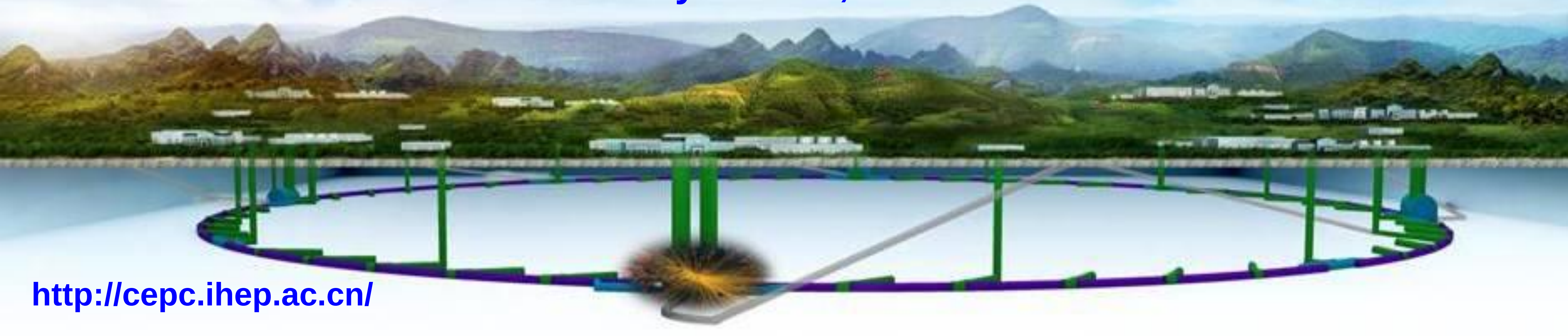
Overview of the CEPC Project

Haijun Yang (for the CEPC working group)

上海交通大學 SHANGHAI JIAO TONG UNIVERSITY | 李政道研究所 Tsung-Dao Lee Institute

Joint Workshop of the CEPC Physics, Software and New Detector Concept

May 23 – 25, 2022



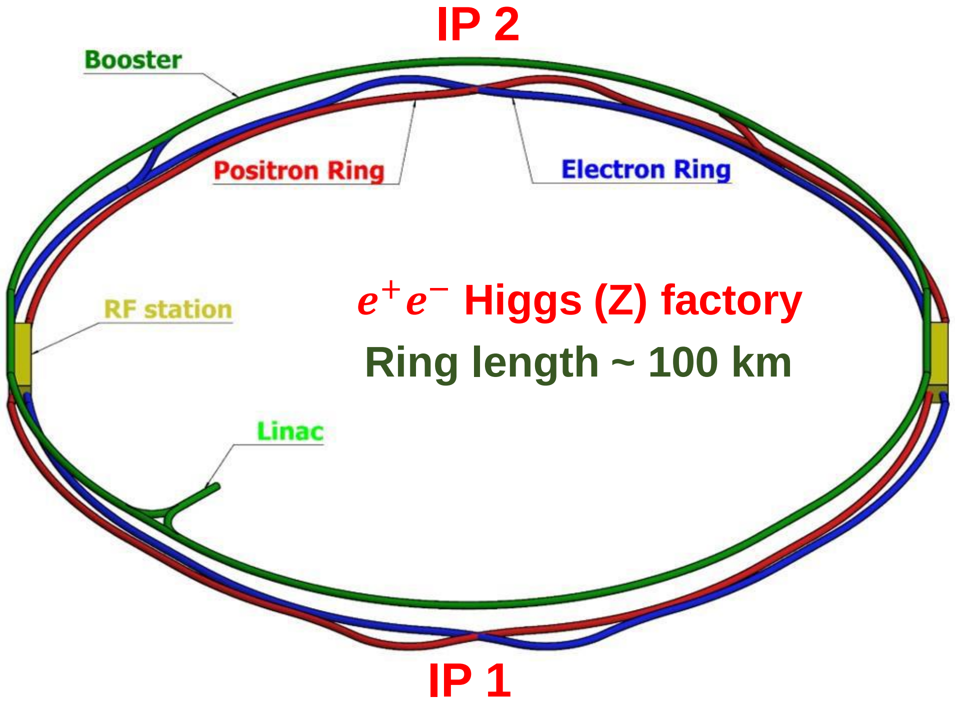
http://cepc.ihep.ac.cn/

Outline

- Introduction of the CEPC
  - Goals and Plan
  - Roadmap & Schedule
  - International Efforts
  - Collaboration with Industrial
- CEPC Project Development
  - Accelerator R&D
  - Physics Program
  - New Detector Concept and R&D
- Summary and Prospect

Circular Electron Positron Collider (CEPC)

- The CEPC aims to start operation in 2030's, as a Higgs (Z/W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ~1M Higgs; at the **Z** pole for ~Tera Z, at the **W^+W^-** pair, and possible $t\bar{t}$ pair production threshold.
- Higgs, EW, flavor physics & QCD, BSM physics (eg. dark matter, EW phase transition, SUSY, LLP, ….)
- Possible Super *pp* Collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the future.

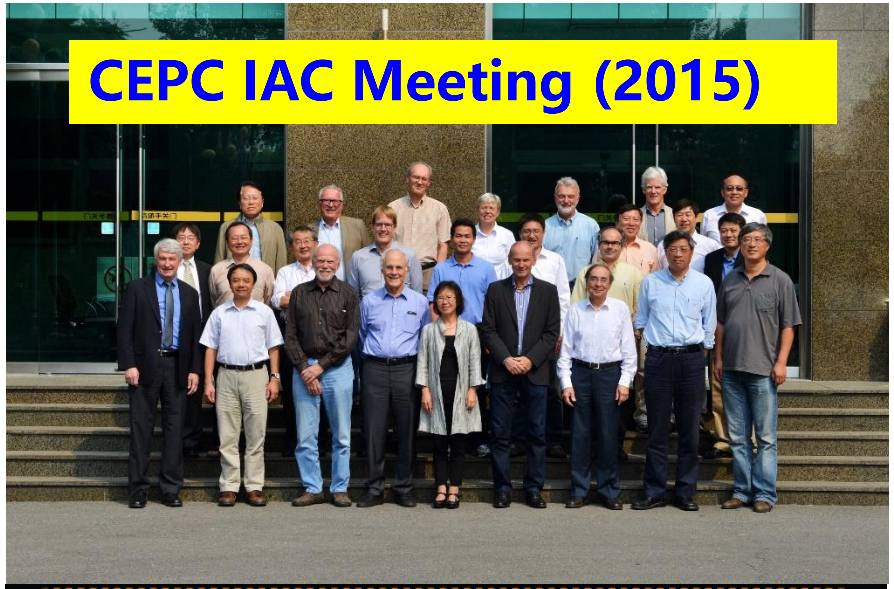


http://cepc.ihep.ac.cn/

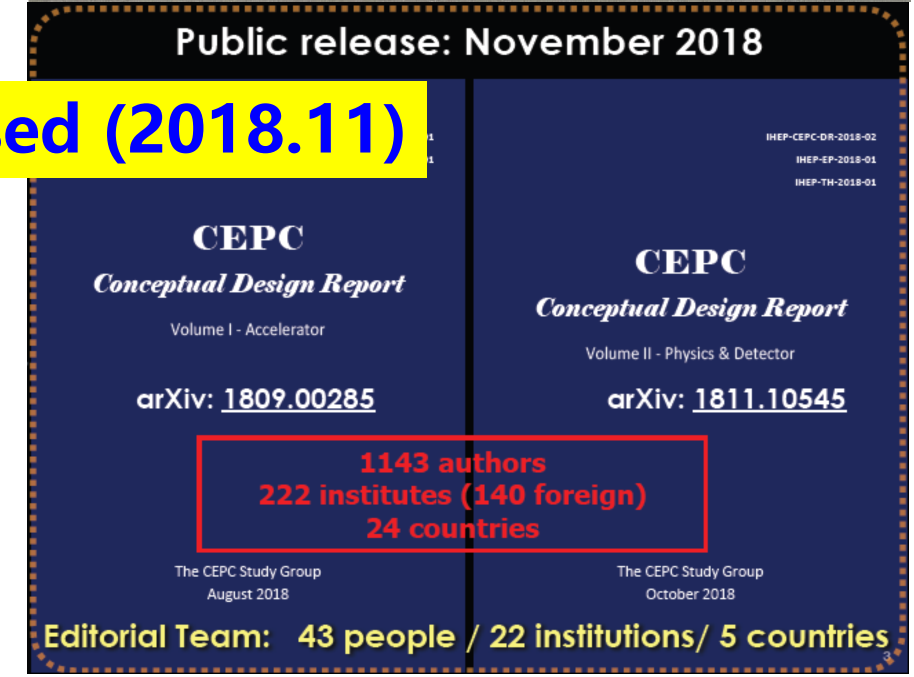
CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

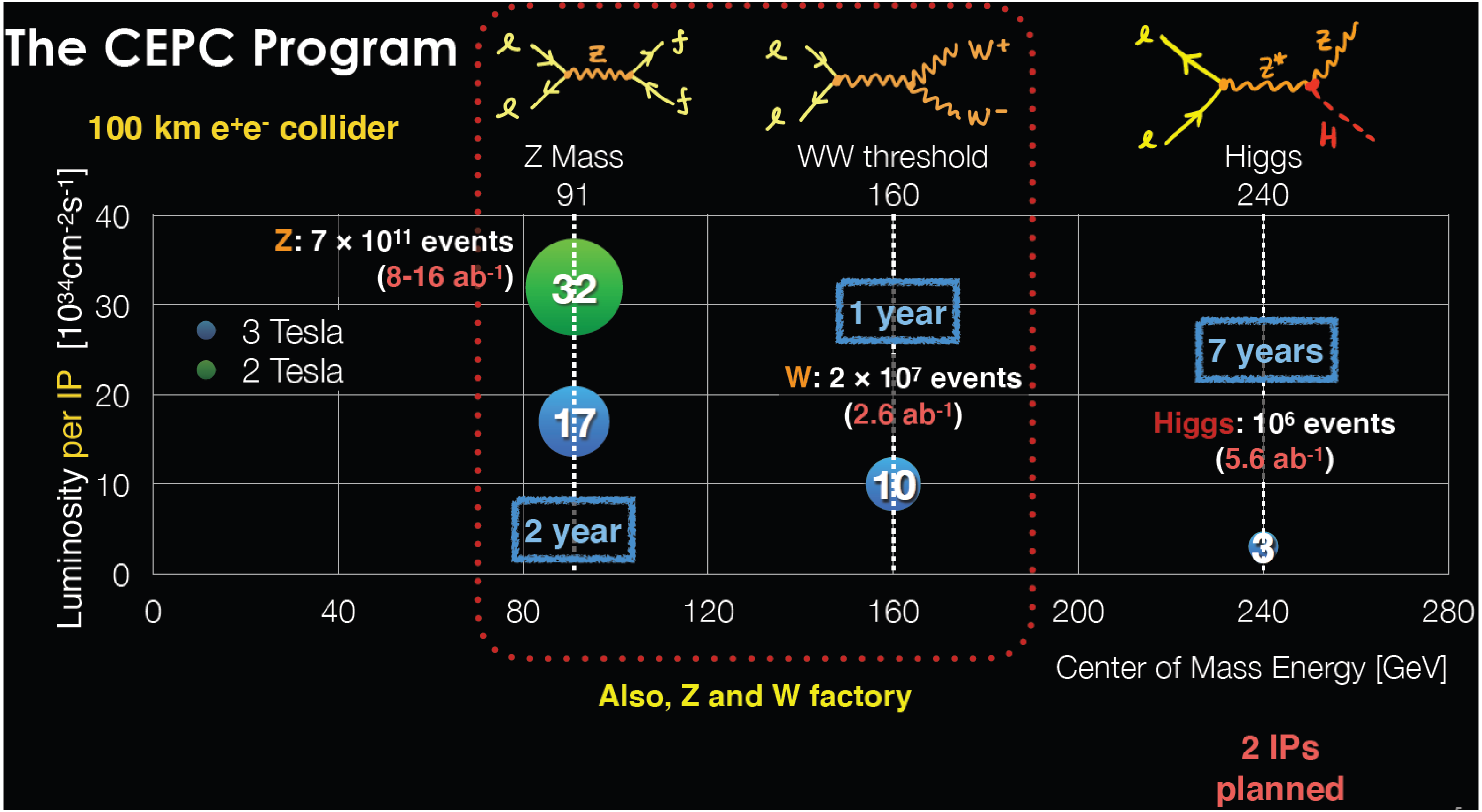
CEPC IAC Meeting (2015)



CEPC CDR Released (2018.11)



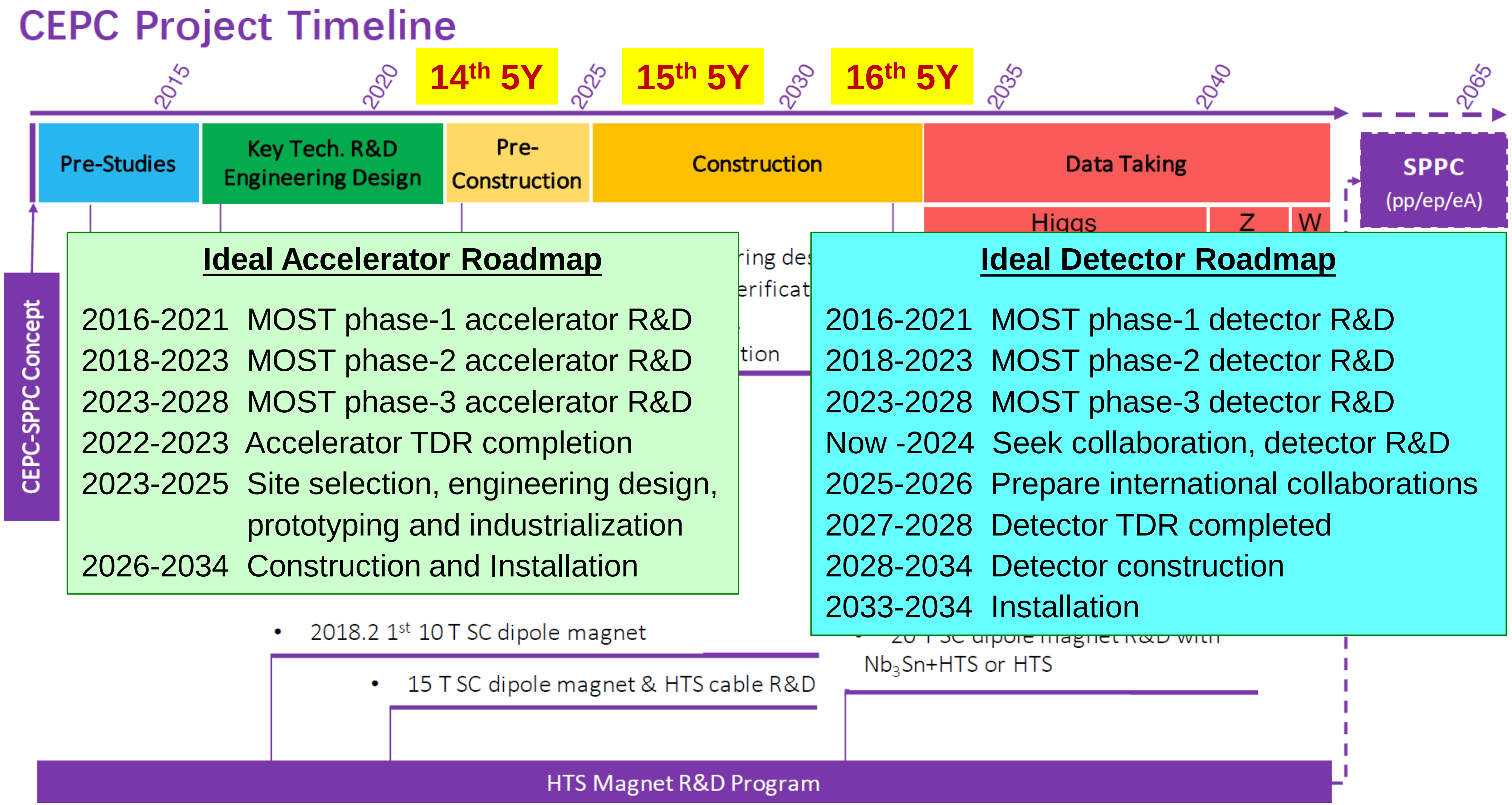
CEPC Physics Program (CDR @ 2018)



The CEPC accelerator design improvement will enable larger collected samples

CEPC Roadmap and Schedule (ideal)

- **2013-2025： Key technology R&D， from CDR to TDR, Site selection, Intl. Collab. etc.**
- **Ideal case: Approval in the 15th Five-Year Plan, and start construction (~8 years)**



Ideal Accelerator Roadmap

2016-2021 MOST phase-1 accelerator R&D
2018-2023 MOST phase-2 accelerator R&D
2023-2028 MOST phase-3 accelerator R&D
2022-2023 Accelerator TDR completion
2023-2025 Site selection, engineering design, prototyping and industrialization
2026-2034 Construction and Installation

Ideal Detector Roadmap

2016-2021 MOST phase-1 detector R&D
2018-2023 MOST phase-2 detector R&D
2023-2028 MOST phase-3 detector R&D
Now -2024 Seek collaboration, detector R&D
2025-2026 Prepare international collaborations
2027-2028 Detector TDR completed
2028-2034 Detector construction
2033-2034 Installation

CEPC Financial Model

Funding Sources	Financial Model #1 （RMB）	Financial Model #2 (RMB)
Central Government	30B	6-10B
Local Government	Land, Infrastructure	25-18B Land, Infrastructure
International Partners	1-5B	1-5B
Companies & Donations	0-3B	0-3B
Total Budget	36B	36B

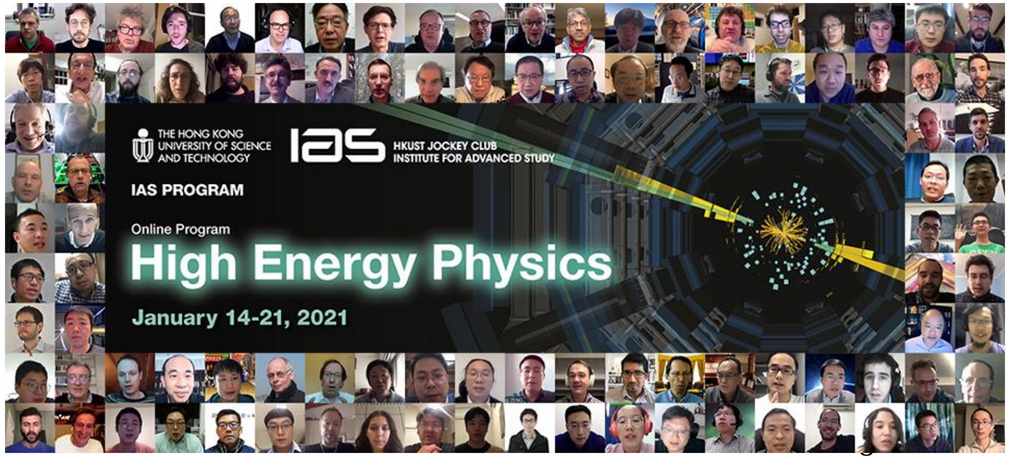
In Oct., 2021: Institute of Science and Technology Strategic Consulting, CAS is carrying out an independent assessment of Social Cost Benefit Analysis for the CEPC project, the report will be available in August, 2022.

International Efforts

- **The 7th annual IAC meeting was held on Nov 1-5, 2021.**
- **International Accelerator Review Committee (IARC),** and **International Detector R&D Review Committee (IDRDRC)** started operating in 2019.
- Currently the CEPC study group consists of ~1/3 international members. **By year 2025-26, two international experiment collaborations should be formed.**
- International collaborating R&D through different channels, including CALICE, LCTPC, RD*, …
- The R&D research are supported by **MOST, NSFC, CAS, institutes, local government**, …

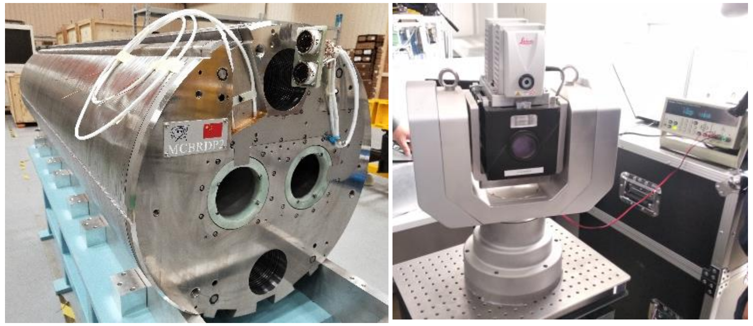
International workshops (with emphasis on CEPC):

- **In China:** Beijing (2017-2019), Shanghai (2020.10),
  Nanjing (2021.11 online, 2022.10)
  Annual HKUST-IAS HEP program (since 2015)
- **In Europe:** Rome (2018.05), Oxford (2019.04), **Marseille (?)**
- **In USA:** Chicago (2019.09), DC (2020.04 / online)



CEPC Collaboration with Industry (CIPC)

CEPC 650MHz Klystron at Kunshan Co.



CERN HL-LHC CCT SC magnet

CEPC SC QD0 coil winding at KEYE Co.

CIPC was established in Nov. 2017, there are 70+ companies join the CIPC so far.

CEPC Detector SC coil winding tools at KEYE Company (Diameter ~7m)

CEPC long magnet measurement coil

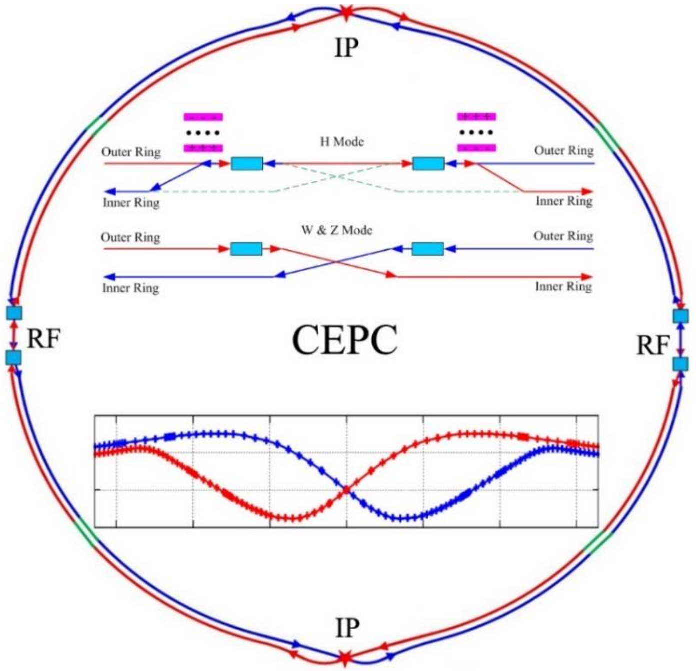
1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Magnet technology
7)Vacuum technologies
8) Mechanical technologies
9)Electronics
10) SRF
11) Power sources
12) Civil engineering
13) Precise machinery
.....

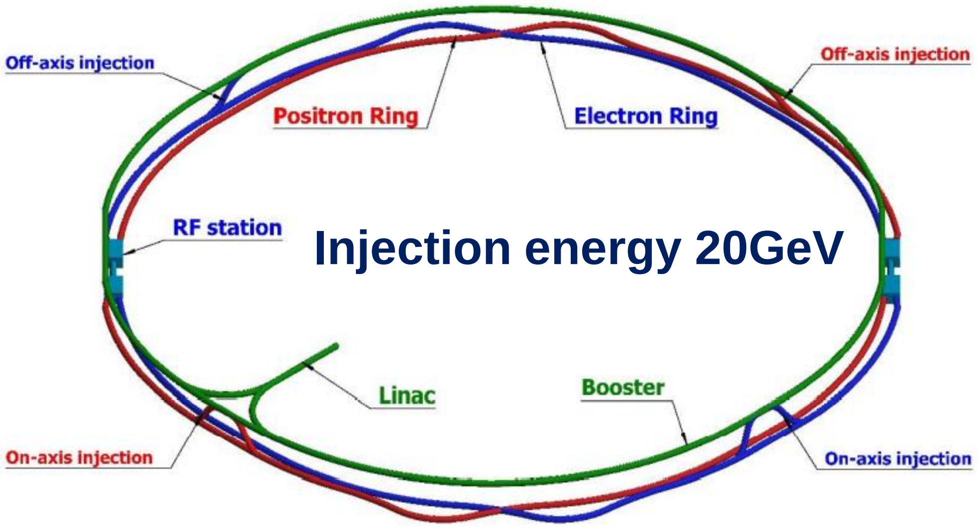
More than 40 companies joined in first phase of CIPC,
and 70 companies now.

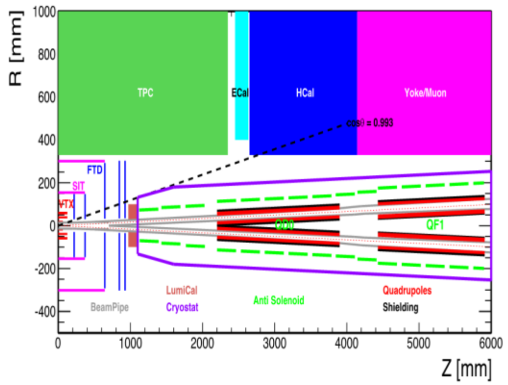
CEPC Accelerator Design Improvement & TDR

- 100 km double ring design (30 MW SR power, upgradable to 50MW).
- Switchable between H & Z, W modes without hardware change (magnet switch).
- New baseline for Linac (C-band, 20GeV) .

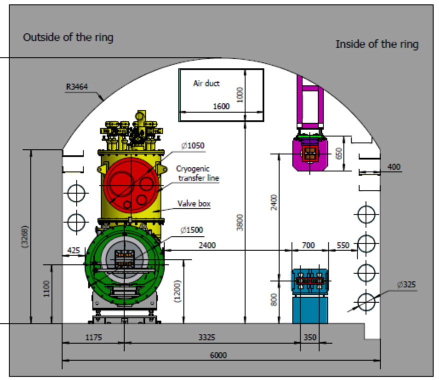
➔ Details at Yuhui Li's talk

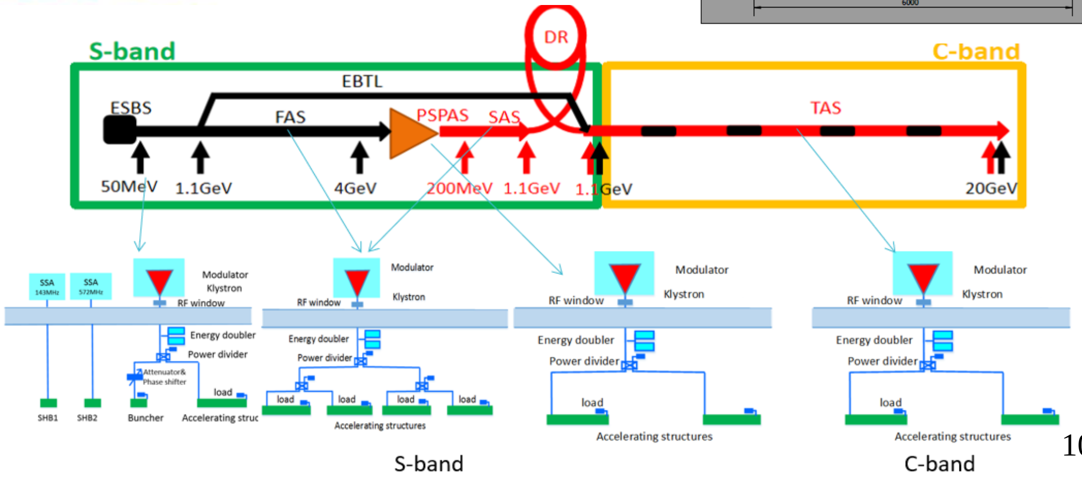






TUNNEL CROSS SECTION OF THE ARC AREA





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

CEPC Accelerator TDR Design Improvement

2018 CDR Baseline Design

	Higgs	W	Z（3T）	Z（2T）
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5 × 2			
Piwinski angle	3.48	7.0	23.8	
Particles /bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number	242	1524	12000 (10% gap)	
Bunch spacing (ns)	680	210	25	
Beam current (mA)	17.4	87.9	461.0	
Synch. radiation power (MW)	30	30	16.5	
Bending radius (km)	10.7			
Momentum compaction (10^{-5})	1.11			
β function at IP β_x^*/β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance x/y (nm)	1.21/0.0024	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.06	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.018/0.109	0.013/0.123	0.004/0.06	0.004/0.079
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz)	650			
Harmonic number	216816			
Natural bunch length σ_z (mm)	2.72	2.98	[illegible]	
Bunch length σ_z (mm)	4.4	[illegible]	[illegible]	
Damping time $\tau_x/\tau_y/\tau_E$ (ms)	[illegible]	[illegible]	[illegible]49.5/849.5/425.0	
Natural Chromaticit[illegible]	[illegible]	[illegible]1161	-491/-1161	-513/-1594
Betatr[illegible]	363.10 / 365.22			
S[illegible]	0.065	0.040	0.028	
H[illegible] (2 cell) (k[illegible]	0.46	0.75	1.94	
Natural energy spread (%)	0.100	0.066	0.038	
Energy spread (%)	0.134	0.098	0.080	
Energy acceptance requirement (%)	1.35	0.90	0.49	
Energy acceptance by RF (%)	2.06	1.47	1.70	
Photon number due to beamstrahlung	0.082	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime† (min)	80/80	>400		
Lifetime (hour)	0.43	1.4	4.6	2.5
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP (10^{34} cm^{-2}s^{-1})	3	10	17	32

† include beam-beam simulation and real lattice

2021 Improved Design

	ttbar	Higgs	W	Z
Number of Ips		2		
Circumference [km]		100.0		
SR power per beam [MW]		30		
Half crossing angle at IP [mrad]		16.5		
Bending radius [km]		10.7		
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	[illegible]27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	[illegible]	[illegible]/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/[illegible]	[illegible]	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	[illegible]	[illegible]0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/[illegible]	[illegible]/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/[illegible]	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Qx/Qy/Qs	0.12/0.22/0.078	0.12/0.22/0.049	0.12/0.22/	0.12/0.22/
Beam lifetime (bb/bs)[min]	81/23	39/18	60/717	80/182202
Beam lifetime [min]	18	12.3	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

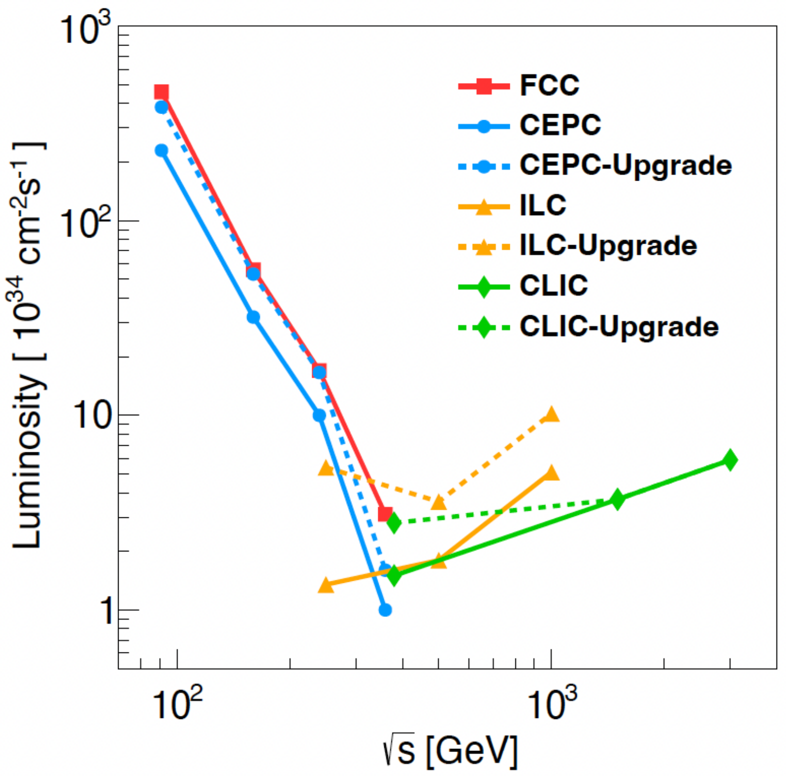
67%⇑

259%⇑

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

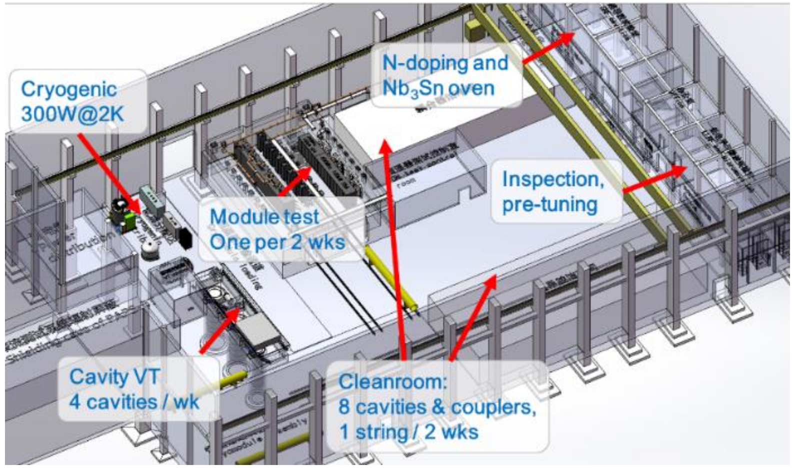


Higher SR power of 50MW, the Lumi. will increase ~66%.

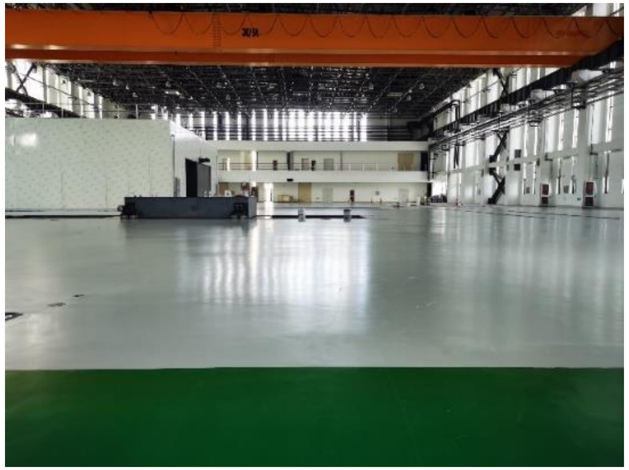
CEPC SCRF Test Facility

CEPC SCRF Test Facility is available：Beijing Huairou (4500m²)

New SC Lab Design (4500m²)



SC New Lab is available in 2021



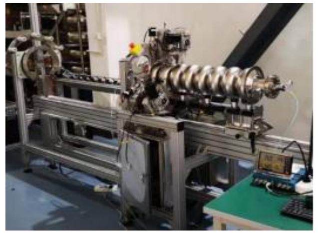
Crygenic system hall

Vacuum furnace (doping & annealing)

Nb3Sn furnace

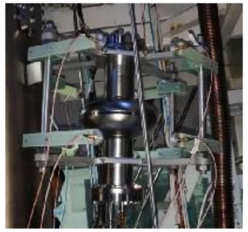
Nb/Cu sputtering device

Cavity inspection camera and grinder

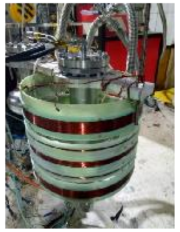


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

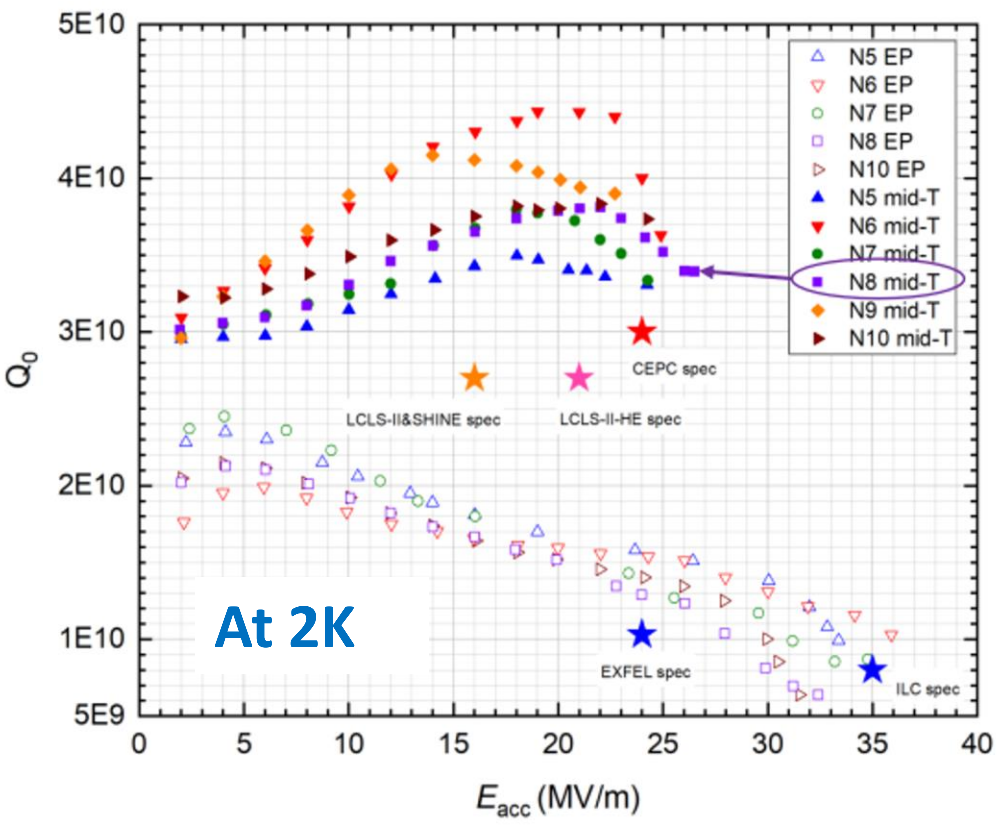
Vertical test dewars

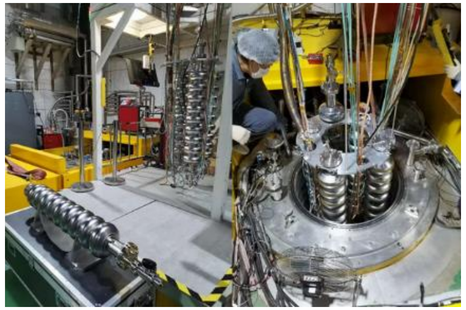
Horizontal test cryostat

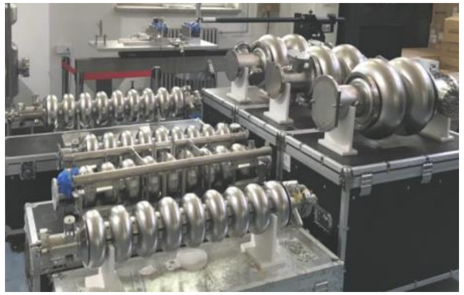
CEPC R&D: High Q SCRF Cavities

- 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
- SCRF cavities for both booster & collider ring reach CEPC design goal

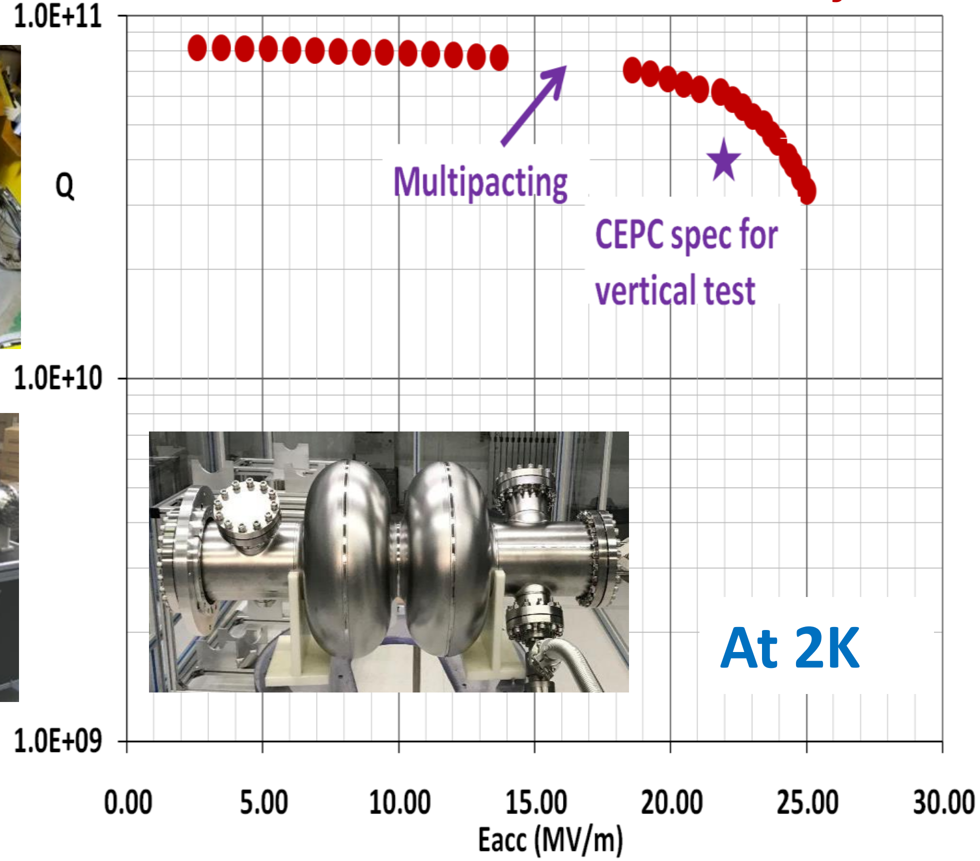
IHEP 1.3 GHz 9-cell Cavity Vertical Test







Vertical test of 650 MHz 2-cell cavity



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

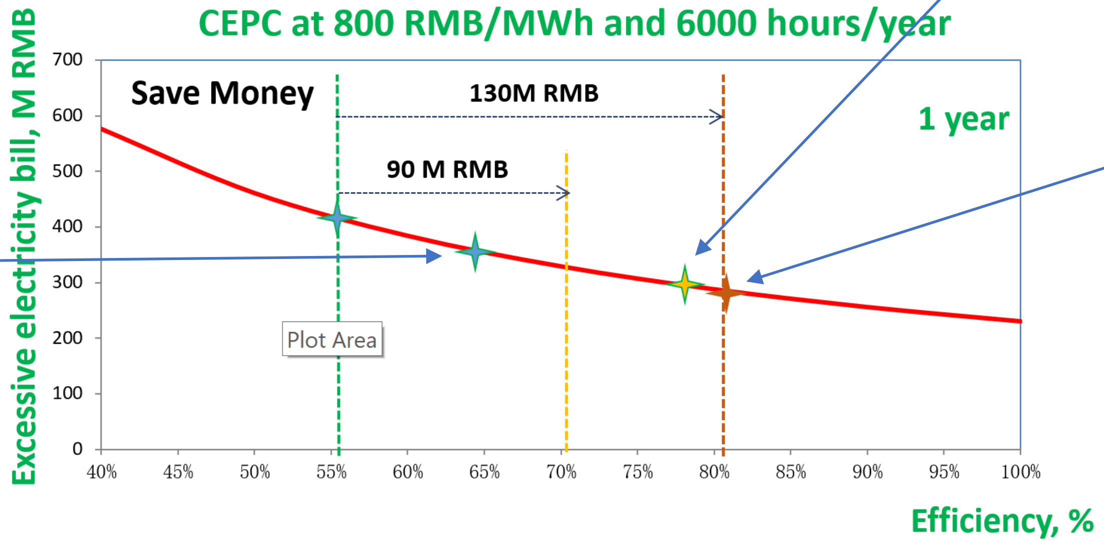
N-infusion adopted to reach Q_0 = 6.0E10 @ 22.0 MV/m

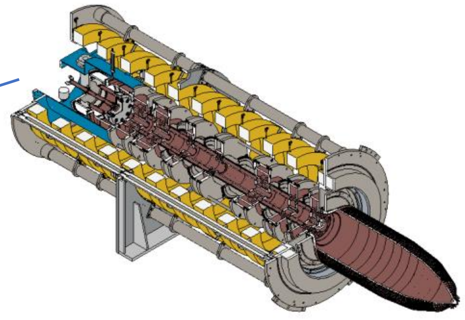
CEPC R&D: High Efficiency Klystrons

- The 1st prototype finished fabrication & passed the max. power test. Output power reaches 700 kW in CW mode, 800 kW in pulsed mode. Design efficiency is 65%, achieved efficiency ~ 62%.
- The 2nd klystron prototype is manufactured and under test at PAPS, design eff is ~ 77%, achieved efficiency ~70%.
- Multi-beam Klystron design is finished, design efficiency is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

The 2nd Klystron (under test)

The 1st Klystron (tested)

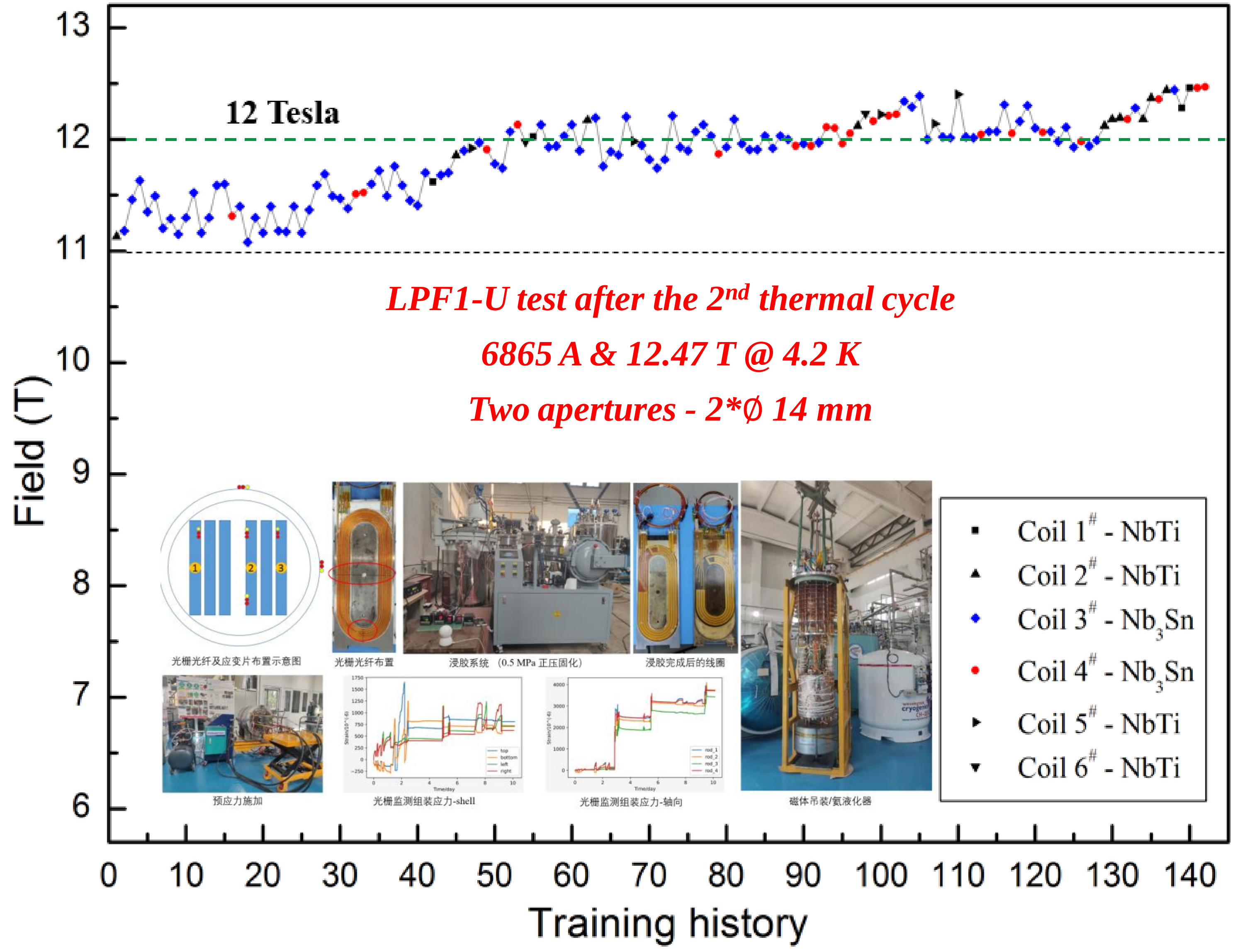


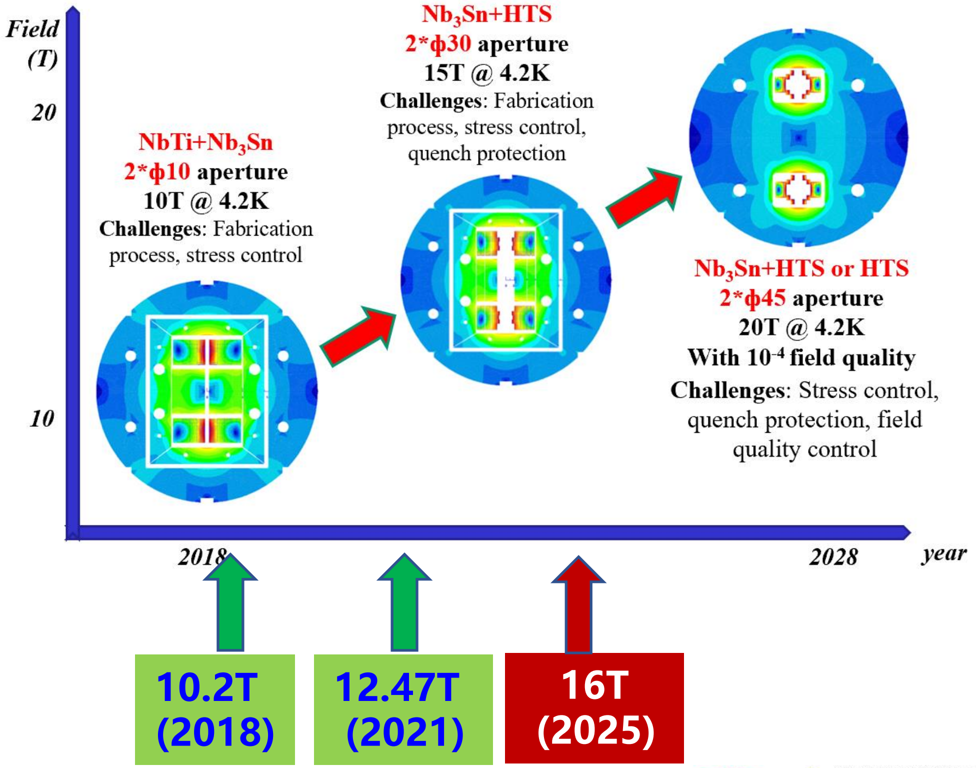


Multi-beam Klystron

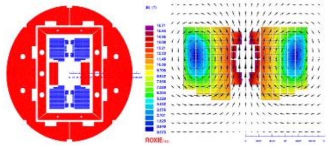
HTS SC Magnet (>12T)

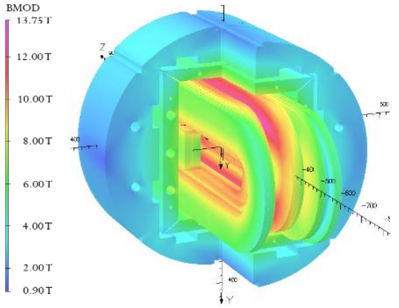
Domestic SC dipole magnet exceeded 12T (IHEP, June, 2021)





LPF3 16T Dipole Magnet:
Nb_3Sn 12~13 T + HTS 3~4 T





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 (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

The large samples: ~10^6 Higgs, ~10^{12} Z, ~10^8 W bosons

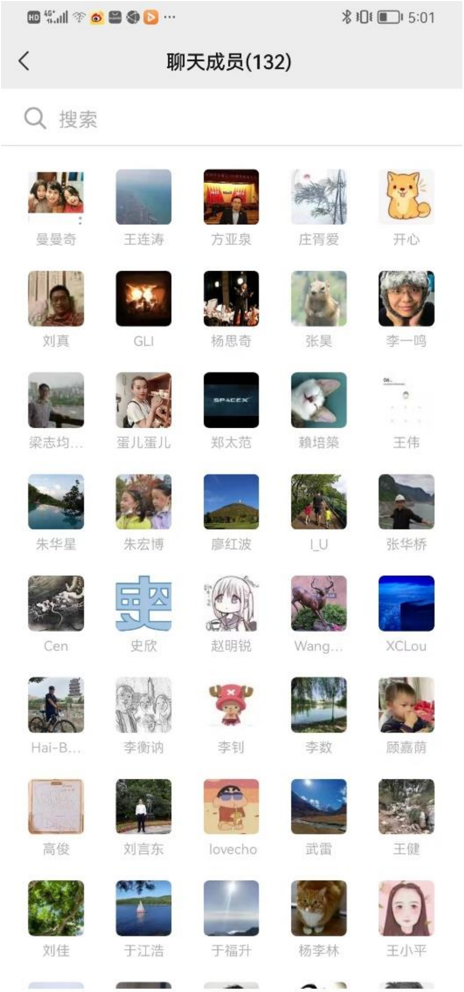
Peking U. (2019)

Yangzhou (2021)

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

CEPC Physics Program: Snowmass LoI



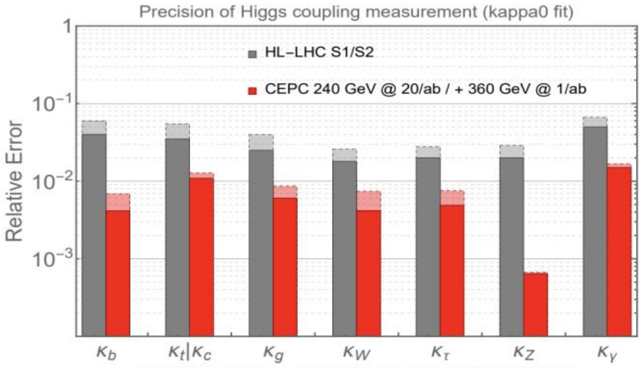
	Submitter	Title
1	Xin	EF01 Higgs boson CP properties at CEPC
2	Yanping	EF01 Measurement of branching fractions of Higgs hadronic decays
3	MJRM & Shu	EF02 Study of EWPT in Exotic Higgs decays with CEPC detector simulation
4	Mingrui Zhao	EF03 Feasibility study of CP violation phase Phi-s measurement via Bs->J/psi Phi at CEPC
5	Peiwen Wu	EF03 Probing top quark FCNC couplings at future electron positron collider
6	Lingfeng Li	EF03 Searching for Bs->Phivv and other b->svv processes at CEPC
7	Siqi Yang	EF04 Measurement of leptonic effective weak mixing angle at CEPC
8	Jiayin Gu	EF04 Probing new physics with measurement of ee->WW at CEPC with optimal observables
9	Bo Li	EF04 Measurement of Rb in hadronic Z decays at the CEPC
10	Zhao Li	EF04 NNLO electroweak correction to Higgs and Z associated production at future Higgs factory
11	Shuang-Yong Zhou	EF04 Positivity bounds on quartic-gauge-boson couplings
12	Qin qin	EF05 Exclusive Z decay
13	Zhao Li	EF05 NNLO EW correction to Higgs and Z associated production at future Higgs factory
14	Yang Zhang	EF08 SUSY Global fits with future colliders using GAMBIT
15	Tianjun li	EF08 Probing SUSY and DM at CEPC, FCC & ILC
16	Mengchao Zhang	EF09 Search for Asymmetric DM model at CEPC by displaced lepton jets
17	Peiwen Wu	EF09 Search for t+j+MET signals from DM models at future electron positron collider
18	Xin Shi & Weiming	EF09 DM via Higgs portal at CEPC
19	Kepan Xie	EF10 Lepton portal DM, Gravitational waves and collider phenomenology
20	Taifan Zheng	RF1 Exploring NP with Bc->Tauv

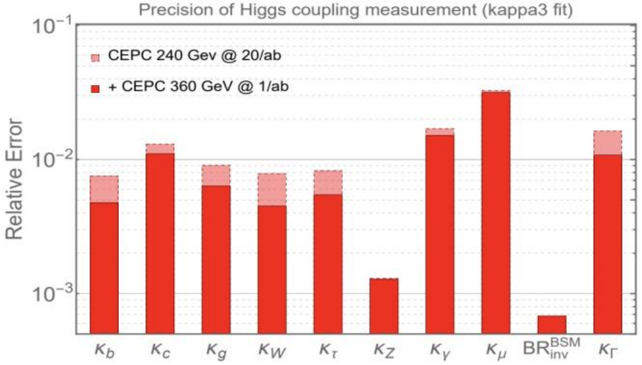
arXiv: 2205.08553

- ✓ With many talks presented at Snowmass meetings
- ✓ Many relevant performance studies, and extra physics analyses

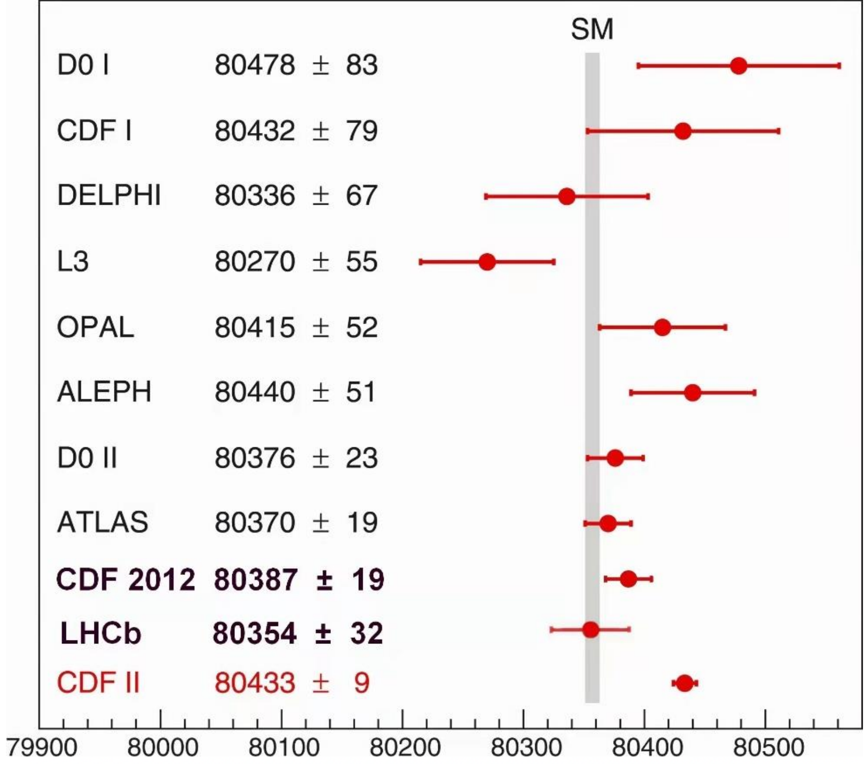
CEPC Physics Program: Higgs and EW

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

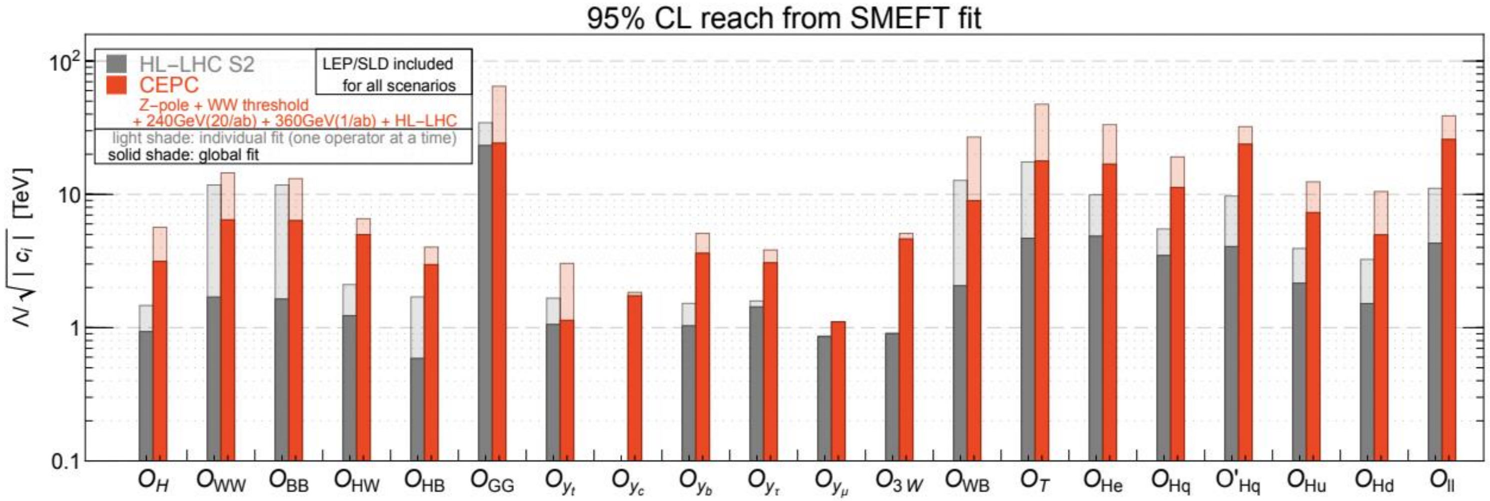




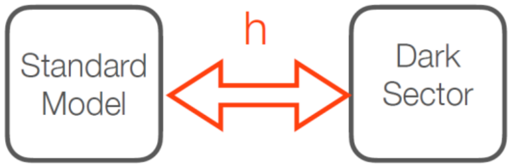
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model



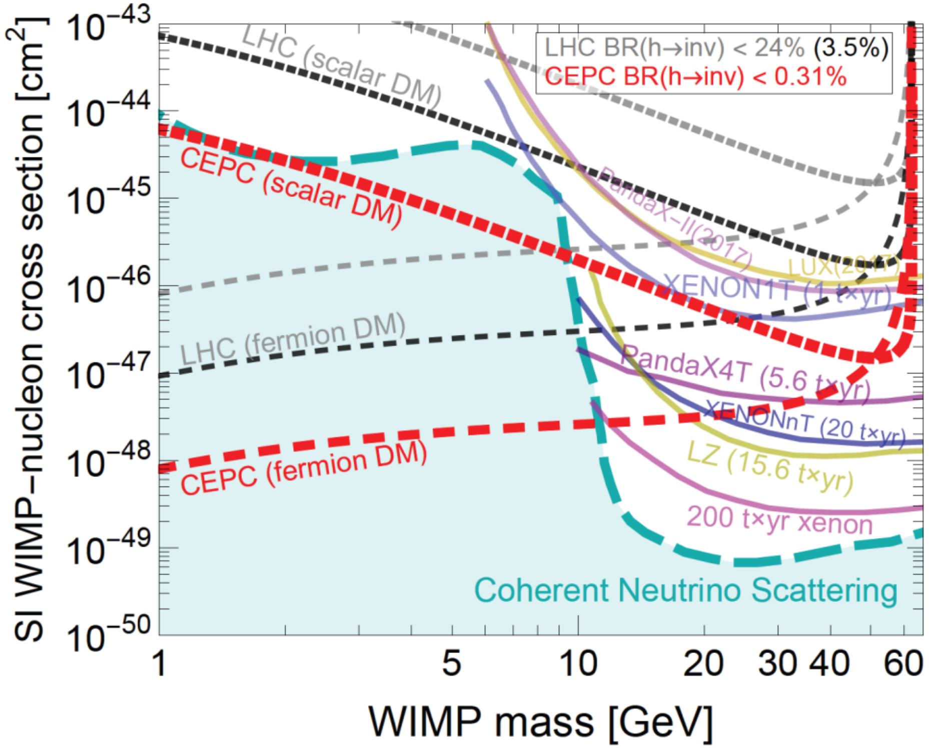
$BR(Z \to \mu e)$	$< 7.5 \times 10^{-7}$	$10^{-8} - 10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z \to \pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$BR(Z \to \pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z \to J/\psi\gamma)$	$< 1.4 \times 10^{-6}$		$10^{-9} - 10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z \to \rho\gamma)$	$< 2.5 \times 10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

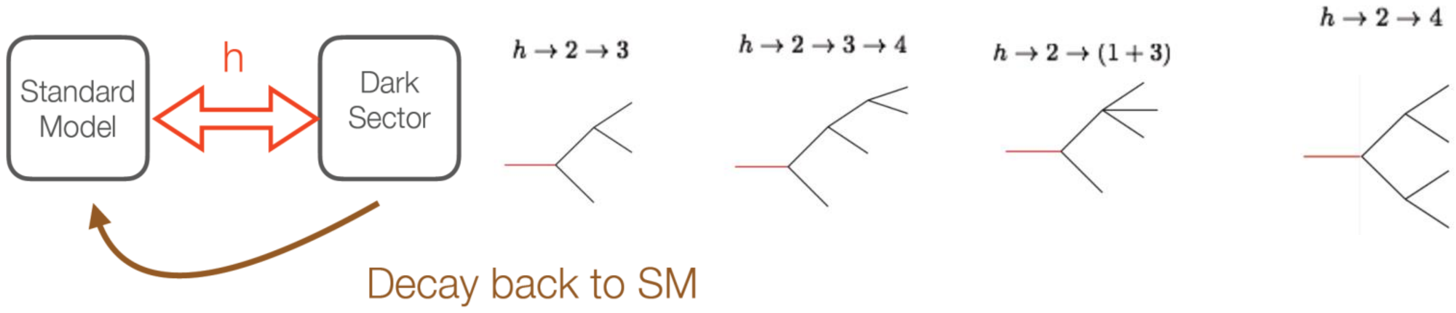


Discovery Potential for New Physics

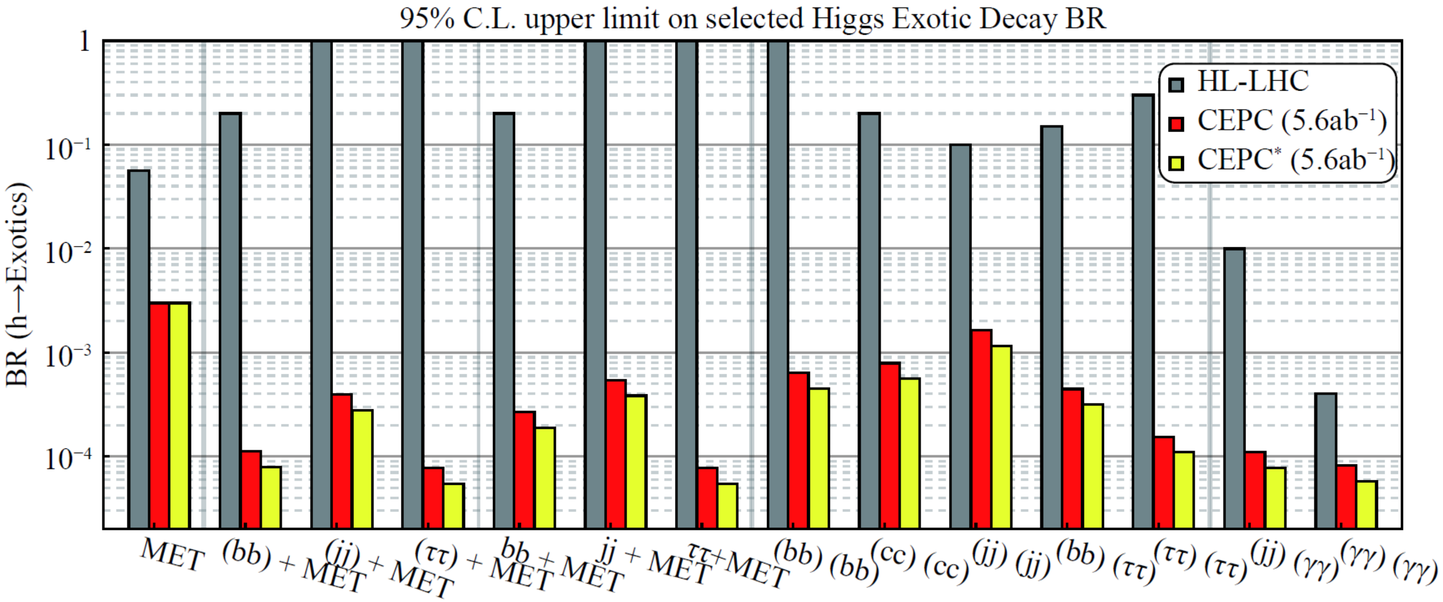


$$h \rightarrow X_{\rm dm} X_{\rm dm}$$



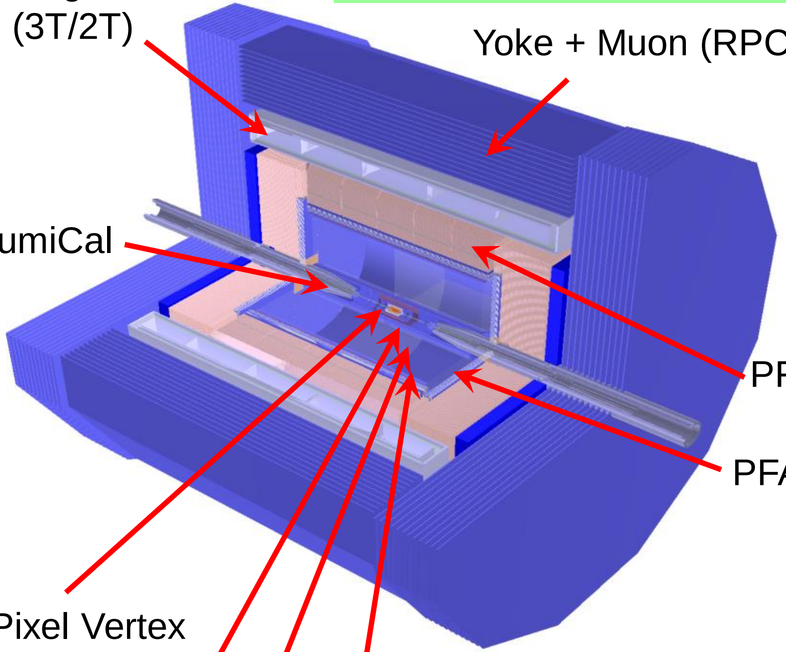


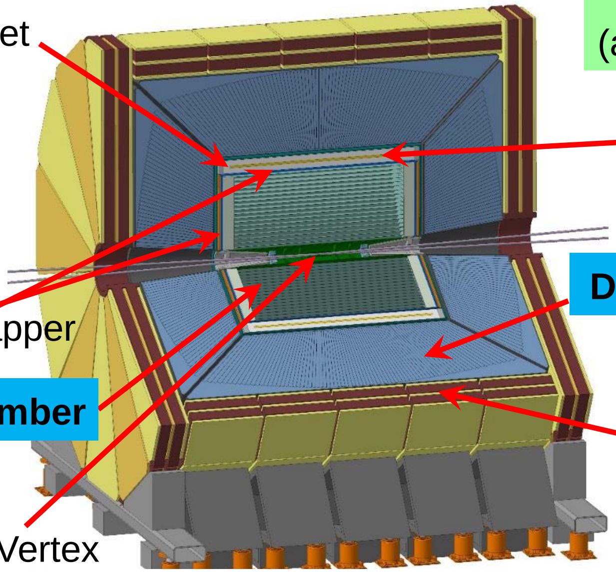
Higgs decays into BSM particles, H→ X_1X_2

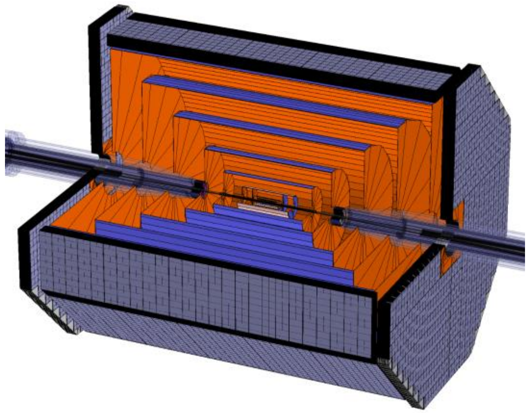


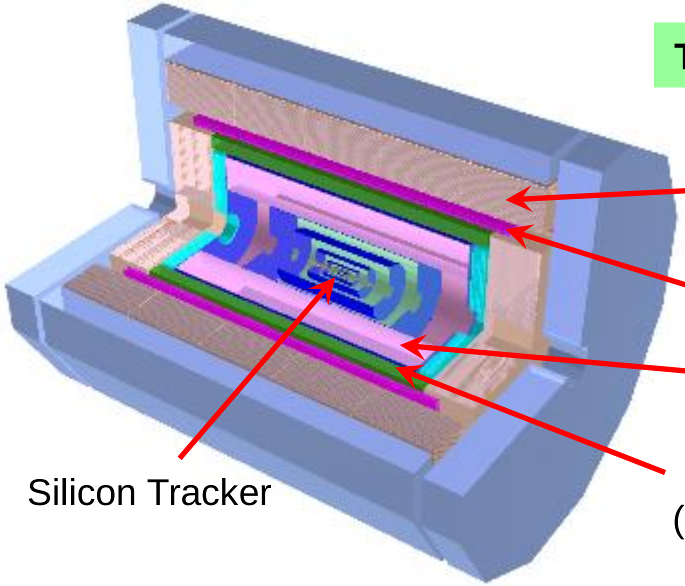
CEPC has significantly better detection sensitivity for dark matter and selected Higgs exotic decays than HL-LHC

Conceptual Detector Designs

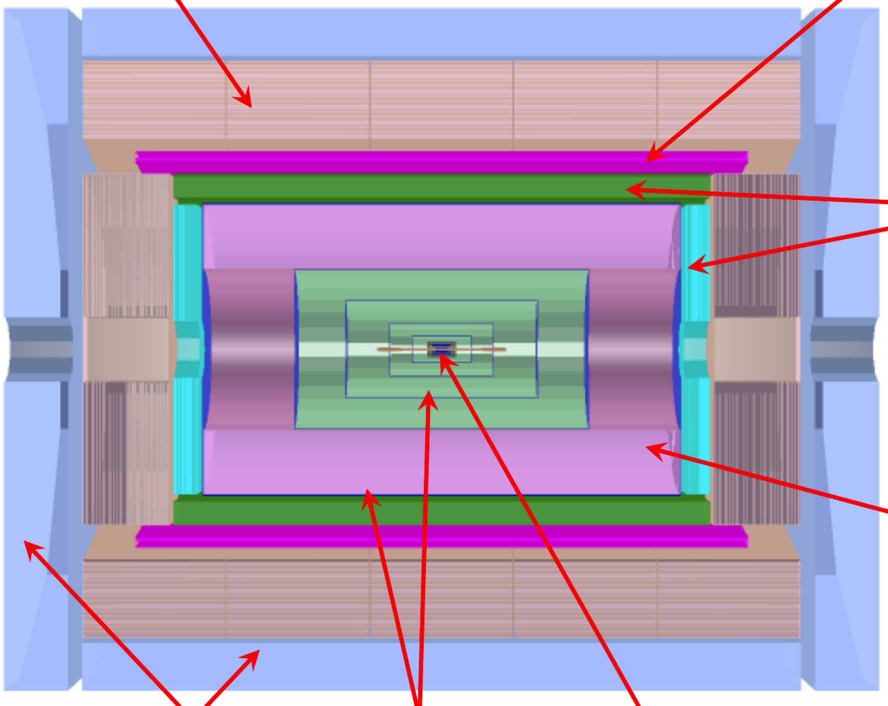








The 4th Conceptual Detector Design



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)
	Stiching
Tracker & PID	TPC
	CEPCPix
	Drift chamber
	PID DC
	LGAD
	Silicon Strip

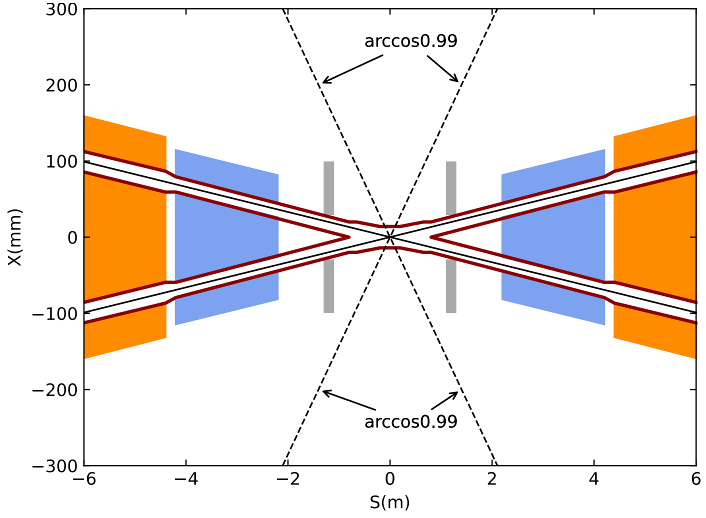
Det	Technology
Calorimeter	Crystal ECAL
	Si+W ECAL
	Scint+W ECAL
	Scint AHCAL
	ScintGlass AHCAL
	RPC SDHCAL
	MPGD SDHCAL
	DR Calorimeter
Muon	Scintillation Bar
	RPC
	μ-Rwell
Lumi	SiTrk+Crystal ECAL
	SiTrk+SiW ECAL

→ Call for names for the 4th conceptual detector

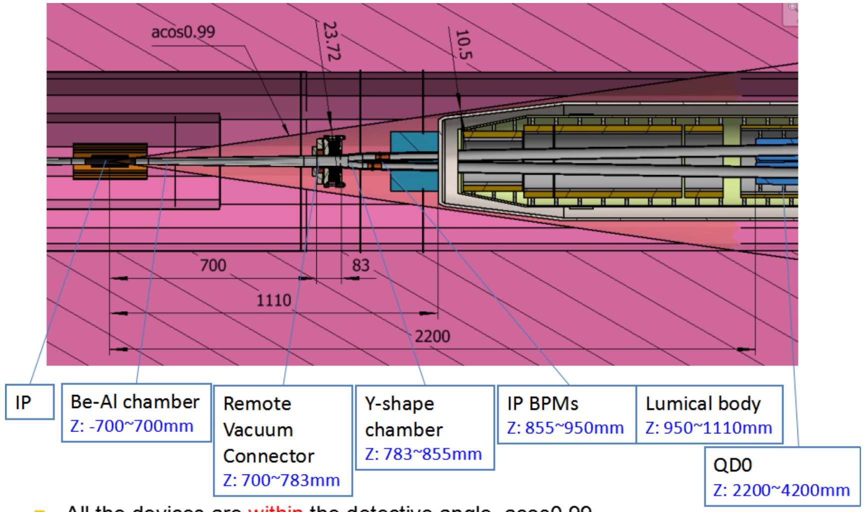
CEPC R&D: Machine Detector Interface (MDI)

Crossing angle: 33 mrad

Focal length: 2.2 m



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

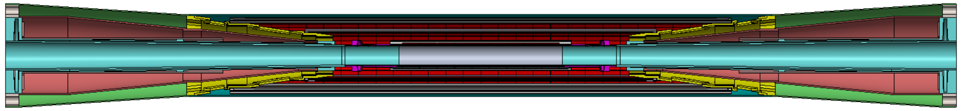


- All the devices are within the detective angle, acos0.99.

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

Beam Pipe

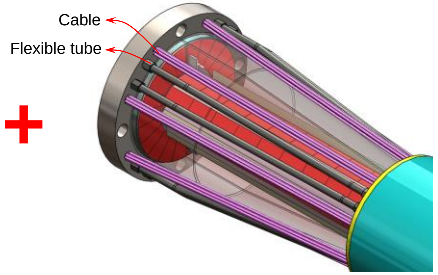
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

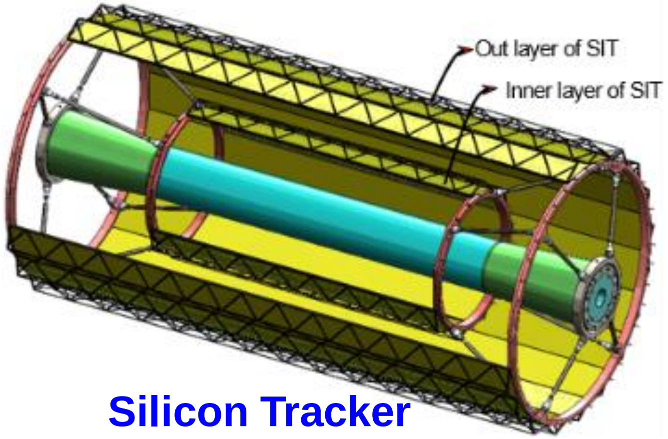


Vertex

+

LumiCal Tracker



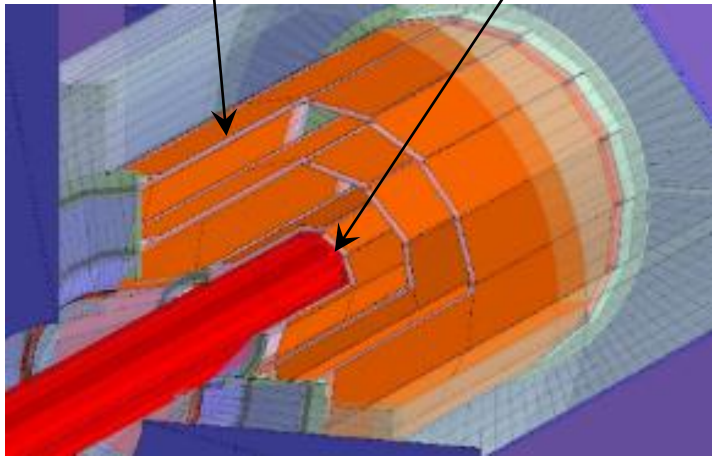


Silicon Tracker

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

CEPC R&D: Silicon Pixel Chips

2 layers / ladder R_{in}~16 mm



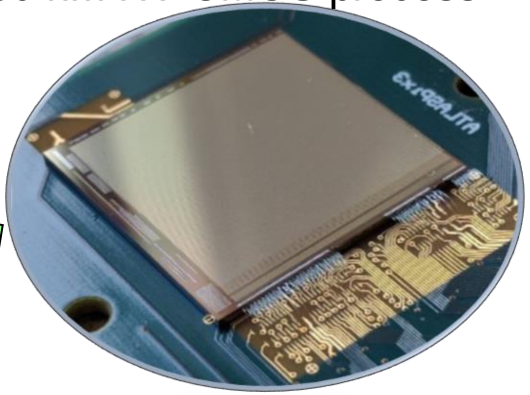
Goal: σ(IP) ~ 5 μm for high P track

CDR design specifications

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

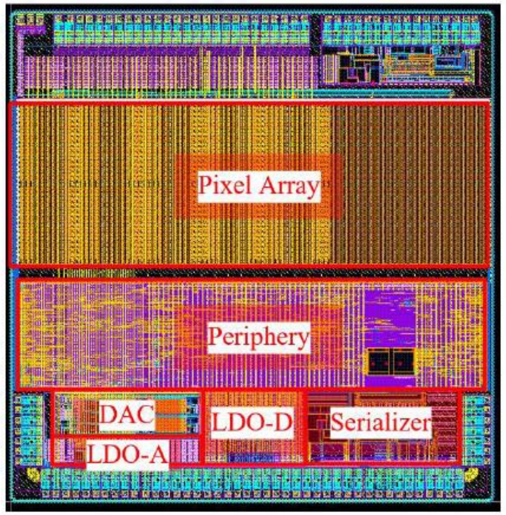


JadePix-3 Pixel size ~16×23 μm^2

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

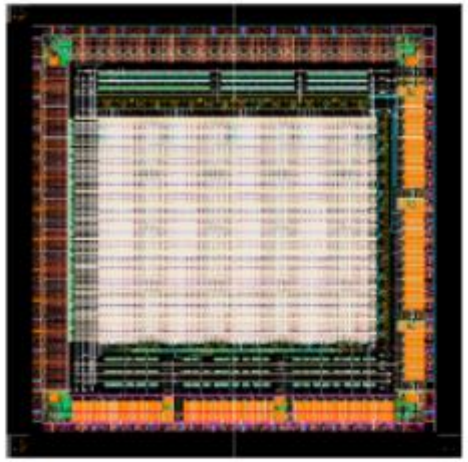
MOST 1

TaichuPix-2, 64×192 array
25×24 μm^2 pixel size

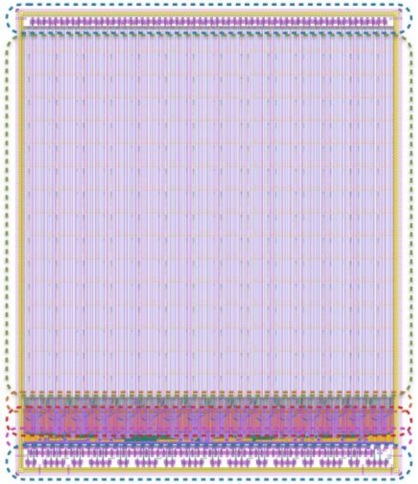


MOST 2

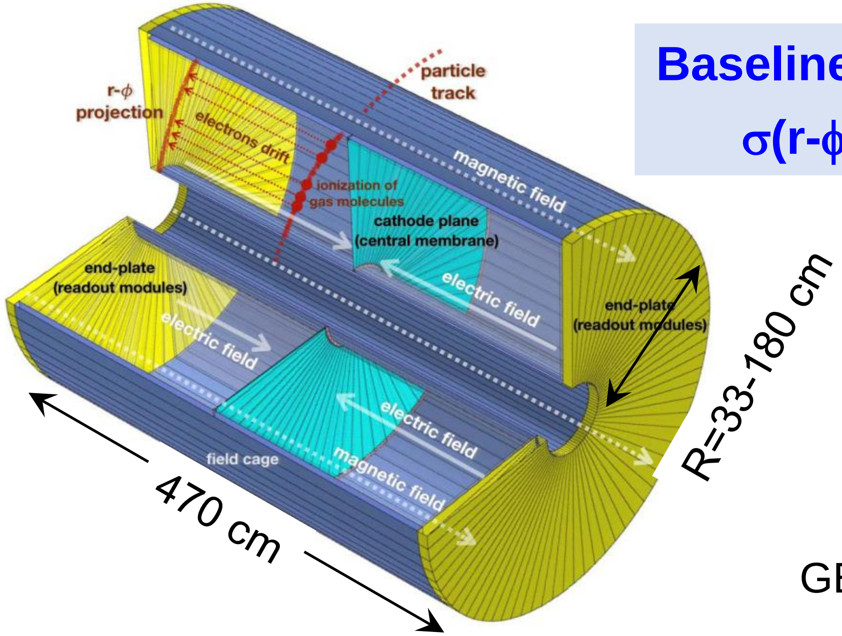
CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size



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

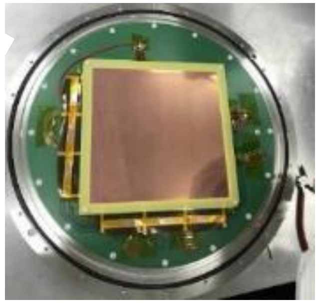


CEPC R&D: Time Projection Chamber

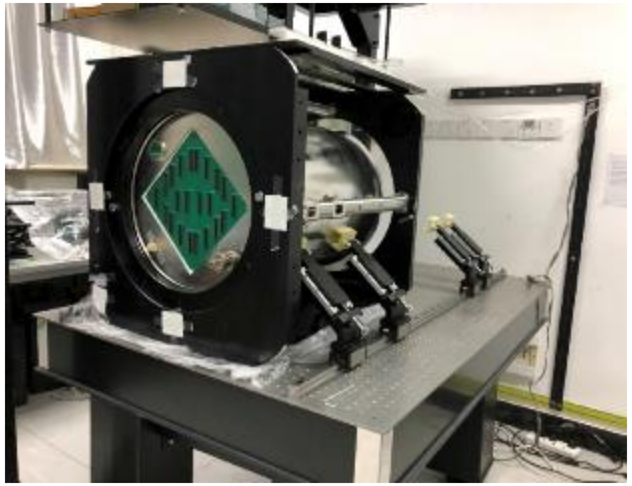


Baseline main tracker

σ(r-ϕ) ~100 μm



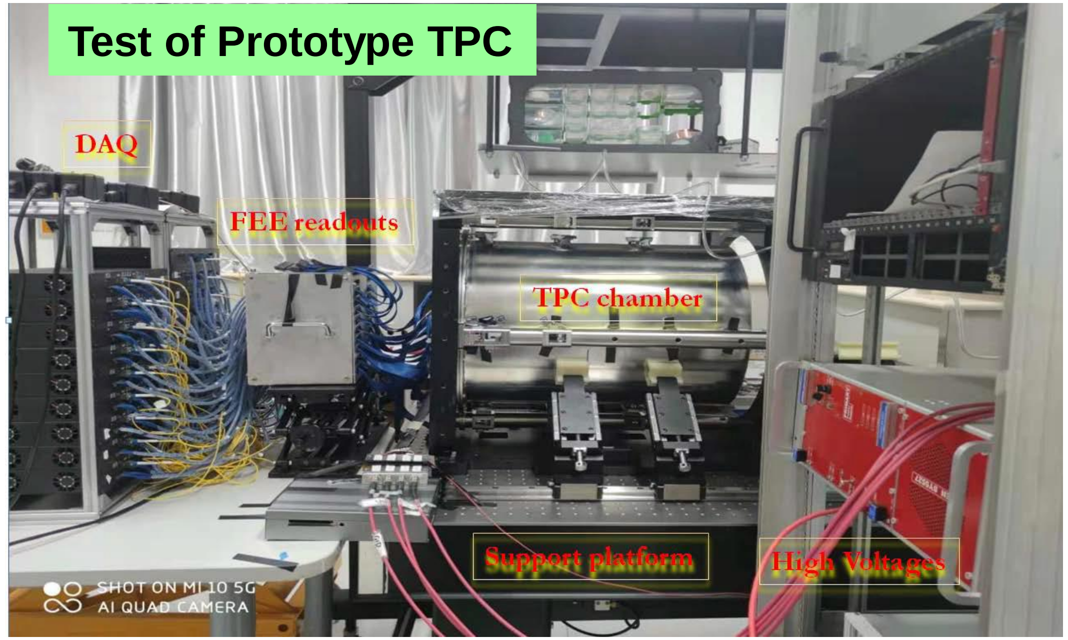
GEM-MM cathode



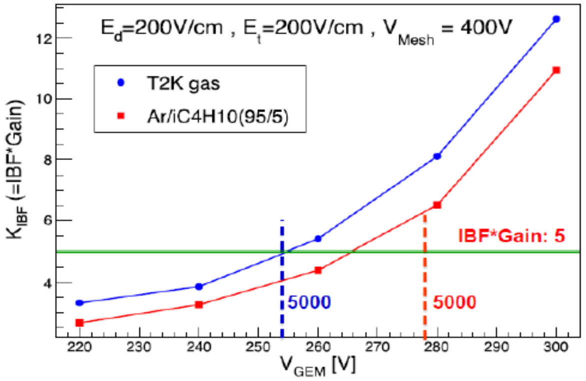
TPC Prototype + UV laser beams

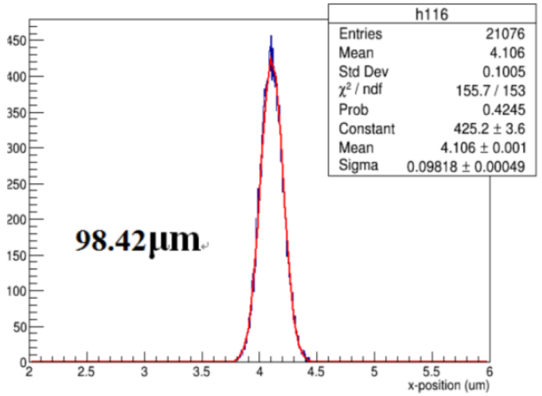
MOST 1 (IHEP+THU)

Low power FEE ASIC



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





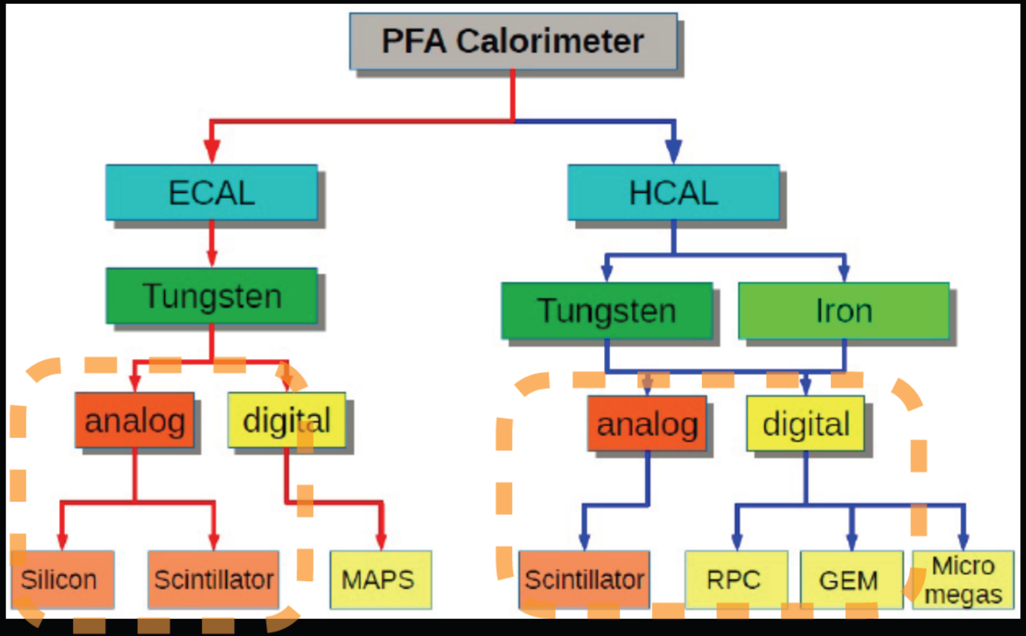
σ_x < 100 μm for drift length of 27cm

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)

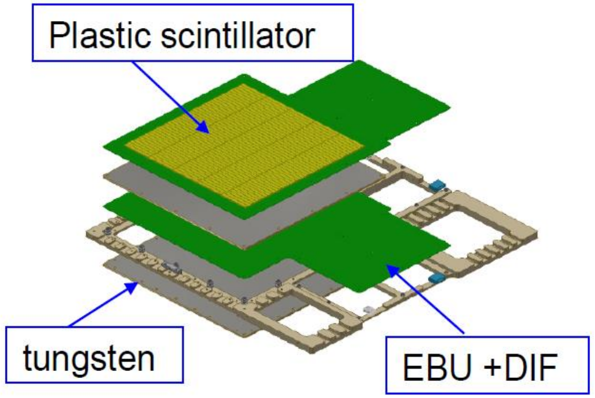
Newer Options

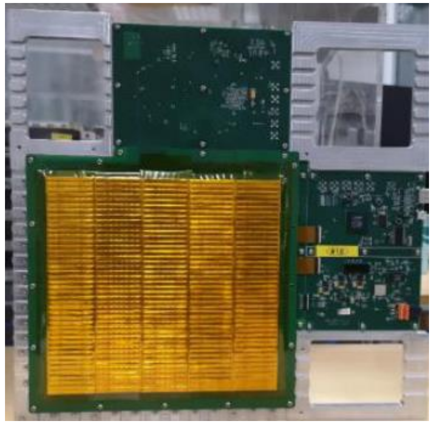
Some longitudinal granularity
- Crystal Calorimeter (LYSO:Ce + PbWO)
- Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

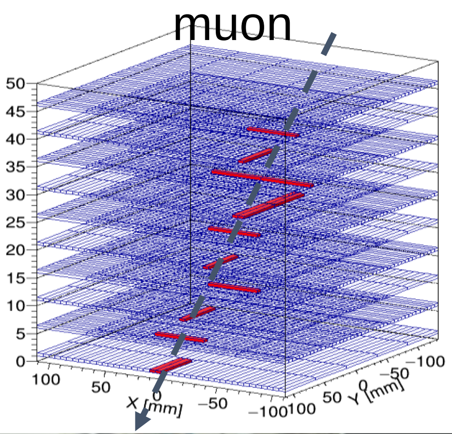
46

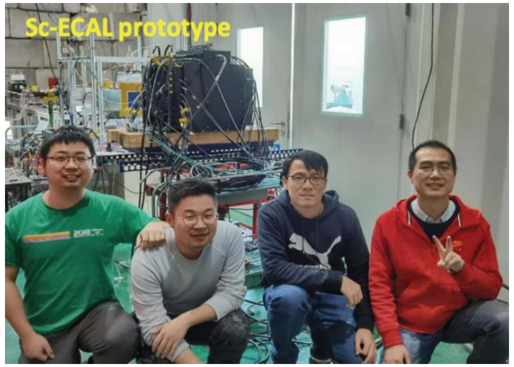
CEPC R&D: Calorimeters

Scintillator-W ECAL Prototype

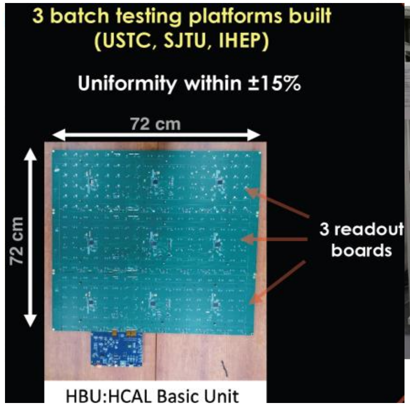


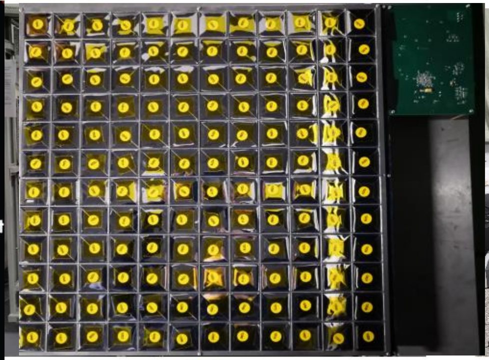






Scintillator + SiPM AHCAL Prototype

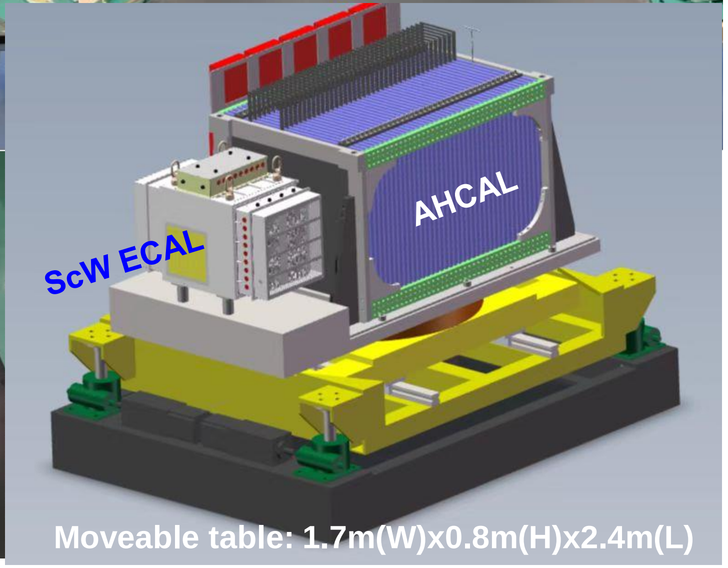




SJTU

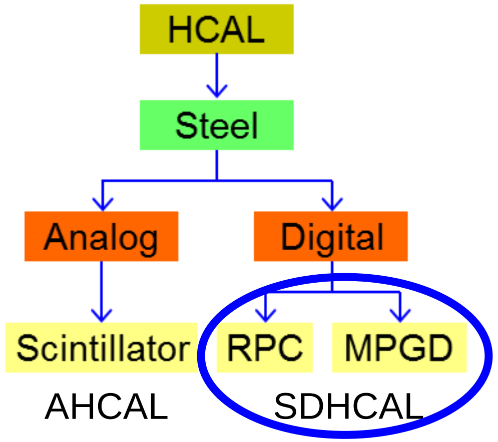
IHEP

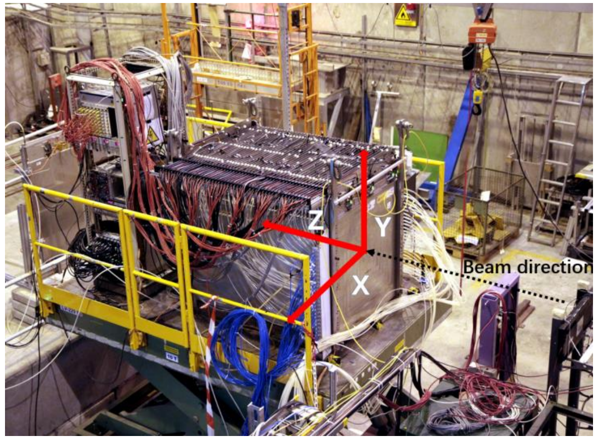
Combined: ScW-ECAL + AHCAL



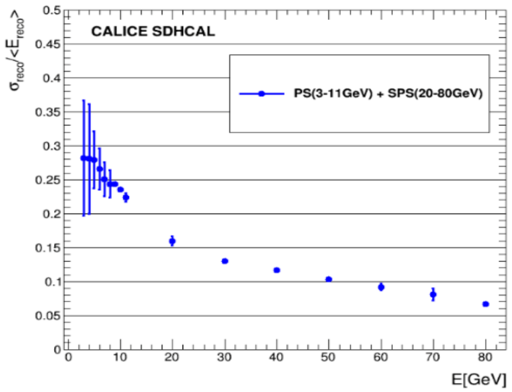
➔ Testbeam at CERN SPS for two prototypes in Oct. 2022

CEPC R&D: SDHCAL

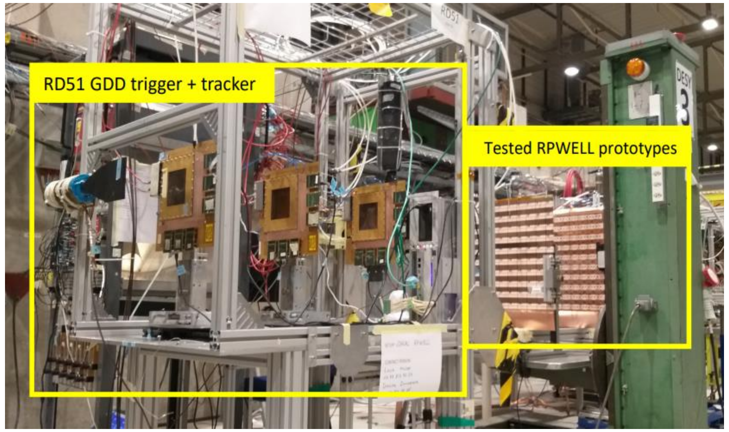




SDHCAL-GRPC (1.3 m^3, IPNL)



JINST 15, P10009 (2020)
arXiv:2202.09684



SDHCAL-RPWELL (50x50cm^2, WIS)

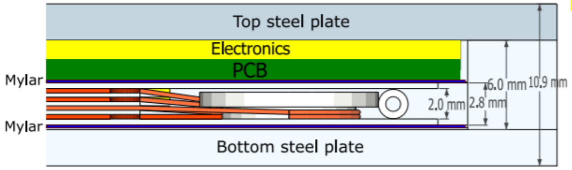
MOST 1: RPC and MPGD (RWELL) R&D， MIP Eff > 95%

GRPC 1m x 1m (SJTU)

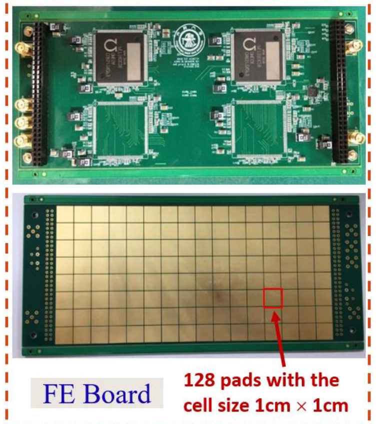
JINST 16 (2021) P12022

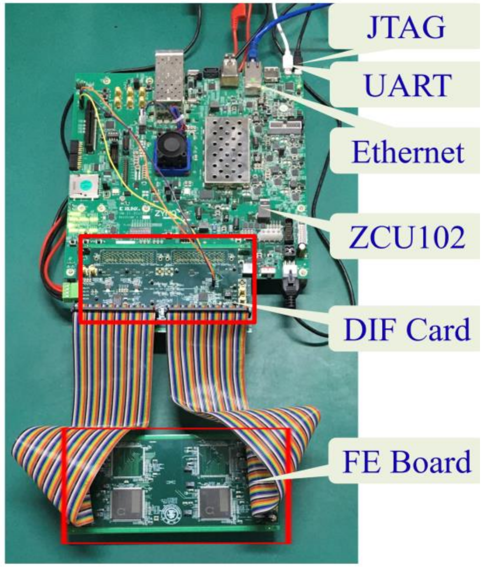
RWELL 0.5m x 1m (USTC+IHEP)

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

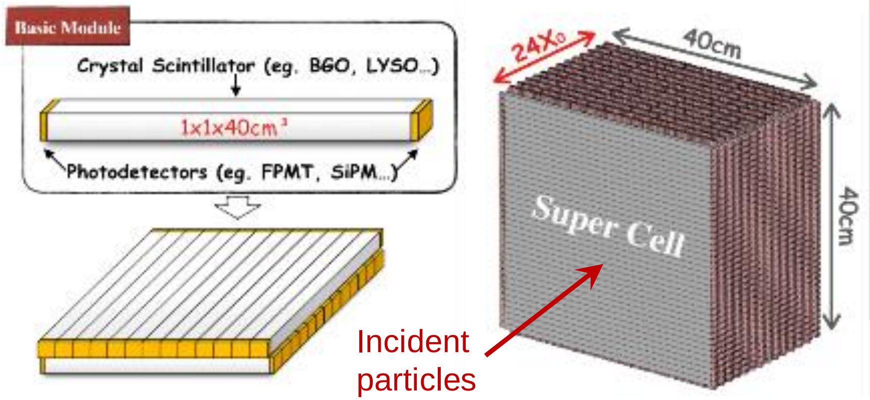


IPNL
SJTU
IJCLab
OMEGA
CIEMAT



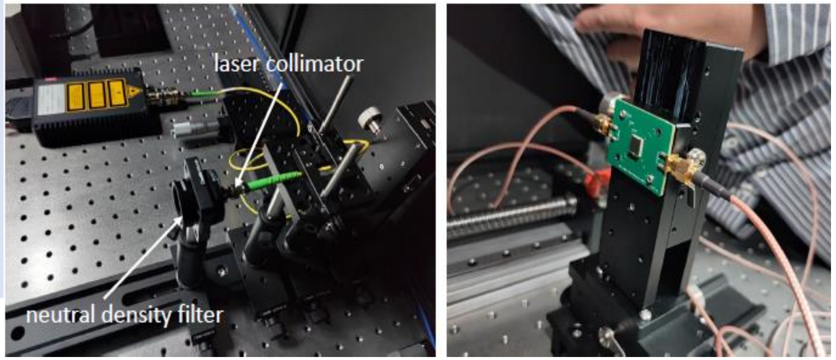


CEPC R&D: High Granularity Crystal ECAL



Goal

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

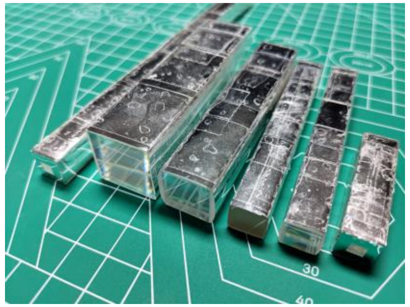


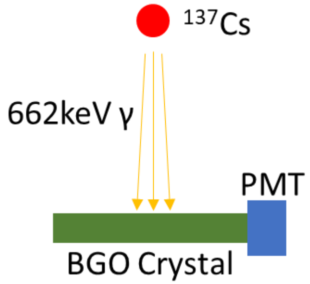
Bench Test

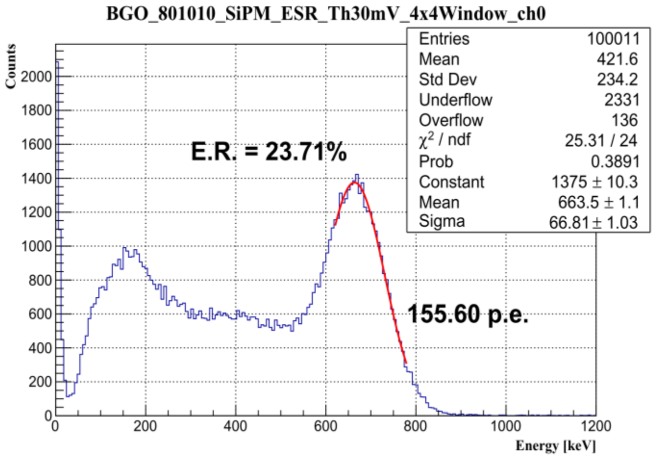
- Timing at two ends for positioning along bar.
- Significant reduction of number of channels.

Conceptual Design

Performance Test



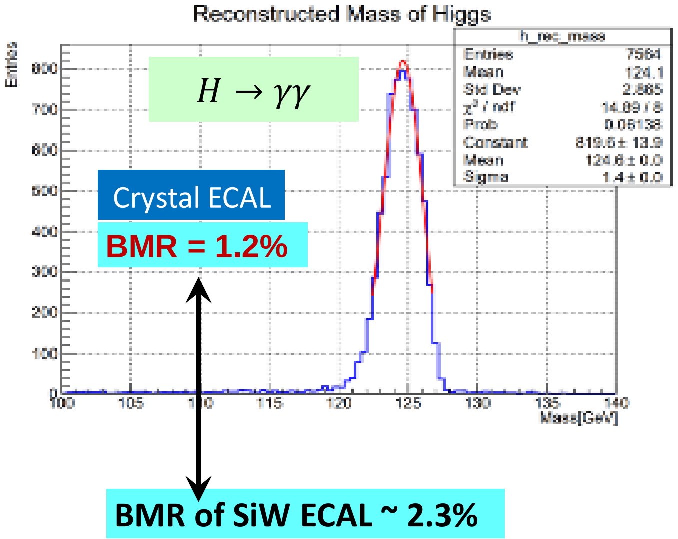




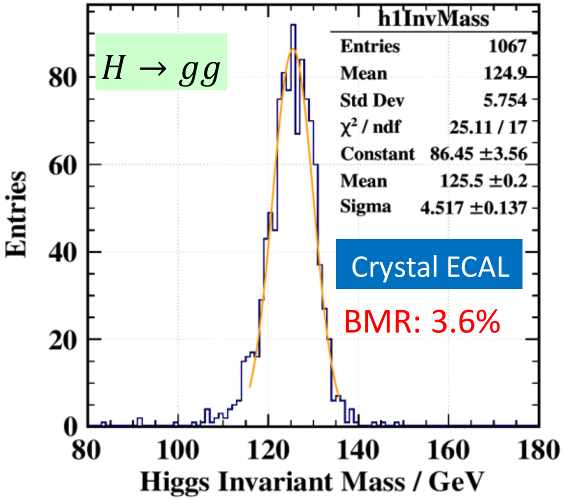
Full Simulation Studies

+ Optimizing PFA for crystals

Performance with photons



Performance with jets



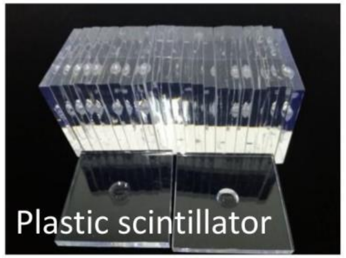
CEPC R&D: New HCAL with Scintillating Glass Tiles

Goal

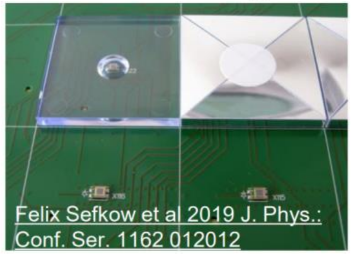
- Better hadronic energy resolution
- Further improve BMR

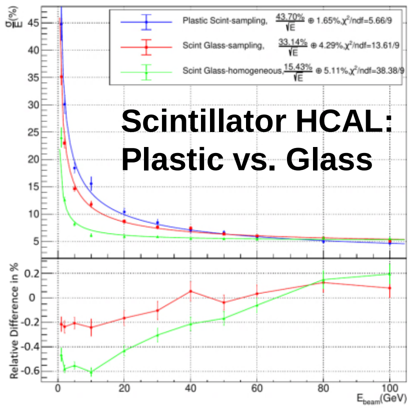
Full simulation studies

Tiles for AHCAL (30x30x3mm)

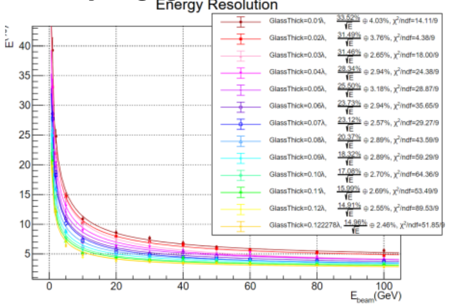


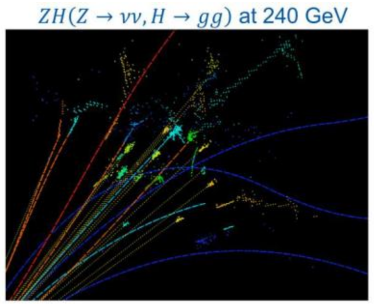
'SiPM-on-Tile" design for HCAL



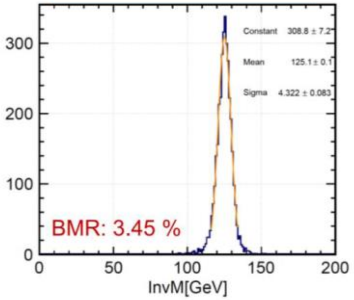


Varying glass thickness

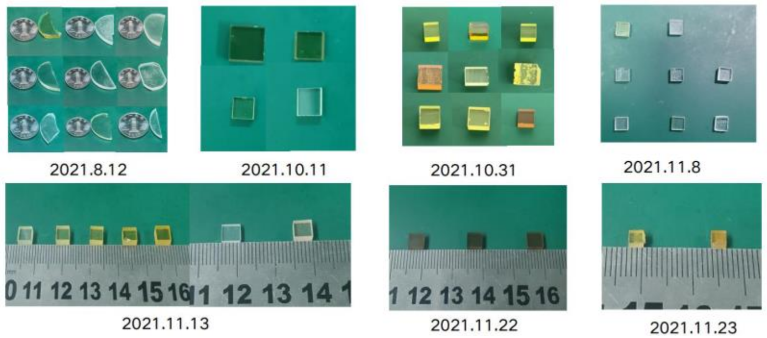




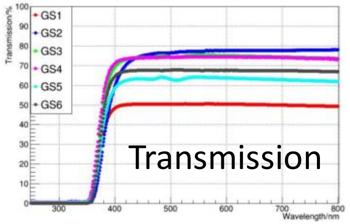
Performance study with jets

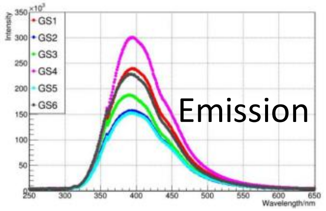


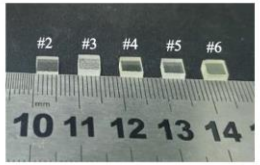
Scintillating Glass R&D

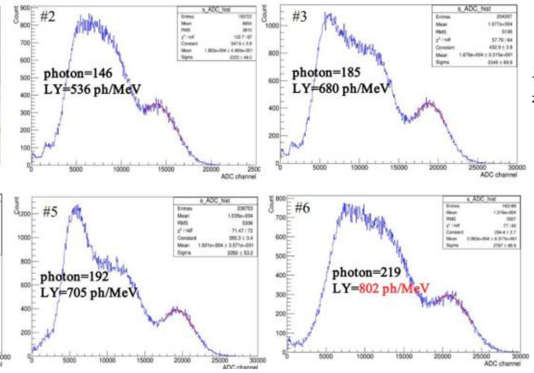


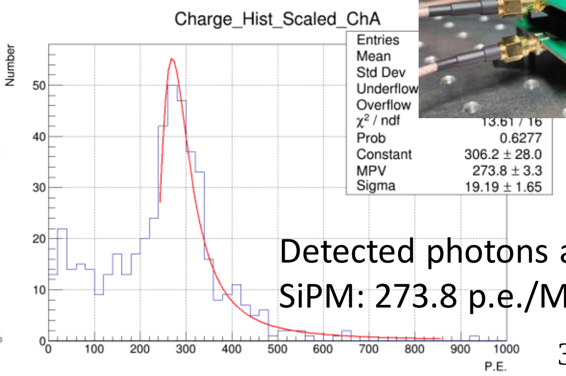
Testing Scintillating Glass Samples

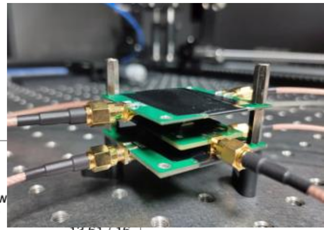






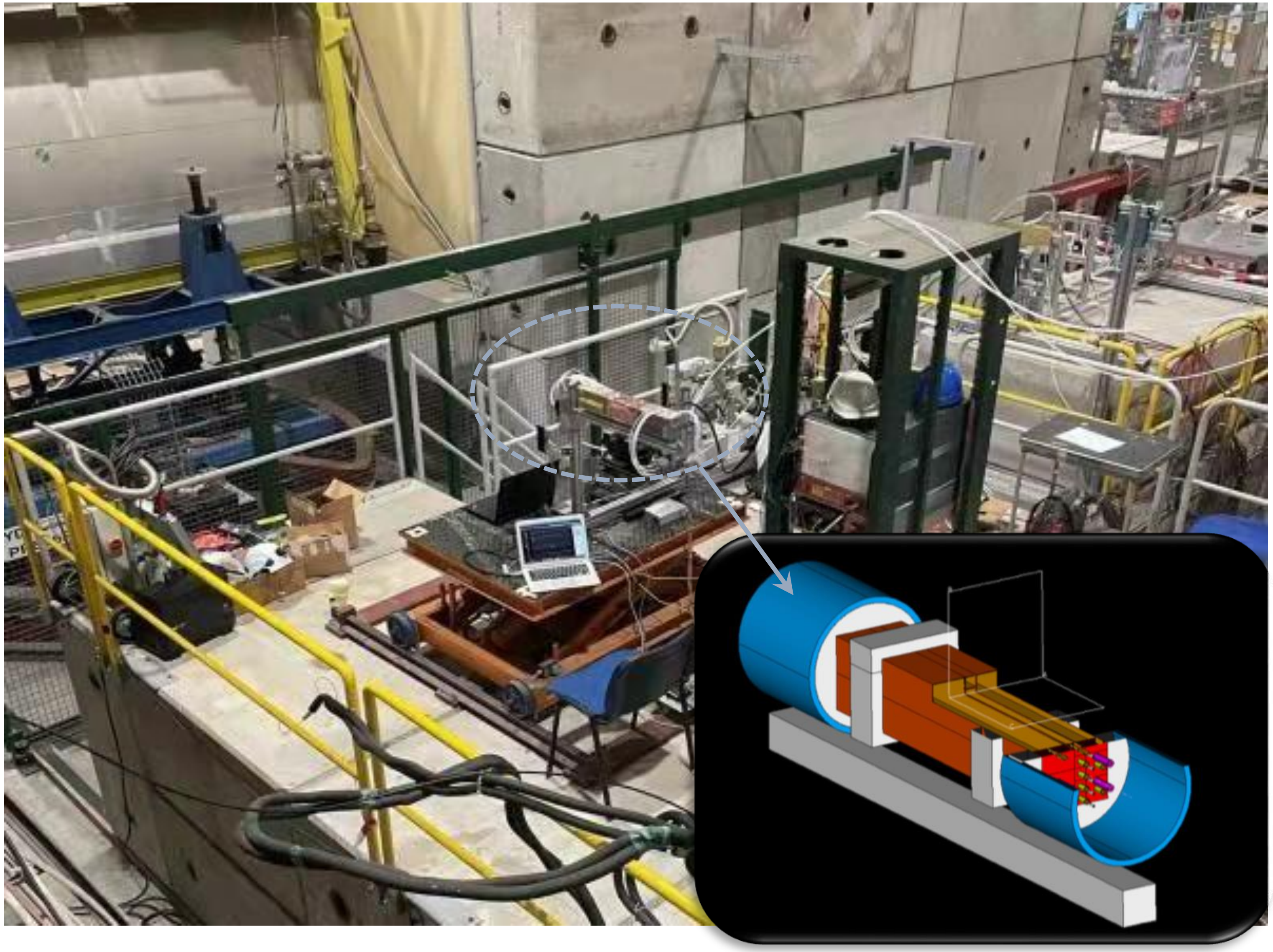


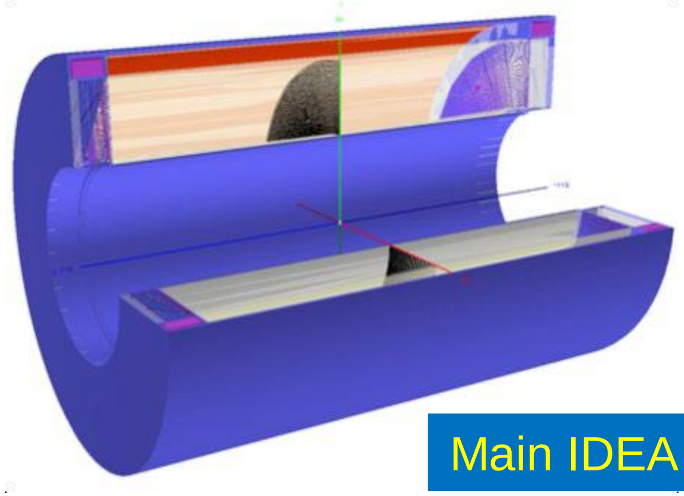




Detected photons at SiPM: 273.8 p.e./MIP

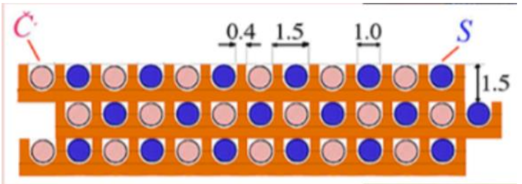
CEPC R&D: IDEA Tracker and Dual Readout Calorimeter

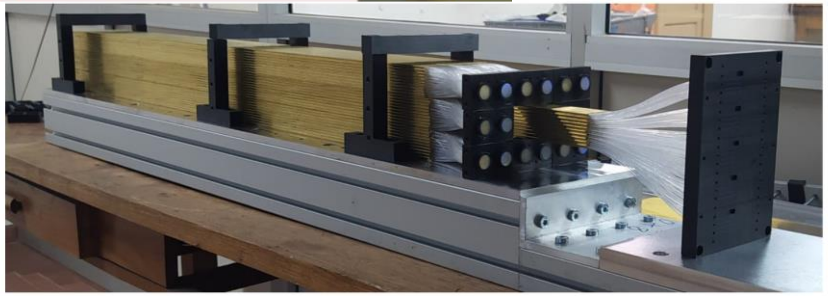




Main IDEA tracker

Dual Readout CAL





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

Summary and Prospects

Continuing R&D and deepen understanding of physics potentials

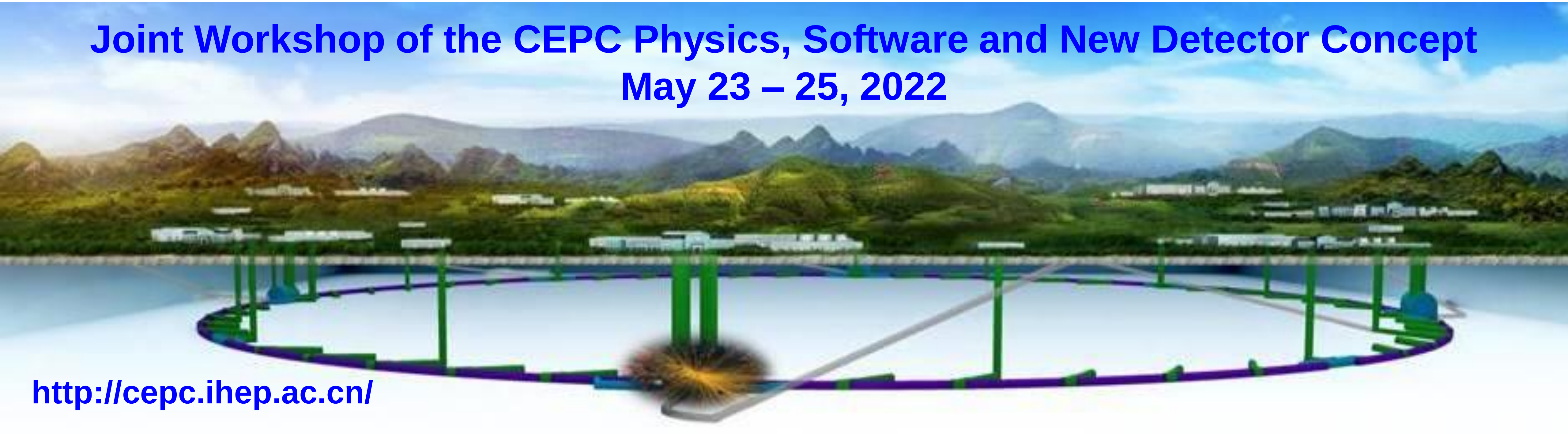
- Made suggestions to **MOST for R&D support** and validations of key technologies & innovations
- Carrying out **design improvement, R&D**, site investigations-study
- R&D and made major **progress + breakthroughs** in common technologies
- **CEPC accelerator and physics whitepapers for Snowmass study in** 2022

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, LPTPC, RD*, …
- Finding and sharing solutions to common issues (design, accelerator/detector components, …)
- Hope to have in-person meeting and collaboration in the near future …

Thank you for your attention !

Many thanks to our colleagues who made significant contributions to the CEPC R&D



Joint Workshop of the CEPC Physics, Software and New Detector Concept
May 23 – 25, 2022

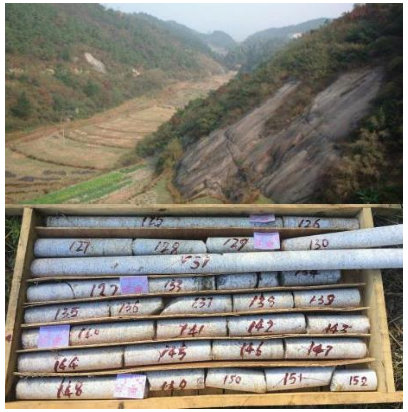
http://cepc.ihep.ac.cn/

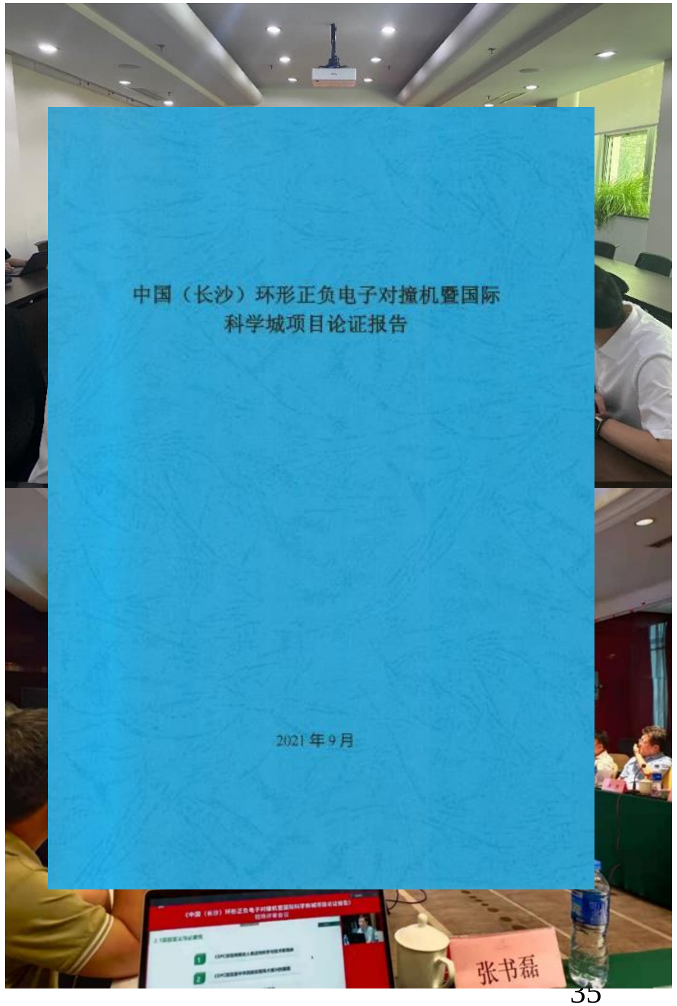
CEPC Newsletters (quarterly)

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

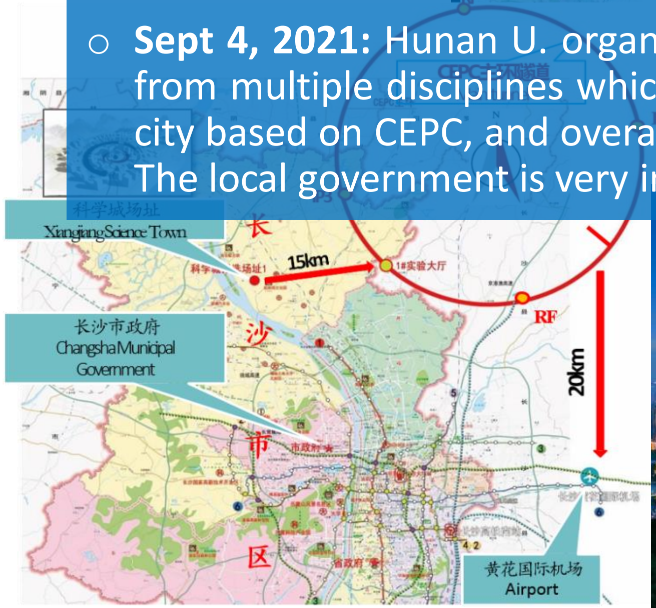
CEPC Site Selection

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



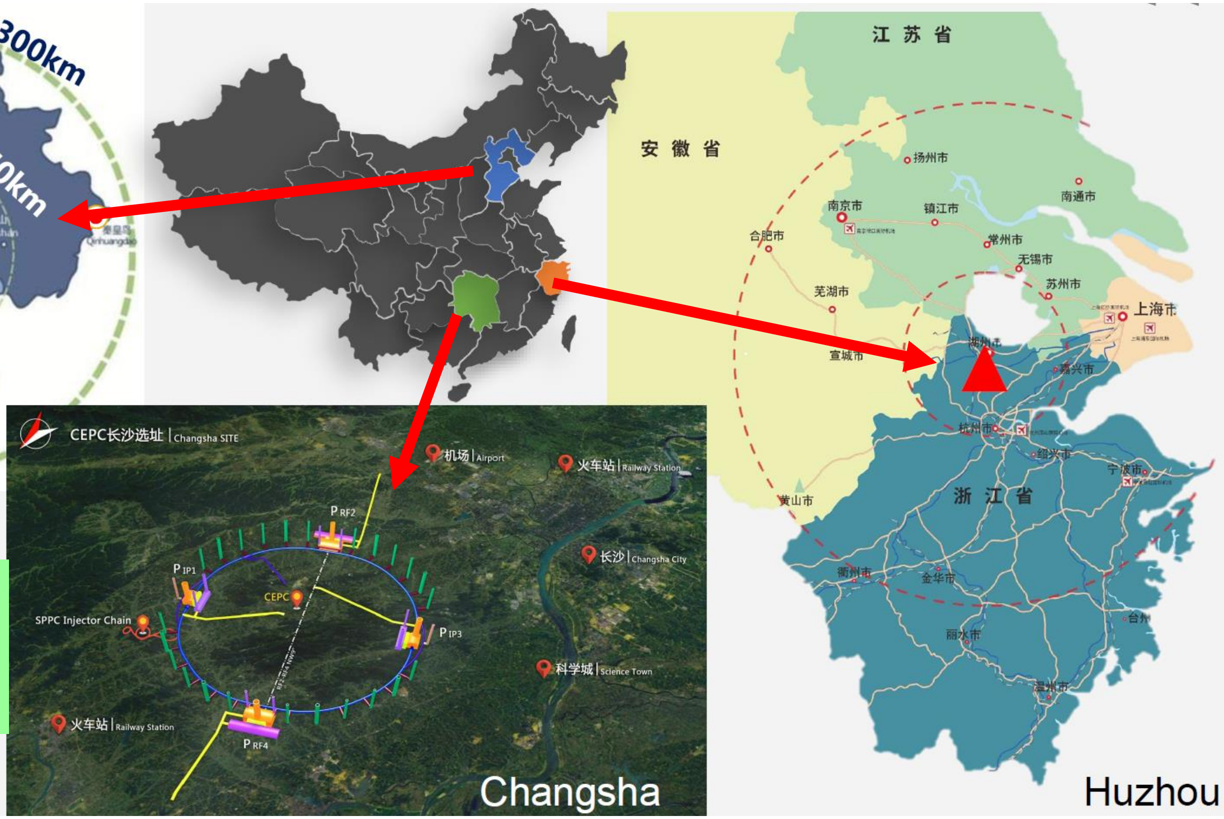


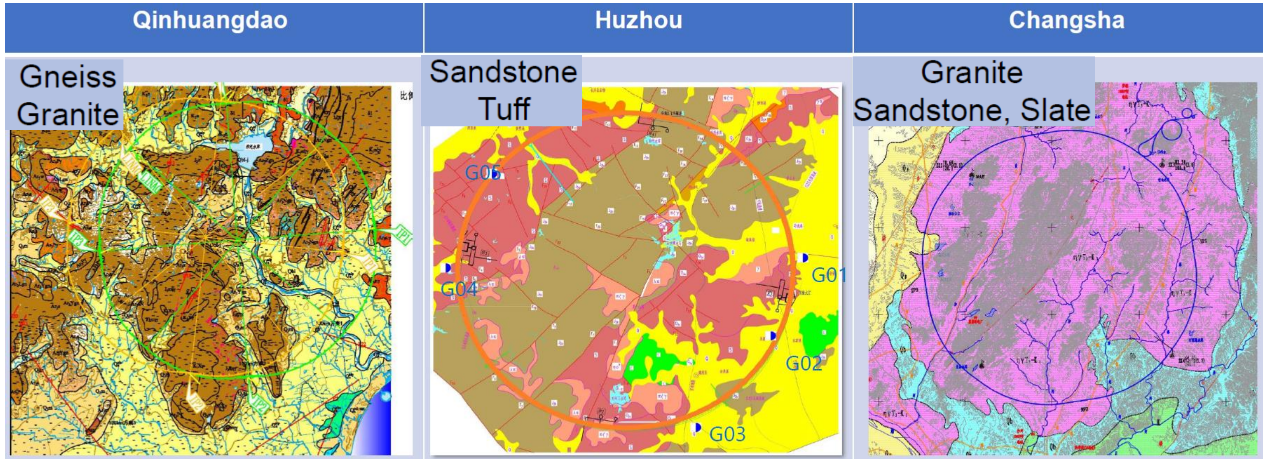
- **July 5, 2021:** Changsha Bureau of S&T entrusted Hunan U. to conduct a feasibility study.
- **Sept 4, 2021:** Hunan U. organized a review meeting by a committee consisting of experts from multiple disciplines which evaluated CEPC for its science, feasibility of a new science city based on CEPC, and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

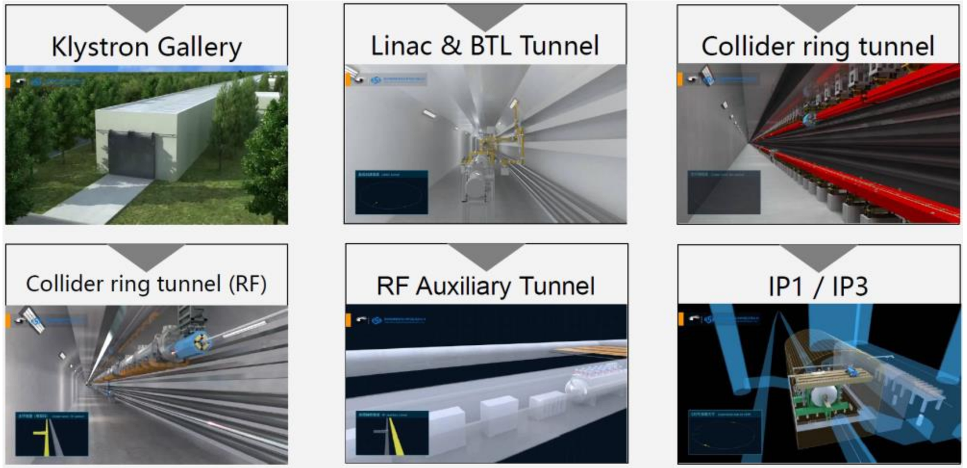


Geology of Candidate Sites and Science Cities

Three sites were presented at the CEPC2021 workshop

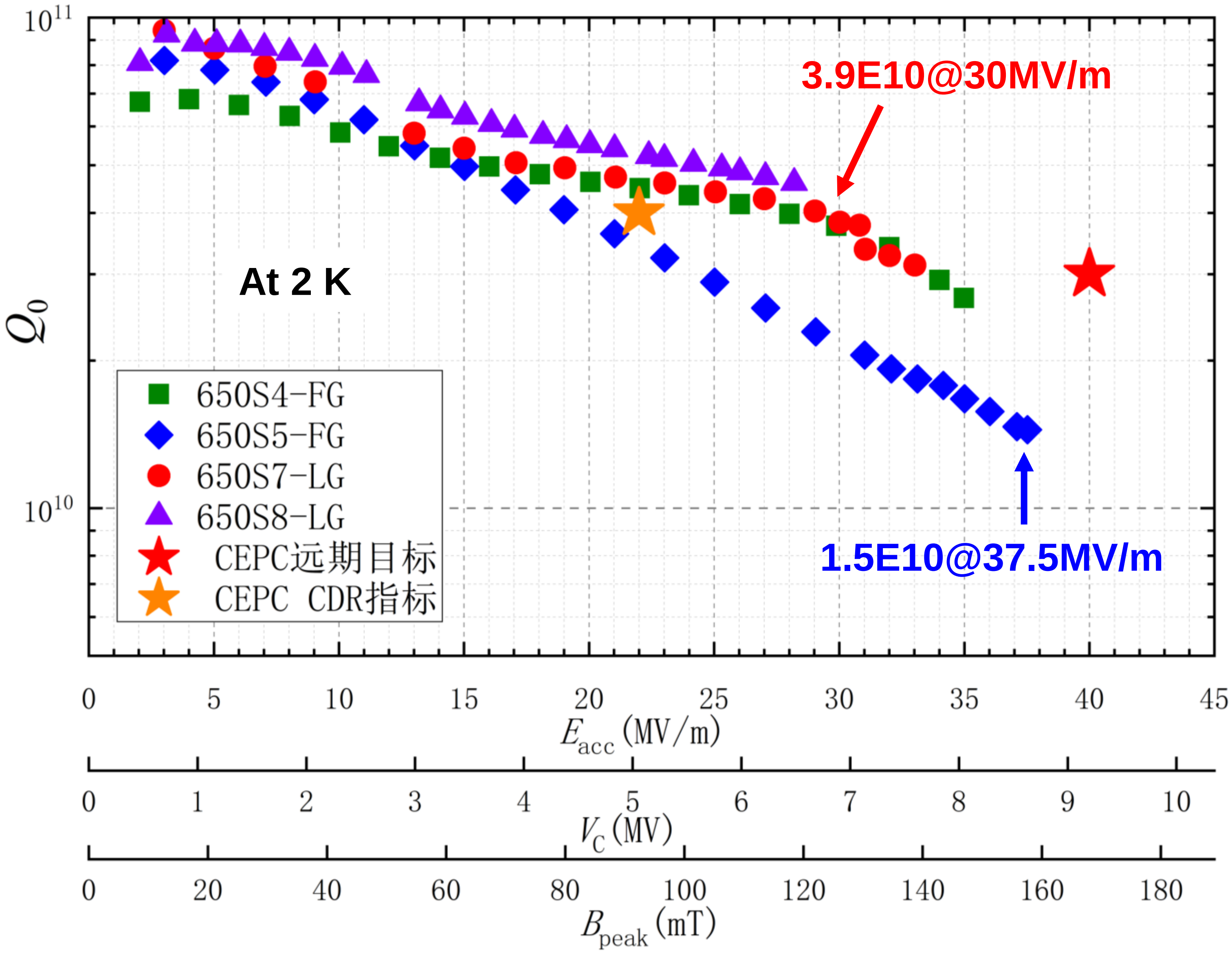






CEPC R&D: High Q SCRF 650 MHz 1-Cell Cavity

➤ **IHEP achieved Q_0=3.9E10@30 MV/m (650MHz 1-cell SCRF Cavity)**



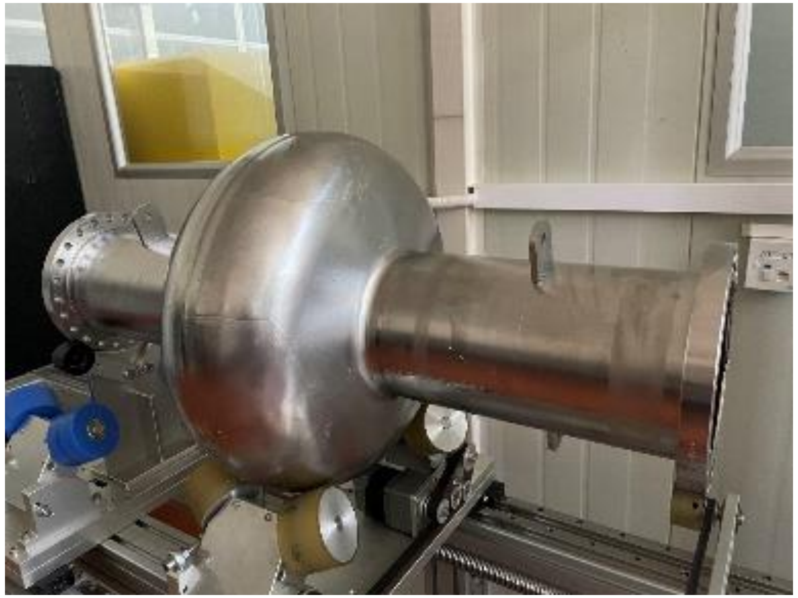
CEPC CDR Goal:

Q_0 = 3.0E10 @ 22 MV/m

Test Results:

Q_0 = 3.9E10 @ 30 MV/m

Q_0 = 1.5E10 @ 37.5 MV/m



Current CEPC Organization (only for Chinese)

October 2021

Institutional Board
YN GAO (PKU)
J. GAO (IHEP)

Steering Committee
YF WANG (IHEP),….

IAC
YK Kim (Chair)

Barry Barish, Caltech
Hesheng Chen, IHEP
Michel Davier, LAL
Marcel Demarteau, ORNL
Brian Foster, DESY
Rohini Godbole, CHEP, Bangalore
David Gross, UCSB
George Hou, Taiwan
Peter Jenni, CERN & Freiburg
Young-Kee Kim (Chair), Chicago
Eugene Levichev, BINP
Lucie Linssen, CERN
Joe Lykken, Fermilab
Luciano Maiani, U. Rome
Michelangelo Mangano, CERN
Hitoshi Murayama, Berkeley & IPMU
Tatsuya Nakada, EPFL
Katsunobu Oide, CERN & KEK
Robert Palmer, BNL
John Seeman, SLAC
Ian Shipsey, Oxford
Steinar Stapnes, CERN
Geoffrey Taylor, Melbourne
Maria Enrica Biagini, INFN-LNF

Project Director
XC LOU (IHEP)
HJ YANG (SJTU)

International Accelerator Review Committee

International Detector R&D Review Committee

Accelerator
J. GAO (IHEP)
JY Tang (SPPC,IHEP)
CH YU (IHEP)
YH LI (IHEP)

Theory
HJ HE (SJTU)
JP MA (ITP)
XG HE (SJTU)

Detector
Joao Costa (IHEP)
JC Wang (IHEP)
JB LIU (USTC)

Tasks：
Intl Relation– J GAO
PR – YN GAO
Conf. – J Shan
TDR – XC Lou et al.
……

IARC and IDRDC

International Accelerator Review Committee

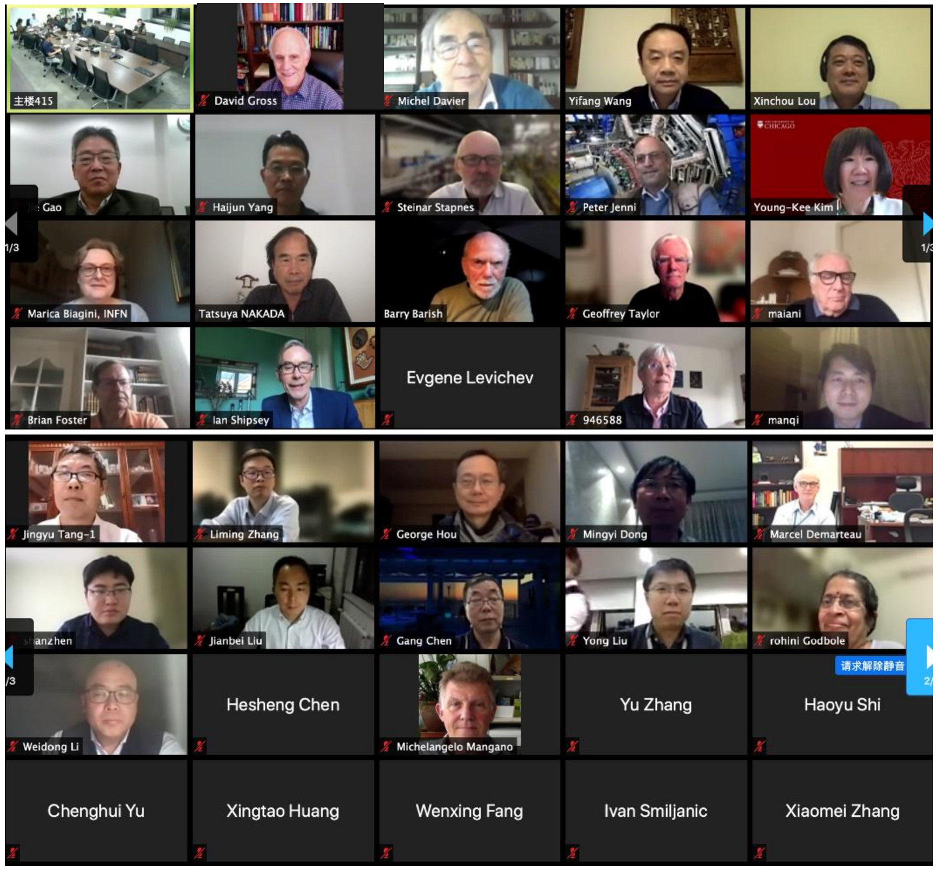
- Phillip Bambade, LAL
- Marica Enrica Biagini (Chair), INFN
- Brian Foster, DESY/U.Hamburg & Oxford U
- In-Soo Ko, POSTTECH
- Eugene Levichev, BINP
- Katsunobu Oide, CERN & KEK
- Anatolii Sidorin, JINR
- Steinar Stapnes, CERN
- Makoto Tobiyama, KEK
- Zhentang Zhao, SINAP
- Norihito Ohuchi, KEK
- Carlo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

The 7th CEPC IAC Meeting

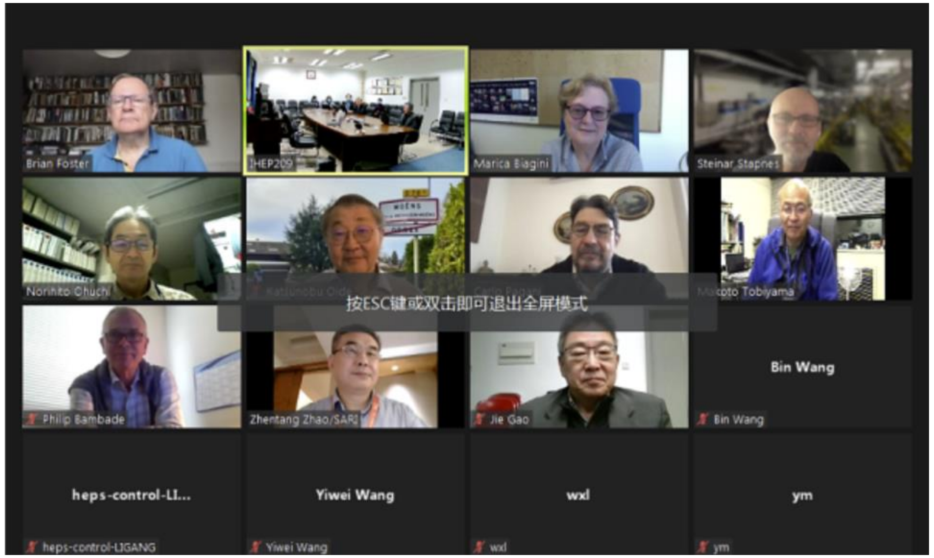
- The 7th CEPC IAC meeting (online) was held on November 1-3, 2021
- Nine talks about CEPC overall progress & technical details, with discussion sessions
- The IAC presented an advisory report with many recommendations on Nov. 5, 2021

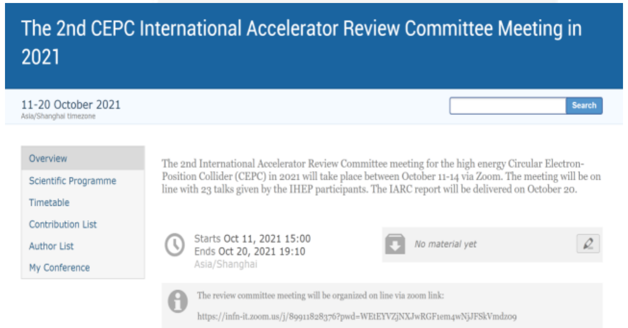


Date and Time	Topics	Speaker
Nov. 1, 20:10 – 20:55	Overview of the CEPC Project and Implementation of 2020 IAC Recommendations	Haijun Yang
Nov. 1, 20:55 – 21:45	CEPC Accelerator	Jie Gao
Nov. 1, 22:00 – 22:45	CEPC Detector R&D, Collaboration and Future	Joao Costa
	IAC Accelerator Group	
Nov. 2, 20:00 – 20:25	SppC Accelerator: HTS progress	Qingjin Xu
Nov. 2, 20:25 – 21:20	IARC Recommendation and Plan	Yuhui Li
Nov. 2, 21:20 – 21:55	Sites and Civil Engineering	Yu Xiao
	IAC Detector Group	
Nov. 2, 20:00 – 20:50	4th Detector Concept and Validation	Jianchun Wang
Nov. 2, 20:50 – 21:35	Physics and White Papers	Yaquan Fang
Nov. 2, 21:35 – 22:00	Software Development	Weidong Li
Nov. 3, 20:00 – 22:00	Discussions sessions (Management, Accelerator, Detector)	

CEPC Accelerator R&D: IARC Meetings

- In 2021, two online International Accelerator Review Committee (IARC) meetings took place,
  - May (11 talks)
  - October (22 talks)
- IARC delivered two dedicated review reports





May, 2021: https://indico.ihep.ac.cn/event/14295

October, 2021: https://indico.ihep.ac.cn/event/15177

The 2021 CEPC International Accelerator Review Committee

Review Report

May 19, 2021

Overview

The CEPC International Accelerator Review Committee was held remotely due to the Covid-19 pandemic on May 11th and 12th 2021. This is the second IARC meeting.

The Circular Electron Positron Collider (CEPC+SppC) Study Group, currently hosted by the Institute of High Energy Physics of the Chinese Academy of Sciences, completed the conceptual design of the CEPC accelerator in 2018. As recommended by the CEPC International Advisory Committee (IAC), the group began the Technical Design Report phase for the CEPC accelerator in 2019, with a completion target year of 2022. Meanwhile an International Accelerator Review Committee (IARC) has been established to advise on all matters related to CEPC accelerator design, the R&D program, the study of the machine-detector interface region, and the compatibility with an upgrade to the t-tbar energy region, as well as with a future SppC. The first IARC meeting took place in Beijing during the CEPC international workshop on Nov. 18-21, 2019.

2021 Second CEPC IARC Meeting

IARC Committee

October 20th, 2021

The Circular Electron Positron Collider (CEPC) and Super Proton-Proton Collider (SppC) Study Group, currently hosted by the Institute of High Energy Physics of the Chinese Academy of Sciences, completed the conceptual design of the CEPC accelerator in 2018. As recommended by the CEPC International Advisory Committee (IAC), the group began the Technical Design Report (TDR) phase for the CEPC accelerator in 2019, with a completion target year of 2022. Meanwhile an International Accelerator Review Committee (IARC) has been established to advise on all matters related to CEPC accelerator design, the R&D program, the study of the machine-detector interface region, and the compatibility with an upgrade to the t-tbar energy region, as well as with a future SppC.

The second 2021 CEPC International Accelerator Review Committee was held remotely due to the Covid-19 pandemic on October 11th to 14th 2021.

A total of 22 talks were presented on a variety of topics.

1 General comments

The Committee congratulates the CEPC team for the work performed in the last months and presented at this meeting. In particular, the progress on the R&D of the hardware components looks very promising. The team has updated the table of parameters for the high-luminosity running, as well as the lattices and components for all accelerator systems: sources, Linac, Booster and Collider.

- **IARC provides positive feedbacks, reminds missing studies & inconsistency, stressing the difficulties of key prototypes, it helps to make CEPC accelerator design a credible and feasible scheme.**

CEPC Accelerator Design Improvement

- **High luminosities at H and Z factories**
  - Optimization of parameters, improving dynamic aperture(DA) to include errors and more effects
  - New lattice for high luminosity at Higgs
  - New RF section layout
  - More detailed study of MDI
  - Optimization of the booster design and magnets
  - A new alternative design of the LINAC injector
  - A new plasma injector design
  - Injection design
  - ……
- **Accelerator Review Committee**
  - Recommended by the IAC, established & met in November, 2019
  - Two IARC meeting held in 2021

CDR scheme (Higgs)

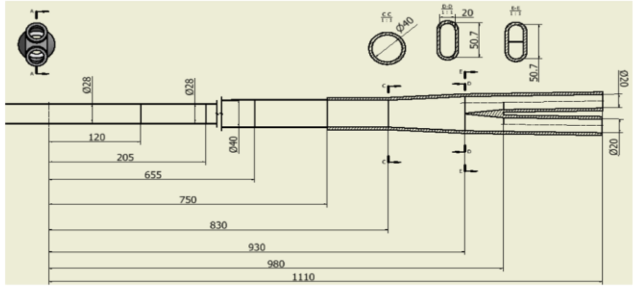
- ✓ **L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Emittance=1.2nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

High luminosity scheme (Higgs)

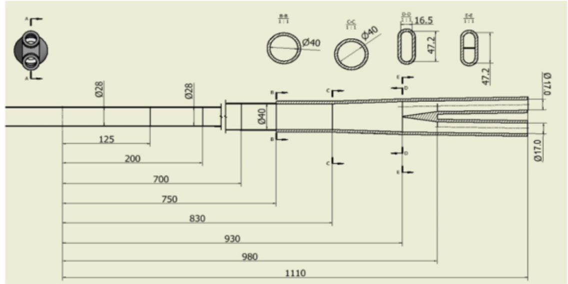
- ✓ **L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.68nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

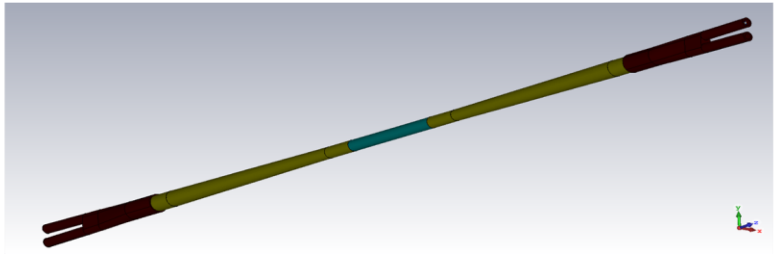
Change of IP chamber

CDR — Be pipe: 28mm, SCQ Beam pipe:20mm



High luminosity — Be pipe: 28mm, Beam pipe:17mm



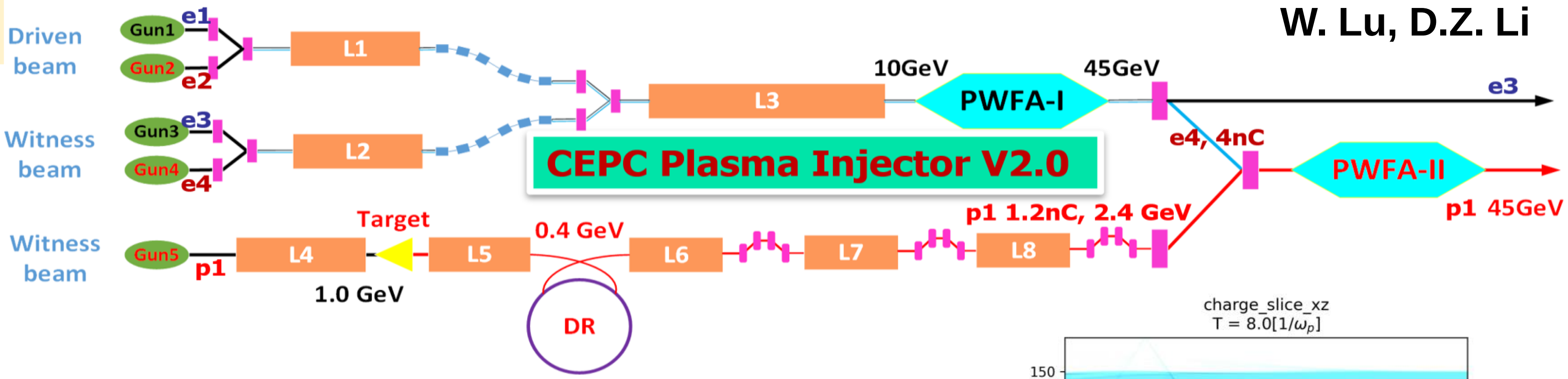


CEPC Accelerator: Plasma Injector

CEPC Plasma Injector V2.0

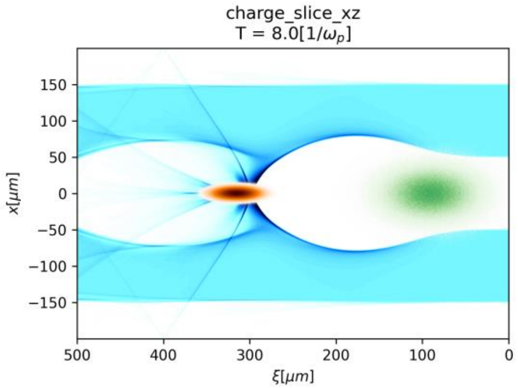
IHEP, THU, BNU

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

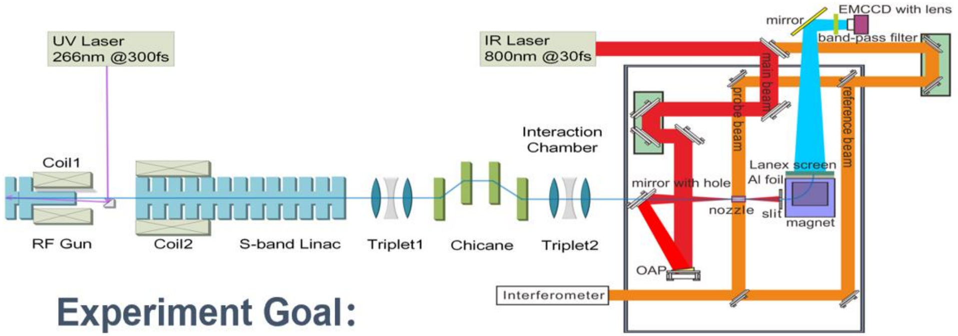


High efficiency uniform wakefield acceleration of a positron beam using stable asymmetric mode in a hollow channel plasma
S.Y. Zhou, W. Lu, et al., arXiv: 2012.06095

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

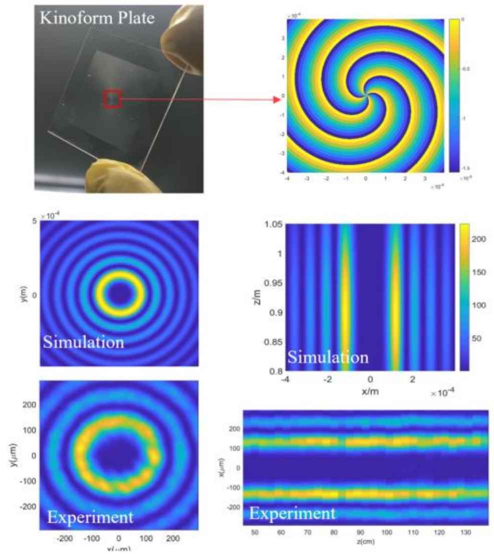


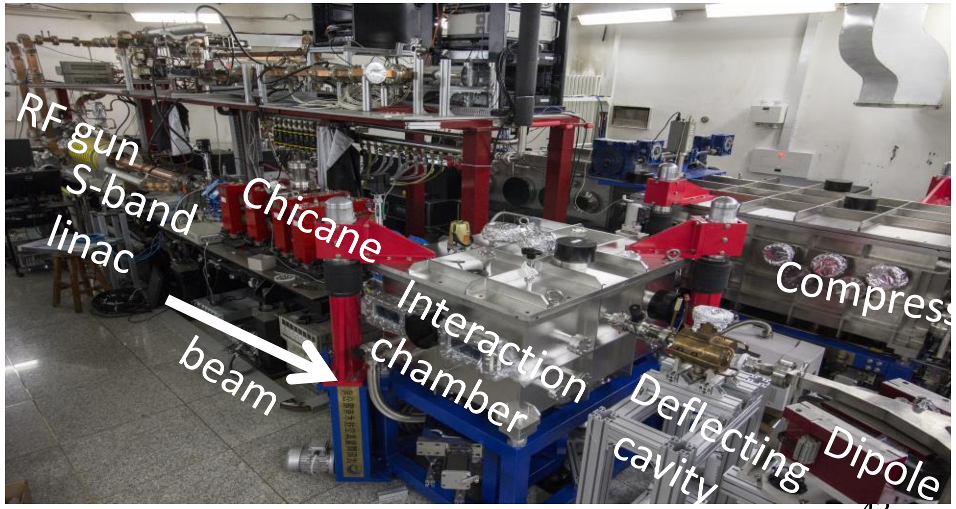
Plasma dechirper exp at SXFEL



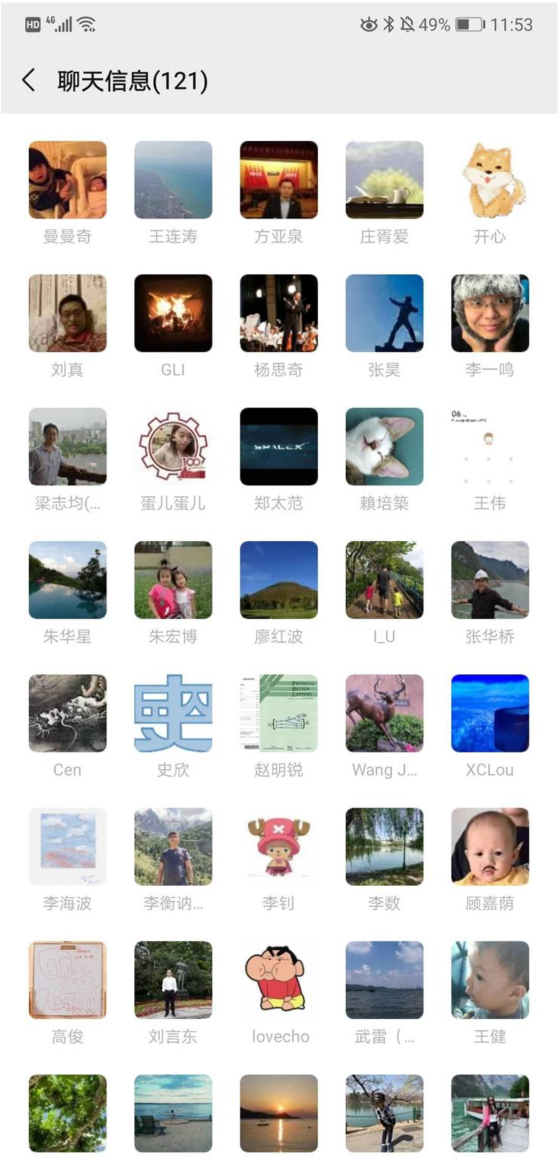
Experiment Goal:

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





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

CEPC Study for Snowmass: Detector R&D

Snowmass — Letters of Intent

14 CEPC-Related Detector LoI submitted

https://indico.ihep.ac.cn/event/12410/

Detector R&D

Conveners: Joao Guimaraes Costa, WANG Jianchun, Mr. Manqi Ruan (IHEP)

15:00 **CEPC Detectors Overview LoI** *1'*
CEPC Detector Overview LOI
SNOWMASS21-EF1_EF4-IF9_IF0-260.pdf
Speakers: Joao Guimaraes Costa, Mr. Manqi Ruan (IHEP), WANG Jianchun
Material: **Paper** **Slides**

15:02 **IDEA Concept** *1'*
Speaker: Franco Bedeschi (INFN-Pisa)
Material: **Paper**

15:03 **Dual Readout Calorimeter** *1'*
Speaker: Roberto Ferrari (INFN)
Material: **Paper**

15:04 **Drift Chamber** *1'*
Speaker: Franco Grancagnolo
Material: **Paper**

15:06 **mu-RWELL (muons, preshower)** *1'*
Speaker: Paolo Giacomelli (INFN-Bo)
Material: **Paper**

15:08 **Time Detector LoI** *1'*
Speaker: Prof. Zhijun Liang (IHEP)
Material: **Slides**

15:09 **Key4hep** *1'*
Speakers: Dr. Weidong Li (高能所), Dr. Tao LIN (高能所), Prof. Xingtao Huang (Shandong University), Wenxing Fang (Beihang University)
Material: **Slides**

15:10 **PFA Calorimeter** *1'*
Speakers: Haijun Yang (Shanghai Jiao Tong University), Dr. Jianbei Liu (University of Science and Technology of China), Dr. Yong Liu (Institute of High Energy Physics)
Material: **Slides**

15:11 **High Granularity Crystal Calorimeter** *1'*
Speaker: Dr. Yong Liu (Institute of High Energy Physics)
Material: **Paper** **Slides**

15:12 **Muon Scintillator Detector** *1'*
Speaker: Dr. Xiaolong Wang (Institute of Modern Physics, Fudan University)
Material: **document**

15:13 **Vertex LoI** *1'*
Speaker: Prof. Zhijun Liang (IHEP)
Material: **Slides**

15:15 **MDI LoI** *1'*
Speaker: Dr. Hongbo ZHU (IHEP)
Material: **Slides**

15:16 **TPC LoI** *1'*
Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)
Material: **Slides**

15:17 **Solenoid R&D LoI** *1'*
Speaker: Dr. Feipeng NING (IHEP)
Material: **Slides**

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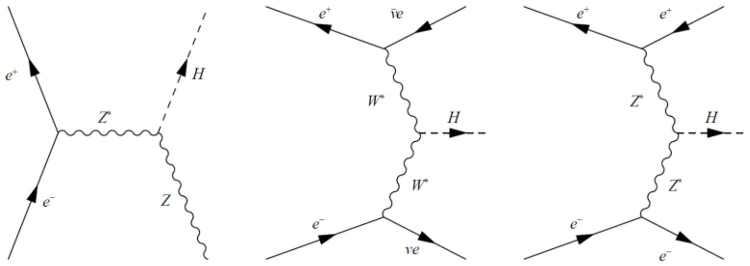
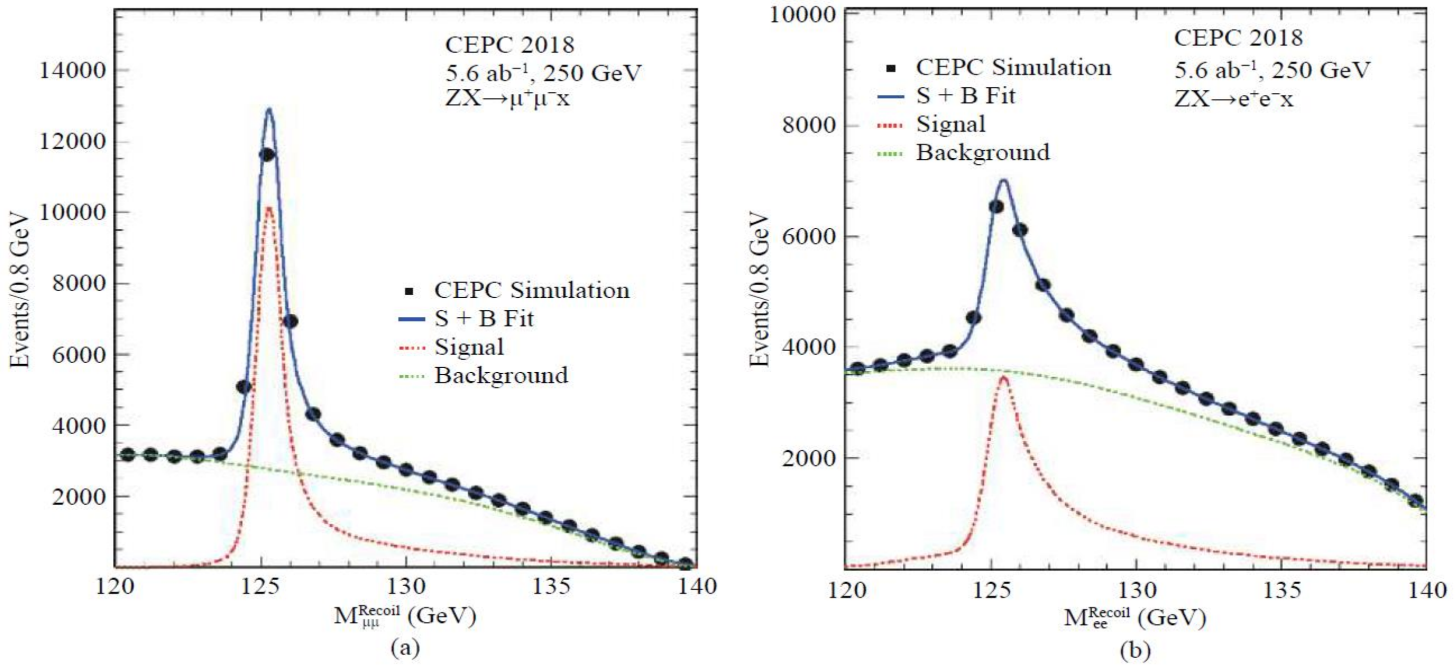
CEPC Physics Performance (CDR)

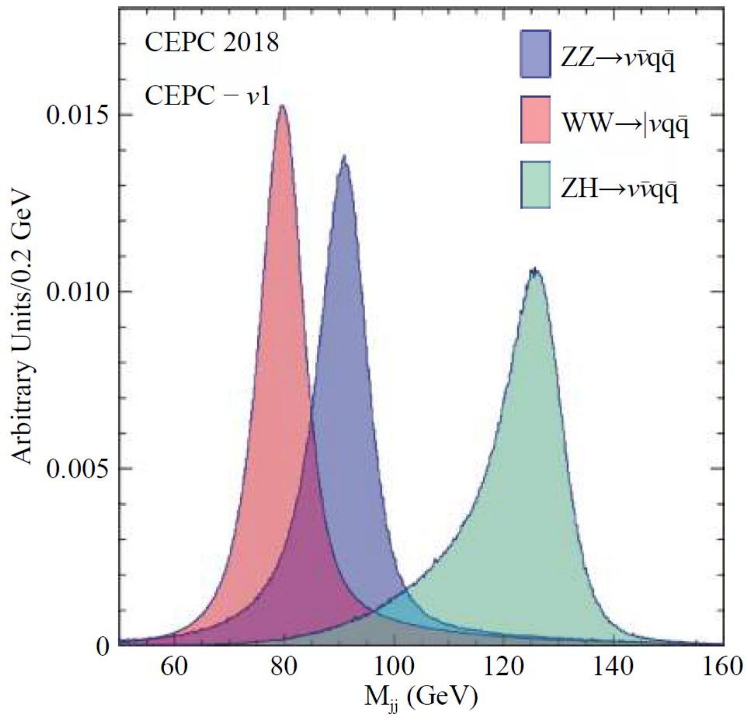
e^+e^- annihilations at the CEPC



- 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



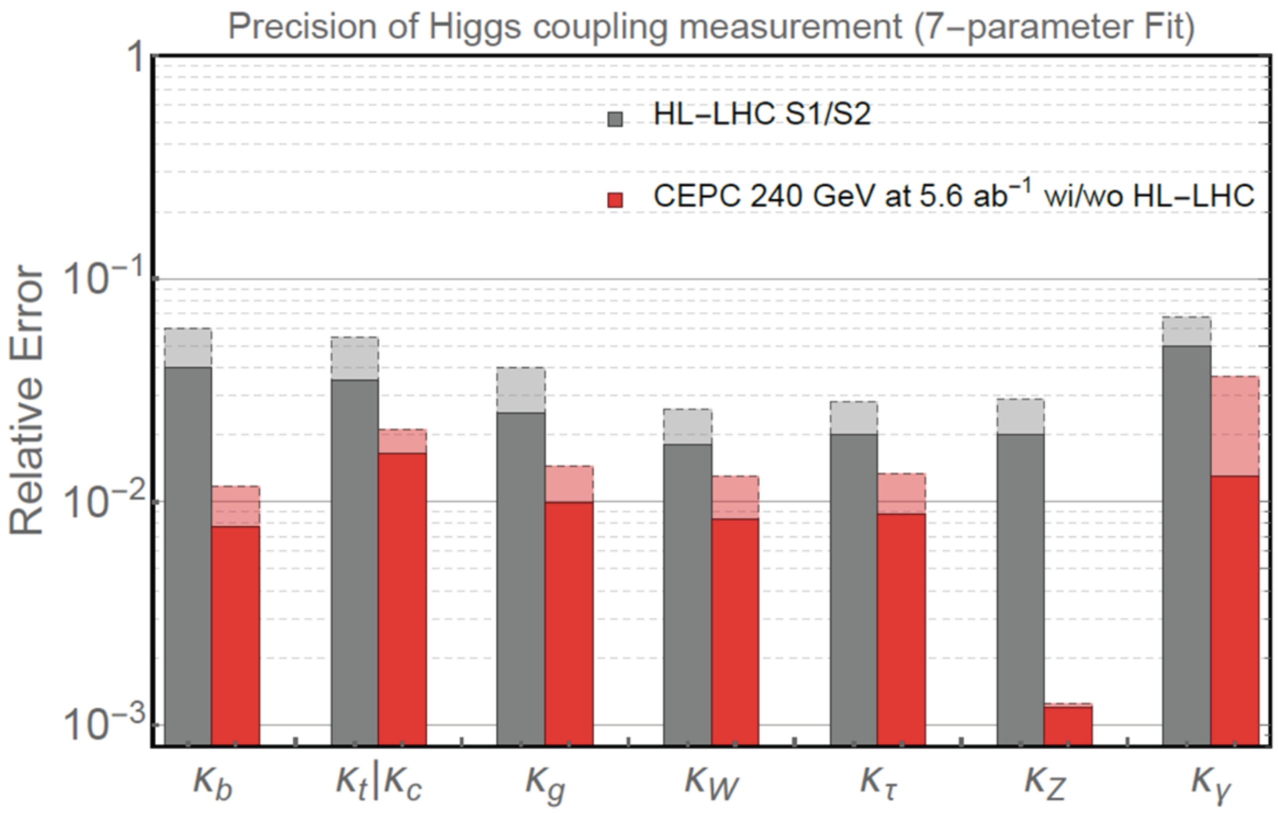
Chinese Physics C Vol. 43, No. 4 (2019) 043002



CEPC Physics Performance (CDR)

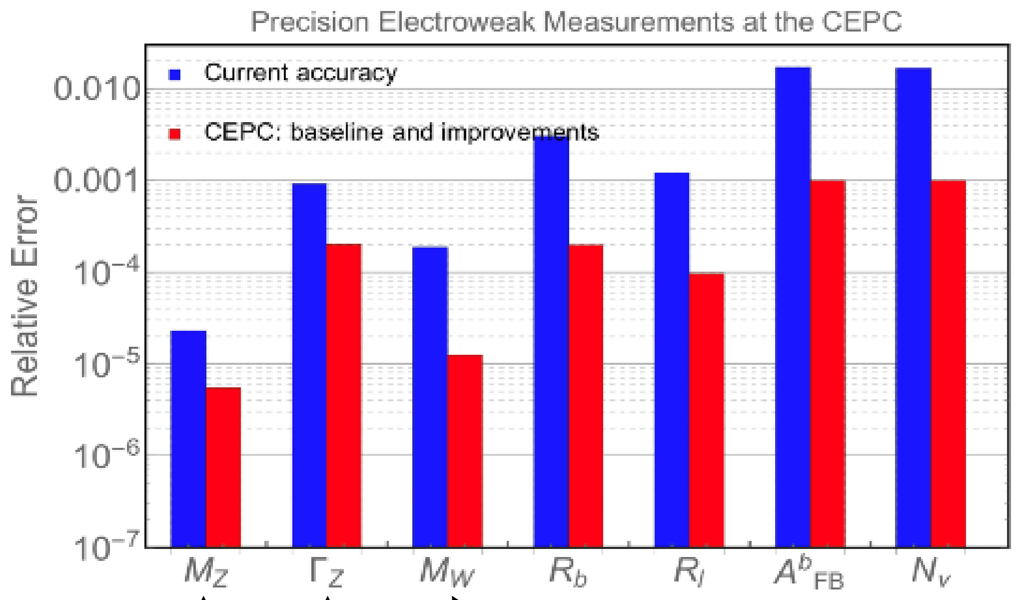
Order of magnitude improvement in precision ⇒ Unknown / discoveries

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



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

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



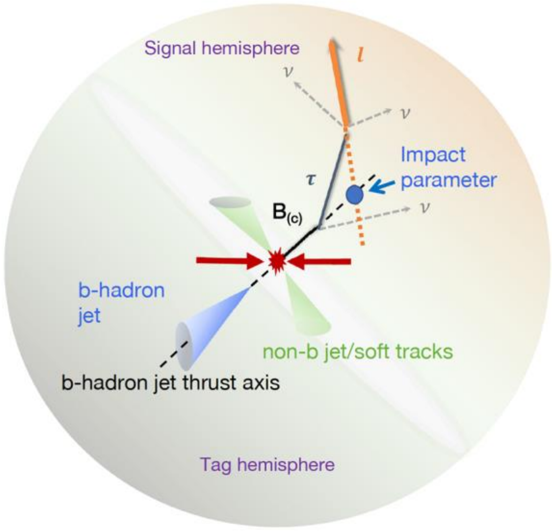
~2→0.5 MeV

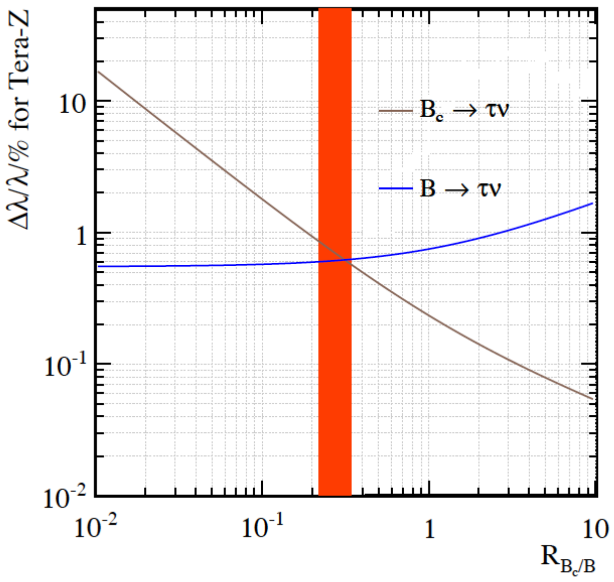
~13→1 MeV

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

CEPC Flavor Physics

Analysis of $B_c \to \tau\nu_\tau$ at CEPC → |Vcb|~O(1%)
T. Zheng et.al., CPC 45, No. 2 (2021)





Chinese Physics C Vol. 45, No. 2 (2021)

Analysis of $B_c \to \tau\nu_\tau$ at CEPC*

Taifan Zheng(郑太范)[1] Ji Xu(徐吉)[2] Lu Cao(曹璐)[3] Dan Yu(于丹)[4] Wei Wang(王伟)[2] Soeren Prell[5]
Yeuk-Kwan E. Cheung(张若筠)[1] Manqi Ruan(阮曼奇)[4†]

[1]School of Physics, Nanjing University, Nanjing 210023, China
[2]INPAC, SKLPPC, MOE KLPPC, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China
[3]Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany
[4]Institute of High Energy Physics, Beijing 100049, China
[5]Department of Physics and Astronomy, Iowa State University, Ames, IA, USA

Abstract: Precise determination of the $B_c \to \tau\nu_\tau$ branching ratio provides an advantageous opportunity for understanding the electroweak structure of the Standard Model, measuring the CKM matrix element $|V_{cb}|$, and probing new physics models. In this paper, we discuss the potential of measuring the process $B_c \to \tau\nu_\tau$ with τ decaying leptonically at the proposed Circular Electron Positron Collider (CEPC). We conclude that during the Z pole operation, the channel signal can achieve five-σ significance with $\sim 10^9$ Z decays, and the signal strength accuracies for $B_c \to \tau\nu_\tau$ can reach around 1% level at the nominal CEPC Z pole statistics of one trillion Z decays, assuming the total $B_c \to \tau\nu_\tau$ yield is 3.6×10^6. Our theoretical analysis indicates the accuracy could provide a strong constraint on the general effective Hamiltonian for the $b \to c\tau\nu$ transition. If the total B_c yield can be determined to $O(1\%)$ level of accuracy in the future, these results also imply $|V_{cb}|$ could be measured up to $O(1\%)$ level of accuracy.

Test of Lepton-Flavor-Universality (LFU)
L.F. Li, T. Liu, JHEP 06 (2021) 064

	Experimental	SM Prediction
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01 [4]
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002 [5]
R_D	0.340 ± 0.030	0.299 ± 0.003
R_{D^*}	0.295 ± 0.014	0.258 ± 0.005

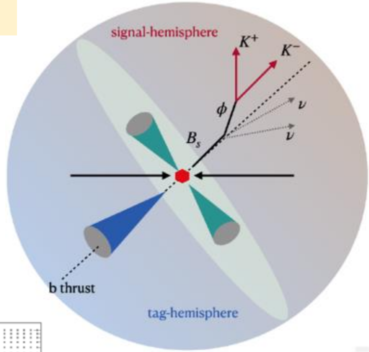
R_{K^*} & R_{D^*} anomalies at level of 2-3σ.

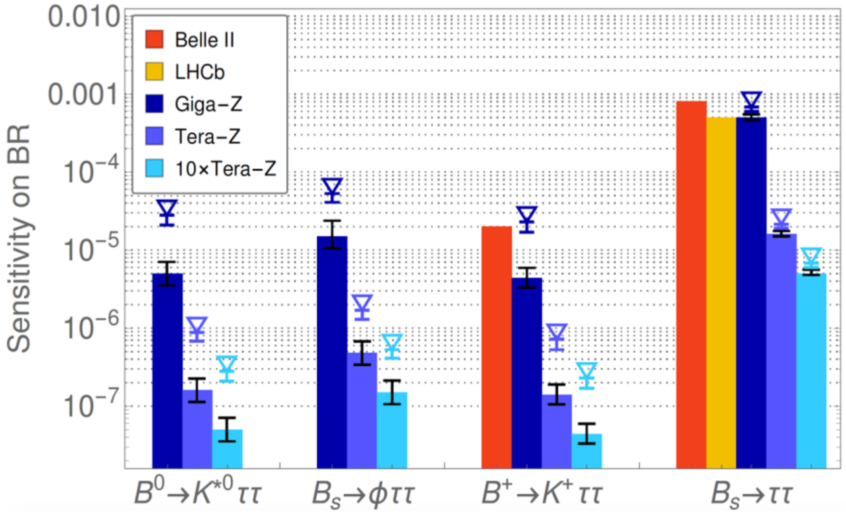
$$R_{K^{(*)}} \equiv \frac{BR(B \to K^{(*)}\mu^+\mu^-)}{BR(B \to K^{(*)}e^+e^-)}$$

$$R_{D^{(*)}} \equiv \frac{BR(B \to D^{(*)}\tau\nu)}{BR(B \to D^{(*)}\ell\nu)}$$

b→s $\tau^+\tau^-$ is motivated to address LFU violating puzzle involving 3rd generation lepton directly.

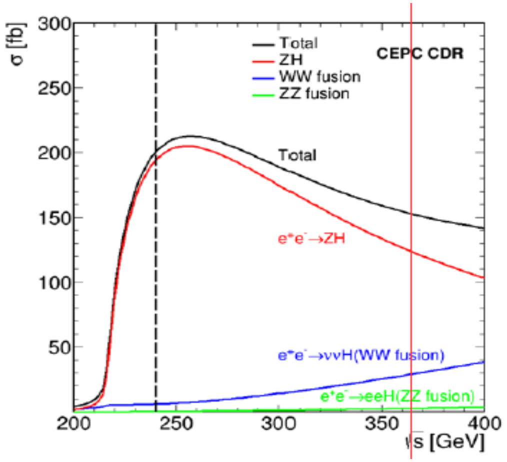
Channel	SM prediction for BR
$B^0 \to K^{*0}\tau^+\tau^-$	$(0.98 \pm 0.10) \times 10^{-7}$ [11]
$B_s \to \phi\tau^+\tau^-$	$(0.86 \pm 0.06) \times 10^{-7}$ [11]
$B^+ \to K^+\tau^+\tau^-$	$(1.20 \pm 0.12) \times 10^{-7}$ [11]
$B_s \to \tau^+\tau^-$	$(7.73 \pm 0.49) \times 10^{-7}$ [12]



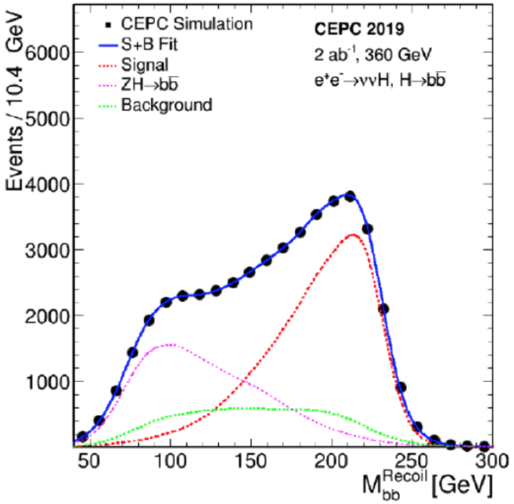


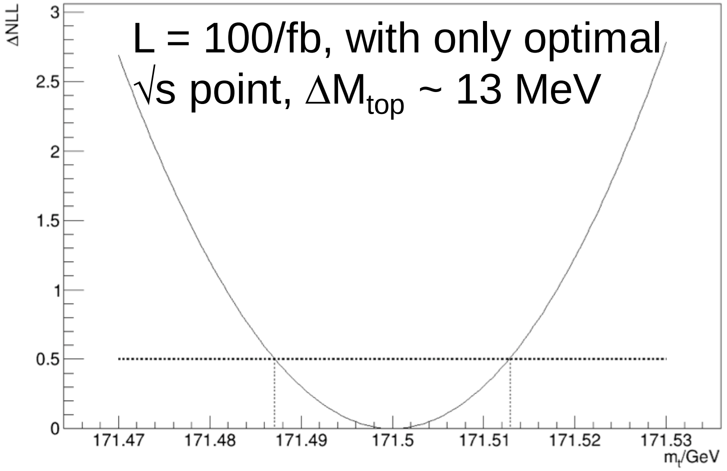
CEPC Physics at 360 GeV

- 360 GeV run provides critical inputs from the WW-fusion Higgs productions
- Useful for measuring $\kappa_W, \kappa_Z, \Gamma_h$, Global EFT fit
- With 2 ab^{-1}, H width precision ~ 1.4% (x2 improvement)

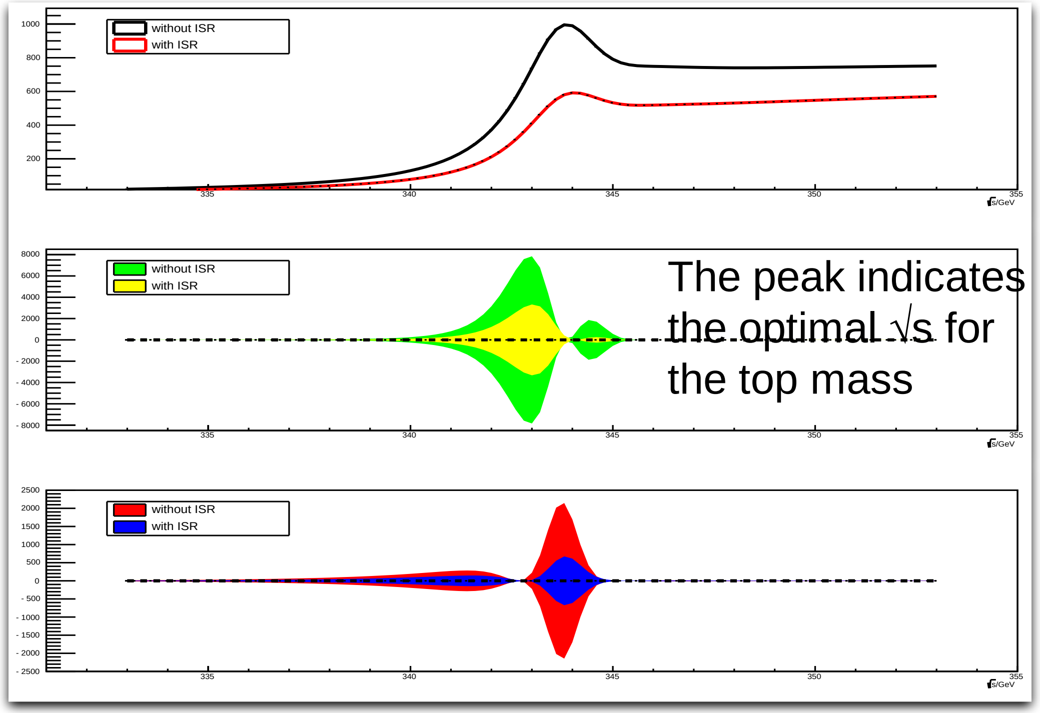


	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	ννH
any	0.50%	1%	\
$H \to bb$	0.27%	0.63%	0.76%
$H \to cc$	3.3%	6.2%	11%
$H \to gg$	1.3%	2.4%	3.2%
$H \to WW$	1.0%	2.0%	3.1%
$H \to ZZ$	7.9%	14%	15%
$H \to \tau\tau$	0.8%	1.5%	3%
$H \to \gamma\gamma$	5.7%	8%	11%
$H \to \mu\mu$	12%	29%	40%
$Br_{upper}(H \to inv.)$	0.2%	\	\
$\sigma(ZH) * Br(H \to Z\gamma)$	16%	25%	\
Width	2.8%	1.4%	





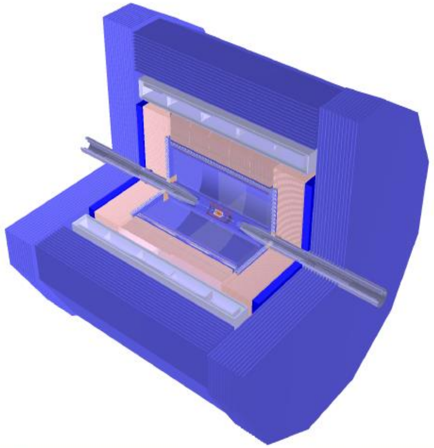
- Currently we study the top mass and width using tt threshold method:
  - One order of magnitude better precision than the LHC is expected
  - A quick energy scan with low lumi to find the optimal energy point before data taking with the full lumi. is proposed

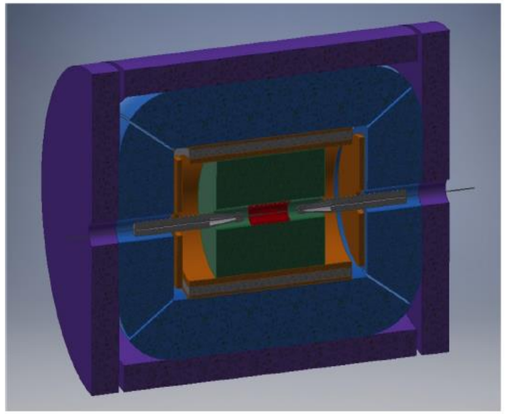


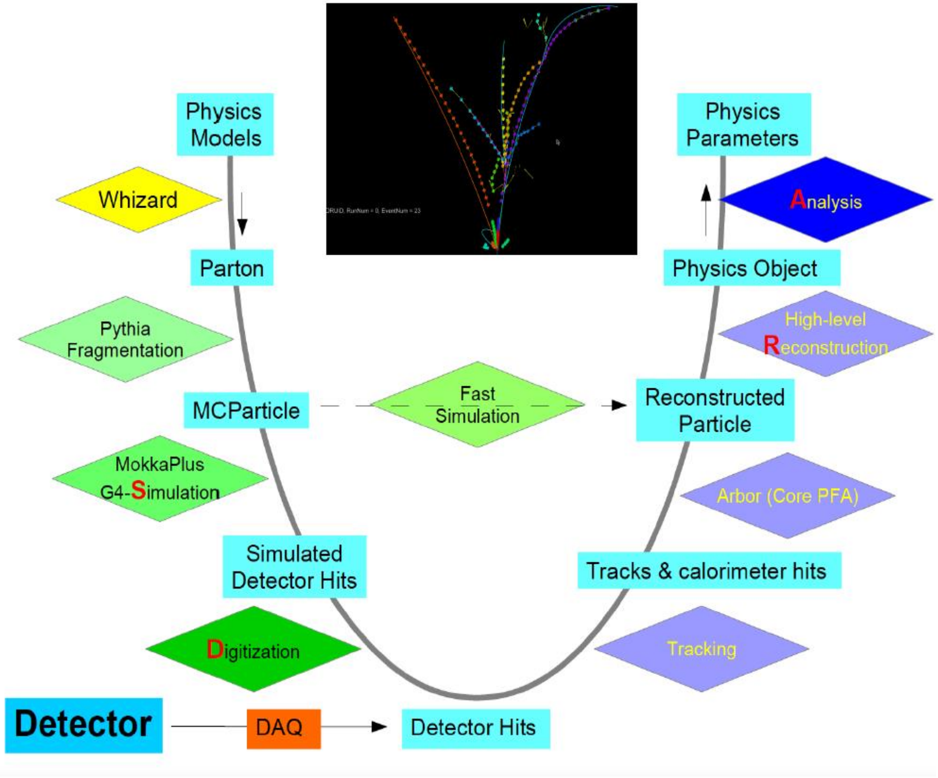
CEPC Detector and Software

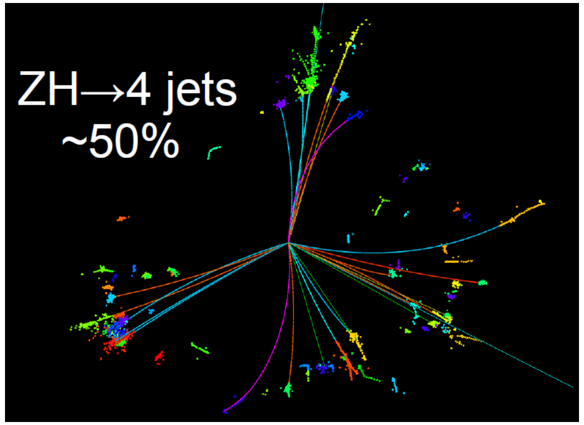
Recent added CEPC software applications:

- **Software for SiTrk + DC design, detector description and track fitting**
- **Cluster counting method of Drift Chamber (DC)**
- **Simulation and simplified digitization of the crystal bar ECal**

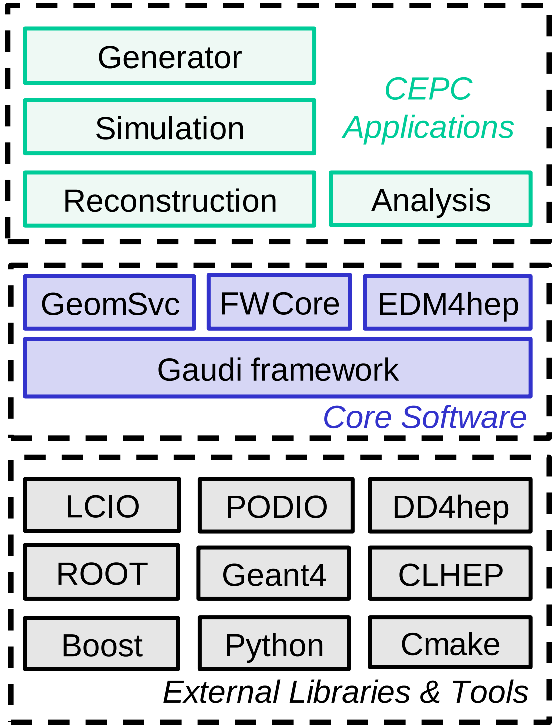








CEPCSW Structure



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

Requirements of CEPC Detector

The physics motivations dictate our selection of detector technologies

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

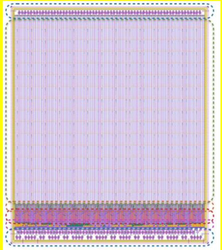
- **Flavor physics ⇒ Excellent PID, better than 2σ separation of π/K at momentum up to ~20 GeV.**
- **EW measurements ⇒ High precision luminosity measurement, $\delta L / L \sim 10^{-4}$.**

Selection of Detector R&D

Pixel Vertex

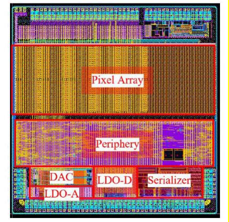
JadePix

Arcadia

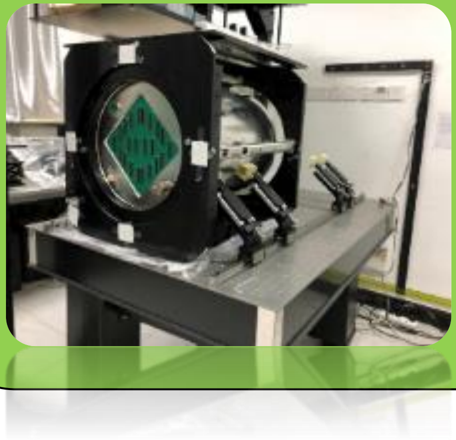


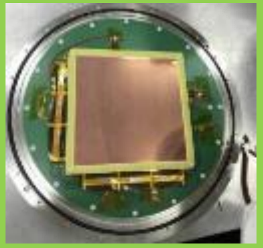
CPV test

TaichuPix

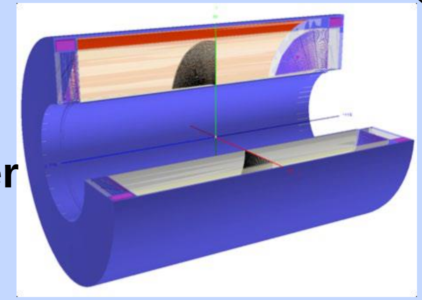


TPC Prototype





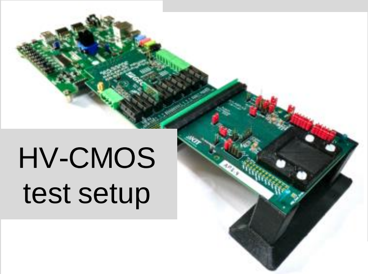
Drift Chamber



AD9689 – 2000 EBZ

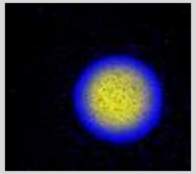
Xilinx KCU105

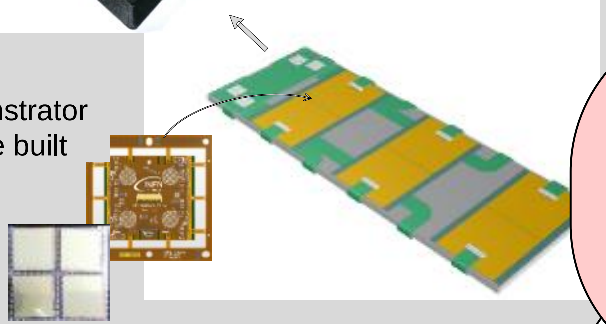
HV-CMOS Tracker



HV-CMOS test setup

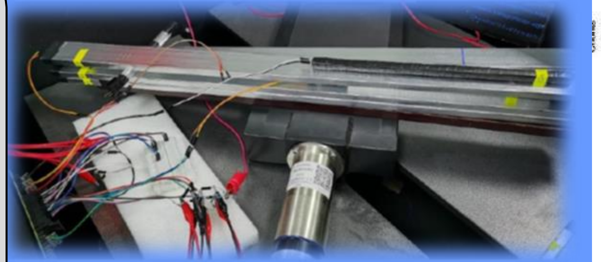
Fe source test

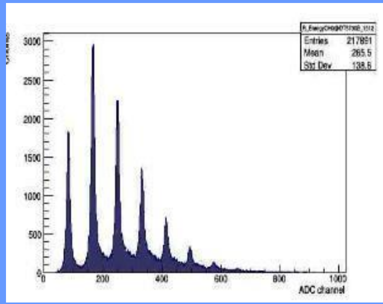




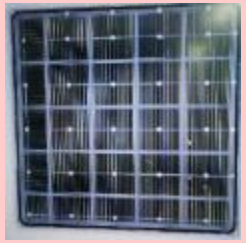
Demonstrator To be built

Scintillator Bar Muon

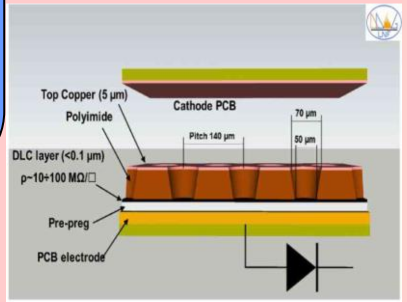


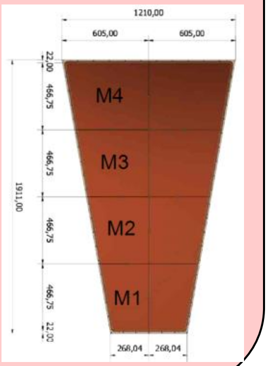


LGAD ToF

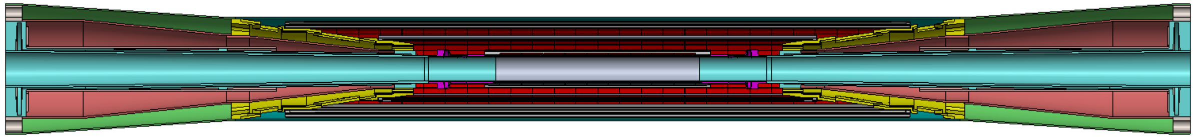


μRWELL for Muon



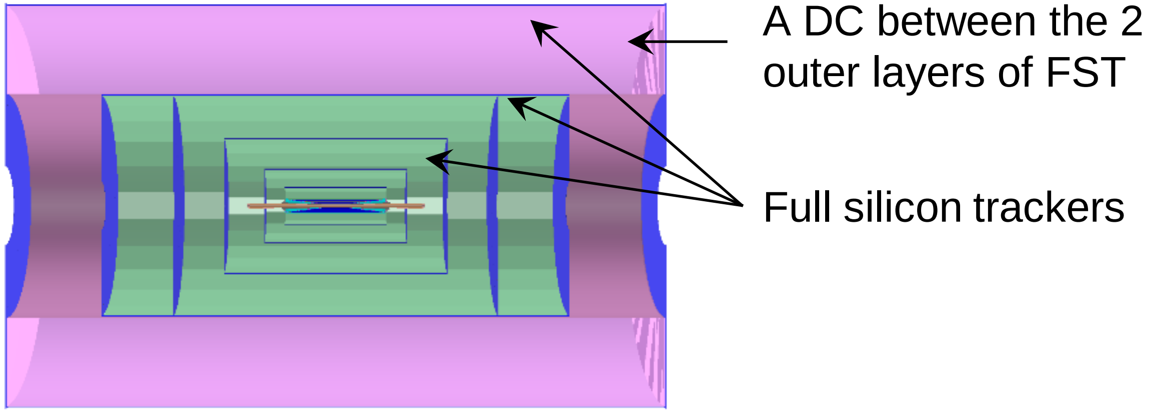


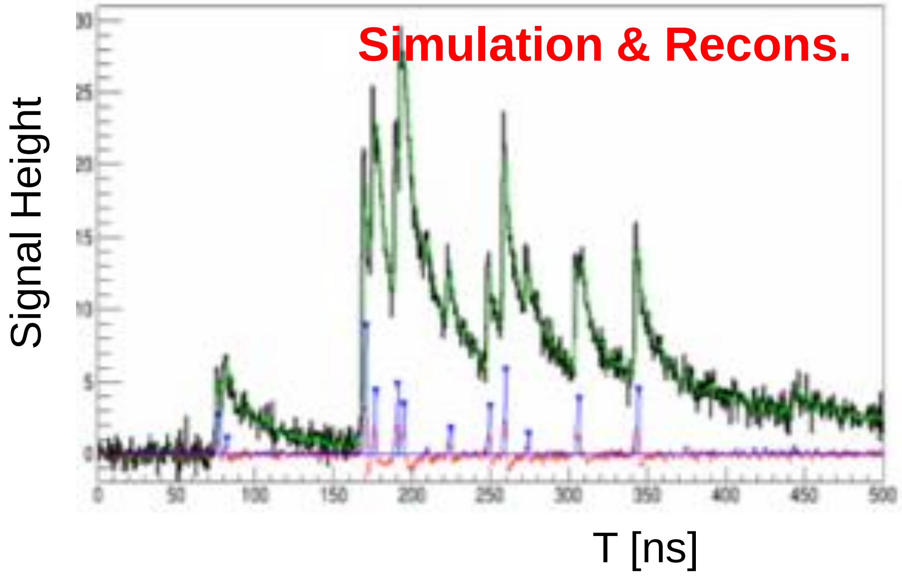
Beampipe Design

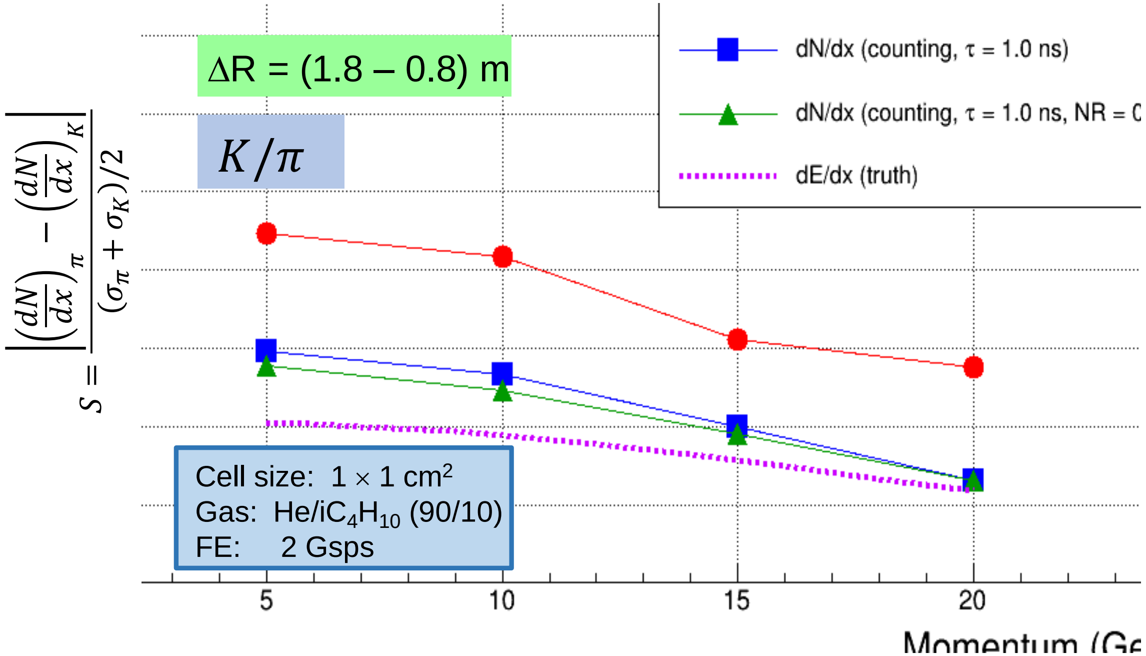


A Drift Chamber That is Optimized for PID

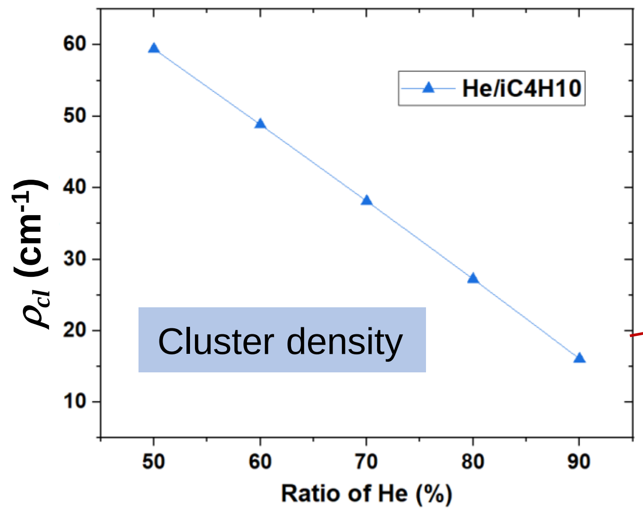
- Goal: 2σ π/K separation at P < ~ 20 GeV/c.
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm development.



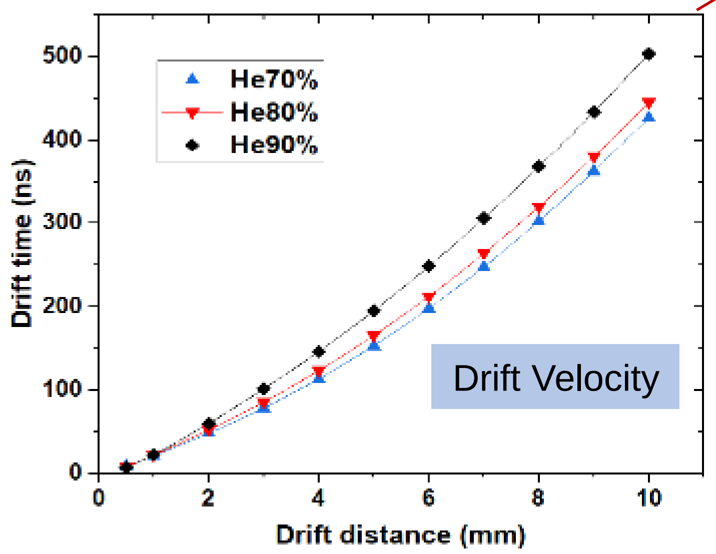


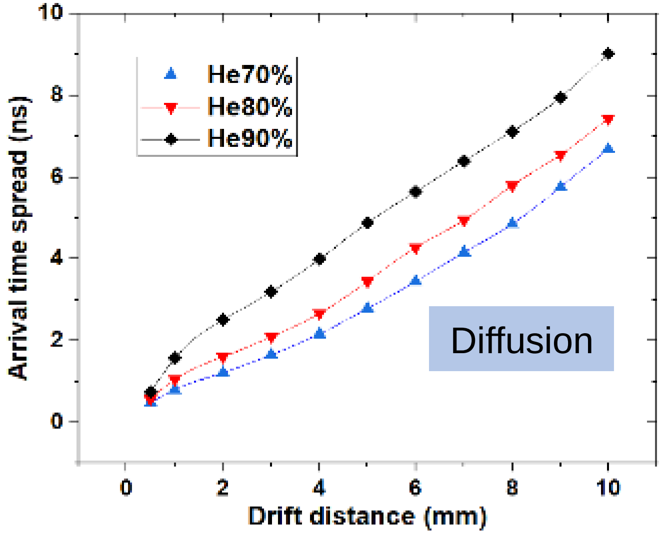


Attempts to Optimize A PID Drift Chamber



$$\frac{\sigma_{dN/dx}}{dN/dx} \propto \frac{1}{\sqrt{L \cdot \rho_{cl} \cdot \varepsilon}}$$

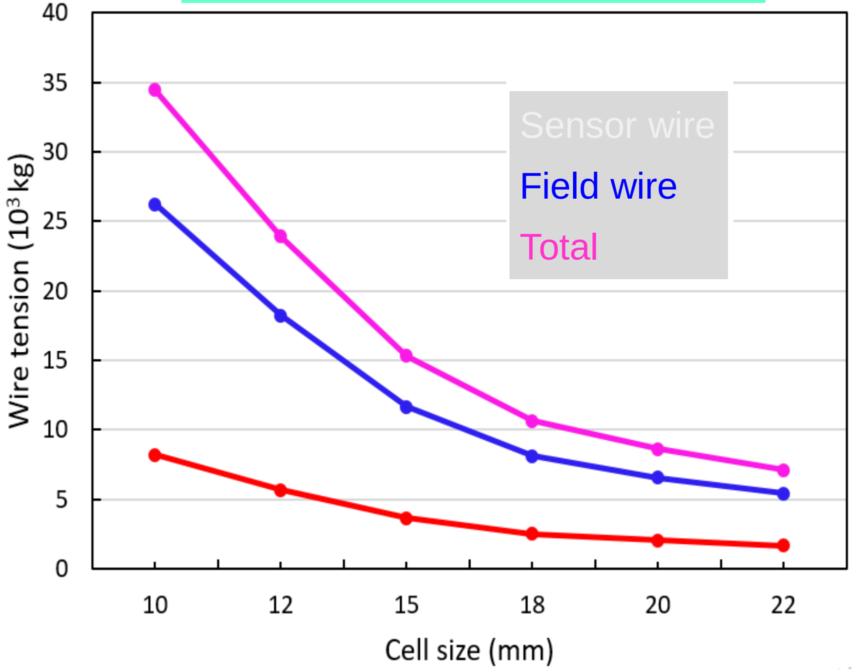




- Reducing the number of cells
  - Has small effect on dN/dX.
  - Reduce support structure material
  - Reduce construction difficulty

L~5.4 m, Sag ~ 240 μm

ΔR = (1.8 – 0.6) m, S:F ~ 1:3



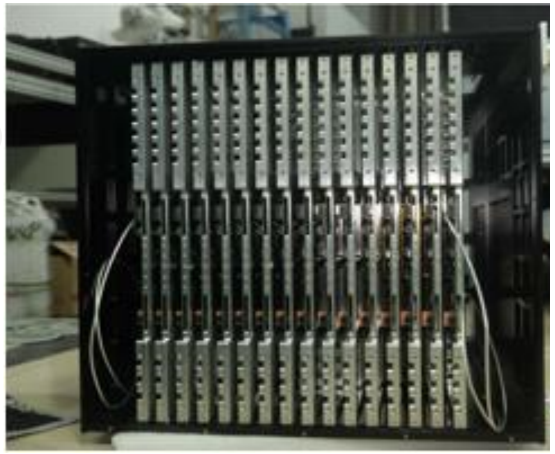
CEPC R&D: ScW-ECAL Prototype

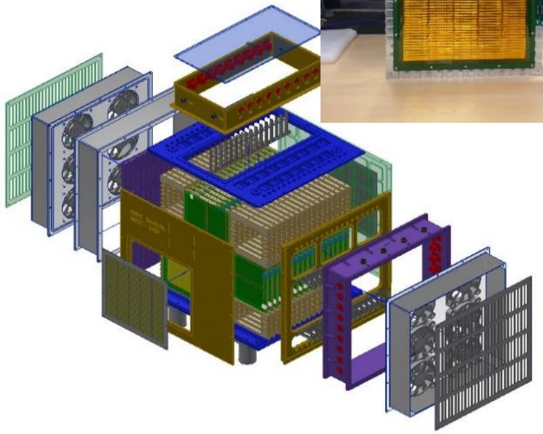
PFA ECAL → Tungsten → Analog → Silicon / Scintillator

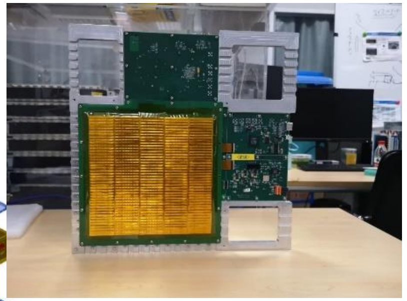
MOST 1

Goal of ECAL+HCAL+…

4% BMR, e.g. in ($Z \to \nu\nu$) ($H \to gg$)







ScECAL prototype with 6700 channels

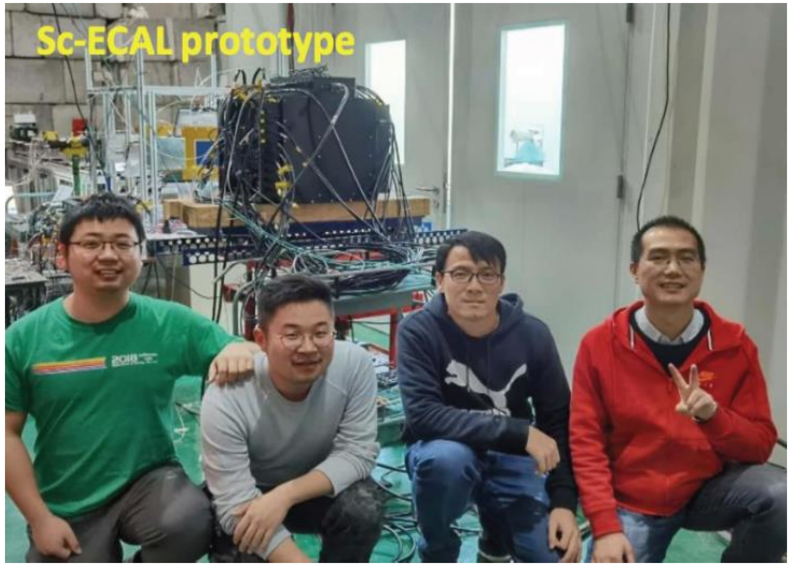
32 layers (EBU), 22 x 22 cm^2, ~22X_0

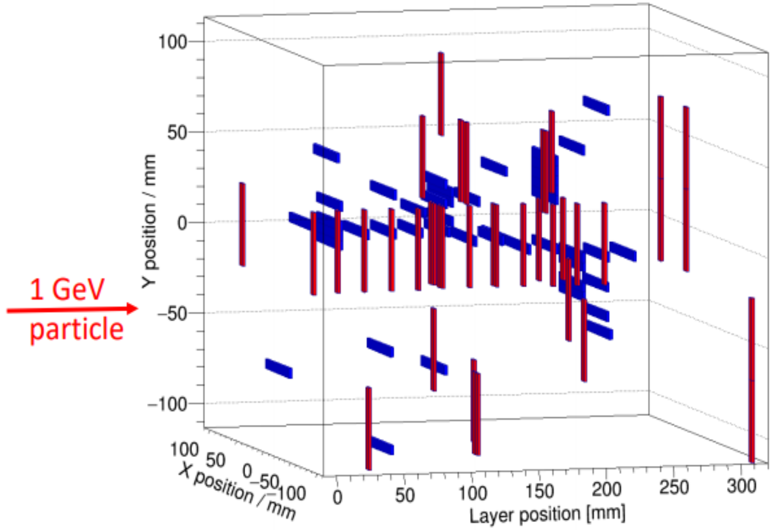
Scintillator (5×45mm^2) + MPPC S12571

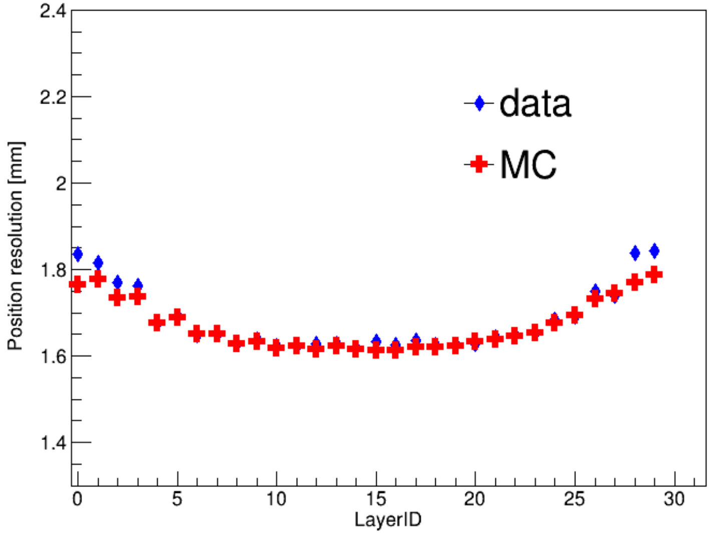
Embedded FEE (192 SPIROC2E ASICs)

It has been tested with cosmic rays & an electron beam at IHEP (Nov. 2020).

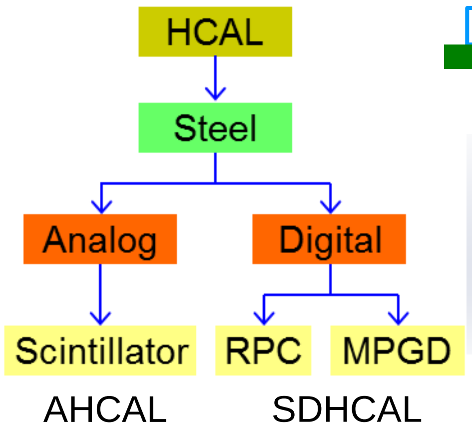
Cell Granularity: 5mm × 5mm
Position resolution: 1.6-1.8mm

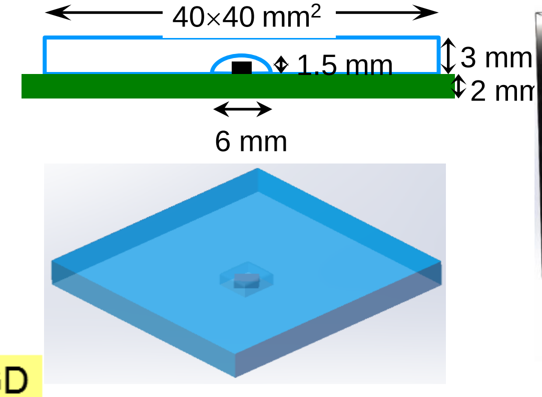


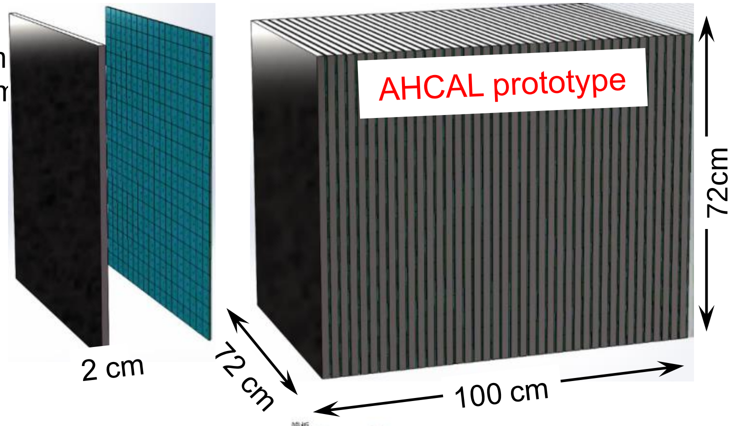


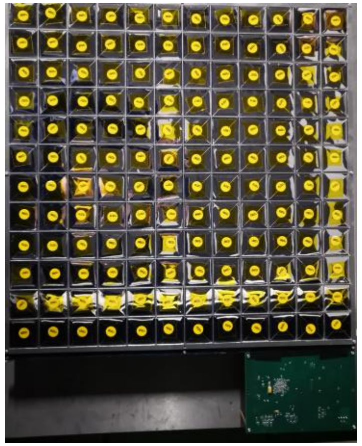


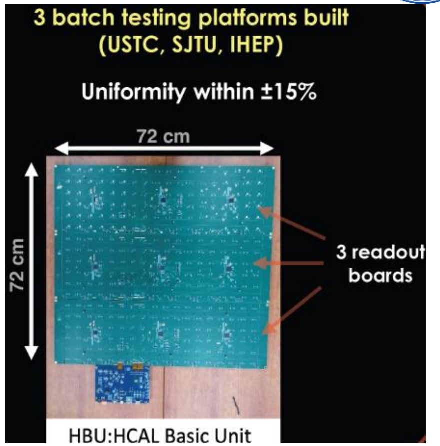
CEPC R&D: PFA HCAL



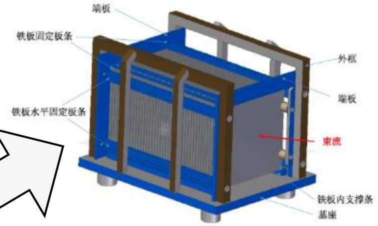


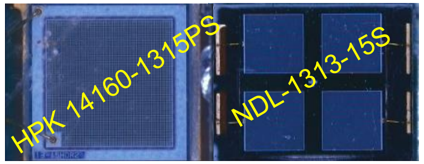






- **AHCAL with Scint.+SiPM (USTC, IHEP, SJTU)**
  - Prototype in production, size 72×72×100 cm³,
  - 40 layers, Fe+Sct+SiPM+PCB=20+3+2=25mm,
  - 12960 Scintillators, cell size 40×40 mm²
  - SiPM: HPK 14160-1315PS and NDL-1313-15S

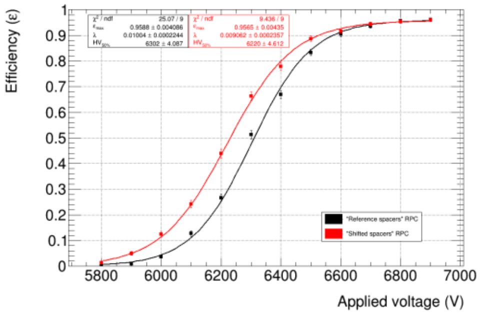




Tested ~ 15k Scintillators
Light Yield: ~ 13 ± 0.66

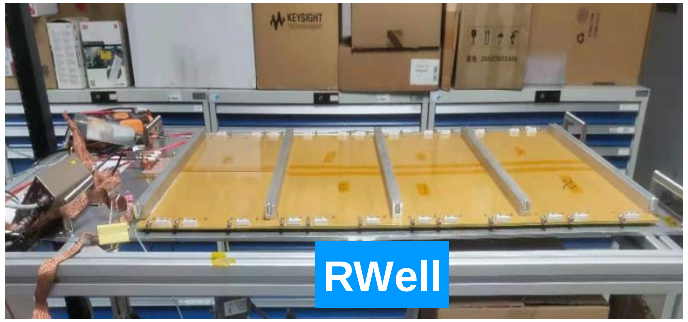
- **SDHCAL based on GRPC (SJTU)**

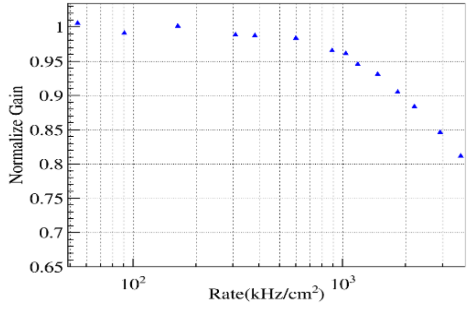
  Constructed 1×1 m² GRPCs, MIP Efficiency ~ 95.7%



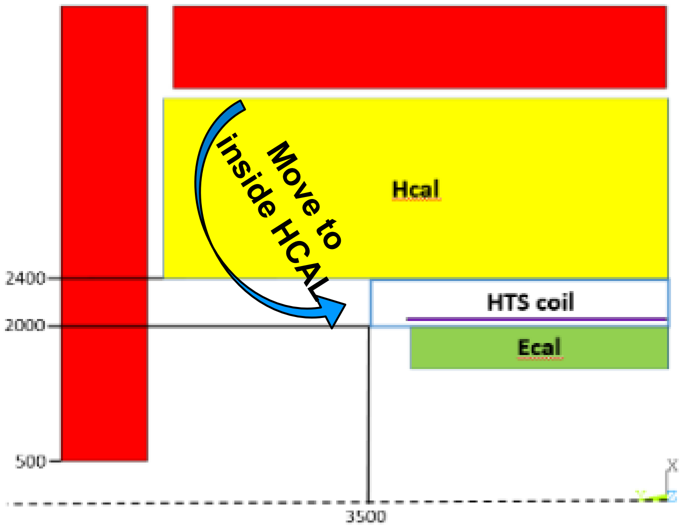
- **SDHCAL based on MPGD (USTC, IHEP)**

  Constructed 1×0.5 m² RWell detector, MIP Efficiency ~ 95.9%, count rate ~ 1.8 MHz/cm²





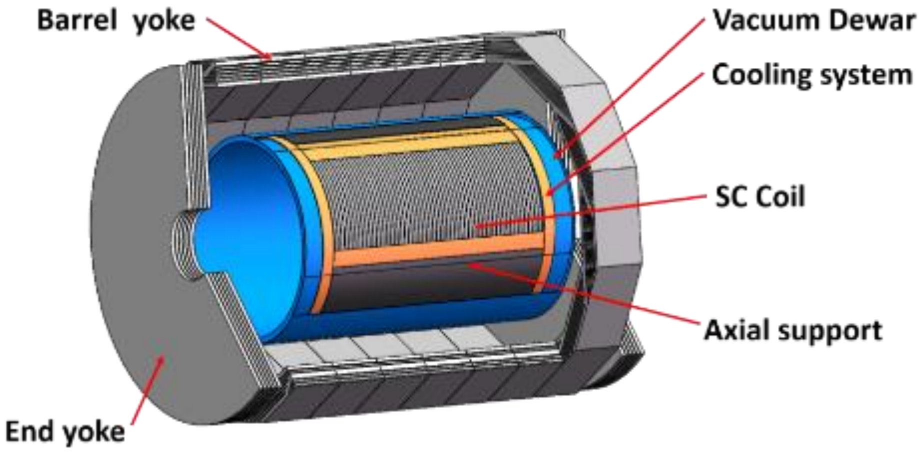
Solenoid Magnet Inside HCAL



Challenges

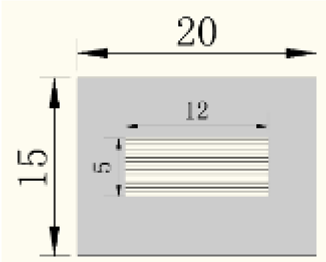
Low mass, ultra-thin, high strength cable

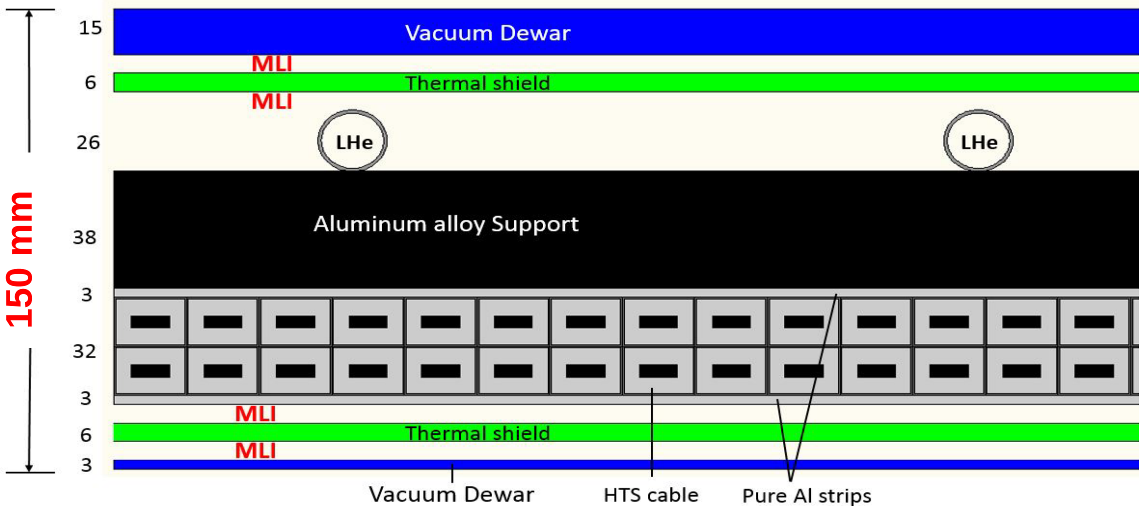
- Inner radius = 2.33m, length < 8m, central magnetic field: 3 T
- Magnet radial thickness < 150 mm
- Mass of magnet < 1.5X_0



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

Al stabilized ReBCO stacked tape cable

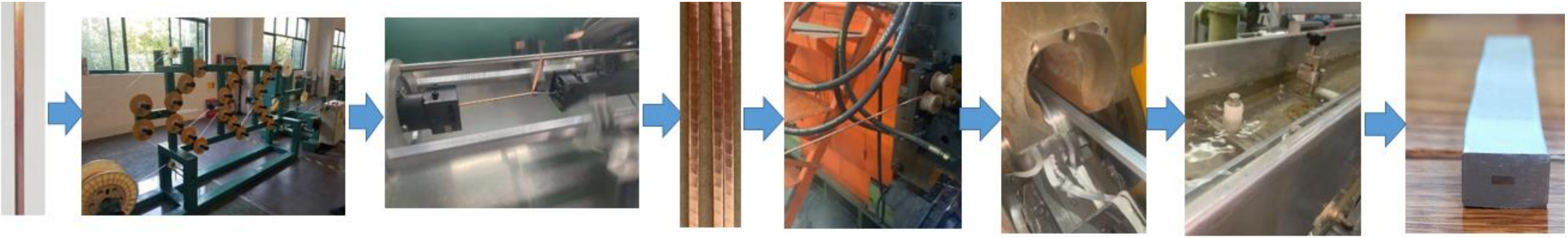




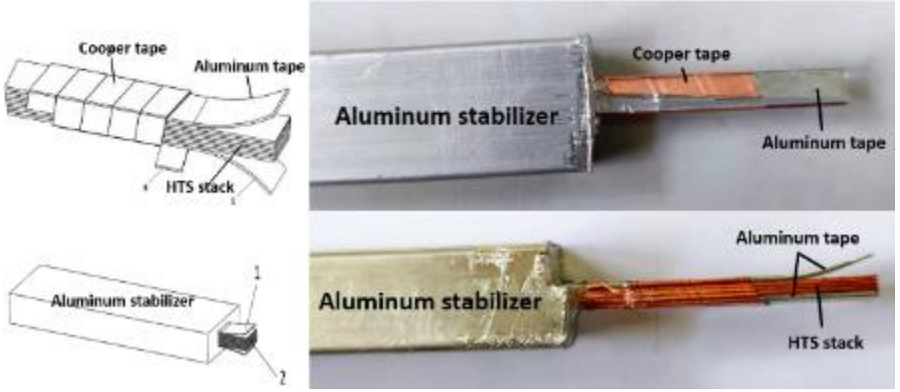
HTS cable length (km)	9
ASTC weight(ton)	9
Operating current(A)	29700
Cold mass weight (ton)	20
Total weight (ton)	35

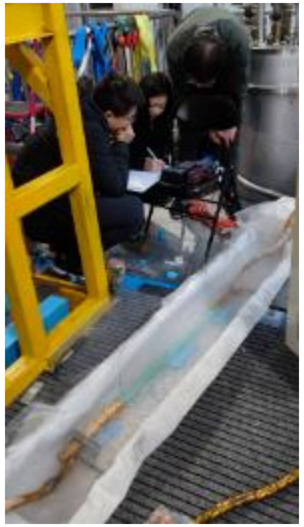
HTS Prototype Cable Development

Prototype cable: 15×10 mm^2 **,** Tape Width: 4 mm, thickness: 80 μm; tape layer: 20, Expected operating current: 6000 A@5K

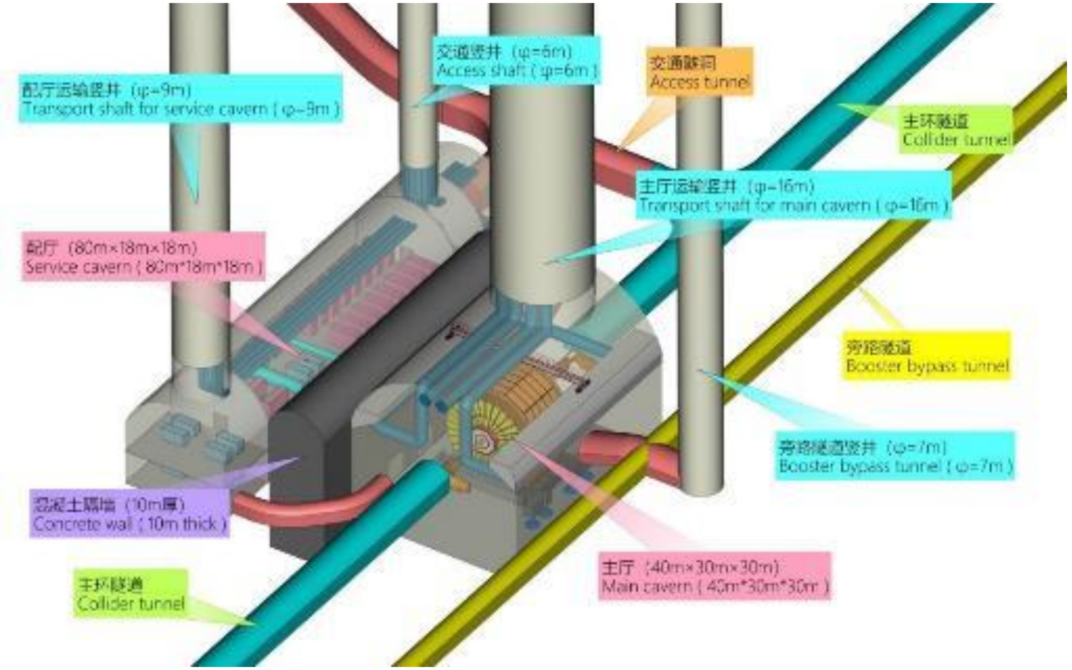


Big Progress: 10 m ASTC prototype cable is ready. Cable test is ongoing.





The Experimental Area



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

Ground level buildings

Thank you !