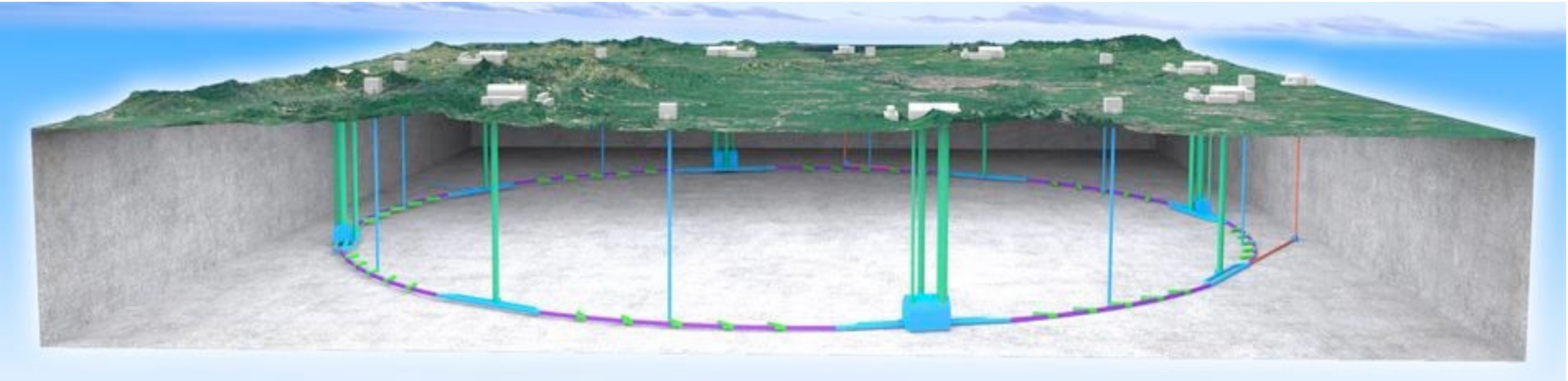
CEPC highlights

Zhijun Liang
(On behalf of the CEPC physics and detector group)
Institute of High energy physics, CAS

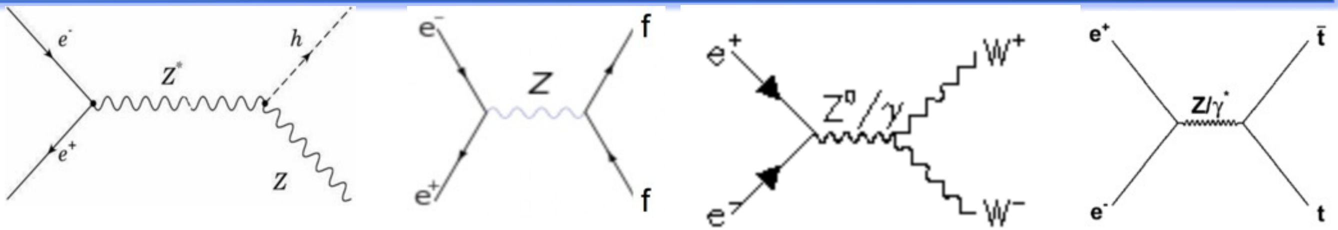
Higgs potential, Hefei, Dec 20, 2024



CEPC physics program

An extremely versatile machine with a broad spectrum of physics opportunities

→ Far beyond a Higgs factory



Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			~240	~91.2	~160	~360
Run time [years]			10	2	1	5
CDR (30 MW)		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	-
Run Time [years]			10	2	1	~5
Latest	**30 MW**	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**
	50 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	8.3	191.7	26.6	**0.8**
		$\int L\,dt$ [ab^{-1}, 2 IPs]	20	96	7	1
		Event yields [2 IPs]	4×10^6	4×10^{12}	5×10^7	5×10^5

- **Huge measurement potential for precision tests of SM: Higgs, electroweak physics, flavor physics, QCD/Top**

CEPC CDR: arXiv:1811.10545

White Paper: arXiv:1810.09037

CEPC Snowmass 2021:

arXiv:2205.08553

CEPC Accelerator TDR:

arXiv:2312.14363

Both 50 MW and $t\bar{t}$ modes are currently considered as CEPC upgrades.

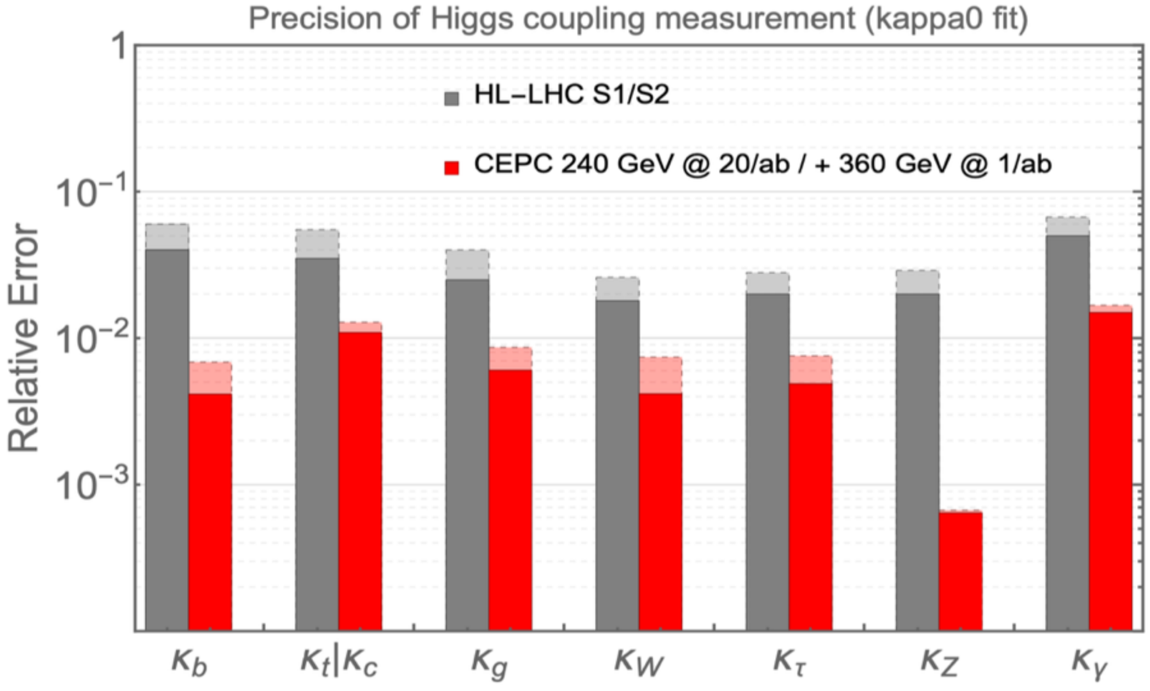
Higgs Precision measurements @ ZH runs

Translated the latest accelerator performance into Higgs measurements

Higgs		
Observable	HL-LHC projections	CEPC precision
M_H	20 MeV	3 MeV
Γ_H	20%	1.7%
$\sigma(ZH)$	4.2%	0.26%
$B(H \to bb)$	4.4%	0.14%
$B(H \to cc)$	-	2.0%
$B(H \to gg)$	-	0.81%
$B(H \to WW^*)$	2.8%	0.53%
$B(H \to ZZ^*)$	2.9%	4.2%
$B(H \to \tau^+\tau^-)$	2.9%	0.42%
$B(H \to \gamma\gamma)$	2.6%	3.0%
$B(H \to \mu^+\mu^-)$	8.2%	6.4%
$B(H \to Z\gamma)$	20%	8.5%
Bupper$(H \to \text{inv.})$	2.5%	0.07%

Higgs width measurement benefits enormously from 360-GeV run

Exploring the full potential of the CEPC with the latest TDR design for Higgs measurements by combining 240-GeV and 360-GeV runs.

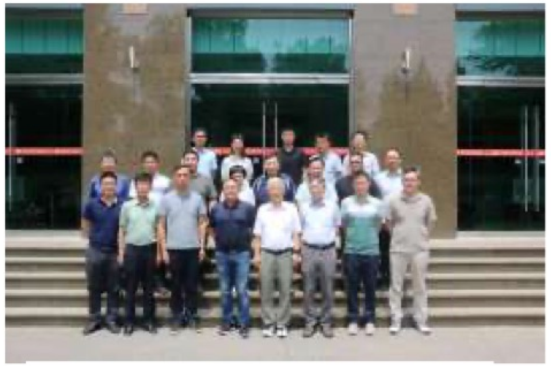


Outperforming HL-LHC significantly

CEPC Accelerator International TDR Review and Cost Review

CEPC Accelerator TDR Review
June 12-16, 2023, Hong Kong

CEPC Accelerator TDR Cost Review
Sept. 11-15, 2023, Hong Kong



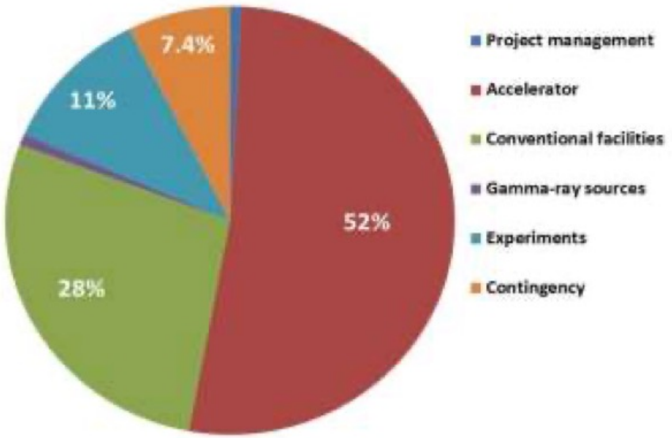
Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP

9th CEPC IAC 2023 Meeting
Oct. 30-31, 2023, IHEP

CEPC Accelerator TDR completion was announced during the ICFA Seminar from Nov. 28-Dec.1, 2023, DESY, Hamburg, Germany

Table 12.1.2: CEPC project cost breakdown. (Unit: 100,000,000 yuan)

Total	364	100%
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



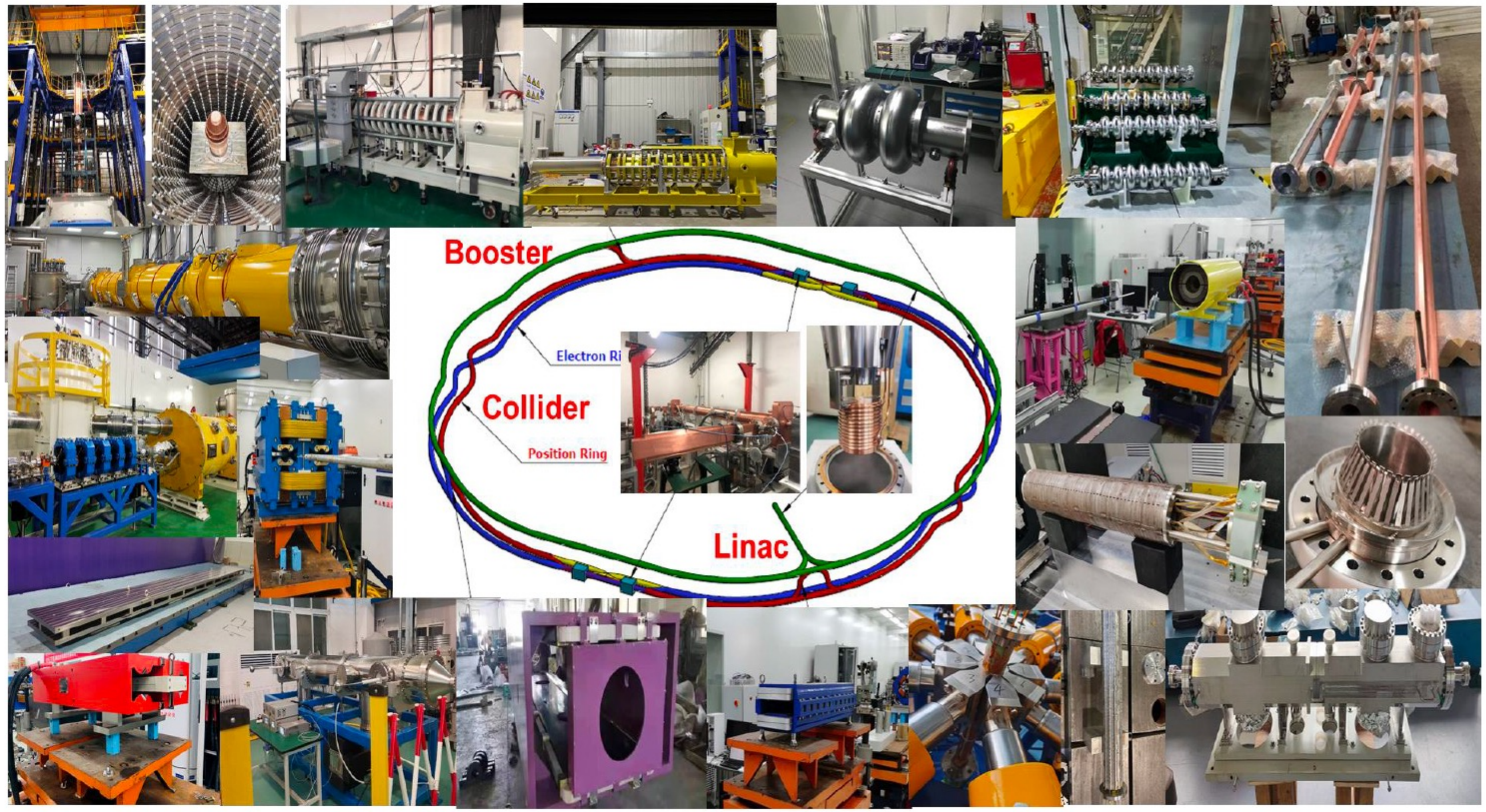
Distribution of CEPC Project total TDR cost of **36.4B RMB (~5.2USD)**

CEPC accelerator TDR has been completed and formally released on December 25, 2023:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html
CEPC accelerator TDR has been published formally in Journal Radiation Detection Technology and Methods (RDTM) on June 3, 2024:
DOI: 10.1007/s41605-024-00463-y
https://doi.org/10.1007/s41605-024-00463-y

More details in Jie Gao's talk in CEPC workshop
https://indico.ihep.ac.cn/event/22089/contributions/167861

CEPC accelerator : key technology

➢ CEPC TDR 加速器关键技术预研覆盖了CDR中列出的所有关键部件
➢ 约90%的部件性能已经达到CEPC指标要求，另外约10% 的部件在研制或测试中，例如 RF功率源、加速器集成和控制系统、检测与准直系统、超导磁铁关键技术等需要进一步研究，预期2026年完成。



✓ Specification Met

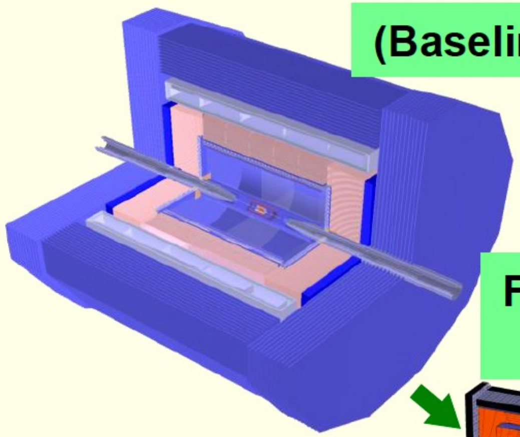
✓ Prototype Manufactured

Accelerator	Fraction
✓ Magnets	27.3%
✓ Vacuum	18.3%
✓ RF power source	9.1%
✓ Mechanics	7.6%
✓ Magnet power supplies	7.0%
✓ SC RF	7.1%
✓ Cryogenics	6.5%
✓ Linac and sources	5.5%
✓ Instrumentation	5.3%
✓ Control	2.4%
✓ Survey and alignment	2.4%
✓ Radiation protection	1.0%
✓ SC magnets	0.4%
✓ Damping ring	0.2%

M
ht

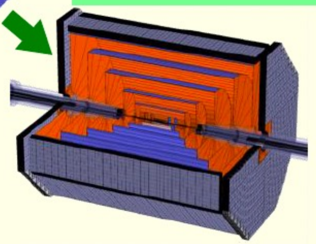
n

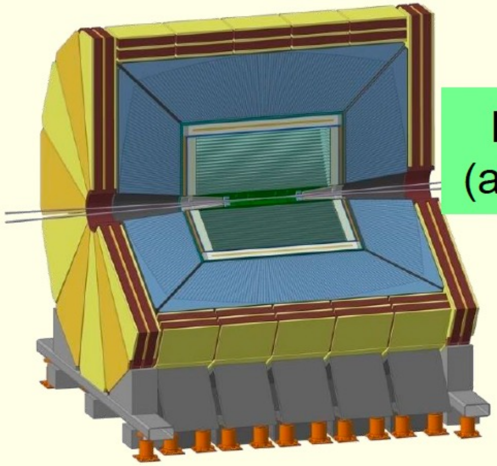
Reference Detector Technical Design Report (ref-TDR)



(Baseline Design)

Full Silicon Tracker

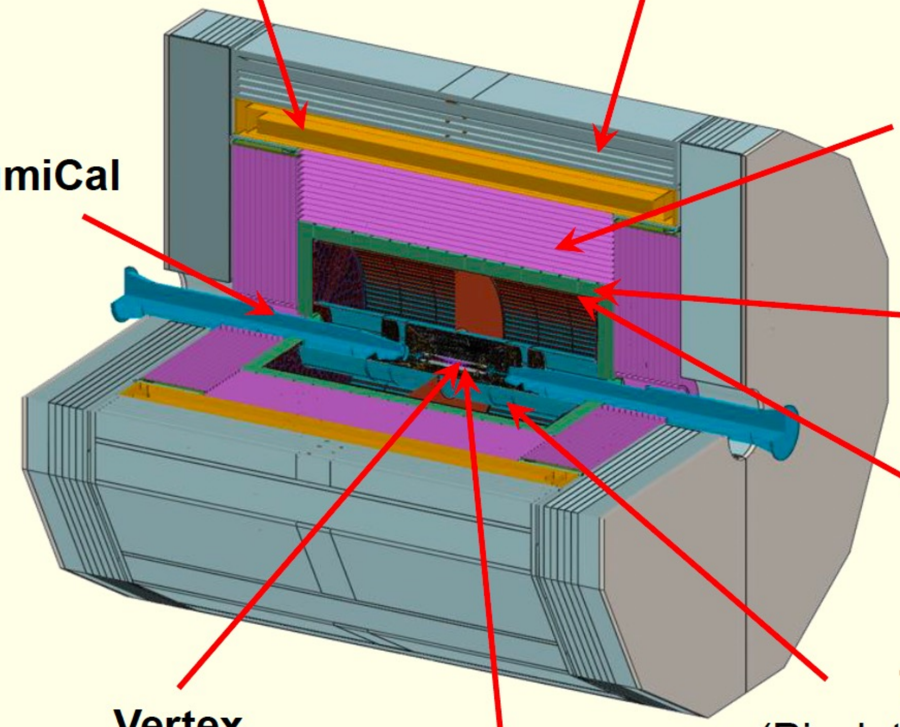




IDEA concept
(also for FCC-ee)

The 4th Concept

Ref-TDR is based on this configuration

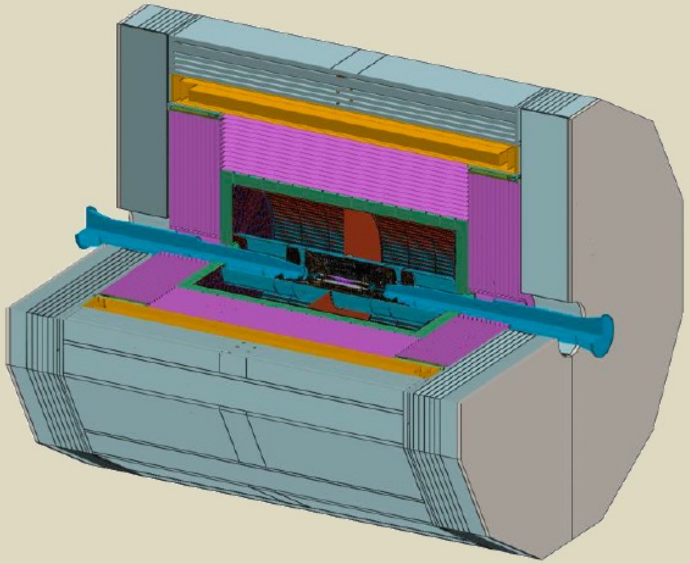


Technology study for Reference Detector TDR

System	Technologies	
	Baseline	Backup / Comparison
Beam pipe	Φ20 mm	
LumiCal	SiTrk + Crystal	
Vertex	CMOS + Stitching	CMOS Si Pixel
Tracker	CMOS Si Pixel ITK	SSD + RO Chip, CMOS SSD
	Pixelated TPC	PID Drift Chamber
	AC-LGAD OTK	SSD / SPD OTK
		LGAD ToF
ECAL	4D Crystal Bar	Stereo Crystal Bar, GS+SiPM, PS+SiPM+W, SiDet+W
HCAL	GS+SiPM+Fe	PS+SiPM+Fe, RPC+Fe
Magnet	LTS	HTS
Muon	PS bar+SiPM	RPC
TDAQ	Conventional	Software Trigger
BE electr.	Common	Independent

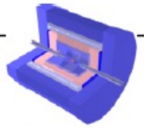
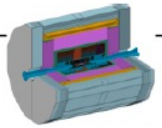
Radius

- The CEPC study group started to compare different technologies in January, 2024
- By the end of June, 2024 the baseline technologies were chosen.
- Multiple factors were considered in the process: performance, cost, R&D efforts, technology maturity, …



- We will continue pursuing better technologies for the two final detectors at CEPC

Reference Detector optimization

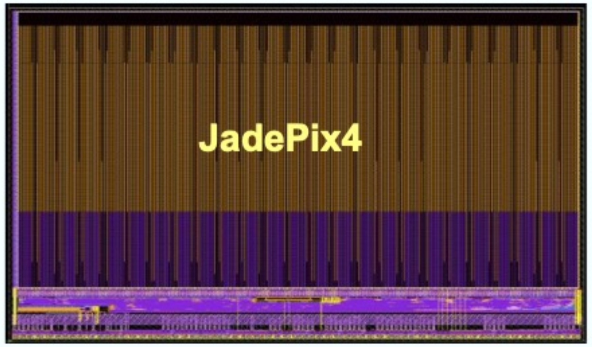
	CDR 	**Ref-TDR** 
VTX	Inner radius of **16 mm**	Inner radius of **11 mm**
	Material Budget: 0.15%*6+0.14%(beampipe)= **1.05% X0**	Material Budget: 0.06%*4(inner)+0.165%*2(outer)+0.2%(beampipe)= **0.77% X0**
Gaseous Tracker	TPC with **1 mm* 6 mm** readout	TPC with **0.5 mm* 0.5 mm** readout To have **dE/dx or dN/dx resolution 3%** (Drift Chamber with the capability of dN/dx as alternative)
ToF	-	AC-LGAD, with **50 ps** per MIP
ECAL	Si-W-ECAL: **17%/√E** ⊕ 1%	Crystal Bar-ECAL: **1.3%/√E** ⊕ 0.7%
HCAL	RPC-Iron: **60%/√E** ⊕ 2%	Glass-Iron: **30%/√E** ⊕ 6.5%

Delphes Card with Ref-TDR geometry information can be found in https://code.ihep.ac.cn/zhangkl/delphes_cepc (working in progress).

- VTX
  - Inner radius: 40% (16 mm → 11 mm)
  - Material 30% (1.05% → 0.77% X0)
- Better TPC, with dE/dx, dN/dx 3%;
- TOF readout;
- ECAL: to Cyber: to 1.3%.
- HCAL: to Glass-Iron, to 30%.

Vertex detector

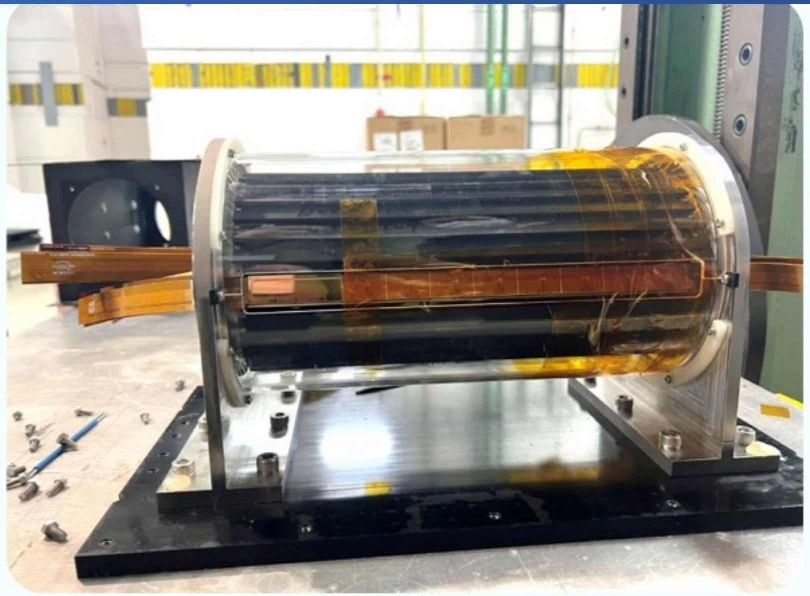
356×498 pixels of 20×29 μm^2
$\sigma_{x/y}$ ~ 3-4 μm, σ_t ~1 μs, ~0.1 W/cm²



Goal: σ(IP) ~ 5 μm for high P

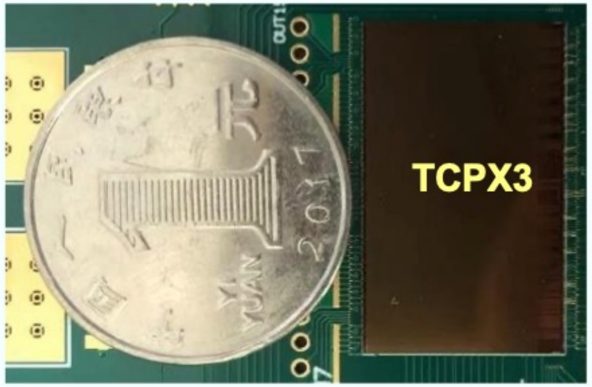
Key specifications:

- Single point resolution ~ 3 μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm²)
- Radiation hard (1 Mrad/year)



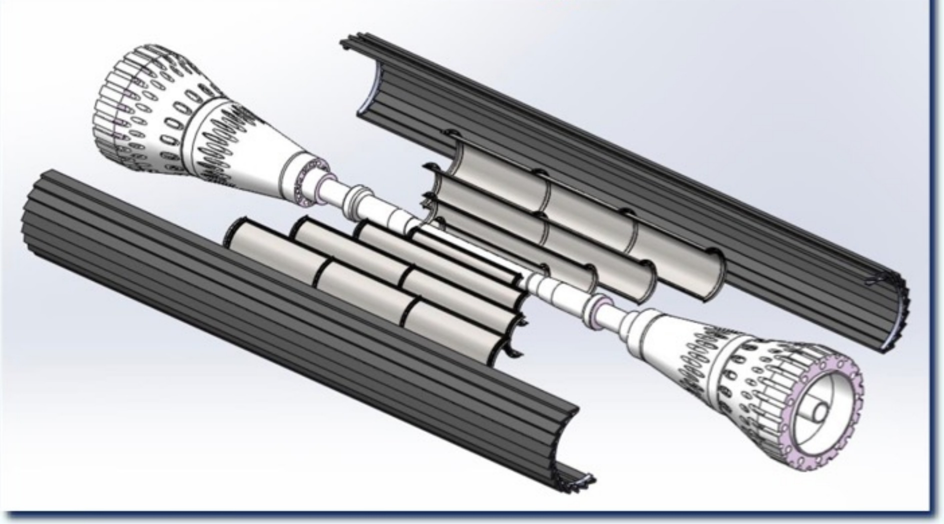
A TaichuPix-based prototype detector was tested at DESY in 2023. SP resolution ~4.9 μm. Thermal and material properties need further improvement.

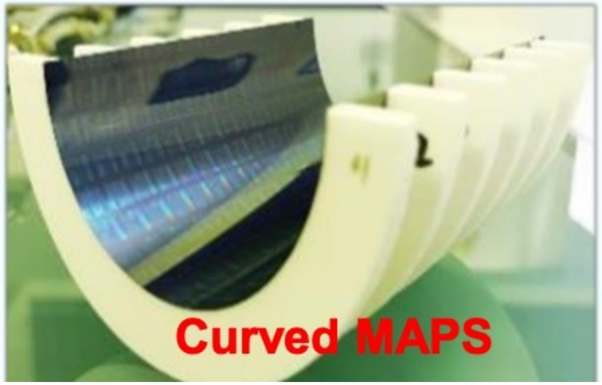
TaichuPix3
1024×512 array of 25×25 μm^2



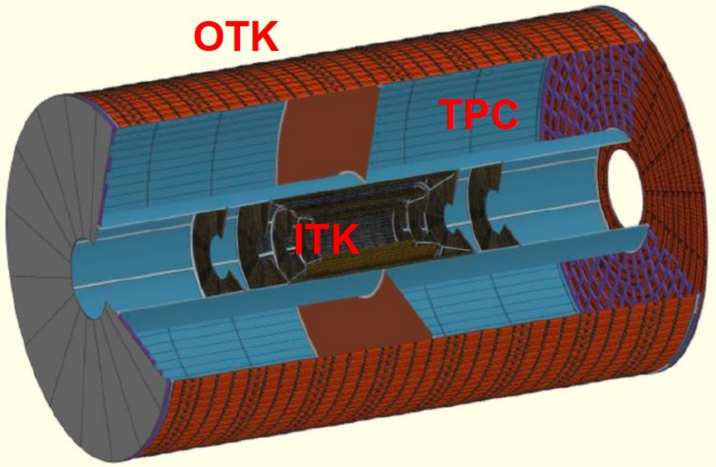
TowerJazz 180nm CIS process

Look into stitching + curved MAPS for less material and easier cooling

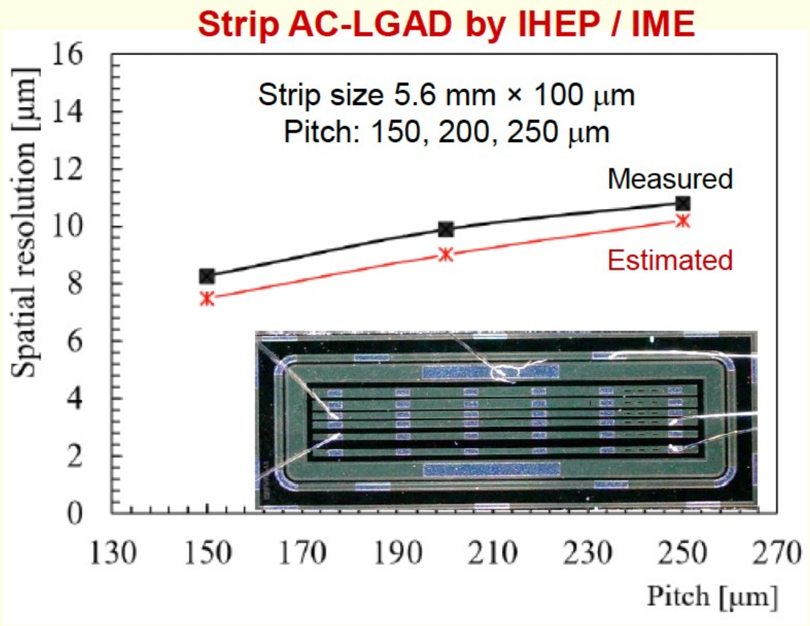


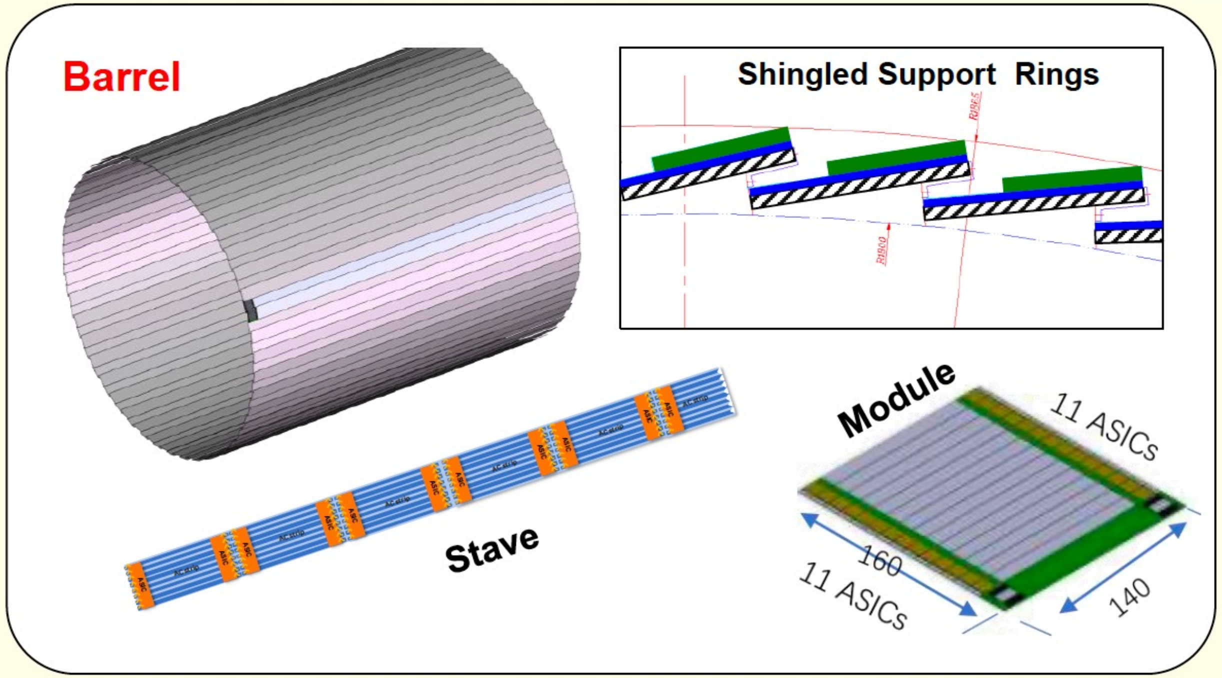


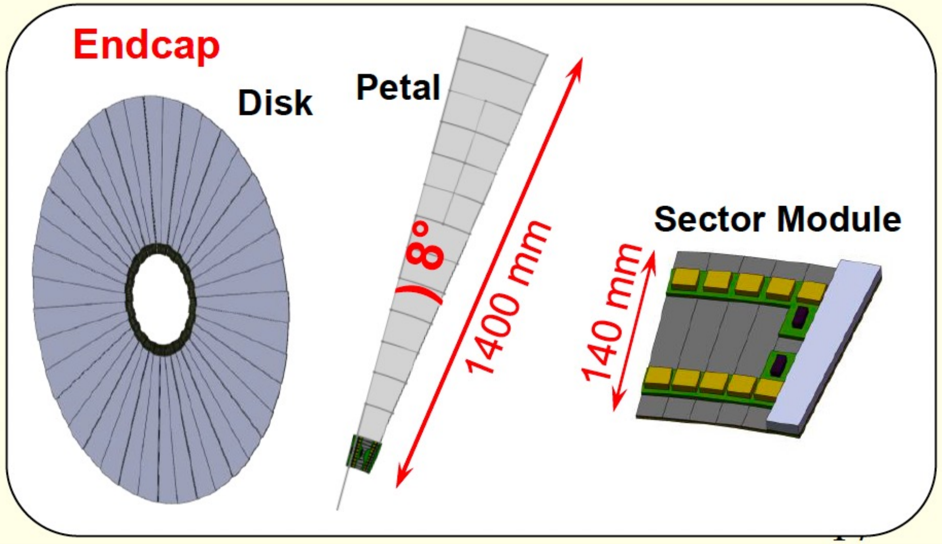
AC-LGAD based outter tracker + time of flight detector



- The outer silicon tracker ~ 85 m^2, the Z precision is not crucial
  $\Rightarrow$ Cost-effective SSD
- A supplemental PID at low energy
  $\Rightarrow$ LGAD ToF
- An AC-LGAD Time Tracker combines the two needs in one detector. We expect σ_t ~30 ps, $\sigma_{R\Phi}$ ~10 μm
- Need to validate with full size sensors

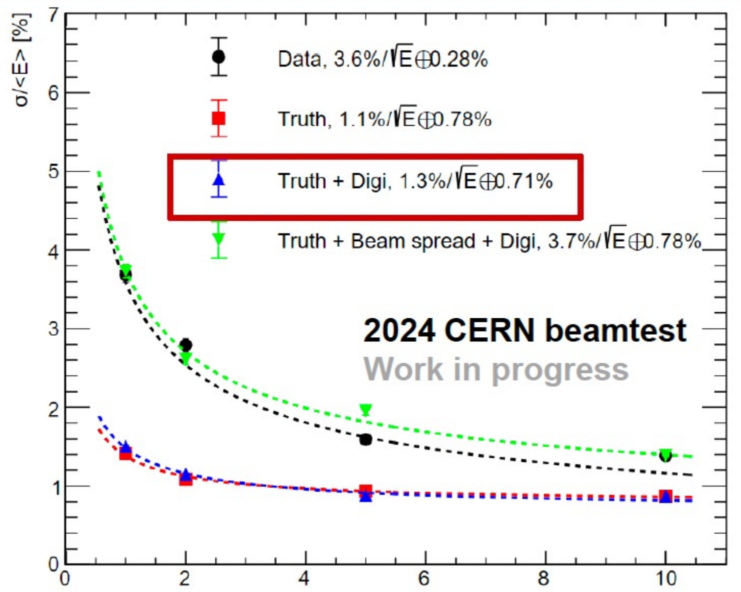


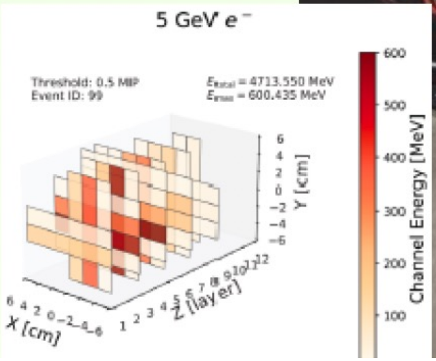


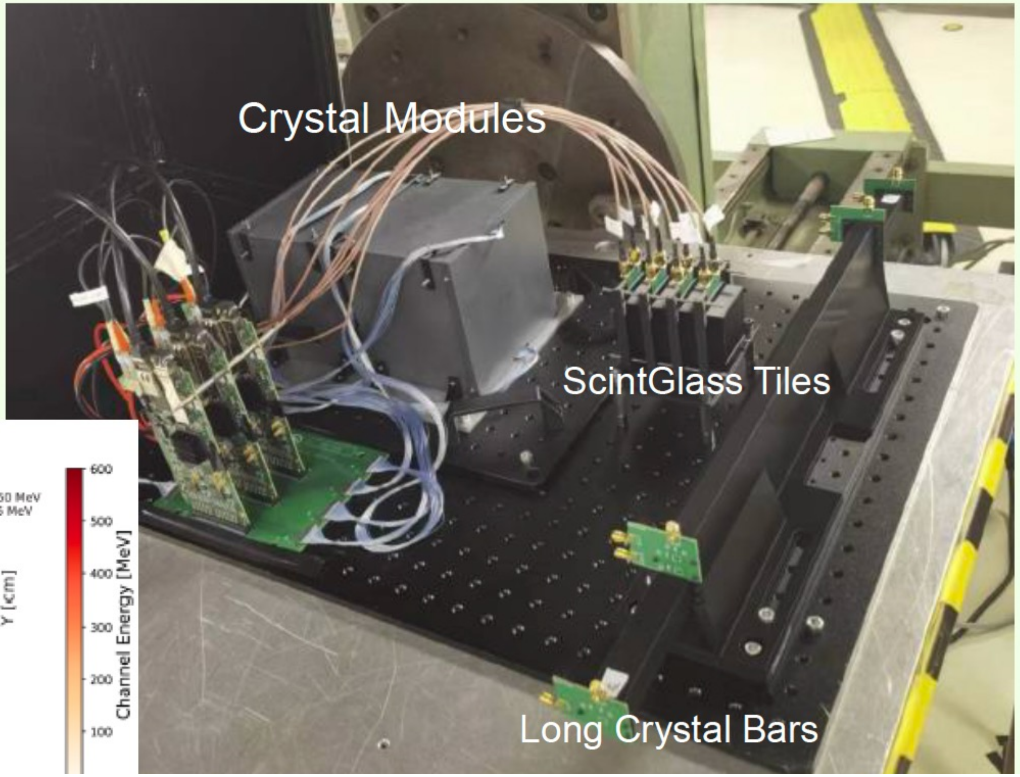


Testbeam of Prototype Crystal ECAL

- Successful testbeam @ DESY, CERN, 2023-2024 with small prototype
  - EM resolution (preliminary): $1.3\%/\sqrt{E} \oplus 0.7\%$
- To address critical issues at system level, validate design of crystal-SiPM, light-weight mechanical structure
- A full size prototype will be constructed
- Module development
  - BGO crystal bars from SIC-CAS
  - SiPM: 3×3 mm² sensitve area, 10μm pixel pitch







Timeline for CEPC ref-TDR

Date	Actions and/or Expectations
Jan 1, 2024	Start the ref-TDR process by comparing different technologies
Jul 1, 2024	Baseline technologies are chosen; start to write TDR and address key issues
Aug 7, 2024	Report to the IDRC chair Prof Daniela Bortoletto
Oct 21-23, 2024	Review of the Ref-TDR plan by the IDRC
Oct 23-27, 2024	Report at the CEPC workshop
Oct 29-30, 2024	Report progresses to the CEPC IAC
~ January 2025	The first draft of the ref-TDR is ready for internal reviews
~ April 2025	Finish international reviews
Jun 30, 2025	The ref-TDR is ready to release

We welcome more international and domestic teams to join the quest.

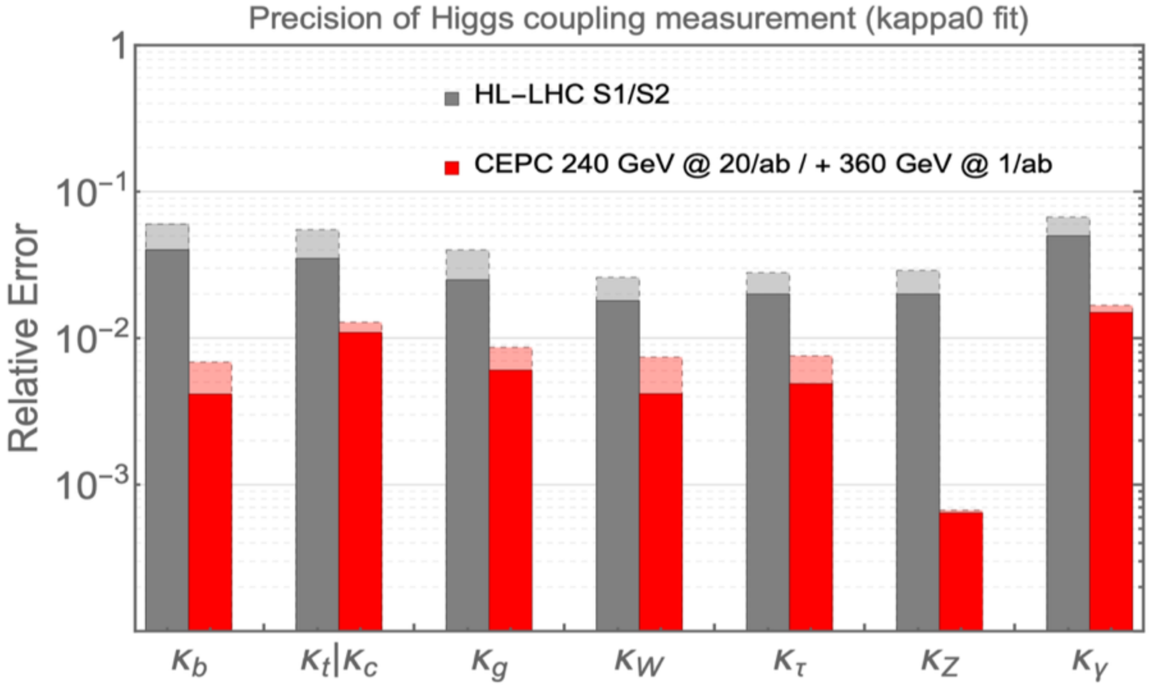
Higgs Precision measurements @ ZH runs

Translated the latest accelerator performance into Higgs measurements

Higgs		
Observable	HL-LHC projections	CEPC precision
M_H	20 MeV	3 MeV
Γ_H	20%	1.7%
$\sigma(ZH)$	4.2%	0.26%
$B(H \to bb)$	4.4%	0.14%
$B(H \to cc)$	-	2.0%
$B(H \to gg)$	-	0.81%
$B(H \to WW^*)$	2.8%	0.53%
$B(H \to ZZ^*)$	2.9%	4.2%
$B(H \to \tau^+\tau^-)$	2.9%	0.42%
$B(H \to \gamma\gamma)$	2.6%	3.0%
$B(H \to \mu^+\mu^-)$	8.2%	6.4%
$B(H \to Z\gamma)$	20%	8.5%
Bupper$(H \to \text{inv.})$	2.5%	0.07%

Higgs width measurement benefits enormously from 360-GeV run

Exploring the full potential of the CEPC with the latest TDR design for Higgs measurements by combining 240-GeV and 360-GeV runs.



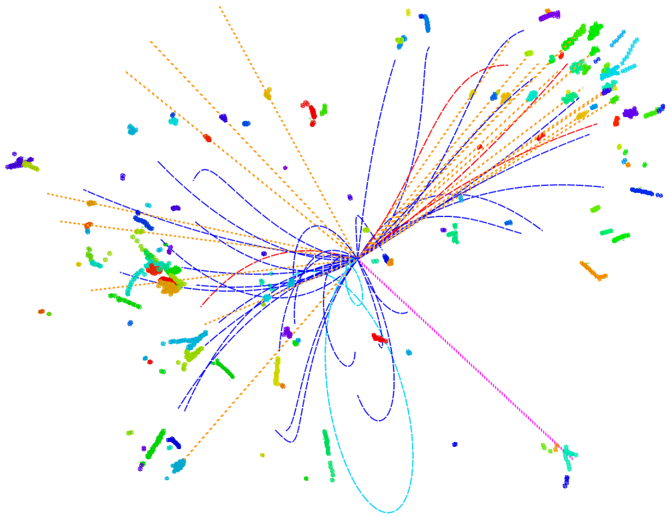
Outperforming HL-LHC significantly

Higgs coupling to quarks： Jet origin identification

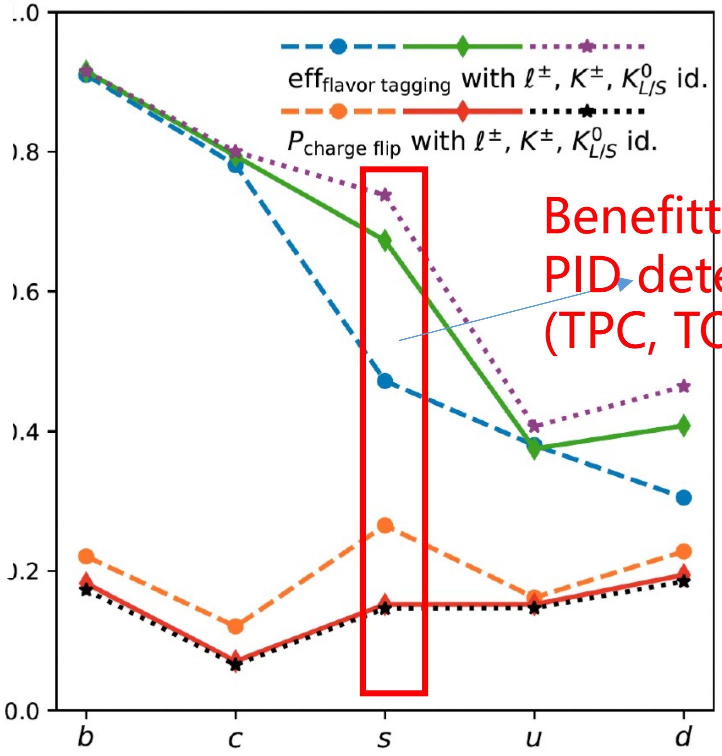
- **Higgs coupling to quarks can be measured to unprecedented precisions**
  - Especially for light quarks (strange quarks) …

PRL 132, 221802 (2024)

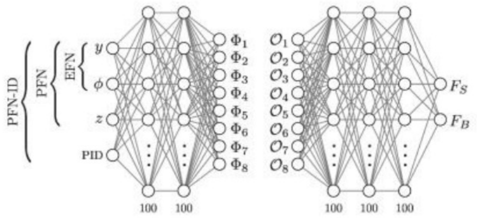
- **Jet origin identification: 11 categories (5 quarks + 5 anti quarks + gluon)**
  - Jet Flavor Tagging + Jet Charge measurements + s-tagging + gluon tagging…
  - PFA algorithm Arbor + ParticleNet (Deep Learning Tech.)



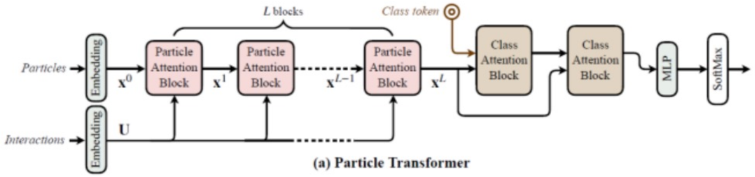
ArXiv:2310.03440
Arxiv:2309.13231



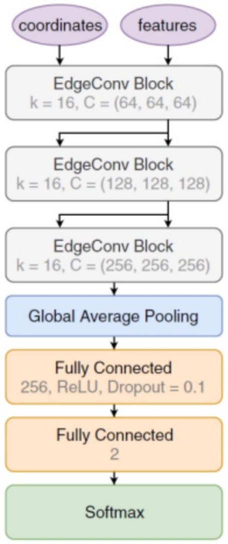
ParticleNet (Deep Learning Tech.)



EFN/PFN: JHEP01(2019)121



ParticleTransformer: 2202.03772



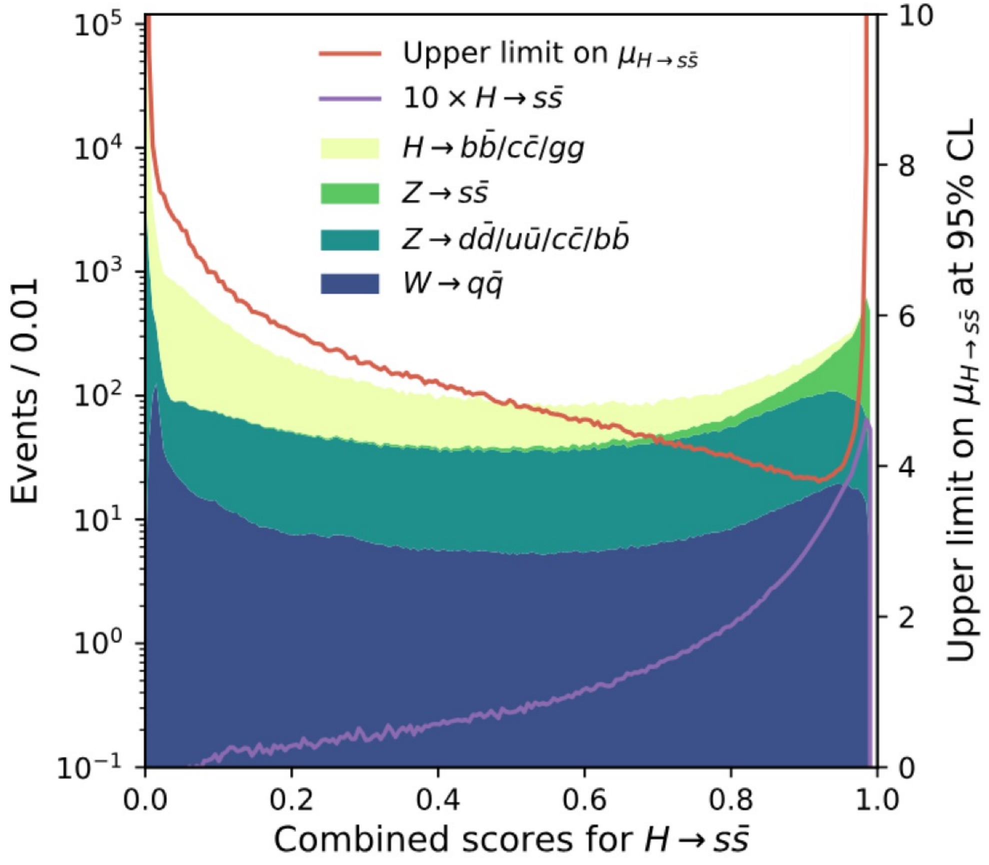
ParticleNet: Phys.Rev.D 101 (2020) 5, 056019

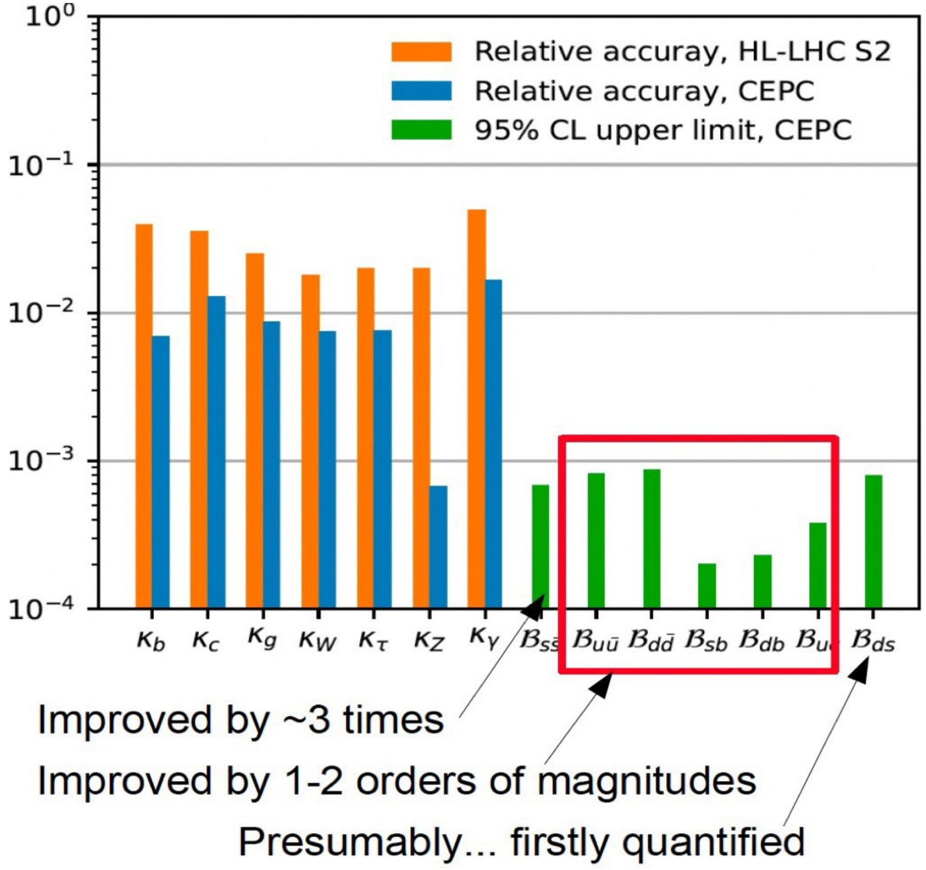
Higgs coupling to quarks： Jet origin identification

- **Higgs coupling to quarks can be measured to unprecedented precisions**

PRL 132, 221802 (2024)

- **From Jet Flavor Tagging to Jet Origin ID:**
  - ν ν H, H→cc: 3% → 1.7%； Vcb: 0.75% → 0.45%





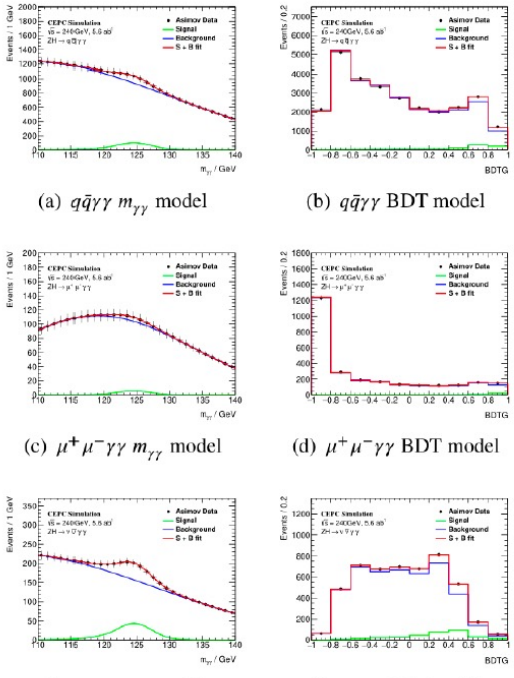
$H \rightarrow \gamma\gamma$

$H \rightarrow \gamma\gamma$

arXiv:2205.13269 by Fangyi Guo;
Previous studied by Feng Wang, Yitian Sun;

- Ecal performance dominated.
- CDR 17% -> Ref-TDR Cyber-PFA: 1.3%.

Channel	μ @ 5.6 ab^{-1}	μ @ 20 ab^{-1}
$q\bar{q}\gamma\gamma$	1.00 ± 0.0879	1.00 ± 0.0465
$\mu^+\mu^-\gamma\gamma$	1.00 ± 0.3571	1.00 ± 0.1920
$\nu\bar{\nu}\gamma\gamma$	1.00 ± 0.1142	1.00 ± 0.0605
Combined	1.00 ± 0.0688	1.00 ± 0.0364

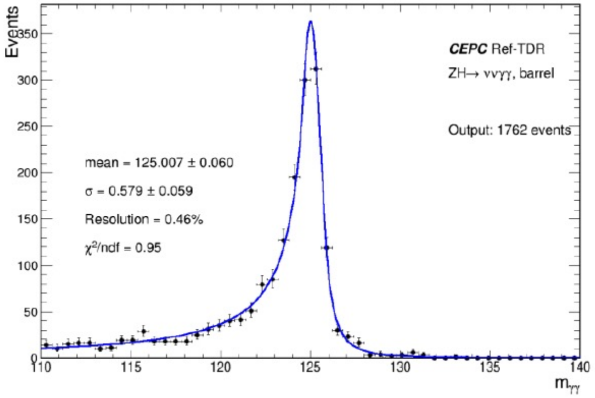


(a) $q\bar{q}\gamma\gamma$ $m_{\gamma\gamma}$ model (b) $q\bar{q}\gamma\gamma$ BDT model

(c) $\mu^+\mu^-\gamma\gamma$ $m_{\gamma\gamma}$ model (d) $\mu^+\mu^-\gamma\gamma$ BDT model

(e) $\nu\bar{\nu}\gamma\gamma$ $m_{\gamma\gamma}$ model (f) $\nu\bar{\nu}\gamma\gamma$ BDT model

More details in Kaili's talk in CEPC workshop
https://indico.ihep.ac.cn/event/22089/contributions/168545



Expect precision to 1.8%.

DSCB fit give resolution 0.46%.
low mass tail can be further controlled with Ecal PFA algorithm.

Higgs width @ CEPC

- Standalone 240GeV 20ab^{-1} run gives ~**1.5%**
- Standalone 360GeV 1ab^{-1} alone gives **3.3%**.
- By combination of 240 and 360GeV run, potential to reach $\Delta\ \Gamma_H$ < **1.0%**

  - 1) tagging Higgs final states

$$\sigma(\mathrm{ee} \to \mathrm{ZH}) \cdot \mathrm{BR}(\mathrm{H} \to \mathrm{ZZ}) \propto \frac{\mathrm{g}_{\mathrm{HZ}}^4}{\Gamma}$$

  - 2) measurements of vector boson fusion production at 350-365 GeV

$$\frac{\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{WW})\cdot\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}{\sigma(\mathrm{ee}\to\nu\nu\mathrm{H})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}$$

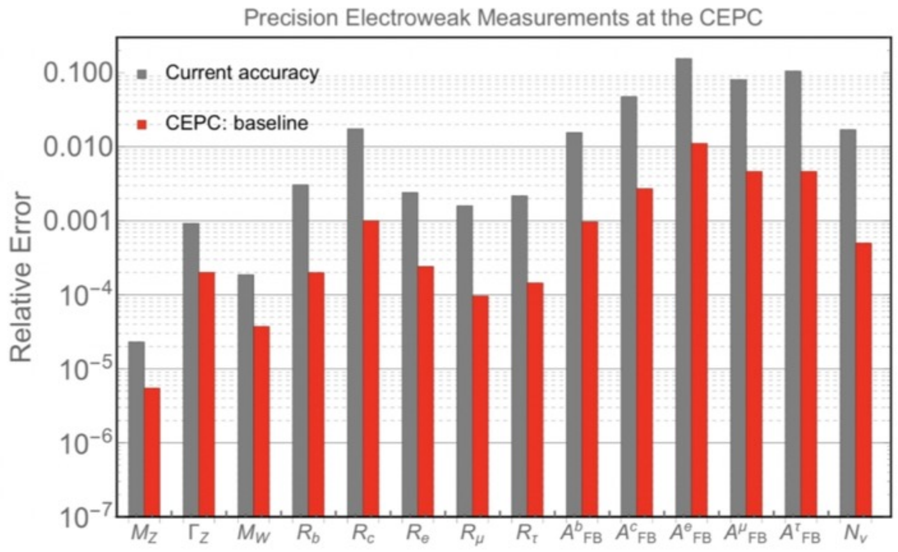
$$\propto \frac{\mathrm{g}_{\mathrm{HZ}}^2\cdot\cancel{\mathrm{g}_{\mathrm{HW}}^2}}{\Gamma}\cdot\frac{\mathrm{g}_{\mathrm{HZ}}^2\cdot\cancel{\mathrm{g}_{\mathrm{Hb}}^2}}{\cancel{\Gamma}}\cdot\frac{\cancel{\Gamma}}{\cancel{\mathrm{g}_{\mathrm{HW}}^2}\cdot\cancel{\mathrm{g}_{\mathrm{Hb}}^2}} = \frac{\mathrm{g}_{\mathrm{HZ}}^4}{\Gamma}$$

  - 3) combination of all measurements

More details in Kaili's talk in CEPC workshop
https://indico.ihep.ac.cn/event/22089/contributions/168545

EWK precision measurements@ CEPC (ZH, Z pole, WW runs)

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

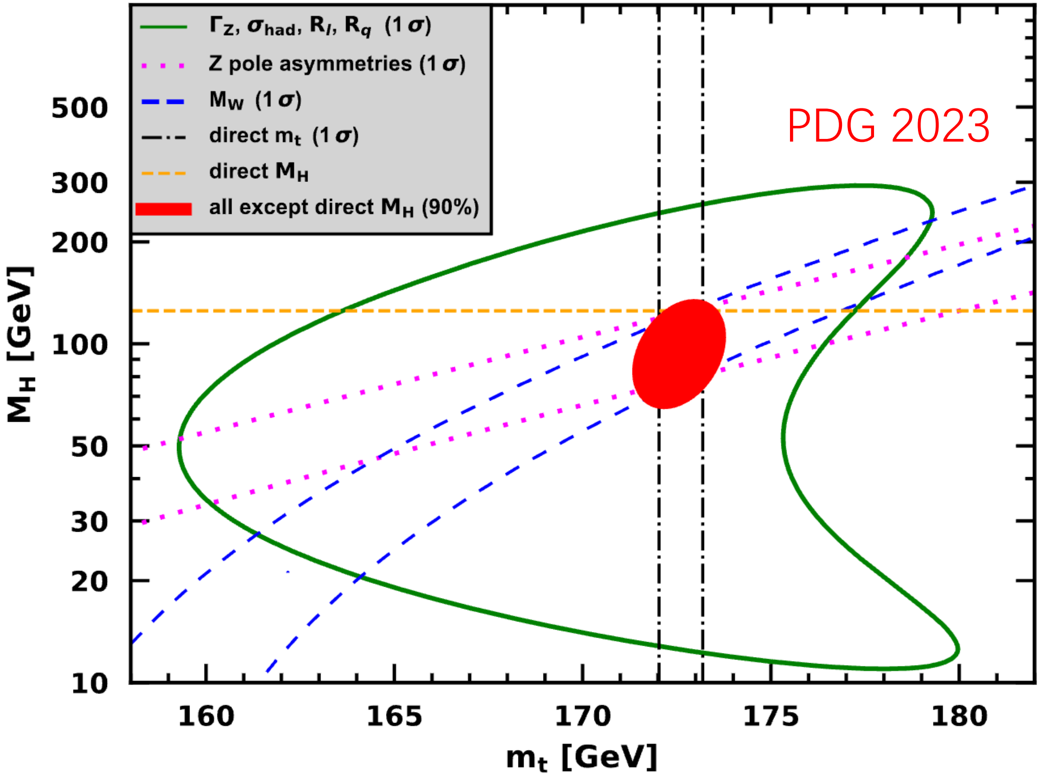


CEPC is expected to improve the current precision by 1-2 orders of magnitude, offering a great opportunity to test the consistency of the SM.

The status of electroweak global fit

❖7 key observables in electroweak global fit

- Consistency study of the standard model electroweak section
- Need CEPC Z pole and WW runs : Precise measurements on EWK observables.

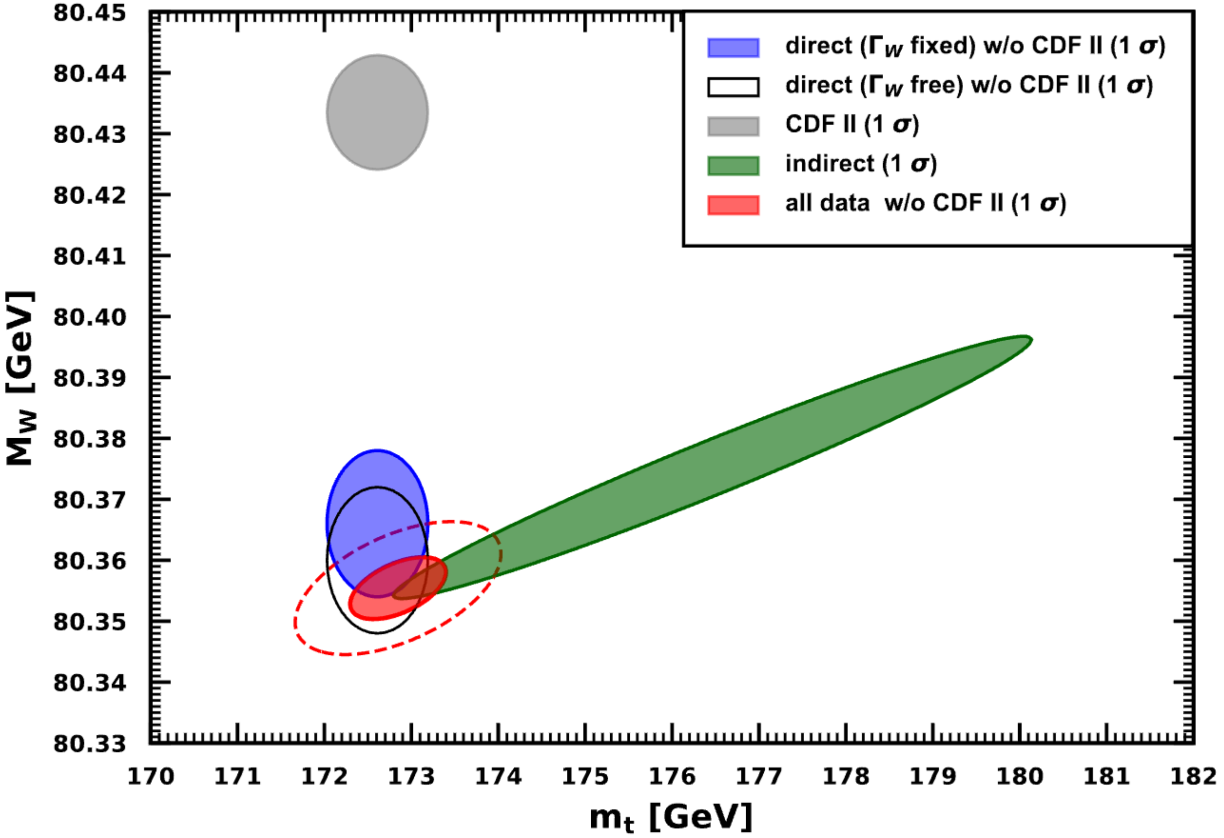


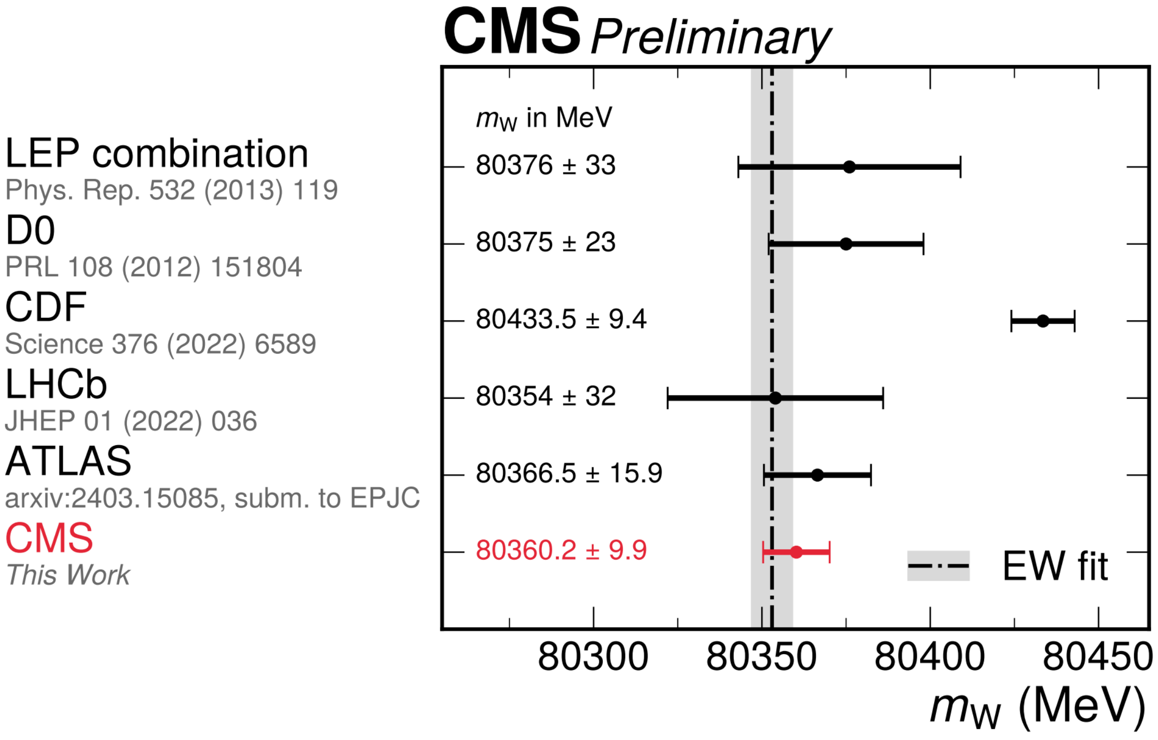
Fundamental constant	δx/x	measurements
$\alpha = 1/137.035999139\ (31)$	1×10^{-10}	$e^{\pm}\ g_2$
$G_F = 1.1663787\ (6) \times 10^{-5}\ \mathrm{GeV}^{-2}$	1×10^{-6}	$\mu^{\pm}$ lifetime
$M_Z = 91.1876 \pm 0.0021$ GeV	1×10^{-5}	LEP
$M_W = 80.379 \pm 0.012$ GeV	1×10^{-4}	LEP/Tevatron/LHC
$\sin^2\theta_W = 0.23152 \pm 0.00014$	6×10^{-4}	LEP/SLD
$m_{top} = 172.74 \pm 0.46$ GeV	3×10^{-3}	Tevatron/LHC
$M_H = 125.14 \pm 0.15$ GeV	1×10^{-3}	LHC

W mass measurement status

❖ **m_W is a key observable to test SM consistency**

- ▶ Significant tension between CDF and latest CMS result
- ▶ m_W Measurement at future collider is essential, large impact to EWK global fit





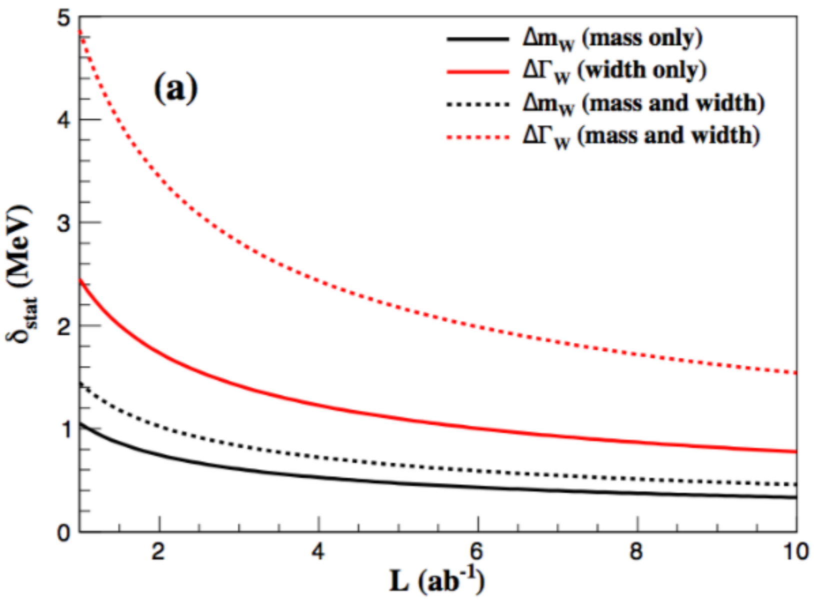
Prospect of W mass measurement at CEPC (WW threshold runs)

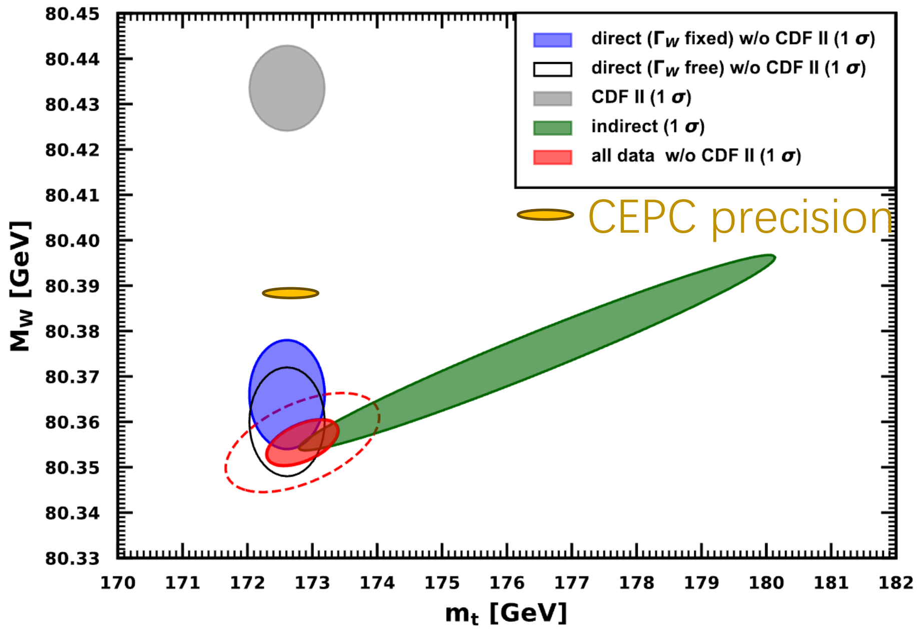
❖ **Expect to reach below 1MeV precision on W mass**

- Four energy scan points:
  - **157.5, 161.5, 162.5(W mass, W width measurements)**
  - **172.0 GeV (αQCD (mW), Br (W->had) , CKM |Vcs|)**

Observable	current precision	CEPC precision (Stat. Unc.)
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)
$\Delta \Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)

Observable	m_W	Γ_W
Source	Uncertainty (MeV)	
Statistics	0.8	2.7
Beam energy	0.4	0.6
Beam spread	–	0.9
Corr. syst.	0.4	0.2
Total	1.0	2.8



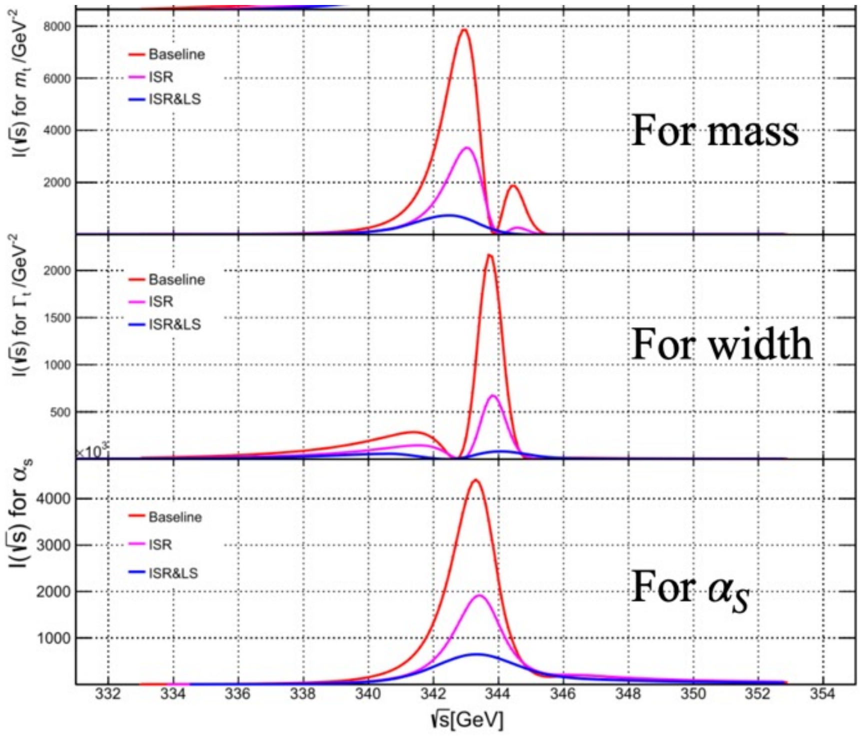


P.X.Shen, P.Azzuri , G.Li et,al,
Eur.Phys.J.C 80 (2020) 1, 66
Joint study of CEPC/Fcc-ee

Top quark measurements @ ttbar threshold runs

$t\bar{t}$ modes are considered as upgrades.

the optimal energy point



$\sqrt{s}$ (GeV)	$\Delta\ m_{top}$	$\Delta\ \Gamma_{top}$	$\Delta\ \alpha_S$
342.75	9 MeV	343 MeV	0.00041
344.00	> 50 MeV	26 MeV	0.00047
343.50	15 MeV	40 MeV	0.00040

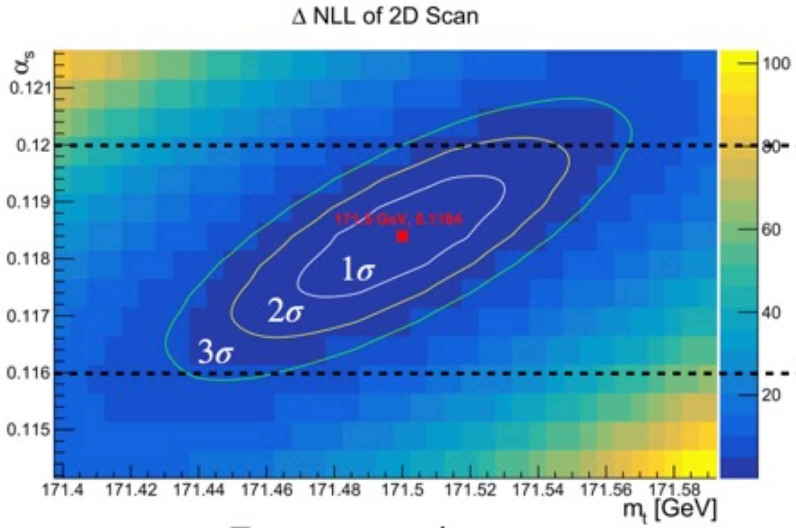
In the table, 342.75 GeV, 344.00 GeV and 343.50 GeV are optimal energy points for top quark mass, width and α_S, respectively

Observable	current precision	CEPC precision (Stat. Unc.)
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]

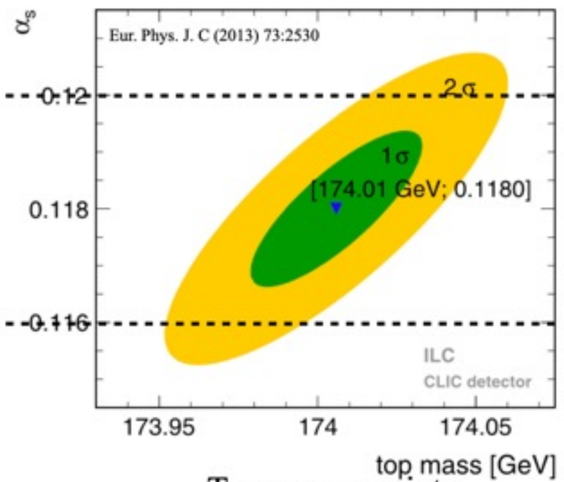
The top quark mass can be measured with an unprecedented precision (one order of magnitude better than hadron colliders can achieve) .

CEPC ttbar runs physics potential is competitive

Top mass Vs alpha_s likelihood

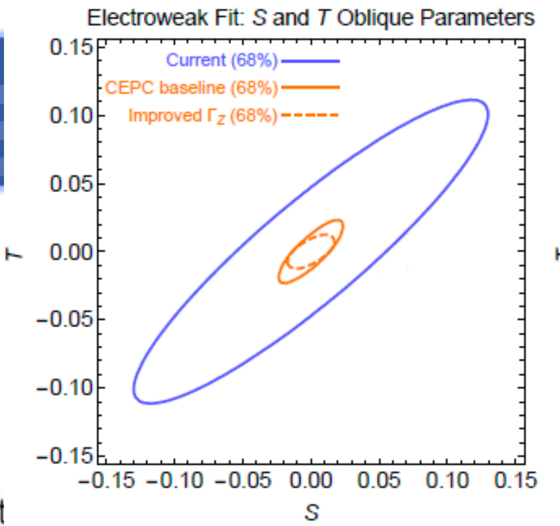


Two energy points

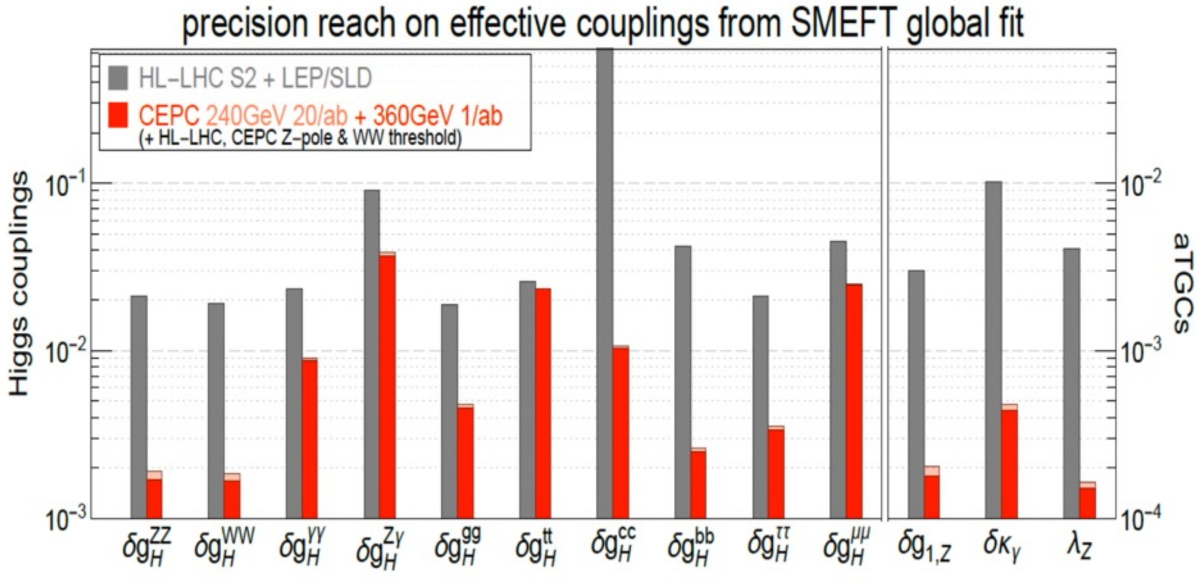


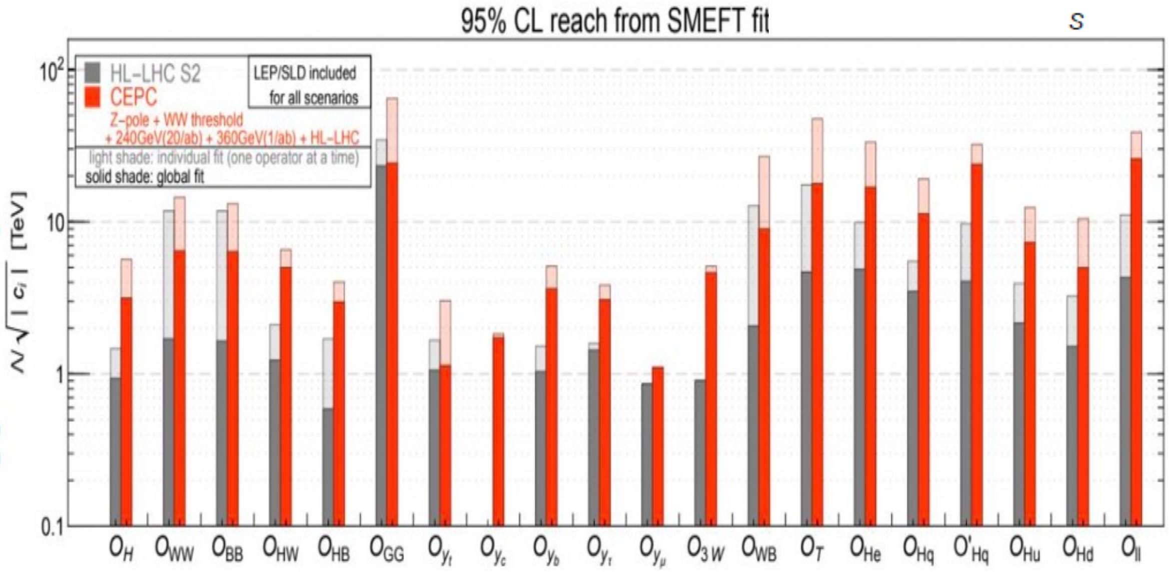
Ten energy points

Global fit with SMEFT: new physics constrains



$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \cdots$$

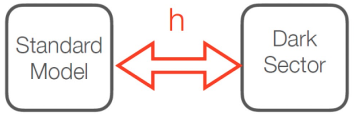




CEPC has potential to reveal new physics @10 TeV by combining Higgs, EWK and top measurements → power of precision

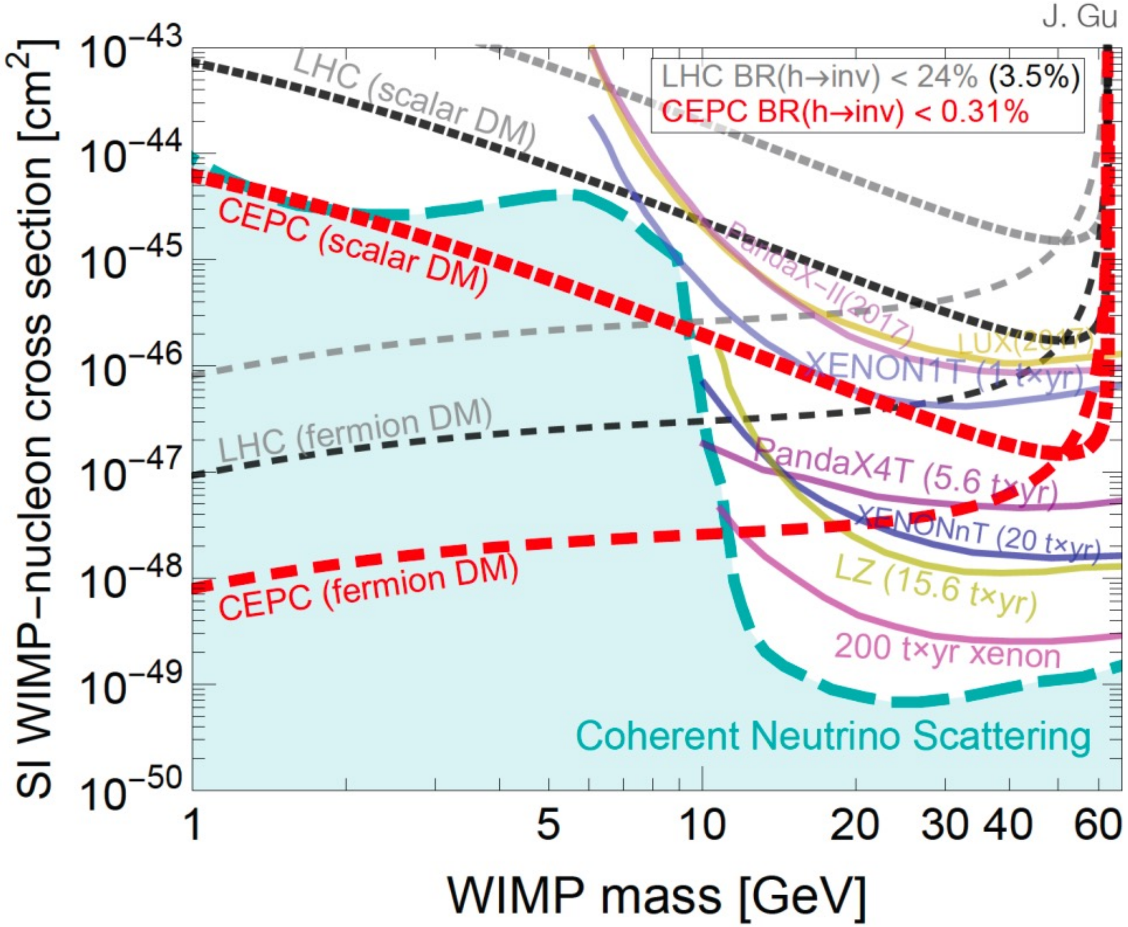
BSM searches: dark matter, SUSY…

❖ **Significantly better detection sensitivity to dark matter and SUSY**

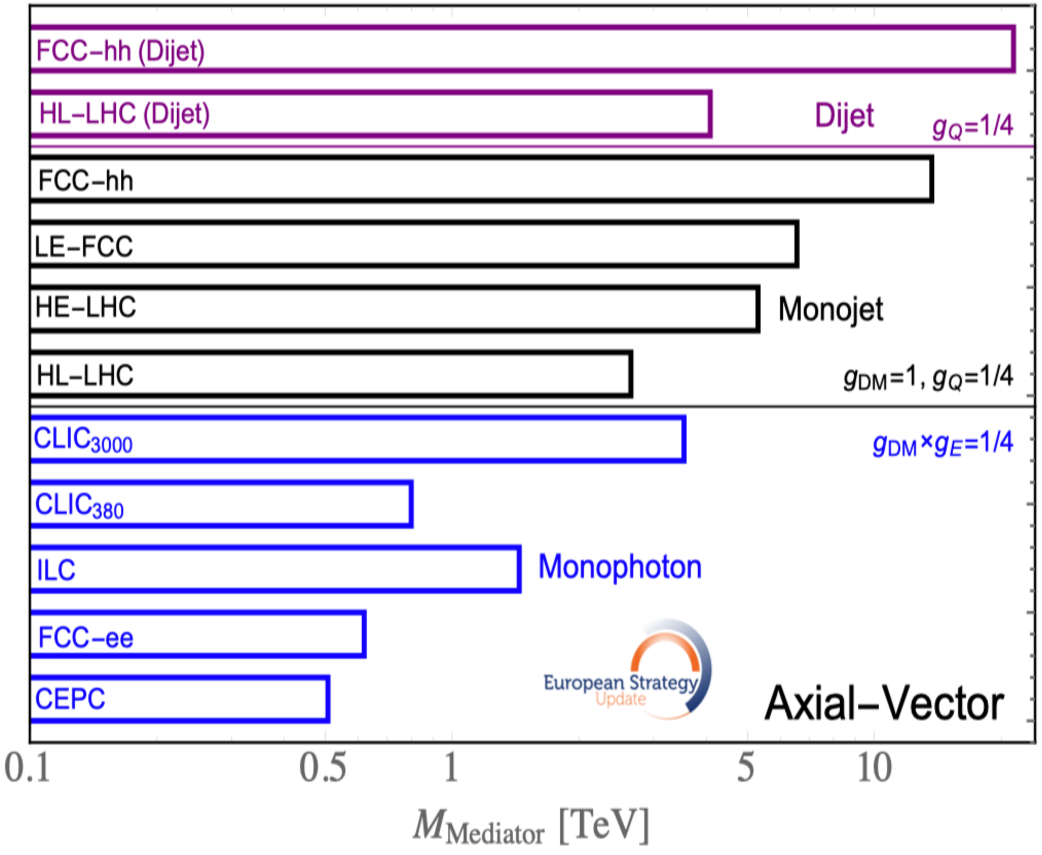


$$h \rightarrow X_{dm} X_{dm}$$

Higgs-portal Dark matter



SUSY Dark matter

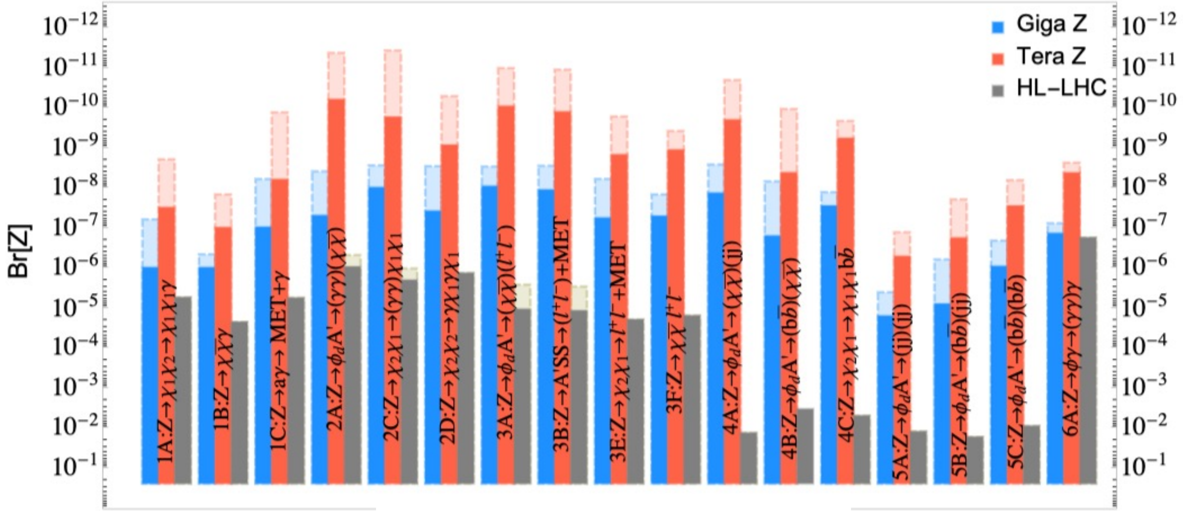


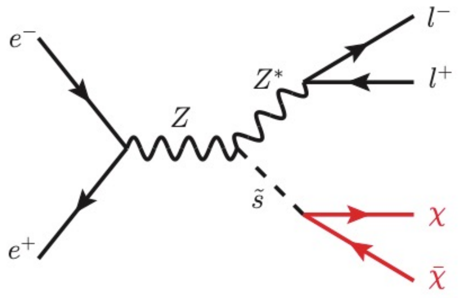
BSM searches: exotic decays, Dark Sector…

❖Significantly better detection sensitivity to Higgs/Z exotic decays than HL-LHC

Dark Sector via exotic Z decay

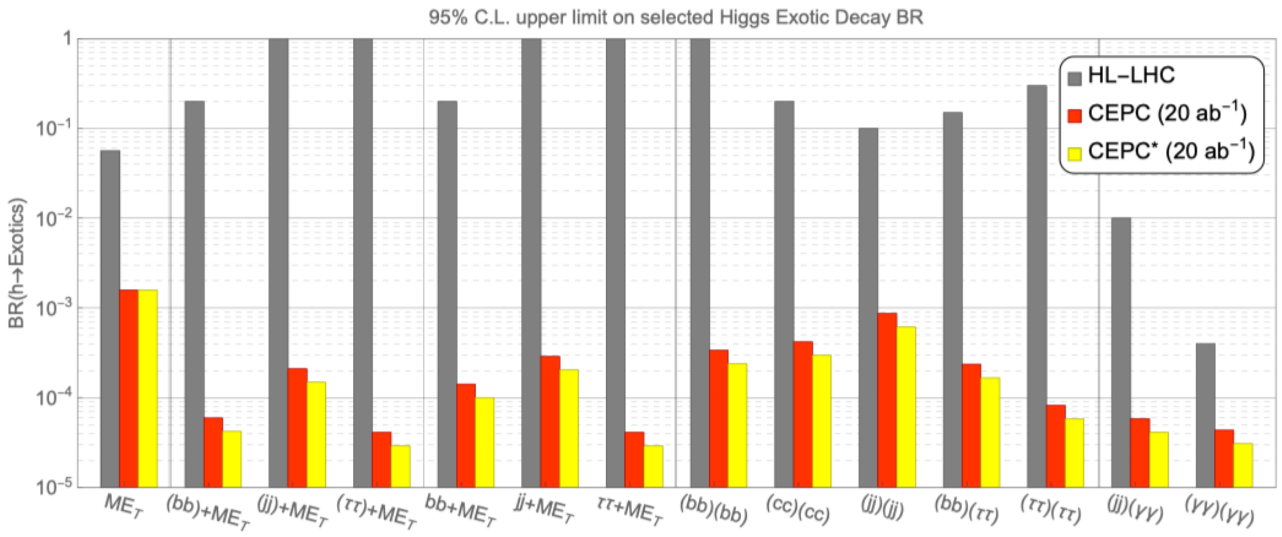
Z. Liu et al. 1612.09284., J. Liu et al. 1712.07237





Good sensitivity of exotic Higgs decay

Z. Liu et al 1612.09284.



Physics case and physics benchmark study in Ref-TDR

❖ **Please consider to join us for Reference detector TDR physics benchmark study**

	Processes @ c.m.s.	Domain	Anticipated relative accuracies/up limit with CDR baseline detector + TDR Luminosity, with JoI	@Ref TDR
H→cc	ννH @ 240 GeV	Higgs	1.7%	1.6%
H→ss [1]			95% up limit of 0.75E-3	95% up limit of 0.70E-3
H→sb [1]			95% up limit of 0.22E-3	95% up limit of 0.20E-3
H→inv [2]	qqH	Higgs/NP	95% up limit of 0.13%	Same
Vcb [3]	WW→lνqq @ 240/160 GeV	Flavor	0.4%	0.36%
W fusion Xsec [2]	ννH @ 360 GeV	Higgs	1.1%	Same
α_s	Z→tautau @ 91.2 GeV	QCD	NAN	Theoretical Uncertainty Dominant
CKM angle $\gamma - 2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	NAN	~o(0.1 - 1) degree
Weak mixing angle [4]	Z@ 91.2 GeV	EW	2.4E-6 using 1 month data (~ 2E11 Z)	~ tiny improvement due to VTX
Higgs recoil [5]	llH	Higgs	δm = 2.5 MeV $\delta\sigma/\sigma$ = 0.25%/0.4% (wi/wo qqH)	Same
H→bb, gg [2]	ννH + qqH	Higgs	bb: 0.14% -> 0.13% gg: 0.81% -> 0.65% (wi/wo JoI)	bb: 0.12% gg: 0.62%
H→di muon [2]	qqH	Higgs	6.4%	Same
H→di photon [2]	qqH	Higgs	3%	1.8%
W mass & Width [6]	W threshold scan @160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab	Same
Top mass & Width [7]	Top threshold scan @360 GeV	EW	9 MeV & 26 MeV @ 100 ifb	Same
Bs→ $\nu\nu\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)	Same, if object recon. ~ CDR
Bc→ $\tau\nu$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)	Same, if object recon. ~ CDR
B0→ $2\pi^0$ [10]	91.2 GeV	Flavor	NAN	0.3%, need to validate photons finding

- H->γγ precisions improves significantly, if low mass tail tamed.
- Physics measurements using JoI, etc, benefit from better VTX and have 5-10% improvements，and assuming that the TDR BMR could eventually reach 3.7%
  - If BMR of 3% achieved, precisions of most benchmarks could be further improved by 5-10%
  - Need further development on pattern recognition capability of Crystal Bar ECAL

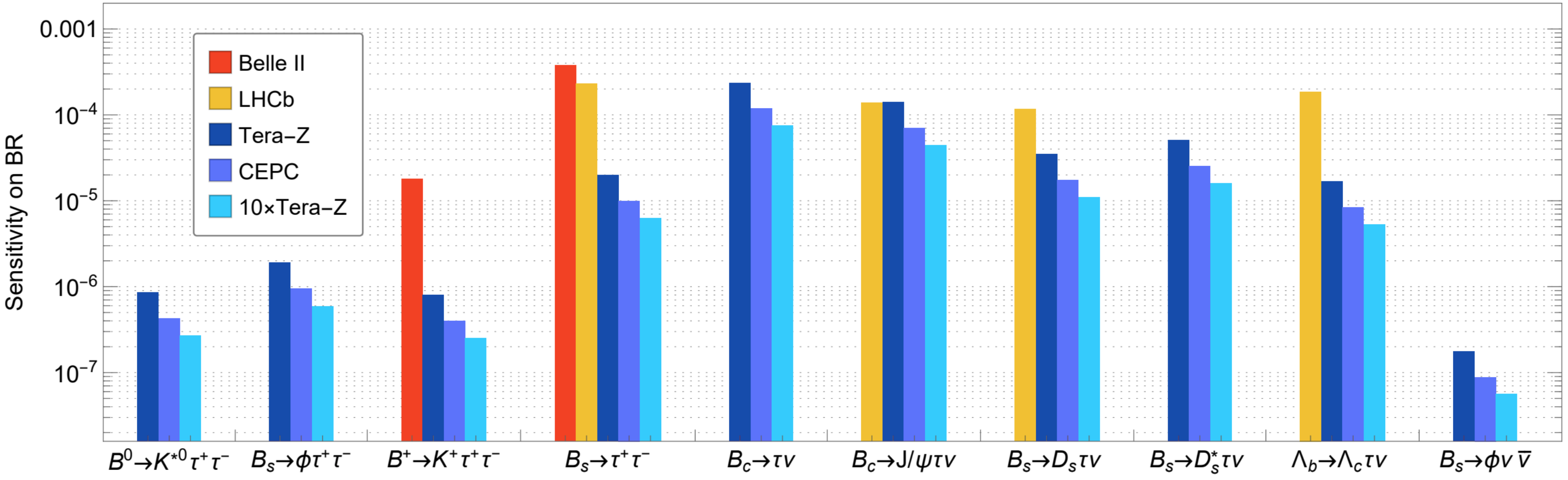
Summary

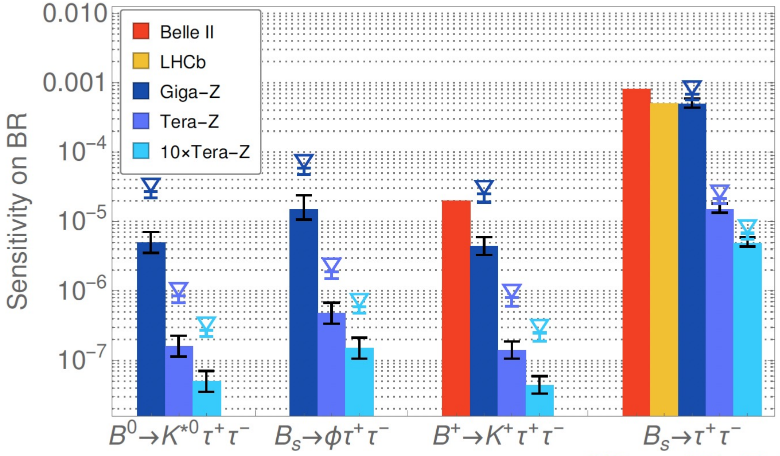
- CEPC physics studies constantly updated, improved and expanded to fully explore the CEPC physics potential.
- Reference detector TDR under preparation, to be completed by the mid-2025 for the proposal of China's 15th 5-year plan.
- Please consider to join us for Reference detector TDR physics benchmark study
- Intense R&D activities are underway on the baseline detector concept targeting key technologies of all sub detectors. Significant progress has been made and several R&D projects have reached milestones.
- It is important to expand international collaboration and explore synergies with other international projects.
  - Existing collaboration: CALICE Collaboration (PFA calorimeters), LCTPC Collaboration (TPC), INFN(Drift chamber), CMOS tracker Collaboration (Silicon tracker), French and Spain institutes (CMOS pixel), DRD1-8 Collaboration

Backup

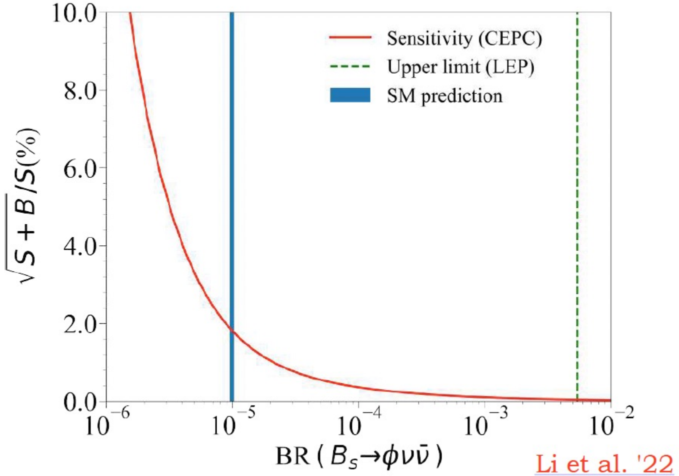
Flavor physics studies @ Z pole

CEPC provides a unique opportunity to study Z LFV decays, rare B decays, tests of LFU in tau decays or Bc decays etc.





Li L. and Liu T. '20



Li et al. '22

White paper draft

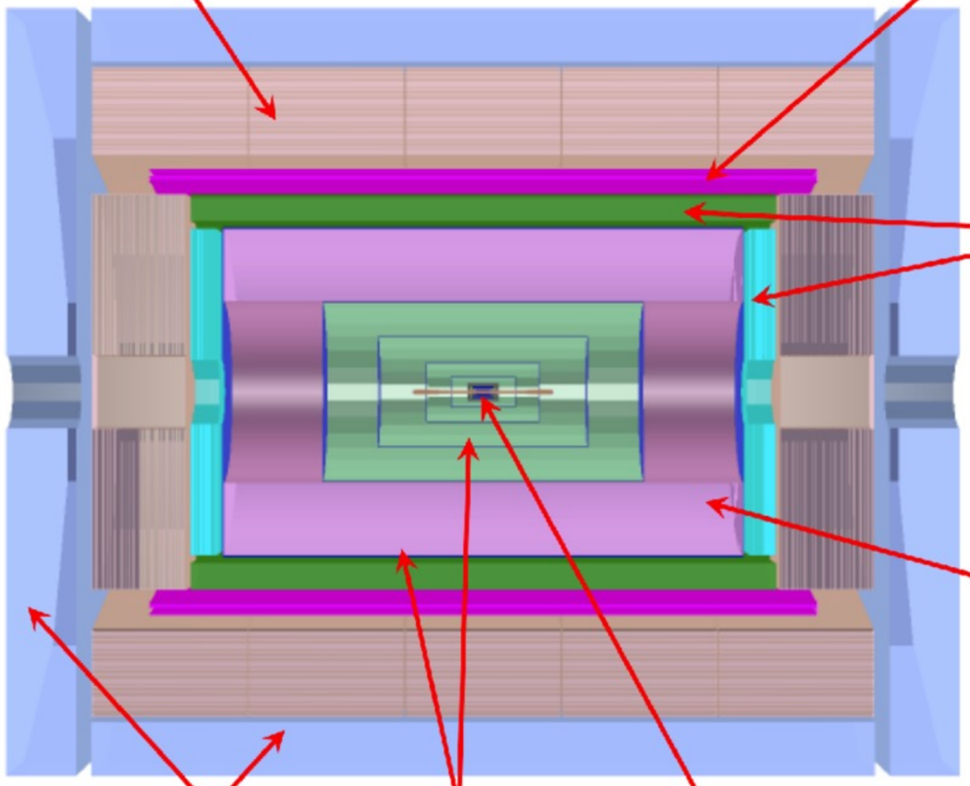
Contents

More details in flavor physics section

The 4th Detector Concept

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.

Crystal 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.

Excellent e/gamma energy resolution;

PID capability;

Better hadronic energy resolution;

Magnet in much reduced size.

BMR: 4% → 3%

The 4th Detector Concept

❖ **Silicon combined with TPC or DC and TOF**

→better tracking and PID

- Good k/pi separation up to 20GeV

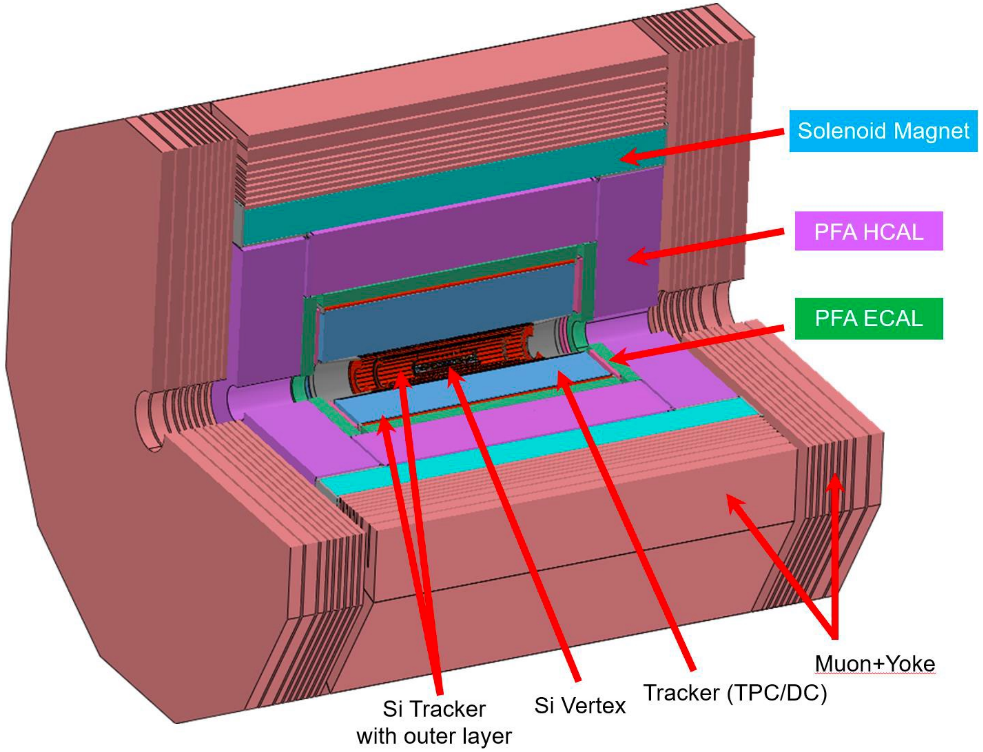
❖ **4D Crystal ECAL with timing**

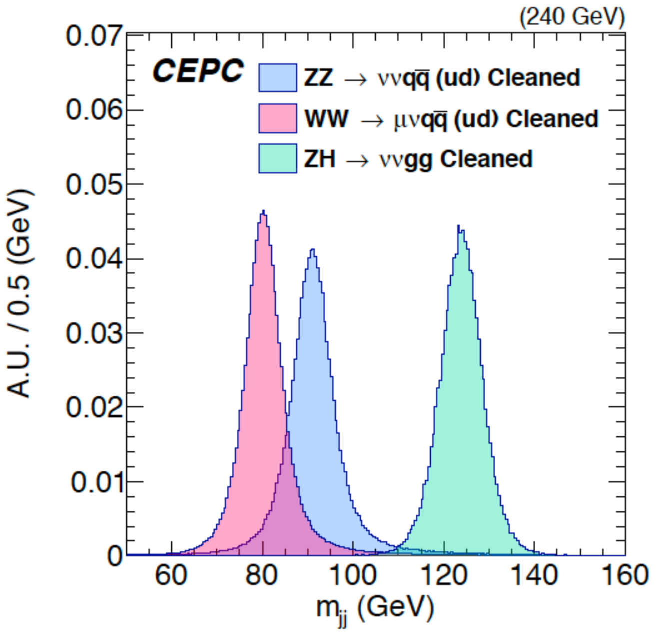
- For PFA and with better EM resolution

❖ **Scintillating glass HCAL:**

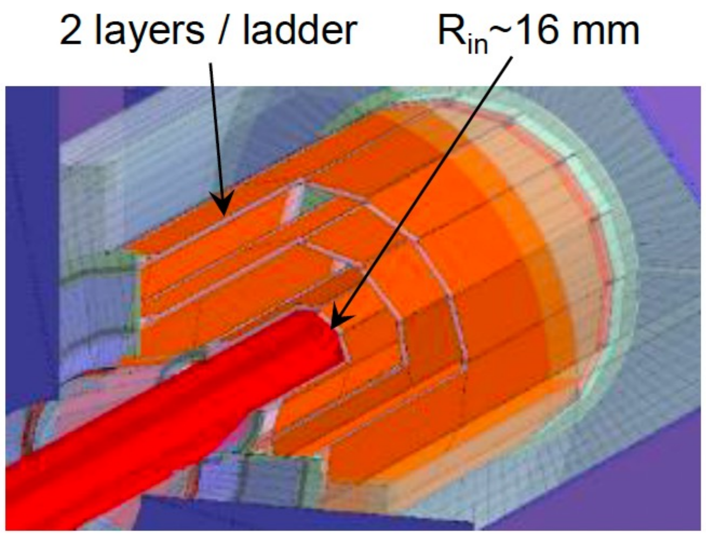
- Cost effective, better jet resolution

❖ **Boson mass resolution (BMR):4% → 3%**





Silicon Pixel Chips for Vertex Detector



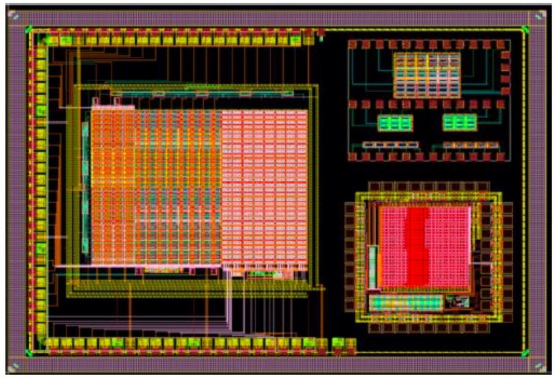
Goal: σ(IP) ~ 5 μm for high P track

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 5 series:
JadePix, TaichuPix, CPV, Arcadia, COFFEE

Develop **COFFEE** for a CEPC tracker using SMIC 55nm HV-CMOS process

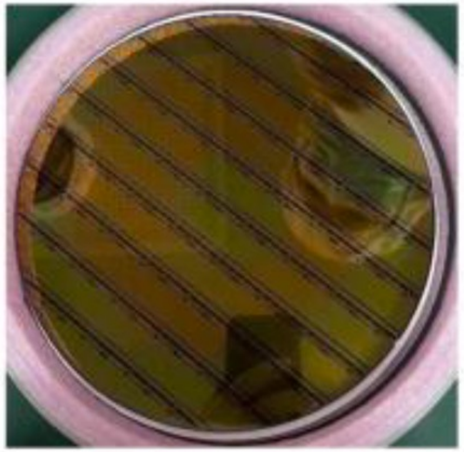


JadePix-3 Pixel size ~16×23 μm^2

Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm^2

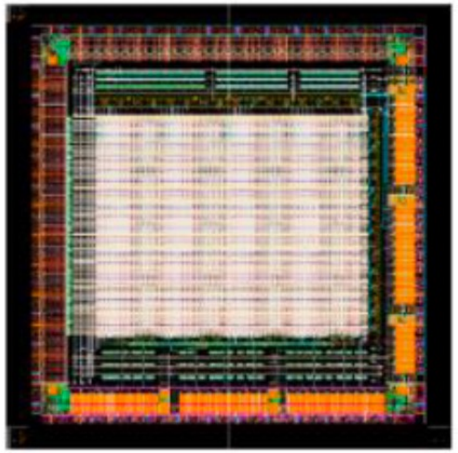
MOST 1

TaichuPix-3, FS 2.5x1.5 cm^2
25×25 μm^2 pixel size

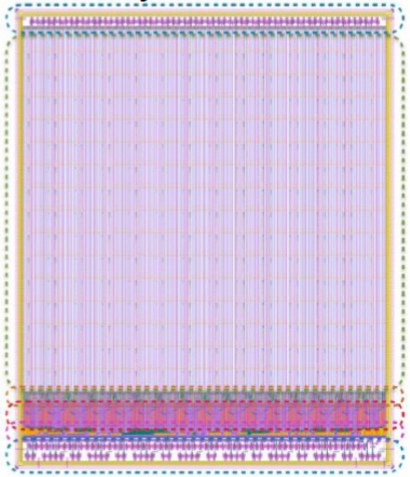


MOST 2

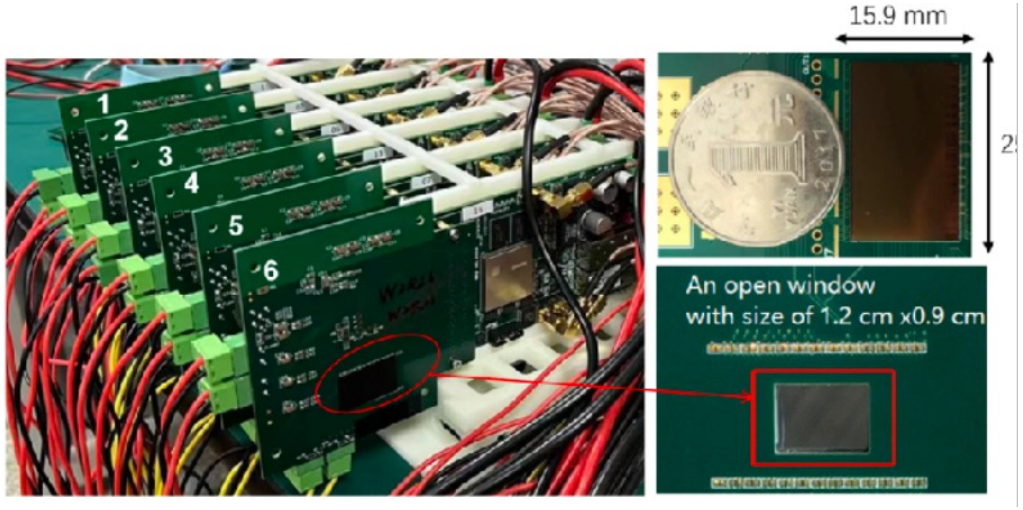
CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size

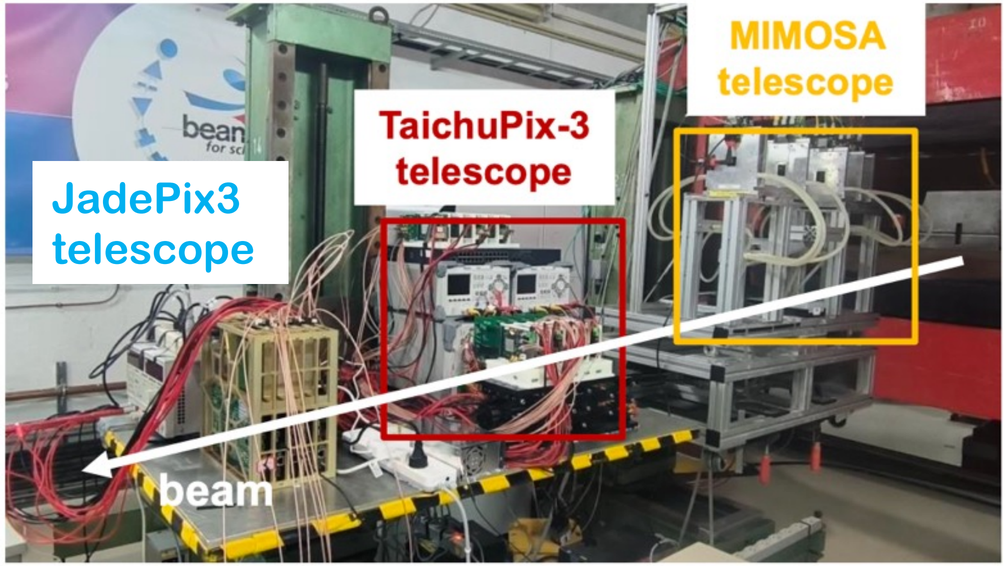


Arcadia by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS



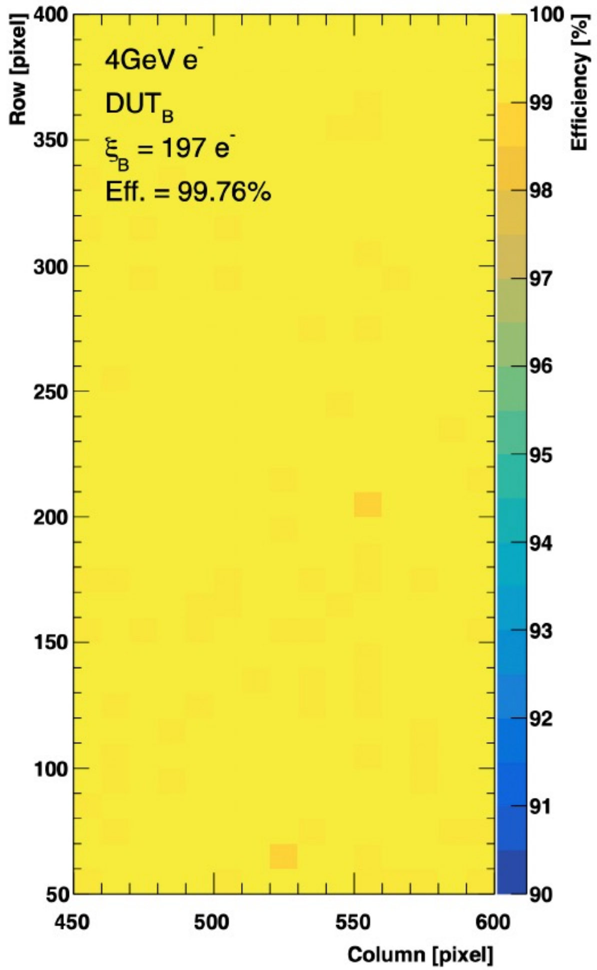
Jadepix3/TaichuPix3 beam test @ DESY



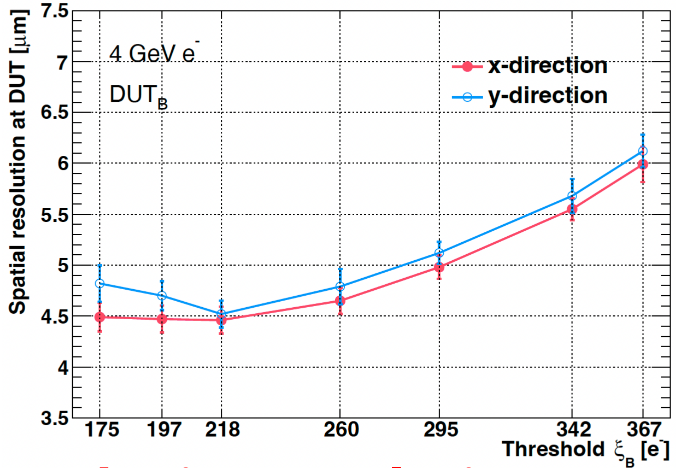


Spatial resolution 4~5um, Efficiency >99%

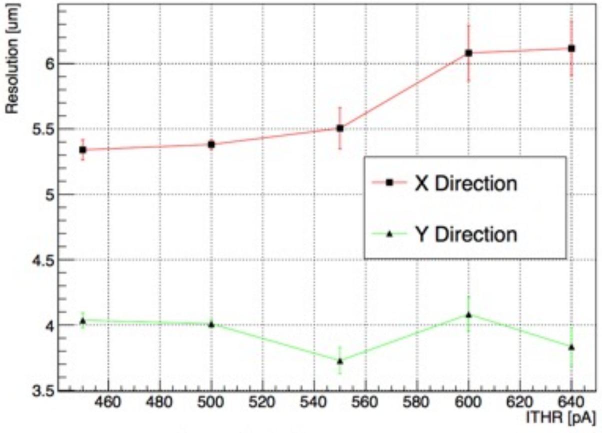
TaichuPix3 efficiency



TaichuPix3 resolution

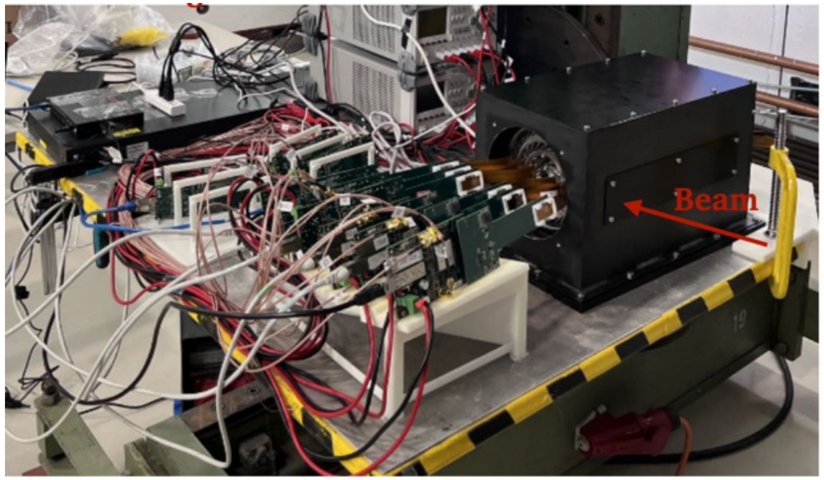


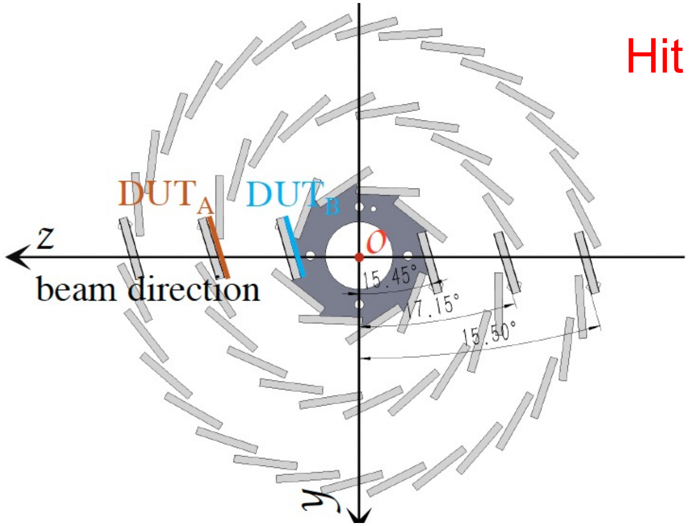
JadePix3 resolution



Collaboration with CNRS and IFAE in Jadepix/TaichuPix R & D

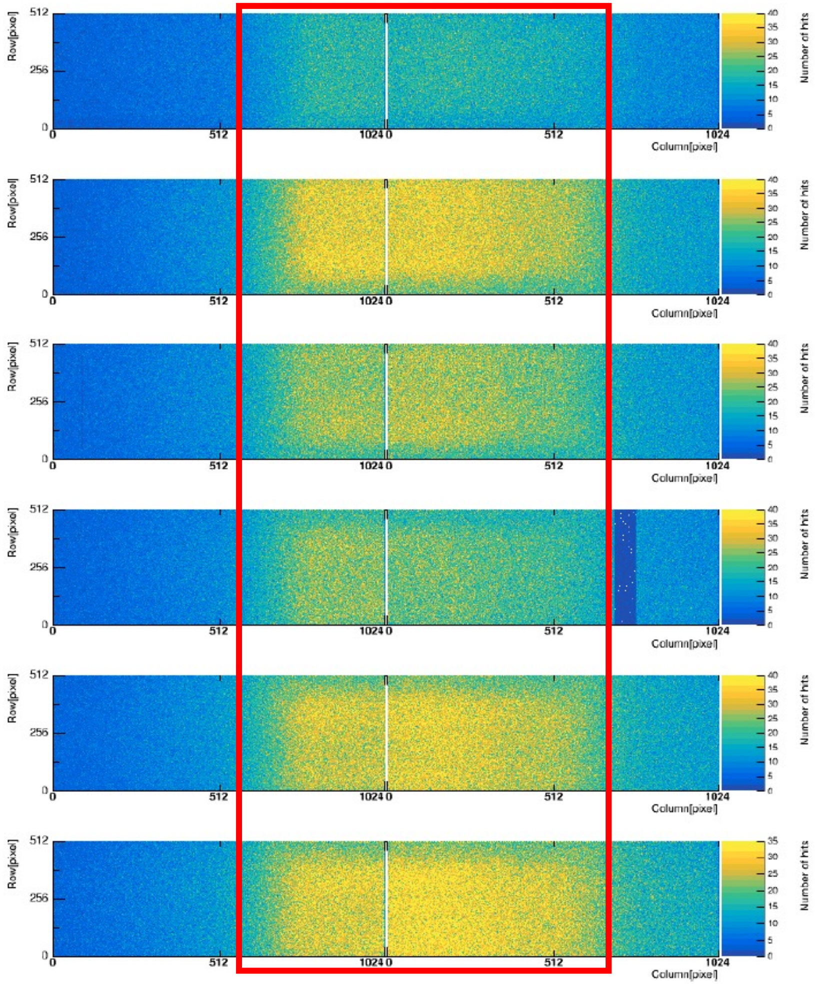
TaichuPix3 vertex detector prototype beam test @ DESY



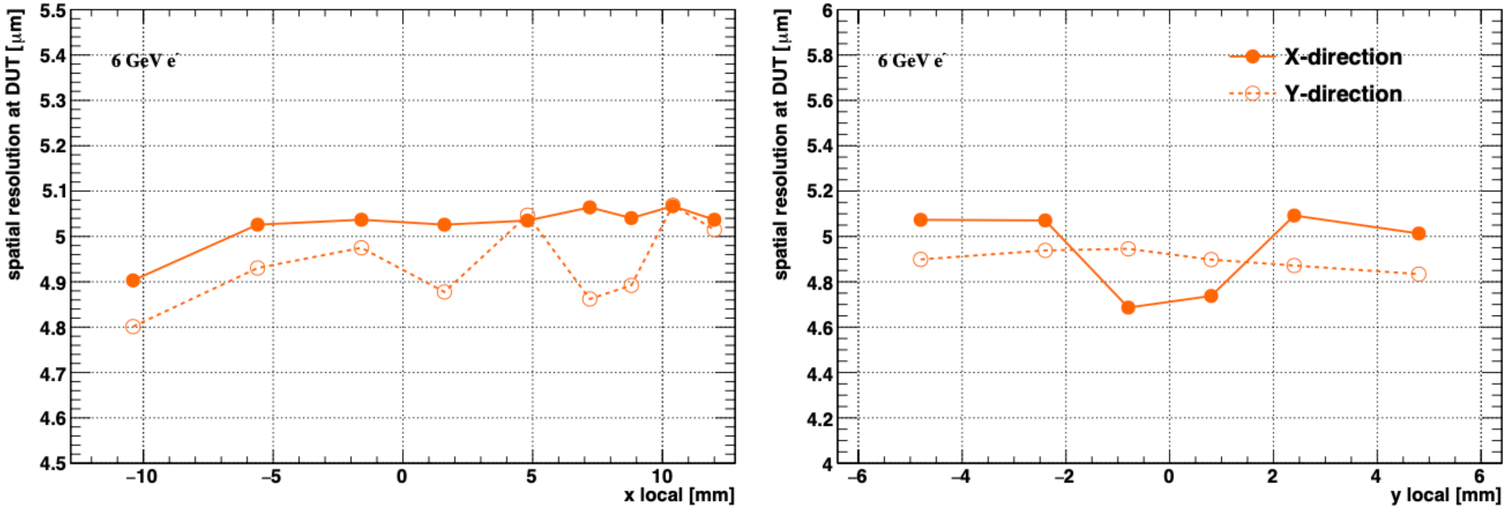


Hit maps of multiple layers of vertex detector

Beam spot

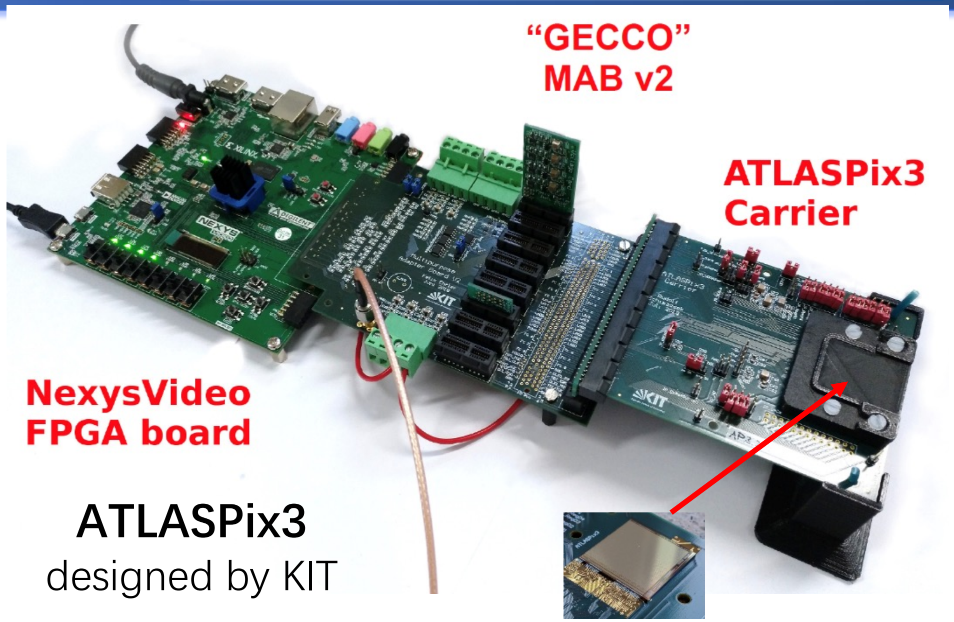


Spatial resolution ~ **5 μm**

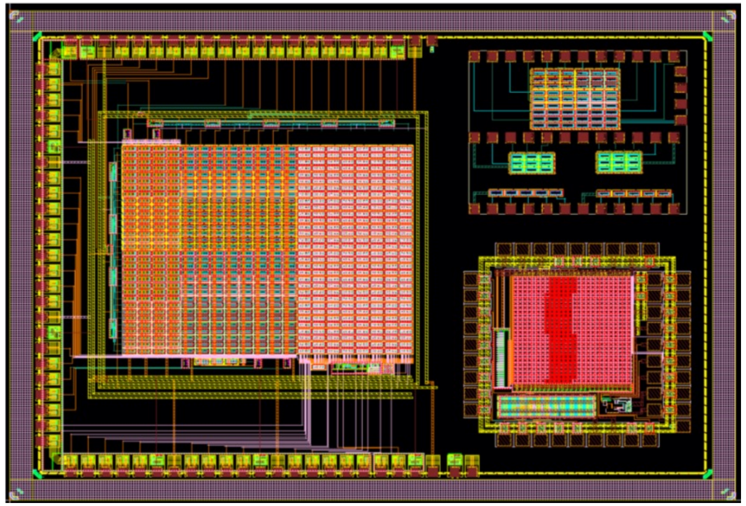


Silicon Tracker using HV-CMOS: ATLASPix → CEPCPix

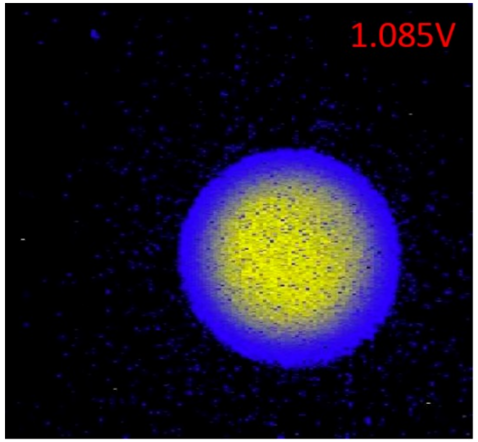
- ❑ Large area: **~70 m²** in TPC+SiTrk ➔ Cost effectiveness
- ❑ Focus on MAPS pixel tracker, also started SSD for outer layers
- ❑ Joint efforts on an ATLASPix3 based demonstrator
- ❑ ATLASPix & MightyPix use TSI 180nm HV process
- ❑ Exploring SMIC 55 nm HV HR proces
  - ➔ Smaller feature size & alternative foundry
- ❑ Other possibilities, e.g. MALTA3, TPSCo-65nm



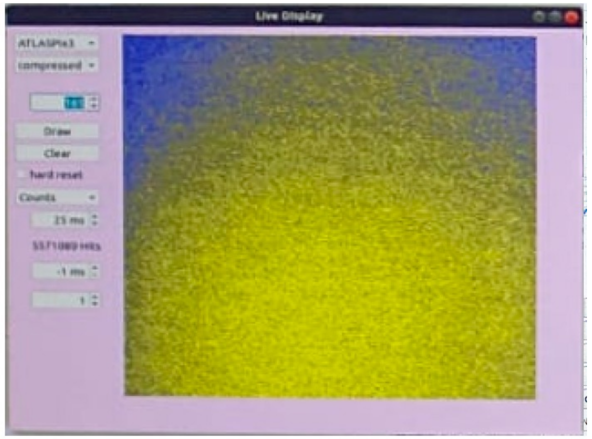
ATLASPix3
designed by KIT



The 2nd design for SMIC 55nm HV HR process



Hitmap with Fe55 source



Hitmap with electron beam

Collaboration with UK/Germany/Italy colleague