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

Status of the CEPC Project

-Towards construction through EDR Phase

J. Gao

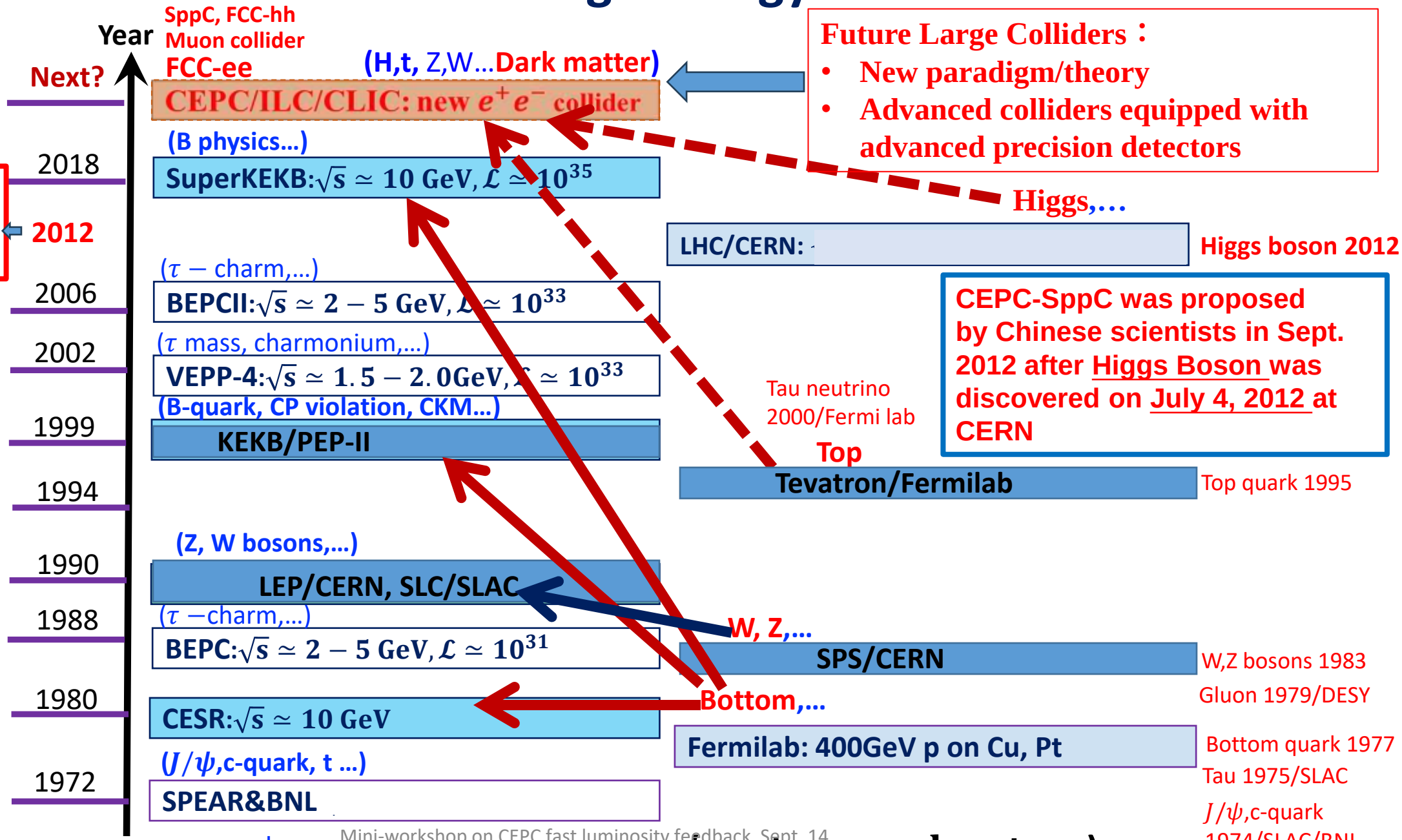
IHEP

On behalf of the CEPC-SppC team

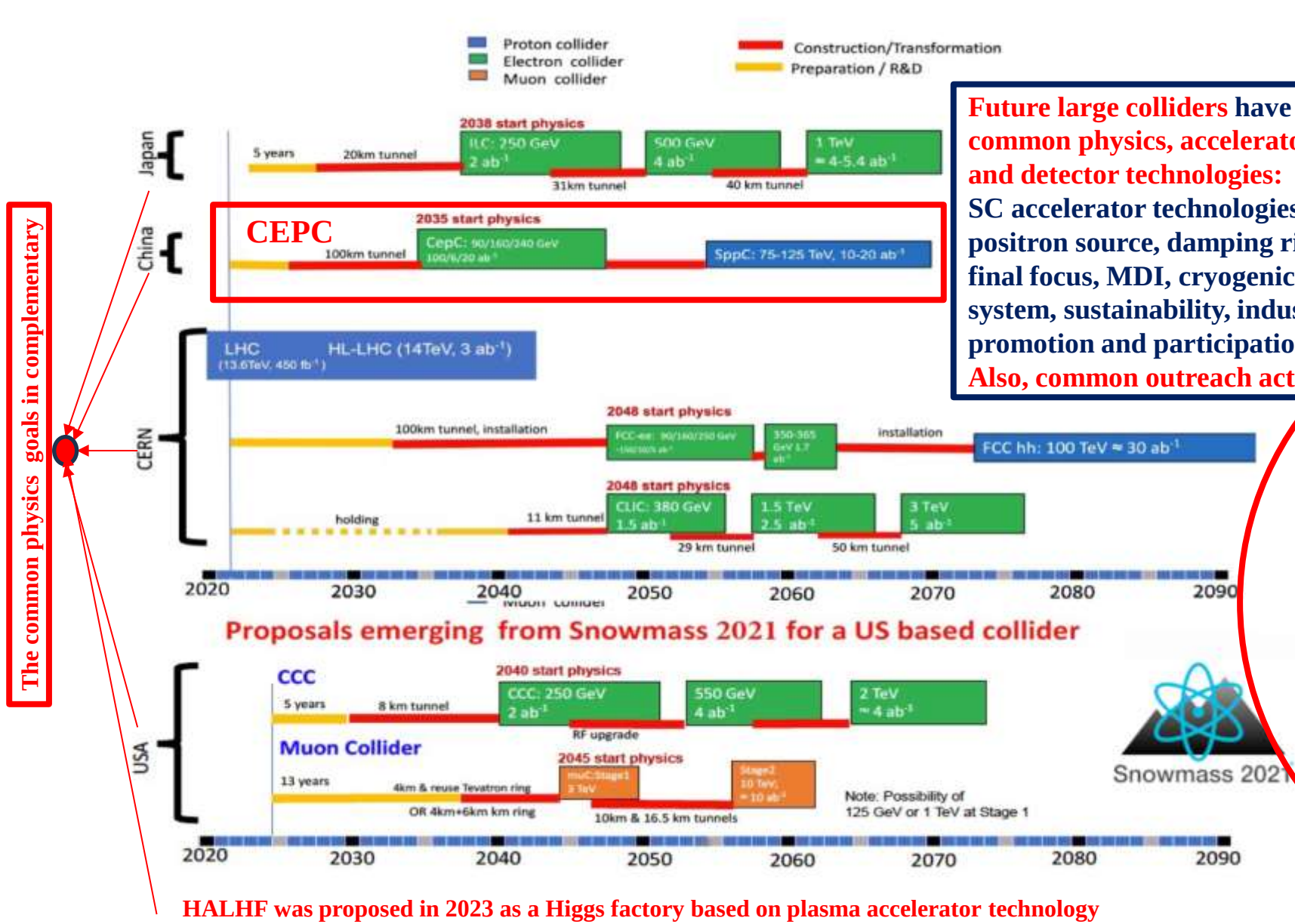
Mini-workshop on CEPC fast luminosity feedback
Sept. 14, 2024, IHEP

Contents

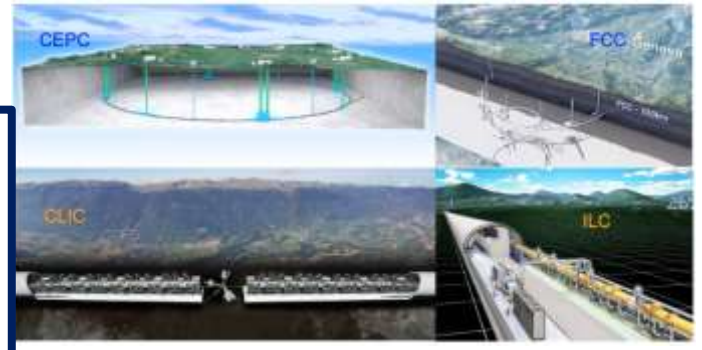
A Brief Historical Recall: High Energy Colliders and Factories

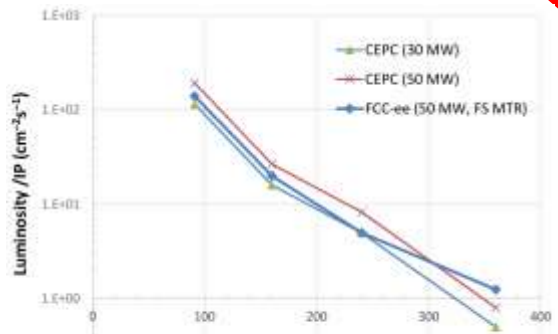


Worldwide High Energy Physics Goal Timelines and Common Efforts



Future large colliders 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





CEPC vs FCCee

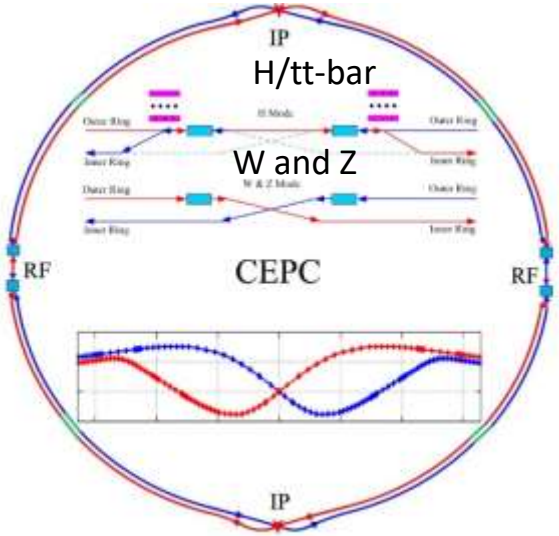
Center of Mass Energy (GeV)

	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	5	115	16	0.5
CEPC (TDR, 50 MW)	8.3	192	26.7	0.8
FCC-ee (FS MTR, 50 MW)	≥ 5.0	140	20	1.25

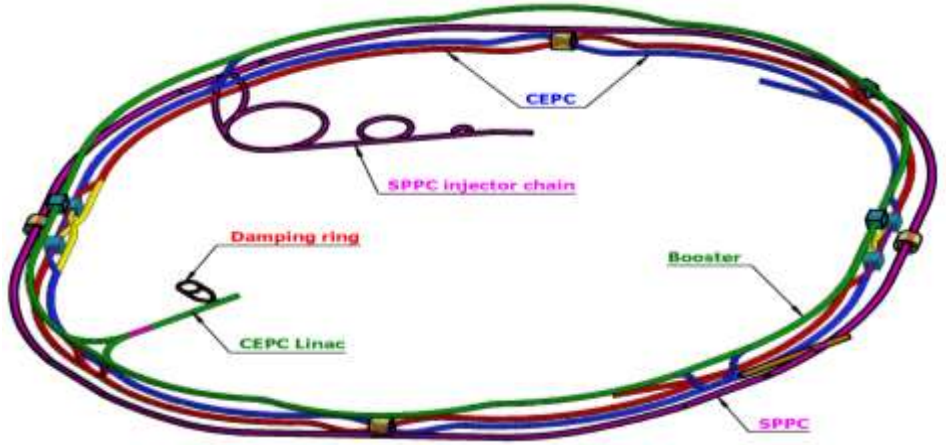
HALHF was proposed in 2023 as a Higgs factory based on plasma accelerator technology

CEPC Higgs Factory and SppC Layout in TDR/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

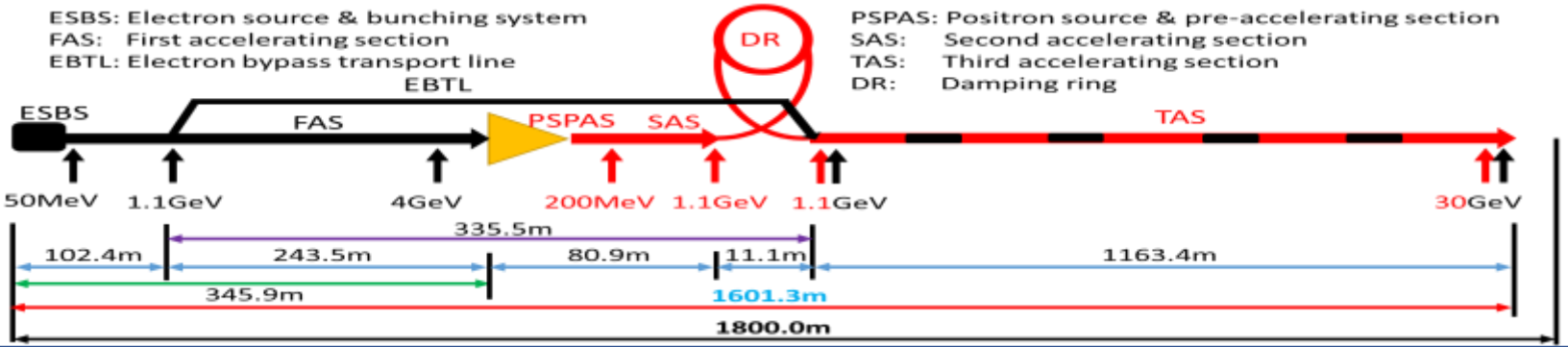


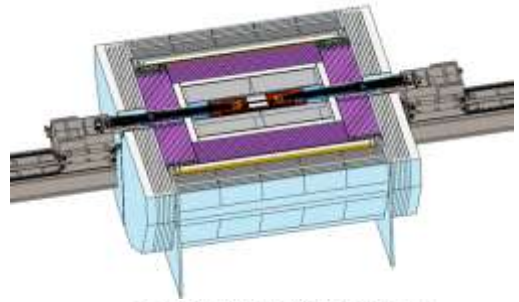
CEPC collider ring (100km)



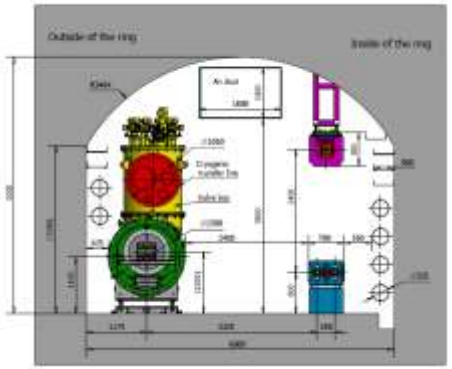
CEPC booster ring (100km)

CEPC TDR S+C-band 30GeV linac injector

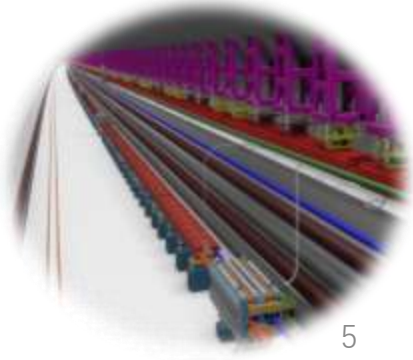




TUNNEL CROSS SECTION OF THE ARC AREA



CEPC/SppC in the same tunnel



CEPC Accelerator System Parameters in TDR/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

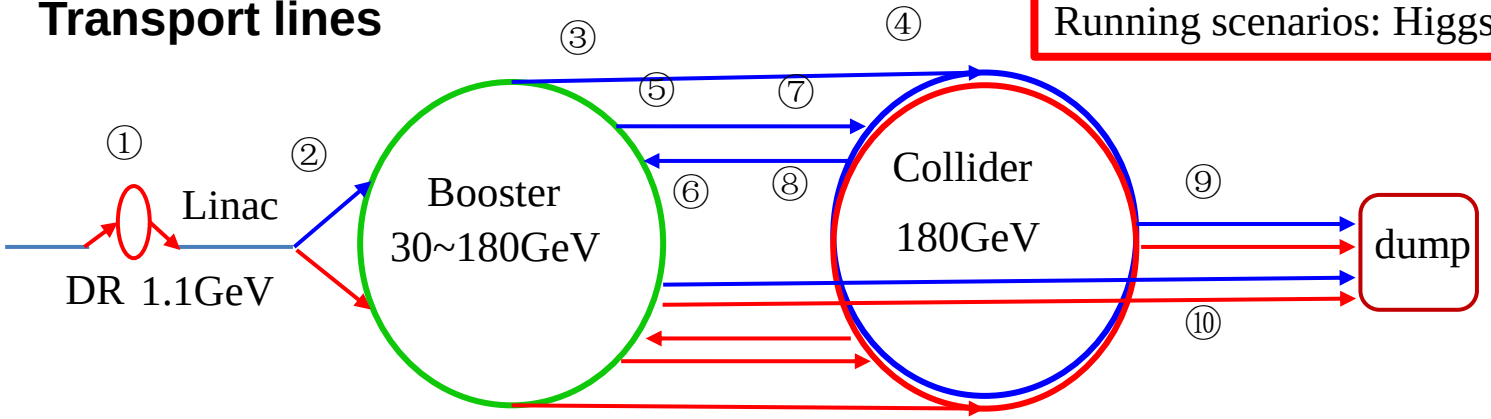
Booster

		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

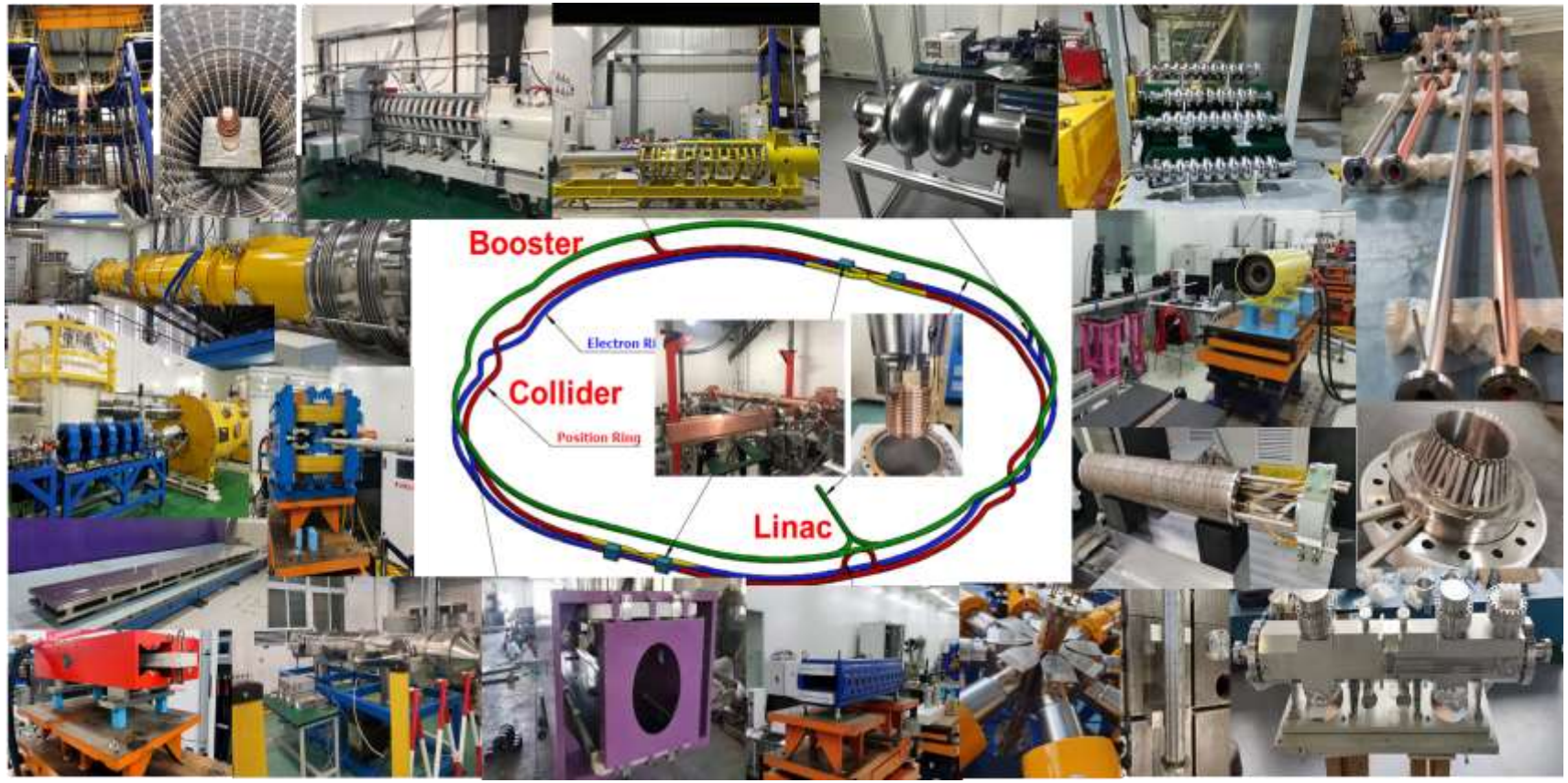


Running scenarios: Higgs 10 years, Z 3 years, W 1 year, ttbar 5 years

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

CEPC Key Technology R&D Status in TDR

Specification Met ✓ Prototype Manufactured ✓



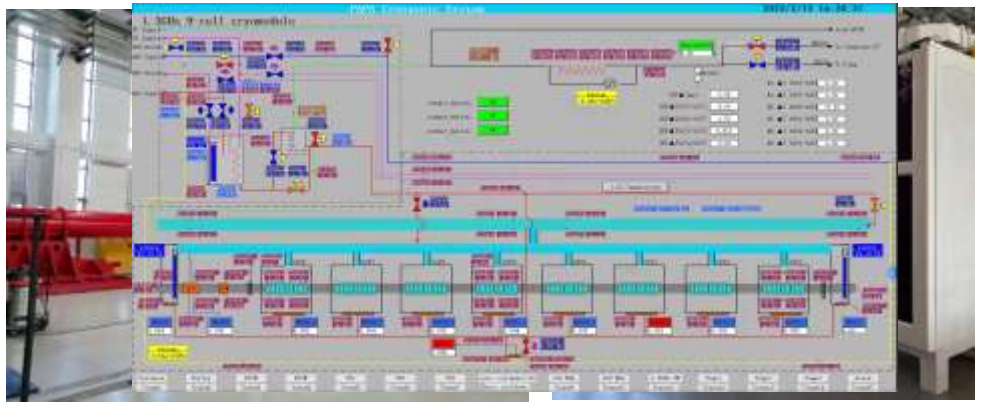
Accelerator	Fraction
✓ Magnets	27.3%
✓ Vacuum	18.3%
✓ RF power source	9.1%
✓ Mechanics	7.6%
✓ Magnet power supplies	7.0%
✓ SC RF	7.1%
✓ Cryogenics	6.5%
✓ Linac and sources	5.5%
✓ Instrumentation	5.3%
✓ Control	2.4%
✓ Survey and alignment	2.4%
✓ Radiation protection	1.0%
✓ SC magnets	0.4%
✓ Damping ring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

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

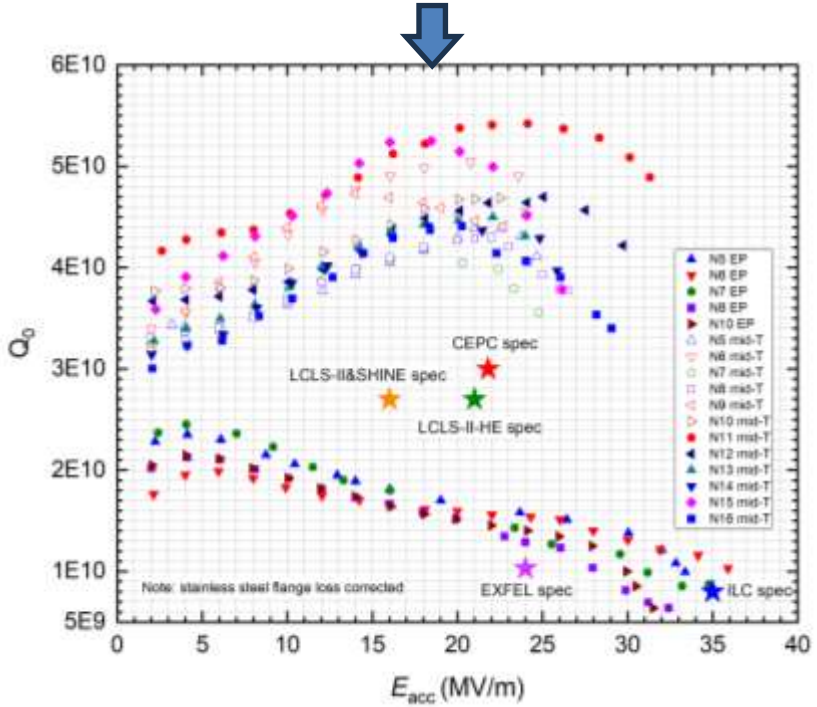
CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

Parameters	Horizontal test results	CEPC Booster Higgs Spec	LCLS-II, SHINE Spec	LCLS-II-HE Spec
Average usable CW E_{acc} (MV/m)	23.1	3.0×10^{10} @ 21.8 MV/m	2.7×10^{10} @ 16 MV/m	2.7×10^{10} @ 20.8 MV/m
Average Q_0 @ 21.8 MV/m	3.4×10^{10}			



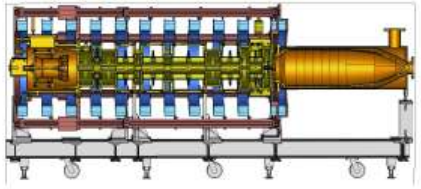
IHEP 1.3GHz 9cell cavity high field high Q Achievement with Mid-T baking technology



CEPC Accelerator Main Technology Development: Klystrons

Klystron R&D

Klystron No. 2
Efficiency 77%
(2021)



Klystron No. 1
Efficiency 65%
(2020)

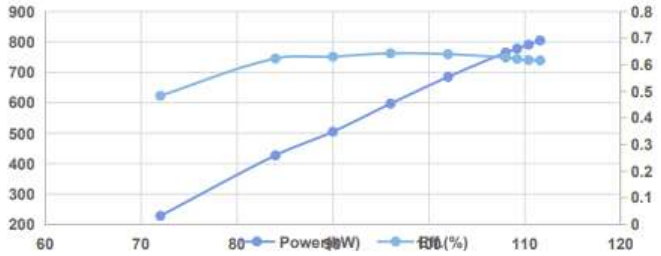
77.2%@849kW pulsed in 2024

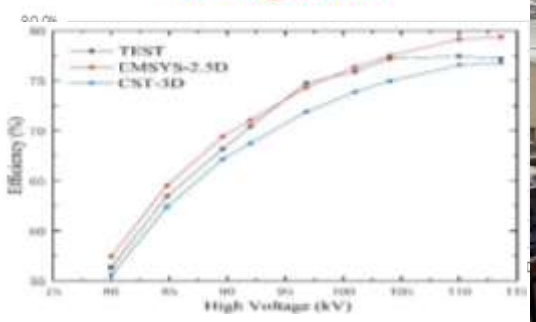
Klystron No. 3 （MBI
Efficiency 80.5%
(under fabrication)

Pulsed RF Mode (30% duty factor, 60ms/5Hz)

70.5% @ 630kW

High Voltage vs. Power&Efficency

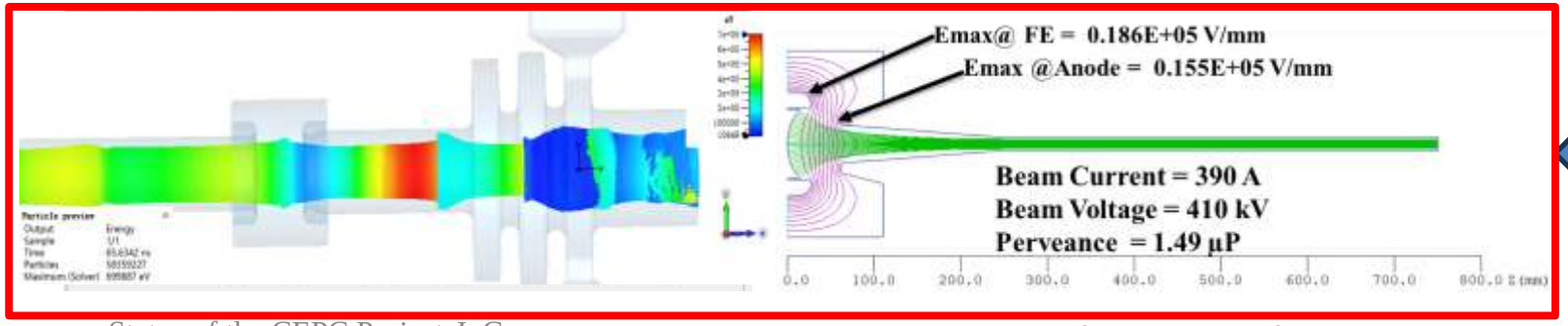




Parameters	Value
Frequency	5720 MHz
Output Power	80MW
Pulsed width	2.5us
Repetition rate	100Hz
Gain	54 dB
Efficiency	47%
$3dB$ bandwith	±5MHz
Beam voltage	420 kV
Beam current	403 A
Focusing field	0.28 T

CEPC collider ring 650MHz klystron development in TDR phase

C band 5720MHz 80MW Klystron

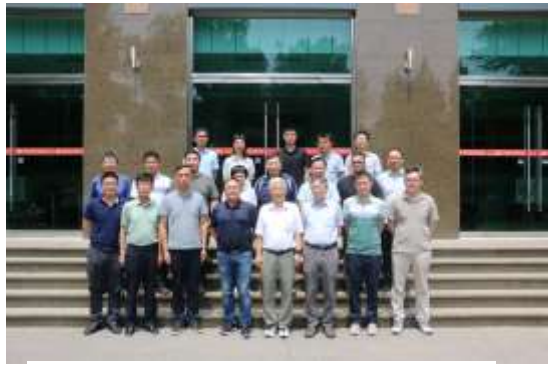


C band 5720MHz 80MW Klystron design progress to be constructed in 2025

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

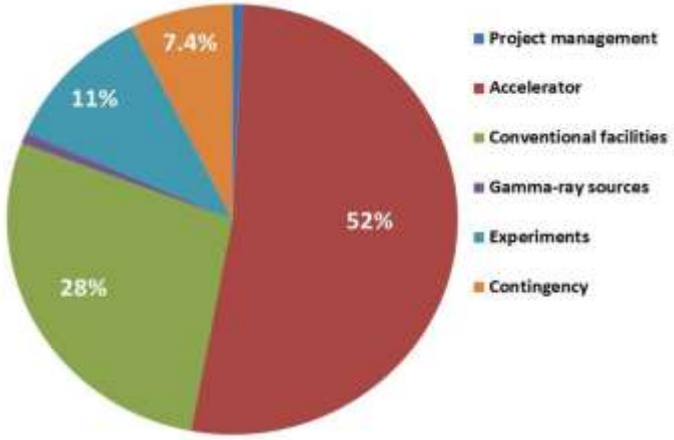


Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP

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

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

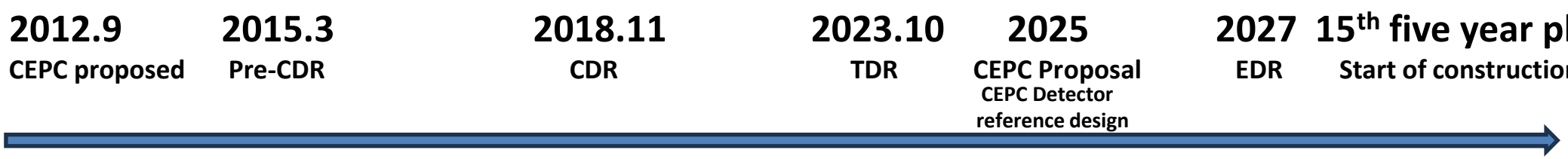
Total	364	100%
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



Distribution of CEPC Project total TDR cost of **36.4B RMB (~5.2USD)**

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

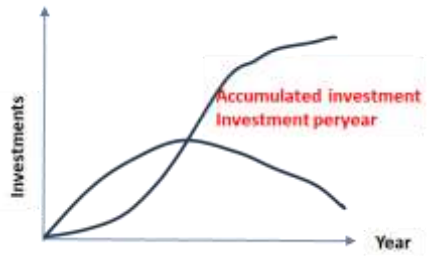
CEPC Accelerator EDR goals, scope and the working plan (preliminary) of 35 WGs summarized in a documents of 20 pages, EDR progress be reviewed by IARC in Sept. 18-20, 2024

CEPC Milestones, Timeline and Human Resources

Year	2012	2013	2015	2017	2018	2023	2025	2027	2030	2035
Human resources (TFE)		~50			~100	~200	~300	~500	~2800	~2500

Year	Accelerator human resource	Accumulated accelerator spending Billion RMB
2015	50	-
2018	100	-
2023	200	0.2
2025	300	0.3
2027	500	0.4
2031	2800	9
2035	2500	20

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

36.4B RMB
Total construction

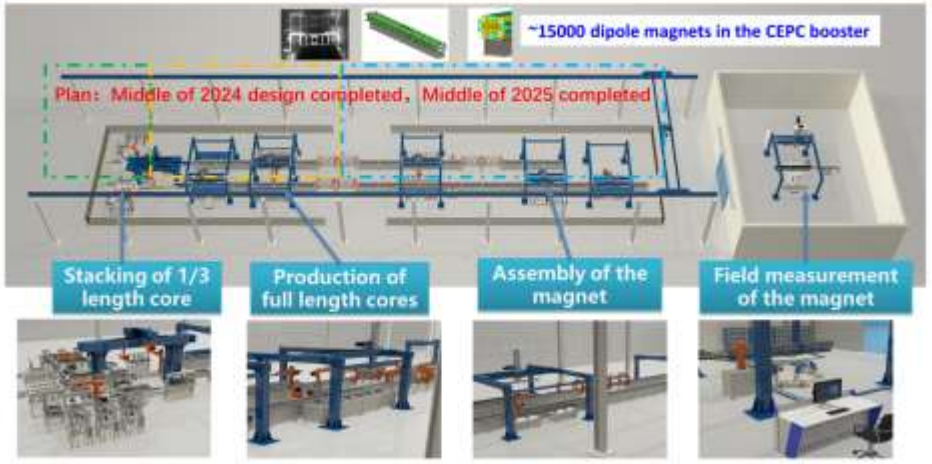
~2B RMB/year
during operation

CEPC EDR Henan site study and civil engineering design

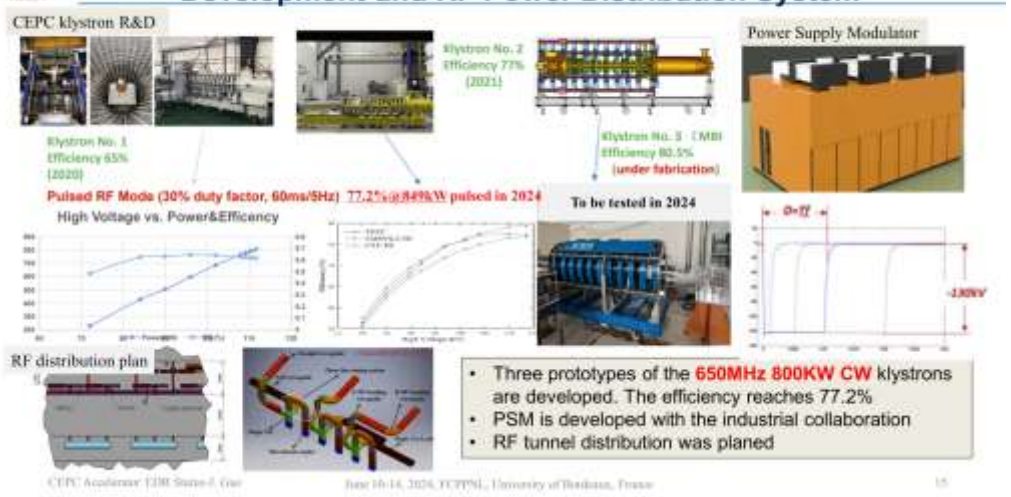
2012.9	2013.9	2015.3	2017.4	2018.11	2023.12	2024	~	2027	~2035
CEPC proposed		Pre-CDR	Progress report	CDR	TDR			EDR start of construction	Completion

CEPC Accelerator Development in EDR-1

CEPC Magnet Automatic Production Line in EDR

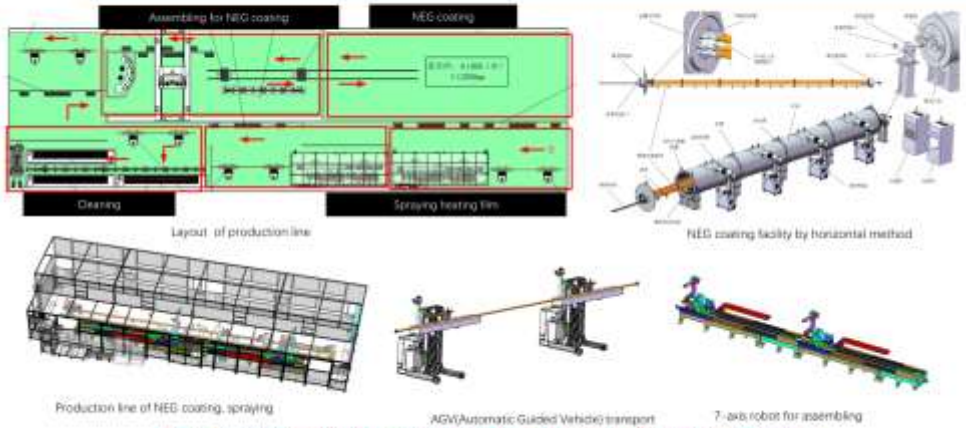


CEPC 650MHz High Efficiency High Power Klystron Development and RF Power Distribution System



- 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

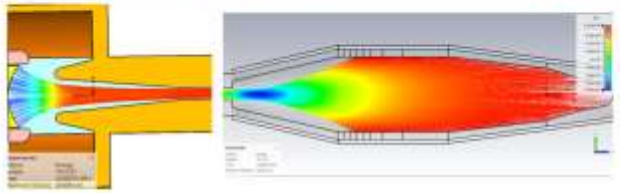
CEPC NEG Coated Vacuum chamber Automatic Production Line in EDR



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

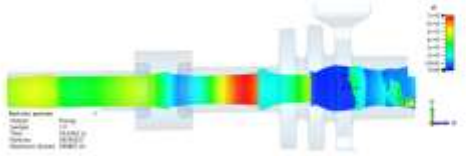
CEPC 80MW C-band Klystron Development in EDR

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

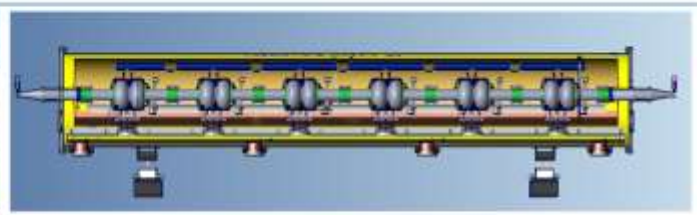


Beam dynamic with CST code

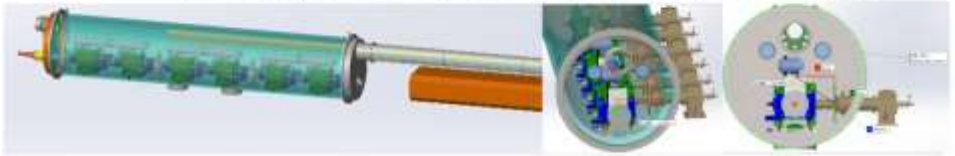
Mechanical configuration

CEPC Accelerator Development in EDR-2

CEPC 650MHz SC Full Size Cryomodule Development in EDR



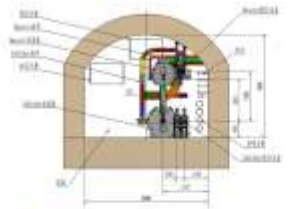
CEPC collider ring 650MHz 2*cell short test module has been completed in TDR phase

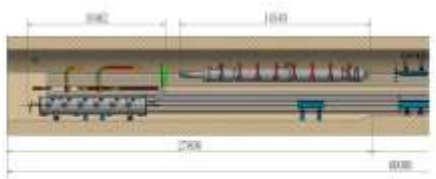


The collider Higgs mode for 30 MW SR power per beam will use 32 units of 11 m-long collider cryomodules will contain six 650 MHz 2-cell cavities, and therefore, a full size 650 MHz cryomodule will be developed in EDR

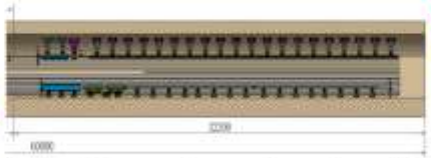
Plan：Middle of 2024 design completed，End of 2025 to be completed

CEPC Mockup Tunnel in EDR





Booster magnets installation



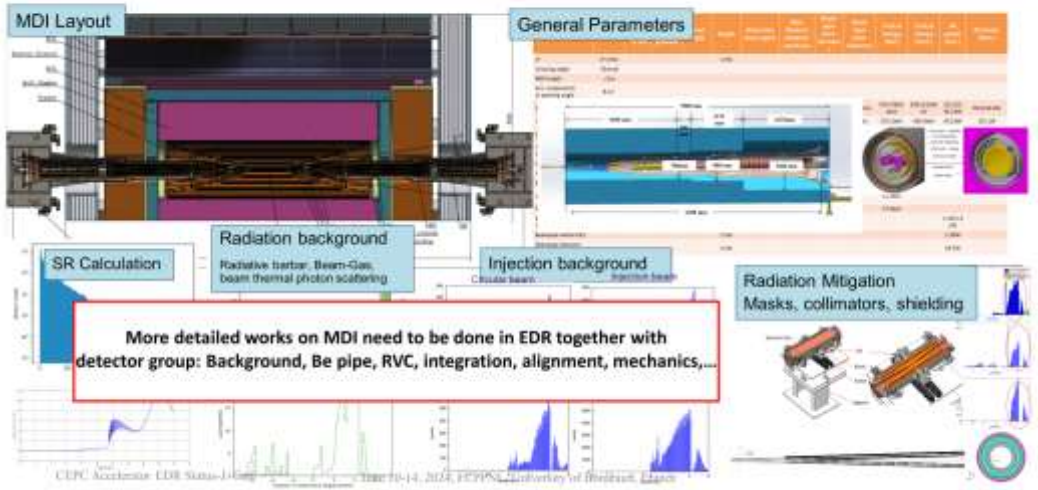
Collider ring magnets supports

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

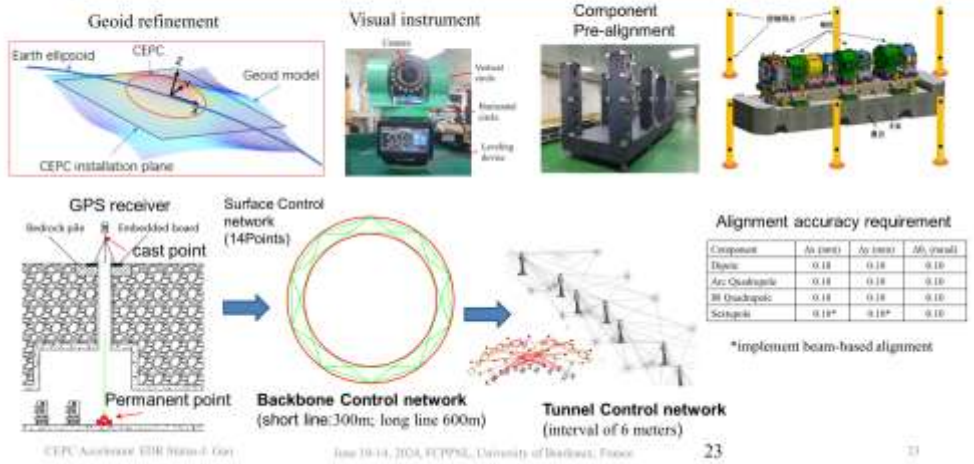
To demonstrate the inside tunnel alignment and installation, especially for booster installation on the roof of the tunnel

Plan：Middle of 2025 to be completed

CEPC MDI in EDR



CEPC Alignment and Installation Plan in EDR

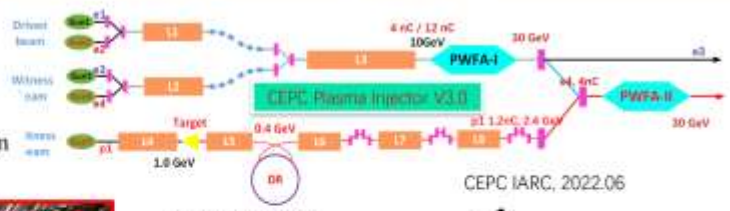


CEPC Accelerator Alternative Options

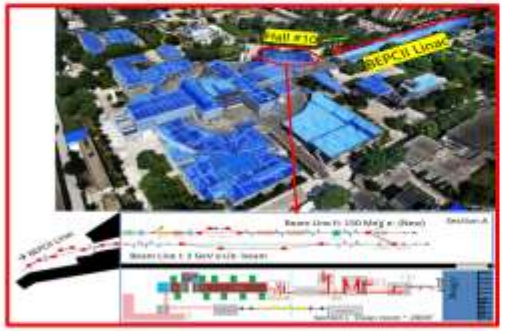
CEPC Plasma Injector (alternative option) and TF Plan

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



CEPC IARC, 2022.06



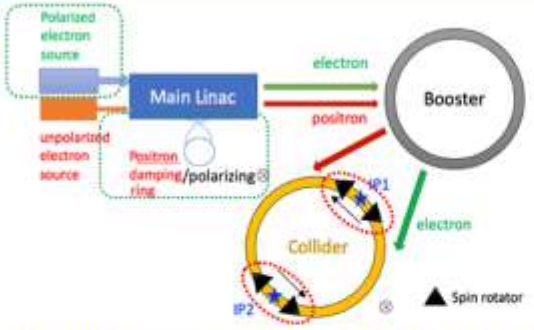
Phase I (Year0-Year2)
1. Re-design and install transport beam
2. Clean room and high power
installation200TW
3. Beam instrumentat
4. RF Gun platfor
5. Commissi

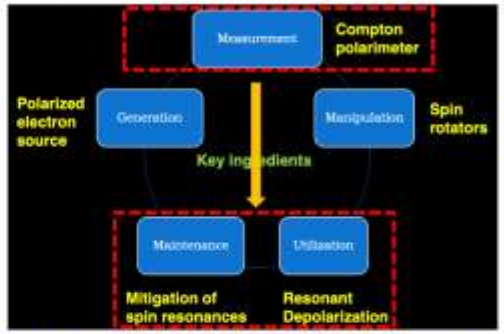
Phase II (Y

- 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**

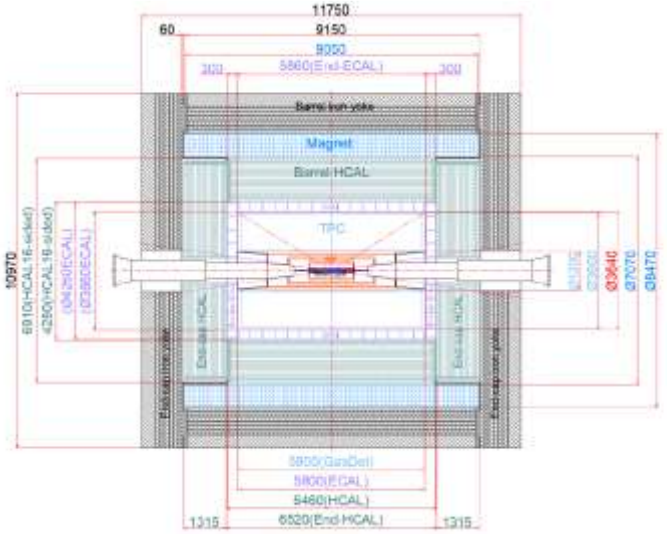
Polarization beam technology development towards **precision physics experiments**

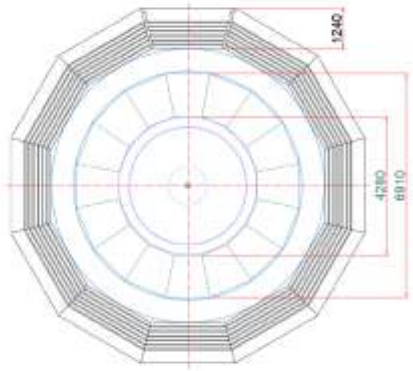
CEPC Detector: Idea of the "4th Concept" towards Reference Design

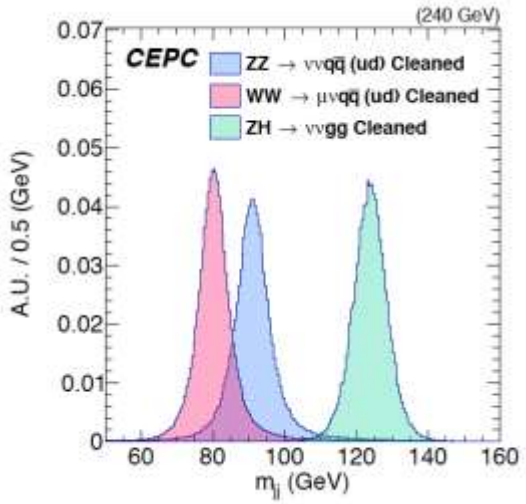
CEPC Detector TDRrd (rd=reference design) will be released in June, 2025

Requirements
boson mass resolution (BMR ~3%)

Challenges
- Support Particle flow with
  - High granularity
  - High precision





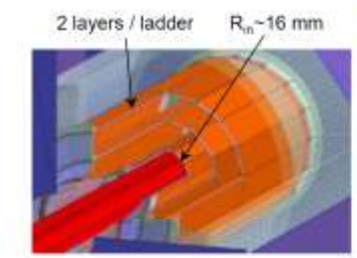


Novel detector design based on PFA calorimeter to improve the BMR from 4% to 3%

Detector	Key parameter	World level	4th concept
PFA based EM calorimeter	EM shower E resolution	~20%/√E	<3%/√E
PFA based Hadron calorimeter	Single hadron E resolution	~50%/√E	~40%/√E

- Silicon combined with gaseous chamber as the tracker and PID
- ECAL based on crystals with timing for 3D shower profile for PFA and EM energy
- Scintillation glass HCAL for better hadron sampling and energy resolution

CEPC Detector R&D: Vertex Detector and Tracker (examples)



Goal: σ(IP) ~ 5 μm for high P track

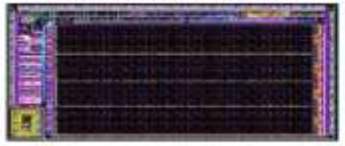
CDR design specifications

- Single point resolution ~ 3μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm²)
- Radiation hard (1 Mrad/year)

Silicon pixel sensor develops in 5 series:
JadePix, TaichuPix, CPV, Arcadia, CEPCPix

Develop **CEPCPix** for a CEPC tracke basing on **ATLASPix3** CN/IT/UK/DE TSI 180 nm HV-CMOS process

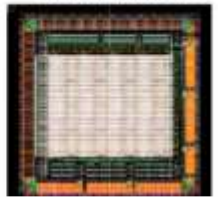
JadePix-3 Pixel size ~16×23 μm²



Tower-Jazz 180nm CIS process
Resolution 5 microns, 53mW/cm²

TaichuPix-3, FS 2.5x1.5 cm² 25×25 μm² pixel size

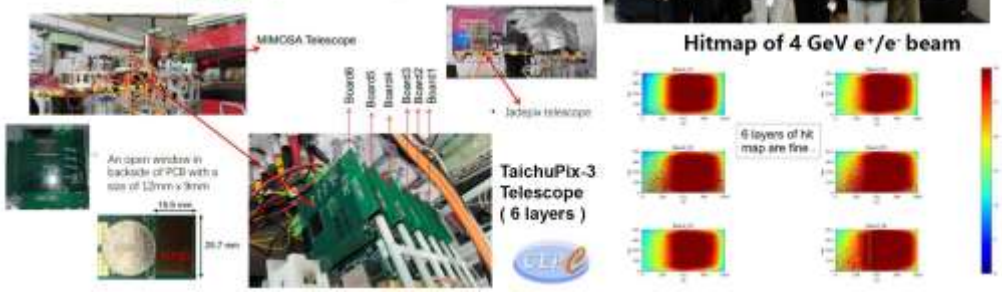
CPV4 (SOI-3D), 64×64 array ~21×17 μm² pixel size



Arcadia by Italian groups for IDEA vertex detector LFoundry 110 nm CMOS

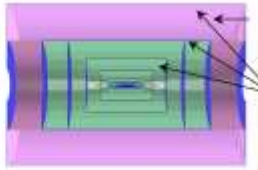
Full vertex detector prototype (TaichuPix-3, JadePix-3) has TB at DESY in Dec. 2022.

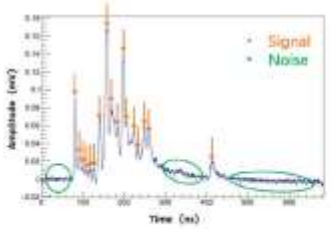
Hitmap of 4 GeV e^+/e^- beam

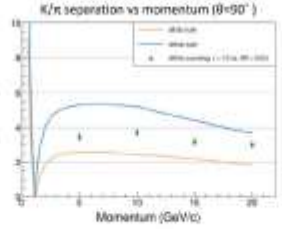


Goal: 3σ π/K separation up to ~20 GeV/c.

- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture
- Garfield++ for simulation, realistic electronics, peak finding algorithm development.

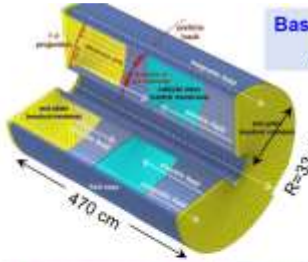


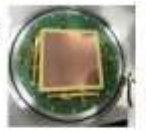




IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022

Baseline main tracker
σ(r-φ) ~100 μm

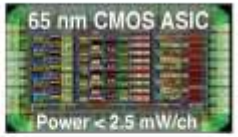




GEM-MM cathode

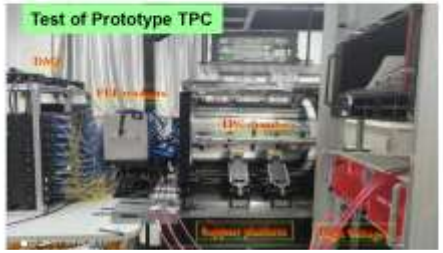
TPC Prototype + UV laser beams

MOST 1 (IHEP+THU)

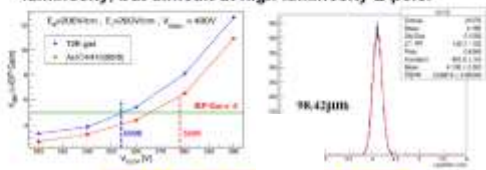


Low power FEE ASIC

Test of Prototype TPC



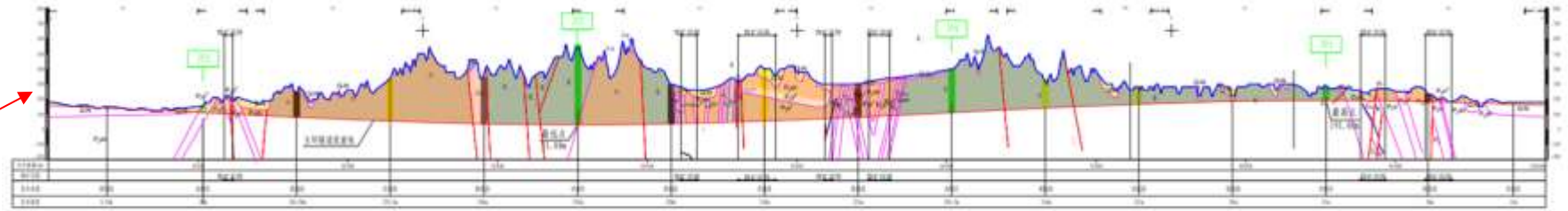
Challenge: Ion backflow (IBF) affects the resolution.
It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.



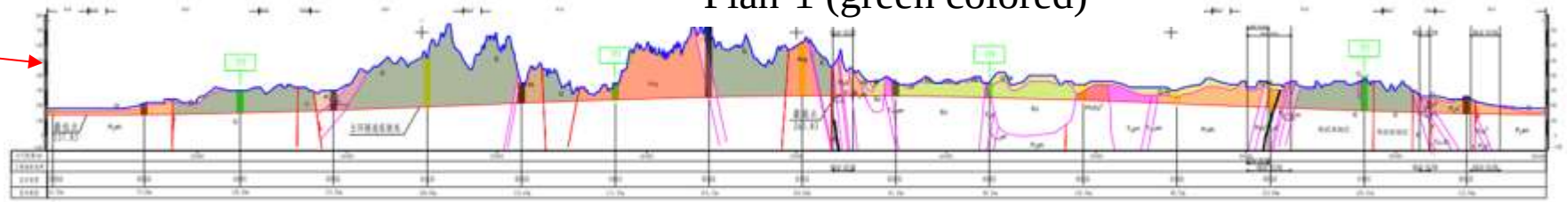
σ_r < 100 μm for drift length of 27cm

CEPC EDR Site Selection and Civil Engineering Design Progresses

Preliminary EDR site selection report (completed)

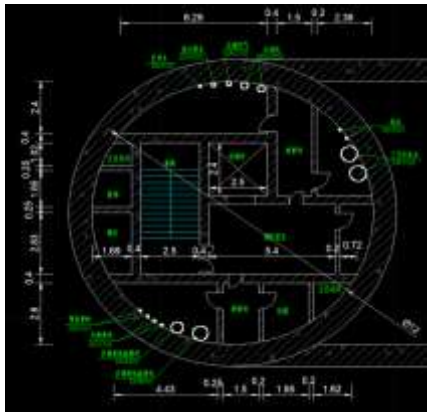


Plan-1 (green colored)



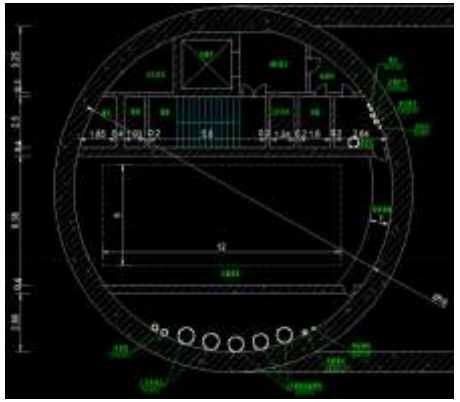
Plan-4 (bleu colored)

The number of shafts is under optimization



Experimental region shaft cross section design

Arc region shaft cross section design



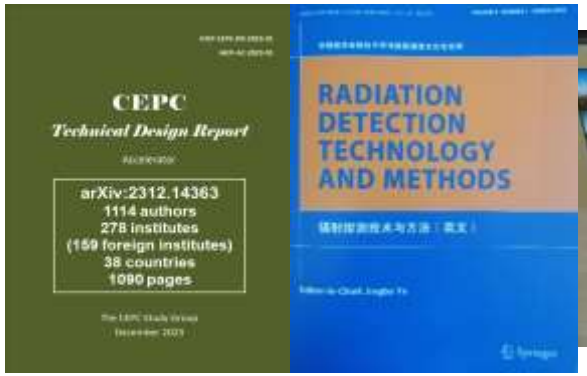
SRF region shaft cross section design

On site geological investigation

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) Published in **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



- 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 2025 HKUST IAS HEP conference: Jan. 13-17, 2025.

CEPC Workshop EU Edition (Barcelona, Spain), May 5-8, 2024

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 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/

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

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

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

FCPPNL, Bordeaux, France, June 10-14, 2024
https://indico.in2p3.fr/event/20434/overview

Participating and Potential Collaborating Companies in China and Worldwide

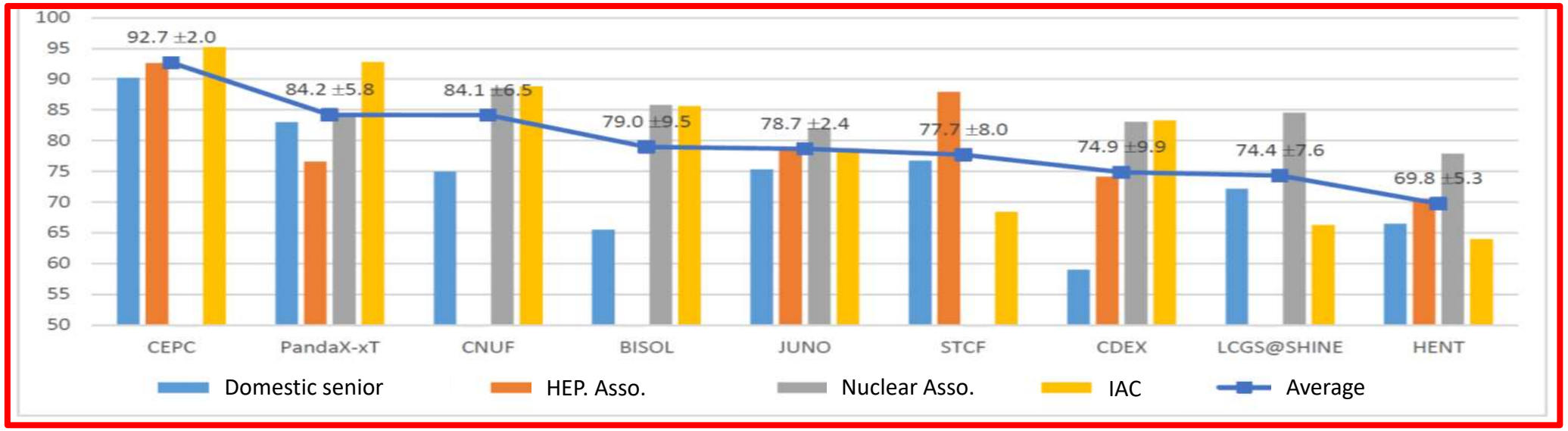
	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

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

Potential international collaborating suppliers and partners worldwide

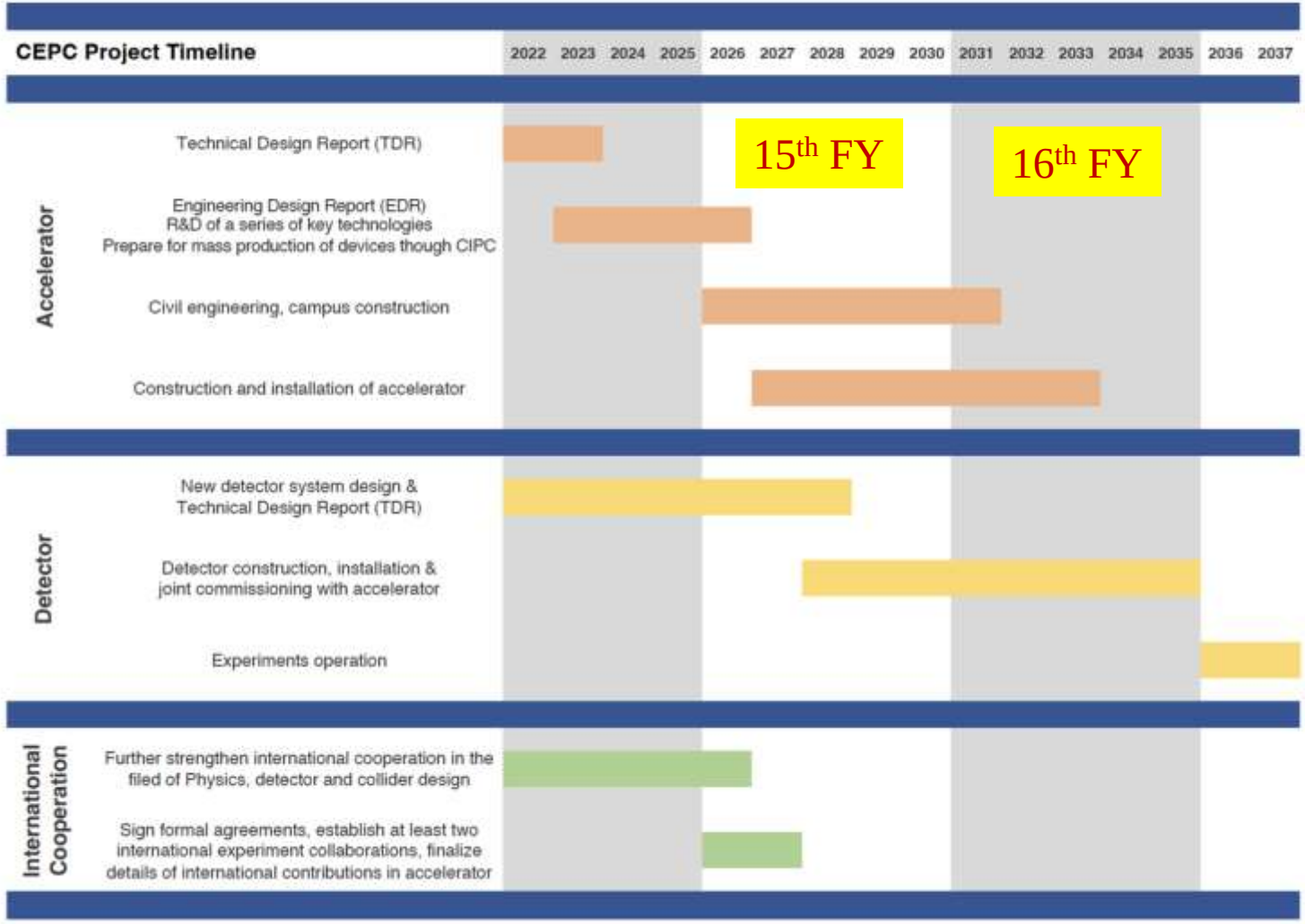
CEPC Project Development towards construction

- **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.**



CEPC Planning, Schedule and Teams

TDR (2023), EDR(2027), start of construction (~2027)



CEPC team (domestic)

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

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 Engineering Design Report (EDR) phase
- Reference detector TDR under preparation, to be completed by 2025 for the proposal of the 15th 5-year plan
- CEPC EDR site is under study
- International collaborations are mostly welcome.

Acknowledgements

Thanks go to CEPC-SppC accelerator team’s hard works, international and CIPC collaborations

Special thanks to CEPC IB, SC, IAC, IARC, IDRC and TDR review (+cost)
committee’s critical advices, suggestions and supports

Thanks for your attention