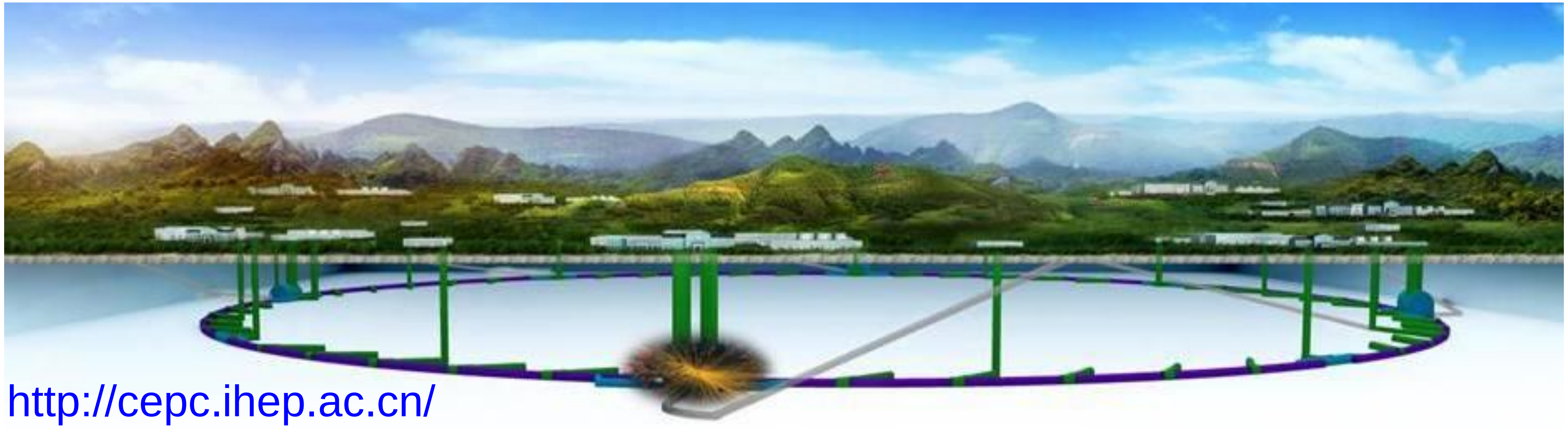
The CEPC Studies, R&Ds and Status, and Synergies with the LC Community

Jingbo Ye (for the CEPC study group)

Institute of High Energy Physics
Chinese Academy of Sciences

LCWS2023 @ SLAC, May 15 – 19, 2023



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

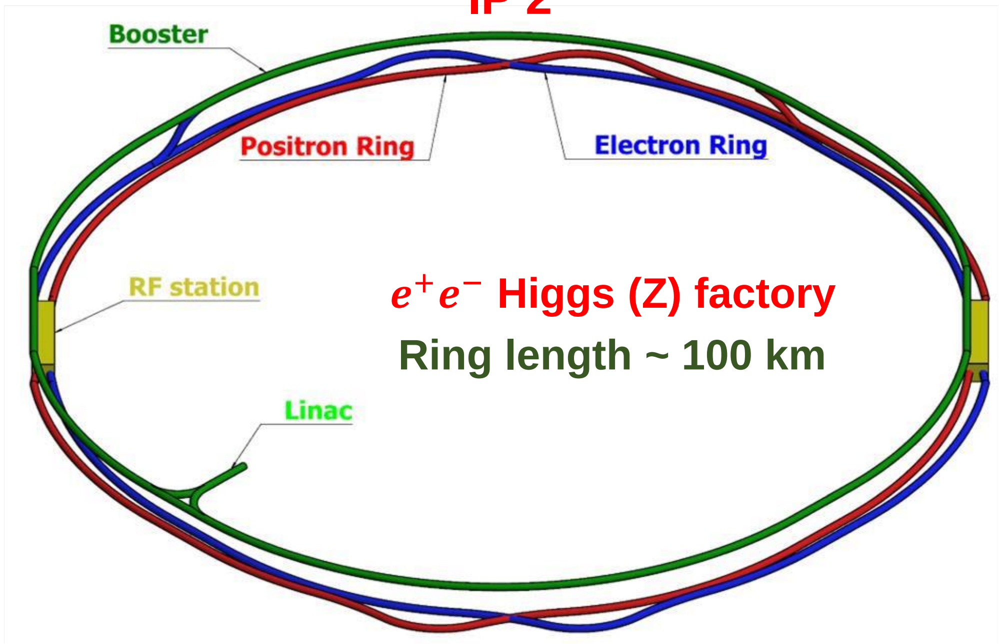
Outline

- Introduction to the Circular Electron Positron Collider (CEPC)
  - Brief history and the Plan
- Studies, R&Ds and Status, and Synergies with the LC Community
  - Physics Programs
  - Accelerator R&Ds
  - Detector R&Ds
  - Synergies with the LC Community
- Other Aspects (briefly and if time permits)
  - Synergies in IHEP and industry engagement
  - the CEPC team, committees, international efforts/contributions
  - Project site candidates and timeline
- Summary and Prospect

CEPC: the Circular Electron Positron Collider

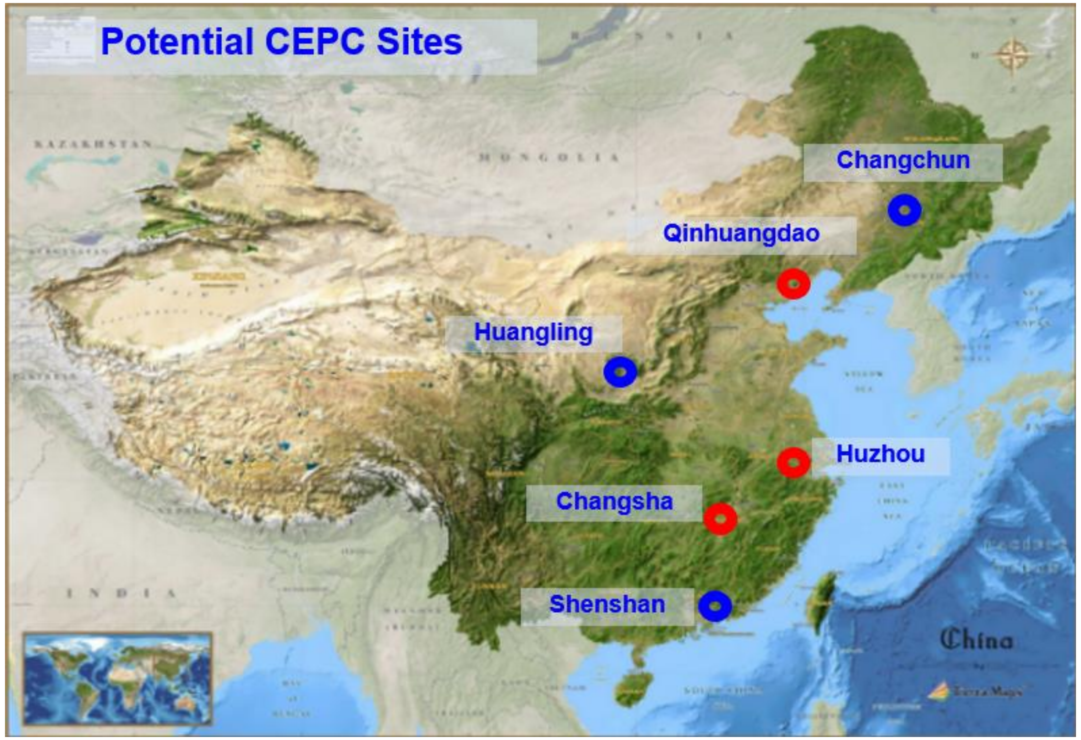
- Proposed in 2012 right after the Higgs discovery, CEPC will be an e^+e^- facility, a Higgs factory producing Higgs, W and Z bosons, and top quarks, for precision measurements and searches of new physics beyond the Standard Model (BSM).
- The penciled construction starts in 2026 and operation in 2030s.
- Upgrade in mind: Super pp Collider (SppC) of $\sqrt{s}$ ~ 100 TeV in the future.

IP 2

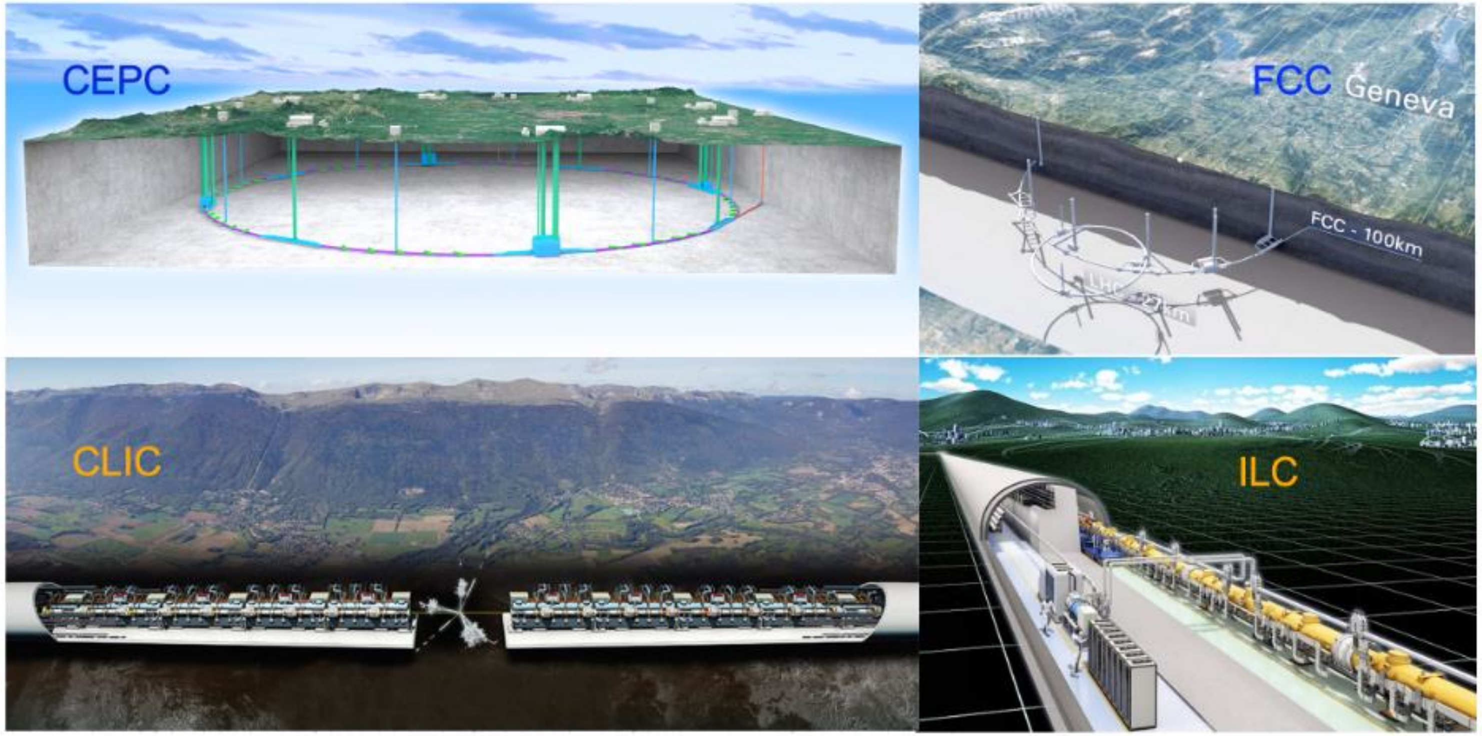


IP 1

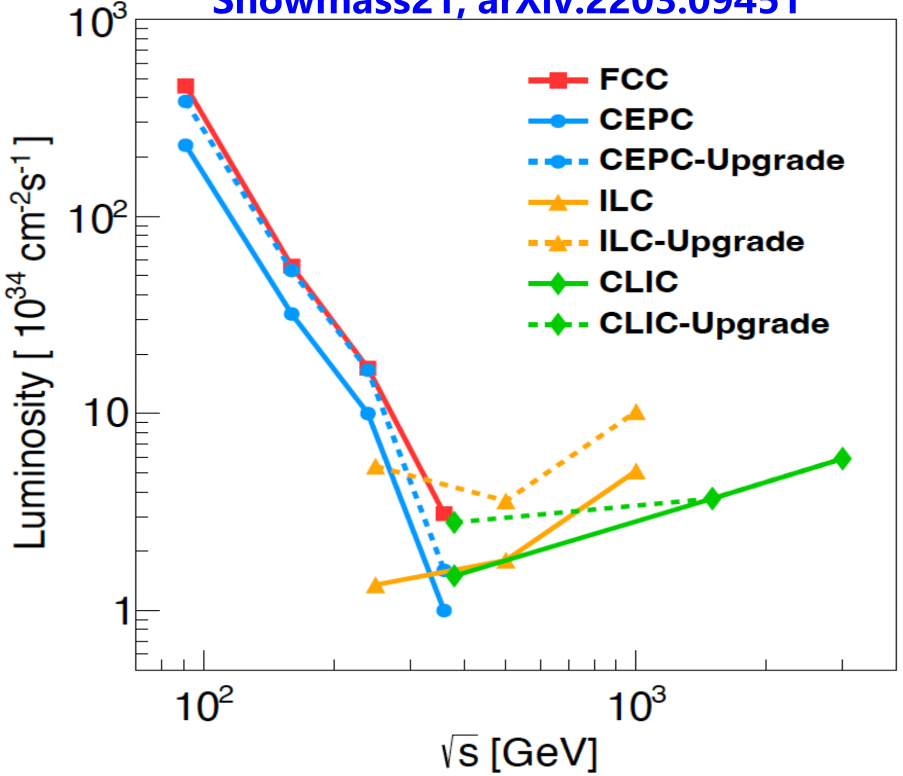
arXiv:1809.00285, arXiv:2203.09451



One of the proposed Higgs factories



CEPC Accelerator white paper for Snowmass21, arXiv:2203.09451



CEPC versus FCC-ee

- Collisions expected in 2030s
- Large tunnel cross section (ee & pp coexistence)
- Lower cost: ~ ½ the construction cost with similar luminosity up to 240 GeV

CEPC versus Linear Colliders

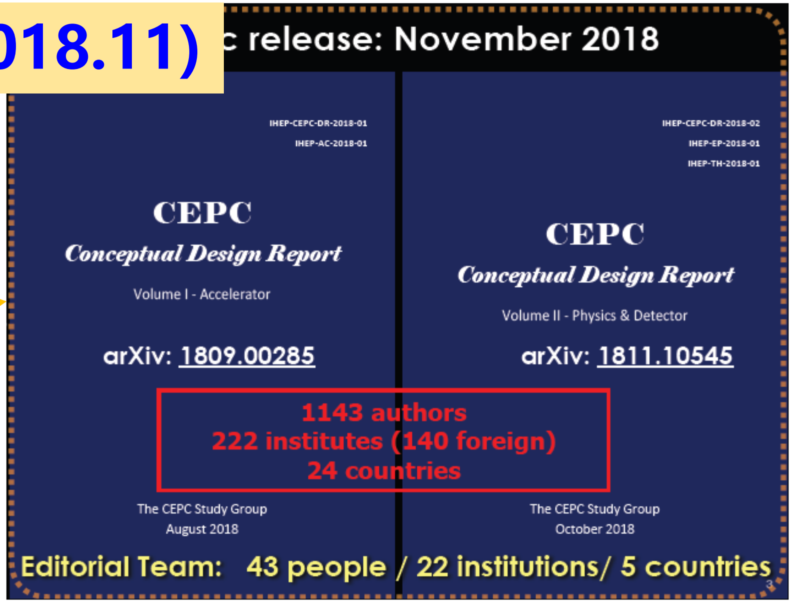
- Higher luminosity for Higgs and Z runs
- Potential upgrade for pp collider
- LCs have higher energy potentials and in principle polarized beams

Reached Major Milestones

CEPC-SPPC Kickoff (2013.9)

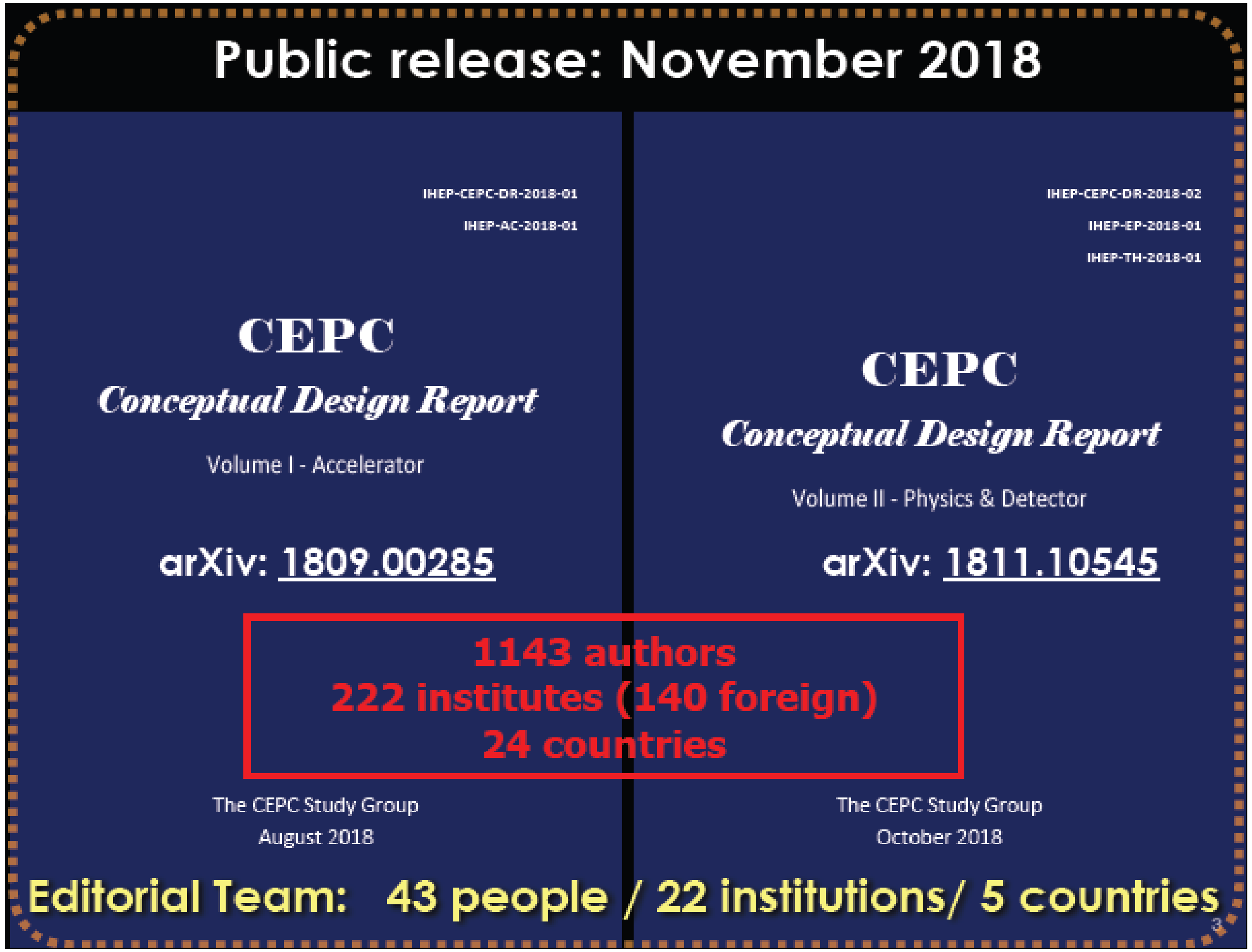
CEPC IAC Meeting (2015.9)

CEPC CDR Released (2018.11)



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 many R&Ds towards

(1) Accelerator TDR (2023)

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

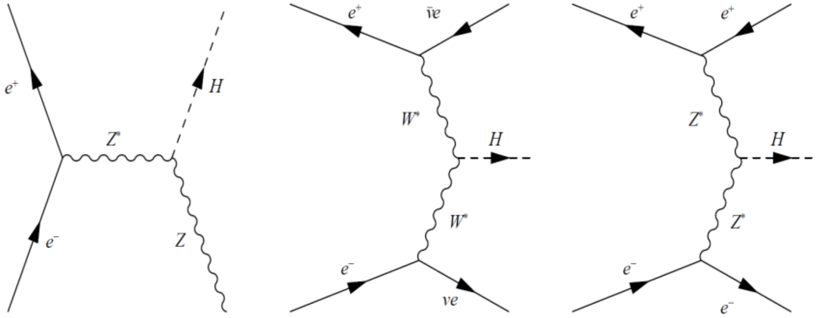
Identify challenges and devise solutions

Studies, R&D and Status, and Synergies with LC

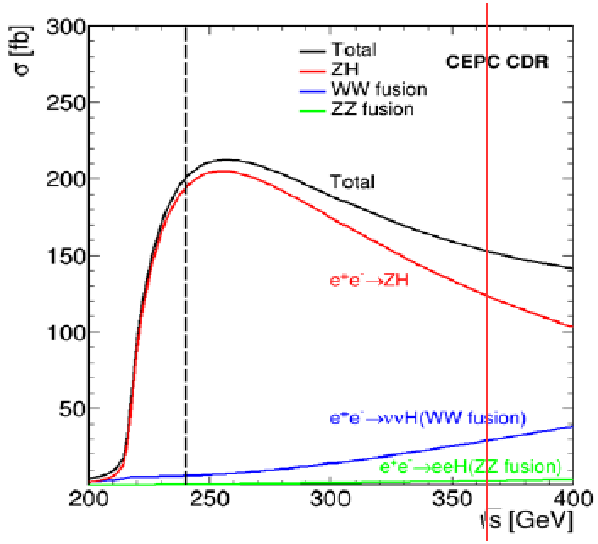
- **Physics Programs**
- **Accelerator R&D**
- **Detector R&D**
- **Synergies with the LC Community**

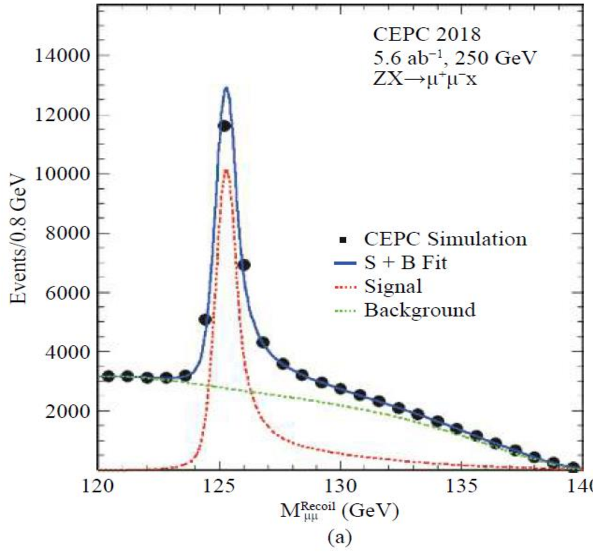
Physics Programs (in CDR)

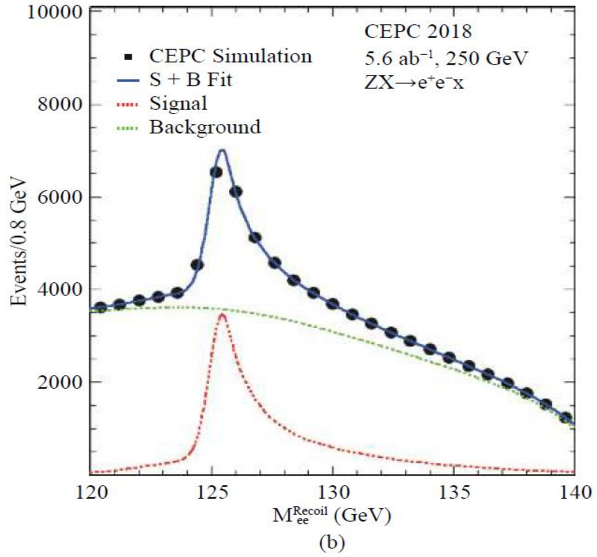
e^+e^- annihilations at the CEPC

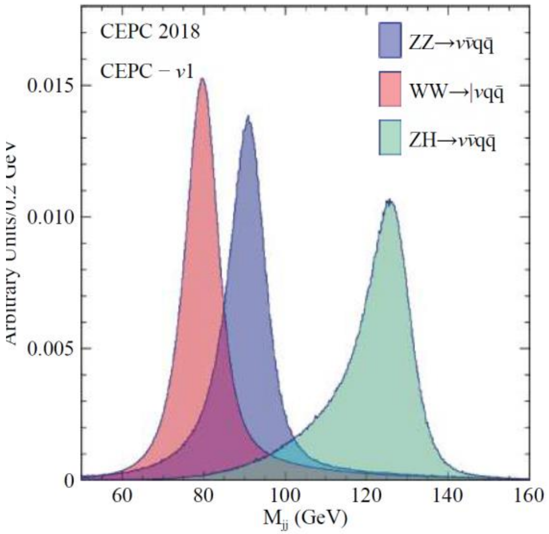


- **Will perform detailed studies of various physics processes**
- **Higgs bosons will be detected via recoil mass of the reconstructed Z, allowing for model independent & full investigation of the Higgs and any new physics that Higgs may reveal**
- **Jets and events with missing neutrinos will be well reconstructed and identified**









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

❖ **O(100) Journal / arXiv papers**

Physics Programs (thrgh workshops + white papers)

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**

	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 [$\times10^{34}$ 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
TDR (50MW) (latest)	L / IP [$\times10^{34}$ 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

Peking U. (2019)

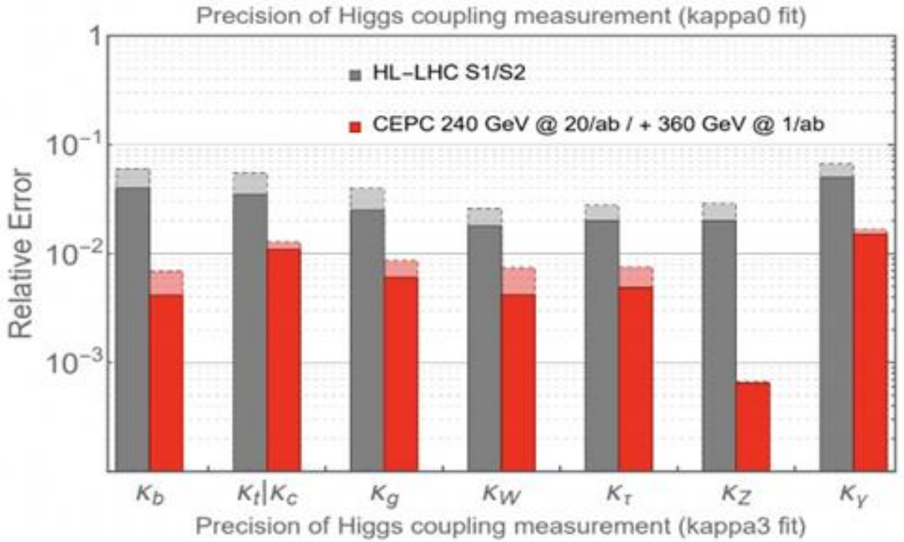
Yangzhou (2021)

Physics Programs (compare w/ LHC)

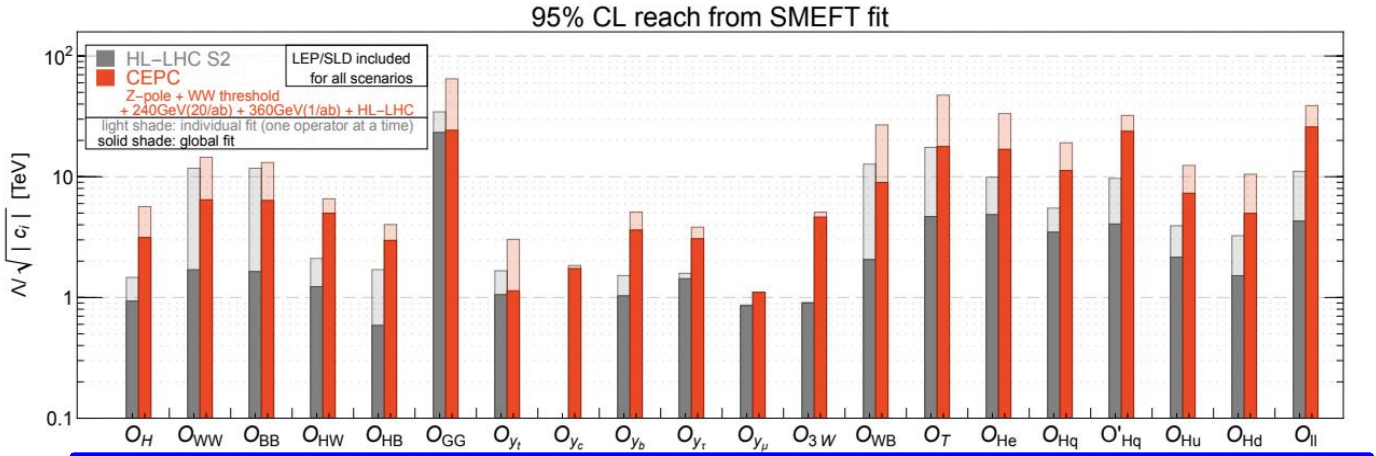
- **Unprecedented precision measurements on Higgs, EW, flavor physics and QCD**
- **BSM physics (e.g. dark matter, EW phase transition, SUSY, LLP, …) probed up to ~10 TeV scale**

	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
$H \to bb$	0.14%	1.59%	0.90%	1.10%	4.30%
$H \to cc$	2.02%		8.80%	16%	20%
$H \to gg$	0.81%		3.40%	4.50%	12%
$H \to WW$	0.53%		2.80%	4.40%	6.50%
$H \to ZZ$	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%		

arXiv:2205.08553



Energy scale probed

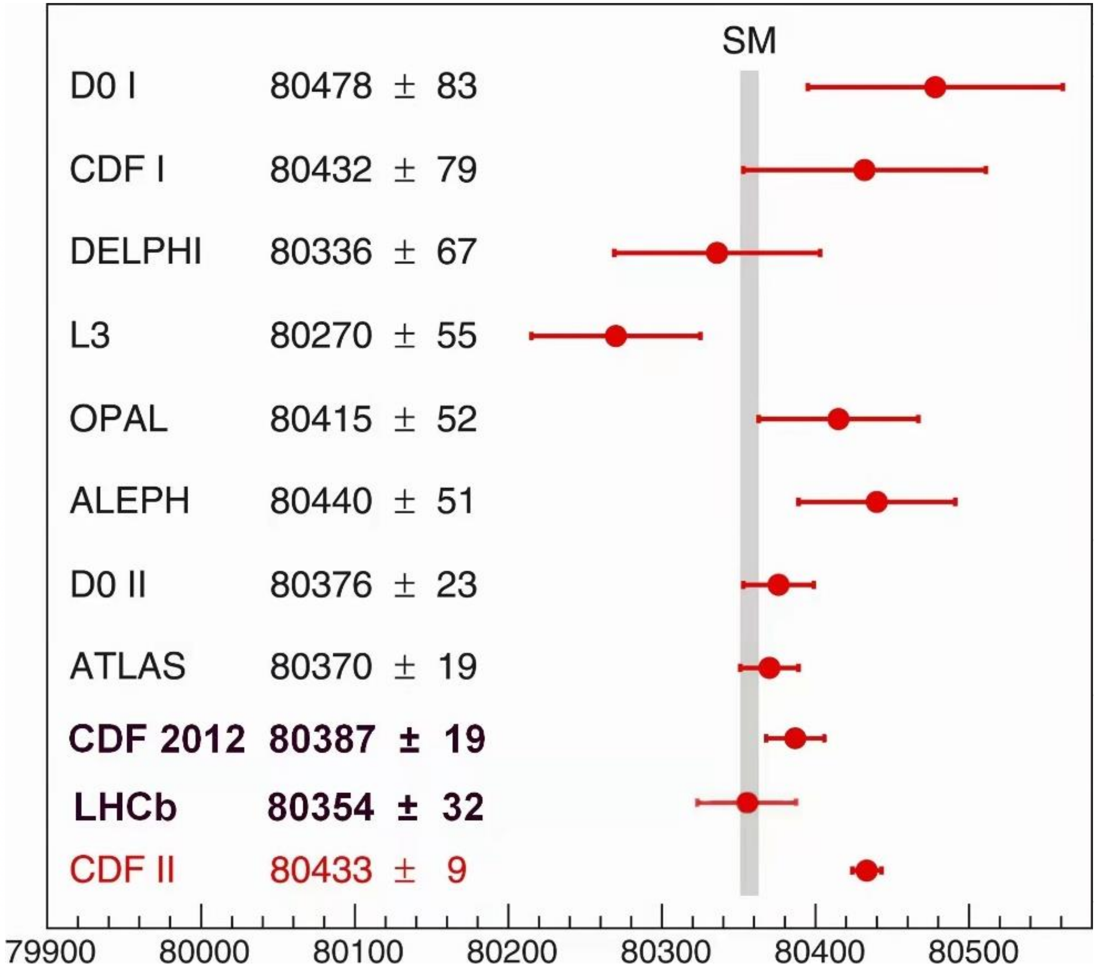


CEPC can reveal new physics at energy ~ 10 TeV or higher

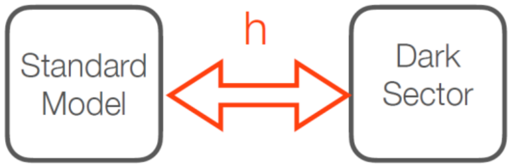
Physics Programs: Higgs and EW

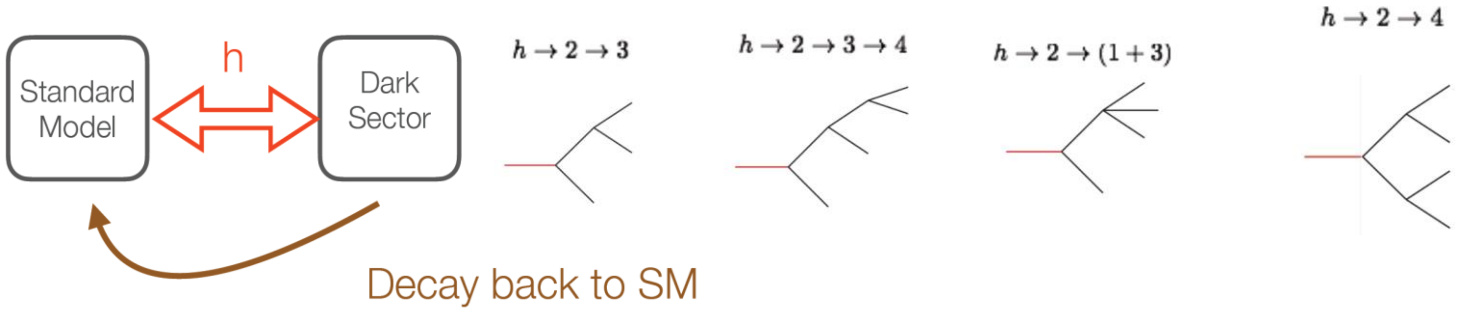
- **Unprecedented precision measurements on Higgs, EW, flavor physics and QCD**
- BSM physics (e.g. dark matter, EW phase transition, SUSY, LLP, …) up to ~10 TeV scale

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

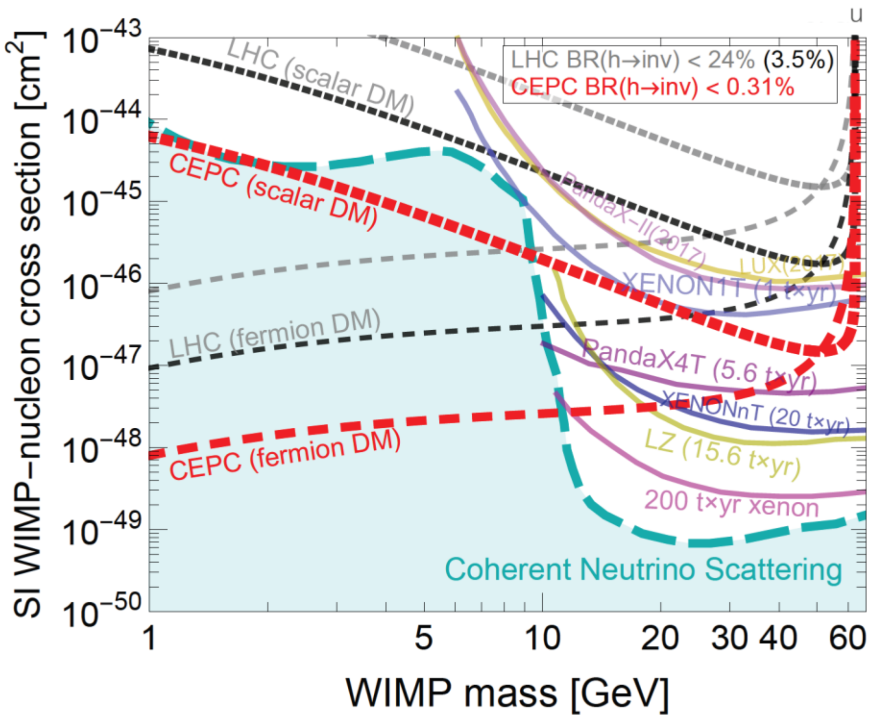


Physics Program: Discovery Potential (BSM)

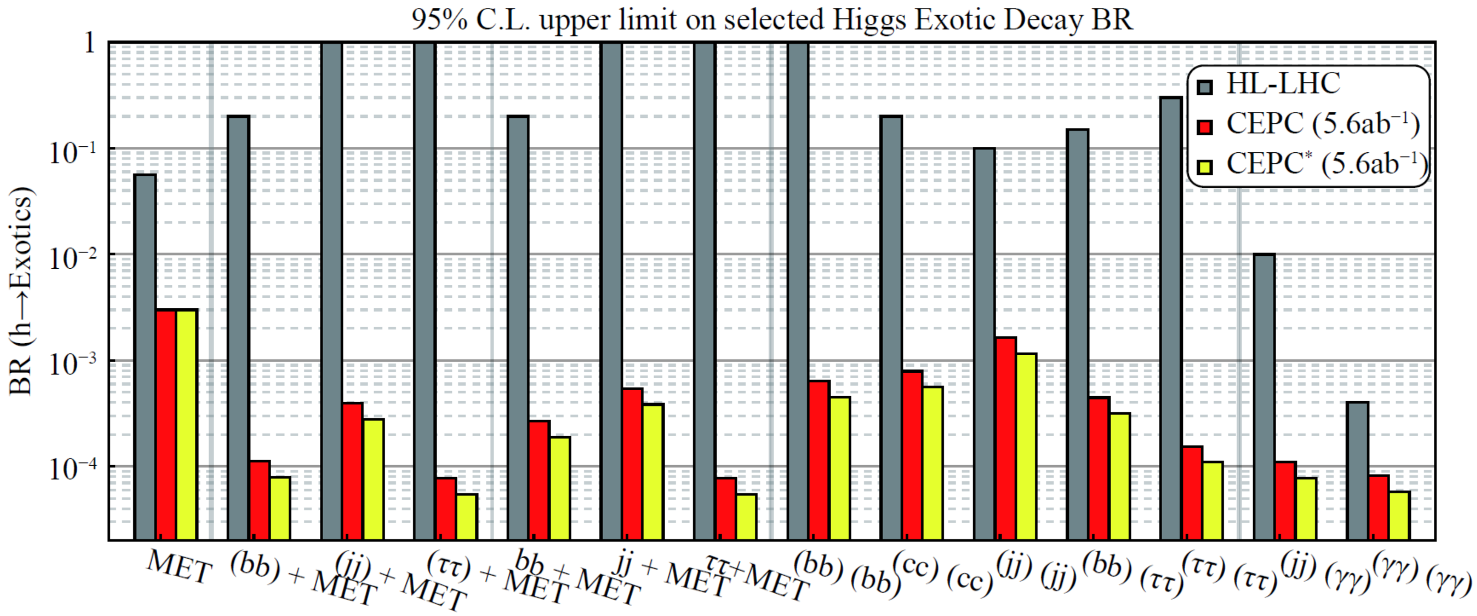




$$h \to X_{\rm dm} X_{\rm dm}$$



Higgs decays into BSM particles, $H \to X_1 X_2$



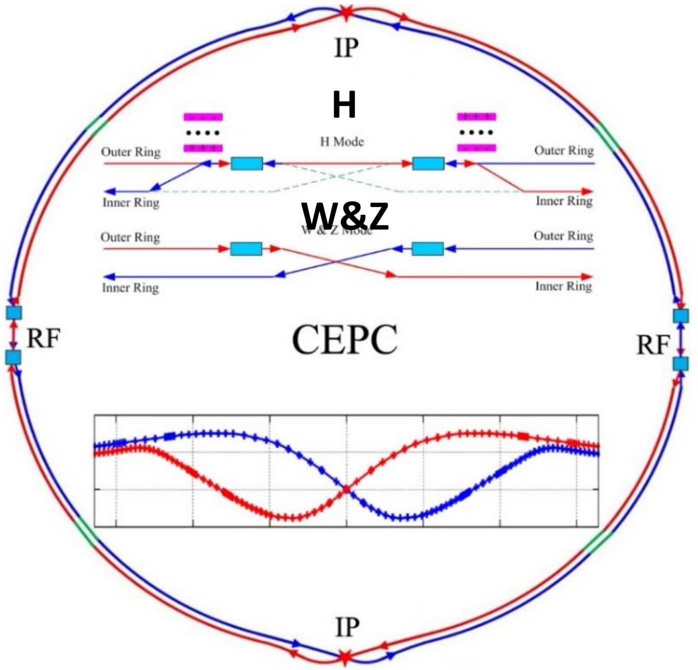
Compared with HL-LHC, CEPC has significantly better detection sensitivity for dark matter and selected Higgs exotic decays. The high luminosities that circular machines offer to physics complement the high energy potential of linear colliders.

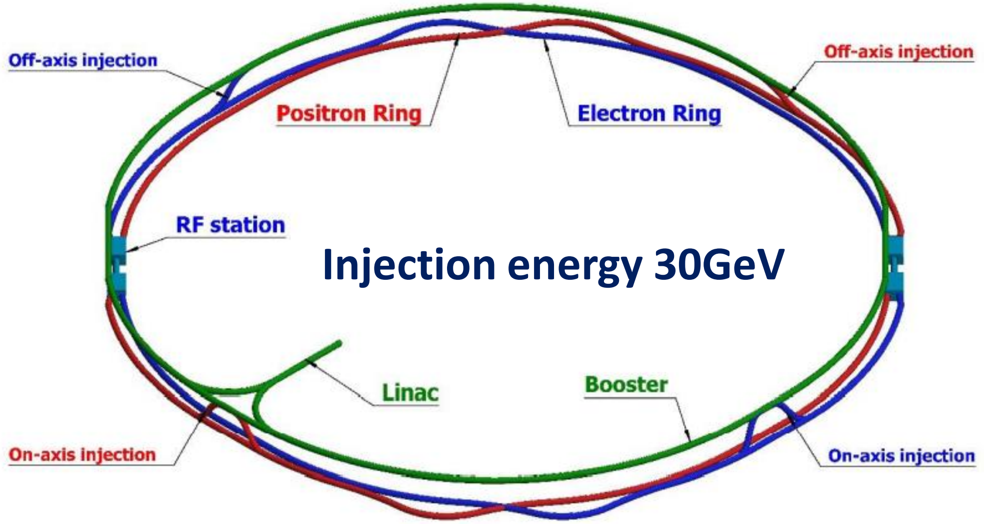
Studies, R&D and Status, and Synergies with LC

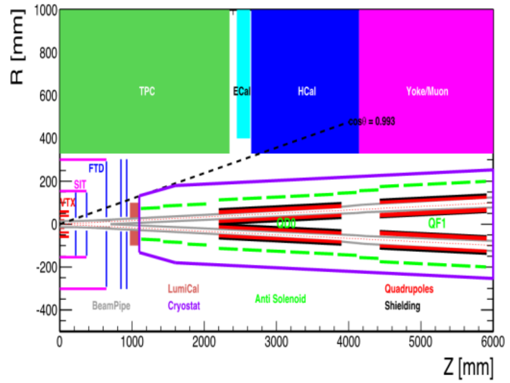
- Physics Programs
- **Accelerator R&D**
- Detector R&D
- Synergies with the LC Community

Design Improvements, from CDR (2018) to TDR (23)

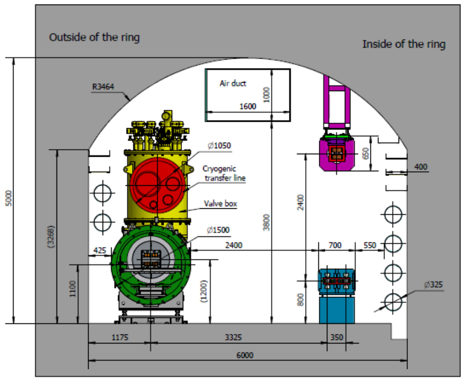
- 100 km double ring design (30 MW SR power, upgradable to 50MW).
- Switchable operation for H & Z, W modes without hardware change.



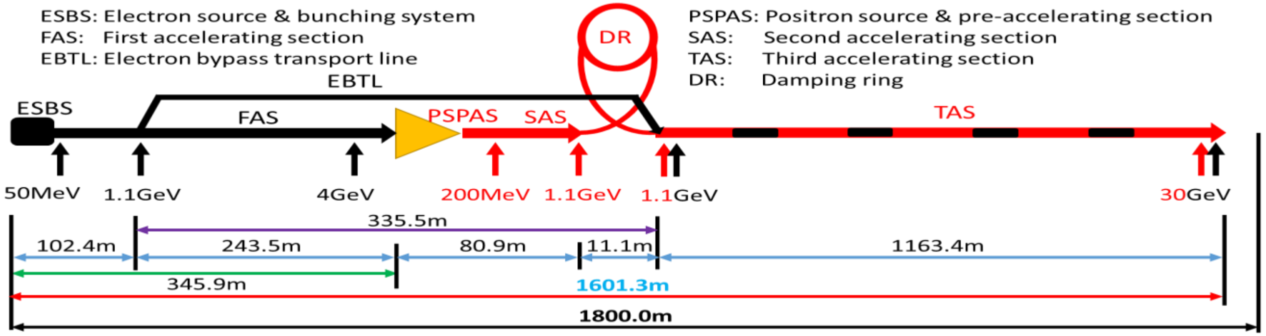




TUNNEL CROSS SECTION OF THE ARC AREA

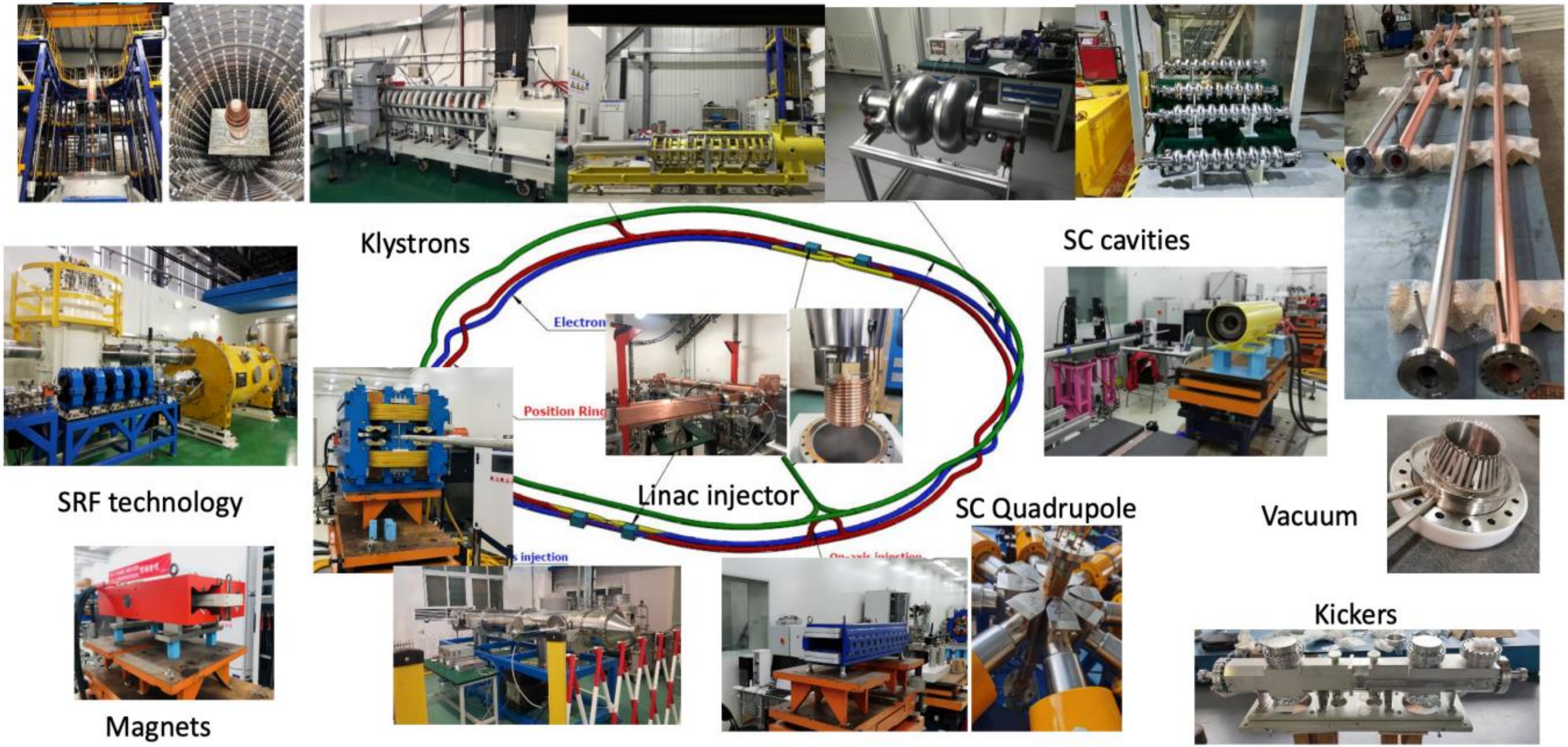


CEPC TDR S+C-band 30GeV Linac Injector



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

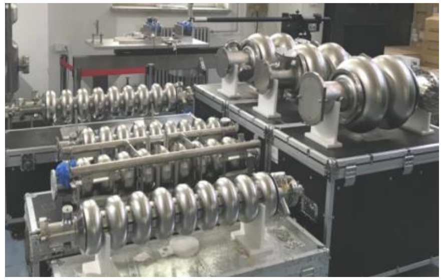
R&Ds on the Key Technologies



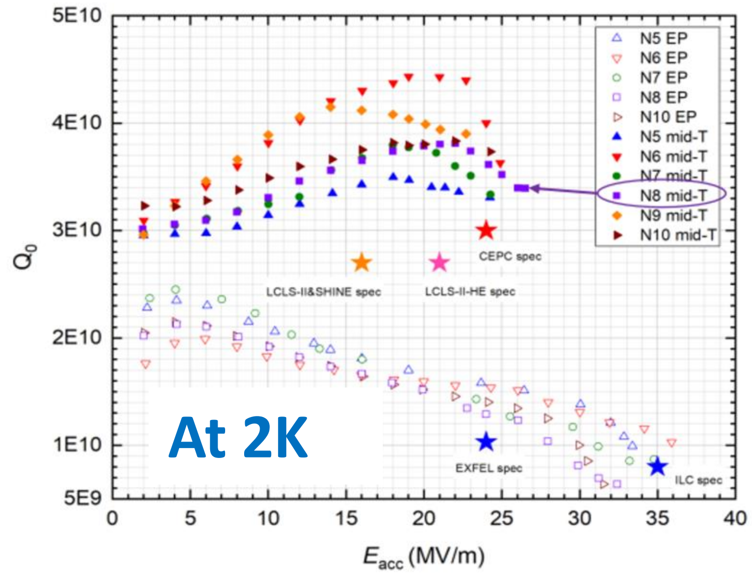
High Q SCRF Cavities

- 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 ! The 1.3 GHz SCRF cavity could be used for LCs

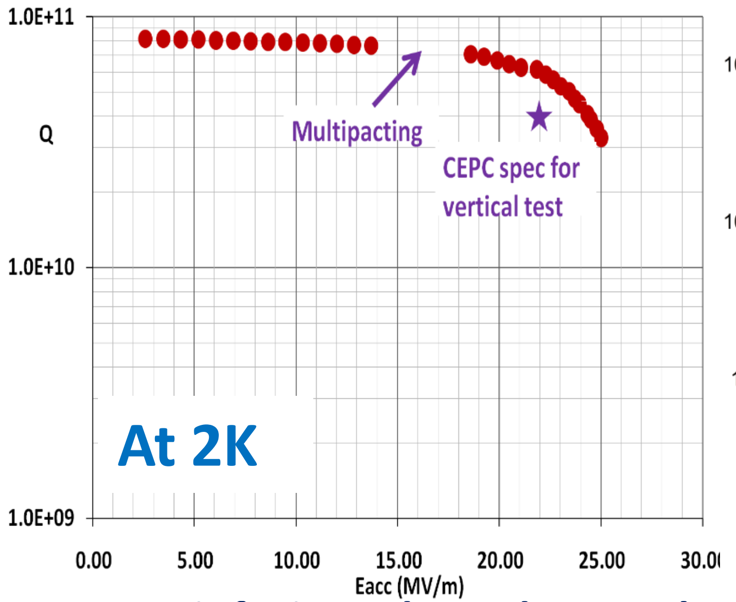


IHEP 1.3 GHz 9-cell Cavity Vertical Test

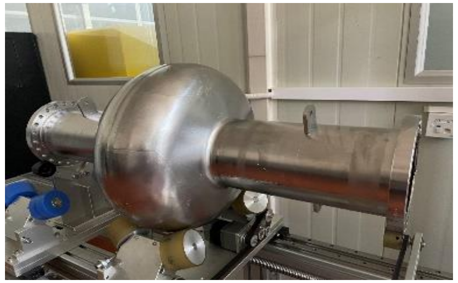


Medium-temperature (Mid-T) annealing adopted to reach Q_0 = 3.4E10 @ 26.5 MV/m

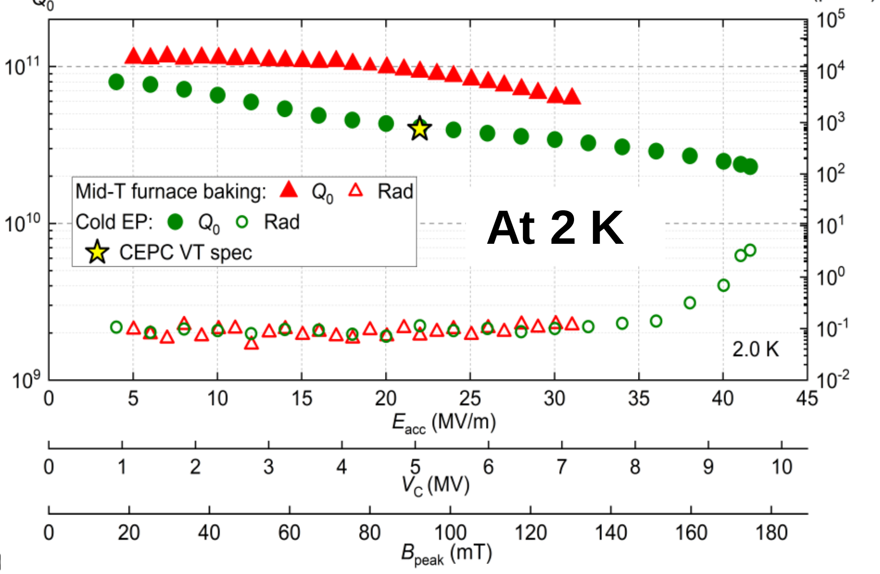
Vertical test of 650 MHz 2-cell cavity



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



650MHz 1-cell SCRF Cavity

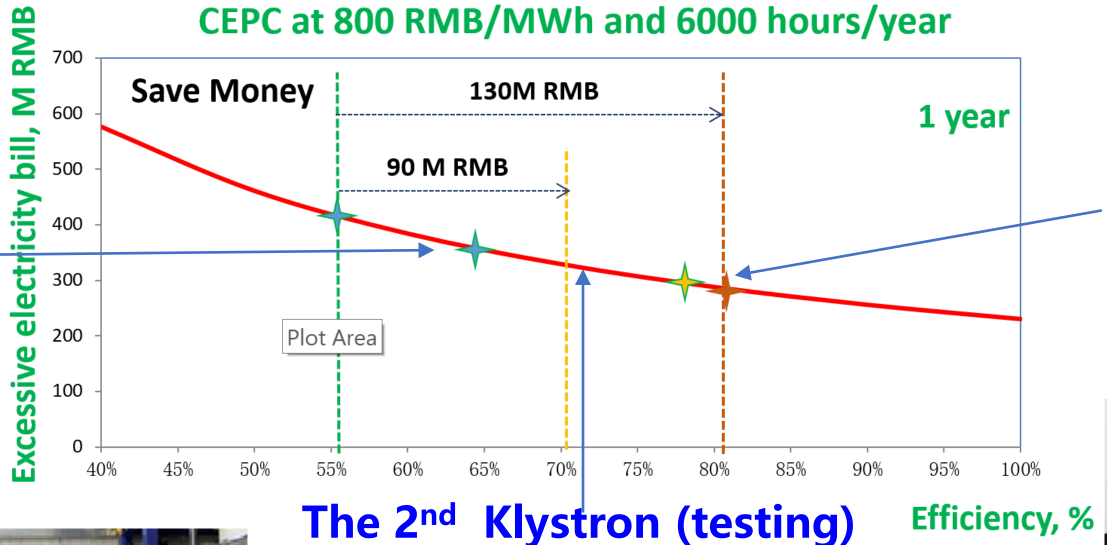


Q_0 = 6.0E10 @ 31 MV/m
Q_0 = 2.1E10 @ 42 MV/m

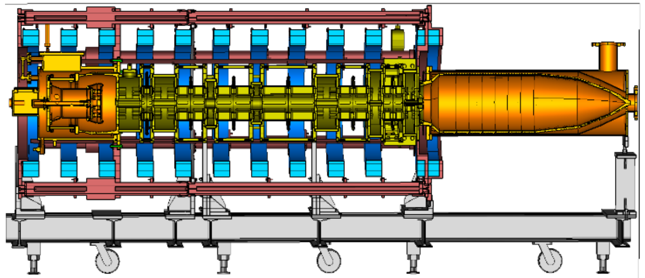
High Efficiency Klystrons

- The 1st Klystron prototype, design 65%, achieved efficiency ~ 63%.
- The 2nd Klystron prototype tested at PAPS in 2022, design eff. is 77%, achieved eff. ~ 70.5% (so far), a window broke, under investigation + repairing
- The 3rd Klystron (MBK) is being fabricated, design eff. is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

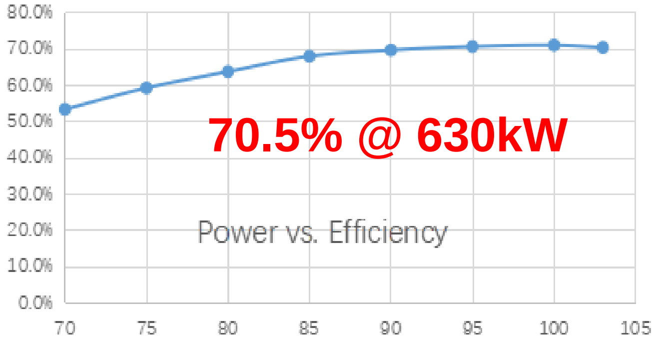
The 1st Klystron (tested)



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

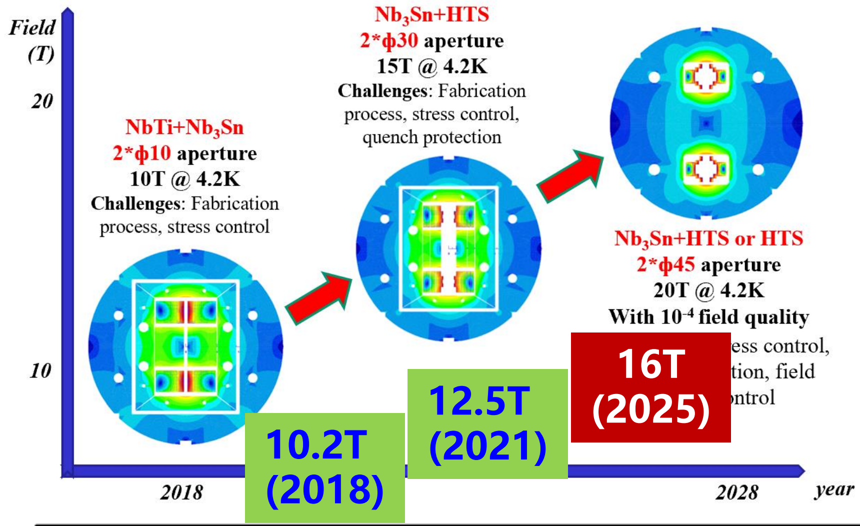


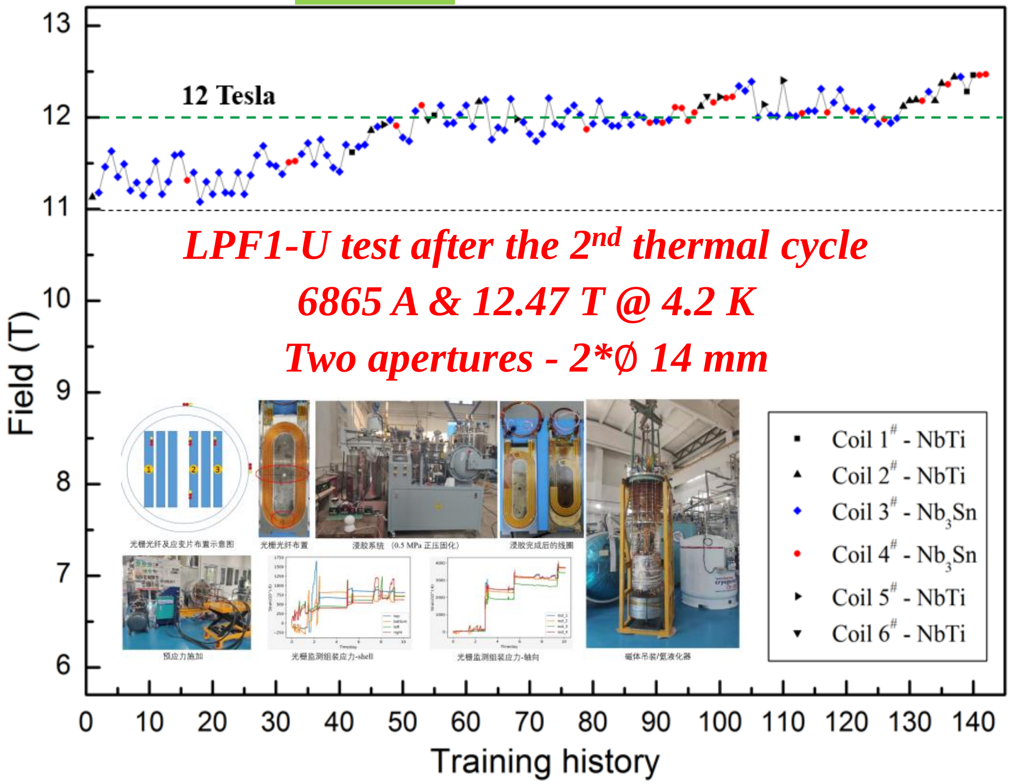
The 2nd Klystron (testing)

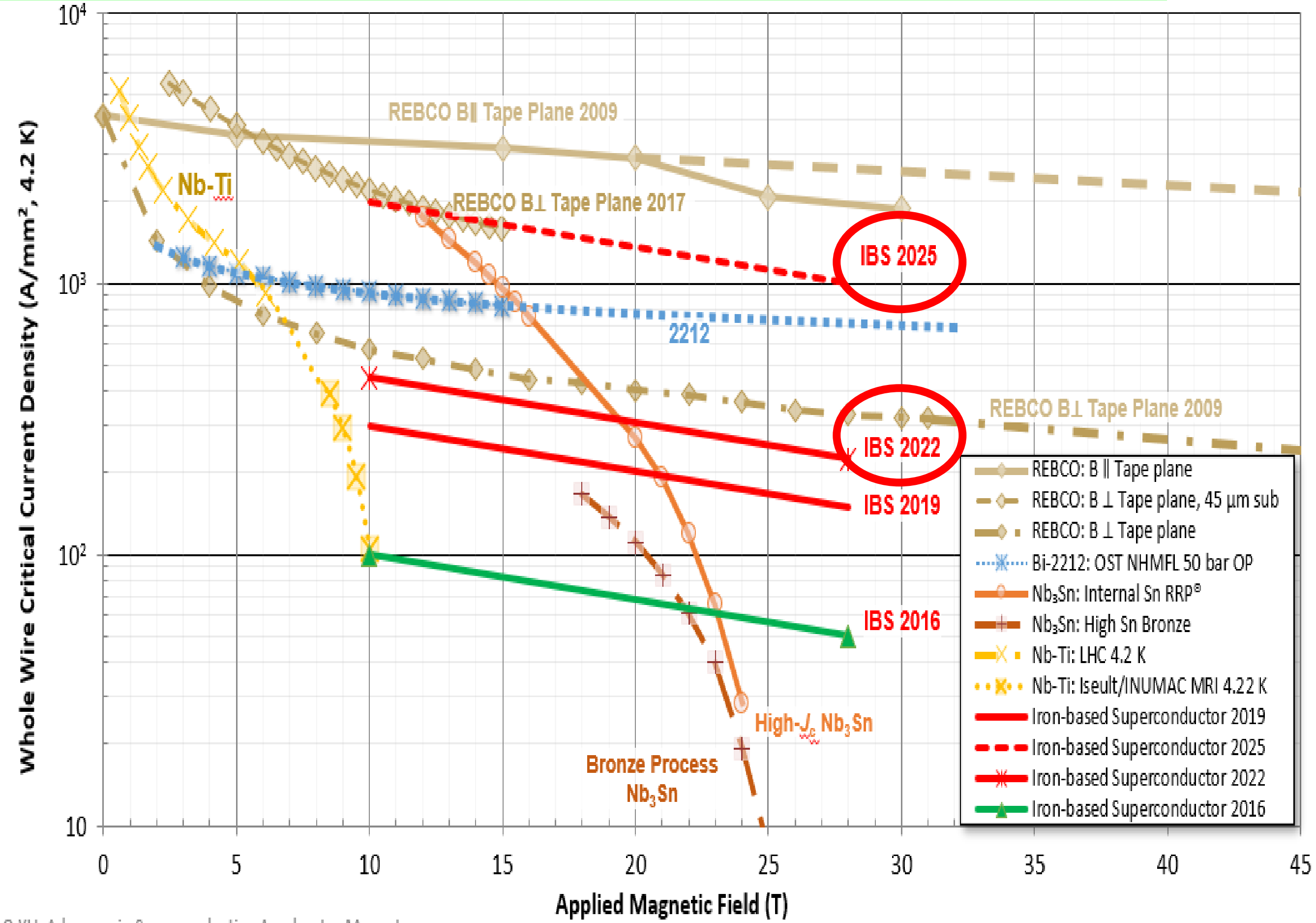


High efficiency Klystrons benefit all accelerators, including LCs

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.**

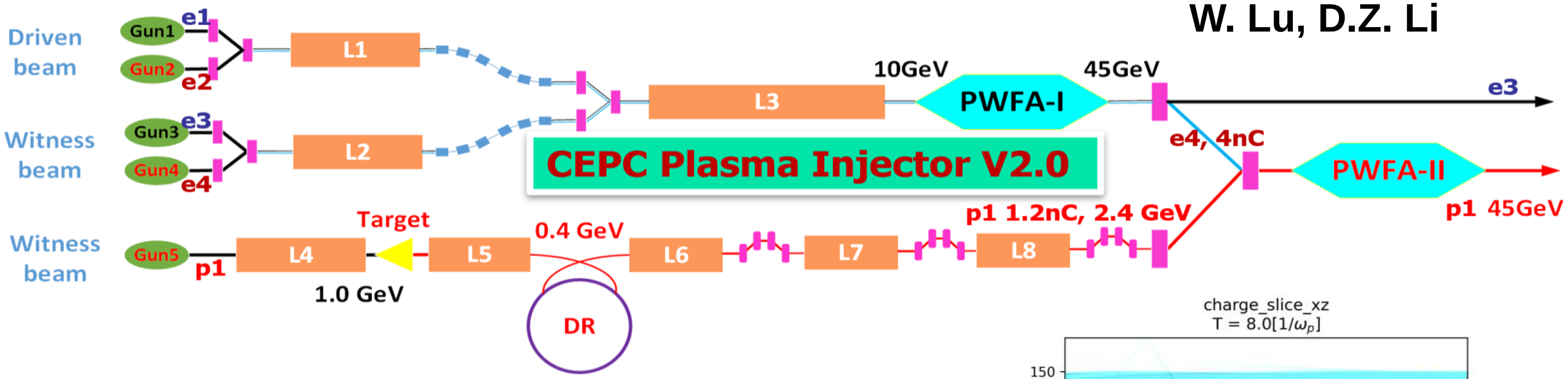
The Plasma Injector

CEPC Plasma Injector V2.0

IHEP, THU, BNU

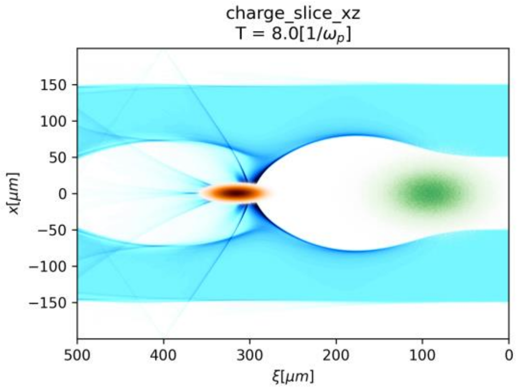
Booster Requirement	
Energy (GeV)	45.5
Bunch Charge (nC)	0.78
Bunch length (um)	<3000
Energy Spread (%)	0.2
ε_N (µm·rad)	<800
Bunch Size (um)	<2000

W. Lu, D.Z. Li

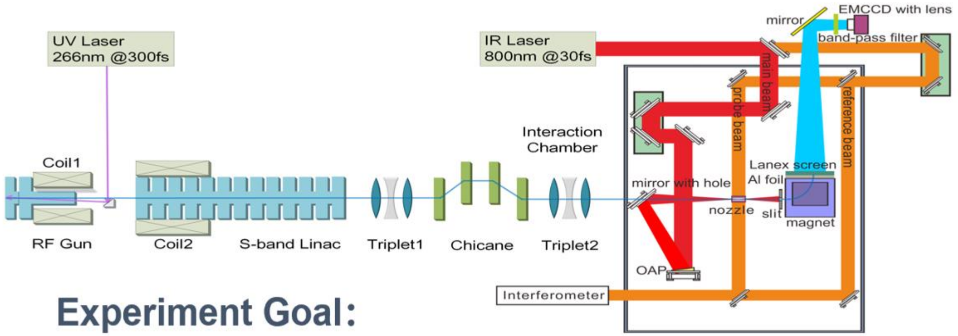


High eff. uniform wakefield acceleration of a positron beam using stable asymmetric mode in a hollow channel plasma

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



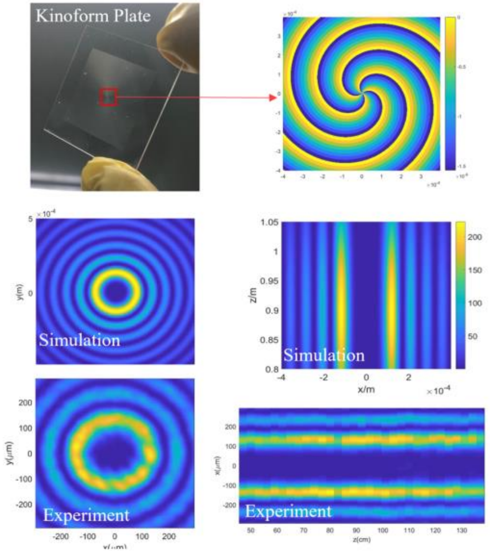
Plasma dechirper exp at SXFEL

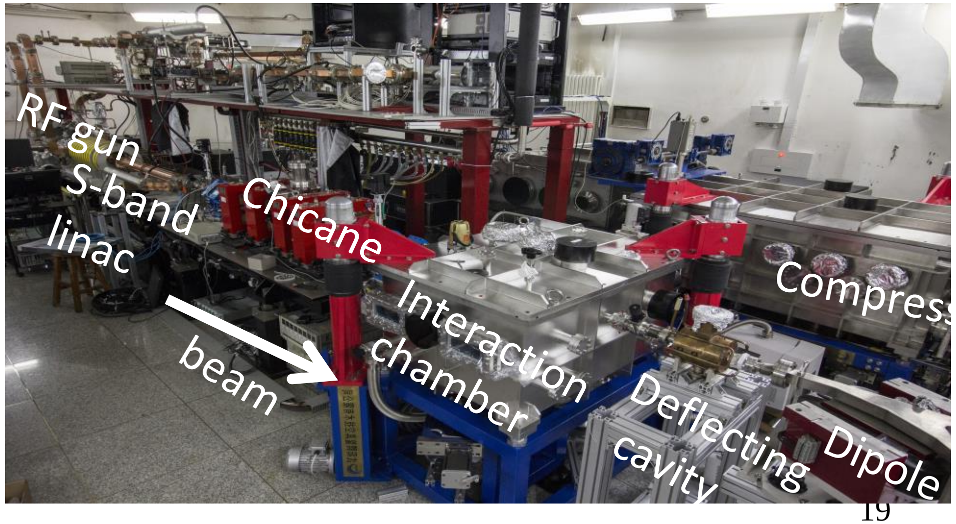


Experiment Goal:

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

PRL 127, 174801 (2021)





IHEP's 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 in operation since June 2021

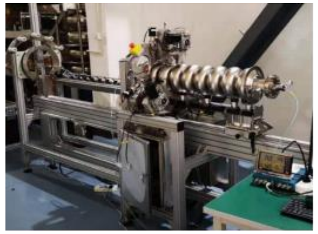
Cryogenic system hall

Vacuum furnace (doping & annealing)

Nb3Sn furnace

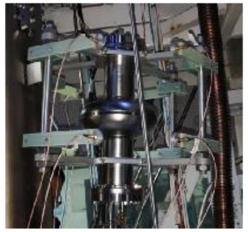
Nb/Cu sputtering device

Cavity inspection camera and grinder

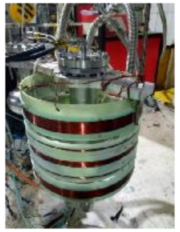


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

Vertical test dewars

Horizontal test cryostat

Studies, R&D and Status, and Synergies with LC

- Physics Programs
- Accelerator R&D
- **Detector R&D**
- Synergies with the LC Community

Several Conceptual Detector Designs

(Baseline Design)
Particle Flow Approach

Magnet (3T/2T)

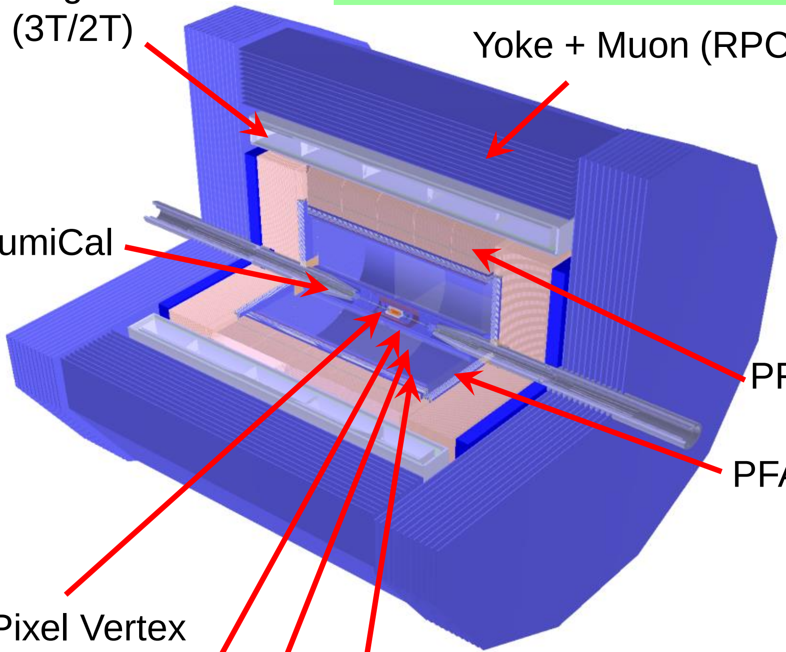
Yoke + Muon (RPC or μ-RWELL)

LumiCal

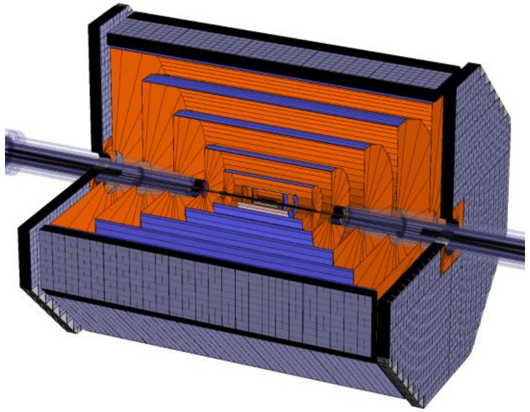
PFA HCAL

PFA ECAL

Si Pixel Vertex



SIT TPC SET
FTD ETD



FST concept
(Full Silicon Tracker)

IDEA concept
(also proposed for FCC-ee)

2T Magnet

Preshower (μ-RWELL)

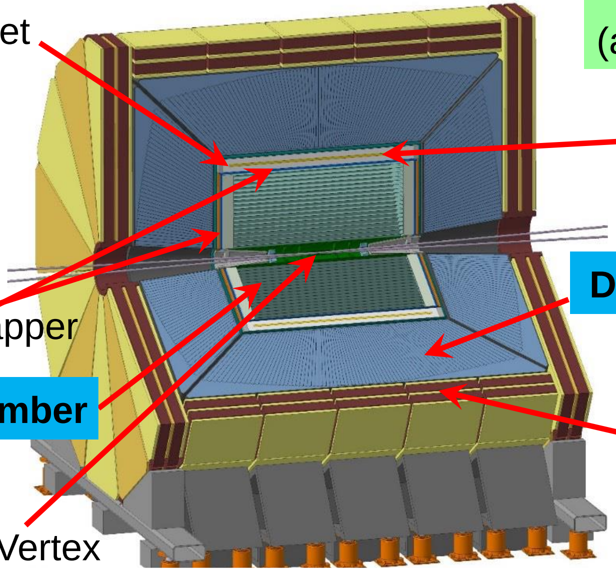
Silicon wrapper

Dual-readout calorimeter

Drift chamber

Yoke + Muon (μ-RWELL)

Si Pixel Vertex



The 4th Concept

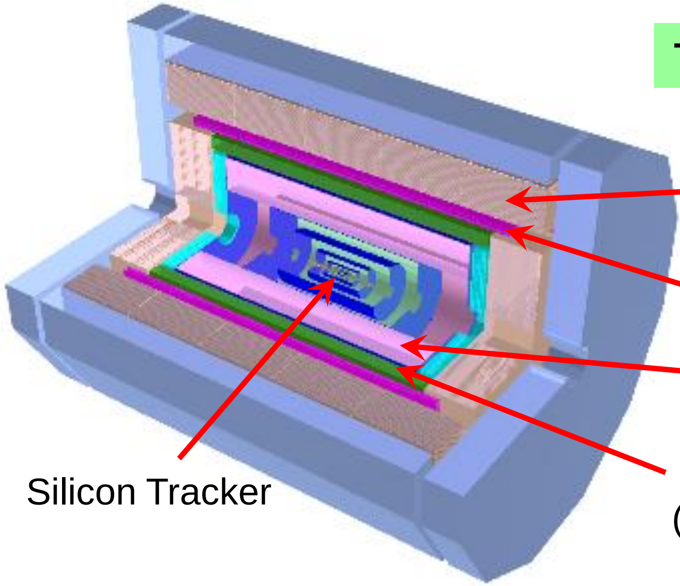
PFA HCAL
Partially Yoke

Magnet (3T/2T)

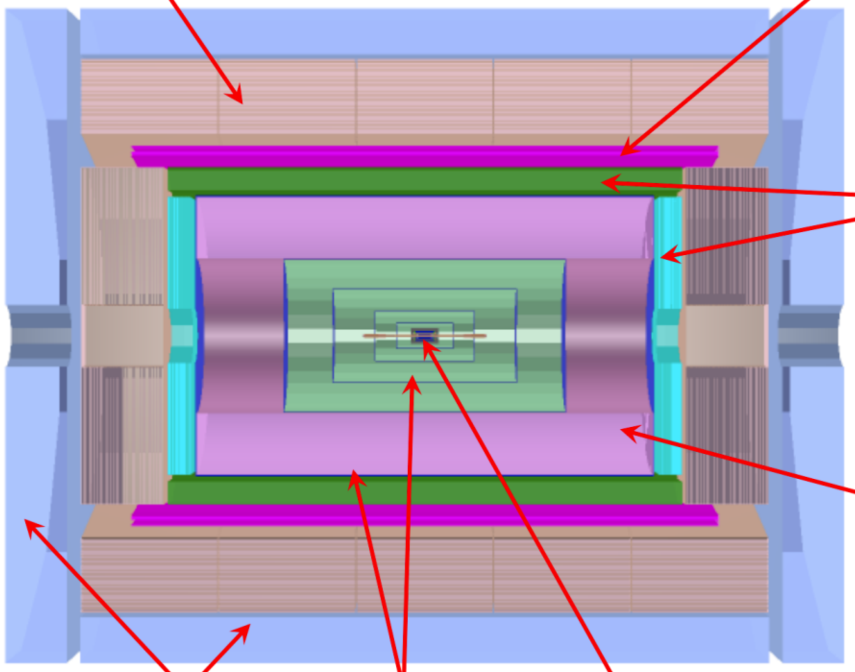
PID (DC+ToF)

Silicon Tracker

Crystal ECAL
(Transverse bar)



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

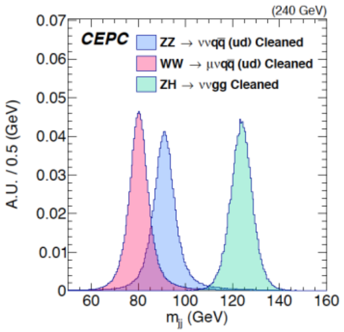
Advantage: better π^0/γ reconstruction.
Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

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

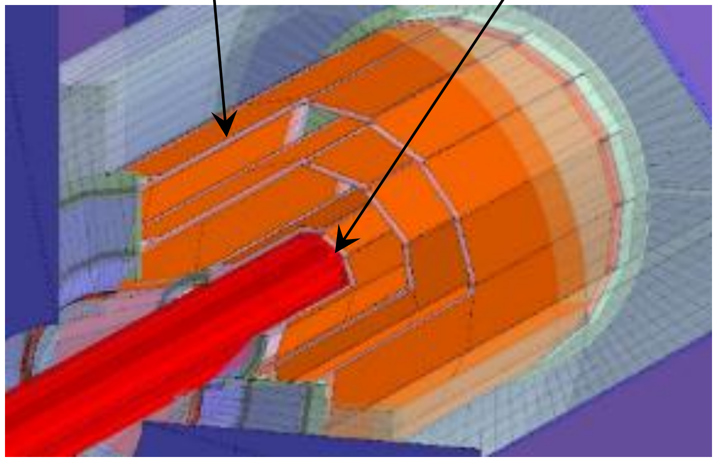


Novel detector design based on PFA calorimeter. Aim at improving BMR 4% → 3%

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)

R&Ds on Silicon Pixel Chips

2 layers / ladder R_{in}~16 mm



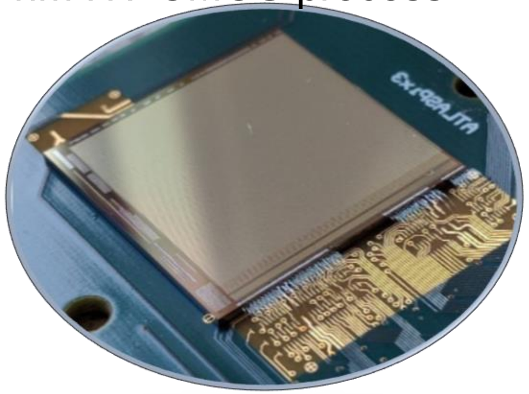
Goal: σ(IP) ~ 5 μm for high momentum track

CDR design specifications

- **Single point resolution ~ 3μm**
- **Low material (0.15% X_0 / layer)**
- **Low power (< 50 mW/cm^2)**
- **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

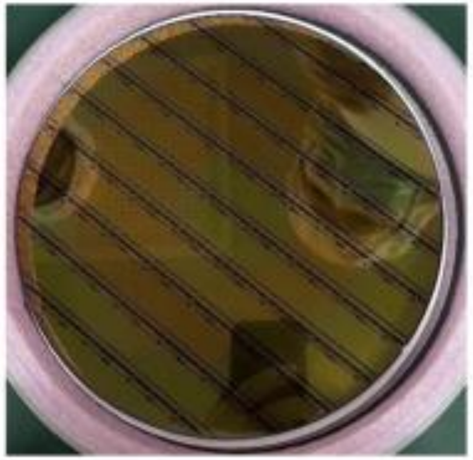


JadePix-3 Pixel size ~16×23 μm^2

Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm^2

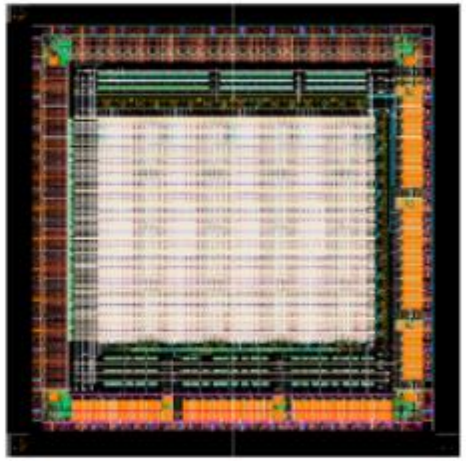
MOST 1

TaichuPix-3, FS 2.5x1.5 cm^2
25×25 μm^2 pixel size

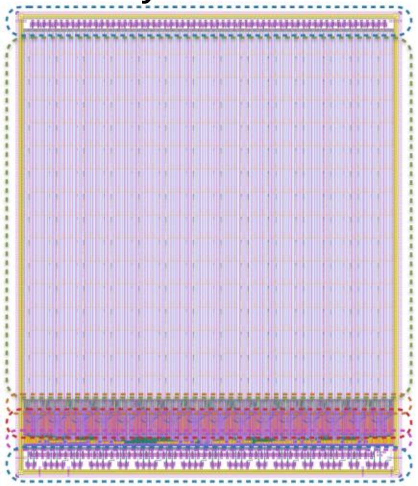


MOST 2

CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size

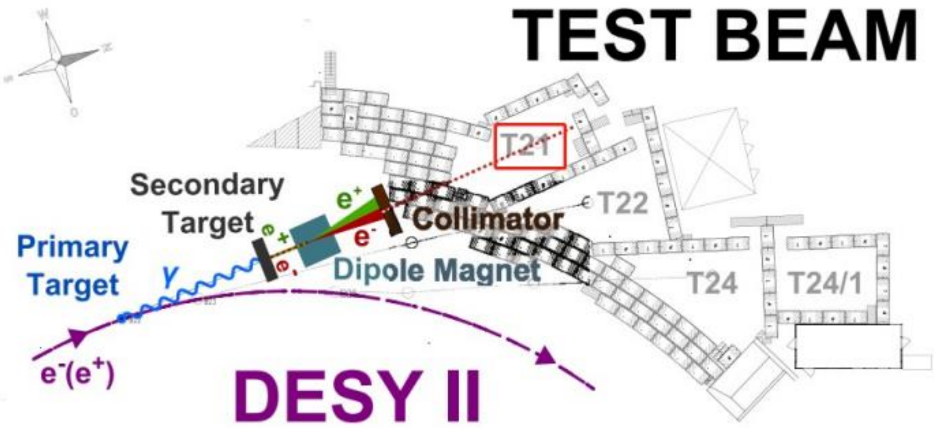


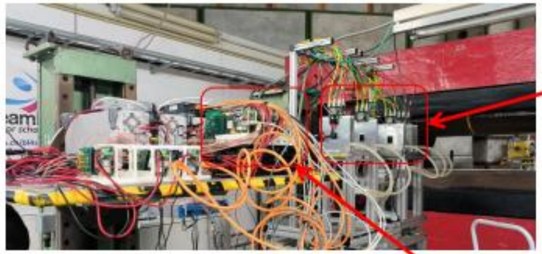
Arcadia by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS



R&Ds on Vertex Detector Prototype

Beam tests on the full vertex detector prototype (TaichuPix-3, JadePix-3) in DESY, Dec. 2022 and Apr. 2023:

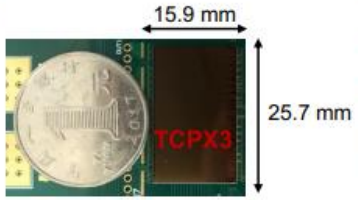


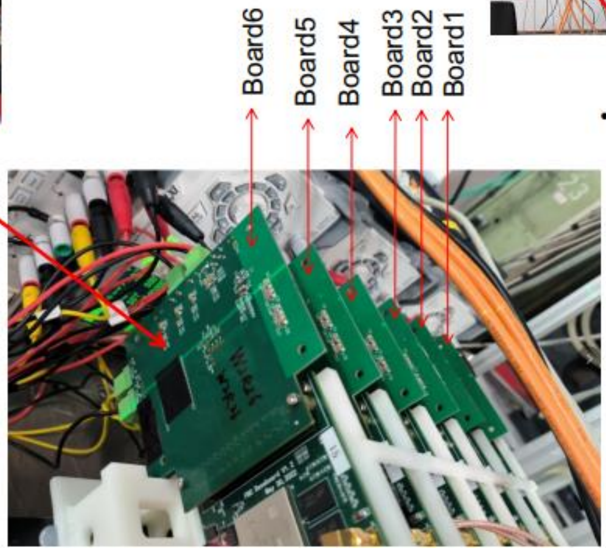


MIMOSA Telescope

- Jadepix telescope

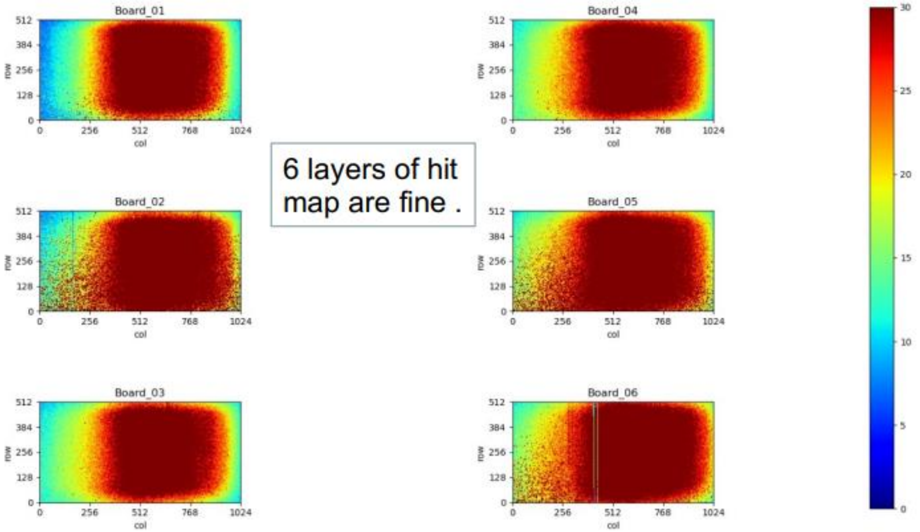
An open window in backside of PCB with a size of 12mm x 9mm





TaichuPix-3 Telescope (6 layers)

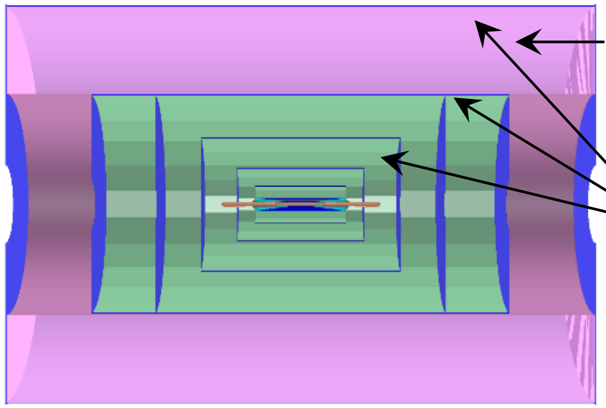
Hitmap of 4 GeV e^+/e^- beam

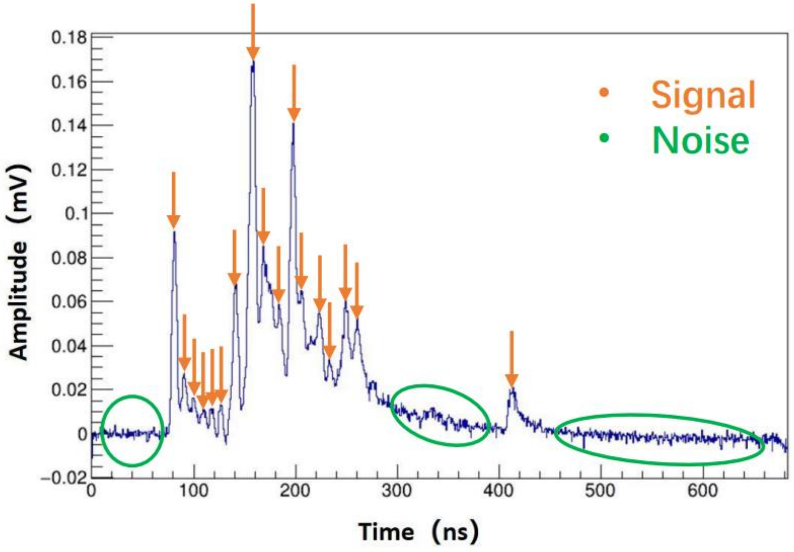


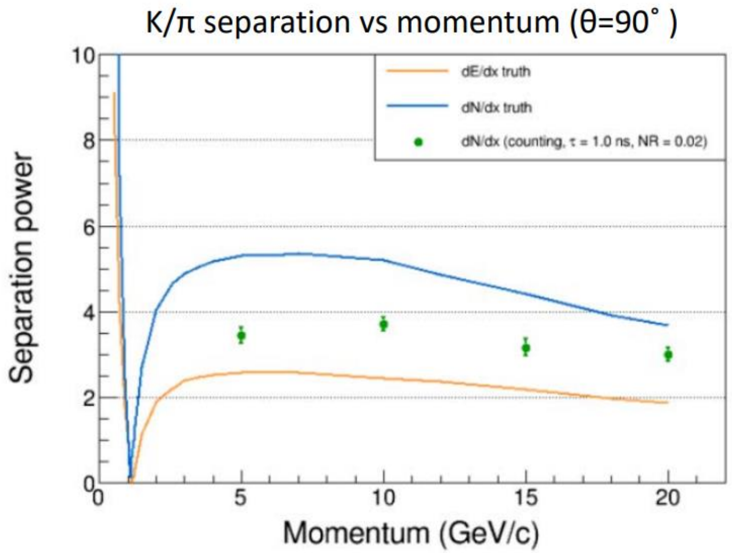
6 layers of hit map are fine .

R&Ds on 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.

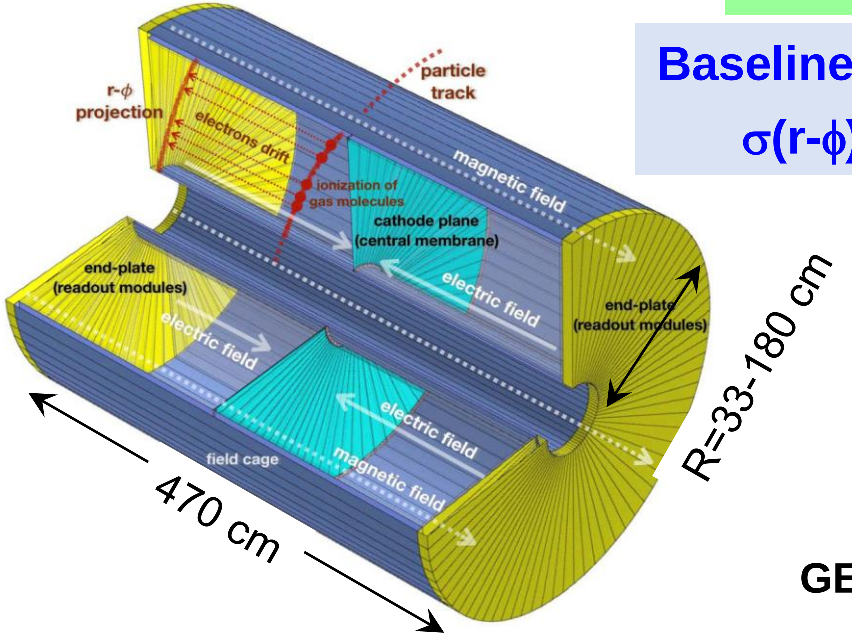






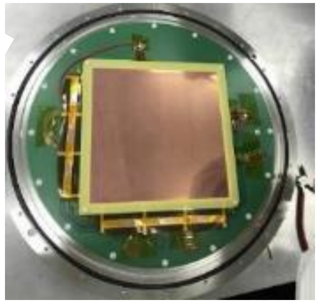
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the beam-tests led by the INFN group in 2021 and 2022

R&Ds on the Time Projection Chamber

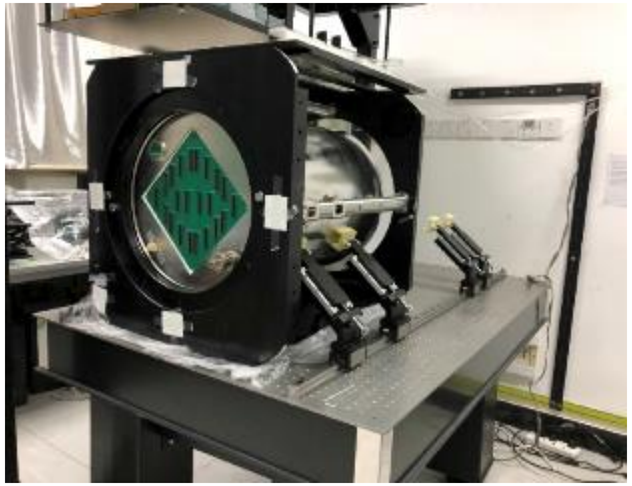


Baseline main tracker

$\sigma(r\text{-}\phi)$ ~100 μm



GEM-MM cathode

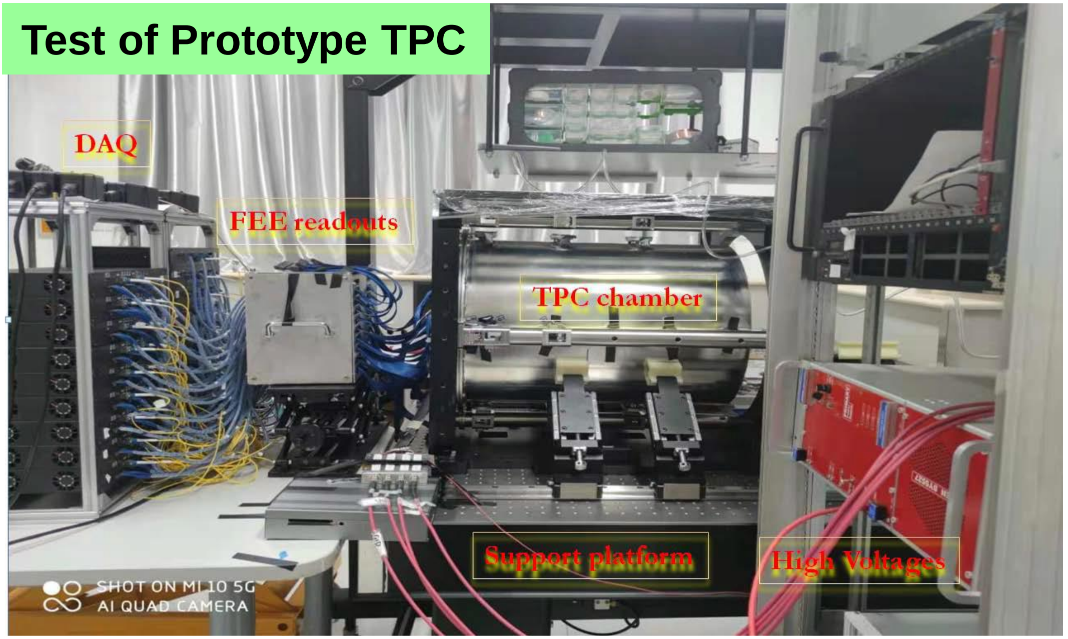


TPC Prototype + UV laser beams

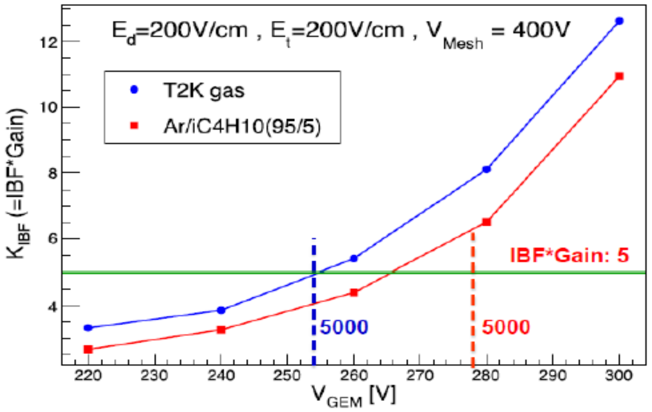
MOST 1 (IHEP+THU)

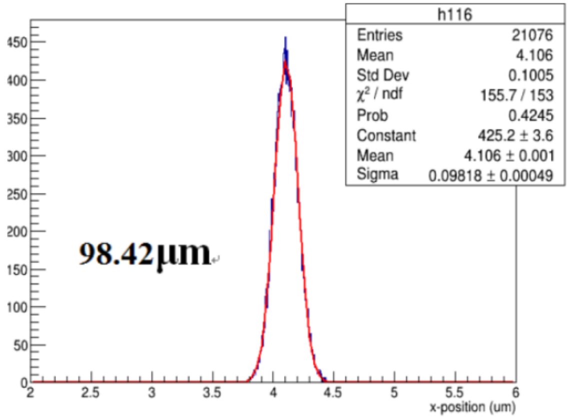
Low power FEE ASIC

Test of Prototype TPC



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





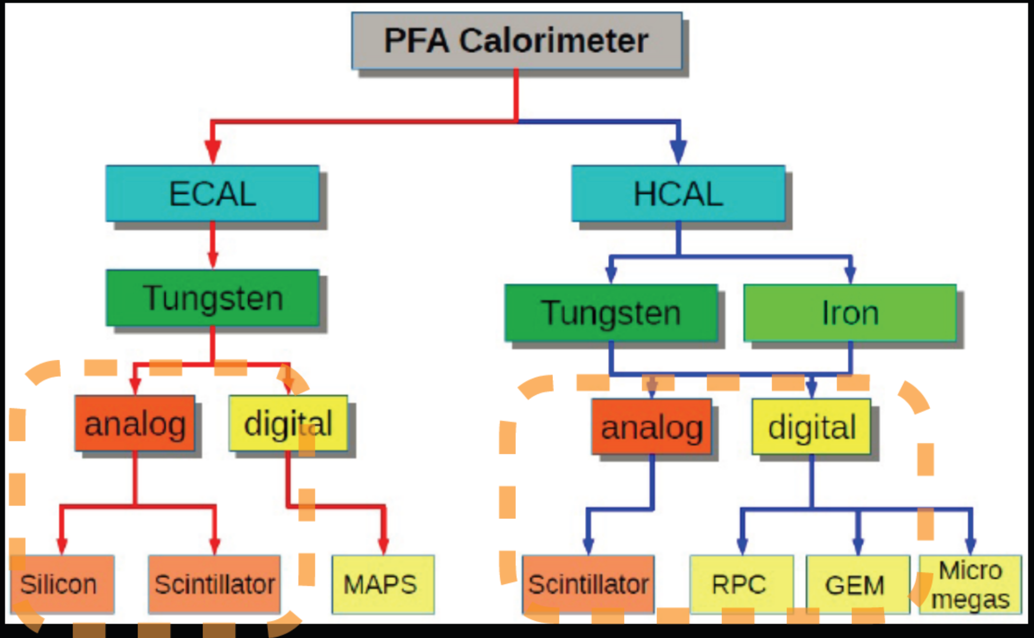
σ_x < 100 μm for drift length of 27cm

R&Ds on 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)

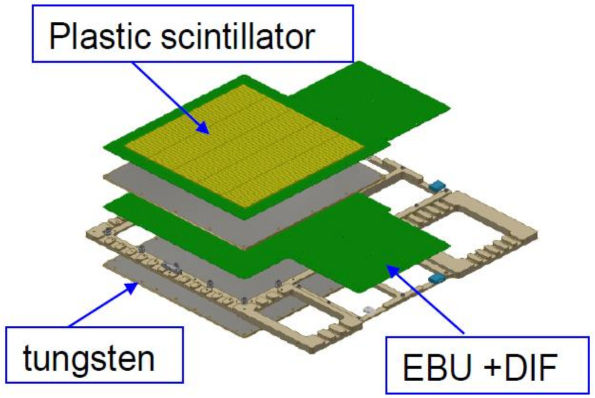
Newer Options

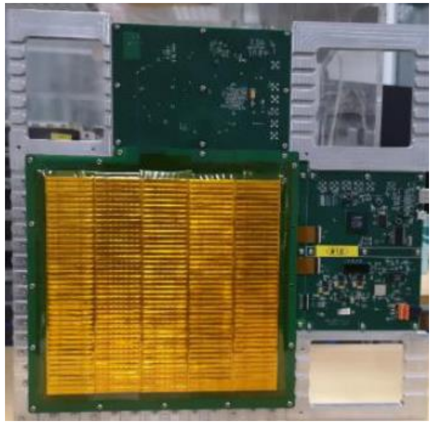
Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

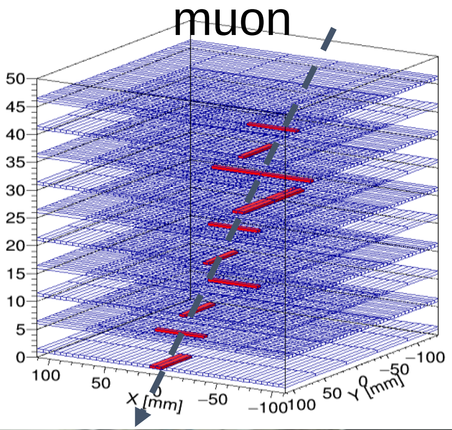
46

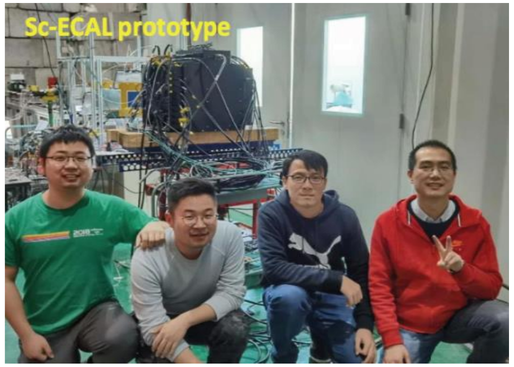
PFA Calorimeter Prototypes

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

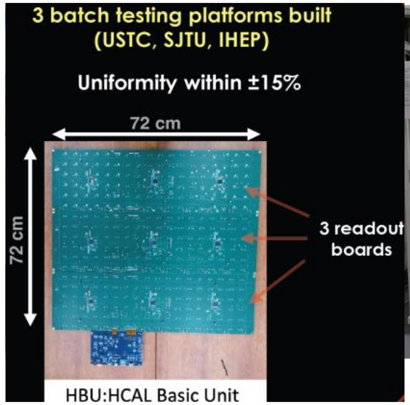


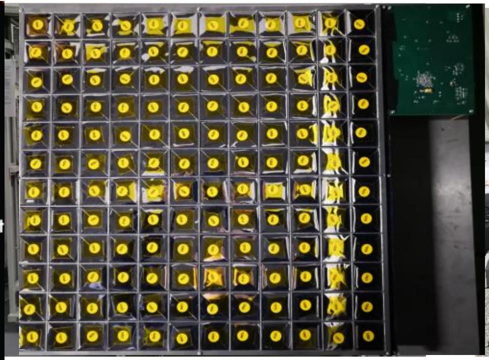






Sct + SiPM AHCAL Prototype (40-layer, 12960-ch)

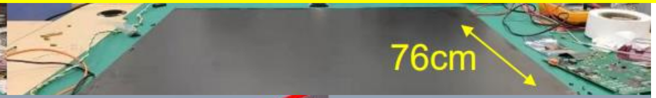


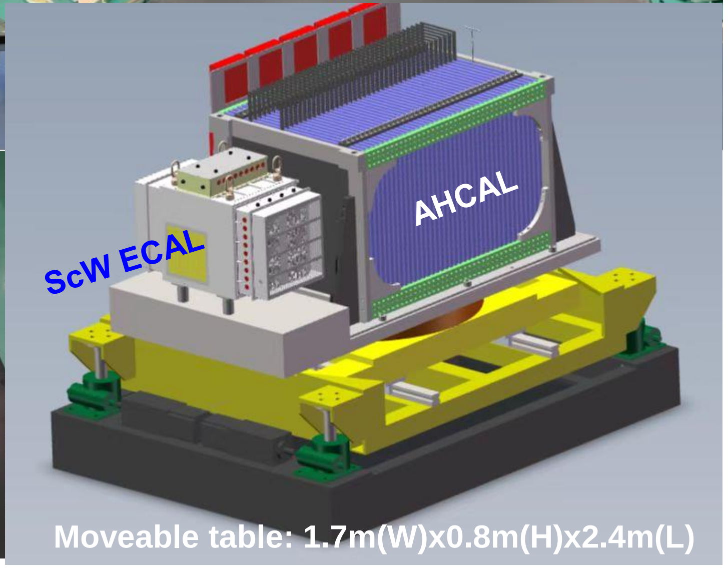


SJTU

IHEP

Combined: ScW-ECAL + AHCAL

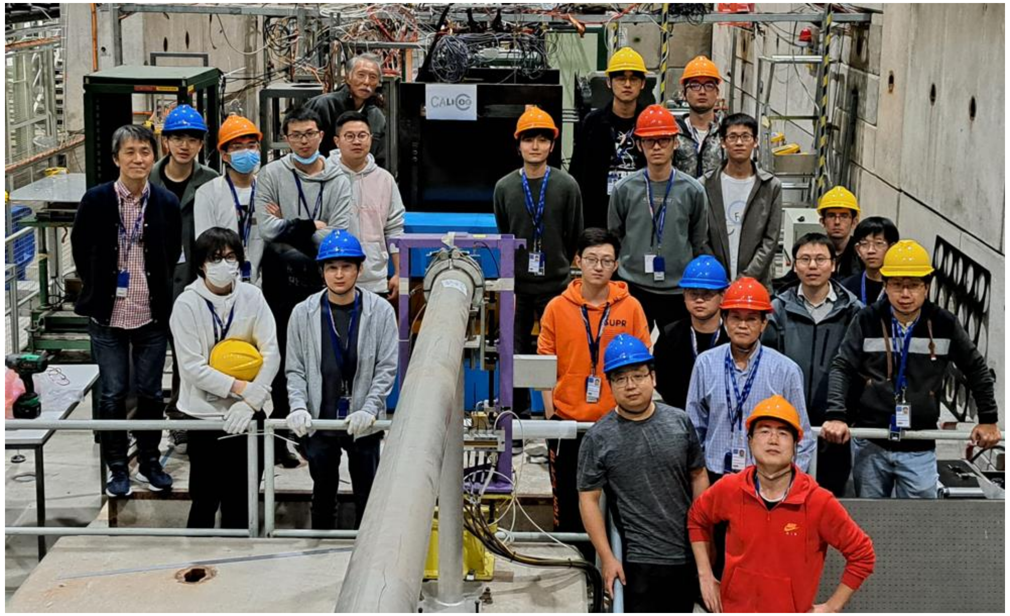


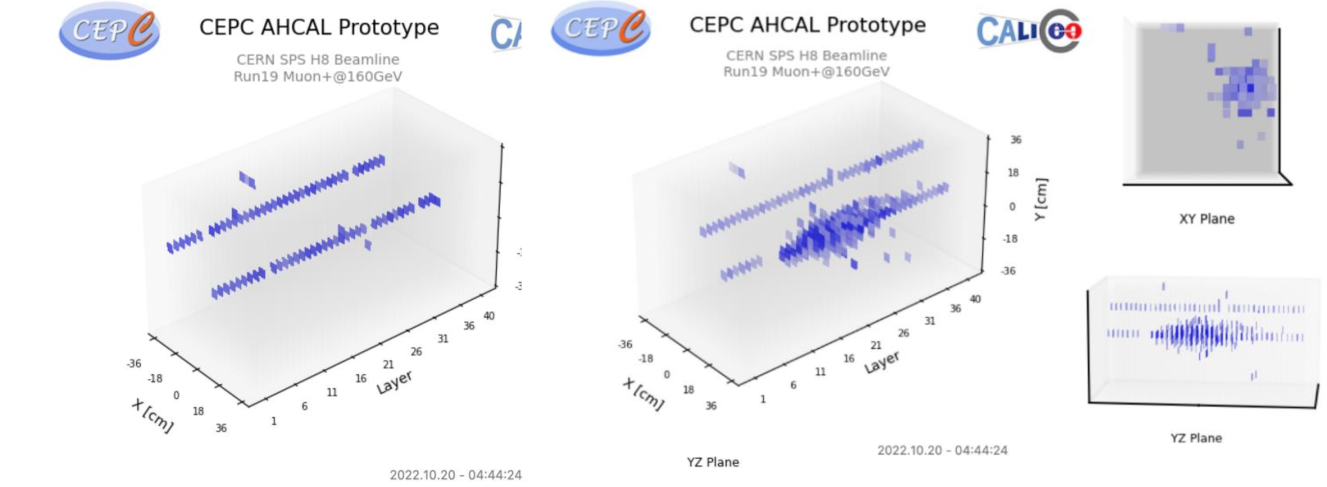


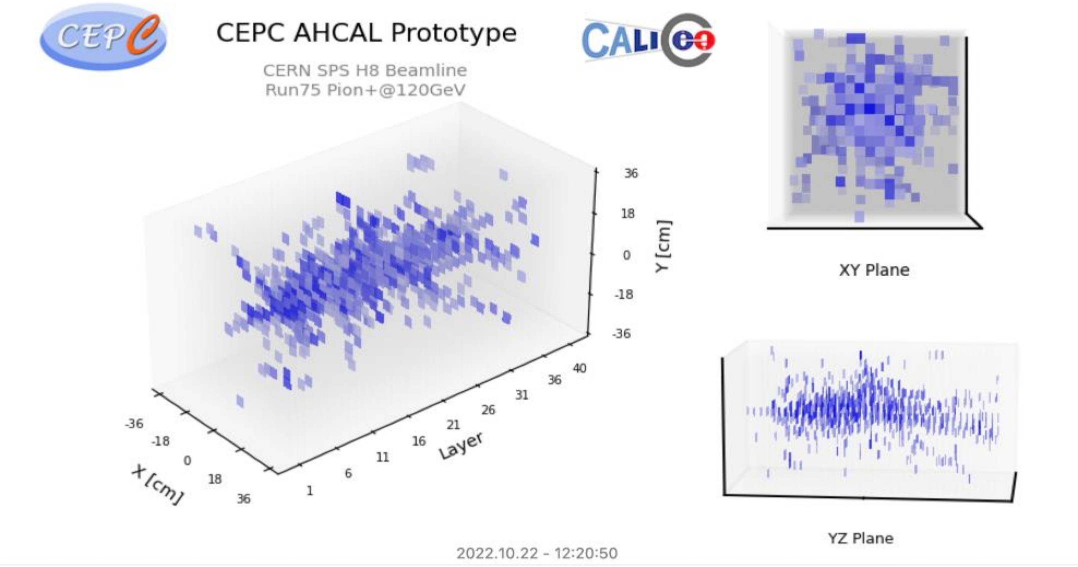
➔ Beam-test at CERN SPS for two prototypes in Oct. 2022

PFA Calorimeter Prototypes

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

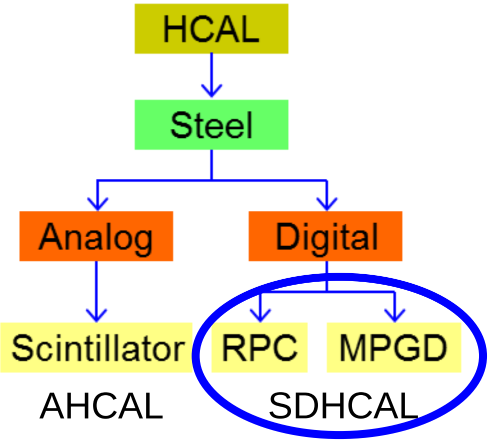


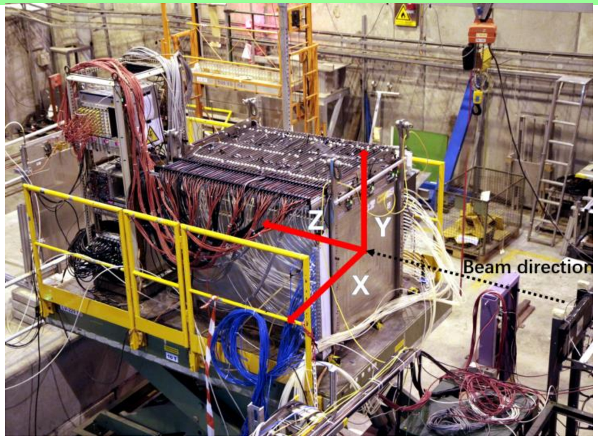




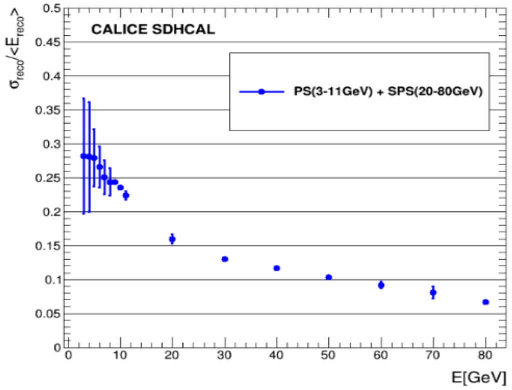
USTC, IHEP, SJTU, Japanese & Israel groups have close collaboration and regular meetings.
The next beam test is April – May (now) at CERN.

R&Ds on SDHCAL

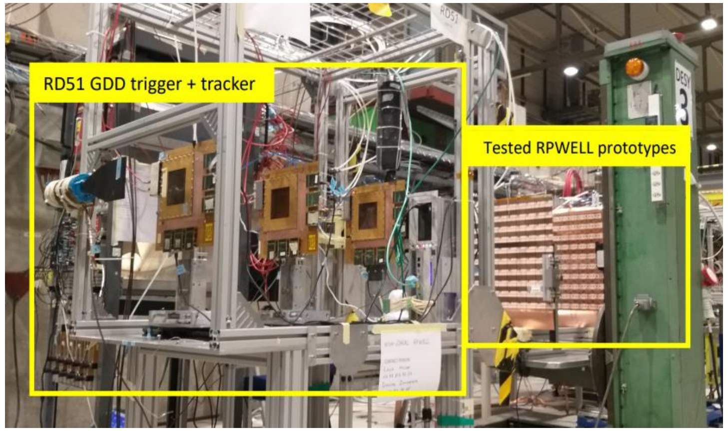




SDHCAL-GRPC (1.3 m^3, IPNL)



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



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

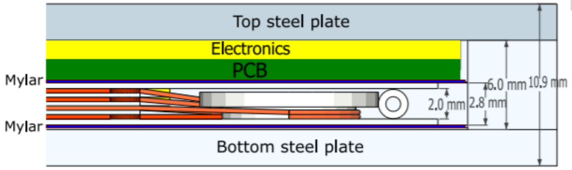
MOST 1: RPC and MPGD (RWELL) R&D， MIP Eff > 95%

GRPC 1m x 1m (SJTU)

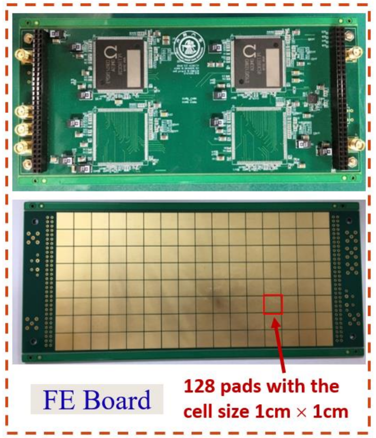
JINST 16, P12022 (2021)

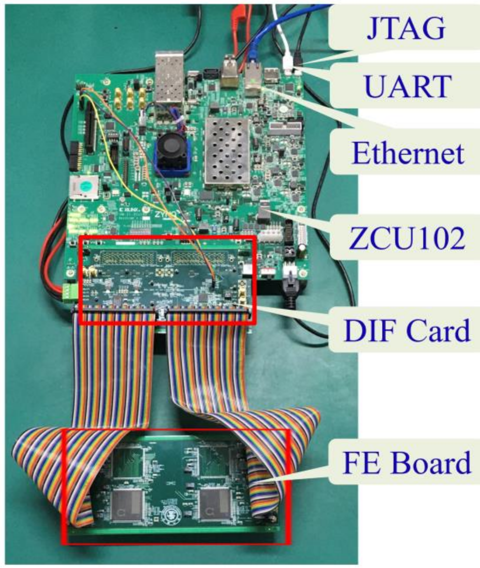
RWELL 0.5m x 1m (USTC+IHEP)

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

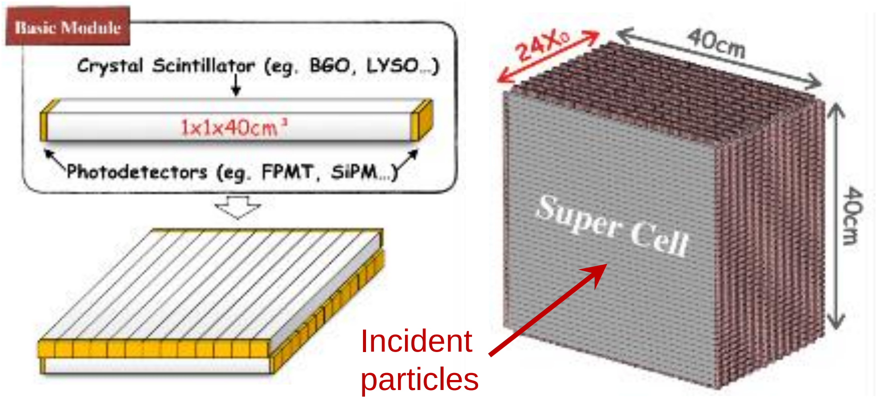


SJTU
IPNL
IJCLab
OMEGA
CIEMAT



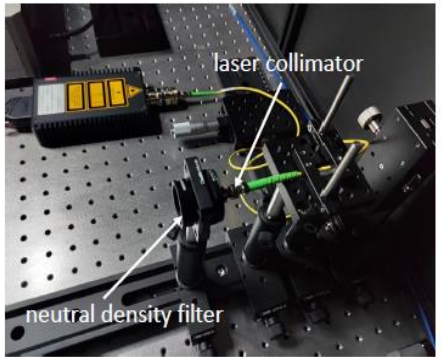


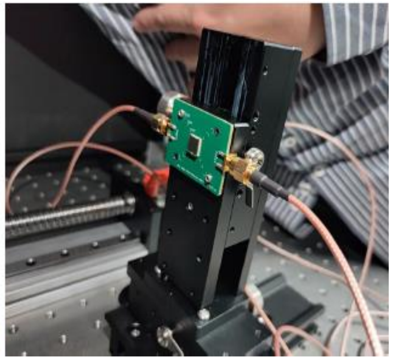
R&Ds on High Granularity Crystal ECAL



Goal

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





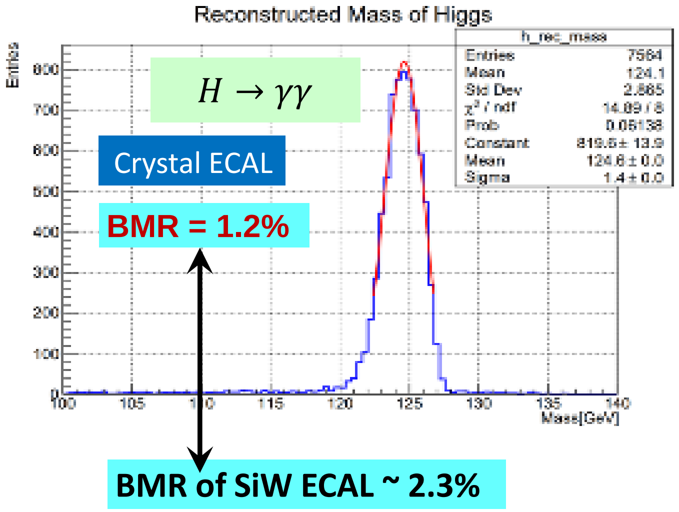
- Long bars: 1 x 40 cm, super-cell: 40x40 cm^2
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

Bench Test

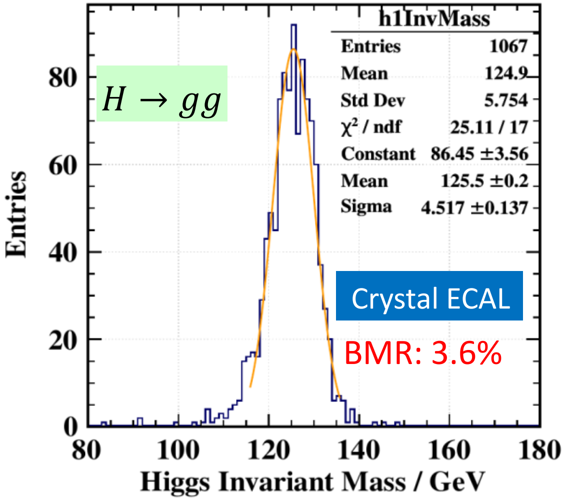
Full Simulation Studies

+ Optimizing PFA for crystals

Performance with photons

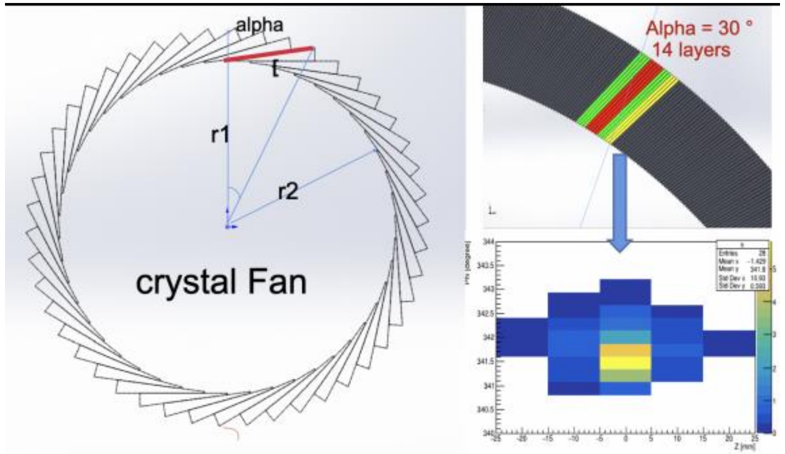


Performance with jets



Crystal Fan Design

Fine segmentation in Z, ϕ, r

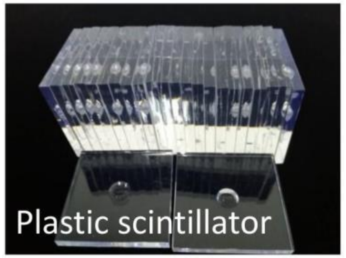


Dual readout crystal calorimeter also being considered by USA and Italian colleagues

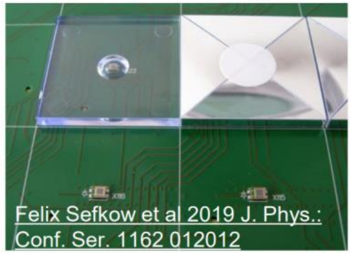
R&Ds on New HCAL with Scintillating Glass Tiles

Full simulation studies

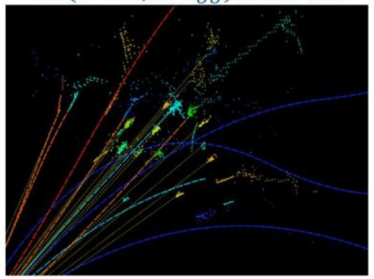
Tiles for AHCAL (30x30x3mm)

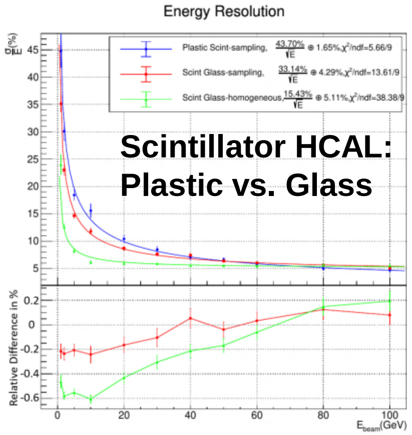


'SiPM-on-Tile" design for HCAL

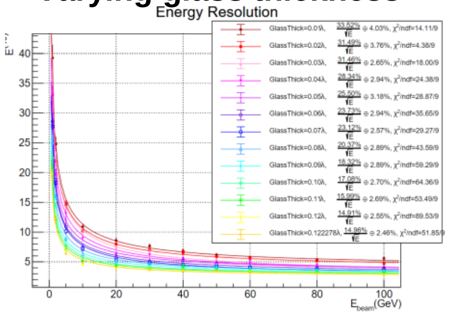


$ZH(Z \to \nu\nu, H \to gg)$ at 240 GeV

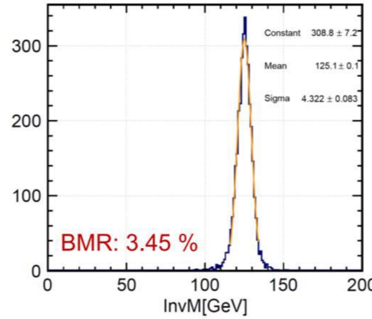




Varying glass thickness

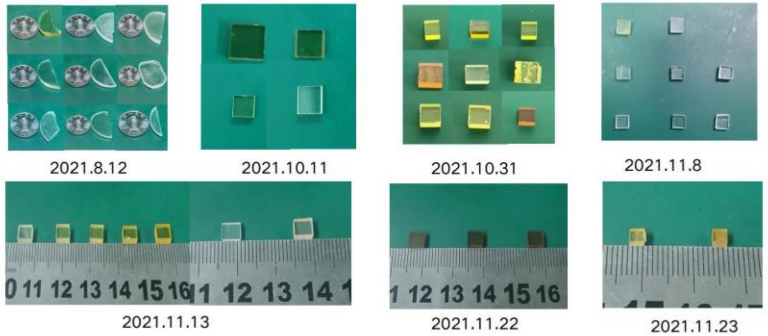


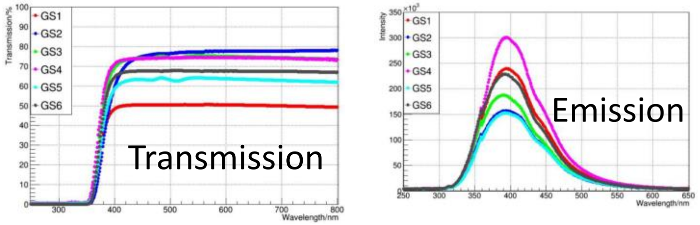
Performance study with jets

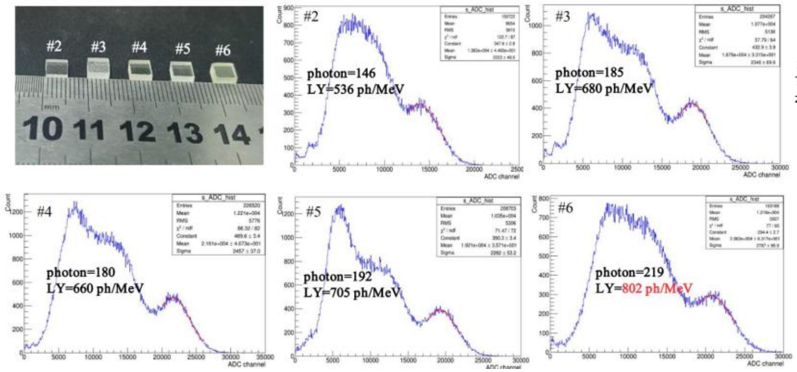


Goal

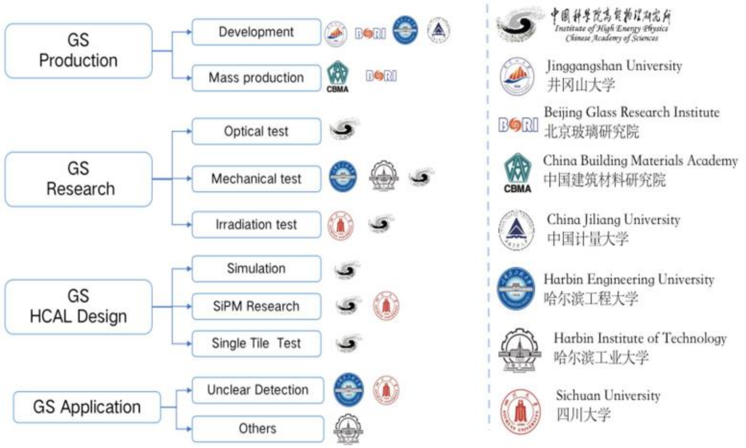
- Better hadronic energy resolution
- To further improve BMR



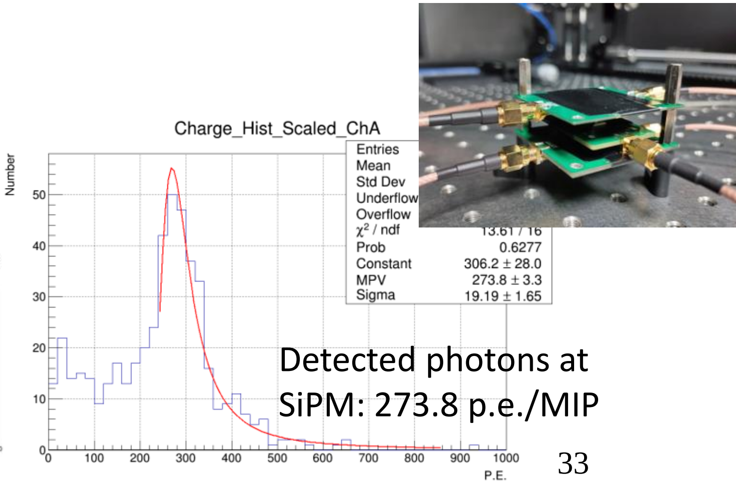




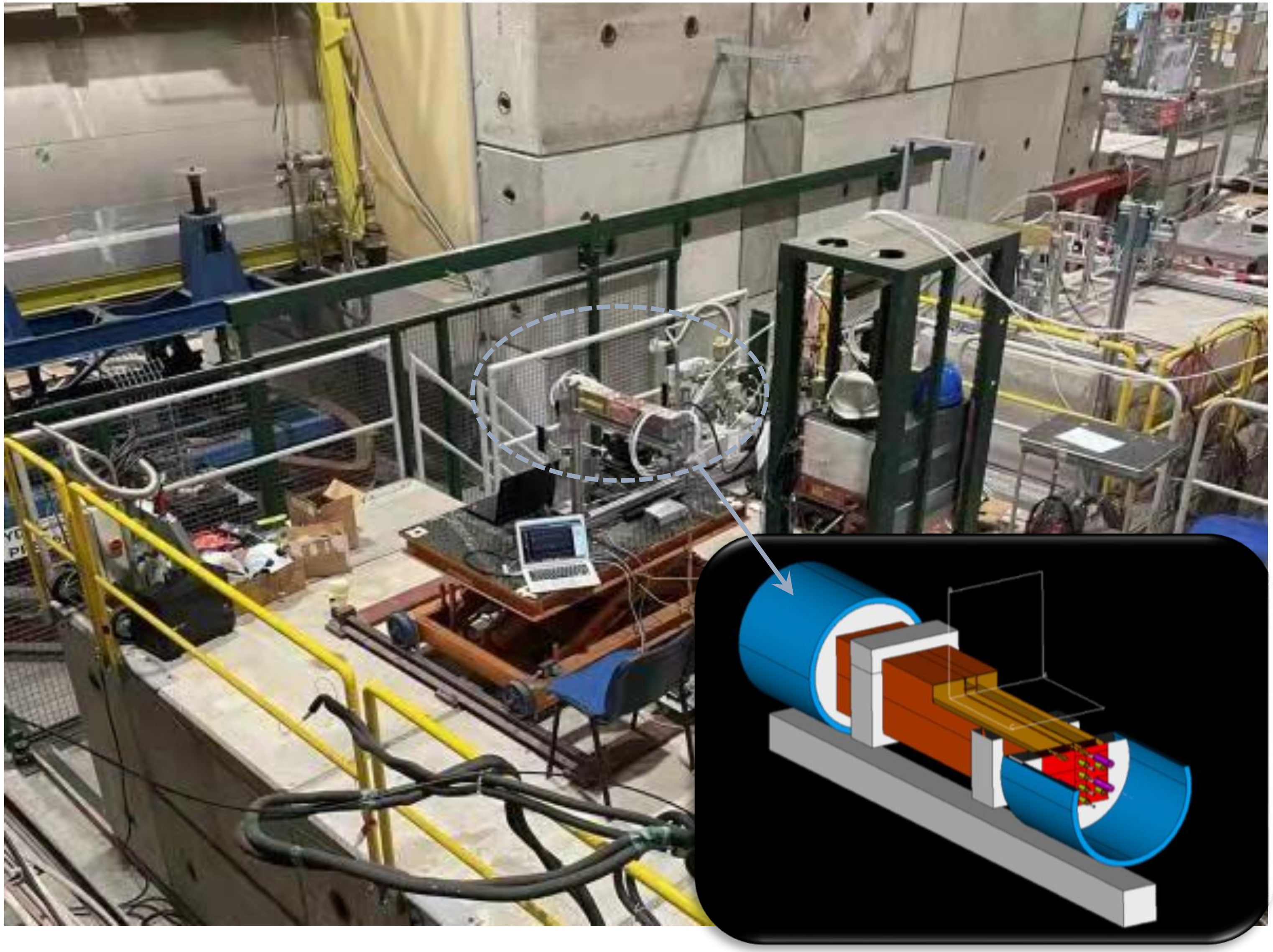
Scintillating Glass R&D

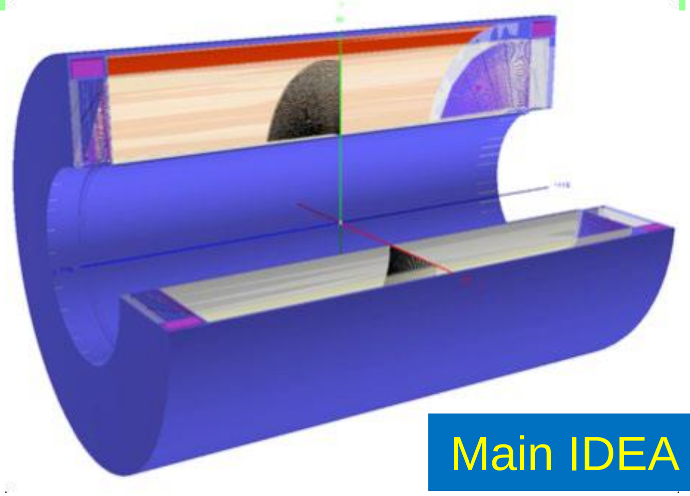


Testing Scintillating Glass Samples



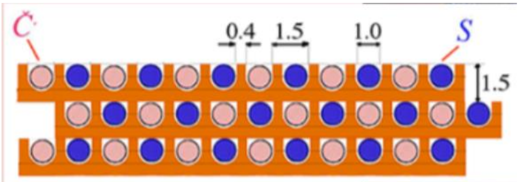
R&Ds on IDEA Tracker and Dual Readout Calorimeter

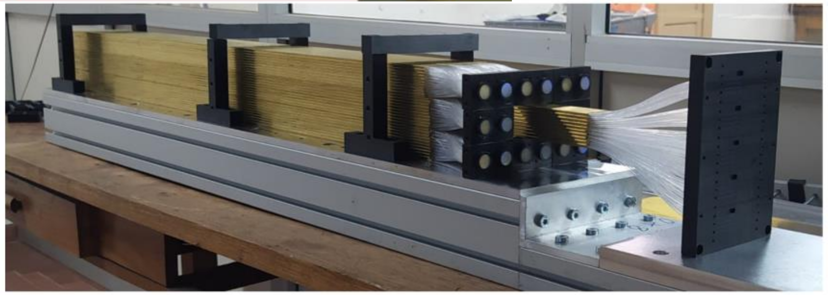




Main IDEA tracker

Dual Readout CAL



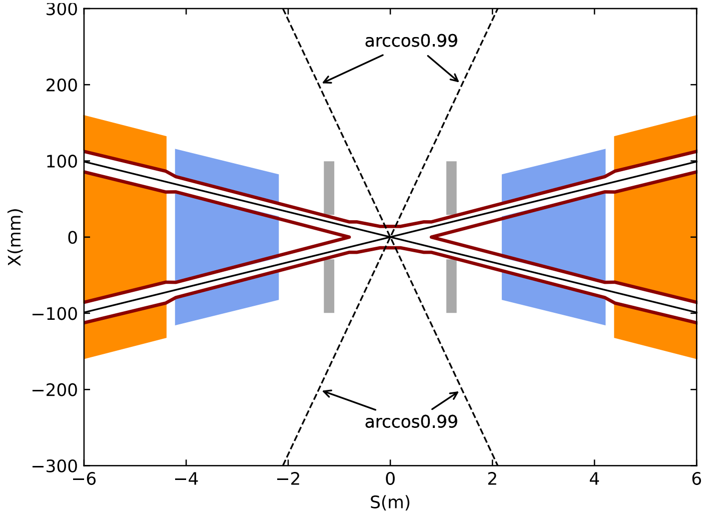


Italian groups and IHEP colleagues participated the beam test at CERN.

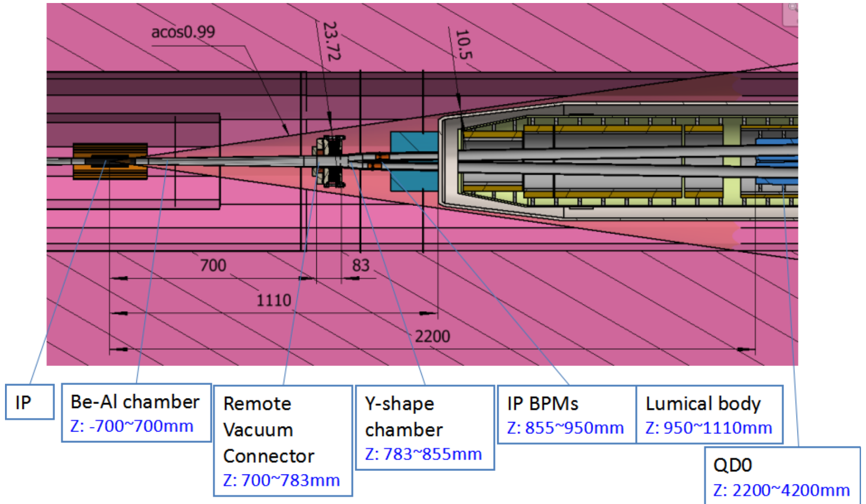
Machine Detector Interface (MDI)

Crossing angle: 33 mrad

Focal length: 2.2 m



Final focusing magnets (QD0, QF1) with Segmented Anti-Solenoidal Magnets



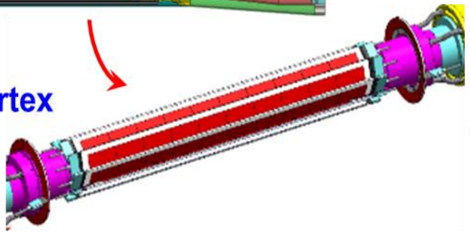
- All the devices are within the detective angle, acos0.99.

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

Beam Pipe

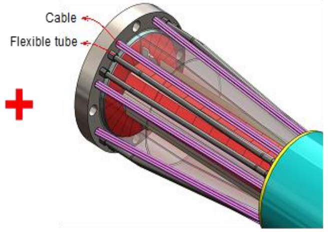
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

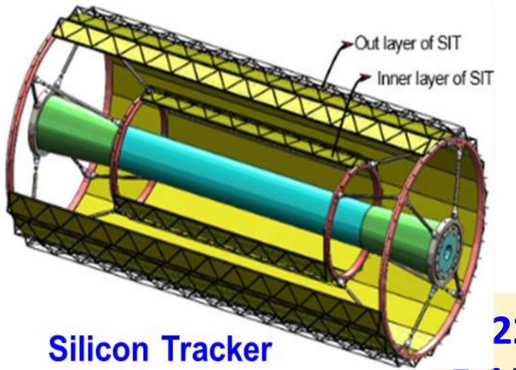
Vertex



+

LumiCal Tracker





Silicon Tracker

22 Workshop on CEPC Detector & MDI Mechanical Design, Mar.30 – Apr. 1, 2023:
https://indico.ihep.ac.cn/event/19071/

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

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

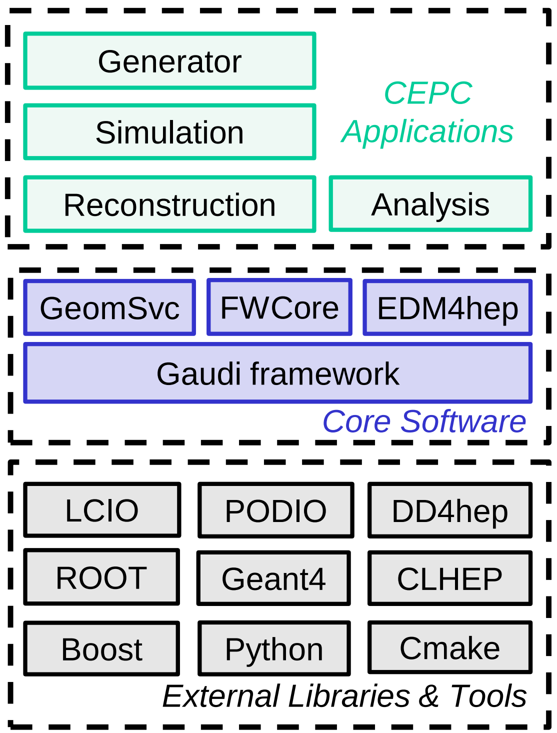
Architecture of CEPCSW

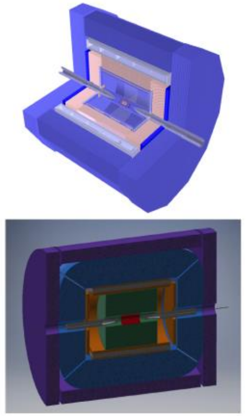
- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

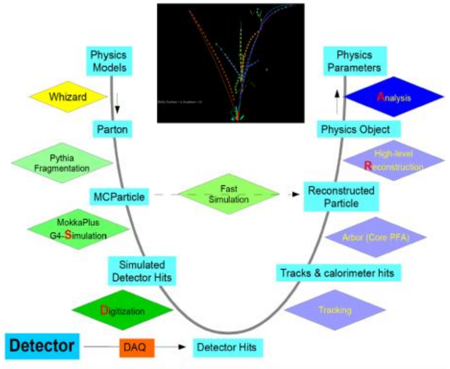
Core Software

- 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

CEPCSW Structure



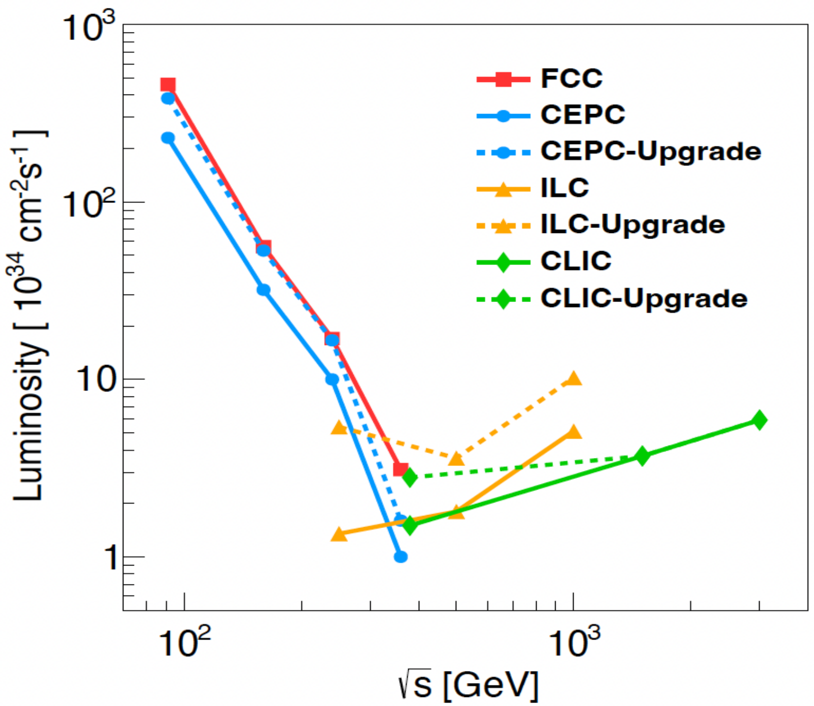




Full simulation reconstruction Chain functional, iterating/validation with hardware studies

Synergies with LC

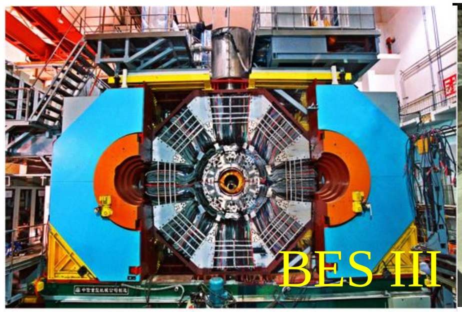
- Circular machine's high luminosities at relatively low energies complement the high energies of linear colliders.
- The R&Ds on 1.3 GHz SCRF cavity and the high efficiency Klystron will benefit the accelerator communities, including the LCs'.
- The studies of machine and detector interface will benefit circular and linear colliders.
- The CPEC detector came from ILC-ILD. Due to different working modes and accelerator energy ranges, a lot of R&Ds and optimizations have been carried out. With the 4th concept CEPC detector, progresses made in PIDs, PFA Calorimeters, the possible use of scintillating glass tiles, and the idea of a SC magnet between the ECAL and HCAL, all will contribute to detector technologies, on circular machines and on linear colliders alike.

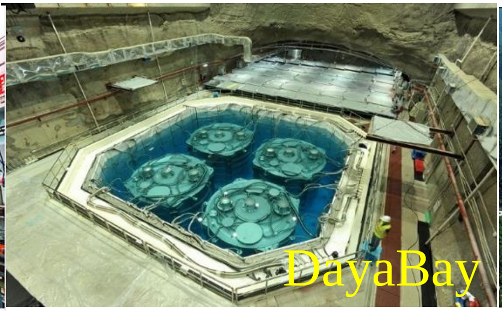


Other Aspects of CEPC

- Synergies in IHEP and industry engagement
- the CEPC team, committees, international efforts/contributions
- Project site candidates and timeline

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 has successful constructed many large scientific facilities**
  - **It has full coverage of all technical disciplines for accelerators and detectors, in particular for the design, construction and operation of the circular e+e- collider (BEPCII) and the detector (BESIII)**
  - **It has all necessary infrastructures for constructions of large facilities**
  - **It has successfully hosted international projects such as BESIII, Daya Bay, JUNO, LHAASO, etc.**
- **IHEP is committed in CEPC, its workplan is endorsed by CAS**

CEPC R&D and Tech Validation thrgh Running Prgms

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.

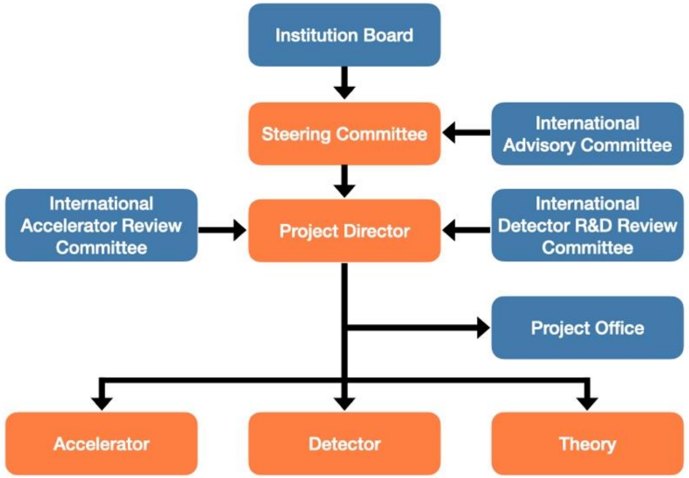
CCT SC Magnet

Klystron

SC Coil Winding

The CEPC Team so far

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

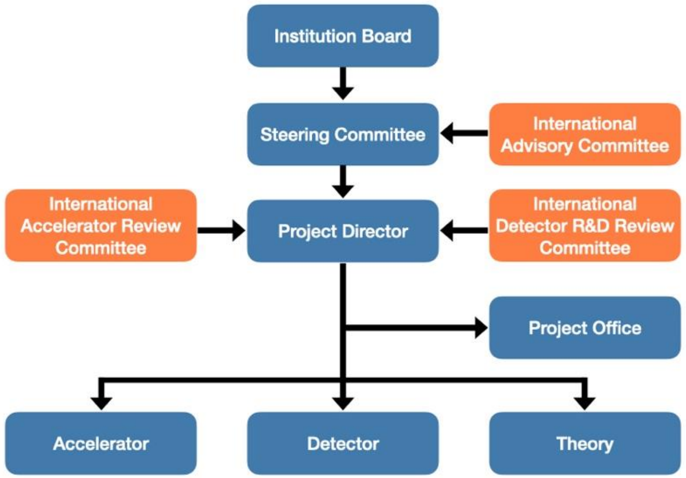
Table 7.4: Team of the CEPC detector system

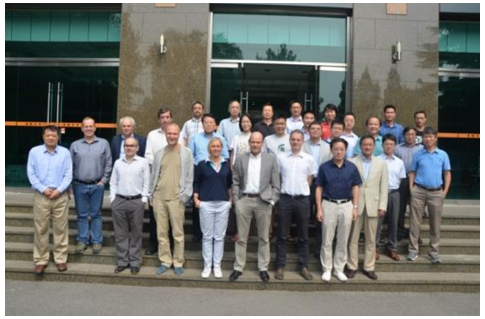
Number	Sub-system	Conveners	Institutions	Team (senior staff)
1	Pixel Vertex Detector	Zhijun Liang, Qun Ouyang, Xiangming Sun , Wei Wei	CCNU, IFAE, IHEP, NJU, NWPU, SDU, Strasbourg, ...	∼ 40
2	Silicon Tracker	Harald Fox, Meng Wang, Hongbo Zhu	IHEP, INFN, KIT, Lancaster, Oxford, Queen Mary, RAL, SDU, Tsinghua,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

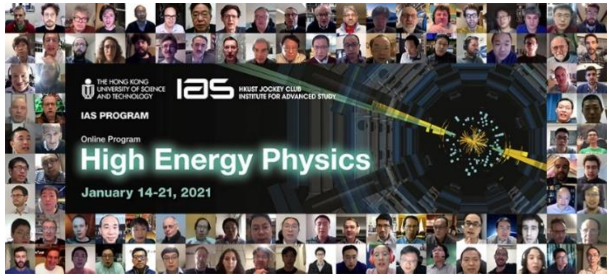
- **IAC**: global renowned scientists and top laboratory or project leaders who have ample experience in project management, planning, and execution of strategies, operating since 2015
- **IARC & IDRC**: leading experts of this field, provide guide to the project director

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 to 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)
- The recent CEPC Workshop: Oct. 24-28, 2022 (423 registrants, 285 talks, 38 posters)
- The next CEPC EU Workshop: 3 – 6 July 2023, the Univ. of Edingurgh.

https://events.ph.ed.ac.uk/cepceu2023



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… …oposed for the… …ncepts can full…

… 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.

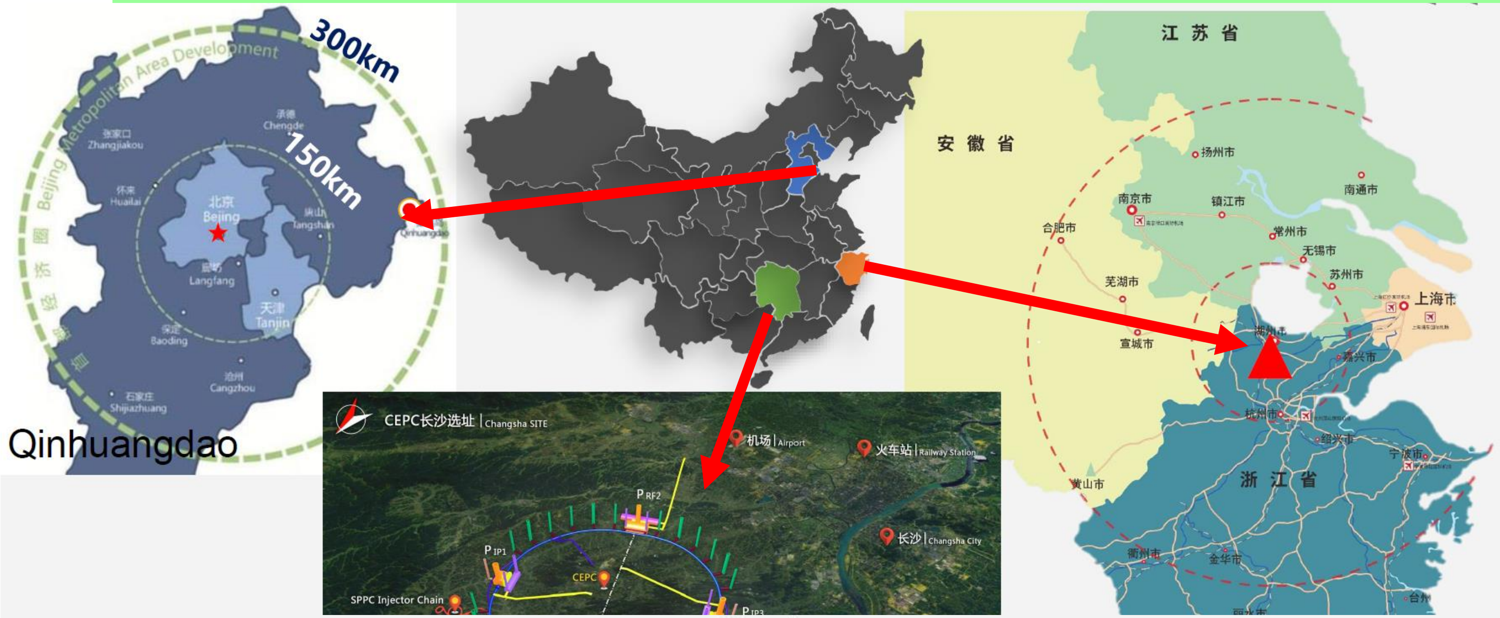
The CEPC is a large international scientific project initiated and to be hosted by China. It was presented for the first time to the international community at the ICFA Workshop "*Accelerators for a Higgs Factory: Linear vs. Circular*" (HF2012) in Novemb… …the White R… …the Yellow … …was made. Th… …[3] 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

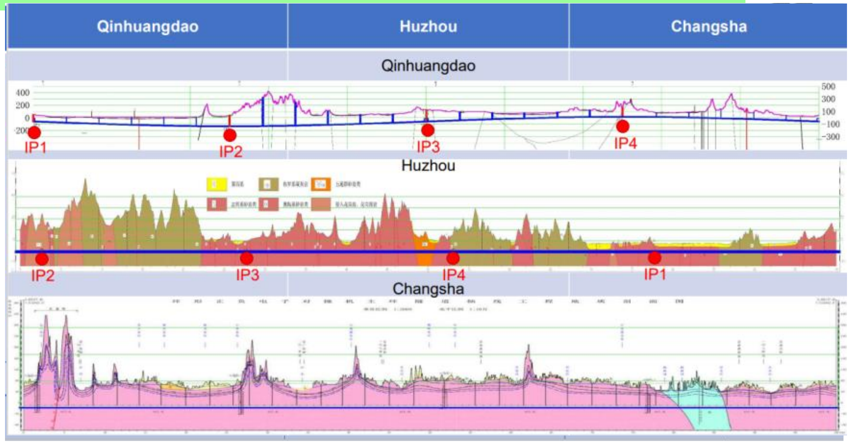
[1] Correspondance: J. Gao, Institute of High Energy Physics, CAS, China
Email: gaoj@ihep.ac.cn

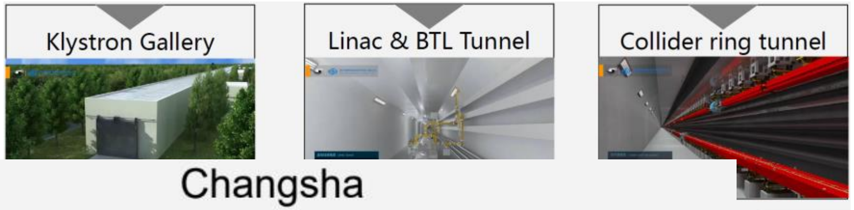
arXiv: 2203.09451
2205.08553

- **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.**

Candidate Sites and Science Cities





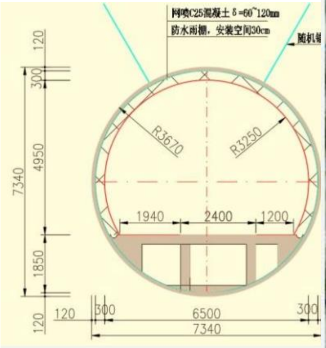


Huzhou

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



TBM tunnel
(D6.5m)

034

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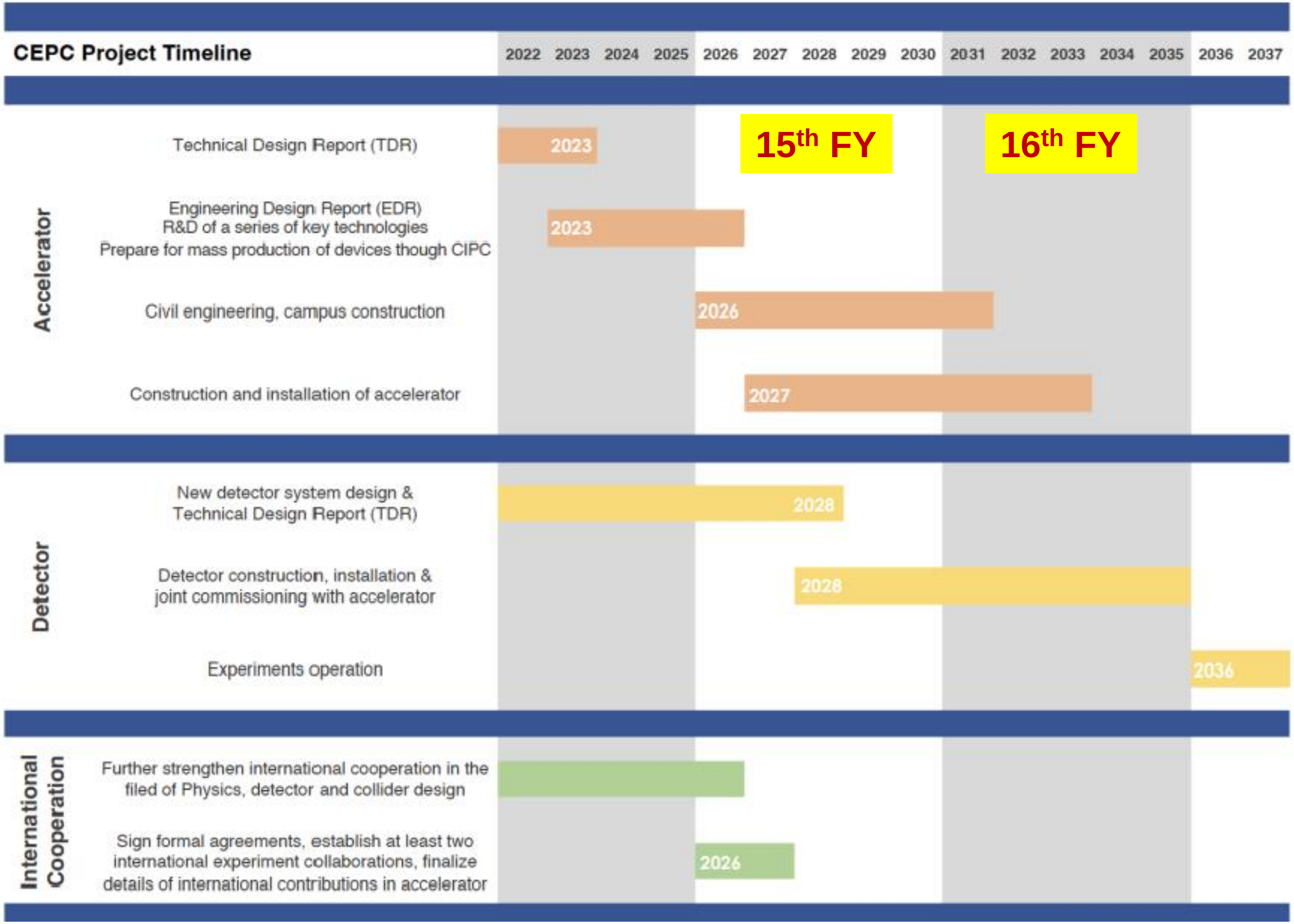
CEPC Project Timeline

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

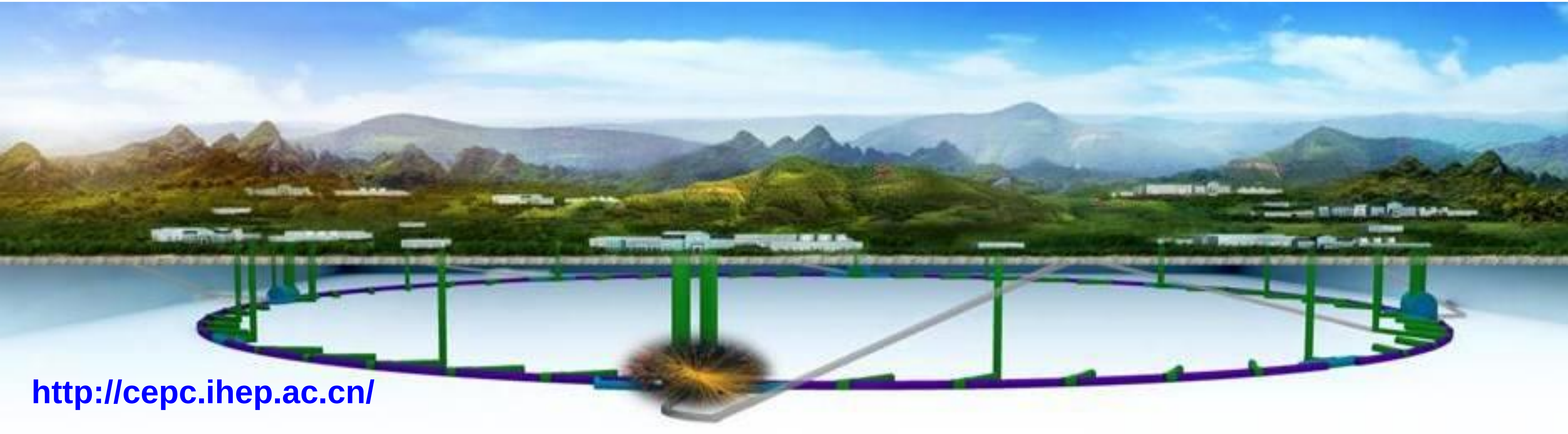


Summary and Prospects

- Since the CDR, lots of progresses have been made in physics program studies, accelerator and detector R&Ds. Contributions in the HEP international community (e.g. Snowmass21). Progresses and breakthroughs from the R&Ds may contribute to common technologies for other proposed Higgs factories.
- The Accelerator TDR is schedule to be in this year.
- The physics driven time-line is very aggressive. Lots of people (young and young at heart) are working hard towards the official start-line.
- Everyone in CEPC extends open arms to collaborations from the HEP community and beyond.

Acknowledgements

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



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Thank you !