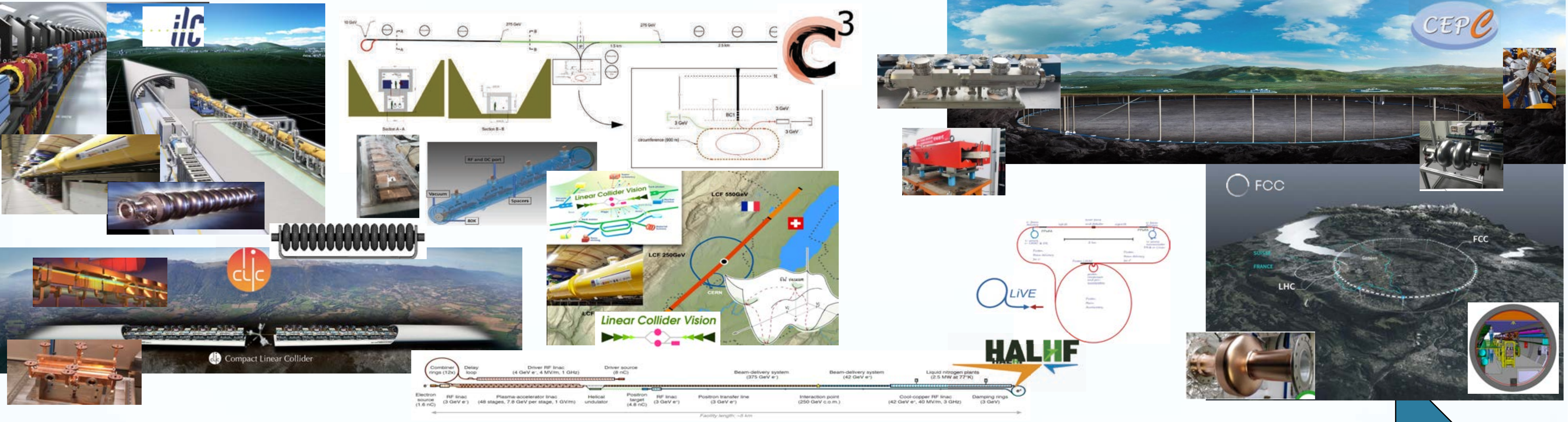


Accelerator R&D for next HEP e^+e^- Colliders

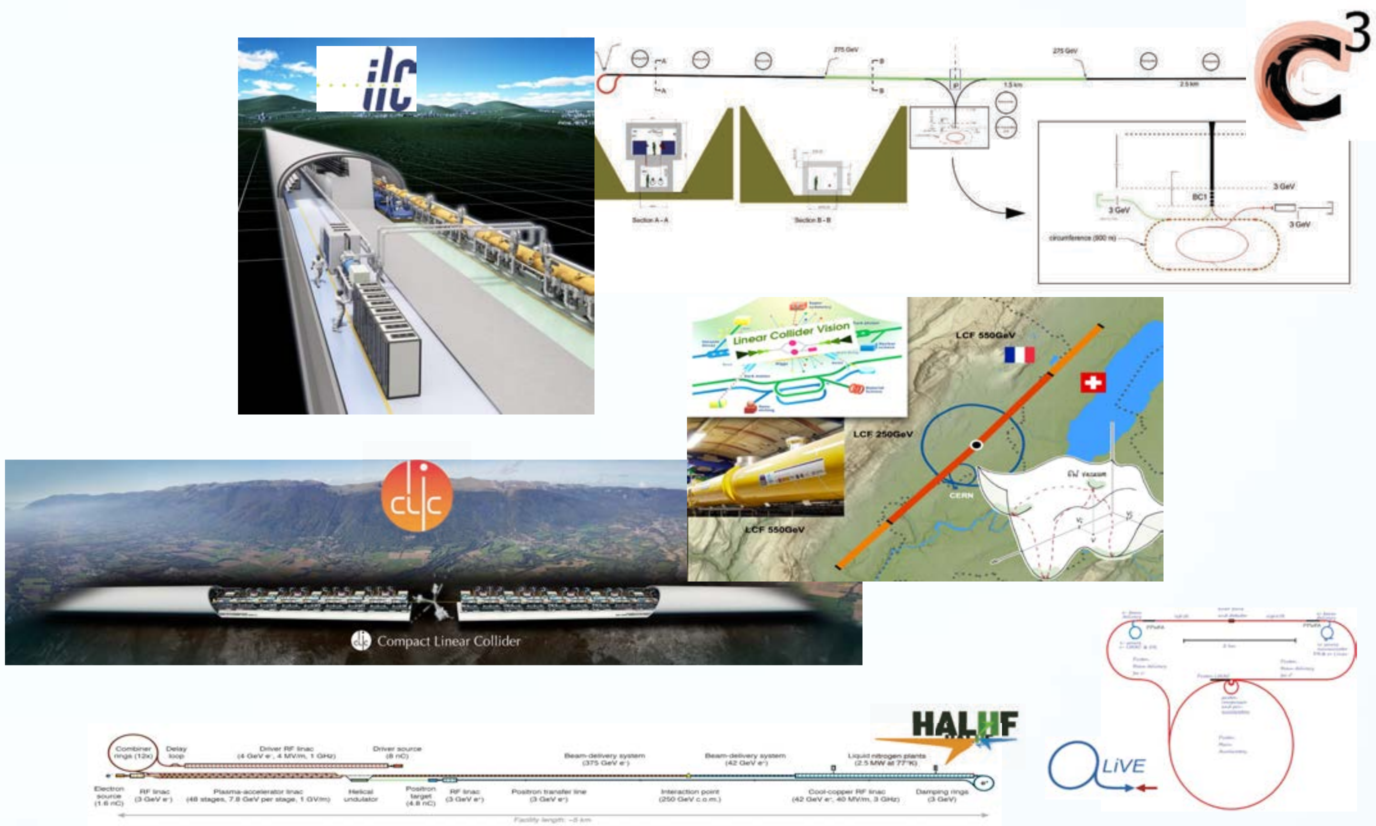
Dr. Angeles Faus-Golfe

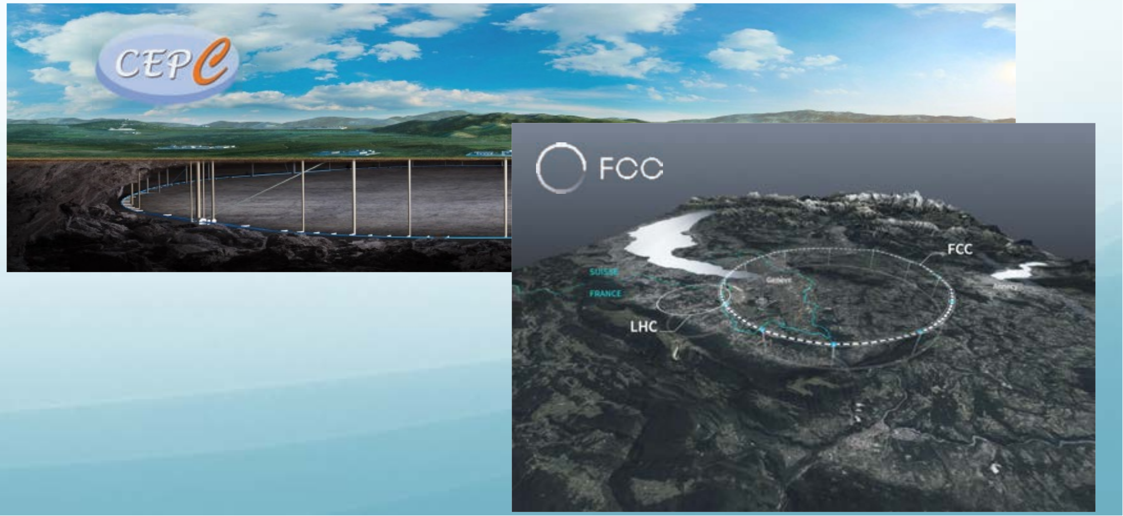
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

cnrs NUCLÉAIRE & PARTICULES

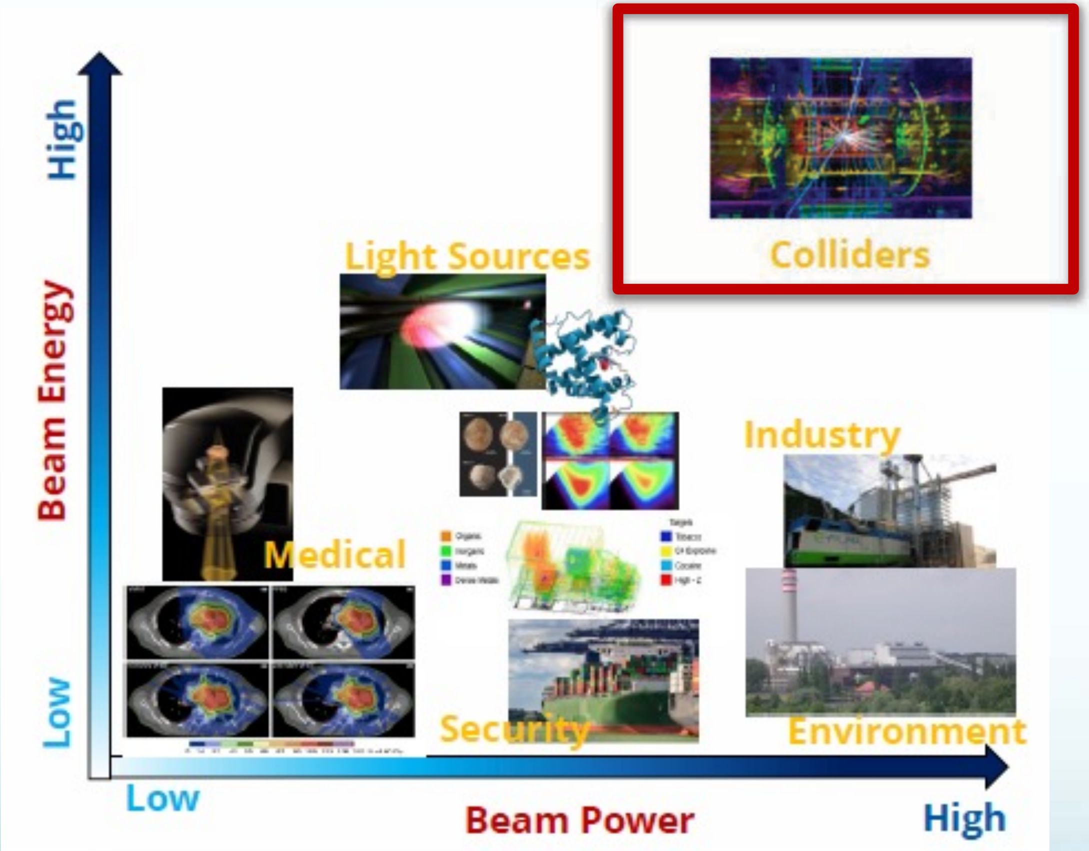
Outline

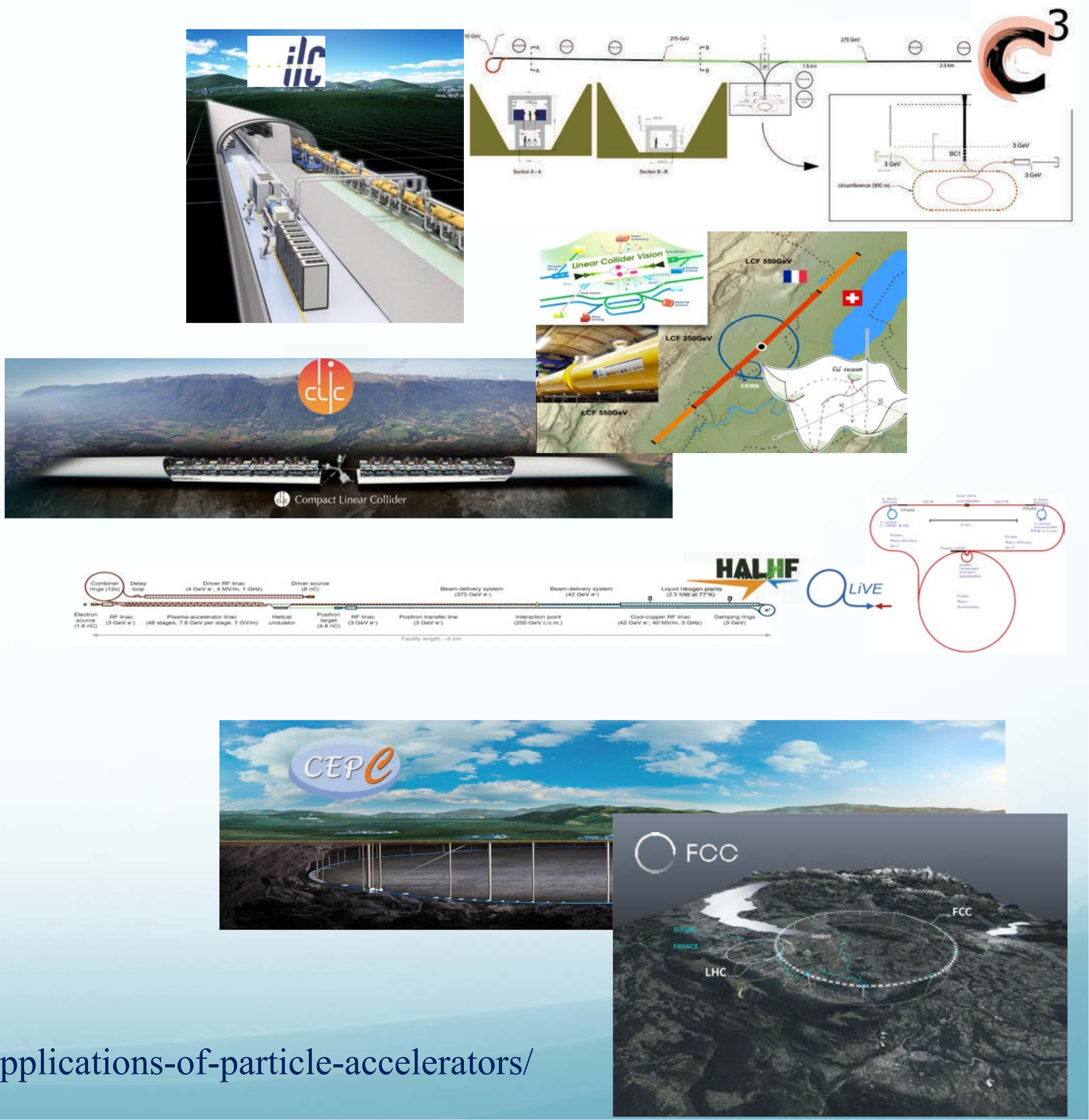
- Introduction to Colliders
- HEP Context:
  - EPPSU2020 & Snowmass 2021
  - Next ESPPU2026
- e+e- colliders frontiers
  - Luminosity & Energy frontiers
  - Sustainability frontier
- Conventional e+e- colliders
  - CC projects: FCC-ee (CepC)
  - LC projects: ILC, CLIC, C3, LCF@CERN
- Advanced e+e- colliders
  - Boosting the performances: HG SRF, ERLs
  - LPA e+e- collider subsystem: injectors
  - LPA based e+e- colliders





Where are we?





http://mooc.particle-accelerators.eu/applications-of-particle-accelerators/

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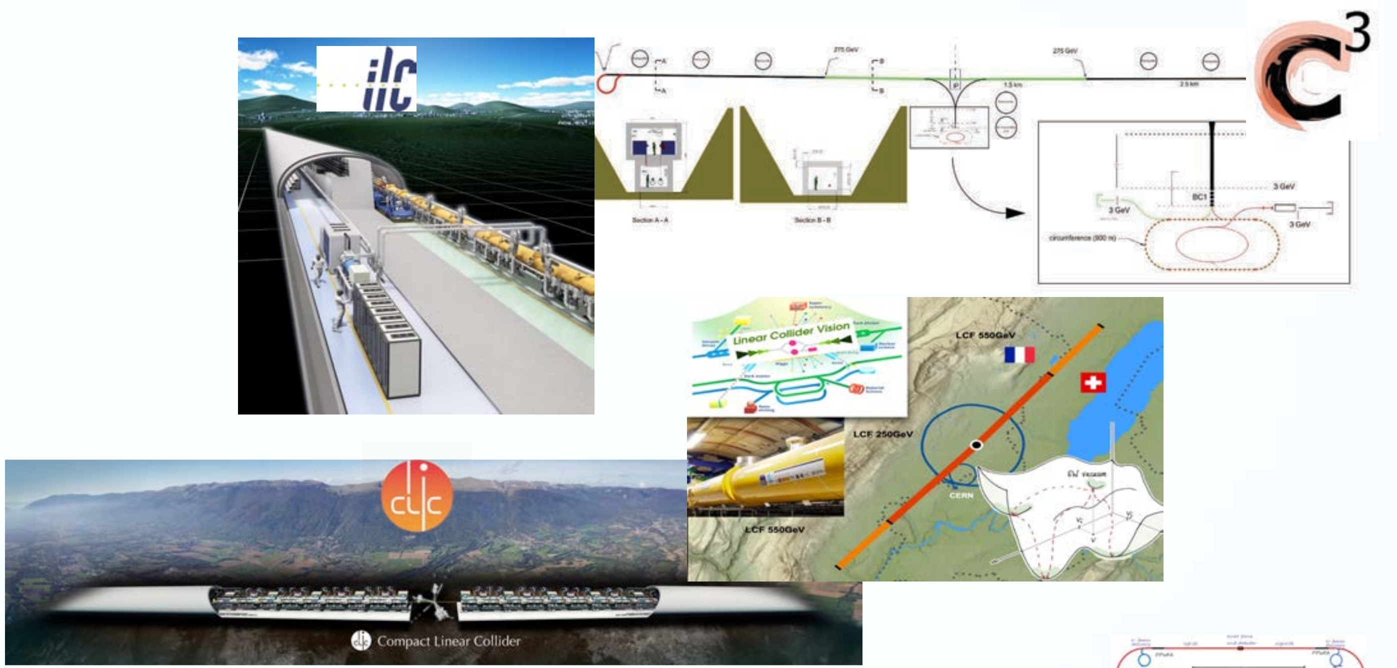
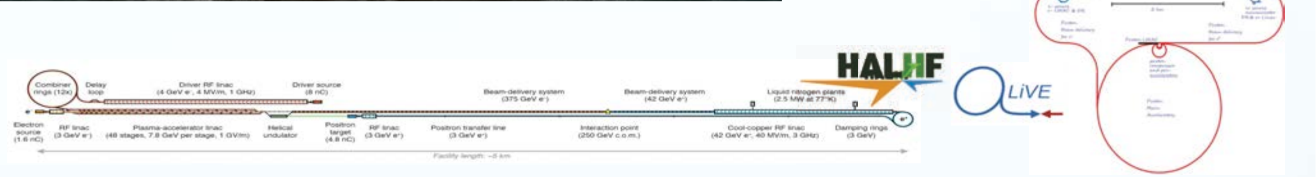
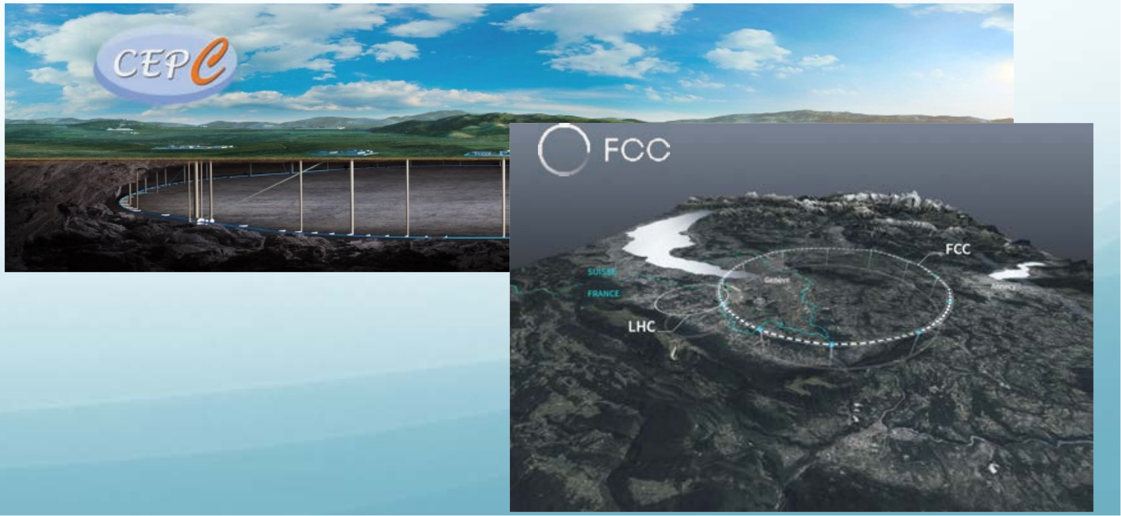
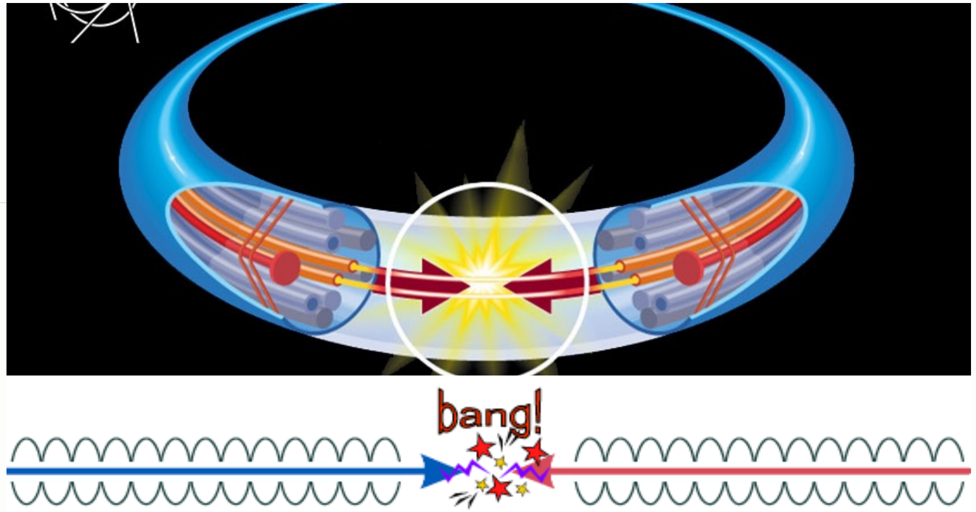






COLLIDERS FOR HEP



COLLIDERS ARE THE MOST POWERFUL INSTRUMENTS FOR DISCOVERIES AND PRECISION MEASUREMENTS

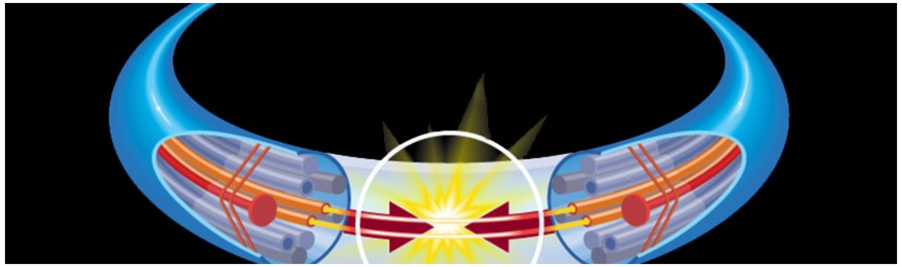
The main advances in High-Energy Physics in the last century have been possible thanks to the Colliders

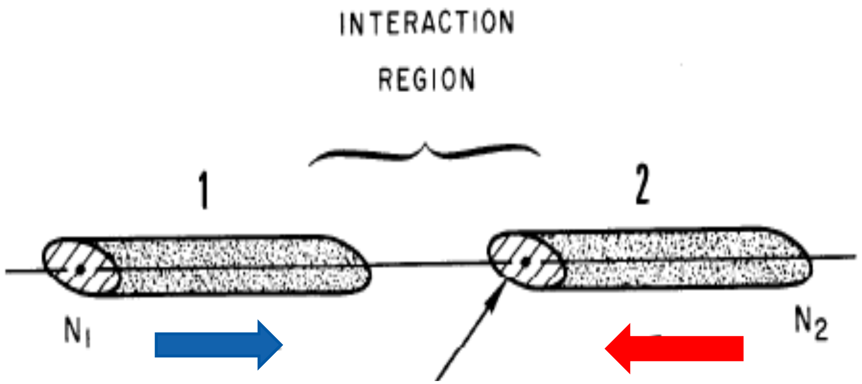
THE PERFORMANCE OF A PARTICLE COLLIDER IS QUANTIFIED BY:

Energy
available for production of new effects

Luminosity
number of useful interactions

PERFORMANCE OF COLLIDERS





AREA

Energy

$$E_{cm}^2 = (E_1+E_2)^2 - (\overrightarrow{p_1}+\overrightarrow{p_2})^2$$

BEAM ENERGY

MOMENTUM

$$\overrightarrow{p_1} = -\overrightarrow{p_2} \quad or \quad \overrightarrow{p_2} = 0$$

COLLIDER

FIXED TARGET

Luminosity

$$\frac{dR}{dt} = \mathcal{L}\,\sigma_p$$

$$\frac{f\,N_b\,N_1 N_2}{A}$$

NUMBER OF PARTICULES

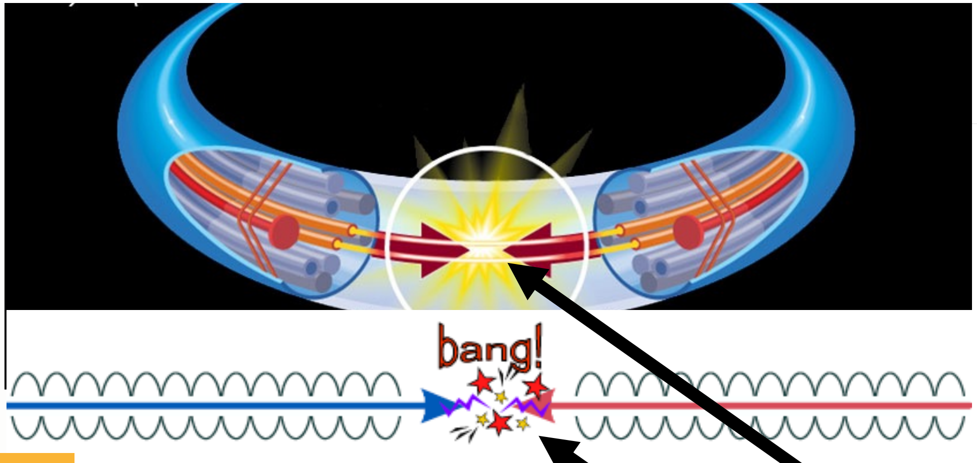
GAUSSIAN BUNCH SIZE

$$4\pi\sigma_x\sigma_y$$

REVOLUTION FREQUENCY

NUMBER OF BUNCHES

MAXIMIZING PERFORMANCE



Maximum Luminosity

- Beam-Beam $\propto N$
- Beam density $\frac{\boldsymbol{N}}{\boldsymbol{A}} < \mathrm{D_c}$

Precision Frontier

INCREASING LUMINOSITY REQUIRES HIGH BEAM CURRENTS.

HIGHER ENERGIES IMPLY INCREASING THE SIZE AND THE USE OF TECHNOLOGICAL IMPROVEMENTS

Higher Energy

- $E_{cm} \propto \rho B$
- $E_{cm} \propto L\, G_{RF}$

BENDING RADIUS

MAGNETIC FIELD

LENGHT

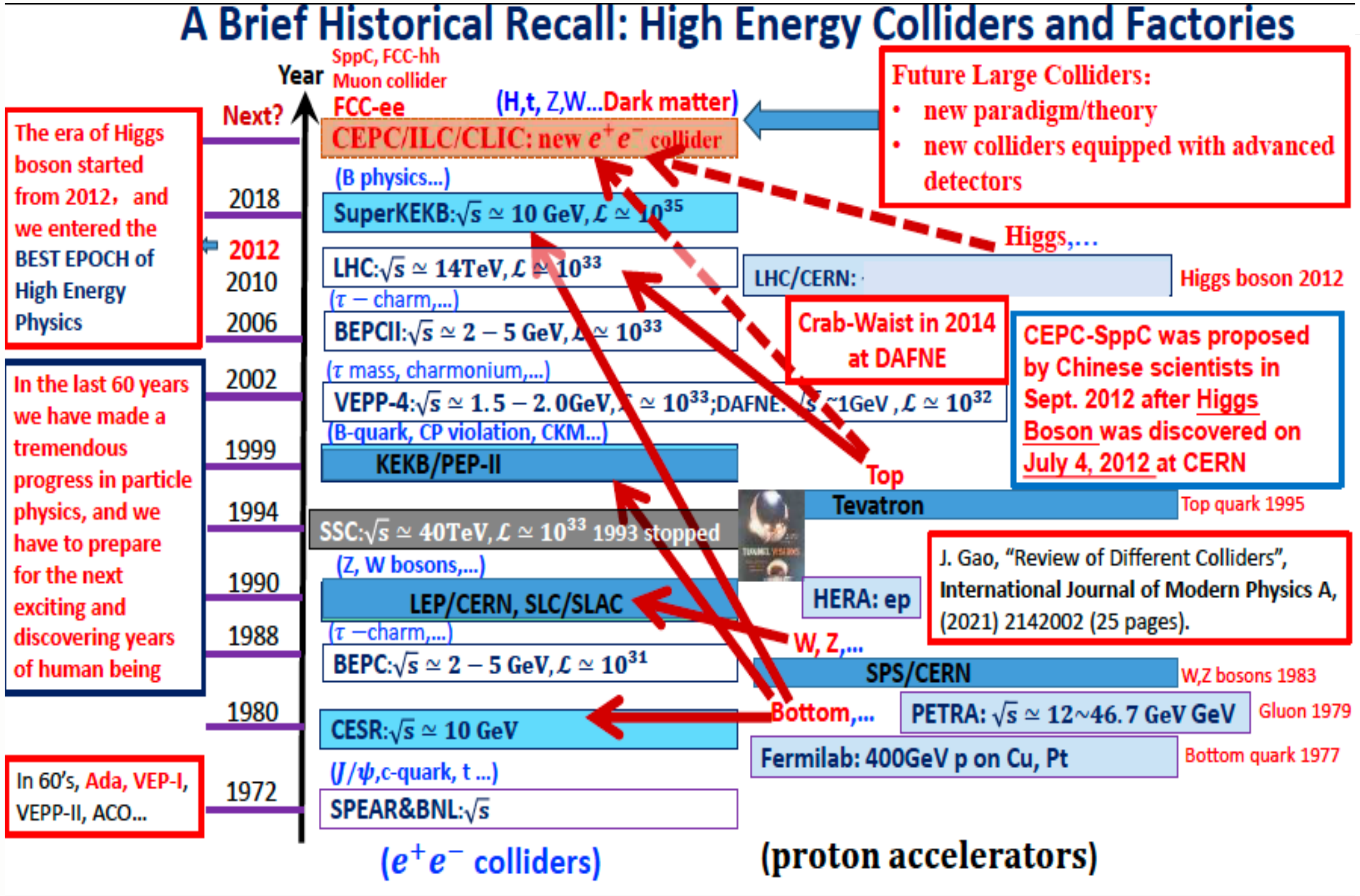
RF GRADIENT

Energy Frontier

20TH CENTURY COLLIDERS

ALL THE HEAVIER PARTICLES OF THE STANDARD MODEL WERE PRODUCED IN COLLIDERS

Since the 60s, when the first colliders were constructed to the LHC, colliders have become 3x10^4 LARGER and now achieve 10^7 times higher luminosity and energy.



A Brief Historical Recall: High Energy Colliders and Factories

The era of Higgs boson started from 2012，and we entered the BEST EPOCH of High Energy Physics

In the last 60 years we have made a tremendous progress in particle physics, and we have to prepare for the next exciting and discovering years of human being

In 60's, Ada, VEP-I, VEPP-II, ACO...

Year

Next?

2018

2012

2010

2006

2002

1999

1994

1990

1988

1980

1972

SppC, FCC-hh

Muon collider

FCC-ee

(H,t, Z,W...Dark matter)

CEPC/ILC/CLIC: new e^+e^- collider

(B physics...)

SuperKEKB:$\sqrt{s} \simeq 10$ GeV, $\mathcal{L} \simeq 10^{35}$

LHC:$\sqrt{s} \simeq 14$TeV, $\mathcal{L} \simeq 10^{33}$

(τ − charm,...)

BEPCII:$\sqrt{s} \simeq 2-5$ GeV, $\mathcal{L} \simeq 10^{33}$

(τ mass, charmonium,...)

VEPP-4:$\sqrt{s} \simeq 1.5-2.0$GeV, $\mathcal{L} \simeq 10^{33}$;DAFNE: $\sqrt{s}$ ~1GeV , $\mathcal{L} \simeq 10^{32}$

(B-quark, CP violation, CKM...)

KEKB/PEP-II

SSC:$\sqrt{s} \simeq 40$TeV, $\mathcal{L} \simeq 10^{33}$ 1993 stopped

(Z, W bosons,...)

LEP/CERN, SLC/SLAC

(τ −charm,...)

BEPC:$\sqrt{s} \simeq 2-5$ GeV, $\mathcal{L} \simeq 10^{31}$

CESR:$\sqrt{s} \simeq 10$ GeV

(J/ψ,c-quark, t ...)

SPEAR&BNL:$\sqrt{s}$

(e^+e^- colliders)

Future Large Colliders:
- new paradigm/theory
- new colliders equipped with advanced detectors

Higgs,...

LHC/CERN:

Higgs boson 2012

Crab-Waist in 2014 at DAFNE

CEPC-SppC was proposed by Chinese scientists in Sept. 2012 after Higgs Boson was discovered on July 4, 2012 at CERN

Top

Tevatron

Top quark 1995

J. Gao, "Review of Different Colliders", International Journal of Modern Physics A, (2021) 2142002 (25 pages).

HERA: ep

W, Z,...

SPS/CERN

W,Z bosons 1983

Bottom,...

PETRA: $\sqrt{s} \simeq 12$~46.7 GeV GeV

Gluon 1979

Fermilab: 400GeV p on Cu, Pt

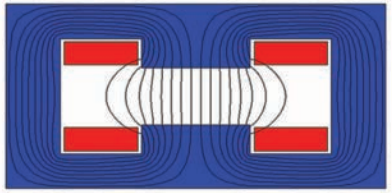
Bottom quark 1977

(proton accelerators)

COLLIDERS PROGRESS WAS ENABLED BY THE INTRODUCTION OF NEW CONCEPTS AND EMERGENCE OF NEW TECHNOLOGIES

CURRENT COLLIDER CONCEPTS

Separate function magnets



Dipoles for guiding

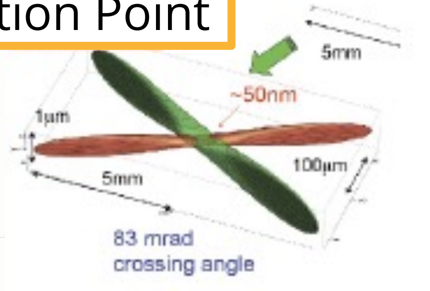
Quadrupoles for focusing

- **higher field levels**
- **more optics flexibility**

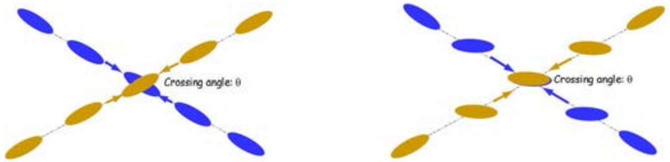
Strong focusing

Sequence of alternately converging and diverging magnetic lenses of equal strength is itself converging

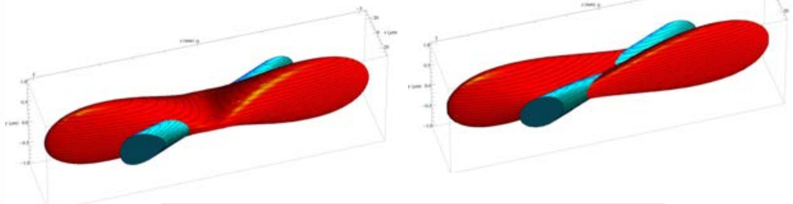
Nano beam sizes at Interaction Point



Colliding beams



Crab crossing schemes



Crab waist schemes

CURRENT TECHNOLOGIES

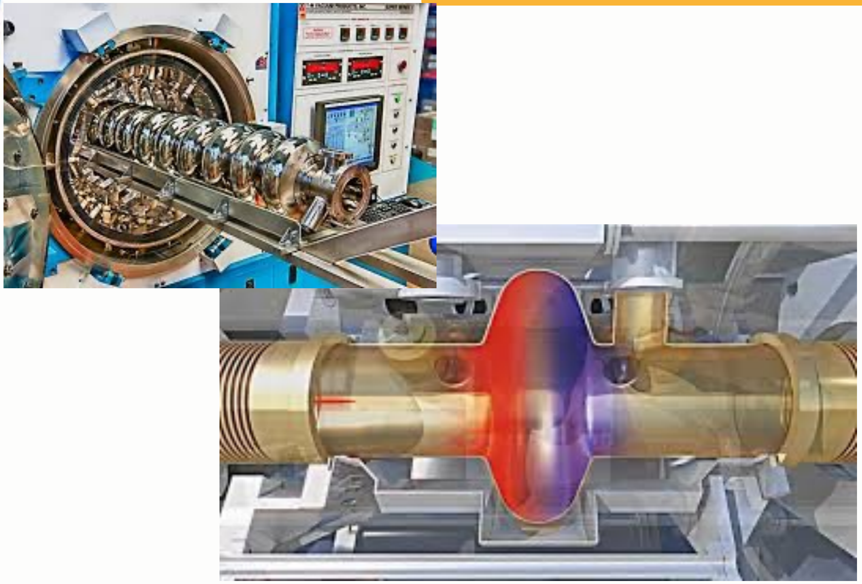
Superconducting RF systems

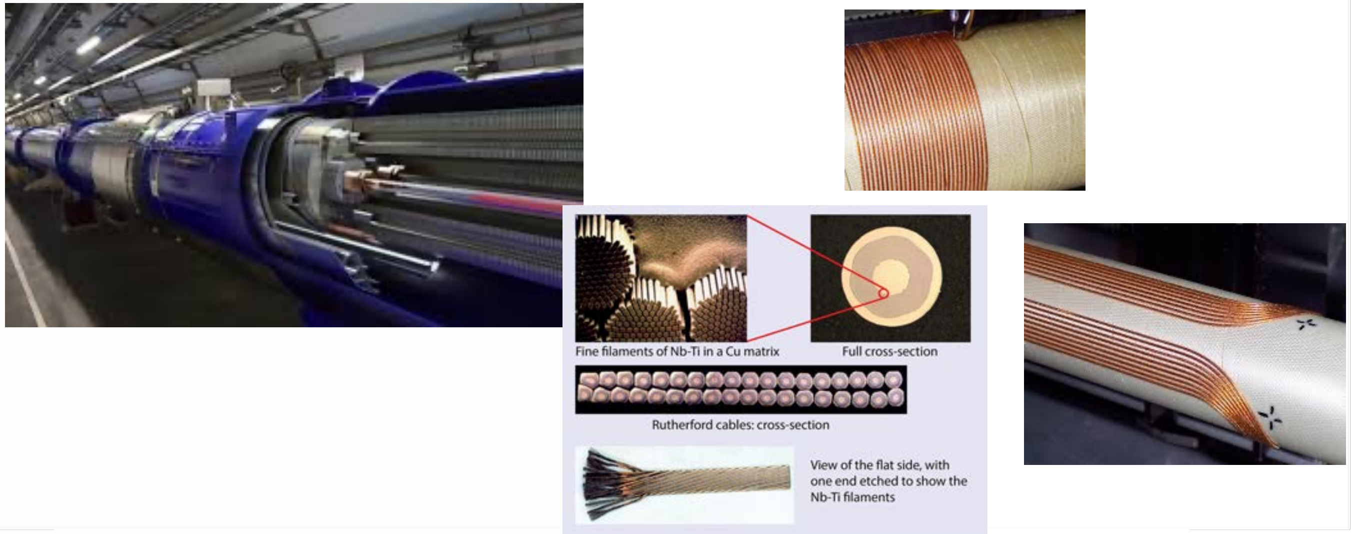
PETRA, TRISTAN and LEP-II started the massive use of SC RF systems

Superconducting magnets

TEVATRON was the first accelerator based in SC magnets

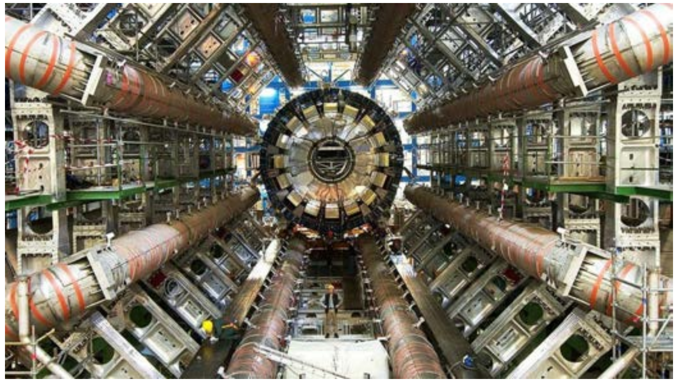
HERA, RHIC and LHC use both SC RF and SC magnets

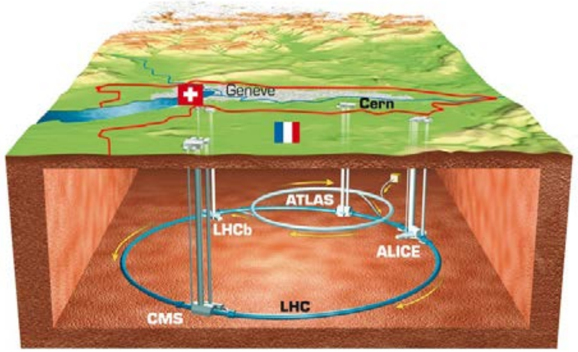


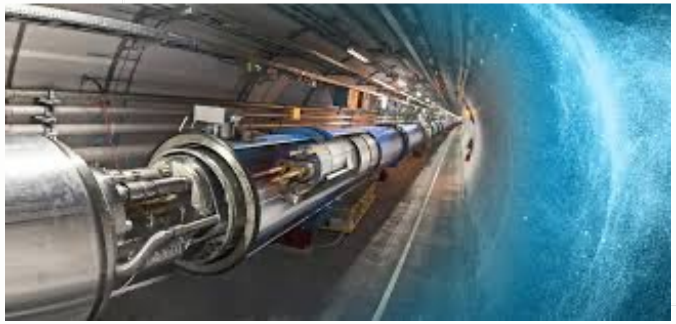


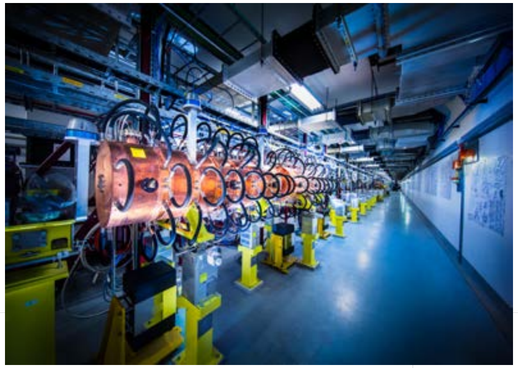
The Large Hadron Collider

The LHC is the world's largest and most powerful collider. The LHC consists of a 27 km ring of thousands of SC magnets with a number of RF accelerating structures to boost the energy of the protons up to 7 TeV.









21ST CENTURY COLLIDERS

Pushing Precision frontier

Pushing Energy frontier

ACCELERATORS TECHNOLOGIES ARE READY TO GO FORWARD FOR LEPTON COLLIDERS, HIGGS FACTORIES.

NEW SC HIGH-FIELD MAGNETS AND ENERGY MANAGEMENT STRATEGIES ARE NECCESARY FOR ENERGY FRONTIER COLLIDERS

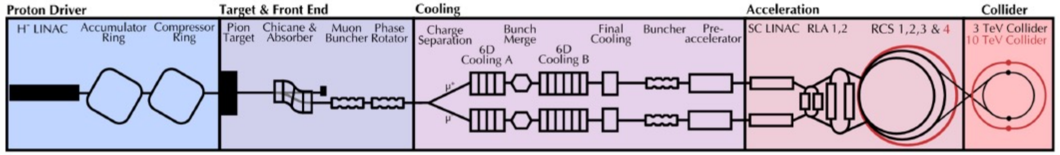
Higgs factories: ILC, CLIC, FCCee and CepC

Energy frontier colliders: FCChh and SppC

ULTIMATE COLLIDERS

COOLING-FREE MUON COLLIDERS, PROMISE AN ENERGY EFFICIENT PATH TOWARDS LEPTON COLLISIONS. WHILE PLASMA ACCELERATORS OFFER UNPRECEDENT HIGH GRADIENTS HENCE COMPACT COLLIDERS

Muons colliders



Short, intense proton bunch

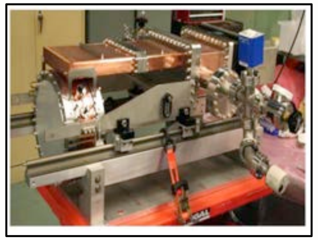
Protons produce pions which decay into muons which are captured

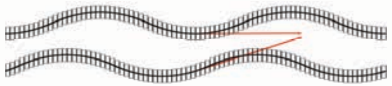
Ionisation cooling of muon in matter

Acceleration to collision energy

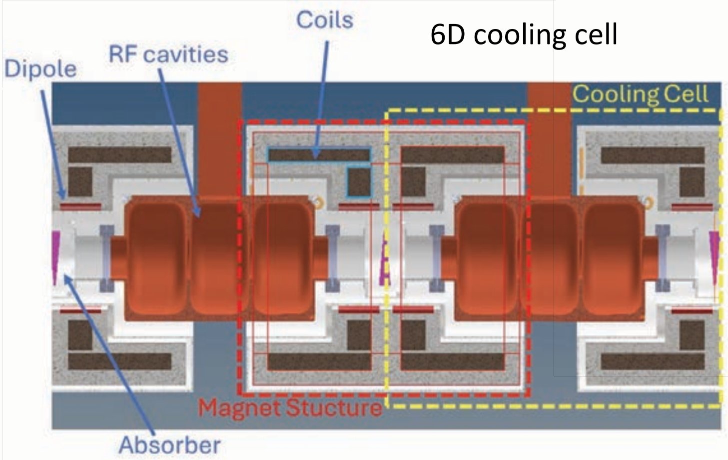
Collision

MuCool demonstrated >50 MV/m in 5 T



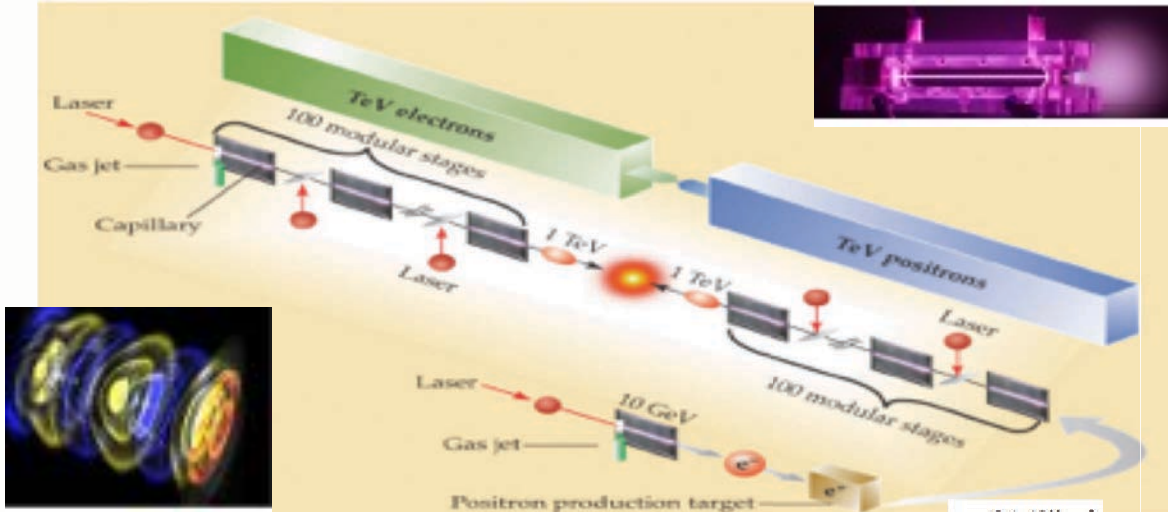


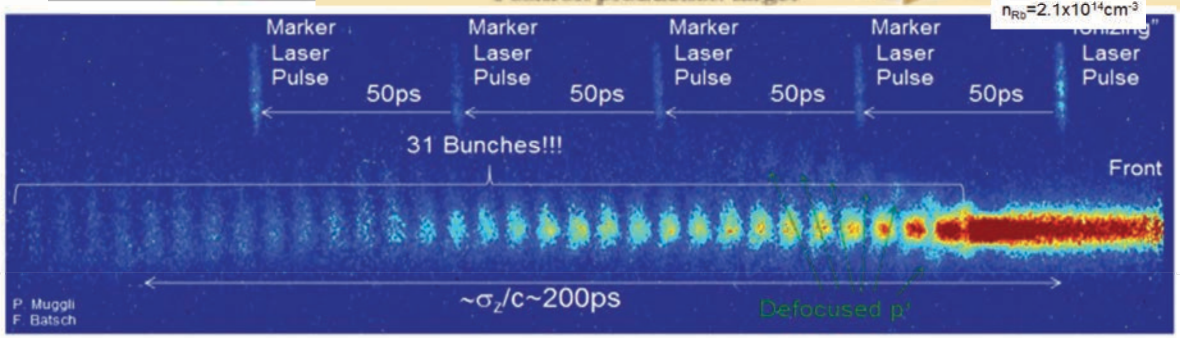
Arc mitigation concept



6D cooling cell

Plasma accelerators





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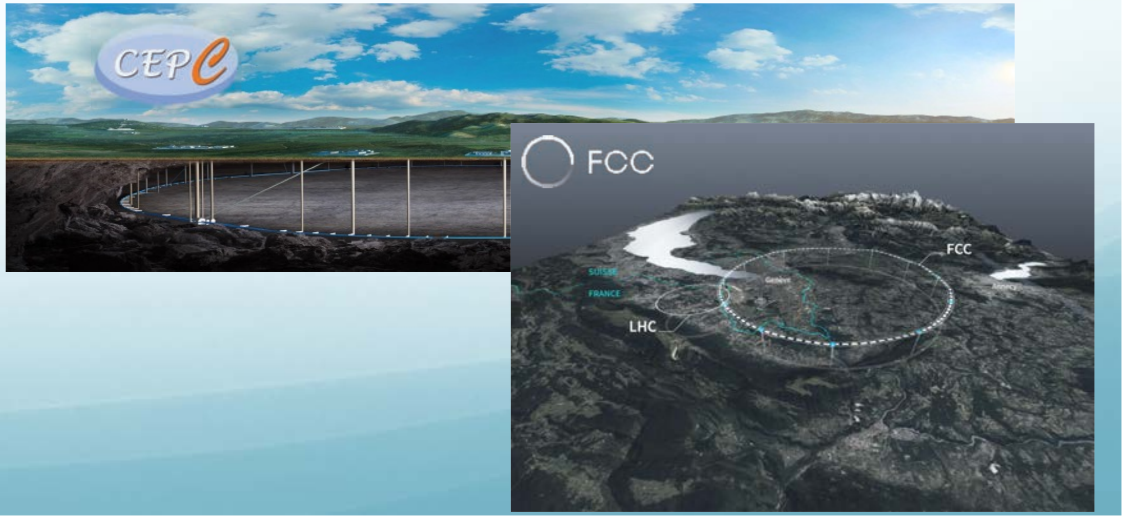
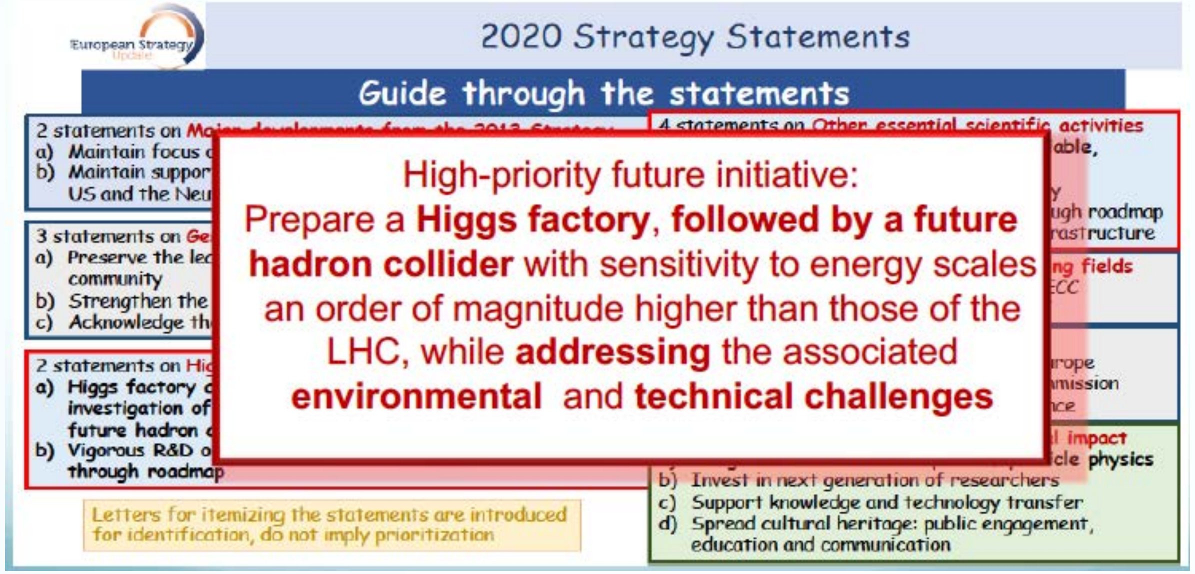


Context: EPPSU 2020 and Snowmass 2021



European Strategy Update

2020 Strategy Statements

Guide through the statements

2 statements on Ma
a) Maintain focus
b) Maintain suppor
US and the Neu

3 statements on Ge
a) Preserve the lea
community
b) Strengthen the
c) Acknowledge th

2 statements on Hig
a) Higgs factory
investigation of
future hadron
b) Vigorous R&D o
through roadmap

4 statements on Other essential scientific activities
able,
y
ugh roadmap
rastructure

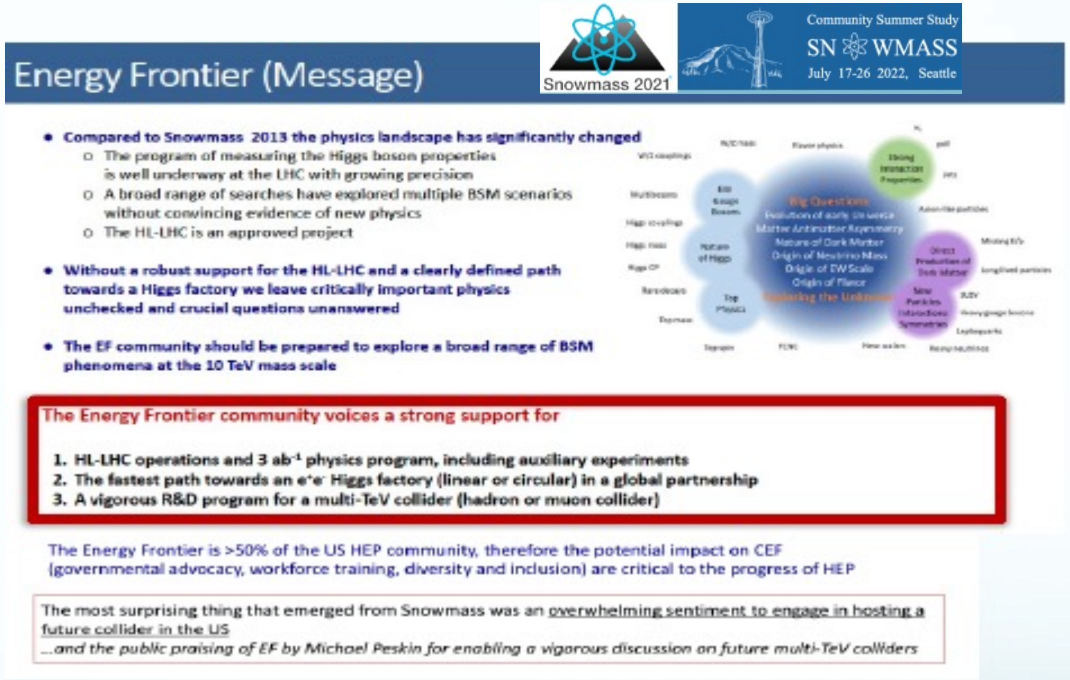
ng fields
ECC

rope
mission
nce

l impact
icle physics
b) Invest in next generation of researchers
c) Support knowledge and technology transfer
d) Spread cultural heritage: public engagement, education and communication

Letters for itemizing the statements are introduced for identification, do not imply prioritization

High-priority future initiative:
Prepare a **Higgs factory**, **followed by a future hadron collider** with sensitivity to energy scales an order of magnitude higher than those of the LHC, while **addressing** the associated **environmental** and **technical challenges**



Energy Frontier (Message)

Snowmass 2021

Community Summer Study
SNOWMASS
July 17-26 2022, Seattle

- **Compared to Snowmass 2013 the physics landscape has significantly changed**
  - The program of measuring the Higgs boson properties is well underway at the LHC with growing precision
  - A broad range of searches have explored multiple BSM scenarios without convincing evidence of new physics
  - The HL-LHC is an approved project
- **Without a robust support for the HL-LHC and a clearly defined path towards a Higgs factory we leave critically important physics unchecked and crucial questions unanswered**
- **The EF community should be prepared to explore a broad range of BSM phenomena at the 10 TeV mass scale**

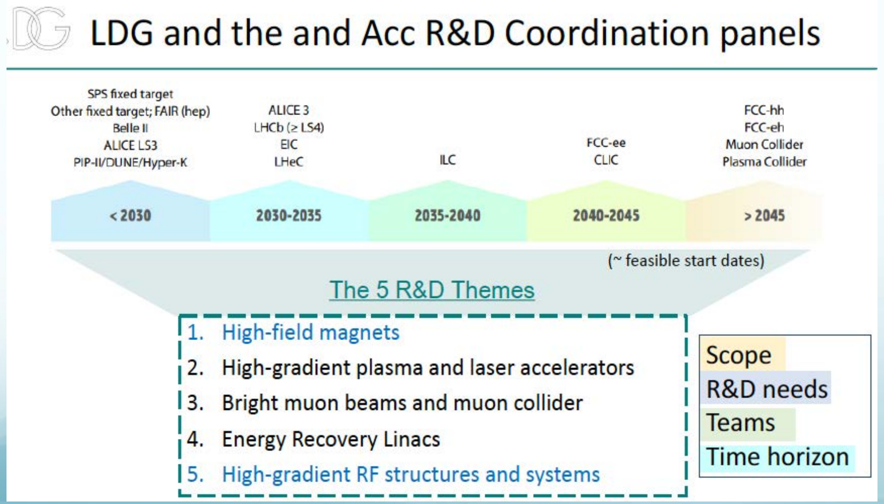
The Energy Frontier community voices a strong support for

1. **HL-LHC operations and 3 ab^{-1} physics program, including auxiliary experiments**
2. **The fastest path towards an e^+e^- Higgs factory (linear or circular) in a global partnership**
3. **A vigorous R&D program for a multi-TeV collider (hadron or muon collider)**

The Energy Frontier is >50% of the US HEP community, therefore the potential impact on CEF (governmental advocacy, workforce training, diversity and inclusion) are critical to the progress of HEP

The most surprising thing that emerged from Snowmass was an overwhelming sentiment to engage in hosting a future collider in the US
...and the public praising of EF by Michael Peskin for enabling a vigorous discussion on future multi-TeV colliders

- **LDG Report (2022)**



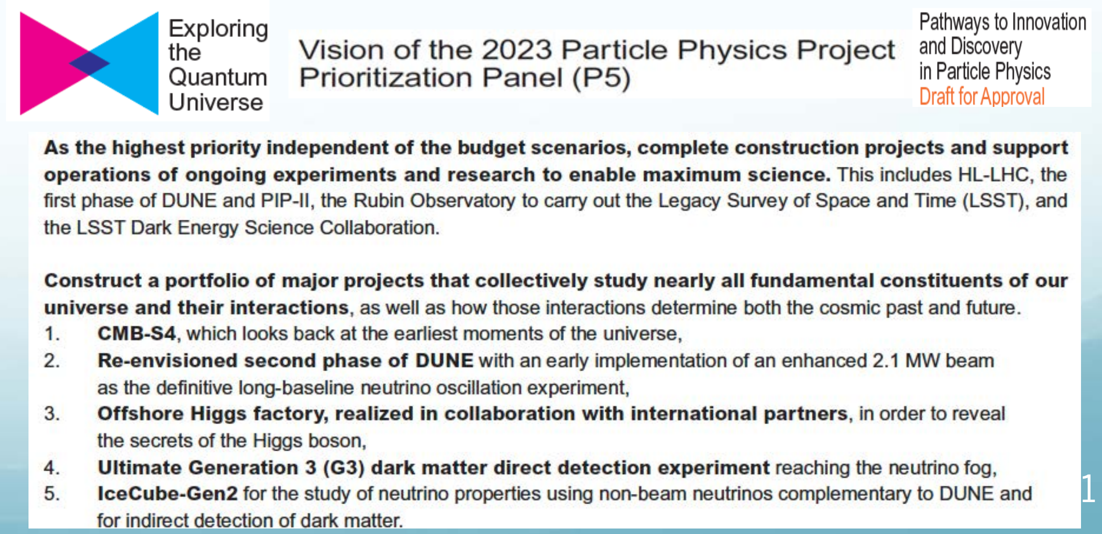
LDG and the and Acc R&D Coordination panels

(~ feasible start dates)

The 5 R&D Themes

1. High-field magnets
2. High-gradient plasma and laser accelerators
3. Bright muon beams and muon collider
4. Energy Recovery Linacs
5. High-gradient RF structures and systems

Scope
R&D needs
Teams
Time horizon



Exploring the Quantum Universe

Vision of the 2023 Particle Physics Project Prioritization Panel (P5)

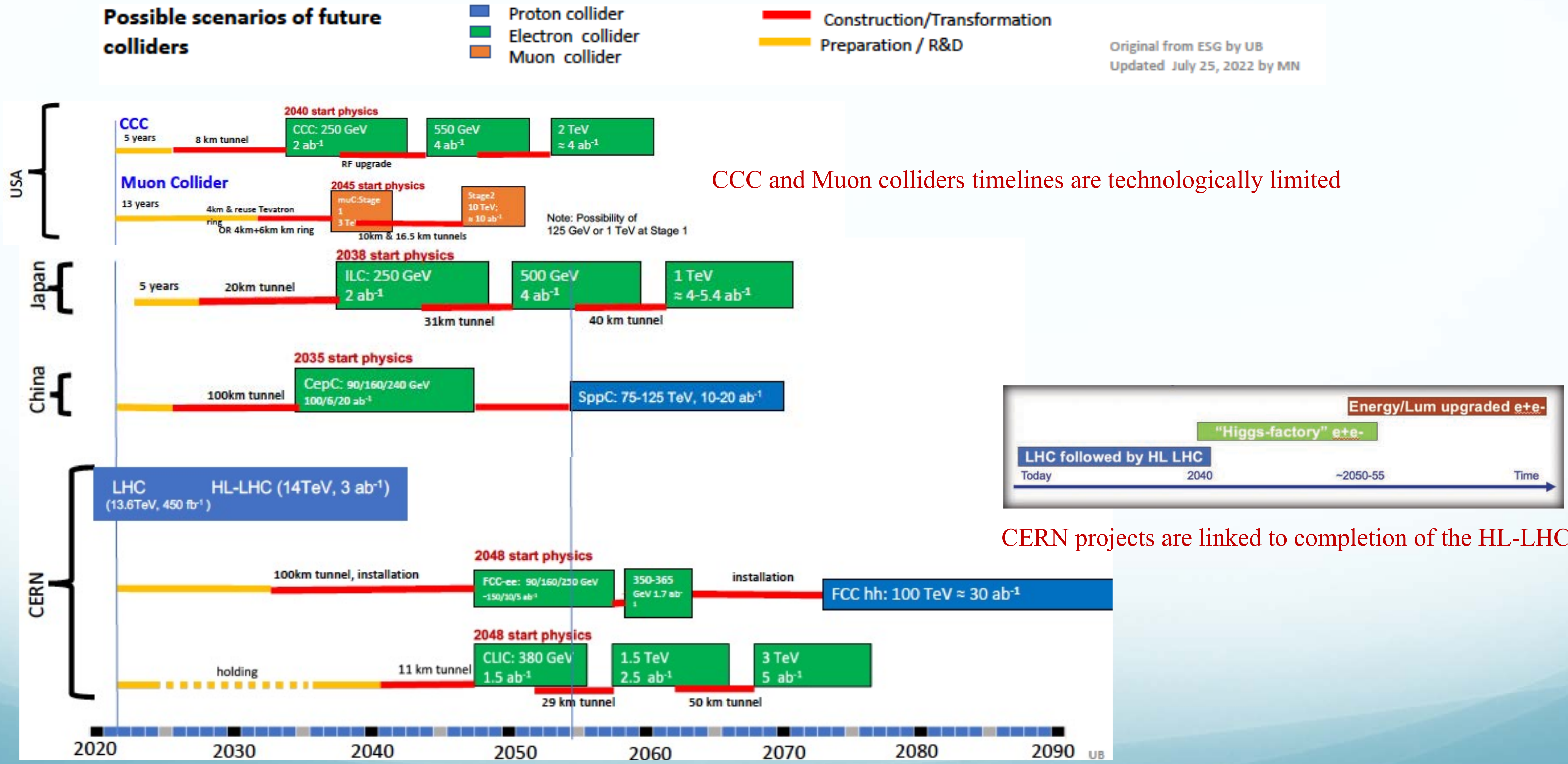
Pathways to Innovation and Discovery in Particle Physics
Draft for Approval

As the highest priority independent of the budget scenarios, complete construction projects and support operations of ongoing experiments and research to enable maximum science. This includes HL-LHC, the first phase of DUNE and PIP-II, the Rubin Observatory to carry out the Legacy Survey of Space and Time (LSST), and the LSST Dark Energy Science Collaboration.

Construct a portfolio of major projects that collectively study nearly all fundamental constituents of our universe and their interactions, as well as how those interactions determine both the cosmic past and future.

1. **CMB-S4**, which looks back at the earliest moments of the universe,
2. **Re-envisioned second phase of DUNE** with an early implementation of an enhanced 2.1 MW beam as the definitive long-baseline neutrino oscillation experiment,
3. **Offshore Higgs factory, realized in collaboration with international partners**, in order to reveal the secrets of the Higgs boson,
4. **Ultimate Generation 3 (G3) dark matter direct detection experiment** reaching the neutrino fog,
5. **IceCube-Gen2** for the study of neutrino properties using non-beam neutrinos complementary to DUNE and for indirect detection of dark matter.

Context: HEP FC new Timelines Snowmass 21



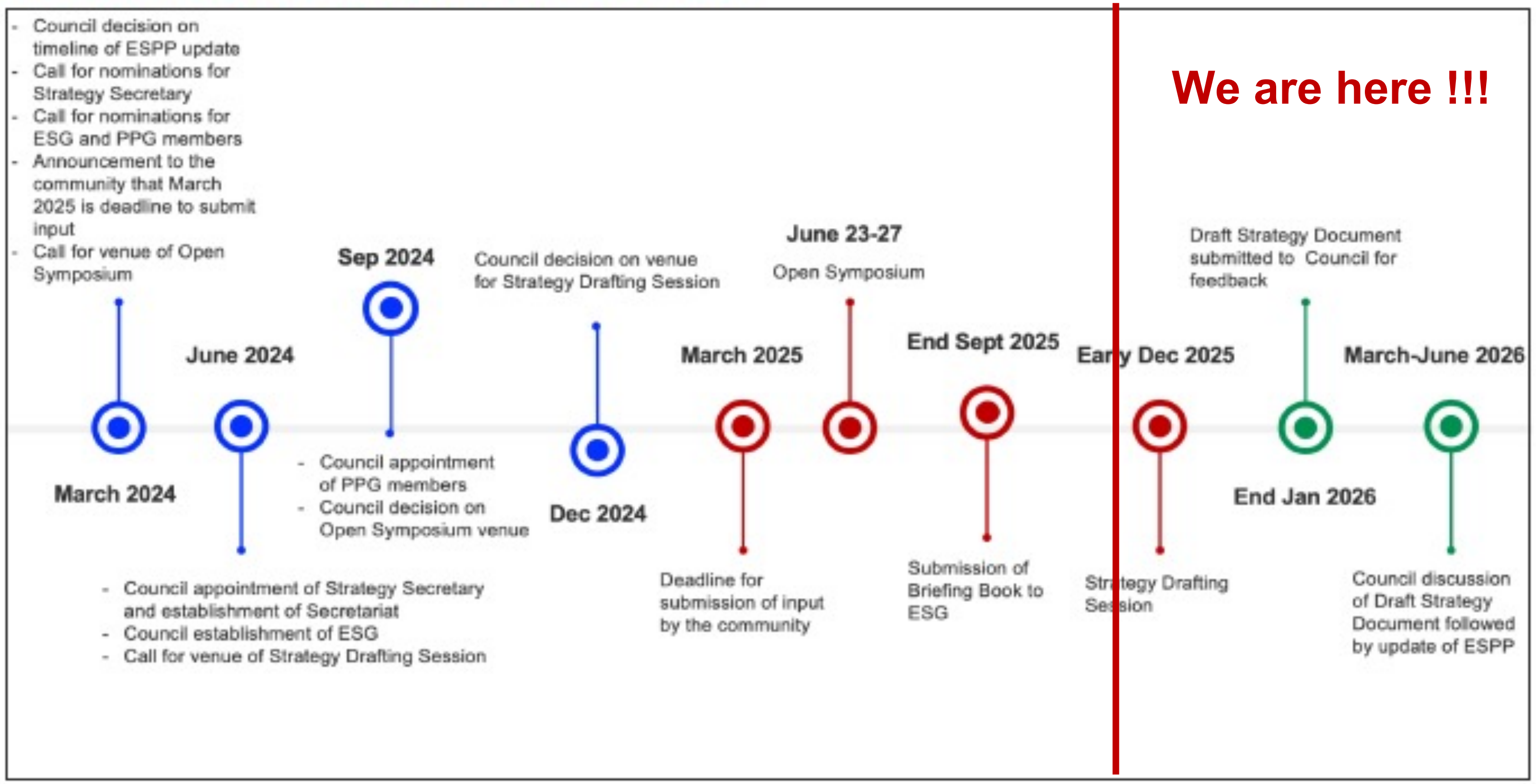
CCC and Muon colliders timelines are technologically limited

CERN projects are linked to completion of the HL-LHC

Timeline for European Strategy Update 2026

- ☐ June 2024: appointment of Strategy Secretary, Strategy Secretariat and European Strategy Group (ESG) by CERN Council
- ☐ March 2025: deadline for submission of community input
- ☐ June 23-27, 2025: Open Symposium
- ☐ Early Dec 2025: Strategy Drafting Session
- ☐ June 2026: Strategy update by CERN Council → end of the process

CepC not entered in the 2025-2030 China strategic plan



We are here !!!

March 2024
- Council decision on timeline of ESPP update
- Call for nominations for Strategy Secretary
- Call for nominations for ESG and PPG members
- Announcement to the community that March 2025 is deadline to submit input
- Call for venue of Open Symposium

June 2024
- Council appointment of Strategy Secretary and establishment of Secretariat
- Council establishment of ESG
- Call for venue of Strategy Drafting Session

Sep 2024
- Council appointment of PPG members
- Council decision on Open Symposium venue

Dec 2024
Council decision on venue for Strategy Drafting Session

March 2025
Deadline for submission of input by the community

June 23-27
Open Symposium

End Sept 2025
Submission of Briefing Book to ESG

Early Dec 2025
Strategy Drafting Session

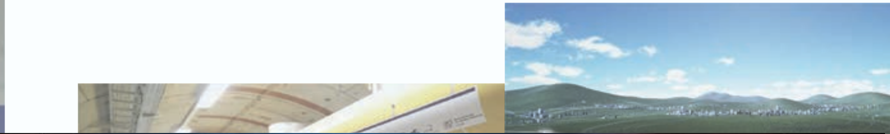
End Jan 2026
Draft Strategy Document submitted to Council for feedback

March-June 2026
Council discussion of Draft Strategy Document followed by update of ESPP

Present and Future Large Accelerator projects

An uncompleted view …

In operation
In construction
Under study



International Large Scale

EPPSU
FCC/CLIC, ILC ?

2018 2020 2022 2024 2026 … 2048 2050 2052 2054 2056

LHC
ATF2
Super KEKB
XFEL
…

ESS
SC linac

HL-LHC
11T Nb$_3$Tn

FAIR

ATF3

-LHC (HL-LHC)
Nb$_3$Tn/NbTn

FCChh (FCCee)
16T Nb$_3$Tn/NbTn

$\mu^+\mu^-$

A complex choice

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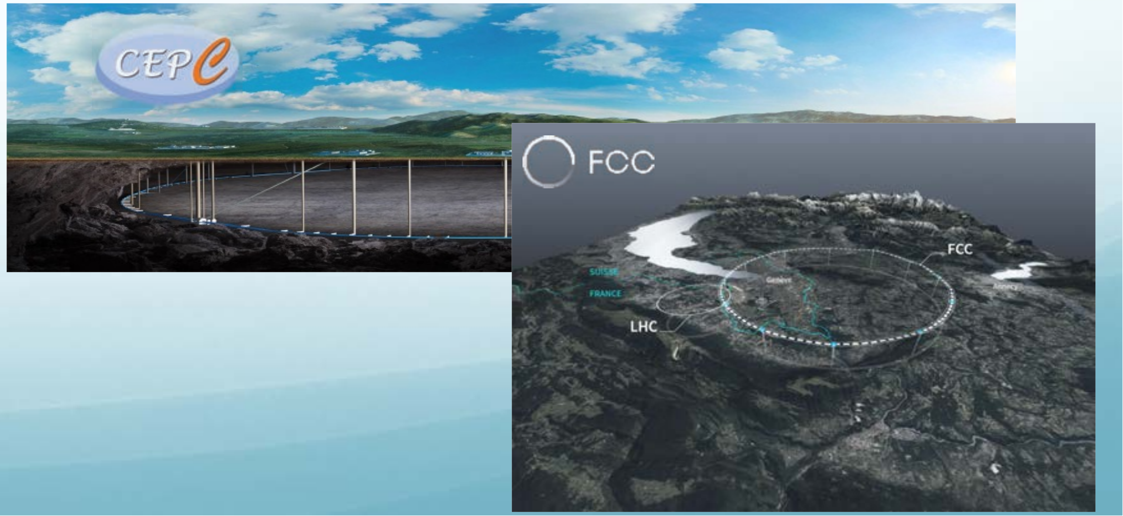
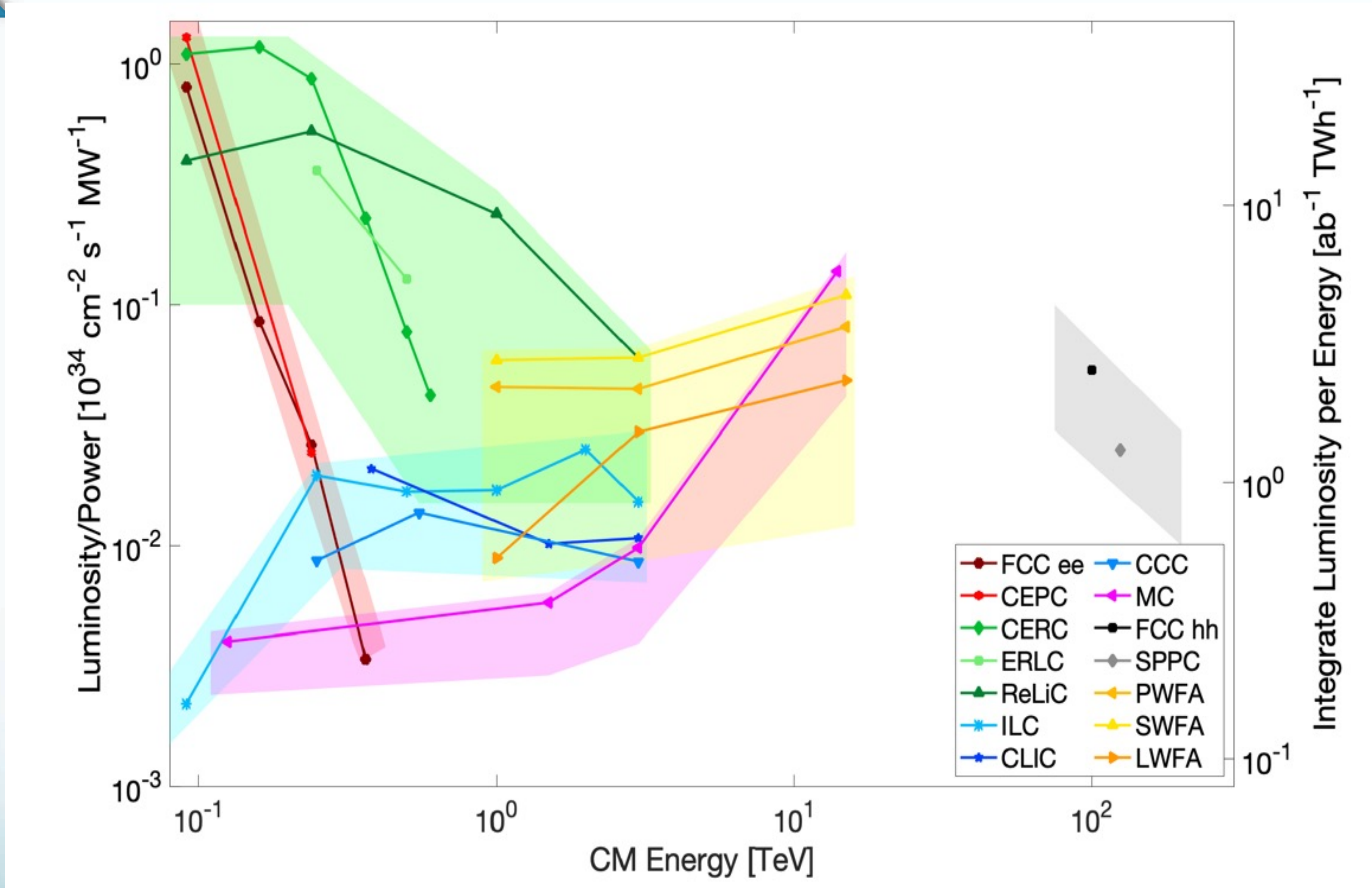
  - LPA e+e- collider subsystem: injectors
  - LPA based e+e- colliders

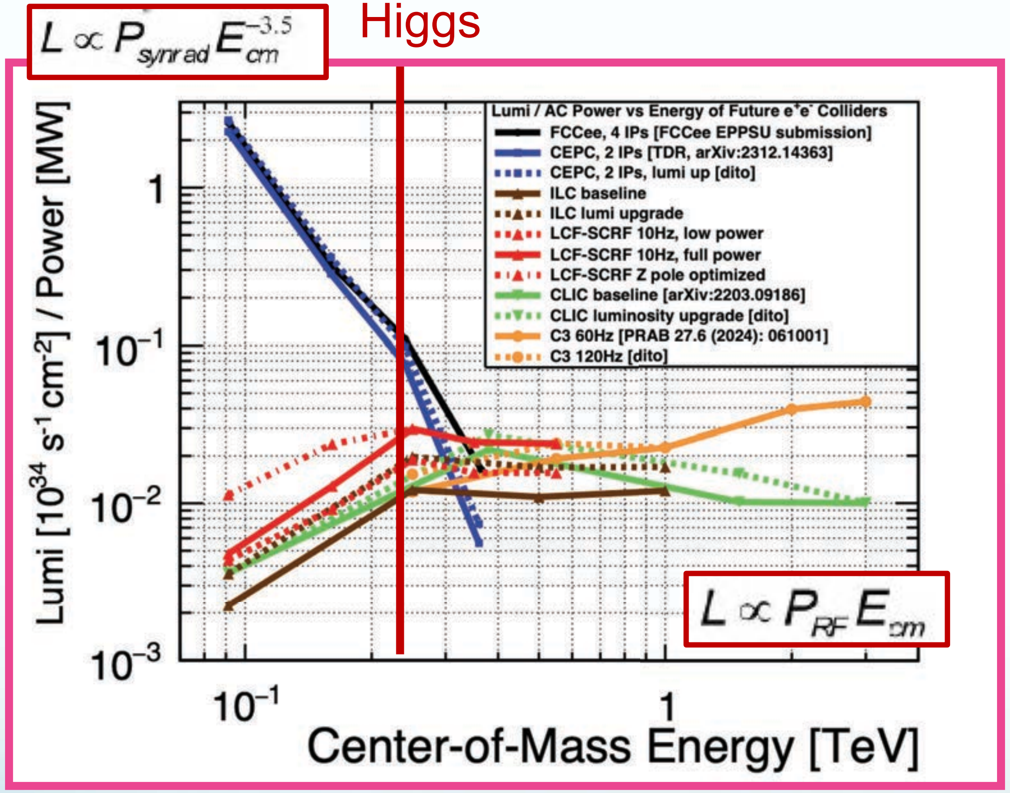


Luminosity & Energy Frontiers

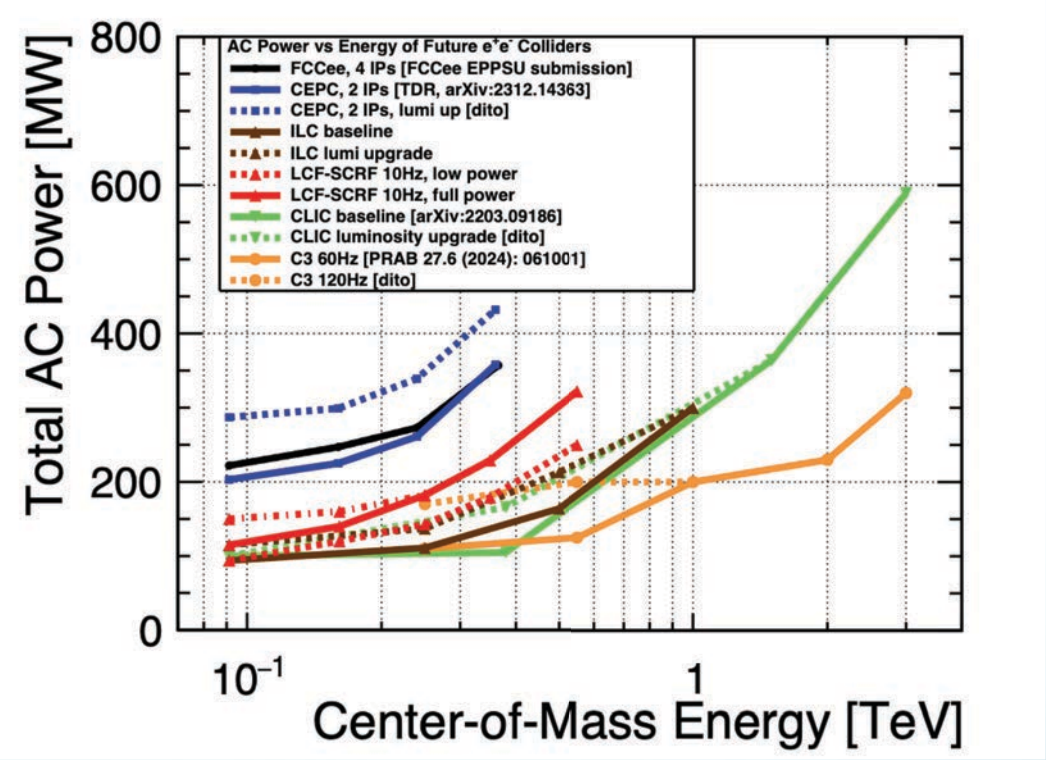


Luminosity & Energy Frontiers

Sustainability Frontier

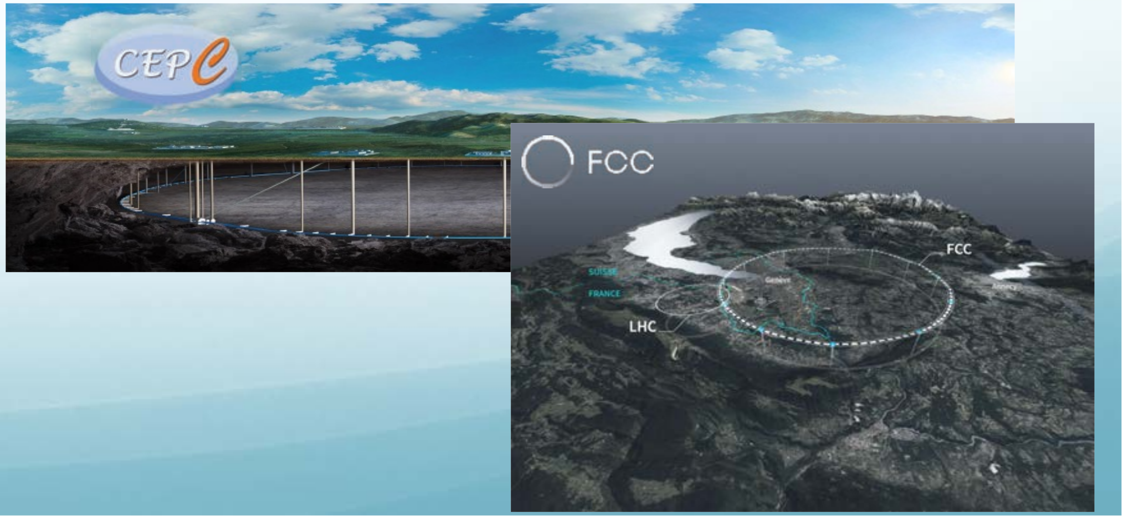

$L \propto P_{synrad} E_{cm}^{-3.5}$

$L \propto P_{RF} E_{cm}$



Outline

- Introduction to Colliders
- HEP Context:
  - EPPSU2020 & Snowmass 2021
  - Next ESPPU2026
- e+e- colliders frontiers
  - Luminosity & Energy frontiers
  - Sustainability frontier
- Conventional e+e- colliders
  - CC projects: FCC-ee (CepC)
  - LC projects: ILC, CLIC, C3, LCF@CERN
- Advanced e+e- colliders
  - Boosting the performances: HG SRF, ERLs
  - LPA e+e- collider subsystem: injectors
  - LPA based e+e- colliders



CCs Accelerator Challenges and Key Technologies

Energy

$$P_{SR} = I_e \, C_\gamma \frac{E^4}{\rho_0}$$

Luminosity

$$L = \frac{f_{rev} \, n_b N_e{}^2}{4\pi \, \sigma_x^* \sigma_y^*}$$

Operation cost
$ ~ P_{SR}

RF Technology

SCRF

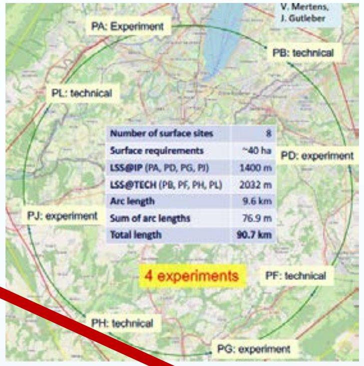
low R/Q, HOM damping, powered by 1 MW RF coupler and high efficiency klystron

moderate gradient and HOM damping requirements: 500 kW / cavity, allowing reuse of klystrons already installed for Z

high RF voltage and limited footprint thanks to multicell cavities and higher RF frequency: 200 kW/ cavity

RF Technology

Construction cost
$ ~ C



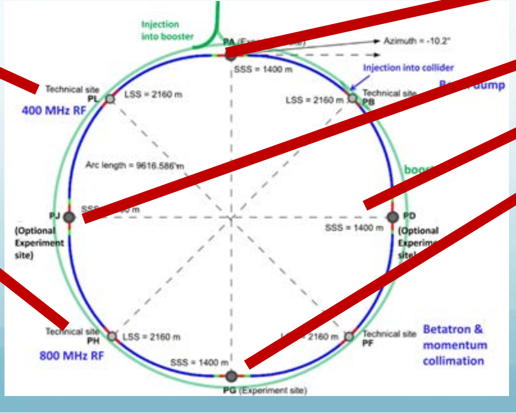
Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	90.7 km

$$f_{rev} = \frac{c}{C}$$

$$I_e = N_e \, n_b \, f_{rev} \, e$$

$$L = \frac{I_e{}^2}{4\pi \sigma_x^* \sigma_y^* \, f_{rev} \, e^2}$$

Key Technologies

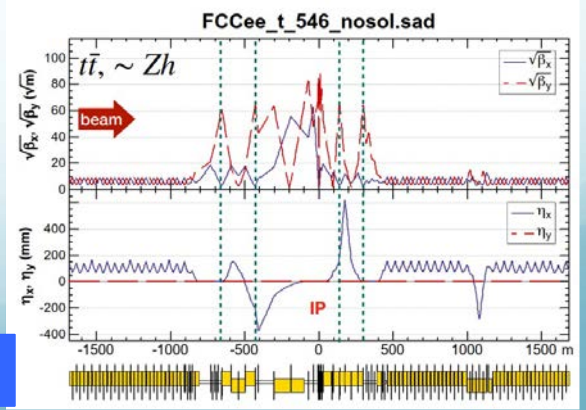


Small beamspot $\sigma^*_x\sigma^*_y$

$$\sigma^* = \sqrt{\beta^* \, \varepsilon}$$

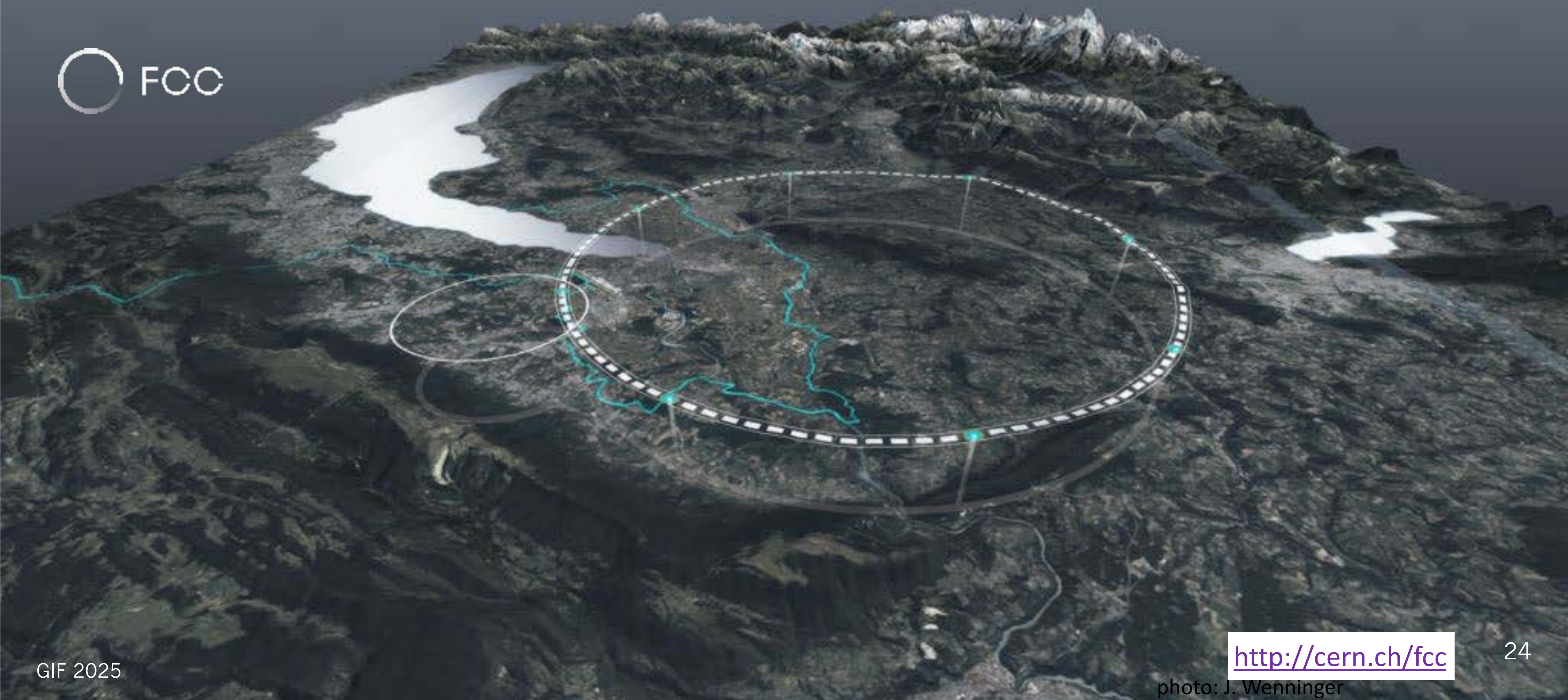
Nanobeam Technology

- Injector / booster / arcs (ε)
- Final focus (β^*)



Nanobeam Technology

The FCC Integrated Program

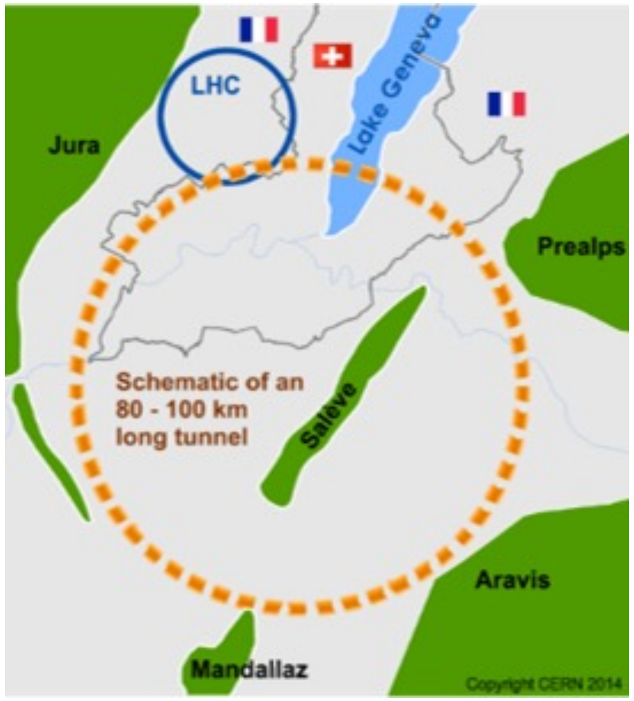


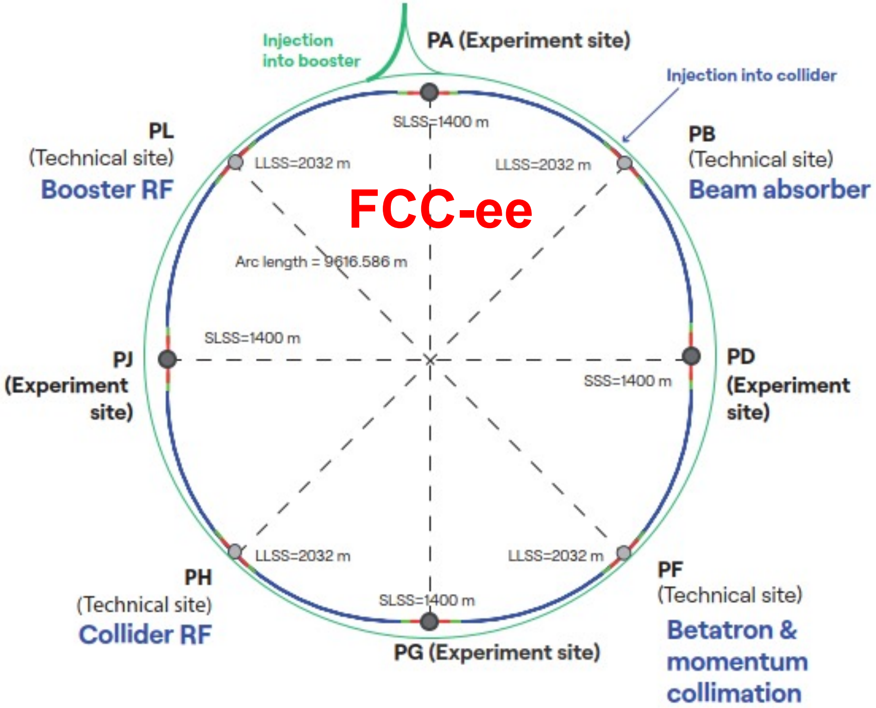
http://cern.ch/fcc

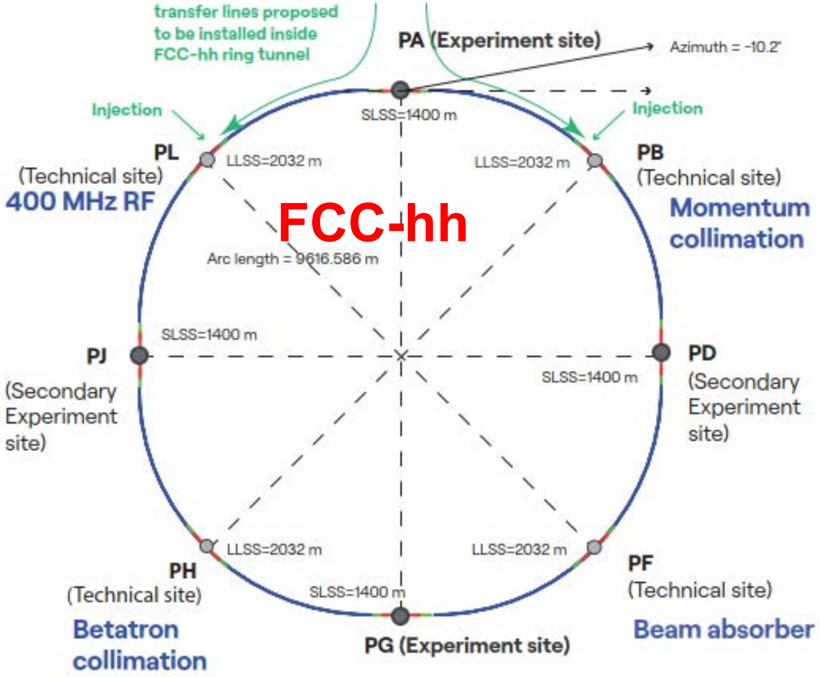
photo: J. Wenninger

FCC integrated program – scope

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- **common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure**
- **FCC integrated project allows the start of a new, major facility at CERN within few years of the end of HL-LHC exploitation**







2020 - 2045 **2046 - 2065** **2070 - 2100**

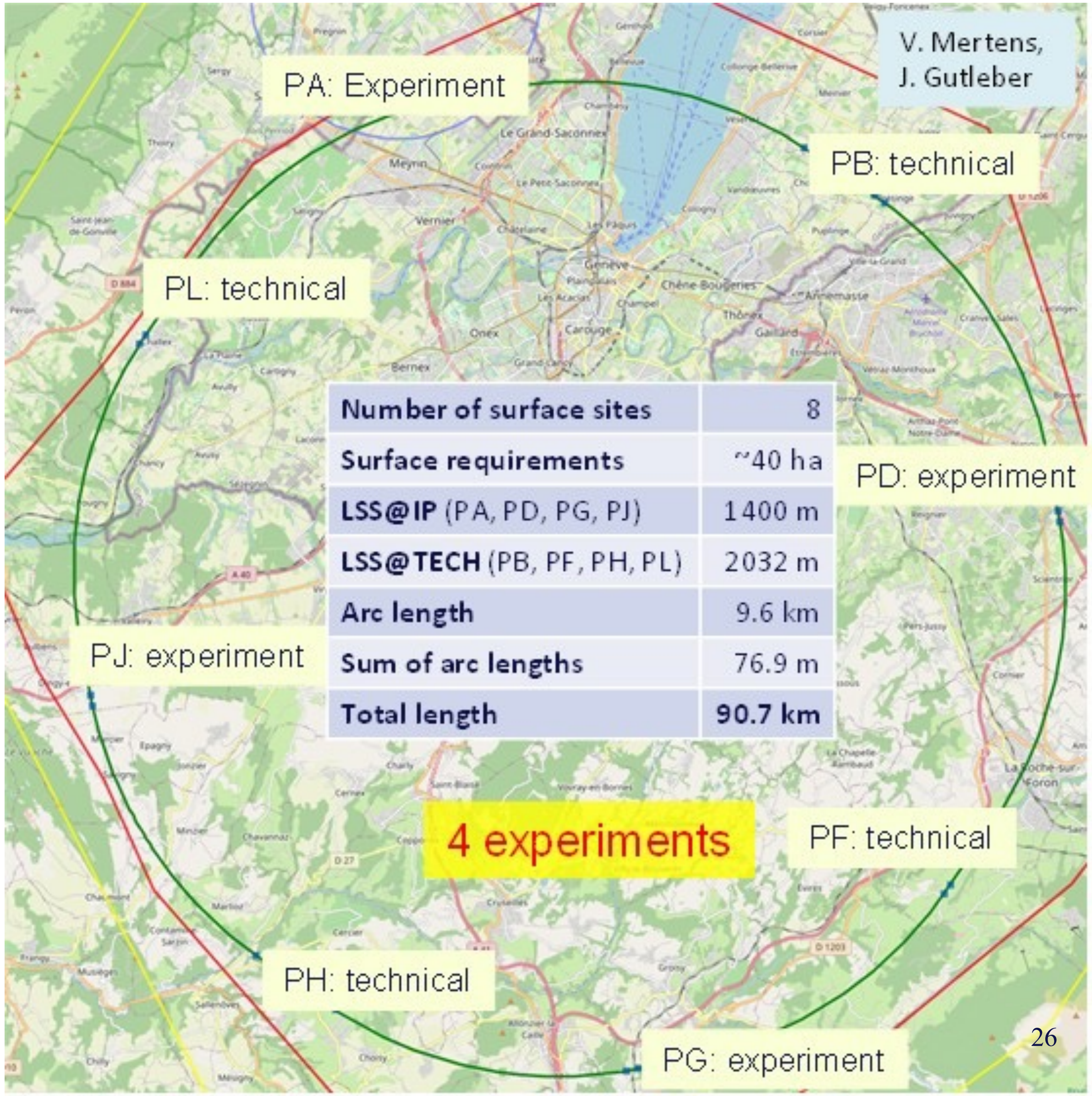
Reference layout and implementation: PA31 - 90.7 km

Layout chosen out of ~ 100 initial variants, based on several criterias:

- **geology,**
- **surface constraints** (land availability, urbanistic, etc.),
- **environment,** (protected zones),
- **infrastructure** (electricity, transport),
- **machine performance**

"Avoid-reduce-compensate" principle of EU and French regulations.

Overall lowest-risk baseline: 90.7 km ring, 8 surface points, 4-fold symmetry



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Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**

FCC-ee collider concept for maximizing luminosity

double ring collider

- many bunches, high current, like LHC and B factories, different from LEP

top-up injection

- standard at modern light sources, like SLS
- used at recent e^+e^- colliders, PEP-II (USA), KEKB (Japan), BEPCII (China)

crab-waist collision scheme

- successfully demonstrated at DAΦNE (Italy) and SuperKEKB (Japan)

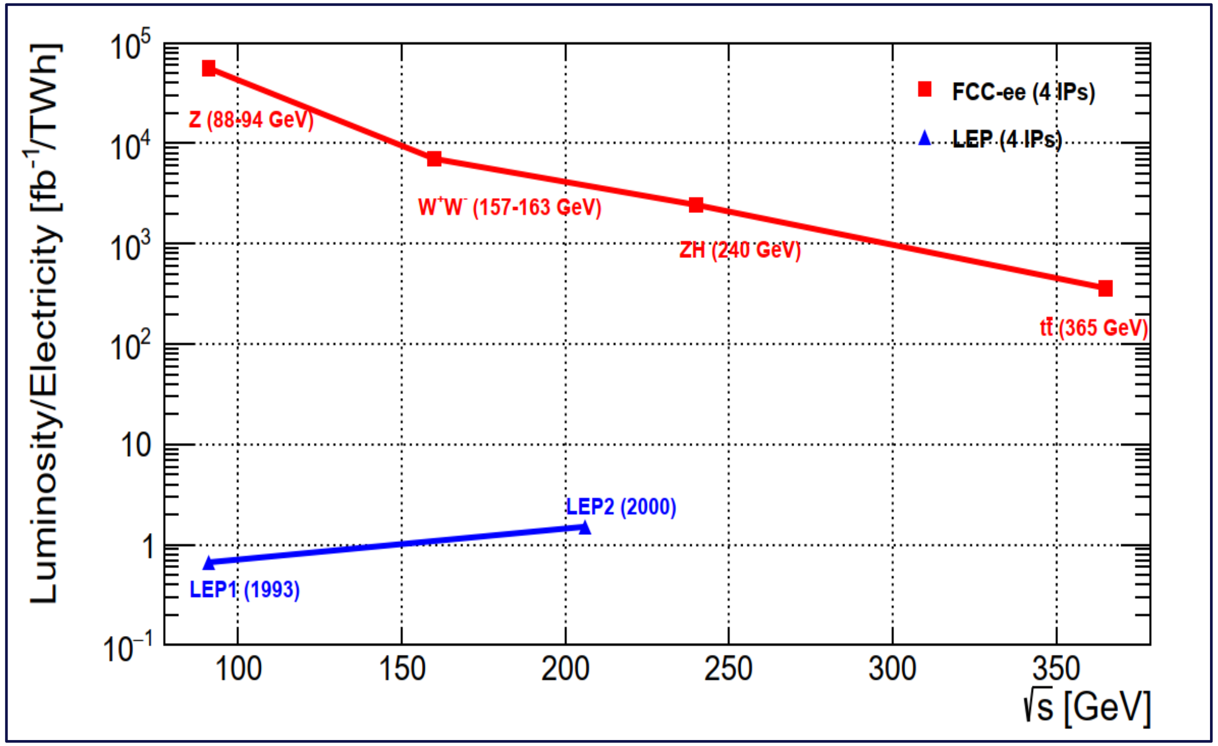
superconducting radiofrequency system

- Nb/Cu 400 MHz SC cavities pioneered at former CERN LEP
- bulk Nb 800 MHz SC cavities similar to ESS (Sweden), EuXFEL (Germany)
- revolutionary highly efficient RF power sources
- new operation scheme for flexible energy switching & reduced complexity

Combining concepts from past and present lepton colliders results in a giant step in efficiency:

→10^4 - 10^5 x luminosity/energy of LEP

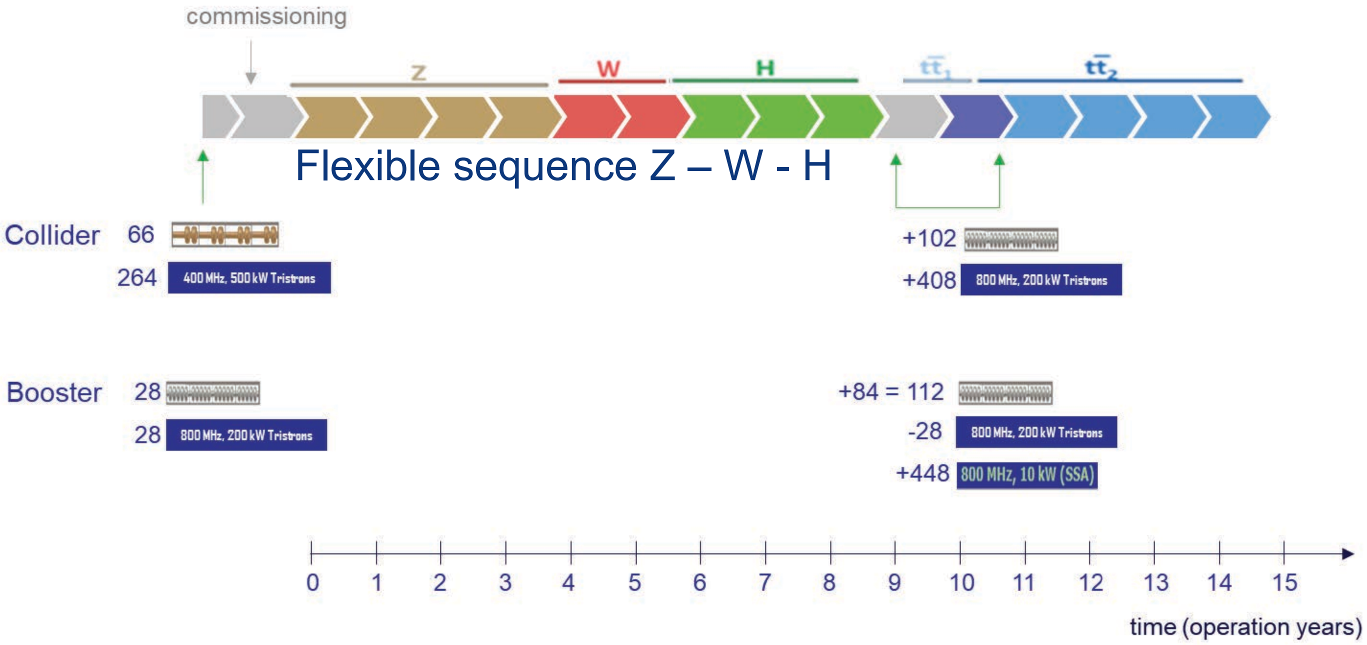
→ sustainable physics



FCC-ee main parameters and operation plan

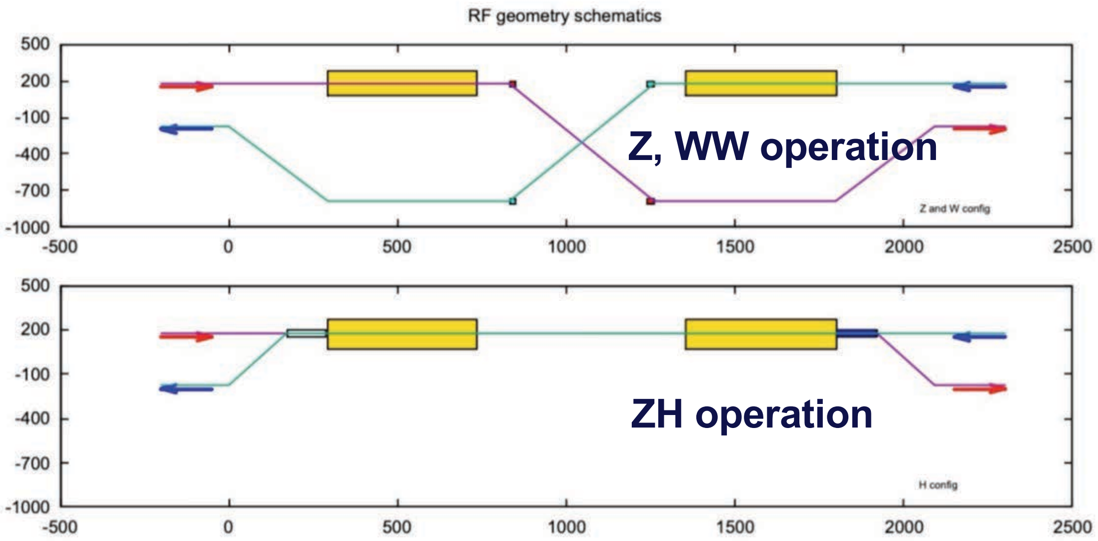
parameter	Z	WW	H (ZH)	$t\bar{t}$	
Collision energy $\sqrt{s}$ [GeV]	88, 91, 94	157, 163	240	340-350	365
synchrotron radiation/beam [MW]	50	50	50	50	50
beam current [mA]	1294	135	26.8	6.0	5.1
number bunches / beam	11200	1852	300	70	64
total RF voltage 400 / 800 MHz [GV]	0.08 / 0	1.0 / 0	2.1 / 0	2.1 / 7.4	2.1 / 9.2
luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	144	20	7.5	1.8	1.4
luminosity / year [ab^{-1}]	68	9.6	3.6	0.83	0.67
run time (including lumi ramp-up) [years]	4	2	3	1	4
total integrated luminosity [ab^{-1}]	205	19.2	10.8	0.4	2.7
total number of events	$6\ 10^{12}$ Z	$2.4\ 10^{8}$ WW (incl. WW at higher $\sqrt{s}$)	$2.2\ 10^{6}$ ZH 65k WW → H	$2\ 10^{6}$ $t\bar{t}$ + 370k ZH + 92k WW → H	

FCC-ee operation sequence and SRF concept



Flexible sequence Z – W - H

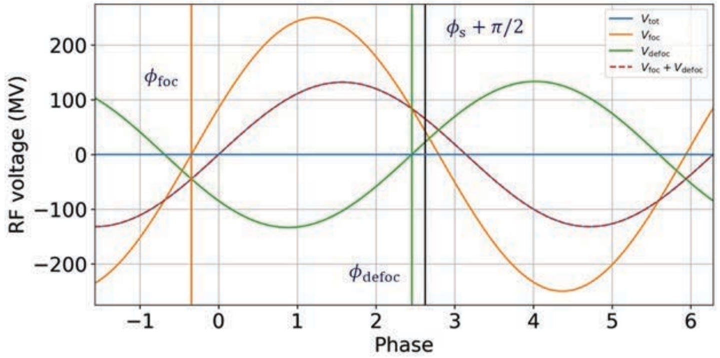
400 MHz RF layout and beam switching



Z, WW operation

ZH operation

- **2-cell 400 MHz SRF system for Z, W and ZH**, entire system installed at operation start
  - flexibility for switching between Z, WW, ZH operation
  - reverse phase operation at Z allows constant cavity coupling
  - suppression of the single-cell 400 MHz system
  - reduced R&D, installation, commissioning, etc…



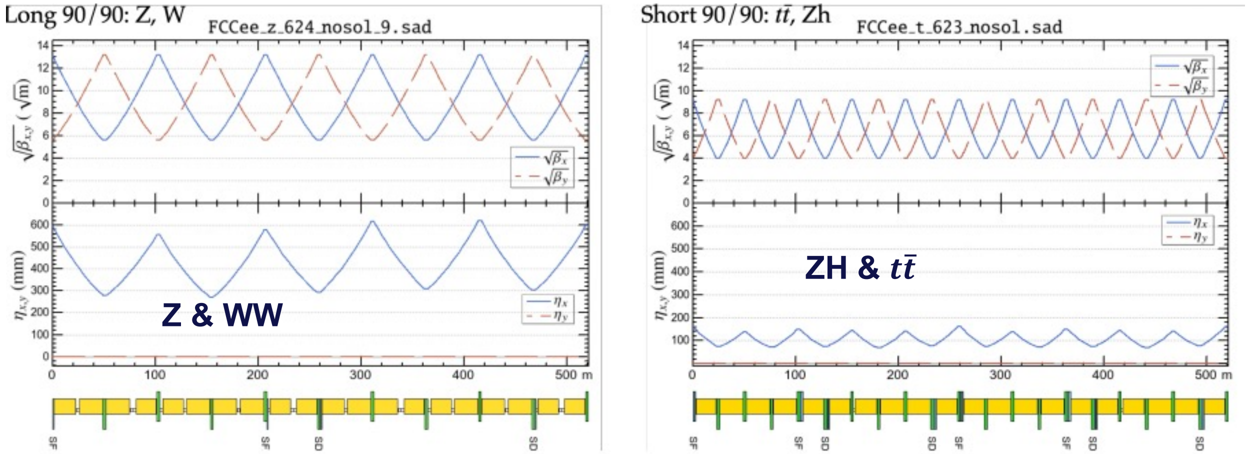
- **6-cell 800 MHz SRF system for collider ttbar operation and booster at all energies**

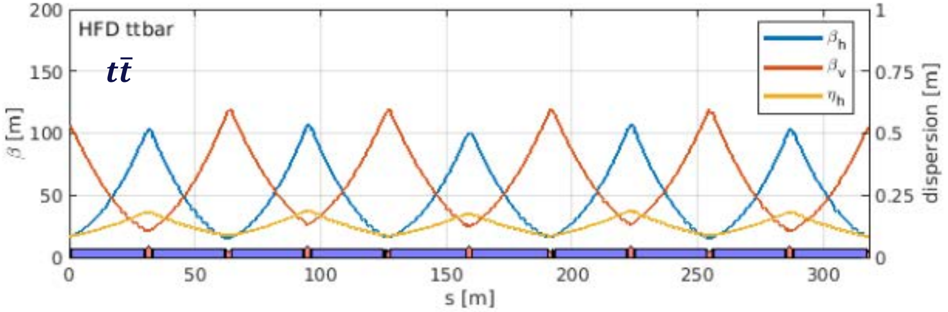
FCC-ee optics: 2 solutions meeting the requirements (ε, DA, MA)

Baseline “GHC”, K. Oide et al.

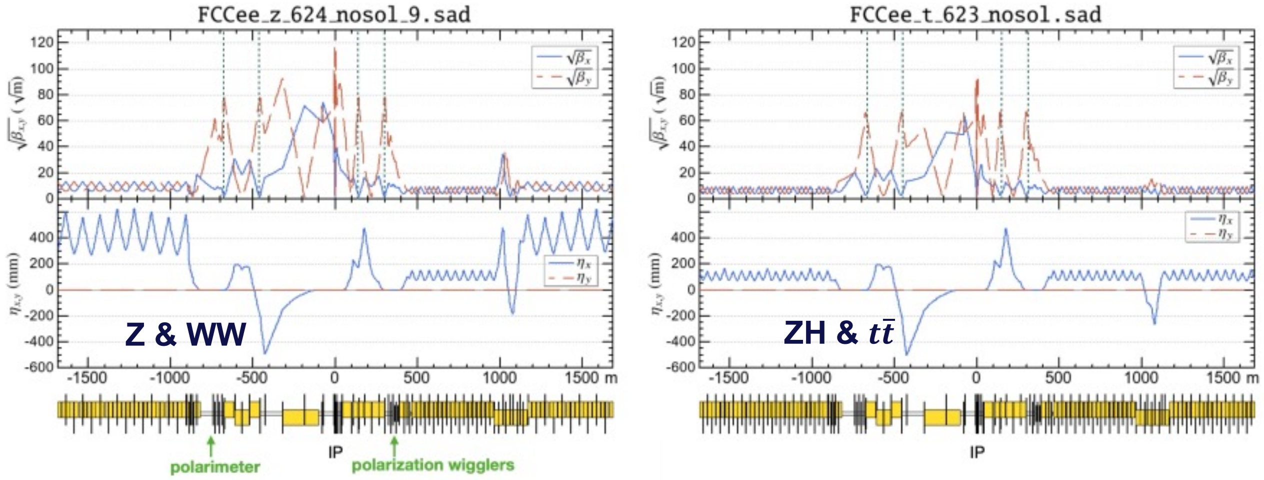
Alternative “LCC”, P. Raimondi, S. Liuzzo, et al.

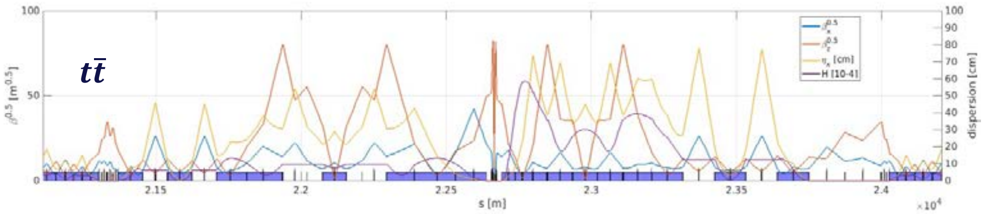
arc





experimental straight





PRAB **19**, 111005 (2016)

PRAB 28, 021002 (2025)

FCC-ee optics: beam dynamics studies

sensitivity to errors

K. Oide, UNIGE
P. Raimondi, FNAL
S. Liuzzo, S. White, ESRF
K. Andre, M. Hofer, CERN

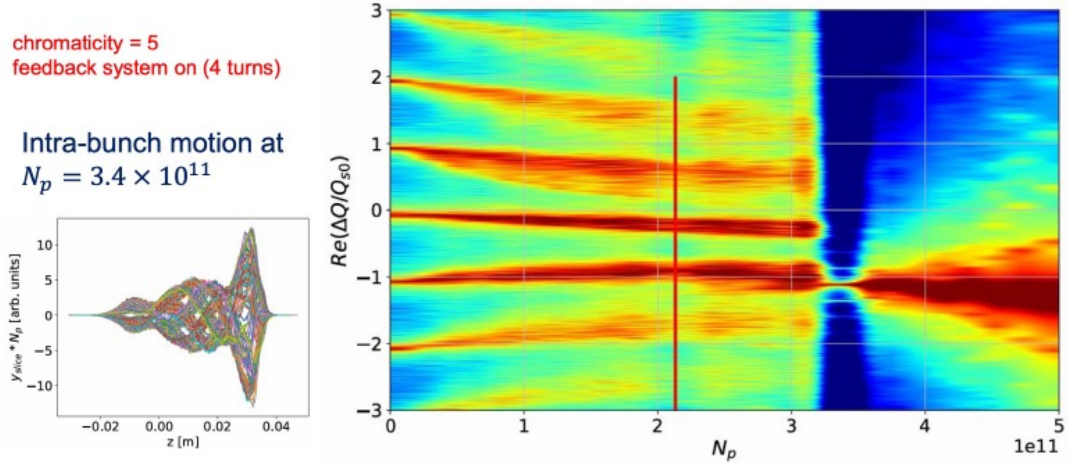
Magnet Misalignments Leading to 1% rms Beta Beating or 1 mm rms Dispersion:

Optics	$\Delta\beta_x/\beta_x$	$\Delta\beta_y/\beta_y$	D_y
GHC quadr.	2.9 μm	0.7 μm	0.1 μm
LCC quadr.	6.1 μm	0.5 μm	0.26 μm
GHC sext.	17 μm	8.5 μm	2.6 μm
LCC sext.	>100 μm	46 μm	10 μm

Collective effects in transverse plane (TMCI)

chromaticity = 5
feedback system on (4 turns)

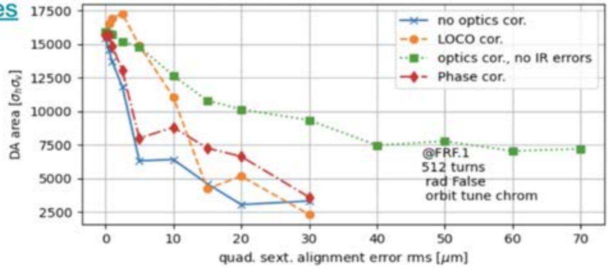
Intra-bunch motion at $N_p = 3.4 \times 10^{11}$



dynamic aperture with errors

DA after optics tuning simulations with sextupole ramp-up

S. Liuzzo's slides



GHC Z lattice

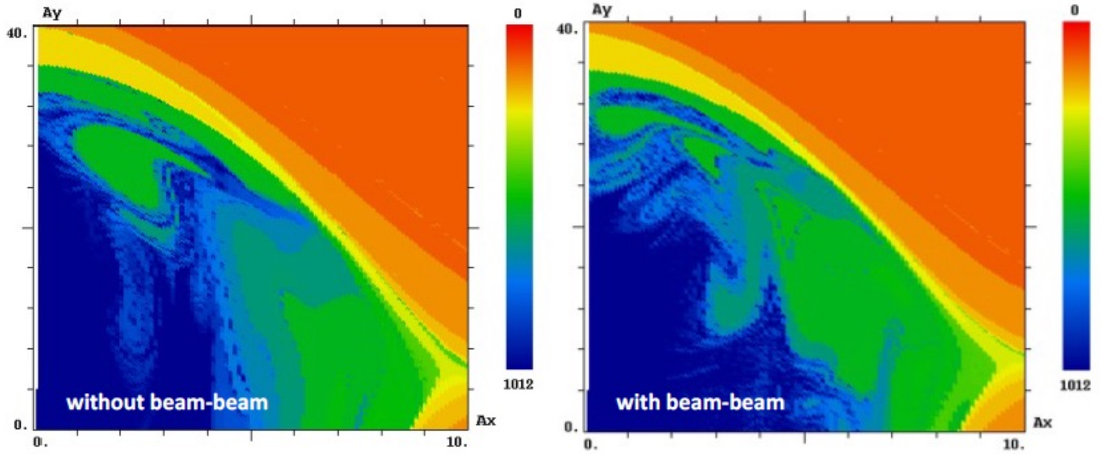
Severe reduction of DA with IR errors →Dedicated alignment system might be needed.

Mild reduction of DA when errors only applied to arcs up to 70 µm and likely beyond.

Phase advance correction does not show significant improvement for DA…

dynamic aperture with errors & w beam-beam

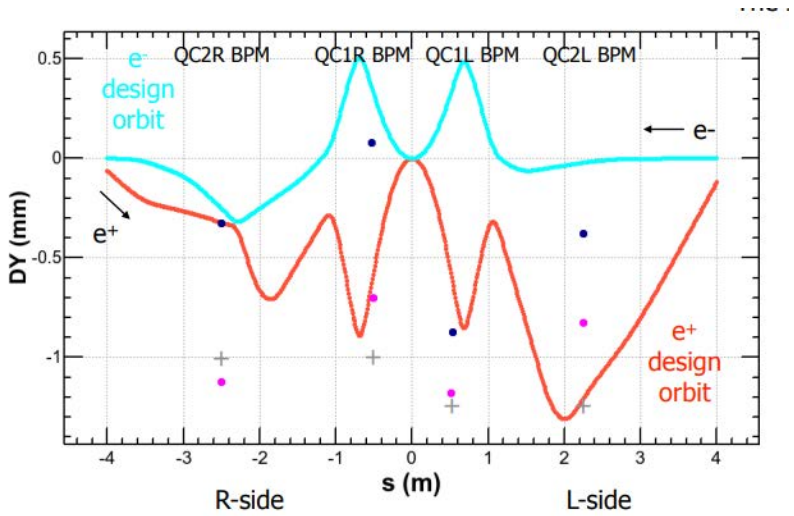
LCC, Z mode, CW 90%, δ=0.005



D. Shatilov, BINP

SuperKEKB as FCC-ee demonstrator

- FCC-ee's **"virtual" crab waist scheme** successfully implemented in ~2020
- routine operation at FCC-ee's β_y^***~1 mm**
- **beam currents > 1.3 A** (FCC-ee maximum current)

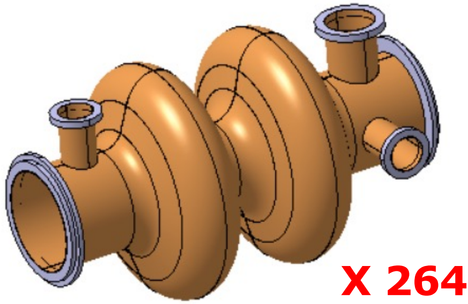


Aspects specific to SuperKEKB

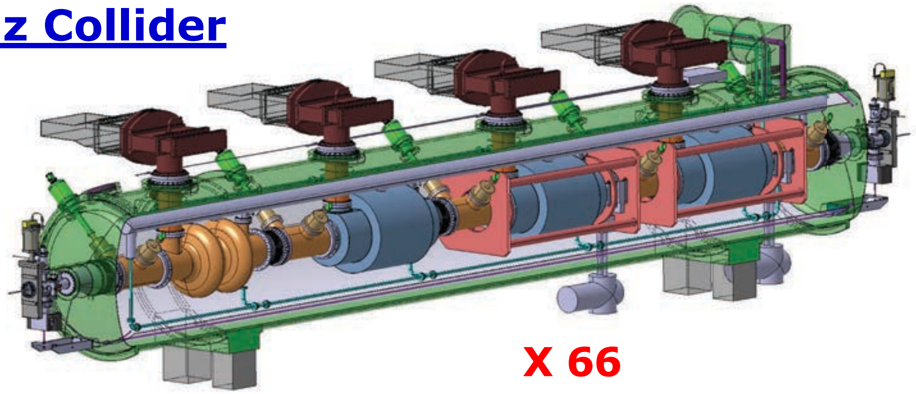
- complex **interaction region** with superimposed magnets, non-closure of optical aberrations + magnet coil manufacturing error
- **sudden beam loss** due to combination of special "MO" flange (only at KEK) and use of vacuum sealant (intruding into the chamber)
- poor injection efficiency at β_y^*~1 mm, and impossibility to squeeze much further, due to **large injected beam** (huge blow up in both transfer lines, SuperKEKB: $\varepsilon_y^{\mp} \sim 10$ nm ($\gamma\varepsilon_y^{\mp} \sim 100$ μm), FCC-ee: $\varepsilon_y^{\mp} \sim 10$ pm (1000x smaller!)
- **low specific luminosity** due to residual (large) linear & chromatic coupling at IP, space charge and feedback noise

FCC-ee RF system – key technology

400 MHz Collider



X 264



X 66

Superconducting elliptical cavity

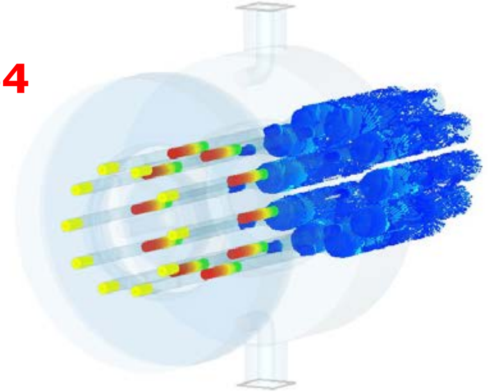
- 400 MHz, 2-cell, copper Nb coated
- 1.5 m. long

400 MHz Cryomodule

Power source: Multibeam Tristron

- Very efficient ~90 % ! <<OPEX
- 3 m long
- 50 kV
- 500 kW, CW

X 264



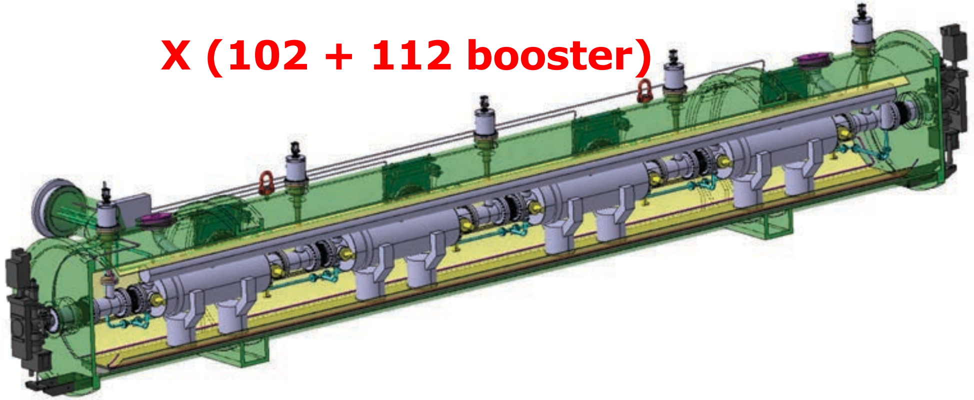
X 204

+ 448 x 10 kW SSA booster

800 MHz Collider + Booster

X (408 + 448 booster)

X (102 + 112 booster)



Superconducting elliptical cavity

- 800 MHz, 6-cell, bulk Nb
- Nb_3Sn if R&D is successful

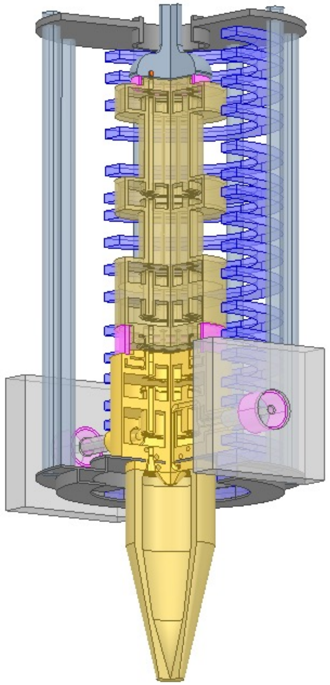
800 MHz Cryomodule

RF power source R&D – operation efficiency, sustainability, etc.

- For Z, W, ZH operation: 100 MW RF required via 264 klystron + 2-cell cavity units, 400 MHz CW.
- New 380 kW klystron prototype built with industry (HL-LHC) η = 70%, as design simulation.
- Two-stage klystron design made for η = 86%, similar to CLIC drive-beam and ILC klystrons.
- Concept for multi-beam tristron developed, η = 93% over wider range of powers → prototype 2027.
- Assumption for present FCC-ee power consumption is η = 80%.

HL-LHC (relevant prototype)

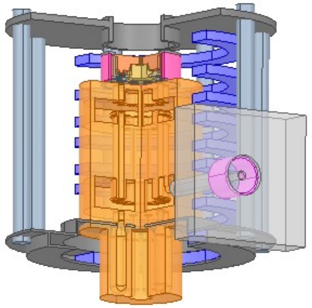
→



Two-stage klystron (design)

→

Tristron (concept)



R&D topics – energy and operational efficiency, industrialisation

3 * 92km of beam vacuum chamber
NEG-coated technology for collider
synchrotron radiation absorbers and shielding
Prototyping started

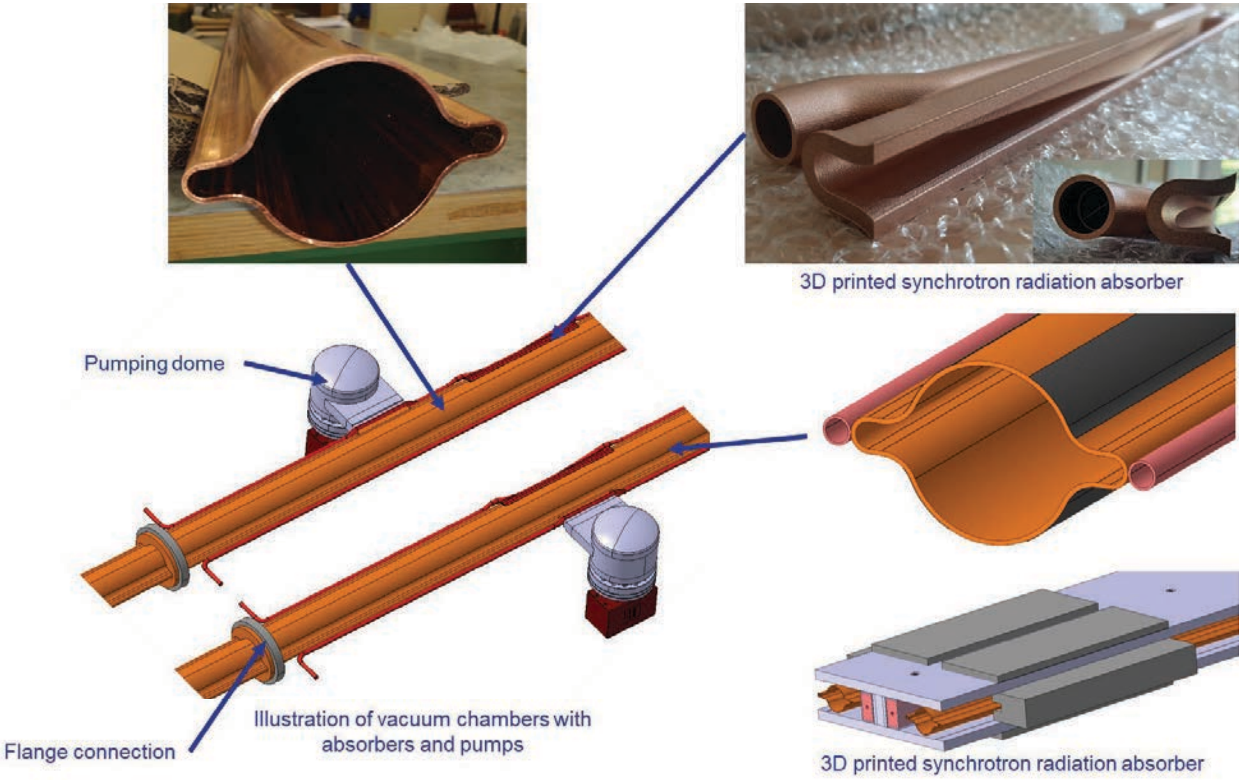
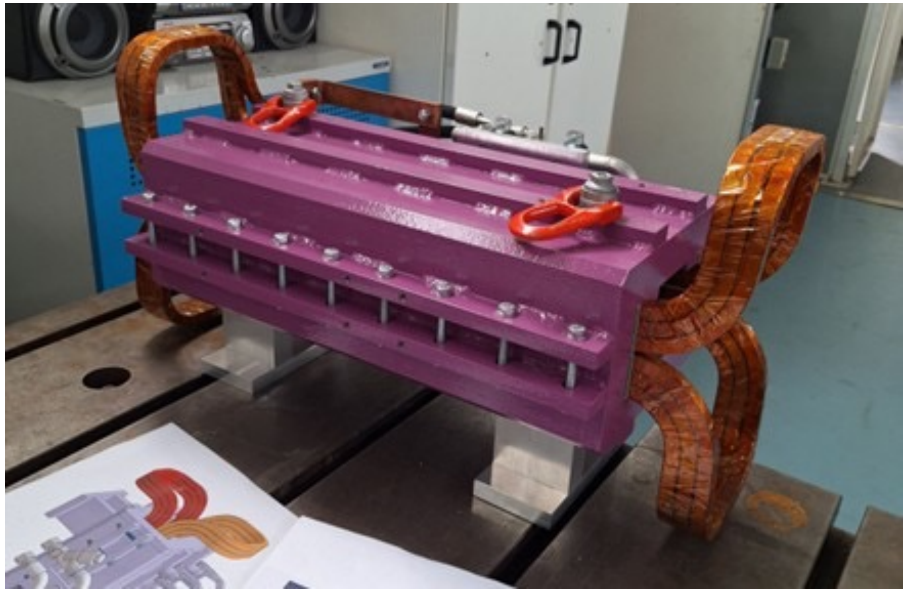

3D printed synchrotron radiation absorber

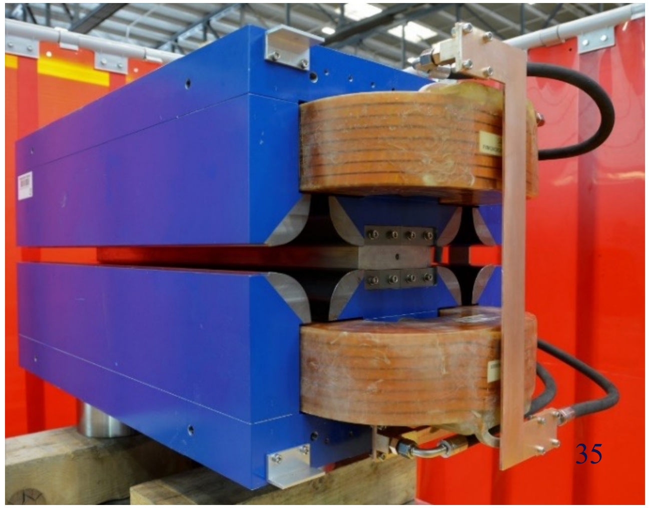
Illustration of vacuum chambers with absorbers and pumps

3D printed synchrotron radiation absorber

Booster dipole
low-field
cycling magnet

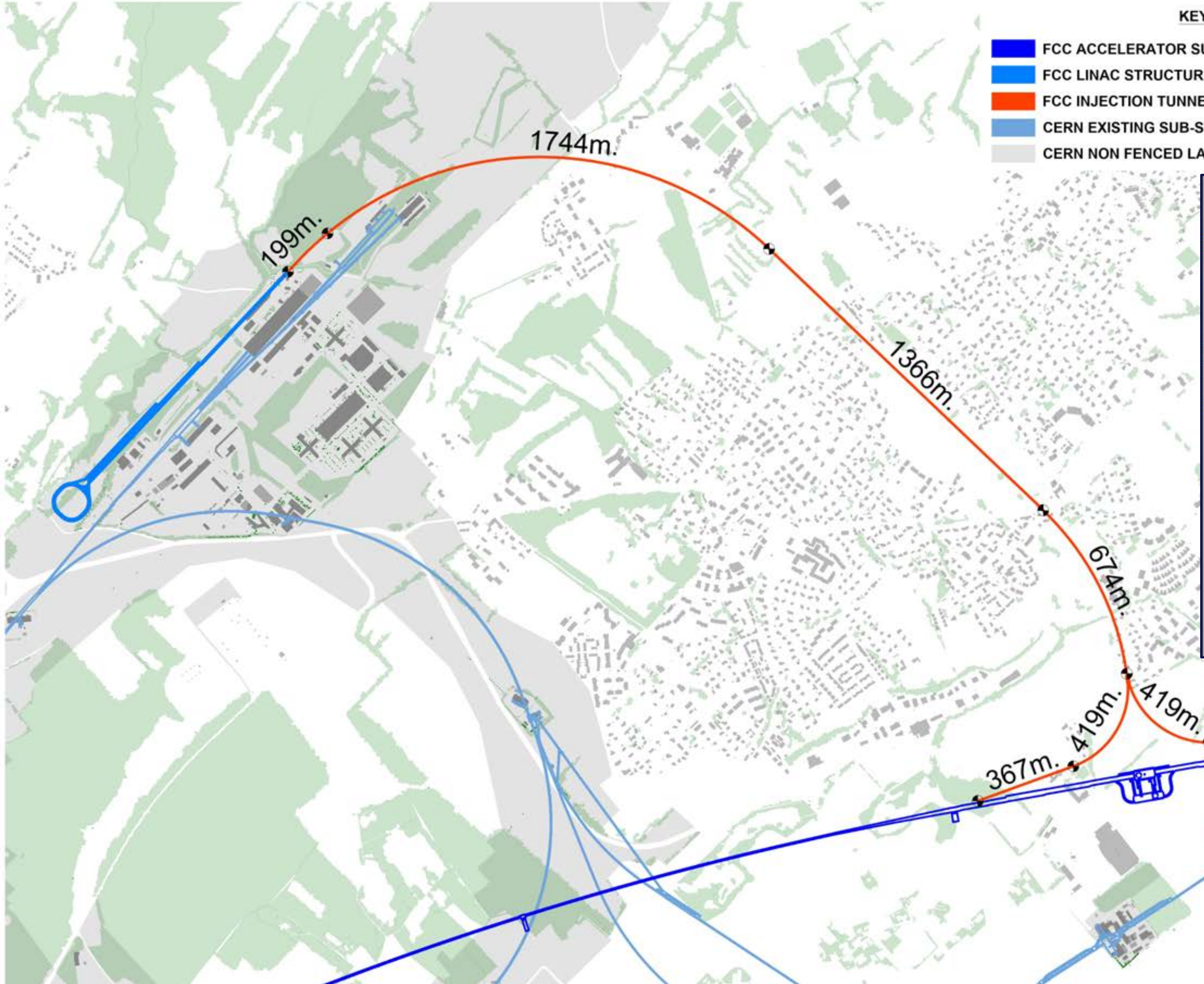


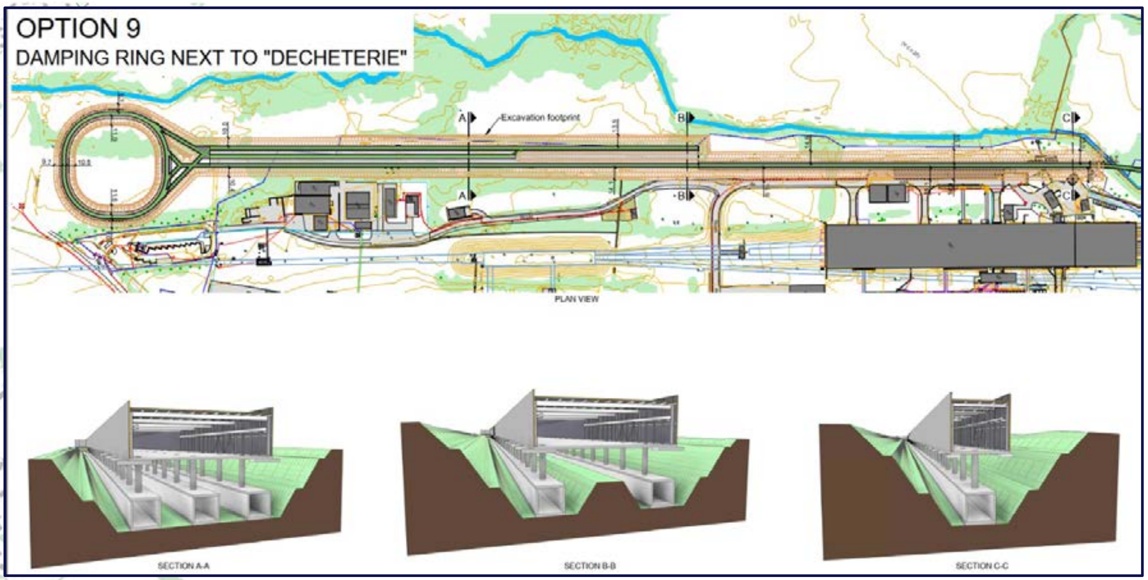
Twin F/D arc
quad design with
2× power saving
25 MW (at 175
GeV), with Cu
conductor



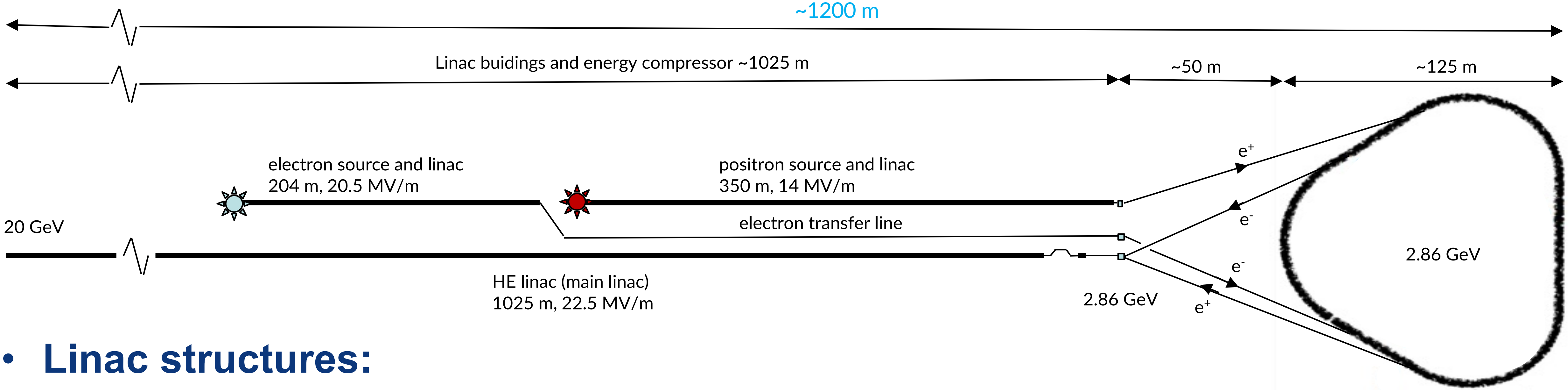
FCC-ee injector with HE Linac

- Located on CERN Prévessin site
- possible connection to North Area
- transfer line to FCC PA (LHC P8)
- “cut and cover” construction

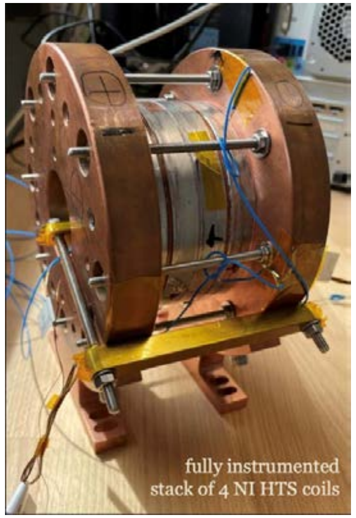


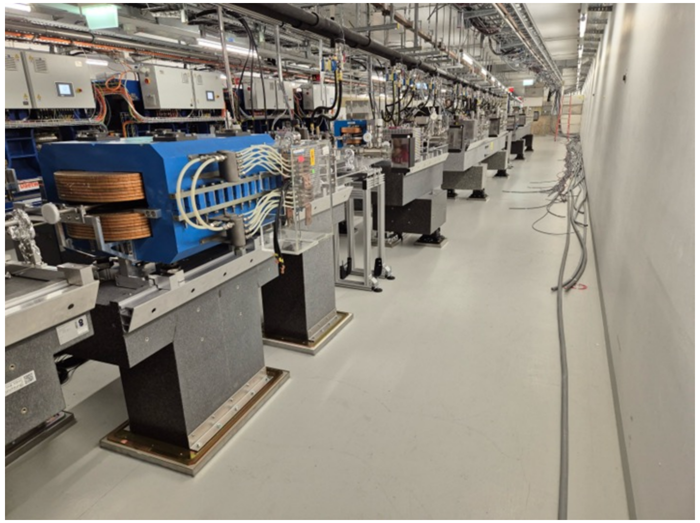


FCC-ee injector



- **Linac structures:**
  - Based on SwissFEL Linac structures;
  - 100 Hz repetition rate and moderate gradients (~20 MV/m) for reliability and low power consumption.
- **Positron source prototyping**
  - Positron yield similar to SuperKEKB
  - HTS solenoid as focusing device (tested 18 T @ 12 K)
  - proof-of-principle beam tests at PSI SwissFEL in 2026


fully instrumented
stack of 4 NI HTS coils



Environmental initial state analysis

IMPACTS SUR L'ÉCONOMIE AGRICOLE : PRÉSENTATION DES DONNES DU TABLEAU

Contract/Agreement No: B1722/SCE

Future Circular Collider

NOTE

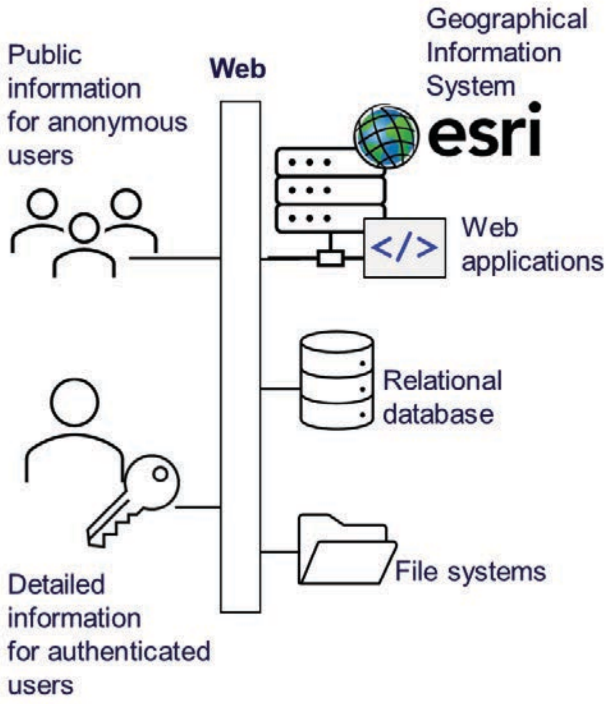
IMPACTS SUR L'ECONOMIE AGRICOLE - PRESENTATION DES DONNES TABLEUR

Document identifier:	FCC-2411180830-SEM-TableurImpactsE... Ba-V0001
Due date:	Mid-November 2024
Date:	18/11/2024
Work package/unit:	Environmental studies
Organisation:	SEM
Version:	V0001
Status:	IN WORK
Domain:	Environment
Keywords:	Agriculture

Distribution list:
Johannes Gutleber, Patrycja Laidouni, Beatriz Arias Alonso

Contract B1722/SCE PUBLIC

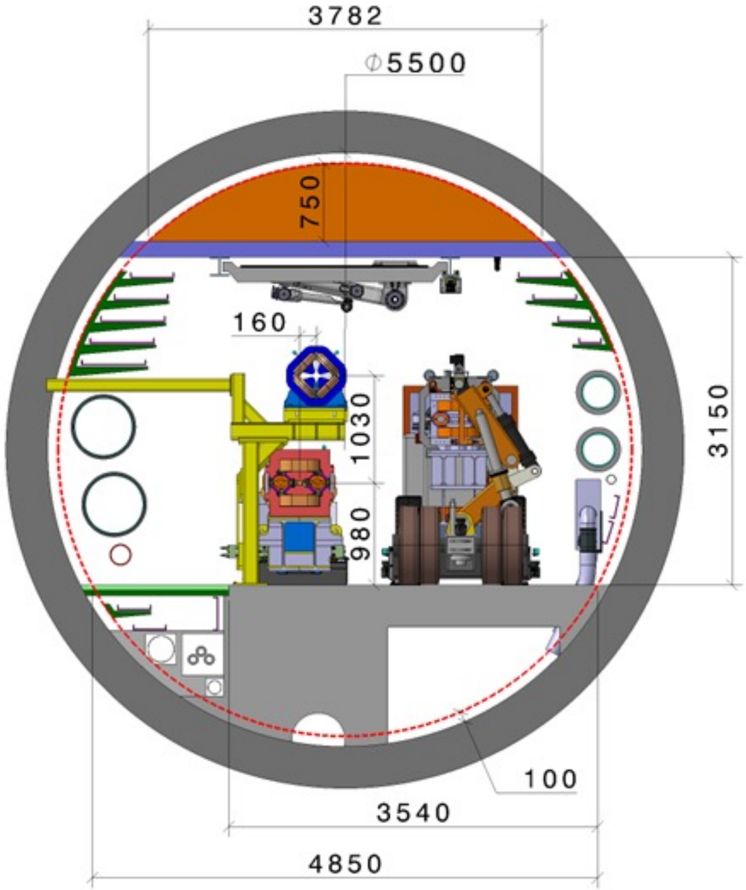
Environmental information system



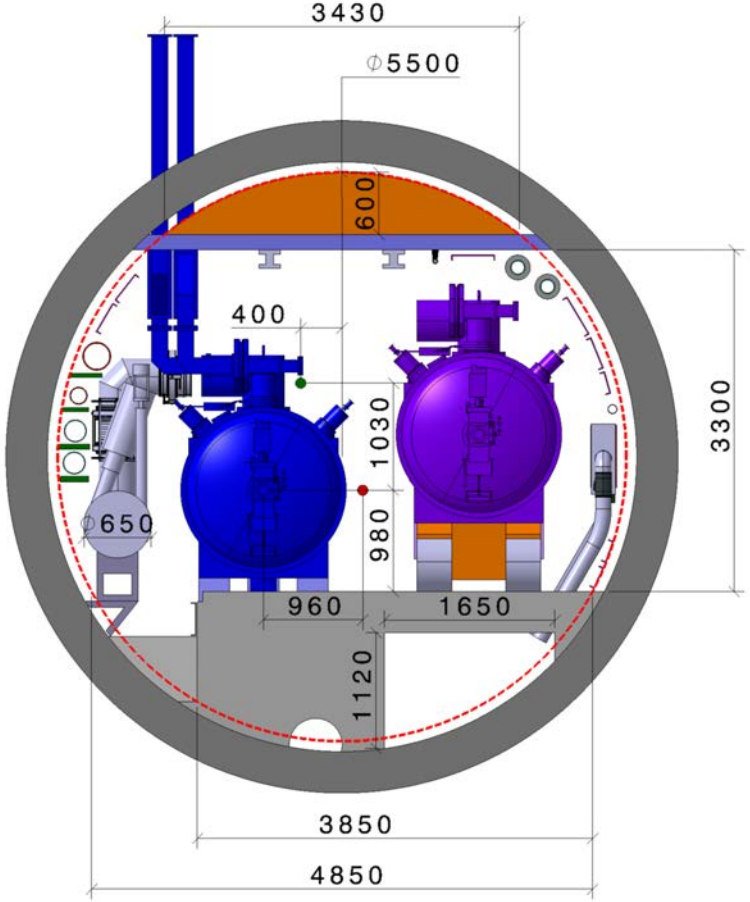
- The environmental **initial state analysis** at the eight surface site locations (~600 ha covered) **did not reveal principal showstoppers for the project**.
- **Basis for detailed optimisation of surface sites.**
- **Reference for the environmental impact assessment.**

FCC – main tunnel integration – 5.5 m inner diameter

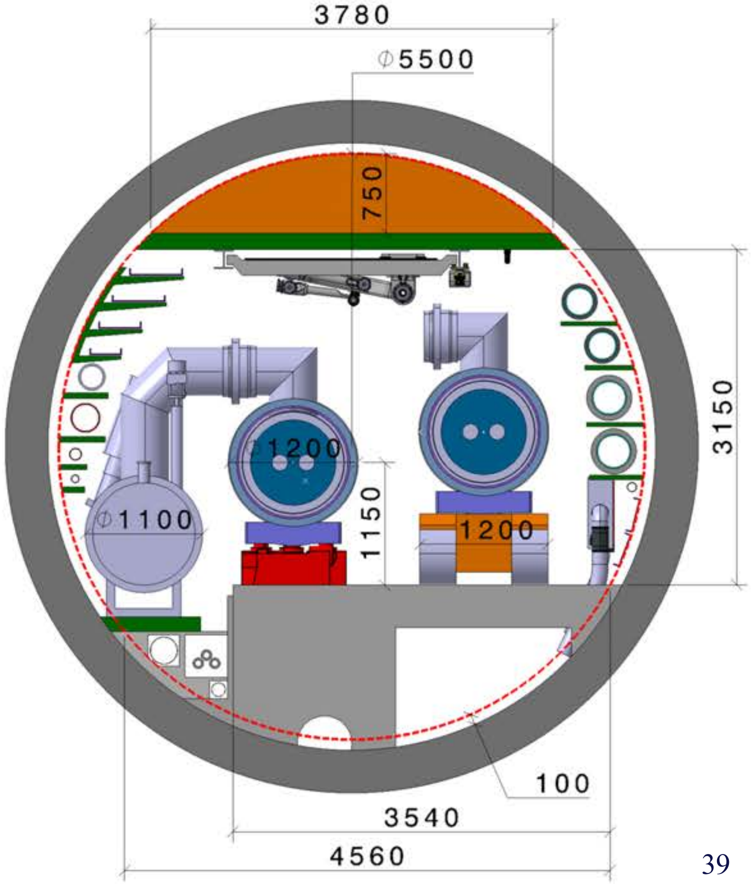
FCC-ee arc



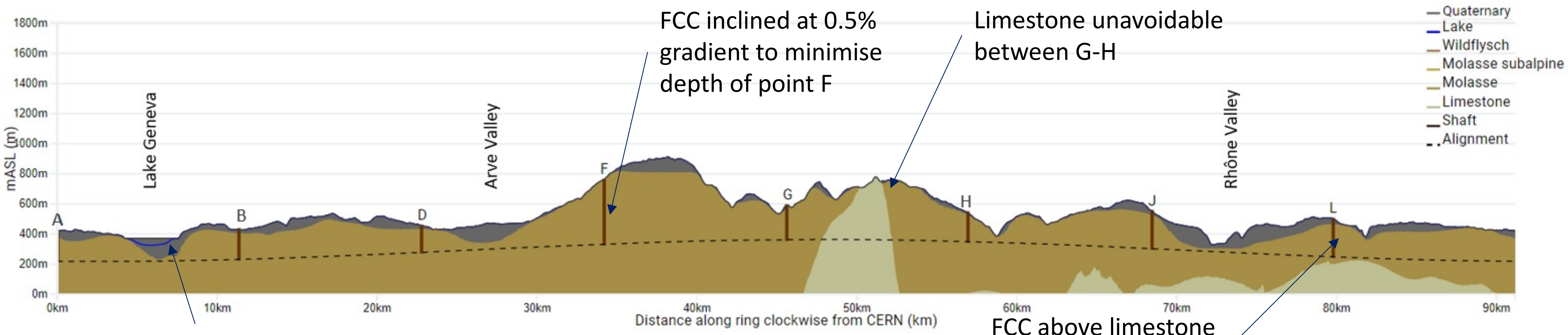
FCC-ee 400 MHz RF section



FCC-hh arc



Optimum placement of FCC tunnel and geology



FCC inclined at 0.5% gradient to minimise depth of point F

Limestone unavoidable between G-H

FCC above limestone

FCC passes below Lake Geneva moraines

Tunneling mainly in molasse layer (soft rock), well suited for fast, low-risk TBM construction.

6 million m^3 excavated volume → 8.5 million m^3 excavation material on surface

CE Designs of all underground structures developed

Average shaft depths ~240 m

To fix the vertical position of the tunnel, interfaces between geological layers have to be known

FCC – Initial Sub-Surface Investigations

28 boreholes and 80 km of seismics planned between October 2024 and December 2025

Site investigation results provide:

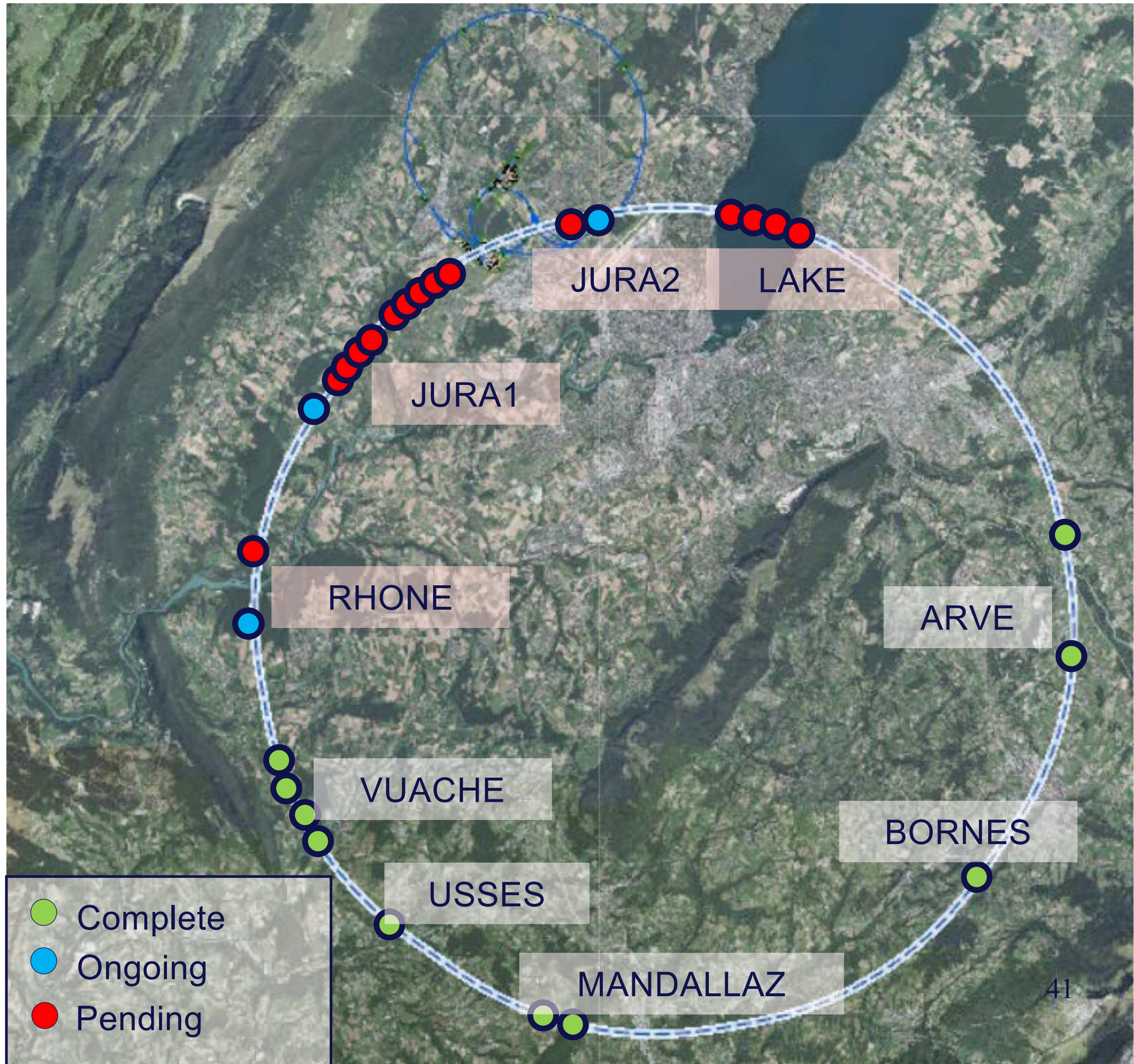
- Locations of geologic interfaces, **permitting to fix vertical position and inclination of tunnel**
- Molasse versus limestone/moraines

Southern work package status mid May 2025

- Geophysics acquisition & interpretation completed (40 km)
- All drillings completed (logging and testing ongoing)
- Preliminary results positive, confirming 3D geol model.
- Limestone passage Mandallaz less extensive.

Northern work package status mid May 2025

- 3 drill sites in France currently active, 2 more to start soon
- Still pending permits for the works in Switzerland



Reuse of excavated materials: OpenSkyLab project

- Develop a quality-managed processes to transform excavated materials into fertile soil
- Permit reuse in renaturalisation, agriculture, etc.
- Additives as compost etc. in various mixtures
- Location: 1 ha field, LHC P5 CMS Cessy (FR)
- Applicable to entire alpine molasse region!

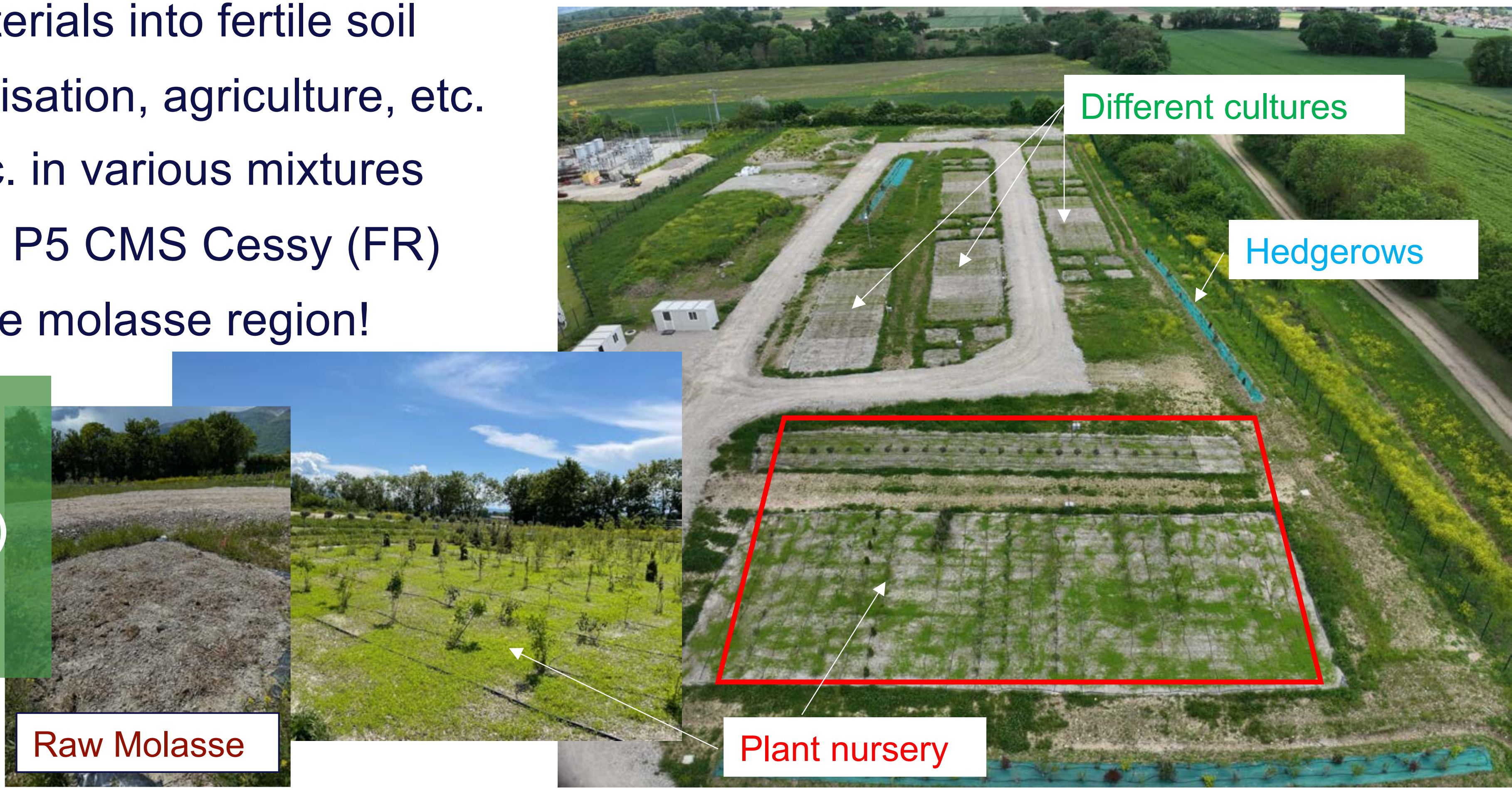
Estimate of reuse quantities:

40% refill of quarries (~ 7.5 Mt)

25% reconstituted soil (~ 4 Mt)

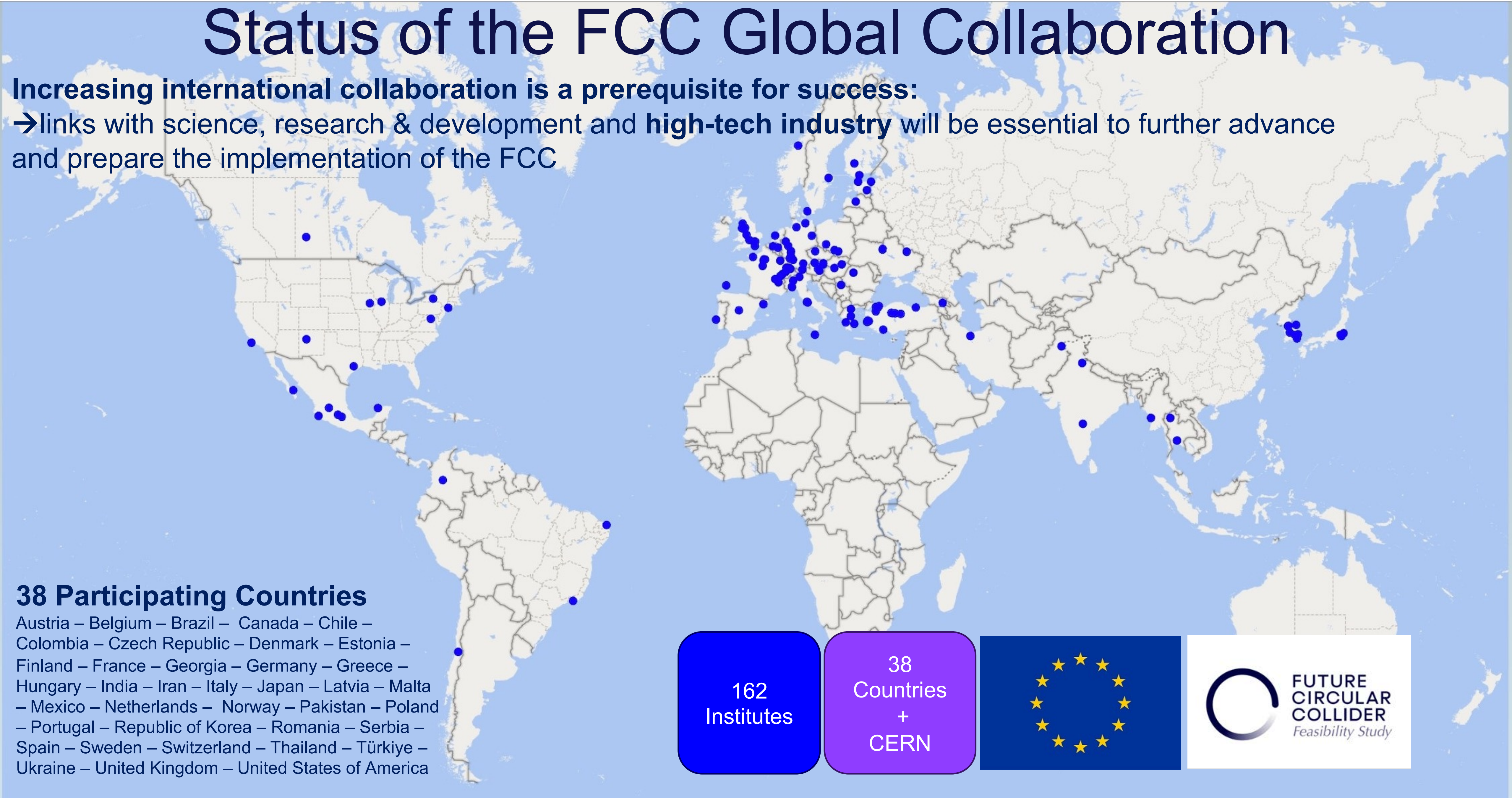
30% deposit (~ 5 Mt)

5% other reuse



hepia Haute école du paysage, d'ingénierie et d'architecture de Genève · brgm Géosciences pour une Terre durable · EDAPHOS ENGINEERING · BOKU UNIVERSITY · microhumus · MONTAN UNIVERSITÄT LEOBEN · BECC · wsp

Status of the FCC Global Collaboration



Increasing international collaboration is a prerequisite for success:
→links with science, research & development and **high-tech industry** will be essential to further advance and prepare the implementation of the FCC

38 Participating Countries

Austria – Belgium – Brazil – Canada – Chile – Colombia – Czech Republic – Denmark – Estonia – Finland – France – Georgia – Germany – Greece – Hungary – India – Iran – Italy – Japan – Latvia – Malta – Mexico – Netherlands – Norway – Pakistan – Poland – Portugal – Republic of Korea – Romania – Serbia – Spain – Sweden – Switzerland – Thailand – Türkiye – Ukraine – United Kingdom – United States of America

162 Institutes

38 Countries + CERN

FUTURE CIRCULAR COLLIDER *Feasibility Study*

LCs Accelerator Challenges and Key Technologies

Construction cost
$ ~ l

Energy

$$E_{CM} = l\,g$$

Luminosity

$$L = \frac{\eta P_{\mathrm{AC}}}{E_{\mathrm{CM}}} \cdot \frac{N_{\mathrm{e}}}{4\pi\sigma_{\mathrm{x}}^{*}\sigma_{\mathrm{y}}^{*}} H_{\mathrm{D}}$$

Operation cost
$ ~ P_{AC}

High Gradient g

Main Linac Technology

High Efficiency η

Small Beamspot $\sigma^*_x\sigma^*_y$

$$\sigma^* = \sqrt{\beta^*\,\varepsilon}$$

Losses in cavity walls

$$\frac{P_{\mathrm{wall}}}{l} \propto \frac{g^2 R_{\mathrm{s}}}{\omega}$$

Nanobeam Technology

- Damping ring (ε)
- Final focus (β^*)

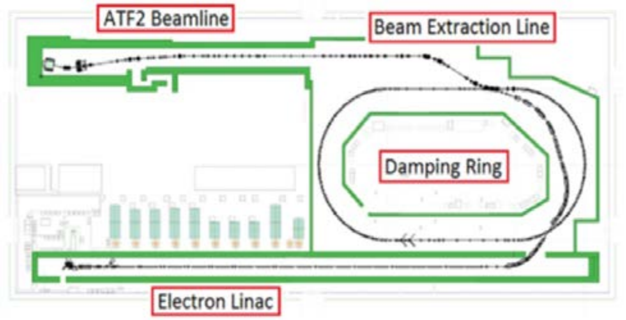
Low resistivity

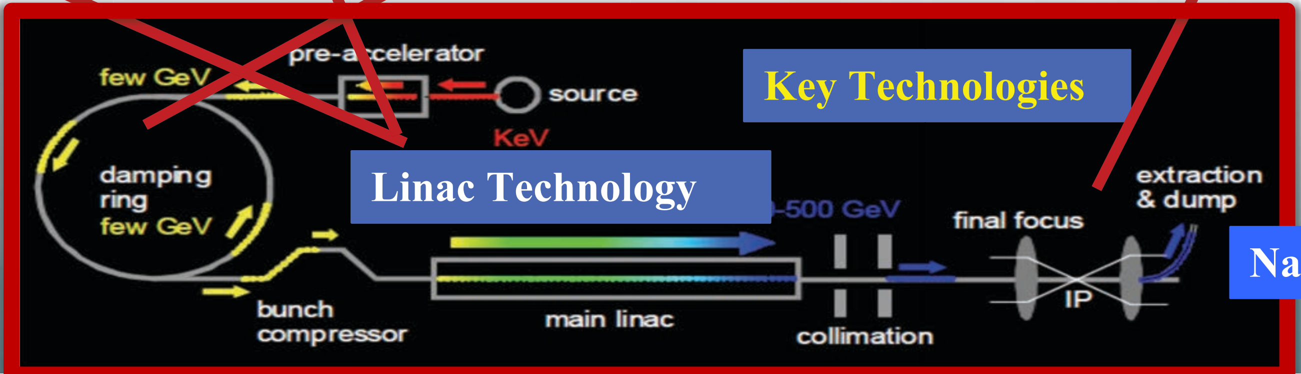
Small duty cycle:
Pulsed operation

High frequency &
Ultra-short pulses

ILC SCRF

CLIC NCRF
2 beam acceleration



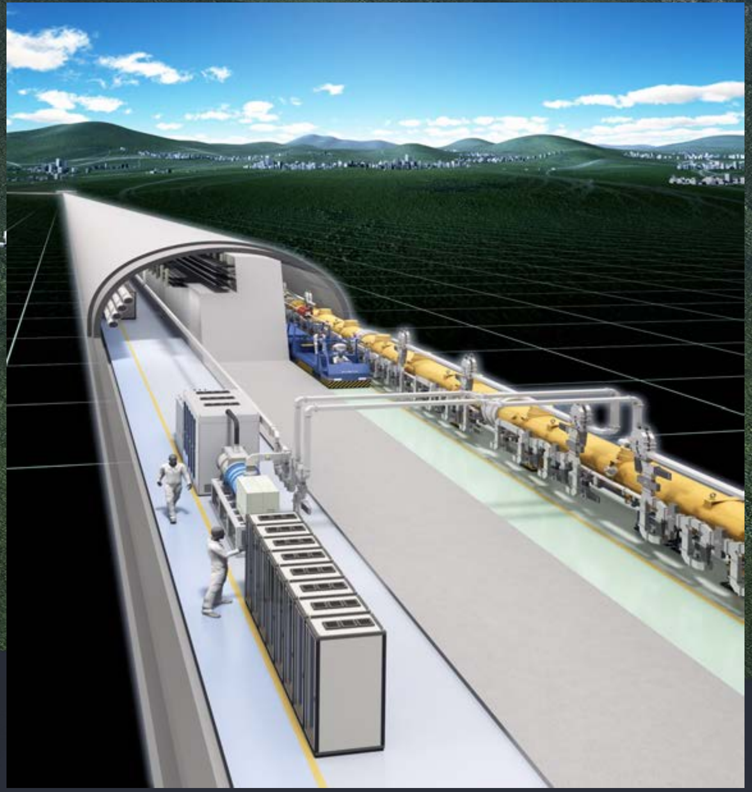


Key Technologies

Linac Technology

Nanobeam Technology

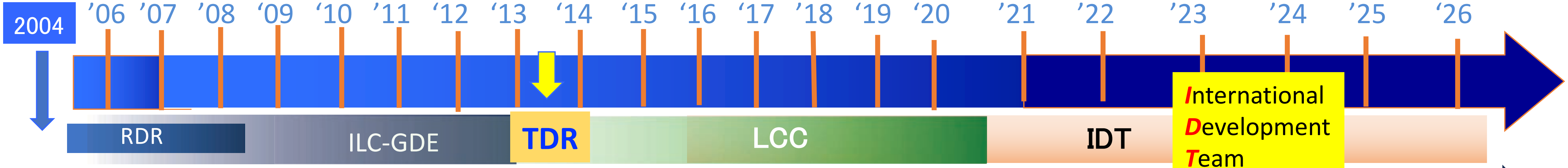
ILC accelerator: Technology updates



http://www.linearcollider.org/

History of ILC Collaboration

S. Michizono, LCWS 2025



International ***D***evelopment ***T***eam

Technology Selection by ITRP

ILC technical design

- Welcome
- Agenda
- Accomodation
- Social Program
- Registration
- Participants
- Location
- Org. Committee

International Linear Collider (ILC) Workshop

(ILC-ECFA and GDE Joint Meeting)

Valencia, 6-10 November 2006

- **General Information**

This year, the International Linear Collider Workshop organized by the European Committee for Future Accelerators (ECFA) to study the physics and detectors for a linear collider will be held together with the meeting of the Global Design Effort (GDE) committee. The event will take place in Valencia (Spain) at *Ateneo Mercantil de Valencia* and *Fundacio Universitat Empresa (ADEIT)* .

For any consultation the local contacts, telephones and address is:
Institut de Física Corpuscular (IFIC)
Edificio de Institutos de Paterna. Poligono La Coma. E-46071 Valencia.
Tel. +34 96 354 3473; +34 96 354 3474; Fax. +34 96 354 3488

- **Latest News (25/10/2006)**

You can get the poster of the conference

20 Grants for attending the conference have been assigned. They fully cover the registration fee. The accomodation could not be covered by the organization but people will be placed in the students' residences. If people having asked for a grant have not been notified of the result please contact urgently the organization (either Juan.Fuster@ific.uv.es or/and totnou@totnou.com).

People are invited to join the SiD Lunch on Thursday

Coffee-breaks will all be served at ATENEO: Salon Stolz

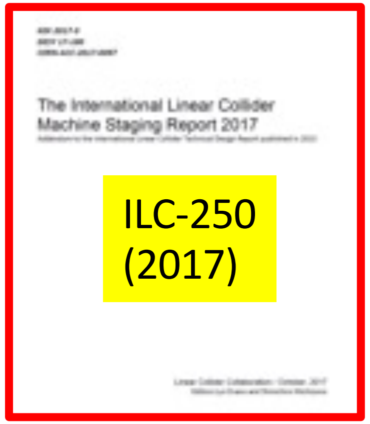
Warning: fopen(): Unable to access

https://ific.uv.es/~ilc/ECFA-GDE2006/Events.htm

Lyn Evans
LCC director
(former LHC project manager)

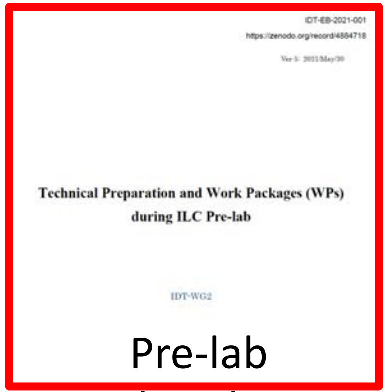
Tatsuya Nakada (EPFL)
IDT chair

ILC Technology Network (ITN)



The International Linear Collider Machine Staging Report 2017

ILC-250 (2017)

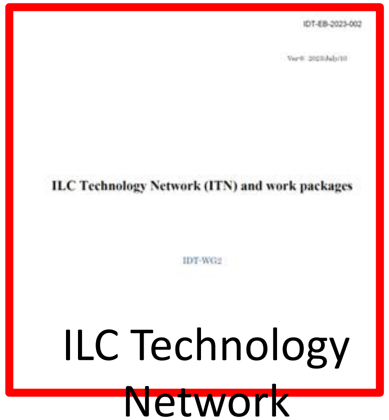


IDT-EB-2021-001
https://zenodo.org/record/4584718

Technical Preparation and Work Packages (WPs) during ILC Pre-lab

IDT-WG2

Pre-lab workpackages (May 2021)



IDT-EB-2023-002

ILC Technology Network (ITN) and work packages

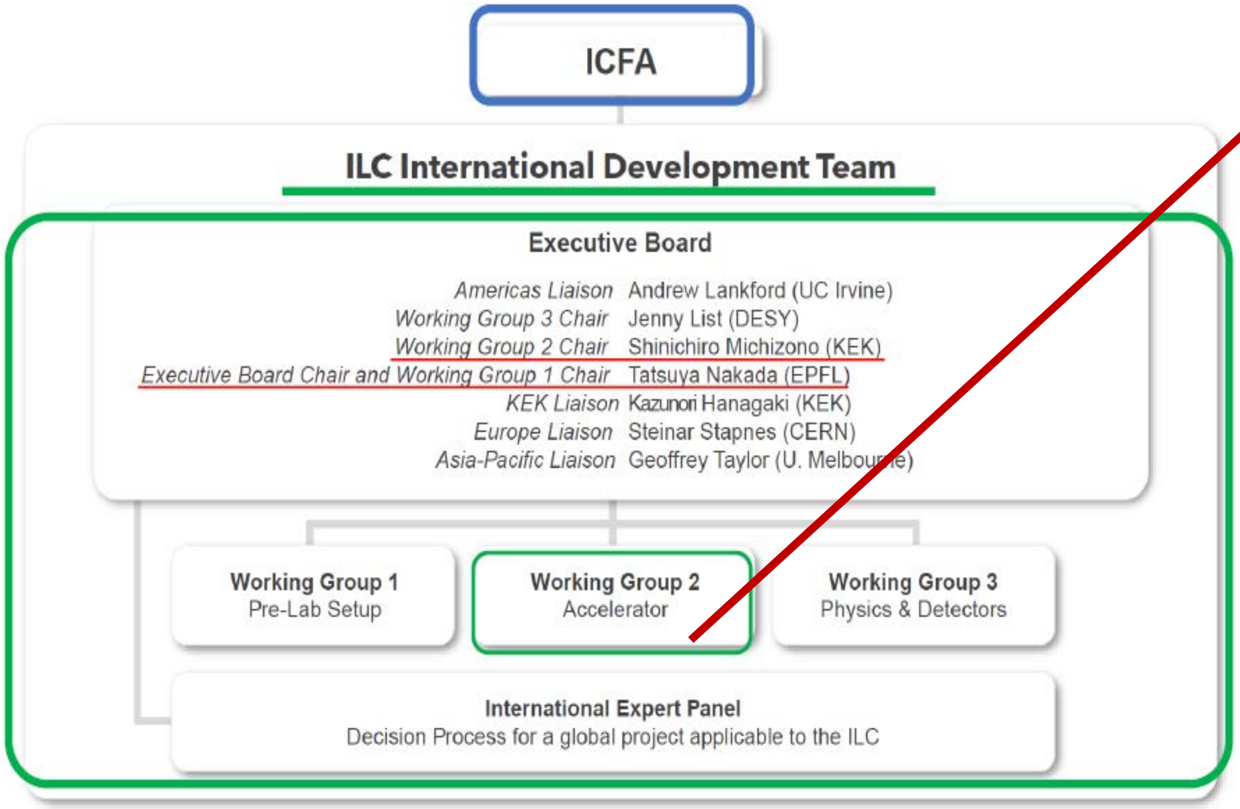
IDT-WG2

ILC Technology Network (July 2023)

IDT organization: IDT-WG2

S. Michizono, LCWS 2025

IDT organization



ICFA

ILC International Development Team

Executive Board

Americas Liaison	Andrew Lankford (UC Irvine)
Working Group 3 Chair	Jenny List (DESY)
Working Group 2 Chair	Shinichiro Michizono (KEK)
Executive Board Chair and Working Group 1 Chair	Tatsuya Nakada (EPFL)
KEK Liaison	Kazunori Hanagaki (KEK)
Europe Liaison	Steinar Stapnes (CERN)
Asia-Pacific Liaison	Geoffrey Taylor (U. Melbourne)

Working Group 1
Pre-Lab Setup

Working Group 2
Accelerator

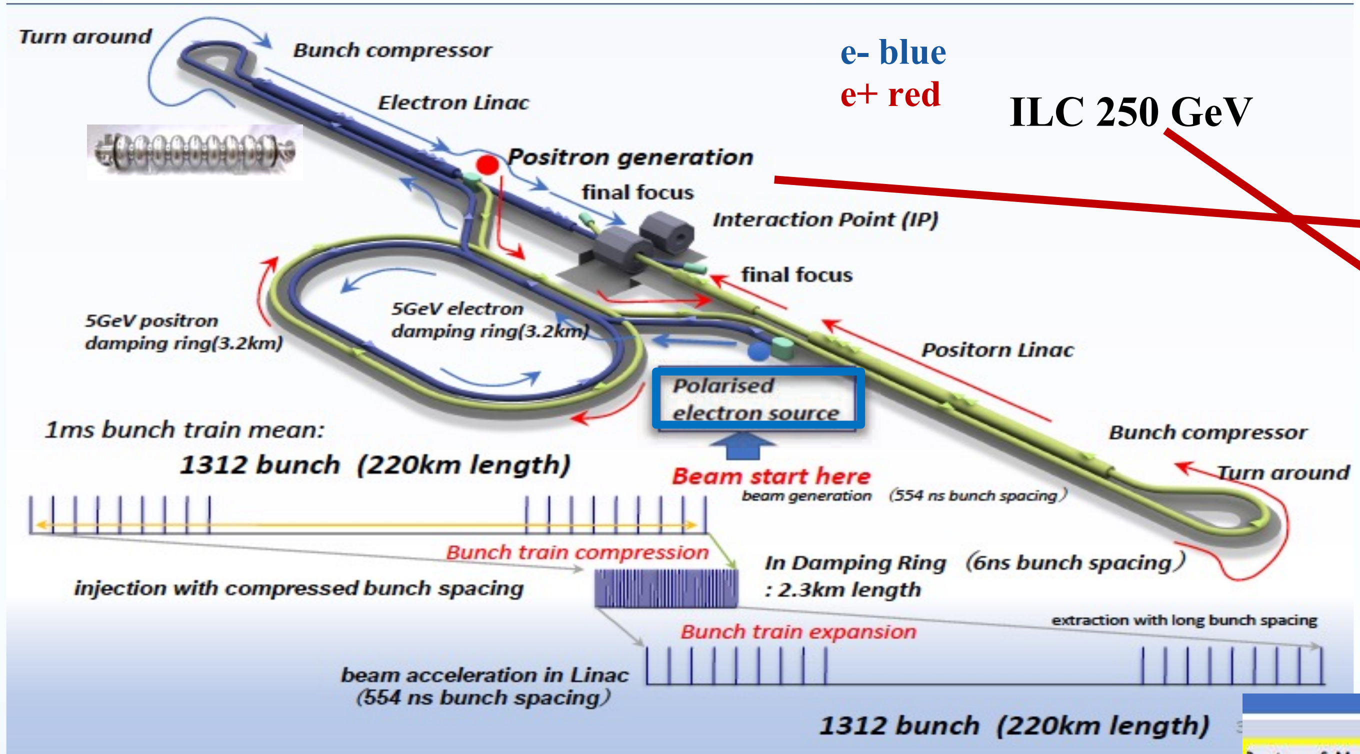
Working Group 3
Physics & Detectors

International Expert Panel
Decision Process for a global project applicable to the ILC

IDT-WG2

IDT-WG2 has about 50 accelerator researchers from around the world participating in discussions on ILC accelerator development research.

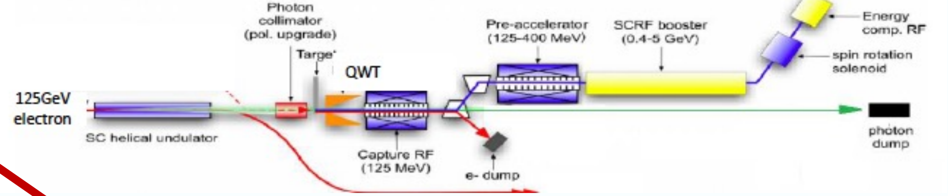
ILC parameters and beam accelerator sequence



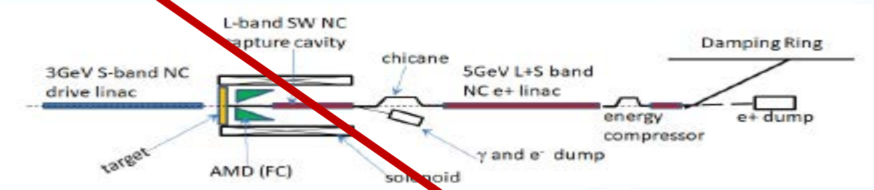
e- blue
e+ red

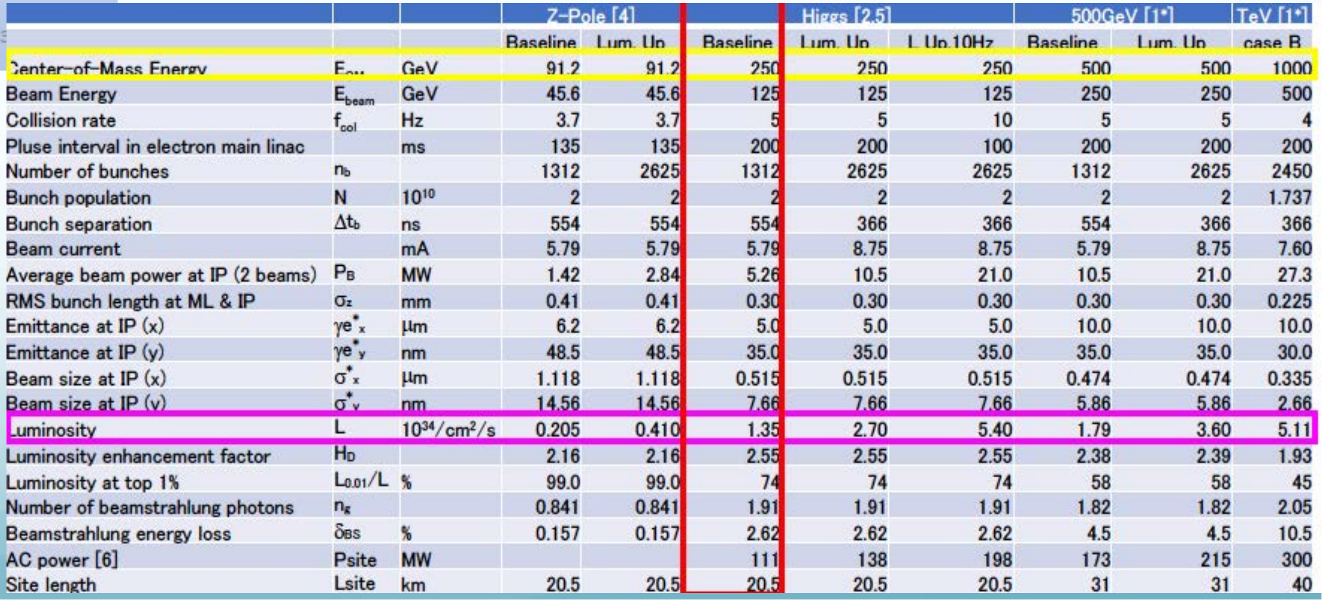
ILC 250 GeV

- **SC helical undulators** (baseline): rotating target, polarized (e$^-$ at 125 GeV)



- **Electron driven source**: dedicated 3 GeV NC S-band TW e$^-$ (pair production).

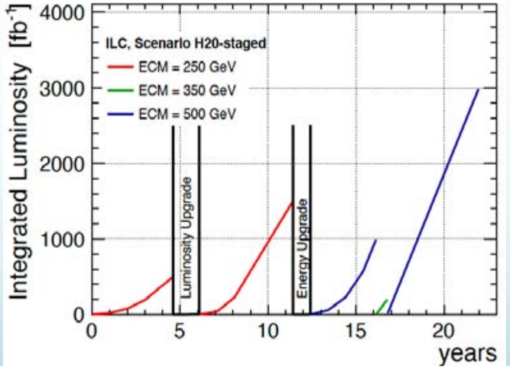


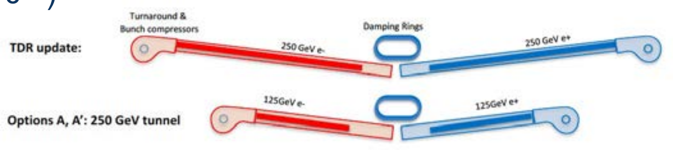


			Z-Pole [4]			Higgs [2.5]		500GeV [1*]		TeV [1*]
			Baseline	Lum. Up	Baseline	Lum. Up	L Up.10Hz	Baseline	Lum. Up	case B
Center-of-Mass Energy	E_{CM}	GeV	91.2	91.2	250	250	250	500	500	1000
Beam Energy	E_{beam}	GeV	45.6	45.6	125	125	125	250	250	500
Collision rate	f_{col}	Hz	3.7	3.7	5	5	10	5	5	4
Pluse interval in electron main linac		ms	135	135	200	200	100	200	200	200
Number of bunches	n_b		1312	2625	1312	2625	2625	1312	2625	2450
Bunch population	N	10^{10}	2	2	2	2	2	2	2	1.737
Bunch separation	Δt_b	ns	554	554	554	366	366	554	366	366
Beam current		mA	5.79	5.79	5.79	8.75	8.75	5.79	8.75	7.60
Average beam power at IP (2 beams)	P_B	MW	1.42	2.84	5.26	10.5	21.0	10.5	21.0	27.3
RMS bunch length at ML & IP	σ_z	mm	0.41	0.41	0.30	0.30	0.30	0.30	0.30	0.225
Emittance at IP (x)	γe^*_x	μm	6.2	6.2	5.0	5.0	5.0	10.0	10.0	10.0
Emittance at IP (y)	γe^*_y	nm	48.5	48.5	35.0	35.0	35.0	35.0	35.0	30.0
Beam size at IP (x)	σ^*_x	μm	1.118	1.118	0.515	0.515	0.515	0.474	0.474	0.335
Beam size at IP (y)	σ^*_y	nm	14.56	14.56	7.66	7.66	7.66	5.86	5.86	2.66
Luminosity	L	$10^{34}/cm^2/s$	0.205	0.410	1.35	2.70	5.40	1.79	3.60	5.11
Luminosity enhancement factor	H_D		2.16	2.16	2.55	2.55	2.55	2.38	2.39	1.93
Luminosity at top 1%	$L_{0.01}/L$	%	99.0	99.0	74	74	74	58	58	45
Number of beamstrahlung photons	n_γ		0.841	0.841	1.91	1.91	1.91	1.82	1.82	2.05
Beamstrahlung energy loss	δ_{BS}	%	0.157	0.157	2.62	2.62	2.62	4.5	4.5	10.5
AC power [6]	Psite	MW			111	138	198	173	215	300
Site length	Lsite	km	20.5	20.5	20.5	20.5	20.5	31	31	40

- **Energy upgrades**: 500 GeV (31.5 MV/m $Q_0=1 \times 10^{10}$) , 1TeV (45 MV/m $Q_0=2 \times 10^{10}$, 300 MW) more SCRF, tunnel extension
  - Kitakami site: 50km long, sufficient for 1TeV

- **Luminosity upgrades**:
  - 2 x bunches, 2 x RF (1.35 -> 2.7x10^{34})
  - Run = 500GeV machine at 250GeV, 10Hz: factor 2 (2.7x10^{34} -> 5.4x10^{34})
  - Improve power efficiency





ILC Technology Network

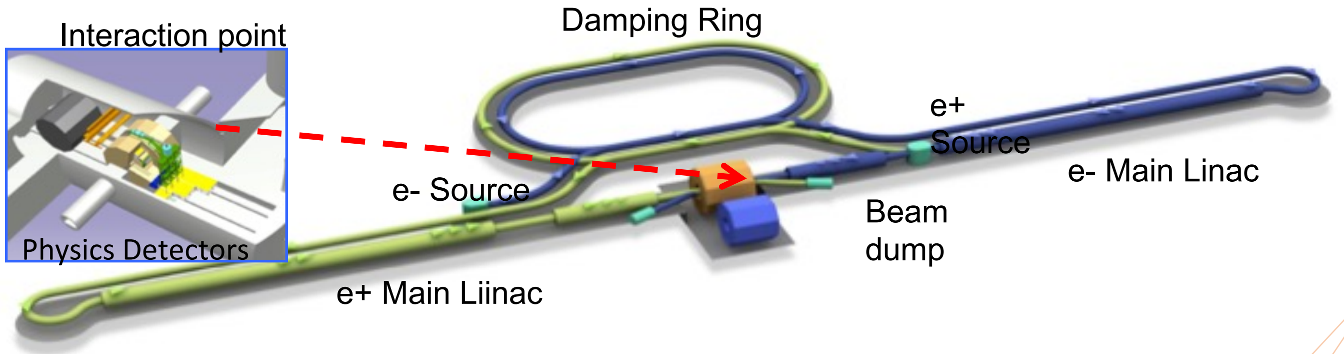
S. Michizono, LCWS 2025

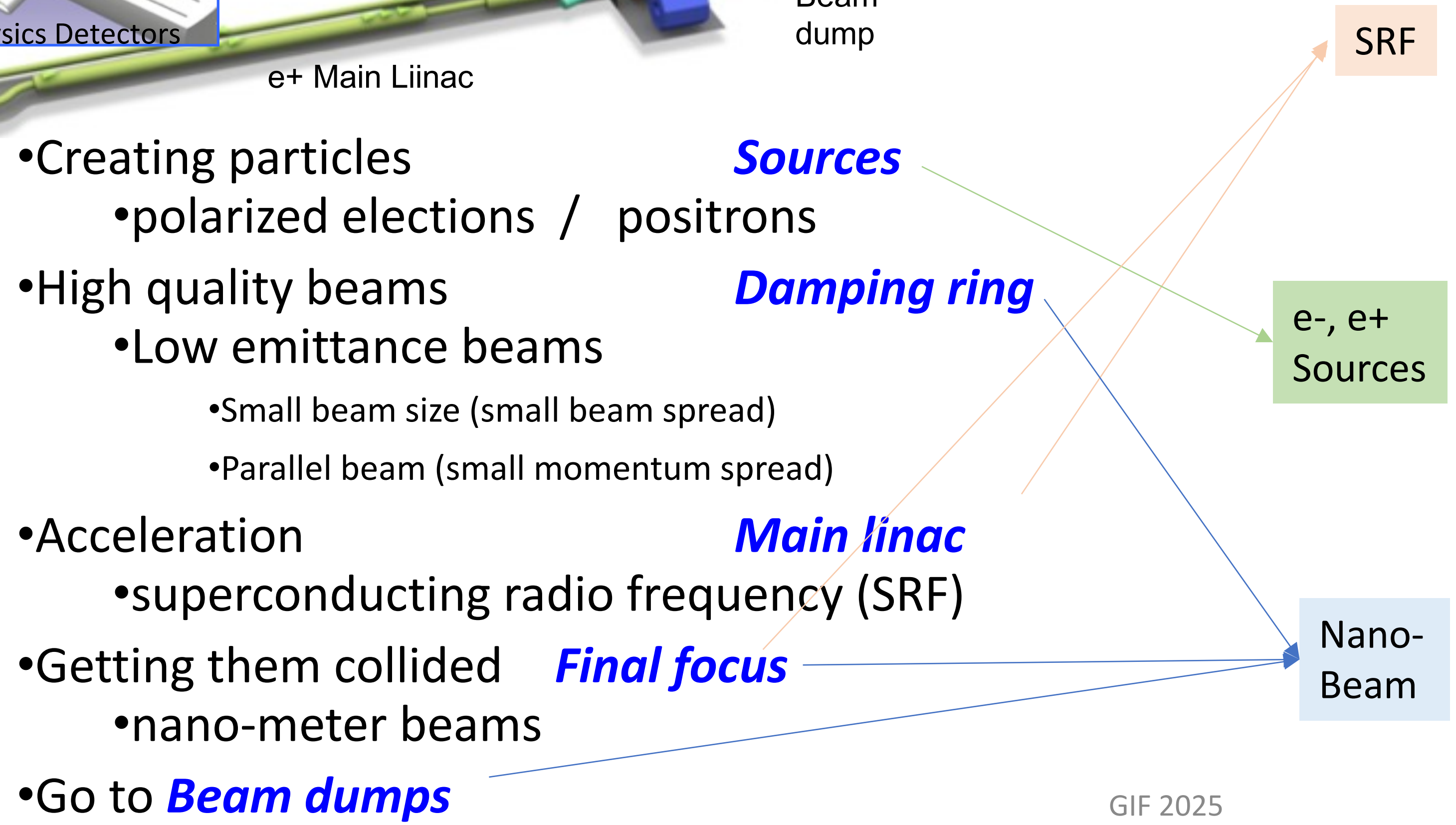
Time-consuming and essential work packages for ILC are summarized as **ILC Technology Network (ITN)**. (~4-year plan)
https://linearcollider.org/wp-content/uploads/2023/09/IDT-EB-2023-002.pdf

ILC Technology Network (ITN)

-- global collaboration program--

- **Acc. R&Ds** focusing on
  - SRF
  - e- & e+ Sources
  - Nano-beam





- Creating particles *Sources*
  - polarized elections / positrons
- High quality beams *Damping ring*
  - Low emittance beams
    - Small beam size (small beam spread)
    - Parallel beam (small momentum spread)
- Acceleration *Main linac*
  - superconducting radio frequency (SRF)
- Getting them collided *Final focus*
  - nano-meter beams
- Go to *Beam dumps*

WPP	1	Cavity production	Jp., Eu. ,Kr.
WPP	2	CM design	Jp., Eu. ,Kr.
WPP	3	Crab cavity	
WPP	4	E- source	
WPP	6	Undulator target	Ger.
WPP	7	Undulator focusing	Ger.
WPP	8	E-driven target	Jp.
WPP	9	E-driven focusing	Jp.
WPP	10	E-driven capture	Jp.
WPP	11	Target replacement	Jp.
WPP	12	DR System design	Jp. Kr., Au.
WPP	14	DR Injection/extraction	UK
WPP	15	Final focus	Jp., Eu., Kr.
WPP	16	Final doublet	
WPP	17	Main dump	Jp.

ILC Technology Network

S. Michizono, LCWS 2025

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https://linearcollider.org/wp-content/uploads/2023/09/IDT-EB-2023-002.pdf

ITN is useful not only for the ILC but also **for various advanced accelerators**

- Creating particles
  - polari
- High qu
  - Low
    - S
    - Pa ead)
- Acceleratio *Main linac*
  - superco ting radio frequency (SRF)
- Getting them collided *Final focus*
  - nano-meter beams
- Go to ***Beam dumps***

e-, e+ Sources

Nano-Beam

ILC Technology Network (ITN)

-- global collaboration program--

cc. R&Ds focusing on

SRF

e- & e+ Sources

ano-beam

		roduction	Jp., Eu. ,Kr.
		design	Jp., Eu. ,Kr.
		Crab cavity	
WPP	4	E- source	
WPP	6	Undulator target	Ger.
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WPP	14	DR Injection/extraction	UK
WPP	15	Final focus	Jp., Eu., Kr.
WPP	16	Final doublet	
WPP	17	Main dump	Jp.

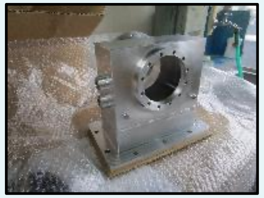
WPP-1/2 cavity fabrication & cryomodule (KEK plan)

S. Michizono, LCWS 2025

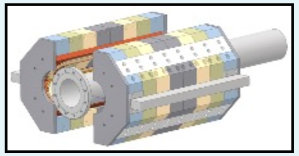
Production ~2025

L-band SC 9-cell cavity

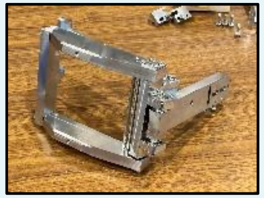
Power coupler



SCQ magnet



Frequency tuner

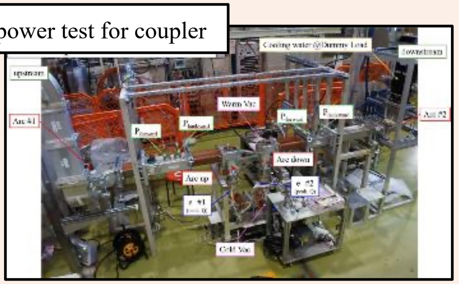


Magnetic shield

Component Test 2025/26

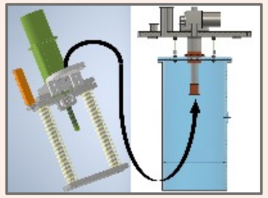
Vertical test for cavity

High power test for coupler



Conduction cooling system for SCQ

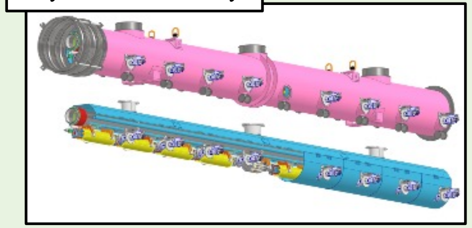
Cold test for motor



Installation ~2026

Demagnetization of cryo-vessel

Cryomodule assembly

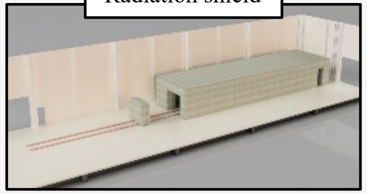


Preparation

Cryogenic

CM assembly hall

Radiation shield



CM Test ~2027

Waveguide assembly

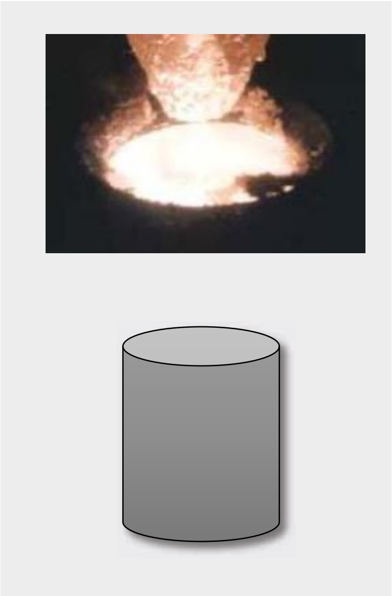
Installation into bunker

Cold test at bunker

Manufacture methods of Fine-Grain / Medium-Grain Nb discs

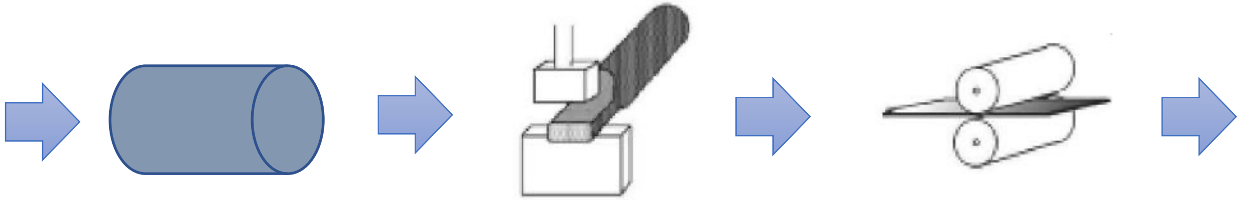
S. Michizono, LCWS 2025

Nb melting

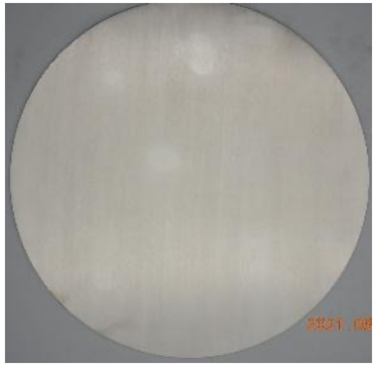


Niobium ingot
(Raw material)

Fine Grain Nb fabrication



Nb Ingot → Forging → Rolling

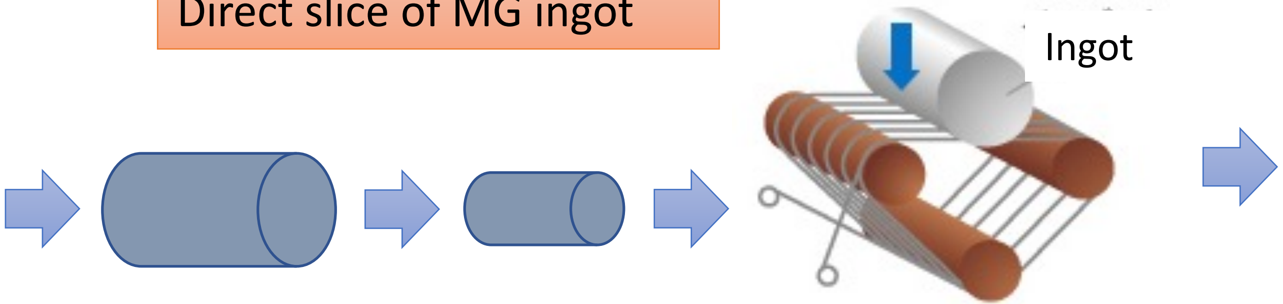


Fine Grain (FG) Disc
Grain Size: 50 - 100 um

FG Nb

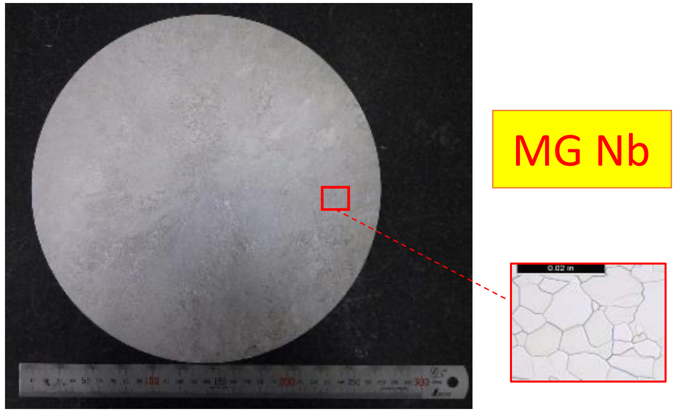
- Aiming for clean, mechanically stable, and cost-effective SRF cavity production.

Direct slice of MG ingot



Ingot, forged
and annealed

Slicing image
by wire-saw



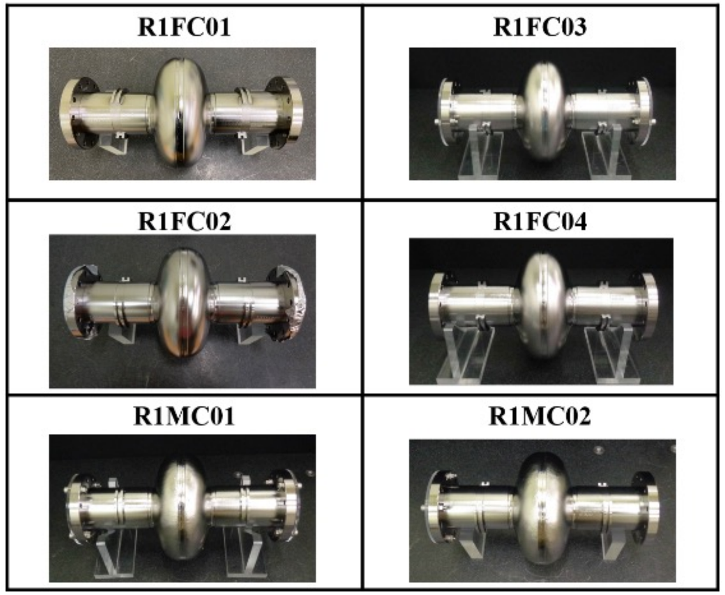
MG Nb

A New Approach:
Medium Grain (MG) Disc
Grain Size < **1 mm**

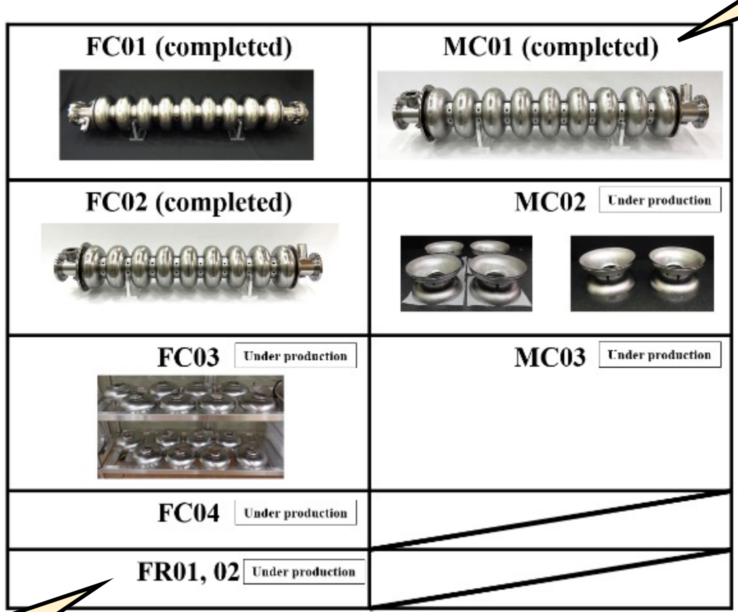
WPP-1 cavity fabrication by KEK

S. Michizono, LCWS 2025

Six 1-cell cavities produced



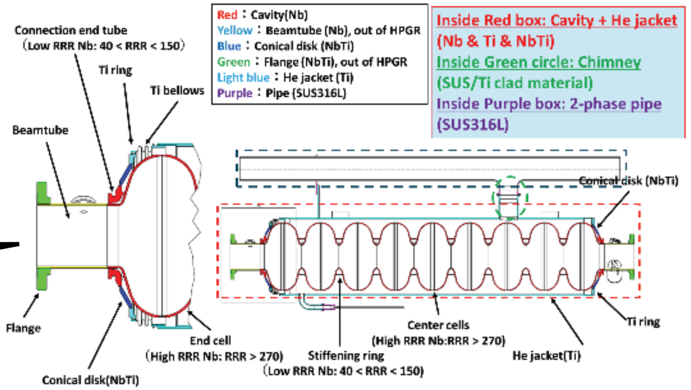
Three 9-cell cavity produced
Six 9-cell cavities are under production



The world's first MG cavity!

These cavities are made by RI!
(for the first time at KEK)

Categories related to HPGS

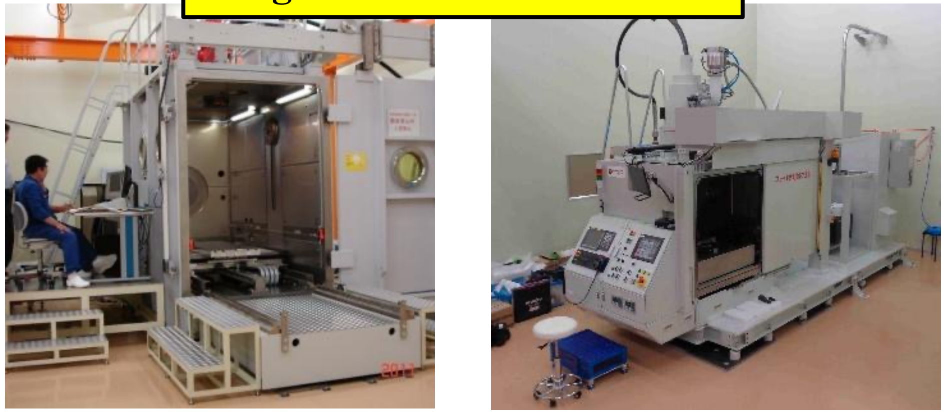


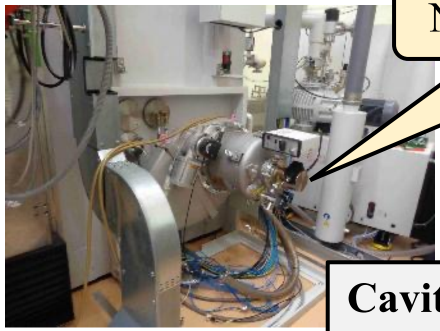
Red : Cavity(Nb)
Yellow : Beamtube (Nb), out of HPGR
Blue : Conical disk (NbTi)
Green : Flange (NbTi), out of HPGR
Light blue : He jacket (Ti)
Purple : Pipe (SUS316L)

Inside Red box: Cavity + He jacket (Nb & Ti & NbTi)
Inside Green circle: Chimney (SUS/Ti clad material)
Inside Purple box: 2-phase pipe (SUS316L)

Takayuki Saeki/Takeshi Dohmae

Large/Small EBW machines





New cryopump replaced

Cavity Fabrication Facility
- Large EBW
- Small EBW
- Chemical polish
- Press machine
- 3D measurement device

Surface treatment recipe at KEK

S. Michizono, LCWS 2025

Based on the results of past R&D, we chose **2-step baking** for this project.
VT for six 1-cell cavities was successfully done, 9-cell cavities will start from next year.

KEK's recipe

Bulk EP (150 µm)

⇩

Heat treatment (900°C, 3h)

⇩

Final EP (cold EP, 20µm)

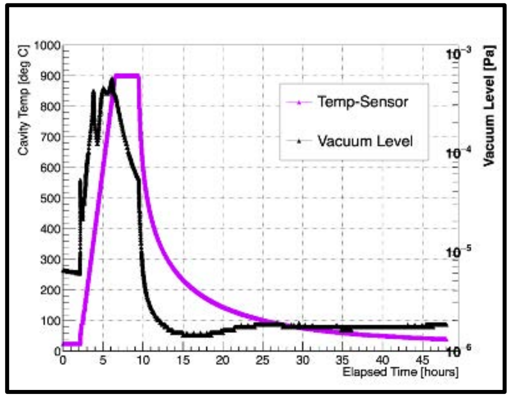
⇩

HPR
Clean (dry) Assembly

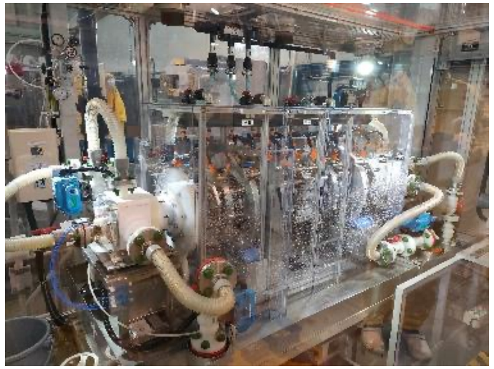
⇩

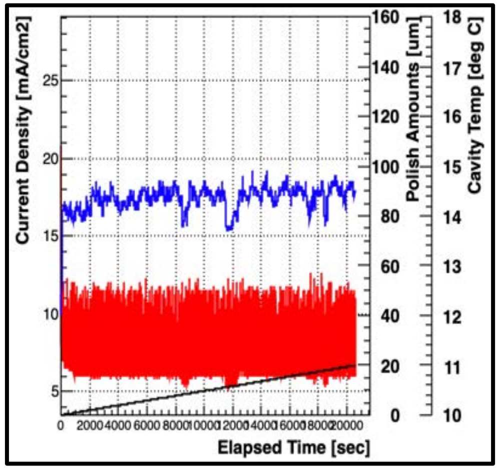
2-step Baking (75°C, 4h + 120°C, 48h)

Heat treatment

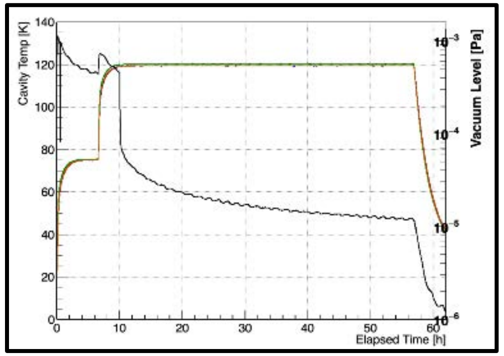


Cold EP

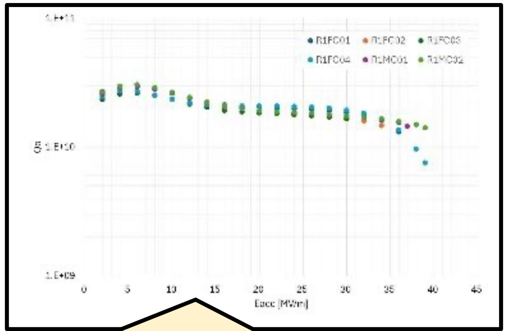




Baking



VT



All cavities passed the spec. ±20%!

Kensei Umemori/Ryo Katayama

WPP-1 in Europe

Single-cell R&D activity

Material procurement and ECS (Nb):

✓ Done

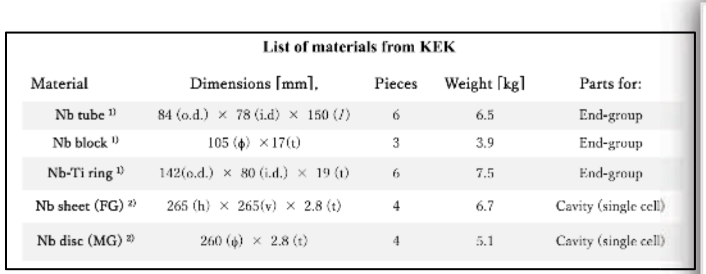
Mechanical production and treatments:

✓ Specs prepared by CEA-INFN-CERN (treatments as option)

✓ Order (mechanical + baseline) placed in industry (RI) in March 2025

✓ Delivery of materials: expected in two weeks

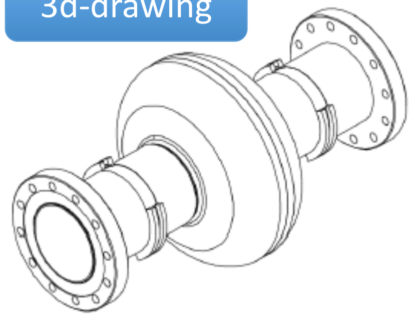
✓ **CEA/INFN** responsible of the **technical support at RI** (QC, etc.)

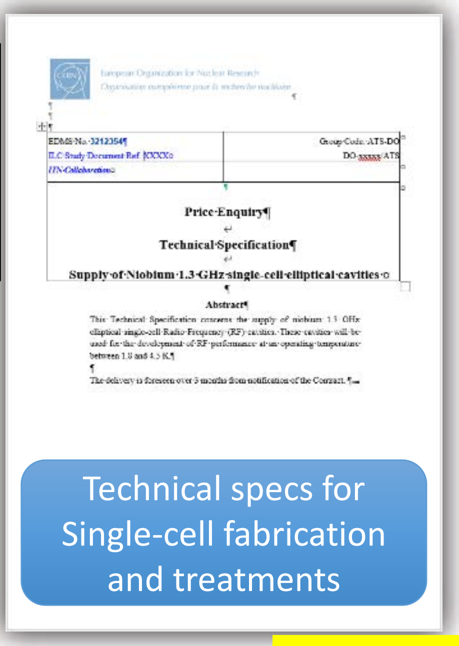


List of materials from KEK

Material	Dimensions [mm].	Pieces	Weight [kg]	Parts for:
Nb tube [1)]	84 (o.d.) × 78 (i.d) × 150 (*l*)	6	6.5	End-group
Nb block [1)]	105 (ϕ) ×17(t)	3	3.9	End-group
Nb-Ti ring [1)]	142(o.d.) × 80 (i.d.) × 19 (t)	6	7.5	End-group
Nb sheet (FG) [2)]	265 (h) × 265(v) × 2.8 (t)	4	6.7	Cavity (single cell)
Nb disc (MG) [2)]	260 (ϕ) × 2.8 (t)	4	5.1	Cavity (single cell)

3d-drawing





European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

EDMS No. 3212354 ILC Study Document Ref. XXXX ITN-Collaboration	Group Code: ATS-DO DO-xxxxx/ATS

Price Enquiry

Technical Specification

Supply of Niobium 1.3 GHz single-cell elliptical cavities

Abstract

This Technical Specification concerns the supply of niobium 1.3 GHz elliptical single-cell Radio Frequency (RF) cavities. These cavities will be used for the development of RF performance at an operating temperature between 1.8 and 4.5 K.

The delivery is foreseen over 3 months from notification of the Contract.

Technical specs for Single-cell fabrication and treatments

L. Monaco @TTC2025

9-cells industrialization activities: goals and strategy

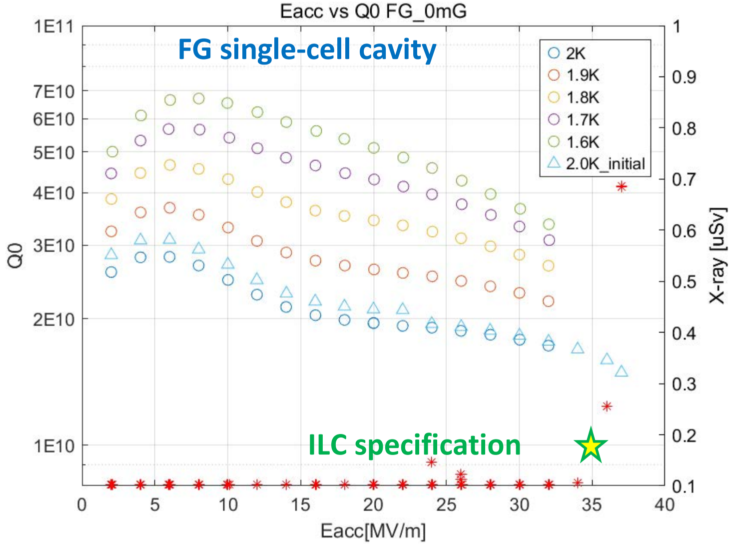
ITN-EU main goals for 9-cells cavities:

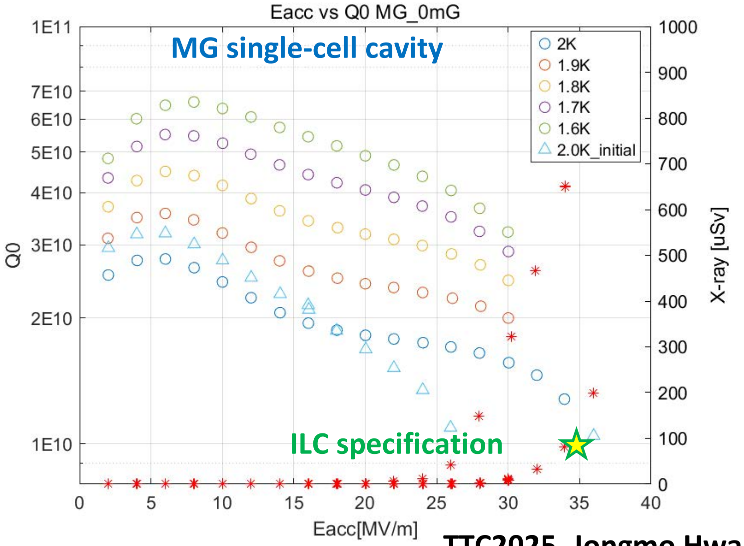
- Production of **9-cells jacketed cavities** at the **EU Industries** (RI and Zanon)
- **Qualification of EU Industries** in term of pressure vessel code (harmonization with **HPGS**)
- **Installation** into the **ILC type cryomodule (KEK)** of **2 EU cavities**

WPP-1 in South Korea

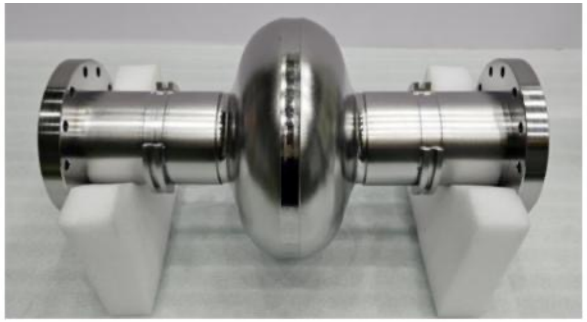
S. Michizono, LCWS 2025

- Korea Univ. fabricated two 1-cell cavities.
- Single cell cavities satisfied ILC specification

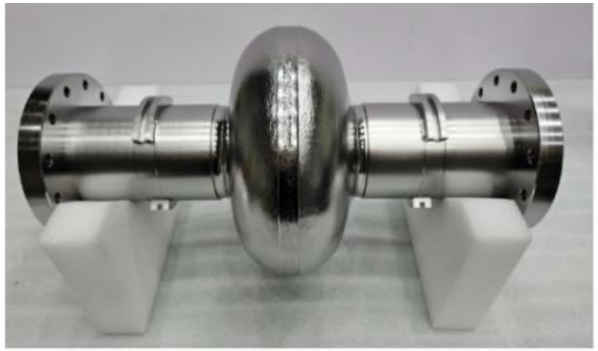




TTC2025, Jongmo Hwang



1.3 GHz FG 1-cell cavity



1.3 GHz MG 1-cell cavity

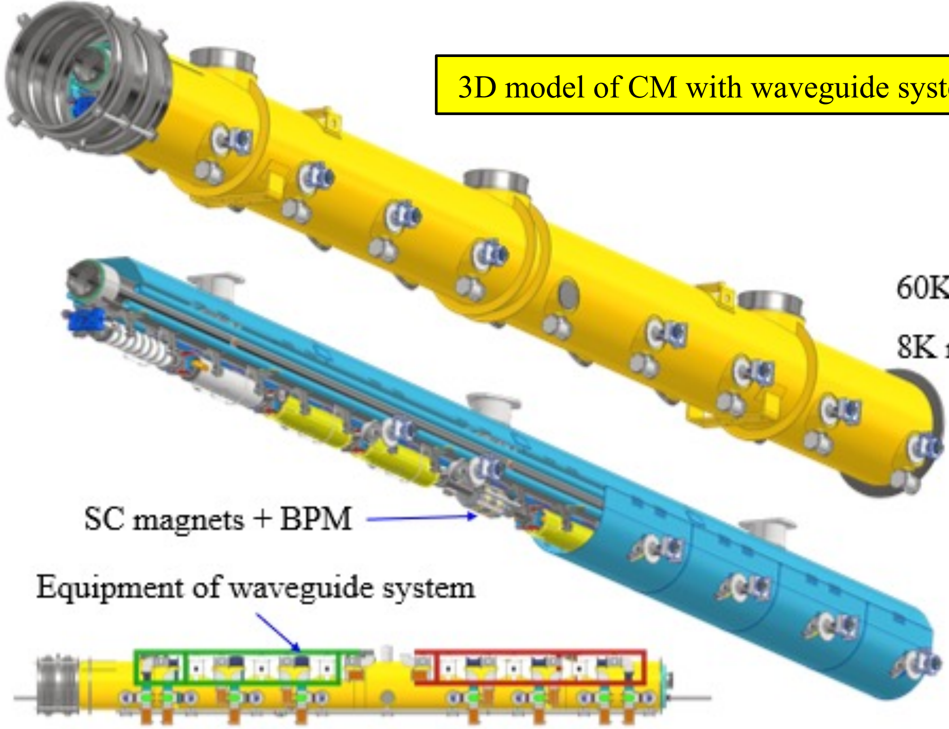
WPP-2 Cryomodule design in KEK

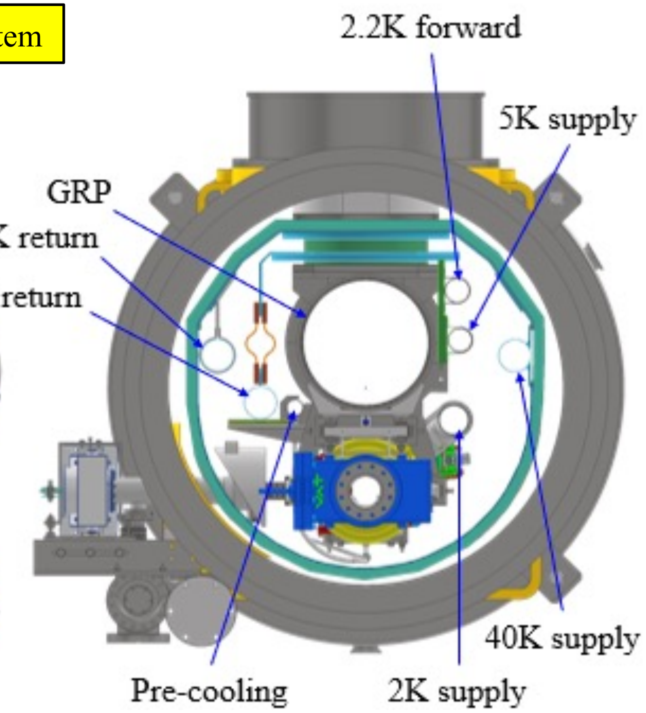
- ILC “Type B” CM chosen (eight cavities + one SC magnet/BPM)
- Single thermal shield @40K **(5K dropped (t.b.d.))**
- Tuner access available
- 3D model completed
- Heat load simulation done (dynamic under progress)
- Waveguide support frame designed
- Total cost for contract under estimation

Specifications

Type	B
Thermal shield	Single
Vacuum vessel length	12,652 m
Vacuum vessel diameter	OD965mm, ID946mm
Coupler pitch distance	1326.7 mm
Cavity length	1247.4 mm

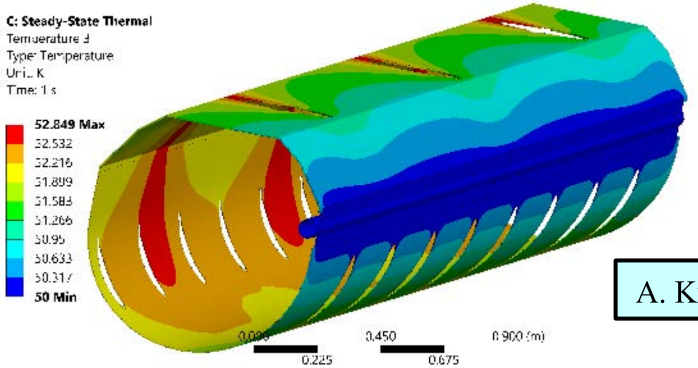
3D model of CM with waveguide system





Takeshi Dohmae/Tomohiro Yamada/Takafumi Hara

Thermal analysis for 40K shield

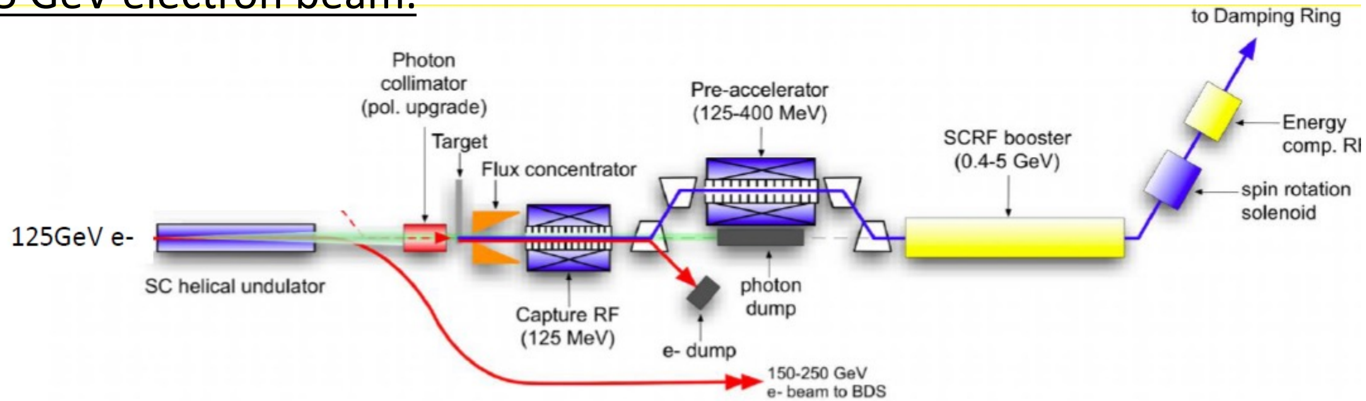


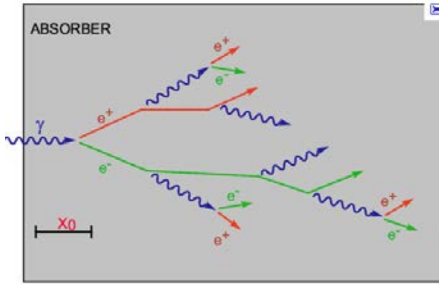
A. Kumar

Undulator scheme and e-driven scheme positron source

S. Michizono, LCWS 2025

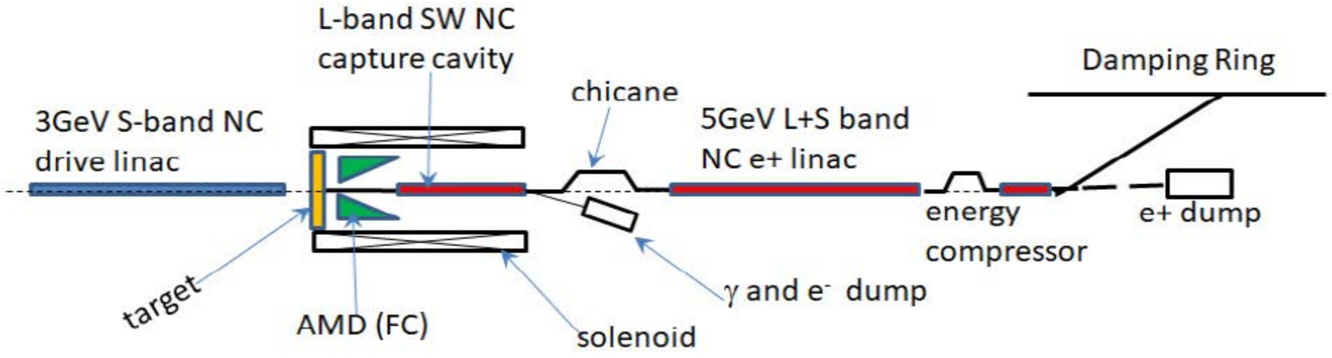
<u>Undulator method (baseline):</u> 125 GeV electrons are passed through a helical undulator, and the produced gamma rays hit the target to produce electron-positron pairs. <u>Polarized positrons (30%) are obtained. Need 125 GeV electron beam.</u>





Developed <u>in mainly EU</u>.

<u>Electron driven method</u>：3GeV electrons hit the target to produce electron-positron pairs. <u>High-energy electrons are not required, and the commissioning of the positron production is independent from electron beam commissioning.</u>



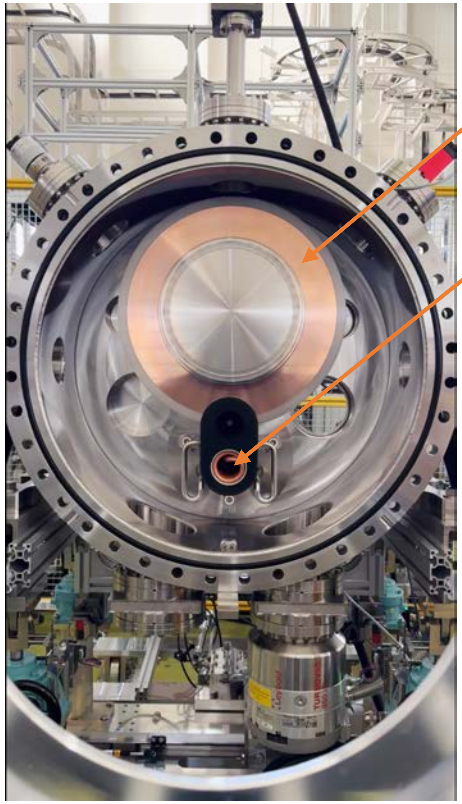
Developed <u>mainly in Japan.</u>

Both needs strong target and sophisticated design of Flux concentrator and capture section (cavity and solenoid) **<u>→ In KEK, prototype of positron source based on e-driven method start to develop.</u>**

WPP-8/9/10: e-Driven positron source in KEK

S. Michizono, LCWS 2025

- **Fabrication of Target disk (W-Cu)**
- Install Flux Concentrator (FC)
- Fabrication of collimator with pillow seal
- Fabrication of solenoid

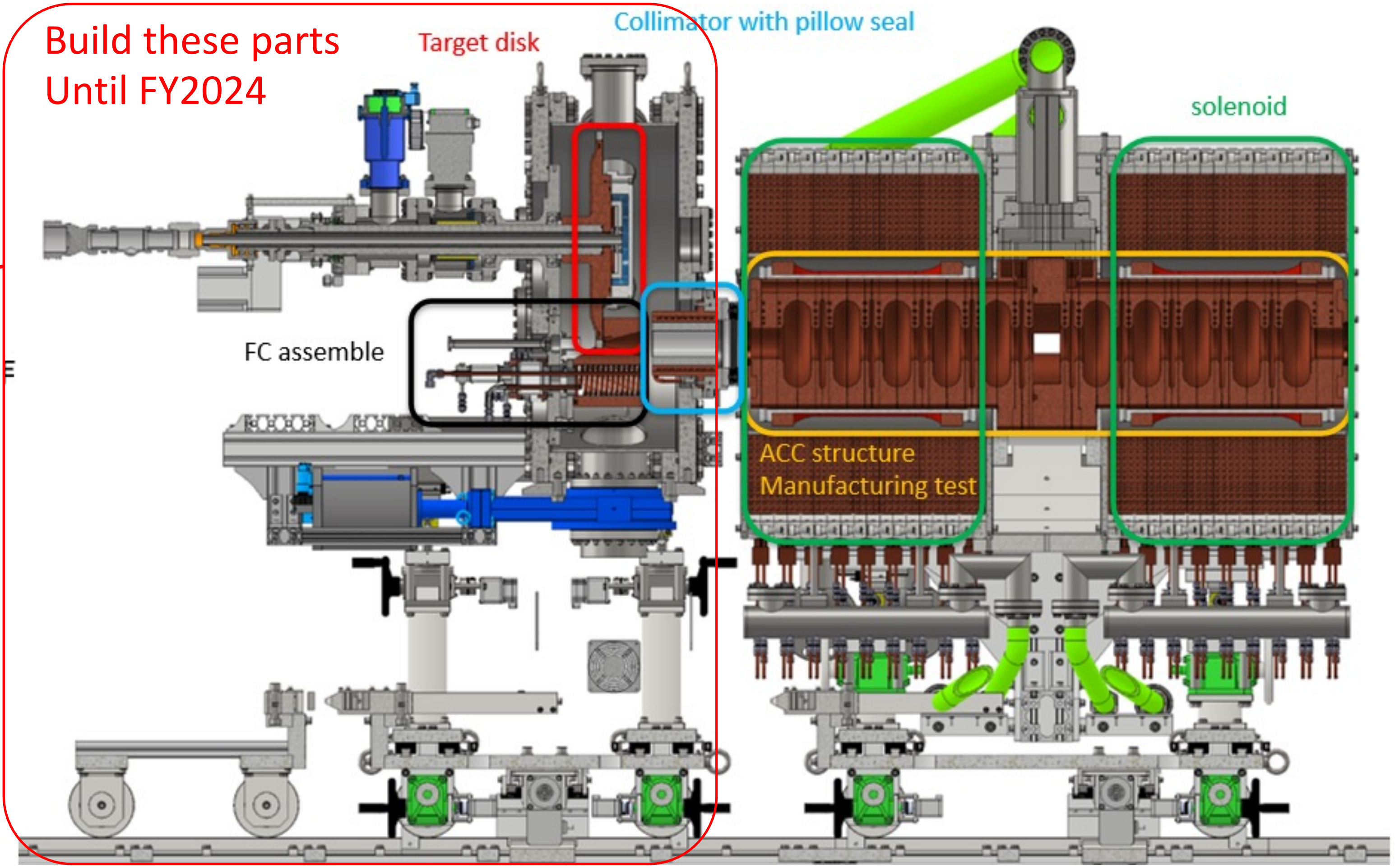


rotating target.

Flux concentrator

Movie

About **200 r p m with water cooling.** Vacuum is **around 10^-6 Pa level.** (last year & this year)



The infrastructure for positron test stand was developed until JFY2024, including a **cold fit test of the W-Cu target**. From 2025, we will conduct the accelerator structure fabrication.

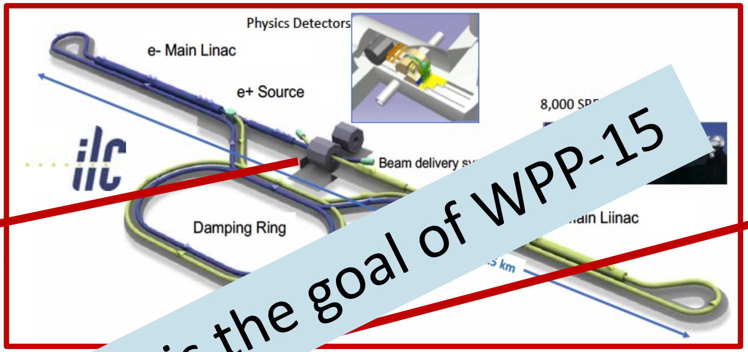
Stable rotating target was produced under good vacuum condition. → **impressive progress for future e+e- colliders**

WPP-15: Final focus at ATF in KEK

Develop **nano-beam technologies** for ILC-CLIC

Goals: - Realize **nanobeam size**

- **Stabilize** its **position**

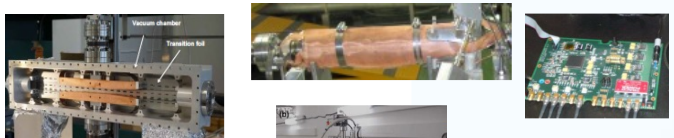


Long-term (a few days) stabilization is the goal of WPP-15

ATF2 final focus test beamline

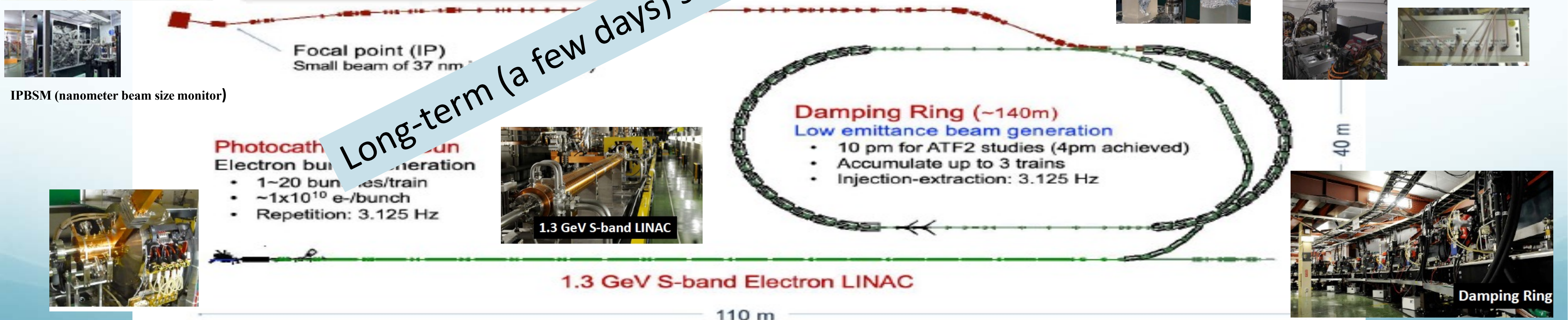
Nanometer beam development

- Final focus System R&D
- Intra-train ultra-fast beam feedback



...d Beam Instruments R&D

...ication of Low-emittance beam



Focal point (IP)
Small beam of 37 nm

IPBSM (nanometer beam size monitor)

Photocath... ...un

Electron bu... ...neration

- 1~20 bun... ...es/train
- ~1x10^{10} e-/bunch
- Repetition: 3.125 Hz

Damping Ring (~140m)

Low emittance beam generation

- 10 pm for ATF2 studies (4pm achieved)
- Accumulate up to 3 trains
- Injection-extraction: 3.125 Hz

1.3 GeV S-band Electron LINAC

110 m

ATF2 past experimental results achieved

PRAB 19, 091002 (2016)

Wakefield model

Octupoles

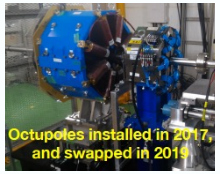
Orbit stabilization
5 FF sextupoles
Skew sextupole modif.
FONT feedback on

4 FF sextupoles

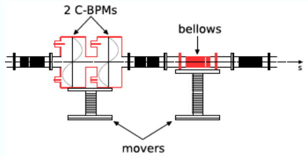
KEK Report 2020-4 (2020)

Major Review

ILC-IDT


Octupoles installed in 2017, and swapped in 2019

Octupoles swap



1st wakefield setup

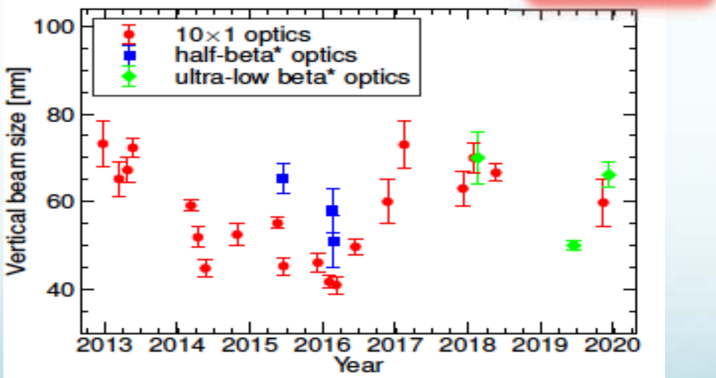
2013 2014 2015 2016 2017 2018 2019 2020

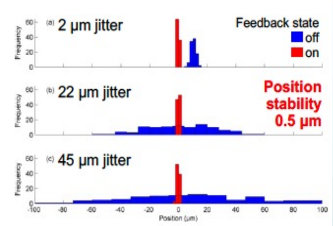
44 nm

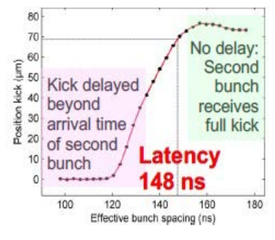
41 nm

FB latency 133 nsec
Position jitter at ATF2 IP: 41 nm

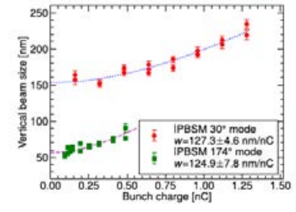
Intensity dependence





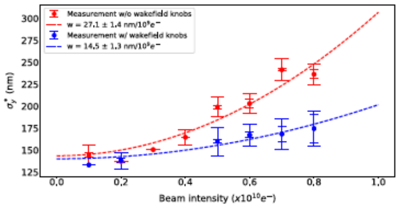


PRAB 21, 122802 (2018)



$\sigma_y = \sqrt{\sigma_{y,0}^2 + w^2 N^2}$

Ultra low-b optics



$\overline{\sigma_y^{*}}^2 = \overline{\sigma_{y0}^{*}}^2 + w^2 \times Q^2,$

10x1 optics

PRAB 23, 121004 (2020)

GIF 2025

Small beam sizes were obtained with reduced beam intensities of 0.5-1.5 10^9 e⁻/bunch (10^{10} design value) and reduced aberration optics ($10\beta_x^*$ x β_y^*)

ATF2-3 recent and current status

Lessons learned

- **Hardware** ATF **issues** were identified (retrofitted / re-used components)
- Mitigation plan is in progress (MEXT ATD)
- Detailed studies to assess the ILC/CLIC **FFS** system design from the point of view of the **technological/hardware choices** are of paramount importance (wakefields, magnet field errors...)

Major Review

ILC-IDT

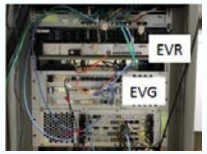
Hardware upgrades

ATF2 beam line upgrade is ongoing in the framework of the new Advanced Accelerator Element Technology Development (MEXT ATD) grant started in April 2023 and will continue over 5 years.


IPBSM


Skew sextupole


QD0


EVR/EVG timing system

2019 2020 2021 2022 2023 2024 2025 2026


Magnet mover control box prototype


Low-impedance bellow

IPBSM laser

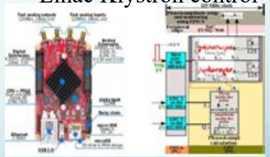
Magnets:
- QD0, QF1, SD0, SD1
- Magnet movers

Vacuum chambers:
- Bellows shielding and flanges
- Cavity BPM tapering
- Stripline BPMs
- Dipole chamber

CBPMs:
- Re-installation of all CBPMs
- Fast small movers
- Electronics & Digitizers:

Kicker system
Ceramic and new chamber


New ceramic chamber


Linac Klystron control

Timing systems
- New VME based Event Genarator/receiver system
- Renew optical signal distribution system for reference clocks linac&DR

ATF2-3 recent and current status

Lessons learned

- Outstanding and unique results achieved in ATF/ATF2. Based on ATF2 achievements **no showstoppe**r for ILC has been found
- ATF2 **beam intensity dependence** is compatible with **wakefields** impact and long bunch lengths. ATF2 low-intensity is “roughly” equivalent to ILC nominal intensity.

KEK Report 2020-4 (2020)
CERN-THESIS-2020-095 (2020)

- ATF2 **optics limitation** could be explained by **alignment**, **jitters**, and **multipolar aberrations**. Comparative simulations shown than ATF2 10x1 optics has closer tolerances to ILC optics than ATF2 1x1 optics.

PRAB 17, 023501 (2014)

Major Review

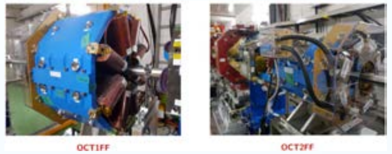
ILC-IDT

Performance Optimization

ATF3 plan is to pursue the necessary **R&D** to maximize the **luminosity potential of ILC.** In particular the assessment of the ILC FFS system design specs and the technological/hardware choices and the long-term stability operation issues.

19 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

High-order aberrations

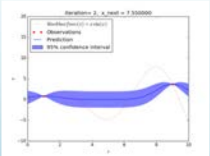


Octupoles

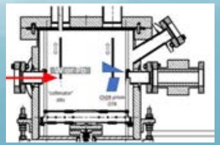
Wakefield mitigation


Wakefield test station

Long Term stability

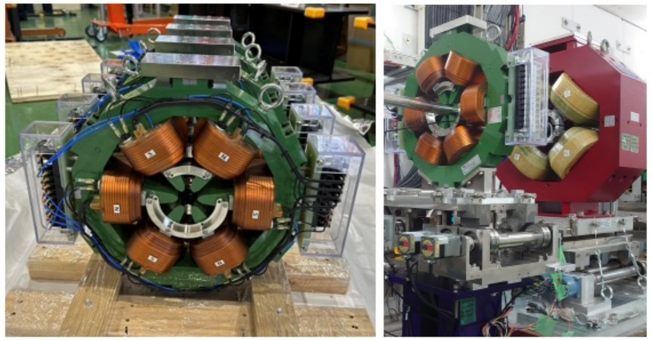

beam tuning (ML based)

Beam Instrumentation

iChDR


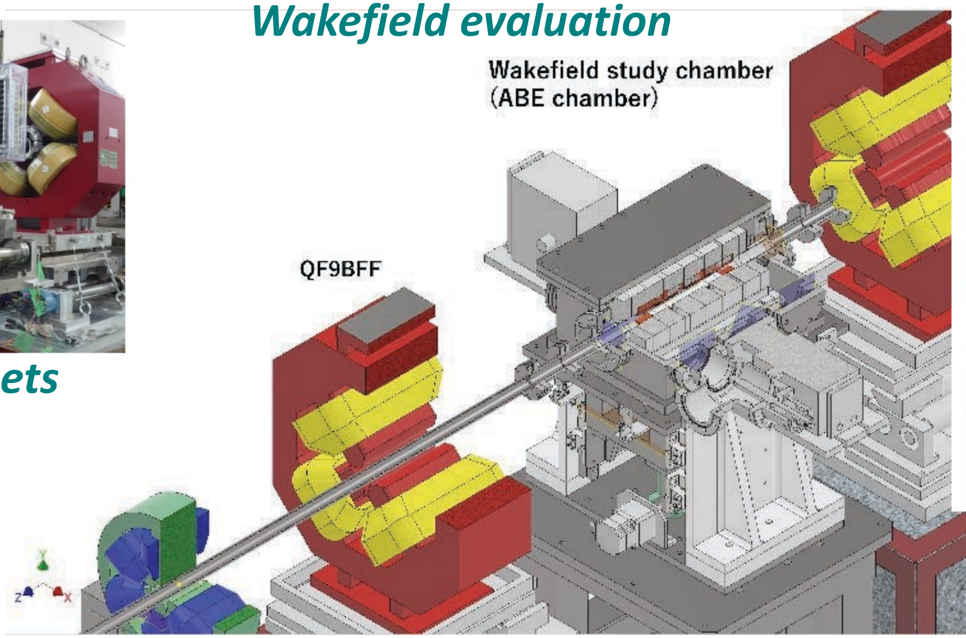
WPP-15: Final focus at ATF in KEK

Increased operating weeks to 20 weeks in JFY2024.



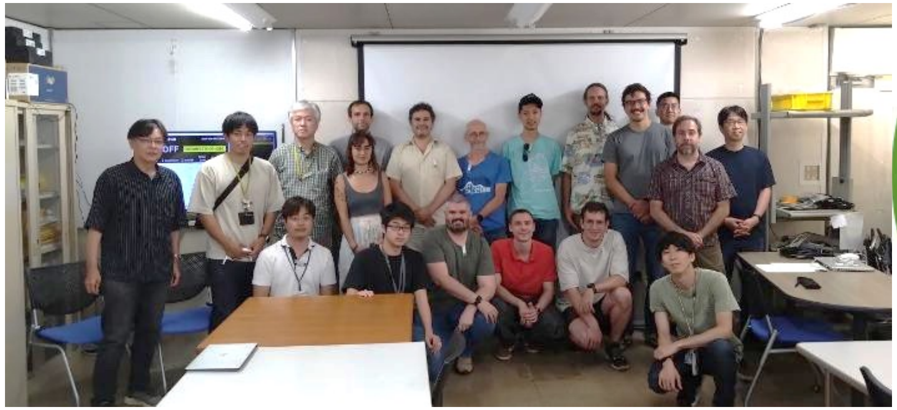
Skew Sextupole magnets

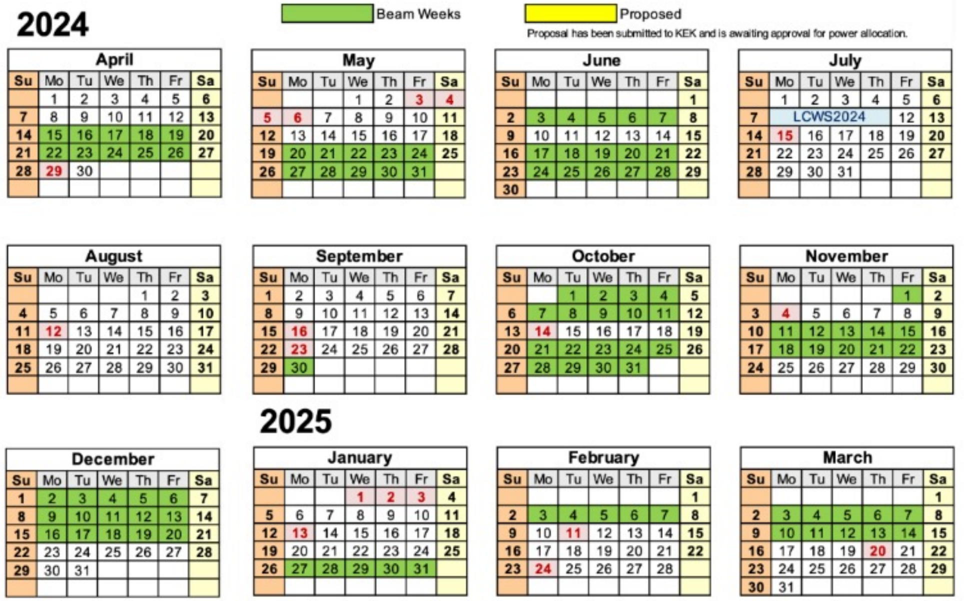
Wakefield evaluation



Install to ATF beamline step-by-step

Magnet mover control system





2024

🟩 Beam Weeks

🟨 Proposed

Proposal has been submitted to KEK and is awaiting approval for power allocation.

April

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

May

Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

June

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

July

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	LCWS2024				12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

August

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

September

Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

October

Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

November

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

2025

December

Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

January

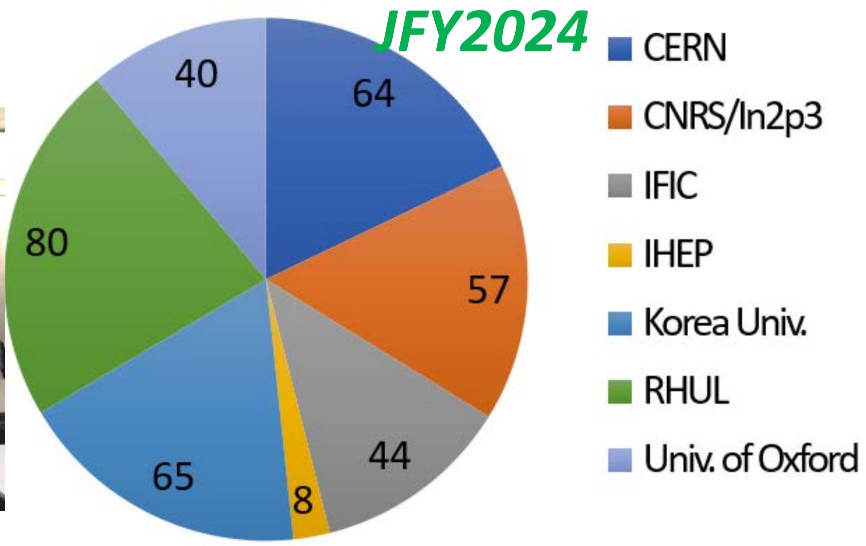
Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

February

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	

March

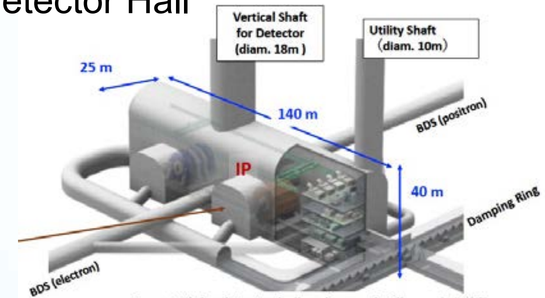
Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					



JFY2024

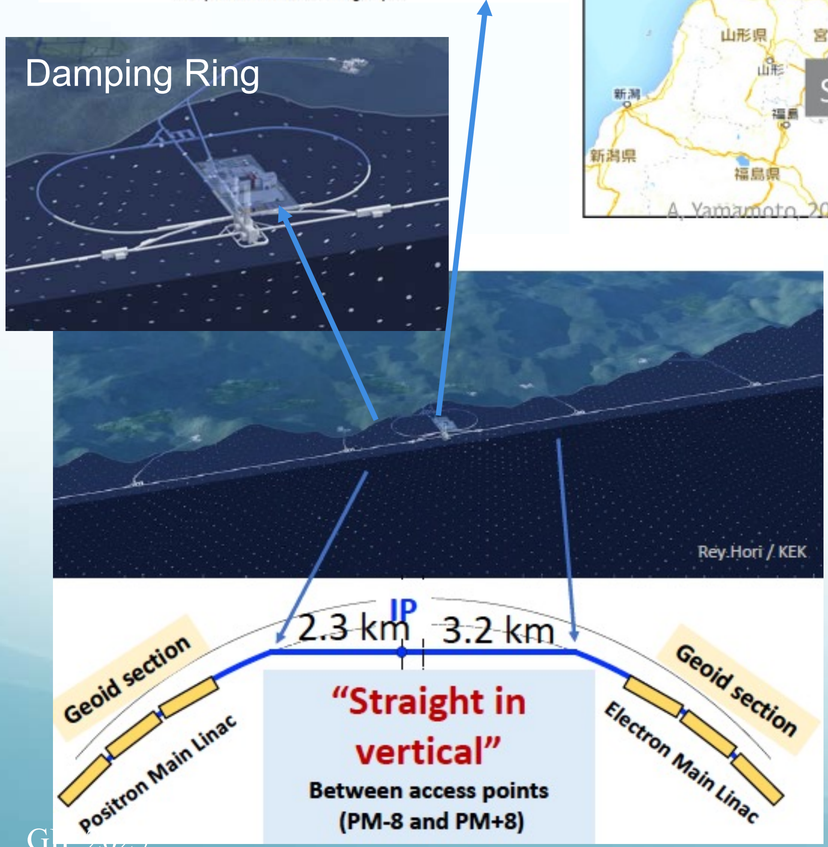
ILC Site Study and Civil Engineering

Detector Hall



Layout of the detector hall and around will be optimized with detector groups.

Damping Ring



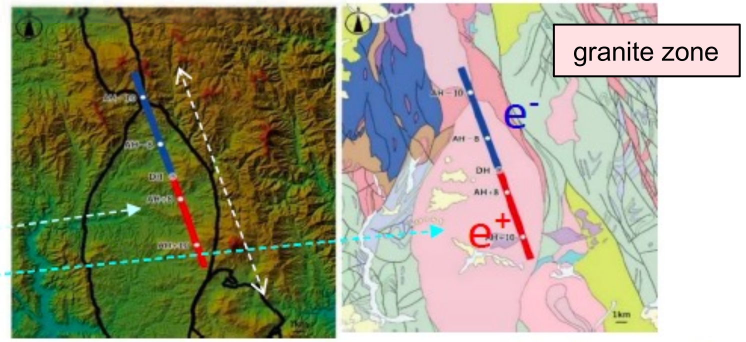
"Straight in vertical"

Between access points (PM-8 and PM+8)

Kitakami mountains

① ILC Location

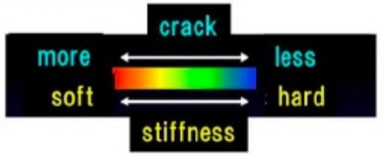
ILC accelerator area : inside the granite rock bodies
→ inside black curves (left)
→ in the pink color (right)
→ possible up to 50 km

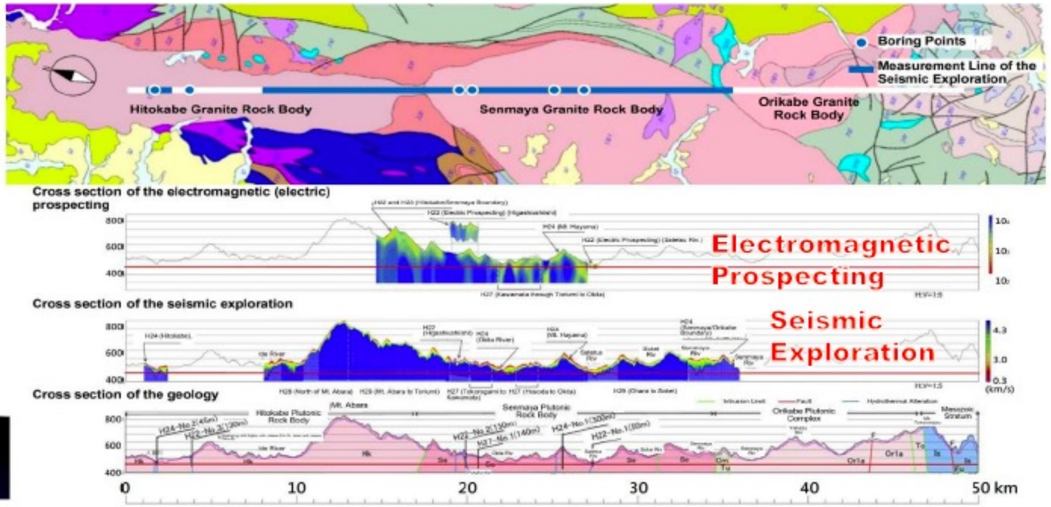


→ On-going jobs : Optimal accelerator placement, considering surface environment, land-use and land-acquisition

② Geological Surveys

- Electric Prospecting (crack)
- Seismic Exploration (stiffness)
- Boring Survey
- Borehole Camera
- Measurement of Initial Stress of the Ground





→ no issues from previous surveys

→ requiring : additional surveys around access tunnel head and access tunnel inside for detailed designing

“Green ILC” and Carbon neutrality

Although SRF has been adopted, the AC power consumption for ML part is <50%, what is a total of 110 MW

- **“Green ILC”**: Past efforts include increasing the efficiency of accelerators (SC, klystron) https://green-ilc.in2p3.fr/documents/
- **Carbon neutrality**: Common challenge for all future HEP accelerators. The use of SC will contribute to carbon neutrality in the future.

Work is ongoing to study these issues in collaboration the "ILC Environmental Assessment Advisory Board"

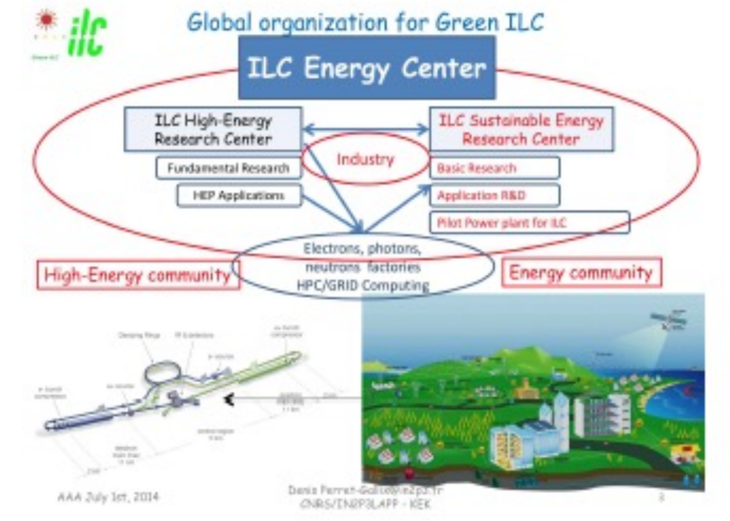
Green-ILC AAA-2014 Report


WSFA2023 2023.9.25(mon) - 27(wed)
Aiina room501 / Morioka city / Iwate Pref. : 1st day Group Photo

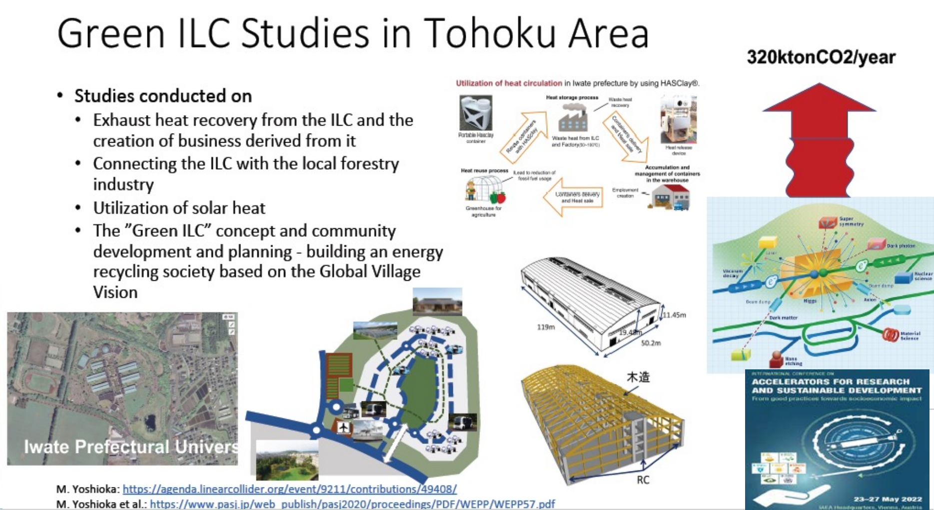
https://wsfa2023.huhep.org/


ILC Energy center (artistic) view

AAA July 1st, 2014
Denis Perret-Gallix@in2p3.fr
CNRS/IN2P3LAPP - KEK


Global organization for Green ILC

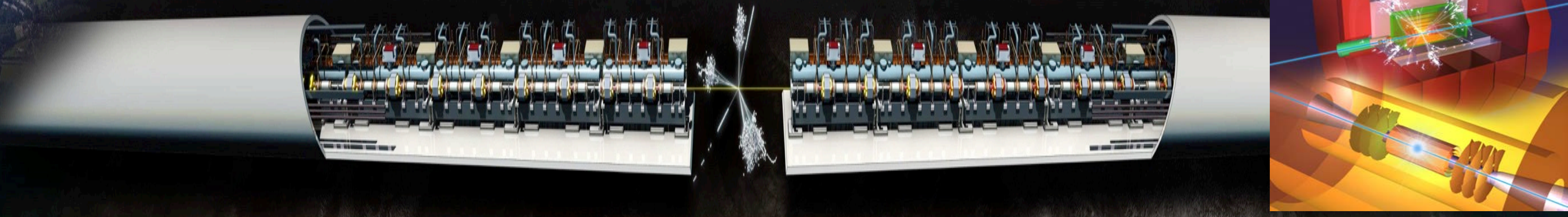
AAA July 1st, 2014
Denis Perret-Gallix@in2p3.fr
CNRS/IN2P3LAPP - KEK


Green ILC Studies in Tohoku Area

- Studies conducted on
  - Exhaust heat recovery from the ILC and the creation of business derived from it
  - Connecting the ILC with the local forestry industry
  - Utilization of solar heat
  - The ”Green ILC” concept and community development and planning - building an energy recycling society based on the Global Village Vision

M. Yoshioka: https://agenda.linearcollider.org/event/9211/contributions/49408/
M. Yoshioka et al.: https://www.pasj.jp/web_publish/pasj2020/proceedings/PDF/WEPP/WEPP57.pdf

CLIC accelerator: Technology update

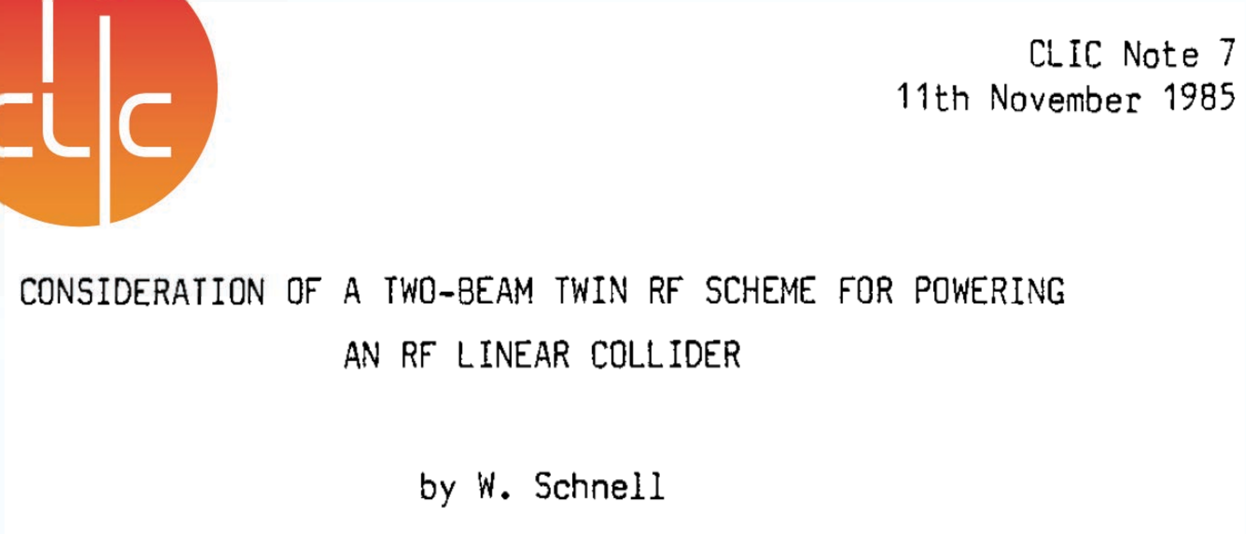


http://clic-study.web.cern.ch/

Compact Linear Collider

CLIC "novel" concept

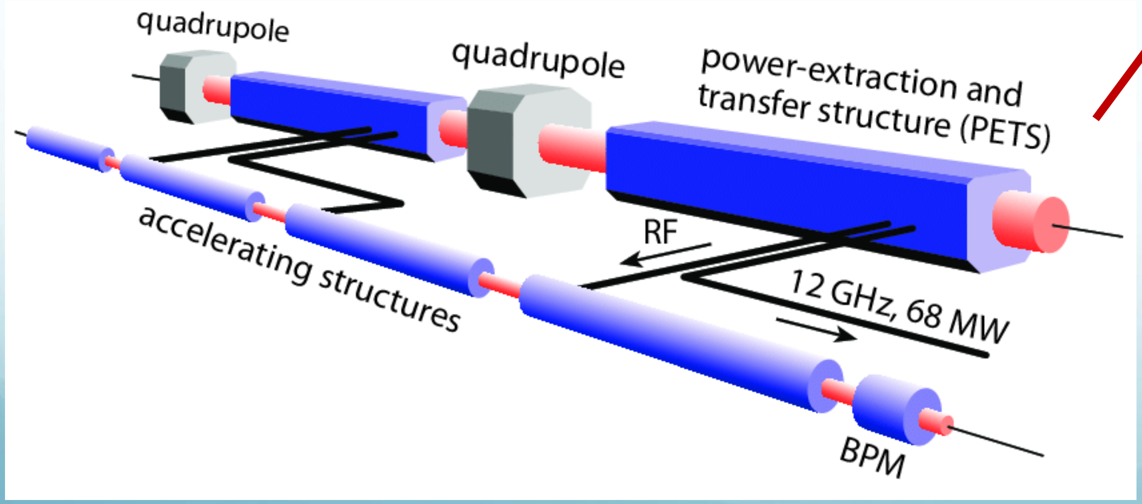
Coming up on the 40th anniversary!

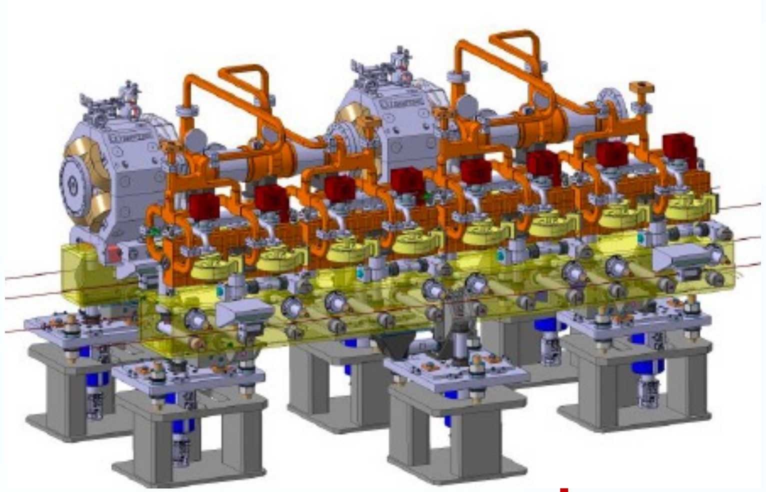


CLIC Note 7
11th November 1985

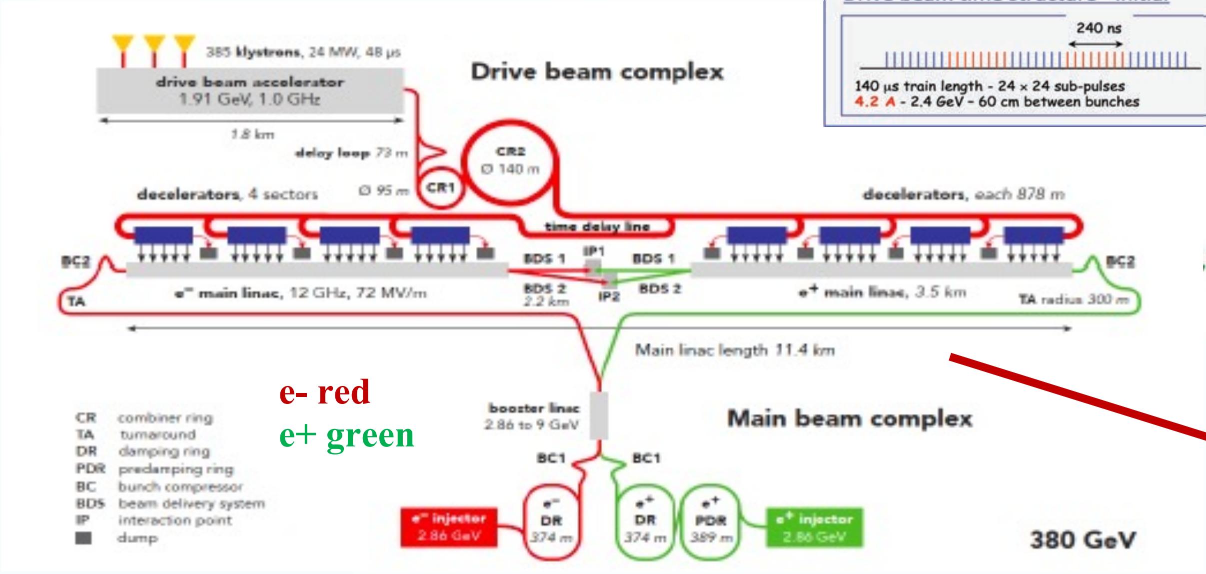
CONSIDERATION OF A TWO-BEAM TWIN RF SCHEME FOR POWERING
AN RF LINEAR COLLIDER

by W. Schnell

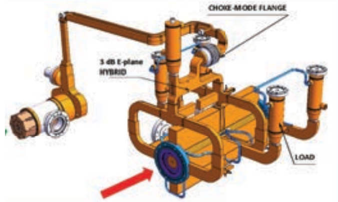




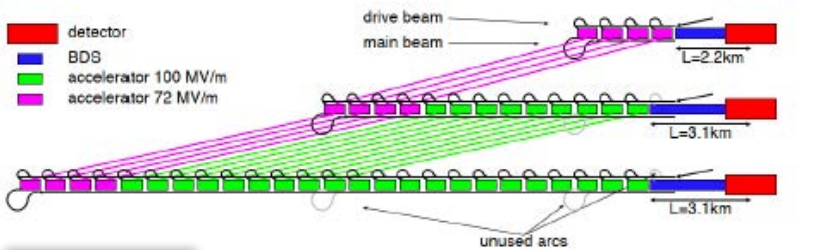
CLIC parameters and beam accelerator sequence

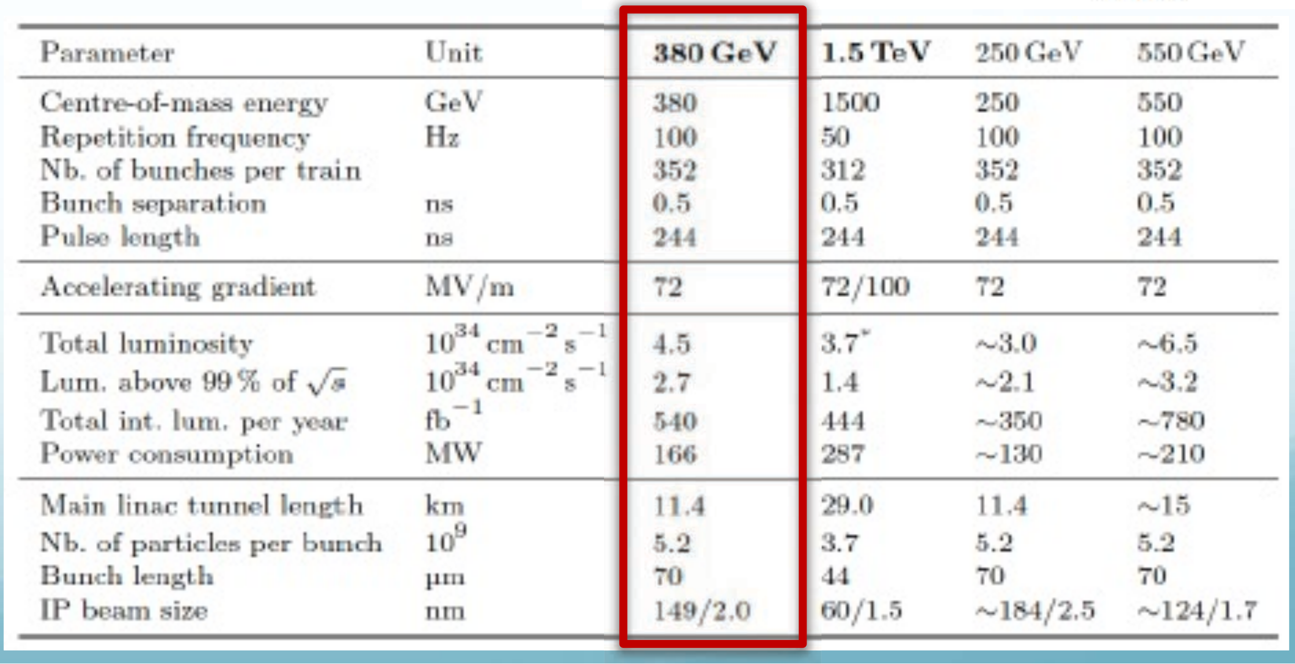


e- red
e+ green

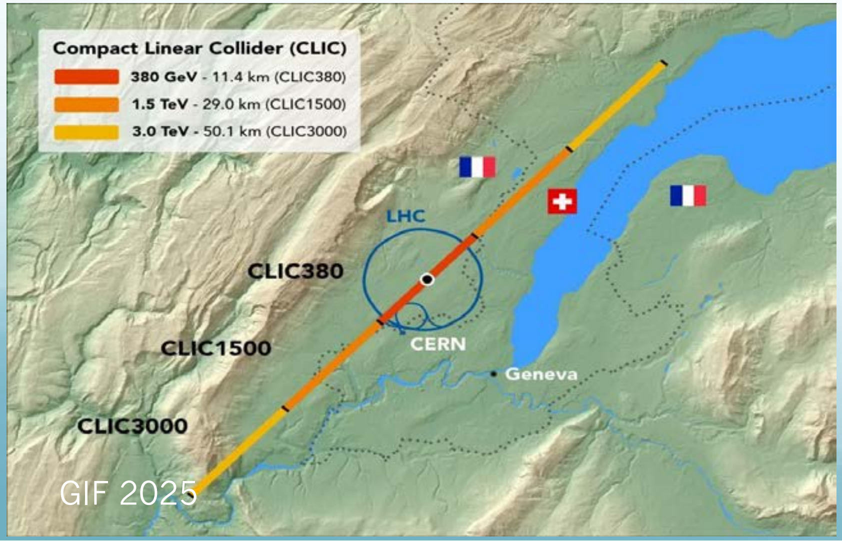


Energy staging



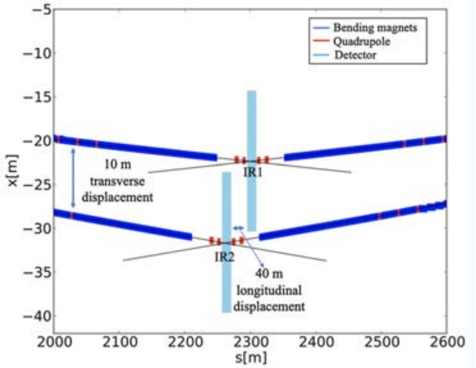


Parameter	Unit	380 GeV	1.5 TeV	250 GeV	550 GeV
Centre-of-mass energy	GeV	380	1500	250	550
Repetition frequency	Hz	100	50	100	100
Nb. of bunches per train		352	312	352	352
Bunch separation	ns	0.5	0.5	0.5	0.5
Pulse length	ns	244	244	244	244
Accelerating gradient	MV/m	72	72/100	72	72
Total luminosity	10^{34} cm^{-2} s^{-1}	4.5	3.7*	~3.0	~6.5
Lum. above 99 % of $\sqrt{s}$	10^{34} cm^{-2} s^{-1}	2.7	1.4	~2.1	~3.2
Total int. lum. per year	fb^{-1}	540	444	~350	~780
Power consumption	MW	166	287	~130	~210
Main linac tunnel length	km	11.4	29.0	11.4	~15
Nb. of particles per bunch	10^9	5.2	3.7	5.2	5.2
Bunch length	μm	70	44	70	70
IP beam size	nm	149/2.0	60/1.5	~184/2.5	~124/1.7



CLIC new design highlights

S. Stapnes, LCWS 2025

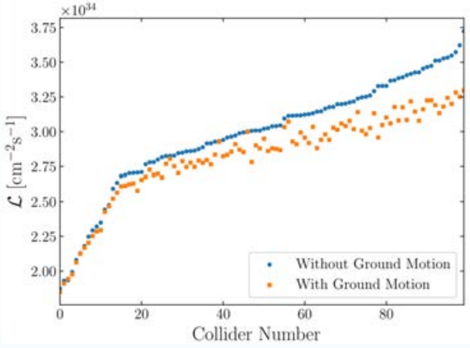


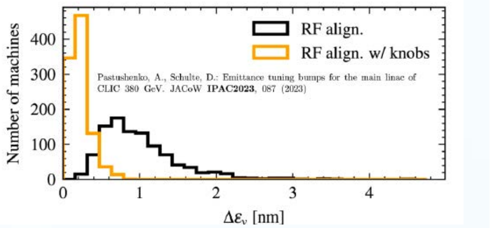
Two Interaction Regions

- Addresses a long-standing concern: a single IR does not sufficiently serve the particle physics community
- Two detectors can be operated each at an average rate of 50 Hz
- All the luminosity can also be delivered to a single detector at 100 Hz

Emittance budgets to full start-to-end simulation

- For the expected alignment imperfections and with a conservative ground motion model, 90% of machines achieve a luminosity of 4.5 × 10^{34} /cm^2/s or greater, at 380 GeV, 100 Hz.
- The average luminosity achieved in simulations is 5.6×10^{34} /cm^2/s (380 GeV, 100 Hz).
- Future improvements to the technologies used to mitigate imperfections, such as better pre-alignment, active stabilization systems and additional beam-based tuning, will also help increasing this luminosity surplus further. A start-to-end simulation of a perfect machine shows that a luminosity of 8.6 × 10^{34} /cm^2/s would be achieved (380 GeV, 100 Hz).



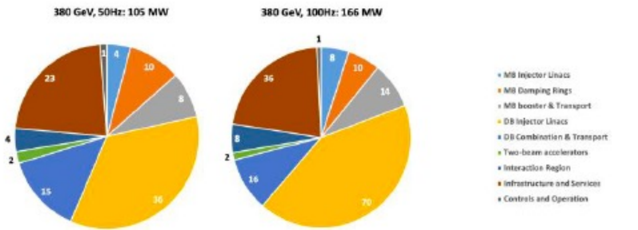


Pastushenko, A., Schulte, D.: Emittance tuning bumps for the main linac of CLIC 380 GeV. JACoW **IPAC2023**, 087 (2023)

50 and 100 Hz operation

- Re-evaluation of the level and distribution of power consumption at 380 GeV made clear that repetition rate – luminosity! - could be doubled with only 60% increase in power consumption.
- Due to large fraction of non-pulsed consumption, magnets, infrastructure etc.
- Contributes also to implementing two interaction regions.

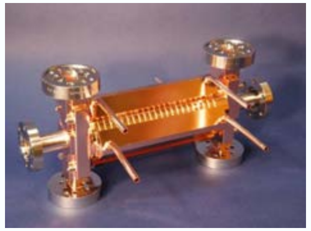
Parameter	Symbol	Unit	380 GeV, 100 Hz	380 GeV, 50 Hz
Centre-of-mass energy	$\sqrt{s}$	GeV	380	380
Number of interaction points	N_{IP}		2	1
Repetition frequency	f_{rep}	Hz	100	50
Number of bunches per train	n_b		352	352
Bunch separation	Δt	ns	0.5	0.5
Pulse length	τ_{RF}	ns	244	244
Accelerating gradient	G	MV/m	72	72
Total luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	4.5	2.3
Luminosity above 99% of $\sqrt{s}$	$\mathcal{L}_{0.01}$	$10^{34}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	2.7	1.3
Beamstrahlung photons per particle	n_γ		1.5	1.5
Total integrated luminosity per year	$\mathcal{L}_{\mathrm{int}}$	fb^{-1}	540	270
Power consumption	P	MW	166	105

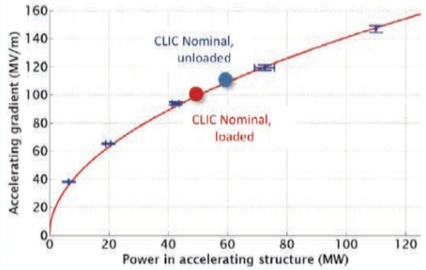


CLIC accelerator challenges/technologies

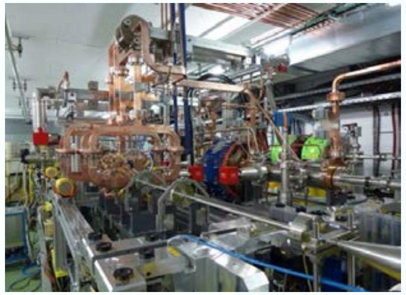
S. Stapnes, LCWS 2025

- **CLIC baseline** – a **drive-beam** based machine with an initial stage at **380 GeV**. The main challenges:
  - High-current drive beam bunched at 12 GHz
  - Power transfer and main-beam acceleration, efficient RF power
  - Towards 100 MV/m gradient in main-beam X-band cavities
  - Alignment and stability (“nano-beams”)
- **CLIC 380 GeV** with **X-band klystrons** (larger tunnel, klystron design not optimized…)
- The CLIC Test Facility at CERN (**CTF3**) programme addressed all **drive-beam** production **issues**
- Other **critical technical systems** (alignment, damping rings, beam delivery, etc.) addressed via design and/or test-facility demonstrations
- **X-band technology** developed and verified with **prototyping**, **test-stands**, and use in **smaller systems** and linacs

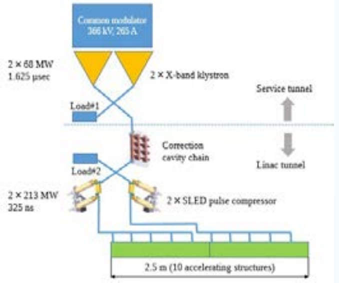




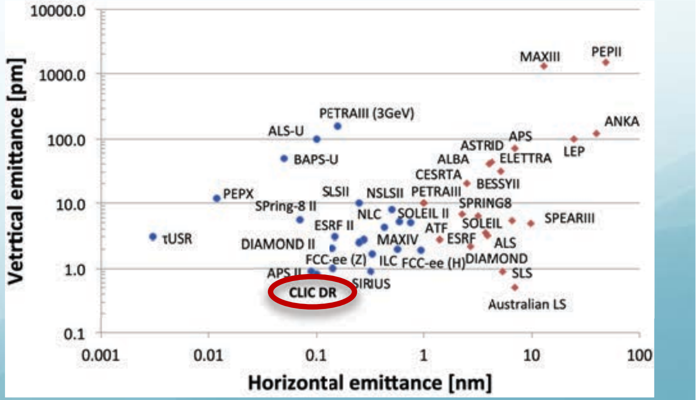
CTF3 facility



XBox facility



Target and achieved emittance in existing and planned machines



Examples of technical developments

CLIC Technical developments of key elements

S. Stapnes, LCWS 2025

Extensive prototyping over the last ~5-10 years

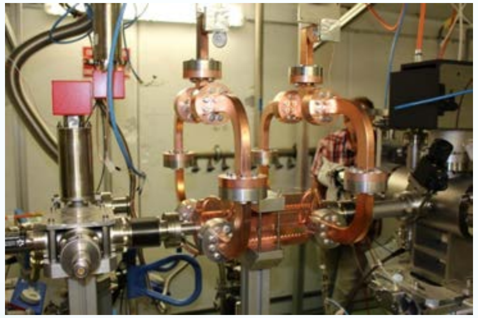
X-band high-gradient results

Progress in X-band Technical Systems

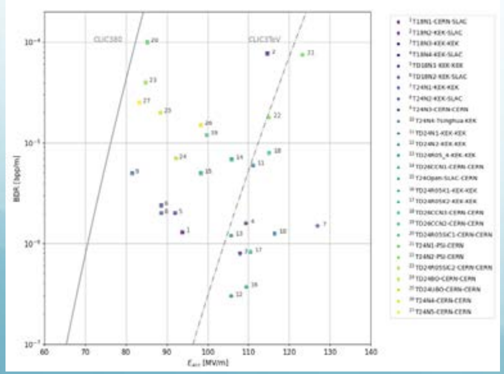
S. Stapnes, LCWS 2025

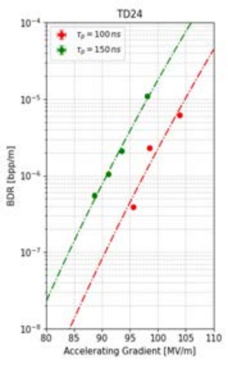
➢ Fundamental process for high-fields and material dynamics

Structures and components production program to study designs, operation, conditioning, manufacturing, industry qualification/experience. Understanding the limits by: Field emission, Vacuum arcing (breakdown) and Fatigue due to pulsed surface heating



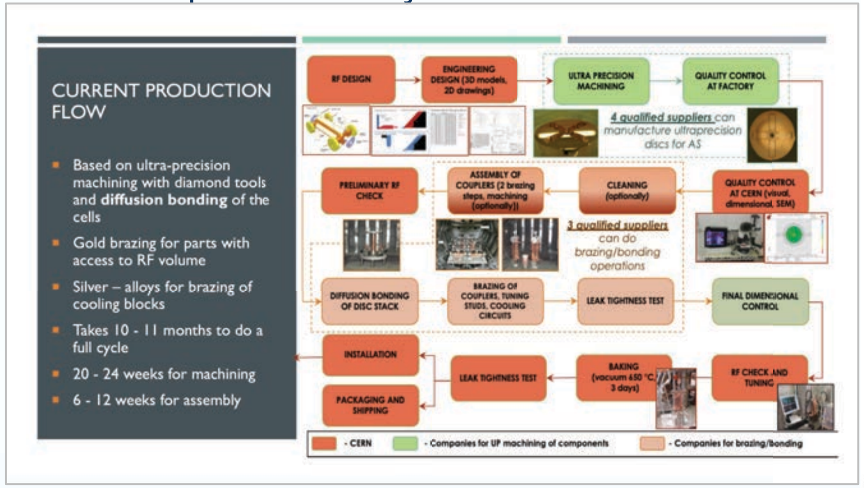
X-box studies





➢ X band RF structures fabrication:

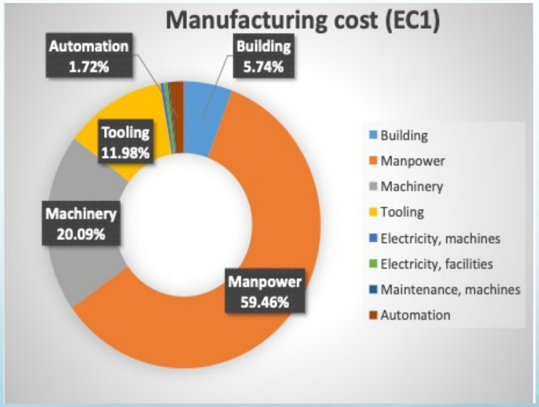
Processes, Developments (rectangular disks, brazing, halves), Fabrication capacity and Components for system.



CURRENT PRODUCTION FLOW

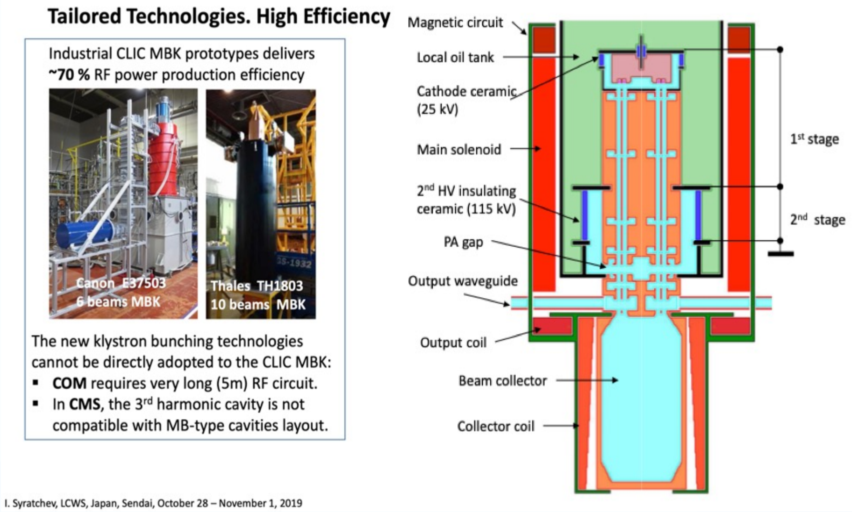
- Based on ultra-precision machining with diamond tools and **diffusion bonding** of the cells
- Gold brazing for parts with access to RF volume
- Silver – alloys for brazing of cooling blocks
- Takes 10 - 11 months to do a full cycle
- 20 - 24 weeks for machining
- 6 - 12 weeks for assembly

Industrial questionnaire: Based on the companies feedback, the preparation phase to the mass production could take about five years. Capacity clearly available.



➢ High Efficiency Klystrons:

for LHC, CLIC, FCC-ee and ILC. For CLIC, this includes the L-band and X-band sources



Tailored Technologies. High Efficiency

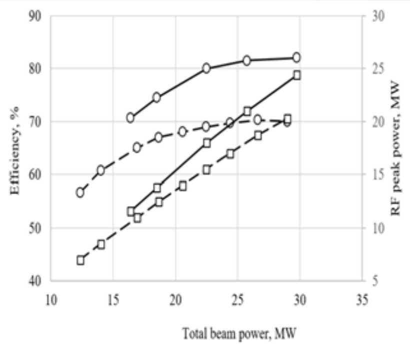
Industrial CLIC MBK prototypes delivers **~70 %** RF power production efficiency

The new klystron bunching technologies cannot be directly adopted to the CLIC MBK:

- **COM** requires very long (5m) RF circuit.
- In **CMS**, the 3rd harmonic cavity is not compatible with MB-type cavities layout.

I. Syratchev, LCWS, Japan, Sendai, October 28 – November 1, 2019

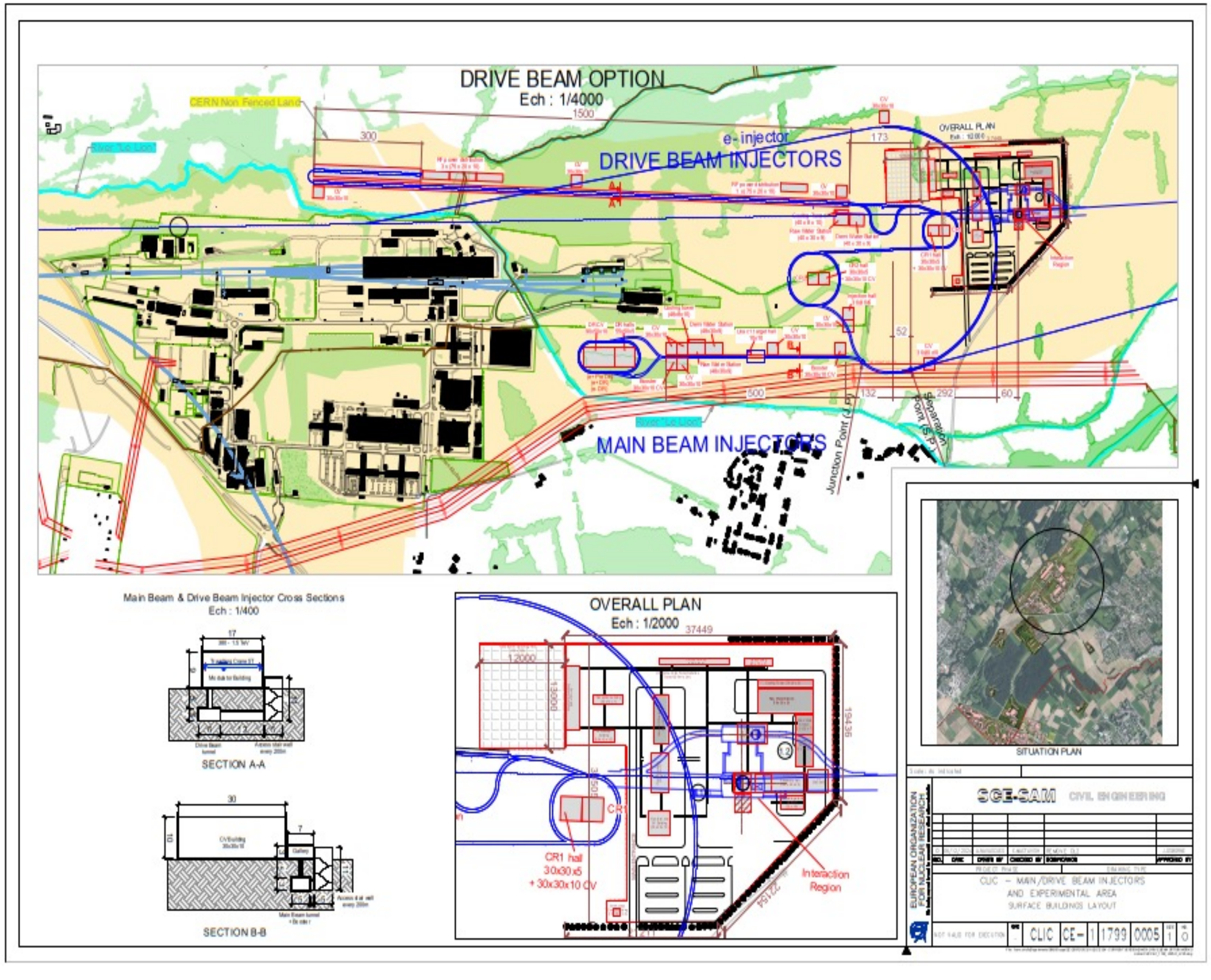
Drivebeam klystron: The klystron efficiency (circles) and the peak RF power (squares) simulated for the CLIC TS MBK (solid lines) and measured for the Canon MBK E37503 (dashed lines) vs total beam power. https://ieeexplore.ieee.org/document/9115885



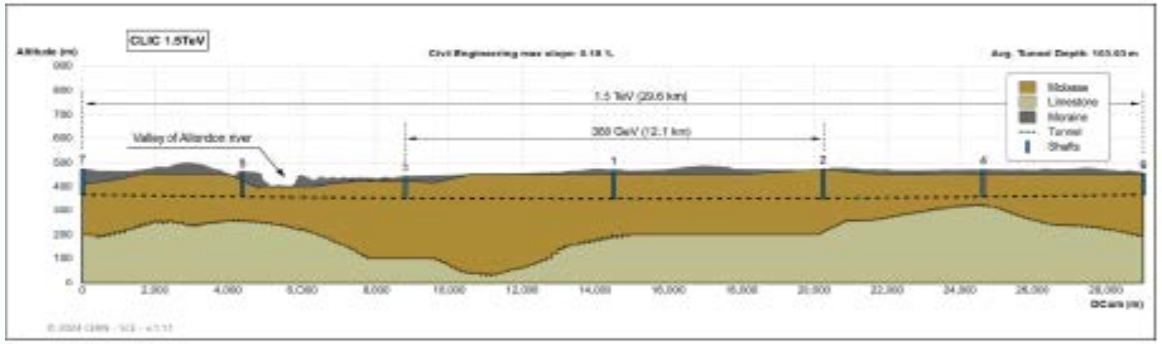
CLIC Site implementation and Civil Engineering

S. Stapnes, LCWS 2025

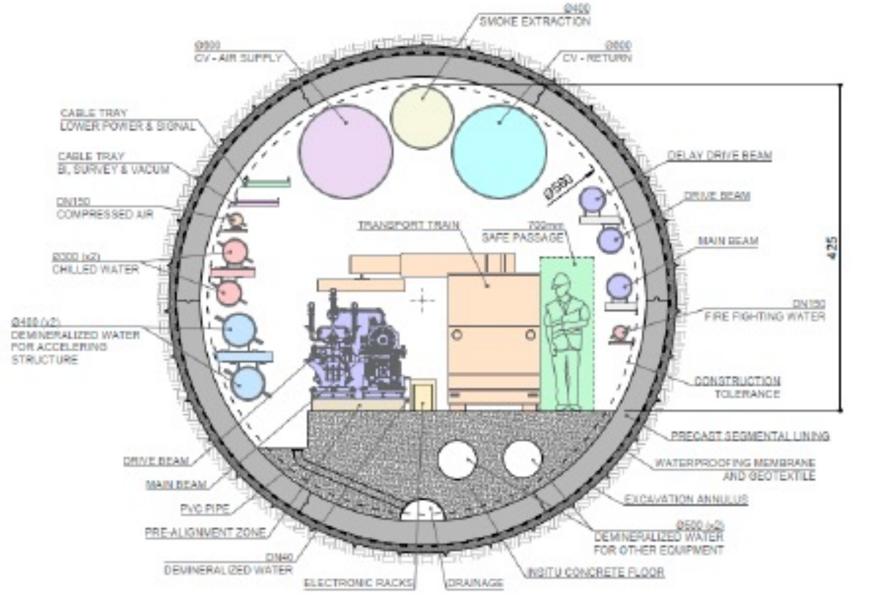
Implementation central complexes entirely on CERN property



Geological profile of the two stages collider



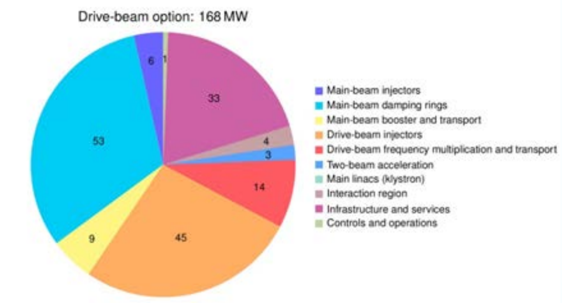
Cross-section of the underground tunnel

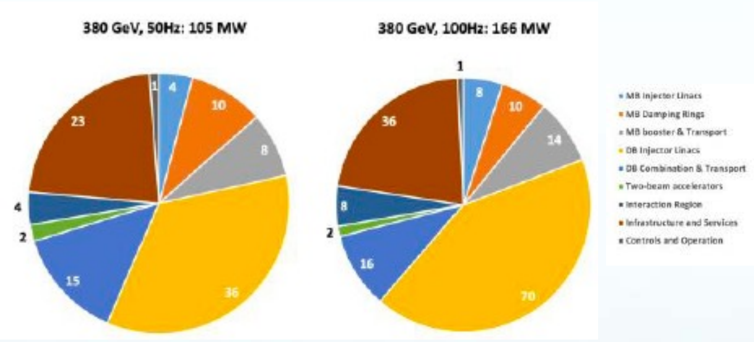


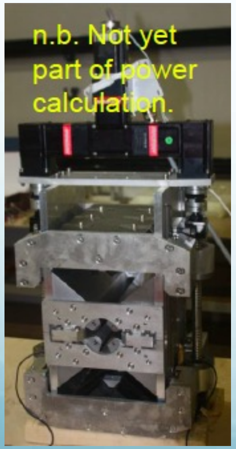
“Green CLIC” and Carbon neutrality

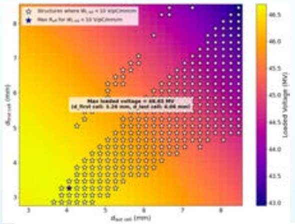
➢ Energy consumption:

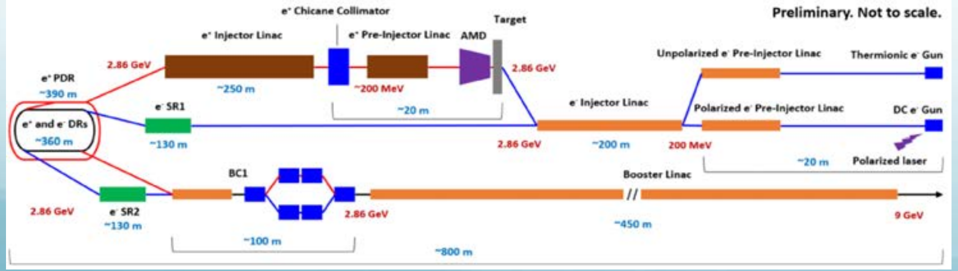
- Very **large reductions** since **CDR**, better estimates of nominal settings, much more optimized drive-beam complex, more efficient klystrons and optimized injectors.
- Further savings possible, as permanents magnets







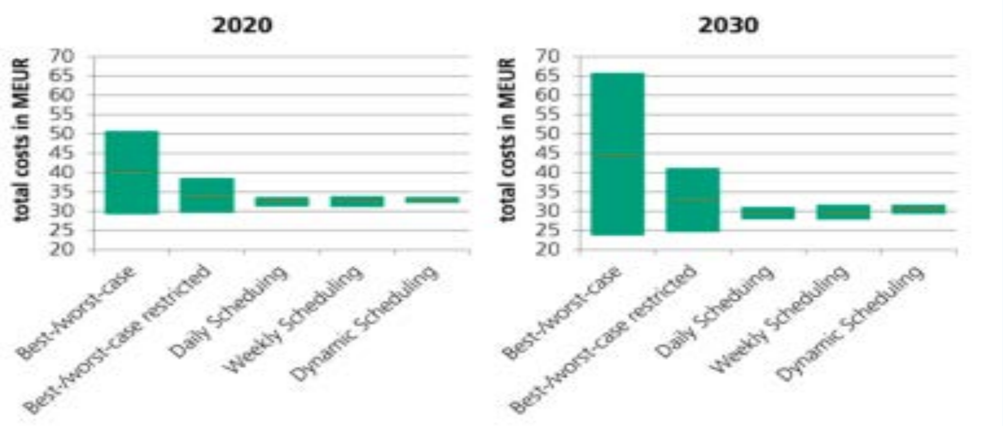




S. Stapnes, LCWS 2025

➢ Energy studies:

- Running when energy is cheap



Relative energy cost by no scheduling, avoiding the winter months (restricted), daily, weekly and dynamic scheduling. Central values of the ranges shown should be considered best estimates. The absolute cost scale will depend on price, contracts and detailed assumption about running times, but the relative cost differences indicate that significant cost-reductions could be achieved by optimizing the running schedule of CLIC to avoid high-energy cost periods (Fraunhofer)

- Renewable energy (carbon footprint)
- Recovering energy

Asurnipal CC-BY-SA-4.0

Victor Gleim CC-BY-SA-4.0

Cool Copper Collider: Technology updates

web.slac.stanford.edu/c3/

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University

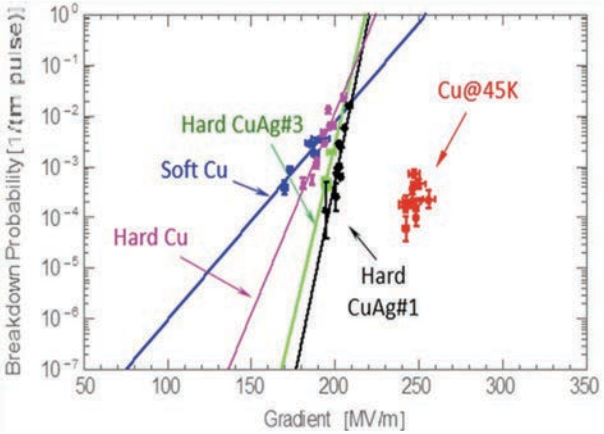
U.S. DEPARTMENT OF ENERGY

GIF 2025

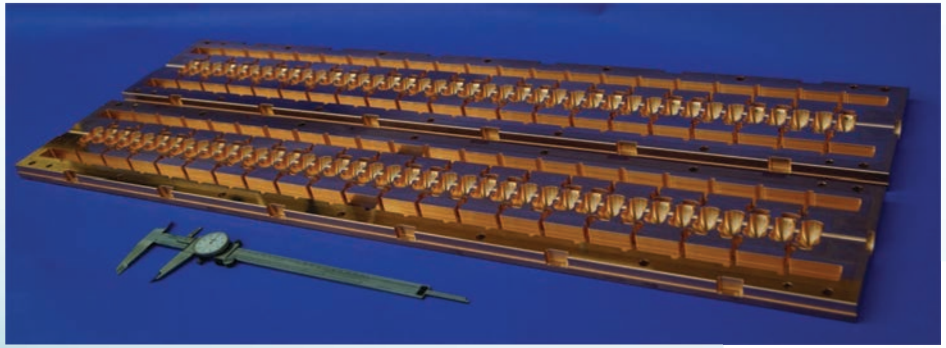
C^3 RF technology

E. Nanni, LCWS 2025

- C^3 is based on a new RF technology
  - Dramatically **improving efficiency** and **breakdown rate**
- **Distributed power** to each cavity from a common RF manifold
- Operation at **cryogenic temperatures** (LN_2~80K)
- Potential for High gradient: **155 MeV/m**
- Scalable to multi-TeV operation

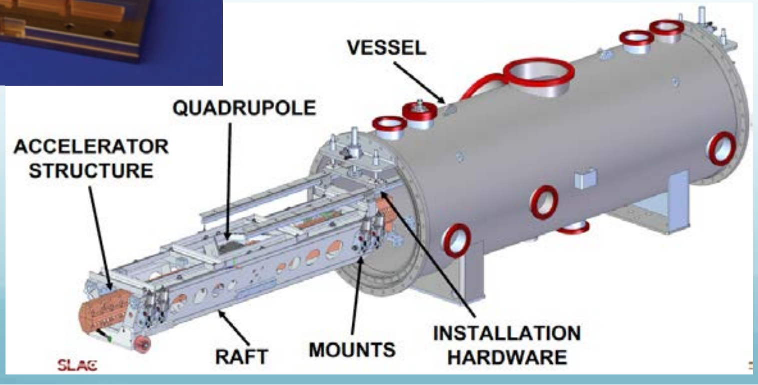


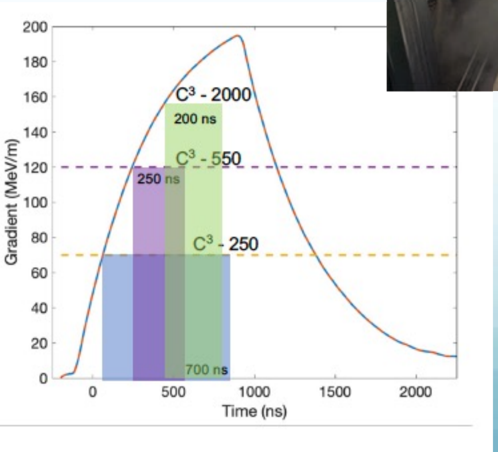
High power Test at Radiabeam



C^3 Prototype One Meter Structure

Quarter cryomodule





Exceeding Gradients and Pulse Lengths Required for C^3

C^3 Accelerator complex and performances

E. Nanni, LCWS 2025

8 km footprint for 250/550 GeV CoM ⟹ 70/120 MeV/m

- 7 km footprint at 155 MeV/m for 550 GeV CoM – present Fermilab site

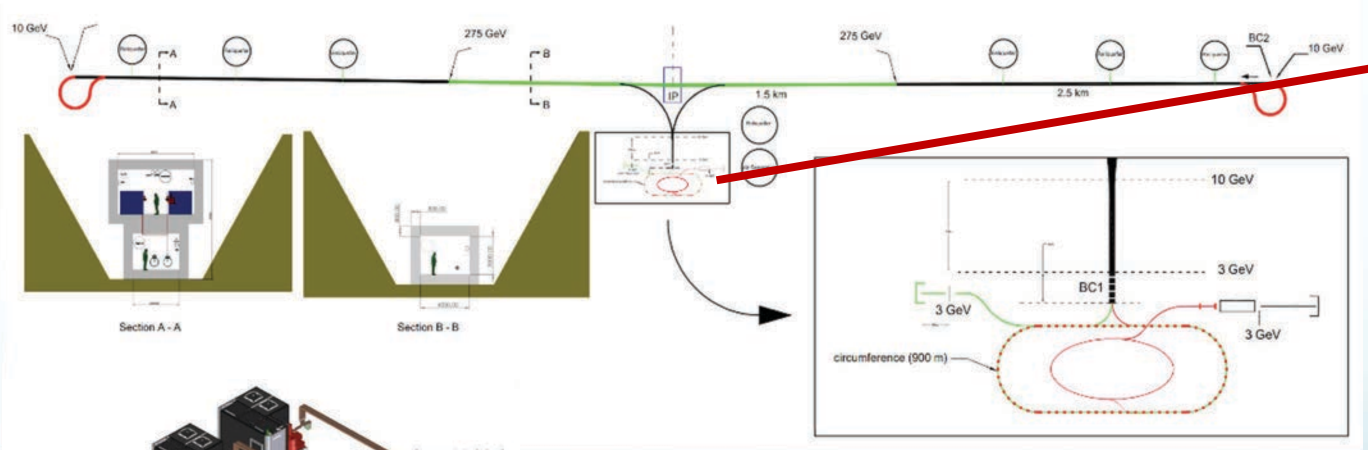
Large portions of accelerator complex are compatible between LC technologies

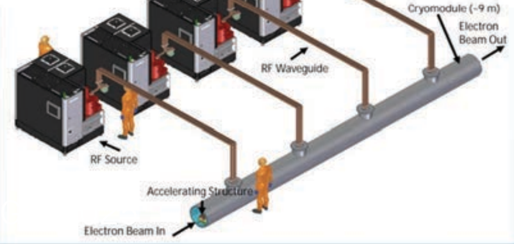
- Beam delivery and IP modified from ILC (1.5 km for 550 GeV CoM)
- Damping rings and injectors to be optimized with CLIC as baseline
- Costing studies use LC estimates as inputs

Scenario	C^3-250 s.u.	C^3-550 s.u.	C^3-250 high lumi	C^3-550 high lumi
Luminosity [x10^{34}cm^{-2}s^{-1}]	1.3	2.4	7.6	4.8
Gradient [MeV/m]	70	120	70	120
Effective Gradient [MeV/m]	63	108	63	108
Num. Bunches per Train	266	150	532	300
Train Rep. Rate [Hz]	60	60	120	60
Bunch Spacing [ns]	2.65	1.75	2.65	1.75
Single Beam Power [MW]	2	2.45	8	4.9
Site Power [MW]	~110	~125	~180	~180
Parameter Set [6]	PS1	PS2	PS2	PS2

Ntounis, et al., Phys. Rev. Accel. Beams ***27****, 061001, 2024*

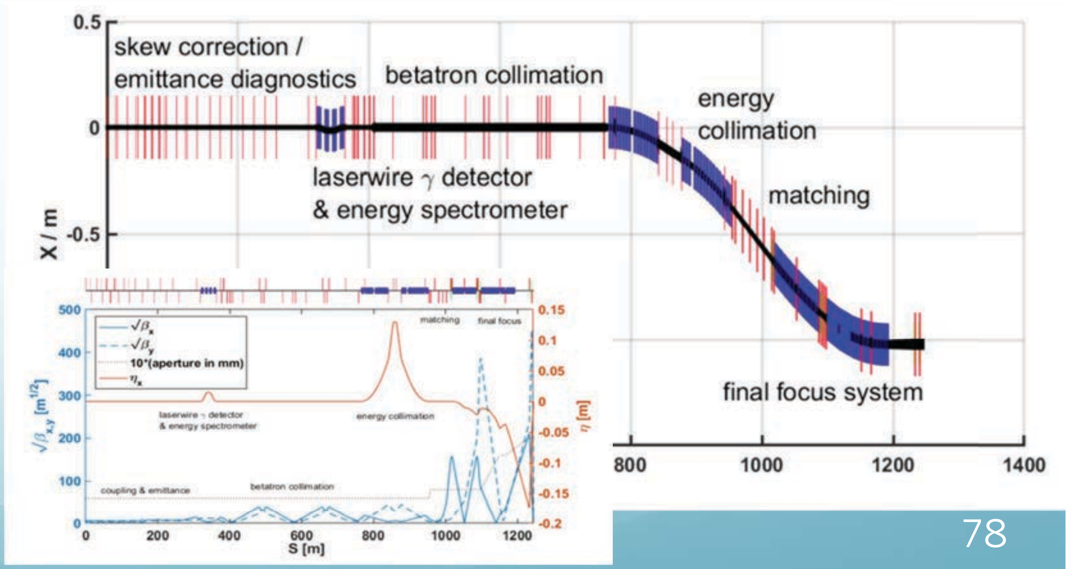
C^3 - 8 km Footprint for 250/550 GeV





Cryomodule Unit - 9 m
(630 MeV/1 GeV)

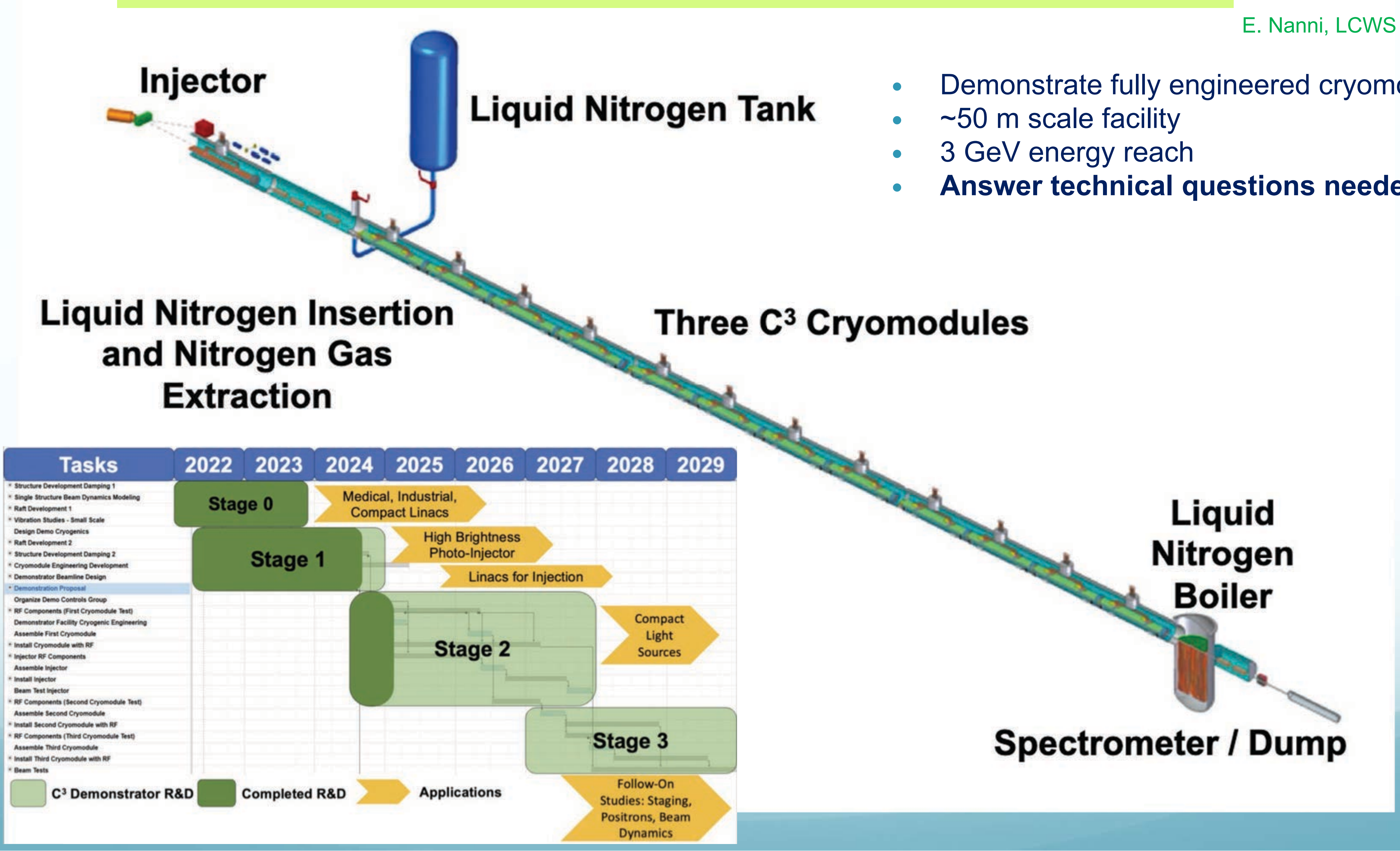
C^3 Beam Delivery System (Adapted from ILC/NLC)



The Complete C^3 Demonstrator

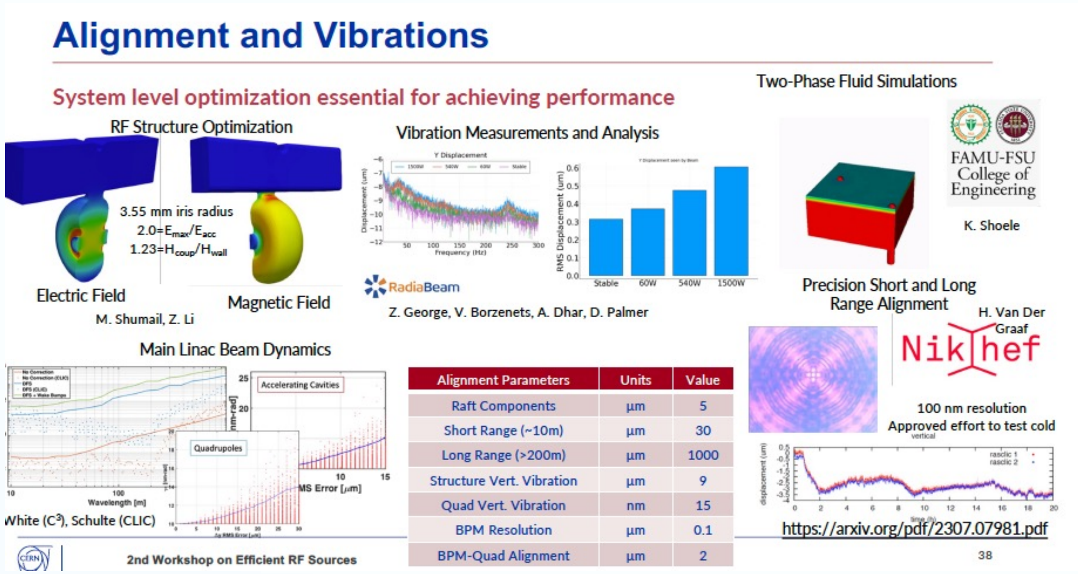
E. Nanni, LCWS 2025

- Demonstrate fully engineered cryomodule
- ~50 m scale facility
- 3 GeV energy reach
- **Answer technical questions needed for CDR**



C^3 R&D programme

E. Nanni, LCWS 2025



Alignment and Vibrations

System level optimization essential for achieving performance

RF Structure Optimization

3.55 mm iris radius

$2.0 = E_{max}/E_{acc}$

$1.23 = H_{coup}/H_{wall}$

Electric Field

Magnetic Field

M. Shumail, Z. Li

Vibration Measurements and Analysis

Z. George, V. Borzenets, A. Dhar, D. Palmer

Two-Phase Fluid Simulations

K. Shoele

Precision Short and Long Range Alignment

H. Van Der Graaf

100 nm resolution
Approved effort to test cold

https://arxiv.org/pdf/2307.07981.pdf

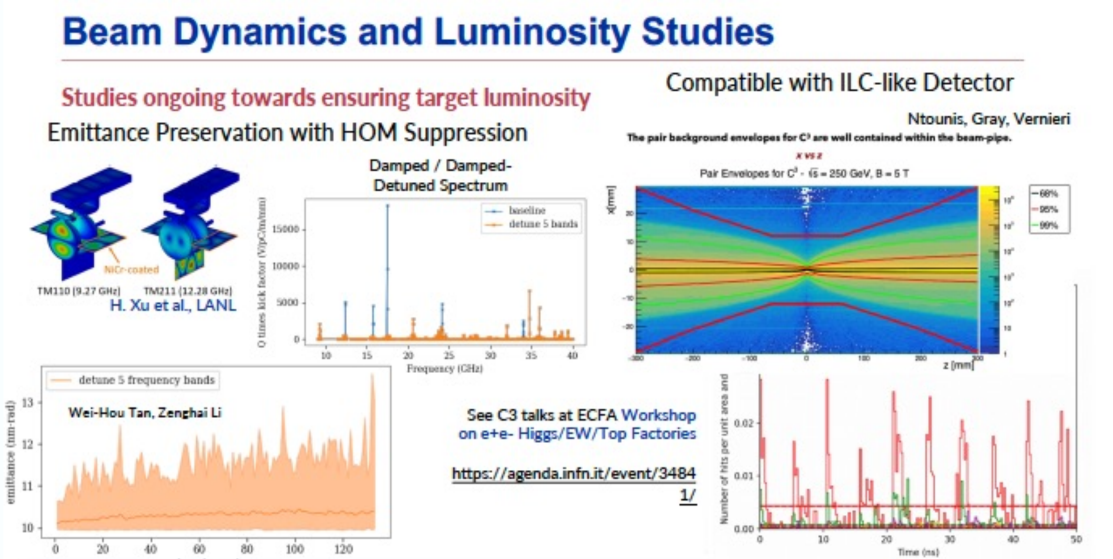
Main Linac Beam Dynamics

White (C^3), Schulte (CLIC)

Alignment Parameters	Units	Value
Raft Components	µm	5
Short Range (~10m)	µm	30
Long Range (>200m)	µm	1000
Structure Vert. Vibration	µm	9
Quad Vert. Vibration	nm	15
BPM Resolution	µm	0.1
BPM-Quad Alignment	µm	2

2nd Workshop on Efficient RF Sources

38



Beam Dynamics and Luminosity Studies

Studies ongoing towards ensuring target luminosity

Emittance Preservation with HOM Suppression

H. Xu et al., LANL

Damped / Damped-Detuned Spectrum

Wei-Hou Tan, Zenghai Li

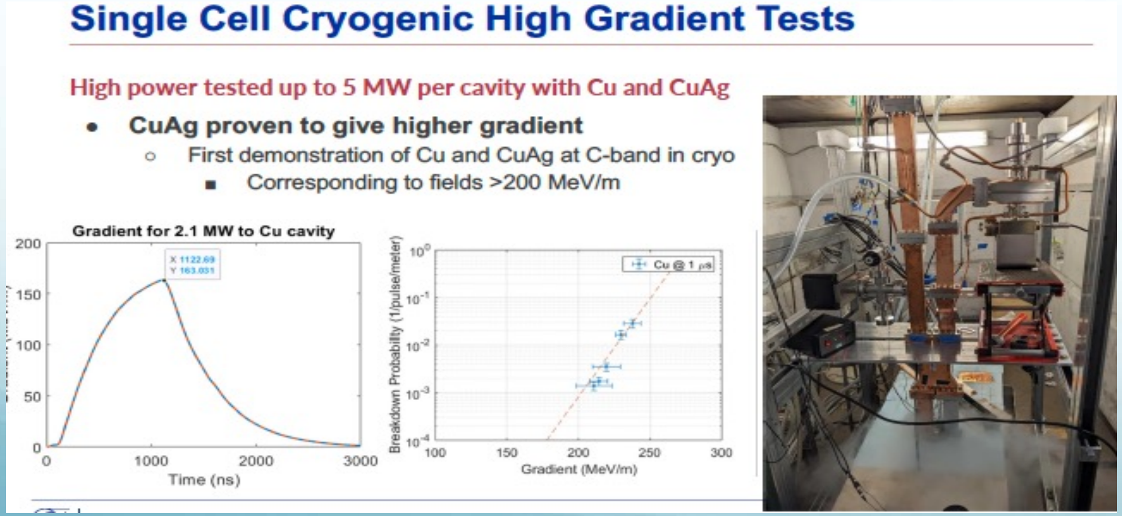
Compatible with ILC-like Detector

Ntounis, Gray, Vernieri

The pair background envelopes for C^3 are well contained within the beam-pipe.

See C3 talks at ECFA Workshop on e+e- Higgs/EW/Top Factories

https://agenda.infn.it/event/34841/

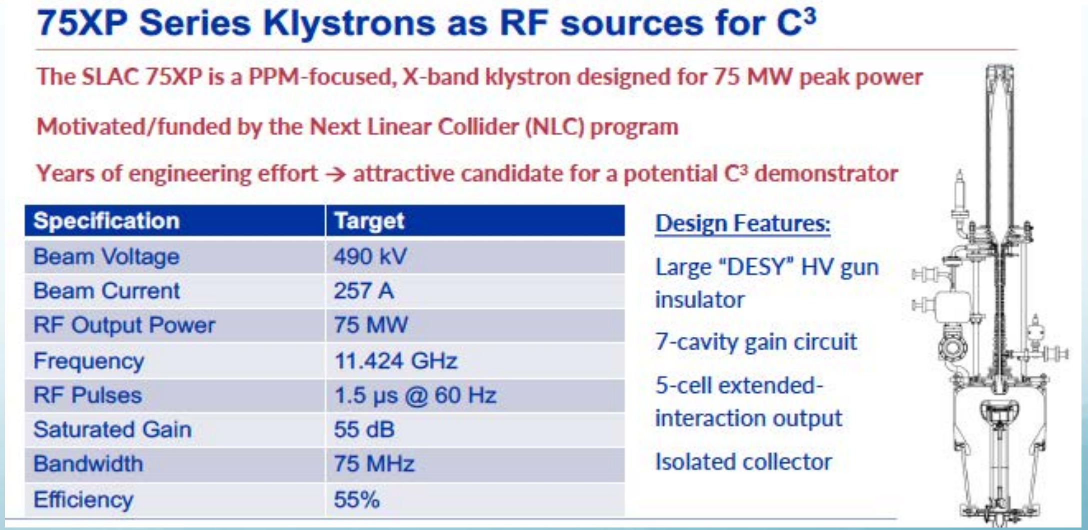


Single Cell Cryogenic High Gradient Tests

High power tested up to 5 MW per cavity with Cu and CuAg

- CuAg proven to give higher gradient
  - First demonstration of Cu and CuAg at C-band in cryo
    - Corresponding to fields >200 MeV/m

Gradient for 2.1 MW to Cu cavity



75XP Series Klystrons as RF sources for C^3

The SLAC 75XP is a PPM-focused, X-band klystron designed for 75 MW peak power

Motivated/funded by the Next Linear Collider (NLC) program

Years of engineering effort → attractive candidate for a potential C^3 demonstrator

Specification	Target
Beam Voltage	490 kV
Beam Current	257 A
RF Output Power	75 MW
Frequency	11.424 GHz
RF Pulses	1.5 µs @ 60 Hz
Saturated Gain	55 dB
Bandwidth	75 MHz
Efficiency	55%

Design Features:

Large "DESY" HV gun insulator

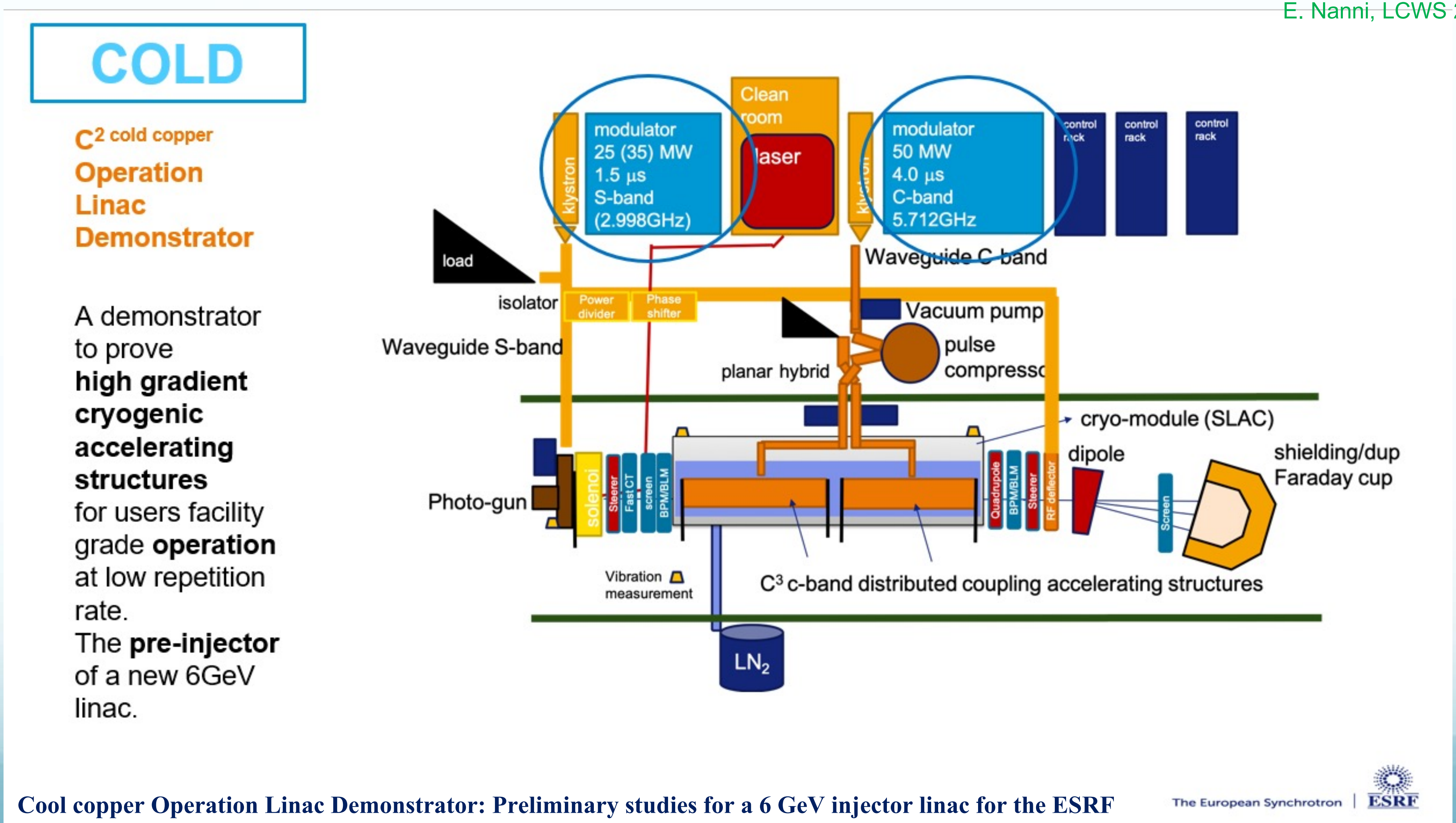
7-cavity gain circuit

5-cell extended-interaction output

Isolated collector

The injector linac Demonstrator

E. Nanni, LCWS 2025



COLD

C^2 cold copper Operation Linac Demonstrator

A demonstrator to prove **high gradient cryogenic accelerating structures** for users facility grade **operation** at low repetition rate.
The **pre-injector** of a new 6GeV linac.

Cool copper Operation Linac Demonstrator: Preliminary studies for a 6 GeV injector linac for the ESRF

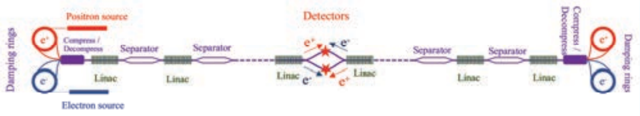
The European Synchrotron | ESRF

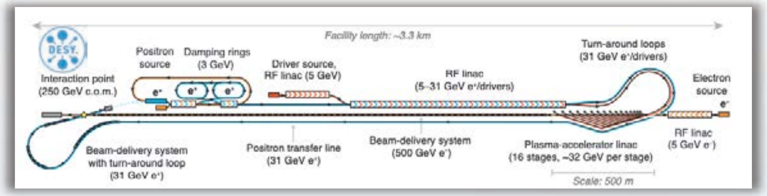
The LC@CERN baseline

The Roadmap

Basic assumption is to provide a scenario that can start “now” and that can be progressively upgraded to cover the physics needs and/or to be able to react on “surprises”. The guiding line should be to avoid as much as possible major civil construction for the upgrades. Upgrades should benefit from technology updates with the aim that the LC project benefits but also drives the innovation.

- The first step is construction of **250 GeV ILC** at CERN. This requires a 21 Km tunnel in the CERN area, a first implementation already studied by CLIC project, with **2 IRs** sharing Luminosity.
- After 10 years construction and 10 years data taking at at 250 GeV, the accelerator will be upgraded in stages with more advanced technologies to achieve higher-energies (500 GeV – 1 TeV) or higher-luminosities as:
  - Higher-gradient SRF, NCRF CLIC or Cool Copper C^3
  - ERL
  - Plasma wakefield
  - $\gamma\gamma$ collider (optical or XFEL lasers)
  - ...

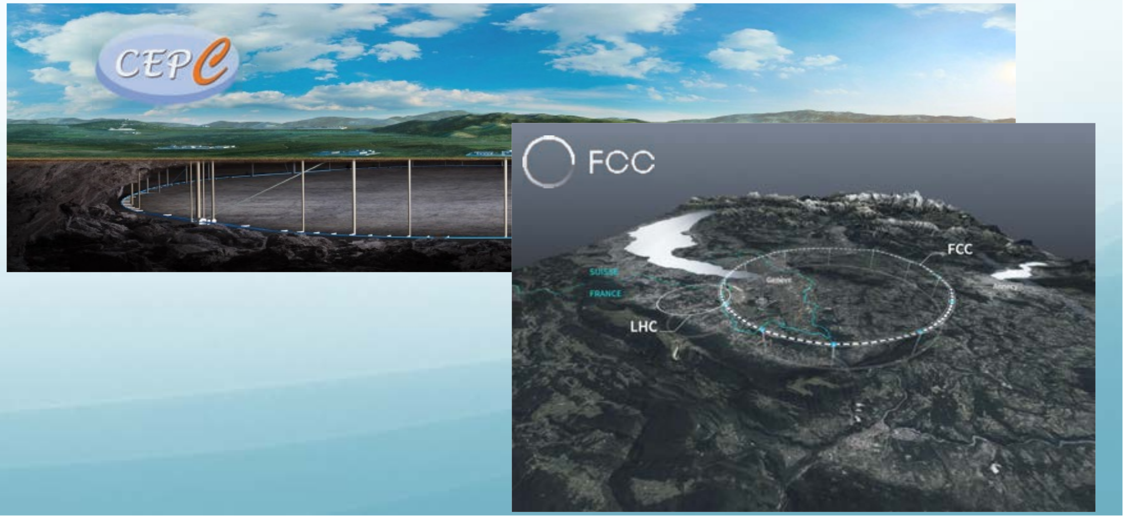




- Upgrades have to be understanded like: we have a tunnel with an ILC machine available and we need R&D to see how the new technologies can fit in such a facility, where DRs exists, tunnel diameter is fixed and a cryo-system is available.
- In later stages the 2IRS can be used by sharing luminosity by running parallel programs at higher and lower energy as a testbed for technology development.

Outline

- Introduction to Colliders
- HEP Context:
  - EPPSU2020 & Snowmass 2021
  - Next ESPPU2026
- e+e- colliders frontiers
  - Luminosity & Energy frontiers
  - Sustainability frontier
- Conventional e+e- colliders
  - CC projects: FCC-ee (CepC)
  - LC projects: ILC, CLIC, C3, LCF@CERN
- **Advanced e+e- colliders**
  - **Boosting the performances: HG SRF, ERLs**
  - **LPA based e+e- colliders**



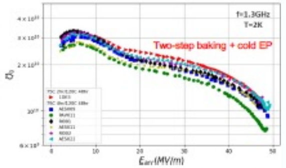
Boosting the performances of LCs: HG SCRF

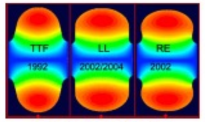
What can be done with bulk Nb within a 5-year horizon?

On a short timescale of about 5 years, the **focus** shall be on **improving the reliability and repeatability** of the selected technologies and **demonstration of their industrialization**.

- The most relevant for ILC recently developed surface treatment is a combination of cold electropolishing and two-step baking (75/120°C). It paved the way for gradients near 50 MV/m in single-cell TESLA-shape cavities. Combining this advanced treatment with developed earlier improved shape standing wave SRF cavities holds the prospect of gradients close to 60 MV/m in single-cell cavities and 50-55 MV/m in 9-cell cavities in a cryomodule.
- Applying these advances in accelerating gradients to ILC upgrades must be accompanied by 1) R&D on improving Q_0 at high gradients to avoid increase of the collider power consumption, and 2) developing methods to mitigate field emission during cryomodule assembly (e.g., robot-assisted automation) and after installation, e.g., plasma processing.
- Equally important is the continuation in development of "companion" technologies, such as high-efficiency high-power RF sources, modern LLRF with AI/ML tools (including precise cavity resonance control at high gradients), robust RF power distribution network.

If **50 MV/m** can be **reliably achieved in cryomodules**, the ILC can be upgraded to collisions at **380 GeV** center of mass energy within the ~20 km facility site. With an improvement of the cavity quality factor to 2×10^{10}, the overall site power will be **about 135 MW**, as compared to 111 MW for ILC250. New high-efficiency klystrons would reduce the overall site power.



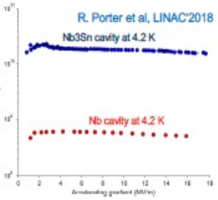


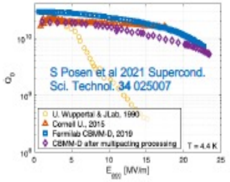
Examples of optimized cavity geometries


Fastening coupler flange after

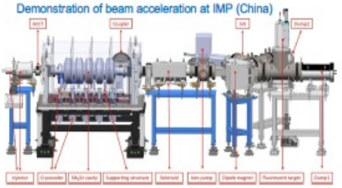
R&D on advanced SRF superconductors: Nb_3Sn

- The most developed alternative SRF superconductor is Nb_3Sn. SRF Nb_3Sn cavities have a potential to be a game changer, bringing **higher gradients at higher cryogenic efficiency**: Nb_3Sn has higher T_c of 18.3 K, compared to the 9.2 K of Nb, and higher DC superheating field (B_{sh}), approximately twice that of Nb.
- 1.3 GHz Nb cavities must operate at 2 K to have $Q_0 > 1\times10^{10}$. 2 K cryogenic systems are inefficient, COP ≈ 800 W/W. Nb_3Sn can have similar Q_0 but at 4.2 K where the cryogenic efficiency ~3 times better.
- Nb_3Sn cavities might reach 90-100 MV/m with good system efficiency at the same time. However, despite continuous efforts, the accelerating gradients achieved to date remain ≤ 24 MV/m.
- First applications are in compact accelerators, including conduction-cooled. If the technology will mature even at this gradient level, it could be useful for an ERL-based LC.
- The most progress to date has been made with the vapor diffusion process. Other processes of making Nb_3Sn are under investigation: electroplating, CVD deposition, magnetron sputtering... As these techniques mature, we should expect further progress. If there is a breakthrough, one could potentially apply Nb_3Sn to traveling wave structures, making even higher accelerating gradients reachable.

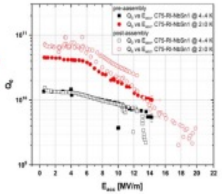

R. Porter et al, LINAC'2018


S Posen et al 2021 Supercond. Sci. Technol. **34** 025007

Demonstration of beam acceleration at IMP (China)




Two 5-cell Nb_3Sn cavities in a cryomodule at JLAB



Traveling wave SRF: Prime-time ready on a 10-year timescale

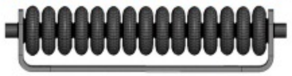
Further improvements in accelerating gradients of bulk Nb structures are possible but require developing an alternative approach, utilizing a traveling wave (TW) in a resonant ring configuration. The SRF TW structure has several advantages compared to the standing wave structures. The most salient advantages are :

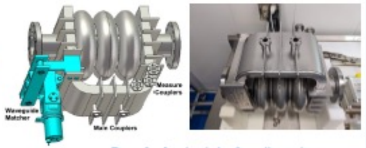
- Substantially lower k_M promises achieving higher E_{acc} at the same magnetic quench limit.
- Approximately a factor of 2 higher R/Q (even at lower G) would ensure lower cryogenic losses.
- In addition, the TW structure provides high stability of the field distribution along the structure with respect to geometrical perturbations. This allows for much longer accelerating structures than ILC cavities, limited by the manufacturing technology only.

Assuming the accelerating gradient of **65 MV/m** and the quality factor of 1.4×10^{10} (for the surface resistance corresponding to $Q_0 = 2\times10^{10}$ of ILC cavity), the superconducting collider built with TW cavities could reach **500 GeV** center of mass collision energy within the **20 km** footprint. The total site power is estimated at **168 MW**.

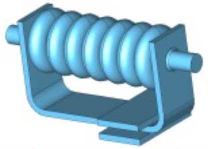
P.S. Presently the progress towards proof-of-principle experimental demonstration on a 3-cell structure and developing a longer structure is slow due to intermittent funding. Proper investment in this technology could bring it to "prime time" readiness – demonstrated performance in a full-scale cryomodule – on a 10-year time scale. After that, a TW-based linear collider should be feasible.


ILC (TESLA) 9-cell standing wave cavity


Traveling wave 15-cell SRF cavity

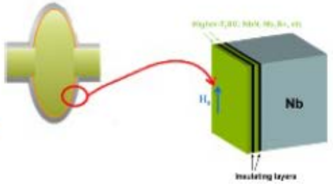


Proof-of-principle 3-cell cavity

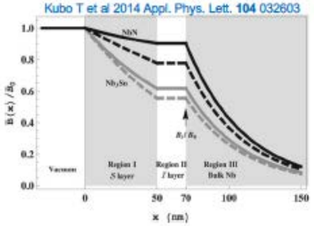

3D model of a 7-cell TW cavity

R&D on advanced SRF superconductors: multilayers

- A concept to overcome limitations of Nb is to create a multilayer structure called S-I-S.
- It is achieved by coating the cavity surface with alternating insulating and superconducting thin films (hence SIS) with thickness d thinner than the London penetration depth λ.
- Theory suggests increase of max. E_{acc} because magnetic shielding improvement, caused by counter currents at each interface, and the Meissner state can be maintained at a magnetic field much higher than the bulk critical magnetic field. However, surface defects, grain boundaries, etc. can allow for flux penetration at field levels below B_{sh}.
- RF field is dominant in the top superconducting layer with higher energy gap Δ compared to Nb. This will reduce losses because $R_{BCS} \propto \exp(-\Delta/k_B T_c) \rightarrow$ higher Q_0.
- **Technological readiness level is still low** – successful sample studies need to be transferred to cavities.
- Teams in Asia, Europe and America are working on several materials (NbTiN, NbN, Nb_3Sn), using various deposition techniques (sputtering, ALD, CVD, PVD) and applying different post-deposition processing steps.
- A sustained investment into the basic R&D studies, infrastructure, analytical instruments is needed before we can expect first practical multilayer SRF cavities.
- **Goal is to achieve ~70 MV/m with a Q_0 of 10^{10}** (optional: at 4K) **on single cell cavities within next ~10 years.**



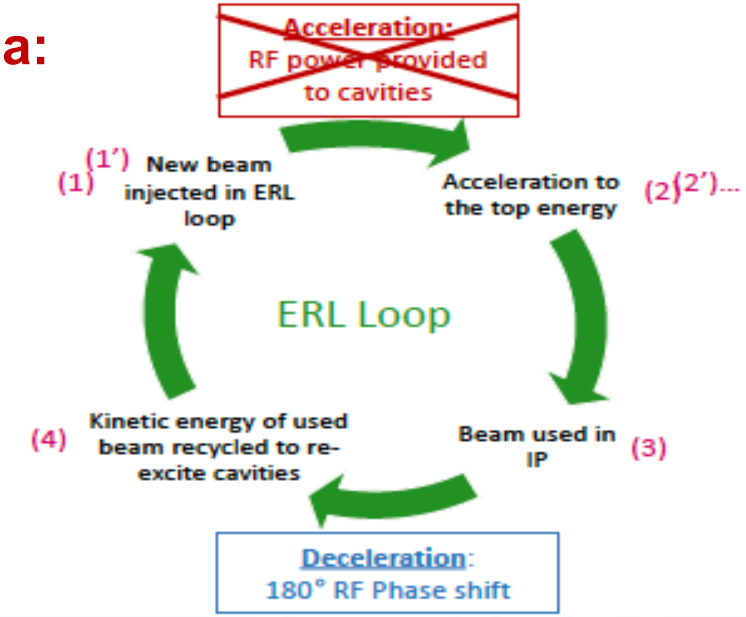
Kubo T et al 2014 Appl. Phys. Lett. **104** 032603

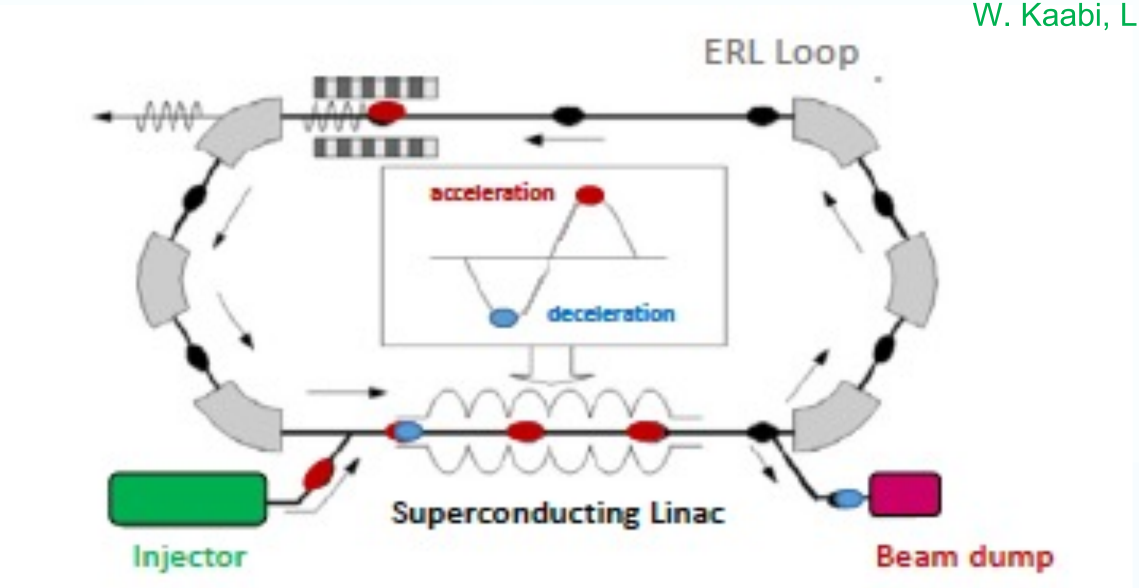


Boosting the performances of LCs: ERLs

W. Kaabi, LCWS 2025

The idea:





The benefits:

- Important reduction of **RF power consumption**
- Dumping the beam at injection power
- Fresh beam in IP with the same characteristics

More advantages:

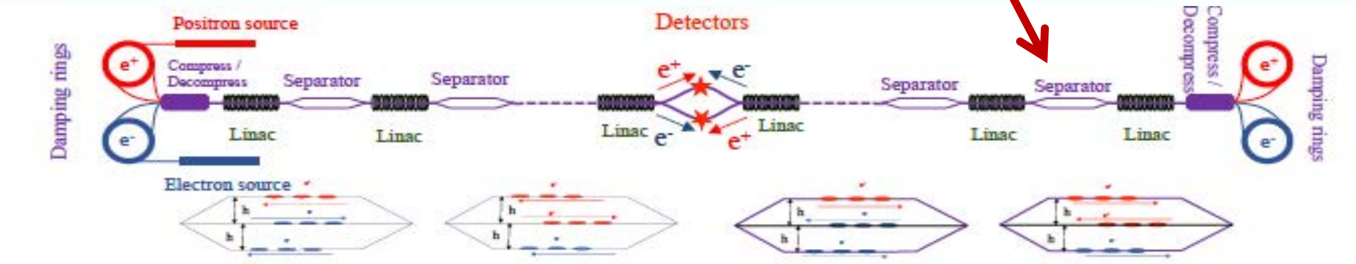
- Linac-like beam quality with extremely flexible time structure
- High operating efficiency
- Multi-pass configuration: High current carrying capability (no RF power limit) + High beam power in a compact machine

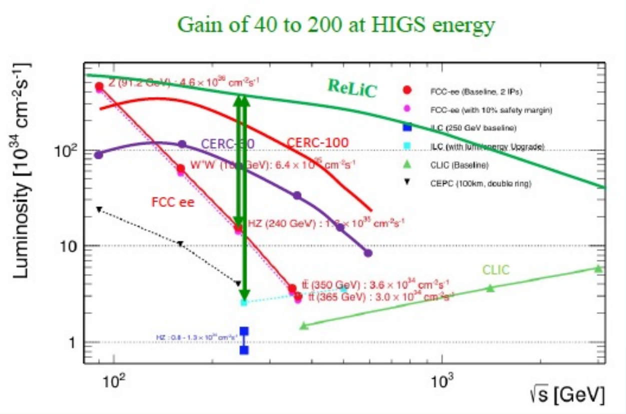
Boosting the performances of LCs: ERLs

W. Kaabi, LCWS 2025

LCs with **energy recovery** potential reach **luminosities 2 orders of magnitude** higher than ILC. **Two different concepts of LC** with energy recovery:

- After the IP, the beams are **decelerated** and **stored in damping rings** until the beam properties (emittance, energy spread, etc) are restored. Then, accelerated again (ReLiC)
- After IP, the beams are **decelerated** and weakly **damped by wigglers** (single pass). Then, accelerated again (ERLC, Ghost Collider)



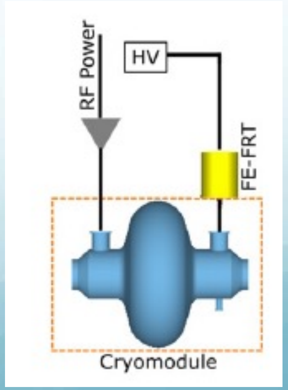


polarized e+e- Recycling Linear Collider with high-energy, high luminosity reach (ReLiC)

C.M. energy	GeV	250	3000
Length of accelerator	km	21	276
Section length	m	500	250
Bunches per train		5	21
Particles per bunch	10^{10}	4	1
Collision frequency	MHz	3	18
Beam currents in linacs	mA	18	29
εx, norm	mm mrad	4	8
εy, norm	µm mrad	1	2
βx	m	5	100
βy, matched	mm	0	7
σ_z	mm	1	5
Disruption parameter, Dx		0	0
Disruption parameter, Dy		109	3
Luminosity per detector	10^{34} cm^{-2}sec^{-1}	215	20
Total luminosity	10^{34} cm^{-2}sec^{-1}	429	40

Accelerator R&D Challenges

- High efficiency LiHe refrigeration systems
- Very high-Q SRF cavities
- Reactive tuners in SRF systems
- Damping rings
- MHz rated kickers



1.5 GHz SRF,
Q > 10^{11} , 1.5 K

Boosting the performances of LCs: ERLs

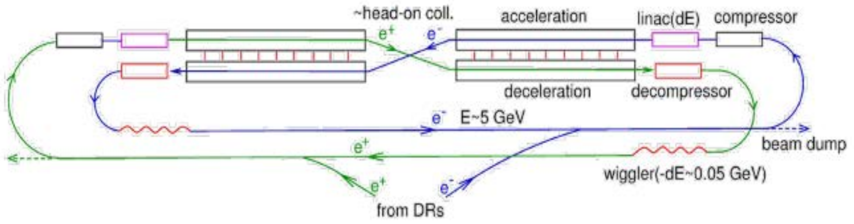
W. Kaabi, LCWS 2025

LCs with **energy recovery** potential reach **luminosities 2 orders of magnitude** higher than ILC. **Two different concepts** of LC with energy recovery:

- After the IP, the beams are **decelerated** and **stored in damping rings** until the beam properties (emittance, energy spread, etc) are restored. Then, accelerated again (ReLiC).
- After IP, the beams are **decelerated** and weakly **damped by wigglers** (single pass). Then, accelerated again (ERLC, Ghost Collider)

ERLC: A re-imagining of the ILC as an ERL

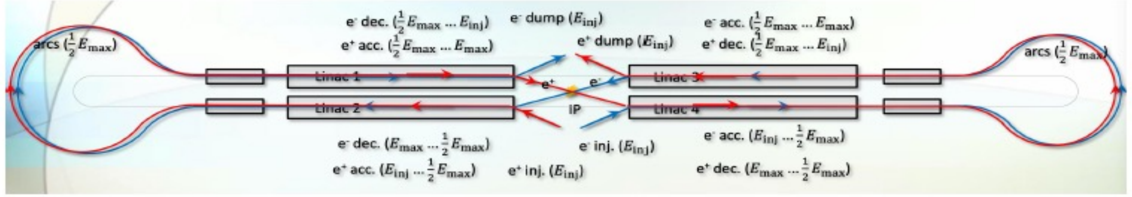
Twin LC with the energy recovery



- In each side of the IR, 2 parallel SC linacs, one for acceleration and the other for deceleration, connected one to the other with **twin-axis cavities** to exchange recovered beam power.
- To reduce the energy spread arising from beam collisions, damping is ensured by wigglers at a return energy of about 5 GeV.
- Duration of cycle is of several second (partial CW RF), imposed by the cryogenic consumption.

The Ghost Collider

A new ERL-based concept of an e+ e- linear collider, 550 GeV center-of-mass, initially inspired by ERLC design, then evolved thanks to the properties of "**ghost bunches**".

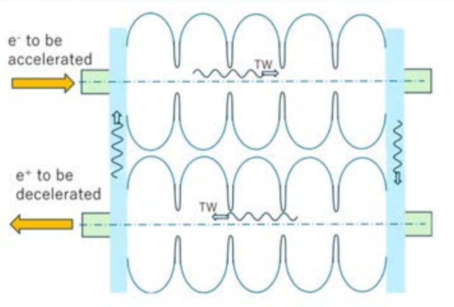


Linacs are the same length as the ILC ones, with partial CW RF (2s on- 4s off), or later full CW RF @ 4.5K.

Shape of arcs was optimised, reducing synchrotron radiation by 35.8%.

Accelerator R&D Challenges

- Traveling Wave (TW) cavities (HELEN type), combined with the development of twin axis cavities



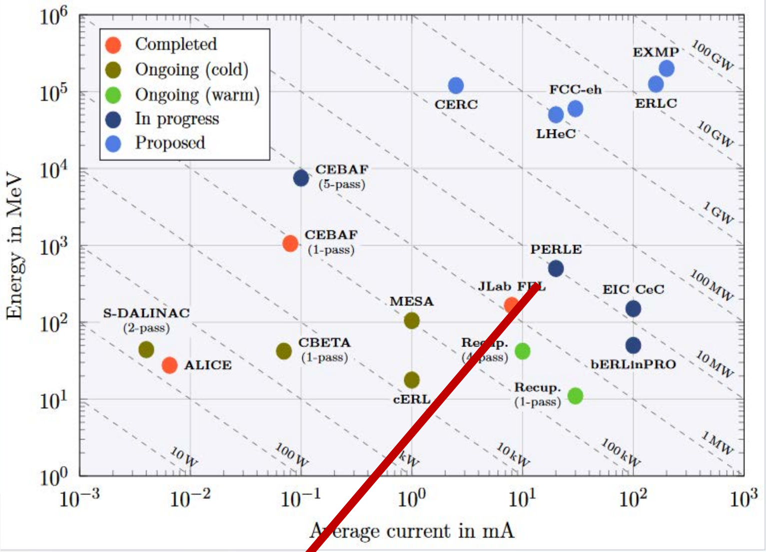
- Ghost bunches are **electrically neutral**: equal numbers of e- and e+ traveling together in the same Linac buckets → No electromagnetic interactions with the linac environment: No excitation of High Order Modes (HOM) or multi-bunch Beam Breackup (MBBU)
- **Energy transferred** between e- and e+ **in the same bunch**, decelerating one and accelerating the other → No need to couple linacs in the same side to transfer the power (no twin-cavity needed)
- No electromagnetic interactions between ghost bunches travelling in opposite direction → Single bidirectional linac on either side of the IR
- No electromagnetic interaction in IP as bunches are neutral → Possible to have several IPs in the IR, each of them with the design luminosity (1.6 10^{34} cm^{-2} s^{-1}).

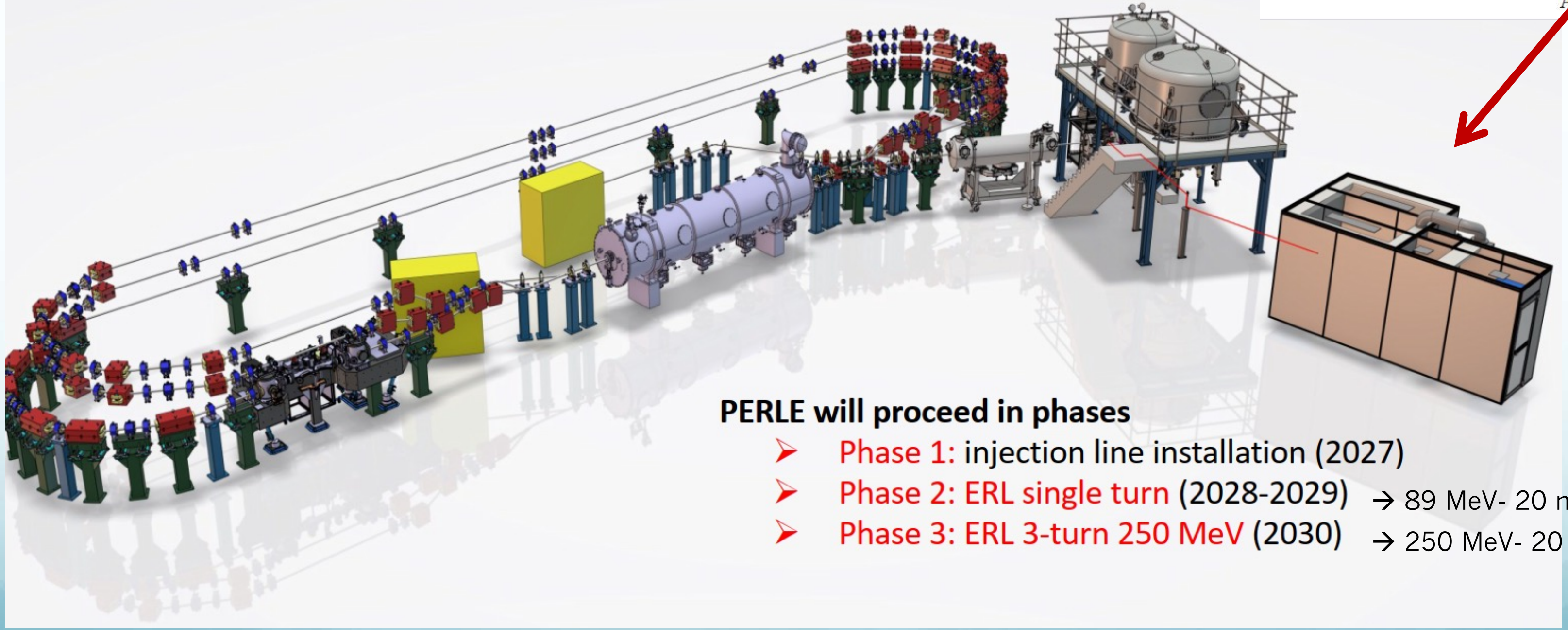
Boosting the performances of LCs: ERL demo

W. Kaabi, LCWS 2025

PERLE configuration and main parameters:

- Multi-turn ERL (3 pass up, 3 pass down)
- Top energy: 250 MeV, ~ 82 MeV /Linac
- 500 pc bunch charge @ 40 MHz → 20 mA
- 802 MHz SRF system, targeted Q_0= 3. 10^{10}
- Beam damped at injection energy (7 MeV)





PERLE will proceed in phases

- ➤ Phase 1: injection line installation (2027)
- ➤ Phase 2: ERL single turn (2028-2029) → 89 MeV- 20 mA
- ➤ Phase 3: ERL 3-turn 250 MeV (2030) → 250 MeV- 20 mA

LPA recent progress on the Technology R&D

M. Turner, LCWS 2025

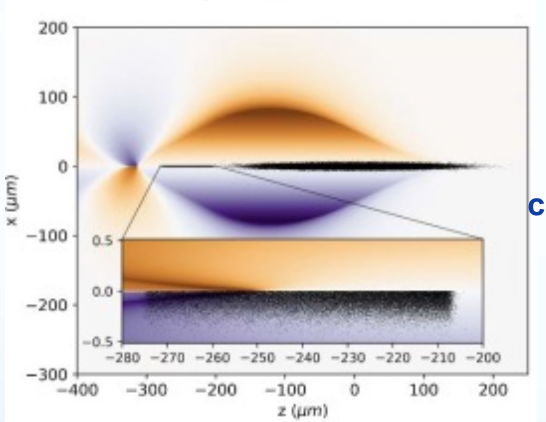
Highlights

Simulation Tools

E.g. using..

S. Diederichs et al., Comput. Phys. Comm. 276 108421 (2022)
Open-source: https://github.com/Hi-PACE/hipace

HiPACE++



Numerical convergence: few hrs on few GPU's

Multiple open source codes available to simulate collider quality beams

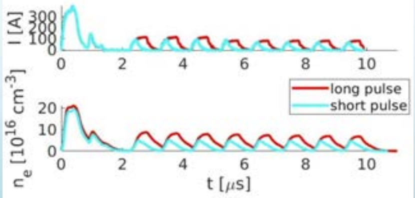
Plasma Sources

Development of **scalable** plasma sources at CERN

2x10⁷ discharges
10-150 Hz operation

FLASHForward HALHF

low voltage solid-state discharge system
☐ MHz repetition rate



Efficient Laser Drivers

Multiple technologies being investigated, e.g.
Ti:Sa, fiber lasers, TmYLF,
Tm-doped ceramics

Development of Joule-class kHz laser systems:

KALDERA → based on Ti:Sa technology, started commissioning

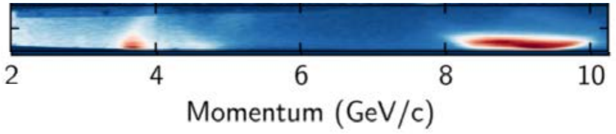
kBELLA → efficient coherent combination of fiber lasers 10's mJ at kHz, 100+ mJ in progress scheduled for next year

LPA recent progress in experiments

M. Turner, LCWS 2025

Energy

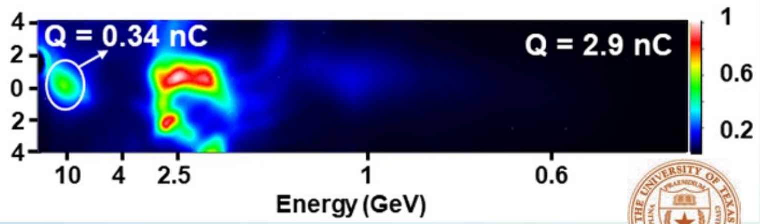
Matched Guiding and Controlled Injection in Dark-Current-Free, 10-GeV-Class, Channel-Guided Laser-Plasma Accelerators
A. Picksley et al., Phys. Rev. Lett. 133, 255001 (2024)



- ☐ **~9.2 GeV** energy gain over 30 cm
- ☐ Laser-created 'free-standing' plasma channels that can be recreated at the repetition rate of the laser

→ Multiple independent results

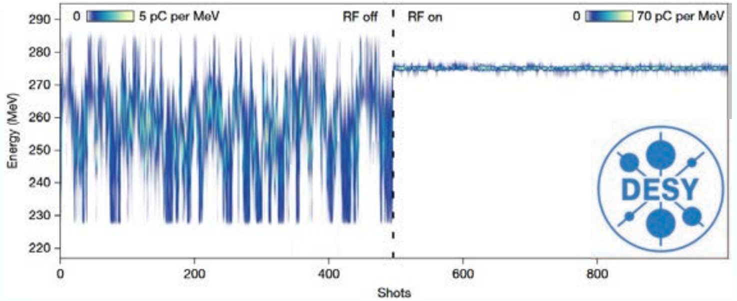
C. Aniculaesei et al., The acceleration of a high-charge electron bunch to 10 GeV in a 10-cm nanoparticle-assisted wakefield accelerator. *Matter Radiat. Extremes* 2024; 9 (1): 014001



- ☐ **~10 GeV** energy gain over 10 cm
- ☐ Multiple acceleration regimes that may be difficult to control

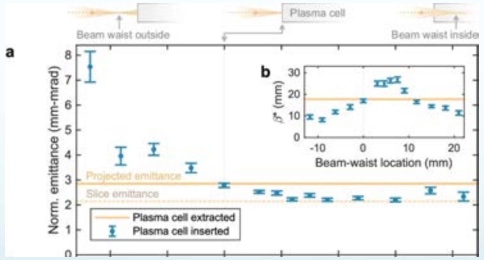
Beam Quality

Winkler, P. *et al.* Active energy compression of a laser-plasma electron beam. *Nature* **640**, 907–910 (2025).



→ Energy spread below the **permille level**
→ Employing active stabilization

Lindstrøm, C.A., Beinortaitė, J., Björklund Svensson, J. *et al.* Emittance preservation in a plasma-wakefield accelerator. *Nat Commun* **15**, 6097 (2024)

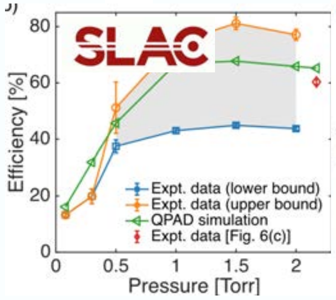


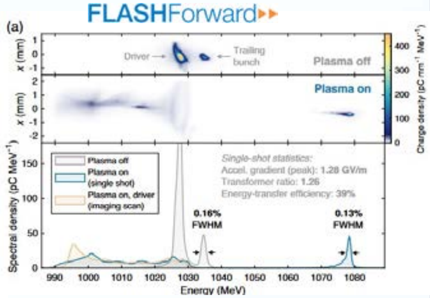
☐ **Emittance preservation** at micron level for 40 MeV energy gain (on top of 1 GeV)

Efficiency

C Zhang *et al* 2024 *Plasma Phys. Control. Fusion* 66 025013

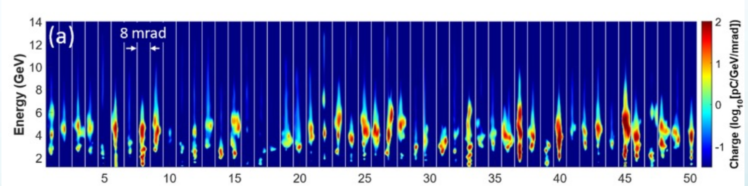
C. A. Lindstrøm et al., Phys. Rev. Lett. **126**, 014801 (2021)





- ☐ **~60%** driver depletion
- ☐ **42%** local energy transfer efficiency

E. Rockafellow et a;., High charge laser acceleration of electrons to 10 GeV NIM A, Volume 1077, August 2025, 170586



- ☐ Laser to electron conversion efficiency of at least ~**30%**
- ☐ Multi-GeV energy gain

LPA recent progress in experiments

M. Turner, LCWS 2025

Energy

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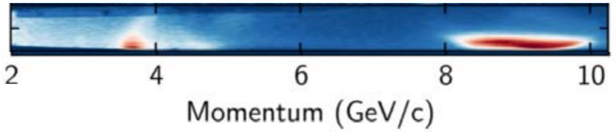

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repetition rate of the laser
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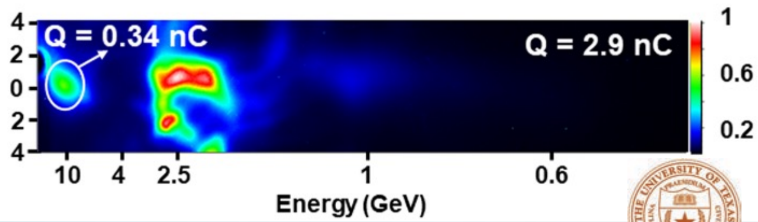

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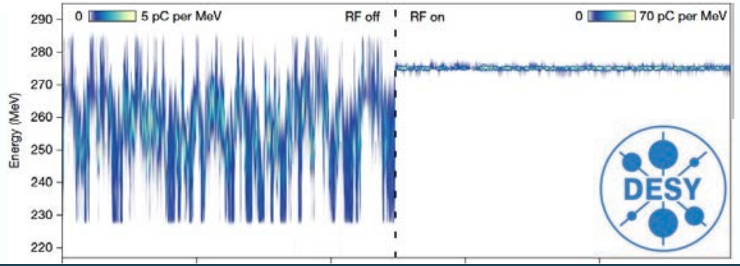
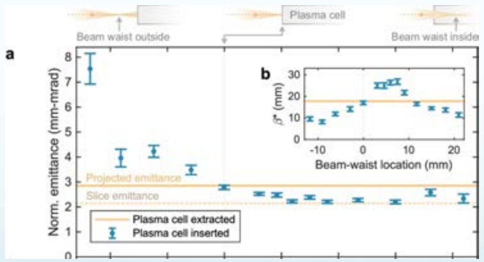


preservation in a plasma-wakefield accelerator. *Nat Commun* **15**, 6097 (2024)



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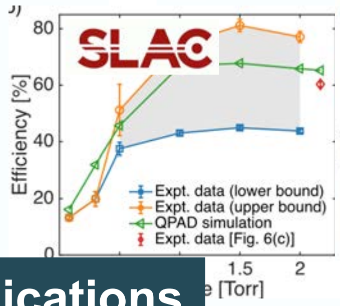

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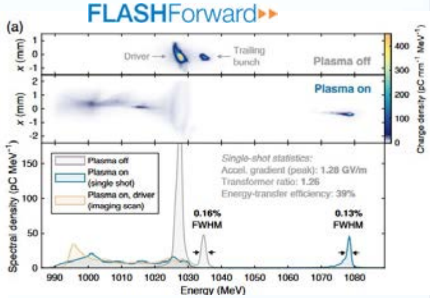
C. A. Lindstrøm et al., Phys. Rev. Lett. **126**, 014801 (2021)



☐ **42%** local energy transfer efficiency

., High charge laser acceleration of electrons to 10 GeV
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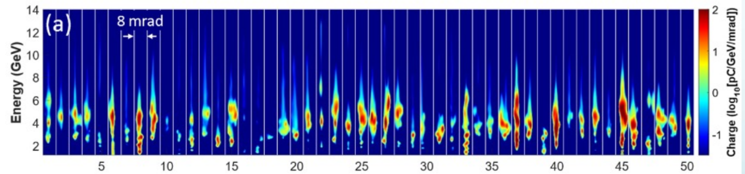


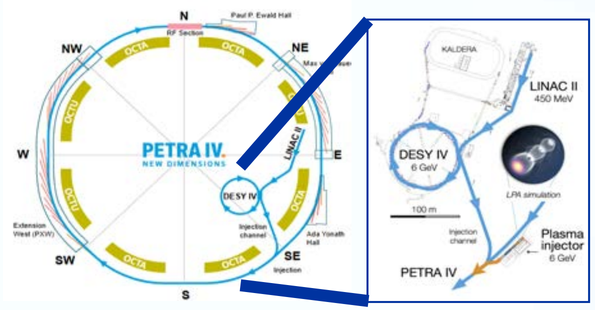
☐ Laser to electron conversion efficiency of at least ~**30%**
☐ Multi-GeV energy gain

- **→ Towards delivering beams for first applications**
- **Application will be used to mature wakefield acceleration technology**

LPA recent progress in applications

M. Turner, LCWS 2025

Laser and Beam-Driven



- Laser-Driven Plasma Wakefield Injector for **PETRA IV injector** complex :
  - Final Goal:
    6 GeV injector, to decrease the spatial footprint and power requirements

PIP4 CDR A. Martinez de la Ossa et al. doi:10.3204/PUBDB-2024-06078

- AWAKE Proton-driven plasma wakefield experiment at CERN) Run 2c and d approved
  fixed-target applications after LS4

- 
  IHEP-CEPC-DR-2018-01
  IHEP-AC-2018-01
  CEPC
  Conceptual Design Report
  Volume I - Accelerator

  → **CEPC Injector**

CEPC Plasma Injector (alternative option) and TF Plan

CEPC plasma injector scheme:
From 10 GeV → 30 GeV → TR ≥ 2

Simulation results show that it works on paper with reasonable error tolerances for both electron and positron beams injected to the booster

CEPC IARC, 2023.06

Positron and electron acceleration
Cascading acceleration
Future linear collider technologies
High energy beam for detector R&D
(possible applications)

PWFA/LWFA TF based on BEPC-II Linac and HPL has been founded by CAS 90M RMB in Sept. 2023
Under development in the experimental hall #10 of BEPC-II

- EuPRAXIA (Particle accelerator research infrastructure based on novel plasma acceleration)
  → *FEL user facility by 2031*
  - **FEL lasing achieved by 4 groups!**
    - Enabled by improved beam-quality and stability

PACRI

LPA e^+e^- colliders: Challenges

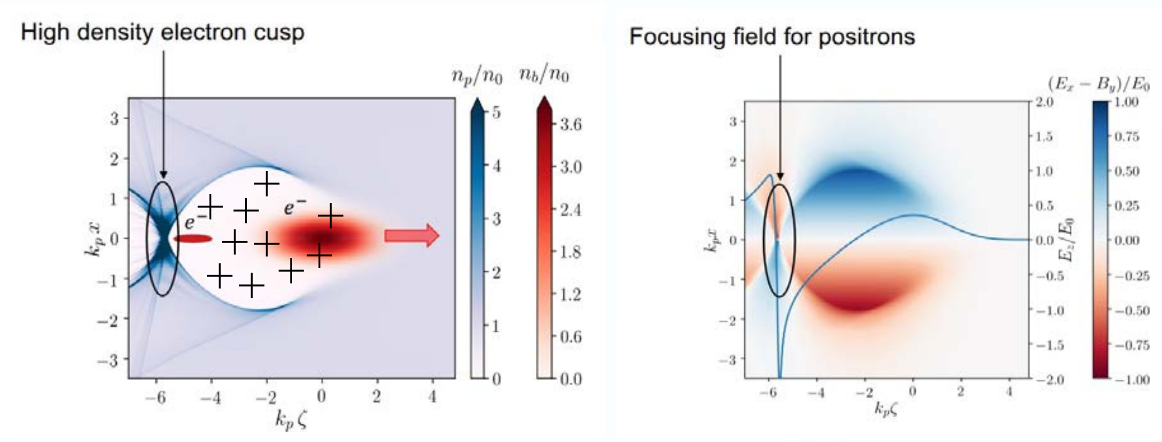
M. Turner, LCWS 2025

Wakefield Acceleration Comes with Unique Challenges

1) **Positron Acceleration in Plasma**

- Acceleration in the non-linear regime is **not** symmetric for positive and negative charges

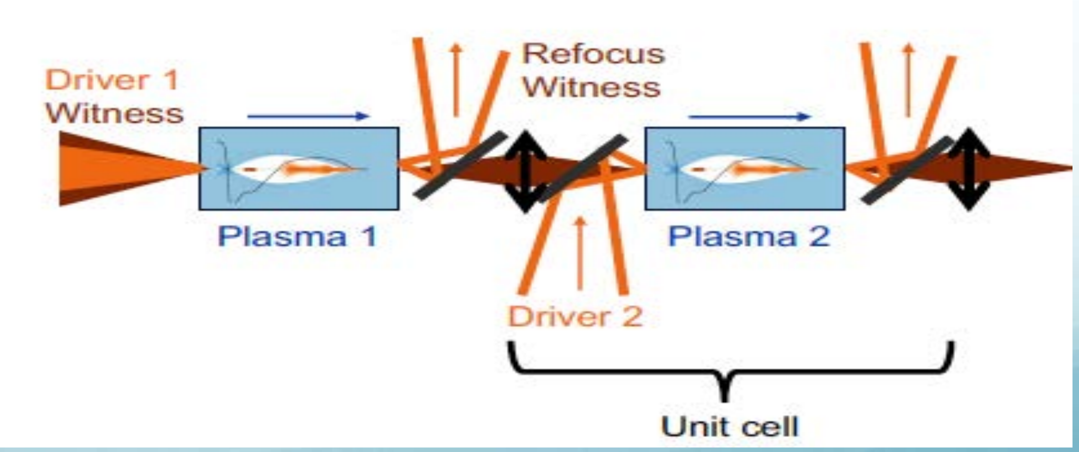
Positron acceleration: TRL 1!



2) **Staging**

- Tight tolerances, matching
- Must be compact

Concepts exist.
No experimental demonstration with high charge transfer yet!

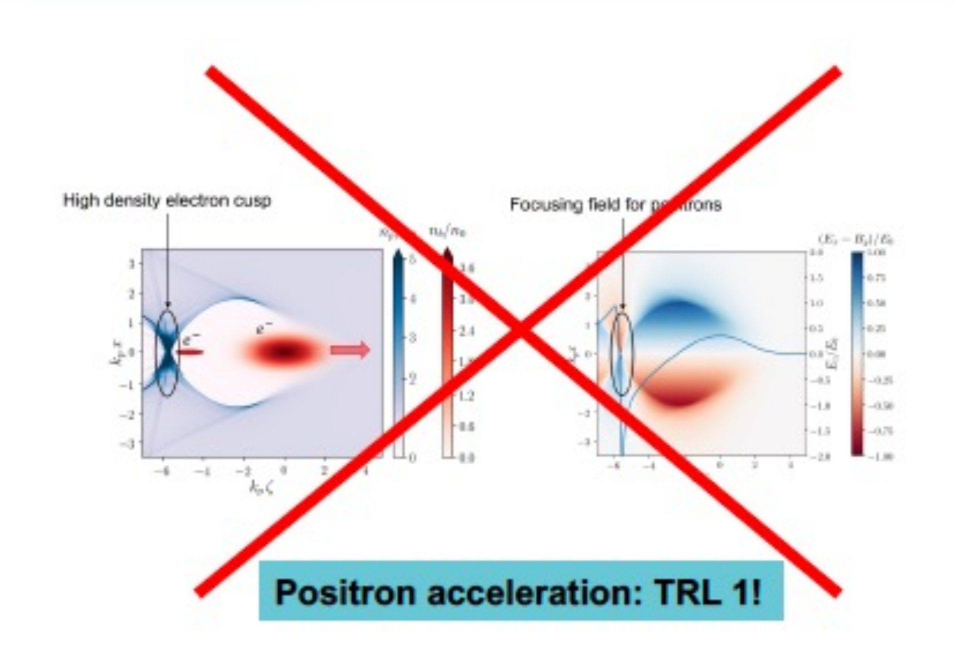


LPA e^+e^- colliders: Challenges

M. Turner, LCWS 2025

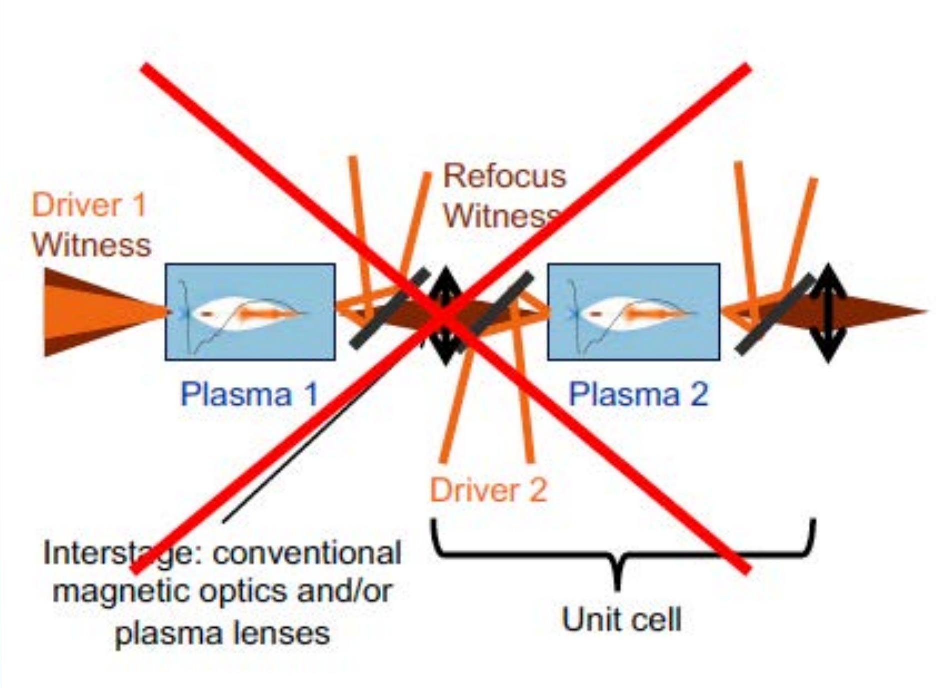
Wakefield Acceleration Comes with Unique Challenges

Strategy 1: Avoid Positron Acceleration



Positron acceleration: TRL 1!

Strategy 2: Avoid Staging



LPA e^+e^- colliders: design studies

M. Turner, LCWS 2025

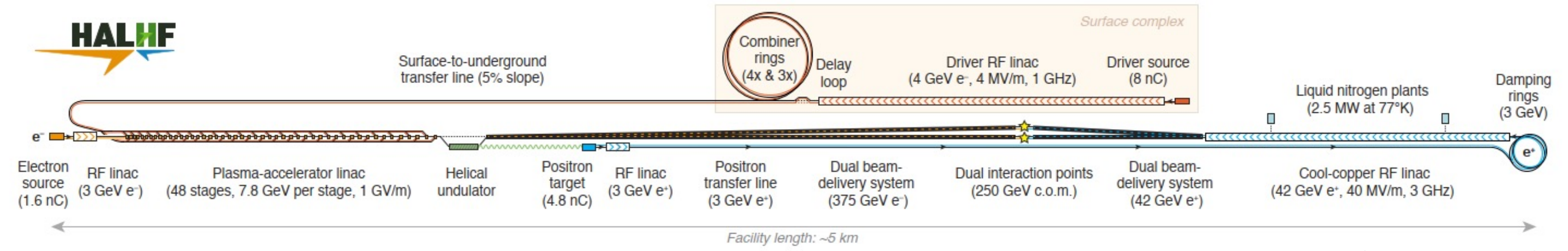
HALHF Since 2023

HALHF

Hybrid, **A**symmetric, **L**inear **H**iggs Factory

- e^- acceleration in **e^- beam–driven plasma wakefields**
- e^+ acceleration in radiofrequency cavities (C^3 technology)
- To make most effective use of space → collision of polarised 375 GeV e^- with 42 GeV e^+

Advantages:
+ most advanced wakefield collider concept → avoids e^+ acceleration in plasma
+ compact footprint, ~5 km



Foster et al., Phys. Open 23, 100261 (2025)

- Asymmetric collisions: **375 GeV polarized e^-** with **41.7 GeV polarized e^+** (boost: γ=1.67), Center-of-mass energy: **250 GeV.**
  - → **upgrades 380, 550 GeV** center-of-mass energy discussed

Estimated luminosity: **1.2×10^{34} $cm^{-2}s^{-1}$ two IPs**
Estimated total power usage: **106 MW**

Challenges:
High repetition rate plasma operation and cooling, Staging, Production and acceleration of polarized beams, BDS design,…

Estimated R&D time (technically limited):
10-15 years

LPA e^+e^- colliders: design studies

M. Turner, LCWS 2025

Since 2024

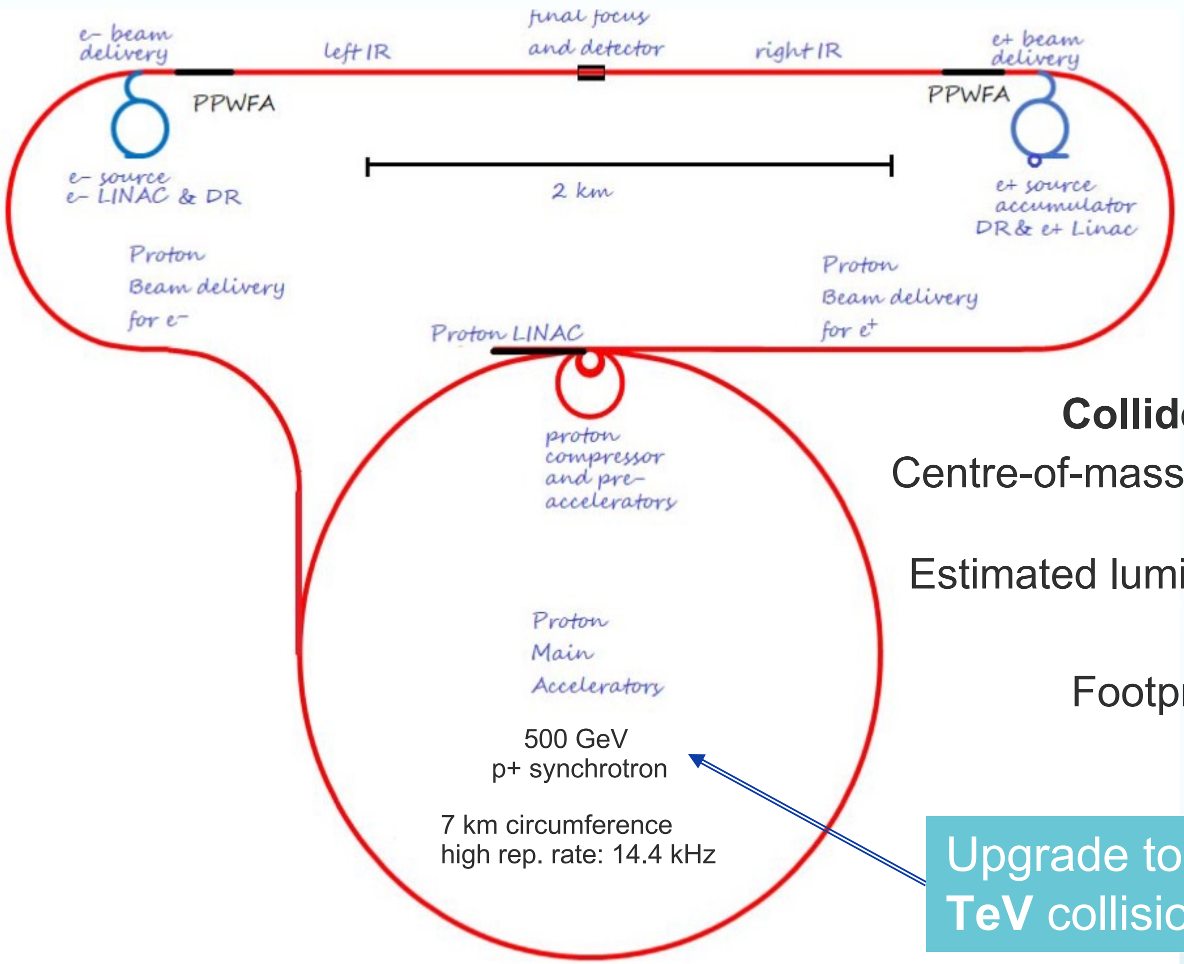
ALiVE

A Linear accelerator for Very high Energies

- e^- and e^+ acceleration in single stage **p^+ beam-driven plasma wakefields**
  - Enabled by the energetic and short **p^+** drivers
  - **p^+** drivers: high-rep.-rate 500 GeV synchrotron

Advantages:
+ avoids staging
+ compact footprint
+ scaling to higher energies (10 TeV)

Preliminary investigation of a Higgs factory based on proton-driven plasma wakefield acceleration
J. Farmer et al., 2024 New J. Phys. 26 113011



500 GeV
p+ synchrotron

7 km circumference
high rep. rate: 14.4 kHz

Collider Parameters:

Centre-of-mass energy (CoM): **250 GeV**

Estimated luminosity: **$1.7\text{x}10^{34}$ $\text{cm}^{-2}\text{s}^{-1}$**

Footprint: **~4 x 2 km**.

Upgrade to ~7 TeV for **10 TeV** collisions

Challenges:
High power synchrotron, Proton Bunch Compression, Plasma Source Development, Positron Acceleration, Energy Transfer Efficiency, Beam Quality Preservation,...

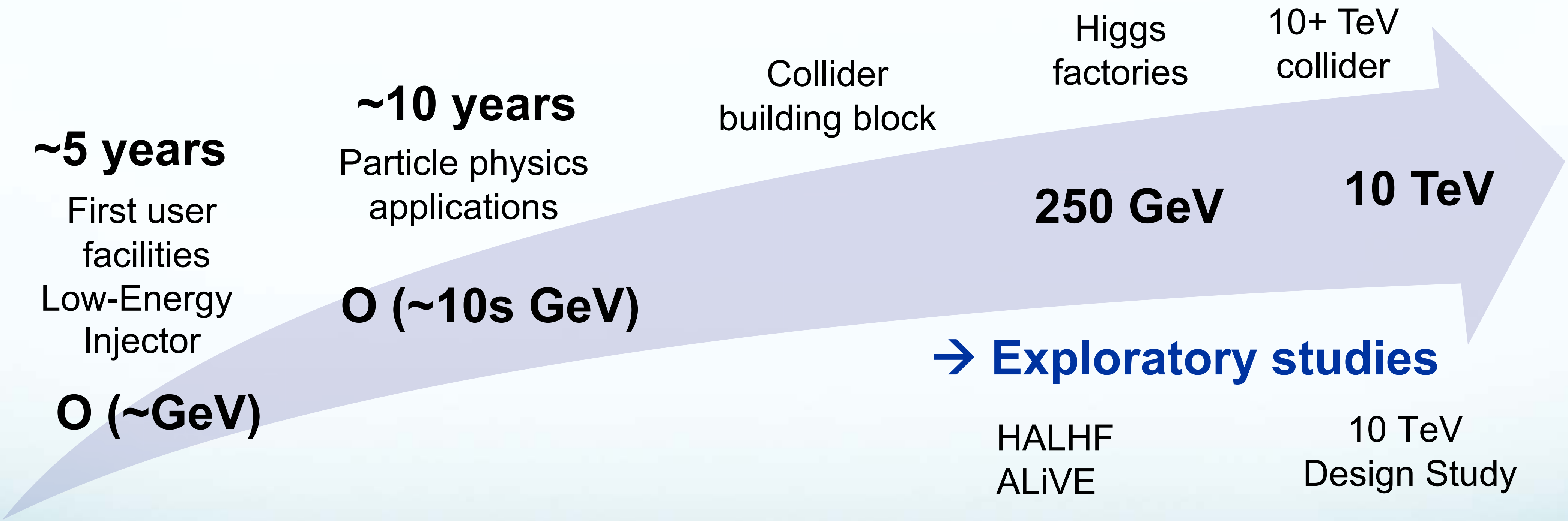
LPA e^+e^- colliders: Challenges

M. Turner, LCWS 2025

Wakefield Acceleration Comes with Unique Challenges

Strategy 3: Aim Longer Term

→ And very high energies: 10+ TeV



~5 years

First user facilities

Low-Energy Injector

O (~GeV)

~10 years

Particle physics applications

O (~10s GeV)

Collider building block

Higgs factories

250 GeV

10+ TeV collider

10 TeV

→ Exploratory studies

HALHF
ALiVE

10 TeV
Design Study

LPA e^+e^- colliders: design studies

M. Turner, LCWS 2025

Since 2025

10 TeV

Design Initiative for a **10 TeV** pCM Wakefield Collider

Technology candidates:

- Laser-Driven Plasma Wakefields
- Beam-Driven Plasma Wakefields
- Structure Wakefields

Collider type:

- e^+e^-
- e^-e^-
- γγ

Goals include delivery of:
+ end-to-end design study report in 2028
+ roadmaps and resource estimates

The Design Study aims to produce a unified, self-consistent concept for a 10 TeV parton-center-of-mass (pCM) collider based on wakefield accelerator (WFA) technology.

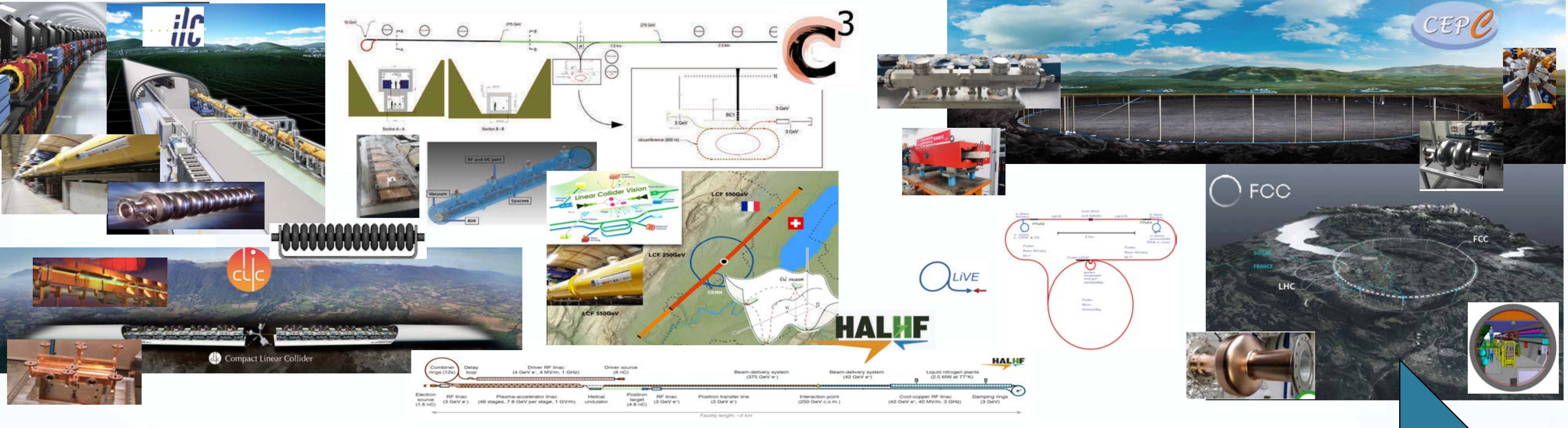
- **Assume for now that is an upgrade to another linear collider facility.**

Chosen design constraints:

- $E_{z,avg} > 500$ MeV/m
- $\mathcal{L}/P_{tot} > 10^{32}$ cm^{-2}s^{-1} MW^{-1}

Broad participation: detector physicists, particle physicists, etc…

https://indico.slac.stanford.edu/category/138/



Let’s dream

- **Colliders are an essential tool for the future of Particle Physics.**
- **Building a collider demands an enormous effort and requires many different scientific and technical experts coming together with a common goal.**
- **A rich R&D program is driving the developing and building of these new facilities**
- **New and revolutionary ideas are needed to push the precision and the energy frontier**

THE BRAVE FCs COLLABORATORS

A. Yamamoto, S. Michizuno, T.Okugi, N. Terunuma, K. Yokoya, H. Sakai, A. Arishev. T. Abe, K. Popov, S. Stapnes, R. Tomas, Y. Papaphilippou, N. Catalan Lasheras, F. Zimmermann, M. Benedikt, A. Pastushenko, V. Cilento, R. Yang, A. Latina, P. Korysko, T. Lefevre, W. Kaabi, I Chaivkoska, A. Korsun, R. Poeschl, F. Richard, M. Winter, M. Titov, N. Fuster, L.Pedraza, B. Gimeno, J. List, B. List, P. Burrows, D. Bett
M. Turner, J. Gao

Useful Links

- FCC Week 2025 (19-23 May 2025) https://indico.cern.ch/event/1408515/
- Open Symposium on the European Strategy for Particle Physics (23-27 June 2025), https://agenda.infn.it/event/44943/overview
- International Workshop on Future Linear Colliders 2025 (20-24 October 2025) https://agenda.linearcollider.org/event/10594/