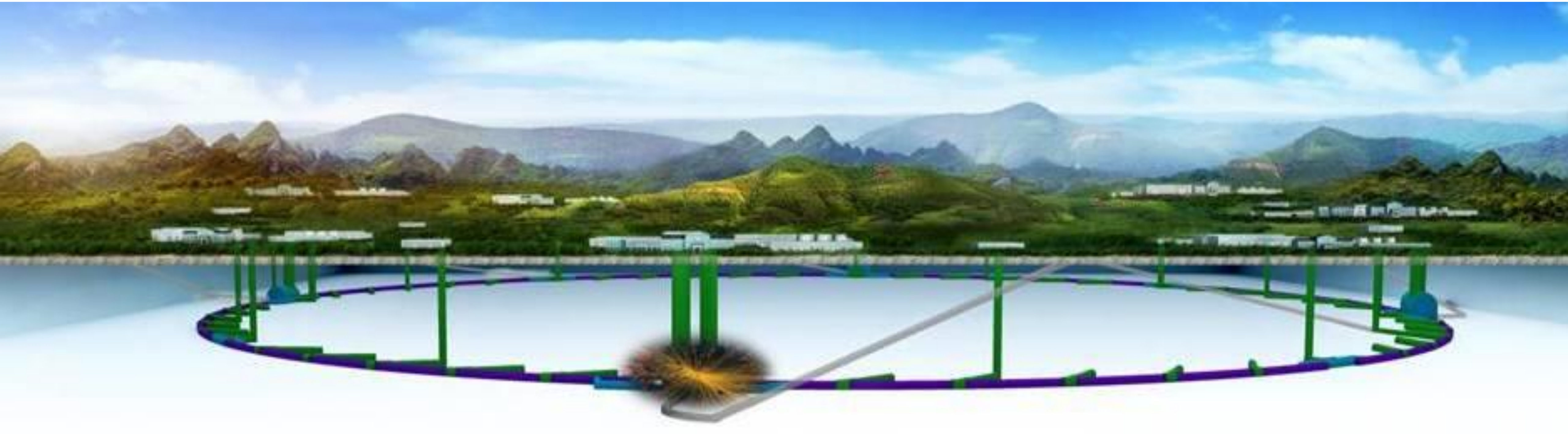
Overview of the CEPC Project

Haijun Yang (SJTU and TDLI)
(for the CEPC working group)

The 2021 International Workshop on the High Energy Circular Electron Positron Collider, Nov. 8-12, 2021

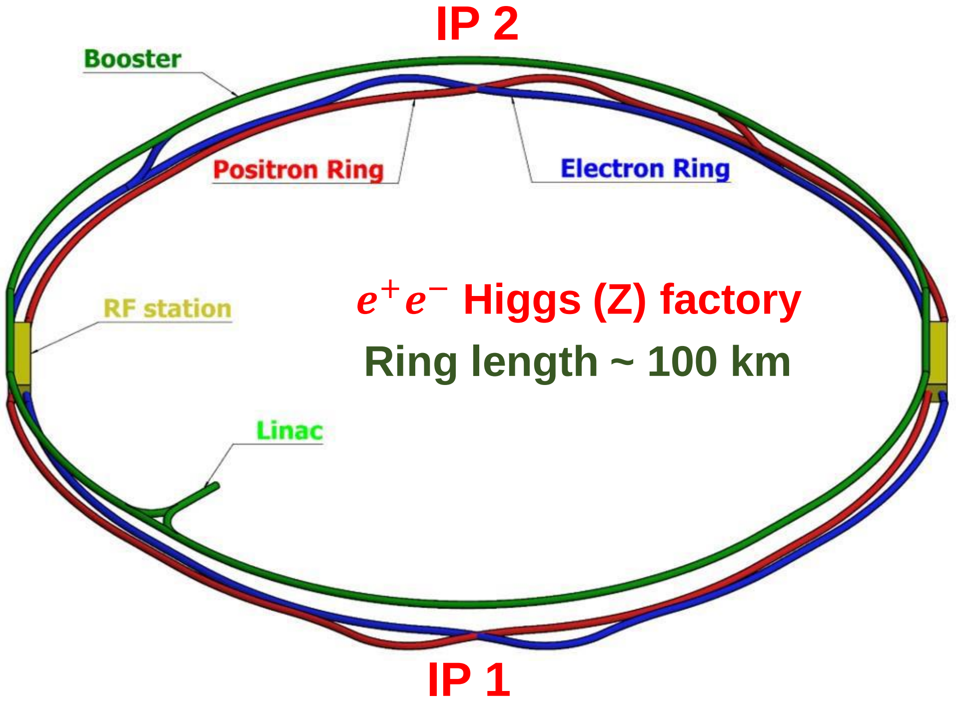


Outline

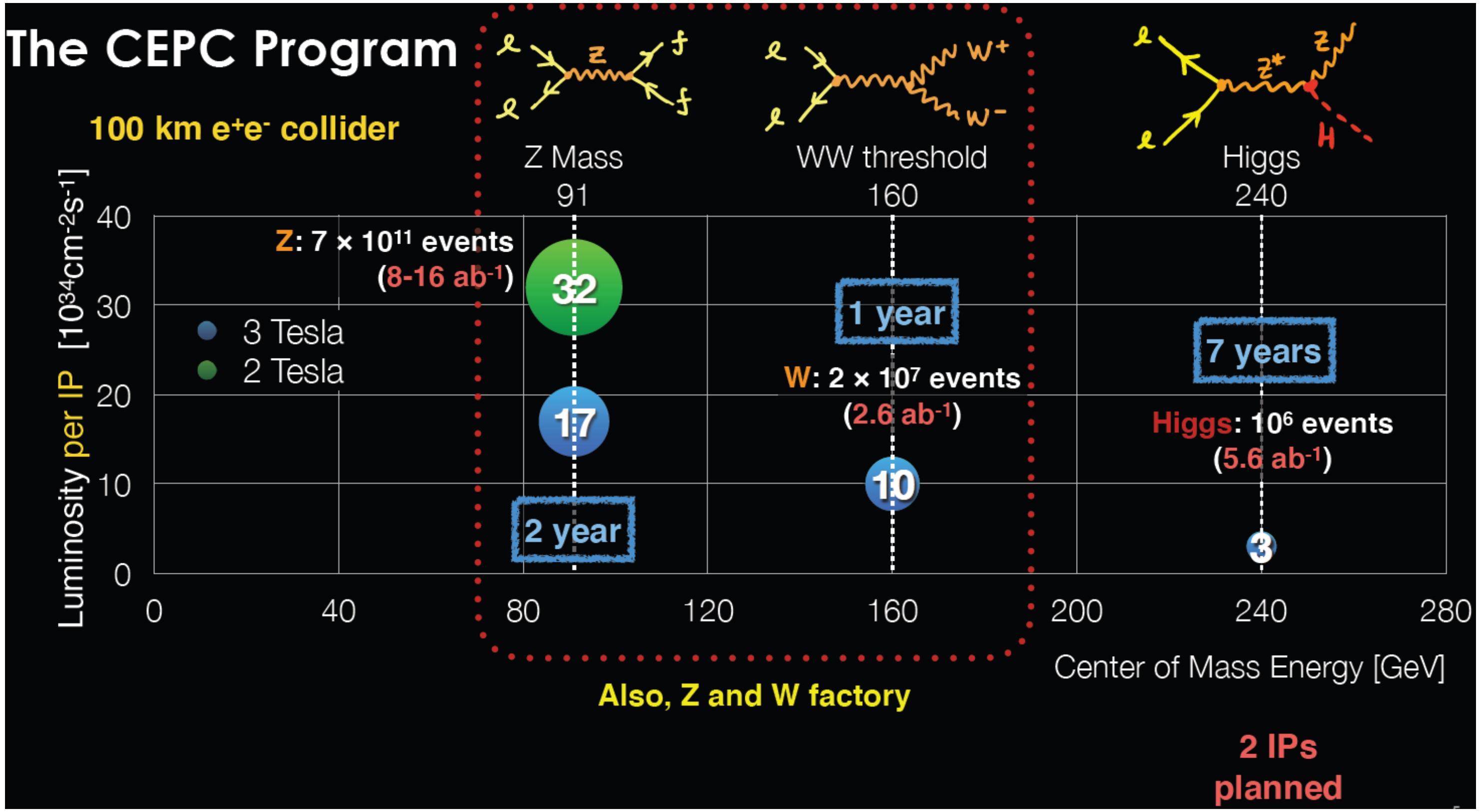
- Introduction of the CEPC
  - Goals and Plan
  - Roadmap and Schedule
  - Site Investigation
  - Collaboration with Industrial
  - Financial Model
- CEPC Project Development
  - Accelerator R&D
  - Physics Program
  - New Detector Concept and R&D
- Summary and Prospect

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.



CEPC Accelerator: Yuhui Li
CEPC Detector: Jianbei Liu

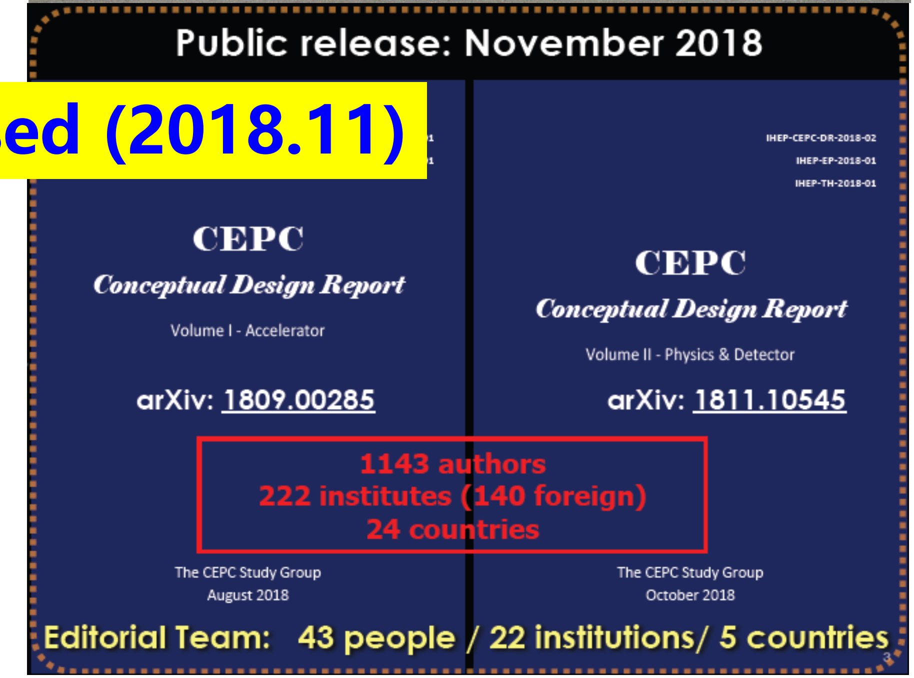


CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

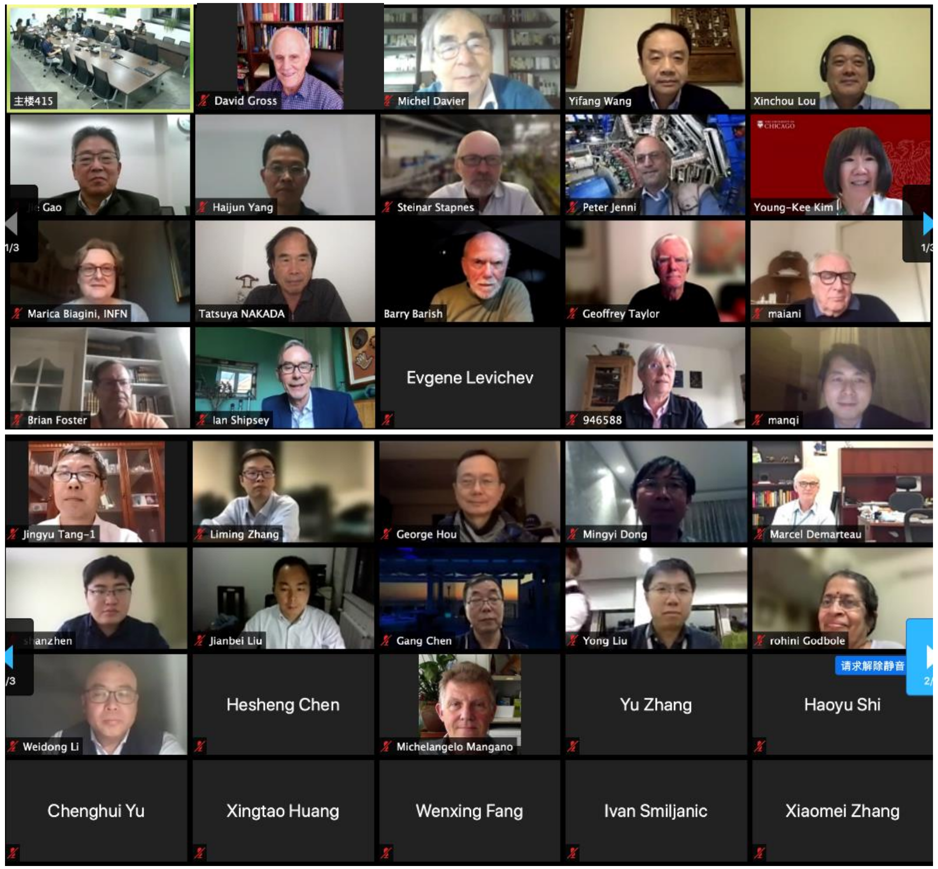
CEPC IAC Meeting (2015)

CEPC CDR Released (2018.11)



The 7th CEPC IAC Meeting

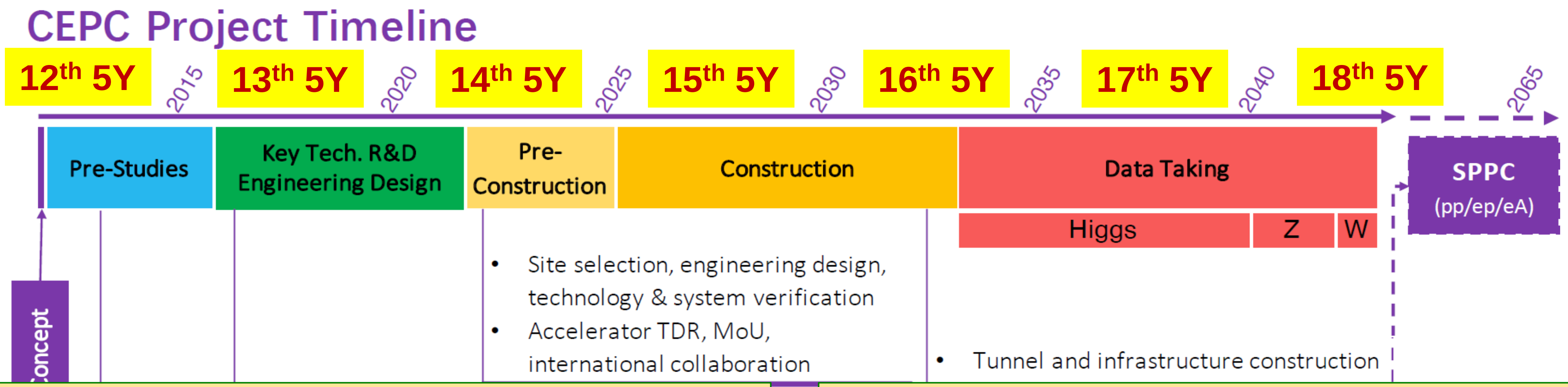
- The 7th CEPC IAC meeting (online) was held on November 1-3, 2021
- Nine talks about CEPC overall progress & technical details, with discussion sessions
- The IAC presented an advisory report with many recommendations on Nov. 5, 2021



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 Roadmap and Schedule (ideal)

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



The CEPC accelerator roadmap (ideal)

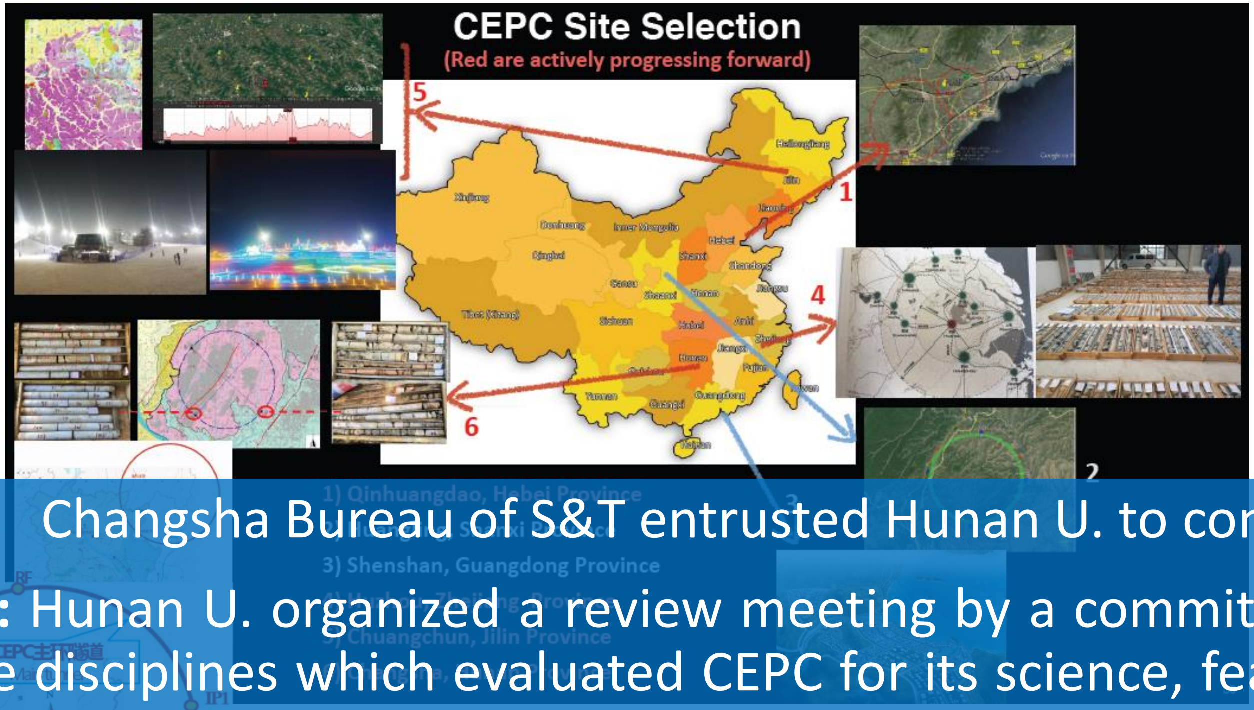
2016-2021 MOST phase-1 accelerator R&D
2018-2023 MOST phase-2 accelerator R&D
2023-2028 MOST phase-3 accelerator R&D
2022-2023 Accelerator TDR completed
2023-2025 Site selection, engineering design, prototyping and industrialization
2026-2034 Construction and Installation

The CEPC detector roadmap (ideal)

2016-2021 MOST phase-1 detector R&D
2018-2023 MOST phase-2 detector R&D
2023-2028 MOST phase-3 detector R&D
Present-2024 Seek intl. collab., detector R&D
2025-2026 Prepare for intl. collab.
2027-2028 Detector TDR completed
2028-2034 Detector construction
2033-2034 Installation

CEPC Site Selection

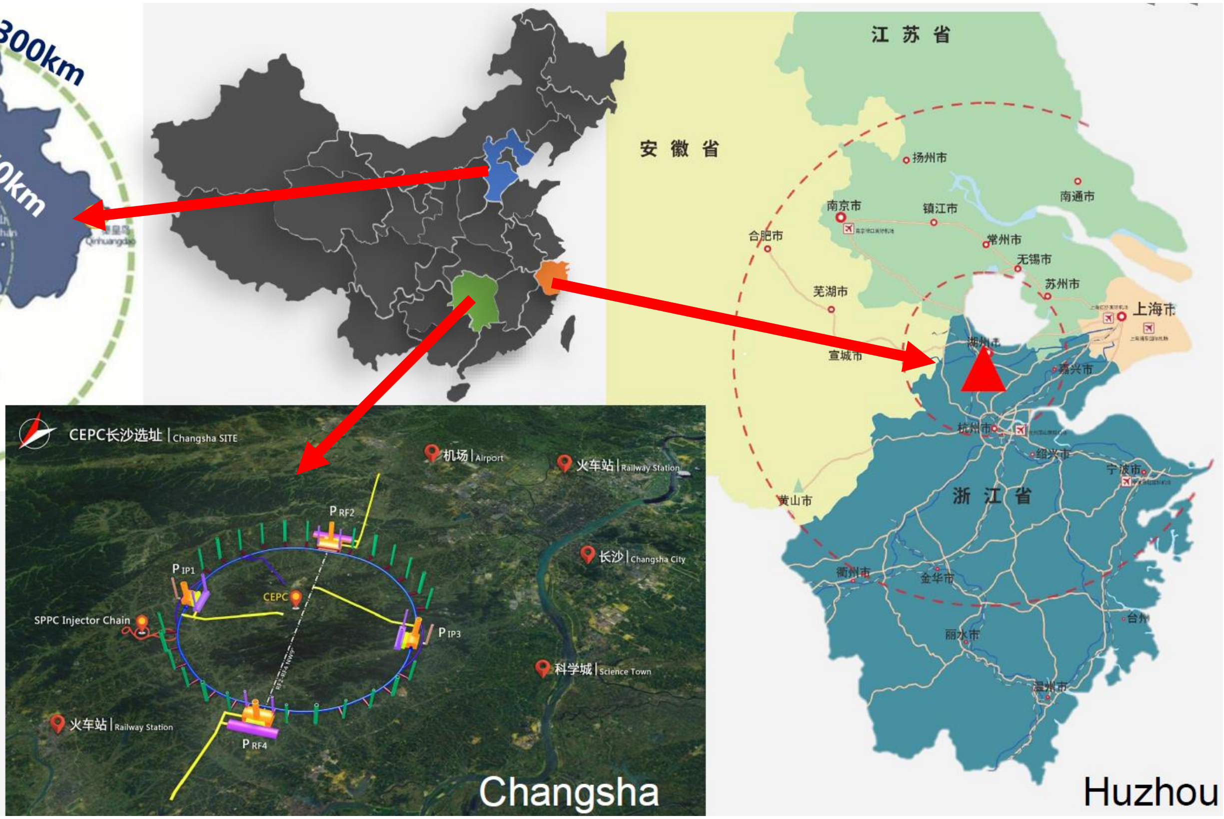
CEPC Sites choice & technical challenges:
Y. Xiao (Qinhuangdao)
K. Huang, (Huzhou)
Z. LI (Changsha)



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

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

CEPC Sites, Geology and Science Cities



Sites choice and technical challenges:
Y. Xiao (Qinhuangdao)
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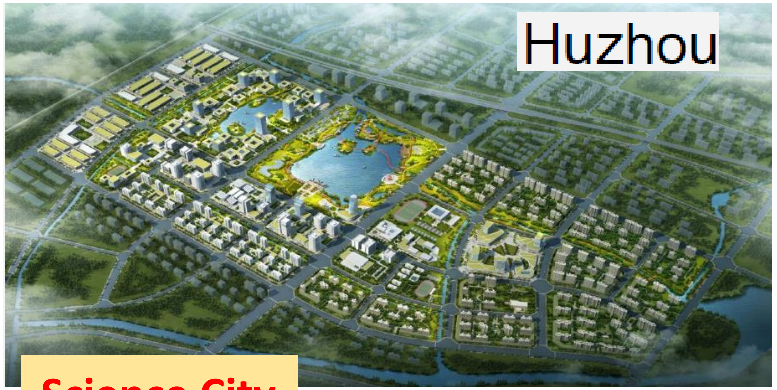
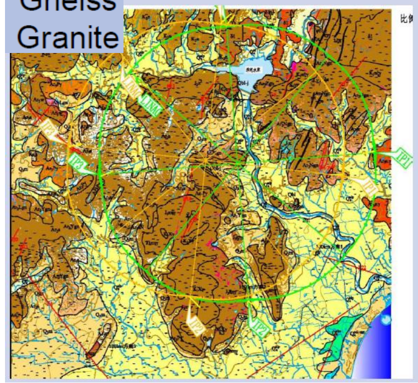
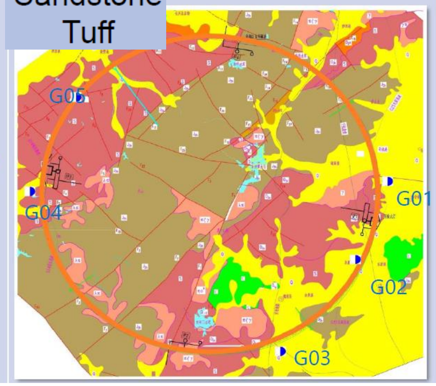
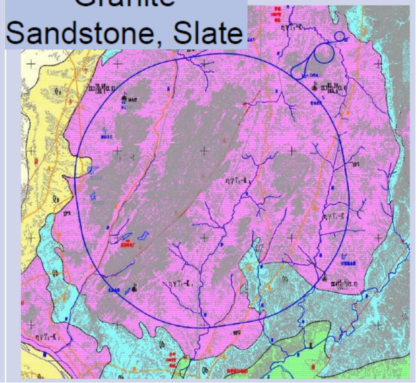


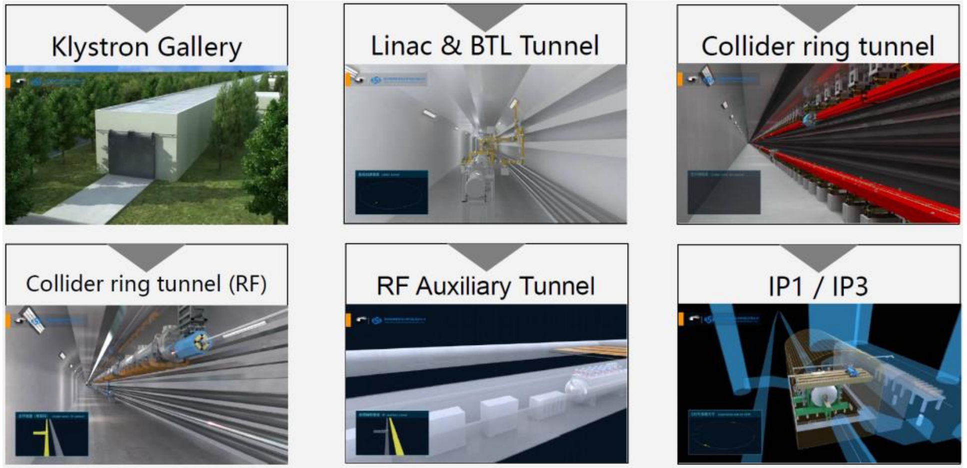
Science City

Qinhuangdao	Huzhou	Changsha
Gneiss Granite	Sandstone Tuff	Granite Sandstone, Slate



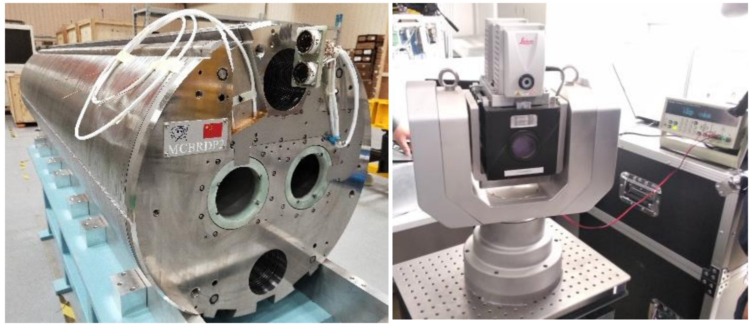






CEPC Collaboration with Industry (CIPC)

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
.....

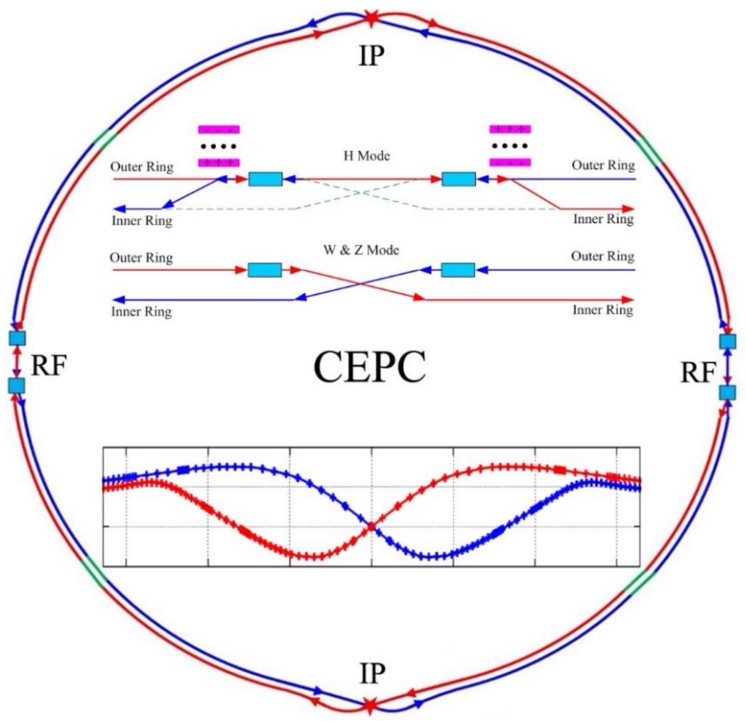
More than 40 companies joined in first phase of CIPC,
and 70 companies now.

CEPC Financial Model

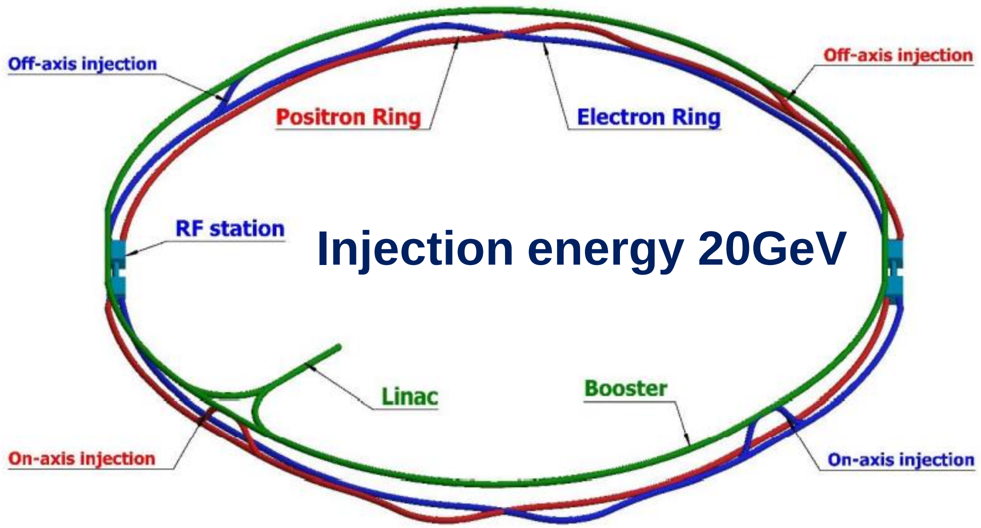
Funding Sources	Financial Model #1 （RMB）	Financial Model #2 (RMB)
Central Government	30B	6-10B
Local Government	Land, Infrastructure	25-18B Land, Infrastructure
International Partners	1-5B	1-5B
Companies & Donations	0-3B	0-3B
Total Budget	36B	36B

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.

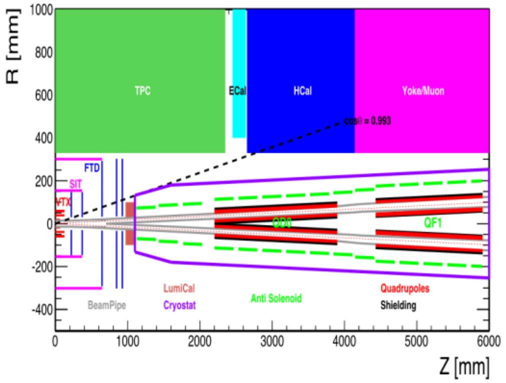
CEPC High Luminosity TDR Layout



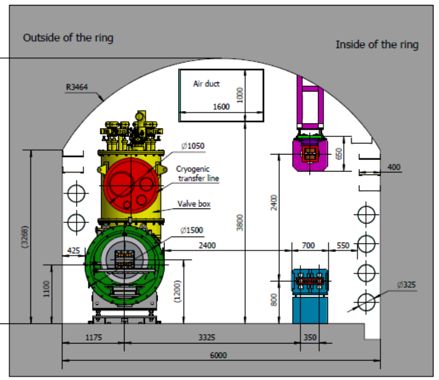
- 100 km collider and booster ring



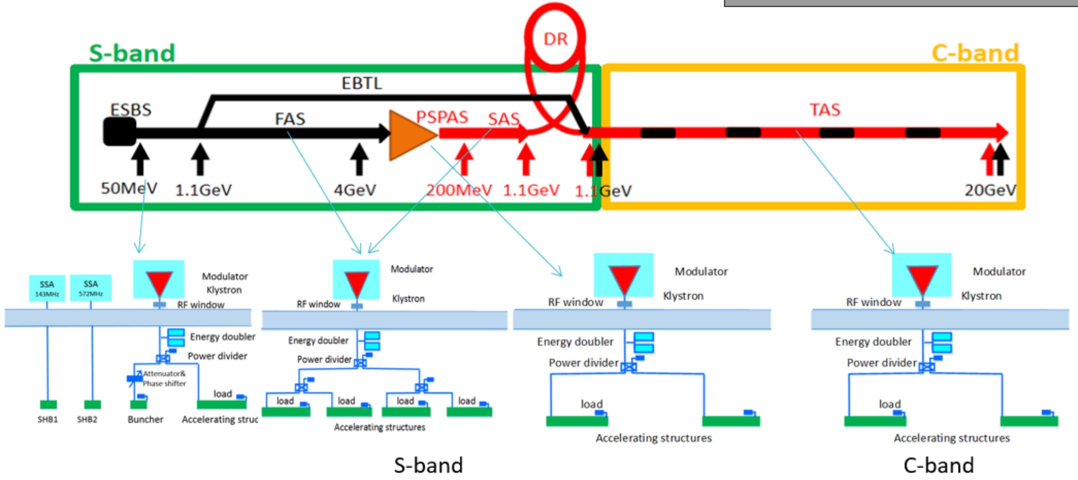
Injection energy 20GeV



TUNNEL CROSS SECTION OF THE ARC AREA



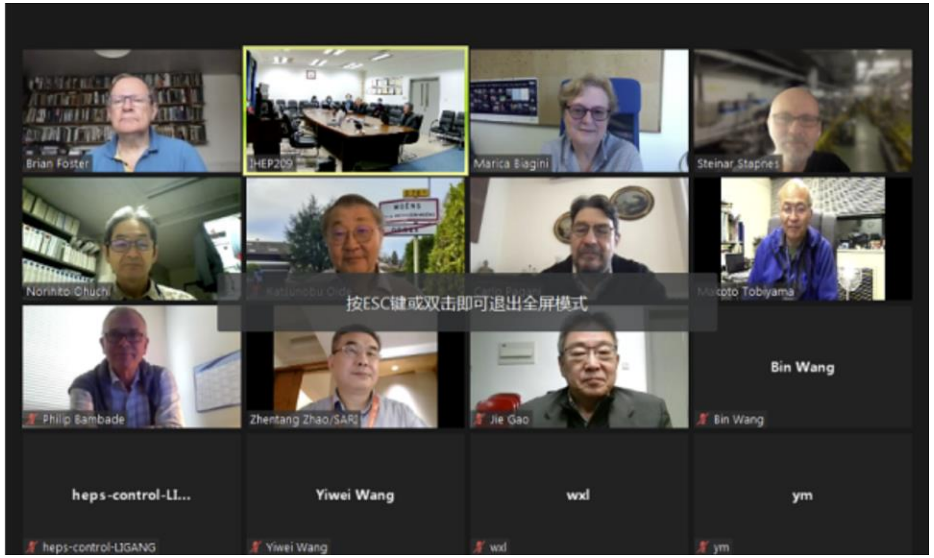
- CEPC as Higgs / Z / W factory
- Maximum energy of 180 GeV for ttbar
- New baseline for Linac (C-band, 20GeV)



CEPC Accelerator R&D：Yuhui Li

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



The first 2021 CEPC International Accelerator Review Committee Meeting

11-19 May 2021
Asia/Shanghai timezone

Overview | Scientific Programme | Timetable | Contribution List | Author List | My Conference

The 2021 International Accelerator Review Committee meeting for the high energy Circular Electron-Position Collider (CEPC) will take place between May 11-12 and on 19th May via zoom. The meeting will be on line with 11 talks given by the IHEP participants. The IARC committee discussion and report writing will mainly carry out on 19th May with the closed session.
The meeting intends to overview the progress about the accelerator division for CEPC. Update about the physical design as well as the development of key technologies will be presented at the meeting. According discussion and report given by the committee will promote the plans towards TDR for CEPC.

Starts May 11, 2021 15:00
Ends May 19, 2021 20:00
Asia/Shanghai

Slides

The 2nd CEPC International Accelerator Review Committee Meeting in 2021

11-20 October 2021
Asia/Shanghai timezone

Overview | Scientific Programme | Timetable | Contribution List | Author List | My Conference

The 2nd International Accelerator Review Committee meeting for the high energy Circular Electron-Position Collider (CEPC) in 2021 will take place between October 11-14 via Zoom. The meeting will be on line with 23 talks given by the IHEP participants. The IARC report will be delivered on October 20.

Starts Oct 11, 2021 15:00
Ends Oct 20, 2021 19:10
Asia/Shanghai

No material yet

The review committee meeting will be organized on line via zoom link:
https://infn-it.zoom.us/j/89911828376?pwd=WEtEYVZjNXJwRGF1em4wNjJFSkVmdz09

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.

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

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

- 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 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 Chromaticity [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) (kw)	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

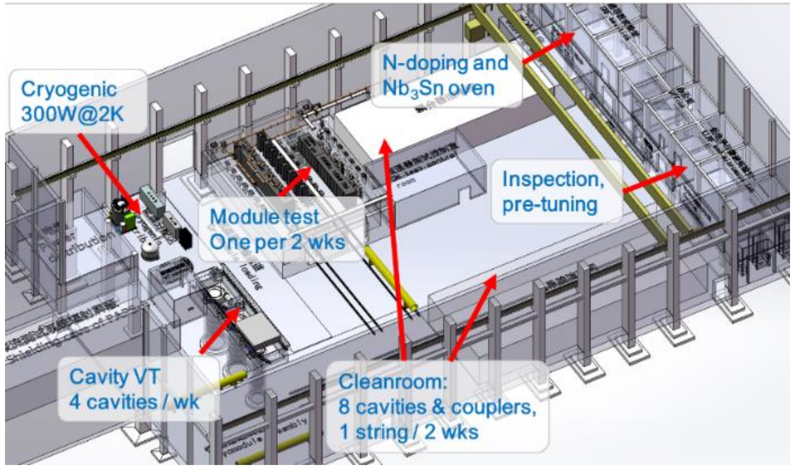
	ttbar	Higgs	W	Z
Number of Ips		2		
Circumference [km]		100.0		
SR power per beam [MW]		30		
Half crossing angle at IP [mrad]		16.5		
Bending radius [km]		10.7		
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
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	[illegible]	[illegible]	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	[illegible]	[illegible]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%⇑

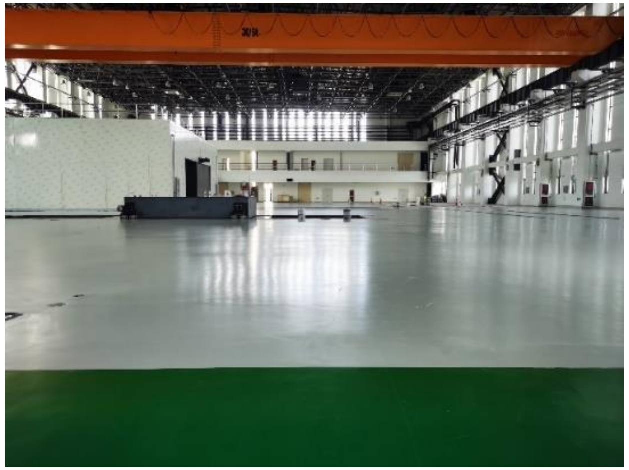
CEPC SCRF Test Facility

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

New SC Lab Design (4500m²)



SC New Lab is available in 2021



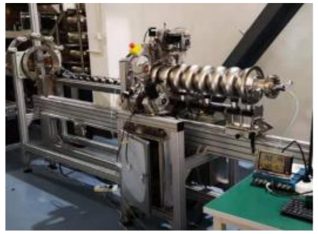
Crygenic system hall in 2020

Vacuum furnace (doping & annealing)

Nb3Sn furnace

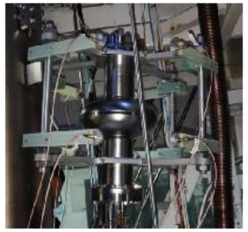
Nb/Cu sputtering device

Cavity inspection camera and grinder

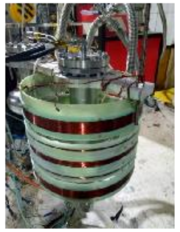


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



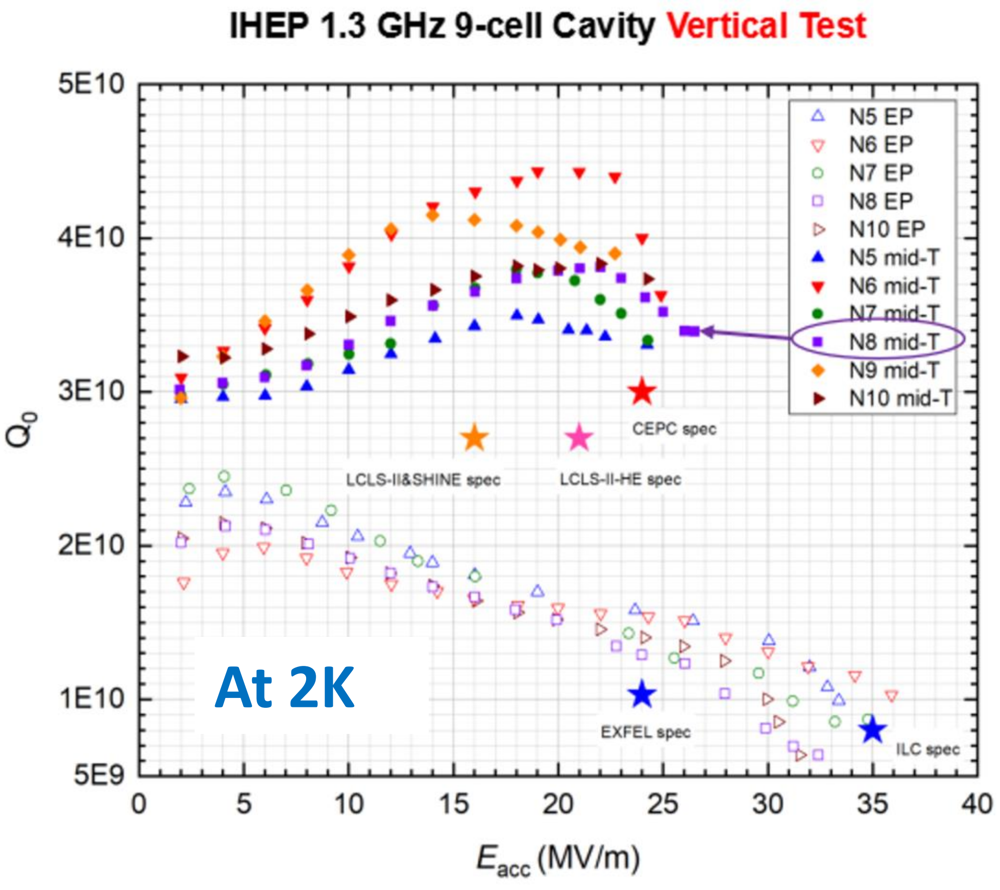
Helmholtz coil for cavity vertical test

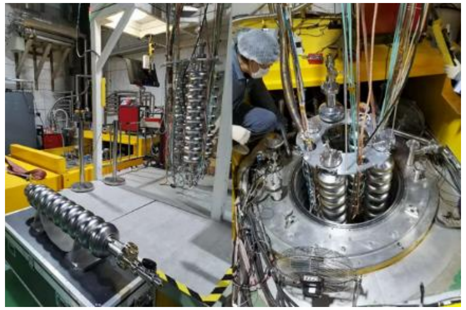
Vertical test dewars

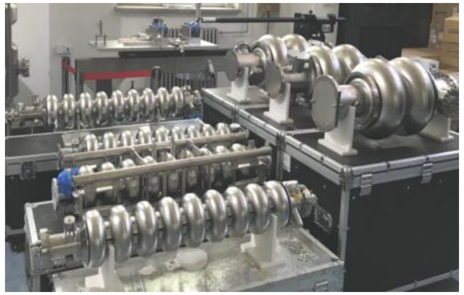
Horizontal test cryostat

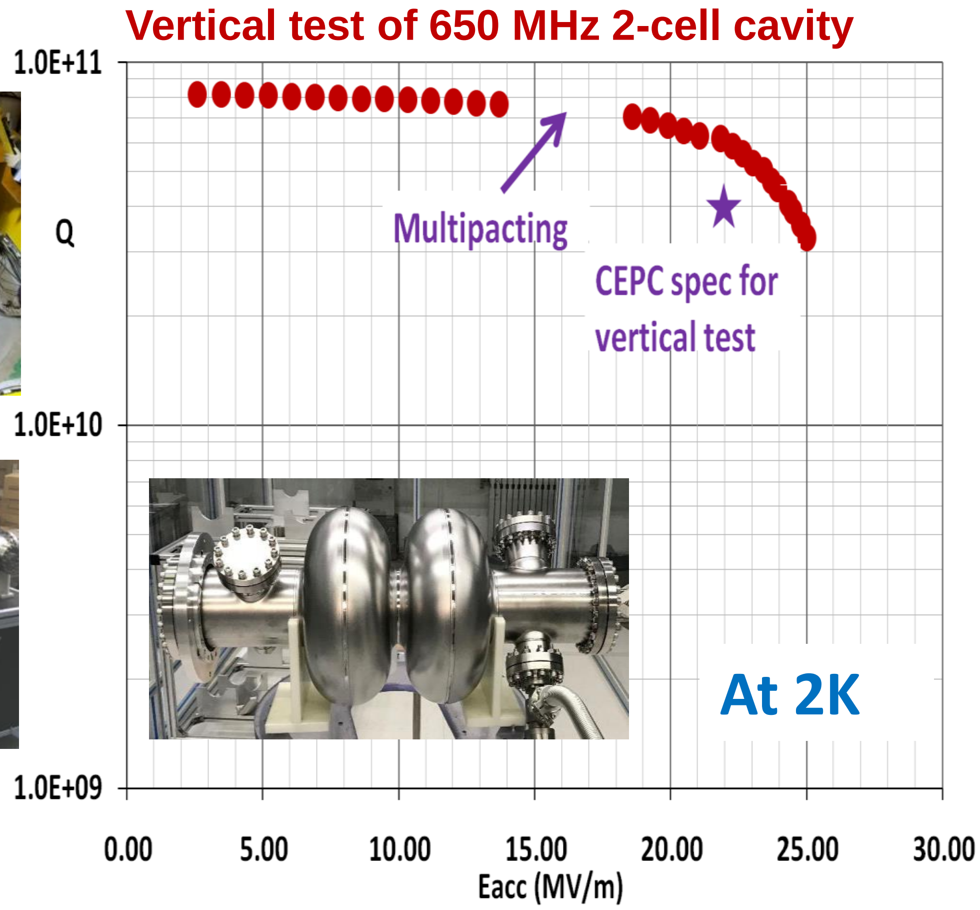
CEPC R&D: High Q SCRF Cavities

- 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







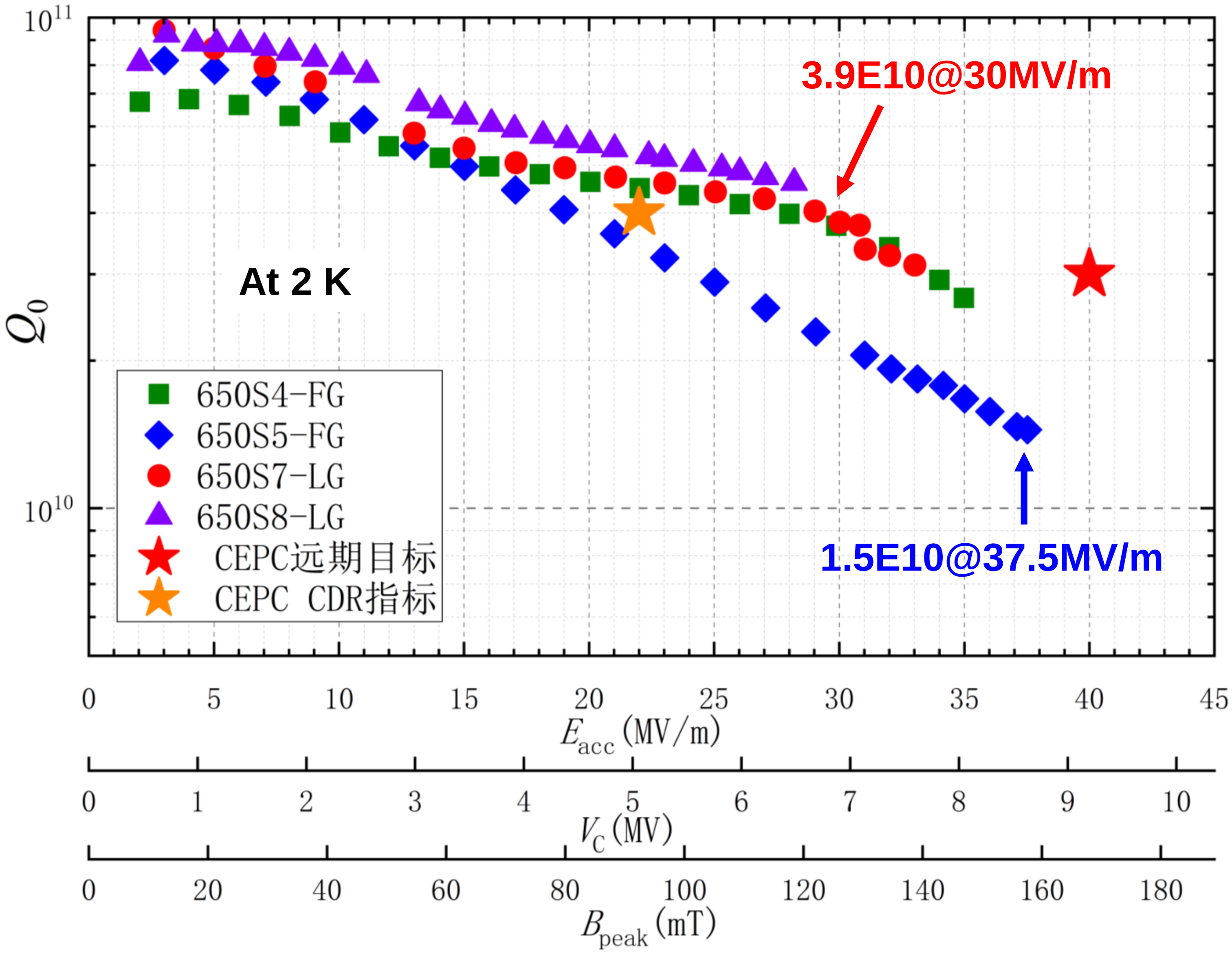


Medium-temperature (Mid-T) annealing adopted to reach Q_0 = 3.4E10 @ 26.5 MV/m

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

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

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



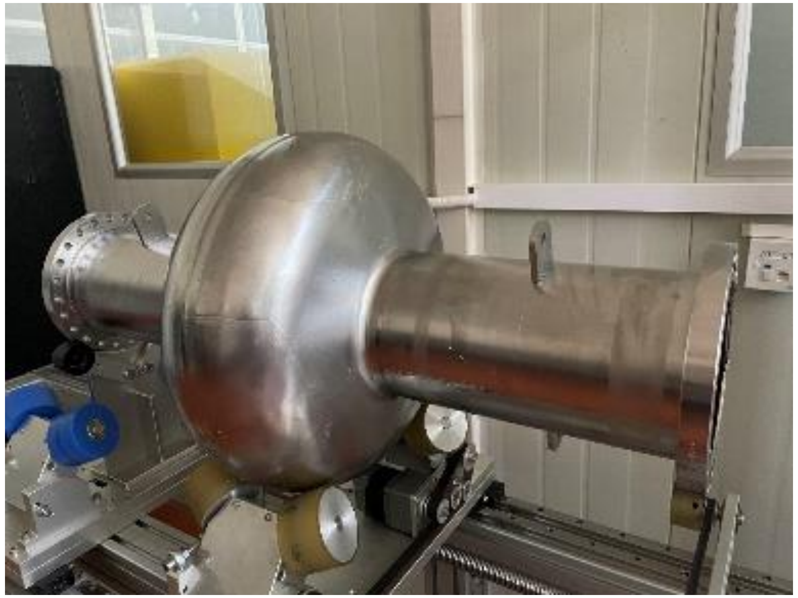
CEPC CDR Goal:

Q_0 = 3.0E10 @ 22 MV/m

Test Results:

Q_0 = 3.9E10 @ 30 MV/m

Q_0 = 1.5E10 @ 37.5 MV/m

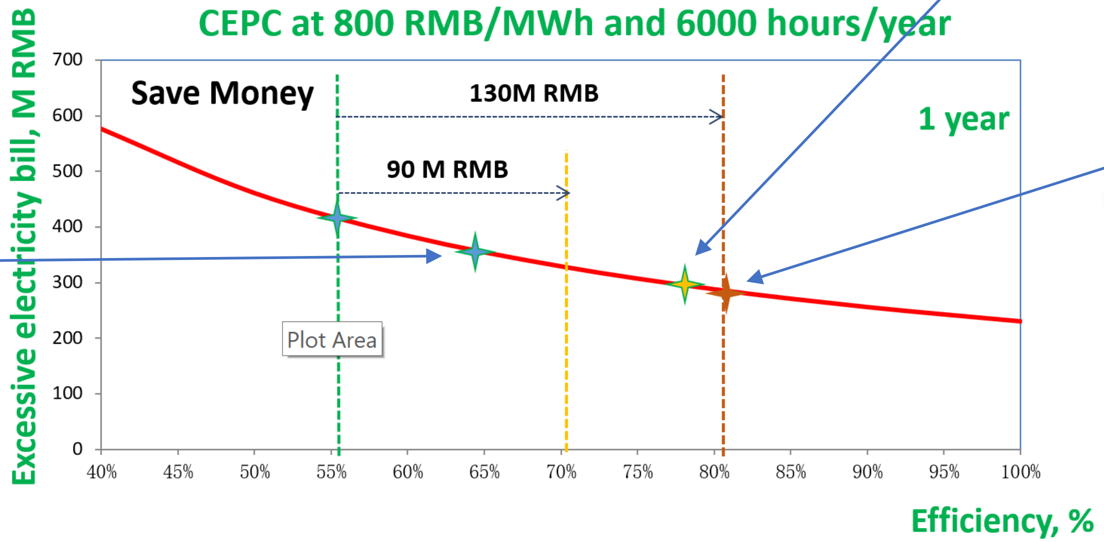


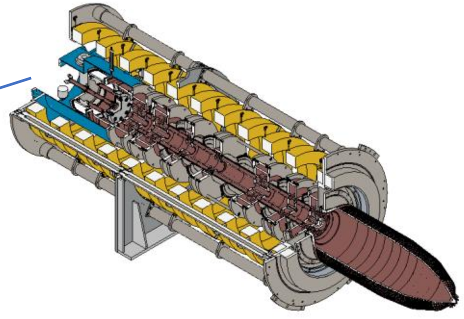
CEPC R&D: High Efficiency Klystrons

- 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 being baked out, to be tested at PAPS in 2021, design efficiency is ~ 77%.
- Multi-beam Klystron design is finished, design efficiency is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

The 2nd Klystron (assembly)

The 1st Klystron (tested)

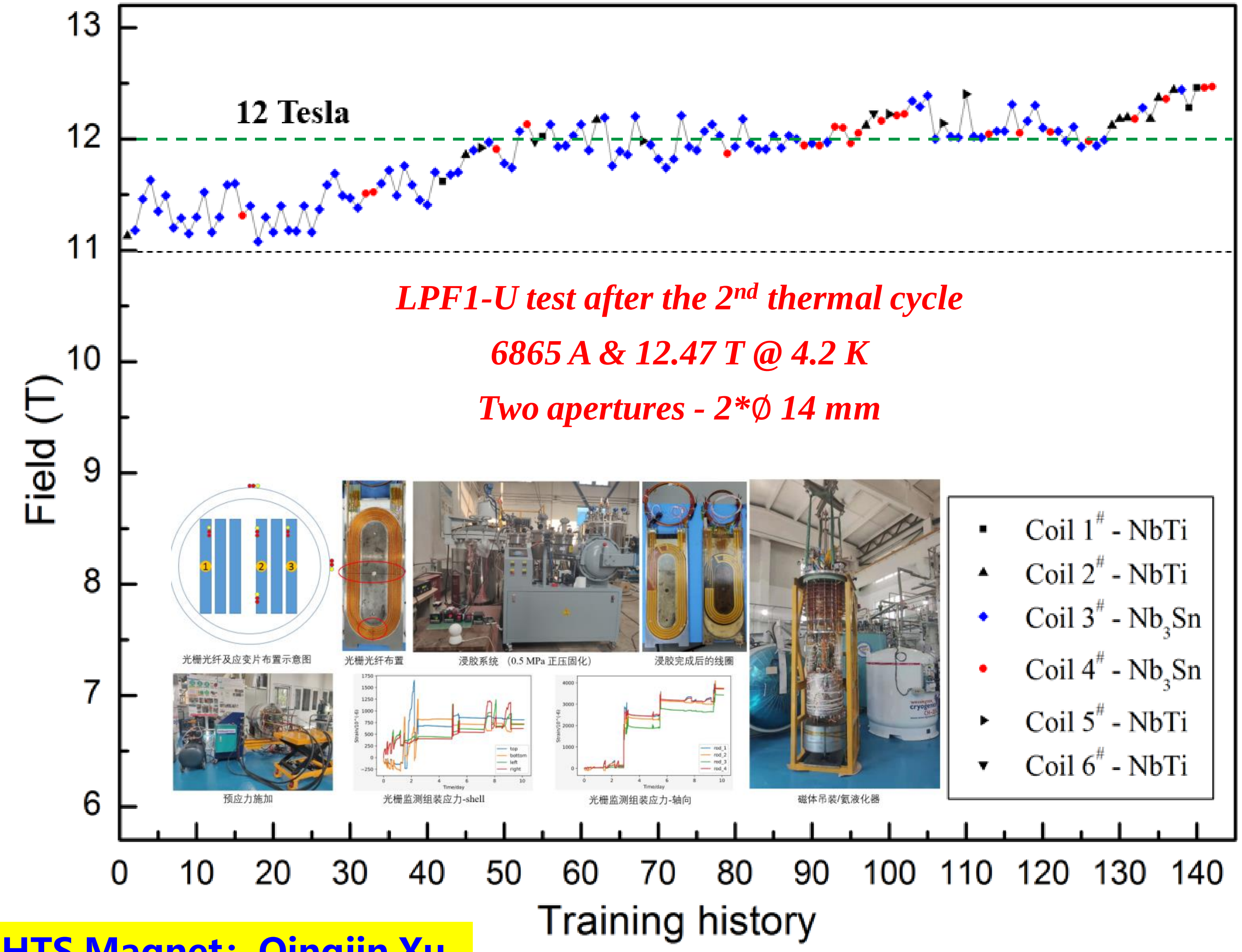


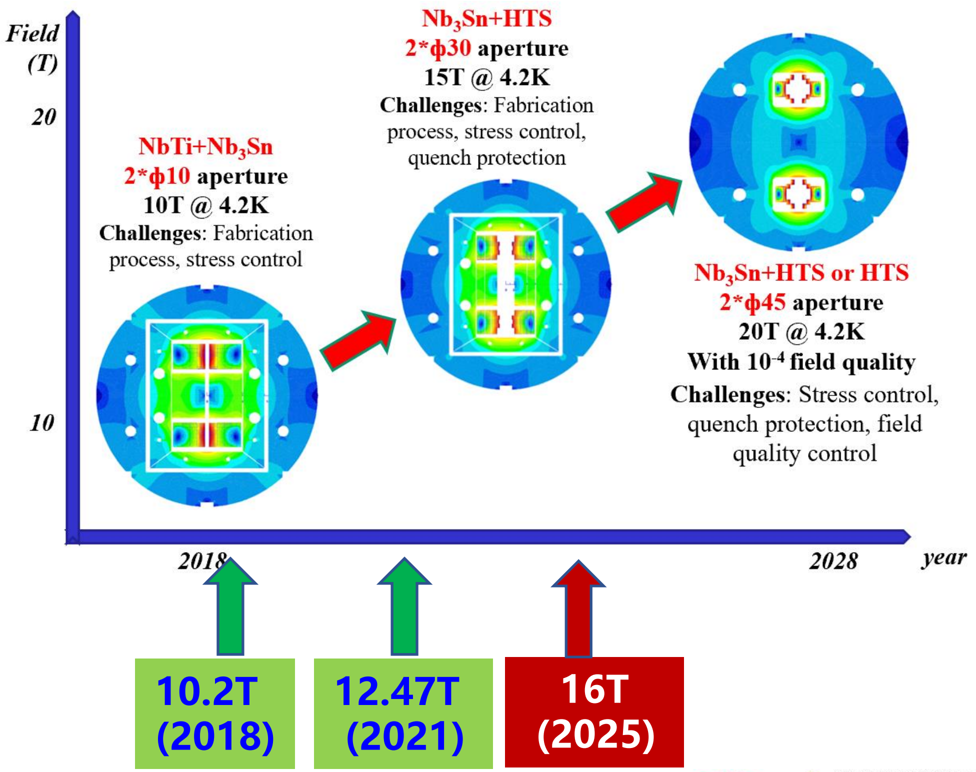


Multi-beam Klystron

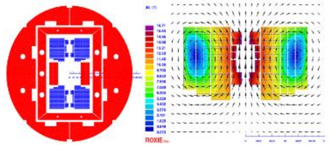
HTS SC Magnet (>12T)

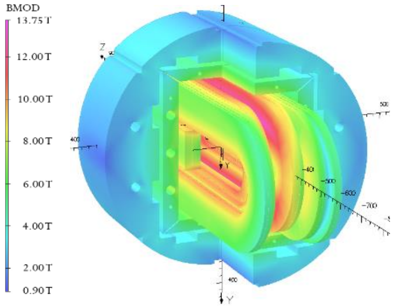
Domestic SC dipole magnet exceeded 12T (IHEP, June, 2021)





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

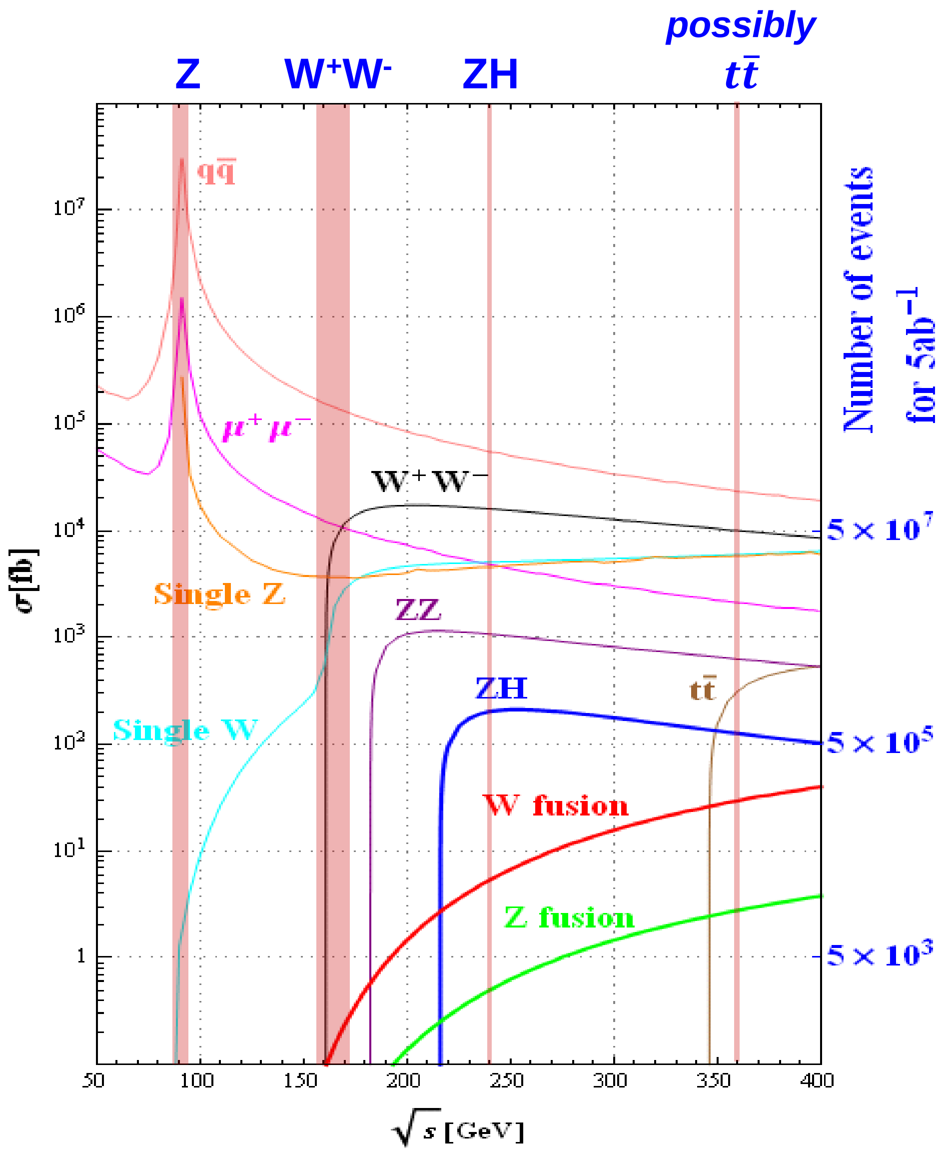




HTS Magnet：Qingjin Xu

The CEPC Physics Program

CEPC Physics Opportunities: Sven Heinemeyer



Operation mode		ZH	Z	W+W-	ttbar (new)
$\sqrt{s}$ [GeV]		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	7.7
CDR	*L* / IP [×10³⁴ cm⁻²s⁻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	
Latest	*L* / IP [×10³⁴ cm⁻²s⁻¹]	5.0	115	15.4	0.5
	$\int L\,dt$ [ab⁻¹, 2 IPs]	9.3	57.5	4.0	1.0
	Event yields [2 IPs]	1.7×10^6	2.5×10^{12}	3×10^7	3×10^5

- **CEPC Conceptual Design Report:**
  Volume 1 – Accelerator, arXiv:1809.00285
  Volume 2 – Physics & Detector, arXiv:1811.10545

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

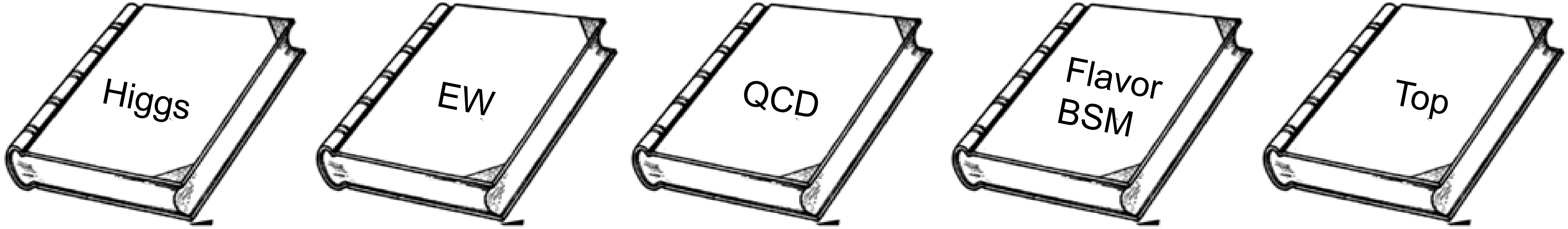
CEPC White Papers

- **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**

  (45 physics talks, 10 performance/optimization study talks)

- ***Higgs: Impact of 360 GeV Runs***
- ***Top physics at 360 GeV***
- ***EW: Draft ready***
- ***QCD: intensive discussions…***
- ***Flavor + BSM***

Physics studies at parallel sessions



https://indico.ihep.ac.cn/event/13888/

The 4th 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

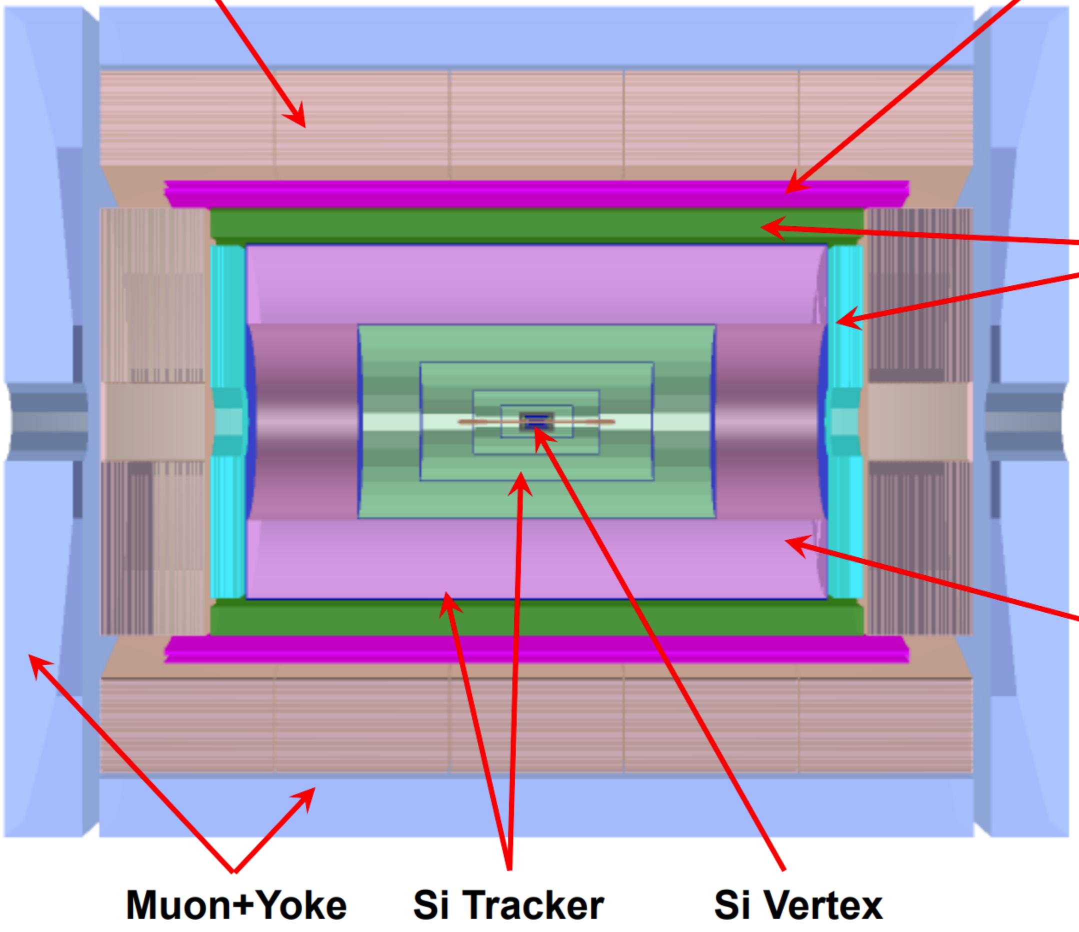
Advantage: better π^0/γ reconstruction.

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.



CEPC Detector R&D: Jianbei Liu

Summary and Prospects

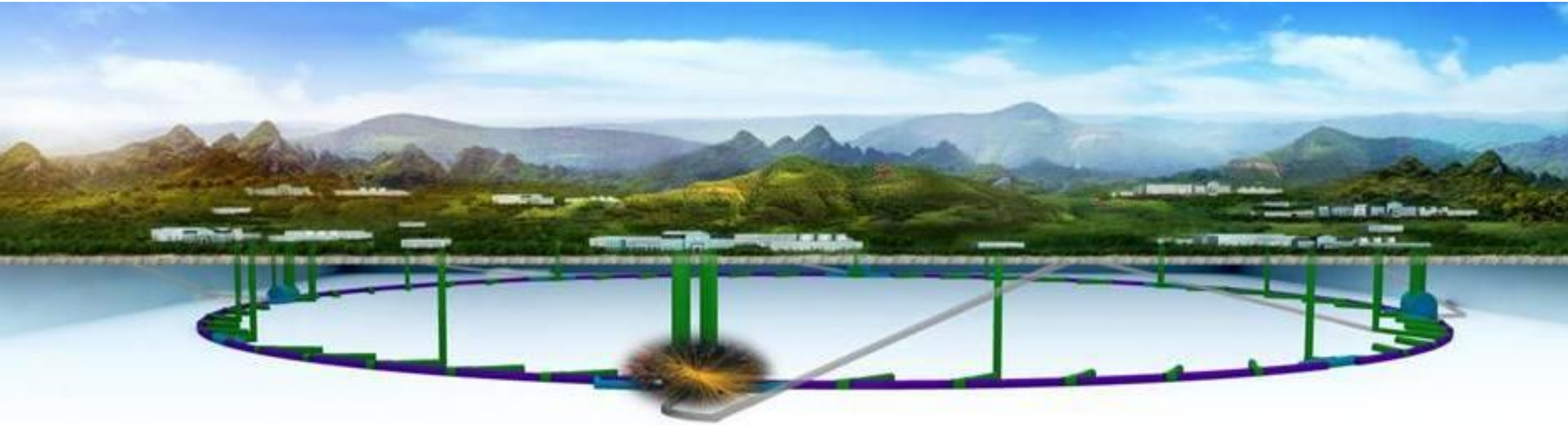
Continuing R&D and deep understanding of physics potentials

- Made suggestions to **MOST for R&D support** and validations of key technologies & innovations
- Carrying out **design improvement, R&D**, site investigations-study
- R&D and made major **progress + breakthroughs** in common technologies
- **CEPC physics whitepapers**; physics potentials in Snowmass 2021/2022

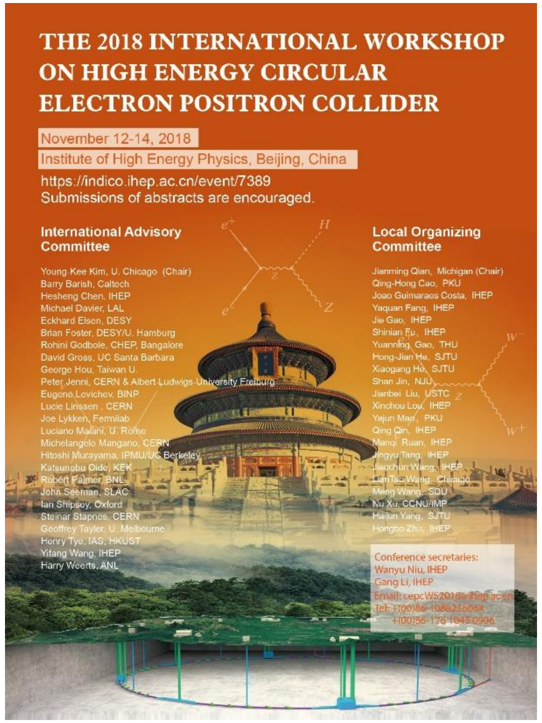
International Collaboration and Engagement

- 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, …)
- **Due to COVID-19 pandemic, it's impossible to have in-person meetings ……**

Thank you !



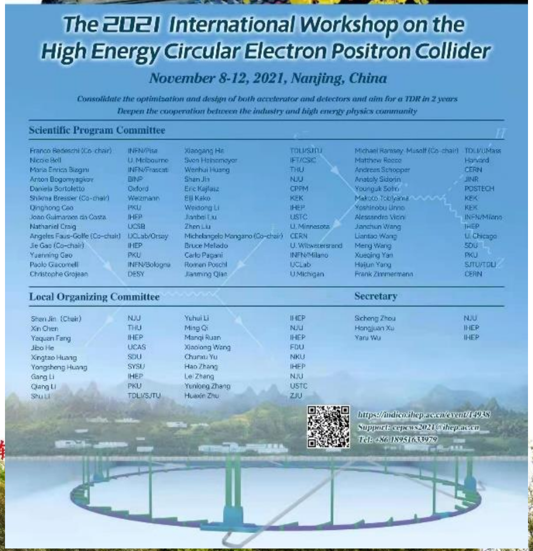
Recent CEPC Workshops



CEPC2021 International Workshop
Nanjing U. (online), Nov. 8-12, 2021

You are very welcome to participate

https://indico.ihep.ac.cn/event/14938/



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

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)

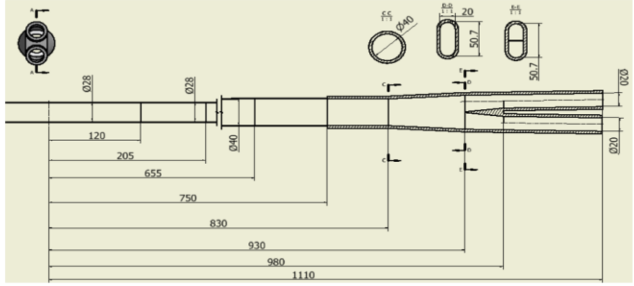
- ✓ **L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Emittance=1.2nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

High luminosity scheme (Higgs)

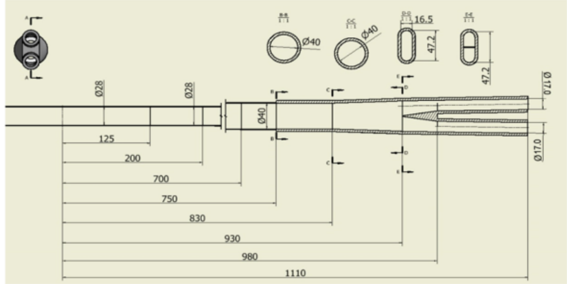
- ✓ **L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.68nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

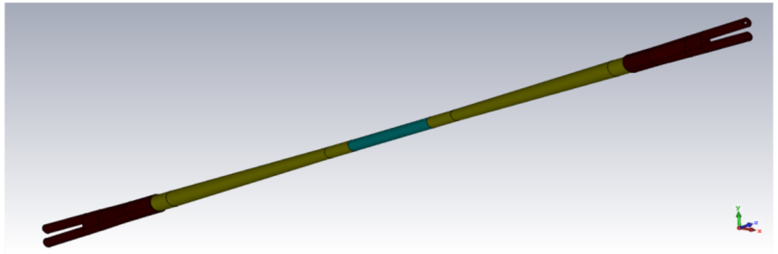
Change of IP chamber

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



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





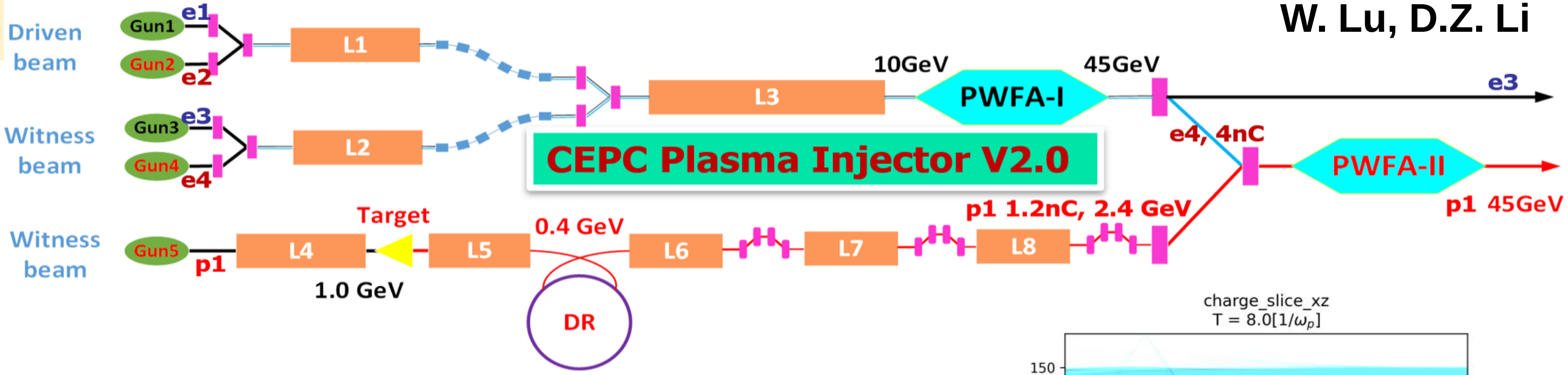
CEPC Accelerator: Plasma Injector

CEPC Plasma Injector V2.0

IHEP, THU, BNU

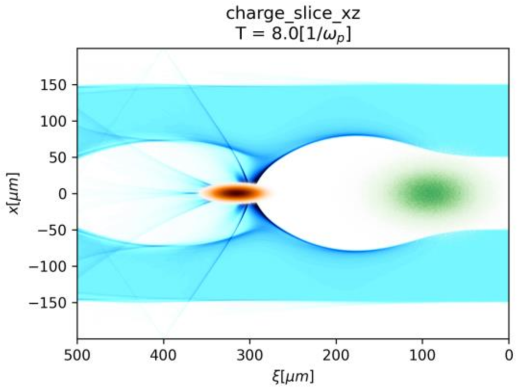
W. Lu, D.Z. Li

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

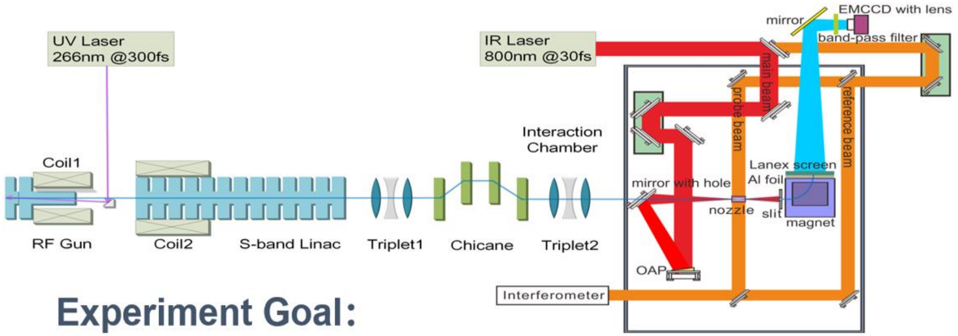


High efficiency uniform wakefield acceleration of a positron beam using stable asymmetric mode in a hollow channel plasma
S.Y. Zhou, W. Lu, et al., arXiv: 2012.06095

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

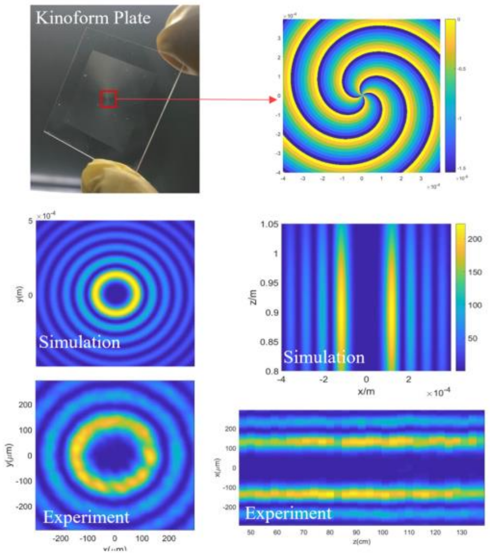


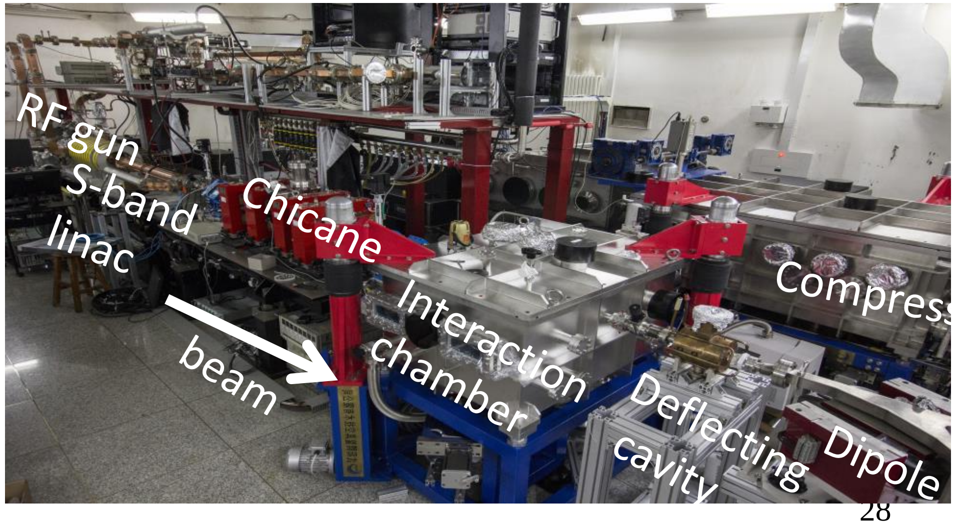
Plasma dechirper exp at SXFEL



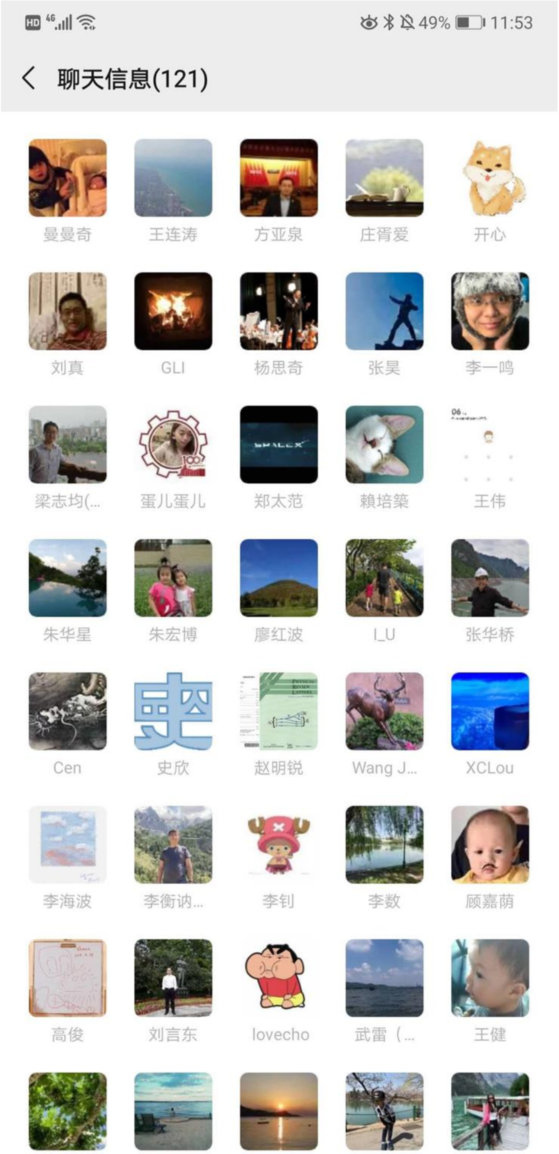
Experiment Goal:

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

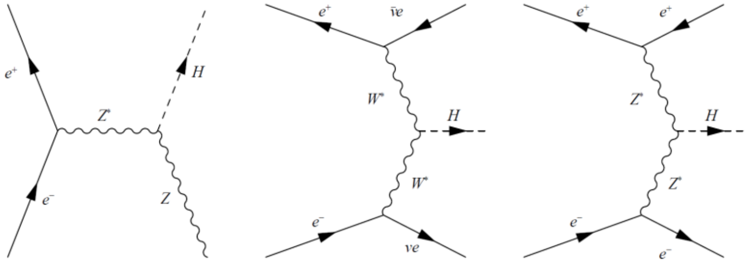
15:16 **TPC LoI** *1'*
Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)
Material: Slides

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

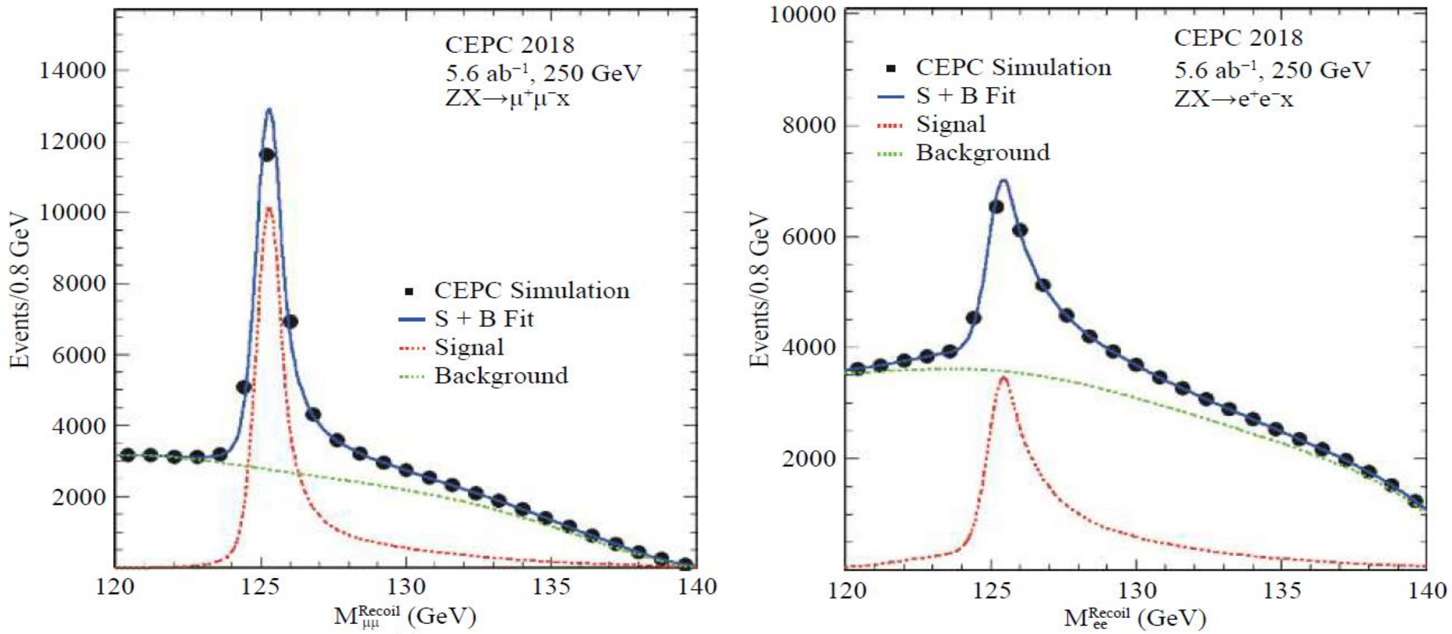
34

CEPC Physics Performance (CDR)

e^+e^- annihilations at the CEPC

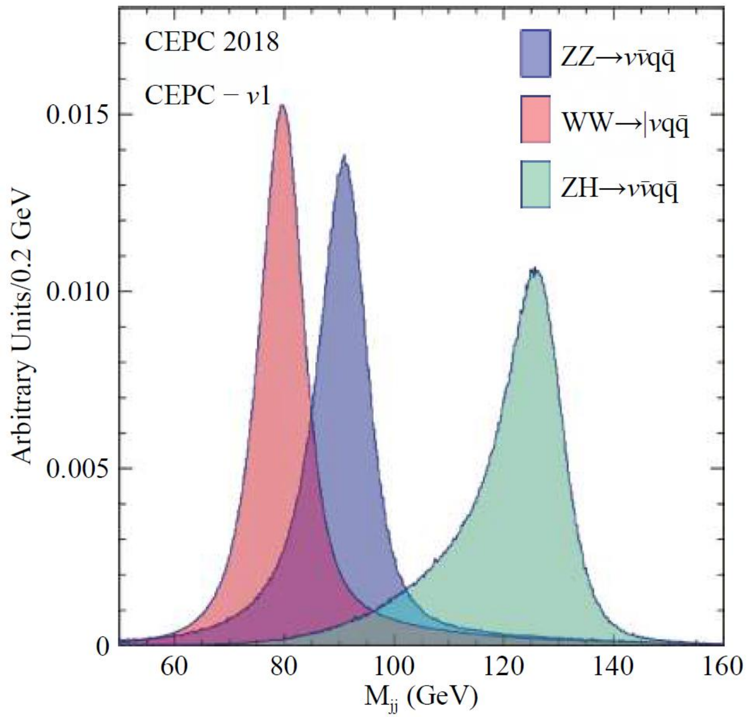


- **CEPC can make detailed study of various physics processes**
- **Higgs bosons are detected via recoil mass of the reconstructed Z, allowing for model independent & full investigation of the Higgs and any new physics that Higgs may reveal**
- **Very challenging events with missing neutrinos and jets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



(a) (b)

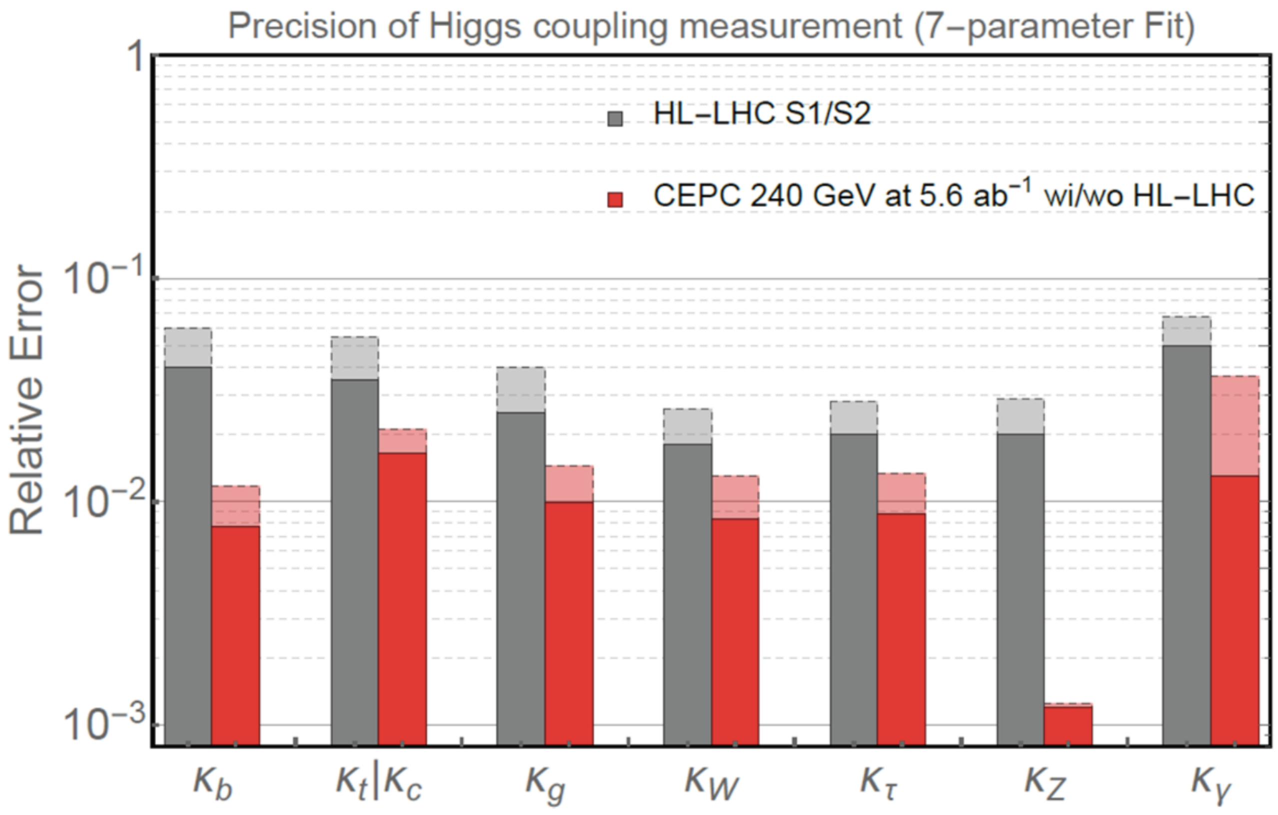
Chinese Physics C Vol. 43, No. 4 (2019) 043002



CEPC Physics Performance (CDR)

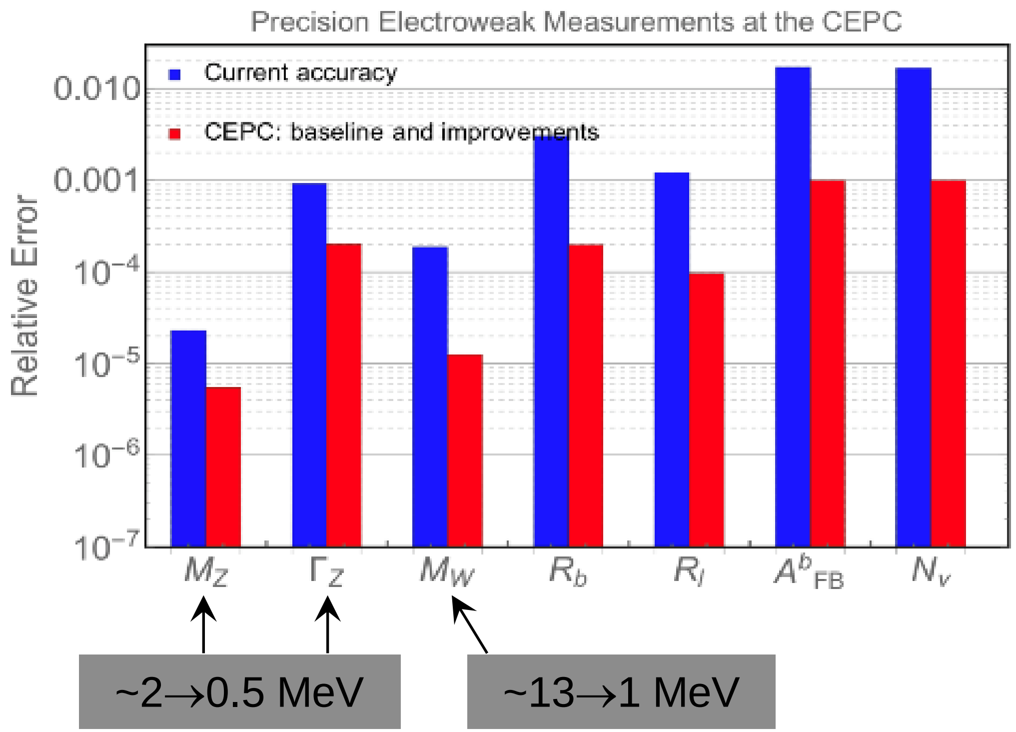
Order of magnitude improvement in precision ⇒ Unknown / discoveries

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



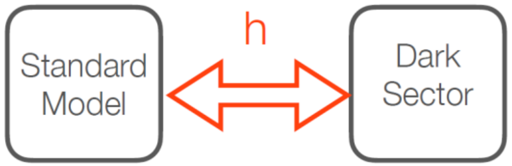
Chinese Physics C Vol. 43, No. 4 (2019) 043002

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

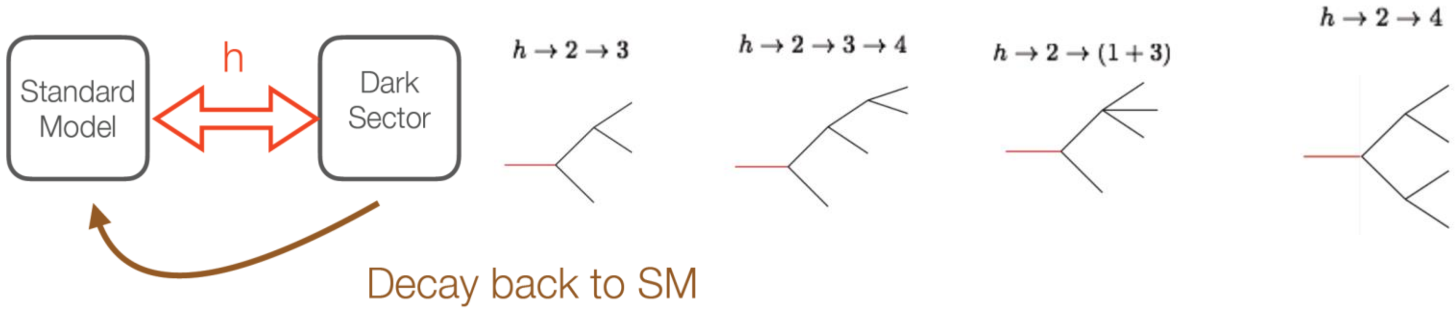


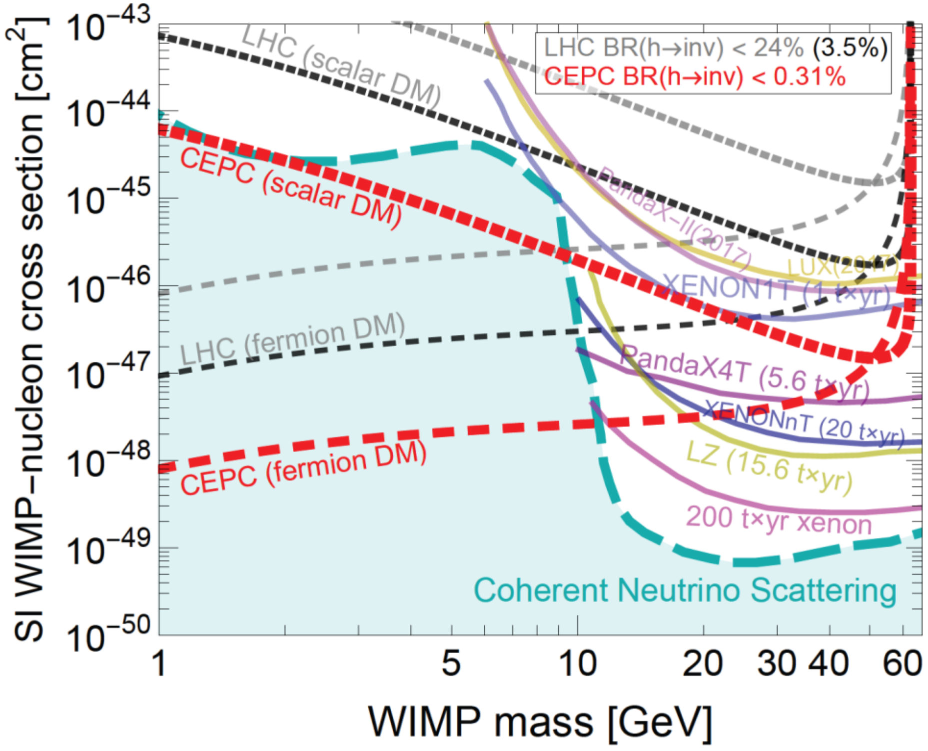
- ❑ **Precision EW measurements,**
- ❑ **Flavor physics (b, c, tau),**
- ❑ **Study of QCD,**
- ❑ **Probe physics BSM.**

Discovery Potential for New Physics

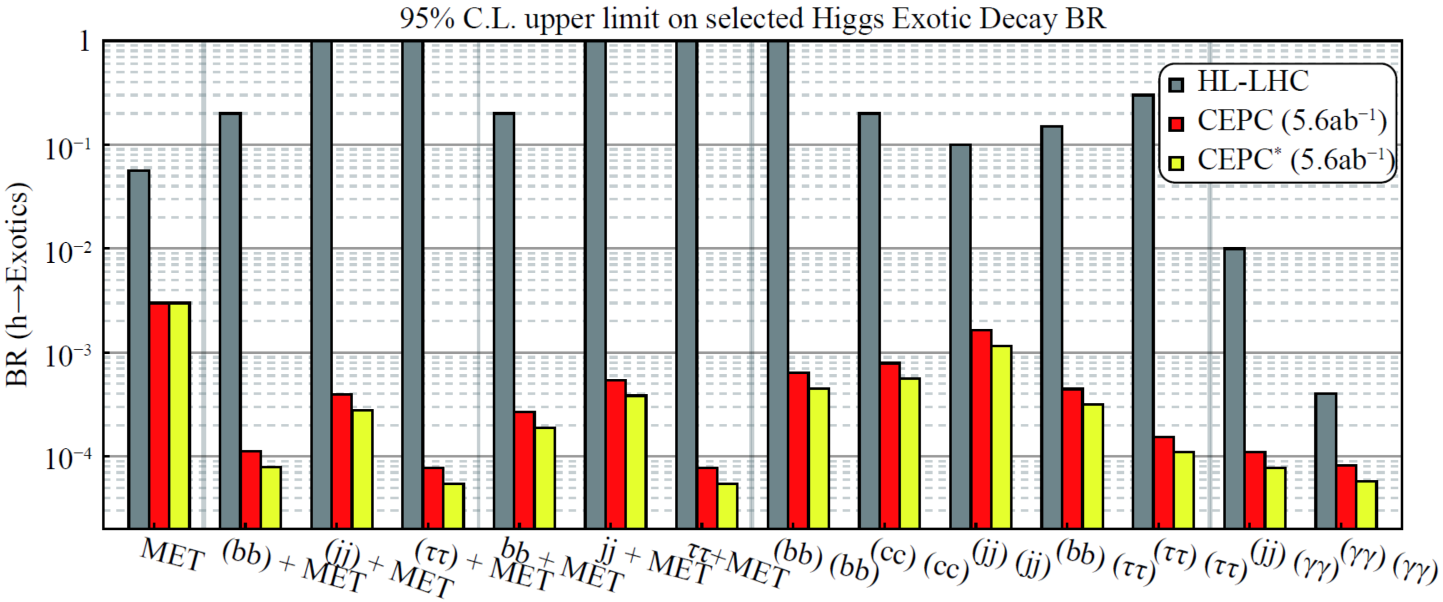


$$h \rightarrow X_{dm} X_{dm}$$





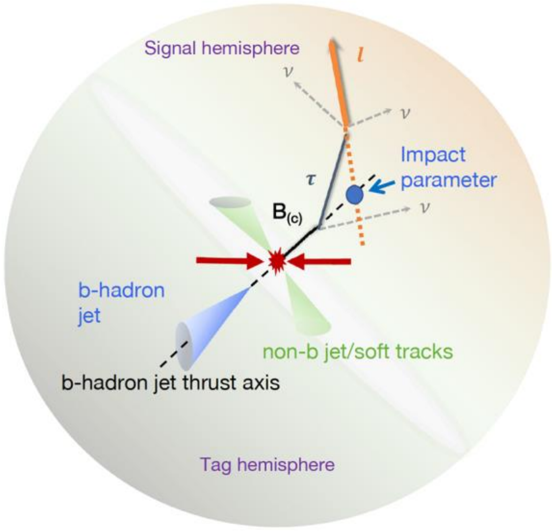
Higgs decays into BSM particles, $H \rightarrow X_1X_2$

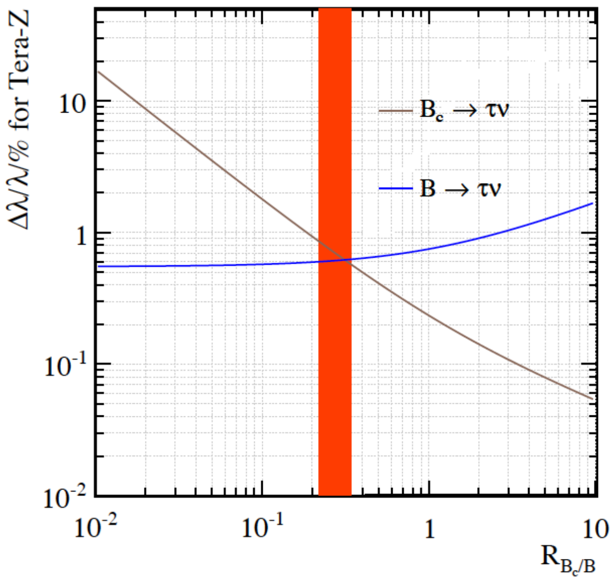


CEPC has significantly better detection sensitivity for dark matter and selected Higgs exotic decays than HL-LHC

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†]

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[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

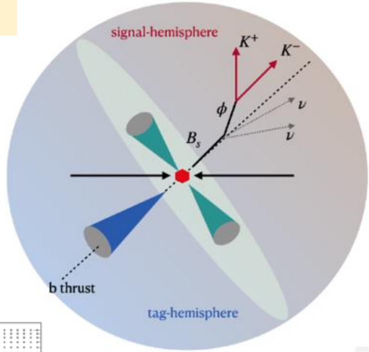
R_{K^*} & R_{D^*} anomalies at level of 2-3σ.

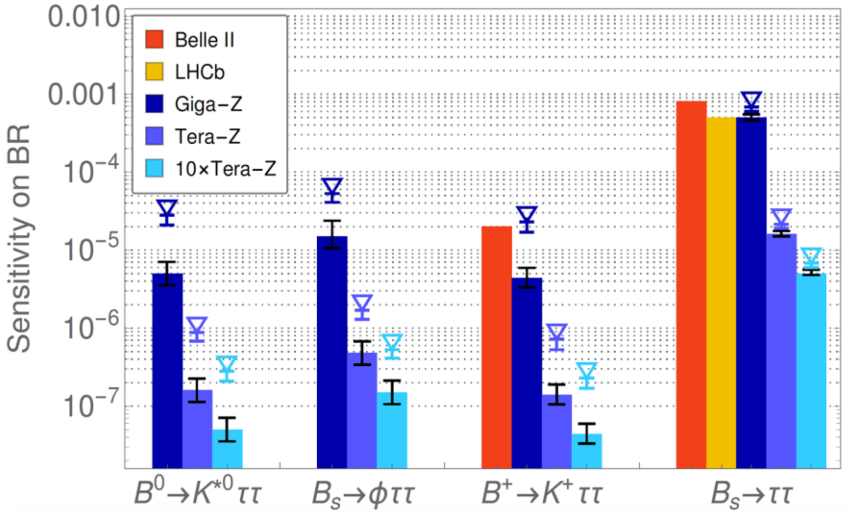
$$R_{K^{(*)}} \equiv \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)}$$

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

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

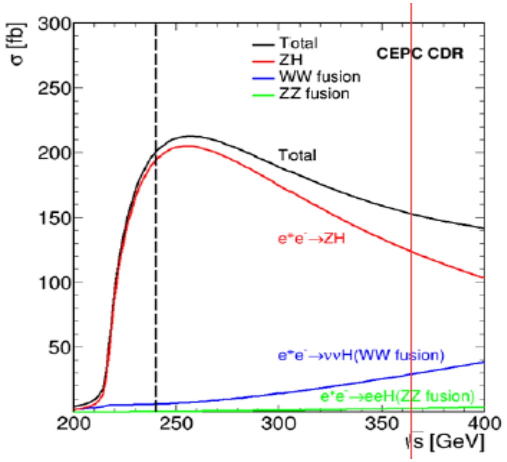
Channel	SM prediction for BR
$B^0 \to K^{*0}\tau^+\tau^-$	$(0.98 \pm 0.10) \times 10^{-7}$ [11]
$B_s \to \phi\tau^+\tau^-$	$(0.86 \pm 0.06) \times 10^{-7}$ [11]
$B^+ \to K^+\tau^+\tau^-$	$(1.20 \pm 0.12) \times 10^{-7}$ [11]
$B_s \to \tau^+\tau^-$	$(7.73 \pm 0.49) \times 10^{-7}$ [12]



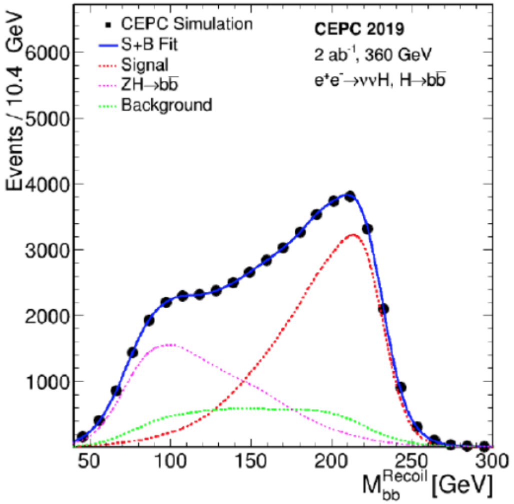


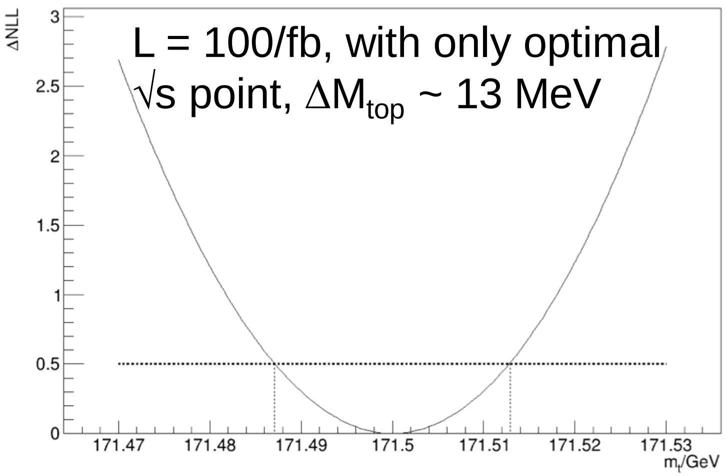
CEPC Physics at 360 GeV

- 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)

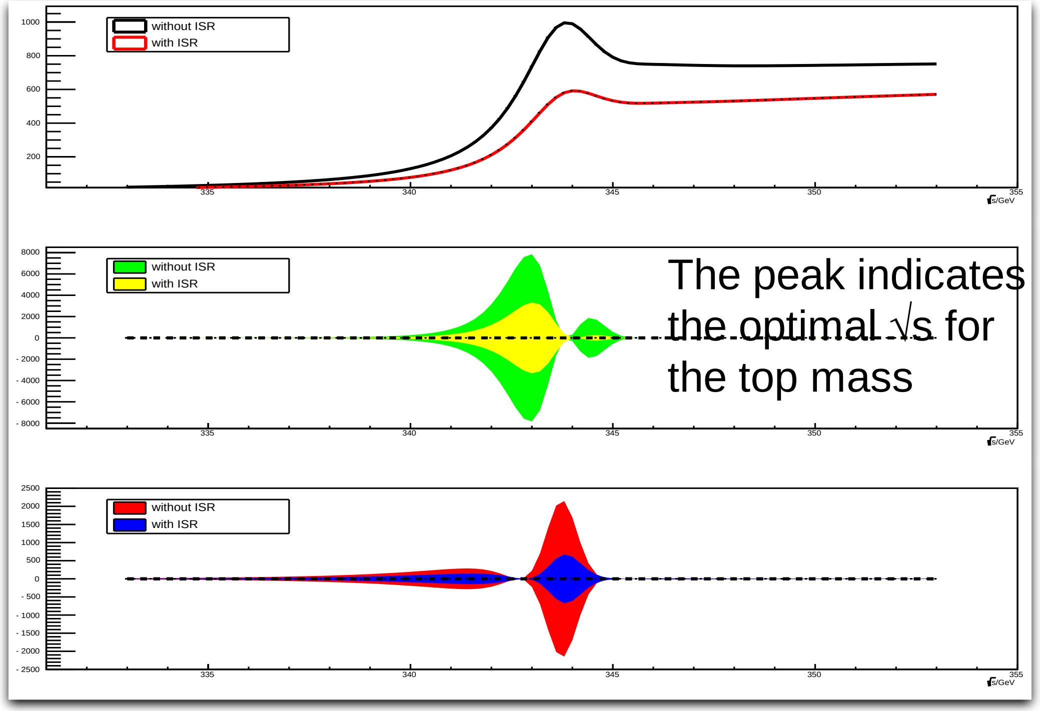


	240GeV, $5.6ab^{-1}$	360GeV, $2ab^{-1}$	
	ZH	ZH	ννH
any	0.50%	1%	\
$H \to bb$	0.27%	0.63%	0.76%
$H \to cc$	3.3%	6.2%	11%
$H \to gg$	1.3%	2.4%	3.2%
$H \to WW$	1.0%	2.0%	3.1%
$H \to ZZ$	7.9%	14%	15%
$H \to \tau\tau$	0.8%	1.5%	3%
$H \to \gamma\gamma$	5.7%	8%	11%
$H \to \mu\mu$	12%	29%	40%
$Br_{upper}(H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





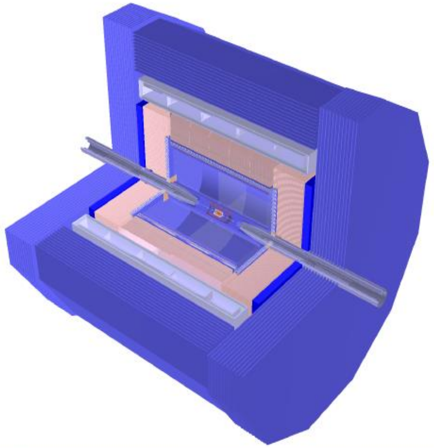
- Currently we study the top mass and width using tt threshold method:
  - One order of magnitude better precision than the LHC is expected
  - A quick energy scan with low lumi to find the optimal energy point before data taking with the full lumi. is proposed

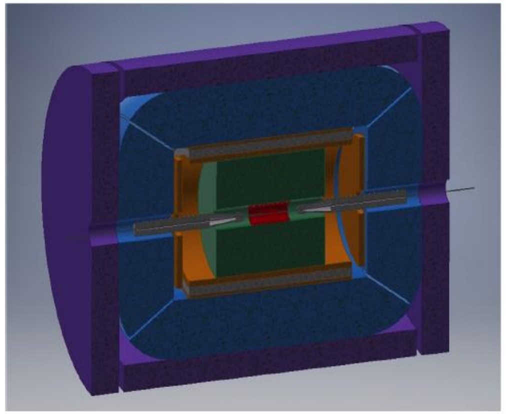


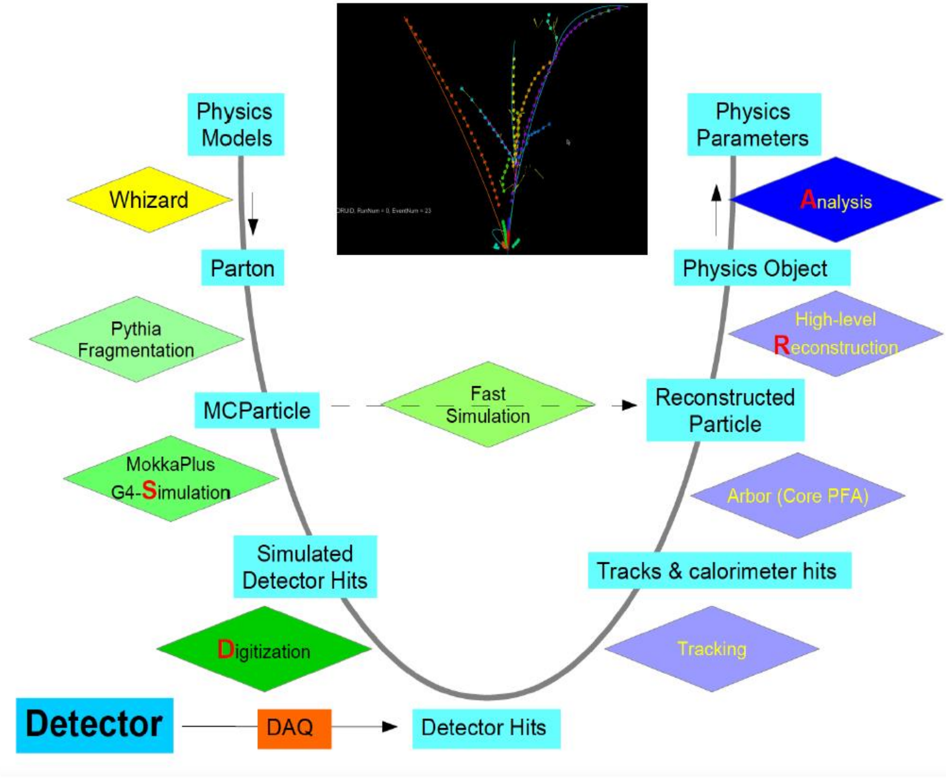
CEPC Detector and Software

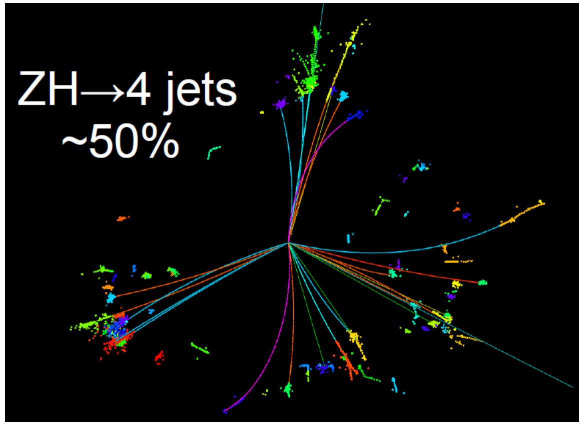
Recent added CEPC software applications:

- **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**

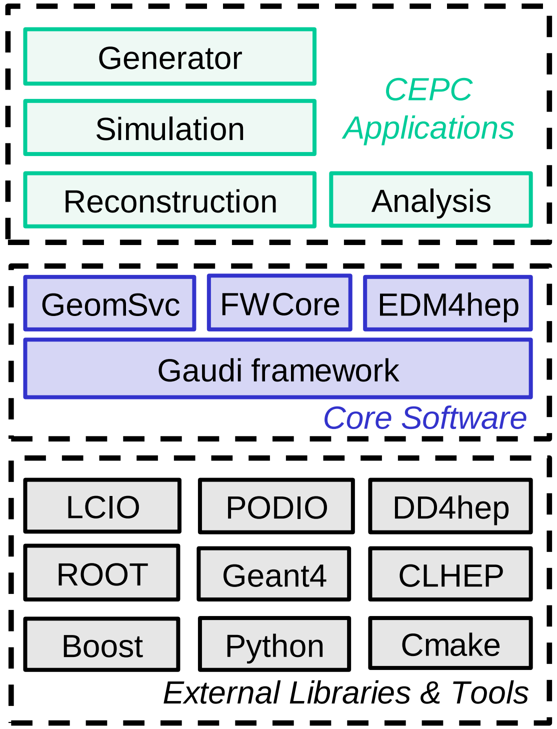








CEPCSW Structure



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

Requirements of CEPC Detector

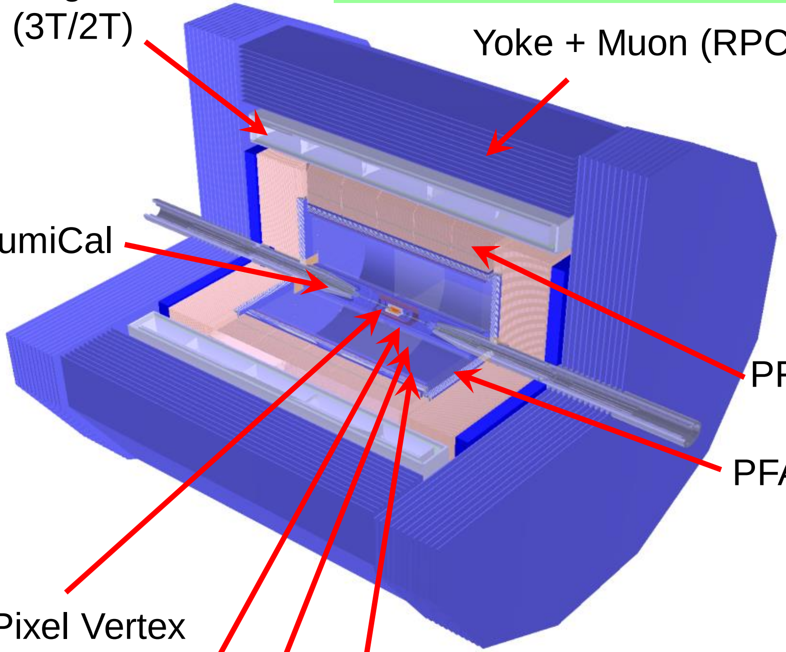
The physics motivations dictate our selection of detector technologies

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	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

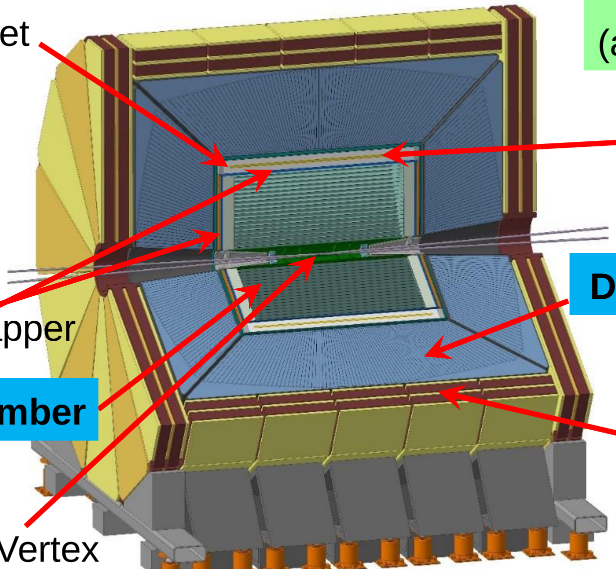
- **Flavor physics ⇒ Excellent PID, better than 2σ separation of π/K at momentum up to ~20 GeV.**
- **EW measurements ⇒ High precision luminosity measurement, $\delta L / L \sim 10^{-4}$.**

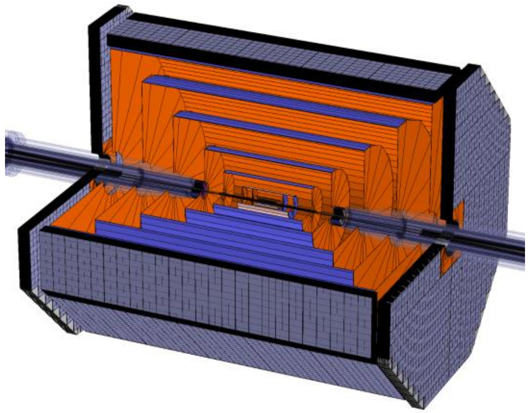
Conceptual Detector Designs

(Baseline Design)
Particle Flow Approach



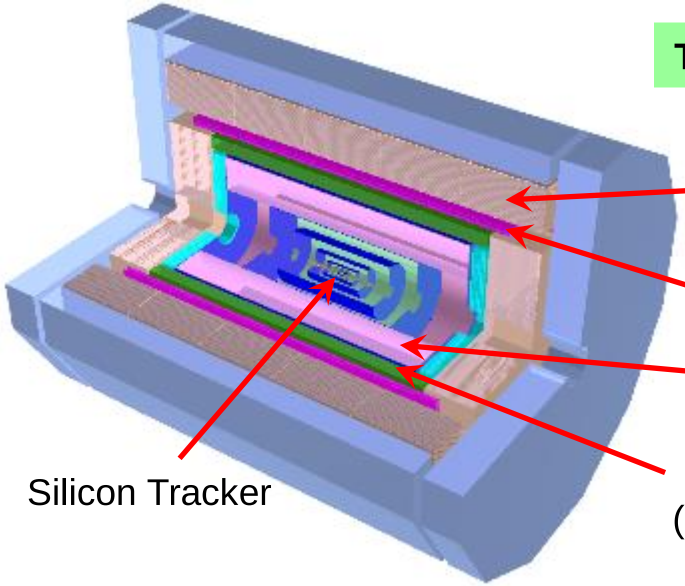
IDEA concept
(also proposed for FCC-ee)





FST concept
(Full Silicon Tracker)

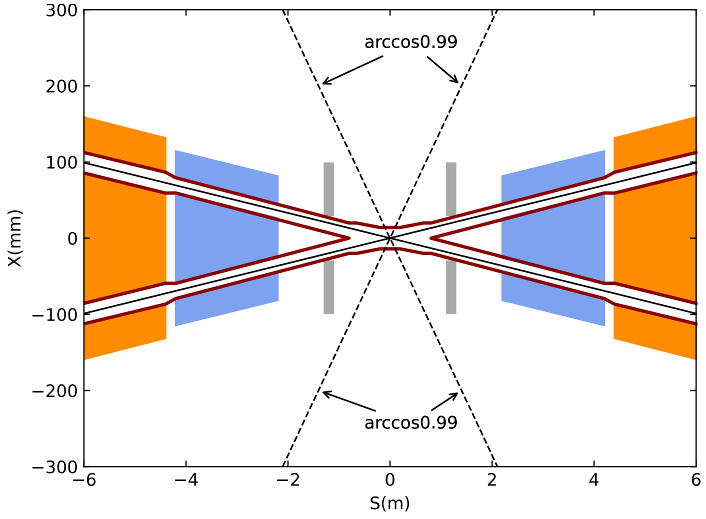
The 4th Concept



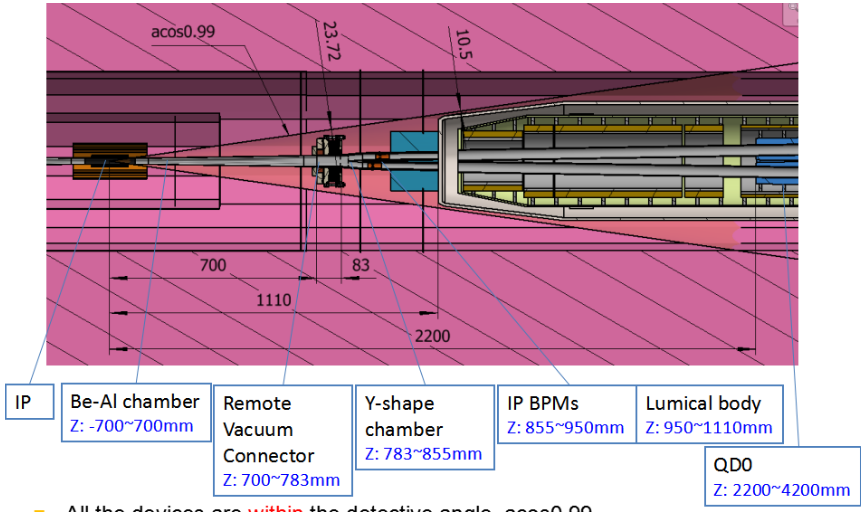
CEPC R&D: Machine Detector Interface (MDI)

Crossing angle: 33 mrad

Focal length: 2.2 m



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

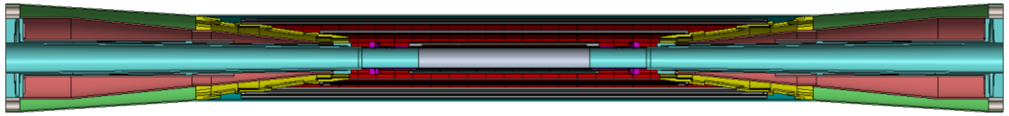


- All the devices are within the detective angle, acos0.99.

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

Beam Pipe

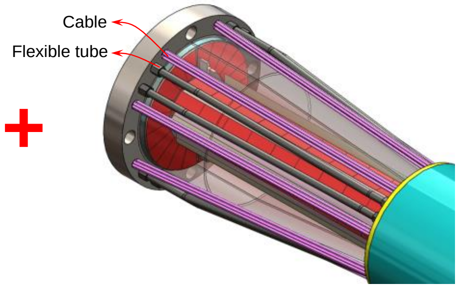
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

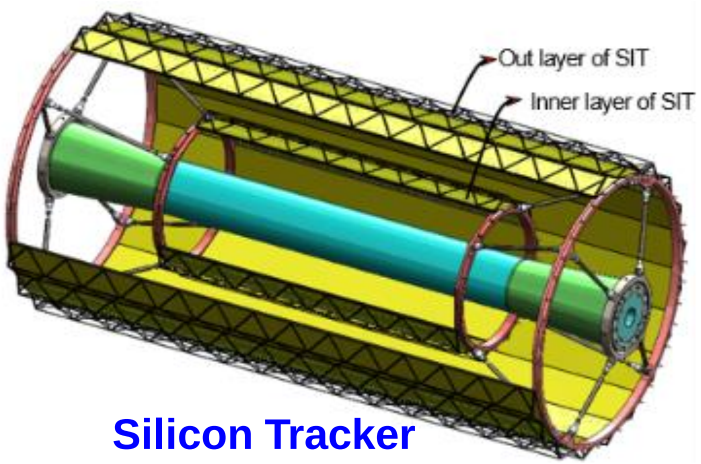


Vertex

+

LumiCal Tracker

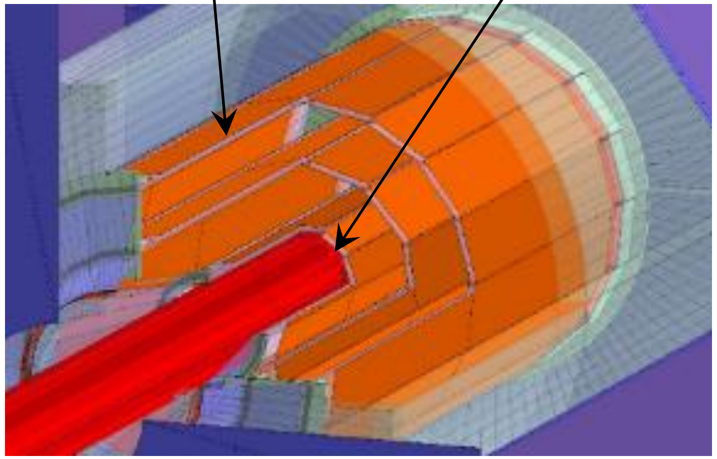




Silicon Tracker

CEPC R&D: Silicon Pixel Chips

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track

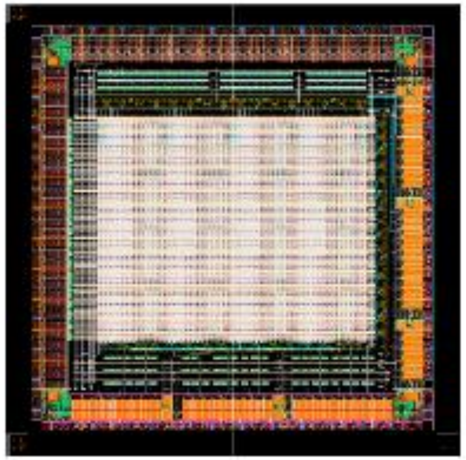
CDR design specifications

- **Single point resolution ~ 3μm**
- **Low material (0.15% X_0 / layer)**
- **Low power (< 50 mW/cm^2)**
- **Radiation hard (1 Mrad/year)**

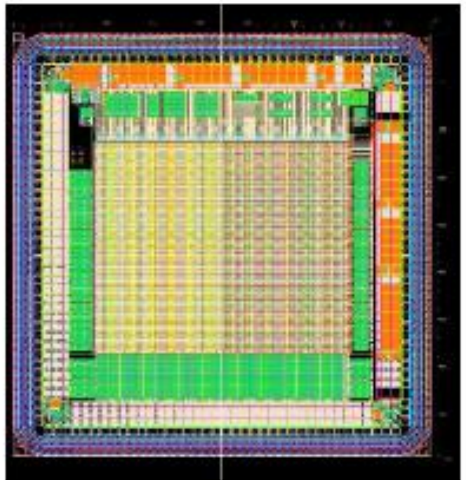
Silicon pixel sensor develops in 3 series:
JadePix, TaichuPix, CPV

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

Upper chip



Lower chip

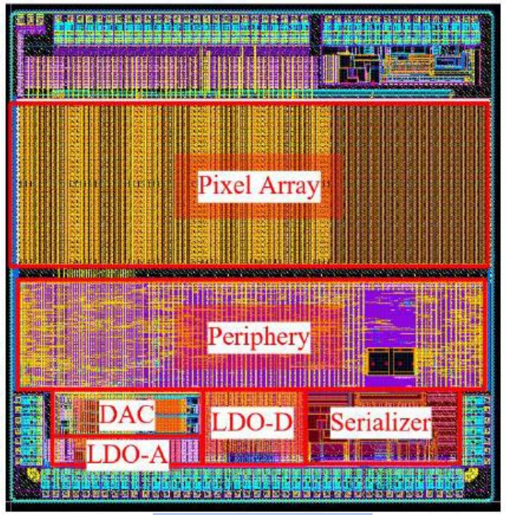


JadePix-3 Pixel size ~16×23 μm^2

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

MOST 1

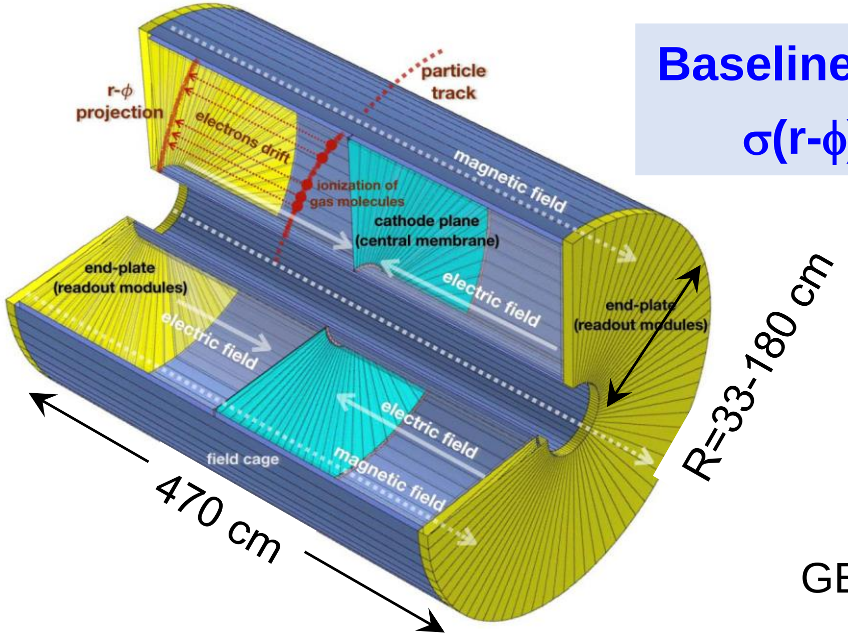
TaichuPix-2, 64×192 array
25×24 μm^2 pixel size



Full size TaichuPix-3 to be used for prototyping ladder

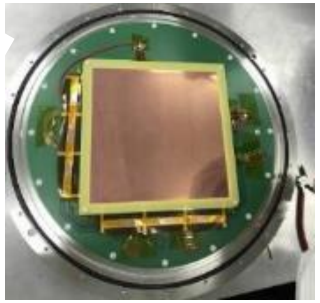
MOST 2

CEPC R&D: Time Projection Chamber

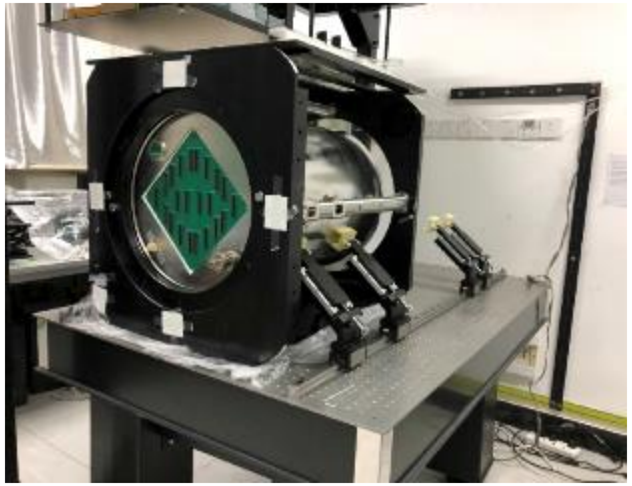


Baseline main tracker

$\sigma(r\text{-}\phi)$ ~100 μm



GEM-MM cathode

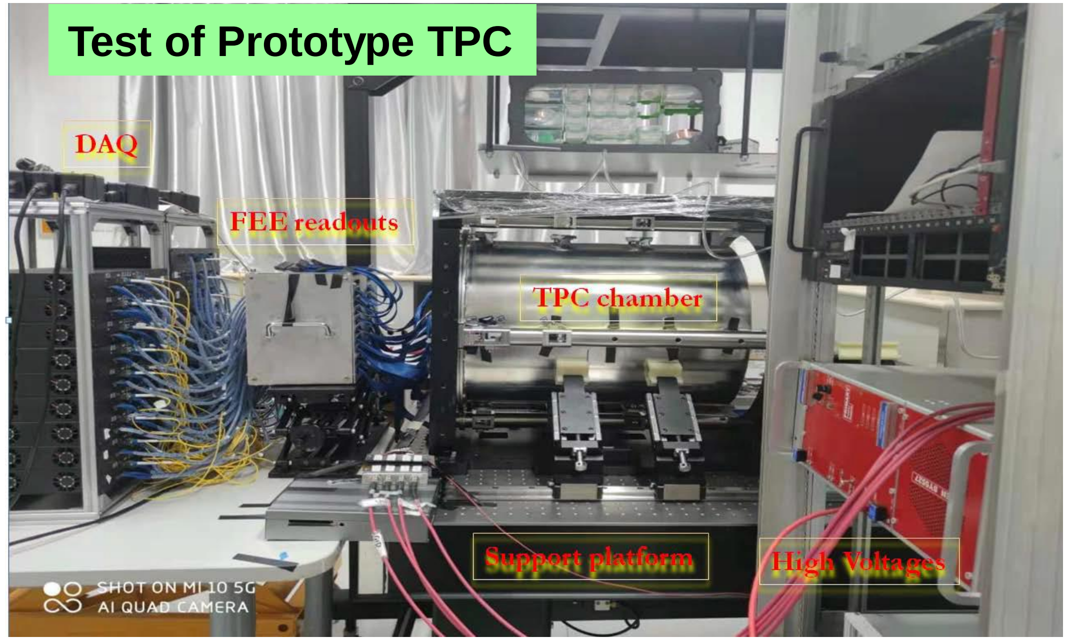


TPC Prototype + UV laser beams

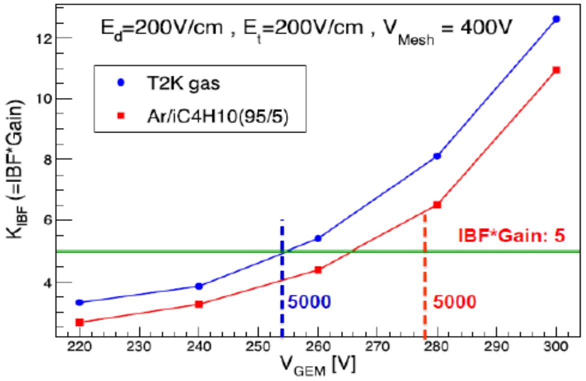
MOST 1

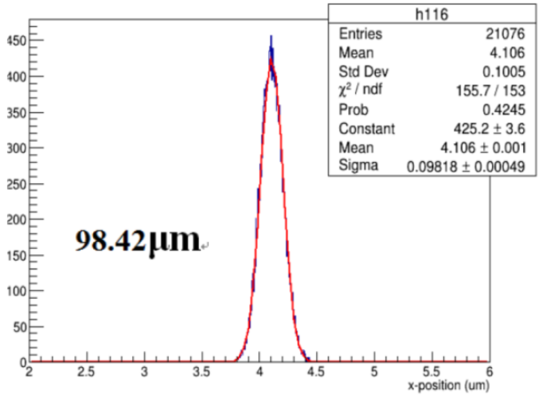
Low power FEE ASIC

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.**



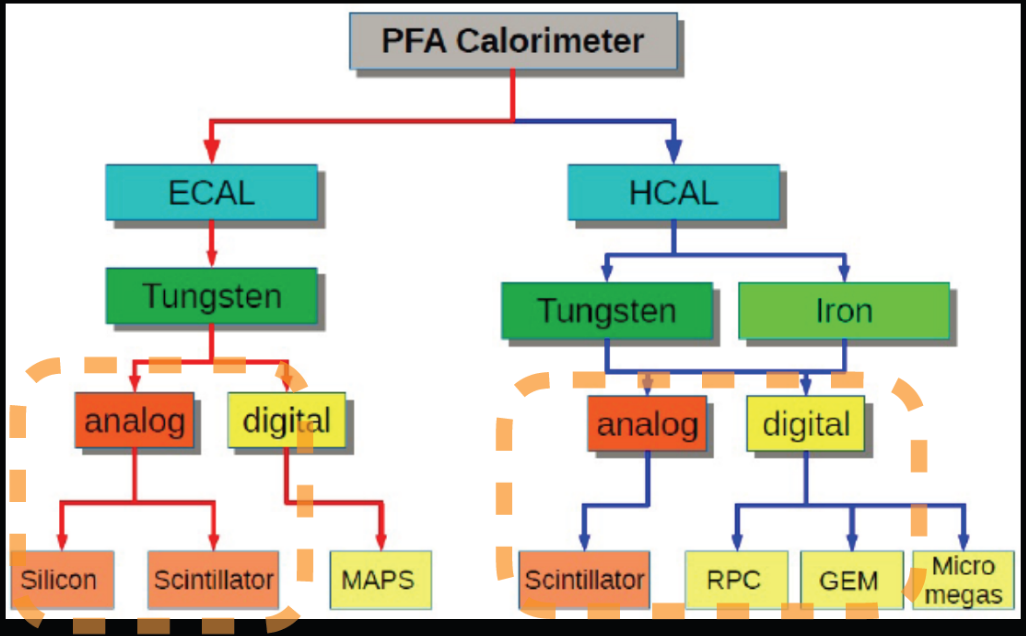


σ_x < 100 μm for drift length of 27cm

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

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



High Granularity

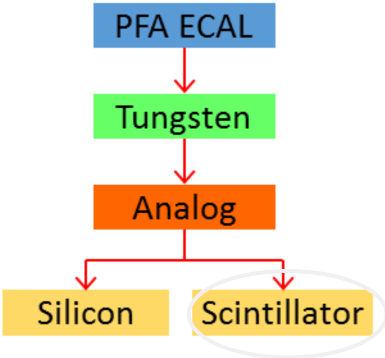
Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
Hadronic	SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP +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

Newer Options

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

46

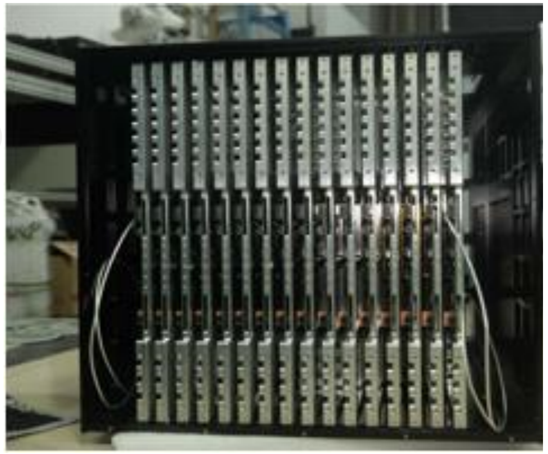
CEPC R&D: ScW-ECAL Prototype

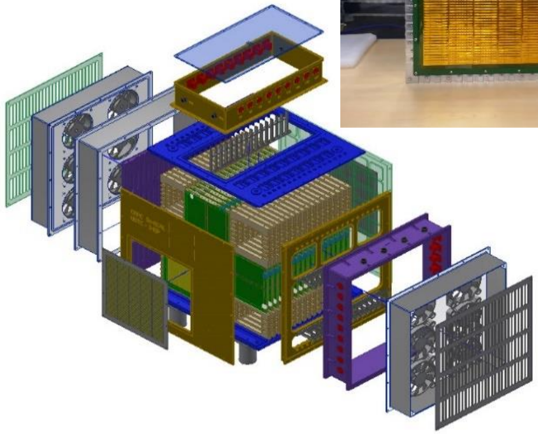


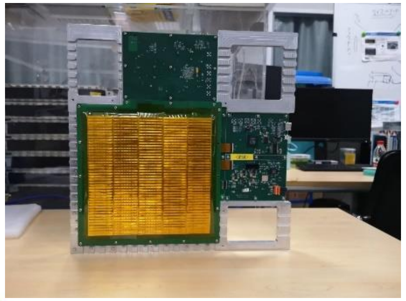
MOST 1

Goal of ECAL+HCAL+…

4% BMR, e.g. in (Z→νν) (H→gg)







ScECAL prototype with 6700 channels

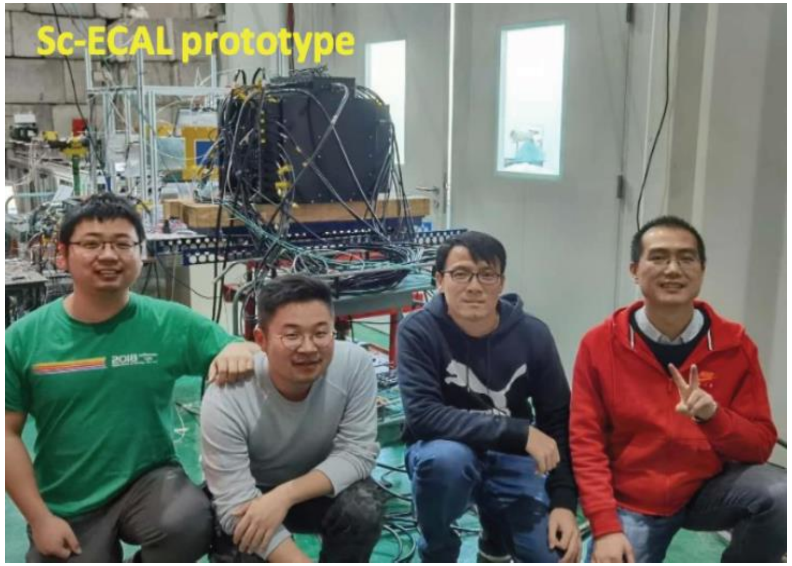
32 layers (EBU), 22 x 22 cm^2, ~22X_0

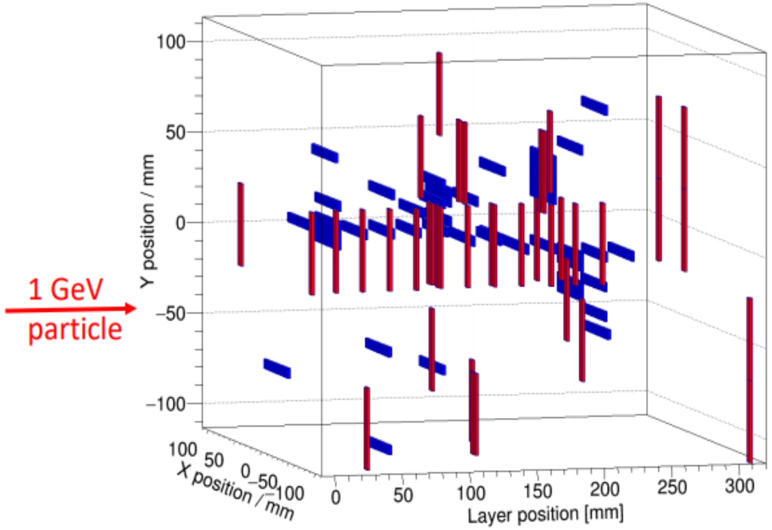
Scintillator (5×45mm^2) + MPPC S12571

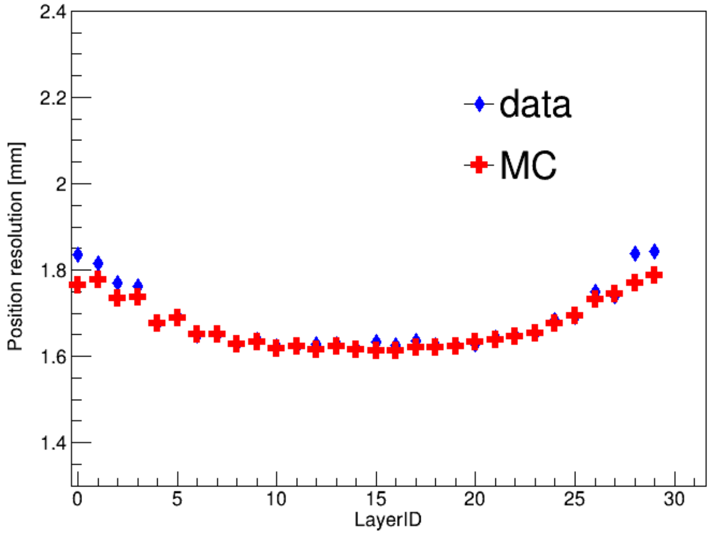
Embedded FEE (192 SPIROC2E ASICs)

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

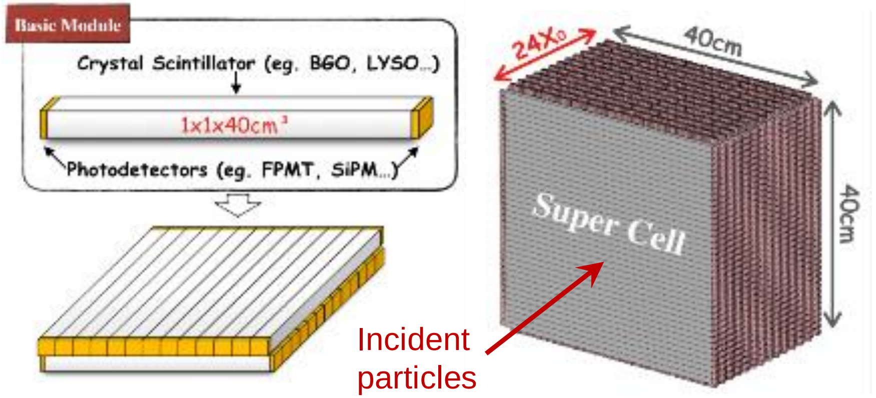
Cell Granularity: 5mm × 5mm
Position resolution: 1.6-1.8mm







CEPC R&D: High Granularity Crystal ECAL



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

Design Idea

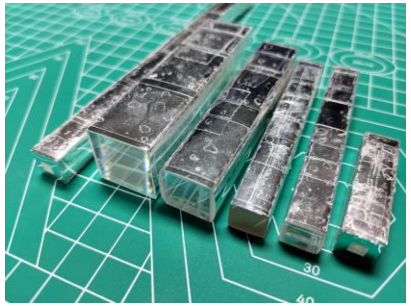
Goal

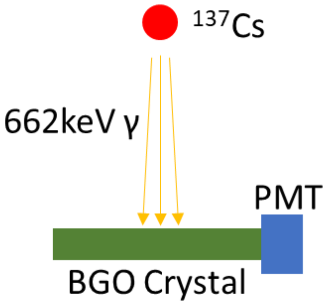
- Comparable BMR resolution as with the Sci+W ECAL.
- Much better sensitivity to γ/e, especially at low energy.

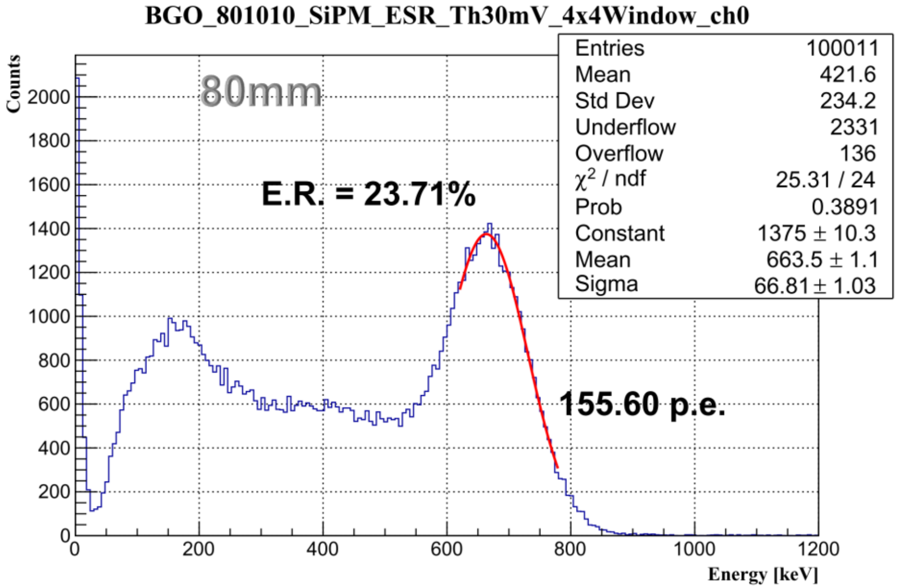

Test board for KLauS-5 in BGA package

Bench Test

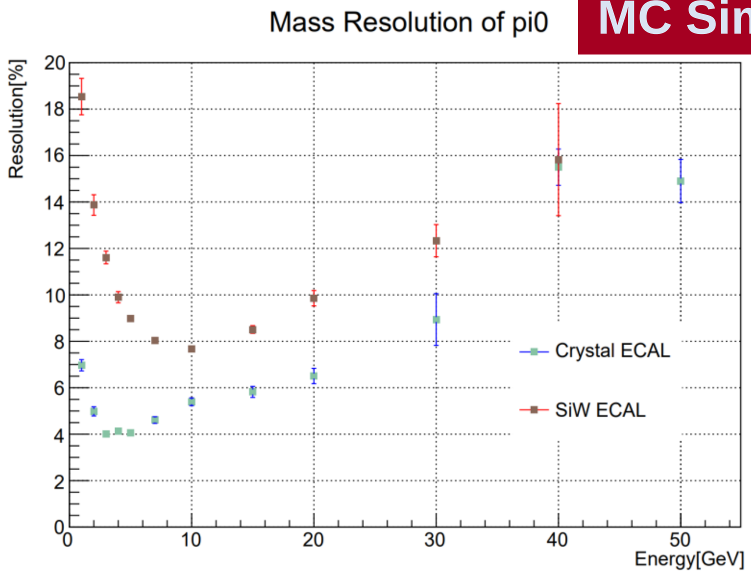
Performance Test



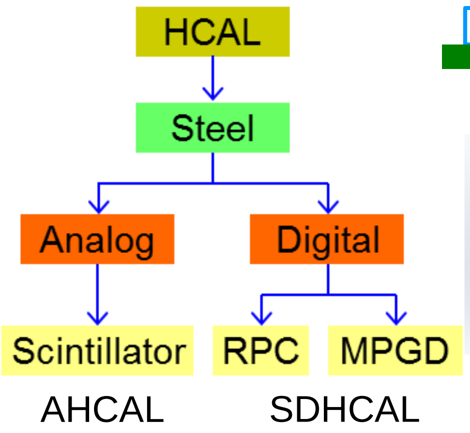


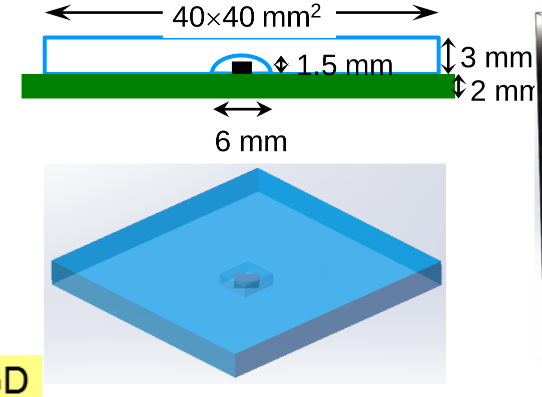


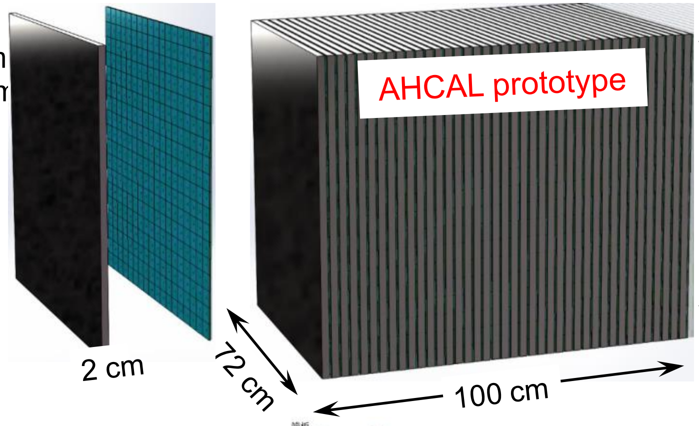
MC Simulation

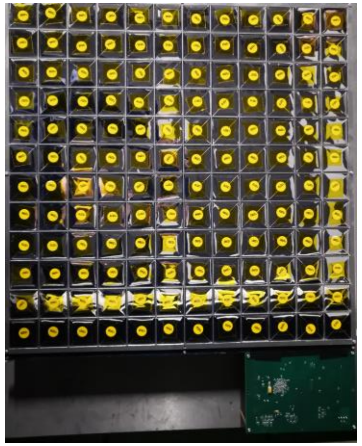


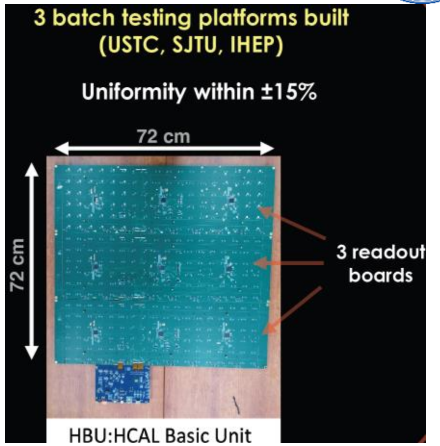
CEPC R&D: PFA HCAL

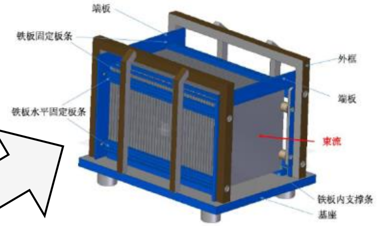


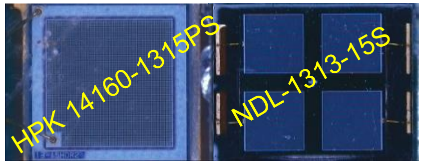






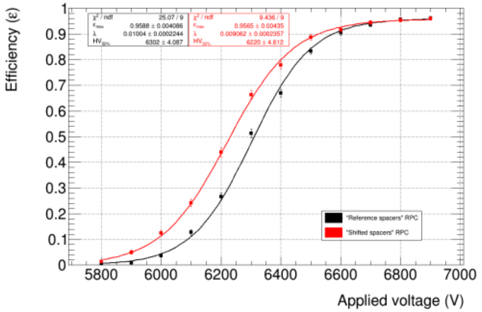






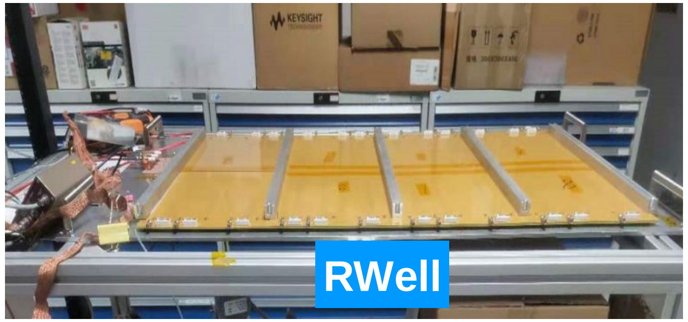
Tested ~ 15k Scintillators
Light Yield： ~ 13 ± 0.66

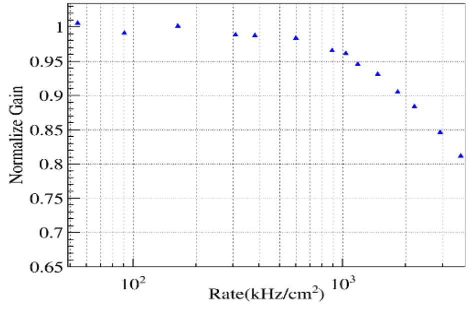
- **AHCAL with Scint.+SiPM (USTC, IHEP, SJTU)**
  - Prototype in production, size 72×72×100 cm^3,
  - 40 layers, Fe+Sct+SiPM+PCB=20+3+2=25mm,
  - 12960 Scintillators, cell size 40×40 mm^2
  - SiPM: HPK 14160-1315PS and NDL-1313-15S



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

  Constructed 1×1 m^2 GRPCs, MIP Efficiency ~ 95.7%

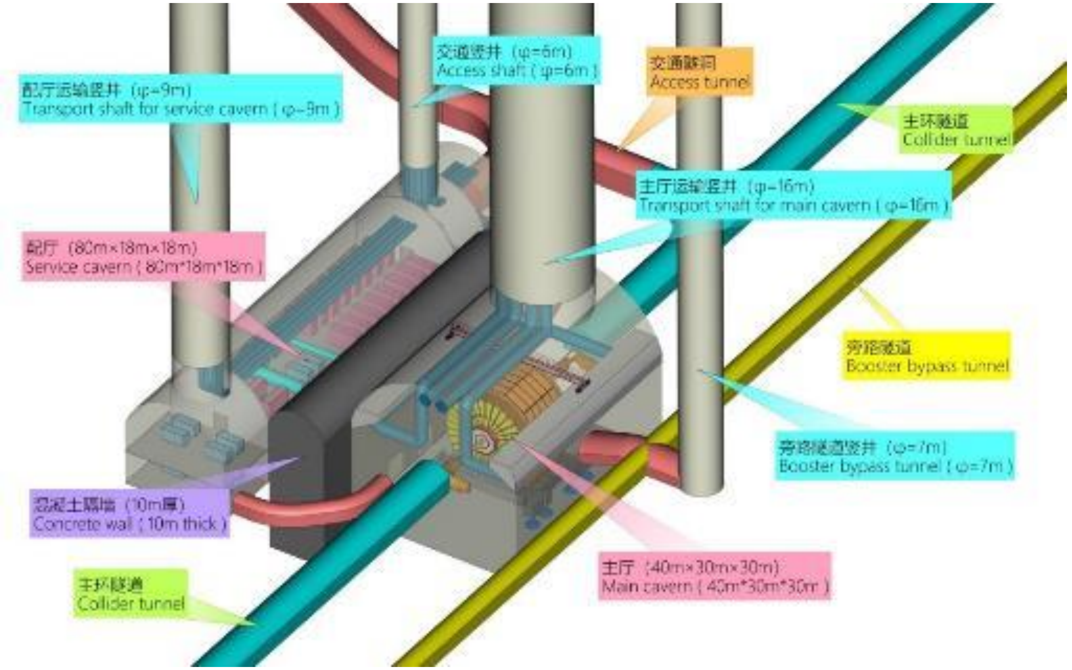




- **SDHCAL based on MPGD (USTC, IHEP)**

  Constructed 1×0.5 m^2 RWell detector, MIP Efficiency ~ 95.9%, count rate ~ 1.8 MHz/cm^2

The Experimental Area



Ground level buildings

Main cavern to host the detector

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

Auxiliary cavern for peripheral equipment and devices

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

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Thank you !