CEPC Physics and Detector

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(On behalf of the CEPC physics and detector group)

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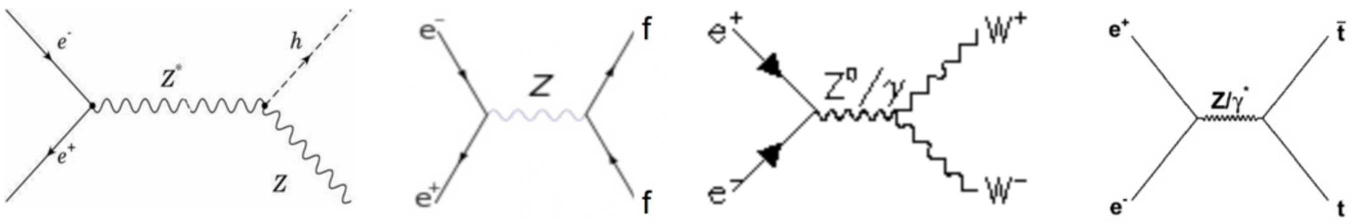
CEPC physics program



Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			240	91	160	360
Run time [years]			7	2	1	-
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
TDR (Latest)	30 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	0.5
		$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.65
		Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
	50 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**8.3**	**192**	**26.7**	**0.8**
		$\int L\,dt$ [ab^{-1}, 2 IPs]	21.6	100	6.9	1.0
		Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

- **The centerpiece: precise measurement of the Higgs boson properties (width, couplings, mass …)**
- **huge measurement potential for precision tests of SM: electroweak physics, flavor physics, QCD**
- **Searching for exotic or rare decays of H, Z, B and τ, and new physics**
- **Top quark physics**

An extremely versatile machine with a broad spectrum of physics opportunities → Far beyond a Higgs factory

Milestones and activities of CEPC physics studies

- ❖ **Public documents released: CDR(2018) → Higgs white paper (2019) → Snowmass white paper (2022) → Flavor white paper to come out soon → more in preparation (EWK white paper, New physics white paper)**
- ❖ **CEPC physics and detector workshops in series: May 2019, April 2021, August 2023**
- ❖ **Physics studies for the IAS-HEP program and Snowmass exercise**
- ❖ **Communication and collaboration with international partners: ECFA studies …**

❖ **O(100) Journal / arXiv papers**

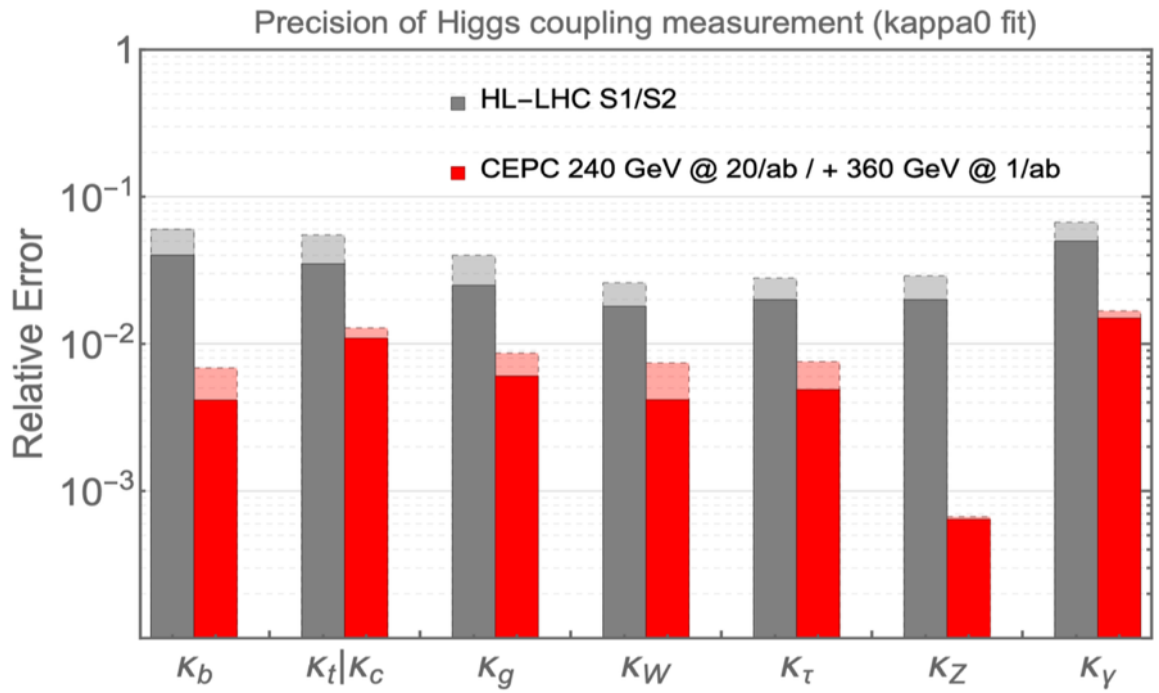
Higgs Precision measurements

Translated the latest accelerator performance into Higgs measurements

	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%		

Higgs width measurement benefits enormously from 360-GeV run

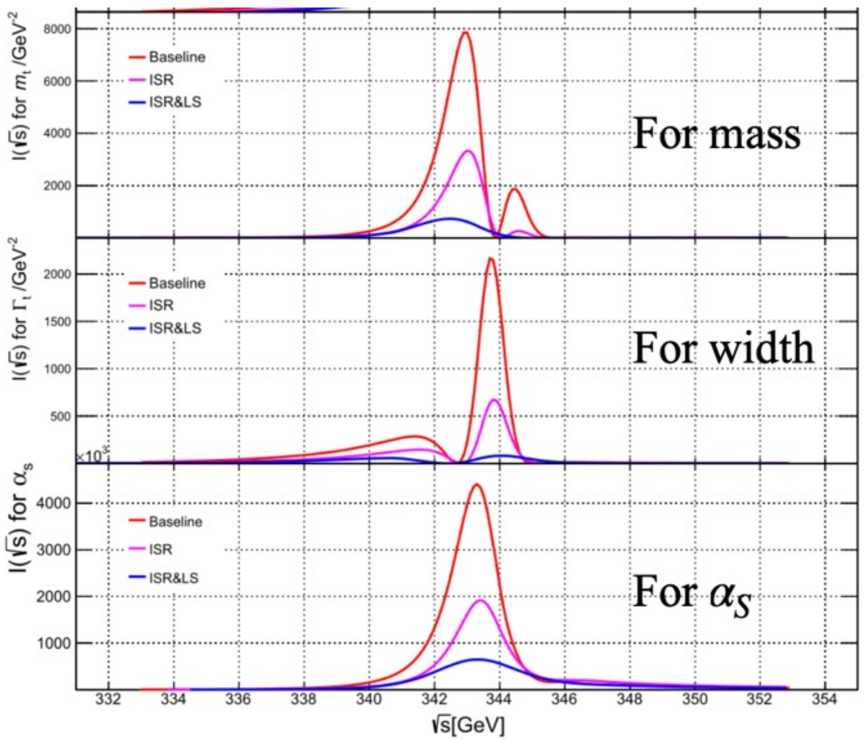
Exploring the full potential of the CEPC with the latest TDR design for Higgs measurements by combining 240-GeV and 360-GeV runs.



Outperforming HL-LHC significantly

Top quark measurments : mass, width and alfa_s

Choice of 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

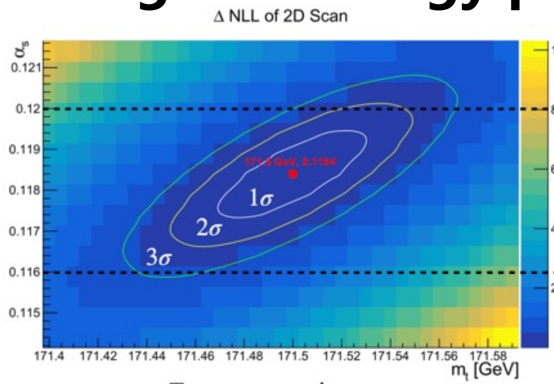
In the table, 342.75 GeV, 344.00 GeV and 343.50 GeV are optimal energy points for top quark mass, width and α_S, respectively

Measurement with a single energy point

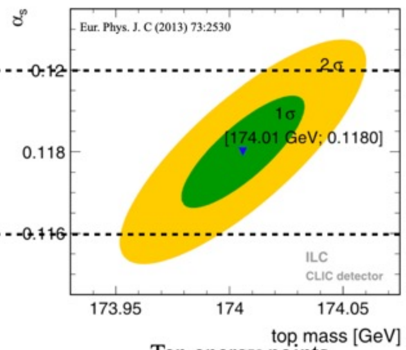
	Top mass uncertainties (MeV)	
	Optimistic	Conservative
Statistics	9	9
Theory	8	24
Quick scan	2	2
α_S	17	17
Width	10	10
Experimental efficiency	5	44
Background	2	14
Beam energy	2	2
Luminosity spectrum	3	6
Total	24	57

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

Measuring two parameters simultaneously by using two energy points



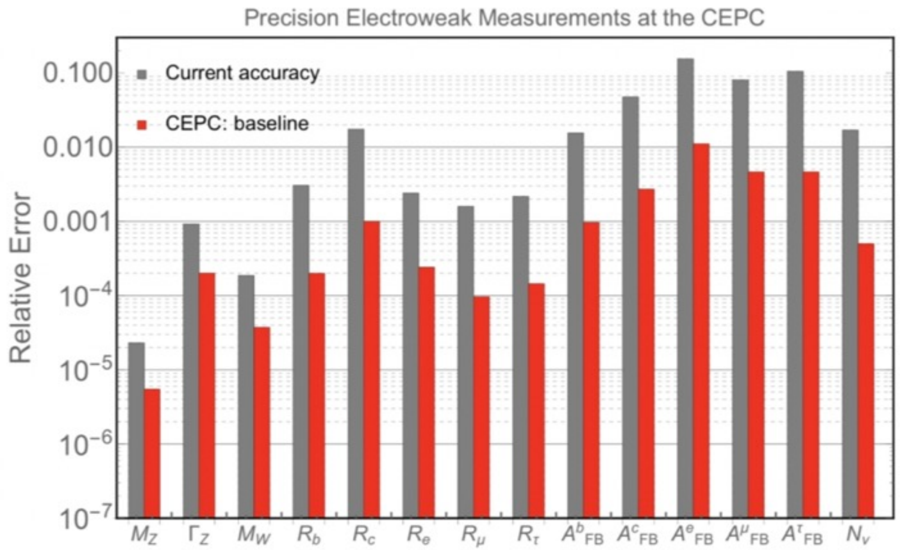
Two energy points



Ten energy points

EWK precision measurements

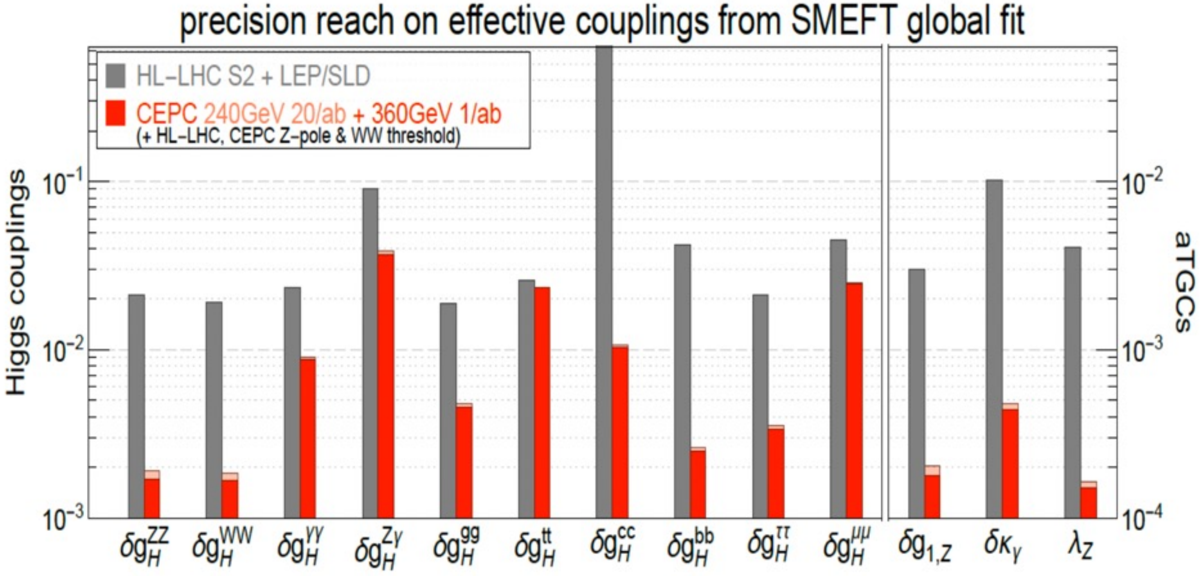
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 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

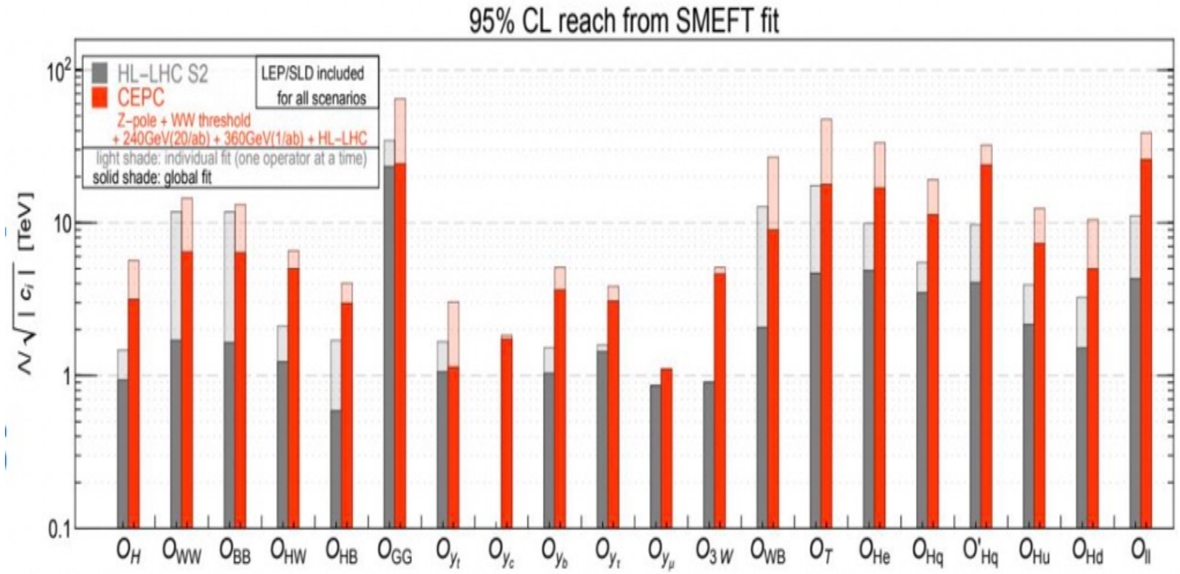


CEPC is expected to improve the current precision by 1-2 orders of magnitude, offering a great opportunity to test the consistency of the SM.

Global fit with SMEFT: new physics constrains

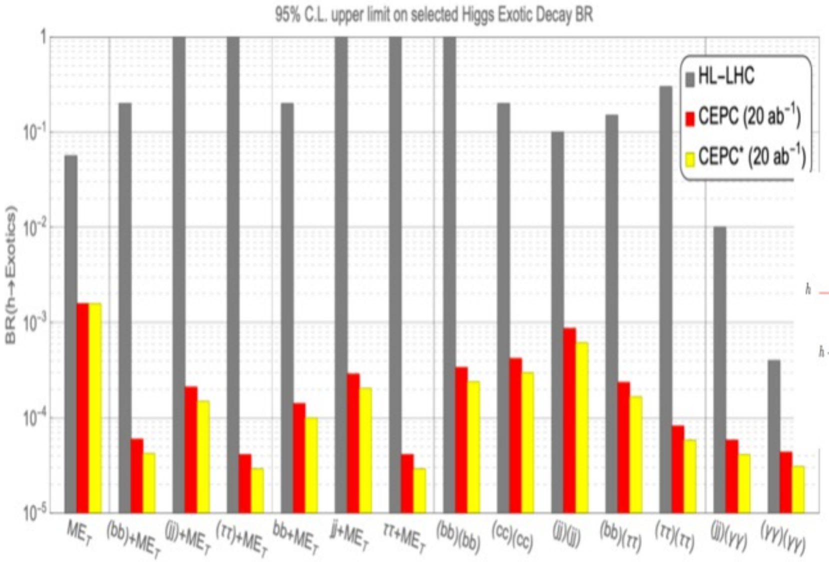
$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \cdots$$

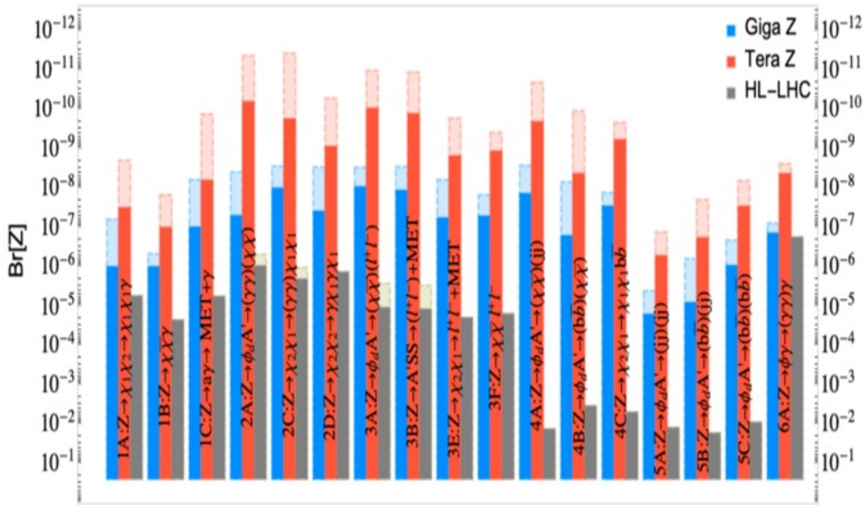




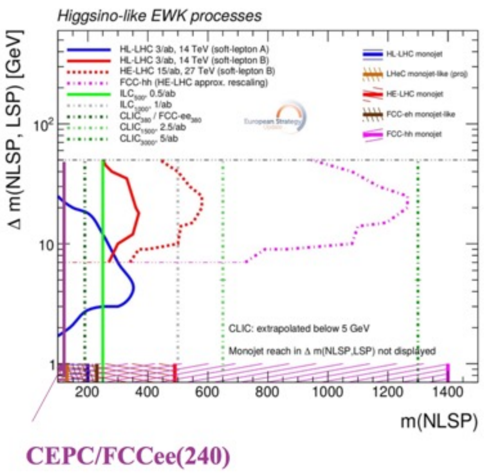
CEPC has potential to reveal new physics @10 TeV by combining Higgs, EWK and top measurements → power of precision

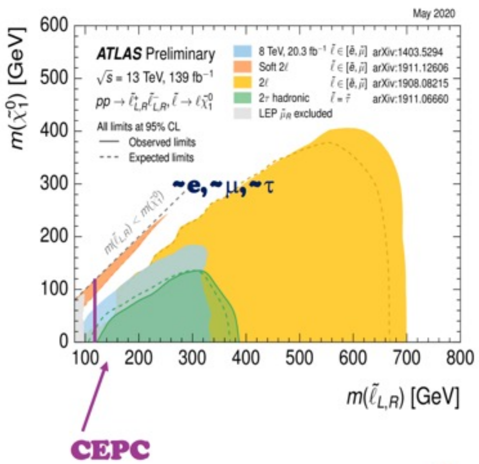
BSM searches: exotic decays, dark matter, SUSY, LLP …

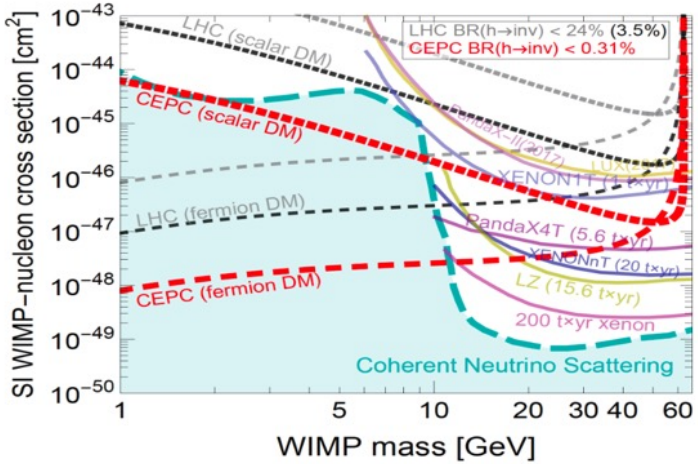




Measurement	Current	FCC Projection	Update	Comments
Lifetime [sec]	$\pm 5\times10^{-16}$	$\pm 1\times10^{-18}$		3-prong decays, stat. limited
$BR(\tau\to\ell\nu\bar{\nu})$	$\pm 4\times10^{-4}$	$\pm 3\times10^{-5}$		Assumed 0.1× syst.(ALEPH)
$m(\tau)$ [MeV]	± 0.12	$\pm 0.004\pm 0.1$		$\sigma(\vec{p}_{track})$ 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
$BR(\tau\to\mu\gamma)$	$<4.4\times10^{-8}$	$\sim 2\times10^{-9}$	$\mathcal{O}(10^{-10})$	$Z\to\tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau\to e\gamma)$	$<3.3\times10^{-8}$	$\sim 2\times10^{-9}$		$Z\to\tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z\to\tau\mu)$	$<1.2\times10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(\vec{p}_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z\to\tau e)$	$<9.8\times10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(\vec{p}_{track})$ & $\sigma(E_{beam})$ limited
$BR(Z\to\mu e)$	$<7.5\times10^{-7}$	$10^{-8}-10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$Z\to\pi^+\pi^-$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$Z\to\pi^+\pi^-\pi^0$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$Z\to J/\psi\gamma$	$<1.4\times10^{-6}$		$10^{-9}-10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$Z\to\rho\gamma$	$<2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(\vec{p}_{track})$ limited







Significantly better detection sensitivity to dark matter and exotic decays than HL-LHC

Flavor physics studies

- Measuring BR($B^0_{(s)} \to \pi^0\pi^0 \to 4\gamma$)
  uncert.($B^0 \to \pi^0\pi^0 \to 4\gamma$) $\sim$ 0.45%
  uncert.($B^0_s \to \pi^0\pi^0 \to 4\gamma$) $\sim$ 4.5%
  [Not observed]
- Measuring BR($B^0_{(s)} \to \eta^0\eta^0 \to 4\gamma$)
  uncert.($B^0 \to \eta^0\eta^0 \to 4\gamma$) $\sim$ 18%
  [Not observed]
  uncert.($B^0_s \to \eta^0\eta^0 \to 4\gamma$) $\sim$ 0.95%
  [Not observed]
- Measuring BR($B^0 \to K^{*0}\tau^+\tau^-$), BR($B_s \to \phi\tau^+\tau^-$), BR($B^+ \to K\tau^+\tau$
  uncert.$\sim \mathcal{O}(10^{-7} - 10^{-6})$**[Not observed]**
- Measuring BR($B_s \to \tau^+\tau^-$)
  uncert.$\sim \mathcal{O}(10^{-5})$**[Not observed]**
- Measuring α_s from $\bar{B}_s(B_s) \to D_s^{\pm}K^{\mp}$
  uncert.(α_s) $\sim 0.4°$
- Measuring β_s from $\bar{B}_s(B_s) \to J/\psi\phi$
  uncert.(β_s) $\sim 0.035°$
- Measuring γ_s from $B^{\pm} \to \bar{D}^0(D^0)K^{\pm}$
  uncert.(γ_s) $\sim \mathcal{O}(1°)$

- Measuring BR($B^0_s \to \mu^+\mu^-$), BR($B^0 \to \mu^+\mu^-$)
  BR($B^0 \to \mu^+\mu^-$) affected by $B^0 \to \pi^+\pi^-$ **mis-ID**
- Measuring $B_c \to \tau\nu$
  uncert.(BR) $\sim \mathcal{O}(10^{-4})$ **[Not observed]**
  uncert.($|V_{cb}|$) $\sim \mathcal{O}(1\%)$
- Measuring BR($B_s \to \phi\nu\nu$)
  uncert. $\sim \mathcal{O}(1\%)$
- Measuring $\alpha(\phi_2)$ from $B^0 \to \pi^0\pi^0 \to 4\gamma$
  uncert.(α) $\sim 0.4°$
- Measuring BR($\tau \to \ell\nu\bar{\nu}$)
  Improvement: $\sim \mathcal{O}(10^2)$
- Measuring τ lifetime
  Improvement: $\sim \mathcal{O}(10^3)$
- Measuring BR($\tau \to 3\mu$) and BR($\tau \to \mu\gamma$)
  Improvement: $\sim \mathcal{O}(10 - 10^2)$
- Measuring BR($Z \to \ell\ell'$) with ($\ell \neq \ell'$)
  Limits $\sim \mathcal{O}(10^{-8} - 10^{-10})$

White paper draft

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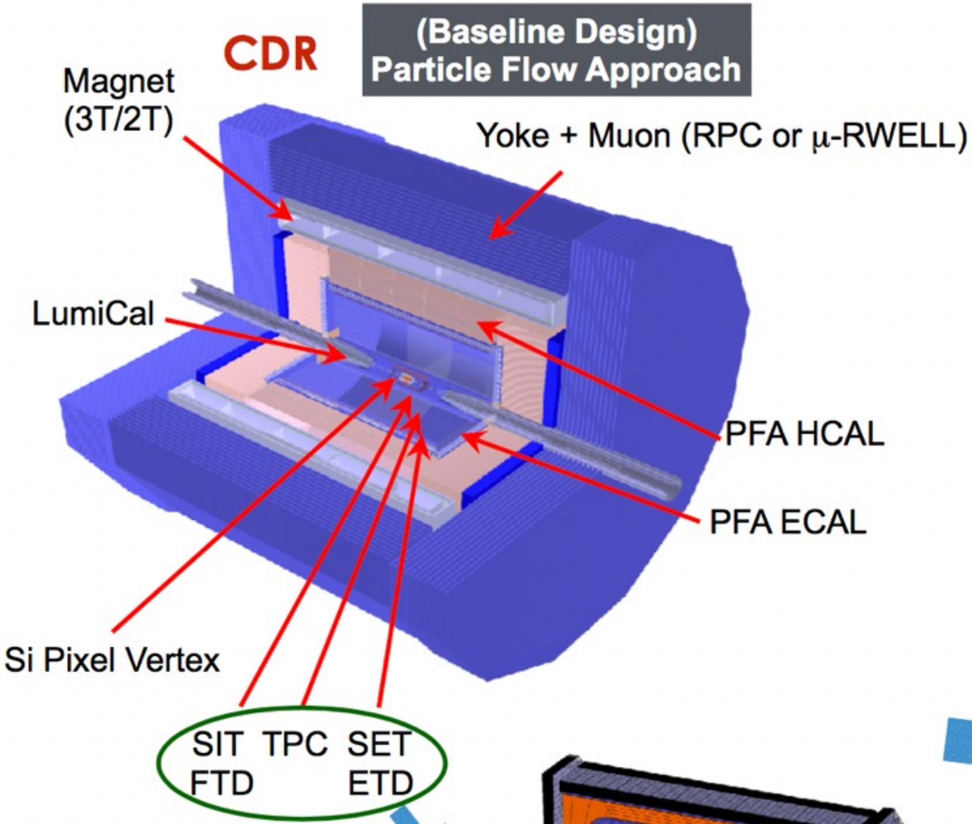
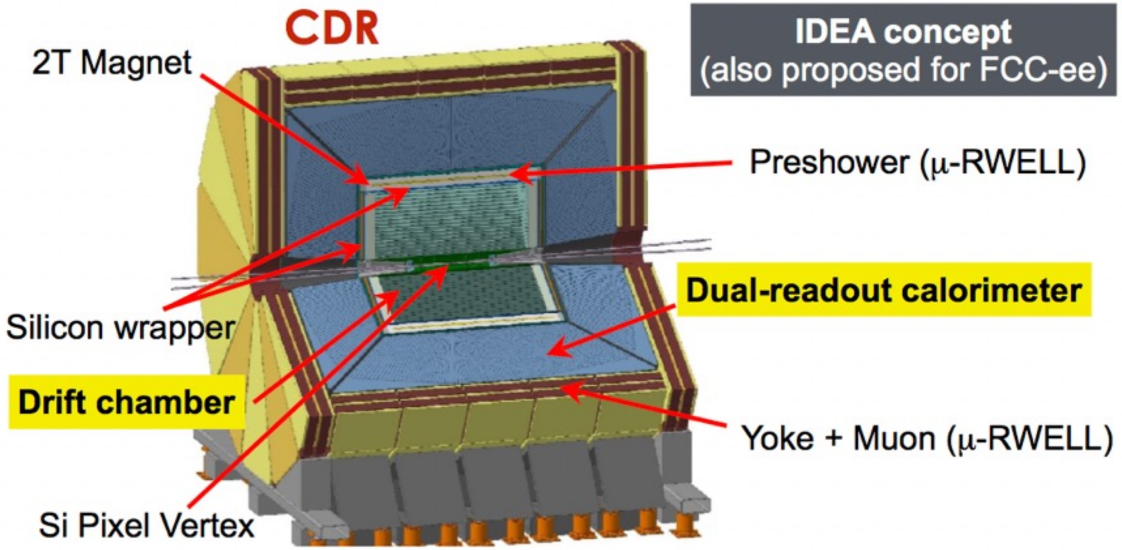
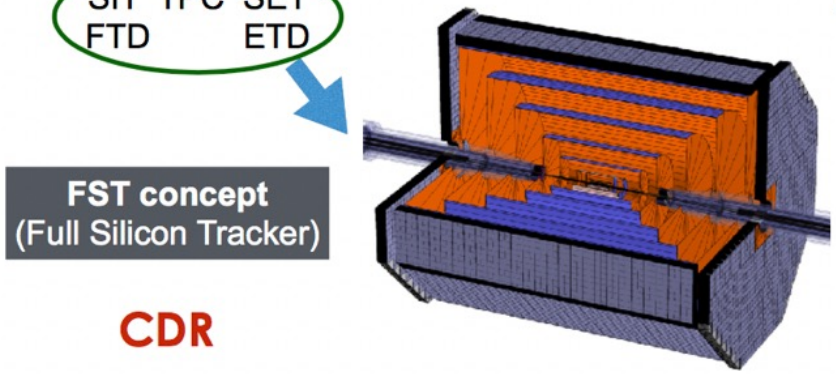
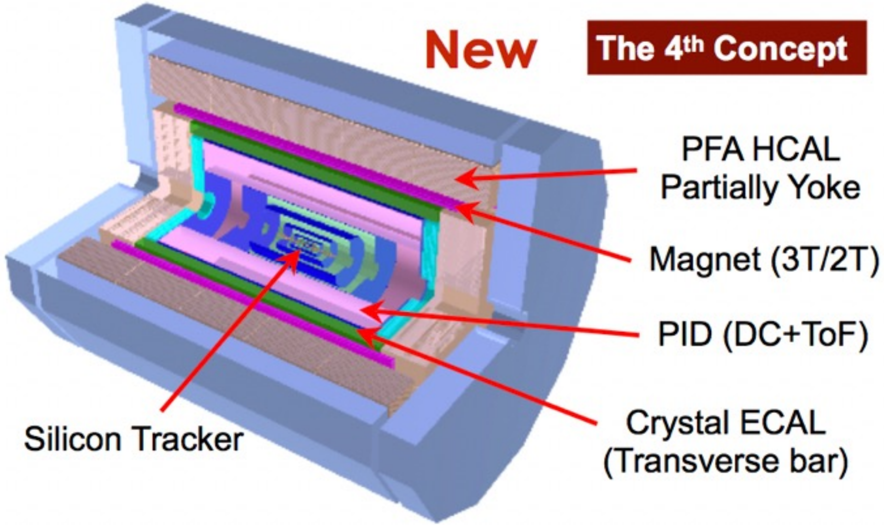
CEPC Detector Conceptual Designs









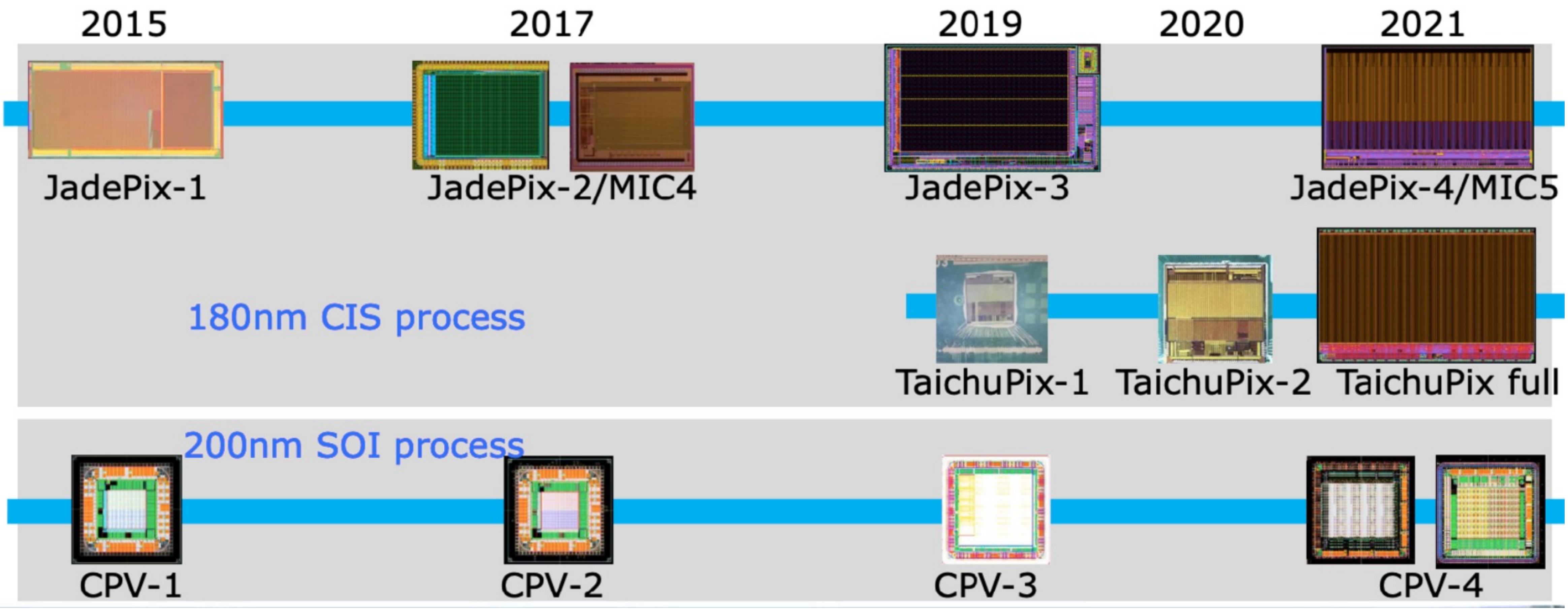
Detector requirements and R&D status

Sub-detector	Specification	Requirement	CEPC prototype
Pixel detector	Spatial resolution	$\sim 3\ \mu m$	$3-5\ \mu m$ [14–16]
TPC/drift chamber	dE/dx (dN/dx) resolution	$\sim 2\%$	$\sim 4\%$ [19–21]
Scintillator-W ECal	Energy resolution Granularity	$< 15\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\ \mathrm{cm}^2$	Prototype built and tested
4D crystal ECal	EM energy resolution 3D Granularity	$\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\times 2\ \mathrm{cm}^3$	Prototyping [25] $\sim 3\%/\sqrt{E(\mathrm{GeV})}$ $\sim 2\times 2\times 2\ \mathrm{cm}^3$
Scintillator-Steel HCal	Support PFA, Single hadron σ_E^{had}	$< 60\%/\sqrt{E(\mathrm{GeV})}$	Prototype built and tested
Scintillating glass HCal	Support PFA Single hadron σ_E^{had}	$\sim 40\%/\sqrt{E(\mathrm{GeV})}$	Prototyping $\sim 40\%/\sqrt{E(\mathrm{GeV})}$
Low-mass Solenoid magnet	Magnet field strength Thickness	$2\ \mathrm{T} - 3\ \mathrm{T}$ < 150 mm	Prototyping

R&D for the baseline detector concept

- Vertex Detector
- Silicon tracker
- TPC
- PFA calorimetry : ECAL and HCAL
- Muon detector

Vertex detector sensor R&D timeline



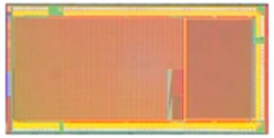
CMOS MAPS sensors development

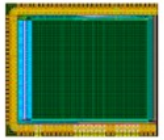
All developed with TowerJazz CIS 180 nm process

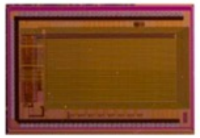
	JadePix1 (2015)	JadePix2 (2017)	MIC4	JadePix3 (2019)
Architecture	Roll. Shutter + Analog output	Roll. Shutter + In pixel discri.	Data-driven r.o. + In pixel discri.	Roll. shutter + end of col. priority encoder
Pitch (μm²)	33 × 33 /16 × 16	22 × 22	25 × 25	16 × 26 16 × 23.11
Power con. (mW/cm²)	--	--	150	~ 55* / <100
Integration time (μs)*	--	40-50	~3	~100
Prototype size (mm²)	3.9 × 7.9 (36 individual r.o)	3 × 3.3	3.1 × 4.6	10.4 × 6.1
Main goals	Sensor optimization	Small binary pixel	Small pixel + Fast readout+ nearly full functional	Smaller pixel + Low power + fully functional

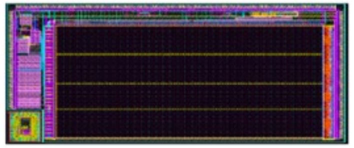
* Assuming a matrix of 512 × 1024 pixels

All prototypes in TowerJazz 180 nm process

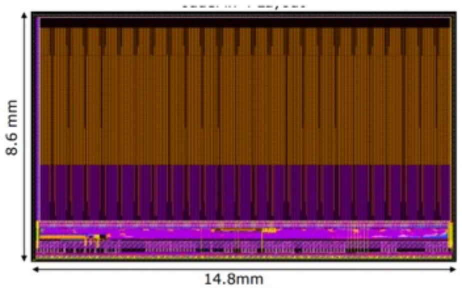

JadePix1 (IHEP)


JadePix2 (IHEP)


MIC4 (CCNU & IHEP)


JadePix3 (IHEP, CCNU, Dalian Minzu Unv., SDU)

JadePix4 **Design finalized, to be taped off**

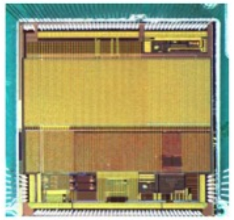


	S.P. resolution	Integration time	Average power
JadePix-4	<5 μm	~1 μs	< 100 mW/cm²
JadePix-3	<3 μm	<100 μs	< 100 mW/cm²

Optimized for fast readout

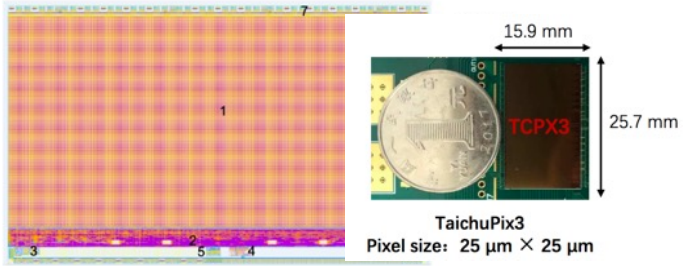
Taichupix1

Taichupix2



Chip size: 5 mm × 5 mm
Pixel size: 25 μm × 25 μm

Full-size Taichupix

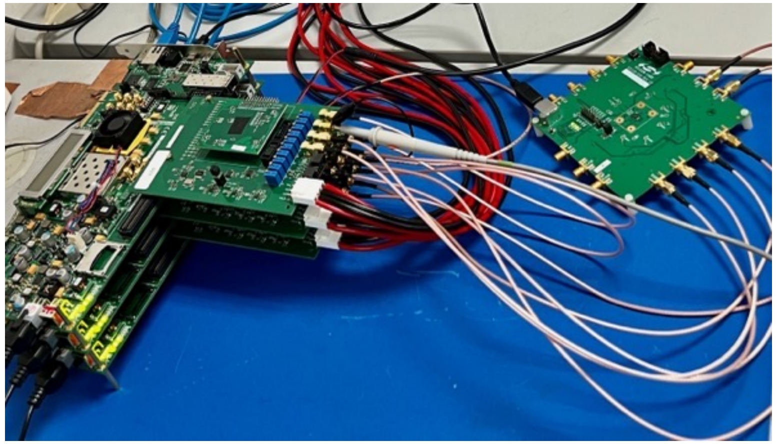


1024*512 pixel array, FE-I3-like

High speed, deadtime~50ns@40MHz, time stamp precision 25/50ns

Full-size chips produced and tested

JadePix3 characterization and beam test



Tested with electrical pulse, infra-red laser beam, radioactive source:

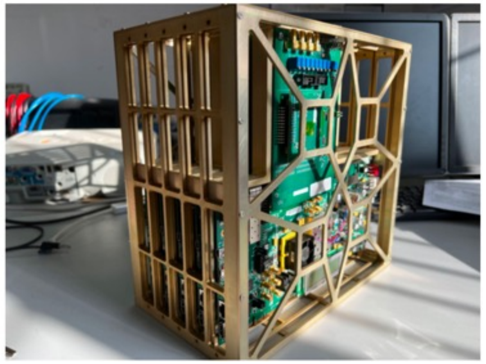
Threshold: 90 e- to 140 e-

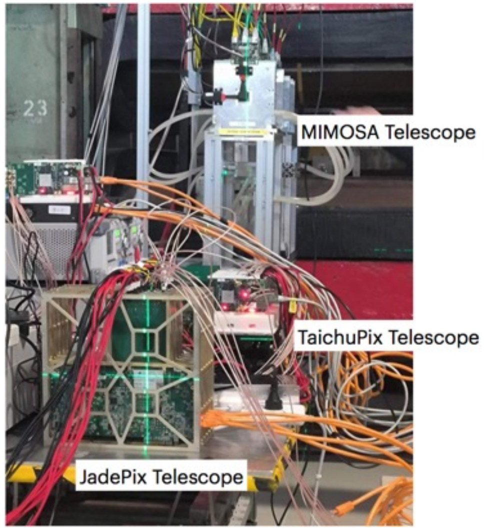
Noise hit rate < 1×10^{-10}/frame/pixel

Power consumption: ~90 mW/cm^2

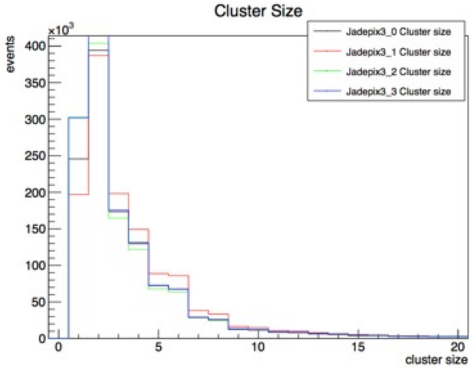
Spatial resolution < 3um (laser)

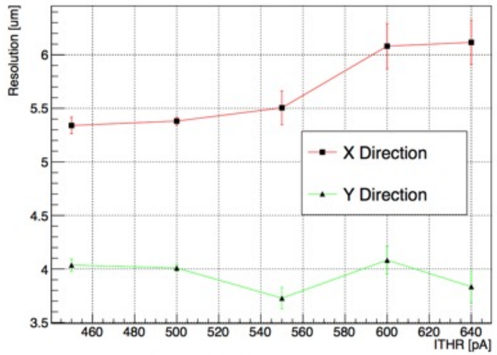
Beam test @DESY

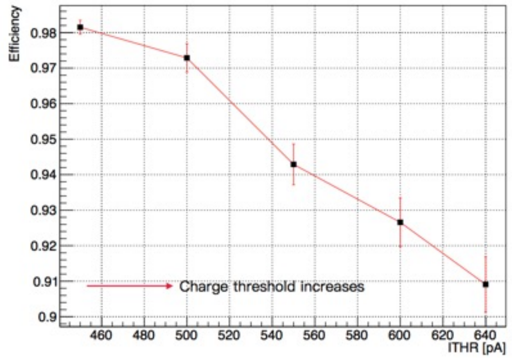




Spatial resolution ~4/~5um, Efficiency ~97%

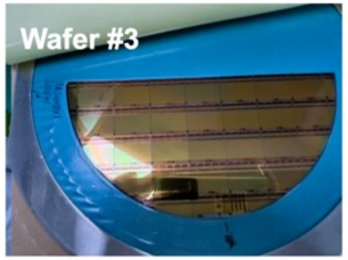




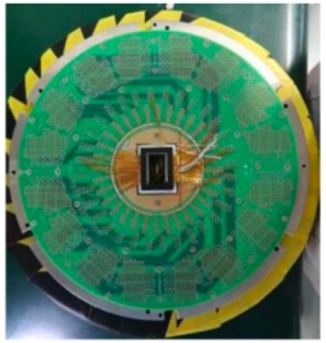


TaichuPix3 production and characterization

❖ 12 TaichuPix3 wafers produced, thinned and diced



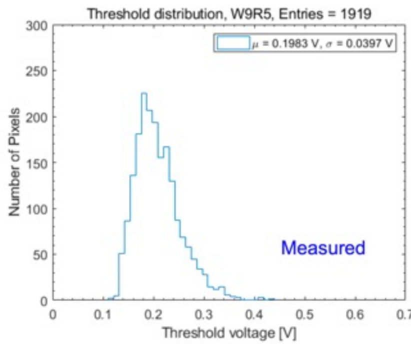
❖ wafers tested on a probe station for chip selection and yield evaluation

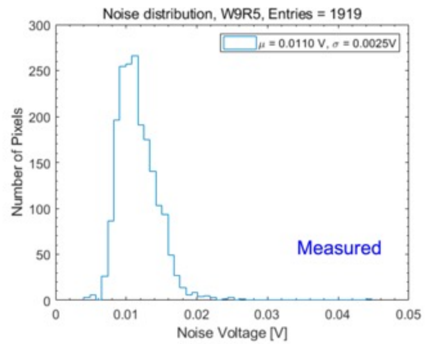


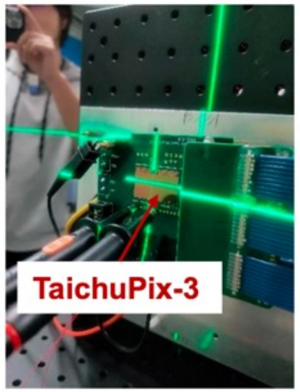
Probe card for wafer test

An example of wafer test result

❖ Average threshold ~215 e, threshold dispersion ~43 e, temporal noise ~12 e @ nominal bias setting

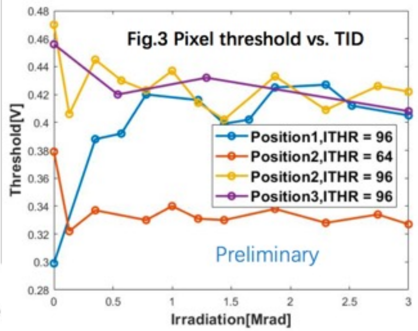


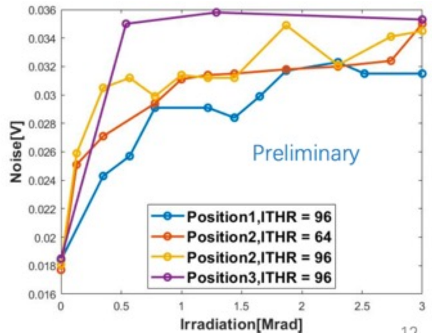




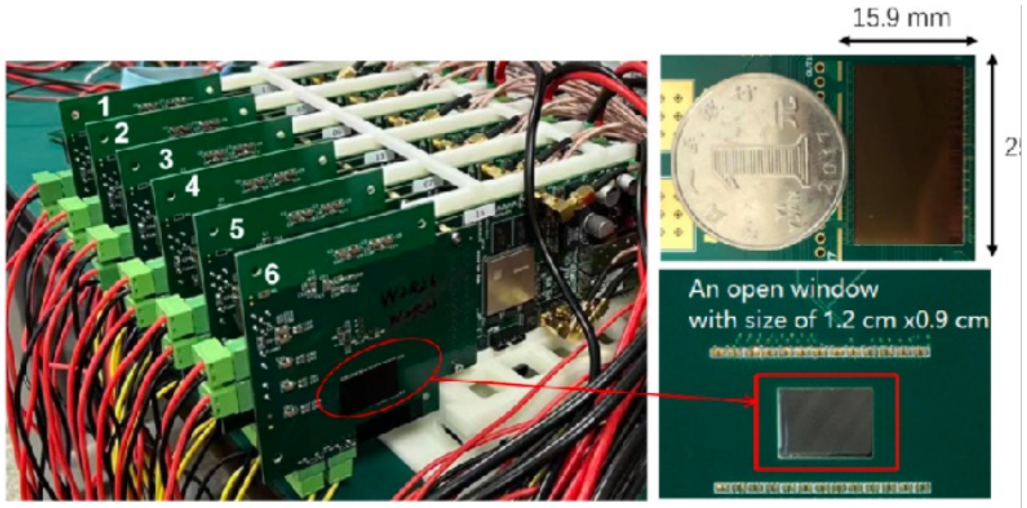
TC3 at BSRF 1W2B beamline

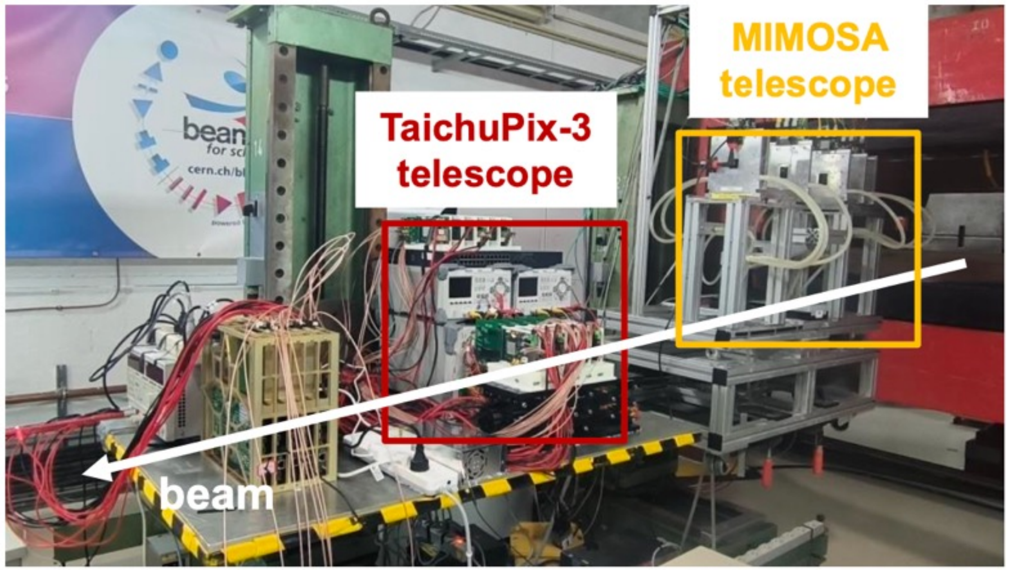
❖ The chips radiation hardness proved up to 3 Mrad TID

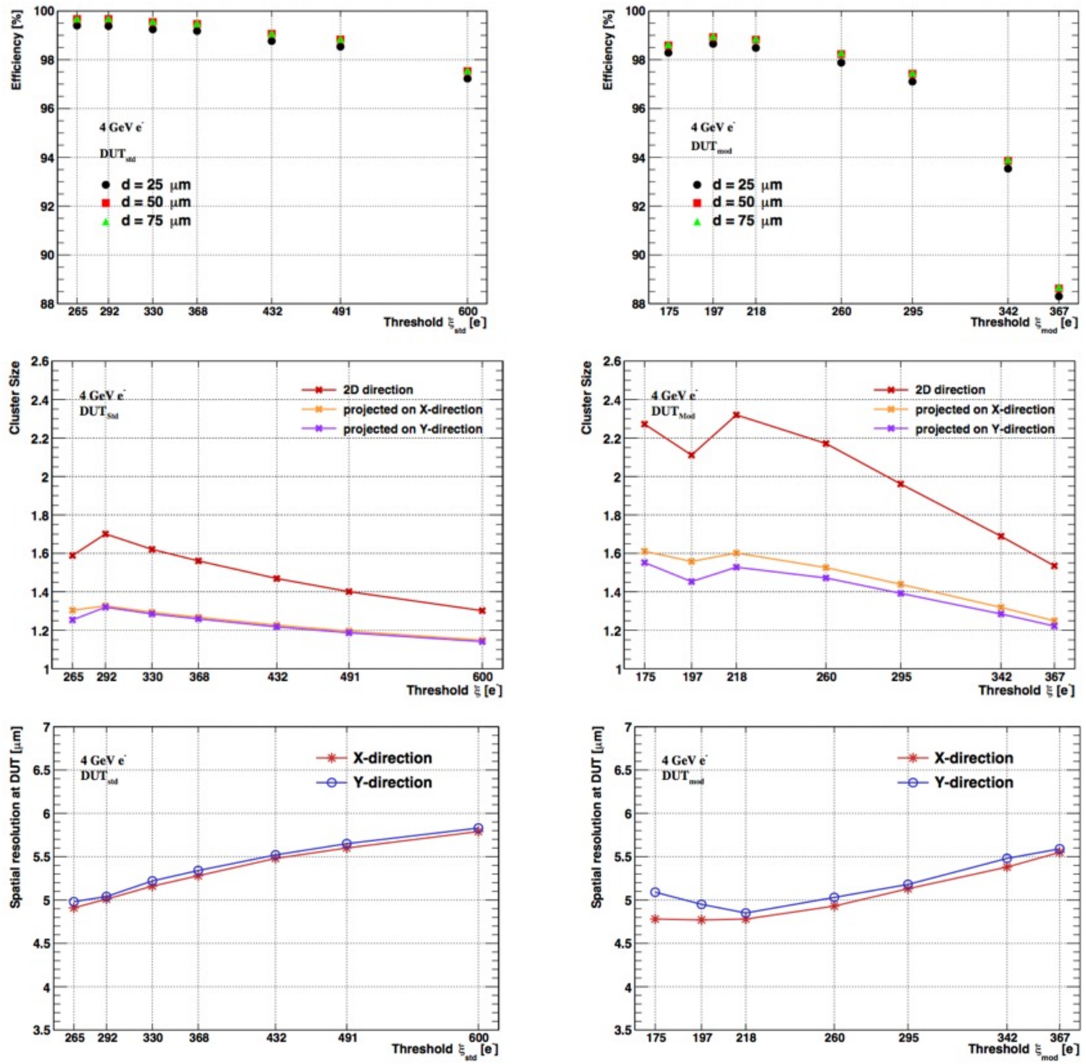




TaichuPix3 beam test @ DESY



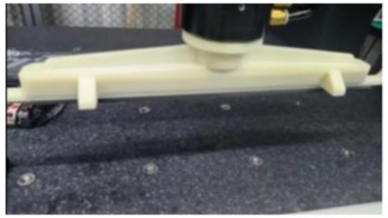




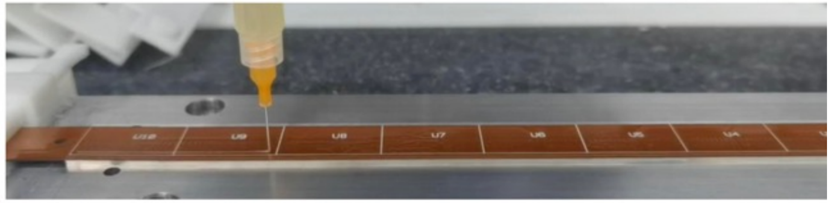
Spatial resolution ~5um, Efficiency >98%

TaichuPix3 vertex detector prototype

New pickup tools

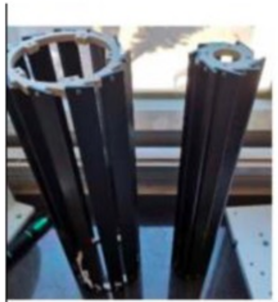


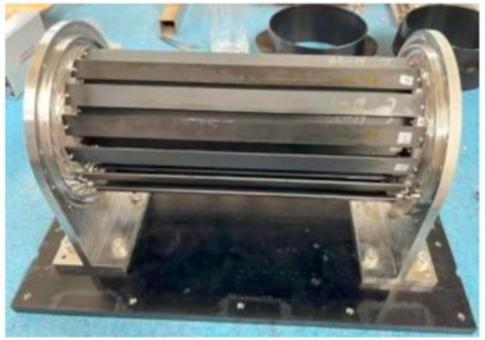
Dummy ladder glue automatic dispensing using gantry

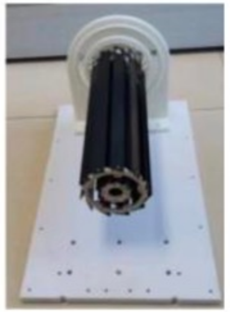


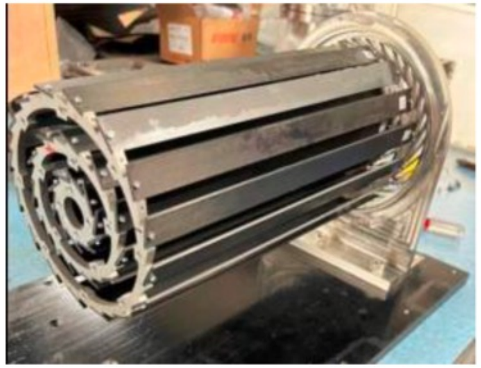
Ladder on wire bonding machine

Dummy Ladder on holder



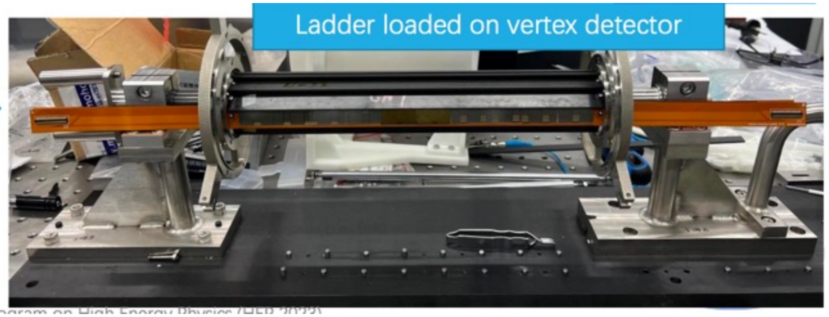




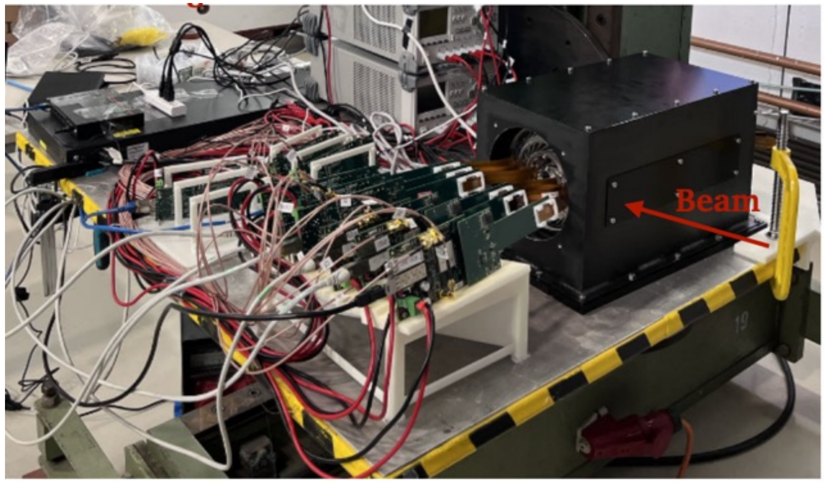


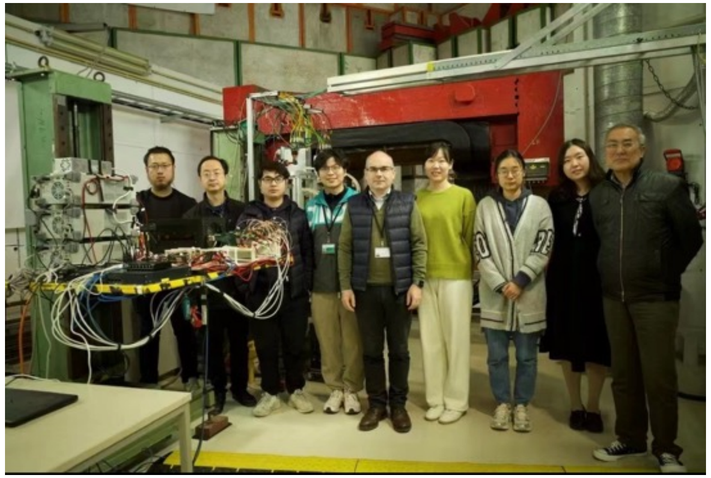
Ladder support tools

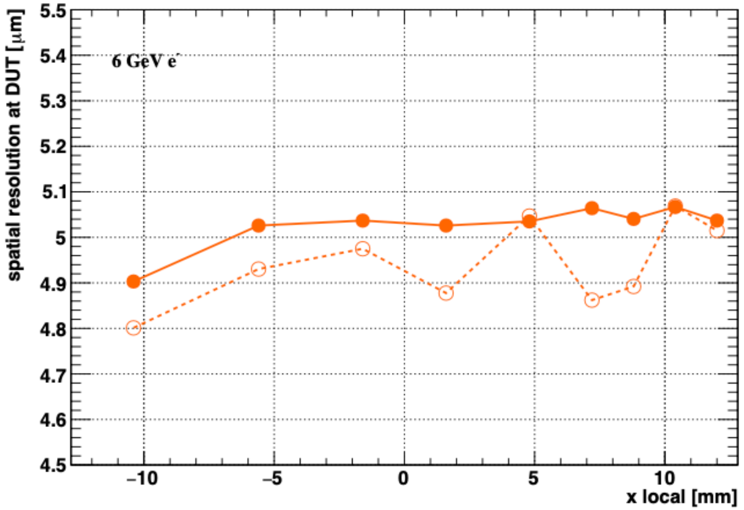
Ladder loaded on vertex detector

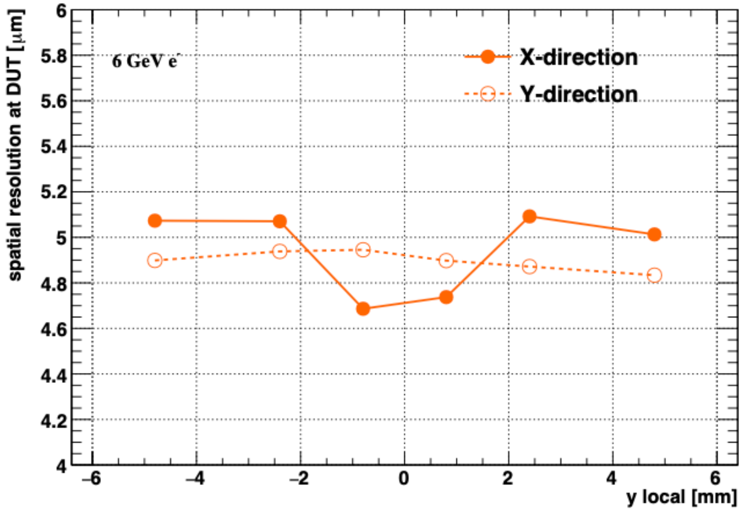


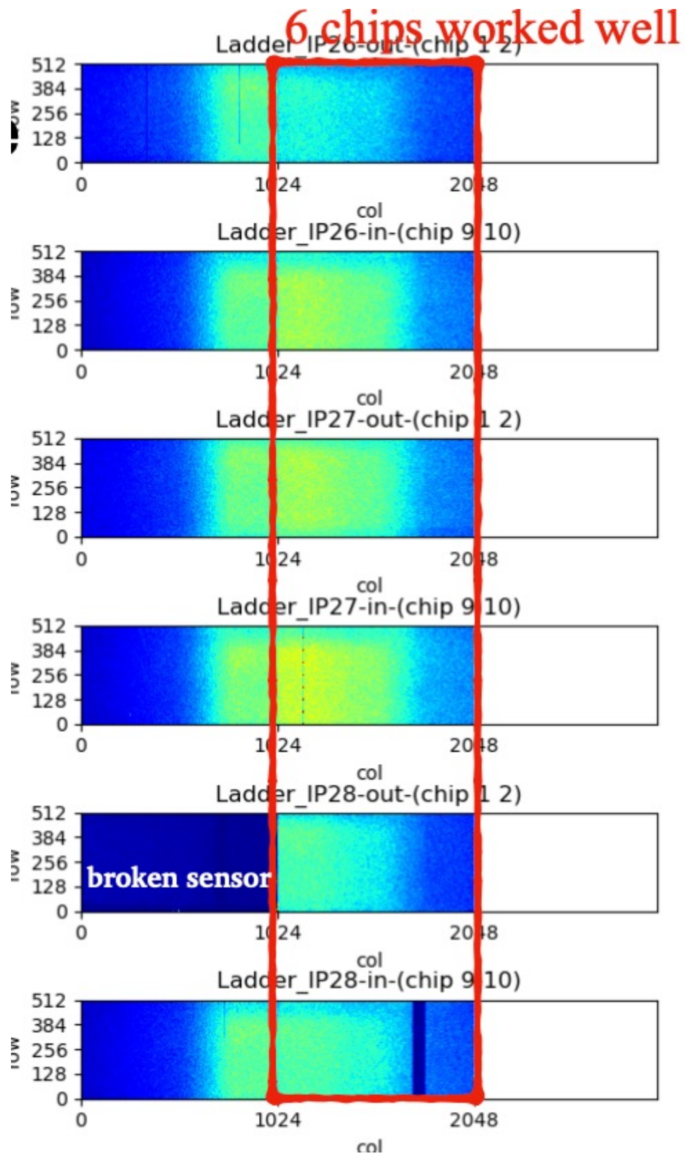
TaichuPix3 vertex detector prototype beam test @ DESY







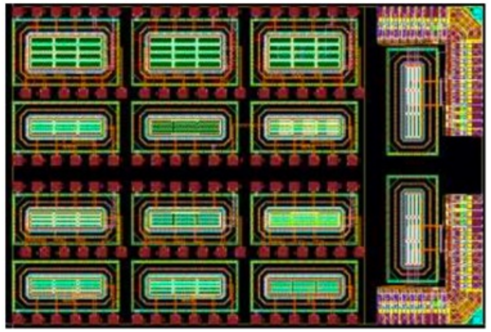


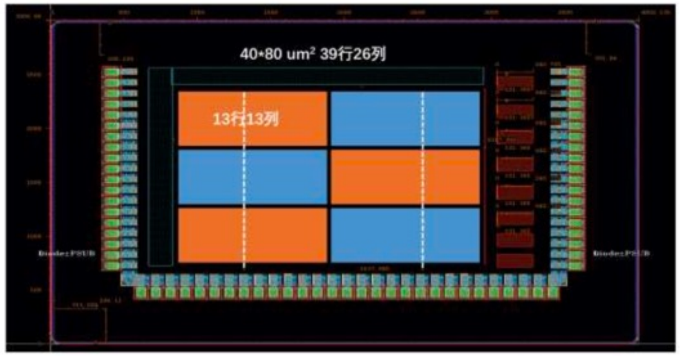


Spatial resolution ~5um

Silicon Tracker using HV-CMOS: ATLASPix → CEPCPix

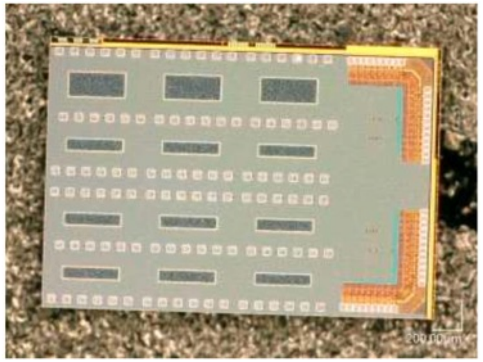
- **A HV-CMOS sensor - CEPCPix is being developed following ATLASPix : smaller pixel size (50μm→25μm) , Low-power amplifiers and comparators, daisy chain of readout.**
- **Efforts being made to explore foundries in China for a few years**
  - SMIC 55nm without HV: MPW in October 2022 to verify the DNW structure; 25*150um^2 for 3*2mm^2, a variety of passive diode arrays with simple amplifiers.
  - SMIC 55nm with HV: MPW planned for August 2023. Will be real validation of the sensor with high resistance wafer. Will explore variation of diode structure. Will add analog amplifiers and switch circuit.



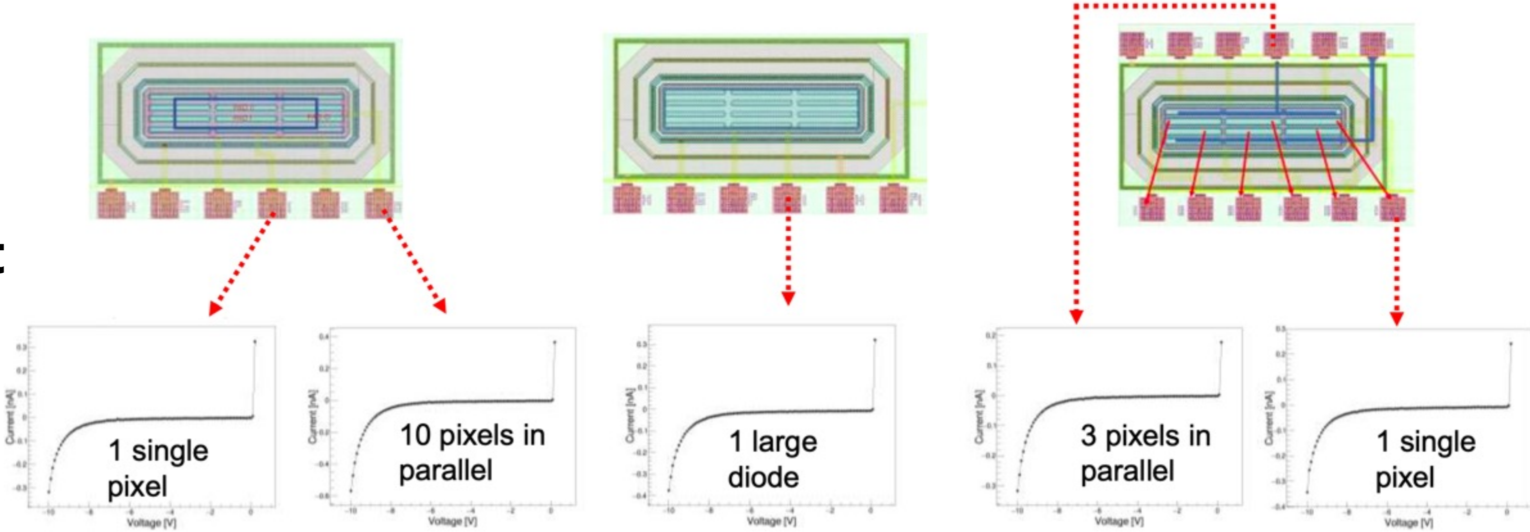


Characterization of the SMIC 55nm chips

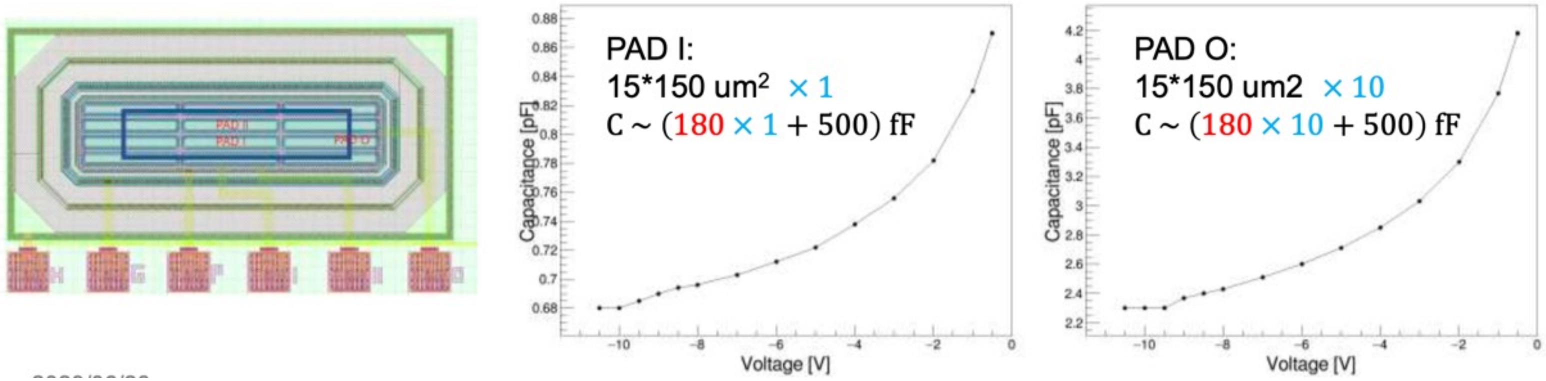
❖ **40 chips with SMIC 55nm (non-HV) received at the end of April 2023. Lab tests are underway.**



IV test



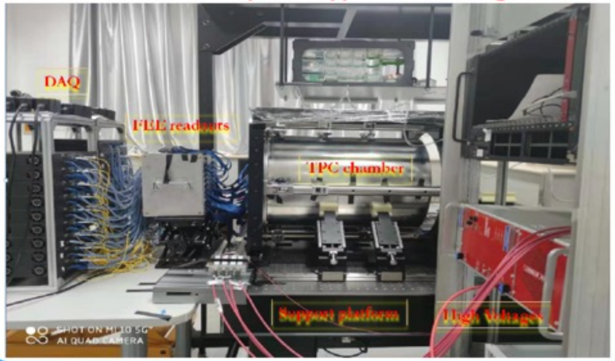
CV test

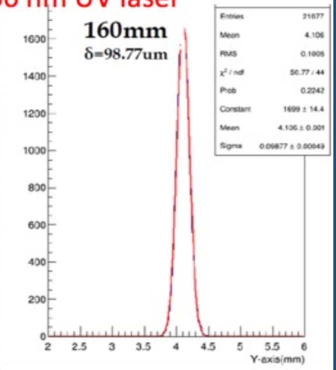


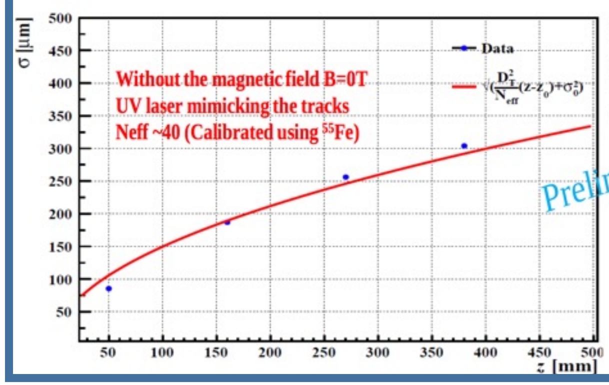
TPC: going from pad to pixel

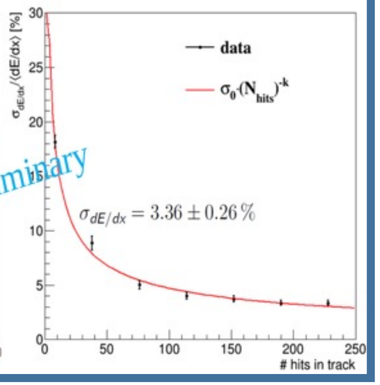
- CEPC TPC detector prototyping roadmap:
  - From TPC module to TPC prototype R&D for beam test
  - Low power consumption FEE ASIC R&D (reach **<5mW/ch** including ADC)
- Achievement by far:
  - Supression ions hybrid GEM+Micromegas module
    - IBFxGain **~1 at Gain=2000** validation with GEM/MM readout
  - Spatial resolution of **$\sigma_{r\phi}$≤100 μm** by TPC prototype
  - dE/dx for PID: **<4%** (as expected for CEPC baseline detector concept)

TPC prototype with integrated 266 nm UV laser









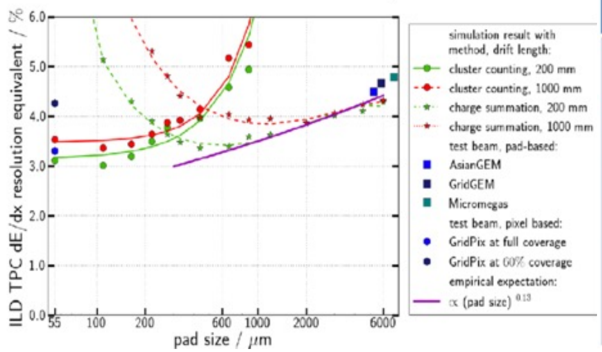
Current full CEPC TPC reconstruction: 6 mm pads → ~4.8% dE/dx resolution

6mm → 1mm: 15% improved resolution via the charge summation (dE/dx)

6mm → 0.1mm: 30% improved resolution via the cluster counting (dN/dx)

High readout granularity VS the primary cluster size optimization ongoing at IHEP

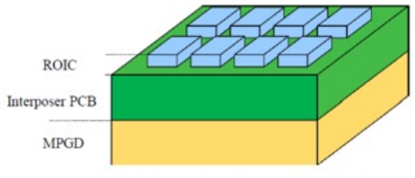
current resolution in the full CEPC TPC recostruction with 6mm pads



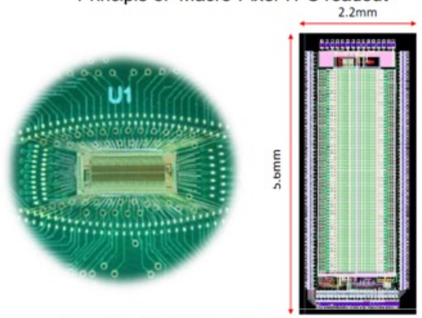
Pad size of about 300μm can record ~1 primary cluster along track length with T2K gas

Bump bond pixelated readout with Micromegas detector	Module size	To be addressed by R&D
• ≥300 μm×300 μm • Developed the readout chip by Tsinghua • Developed the Micromegas detector sensor at IHEP • Development of the new module and prototype	1-2 cm^2	• Research on pixelated readout technology realization • Optimization of cluster profile and pad size • Study of the 'dN$_{cl}$+dx'
	100 cm^2	• Study the distortion using UV laser tracks and UV lamp to create ions disk • In-situ calibration with UV Laser system • Study of the 'dE/dx+dN$_{cl}$/dx'

- **R&D on Macro-Pixel TPC readout for CEPC**
  - Macro-Pixel TPC ASIC chip was started to developed in this year and **1st prototype wafer has done in last year**.
  - The first version ROIC has been received and under testing.
  - The **TOA and TOT** can be selected as the initiation function in the ASIC chip.
    - 1mm×6mm → 500μm×500μm pixel readout
    - Higher precision and higher rate (MHz/cm^2)
    - Gain of the amplification: >40mV/fC
    - Channels: 128
    - Time resolution: **14bit** (5ns bin)
    - Time discriminator: TOA (Time of Arrival)
    - **Power consumption: <1mW/pixel (1st prototype)**
      - **~400mW/cm^2**
      - **100mW/cm^2 (Goal and final design)**
    - Technology: 180nm CMOS -> 60nm CMOS
    - High metal coverage: 4-side bootable



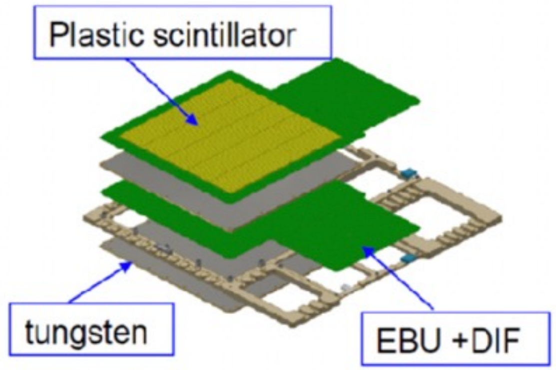
Principle of Macro-Pixel TPC readout

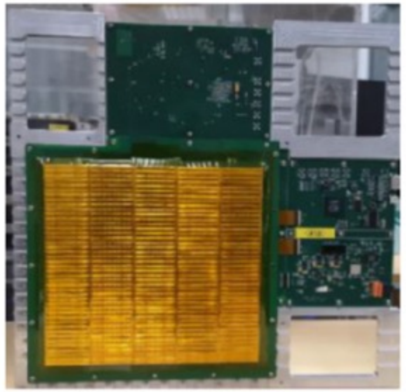


1st readout PCB board and the ASIC layout

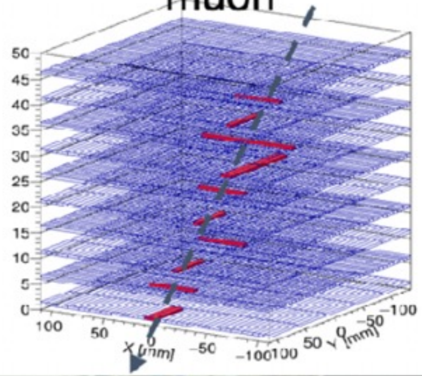
High granularity Sci-W ECAL and Sci-Fe HCAL (AHCAL)

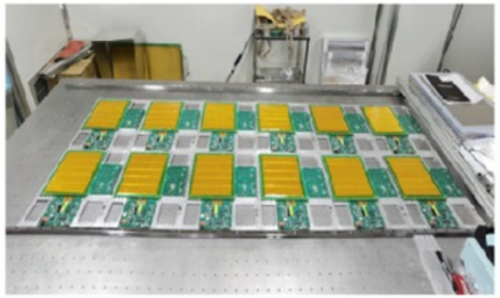
Scintillator-W ECAL Prototype



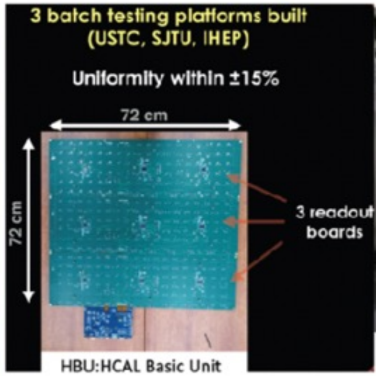


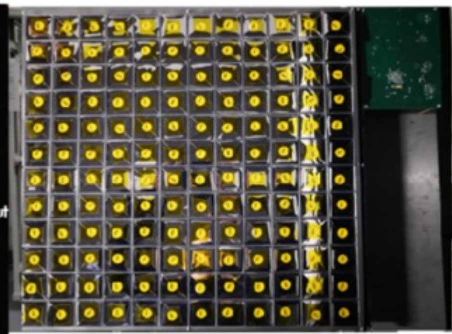
muon





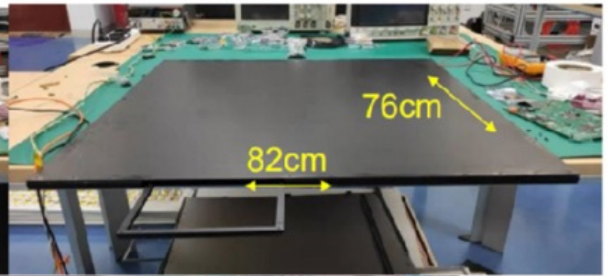
Scintillator + SiPM AHCAL Prototype

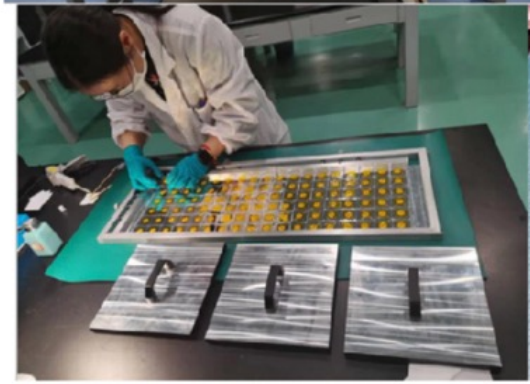


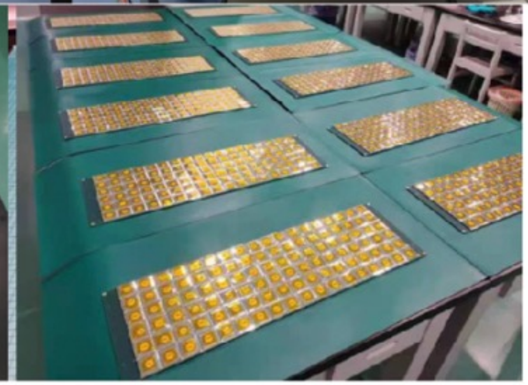


SJTU

IHEP







Both are read out with SiPM

Sci-W ECAL and AHCAL technological prototypes

Sci-W ECAL

Sci-Fe HCAL

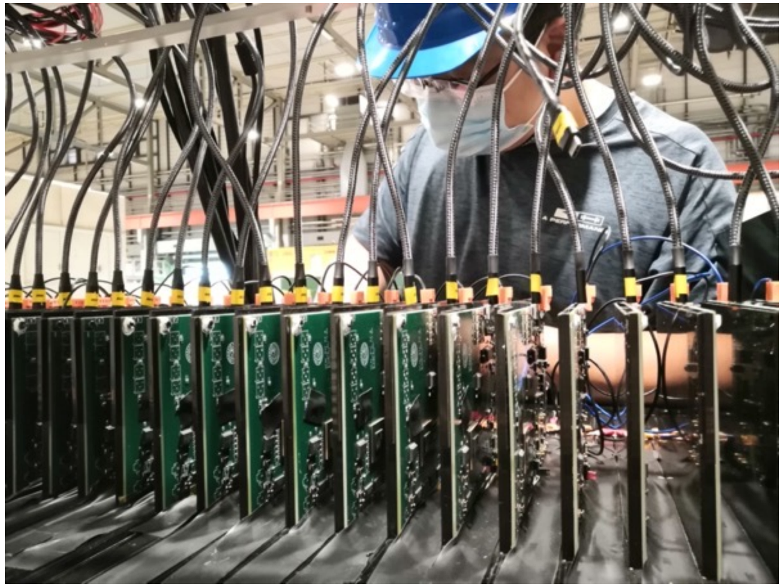
Calo	Sampling No.	Sensitive detector	Absorber	Granularity	Electronics	Absorb length	Energy Resolution	weight
Sci-W ECAL	32	PSD+SiPM	W-Cu	5mm×5mm	SP-2E	22 X_0	16%@ 1 GeV	0.3 T
AHCAL	40	PSD+SiPM	Fe	40mm×40mm	SP-2E	4.7 NIL	60%@ 1 GeV	5.0 T

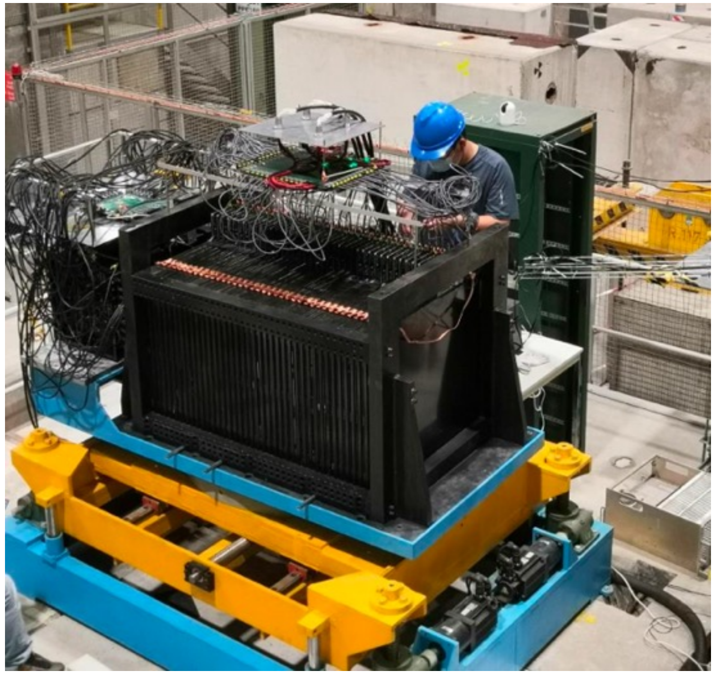
Transverse size

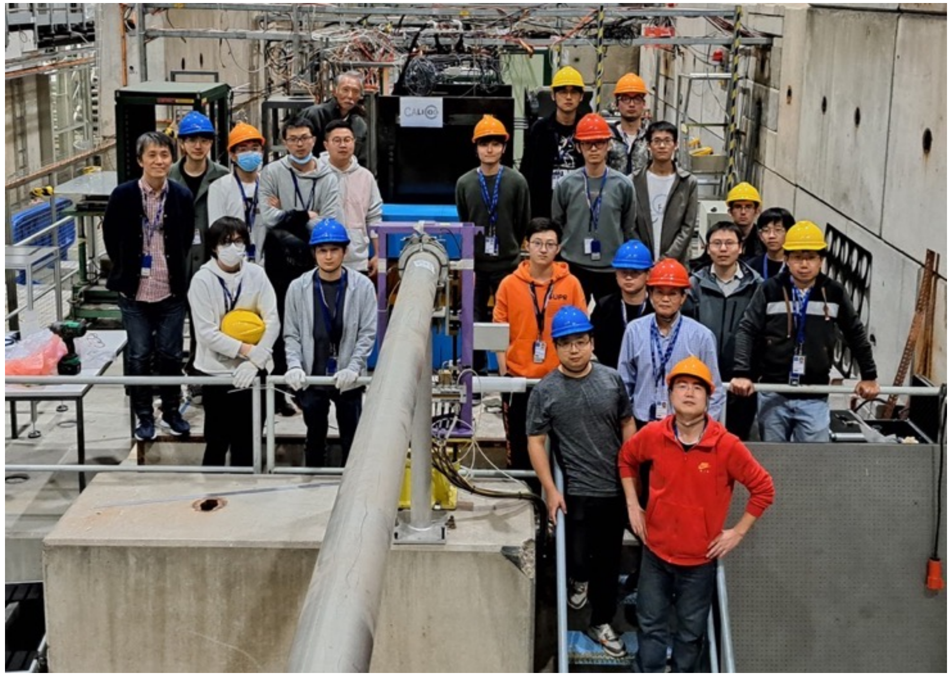
23cm*23cm

72cm*72cm

Standalone and combined beam tests @ CERN SPS







USTC: Hao Liu, Jianbei Liu, Zhongtao Shen, Yukun Shi, Jiaxuan Wang, Yunlong Zhang

IHEP: Yuzhi Che, Fangyi Guo, Peng Hu, Xinghua Li, Yong Liu, Baohua Qi, Qi Wu

SJTU: Francois Lagarde, Siyuan Song, Zhen Wang, Haijun Yang

U. Shinshu: Tohru Takeshita

U. Tokyo: Ryunosuke Masuda, Tatsuki Murata, Wataru Ootani,, Yuki Ueda

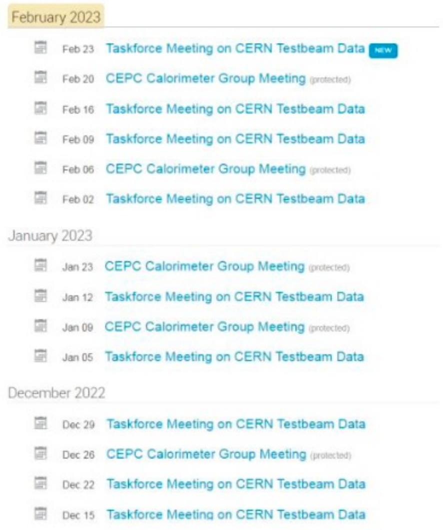
Weizmann: Luca Moleri, Giannis Maniatis

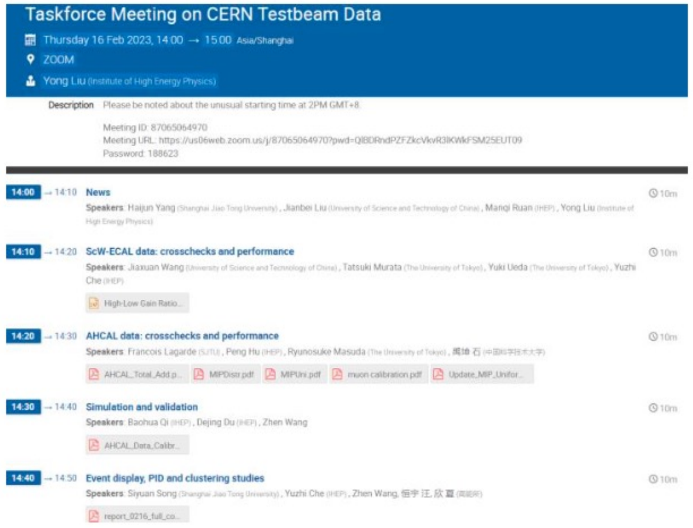
- ◆ Two weeks at H8@SPS in Oct, 2022
- ◆ Two weeks at H2@SPS in April, 2023
- ◆ Two weeks at T9@PS in May, 2023
  - $e^{\pm}$: 0.5-250 GeV/c
  - $\pi^{\pm}$: 1-120 GeV/c
  - High energy μ for calibration

65 million events collected in total

Test beam data analysis task force

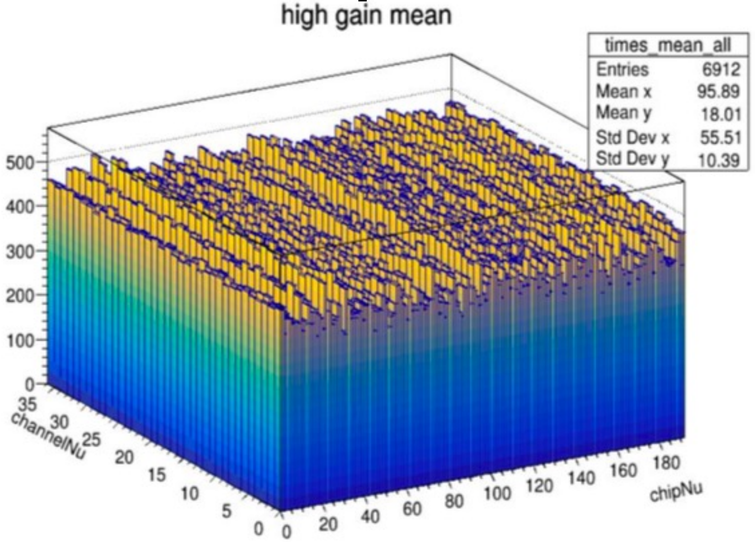
- Taskforce on data conversion and analysis (same groups that participated the CERN beamtest)
  - Data conversion and cross checks (4): Jiaxuan Wang, Yukun Shi; Yuzhi Che; Francois Lagarde
  - Event display (5): Siyuan Song, Zhen Wang; Yuzhi Che, Baohua Qi, Hengyu Wang
  - Data analysis and software tooling (5): Hongbin Diao, Jiaxuan Wang, Yukun Shi; Yuzhi Che, Peng Hu; Francois Lagarde
  - Full simulation and validation (5): Dejing Du, Baohua Qi; Yukun Shi; Zhen Wang, Zixun Xu
  - Arbor clustering studies (3): Yuzhi Che, Hengyu Wang, Xin Xia
  - Japanese groups on ScW-ECAL performance (5): Ryunosuke Masuda, Tatsuki Murata, Wataru Ootani, Tohru Takeshita, Yuki Ueda
  - Coordination: Yong Liu
- Institutions involved in the taskforce
  - China (14): IHEP, SJTU, USTC
  - Japan (5): U. Shinshu, U. Tokyo
- Weekly meetings: updates, questions and discussions
  - https://indico.ihep.ac.cn/category/322/
- Welcome new members to join
  - A full task list (evolving) prepared for data analysis



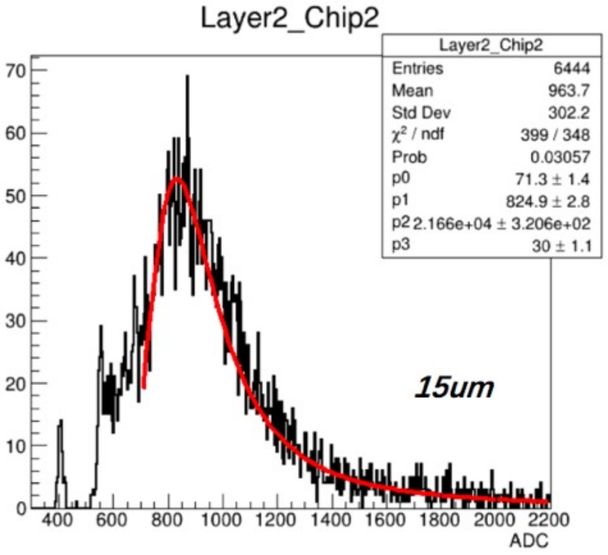


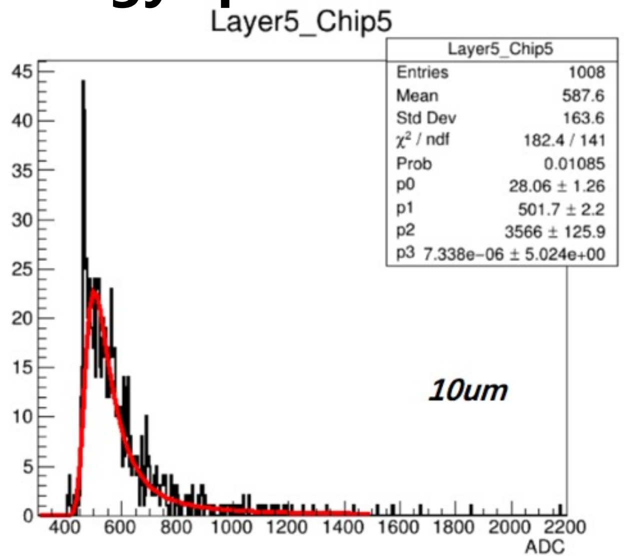
Preliminary Results

ECAL pedestal

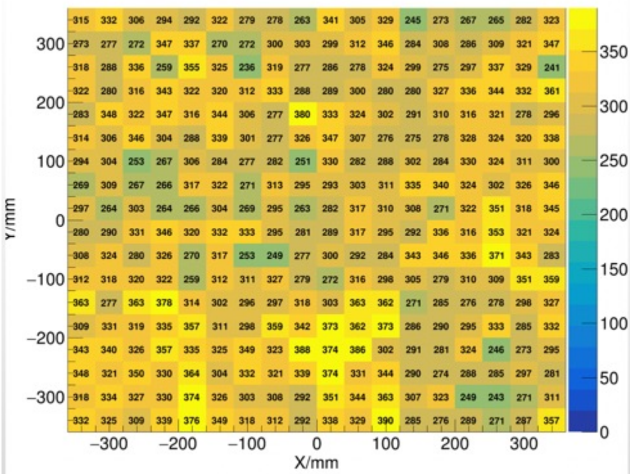


ECAL MIP hit energy spectrum

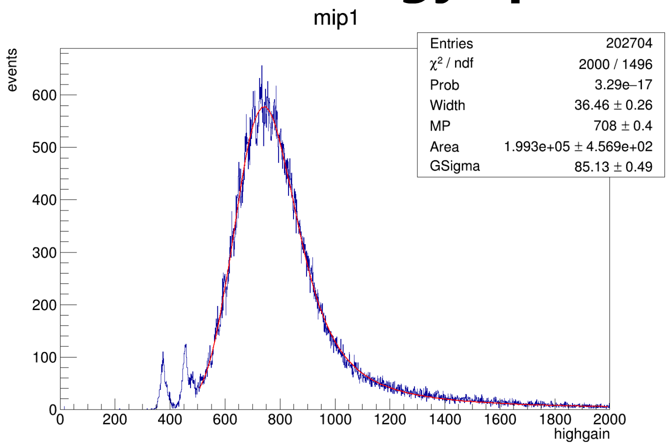




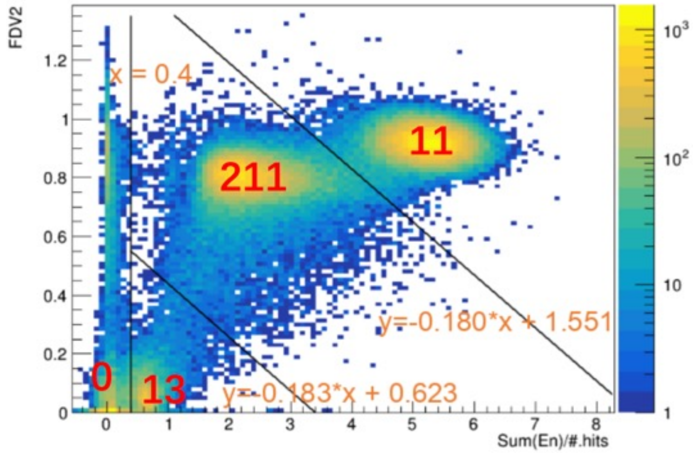
AHCAL pedestal



AHCAL MIP hit energy spectrum

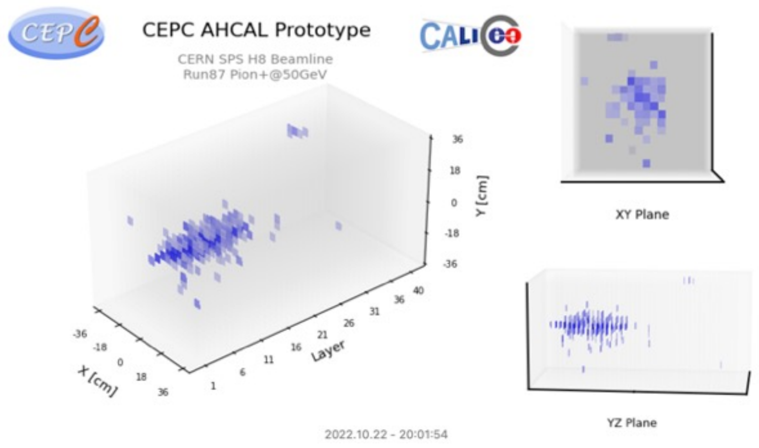


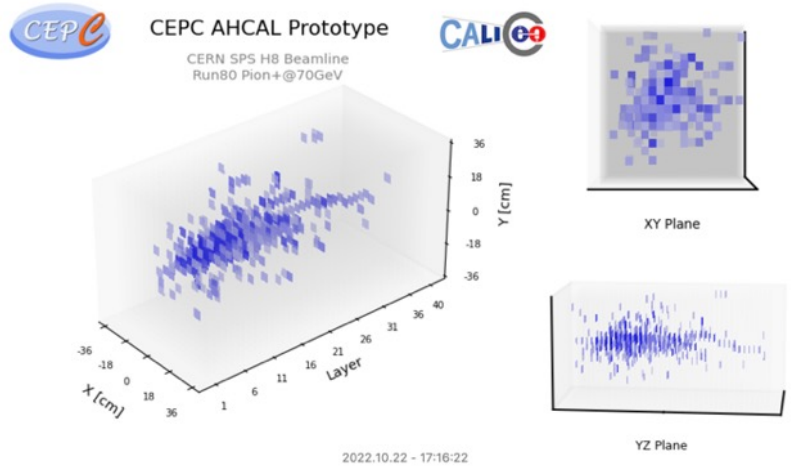
PID with AHCAL

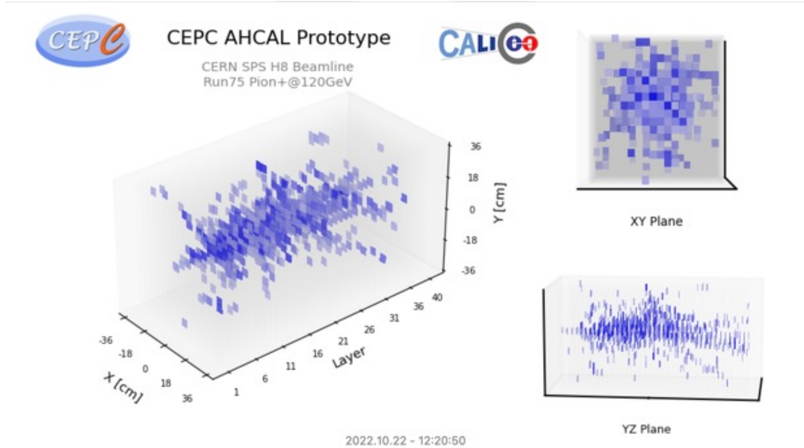


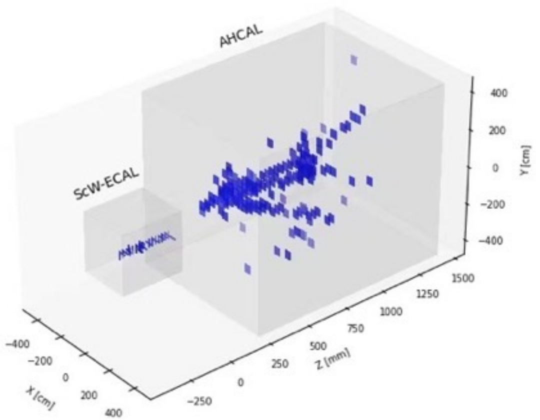
Display of hadronic showers : display of the imaging power

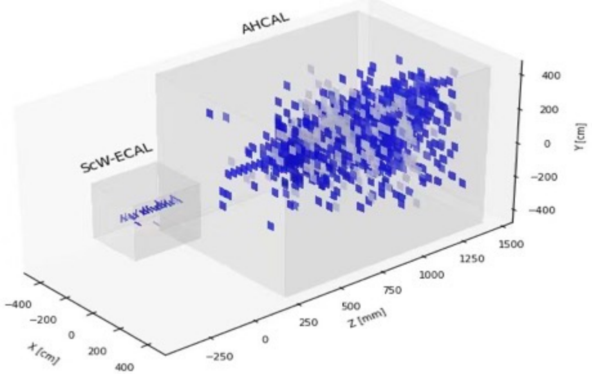
- **The calorimeter system is able to contain high energy hadronic showers and record their details.**



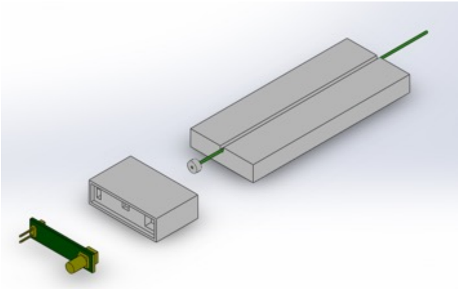


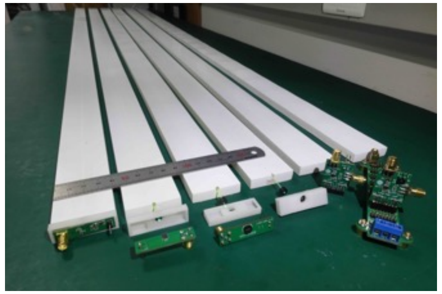


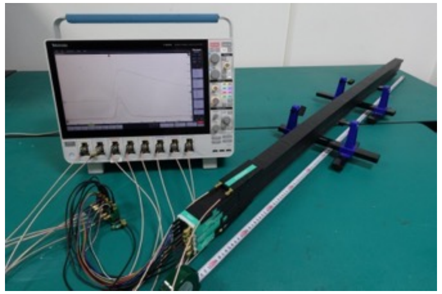


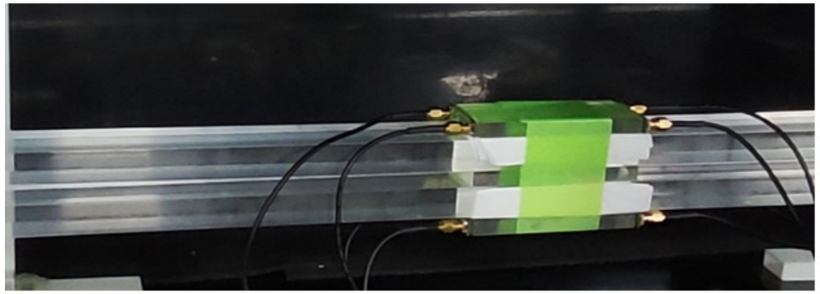


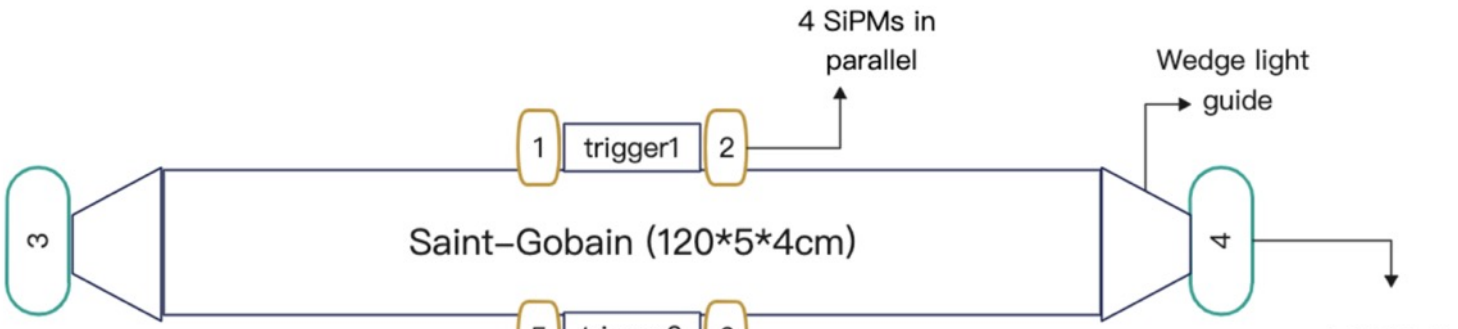
Scintillator Muon Detector R&D

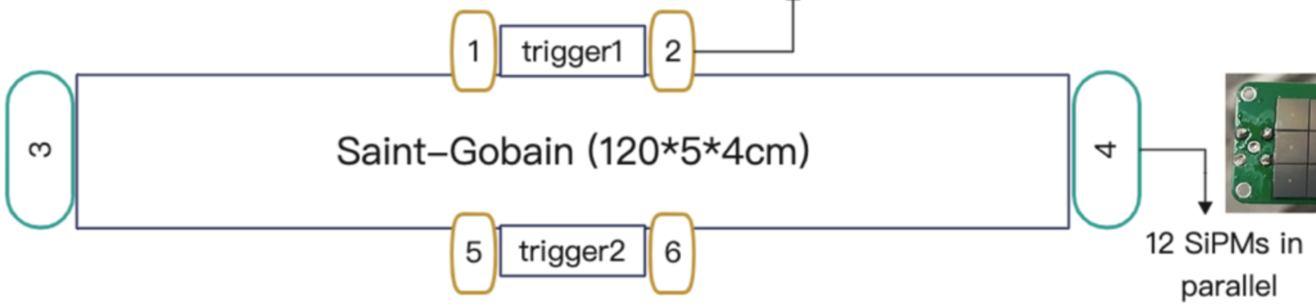


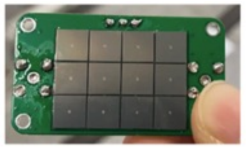


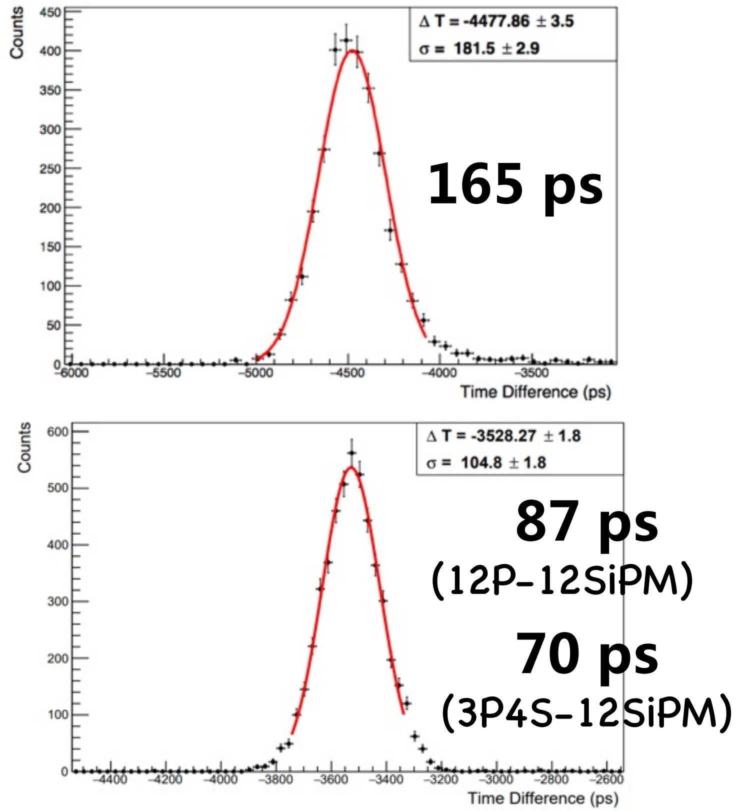










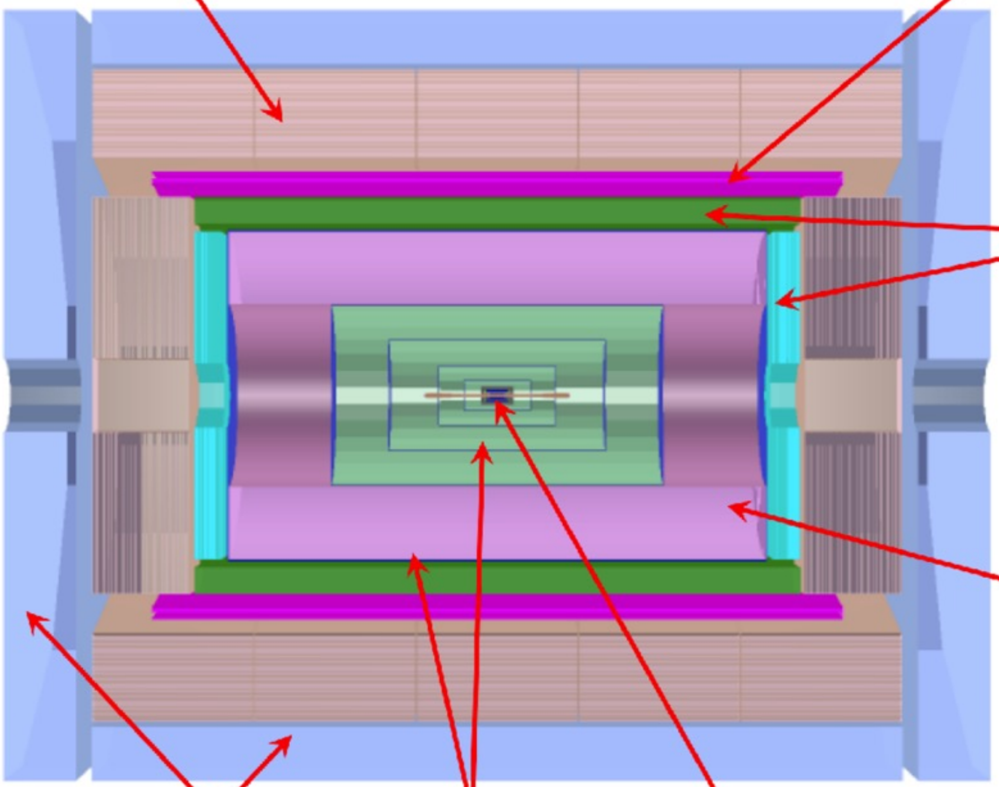


The 4th Detector Concept

Scint Glass PFA HCAL

Advantage: Cost efficient, high density

Challenges: Light yield, transparency, massive production.



Muon+Yoke

Si Tracker w/TOF outer layer

Si Vertex

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;

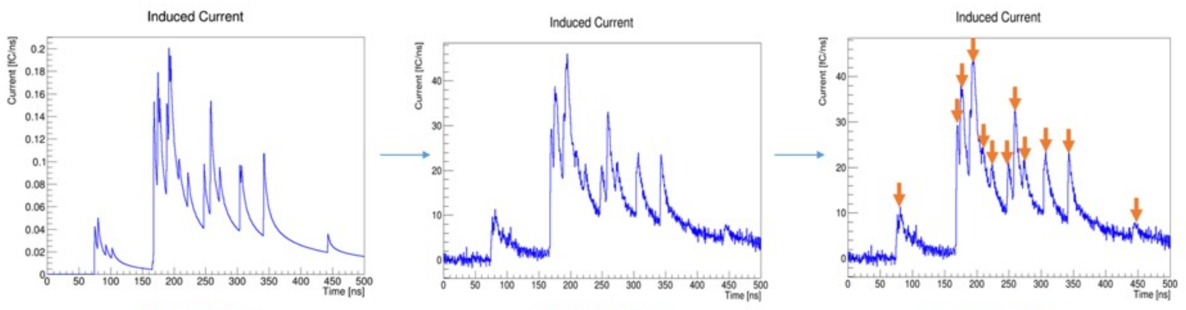
Magnet in much reduced size.

BMR: 4% → 3%

R&D for the 4th detector concept

- ❖ Drift chamber
- ❖ TOF detector
- ❖ Crystal ECAL
- ❖ Glass-scintillator HCAL

Drift chamber simulation and design optimization



Signal generator (Garfield++)

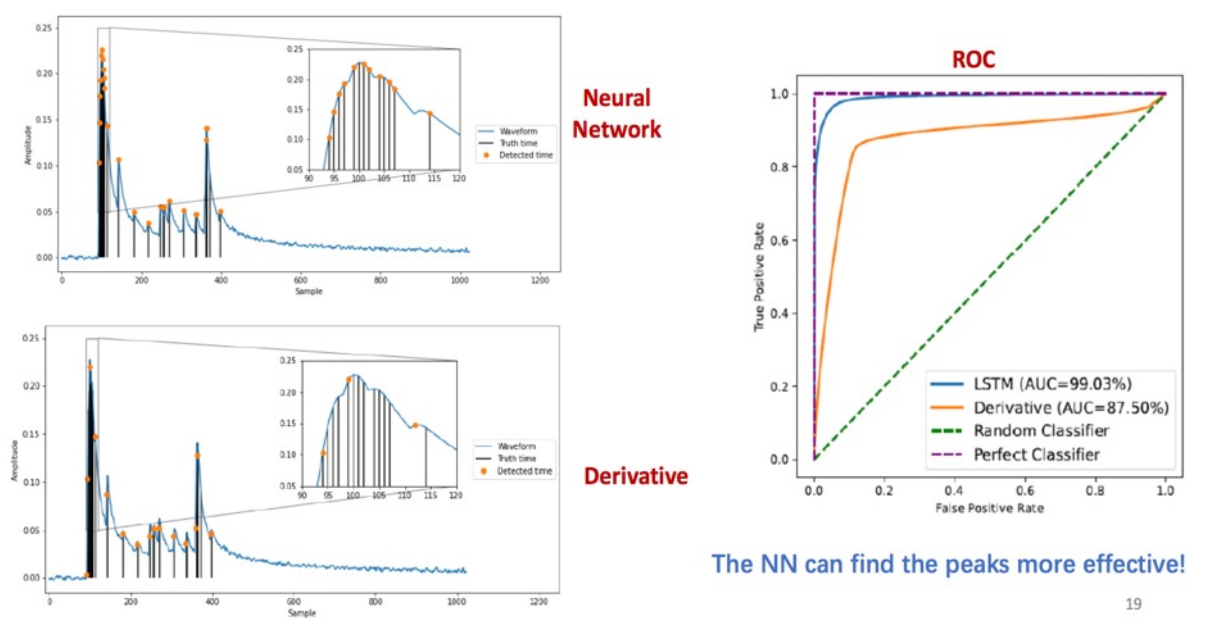
- Heed: ionization process
- Magboltz: gas properties (drift/diffusion)

Electronics:

- Preamplifier
- Noise
- ADC sampling rate

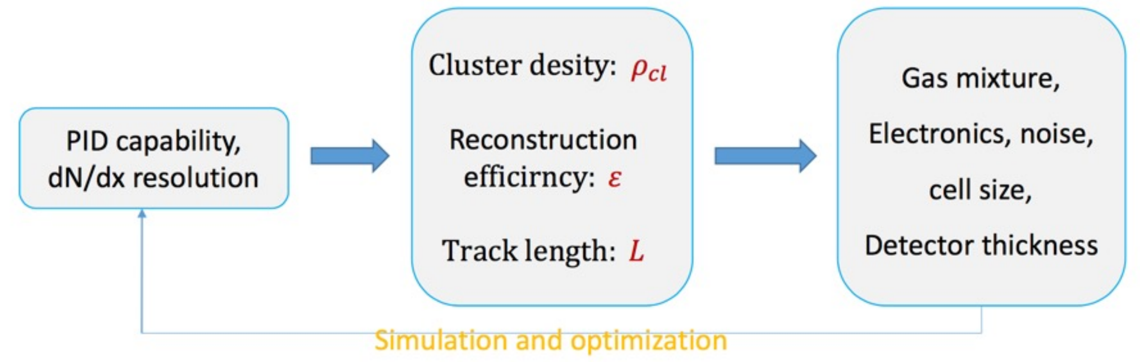
Peak finding algorithm

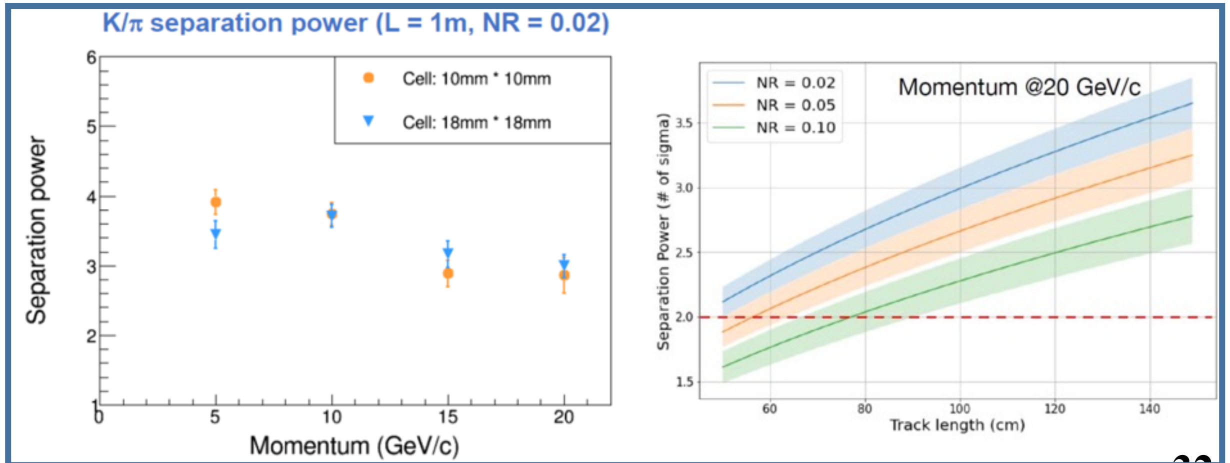
- Second derivative
- Machine Learning



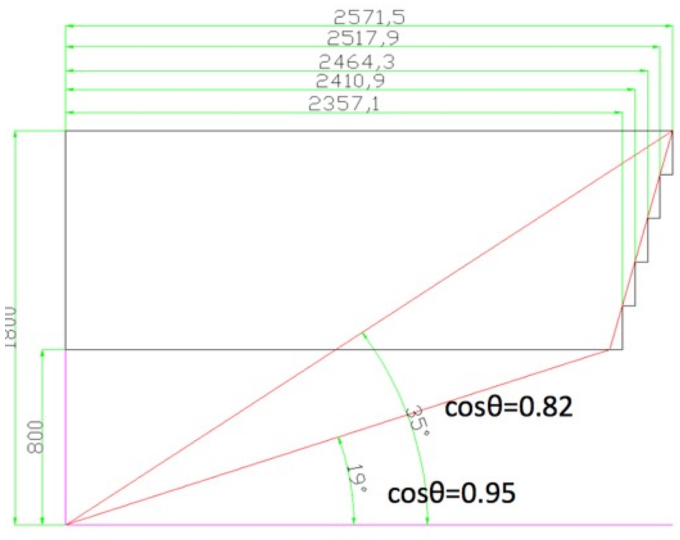
The NN can find the peaks more effective!

19

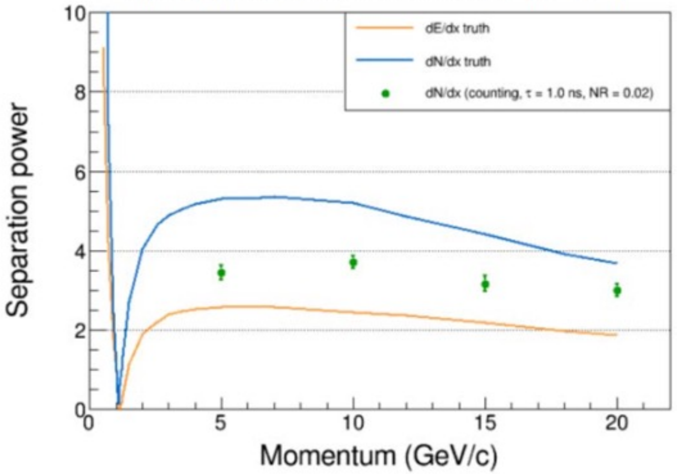


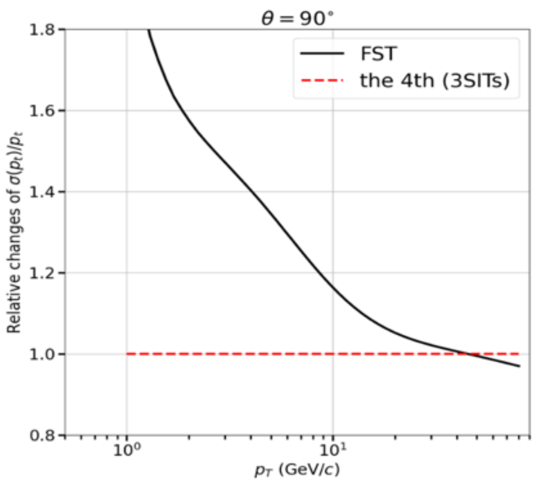


Optimized drift chamber design, detector R&D

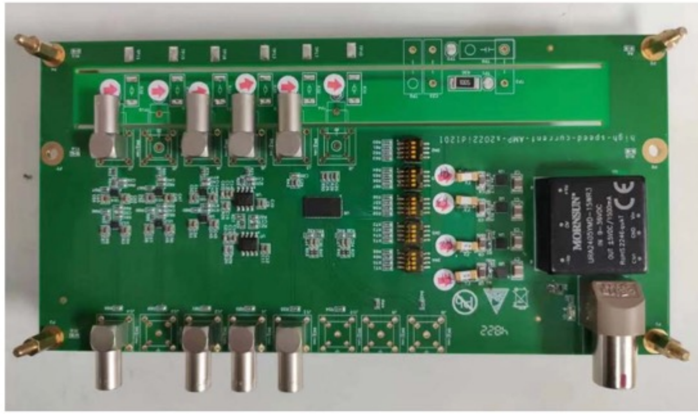


Radius extension	800-1800mm
Length of outermost wires（cosθ=0.82）	5143mm
Thickness of inner CF cylinder：	200μm
Outer CF frame structure：	Equivalent CF thickness: 1.63mm
Thickness of end Al plate	35mm
Cell size:	~ 18 mm × 18 mm
Number of cell	24766
Ratio of field wires to sense wires	3:1
Gas mixture	He/iC_4H_{10}=90:10

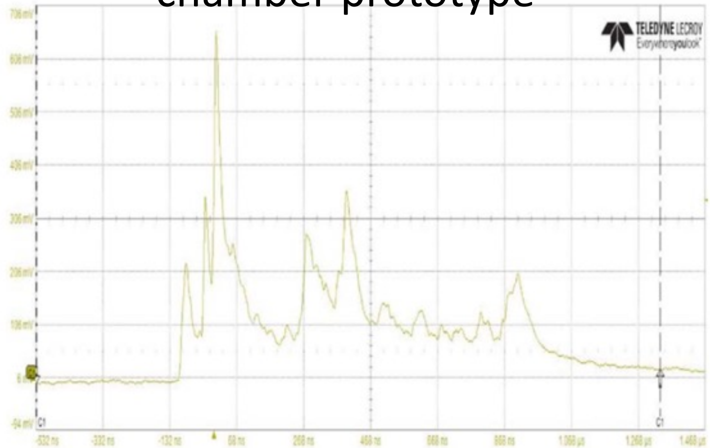




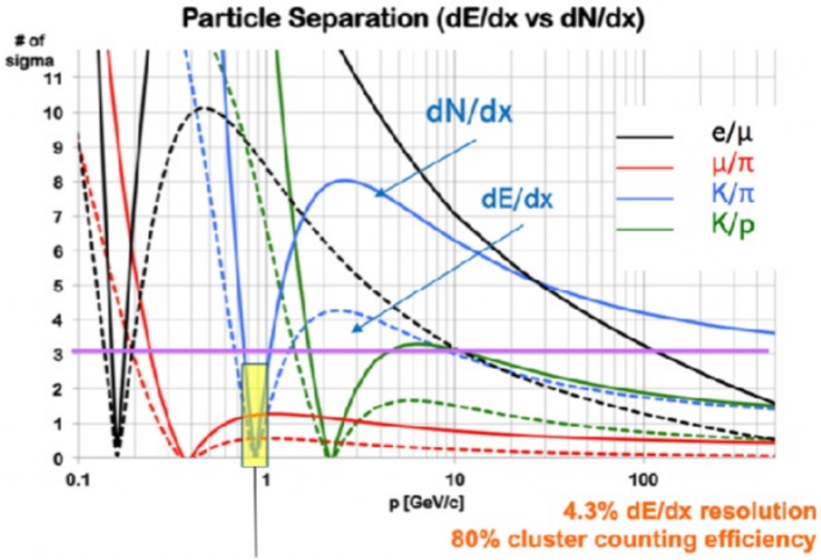
Developed High bandwidth preamplifier

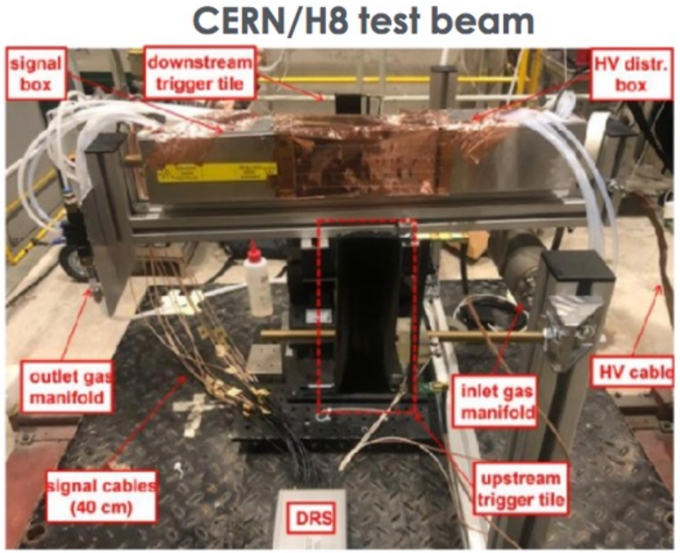


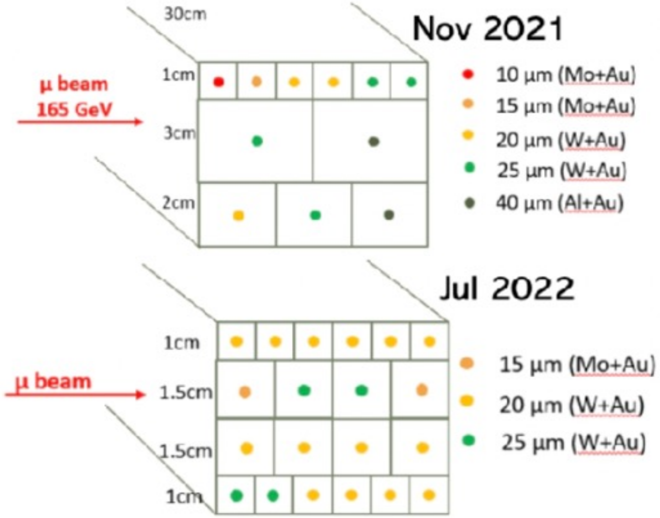
Waveform recorded of a drift chamber prototype

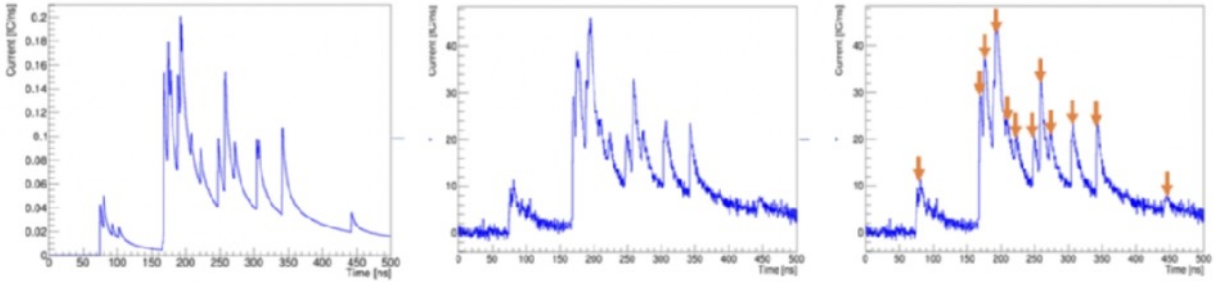


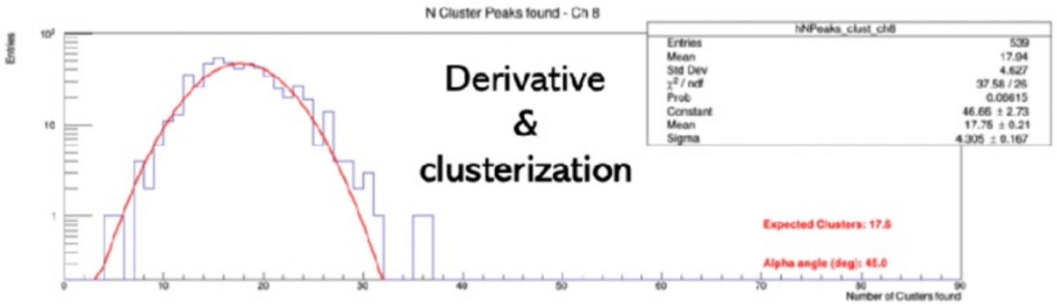
Joint test beam and data analysis efforts, regular meetings





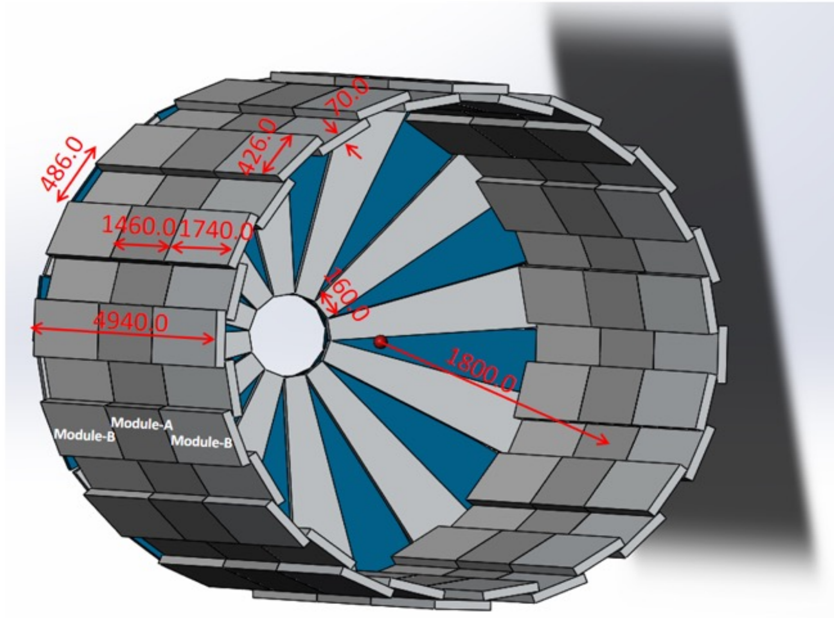






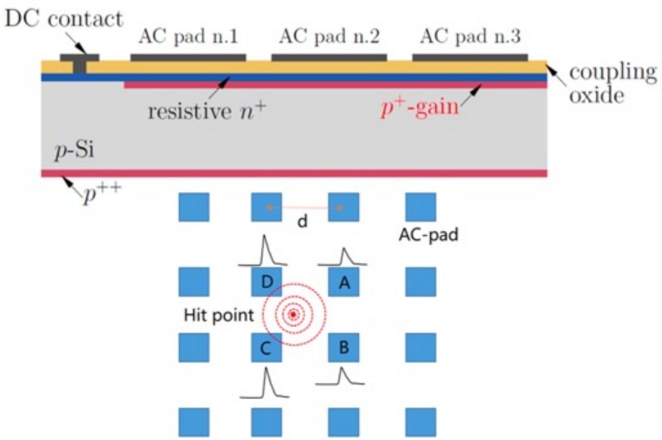
TOF detector options

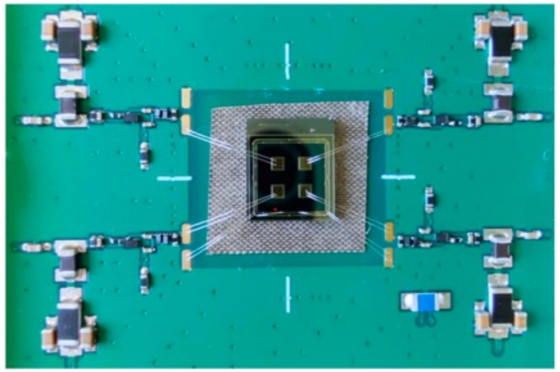
MRPC

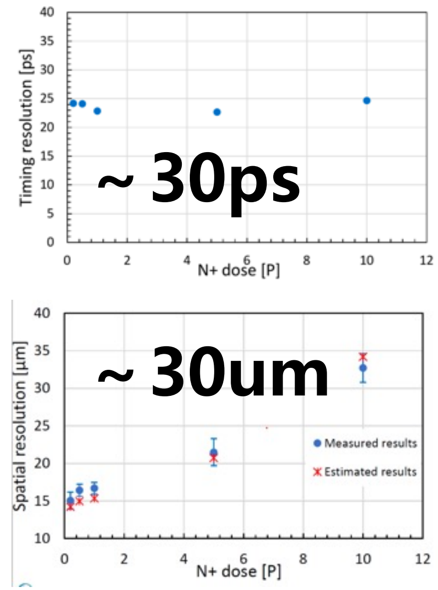


1、时间分辨：<35ps
2、PID of π/k: 2.5GeV @3σ
3、TOF面积：~77m^2
4、电子学道数：37632
5、电子学功耗：17mW/道
6、造价估算：3420万RMB (MRPC 784万元)

AC-LGAD

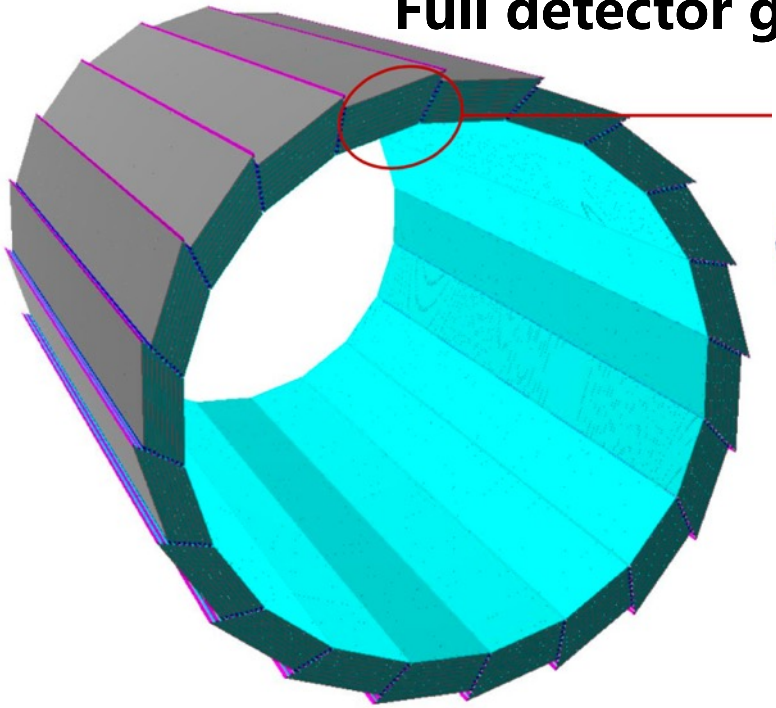


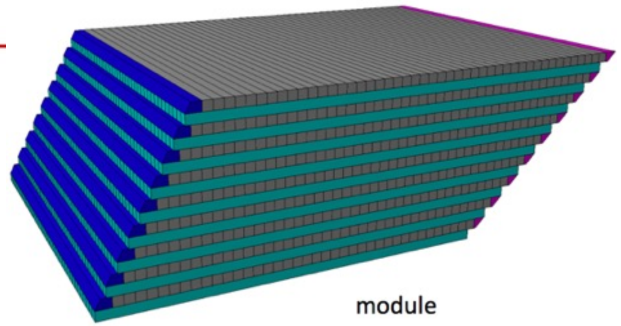




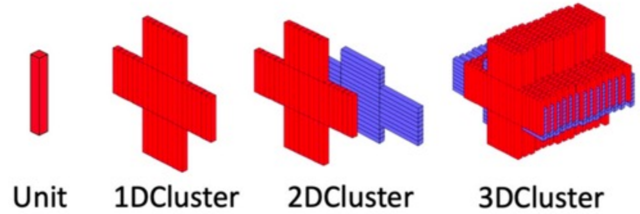
High granularity crystal ECAL with long bars

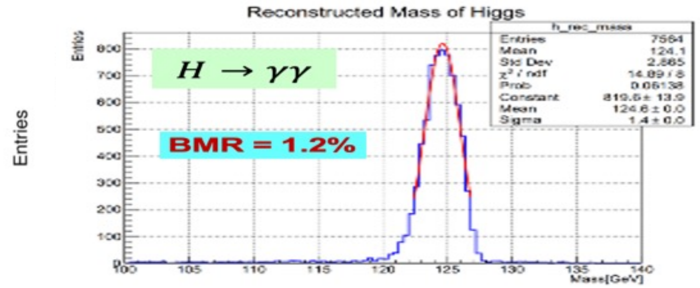
Full detector geometry



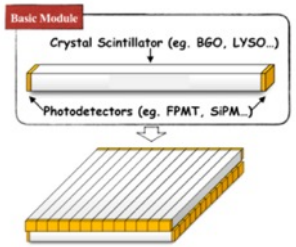


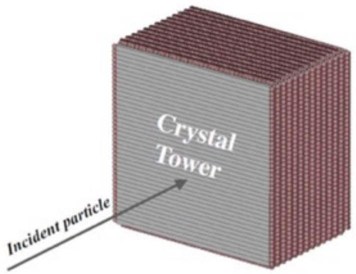
Reconstruction

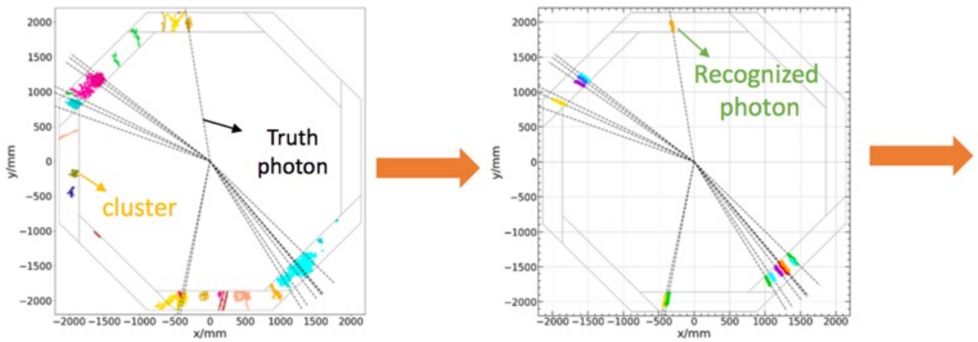




transverse size: 1-2 cm
length 40-60cm

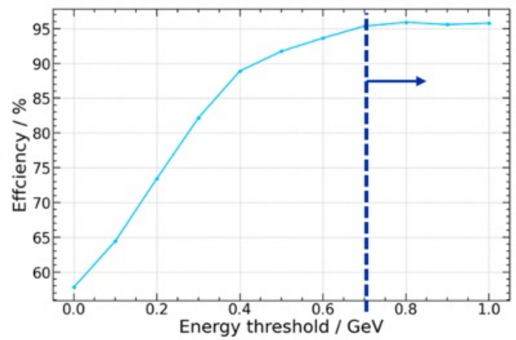






Clustering

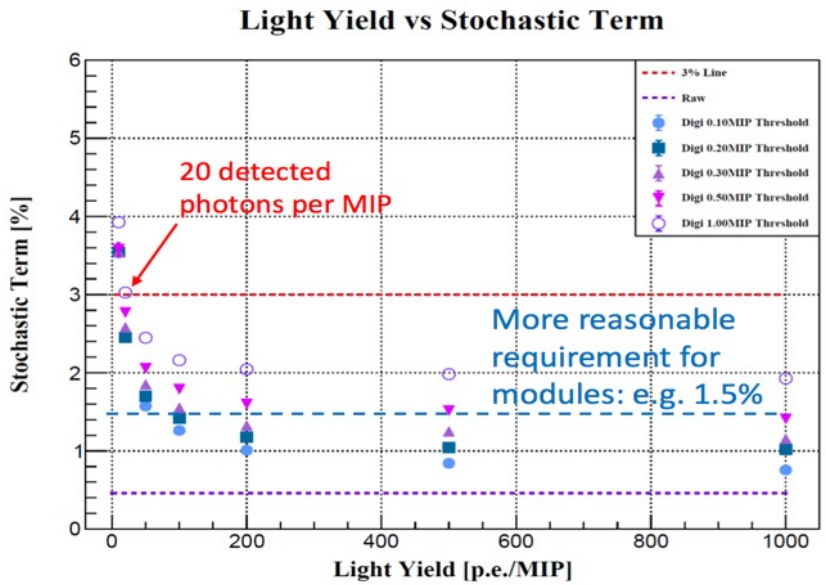
Photon recognition



Recognition efficiency

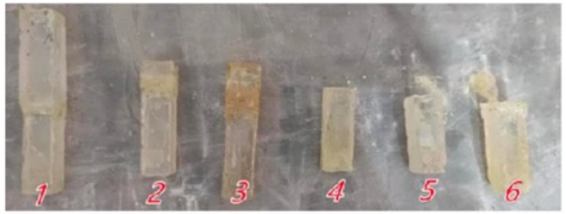
Photon identification efficiency > 95% when E > 0.7 GeV

Crystal ECAL R&D

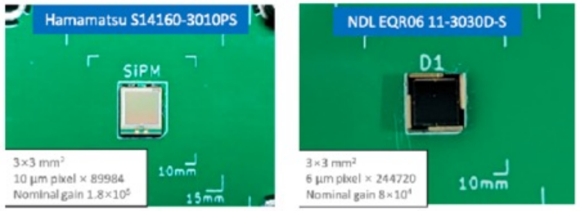


Study of crystal-SiPM units

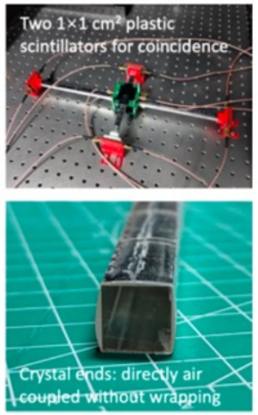
BGO crystals

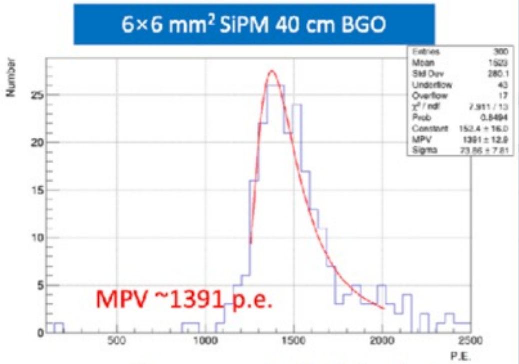


Large dynamics SiPMs



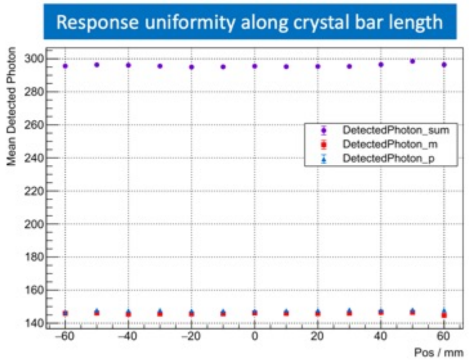
Cosmic ray test

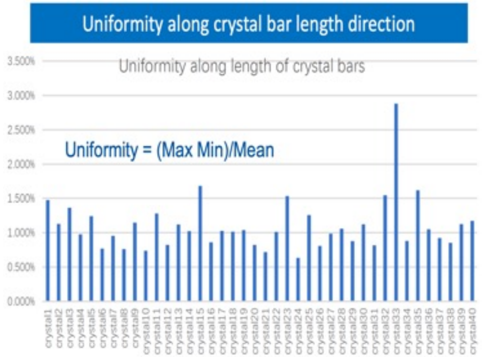




good enough light yield

Response uniformity





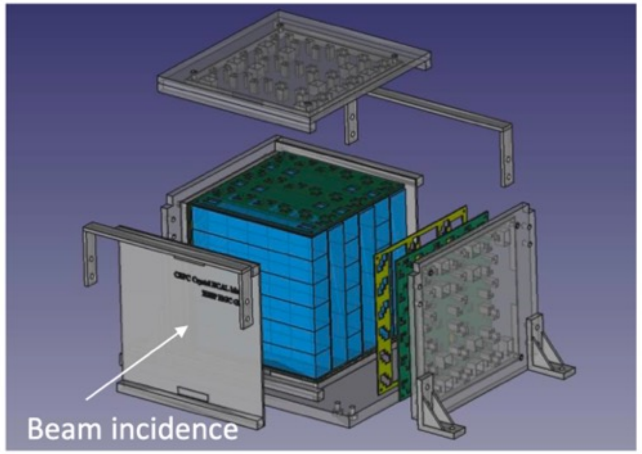
Crystal ECAL module prototype and beam test

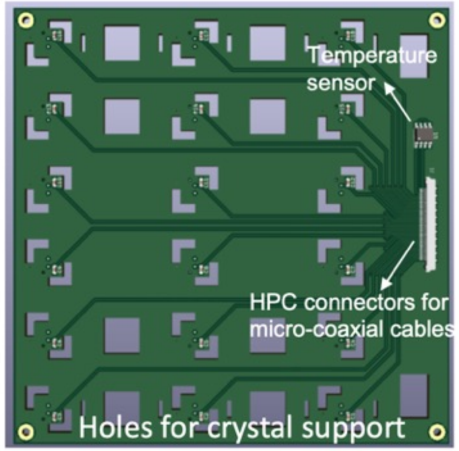
$2*2*12cm^3$ crystal bars with $3*3mm^2$ SiPMs

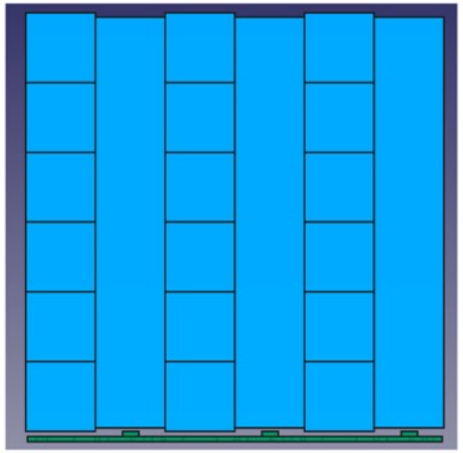
Module prototype design and development

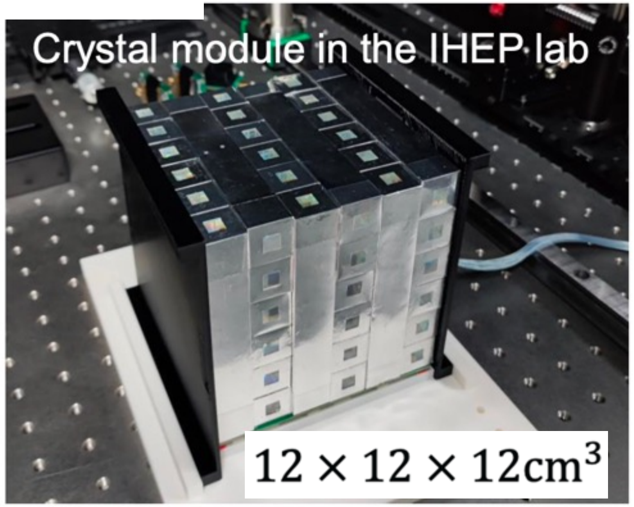
Custom SiPM readout PCB

Module dimensions

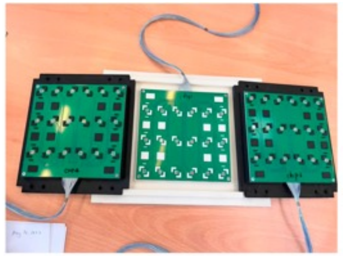


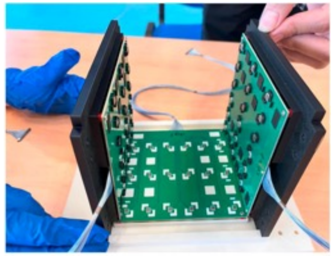


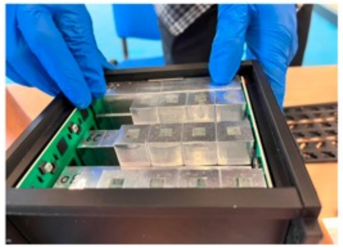




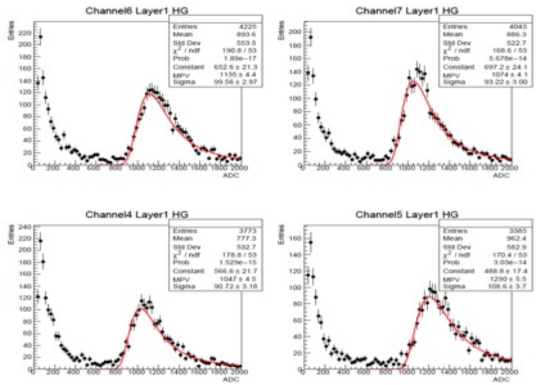
Module assembling at CERN PS beam site







Tested with 10 GeV μ and π, and 0.5-5 GeV e

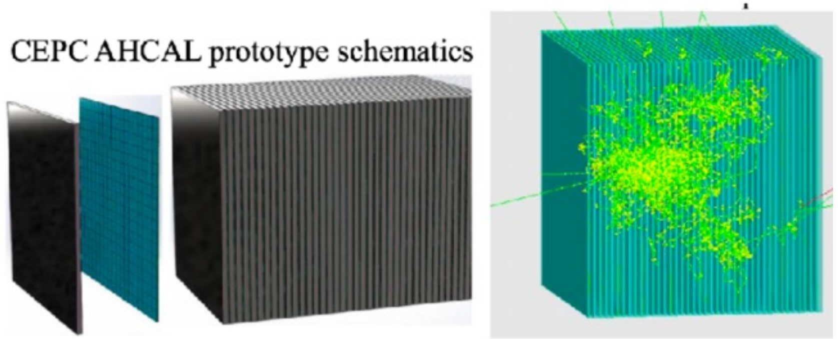


Data analysis is underway

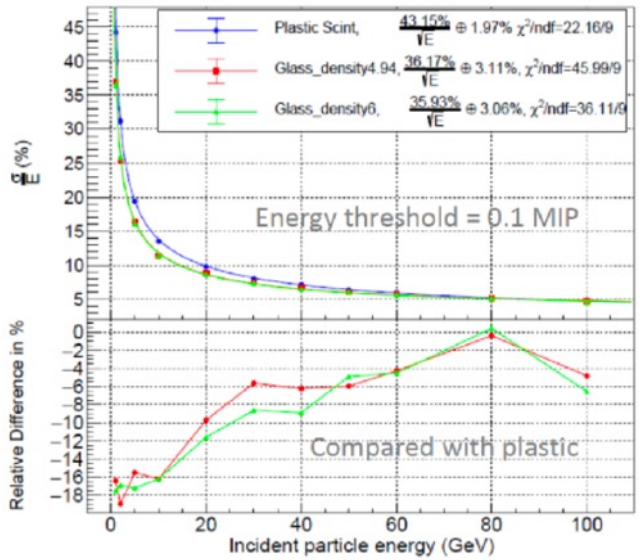
A new AHCAL concept with glass scintillator tiles

- **CEPC detector: highly granular calorimeter + tracker**
  - Boson Mass Resolution (BMR) ~4% has been realized in baseline design
  - Further performance goal: BMR 4%→3%
- **New Option: Glass Scintillator HCAL (GS-HCAL)**
  - Higher density provides higher sampling fraction
  - Doping with neutron-sensitive elements: improve hadronic response (Gd)

Design similar to baseline AHCAL

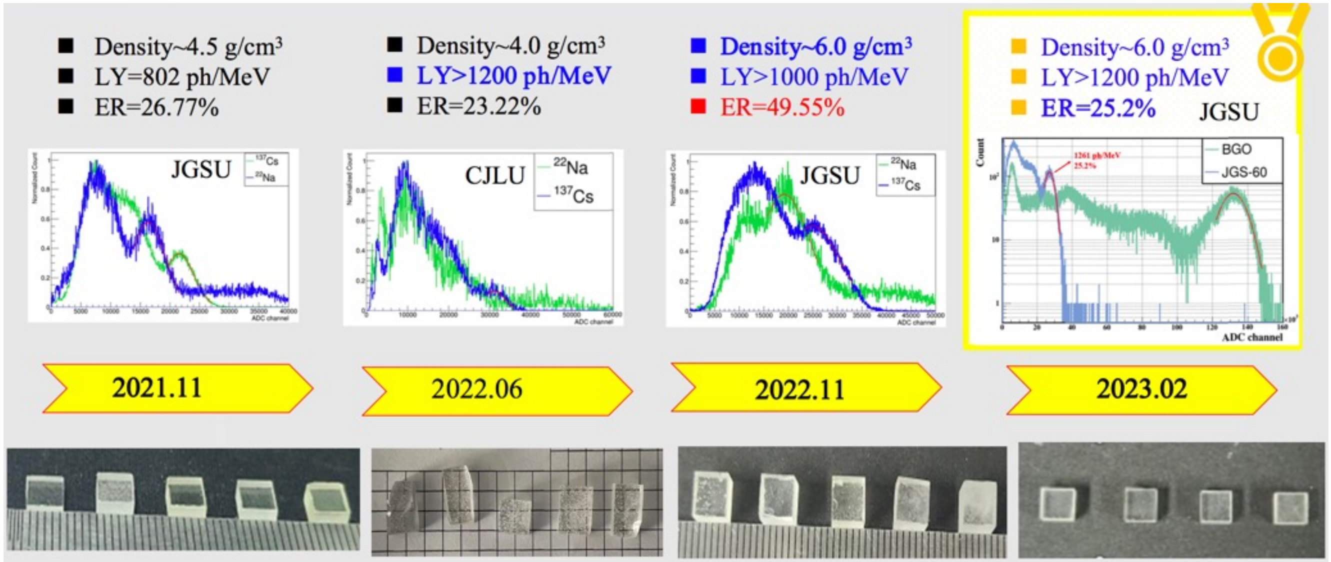


Key parameters	Value	Remarks
Tile size	~30×30 mm^2	Reference CALICE-AHCAL, granularity, number of channels
Tile thickness	~10 mm	Energy resolution, Uniformity and MIP response
Density	**6-7 g/cm^3**	More compact HCAL structure with higher density
Intrinsic light yield	**1000-2000 ph/MeV**	Higher intrinsic LY can tolerate lower transmittance
Transmittance	~75%	
MIP light yield	~150 p.e./MIP	Needs further optimizations: e.g. SiPM type, SiPM-glass coupling
Energy threshold	~0.1 MIP	Higher light yield would help to achieve a lower threshold
Scintillation decay time	~100 ns	Mitigation pile-up effects at CEPC Z-pole (91 GeV)
Emission spectrum	Typically 350-600 nm	To match SiPM PDE and transmittance spectra



Better energy resolution than scintillator

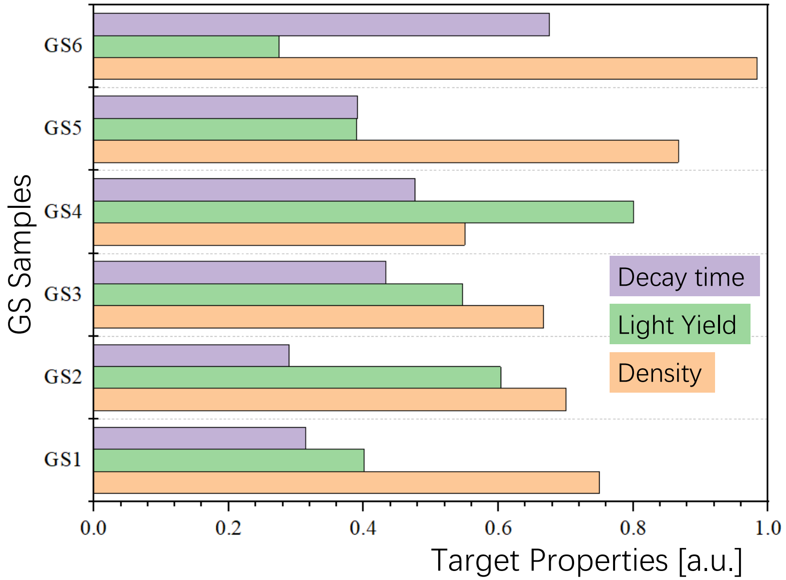
Scintillator glass R&D



闪烁玻璃合作组
Glass Scintillator Collaboration

A collaboration with 11 institutes has been formed on large area glass scintillator R&D

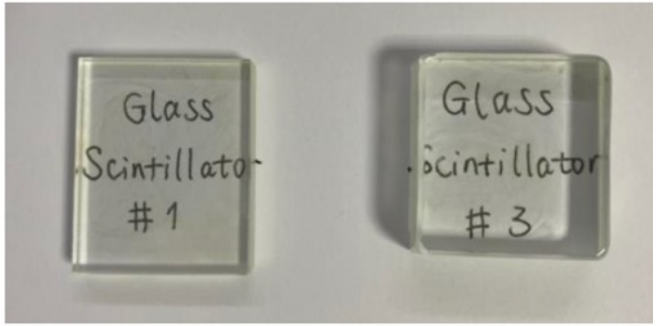
➔ scintillator glass with high density, large light yield, fast decay time and low cost.

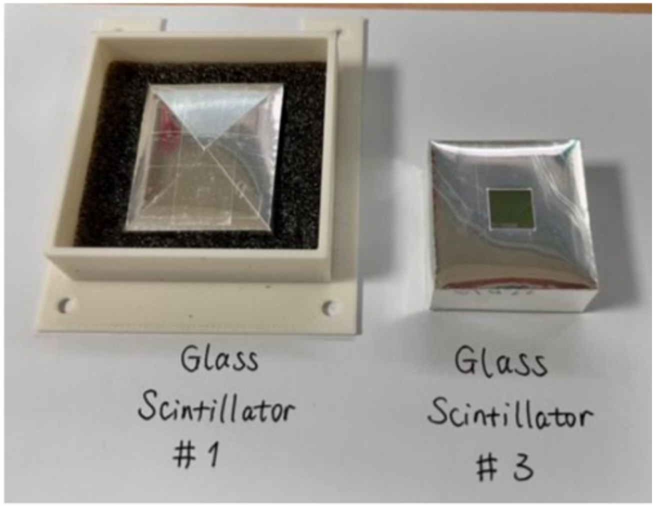


Steady and impressive progress in meeting the targets of the R&D effort

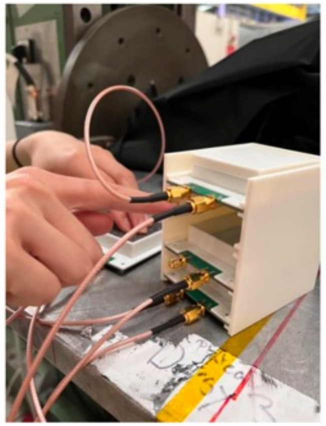
Beam test of scintillator glass samples

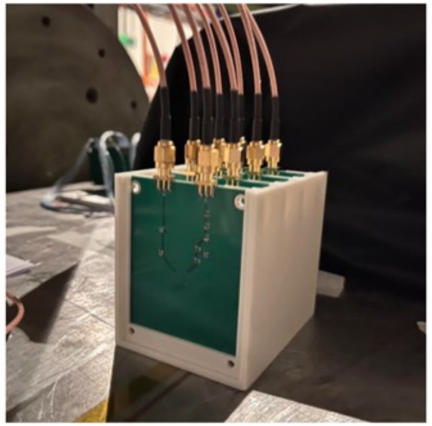
Scintillator glass samples

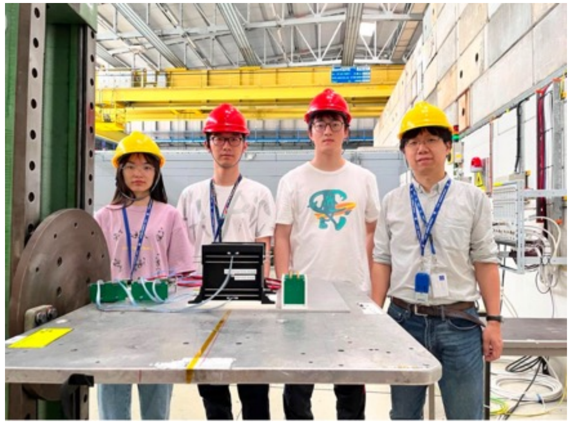


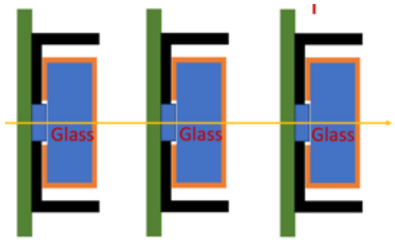


Tested with 10 GeV μ @ CERN PS





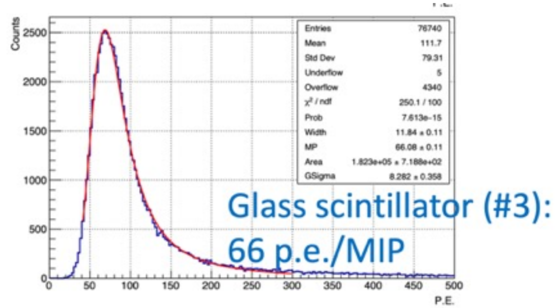




Light yields for MIP (10 GeV muon)

Index	Dimensions (mm)	Transmittance	Decay Time (ns)	Muon response (p.e./MIP)	Scale to 10mm thickness (p.e/MIP)
#1	33.5×27.6×5.1	69 %	300 (19%), 881	15	29
#1 ESR				42	82
#2	30.2×29.5×6.6	61 %	114 (11%), 770	35	53
#3	29.9×28.1×10.2	70 %	90 (6%), 754	66	65
#3 ESR				69	68
#4	37.2×35.1×5.3	80 %	96 (6%), 1024	31	59
#5	40.0×35.1×4.2	78 %	335 (26%), 1068	38	91
#6	30.3×29.8×9.4	55 %	134 (5%), 1132	67	71
#7	34.8×34.8×7.5	65 %	113 (27%), 394	60	80
#8	27.8×25.6×5.0	81 %	136 (23%), 933	41	82
#9	34.6×34.7×7.5	49 %	141 (12%), 771	69	92
#10	34.7×35.2×7.4	64 %	129 (10%), 819	74	100
#11	30.5×30.0×8.7	81 %	153 (12%), 1085	73	84

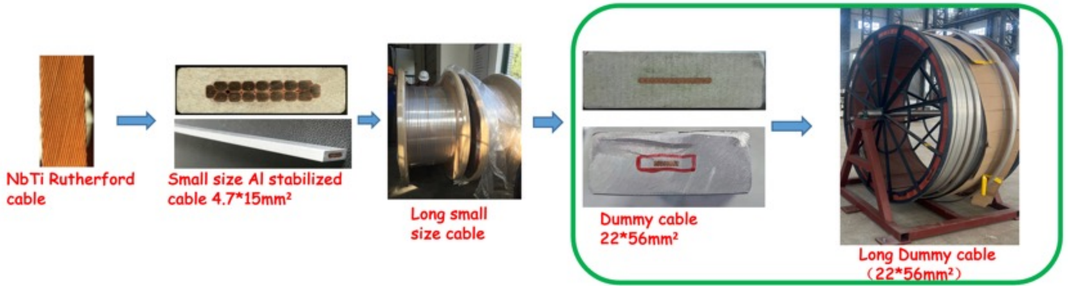
Typical energy spectrum for MIP

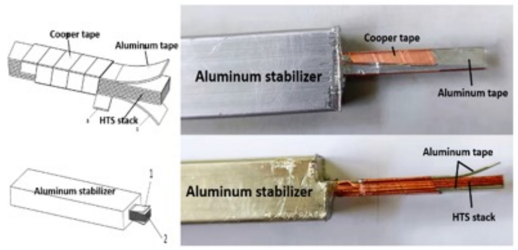


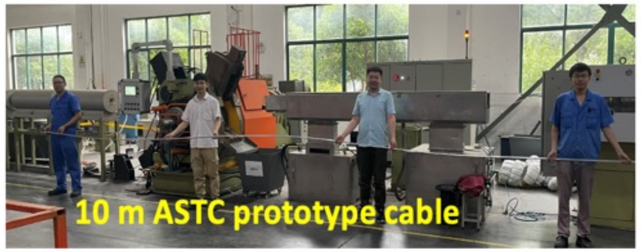
Data analysis is ongoing

Other activities

❖ Detector magnet R&D on both LTS (for baseline detector) and HTS (for the 4th detector) technologies







❖ Beam background study has been closely following modifications and updates of the accelerator design including those of IR and beam pipe designs. Particle tracking , detector response simulation and other tools will continue to improve. Beam background with the updated accelerator design estimated by simple scaling indicates a significantly enhanced level of background in detectors. This would require rigorous measures for mitigation.

Summary

- **CEPC physics studies constantly updated, improved and expanded to fully explore the CEPC physics potential.**
- **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.**
- **The 4th detector effort has been ramping up on detailed simulation and global optimization, and even more on detector R&D.**
- **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)