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

Introduction to CEPC Project

-Towards construction through EDR

J. Gao

IHEP

On behalf of the CEPC-SppC team

ASSCA2025
March 24, 2025, IHEP, China

Contents

Continious Efforts in Particle Physics

Research of Human Being

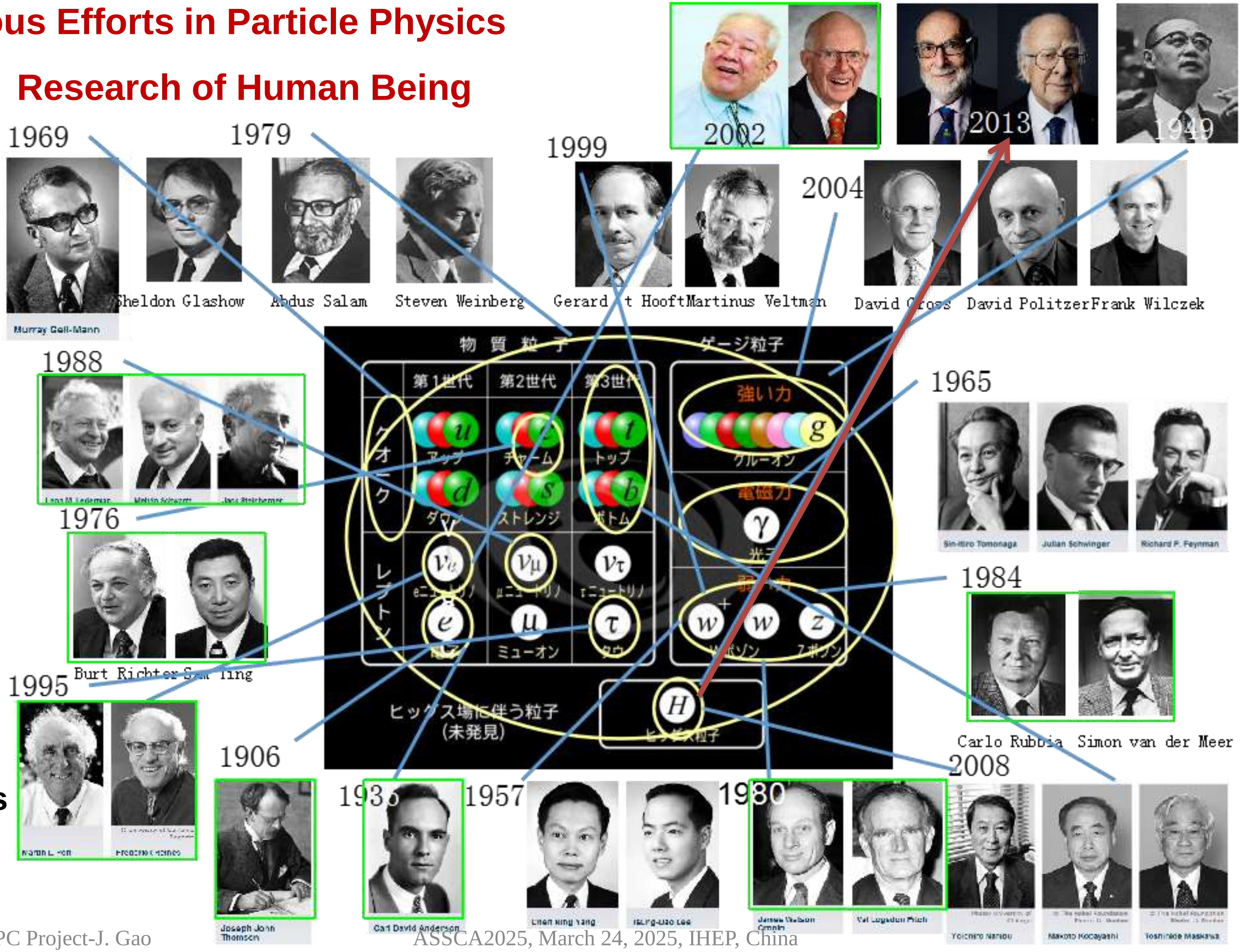
Nobel Prize distribution:

- **SM related 9 times**
- **Particle discovery 8 times**
- **Accelerator and detector related 3 times**

E.O. Lawrence (1932)

S. Van der Meer (1984)

G. Charpak(1992)



Higgs Boson was discovered on July 4, 2012 at LHC of CERN

Particle accelerators played a key role in particle discoveries and precise measurements

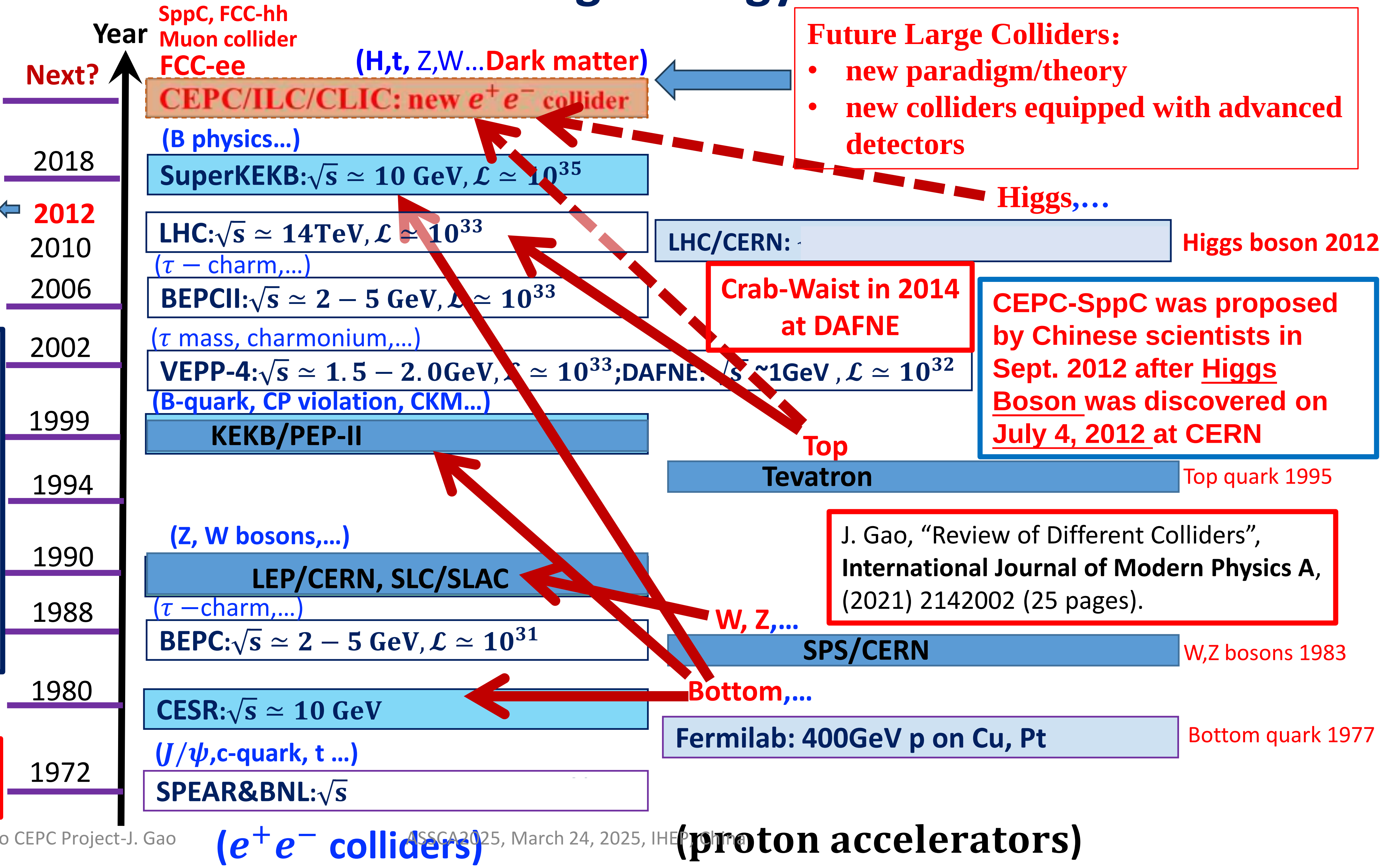
What will be the NEXT discovery? DM? New theory? New particles?

A Brief Historical Recall: High Energy Colliders and Factories

The era of Higgs boson started from 2012

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…

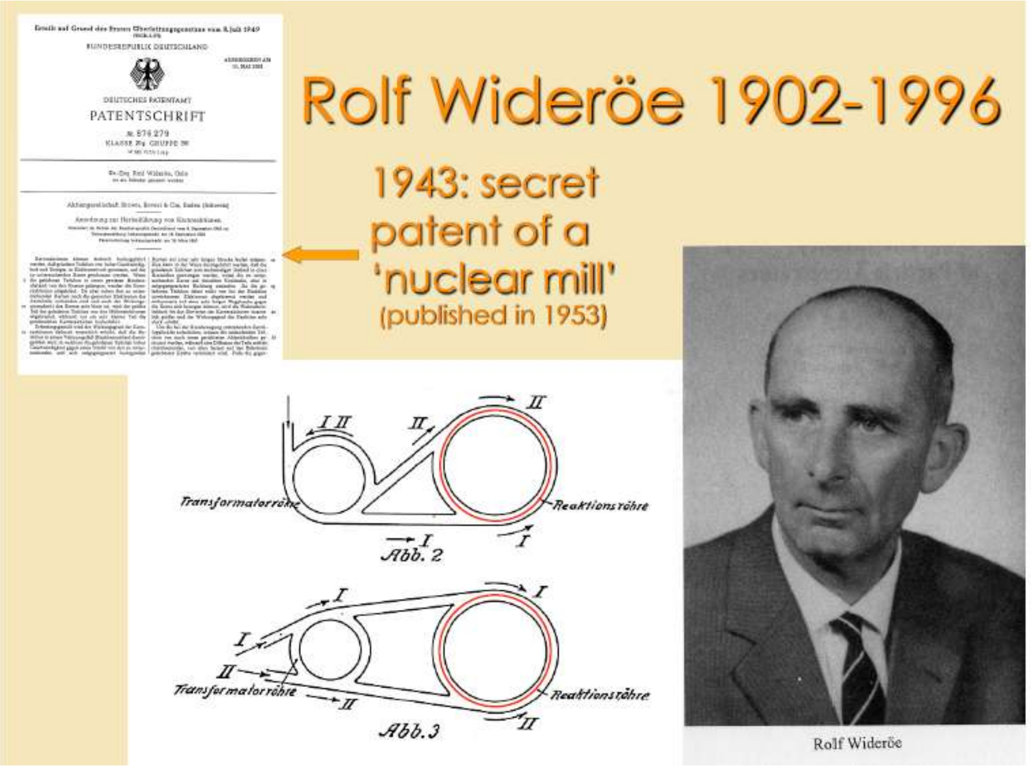


J. Haissinski, “A historical account of the first electron positron circular collider-Ada”

IHEP Seminar, Oct. 9, 2018 invited by Prof. Jie Gao

Historical Review of Storage Ring Collider

1rst Proposal (1943)



Rolf Videröe

was a Norwegian engineer who had given some thoughts to the betatron principle while completing his training in Karlsruhe (1923).

About his circular collider scheme, he wrote:

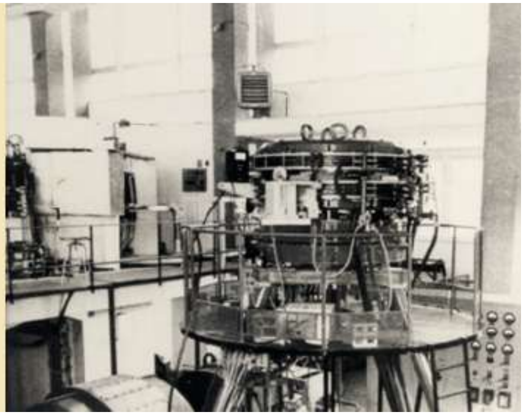
“…and this is when (1943) I had my idea. If it were possible to store the particles in rings for longer periods, and if these 'stored' particles were made to run in opposite directions, the result would be one opportunity for collision at each revolution…”

Historical Review-Ada

The AdA collaboration in Orsay

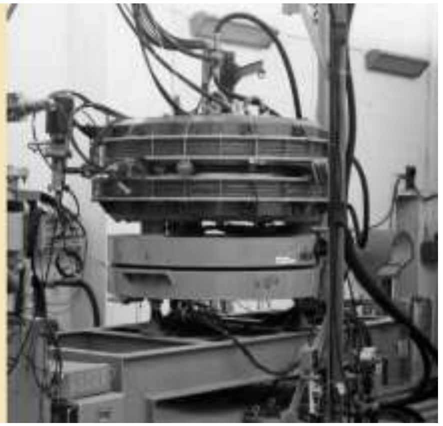
C. Bernardini, G. Corazza, G. Di Giugno, J. Haïssinski, P. Marin, R. Querzoli, B. Touschek

AdA in the electron synchrotron hall in the Frascati Laboratory (1961-62)



1962

AdA at LAL



AdA: a short story

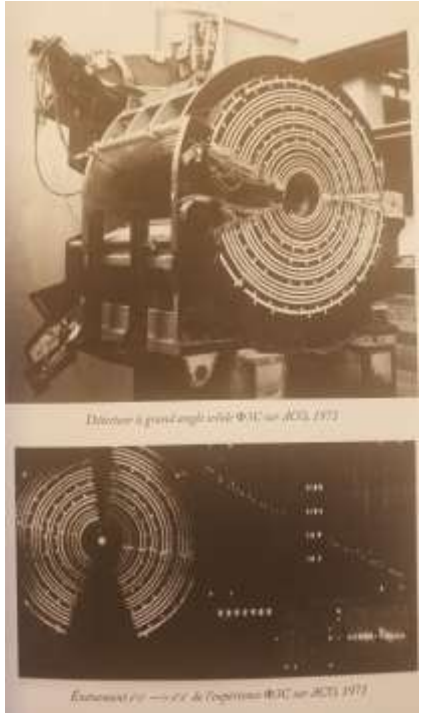
- March 1960: Decision to study the possibility of a colliding beam experiment at Frascati.
- May 1961: First electrons stored in AdA.
- July 1962 – AdA is brought to the *Laboratoire de l'Accélérateur Linéaire* at Orsay.
- Spring 1963: Discovery of the Touschek effect.
- Fall 1963 - Spring 1964: First evidence ever for collisions between counter-rotating stored particles.

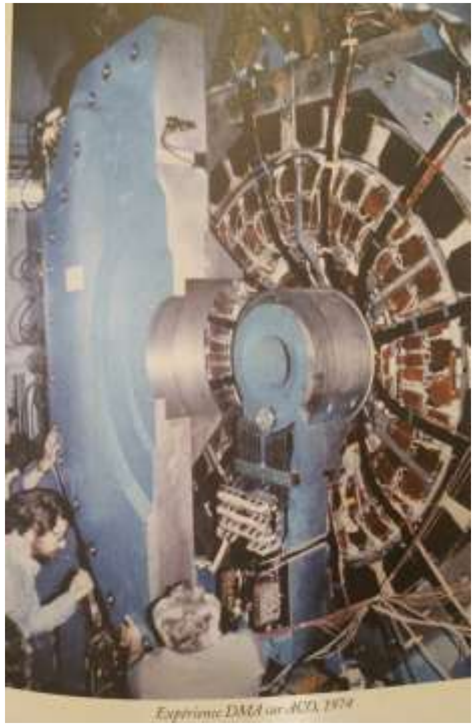
Main parameters of AdA

Parameter	Typical operation value	Units
Energy per beam	200	MeV
Circumference	4	m
Luminosity	$\sim 10^{25}$	$cm^{-2}\,s^{-1}$
Beam current, per beam	0.5	mA
Injector (linac) energy	500	MeV
Max field on the orbit	1.45	T
Field index (dB/B)/(dr/R)	0.54	
Vacuum pressure	1	nTorr
RF peak voltage	5.5	kV

The Orsay linear accelerator wave guide

Historical Review-ACO (1962-1975)





J. Le Duff

The first beam-beam tune shift limitation found in the world

The first diople magnet detector and antisolenoid

The first using sextupoles to correct chromaticity

The first observation experimentally electron and positron polarisation

The first observation of bunch lengthening

....

P. Marin

ACO as a museum in LAL, Orsay

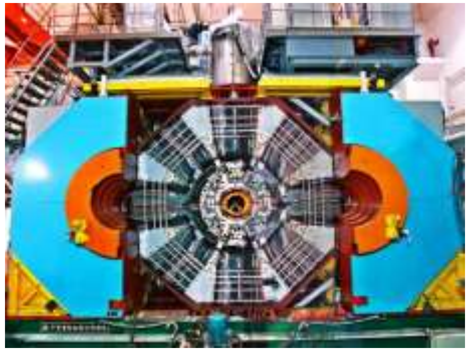
The book of P. Marin was published with the help of ACO Association after P. Marin passed away in 2003

From BEPC, BEPCII, BEPCII-U to CEPC

BEPC, the first collider in China, was completed in 1988 with luminosity $1\times10^{31}cm^{-2}s^{-1}$ @1.89GeV
BEPC II was completed in 2009
Luminosity reached on April 5, 2016: $10\times10^{32}cm^{-2}s^{-1}$ @1.89GeV

After BEPCII what is the next high energy collider?

Thanks to the discovery of Higgs at LHC@CERN in July 4, 2012, the answer is clear, CEPC!



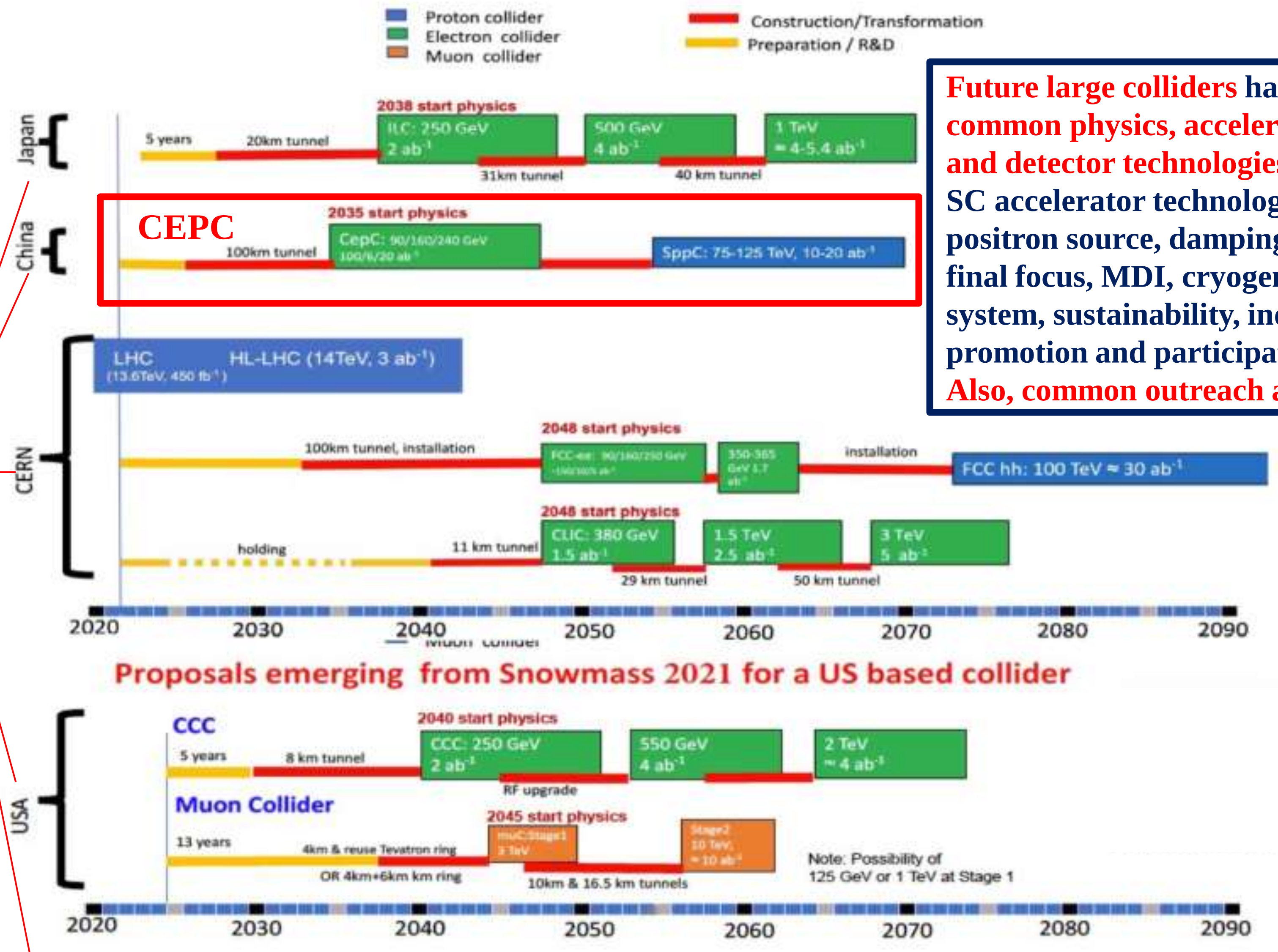
National Scientific and Technology Progress First Prize
for 2016 has been awarded to Prof. J. L. Xie on Jan 9, 2017

IPAC (Asia) Prize name with J.L. Xie

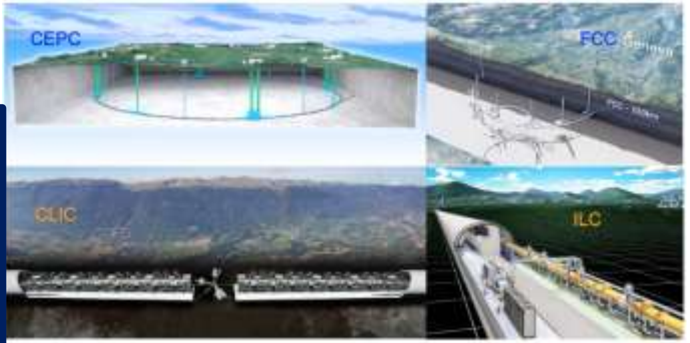
Prof. J. L. Xie

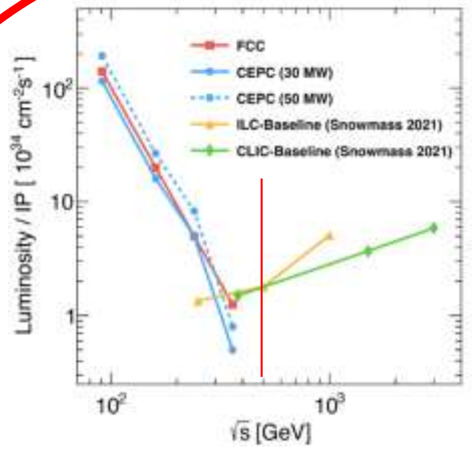
Worldwide High Energy Physics Goal Timelines and Common Efforts

The common physics goals in complementary



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



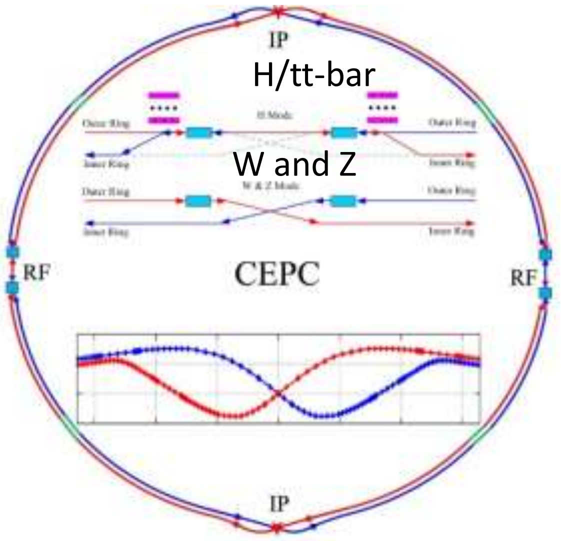


	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	5	115	16	0.5
CEPC (TDR, 50 MW)	8.3	192	26.7	0.8
FCC-ee (FS MTR, 50 MW)	≥ 5.0	140	20	1.25

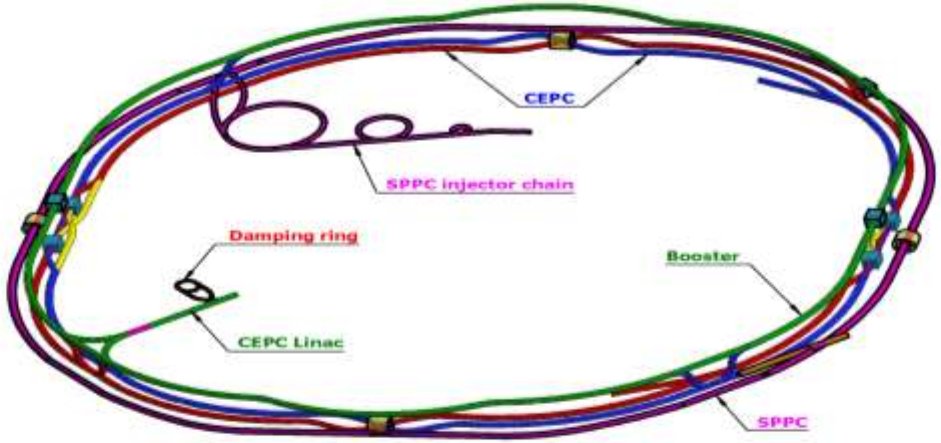
HALHF was proposed in 2023 as a Higgs factory based on plasma accelerator technology

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

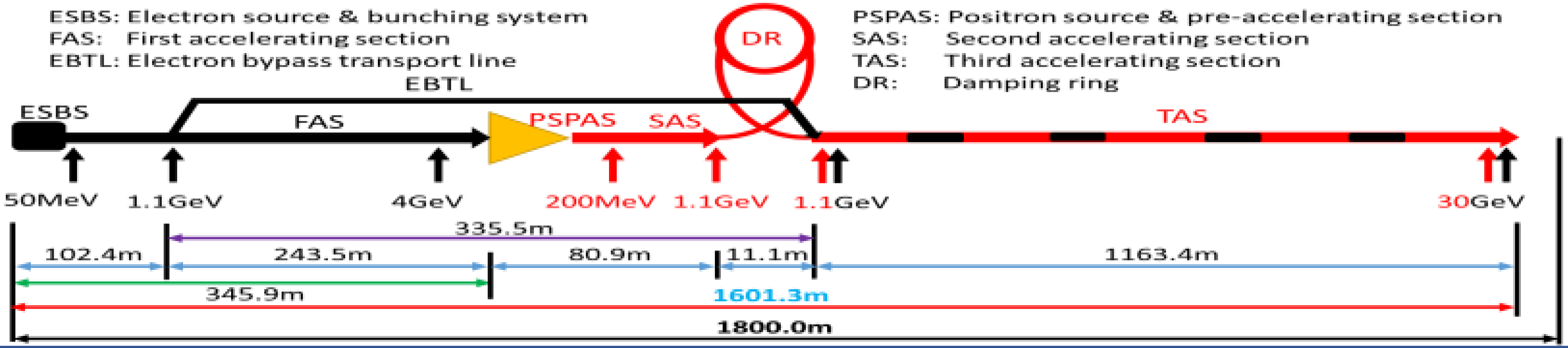


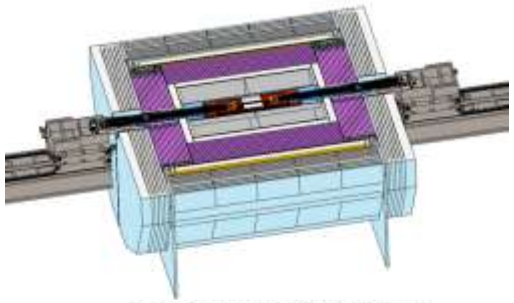
CEPC collider ring (100km)



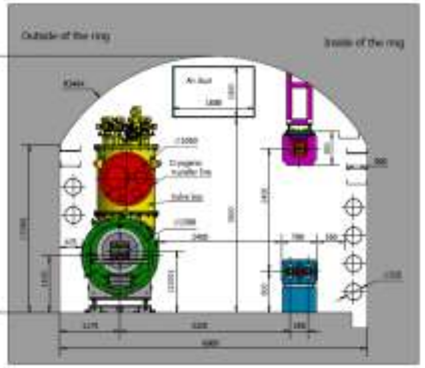
CEPC booster ring (100km)

CEPC TDR S+C-band 30GeV linac injector

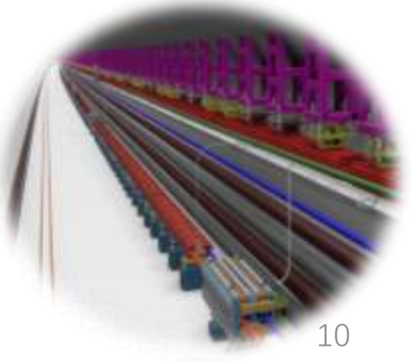




TUNNEL CROSS SECTION OF THE ARC AREA



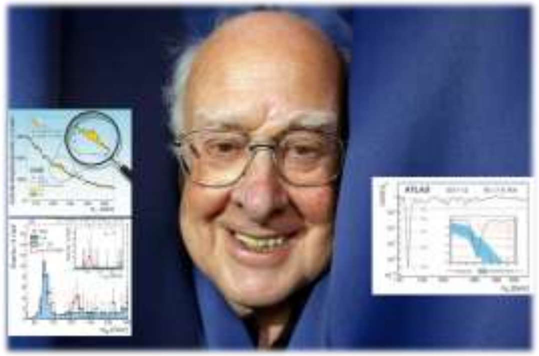
CEPC/SppC in the same tunnel



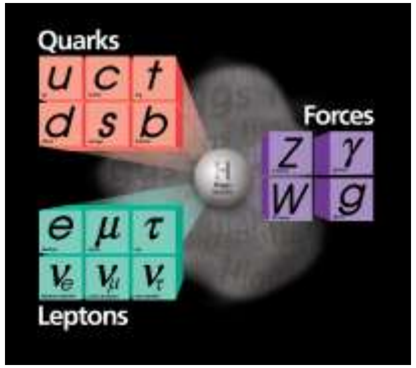
The CEPC-SppC Kick-off Meeting in Beijing

- The Chinese CEPC+ppPC Study Group kick-off meeting took place Sept. 13-14,2013
- Participation by over 120 physicists from 19 domestic institutes
- Domestic accelerator, theoretical and experimental physicists were organized
- International collaboration is open

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



CEPC was firstly reported in the ICFA beam Dynamics Workshop, Accelerators for a Higgs Factory: Linear vs Circular Nov. 14-16, 2021, Fermi National Lab. USA



CEPC Physics Goals, Operation Plan and Goals in TDR/EDR

Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	5
30 MW	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.65
	Event yields [2 IPs]	2.6×10^{6}	2.5×10^{12}	1.3×10^{8}	4×10^{5}
50 MW	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**8.3**	**192**	**26.7**	**0.8**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	21.6	100	6.9	1
	Event yields [2 IPs]	4.3×10^{6}	4.1×10^{12}	2.1×10^{8}	6×10^{5}

* 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 physics white papers:

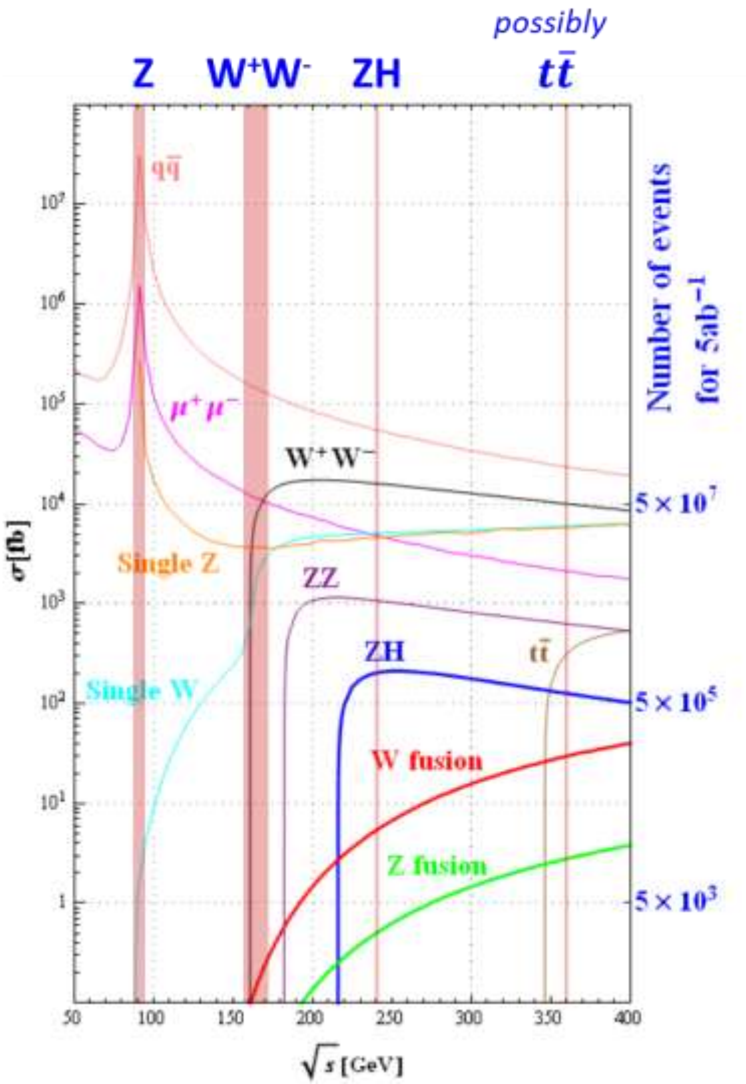
1: Higgs physics, Chinese Physics C Vol. 43, No. 4 (2019) 043002 https://arxiv.org/pdf/1810.09037

2: Flavor physics, https://arxiv.org/pdf/2412.19743 (2024)

3: Electroweak physics, to be published

4: New physics, to be published

5: QCD, to be published



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

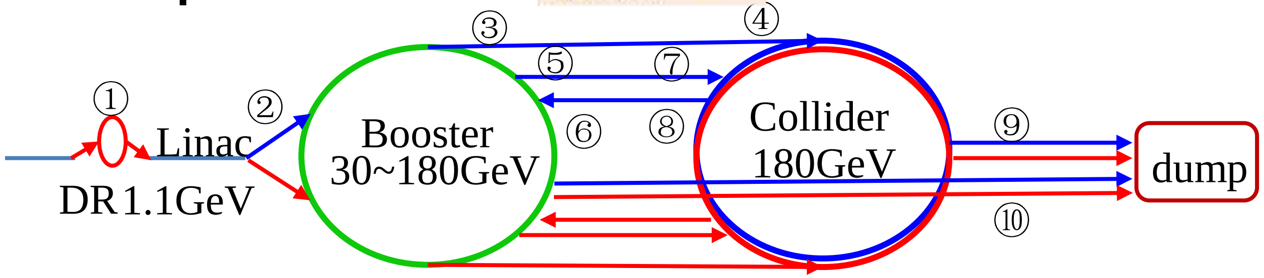
	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	**100.0**			
SR power per beam (MW)	**30**			
Energy (GeV)	**120**	**45.5**	**80**	**180**
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP σ_x/σ_y (um/nm)	14/36	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**
Luminosity per IP (10^{34} cm^{-2} s^{-1}) From J. Gao's formula below	**5**	**115**	**12**	**0.59**

Running scenarios: Higgs 10 years, Z 2 years, W 1 year, ttbar 5 years

Factory of
4 Million Higgs
4 Trillion Z bosons
200 Million W⁺W⁻ pairs
600K $t\bar{t}$ pairs

$$L_{max}\,[cm^{-2}\ s^{-1}] = 0.158\times10^{34}\,\frac{(1+r)}{\beta_y[mm]}\sqrt{\frac{R[m]}{C_\gamma[mGeV^3]N_{IP}}}\,(P_b[MW]/E[GeV]^2)\,e^{\frac{\sqrt{\Phi_p}}{3.22}}\,(1+0.000505*\Phi_p^2)$$ (J. Gao's formula)

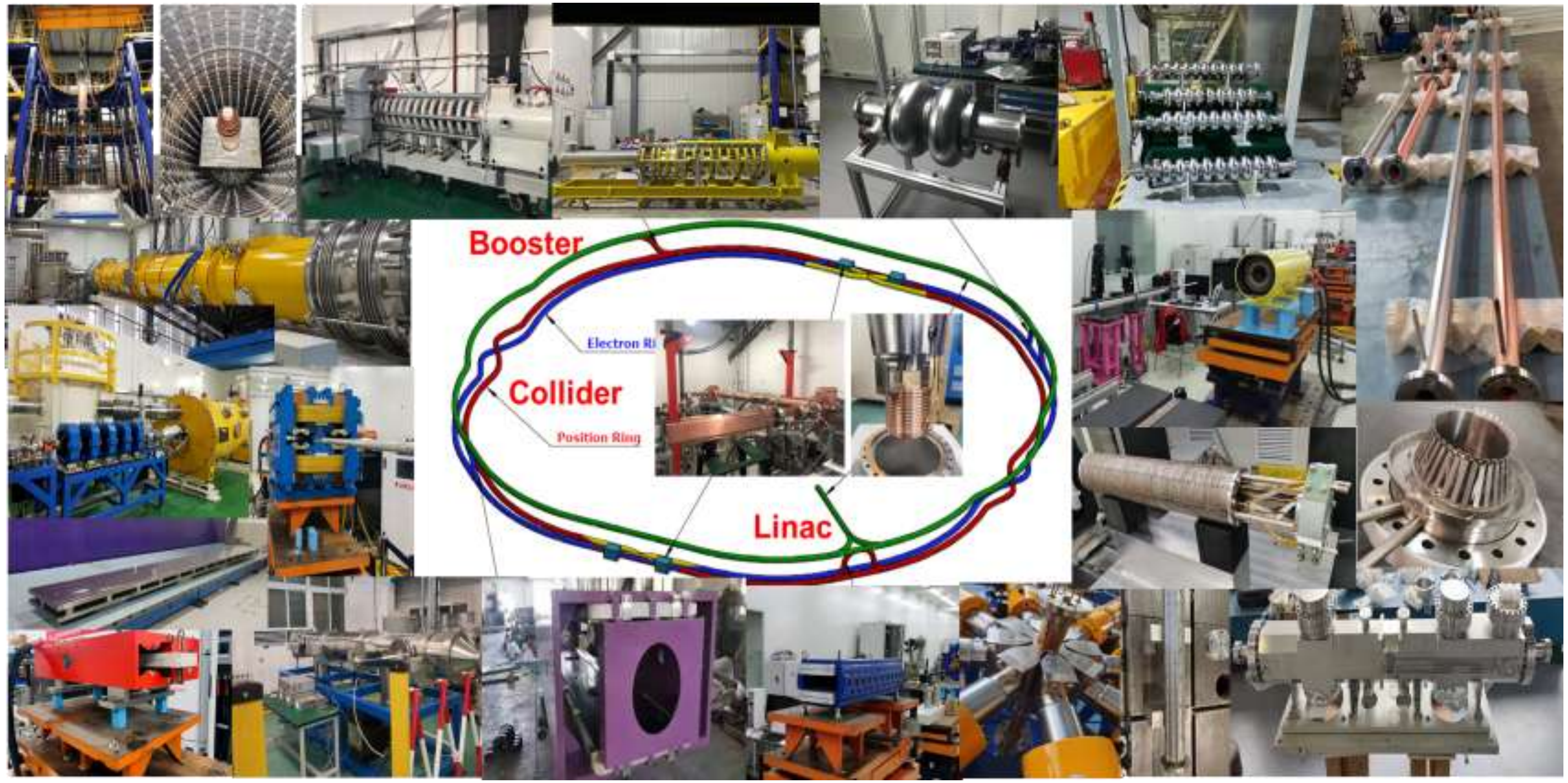
Transport lines



CEPC Technical Design Report (TDR) includes:
1) CEPC Accelerator TDR released on Dec. 25, 2023
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 ✓



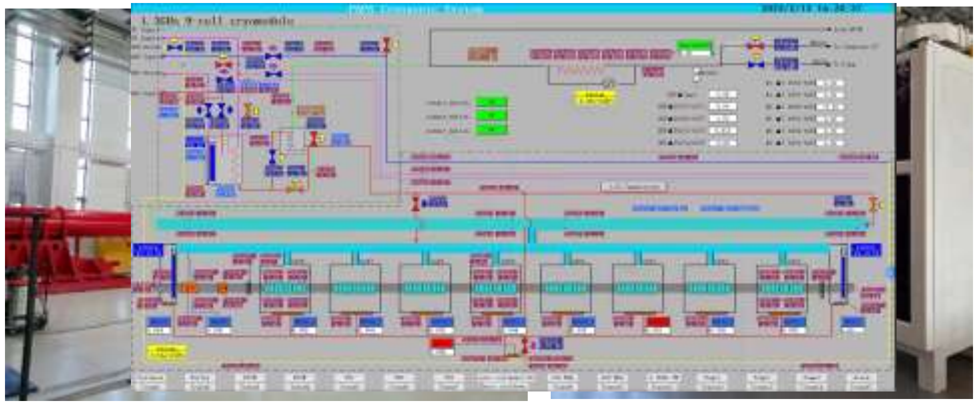
	Accelerator	Fraction
Specification Met	Magnets	27.3%
Specification Met	Vacuum	18.3%
Prototype Manufactured	RF power source	9.1%
Specification Met	Mechanics	7.6%
Specification Met	Magnet power supplies	7.0%
Specification Met	SC RF	7.1%
Specification Met	Cryogenics	6.5%
Specification Met	Linac and sources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

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

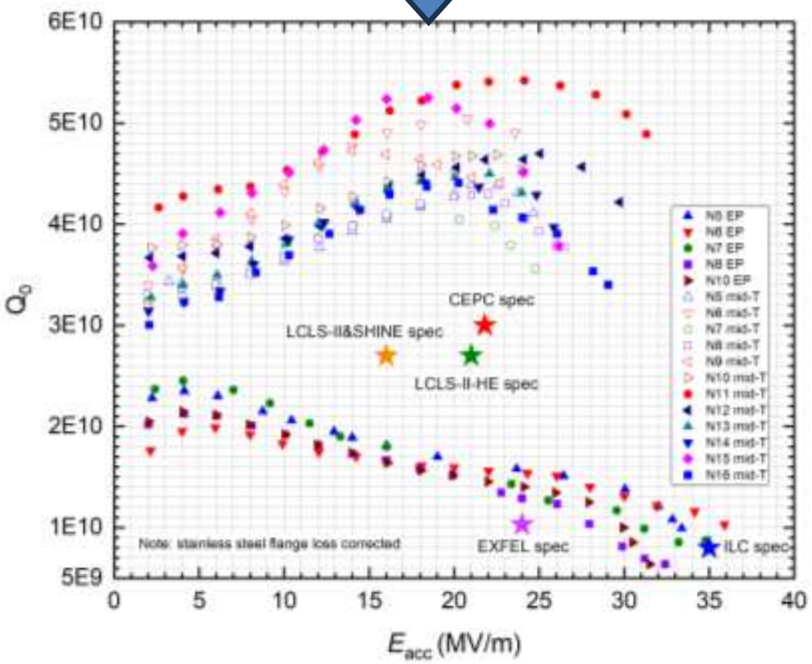
CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

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}			



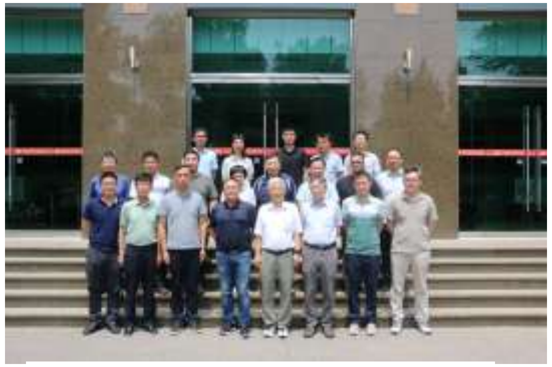
IHEP 1.3GHz 9cell cavity high field high Q Achievement with Mid-T baking technology



CEPC Accelerator 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

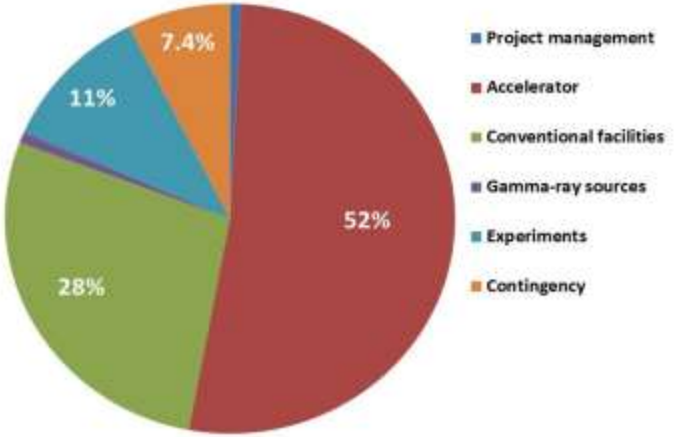


Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP

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%



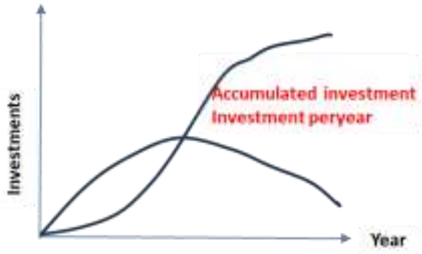
Distribution of CEPC Project total TDR cost of **36.4B RMB (~5.2USD)**

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

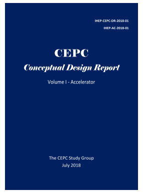
CEPC Milestones, Timeline and Human Resources

Year	2012	2013	2015	2017	2018	2023	2025	2027	2030	2035
Human resources			~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



2025

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

36.4B RMB
Total construction

CEPC detector reference design will be completed by June 2025

CEPC EDR site study and civil engineering design

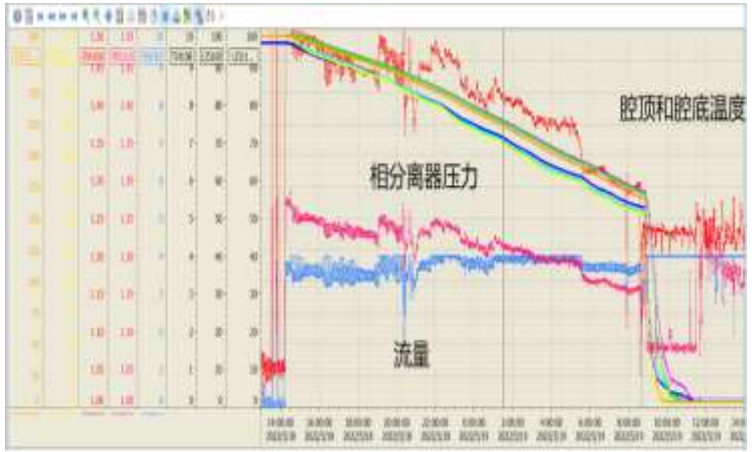
2012.9 CEPC proposed
2013.9
2015.3 Pre-CDR
2017.4 Progress report
2018.11 CDR
2023.12 TDR
2024 ~ 2027 EDR
start of construction
~2035 Completion

CEPC EDR Milestones before Construction

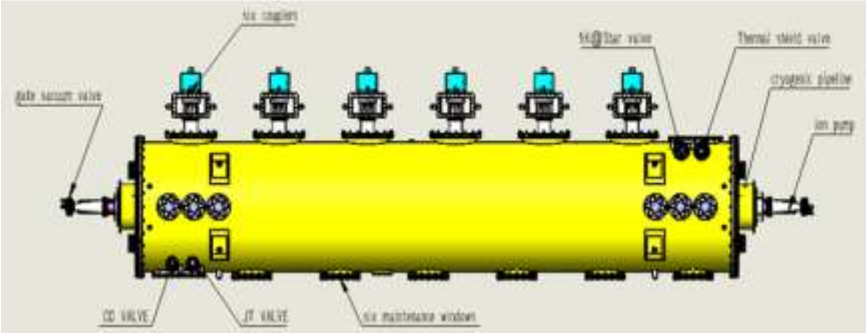
Year: 2024 2025 2026 EDR period 2027 2028

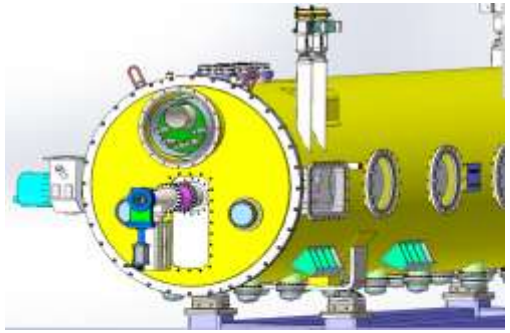
- **2025:** Start EDR site geological studies by civil engineering company; EDR items started to be executed in an industrial way, such as magnet and vacuum NEG coating automatic lines, 650MHz full size cryomodule, C-band 80 MW klystron, C-band accelerator test band, CEPC 60m mockup tunnel, MDI SC CCT type quadrupole magnet, MDI design with SC quadrupole cryomodule, booster and collider ring magnets, civil engineering design, etc.
- Complete Detector TDR ref Design report; CEPC proposal to government,
- **2026:** EDR site geological study completed with good understanding of EDR site for starting site dependent civil engineering design; Complete following key EDR items: magnet and vacuum NEG coating automatic lines, 650MHz full size cryomodule, C-band 80 MW klystron, CEPC 60m mockup tunnel, etc. ; Continue C-band accelerator test band, MDI SC CCT type quadrupole magnet, MDI design with SC quadrupole cryomodule, booster and collider ring magnets, civil engineering design, etc. Obtaining government approval.
- **2027:** EDR site dependent civil engineering design completed; Complete EDR report with following key EDR items completed: magnet and vacuum NEG coating automatic lines in operation, 650MHz full size cryomodule, C-band 80 MW klystron, CEPC 60m mockup tunnel, C-band accelerator test band, MDI SC CCT type quadrupole magnet, MDI design with SC quadrupole cryomodule, booster and collider ring magnets, etc., ready for construction with government approval.
- **2028:** Start construction

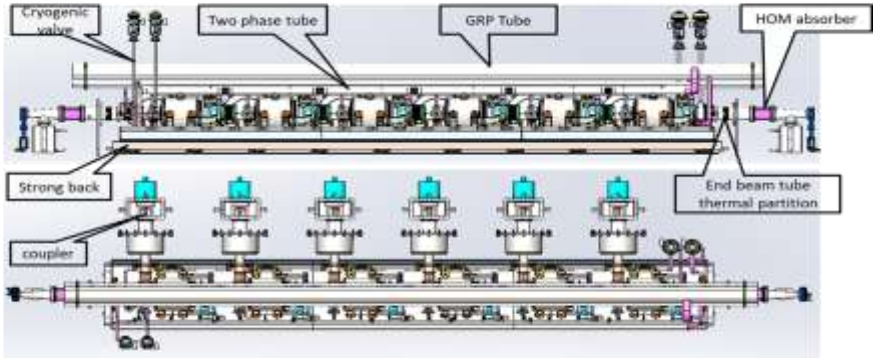
CEPC Accelerator SRF Development in EDR



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



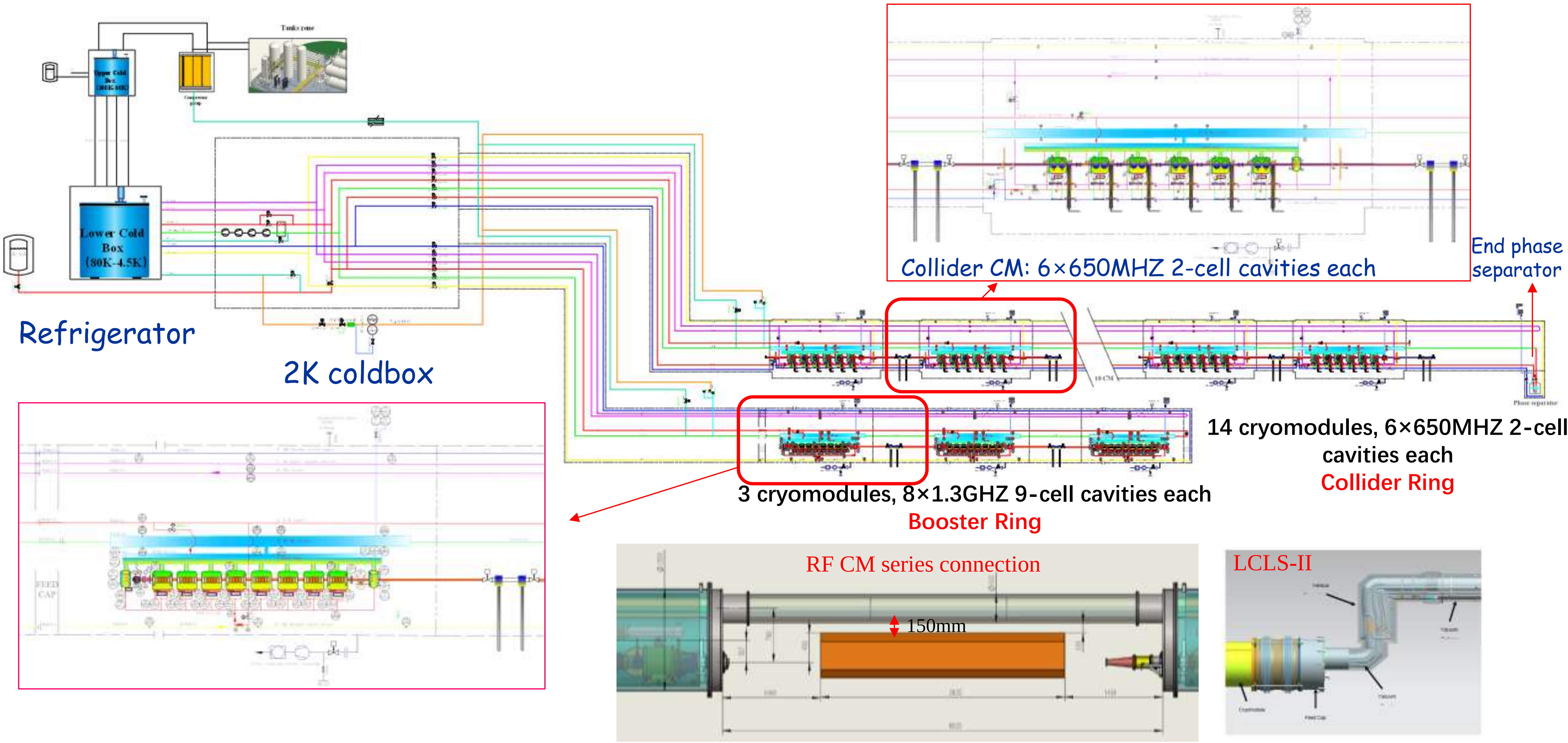




The collider Higgs mode for 30 MW SR power per beam will use 32 units of 11 m-long collider cryomodules will contain six 650 MHz 2-cell cavities, and therefore, a full size 650 MHz cryomodule will be developed in EDR

Status： construction started, to be completed in 2025

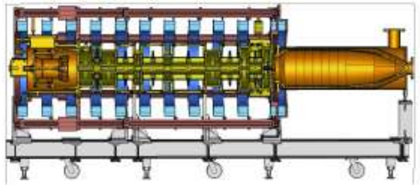
CEPC Cryogenic System Process Flow Diagram in the SRF System



CEPC Accelerator Main EDR Development: Klystrons

Klystron R&D

Klystron No. 2
Efficiency 77%
(2021)



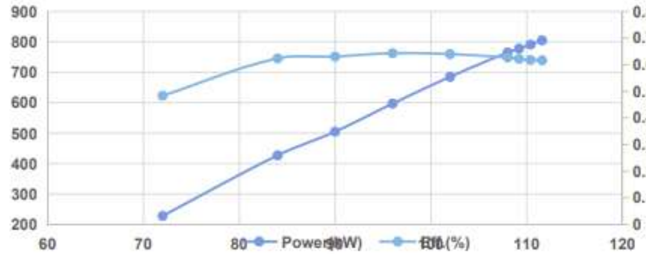
Klystron No. 1
Efficiency 65%
(2020)

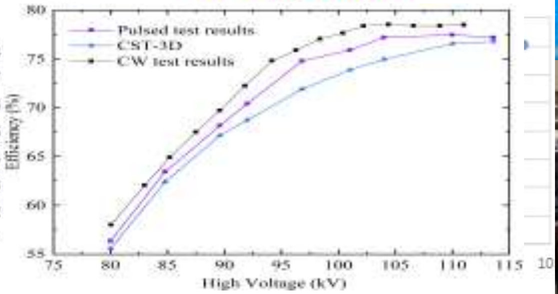
Klystron No. 3 （MBK
Efficiency 80.5%

To be completed in 2024

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

78.5%@803kW CW in 2024

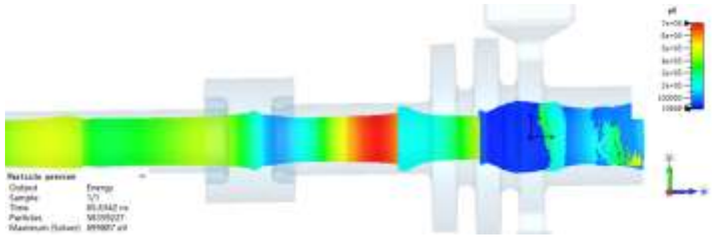


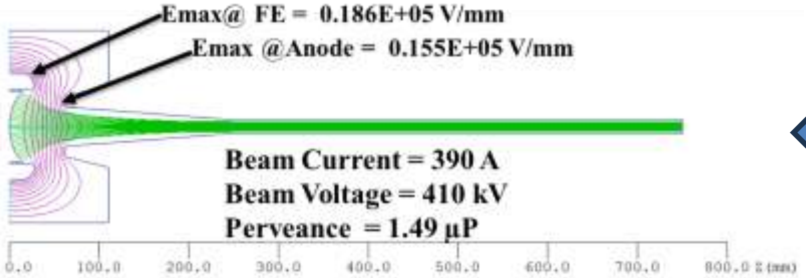


CEPC collider ring 650MHz klystron development in TDR phase

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

C band 5720MHz 80MW Klystron

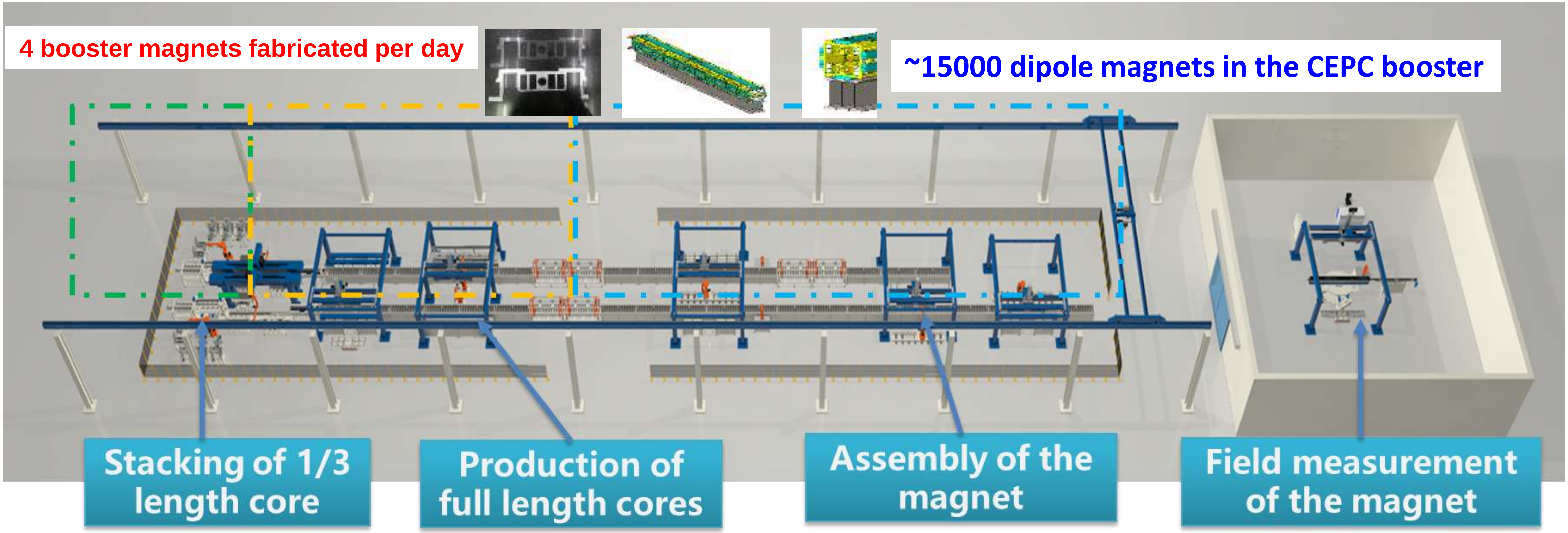


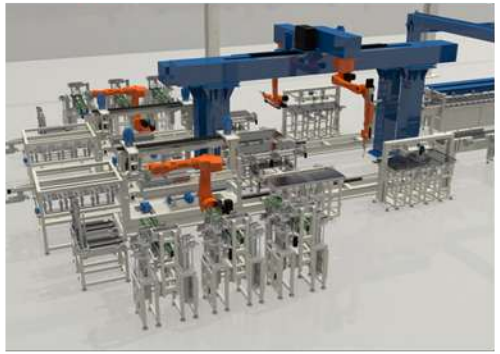


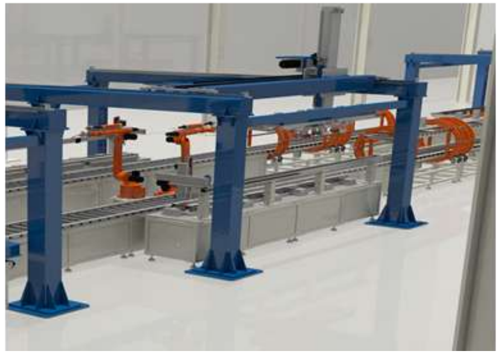
C band 5720MHz 80MW Klystron design completed

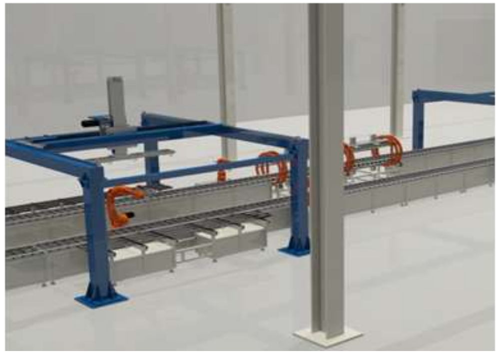
Technical assessment has been done on August 12, 2024, construction started , to be completed on 2025

CEPC Magnet Automatic Production Line in EDR



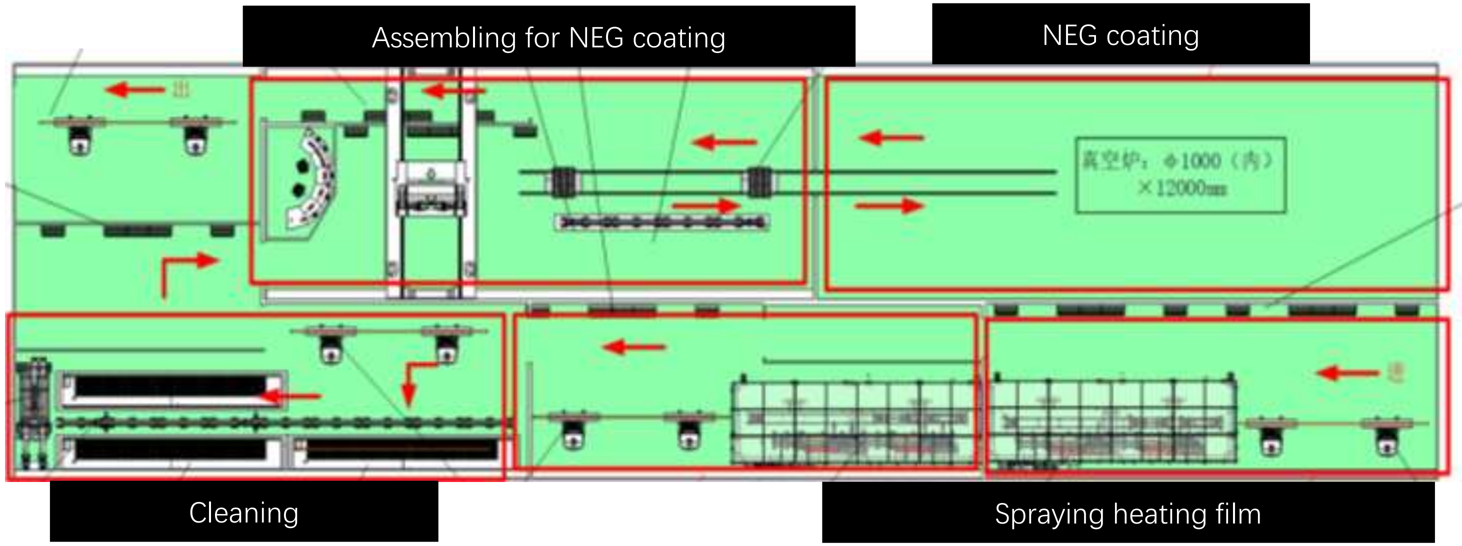




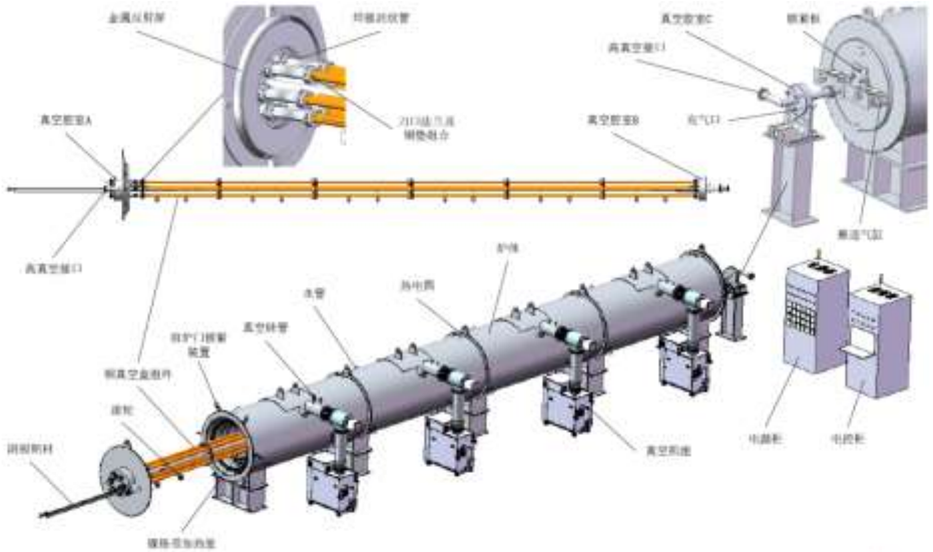


Status： construction started, to be completed in 2025

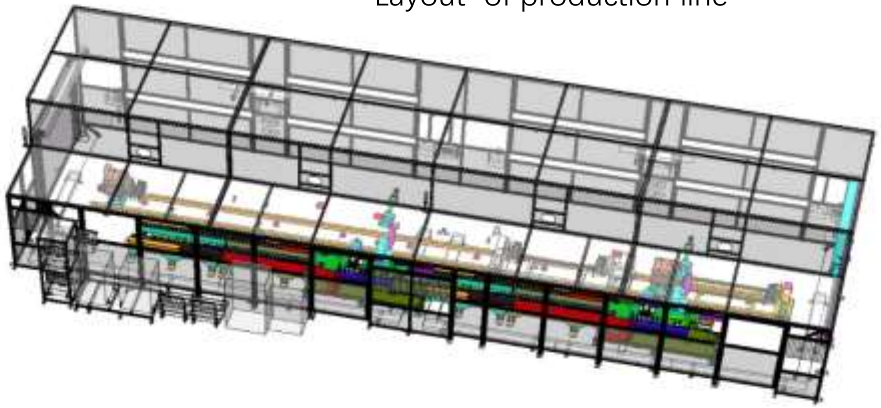
CEPC NEG Coated Vacuum Chamber (200km) Automatic Production Line in EDR



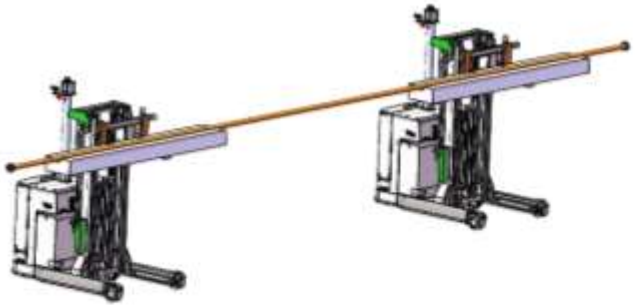
Layout of production line



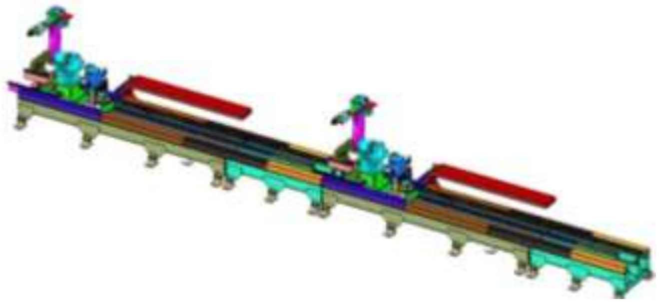
NEG coating facility by horizontal method



Production line of NEG coating, spraying



AGV(Automatic Guided Vehicle) transport

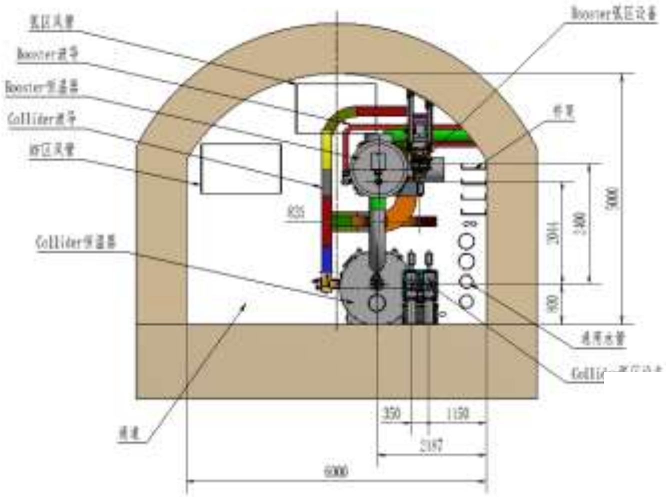


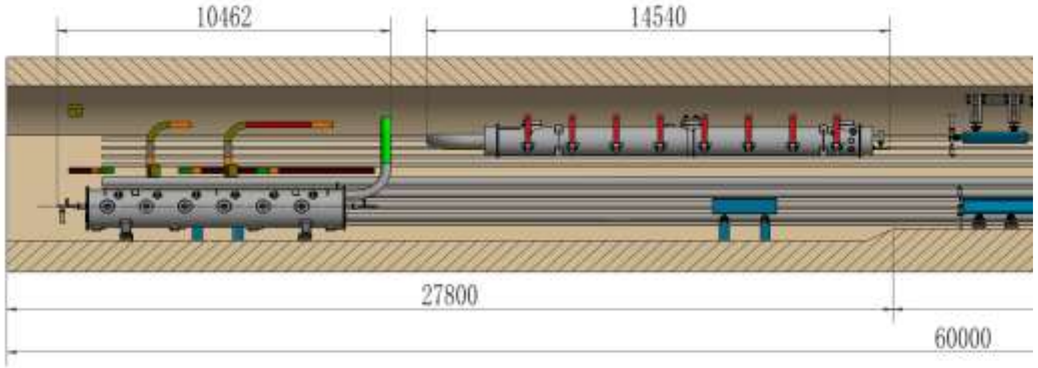
7-axis robot for assembling

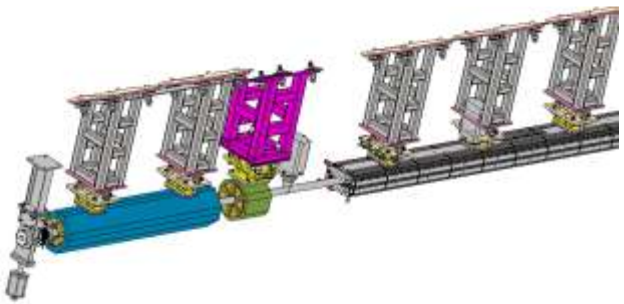
Status： construction started, to be completed in 2025

CEPC Tunnel Mockup for Installation in EDR

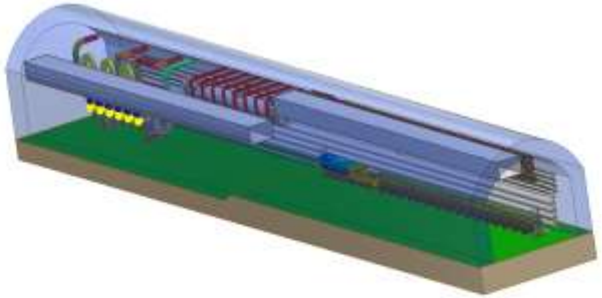
Haijing Wang

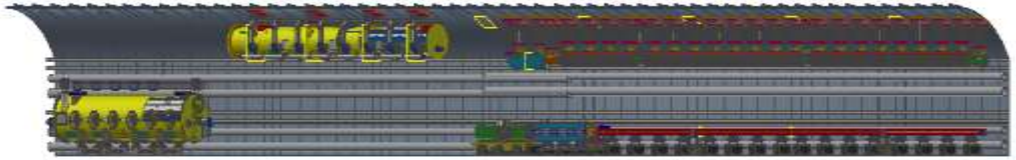


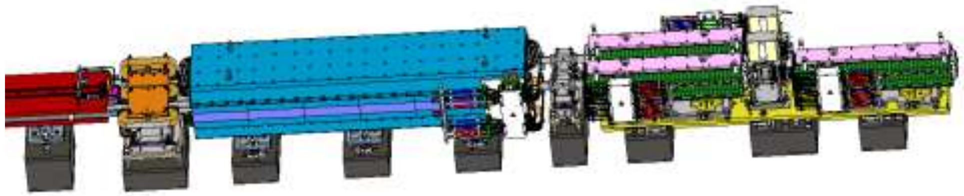


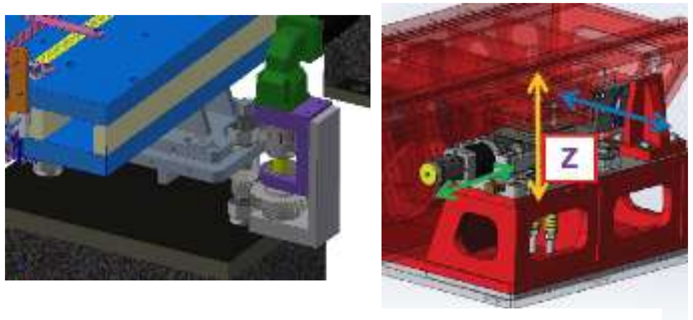


Booster magnets installation









Collider ring magnets supports

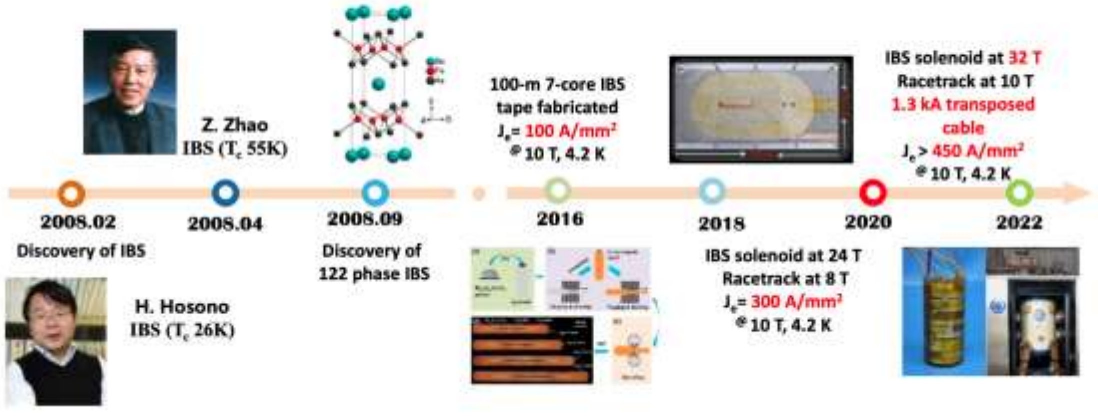
A 60 m long tunnel mockup, including parts of arc section and part of RF section

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

Plan：to be completed in 2025

Advanced Technologies Development in Progress

IBS Technology for High Field Magnets

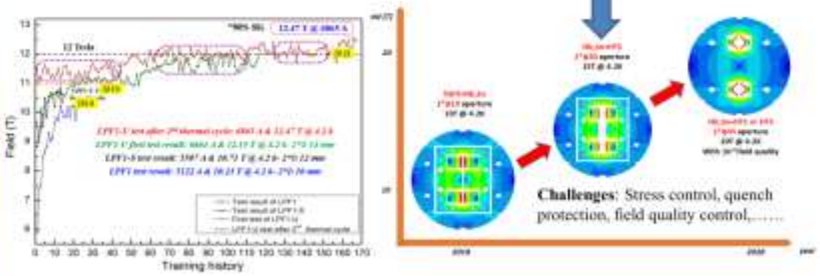


J_e of IBS expected to be similar as ReBCO in 5 years with better mechanical properties and lower cost

SppC HF Magnet Development

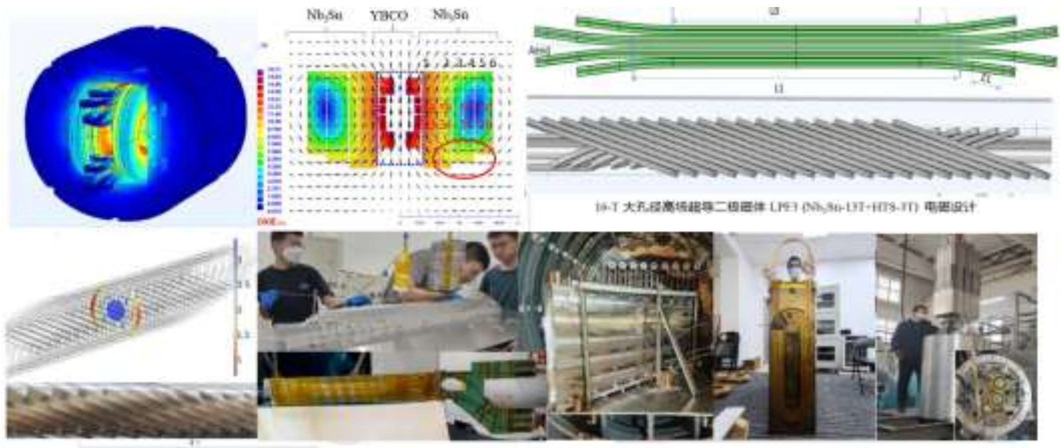
SppC 16 T Model Dipole: Nb_3Sn 12~13 T + HTS 3~4 T;
14T has been reached, more test in 2024

Picture of LPF1-U

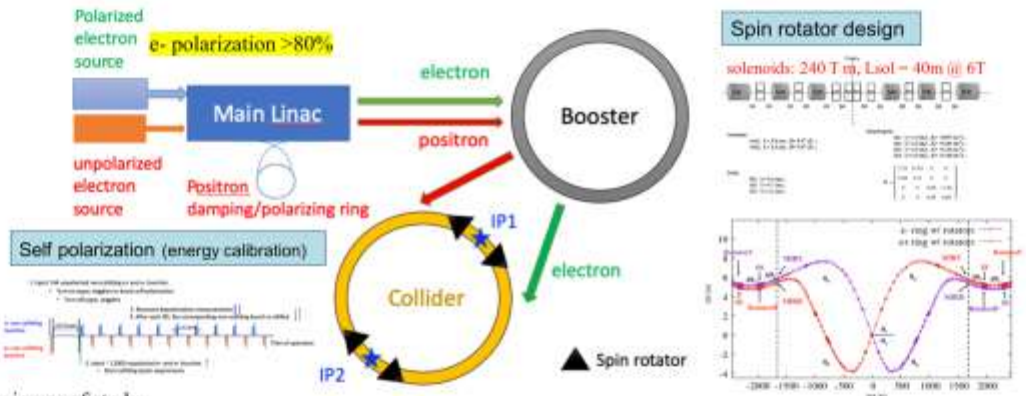


Dual aperture superconducting dipoles achieve 12T@4.2 K and 14T@4.2K entirely fabricated in China. The next step is reaching 16-20T

Highest Quench Field Reached in 2024: over 14T @4.2K



CEPC Polarized Beam Studies(alternative option)



Key issues of study:

- Energy calibration in collider ring with transverse polarization (self polarization & inj. polarization)
- Longitudinal polarization for collision
- Polarization beam injection, positron polarization and ramping in booster

Key technology development for polarized electron beam generation, measurement and manipulation have been started

IHEP Accelerator Activities

BEPC
Construction years: 1984-1988
Budget: 0.24 Billion CNY
On time, on budget

BEPCII & BESIII
Construction years: 2004-2008
Budget: 0.64 Billion CNY
On time, on budget

ADS
Construction years: 2011-2016
Budget: 0.40 Billion CNY
On time, on budget

CSNS
Construction years: 2011-2018
Budget: 1.87 Billion CNY
On time, on budget

HEPS
Construction years: 2019-2025
Budget: 4.8 Billion CNY
Completed in 2024, on schedule, on budget

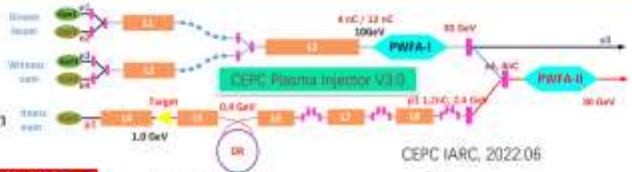
IHEP has constructed large-scale accelerator facilities since 1980's, including **circular collider**, **proton superconducting linac**, **spallation neutron source**, and a **synchrotron radiation source**. All these high-budget accelerators have been built on schedule and on budget

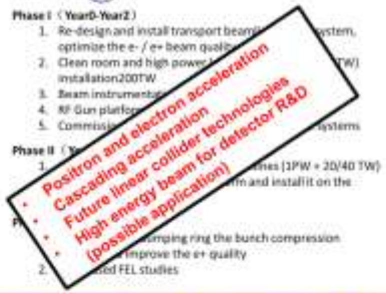
BEPCII-based PWFA Test Facility Development Status

CEPC Plasma Injector (alternative option) and TF Plan

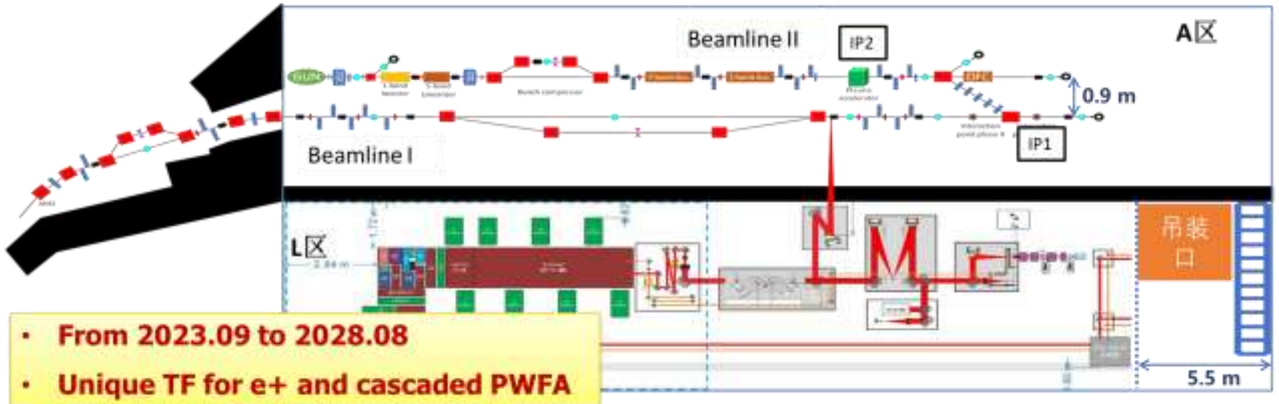
CEPC plasma injector scheme:
From 10 GeV → 30 GeV → **TR ≥ 2**

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





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

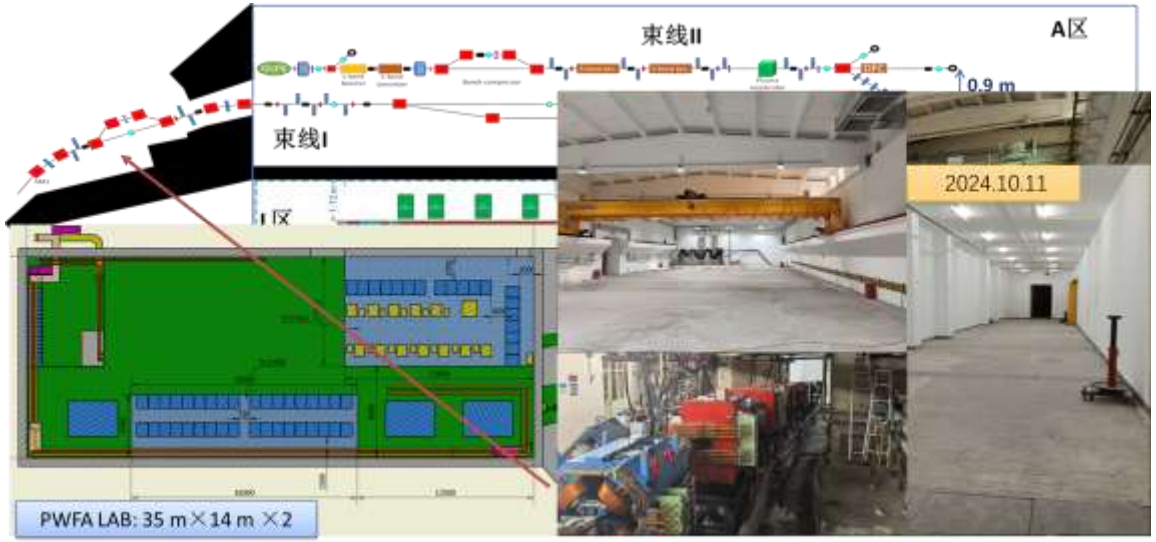


- **From 2023.09 to 2028.08**
- **Unique TF for e+ and cascaded PWFA**

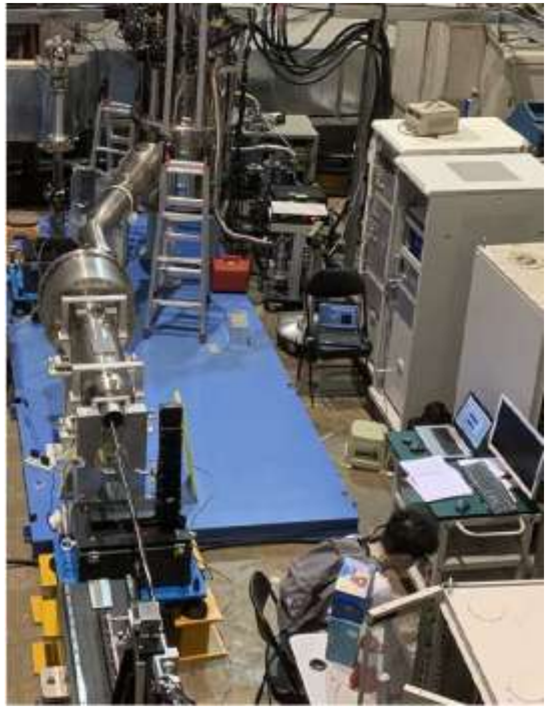
Beam quality → Beamline I

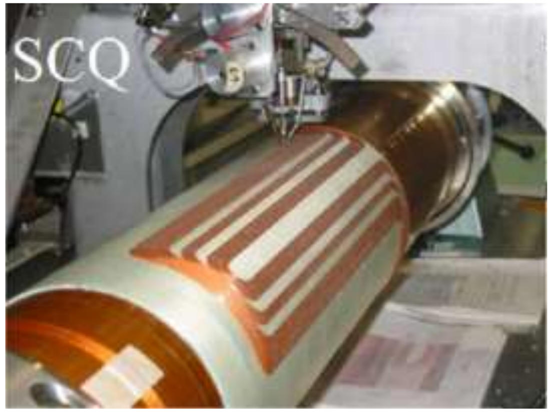
Parameters	Unit	BL-I e- (AM3)	BL-I e- (IP1)	BL-I e+ (AM3)	BL-I e+ (IP1)	BL-I e- (IP1, block)	BL-I e+ (IP1, block)
Energy	GeV	2	2	2	2	2	2
Charge	pC	2000	2000	100	100	9.4	0.2
bunch length	ps	10	1	10	1	~1	~1
Geo. emittance	mm-mrad	0.1/0.1	0.1/0.1	0.4/0.4	0.4/0.4	0.011/0.005	0.04/0.02
RMS beam size	μm	-	150/150	-	300/300	30/40	54/76

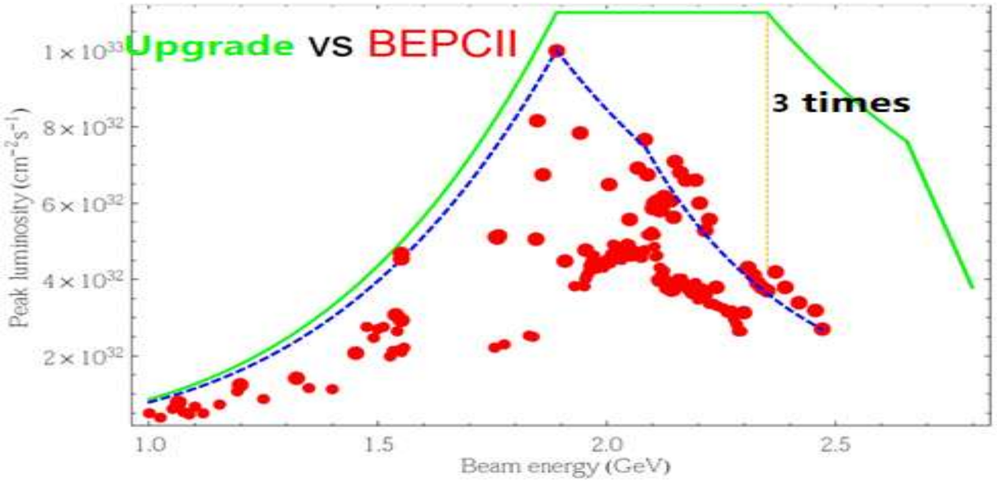
33



IHEP Actual Activities in e+e- Collider: BEPCII-U







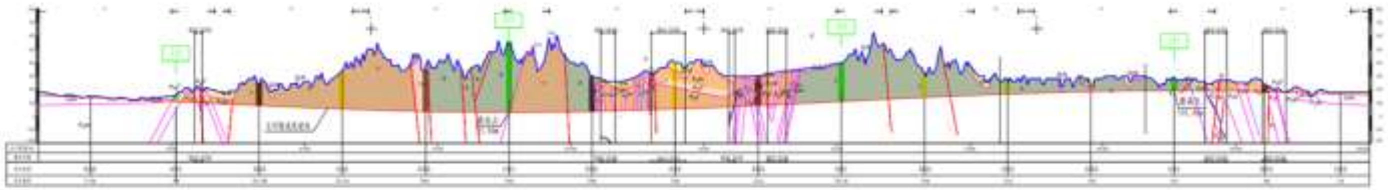
BEPCII-U will start commissioning in March 2025

CEPC Site Preparations (three candidates in TDR)

CEPC EDR Site Investigation

CEPC EDR site implementation plan

CEPC EDR site geological study has been started and the geological feasibility study will be completed in 2025

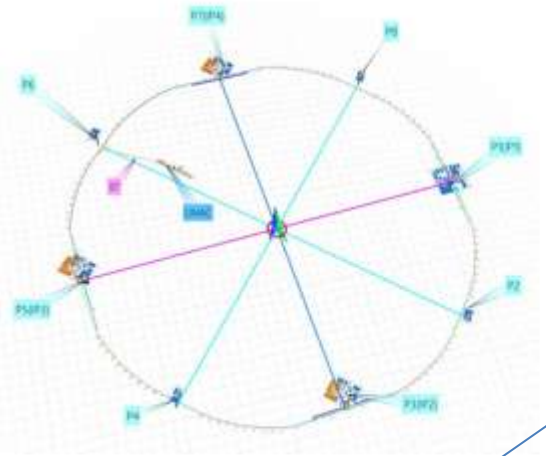


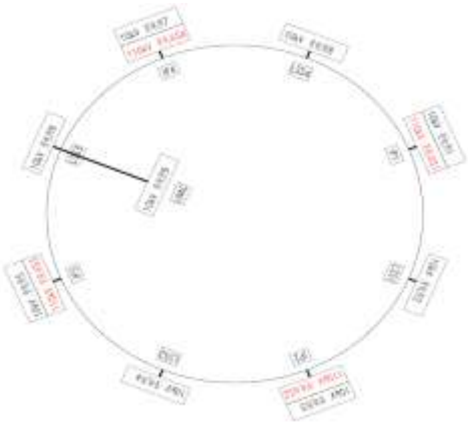
CEPC construction plan

The number of shafts is under optimization (10 shafts)

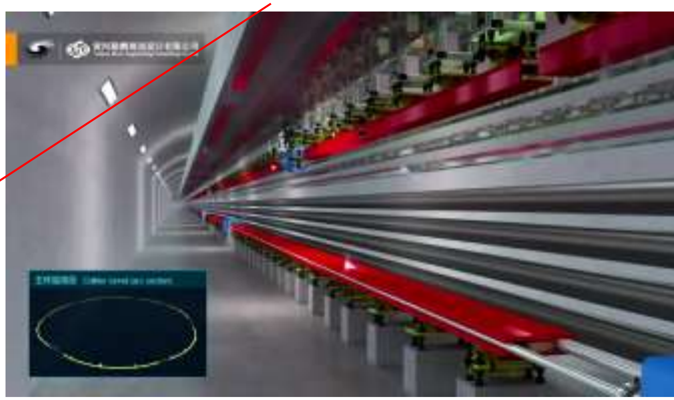
CEPC Civil Engineering and Conventional Facility in EDR

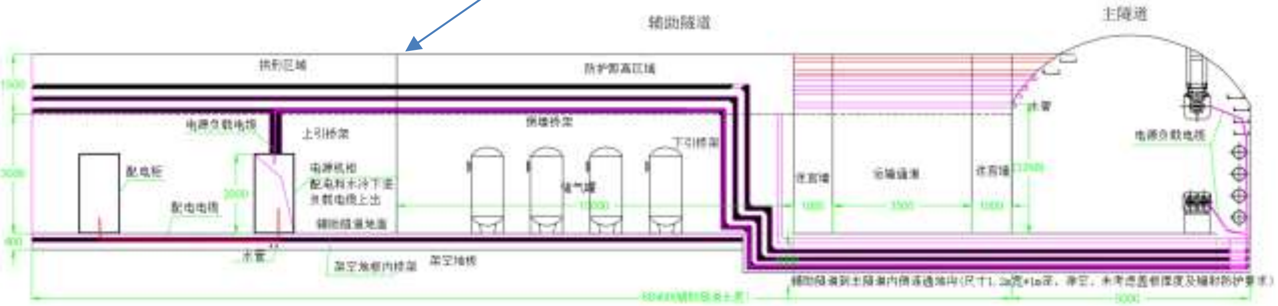
General Layout in Auxiliary Tunnel/500m along 100km

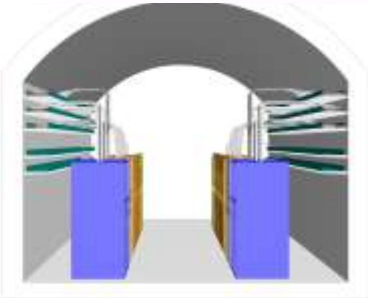


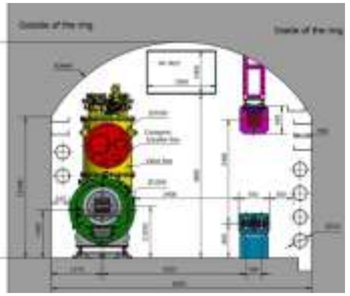


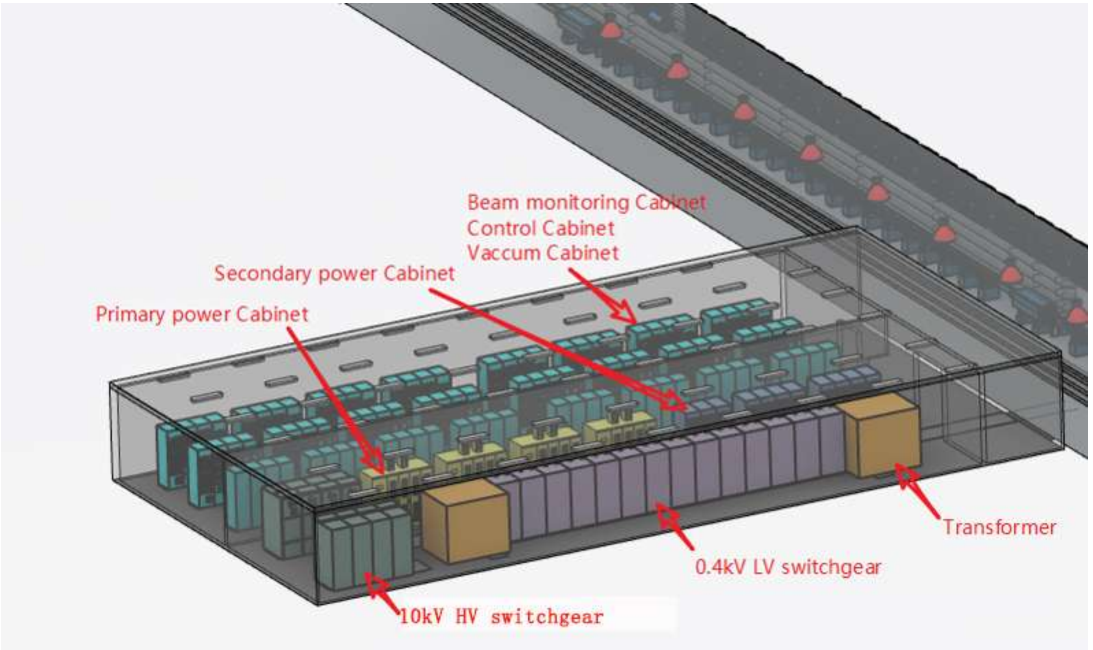
Cables installed!



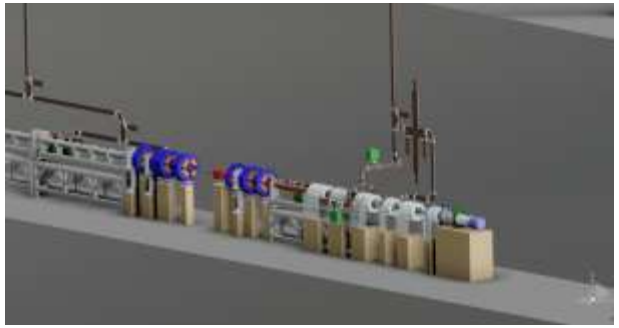




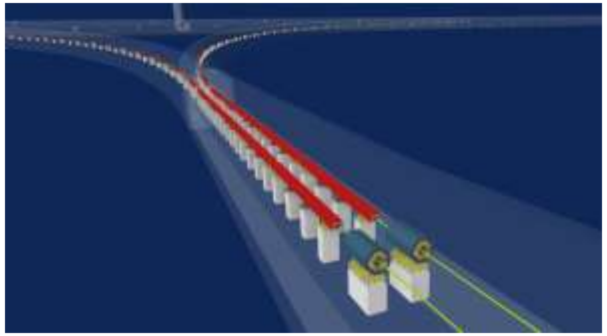




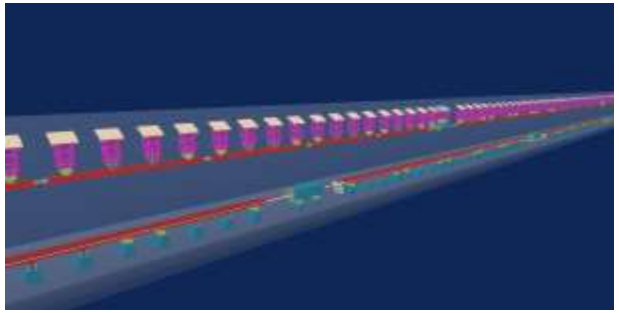
CEPC Civil Engineering



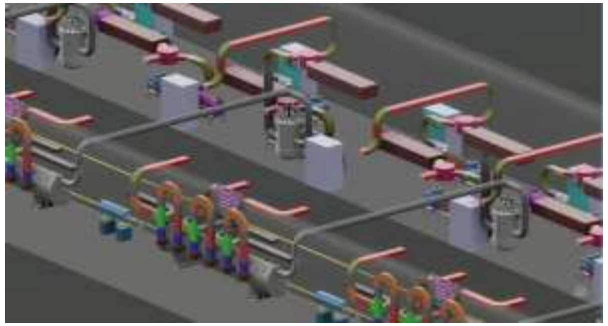
Electron source



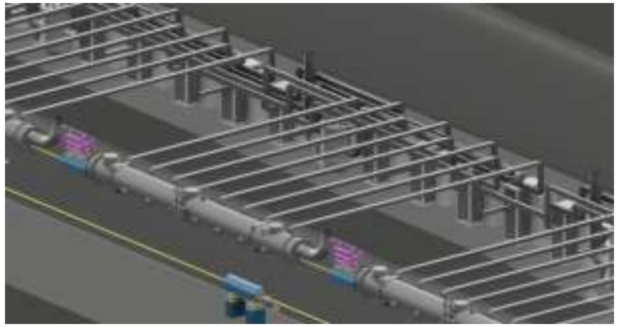
Linac to Booster



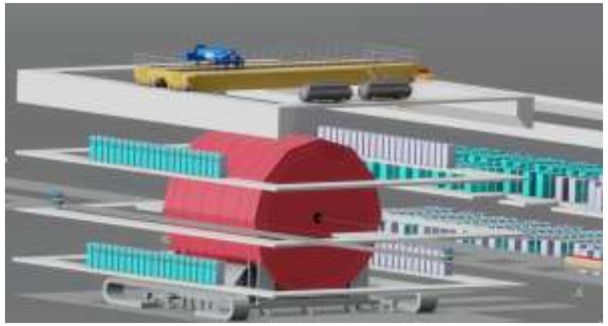
Booster and collider ring tunnel



Collider ring SCRF

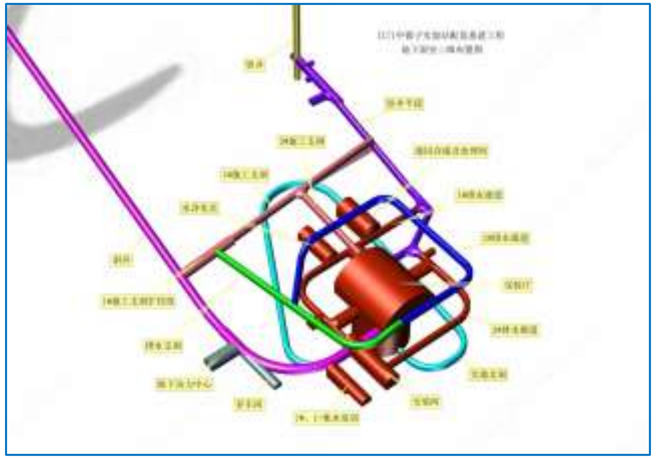


Booster SCRF



Detector hall

JUNO and CEPC



JUNO will be put into operation in 2025

JUNO detector hall:
56.25m×49m×27m

Green CEPC and Sustainability

- **SR power per beam: 30 MW** (CEPC-TDR p965)
  - Total electricity consumption: 262 MW
    - RF power (109 MW)
    - Magnet (58 MW)
    - Utilities (44 MW)
    - Cryogenics (11.6 MW)
    - Other auxiliary power combined (29 MW)

  } Need to improve these

- **SR power per beam: 50 MW** (CEPC-TDR p967)
  - Total electricity consumption: 340 MW
    - RF power (177 MW)
    - Magnet (58 MW)
    - Utilities (54 MW)
    - Cryogenics (11.1 MW)
    - Other auxiliary power combined (29 MW)

  } Need to improve these

On-going sustainability projects:

- High efficiency klystron:
  - 650 MHz
  - 80 MW C-band
- Permanent magnets for damping ring and transport lines
- High Q-factor SRF cryogenic-modules
- Recovery of waste heat (HEPS)
- Recovery and recycling of Helium
- Photovoltaic (PV) power generation systems (HEPS)

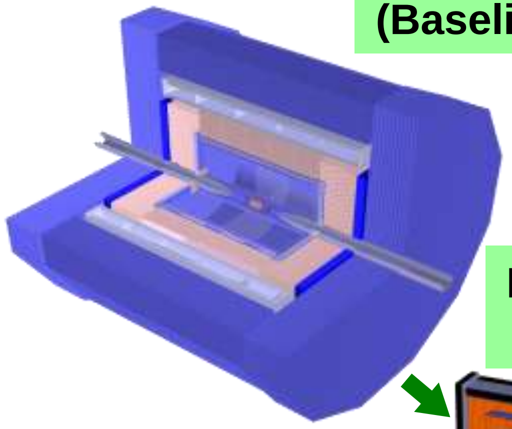
Prototypes have been developed addressing green collider technologies

Power efficiency, energy recycling, and clean energy generation are being addressed as comprehensive measures for sustainable operation

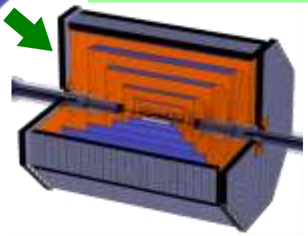
Publication: Dou Wang; Jie Gao; Yuhui Li; Jinshu Huang; Song Jin; Manqi Ruan; Mingshui Chen; Shanzhen Chen, "The carbon footprint and CO2 reduction optimization of CEPC", accepted to be published in RDMT in 2025

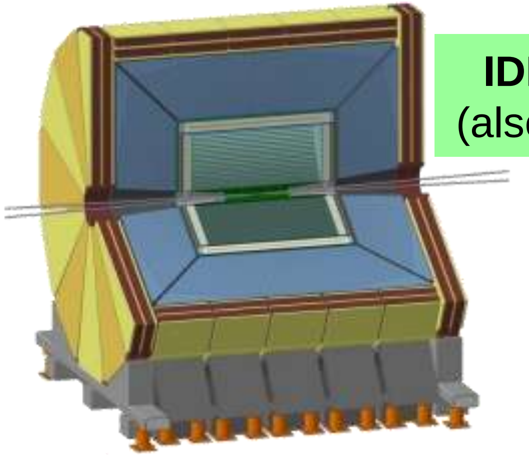
CEPC Detector Progresses

(Baseline Design)



Full Silicon Tracker

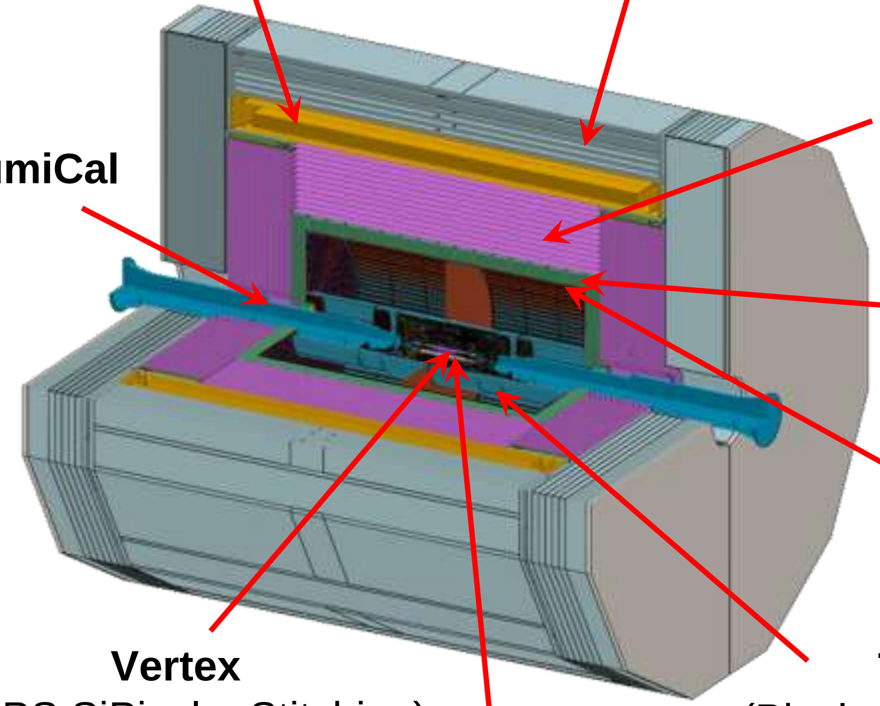




IDEA concept
(also for FCC-ee)

The 4th Concept

Ref-TDR is based on this configuration

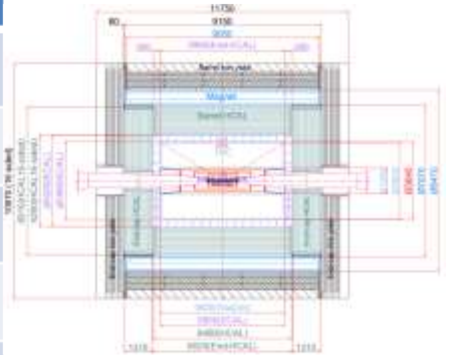


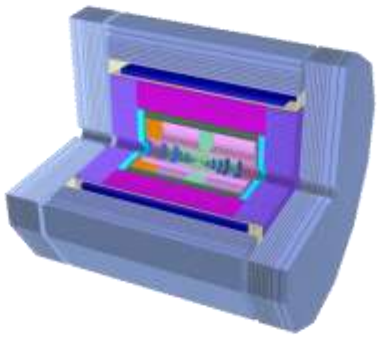
Technologies for CEPC Detector Ref-TDR

System	Technologies	
	Baseline	For comparison
Beam pipe	Φ20 mm	
LumiCal	SiTrk+Crystal	
Vertex	CMOS+Stitching	CMOS Pixel
Tracker	CMOS SiDet ITrk	
	Pixelated TPC	PID Drift Chamber
	AC-LGAD OTrk	SSD / SPD OTrk
		LGAD ToF
ECAL	4D Crystal Bar	PS+SiPM+W, GS+SiPM, etc
HCAL	GS+SiPM+Fe	PS+SiPM+Fe, etc
Magnet	LTS	HTS
Muon	PS bar+SiPM	RPC
TDAQ	Conventional	Software Trigger
BE electr.	Common	Independent

Radius

Subsystem	Supported By
Barrel Yoke	Base
Magnet	Barrel Yoke
Barrel HCAL	Barrel Yoke
Barrel ECAL	Barrel HCAL
TPC+ Barrel OTK	Barrel ECAL
ITK	TPC
Beampipe+VTX+LumiCal	ITK
Endcap Yoke	Base
Endcap HCAL	Barrel HCAL
Endcap ECAL+OTK	Barrel HCAL





- The CEPC study group started to compare different technologies in January, 2024
- By the end of June, 2024 the baseline technologies were chosen.
- Multiple factors were considered in the process: performance, cost, R&D efforts, technology maturity, …

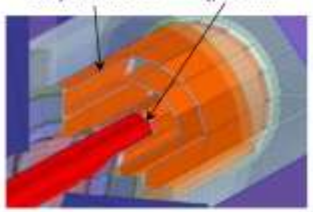
CEPC TDR-ref Detector Specifications

Sub-system	Key technology	Key Specifications
Vertex	6-layer CMOS SPD	$\sigma_{r\phi} \sim 3\ \mu m$, $X/X_0 < 0.15\%$ per layer
Tracking	CMOS SPD ITK, AC-LGAD SSD OTK, TPC + Vertex detector	$\sigma\left(\frac{1}{P_T}\right) \sim 2 \times 10^{-5} \oplus \frac{1 \times 10^{-3}}{P \times sin^{3/2}\theta}(GeV^{-1})$
Particle ID	dN/dx measurements by TPC Time of flight by AC-LGAD SSD	Relative uncertainty ~ 3% $\sigma(t) \sim 30$ ps
EM calorimeter	High granularity crystal bar PFA calorimeter	EM resolution ~ $3\%/\sqrt{E(GeV)}$ Effective granularity ~ $1 \times 1 \times 2\ cm^3$
Hadron calorimeter	Scintillation glass PFA hadron calorimeter	Support PFA jet reconstruction Single hadron $\sigma_E^{had} \sim 40\%/\sqrt{E(GeV)}$ Jet $\sigma_E^{jet} \sim 30\%/\sqrt{E(GeV)}$

- Design of the CEPC detector evolves with the R&D progressing and our better understanding of the physics reach.
- The key specifications continue to be optimized.

CEPC Detector R&D Progresses-1

Vertex detector



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

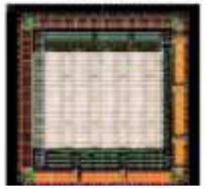
Develop **CEPCPix** for a CEPC tracke basing on **ATLASPix3** CN/IT/UK/DE TSI 180 nm HV-CMOS process

JadePix-3 Pixel size ~16×23 μm²

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

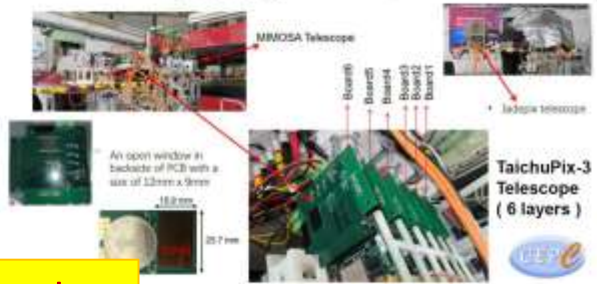
TaichuPix-3, FS 2.5x1.5 cm² 25x25 μm² pixel size

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

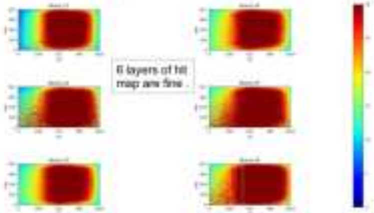


Arcadia by Italian groups for IDEA vertex detector LFoundry 110 nm CMOS

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

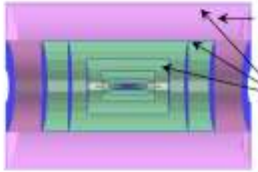


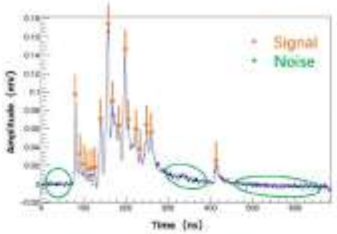
Hitmap of 4 GeV e⁺/e⁻ beam

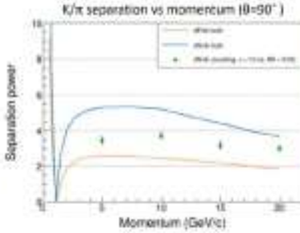


particle ID +main tracker

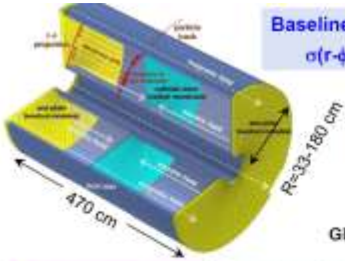
- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm development.



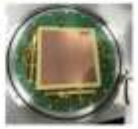




IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022



Baseline main tracker
σ(r-ϕ) ~100 μm

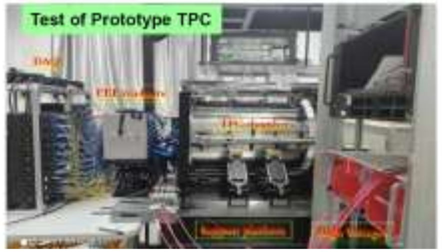


GEM-MM cathode TPC Prototype + UV laser beams

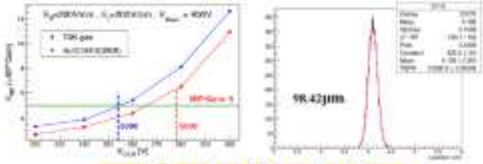
MOST 1 (IHEP+THU)

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.

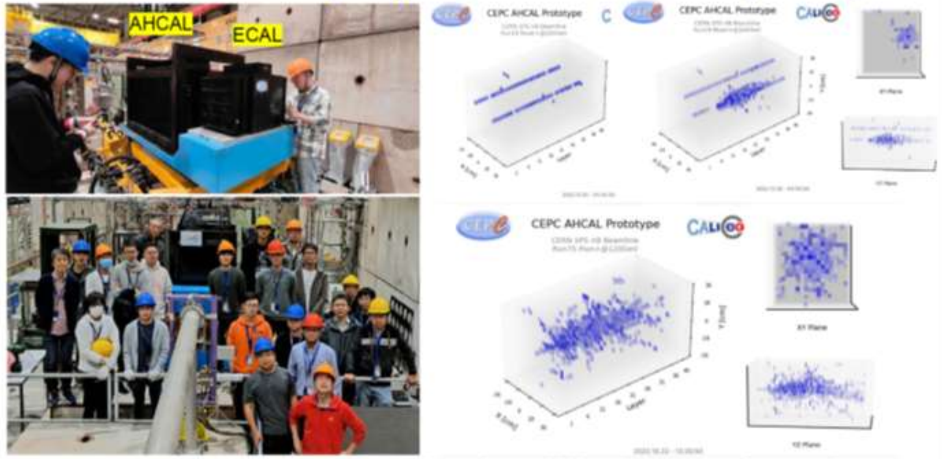


σ_x < 100 μm for drift length of 27cm

CEPC Detector R&D Progresses-2

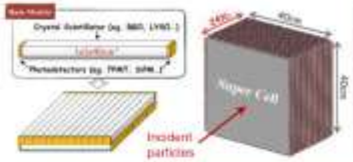
EM + hadron colarimeters： prototypes

➤ PFA ScW-ECAL & AHCAL prototypes: Test Beam at CERN SPS H8 (Oct. 2022)



USTC, IHEP, SJTU, Japanese & Israel groups have close collaboration and regular meetings

new crystal EM calorimeter for better resolution



Goal

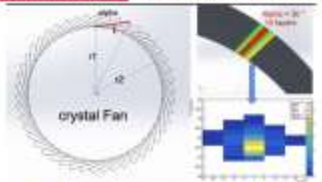
- Boson Mass Resolution < 4%
- Better BMR than ScW-ECAL
- Much better sensitivity to γ/e, especially at low energy.

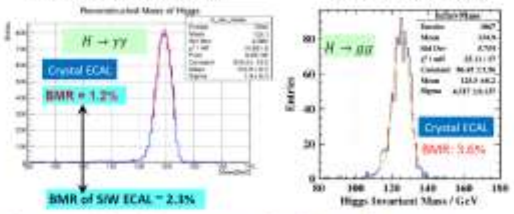
Bench Test

- Long bars: 1 x 40 cm, super-cell: 40x40 cm²
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

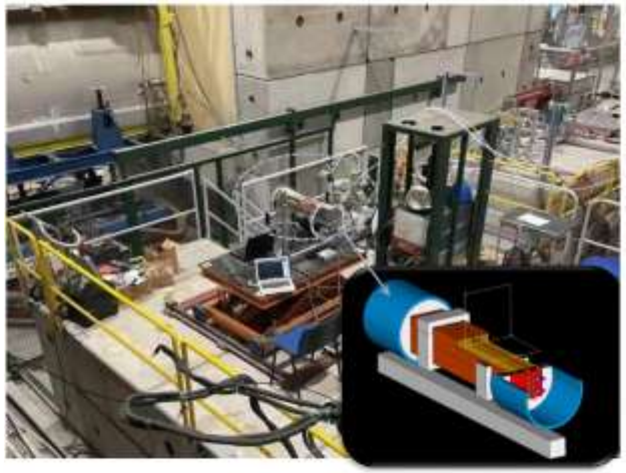
Full Simulation Studies + Optimizing PFA for crystals

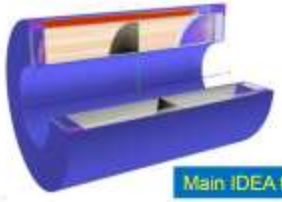
Crystal Fan Design Fine segmentation in Z, ϕ, r

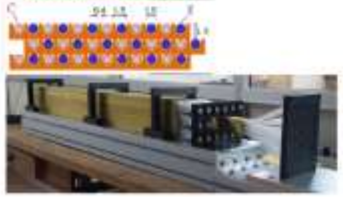




Dual readout crystal calorimeter also being considered by USA and Italian colleagues







Italian groups and IHEP colleagues participated the test beam at CERN.

software

- Key4hep: an international collaboration with CEPC participation
- CEPCSW: a first application of Kep4hep – Tracking software
- CEPCSW is already included in Key4hep software stack

https://github.com/cepc/CEPCSW

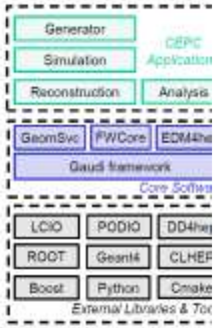
Architecture of CEPCSW

- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

Core Software

- Gaudi framework: defines interfaces of all software components and controls the event loop
- EDM4hep: generic event data model
- FWCore: manages the event data
- GeomSvc: DD4hep-based geometry management service

CEPCSW Structure



Participating and Potential Collaborating Companies in China (CIPC) 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 worldwide

40

CEPC Industrial Preparation

Large-scale Cryogenic Refrigeration & Liquefaction Equipment 中科富海 (CIPC member)

First 18kW@4.5K helium refrigerator fabricated in in China passes inspection

-It was developed by the Institute of TIPC,CAS, and integrated and manufactured by Fullcryo.

-The super large horizontal cold box with a length of 28m and a diameter of 4.2m achieves ultra-high vacuum and extremely low leakage.

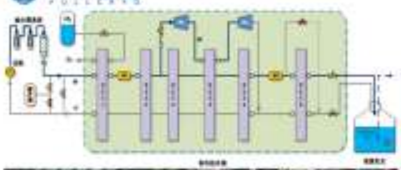
-The horizontal cold box at megawatt-level is the largest of its kind in China and even in the world.

-The horizontal cold box system has exceeded the set targets.

-On-site testing: 1. The airtightness test of each internal channel revealed a pressure drop of 0, surpassing the target value of 0.02 bar. 2. The overall leakage rate is 9.1×10^{-10} Pa.m³/s, surpassing the target value of 1×10^{-7} Pa.m³/s.

-Expected Goals: Achieving 3 operational mode adjustments: the cooling capacity ≥ 18kW@4.5K; the cooling capacity in the superfluid helium temperature range ≥4kW@2K.

中科富海



北京中科富海低温科技有限公司
Beijing Sinoscience Fullcryo Technology CO., Ltd. (CIPC member)

CEPC cryogenic system need four 14kW@4K cryogenic refrigerators
SppC needs 18kW@4.5K helium refrigerator as well

CEPC 650MHz 800kW CW High Efficiency Klystrons

国力研究院 GUOLI INSTITUTE (CIPC member)

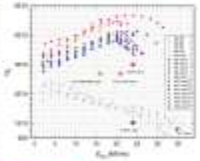
Preliminary mechanical design for UHFKP8001

78.5%@803kW CW in August 18, 2024

Kunshan National Research Institute has successively developed **650MHz/800KW klystron sample tubes, 650MHz/800KW high-efficiency klystron sample tubes, 648MHz pulse klystron tubes, 650MHz/800KW multi-injection klystron beam tubes**, and the latest 324MHz pulse klystron tubes Electro vacuum products for 50 years. Provide high power thyristor of GL1536A in batches for BEPCII in 2012.

HE-RACING Technology and OTIC on SRF Technologies (CIPC members)

高能锐新 (CIPC member)



1.3GHz cryomodule assembly

东方钽业 OTIC (CIPC member)

2011 DESY - XFEL
RRR300 Nb: 8 tons, 30% of the project
2012 Michigan State University - FRIB
RRR250 Nb: 8.5 tons, 70% of the project
2014 Fermilab - LCLS II
RRR300 Nb: 5 tons, 50% of the project
2017 INFN and STFC - ESS
RRR300 Nb: 12.5 tons, 100% of the project
2019 IBS - RISP, CERN - HL-LHC, Fermilab - PIP-II, Shanghai - SHINE
RRR300 niobium material procurement in progress

High RRR Nb sheet

High RRR Nb ingod

High RRR large grain Nb

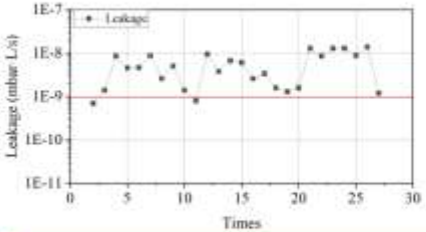
CEPC booster and colliders: 2GeV 1.3GHz and 650MHz SRF accelerators (Higgs); 10GeV 1.3GHz and 650MHz SRF accelerators (ttar)

We had built the business relationship with many great customers such as DESY, MSU, Fermilab, JLAB, INFN, STFC, CERN, TRIUMF, RI, ZANON, IHEP, IBS, RRCAT etc.

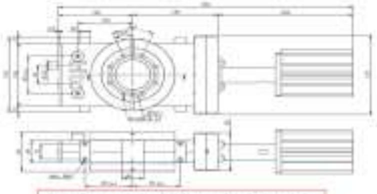
RF Shielding all Metal Gate Vacuum Valve

日揚科技

- Two prototypes of RF shielding All metal gate valve have been developed, and the leakage of one of them have been tested.
- The delivery inspection leakage test results for two valves, conducted by the manufacturer, were found to be < 1×10^{-9} mbar ·L/s (30 times open and closed).
- The difference of leakage by IHEP & manufacture will be checked and retested in next.



- Tested by IHEP
- Expectation leakage < 1×10^{-9} mbar ·L/s

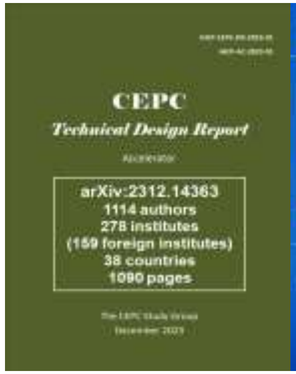


CEPC needs ~1700 all metal valves

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



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

CEPC International Collaboration-2

27 Collaboration Agreement MoUs related to CEPC signed

No.	Year	Organization	Coutry/Region
1	2016	VINCA	Serbia
2	2016	INR	Russia
3	2016	WRCP	Hungary
4	2016	BINP	Russia
5	2016	INFN	Italy
6	2016	TAU	Israel
7	2016	CoEPP	Australia
8	2016	NCTS	Taiwan region
9	2017	South Africa	Wits
10	2017	USA	ISU
11	2017	CERN	CERN
12	2017	IPAS	Taiwan region
13	2017	KEK	Japan
14	2017	MEPhI	Russia
15	2018	IEF	Germany
16	2018	CERN	CERN
17	2019	INP BSU	Belarus
18	2019	VINCA,UB,UPS	Serbia
19	2019	CERN(CCICC)	CERN
20	2019	JINR	Russia
21	2020	UChicago	USA
22	2022	BINP	Russia
23	2023	INR	Russia
24	2023	VINCA	Serbia
25	2024	LPI	Russia
26	2024	KU	Korea
27	2024	Mainz U	Germany

Chinese participation in LHC Upgrades

	Detector	Basic technology	Major Contributions
ATLAS	NSW / LS2	Small strip thin gap chamber	sTGC panel, FEBs
	ITk / LS3	Silicon strip detector	Module production
	HGTD / LS3	LGAD	Whole process, project management
	Muon / LS3	RPC, sMDT, TGC	RPC trigger detector, MDT TDC ASIC, high-eta tagger
CMS	CPPF / LS2	Electronics for muon trigger	Concentrator, preprocessor and fan-out for Muon L1 trigger
	CSC / LS2	Cathode Strip Chambers	Module production
	HGCAL / LS3	Endcap calorimeter, sampling	Module construction
	MIP-TD / LS3	Mip timing detector, LYSO+SiPM	Electronics board, module test, …
	Muon & Trigger / LS3	Large area GEM, and electronics	GEM electronics board, GEM modules,
LHCb	UT / LS2	Silicon strip detector	Radiation hardness, installation & commissioning
	SciFi / LS2	Scintillation fibers + SiPM	Front end electronics
	UT / LS4	Monolithic silicon pixel detector	Sensor design, module/stave construction, project management
	SPACAL / LS4,3	Spaghetti calorimeter	GAGG crystal sensor, 3D printing W absorber
ALICE	ITS2 / LS2	ALPIDE pixel detector	Module production
	MFT / LS2	ALPIDE	Disc boards
	ITS3 / LS3	Monolithic stitched sensor MOSS	Sensor design
	FoCal / LS3	ALPIDE + absorber	R&D on pixel layer for 2 gamma separation, …
	ITS4 / LS4	Large size ALPIDE chip	Planning
	ToF / LS4	LGAD, or LGAD with MAPS	Planning

IHEP-KEK SC Technology Collaboration for 20 years

http://www.ihep.ac.cn/xwdt2022/gnxw/hotnews/2024/202412/t20241220_7507219.html

CEPC International Collaboration-3

HKUST IAS23 HEP Conference, Feb. 14-16, 2023, Hong Kong

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 fundamental physics conference: Jan. 14-17, 2025, Hong Kong
https://indico.cern.ch/event/1454867/overview

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) was 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/

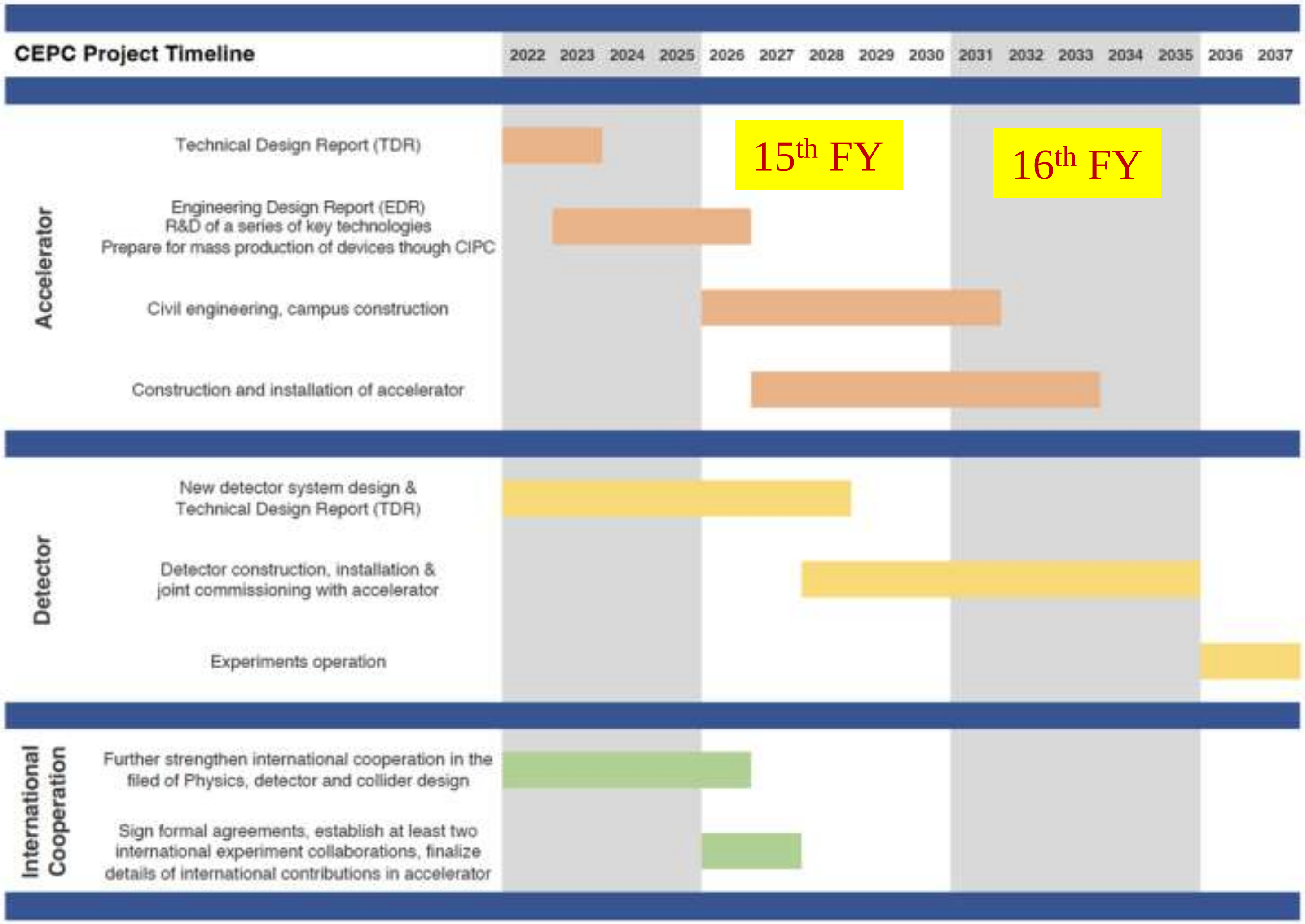
Professor Peter Higgs passed away on **April 8, 2024**. We miss him.

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

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** in the following relevant 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, LHAASO, etc.**

-CEPC international partners and collaborators

CEPC Proposal Preparation (2025)

CEPC inputs to EPPSU2026 preparation is under way, and will be submitted before March 2025

国家重大科技基础设施建设项目

环形正负电子对撞机
项目建议书

主 管 部 门： 中国科学院

项目法人单位： 中国科学院高能物理研究所
共建单位：

2025 年 XX 月

We will submit in 2025 the CEPC Proposal (in Chinese) to China's "15th five year plan" process

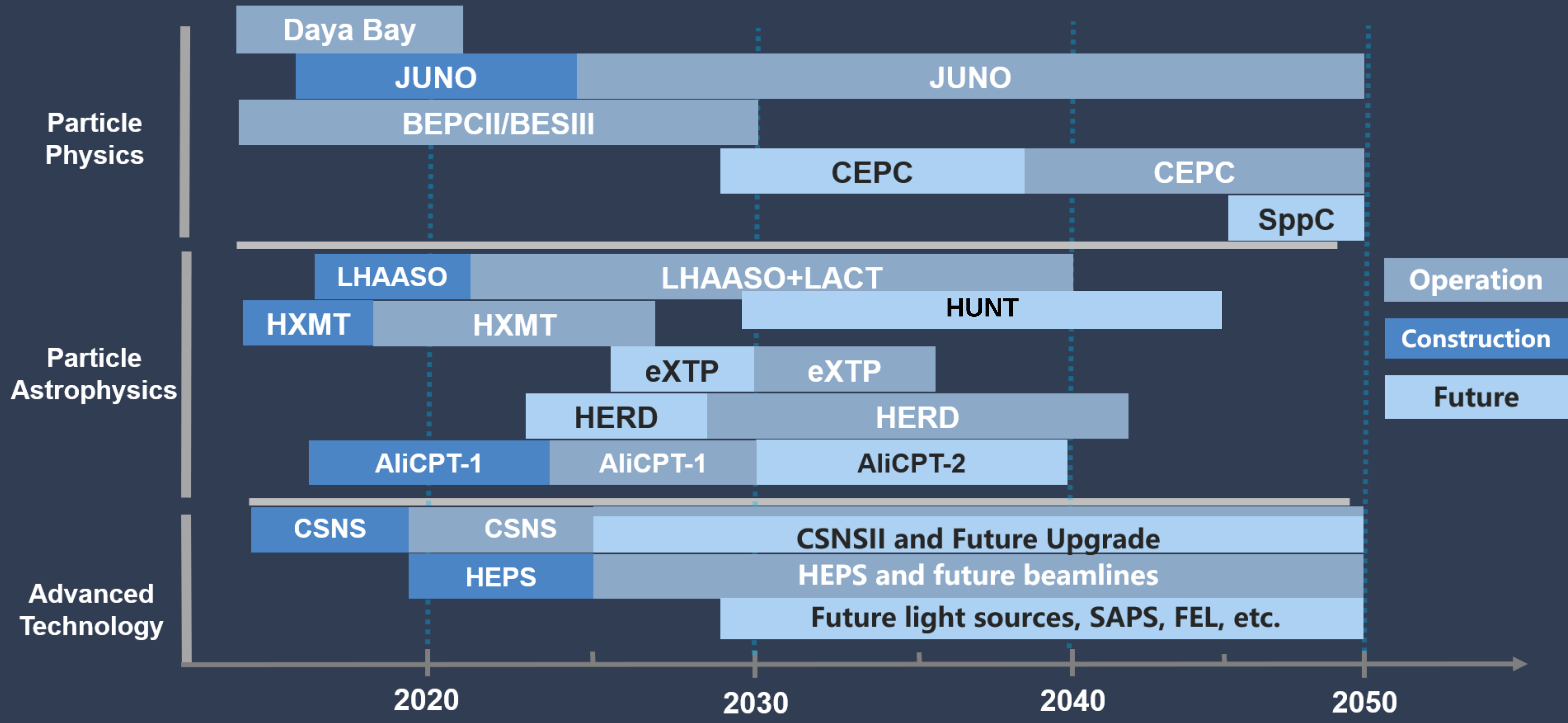
CEPC in Synergy with other Accelerator Projects in China

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 Host Lab IHEP and its Large Science Facilities

Roadmap of IHEP



Summary

- The CEPC TDR optimizations designs with high luminosity (**30MW and 50MW**) operations for all four energies (**Higgs, W/Z and ttbar**) satisfy the CEPC scientific goals.
- CEPC accelerator **TDR international review and cost review** were held from **June 12-16, 2023 and Sept. 11-15, 2023**, respectively, and endorsed by **IAC meeting** held from **Oct. 30-31, 2023**. **CEPC Accelerator TDR has be released formally on December 25, 2023 (**arXiv： 2312.14363**) and published 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 detector reference design will be released by June 2025.**
- **EDR site selection and geological feasibility studies have been started and completed in 2025.**
- Detailed preparation of **CEPC EDR** phase (**2024-2027**) before construction working plan and beyond have been established and executed 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**.
- **CEPC Accelerator EDR have progressed well with corresponding EDR funds and EDR human resources available, and have been reviewed by IARC in Sept. 18-20, 2024, IDRC in Oct. 21-23, 2024 and IAC in Oct. 29-30, 2024 at IHEP. The 2nd IARC EDR meeting will be held in Sept. 2025.**
- **International collaboration and participation are warmly 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,TDR review (+cost) committee’s critical advices, suggestions and supports

Thanks for your attention