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

CEPC-SppC General Status and Perspectives

-Towards construction through EDR Phase

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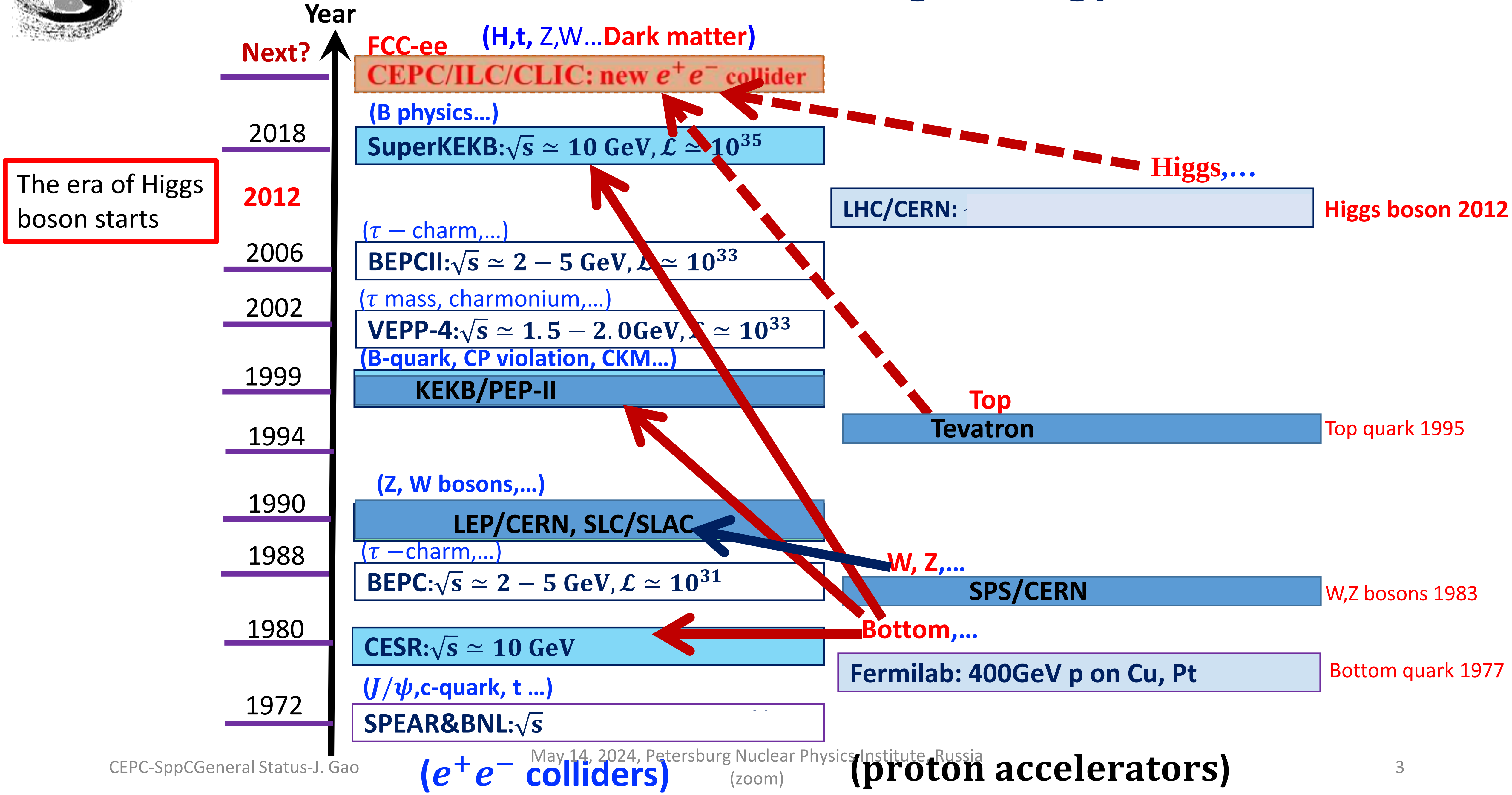
IHEP

On behalf of the CEPC-SppC team

Petersburg Nuclear Physics Institute of National Research Center “Kurchatov Institute”
May 14, 2024, Saint Petersburg, Russia (Zoom)

Contents

A Brief Historical Recall: High Energy Colliders



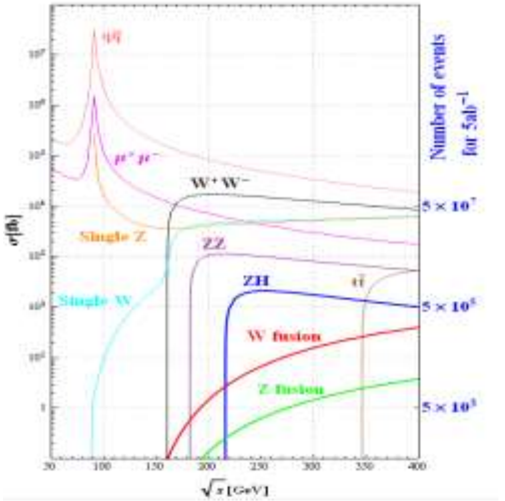
Physics Goals of CEPC-SppC

- **Circular Electron-Positron Collider (CEPC) as a Higgs Factory (91, 160, 240, 360 GeV)**
  - **Higgs Factory** (>10^6 Higgs) :
    - Precision study of Higgs(mH, JPC, couplings), **complementary** to Linear colliders
    - Looking for hints of new physics, Dark Matter...
  - Z & W factory (>10^10 Z0) :
    - precision test of SM
    - Rare decays ?
  - Flavor factory: b, c, t and QCD studies
- **Super proton-proton Collider(SppC) (~100 TeV)**
  - Directly search for new physics beyond SM
  - Precision test of SM
    - e.g., h3 & h4 couplings

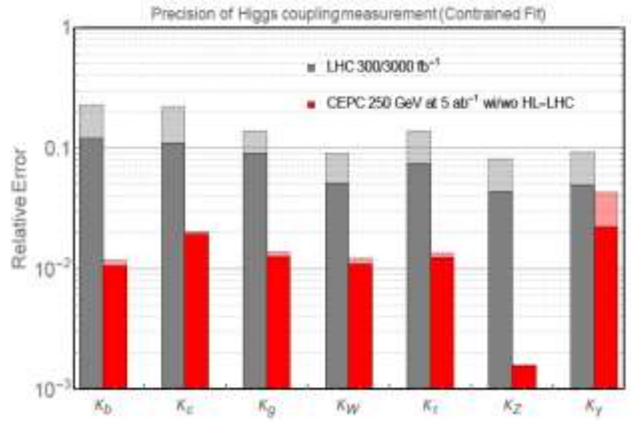
Precision measurement + Searches for new physics: complementary with each other (lepton and hadron colliders)

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

Started from **2012**, Human being entered into the **era of Higgs**.
A new calendar of Science-Anno Higg is proposed by J. Gao, i.e. **2012AD=0AH**. Year **2024AD** is also**12AH**



Cross sections for major SM physics processes at the electron positron collider



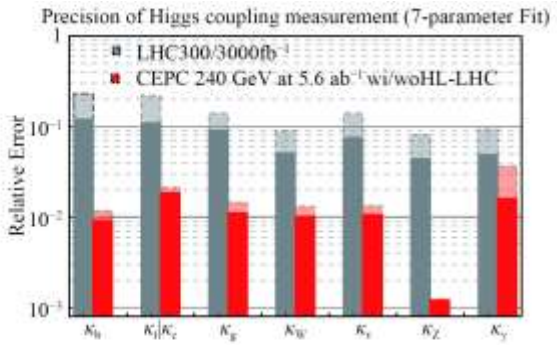
Anticipated accuracy on Higgs properties at CEPC and at LHC/HL-LHC

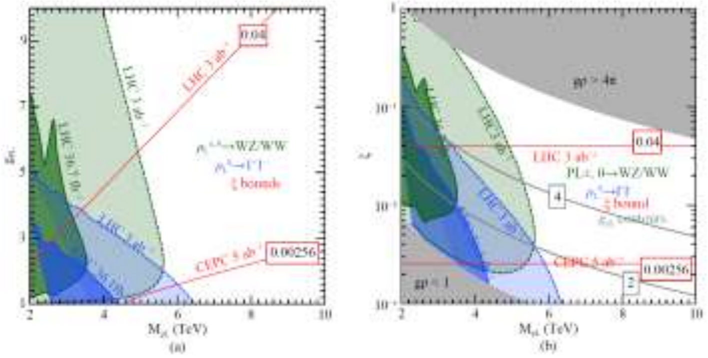
Scientific Objectives: "Discovery + Precision Measurement"

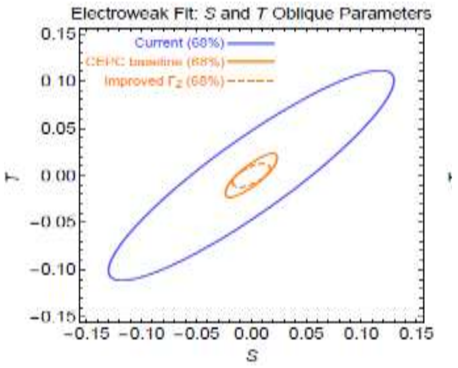
Higgs coupling measurement can be improved by orders magnititude

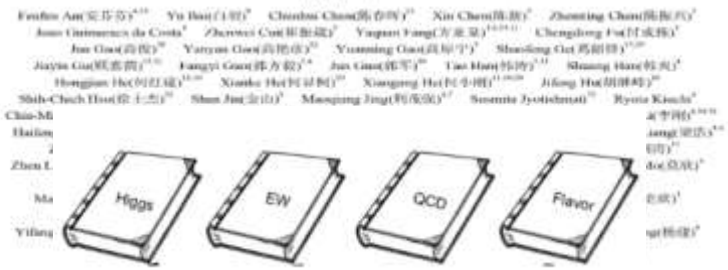
Direct and indirect probe to new physics up to 10 TeV, an order of magntitude higher than HL-LHC

Electroweak measurement can be improved by a large factor



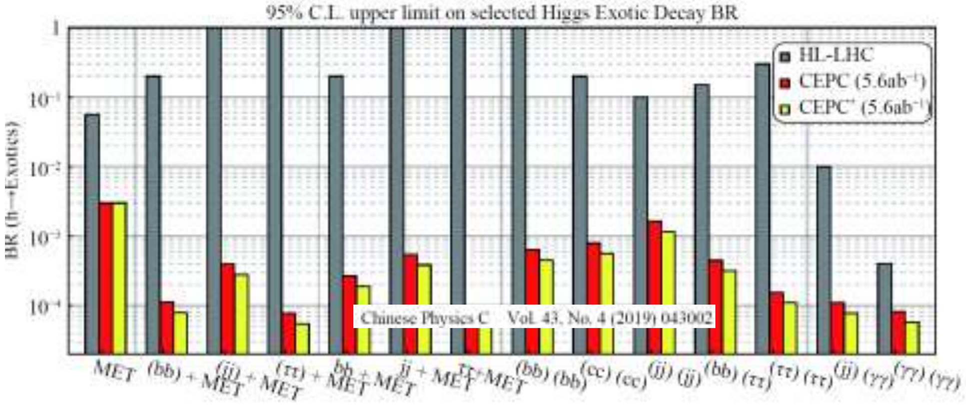





Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC

Physics white papers published and to be published



Key Scientific Issues and Technological Route

New Physics
~10 TeV

- ✓ Dark Matter
- ✓ Extended Higgs
- ✓ Composite Higgs
- ✓ Supersymmetry
- ……

High Precision
~1%

- ✓ Higgs: 1%-0.1%
- ✓ EW : $O(10^2\text{-}10^3)$ vs current
- ✓ Flavor
- ……

Detector
Particle Flow

- ✓ High Granularity
- ✓ Good Resolution
- ✓ Reliable PID
- ……

Design & Implementation
Detector & Accelerator

- ✓ Multi-purposed Acc.
- ✓ New concept Detector
- ✓ Cost, added values
- ✓ Spill-over
- ……

- ✓ Management
- ✓ Collaboration
- ……

High Lumi.
$\sim 10^{34\text{-}36} cm^{-2} s^{-1}$

- ✓ Higgs: 20 ab^{-1}
- ✓ Z: 100 ab^{-1}
- ✓ W: 6 ab^{-1}
- ✓ Top: 1 ab^{-1}

Accelerator
2 IPs/100 km

- ✓ Switchable Operations
- ✓ Upgradability
- ✓ Large Piwinski angle with Crab-waist
- ……

Operation mode	Z	W	Higgs
Center-of-mass energy (GeV)	91	160	240
Operation time (year)	2	1	10
Instantaneous luminosity/IP ($10^{34} cm^{-2} s^{-1}$)	115	16.0	5.0
Integrated luminosity (ab^{-1}, 2 IPs)	60	3.6	12
Event yield (30 MW)	2.5×10^{12}	1.0×10^{8}	2.5×10^{6}
Event yield (50 MW)	4.0×10^{12}	1.6×10^{8}	4.0×10^{6}

Physics ⟹ Detector ⟹ MDI ⟹ Accelerator

CEPC Operation Plan and Goals in TDR

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.

The Global HEP Consensus on Higgs Factories

The scientific importance and strategical value of an electron positron Higgs factory is clearly identified worldwide

China

2013, 2016: Xiangshan Science Conferences concluded that the CEPC is the best approach and a major historical opportunity for the national development of accelerator-based high-energy physics program.

JAHEP Japan

2017: Japan Association of High Energy Physicists (JAHEP) proposes to construct a 250 GeV center-of-mass ILC promptly as a Higgs factory.

Europe

2020: An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

ICFA

In April **2022**, the International Committee for Future Accelerators (ICFA) "reconfirmed the international consensus on the importance of a Higgs factory as the highest priority for realizing the scientific goals of particle physics", and expressed support for the above-mentioned Higgs factory proposals

Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the Particle Physics Project Prioritization Panel 2023

Exploring the Quantum Universe

Recommendation 6

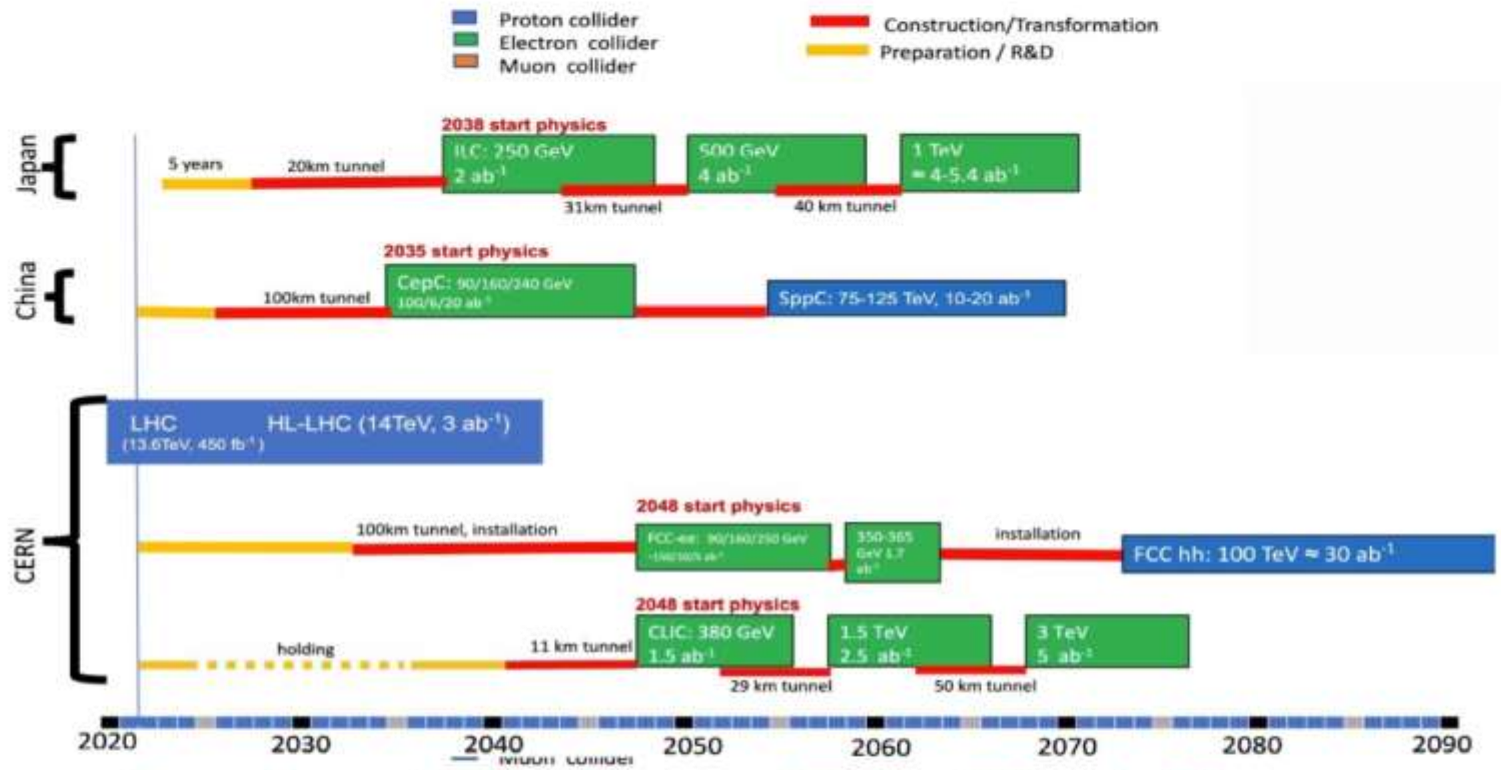
Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed.

The panel would consider the following:

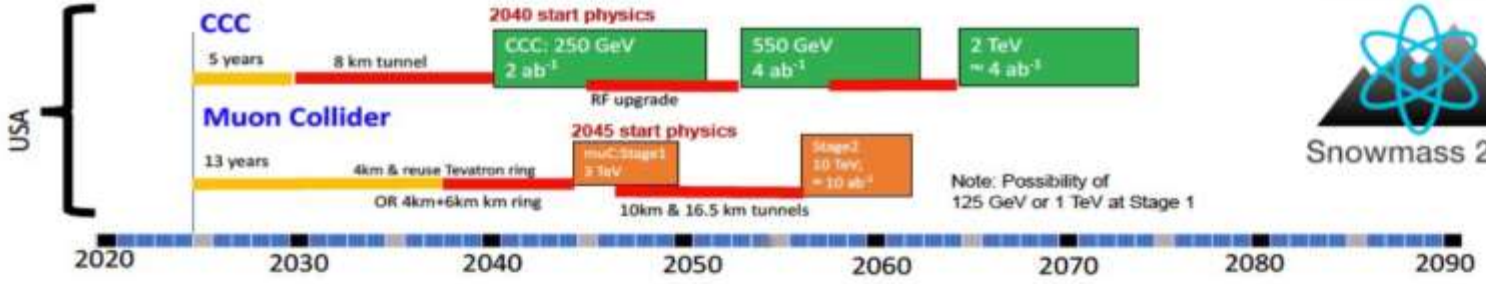
1. The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
2. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
3. A plan for the evolution of the Fermilab accelerator complex consistent with the longterm vision in this report, which may commence construction in the event of a more favorable budget situation.

P5 report, USA, 2023

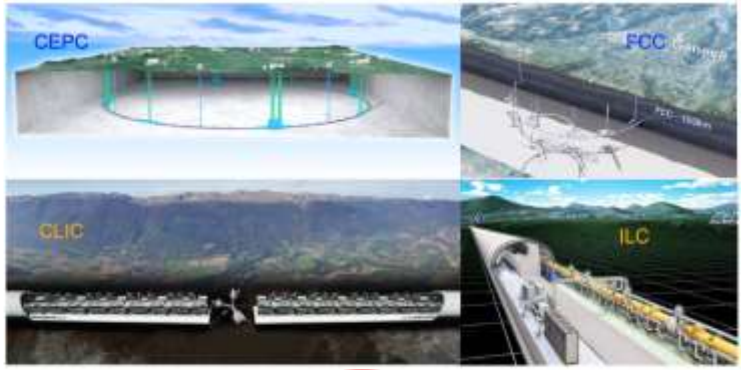
Timelines in Snowmass Energy Frontier Summary



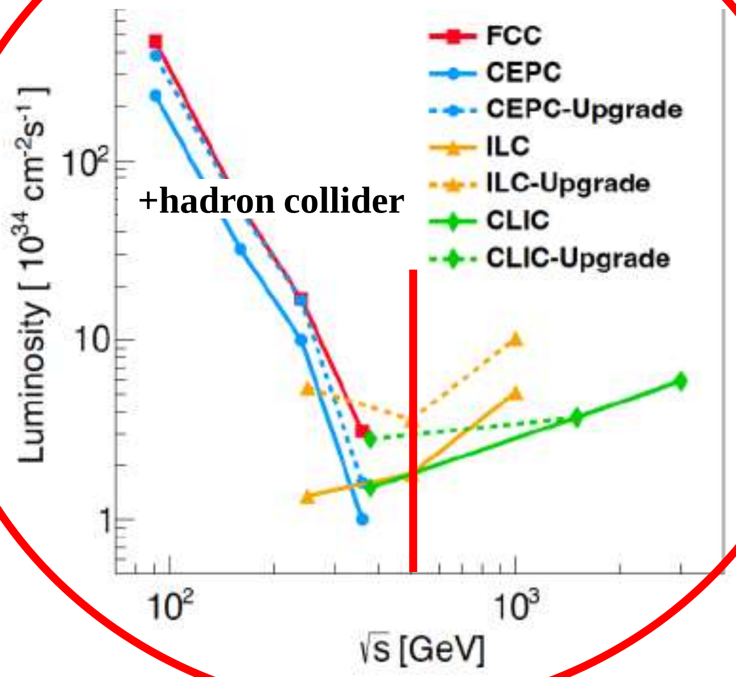
Proposals emerging from Snowmass 2021 for a US based collider



Snowmass 2021

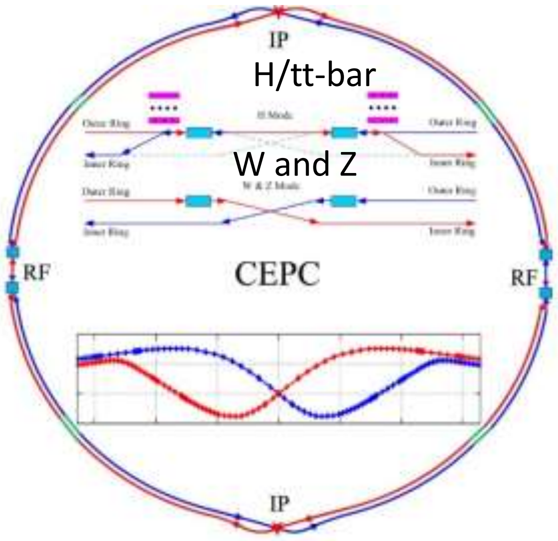


Complementarity between Circular and Linear colliders

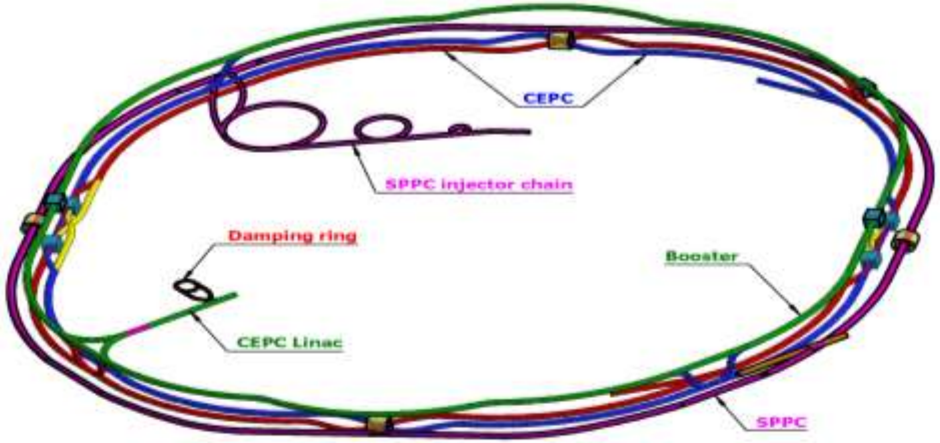


CEPC Higgs Factory and SppC Layout in TDR

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

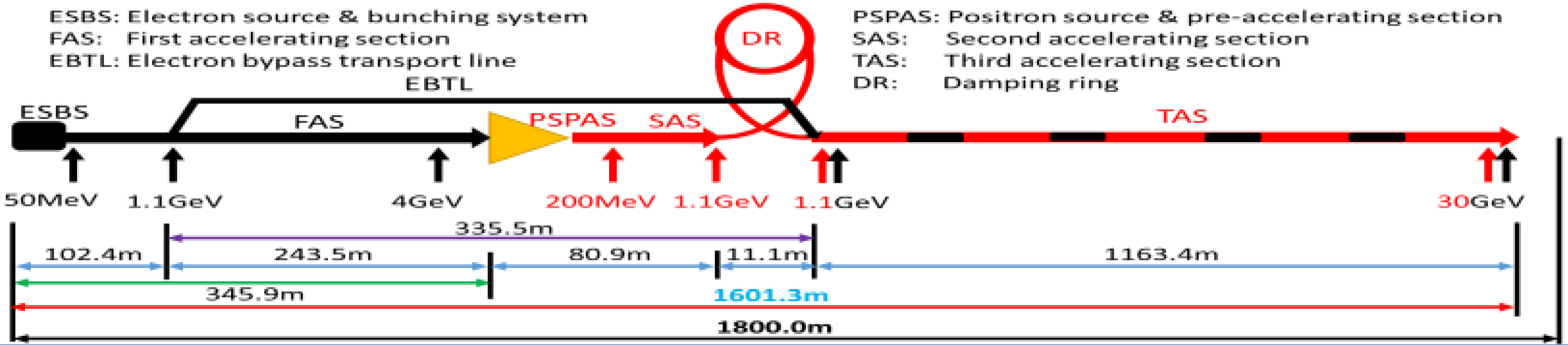


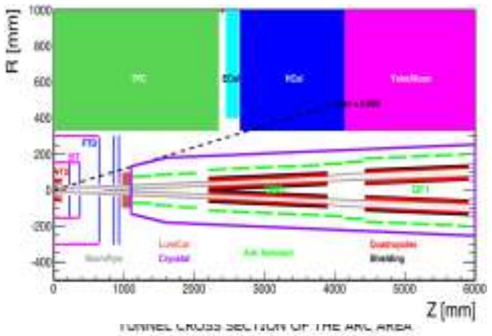
CEPC collider ring (100km)

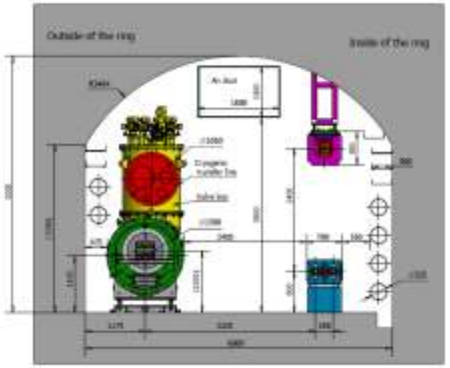


CEPC booster ring (100km)

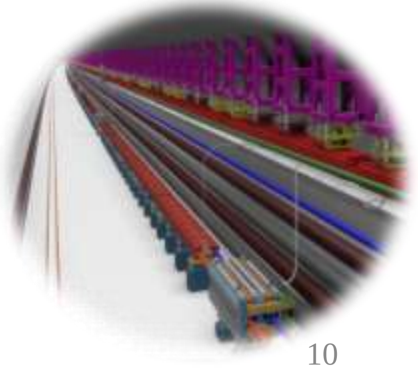
CEPC TDR S+C-band 30GeV linac injector







CEPC/SppC in the same tunnel



CEPC Accelerator System Parameters in TDR

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

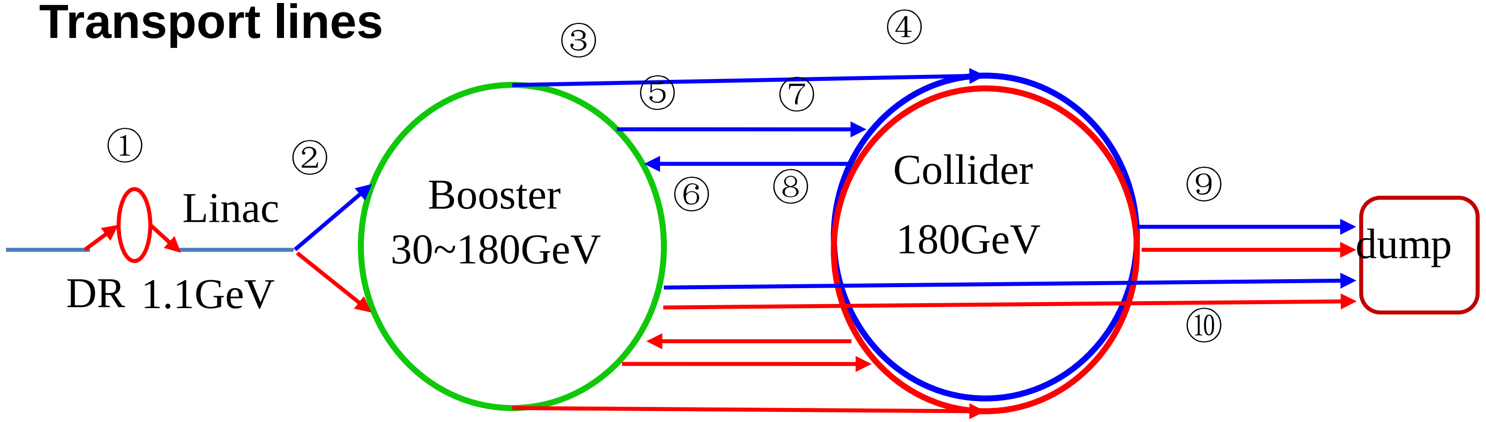
Booster

		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

Machine Design for all Operation Modes

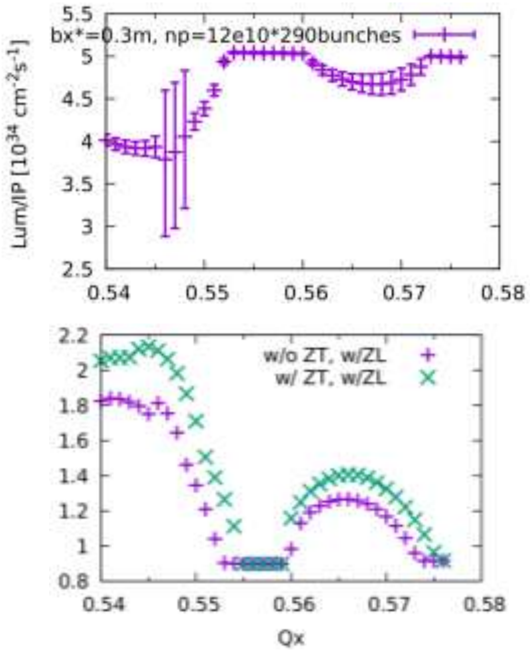
Goal

- e+e- circular collider as a high lumi. Higgs factory
- Compatible operation for Higgs, W, Z and Top
- Increasing Luminosity

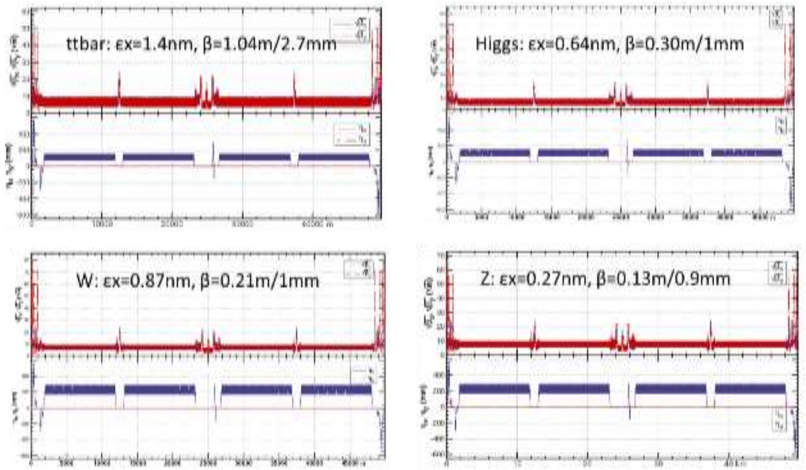
Design

- Lattice optimization for all energies
- Sufficient DA for all energies
- Beam-beam & collective instability
- Crab waist scheme with large cross angle and sextuples

Beam-beam effect study

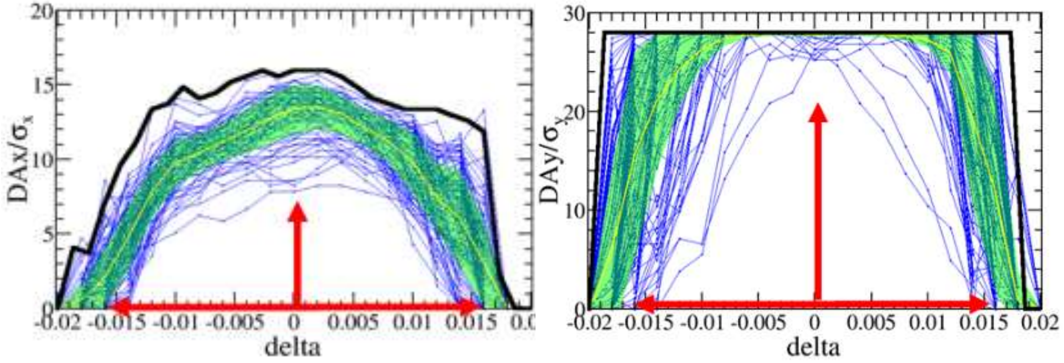


Lattice for all energies

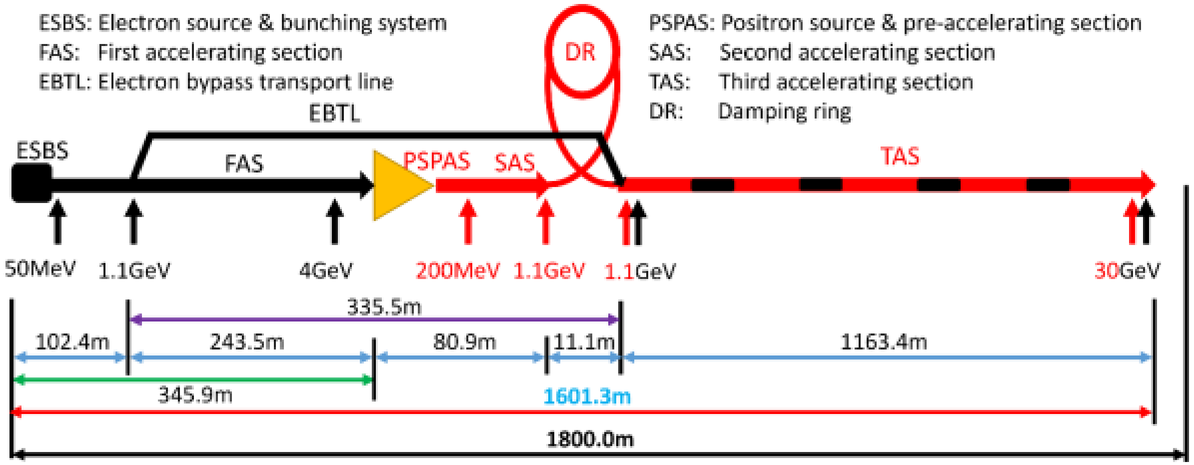


Dynamic Aperture (DA) optimization

Requirement met Higgs (w/error): $7\sigma_x \times 16\sigma_y \times 1.6\%$

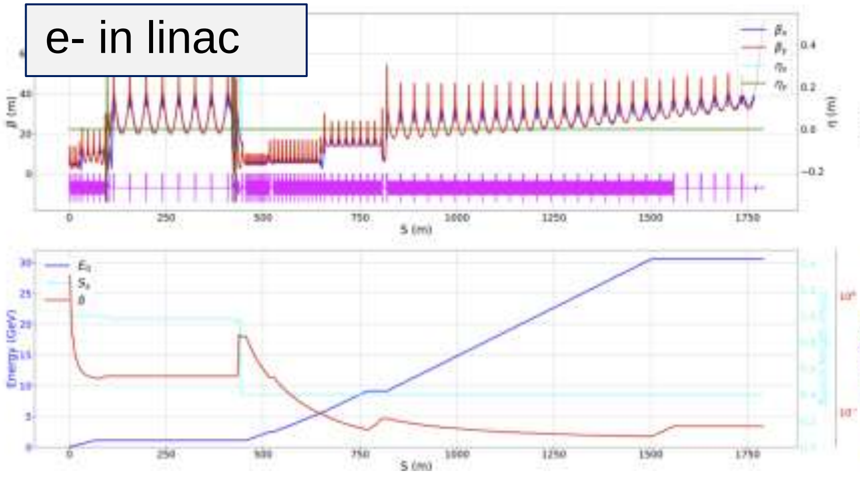


CEPC e- and e+ Injection Linac Designs in TDR

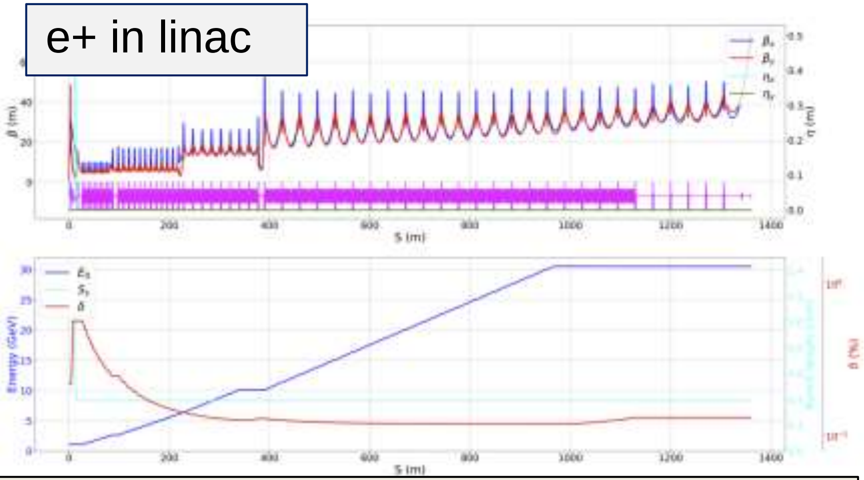


Parameter	Symbol	Unit	Design value
Energy	E	GeV	30
Repetition rate	f_{rep}	Hz	100
Number of bunches per pulse			1 or 2
Bunch charge		nC	1.5
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5
Electron energy at target		GeV	4
Electron bunch charge at target		nC	10
Tunnel length	L	m	1800

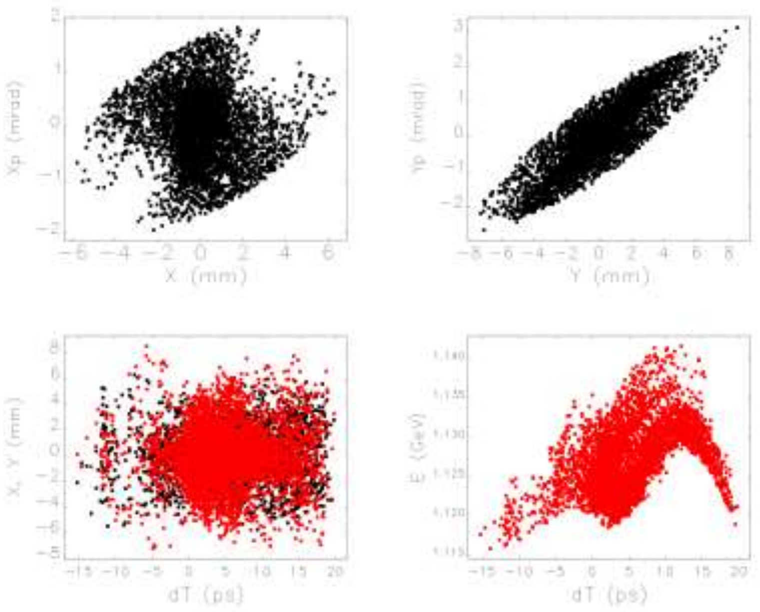
e- in linac



e+ in linac



Phase space @ SAS exit



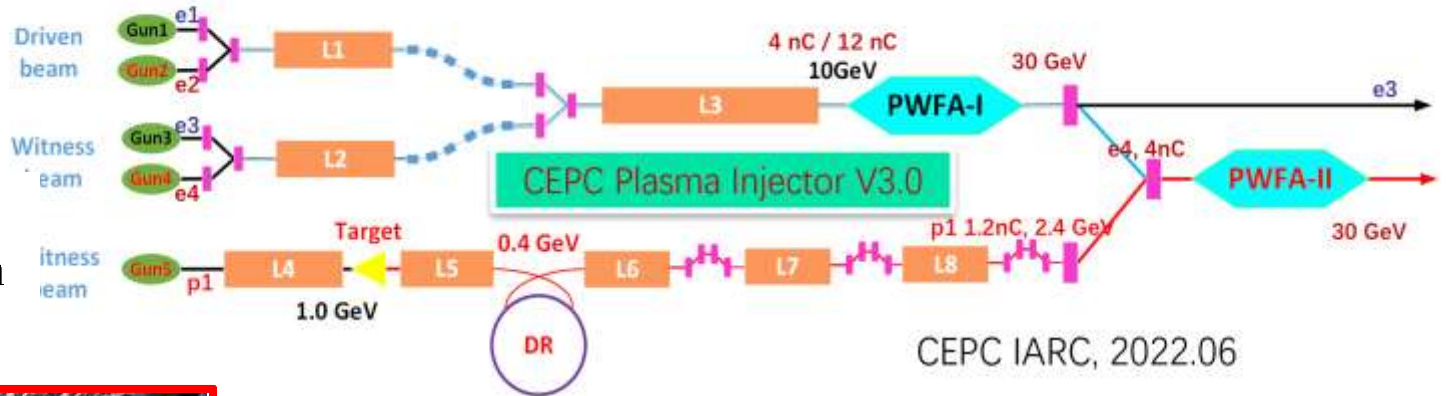
- Linac energy increases to **30 GeV**, with **S+C band** Accelerator;
- Start-to-end simulations with errors have been conducted for both electron/positron beams, with qualities satisfying design requirements.

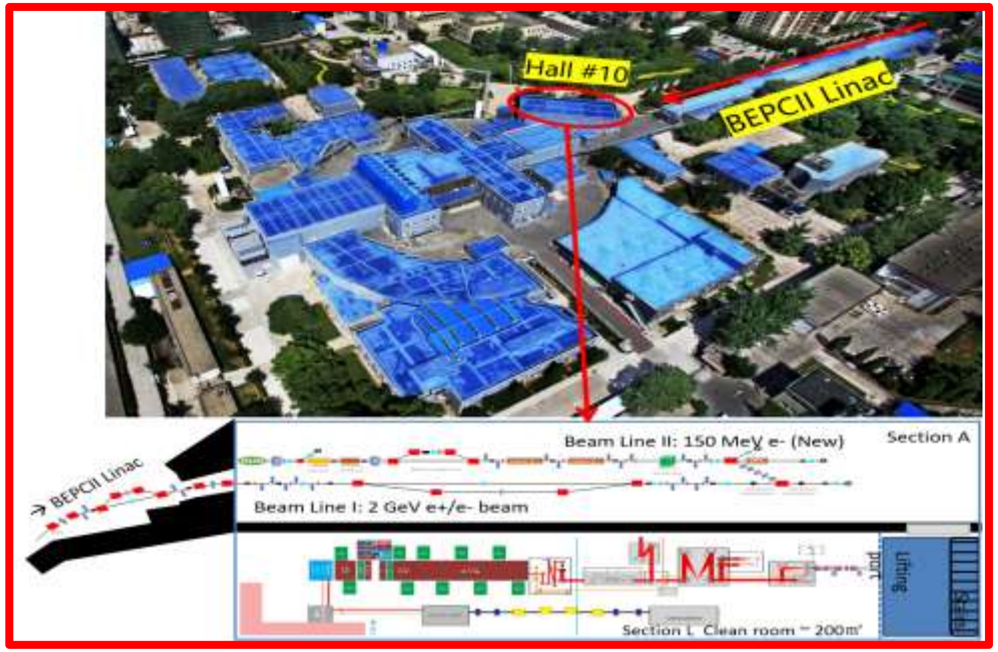
CEPC Plasma Injector (alternative option) and TF Plan

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 beaml… system, optimize the e- / e+ beam quality…
2. Clean room and high power l… TW) installation200TW
3. Beam instrumentati…
4. RF Gun platfor…
5. Commissio… systems

Phase II（Ye…

1. … lines (1PW + 20/40 TW) … rm and install it on the …

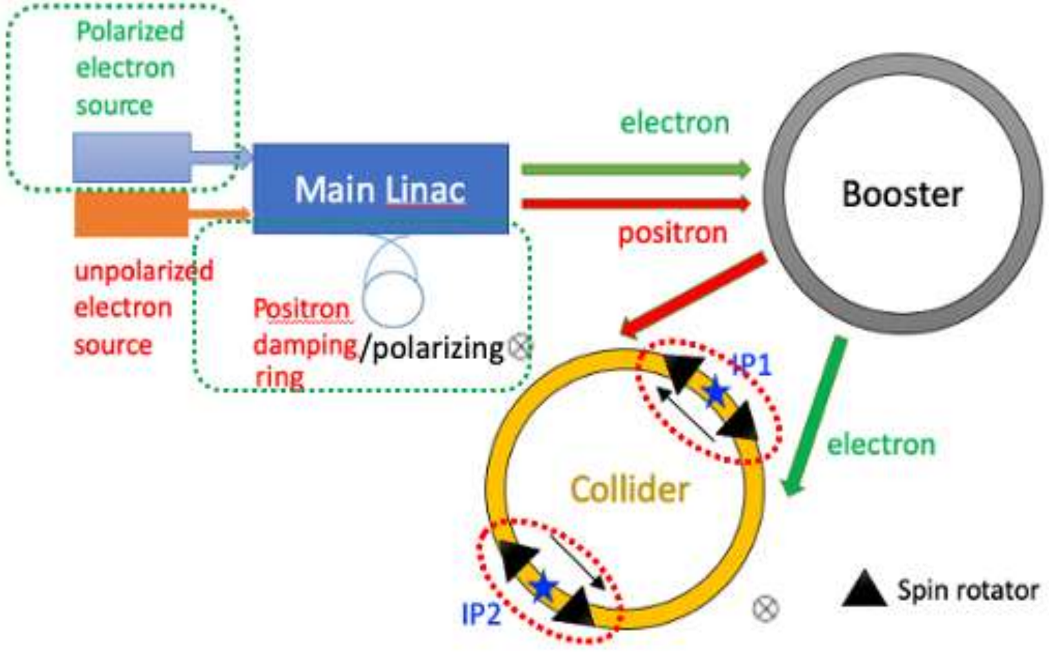
Pl…

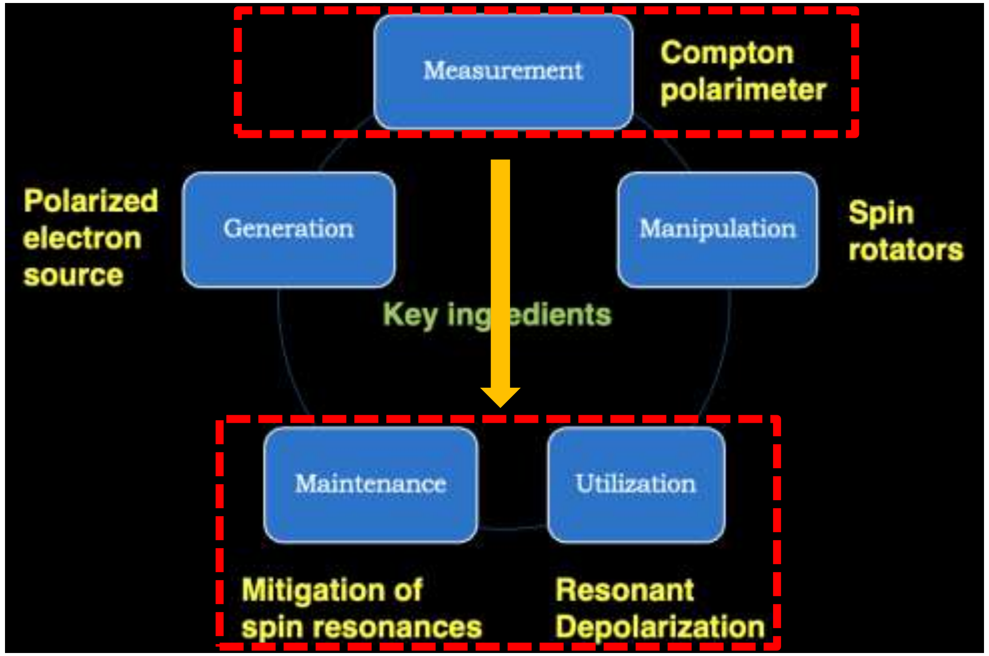
1. … umping ring the bunch compression … improve the e+ quality
2. … sed FEL studies

- 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)



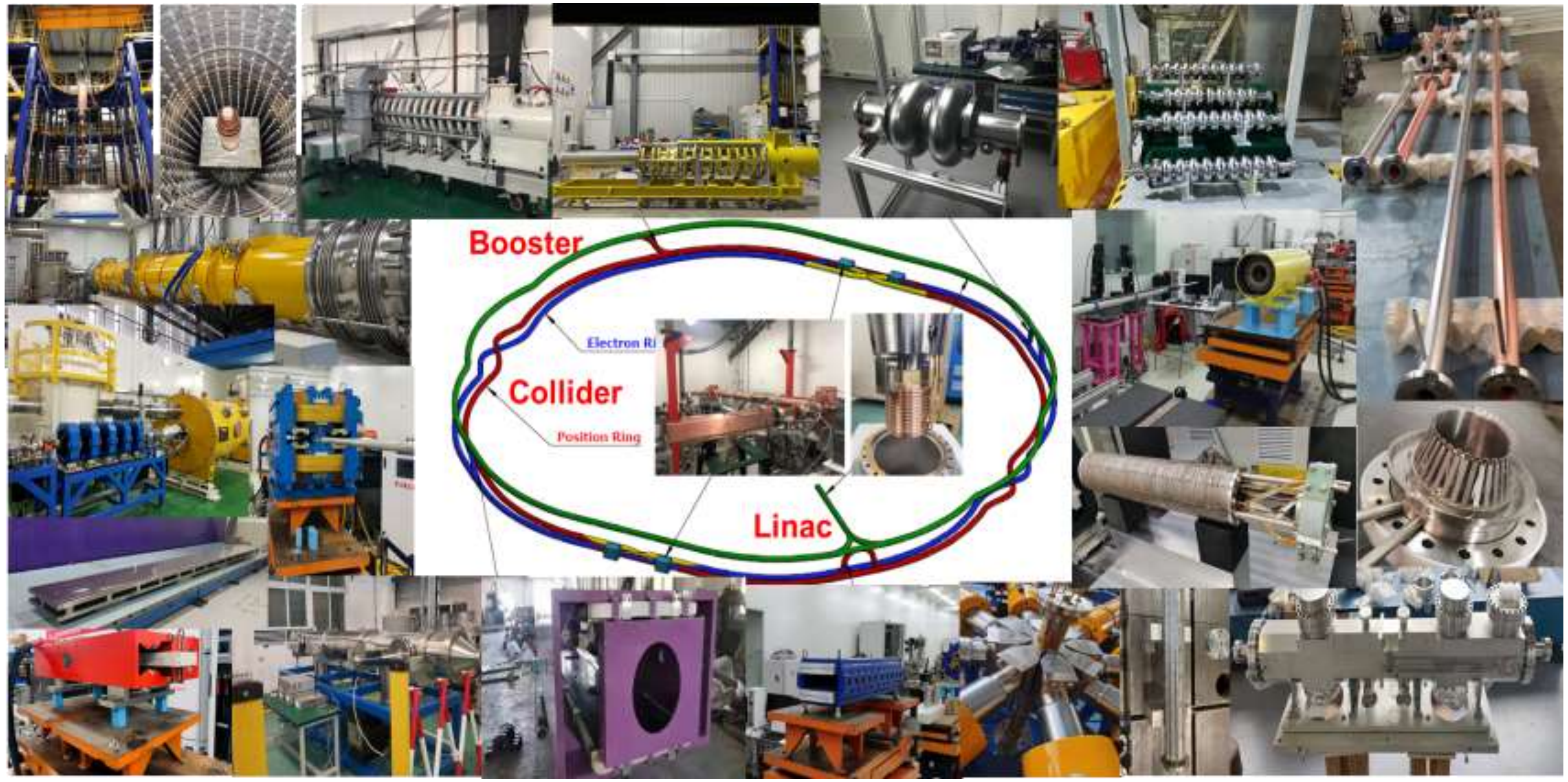


Both the transverse and longitudinal polarization and Z, W, are feasible (Higgs under study)

- 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

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%

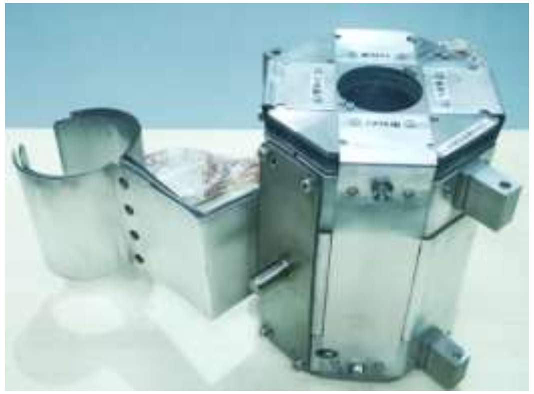
Key technology R&D in TDR spans all component lists in CEPC CDR

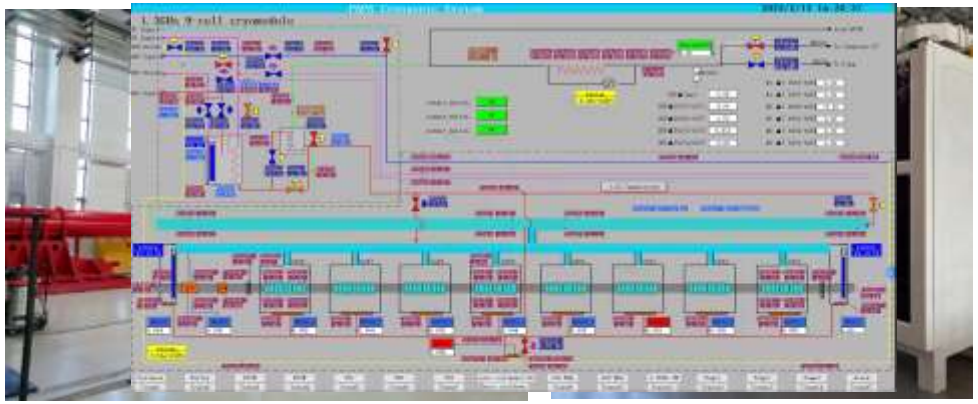
CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

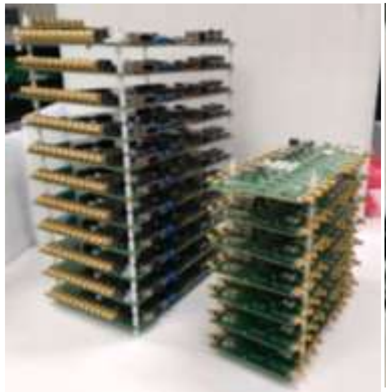
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

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}			



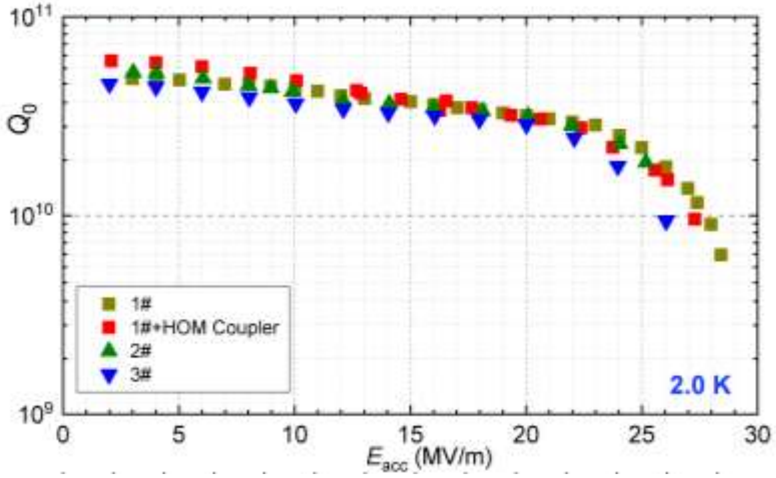



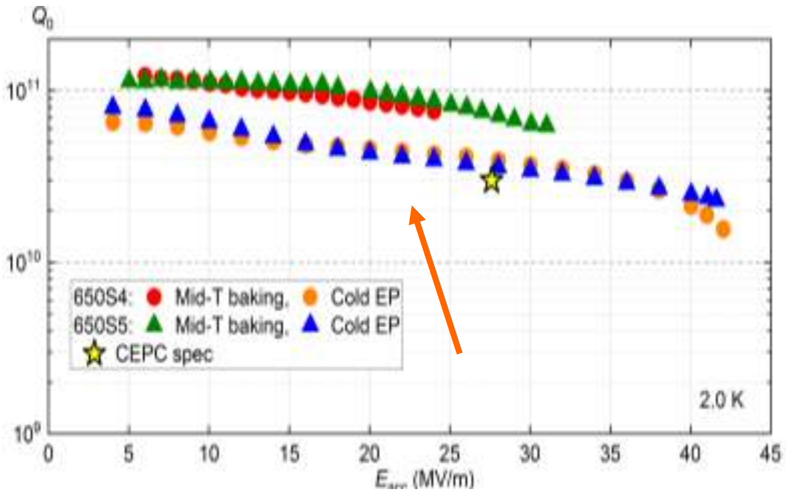



CEPC R&D: 650 MHz SRF Cavities for collider

- First three 2-cell cavities based mainly on BCP shows reasonable performance
- Recent 1-cell cavity based on cold-EP and Mid-temperature baking achieved the world best results, exceeding CEPC spec.
- Continue to develop multi-cell cavities

Vertical test of 650 MHz 2-cell cavity



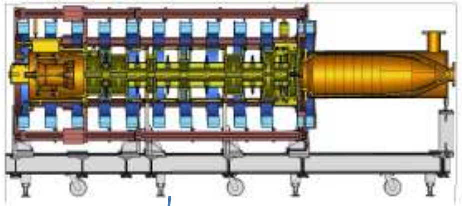


Vertical test of 650 MHz 1-cell cavity

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

CEPC klystron R&D

Klystron No. 2
Efficiency 77%
(2021)



Power Supply Modulator

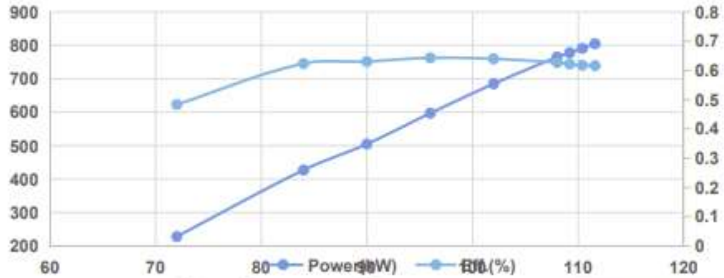
Klystron No. 1
Efficiency 65%
(2020)

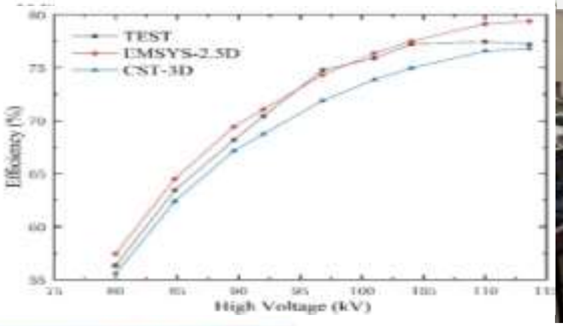
Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

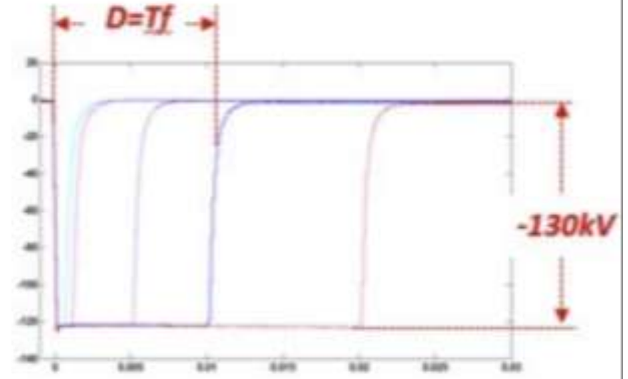
Pulsed RF Mode (30% duty factor, 60ms/5Hz) 77.2%@849kW pulsed in 2024

To be tested in 2024

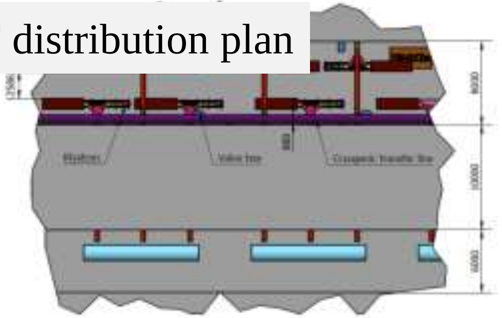
High Voltage vs. Power&Efficency

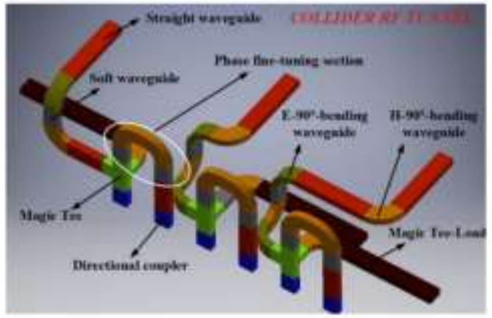






RF distribution plan





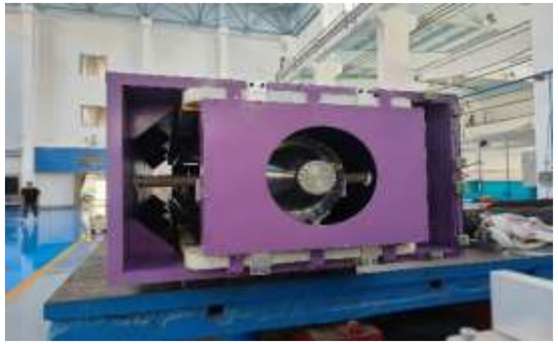
- Three prototypes of the **650MHz 800KW CW** klystrons are developed. The efficiency reaches 70%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

R&D: Other Prototypes

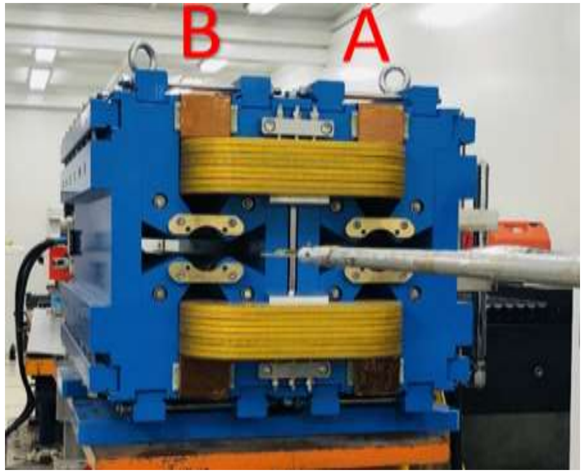
Collider dipole magnet

booster dipole magnet

EM deflector



Collider quad magnet



Vacuum pipes and RF shielding bellows

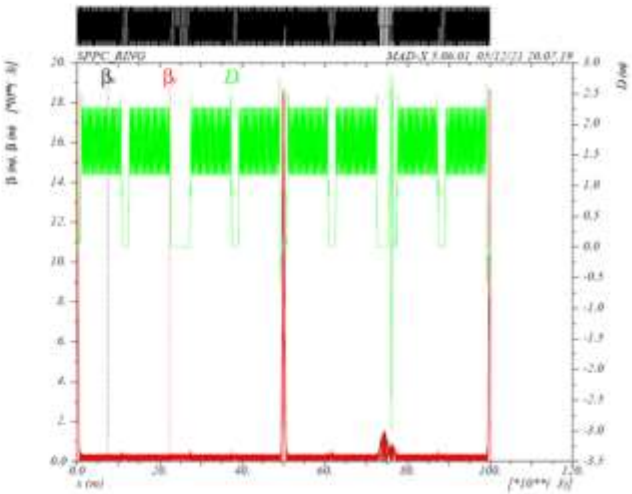
Lambertson magnets

SppC Collider Parameters in TDR

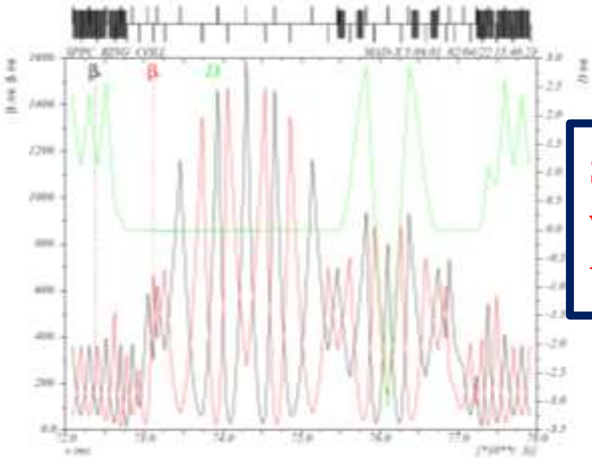
-Parameter list (updated Feb. 2022)

Main parameters		
Circumference	100	km
Beam energy	62.5	TeV
Lorentz gamma	66631	
Dipole field	20.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	19.53	
Injection energy	3.20	TeV
Number of IPs	2	
Revolution frequency	3.00	kHz
Revolution period	333.3	μs
Physics performance and beam parameters		
Initial luminosity per IP	4.3E+34	$cm^{-2}s^{-1}$
Beta function at initial collision	0.5	m
Circulating beam current	0.19	A
Nominal beam-beam tune shift limit per	0.015	
Bunch separation	25	ns
Bunch filling factor	0.756	
Number of bunches	10080	
Bunch population	4.0E+10	
Accumulated particles per beam	4.0E+14	

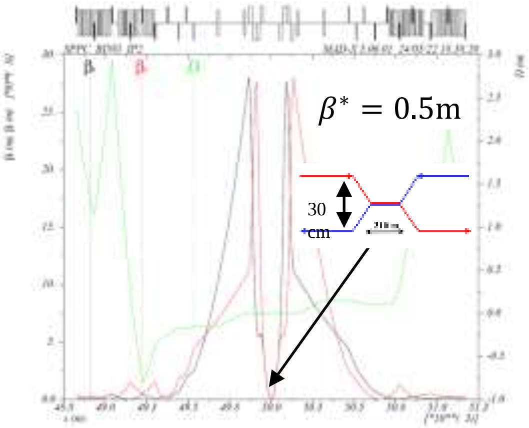
Lattice of SPPC



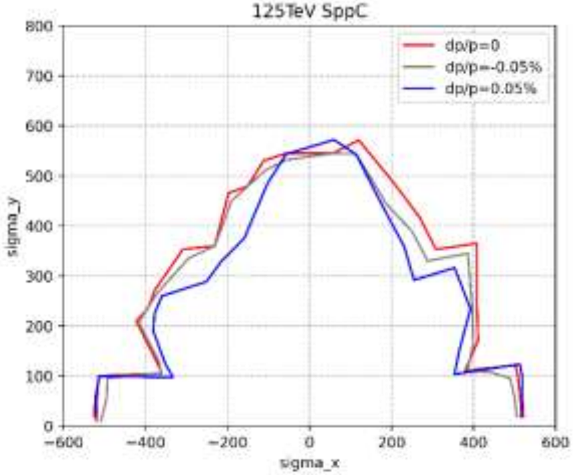
Whole ring



Collimation



IP



Dynamic Aperture

SppC is compatible with CEPC in the same tunnel

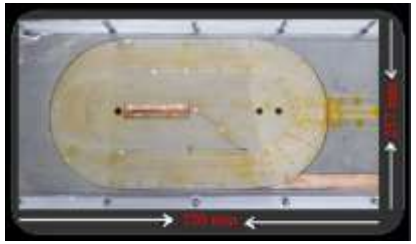
Ecm=125TeV with dipole field of 20T

IBS Technology for High Field Magnets

R&D under way

Z. Zhao
IBS (T_c 55K)

100-m 7-core IBS tape fabricated
J_e= 100 A/mm²
@ 10 T, 4.2 K



IBS solenoid at 32 T
Racetrack at 10 T
1.3 kA transposed cable
J_e > 450 A/mm²
@ 10 T, 4.2 K

2008.02 — Discovery of IBS

2008.04

2008.09 — Discovery of 122 phase IBS

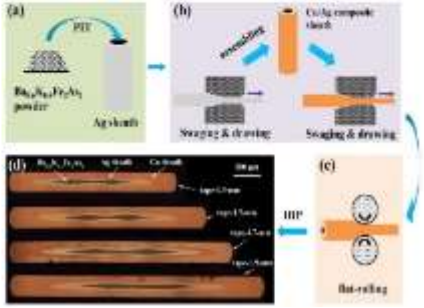
2016

2018

2020

2022

H. Hosono
IBS (T_c 26K)



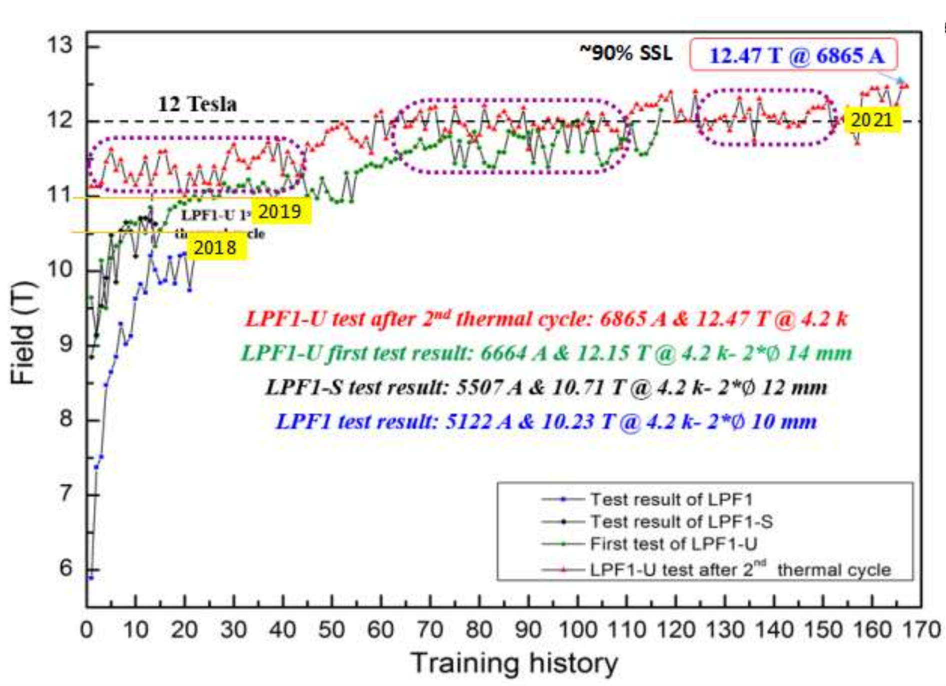
- IBS solenoid at 24 T
  Racetrack at 8 T
  J_e= 300 A/mm²
  @ 10 T, 4.2 K

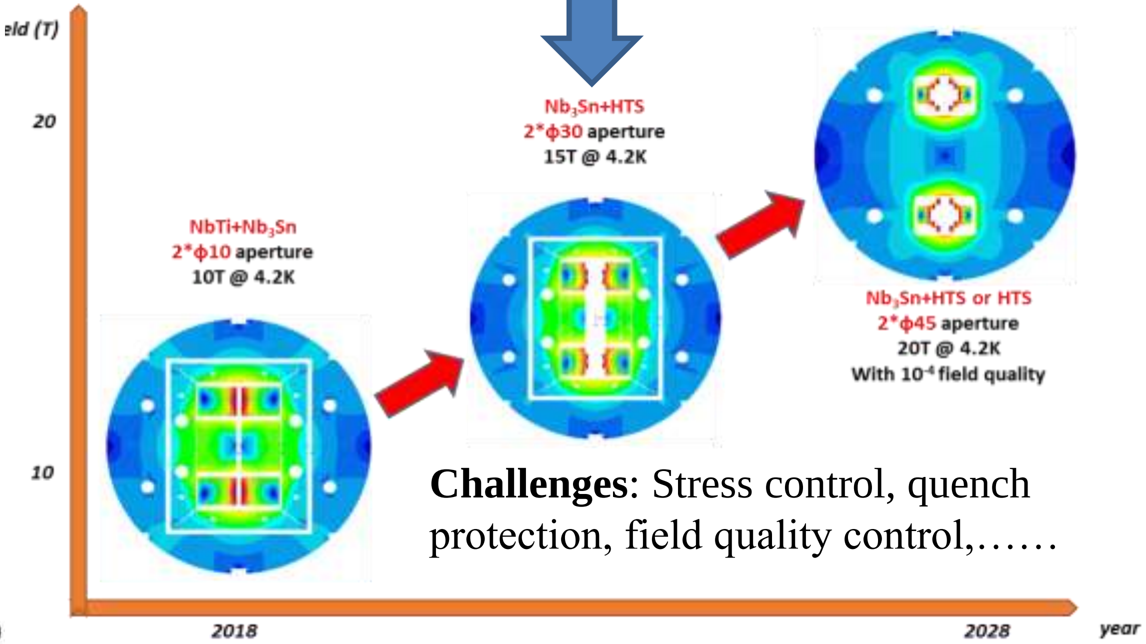
J_e of IBS expected to be similar as ReBCO in 2020s with better mechanical properties and lower cost，ready for mass applications in ultra high field magnets

HF Magnet Development

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





Challenges: Stress control, quench protection, field quality control,……

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

CEPC Site Preparations (three candidates in TDR)

Power Consumption of CEPC @ Higgs

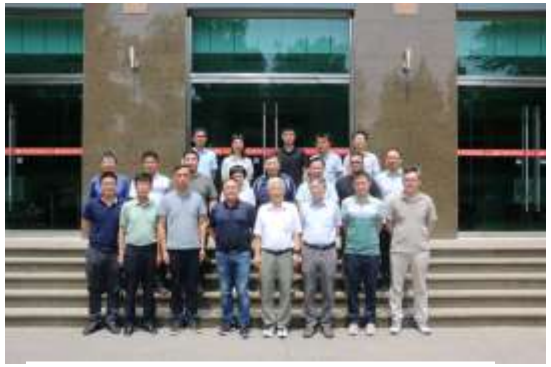
SN	System	Higgs 30MW							Higgs 50MW						
		Collider	Booster	Linac	BTL	IR	Surface building	Total	Collider	Booster	Linac	BTL	IR	Surface building	Total
1	RF Power Source	96.90	1.40	11.10				109.40	161.60	1.73	14.10				177.40
2	Crygenic system	9.72	1.71			0.14		11.57	9.17	1.77			0.14		11.08
3	Vacuum System	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

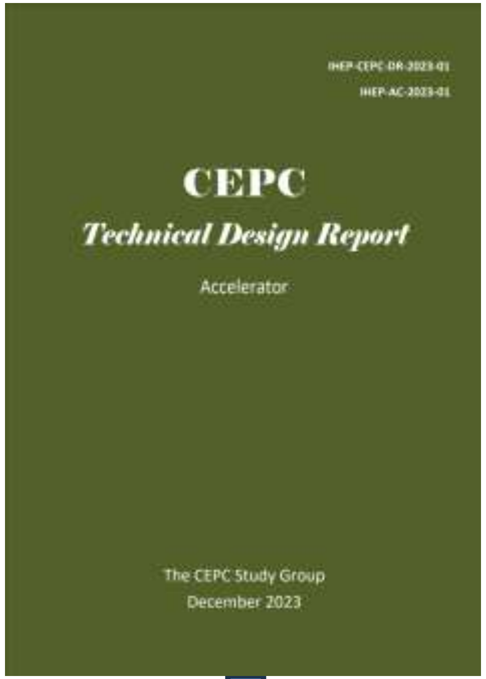
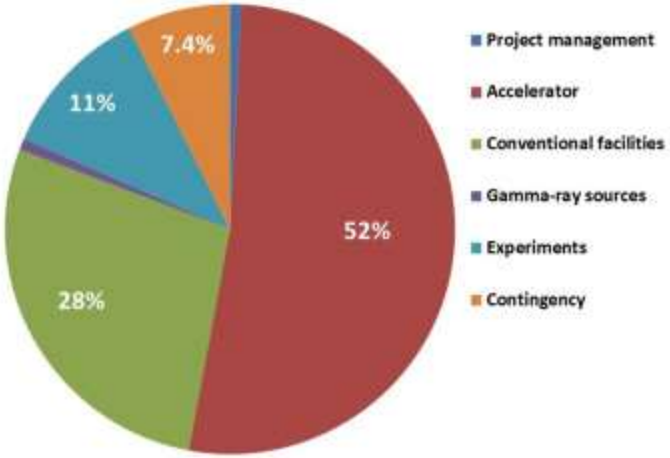


Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

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

CEPC accelerator TDR link: （arXiv： 2312.14363）

CEPC accelerator TDR releasing news:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html

CEPC Accelerator TDR International Reviews and CEPC IAC Meeting Endorsement

June 12-16, 2023, in HKUST-IAS, Hong Kong

Chaired by Frank Zimmermann

Phase 1 CEPC TDR Review Report

CEPC TDR Technical Review Committee

15 July 2023

The CEPC Study Group, hosted by the Institute of High Energy Physics (IHEP), has been working on the design and development of a forefront e^+e^- collider as a Higgs factory that can extend to energies corresponding to the Z, WW and the top-quark pairs, with the upgrade potential to a high-energy pp collider. The CEPC represents a "grand plan" proposed, studied, and to be constructed by Chinese scientists in close collaboration with international partners. Since the release of the CEPC Conceptual Design Report in 2018, the CEPC Study Group has devoted significant effort to the design optimisation, the R&D of key technologies and the study of the technical systems of the CEPC.

The CEPC Study Group has produced a draft Technical Design Report (TDR). The International Review Committee, chaired by Dr. Frank Zimmermann (CERN), was asked to conduct a first phase review of this TDR draft. This first phase review shall cover all but the cost and site aspects of the CEPC.

The Phase 1 CEPC TDR Review Committee meeting was held in person at HKUST from 12 to 16 June 2023.

https://indico.ihep.ac.cn/event/19262/timetable/

Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

Chaired by Loinid Rivkin

CEPC Accelerator TDR Cost Review

The CEPC Accelerator TDR Cost Review committee examined the cost estimate of the TDR of accelerator systems for the first stage of the CEPC project operated as a Higgs factory with synchrotron radiation power up to 30 MW per beam (including all infrastructure that is not easily upgradeable and is already designed to operate up to the ttbar energy and at 50 MW). The cost estimate under review does not include the civil engineering, the detectors at the IPs with their technical services, and the central computing services.

In the opinion of the committee the cost estimate presented is sufficiently complete to form a proper basis for the next iteration that will be done during the EDR stage.

https://indico.ihep.ac.cn/event/19262/timetable/

Oct. 30-31, 2023, in IHEP

Chaired by Brian Foster

The Ninth Meeting of the CEPC-SppC International Advisory Committee

IAC Committee
M. E. Biagini, Y.-H. Chang, A. Cohen,
M. Davier, M. Demarteau, B. Foster (Chair),
B. Heinemann, K. Jakobs, L. Linssen,
L. Maiani, M.L. Mangano, T. Nakada, S. Stapnes,
G. N. Taylor, A. Yamamoto, H. Zhao

November 14th, 2023

https://indico.ihep.ac.cn/event/20107

The IAC also supports another key conclusion in the TDR Review Report, that the accelerator team is well prepared to enter the EDR phase.

-The IAC also support another conclusion in the TDR Review Report that the accelerator team is well prepared to **enter the EDR phase**

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CEPC Engineering Design Report (EDR) Goal

2012.9	2015.3	2018.11	2023.10	2025	2027	15th five year plan
CEPC proposed	Pre-CDR	CDR	TDR	CEPC Proposal CEPC Detector reference design	EDR	Start of construction

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

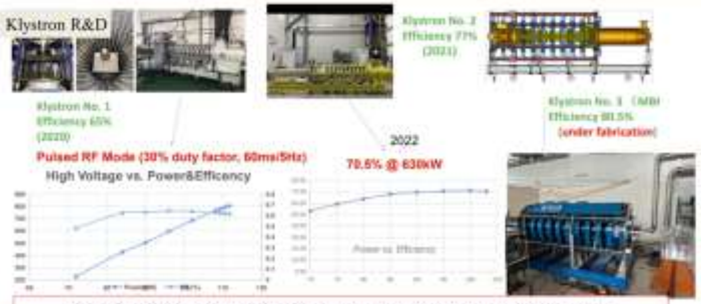
Some Key Issues in EDR (examples)-1

CEPC Accelerator Main EDR Development: SRF

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

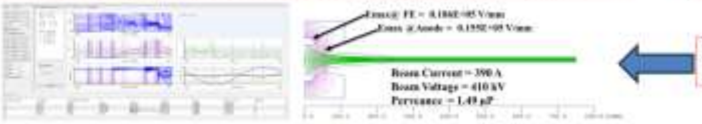
CEPC Accelerator Main EDR Development: Klystrons



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

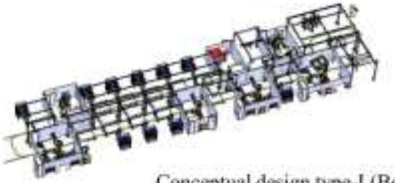
C band 5720MHz 80MW Klystron



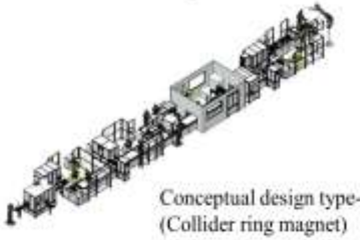
C band 5720MHz 80MW Klystron design progress

CEPC Magnets' Automatic Production Lines in EDR

To reduce the fabrication cost of the magnets of CEPC, automatic magnet production lines will be demonstrated in EDR and used during construction



Conceptual design type-I (Booster magnet)



Conceptual design type-II (Collider ring magnet)

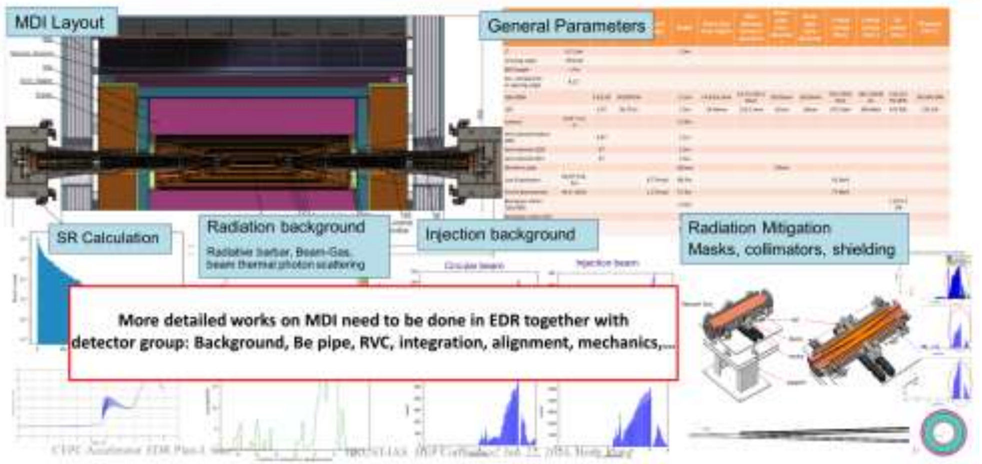
Jan.-Sept. 2024： Complete the CEPC booster magnet automatic fabrication facility design.
Oct. 2024-Jun. 2025： Complete the small scale demonstration facility for booster iron core fabrication.

Massive Production Line of NEG Coating Vacuum Chambers in EDR

- The coating device A: Vacuum chambers are connected in parallel to 6 groups, each group of vacuum chambers length should be lower than 3.5m, outer diameter is about 0.47m;
- The coating device B: Antechamber are connected in parallel to 4 groups, each group of vacuum chambers length should be lower than 1.5m, due to its discharge difficulty.
- Two setups of NEG coating have been built for vacuum pipes of HEPS at IHEP Lab. And a lot of test vacuum pipes have been coated, which shows that NEG film has good adhesion and thickness distribution.
- **In EDR phase a dedicated CEPC NEG coated vacuum chamber production line is planned**

Some Key Issues in EDR (examples)-2

CEPC MDI in EDR



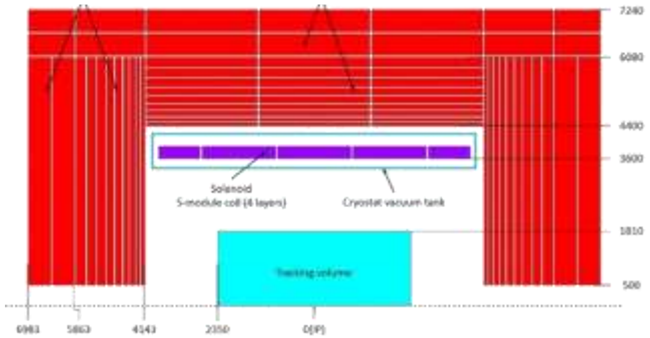
Winding platform

Dummy coil winding

Leak detection before vacuum impregnation

coil after vacuum epoxy impregnation

Detector dummy coil development

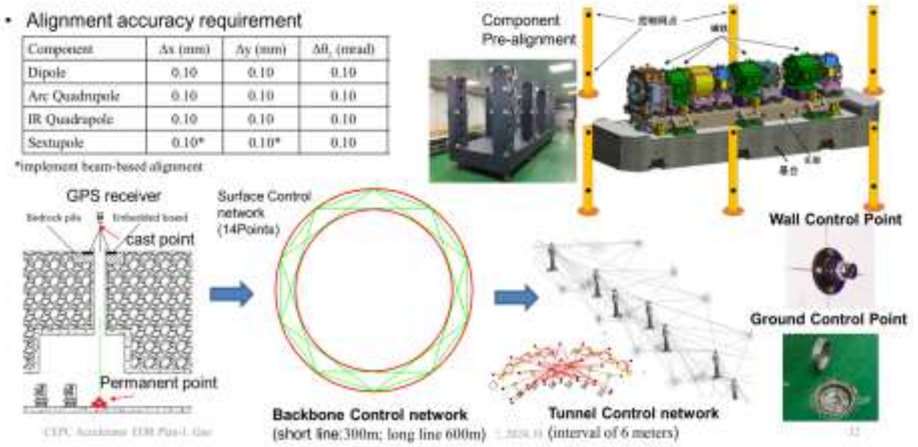


CEPC Alignment and Installation Plan in EDR

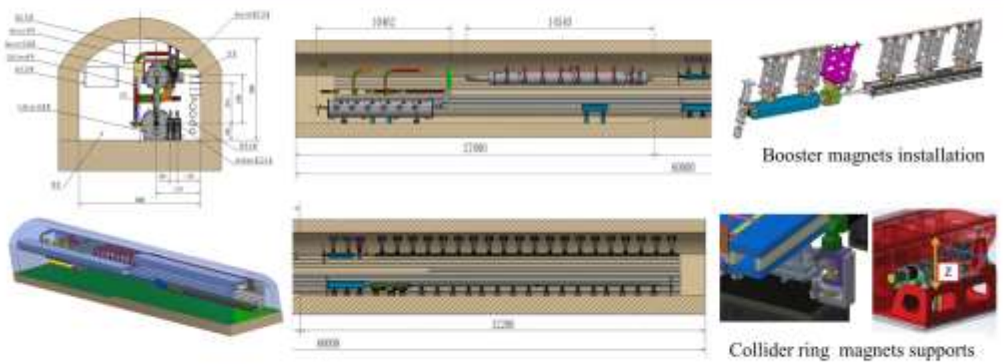
- Alignment accuracy requirement

Component	Δx (mm)	Δy (mm)	Δθ, (mrad)
Dipole	0.10	0.10	0.10
Arc Quadrupole	0.10	0.10	0.10
IR Quadrupole	0.10	0.10	0.10
Sextupole	0.10*	0.10*	0.10

*implement beam-based alignment



CEPC Tunnel Mockup for Installation in EDR



Booster magnets installation

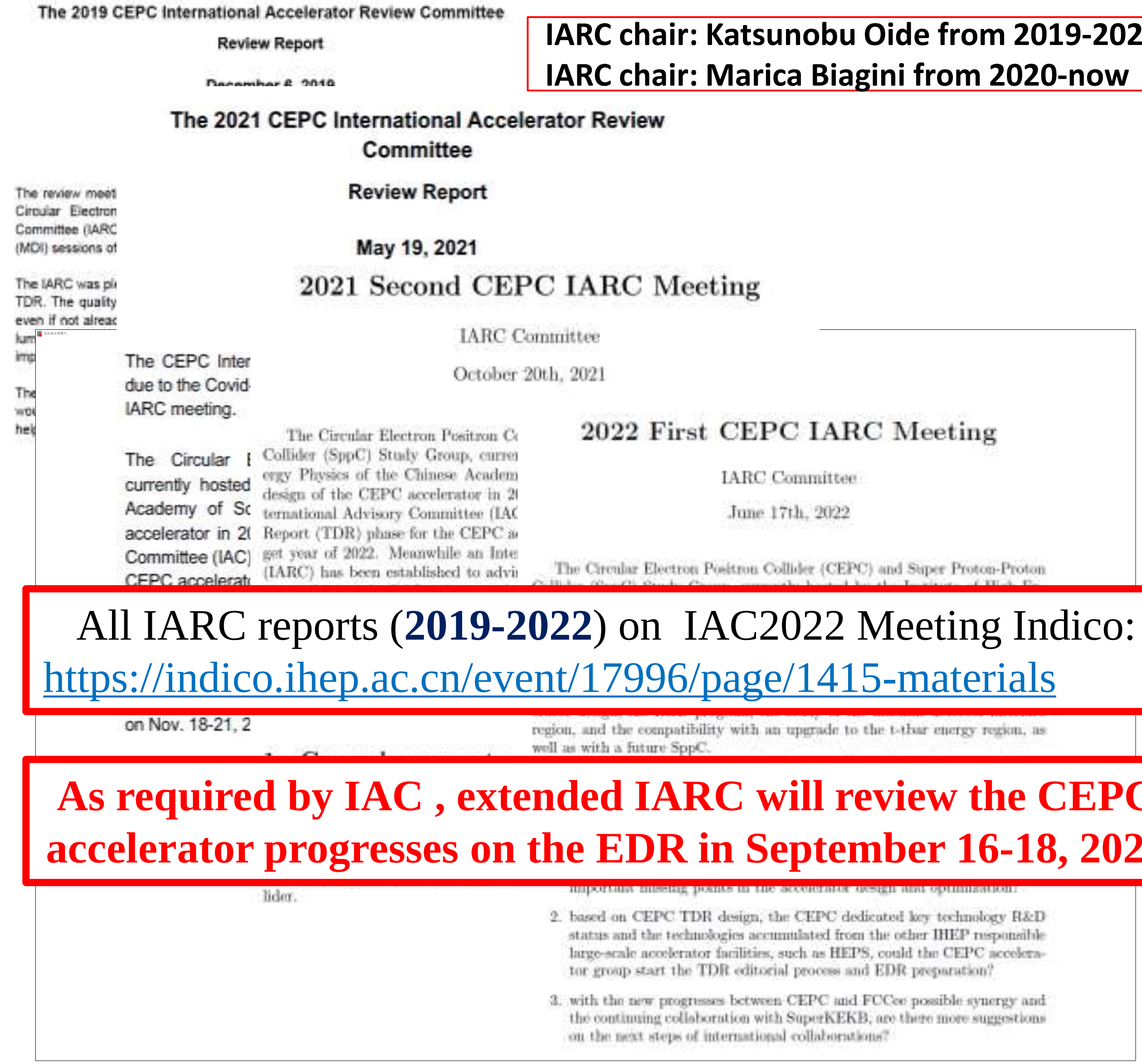
Collider ring magnets supports

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

CEPC Accelerator IARC Meetings in TDR and EDR

International Accelerator Review Committee (IARC) under IAC



IARC chair: Katsunobu Oide from 2019-2020
IARC chair: Marica Biagini from 2020-now

Nov. 2019: https://indico.ihep.ac.cn/event/9960/
May, 2021: https://indico.ihep.ac.cn/event/14295
October, 2021: https://indico.ihep.ac.cn/event/15177
June, 2022: https://indico.ihep.ac.cn/event/16801/

All IARC reports (**2019-2022**) on IAC2022 Meeting Indico: https://indico.ihep.ac.cn/event/17996/page/1415-materials

Jan. 2024: preparation zoom meeting
Sept. 2024: first extended IARC meeting in EDR phase

As required by IAC , extended IARC will review the CEPC accelerator progresses on the EDR in September 16-18, 2024

After the completion of CEPC CDR in Nov. 2018, since the first CEPC IARC meeting in **2019**, there has been **totally 4 IARC meetings till 2022**, with each meeting a carefully written IARC report, which are very helpful for CEPC accelerator in TDR phase and beyond.

CEPC Detector R&D Status

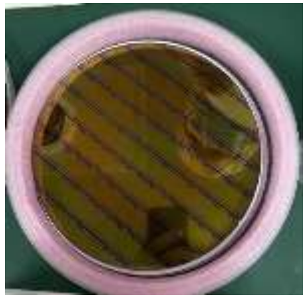
- **Lots of R&D benefitted from past experience**
  - Silicon strip detector: Experience from ATLAS upgrade
  - Drift chamber: Lots of Experience from BESIII
  - Super-conducting magnet: Experience from BESIII
- **New R&D on key technology**
  - Vertex detector
  - TPC drift chamber
  - PFA calorimeter

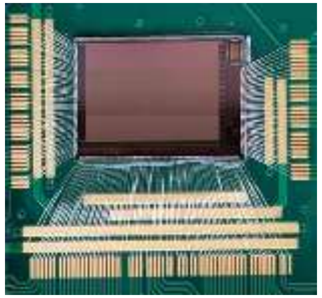
CEPC Detector TDRrd (rd=reference design) will be released in June, 2025

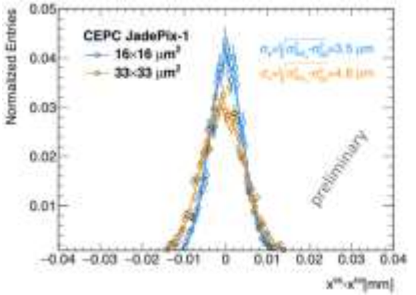
Prototype Manufactured

Sub-detector	Specification	Requirement	World-class level	CEPC prototype
Pixel detector	Spatial resolution	$\sim 3\ \mu m$	$3-5\ \mu m$ [12, 13]	$3-5\ \mu m$ [14–16]
TPC/drift chamber	dE/dx (dN/dx) resolution	$\sim 2\%$	$\sim 4\%$ [17, 18]	$\sim 4\%$ [19–21]
Scintillator-W ECal	Energy resolution Granularity	$< 15\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\ \mathrm{cm}^2$	12.5% [22]	Prototype built to be measured $0.5\times 0.5\ \mathrm{cm}^2$
4D crystal ECal	EM energy resolution 3D Granularity	$\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\times 2\ \mathrm{cm}^3$	$2\%/\sqrt{E(\mathrm{GeV})}$ [23, 24] N/A	Prototyping [25] $\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\times 2\ \mathrm{cm}^3$
Scintillator-Steel HCal	Support PFA, Single hadron σ_E^{had}	$< 60\%/\sqrt{E(\mathrm{GeV})}$	$57.6/\sqrt{E(\mathrm{GeV})}\%$ [26]	Prototyping
Scintillating glass HCal	Support PFA Single hadron σ_E^{had}	$\sim 40\%/\sqrt{E(\mathrm{GeV})}$	N/A	Prototyping $\sim 40\%/\sqrt{E(\mathrm{GeV})}$
Low-mass Solenoid magnet	Magnet field strength Thickness	$2\ \mathrm{T} - 3\ \mathrm{T}$ < 150 mm	$1\ \mathrm{T} - 4\ \mathrm{T}$ [27–29] > 270 mm	Prototyping

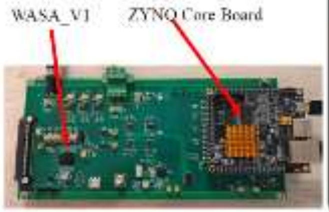
Vertex detector R & D (3- 5 μm reso.)

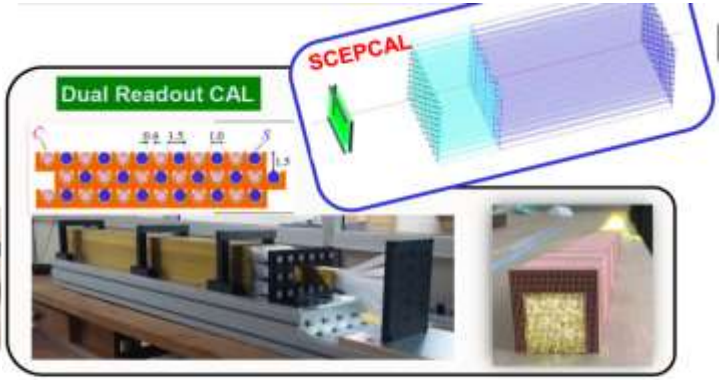






TPC prototype (low power electronics)





CEPC Detector Technology R&D Breakdown

Det	Technology	Det	Technology
Pixel Vertex	JadePix	Calorimeter	Crystal ECAL
	TaichuPix		Stereo Crystal ECAL
	CPV(SOI)		Scint+W ECAL
	Stitching		Si+W ECAL
	Arcadia		Scint+Fe AHCAL
Tracker & PID	CEPCPix		ScintGlass AHCAL
	Silicon Strip		RPC SDHCAL
	TPC		MPGD SDHCAL
	Drift chamber		DR Calorimeter
	PID drift chamber	Muon	Scintillation Bar
	LGAD ToF		RPC
Lumi	SiTrk+Crystal ECAL		μ-Rwell
	SiTrk+SiW ECAL		HTS / LTS Magnet
	CEPC SW		MDI & Integration
	TDAQ		

Large number of detector R&D projects on-going:

Not all at the same level of maturity, some have reach the large-scale prototype level.

Need to converge soon to a CEPC Detector TDR reference:

- Start preparation in January of 2024
- A draft version by December, 2024
- **Official release by June 30, 2025.**

International detector collaborative efforts:

- DRD collaborations
- HL-LHC detector R&D's, help preparing teams for the CEPC detectors.

The 4th Conceptual Detector towards a Reference Design

Scintillator Glass PFA HCAL

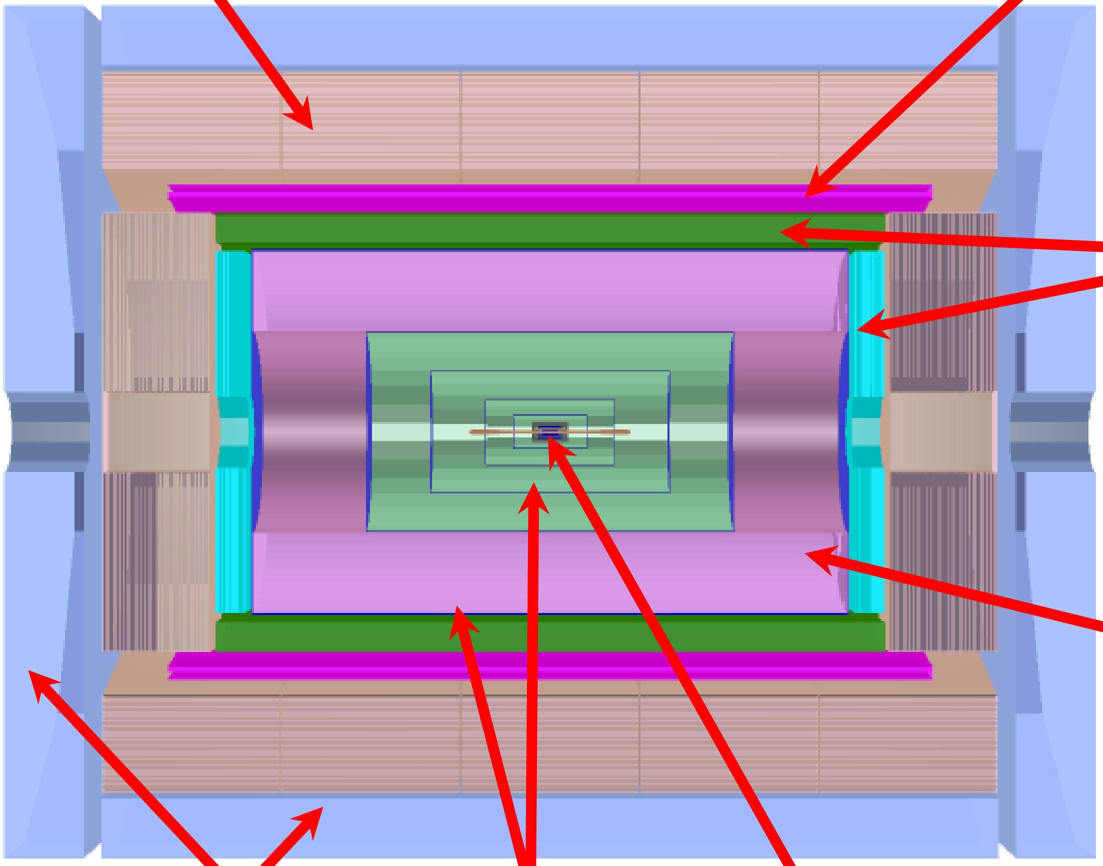
Advantage: Cost efficient, high density

Challenges: Light yield, transparency, radiation hardness, massive production

HTS Solenoid Magnet (3T / 2T)
Between HCAL & ECAL, or inside HCAL

Advantage: HCAL absorbers act as part of the magnet return yoke.

Challenges: Thin enough not to affect the jet resolution; Stability.



Transverse Crystal bar ECAL

Advantage: Better π^0/γ reconstruction

Challenges: Minimum number of readout channels; Compatible with PFA calorimeter; Maintain good jet resolution.

A Drift chamber optimized for PID

Advantage: Work at high luminosity Z runs

Challenges: Sufficient PID power; Thin enough not to affect the moment resolution; Need supplementary ToF detector

Muon+Yoke

Si Tracker
w/TOF outer layer

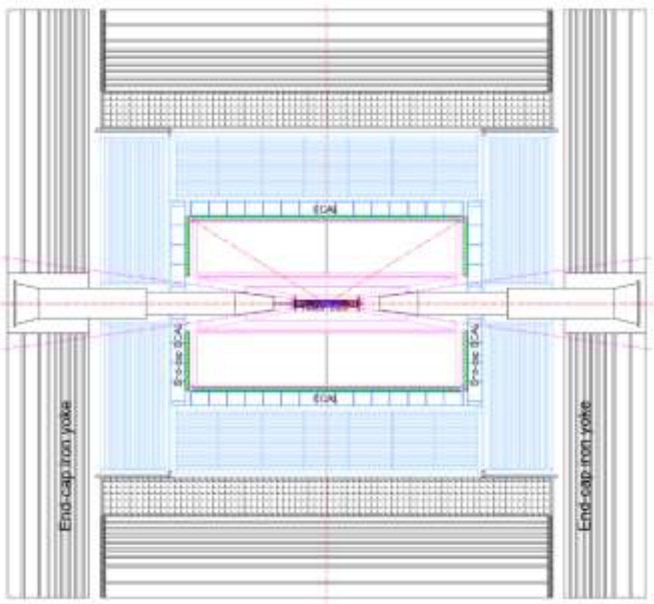
Si Vertex

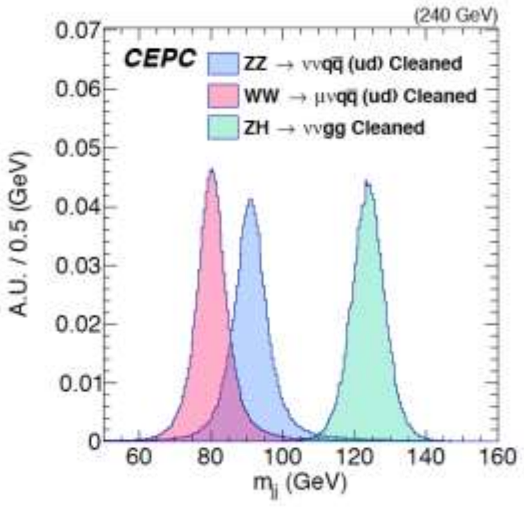
CEPC Detector: Idea of the “4th Concept”

Requirements
boson mass resolution (BMR ~3%)

→

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



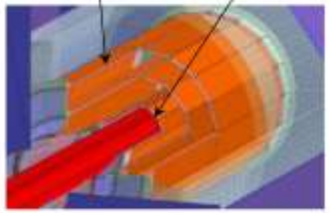


Novel detector design based on PFA calorimeter to improve the BMR from 4% to 3%

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

R&D: Vertex Detector and Tracker



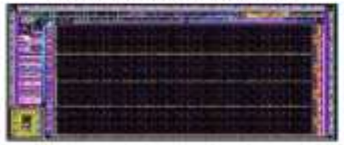
Goal: σ(IP) ~ 5 μm for high P track

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

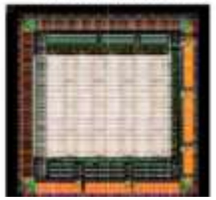
JadePix-3 Pixel size ~16×23 μm²



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

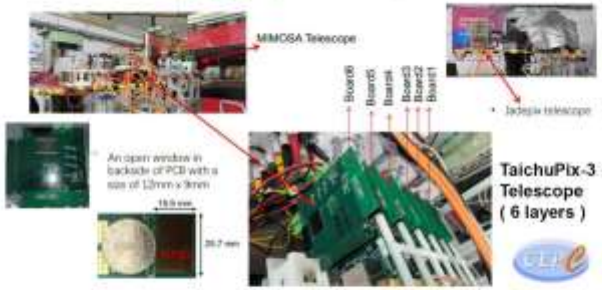
TaichuPix-3, FS 2.5x1.5 cm², 25×25 μm² pixel size

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

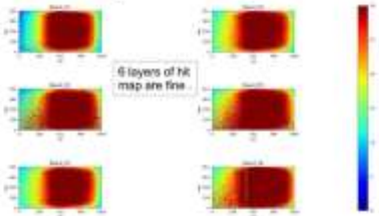


Arcadia by Italian groups for IDEA vertex detector LFoundry 110 nm CMOS

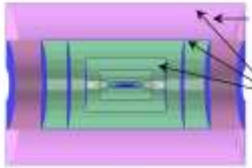
Full vertex detector prototype (TaichuPix-3, JadePix-3) has TB at DESY in Dec. 2022.

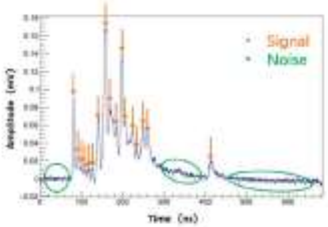


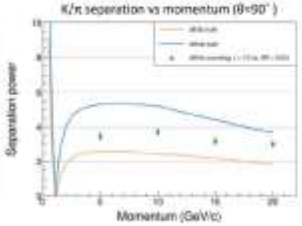
Hitmap of 4 GeV e⁺/e⁻ beam



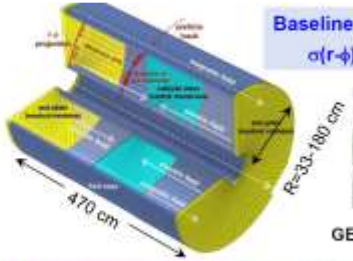
- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture
- Garfield++ for simulation, realistic electronics, peak finding algorithm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



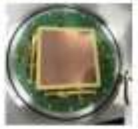




IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022



Baseline main tracker σ(r-ϕ) ~100 μm

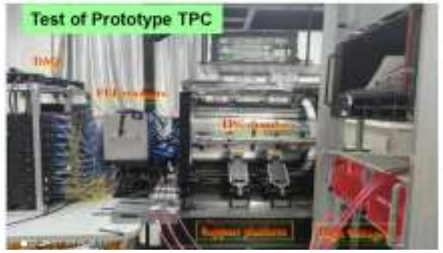


GEM-MM cathode

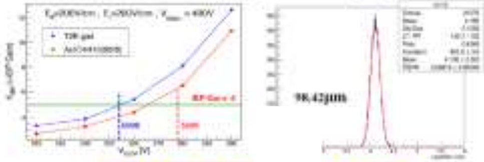
TPC Prototype + UV laser beams

MOST 1 (IHEP+THU)

Low power FEE ASIC



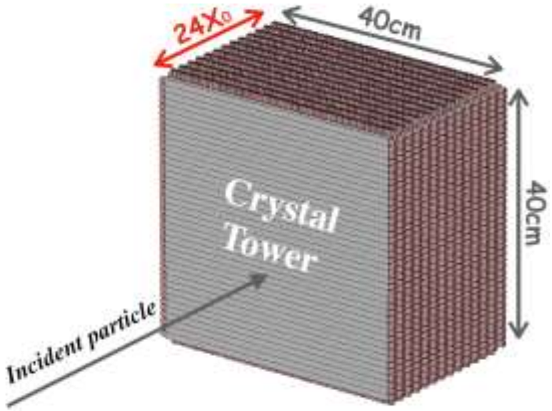
Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.



σ_x < 100 μm for drift length of 27cm

R&D: Calorimeters with PFA

Crystal ECAL



Energy resolution $\frac{\sim 3\%}{\sqrt{E}} \oplus \sim 1\%$

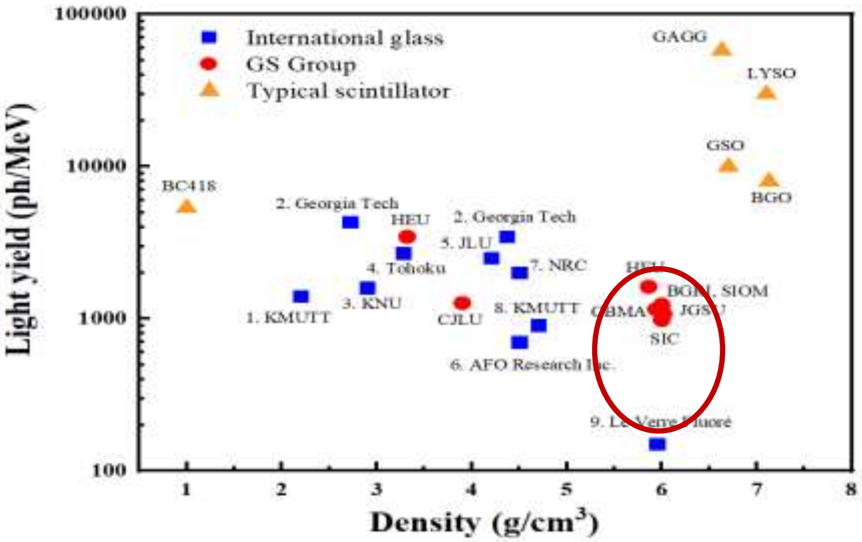
Features:

- Good energy resolution
- 3D shower info. with limited readout channel
- Shower separation < 4 cm

Main issues for R&D

- Jet reconstruction and PFA algorithm

Scintillation Glass HCAL



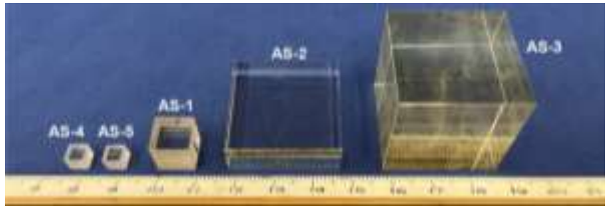
Energy resolution ~40%/√E ± ~ 2%

Features:

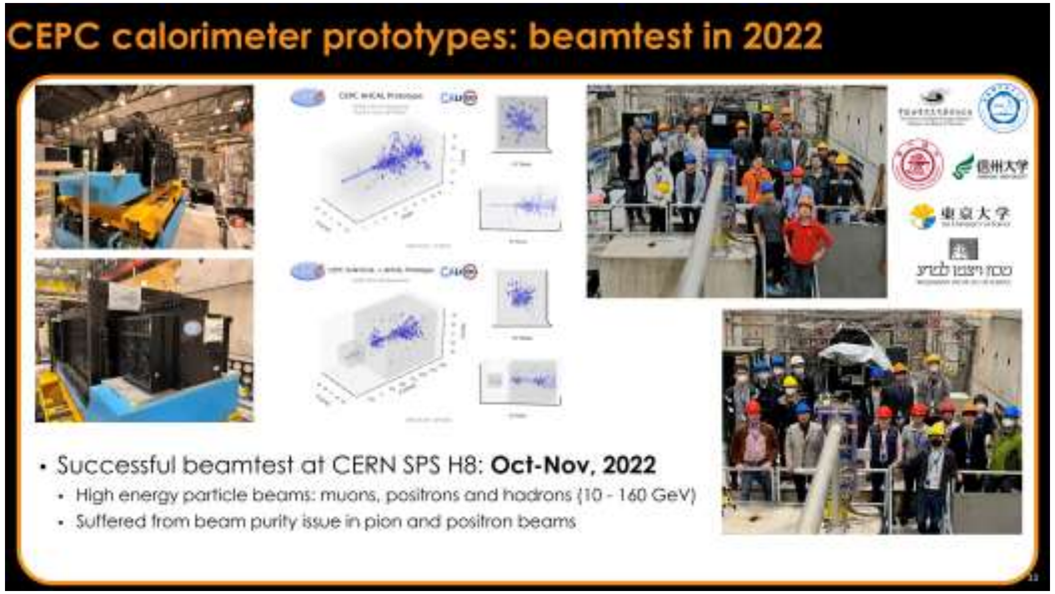
- Large sampling ratio at low cost

Main issues for R&D

- high density, high light yield, radiation hardness, production



CEPC Sub-detectors with Beam Tests



ECFA DRD Proposals From Chinese Institutes/Universities

- Not all information are available. T**here could be small errors in the table.**

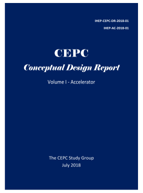
DRD Themes	Proposals	Institutes	People
1 Gaseous detectors	7 (DD)	IHEP, USTC, SJTU, JLU, SIAT, THU, WHU	46
2 Liquid detectors	2 (PA)	IHEP	7
3 Solid state detectors	4 (HJ)	SCNU, SDU, SJTU, THU	10
4 PID and photo detectors	3 (HJ)	IHEP, Henan NU, SDU	11
5 Quantum & emerging tech	2 (HJ)	SDU, THU	7
6 Calorimetry	6 (PA)	IHEP, SDU, SCNU, PKU	37
7 Electronics	3 (HJ)	IHEP, SDU, SJTU	5
8 Integration	3 (HJ)	IHEP	8
Total	**30**	**11 institutes**	**131**

- The total funding, already allocated or wished for, is ~50 MCNY
- Many of the CEPC ongoing R&Ds are in this list. Some may be missing. We will go through all directly related projects and make sure that all necessary ones have proper collaboration.

CEPC Evolution Milestones

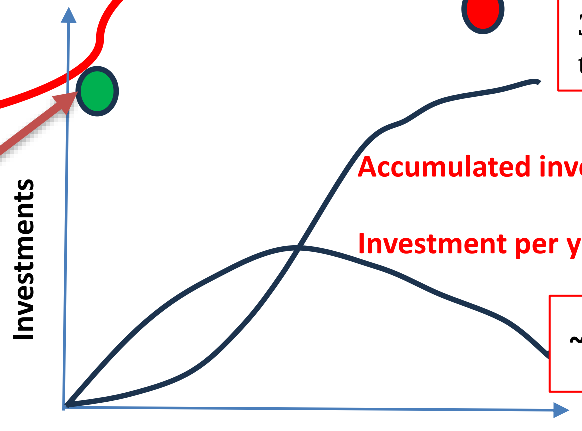
Year	2012	2013	2015	2017	2018	2023	2025	2027	2030	2035

CEPC kickoff meeting in Sept. 2013



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

EDR is the critical path towards CEPC construction starting around 2027



36.4B RMB total

~2B RMB/year

2012.9 CEPC proposed

2013.9

2015.3 Pre-CDR

2017.4 Progress report

2018.11 CDR

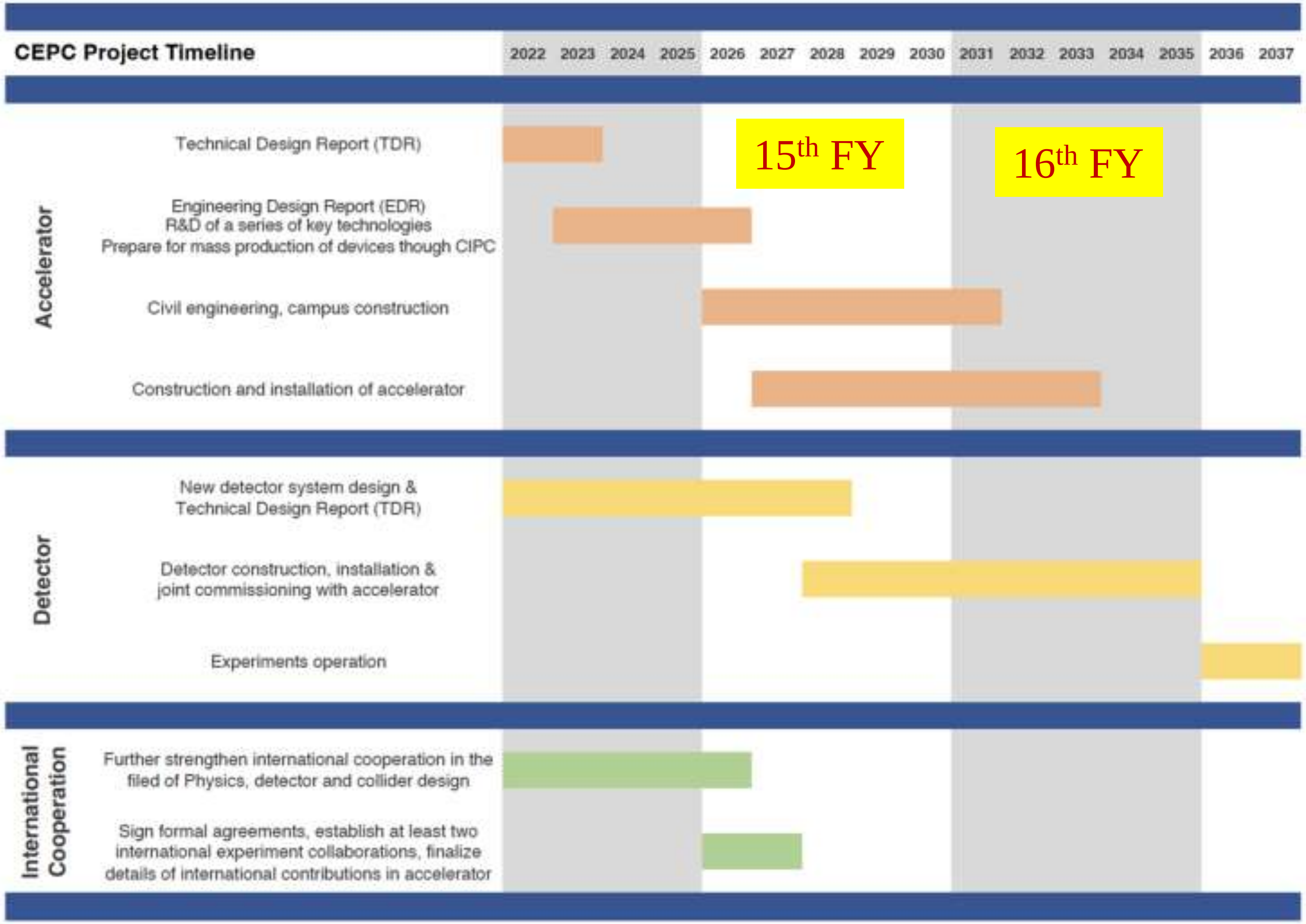
2023.12 TDR

2024 ~ 2027 EDR start of construction

~2035 Completion

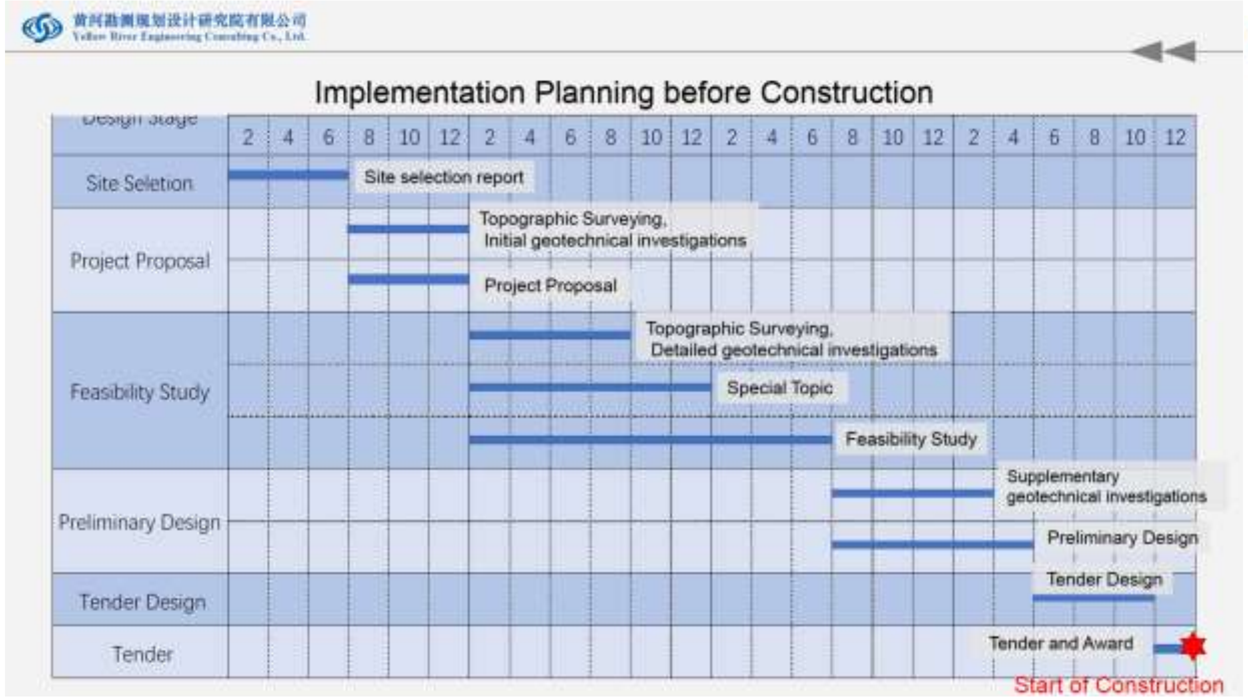
CEPC Planning and Schedule

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



CEPC Site Implementation and Construction Plans

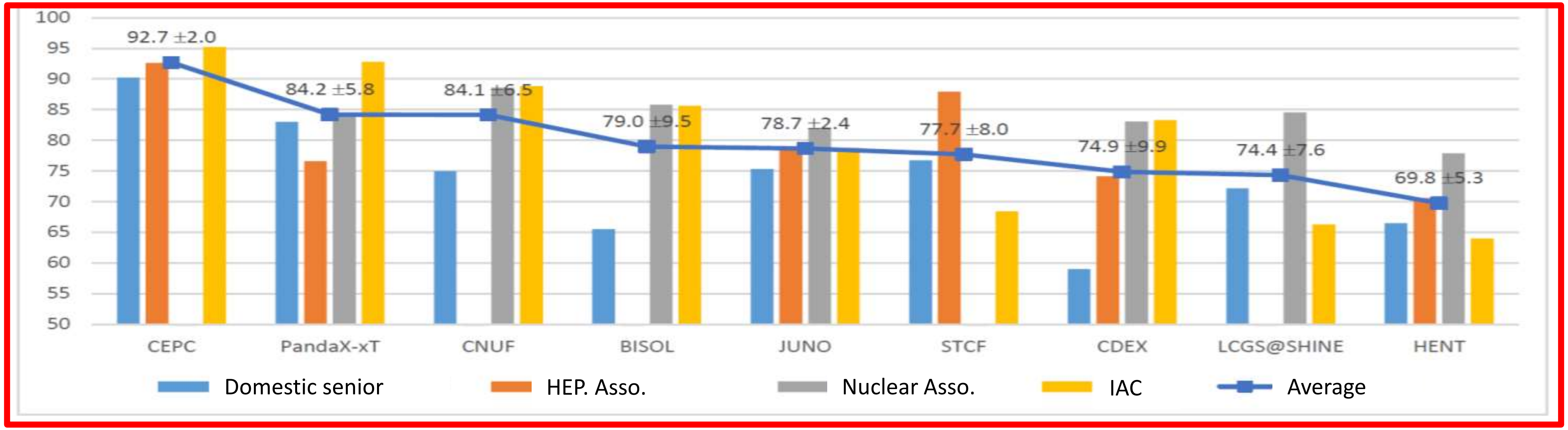
CEPC site implementation plan in EDR



CEPC construction plan

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

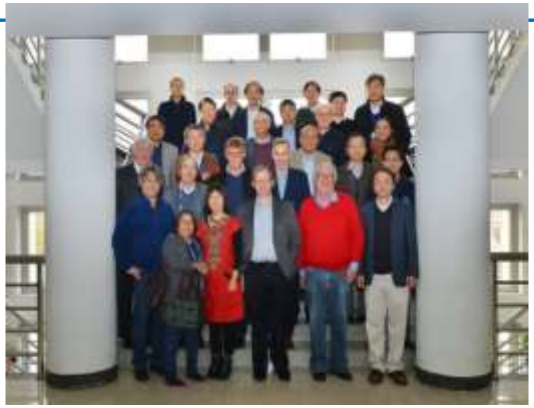
Accelerator TDR report: 1114 authors from 278 institutes (including 159 International Institutes, 38 countries) arXiv: 2312.14363

- 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

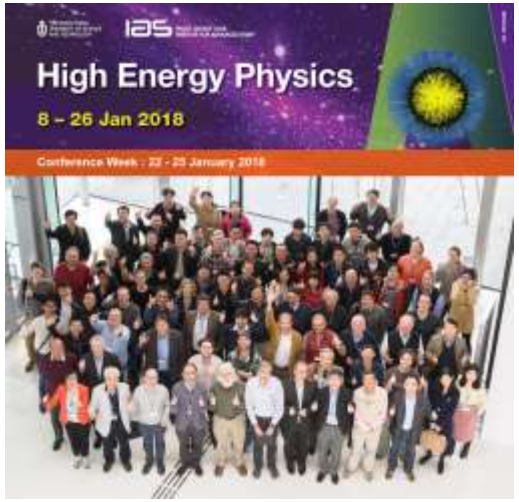
CEPC International Collaboration-2

The first CEPC-SppC international Collaboration Workshop
Nov 6-8, 2017, IHEP, Bejing
http://indico.ihep.ac.cn/event/6618

Workshop on the Circuar Electron Positron Collider-EU edition
May 24-26, 2018, Università degli Studi Roma Tre, Rome, Italy
https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816



3rd CEPC IAC, Nov 8-9, 2017,
IHEP, Beijing



IAS Higgh Energy Physics Workshop
(Since 2015)
http://iasprogram.ust.hk/hep/2018

CEPC Workshop-EU , 2019 Sep 2019, Oxford,UK
https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816

CEPC Workshop, University of Chicago ,
September 16-18, 2019
http://cepc.uchicago.edu/

CEPC Workshop, he Catholic University of America,
22-23 April 2020, Washingtong, USA (online)
https://indico.cern.ch/event/863751/

More than 20 MoUs have been signed with international institutions and universities

CEPC International Collaboration-3

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

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 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 2024 international workshop on the high energy Circular Electron Positron Collider (CEPC) will be held from Oct. 23-27, 2024, Hangzhou, China

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

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

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
- Reference detector TDR under preparation, to be completed by 2025 for the proposal of the 15th 5-year plan
- A strong and experienced team, 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.

Acknowledgements

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

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

Thanks for your attention