The FCC Project

Luc Poggioli

- Project
- Physics reach
- Challenges
- Ongoing
- Next

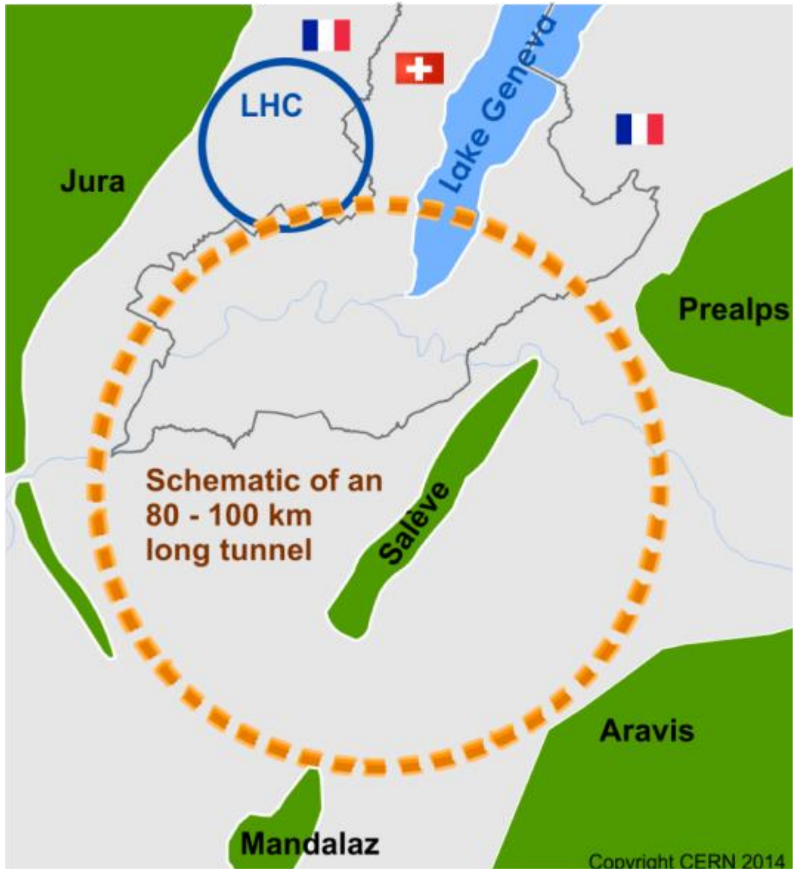
The FCC integrated program

M. Benedikt

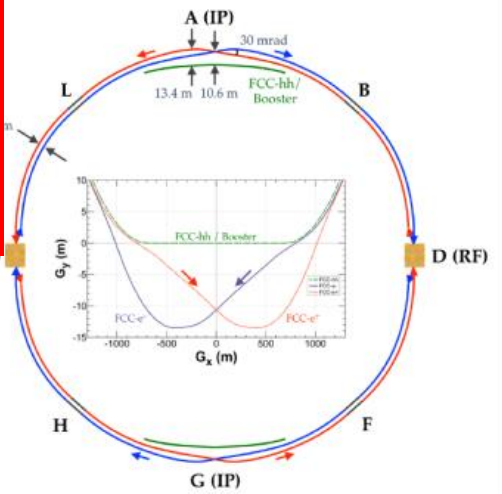
inspired by successful LEP – LHC programs at CERN

Comprehensive cost-effective program maximizing physics opportunities

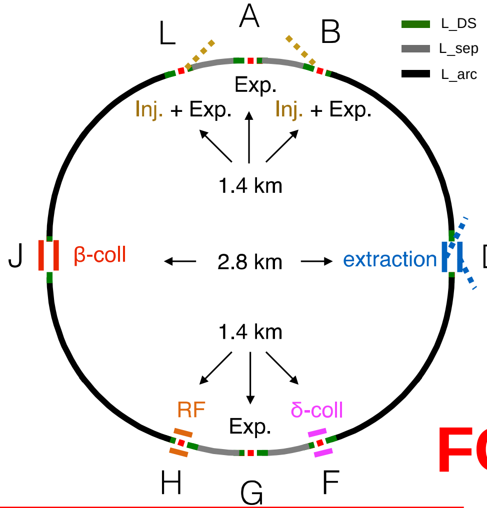
- **Stage 1: FCC-ee (Z, W, H, tt) as first generation Higgs factory, EW and top factory at highest luminosities.**
- **Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options.**
- Complementary physics
- Integrating an ambitious high-field magnet R&D program
- Common civil engineering and technical infrastructures
- Building on and reusing CERN's existing infrastructure.
- FCC integrated project plan is fully integrated with HL-LHC exploitation and provides for seamless continuation of HEP.



Experience from LEP, DAFNE, S-KEKB



FCC-ee

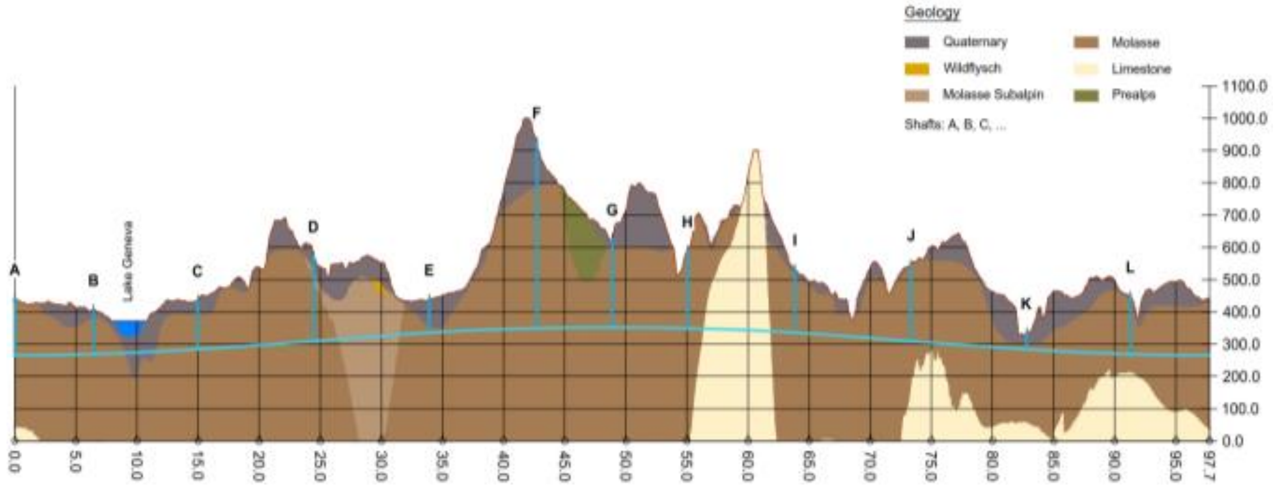


FCC-hh

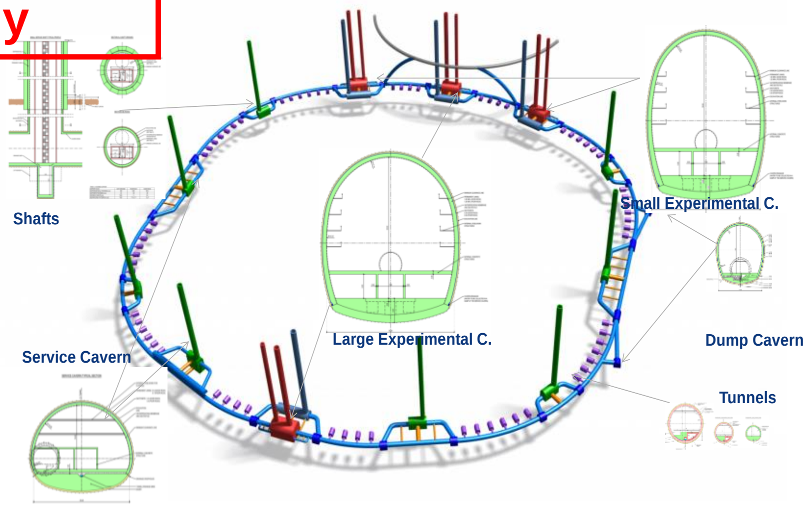
Asymmetric IR layout & optics to limit synchrotron radiation

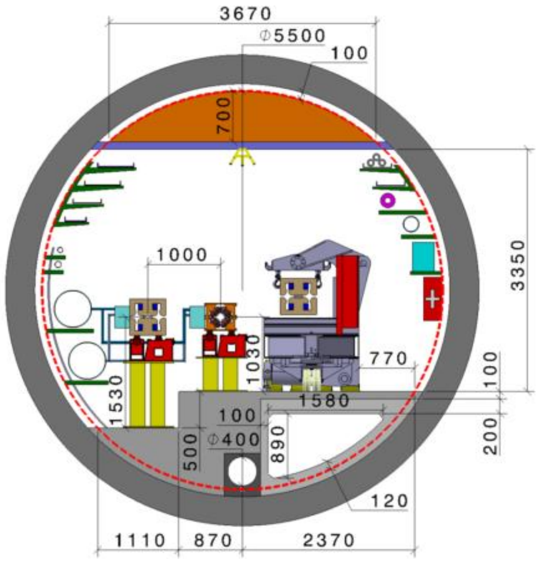
Implementation

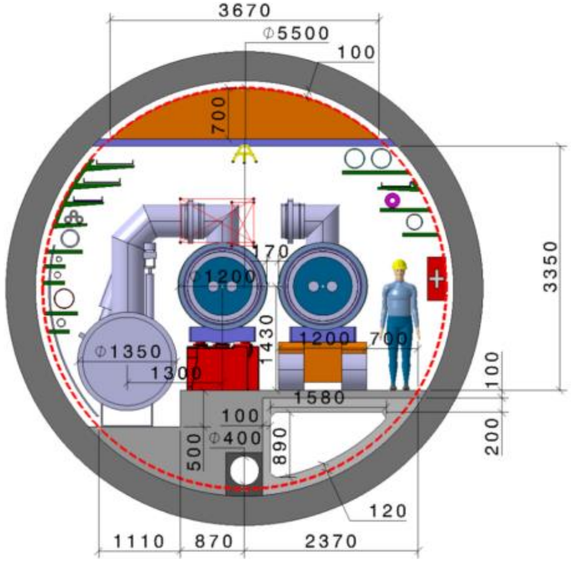
M. Benedikt

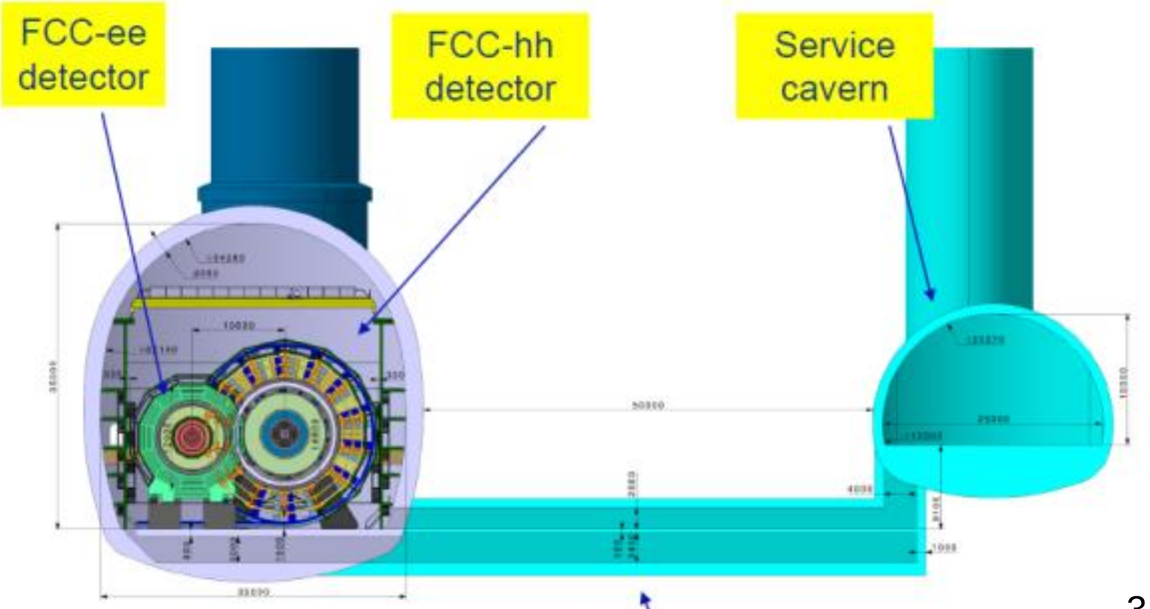


FCC-ee Baseline 2IP
4IP under study









FCC-ee discovery potential & more

A. Blondel

Today we do not know how nature will surprise us. A few things that FCC-ee could discover :

EXPLORE 10-100 TeV energy scale (and beyond) with Precision Measurements
-- ~20-100 fold improved precision on many EW quantities (equiv. to factor 5-10 in mass)
m_Z, m_W, m_{top} , $\sin^2 \theta_w^{eff}$, R_b , α_{QED} (m_z) α_s (m_z m_W m_τ), Higgs and top quark couplings
model independent «fixed candle» for Higgs measurements

DISCOVER a violation of flavour conservation or universality and unitarity of PMNS @10^{-5}
-- ex FCNC (Z --> $\mu\tau$, $e\tau$) in 5 10^{12} Z decays and τ BR in 2 10^{11} Z→ $\tau\tau$
+ flavour physics (10^{12} bb events) (B→s $\tau\tau$ etc..)

DISCOVER dark matter as «invisible decay» of H or Z (or in LHC loopholes)

DISCOVER very weakly coupled particle in 5-100 GeV energy scale
such as: Right-Handed neutrinos, Dark Photons, ALPS, etc…

+ and many opportunities in – e.g. QCD (α_s @ 10^{-4}, fragementations, H→ gg) etc….

NB Not only a «Higgs Factory»! «Z factory» and «top» are important for 'discovery potential'

FCC-hh discovery potential & more

A. Blondel

FCC-hh is a HUGE discovery machine (if nature …), but not only.

FCC-hh physics is dominated by three features:

FCC-hh will explore the Higgs in completely new and different kinematic regimes

C. Grojean

-- Highest center of mass energy –> a big step in high mass reach!
ex: strongly coupled new particle up to >30 TeV
Excited quarks, Z', W', up to ~tens of TeV
Give the final word on natural Supersymmetry, and WIMPS
extra Higgs etc.. reach up to 5-20 TeV
Sensitivity to high energy phenomena in e.g. WW scattering

-- HUGE production rates for single and multiple production of SM bosons (H,W,Z) and quarks
-- Higgs precision tests using ratios to e.g. $\gamma\gamma/\mu\mu/\tau\tau$/ZZ, ttH/ttZ @<% level
-- Precise determination of triple Higgs coupling (~2% stat. level) and quartic Higgs coupling

Understanding EWPT

-- detection of rare decays H→ Vγ (V= ρ, φ, J/ψ, Υ, Z …)
-- search for invisibles (DM searches, RH neutrinos in W decays)
-- renewed interest for long lived (very weakly coupled) particles.
-- rich top and HF physics program

-- Cleaner signals for high Pt physics
-- allows clean signals for channels presently difficult at LHC (e.g. H→ bb)

FCC-eh discovery potential & more

A. Blondel

FCC-ep explores hitherto untouched domain of (x,q2) DIS plane and provides production of high mass SM particles (H, top) in cleaner conditions than pp.

-- extremely precise structure function work

important input on structure functions for FCC-hh

complete resolution of the partonic contents of the proton, for the first time

high precision α_s $O(10^{-4})$ similar to FCC-ee from totally different source

-- $2\ 10^6$ Higgs produced from from W & Z to deliver precise H couplings complementary to ee -- esp (g_{HWW})

-- Searches for new physics (Leptoquarks, RH neutrinos, etc...) in new domain of mass and couplings

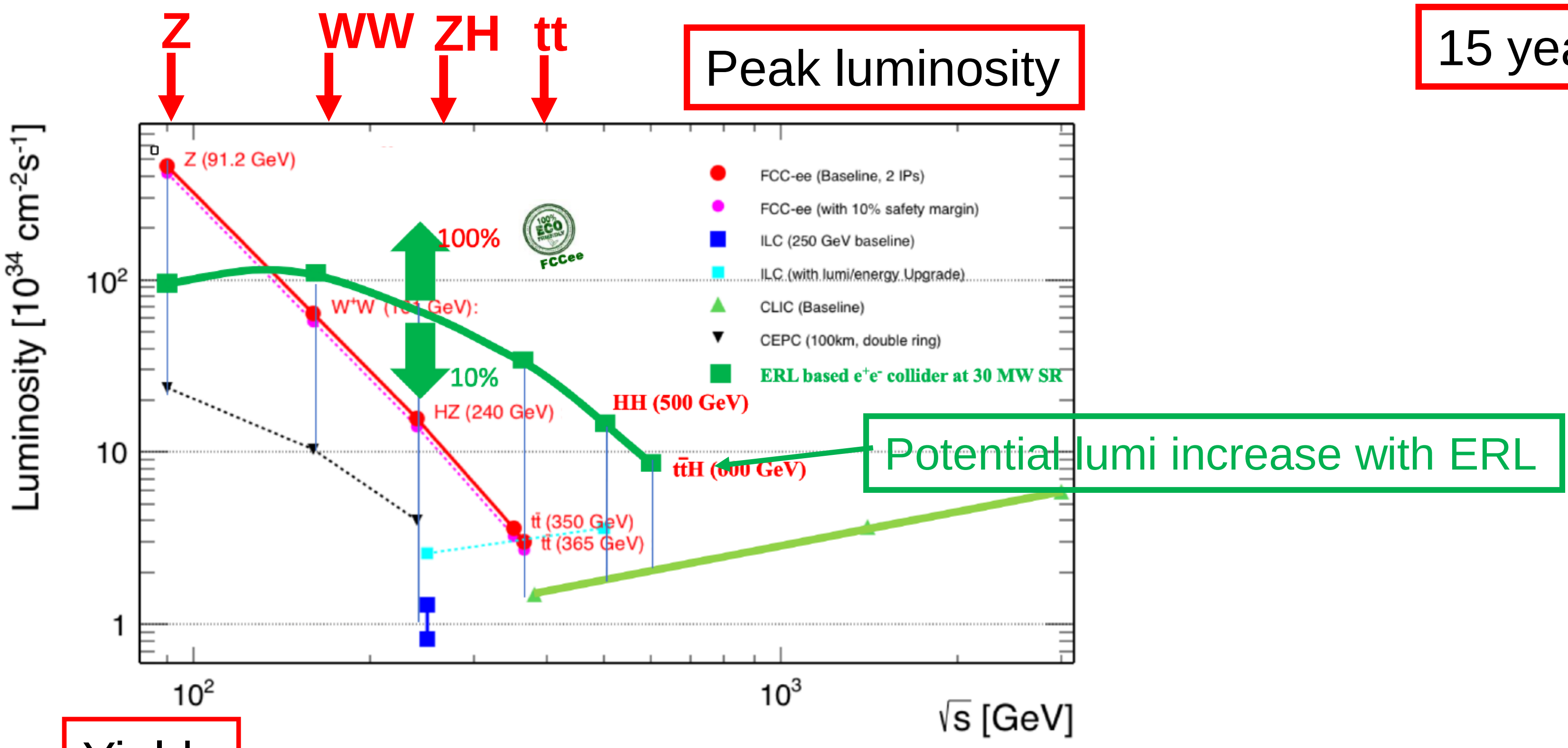
-- rich top (Vtb @% level, FCNC) and HF physics program

-- Discovery in QCD: non-linear parton evolutions, instantons?, ..

-- Unique electron-ion physics related to QGP physics

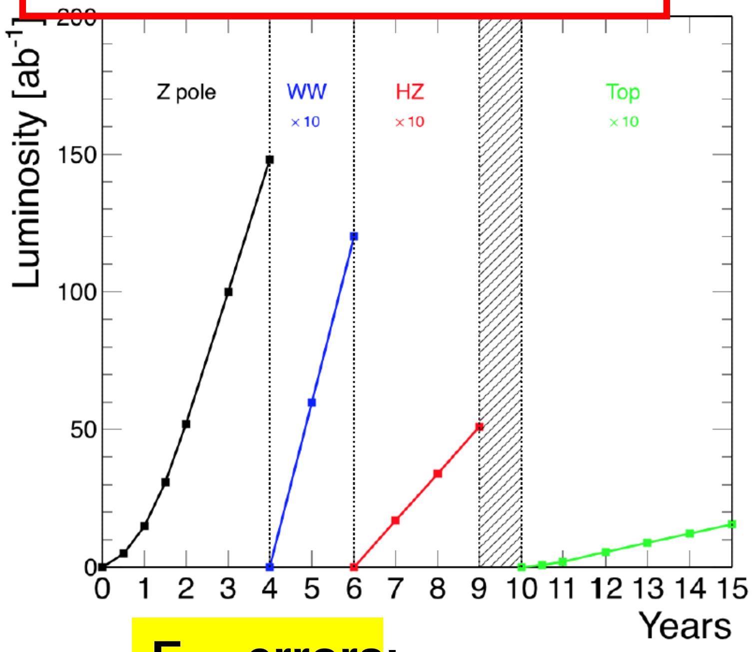
Operation FCC-ee

Peak luminosity



15 years running - Integrated luminosity

2 IP – Gain x1.7 with 4 IP



Yields

				E_{CM} errors:
Z peak	**E_{cm} : 91 GeV**	**$5\ 10^{12}$ e+e- → Z**	**LEP x 10^5**	<100 keV
WW threshold	**E_{cm} : 161 GeV**	**10^8 e+e- → WW**	**LEP x 2.10^3**	<300 keV
ZH threshold	**E_{cm} : 240 GeV**	**10^6 e+e- → ZH**	**Never done**	2 MeV
$t\bar{t}$ threshold	**E_{cm} : 350 GeV**	**10^6 e+e- → $t\bar{t}$**	**Never done**	5 MeV

NB: **Complementarity FCC-ee/ILC studies ongoing**

Operation FCC-hh

parameter	FCC-hh		HL-LHC
collision energy cms [TeV]	100		14
dipole field [T]	16		8.33
beam current [A]	0.5		1.1
bunch spacing [ns]	25	25	25
synchr. rad. power / ring [kW]	2400		7.3
SR power / length [W/m/ap.]	28.4		0.33
long. emit. damping time [h]	0.54		12.9
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	5 (lev.)
events/bunch crossing	170	1000	132
stored energy/beam [GJ]	8.4		0.7
Integrated luminosity (ab^{-1})	20 (25 years)		3

Challenges

- Pile-up
- Power dissipation
  - Cryogenics
- High-B magnets
  - 8.3T NbTi (LHC)
  - 11T Nb_3Sn (HL-LHC)
  - 16T Nb_3Sn (FCC)

Cost

- hh standalone 25BCHF
- With ee 17BCHF
  - Cost ee 11.6BCHF

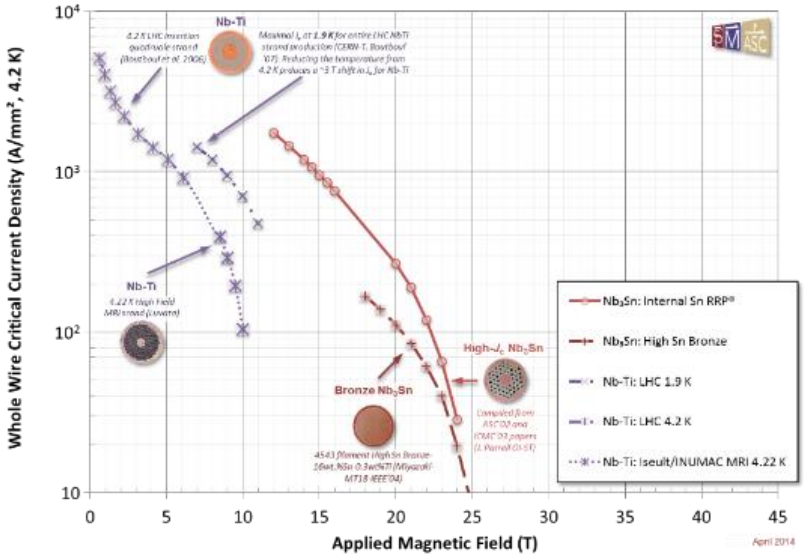
(incl. infra., tunnel)

NB: Going from 2 to 4 IP for FCC-ee has big impact on FCC-hh design

R&D for Accelerators

From FCC-FR Wkshop, Nov’19

- Magnets for hh: NbTi to Nb3Sn
  - Consistent path -> 16T

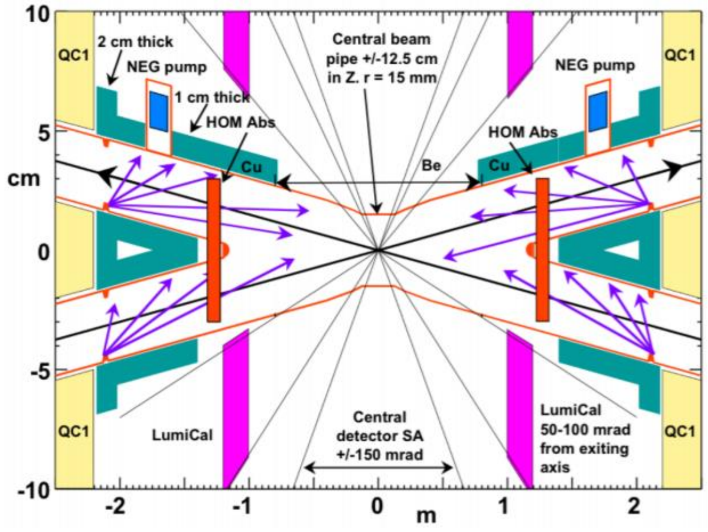


CEA

- R&D cavities for ee
- Cryogenics
  - Load x5 wrt LHC
- Positron source for ee (critical for linear)

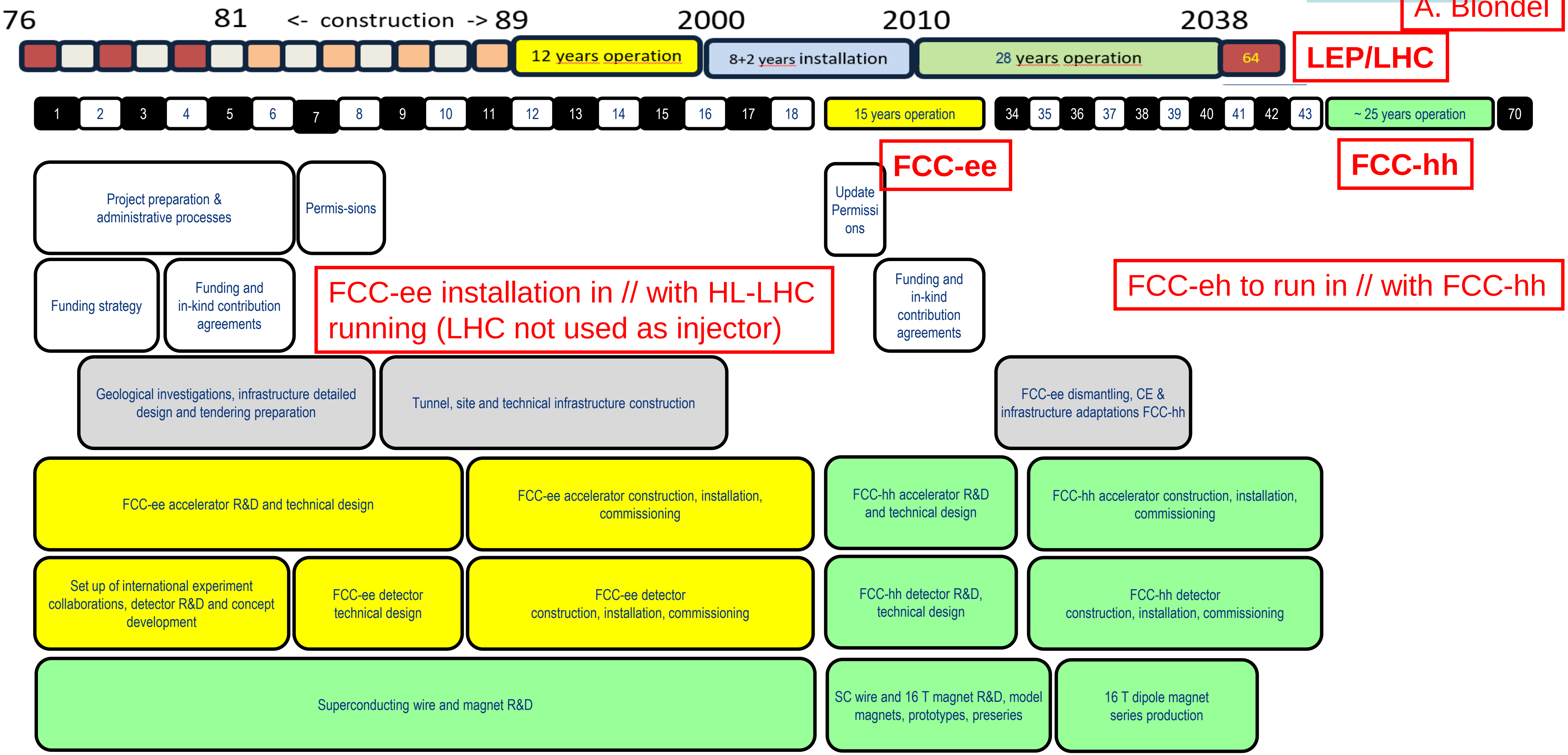
LAL

- Beam dynamics & electron cloud for hh
- Energy Recovery Linac for ee
- MDI and beam alignment LAPP
  - In line w/ CLIC & SuperKEK-B R&D



Timescale – Comparison with LEP/LHC

A. Blondel



Achieved/Ongoing

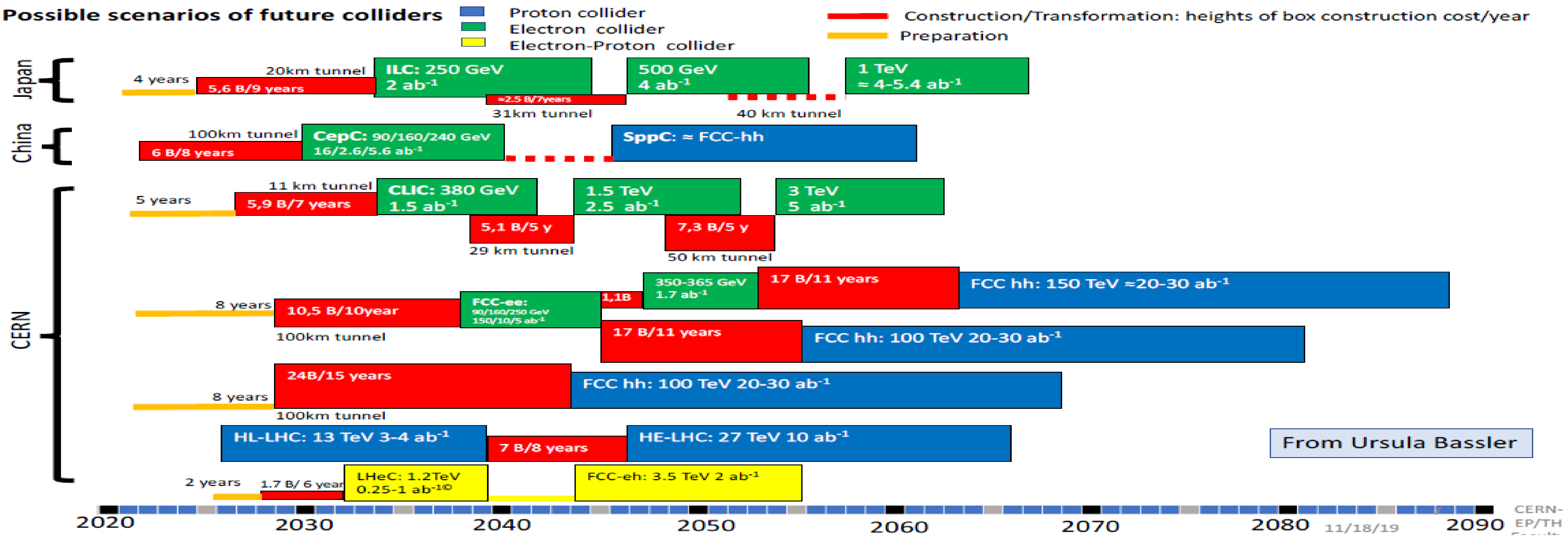
- Collaboration
  - Conceptual Design Report (March 2019)
    - https://fcc-cdr.web.cern.ch/ and Presentation at CERN
  - FCC work with host states (eg Civil Engineering)
  - Future Circular Collider Innovation Study FCC-IS
    - Inside H2020 - Co-financing for planned FCC activities – Approved 03/2020
- Organization
  - Workshop: FCC Physics & Expts 1/year
    - 3rd FCC physics & Expts Workshop Jan 2020, CERN
  - FCC week 1/year Next Paris (April 2021)
  - Regular meetings Physics ee, WG11 (Detector ee), software, …

Next 2020-2026

- Of course dependent of ESPP recommendation
  - Feedback end May/June
  - A priori 'FCC' (ie no mention ee or/and hh) strongly supported
- Goal
  - Perform all needed studies to allow for final project decision by 2025-2026 (next ESPP recom.) -> Able to start digging tunnel by 2028/2029
- Steps
  - Setting up Governance model, Financing strategy, Civil Engineering (site investigation, discussion with host states)
- In parallel
  - TDRs for machine, beam elements by 2025/2026
  - Establish user communities, work towards proto experiment collaboration by 2025/26 (Letter of Intent)

BACKUP

Different projects timescale



Slightly wrong: All ee machines to start ~2040

- FCC & CLIC after HL-LHC, ILC after H2K
- Big unknown on CepC schedule ~2030: Ideal case and financing

Other options

P. Janot

Alternatives to FCC-ee en route to FCC-hh

- **LE-FCC, then FCC-hh**
  - Not complementary nor synergetic with FCC-hh
    - Brings no additional measurement wrt FCC-hh
    - Kills all FCC-ee synergies/complementarities
  - Weakens the physics case of FCC-hh
    - Reduces the CM energy increment (HIGH RISK!)
    - No more guidance from FCC-ee
  - Reduces CERN attractiveness (only pp physics)
  - More expensive than FCC-INT

- **CLIC-380, then FCC-hh**
  - Higgs + Top physics programme ~ FCC-ee (365)
  - Measurements less precise than FCC-ee
    - Only 175,000 Higgs boson (vs 1.3×10^6)
    - m_H precision ~ 80 MeV: affects g_{HWW}, g_{HZZ} precision
    - Γ_H precision ~ 2.6% $\rightarrow$ inferior standard candle
    - No ee $\rightarrow$ H possibility (too small luminosity)
  - CLIC GigaZ: Poor E_{beam} determination, $\lll 5\ 10^{12}$ Z
  - More expensive than FCC-INT

- **CLIC 3 TeV, no FCC-hh: ONE Experiment**
  - Similar shortcomings as CLIC-380 + GigaZ
    - Lack of precision of EW measurements (stat, E_{beam})
    - $\lll 5\ 10^{12}$ Z (no ALPs, no RHνs, no flavours, …)
    - No ee $\rightarrow$ H possibility
  - Short of statistics with respect to FCC-hh
    - Higgs rare decays, g_{HHH}, W's, b's and top's
  - Limited high energy exploration
  - Cost (~FCC-hh) incompatible with hadron program

- **ILC in Japan**
  - Not incompatible/complementary with FCC-ee
    - Many FCC-ee measurements are unique (Z, W, H)
    - Added value of ILC in the higher energy range
      - ➔ 350 GeV and above, with long. Polarization
      - ➔ Complementary to FCC-ee (350/365)
    - Remember LEP vs SLC
  - FCC-ee remains the richest/fastest way to FCC-hh
  - ILC cost to be supported by Japan