Overview of the CEPC Project

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HKUST IAS HEP Program, February 12 – 16, 2023

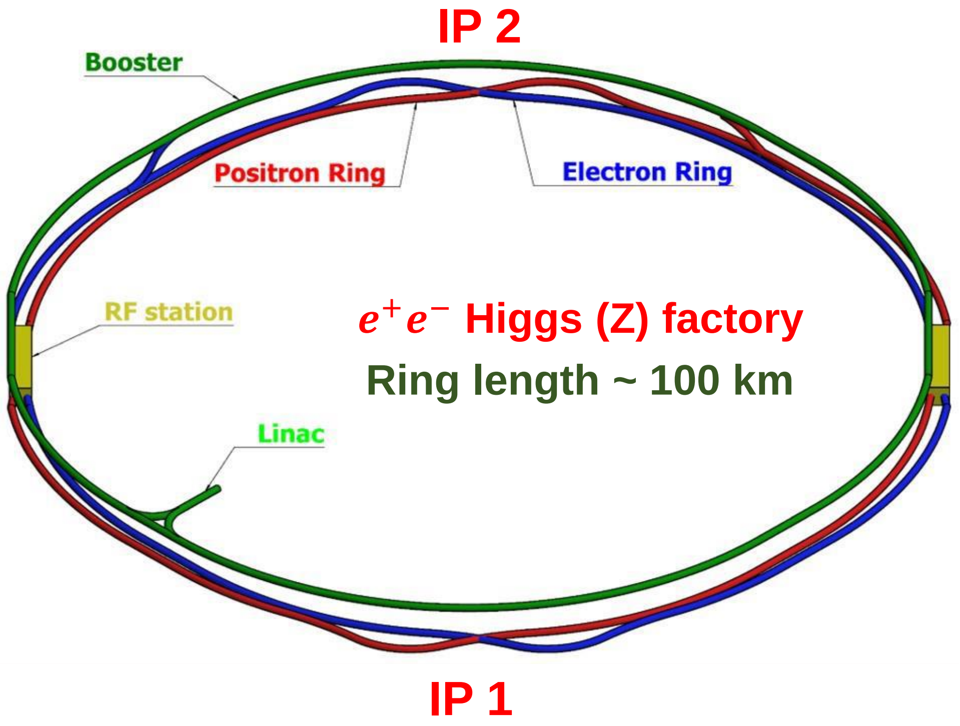
http://cepc.ihep.ac.cn/

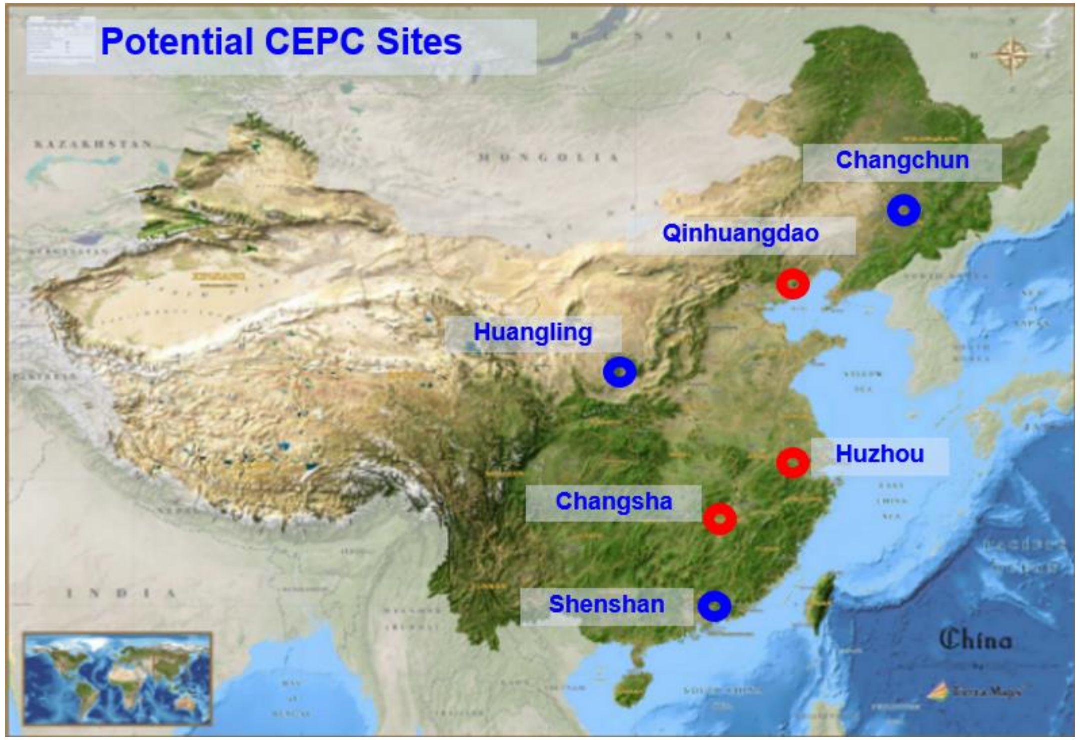
Outline

- Introduction to CEPC
  - Goal and Plan
  - Consensus on e^+e^- Higgs Factory
- Highlights of CEPC R&D
  - Physics Program
  - Accelerator R&D
  - Detector R&D
- Project Global Aspects
  - Core Team, Institutions, Internationalization
  - Funding for R&D and Industrial Engagement
  - Project Cost Estimation and Sharing
  - Project Timeline
- Summary and Prospect

Circular Electron Positron Collider (CEPC)

- CEPC is an e^+e^- Higgs factory producing Higgs / W / Z bosons and top quarks, aims at discovering new physics beyond the Standard Model
- Proposed in 2012 right after the Higgs discovery
- Proposed to commence construction in ~2026 and start operation in 2030s.
- Upgrade: Super pp Collider (SppC) of $\sqrt{s}$ ~ 100 TeV in the future.





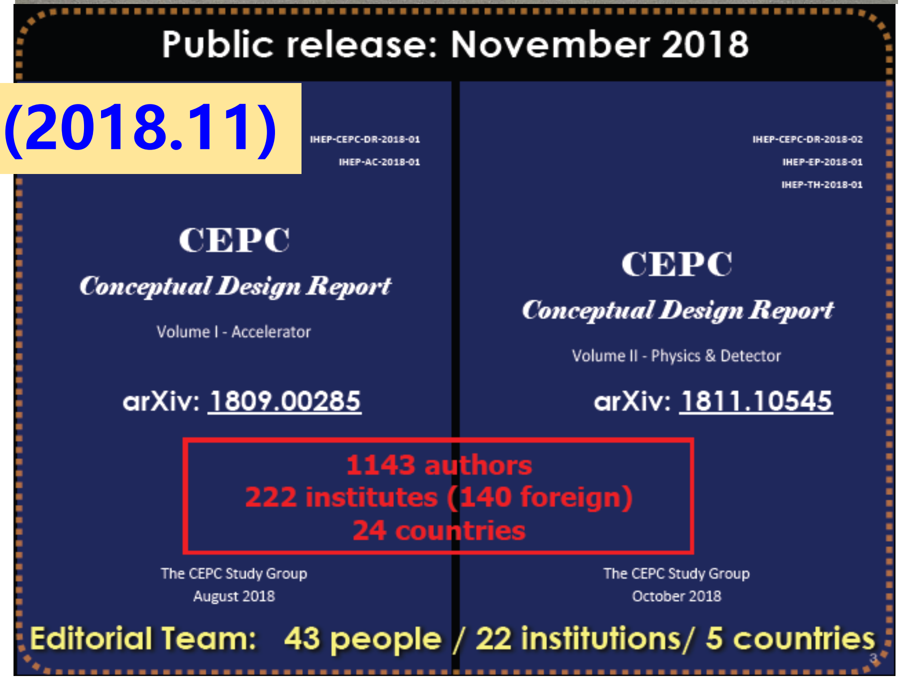
arXiv:1809.00285, arXiv:2203.09451

CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

CEPC IAC Meeting (2015.9)

CEPC CDR Released (2018.11)



CEPC Action Plan Since CDR

CEPC CDR: first for a circular e^+e^- Higgs factory

Public release: November 2018

IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC

Conceptual Design Report

Volume I - Accelerator

arXiv: 1809.00285

The CEPC Study Group
August 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

arXiv: 1811.10545

The CEPC Study Group
October 2018

1143 authors
222 institutes (140 foreign)
24 countries

Editorial Team: 43 people / 22 institutions/ 5 countries

Since 2019

CEPC project with R&D towards

(1) Accelerator TDR (2023)

(2) Detector key technologies R&D and establishment of seeds for International Collaborations

Identify challenges and devise solutions

Consensus in HEP Community for e^+e^- Higgs Factory

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

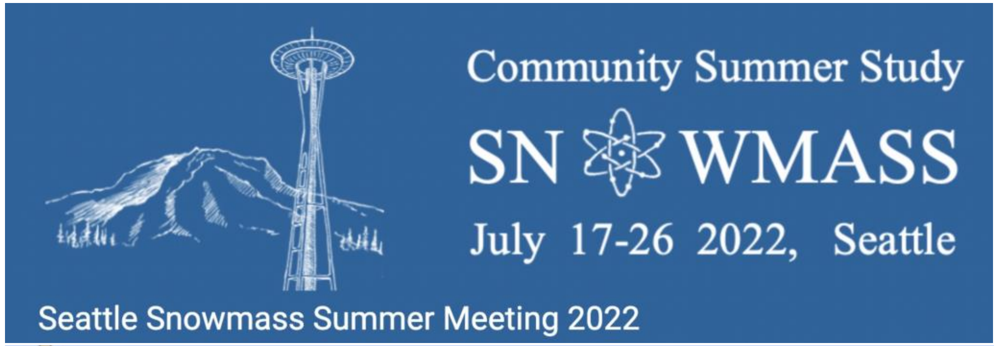
XIANGSHAN SCIENCE CONFERENCES

Clear consensus in HEP community

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

2020 European Strategy Update

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:



Conclusion from Executive Summary

Given the **strong motivation** and existence of proven technology to build an **e^+e^- Higgs Factory in the next decade**, the **US should participate** in the construction of **any facility that has firm commitment** to go forward.

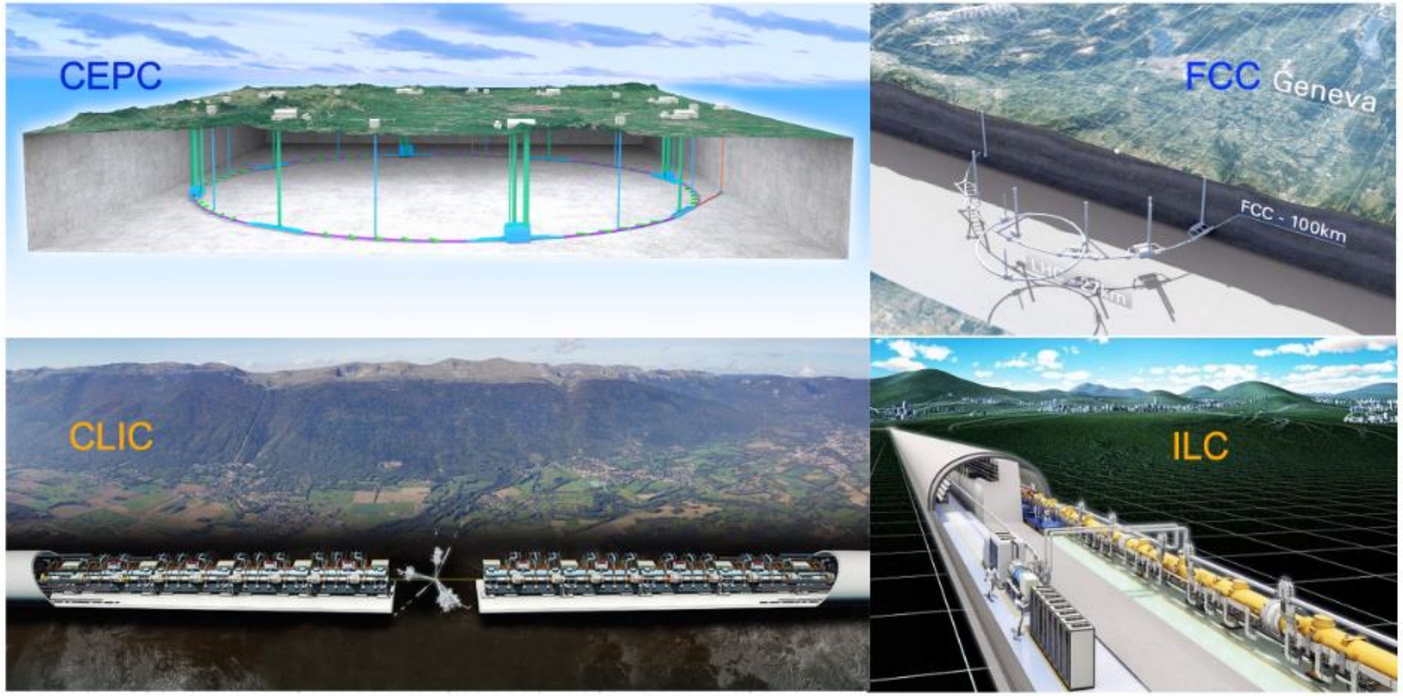
The e^+e^- colliders are the vehicle that will enable a high-precision physics program in the EW sector by increasing the precision of SM measurements. The physics case for an e^+e^- Higgs factory is compelling and the program is possible essentially with current technology. The various proposed facilities have a strong core of common physics goals that underscores the importance of realizing at least one such collider somewhere in the world. A timely implementation of a Higgs factory is important, as there is considerable US support for initiatives that can be achieved on a time scale relevant for early career physicists.

arXiv:2211.11084 COMMUNITY PLANNING EXERCISE: SNOWMASS 2021

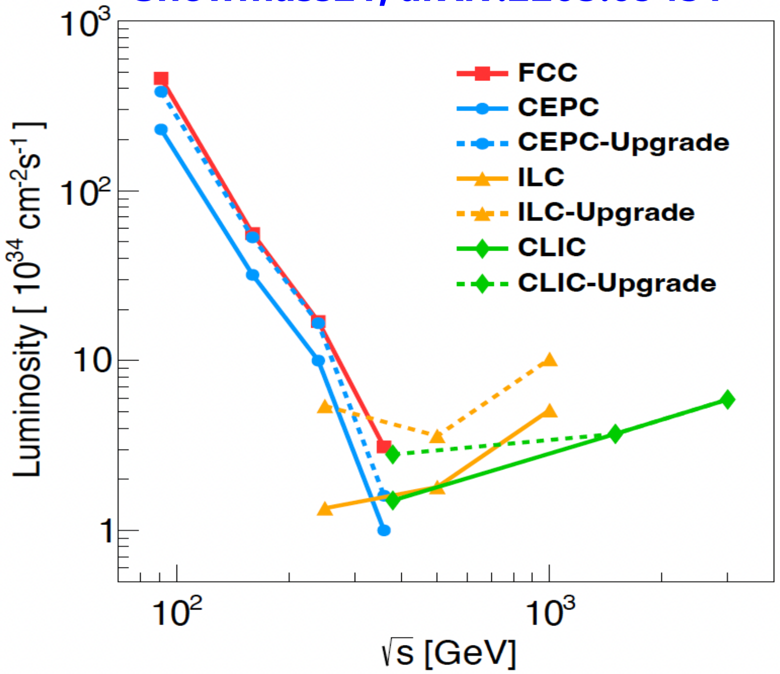
ICFA

*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. Recently, the United States also proposed a new linear collider concept based on the cool copper collider (C3) technology [31].*

Comparison with other international Higgs factories



CEPC Accelerator white paper for Snowmass21, arXiv:2203.09451



CEPC has substantive advantage 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 cost: ~ ½ the construction cost with similar luminosity up to 240 GeV

Versus Linear Colliders

- Higher luminosity for Higgs and Z runs
- Potential upgrade for pp collider

Highlights of CEPC R&D

CEPC Physics Program (White Papers)

CEPC Operation mode		ZH	Z	W^+W^-	ttbar
$\sqrt{s}$ [GeV]		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	-
CDR (30MW)	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	3	32	10	-
	$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
	Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run time [years]		10	2	1	5
Latest TDR (50MW)	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	8.3	191.7	26.6	0.8
	$\int L\,dt$ [ab^{-1}, 2 IPs]	20	96	7	1
	Event yields [2 IPs]	4×10^6	4×10^{12}	5×10^7	5×10^5

Physics similar to FCC-ee, ILC, CLIC

- 2019.3 **Higgs** White Paper published *(CPC V43, No. 4 (2019) 043002)*
- 2019.7 Workshop@PKU: **EW, Flavor, QCD** working groups formed
- 2020.1 Workshop@HKUST-IAS: Review progress, EW draft ready
- 2021.4 Workshop@Yangzhou: **BSM** working group formed
- **2022.5 Workshop of CEPC physics, software and detector**
- **2022 Input for Snowmass study**

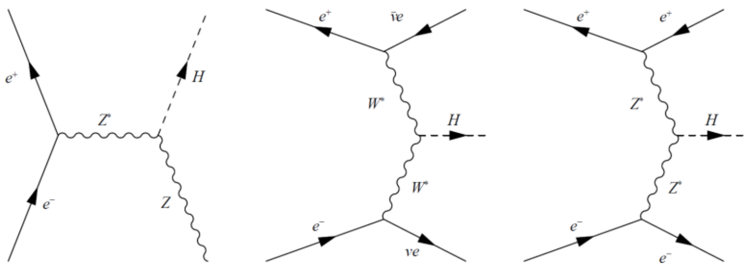
arXiv:2205.08553

Peking U. (2019)

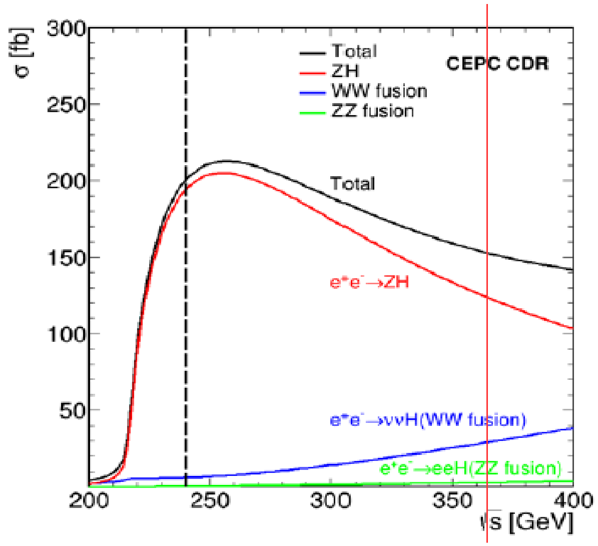
Yangzhou (2021)

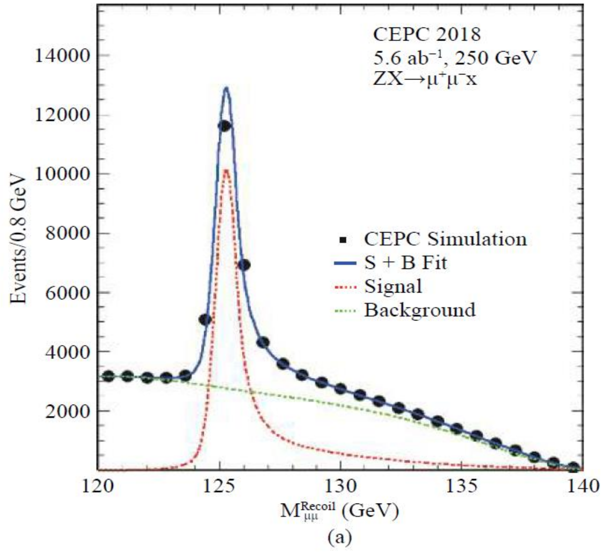
CEPC Physics Program (CDR)

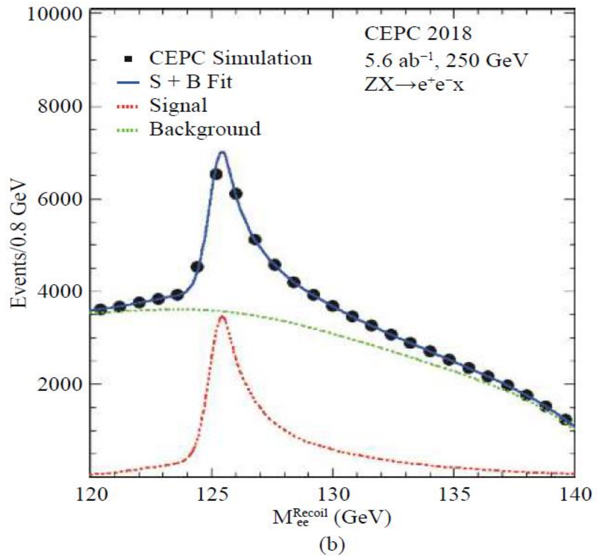
e$^+$e$^-$ annihilations at the CEPC

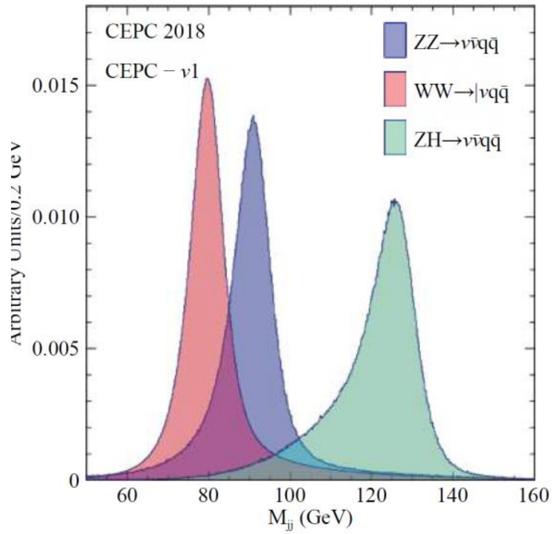


- **CEPC can make detailed study of various physics processes**
- **Higgs bosons are detected via recoil mass of the reconstructed Z, allowing for model independent & full investigation of the Higgs and any new physics that Higgs may reveal**
- **Very challenging events with missing neutrinos and jets are well reconstructed and identified**









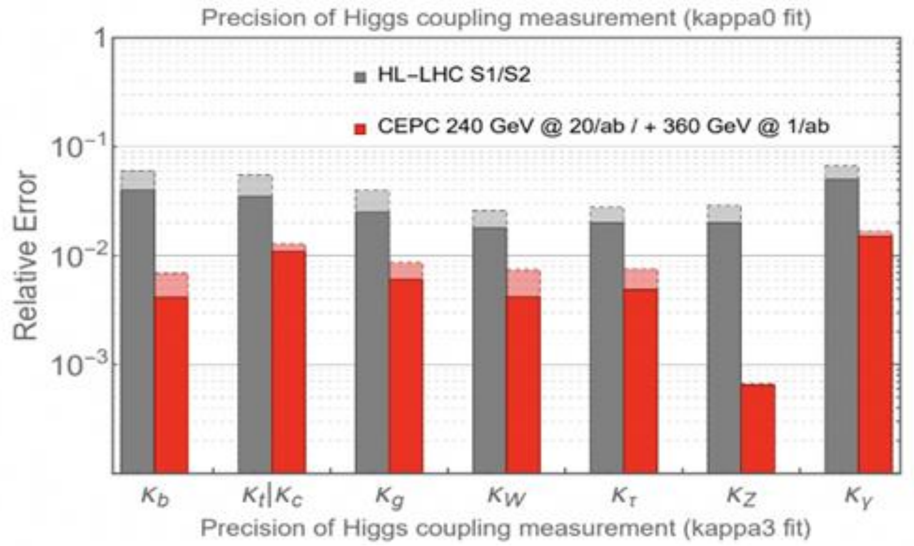
Chinese Physics C Vol. 43, No. 4 (2019) 043002

❖ **O(100) Journal / arXiv papers**

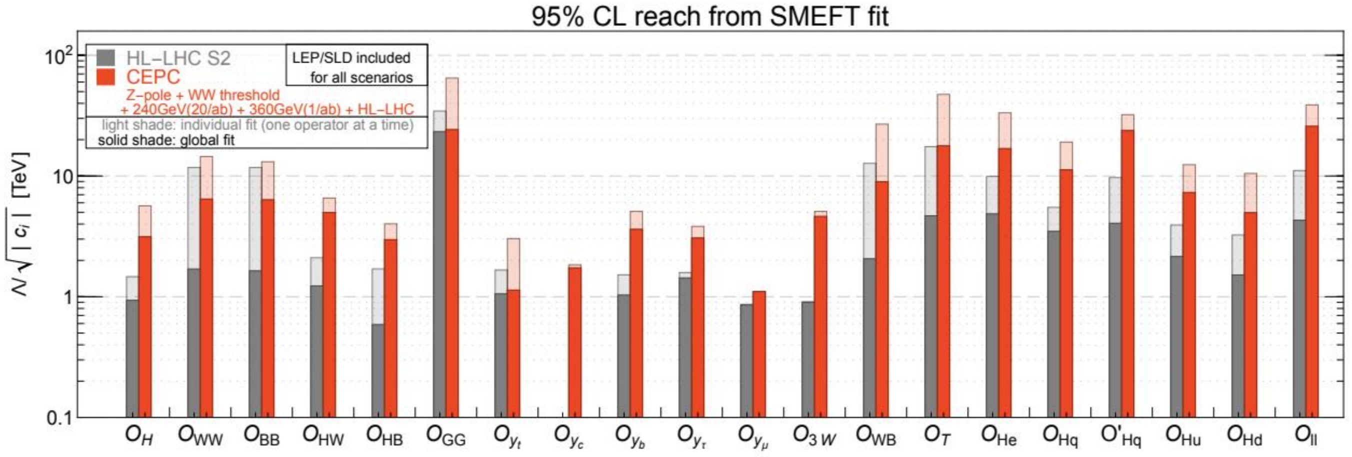
CEPC Physics Program

- **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**

	$240\,\mathrm{GeV},\ 20\ \mathrm{ab}^{-1}$		$360\,\mathrm{GeV},\ 1\ \mathrm{ab}^{-1}$		
	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%		
$\mathrm{Br}_{upper}(H \to inv.)$	0.07%				
Γ_H	1.65%		1.10%		



Energy scale probed



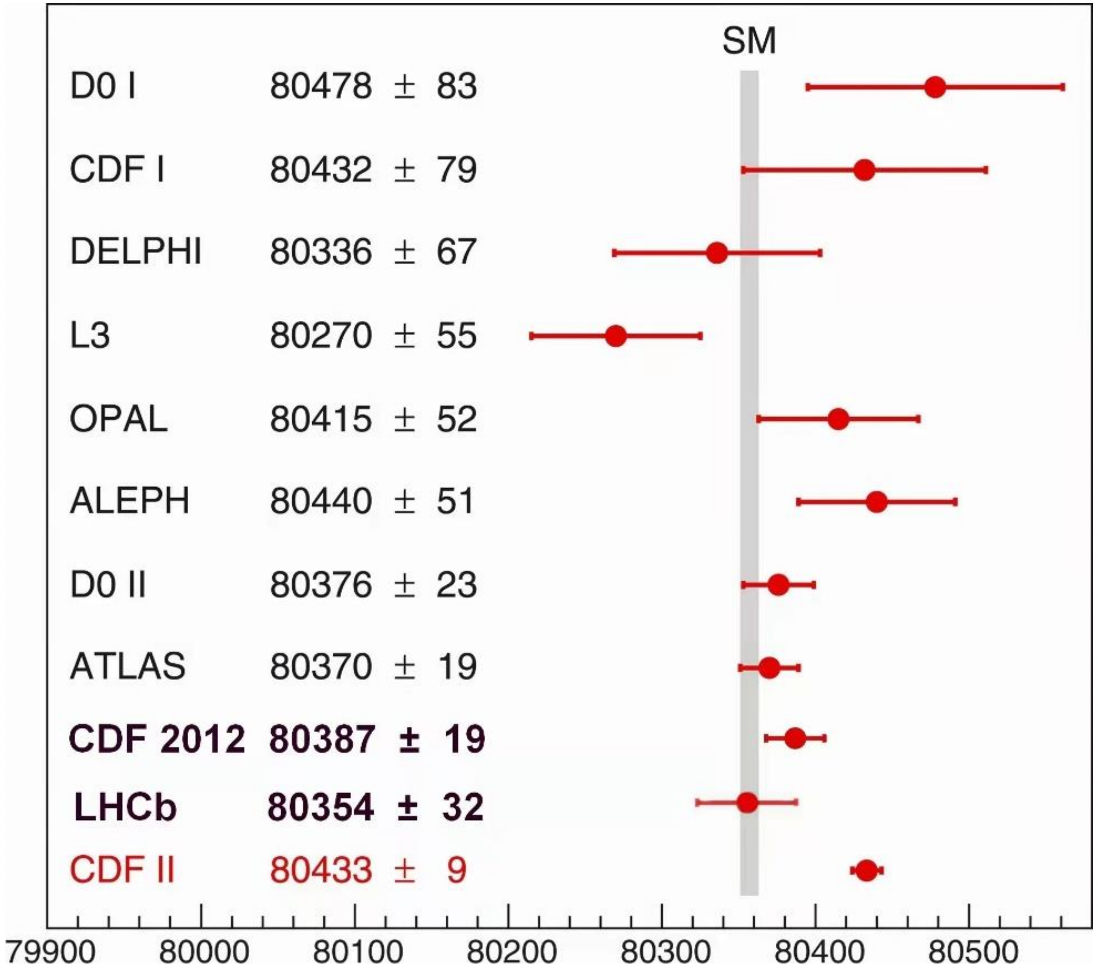
arXiv:2205.08553

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

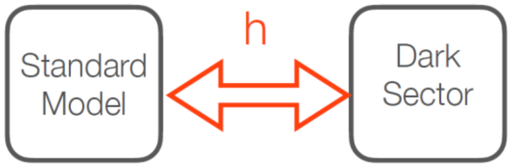
CEPC Physics Program: Higgs and EW

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

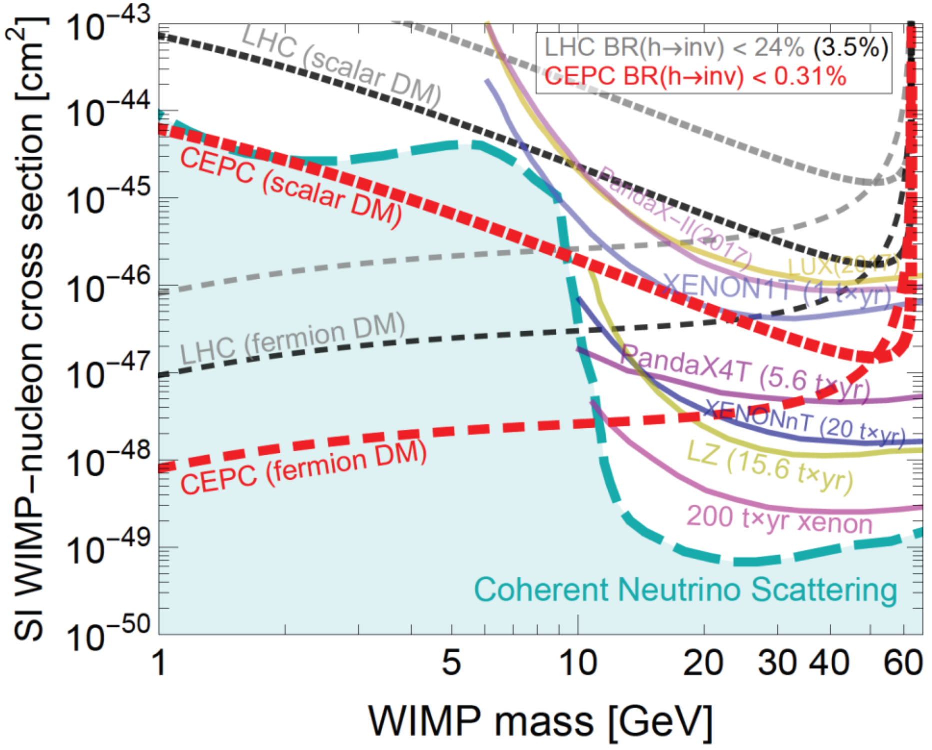
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 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

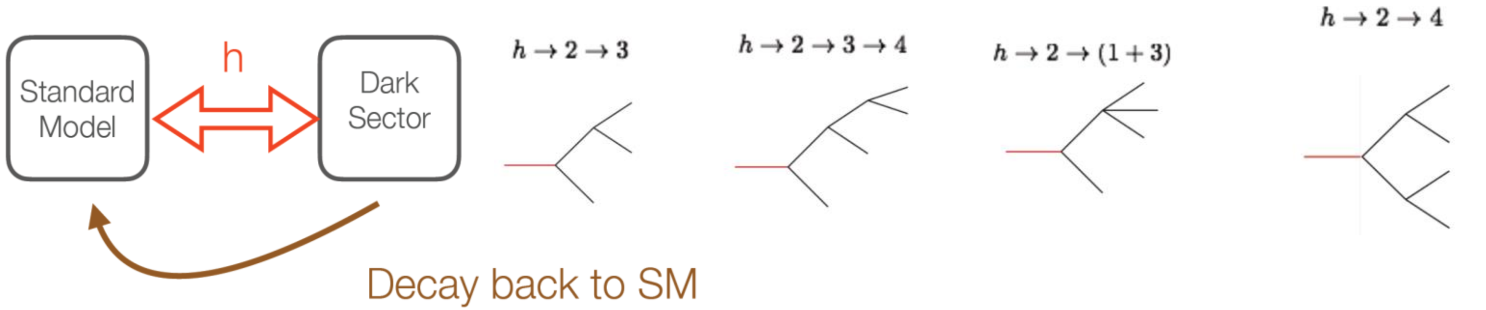


CEPC Physics Program: Discovery Potential

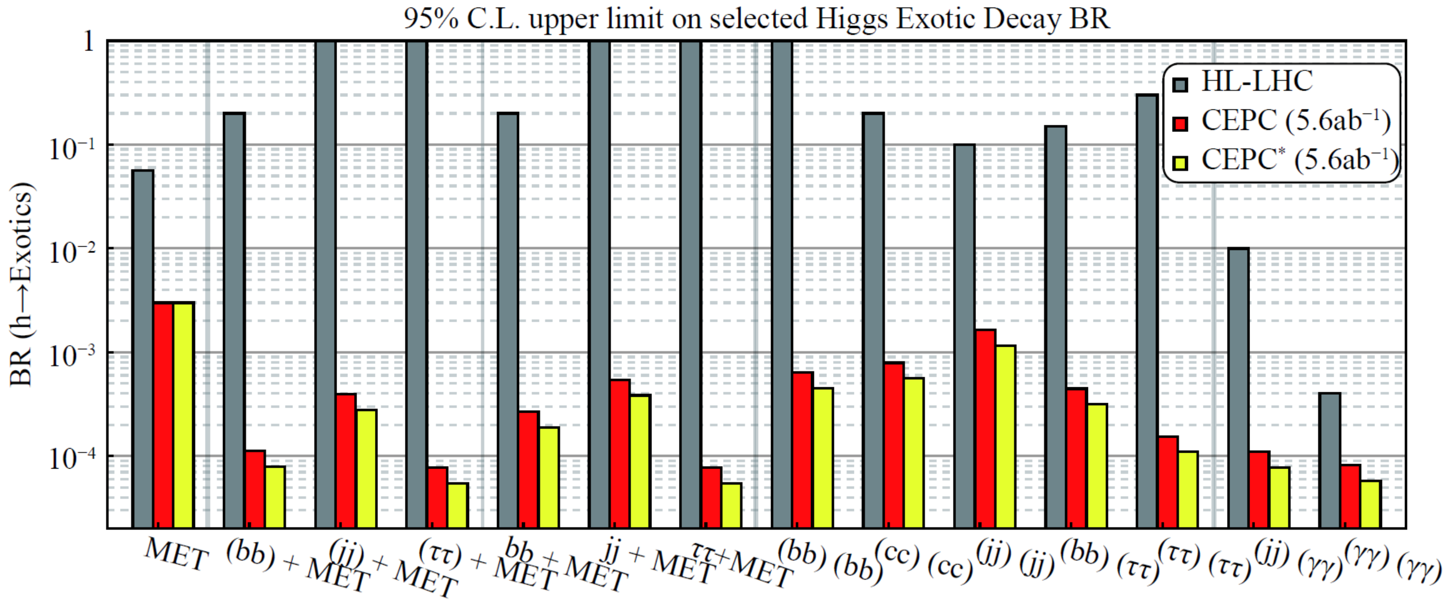


$$h \to X_{dm} X_{dm}$$





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

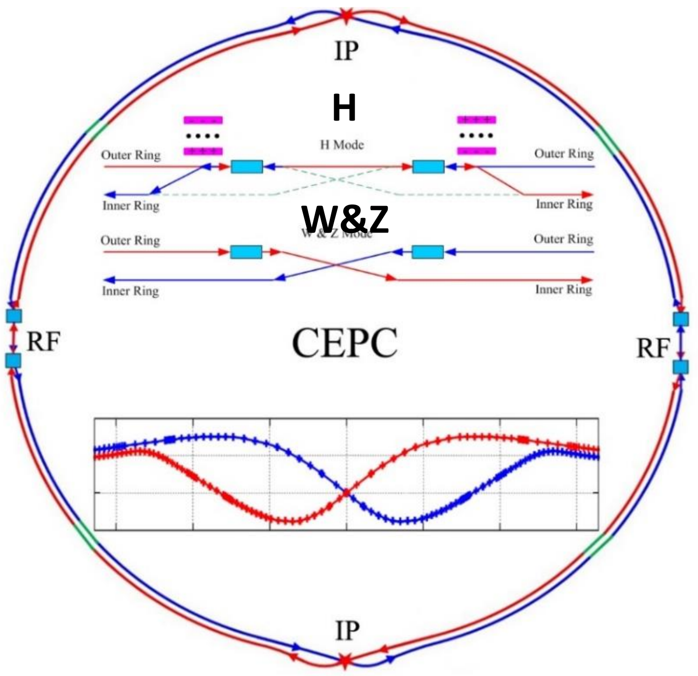
CEPC Design and Technical Requirements

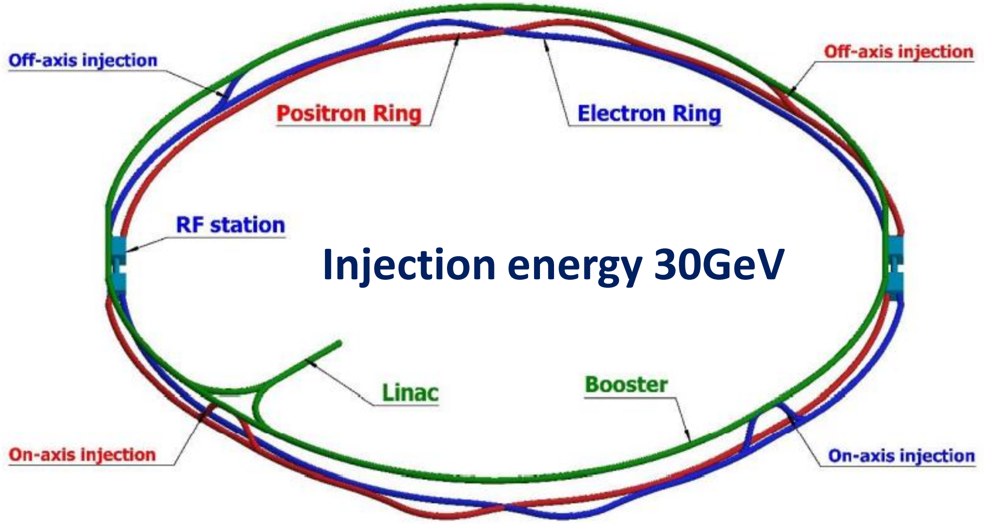
Innovative Design	➢ 100km Full/Partial Double Rings ➢ Switchable operation for Higgs, W and Z ➢ Flexible injection modes to satisfy different energies ➢ World's 1st design of a high energy/flux γ-ray synchrotron light
Technical Performance	➢ High efficiency Klystron (aim at highest transfer efficiency) ➢ High performance SRF cavities (state-of-the-art Q and gradient) ➢ Novel magnets: Weak field dipole, dual aperture magnets (First Qualified Prototype)
Major Technology Breakthrough	➢ Plasma wakefield acceleration for Injector(New Acceleration Principle) ➢ High field superconducting magnet (Iron based HTS proposal)

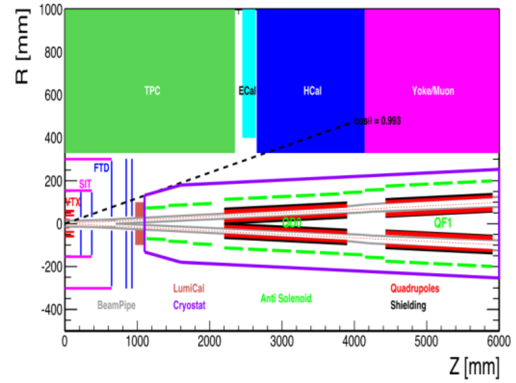
CEPC focuses on innovative designs and key technology R&D to fulfill the challenging design requirement !

CEPC Accelerator Design Improvement & TDR

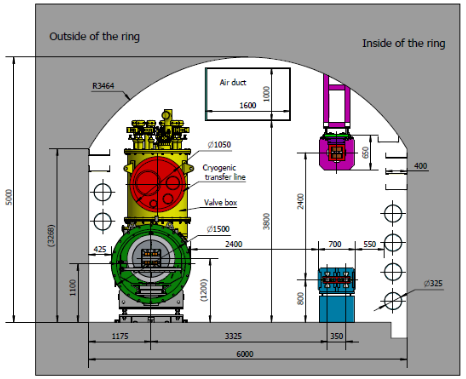
- 100 km double ring design (30 MW SR power, upgradable to 50MW).
- Switchable operation for H & Z, W modes without hardware change.



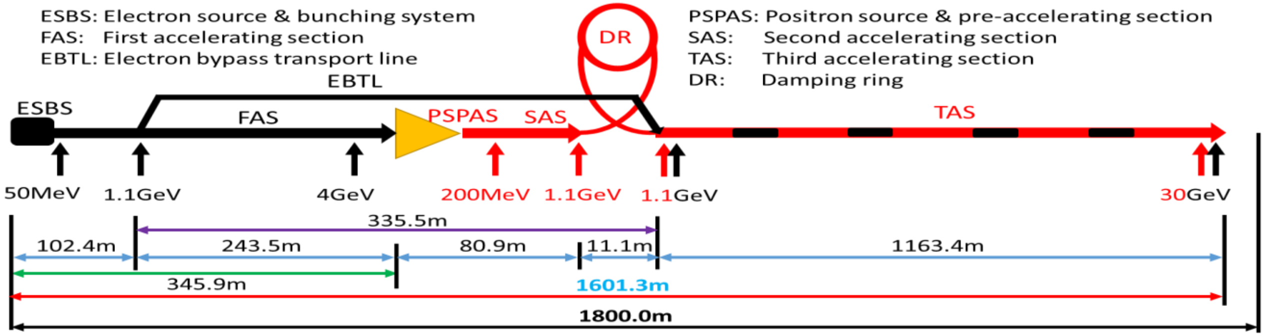




TUNNEL CROSS SECTION OF THE ARC AREA



CEPC TDR S+C-band 30GeV Linac Injector



Operation mode		ZH	Z	W^+W^-	tt
$\sqrt{s}$ [GeV]		~240	~91.2	158-172	~360
L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	CDR (2018)	3	32	10	-
	TDR (30MW)	5.0	115	16	0.5
	TDR (50MW)	8.3	191.7	26.6	0.8

Status of CEPC Accelerator R&D

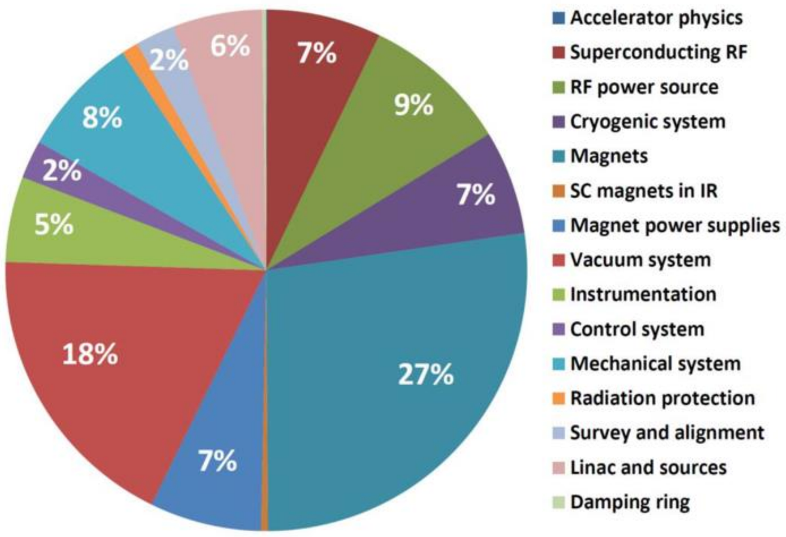


Figure 12.3: Cost breakdown of the CEPC accelerator technical systems.

✓ Specification Met

☑ Prototype Manufactured

	Accelerator	Cost (billion CNY)	Ratio
✓	Magnets	4.47	27.3%
✓	Vacuum	3.00	18.3%
☑	RF power source	1.50	9.1%
✓	Mechanics	1.24	7.6%
✓	Magnet power supplies	1.14	7.0%
✓	SCRF	1.16	7.1%
✓	Cryogenics	1.06	6.5%
✓	Linac and sources	0.91	5.5%
✓	Instrumentation	0.87	5.3%
☑	Control	0.39	2.4%
☑	Survey and alignment	0.40	2.4%
✓	Radiation protection	0.17	1.0%
☑	SC magnets	0.07	0.4%
✓	Damping ring	0.04	0.2%

IHEP New SCRF Lab (PAPS) in Operation

CEPC SCRF Test Facility is located at IHEP Huairou Area (4500m²)

New SC Lab Design (4500m²)

SC New Lab (PAPS) has been put to operation in June 2021

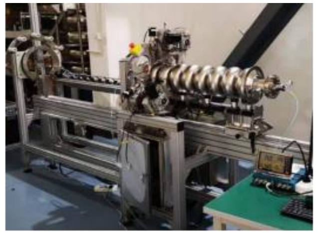
Crygenic system hall

Vacuum furnace (doping & annealing)

Nb3Sn furnace

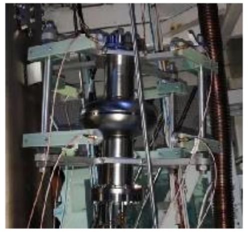
Nb/Cu sputtering device

Cavity inspection camera and grinder

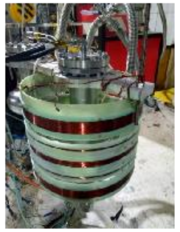


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

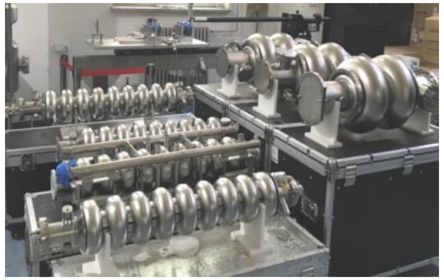
Vertical test dewars

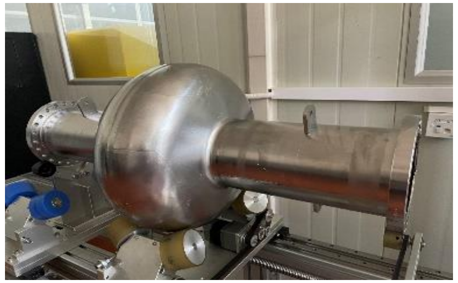
Horizontal test cryostat

CEPC R&D: High Q SCRF Cavities

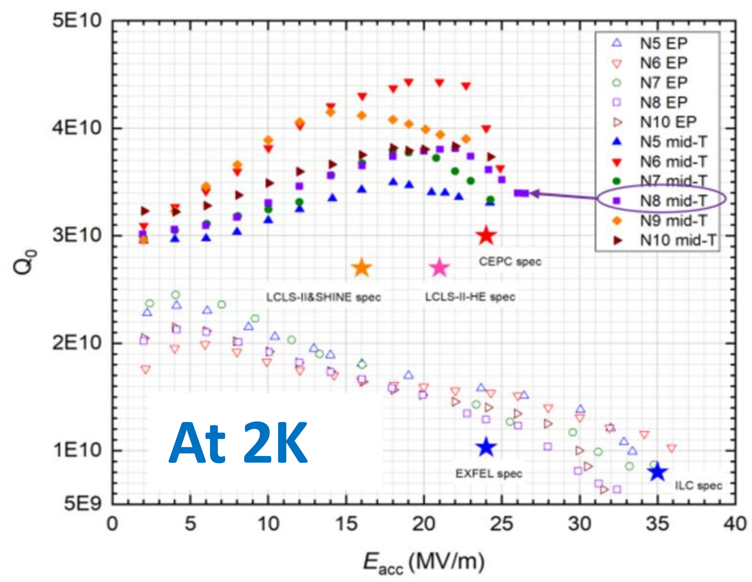
- 1.3 GHz 9-cell SCRF cavity for booster: Q_0 = 3.4E10 @ 26.5 MV/m
- 650 MHz 2-cell SCRF cavity for collider ring: Q_0 = 6.0E10 @ 22.0 MV/m
- 650 MHz 1-cell SCRF cavity for collider ring: Q_0 = 6.0E10 @ 31.0 MV/m

All SCRF satisfied CEPC design specifications !

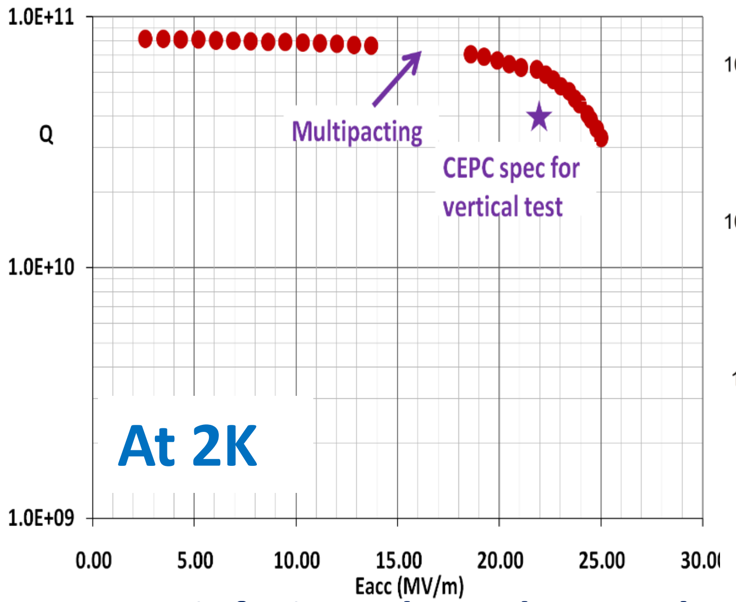




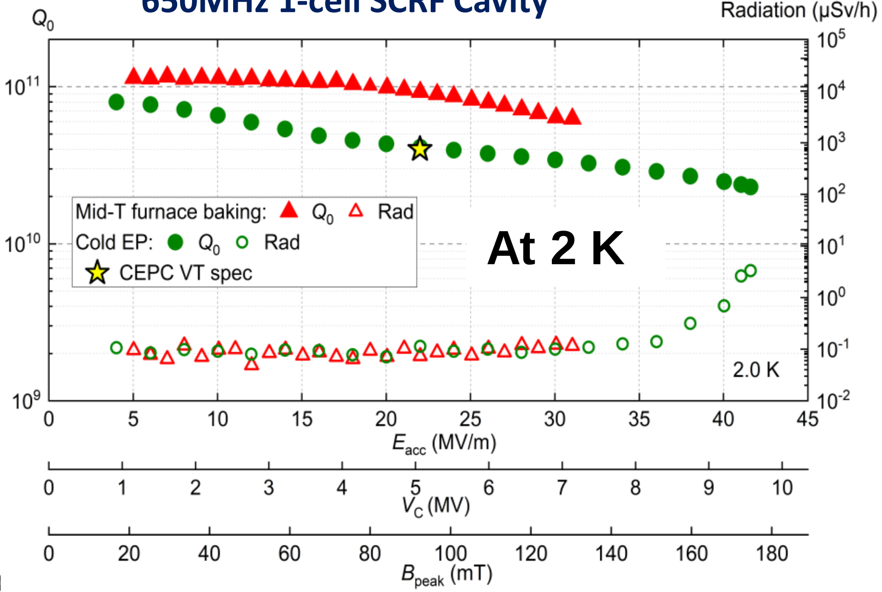
IHEP 1.3 GHz 9-cell Cavity Vertical Test



Vertical test of 650 MHz 2-cell cavity



650MHz 1-cell SCRF Cavity



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

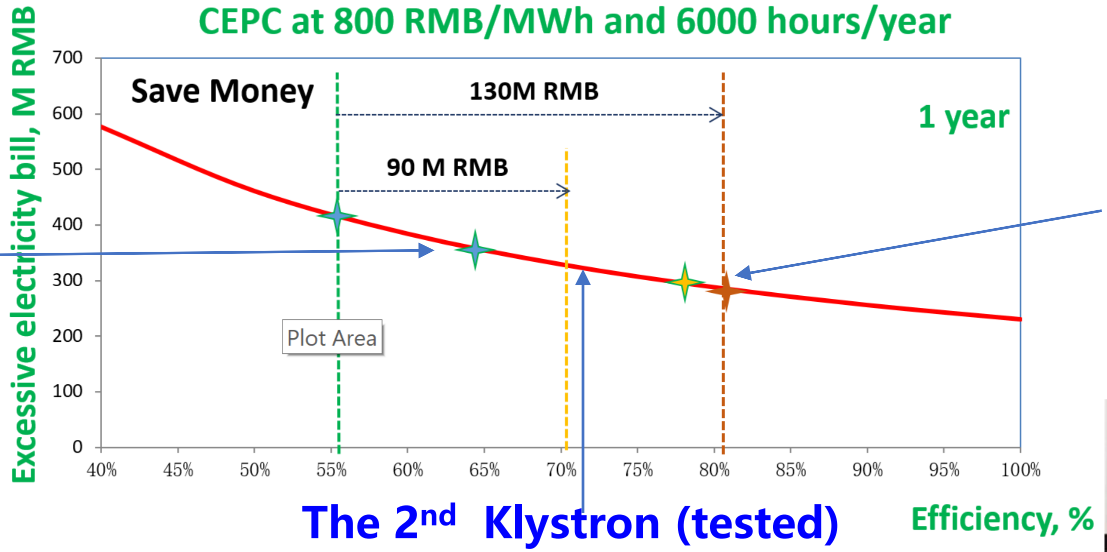
N-infusion adopted to reach Q_0 = 6.0E10 @ 22.0 MV/m

Q_0 = 6.0E10 @ 31 MV/m
Q_0 = 2.1E10 @ 42 MV/m

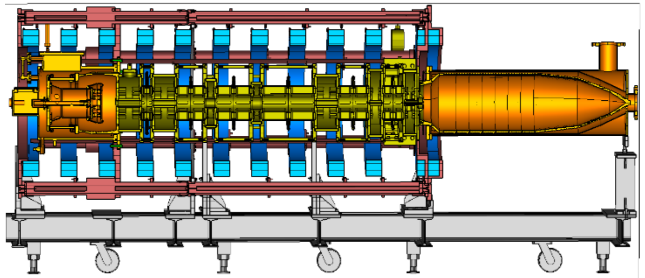
CEPC R&D: High Efficiency Klystrons

- The 1st Klystron prototype, achieved efficiency ~ 65%.
- The 2nd Klystron prototype tested at PAPS in 2022, design eff. is 77%, achieved eff. ~ 70.5%
- The 3rd Klystron (MBK) is under fabrication, design eff. is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

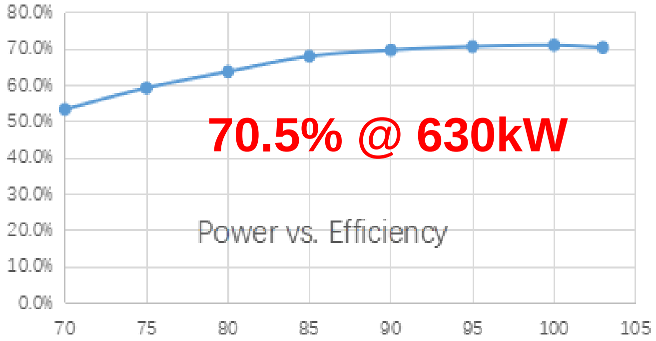
The 1st Klystron (tested)



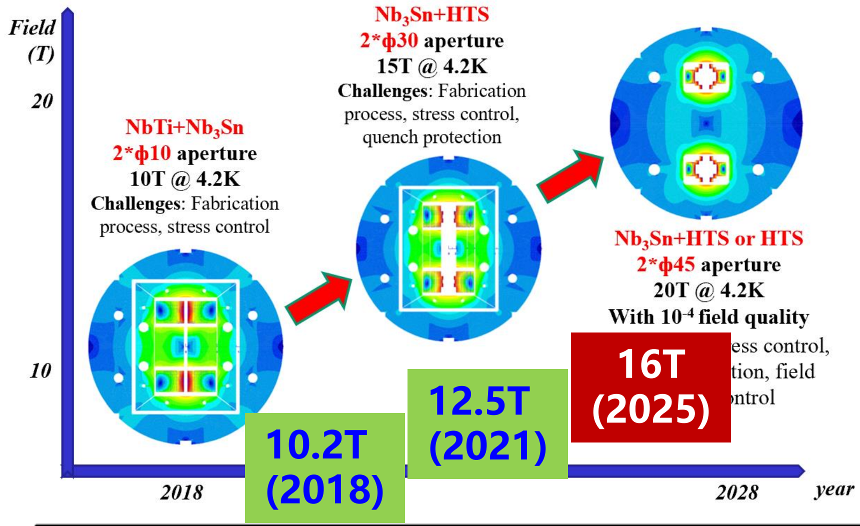
The 3rd multi-beam Klystron (MBK) under fabrication

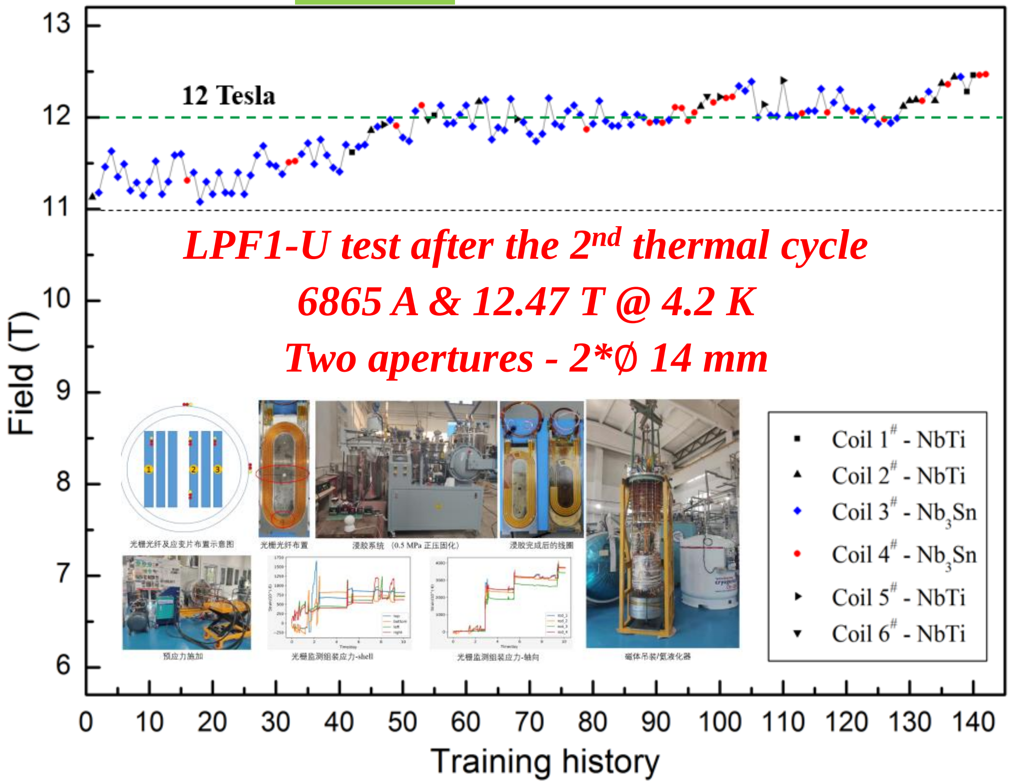


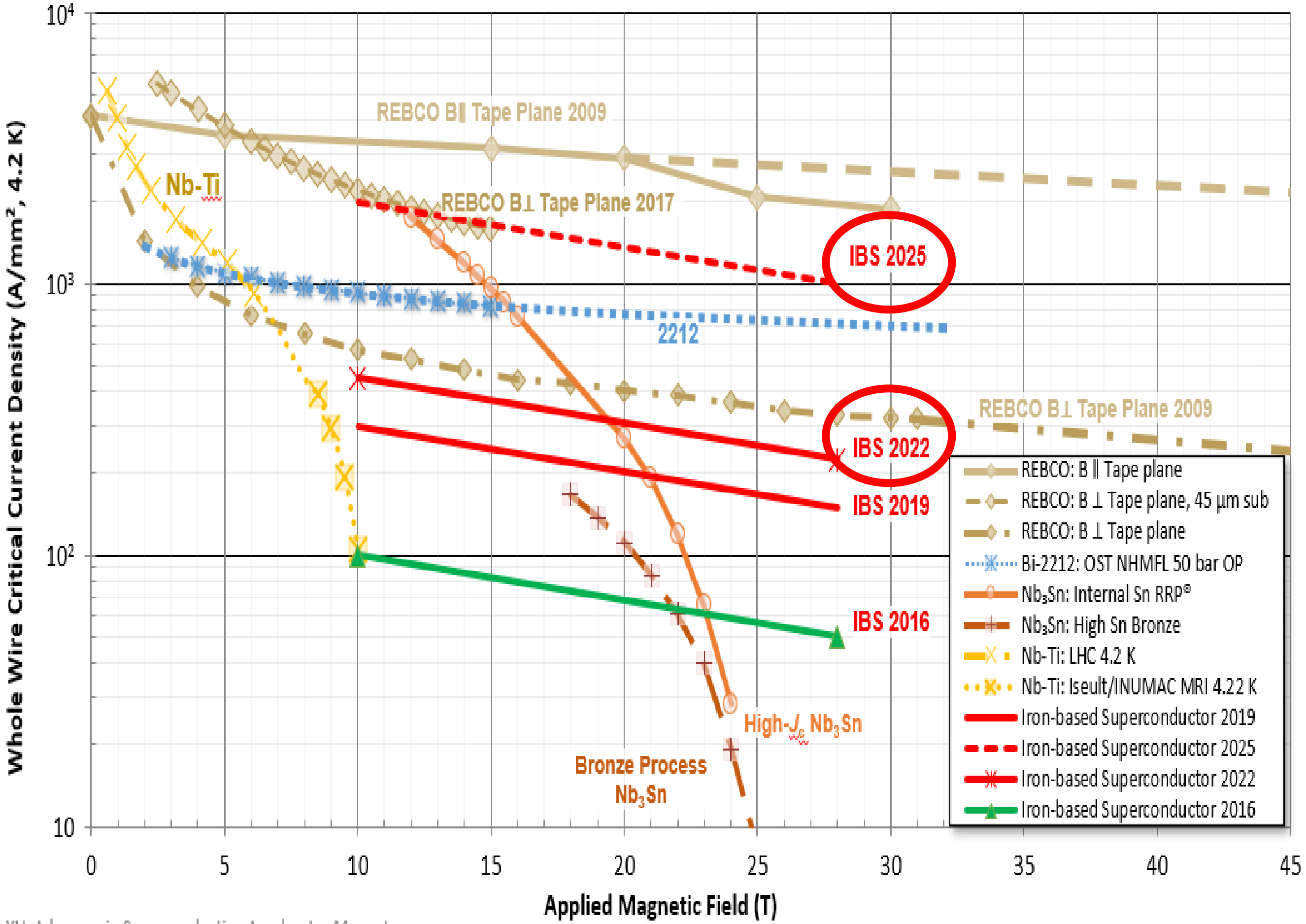
The 2nd Klystron (tested)



HTS SC Magnet and Iron-Based Superconductor







Q XU, Advances in Superconducting Accelerator Magnets

- **Stainless-steel stabilized IBS tape achieved the highest J_e in 2022**
- **Significantly reduced the cost and improve mechanical properties of IBS conductor.**

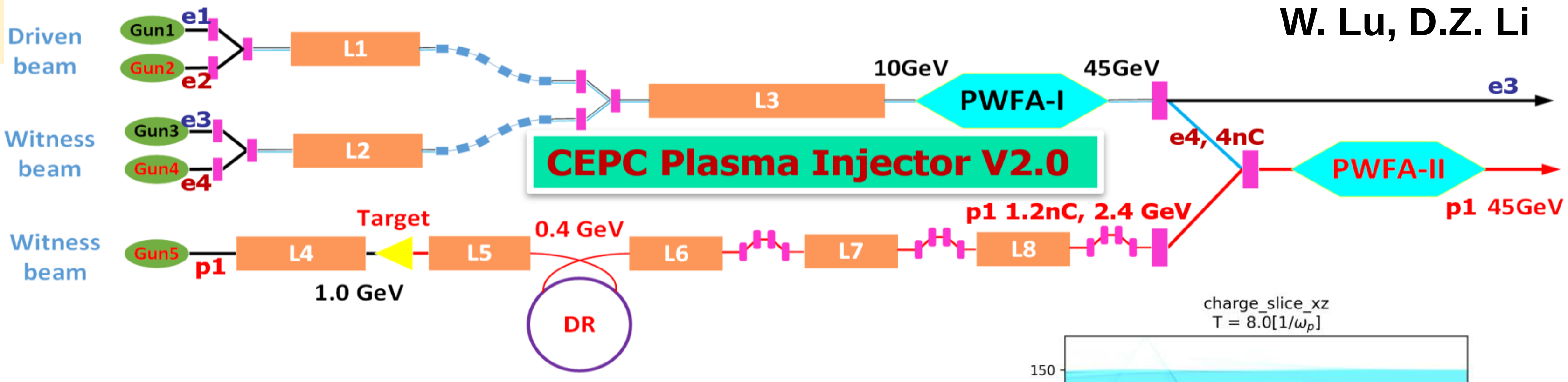
CEPC Accelerator: Plasma Injector

CEPC Plasma Injector V2.0

IHEP, THU, BNU

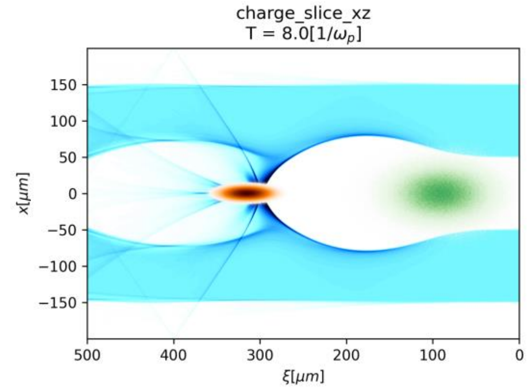
W. Lu, D.Z. Li

Booster Requirement	
Energy (GeV)	45.5
Bunch Charge (nC)	0.78
Bunch length (um)	<3000
Energy Spread (%)	0.2
ε_N (µm·rad)	<800
Bunch Size (um)	<2000



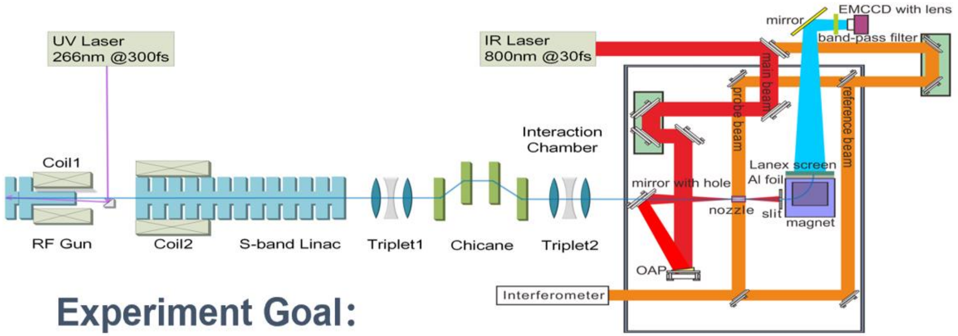
High eff. uniform wakefield acceleration of a positron beam using stable asymmetric mode in a hollow channel plasma

3D Quasi-static PIC simulations show:
Energy extraction efficiency ~ 30%
Energy spread ~ 1%



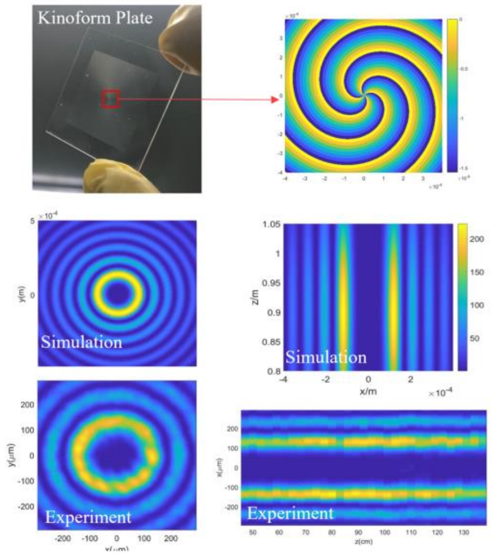
PRL 127, 174801 (2021)

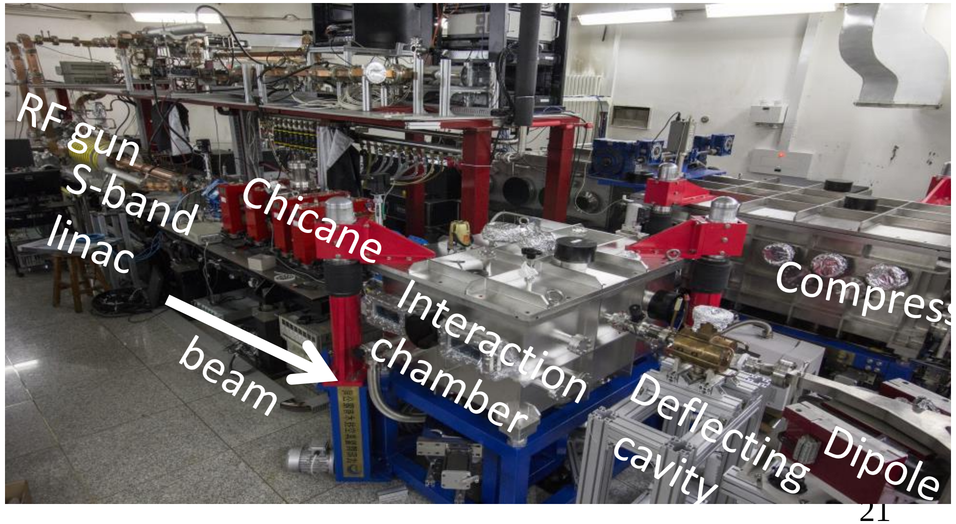
Plasma dechirper exp at SXFEL



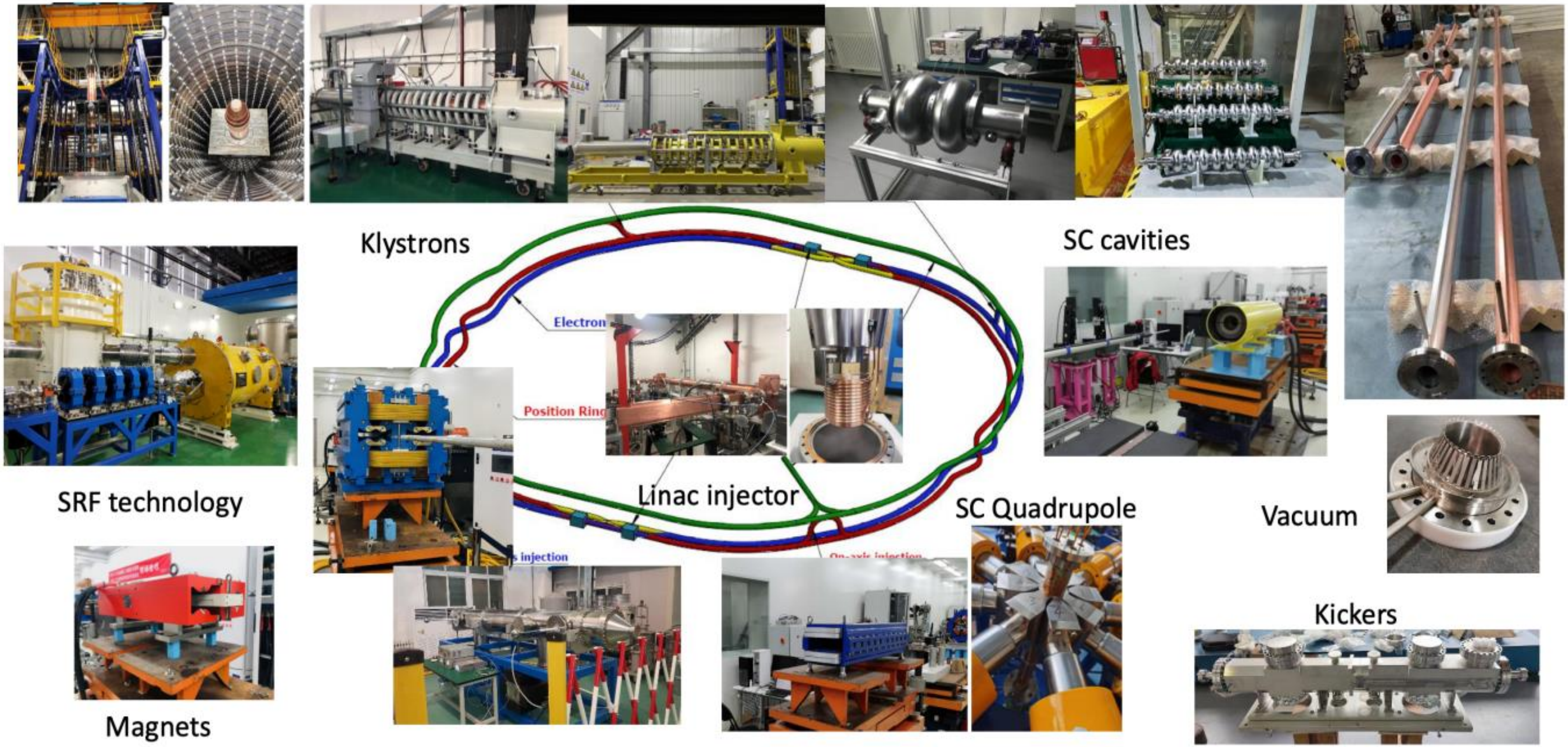
Experiment Goal:

1. Decrease the energy spread from 1% to 0.1%
2. Study Hollow channel impact on beam quality



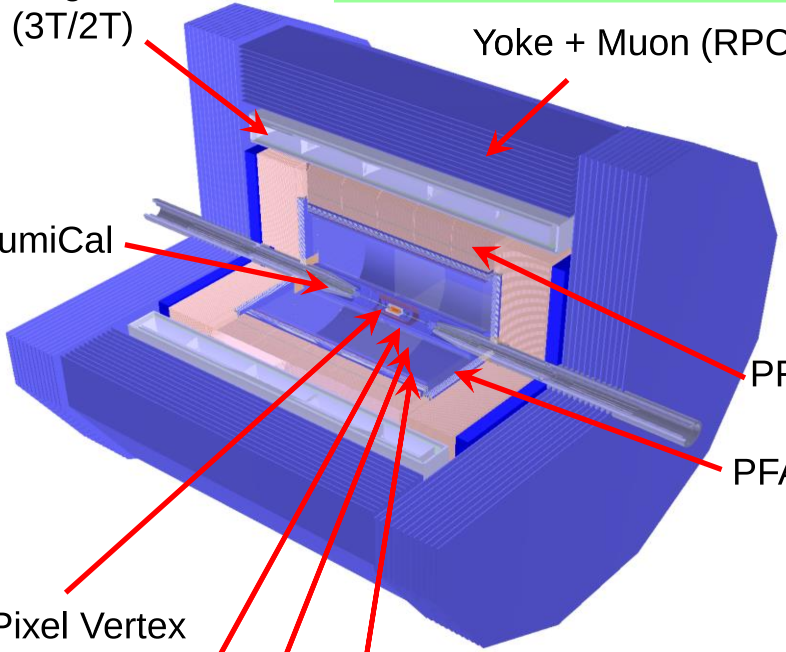


CEPC Key Technologies R&D

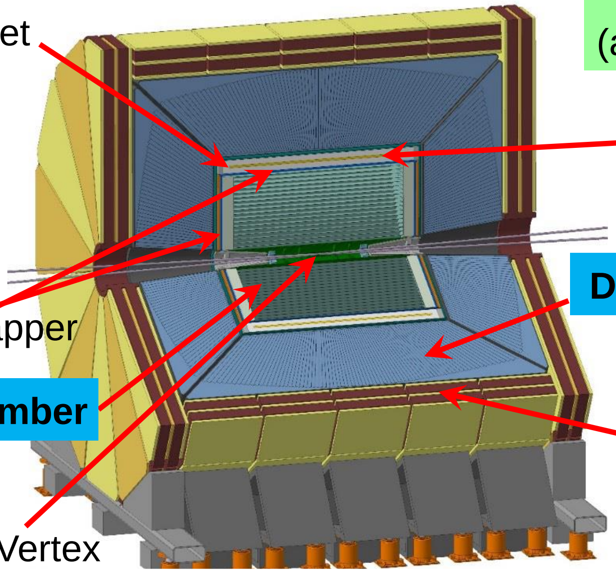


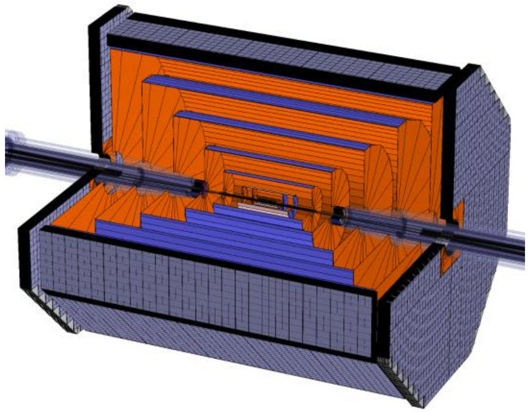
CEPC Conceptual Detector Designs

(Baseline Design)
Particle Flow Approach



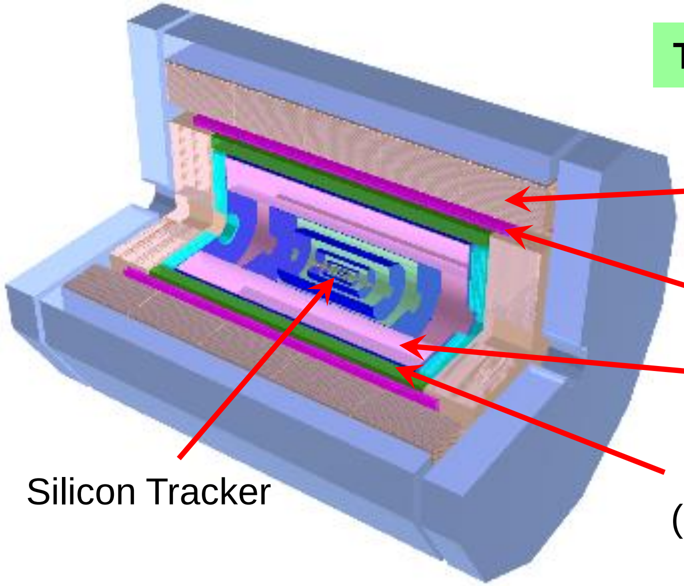
IDEA concept
(also proposed for FCC-ee)





FST concept
(Full Silicon Tracker)

The 4th Concept



Novel Conceptual Detector Design

Scint Glass PFA HCAL

Advantage: Cost efficient, high density
Challenges: Light yield, transparency, massive production.

Solenoid Magnet (3T / 2T) Between HCAL & ECAL

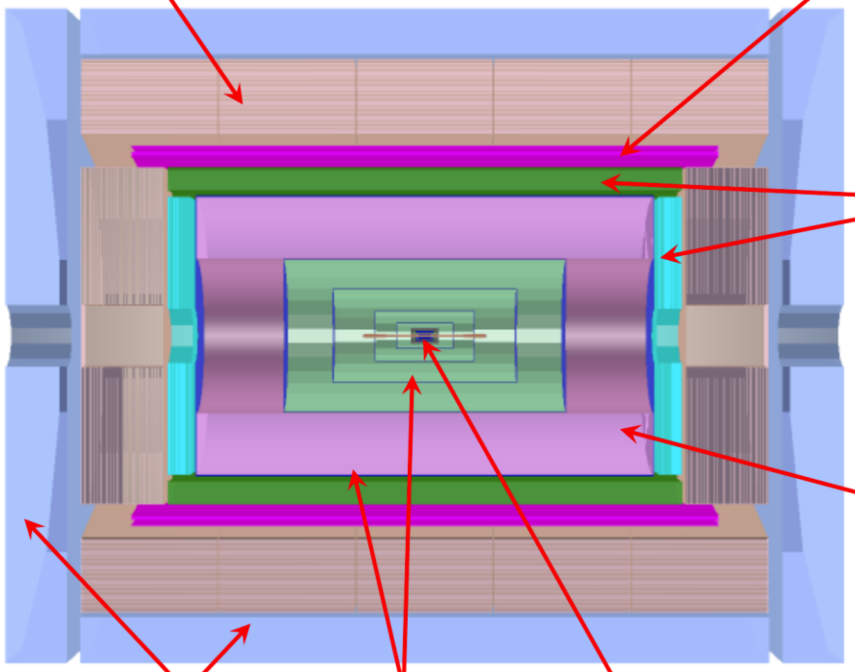
Advantage: the HCAL absorbers act as part of the magnet return yoke.
Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.
Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

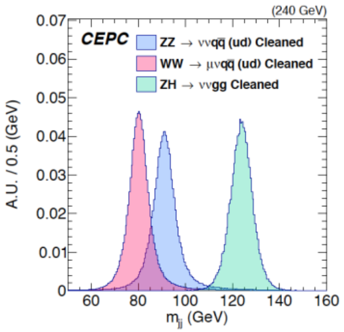
A Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs
Challenges: sufficient PID power; thin enough not to affect the moment resolution.



Det	Technology
Pixel Vertex	JadePix
	TaichuPix
	Arcadia
	CPV(SOI)
	Stitching
Tracker & PID	TPC
	CEPCPix
	Drift chamber
	PID DC
	LGAD
	Silicon Strip

Det	Technology
Calorimeter	Crystal ECAL
	Si+W ECAL
	Scint+W ECAL
	Scint AHCAL
	ScintGlass AHCAL
	RPC SDHCAL
	MPGD SDHCAL
	DR Calorimeter
Muon	Scintillation Bar
	RPC
	μ-Rwell
Lumi	SiTrk+Crystal ECAL
	SiTrk+SiW ECAL



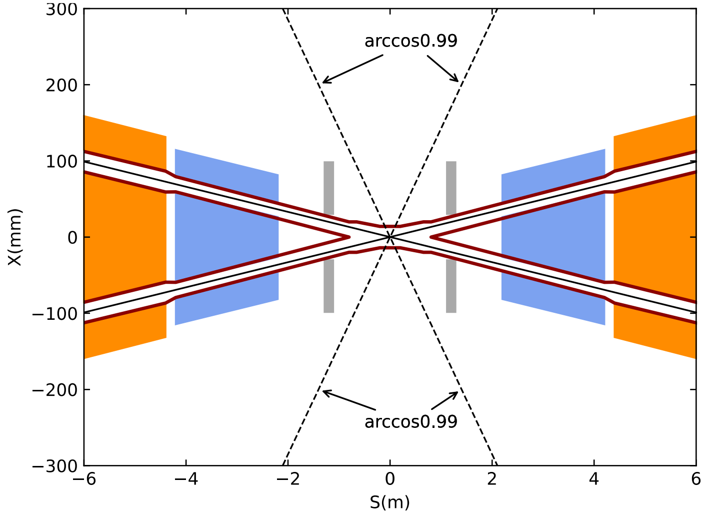
Novel detector design based on PFA calorimeter. Aim at improving BMR 4% → 3%

Detector	World-class level	CEPC design
PFA based (ECAL)	～ 15% / √E	< 3% / √E (Crystal ECAL)
PFA based (HCAL)	～ 50% / √E	～ 40% / √E (Scintillating glass HCAL)

CEPC R&D: Machine Detector Interface (MDI)

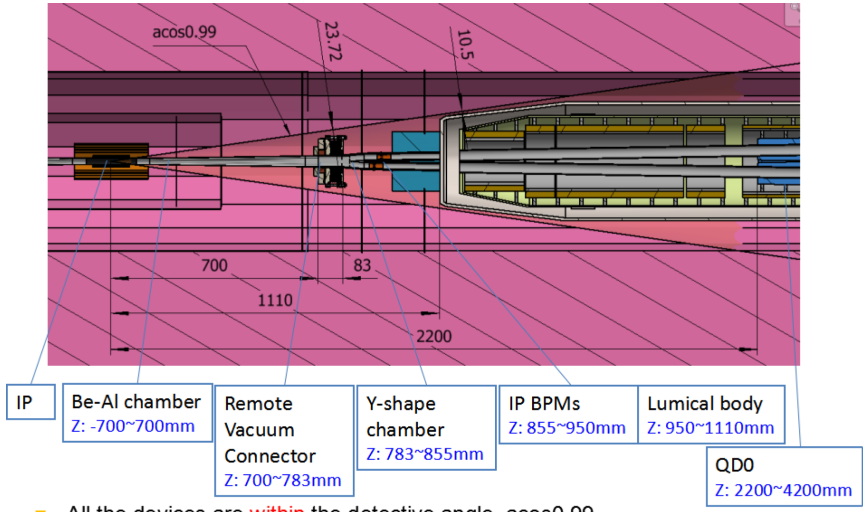
Crossing angle: 33 mrad

Focal length: 2.2 m



Final focusing magnets (QD0, QF1) with

Segmented Anti-Solenoidal Magnets

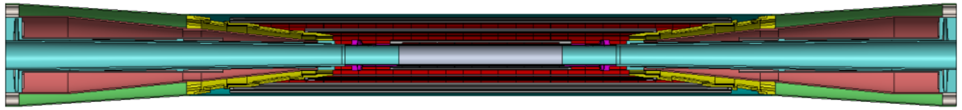


- All the devices are within the detective angle, acos0.99.

2021 Workshop on CEPC Detector & MDI Mechanical Design, Oct.22-23
https://indico.ihep.ac.cn/event/14392/

Beam Pipe

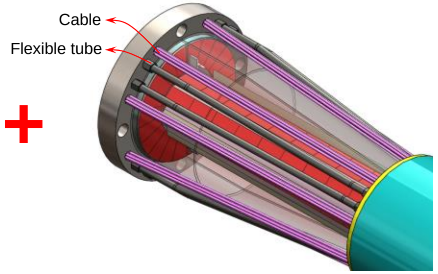
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

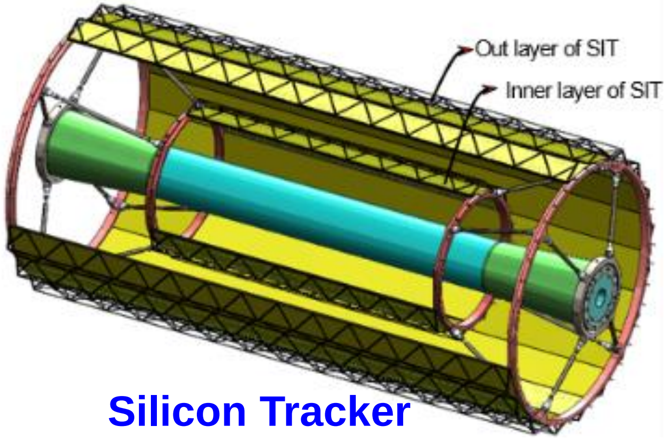


Vertex

+

LumiCal Tracker

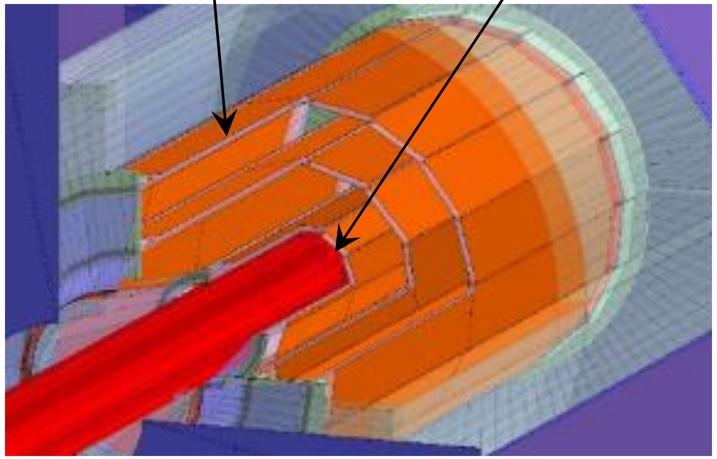




Silicon Tracker

Workshop on CEPC Central Beampipe and Beryllium Application
May 6, 2022, https://indico.ihep.ac.cn/event/16173/

CEPC R&D: Silicon Pixel Chips



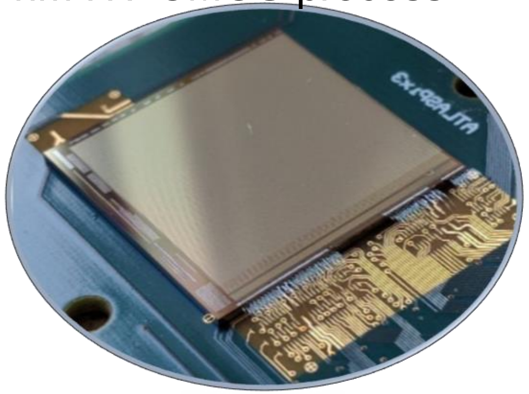
Goal: σ(IP) ~ 5 μm for high P track

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 tracker basing on **ATLASPix3** **CN/IT/UK/DE**
TSI 180 nm HV-CMOS process

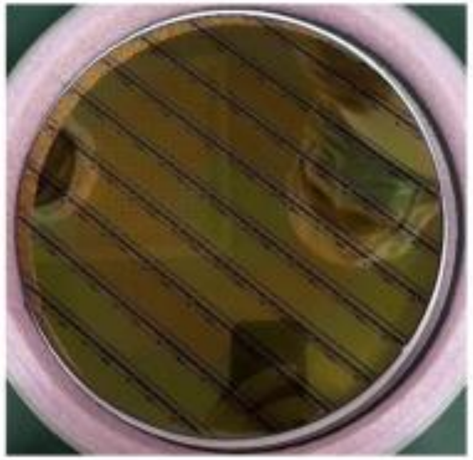


JadePix-3 Pixel size ~16×23 μm²

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

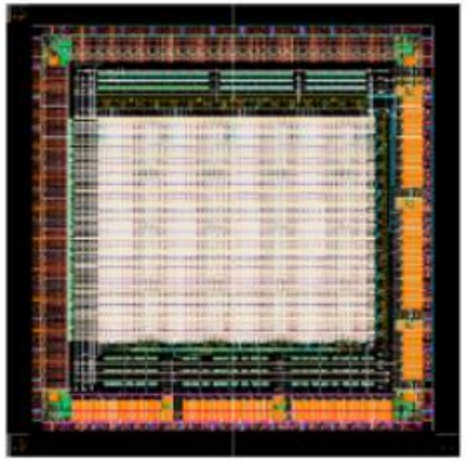
MOST 1

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

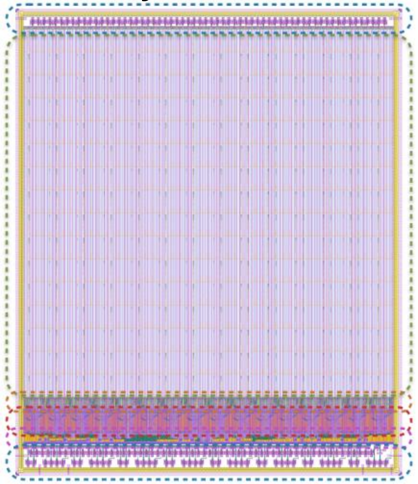


MOST 2

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

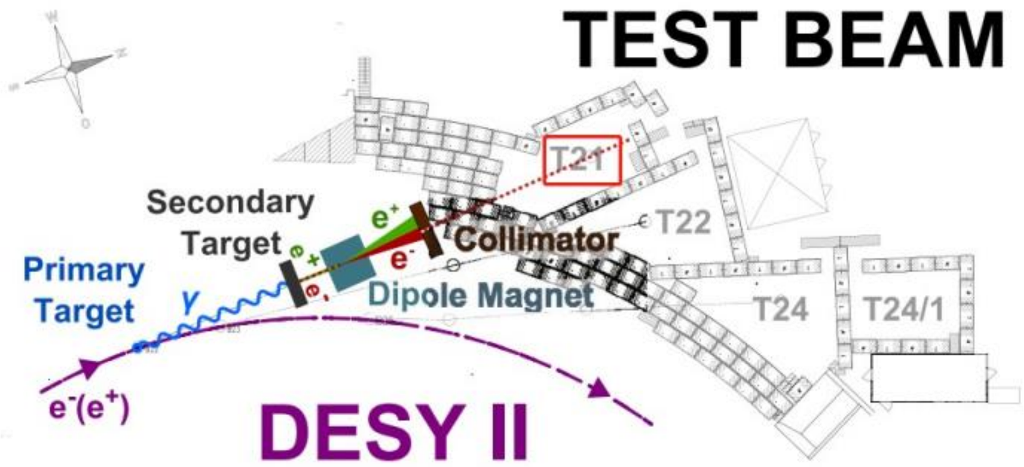


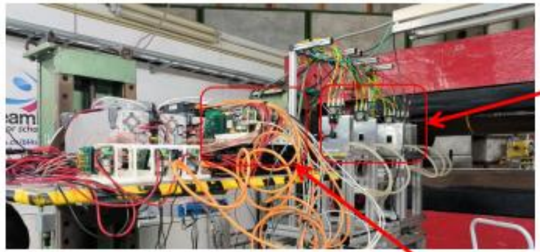
Arcadia by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS



CEPC R&D: Vertex Detector Prototype

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





MIMOSA Telescope

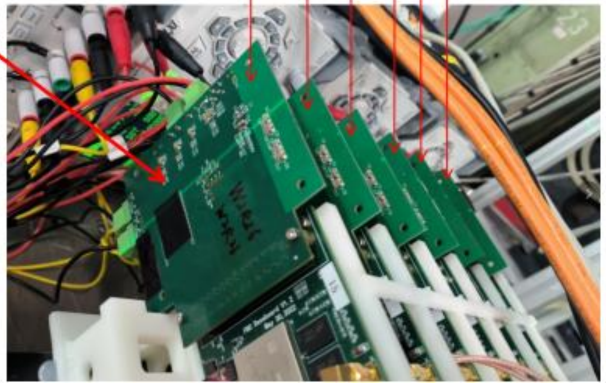
- Jadepix telescope

An open window in backside of PCB with a size of 12mm x 9mm

15.9 mm

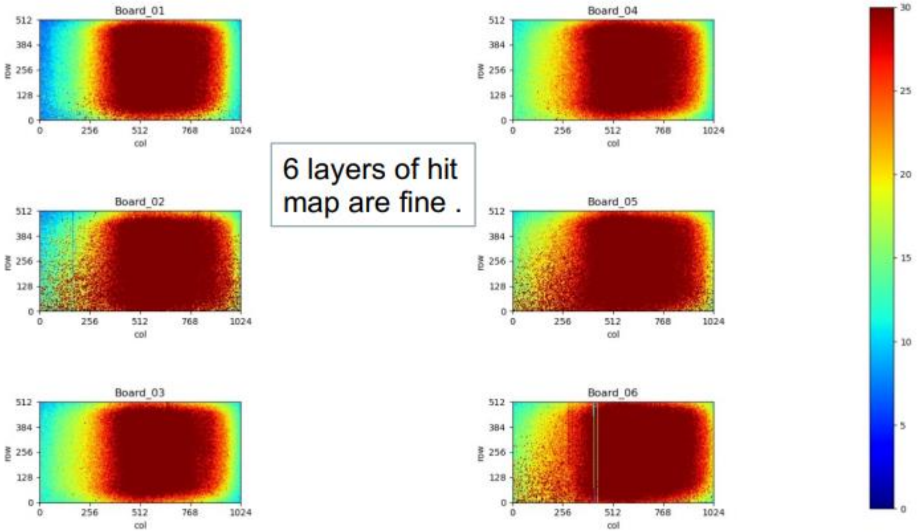
25.7 mm

Board6 Board5 Board4 Board3 Board2 Board1



TaichuPix-3 Telescope (6 layers)

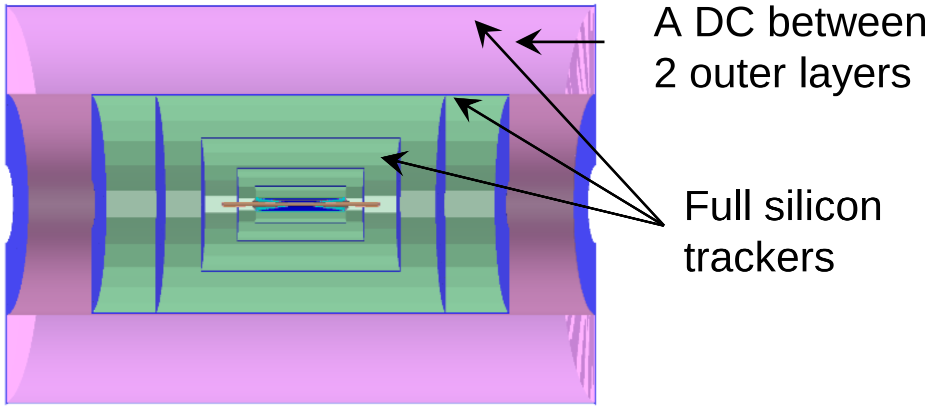
Hitmap of 4 GeV e^+/e^- beam

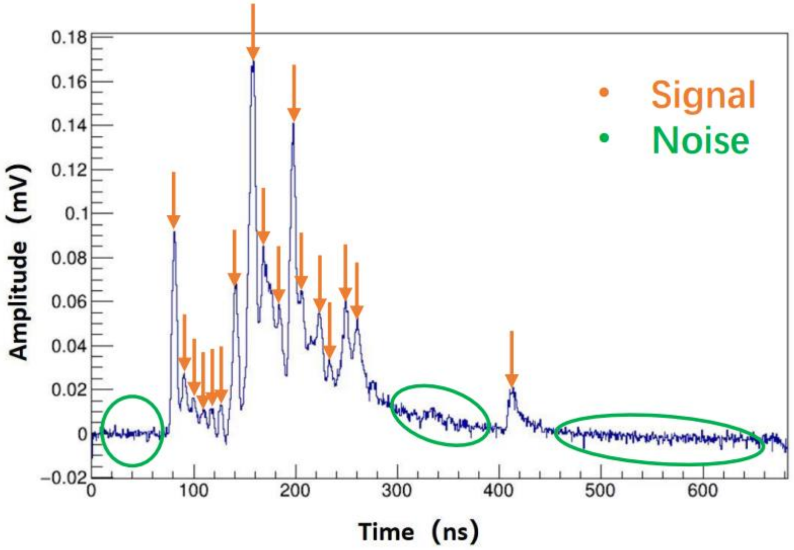


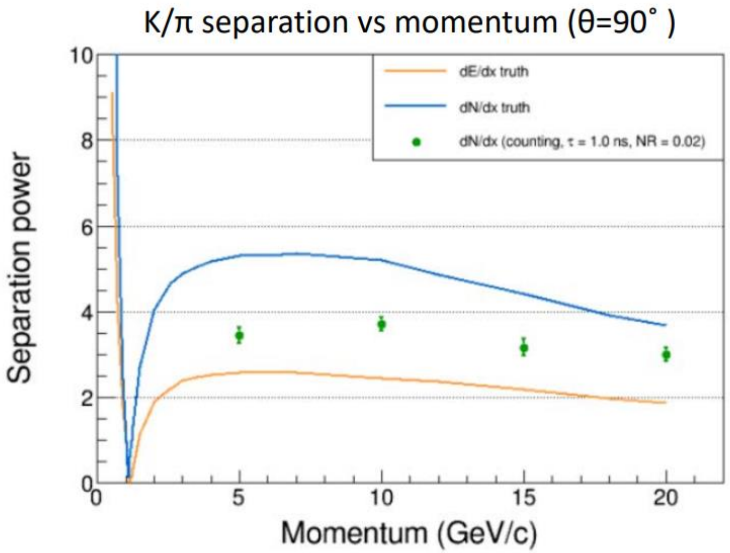
6 layers of hit map are fine .

CEPC R&D: Drift Chamber for PID

- **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.

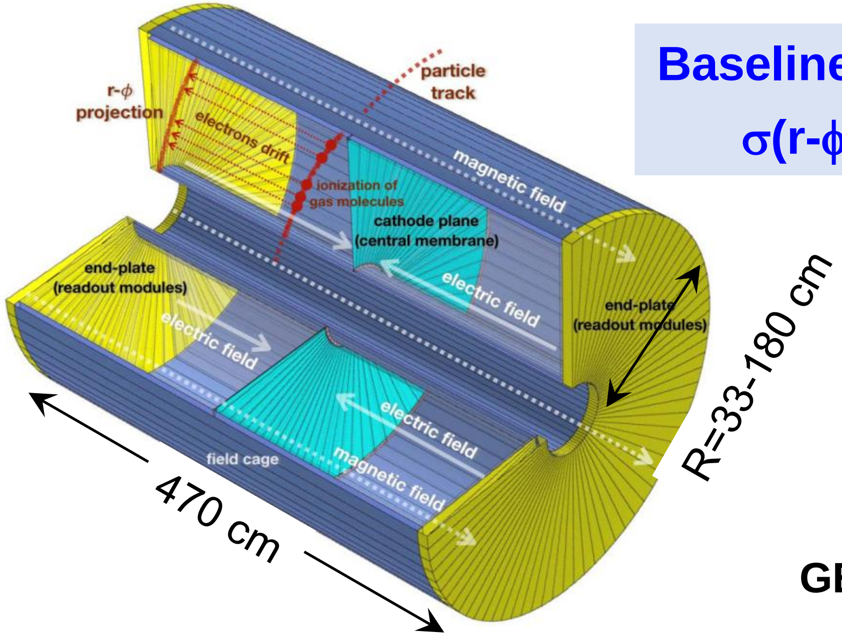






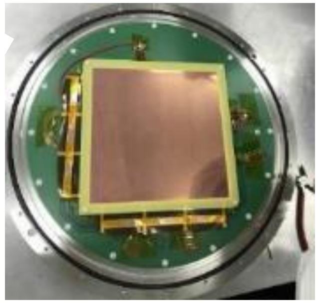
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022

CEPC R&D: Time Projection Chamber

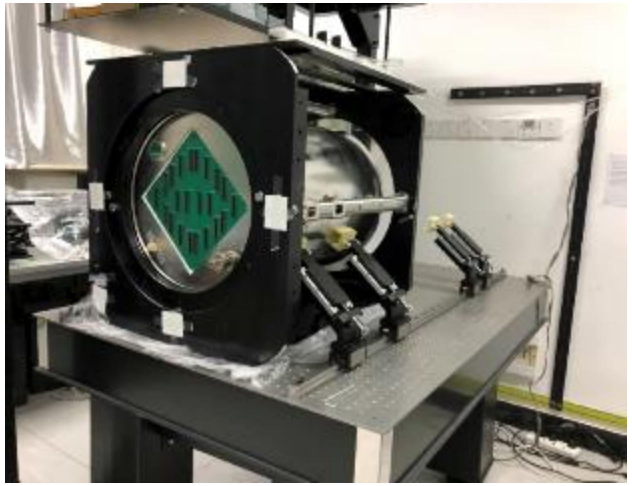


Baseline main tracker

$\sigma(r\text{-}\phi)$ ~100 μm



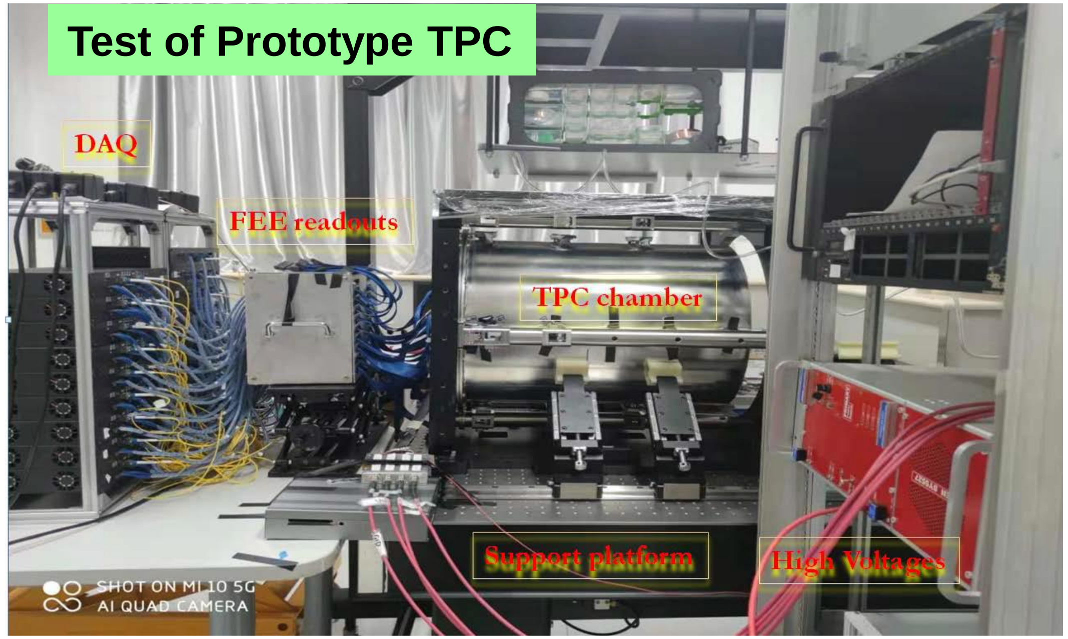
GEM-MM cathode



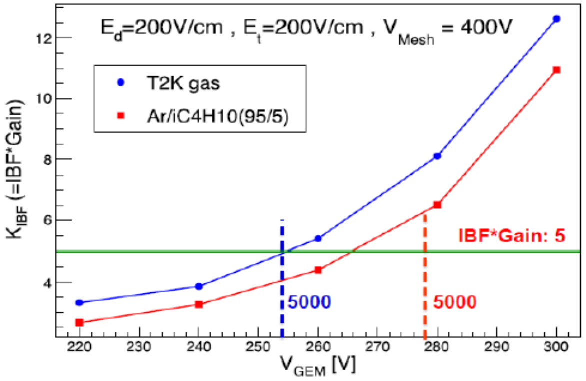
TPC Prototype + UV laser beams

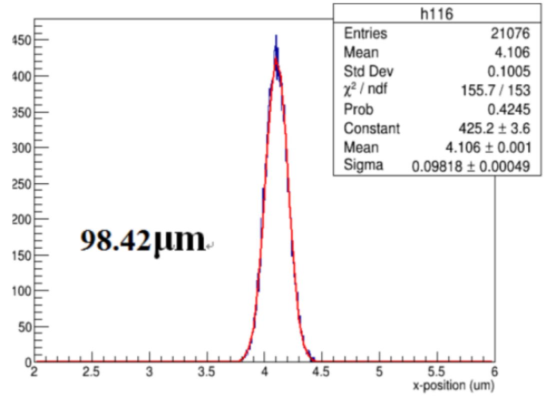
MOST 1 (IHEP+THU)

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.





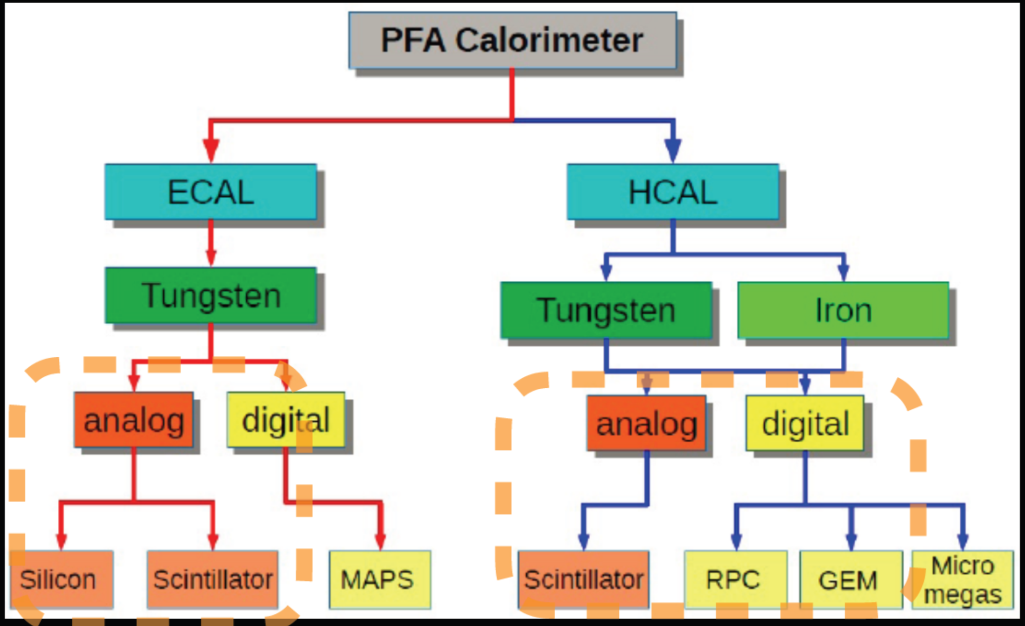
σ_x < 100 μm for drift length of 27cm

CEPC R&D: PFA Calorimeters

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding



High Granularity

Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)

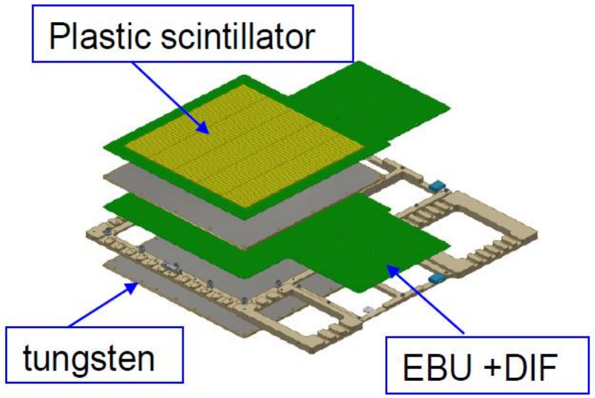
Newer Options

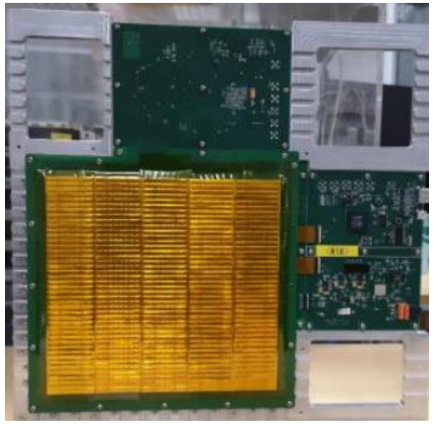
Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

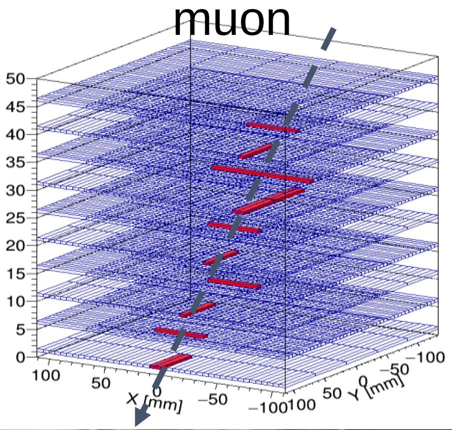
46

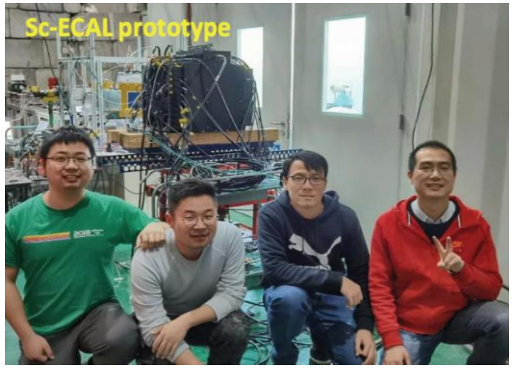
CEPC R&D: PFA Calorimeter Prototypes

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

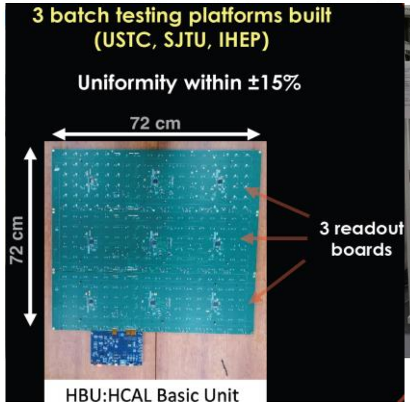


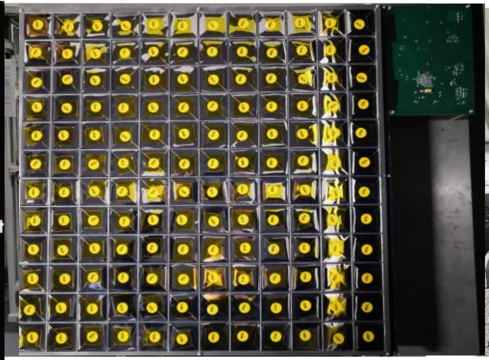






Sct + SiPM AHCAL Prototype (40-layer, 12960-ch)

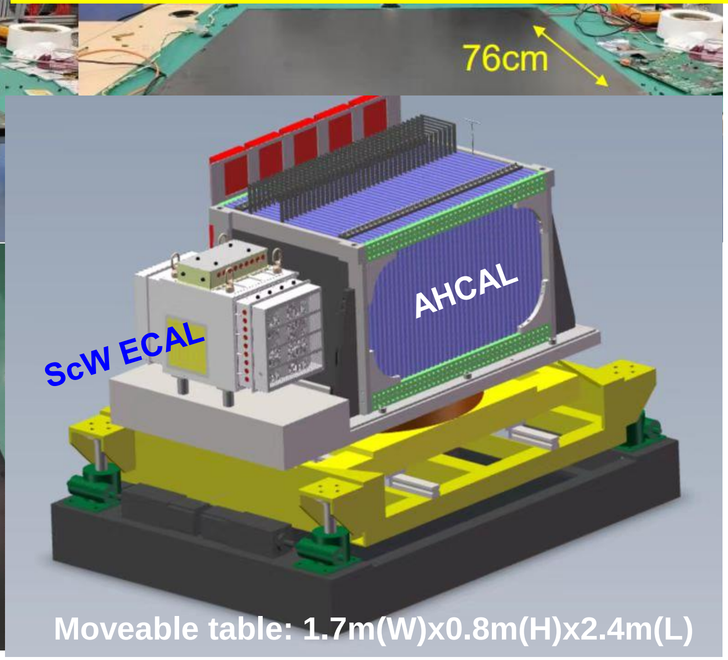




SJTU

IHEP

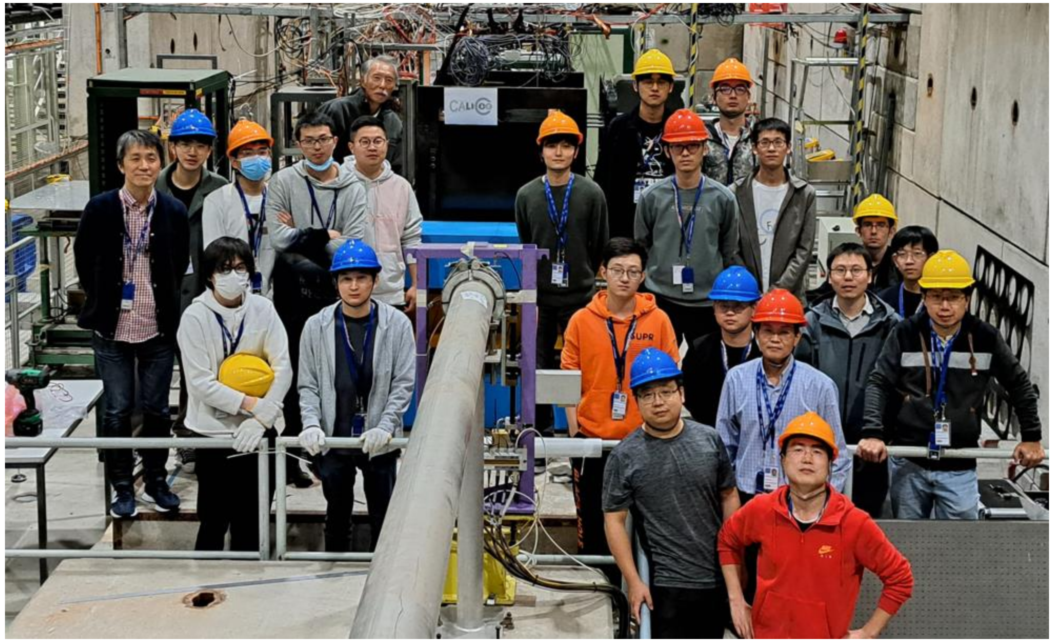
Combined: ScW-ECAL + AHCAL

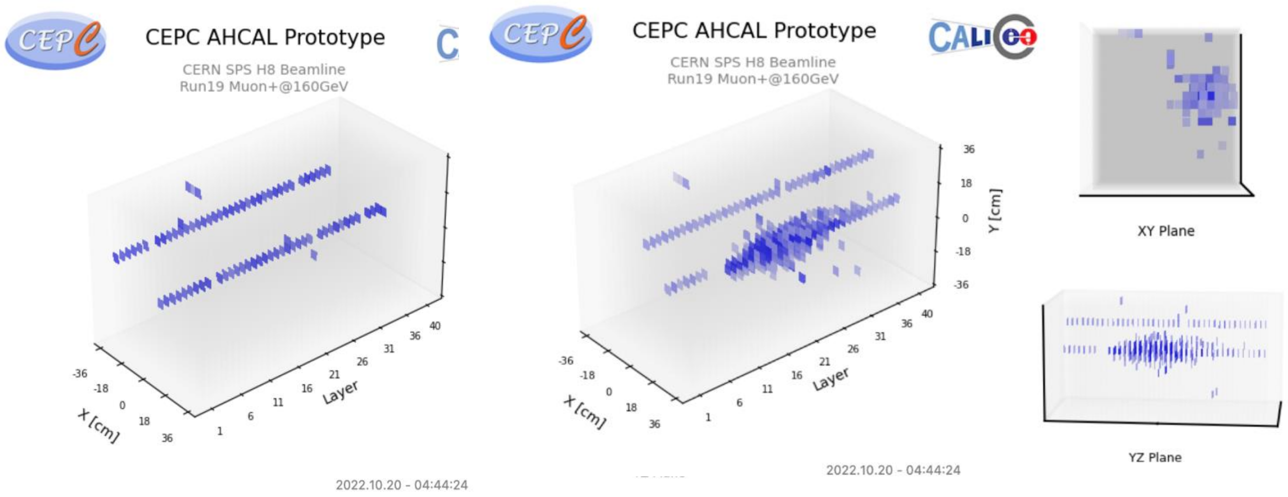


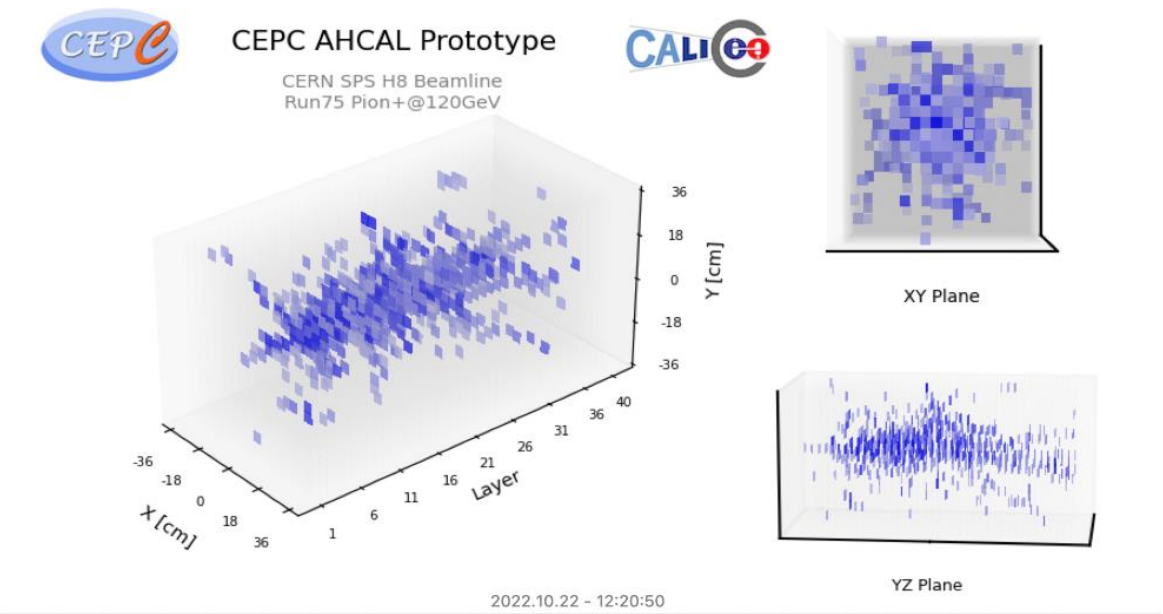
➔ Testbeam at CERN SPS for two prototypes in Oct. 2022

CEPC R&D: PFA Calorimeter Prototypes

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

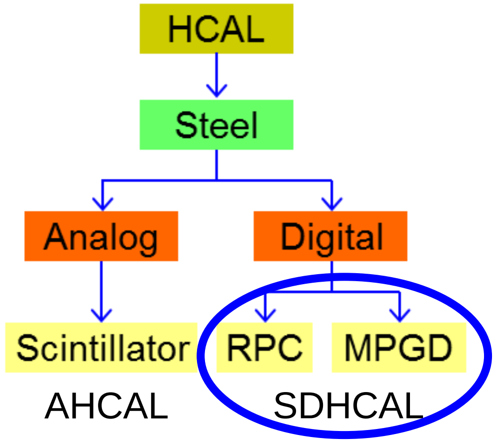


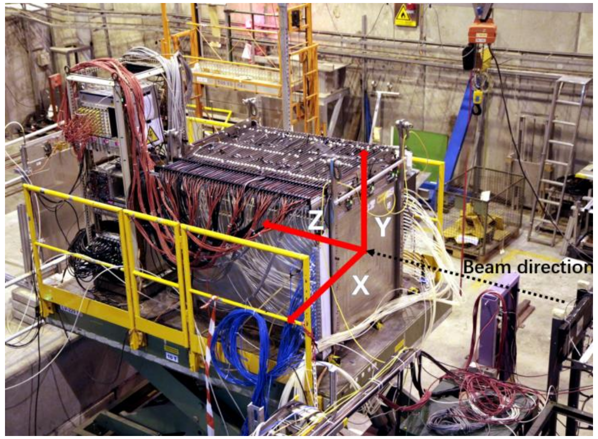




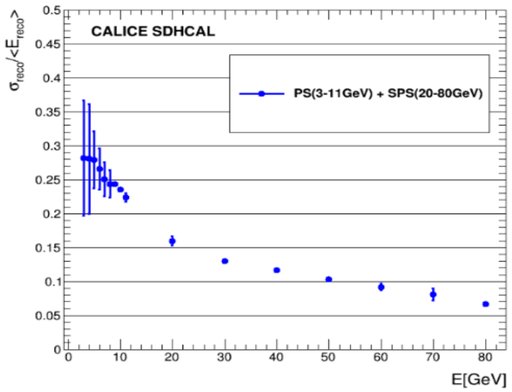
USTC, IHEP, SJTU, Japanese & Israel groups have close collaboration and regular meetings

CEPC R&D: SDHCAL

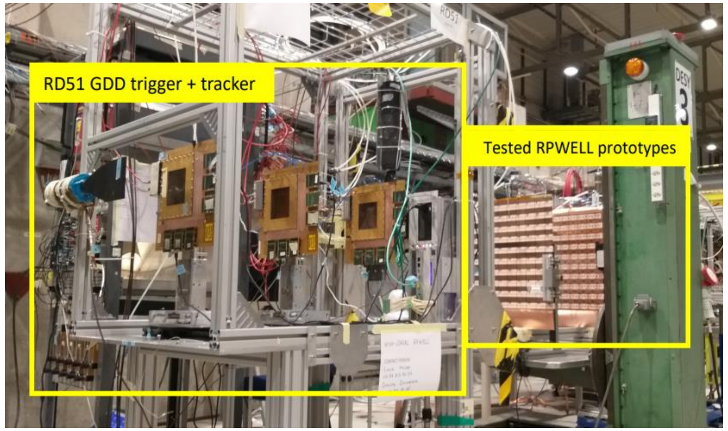




SDHCAL-GRPC (1.3 m^3, IPNL)



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



RPWELL (50x50cm^2, WIS+IIT, Israel)

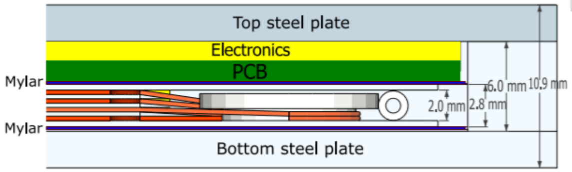
MOST 1: RPC and MPGD (RWELL) R&D， MIP Eff > 95%

GRPC 1m x 1m (SJTU)

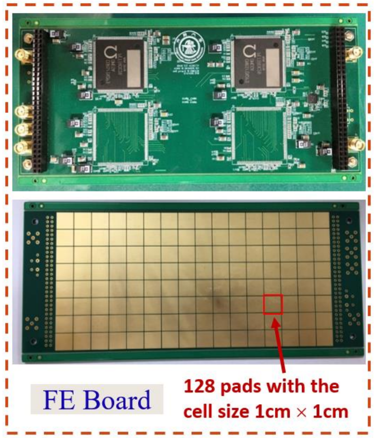
JINST 16, P12022 (2021)

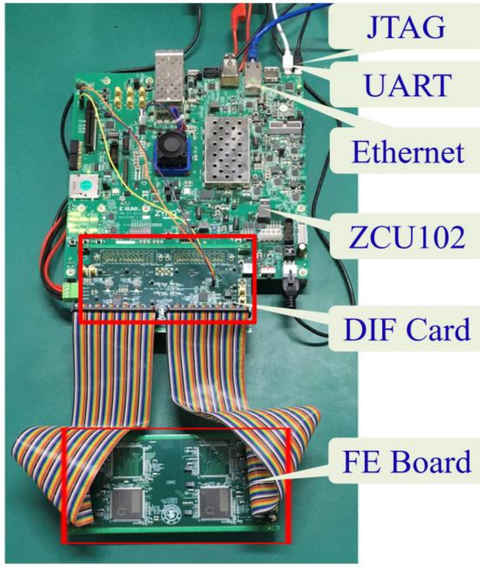
RWELL 0.5m x 1m (USTC+IHEP)

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

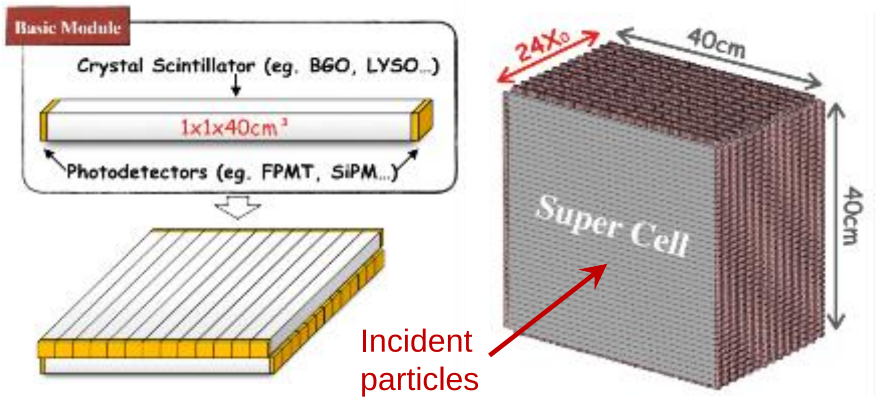


SJTU
IPNL
IJCLab
OMEGA
CIEMAT



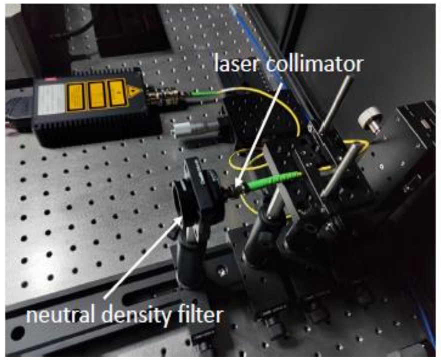


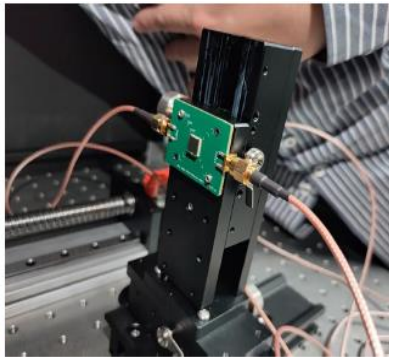
CEPC R&D: High Granularity Crystal ECAL



Goal

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



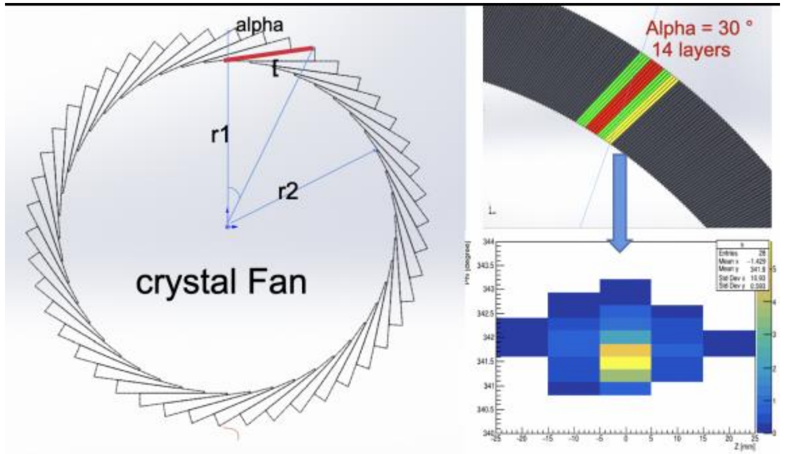


Bench Test

- Long bars: 1 x 40 cm, super-cell: 40x40 cm^2
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

Crystal Fan Design

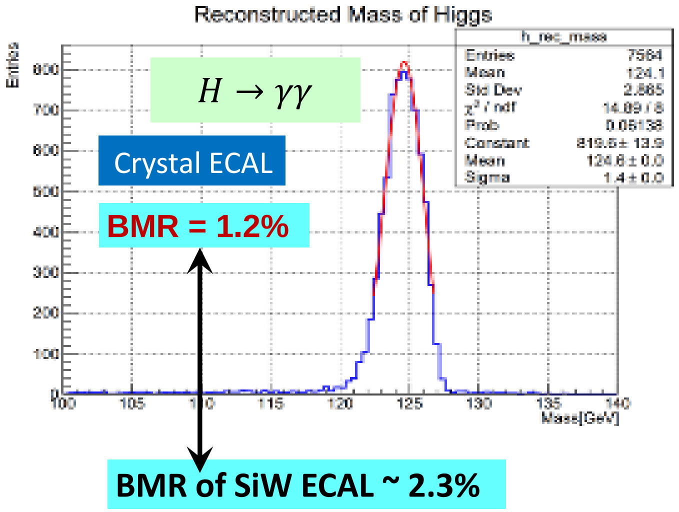
Fine segmentation in Z, ϕ, r



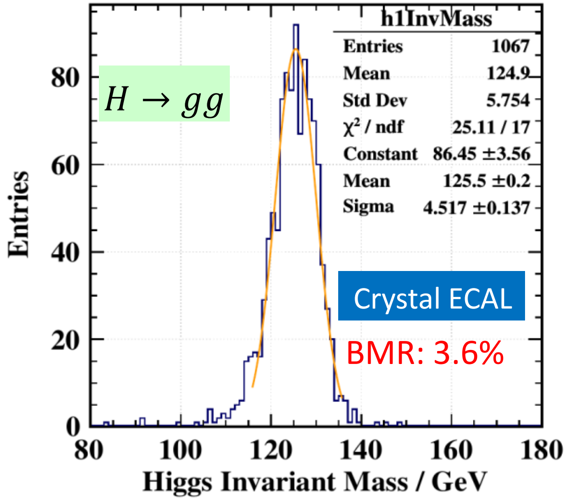
Full Simulation Studies

+ Optimizing PFA for crystals

Performance with photons



Performance with jets



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

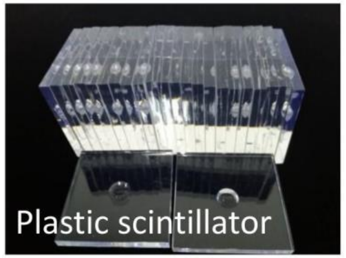
CEPC R&D: New HCAL with Scintillating Glass Tiles

Goal

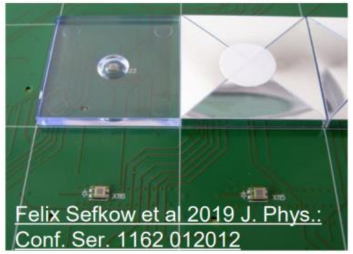
- Better hadronic energy resolution
- To further improve BMR

Full simulation studies

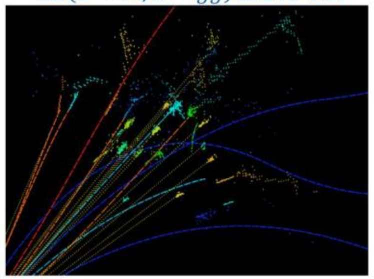
Tiles for AHCAL (30x30x3mm)

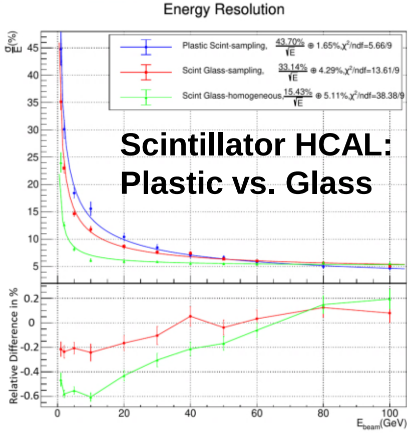


'SiPM-on-Tile" design for HCAL

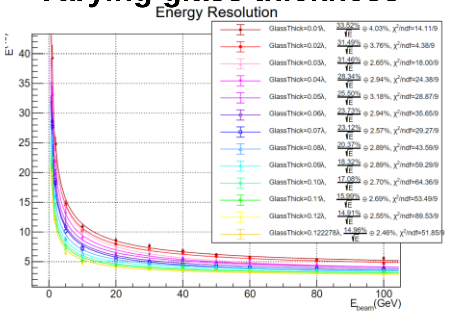


$ZH(Z \to \nu\nu, H \to gg)$ at 240 GeV

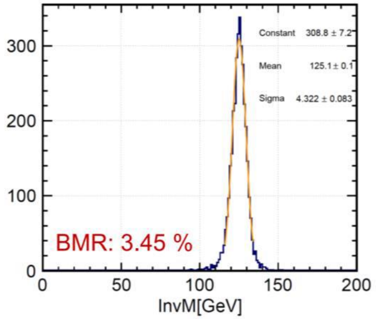


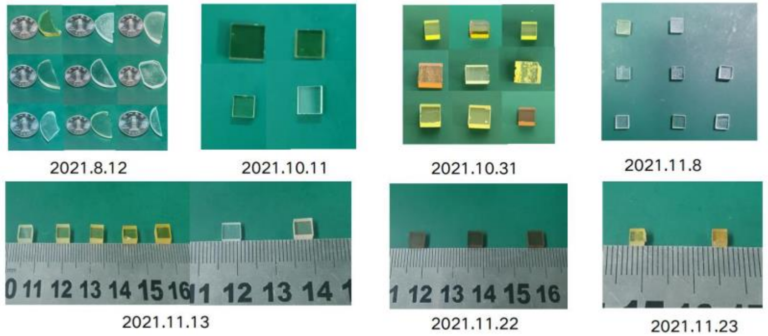


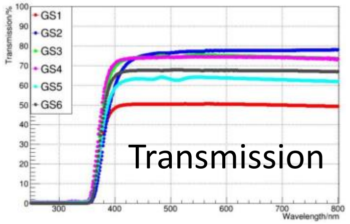
Varying glass thickness

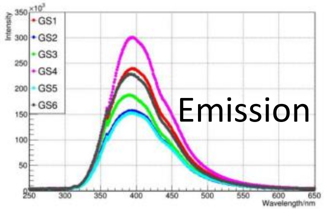


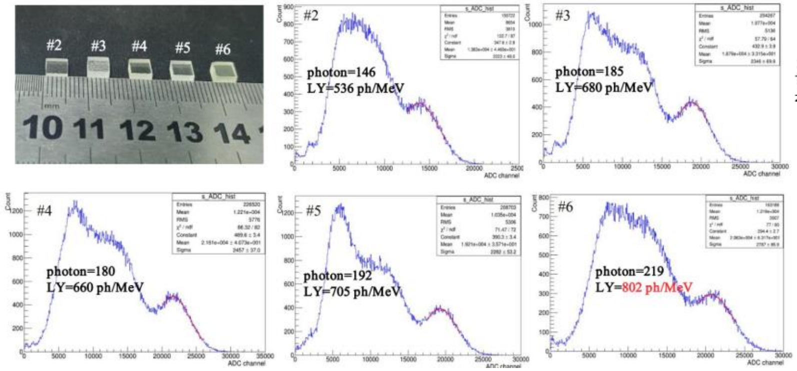
Performance study with jets





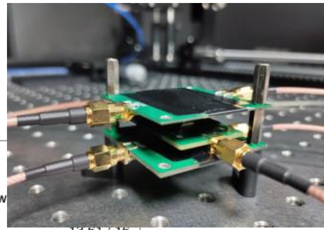


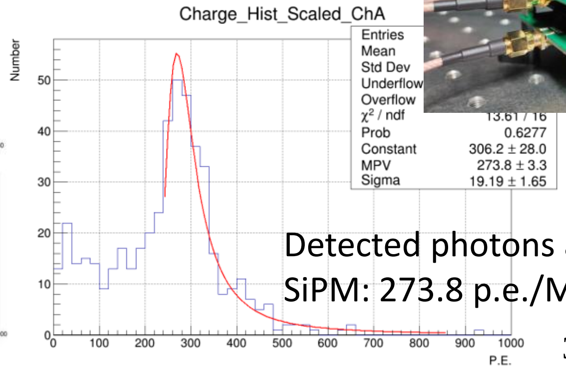




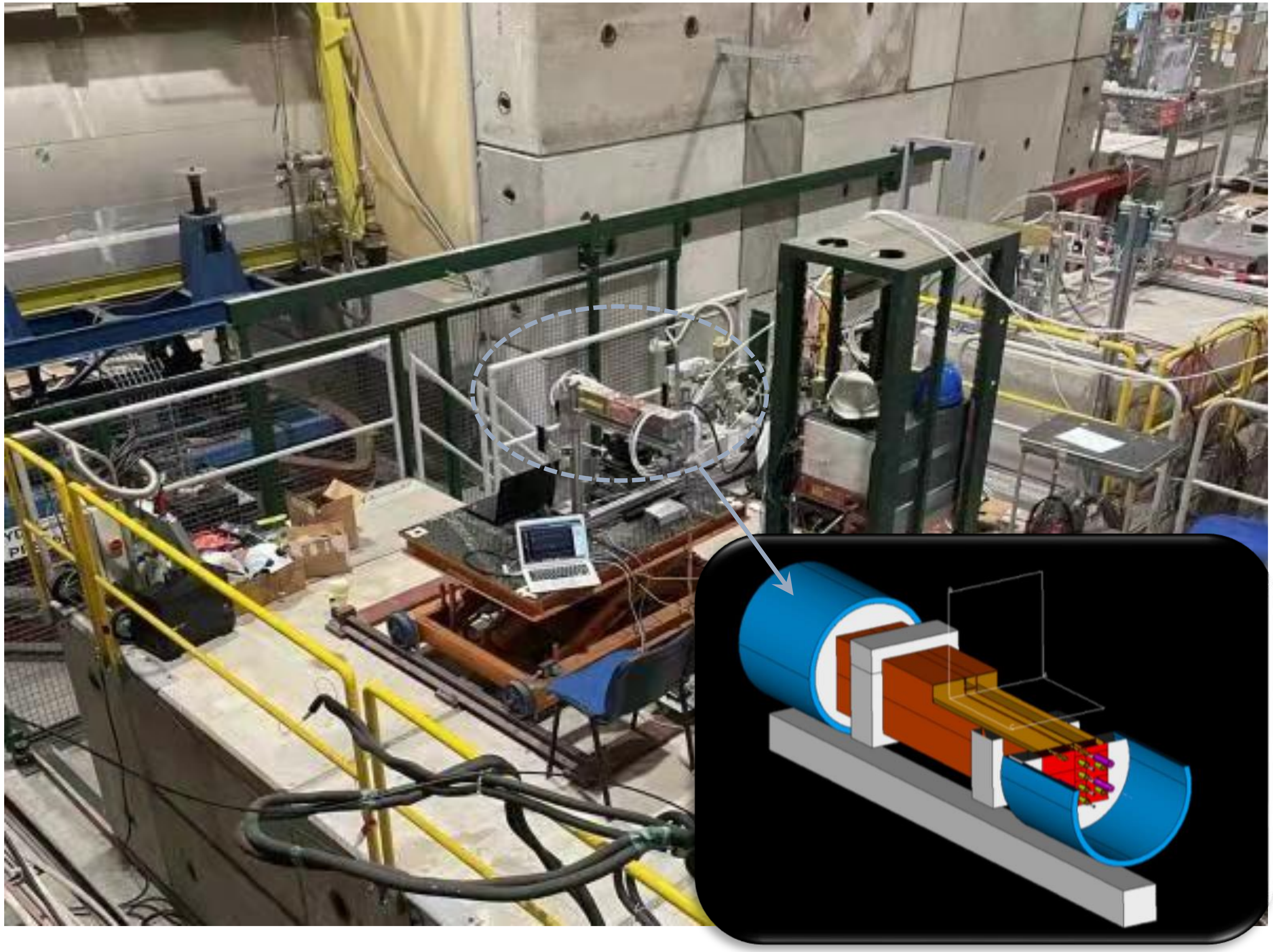
Scintillating Glass R&D

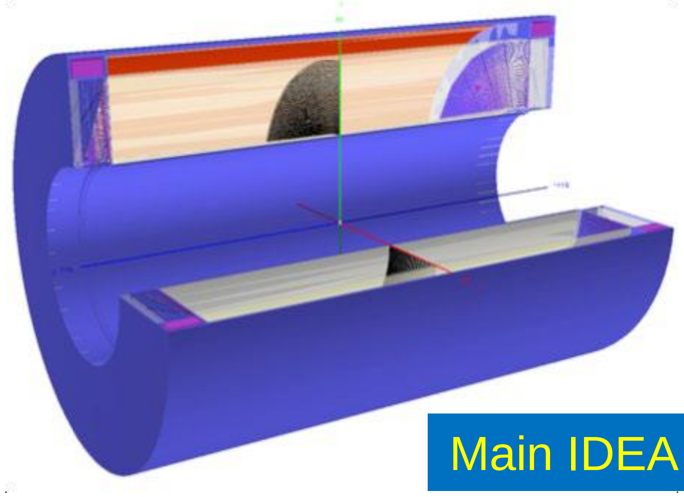
Testing Scintillating Glass Samples





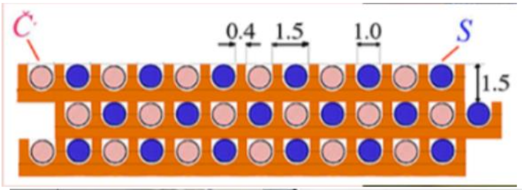
CEPC R&D: IDEA Tracker and Dual Readout Calorimeter

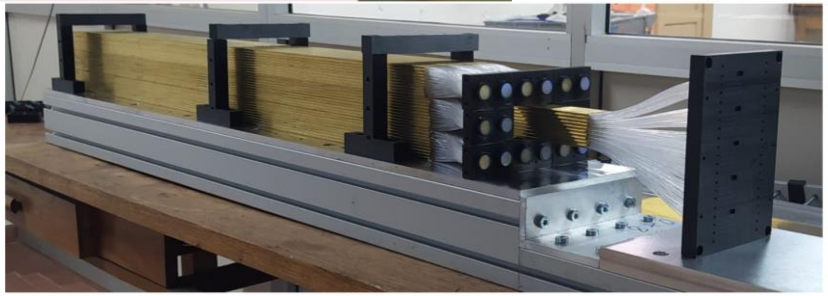




Main IDEA tracker

Dual Readout CAL





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

CEPC Software Migration to Key4hep

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

https://github.com/cepc/CEPCSW

Architecture of CEPCSW

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

Core Software

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

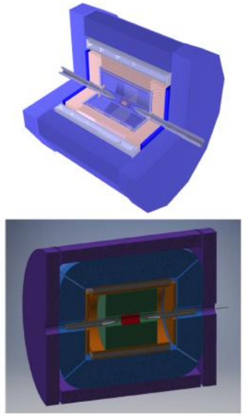
Ref: Weidong Li, Xingtao Wang's talk

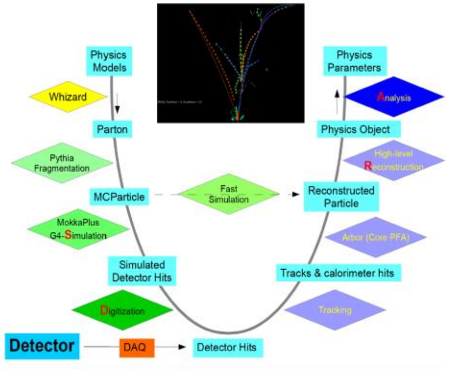
CEPCSW Structure

CEPC Applications: Generator, Simulation, Reconstruction, Analysis

Core Software: GeomSvc, FWCore, EDM4hep, Gaudi framework

External Libraries & Tools: LCIO, PODIO, DD4hep, ROOT, Geant4, CLHEP, Boost, Python, Cmake

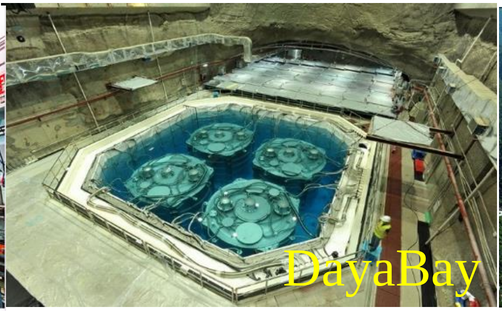




Full simulation reconstruction Chain functional, iterating/validation with hardware studies

Project Global Aspects

Synergies: IHEP experience with large projects



- **IHEP is one of the few institutions in the world that can host a project like the CEPC:**
  - **It has rich management experience and successful constructed many large scientific facilities**
  - **It has full coverage of all technical disciplines for accelerators and detectors, in particular for the design and construction of circular e+e- collider (BEPCII) and the detector(BESIII)**
  - **It has all needed infrastructure for construction of large facilities**
  - **It has successfully hosted international projects such as BESIII, Daya Bay, JUNO, LHAASO, etc.**
- **CEPC is committed by IHEP and workplan endorsed by CAS**

CEPC R&D Status

- CEPC received ~ 260 Million CNY from MOST, CAS, NSFC, etc for R&D
- Large amount of key technologies validated in other projects: BEPCII, HEPS, …

CEPC R&D ~ 50% cost of acc. components	➢ High efficiency klystron ➢ 650MHz SRF cavities ➢ Key components to e+ source ➢ High performance Linac ➢ Electrostatic Deflector ➢ Cryogenic system	➢ Novel magnets: Weak field dipole, dual aperture magnets ➢ Extremely fast injection/extraction ➢ Vacuum chamber tech. ➢ Survey & Alignment for ultra large Acc. ➢ MDI
BEPCII / HEPS ~ 40% cost of acc. components	➢ High precision magnet ➢ Stable magnet power source ➢ Vacuum chamber with NEG coating ➢ Instrumentation, Feedback system ➢ Traditional RF power source ➢ SRF cavities	➢ Electron Source, traditional Linac ➢ Survey & Alignment ➢ Ultra stable mechanics ➢ Radiation protection ➢ Cryogenic system ➢ MDI

~ 10% missing items consist of anticipated challenges in the machine integration, commissioning etc. and the corresponding international contribution

CEPC Industrial Promotion Consortium (CIPC)

- CIPC, established in 2017, composed of ~ 70 high tech. enterprises, covers Superconducting materials, SC cavities, cryomodules, cryogenics, Klystrons, electronics, power source, vacuum, civil engineering, etc. CIPC actively joins the Key technology R&D and prepares for the mass production for the CEPC construction.
- CEPC strongly promote relevant technology development (cost-benefit).
- CEPC study group is surveying main international suppliers.

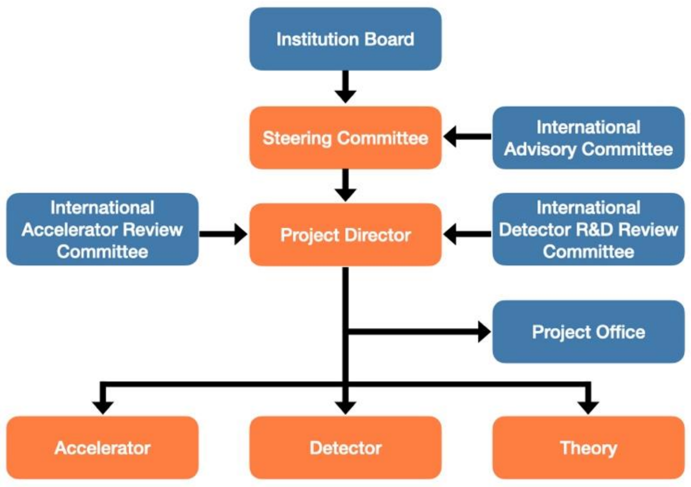
CCT SC Magnet

Klystron

SC Coil Winding

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

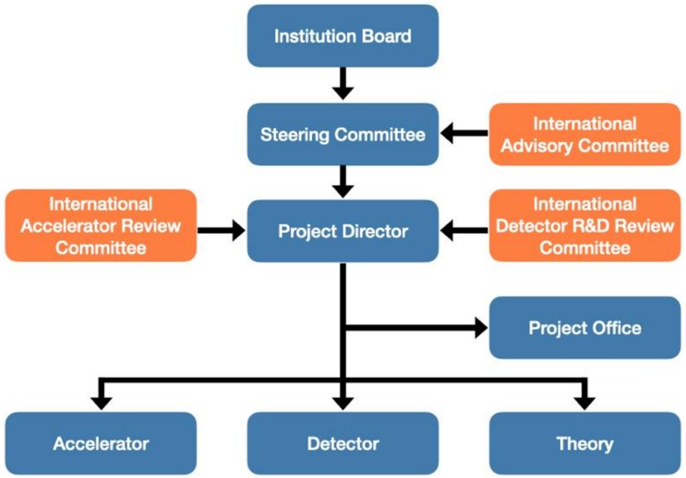
Table 7.4: Team of the CEPC detector system

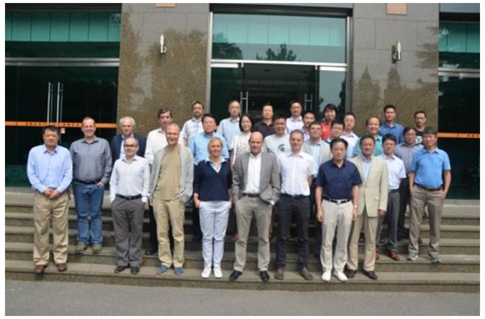
Number	Sub-system	Conveners	Institutions	Team (senior staff)
1	Pixel Vertex Detector	Zhijun Liang, Qun Ouyang, Xiangming Sun , Wei Wei	CCNU, IFAE, IHEP, NJU, NWPU, SDU, Strasbourg, ...	~ 40
2	Silicon Tracker	Harald Fox, Meng Wang, Hongbo Zhu	IHEP, INFN, KIT, Lancaster, Oxford, Queen Mary, RAL, SDU, Tsinghua, 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 International Efforts

CEPC attracts significant International participation

- Conceptual Design Report: 1143 authors from 221 institutes (including 140 Intl. Institutes)
- 20+ MoUs signed and executed
- Intensive collaboration on Physics studies
- Oversea scientists made substantial contributions to the R&D, especially the detector system
- CEPC International Workshop since 2014
- EU-US versions of CEPC WS: Next one at Marseille
- Annual working month at HKUST-IAS (since 2015)
- Recent CEPC Workshop: Oct. 24-28, 2022

(423 registrants, 285 talks, 38 posters)

CEPC International Efforts

ESPPU input

CEPC Input to the ESPP 2018 - Physics and Detector

CEPC Physics-Detector Study Group

Abstract

The Higgs boson, discovered in 2012 by the ATLAS and CMS Collaborations at the Large Hadron Collider (LHC), plays a central role in the Standard Model. Measuring its properties precisely will advance our understandings of some of the most important questions in particle physics, such as the naturalness of the electroweak scale and the nature of the electroweak phase transition. The Higgs boson could also be a window for exploring new physics, such as dark matter and its associated dark sector, heavy sterile neutrino, et al. The Circular Electron Positron Collider (CEPC), proposed by the Chinese High Energy community in 2012, is designed to run at a center-of-mass energy of 240 GeV as a Higgs factory. With about one million Higgs bosons produced, many of the major Higgs boson couplings can be measured with precisions about one order of magnitude better than those achievable at the High Luminosity-LHC. The CEPC is also designed to run at the Z-pole and the W pair production threshold, creating close to one trillion Z bosons and 100 million W bosons. It is projected to improve the precisions of many of the electroweak observables by about one order of magnitude or more. These measurements are complementary to the Higgs boson coupling measurements. The CEPC also offers excellent opportunities for searching for rare decays of the Higgs, W, and Z bosons. The large quantities of bottom-quarks, charm-quarks, and tau leptons produced from the decays of the Z bosons are interesting for flavor physics. The clean collision environment also makes the CEPC an ideal facility to perform pre… …posed for the… …ncepts can full…

…s potential and… …tail in the Co… …so outline fut… …scribe the planning and the international organization of the CEPC. The next step for the CEPC team is to perform detailed technical design studies. Effective international collaboration would be crucial at this stage. This submission for consideration by the ESPP is part of our dedicated effort in seeking international collaboration and support. Given the importance of the precision Higgs boson measurements, the ongoing CEPC activities do not diminish our interests in participating in the international collaborations of other future electron-positron collider based Higgs factories.

arXiv: 1901.03170
1901.03169

Snowmass input

Snowmass2021 White Paper AF3- CEPC

CEPC Accelerator Study Group[1]

1. Design Overview

1.1 Introduction and status

The discovery of the Higgs boson at CERN's Large Hadron Collider (LHC) in July 2012 raised new opportunities for large-scale accelerators. The Higgs boson is the heart of the Standard Model (SM), and is at the center of many biggest mysteries, such as the large hierarchy between the weak scale and the Planck scale, the nature of the electroweak phase transition, the original of mass, the nature of dark matter, the stability of vacuum, etc. and many other related questions. Precise measurements of the properties of the Higgs boson serve as probes of the underlying fundamental physics principles of the SM and beyond. Due to the modest Higgs boson mass of 125 GeV, it is possible to produce it in the relatively clean environment of a circular electron–positron collider with high luminosity, new technologies, low cost, and reduced power consumption. In September 2012, Chinese scientists proposed a 240 GeV *Circular Electron Positron Collider* (CEPC), serving two large detectors for Higgs studies and other topics as shown in Fig. 1. The ~100 km tunnel for such a machine could also host a *Super Proton Proton Collider* (SPPC) to reach energies well beyond the LHC.

The CEPC is a large international scientific project initiated and to be hosted by China. It was presented for the first time to the international community at the ICFA Workshop *"Accelerators for a Higgs Factory: Linear vs. Circular"* (HF2012) in Novemb… …the White R… …the Yellow … …was made. T… …[3] has been… …an internati… …18. In May … …gy Physics … …R, CEPC accelerator entered the phase of Technical Design Report (TDR) endorsed by CEPC International Advisory Committee (IAC). In TDR phase, CEPC optimization design with higher performance compared with CDR and the key technologies such as 650MHz high power and high efficiency klystron, high quality SRF accelerator technology, high precision magnets for booster and collider rings, vacuum system, MDI, etc. have been carried out, and the CEPC accelerator TDR will be completed at

[1] Correspondance: J. Gao, Institute of High Energy Physics, CAS, China
Email: gaoj@ihep.ac.cn

arXiv: 2203.09451
2205.08553

- CEPC provides critical input to ESPPU & Snowmass as a major player
- Team member actively participated intl. study (ESPPU and Snowmass committees) and Panel discussions
- CEPC attracts intensive international collaboration, ensuring that the CEPC design and technology are among the most advanced in the world.

CEPC Cost Estimation and Sharing

CDR Cost: ~ 1000 independent items added up

- **Cost estimated with two indpendent methods, agrees at 10% level**
- **CEPC design relies on well studied, or mature technology reducing uncertainties on Cost estimation**
- **Cost estimation for TDR phase is progressing: no major change**

Table 8.1: Cost estimation of the CEPC

Tier I	Tier II	Amount (100 M CNY)
Accelerator	Collider	99.2
	Booster	39.2
	Linac and sources	9.1
	Damping ring	0.44
	Common: Cryogenics	10.6
	Survey & alignment	4
	Radiation protection	1.7
Conventional facilities	-	102
Detectors	-	40
γ-ray beam lines	-	3
Project management (1%)	-	3
Contingency (15%)	-	46
Total	-	358

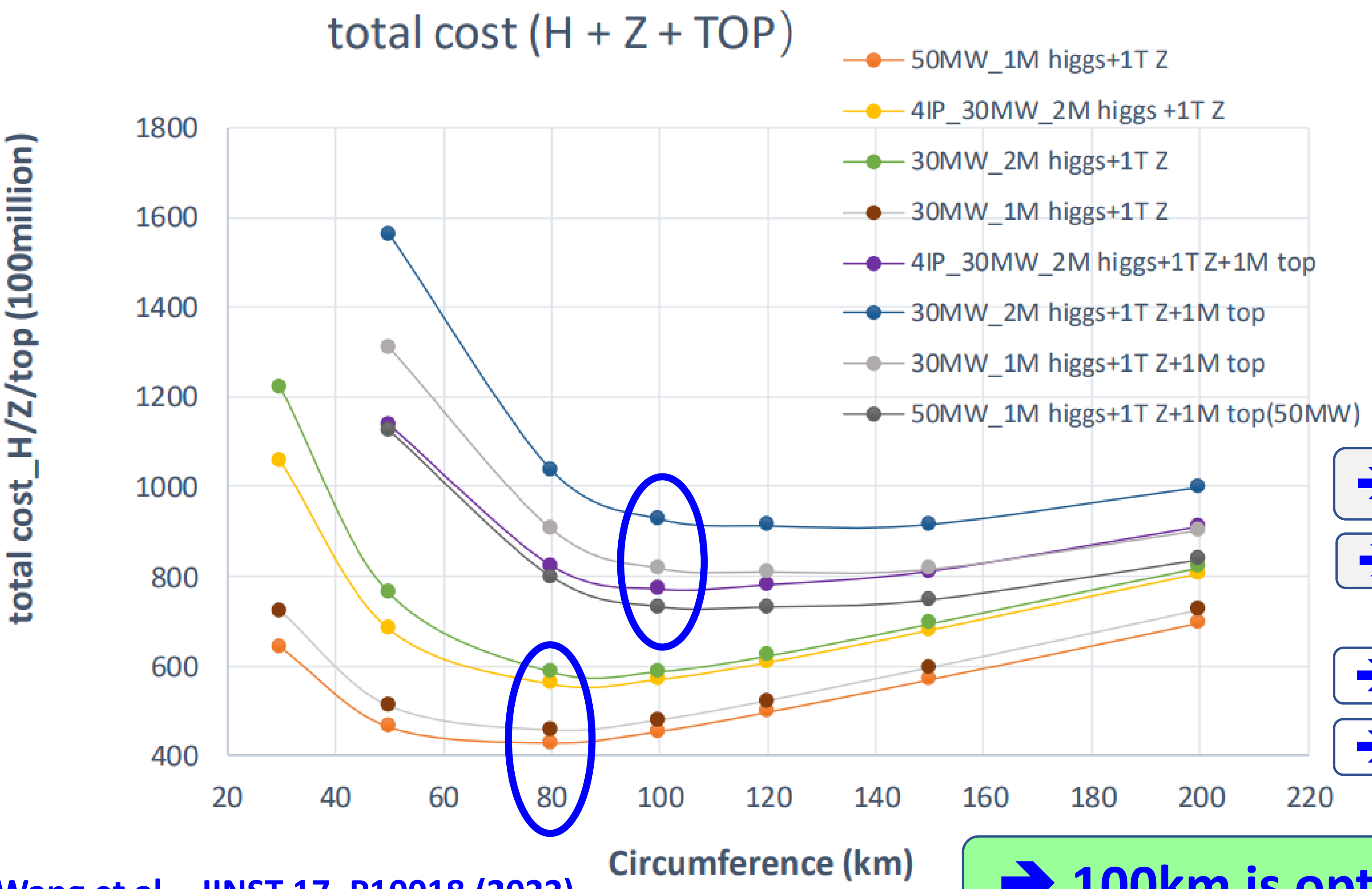
~ 5B CHF

Funding Sources	Funding Model #1 (Billion RMB)	Funding Model #2 (Billion RMB)
Central Government	25	10
Local Government	5	20
International Partners	6	6

CEPC Cost Estimation and Optimization

- Optimization of CEPC total cost with physics operation vs. Circumference (km)

$$\mathrm{Cost}_{total} = \mathrm{Cost}_{machine} + \mathrm{Cost}_{detector} + \mathrm{Cost}_{elect} + \mathrm{Cost}_{repair} + \mathrm{Cost}_{staff}$$



$$\mathrm{Cost}_{machine} = \frac{C}{100} \cdot 24(billion) + 6(billion)$$

$$\mathrm{Cost}_{detector} = 2(billion) \times N_{IP}$$

$$\mathrm{Cost}_{elect} = P_{SR} \times 10 \times N_{year} \times month_{operation} \times 30 \times 24 \times 0.5$$

$$\mathrm{Cost}_{repair} = \mathrm{Cost}_{machine} \times 3\% \times N_{year}$$

$$\mathrm{Cost}_{staff} = \left(\mathrm{Cost}_{machine} \times 1\% + 0.1(billion)\right) \times N_{year}$$

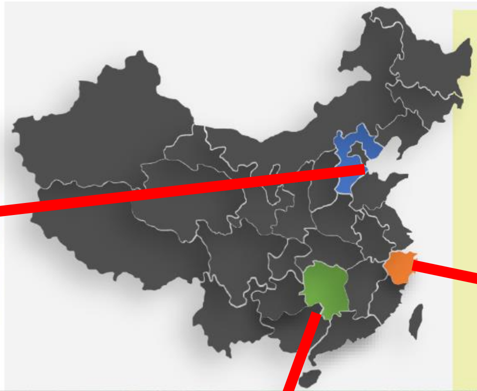
➔ 2M H + 1T Z + 1M Top
➔ 1M H + 1T Z + 1M Top
➔ 100km

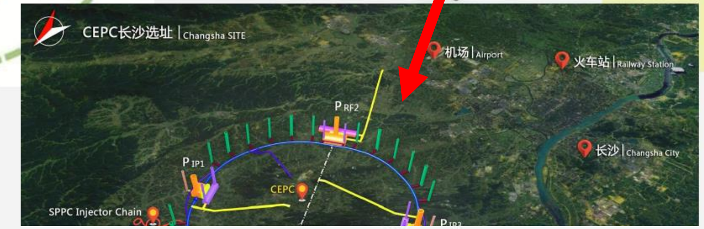
➔ 2M H + 1T Z
➔ 1M H + 1T Z
➔ 80km

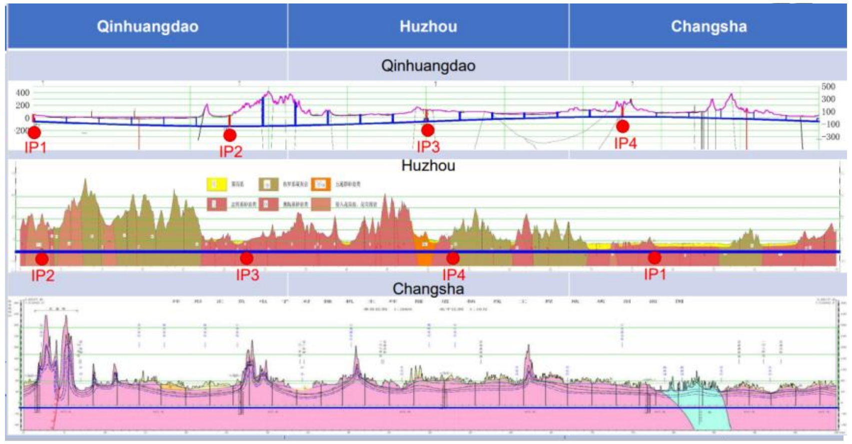
D. Wang et al., JINST 17, P10018 (2022)

➔ 100km is optimal for CEPC and SppC

Candidate Sites and Science Cities







Qinhuangdao

Huzhou

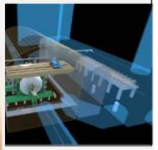
Changsha

Klystron Gallery

Linac & BTL Tunnel

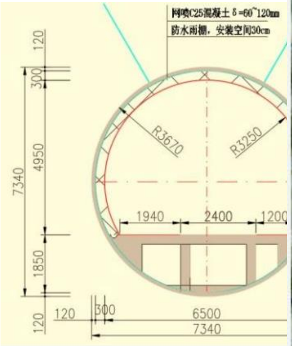
Collider ring tunnel

1 / IP3



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



TBM tunnel (D6.5m)

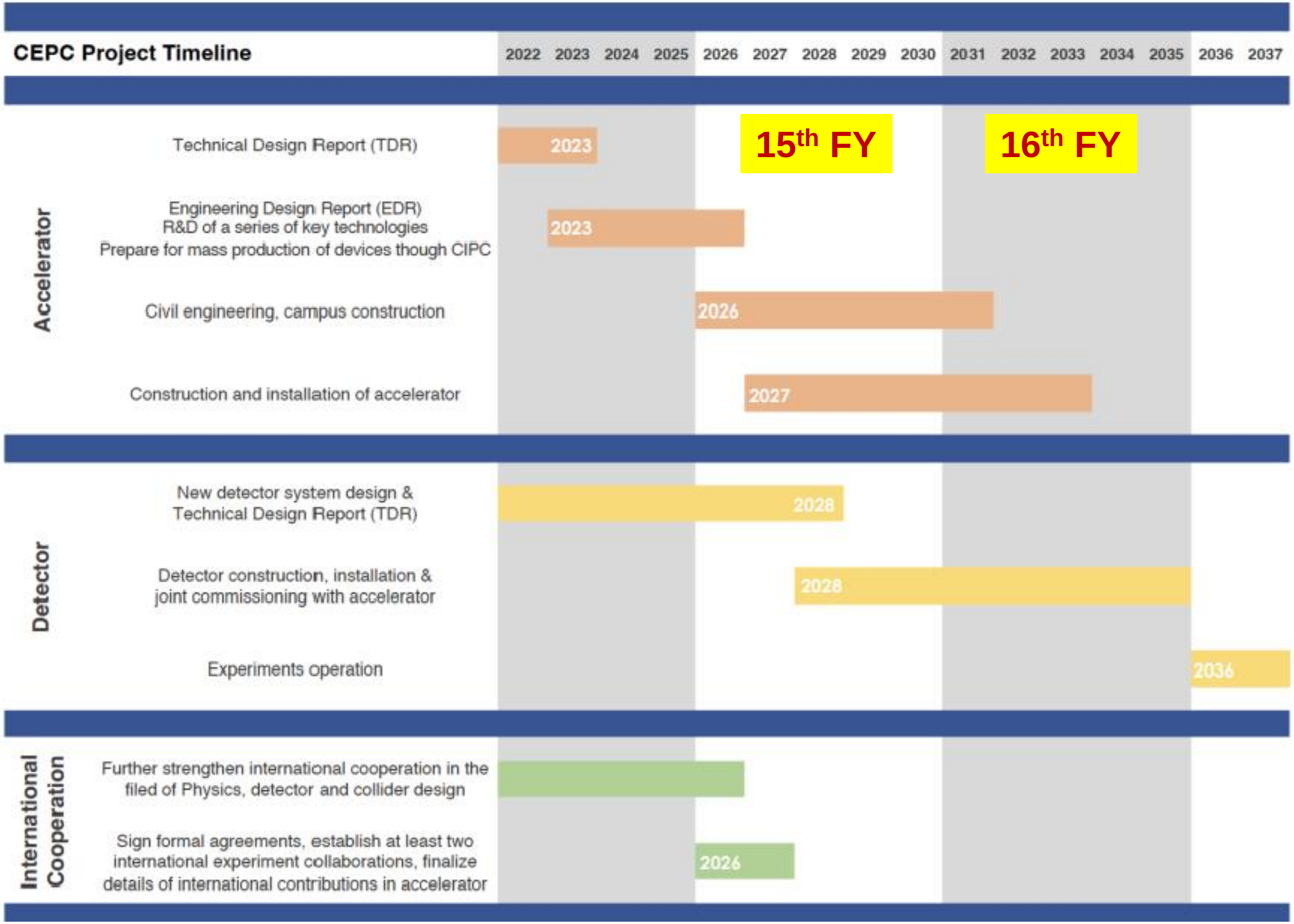
2034

⑧

ject is

CEPC Project Timeline

- 2023: Accelerator TDR; 2026: EDR; Start construction upon approval



Summary and Prospects

Continuing R&D and deep understanding of physics potentials

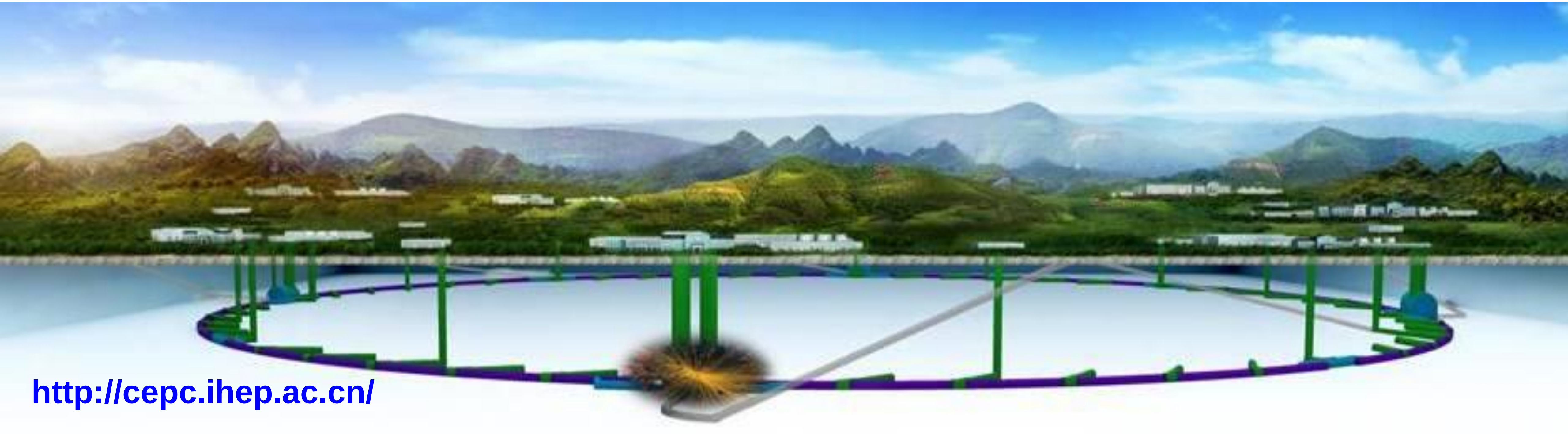
- Made suggestions to **MOST for R&D support** and validations of key technologies & innovations
- Carrying out **design improvement, R&D**, site investigations-study
- R&D and made major **progress + breakthroughs** in common technologies
- **CEPC physics whitepaper**; physics potentials input for Snowmass

International Collaboration and Engagement

- Engaging actively in **ILC, FCC as well as HL-LHC upgrade** activities, enhancing CERN-China relationship
- Actively participating international **detector R&D** collaborations: CALICE, LCTPC, RD*, ECFA-DRD, …
- Finding and sharing solutions to common issues (design, accelerator/detector components, …)
- **Hope we will have more in-person meetings and closer collaboration in the coming years**

Acknowledgements

Many thanks to the CEPC study group
for enormous efforts and achievements !

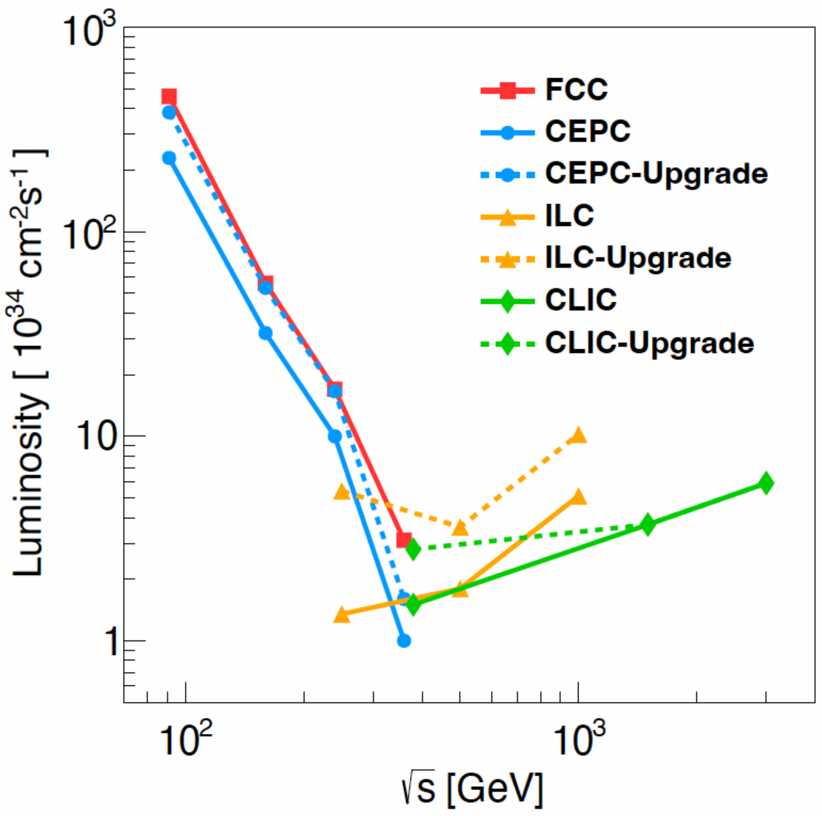


http://cepc.ihep.ac.cn/

CEPC Accelerator TDR Design (Upgrade)

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	58
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

CEPC accelerator whitepaper for Snowmass21, arXiv:2203.09451



Higher SR power of 50MW, the Lumi. will increase ~66%.

Status of CEPC Detector R&D

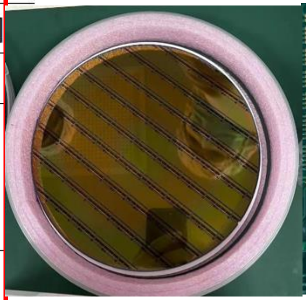
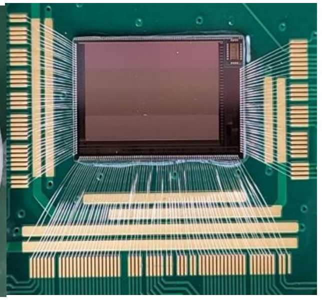
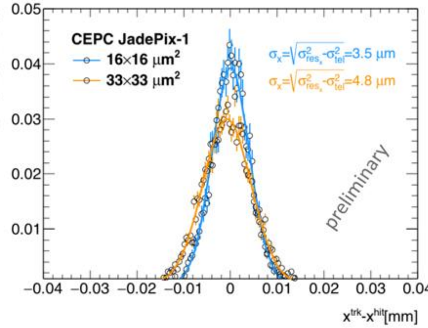
- **Extensive detector R&D benefitted from experience**
  - Silicon strip : from ATLAS detector upgrade
  - MDI, Drift chamber & SC magnet : from BESIII
- **CEPC R&D on key technologies**
  - Silicon pixel, silicon tracker and TPC
  - PFA calorimeter

- **With international partners, all sub-detector covered**
  - PFA calorimeter: with CALICE Collaboration
  - TPC: with LCTPC Collaboration
  - Drift chamber: with Italian colleague
  - Silicon tracker: with UK/Germany/Italian colleague
  - Silicon vertex: with French/Spain colleague

PFA calorimeter

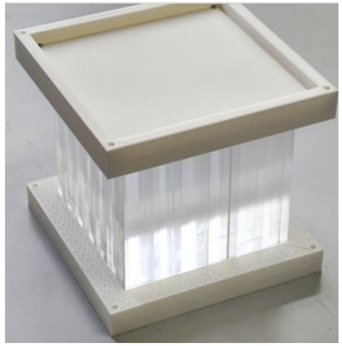
Sub-detector	Specification	Requirement	World-class level	CEPC prototype
Pixel detector	Spatial resolution	$\sim 3\ \mu m$	$3-5\ \mu m$ [12, 13]	$3-5\ \mu m$ [14–16]
TPC/drift chamber	dE/dx (dN/dx) resolution	$\sim 2\%$	$\sim 4\%$ [17, 18]	$\sim 4\%$ [19–21]
Scintillator-W ECal	Energy resolution Granularity	$< 15\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\ \mathrm{cm}^2$	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

Silicon vertex detector R&D (3-5μm)

PFA ScW-ECAL and AHCAL

4D crystal ECAL

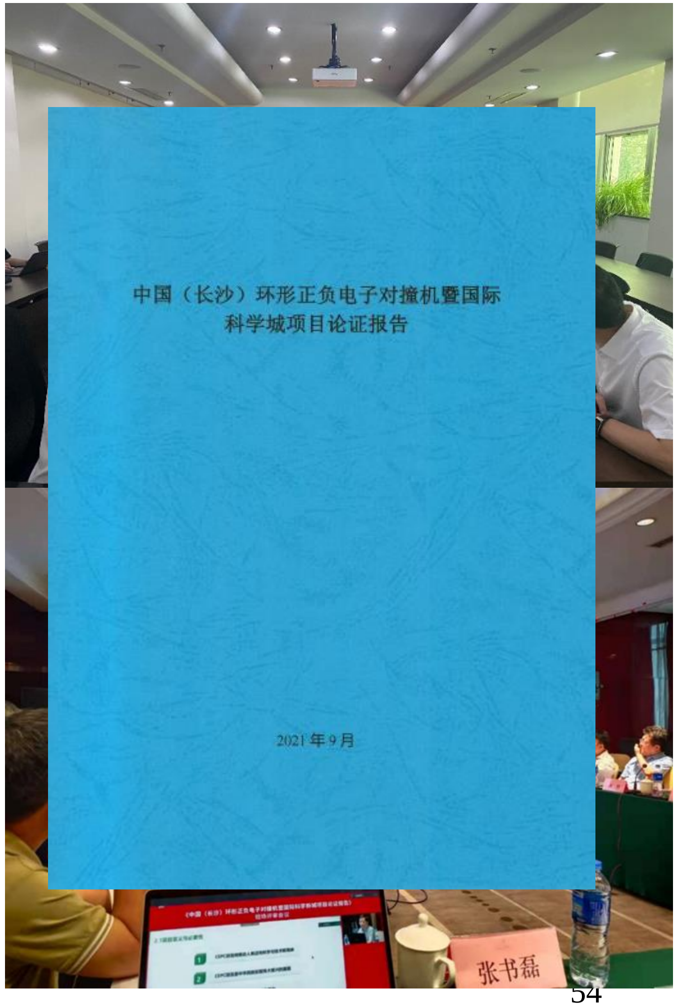


➔ **CEPC Detector R&D: Joao G. da Costa**

CEPC Site Selection

- Site selection is based on geology, electricity supply, transportation, environment for foreigners
- Local support & economy, …

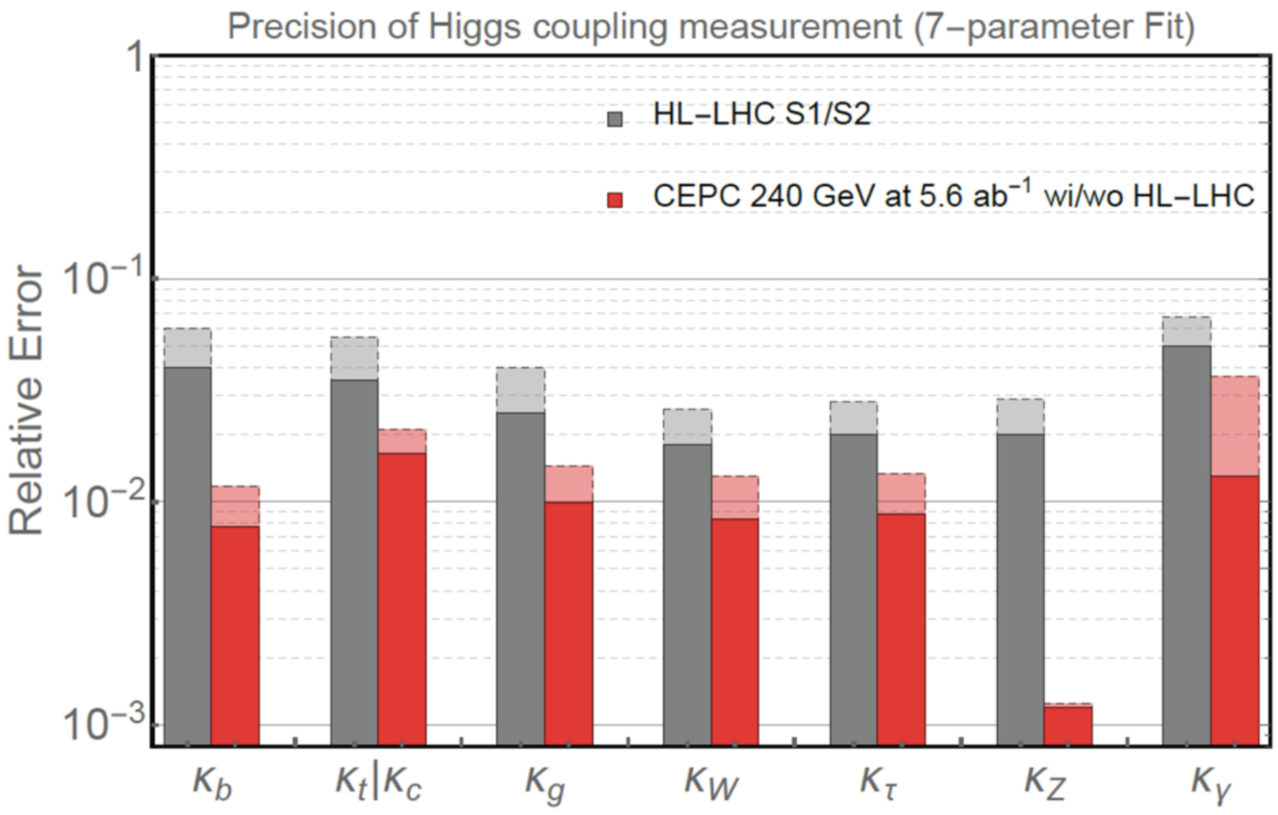
- **July 5, 2021:** Changsha Bureau of S&T entrusted Hunan U. to conduct a feasibility study.
- **Sept 4, 2021:** Hunan U. organized a review meeting by a committee consisting of experts from multiple disciplines which evaluated CEPC for its science, feasibility of a new science city based on CEPC, and overall impact on Changsha. The overall conclusion is very positive. The local government is very interested in and supportive of the CEPC project.



CEPC Physics Program (CDR)

Order of magnitude improvement in precision ⇒ Unknown / discoveries

Compare to the HL-LHC, CEPC can improve the precision of Higgs couplings significantly



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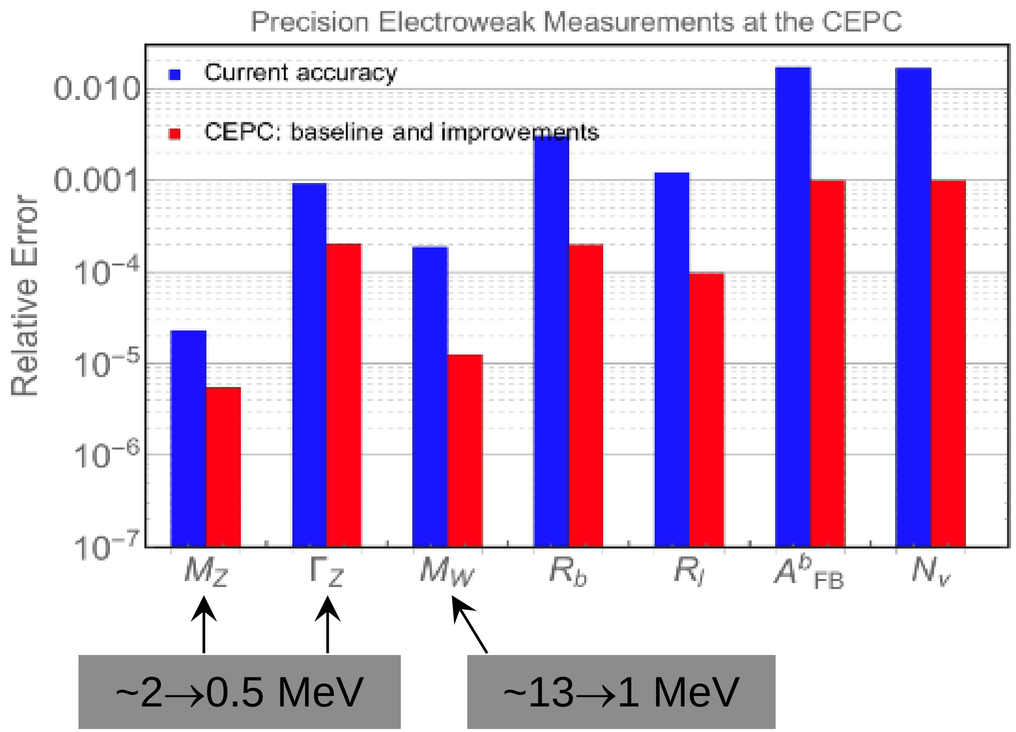
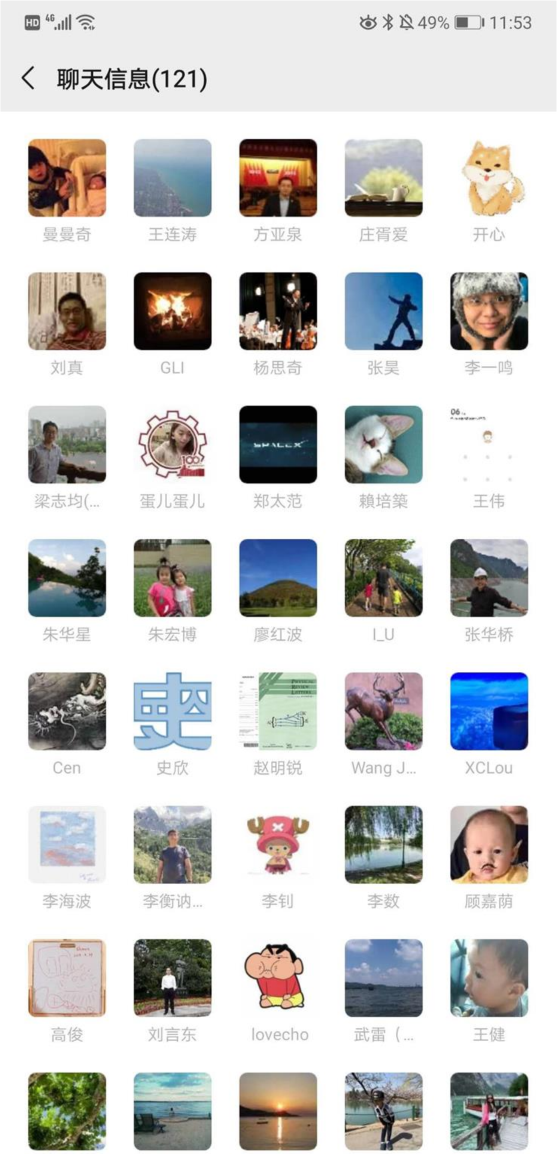
CEPC can improve the precision of the EW parameters by a factor of ~ 5-10



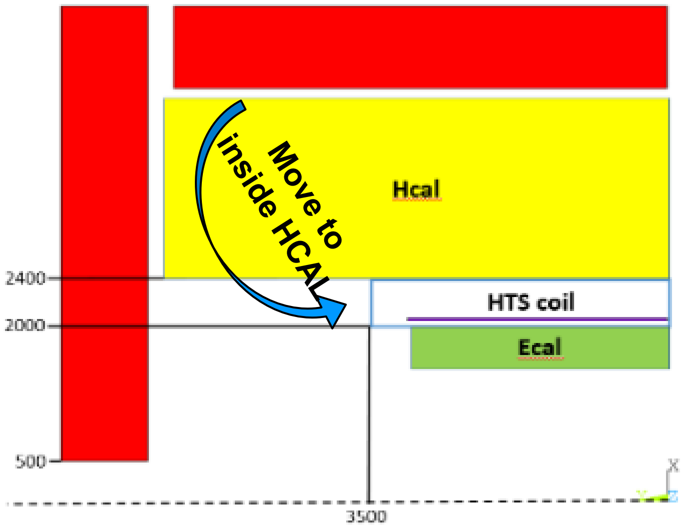
- ❑ **Precision EW measurements,**
- ❑ **Flavor physics (b, c, tau),**
- ❑ **Study of QCD,**
- ❑ **Probe physics BSM.**

CEPC Study for Snowmass: Physics



WG	LoI
EF01	Higgs boson CP properties at CEPC
	Measurement of branching fractions of Higgs hadronic decays
EF02	Study of Electroweak Phase Transition in Exotic Higgs Decays with CEPC Detector Simulation
	Complementary Heavy neutrino search in Rare Higgs Decays
EF03	Feasibility study of CP-violating Phase ϕs measurement via Bs → J/Ψϕ channel at CEPC
	Probing top quark FCNC couplings tq\gamma, tqZ at future e+e- collider
	Searching for Bs → ϕ νν and other b → sνν processes at CEPC
EF04	Measurement of the leptonic effective weak mixing angle at CEPC
	Probing new physics with the measurements of e+e- → W+W- at CEPC with optimal observables
	NNLO electroweak correction to Higgs and Z associated production at future Higgs factory
EF05-07	Exlusive Z decays
EF08	SUSY global fits with future colliders using GAMBIT
	Probing Supersymmetry and Dark Matter at the CEPC, FCCee, and ILC
EF09-10	Search for t + j + MET signals from dark matter models at future e+e- collider
	Search for Asymmetric Dark Matter model at CEPC by displaced lepton jets
	Dark Matter via Higgs portal at CEPC
	Lepton portal dark matter, gravitational waves and collider phenomenology

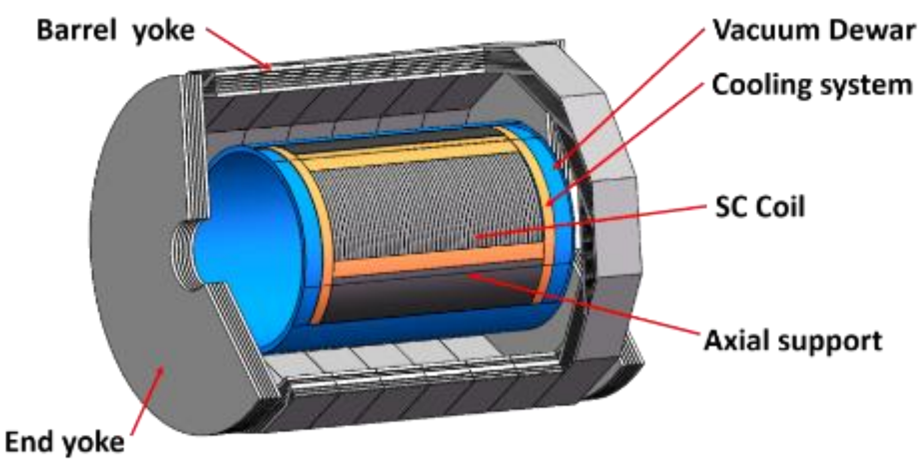
Solenoid Magnet Inside HCAL



Challenges

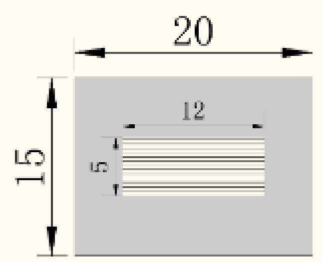
Low mass, ultra-thin, high strength cable

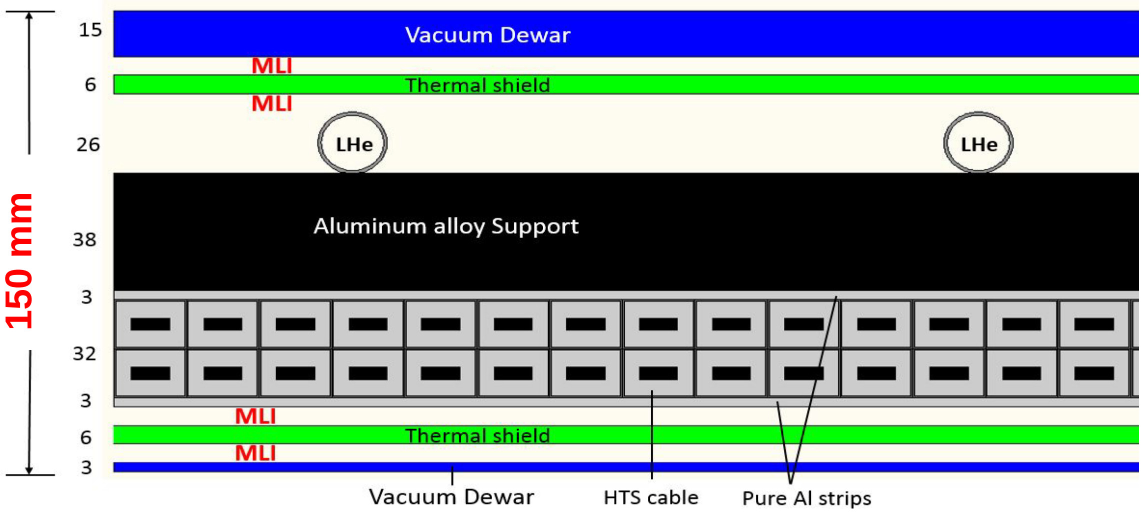
- Inner radius = 2.33m, length < 8m, central magnetic field: 3 T
- Magnet radial thickness < 150 mm
- Mass of magnet < $1.5X_0$



R&D: high strength HTS cable, ultra-thin cryostat.

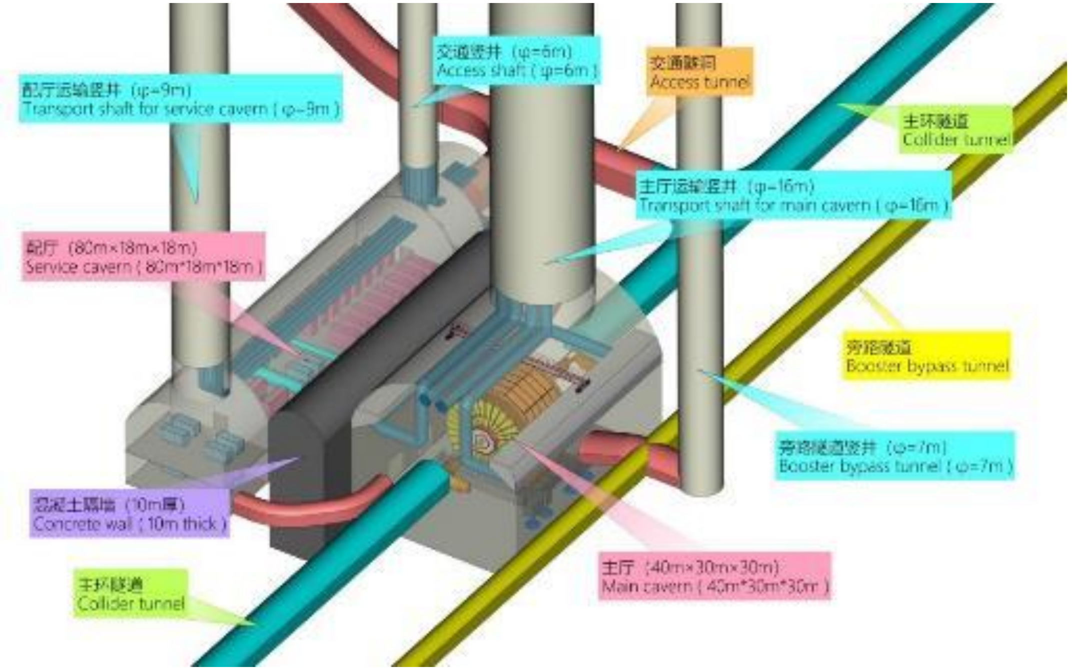
Al stabilized ReBCO stacked tape cable





HTS cable length (km)	9
ASTC weight(ton)	9
Operating current(A)	29700
Cold mass weight (ton)	20
Total weight (ton)	35

The Experimental Area



Ground level buildings

Main cavern to host the detector

- $40*30*30$ m^3 (L*H*W)
- One main access shaft, Ø16 m
- An 1K-ton gantry crane for large heavy objects

Auxiliary cavern for peripheral equipment and devices

- $80*18*18$ m^3 (L*H*W)
- One service shaft of Ø9 m
- One personnel access shaft Ø6 m

Thank you !