Status of the Circular Electron Positron Collider

João Guimarães da Costa
for the CEPC Study Group

Institute of High Energy Physics
Chinese Academy of Sciences

The 2022 International Workshop on the high energy Circular Electron-Positron Collider
October 24-28, 2022

Outline

- Introduction to CEPC
  - Goals and plans
  - CEPC Physics Program
- CEPC Accelerator developments
- Detector R&D developments
- Project global aspects
  - Core team, institutions and internationalization
  - Budget for R&D and construction
  - Timeline
- Summary

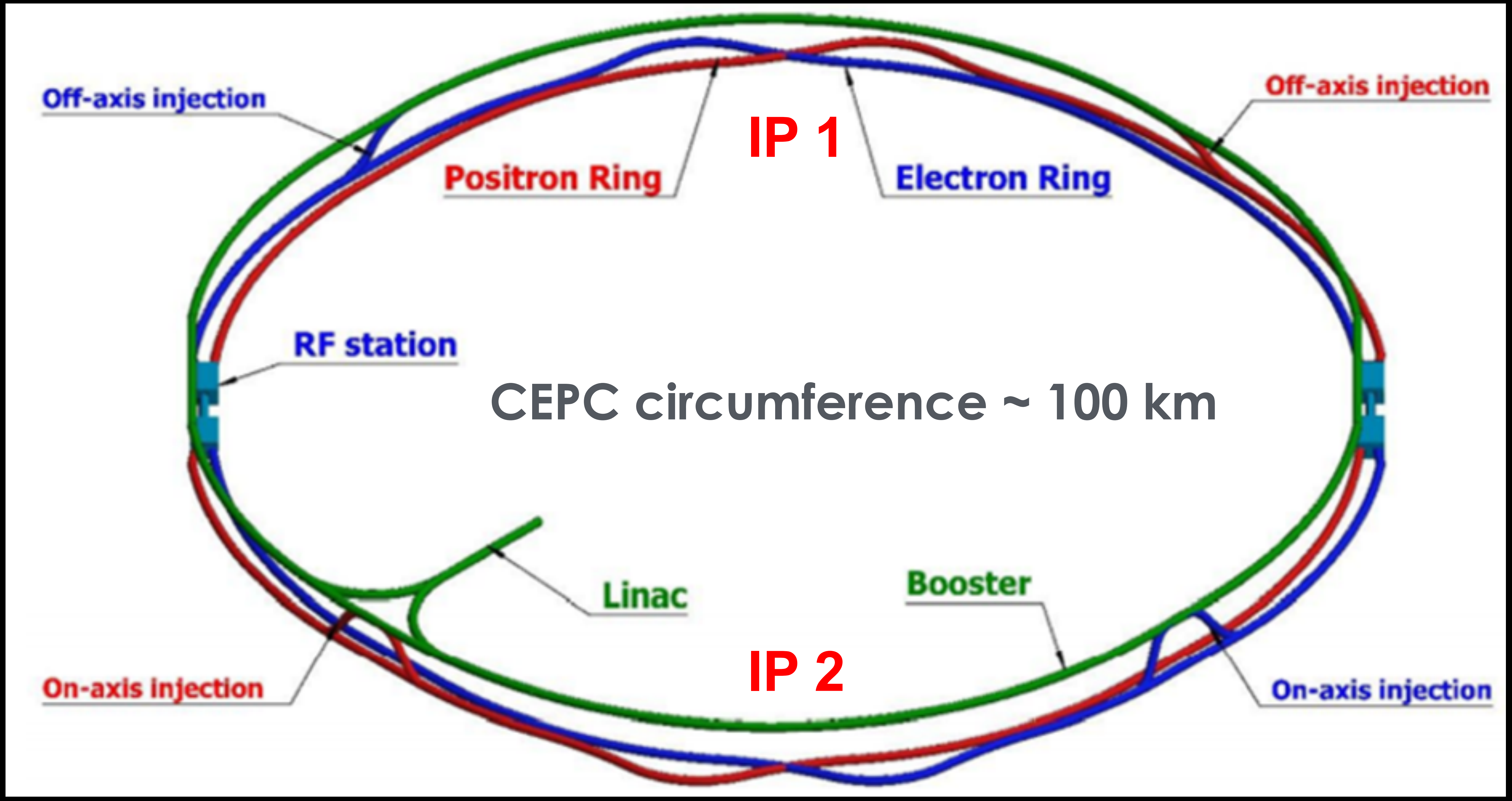
Circular Electron Positron Collider (CEPC) Overview

CEPC is an e^+e^- Higgs factory producing Higgs, W and Z bosons
aims at discovering new physics beyond the Standard Model

Proposed in 2012 right after the Higgs discovery

Upgrade path

1. Higher energy → top quark pair production
2. Super pp Collider (SppC) at > 100 TeV



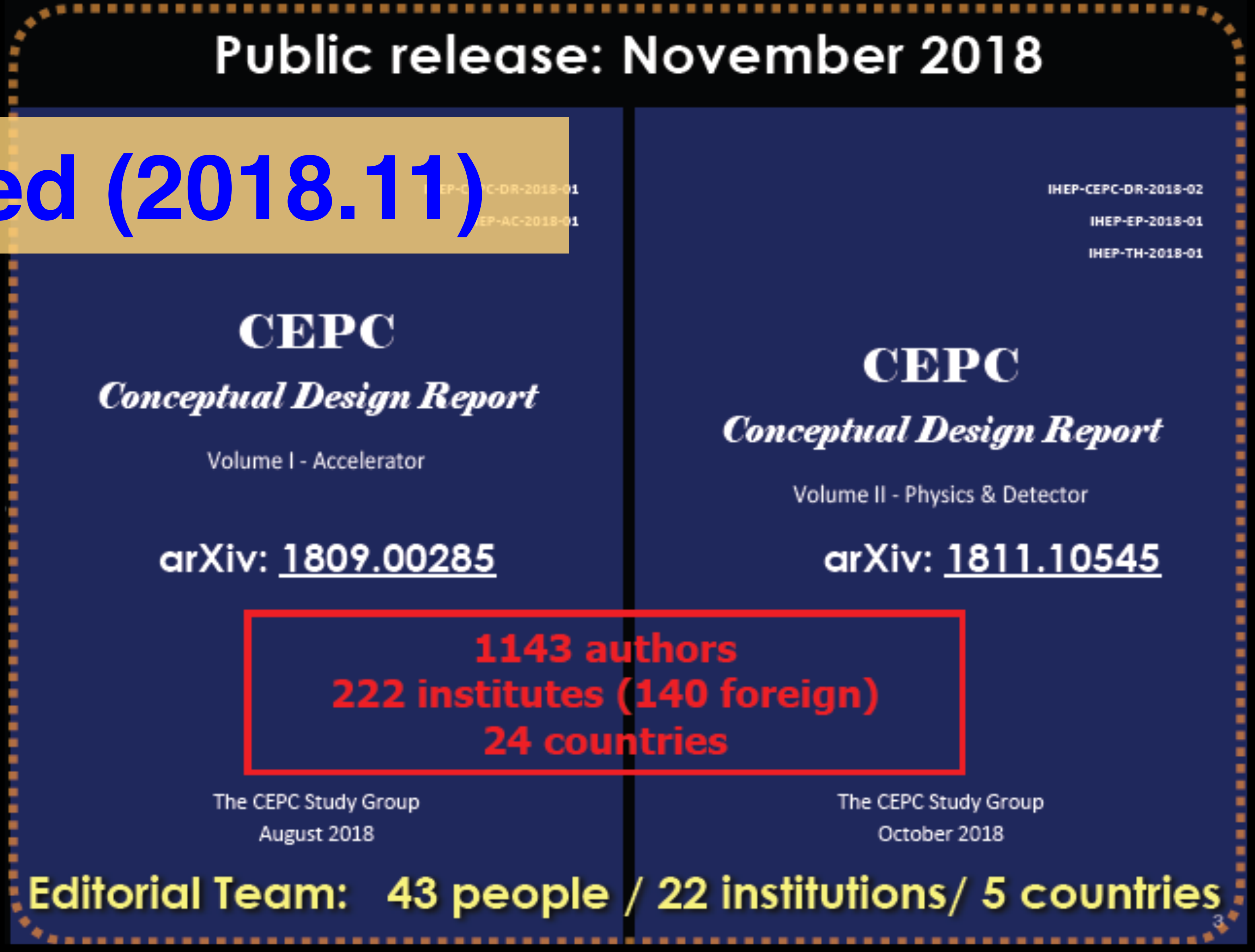
Proposed to commence construction in ~2026 and deliver Higgs data in 2030s

CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

CEPC IAC Meeting (2015)

CEPC CDR Released (2018.11)



CEPC action plan since CDR

Public release: November 2018

IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC

Conceptual Design Report

Volume I - Accelerator

arXiv: 1809.00285

The CEPC Study Group
August 2018

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

CEPC

Conceptual Design Report

Volume II - Physics & Detector

arXiv: 1811.10545

The CEPC Study Group
October 2018

First for a circular e^+e^- Higgs factory

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

Since 2019

Cement project with R&D towards:

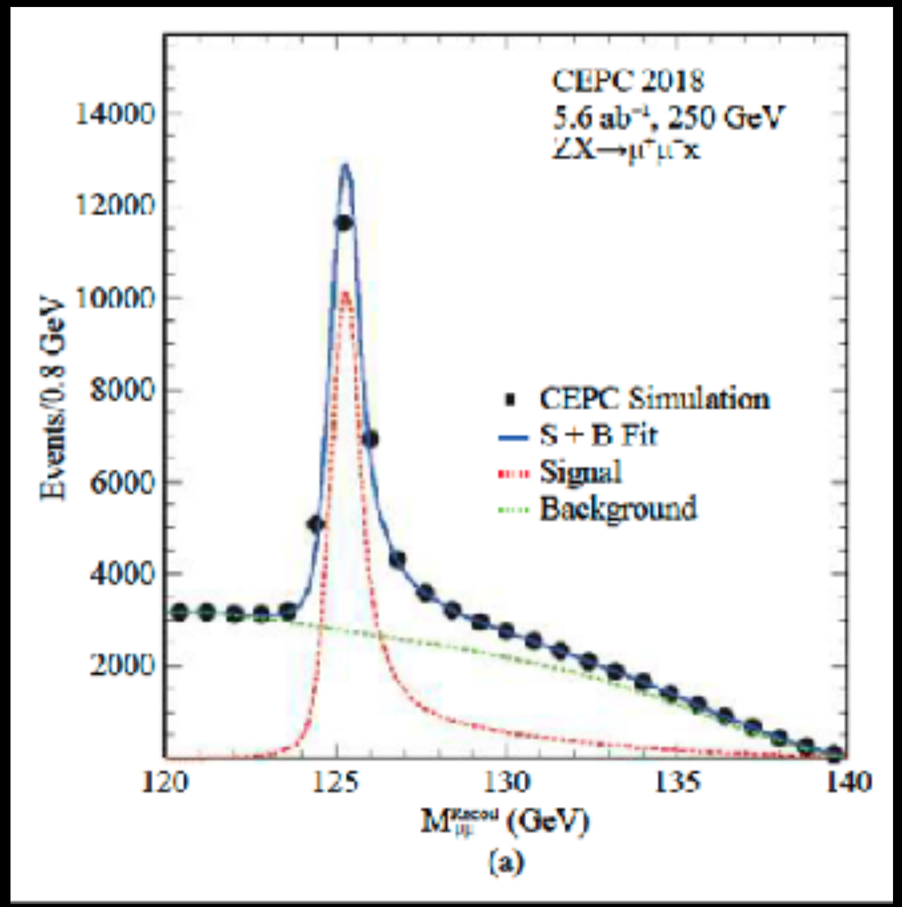
(1) Accelerator TDR, planned for 2023

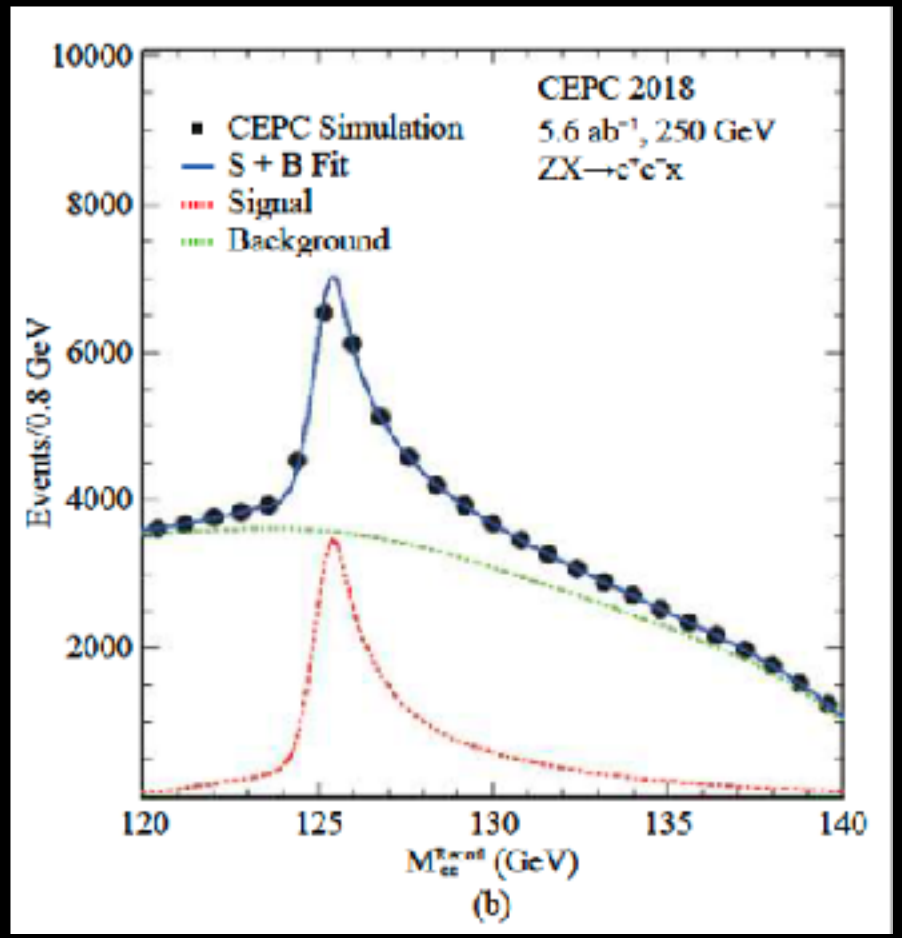
(2) Detector technologies development and establishment of seeds for International Collaborations

Identify challenges and devise solutions

CEPC Physics Program

- Precision Higgs, EW, flavor physics & QCD measurements
- BSM physics (eg. dark matter, EW phase transition, SUSY, LLP, ….) up to ~10 TeV scale





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

Precision Higgs physics at the CEPC*

Fenfen An(安芬芬)[4,23] Yu Bai(白羽)[9] Chunhui Chen(陈春晖)[23] Xin Chen(陈新)[5] Zhenxing Chen(陈振兴)[3]
Joao Guimaraes da Costa[4] Zhenwei Cui(崔振崴)[3] Yaquan Fang(方亚泉)[4,6,34;1)] Chengdong Fu(付成栋)[4]
Jun Gao(高俊)[10] Yanyan Gao(高艳彦)[22] Yuanning Gao(高原宁)[3] Shaofeng Ge(葛韶锋)[15,29]
Jiayin Gu(顾嘉荫)[13;2)] Fangyi Guo(郭方毅)[1,4] Jun Guo(郭军)[10] Tao Han(韩涛)[5,31] Shuang Han(韩爽)[4]
Hongjian He(何红建)[11,10] Xianke He(何显柯)[10] Xiaogang He(何小刚)[11,10,20] Jifeng Hu(胡继峰)[10]
Shih-Chieh Hsu(徐士杰)[32] Shan Jin(金山)[8] Maoqiang Jing(荆茂强)[4,7] Susmita Jyotishmati[33] Ryuta Kiuchi[4]
Chia-Ming Kuo(郭家铭)[21] Peizhu Lai(赖培筑)[21] Boyang Li(李博扬)[5] Congqiao Li(李聪乔)[3] Gang Li(李刚)[4,34;3)]
Haifeng Li(李海峰)[12] Liang Li(李亮)[10] Shu Li(李数)[11,10] Tong Li(李通)[12] Qiang Li(李强)[3] Hao Liang(梁浩)[4,6]
Zhijun Liang(梁志均)[4] Libo Liao(廖立波)[4] Bo Liu(刘波)[4,23] Jianbei Liu(刘建北)[1] Tao Liu(刘涛)[14]
Zhen Liu(刘真)[26,30;4)] Xinchou Lou(娄辛丑)[4,6,33,34] Lianliang Ma(马连良)[12] Bruce Mellado[17,18] Xin Mo(莫欣)[4]
Mila Pandurovic[16] Jianming Qian(钱剑明)[24;5)] Zhuoni Qian(钱卓妮)[19] Nikolaos Rompotis[22]
Manqi Ruan(阮曼奇)[4;6)] Alex Schuy[32] Lianyou Shan(单连友)[4] Jingyuan Shi(史静远)[9] Xin Shi(史欣)[4]
Shufang Su(苏淑芳)[25] Dayong Wang(王大勇)[3] Jin Wang(王锦)[4] Liantao Wang(王连涛)[27;7)]
Yifang Wang(王贻芳)[4,6] Yuqian Wei(魏彧骞)[4] Yue Xu(许悦)[5] Haijun Yang(杨海军)[10,11] Ying Yang(杨迎)[4]
Weiming Yao(姚为民)[28] Dan Yu(于丹)[4] Kaili Zhang(张凯栗)[4,6;8)] Zhaoru Zhang(张照茹)[4]
Mingrui Zhao(赵明锐)[2] Xianghu Zhao(赵祥虎)[4] Ning Zhou(周宁)[10]

[1]Department of Modern Physics, University of Science and Technology of China, Anhui 230026, China
[2]China Institute of Atomic Energy, Beijing 102413, China
[3]School of Physics, Peking University, Beijing 100871, China
[4]Institute of High Energy Physics, Beijing 100049, China
[5]Department of Engineering Physics, Physics Department, Tsinghua University, Beijing 100084, China
[6]University of Chinese Academy of Science (UCAS), Beijing 100049, China
[7]School of Nuclear Science and Technology, University of South China, Hengyang 421001, China
[8]Department of Physics, Nanjing University, Nanjing 210093, China
[9]Department of Physics, Southeast University, Nanjing 210096, China
[10]School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai 200240, China
[11]Tsung-Dao Lee Institute, Shanghai 200240, China
[12]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao 266237, China
[13]PRISMA Cluster of Excellence & Mainz Institute of Theoretical Physics, Johannes Gutenberg-Universität Mainz, Mainz 55128, Germany
[14]Department of Physics, Hong Kong University of Science and Technology, Hong Kong
[15]Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan
[16]Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade 11000, Serbia
[17]School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johannesburg 2050, South Africa

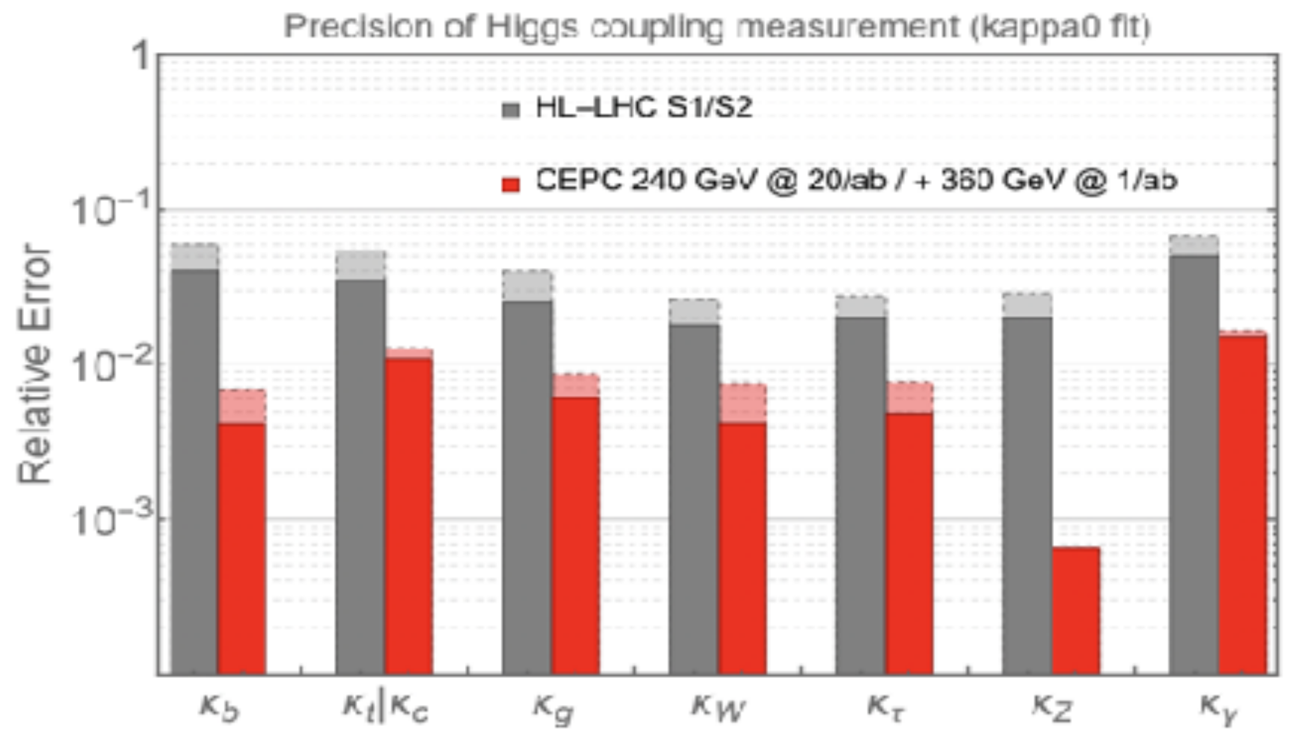
CEPC physics studies continued via full simulation and phenomenology studies

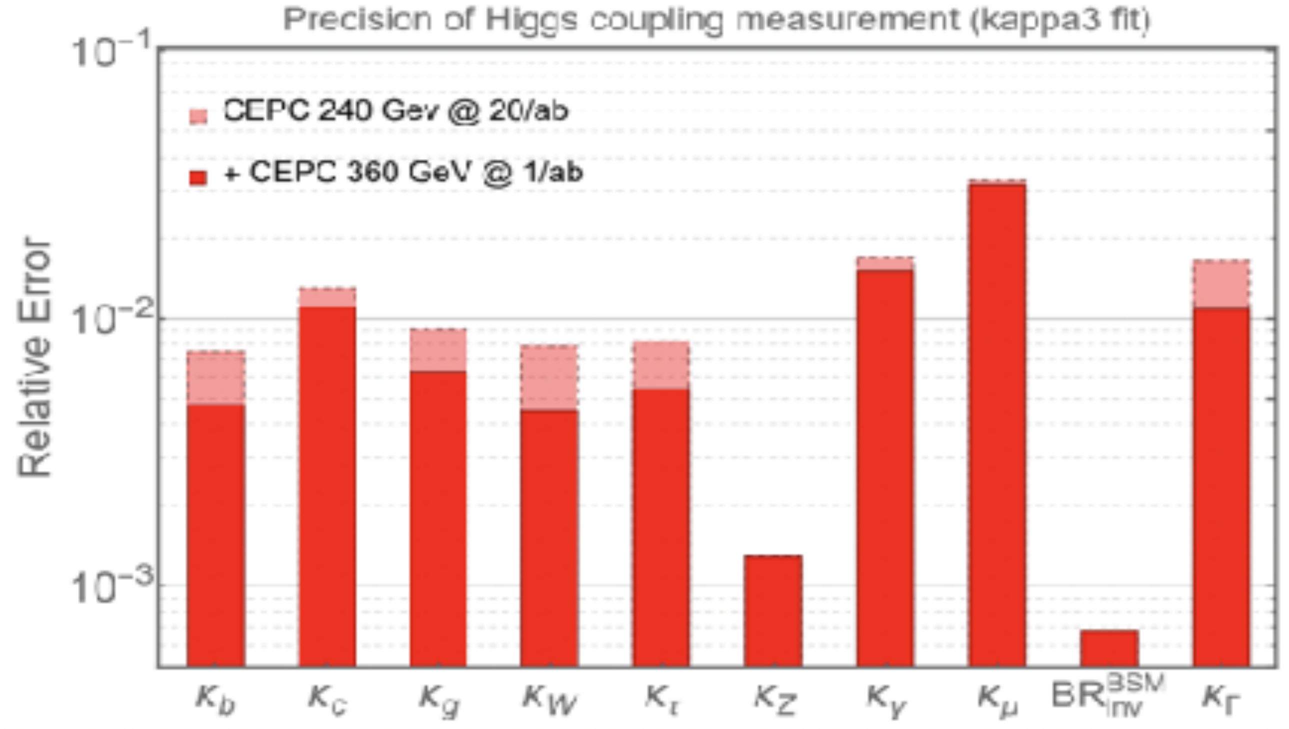
+ O(100) journal/arXiv papers

CEPC Higgs White Paper

CEPC Physics Program: Higgs and EW

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

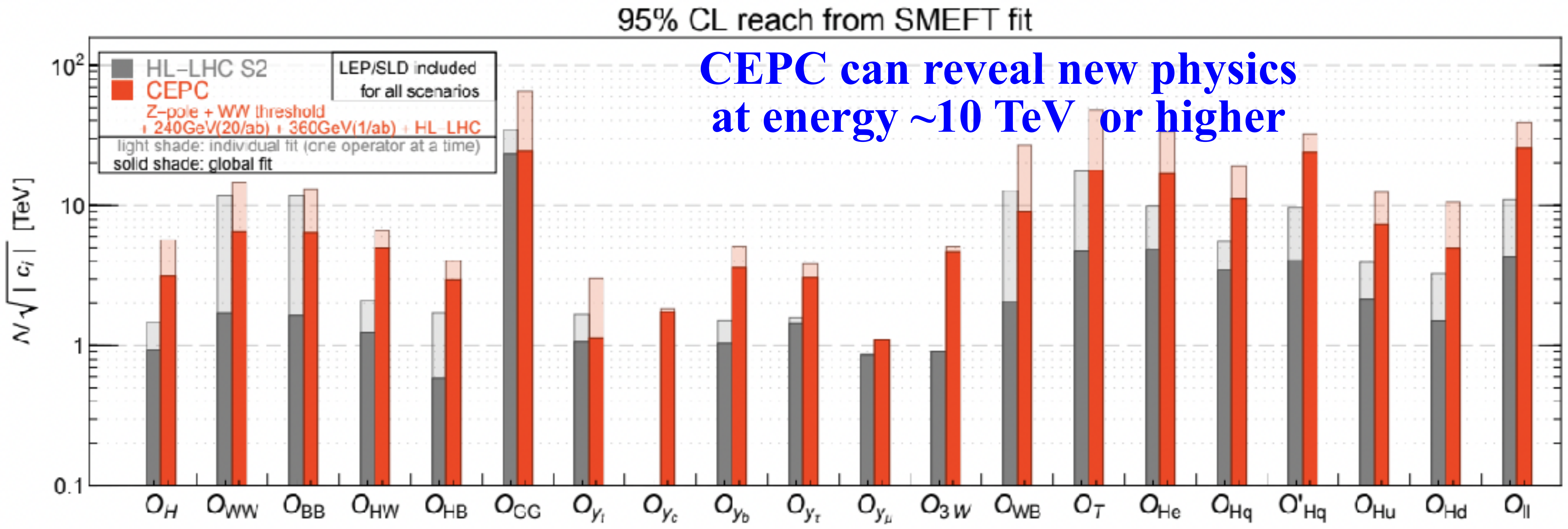




Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale

Measurement	Current [126]	FCC [115]	Tera-Z Prelim. [127]	Comments
Lifetime [sec]	$\pm5\times10^{-16}$	$\pm1\times10^{-18}$		from 3-prong decays, stat. limited
$BR(\tau \to \ell\nu\bar{\nu})$	$\pm4\times10^{-4}$	$\pm3\times10^{-5}$		0.1× the ALEPH systematics
$m(\tau)$ [MeV]	±0.12	$\pm0.004\pm0.1$		$\sigma(p_{track})$ limited
$BR(\tau \to 3\mu)$	$< 2.1\times10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
$BR(\tau \to 3e)$	$< 2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to e\mu\mu)$	$< 2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to \mu ee)$	$< 1.8\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau \to \mu\gamma)$	$< 4.4\times10^{-8}$	$\sim2\times10^{-9}$	$\mathcal{O}(10^{-10})$	$Z \to \tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau \to e\gamma)$	$< 3.3\times10^{-8}$	$\sim2\times10^{-9}$		$Z \to \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z \to \tau\mu)$	$< 1.2\times10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \tau e)$	$< 9.8\times10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \mu e)$	$< 7.5\times10^{-7}$	$10^{-8}-10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z \to \pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$BR(Z \to \pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z \to J/\psi\gamma)$	$< 1.4\times10^{-6}$		$10^{-9}-10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z \to \rho\gamma)$	$< 2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

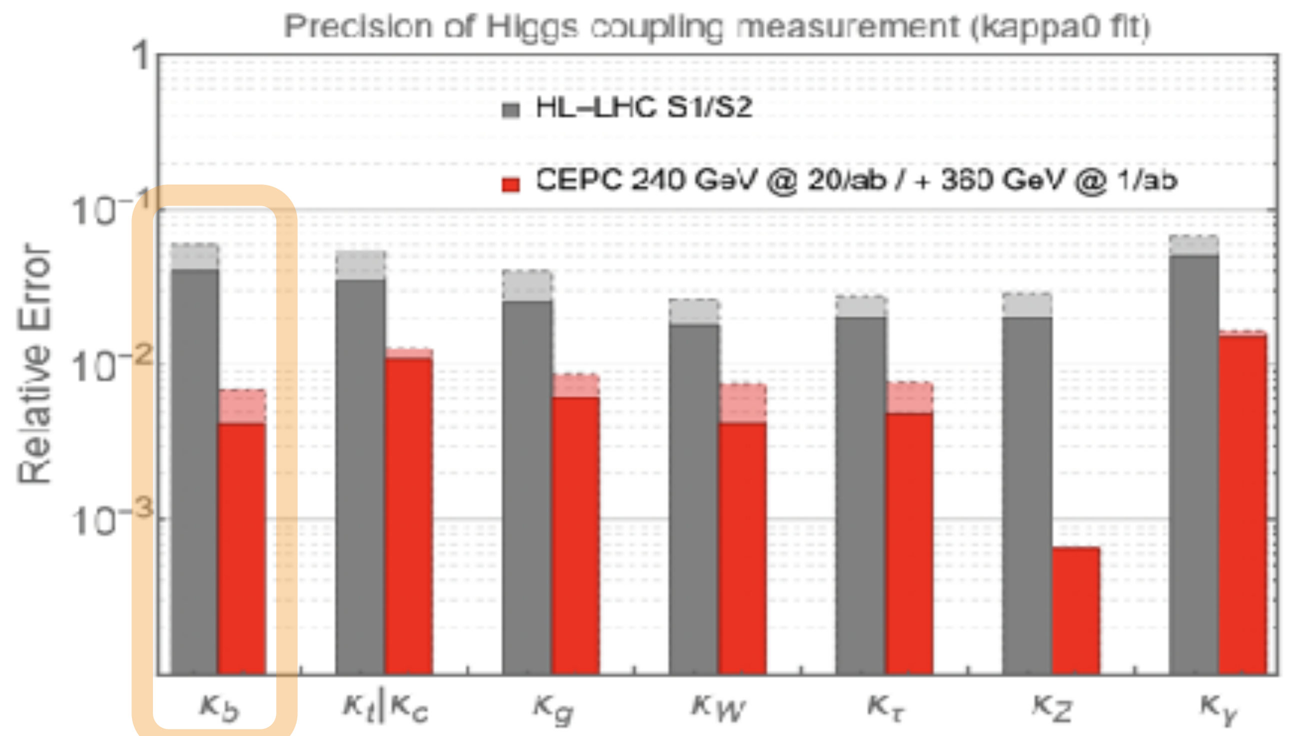
Energy Scale probed

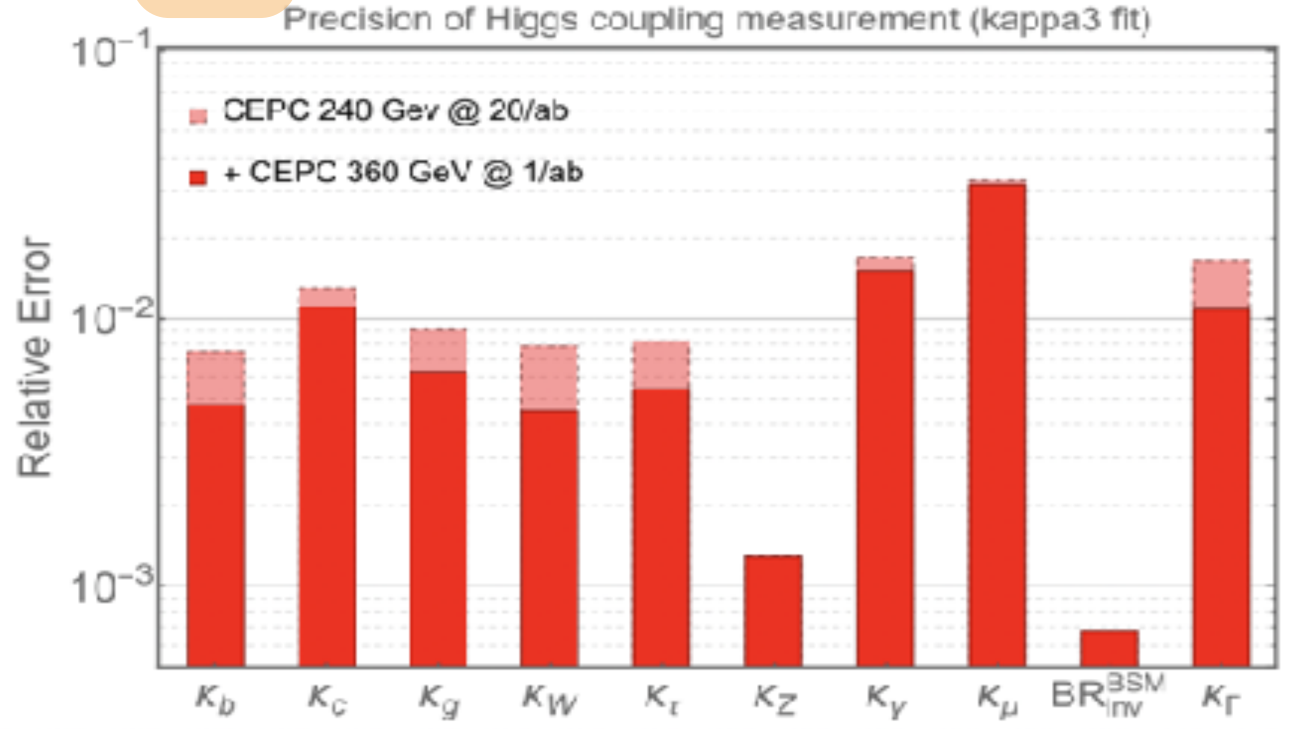


CEPC can reveal new physics at energy ~10 TeV or higher

CEPC Physics Program: Higgs and EW

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



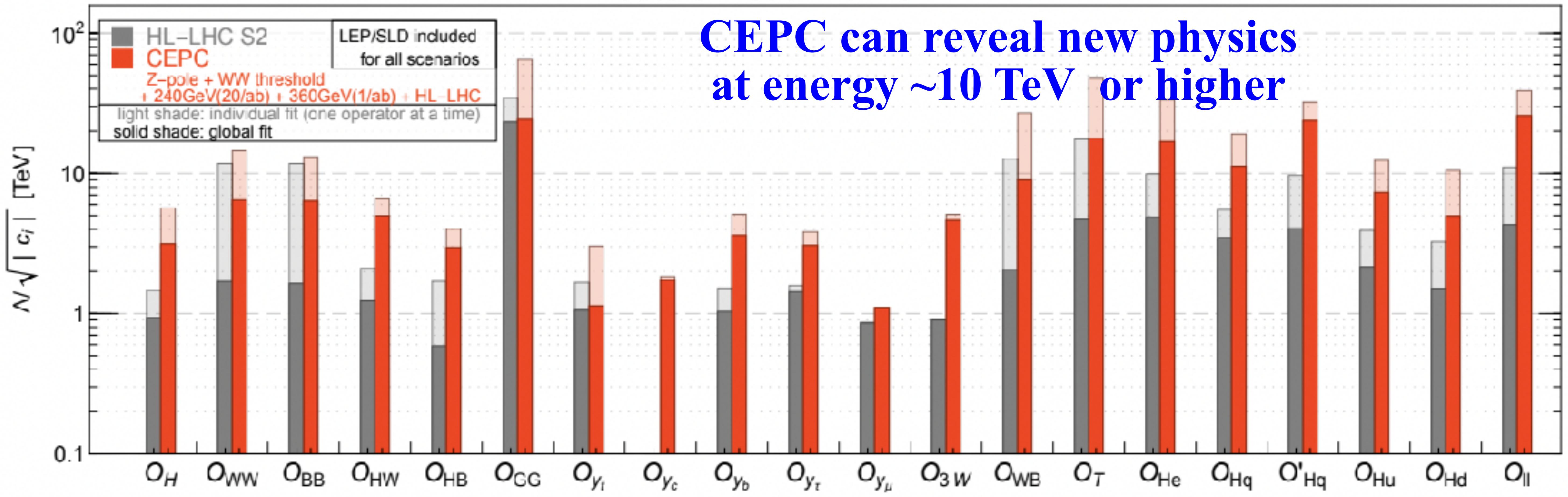


Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z\to\tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z\to\mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z\to\tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale

Measurement	Current [126]	FCC [115]	Tera-Z Prelim. [127]	Comments
Lifetime [sec]	$\pm5\times10^{-16}$	$\pm1\times10^{-18}$		from 3-prong decays, stat. limited
$BR(\tau\to\ell\nu\bar{\nu})$	$\pm4\times10^{-4}$	$\pm3\times10^{-5}$		0.1× the ALEPH systematics
$m(\tau)$ [MeV]	±0.12	$\pm0.004\pm0.1$		$\sigma(p_{track})$ limited
$BR(\tau\to3\mu)$	$<2.1\times10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
$BR(\tau\to3e)$	$<2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm\to e\mu\mu)$	$<2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm\to\mu ee)$	$<1.8\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau\to\mu\gamma)$	$<4.4\times10^{-8}$	$\sim2\times10^{-9}$	$\mathcal{O}(10^{-10})$	$Z\to\tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau\to e\gamma)$	$<3.3\times10^{-8}$	$\sim2\times10^{-9}$		$Z\to\tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z\to\tau\mu)$	$<1.2\times10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z\to\tau e)$	$<9.8\times10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z\to\mu e)$	$<7.5\times10^{-7}$	$10^{-8}-10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z\to\pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$BR(Z\to\pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z\to J/\psi\gamma)$	$<1.4\times10^{-6}$		$10^{-9}-10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z\to\rho\gamma)$	$<2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

Energy Scale probed

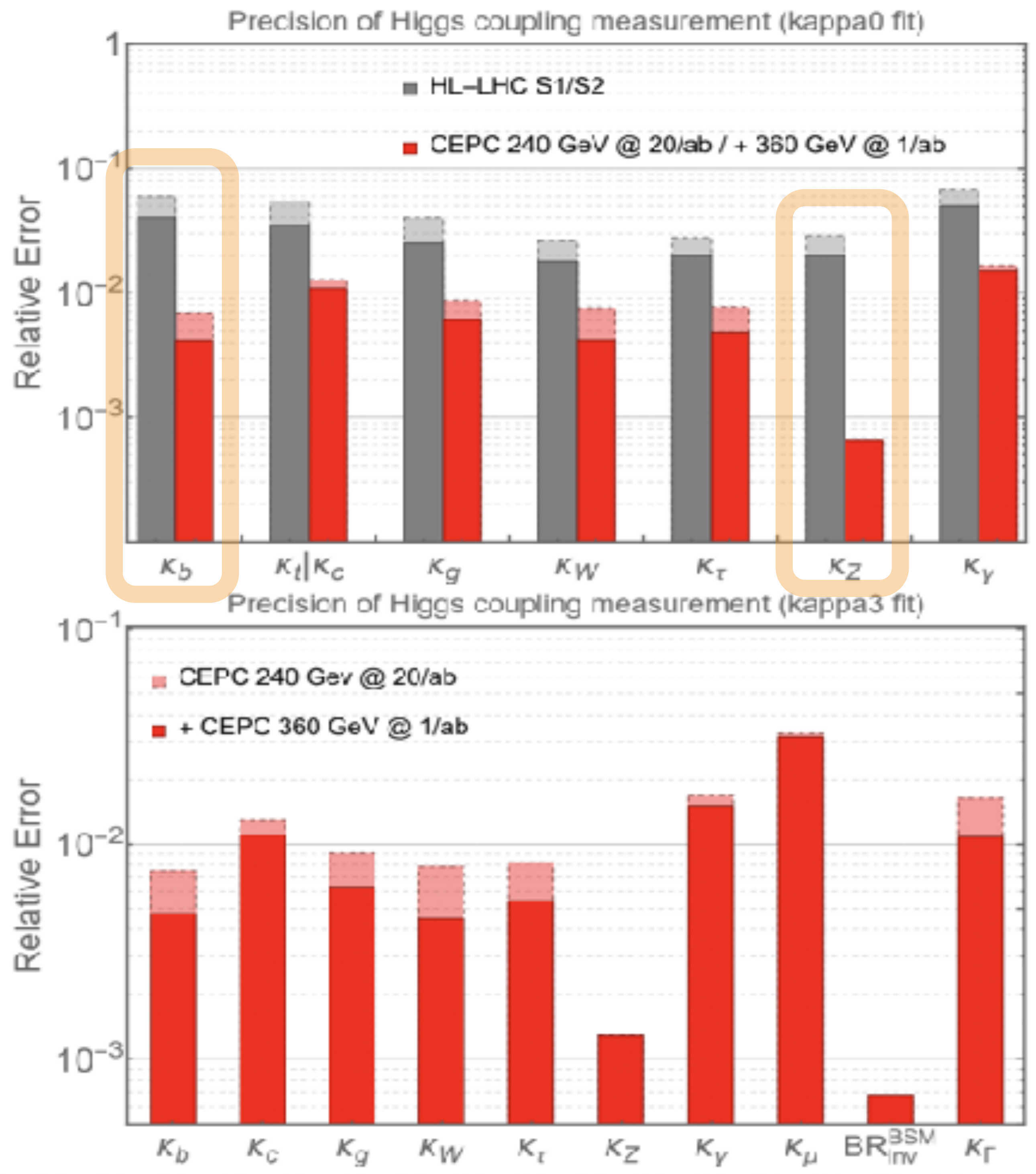
95% CL reach from SMEFT fit



CEPC can reveal new physics at energy ~10 TeV or higher

CEPC Physics Program: Higgs and EW

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



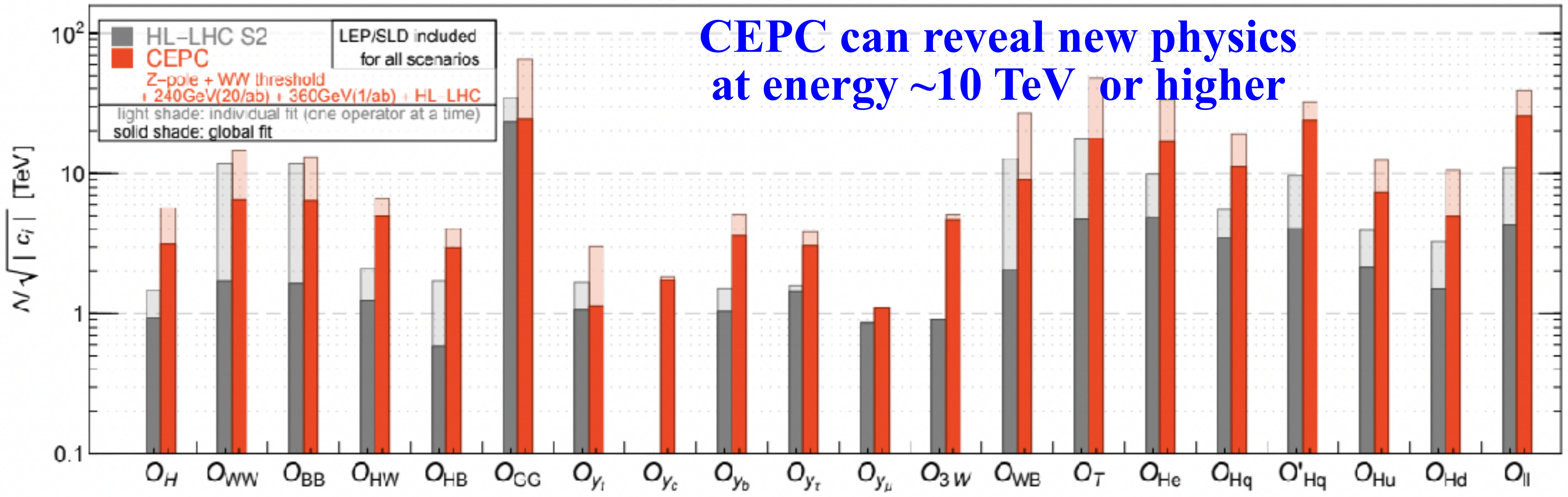
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z\to\tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z\to\mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z\to\tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale

Measurement	Current [126]	FCC [115]	Tera-Z Prelim. [127]	Comments
Lifetime [sec]	$\pm5\times10^{-16}$	$\pm1\times10^{-18}$		from 3-prong decays, stat. limited
$BR(\tau\to\ell\nu\bar{\nu})$	$\pm4\times10^{-4}$	$\pm3\times10^{-5}$		0.1× the ALEPH systematics
$m(\tau)$ [MeV]	±0.12	$\pm0.004\pm0.1$		$\sigma(p_{track})$ limited
$BR(\tau\to3\mu)$	$<2.1\times10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
$BR(\tau\to3e)$	$<2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm\to e\mu\mu)$	$<2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm\to\mu ee)$	$<1.8\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau\to\mu\gamma)$	$<4.4\times10^{-8}$	$\sim2\times10^{-9}$	$\mathcal{O}(10^{-10})$	$Z\to\tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau\to e\gamma)$	$<3.3\times10^{-8}$	$\sim2\times10^{-9}$		$Z\to\tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z\to\tau\mu)$	$<1.2\times10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z\to\tau e)$	$<9.8\times10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z\to\mu e)$	$<7.5\times10^{-7}$	$10^{-8}-10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z\to\pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$BR(Z\to\pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z\to J/\psi\gamma)$	$<1.4\times10^{-6}$		$10^{-9}-10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z\to\rho\gamma)$	$<2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

Energy Scale probed

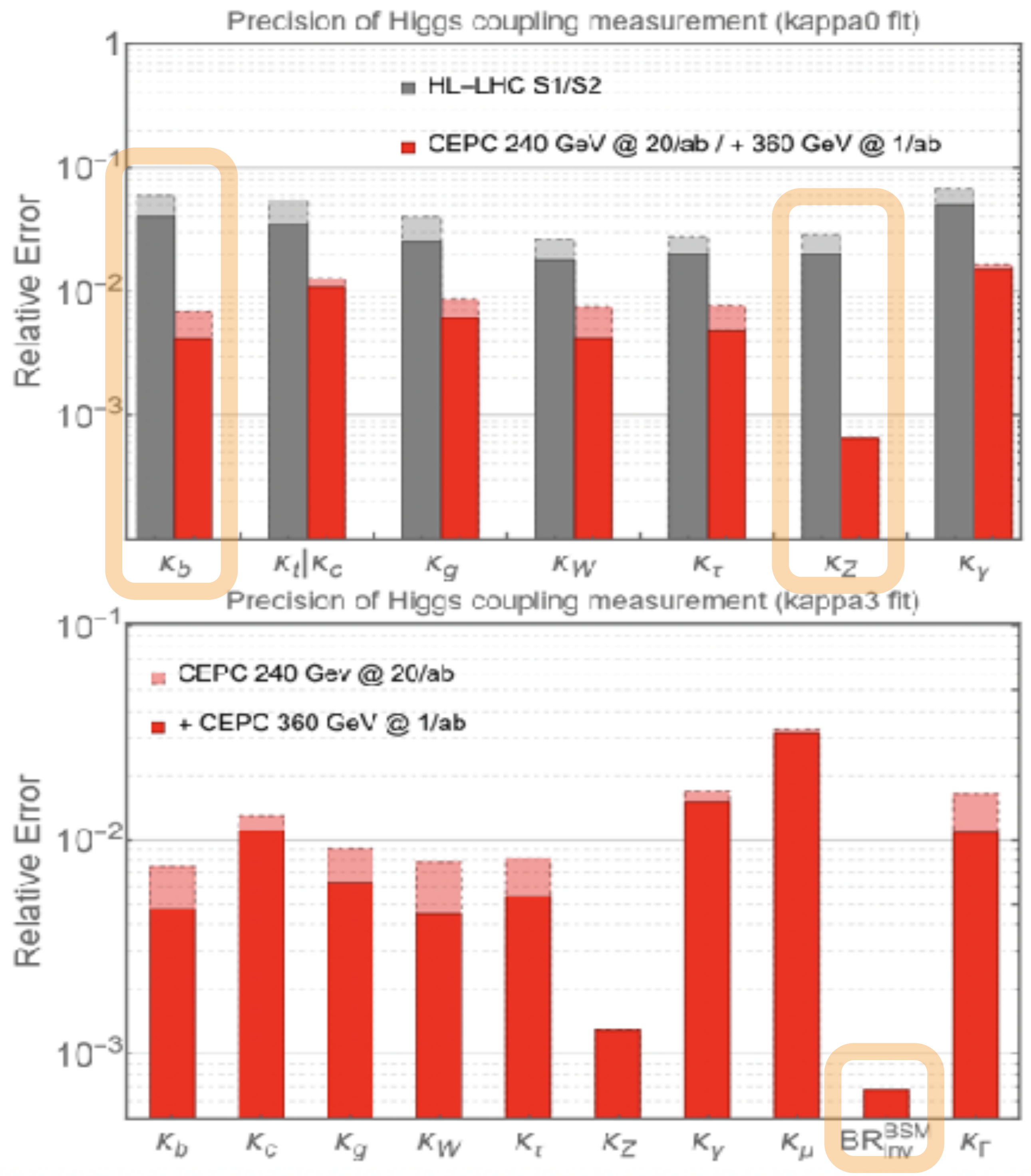
95% CL reach from SMEFT fit

CEPC can reveal new physics at energy ~10 TeV or higher



CEPC Physics Program: Higgs and EW

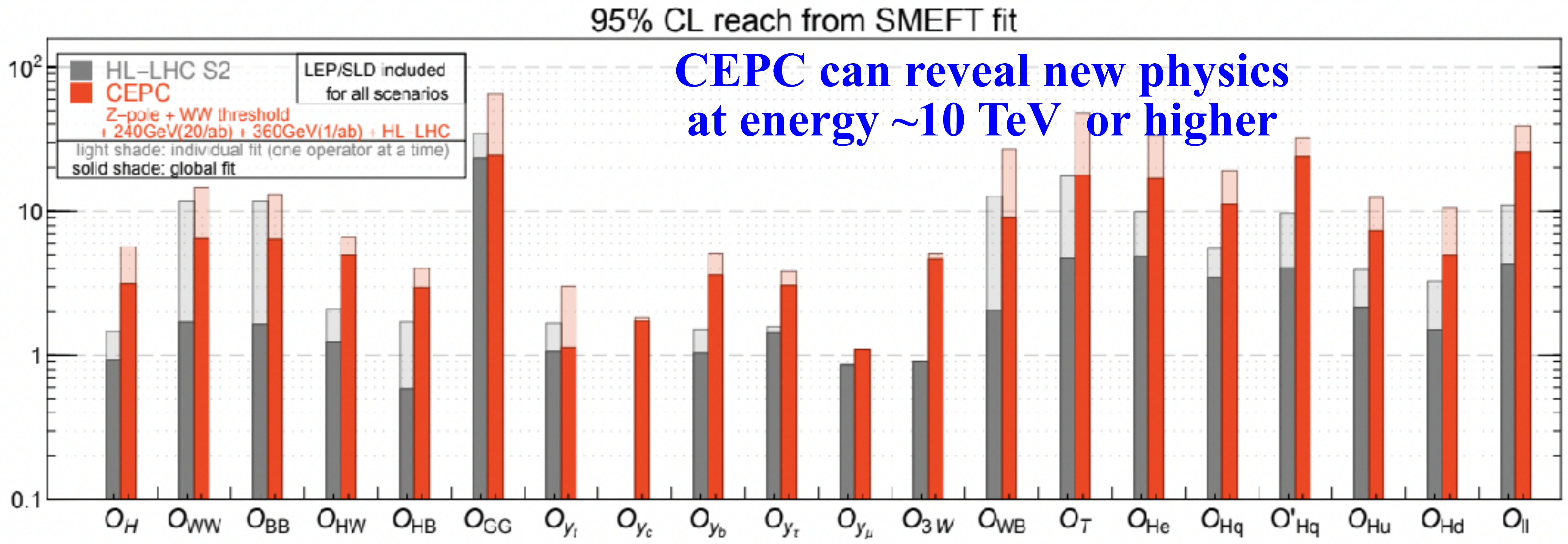
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%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



Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta \Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta \Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta \sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale

Measurement	Current [126]	FCC [115]	Tera-Z Prelim. [127]	Comments
Lifetime [sec]	$\pm5\times10^{-16}$	$\pm1\times10^{-18}$		from 3-prong decays, stat. limited
$BR(\tau \to \ell\nu\bar{\nu})$	$\pm4\times10^{-4}$	$\pm3\times10^{-5}$		0.1× the ALEPH systematics
$m(\tau)$ [MeV]	±0.12	$\pm0.004 \pm 0.1$		$\sigma(p_{track})$ limited
$BR(\tau \to 3\mu)$	$< 2.1\times10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
$BR(\tau \to 3e)$	$< 2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to e\mu\mu)$	$< 2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to \mu ee)$	$< 1.8\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau \to \mu\gamma)$	$< 4.4\times10^{-8}$	$\sim2\times10^{-9}$	$\mathcal{O}(10^{-10})$	$Z \to \tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau \to e\gamma)$	$< 3.3\times10^{-8}$	$\sim2\times10^{-9}$		$Z \to \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z \to \tau\mu)$	$< 1.2\times10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \tau e)$	$< 9.8\times10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \mu e)$	$< 7.5\times10^{-7}$	$10^{-8} - 10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z \to \pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$BR(Z \to \pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z \to J/\psi\gamma)$	$< 1.4\times10^{-6}$		$10^{-9} - 10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z \to \rho\gamma)$	$< 2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

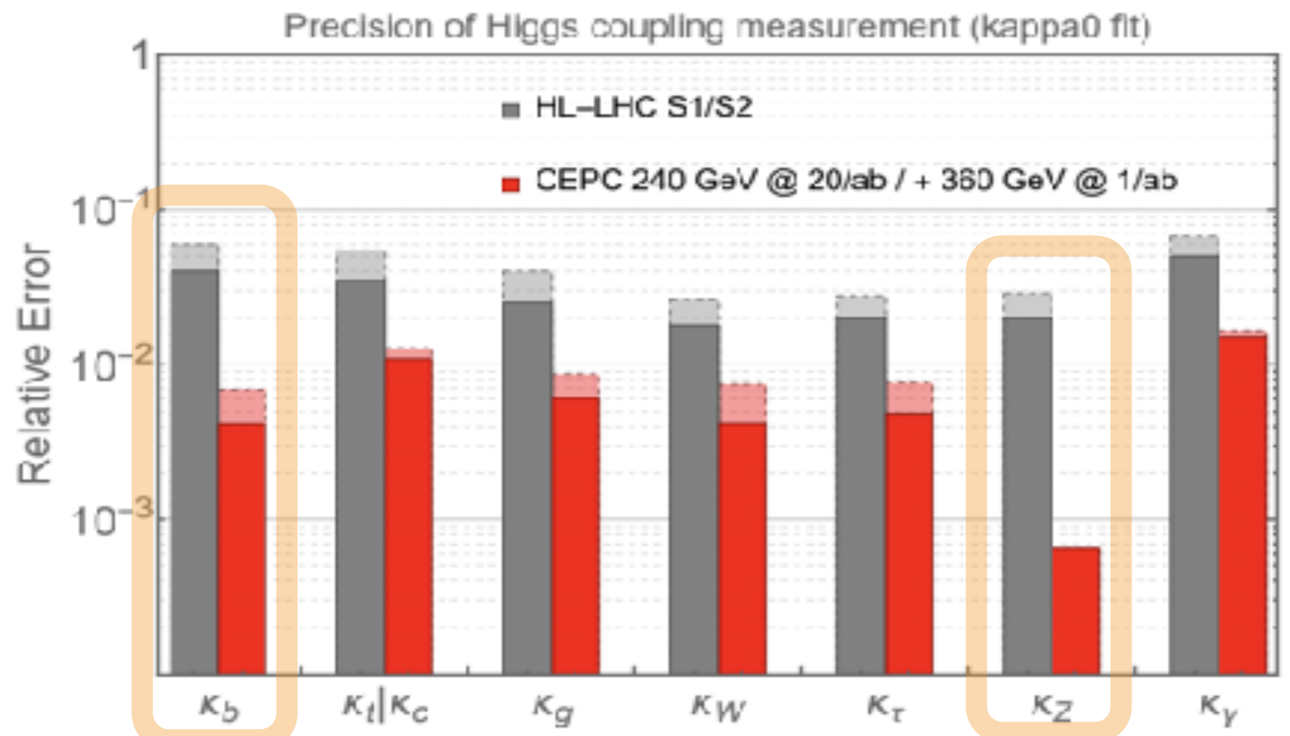
Energy Scale probed

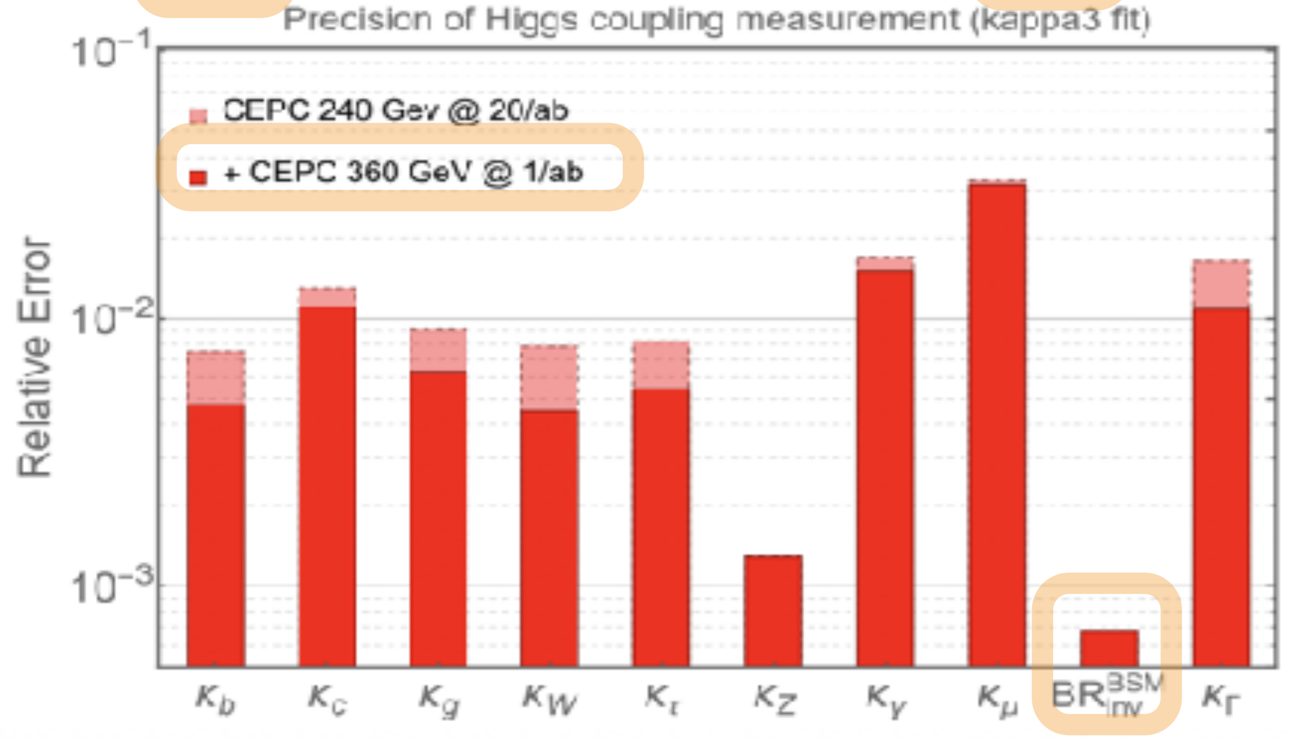


CEPC can reveal new physics at energy ~10 TeV or higher

CEPC Physics Program: Higgs and EW

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

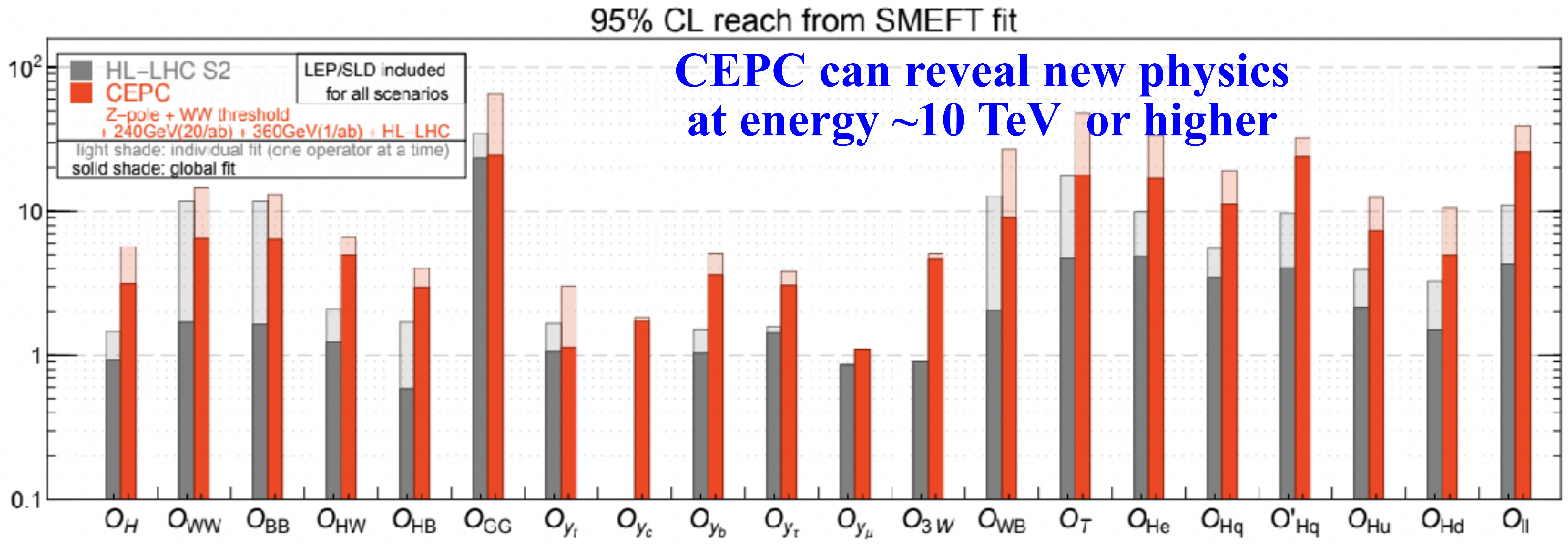




Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5}(1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale

Measurement	Current [126]	FCC [115]	Tera-Z Prelim. [127]	Comments
Lifetime [sec]	$\pm5\times10^{-16}$	$\pm1\times10^{-18}$		from 3-prong decays, stat. limited
$BR(\tau \to \ell\nu\bar{\nu})$	$\pm4\times10^{-4}$	$\pm3\times10^{-5}$		$0.1\times$ the ALEPH systematics
$m(\tau)$ [MeV]	±0.12	$\pm0.004 \pm 0.1$		$\sigma(p_{track})$ limited
$BR(\tau \to 3\mu)$	$< 2.1\times10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
$BR(\tau \to 3e)$	$< 2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to e\mu\mu)$	$< 2.7\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to \mu ee)$	$< 1.8\times10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau \to \mu\gamma)$	$< 4.4\times10^{-8}$	$\sim2\times10^{-9}$	$\mathcal{O}(10^{-10})$	$Z \to \tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau \to e\gamma)$	$< 3.3\times10^{-8}$	$\sim2\times10^{-9}$		$Z \to \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z \to \tau\mu)$	$< 1.2\times10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \tau e)$	$< 9.8\times10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \mu e)$	$< 7.5\times10^{-7}$	$10^{-8} - 10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z \to \pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\bar{p}_{track})$ limited, good PID
$BR(Z \to \pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z \to J/\psi\gamma)$	$< 1.4\times10^{-6}$		$10^{-9} - 10^{-10}$	$\ell\ell\gamma$+$\tau\tau\gamma$ bkg
$BR(Z \to \rho\gamma)$	$< 2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

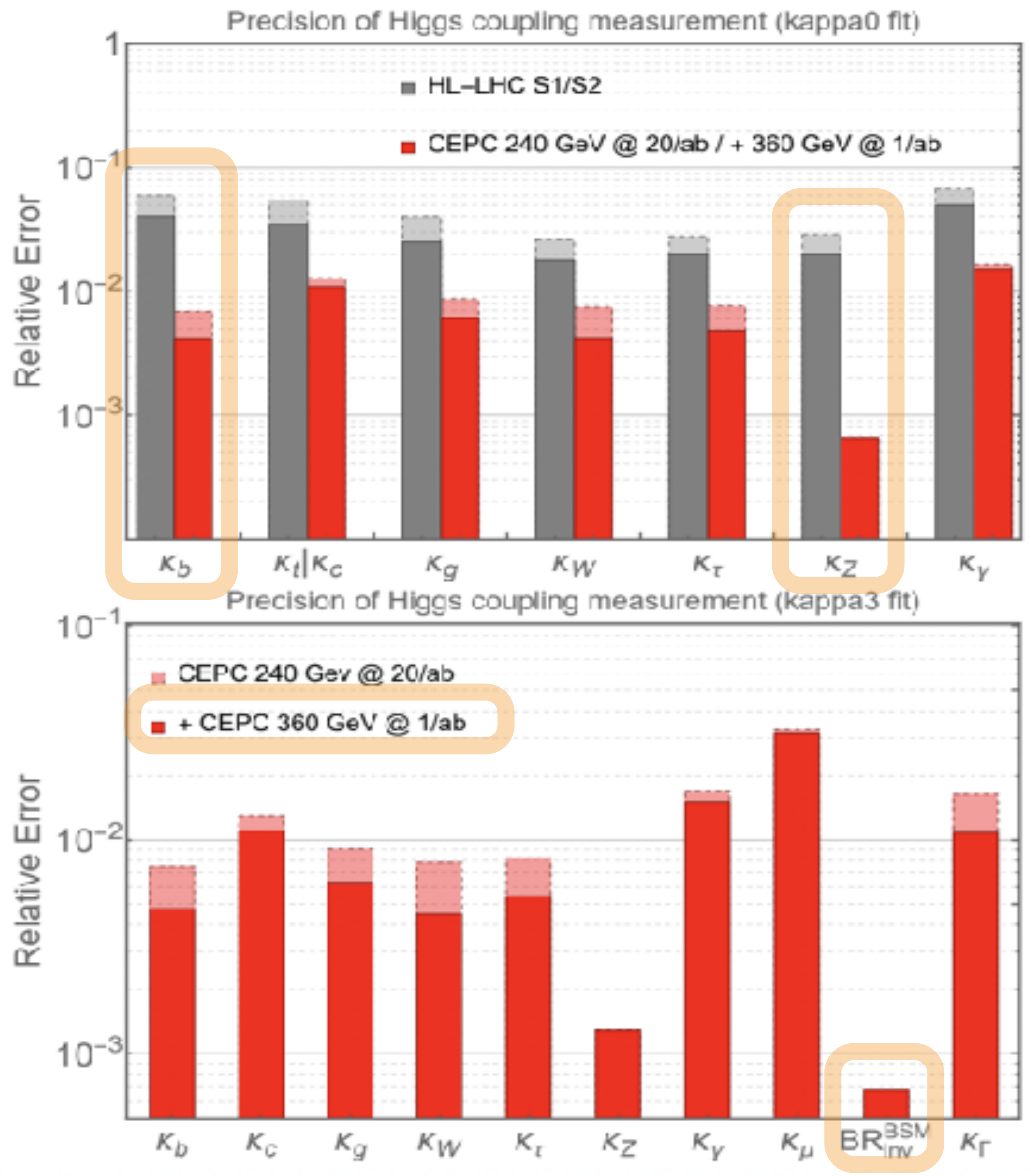
Energy Scale probed



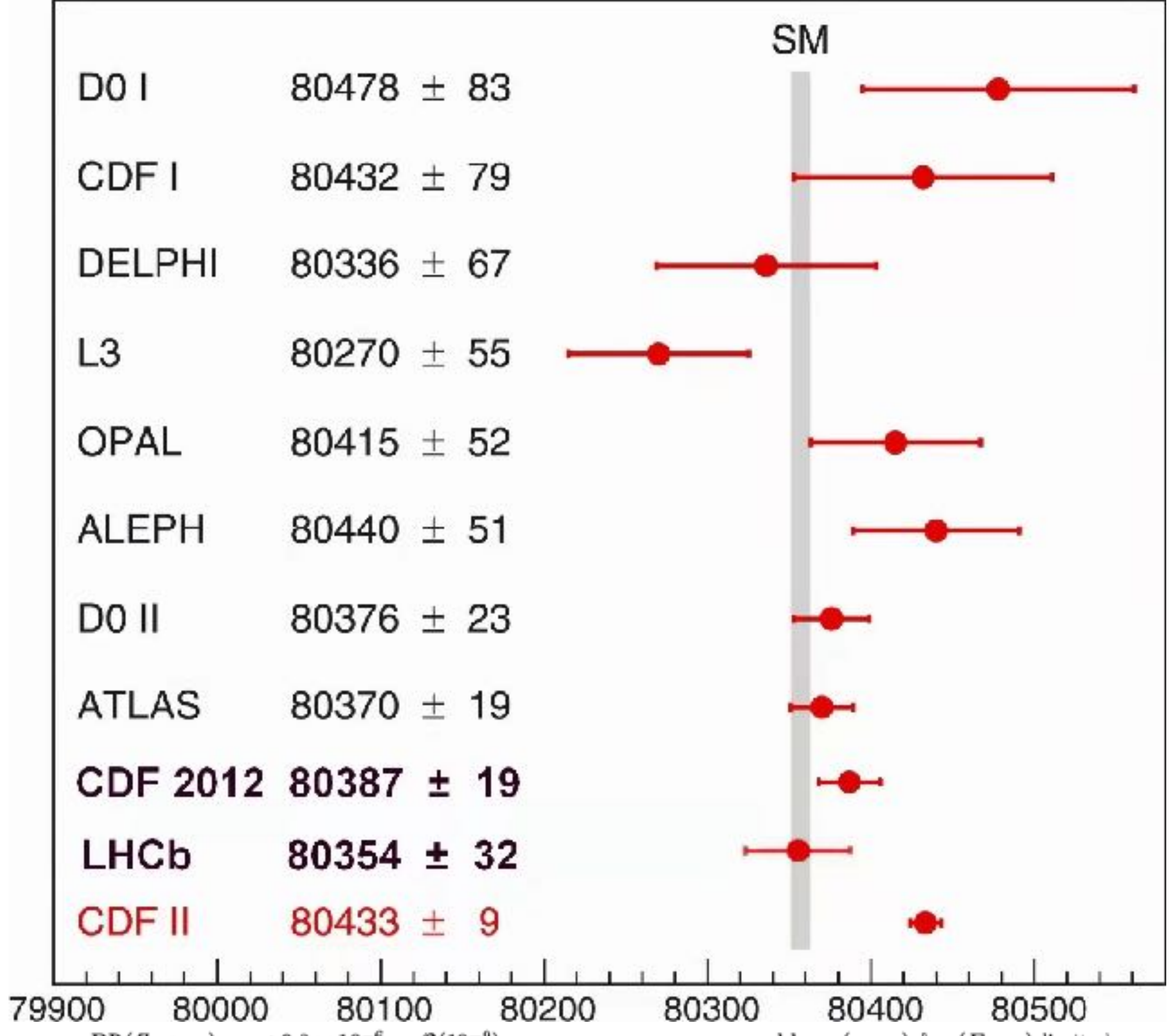
CEPC can reveal new physics at energy ~10 TeV or higher

CEPC Physics Program: Higgs and EW

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



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

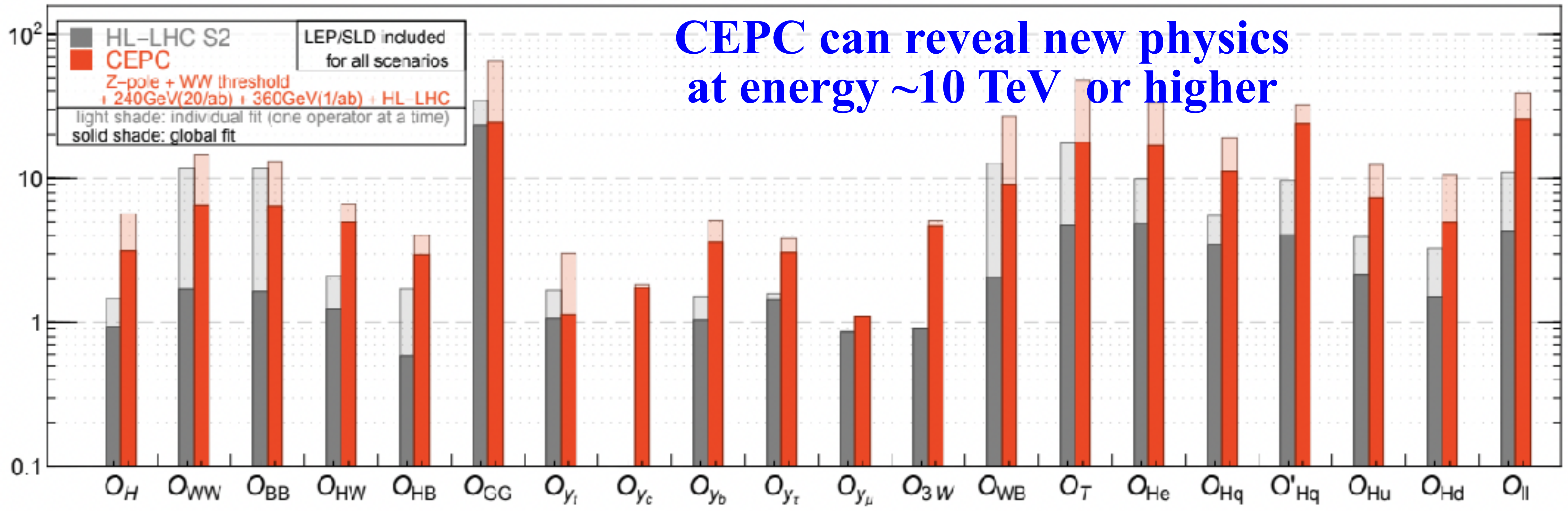


$BR(Z \to \tau e)$	$< 9.8 \times 10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(p_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z \to \mu e)$	$< 7.5 \times 10^{-7}$	$10^{-8} - 10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z \to \pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\bar{p}_{track})$ limited, good PID
$BR(Z \to \pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z \to J/\psi\gamma)$	$< 1.4 \times 10^{-6}$		$10^{-9} - 10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z \to \rho\gamma)$	$< 2.5 \times 10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

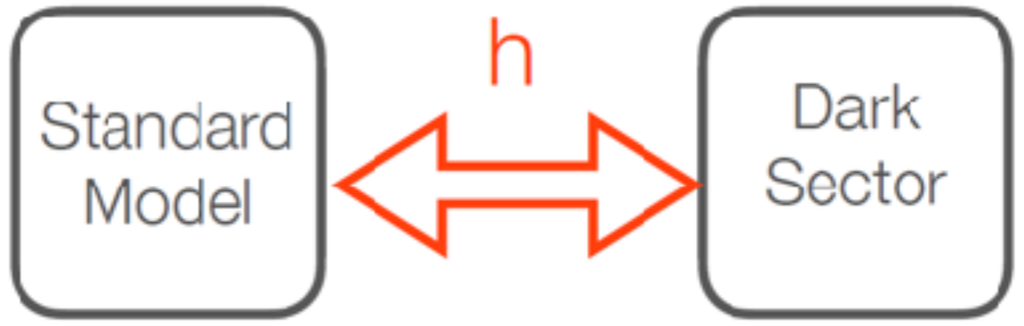
95% CL reach from SMEFT fit

CEPC can reveal new physics at energy ~10 TeV or higher

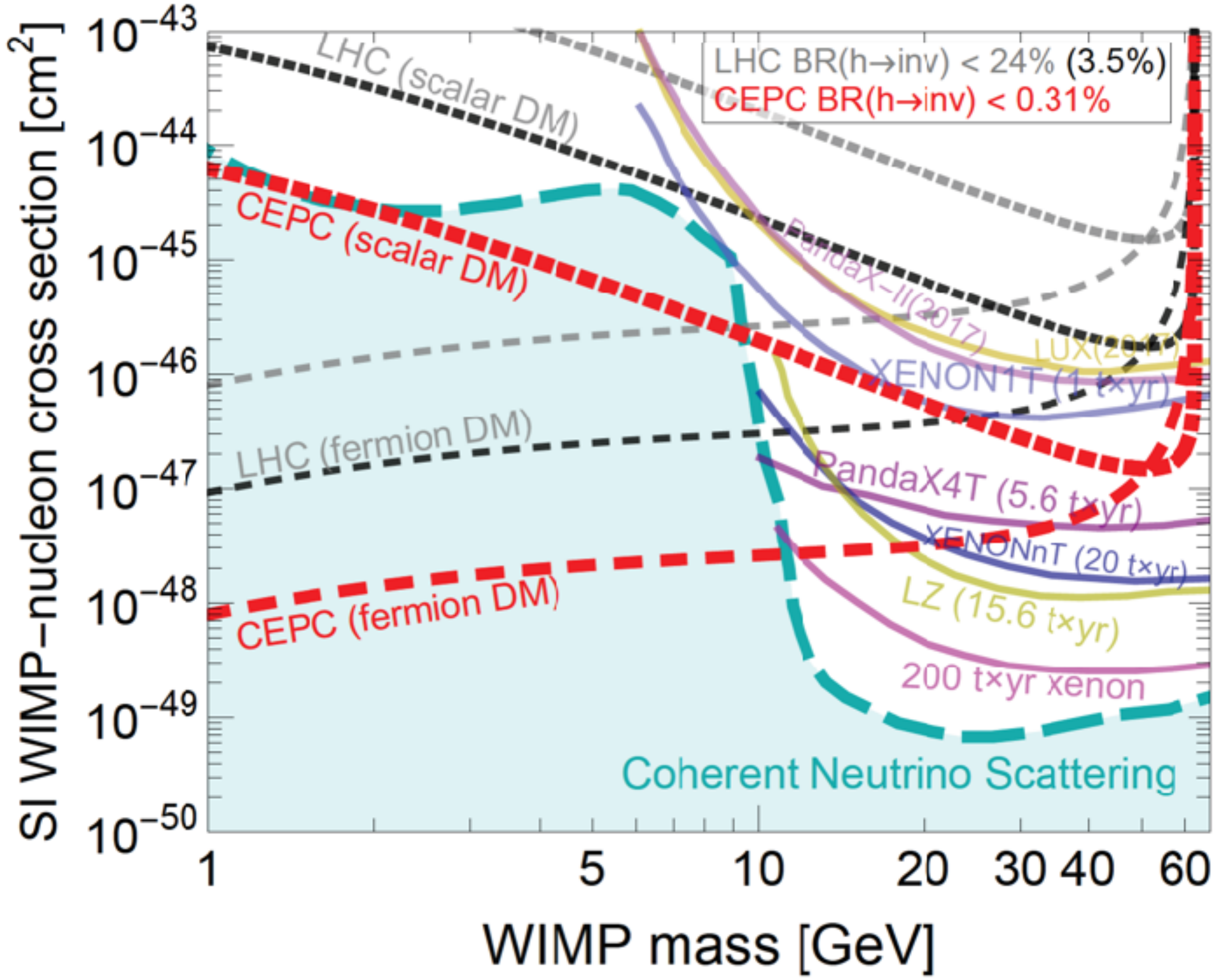
Energy Scale probed



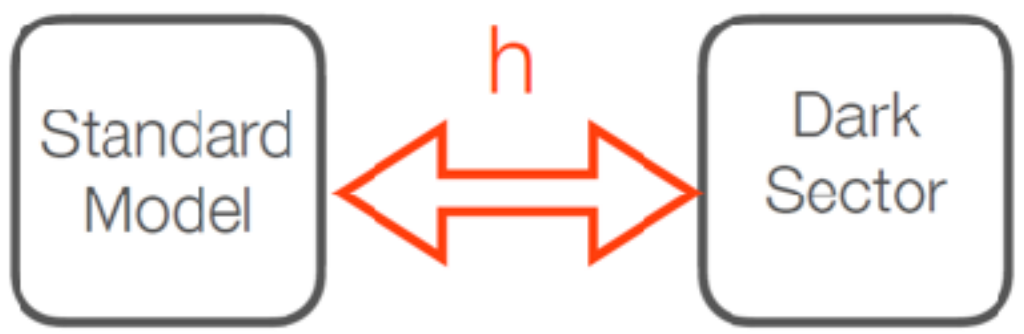
Discovery Potential for New Physics



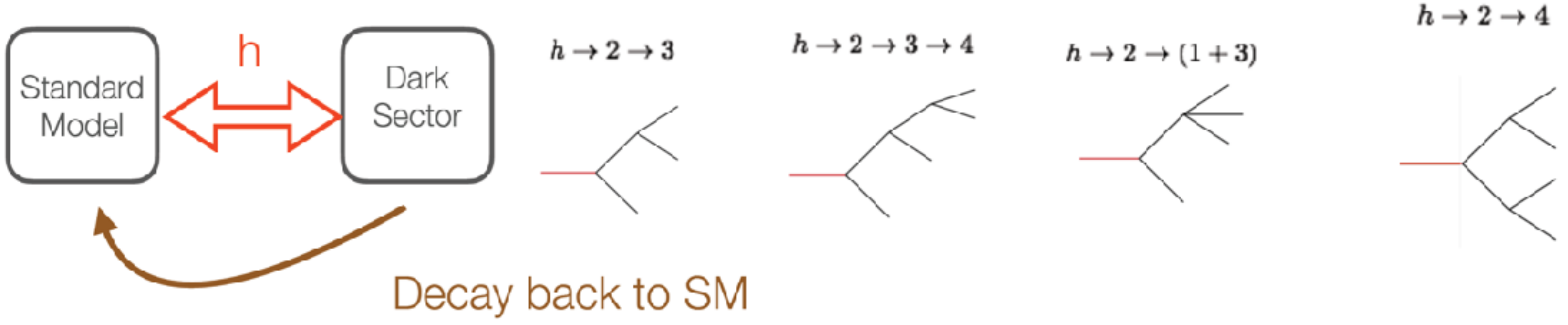
$$h \rightarrow X_{\rm dm} X_{\rm dm}$$

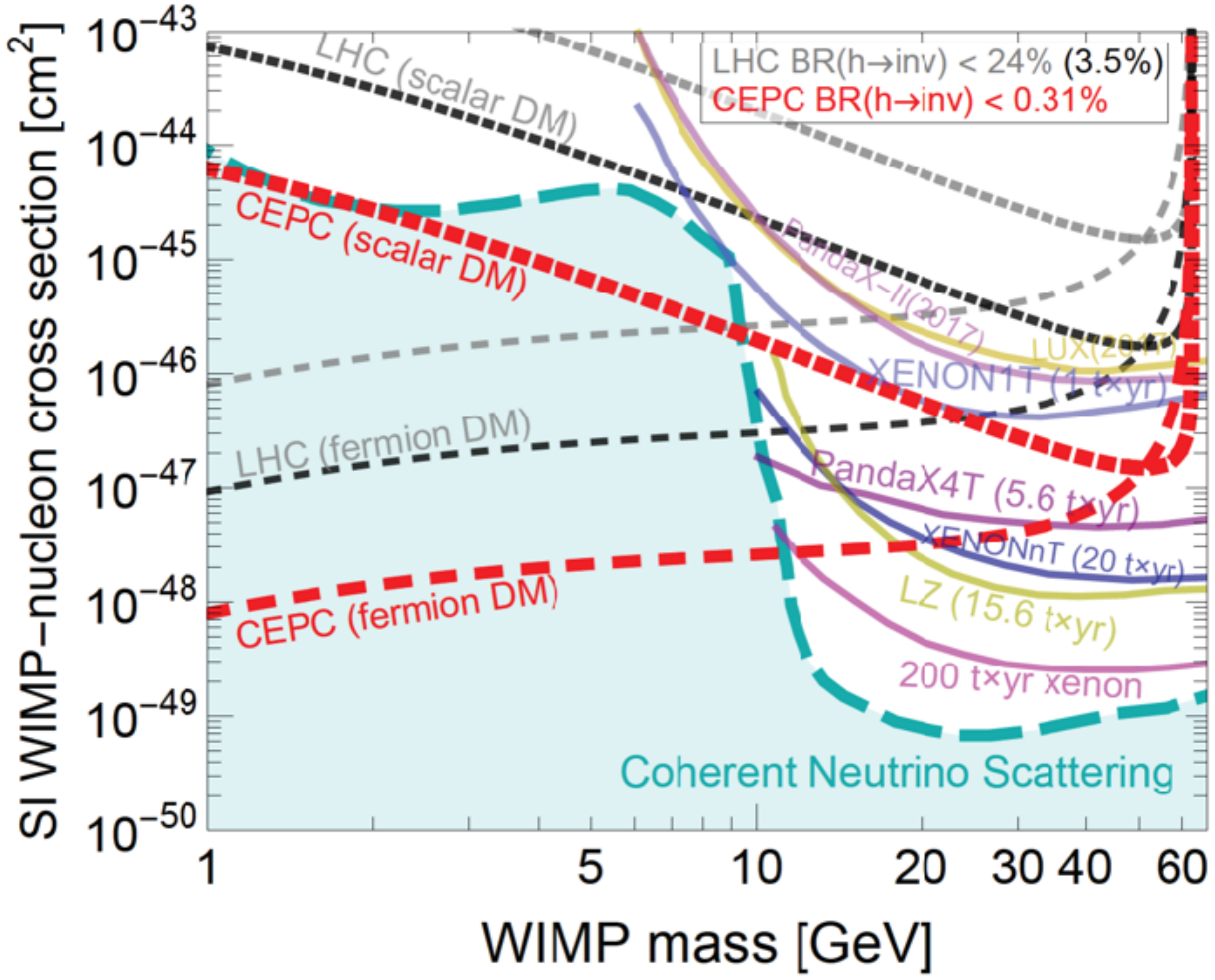


Discovery Potential for New Physics

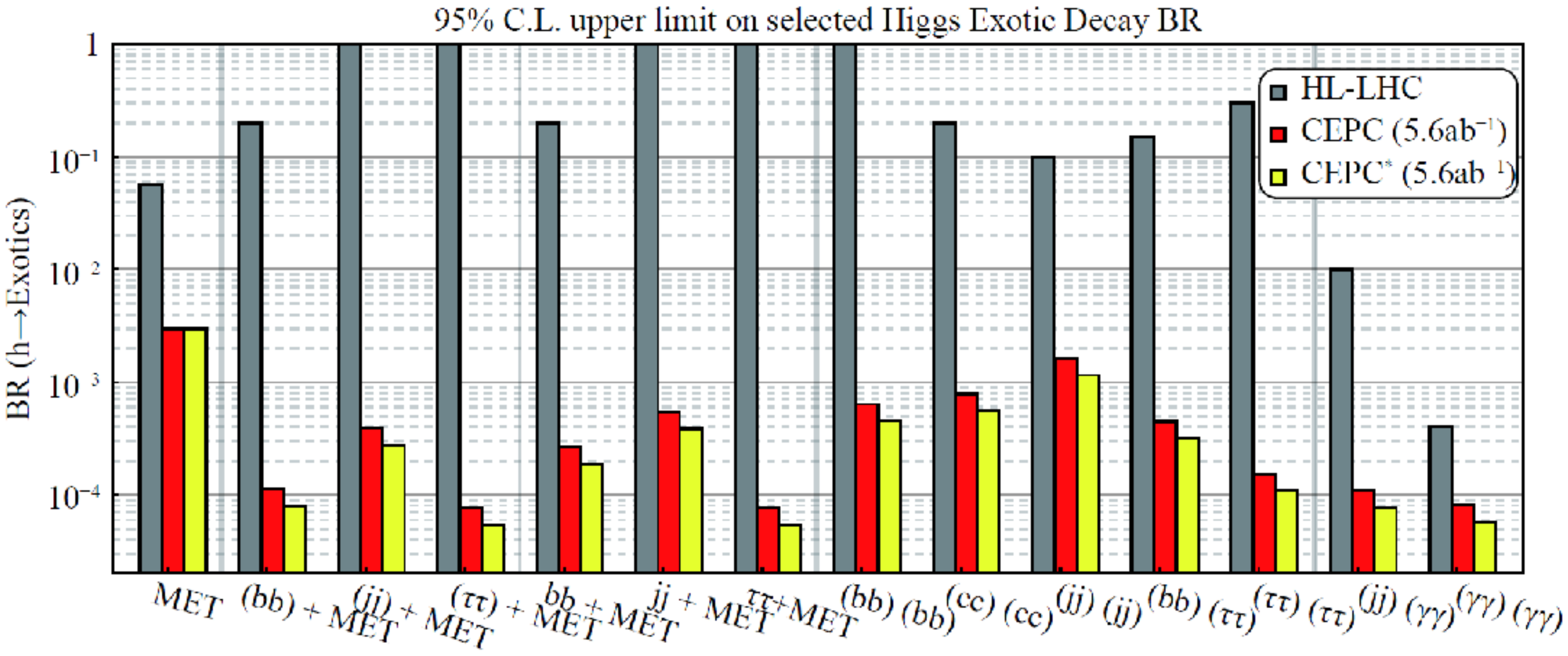


$$h \to X_{\rm dm} X_{\rm dm}$$





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

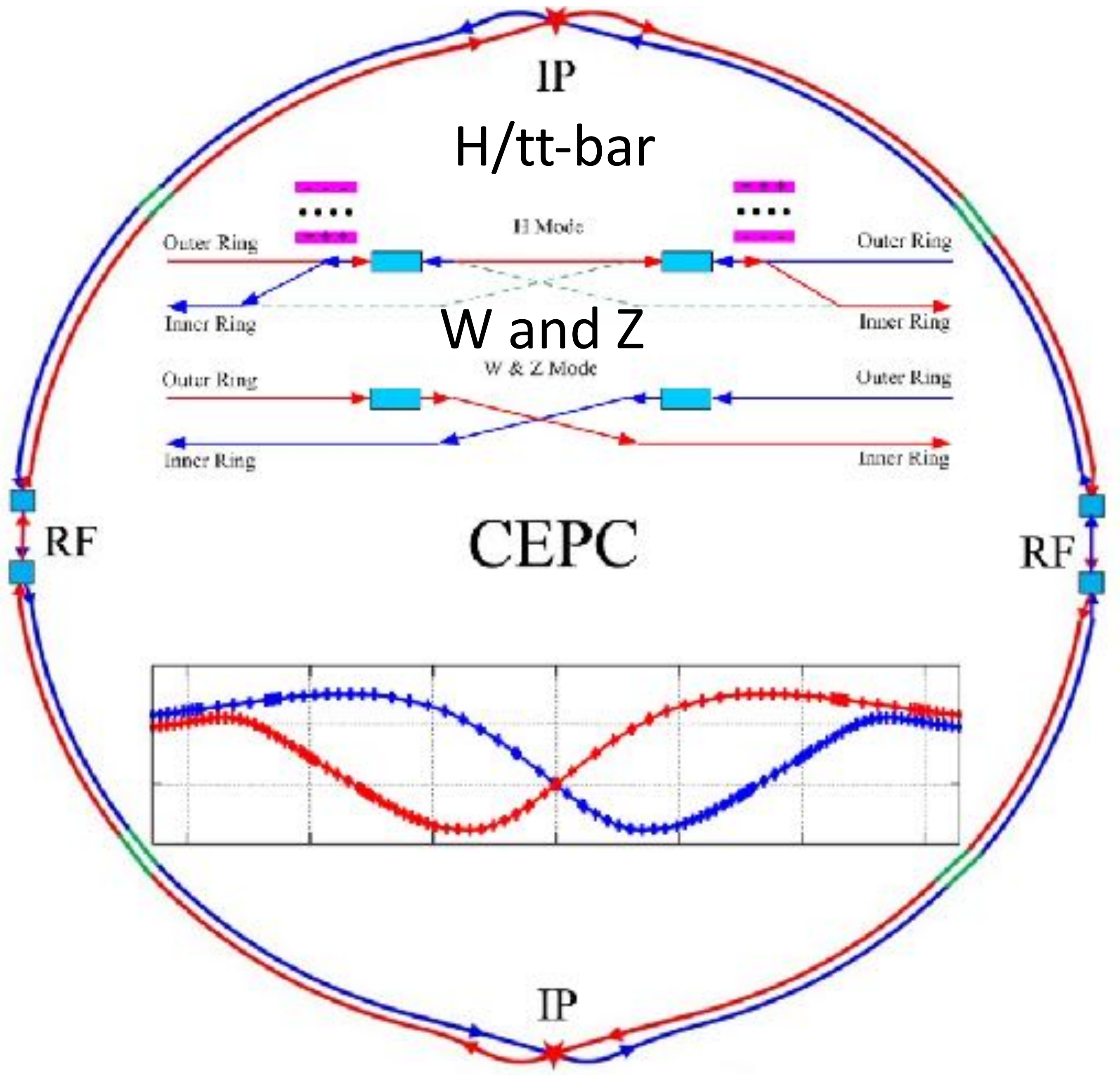


CEPC has significantly better detection sensitivity for dark matter and selected Higgs exotic decays than HL-LHC

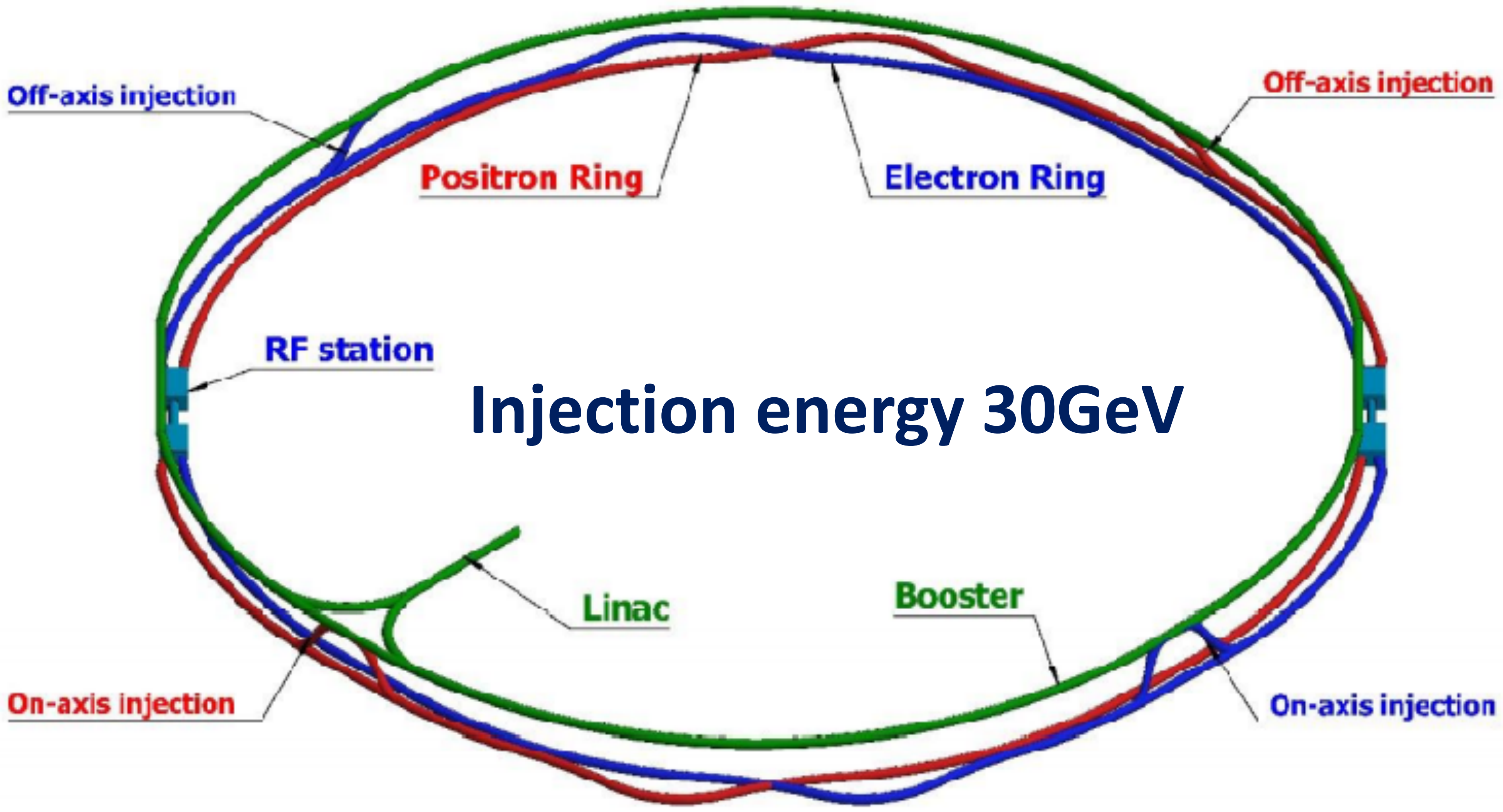
Circular Electron Position Collider (CEPC) - TDR Layout

CEPC as a Higgs Factory： H, W, Z, upgradable to tt-bar, followed by a SppC ~125TeV

30MW SR power per beam (upgradable to 50MW)



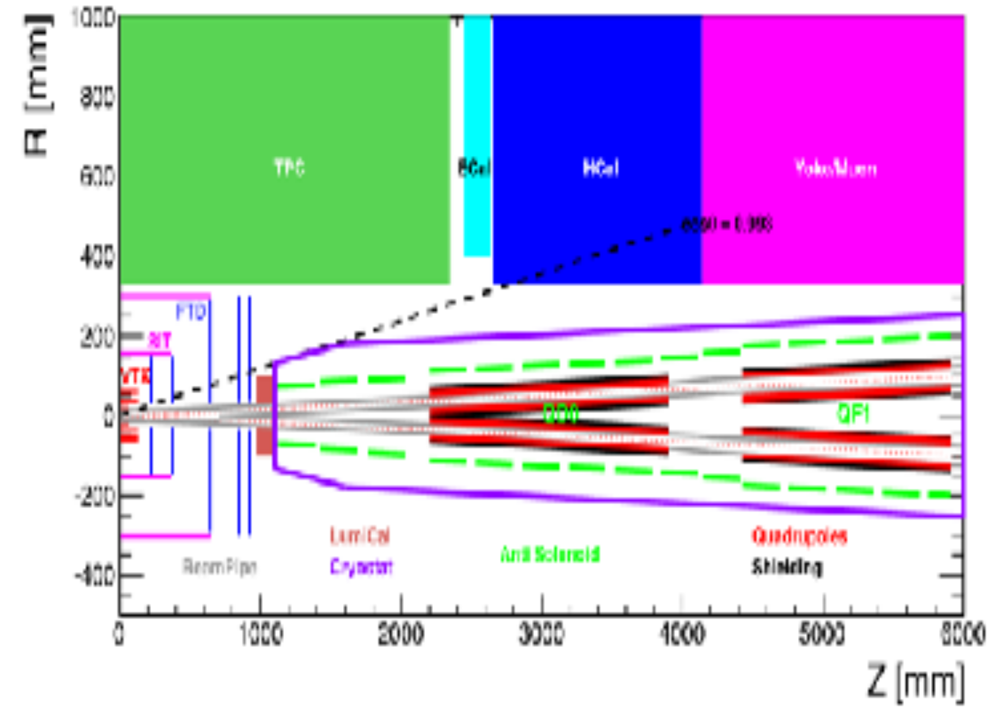
CEPC collider ring (100km)



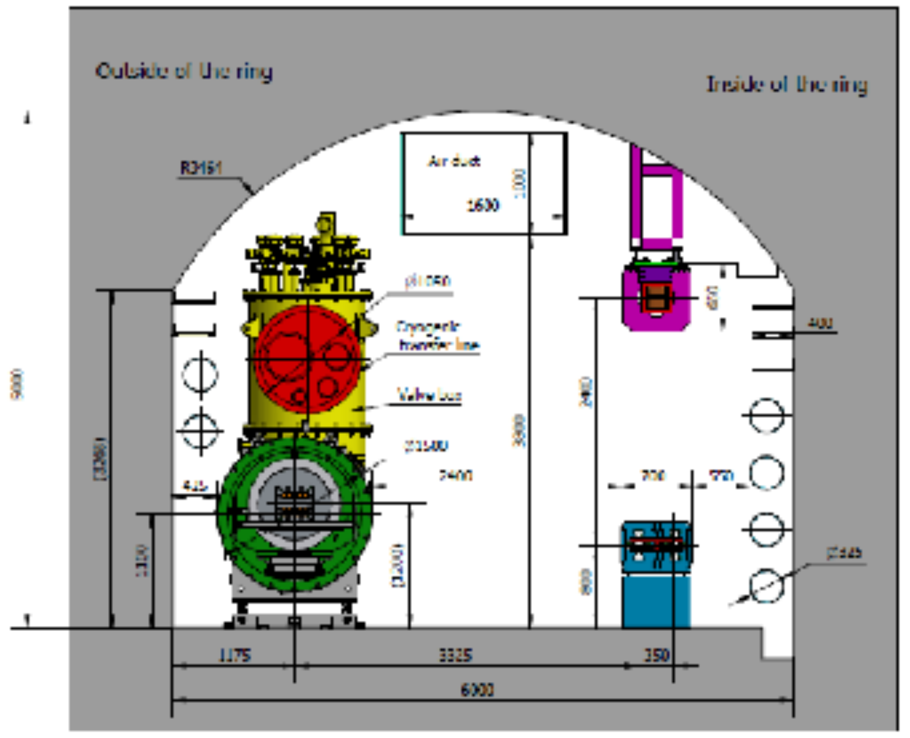
CEPC booster ring (100km)

Common tunnel for booster/collider & SppC

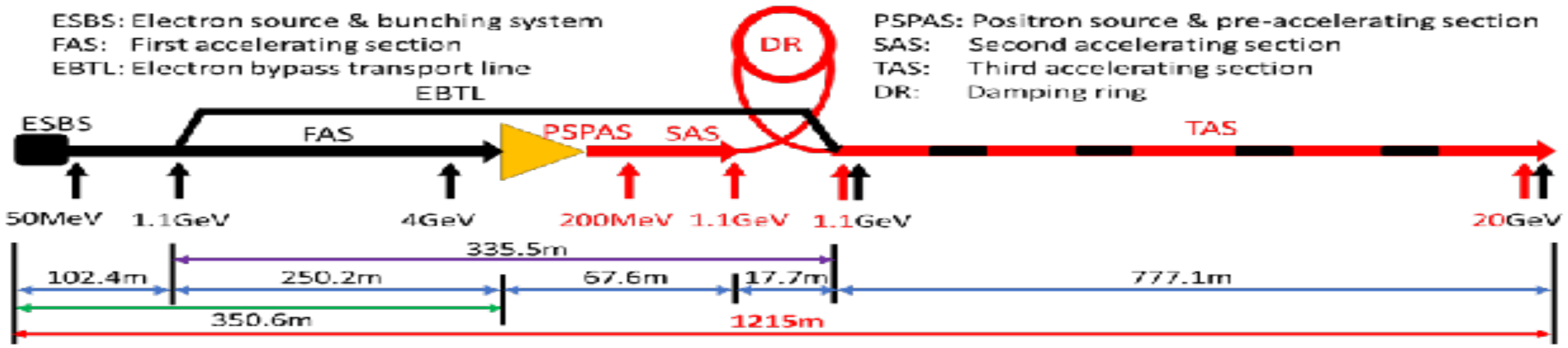
CEPC MDI



CEPC Civil Engineering



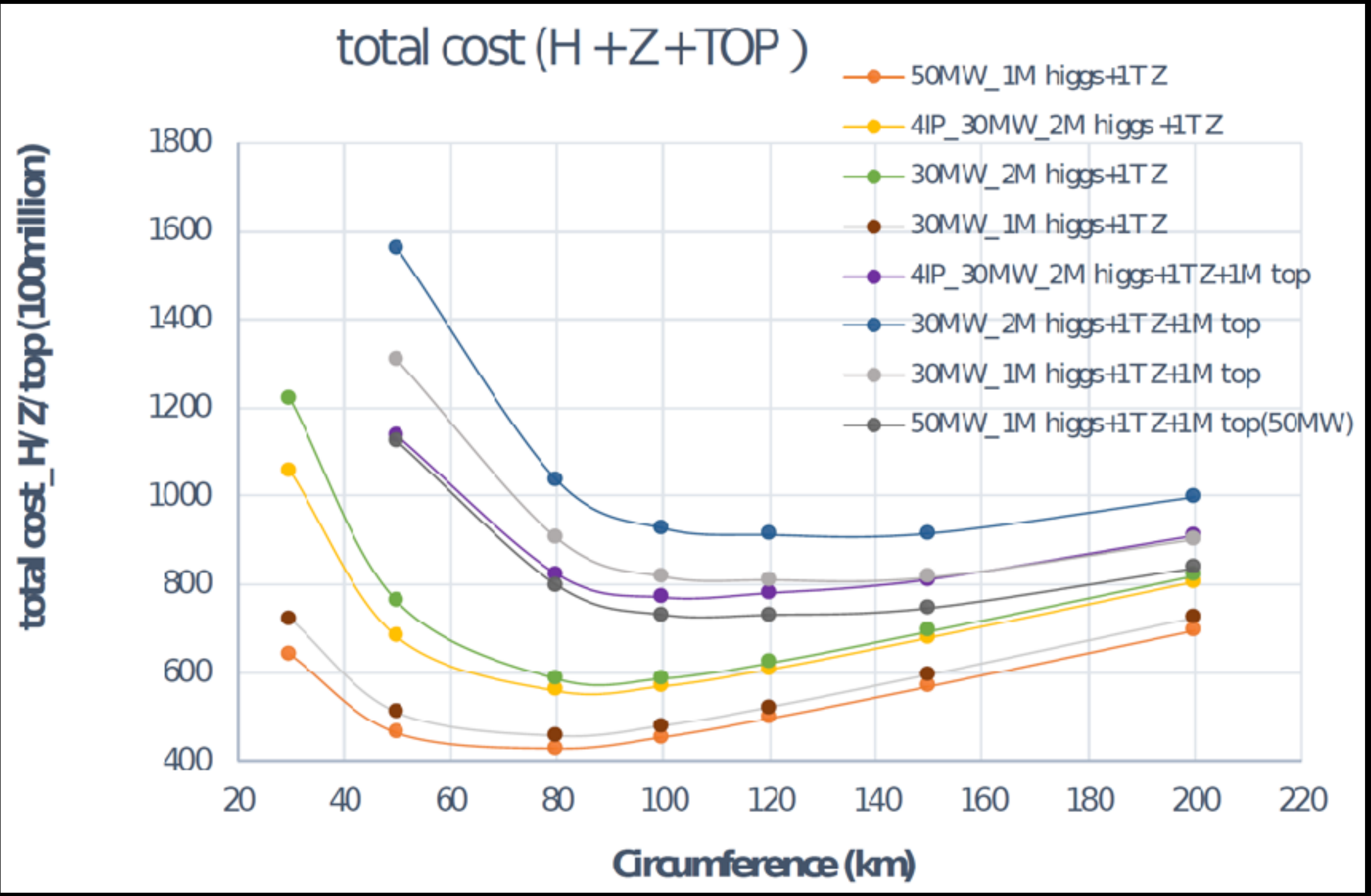
CEPC TDR S+C-band 30 GeV linac injector



Operation mode		ZH	Z	W+W-	tt
		~240	~91.2	158-172	~360
L / IP [×10^34 cm^-2s^-1]	CDR (2018)	3	32	10	
	TDR (30MW)	5.0	115	16	0.5

CEPC TDR Parameters (upgrade version)

Cost optimization vs. circumference



D. Wang *et al* 2022 *JINST* **17** P10018

Main Parameters: High luminosity as a Higgs Factory

	Higgs	**W**	**Z**	**ttbar**
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	**50**			
Energy [GeV]	**120**	**80**	**45.5**	**180**
Bunch number	415	2161	19918	59
Emittance (εx/εy) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (σx/σy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Beam-beam parameters (ξx/ξy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF frequency [MHz]	650			
Luminosity per IP[10^{34}/cm^2/s]	**8.3**	**27**	**192**	**0.83**

50 MW and 100 km ring a cost effective solution for a higgs, W, Z and top machine

CEPC Physics Program

CEPC Operation mode		ZH	Z	W^+W^-	ttbar
		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	-
CDR (30MW)	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	3	32	10	-
	[ab^{-1}, 2 IPs]	5.6	16	2.6	-
	Event yields [2 IPs]	**1×10^6**	**7×10^{11}**	**2×10^7**	-
Run time [years]		10	2	1	5
Latest (50MW)	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	8.3	192	27	0.83
	[ab^{-1}, 2 IPs]	20	96	7	1
	Event yields [2 IPs]	**4×10^6**	**4×10^{12}**	**5×10^7**	**5×10^5**

Large physics samples: ~10^6 Higgs, ~10^{12} Z, ~10^8 W bosons, ~10^6 top quarks

Physics potential similar to FCC-ee, ILC, CLIC

Consensus in HEP community for an e^+e^- Higgs factory

The scientific importance and strategical value of an electron positron Higgs factory is clearly identified.

XIANGSHAN SCIENCE CONFERENCES

2013, 2016: the CEPC is the best approach and a major historical opportunity for the national development of accelerator-based high-energy physics program.

2020 European Strategy Update

An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

Community Summer Study SNOWMASS

July 17-26 2022, Seattle

Seattle Snowmass Summer Meeting 2022

Conclusion from Executive Summary

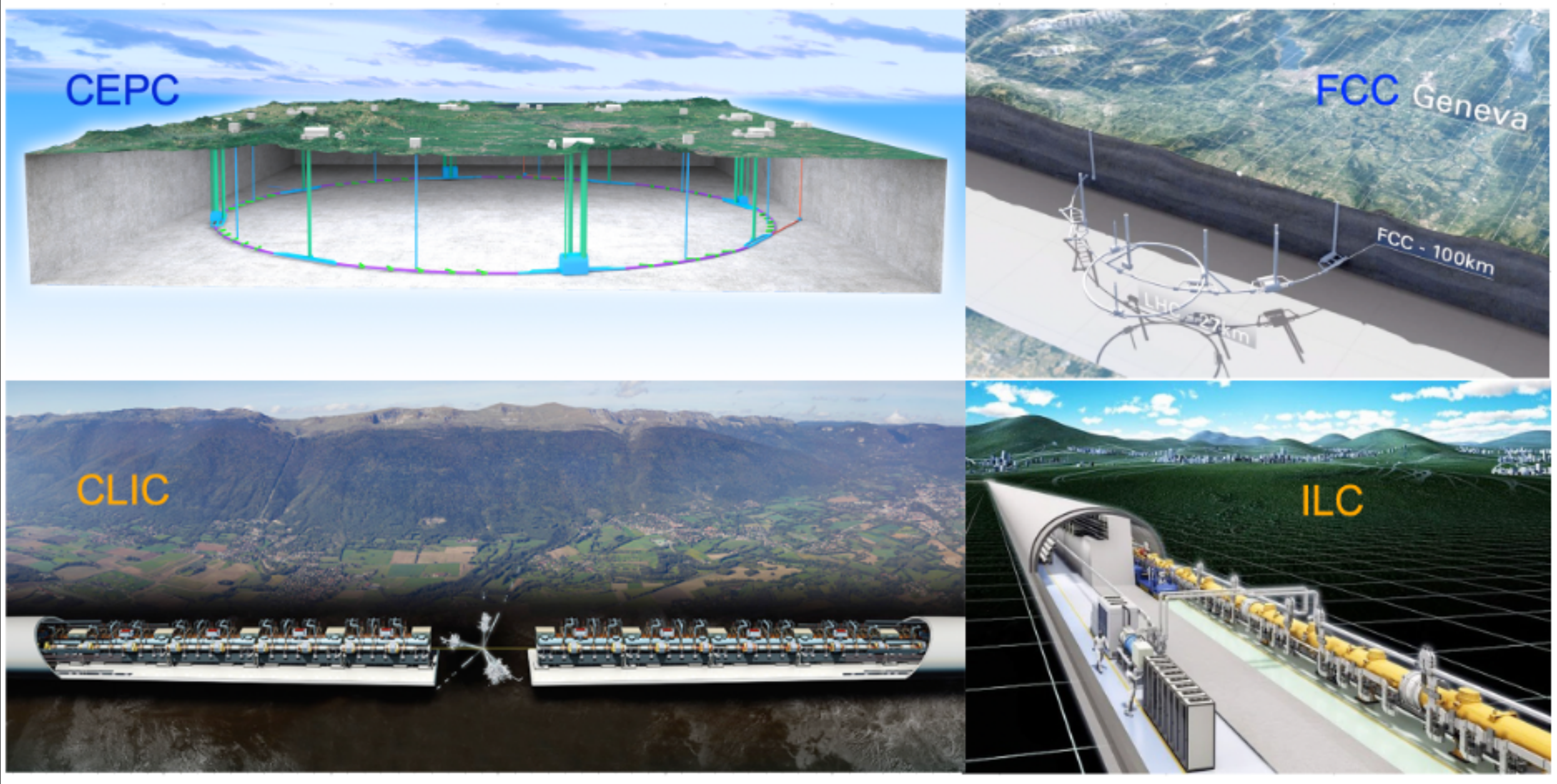
Given the **strong motivation** and existence of proven technology to build an e^+e^- **Higgs Factory in the next decade**, the **US should participate** in the construction of **any facility that has firm commitment** to go forward.

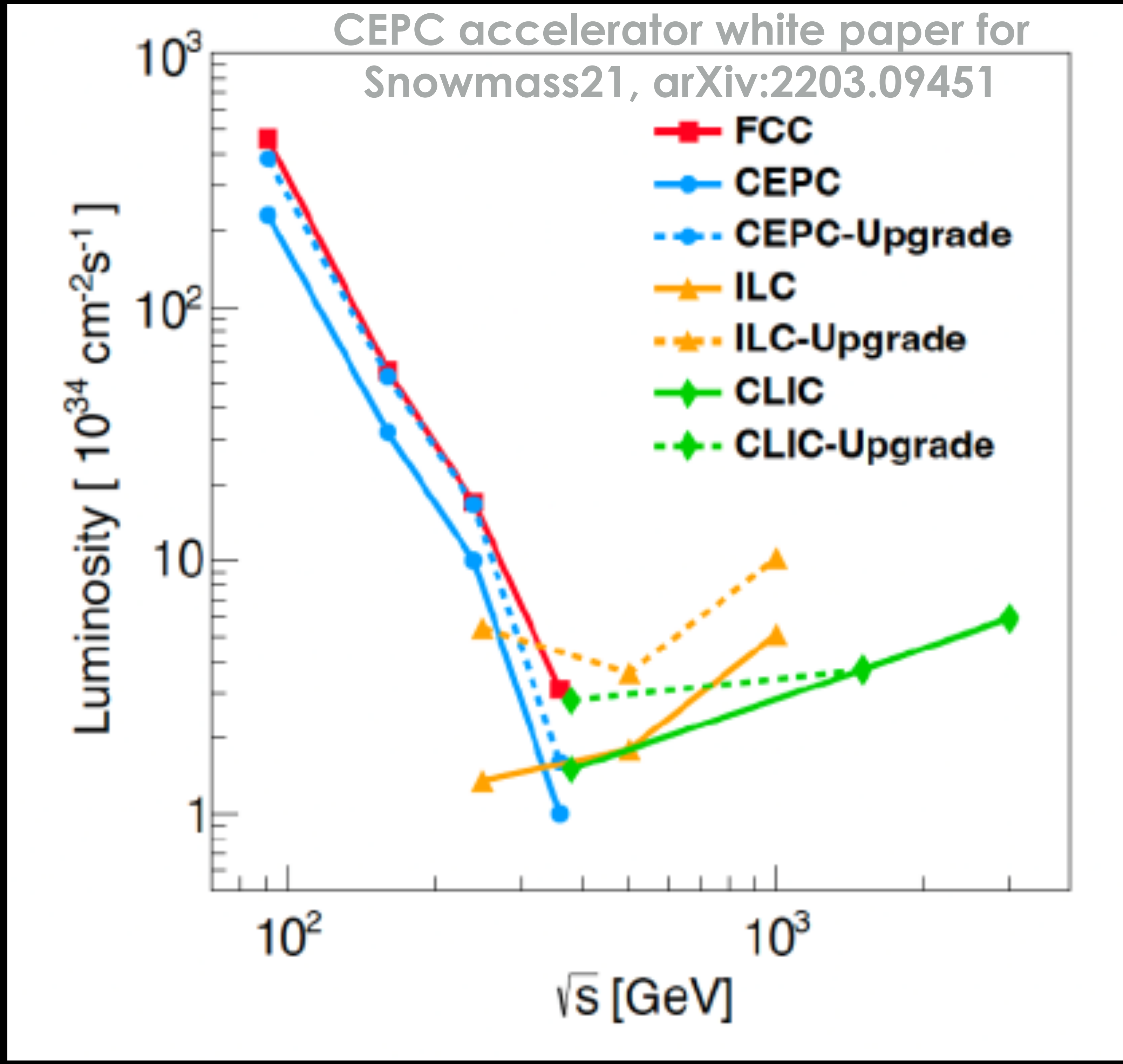
Sridhara Dasu (Wisconsin)

ICFA

In April 2022, the International Committee for Future Accelerators (ICFA) "reconfirmed the international consensus on the importance of ***a Higgs factory as the highest priority for realizing the scientific goals of particle physics****", and expressed support for the above-mentioned Higgs factory proposals. Recently, the United States also proposed a new linear collider concept based on the cool copper collider (C3) technology [31].*

Comparison with other international e+e- Higgs factories





CEPC has strong advantages among mature electron-positron Higgs factories (design report delivered)

Versus FCC-ee

- Earlier data: collisions expected in 2030s (vs. ~ 2040s);
- Larger tunnel cross section (ee, pp coexistence)
- Lower cost: ~1/2 the construction cost with similar luminosity up to 240 GeV

Versus linear colliders

- Higher precision with more Higgs & Z; potential for proton collider upgrade

Accelerator developments

See Gao Jie's talk this morning for details

Innovations and technology breakthroughs in CEPC

Innovative Design	➢ 100km Full/Partial Double Rings ➢ Switchable operation for Higgs, W and Z ➢ Flexible injection modes to satisfy different energies ➢ World's 1st design of a high energy/flux gamma-ray synchrotron light (300 MeV)
Technical Performance	➢ High efficiency Klystron (aim at highest transfer efficiency) ➢ High performance SRF cavities (state-of-the-art Q and gradient) ➢ Novel magnets: Weak field dipole, dual aperture magnets (First Qualified Prototype)
Major Technology Breakthrough	➢ Plasma wakefield acceleration for Injector (New Acceleration Principle) ➢ High field superconducting magnet (Iron based HTS proposal)

Innovative designs and key technology R&D fulfill the challenging requirement

Workable 100km accelerator design for all operation modes – completed

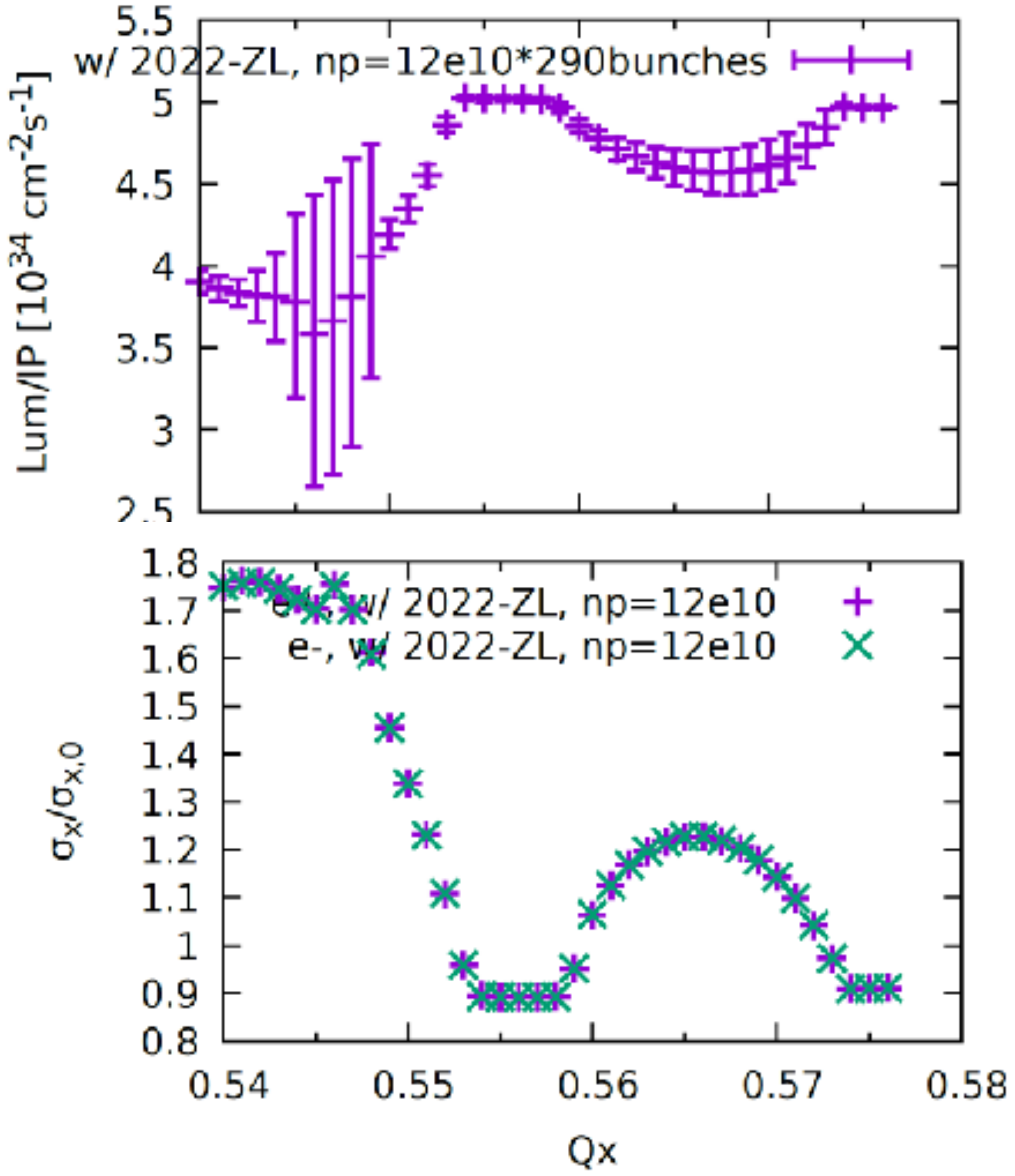
GOAL

- e+e- circular collider as a high lumi. Higgs factory
- Switchable operation for Higgs, W, Z and Top runs
- A green machine with a maximum Luminosity

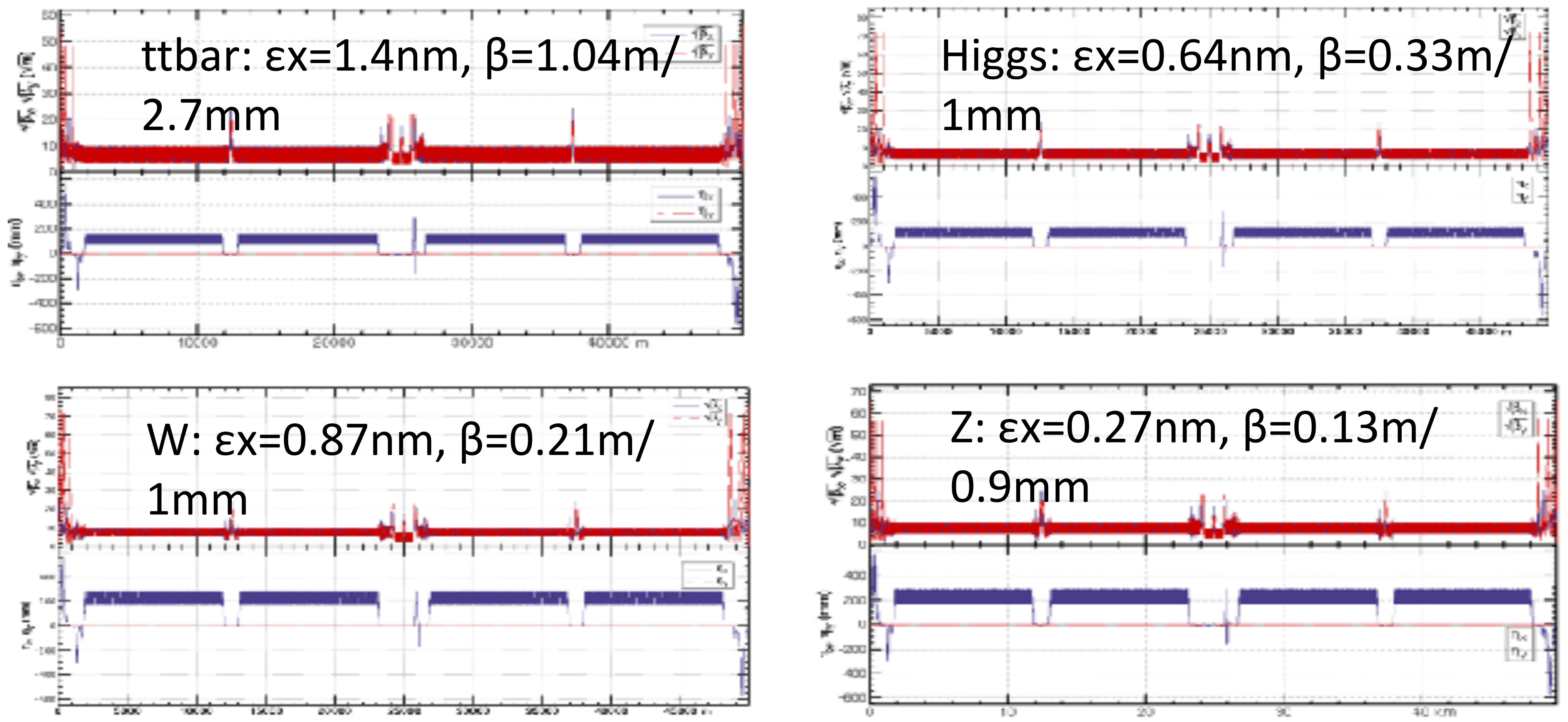
Design

- Complete acc. design w. latest ideas
- Lattice optimization for all energies
- Sufficient DA for all energies
- Beam-beam & collective instability

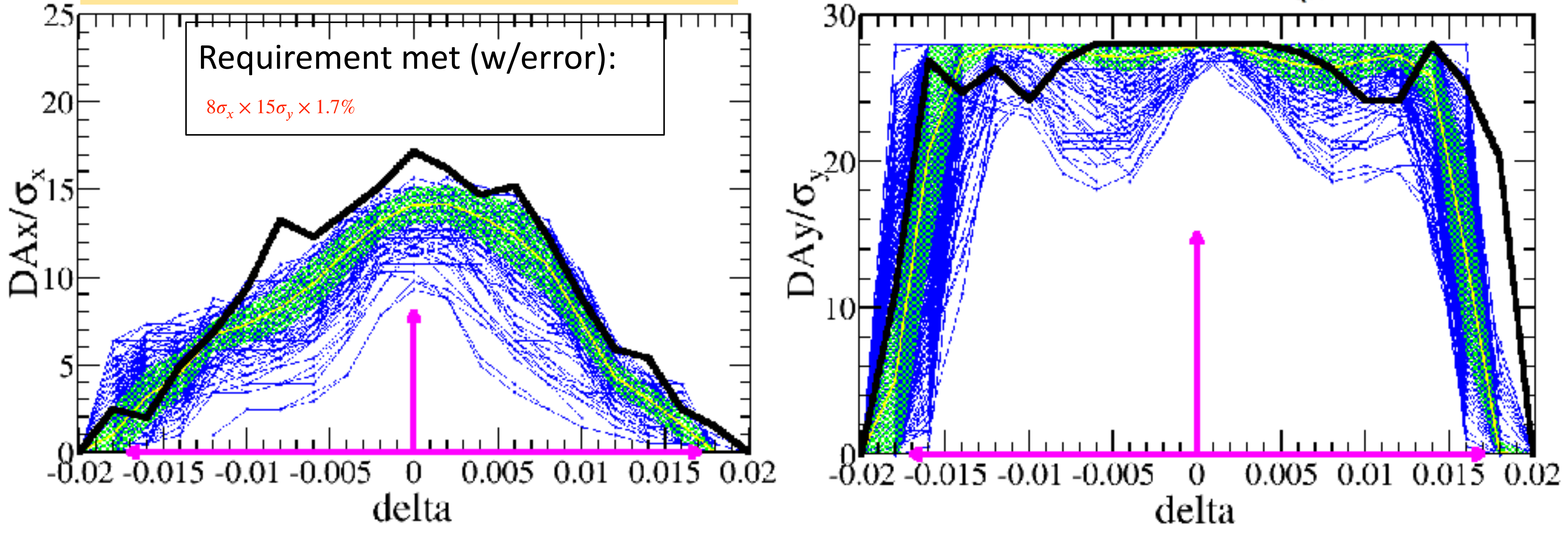
Beam-beam effect study



Lattice for all energies



Dynamic Aperture (DA) optimization



CEPC accelerator technical performance

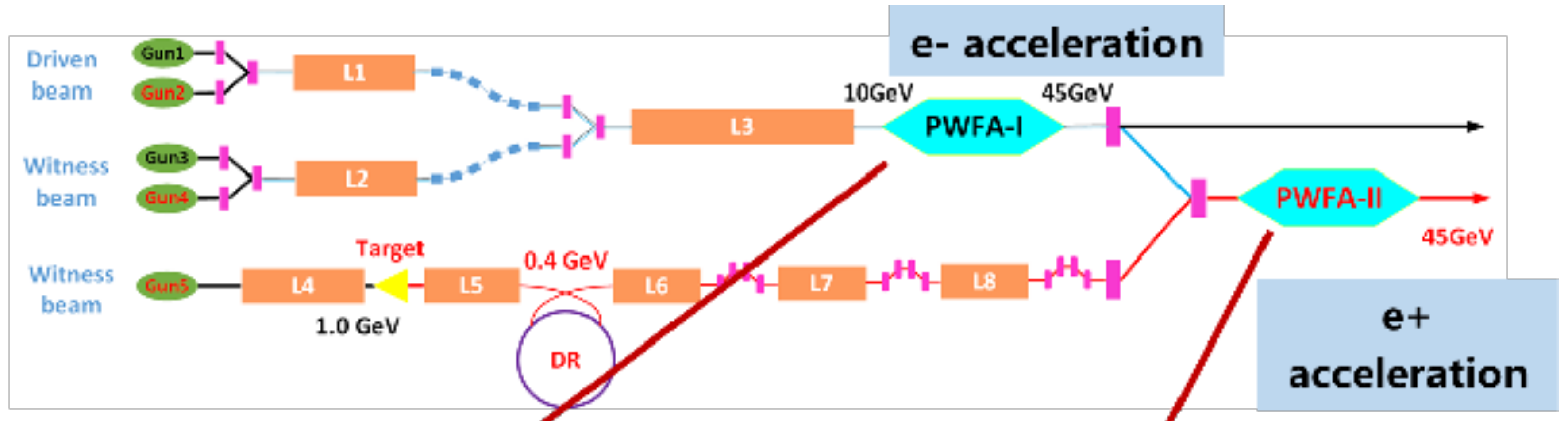
Key Technology	Status
High efficiency klystron	Current eff.>70%, aim at 80%
High Q SRF cavity	Exceeds CEPC requirement
Novel magnet	CEPC requirement met
PWFA injector	Design positron acceleration scheme, >10GeV beam
HTS high field magnet	HTS with IBS

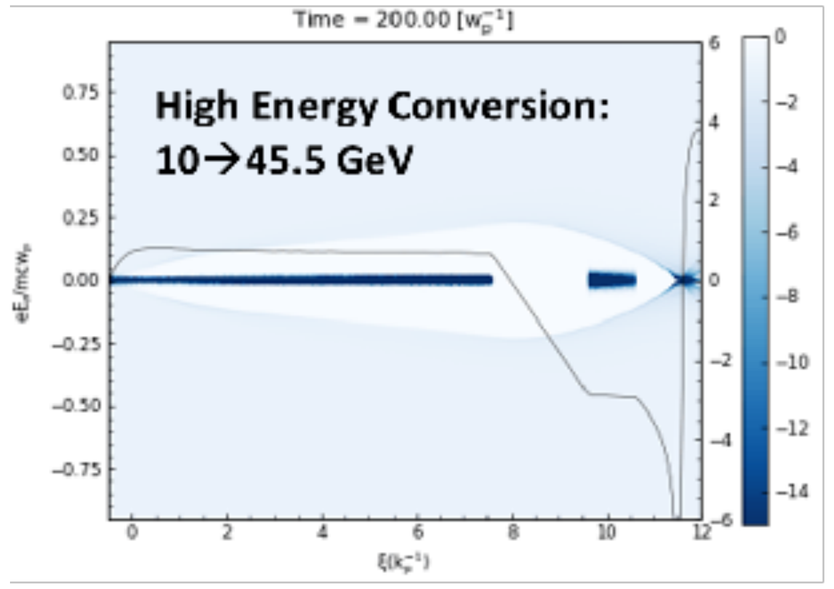
Selected Leading Technologies

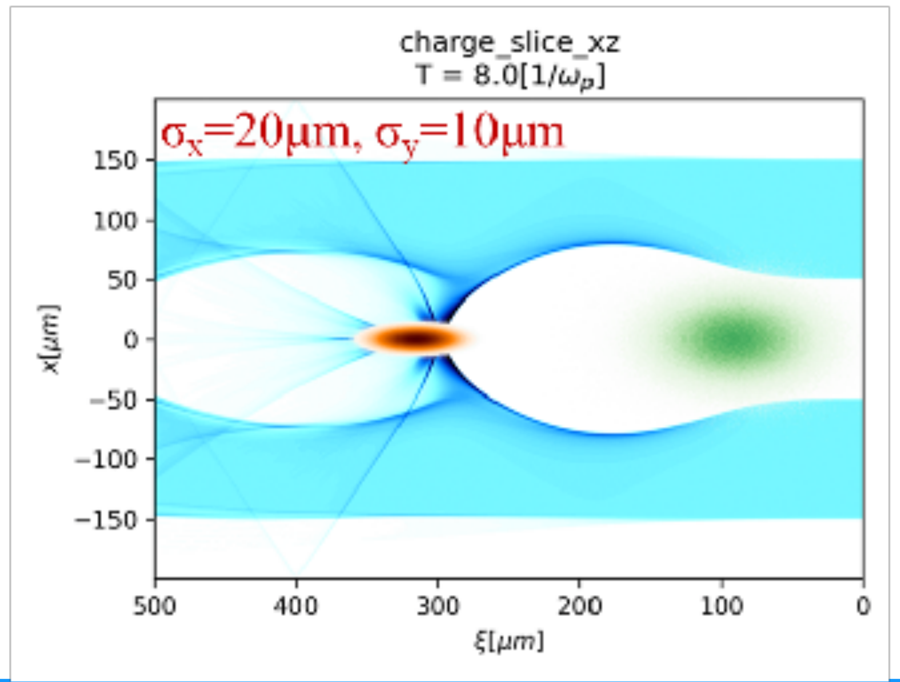
Table 5.3: Status of key technology R&D for CEPC, in comparison with the status quo of world leading accelerator laboratories

Device	Requirement	IHEP status	CERN status	FNAL status	KEK status	LBNL status
1.3 GHz SRF cavity	Q=3 × 10^{10} @24 MV/m	Q=4.3 × 10^{10} @31 MV/m	Preliminary progress	Comparable to IHEP	Comparable to IHEP	N/A
650 MHz 2-cell SRF cavity	Q=4 × 10^{10} @22 MV/m	Q=6 × 10^{10} @22 MV/m	N/A	Comparable to IHEP	N/A	N/A
High-efficiency klystron	Efficiency ≥ 80%	Efficiency ≈ 70%	R&D on Efficiency ≈ 80%	N/A	Efficiency ≈ 60%	N/A
High-field superconducting magnet	20-24 T	12.5 T achieved next goal is 16 T	14-16 T	14.5 T	10 T	14-16 T

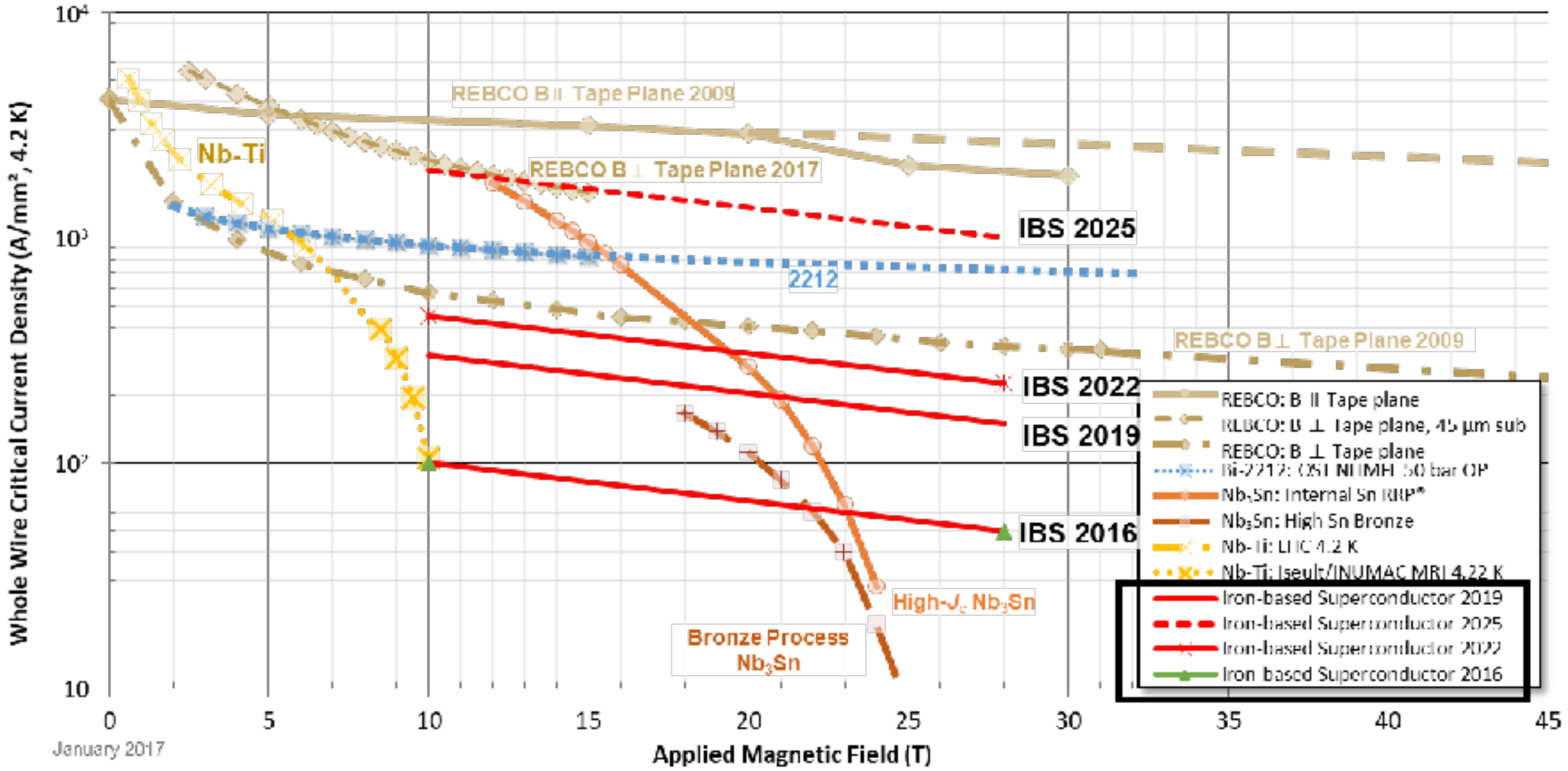
PWFA as an alternative Linac injection



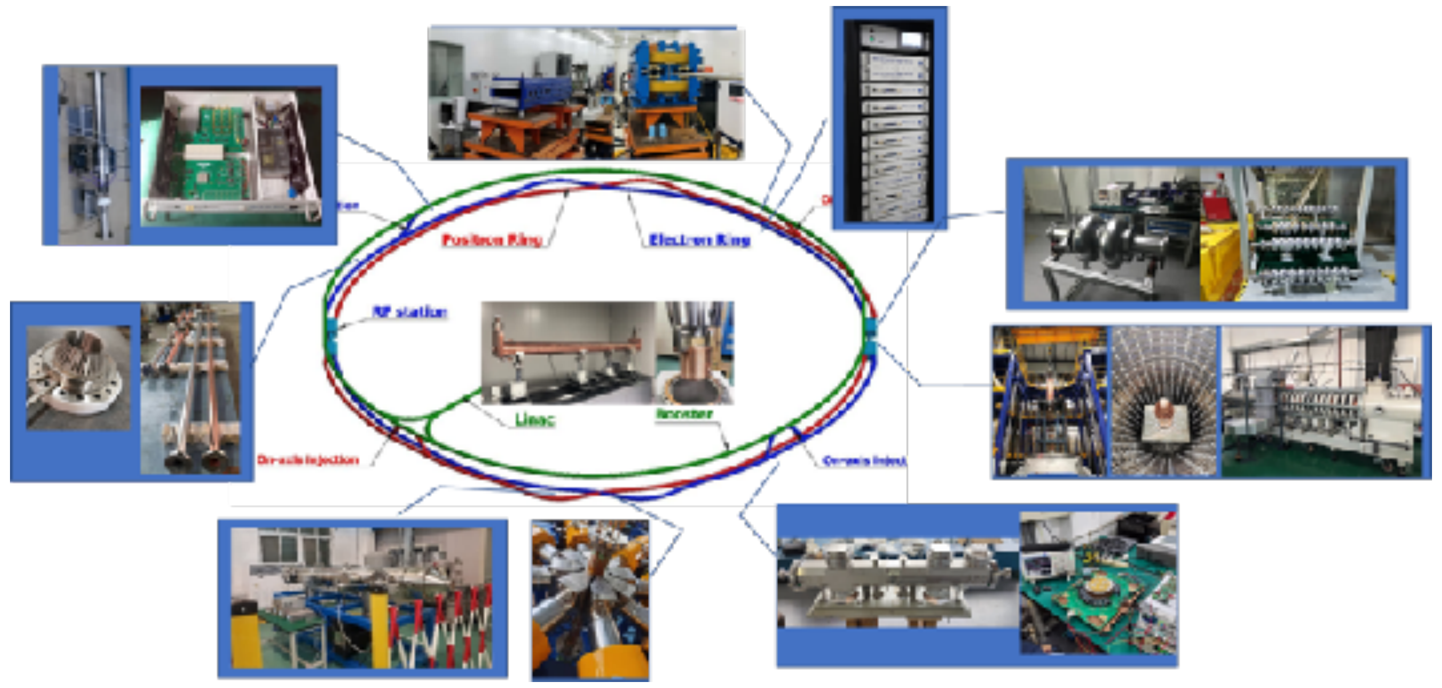




Fast development of IBS material



CEPC accelerator key technologies under R&D



✓ **Specification Met**

☑ **Prototype Manufactured**

	Accelerator	Cost (billion CNY)	Ratio
✓	Magnets	4.47	27.3%
✓	Vacuum	3.00	18.3%
☑	RF power source	1.50	9.1%
✓	Mechanics	1.24	7.6%
✓	Magnet power supplies	1.14	7.0%
✓	SCRF	1.16	7.1%
✓	Cryogenics	1.06	6.5%
✓	Linac and sources	0.91	5.5%
✓	Instrumentation	0.87	5.3%
☑	Control	0.39	2.4%
☑	Survey and alignment	0.40	2.4%
✓	Radiation protection	0.17	1.0%
☑	SC magnets	0.07	0.4%
✓	Damping ring	0.04	0.2%

Table 5.1: Summary of key technologies under R&D essential for CEPC

Device	Accelerator	Quantity	CEPC specification	R&D status
1.3 GHz SRF cavity (9-cell)	Booster	96	Q=3×10^{10} @ 24 MV/m	Specification met
650 MHz SRF cavity (2-cell)	Collider	240	$Q = 4\times10^{10}$@22 MV/m	Specification met
650 MHz klystron	Collider	120	Efficiency: 80% Power: 800 kW	Prototype manufactured
C-band NC accelerating tube	Linac	292	Gradient: 45 MV/m	Prototype manufactured
S-band bunch compressor	Linac	35	Peak power gain: 7 dB	Prototype manufactured
Positron source flux concentrator	Linac	1	Central peak magnetic field >6 T	Specification met
Dual-aperture dipole magnet	Collider	2384	Field: 140 Gs-560 Gs aperture: 70 mm length: 28.7 m; harmonic< 5×10^{-4} relative field difference<0.5%	Specification met
Dual-aperture quadrupole magnet	Collider	2392	Gradient: 3.2-12.8 T/m length: 2 m; harmonic< 5×10^{-4} aperture: 76 mm relative field difference<0.5%	Specification met
Weak field dipole	Booster	16320	Field error $\leq 10^{-3}$@60 Gs	Specification met
Electrostatic separator	Collider	32	Electric field: 2.0 MV/m field uniformity: 5×10^{-4} good field region: 46 mm*11 mm	Specification met by prototype
Cryogenic refrigerator	Collider/ Booster	4	18 kW @ 4.5 K	Collaboration with IPC CAS, a refrigerator system of 2.5 kW @ 4.5 K has been developed
Ceramic vacuum chamber and coating	Transport lines	~ 20	$75\times56\times5\times1200$mm	Prototype in production
MDI SCQ	Collider	8	Gradient: 136T/m; length: 2m Aperture: 40mm; included angle: 33mrad	Prototype in manufacture
Visual instrument	All	11	Image accuracy: 5 μm+(5 μm/m) horizontal angle: 1.8 arc-second vertical angle: 2.2 arc-second	Prototype completed

Table 5.2: Summary of key technologies in engineering applications essential for CEPC

Device type	Accelerator	Quantity	CEPC specifications
S-band copper accelerating tube	Linac	111	~30 MV/m
vacuum chamber and coating	Collider/ Booster	Total length 200 km	Length: 6 m aperture: 56 mm vacuum: 3×10^{-10} Torr NEG coating pump speed for H_2: 0.5 L/s· cm^2
BPM and electronics	All	~5000	Closed orbit resolution: 0.6 μm
kicker & fast pulser	Transport line	~25	Pulse width <10 ns (strip-line) trapezoidal pulse width <250 ns (slotted-pipe)
Lambertson septum	Transport line	~20	Septum thickness ≤3.5 mm (in-air) thickness ≤2 mm (in-vacuum)
Power supply	All	9294	Stability 100-1000 ppm
RF-shielded bellows	Collider Booster	24000 /12000	Contact force 125±25 g/finger

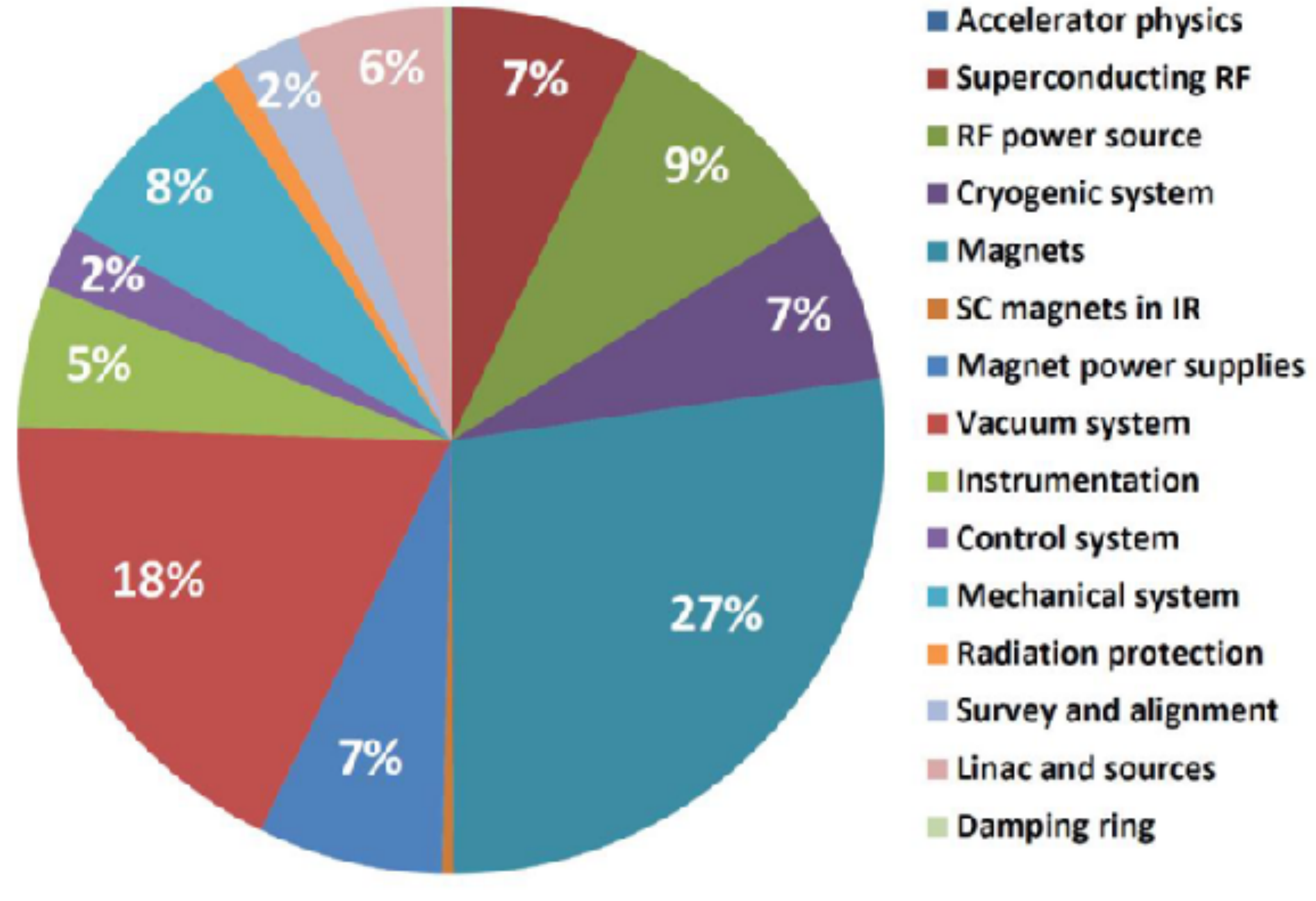
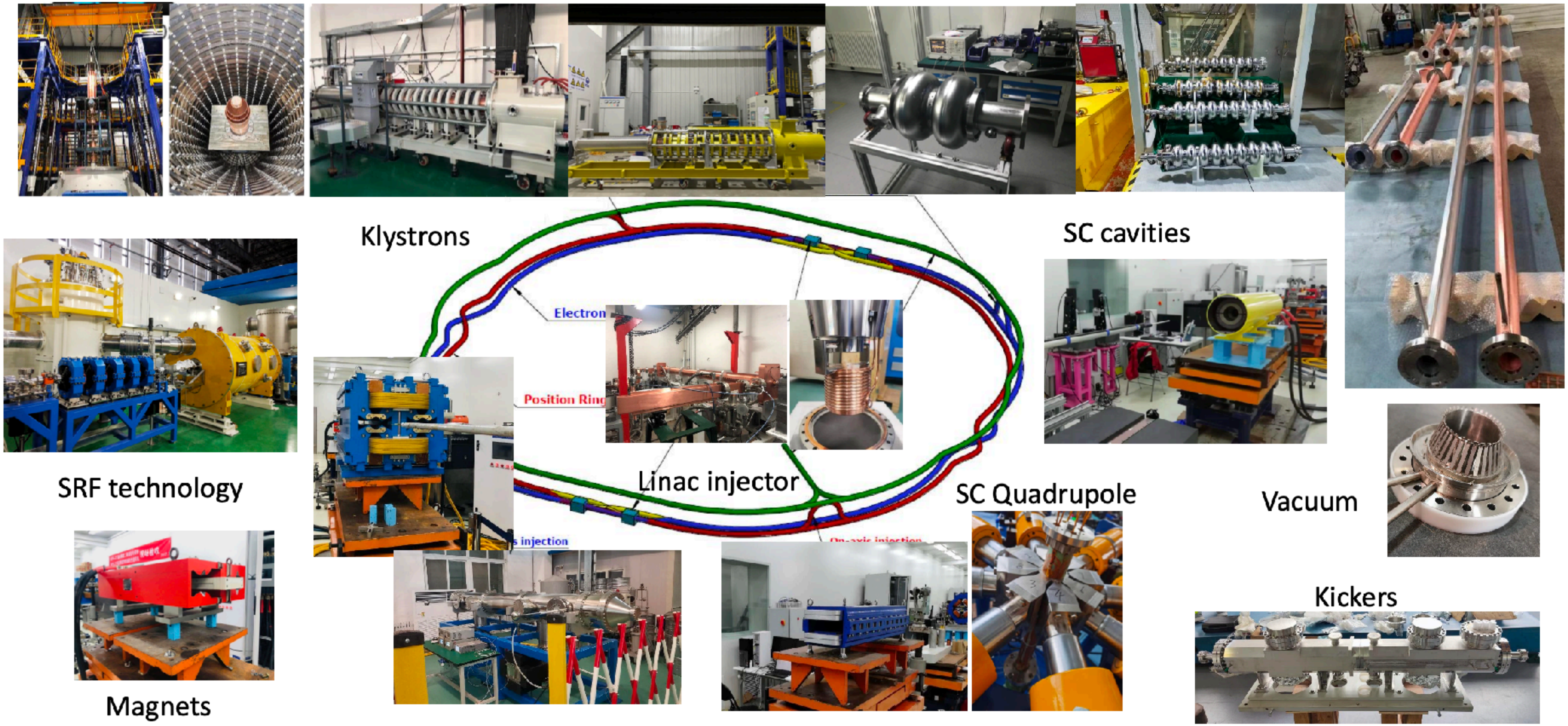


Figure 12.3: Cost breakdown of the CEPC accelerator technical systems.

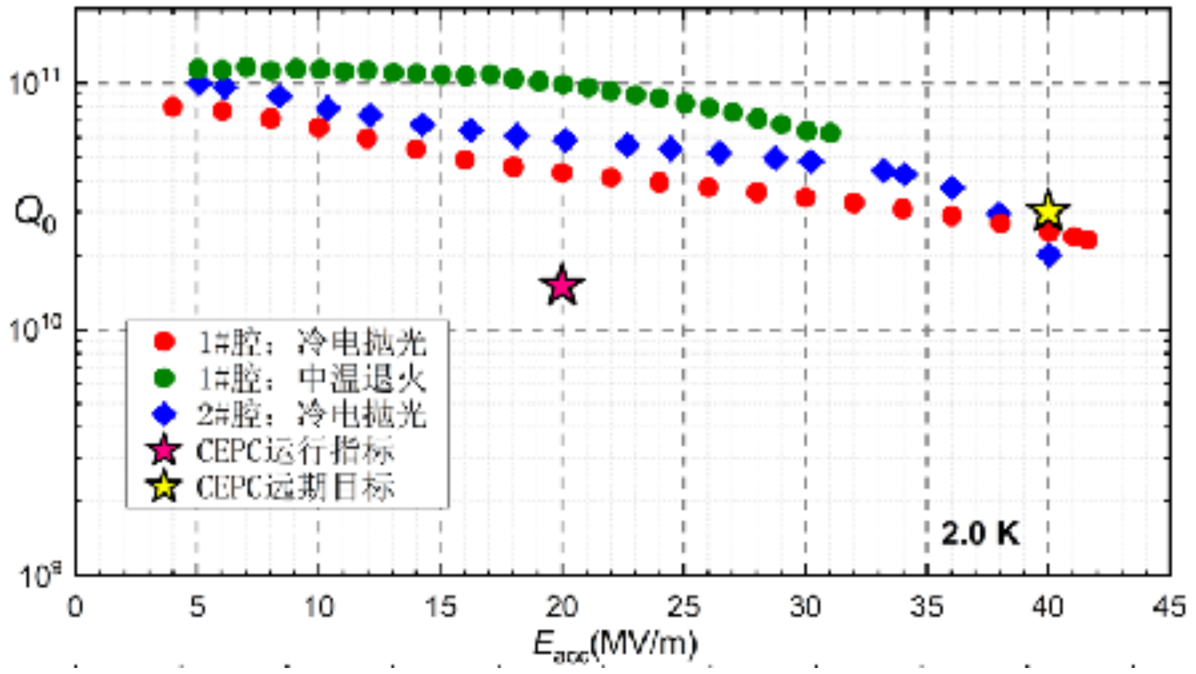
CEPC TDR: R&D Status of Key Technologies



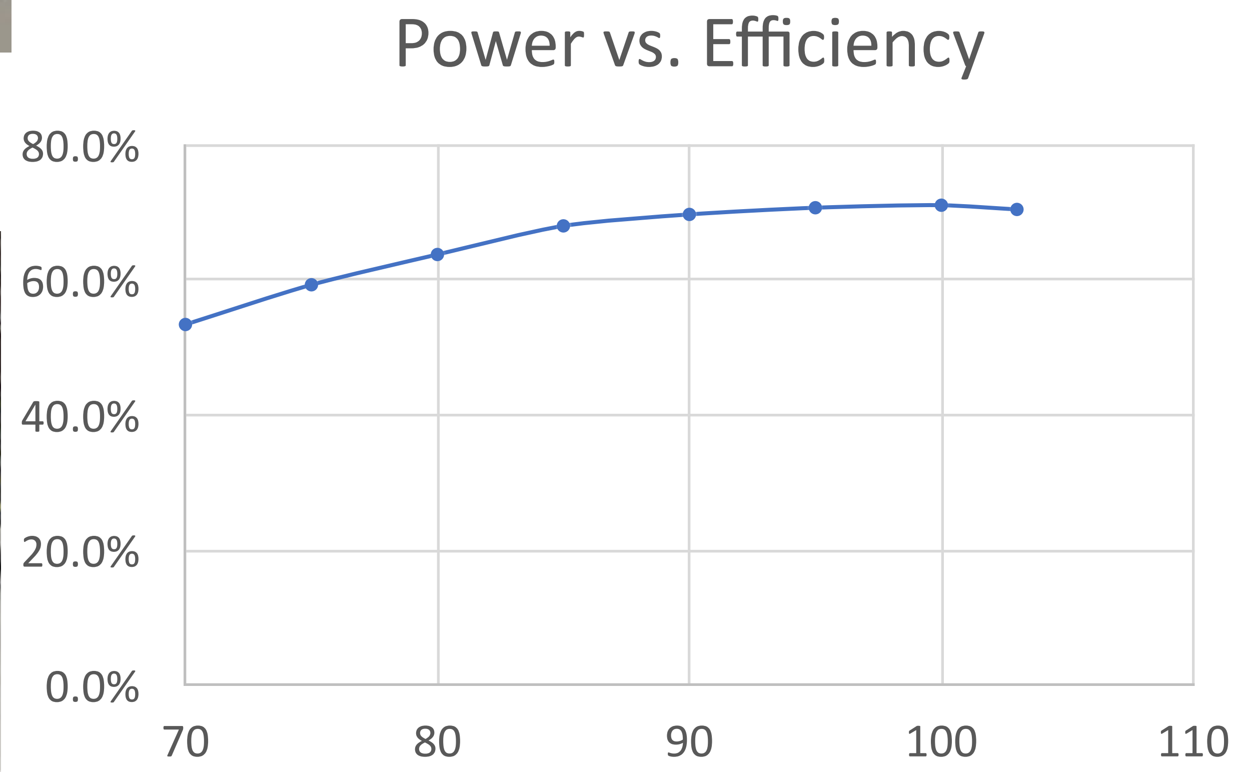
CEPC accelerator critical components

State-of-the-art: Key Components

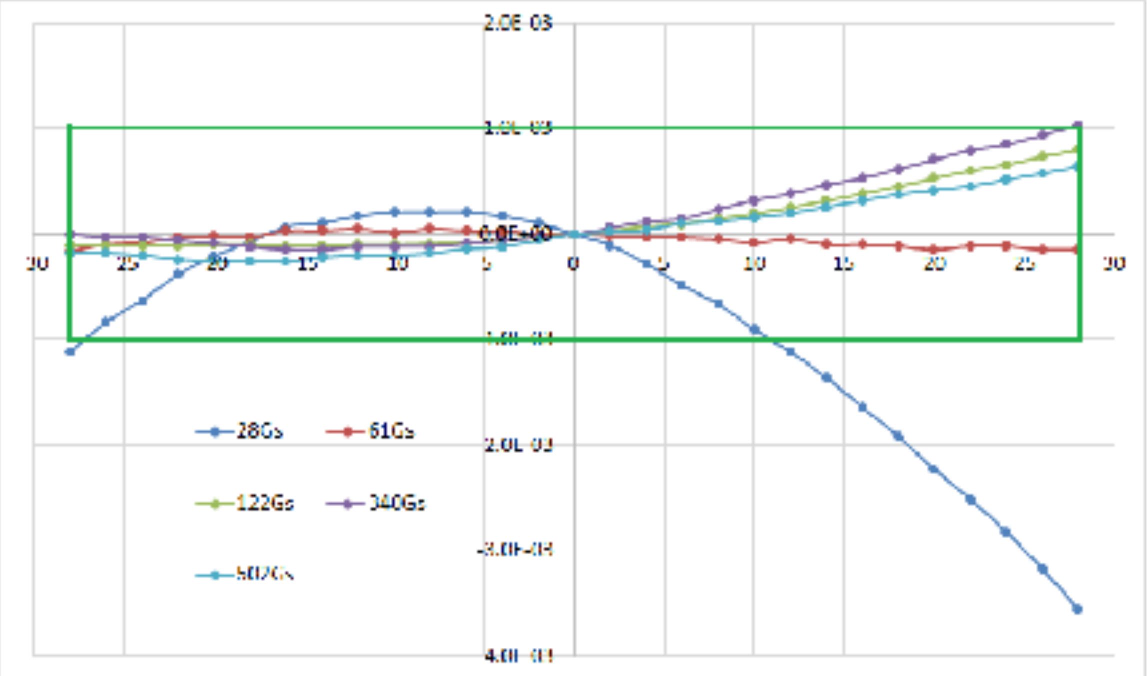
650MHz SRF cavity



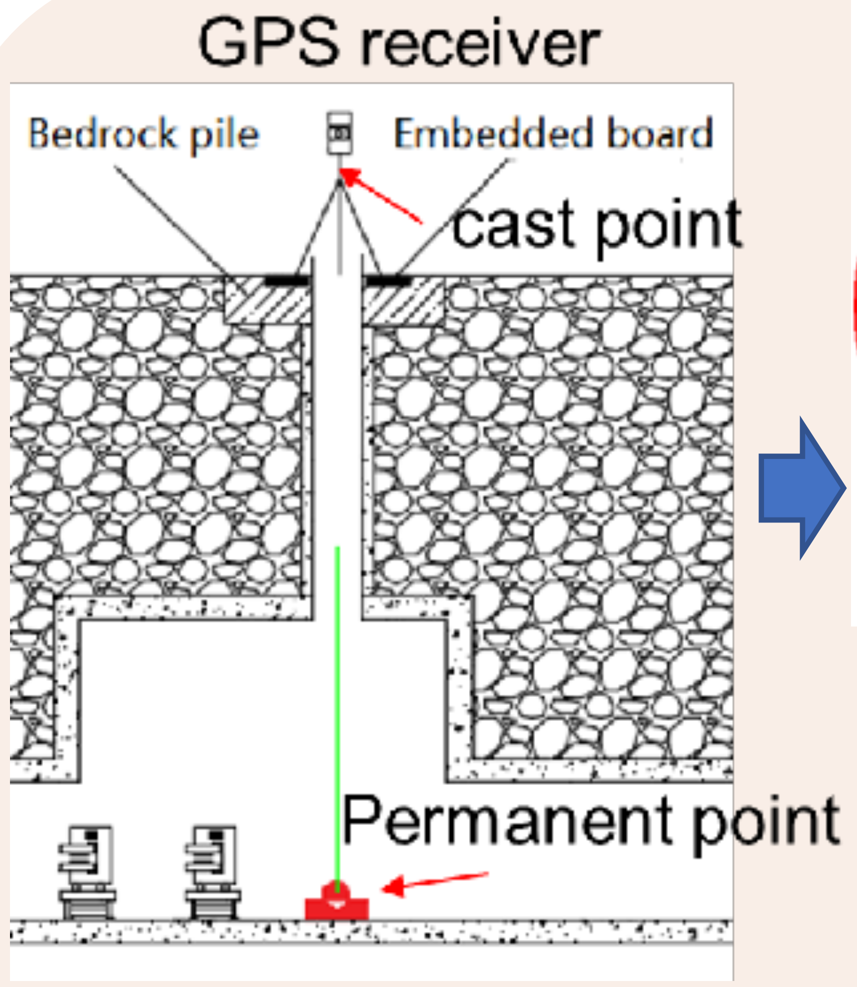
High efficiency klystron



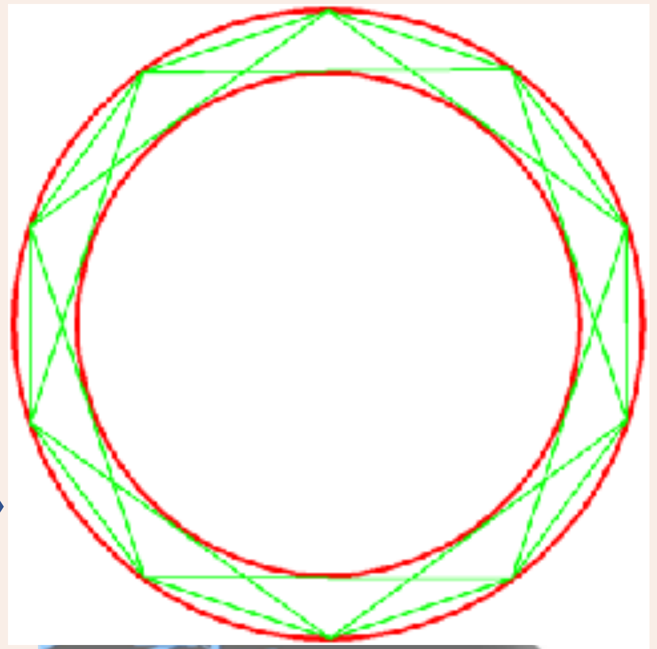
Weak field dipole

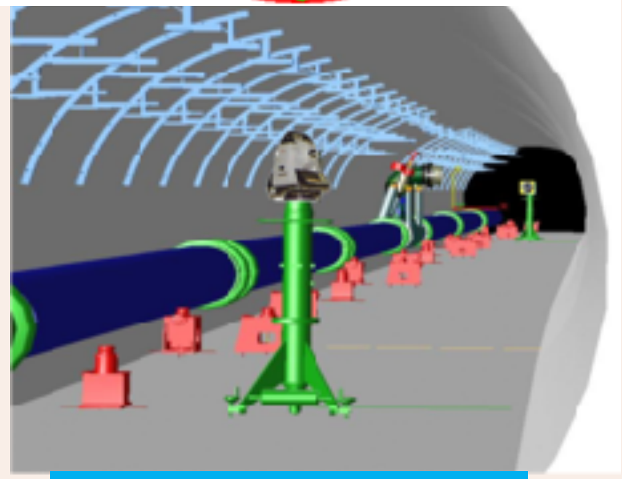


100km Acc. Alignment & Installation R&D

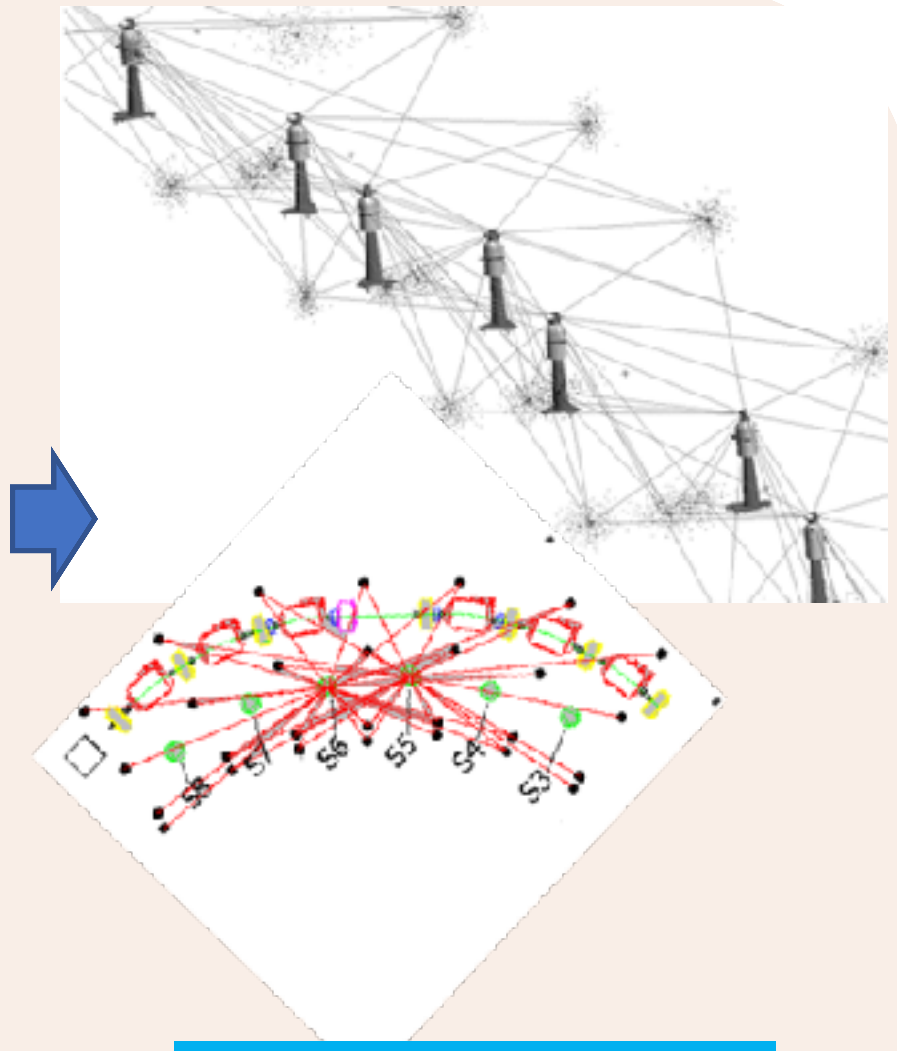


Control Point

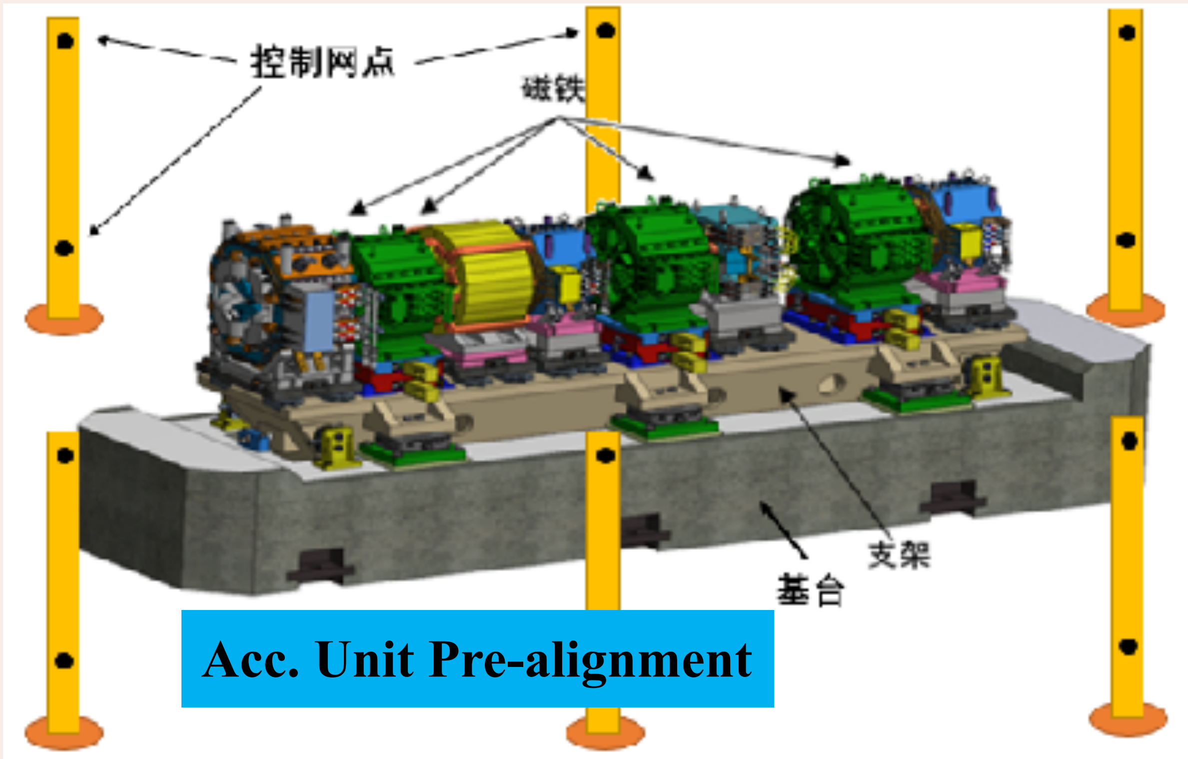




Backbone Network



Tunnel Control Network



Acc. Unit Pre-alignment

Multi Functional Alignment Instrument

Efficient alignment scheme + instrumentation R&D to guarantee the installation within 4 years

IHEP New SCRF Lab (PAPS) in Operation

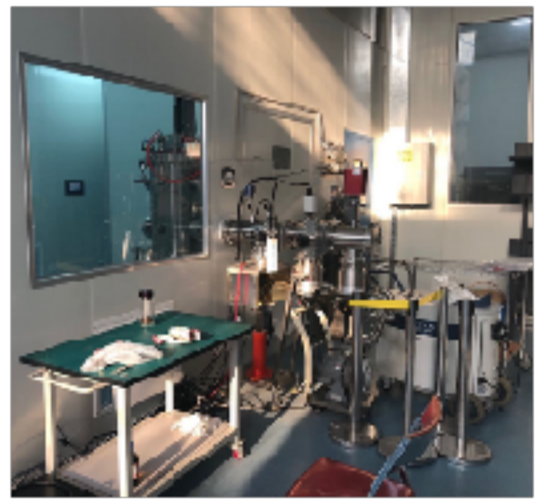
Facility: CEPC SCRF test facility (lab) is located in IHEP Huairou Area of 4500 m^2

New SC Lab Design (4500m^2)

SC New Lab (PAPS) has been put to operation in June 2021

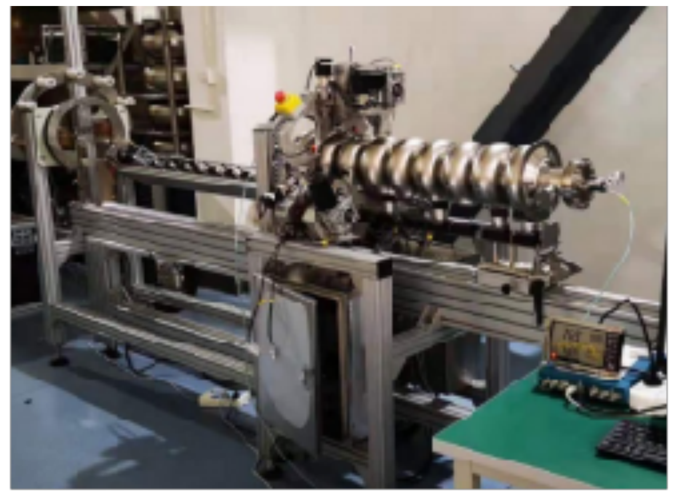
Vacuum furnace (doping & annealing)

Nb3Sn furnace



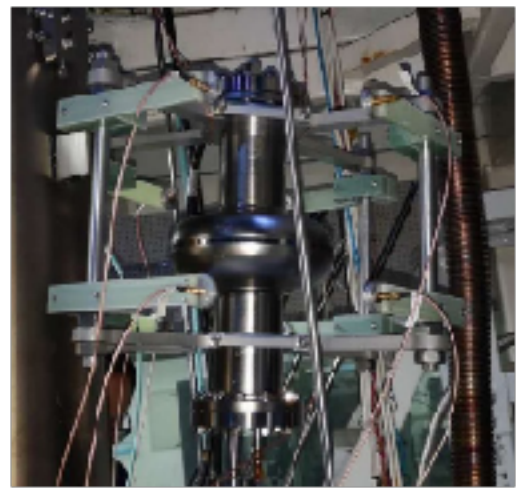
Nb/Cu sputtering device

Cavity inspection camera and grinder

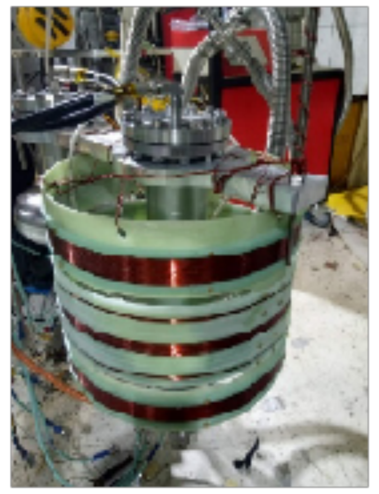


9-cell cavity pre-tuning machine

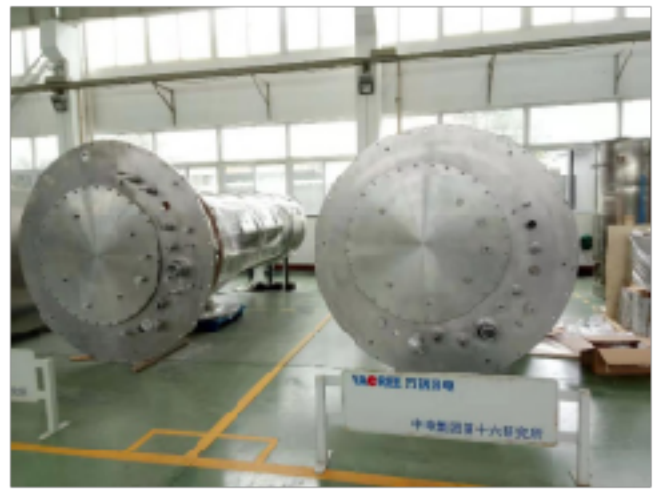
Temperature & X-ray mapping system



Second sound cavity quench detection system



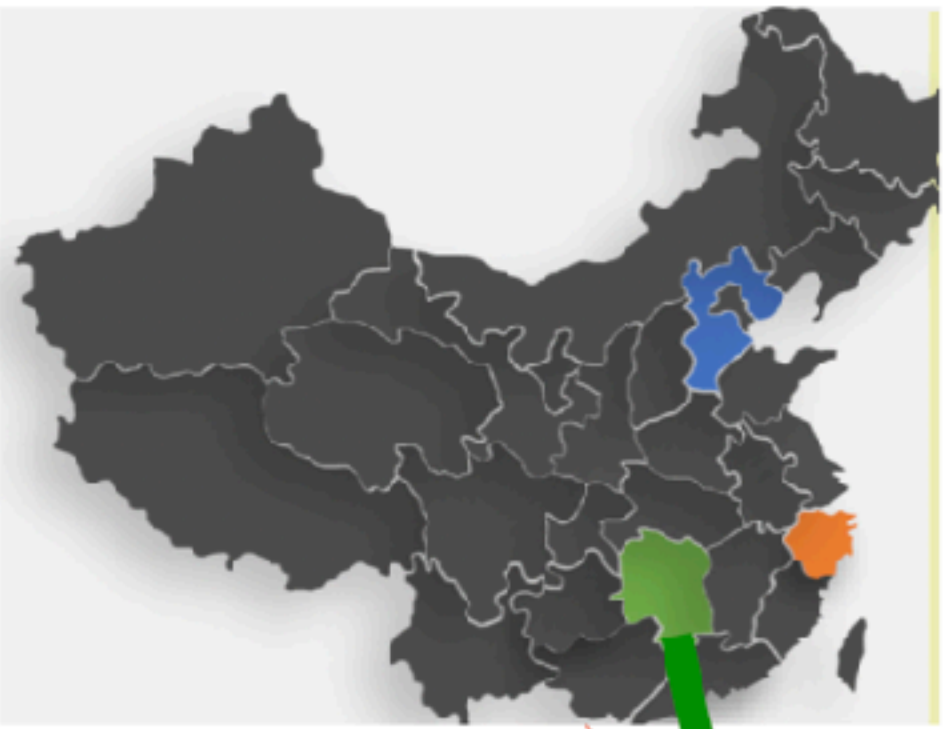
Helmholtz coil for cavity vertical test

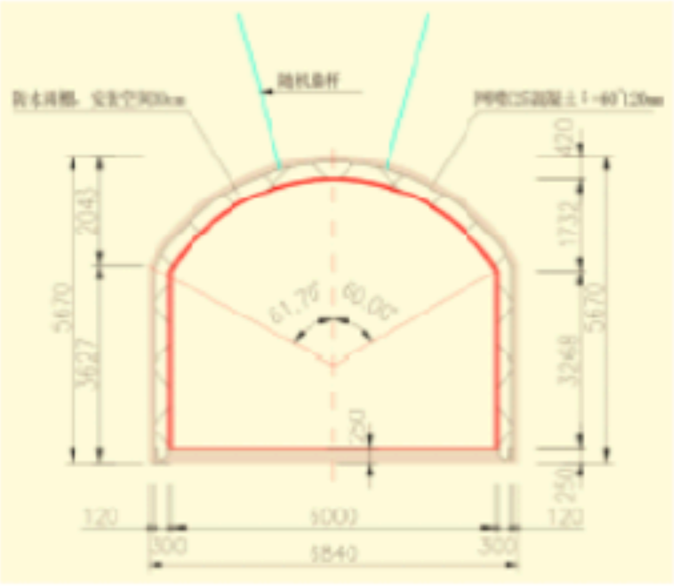


Vertical test dewars

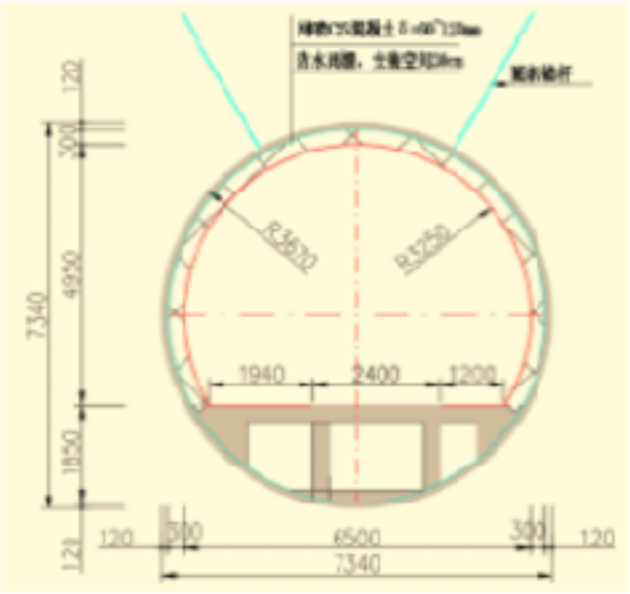
Horizontal test cryostat

CEPC Site Selection: Changsha Site as example



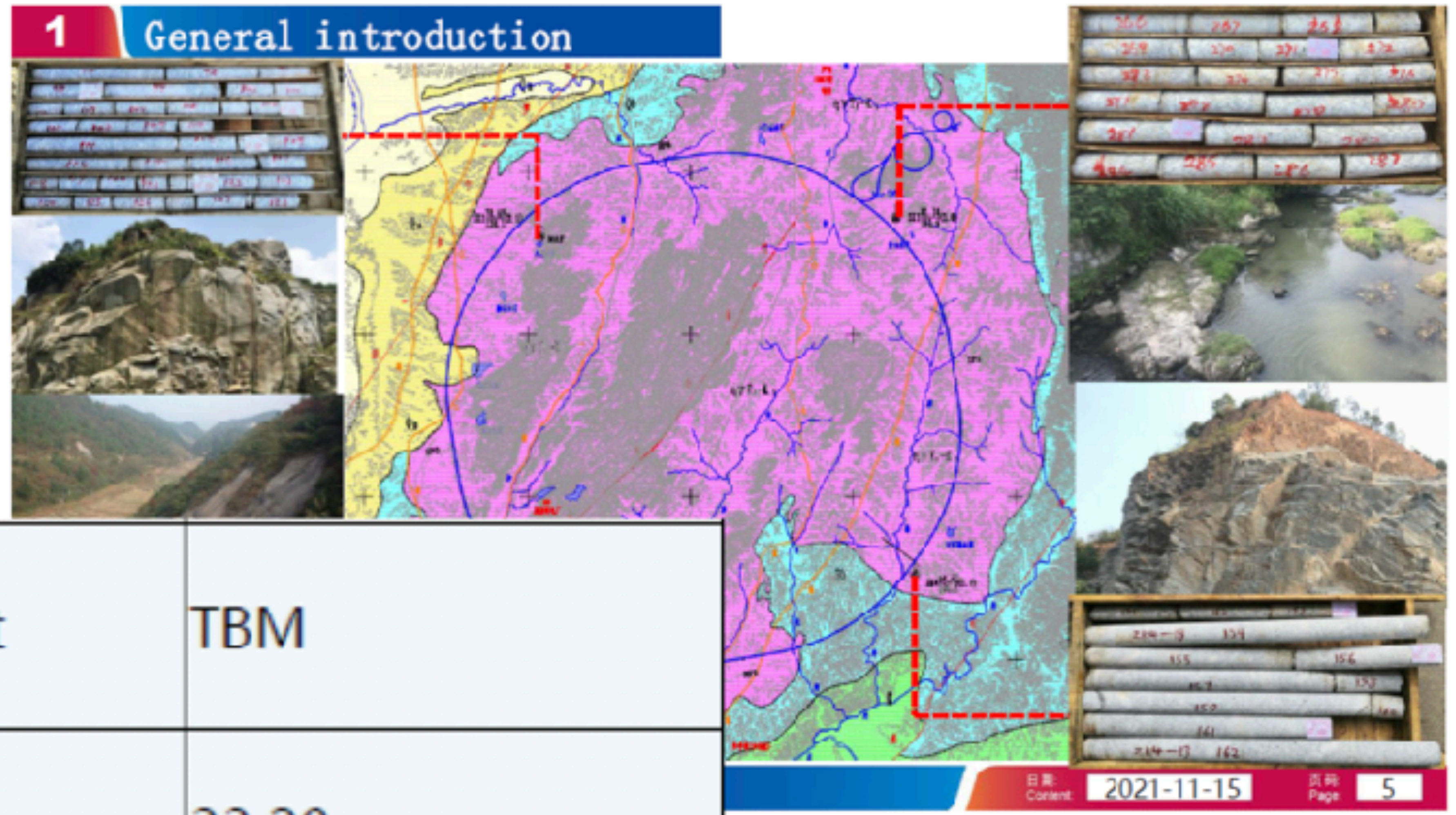


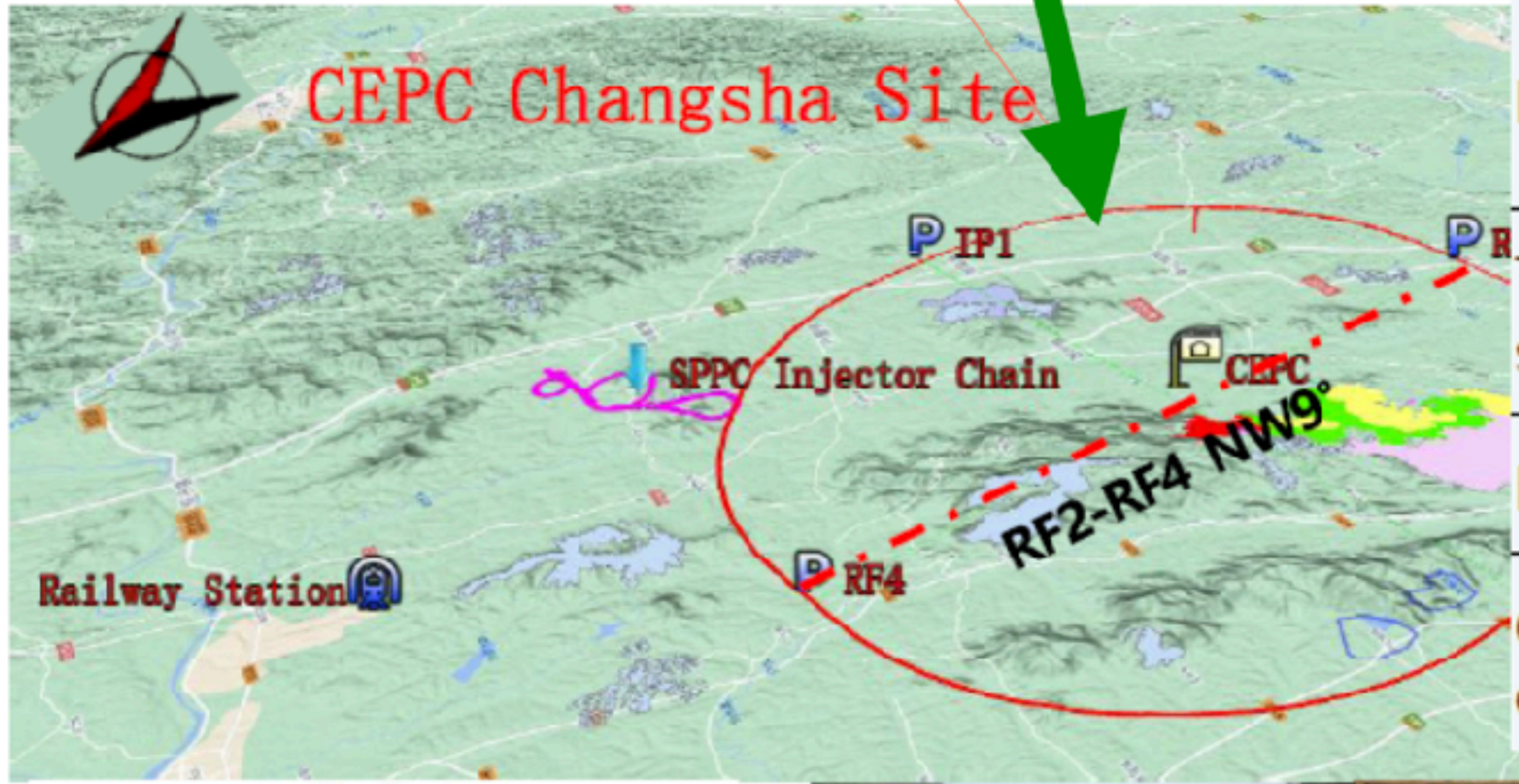
Drill-blast tunnel
(6.0m×5.0m)



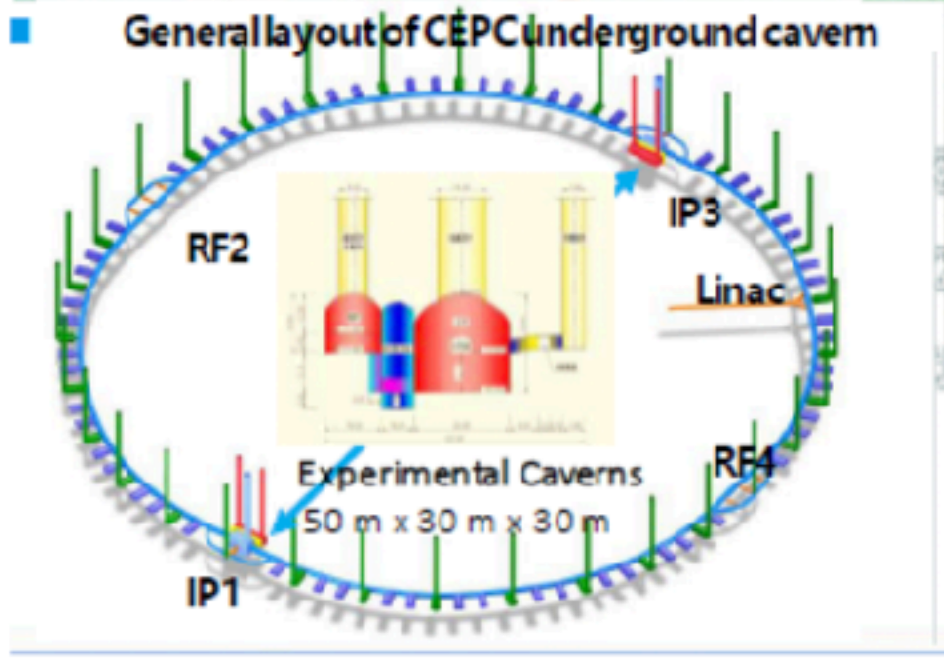
TBM tunnel (D6.5m)

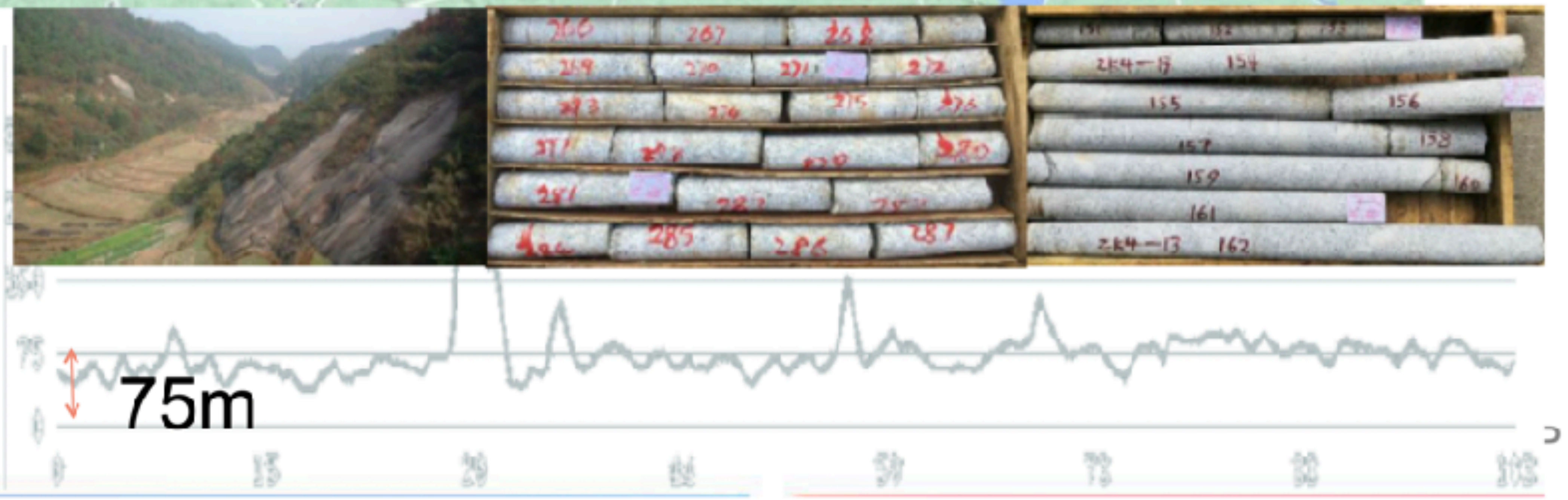
Very good geological condition

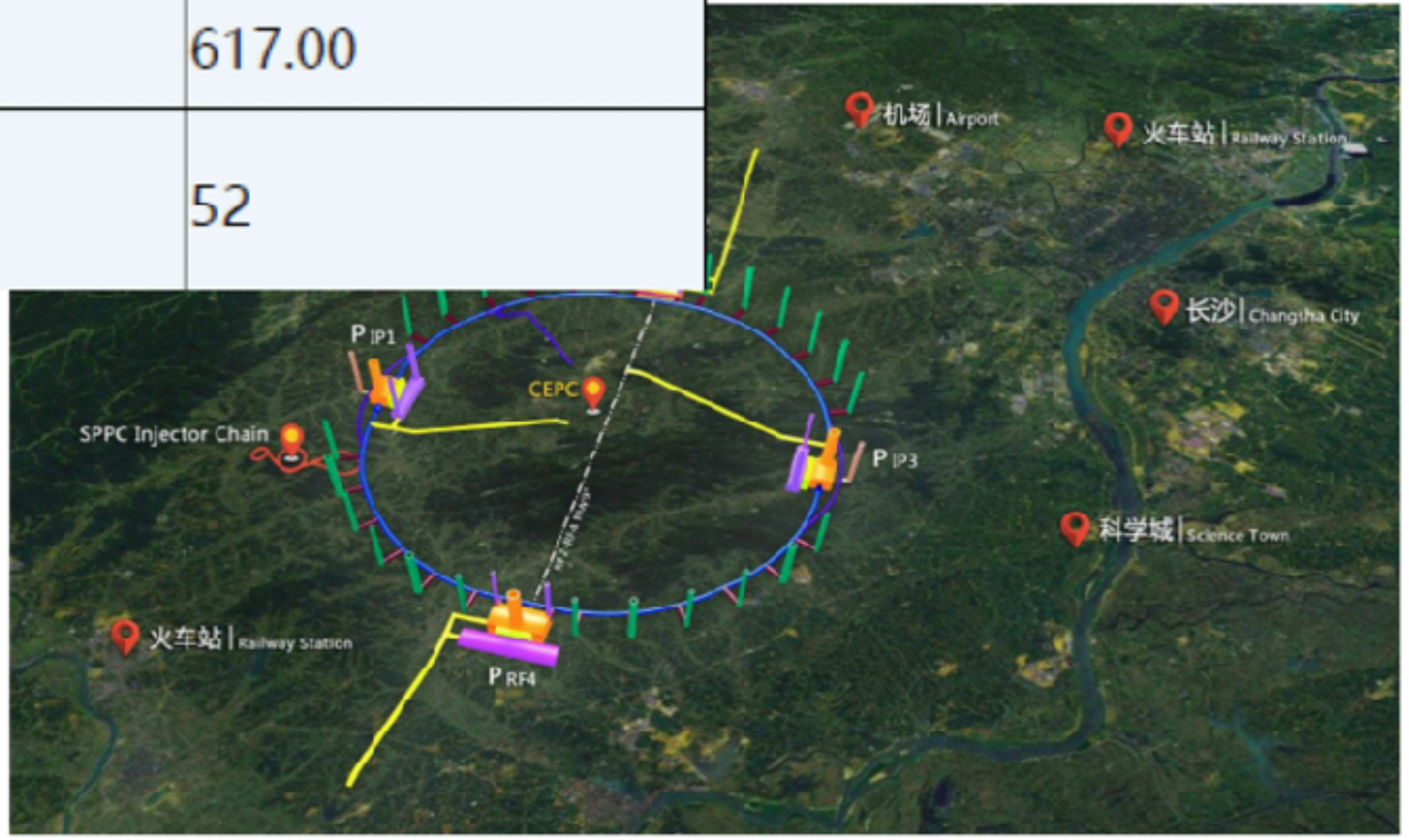




Item	Unit	Drill-blast	TBM
The clearance cross section	㎡	27.00	33.20
Excavation unit price	Yuan/m³	278.28	617.00
Construction duration	Month	50	52

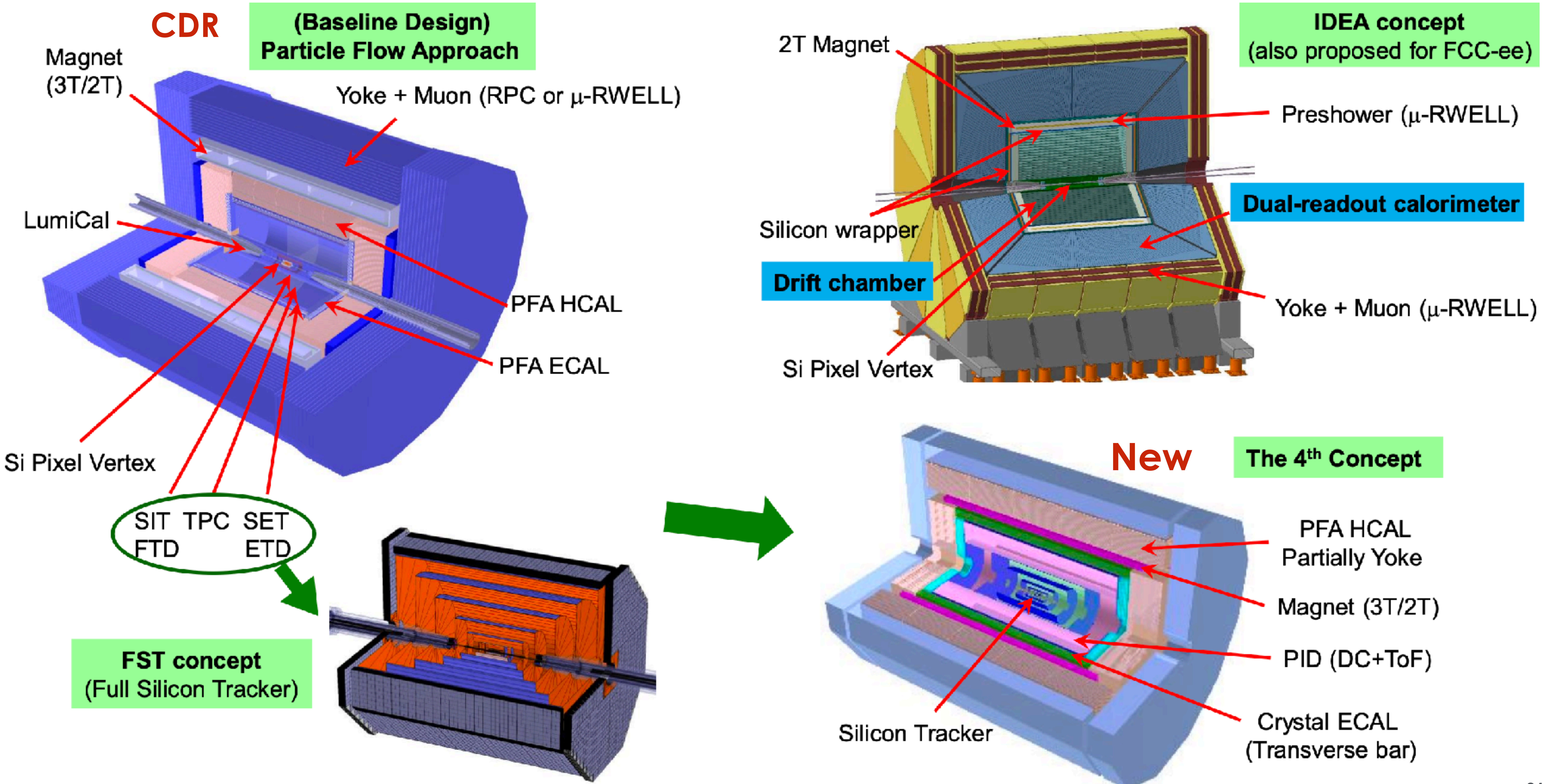




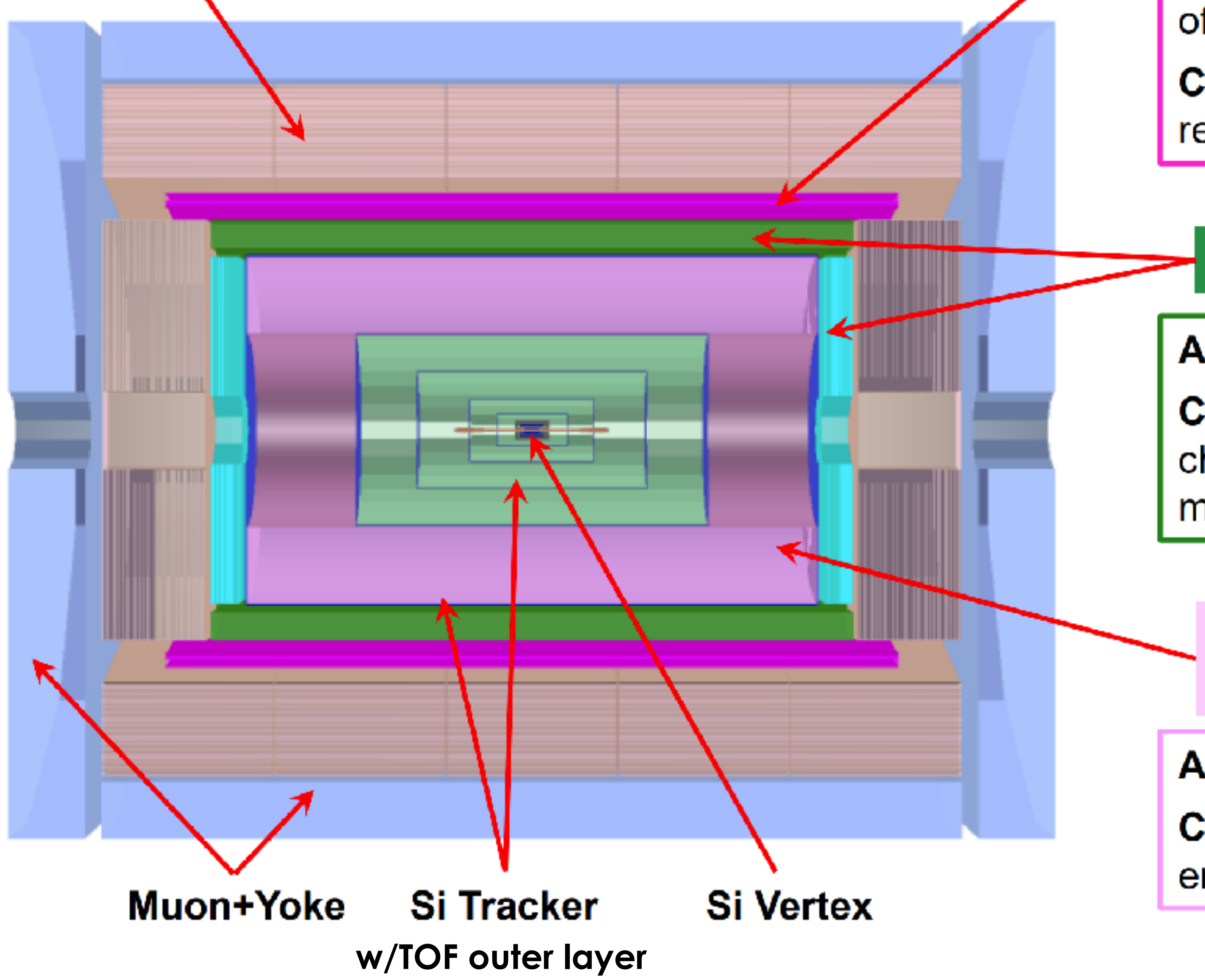


Detector developments

CEPC Detector Concept Designs



The 4th Conceptual Detector Design



Scint Glass PFA HCAL

Advantage: Cost efficient, high density

Challenges: Light yield, transparency, massive production.

Solenoid Magnet (3T / 2T) Between HCAL & ECAL

Advantage: the HCAL absorbers act as part of the magnet return yoke.

Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

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

A Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

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

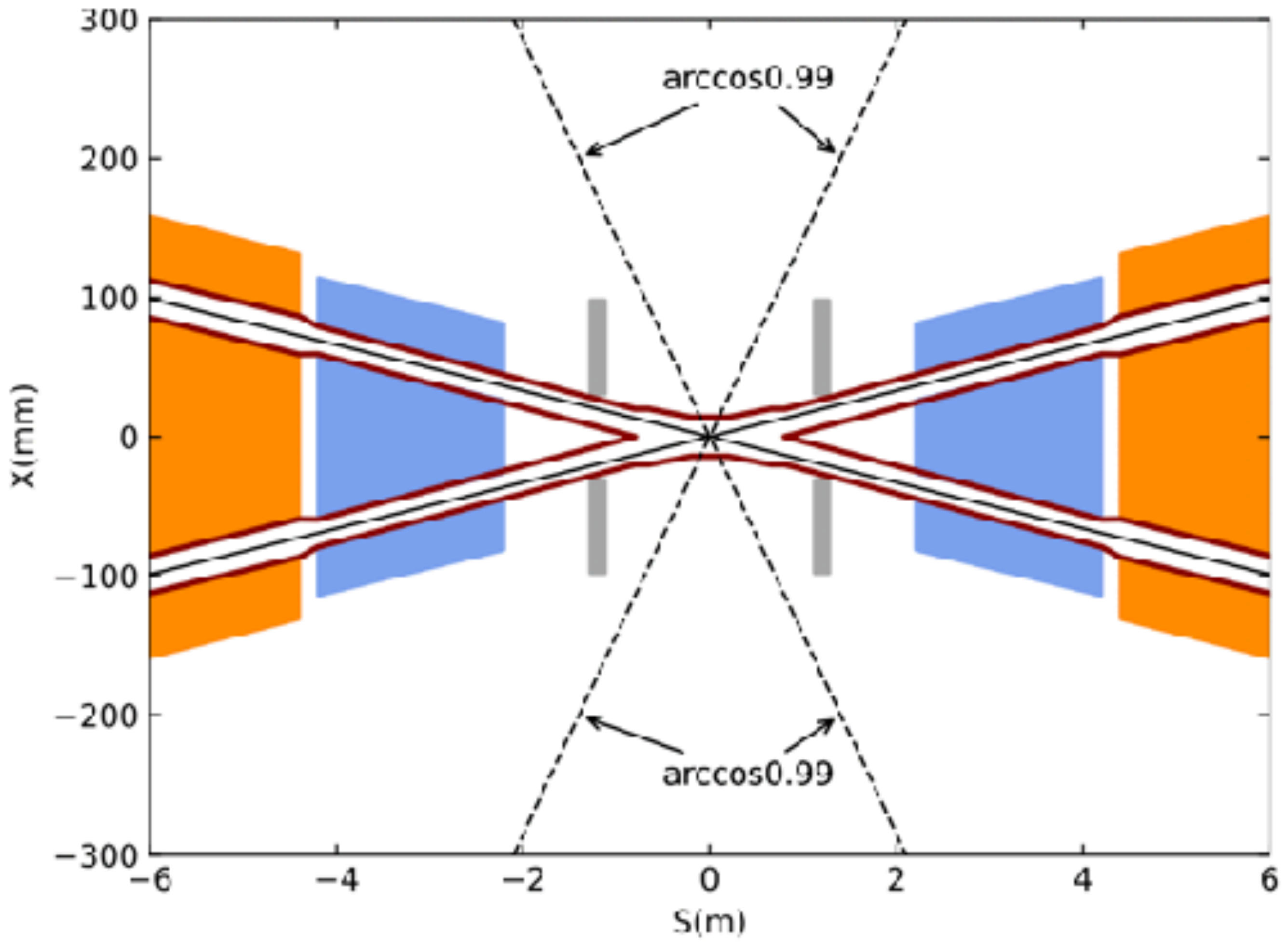
Technologies

Det	Technology
Pixel Vertex	JadePix
	TaichuPix
	Arcadia
	CPV(SOI)
	Stiching
Tracker & PID	TPC
	CEPCPix
	Drift chamber
	PID DC
	LGAD
	Silicon Strip

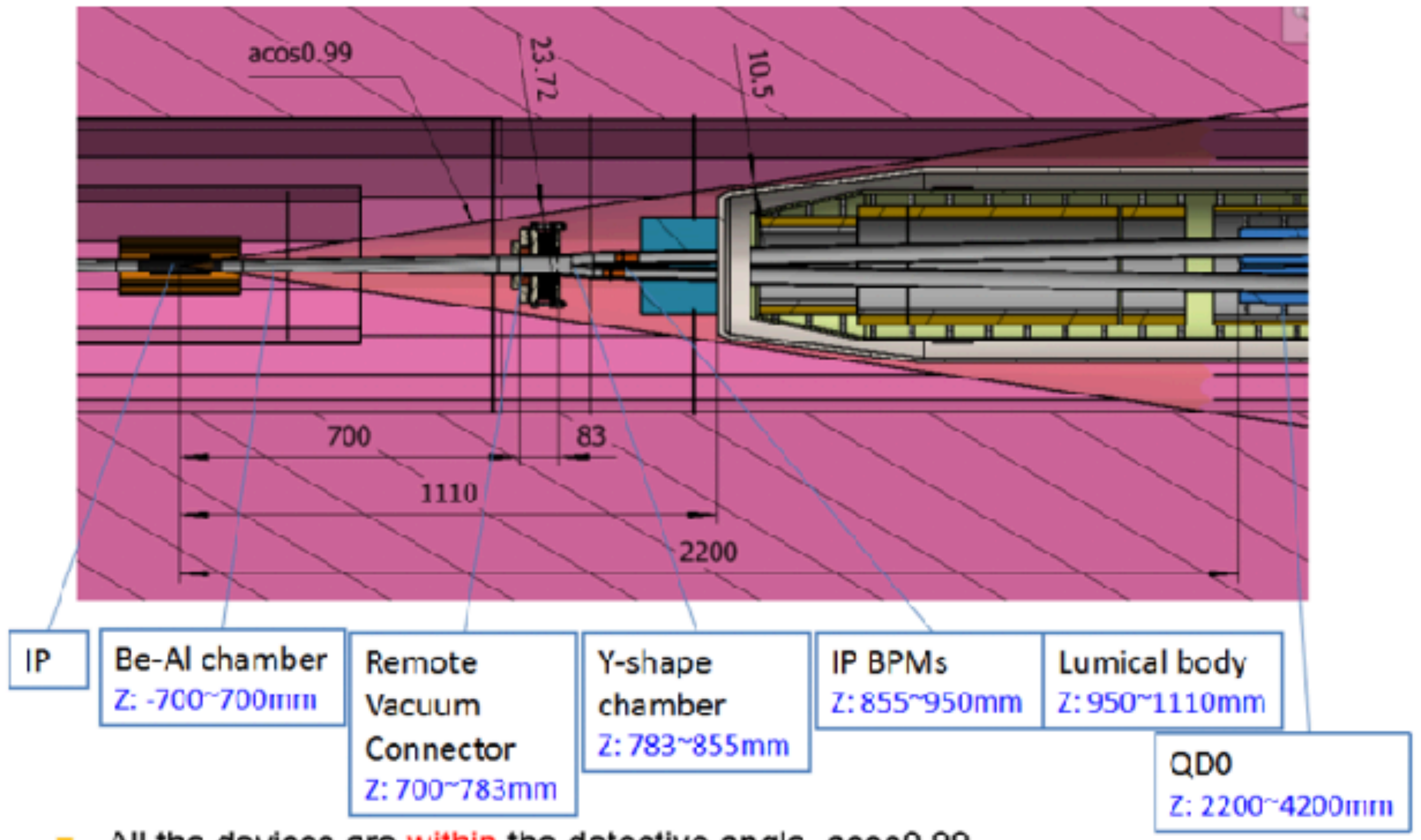
Det	Technology
Calorimeter	Crystal ECAL
	Si+W ECAL
	Scint+W ECAL
	Scint AHCAL
	ScintGlass AHCAL
	RPC SDHCAL
	MPGD SDHCAL
	DR Calorimeter
Muon	Scintillation Bar
	RPC
	μ-Rwell
Lumi	SiTrk+Crystal ECAL
	SiTrk+SiW ECAL

CEPC R&D: Machine Detector Interface (MDI)

Crossing angle: 33 mrad
Focal length: 2.2 m



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



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

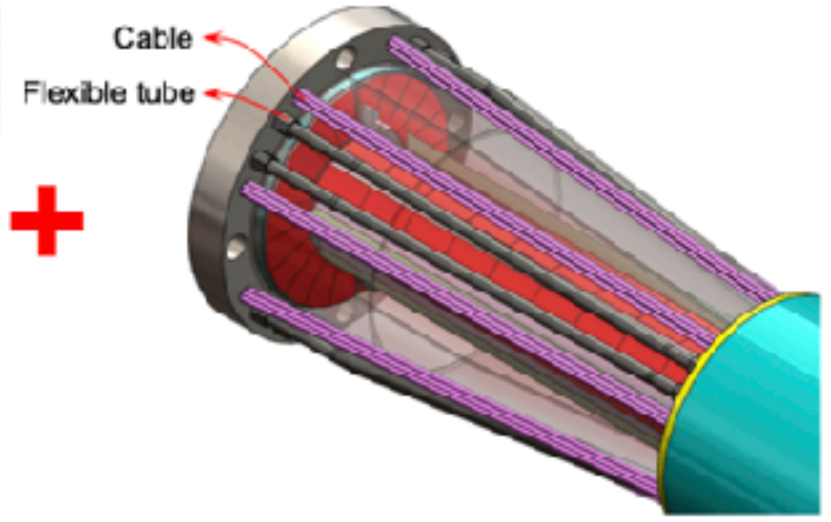
2021 Workshop on CEPC Detector & MDI Mechanical Design, Oct.22-23
https://indico.ihep.ac.cn/event/14392/

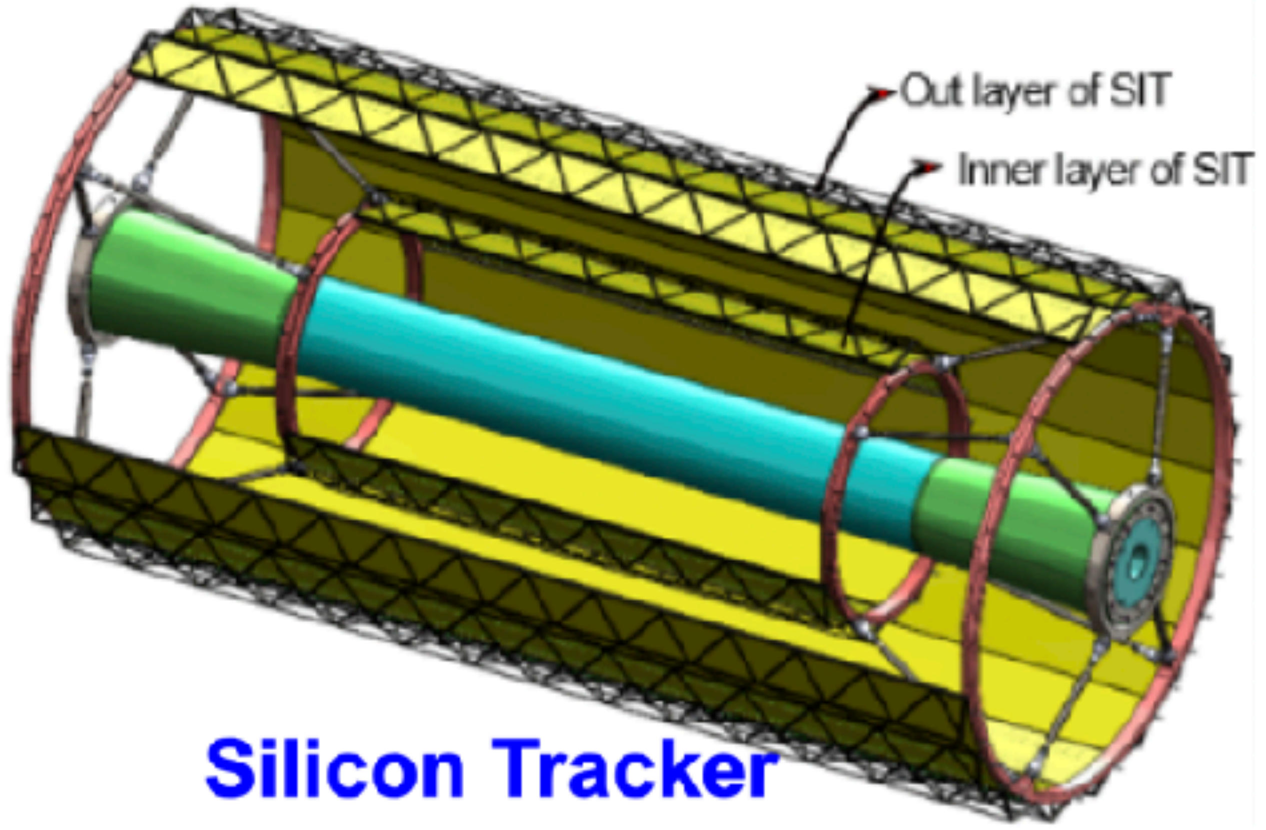
Beam Pipe
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

Vertex

\+

LumiCal Tracker



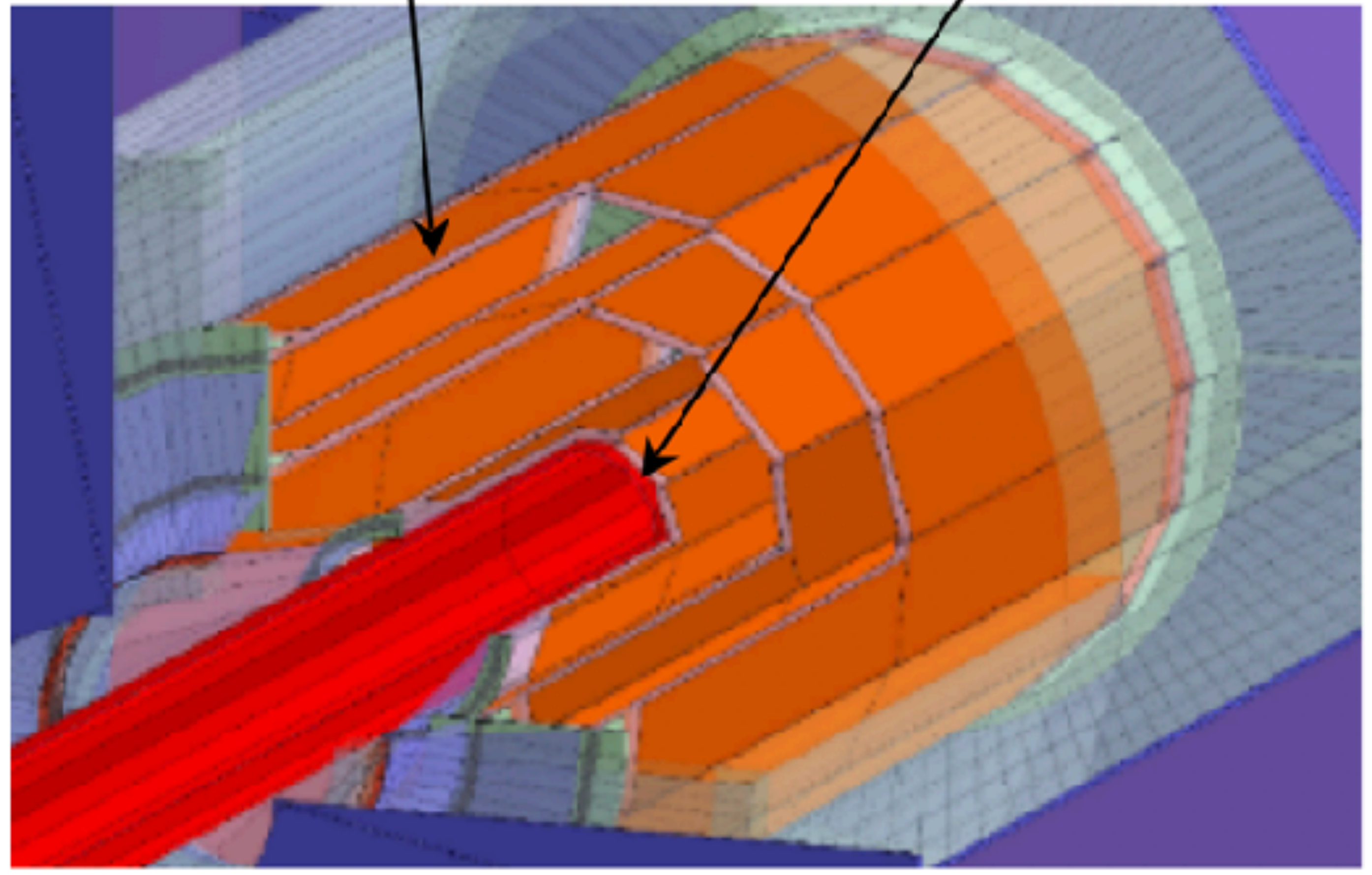


Silicon Tracker

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

CEPC R&D: Silicon Pixel Sensors

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track

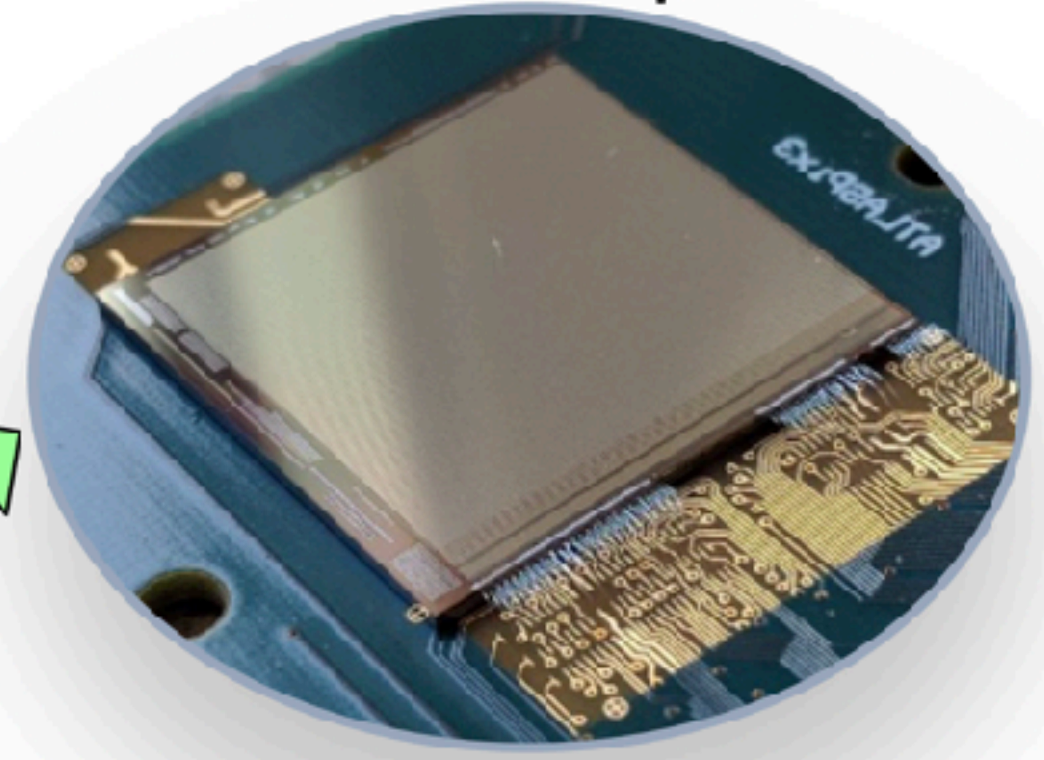
CDR design specifications

- 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 5 series:
JadePix, TaichuPix, CPV, Arcadia, CEPCPix

Develop **CEPCPix** for a CEPC tracker based on **ATLASPix3** CN/IT/UK/DE

TSI 180 nm HV-CMOS process

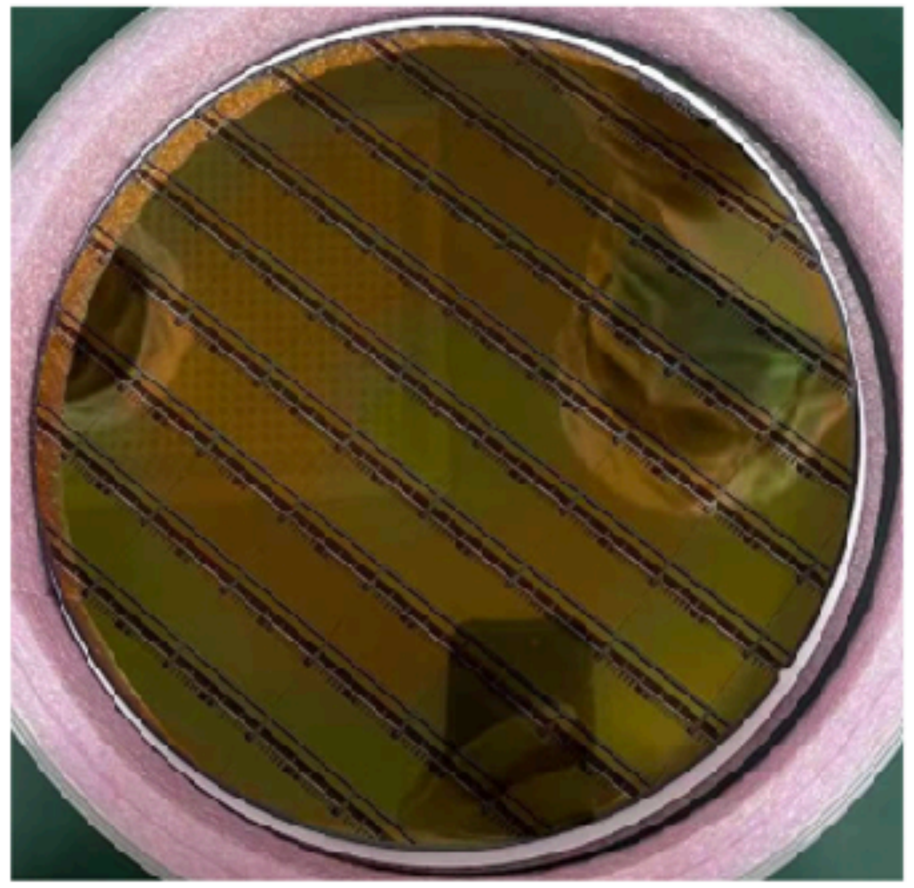


JadePix-3 Pixel size ~16×23 μm²

Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm²

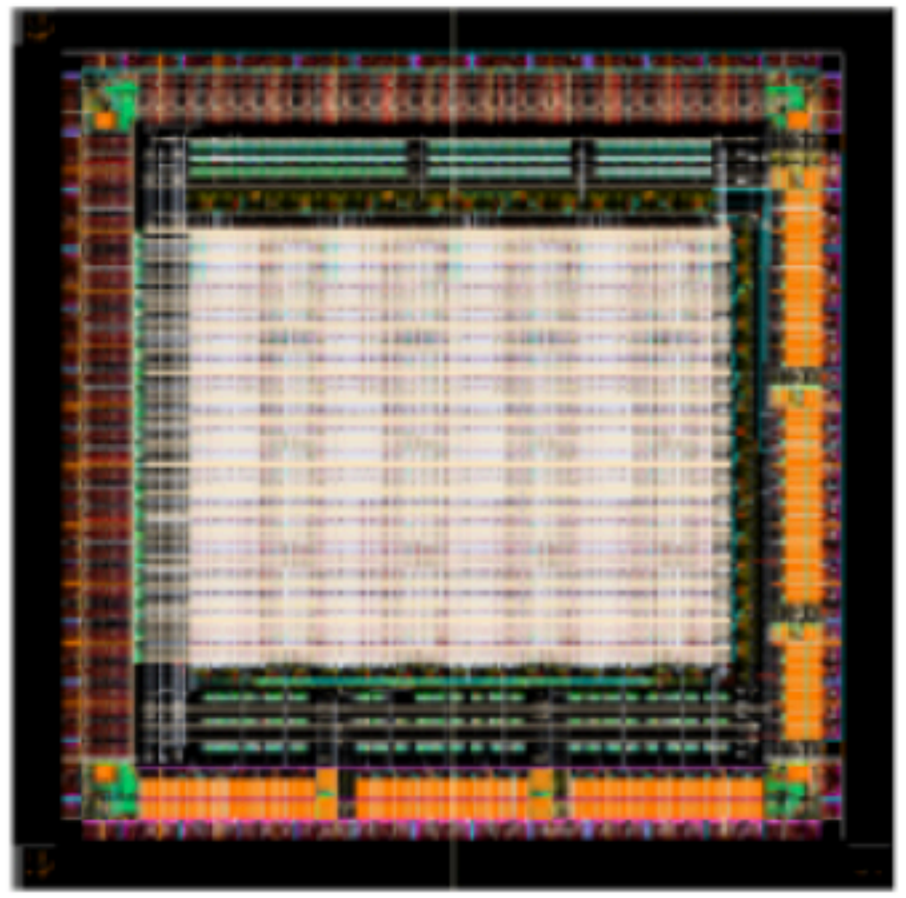
MOST 1

TaichuPix-3, FS 2.5x1.5 cm²
25×25 μm² pixel size

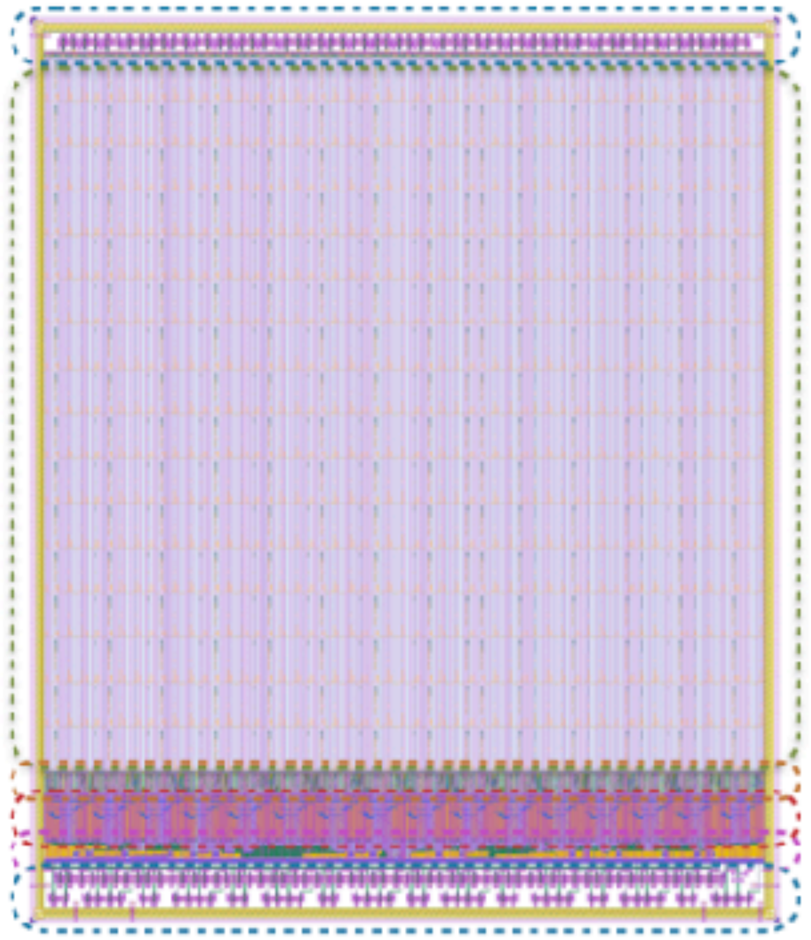


MOST 2

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



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

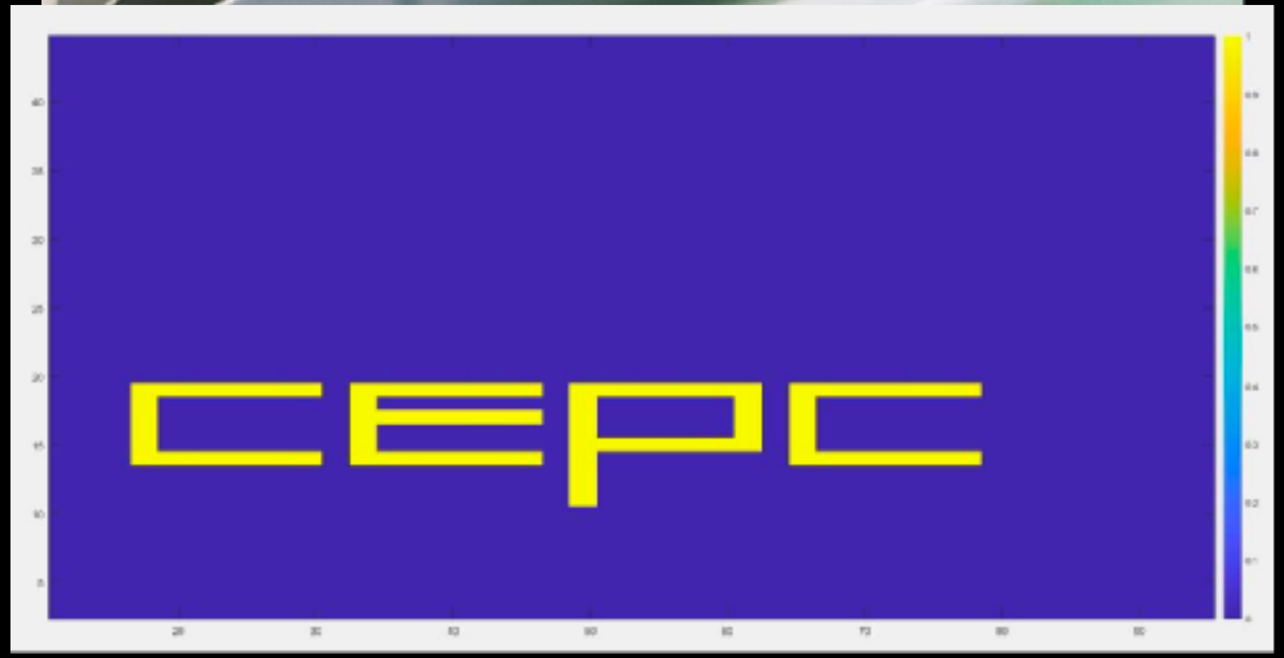


CEPC R&D: Vertex Detector Prototype

Low-mass vertex detectors require sensors with:
- integrated readout electronics
- low power consumption

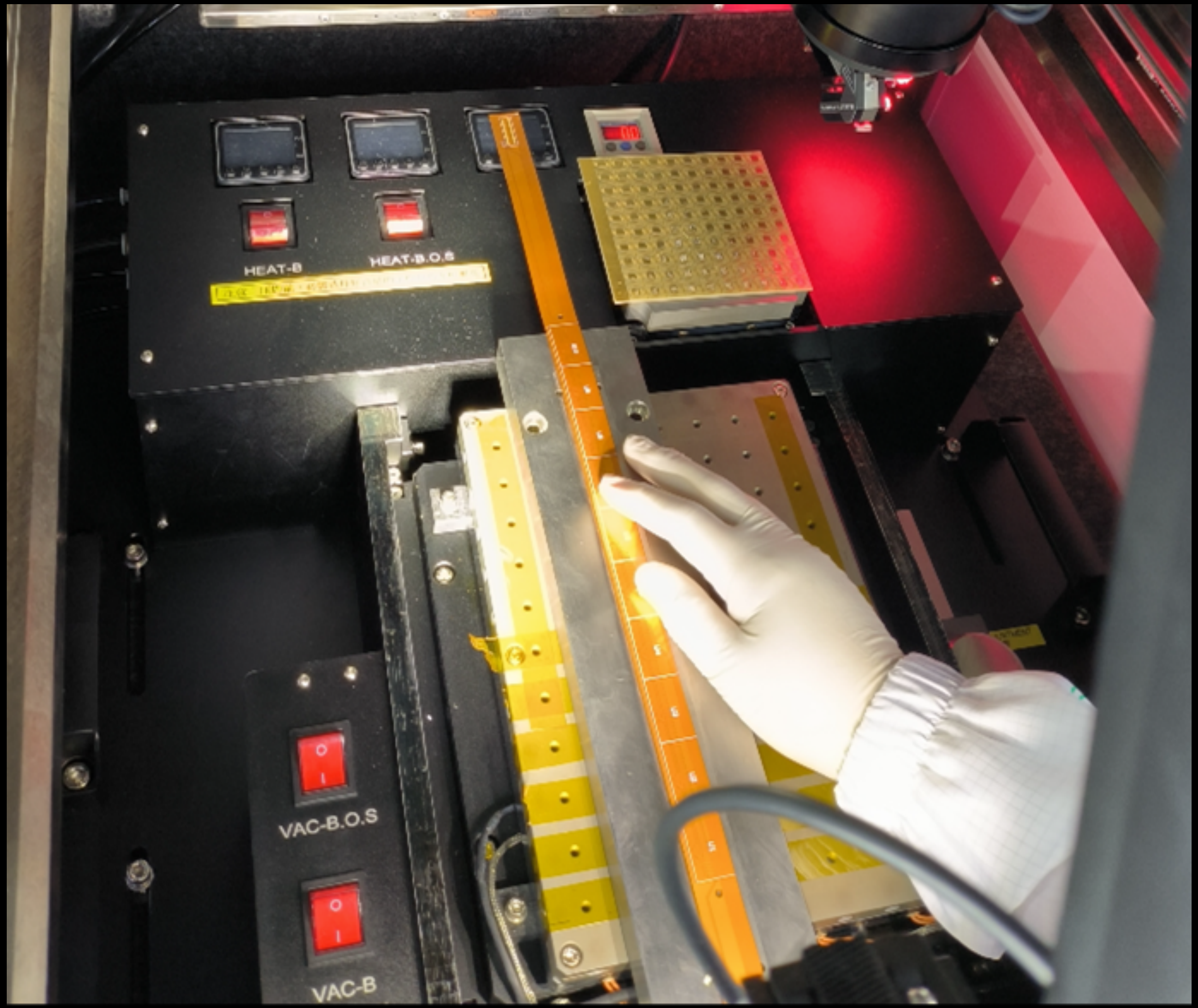
TaichuPix3 chips at IHEP

Produced by TowerJazz, in collaboration with IFAE, Spain



Chip working well

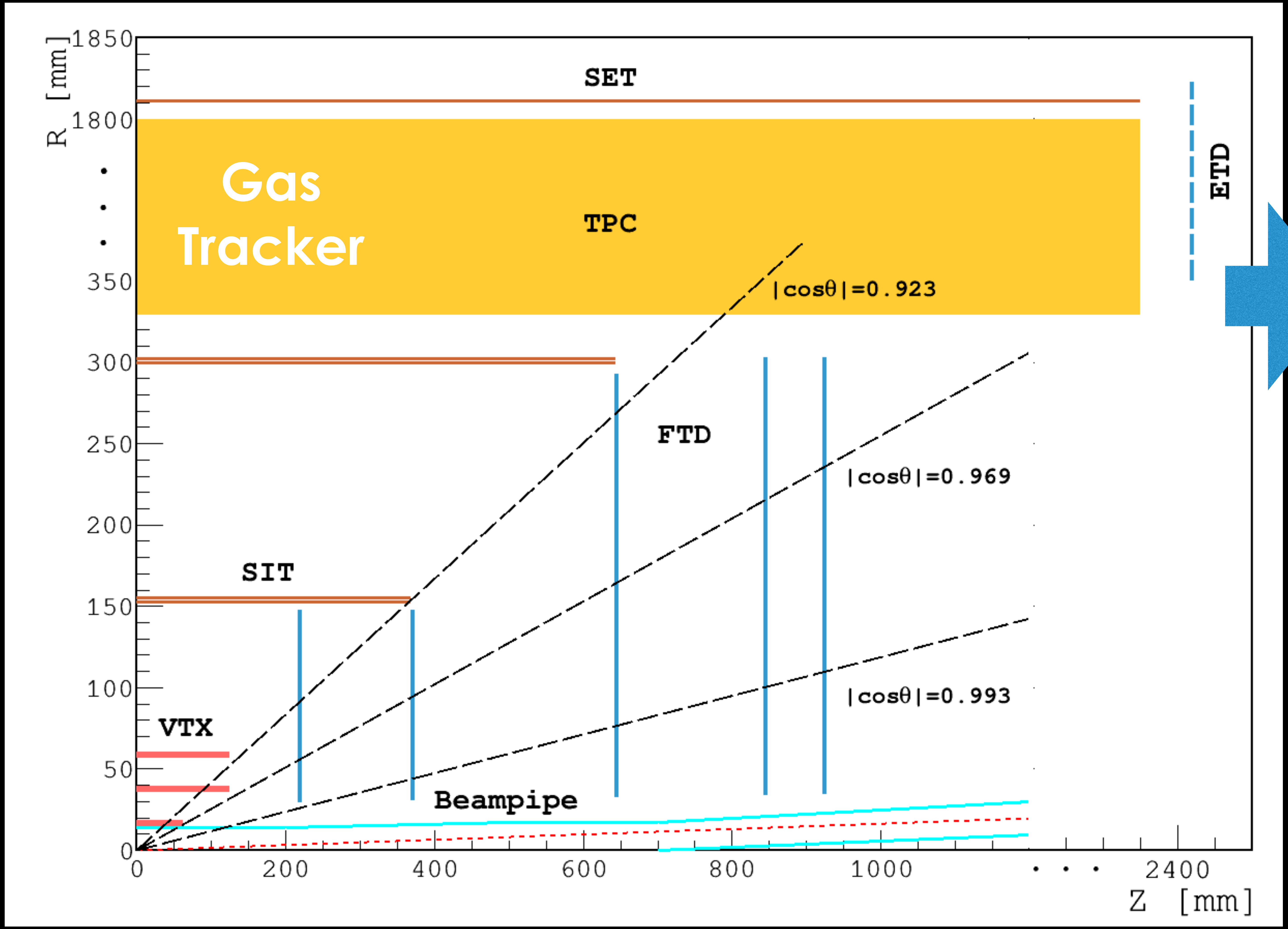
Ladder wire bonding preparations



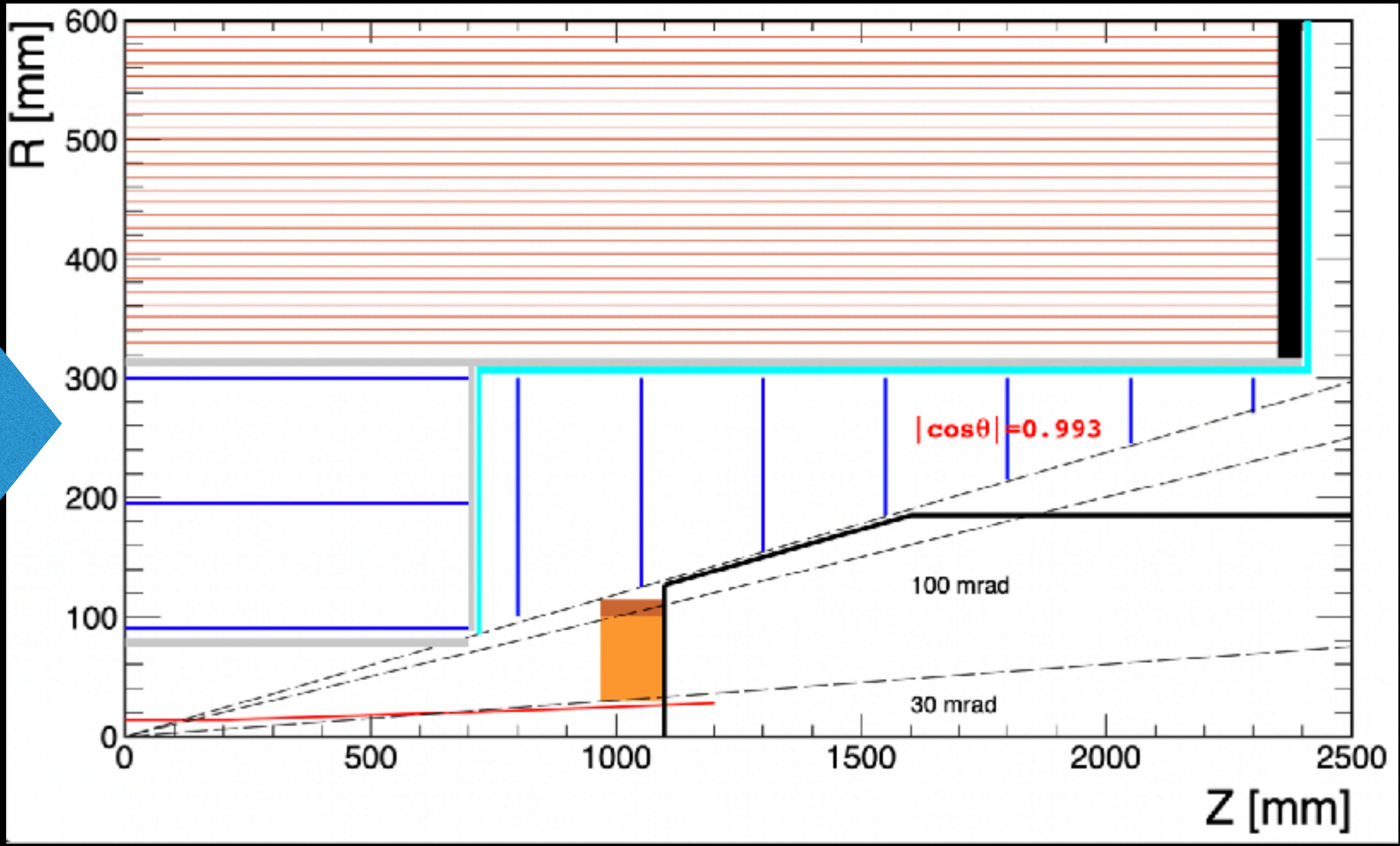
Assembly tooling designed

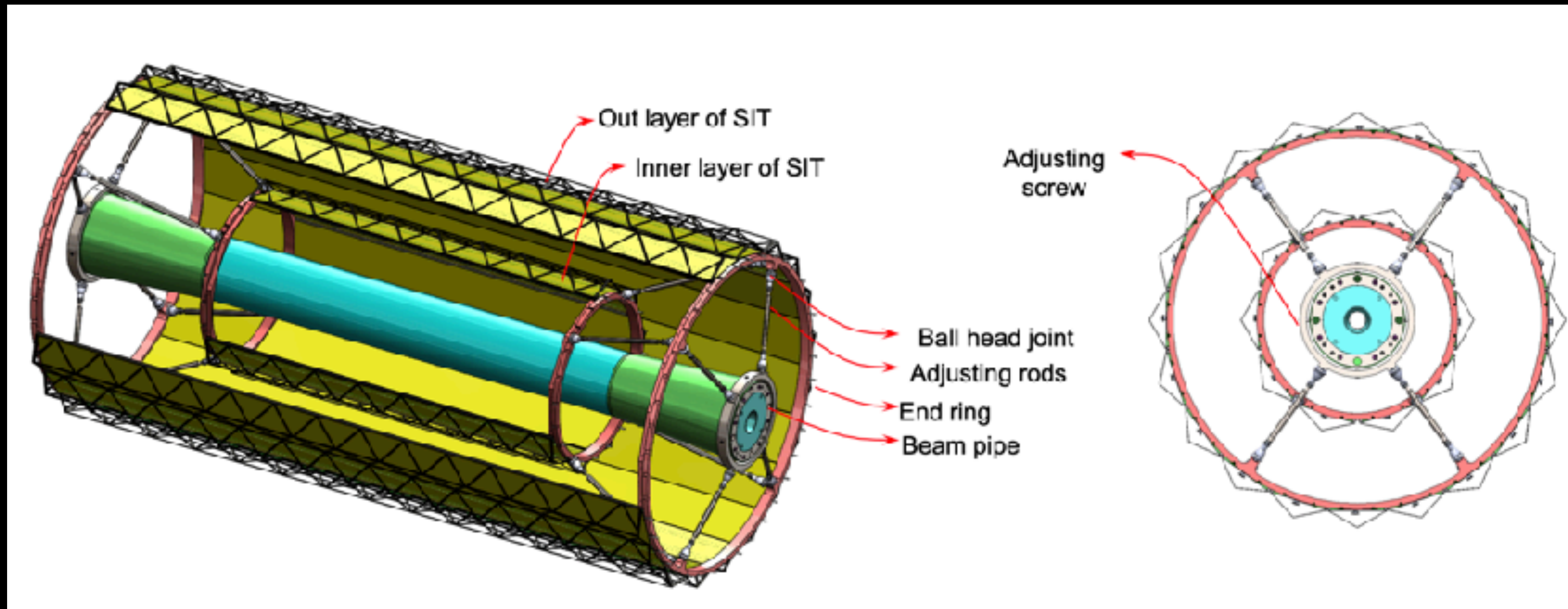
Full vertex detector prototype test beam planned for DESY December 2022

CEPC R&D: Silicon Tracker design



Optimization: tracker layout taskforce





Silicon tracker demonstrator with international partners

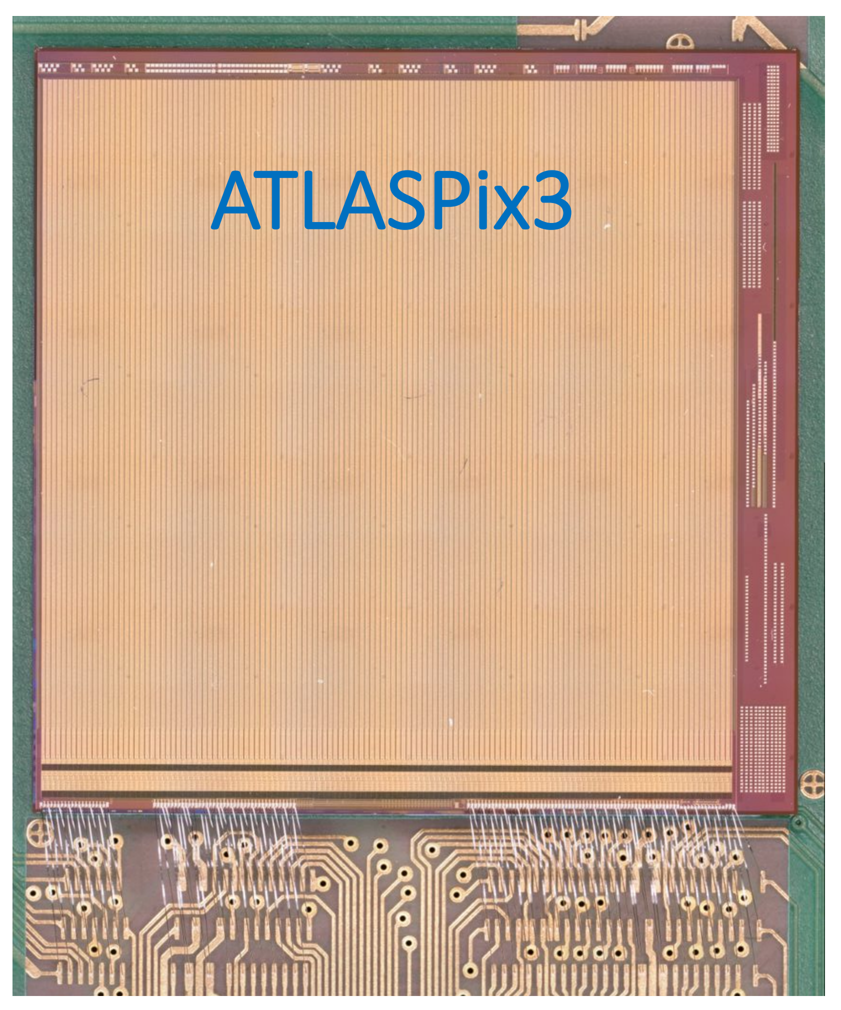
HV-CMOS Tracker Demonstrator

International collaboration

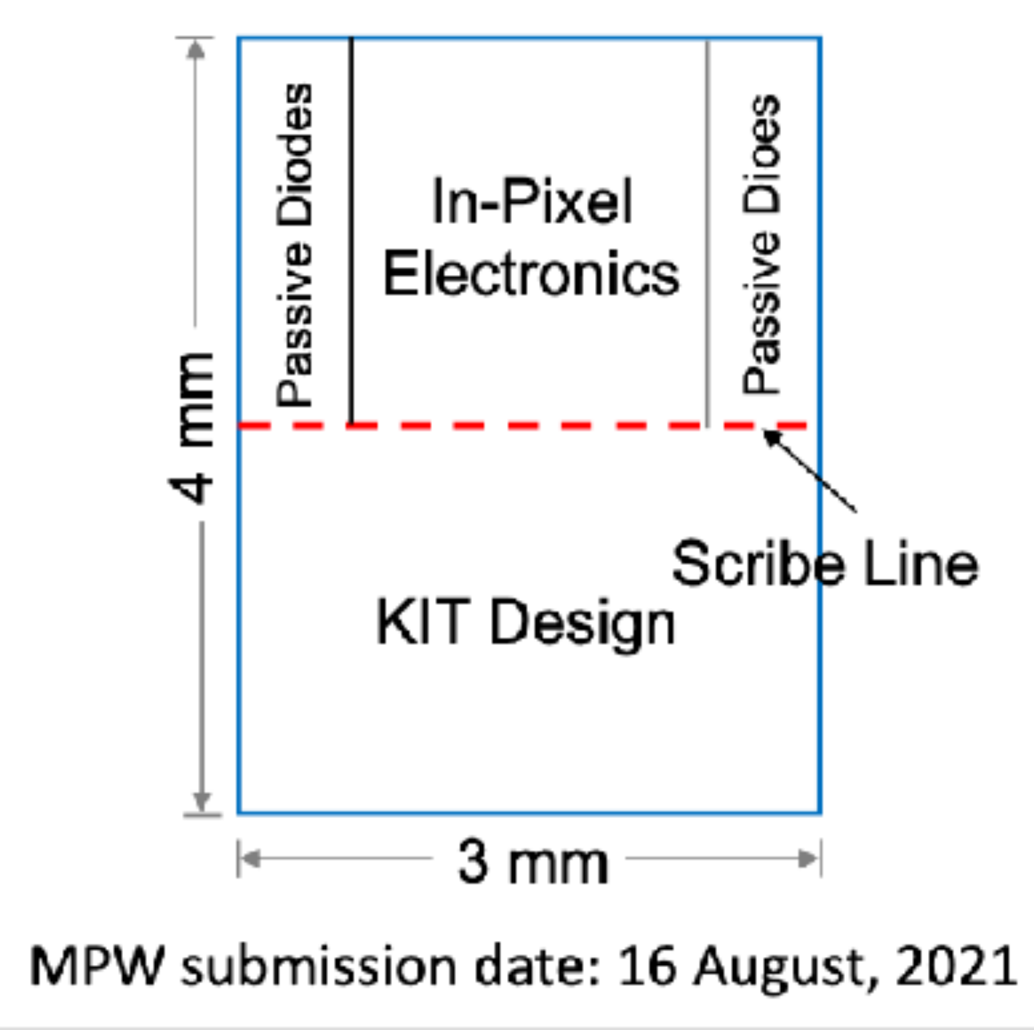
- **China**
  - Institute of High Energy Physics, CAS
  - Shangdong University
  - Tsinghua University
  - University of Science and Technology of China
  - Northwestern Polytechnical University
  - T.D. Lee Institute – Shanghai Jiao Tong University
  - Harbin Institute of Technology
  - University of South China
- **Italy**
  - INFN Sezione di Milano, Università di Milano e Università dell'Insubria
  - INFN Sezione di Pisa e Università di Pisa
  - INFN Sezione di Torino e Università di Torino
- **Germany**
  - Karlsruhe Institute of Technology
- **UK**
  - University of Bristol
  - STFC – Daresbury Laboratory
  - University of Edinburgh
  - Lancaster University
  - University of Liverpool
  - Queen Mary University of London
  - University of Oxford
  - University of Sheffield
  - University of Warwick

Test beam at DESY in April 2022

Start by using components developed for other projects



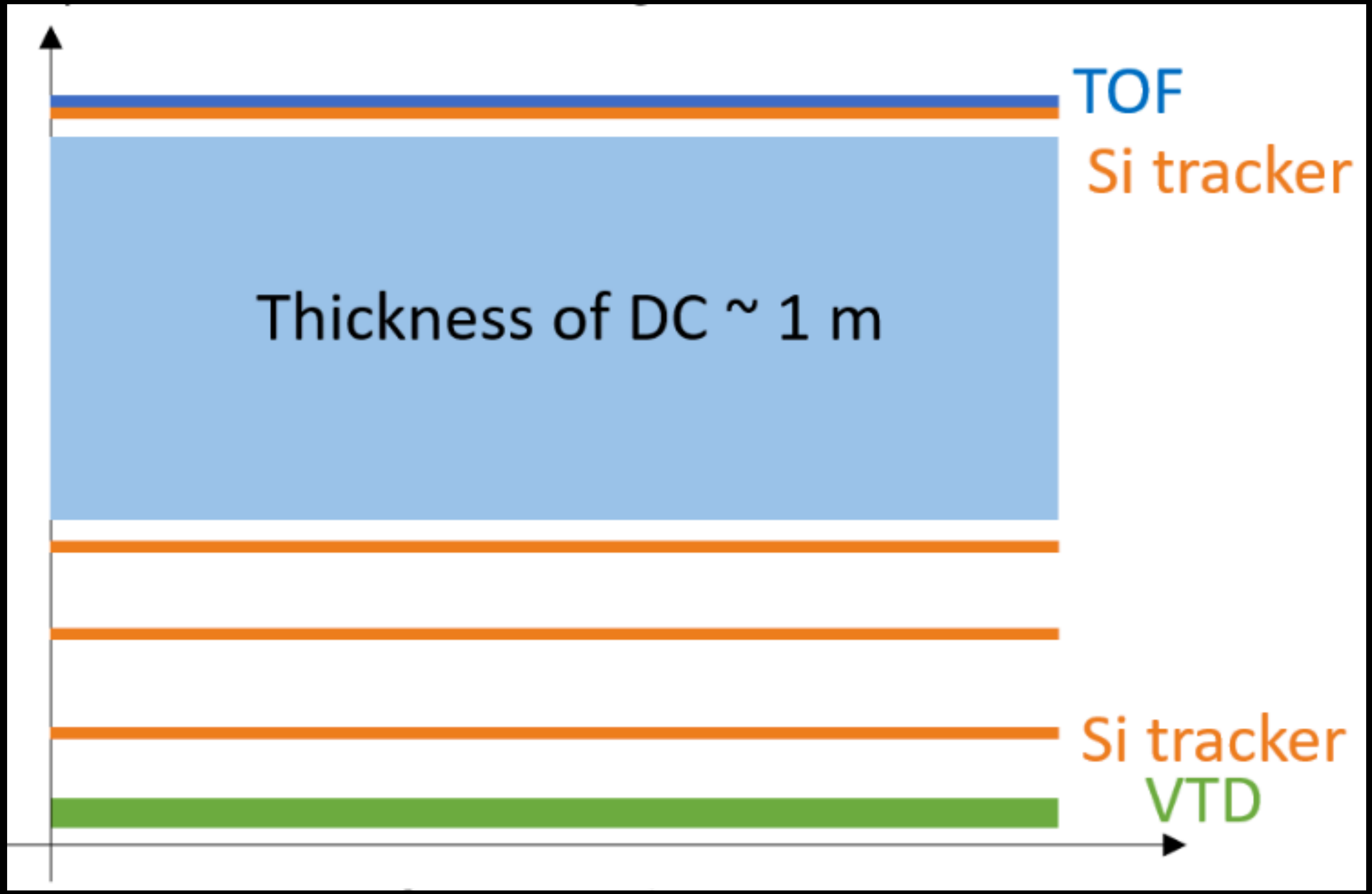
smaller pixel size ($25\times150\ \mu m^2$)

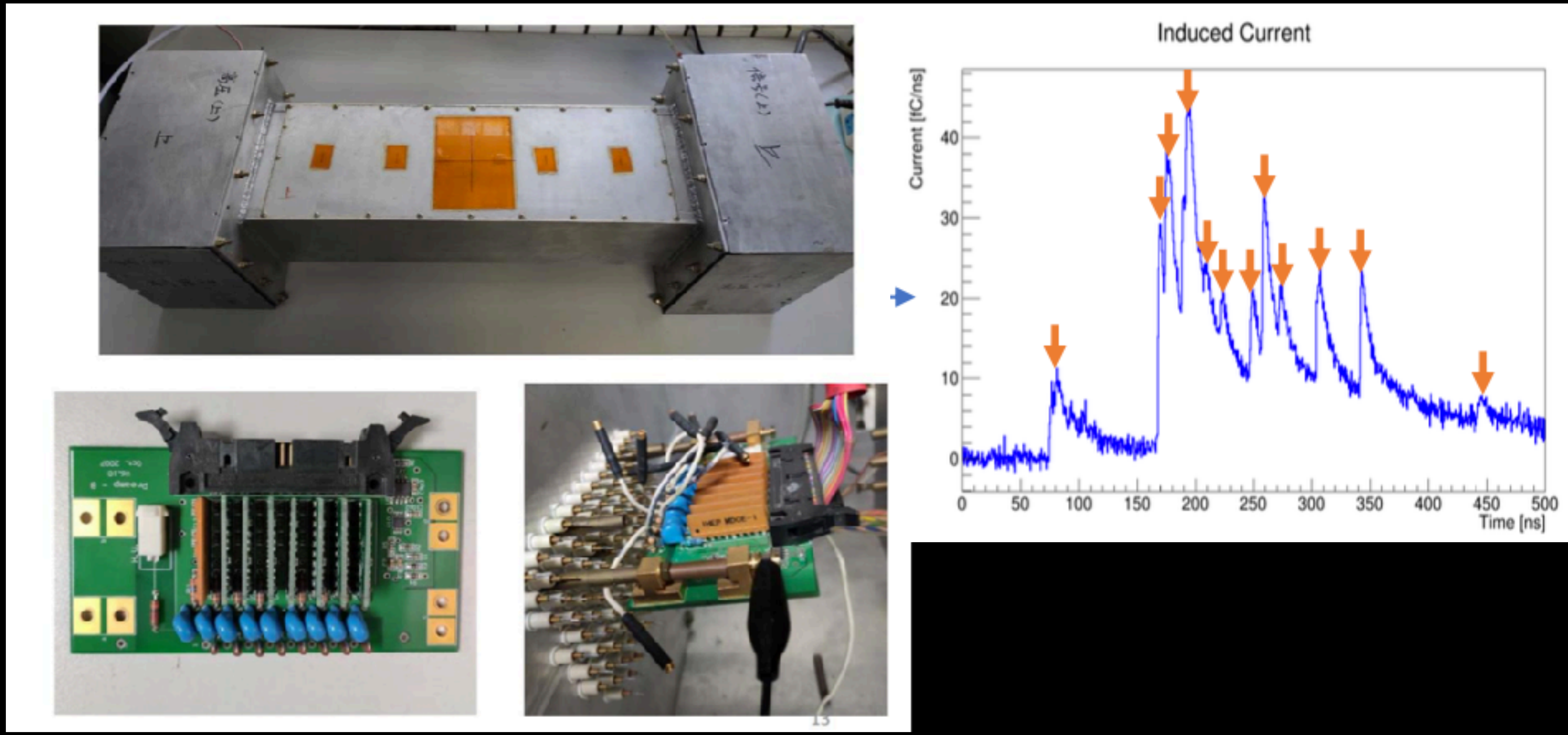


Migrate to a new process: HLMC 55 nm HV-CMOS

CEPC R&D: Particle Identification: Drift Chamber (dN_{cl}/dx) + TOF

Cluster counting potentially a factor ~2 better than dE/dx, but requires fast electronics and good counting algorithms





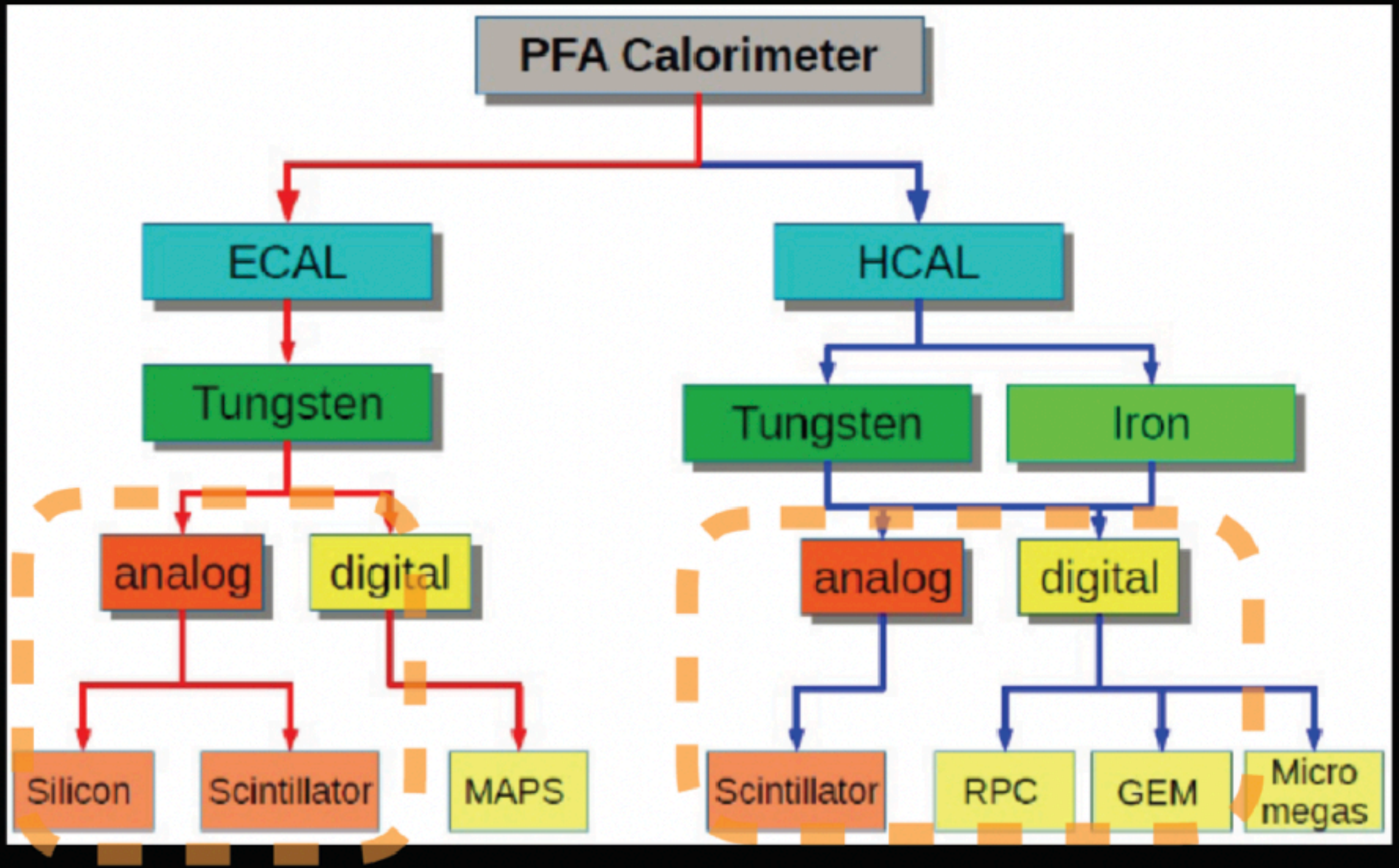
Work on-going in Italy and IHEP

Cluster counting regular meetings, led by Franco G. and Linghui

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

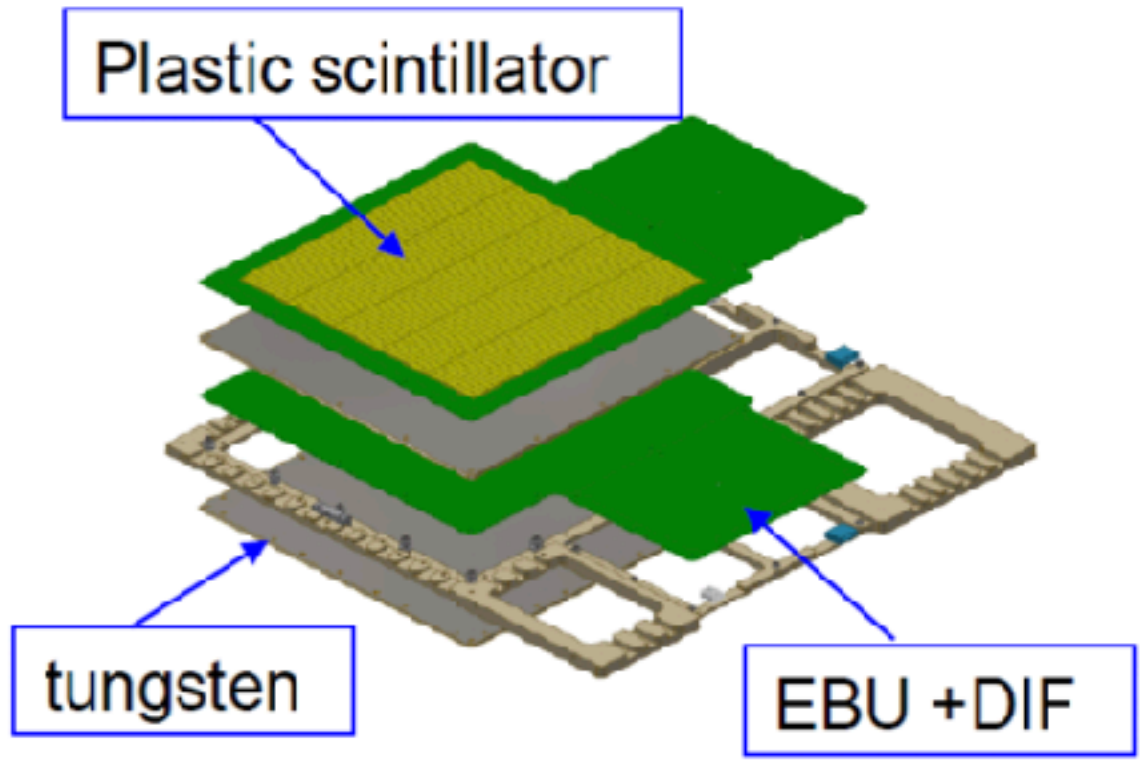
R&D supported by MOST, NSFC and IHEP seed funding

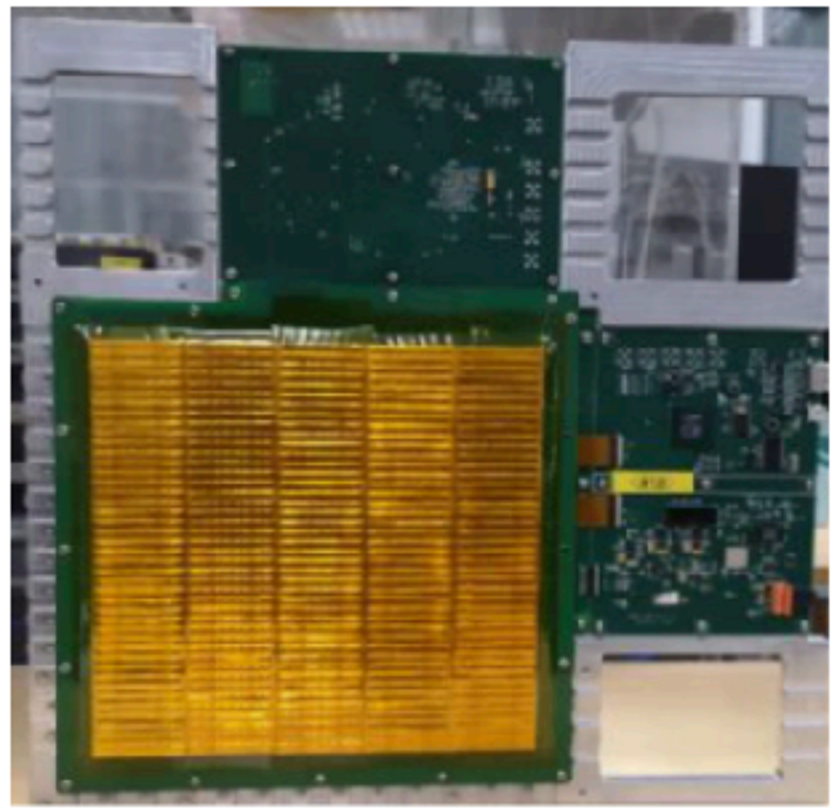


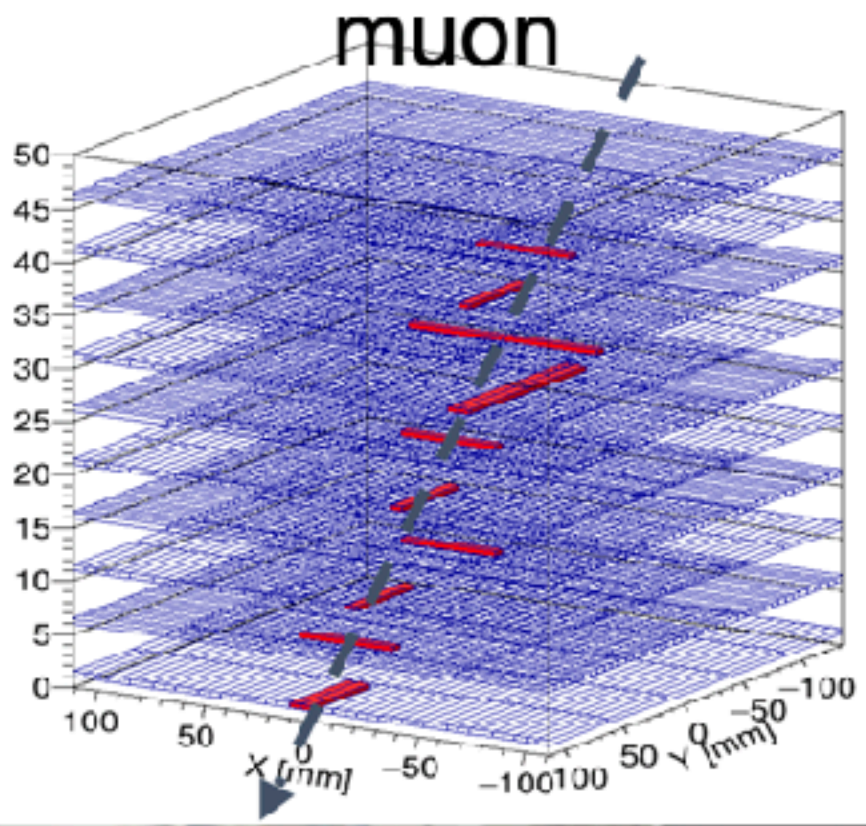
High Granularity	Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
	Hadronic	SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)
Newer Options	Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

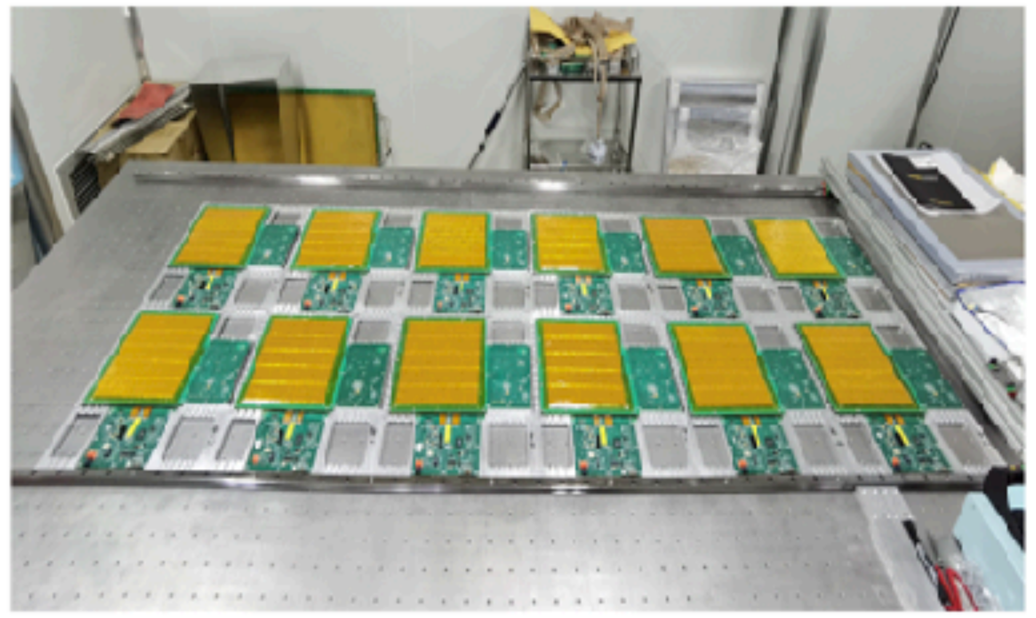
CEPC R&D: Scintillating Calorimeters (ECAL, AHCAL)

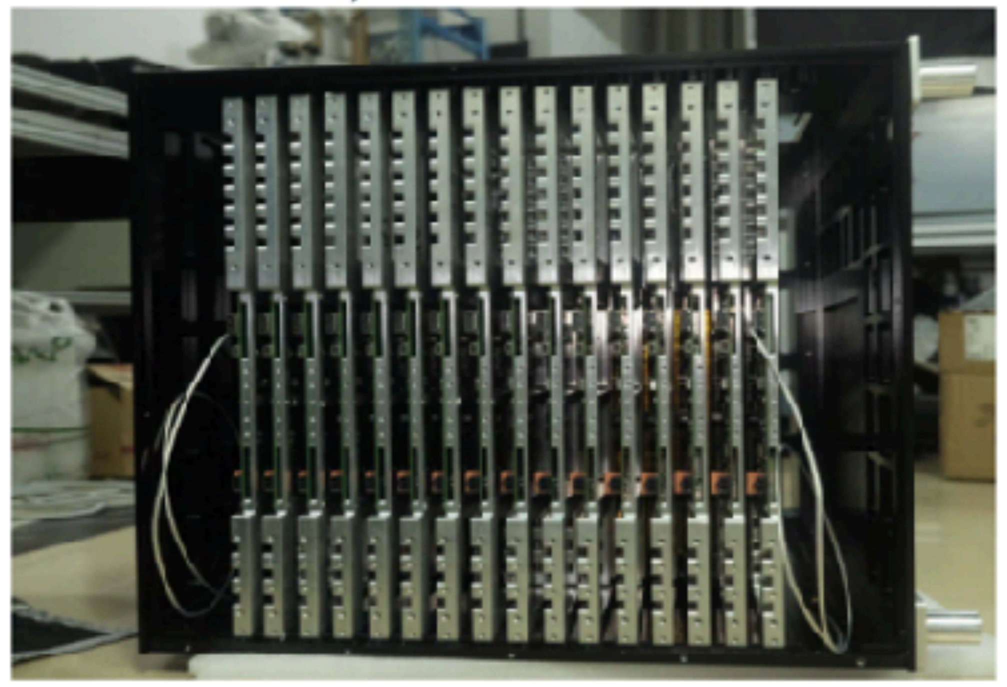
Scintillator-W ECAL Prototype

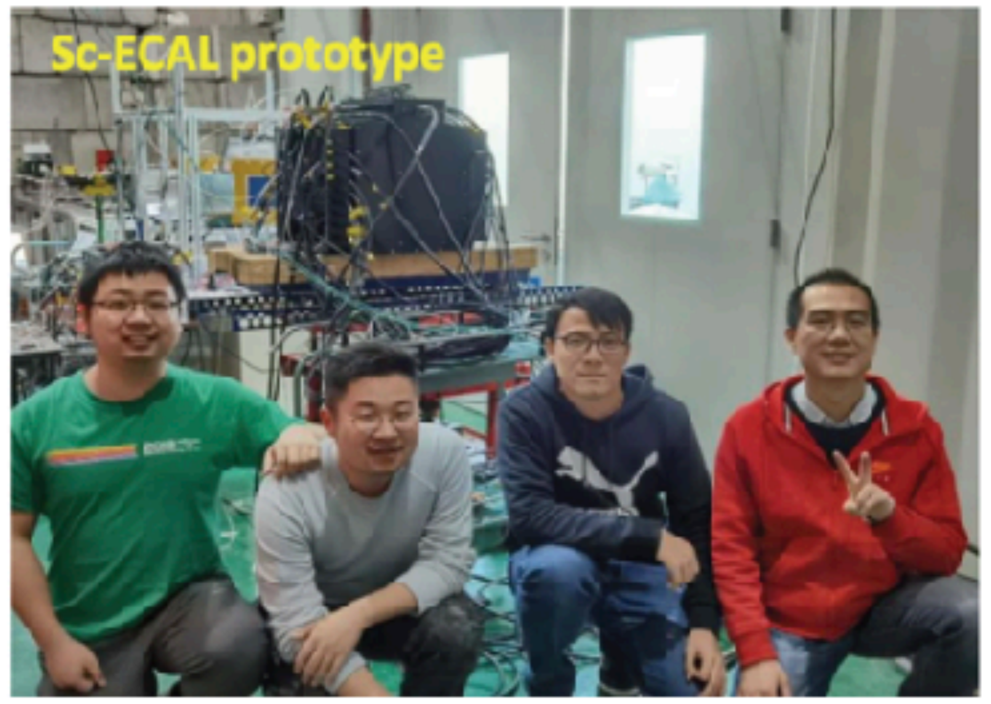




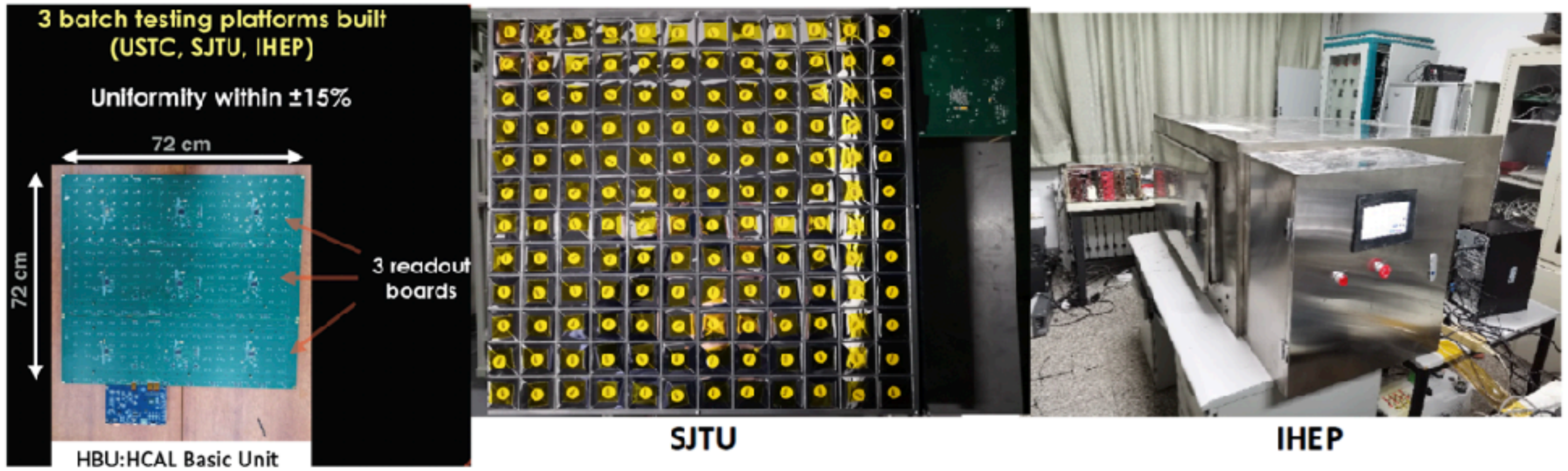


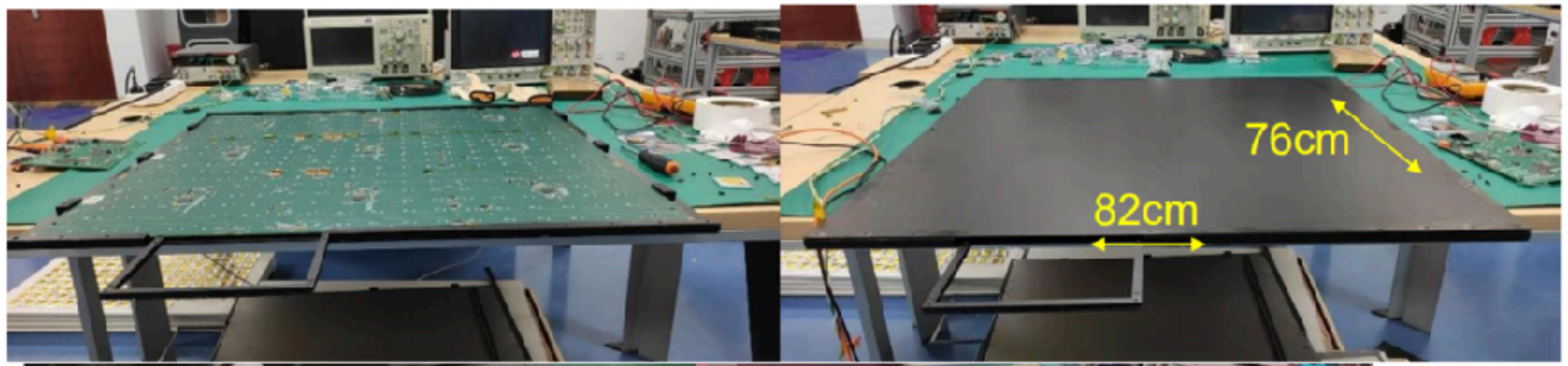


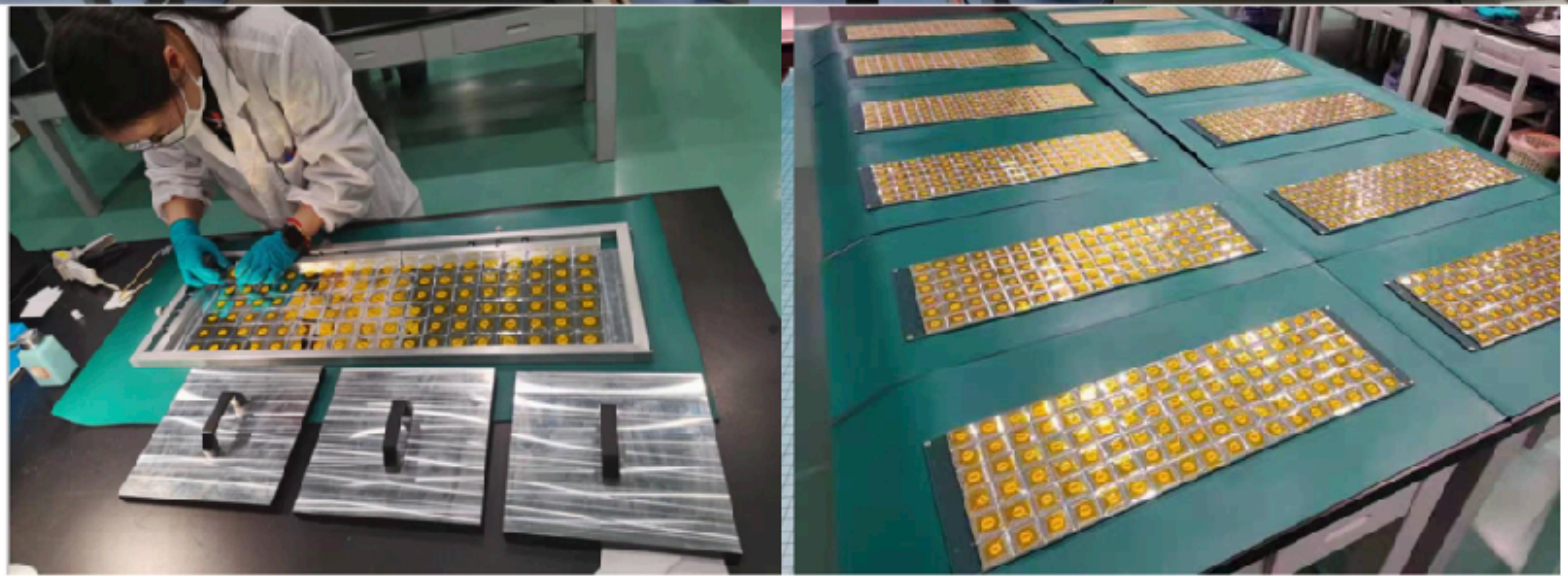




Scintillator + SiPM AHCAL Prototype



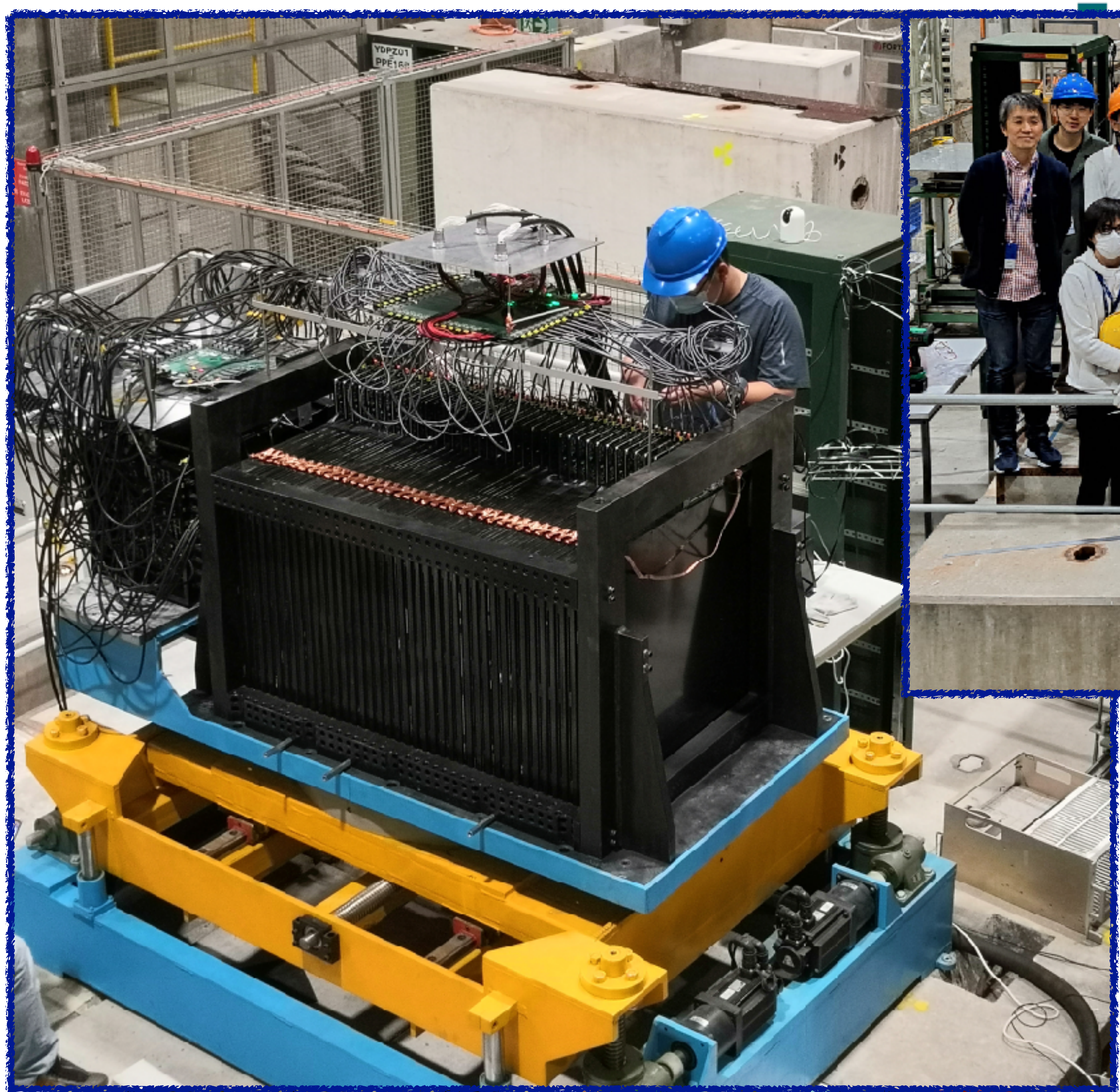


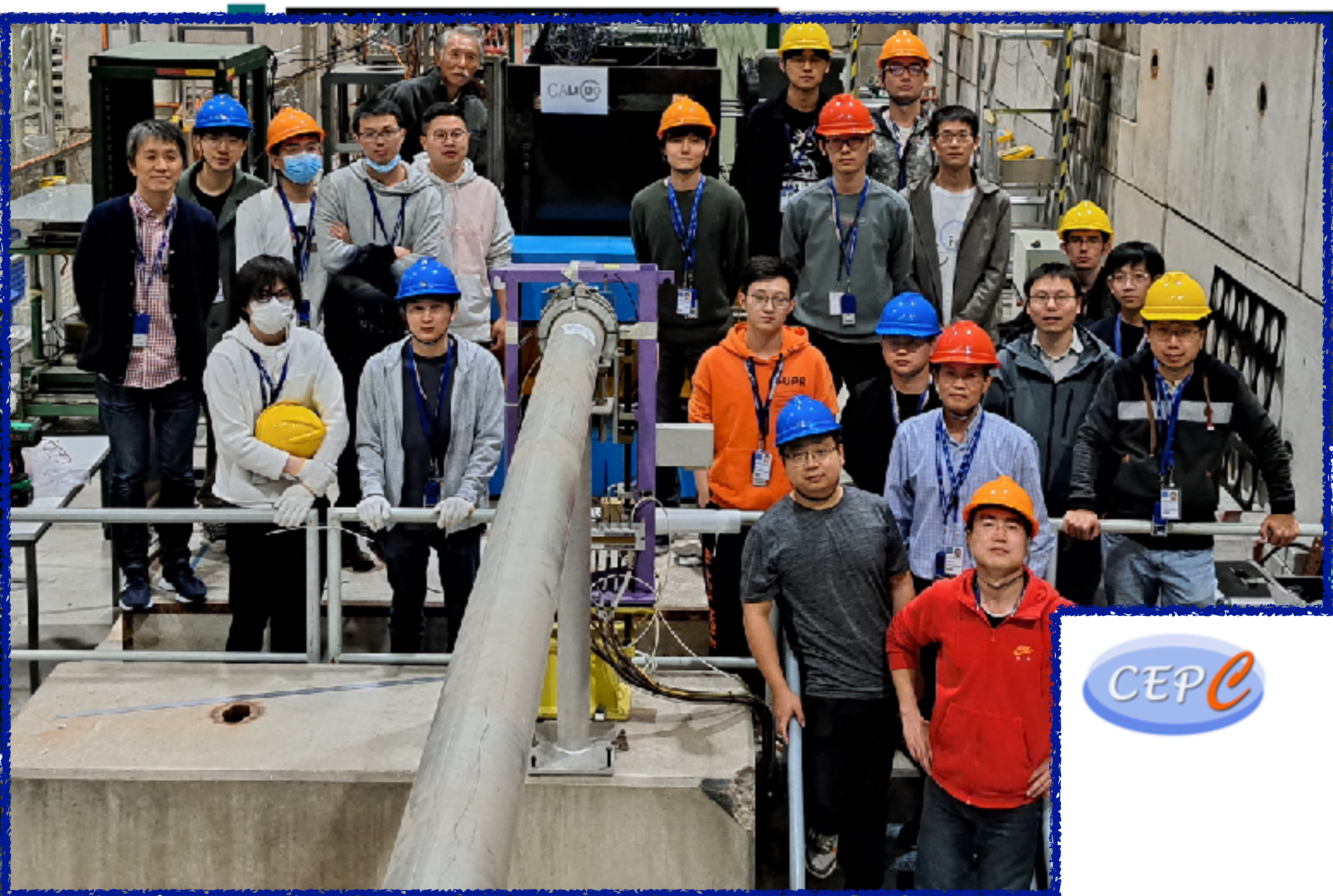


Test beam at CERN SPS on-going, together with CALICE

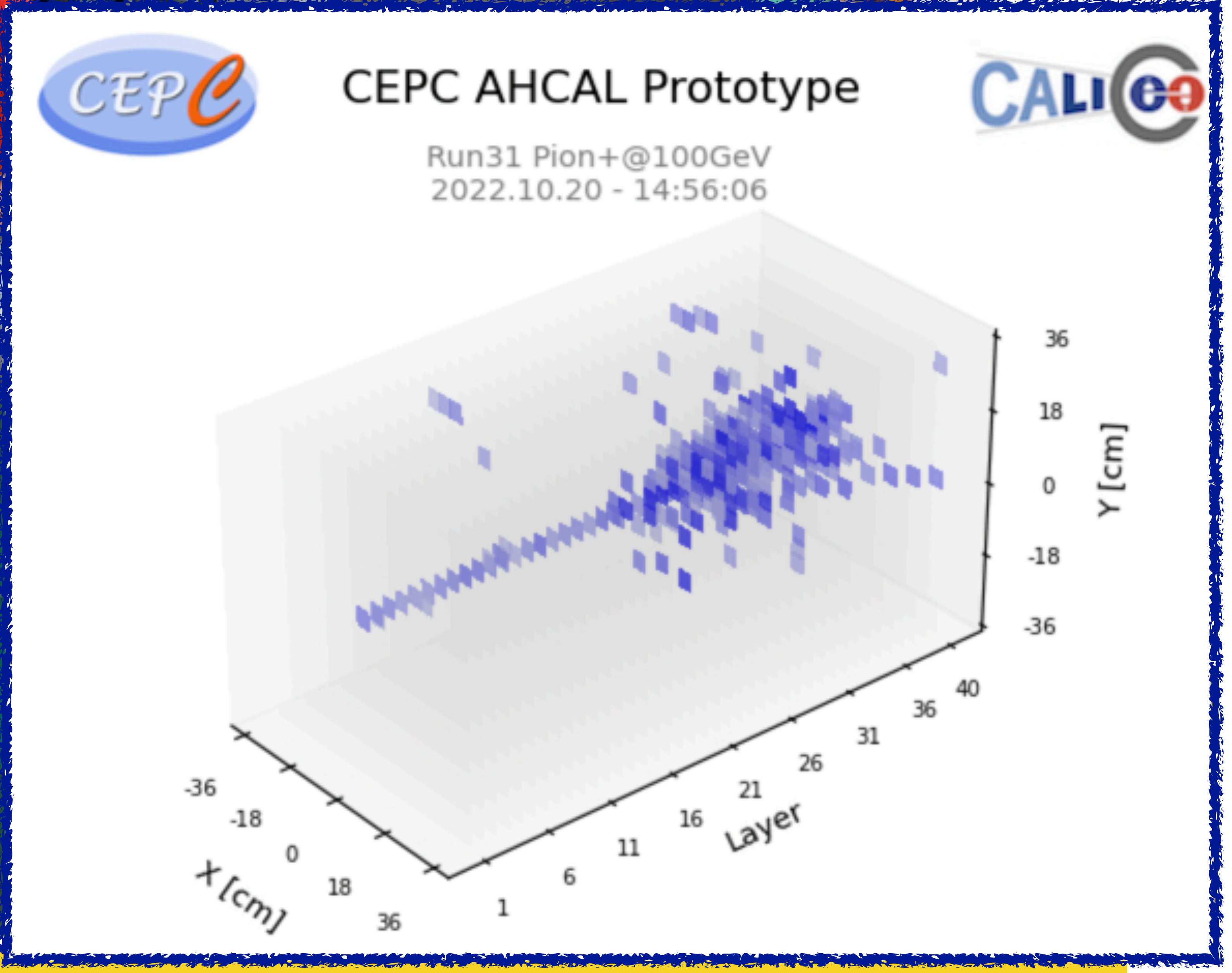
CEPC R&D: Scintillating Calorimeters (ECAL, AHCAL)

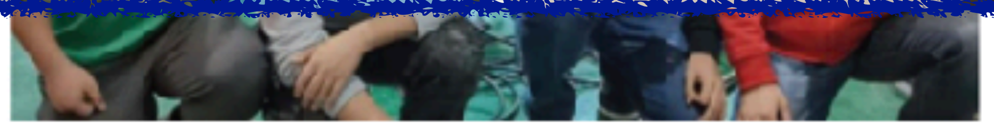
Combined ScW-ECAL and AHCAL test beam





IHEP

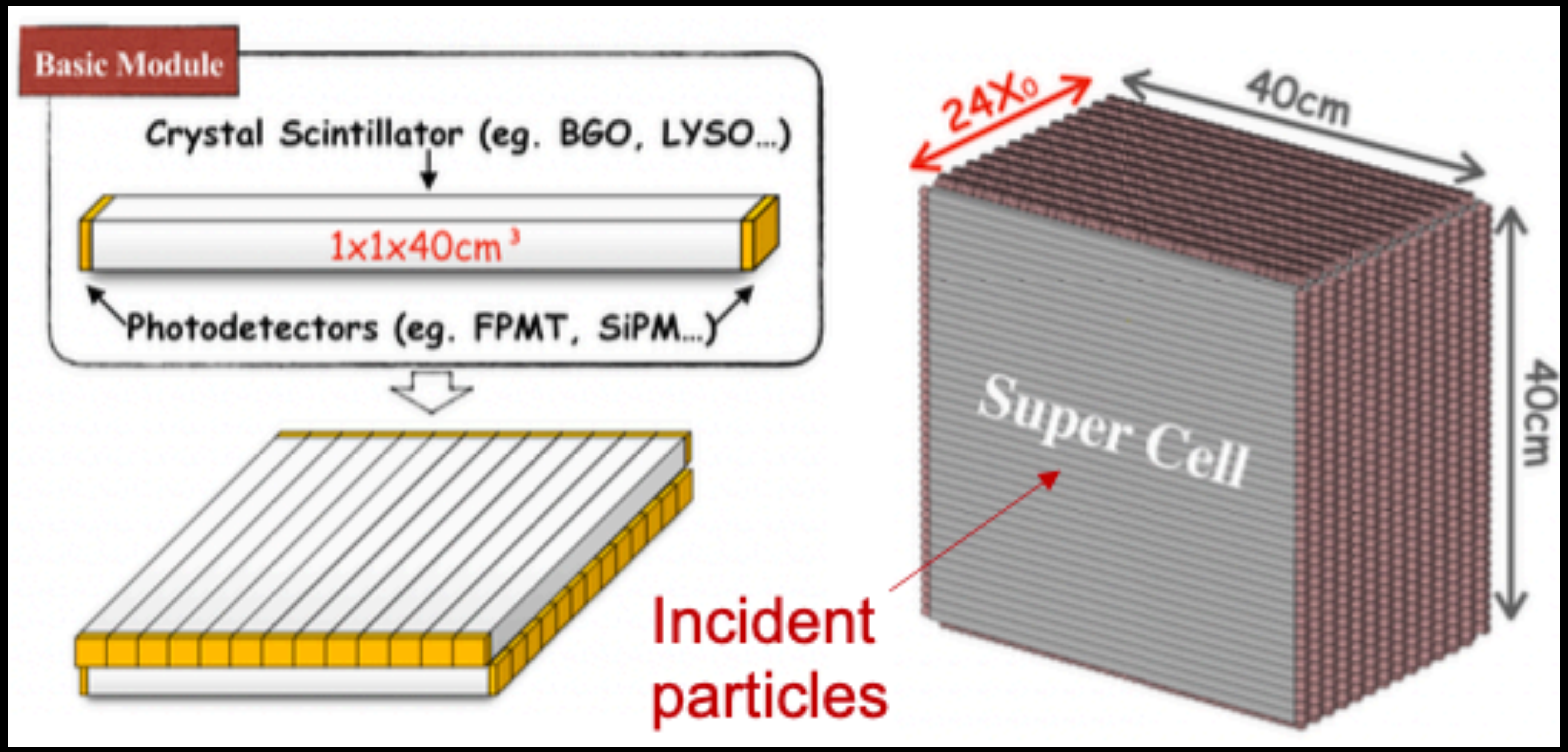




Test beam at CERN SPS on-going, together with CALICE

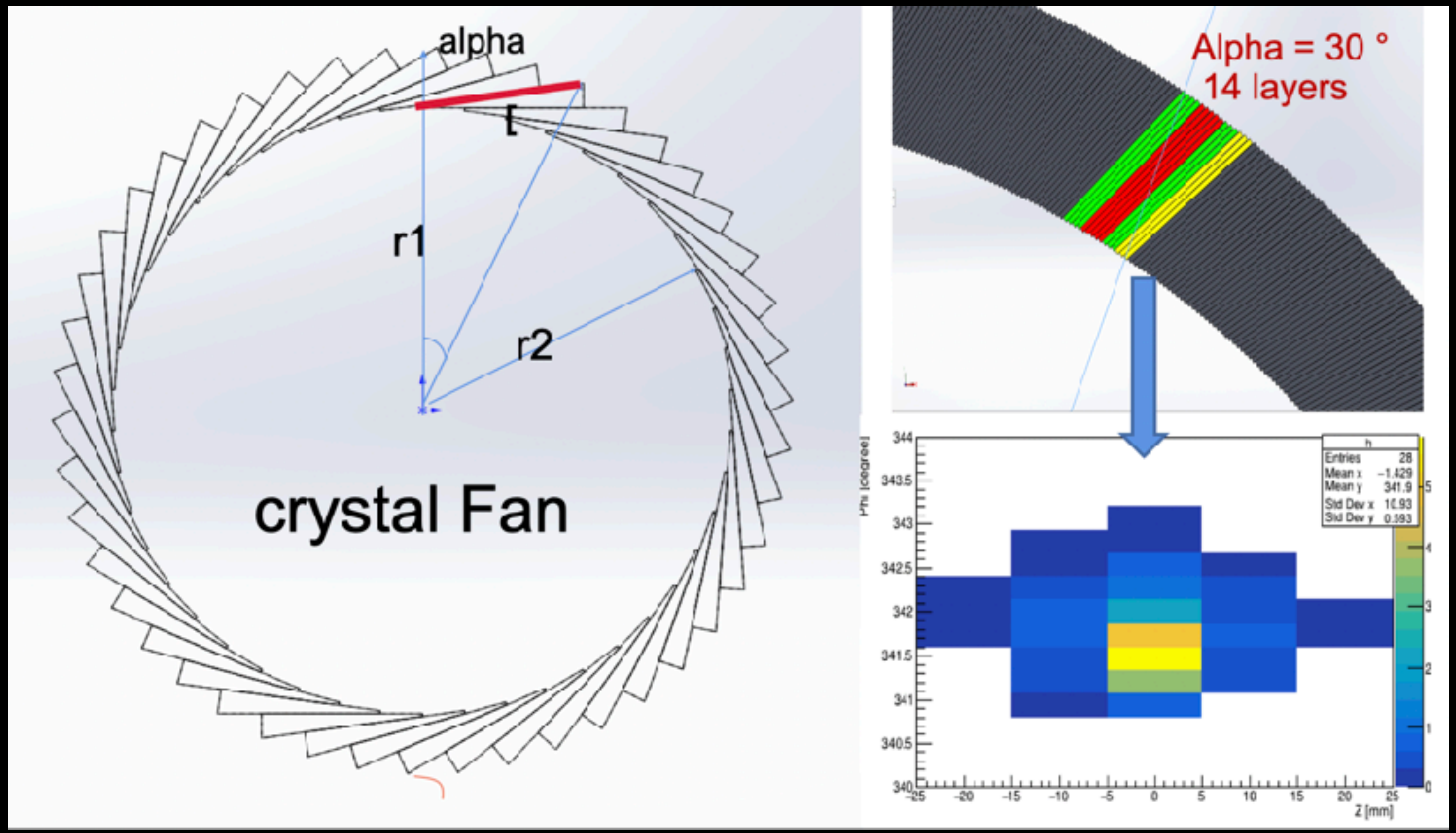
CEPC R&D: High Granularity Crystal ECAL

New segmented ECAL designs based on crystals



- Long bars: 1 × 40 cm
  - Super-cell: 40 × 40 cm cube
- Double-sided readout
  - Timing at both sides, gives position along bar
- Key concerns:
  - Ambiguities in separation of close showers
  - Impact on Jet Energy Resolution (JER)

Crystal Fan Design



- Fine segmentation in Z, ϕ and r
  - Resolutions (mm) : Z ~ 1 ; ϕ ~ 2; r ~ 8
  - Reduced readout electronics channels

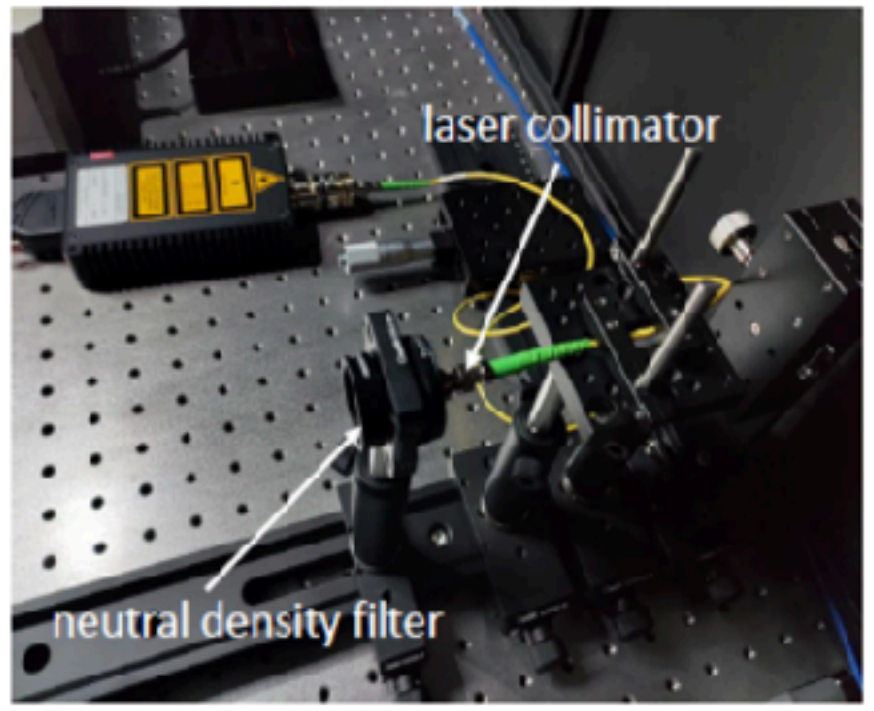
Dual Readout Crystal Calorimeter also being consider by USA and Italian colleagues

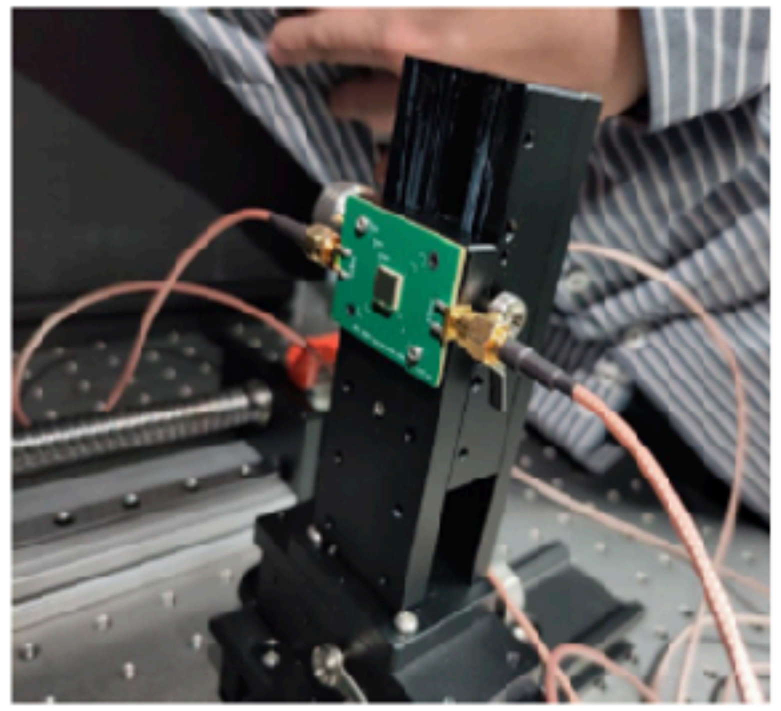
CEPC R&D: High Granularity Crystal ECAL

Goal

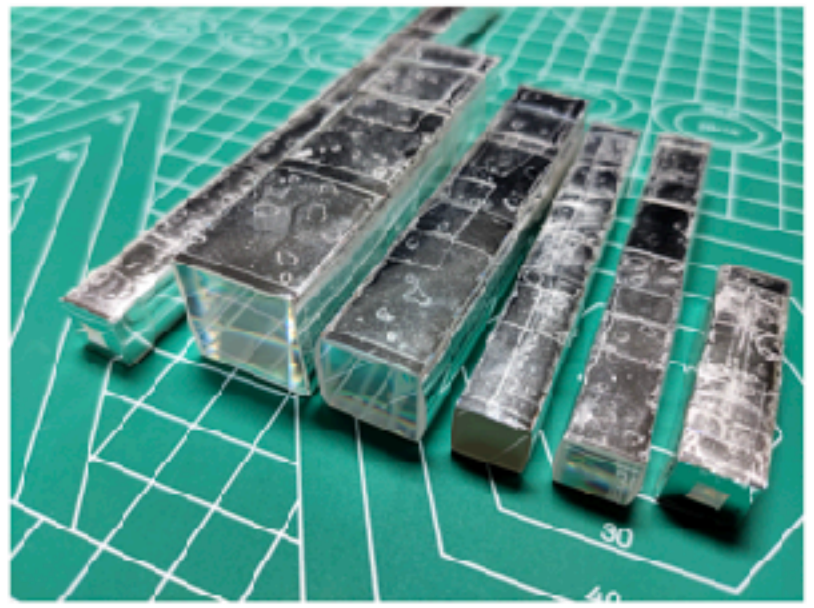
- **Boson Mass Resolution < 4%**
- **Better BMR than ScW-ECAL**
- **Much better sensitivity to γ/e, especially at low energy.**

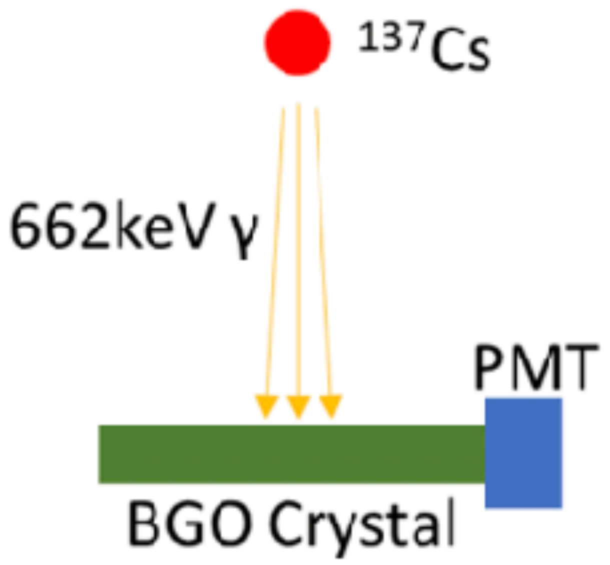
Bench Test

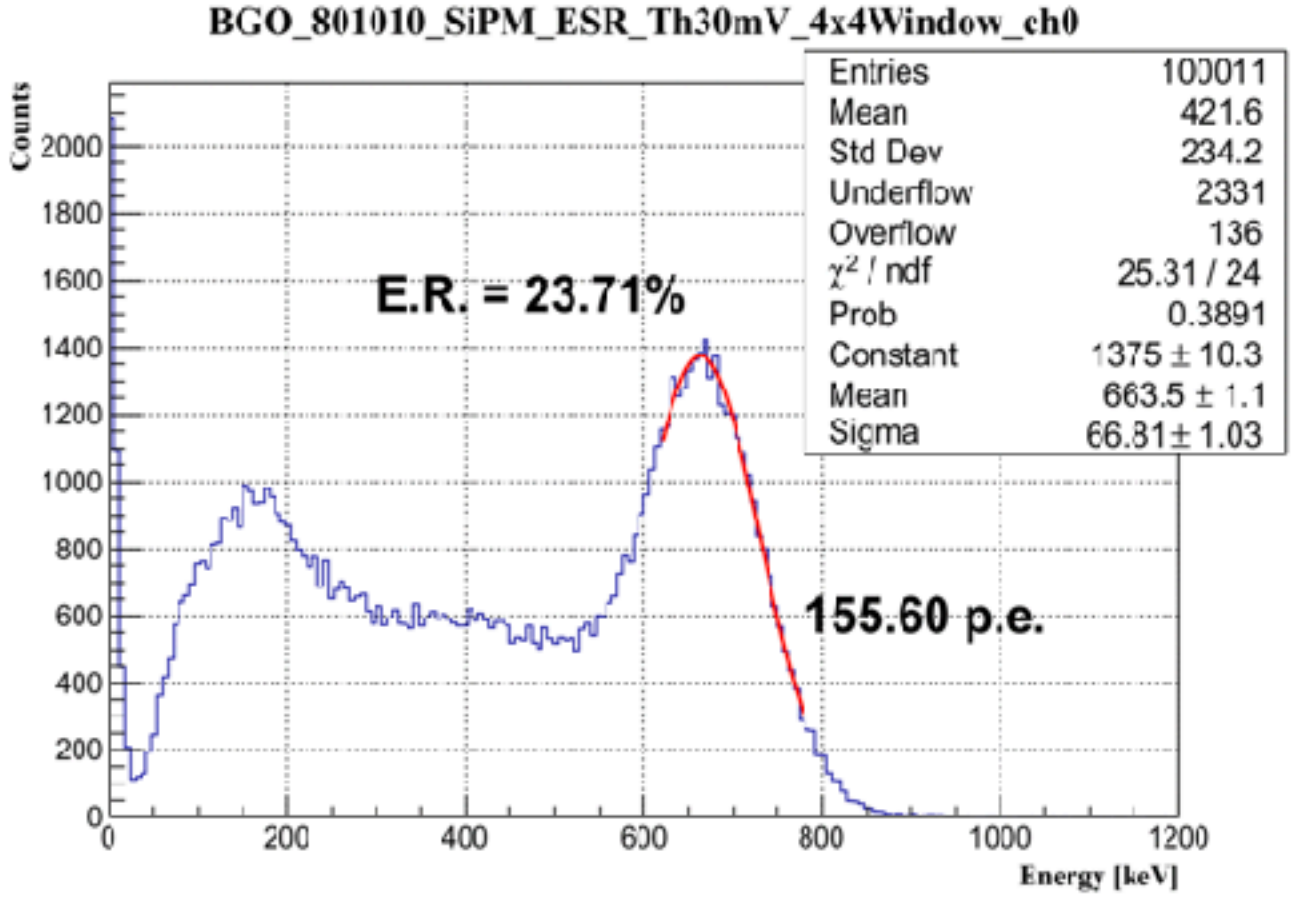




Performance Test



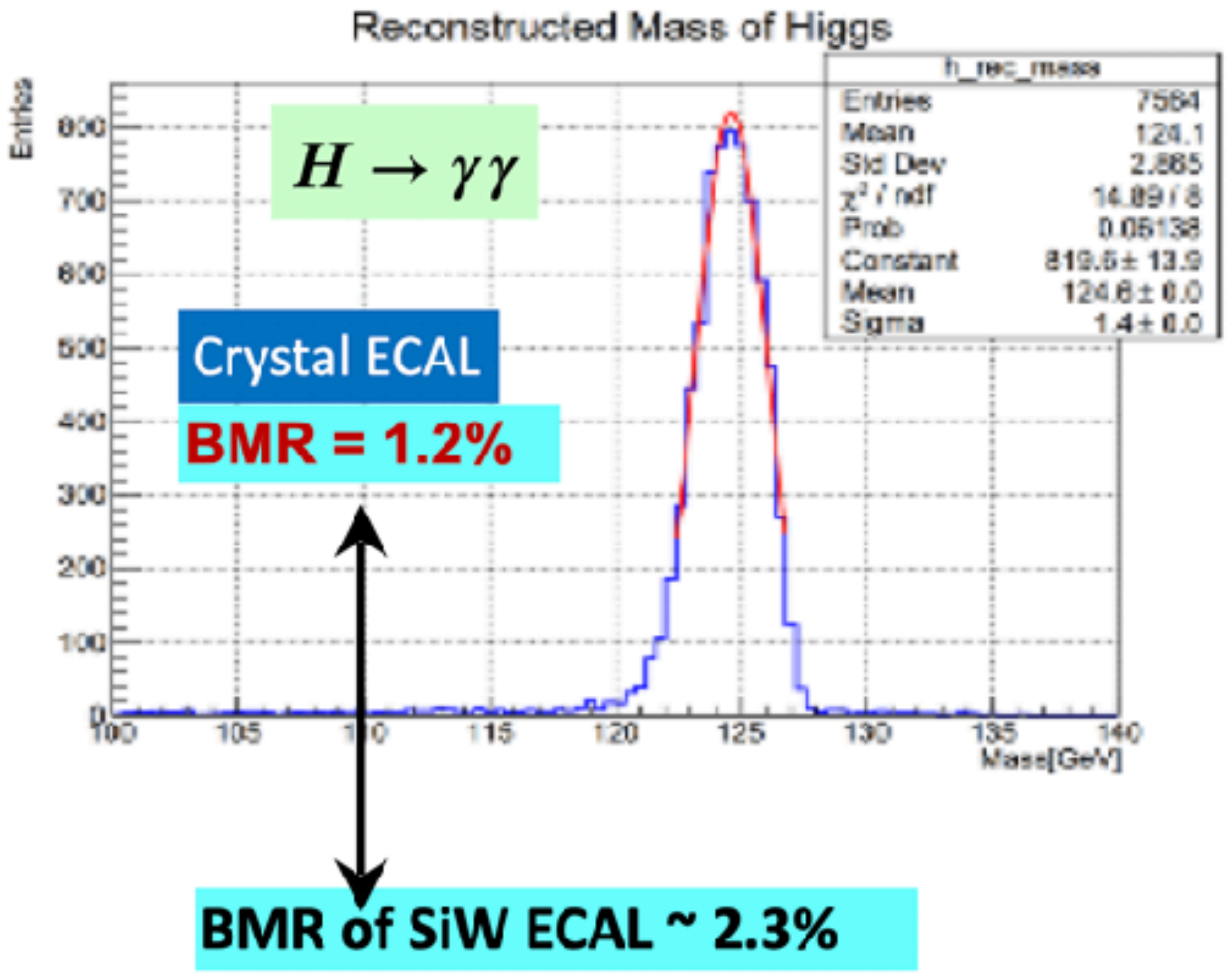




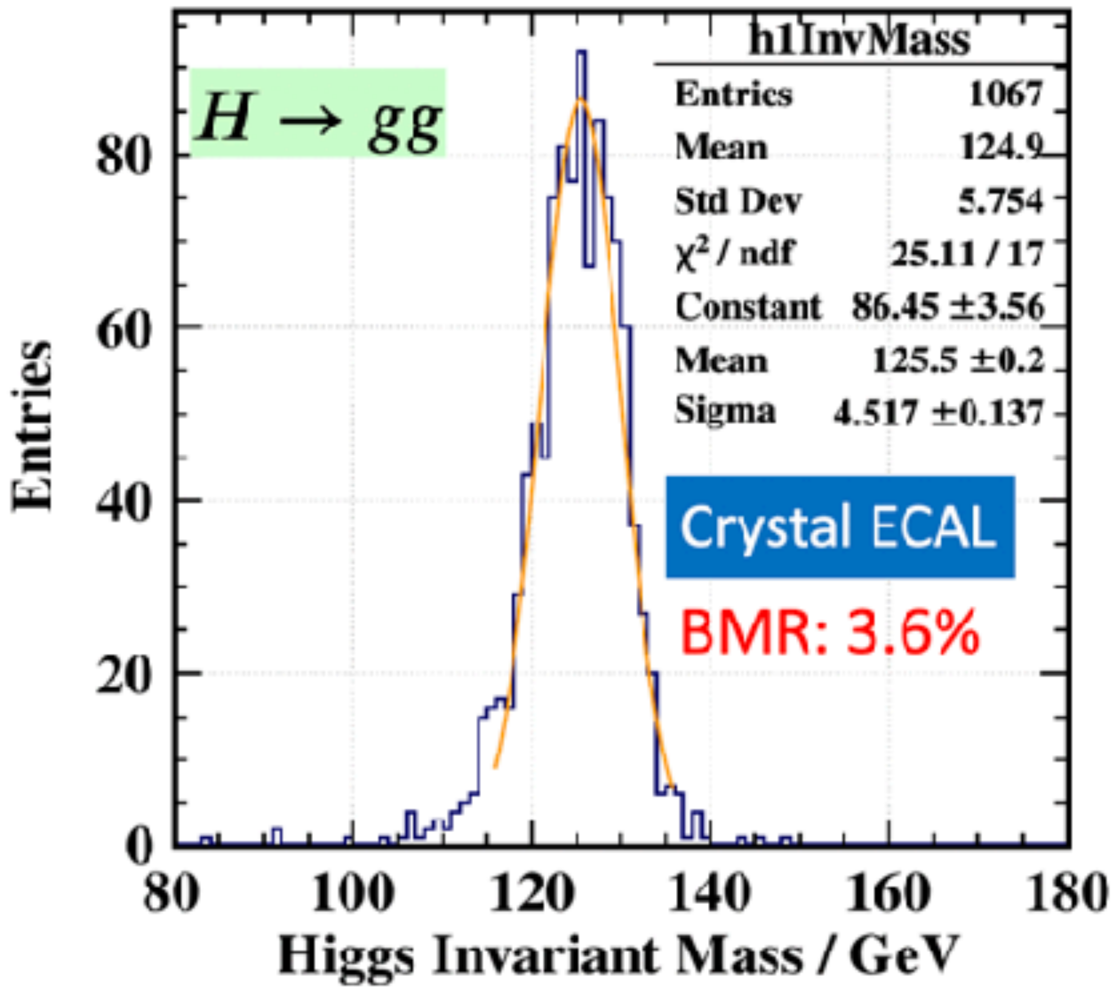
- **Different crystals investigated**
  - **BGO, PbWO**

Full Simulation Studies **+ Optimizing PFA for crystals**

Performance with photons



Performance with jets

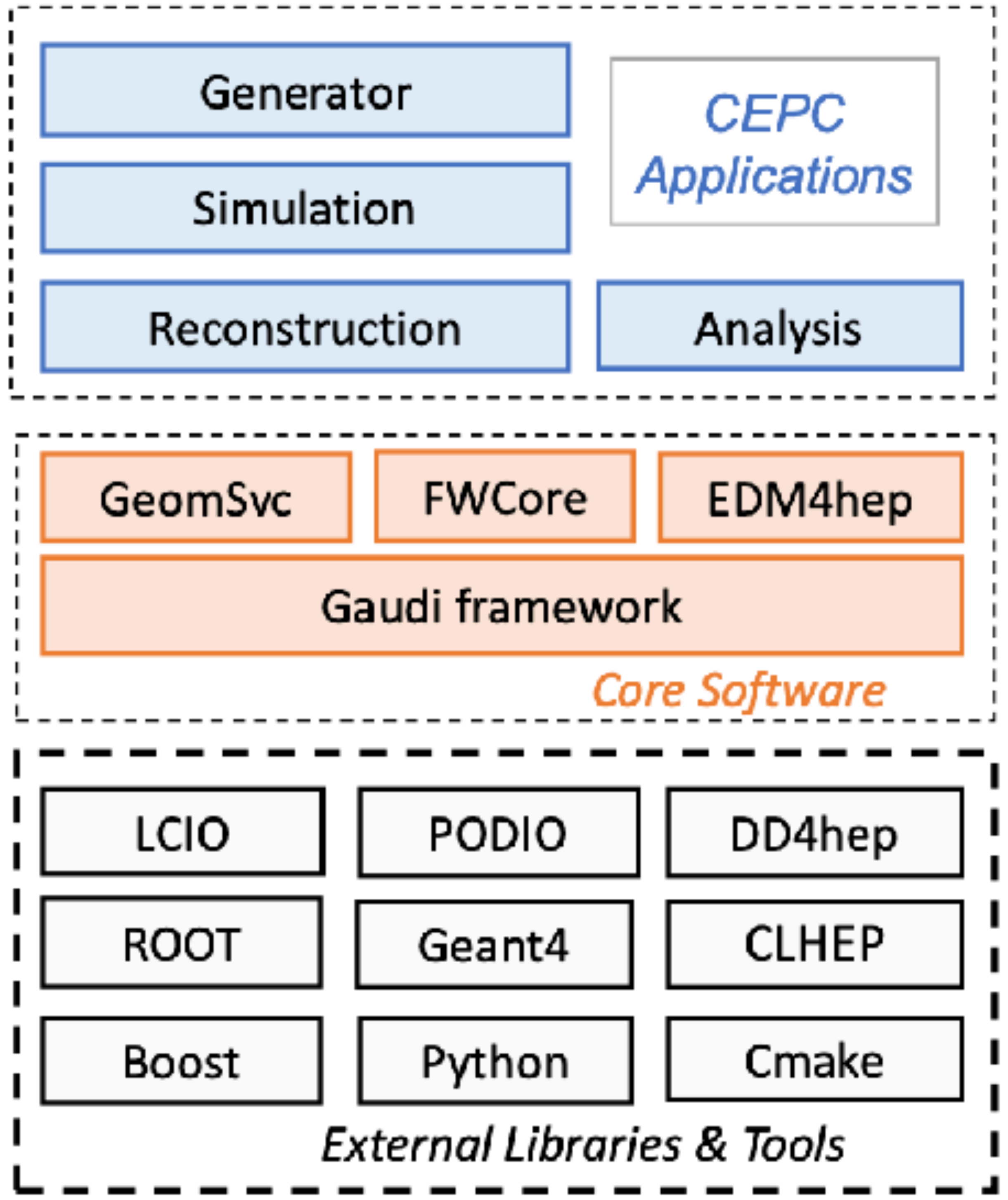


CEPC Software migration to Key4hep

Key4hep, an international collaboration with CEPC participation

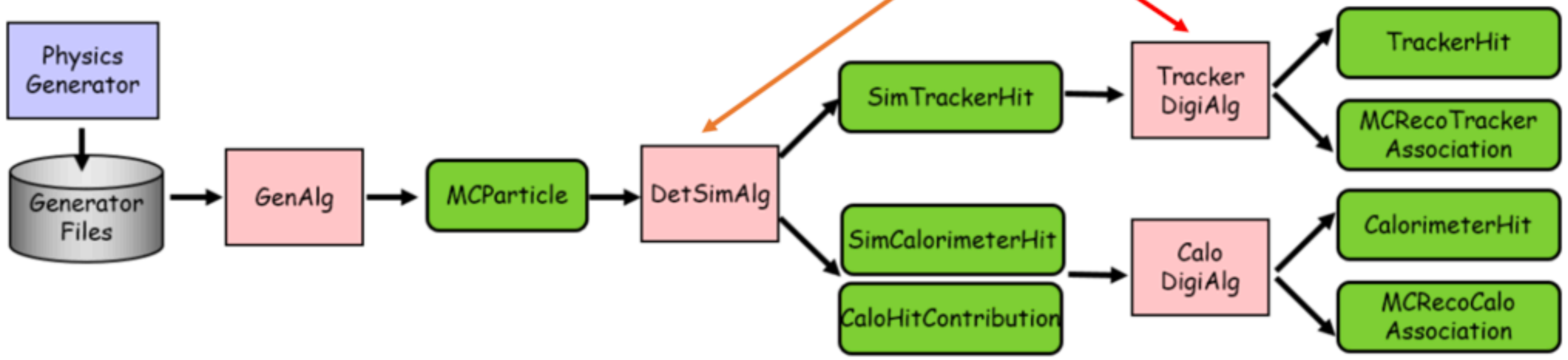
CEPCSW: a first application of Key4hep — Tracking Software

- Architecture of CEPCSW
  - external libraries
  - core software
  - CEPC applications for simulation, reconstruction and analysis.
- Core software
  - Gaudi framework: defines interfaces of all the software components and controls the event loop.
  - EDM4hep: generic event data model.
  - FWCore: manages the event data.
  - GeomSvc: DD4hep-based geometry management service.
- CEPCSW is already included in Key4hep software stack.



https://github.com/cepc/CEPCSW

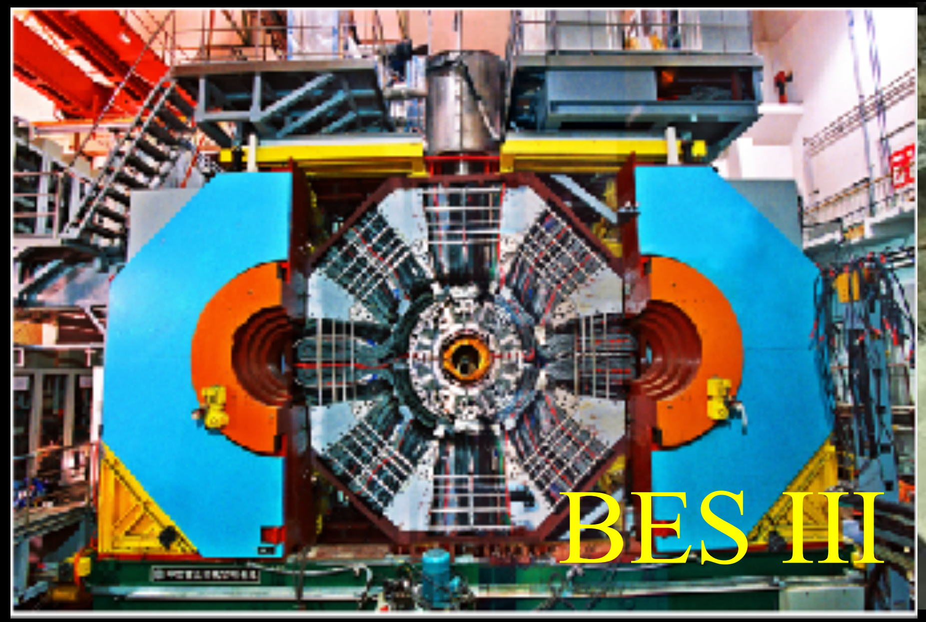
- DDG4 provides API from xml compact files and DD4hep constructor to Geant4 geometry, DDCore for interface to DD4hep geometry (DetElement, Surface, etc) & Gear geometry
  - ✓ a single source of information for Geometry, materials, visualization, readout, alignment, calibration, reconstruction etc



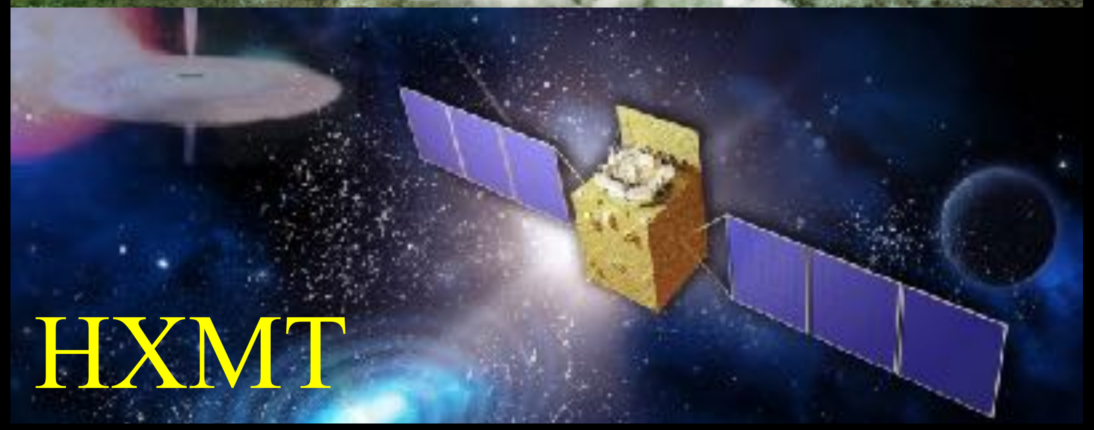
- **Silicon tracks**
- **TPC**
- **Drift chamber**

Project global aspects

Synergies: IHEP experience with large scientific projects



- IHEP is one of the few institutions in the world that can host a project like the CEPC:
  - It has rich management experience and successful constructed many large scientific facilities
  - It has full coverage of all technical disciplines for accelerators and detectors, in particular for the design and construction of circular e^+e^- colliders (BEPCII) and the detectors (BESIII)
  - It has all needed infrastructure for the construction of large facilities
  - It has successfully hosted international projects such as BESIII, Daya Bay, JUNO, LHAASO, etc.



Funding for CEPC R&D

- CEPC received ~ 260 Million CNY for R&D, from MOST, CAS, NSFC, etc
- Large amount of key technologies validated in other projects by IHEP: BEPCII, HEPS, …

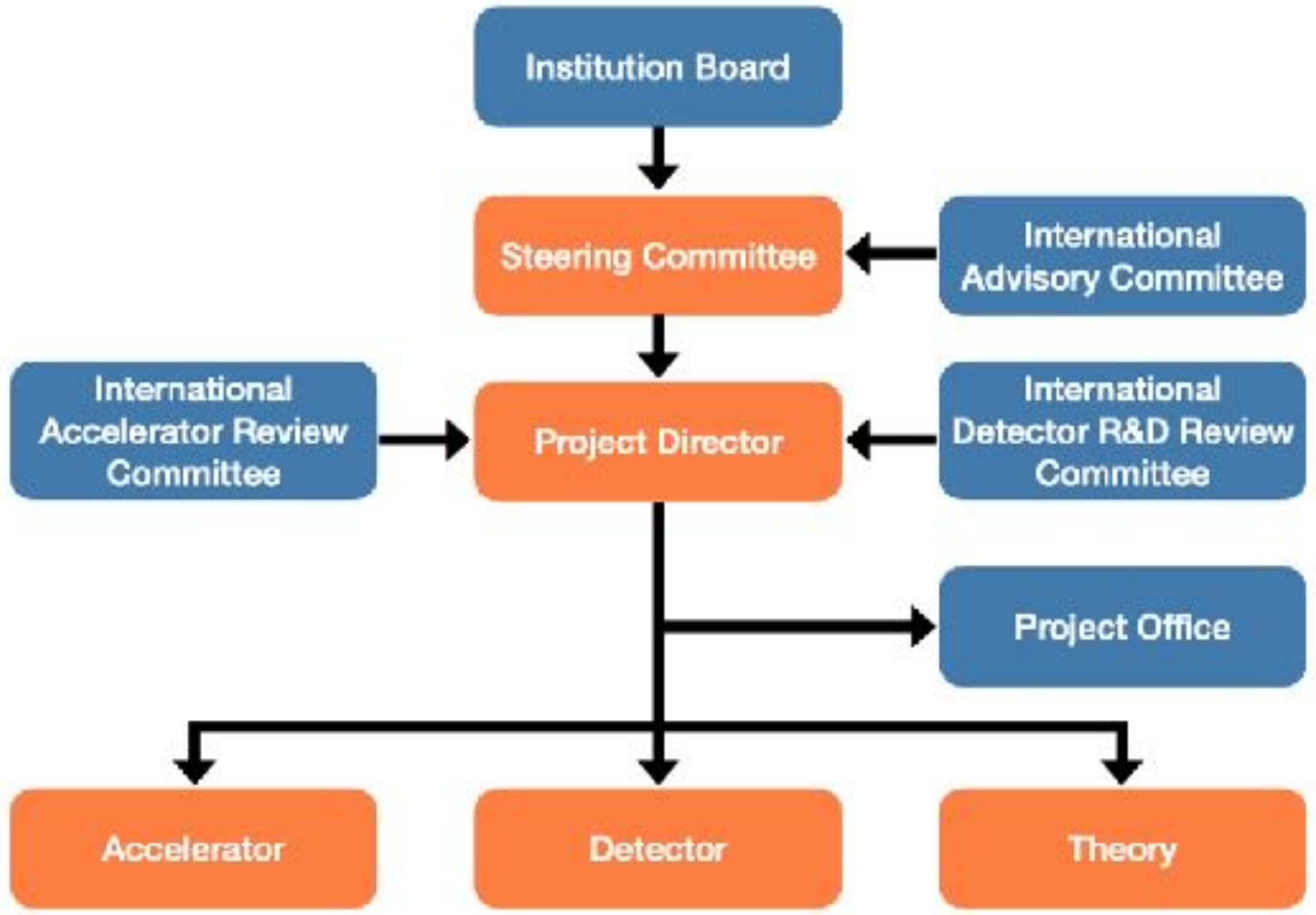
CEPC R&D ~ 50% cost of acc. components	➢ High efficiency klystron ➢ 650MHz SRF cavities ➢ Key components to e+ source ➢ High performance Linac ➢ Electrostatic Deflector ➢ Cryogenic system	➢ Novel magnets: Weak field dipole, dual aperture magnets ➢ Extremely fast injection/extraction ➢ Vacuum chamber tech. ➢ Survey & Alignment for ultra large Acc. ➢ MDI
BEPCII / HEPS ~ 40% cost of acc. components	➢ High precision magnet ➢ Stable magnet power source ➢ Vacuum chamber with NEG coating ➢ Instrumentation, Feedback system ➢ Traditional RF power source ➢ SRF cavities	➢ Electron Source, traditional Linac ➢ Survey & Alignment ➢ Ultra stable mechanics ➢ Radiation protection ➢ Cryogenic system ➢ MDI

~10% missing items consist of anticipated challenges in the machine integration, commissioning etc. and the corresponding international contribution

Industrial engagement (CIPC)

- CIPC, established in 2017, composed of ~ 70 high tech. enterprises, covers Superconducting materials, Superconducting cavities, cryomodules, cryogenics, Klystrons, electronics, power source, vacuum, civil engineering, etc. CIPC actively joins the Key technology R&D and prepares for the mass production for the CEPC construction
- CEPC study group is surveying main international suppliers
- CEPC strongly promote these relevant technology development (cost-benefit)

CEPC team



- Institution Board: 32 institutes, top universities/institutes in China
- Management team: comprehensive management experience at construction projects of BEPCII/CSNS/HEPS, and international projects of BESIII/Daya Bay/JUNO/…
- Accelerator team: fully over all disciplines with rich experiences at BEPCII, HEPS…
- Physics and Detector team: fully over all disciplines with rich experiences at BESIII, Daya Bay, JUNO, ATLAS, CMS, …

Table 7.2: Team of Leading and core scientists of the CEPC

Name	Brief introduction	Role in the CEPC team
Yifang Wang	Academician of the CAS, director of IHEP	The leader of CEPC, chair of the SC
Xinchou Lou	Professor of IHEP	Project manager, member of the SC
Yuanning Gao	Academician of the CAS, head of physics school of PKU	Chair of the IB, member of the SC
Jie Gao	Professor of IHEP	Convener of accelerator group, vice chair of the IB, member of the SC
Haijun Yang	Professor of SJTU	Deputy project manager, member of the SC
Jianbei Liu	Professor of USTC	Convener of detector group, member of the SC
[illegible]	[illegible]	[illegible] group, member of the SC
Shan Jin	Professor of NJU	Member of the SC
Nu Xu	Professor of IMP	Member of the SC
Meng Wang	Professor of SDU	Member of the SC
Qinghong Cao	Professor of PKU	Member of the SC
Wei Lu	Professor of THU	Member of the SC
Joao Guimaraes da Costa	Professor of IHEP	Convener of detector group
Jianchun Wang	Professor of IHEP	Convener of detector group
Yuhui Li	Professor of IHEP	Convener of accelerator group
Chenghui Yu	Professor of IHEP	Convener of accelerator group
Jingyu Tang	Professor of IHEP	Convener of accelerator group
Xiaogang He	Professor of SJTU	Convener of theory group
Jianping Ma	Professor of ITP	Convener of theory group

Management team

Number	Sub-system	Team (senior staff)
1	Accelerator physics	18
2	Magnets	12
3	Cryogenic system	11
4	SC RF system	12
5	Beam Instrumentation	7
6	SC magnets	10
7	Power supply	9
8	Injection & extraction	7
9	Mechanical system	4
10	Vacuum system	5
11	Control system	6
12	Linac injector	13
13	Radiation protection	3

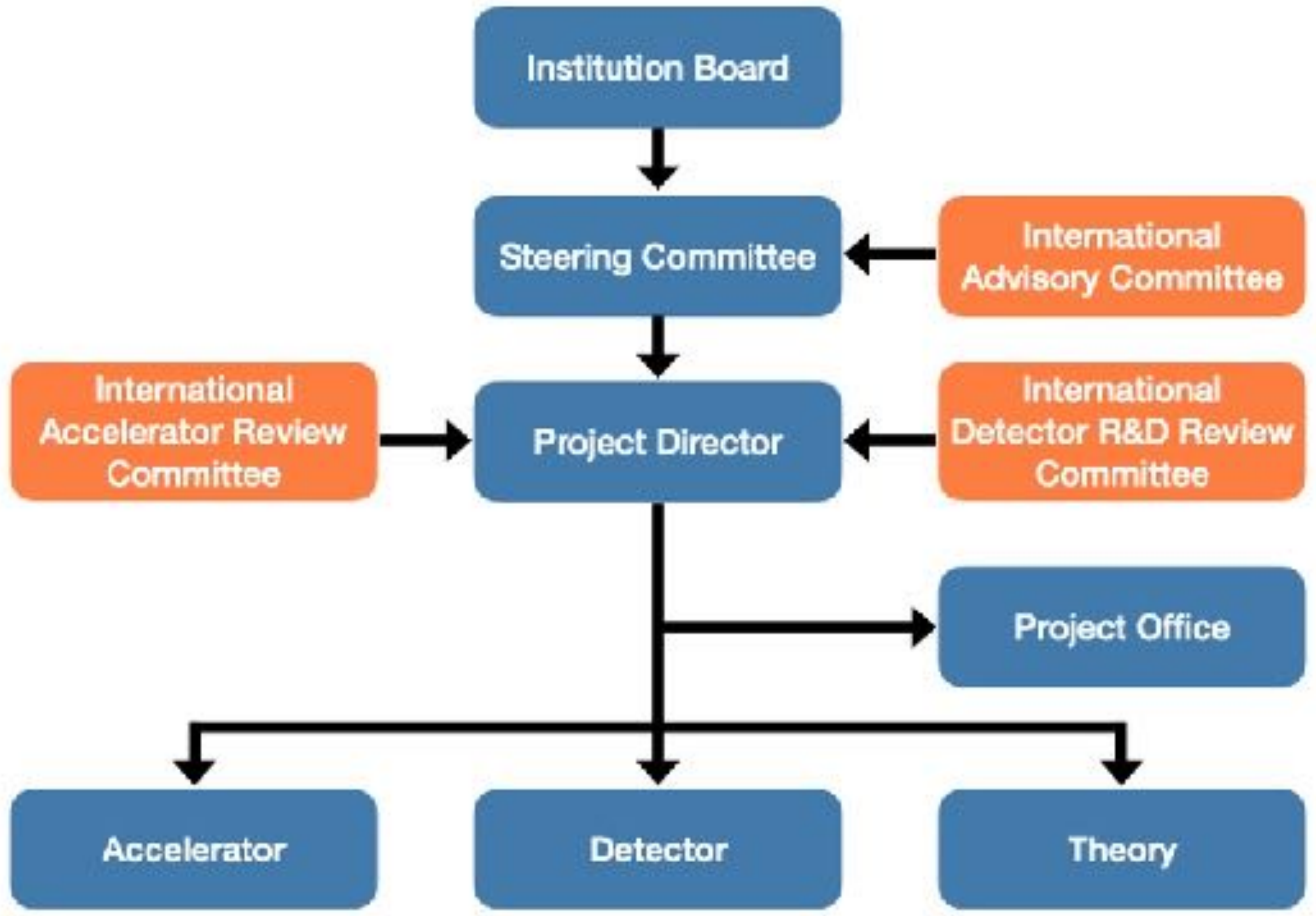
117

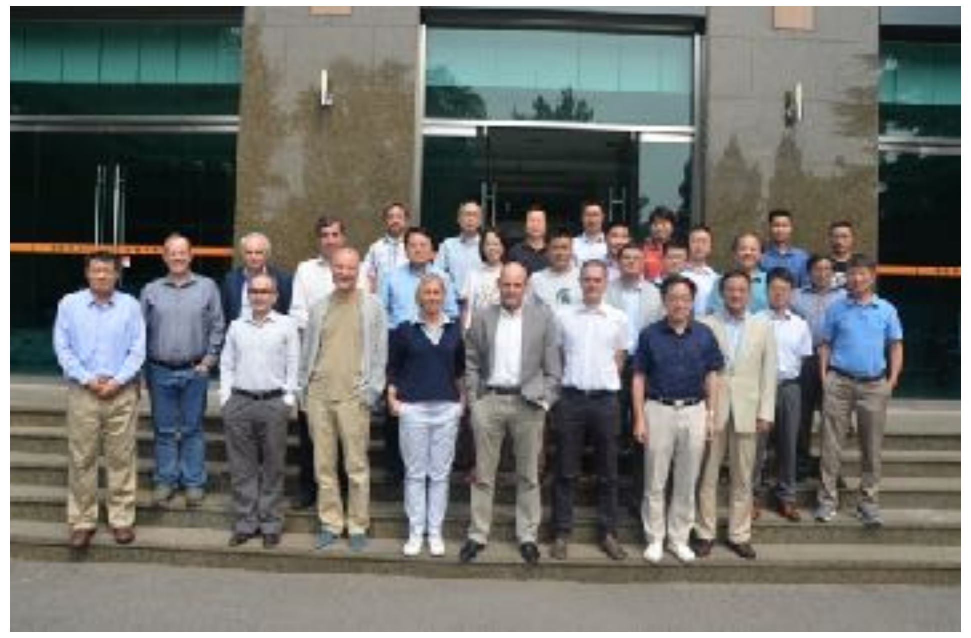
Number	Sub-system	Institutions	Team (senior staff)
1	Pixel Vertex Detector	CCNU, IFAE, IHEP, NJU, NWPU, SDU, Strasbourg, ...	~ 40
2	Silicon Tracker	IHEP, INFN, KIT, Lancaster, Oxford, Queen Mary, RAL, SDU, Tsinghua, Bristol, Edinburgh, Livepool, USTC, Warwick, Sheffield, ZJU, ...	~ 60
3	Gaseous detector	CEA-Saclay, DESY, LCTPC Collab., IHEP, INFN, NIKHEF, THU ...	~ 30
4	Magnet	IHEP	[illegible]
5	Calorimetry	CALICE Collab., IHEP, [illegible] SJTU, USTC, ...	~ 40
[illegible]	Muon	FDU, IHEP, INFN, SJTU, ...	~ 20
7	Physics	IHEP, FDU, SJTU, ...	~ 80
8	Software	IHEP, SDU, FDU, ...	~ 20

~300

117 accelerator + ~300 detector staffs currently, + ~ 400 from BEPC/BESIII/JUNO/HEPS…once CEPC approved

International Committees





Name	Affiliation	Country
Tatsuya Nakada	EPFL	Japan
Steinar Stapnes	CERN	Norway
Rohini Godbole	CHEP, Bangalore	India
Michelangelo Mangano	CERN	Switzerland
Michael Davier	LAL	France
Lucie Linssen	CERN	Holland
Luciano Maiani	U. Rome	San Marino
Joe Lykken	Fermilab	U.S.
Ian Shipsey	Oxford/DESY	U.K.
Hitoshi Murayama	IPMU/UC Berkeley	Japan
Geoffrey Taylor	U. Melbourne	Australia
Eugene Levichev	BINP	Russia
David Gross	UC Santa Barbara	U.S.
Brian Foster	Oxford	U.K
Marcel Demarteau	ORNL	USA
Barry Barish	Caltech	USA
Maria Enrica Biagini	INFN Frascati	Italy
Yuan-Hann Chang	IPAS	Taiwan, China
Akira Yamamoto	KEK	Japan
Hongwei Zhao	Institute of Modern Physics, CAS	China
Andrew Cohen	University of Science and Techbnology	Hong Kong, China
Karl Jakobs	University of Freiburg/CERN	Germany
Beate Heinemann	DESY	Germany

International Accelerator Review Committee

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

International Detector R&D Review Committee

- Jim Brau, USA, Oregon
- Valter Bonvicini, Italy, Trieste
- Ariella Cattai, CERN, CERN
- Cristinel Diaconu, France, Marseille
- Brian Foster, UK, Oxford
- Liang Han, China, USTC
- Dave Newbold, UK, RAL (chair)
- Andreas Schopper, CERN, CERN
- Abe Seiden, USA, UCSC
- Laurent Serin, France, LAL
- Steinar Stapnes, CERN, CERN
- Roberto Tenchini, Italy, INFN
- Ivan Villa Alvarez, Spain, Santader
- Hitoshi Yamamoto, Japan, Tohoku

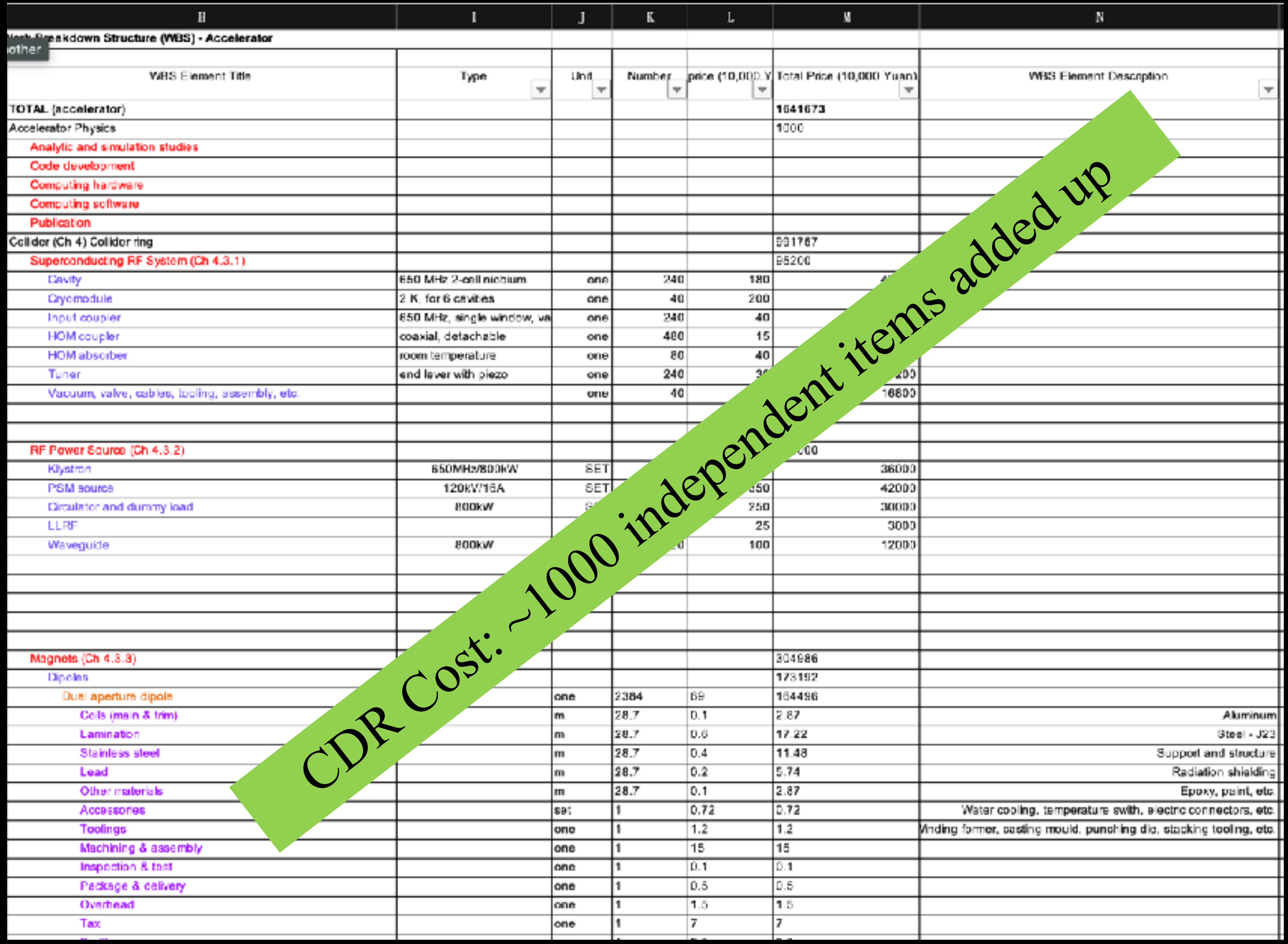
IAC: global renowned scientists and top laboratory or project leaders who have ample experience in project management, planning, and execution of strategies, **operating since 2015**

IARC & IDRC: leading experts of this field, provide guide to the project director

Budget for CEPC construction

CEPC Cost estimation from CDR

Tier I	Tier II	Amount (100 M CNY)
Accelerator	Collider	99.2
	Booster	39.2
	Linac and sources	9.1
	Damping ring	0.44
	Common: Cryogenics	10.6
	Survey & alignment	4
	Radiation protection	1.7
Conventional facilities	-	102
Detectors	-	40
γ-ray beam lines	-	3
Project management (1%)	-	3
Contingency (15%)	-	46
Total	-	358



- **Cost estimated with two indpendent methods, agrees at 10% level**
- **CEPC design relies on well studied, or mature tech. reducing uncertainties on cost estimation**
- **Cost estimation for TDR phase is in progress**

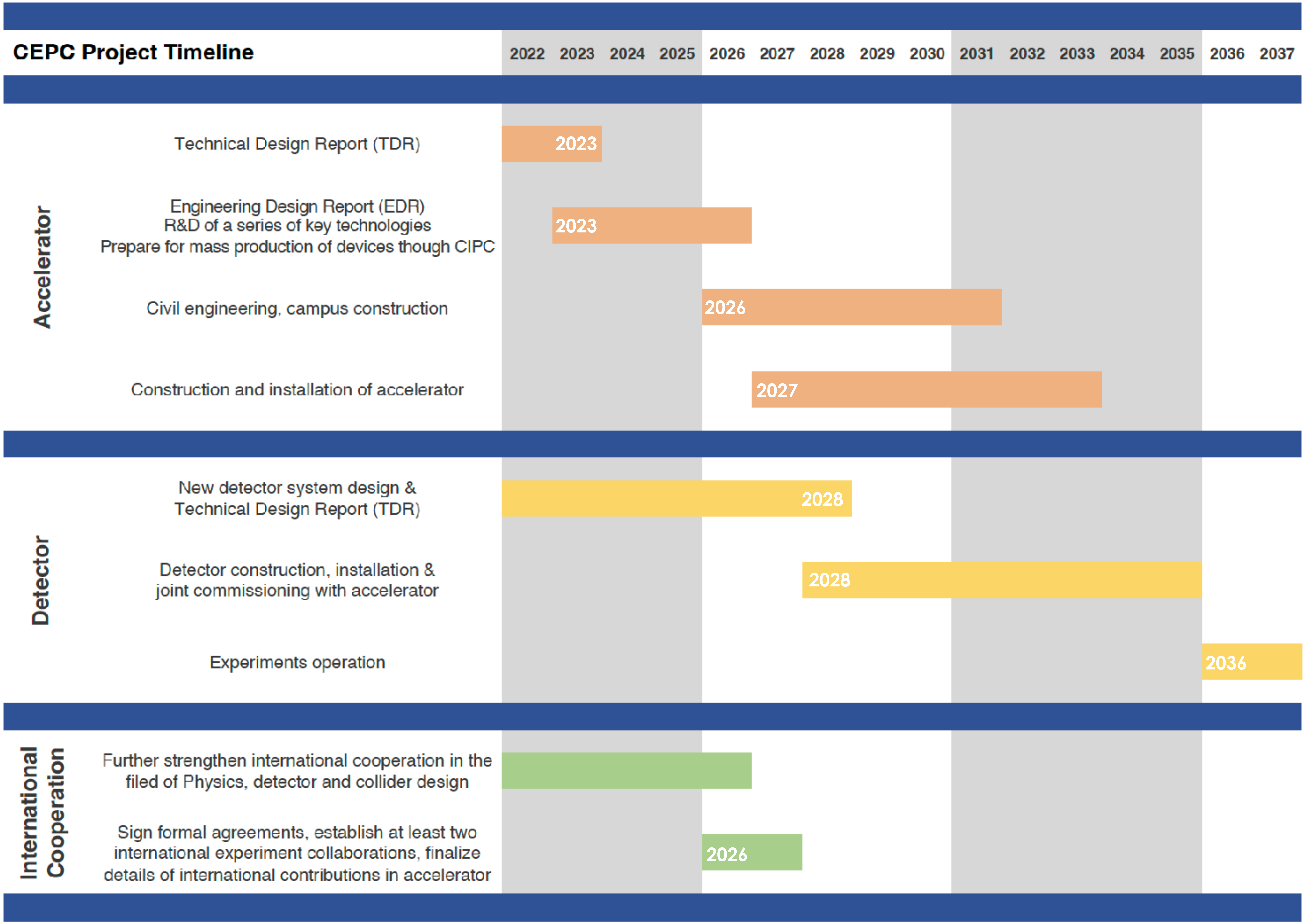
CEPC Financial Model

Total required funding: 36 Billion RMB (5 Billion CHF at today's exchange rate)

Funding Sources	Funding Model #1 (B RMB)	Funding Model #2 (B RMB)
Central Government	25	10
Local Government	5	20
International contributions	6	6
Donations	0-3.5	0-3.5

Funding model: Iteration and interaction with relevant entities, especially Local governments (leading contributors)

CEPC Project timeline



Final remarks

CEPC accelerator R&D efforts progressing well towards TDR

Next milestone: TDR in 2023

Engineering Design Report (EDR) Phase:Jan. 2023-Dec. 2025

EDR document completed for government's approval of starting construction around 2026 (the starting of the "15th five year plan" of China)

Key detector technologies R&D continues and many are put to prototyping

Several CEPC R&D detector projects reaching a successful conclusion others are starting

International collaboration continues to be a main goal of the CEPC

CEPC R&D goals common to FCC-ee

Welcome to join the CEPC effort, or both CEPC and FCC-ee where synergies are plentiful

The End

Extra Slides

Accelerator Design, R&D and Maturity

Funding breakdown for Accelerator R&D

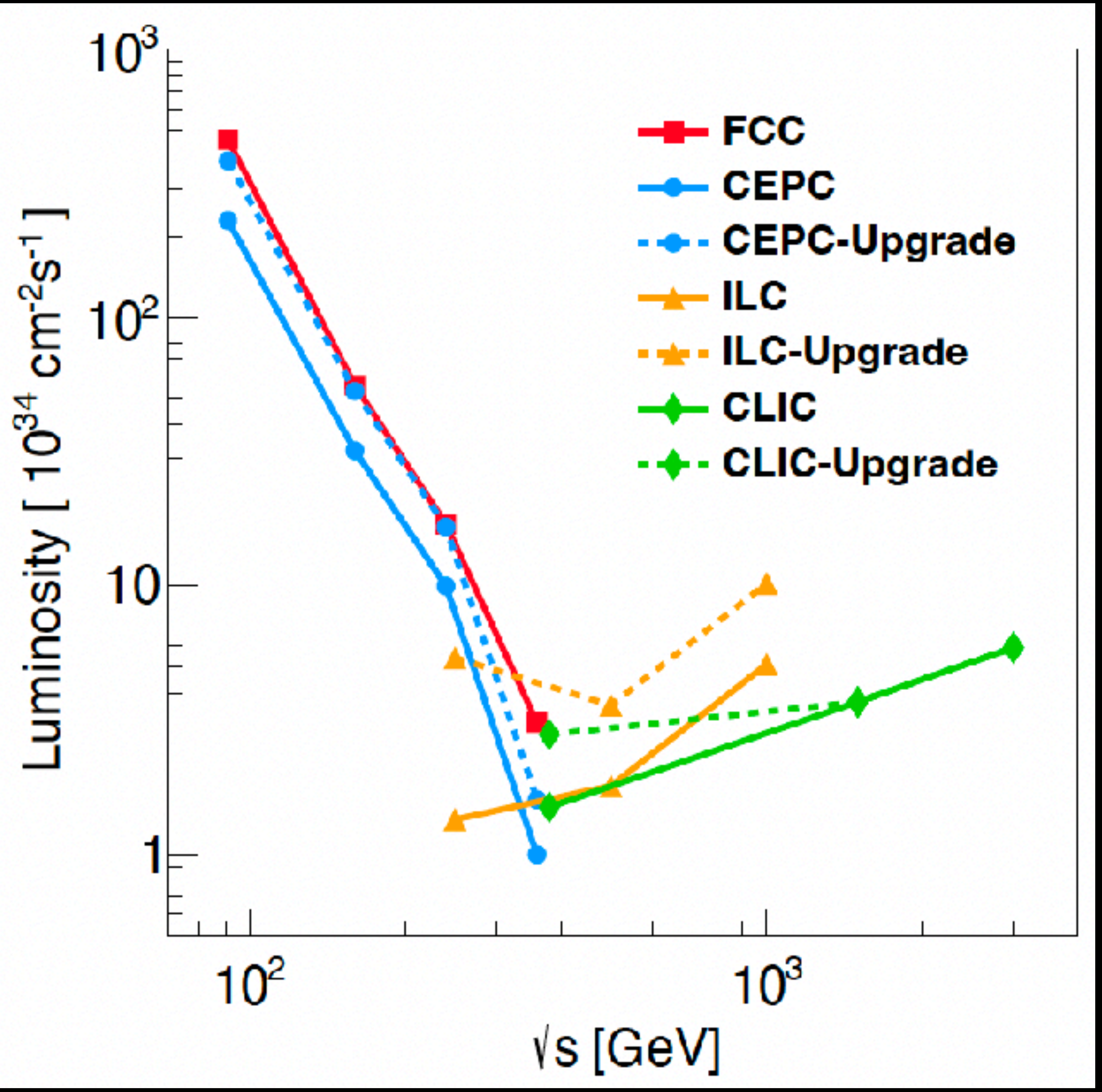
Accelerator	Cost (billion CNY)	Ratio	CEPC R&D	BEPCII/HEPS
Magnets	4.47	27.3%	20.0%	7.0%
Vacuum	3.00	18.3%	10.0%	8.0%
RF power source	1.50	9.1%	5.0%	2.0%
Mechanics	1.24	7.6%	N.A	6.6%
Magnet power supplies	1.14	7.0%	0.5%	6.5%
SCRF	1.16	7.1%	5.1%	2.0%
Cryogenics	1.06	6.5%	3.0%	2.5%
Linac and sources	0.91	5.5%	2.0%	2.5%
Instrumentation	0.87	5.3%	2.3%	3.0%
Control	0.39	2.4%	0.1%	0.5%
Survey and alignment	0.40	2.4%	1.4%	1.0%
Radiation protection	0.17	1.0%	0.1%	0.2%
SC magnets	0.07	0.4%	0.2%	0.1%
Damping ring	0.04	0.2%	N.A.	N.A.
Total			**49.7%**	**41.9%**

CEPC TDR Parameters (upgrade version)

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	58
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

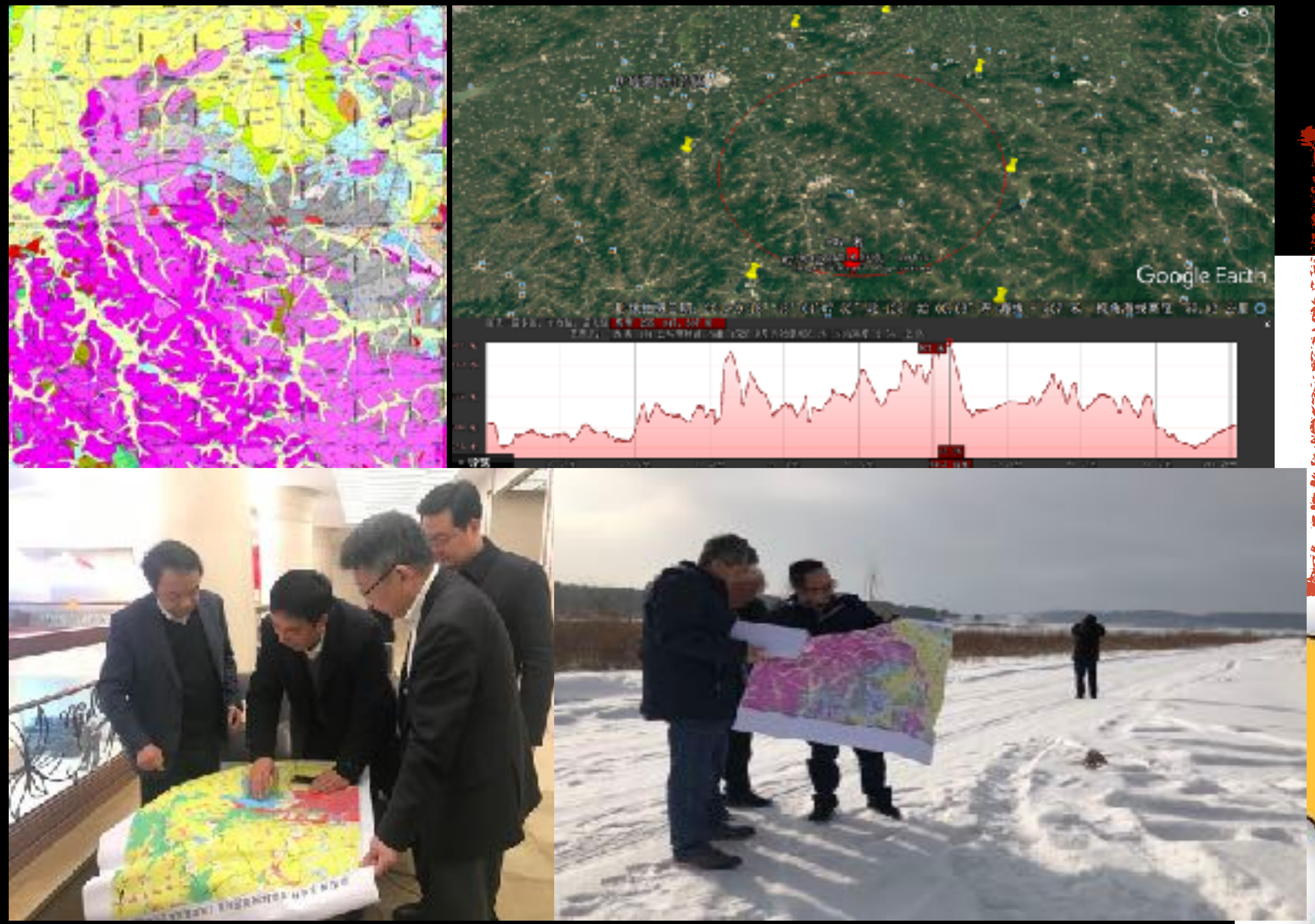
Higher SR power of 50MW: Luminosity increase ~66%.

CEPC accelerator white paper for Snowmass21, arXiv:2203.09451

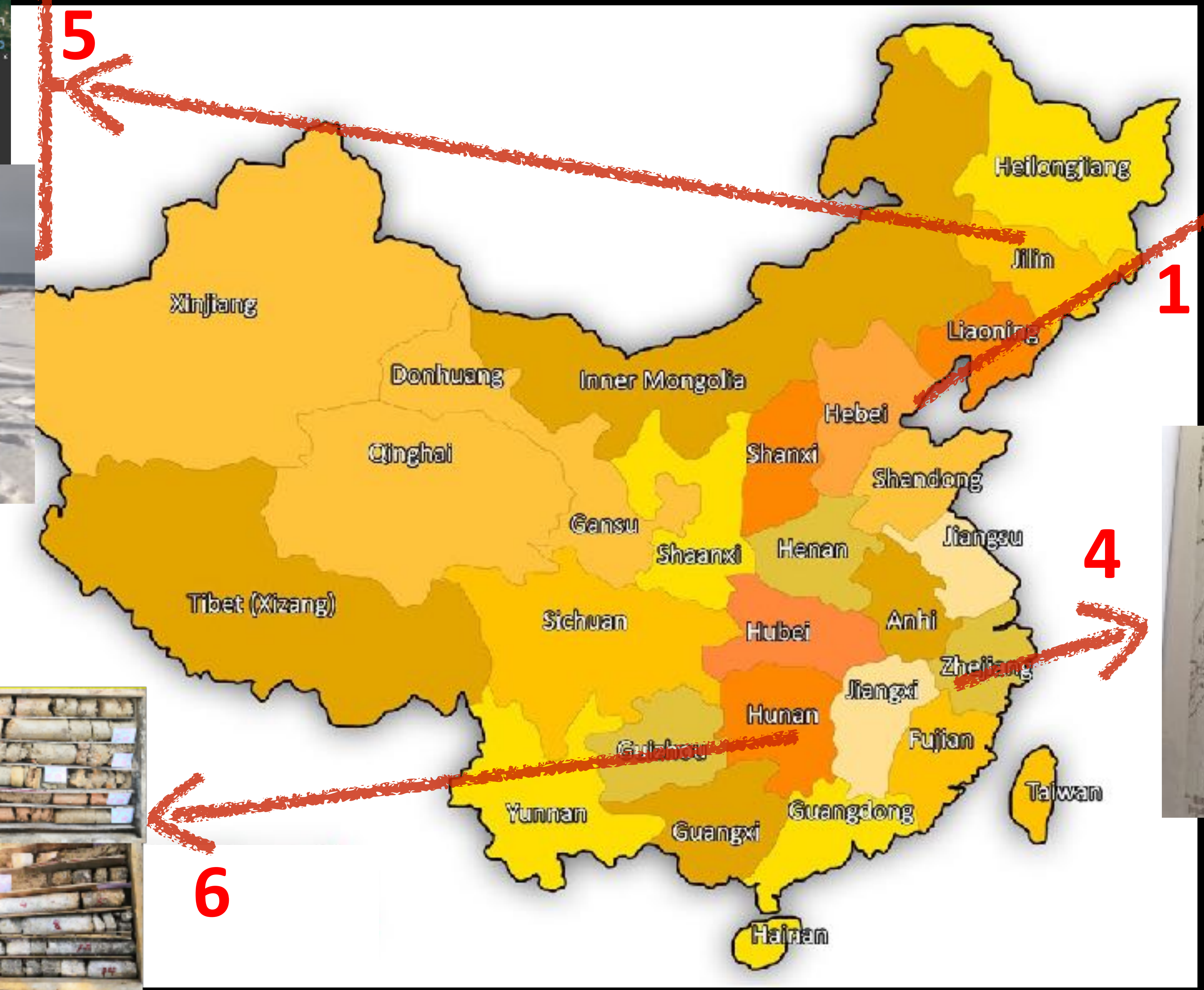


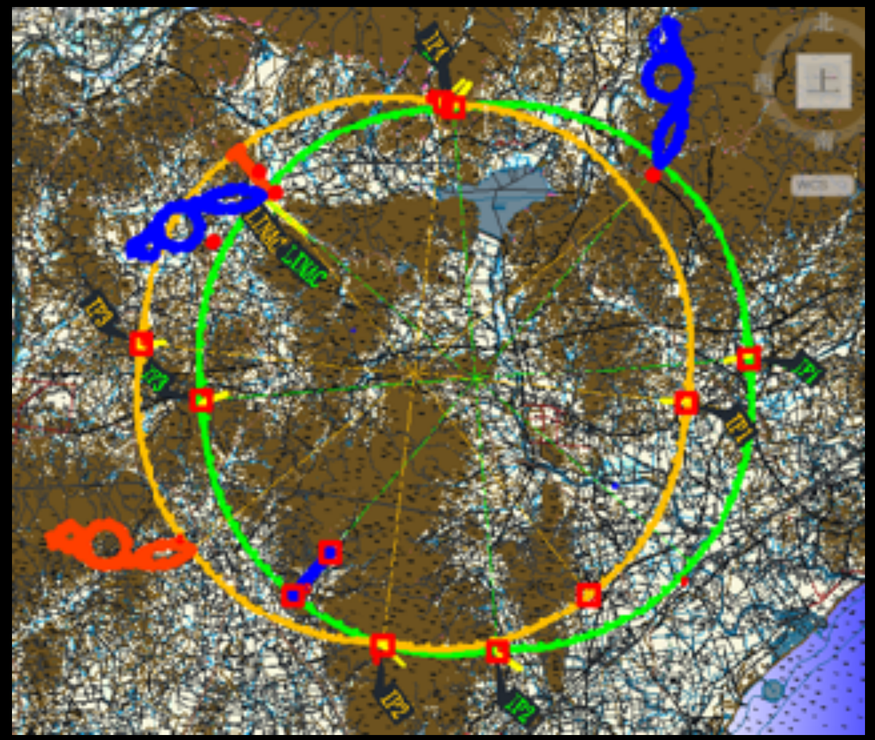
CEPC Site Selection

(Red are actively progressing forward)



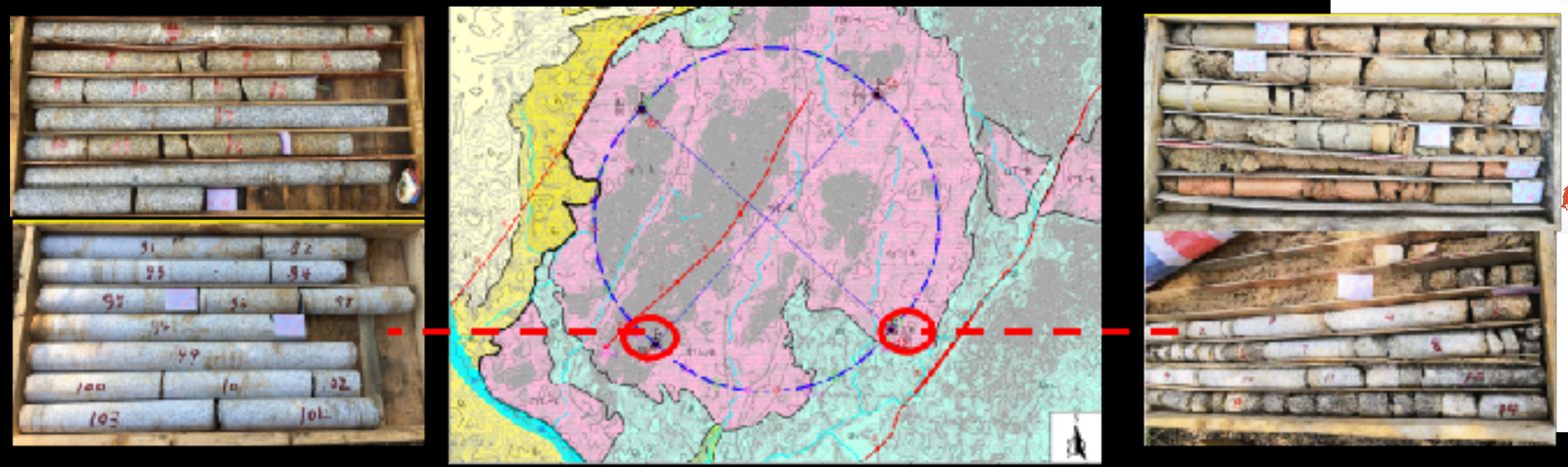
2019/12-2020/1:
Chuangchun update

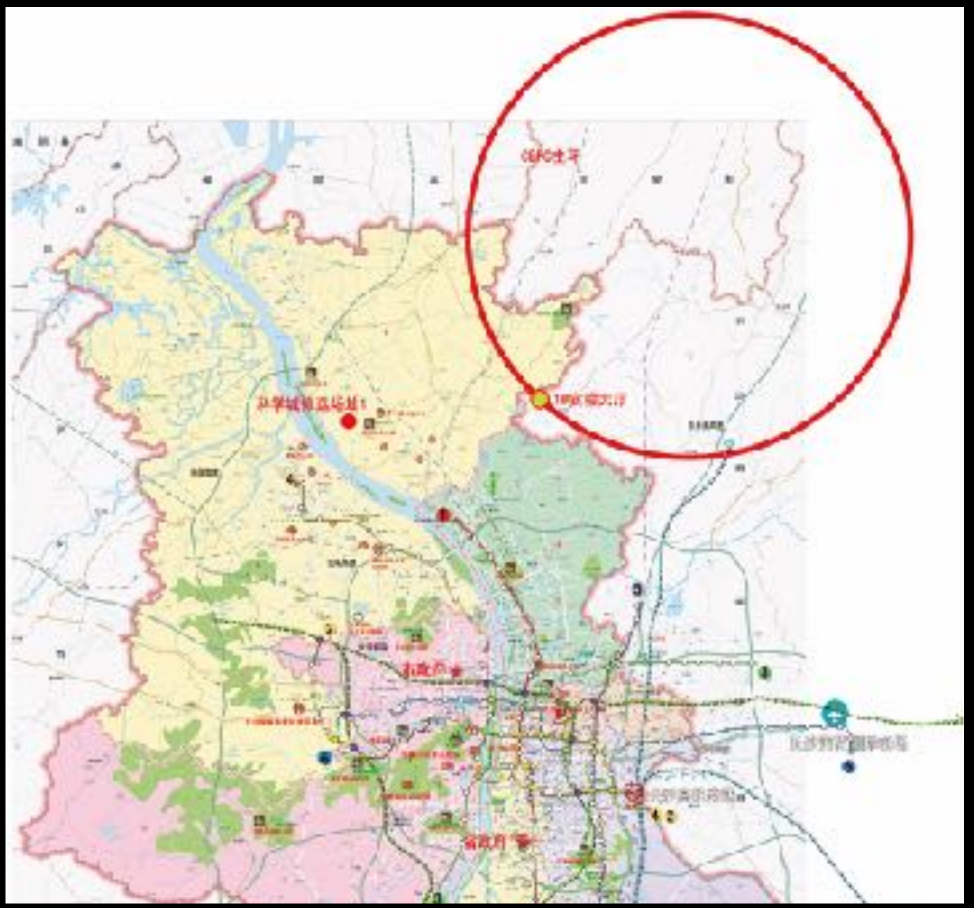




2020/9: Qinhuangdao update

2019/12: Huzhou update





2019/08: Changsha update

1) Qinhuangdao, Hebei Province (Completed in 2014)

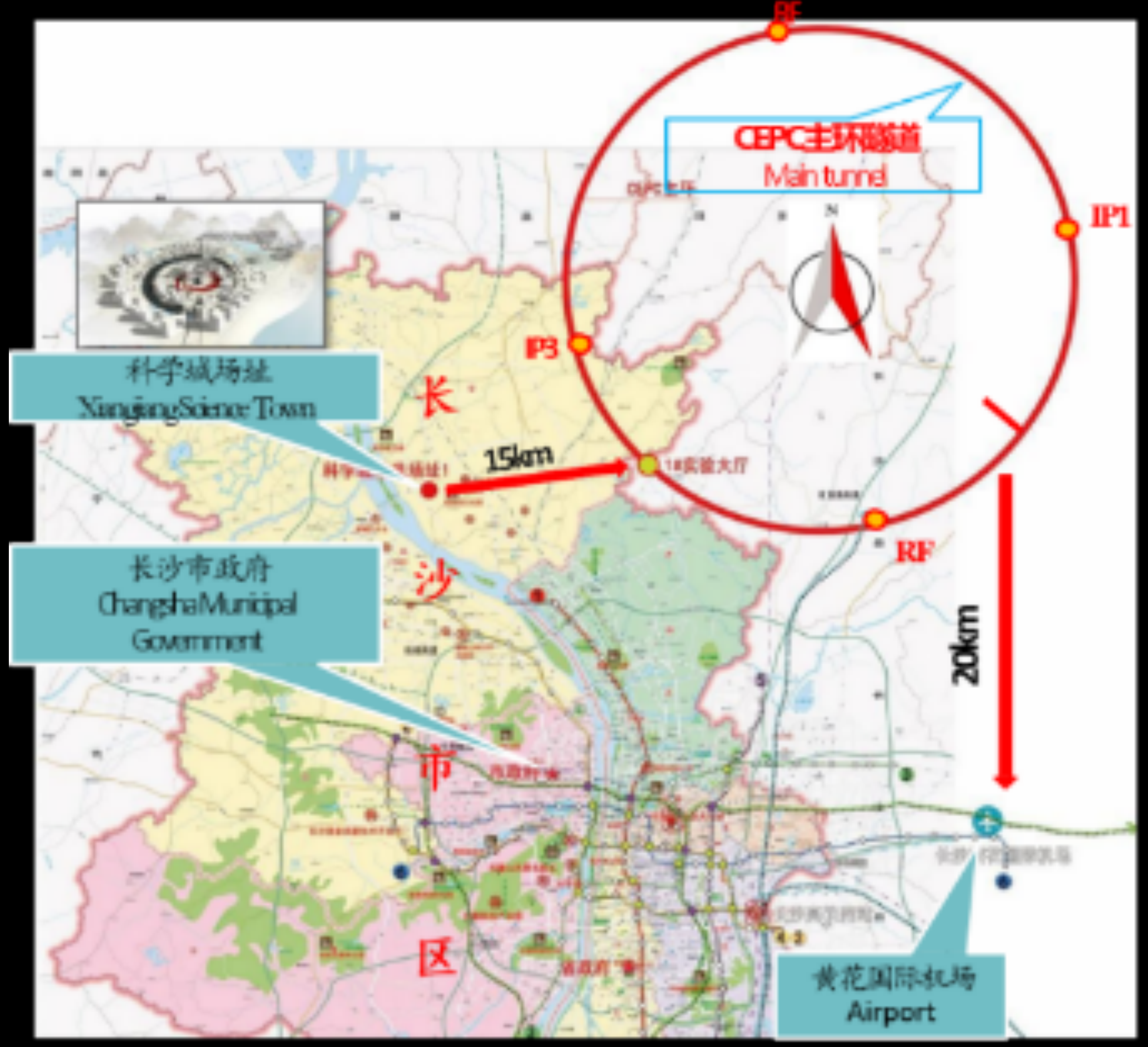
2) Huangling, Shanxi Province (Completed in 2017)

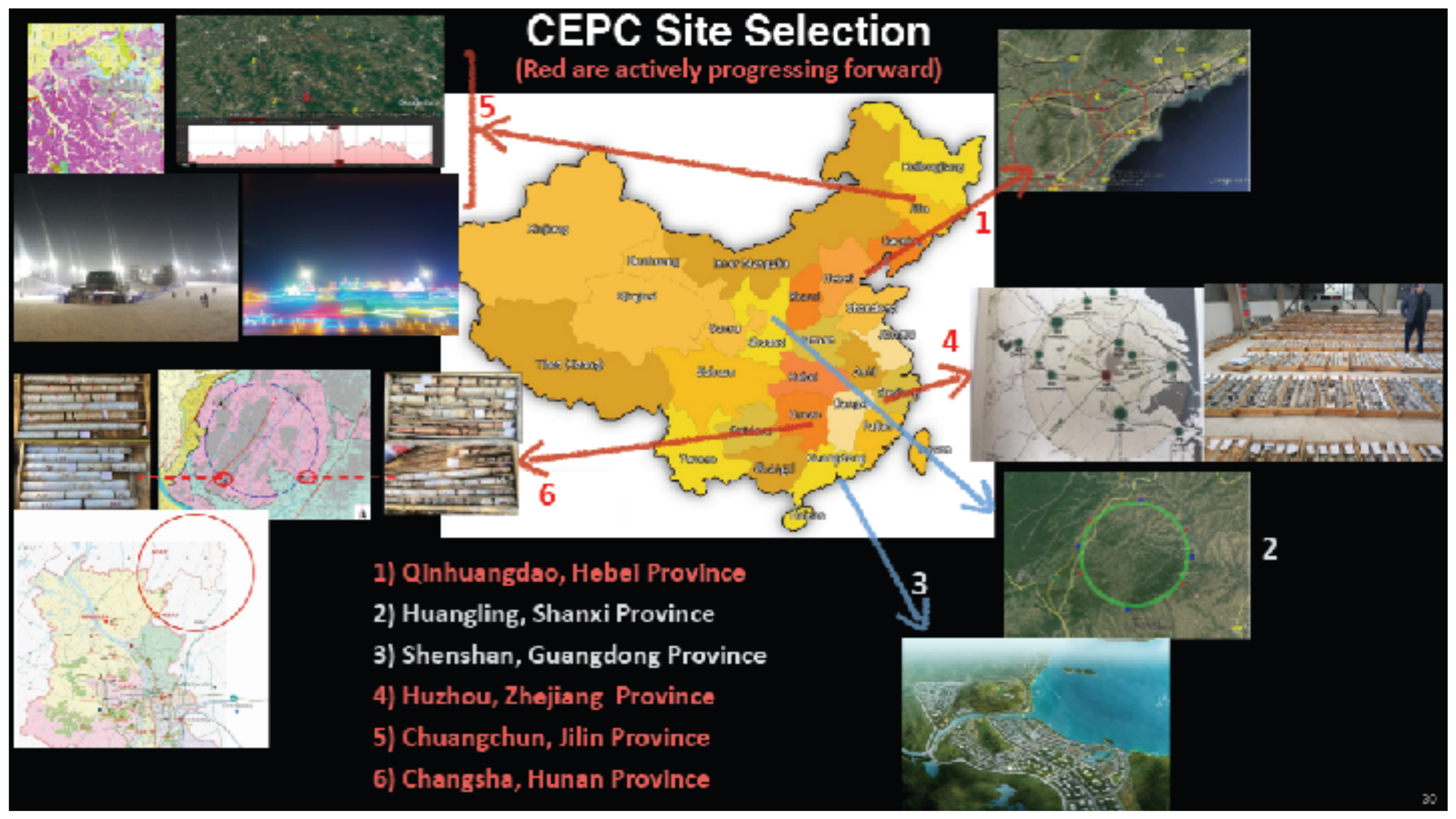
3) Shenshan, Guangdong Province (Completed in 2016)

4) Huzhou, Zhejiang Province (Started in March 2018)

5) Chuangchun, Jilin Province (Started in May 2018)

6) Changsha, Hunan Province (Started in Dec 2018)





Factors: geology, electricity supply, transportation, international-friendly, local supports …

July 5, 2021: Changsha Bureau of S&T entrusted Hunan U. to conduct a feasibility study.

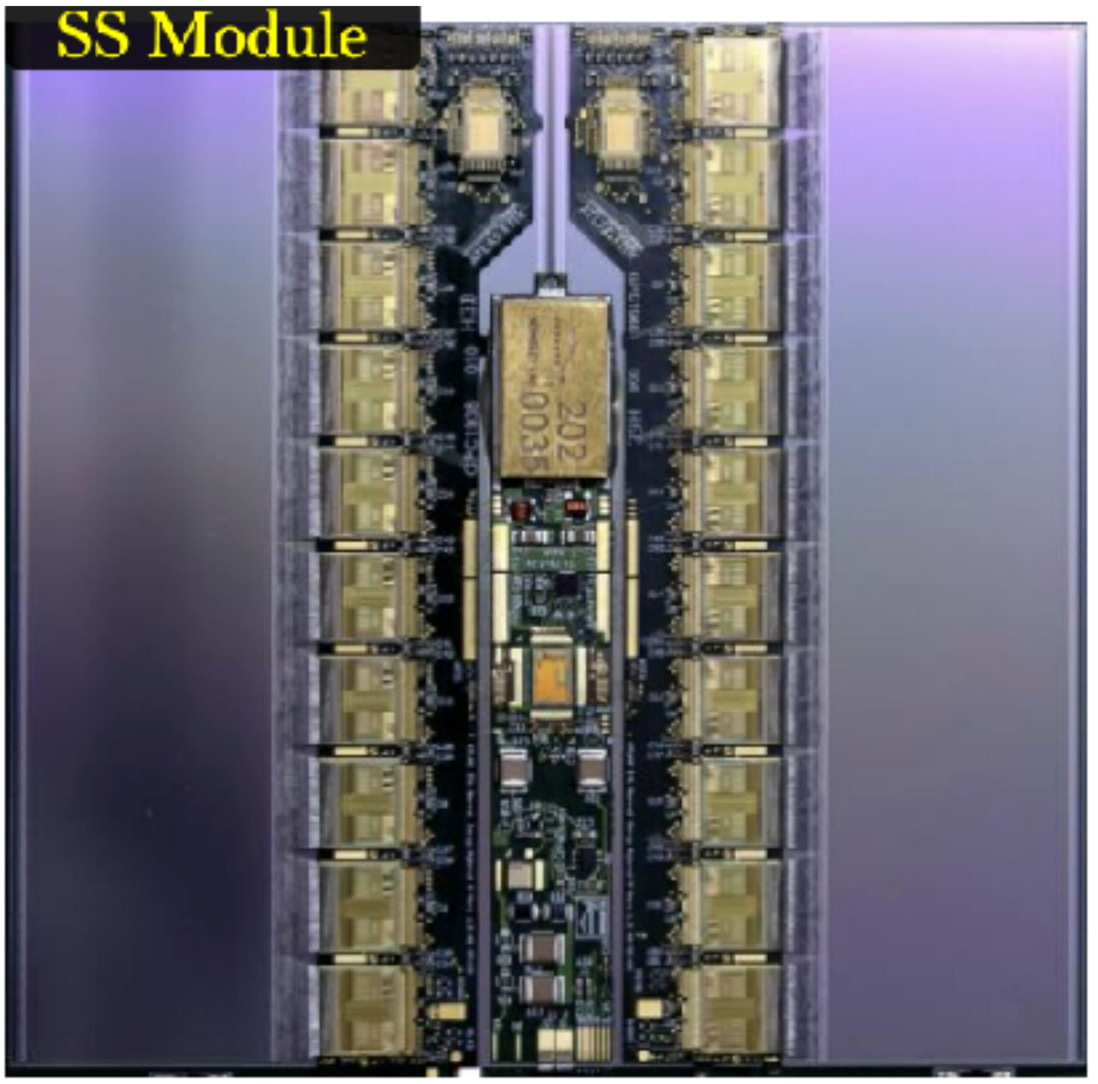
Sept 4, 2021: Hunan U. organized a review by a committee of experts from multiple disciplines. The committee evaluated scientific potential of CEPC, feasibility of a new science city based on CEPC, and overall impact on Changsha. The overall conclusion is very positive. The local government is interested and very supportive to the CEPC project.

Other projects

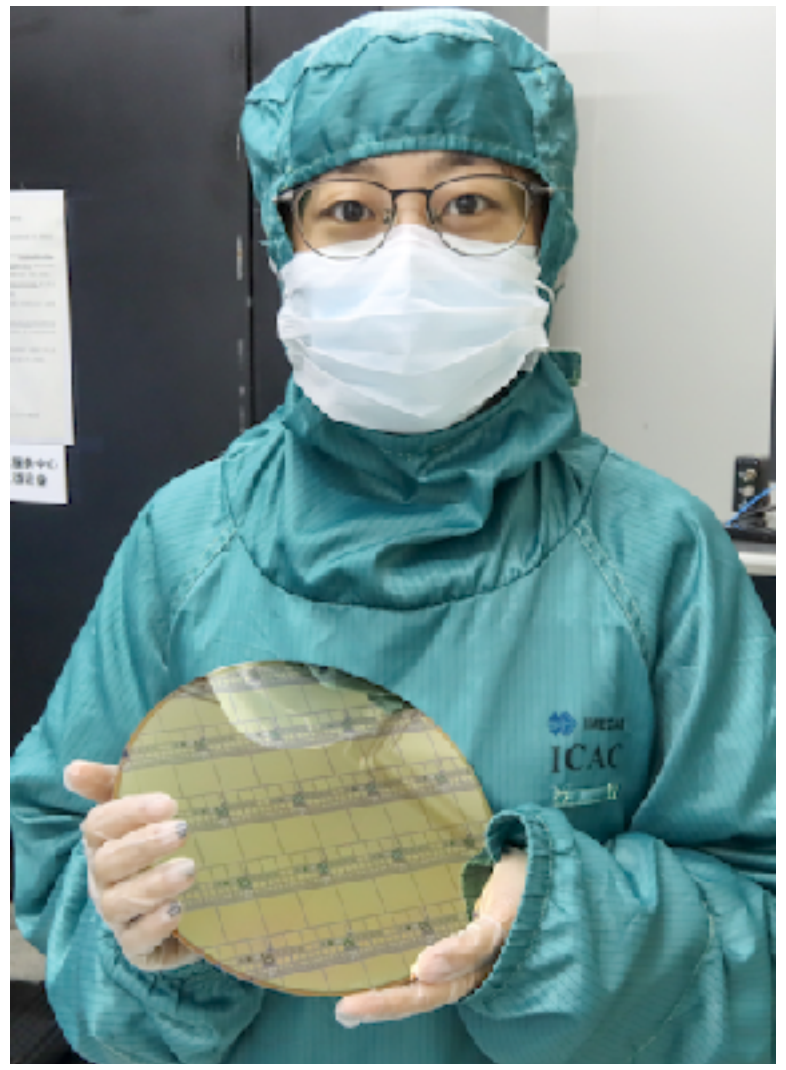
CEPC Team @ LHC upgrade

LHC upgrade Project	Contribution	IHEP member Leadership
ATLAS high granularity timing detector (HGTD)	~34% modules and sensors (~2700 modules, sensor by Chinese foundry)	Project leader Coordinators in Sensors/ modules
LHCb UT tracker upgrade	System design, test and integration	Deputy project leader
ATLAS ITK strip detector upgrade	~10% modules in Barrel (100 modules)	Coordinator in China/UK cluster
CMS HGcal	~ 20% modules (~100 m^2 area) silicon module	
High luminosity LHC upgrade	Contributing 13 CCT magnetic	

ATLAS ITK strip upgrade
Module prototyping

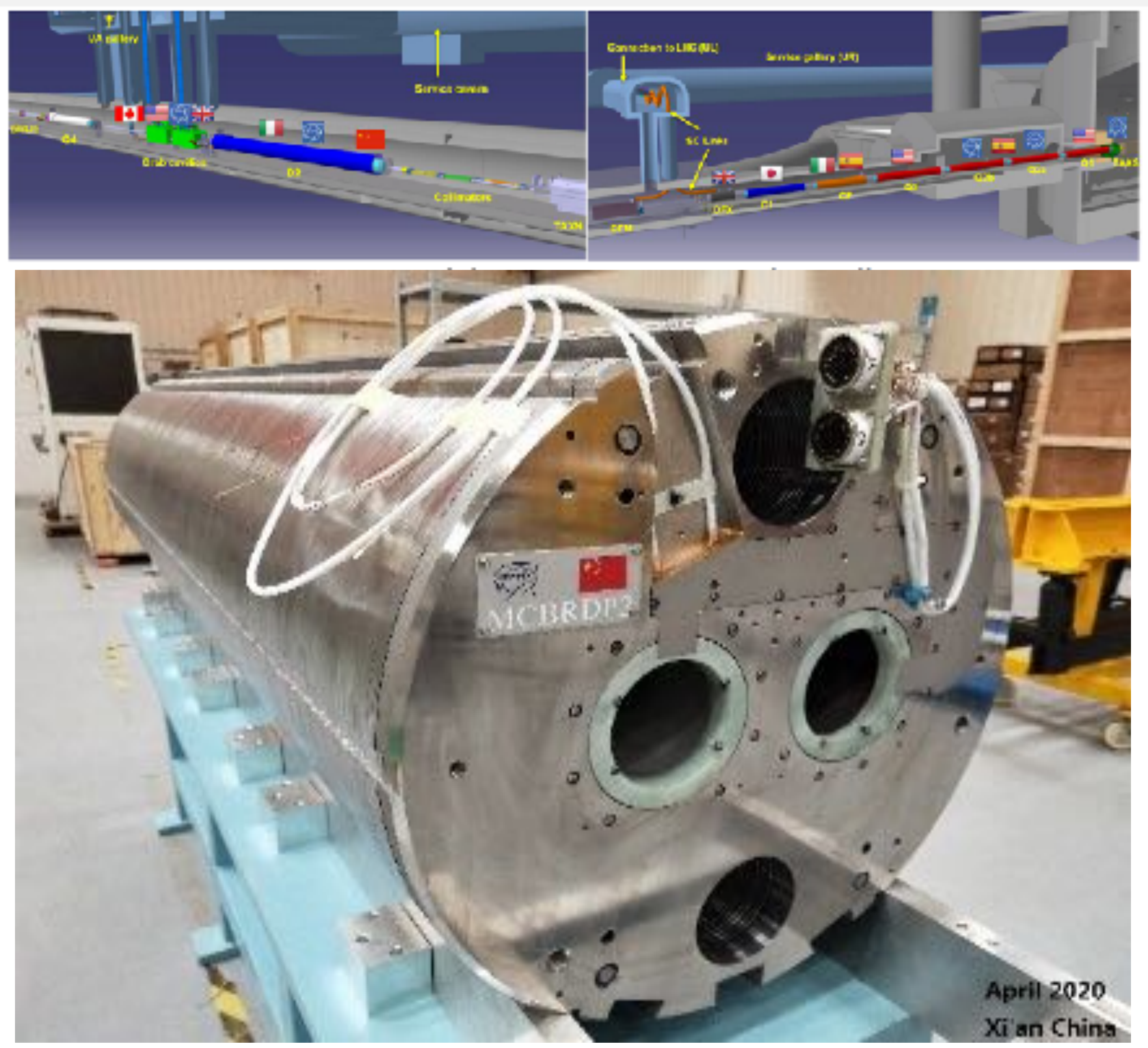


ATLAS HGTD
Sensor developed by IHEP



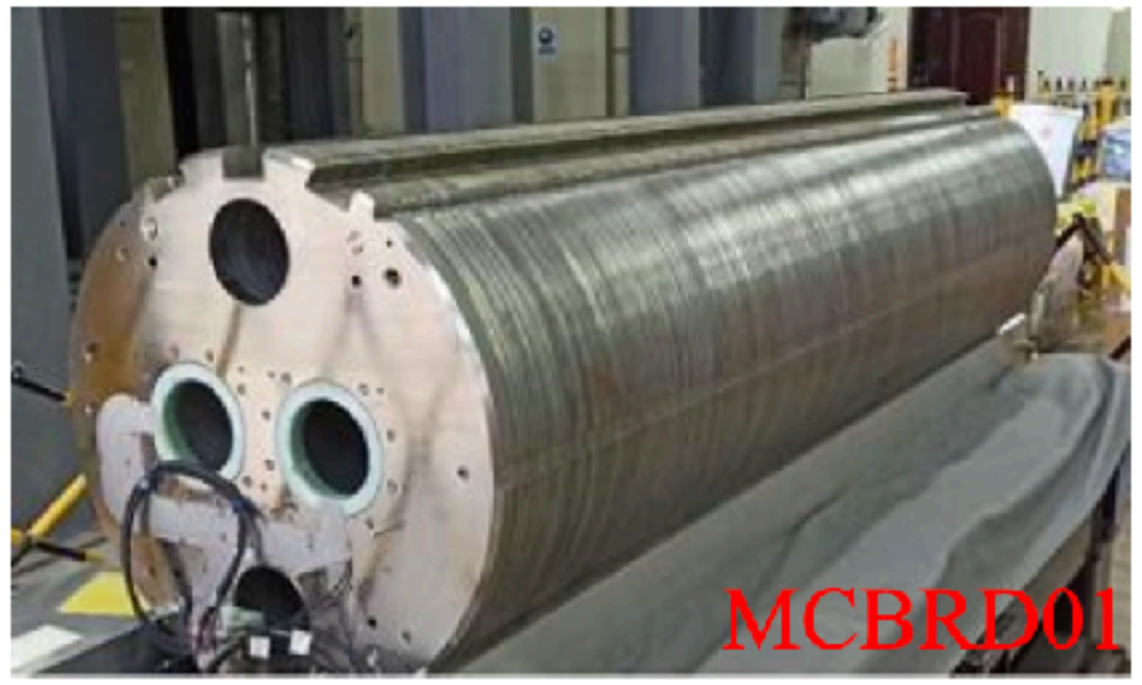
CMS HGcal
module prototyping

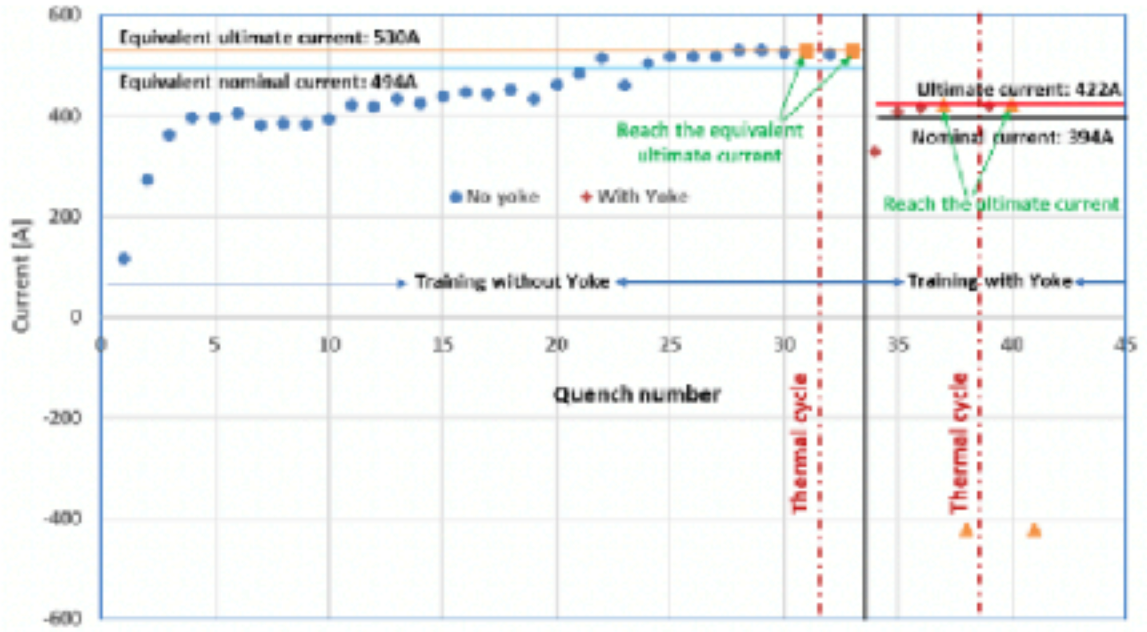
HL-LHC accelerator CCT magnet

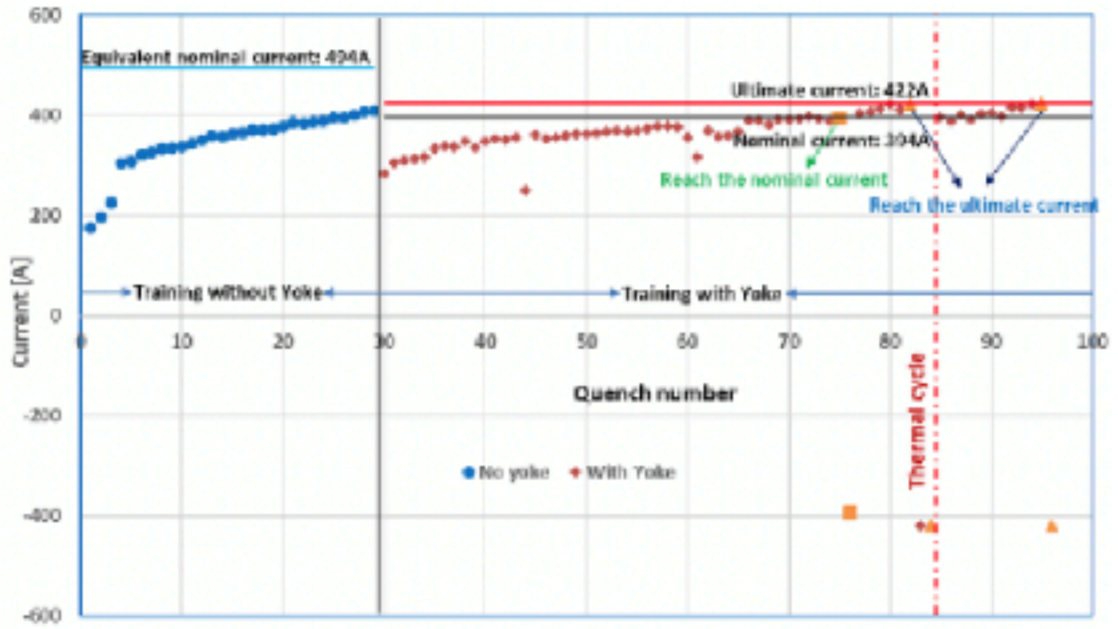


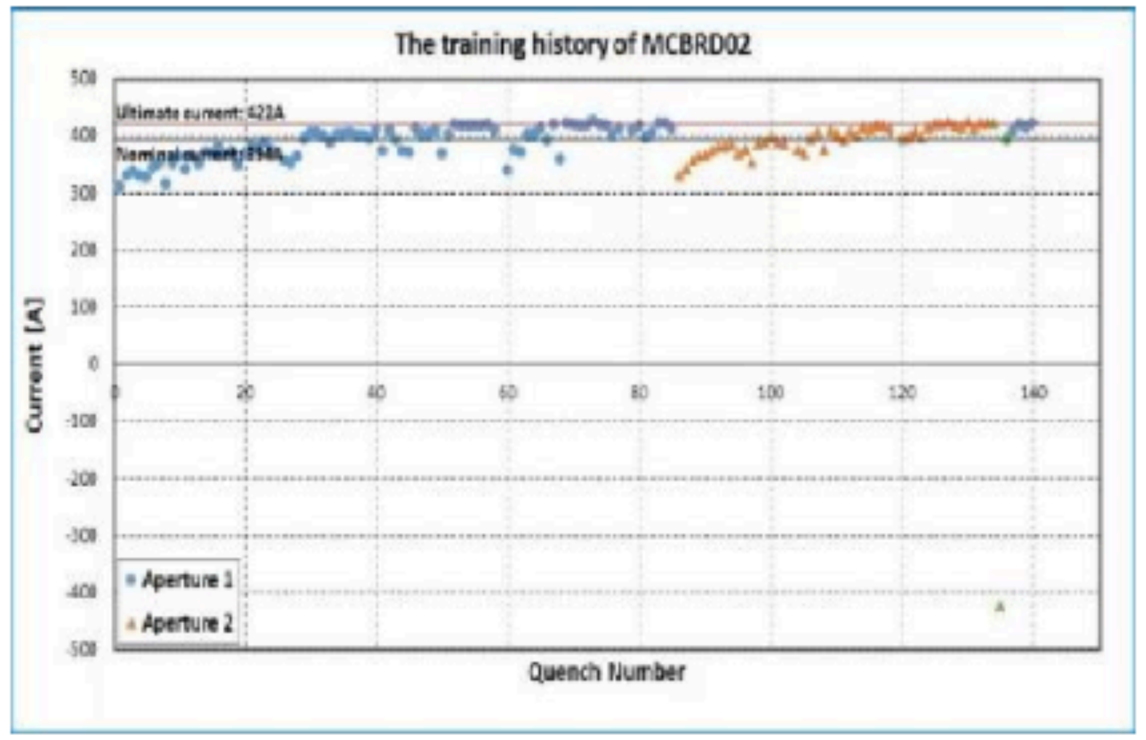
China-CERN HL-LHC CCT Project

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

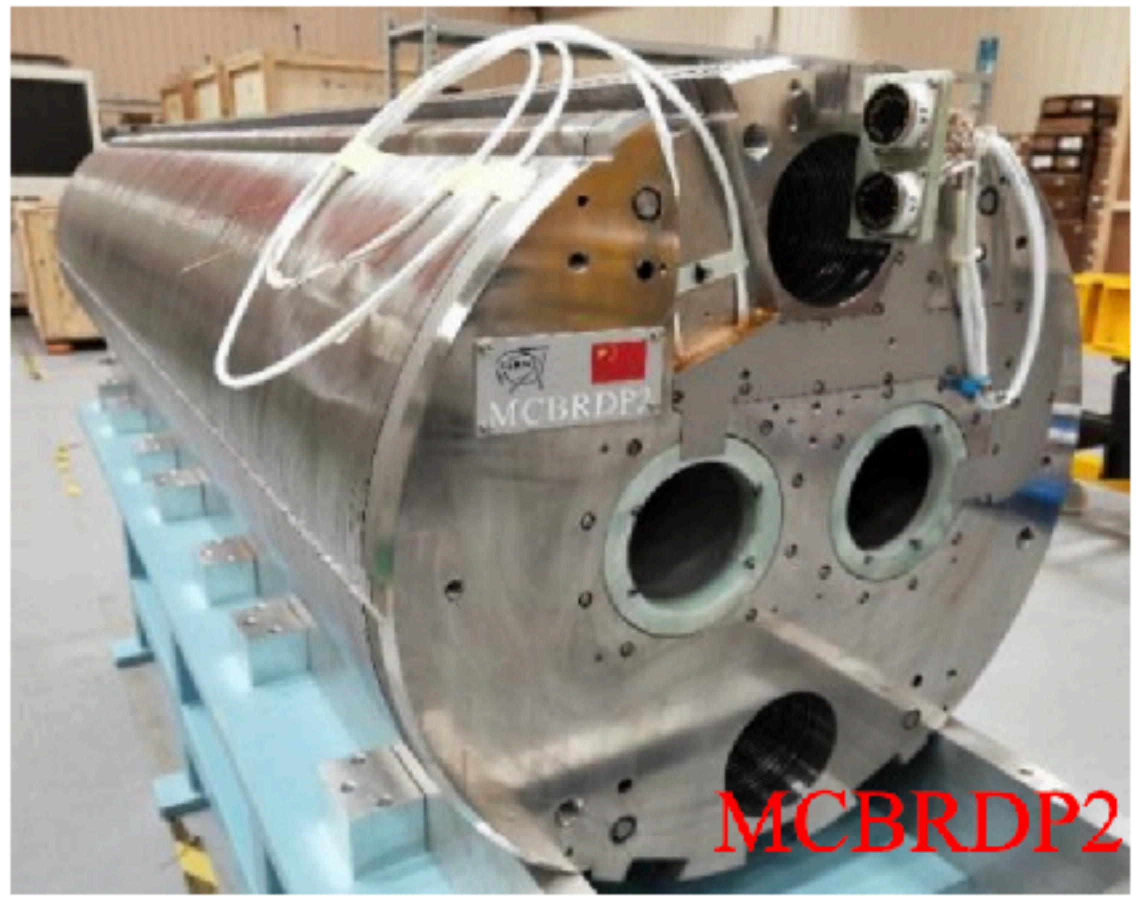


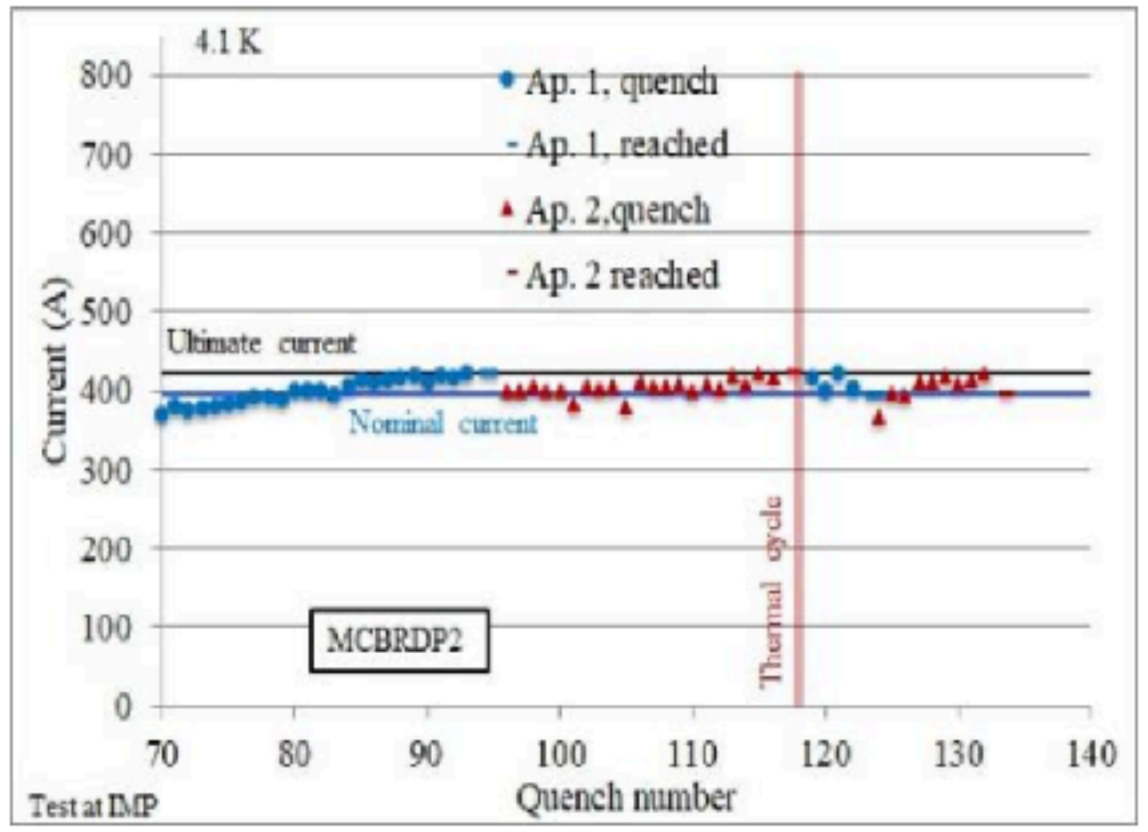






- ➢ A first set of CCT superconducting magnets MCBRD01 with satisfactory field strength and field quality were shipped to Europe in October, 2021.





- ➢ Assembly of a 2nd set of HL-LHC CCT superconducting magnets was finished in Jan, 2022. The magnet is being tested at IMP.
- ➢ Full size prototype magnet MCBRDP2 was completed in May, 2020. Both apertures reached the ultimate current.

Large-Scale Acc. Facilities: High Energy Photon Source

beam energy 6 GeV, 1.36KM, ≤ 0.06nm·rad, 14 beam lines

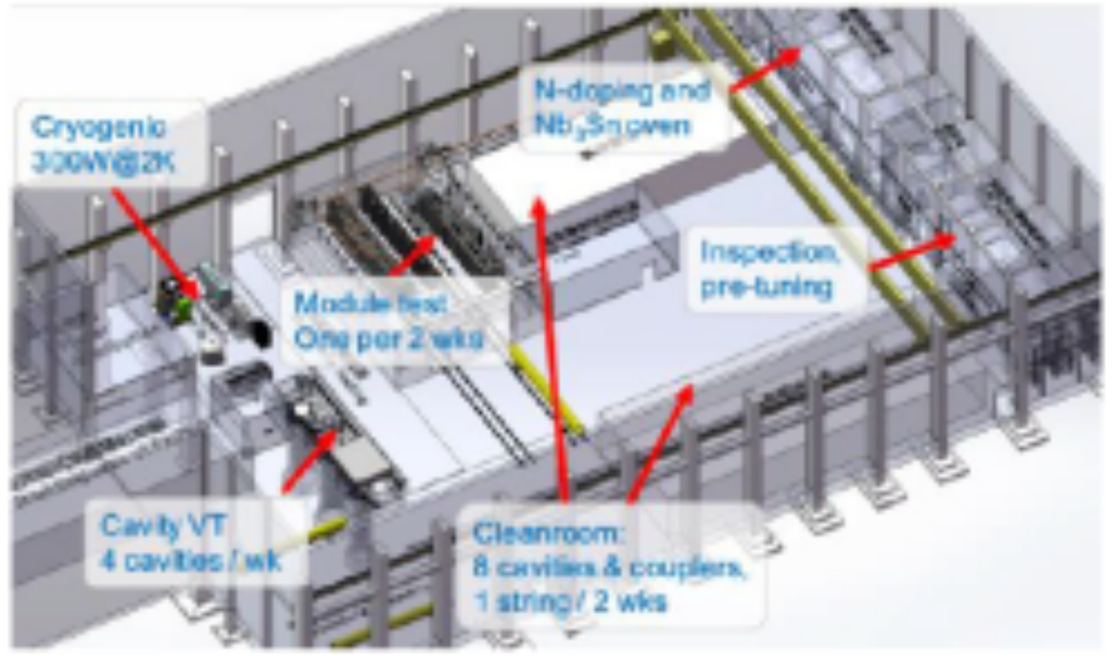
Carried out by IHEP, to be completed in 2025
Great training and preparation for CEPC: validate significant part of CEPC technologies

Device type	Accelerator	Quantity	CEPC specifications
S-band copper accelerating tube	Linac	111	~30 MV/m
vacuum chamber and coating	Collider/ Booster	Total length 200 km	Length: 6 m aperture: 56 mm vacuum: 3×10^{-10} Torr NEG coating pump speed for H_2: 0.5 L/s· cm^2
BPM and electronics	All	~5000	Closed orbit resolution: 0.6 μm
kicker & fast pulser	Transport line	~25	Pulse width <10 ns (strip-line) trapezoidal pulse width <250 ns (slotted-pipe)
Lambertson septum	Transport line	~20	Septum thickness ≲3.5 mm (in-air) thickness ≲2 mm (in-vacuum)
Power supply	All	9294	Stability 100-1000 ppm
RF-shielded bellows	Collider Booster	24000 /12000	Contact force 125±25 g/finger

Support by Platform of Advanced Photon Source (PAPS)

- **Support Key Technology R&D:**
  - ➢ SRF ➢ Magnet ➢ Vacuum ➢ Klystron ➢ Electric Power Source ➢ Cryogenic System
  - ➢ Mechanical system & Alignment ➢ e- gun

Facility: CEPC SCRF test facility (lab) is located in IHEP Huairong Area of 4500m^2



New SC Lab Design (4500m^2)

New SC Lab will be fully functional 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

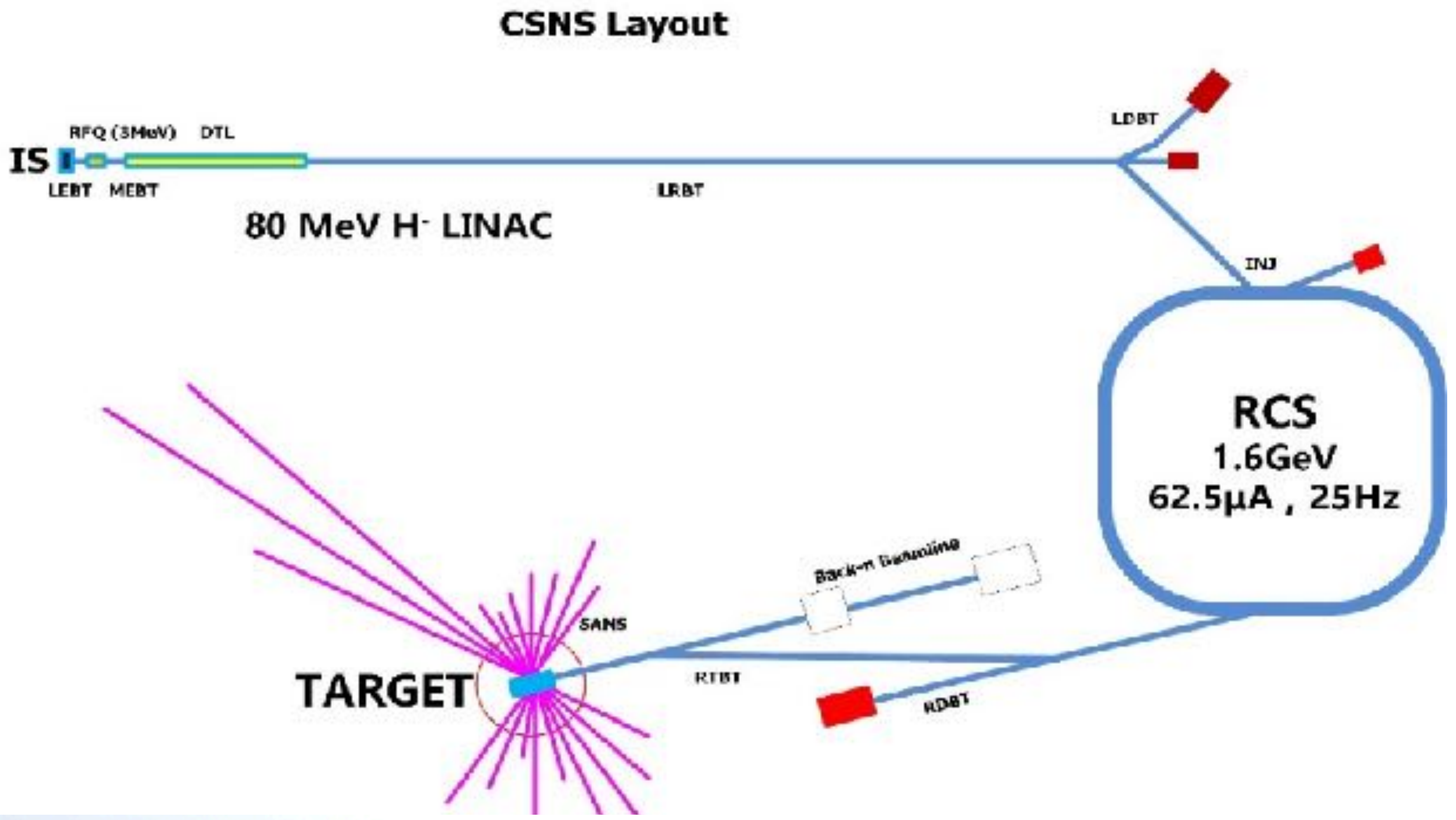
Second sound cavity quench detection system

Helmholtz coil for cavity vertical test

Vertical test dewars

Horizontal test cryostat

Large-Scale Acc. Facilities: China Spallation Neutron Source



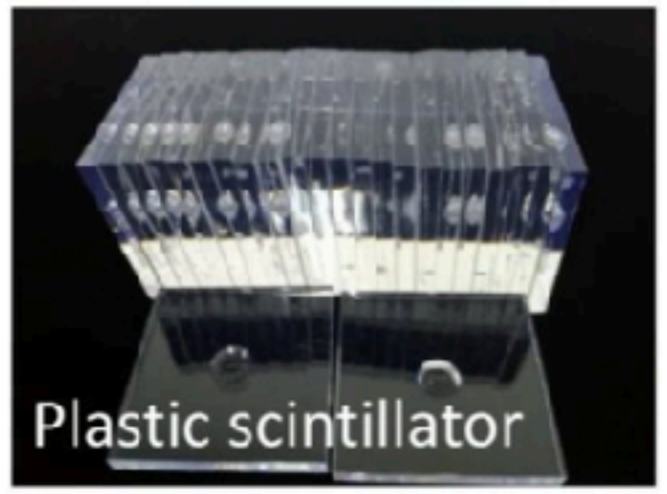
- One of the four pulsed Spallation Neutron Sources in the world
- Construction completed in 2018

Detector

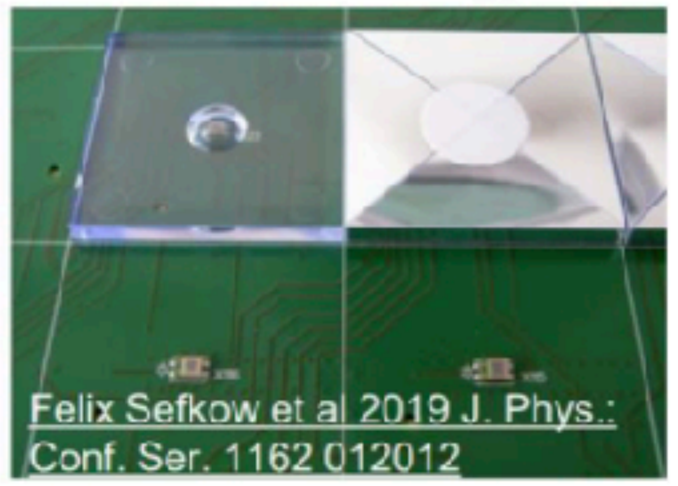
CEPC R&D: New HCAL with Scintillating Glass Tiles

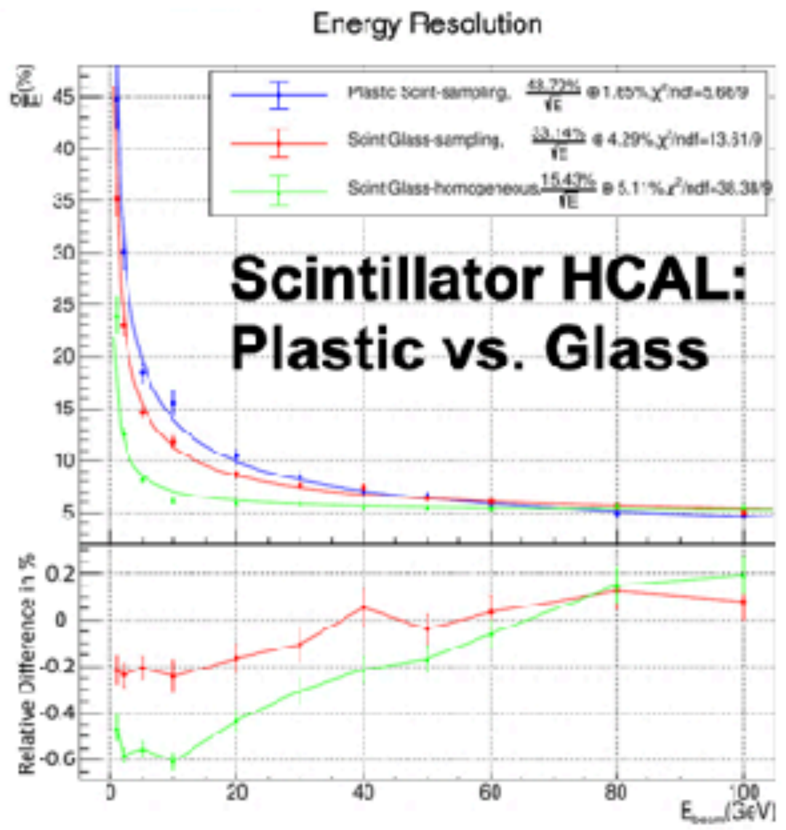
Full simulation studies

Tiles for AHCAL (30x30x3mm)

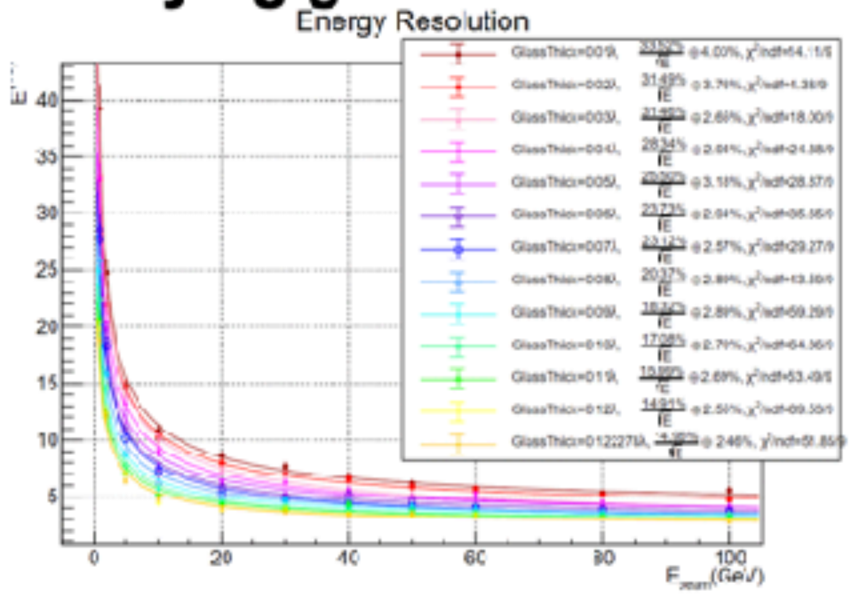


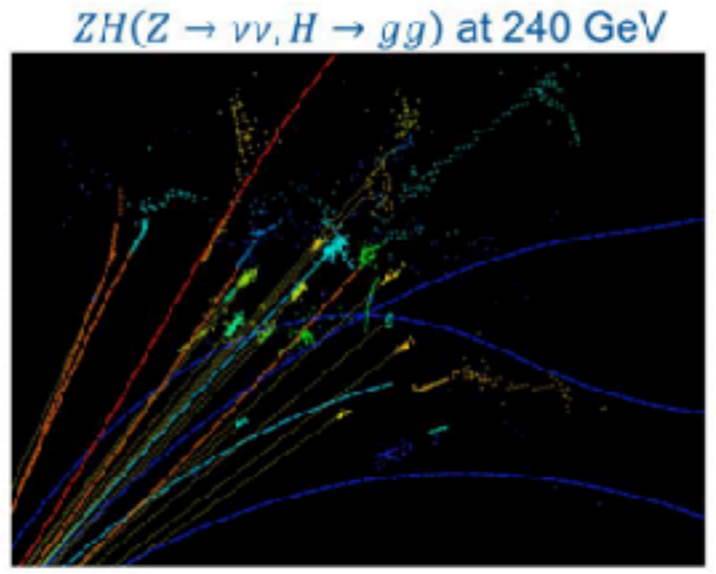
'SiPM-on-Tile" design for HCAL



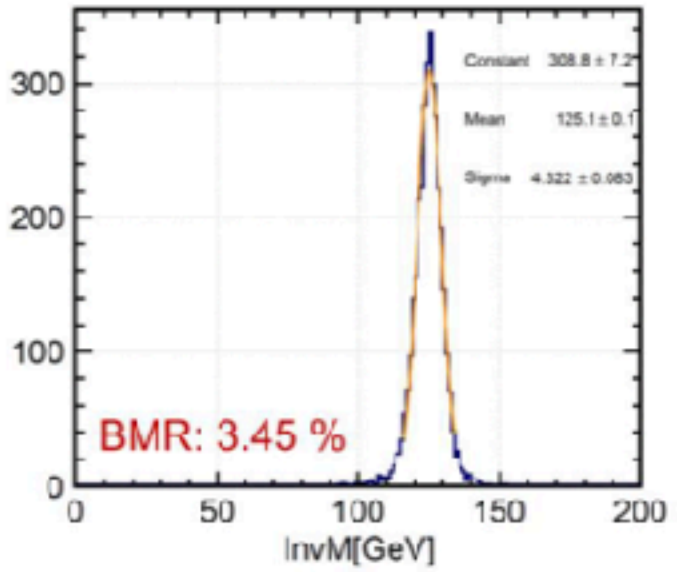


Varying glass thickness



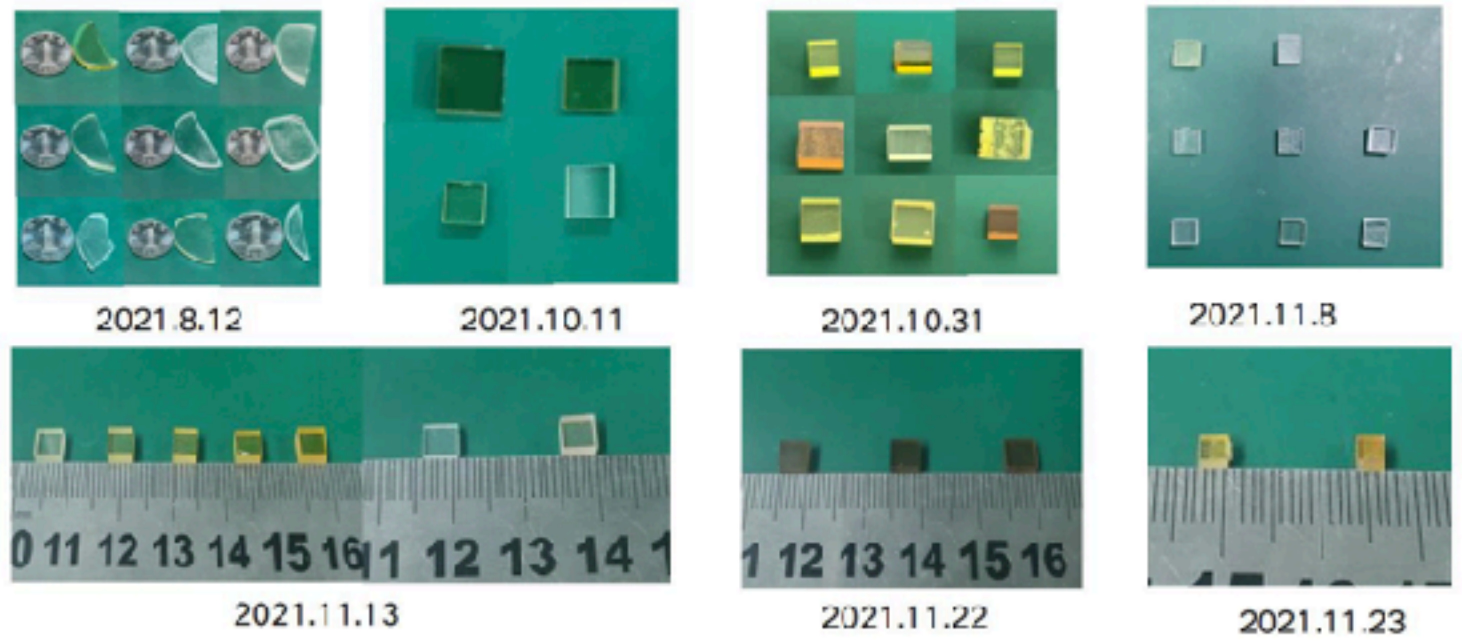


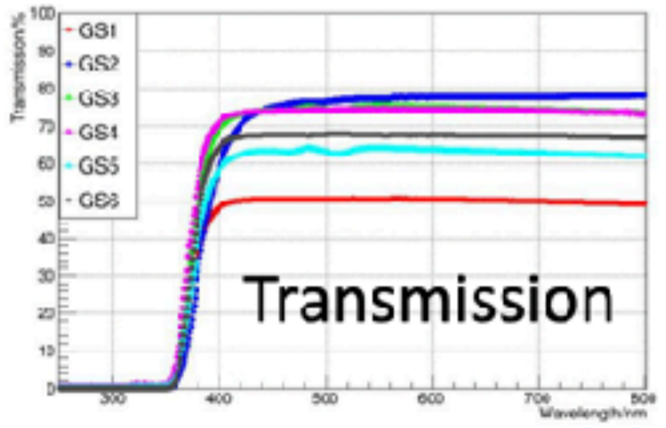
Performance study with jets

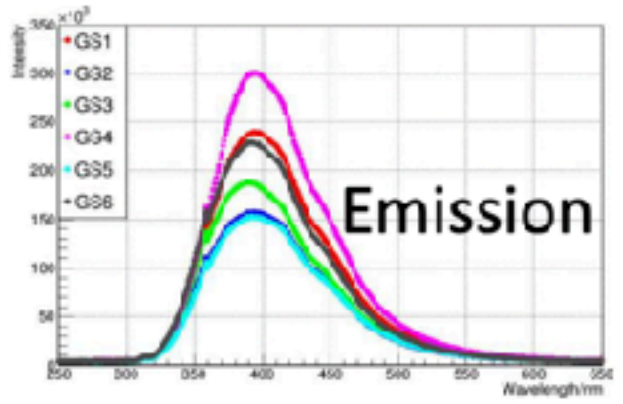


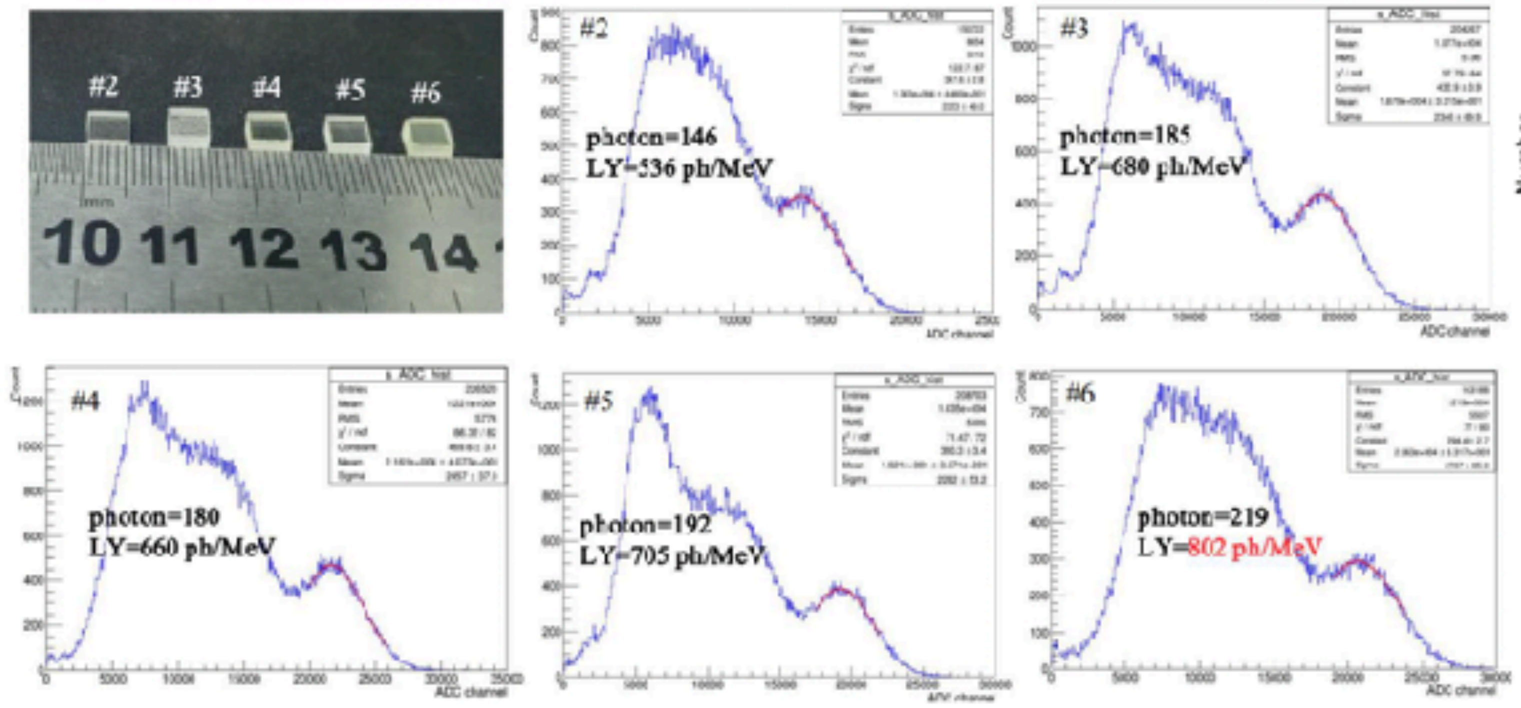
Goal

- **Better hadronic energy resolution**
- **Further improve BMR**



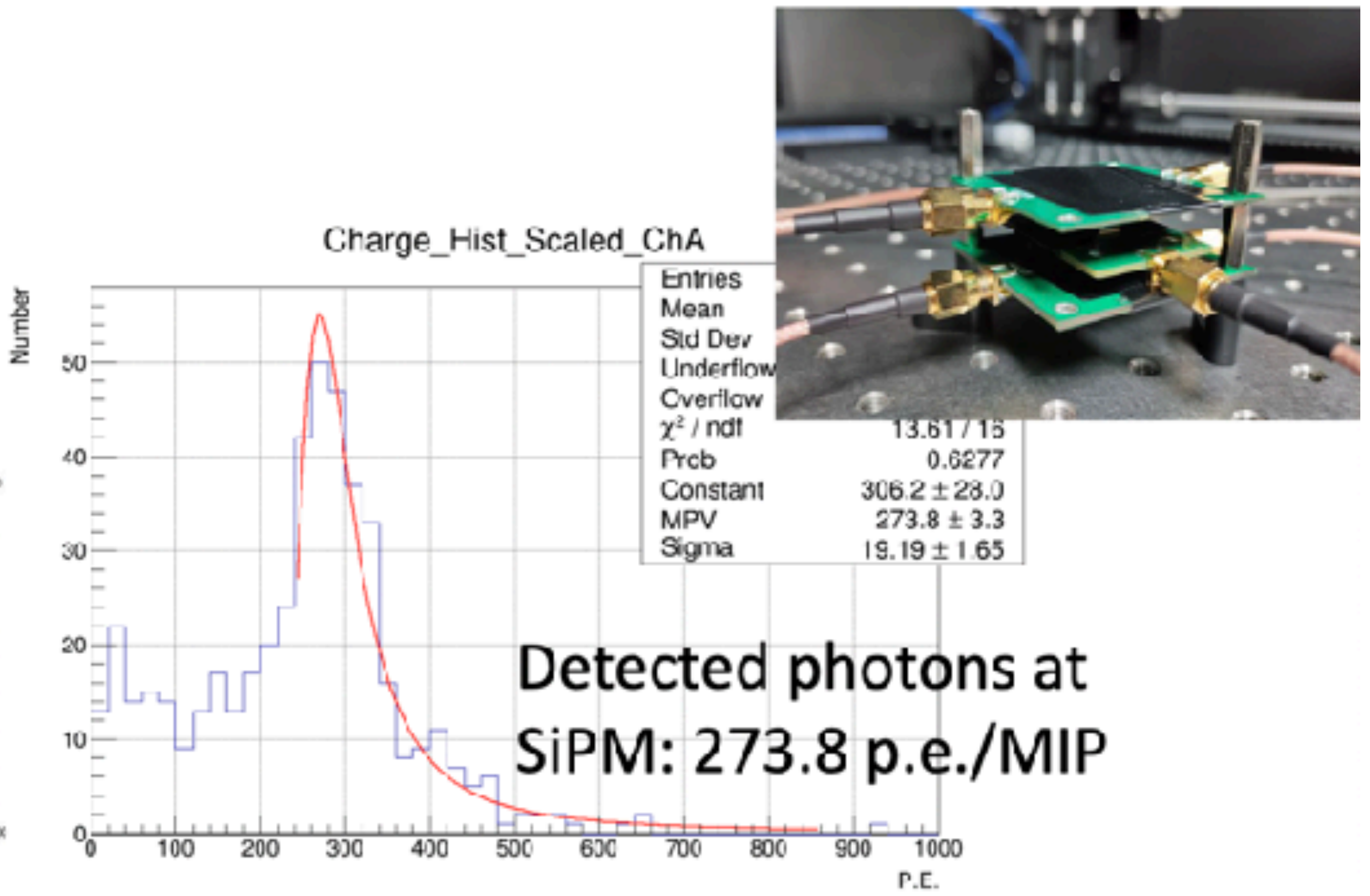






Scintillating Glass R&D

Testing Scintillating Glass Samples



Projects overview: R&D schedule

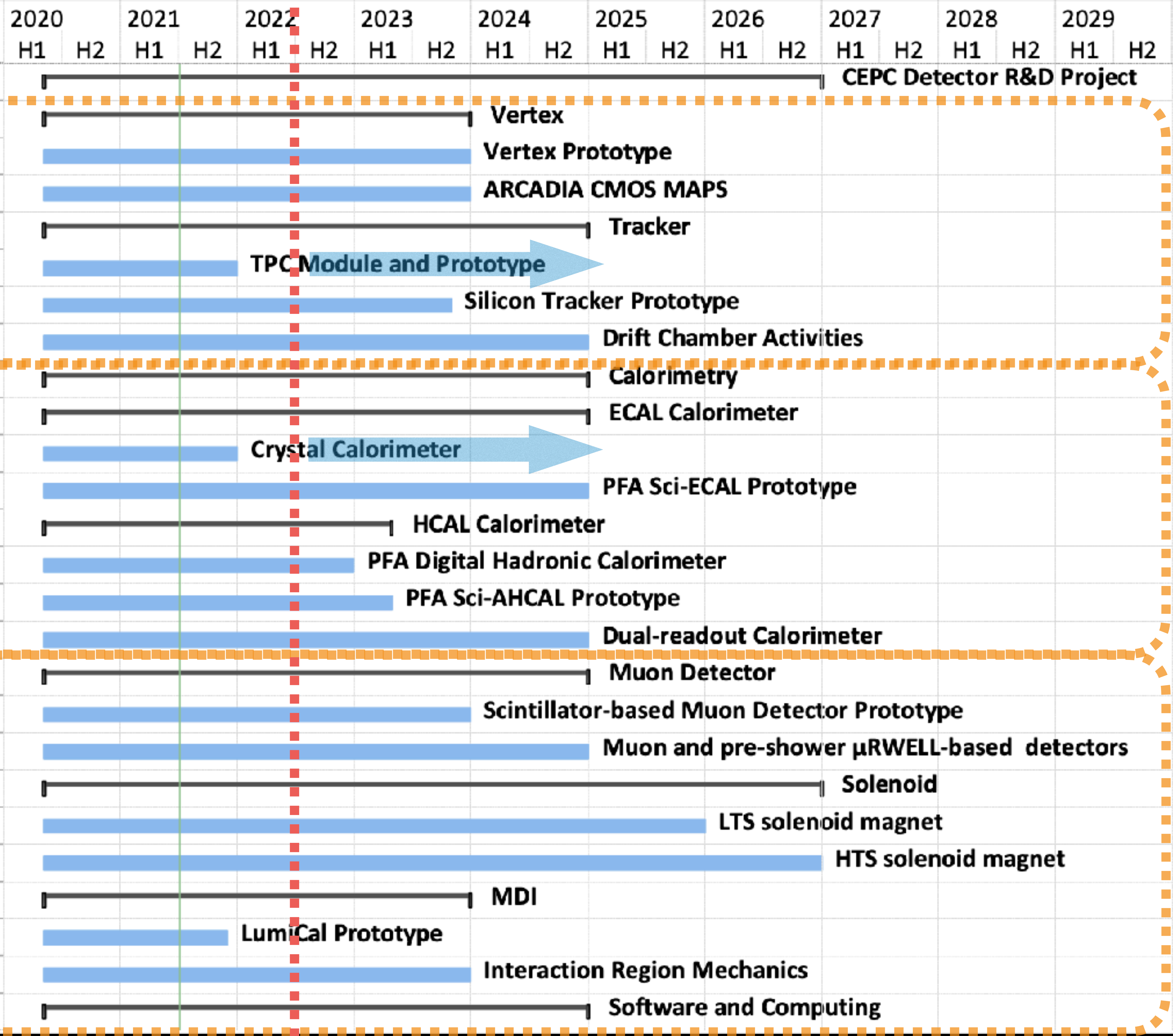
PBS	Task Name
	CEPC Detector R&D Project
1	**Vertex**
1.1	Vertex Prototype
1.2	ARCADIA CMOS MAPS
2	**Tracker**
2.1	**TPC Module and Prototype**
2.2	**Silicon Tracker Prototype**
2.3	**Drift Chamber Activities**
3	**Calorimetry**
3.1	**ECAL Calorimeter**
3.1.1	Crystal Calorimeter
3.1.2	PFA Sci-ECAL Prototype
3.2	**HCAL Calorimeter**
3.2.1	PFA Digital Hadronic Calorimeter
3.2.2	PFA Sci-AHCAL Prototype
3.3	**Dual-readout Calorimeter**
4	**Muon Detector**
4.1	Scintillator-based Muon Detector Prototype
4.2	Muon and pre-shower μRWELL-based detecto
5	**Solenoid**
5.1	LTS solenoid magnet
5.2	HTS solenoid magnet
6	**MDI**
6.1	LumiCal Prototype
6.2	Interaction Region Mechanics
8	**Software and Computing**

Total of 103 sub-tasks identified
Summarized in 81-page document
for the International Detector R&D Committee

Similar slide in Franco's talk

Projects overview: R&D schedule

PBS	Task Name	Start	Finish	Duration
	CEPC Detector R&D Project	**2020/5/7**	**2026/12/31**	**1736 days**
1	**Vertex**	**2020/5/7**	**2023/12/29**	**952 days**
1.1	Vertex Prototype	2020/5/7	2023/12/29	952 days
1.2	ARCADIA CMOS MAPS	2020/5/7	2023/12/29	952 days
2	**Tracker**	**2020/5/7**	**2024/12/31**	**1214 days**
2.1	**TPC Module and Prototype**	**2020/5/7**	**2021/12/31**	**432 days**
2.2	**Silicon Tracker Prototype**	**2020/5/7**	**2023/10/31**	**909 days**
2.3	**Drift Chamber Activities**	**2020/5/7**	**2024/12/31**	**1214 days**
3	**Calorimetry**	**2020/5/7**	**2024/12/31**	**1214 days**
3.1	**ECAL Calorimeter**	**2020/5/7**	**2024/12/31**	**1214 days**
3.1.1	Crystal Calorimeter	2020/5/7	2021/12/31	432 days
3.1.2	PFA Sci-ECAL Prototype	2020/5/7	2024/12/31	1214 days
3.2	**HCAL Calorimeter**	**2020/5/7**	**2023/4/28**	**777 days**
3.2.1	PFA Digital Hadronic Calorimeter	2020/5/7	2022/12/30	692 days
3.2.2	PFA Sci-AHCAL Prototype	2020/5/7	2023/4/28	777 days
3.3	**Dual-readout Calorimeter**	**2020/5/7**	**2024/12/31**	**1214 days**
4	**Muon Detector**	**2020/5/7**	**2024/12/31**	**1214 days**
4.1	Scintillator-based Muon Detector Prototype	2020/5/7	2023/12/29	952 days
4.2	Muon and pre-shower µRWELL-based detectc	2020/5/7	2024/12/31	1214 days
5	**Solenoid**	**2020/5/7**	**2026/12/31**	**1736 days**
5.1	LTS solenoid magnet	2020/5/7	2025/12/31	1475 days
5.2	HTS solenoid magnet	2020/5/7	2026/12/31	1736 days
6	**MDI**	**2020/5/7**	**2023/12/29**	**952 days**
6.1	LumiCal Prototype	2020/5/7	2021/12/1	410 days
6.2	Interaction Region Mechanics	2020/5/7	2023/12/29	952 days
8	**Software and Computing**	**2020/5/7**	**2024/12/31**	**1214 days**



Projects overview: FTE

PBS	Task Name	Team
	CEPC Detector R&D Project	
1	Vertex	
1.1	Vertex Prototype	China+ international collaborators
1.2	ARCADIA CMOS MAPS	INFN
2	Tracker	
2.1	TPC Module and Prototype	IHEP, Tsinghua
2.2	Silicon Tracker Prototype	China, UK, INFN
2.3	Drift Chamber Activities	INFN, Novosibirsk
3	Calorimetry	
3.1	ECAL Calorimeter	
3.1.1	Crystal Calorimeter	IHEP, USA, INFN
3.1.2	PFA Sci-ECAL Prototype	USTC, IHEP
3.2	HCAL Calorimeter	
3.2.1	PFA Digital Hadronic Calorimeter	SJTU, IPNL, Weizmann, IIT, USTC
3.2.2	PFA Sci-AHCAL Prototype	USTC, IHEP, SJTU
3.3	Dual-readout Calorimeter	INFN, Sussex, Zagreb, South Korea
4	Muon Detector	
4.1	Scintillator-based Muon Detector	Fudan, SJTU
4.2	Muon and pre-shower µRWELL-	INFN, LNF
5	Solenoid	
5.1	LTS solenoid magnet	IHEP+Industry
5.2	HTS solenoid magnet	IHEP+Industry
6	MDI	
6.1	LumiCal Prototype	AC, IHEP
6.2	Interaction Region Mechanics	IHEP
8	Software and Computing	IHEP, SDU, CERN, INFN