CEPC 项目进展报告

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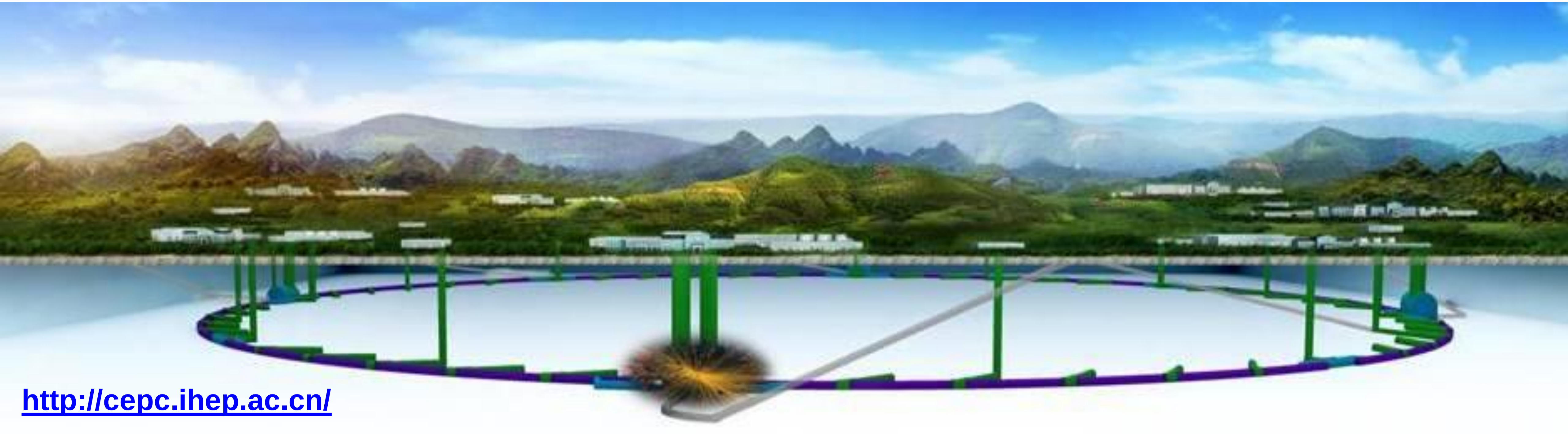
代表CEPC工作组

基于加速器高能量前沿战略研讨会
北京，2021年10月11-12日



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

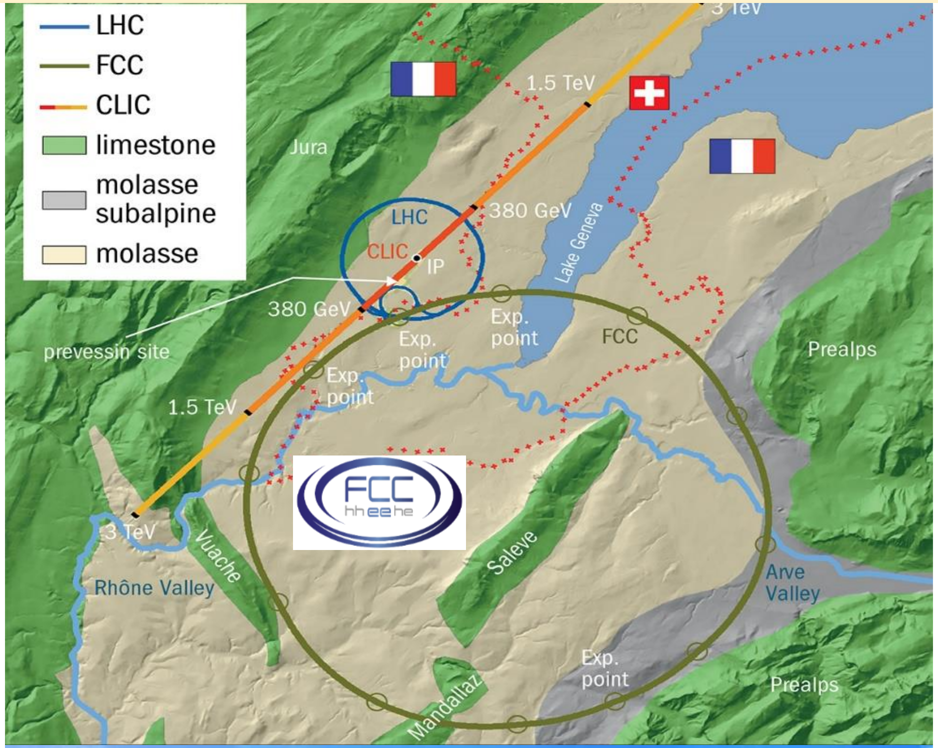
报告提纲

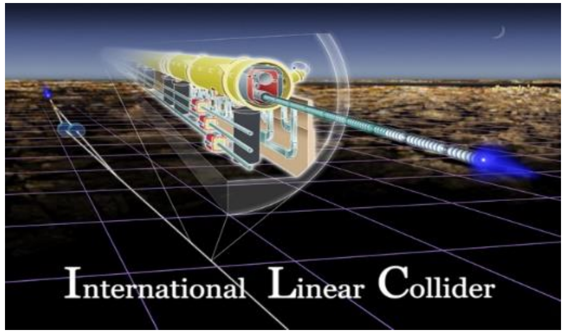
- 国际轻子对撞机简介
- CEPC 项目简介
- 加速器关键技术预研进展
- 物理潜力研究进展
- 新探测器概念设计方案
- 探测器关键技术预研进展
- CIPC 产业促进会活动
- CEPC 选址及时间表
- 总结与展望

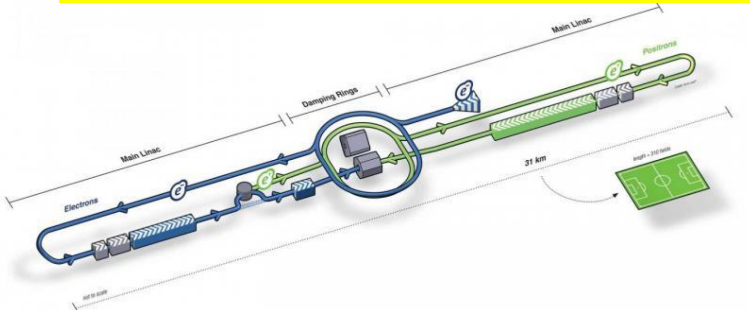
Worldwide Lepton Colliders

- 欧洲粒子物理战略规划提出：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.

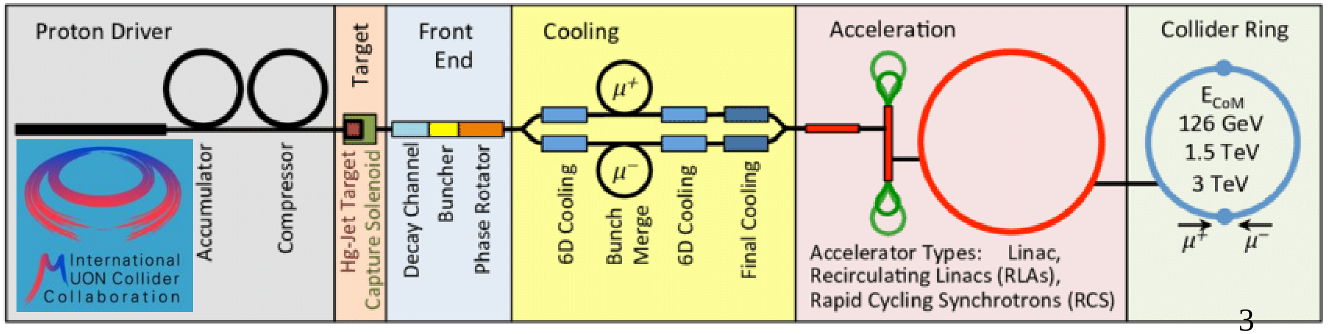
国际形势参见：娄辛丑报告





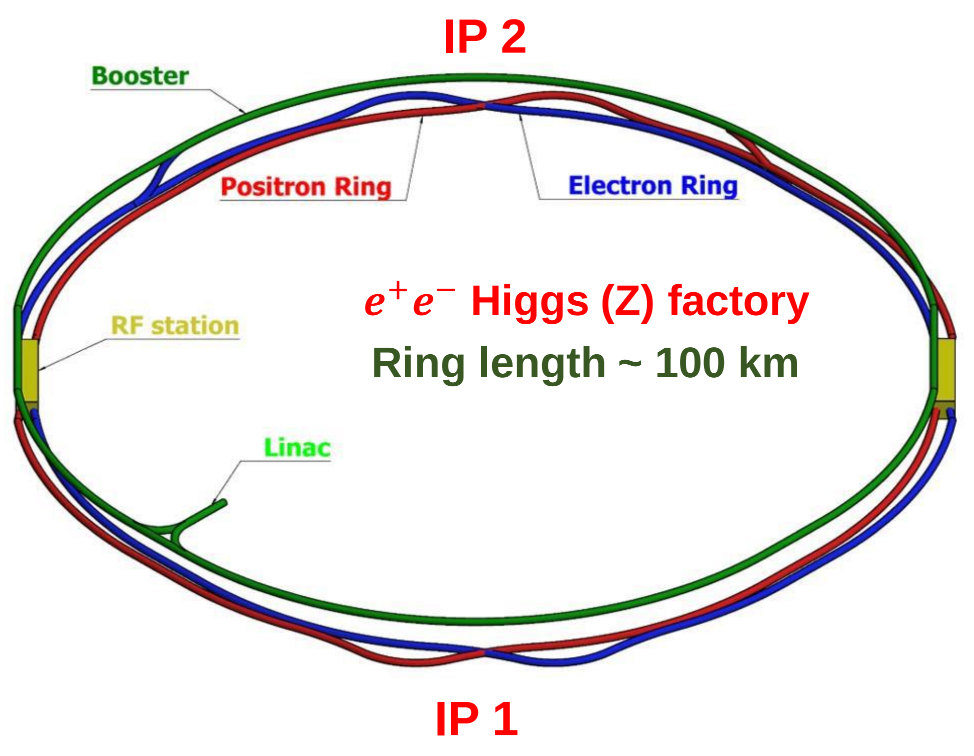


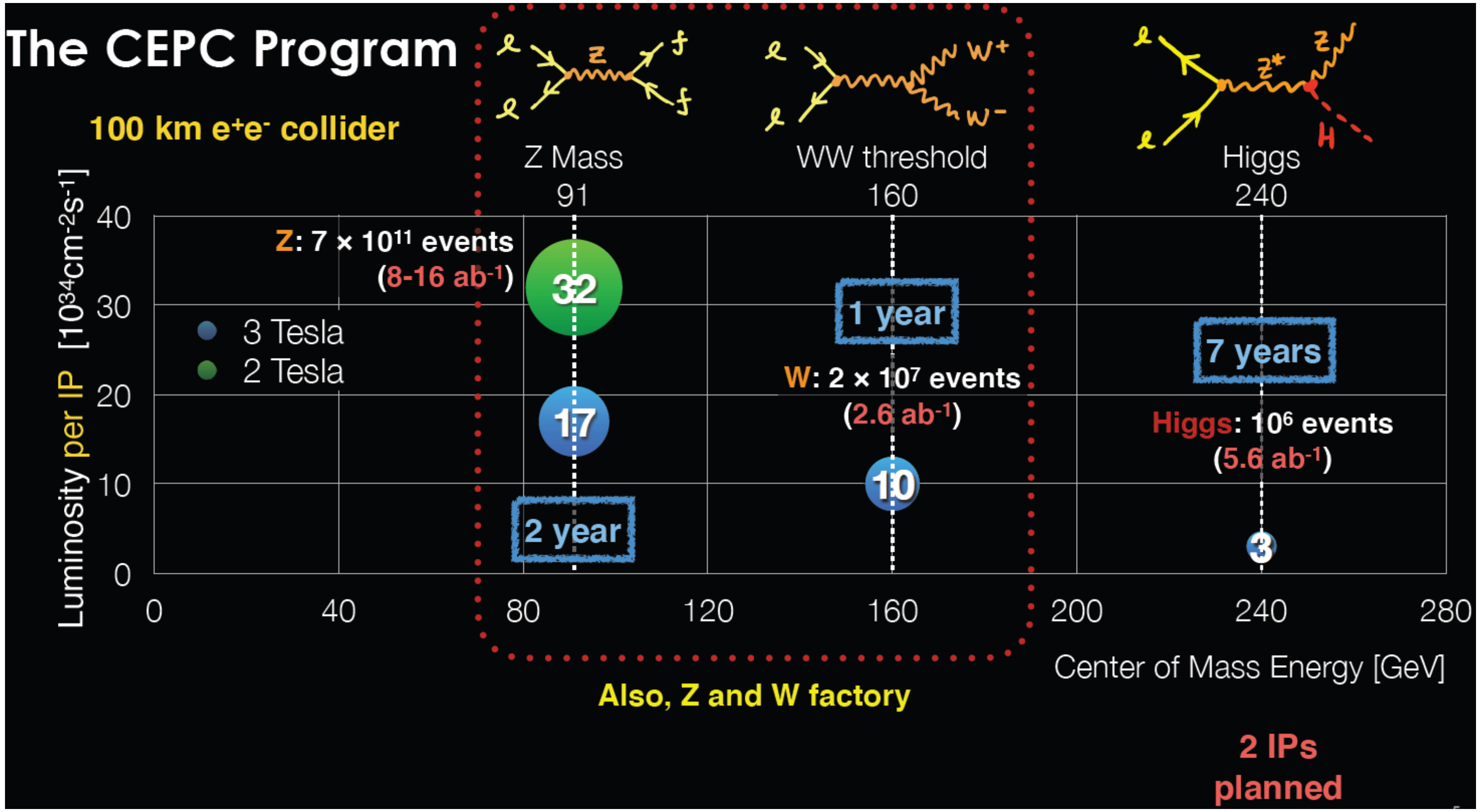
IDT	ILC Pre-Lab				ILC Lab.										
PP	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.



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.



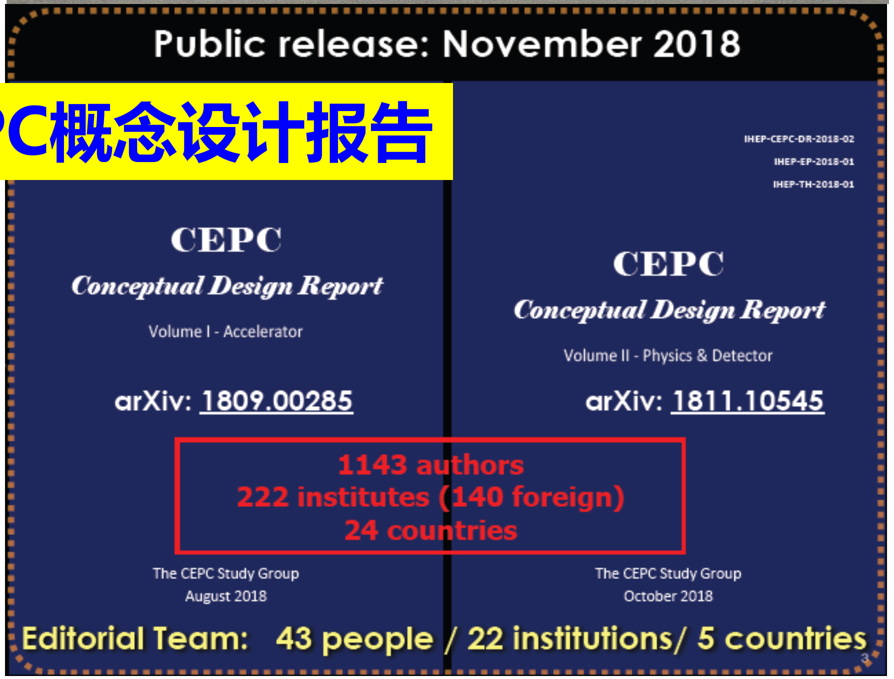


CEPC Major Milestones

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

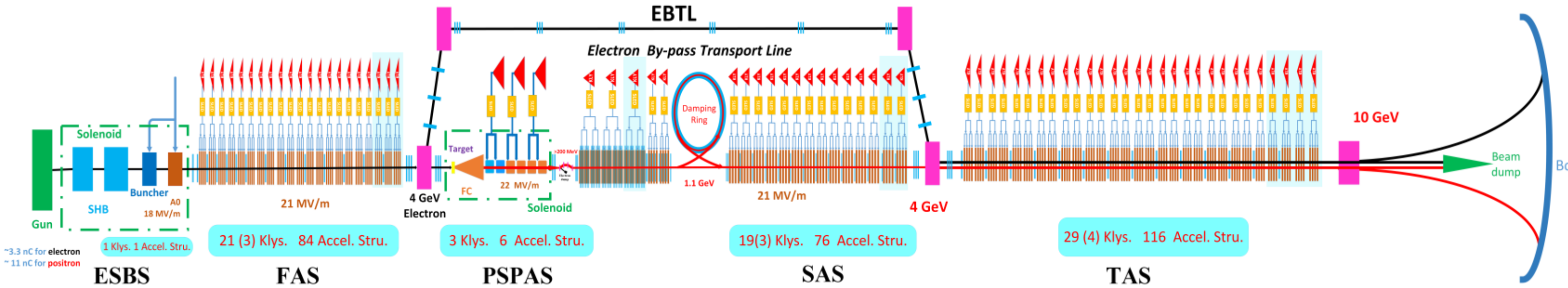


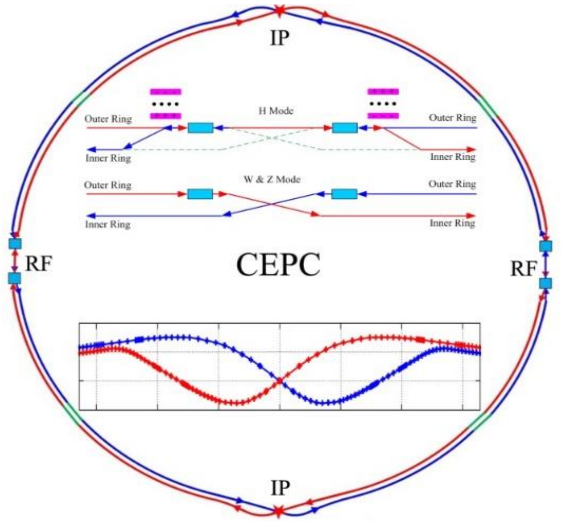
CEPC Accelerator Baseline (CDR)

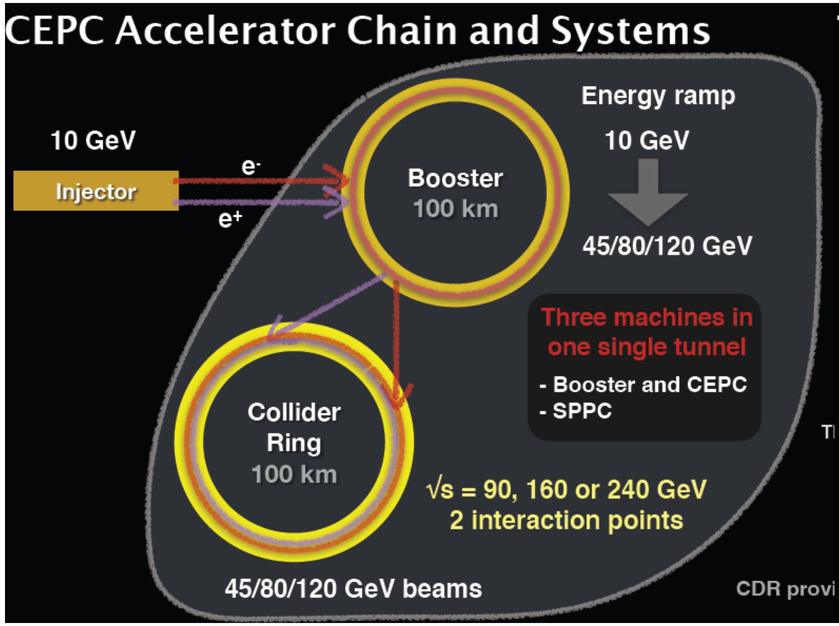
Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

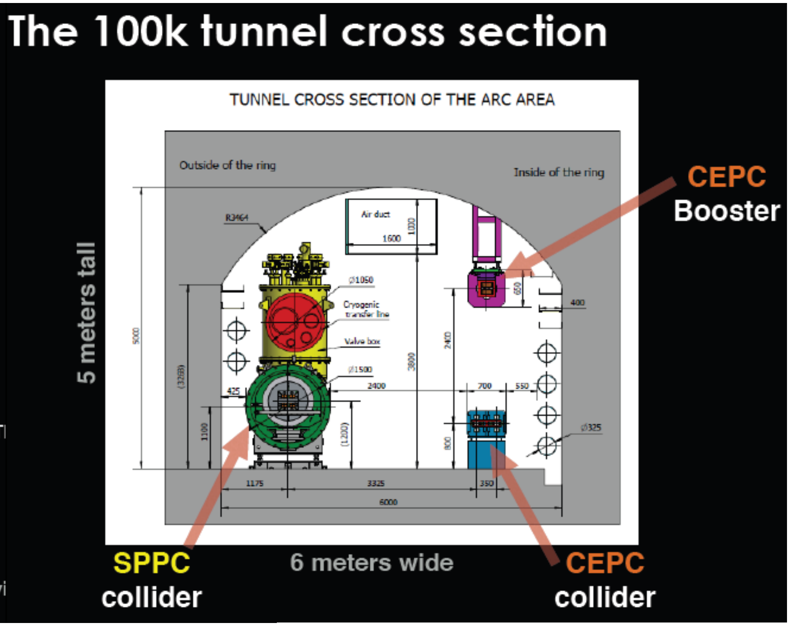
http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf

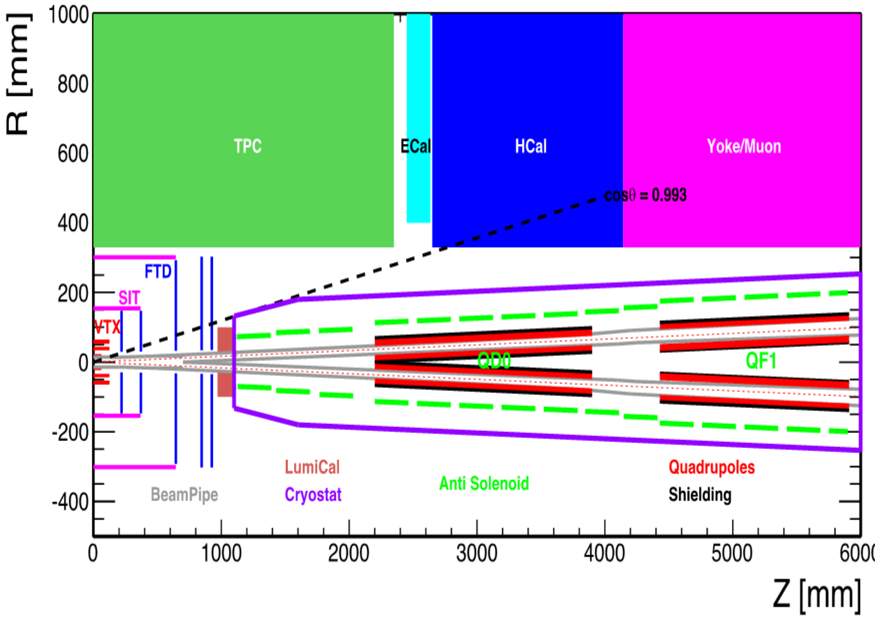
A very active **accelerator** R&D program towards a **TDR ~** the end of 2022









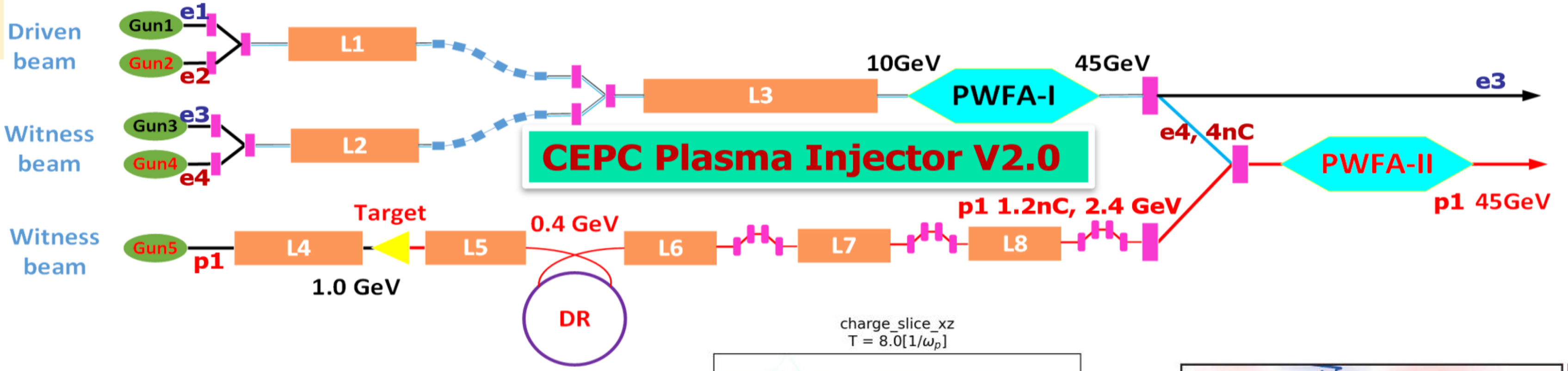


CEPC Accelerator: Plasma Injector

CEPC Plasma Injector V2.0

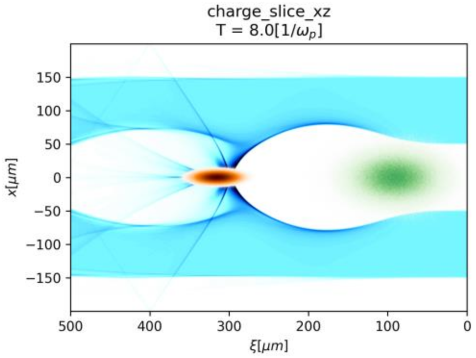
IHEP, THU, BNU

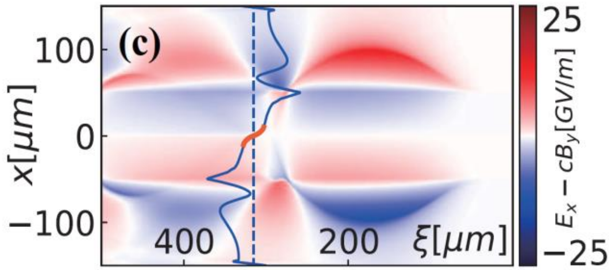
Booster Requirement	
Energy（GeV)	45.5
Bunch Charge（nC)	0.78
Bunch length (um)	<3000
Energy Spread (%)	0.2
ε_N (μm·rad)	<800
Bunch Size (um)	<2000



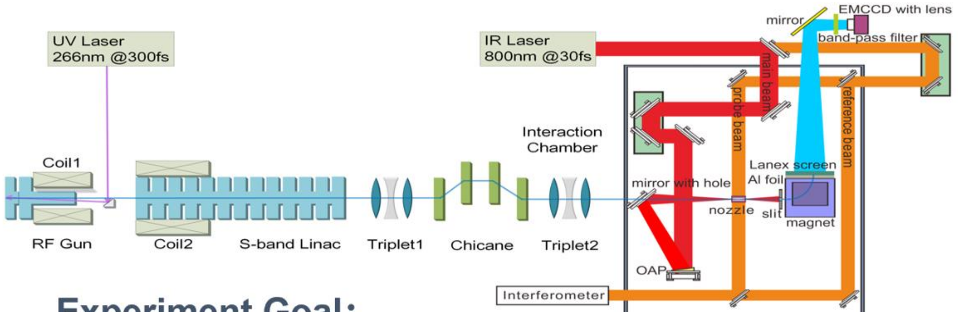
利用中空通道等离子体中稳定的非对称电子束，实现正电子束的高效率尾场加速，效率超过30%，能散约1.6%

W. Lu, et al., arXiv: 2012.06095v2



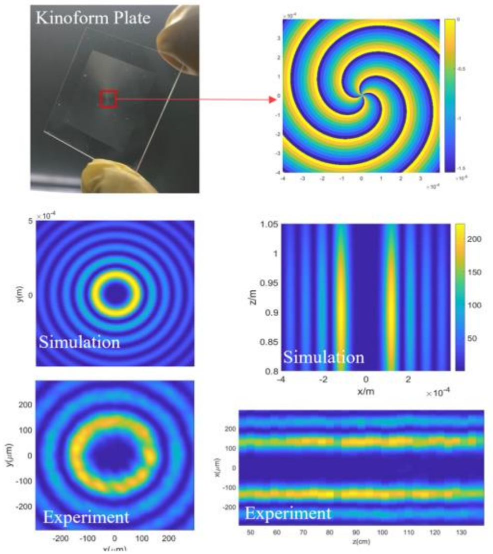


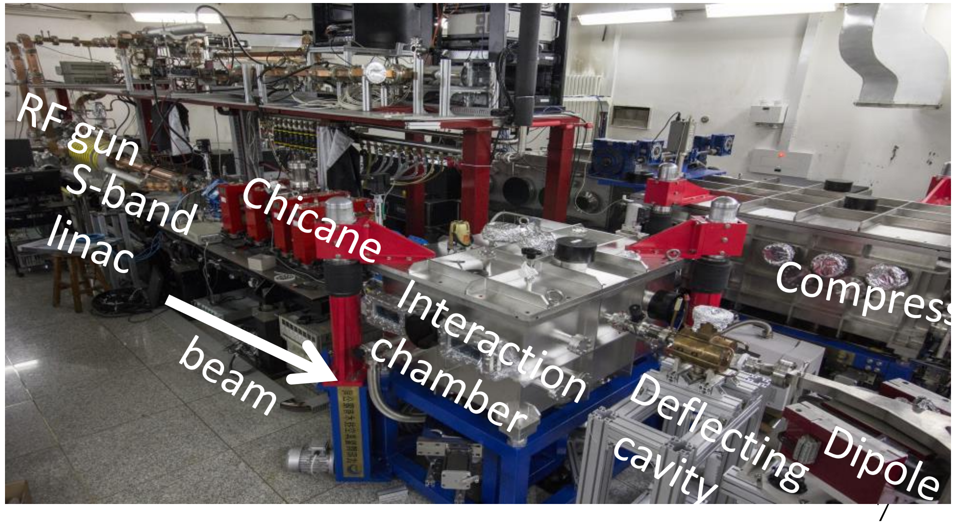
Plasma dechirper exp. at THU



Experiment Goal:

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





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 (ARC)**
  - Recommended by the IAC, established & met in November, 2019
  - Next ARC meeting will be held in Nov., 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)

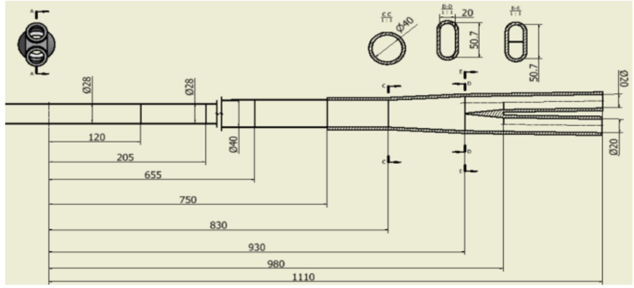
High luminosity scheme (Higgs)

- ✓ **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

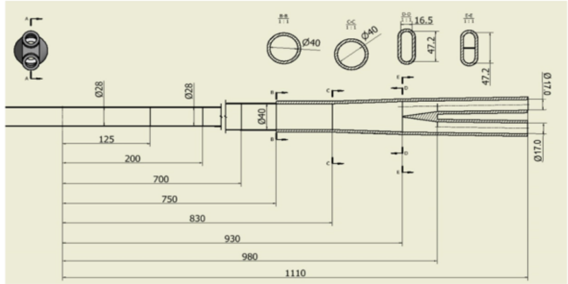
CDR

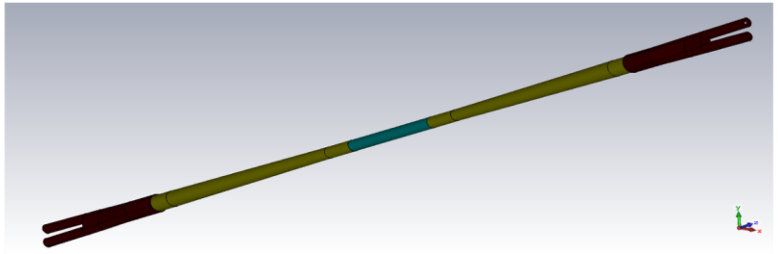
Be pipe: 28mm, SCQ Beam pipe:20mm



High luminosity

Be pipe: 28mm, Beam pipe:17mm





CEPC Accelerator 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 Chromaticity	[illegible]	[illegible]1161	-491/-1161	-513/-1594
[illegible]	363.10 / 365.22			
[illegible]	0.065	0.040	0.028	
[illegible] (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	[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

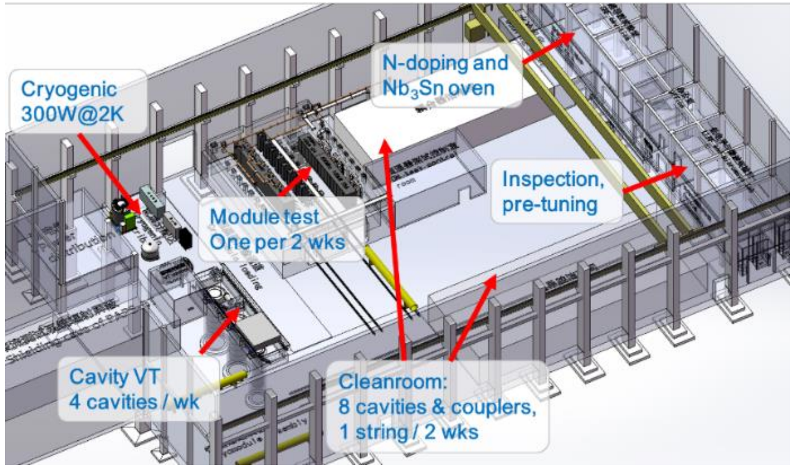
- CEPC 650MHz 800kW klystron: **high efficiency (80%), fabrication will be completed in 2021, test in 2022**
- CEPC 650MHz SC accelerator system (cavities and cryomodules): **to complete test cryomodule in 2022**
- High precision booster dipole magnets: **to complete full-size magnet model in 2021**
- Collider dual aperture dipole, quadrupoles and sextupole magnets: **to [...]plete full-size model in 2022**
- SC magnets including cryostats: **to complete shor[...] 2022**
- Vacuum chamber system: **to c[...]tion and costing test in 2022**
- MDI mechanic syste[...] **[...]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

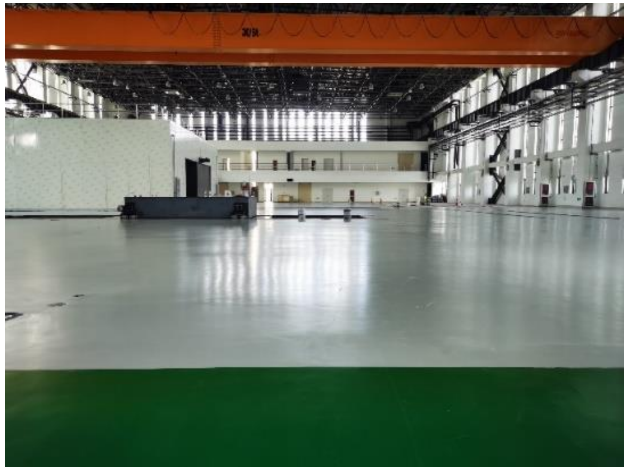
CEPC SCRF Test Facility

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

New SC Lab Design (4500m²)



SC New Lab will be available in 2021



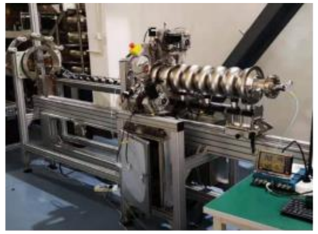
Crygenic system hall in Jan. 16, 2020

Vacuum furnace (doping & annealing)

Nb3Sn furnace

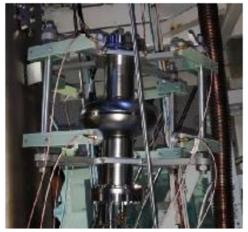
Nb/Cu sputtering device

Cavity inspection camera and grinder

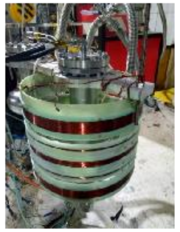


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

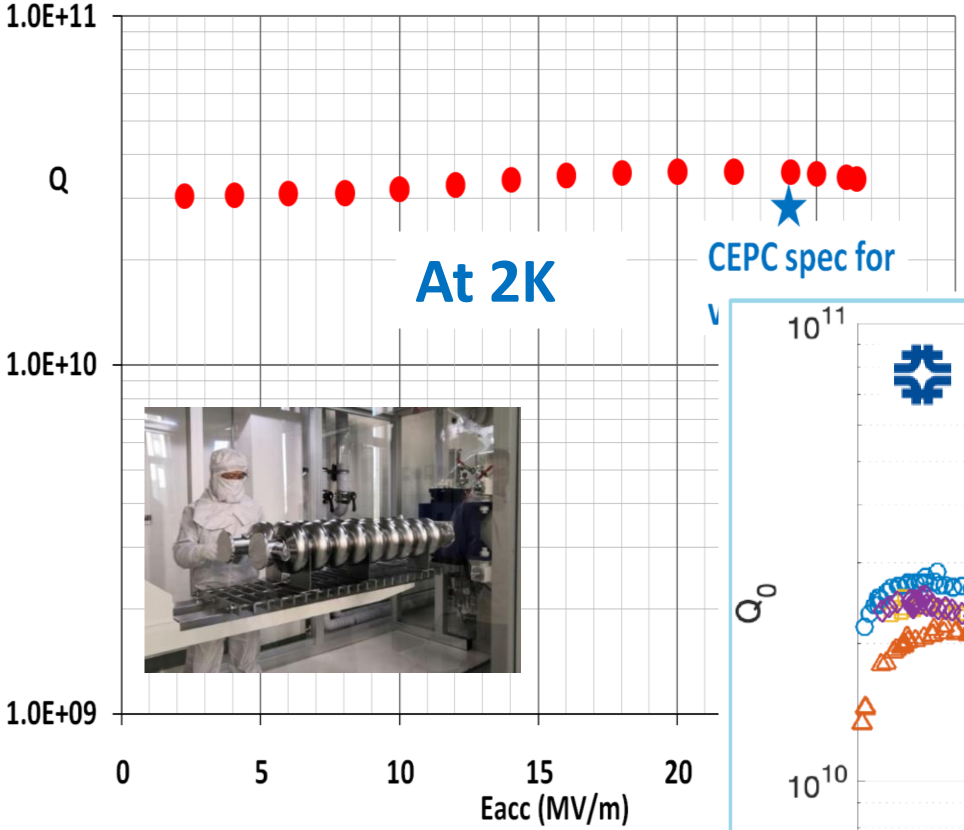
Vertical test dewars

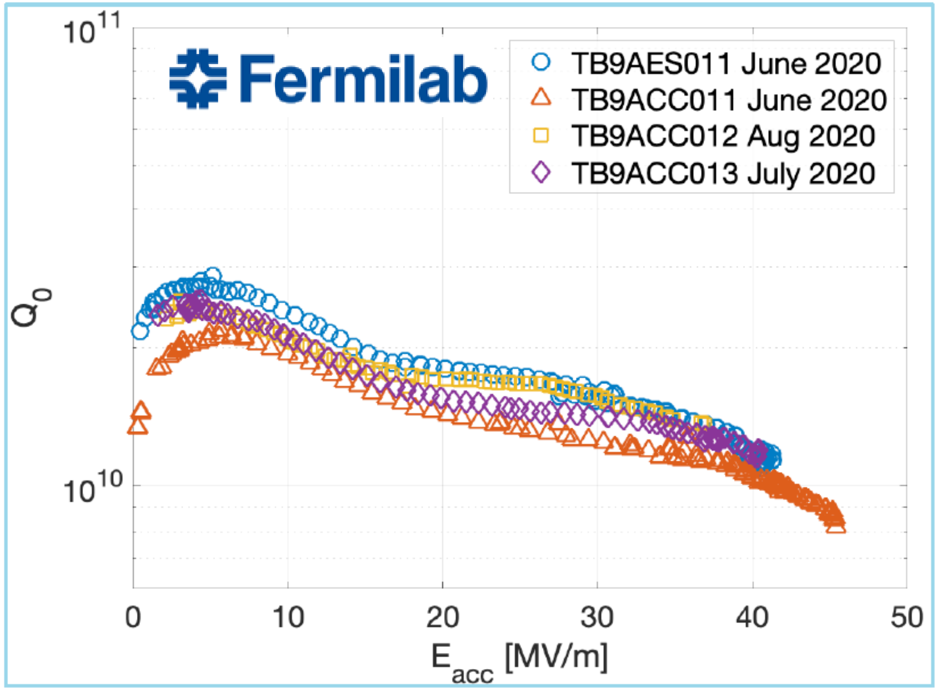
Horizontal test cryostat

CEPC R&D: High Q SCRF Cavities

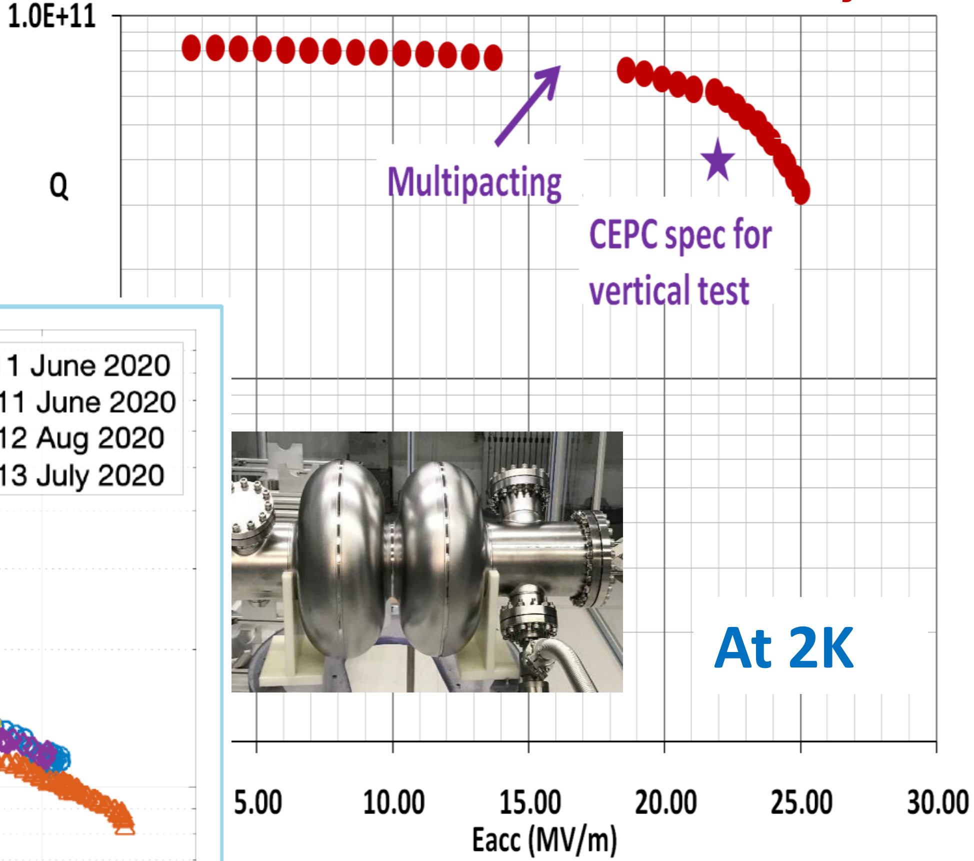
- Booster 1.3 GHz 9-cell SCRF cavity: Q = 3.4E10 @ 26.5 MV/m (中温退火)
- Collider ring 650 MHz 2-cell SCRF cavity: Q = 6.0E10 @ 22.0 MV/m (掺氮)
- IHEP研制的超导加速腔性能指标已经达到并超过了CEPC的设计指标 Q = 3 E10

Vertical test of 1.3 GHz 9-cell cavity





Vertical test of 650 MHz 2-cell cavity

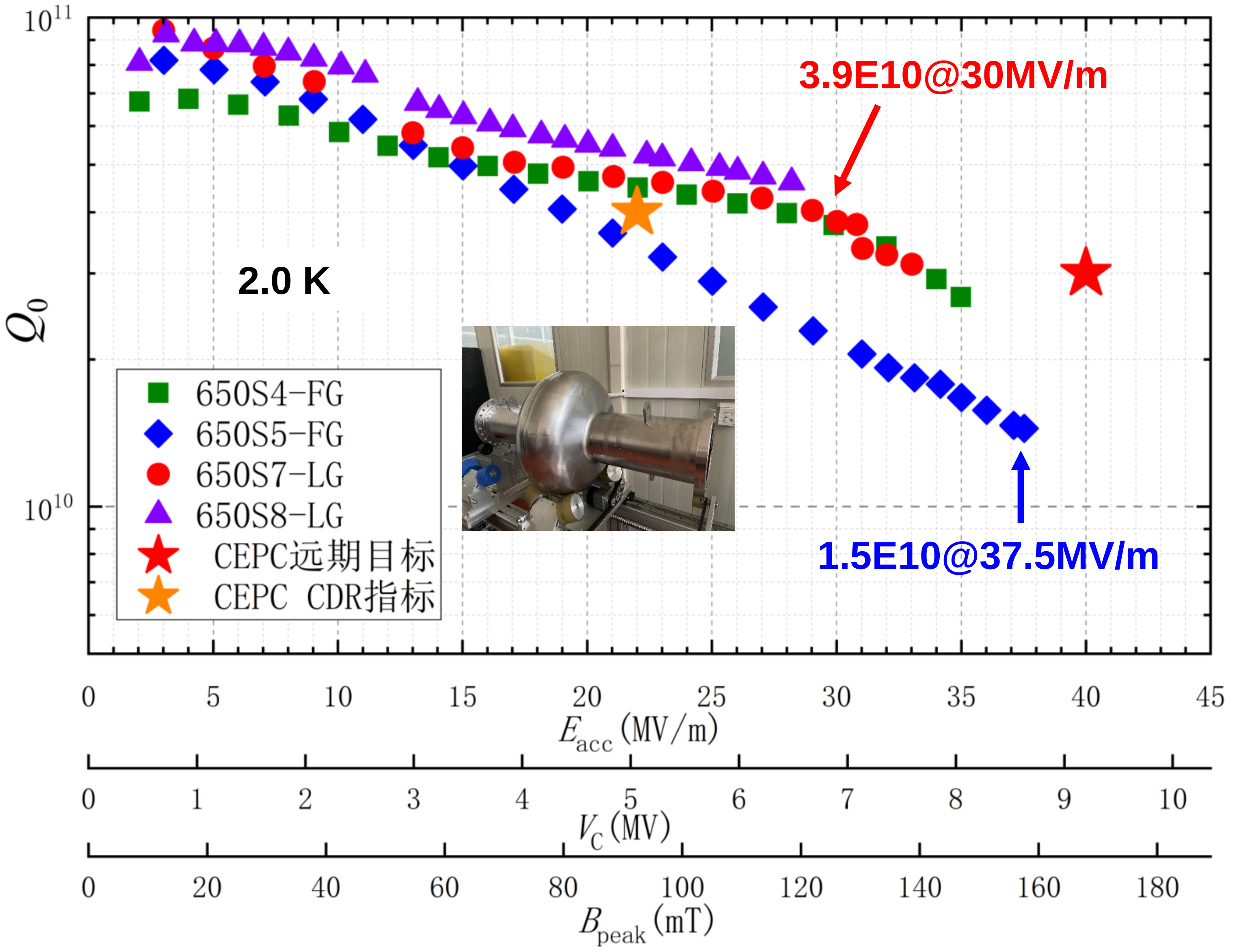


Medium-temperature (Mid-T) an
adopted to reach Q = 3.4E10 @ 2

ion adopted to reach
E10 @ 22.0 MV/m

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

➢ IHEP在国际上首次成功实现3.9E10@30 MV/m (650MHz 1-cell 超导腔)



CEPC目标：

Q_0 = 3.0E10 @ 22 MV/m

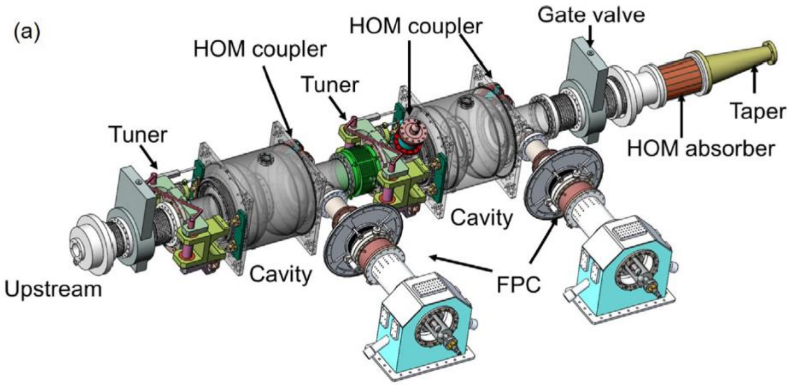
测试结果：

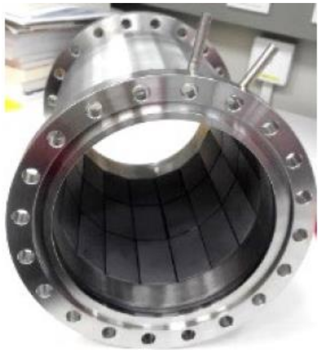
Q_0 = 3.9E10 @ 30 MV/m

Q_0 = 1.5E10 @ 37.5 MV/m

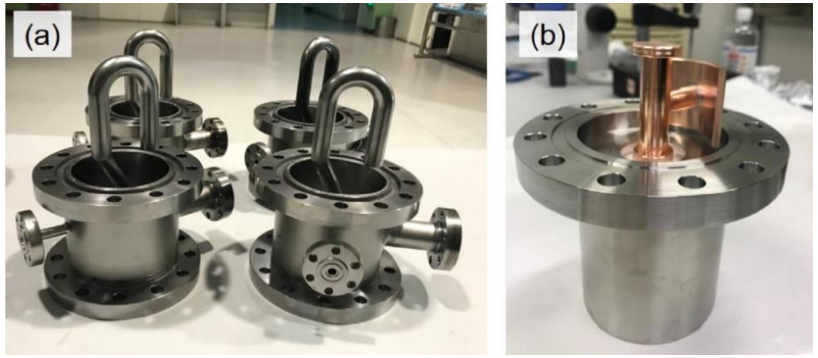
CEPC R&D: 650MHz SCRF Module

- 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。

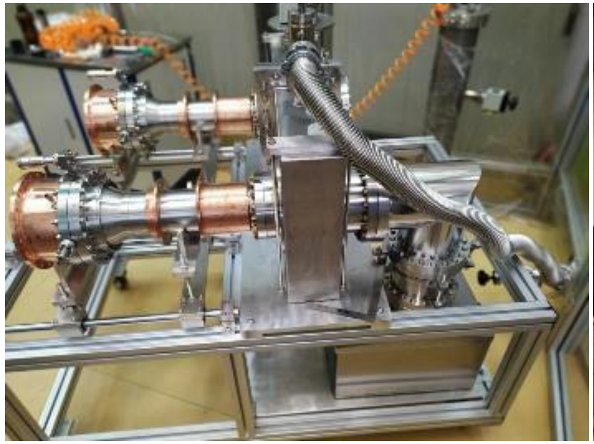




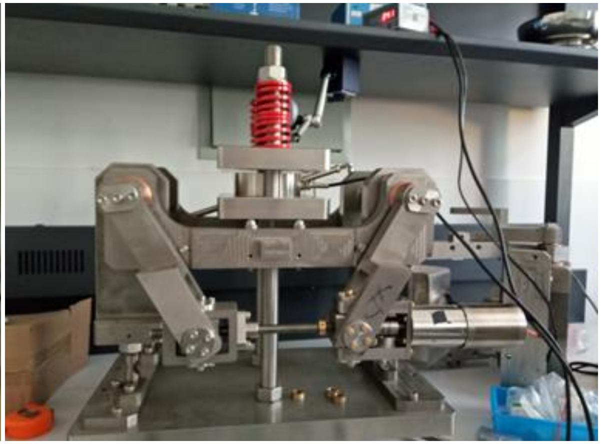
国内首个超导腔大功率高阶模吸收器（5kW）



国内首个可拆卸大功率高阶模耦合器（1kW）



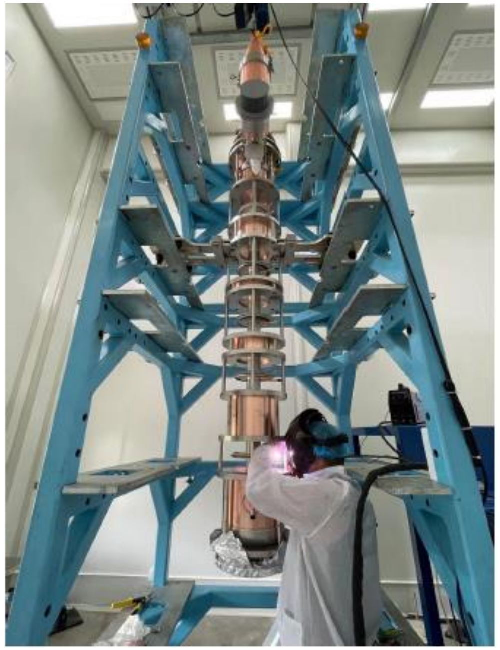
650MHz主耦合器 (400kW)
世界上最大的耦合器之一



超导腔调谐器

CEPC R&D: High Efficiency Klystrons

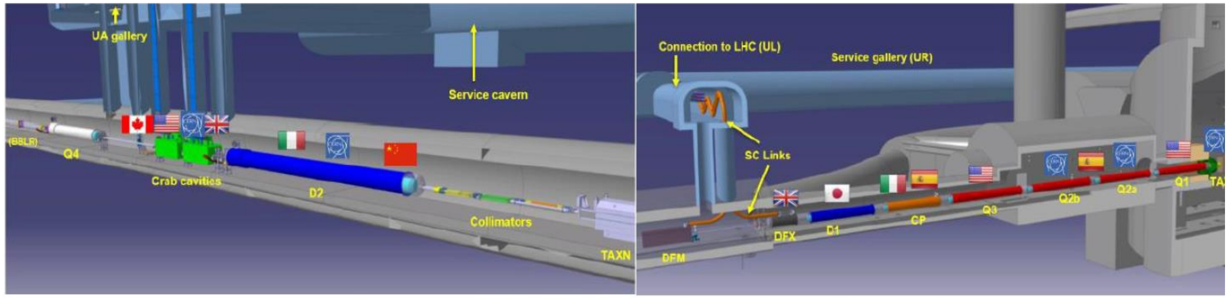
- 高效率束调管是CEPC加速器的关键核心技术之一
- 首个束调管样机通过测试，最大输出功率达到 700 kW (CW) 和 800 kW (Pulsed mode). **功率转换效率达到 ~ 62%**
- 第二个束调管样机已经研制成功，将运送到怀柔先进光源研发与测试平台 （PAPS）进行测试，**设计效率：~77%**
- 多束流束调管设计已完成, **设计效率： ~80.5%**



第二个束调管组装

首个束调管功率测试

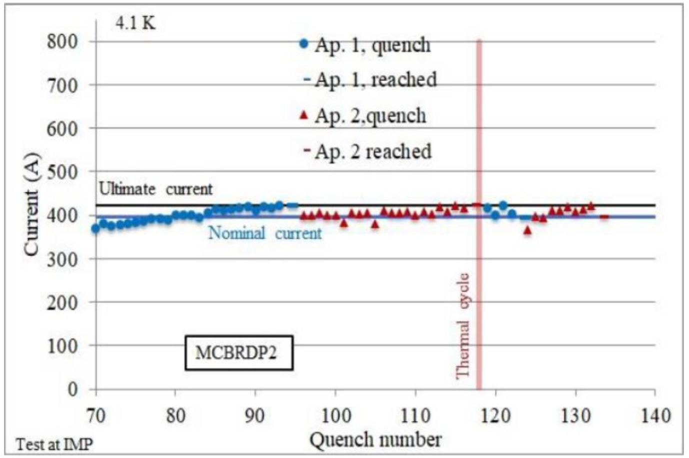
HL-LHC Magnet and HTS SC Magnet

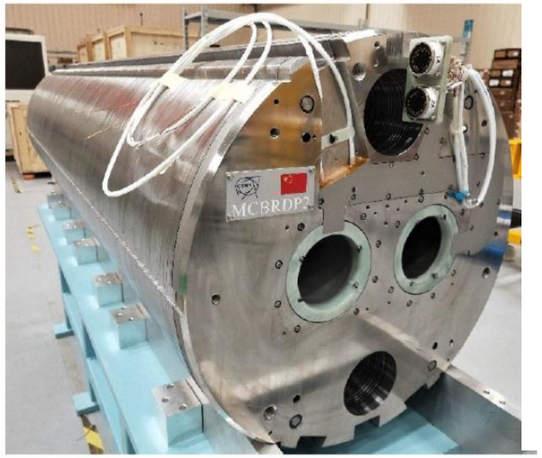


Layout of the HL-LHC Magnets and Contributors

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 ar ultimate current, and the field quality is within the limit.





Domestic Collaboration for HTS R&D

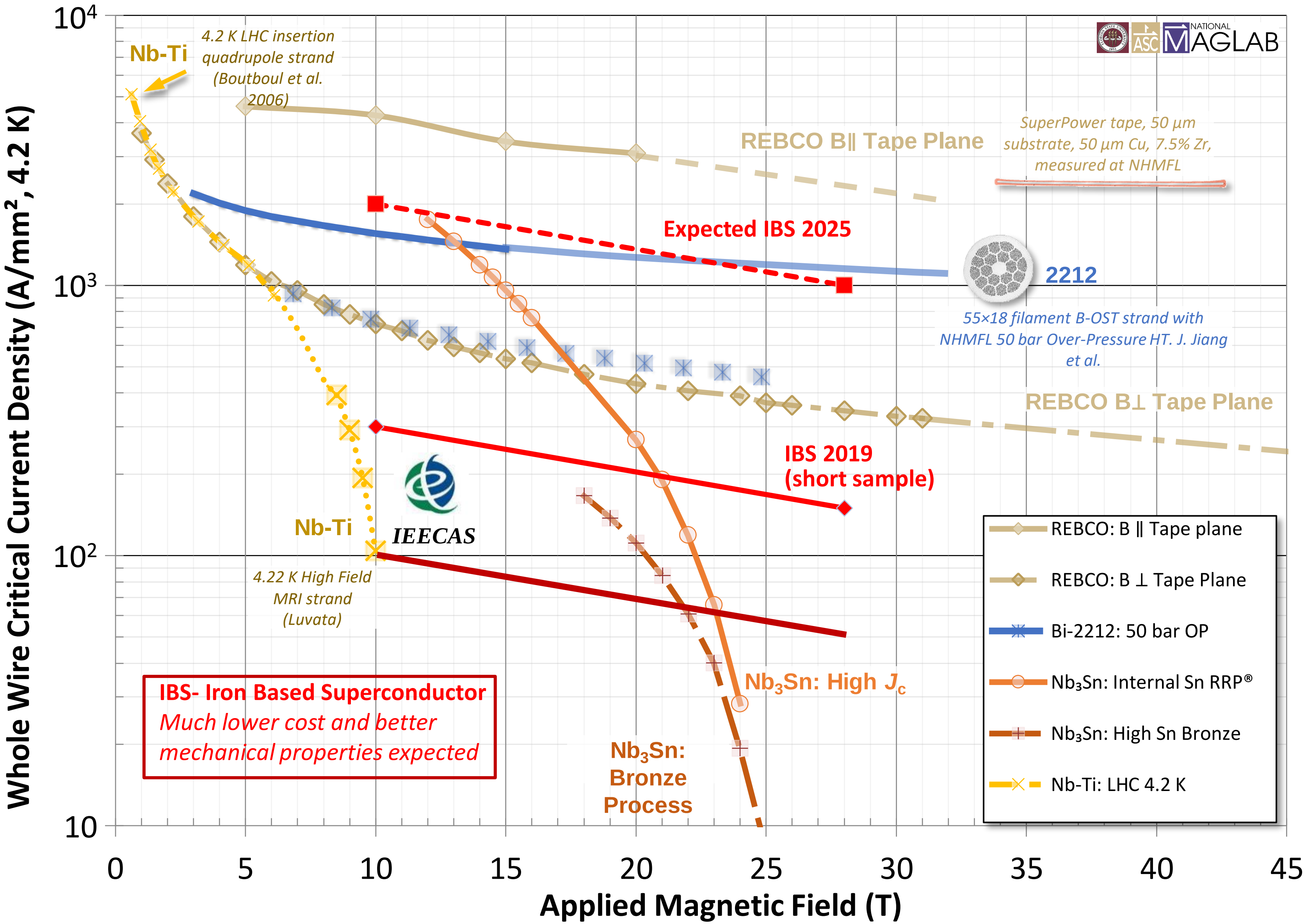
Applied High Temperature Superconductor Collaboration (AHTSC)

- R&D from **Fundamental sciences** of superconductivity, **advanced HTS superconductors** to **Magnet & SRF technology**.
- **Regular meetings every 3 months** from Oct. 2016
- **Goal:**
  - **Increasing** J_c of iron-based superconductor **by 10 times**.
  - **Reducing the cost** of HTS conductors to be **similar with "NbTi conductor"**
  - Industrialization of the **advanced superconductors, magnets and cavities**

2020年国内首个HL-LHC超导磁铁样机(2*2.6T)运到CERN，通过了测试。目前正在批量试制中。

高能所与国内科研单位紧密合作，开展实用化高温超导磁铁研制，取得了重要进展。

HTS SC Magnet



Fabrication and test of IBS solenoid coil at 24T

IOP Publishing — Superconductor Science and Technology

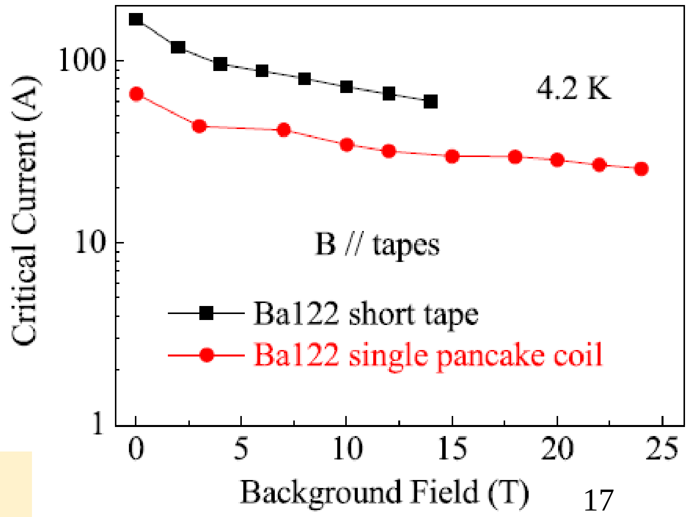
Supercond. Sci. Technol. 32 (2019) 04LT01 (5pp) — https://doi.org/10.1088/1361-6668/ab09a4

Letter

First performance test of a 30 mm iron-based superconductor single pancake coil under a 24 T background field

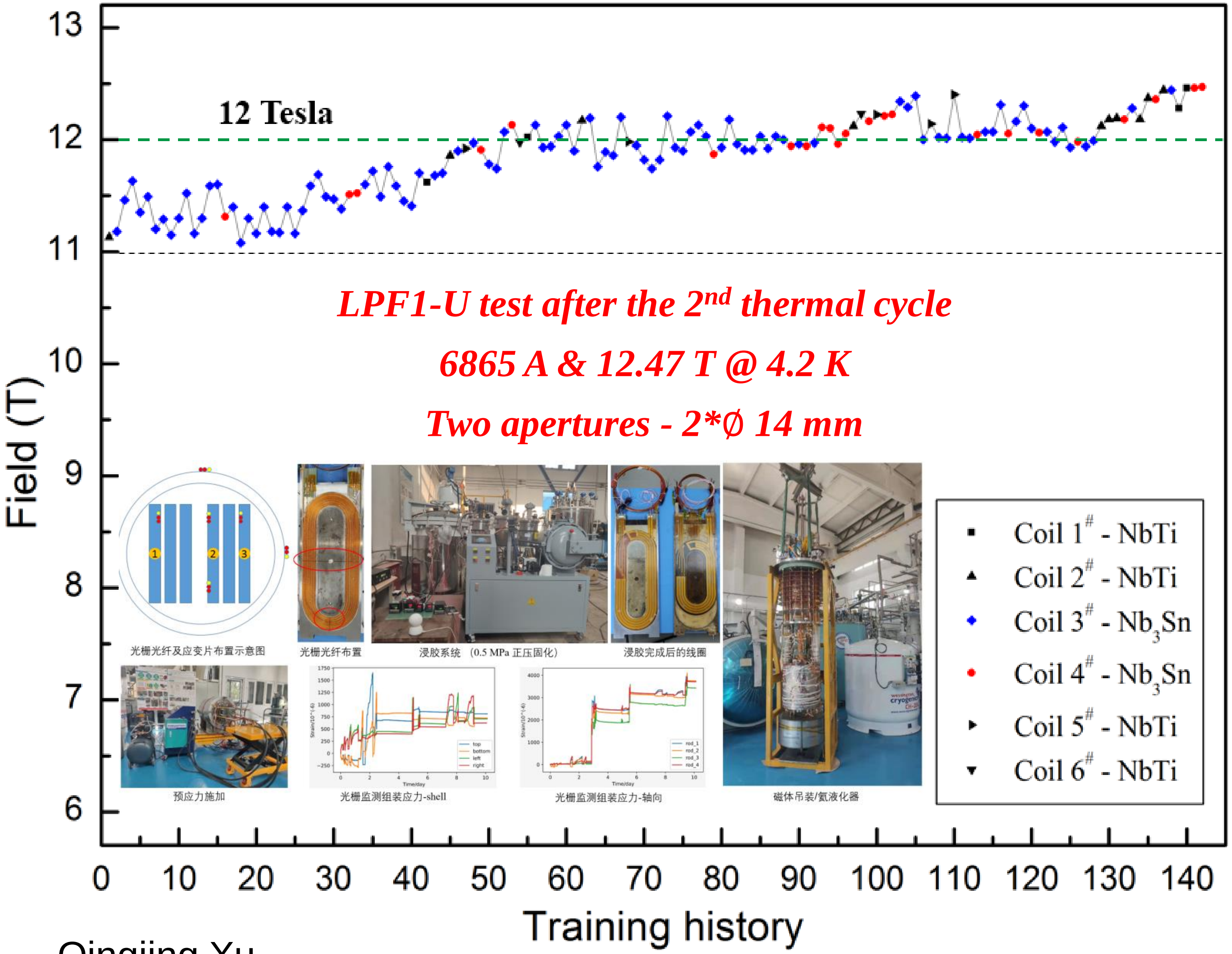
Dongliang Wang[1,2,5], Zhan Zhang[3,5], Xianping Zhang[1,2], Donghui Jiang[4], Chiheng Dong[1], He Huang[1,2], Wenge Chen[4], Qingjin Xu[3,6] and Yanwei Ma[1,2,6]

[1] Key Laboratory of Applied Superconductivity, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, People's Republic of China
[2] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[3] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[4] High Magnetic Field Laboratory, Chinese Academy of Sciences, Hefei 230031, People's Republic of China



开展铁基超导研制，成功研制30mm IBS螺线圈磁铁，测试磁场达到24T

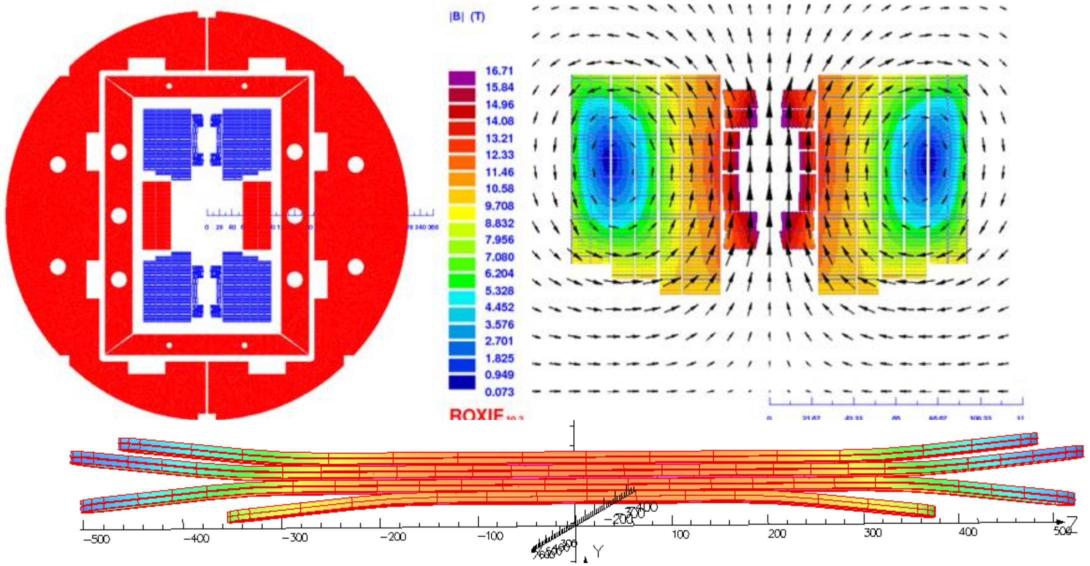
HTS SC Magnet (12T)

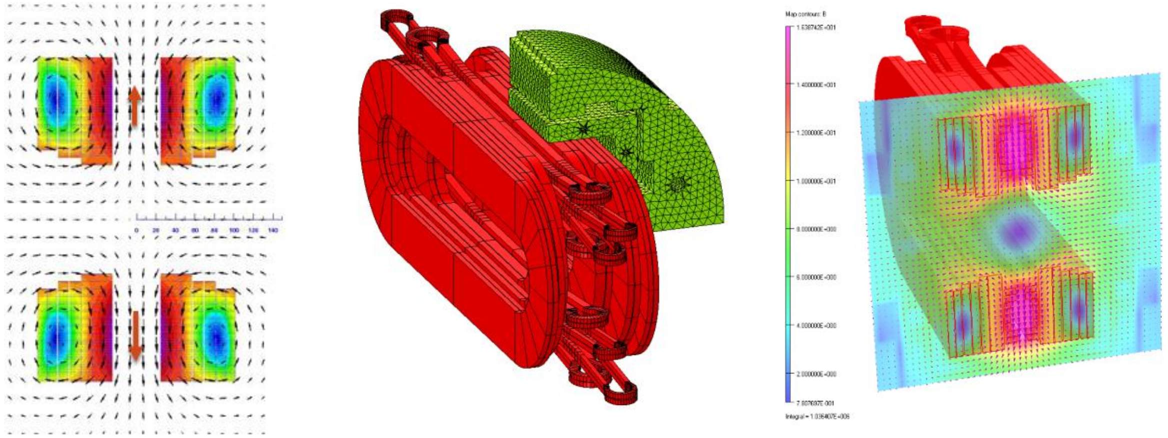


Qingjing Xu.

HTS SC Magnet (16T)

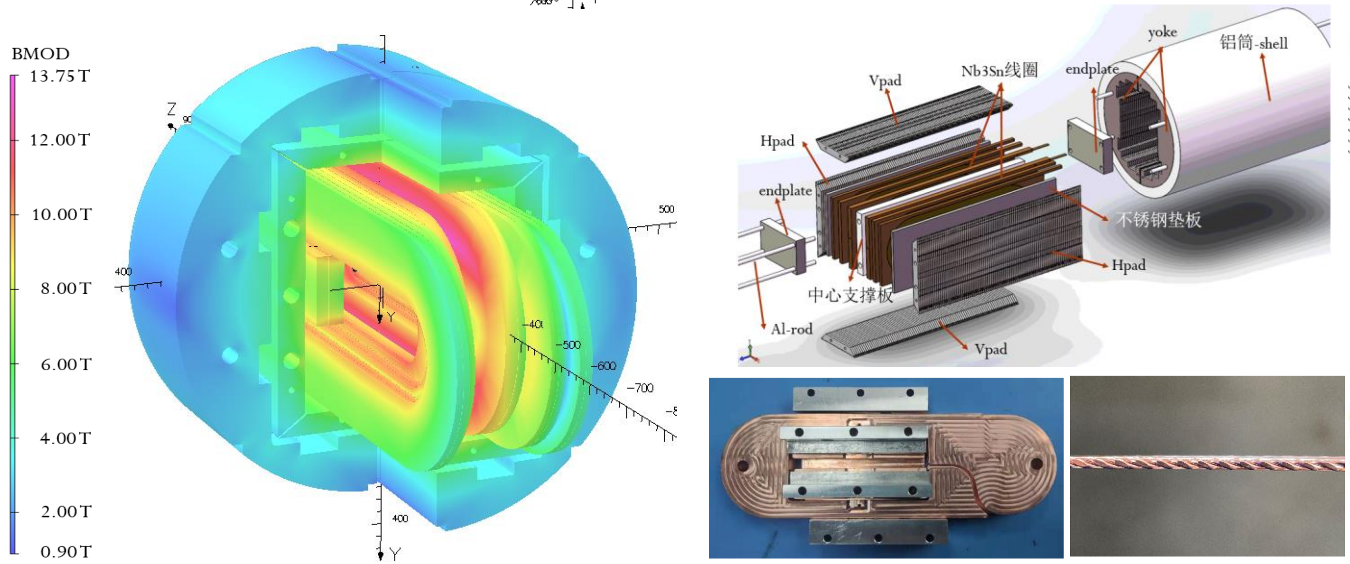
LPF3 16T二极磁体研制: Nb_3Sn 12~13 T + HTS 3~4 T





16-T 大孔径高场超导二极磁体 LPF3 (Nb_3Sn-13T+HTS-3T) 电磁设计

新型HTS换位电缆

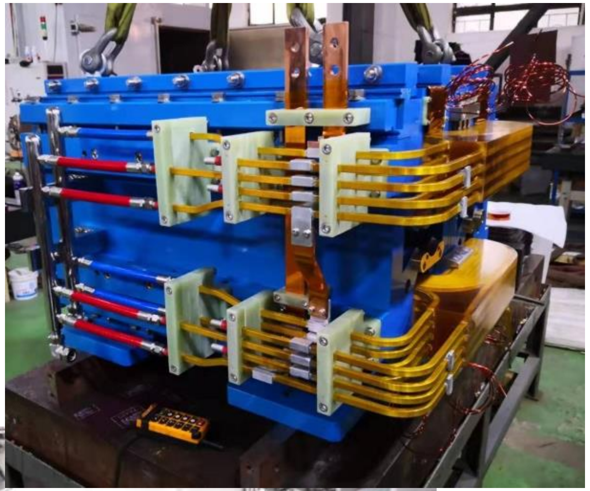


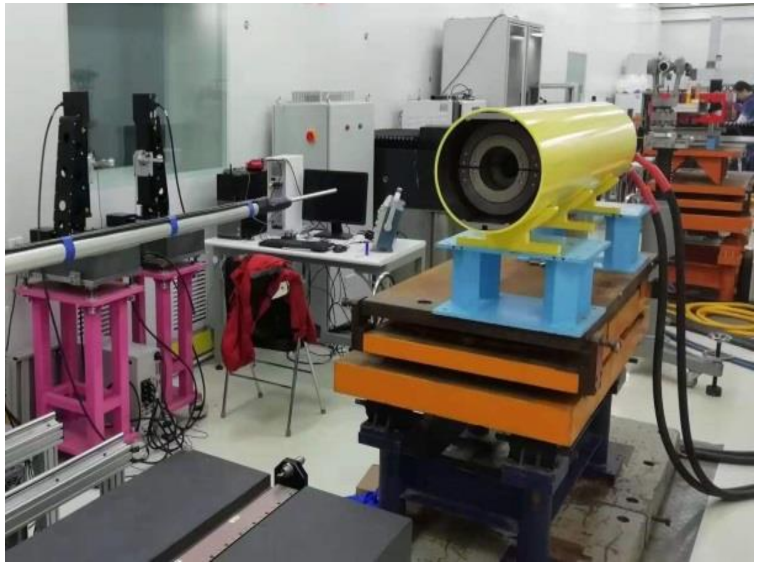
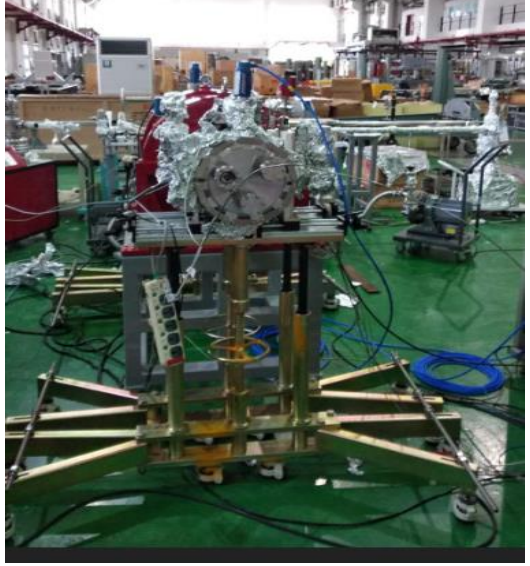
13-T 及以上背场磁体正在研制过程中

LPF3 背场磁体研制计划表

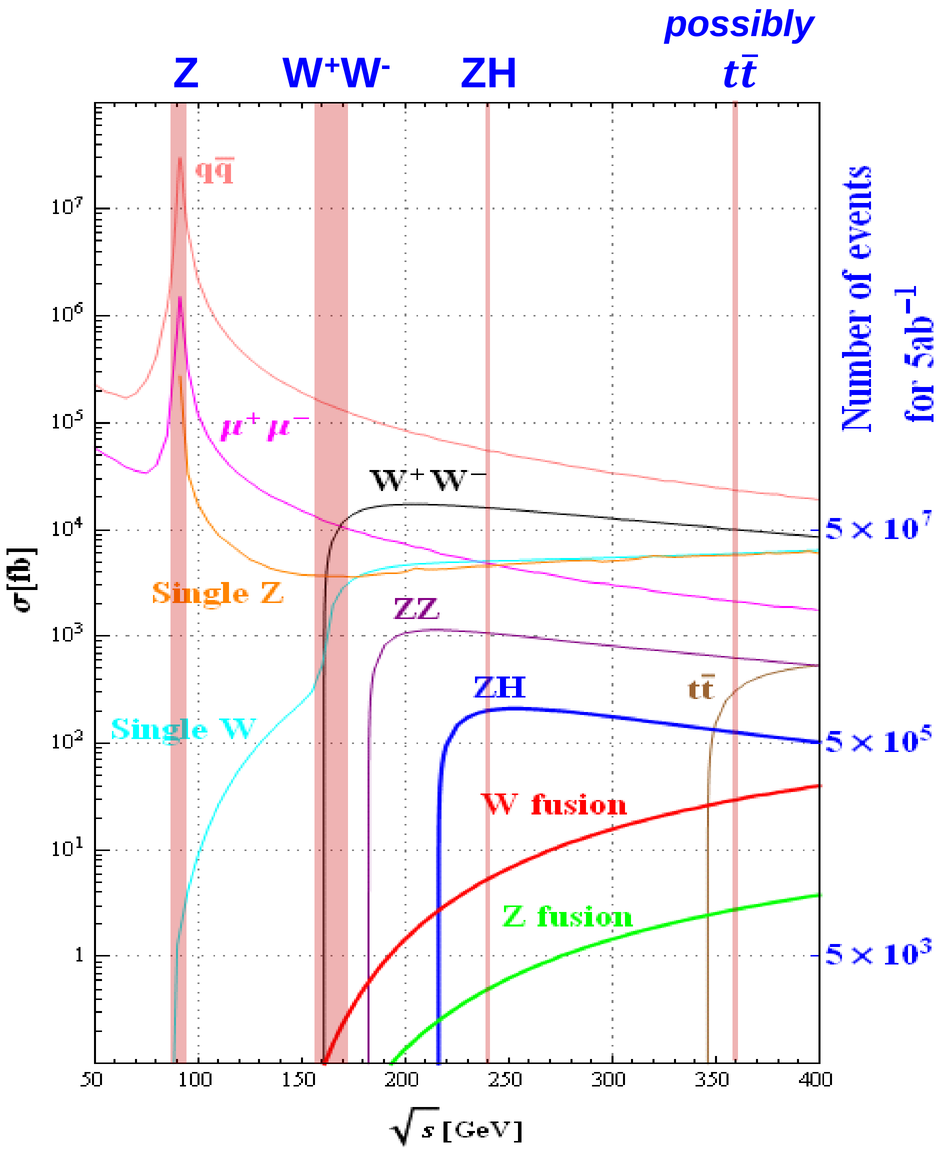
CEPC R&D: Magnets etc.

- **Magnets, EM-separators, Vacuum Pipes, …**


The CEPC Physics Program



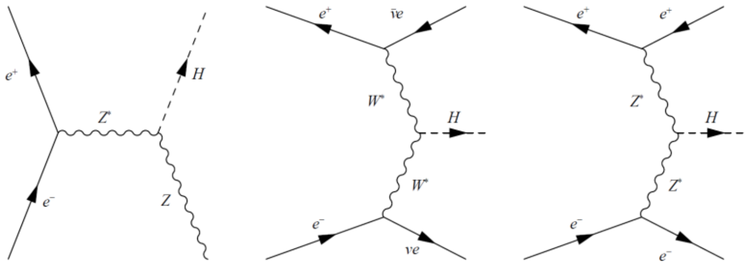
Operation mode		ZH	Z	W⁺W⁻
$\sqrt{s}$ [GeV]		~240	~91.2	158-172
Run time [years]		7	2	1
CDR	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	3	32	10
	$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6
	Event yields [2 IPs]	**1×10^6**	**7×10^{11}**	**2×10^7**
Latest	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	5.0	115	15.4

The large samples from 2 IPs:
~**10^6** Higgs, **~2×10^7** W, **~7×10^{11}** Z bosons

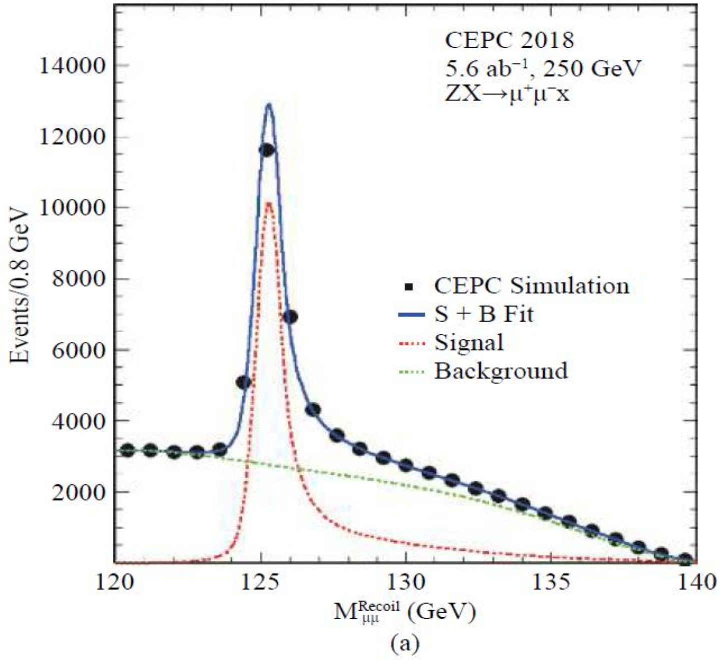
- **CEPC Conceptual Design Report:**
  Volume 1 – Accelerator, arXiv:1809.00285
  Volume 2 – Physics & Detector, arXiv:1811.10545

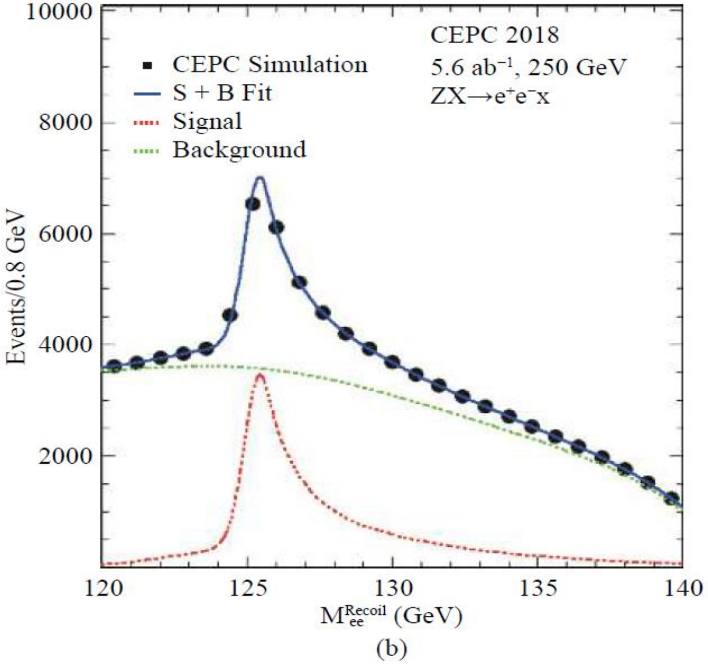
CEPC Physics Performance (CDR)

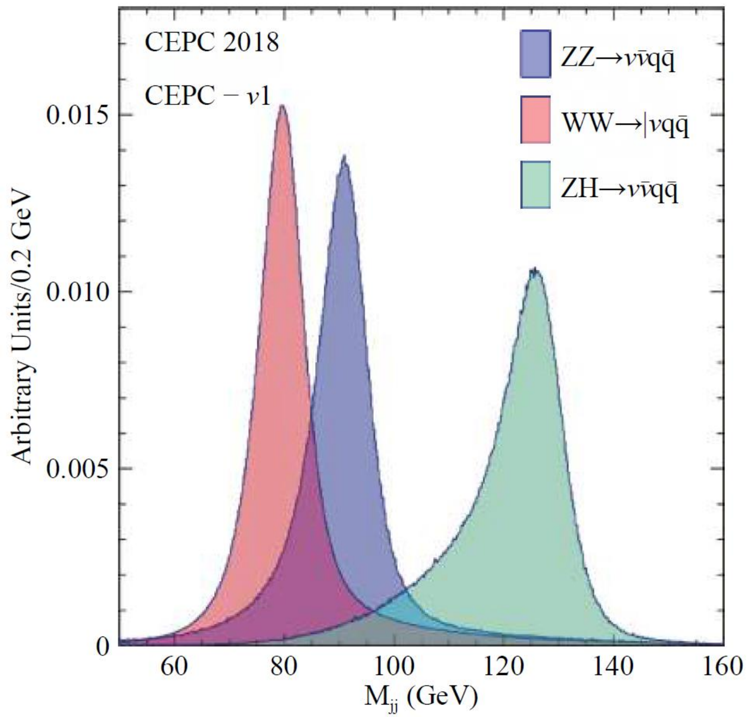
e^+e^- annihilations at the CEPC



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





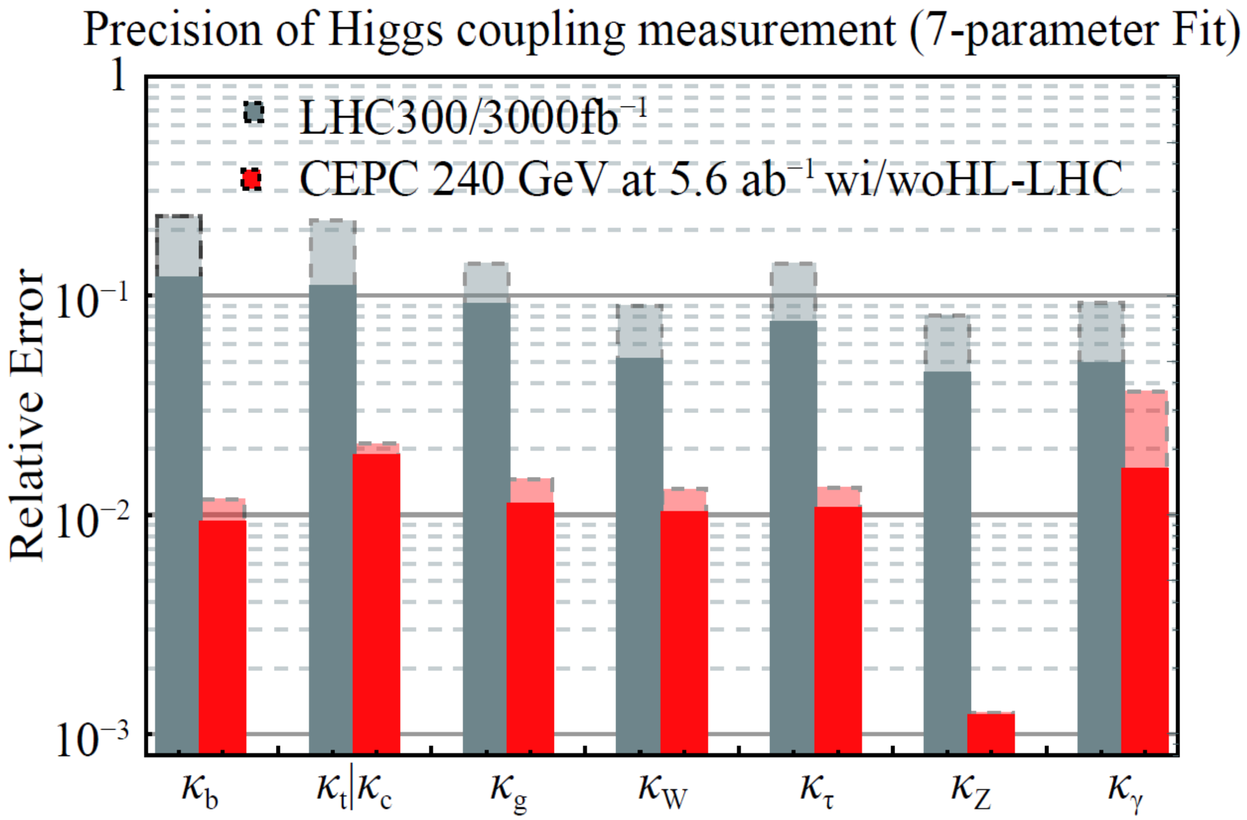


Chinese Physics C Vol. 43, No. 4 (2019) 043002

CEPC Physics Performance (CDR)

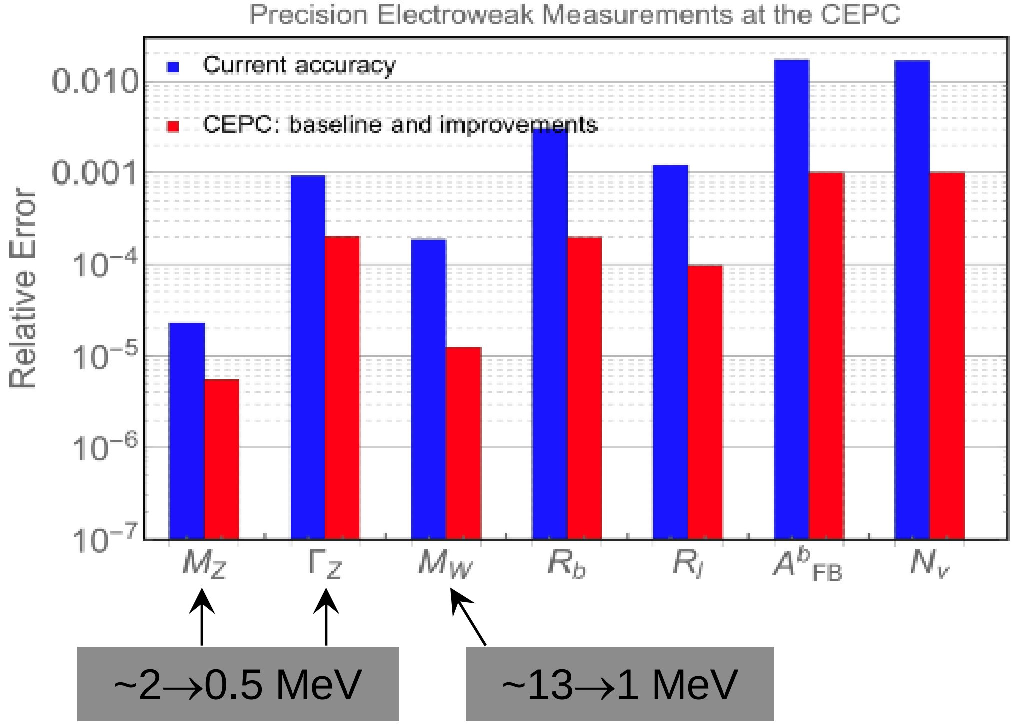
Order of magnitude improvement in precision ⇒ Unknown / discoveries

CEPC 使希格斯耦合参数测量精度比HL-LHC实验提高 5-10 倍



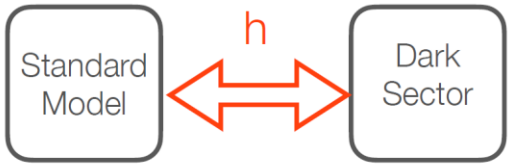
《Precision Higgs Physics at CEPC》
荣获中国物理学会2020年度最有影响论文奖
Chinese Physics C, 43 （2019）043002

CEPC 对电弱参数测量精度比当前实验精度提高约5-10倍

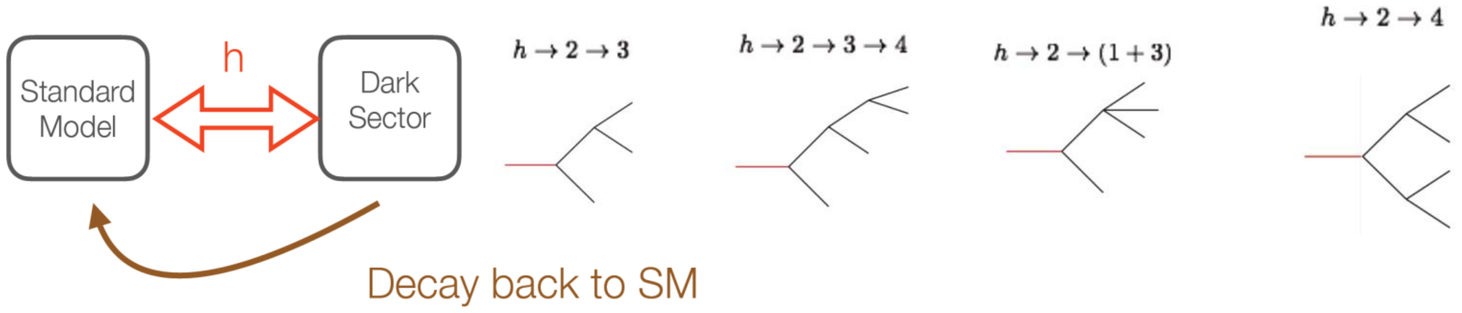


- ❑ **Precision EW measurements,**
- ❑ **Flavor physics (b, c, tau),**
- ❑ **Study of QCD,**
- ❑ **Probe physics BSM.**

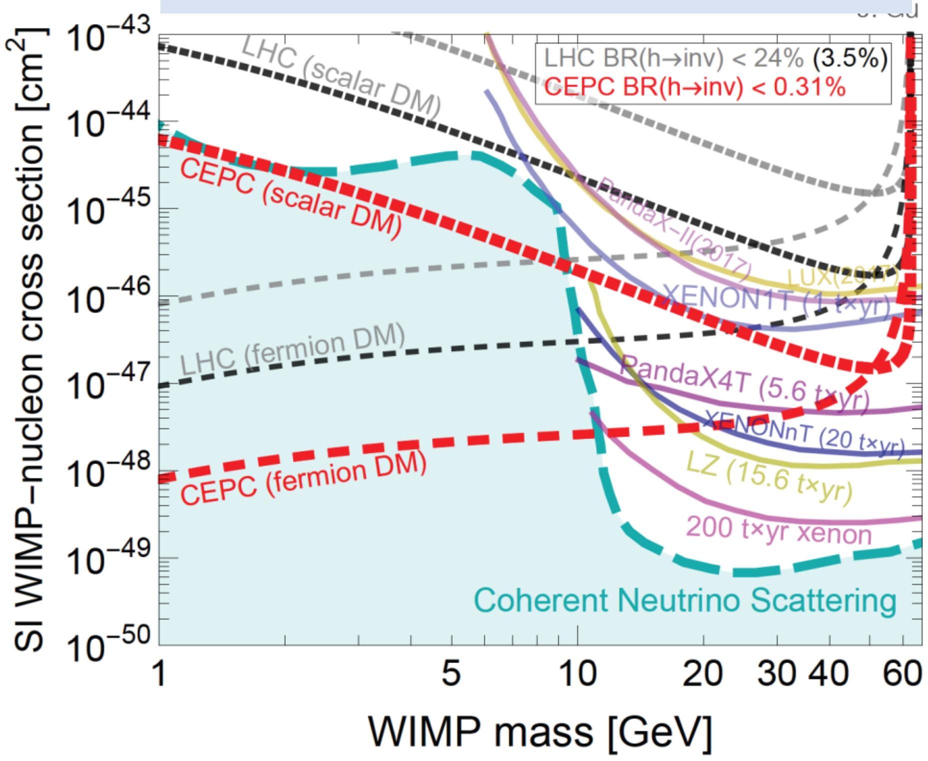
Discovery Potential for New Physics



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

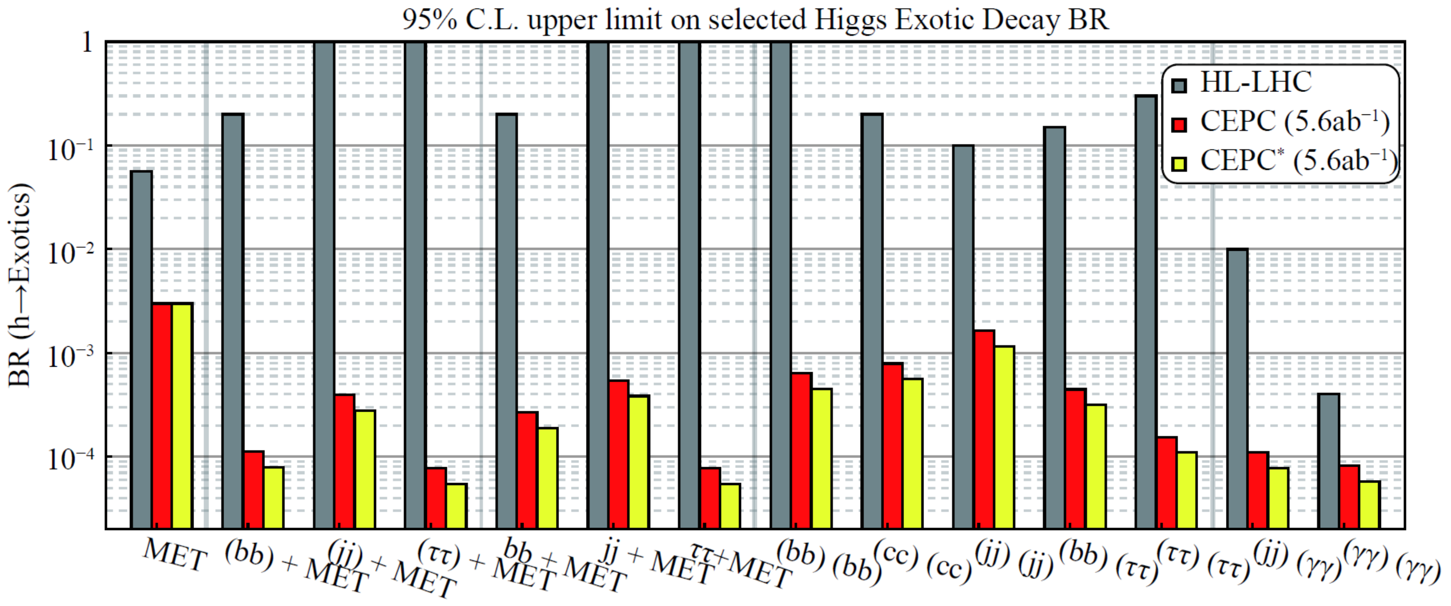


CEPC 对暗物质的探测灵敏度比LHC实验提高约一个数量级

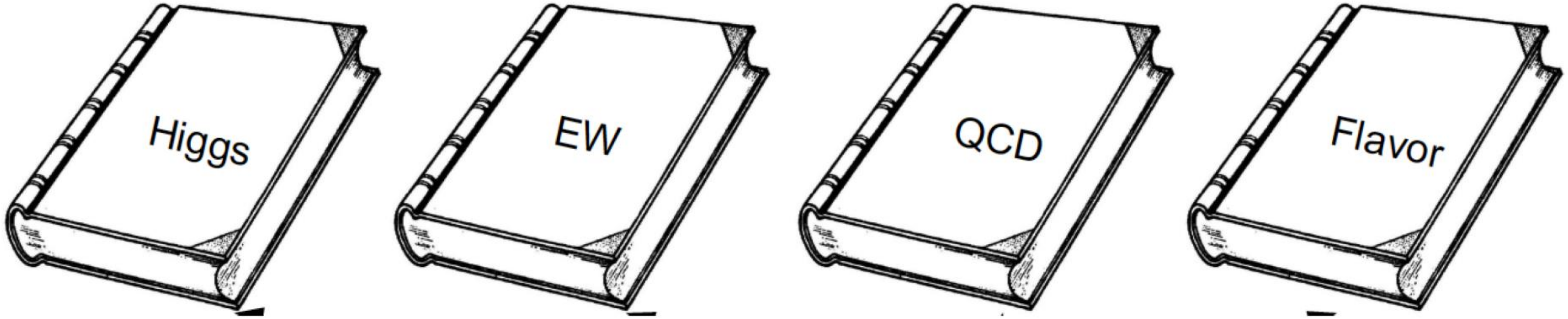


Higgs decays into BSM particles, H→ X_1X_2

CEPC 对新物理探测灵敏度比LHC实验提高约2-3个数量级

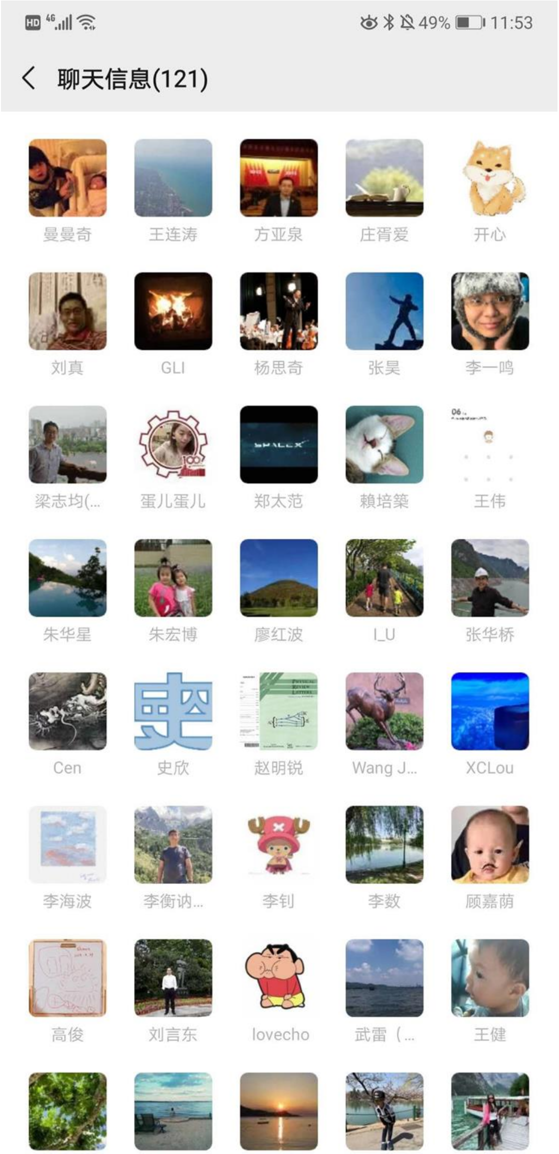


White papers



- 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

CEPC Study for Snowmass: Physics (17 LoI)



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

CEPC Study for Snowmass: Detector R&D

Snowmass — Letters of Intent

14 CEPC-Related Detector LoI submitted

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

Detector R&D

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Requirements of CEPC Detector

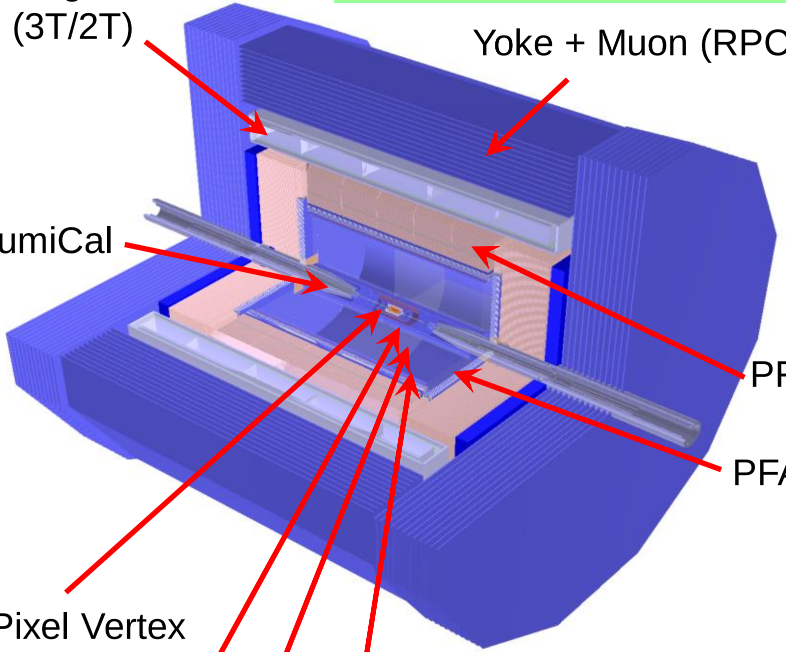
The physics motivations dictate our selection of detector technologies

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

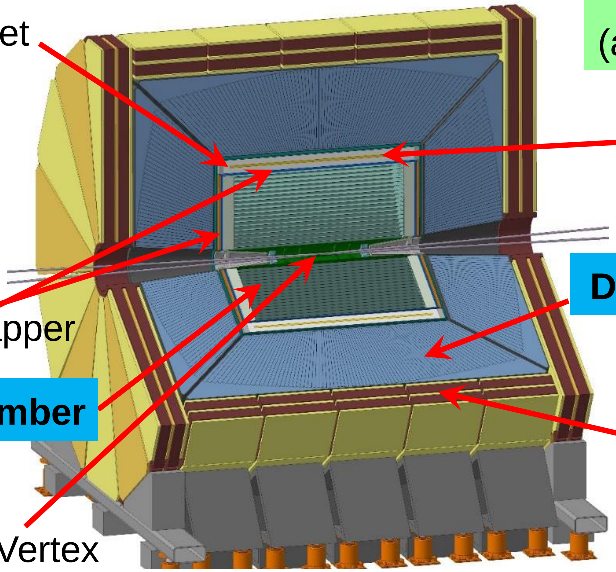
- **Flavor physics** $\Rightarrow$ **Excellent PID, better than 2σ separation of π/K at momentum up to ~20 GeV.**
- **EW measurements** $\Rightarrow$ **High precision luminosity measurement, $\delta L / L \sim 10^{-4}$.**

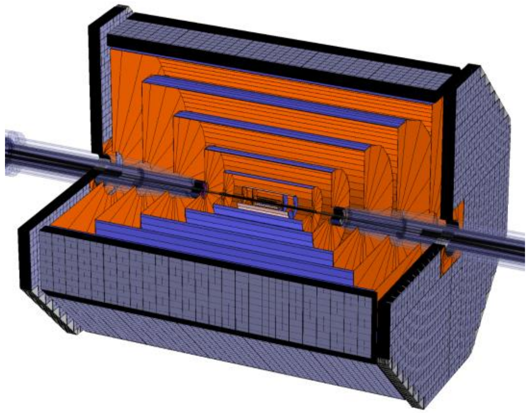
Conceptual Detector Designs

(Baseline Design)
Particle Flow Approach



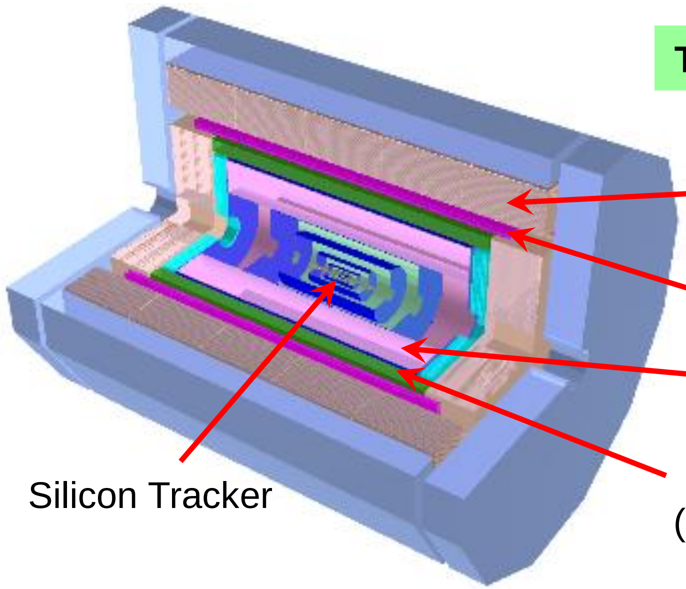
IDEA concept
(also proposed for FCC-ee)





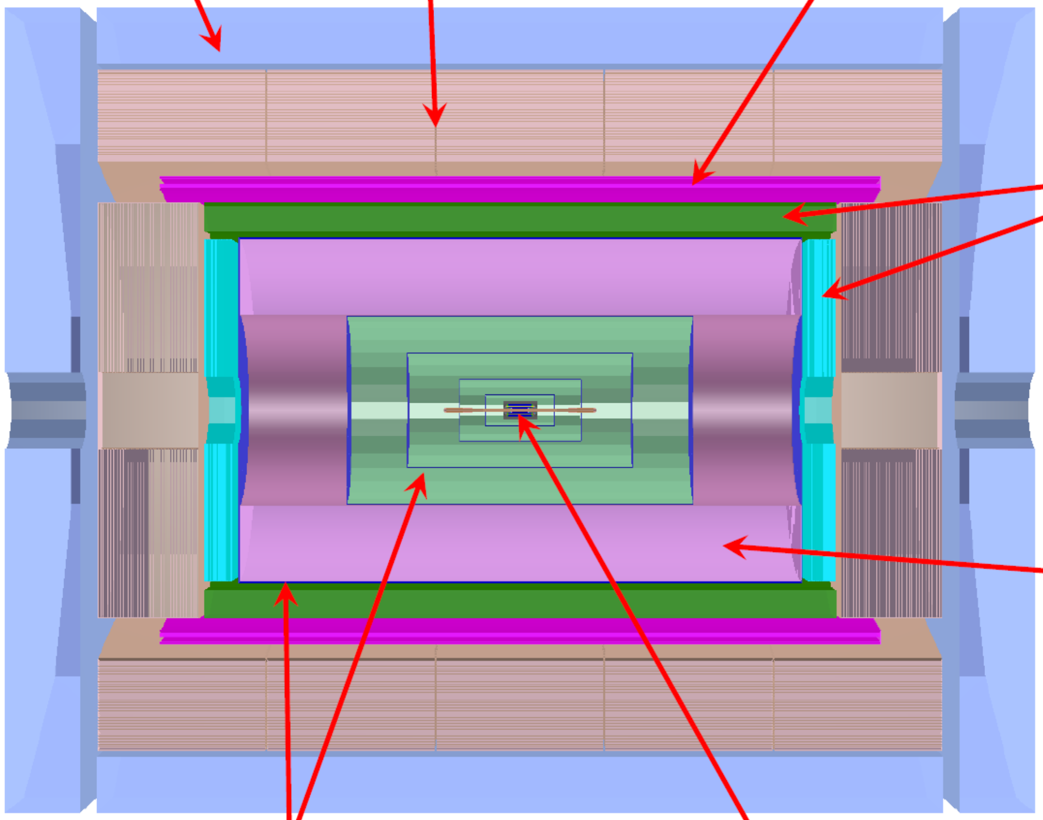
FST concept
(Full Silicon Tracker)

The 4th Concept



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.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

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

Drift chamber that is optimized for PID

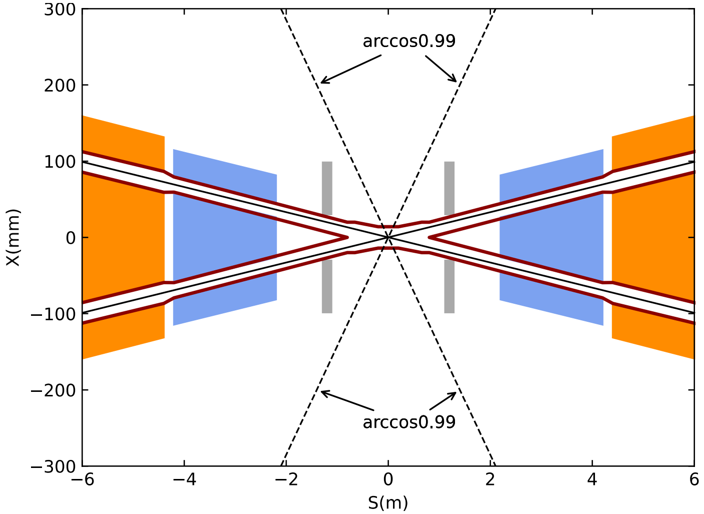
Advantage: Work at high luminosity Z runs

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

CEPC R&D: Machine Detector Interface (MDI)

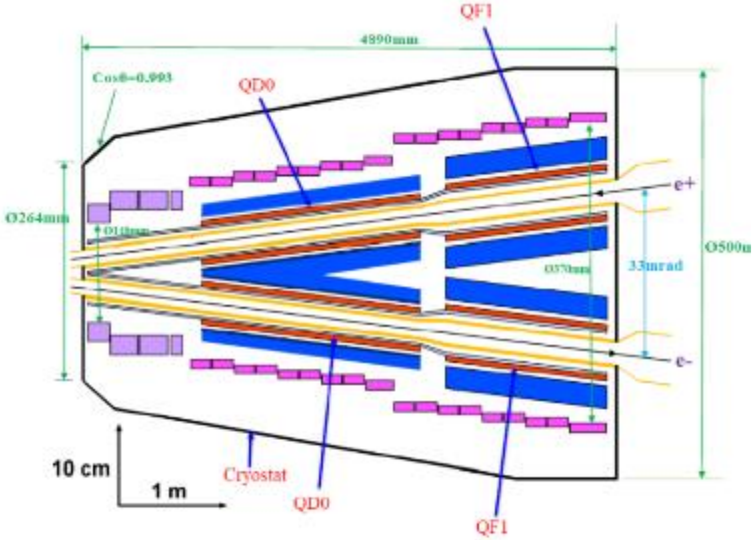
Crossing angle: 33 mrad,

Focal length: 2.2 m



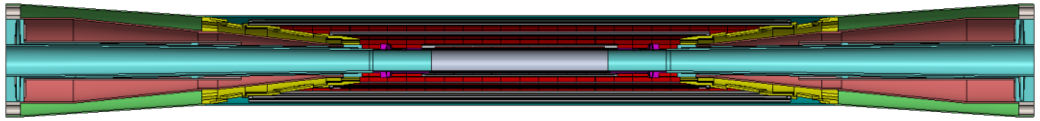
Final focusing magnets (QD0, QF1) with

Segmented Anti-Solenoidal Magnets

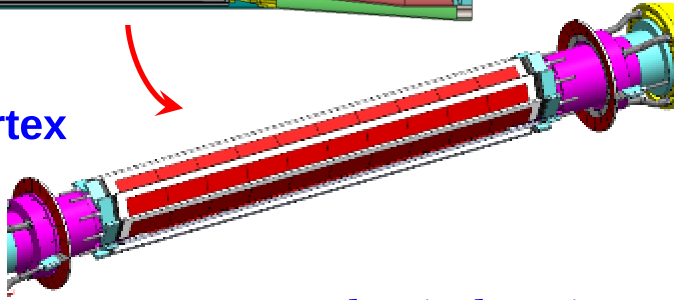


Beam Pipe

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

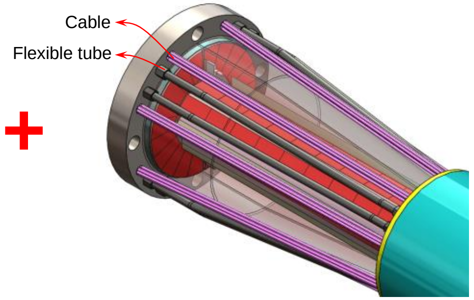


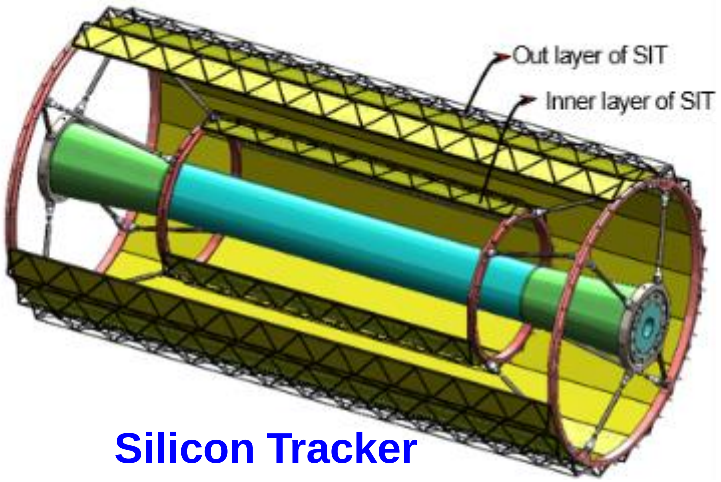
Vertex



+

LumiCal Tracker



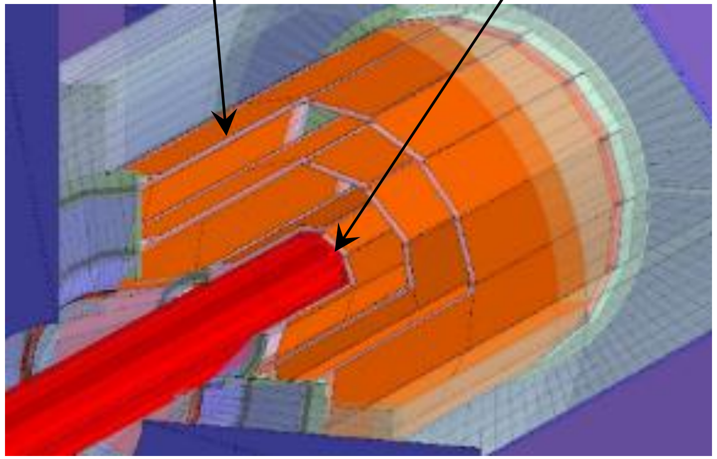


Silicon Tracker

2021 Workshop on CEPC Detector & MDI Mechanical Design
https://indico.ihep.ac.cn/event/14392/ Dongguan, Oct.21-23,2021

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/cm²)**
- **Radiation hard (1 Mrad/year)**

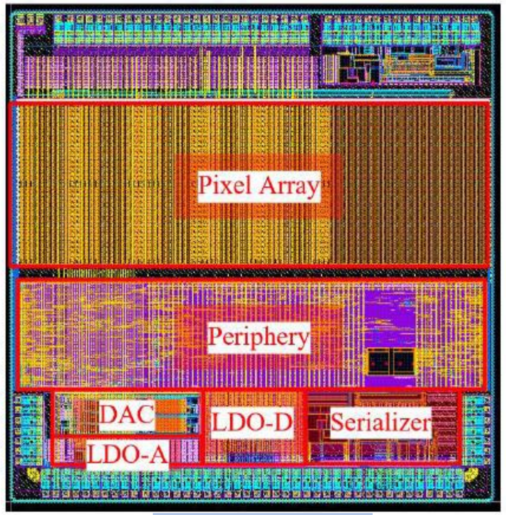
Silicon pixel sensor develops in 3 series:
JadePix / MIC, **TaichuPix**, **CPV**

JadePix-3 Pixel size ~16×23 μm²

Tower-Jazz CiS process

MOST 1

TaichuPix-2, 64×192 array
25×24 μm² pixel size

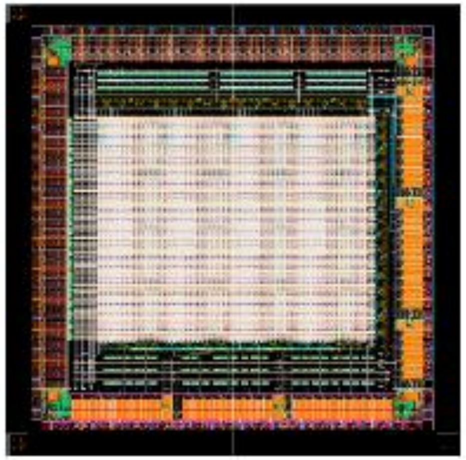


Full size TaichuPix-3 to be used for prototyping ladder

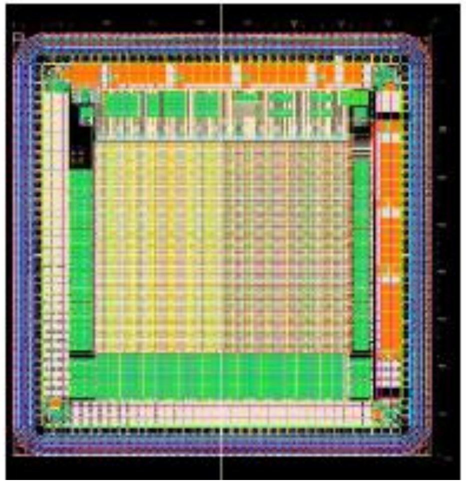
MOST 2

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

Upper chip



Lower chip

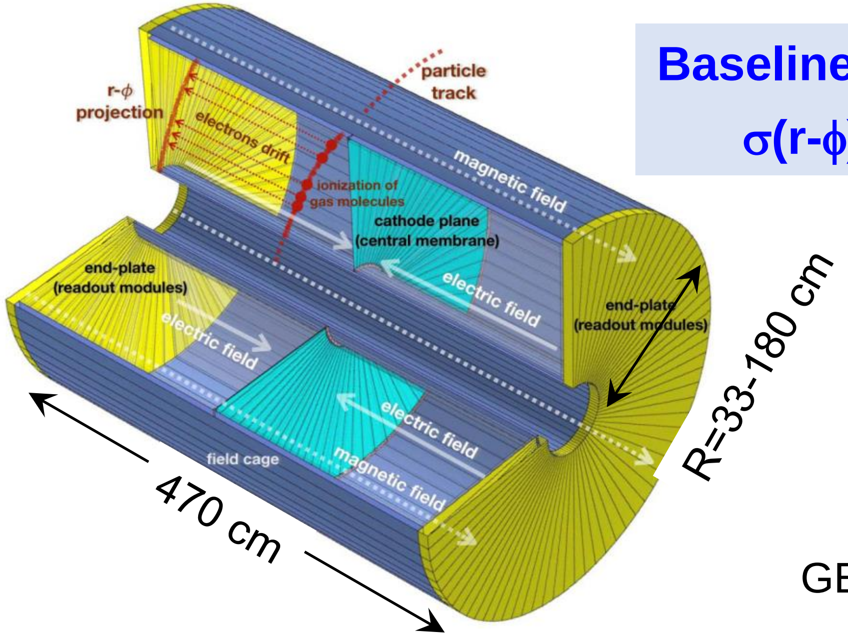


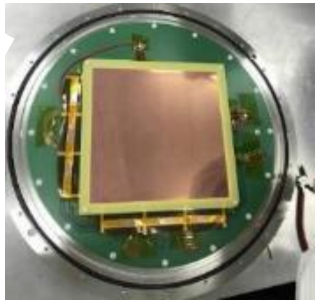
CEPC R&D: Time Projection Chamber

Baseline main tracker

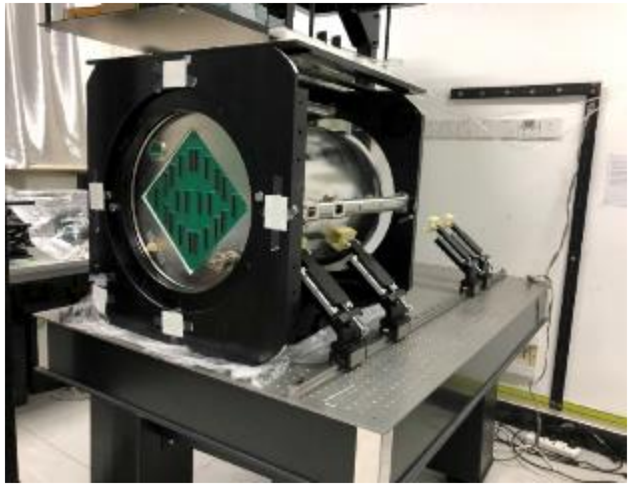
$\sigma(r\text{-}\phi)$ ~100 μm

MOST 1





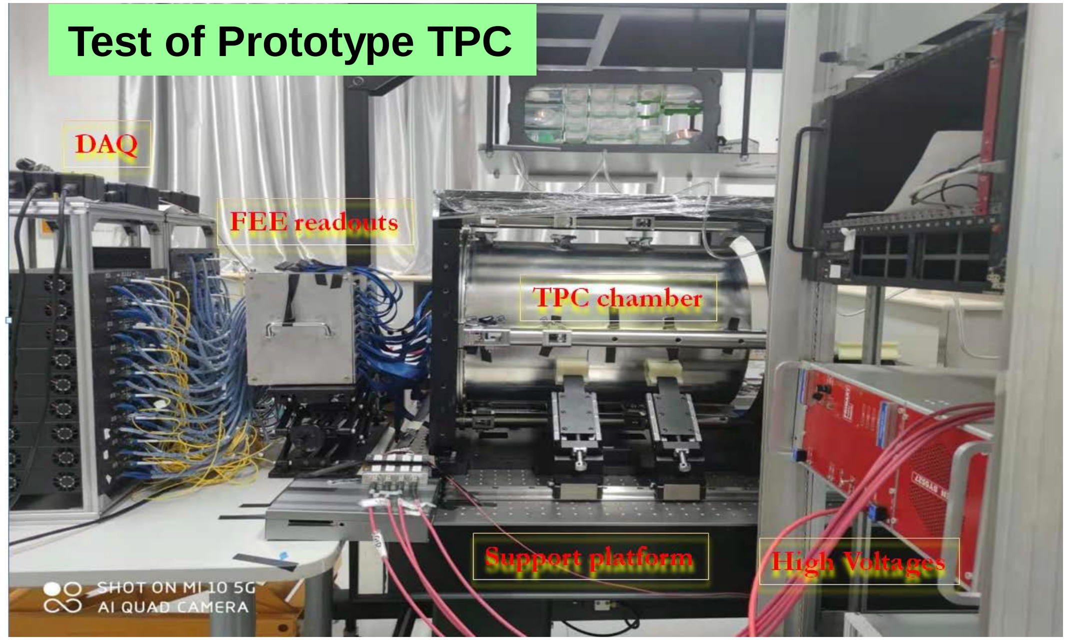
GEM-MM cathode



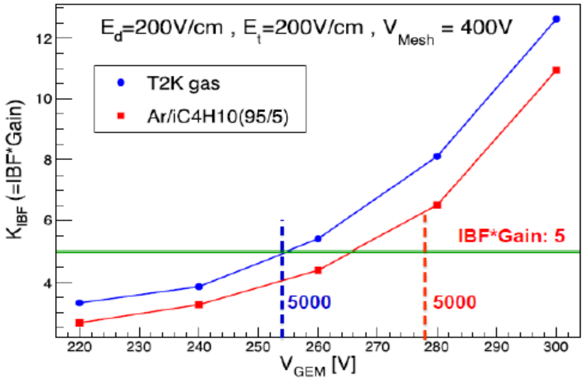
TPC Prototype + UV laser beams

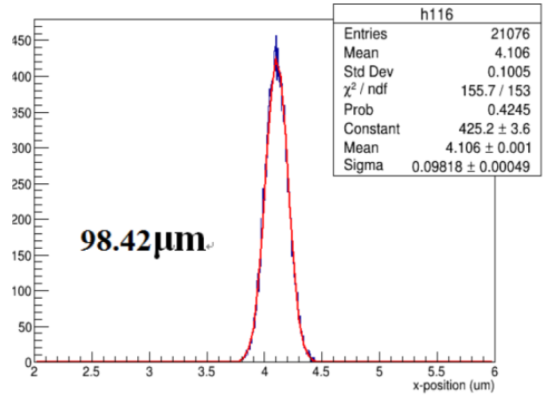
Low power FEE ASIC

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.**





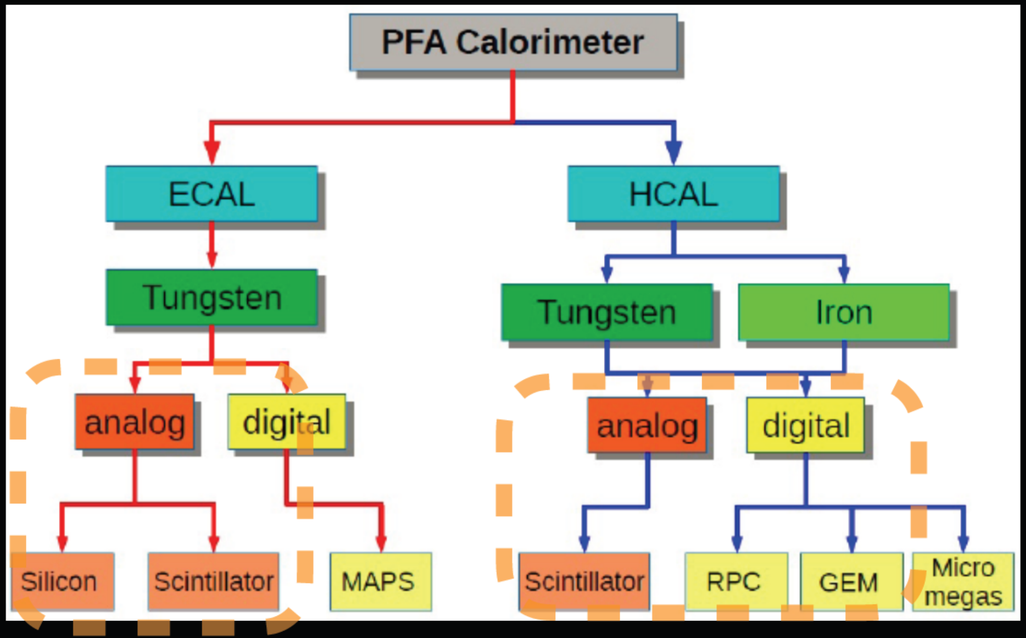
σ_x < 100 μm for drift length of 27cm

CEPC R&D: PFA Calorimeters

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

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



High Granularity

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

Newer Options

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

46

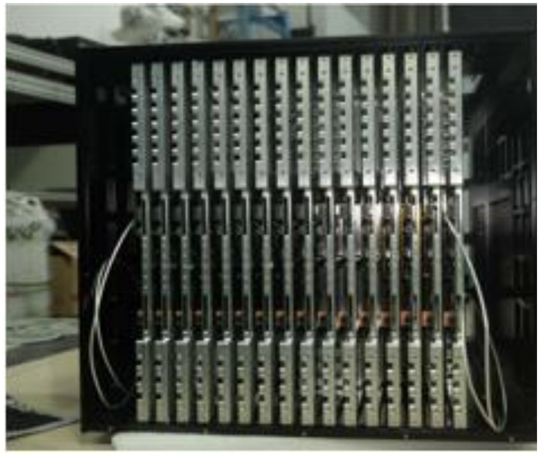
CEPC R&D: ScW-ECAL Prototype

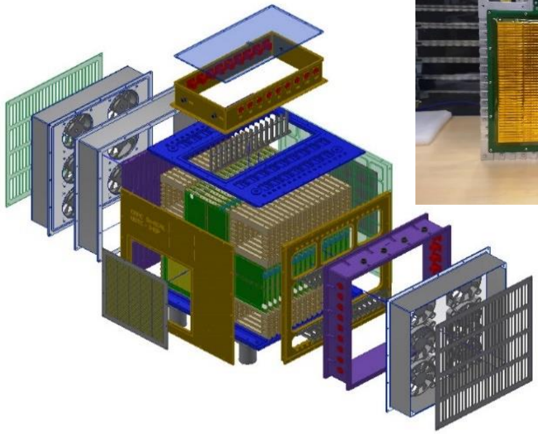
PFA ECAL → Tungsten → Analog → Silicon / Scintillator

MOST 1

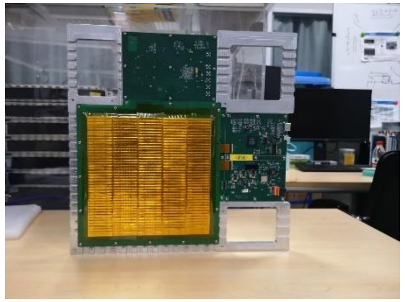
Goal of ECAL+HCAL+…

4% BMR, e.g. in (Z→νν) (H→gg)





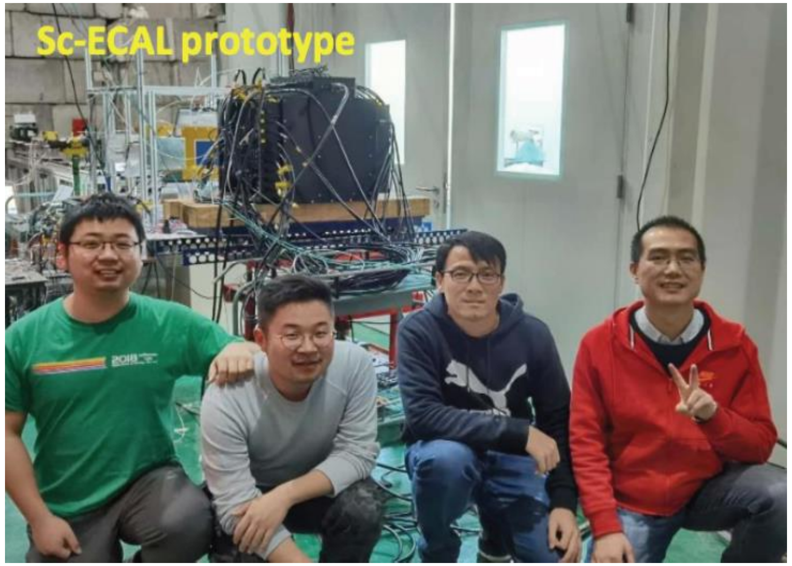
ScW-ECAL Prototype



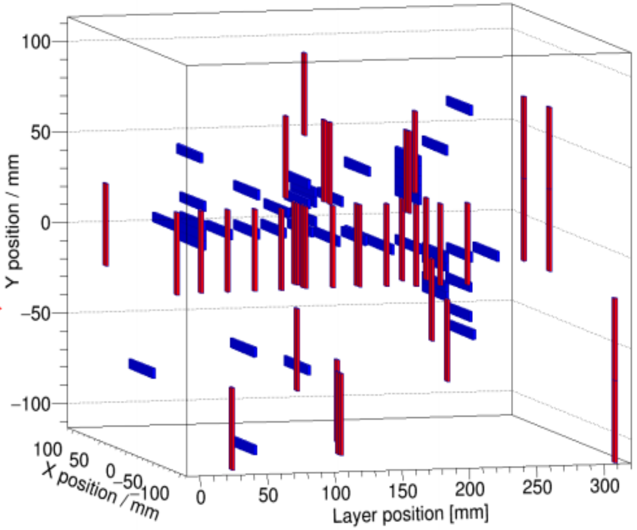
➔ **ScECAL prototype with 6700 channels**

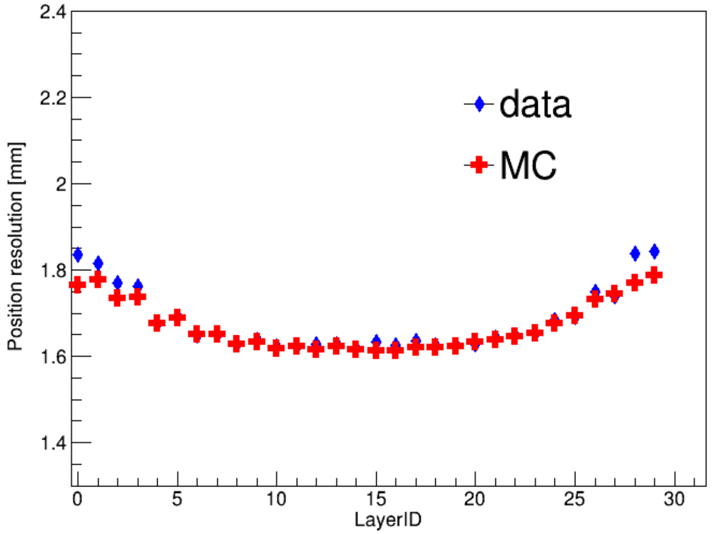
- **32 active layer (EBU), 22 x 22 cm^2, ~22X_0**
- **Scintillator (2x5×45mm^3) + MPPC S12571**
- **Embedded FEE (192 SPIROC2E ASICs)**
- **It has been tested with cosmic rays & an electron beam at IHEP (Nov. 2020).**

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

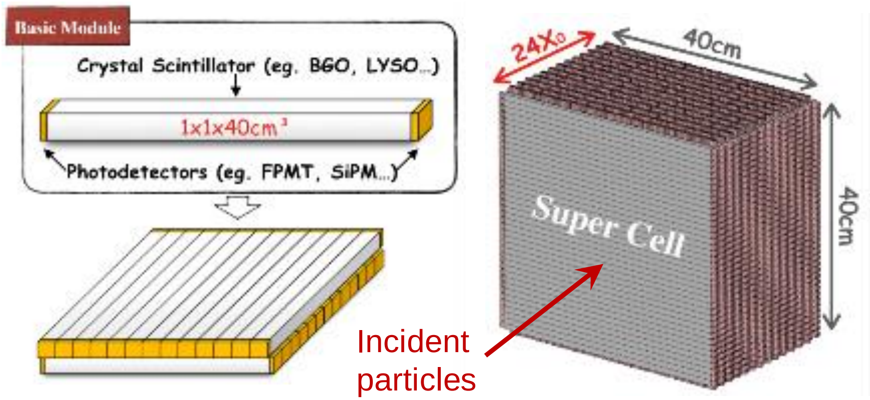


1 GeV particle





CEPC R&D: High Granularity Crystal ECAL



Goal

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

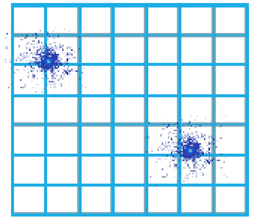
Bench Test

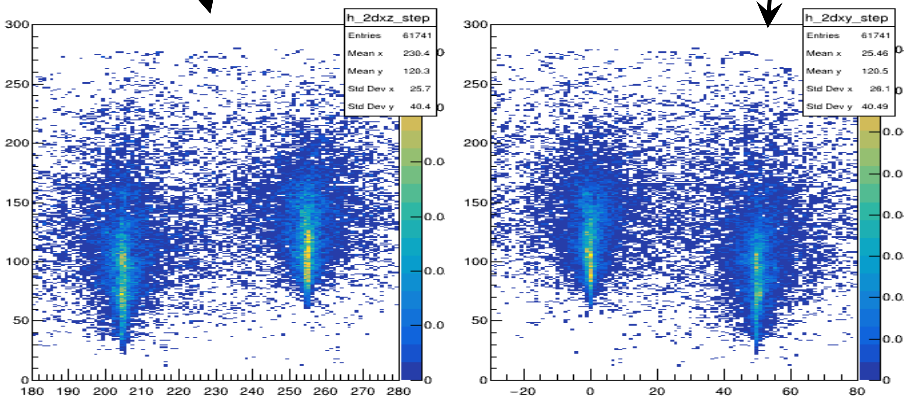
- Timing at two ends for positioning along bar.
- Significant reduction of number of channels.

Design Idea

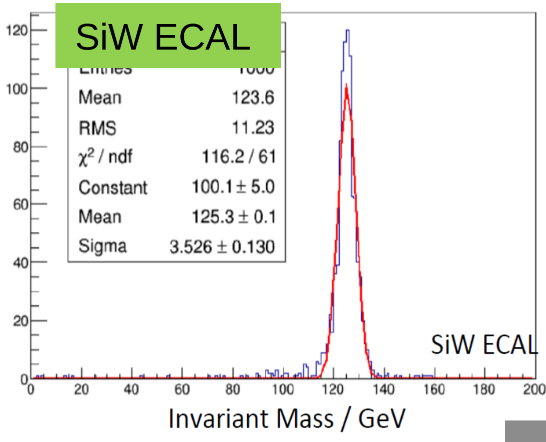
Recon. Algorithm

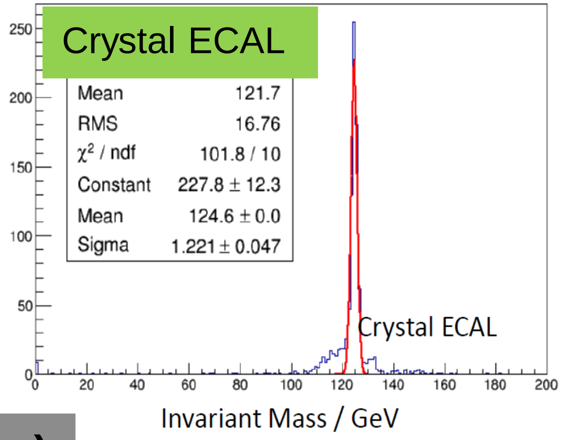
Energy & time matching solves ambiguity





MC Simulation



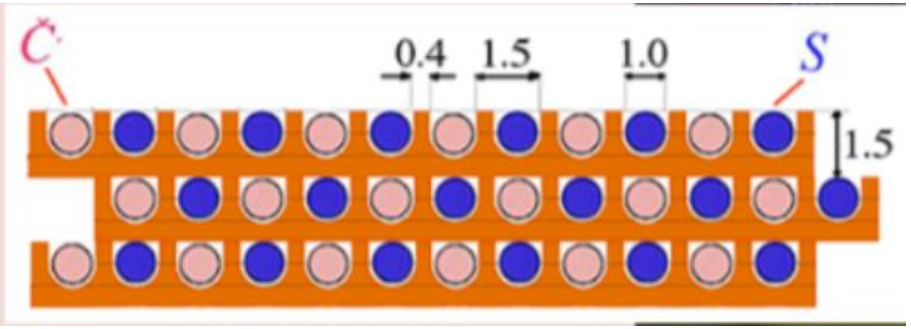


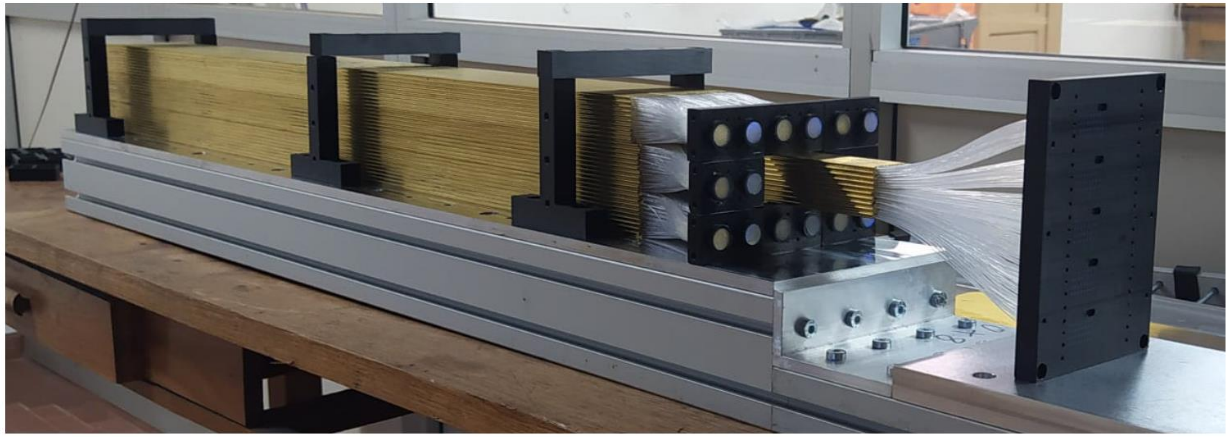
M(H→γγ)

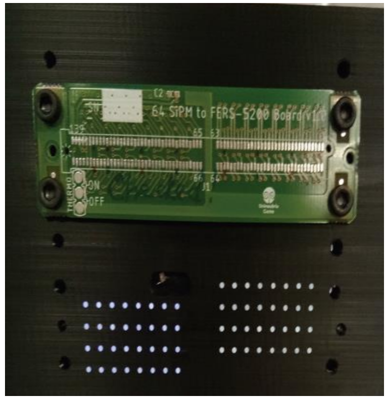
Dual Readout Calorimeter & SCEPCAL

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

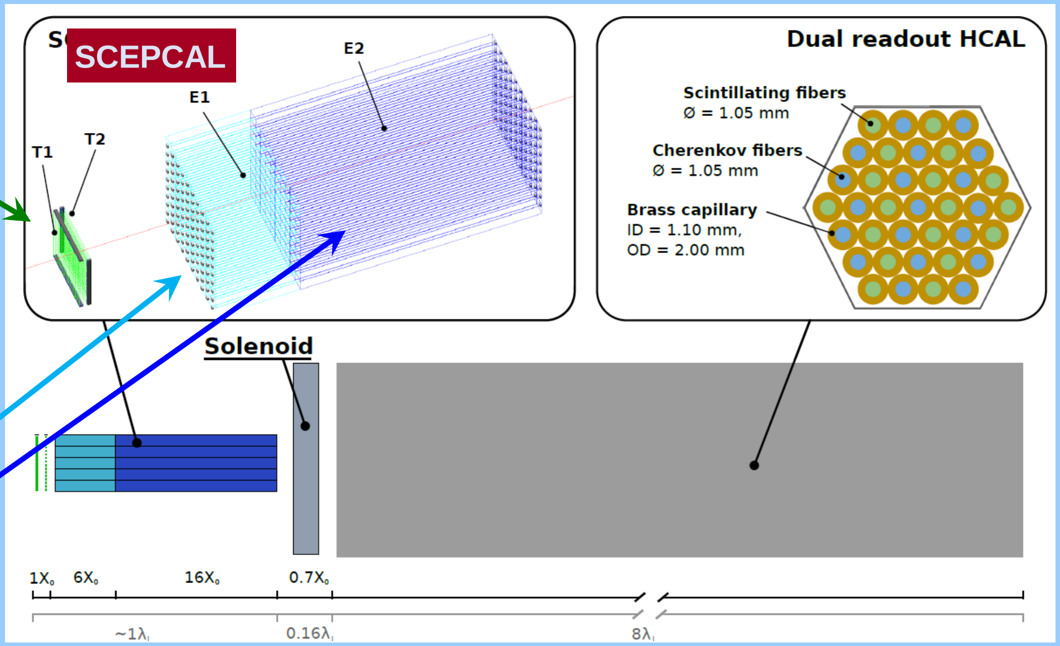
Tower: 20 rows × 16 columns

Combining Crystal ECal and DR Calorimeter

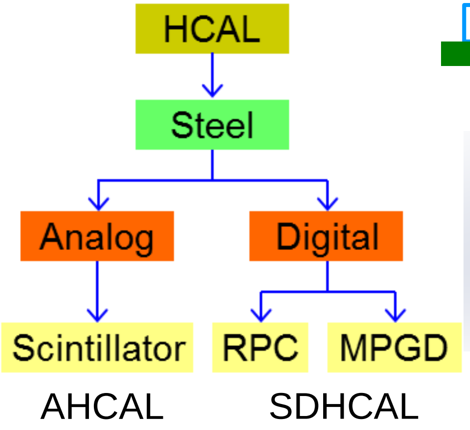
by Eno, Lucchini, and Tully et al. (arXiv:2008.00338)

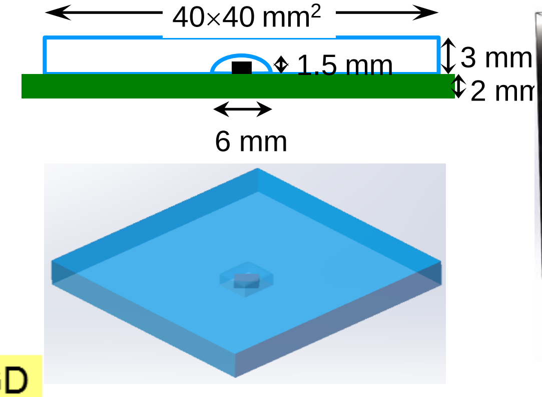
Timing layer $\sigma_t \sim 20$ ps
- LYSO Ce crystal ($\sim 1X_0$)
- $3\times3\times54$ mm^3 active cell
- 3×3 mm^2 SiPMs (15-20 μm)

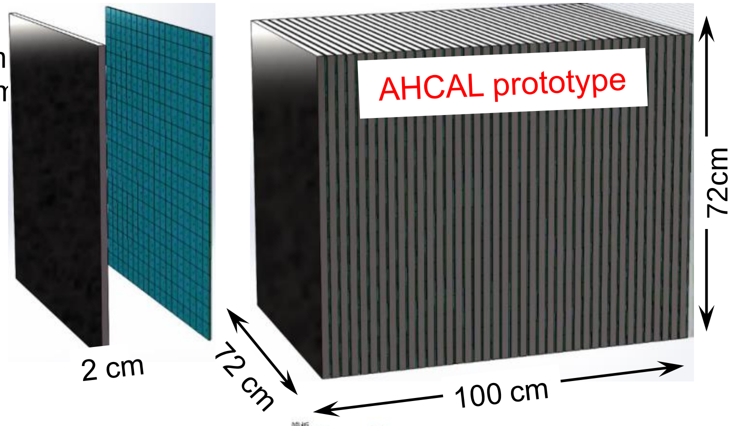
ECAL layer $\sigma_E/E \sim 3\%/\sqrt{E}$
- PbWO crystals
- Front segment (~ 6 X_0)
- Read segment (~ 16 X_0)
- $10\times10\times200$ mm^3 Crystals
- 5×5 mm^2 SiPMs (10-15 μm)

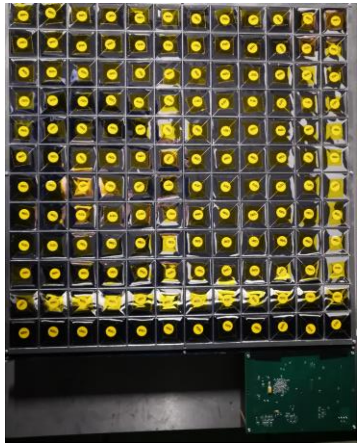


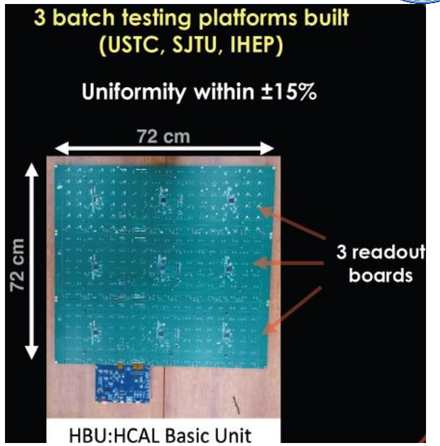
CEPC R&D: PFA HCAL



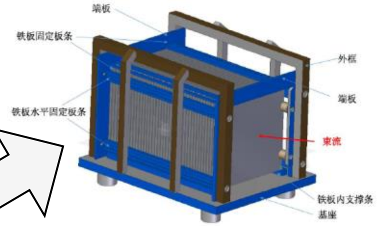


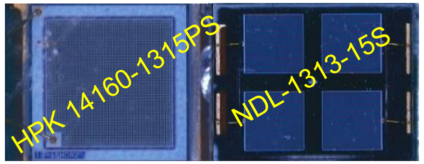






- **AHCAL with Scint.+SiPM (USTC, IHEP, SJTU)**
  - Prototype in production, size 72×72×100 cm^3,
  - 40 layers, Fe+Sct+SiPM+PCB=20+3+2=25mm,
  - 12960 Scintillators, cell size 40×40 mm^2
  - SiPM: HPK 14160-1315PS and NDL-1313-15S

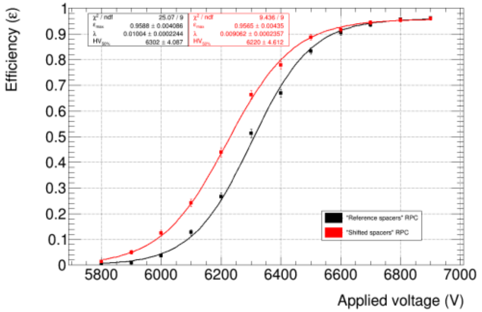




Tested ~ 15k Scintillators
Light Yield: ~ 13 ± 0.66

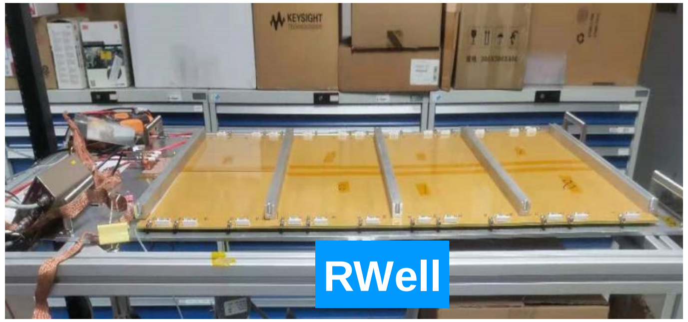
- **SDHCAL based on GRPC (SJTU)**

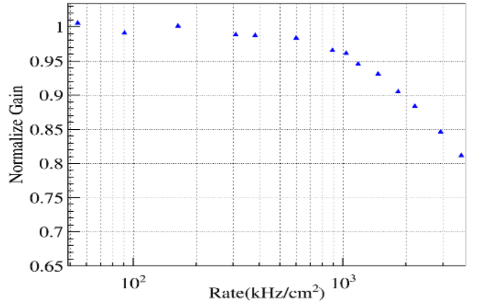
  Constructed 1×1 m^2 GRPCs, MIP Efficiency ~ 95.7%



- **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

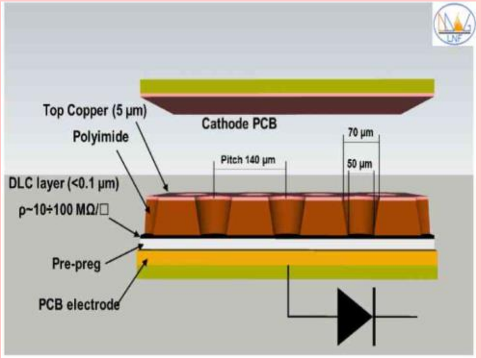


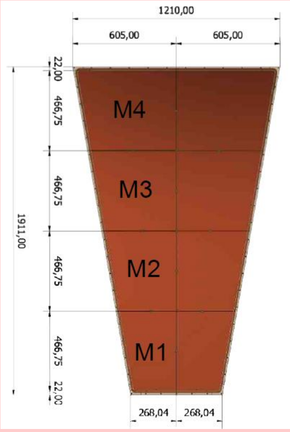


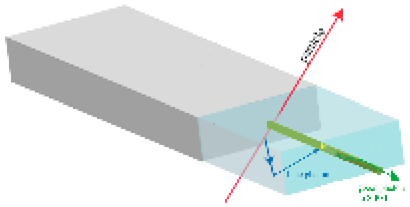
CEPC R&D: Muon Detector

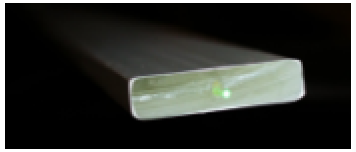
- **RPC R&D applies to both SDHCAL & Muon.**
- An alternative is **μ-RWELL** technology. The concept was proved. Currently focus mainly on industrialization and cost reduction.
- **Scintillator Muon detector. R&D overlaps with Belle II**
  - Building a prototype detector
  - Scintillator strips, improving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

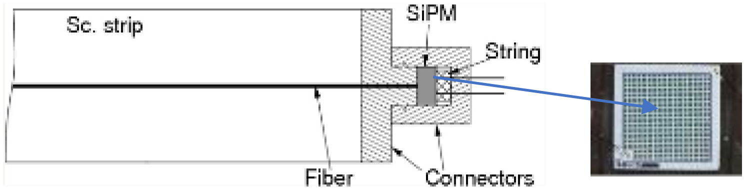
μRWELL for PS & Muon



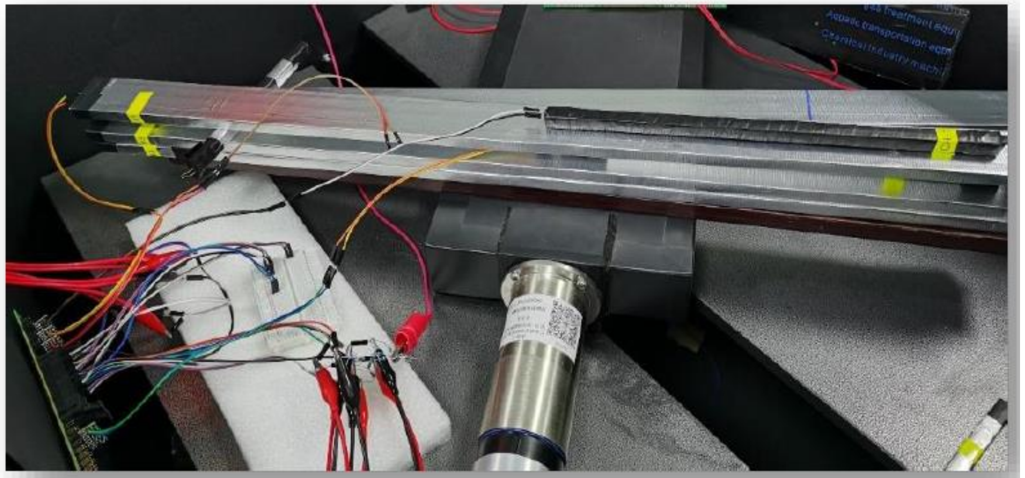


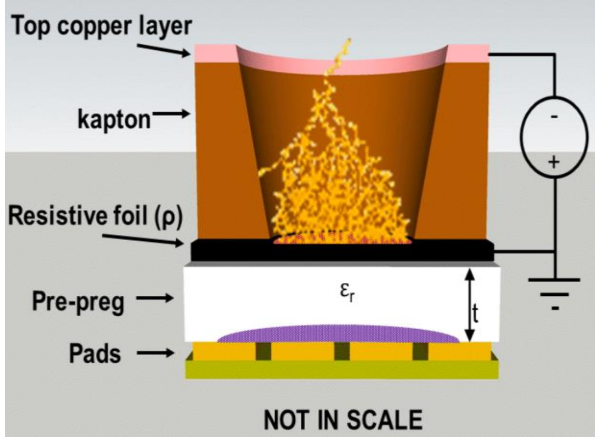






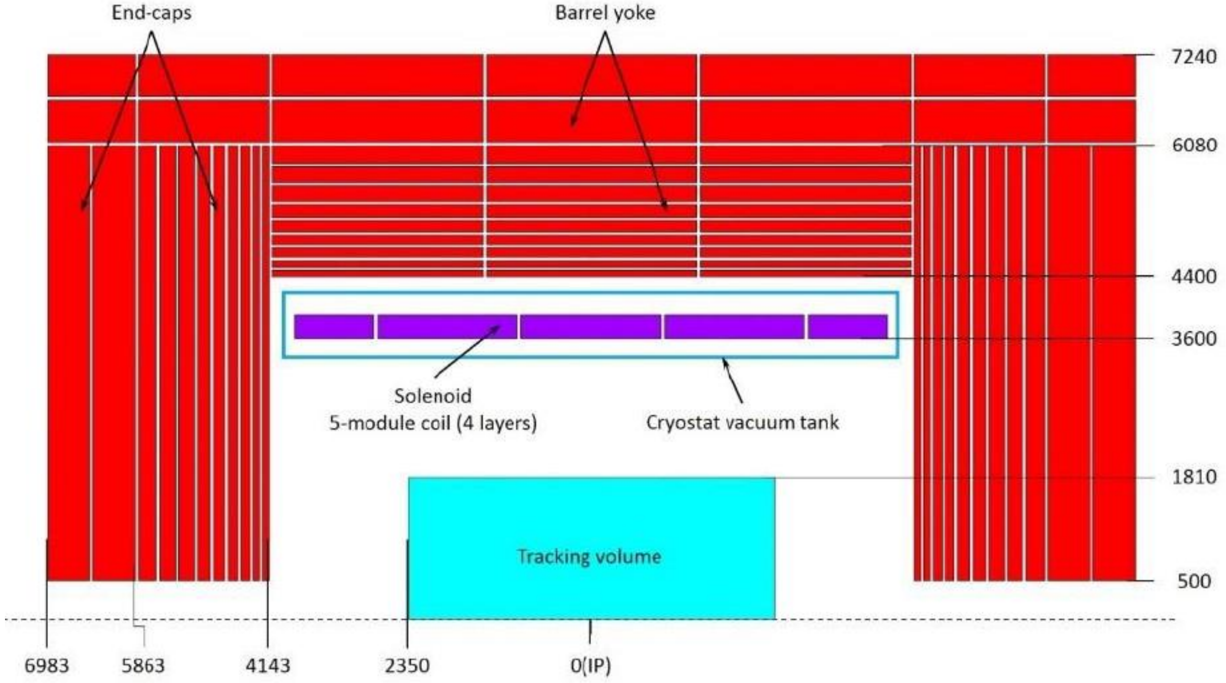
Fudan U.

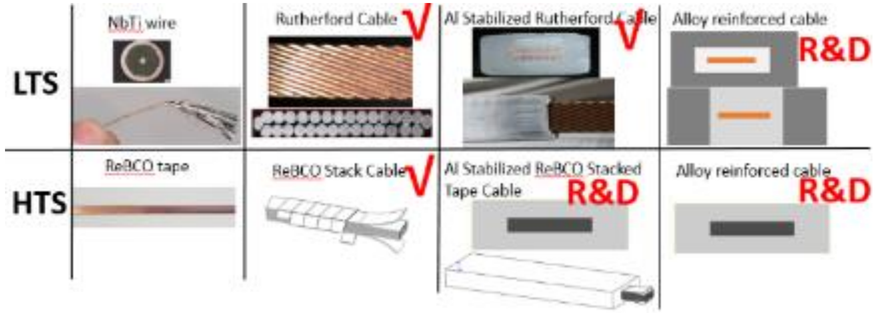


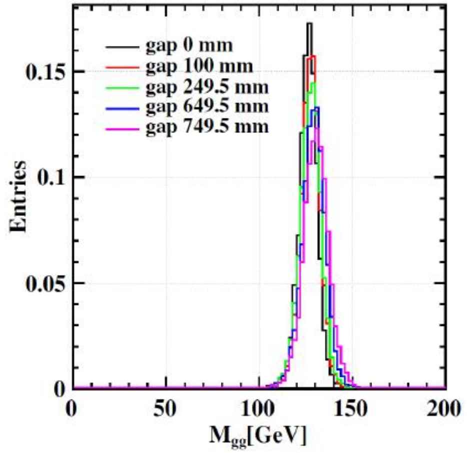


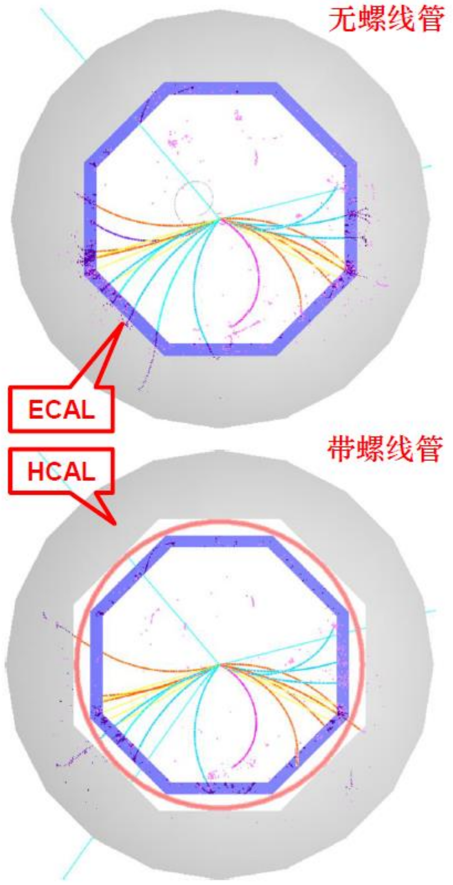
Achieved σ_t~2ns, Aim for 100-200 ps.

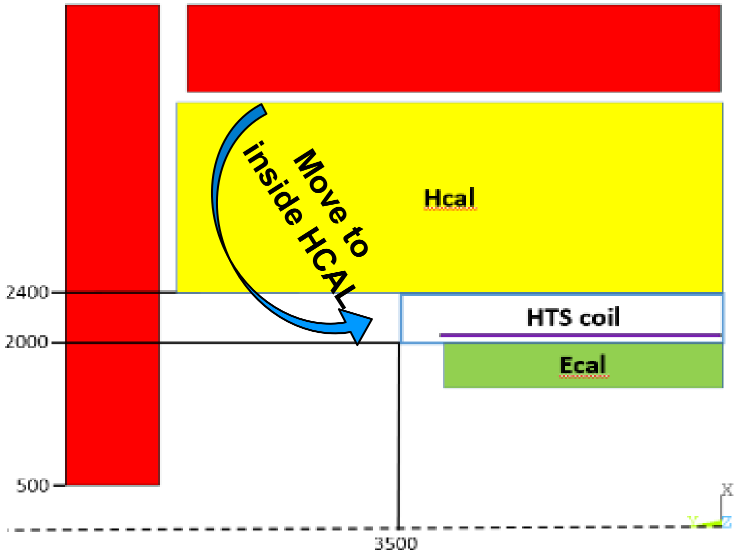
CEPC R&D: Solenoid Magnet











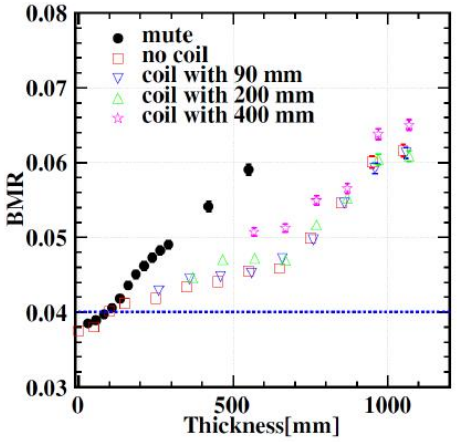
Main Challenges

Low mass

Ultra-thin

High strength cable

Keep BMR ~4%



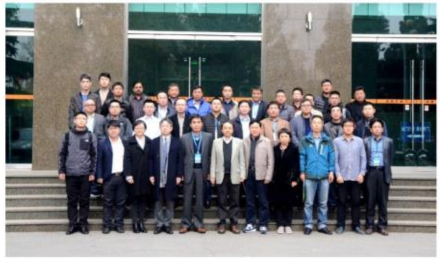
Collaboration with Industry (CIPC)

The CEPC Industrial Promotion Consortium (CICP) is established in Nov 2017. Till now, More than 60 companies joined CICP, with expertise on superconductor, superconducting cavities, cryogenics, vacuum, klystron, electronics, power supply, civil engineering, precise machinery, etc. The CIPC serves as a communication forum for the industrial and the HEP community.

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 first phase of CIPC，**and 70 companies now.**

CEPC产业促进会2018年会
企业代表与高能所合影
Representatives of enterprises in the annual meeting, in July. 26 , 2018
40余家企业，80余人参会

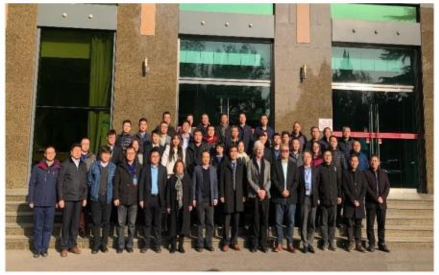


CEPC产业促进会第二次全体会议
企业代表与高能所合影
Representatives of enterprises in the plenary meeting, in Nov. 13 , 2018
30余家企业代表

Review of CIPC annual meeting

Cryogenics workshop on TDR of CEPC
Nov 27, 2018, IHEP, Beijing, China

CIPC working group meeting On June 4,2019

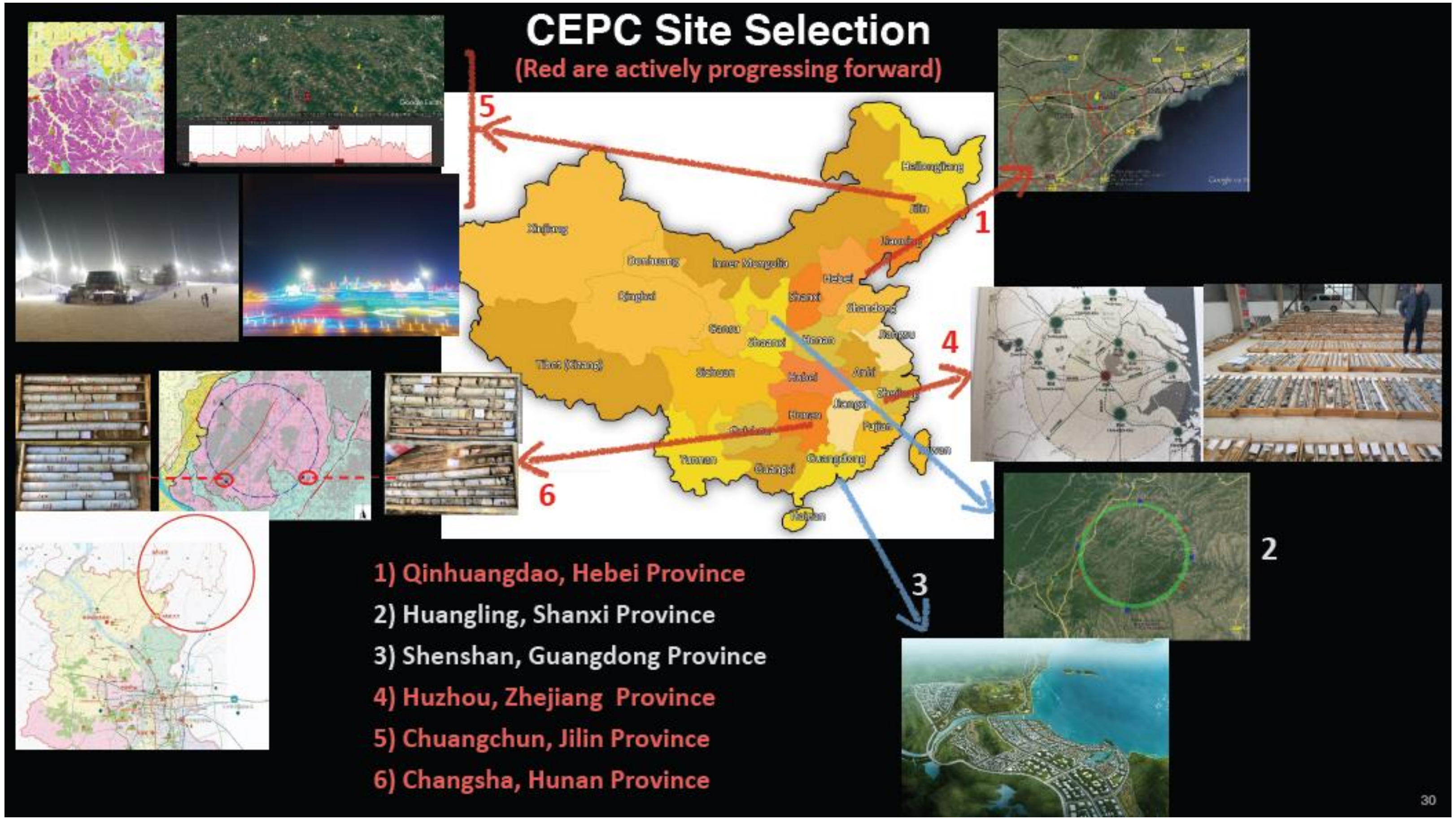


CEPC产业促进会-基金会
企业代表与高能所合影
Representatives of CIPC Foundations in the plenary meeting, in Nov. 21 , 2019

CEPC产业促进会第三次全体会议
企业代表与高能所合影
Representatives of enterprises in the plenary meeting, in Nov. 19 , 2019
64位代表，52个报告

CEPC Site Selection

➢ 候选地址：秦皇岛、陕西、深圳、湖州、长春、长沙等

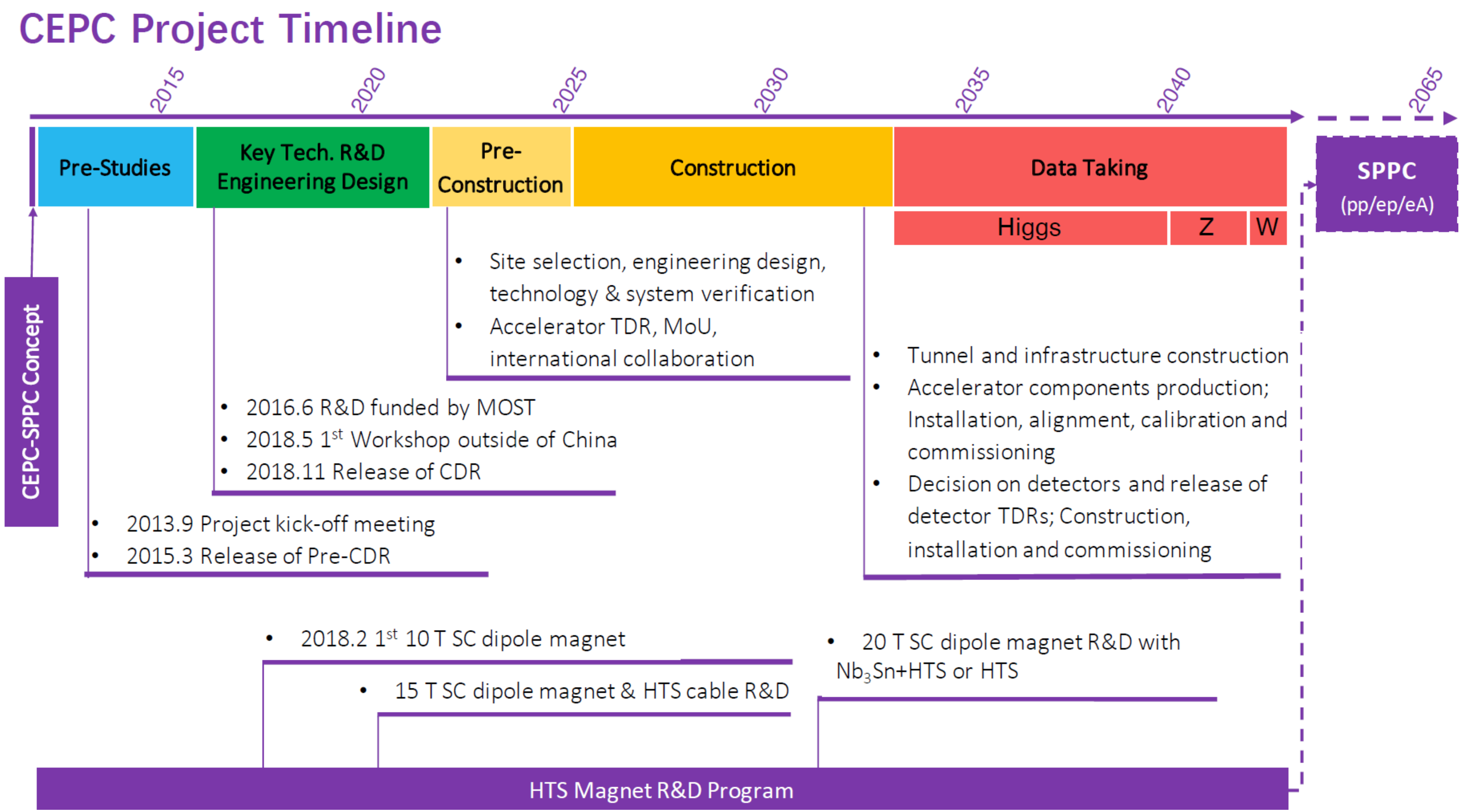


- ❖ More invitations from local governments: Changsha, Changchun, …
- ❖ 团队调研长沙和长春:具有良好的地质条件和便利的交通（近大城市和国际机场~20公里)
- ❖ 长沙市政府非常积极，5月访问高能所；委托湖南大学在9月4日组织召开《中国(长沙)环形正负电子对撞机暨国际科学新城项目论证报告》专家论证会，对项目及国际科学城定位及规划的系统性、技术及投资的可行性等方面给予正面评价；当地政府非常支持项目落地建设。

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

CEPC Project Timeline

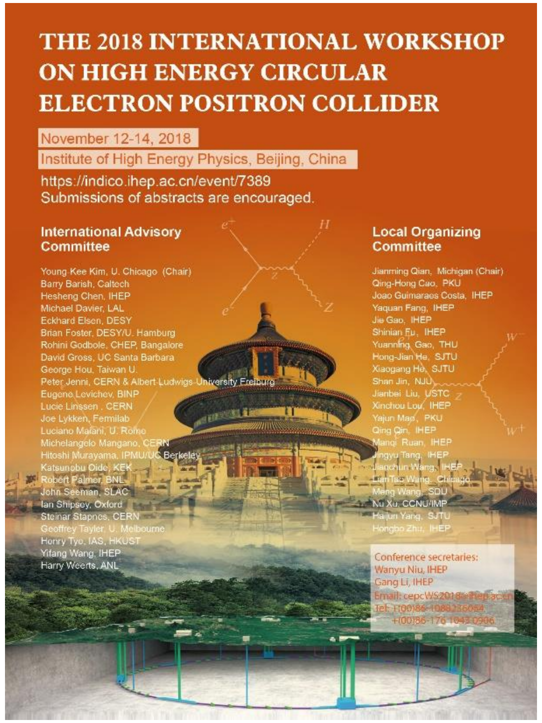
- 2013-2025：开展加速器和探测器关键技术预研，CDR→TDR，选址，国际合作等
- 理想情况下：期望“十五五”期间获政府批准，启动项目建设



总结和展望

- CEPC 是希格斯工厂 + Z工厂 + W工厂，具有丰富的物理和探索新物理的巨大潜力
- 积极准备CEPC白皮书：希格斯物理（已发表），电弱物理，味物理，QCD物理，新物理等
- 优化和提升了希格斯与Z工厂的亮度，预计在2022年发布加速器工程技术设计报告(TDR)
- 提出了新的探测器概念设计，准备探测器技术设计报告
- 加速器和探测器关键技术预研取得了多项重要突破：
  - 成功研制高品质超导腔（1.3 GHz 9-cell, 650 MHz 2-cell, 1-cell），均超过CEPC设计指标
  - 成功研制束调管，效率达到62%；➔ 目标是80%
  - 成功研制磁场强度超过12特斯拉的超导二极磁铁；➔ 近期目标是16T，远期目标20-24T
  - 成功研制硅像素芯片，空间分辨率达到5微米；➔ 目标是达到CEPC设计指标3微米，低功耗，抗辐照
  - 成功研制国际首个基于闪烁体和硅光电倍增管的高颗粒度电磁量能器技术样机;
    ➔ 近期目标是强子量能器技术样机和晶体电磁量能器样机
- 召开了一系列CEPC国际研讨会:
  - 中国： 北京 (2017.11, 2018.11, 2019.11)，上海 (2020.10)，南京 (2021.11.8-12)
    香港科技大学（2015起-)
  - 欧洲： 罗马 (2018.05), 牛津 (2019.04)， 马赛 (2022.05 ?)
  - 美国： 芝加哥(2019.09), 华盛顿特区 (2020.04, online)
- 经费资助：科技部，基金委，中科院，地方政府
- CEPC关键技术预研取得了一系列重要进展，预研工作稳步推进，欢迎大家积极参与!

Recent CEPC Workshops



Next CEPC International Workshop

at Nanjing University, Nov. 8-12, 2021

You are very welcome to participate

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非常感谢CEPC同事帮助准备材料

欢迎大家积极参与CEPC预研

谢谢关注和支持！