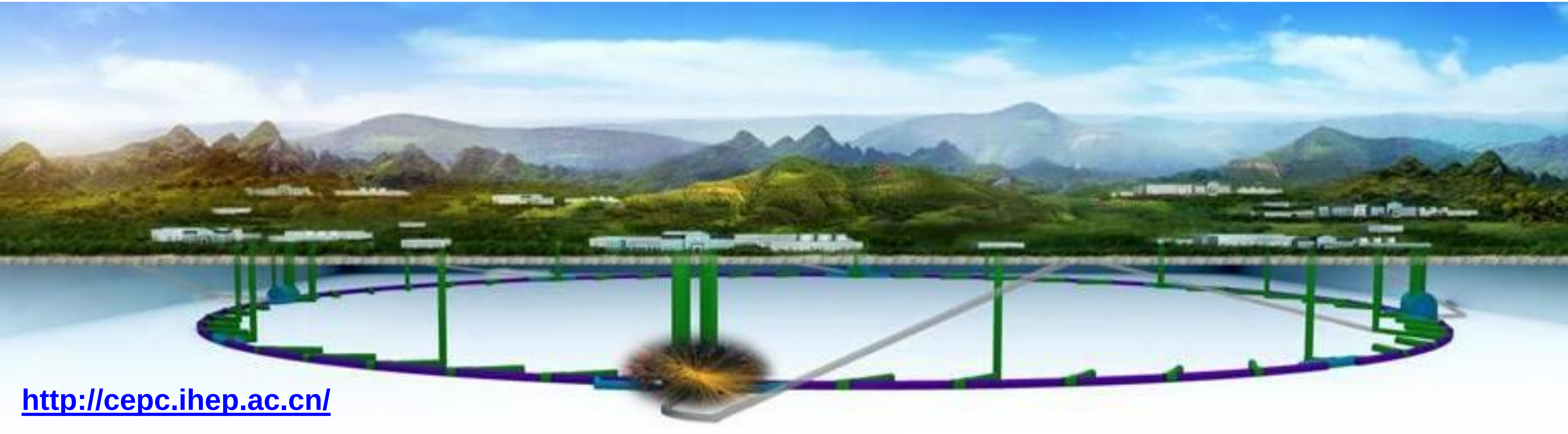
Status of CEPC Project

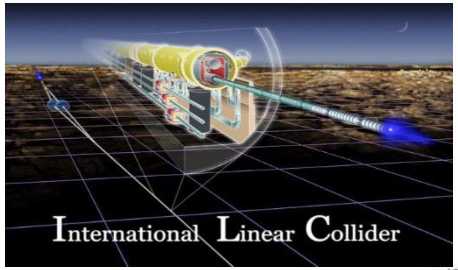
Haijun Yang
(for the CEPC working group)

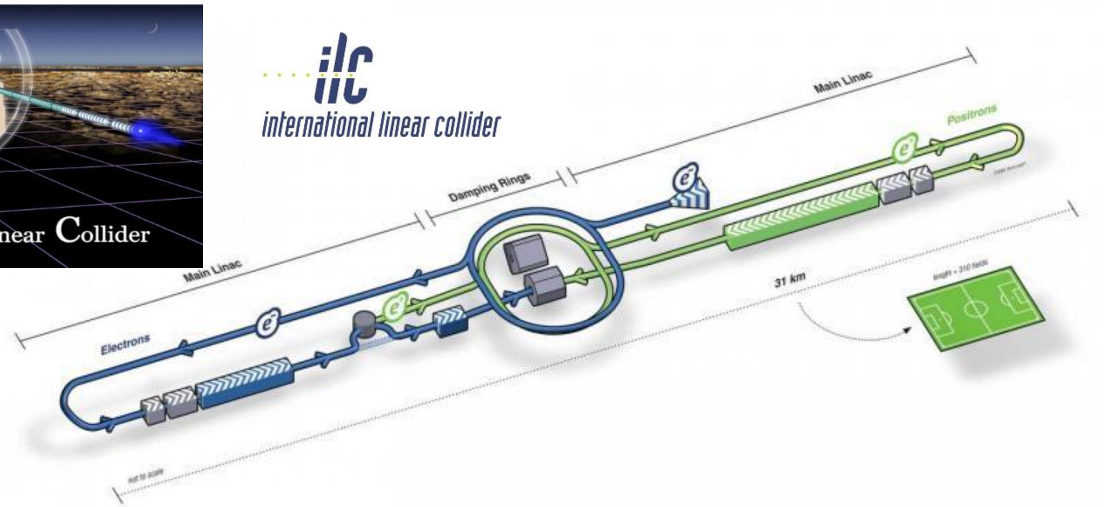
第十五届TeV物理工作组学术研讨会
北京，2021年7月19-21日



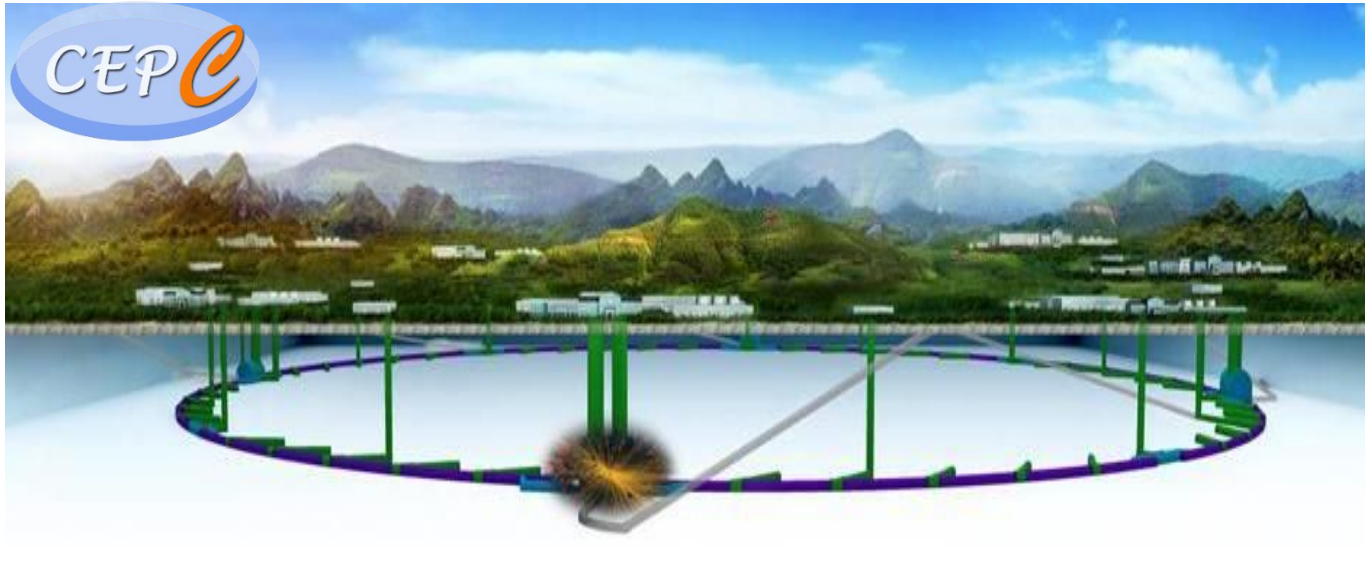
http://cepc.ihep.ac.cn/

Worldwide Higgs Factories





IDT	ILC Pre-Lab				ILC Lab.										
PP	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.



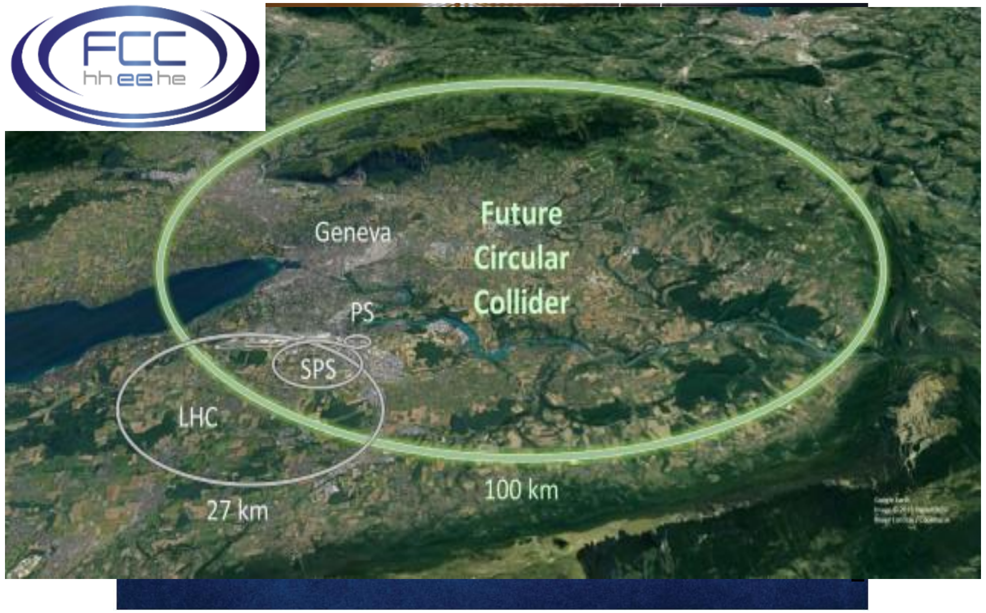
- 欧洲粒子物理战略规划建议正负电子希格斯工厂是优先级最高的下一代对撞机。
- An electron-positron Higgs factory is the highest-priority next collider.

nature Subscribe

NEWS · 19 JUNE 2020 · CORRECTION 23 JUNE 2020

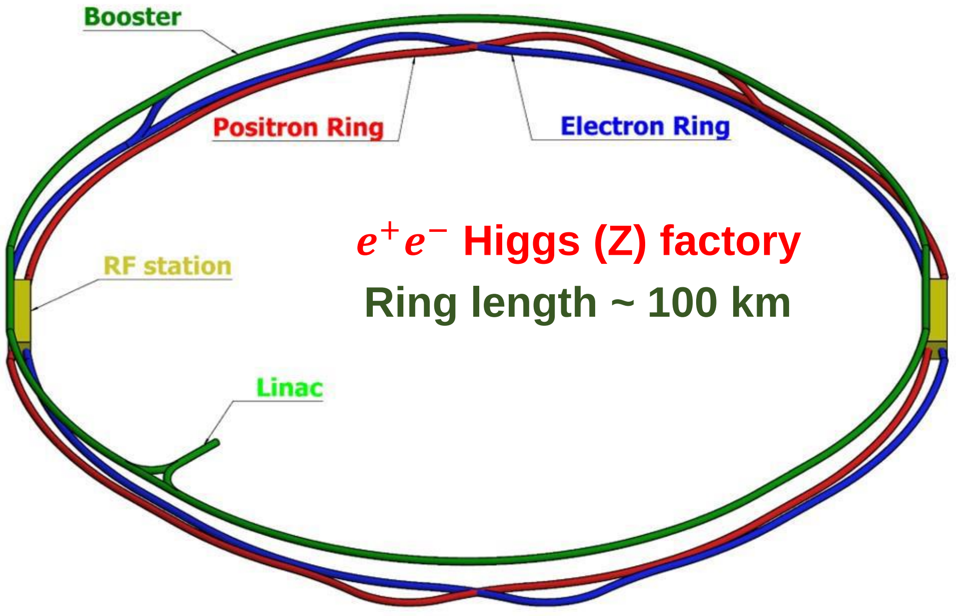
CERN makes bold push to build €21-billion supercollider

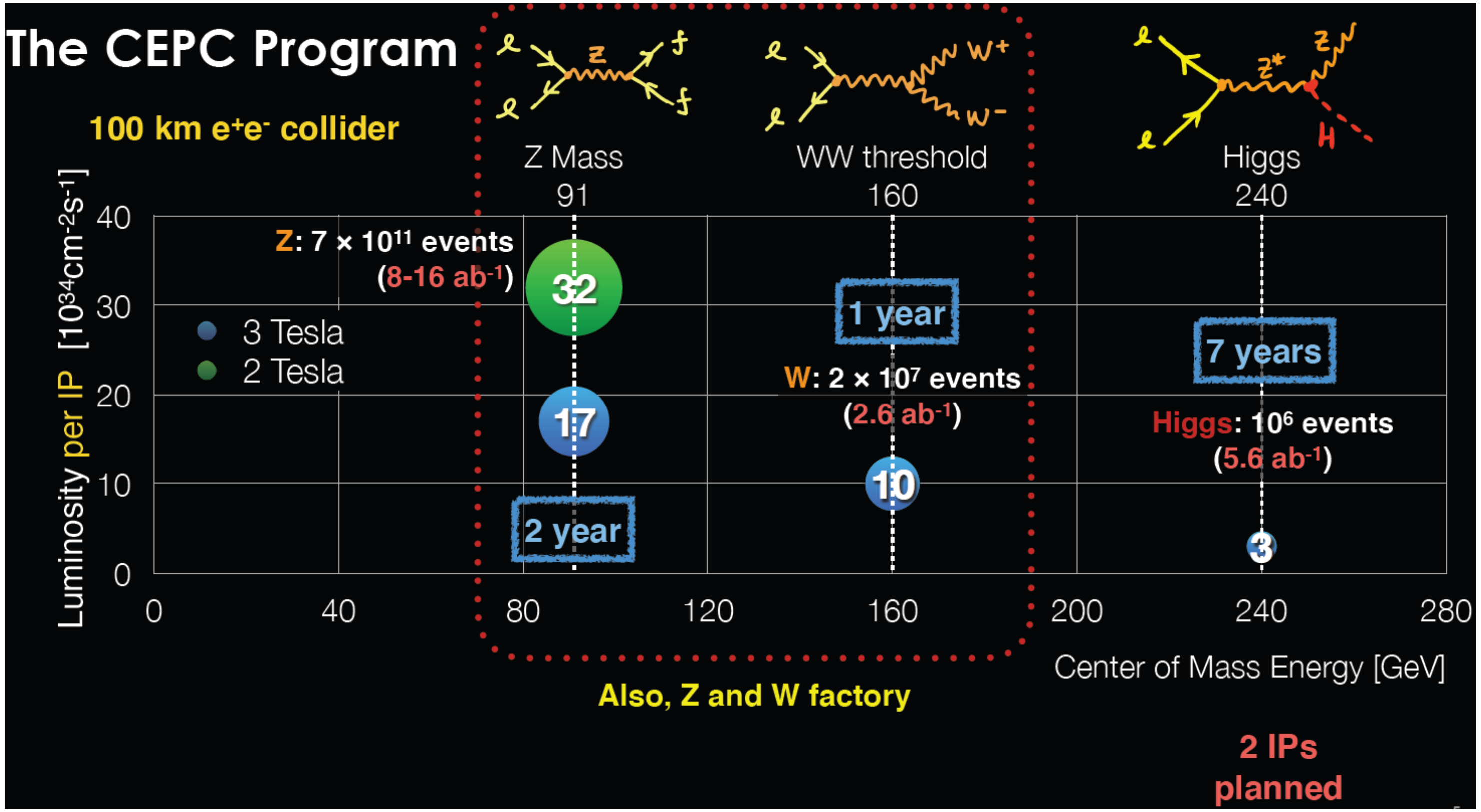
European particle-physics lab will pursue a 100-kilometre machine to uncover the Higgs boson's secrets – but it doesn't yet have the funds.



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 (possible $t\bar{t}$ pair) production threshold.
- High precision Higgs, EW measurements, studies of flavor physics & QCD, probes of BSM physics.
- Possible Super *pp* Collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the future.





CEPC Major Milestones

2013年9月CEPC-SPPC启动会

2015, CEPC IAC Meeting

2018年11月发布CEPC概念设计报告

Public release: November 2018

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

CEPC Conceptual Design Report	CEPC Conceptual Design Report
Volume I - Accelerator	Volume II - Physics & Detector
arXiv: 1809.00285	arXiv: 1811.10545
The CEPC Study Group, August 2018	The CEPC Study Group, October 2018

1143 authors
222 institutes (140 foreign)
24 countries

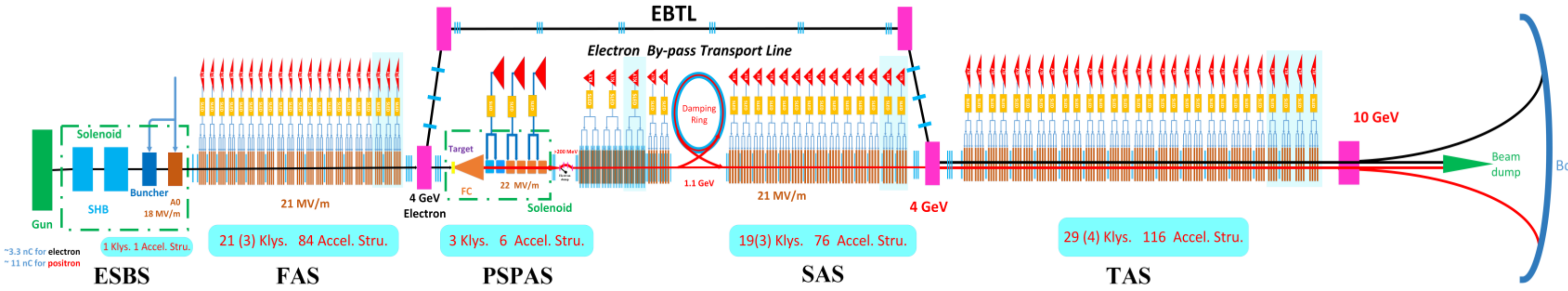
Editorial Team: 43 people / 22 institutions/ 5 countries

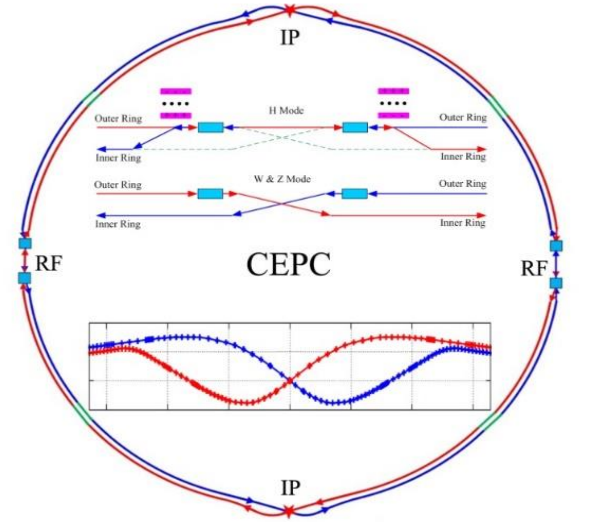
CEPC Accelerator Baseline (CDR)

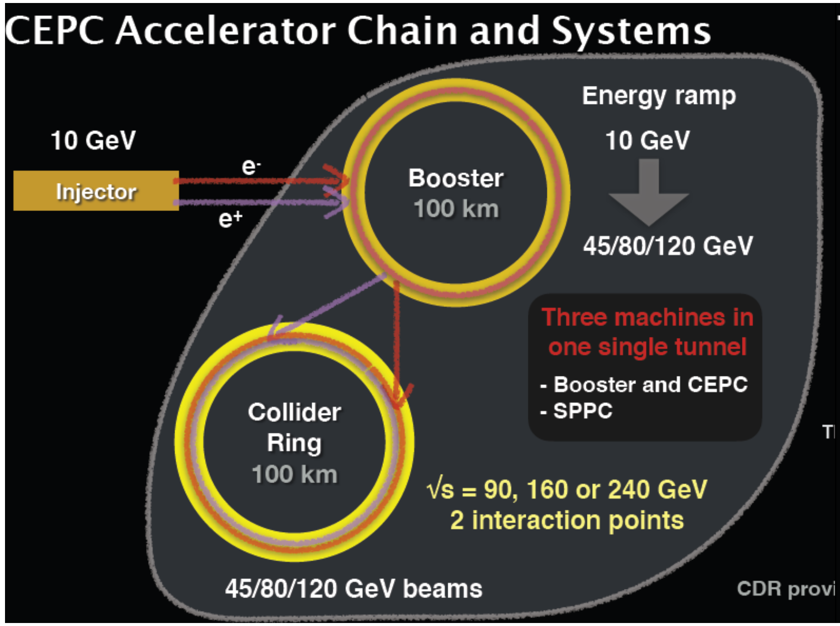
Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

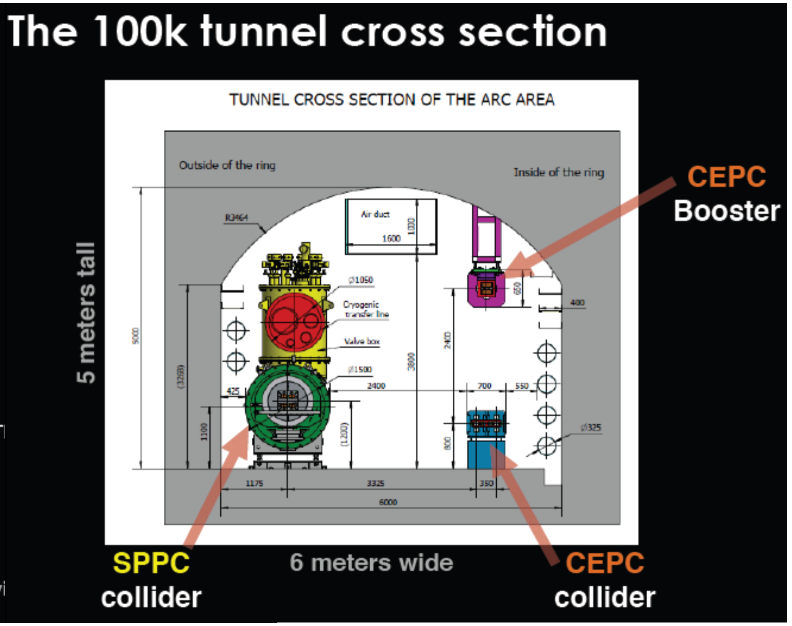
http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf

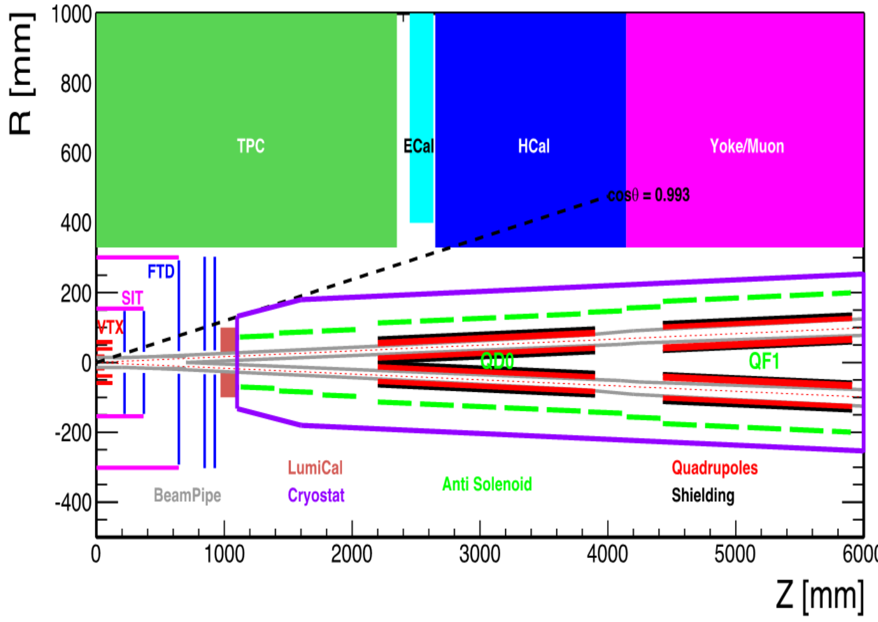
A very active **accelerator** R&D program towards a **TDR ~** the end of 2022











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
  - Next ARC meeting will be held in Nov., 2021

CDR scheme (Higgs)

✓ $L^*=2.2m$, $\theta c=33mrad$, $\beta x^*=0.36m$, $\beta y^*=1.5mm$, Emittance=1.2nm
- Strength requirements of anti-solenoids (peak field $B_z\sim7.2T$)
- Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

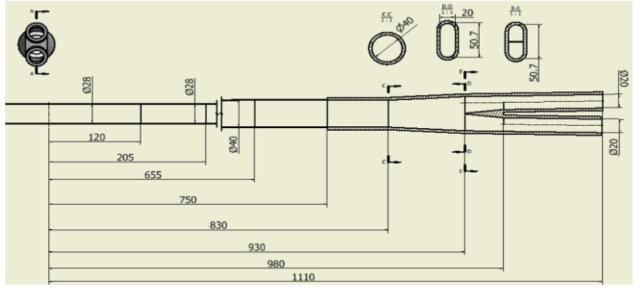
High luminosity scheme (Higgs)

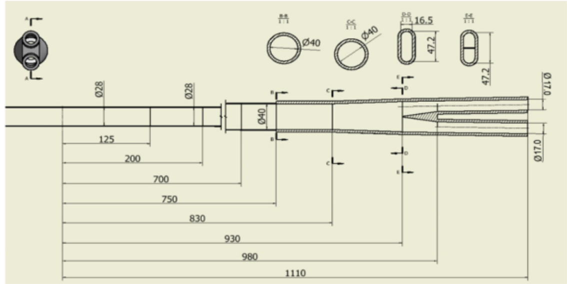
✓ $L^*=1.9m$, $\theta c=33mrad$, $\beta x^*=0.33m$, $\beta y^*=1.0mm$, Emittance=0.68nm
- Strength requirements of anti-solenoids (peak field $B_z\sim7.2T$)
- Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

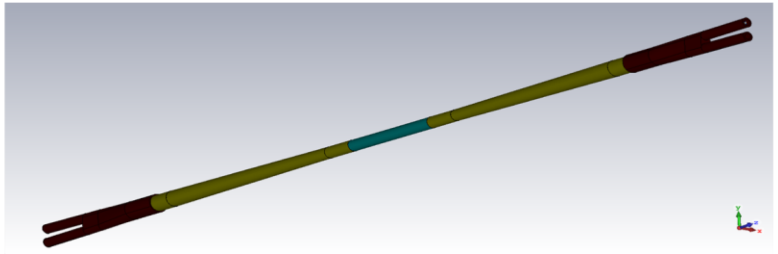
Change of IP chamber

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

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







CEPC Accelerator Design Improvement

	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	[illegible]	[illegible]	
Bunch length σ_z (mm)	4.4	[illegible]	[illegible]	
Damping time $\tau_x/\tau_y/\tau_E$ (ms)	[illegible]	[illegible]	849.5/849.5/425.0	
Natural Chrom[illegible]	[illegible]	[illegible]1161	-491/-1161	-513/-1594
Bet[illegible]	363.10 / 365.22			
[illegible]	0.065	0.040	0.028	
[illegible]ty (2 cell)	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

2018 CDR Baseline 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	[illegible]	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/[illegible]	[illegible]	6/35
Bunch length (SR/total) [mm]	2.2/2.9	[illegible]	[illegible]/4.9	2.5/8.7
Energy spread (SR/total) [%]	[illegible]	[illegible]/0.17	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	[illegible]	1.6/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	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

2021 Improved Design

67%⇑ 259%⇑

CEPC Accelerator R&D: Towards TDR

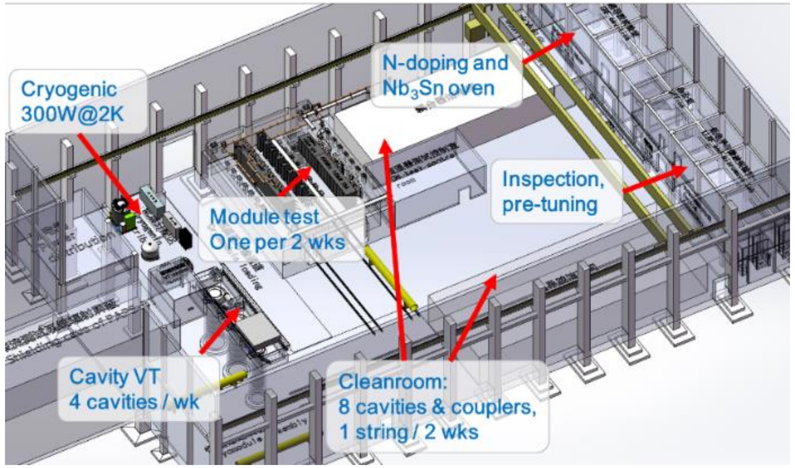
- CEPC 650MHz 800kW klystron: **high efficiency (80%), fabrication will be completed in 2021, test in 2022**
- CEPC 650MHz SC accelerator system (cavities and cryomodules): **to complete test cryomodule in 2022**
- High precision booster dipole magnets: **to complete full-size magnet model in 2021**
- Collider dual aperture dipole, quadrupoles and sextupole magnets: **to [illegible]plete full-size model in 2022**
- SC magnets including cryostats: **to complete sho[illegible] 2022**
- Vacuum chamber system: **to co[illegible]ion and costing test in 2022**
- MDI mechanic syste[illegible]**uum connection removal to be tested in 2022**
- Collimator: **to complete model test in 2022**
- Linac components: **to complete key components test in 2022**
- Civil engineering design: **to complete reference implementation design in 2022**
- Plasma wakefield injector: **to complete the electron accelerator test in 2022**
- 18KW@4.5K cryoplant: **industrial partner**

Aiming for Accelerator TDR in 2022

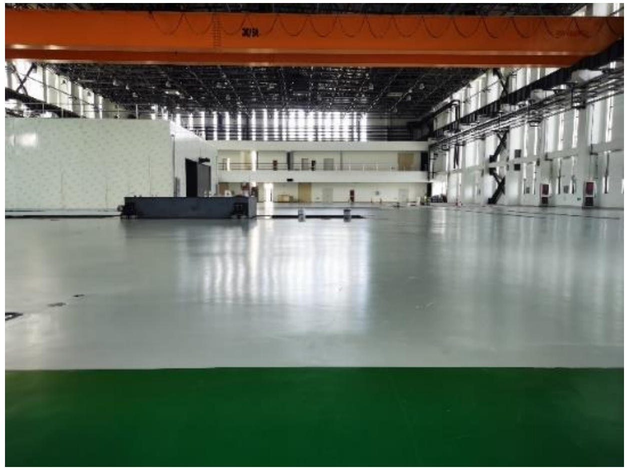
CEPC SCRF Test Facility

CEPC SCRF test facility (Lab)：Beijing Huairou (4500m²)

New SC Lab Design (4500m²)



SC New Lab will be available in 2021



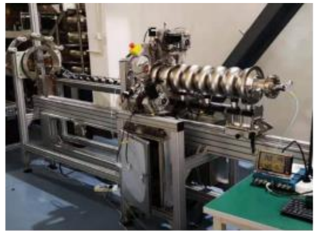
Crygenic system hall in Jan. 16, 2020

Vacuum furnace (doping & annealing)

Nb3Sn furnace

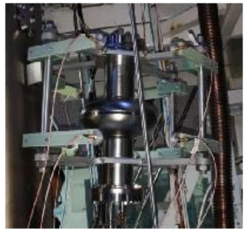
Nb/Cu sputtering device

Cavity inspection camera and grinder

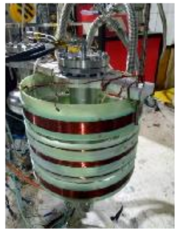


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



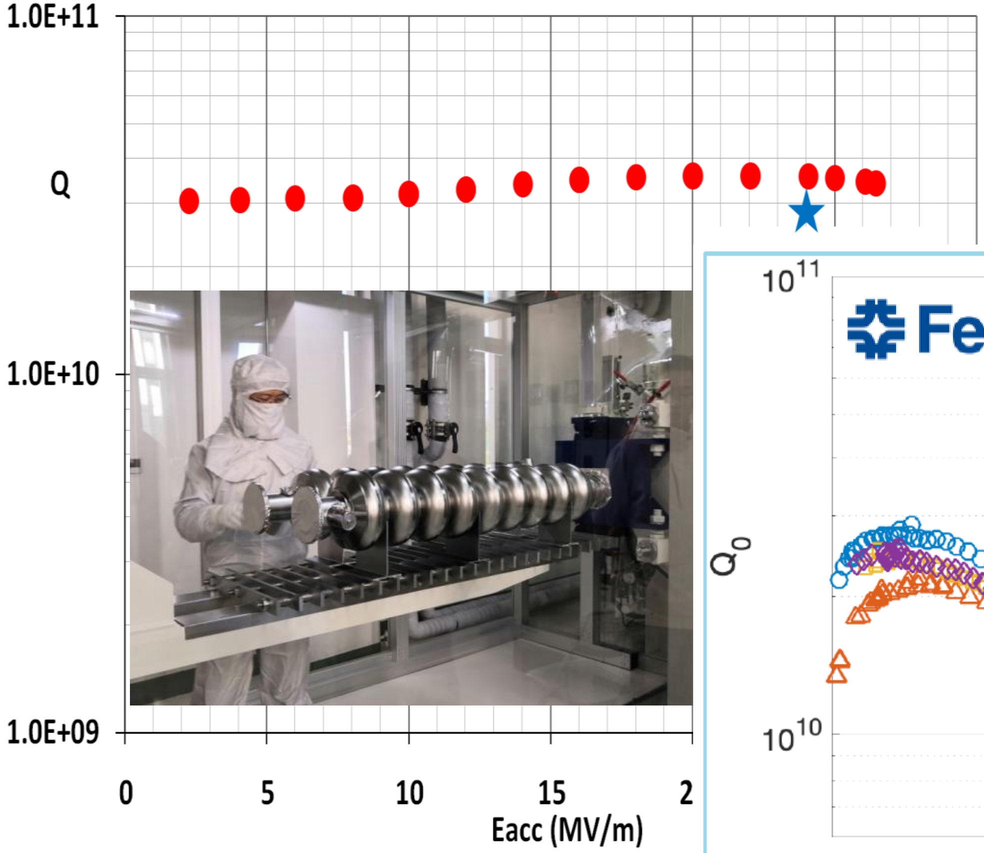
Helmholtz coil for cavity vertical test

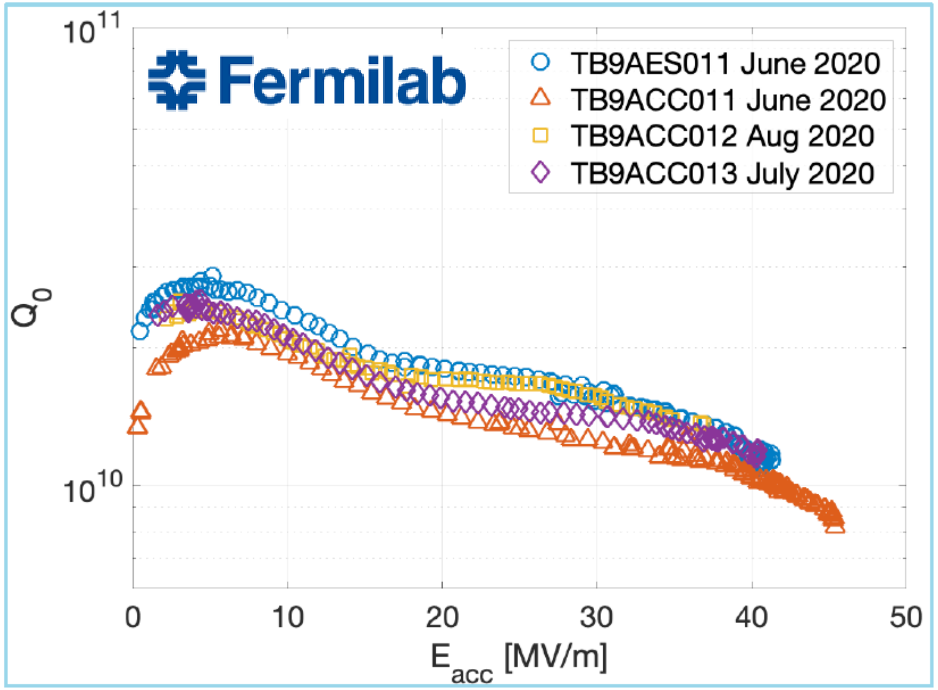
Vertical test dewars

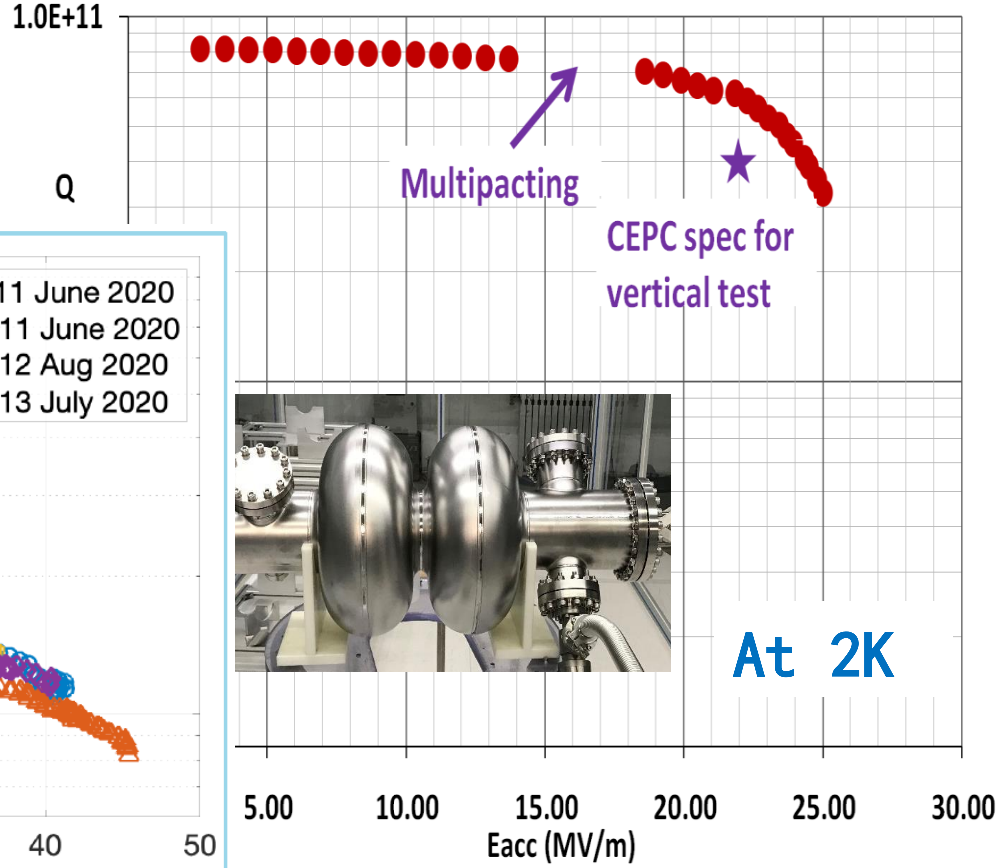
Horizontal test cryostat

CEPC R&D: High Q SCRF Cavities

- IHEP在国际上首次成功实现1.3GHz 9-cell超导腔中温退火工艺和批量试制
- 性能超过美国SLAC的LCLS和上海硬X射线自由电子激光的超导腔设计指标







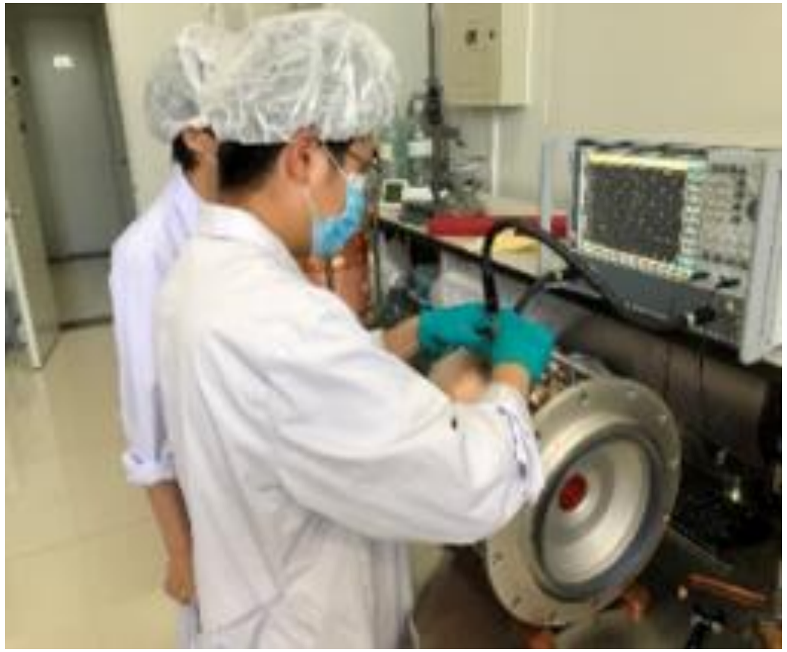
Medium-temperature (Mid annealing adopted to reach Q = 3.4E10 @ 26.5 MV/m

N-infusion adopted to reach Q = 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 and 800 kW in pulsed mode. Power transfer efficiency ~ 62%, goal is to reach ~80%
- One of the key technology and breakthrough for CEPC

Bake out

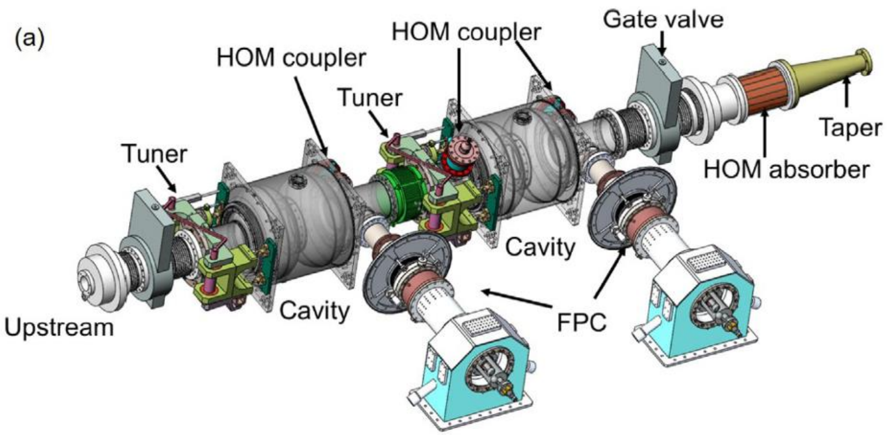


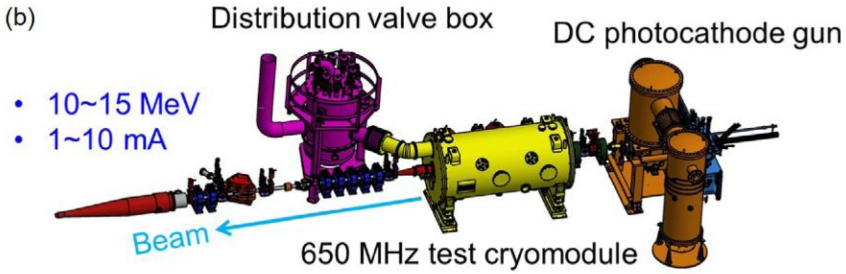
Cold test

High power test

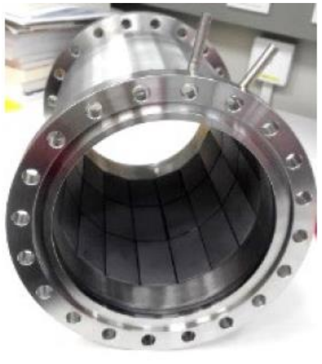
CEPC R&D: 650MHz SCRF Module

- 在先进光源研发与测试平台（PAPS）的支持下，正在研制一台包含2个650MHz 2-cell超导腔及其附件的650MHz模组，用于验证CEPC的关键技术。

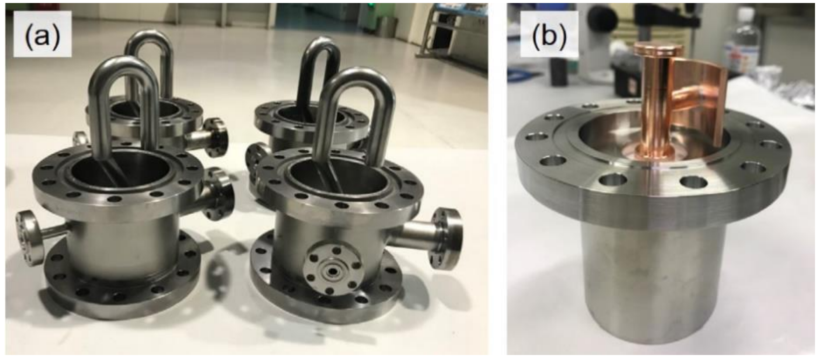




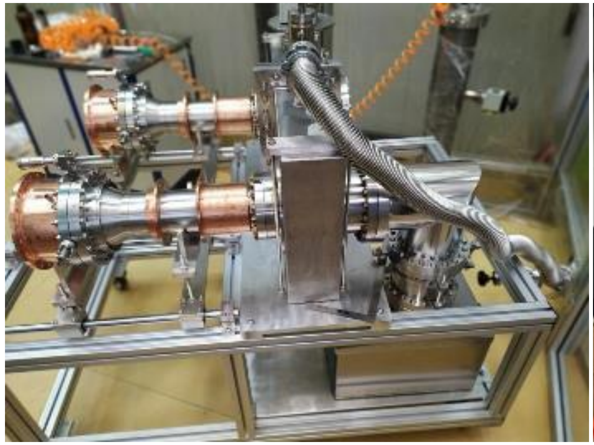
北京怀柔PAPS束流实验装置



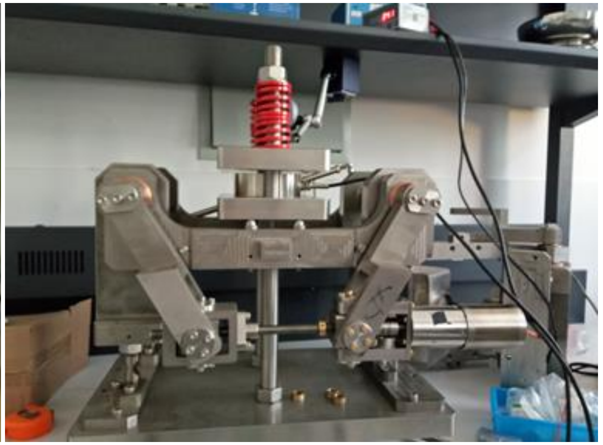
国内首个超导腔大功率高阶模吸收器（5kW）



国内首个可拆卸大功率高阶模耦合器（1kW）



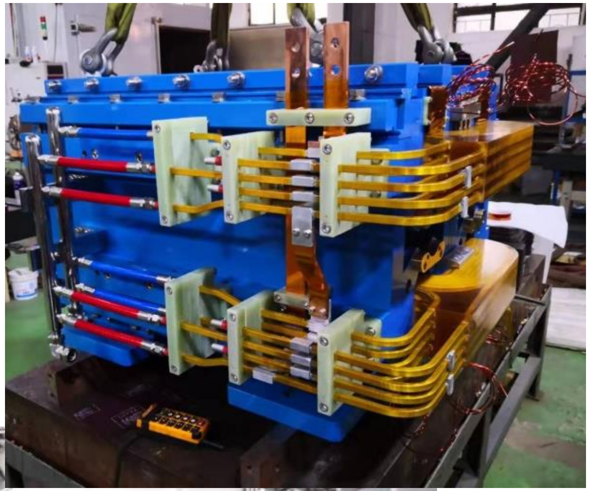
650MHz主耦合器 (400kW) 世界上最大的耦合器之一

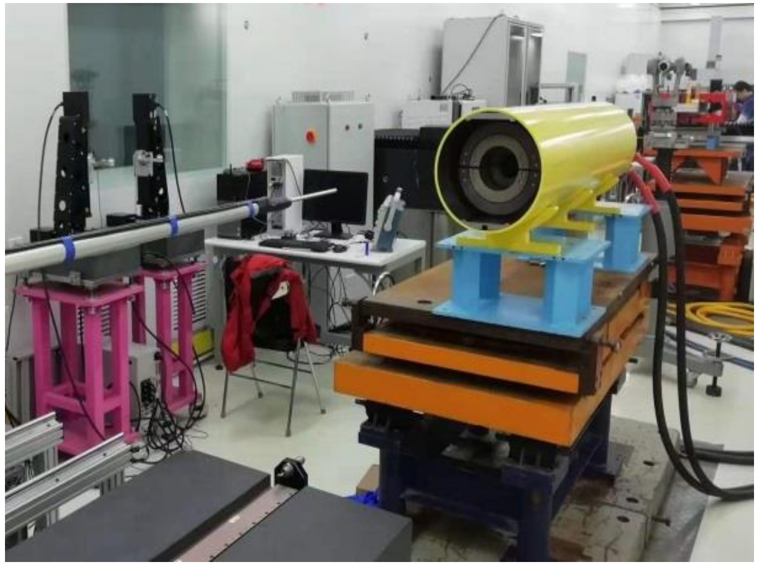


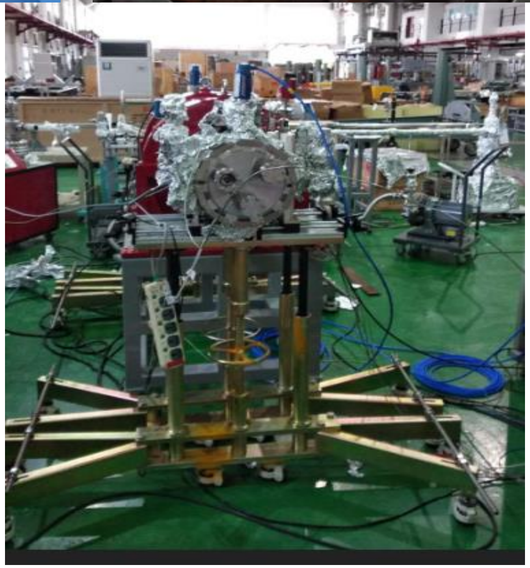
超导腔调谐器

CEPC R&D: Magnets etc.

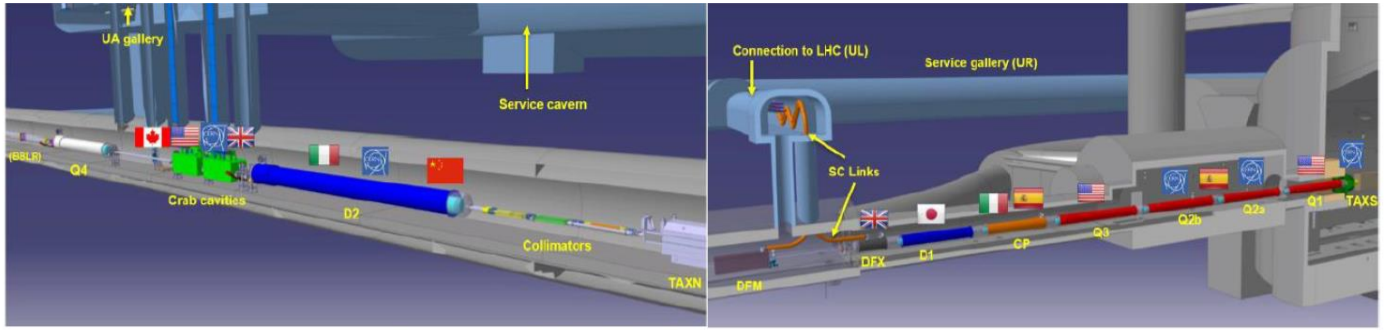
- Magnets, EM-separators, Vacuum Pipes, ...







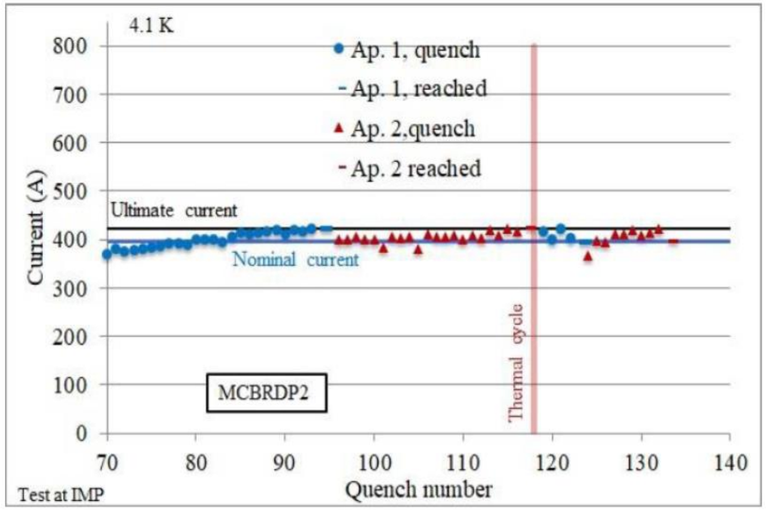
HL-LHC Magnet and HTS SC Magnet

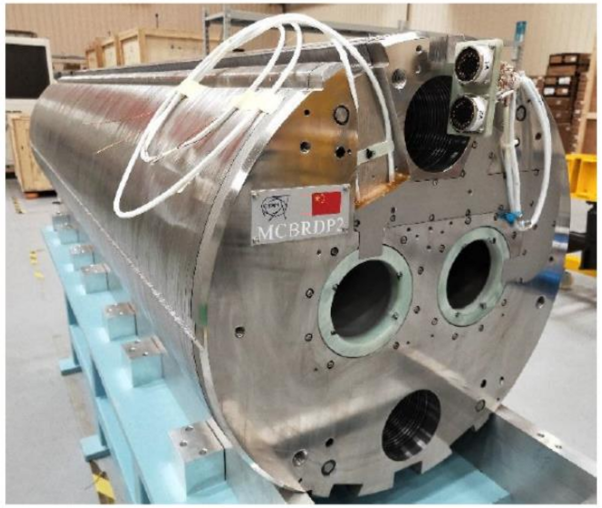


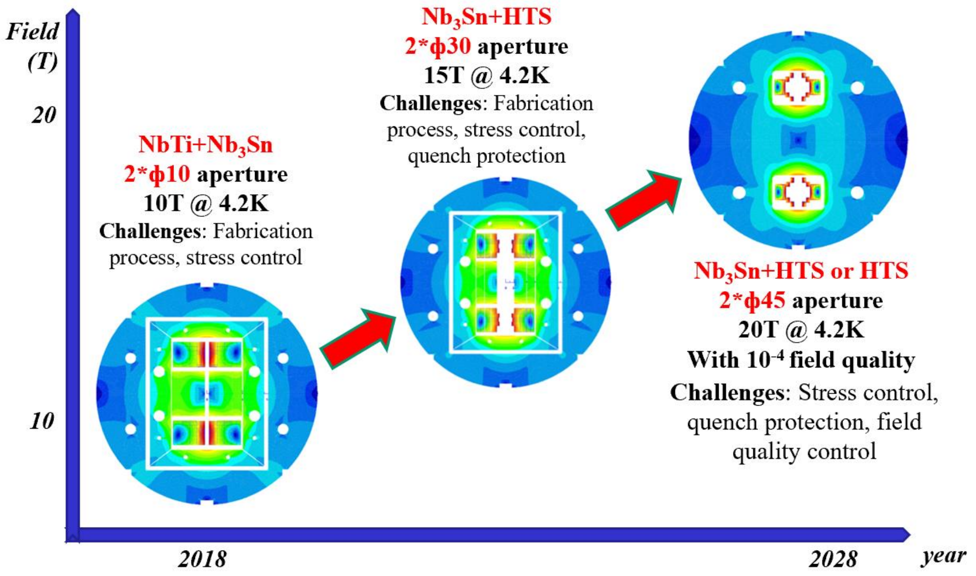
Layout of the HL-LHC Magnets and Contributors

China will provide 12+1 units CCT superconducting magnets for the HL-LHC project

After more than 1 month test and training at 4.2K, both apertures reached the design current and ultimate current, and the field quality is within the limit.

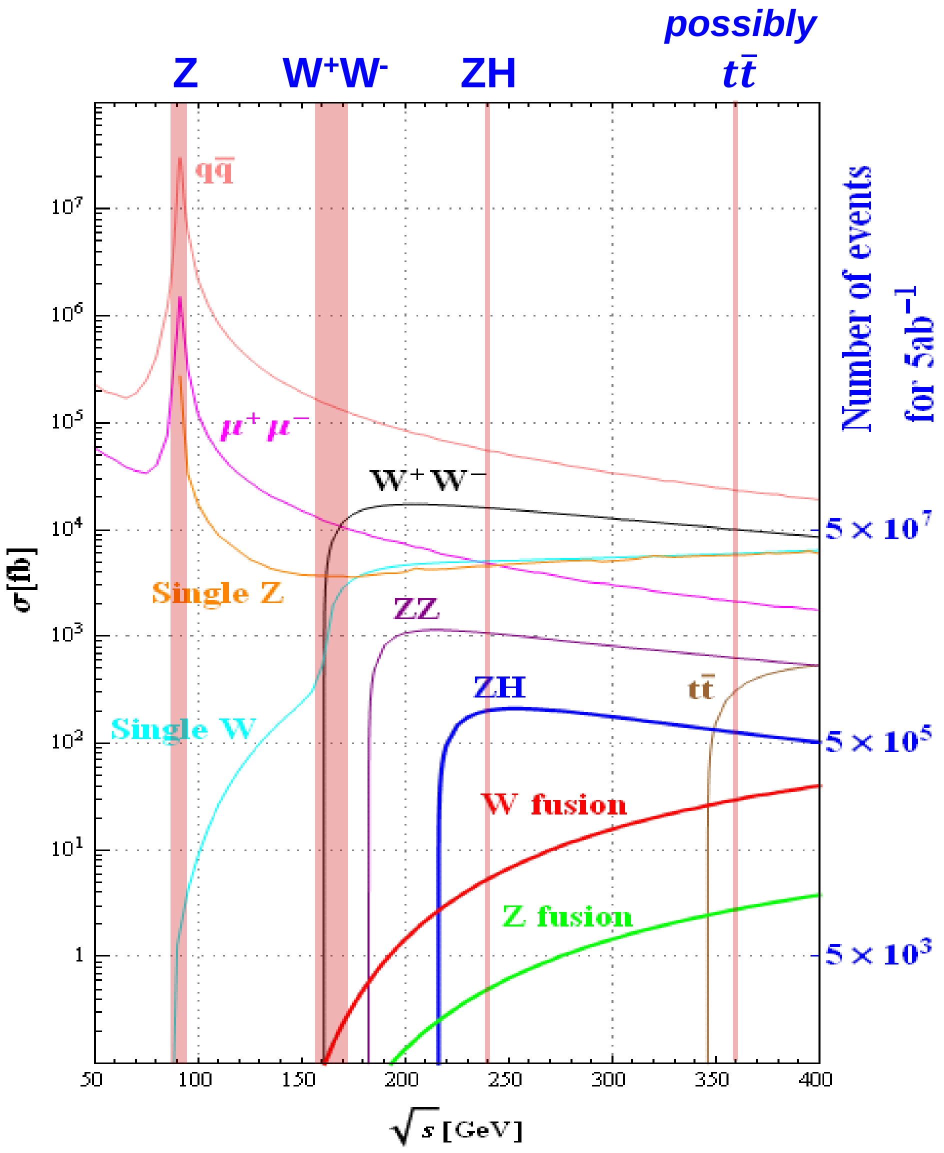






The prototype has been delivered to CERN, mass production has been started.

The CEPC Physics Program



Operation mode		ZH	Z	W⁺W⁻
$\sqrt{s}$ [GeV]		~240	~91.2	158-172
Run time [years]		7	2	1
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]	**1×10⁶**	**7×10¹¹**	**2×10⁷**
Latest	***L*** **/ IP [×10³⁴ cm⁻²s⁻¹]**	5.0	115	15.4

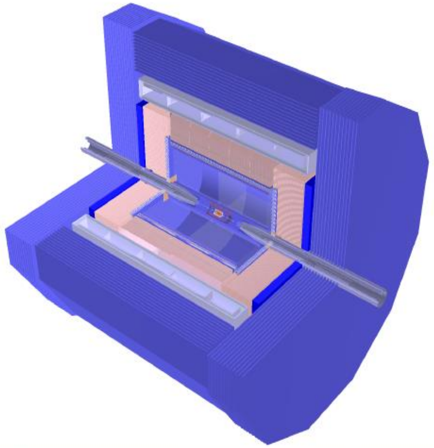
The large samples from 2 IPs:
~$\mathbf{10^6}$ Higgs, **~2x10⁷** W, **~7x10¹¹** Z bosons

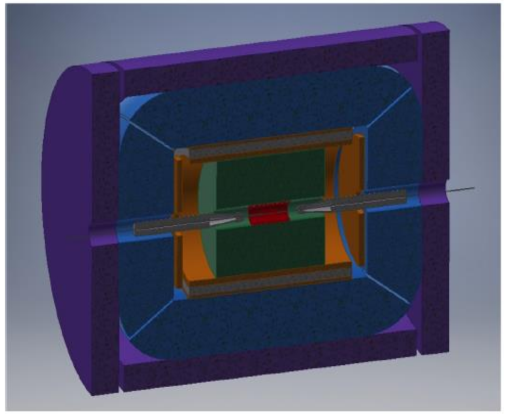
- **CEPC Conceptual Design Report:**
  Volume 1 – Accelerator, [arXiv:1809.00285]
  Volume 2 – Physics & Detector, [arXiv:1811.10545]

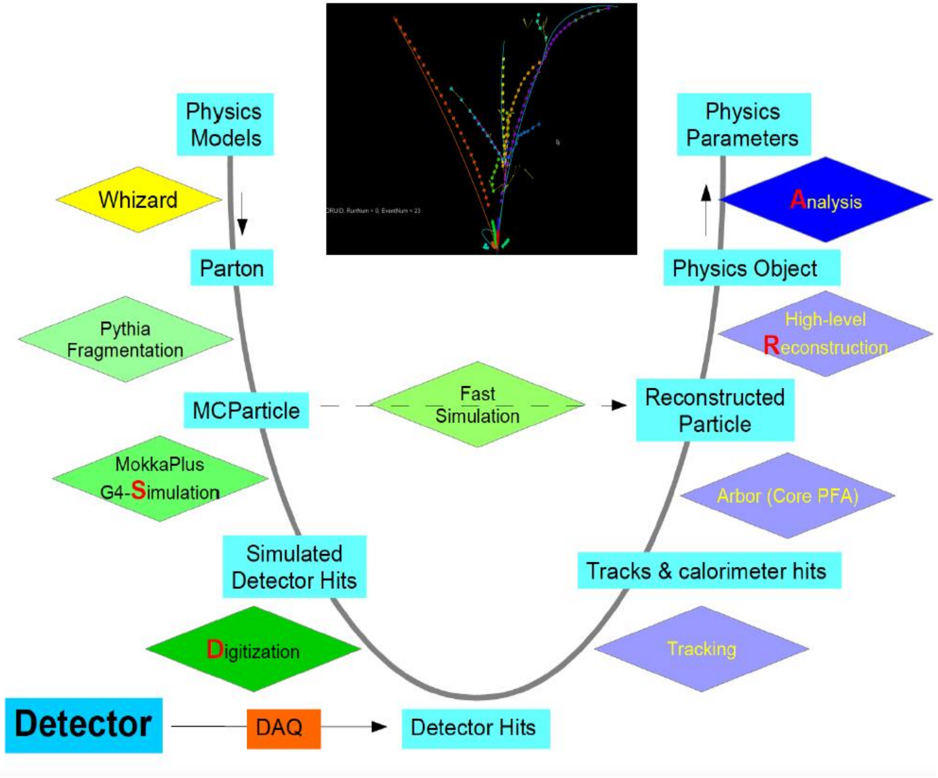
CEPC Detector and Software

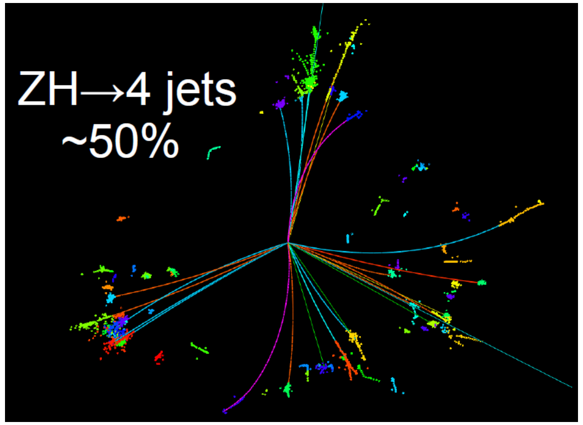
Recent added CEPC software applications:

- 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



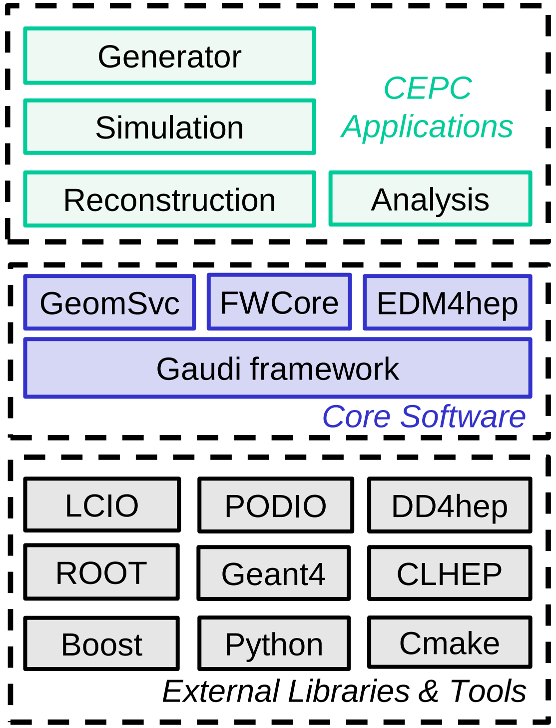






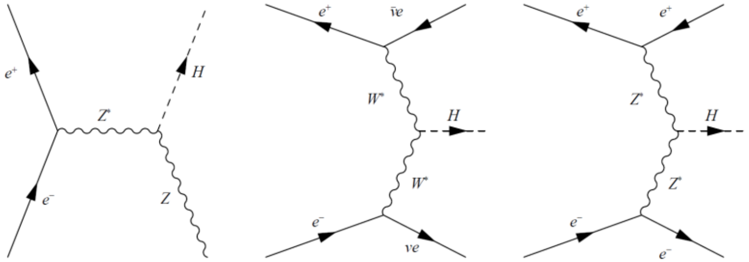
Full simulation reconstruction Chain functional, iterating/validation with hardware studies

CEPCSW Structure

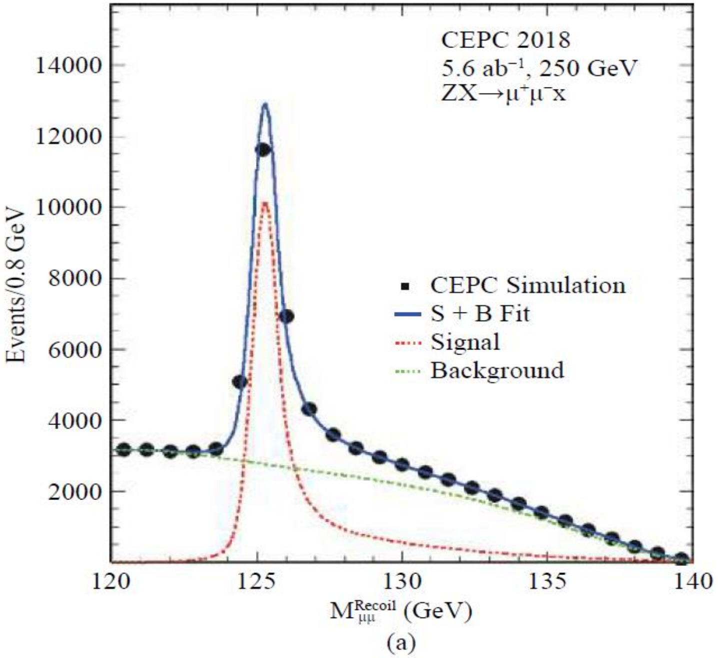


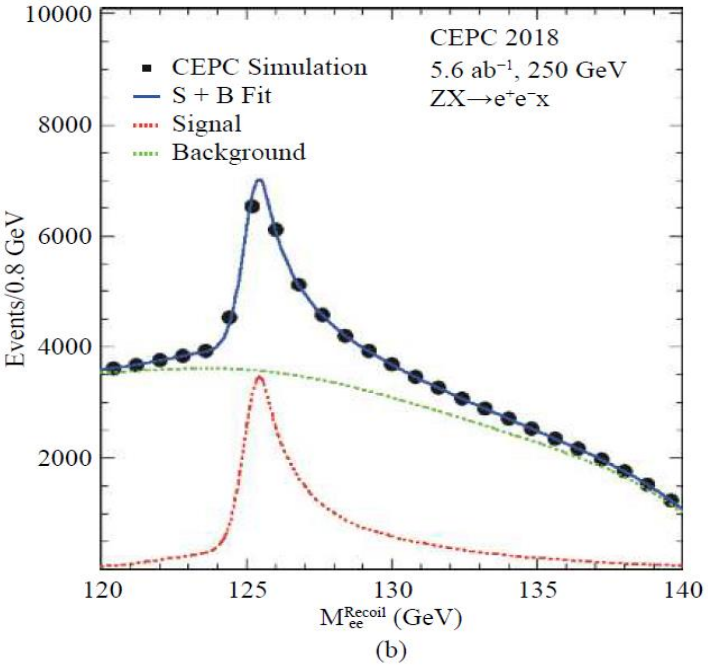
CEPC Physics Performance (CDR)

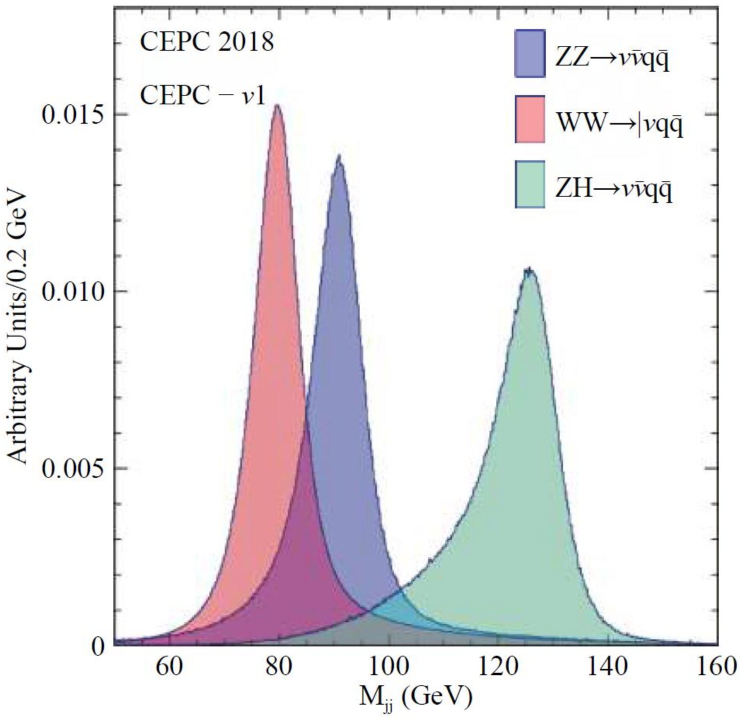
e^+e^- annihilations at the CEPC



- **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**







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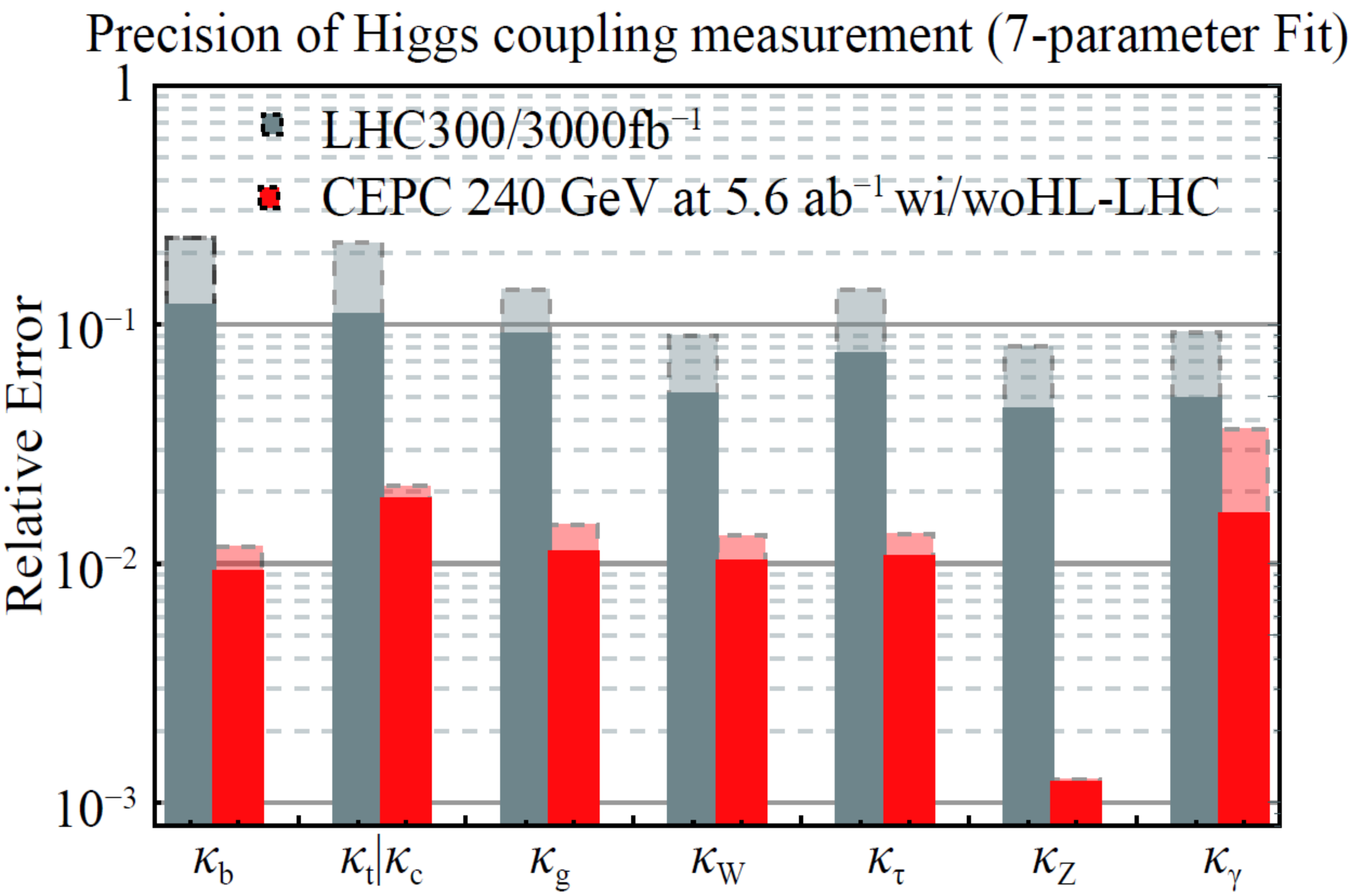
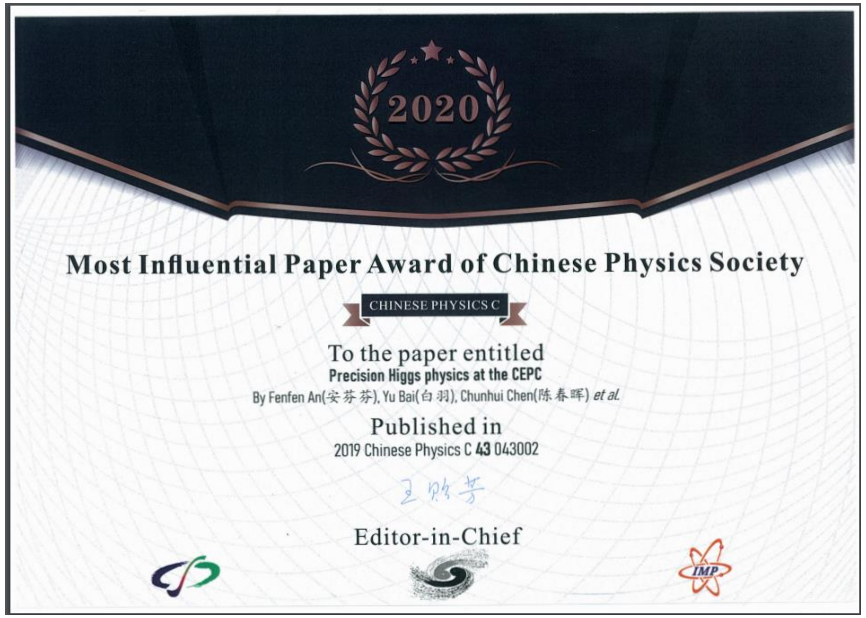
CEPC Physics Performance (CDR)

Order of magnitude improvement in precision ⇒ Unknown/discoveries

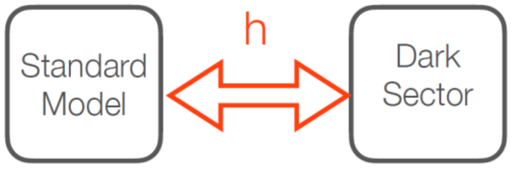


CEPC 使希格斯耦合参数测量精度比HL-LHC实验提高 5-10 倍



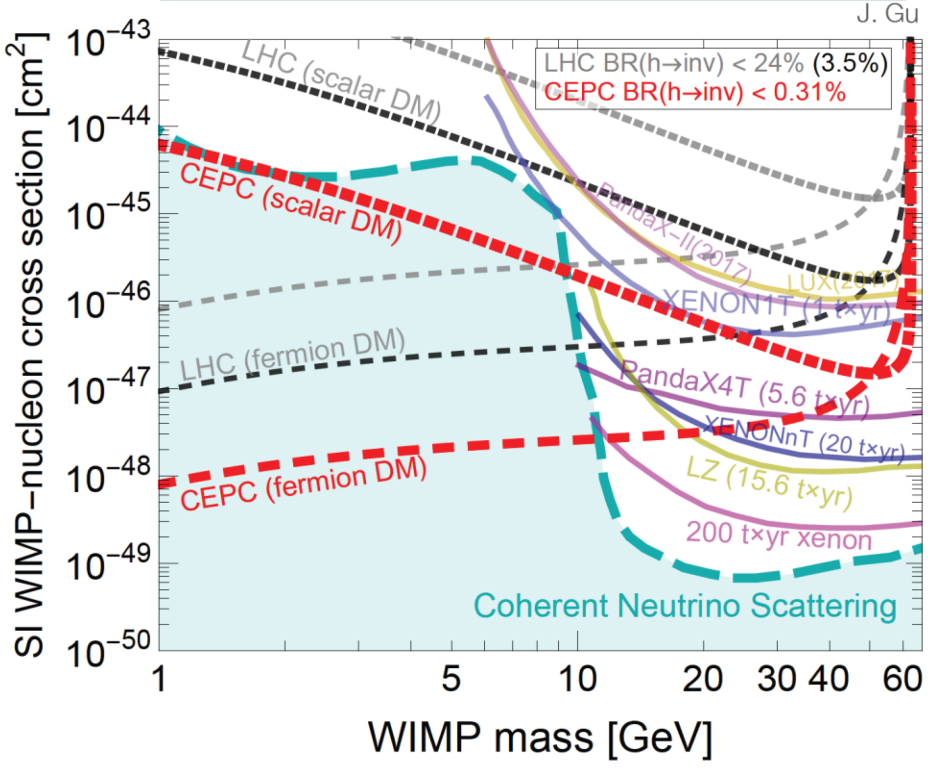
《Precision Higgs Physics at CEPC》
荣获中国物理学会2020年度最有影响论文奖
Chinese Physics C, 43 （2019）043002

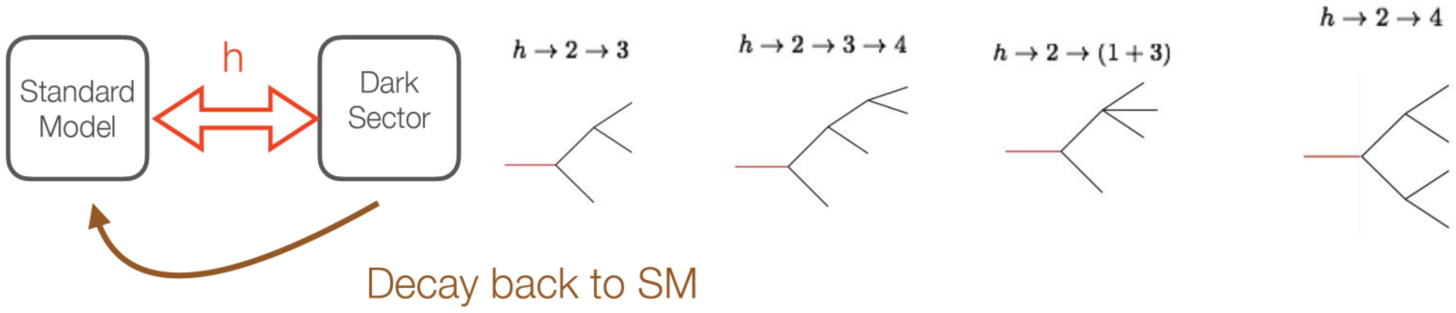
Discovery Potential for New Physics



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

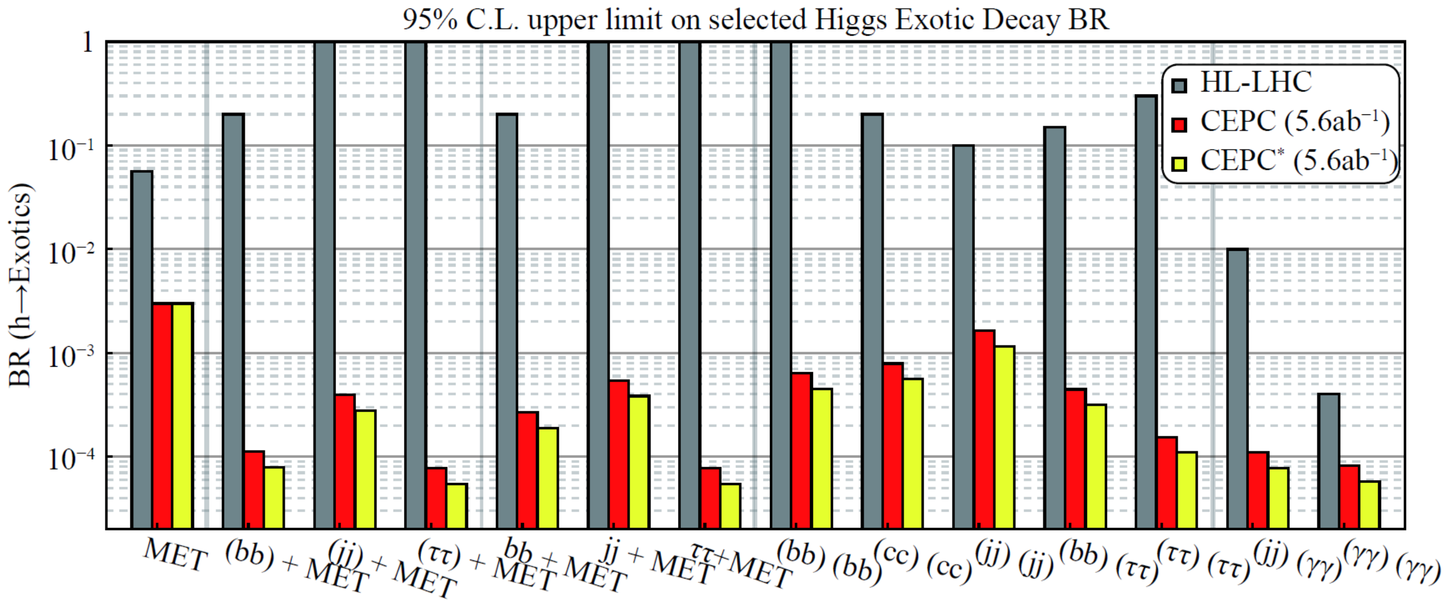
CEPC 对暗物质的探测灵敏度比LHC实验提高约一个数量级





Higgs decays into BSM particles, H→ $X_1 X_2$

CEPC 对新物理探测灵敏度比LHC实验提高约2-3个数量级



Requirements of CEPC Detector

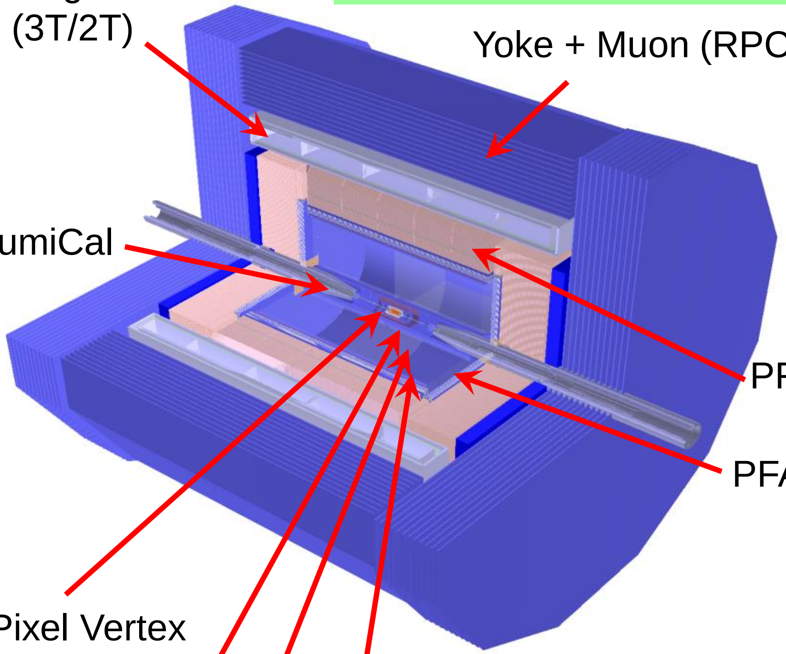
The physics motivations dictate our selection of detector technologies

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

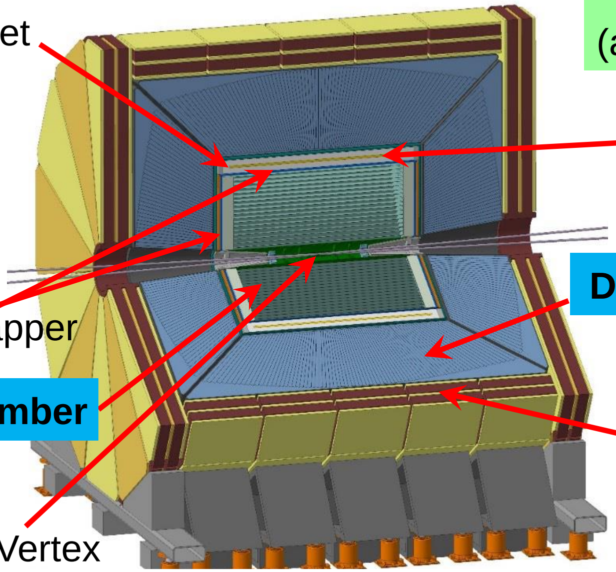
- **Flavor physics ⇒ Excellent PID, better than 2σ separation of π/K at momentum up to ~20 GeV.**
- **EW measurements ⇒ High precision luminosity measurement, δL / L ~ 10^{-4}.**

Conceptual Detector Designs

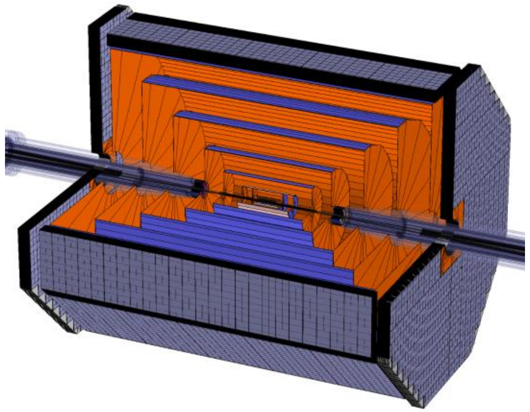
(Baseline Design)
Particle Flow Approach



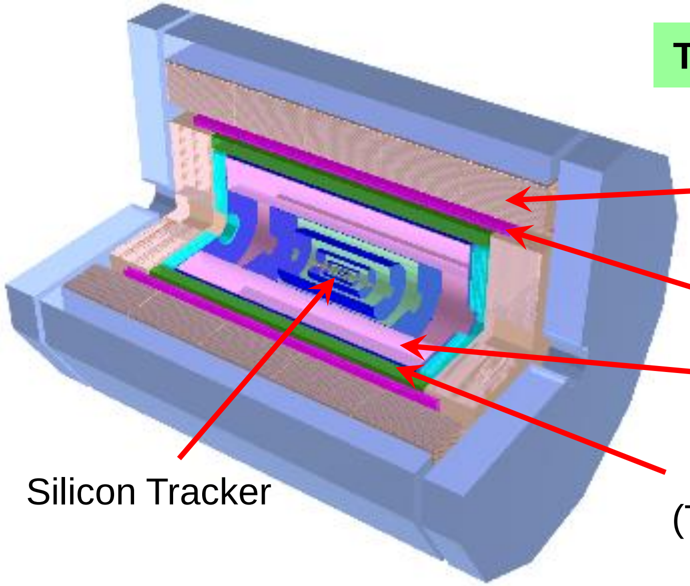
IDEA concept
(also proposed for FCC-ee)



FST concept
(Full Silicon Tracker)

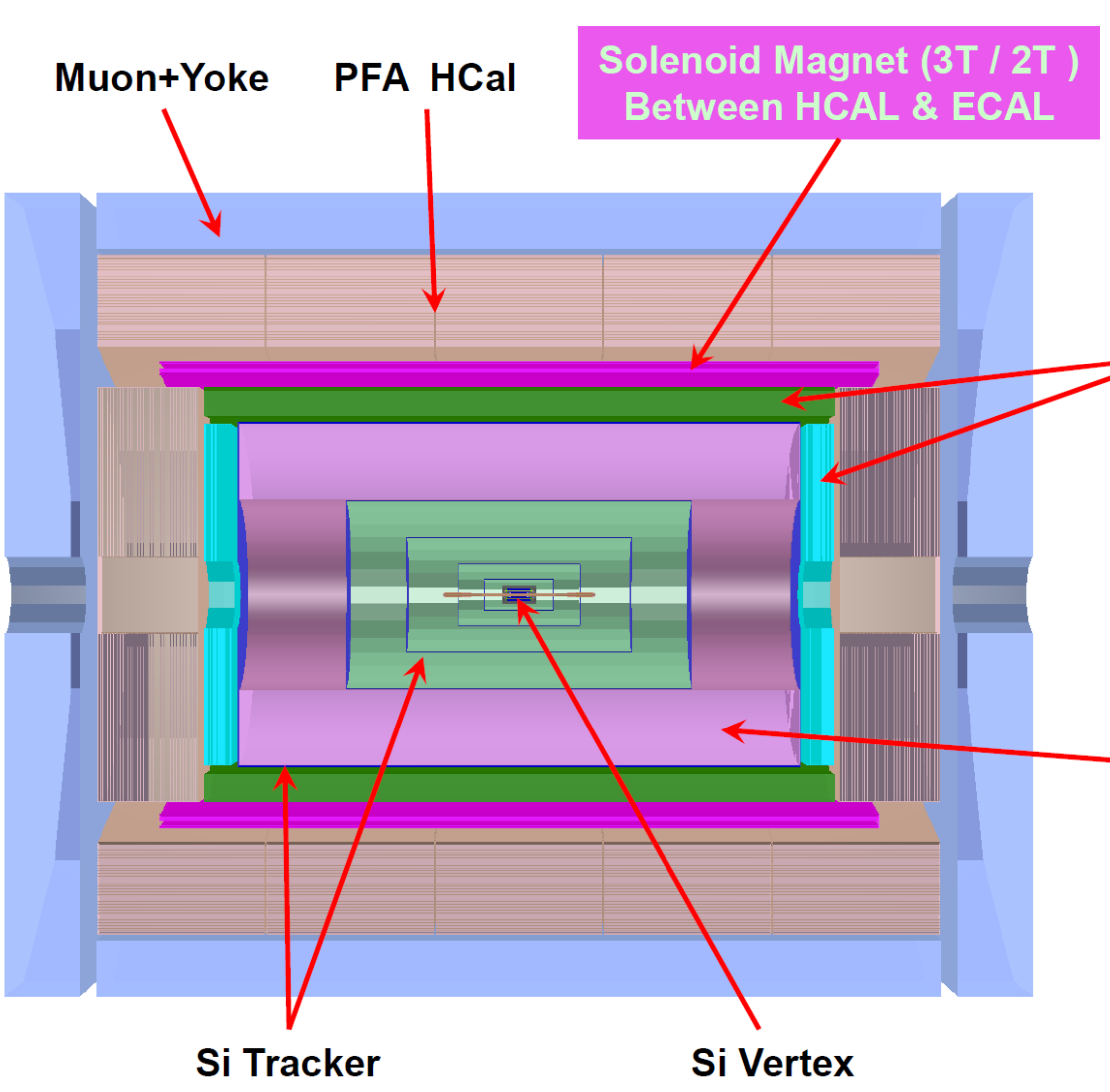


The 4th Concept



The 4th Conceptual Detector Design

➢ 提出新的CEPC探测器方案: 基于硅径迹探测器 + 漂移室PID + 晶体电磁量能器 + 薄螺线管磁铁介于电磁量能器和强子量能器之间



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.

Advantage: better π^0/γ reconstruction.

Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

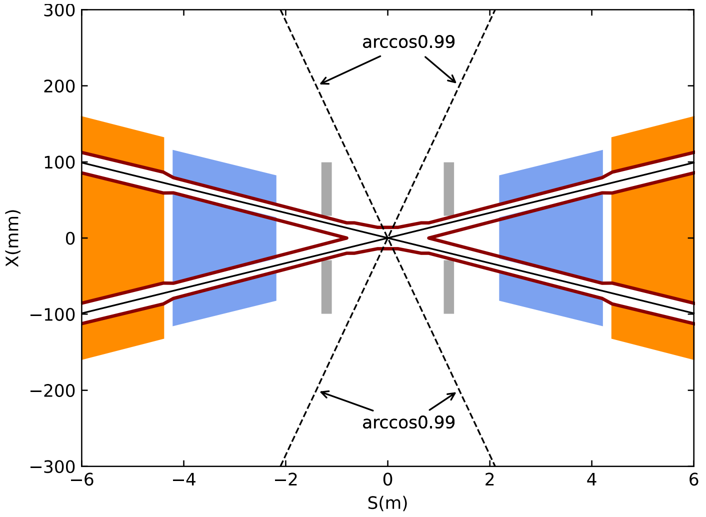
Advantage: Work at high luminosity Z runs

Challenges: sufficient PID power; thin enough not to affect the moment resolution.

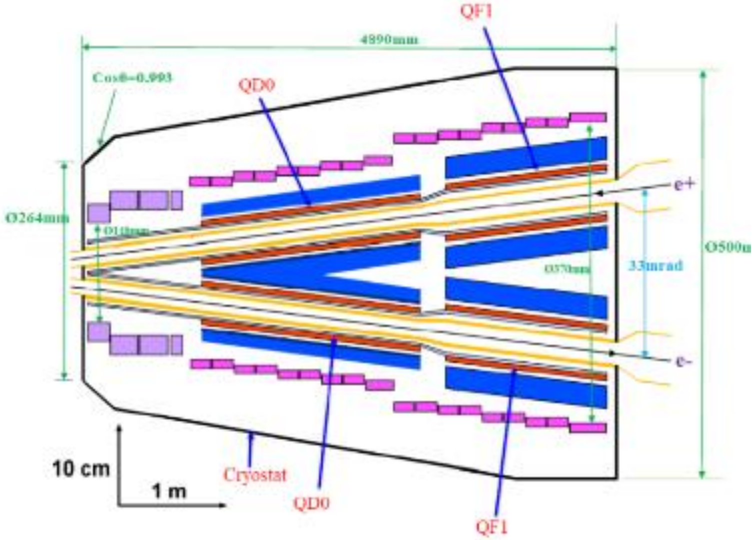
CEPC R&D: Machine Detector Interface (MDI)

Crossing angle: 33 mrad,

Focal length: 2.2 m

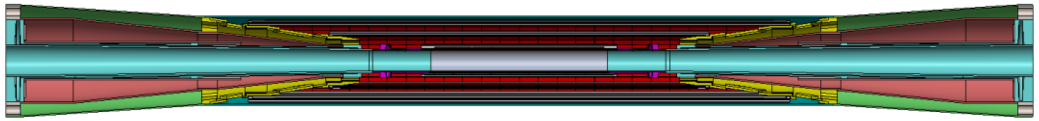


Final focusing magnets (QD0, QF1) with Segmented Anti-Solenoidal Magnets



Beam Pipe

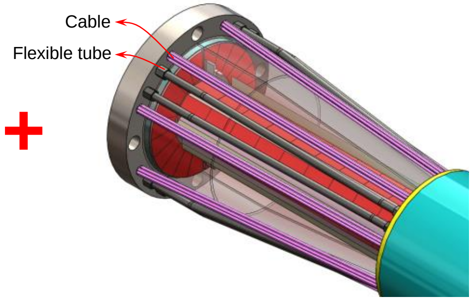
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

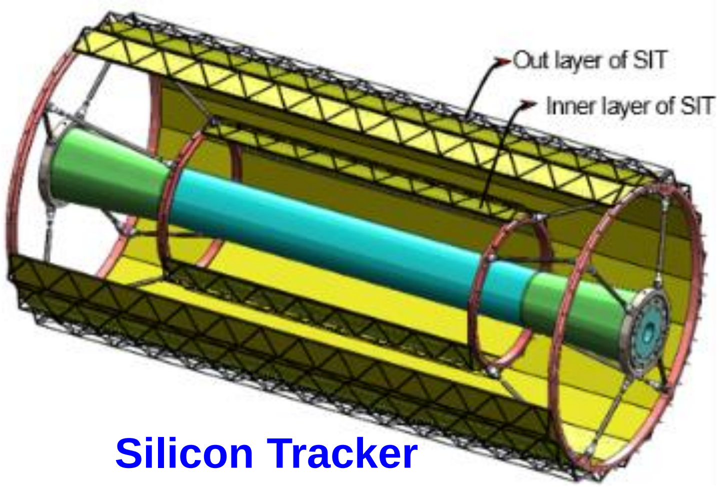


Vertex

+

LumiCal Tracker

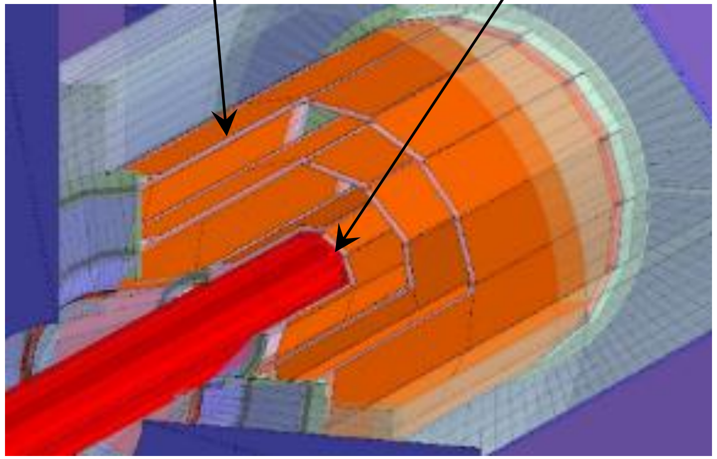




Silicon Tracker

CEPC R&D: Silicon Pixel ASIC 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)**

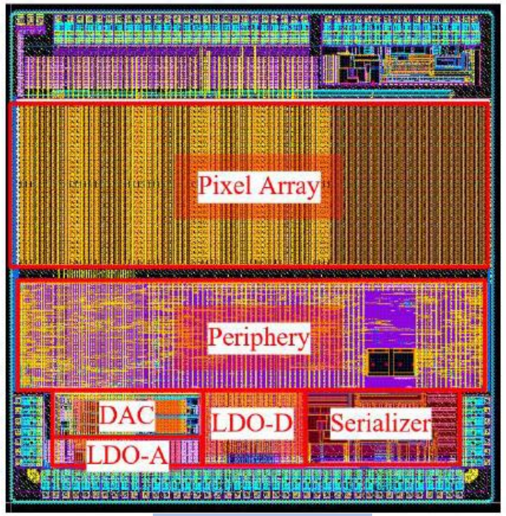
Silicon pixel sensor develops in 3 series:
JadePix / MIC, **TaichuPix**, **CPV**

JadePix-3 Pixel size ~16×23 μm^2

Tower-Jazz CiS process

MOST 1

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

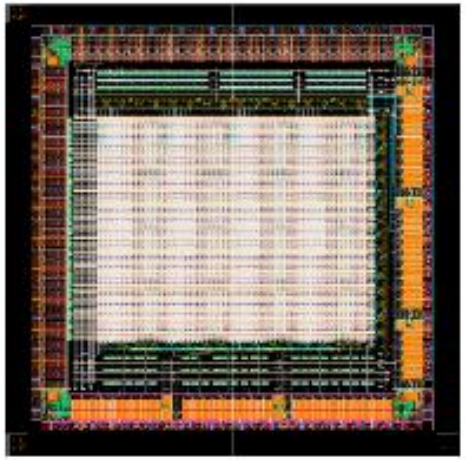


Full size TaichuPix-3 to be used for prototyping ladder

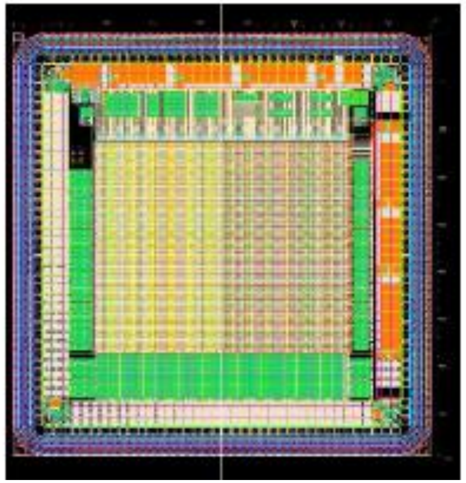
MOST 2

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

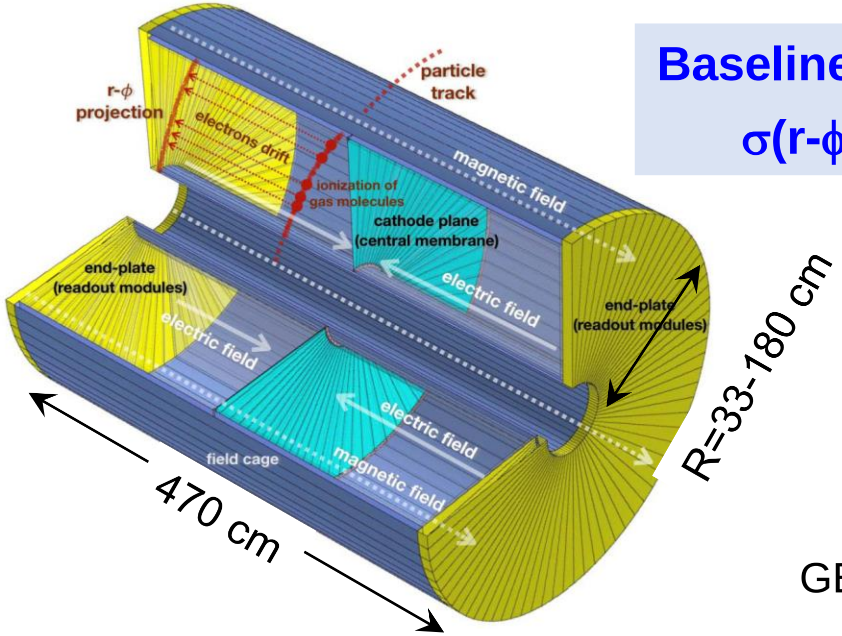
Upper chip



Lower chip



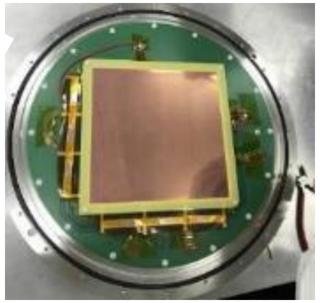
CEPC R&D: Time Projection Chamber



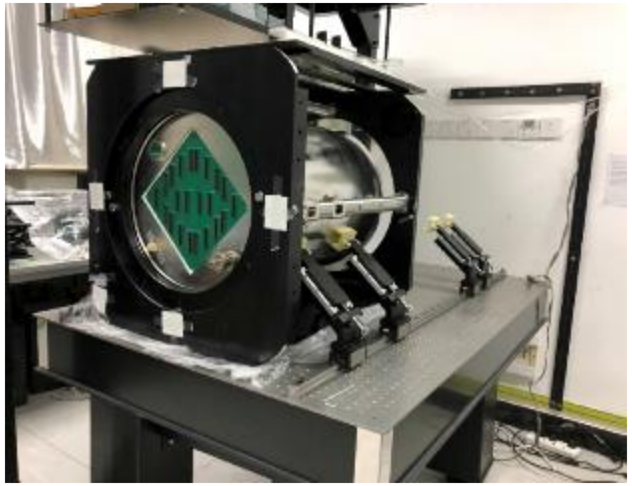
Baseline main tracker

$\sigma(r\text{-}\phi)$ ~100 μm

MOST 1

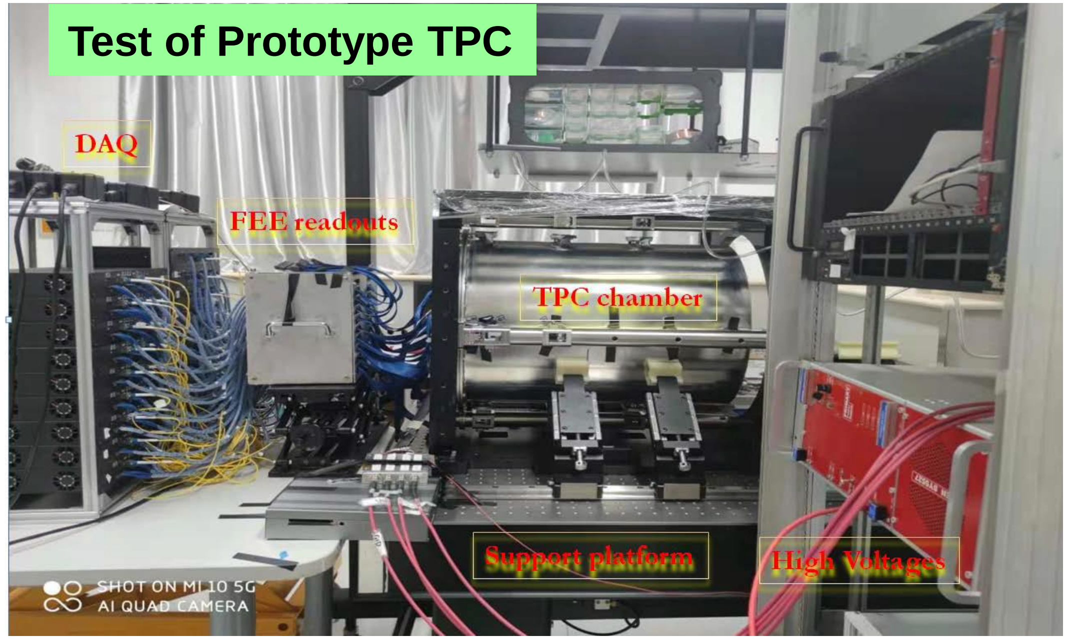


GEM-MM cathode

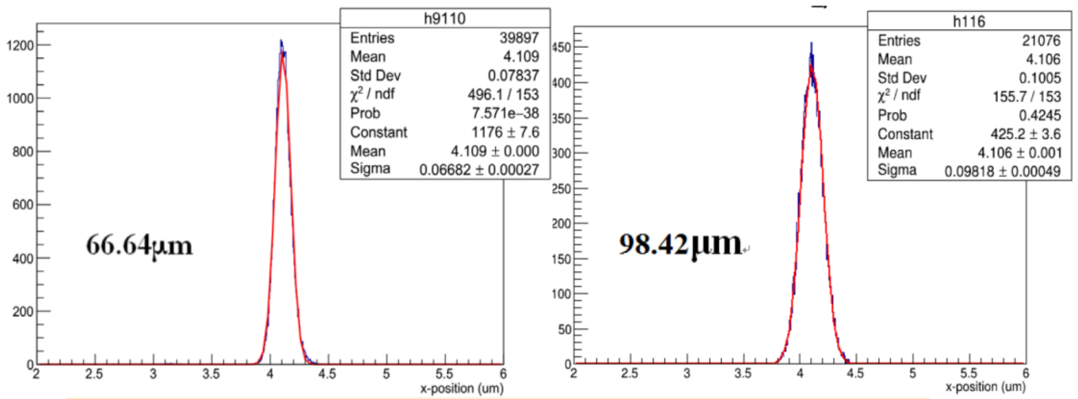


TPC Prototype + UV laser beams

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

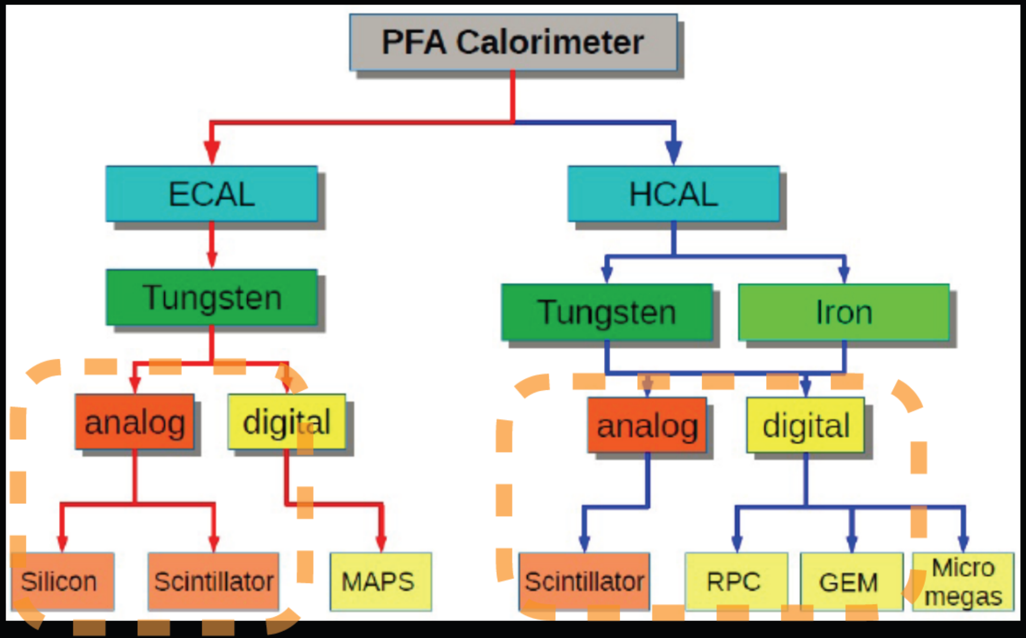
CEPC R&D: PFA Calorimeters

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

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

Calorimeter for ILC



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

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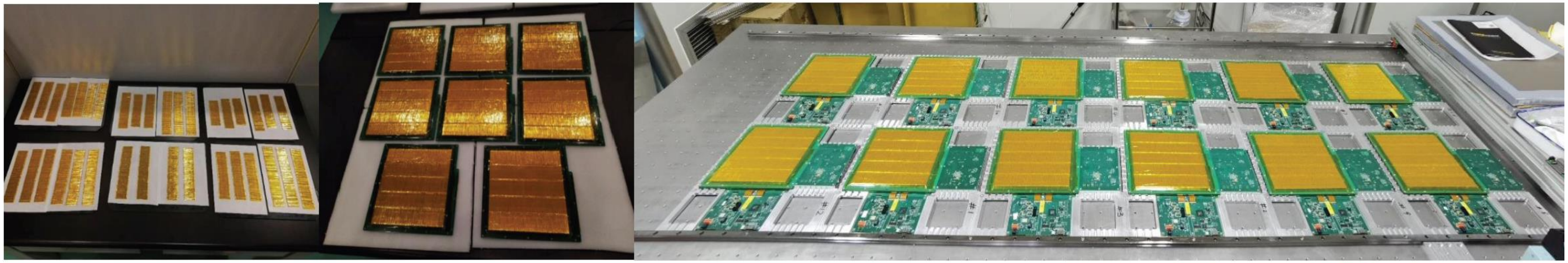
CEPC R&D: ECAL Prototype

Scintillator ECAL Prototype

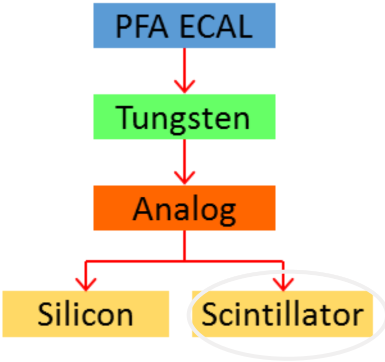
Scintillator-Tungsten Sandwich ECAL



- Energy resolution $< 16\%/\sqrt{E}$, position resolution $< 10mm \times 10mm$
- One EBU: 210 sensitive cells of scintillator strip coupling with SiPM
  - Scintillator strips : $2mm \times 5mm \times 45mm$
  - SiPM (HPK) : S12571-010P (24 layers) and S12571-015P (8 layers)
- Super-layers: two alternate of EBU and absorber layers integrated
- Complete Sc-ECAL prototype has been fabricated
  - Transverse dimension : $226\ mm \times 222\ mm$
  - Radiation length : $22\ X_0$

MOST 1

CEPC R&D: ECAL Prototype

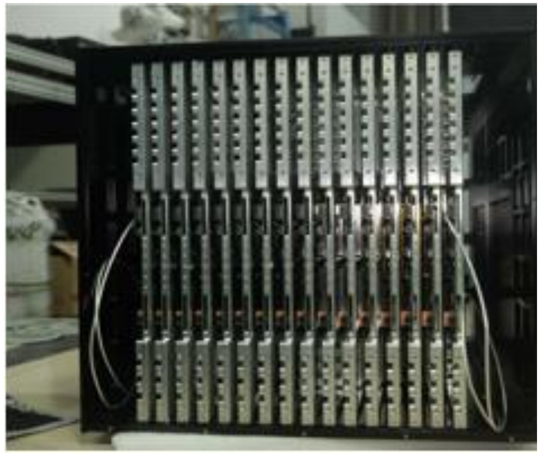


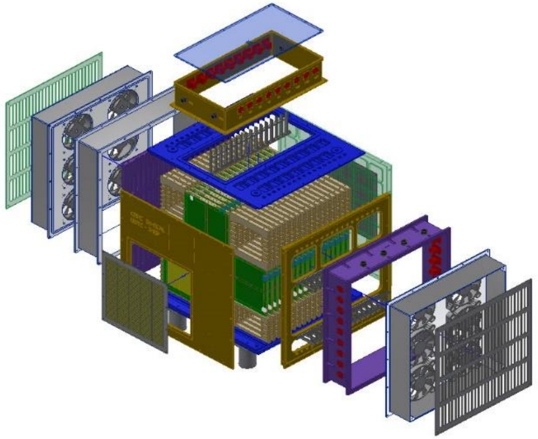
MOST 1

Goal of ECAL+HCAL+…

4% BMR, e.g. in (Z→νν) (H→gg)

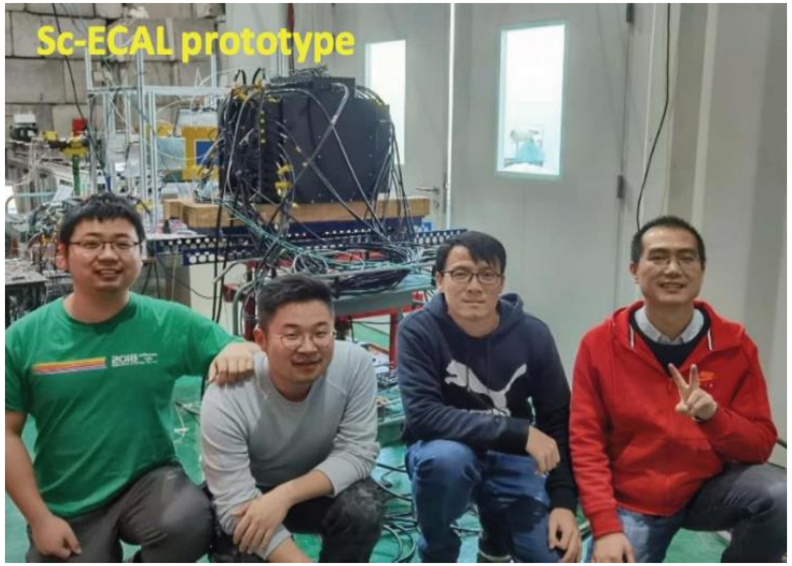
Sc-ECAL Prototype

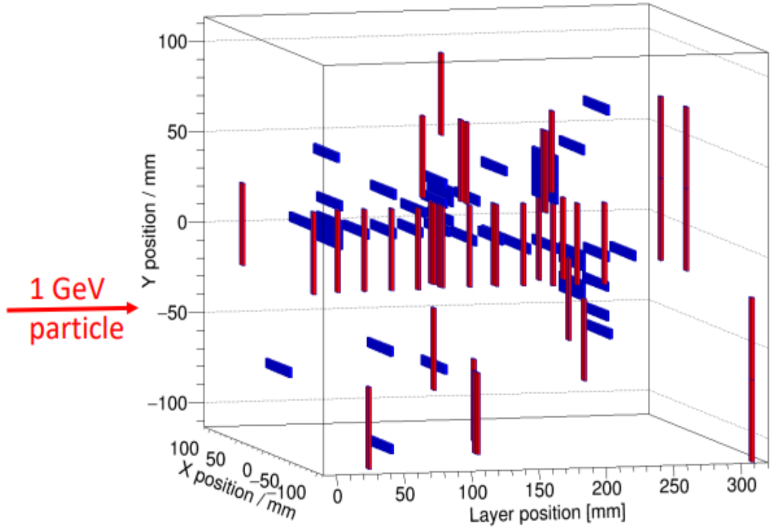


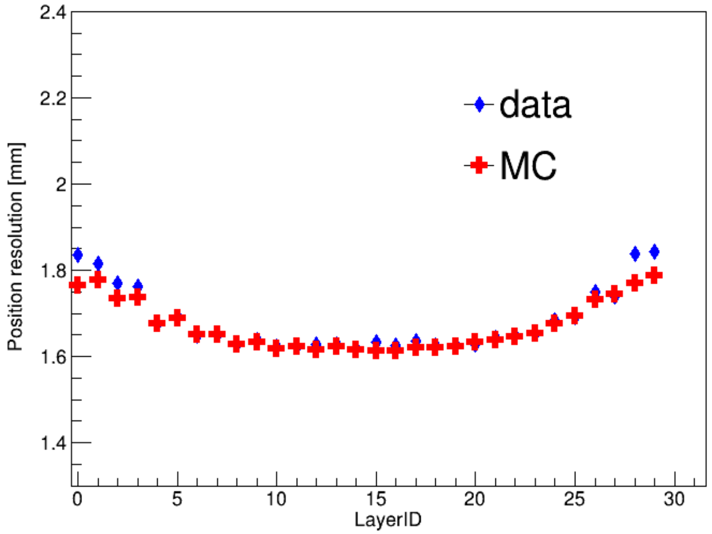


- **A 32-layer ECAL prototype (2-layer from Japanese groups): 3.2 mm thick W-Cu plate, scintillator bar size 5×45×2 mm^3, 1 SiPM/bar.**
- **It has been tested with cosmic rays, and an electron beam at IHEP (Nov. 2020).**

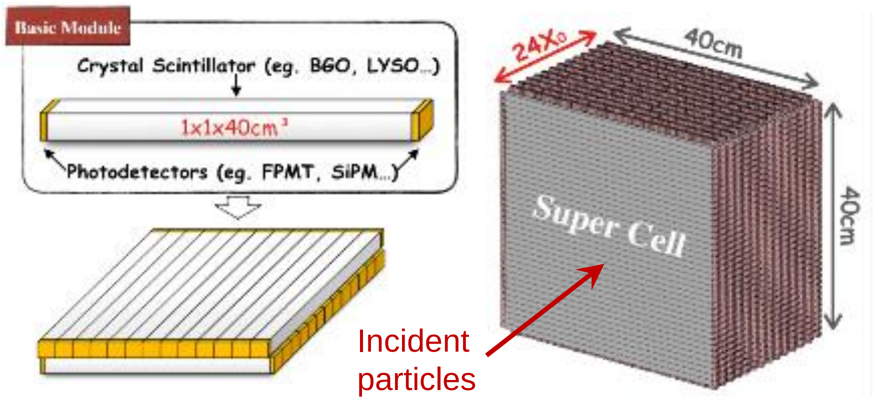
Granularity: 5mm × 5mm
Position resolution: 1.6-1.8mm







CEPC R&D: High Granularity Crystal ECAL



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

Design Idea

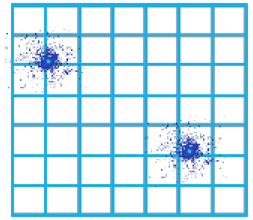
Goal

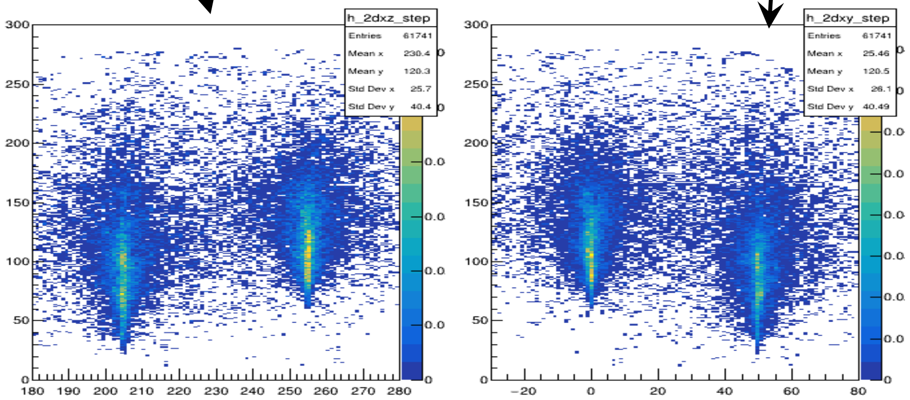
- **Comparable BMR resolution as with the Sci+W ECAL.**
- **Much better sensitivity to γ/e, especially at low energy.**

Bench Test

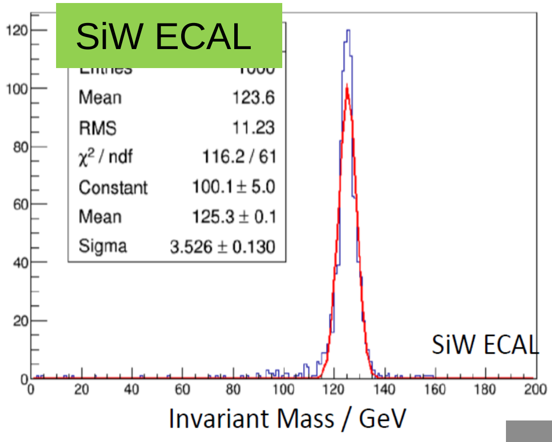
Recon. Algorithm

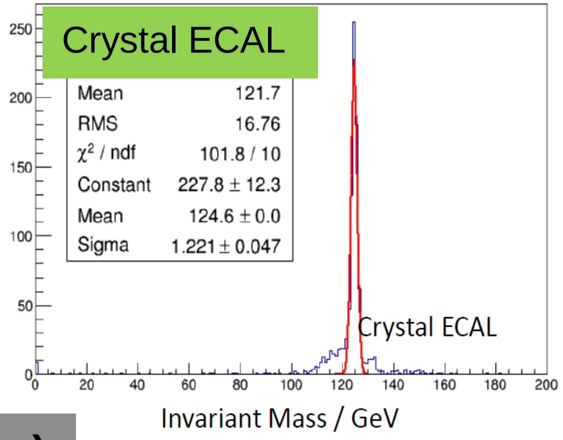
Energy & time matching solves ambiguity





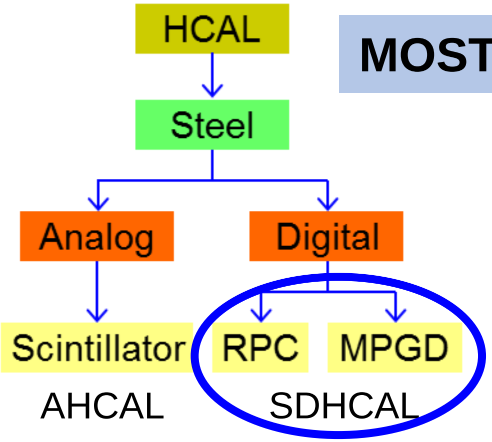
MC Simulation





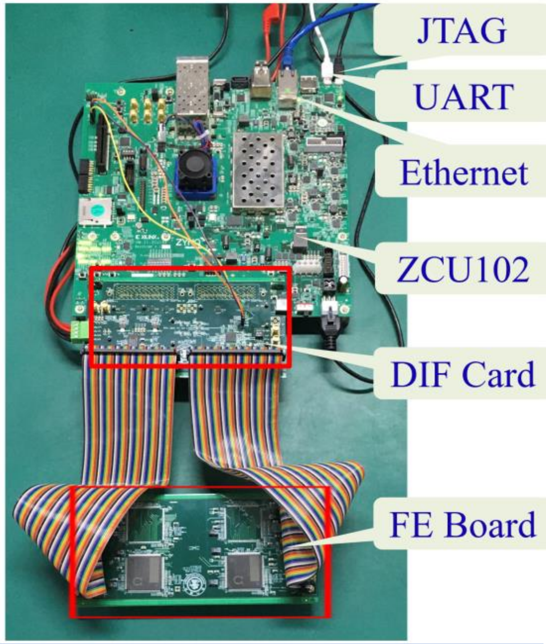
M(H→γγ)

CEPC R&D: SDHCAL



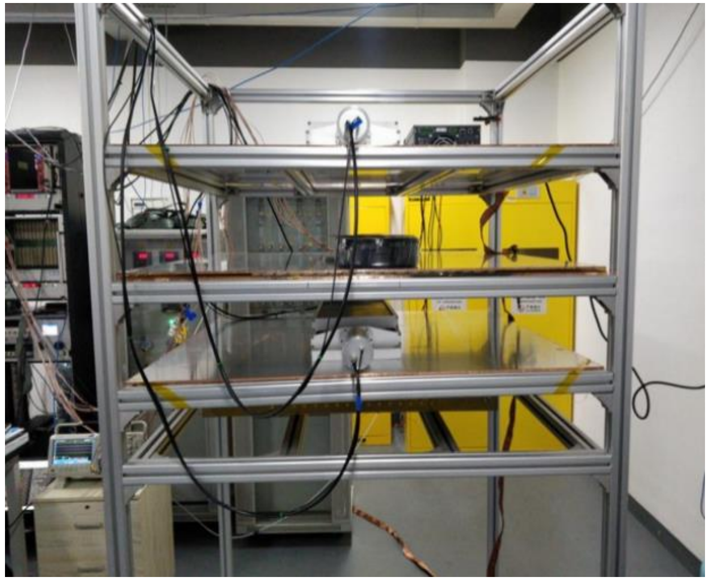
MOST 1

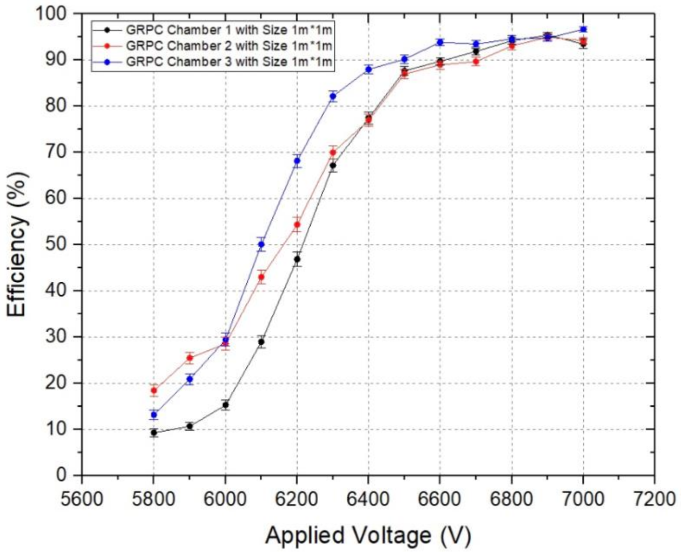
GRPC 100cm x 100cm



- **SDHCAL based on GRPC:**
  Prototype size 1×1×1.3 m^3, 48 layers, 1×1 cm^2 detector cell, 2 cm steel absorber.

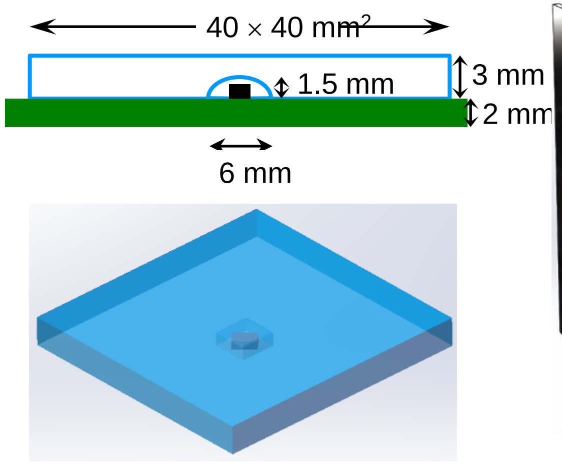
Fast timing PCB readout electronics using PETIROC Chip (~40ps) from Omega group.

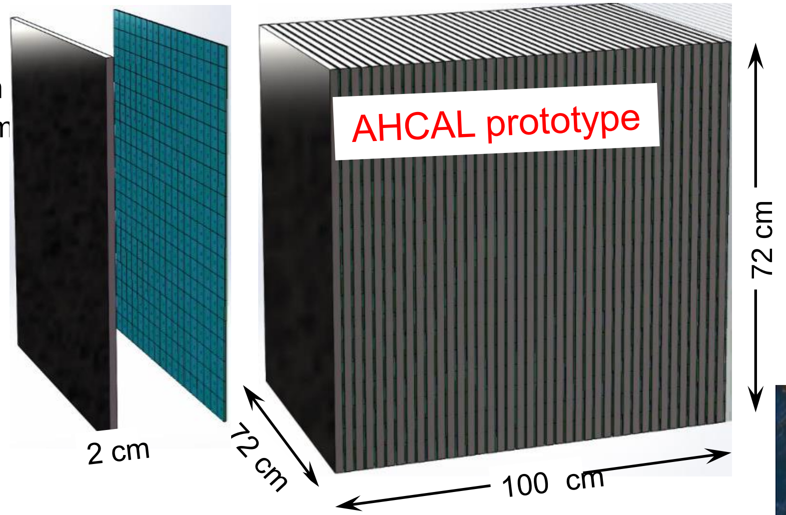


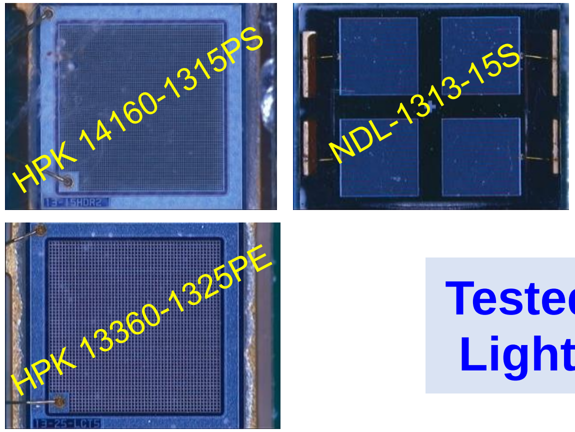


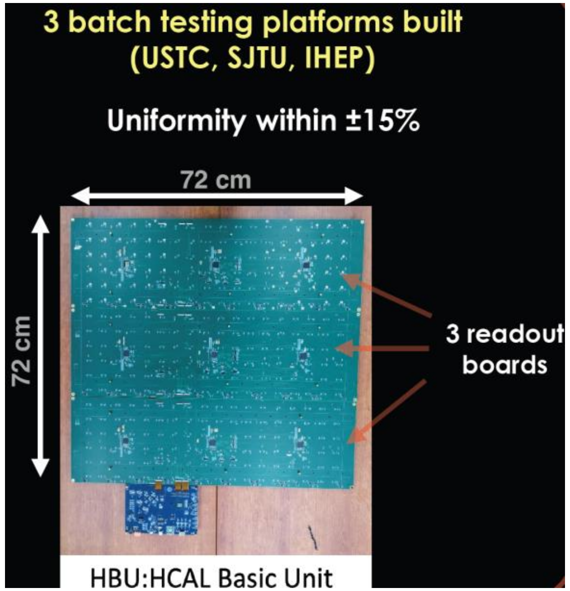
MPGD (RWELL) 50cm x 100cm

CEPC R&D: AHCAL Prototype (Sct+SiPM)





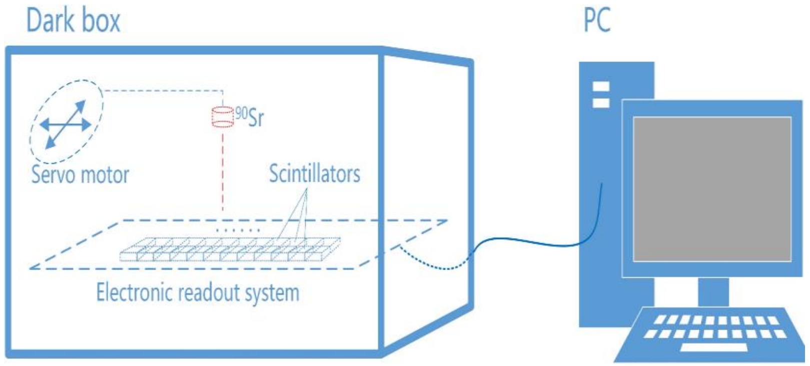




- **AHCAL of Steel, Plastic scintillator, SiPM+SPIROC**
  Prototype in production, size 72×72×100 cm^3, 40 layers
  Steel+Scintillator+PCB=20+3+2=25mm, cell size 4×4 cm^2

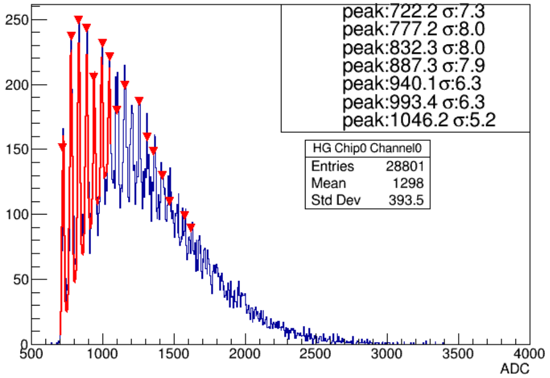
Tested ~ 10k Scintillators
Light Yield: ~ 13 ± 0.66

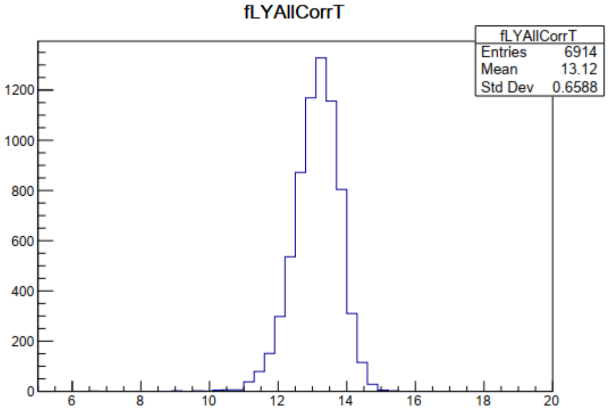
Scintillator batch test: 12 x 12 = 144



MOST 2

USTC/SJTU/IHEP

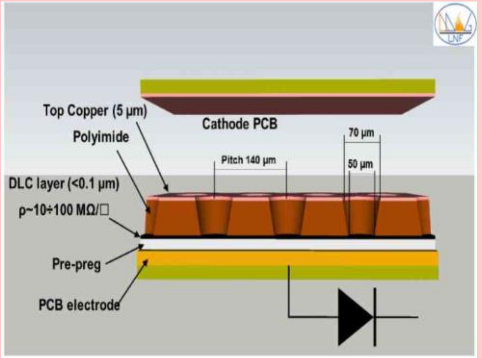


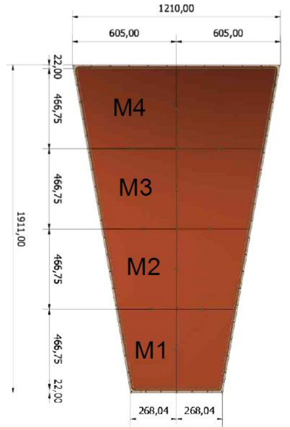


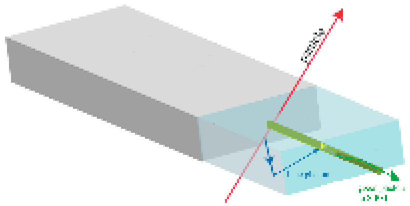
CEPC R&D: Muon Detector

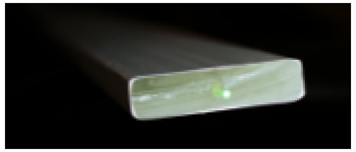
- **RPC R&D applies to both SDHCAL & Muon.**
- An alternative is **μ-RWELL** technology. The concept was proved. Currently focus mainly on industrialization and cost reduction.
- **Scintillator Muon detector. R&D overlaps with Belle II**
  - Building a prototype detector
  - Scintillator strips, improving quality & cost-reduction.
  - WLS fiber: purchased Kuraray, focusing on optical couplings.
  - SiPM Hamamatsu S13360-13**CS, and MPPC option.

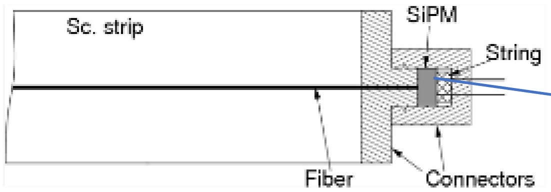
μRWELL for PS & Muon

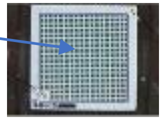


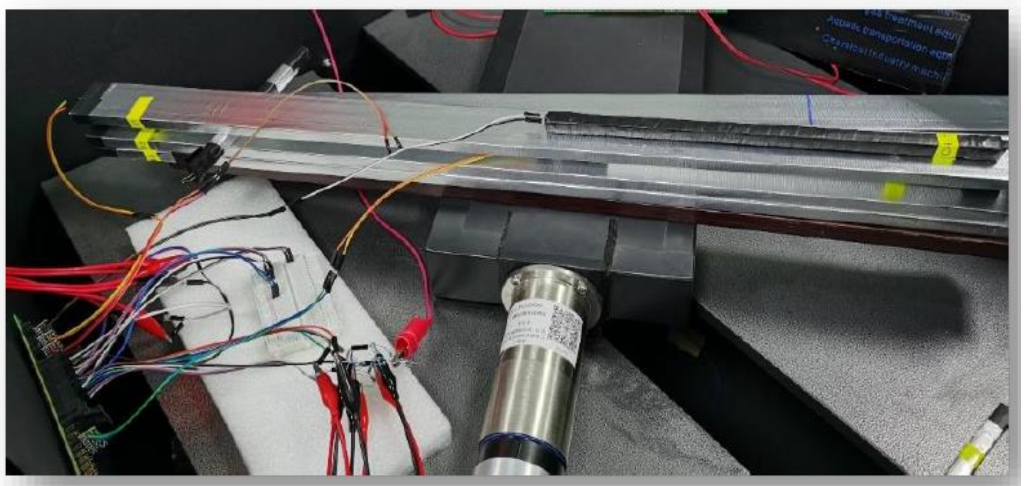


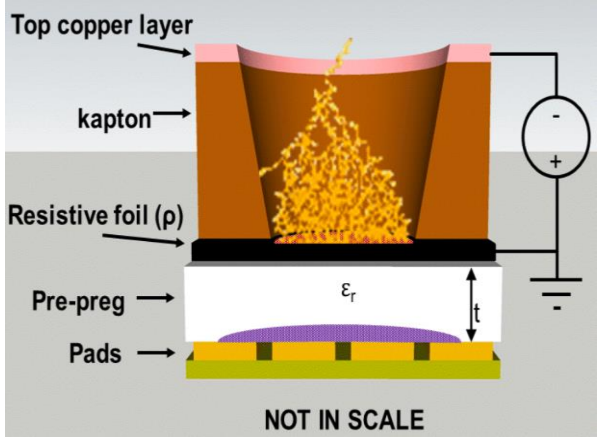








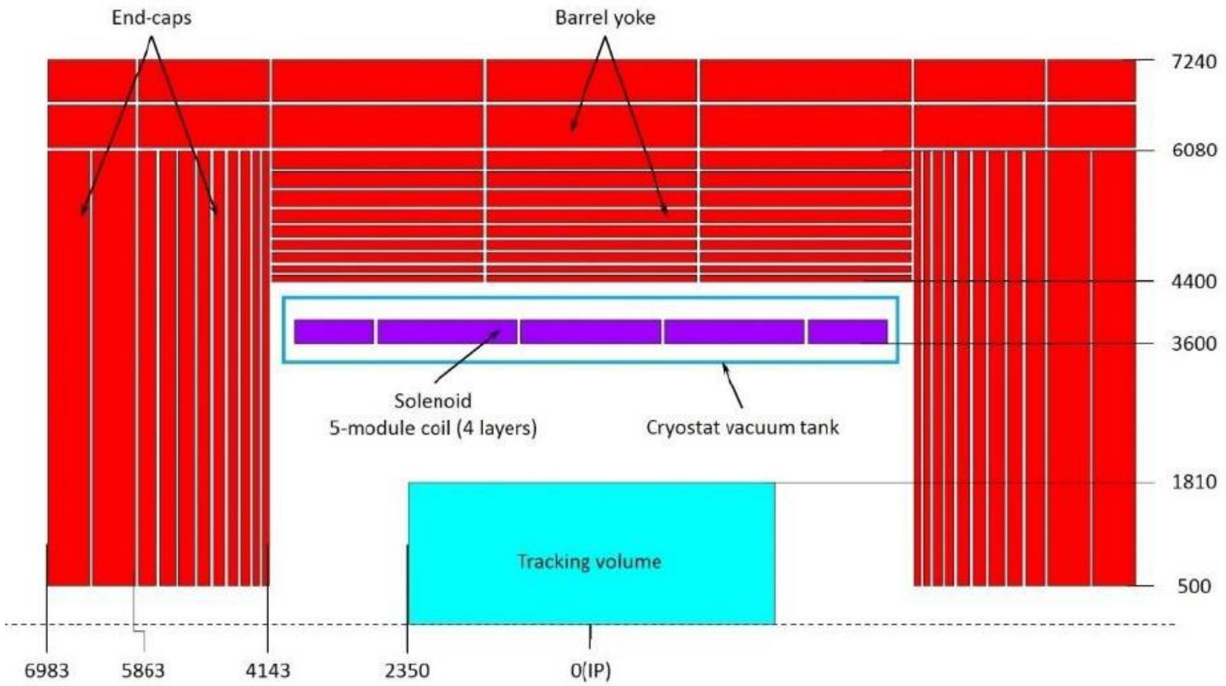


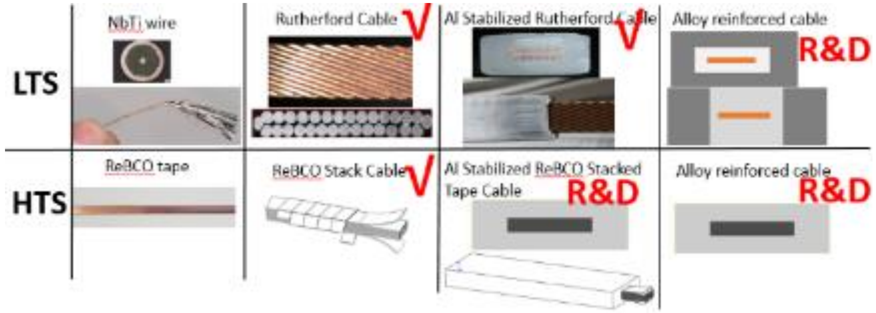


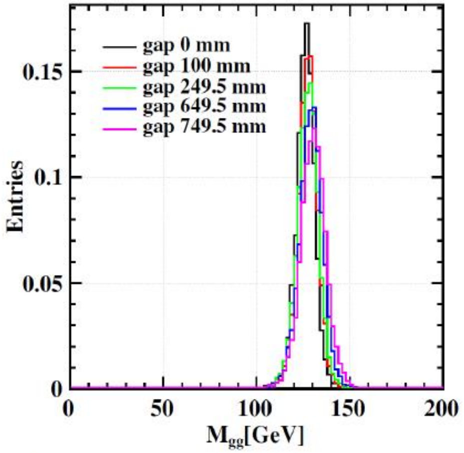
Fudan U.

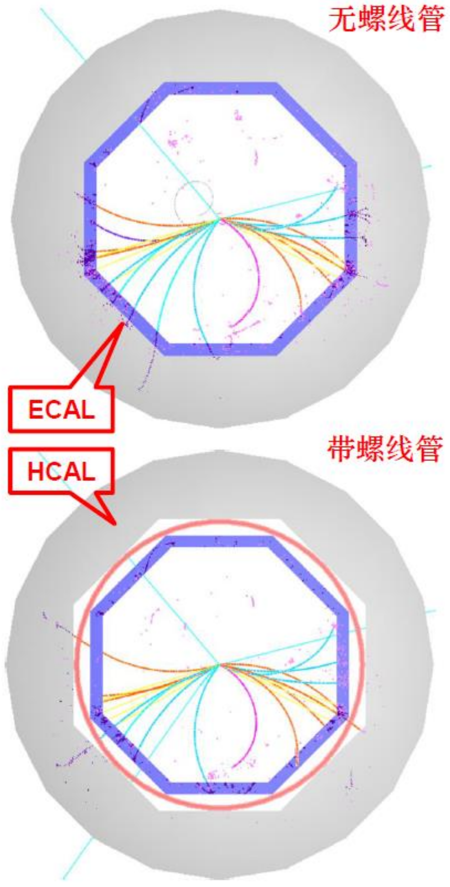
Achieved σ_t~2ns,
Aim for 100-200 ps.

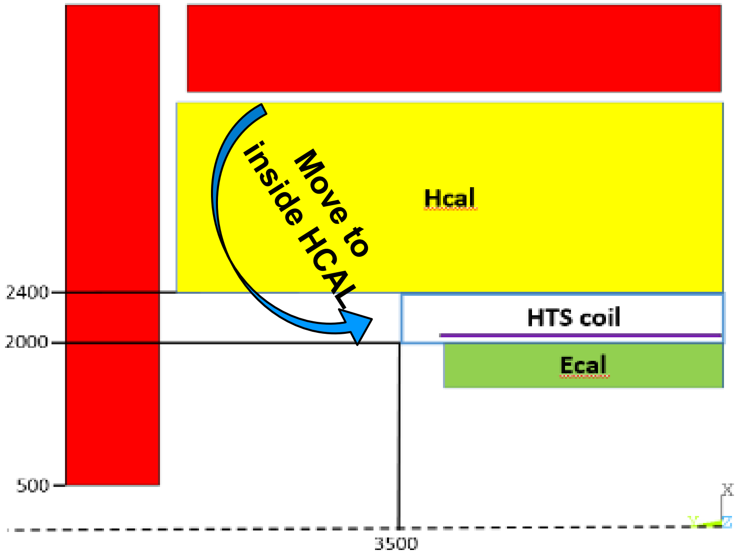
CEPC R&D: Solenoid Magnet





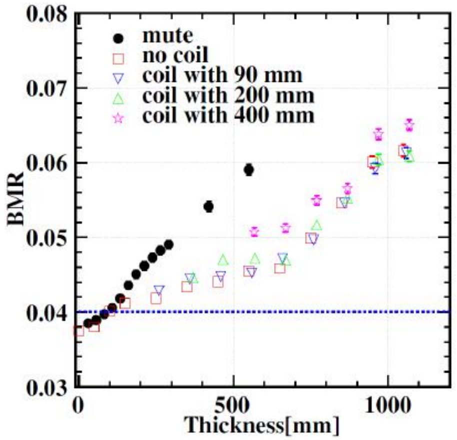




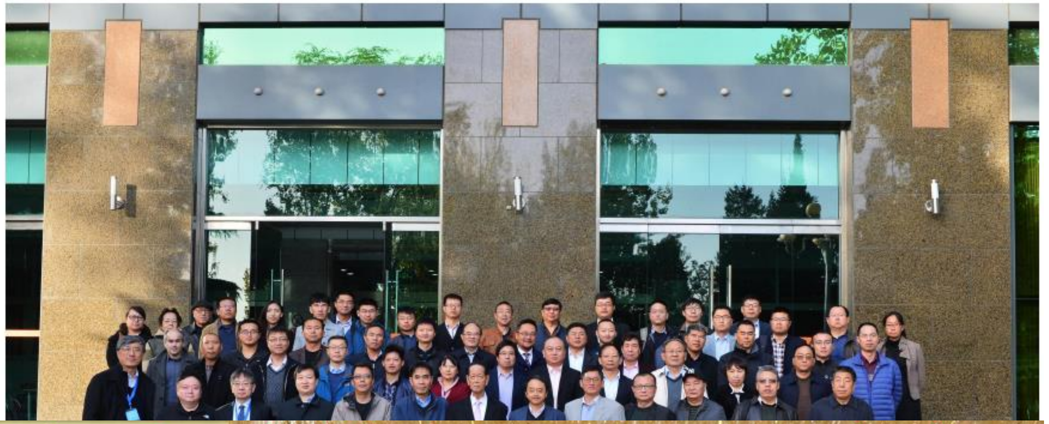


Main Challenges

Low mass, ultra-thin, high strength cable

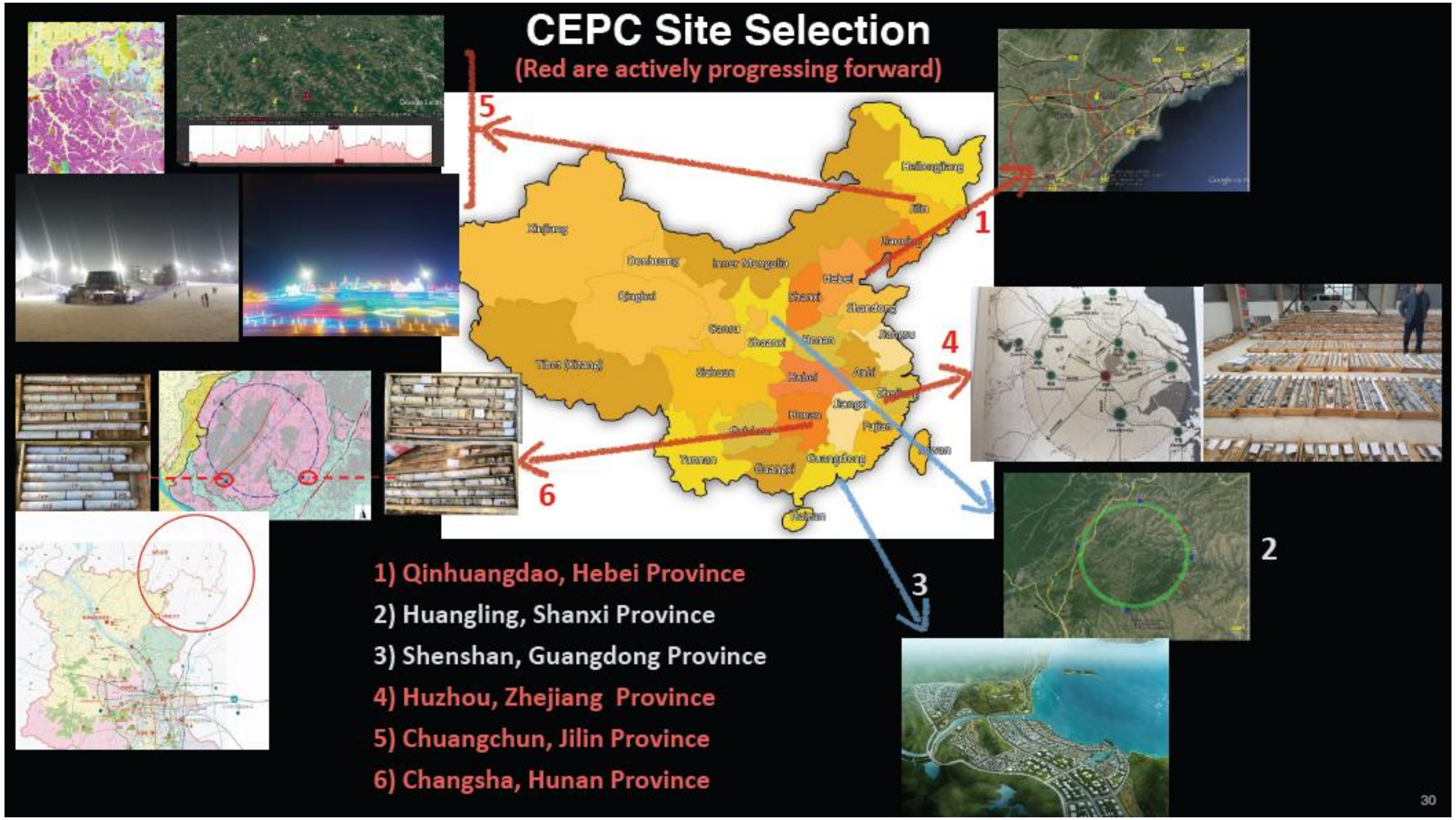


Collaboration with Industry (CIPC)



CEPC Site Selection

➤ 候选地址：秦皇岛、陕西、深圳、湖州、长春、长沙等

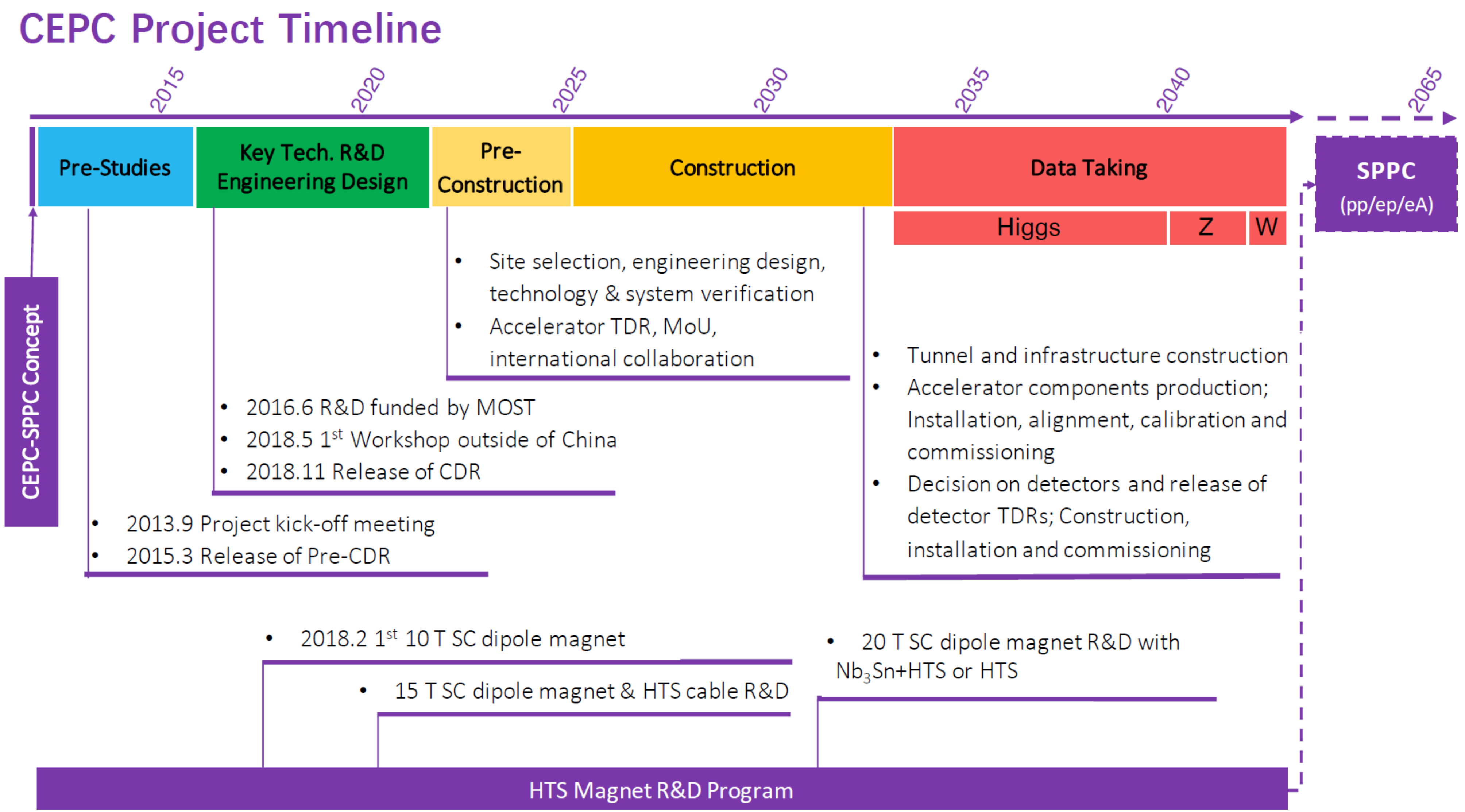


- Site selection is based on geology, electricity supply, transportation, environment for foreigners
- Local support & economy, …
- North site is better for reduction of operation cost
- Initial CDR study is based on Qing-Huang-Dao site

- More invitations from local governments: Changsha, Changchun, …
- Recent visit to Changsha and Changchun: good geology & transportation (~20 km from large city & international airport)
- Changsha government enlisted Hunan Univ. to conduct a study on the benefit that CEPC could bring to Changsha. (visited IHEP in May and July)

CEPC Project Timeline

- **2013-2025：Key technology R&D，from CDR to TDR, Site selection**
- **Ideal situation: Start construction in the 15th Five-Year Plan**



Summary and Prospects

CEPC is a clean Higgs/W/Z factory with great physics potential

- **Improve Higgs/EW precision and BSM sensitivity by 1-2 order of magnitude**
- **Great potential on QCD, Flavor Physics and BSM**

CEPC CDR released in Nov., 2018, towards CEPC TDR

- **Improvement of Higgs/Z luminosity, towards accelerator TDR at the end of 2022**
- **Proposal for the 4th conceptual detector design, towards detector TDR**

Key technology R&D:

- **High Q SCRF, High efficiency Klystron, High field SC magnets, …**
- **Silicon pixel ASIC chip, TPC, PFA ECAL prototype, SDHCAL, AHCAL, …**

CEPC physics whitepaper, physics potential study for Snowmass 2021/2022

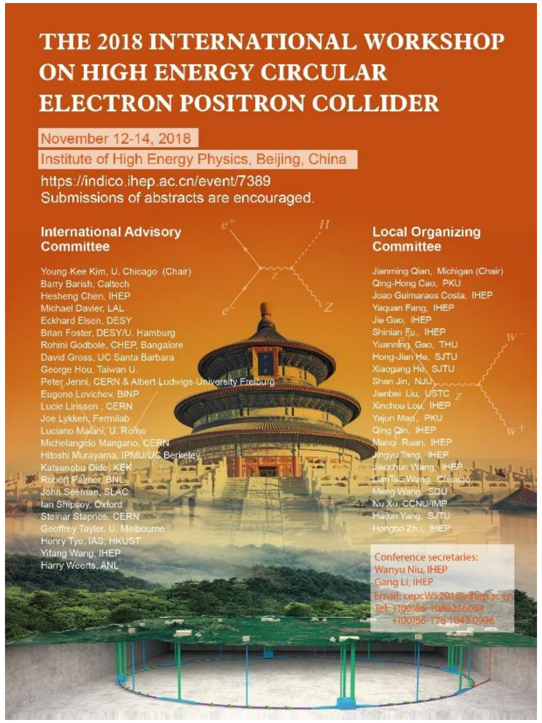
CEPC International Workshops:

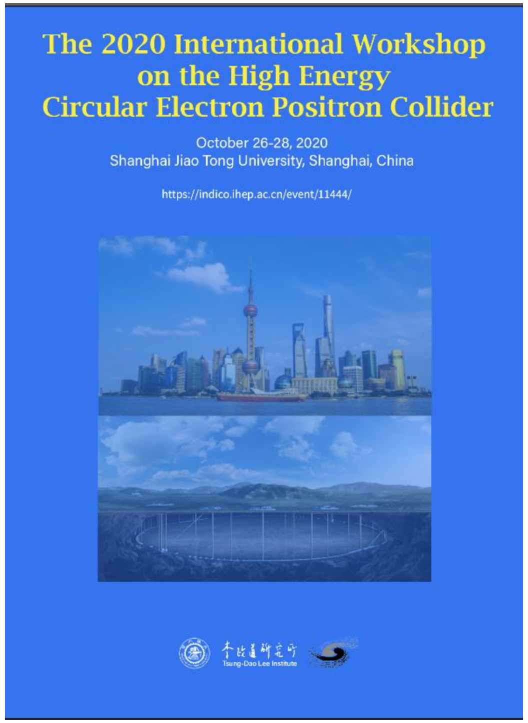
- **In China:** Beijing (2017.11, 2018.11, 2019.11), Shanghai (2020.10), **Nanjing (2021.Nov.8-12)**
- **In Europe:** Rome (2018.05), Oxford (2019.04), Marseille (2022.05 ?)
- **In USA:** Chicago (2019.09), DC (2020.04, online)
- **In HKUST:** Annual IAS HEP program since 2015; specific topics every year

Funding support in China: MOST, NSFC, CAS, institutes, local governments…

You are very welcome to join the CEPC R&D, thanks !

Recent CEPC Workshops





Next CEPC International Workshop

at Nanjing University, Nov. 8-12, 2021

You are very welcome to participate

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

Backup Slides

Summary and Prospects

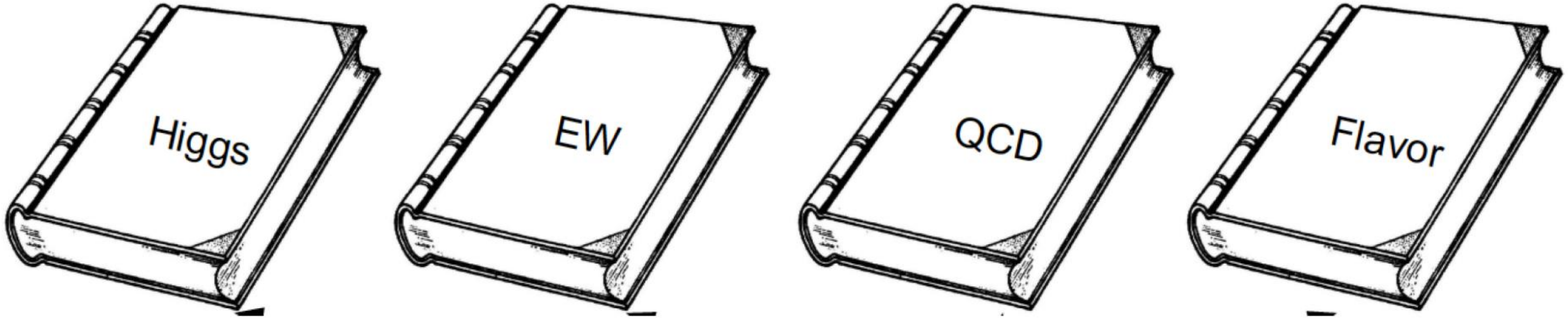
Continuing R&D and deep understanding of physics potentials

- Suggestions to **MOST for R&D support** and validations of key technologies & innovations
- Planning **next round design improvement, R&D**, site investigations-study
- **CEPC physics whitepaper**; physics potentials in Snowmass 2021/2022 arena

International Collaboration and Engagement

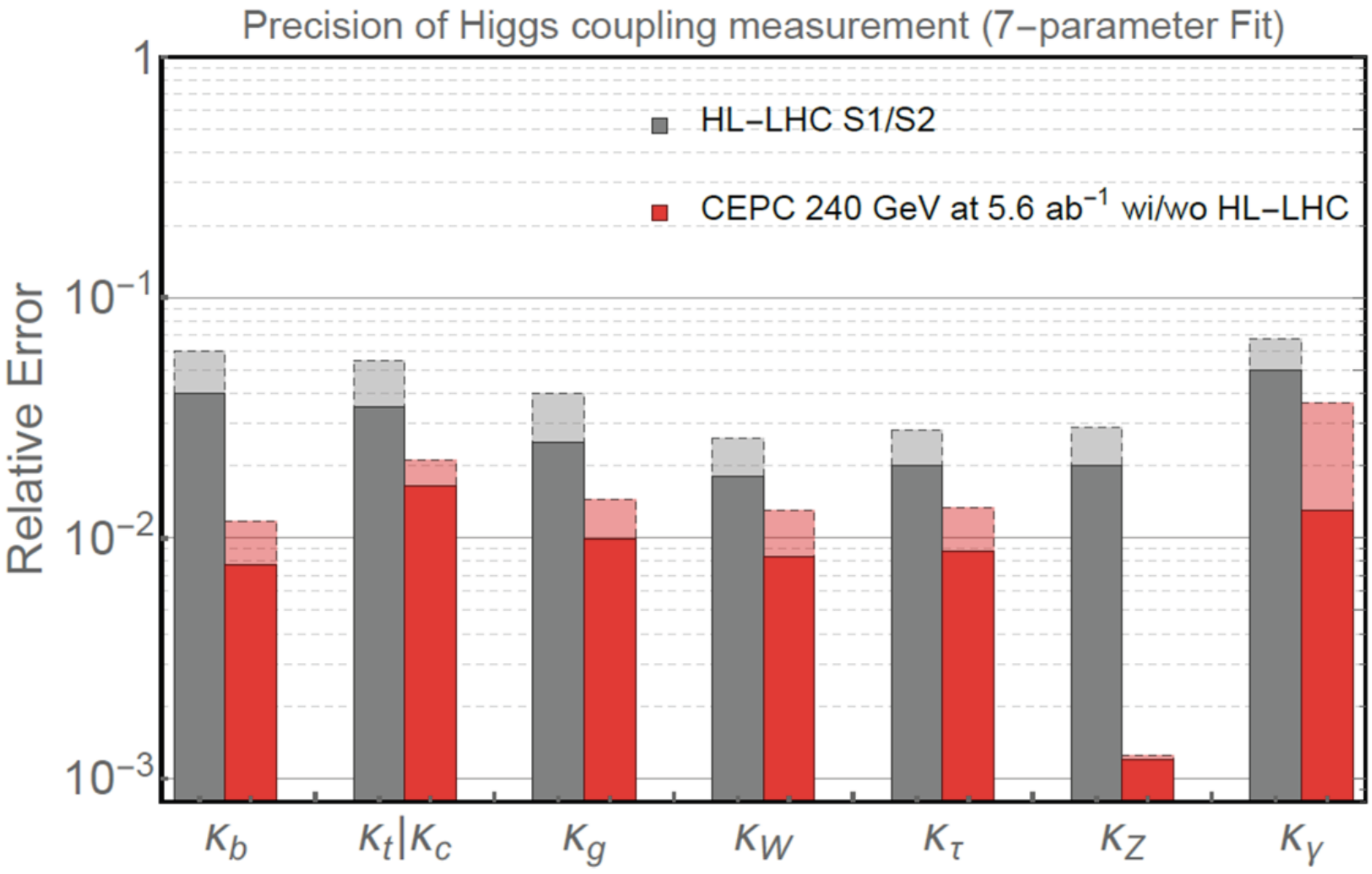
- Regular-formal **annual meetings** with major international labs and partners
- Actively participating in **European Strategy Update and Snowmass** activities
- Engaging actively in **ILC, FCC as well as HL-LHC upgrade** activities
- Actively participating international **detector R&D** collaborations: CALICE, LPTPC, RD*, …
- R&D and make major **progress + breakthroughs** in common technologies
- Plan to form two **international collaborations**
- Finding and sharing solutions to common issues (design, accelerator/detector components, …)
- ……

White papers

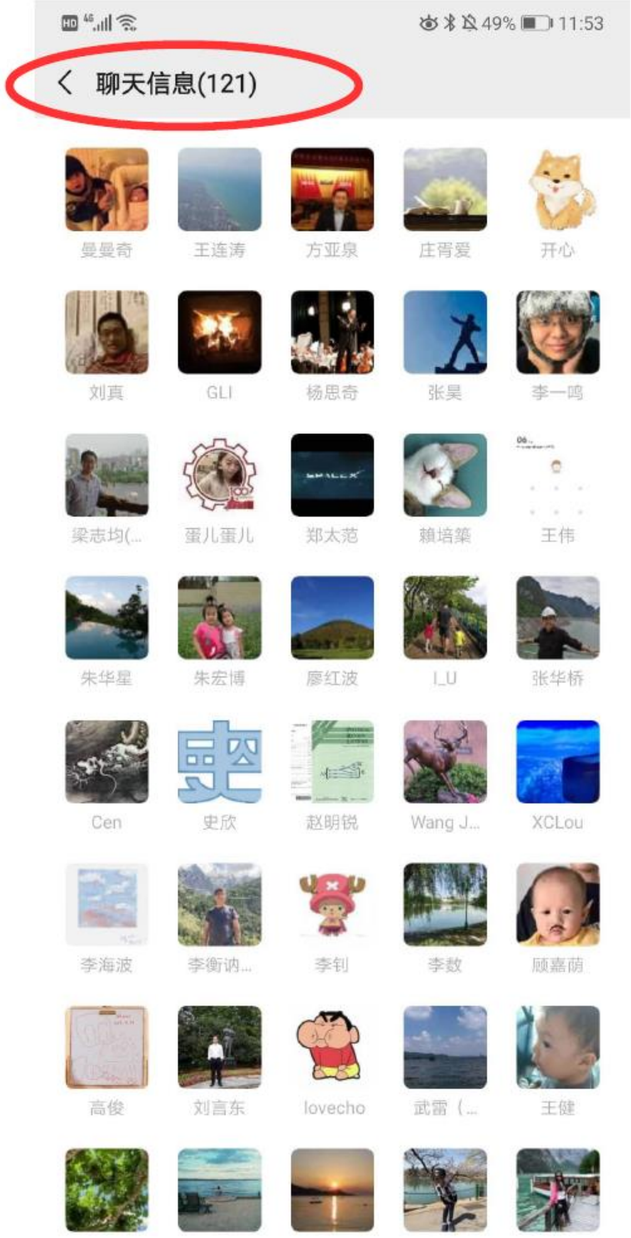


- To promote the physics study at TDR & to converge to the Physics White Papers
- Physics white papers:
  - Physics handbooks for new comers: PostDoc/Student
  - Official references for the physics potential
  - Guideline for future detector design/optimization
- Higgs white paper published in 2019

Updated Higgs Couplings

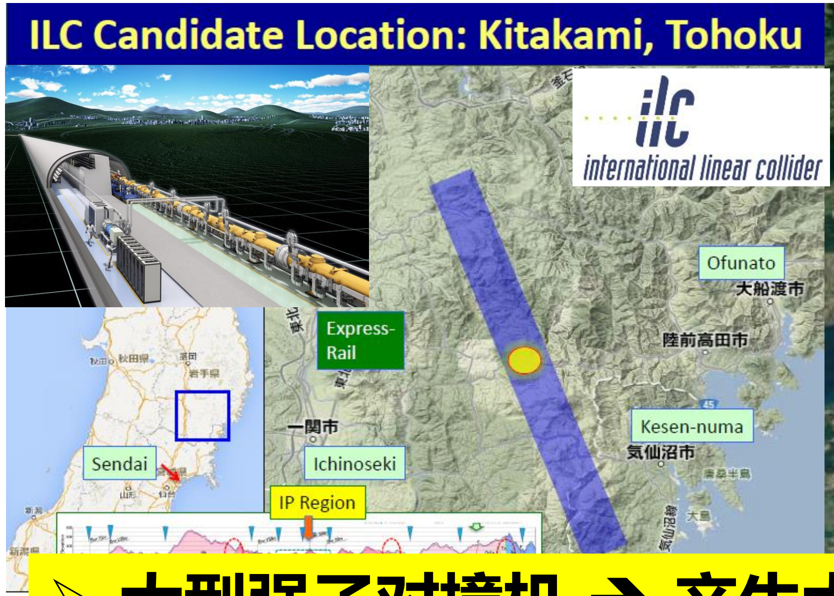


CEPC @ Snowmass

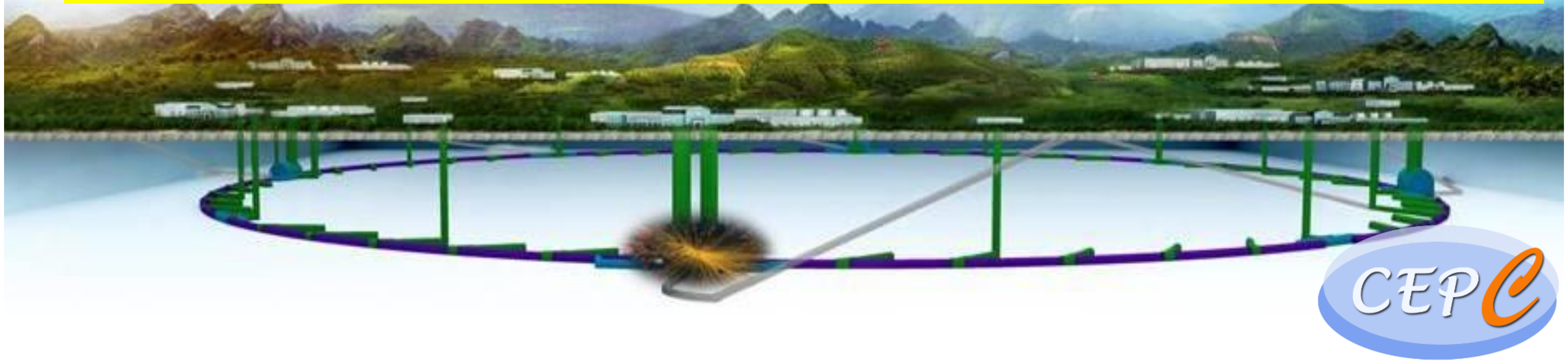


title	ID	author	link	
Study of electroweak phase transition in exotic Higgs decays with CEPC Detector simulation	229-v1	Michael Ramsey-Musolf	URL	
Exclusive Z decays	226-v1	Qin Qin	URL	
Measurement of the leptonic effective weak mixing angle at CEPC	233-v1	Siqi Yang	URL	★
Heavy Neutrino search in Lepton-Rich Higgs Boson Rare Decays	244-v1	Yu Gao	URL	★
Higgs boson CP properties at CEPC	227-v1	Xin Shi	URL	
Measurement of branching fractions of Higgs hadronic decays	228-v1	Yanping Huang	URL	
Feasibility study of CP-violating Phase phi_s measurement via Bs->J/PsiPhi channel at CEPC	230-v1	Mingrui Zhao	URL	★
Probing top quark FCNC couplings tqr, tqZ at future e+e- collider	231-v1	Peiwen Wu	URL	
Searching for $B_s \to \phi\nu\nu$ and other b->dvv processes at CEPC	232-v1	Yanyun Duan	URL	★
Probing new physics with the measurements of e+e- -> W+W- at CEPC with optimal observables	234-v1	Jiayin Gu	URL	
NNLO electroweak correction to Higgs and Z associated production at future Higgs factory	235-v1	Zhao Li	URL	
SUSY global fits with future colliders using GAMBIT	237-v1	Peter Athron	URL	
Probing Supersymmetry and Dark Matter at the CEPC, FCCee, and ILC	238-v1	Waqas Ahmed	URL	
Search for t + j + MET signals from dark matter models at future e+e- collider	239-v1	Peiwen Wu	URL	
Search for Asymmetric Dark Matter model at CEPC by displaced lepton jets	240-v1	Mengchao Zhang	URL	
Dark Matter via Higgs portal at CEPC	241-v1	Tianjun Li	URL	
Lepton portal dark matter, gravitational waves and collider phenomenology	242-v1	Jia Liu	URL	★
CEPC Detectors Letter of Intent	245-v1	Jianchun Wang	URL	

未来高能对撞机方案-希格斯工厂



- 大型强子对撞机 ➔ 产生大量的强子本底 ➔ 难以精确测量
- 正负电子对撞机 ➔ 产生事例非常“干净” ➔ 高精度测量 ➔ 独立测量希格斯的产生截面和衰变分支比



欧洲：计划建造超级对撞机(FCC)

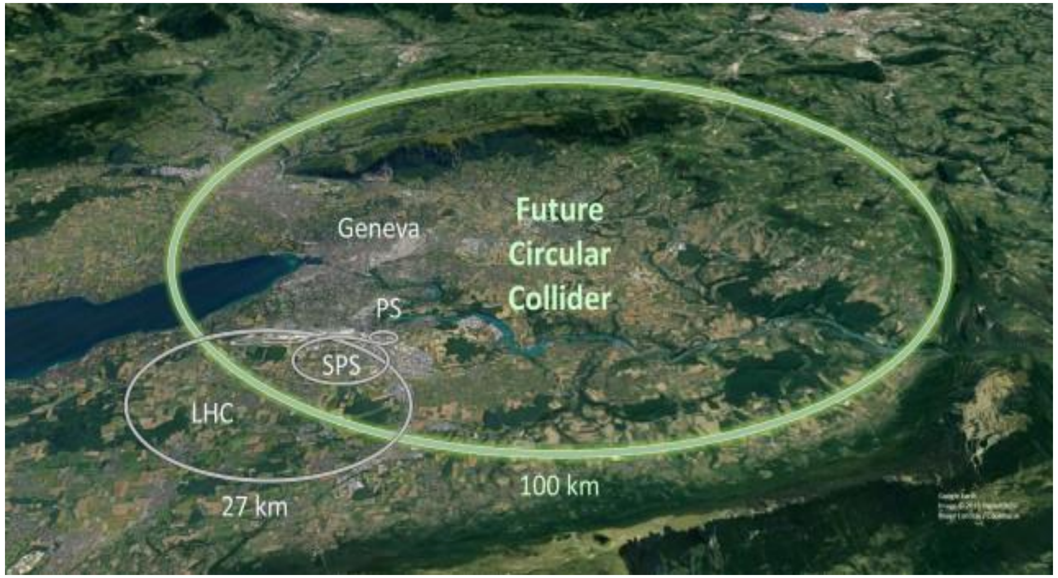
nature 19 JUNE 2020 Subscribe

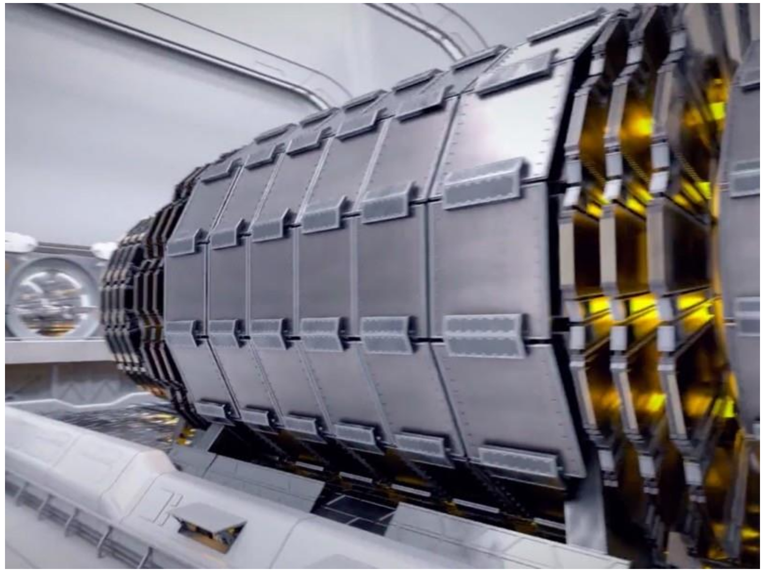
NEWS · 19 JUNE 2020 · CORRECTION 23 JUNE 2020

CERN makes bold push to build €21-billion supercollider

European particle-physics lab will pursue a 100-kilometre machine to uncover the Higgs boson's secrets – but it doesn't yet have the funds.

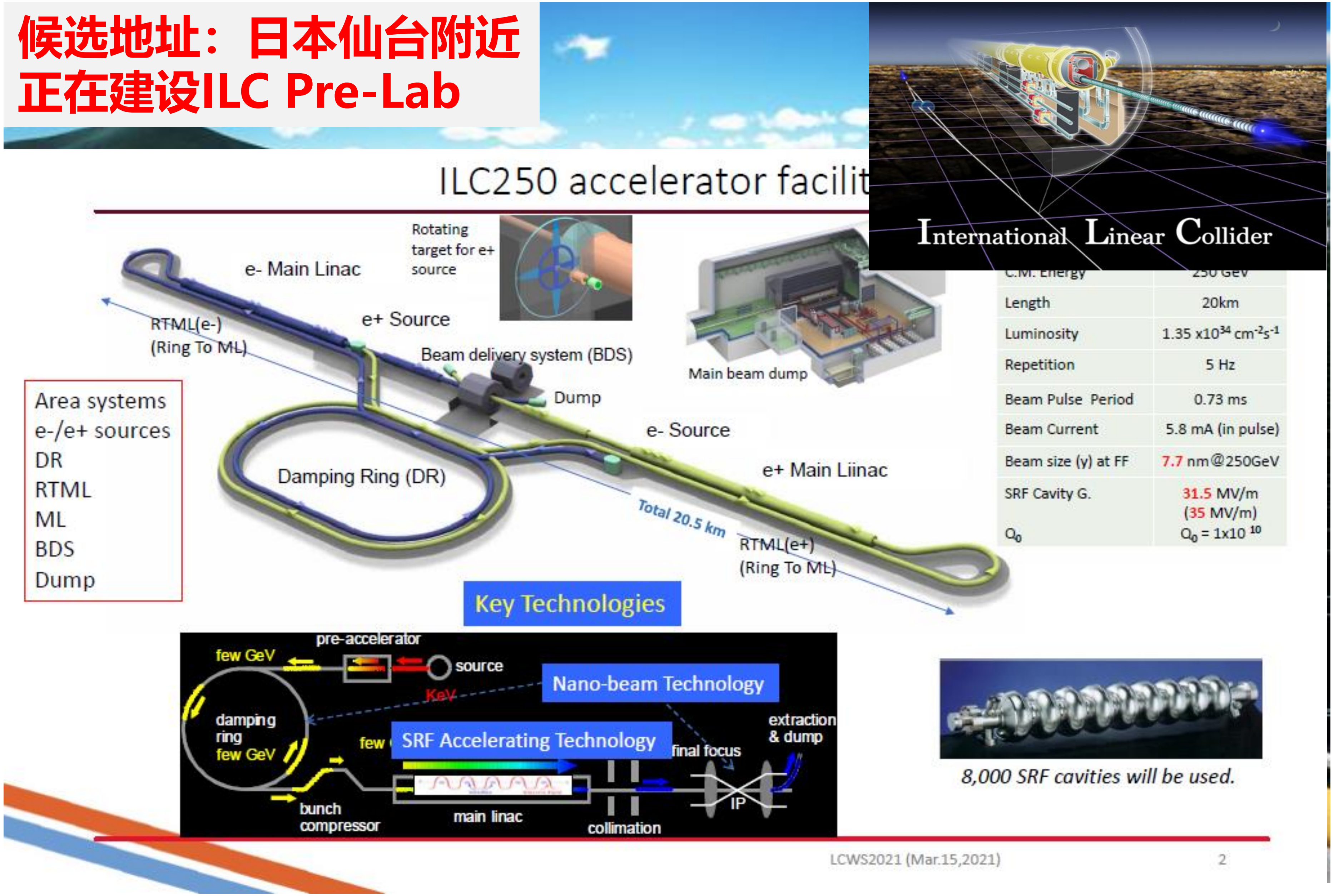
- 欧洲粒子物理战略规划明确建议希格斯工厂是优先级最高的下一代对撞机。
- CERN计划2040前后建造100公里长超级对撞机：
  - FCC-ee (希格斯工厂)
- 更长远的计划
  - FCC-hh (质子对撞机)





日本：国际直线对撞机(ILC)

候选地址：日本仙台附近
正在建设ILC Pre-Lab



C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} cm^{-2}s^{-1}
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm@250GeV
SRF Cavity G.	31.5 MV/m (35 MV/m)
Q_0	Q_0 = 1x10^{10}

日本：国际直线对撞机(ILC)

International Development Team (IDT)

Accelerator activities at ILC Pre-lab phase

international development team

- *Technical preparations (Solve the technical concerns by international cooperation)*
- *Final technical design and documentation (Engineering Design Report, Cost confirmation)*
- *Preparation and planning of mass production*
- *Civil engineering, local infrastructure and site*

+ develop human resources necessary fo

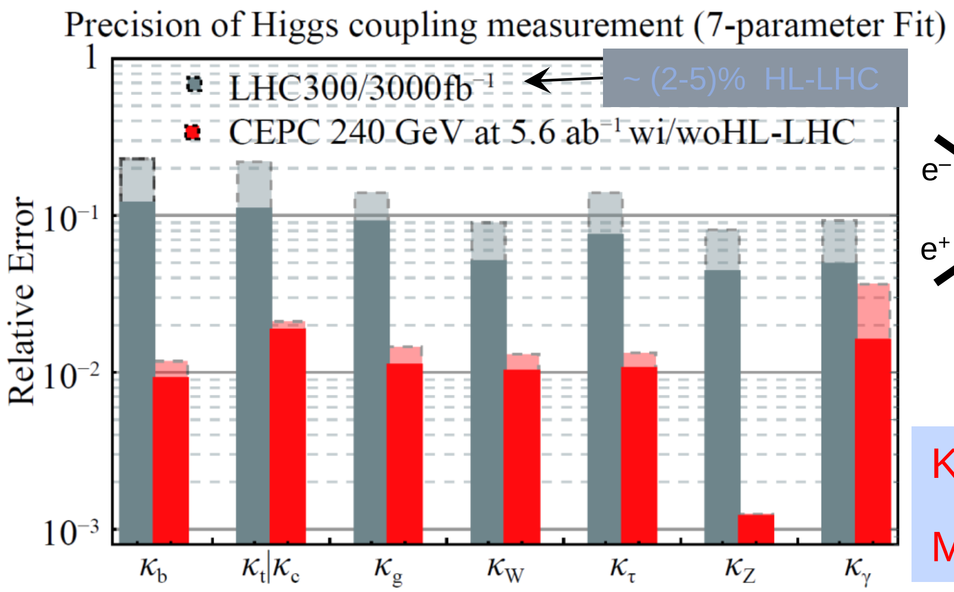
Planning technical preparation was our first work at IDT-WG2

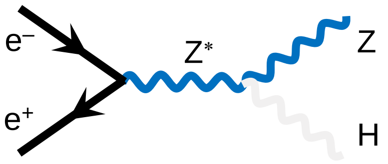
	IDT	ILC Pre-Lab				
	PP	P1	P2	P3	P4	1
Preparation CE/Utility, Survey, Design Acc. Industrialization prep.						
Construction						
Civil Eng.						
Building, Utilities	Following a four-year ILC P					
Acc. Systems	continue for about ten yea					
Installation						
Commissioning						
Physics Exp.						

CEPC Physics Performance (CDR)

The large samples of H, Z & W bosons from the CEPC provide an unique opportunity

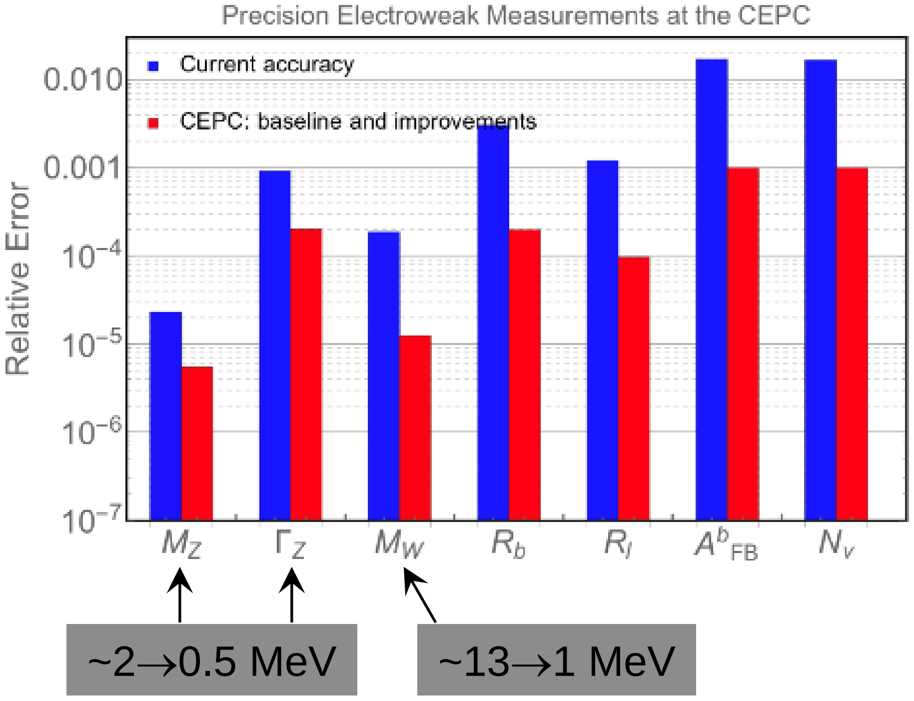
- Higgs physics white paper, arXiv:1810.09037
- Model independent measurement of Higgs boson width.
- Delivers ≤ 1% precision in some key measurements of Higgs properties, some are not accessible @ LHC.
- Sensitive to invisible decay modes of Br ~0.3%, and exotic decay channels.





K_Z uncert. ~ 0.13%

Most others ~ 1%



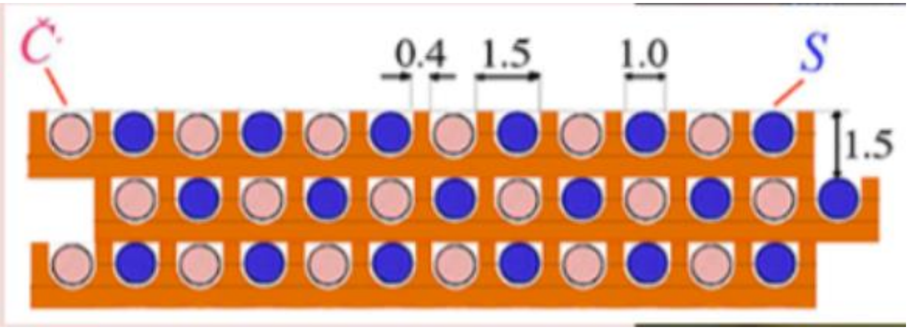
- Precision EW measurements,
- Flavor physics (b, c, tau),
- Study of QCD,
- Probe physics BSM.

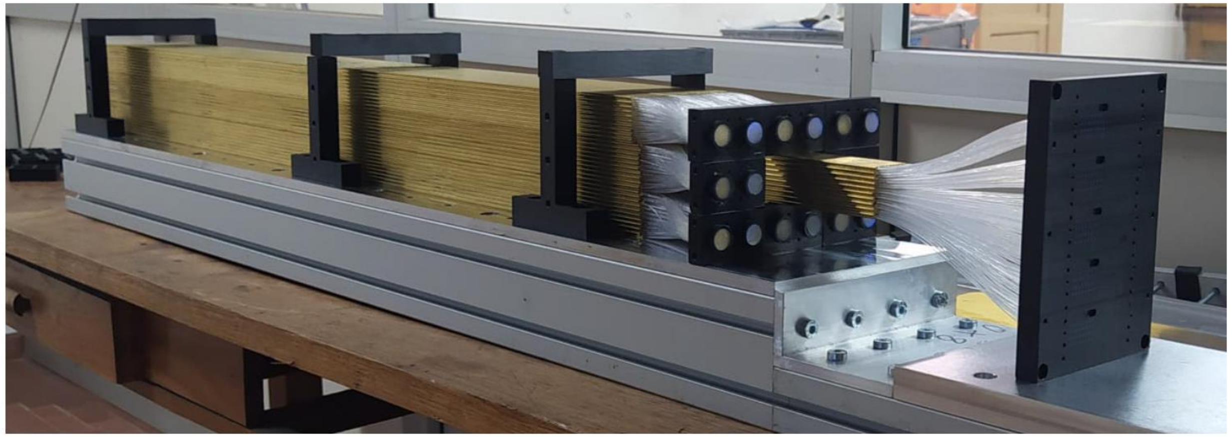
Chinese Physics C, 43 (2019) 043002

DR Calorimeter & SCEPCAL

A 3×3 towers ECal-size prototype has been built, waiting for testbeam.

Dual Readout calorimeter in the IDEA design





160 scint. fibers   160 Cherenkov fibers

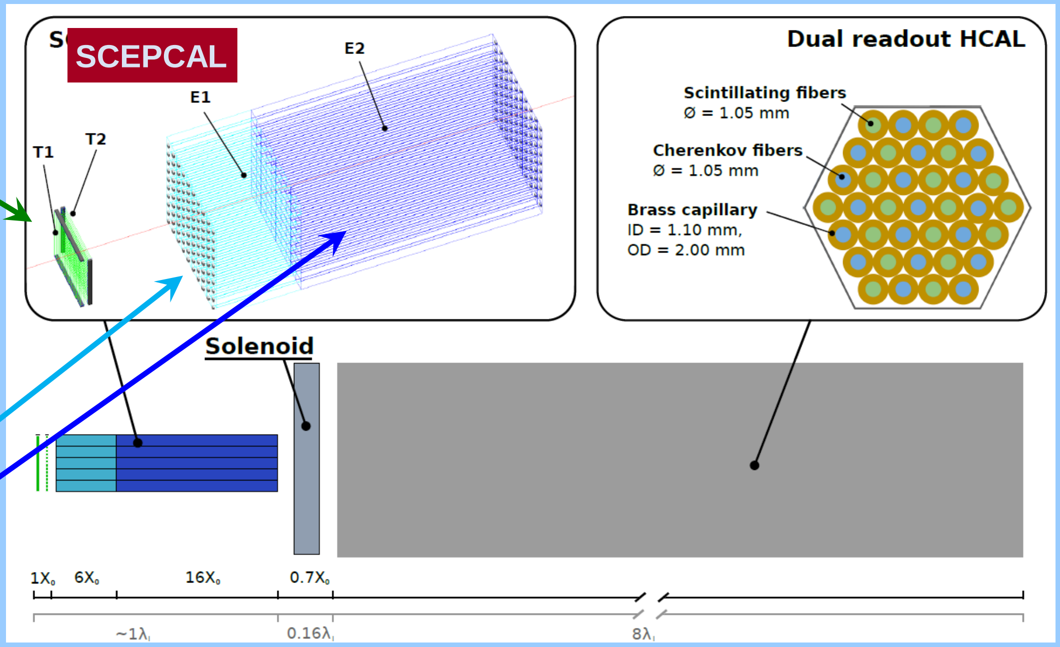
Tower: 20 rows × 16 columns

Combining Crystal ECal and DR Calorimeter

by Eno, Lucchini, and Tully et al. (arXiv:2008.00338)

Timing layer $\sigma_t \sim 20$ ps
- LYSO Ce crystal (~$1X_0$)
- 3×3×54 mm³ active cell
- 3×3 mm² SiPMs (15-20 μm)

ECAL layer $\sigma_E/E \sim 3\%/\sqrt{E}$
- PbWO crystals
- Front segment (~$6\ X_0$)
- Read segment (~$16\ X_0$)
- 10×10×200 mm³ Crystals
- 5×5 mm² SiPMs (10-15 μm)

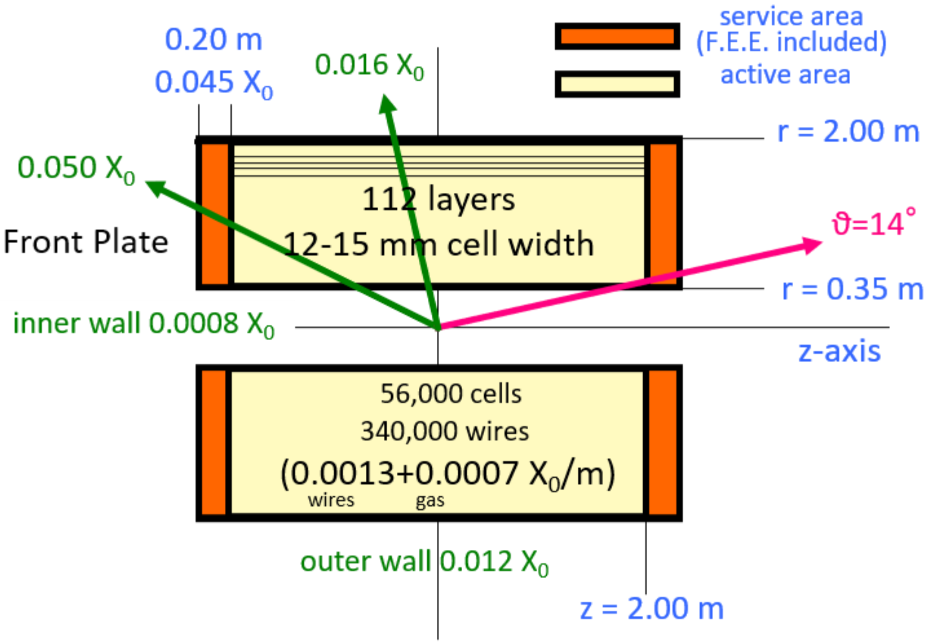


IDEA Drift Chamber

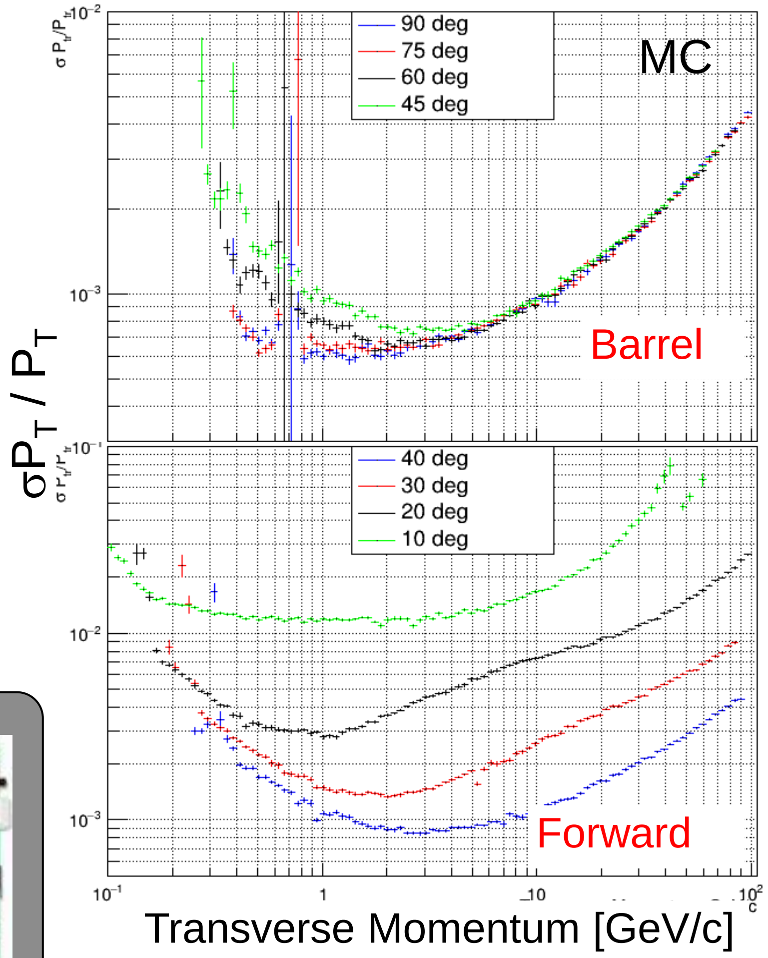
tracking efficiency ε ≈ 1
for ϑ > 14° (260 mrad)
97% solid angle

$0.016\ X_0$ to barrel calorimeter
$0.050\ X_0$ to end-cap calorimeter

The main tracker in IDEA design

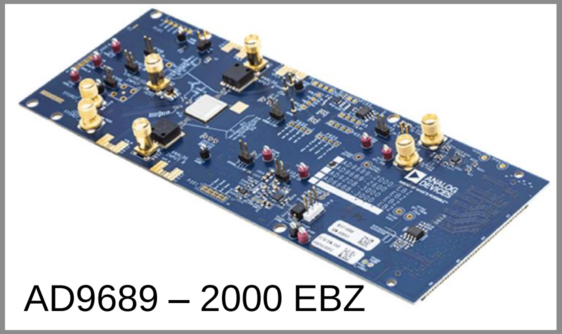


Gas: He/iC_4H_{10} (90:10)%
Spatial resolution: <100 μm
Max drift time: ~ 350 ns



DAQ for prototype drift tube to study front end data compression.

Cluster counting for PID


AD9689 – 2000 EBZ


Xilinx KCU105

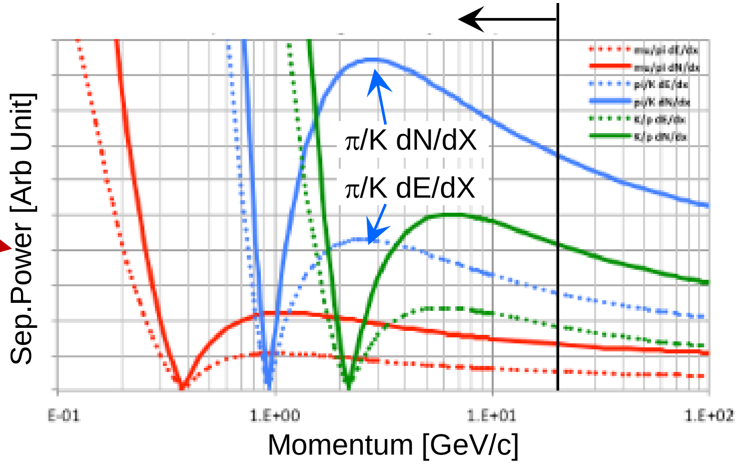
CEPC R&D: TPC/DC for Particle ID

- Both TPC & DC in the two designs have good PID, with dE/dX or dN/dX (cluster counting).
- The FST solution needs a supplement PID. A combination of different PID detectors is also possible.
- **Aim is to for have 2σ π/K separation for P<~20 GeV/c.**

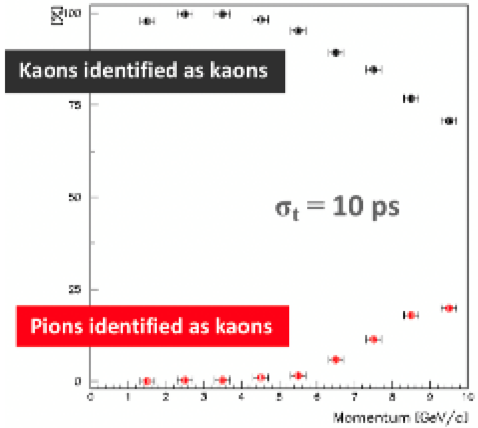
① **Drift chamber** between the outer layers of FST. The dN/dX method is more efficient. It is a joint R&D effort with the IDEA DC. But the DC can be optimized for PID only, not its tracking capability.

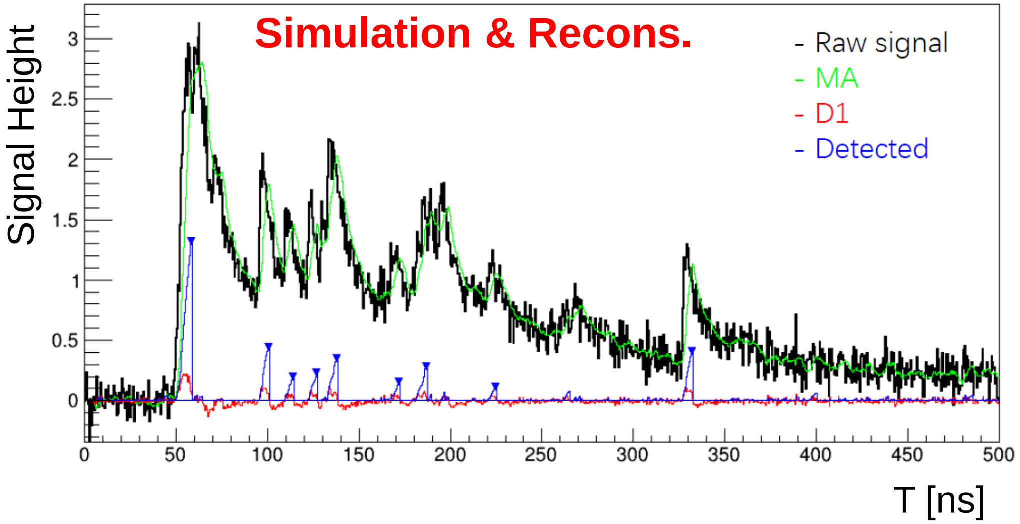
② **Time of flight** detector, e.g. LGAD. The time resolution ~20-30 ps today. Resolution of 10 ps is possible by the time of CEPC.

- Other options, e.g. an aerogel **RICH**, will also be considered.

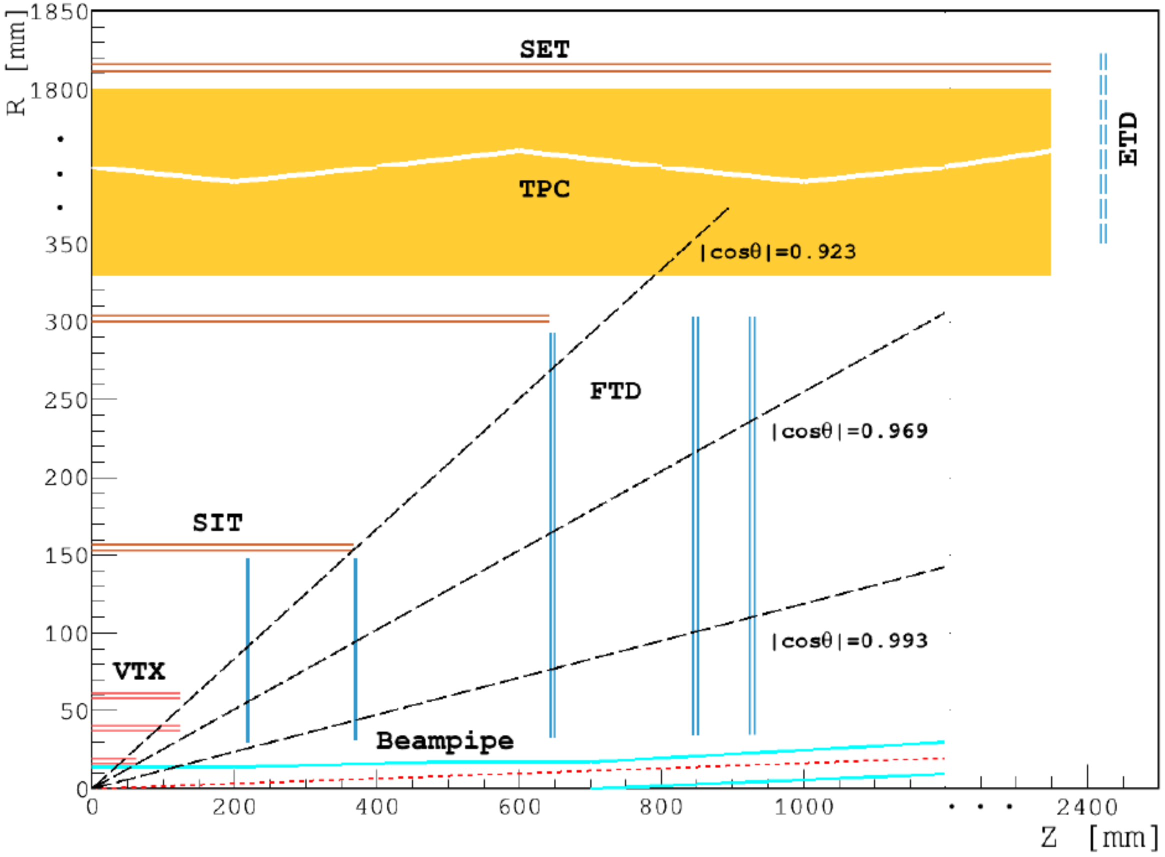


IHEP-NDL LGAD-V2
Pixel size 1.3×1.3 mm^2





CEPC Vertex and Tracker

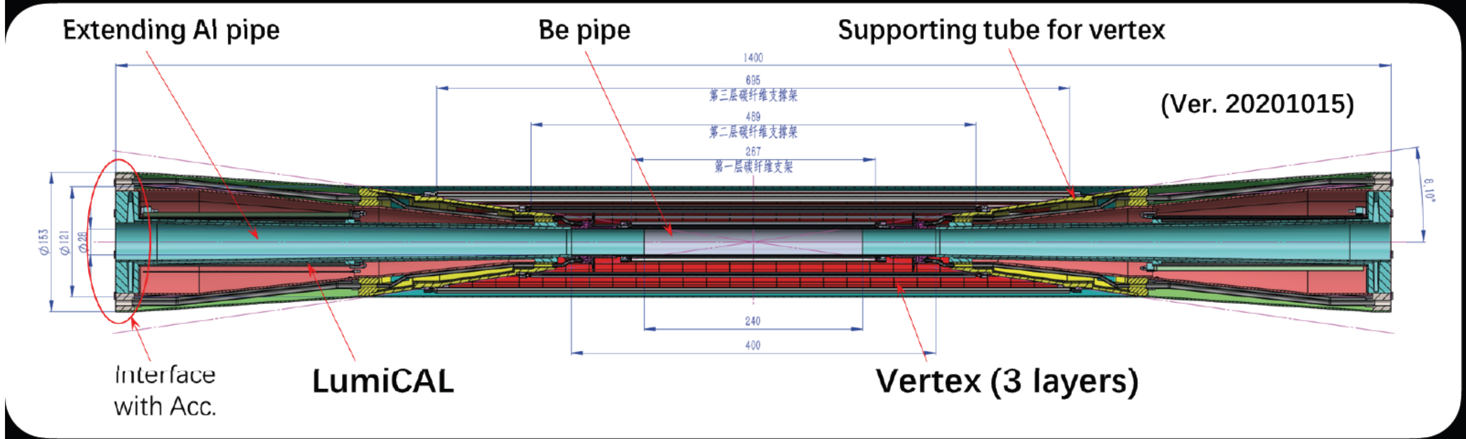


- Single-point resolution of the first layer better than 3 μm;
- Material budget below 0.15% X_0 per layer;
- First layer located close to the beam pipe at a radius of 16 mm, with a material budget of 0.15% X_0 for the beam pipe;
- Detector occupancy not exceeding 1%.

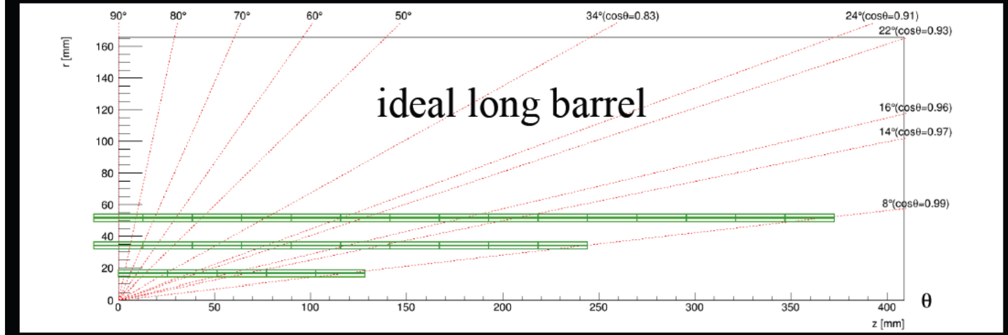
	R (mm)	$\lvert z\rvert$ (mm)	$\lvert\cos\theta\rvert$	σ(μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
Layer 4	39	125.0	0.95	4
Layer 5	58	125.0	0.91	4
Layer 6	60	125.0	0.90	4

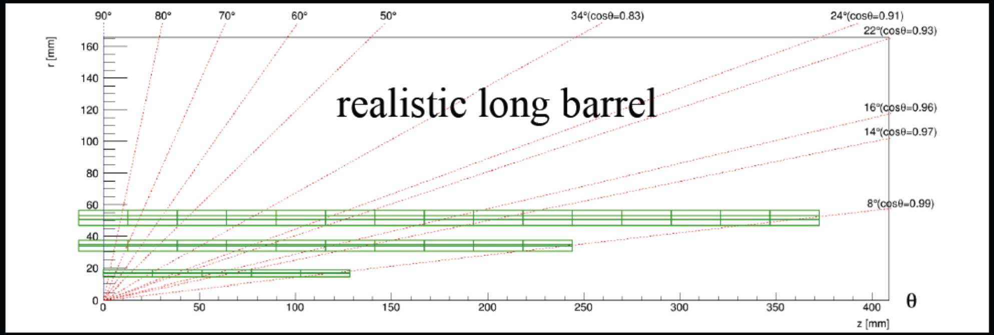
Operation mode	**H (240)**	**W(160)**	**Z (91)**
Hit density (hits $\cdot$ cm^{-2} $\cdot$ BX^{-1})	2.4	2.3	0.25
Bunching spacing (μs)	0.68	0.21	0.025
Occupancy (%)	0.08	0.25	0.23

Pixel Vertex Detector Optimization: Long Barrel Design



- **Positives:**
  - Better solution for air cooling
  - Simple structure
- **Negatives:**
  - Possible vibration of long ladder
  - Stiffer ladder support
  - More readout copper in center





2-layer flex

	Thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

4-layer flex

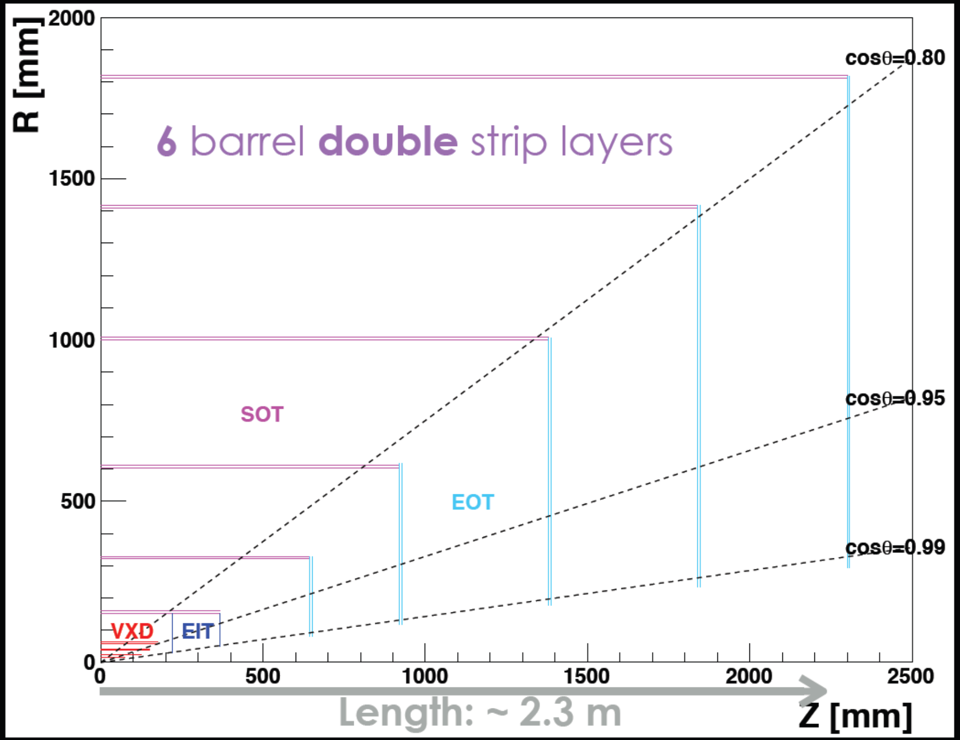
	thickness	Optimization goal
Polyimide	25um	12
Adhesive	28um	15
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
kapton+adhesive	50um	50
Plating Al	17.8um	?
kapton	50um	50
Plating Al	17.8um	?
Adhesive	28um	15
Polyimide	25um	12

Full Silicon Tracker Concept

Full Silicon Tracker Concept

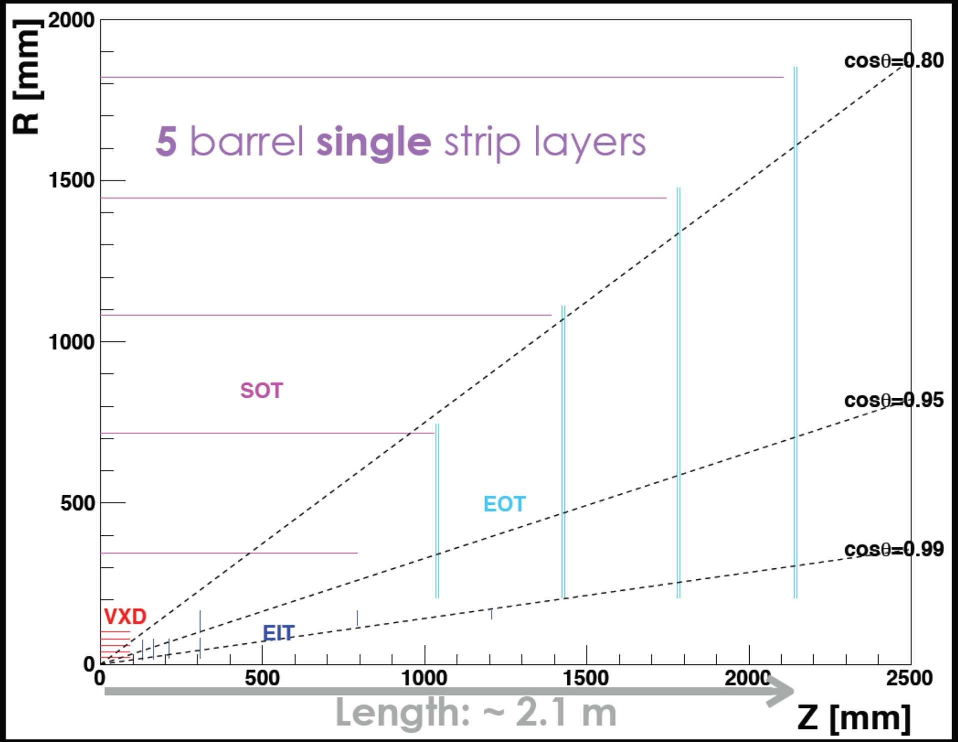
Replace TPC with additional silicon layers

FST layout: Rad length up to 7%



Radius ~ 1.8 m

FST2 layout: Rad length up to 10%



Proposed by Berkeley and Argonne

Drawbacks: higher material density and limited particle identification (dE/dx)

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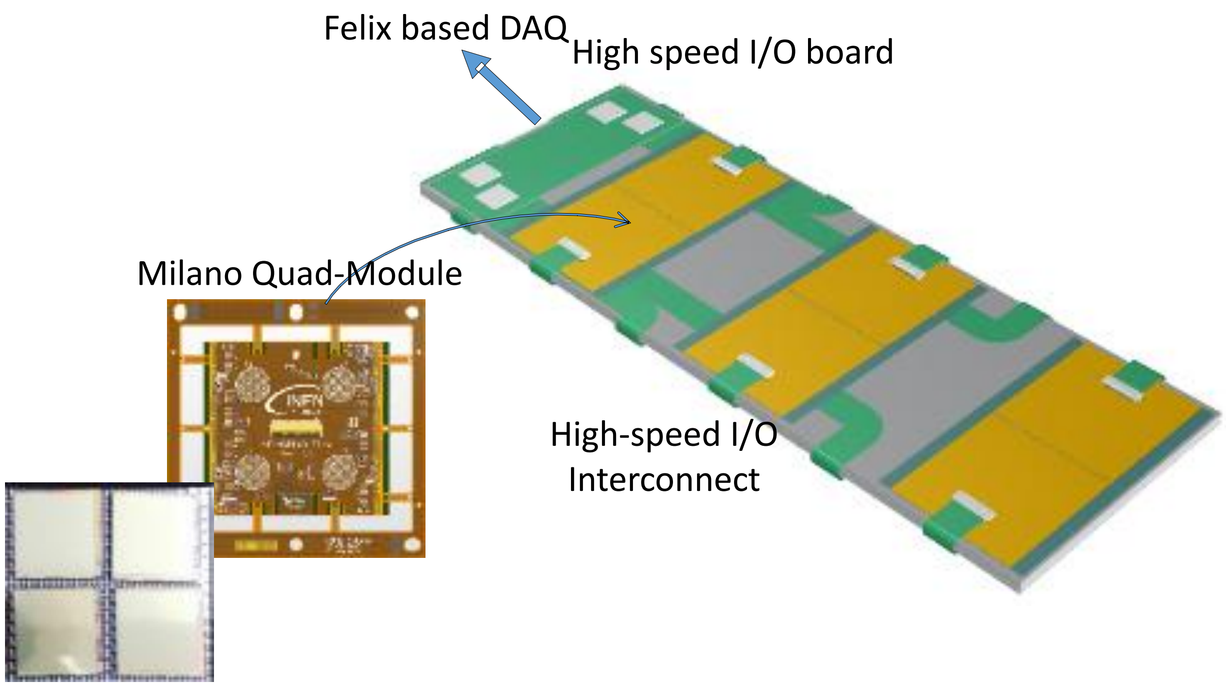
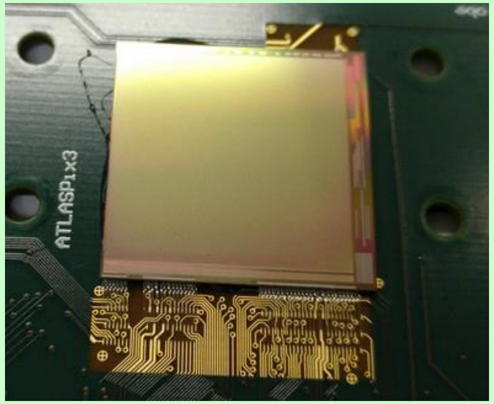
Silicon Tracker

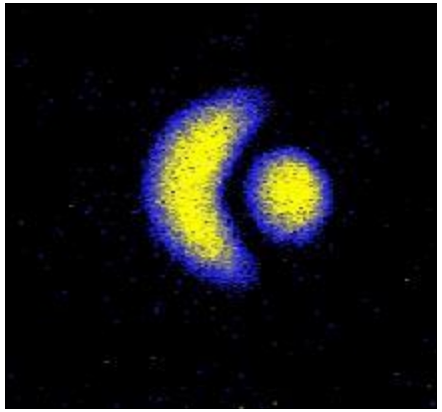
- Area of the silicon tracker is very big: ~70 m^2 in SiTrk+TPC, or ~140 m^2 in FST plans. R&D focuses on cost effective and high performance.
- A HV-CMOS solution based on the ATLASPix3 designed by KIT.
- Study ATLASPix3 with radioactive source, cosmic ray, & particle beam.
- A short stave demonstrator will be constructed.
- A CEPC-version of pixel size 25×150 μm^2 is to be fabricated with the HLMC 55nm technology.



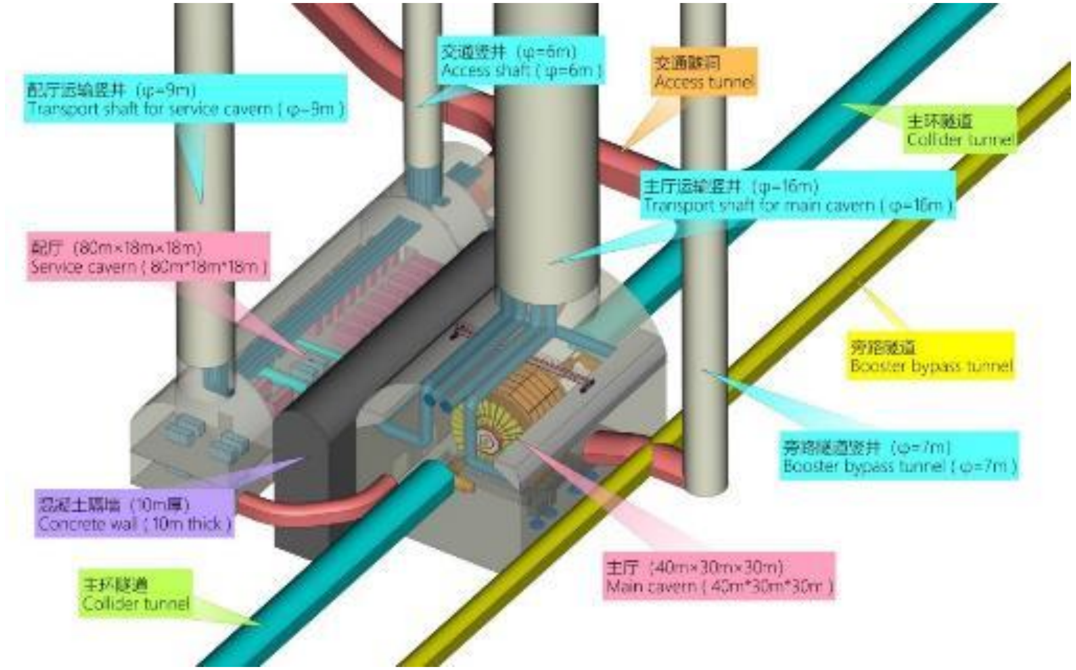
ATLASPix3
132×372 pixels
150×50 μm^2 pixel size.
Time resolution: O(10ns)



Fe-55 with collimator



The Experimental Area



Ground level buildings

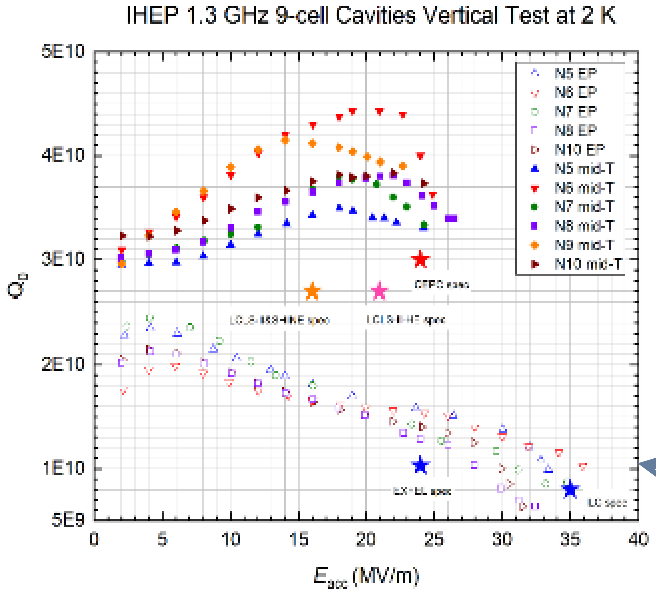
Main cavern to host the detector

- 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

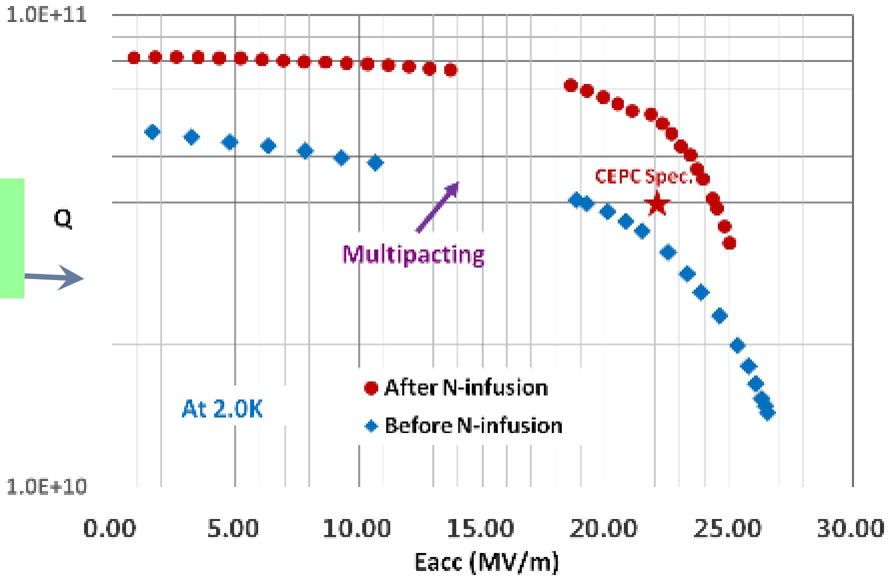
Accelerator R&D: High Q SRF Cavities



Both exceeded the CEPC spec, a milestone towards the TDR

Collider ring 650MHz 2-cell cavity

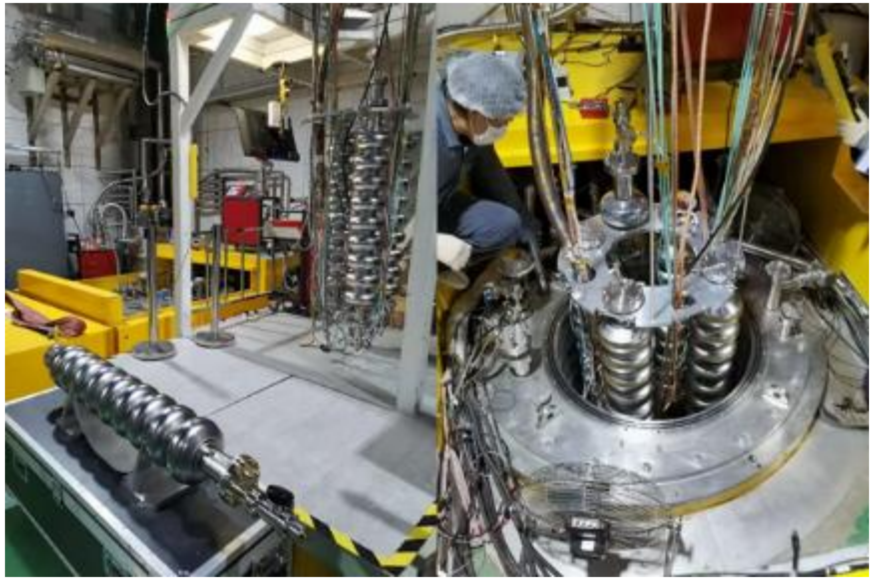
N-infusion adopted, Q = 6.0E10@22MV/m

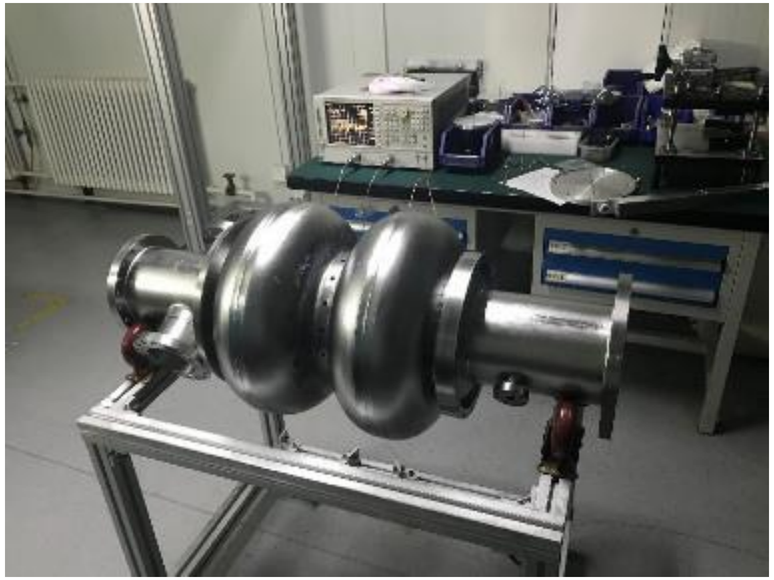


Booster 1.3GHz 9-cell cavity

> 30 MV/m, max 36 MV/m.

Q= 3.4~4.5E10@16~22MV/m





CEPC Software

- Core software, external libraries & tools are the base of the CEPCSW. More packages and components will be added when available.
- CEPC applications are created for CDR design. With new type of detectors introduced, corresponding codes are being developed.
- Recent added CEPC applications:
  - Software for SiTrk + DC design, detector description and track fitting.
  - Cluster counting method of DC
  - Simulation and simplified digitization of the crystal bar ECal.
- Work to be done
  - Further development of simulation & reconstruction for SiTrk+DC and Crystal bar ECal.
  - Non-uniform magnetic field & piling-up of beam backgrounds in simulation
  - Algorithms for building reconstructed particles
  - Continue to check the consistence of software, with benchmark performance studies.

CEPCSW structure