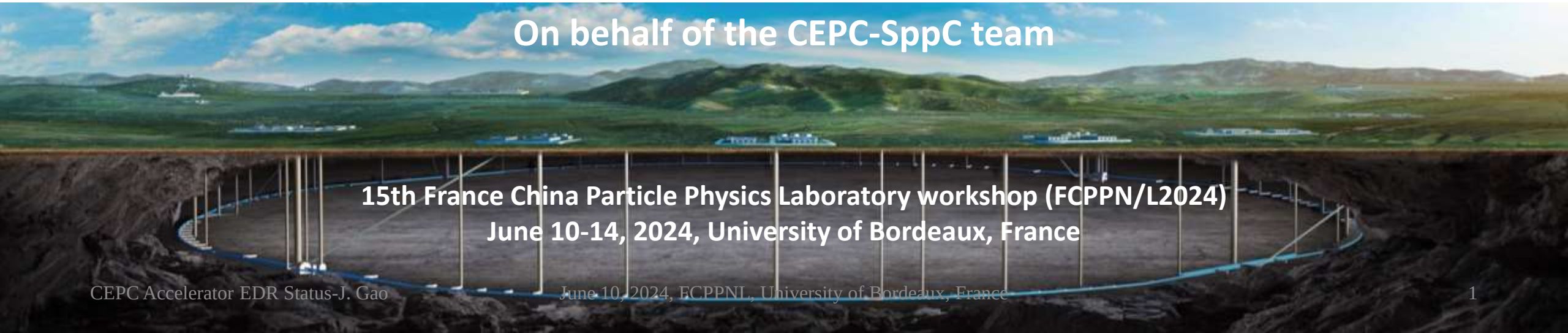
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC Accelerator EDR Status and Perspectives

-Towards construction through EDR Phase

Jie Gao

IHEP



On behalf of the CEPC-SppC team

15th France China Particle Physics Laboratory workshop (FCPPN/L2024)
June 10-14, 2024, University of Bordeaux, France

Contents

- Introduction
- CEPC EDR goals, plans and development towards construction
- CEPC accelerator EDR progress status based on TDR completion
- CEPC industrial preparation and international collaborations
- Summary

A Brief Historical Recall: High Energy Colliders and Factories

The era of Higgs boson started from 2012

Year

Next?

SppC, FCC-hh
Muon collider
FCC-ee
(H,t, Z,W…Dark matter)
CEPC/ILC/CLIC: new e^+e^- collider

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

2018

(B physics…)
SuperKEKB: $\sqrt{s} \simeq 10$ GeV, $\mathcal{L} \simeq 10^{35}$

Higgs,…

2012

LHC/CERN:

Higgs boson 2012

2006

(τ − charm,…)
BEPCII: $\sqrt{s} \simeq 2-5$ GeV, $\mathcal{L} \simeq 10^{33}$

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

2002

(τ mass, charmonium,…)
VEPP-4: $\sqrt{s} \simeq 1.5-2.0$GeV, $\mathcal{L} \simeq 10^{33}$

1999

(B-quark, CP violation, CKM…)
KEKB/PEP-II

Top
Tevatron
Top quark 1995

1994

1990

(Z, W bosons,…)
LEP/CERN, SLC/SLAC

W, Z,…
SPS/CERN
W,Z bosons 1983

1988

(τ −charm,…)
BEPC: $\sqrt{s} \simeq 2-5$ GeV, $\mathcal{L} \simeq 10^{31}$

1980

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

Bottom,…
Fermilab: 400GeV p on Cu, Pt
Bottom quark 1977

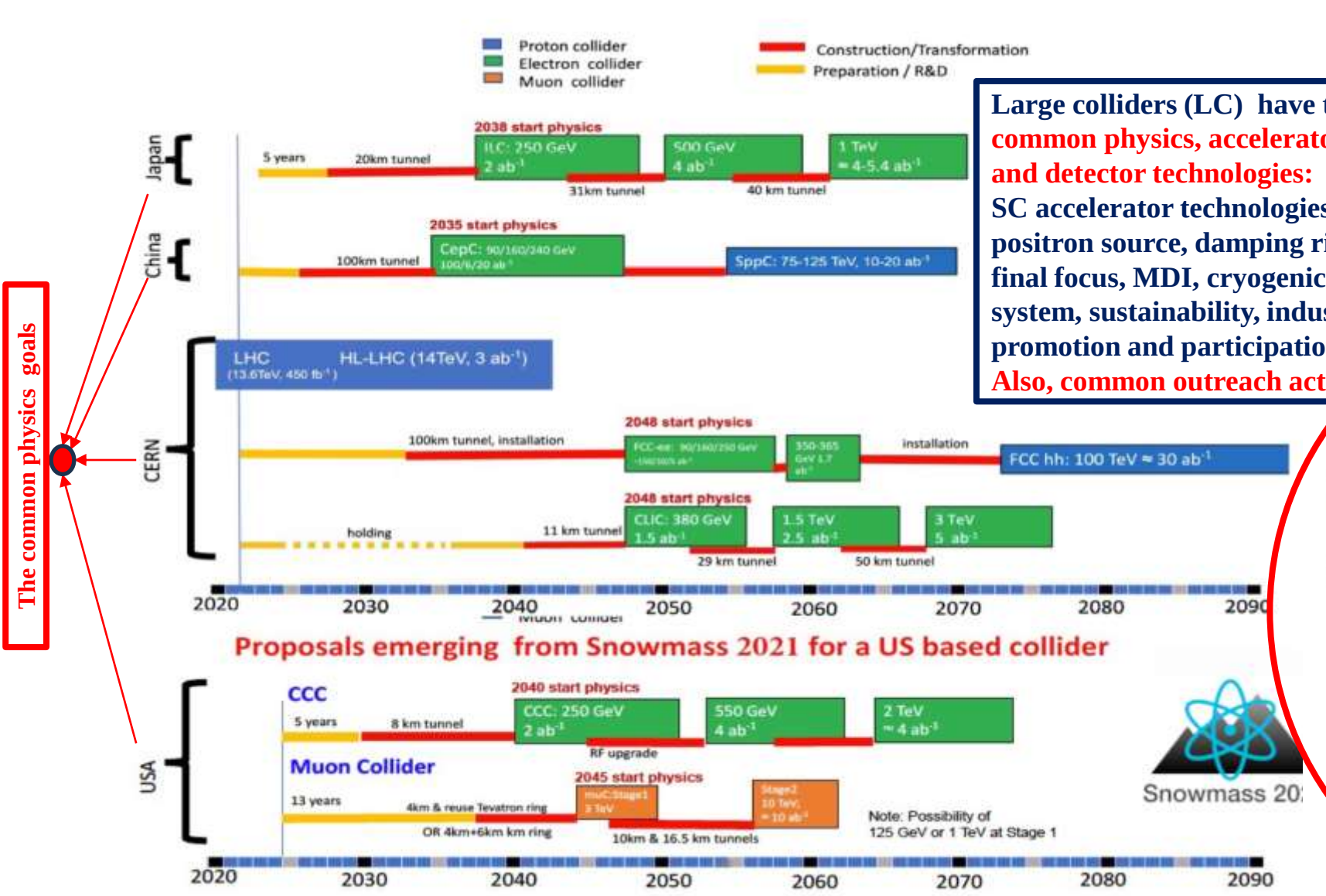
1972

(J/ψ,c-quark, t …)
SPEAR&BNL: $\sqrt{s}$

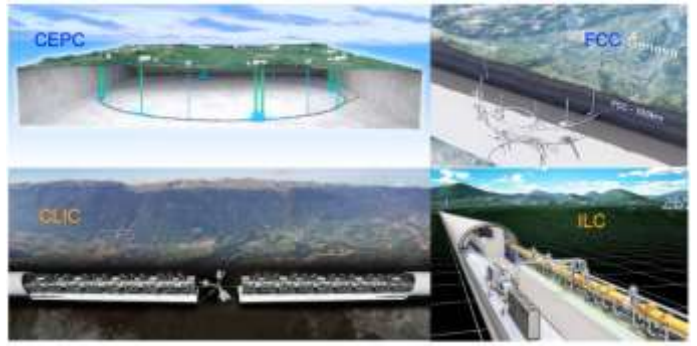
(e^+e^- colliders)

(proton accelerators)

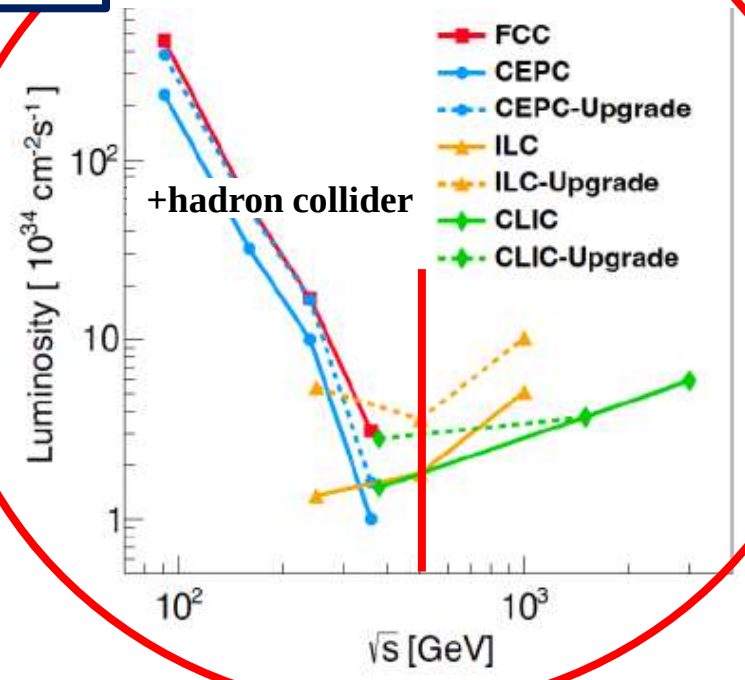
Worldwide High Energy Physics Goal Timelines and Common Efforts



Large colliders (LC) have the common physics, accelerator and detector technologies:
SC accelerator technologies, positron source, damping ring, final focus, MDI, cryogenic system, sustainability, industrial promotion and participation.
Also, common outreach activities

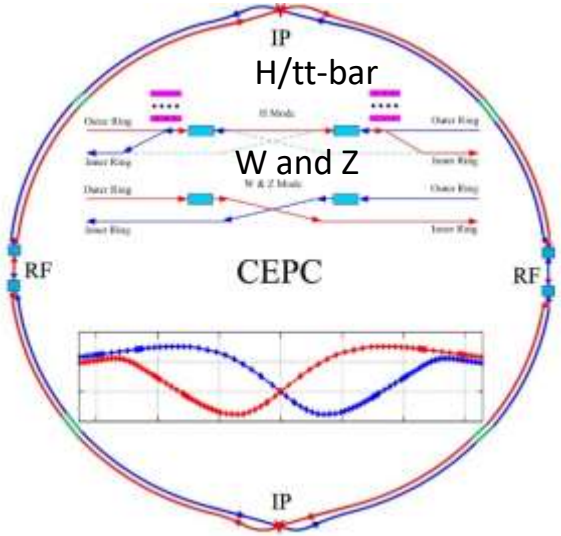


Complementarity between Circular and Linear colliders

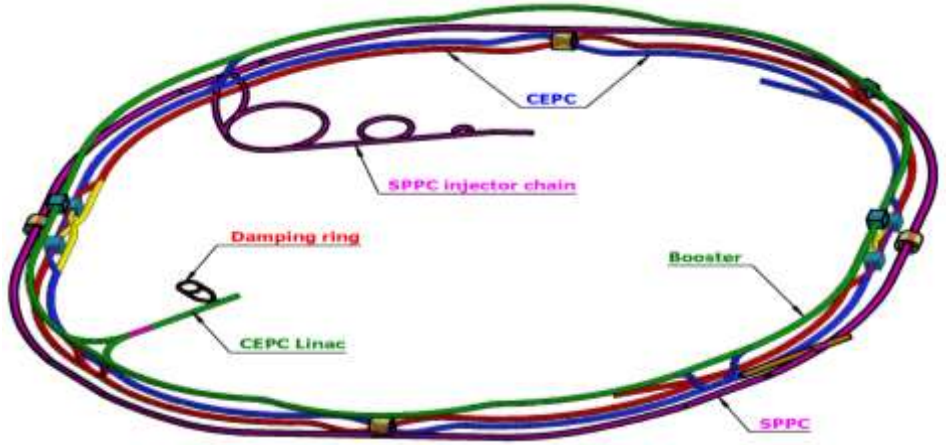


CEPC Higgs Factory and SppC Layout in EDR

CEPC as a Higgs Factory： H, W, Z, upgradable to ttbar, followed by a SppC (a Hadron collider) ~125TeV
30MW SR power per beam (upgradable to 50MW) , high energy gamma ray 100Kev~100MeV

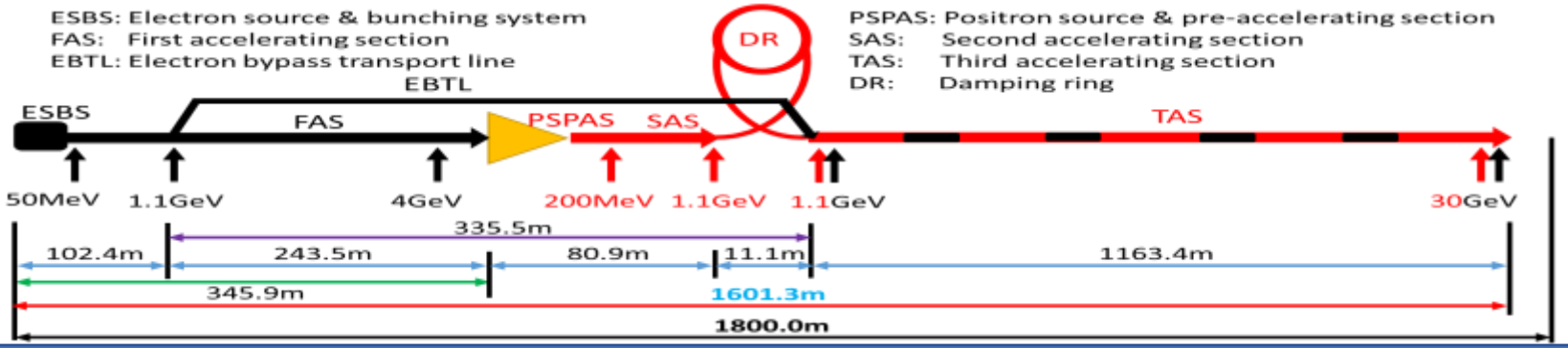


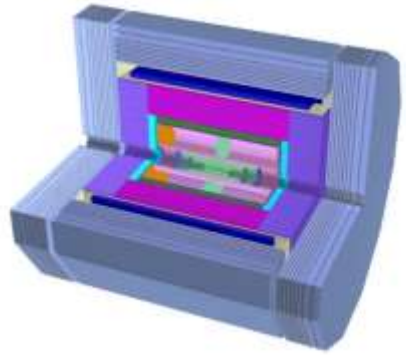
CEPC collider ring (100km)

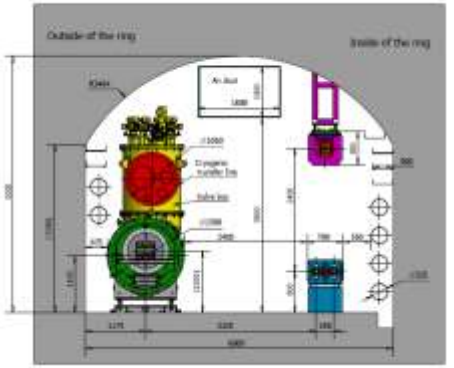


CEPC booster ring (100km)

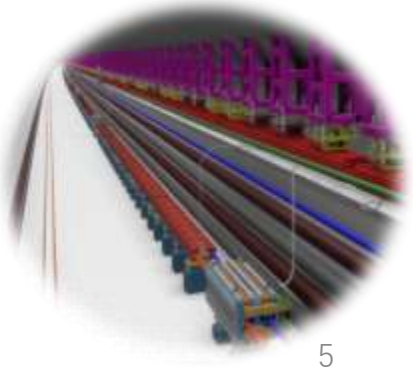
CEPC TDR S+C-band 30GeV linac injector







CEPC/SppC in the same tunnel



CEPC Accelerator System Parameters in TDR and EDR

Linac

Parameter	Symbol	Unit	Baseline
Energy	E_{e-}/E_{e+}	GeV	**30**
Repetition rate	f_{rep}	Hz	100
Bunch number per pulse			1 or 2
Bunch charge		nC	1.5 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

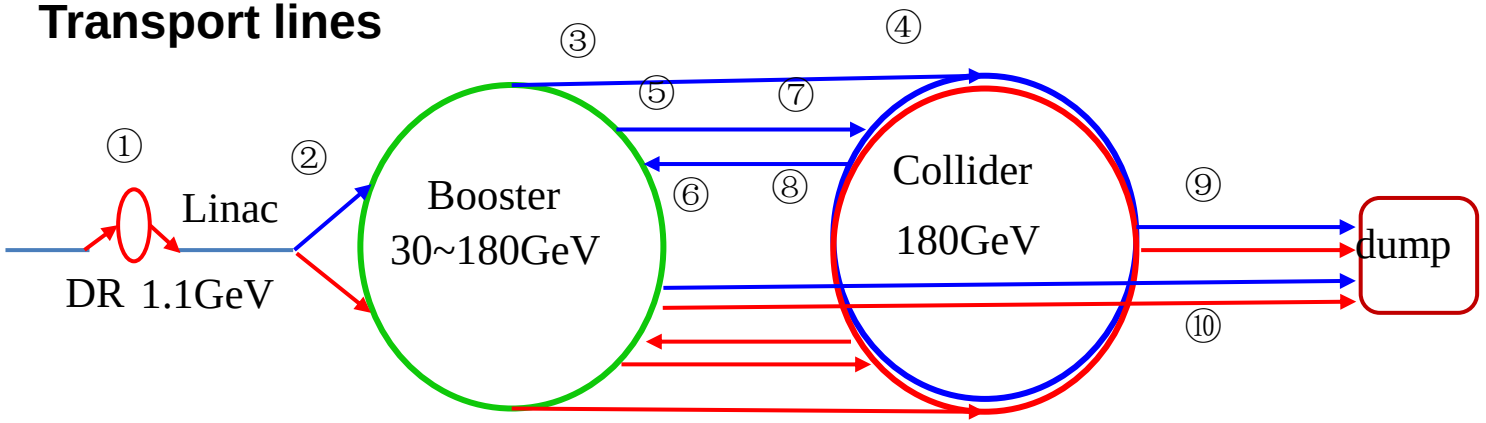
Booster

		tt	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Circumfer.	km	**100**					
Injection energy	GeV	**30**					
Extraction energy	GeV	**180**	**120**		**80**	**45.5**	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Beam current	mA	0.11	0.94	0.98	2.85	9.5	14.4
SR power	MW	0.93	0.94	1.66	0.94	0.323	0.49
Emittance	nm	2.83	1.26		0.56	0.19	
RF frequency	GHz	1.3					
RF voltage	GV	9.7	2.17		0.87	0.46	
Full injection from empty	h	0.1	0.14	0.16	0.27	1.8	0.8

Collider

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	**100.0**			
SR power per beam (MW)	**30**			
Energy (GeV)	**120**	**45.5**	**80**	**180**
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF frequency (MHz)	650			
Luminosity per IP (10^{34} cm^{-2} s^{-1})	**5.0**	**115**	**16**	**0.5**

Transport lines



CEPC Technical Design Report (TDR) includes:
1) CEPC Accelerator TDR
2) CEPC Detector TDRrd (rd=reference design)
will be released by June 2025

CEPC Operation Plan and Goals in EDR

Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. per IP ($10^{34}cm^{-2}s^{-1}$)	Integrated Lumi. per year (ab^{-1}, 2 IPs)	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30	0.5	0.13	0.65	0.4×10^6

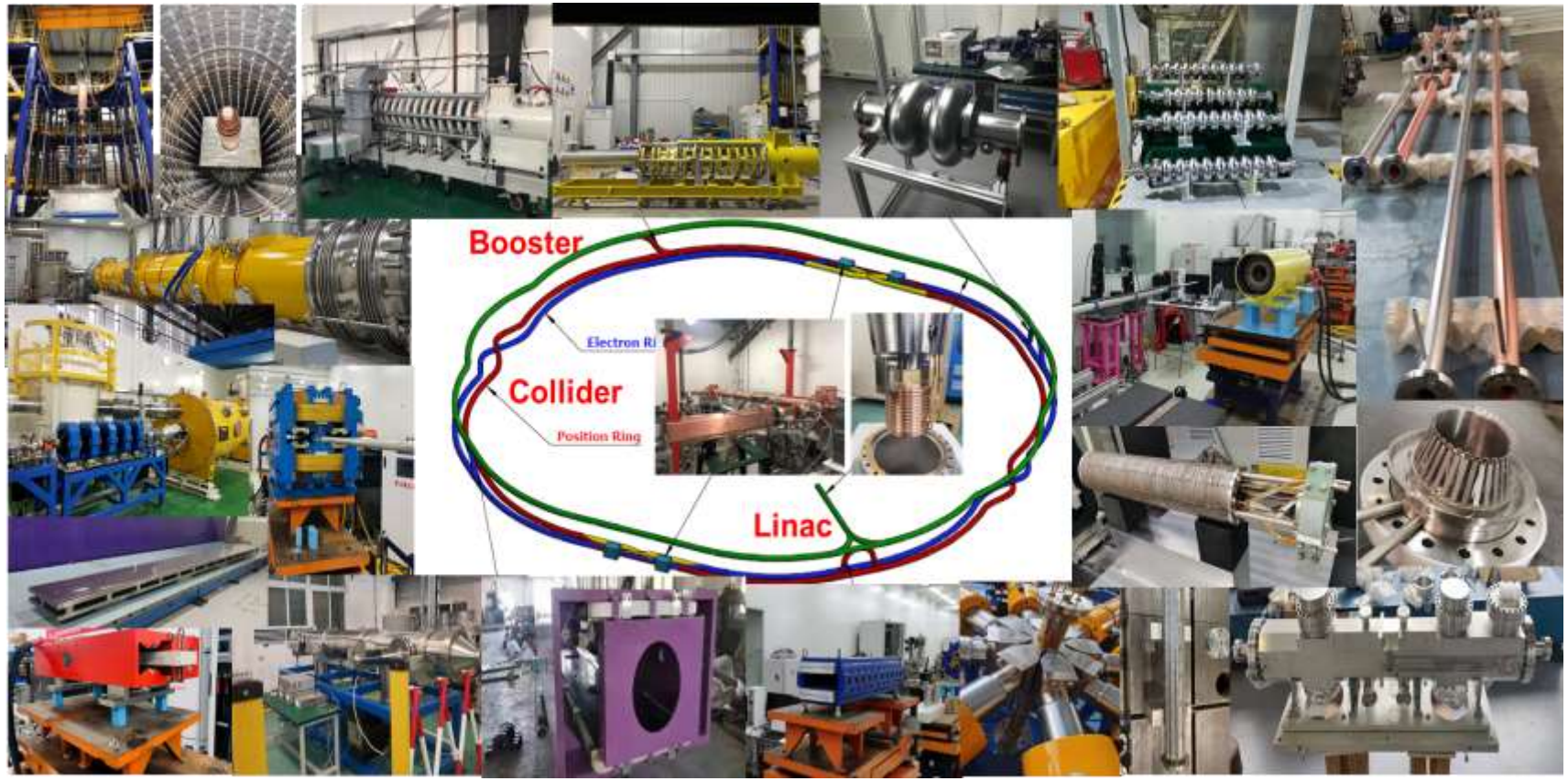
* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.

** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.

CEPC Key Technology R&D Status in TDR

Specification Met ✓ Prototype Manufactured ✓



Accelerator	Fraction
✓ Magnets	27.3%
✓ Vacuum	18.3%
✓ RF power source	9.1%
✓ Mechanics	7.6%
✓ Magnet power supplies	7.0%
✓ SC RF	7.1%
✓ Cryogenics	6.5%
✓ Linac and sources	5.5%
✓ Instrumentation	5.3%
✓ Control	2.4%
✓ Survey and alignment	2.4%
✓ Radiation protection	1.0%
✓ SC magnets	0.4%
✓ Damping ring	0.2%

Key technology R&D in TDR spans all component lists in CEPC CDR

Power Consumption of CEPC @ Higgs

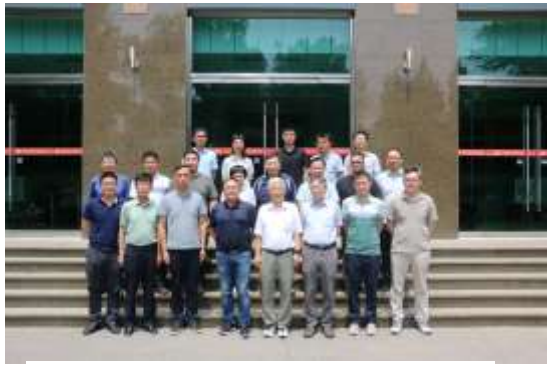
SN	System	Higgs 30MW							Higgs 50MW						
		Collider	Booster	Linac	BTL	IR	Surface building	Total	Collider	Booster	Linac	BTL	IR	Surface building	Total
1	RF Power Source	96.90	1.40	11.10				109.40	161.60	1.73	14.10				177.40
2	Crygenic system	9.72	1.71			0.14		11.57	9.17	1.77			0.14		11.08
3	Vacuum System	5.40	4.20	0.60				10.20	5.40	4.20	0.60				10.20
4	Magnet Power Supplies	44.50	9.80	2.50	1.10	0.30		58.20	44.50	9.80	2.50	1.10	0.30		58.20
5	Instrumentation	1.30	0.70	0.20				2.20	1.30	0.70	0.20				2.20
6	Radiation Protection	0.30		0.10				0.40	0.30		0.10				0.40
7	Control System	1.00	0.60	0.20				1.80	1.00	0.60	0.20				1.00
8	Experimental devices					4.00		4.00					4.00		4.00
9	Utilities	37.80	3.20	1.80	0.60	1.20		44.60	46.40	3.80	2.50	0.60	1.20		54.50
10	General services	7.20		0.30	0.20	0.20	12.00	19.90	7.20		0.30	0.20	0.20	12.00	19.90
	Total	204.12	21.61	16.80	1.90	5.84	12.00	262.27	276.87	22.60	20.50	1.90	5.84	12.00	339.71

Various measures will be studied and implemented towards a green collider, as discussed in the Mini workshop of accelerator, Jan. 18-19, 2024, HKUST-IAS, Hong Kong
https://indico.cern.ch/event/1335278/timetable/?view=standard

CEPC Accelerator International TDR Review and Cost Review June 12-16, and Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

CEPC Accelerator TDR Review
June 12-16, 2023, Hong Kong

CEPC Accelerator TDR Cost Review
Sept. 11-15, 2023, Hong Kong



Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP

9th CEPC IAC 2023 Meeting
Oct. 30-31, 2023, IHEP

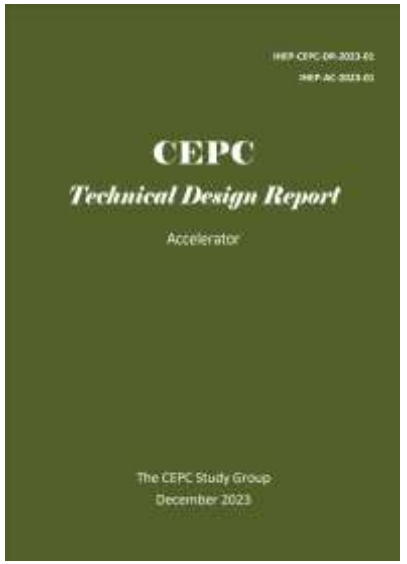
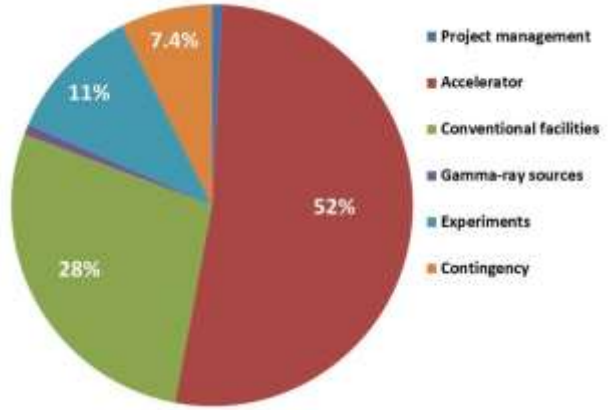


Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

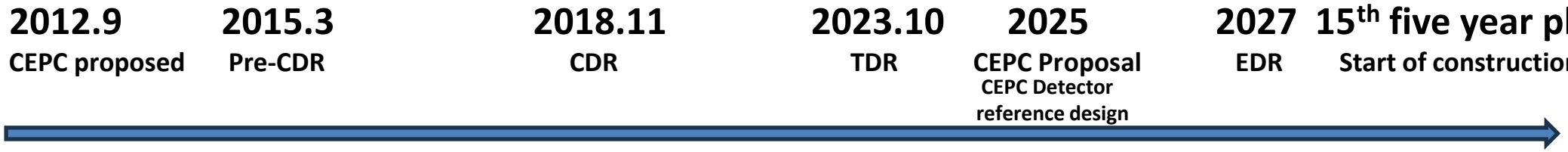
Total	364	100%
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



Distribution of CEPC Project total TDR cost of **36.4B RMB**

CEPC accelerator TDR has been completed and formally released on December 25, 2023:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html
CEPC accelerator TDR has been published formally in Journal Radiation Detection Technology and Methods (RDTM) on June 3, 2024:
DOI: 10.1007/s41605-024-00463-y
https://doi.org/10.1007/s41605-024-00463-y

CEPC Engineering Design Report (EDR) Goal



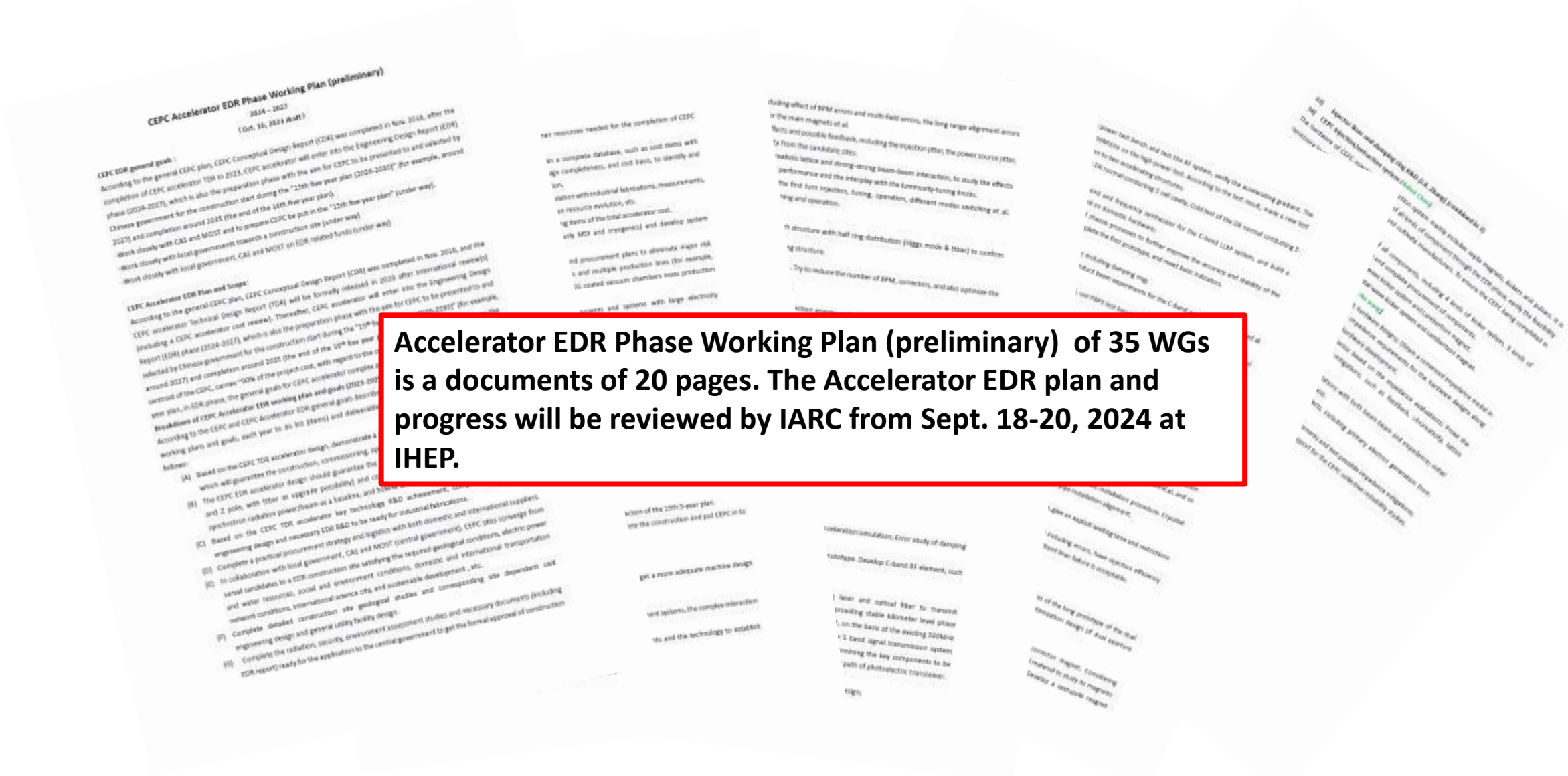
CEPC EDR Phase General Goal: 2024-2027

After completion CEPC accelerator TDR in 2023, CEPC accelerator will enter into the Engineering Design Report (EDR) phase (2024-2027), which is also the preparation phase with the aim for CEPC proposal to be presented to and selected by Chinese government around 2025 for the construction start during the "15th five year plan (2026-2030)" (for example, around 2027) and completion around 2035 (the end of the 16th five year plan).

CEPC EDR includes accelerator and detector (TDRrd)
CEPC detector TDR reference design (rd) will be released by June 30, 2025

CEPC Accelerator EDR Phase goals, scope and the working plan (preliminary) of 35 WGs summarized in a documents of 20 pages to be reviewed by IARC in 2024

CEPC EDR Goal, Plan and Scope



CEPC IARC Members in EDR Phase

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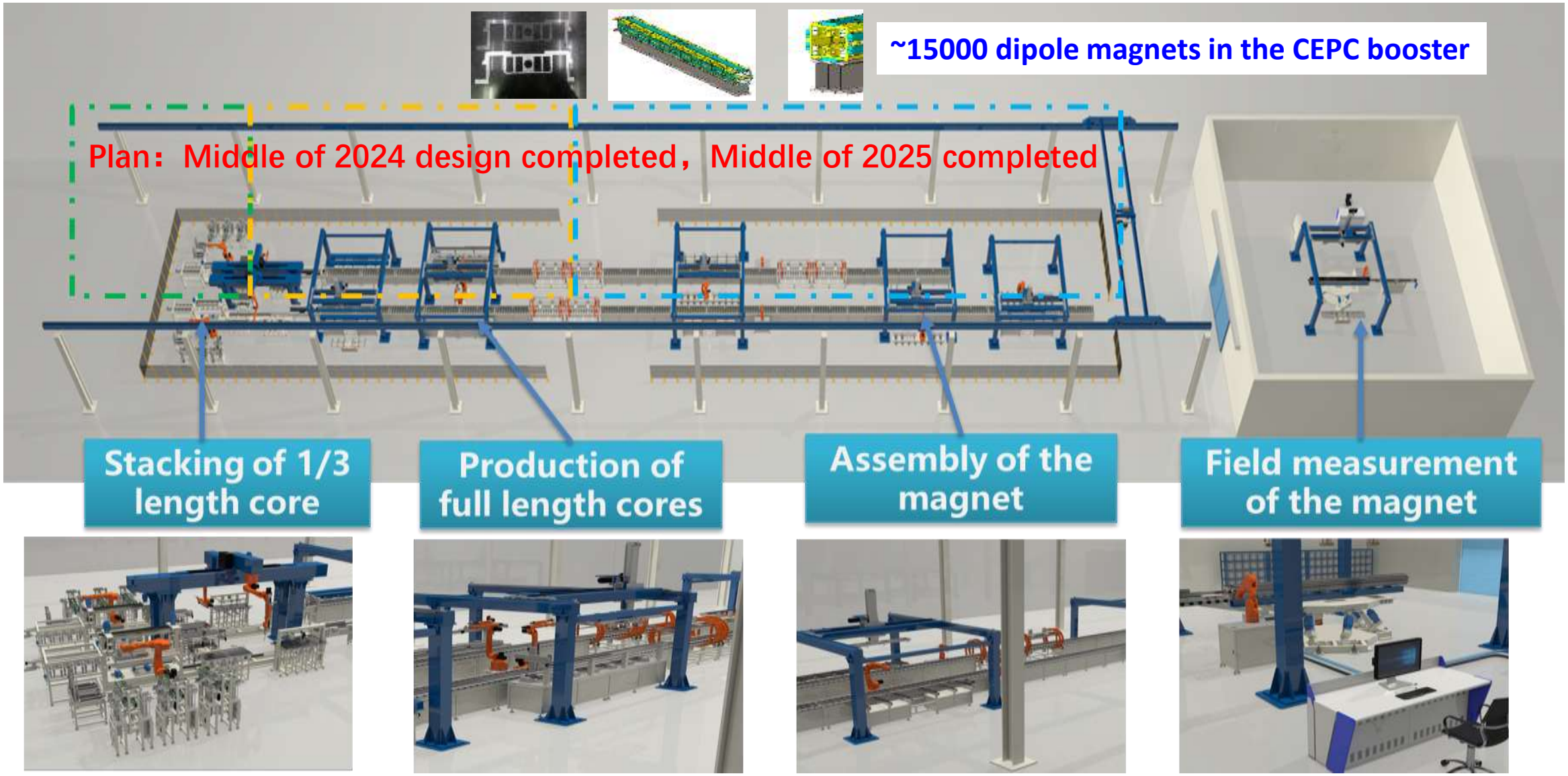
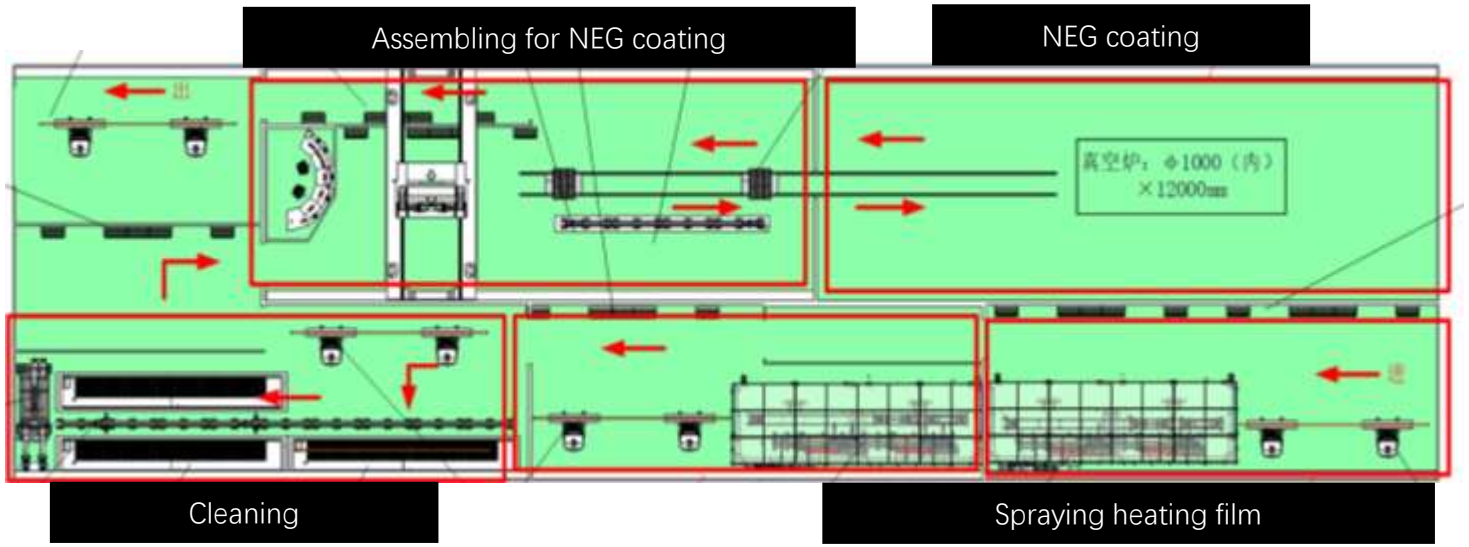
IARC will review CEPC accelerator EDR progress and report to IAC

The first IARC EDR review meeting will take place in Sept. 18-20, 2024, IHEP

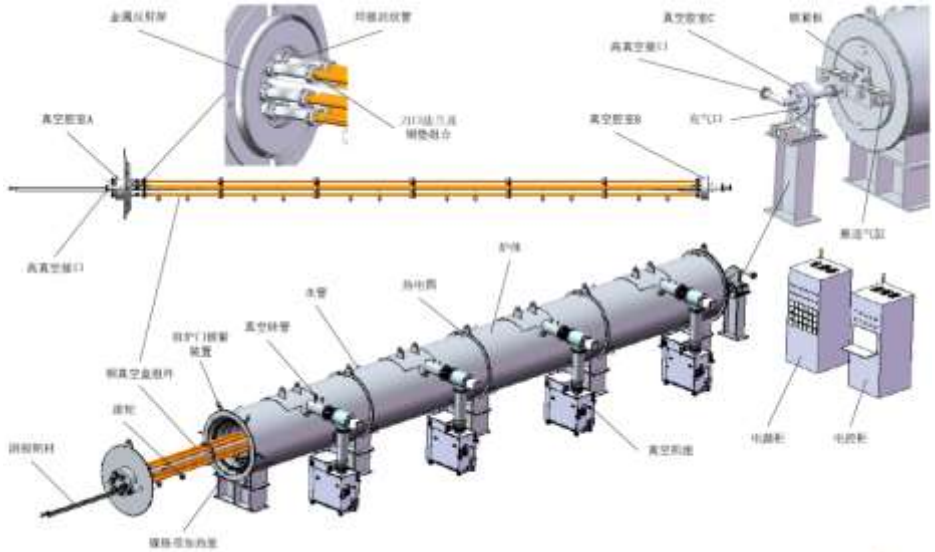
CEPC Magnet Automatic Production Line in EDR



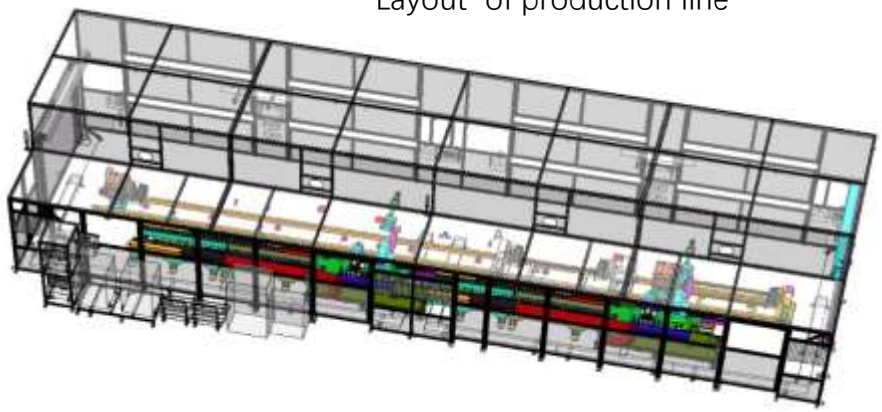
CEPC NEG Coated Vacuum chamber Automatic Production Line in EDR



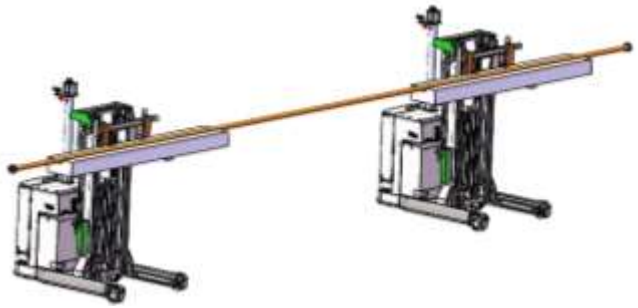
Layout of production line



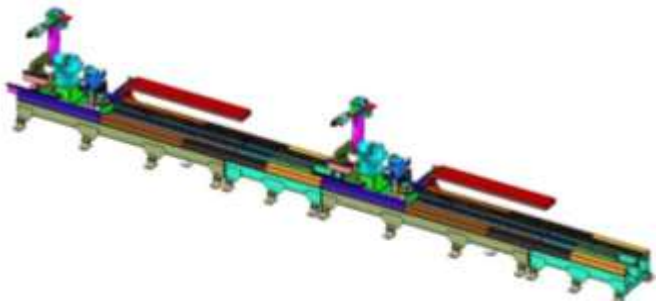
NEG coating facility by horizontal method



Production line of NEG coating, spraying



AGV(Automatic Guided Vehicle) transport



7-axis robot for assembling

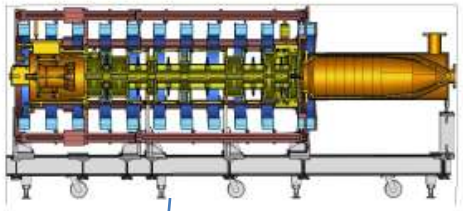
Plan：Middle of 2024 design completed，Middle of 2025 to be completed

CEPC 650MHz High Efficiency High Power Klystron Development and RF Power Distribution System

CEPC klystron R&D

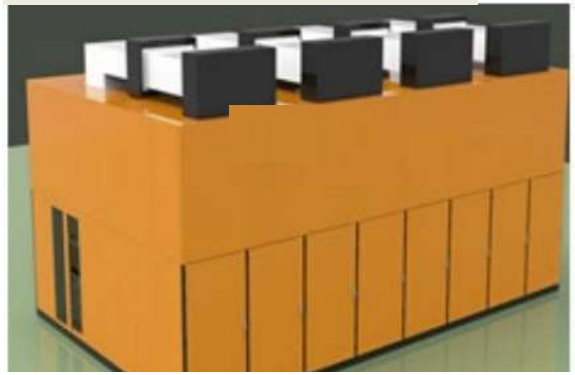
Klystron No. 1
Efficiency 65%
(2020)

Klystron No. 2
Efficiency 77%
(2021)



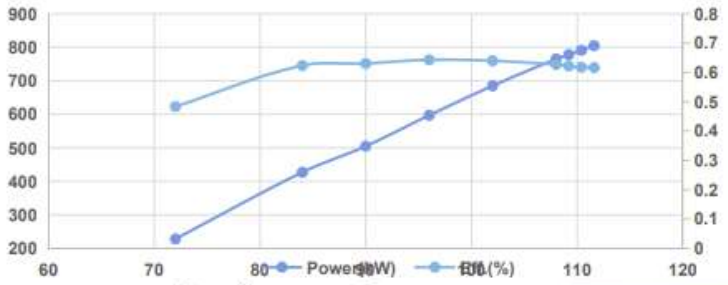
Klystron No. 3 （MBI
Efficiency 80.5%
(under fabrication)

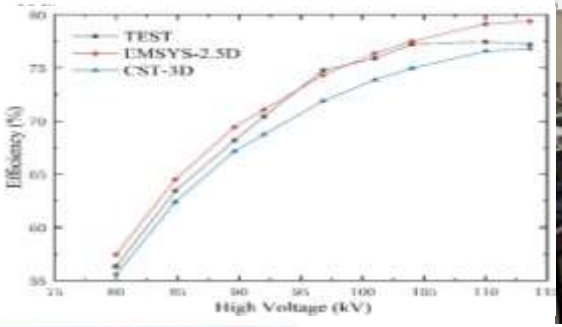
Power Supply Modulator



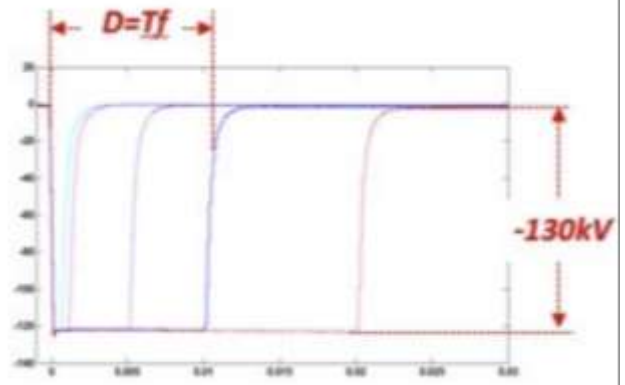
Pulsed RF Mode (30% duty factor, 60ms/5Hz) **77.2%@849kW pulsed in 2024**

High Voltage vs. Power&Efficency

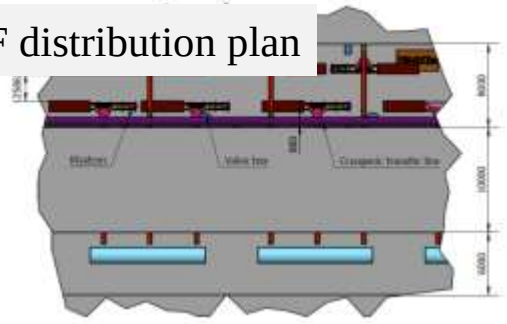


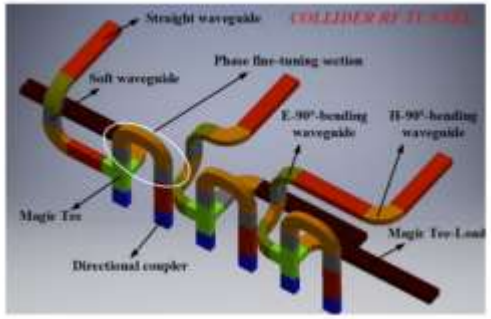


To be tested in 2024



RF distribution plan

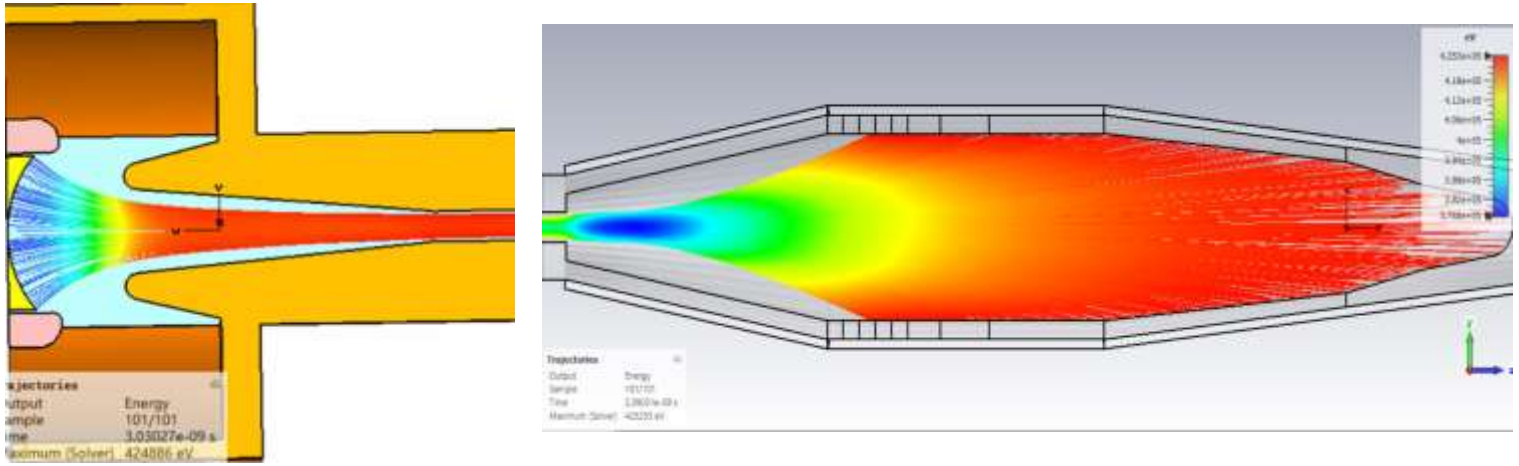




- Three prototypes of the **650MHz 800KW CW** klystrons are developed. The efficiency reaches 77.2%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

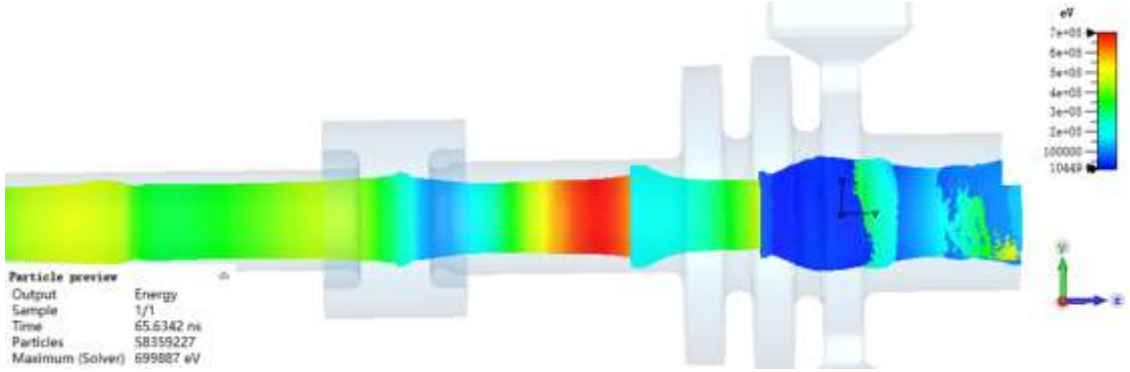
CEPC 80MW C-band Klystron Development in EDR

Plan：Middle of 2024 design completed，March of 2025 high power test

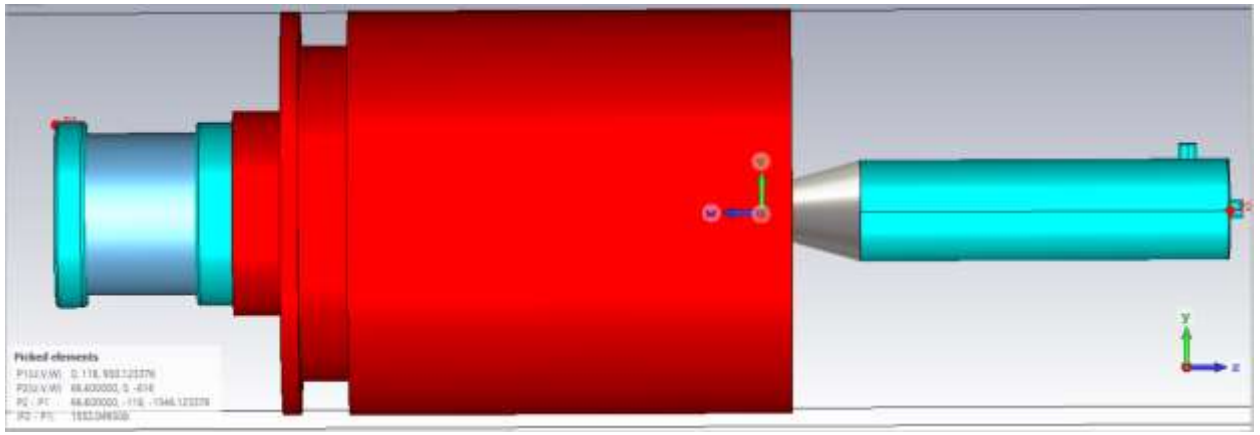


Gun and collector beam optics

Parameters	Value
Frequency	5712 MHz
Output Power	80MW
Drive power	350W
Gain	54 dB
Efficiency	47%
$3dB$ bandwith	±10MHz
Beam voltage	420 kV
Beam current	403 A
Focusing field	~0.27 T maximum



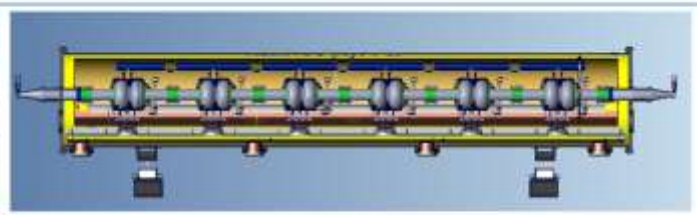
Beam dynamic with CST code



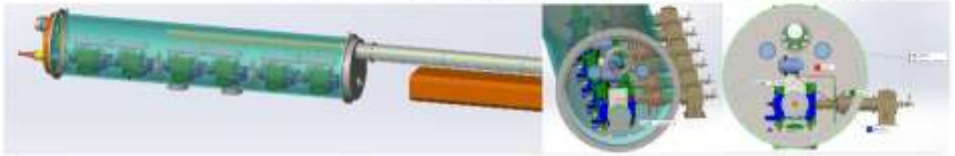
Mechanical configuration

CEPC Accelerator Development in EDR

CEPC 650MHz SC Full Size Cryomodule Development in EDR



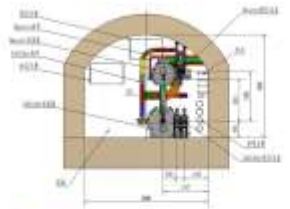
CEPC collider ring 650MHz 2*cell short test module has been completed in TDR phase

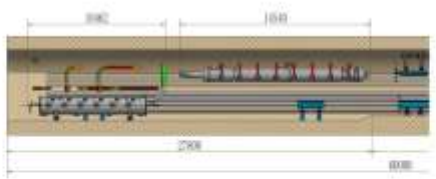


The collider Higgs mode for 30 MW SR power per beam will use 32 units of 11 m-long collider cryomodules will contain six 650 MHz 2-cell cavities, and therefore, a full size 650 MHz cryomodule will be developed in EDR

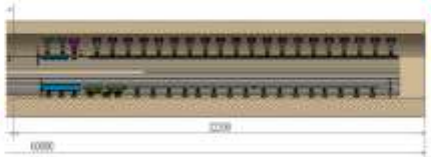
Plan：Middle of 2024 design completed，End of 2025 to be completed

CEPC Mockup Tunnel in EDR





Booster magnets installation



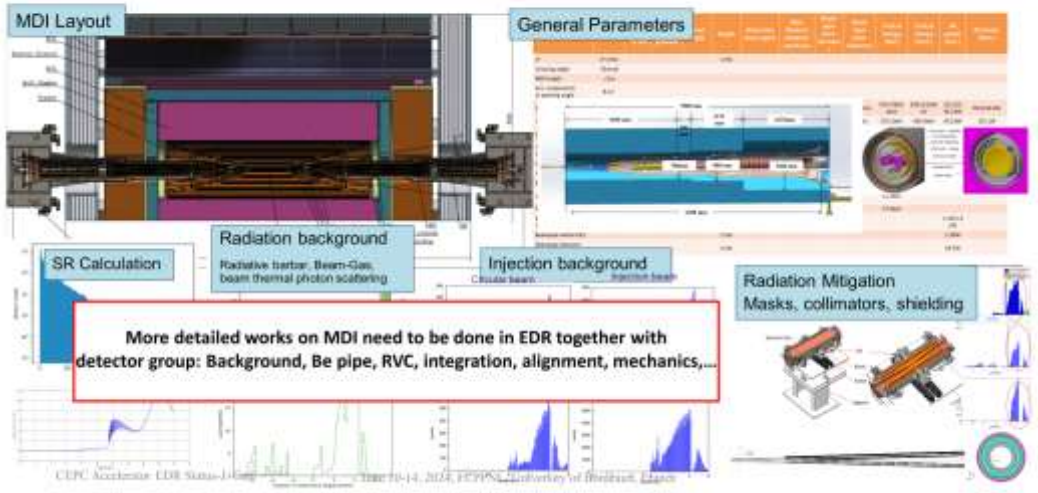
Collider ring magnets supports

A 60 m long tunnel mockup, including parts of arc section and part of RF section

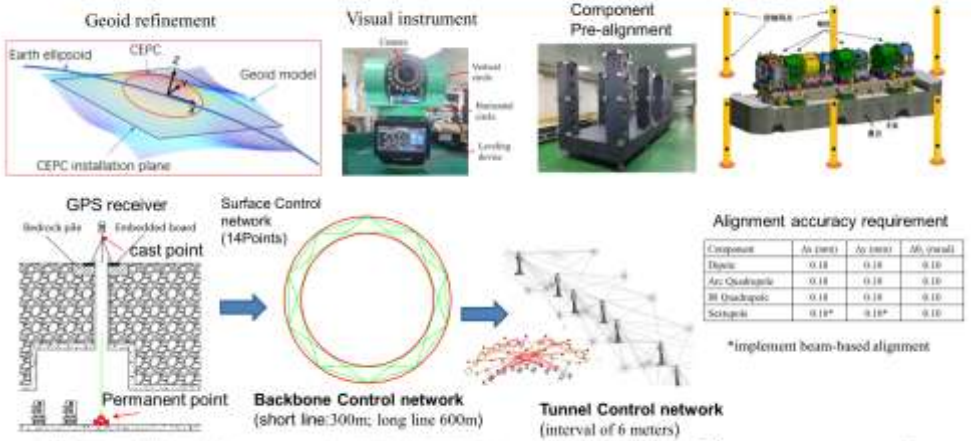
To demonstrate the inside tunnel alignment and installation, especially for booster installation on the roof of the tunnel

Plan：Middle of 2025 to be completed

CEPC MDI in EDR



CEPC Alignment and Installation Plan in EDR

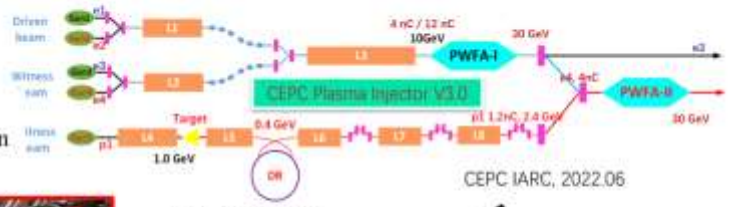


CEPC Accelerator Alternative Options

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



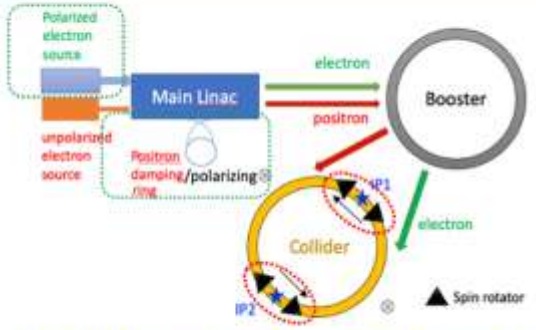
Phase I (Year0-Year2)
1. Re-design and install transport beamli… system,
2. Clean room and high power … TW)
3. Beam instrumentati…
4. RF Gun platfo…
5. Commissi… systems

Phase II (Y…
1. …mes (1PW + 20/40 TW)
…m and install it on the
P…
2. …umping ring the bunch compression
…improve the e+ quality
…ed FEL studies

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

PWFA/LWFA TF based on BEPC-II Linac and HPL has been founded by CAS 90M RMB in Sept. 2023

CEPC Polarization Studies (alternative option)



Both the transverse and longitudinal polarization and Z, W, are feasible (Higgs under study)

- Implement the lattice design to accommodate polarized beams: spin rotator, wiggler, Compton polarimeters, dumping ring and booster design, etc.
- R&D of Compton polarimeter, polarized electron sources, spin rotator, etc.
- Simulate the process and effects of errors
- Carry out experiments at BEPCII & HEPS booster

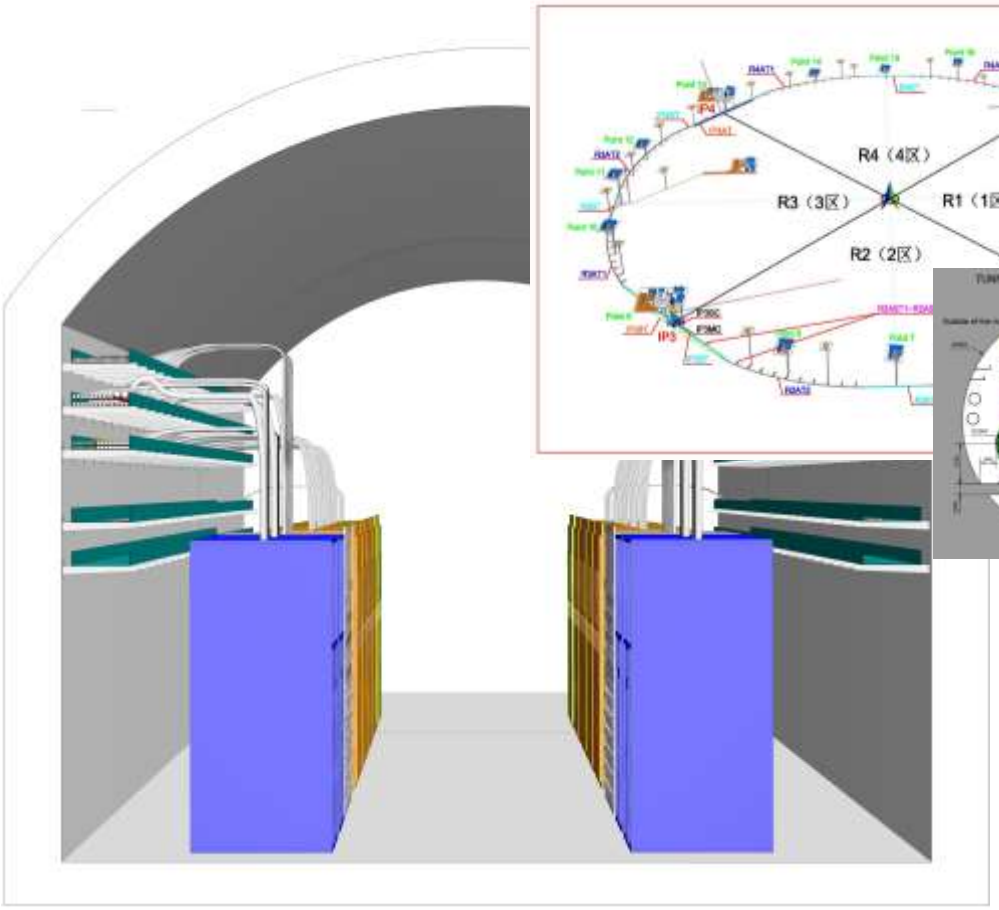
Status of the CEPC Projects-J. Gao LCWS2024, July 8, 2024, Tokyo University, Japan 30

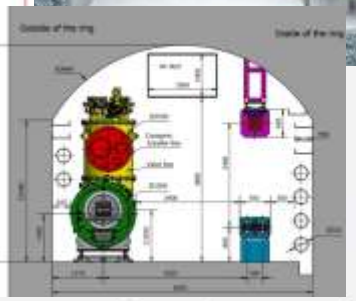
Plasma accelerator technology development towards CEPC injector and **future e+e- linear colliders**

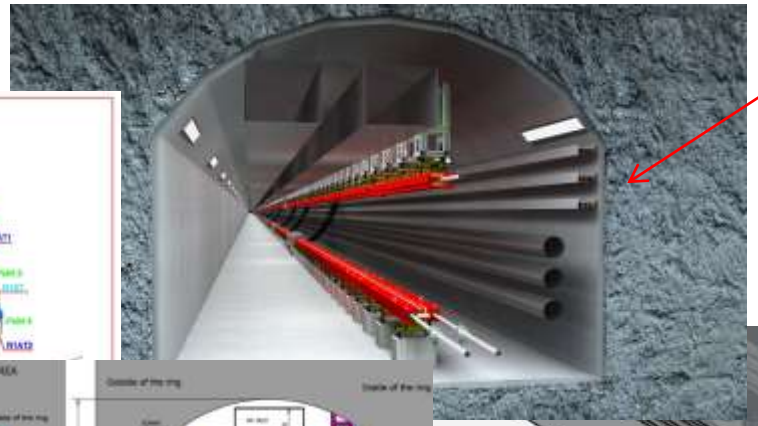
Polarization beam technology development towards **precision physics experiments**

CEPC Conventional Facility and Civil Engineering

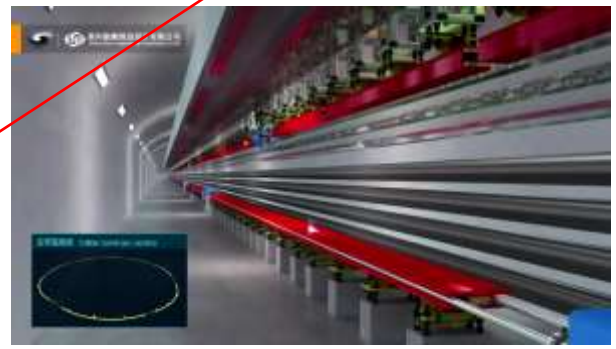
Electrical Equipment General Layout in Auxiliary Tunnel/500m along 100km







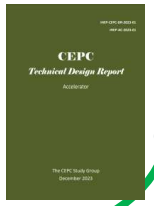
Cables installed!



CEPC Evolution Milestones and Timeline

Year 2012 2013 2015 2017 2018 2023 2025 2027 2030 2035

CEPC kickoff meeting in Sept. 2013



CEPC detector reference design
Will be completed by June 2025

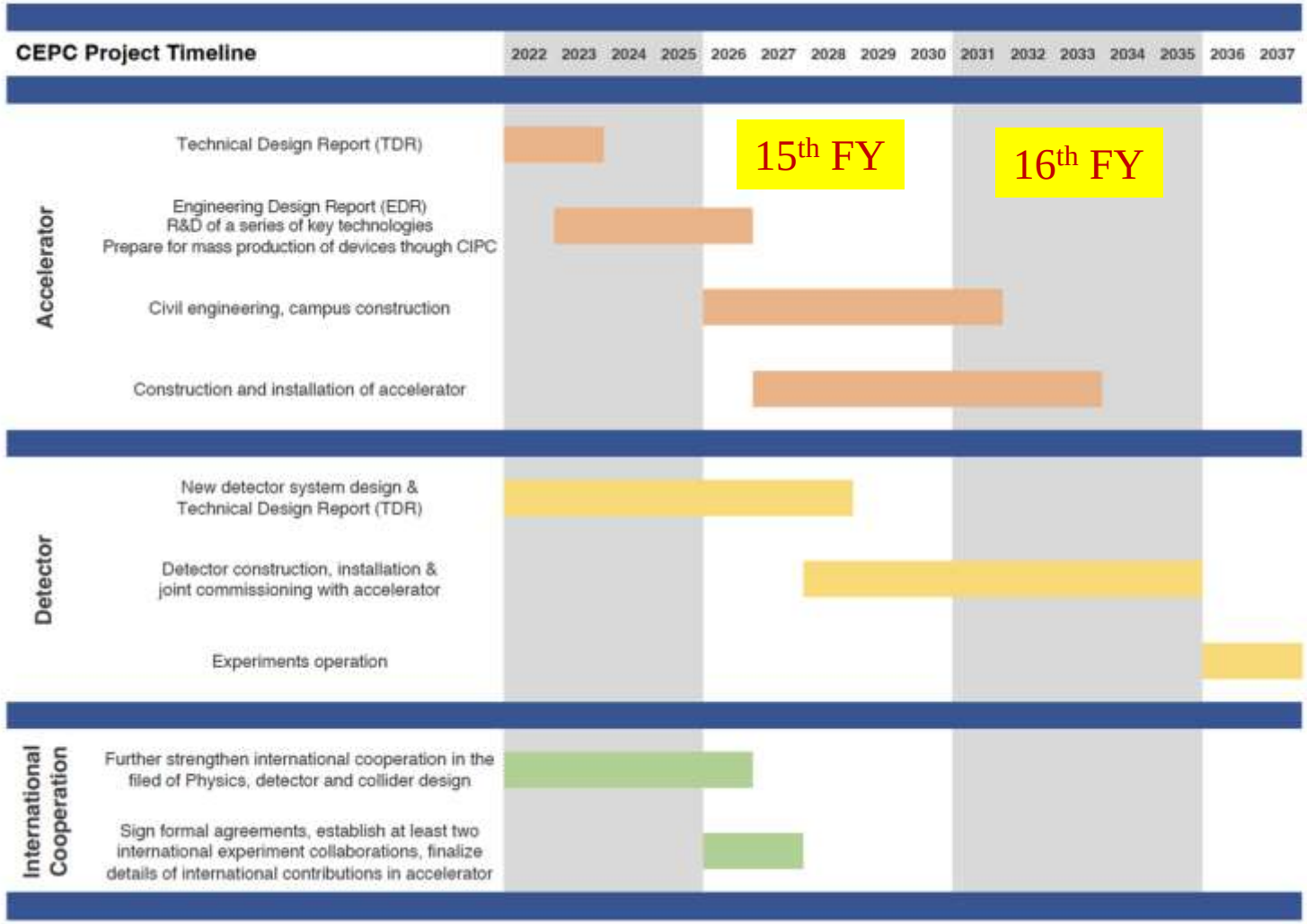
Proposal (2025) for CEPC entering 15th five year plan

CEPC EDR site study and civil engineering design

2012.9 CEPC proposed
2013.9 Pre-CDR
2015.3 Progress report
2017.4 CDR
2018.11 TDR
2023.12 2024 ~ 2027 EDR start of construction
~2035 Completion

CEPC Planning, Schedule and Teams

TDR (2023), EDR(2027), start of construction (2027-8)



CEPC team (domenstic)

CEPC accelerator and detector/experiments/theory group is an highly experienced team with strong international collaboration experiences. It has demonstrated its expertise and achievements is the following related projects, both domestic and international ones, such as:

BEPC-BEPCII (BES-BESIII), BFELP, CSNS, ADS, HEPS, LEP, LHC, LHCb, ILC, EXFEL, HL-LHC, BELLE, BELLE-II, CLEO, Daya Bay, JUNO, etc.

CEPC international partners and collaborators

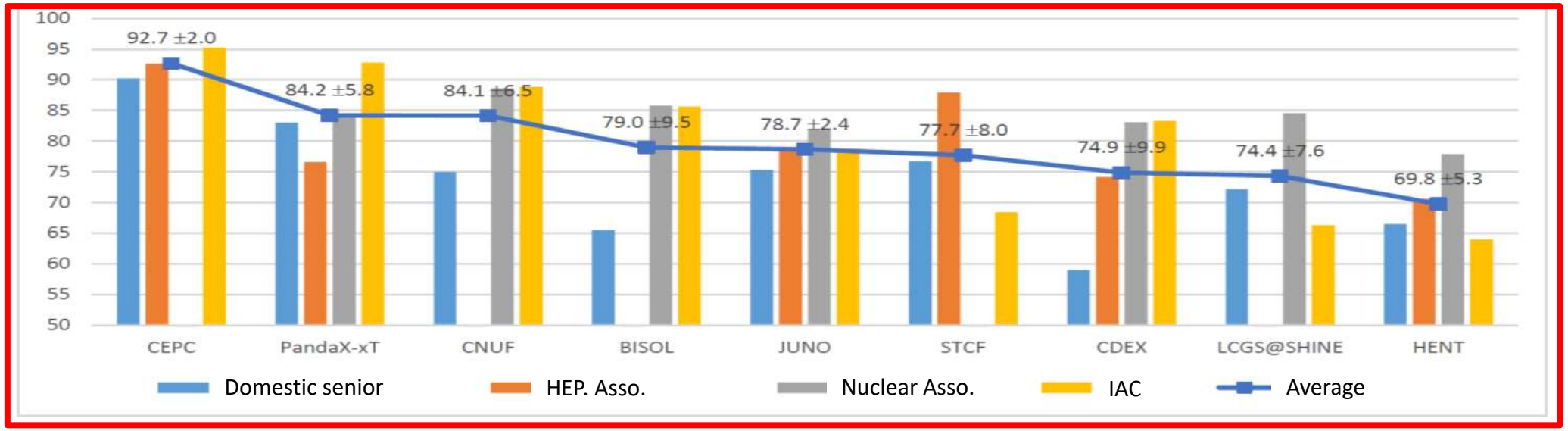
CEPC in Synergy with other Accelerator Projects in China

Project name	Machine type	Location	Cost (B RMB）	Completion time
CEPC	Higgs factory Upto ttar energy	Led by IHEP, China	**36.4 (where accelerator 19)**	Around 2035 (starting time around 2027)
BEPCII-U	e+e-collider 2.8GeV/beam	IHEP (Beijing)	**0.15**	2025
HEPS	4th generation light source of 6GeV	IHEP (Huanrou)	**5**	2025
SAPS	4th generation light source of 3.5GeV	IHEP (Dongguan)	**3**	2031 (in R&D, to be approved)
HALF	4th generation light source of 2.2GeV	USTC (Hefei)	**2.8**	2028
SHINE	Hard XFEL of 8GeV	Shanghai-Tech Univ., SARI and SIOM of CAS (Shanghai)	**10**	2027
S3XFEL	S3XFEL of 2.5GeV	Shenzhen IASF	**11.4**	2031
DALS	FEL of 1GeV	Dalian DICP	**-**	(in R&D, to be approved,)
HIAF	High Intensity heavy ion Accelerator Facility	IMP, Huizhou	**2.8**	2025
CIADS	Nuclear waste transmutation	IMP, Huizhou	**4**	2027
CSNS-II	Spallation Neutron source proton injector of 300MeV	IHEP, Dongguan	**2.9**	2029

The total cost of the accelerator projects under construction:39B RMB more than CEPC cost of 36.4B RMB

CEPC Project Development towards Construction

- **TDR has been completed** (review + revision) to be **formally released on Dec. 25，2023.**
- **CAS is planning for the 15th 5-years plan for large science projects**, and a steering committee has been established, **chaired by the president of CAS**.
- **High energy physics and nuclear physics**, is one of the 8 groups (fields).
- **CEPC is ranked No. 1, with the smallest uncertainties, by every evaluation committee both domestic and international one** among all the collected proposals.
- **A final report has been submitted to CAS for consideration.**
- **The above mentioned actual process is within CAS and the following national selection process will be decisive.**



Participating and Potential Collaborating Companies in China and Worldwide

	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

CEPC Industrial Promotion Consortium (CIPC, established in Nov. 2017)

Potential international collaborating suppliers and partners worldwide

CEPC International Collaboration-1

CEPC attracts significant International participation and collaborations

Accelerator TDR report: 1114 authors from 278 institutes (including 159 International Institutes, 38 countries) arXiv：2312.14363

- More than 20 MoUs have been signed with international institutions and universities
- CEPC International Workshop since 2014
- EU-US versions of CEPC WS since 2018
- Annual working month at HKUST-IAS (mini workshops and HEP conference) since 2015

CEPC International Collaboration-2

HKIAS23 HEP Conference
Feb. 14-16, 2023
https://indico.cern.ch/event/1215937/

The 2024 HKUST IAS Mini workshop and conference were held from Jan. 18-19, and Jan. 22-25, 2024, respectively.
https://indico.cern.ch/event/1335278/timetable/?view=standard

The 2023 International Workshop on Circular Electron Positron Collider, EUEdition,University of Edinburgh, July 3-6, 2023
https://indico.ph.ed.ac.uk/event/259/overview

The 2023 international workshop on the high energy Circular Electron Positron Collider (CEPC)
https://indico.ihep.ac.cn/event/19316/

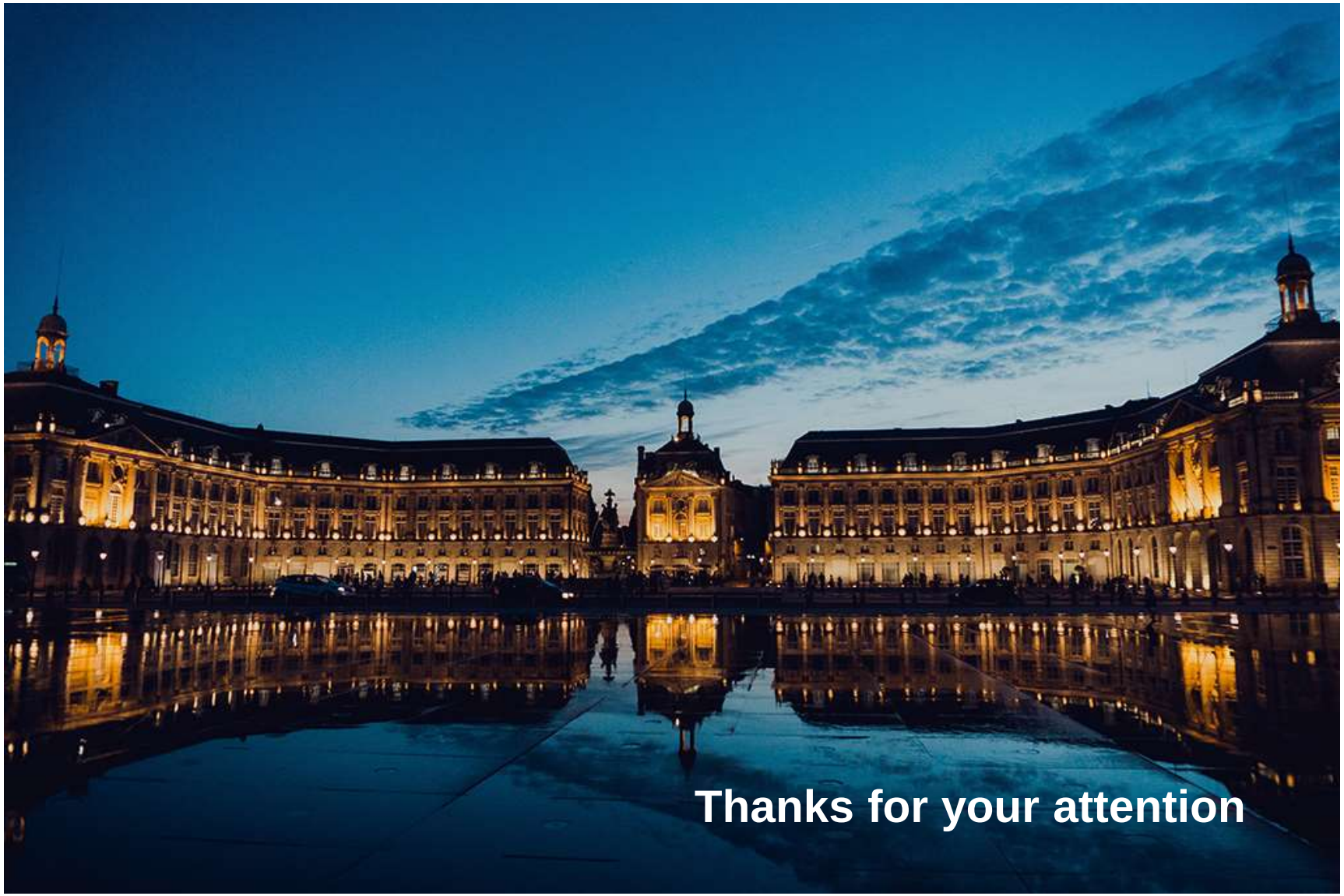
The 2024 international workshop of CEPC, EU-Edition were held in Marseille, France, April 8-11, 2024.
https://indico.in2p3.fr/event/20053/overview

The 2024 international workshop on the high energy Circular Electron Positron Collider (CEPC) will be held from Oct. 23-27, 2024, Hangzhou, China
https://indico.ihep.ac.cn/event/22089/

Professor Peter Higgs passed away on **April 8, 2024**. We miss him.

Summary

- CEPC addressed most pressing & critical science problems in particle physics
- Accelerator design and technology R&D are reaching maturity, TDR completed in 2023, ready for construction in 3-5 years after EDR phase
- CEPC proposal for the China's 15th 5-year plan will be submitted in 2025
- CEPC has a strong and experienced group, backed by IHEP and international teams
- Schedule will follow China's 15th 5-year plan, Call for collaboration and proposals once CEPC is (preliminary) approved
- Continue to work with government and funding agencies to get support
- International collaborations are mostly welcome.


Thanks for your attention