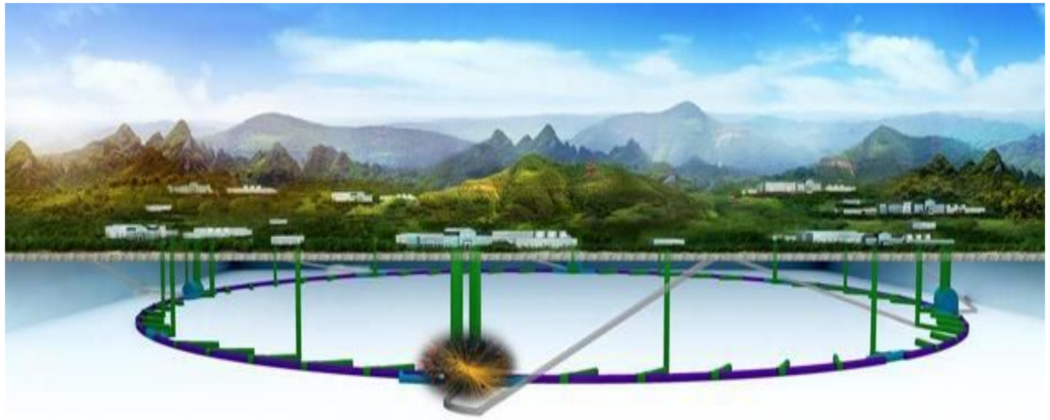
Status of the CEPC Project

Haijun Yang (for the CEPC study group)

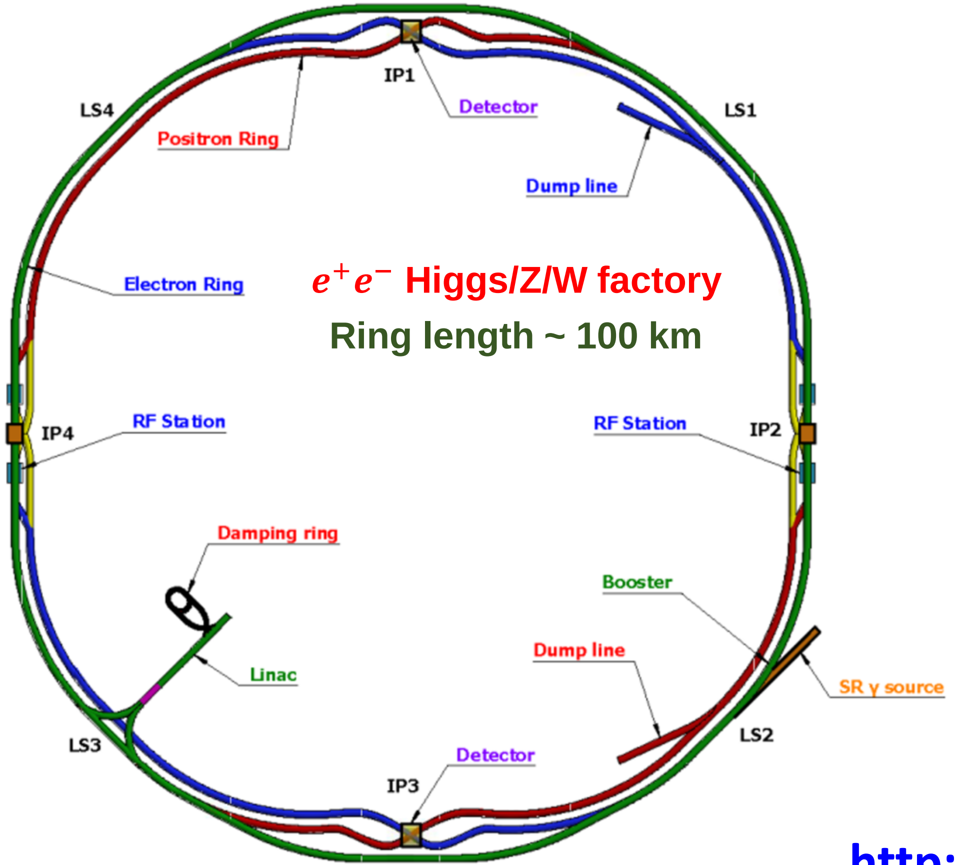
Outline

- Introduction to CEPC
  - Goal and major milestones
  - Consensus on e^+e^- Higgs Factory
- CEPC Status and Progress
  - Physics Program
  - Accelerator R&D
  - Detector R&D
- Project Planning and Development
- Summary



Circular Electron Positron Collider (CEPC)

- The CEPC was proposed by the Chinese HEP community in 2012 right after the Higgs discovery. It aims to start operation in 2030s, as a Higgs / Z / W factory.
- To produce Higgs / W / Z / top for high precision Higgs, EW measurements, studies of flavor physics & QCD, and probes of new physics beyond the SM.
- It is possible to upgrade to a *pp* collider (SppC) of $\sqrt{s}$ ~ 100 TeV in the future.



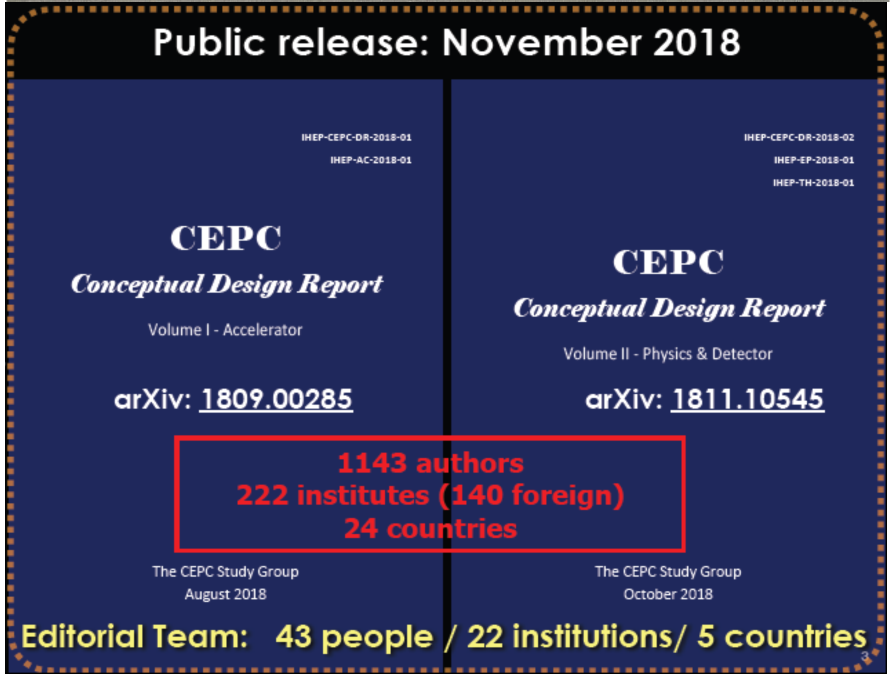
http://cepc.ihep.ac.cn/

CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

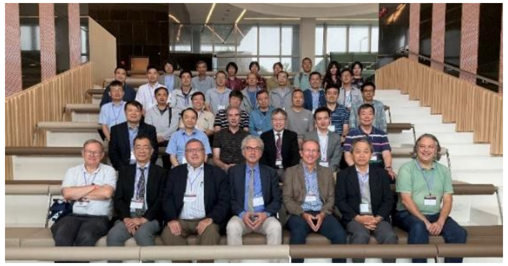
First CEPC IAC Meeting (2015.9)

CEPC CDR Released (2018.11)

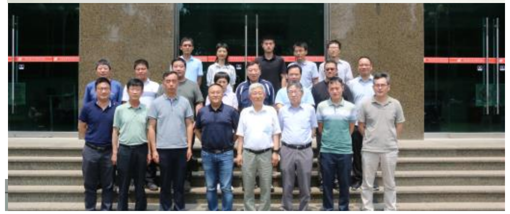


CEPC Major Milestones

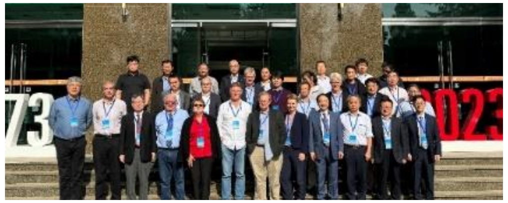
CEPC Accelerator TDR Review
June 12-16, 2023, Hong Kong



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

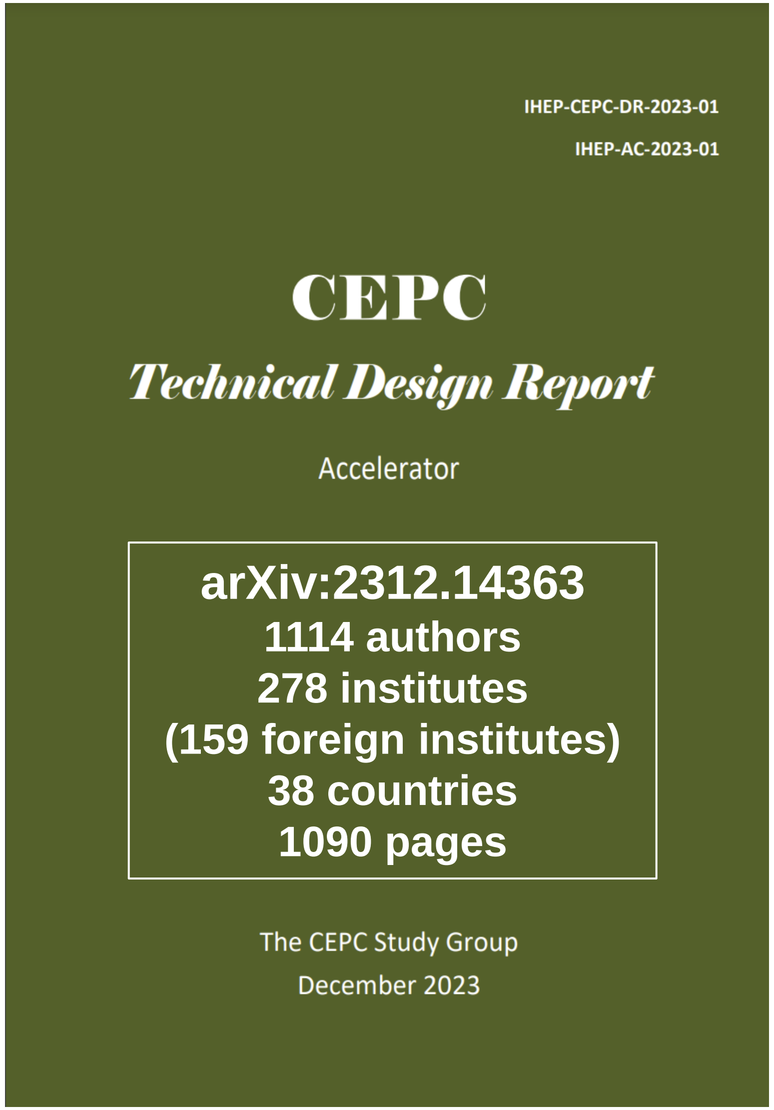


Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP



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

CEPC Accelerator TDR released in December, 2023



IHEP-CEPC-DR-2023-01

IHEP-AC-2023-01

CEPC

Technical Design Report

Accelerator

arXiv:2312.14363
1114 authors
278 institutes
(159 foreign institutes)
38 countries
1090 pages

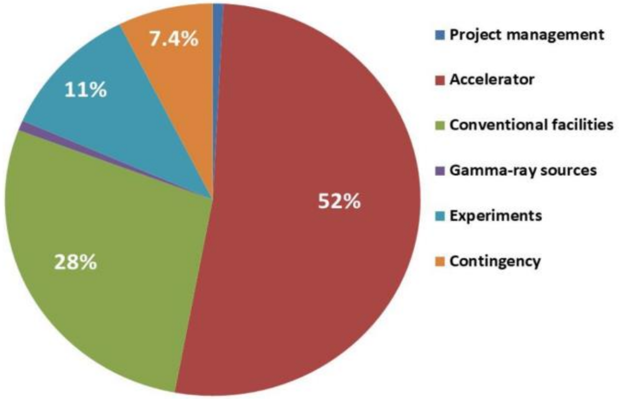
The CEPC Study Group

December 2023

Distribution of CEPC Project **TDR cost** of **36.4B RMB (~4.6B Euro)**

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%



Global HEP Consensus on Higgs Factories

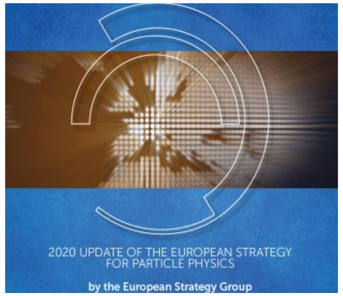
The scientific importance and strategical value of e^+e^- Higgs factories is clearly identified.

China

2013, 2016: *China Xiangshan Science Conference concluded that* ***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: *European Strategy for Particle Physics,* ***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.*

ICFA

2022, *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

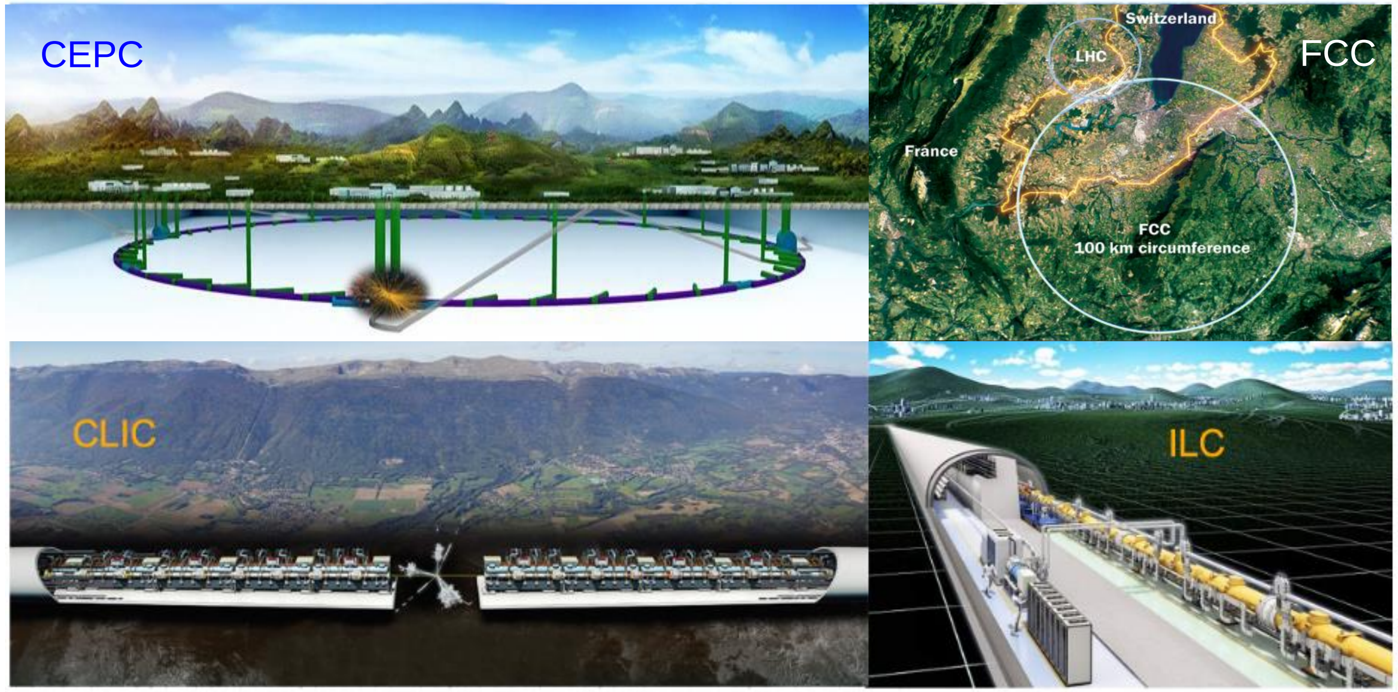
Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio 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:

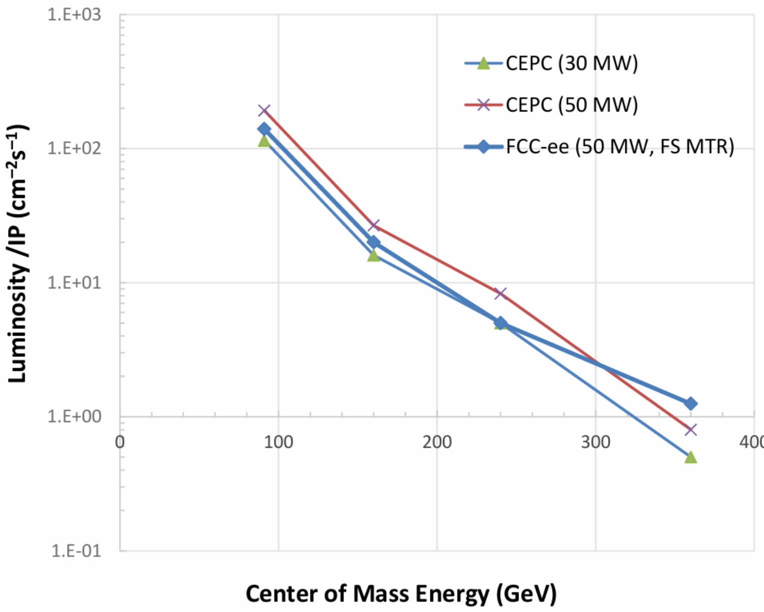
1. The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
2. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
3. A plan for 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

Comparison of Higgs factories: Circular vs Linear



Luminosity / IP (CEPC vs FCC-ee)



Luminosity per IP (10^{34} cm^{-2}s^{-1})	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

CEPC has strong advantages among mature e^+e^- Higgs factories (design report delivered)

Versus FCC-ee

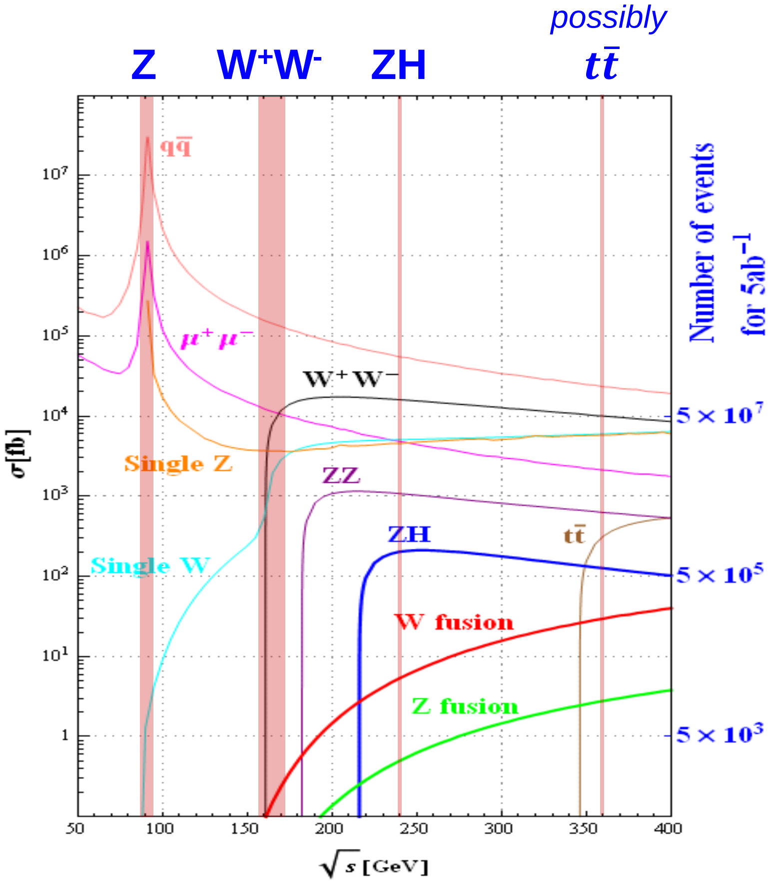
- Earlier data: collisions expected in 2030s (vs. ~ 2040s)
- Large tunnel cross section (ee & pp coexistence)
- Lower construction cost

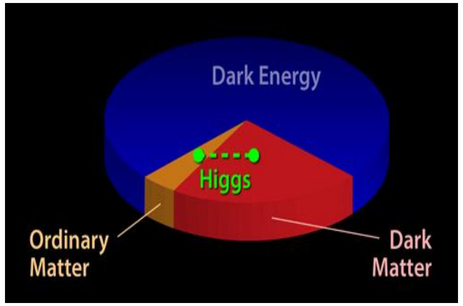
Versus Linear Colliders

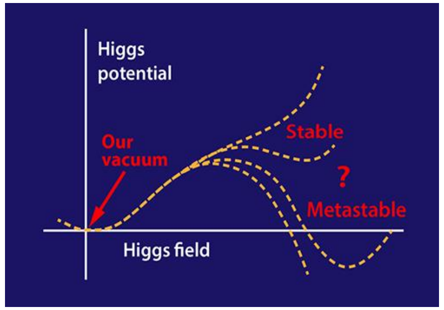
- Higher luminosity / precision for Higgs & Z
- Potential upgrade for pp collider

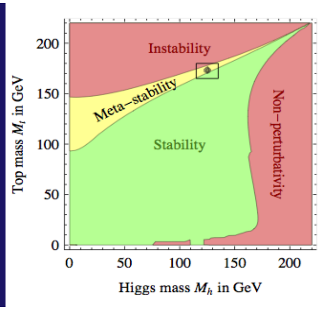
CEPC Physics Program

- **Measurements of Higgs, EW, flavor physics & QCD at unprecedented precision**
- **BSM physics (e.g. dark matter, EWPT, LLP, …) up to ~ 10 TeV scale**







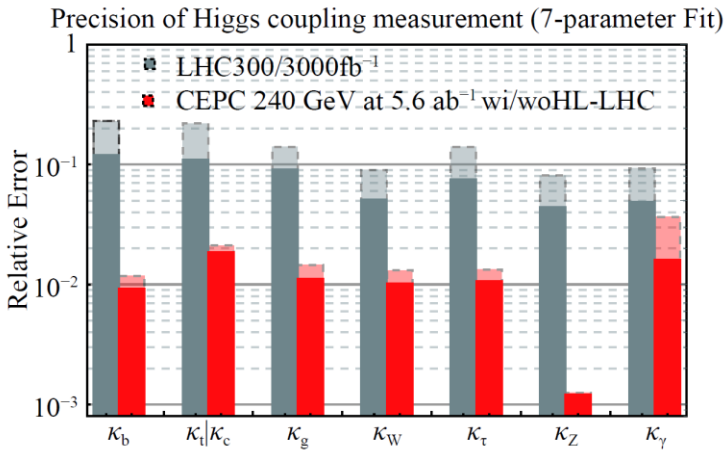


Operation mode		ZH	Z	W+W-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	~5
30 MW	L / IP [×10^{34} cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.6
	Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
50 MW	L / IP [×10^{34} cm^{-2}s^{-1}]	**8.3**	**192**	**26.7**	**0.8**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	22	100	6.9	1
	Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

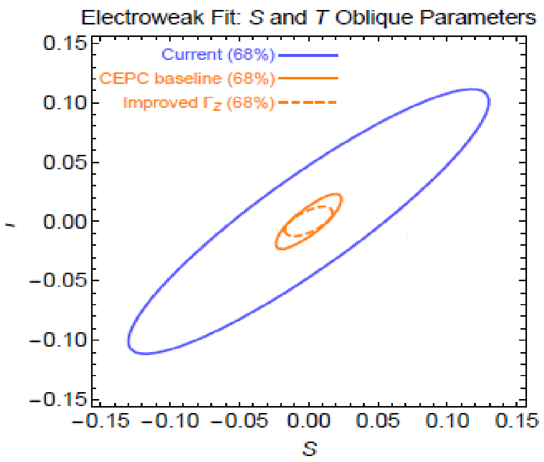
Manqi Ruan' talk: Flavor physics at CEPC
Xuai Zhuang' talk: BSM searches at CEPC

CEPC Physics Program: Precision & Discovery

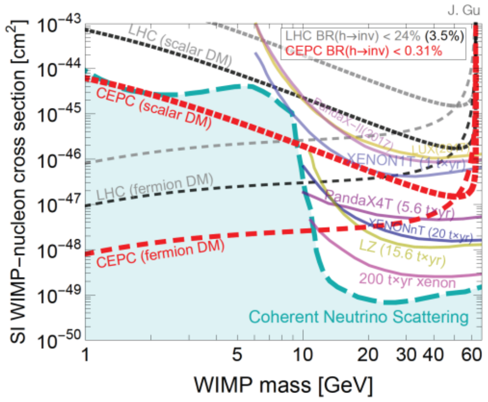
Higgs coupling precision can be improved by an order of magnitude

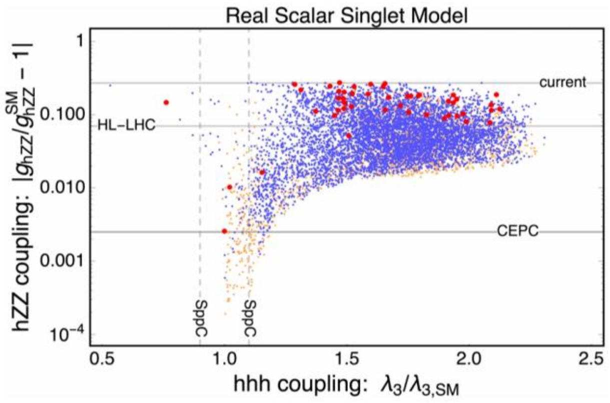


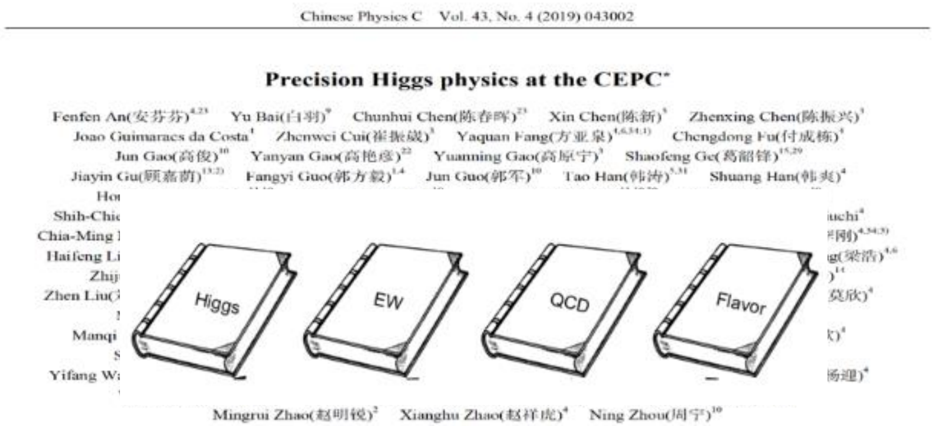
EW measurement can be improved by a large factor



Direct or indirect probe to dark matter and EWPT etc, an order of magnitude more sensitive than the HL-LHC







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

Precision Higgs physics at the CEPC*

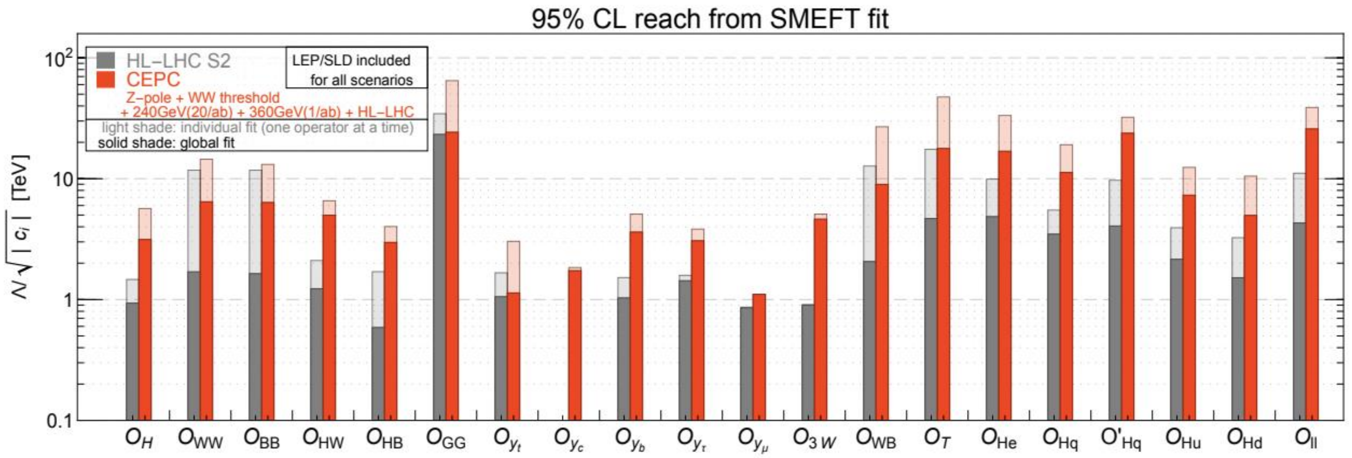
Fenfen An(安芬芬) Yu Bai(白羽) Chunhui Chen(陈春晖) Xin Chen(陈新) Zhenxing Chen(陈振兴) Joao Guimaraes da Costa Zhenwei Cui(崔振崴) Yaquan Fang(方亚泉) Chengdong Fu(付成栋) Jun Gao(高俊) Yanyan Gao(高艳彦) Yuanning Gao(高原宁) Shaofeng Ge(葛韶锋) Jiayin Gu(顾嘉荫) Fangyi Guo(郭方毅) Jun Guo(郭军) Tao Han(韩涛) Shuang Han(韩爽) ... Mingrui Zhao(赵明锐) Xianghu Zhao(赵祥虎) Ning Zhou(周宁)

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

❖ ~ 100 Journal / arXiv papers

CEPC can reveal new physics at energy ~ 10 TeV or higher

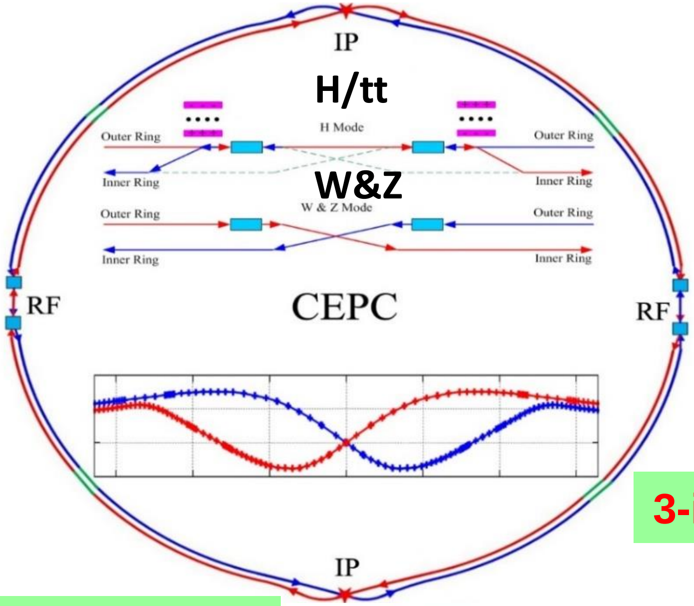
Energy scale probed

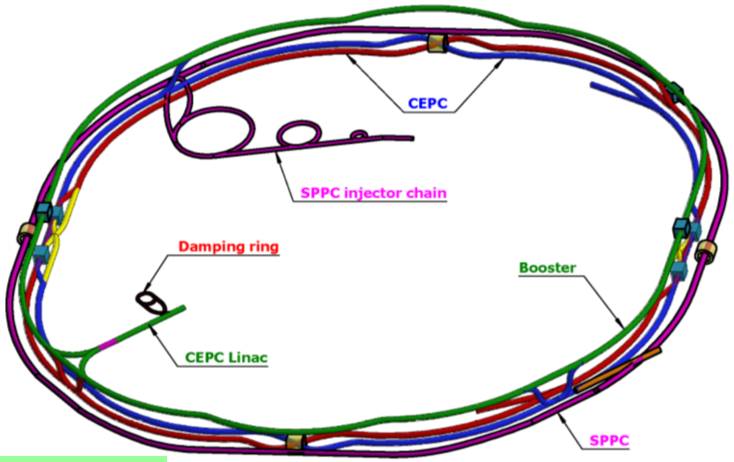


CEPC Accelerator Design and Layout

- 100 km double ring design (30 MW SR, upgradable to 50MW, ttbar)
- Switchable operation for H, Z, W and top modes (bypass scheme)
- Shared tunnel: compatible design for booster, CEPC and SppC

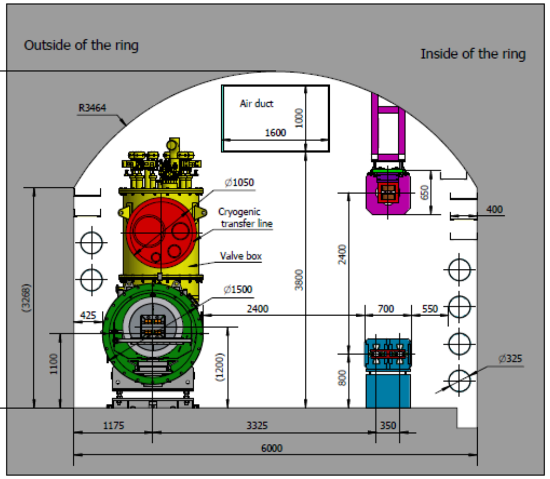
Dou Wang's posters
- CEPC Booster design
- CEPC carbon footprint and CO_2 reduction



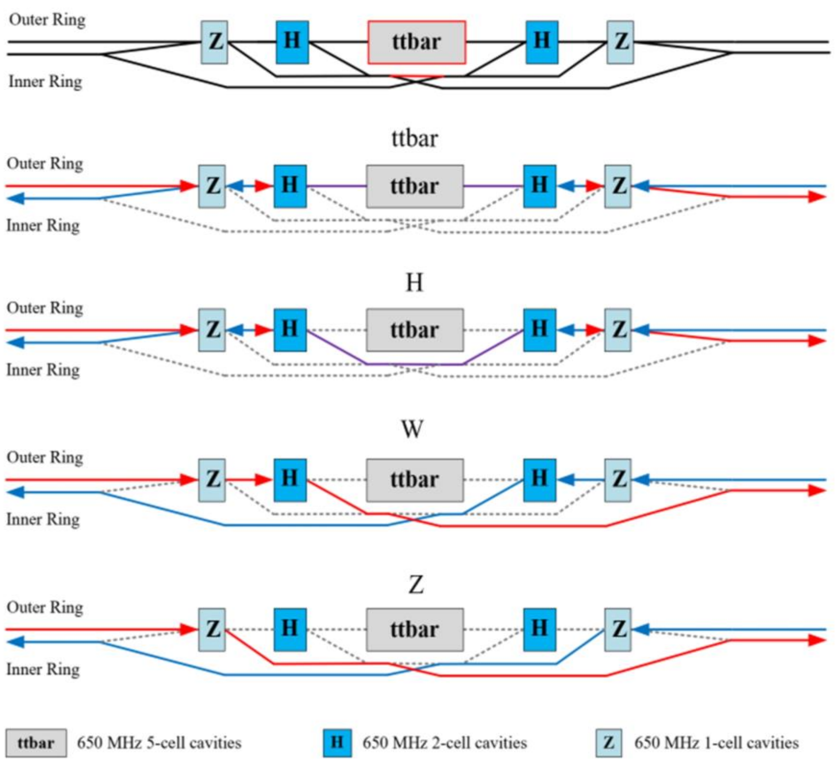


3-in-1 tunnel

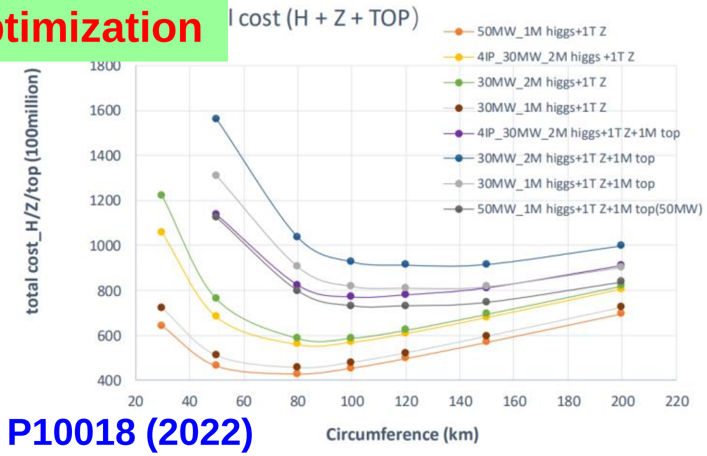
TUNNEL CROSS SECTION OF THE ARC AREA



H/W/Z/tt switchable bypass scheme



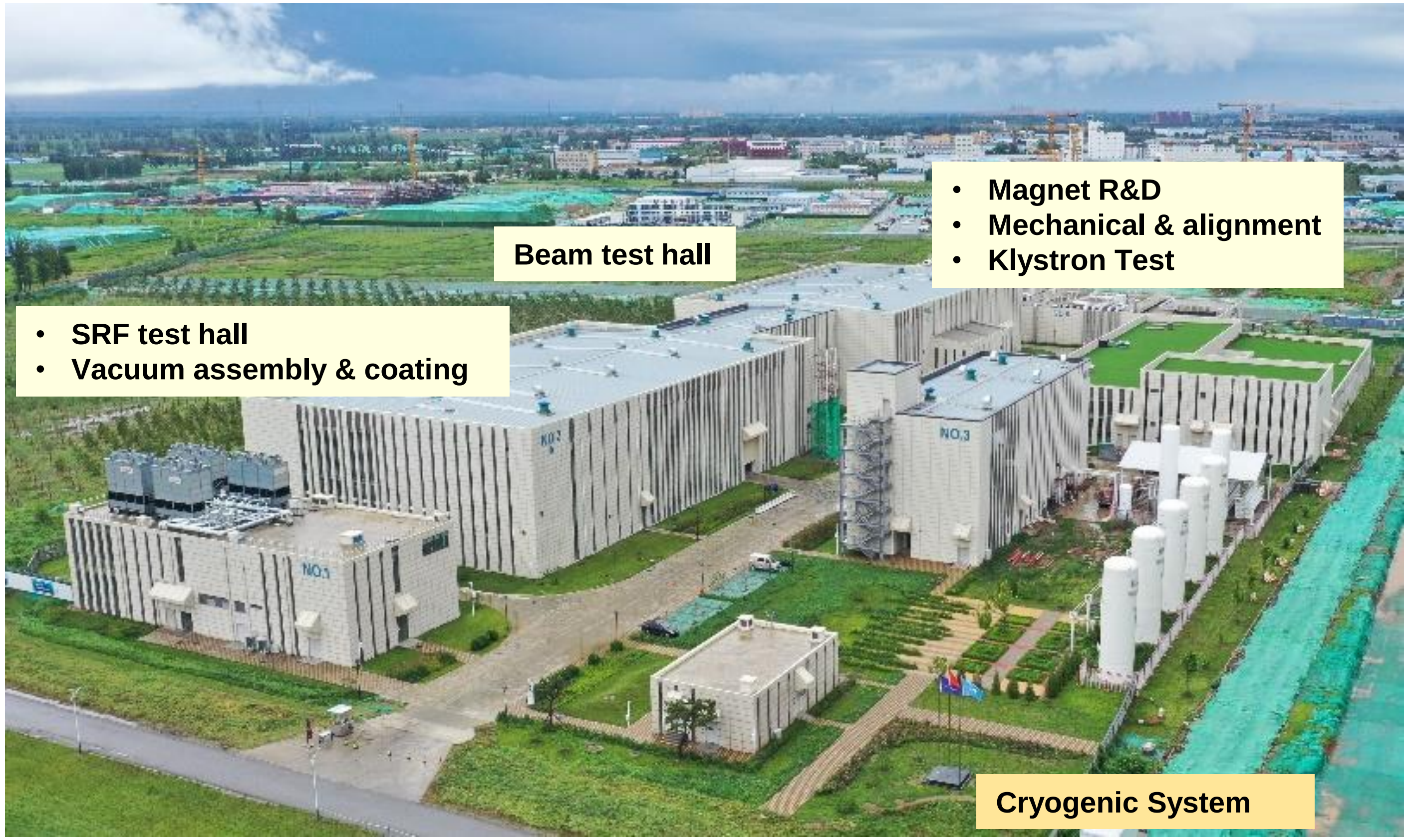
Cost optimization

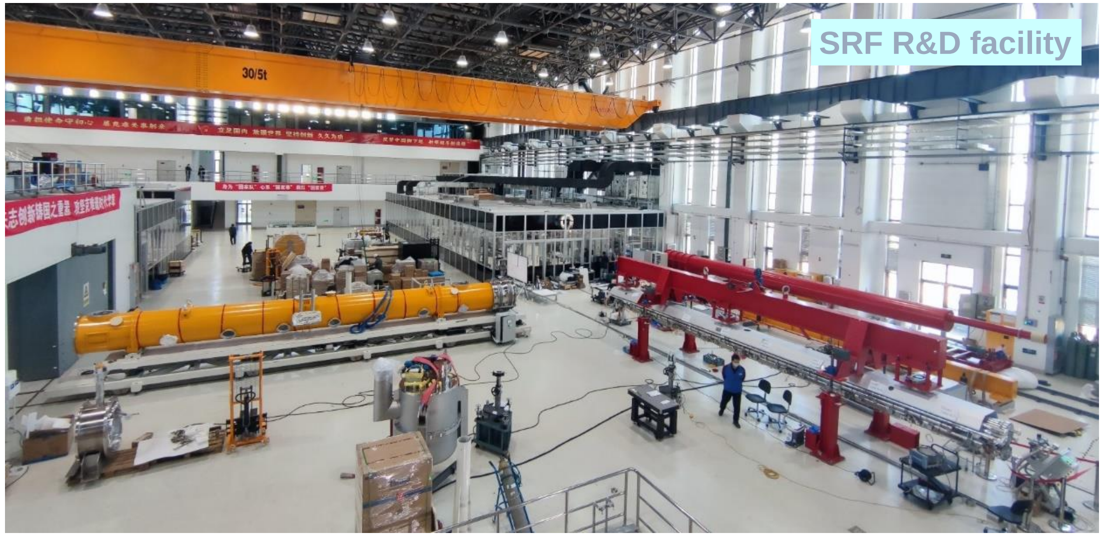


JINST 17 P10018 (2022)

arXiv:2312.14363

CEPC Key Technology R&D Platform



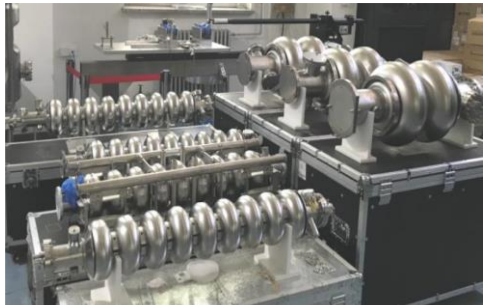


Accelerator key technology R&D platform was established:

- SRF cavity and module
- High precision magnet
- Vacuum assembly & coating
- High efficiency Klystron
- Mechanics and alignment
- Beam test facility

CEPC R&D: High Q SRF Cavities

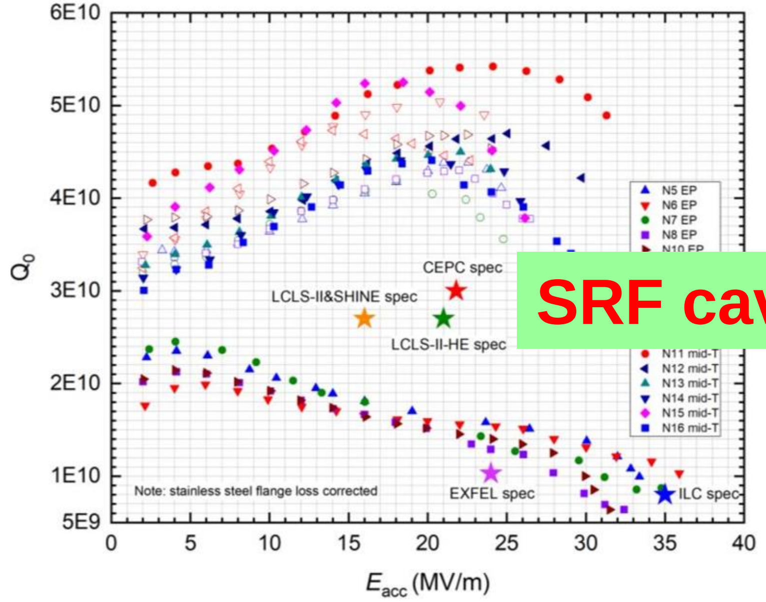
- 1.3 GHz 9-cell SRF cavity for booster: Q_0 = 3.4E10 @ 26.5 MV/m
- 650 MHz 2-cell SRF cavity for collider ring: Q_0 = 6.0E10 @ 22.0 MV/m
- 650 MHz 1-cell SRF cavity for collider ring: Q_0 = 6.0E10 @ 31.0 MV/m



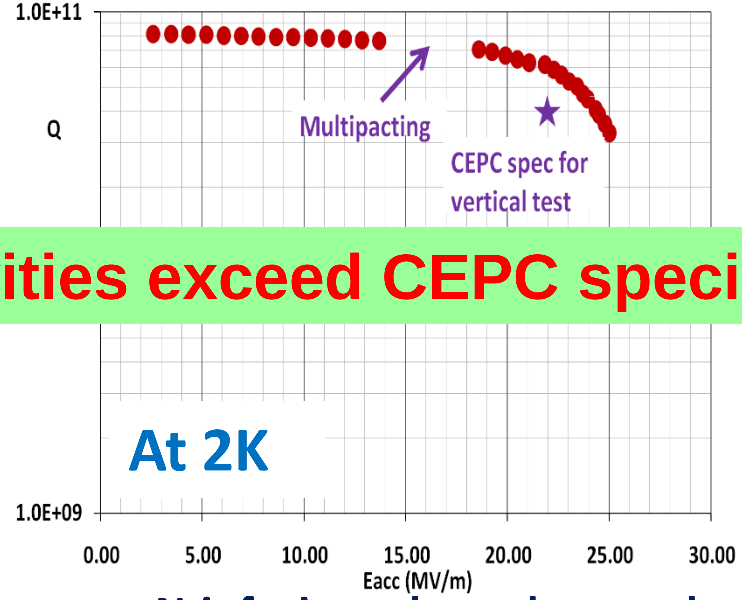
Vertical test of 650 MHz 2-cell cavity

Vertical test of 650MHz 1-cell Cavity

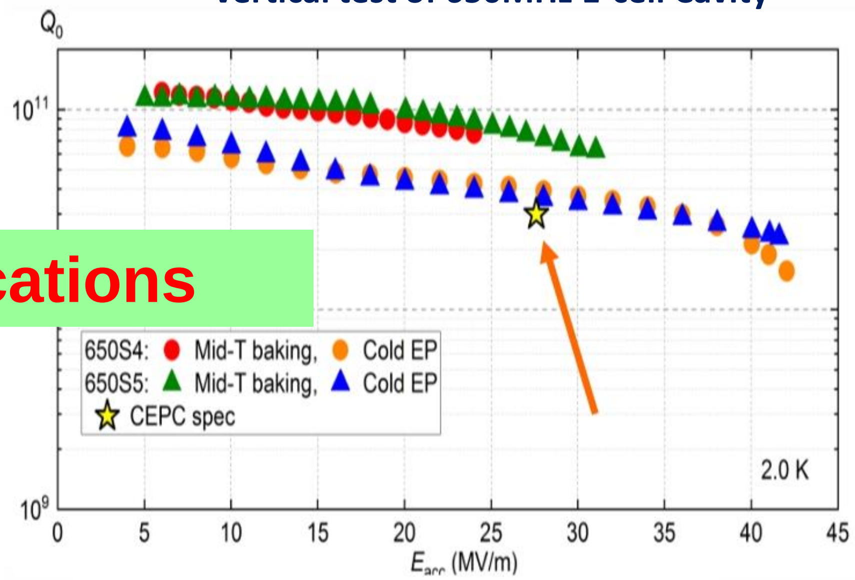
SRF cavities exceed CEPC specifications



Medium-temperature (Mid-T) annealing adopted to reach Q_0 = 3.4E10 @ 26.5 MV/m



N-infusion adopted to reach Q_0 = 6.0E10 @ 22.0 MV/m



Cold-EP and Mid-T baking Q_0 = 6.0E10 @ 31 MV/m

CEPC R&D: 8 × 9-cell High Q Cryomodule

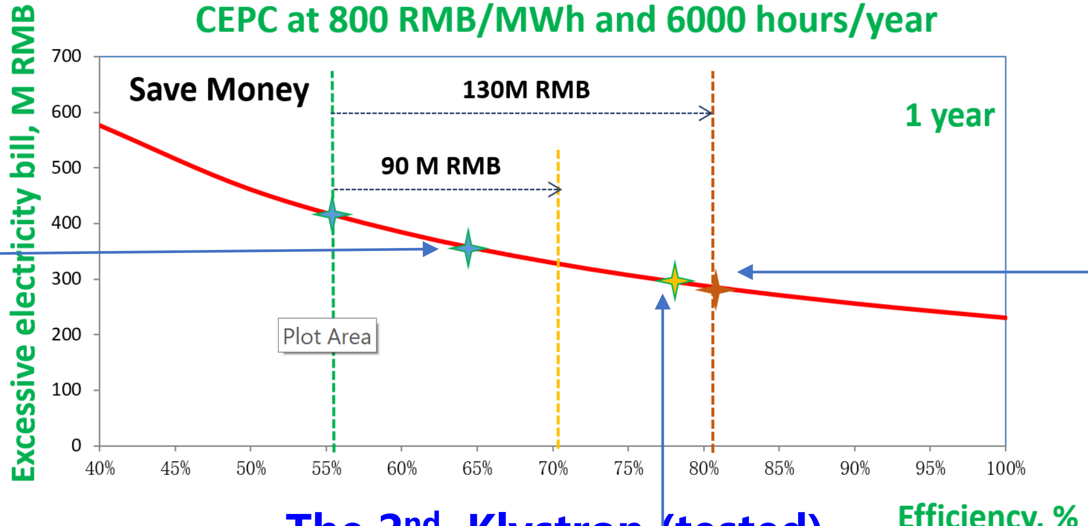
CEPC Booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects

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}			

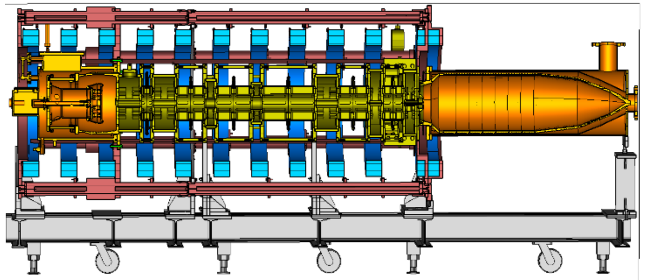
SRF cavities exceed CEPC specifications

CEPC R&D: High Efficiency Klystrons

- The 1st Klystron prototype, achieved efficiency ~ 62%
- The 2nd Klystron prototype was tested in Feb. 2024, achieved efficiency ~ 77.2%
- The 3rd Klystron prototype (MBK) with manufacture underway, design efficiency is ~ 80%
- High efficiency Klystron helps to reduce electricity consumption

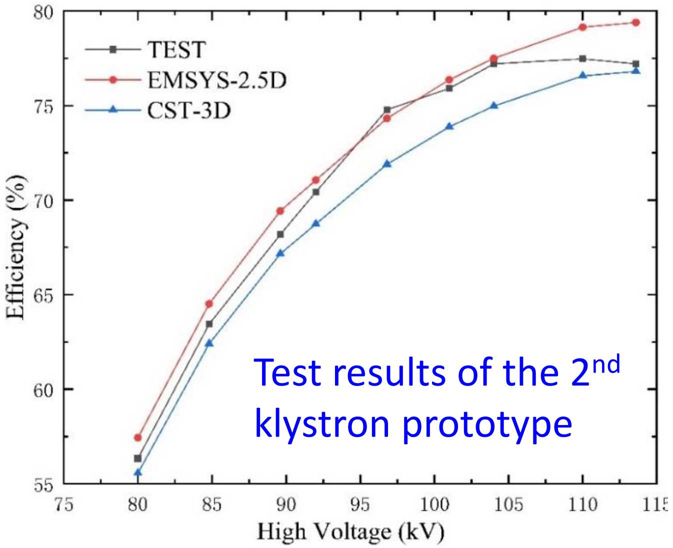


The 3rd multi-beam Klystron (MBK) under fabrication



The 1st Klystron (tested)

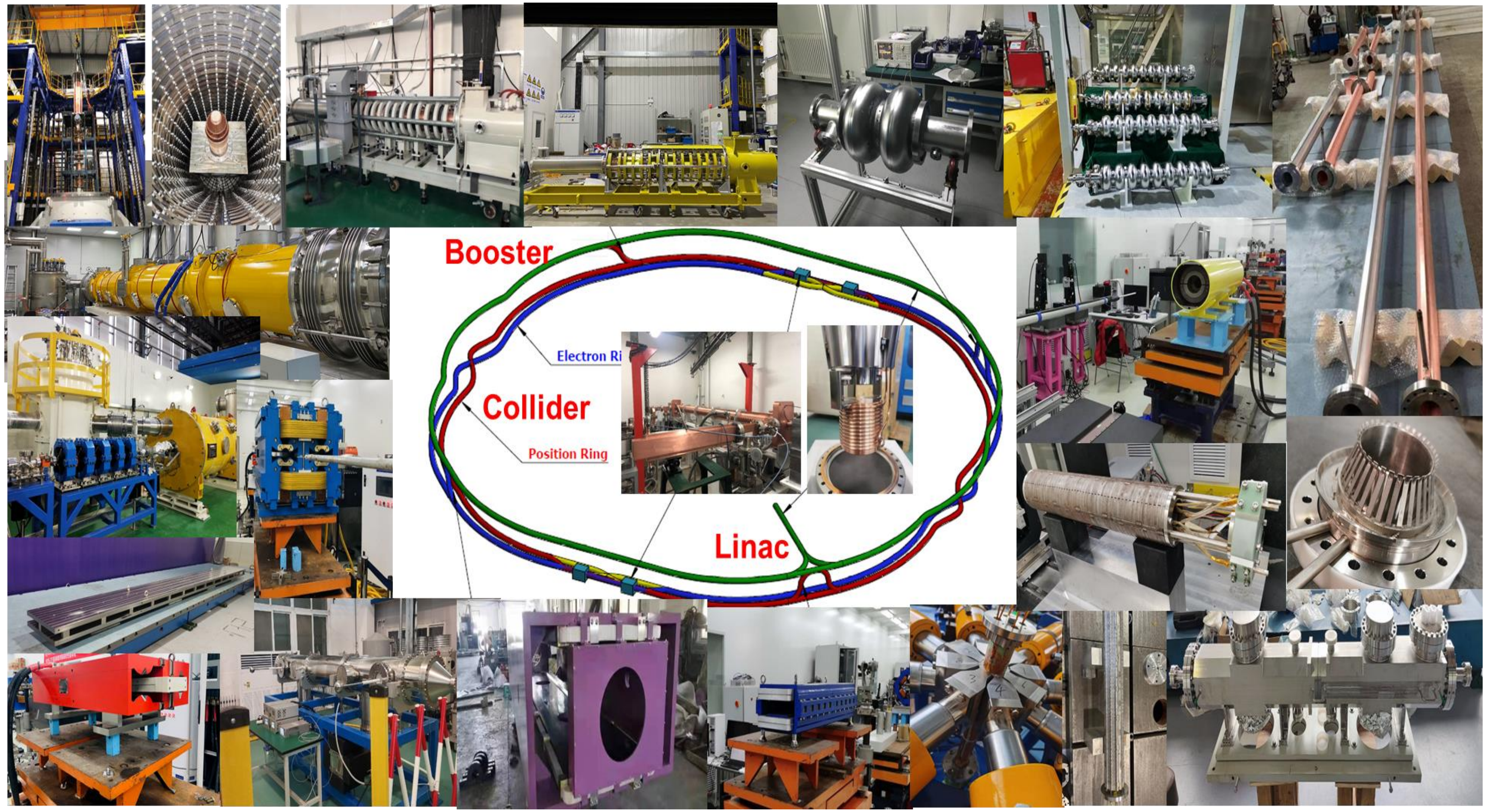
The 2nd Klystron (tested)



Test results of the 2nd klystron prototype

CEPC R&D: Accelerator Key Technologies

- Key technologies R&D span over all components listed in CDR.
- About 10% remaining (eg. RF power source, control, alignment, SC magnets, machine integration) to be completed by 2026.

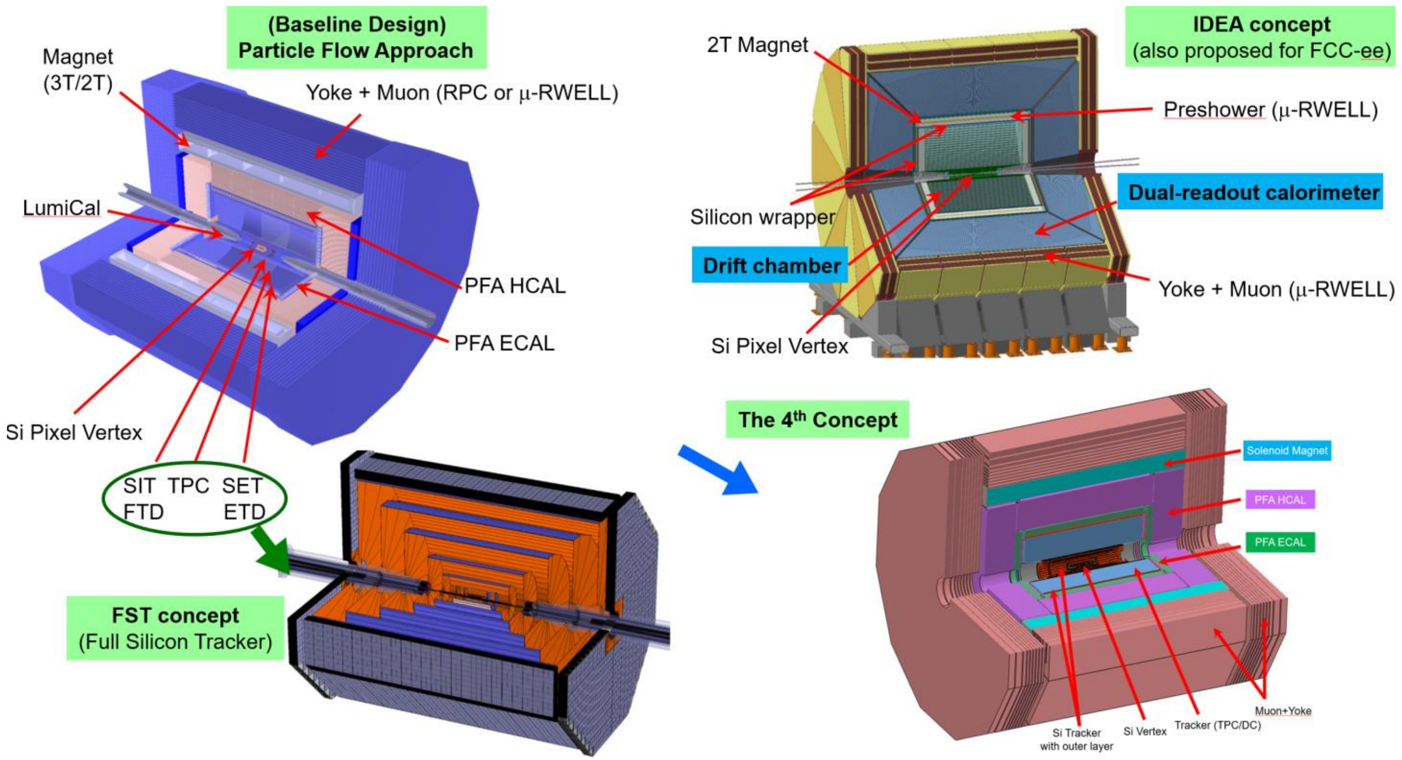


✓ Specification Met

✓ 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%

CEPC Detector Designs: the "4th Concept"



Novel detector design based on PFA calorimeter. Aim at improving BMR from 4% to 3%

Detector	World-class level	4th concept
PFA ECAL	~ 15-20% / √E	~ 3% / √E
PFA HCAL	~ 50-60% / √E	~ 40% / √E

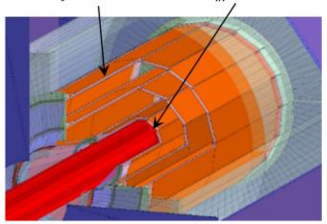
- **Silicon combined with TPC or DC for better tracking & PID**
- **Crystal ECAL with timing for PFA and better EM resolution**
- **Scintillating glass HCAL for better sampling and resolution**

Zhijun Liang' talk: Development of vertex detector prototype for CEPC
Yiming Li's talk: Development of CMOS-based tracker for CEPC
Mingyi Dong's talk: Drift chamber with cluster counting technique for CEPC
Yong Liu's talk: CALICE scintillator-based calorimeter prototypes
Haoyu Shi's talk: Study of beam background and MDI design at CEPC

- **Large number of detector technology options and R&D projects on-going, they are not at similar level of maturity.**
- **Need to converge technology options towards a CEPC reference detector TDR**
  - Start preparation in January 2024
  - **Release of ref-TDR in June, 2025**
- **Intl. detector collaborative efforts**
  - DRD collaboration (DRD1-8), more than 130 colleagues from 11 Chinese institutes joined so far.
  - HL-LHC detector R&D efforts help to prepare teams for CEPC detectors.

CEPC Detector R&D: Silicon, TPC, DC Prototypes

2 layers / ladder R_{in}~16 mm



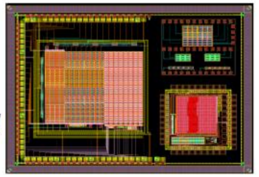
Goal: σ(IP) ~ 5 μm for high P track

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, COFFEE

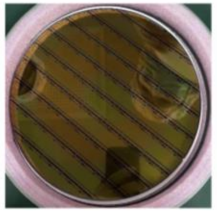
Develop **COFFEE** for a CEPC tracker using SMIC 55nm HV-CMOS process



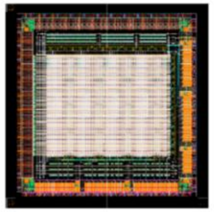
JadePix-3 Pixel size ~16×23 μm²

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

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

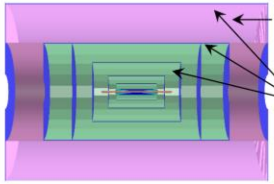


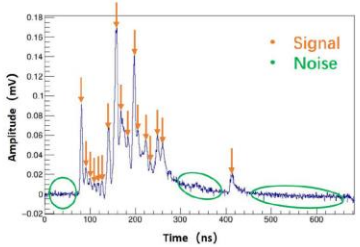
CPV4 (SOI-3D), 64×64 array
~21×17 μm² pixel size

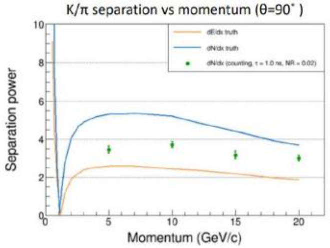


Arcadia by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS

- **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.







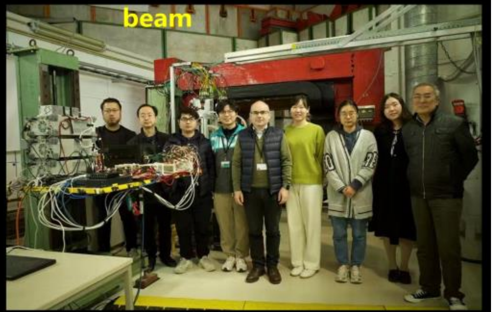
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022

Test beam @ DESY

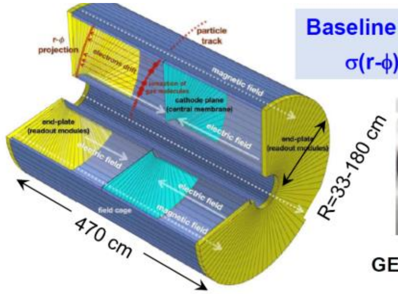
- 2nd testbeam: April 11-23 2023 DESY test beam in Germany (4-6 GeV electron)
  - Vertex detector prototype testbeam
- 1st testbeam: Dec 12-22 2022 DESY test beam in Germany (4-6 GeV electron)
  - TaichuPix Beam Telescope testbeam

2022 DESY test beam

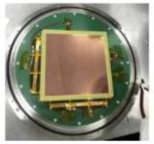
2023 DESY test beam



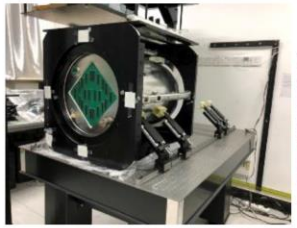
Excellent collaboration with DESY testbeam team



Baseline main tracker
σ(r-ϕ) ~100 μm



GEM-MM cathode

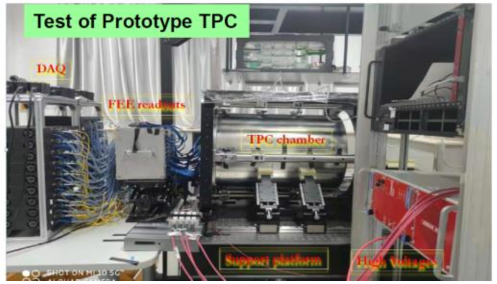


TPC Prototype + UV laser beams

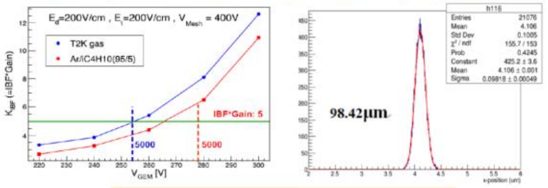
MOST 1 (IHEP+THU)

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.

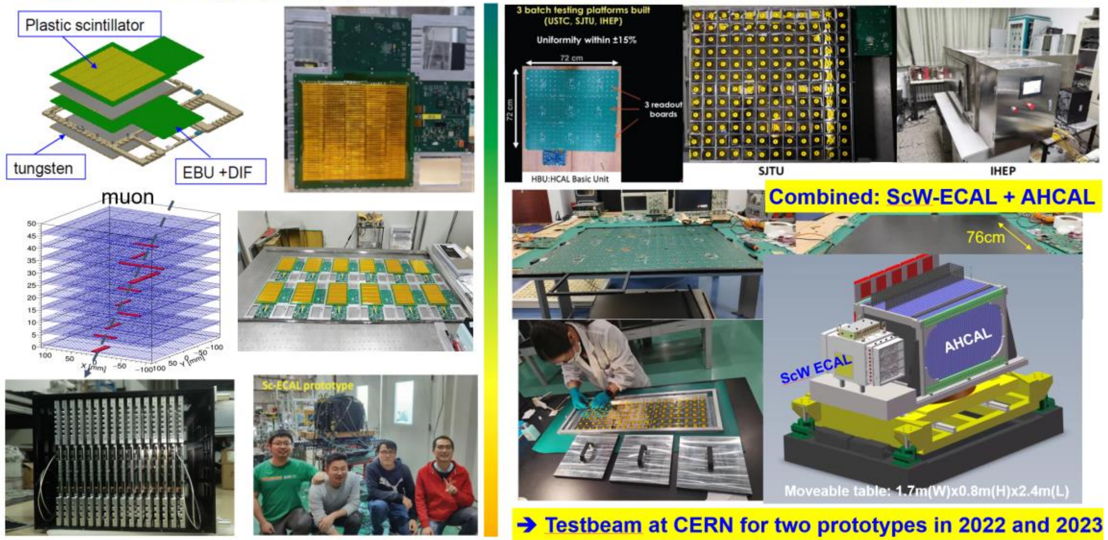


$\sigma_{\cdot}$ < 100 μm for drift length of 27cm

CEPC Detector R&D: Calorimeter Prototypes

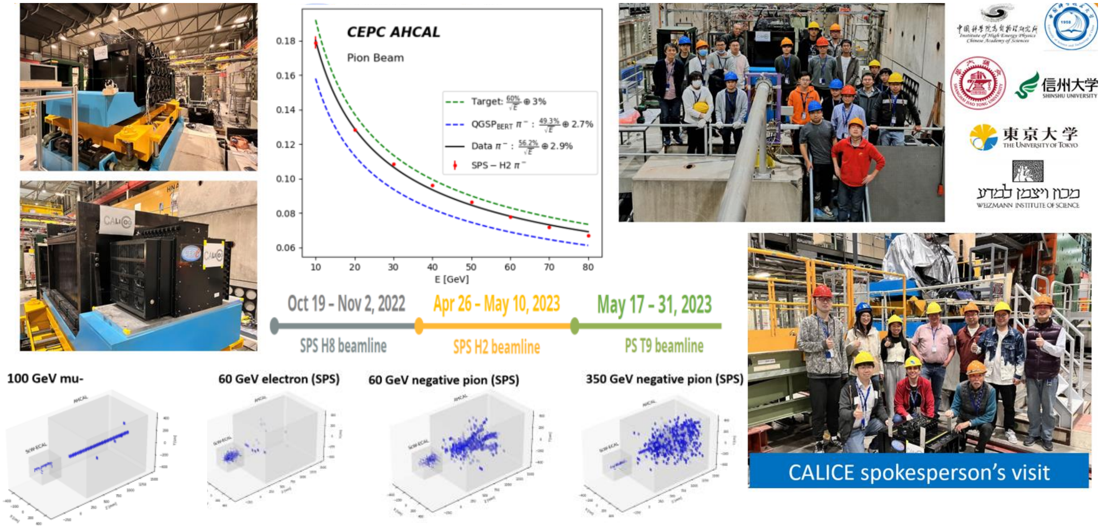
ScW ECAL Prototype (32-layer, 6720-ch)

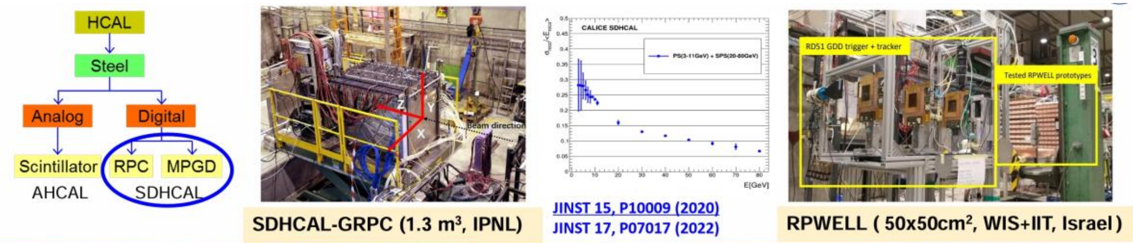
Scintillator + SiPM AHCAL Prototype (40-layer, 12960-ch)



➔ Testbeam at CERN for two prototypes in 2022 and 2023

CEPC Calorimeter Prototypes: beam test at CERN in 2022 & 2023





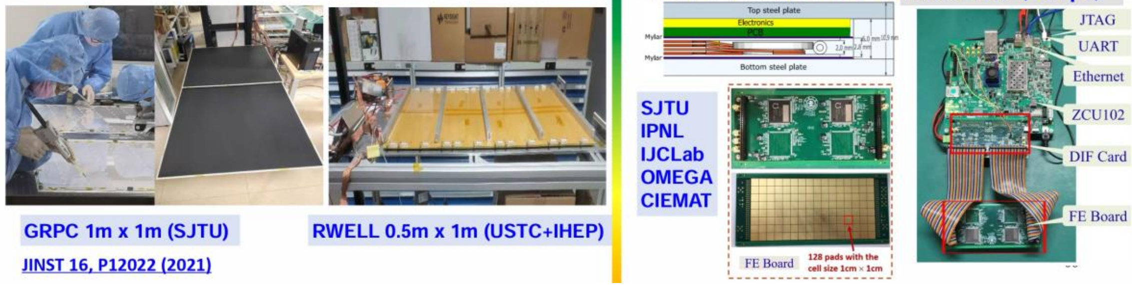
SDHCAL-GRPC (1.3 m³, IPNL)

JINST 15, P10009 (2020)
JINST 17, P07017 (2022)

RPWELL (50x50cm², WIS+IIT, Israel)

MOST 1: RPC and MPGD (RWELL) R&D，MIP Eff > 95%

R&D Plan: 5-D SDHCAL (X, Y, Z, E, Time)
- MRPC + fast timing PETIROC ASIC (~40 ps)

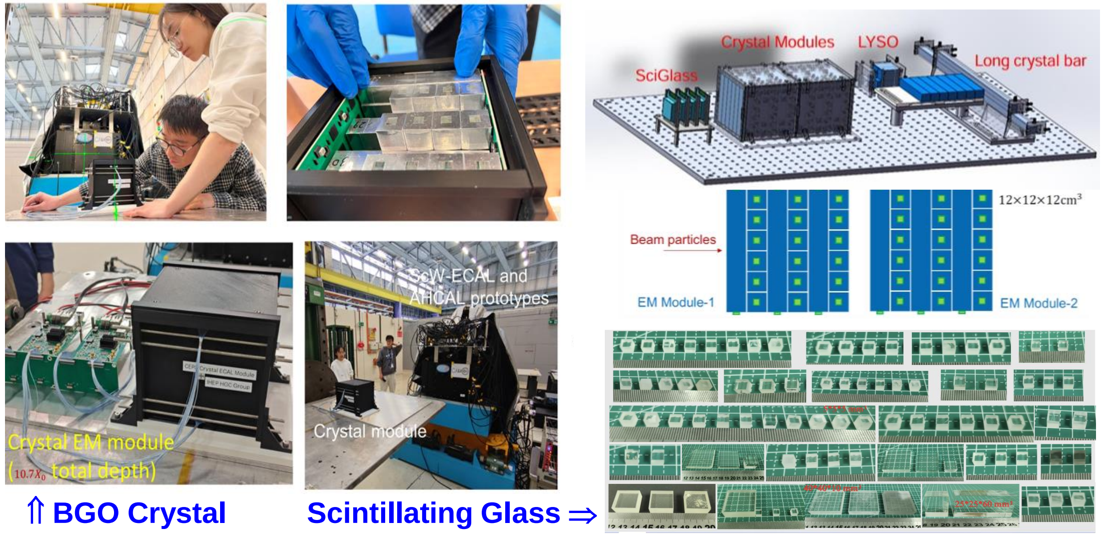


GRPC 1m x 1m (SJTU)

RWELL 0.5m x 1m (USTC+IHEP)

JINST 16, P12022 (2021)

Crystal Modules: beam test at CERN and DESY in 2023 & 2024

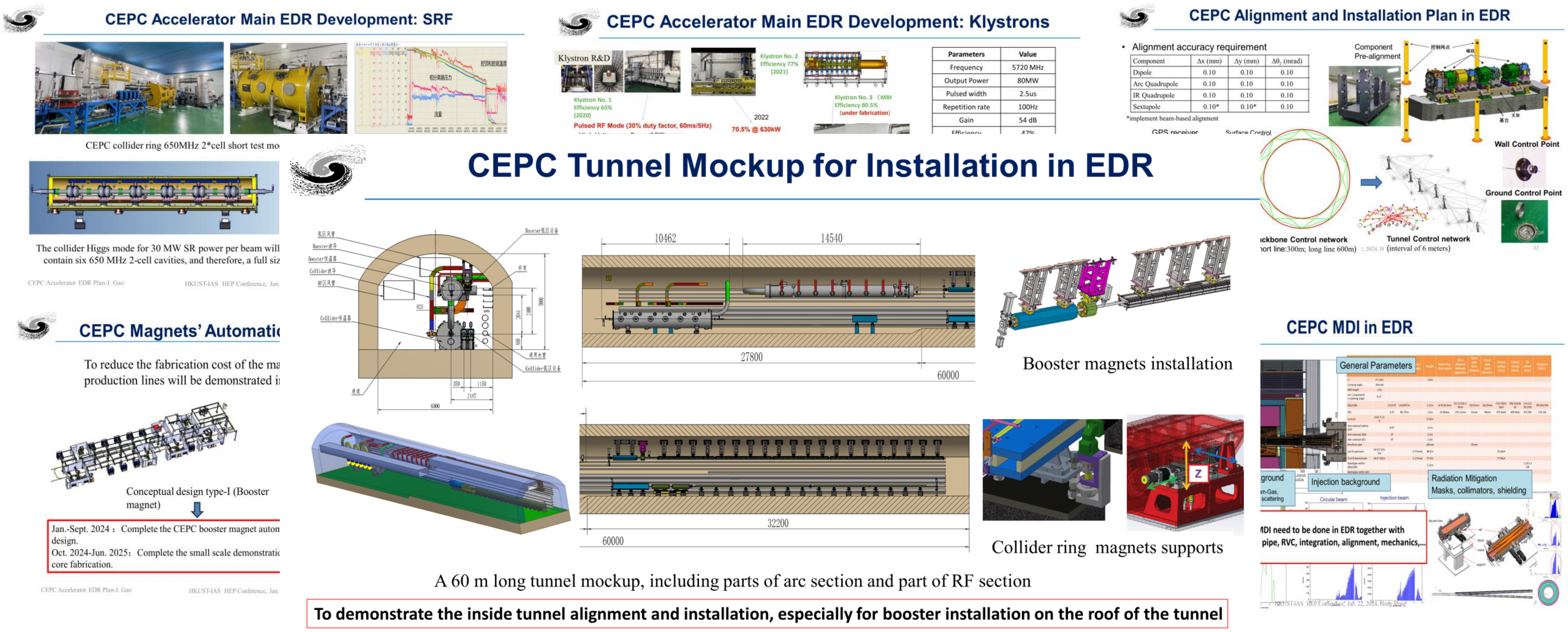


⇑ BGO Crystal

Scintillating Glass ⇒

CEPC Accelerator EDR

CEPC Accelerator EDR tasks start with 35 WGs aiming for key issues, detailed working plan and scope will be reviewed by IARC in Sept. 2024.

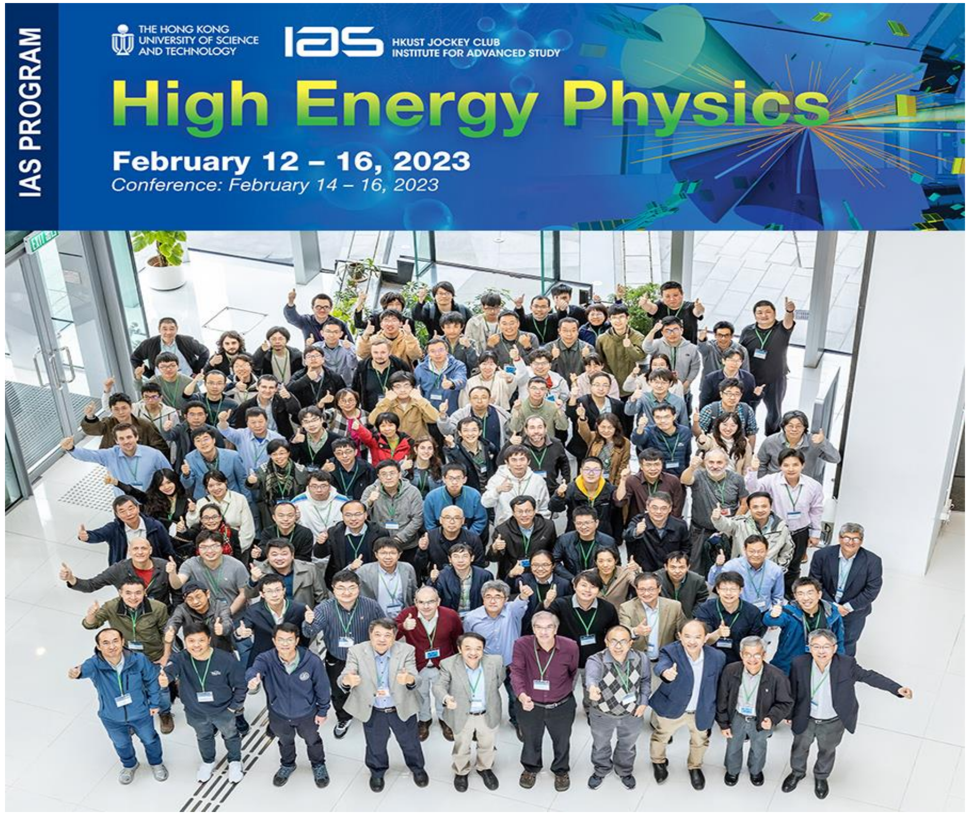


To demonstrate the inside tunnel alignment and installation, especially for booster installation on the roof of the tunnel

CEPC International Collaboration

CEPC attracts significant International participation

- Both CDR and TDR have significant intl. contributions
- 20+ MoUs signed with Intl. institutions and universities
- Intl. collaborative efforts: DRD & HL-LHC detector R&D
- CEPC International Workshop since 2014
- Annual working month at HKUST-IAS since 2015
- EU-US versions of CEPC Workshop since 2018



Industrial Partners and Suppliers 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)

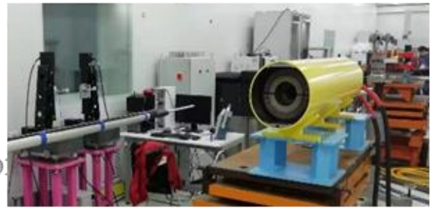
LEIKE 雷科电子 · KAITENG SIFANG · 北广科技 BBEF · TOLY ELECTRIC · 高能锐新 HE-RACING TECHNOLOGY · VACREE · PUSU · 上海超导 · 地矿建设 DIKUANG CONSTRUCTION · Western Superconducting Technologies Co.,Ltd. · 中科富海 FULLCRYO · 江苏克劳特低温 · 普达迪泰 PRODETEC · 中铁装备 CREG · 爱科赛博 ACTIONPOWER · SEALTECH · SKY · HUALUN · 正帆科技 GENTECH · HDKY浩德科仪 · RuiYuan · 中国铁建 · 东方钽业 OTIC 中国有色集团成员企业 · NVT · 冰轮环境 MOON-TECH · JST · 金盘科技 · 东方晨景 East Changing · EDWARDS · CBVAC · 黄河勘测规划设计研究院有限公司 Yellow River Engineering Consulting Co., Ltd. · 华东勘测设计研究院 · 海南展创光电技术有限公司 HZC PHOTONICS · 中国电建 POWERCHINA

Potential international collaborating suppliers and partners worldwide

DANFYSIK · SCANDITRONIX · TOKINARC TOKIN CORPORATION · nichicon · HEINZINGER · DAWONSYS · CAEN Technologies Inc. · Kudos Electrical Contracting · PFEIFFER VACUUM · Leybold · VAT · EDWARDS · mks · Sanei-Kikai Co.,Ltd · CPI Communications & Power Industries · VIC INTERNATIONAL · Fujikin · MPC MIRAPRO · Canon · THALES Building a future we can all trust · Air Liquide · Linde · Lake Shore CRYOTRONICS · SGL research · Osprey Distributed Control Systems · bergoz · INSTRUMENTATION TECHNOLOGIES · COSYLAB · dimtel · ThermoFisher SCIENTIFIC · ELSE NUCLEAR · HEXAGON

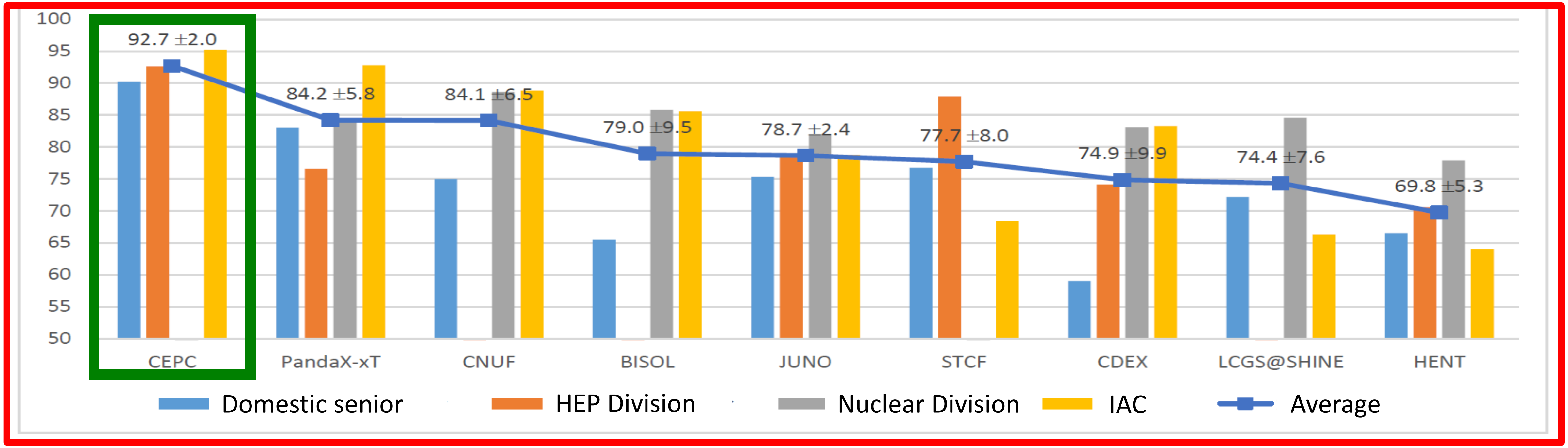





CEPC Planning and Development

- CAS is planning for the 15th 5-year 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 eight groups (fields).
- CEPC is ranked No. 1, by every committee (2 domestic and 1 international).
- A final report was submitted to CAS for consideration, this process is within CAS, and the following national selection process will be decisive.

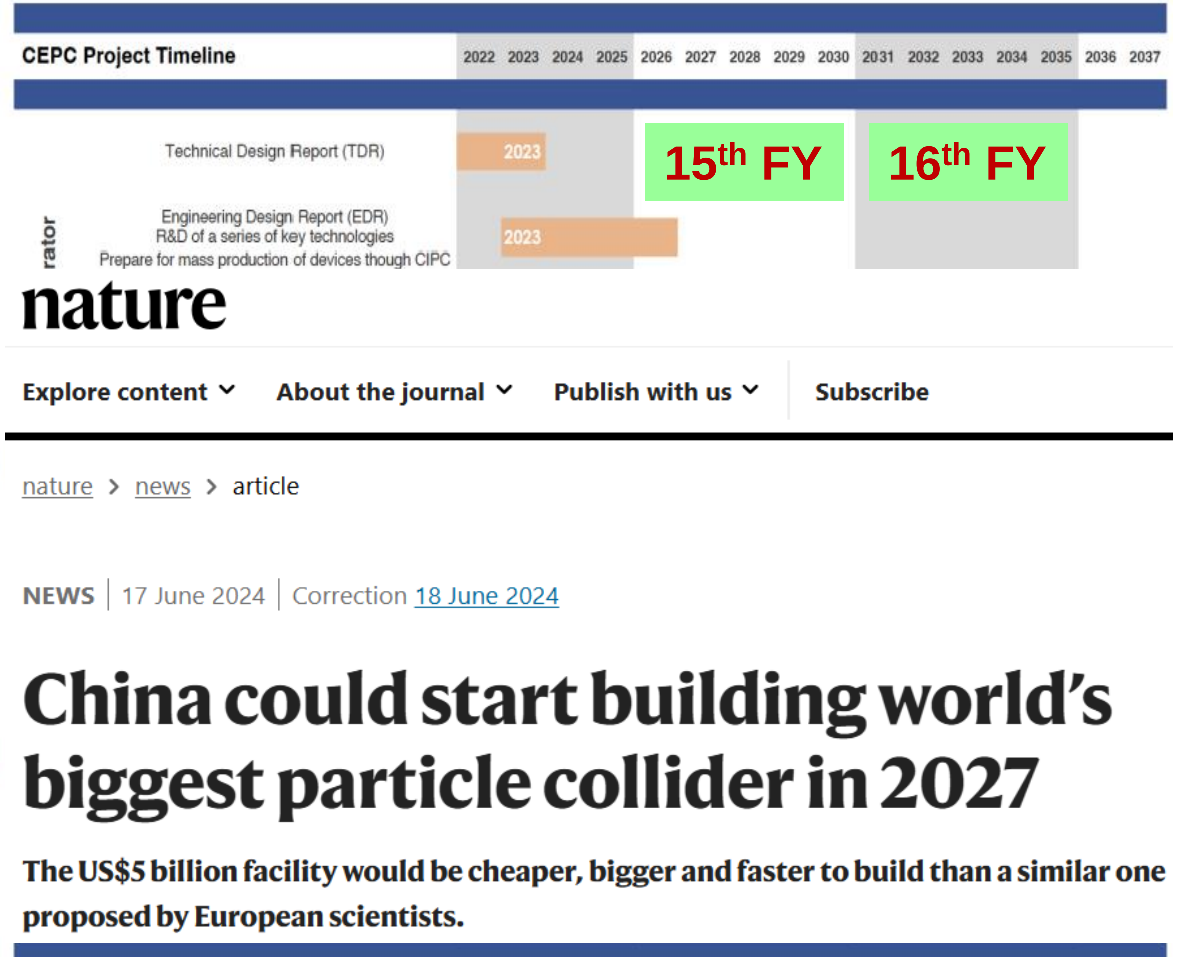


CEPC Planning and Schedule

2012.9	2015.3	2018.11	2023.12	2025.6	2027	15th five year plan (2026-2030)
proposed	Pre-CDR	CDR	Acc. TDR	Det. TDR	EDR	Start of construction

CEPC EDR Phase: 2024-2027

- **CEPC Accelerator EDR** starts with 35 WGs in 2024, to be completed in **2027**
- **CEPC Reference Detector TDR** will be released by June, **2025**
- **CEPC proposal** will be submitted to the Chinese government for approval in **2025**
- **Upon approval**, establish at least two international collaborations on experiments
- **CEPC construction starts** during the 15th five-year plan (2026-2030, e.g. **2027**)
- **CEPC construction complete** around **2035**, at the end of the 16th five-year plan



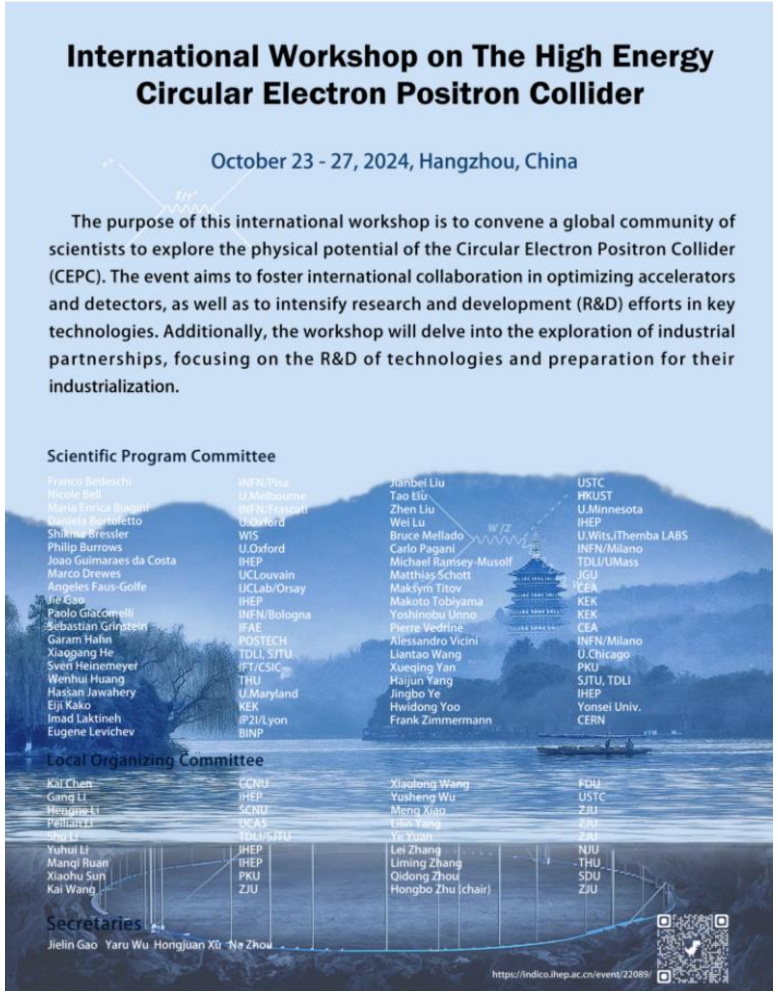
Summary

- CEPC addresses many most pressing and critical science problems in particle physics.
- Accelerator design and technology R&D are reaching maturity, TDR completed, enters EDR phase, ready for construction in 3-5 years.
- Reference detector TDR under preparation, to be completed by the mid-2025 for the proposal of China's 15th 5-year plan.
- Contributions from international colleagues for both accelerator EDR and reference detector TDR are warmly welcome.
- CEPC schedule will follow the 15th 5-year plan, call for international collaborations and proposals once CEPC is approved.
- CEPC will offer the worldwide HEP community an early Higgs factory.

Next CEPC Workshop

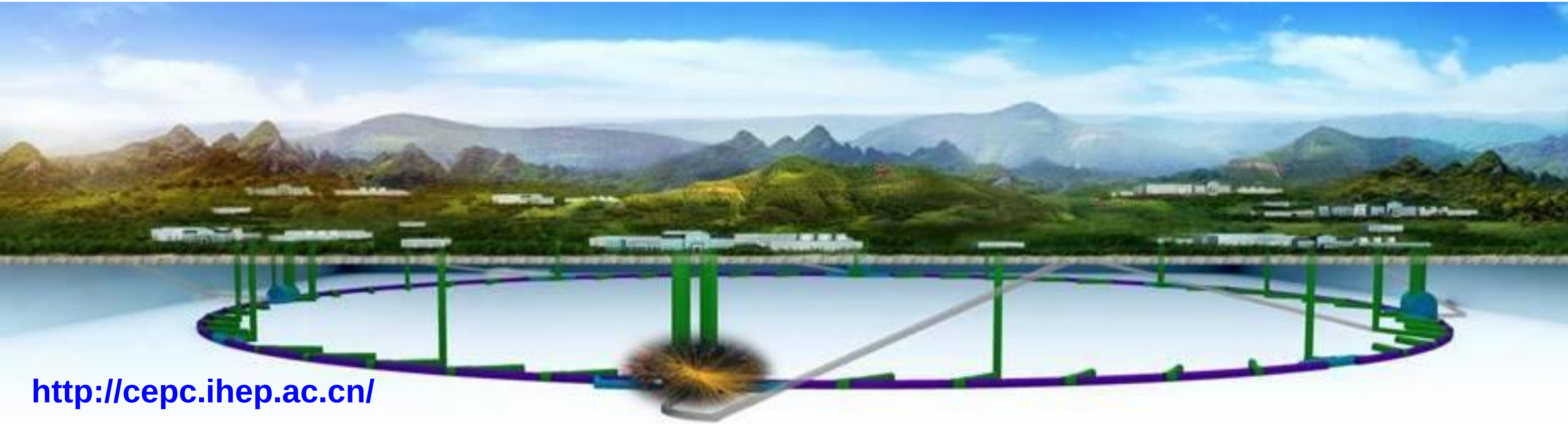
CEPC International Workshop at Hangzhou, Zhejiang U., Oct. 23-27, 2024

China announced 144-hour visa-free transit policy for 54 selected countries



Acknowledgement

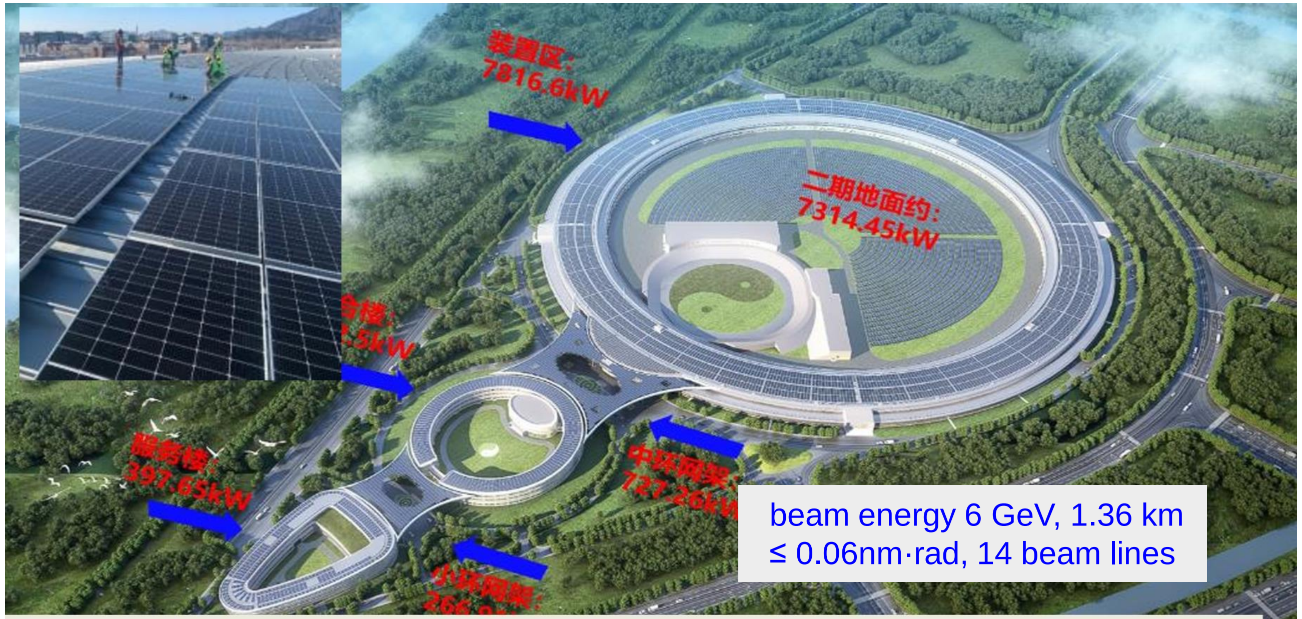
Thanks to CEPC team for enormous efforts and achievements
Special thanks to CEPC IAC, IARC and TDR review committee



http://cepc.ihep.ac.cn/

High Energy Photon Source (HEPS)

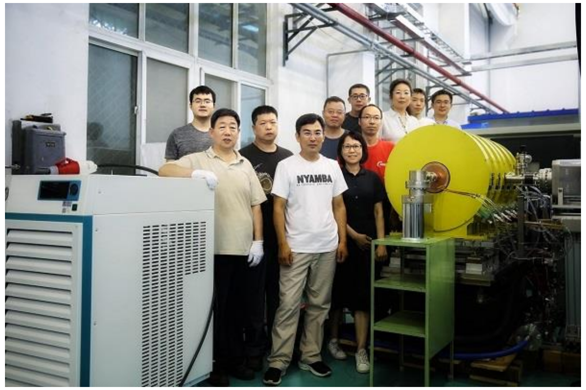
To be completed in 2025, great training and preparation for CEPC ➔ towards a green accelerator



Solar panel on the roof of HEPS

Experience at HEPS

- Solar panel:10 MW ➔ 10% saving
- Permanent magnet: 5.6 GWh saving/year
- Hot water (13 MW @ 42 ^{0}C) for heating



CEPC Machine Parameters

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	30			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	24.23	5.98	1.23
Bunch number	268	11934	1297	35
Bunch spacing (ns)	591 (53% gap)	23 (18% gap)	257	4524 (53% gap)
Bunch population (10^{11})	1.3	1.4	1.35	2.0
Beam current (mA)	16.7	803.5	84.1	3.3
Phase advance of arc FODO (°)	90	60	60	90
Momentum compaction (10^{-5})	0.71	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune n_x/n_y	445/445	317/317	317/317	445/445
Beam size at IP s_x/s_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
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.13	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.7	1.2/2.5	2.0/2.6
Beam-beam parameters x_x/x_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.12	0.7	10
RF frequency (MHz)	650			
Longitudinal tune n_s	0.049	0.035	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	39/40	82/2800	60/700	81/23
Beam lifetime (min)	20	80	55	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	5.0	115	16	0.5

CEPC vs FCC-ee

Table 1: Luminosity per IP (10^{34} cm^{-2}s^{-1})

	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

Table 2: Integrated Luminosity per Year per IP (ab^{-1}/yr/IP)

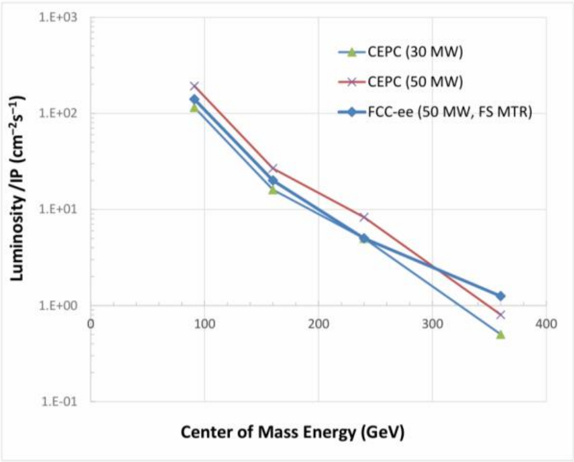
	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	0.65	15	2.1	0.065
CEPC (TDR, 50 MW)	1.1	25	3.5	0.1
FCC-ee (FS MTR, 50 MW)	0.6	17	2.4	0.15

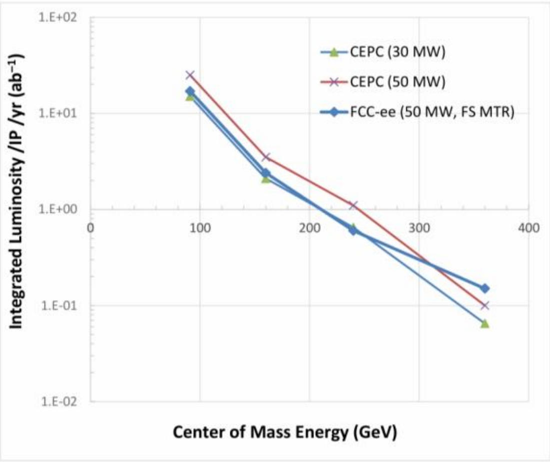
Table 3: Total Integrated Luminosity per Year (ab^{-1}/yr)

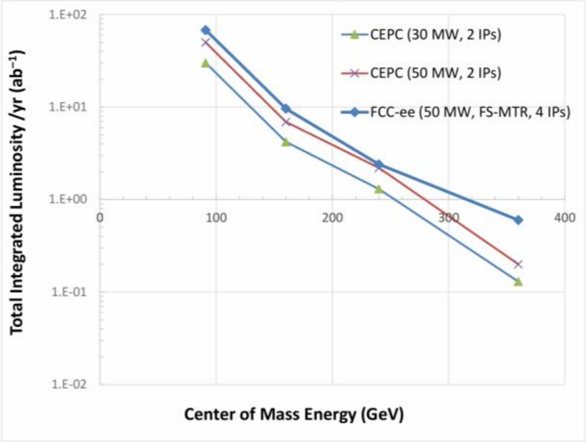
	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW, 2 IPs)	1.3	30	4.2	0.13
CEPC (TDR, 50 MW, 2 IPs)	2.2	50	6.9	0.2
FCC-ee (FS MTR, 50 MW, 4 IPs)	2.4	68	9.6	0.6

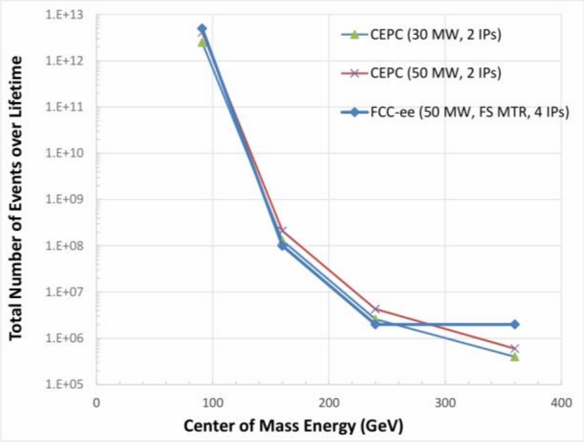
Table 4: Total Number of Events over the Machine Lifetime

	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	2.6×10^6	2.5×10^{12}	1.3×10^8	0.4×10^6
CEPC (TDR, 50 MW)	4.3×10^6	4.1×10^{12}	2.1×10^8	0.6×10^6
FCC-ee (FS MTR, 50 MW)	2×10^6	5×10^{12}	$> 1 \times 10^8$	2×10^6



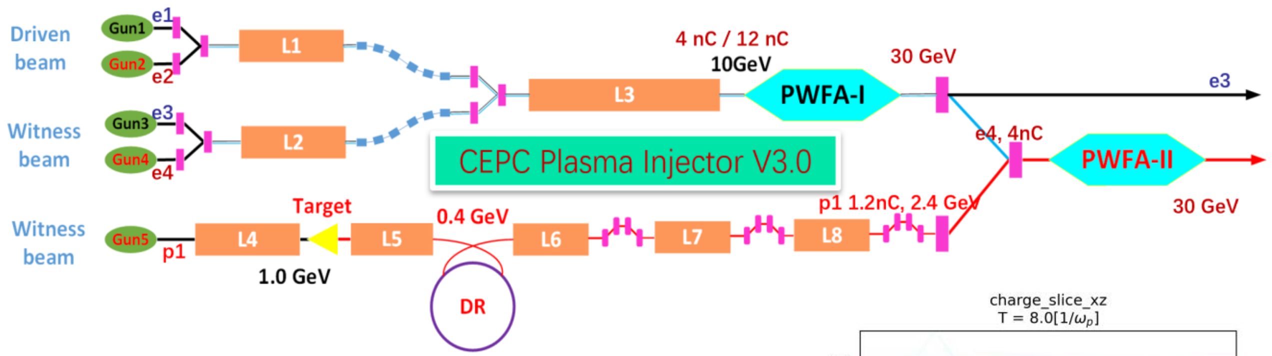






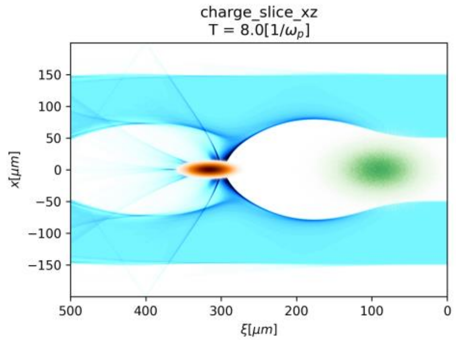
CEPC Accelerator: Plasma Injector

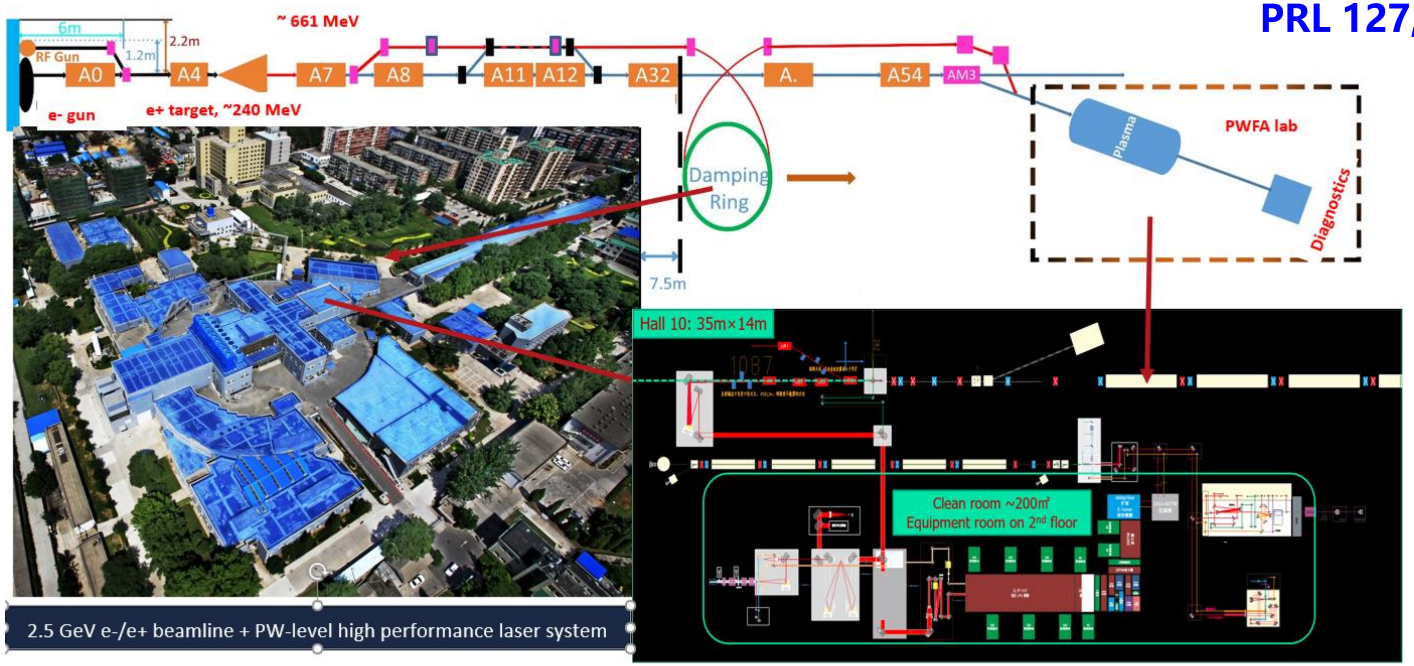
CEPC Plasma Injector Scheme
From 10 GeV → 30 GeV → TR ≥2



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

PRL 127, 174801 (2021)





2.5 GeV e-/e+ beamline + PW-level high performance laser system

Phase I（**Year0-Year2**）

1. Re-design and install transport beamline and FF system, optimize the e- / e+ beam quality
2. Clean room and high power laser system (20... installation200TW
3. Beam instrumentation s...
4. RF Gun platform...
5. Comm...

Phase II（...

1. Up... ...20/40 TW)
2. Test ... install it on the BEPC...

Phase III（**Yea**...

1. Add a positron dumping ring the bunch compression beamline to improve the e+ quality
2. PBA-based FEL studies

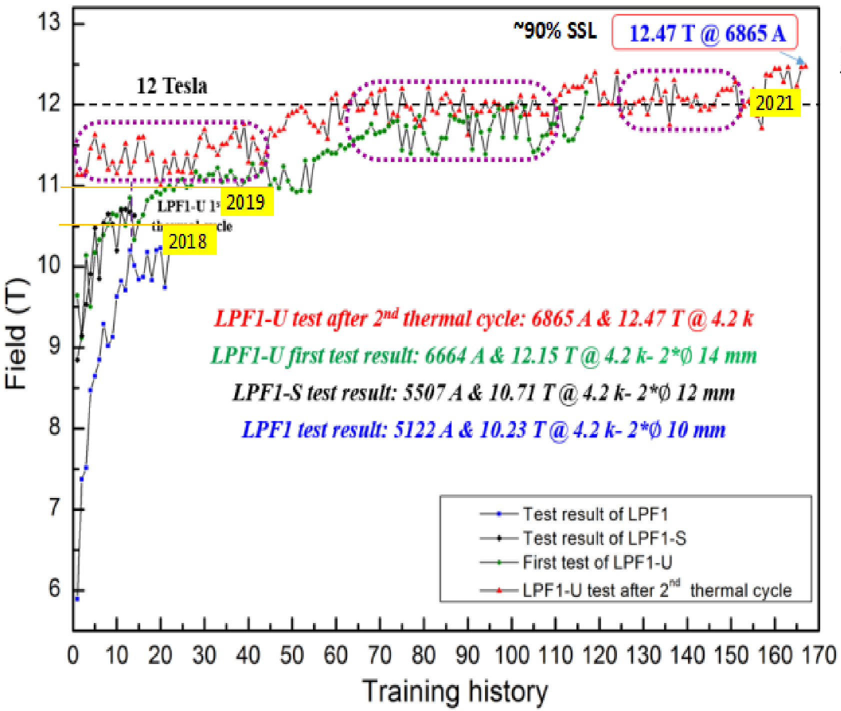
- **Positron and electron acceleration**
- **Cascading acceleration**
- **Future linear collider technologies**
- **High energy beam for detector R&D (possible application)**

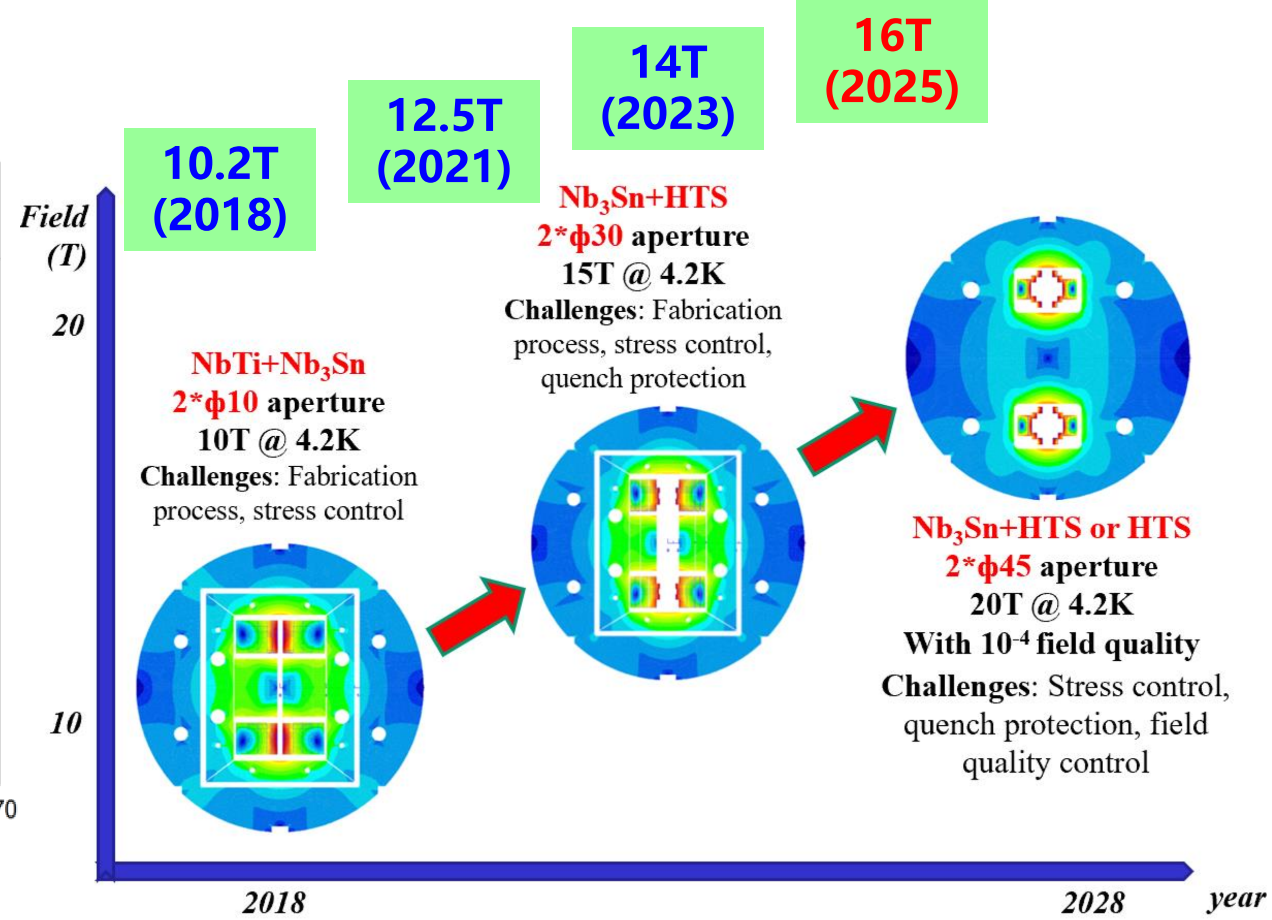
PWFA/LWFA TF based on BEPC-II Linac and HPL has founded by CAS, 120M RMB in Sept. 2023

SPPC R&D: HTS SC Magnet

SppC 16 T Dipole: Nb_3Sn 12~13 T + HTS 3~4 T
Dual aperture superconducting dipoles fabricated in China reached 14T @ 4.2K in 2023. The next goal is 16-20T.

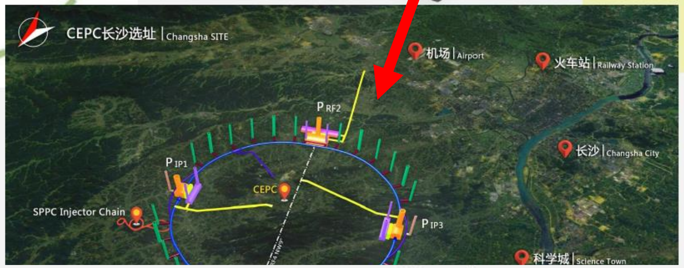
Picture of LPF1-U



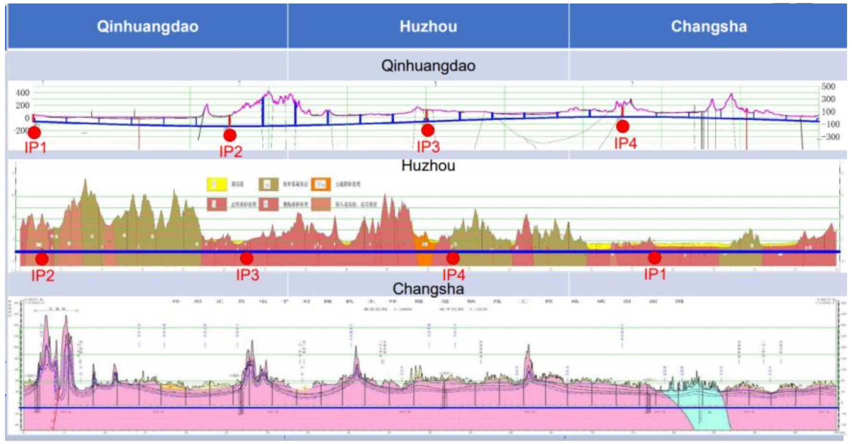


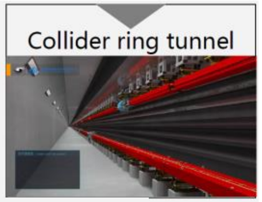
CEPC Site Selection

Qinhuangdao



Huzhou



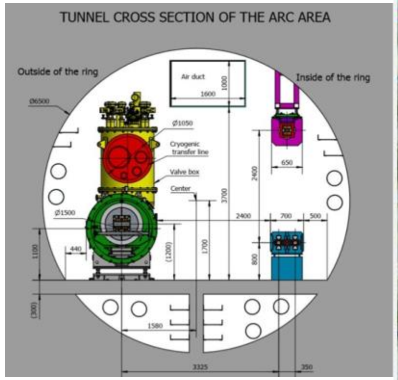


Changsha

中国电建 POWERCHINA 中国电建集团华东勘测设计研究院有限公司 HUADONG ENGINEERING CORPORATION LIMITED

中国电建 POWERCHINA 中南勘测设计研究院有限公司 ZHONGNAN ENGINEERING CORPORATION LIMITED

- 3 sites documented in accelerator TDR
- 75-95% of tunnel in granite, low cost



TBM tunnel

CEPC Concepts

CEPC Key Scientific Issues and Technologies 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
- ……

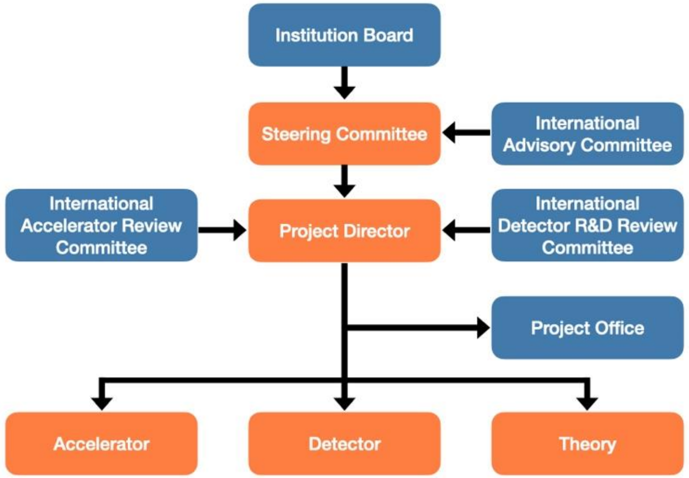
High Lumi.
$\sim 10^{34-36} cm^{-2}s^{-1}$
- ✓ Higgs: 20 ab^{-1}
- ✓ Z: 100 ab^{-1}
- ✓ W: 6 ab^{-1}
- ✓ Top: 1 ab^{-1}

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}

CEPC Team

CEPC Organization



- **Institution Board:** 32 institutes, top universities/institutes in China
- **Management team:** comprehensive management experience at construction projects of BEPCII/CSNS/HEPS, and international projects of BESIII/Daya Bay/JUNO/…
- **Accelerator team:** fully over all disciplines with rich experiences at BEPCII, HEPS…
- **Physics and Detector team:** fully over all disciplines with rich experiences at BESIII, Daya Bay, JUNO, ATLAS, CMS, LHCb …

Table 7.2: Team of Leading and core scientists of the CEPC

Name	Brief introduction	Role in the CEPC team
Yifang Wang	Academician of the CAS, director of IHEP	The leader of CEPC, chair of the SC
Xinchou Lou	Professor of IHEP	Project manager, member of the SC
Yuanning Gao	Academician of the CAS, head of physics school of PKU	Chair of the IB, member of the SC
Jie Gao	Professor of IHEP	Convener of accelerator group, vice chair of the IB, member of the SC
Haijun Yang	Professor of SJTU	Deputy project manager, member of the SC
Jianbei Liu	Professor of USTC	Convener of detector group, member of the SC
Hongjian He	Professor of USTC	Convener of theory group, member of the SC
Shan Jin	Professor of NJU	Member of the SC
Nu Xu	Professor of IMP	Member of the SC
Meng Wang	Professor of SDU	Member of the SC
Qinghong Cao	Professor of PKU	Member of the SC
Wei Lu	Professor of THU	Member of the SC
Joao Guimaraes da Costa	Professor of IHEP	Convener of detector group
Jianchun Wang	Professor of IHEP	Convener of detector group
Yuhui Li	Professor of IHEP	Convener of accelerator group
Chenghui Yu	Professor of IHEP	Convener of accelerator group
Jingyu Tang	Professor of IHEP	Convener of accelerator group
Xiaogang He	Professor of SJTU	Convener of theory group
Jianping Ma	Professor of ITP	Convener of theory group

Management team, leading scientists

Table 7.3: Team of the CEPC accelerator system

Number	Sub-system	Convener	Team (senior staff)
1	Accelerator physics	Chenghui Yu, Yuan Zhang	18
2	Magnets	Wen Kang, Fusan Chen	12
3	Cryogenic system	Rui Ge, Ruixiong Han	11
4	SC RF system	Jiyuan Zhai, Peng Sha	12
5	Beam Instrumentation	Yanfeng Sui, Junhui Yue	7
6	SC magnets	Qingjin Xu	10
7	Power supply	Bin Chen, Fengli Long	9
8	Injection & extraction	Jinhui Chen	7
9	Mechanical system	Jianli Wang, Lan Dong	4
10	Vacuum system	Haiyi Dong, Yongsheng Ma	5
11	Control system	Ge lei, Gang Li	6
12	Linac injector	Jingyi Li, Jingru Zhang	13
13	Radiation protection	Zhongjian Ma	3
Sum			117

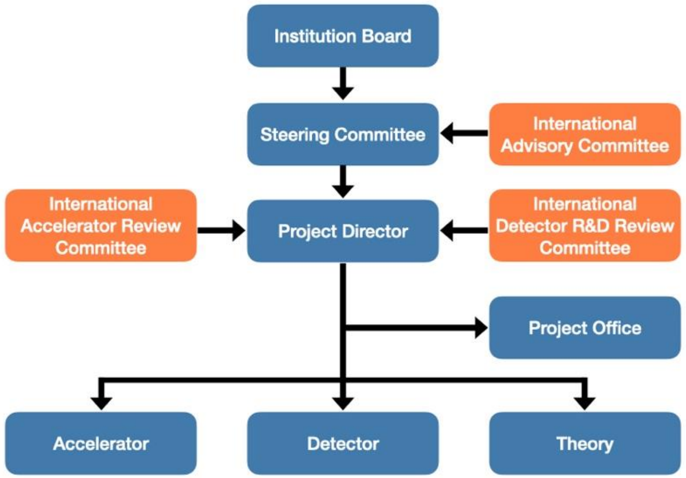
Table 7.4: Team of the CEPC detector system

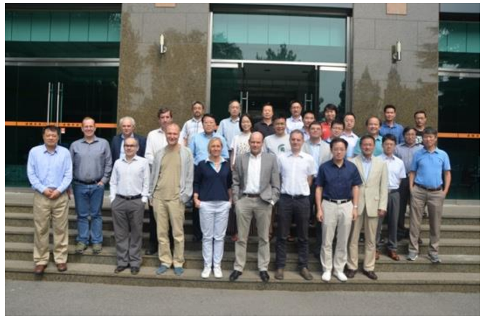
Number	Sub-system	Conveners	Institutions	Team (senior staff)
1	Pixel Vertex Detector	Zhijun Liang, Qun Ouyang, Xiangming Sun , Wei Wei	CCNU, IFAE, IHEP, NJU, NWPU, SDU, Strasbourg, ...	~ 40
2	Silicon Tracker	Harald Fox, Meng Wang, Hongbo Zhu	IHEP, INFN, KIT, Lancaster, Oxford, Queen Mary, RAL, SDU, Tsinghua, Bristol, Edinburgh, Livepool, USTC, Warwick, Sheffield, ZJU, ...	~ 60
3	Gaseous detector	Franco Bedeschi, Zhi Deng, Mingyi Dong, Huirong Qi	CEA-Saclay, DESY, LCTPC Collab., IHEP, INFN, NIKHEF, THU ...	~ 30
4	Magnet	Feipeng Ning	IHEP	~ 10
5	Calorimetry	Roberto Ferrari, Jianbei Liu, Haijun Yang, Yong Liu	CALICE Collab., IHEP, INFN, SJTU, USTC..	~ 40
6	Muon	Paolo Giacomelli, Liang Li, Xiaolong Wang	FDU, IHEP, INFN, SJTU ...	~ 20
7	Physics	Manqi Ruan, Yaquan Fang, Liantao Wang, Mingshui Chen	IHEP, FDU, SJTU, ...	~ 80
8	Software	Shengseng Sun, Weidong Li, Xingtao Huang	IHEP, SDU, FDU, ...	~ 20
Sum				~ 300

117 accelerator + ~300 detector staffs currently,
+ ~ 400 from BEPC/BESIII/JUNO/HEPS/…
once CEPC approved

CEPC International Committees

CEPC Organization





International Advisory Committees

Name	Affiliation	Country
Tatsuya Nakada	EPFL	Japan
Steinar Stapnes	CERN	Norway
Rohini Godbole	CHEP, Bangalore	India
Michelangelo Mangano	CERN	Switzerland
Michael Davier	LAL	France
Lucie Linssen	CERN	Holland
Luciano Maiani	U. Rome	San Marino
Joe Lykken	Fermilab	U.S.
Ian Shipsey	Oxford/DESY	U.K.
Hitoshi Murayama	IPMU/UC Berkeley	Japan
Geoffrey Taylor	U. Melbourne	Australia
Eugene Levichev	BINP	Russia
David Gross	UC Santa Barbara	U.S.
Brian Foster	Oxford	U.K
Marcel Demarteau	ORNL	USA
Barry Barish	Caltech	USA
Maria Enrica Biagini	INFN Frascati	Italy
Yuan-Hann Chang	IPAS	Taiwan, China
Akira Yamamoto	KEK	Japan
Hongwei Zhao	Institute of Modern Physics, CAS	China
Andrew Cohen	University of Science and Techbnology	Hong Kong, China
Karl Jakobs	University of Freiburg/CERN	Germany
Beate Heinemann	DESY	Germany

International Accelerator Review Committee

- Phillip Bambade, LAL
- Marica Enrica Biagini (Chair), INFN
- Brian Foster, DESY/University of Hamburg & Oxford University
- In-Soo Ko, POSTTECH
- Eugene Levichev, BINP
- Katsunobu Oide, CERN & KEK
- Anatolii Sidorin, JINR
- Steinar Stapnes, CERN
- Makoto Tobiyama, KEK
- Zhentang Zhao, SINAP
- Norihito Ohuchi, KEK
- Carlo Pagani, INFN-Milano

International Detector R&D Review Committee

- Jim Brau, USA, Oregon
- Valter Bonvicini, Italy, Trieste
- Ariella Cattai, CERN, CERN
- Cristinel Diaconu, France, Marseille
- Brian Foster, UK, Oxford
- Liang Han, China, USTC
- Dave Newbold, UK, RAL (chair)
- Andreas Schopper, CERN, CERN
- Abe Seiden, USA, UCSC
- Laurent Serin, France, LAL
- Steinar Stapnes, CERN, CERN
- Roberto Tenchini, Italy, INFN
- Ivan Villa Alvarez, Spain, Santader
- Hitoshi Yamamoto, Japan, Tohoku

- **IAC: global renowned scientists and top laboratory or project leaders who have ample experience in project management, planning, and execution of strategies, operating since 2015**
- **IARC & IDRC: leading experts of this field, provide guide to the project director**

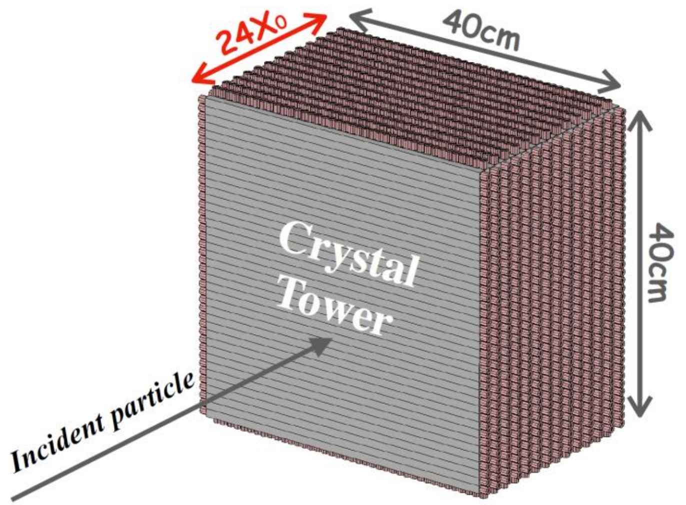
CEPC Reference Detector TDR

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 technology options and R&D projects on-going, they are not at similar level of maturity.**
- **Need to converge technology options towards a CEPC reference detector TDR**
  - Start preparation in Jan. 2024
  - A draft version of TDR in Dec. 2024
  - **Official release of TDR in Jun. 2025**
- **Intl. detector collaborative efforts**
  - DRD collaboration (DRD1-8), more than 130 colleagues from 11 Chinese institutes joined so far.
  - HL-LHC detector R&D efforts help to prepare teams for CEPC detectors.

CEPC R&D: Calorimeters with PFA

Crystal ECAL



Energy resolution ~3%/√E ⊕ ~ 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

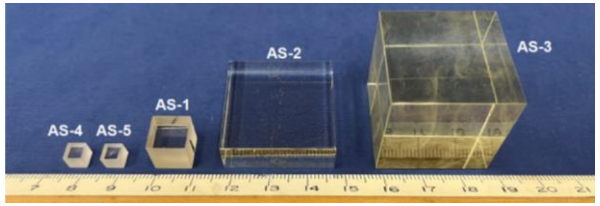
Energy resolution ~40%/√E ⊕ ~ 2%

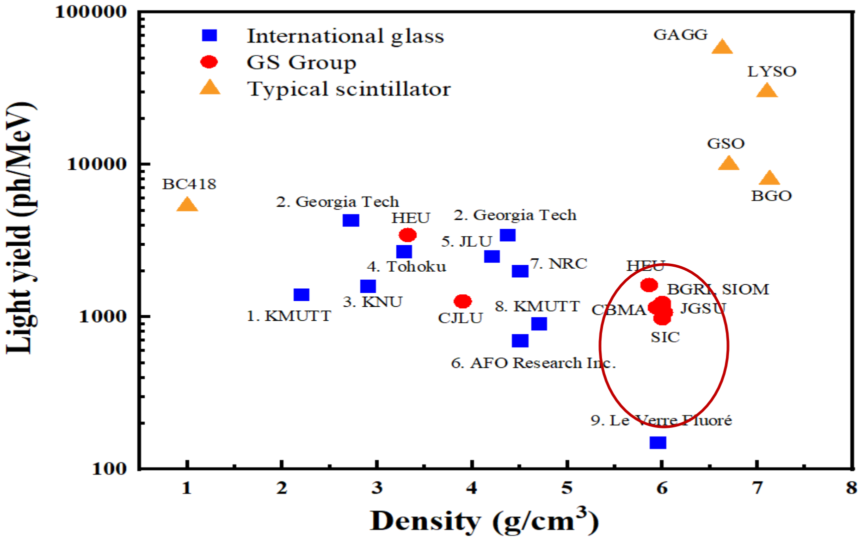
Features：

- ➢ Large sampling ratio at low cost

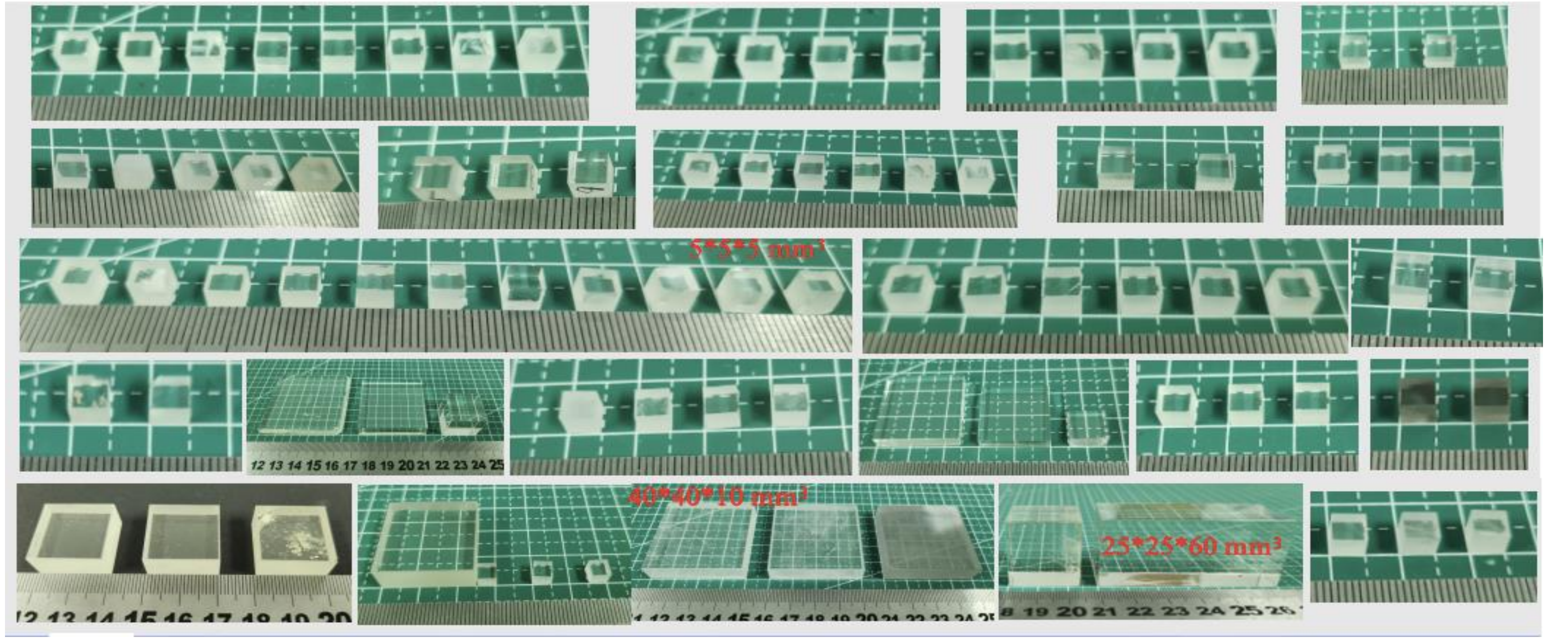
Main issues for R&D

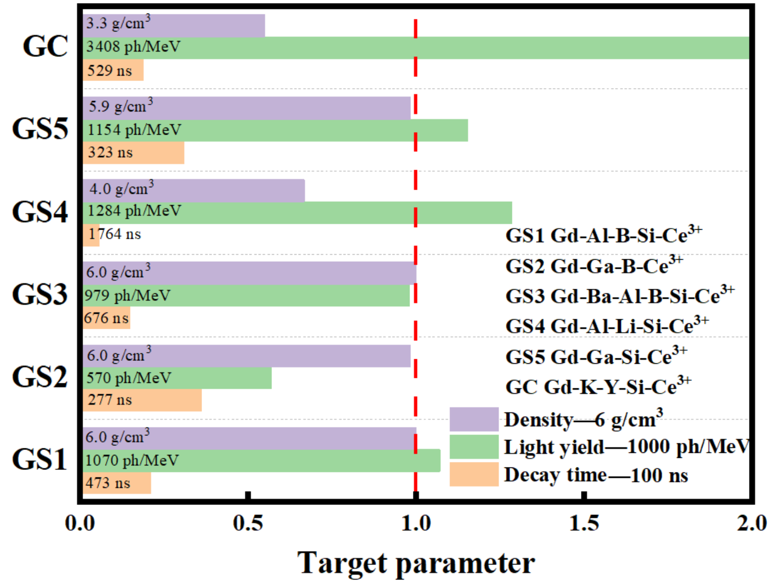
- ➢ high density, high light yield, radiation hardness, production



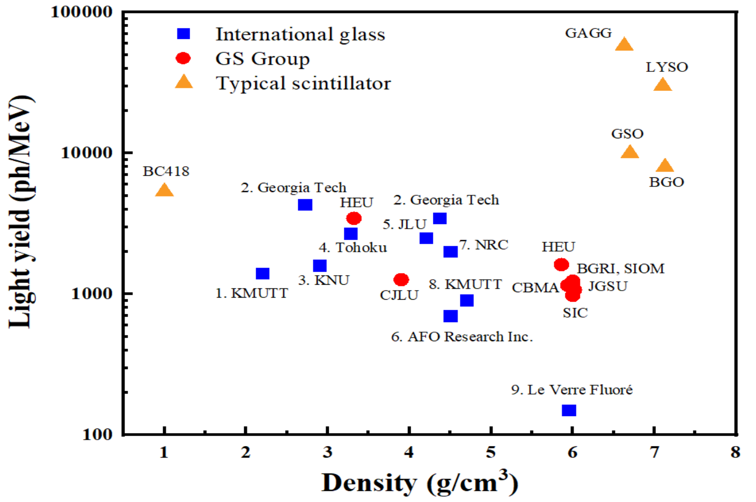


Glass Scintillator Studies

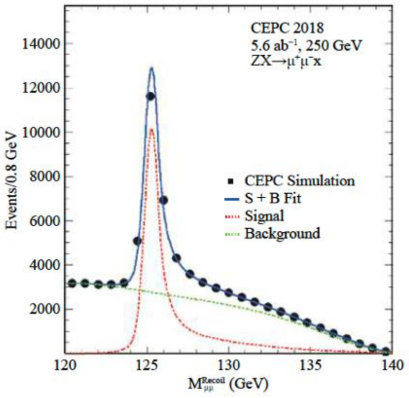


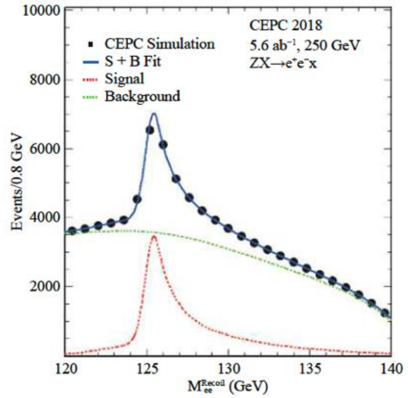


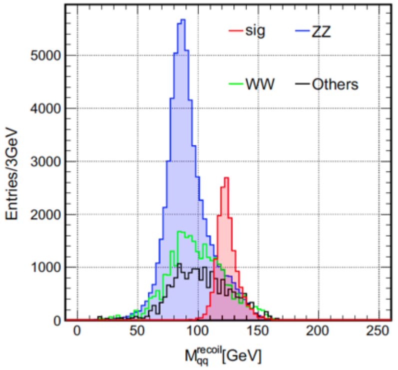
- The performance of the best glass sample: 6 g/cm3 & 1000 ph/MeV & 100 ns
- The GS collab. led by IHEP, with 3 Institutes of CAS, 5 Universities, 3 Factories.

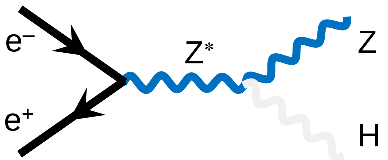


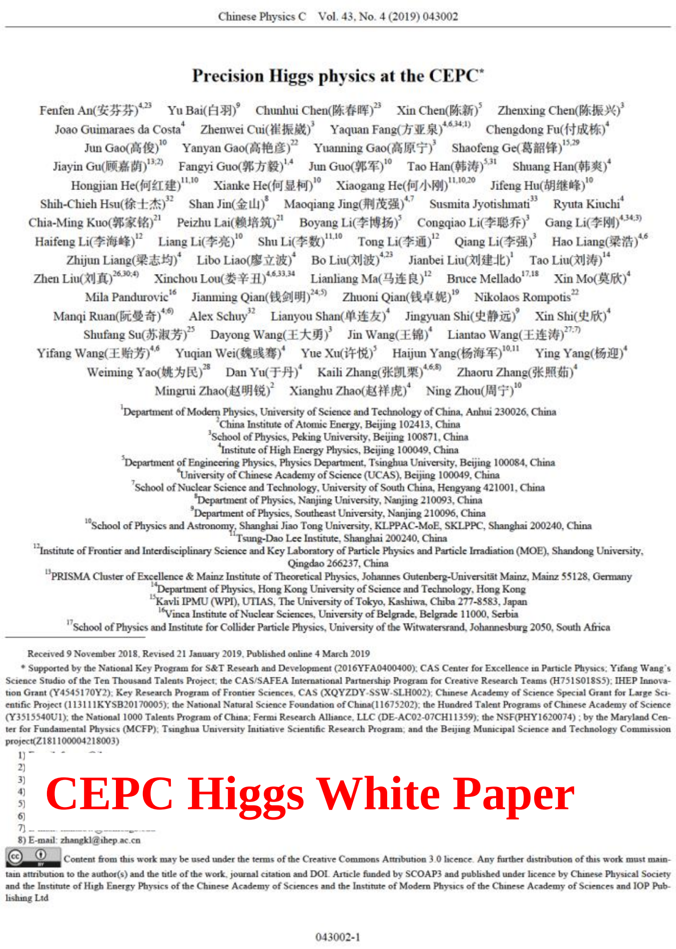
Physics Opportunities @ CEPC











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

Precision Higgs physics at the CEPC*

Received 9 November 2018, Revised 21 January 2019, Published online 4 March 2019

043002-1

CEPC Higgs White Paper

+ o(100) journal/arXiv papers

Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

Higgs			W, Z and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M_{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H \to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H \to cc)$	-	2.0%	Γ_Z	2.3 MeV	0.025 MeV
$B(H \to gg)$	-	0.81%	R_b	3×10^{-3}	2×10^{-4}
$B(H \to WW^*)$	2.8%	0.53%	R_c	1.7×10^{-2}	1×10^{-3}
$B(H \to ZZ^*)$	2.9%	4.2%	R_μ	2×10^{-3}	1×10^{-4}
$B(H \to \tau^+\tau^-)$	2.9%	0.42%	R_τ	1.7×10^{-2}	1×10^{-4}
$B(H \to \gamma\gamma)$	2.6%	3.0%	A_μ	1.5×10^{-2}	3.5×10^{-5}
$B(H \to \mu^+\mu^-)$	8.2%	6.4%	A_τ	4.3×10^{-3}	7×10^{-5}
$B(H \to Z\gamma)$	20%	8.5%	A_b	2×10^{-2}	2×10^{-4}
$Bupper(H \to \text{inv.})$	2.5%	0.07%	N_ν	2.5×10^{-3}	2×10^{-4}

Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

- Higgs: Precisions exceed HL-LHC ~ 1 order of magnitude
- EW: Precision improved from current limit by 1-2 orders
- Flavor Physics, sensitive to NP of 10 TeV or even higher
- Sensitive to varies of New Physics signal
- ...

CEPC Physics Program

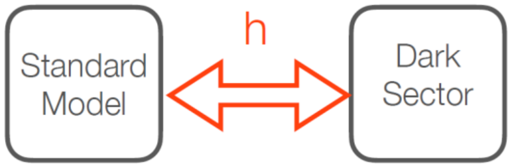
- **Precision Higgs, EW, flavor physics & QCD measurements at unprecedented precision**
- **BSM physics (e.g. dark matter, EW phase transition, SUSY, LLP, …) up to ~ 10 TeV scale**

	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%	16%	
$H \to \mu\mu$	6.36%		41%	57%	
$H \to Z\gamma$	8.50%		35%		
$Br_{upper}(H \to inv.)$	0.07%				
Γ_H	1.65%		1.10%		

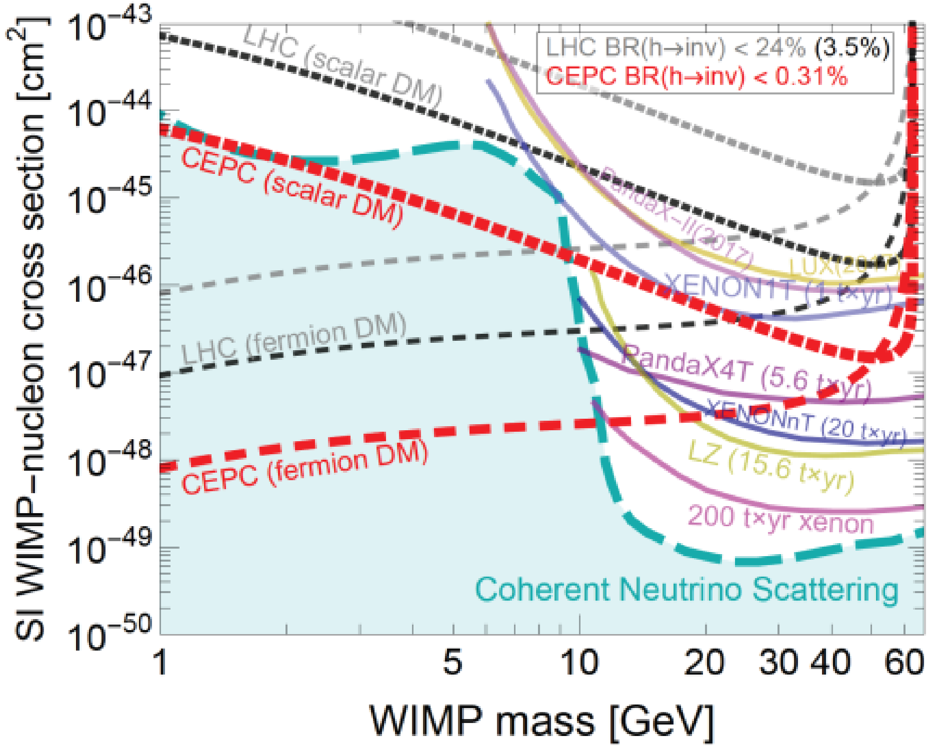
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale

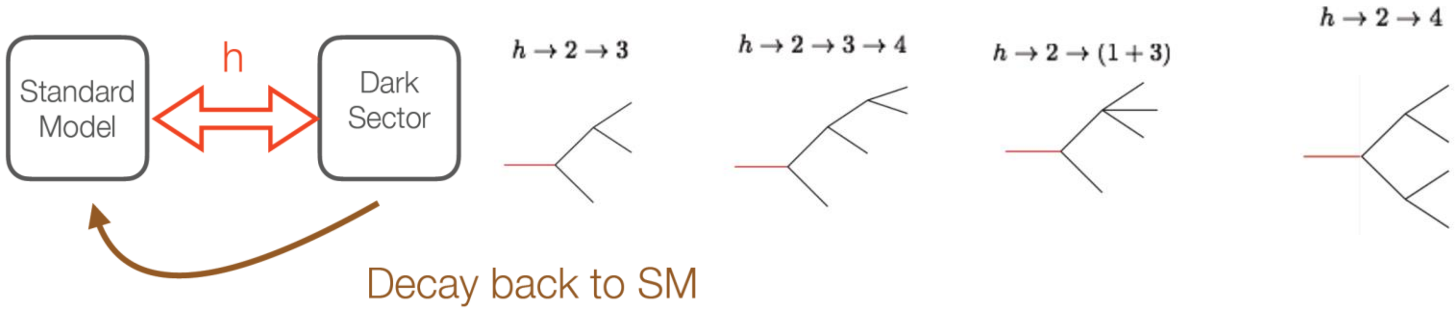
arXiv:2205.08553

CEPC Physics Program: Discovery Potential

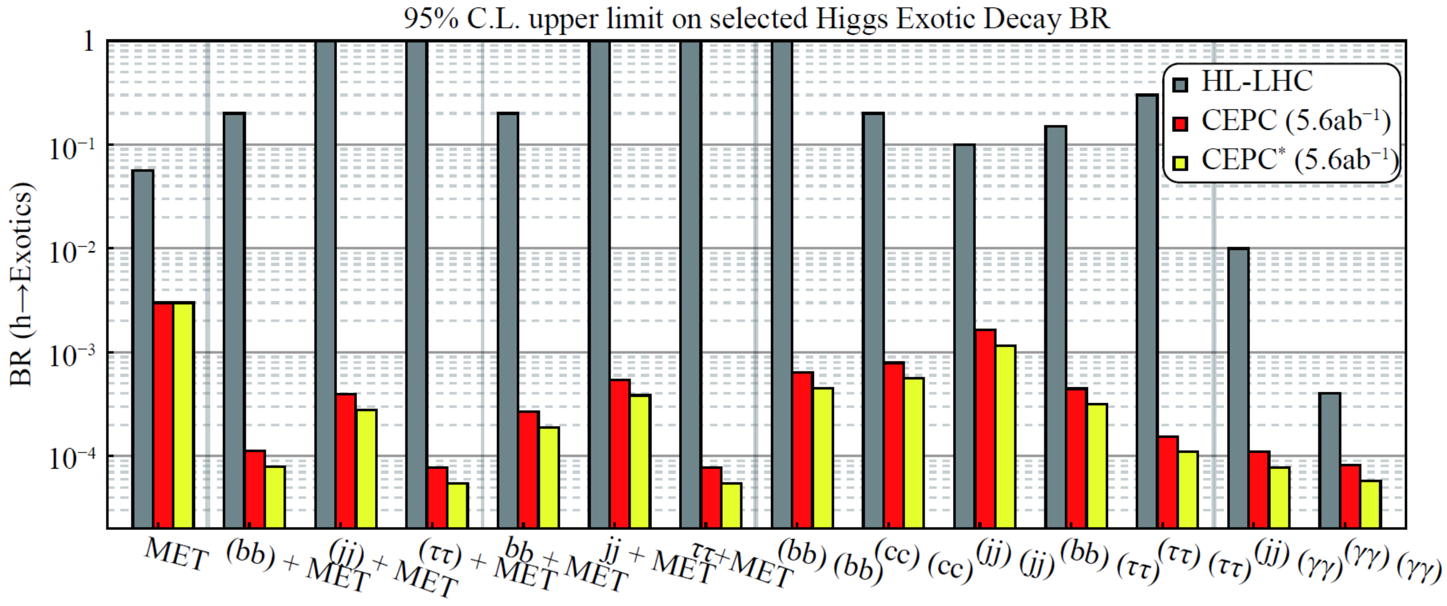


$$h \to X_{dm} X_{dm}$$





Higgs decays into BSM particles, H→ X_1X_2



CEPC has significantly better detection sensitivity for dark matter and selected Higgs exotic decays than HL-LHC