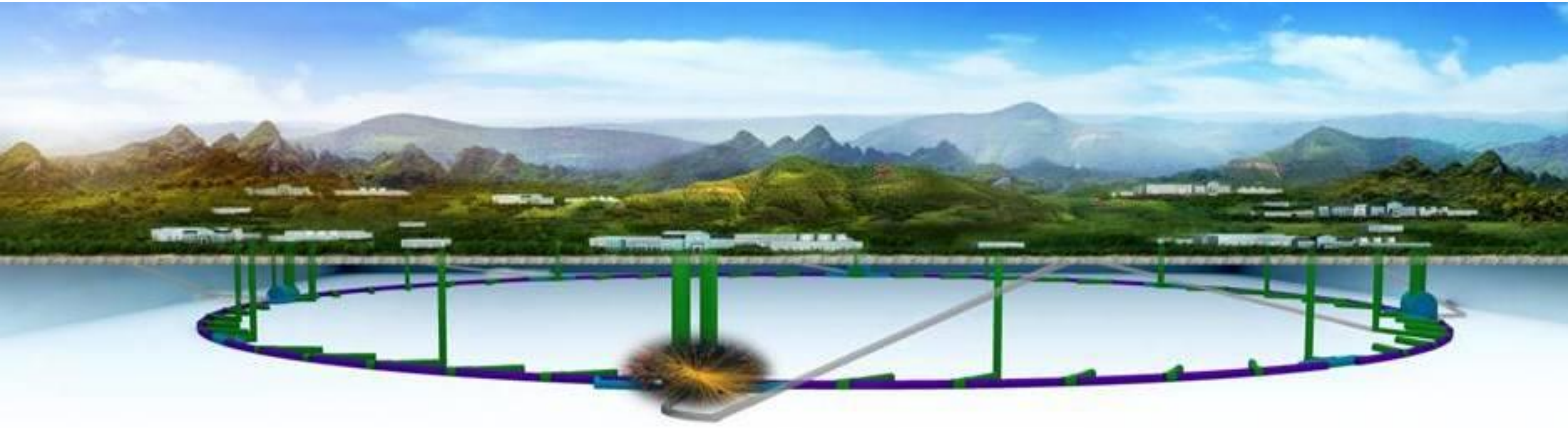
Status of the CEPC Project

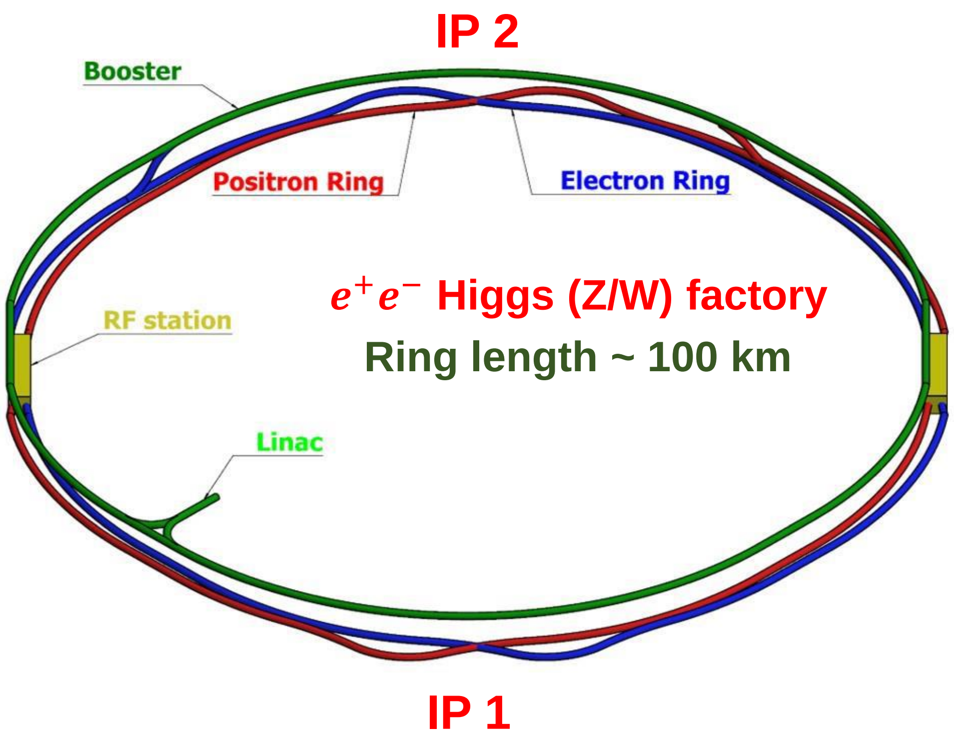
Haijun Yang (SJTU)
(for the CEPC working group)

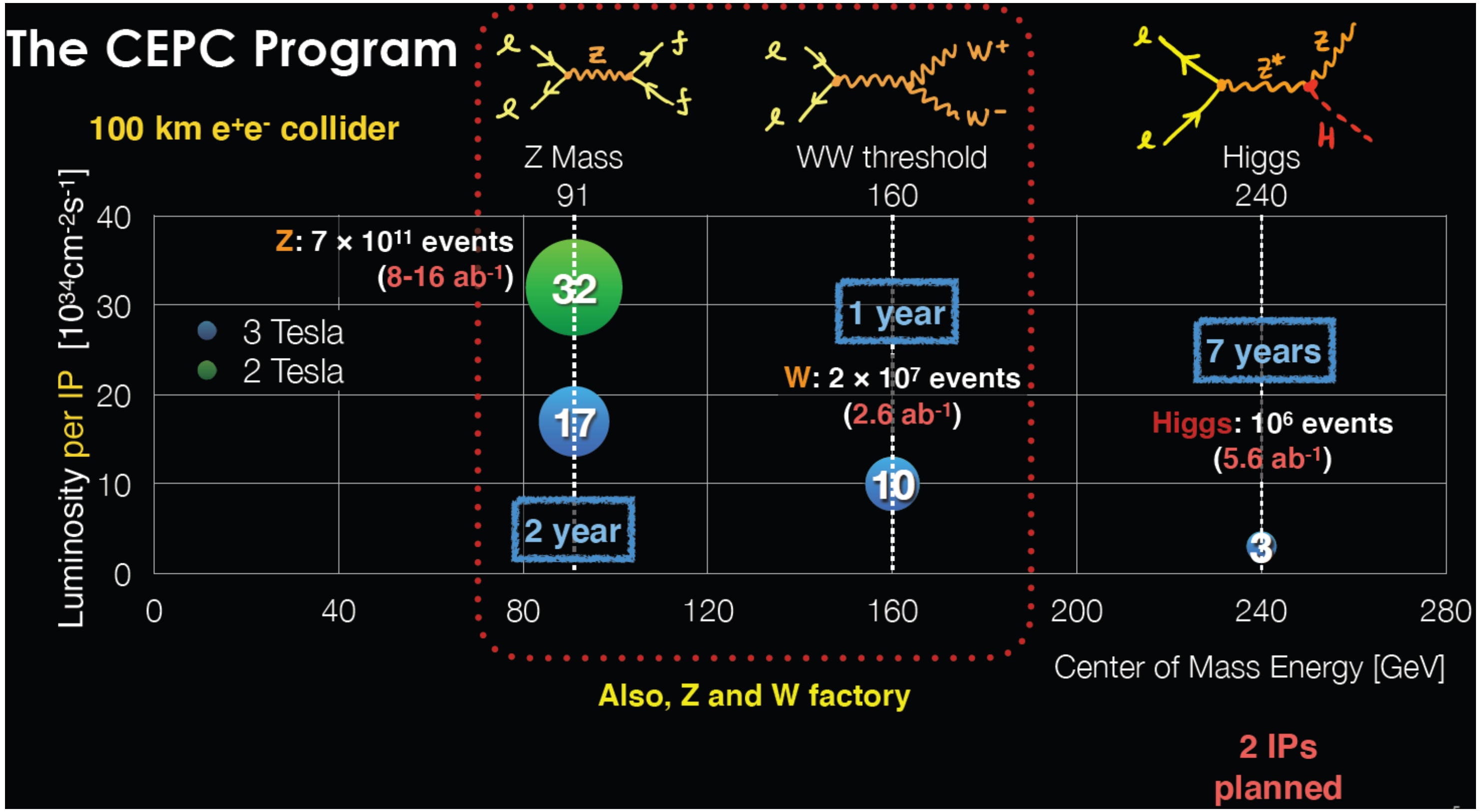
The XXVIII International Conference on Supersymmetry
and Unification of Fundamental Interactions
August 23-28, 2021



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.





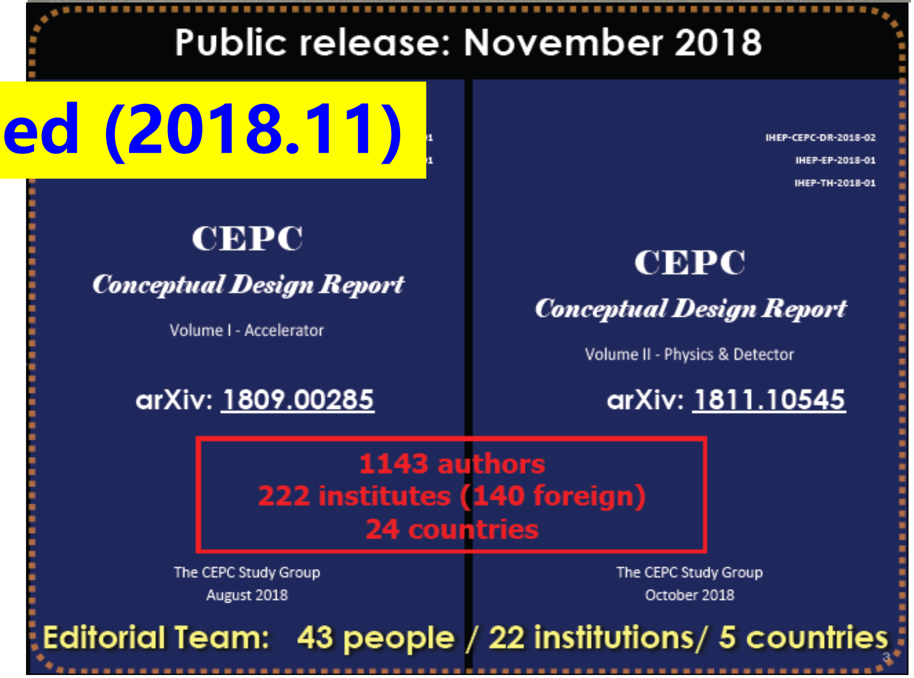
http://cepc.ihep.ac.cn/

CEPC Major Milestones


CEPC-SPPC Kickoff (2013.9)


CEPC IAC Meeting (2015)


CEPC CDR Released (2018.11)


Public release: November 2018

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

CEPC
Conceptual Design Report
Volume I - Accelerator
arXiv: 1809.00285
The CEPC Study Group
August 2018

CEPC
Conceptual Design Report
Volume II - Physics & Detector
arXiv: 1811.10545
The CEPC Study Group
October 2018

1143 authors
222 institutes (140 foreign)
24 countries

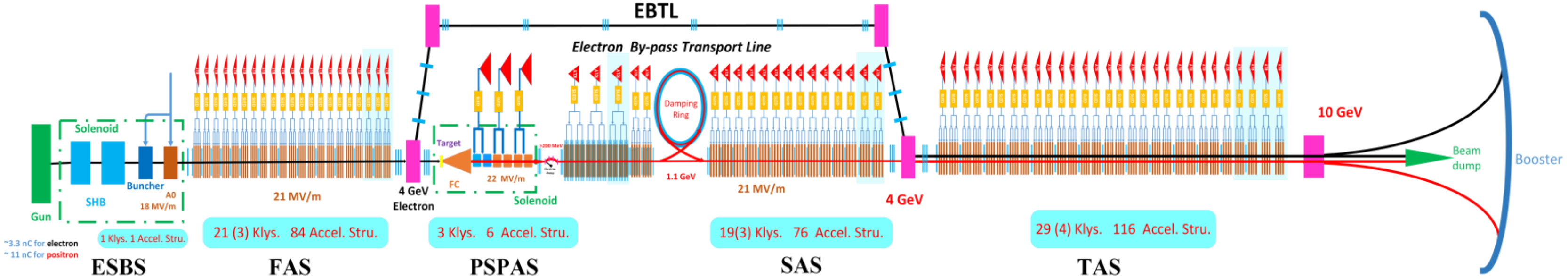
Editorial Team: 43 people / 22 institutions/ 5 countries

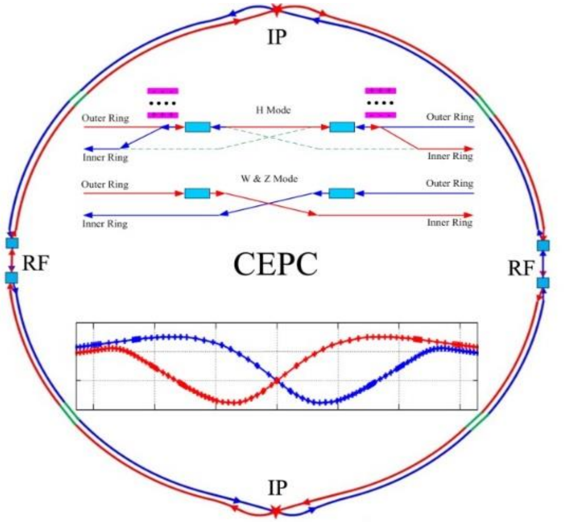
CEPC Accelerator Baseline (CDR)

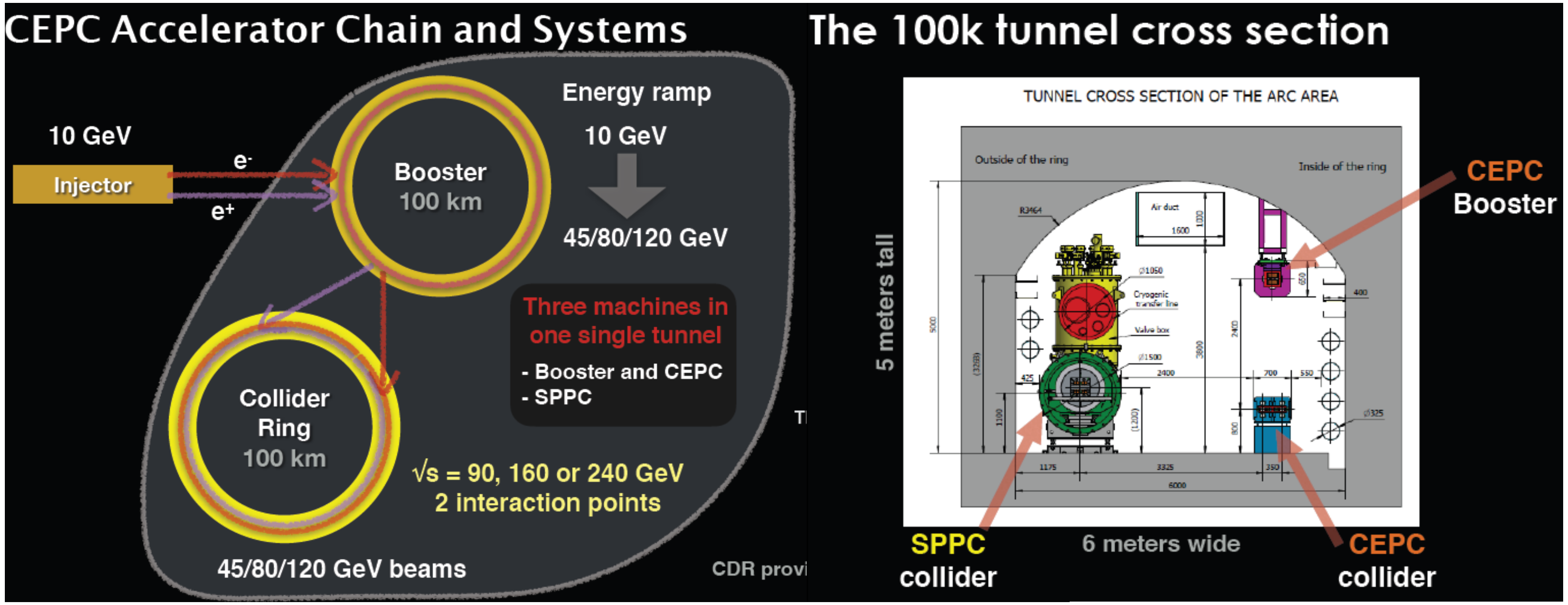
Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

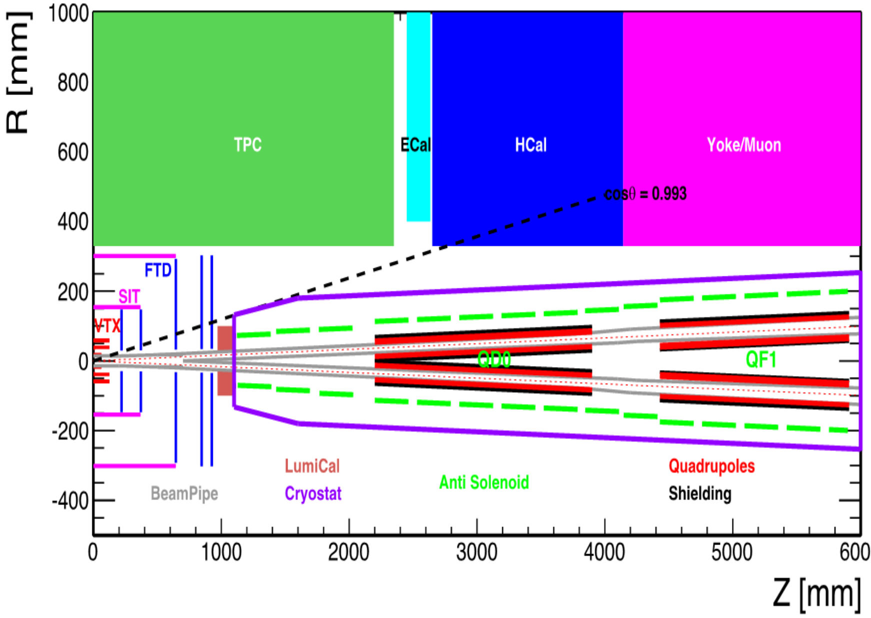
http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf

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







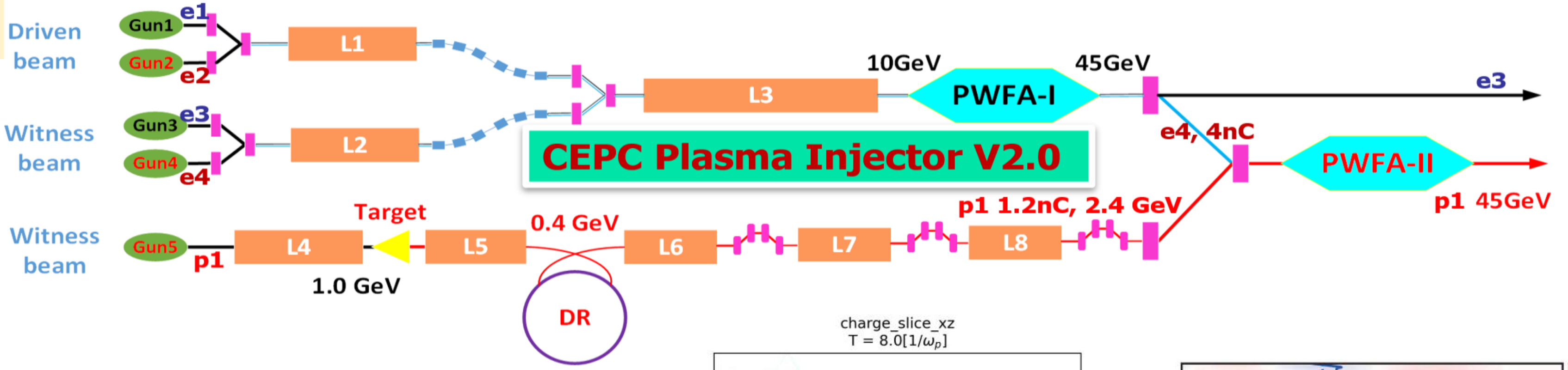


CEPC Accelerator: Plasma Injector

CEPC Plasma Injector V2.0

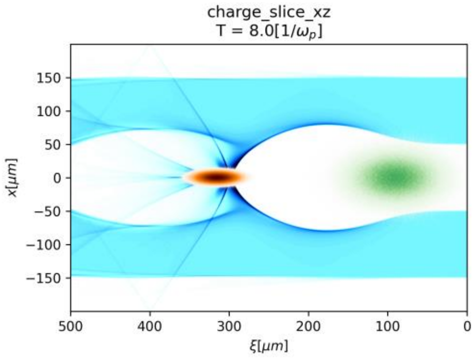
IHEP, THU, BNU

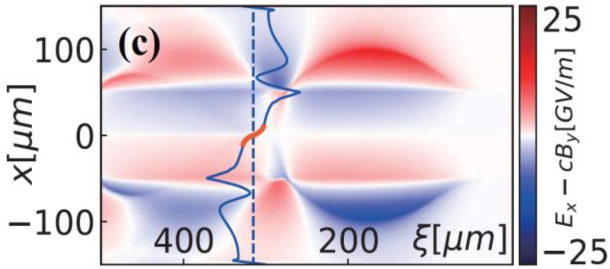
Booster Requirement	
Energy （GeV)	45.5
Bunch Charge （nC)	0.78
Bunch length (um)	<3000
Energy Spread (%)	0.2
ε_N (μm·rad)	<800
Bunch Size (um)	<2000



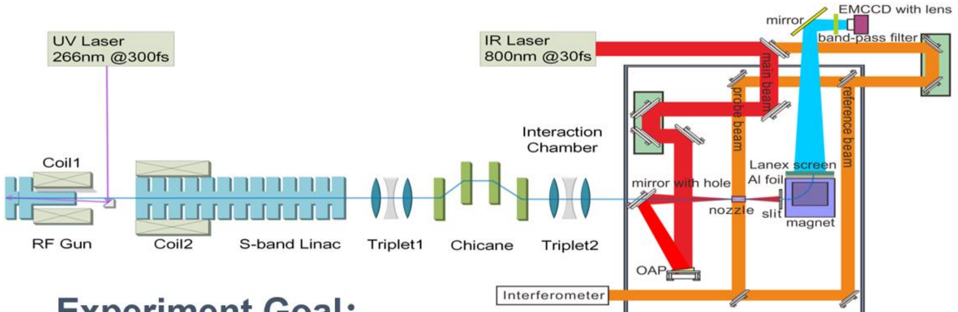
High efficiency uniform wakefield acceleration of a positron beam using stable asymmetric mode in a hollow channel plasma

S.Y. Zhou, W. Lu, et al., arXiv: 2012.06095v2



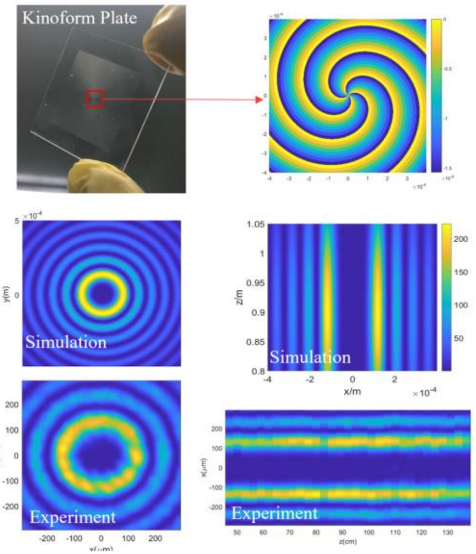


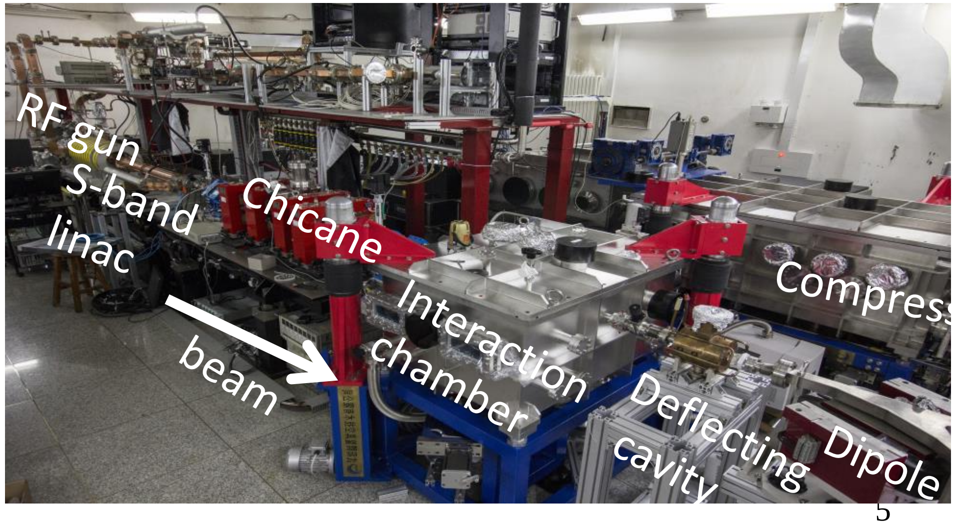
Plasma dechirper exp. at THU



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

- 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)

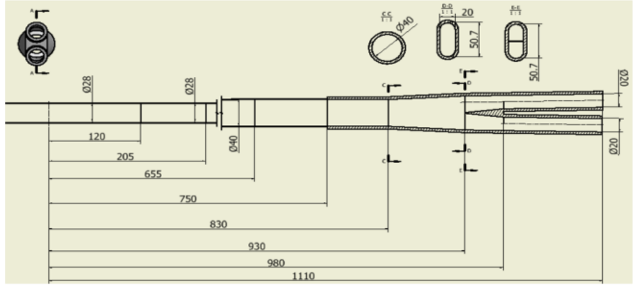
High luminosity scheme (Higgs)

- ✓ **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

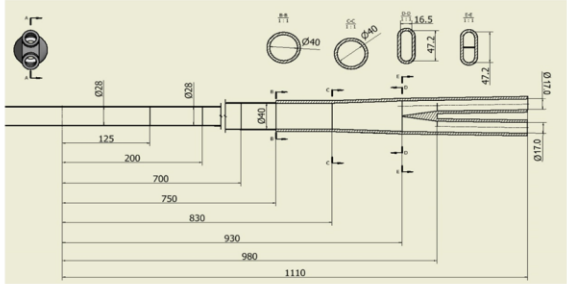
CDR

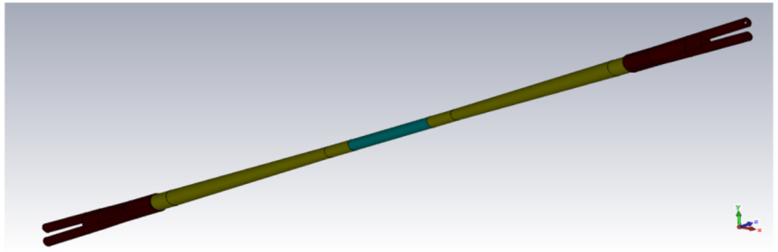
Be pipe: 28mm, SCQ Beam pipe:20mm



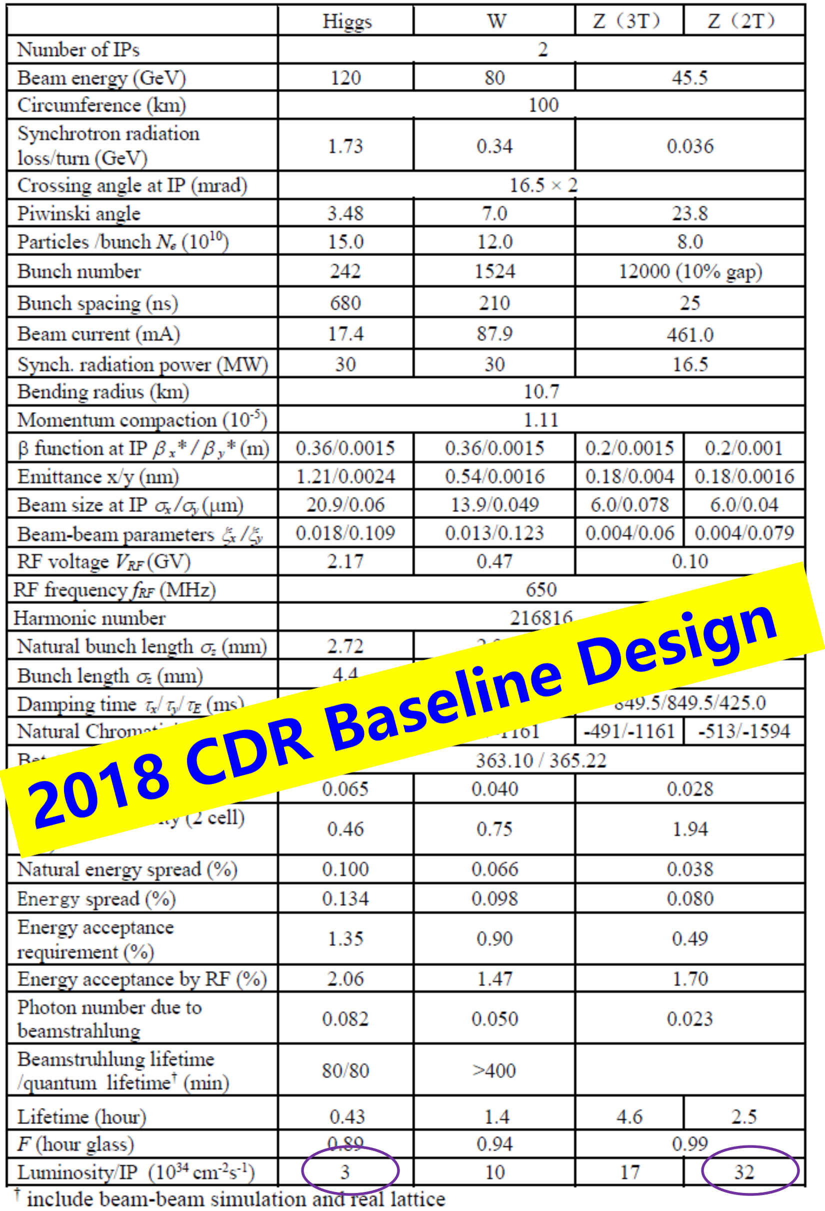
High luminosity

Be pipe: 28mm, Beam pipe:17mm





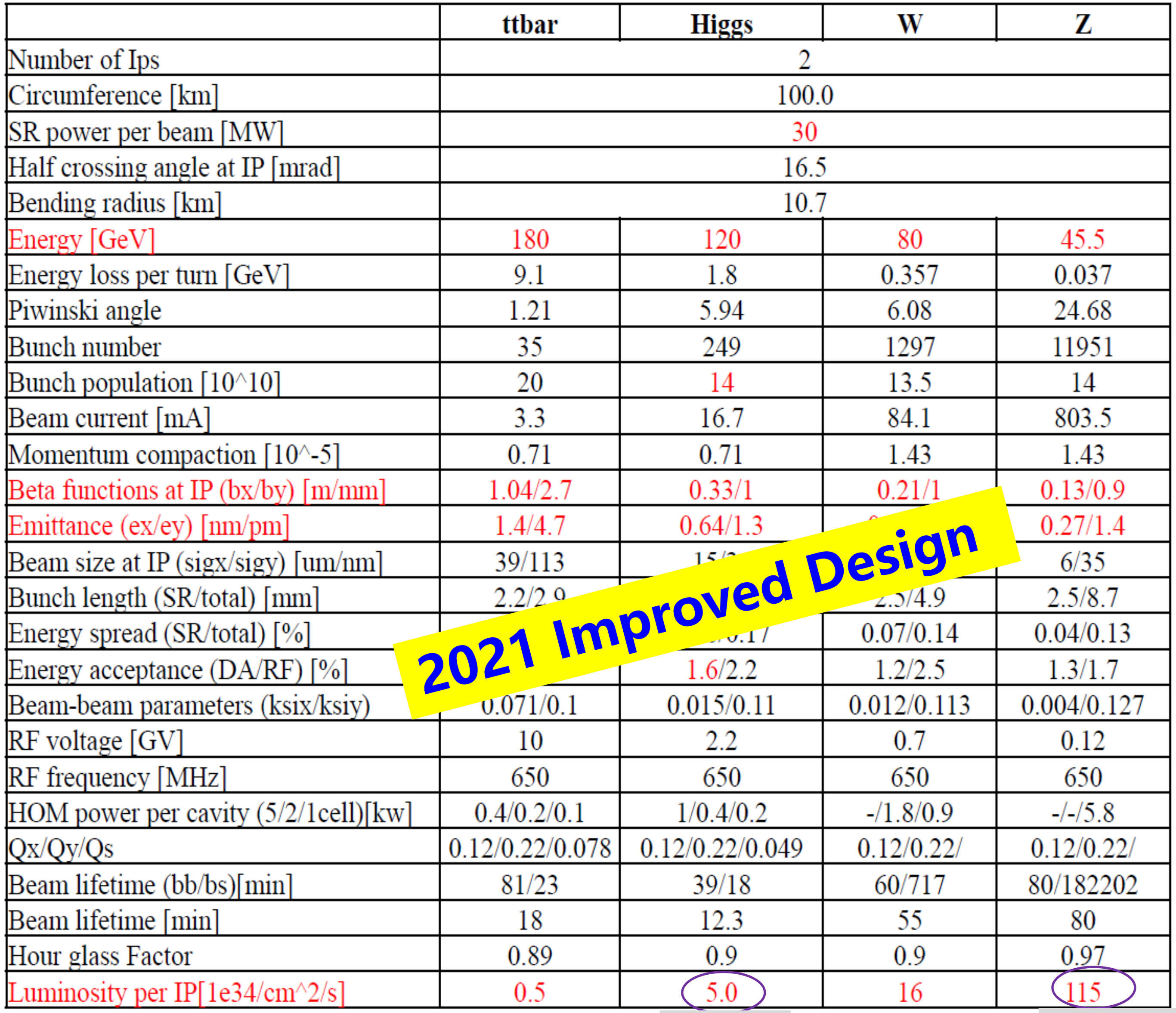
CEPC Accelerator Design Improvement



2018 CDR Baseline Design

	Higgs	W	Z（3T）	Z（2T）
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5 × 2			
Piwinski angle	3.48	7.0	23.8	
Particles /bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number	242	1524	12000 (10% gap)	
Bunch spacing (ns)	680	210	25	
Beam current (mA)	17.4	87.9	461.0	
Synch. radiation power (MW)	30	30	16.5	
Bending radius (km)	10.7			
Momentum compaction (10^{-5})	1.11			
β function at IP β_x^*/β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance x/y (nm)	1.21/0.0024	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.06	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.018/0.109	0.013/0.123	0.004/0.06	0.004/0.079
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz)	650			
Harmonic number	216816			
Natural bunch length σ_z (mm)	2.72	[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 Chromati[illegible]	[illegible]	[illegible]1161	-491/-1161	-513/-1594
[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



2021 Improved Design

	ttbar	Higgs	W	Z
Number of Ips	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	[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

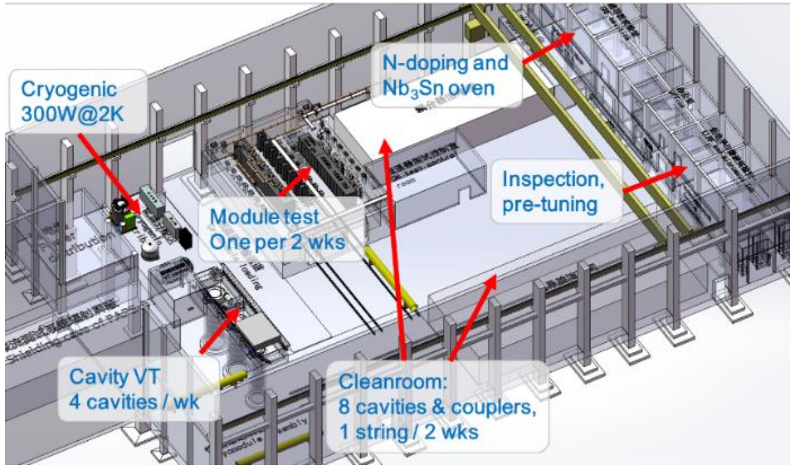
67%⇑

259%⇑

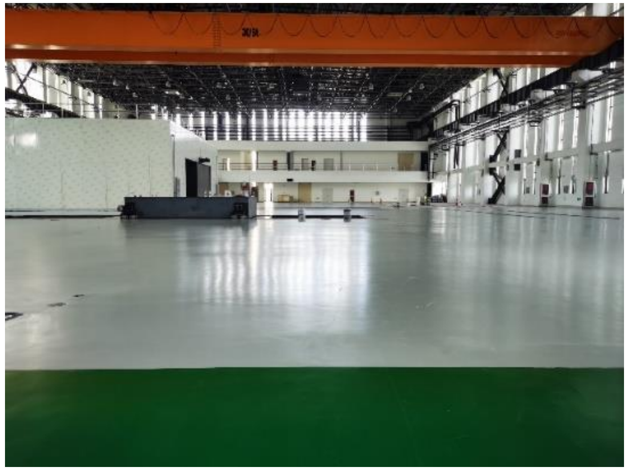
CEPC SCRF Test Facility

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

New SC Lab Design (4500m²)



SC New Lab will be available in 2021



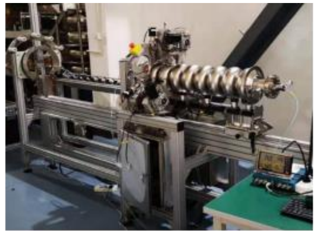
Crygenic system hall in 2020

Vacuum furnace (doping & annealing)

Nb3Sn furnace

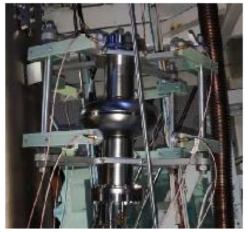
Nb/Cu sputtering device

Cavity inspection camera and grinder

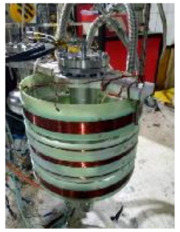


9-cell cavity pre-tuning machine

Temperature & X-ray
mapping system



Second sound cavity
quench detection system



Helmholtz coil for
cavity vertical test

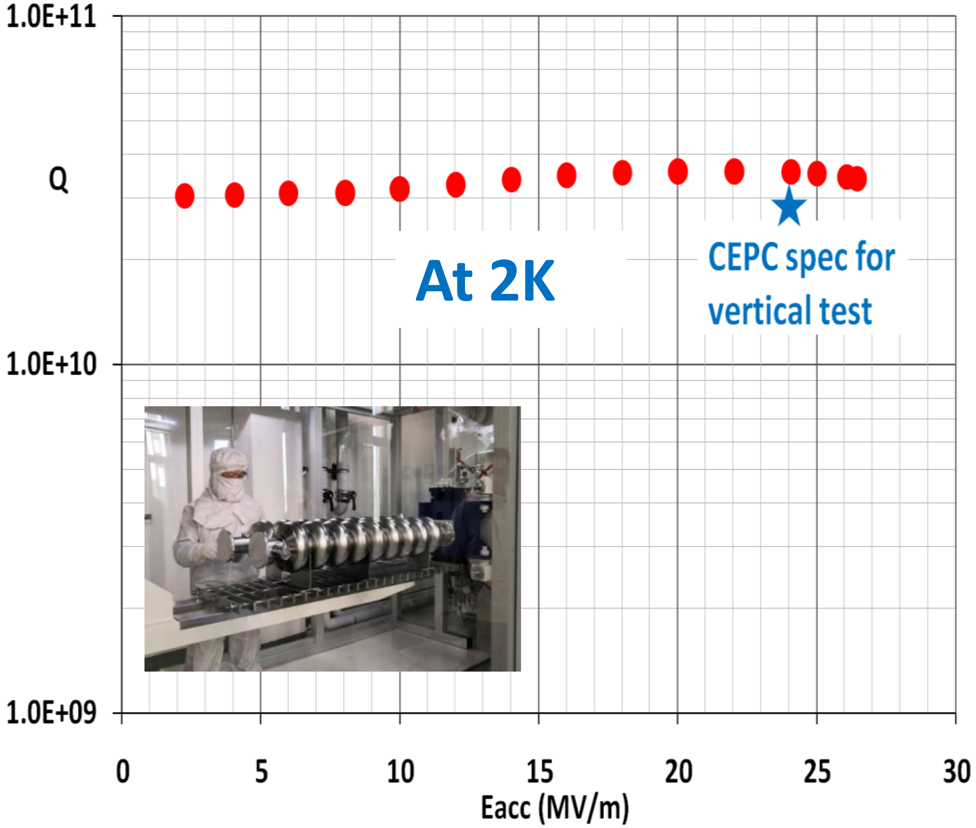
Vertical test dewars

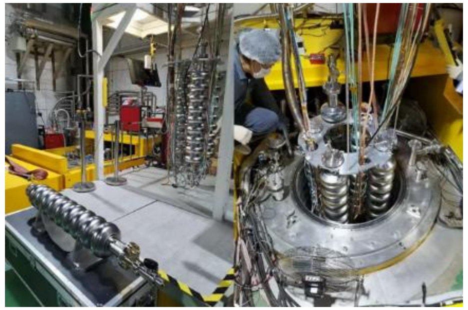
Horizontal test cryostat

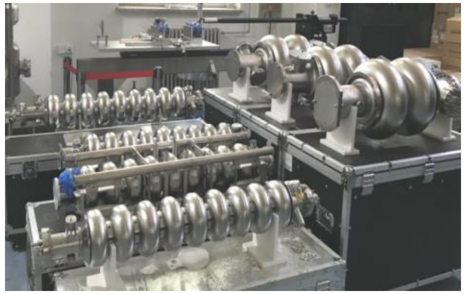
CEPC R&D: High Q SCRF Cavities

- IHEP Booster 1.3 GHz 9-cell SCRF cavity: Q = 3.4E10 @ 26.5 MV/m
- Collider ring 650 MHz 2-cell SCRF cavity: Q = 6.0E10 @ 22.0 MV/m
- SCRF cavities for both booster & collider ring reach CEPC design goal

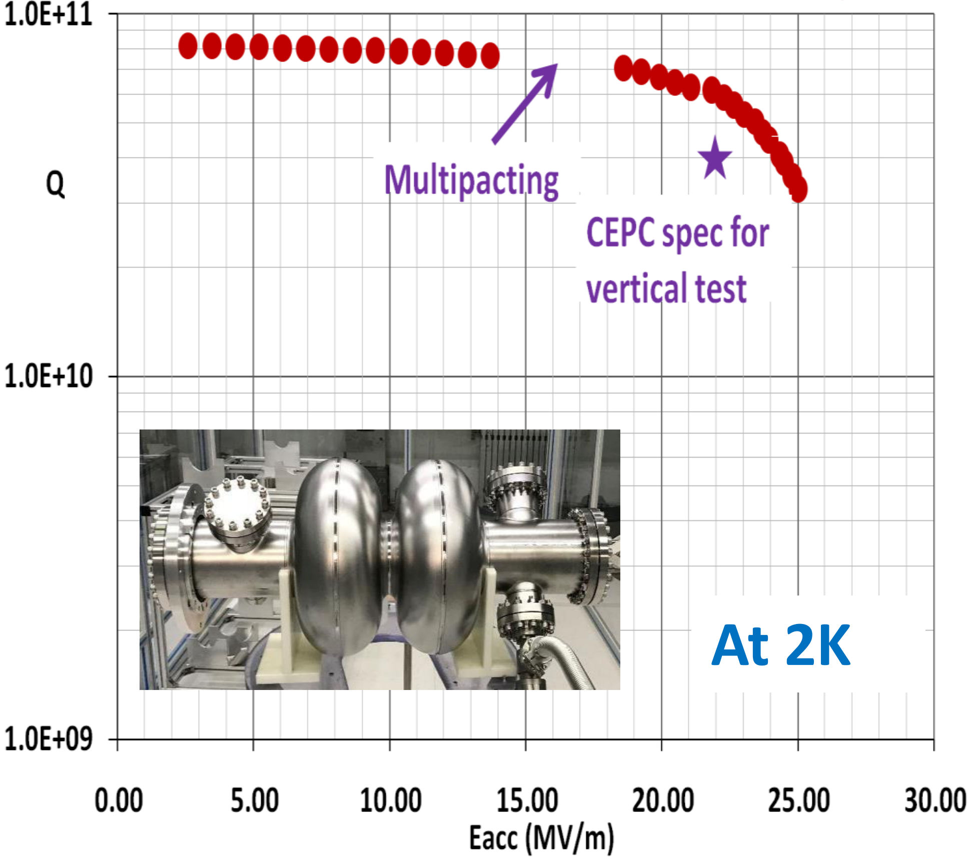
Vertical test of 1.3 GHz 9-cell cavity







Vertical test of 650 MHz 2-cell cavity

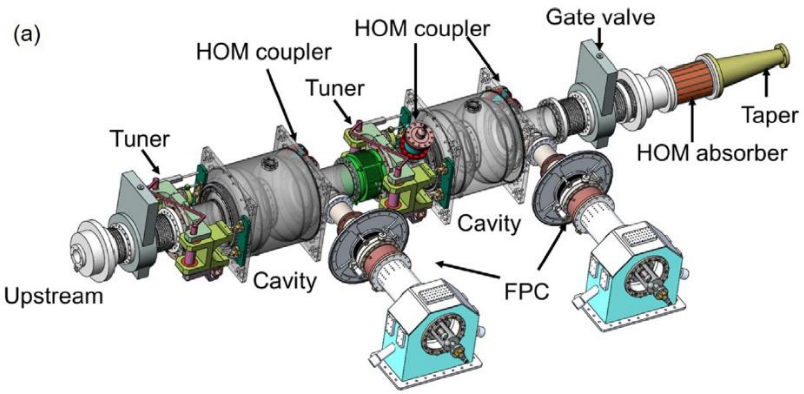


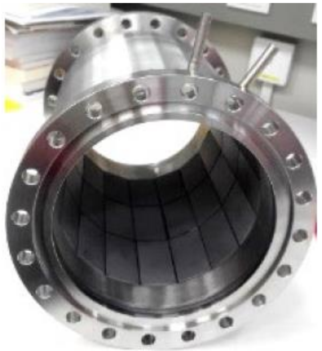
Medium-temperature (Mid-T) annealing adopted to reach Q = 3.4E10 @ 26.5 MV/m

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

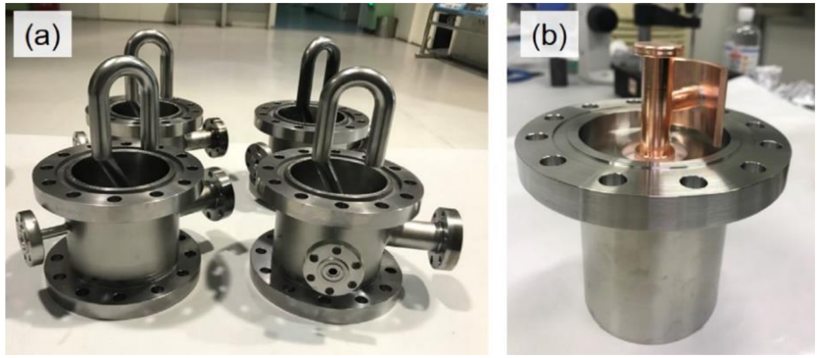
CEPC R&D: 650MHz SCRF Module

- **Beijing PAPS test facility: two 650MHz 2-cell cavity test module is under preparation and for CEPC key technology R&D.**

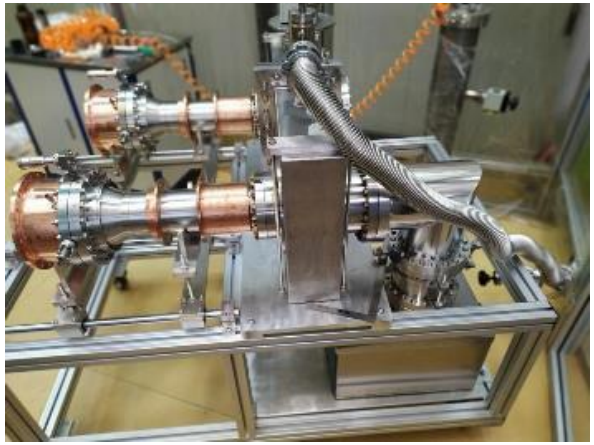




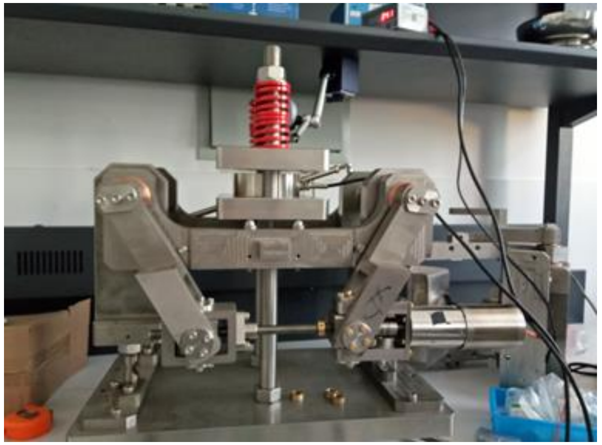
HOM Absorber（5kW）



HOM Coupler（1kW）



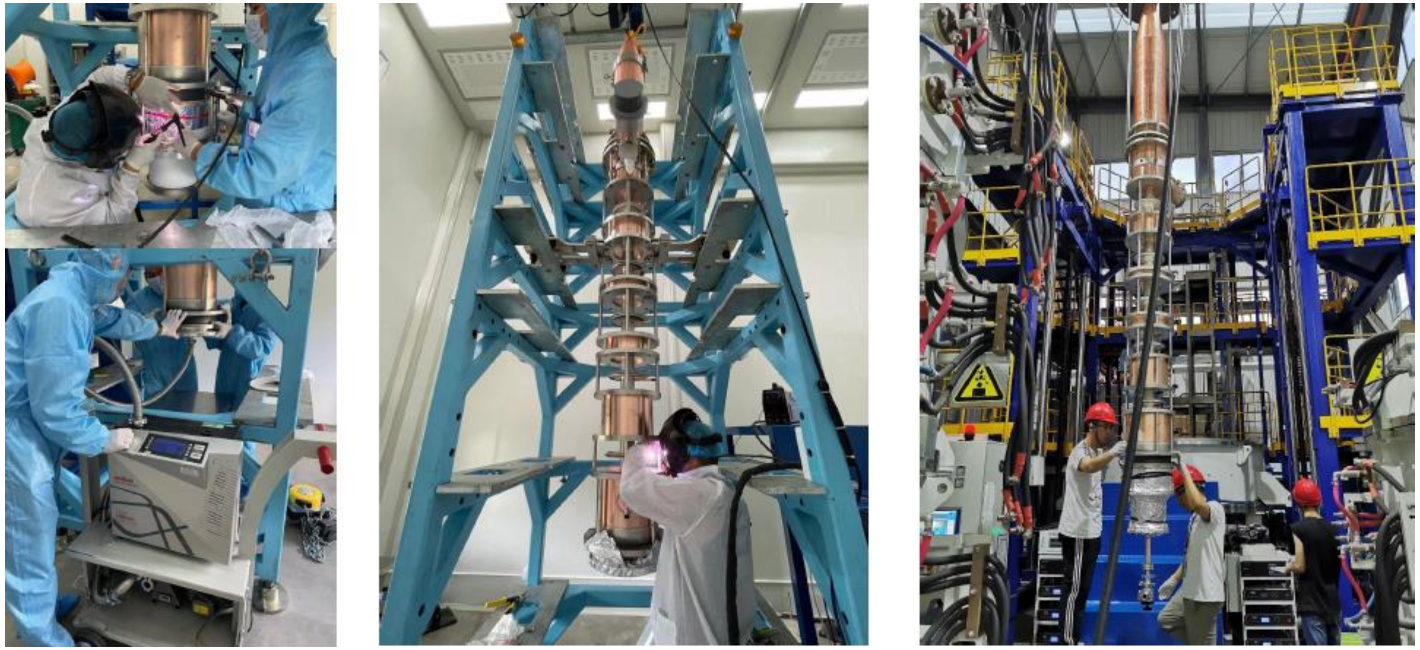
650MHz Mian Coupler (400kW)



SC Cavity Tuner

CEPC R&D: High Efficiency Klystrons

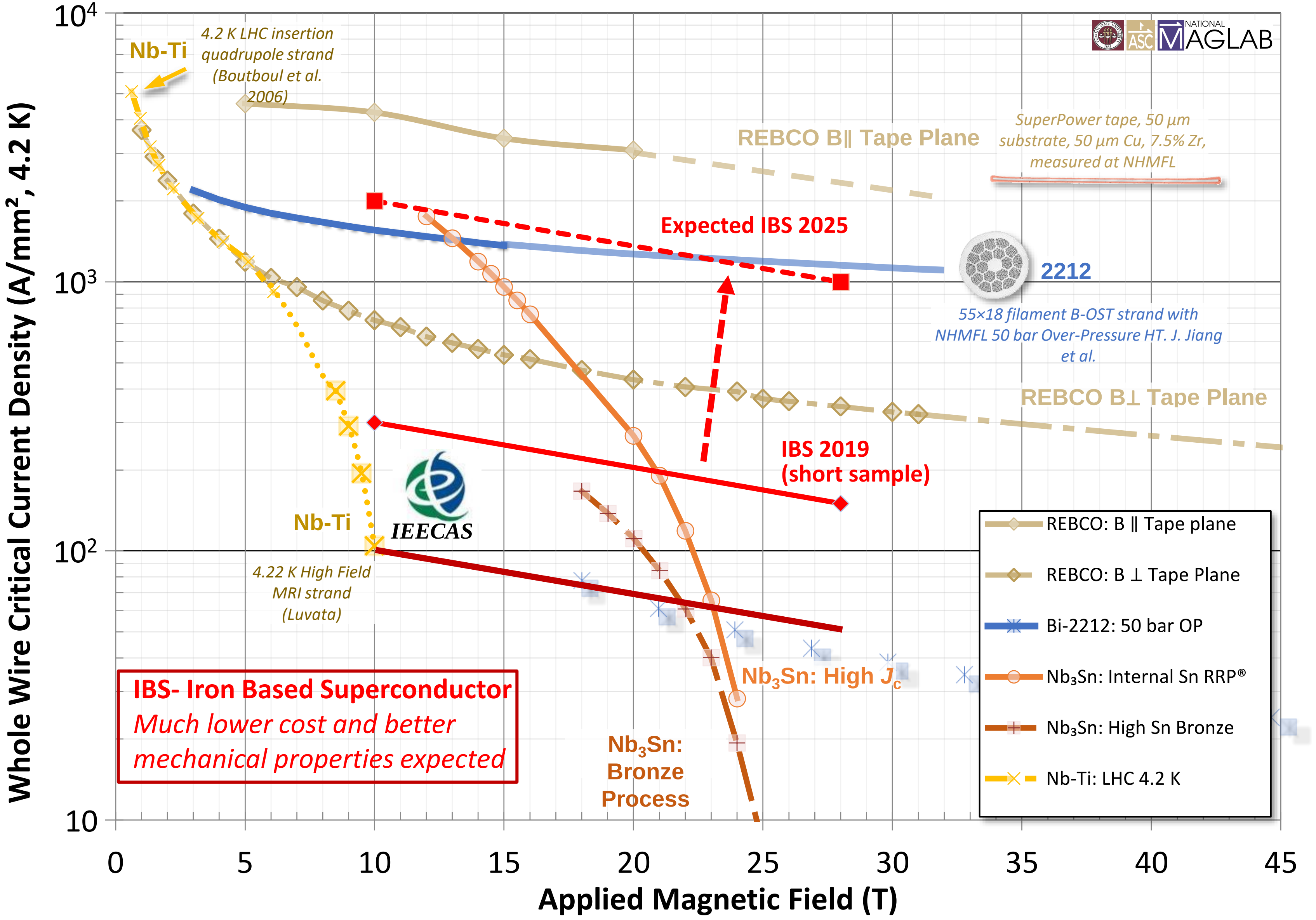
- The 1st prototype finished fabrication & passed the max. power test. Output power reaches 700 kW in CW mode, 800 kW in pulsed mode. Power transfer efficiency achieved ~ 62%.
- The 2nd klystron prototype is manufactured and being baked out, to be tested at PAPS in 2021, designed efficiency is ~ 77%.
- Multi-beam Klystron design is finished, designed efficiency is ~ 80.5%.
- One of the key technologies for the CEPC accelerator R&D



Klystron Assembly

High Power Test

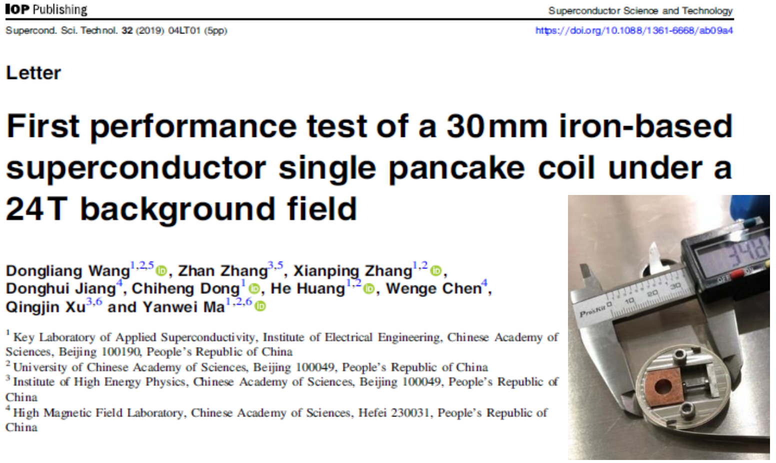
HTS SC Magnet



IBS- Iron Based Superconductor

Much lower cost and better mechanical properties expected

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

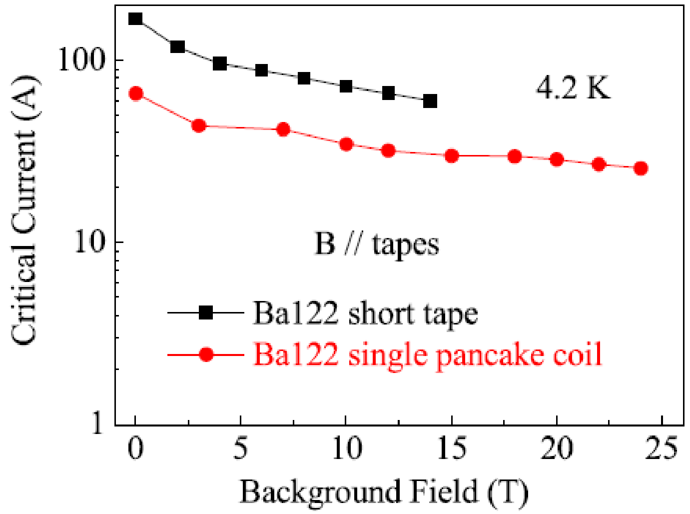
Dongliang Wang[1,2,5], **Zhan Zhang**[3,5], **Xianping Zhang**[1,2], **Donghui Jiang**[4], **Chiheng Dong**[1], **He Huang**[1,2], **Wenge Chen**[4], **Qingjin Xu**[3,6] **and Yanwei Ma**[1,2,6]

[1] Key Laboratory of Applied Superconductivity, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, People's Republic of China

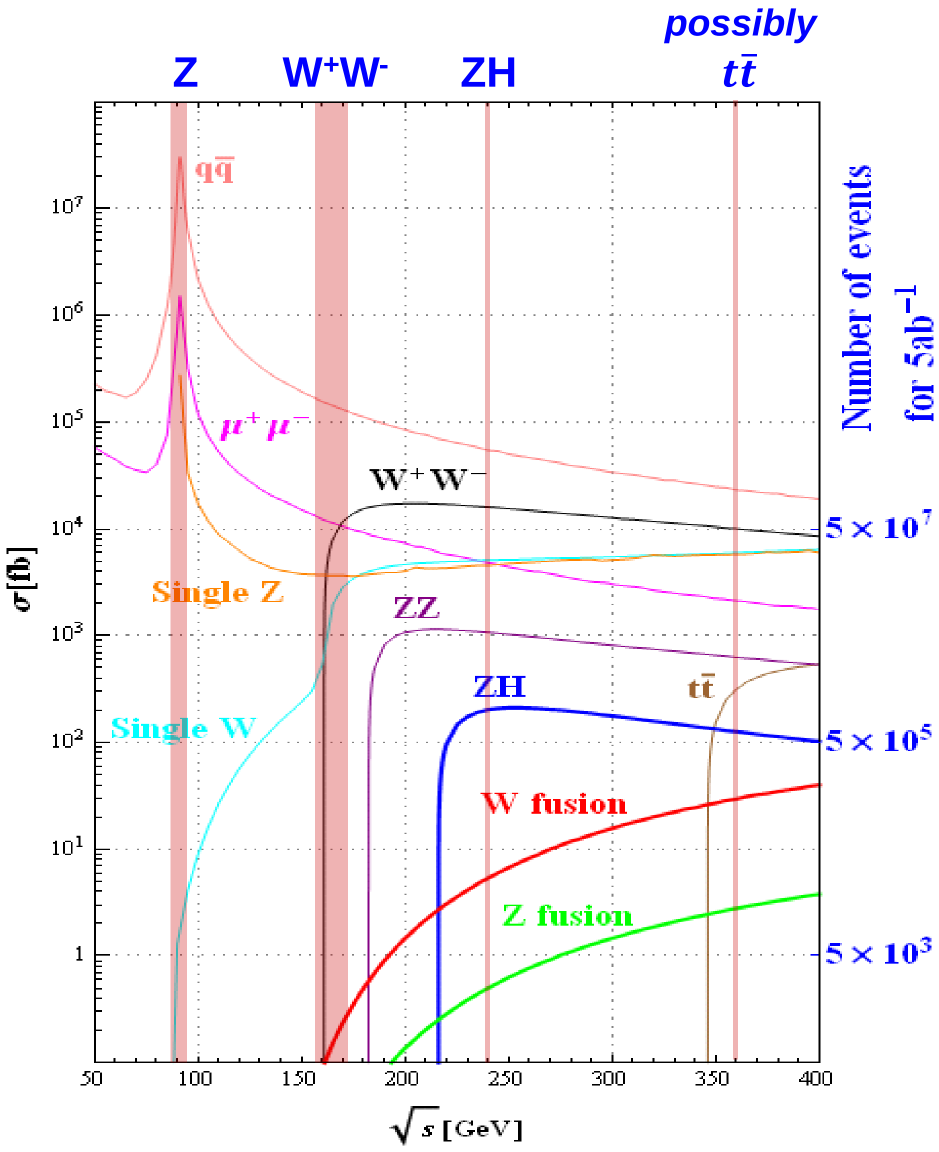
[2] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China

[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



The CEPC Physics Program



See MQ Ruan, YQ Fang and Xuai Zhuang's talks

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

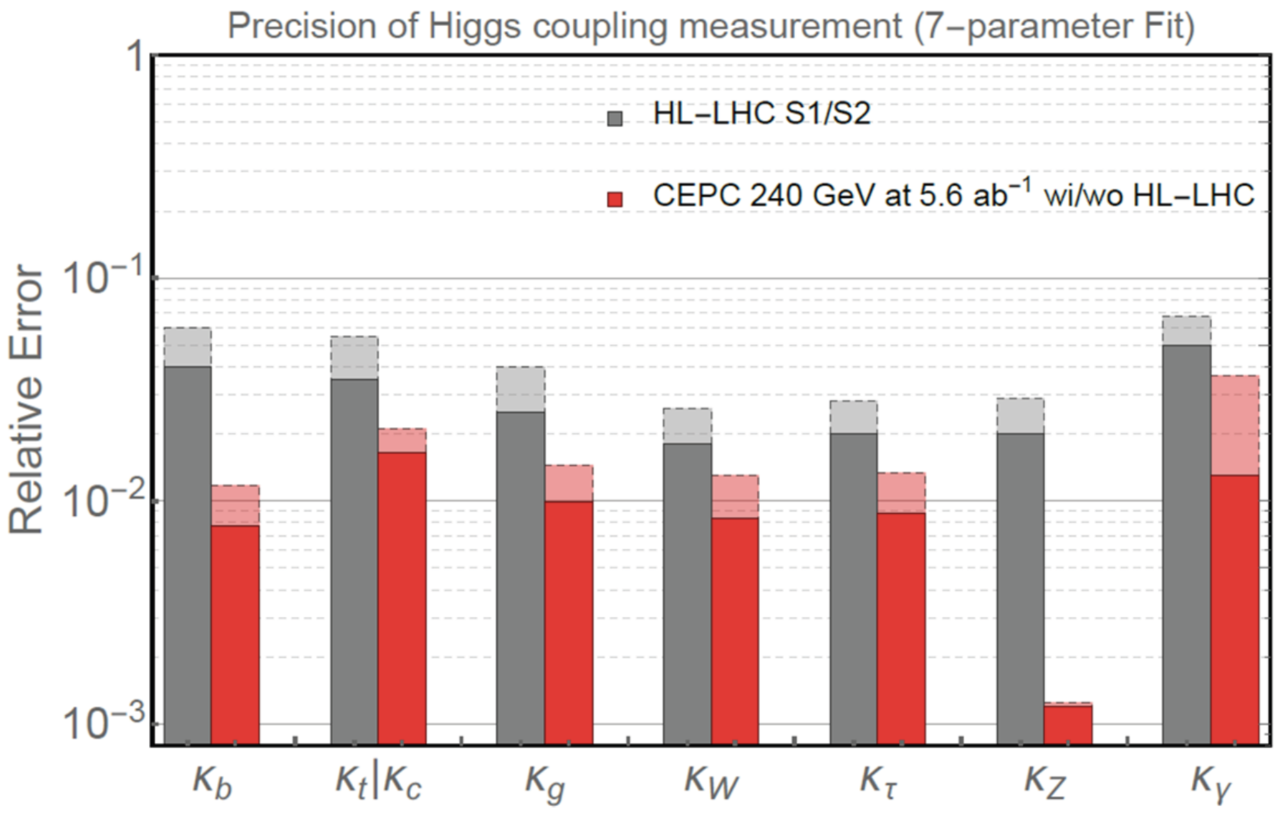
The large samples from 2 IPs:
~**10^6** Higgs, **~$2\text{x}10^7$** W, **~$7\text{x}10^{11}$** Z bosons

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

CEPC Physics Performance (CDR)

Order of magnitude improvement in precision ⇒ Unknown / discoveries

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



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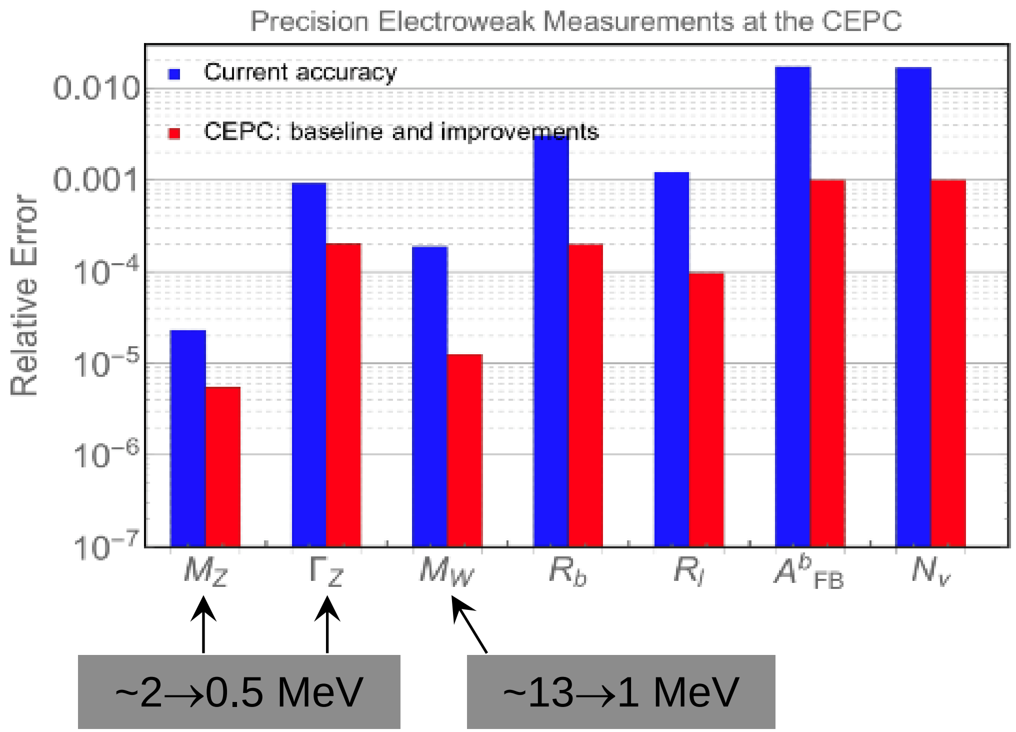
CEPC can improve the precision of the EW parameters by a factor of ~ 5-10

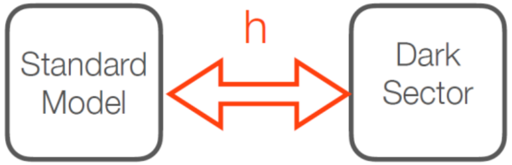


~2→0.5 MeV

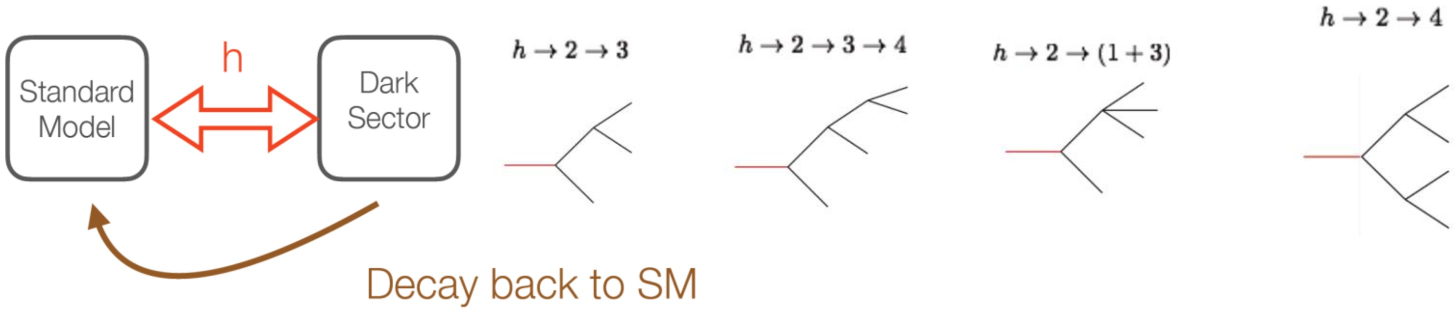
~13→1 MeV

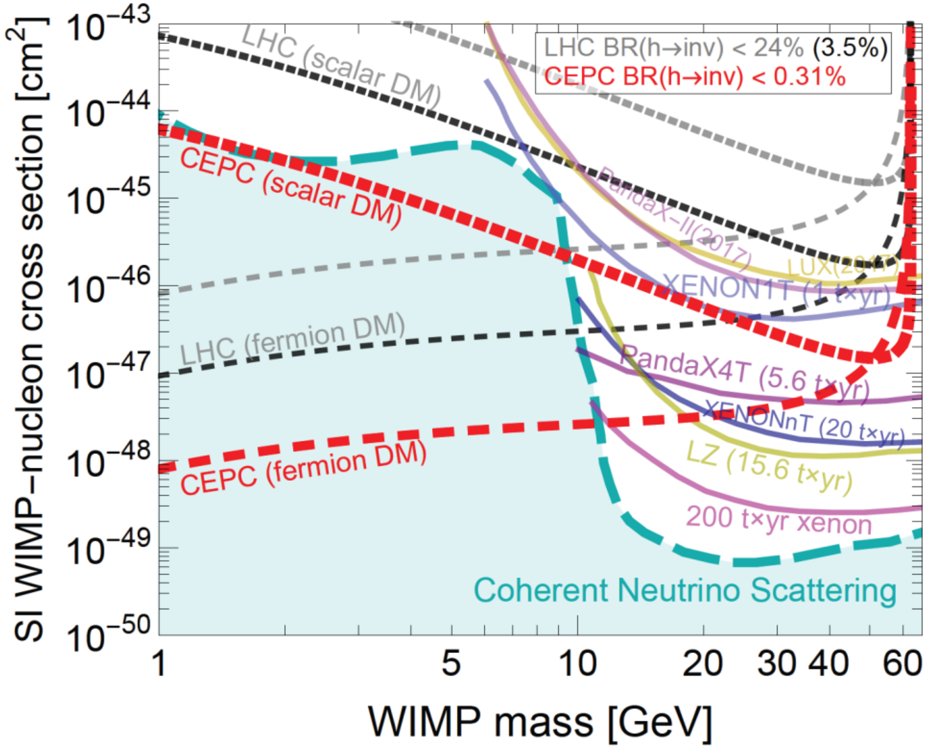
- **Precision EW measurements,**
- **Flavor physics (b, c, tau),**
- **Study of QCD,**
- **Probe physics BSM.**

Discovery Potential for New Physics

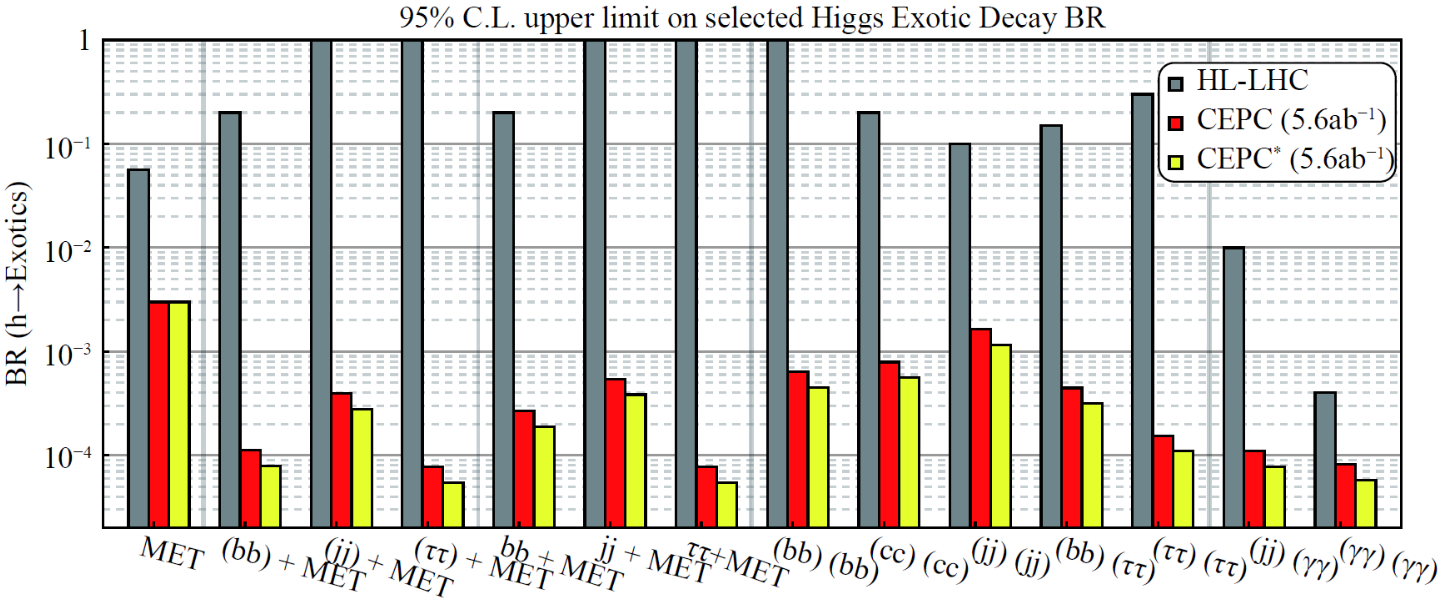


$$h \to X_{\mathrm{dm}} X_{\mathrm{dm}}$$





Higgs decays into BSM particles, H→ X_1X_2



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

Requirements of CEPC Detector

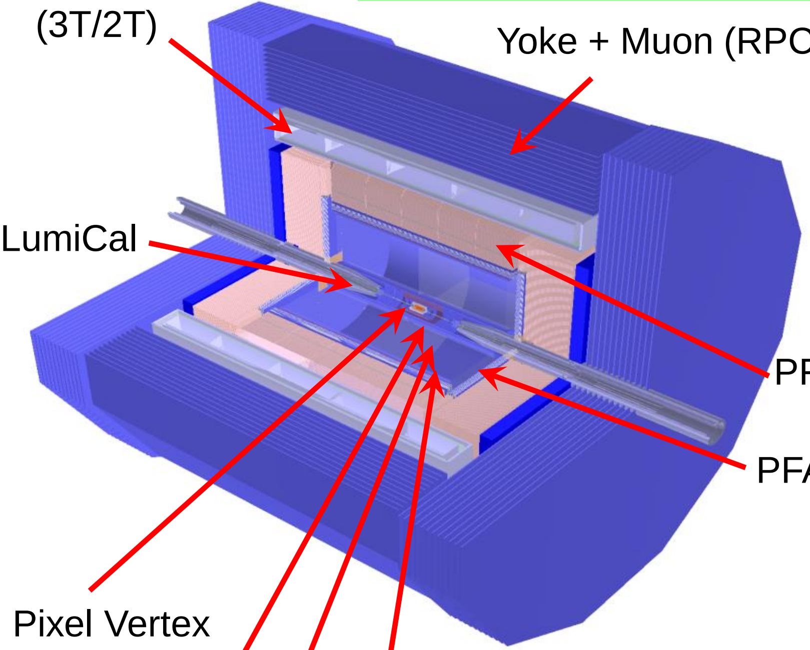
The physics motivations dictate our selection of detector technologies

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



Magnet (3T/2T)

Yoke + Muon (RPC or μ-RWELL)

LumiCal

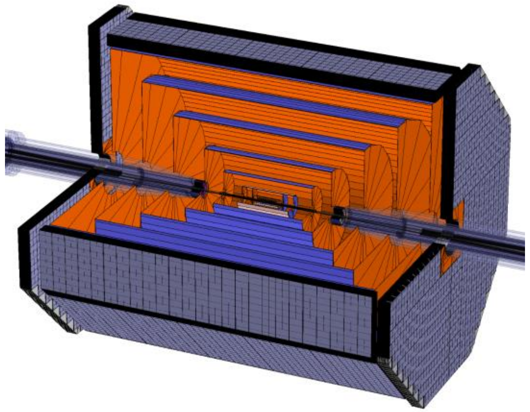
PFA HCAL

PFA ECAL

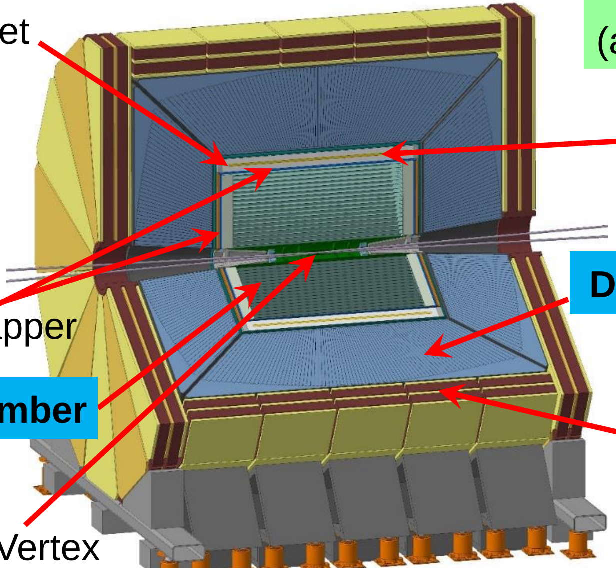
Si Pixel Vertex

SIT TPC SET
FTD ETD

FST concept
(Full Silicon Tracker)



IDEA concept
(also proposed for FCC-ee)



2T Magnet

Preshower (μ-RWELL)

Silicon wrapper

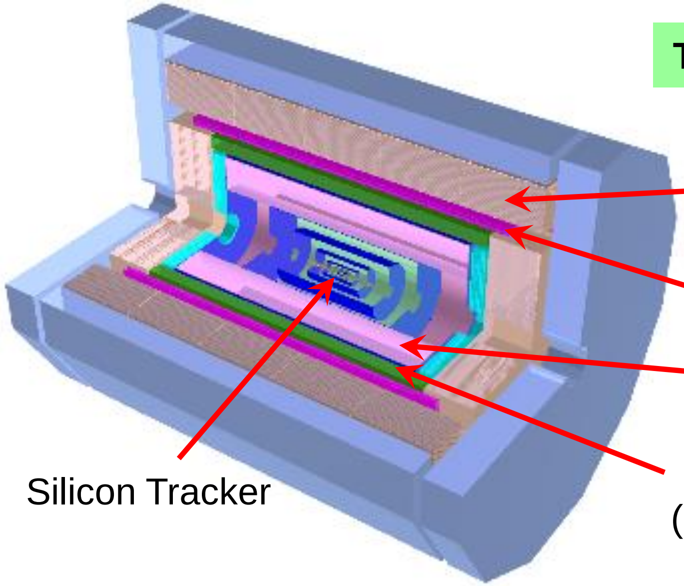
Dual-readout calorimeter

Drift chamber

Yoke + Muon (μ-RWELL)

Si Pixel Vertex

The 4th Concept



PFA HCAL
Partially Yoke

Magnet (3T/2T)

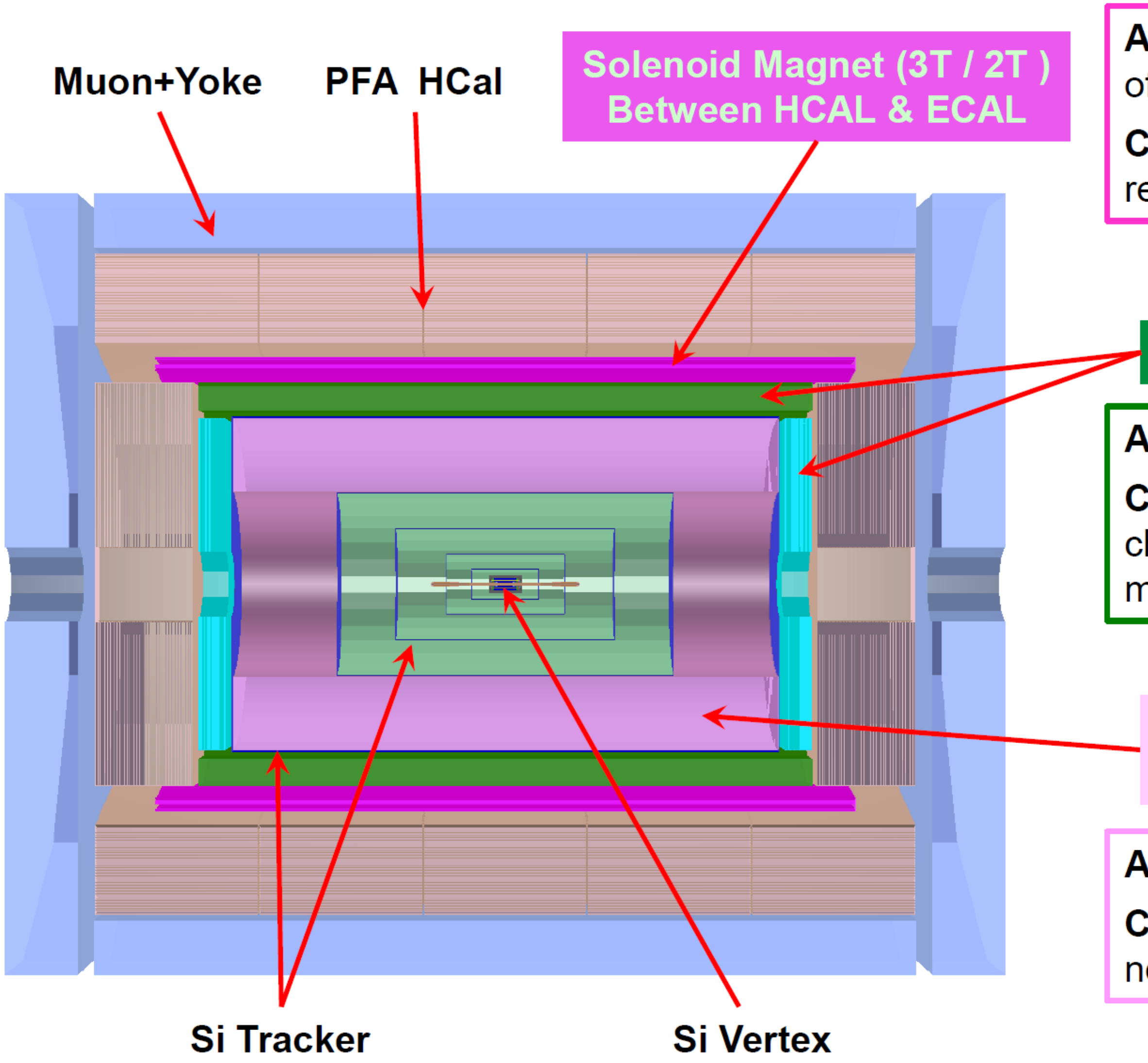
PID (DC+ToF)

Silicon Tracker

Crystal ECAL
(Transverse bar)

The 4th Conceptual Detector Design

- **New detector concept: Si Tracker + DC for PID + PFA Crystal ECAL + Thin Solenoid Magnet btw ECAL and HCAL**



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

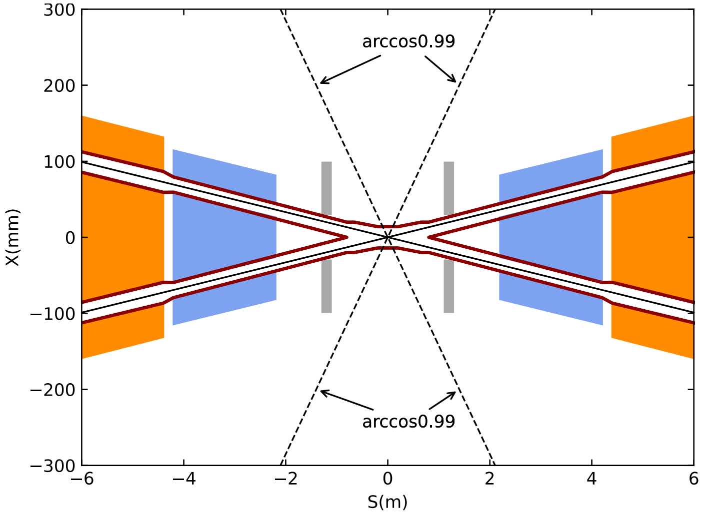
Advantage: Work at high luminosity Z runs

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

CEPC R&D: Machine Detector Interface (MDI)

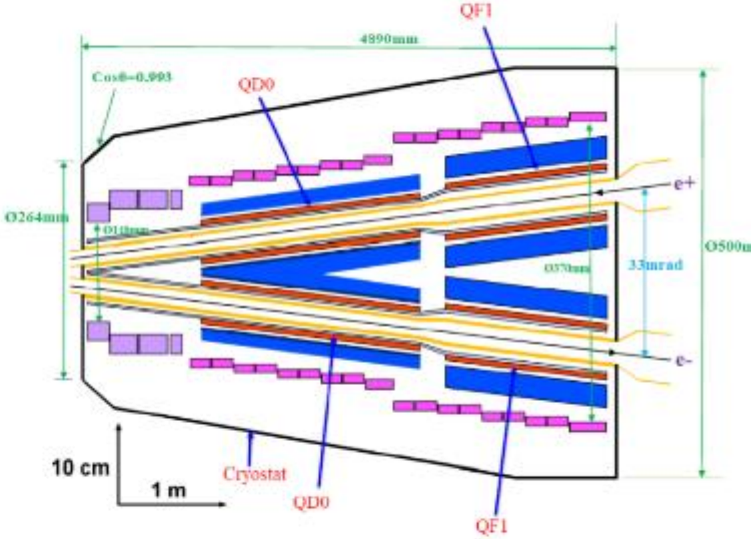
Crossing angle: 33 mrad,

Focal length: 2.2 m



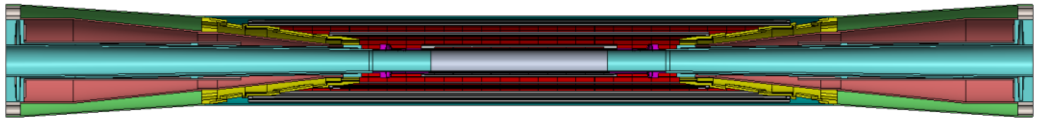
Final focusing magnets (QD0, QF1) with

Segmented Anti-Solenoidal Magnets

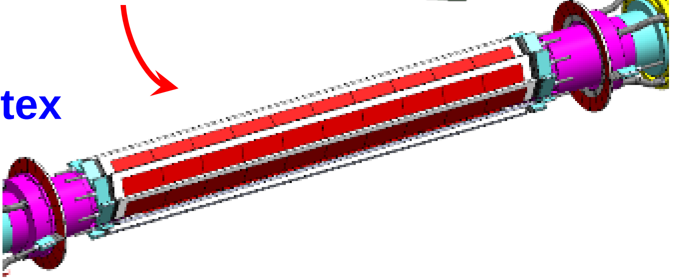


Beam Pipe

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

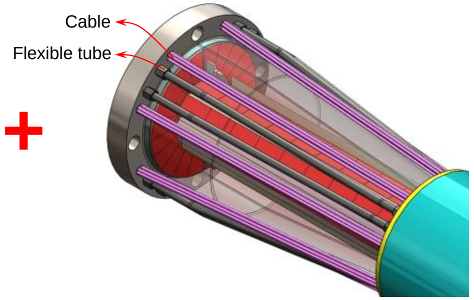


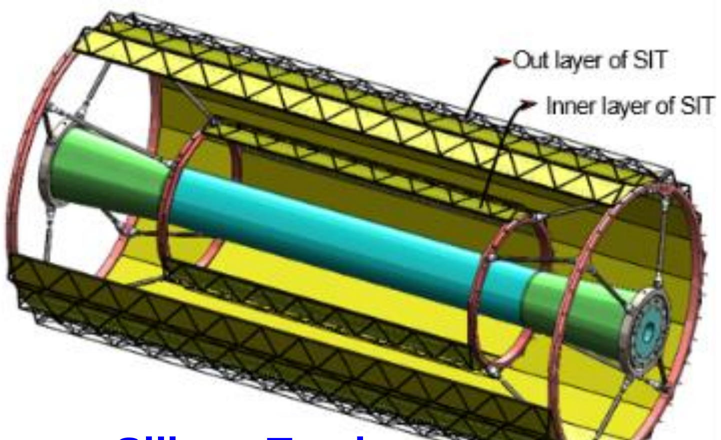
Vertex



+

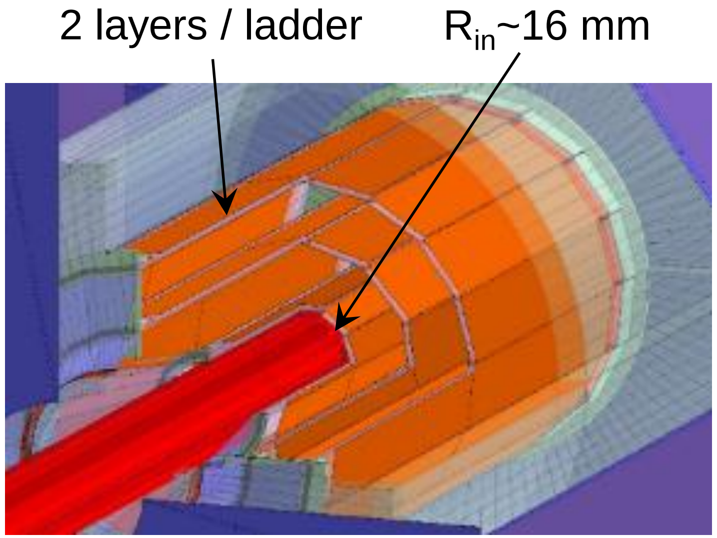
LumiCal Tracker





Silicon Tracker

CEPC R&D: Silicon Pixel ASIC Chips



Goal: σ(IP) ~ 5 μm for high P track

CDR design specifications

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

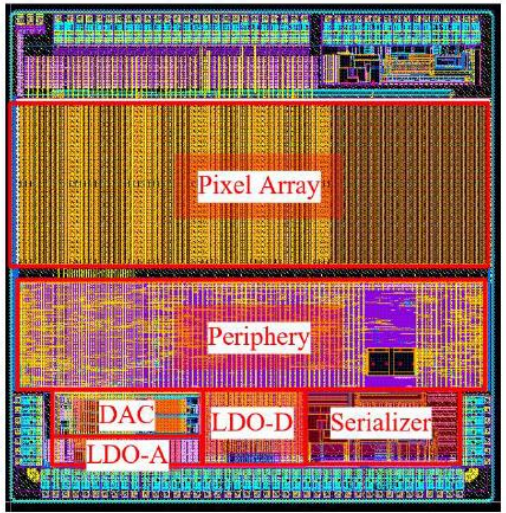
Silicon pixel sensor develops in 3 series:
JadePix, TaichuPix, CPV

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

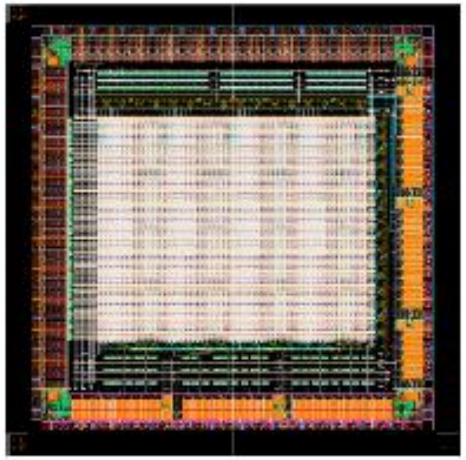


Full size TaichuPix-3 to be used for prototyping ladder

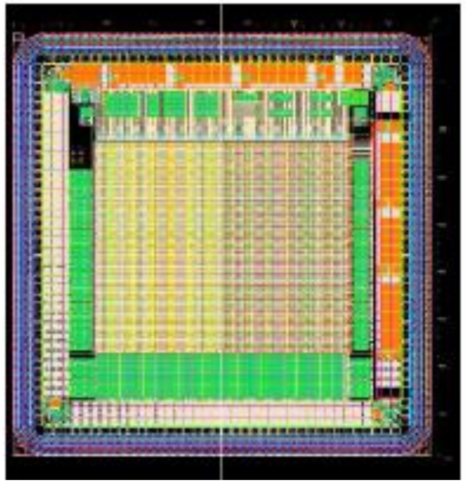
MOST 2

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

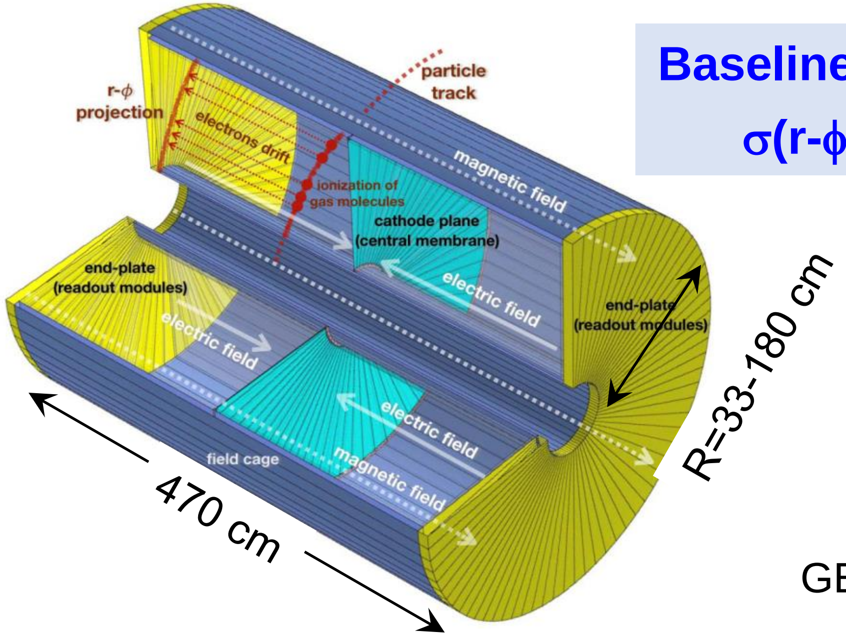
Upper chip



Lower chip

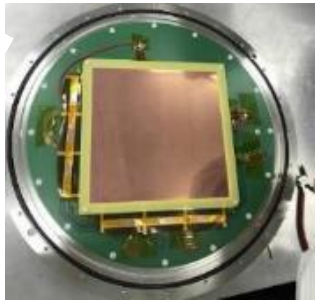


CEPC R&D: Time Projection Chamber

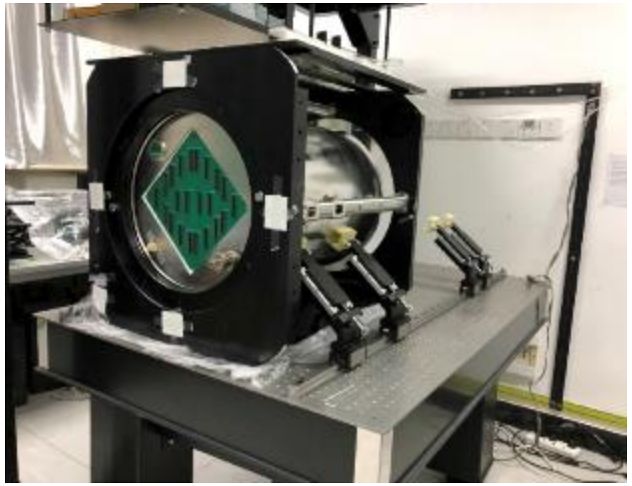


Baseline main tracker

$\sigma(r\text{-}\phi)$ ~100 μm



GEM-MM cathode

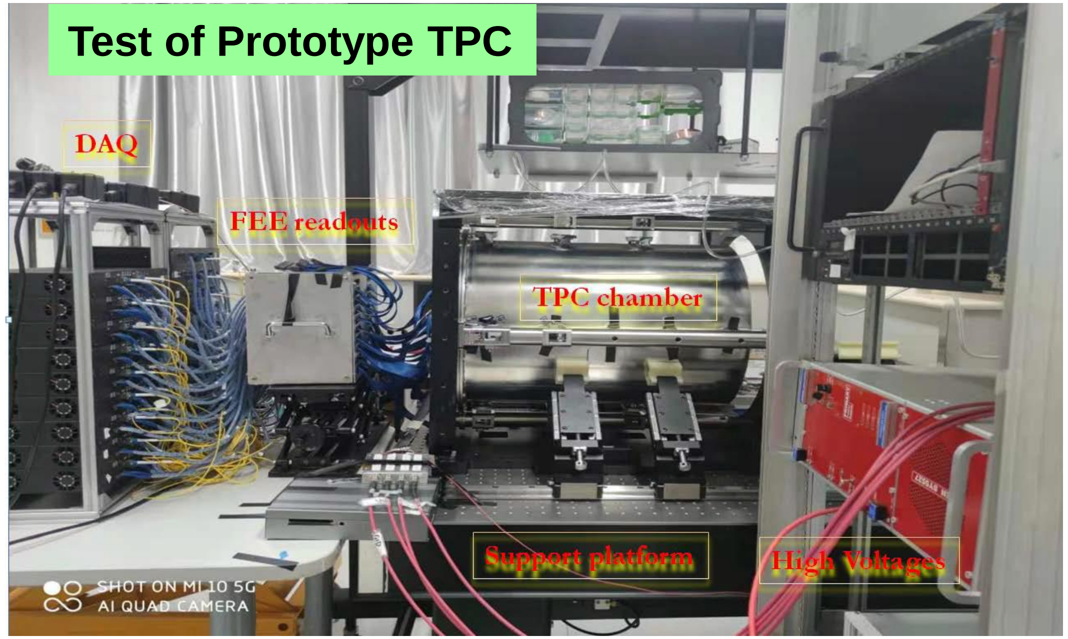


TPC Prototype + UV laser beams

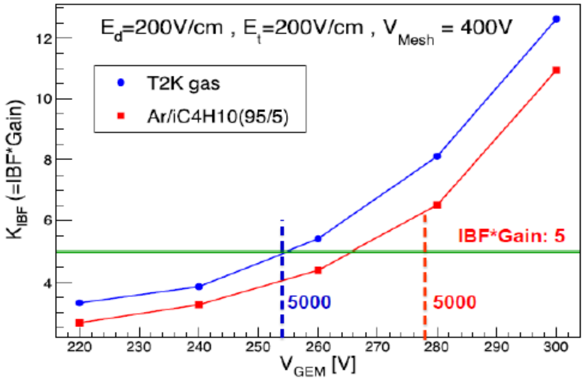
MOST 1

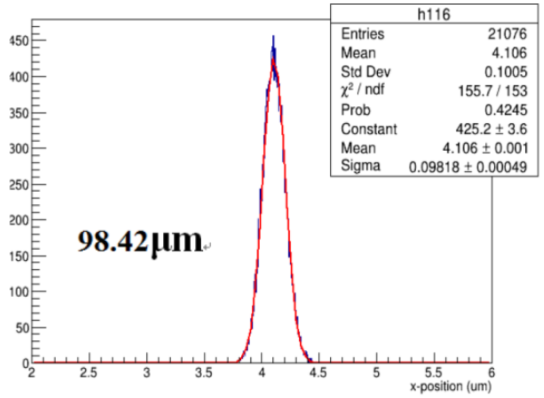
Low power FEE ASIC

Test of Prototype TPC



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





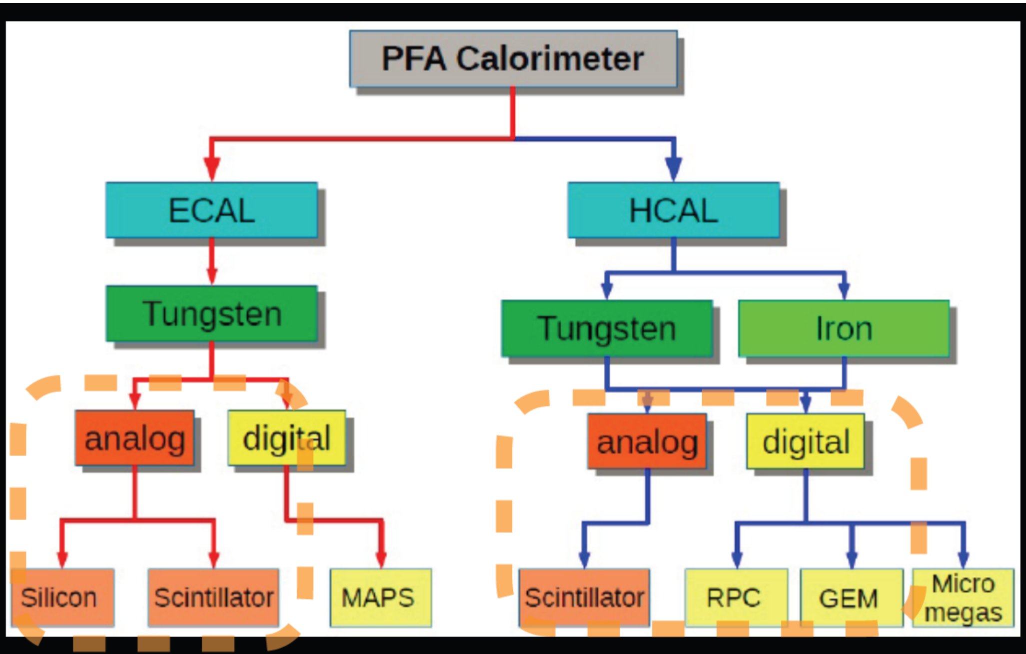
σ_x < 100 μm for drift length of 27cm

CEPC R&D: PFA Calorimeters

Calorimeter options

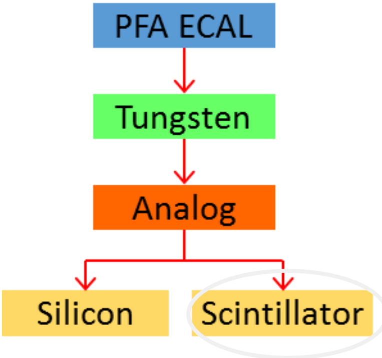
Chinese institutions have been focusing on Particle Flow calorimeters

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

CEPC R&D: ECAL Prototype

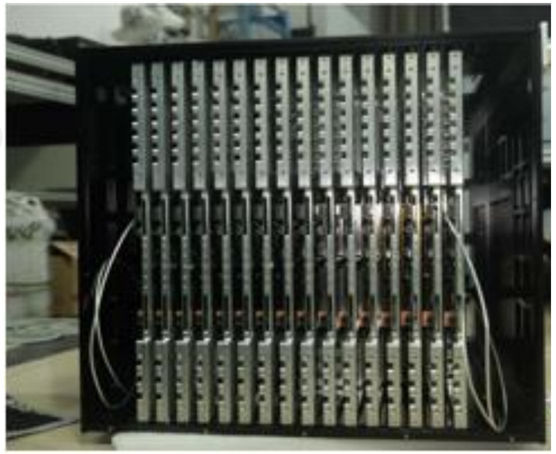


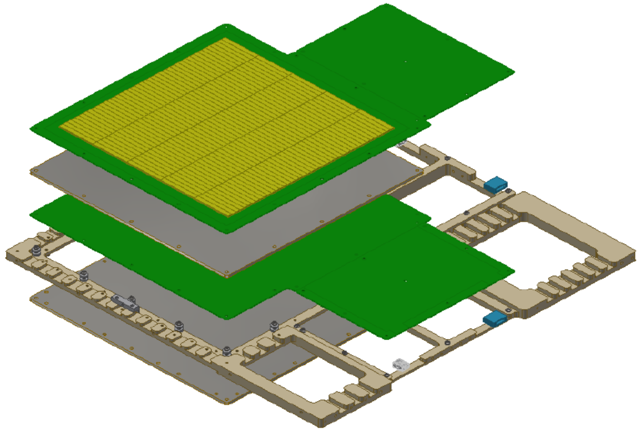
MOST 1

Goal of ECAL+HCAL+…

4% BMR, e.g. in (Z→νν) (H→gg)

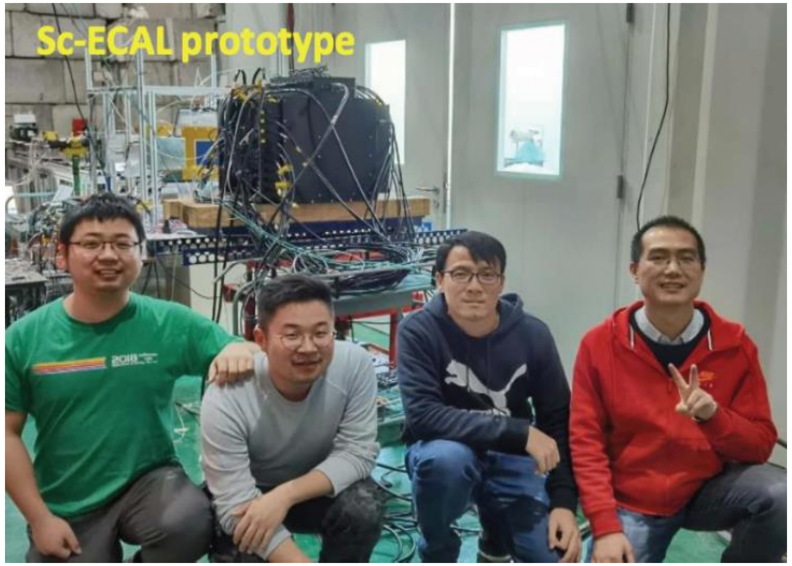
Sc-ECAL Prototype

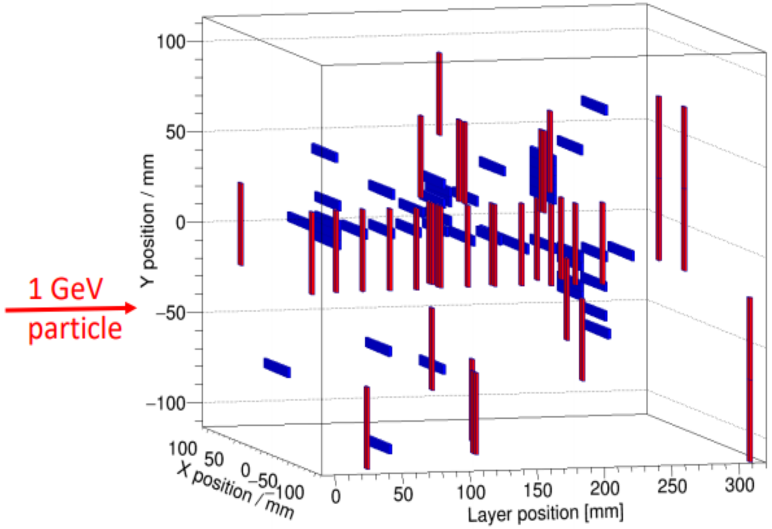


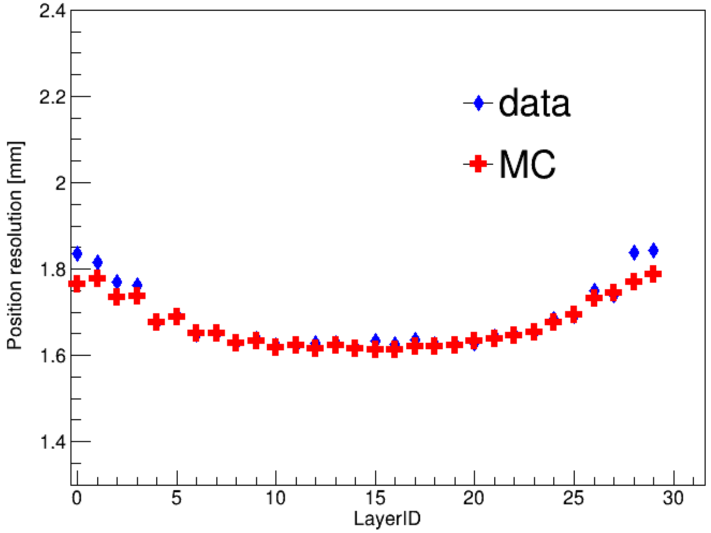


- **ScECAL prototype with 6700 channels**
- **32 active layer (EBU), 22 x 22 cm^2, ~22X_0**
- **Scintillator (5×45mm^2) + MPPC S12571**
- **Embedded FEE (192 SPIROC2E ASICs)**
- **It has been tested with cosmic rays & an electron beam at IHEP (Nov. 2020).**

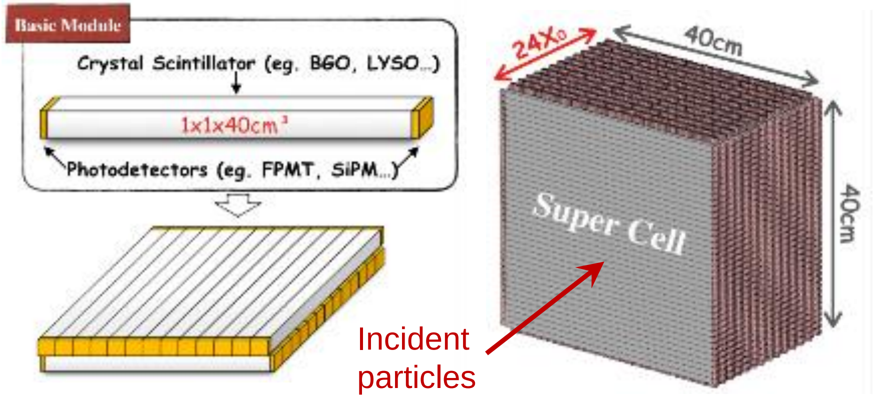
Cell Granularity: 5mm × 5mm
Position resolution: 1.6-1.8mm







CEPC R&D: High Granularity Crystal ECAL



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

Design Idea

Goal

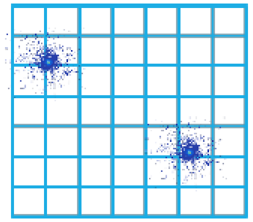
- **Comparable BMR resolution as with the Sci+W ECAL.**
- **Much better sensitivity to γ/e, especially at low energy.**

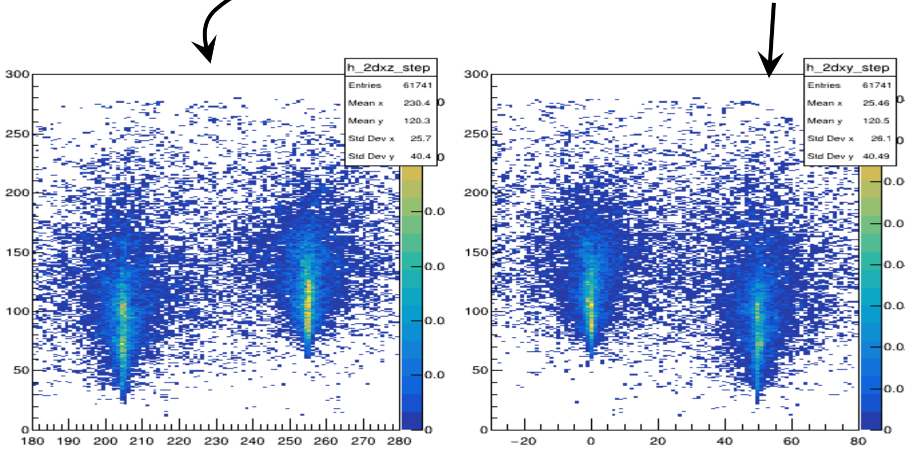
Test board for KLauS-5 in BGA package

Bench Test

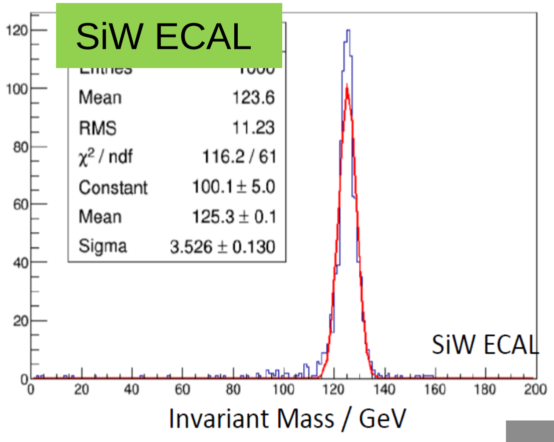
Recon. Algorithm

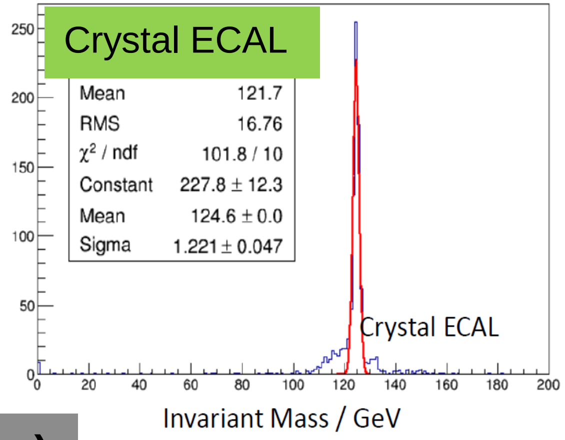
Energy & time matching solves ambiguity





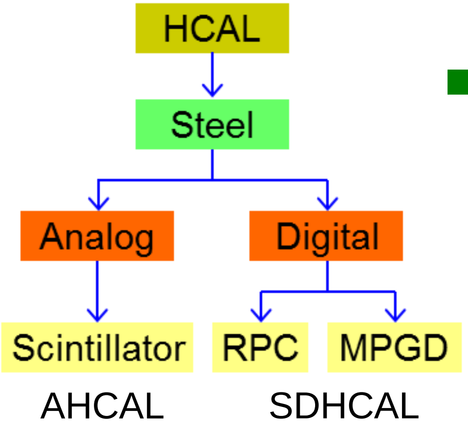
MC Simulation

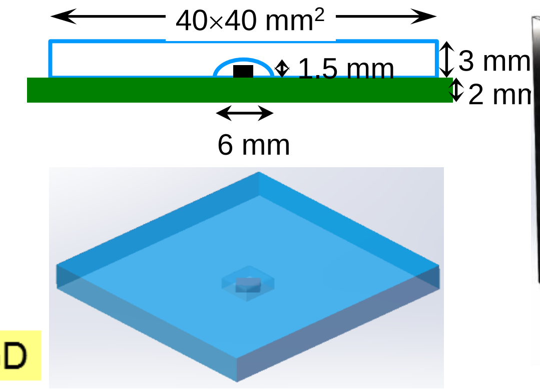


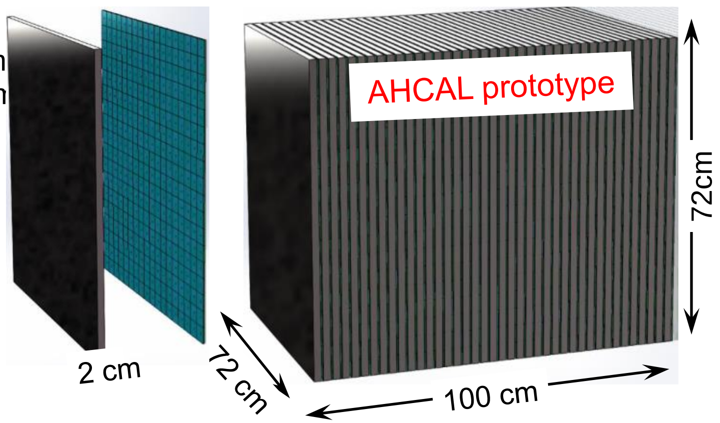


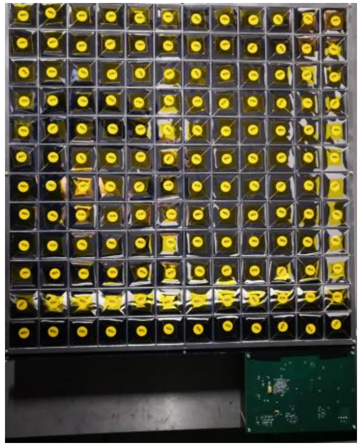
M(H→γγ)

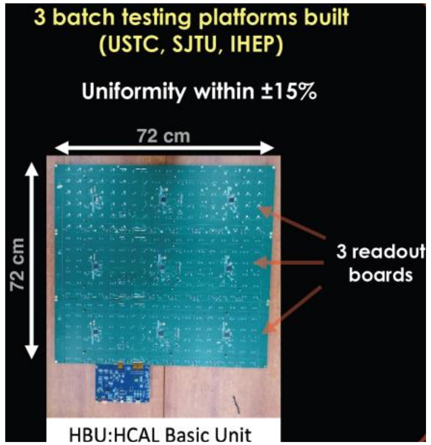
CEPC R&D: PFA HCAL











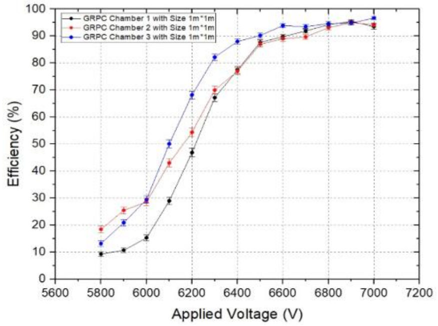
- **AHCAL with plastic scintillator+SiPM+SPIROC**

  Prototype in production, size 72×72×100 cm³, 40 layers, Fe+Sct+SiPM+PCB=20+3+2=25mm, Sct. cell size 40×40 mm²

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

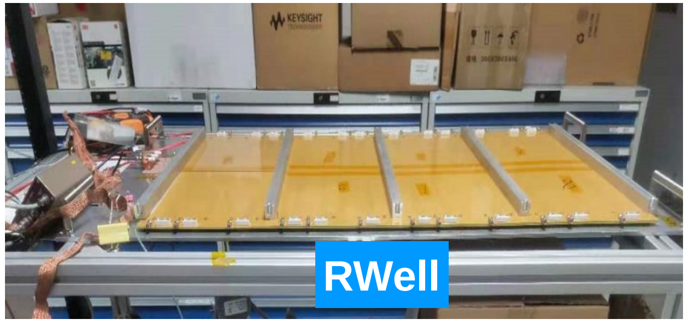
- **SDHCAL based on GRPC**

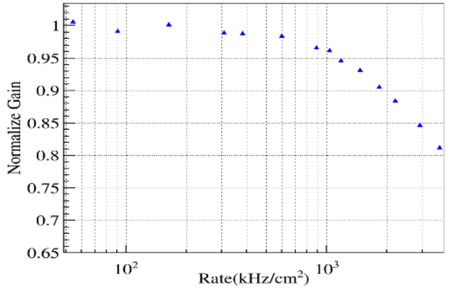
  Constructed 1×1 m² GRPCs, MIP Efficiency ~ 95%



- **SDHCAL based on MPGD**

  Constructed 1×0.5 m² RWell detector, MIP Efficiency ~ 96%, count rate ~ 1.8 MHz/cm²

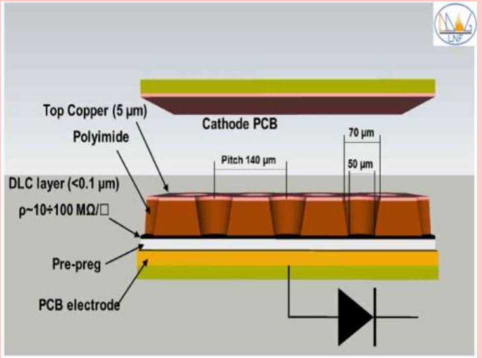


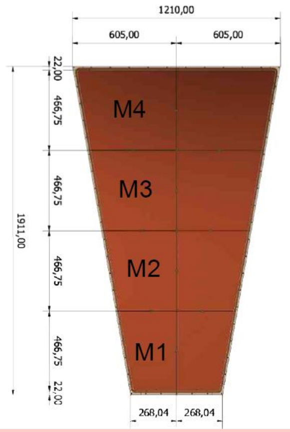


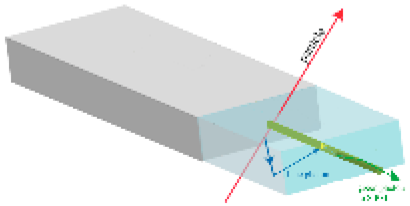
CEPC R&D: Muon Detector

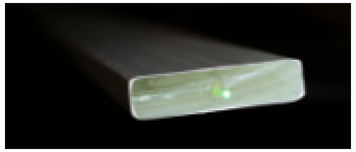
- **RPC R&D applies to both SDHCAL & Muon.**
- An alternative is **μ-RWELL** technology. The concept was proved. Currently focus mainly on industrialization and cost reduction.
- **Scintillator Muon detector. R&D overlaps with Belle II**
  - Building a prototype detector
  - Scintillator strips, improving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

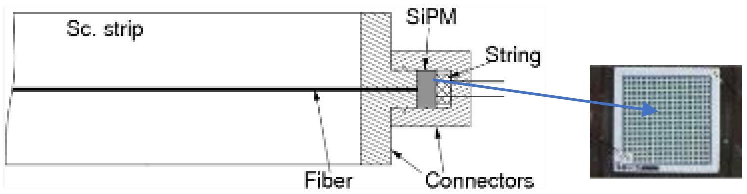
μRWELL for PS & Muon



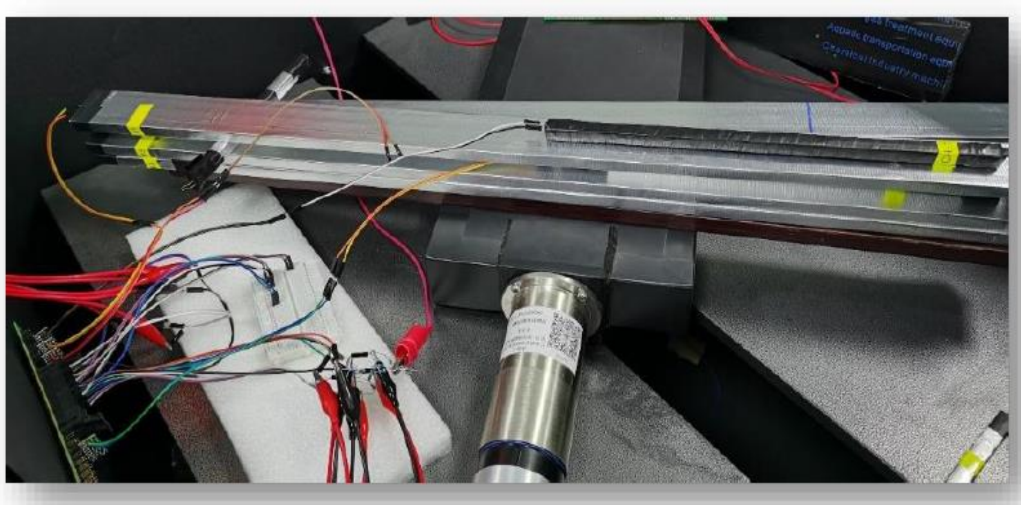


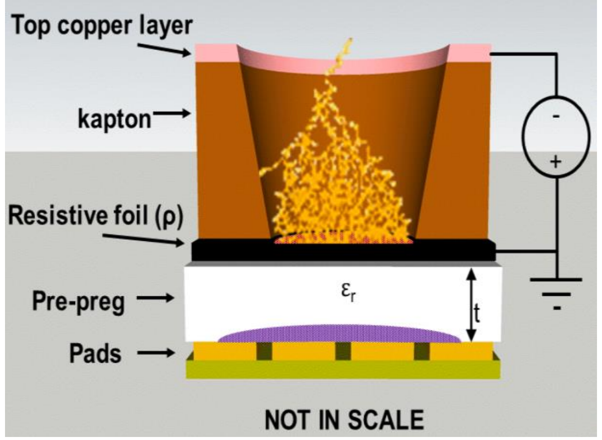






Fudan U.

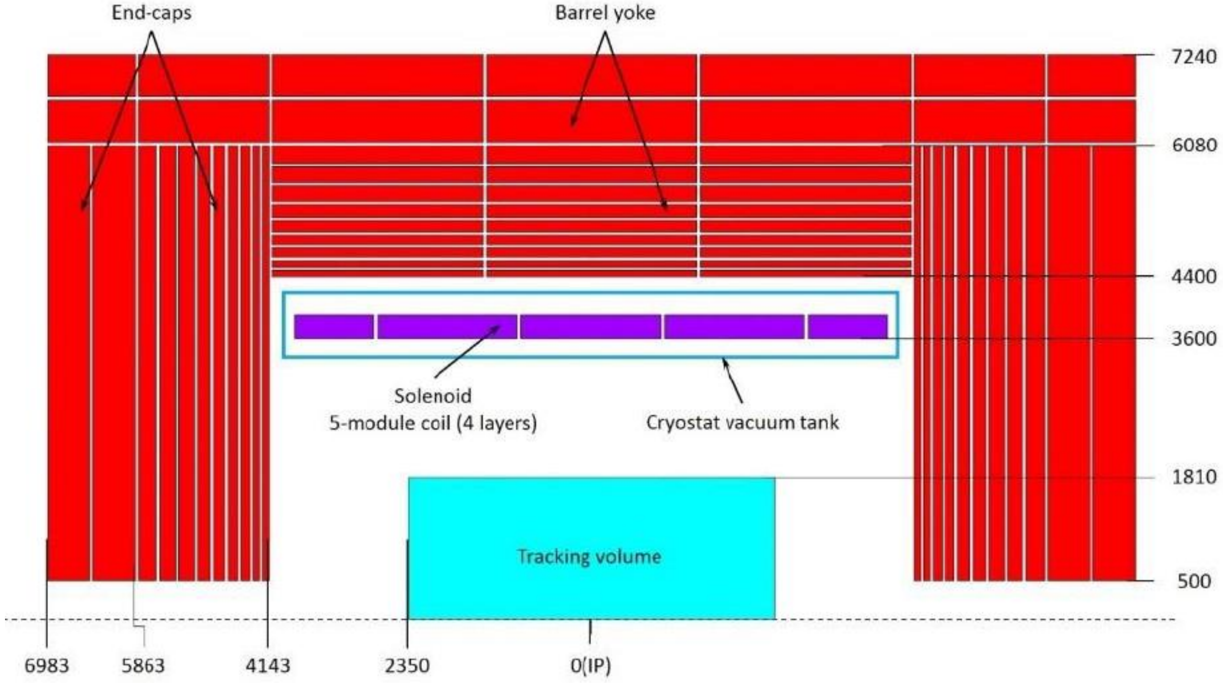


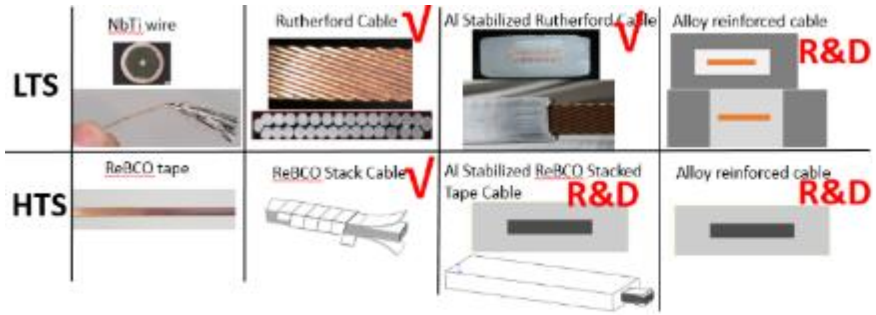


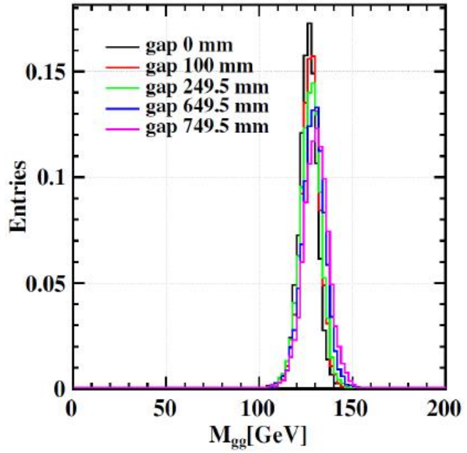
Achieved σ_t~2ns,

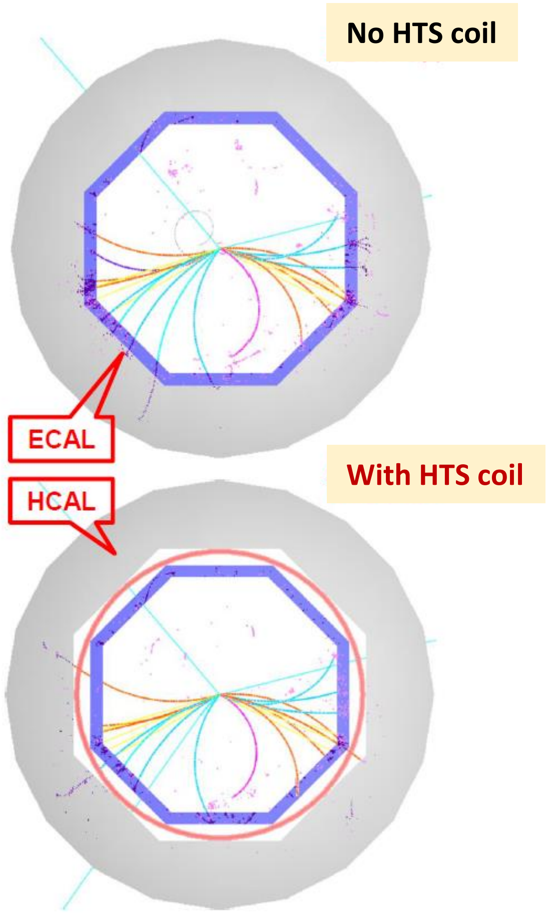
Aim for 100-200 ps.

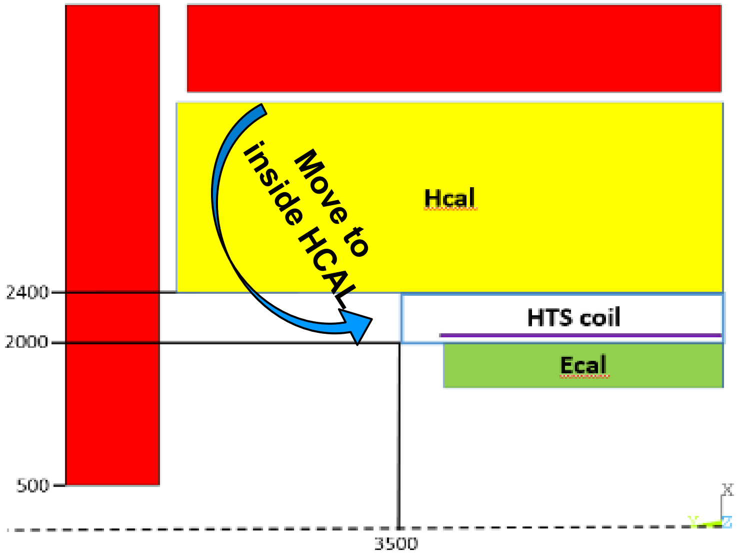
CEPC R&D: Solenoid Magnet

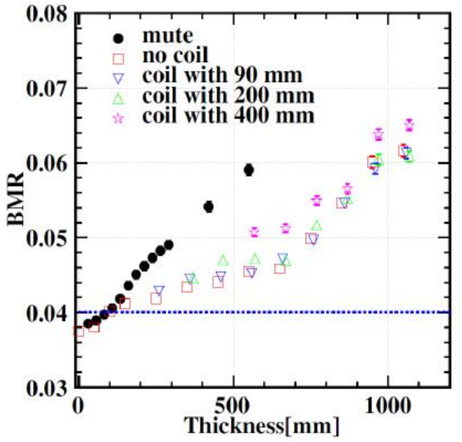












Main Challenges

Low mass, ultra-thin, high strength cable

Collaboration with Industry (CIPC)

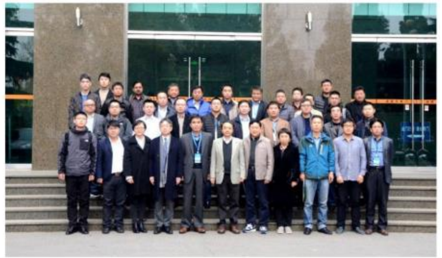

环形正负电子对撞机
Circular Electron Positron Collider
Member of CEPC Industrial Promotion Consortium（CIPC）
CEPC产业促进会
成员单位
北京中科富海低温科技有限公司
BEIJING SINOSCIENCE FULLCRYO TECHNOLOGY CO., LTD.

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

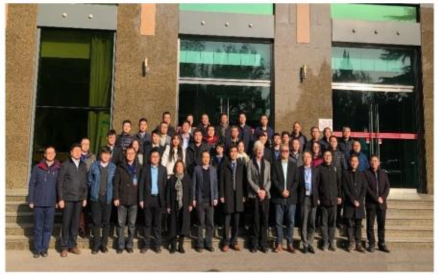


CEPC产业促进会第二次全体会议
企业代表与高能所合影
Representatives of enterprises in the plenary meeting, in Nov. 13 , 2018
30余家企业代表

Review of CIPC annual meeting

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

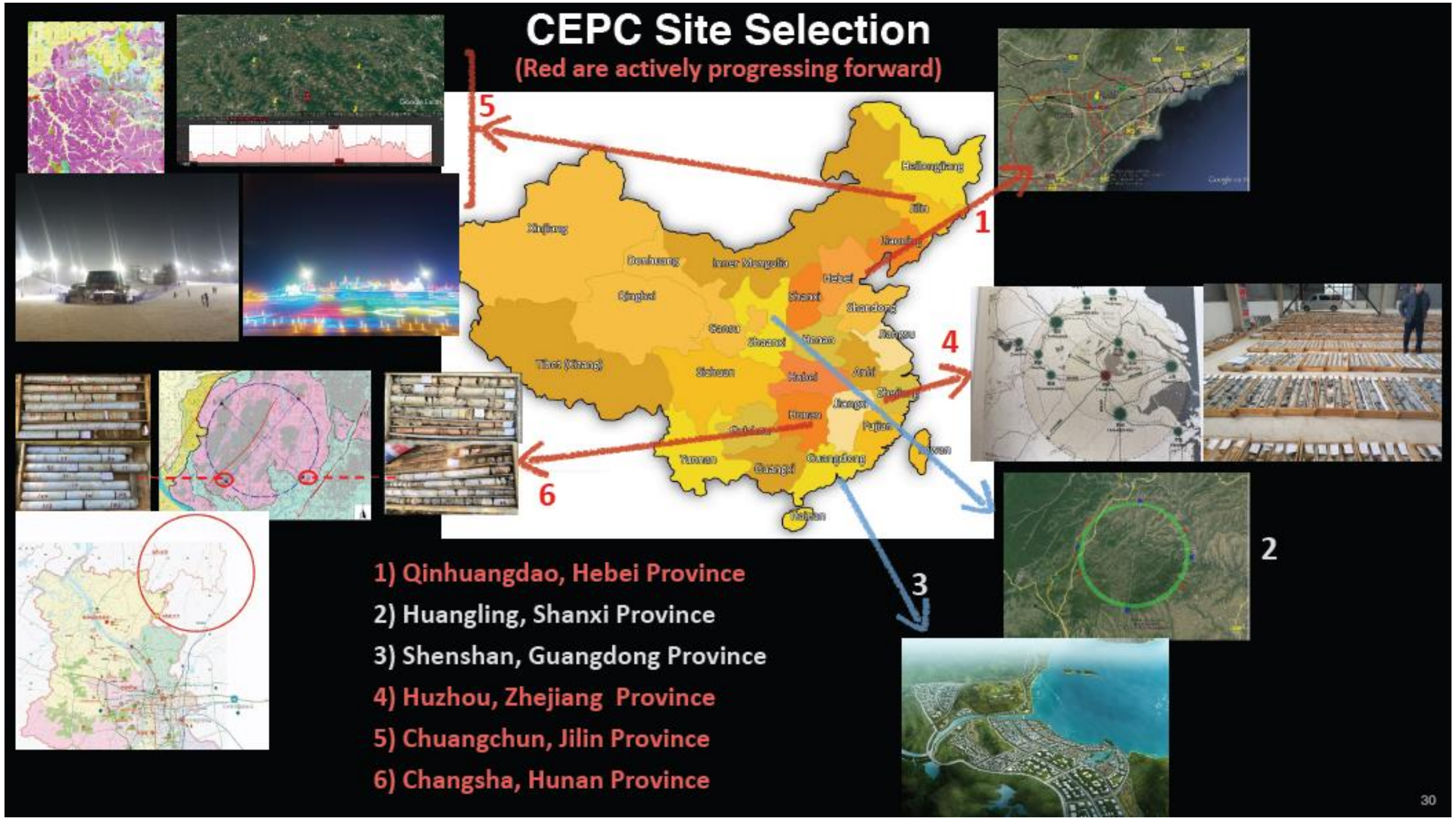
CIPC working group meeting On June 4,2019



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



CEPC Site Selection

(Red are actively progressing forward)

1) Qinhuangdao, Hebei Province
2) Huangling, Shanxi Province
3) Shenshan, Guangdong Province
4) Huzhou, Zhejiang Province
5) Chuangchun, Jilin Province
6) Changsha, Hunan Province

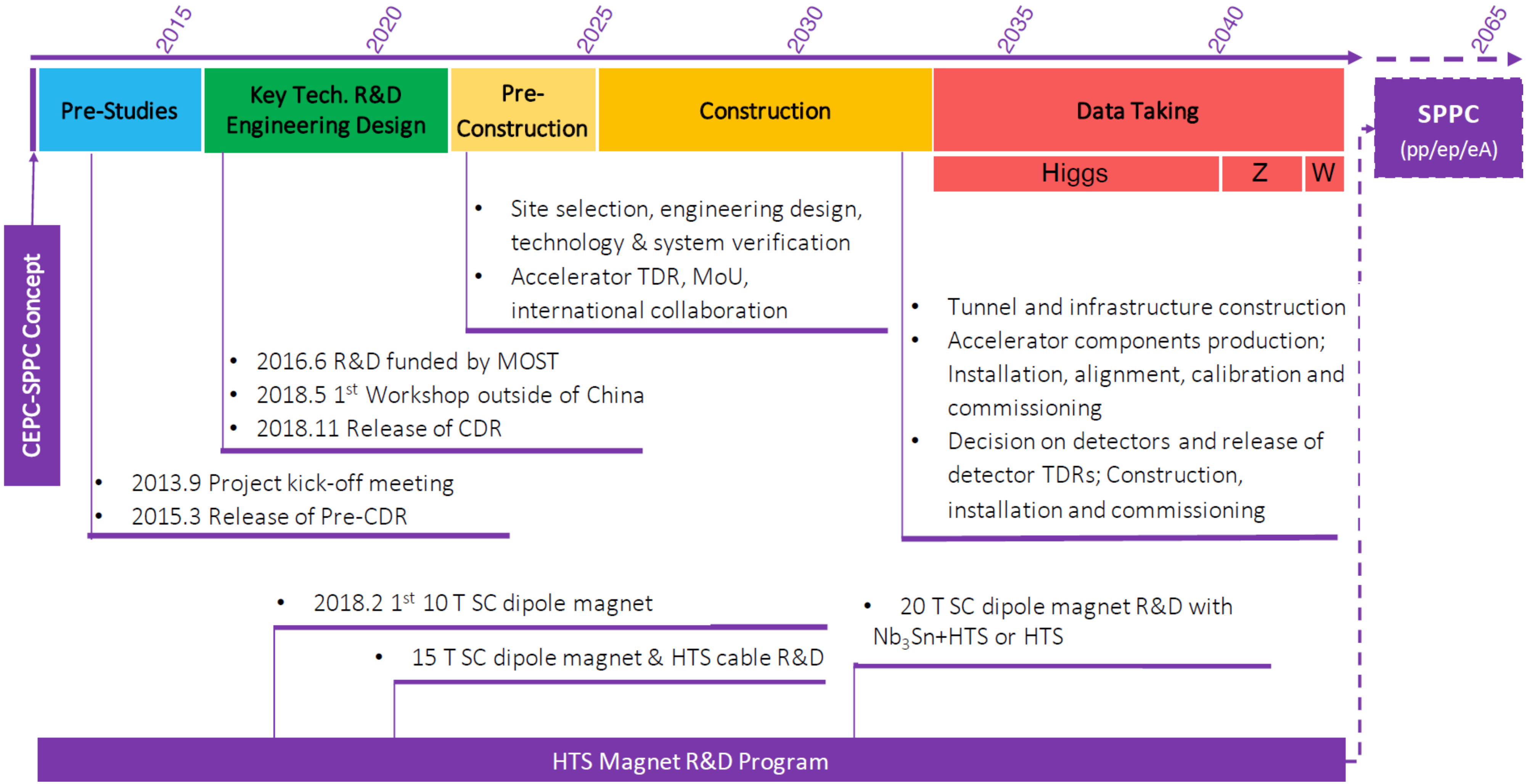
- Site selection is based on geology, electricity supply, transportation, environment for foreigners
- Local support & economy, …
- North site is better for reduction of operation cost
- Initial CDR study is based on Qing-Huang-Dao site

- 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**

CEPC Project Timeline



- Site selection, engineering design, technology & system verification
- Accelerator TDR, MoU, international collaboration

- Tunnel and infrastructure construction
- Accelerator components production; Installation, alignment, calibration and commissioning
- Decision on detectors and release of detector TDRs; Construction, installation and commissioning

- 2016.6 R&D funded by MOST
- 2018.5 1st Workshop outside of China
- 2018.11 Release of CDR

- 2013.9 Project kick-off meeting
- 2015.3 Release of Pre-CDR

- 2018.2 1st 10 T SC dipole magnet
- 15 T SC dipole magnet & HTS cable R&D
- 20 T SC dipole magnet R&D with Nb_3Sn+HTS or HTS

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 cavity, High efficiency Klystron, HTS SC magnets, Plasma Injector, …**
- ○ **Silicon pixel ASIC chip, PFA ECAL prototype, SDHCAL, AHCAL, …**

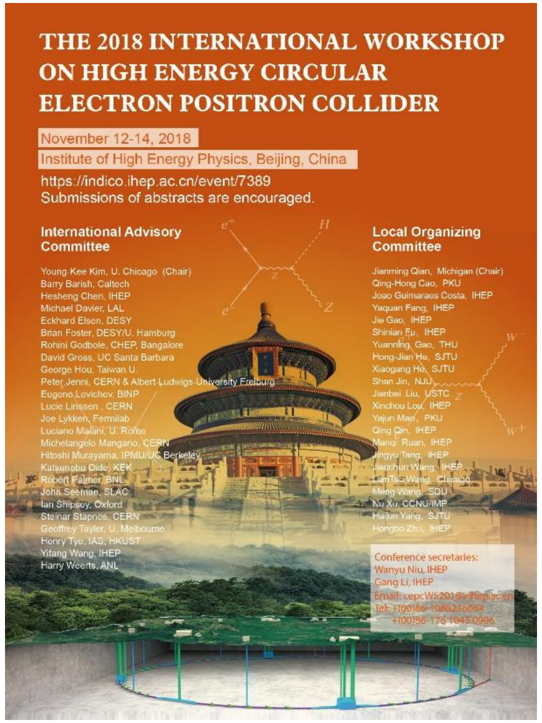
CEPC physics whitepapers, physics potential study for Snowmass 2021/2022

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), Washington 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…

Recent CEPC Workshops


THE 2018 INTERNATIONAL WORKSHOP ON HIGH ENERGY CIRCULAR ELECTRON POSITRON COLLIDER

November 12-14, 2018
Institute of High Energy Physics, Beijing, China
https://indico.ihep.ac.cn/event/7389
Submissions of abstracts are encouraged.

International Advisory Committee

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Barry Barish, Caltech
Hesheng Chen, IHEP
Michael Davier, LAL
Eckhard Elsen, DESY
Brian Foster, DESY/U. Hamburg
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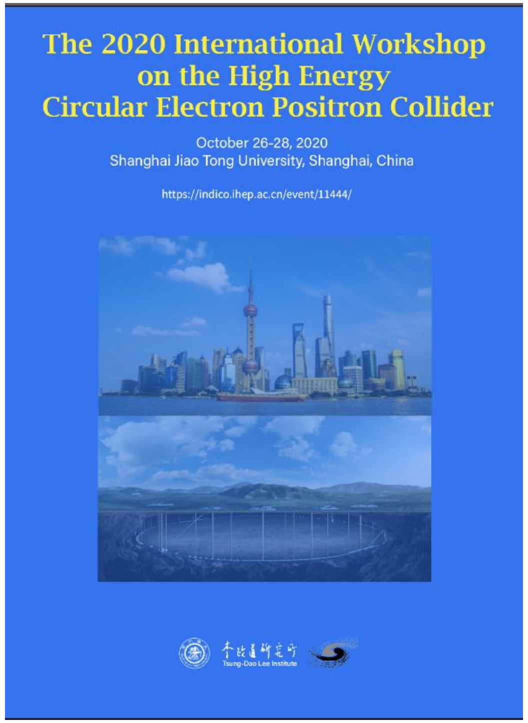
Workshop on the Circular Electron-Positron Collider
EU Edition
Roma, May 24-26 2018
University of Roma Tre


The International Workshop on the Circular Electron Positron Collider
EU EDITION 2019
Oxford, April 15-17, 2019
http://www.physics.ox.ac.uk/confs/CEPC2019/


The 2020 International Workshop on the High Energy Circular Electron Positron Collider
October 26-28, 2020
Shanghai Jiao Tong University, Shanghai, China
https://indico.ihep.ac.cn/event/11444/

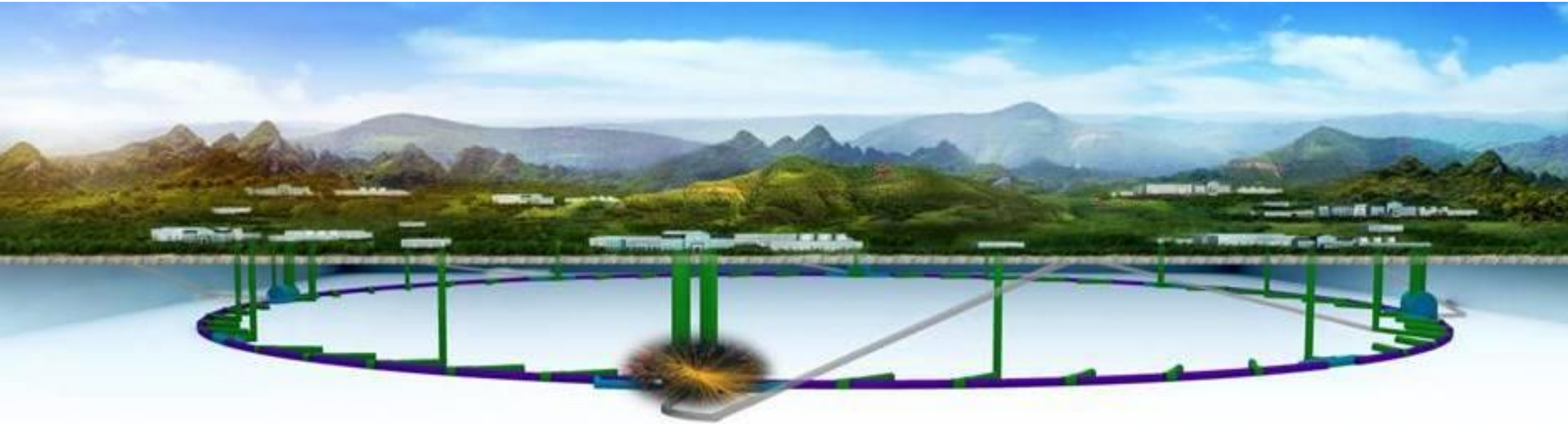
Next CEPC International Workshop

at Nanjing University, Nov. 8-12, 2021

You are very welcome to participate

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

Please stay tuned, thanks



Prospects

Continuing R&D and deep understanding of physics potentials

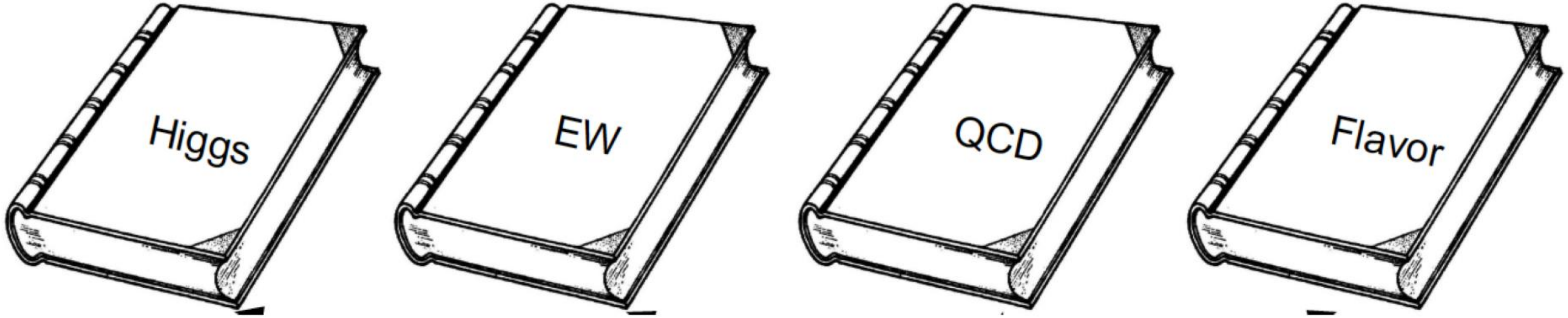
- Suggestions to **MOST for R&D support** and validations of key technologies & innovations
- Planning **next round design improvement, R&D**, site investigations-study
- **CEPC physics whitepaper**; physics potentials in Snowmass 2021/2022 arena

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, …)
- ……

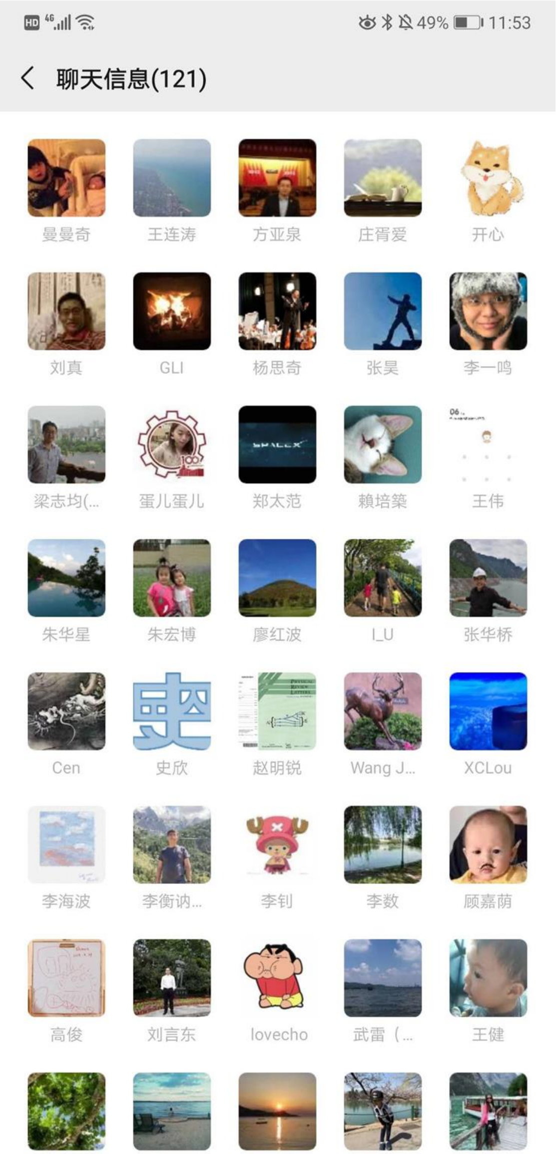
CEPC White Papers

White papers



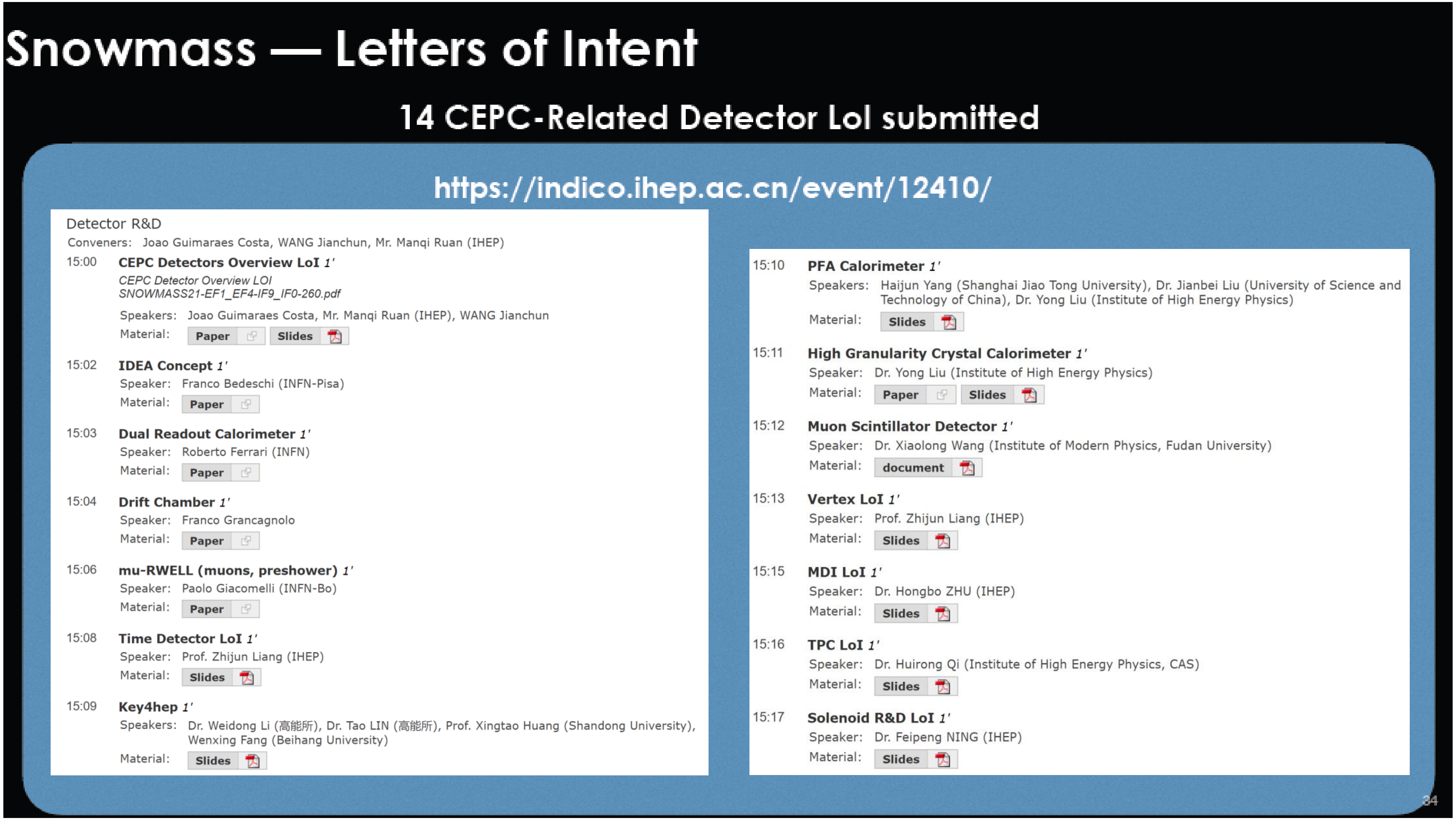
- To promote the physics study at TDR & to converge to the Physics White Papers
- Physics white papers:
  - Physics handbooks for new comers: PostDoc/Student
  - Official references for the physics potential
  - Guideline for future detector design/optimization
- Higgs white paper published in 2019

CEPC Study for Snowmass: Physics



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

CEPC Study for Snowmass: Detector R&D



Snowmass — Letters of Intent

14 CEPC-Related Detector LoI submitted

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

Detector R&D

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

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

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

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

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

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

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

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

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

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

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

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

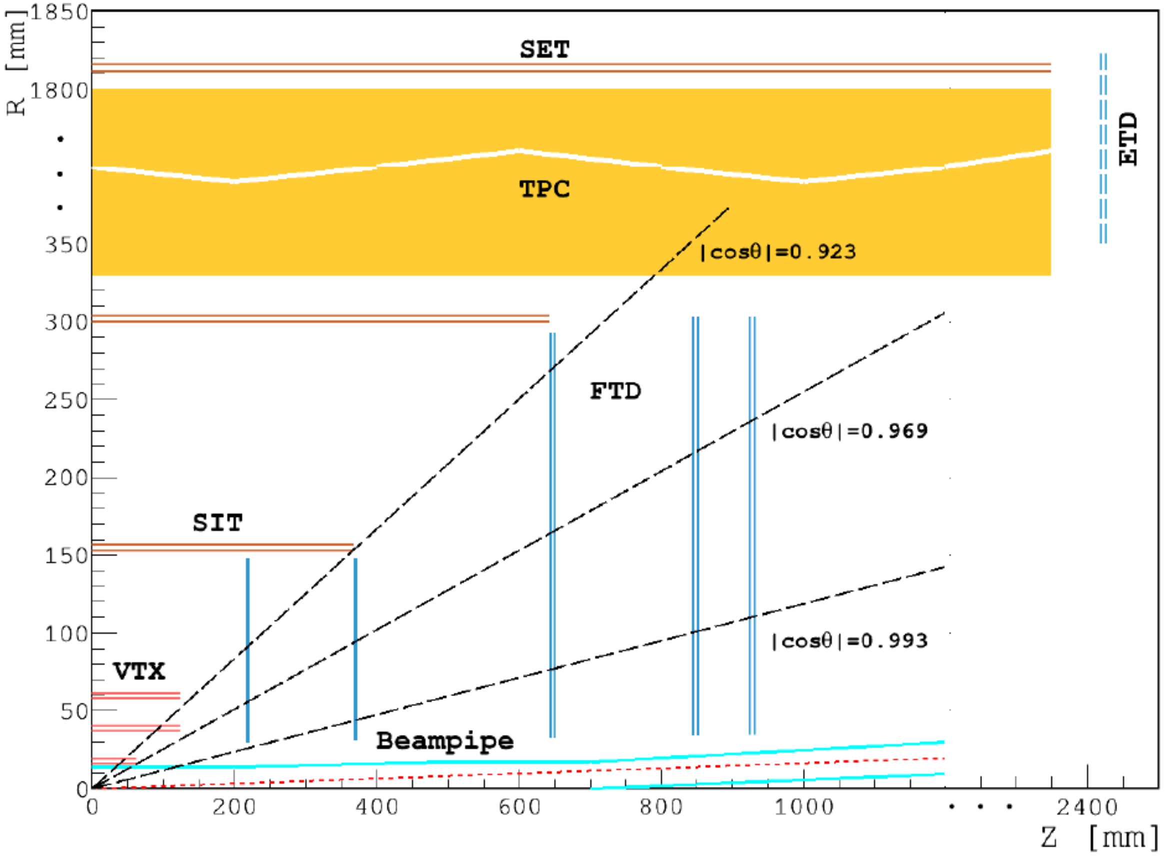
15:15 **MDI LoI** *1'*
Speaker: Dr. Hongbo ZHU (IHEP)
Material: **Slides**

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

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

34

CEPC Vertex and Tracker

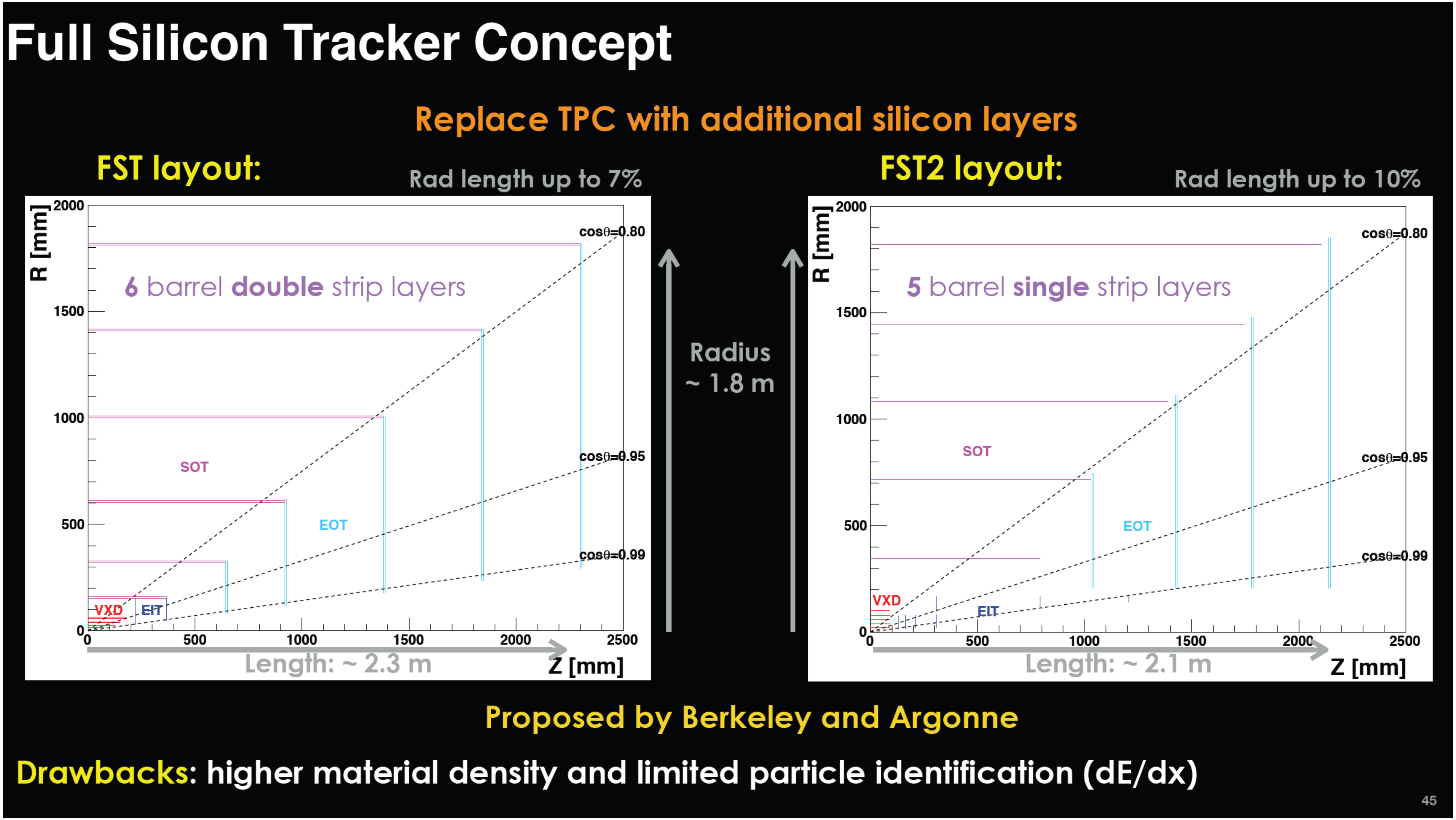


- Single-point resolution of the first layer better than 3 μm;
- Material budget below 0.15% X_0 per layer;
- First layer located close to the beam pipe at a radius of 16 mm, with a material budget of 0.15% X_0 for the beam pipe;
- Detector occupancy not exceeding 1%.

	R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	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

Full Silicon Tracker Concept



Full Silicon Tracker Concept

Replace TPC with additional silicon layers

FST layout: Rad length up to 7%

FST2 layout: Rad length up to 10%

Proposed by Berkeley and Argonne

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

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).

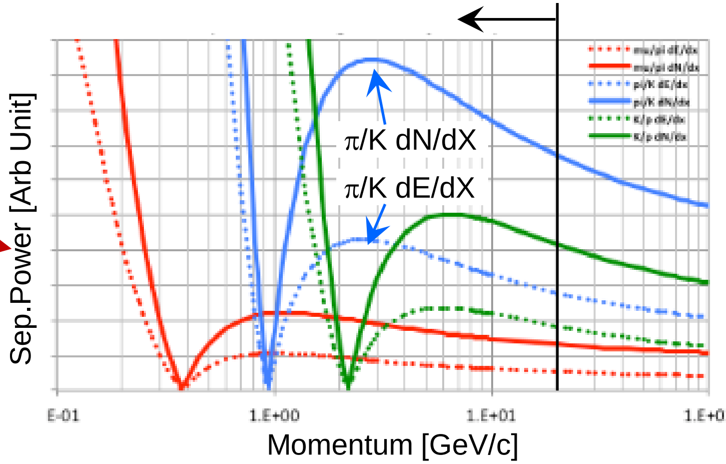
◆ The FST solution needs a supplement PID. A combination of different PID detectors is also possible.

◆ **Aim is to for have 2σ π/K separation for P<~20 GeV/c.**

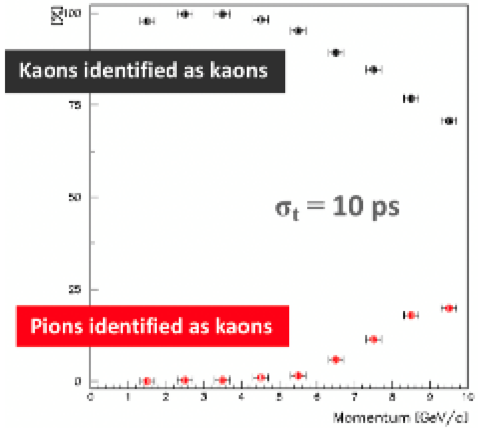
① **Drift chamber** between the outer layers of FST. The dN/dX method is more efficient. It is a joint R&D effort with the IDEA DC. But the DC can be optimized for PID only, not its tracking capability.

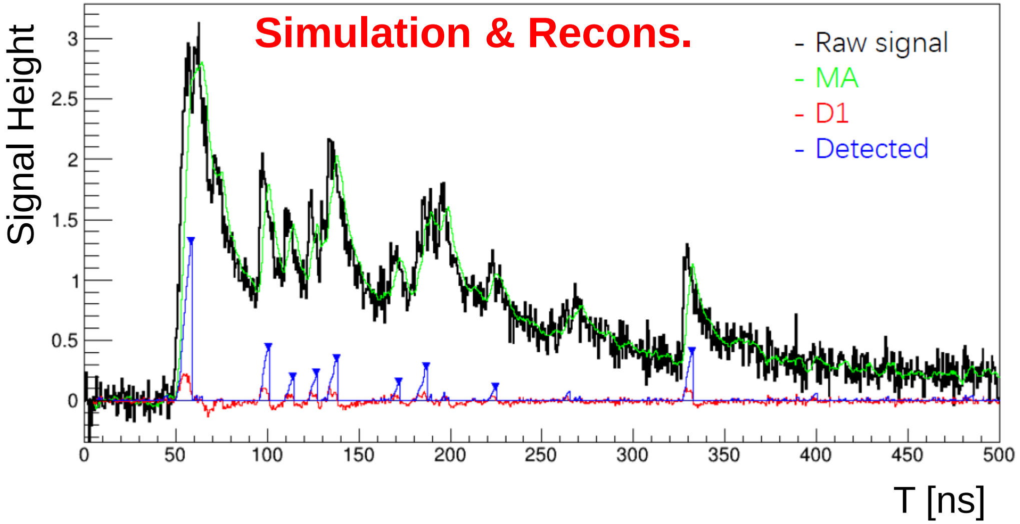
② **Time of flight** detector, e.g. LGAD. The time resolution ~20-30 ps today. Resolution of 10 ps is possible by the time of CEPC.

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



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

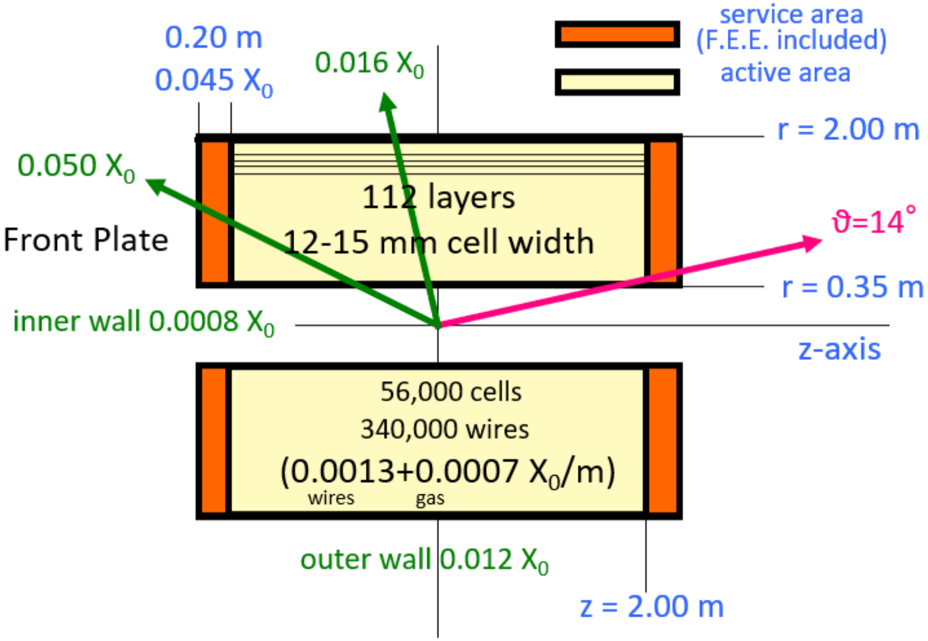




IDEA Drift Chamber

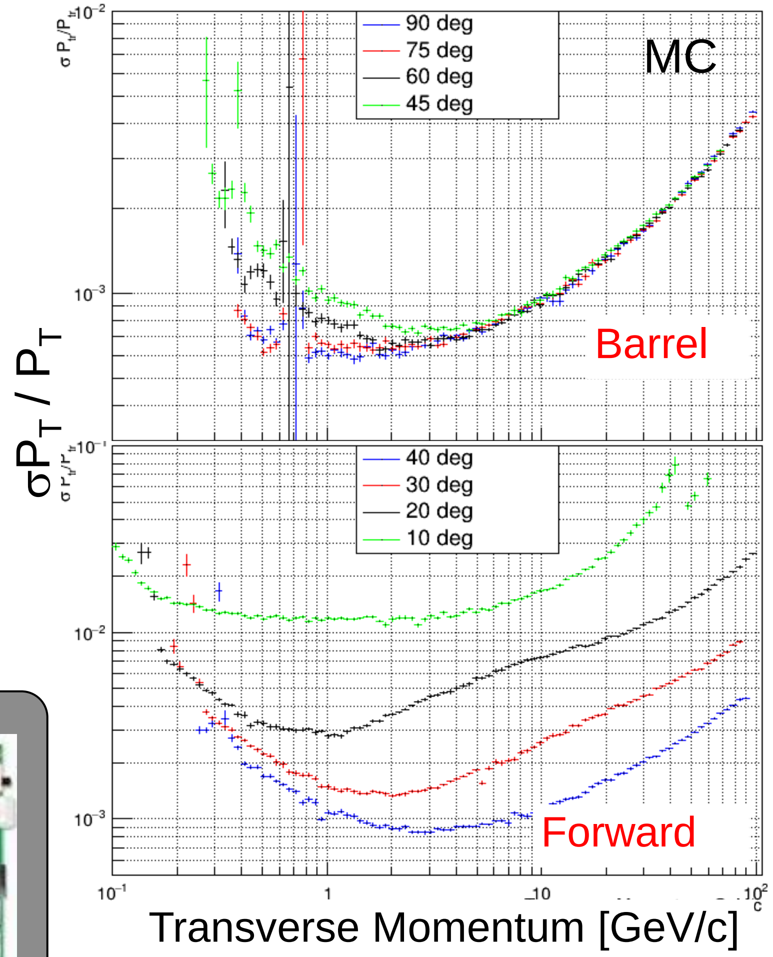
tracking efficiency ε ≈ 1
for ϑ > 14° (260 mrad)
97% solid angle

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



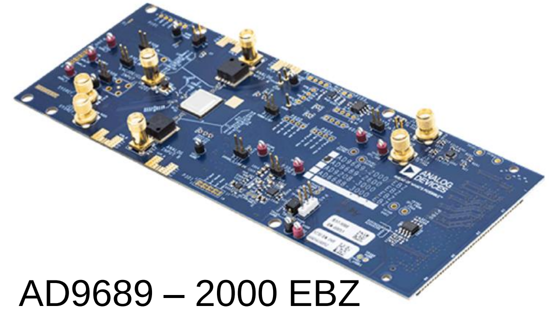
The main tracker in IDEA design

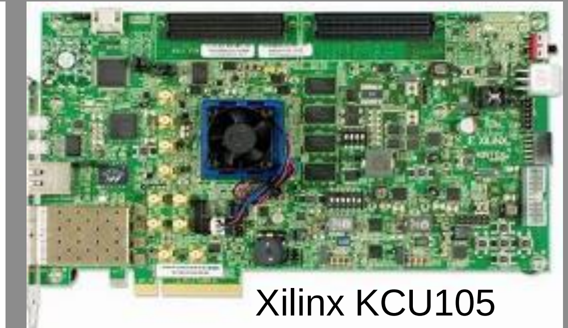
Gas: He/iC_4H_{10} (90:10)%
Spatial resolution: <100 μm
Max drift time: ~ 350 ns



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

Cluster counting for PID

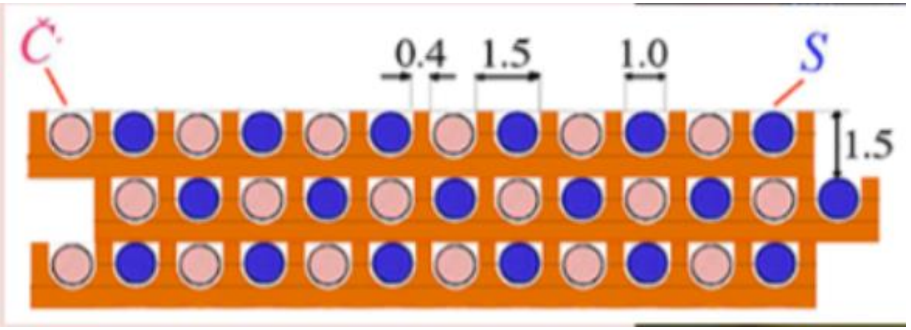

AD9689 – 2000 EBZ

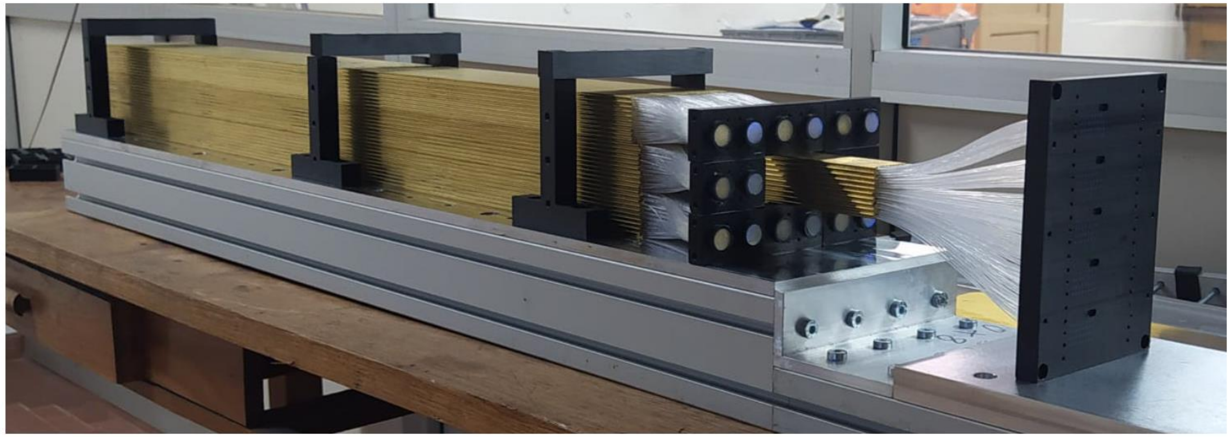

Xilinx KCU105

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

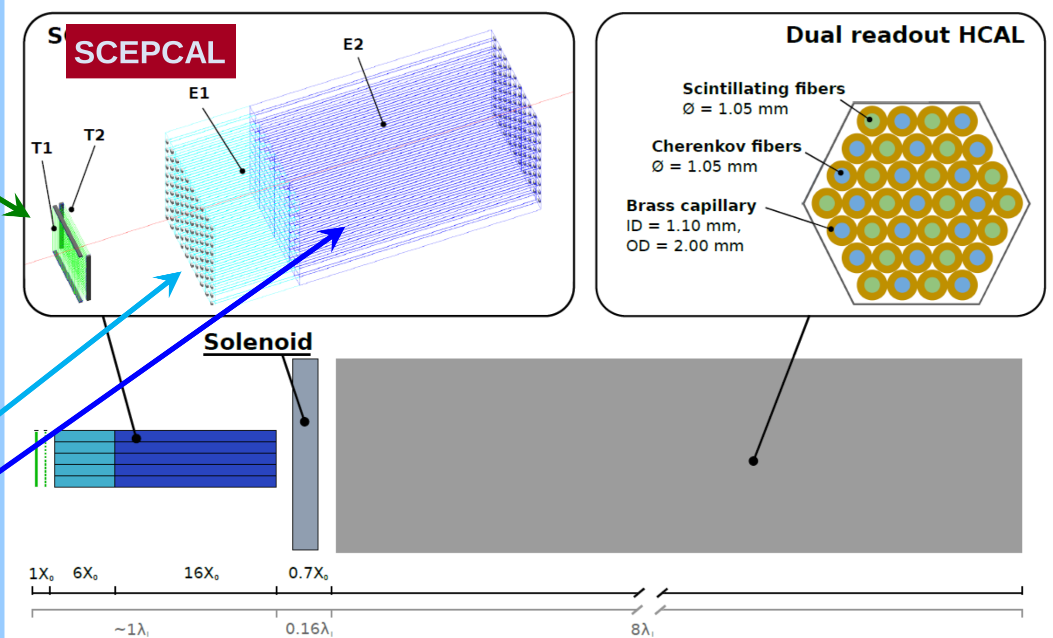
by Eno, Lucchini, and Tully et al. (arXiv:2008.00338)

Timing layer $\sigma_t \sim 20$ ps

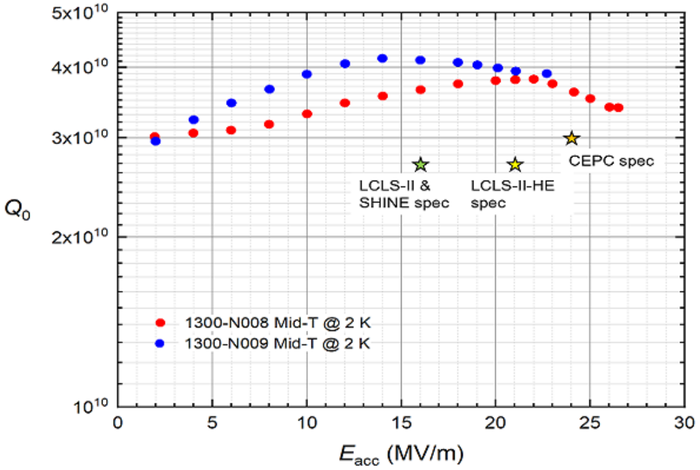
- LYSO Ce crystal (~$1X_0$)
- 3×3×54 mm^3 active cell
- 3×3 mm^2 SiPMs (15-20 μm)

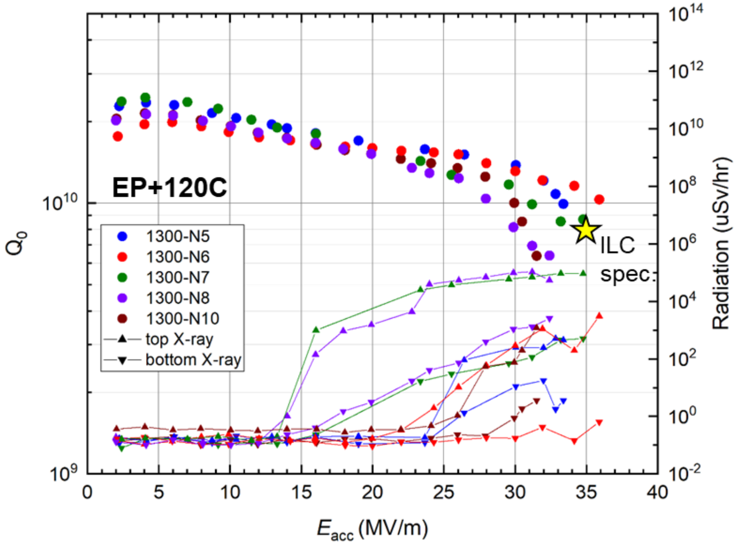
ECAL layer $\sigma_E/E \sim 3\%/\sqrt{E}$

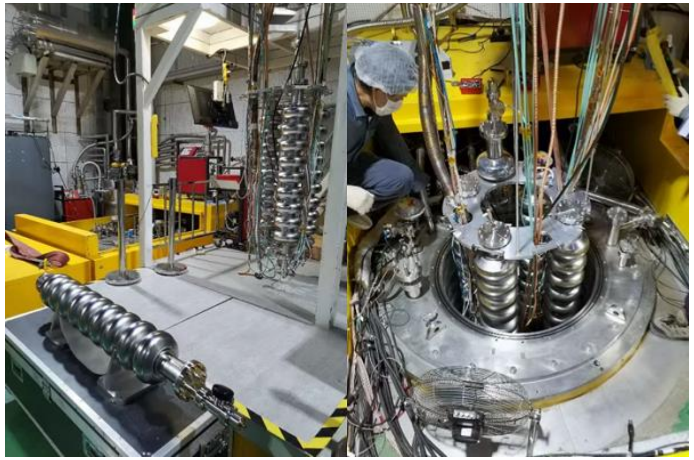
- PbWO crystals
- Front segment (~$6\ X_0$)
- Read segment (~$16\ X_0$)
- 10×10×200 mm^3 Crystals
- 5×5 mm^2 SiPMs (10-15 μm)

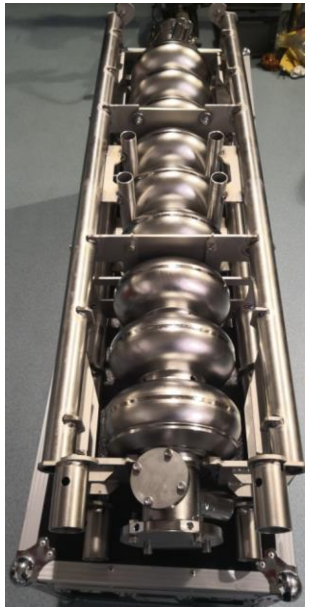


Accelerator R&D: High Q SRF Cavities

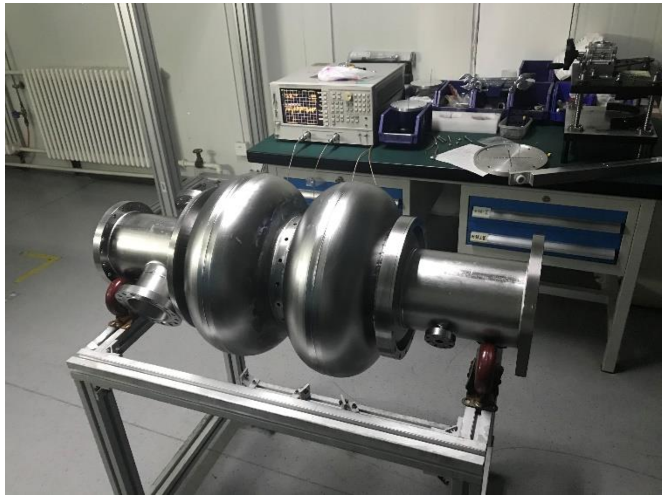




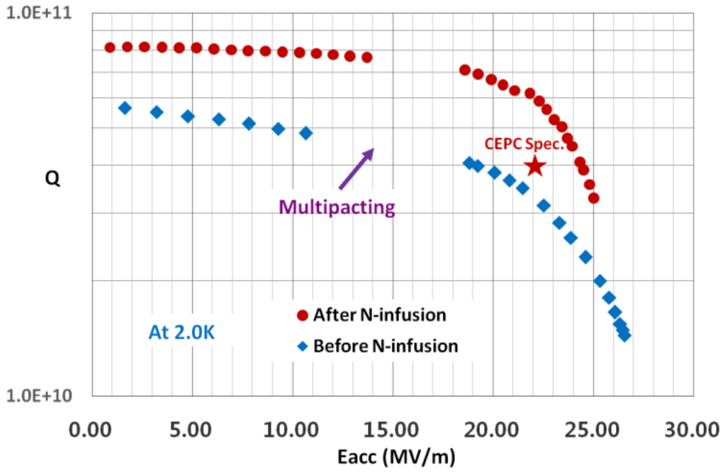




Booster 1.3GHz 9 cell cavity

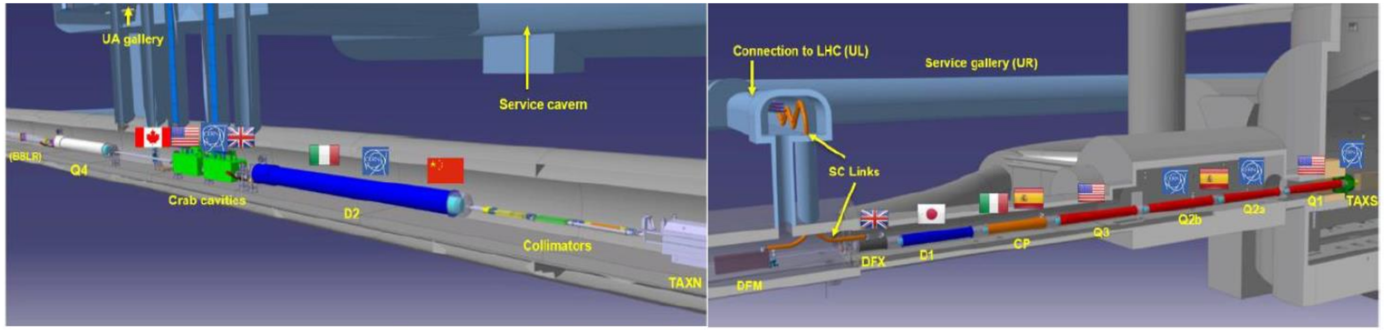


Collider ring 650Mhz 2 cell cavity



650 MHz 2-cell cavity reached **6E10@22MV/m** after N-infusion, which has exceeded CEPC Spec （**Q=4E10@Eacc=22MV/m**）.

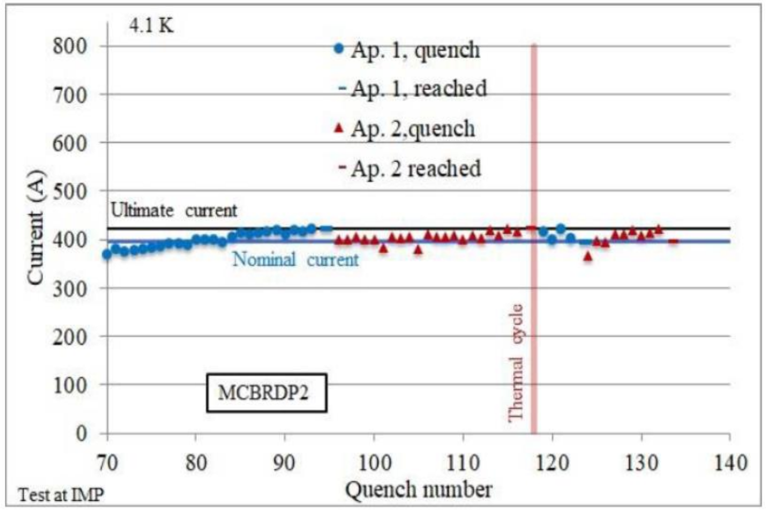
HL-LHC Magnet and HTS SC Magnet

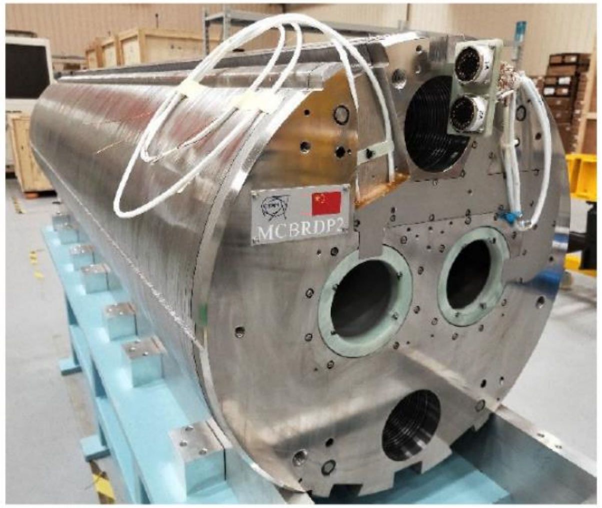


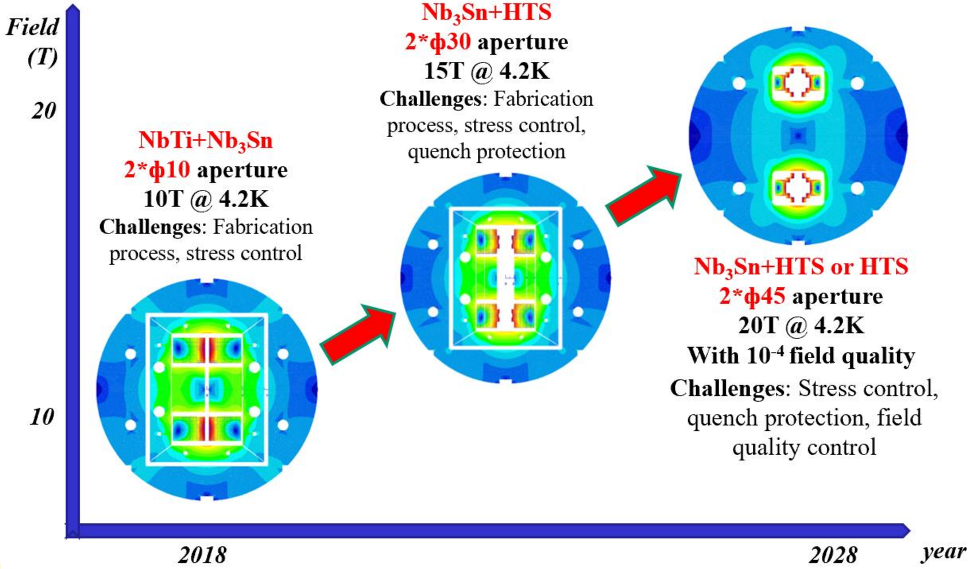
Layout of the HL-LHC Magnets and Contributors

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.







NbTi+Nb$_3$Sn
2*ϕ10 aperture
10T @ 4.2K
Challenges: Fabrication process, stress control

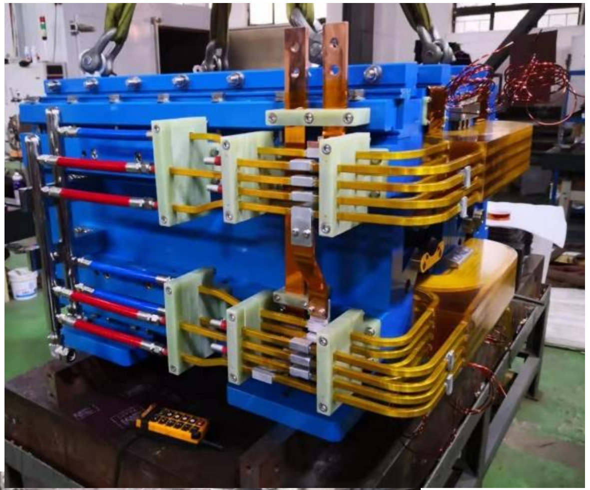
Nb$_3$Sn+HTS
2*ϕ30 aperture
15T @ 4.2K
Challenges: Fabrication process, stress control, quench protection

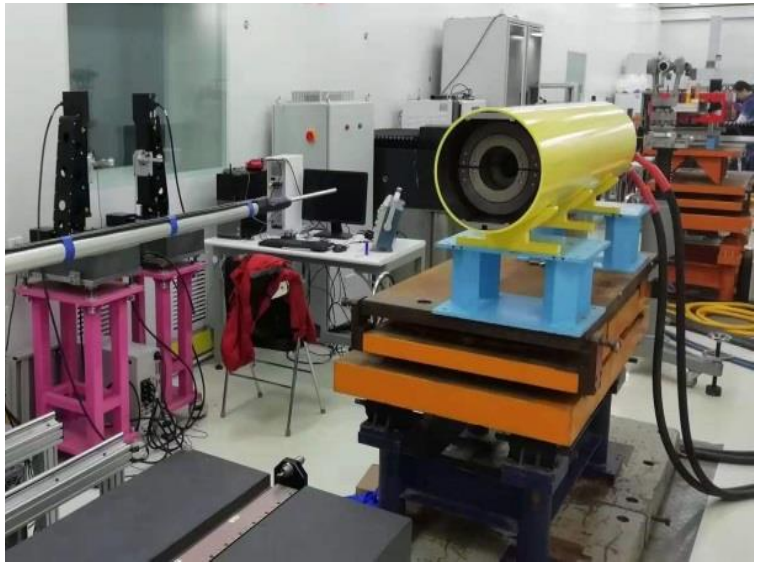
Nb$_3$Sn+HTS or HTS
2*ϕ45 aperture
20T @ 4.2K
With 10^{-4} field quality
Challenges: Stress control, quench protection, field quality control

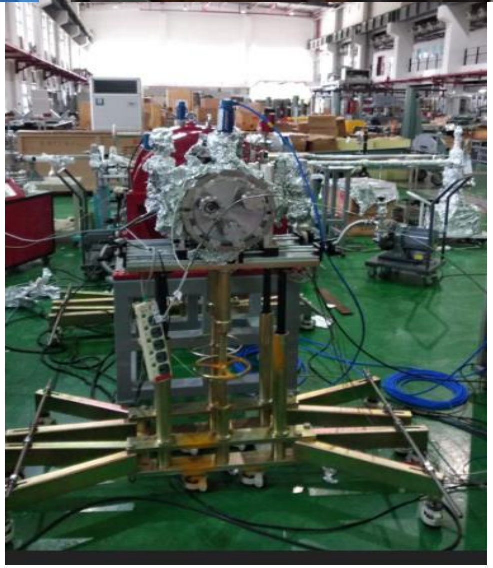
The 1st prototype has been delivered to CERN and successfully tested, production has started.

CEPC R&D: Magnets etc.

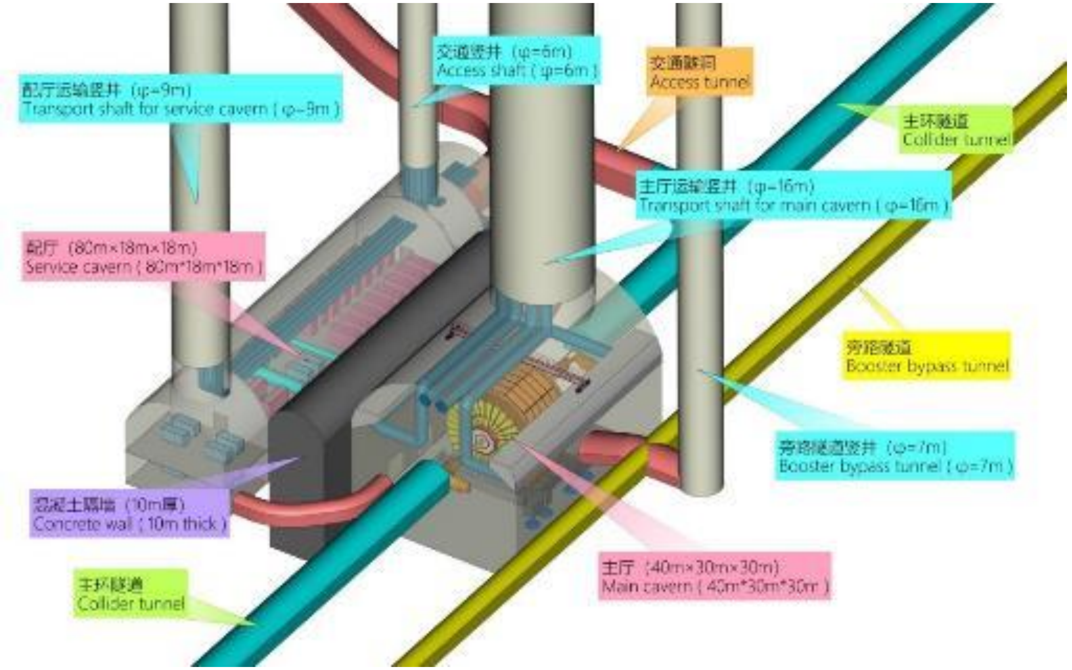
- **Magnets, EM-separators, Vacuum Pipes, …**







The Experimental Area



Main cavern to host the detector

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

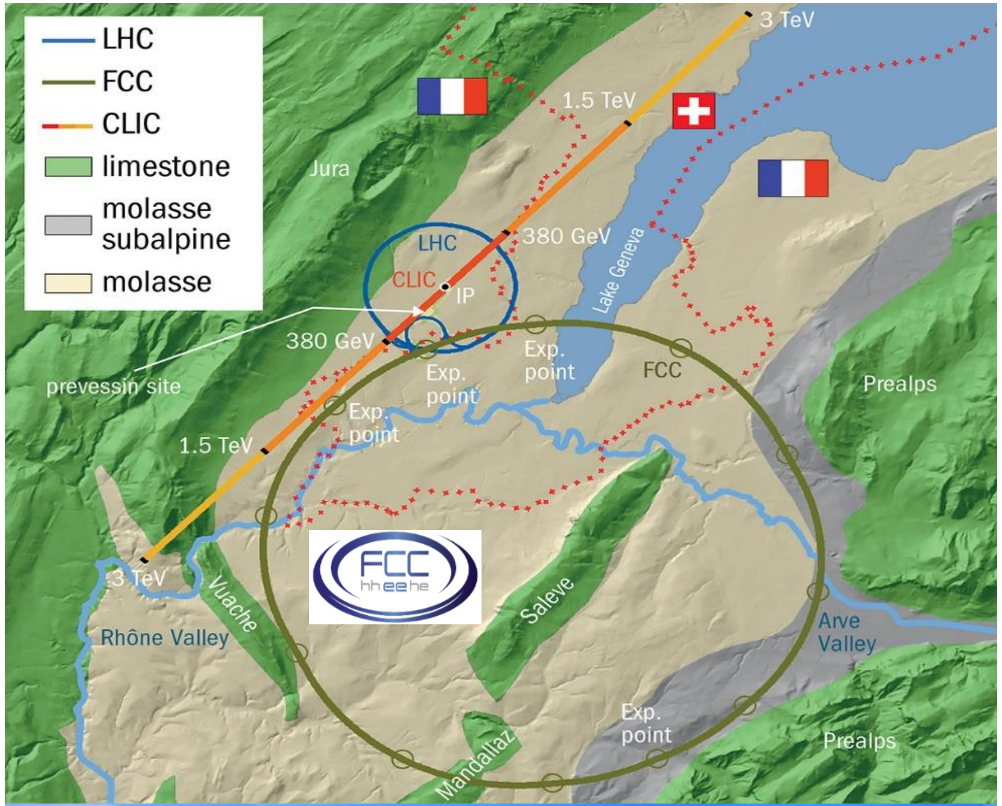
Auxiliary cavern for peripheral equipment and devices

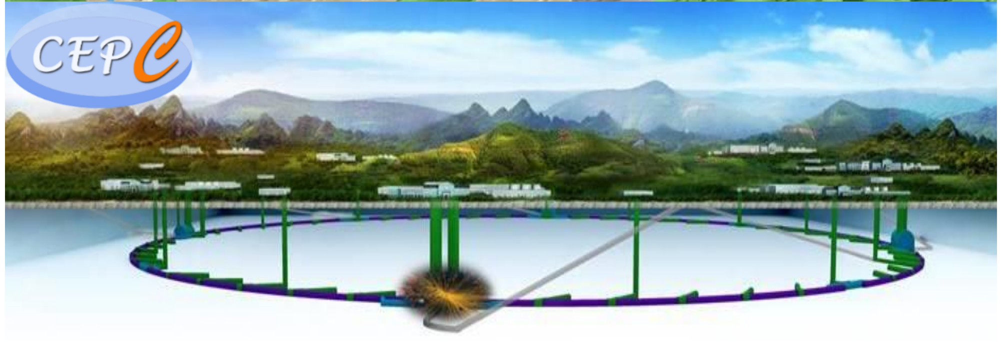
- 80*18*18 m^3 (L*H*W)
- One service shaft of Ø9 m
- One personnel access shaft Ø6 m

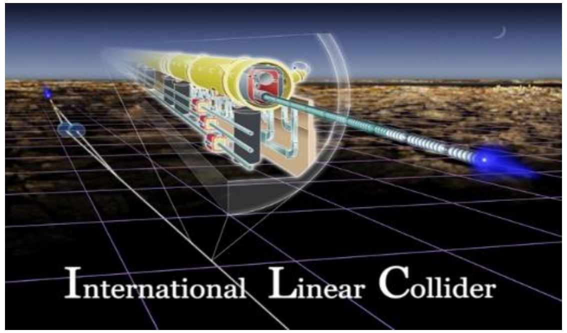
Ground level buildings

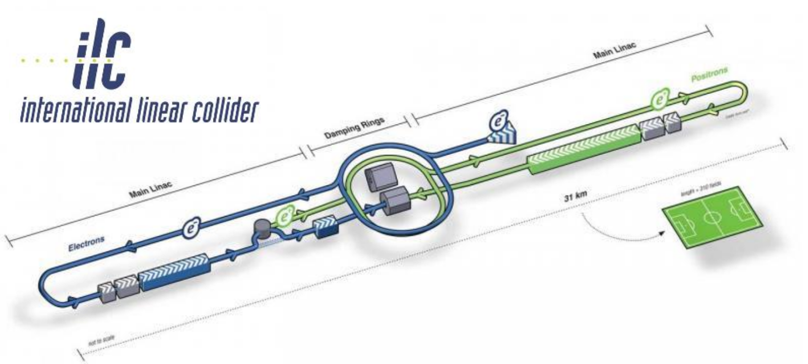
Worldwide Lepton Colliders

- **An electron-positron Higgs factory is the highest-priority next collider.**









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