Partical Identification Detectors on Electron-Ion Colliders

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清華大學
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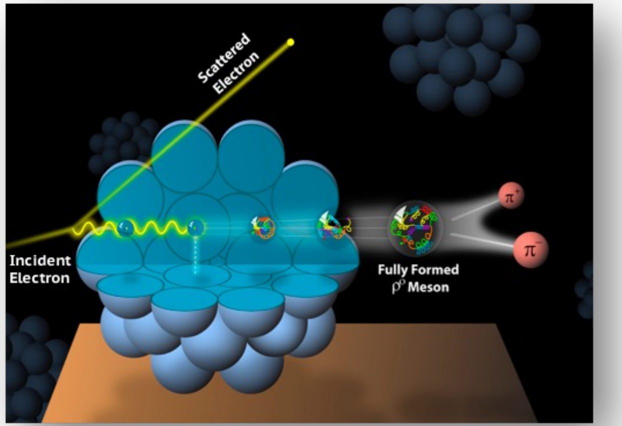
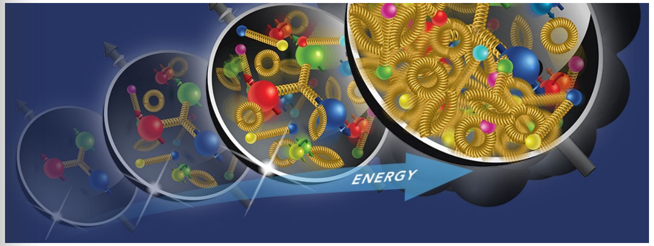
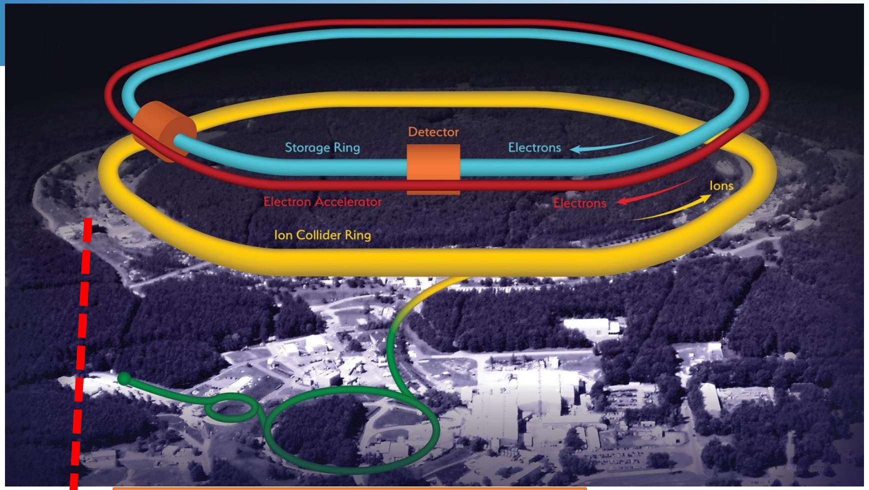
EIC in US (eRHIC)

- Main goals: Study quark and gluon structures in ions

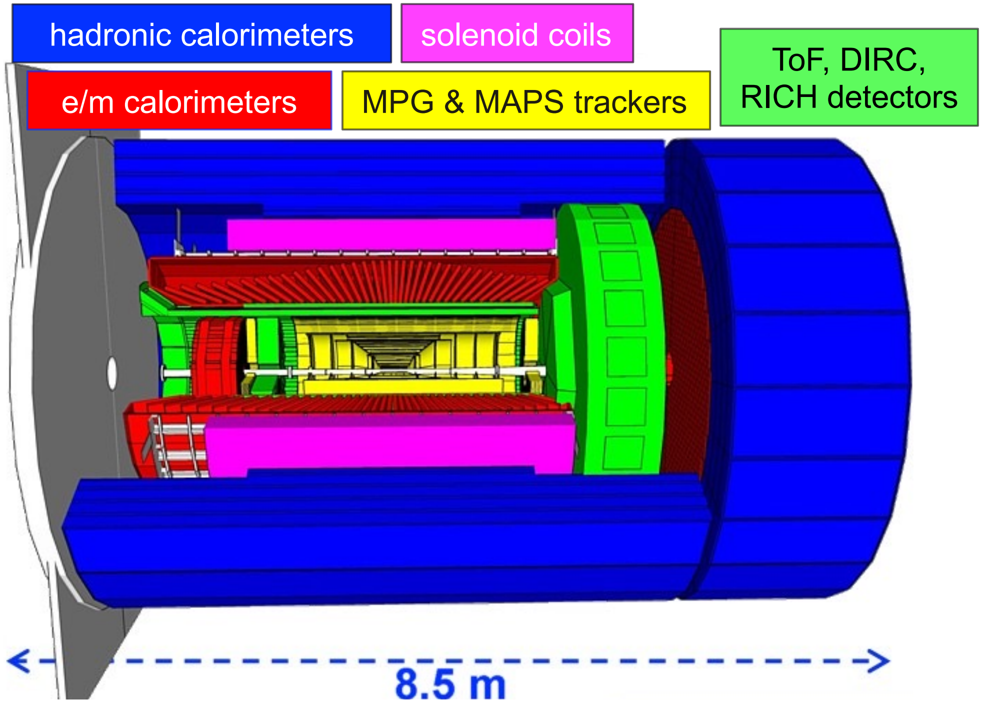
  e.g., spin, mass, exotic states, nuclear-medium effect, gluon saturation, …







ePIC (detector#1)



- To be built at BNL, by BNL and Jefferson Lab
- ~20GeV pol. electron & ~300 GeV/c pol. proton & He3 (+unpolarized ions)
- 2020: approved with $3.5B， 2021 Conceptual Design， 2022 Detector#1 (ePIC)， 2024: Technical Design, …
- Active physics simulation + accelerator design + detector R&D

EIC in China（EicC)

- ❑ Use the existing HIAF ion-accelerator (Huizhou, Guangdong)
- ❑ Add a new 3.5GeV electron-accelerator, collider-rings, IP detector
- ❑ Complementary to eRHIC, but focus on studying sea-quarks
- ❑ Chinese/English white-papers released; working on CDR
- ❑ Active physics simulation, accelerator & detector designs

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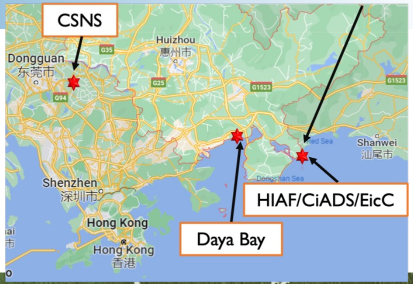
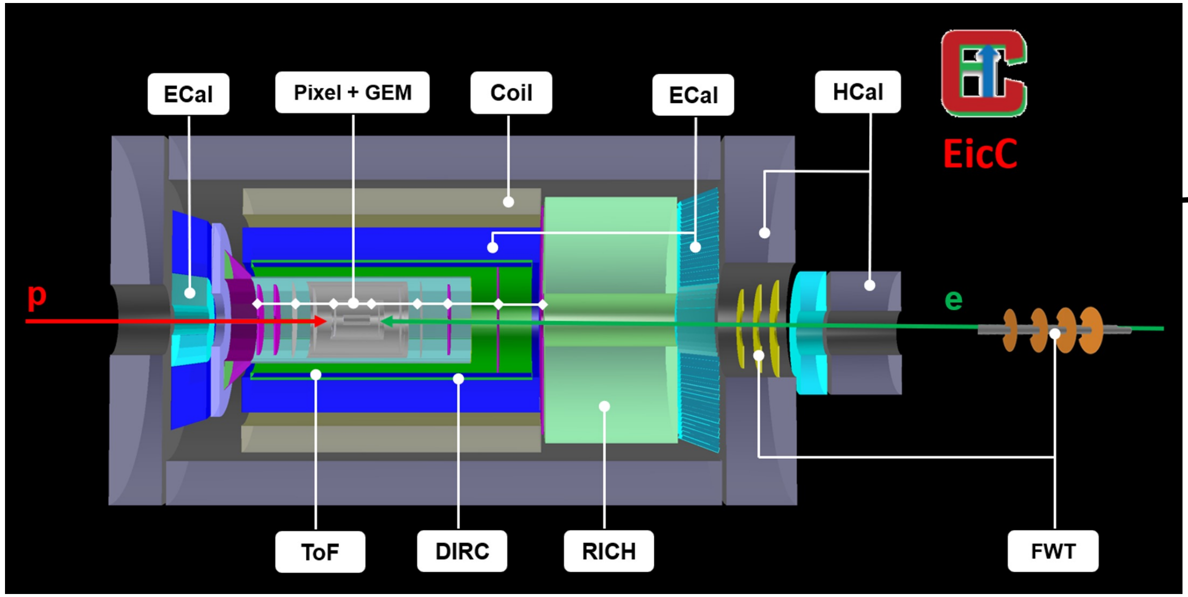
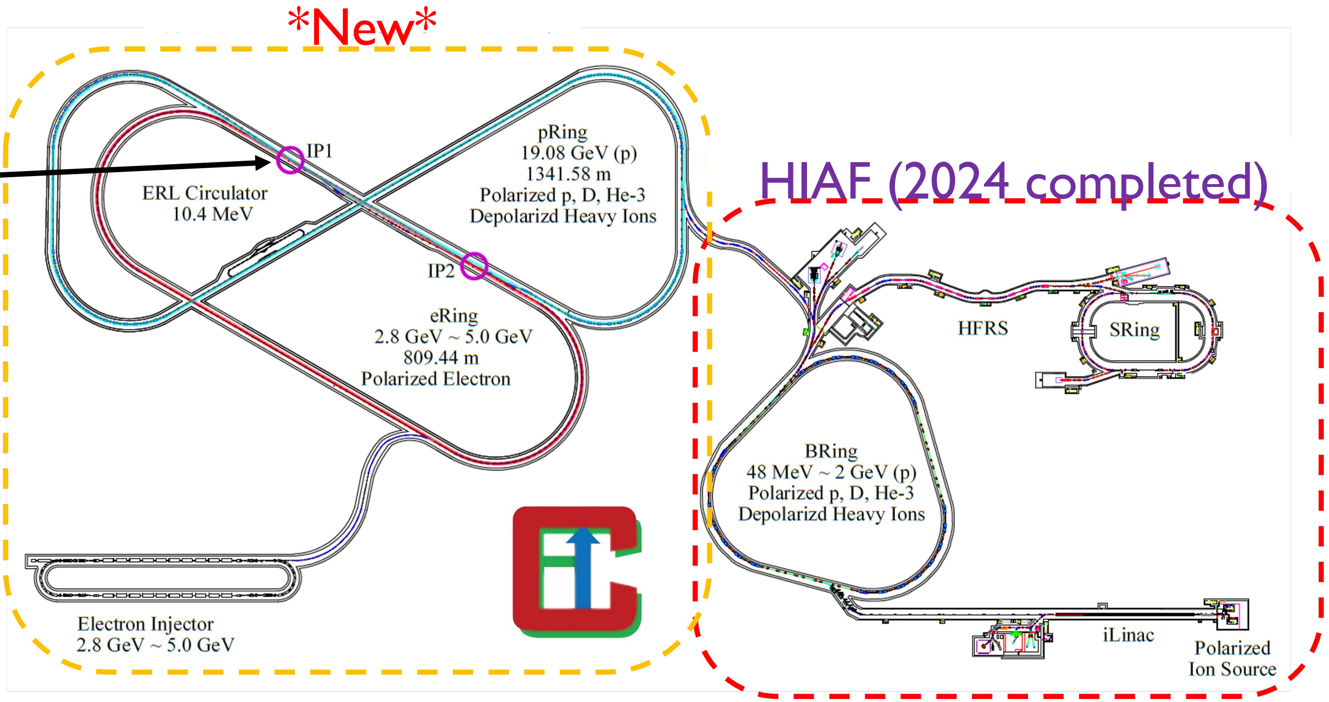




EicC Interaction Point Detector (conceptual)

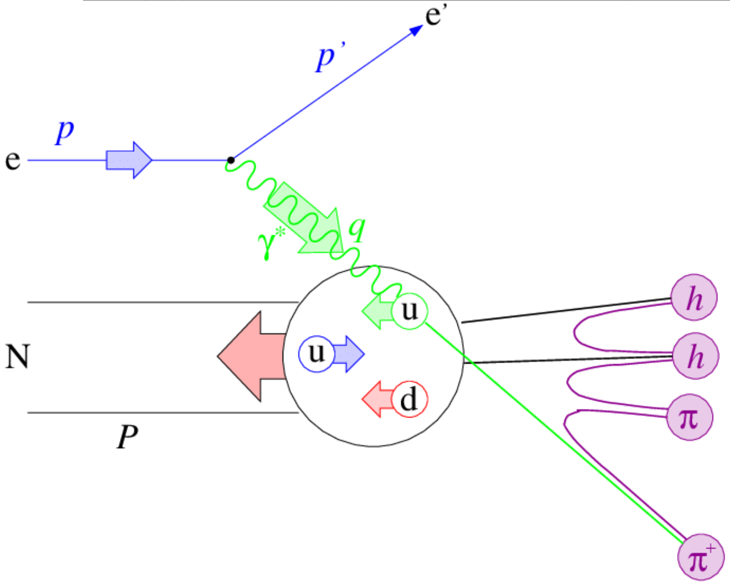


Particle Identification

➢Two Important Physics Reactions: →Access Spin and Angular Momenta

❑ Transverse Momentum Dependent PDF (TMD)

Leading Twist TMDs		Quark Polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1(x,k_T^2)$ - Unpolarized		$h_1^{\perp}(x,k_T^2)$ - Boer-Mulders
	L		$g_1(x,k_T^2)$ - Helicity	$h_{1L}^{\perp}(x,k_T^2)$ - Long-Transversity
	T	$f_{1T}^{\perp}(x,k_T^2)$ - Sivers	$g_{1T}(x,k_T^2)$ - Trans-Helicity	$h_1(x,k_T^2)$ - Transversity; $h_{1T}^{\perp}(x,k_T^2)$ - Pretzelosity

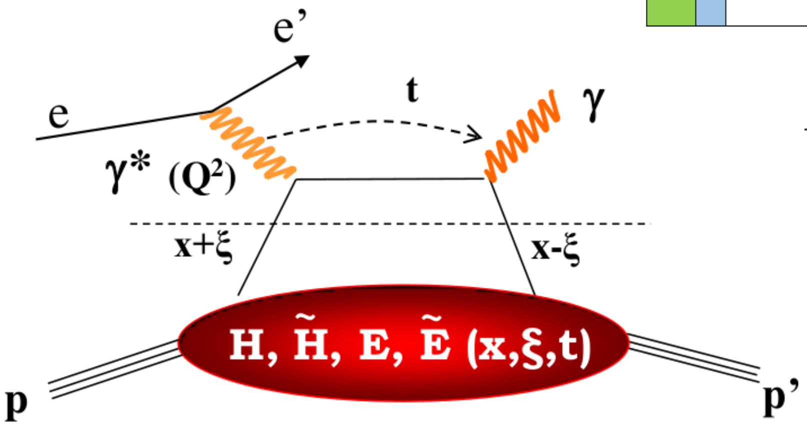


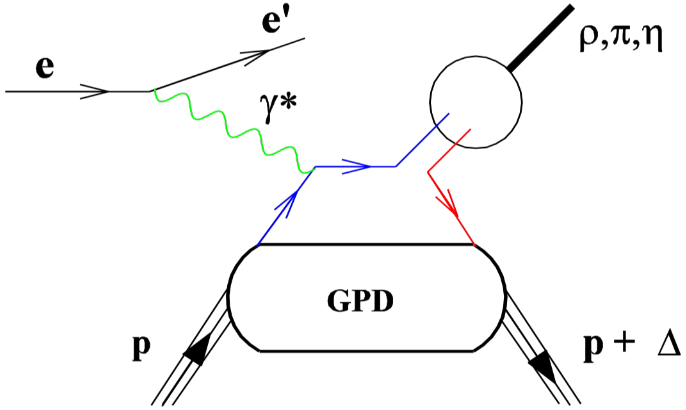
❑ Generalized Parton Distributions (GPD)

✓ Ji's Sum Rule (X. Ji, PRL 78, 610 (1997)

$$J_{q/g} = \lim_{t,\xi\to 0} \frac{1}{2}\int xdx\,[\boldsymbol{H}^{q/g}(x,\xi,t) + \boldsymbol{E}^{q/g}(x,\xi,t)]$$

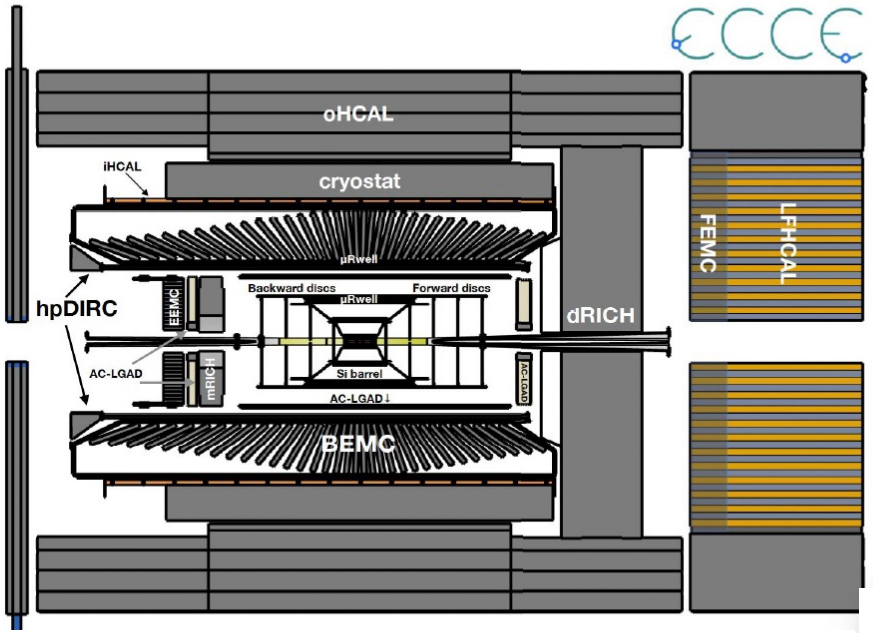
		Quark Polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	H		$2\tilde{H}_T + E_T$
	L		$\tilde{H}$	$\tilde{E}_T$
	T	E	$\tilde{E}$	$H_T, \tilde{H}_T$

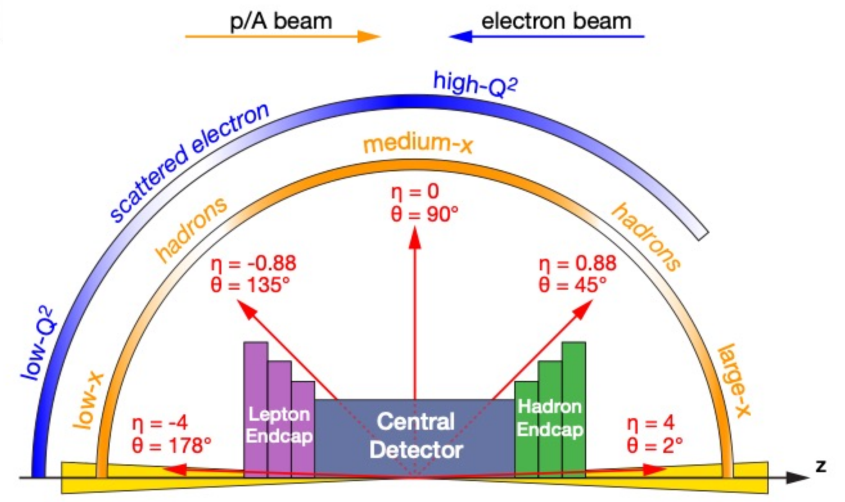




Particle Identification

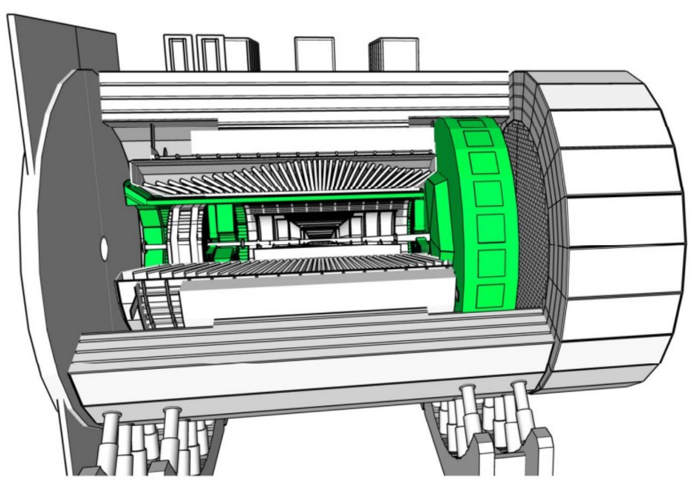
- eRHIC PID Detectors：

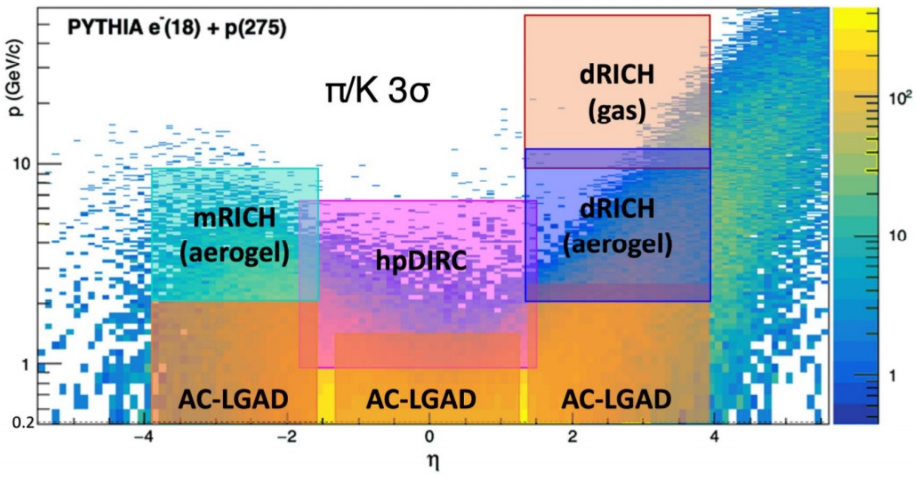




- ❑ Asymmetric & hermetic
- ❑ High granuity
- ❑ Fast responses
- ❑ Compact
- ❑ Magnet tolerance, radiation hard
- ❑ Triggerless

PID	Mode	mRICH	hpDIRC	dRICH aerogel	dRICH gas
π/K	Ring Imaging	2 – 9	1 – 7	2 – 13	12 – 50
	Threshold	0.6 – 2	0.3 – 1	0.7 – 2	3.5 – 12
e/π	Ring Imaging	0.6 – 2.5	< 1.2	0.6 – 13	3.5 – 15
	Threshold	< 0.6	–	< 0.6	< 3.5

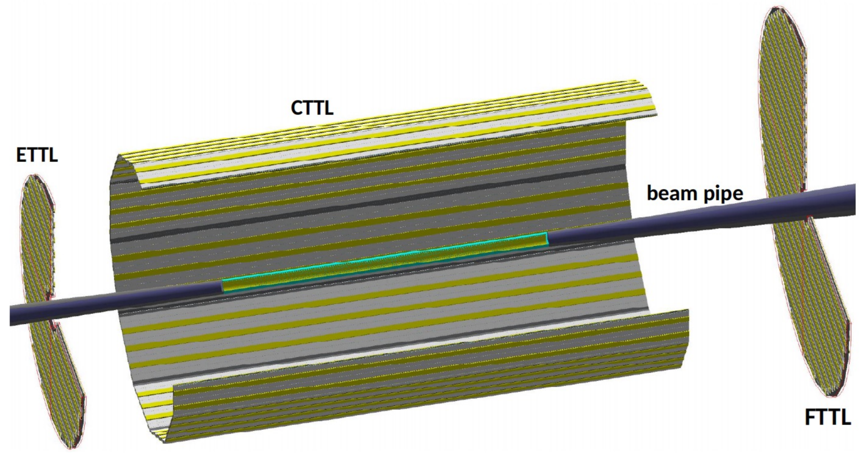




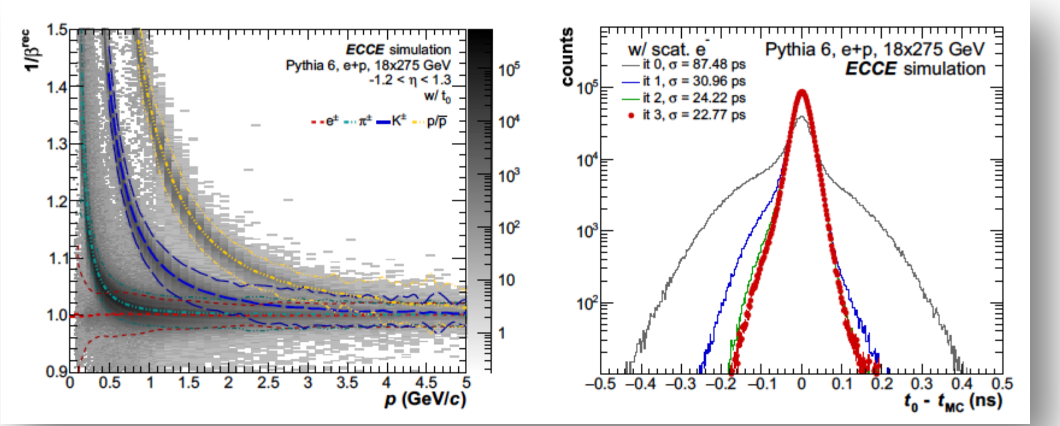
❑ Modular RICH (mRICH) was replaced by pfRICH in 2023

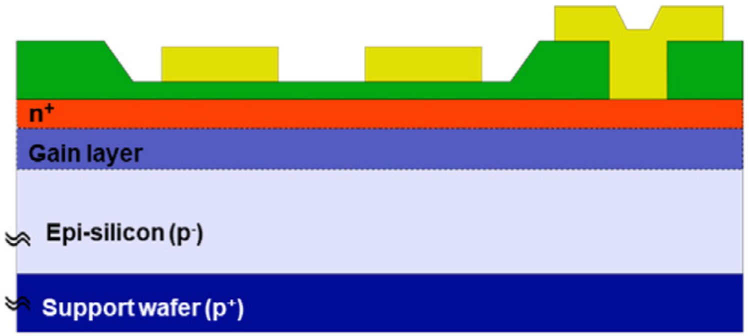
Particle Identification

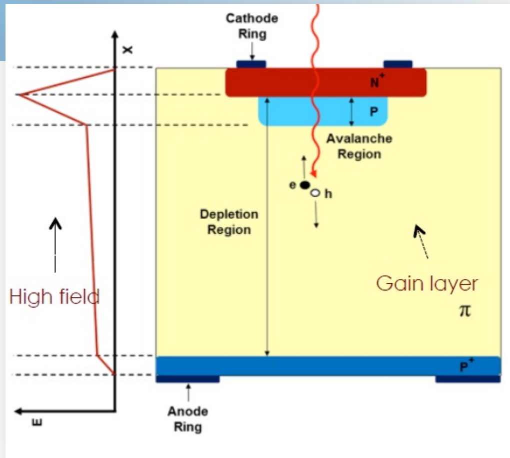
➢ AC-LGAD：



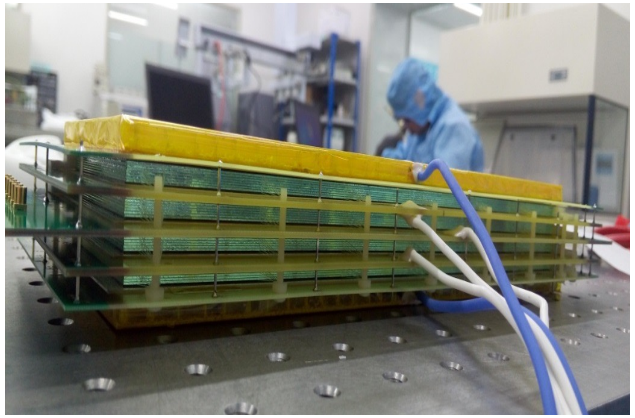
PID	ETTL	CTTL	FTTL
e/π	< 0.5	< 0.45	< 0.6
π/K	< 2.1	< 1.3	< 2.2
K/p	< 3.3	< 2.2	< 3.7

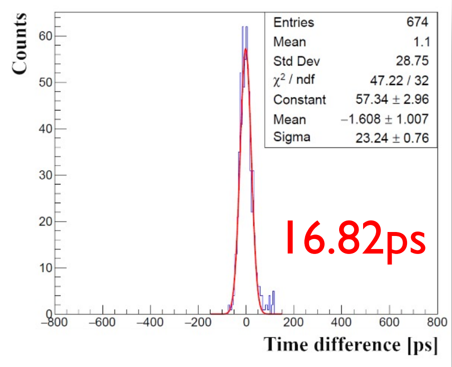






- ❑ New technique, active R&D:
  - o Goals: Time resolution~25ps, Tracking resolution ~100 um
- ❑ Another Option: mRPC



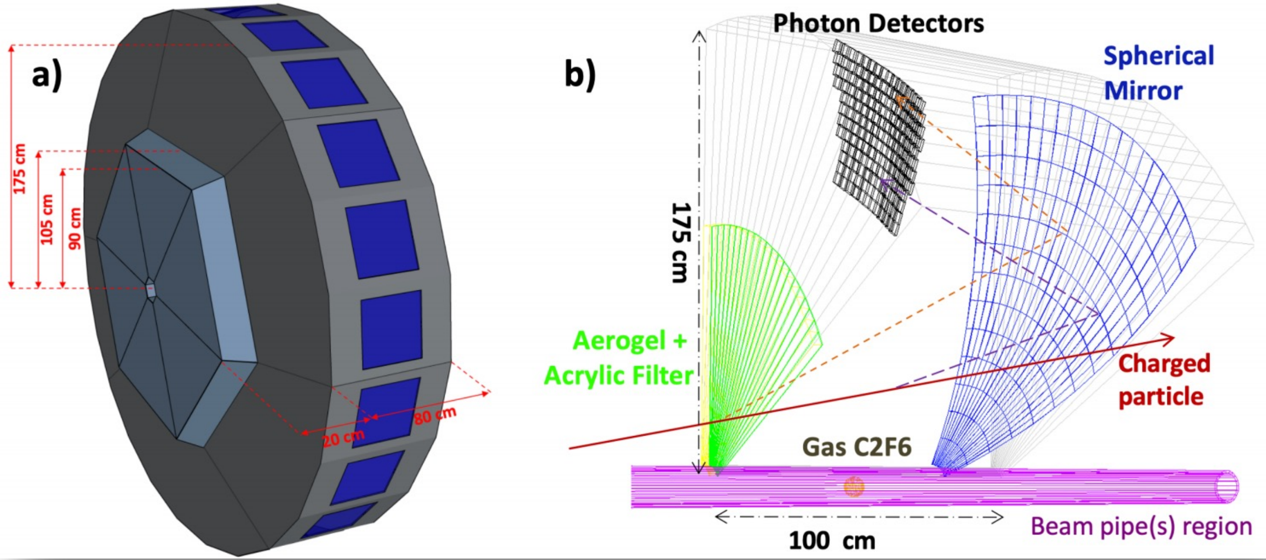


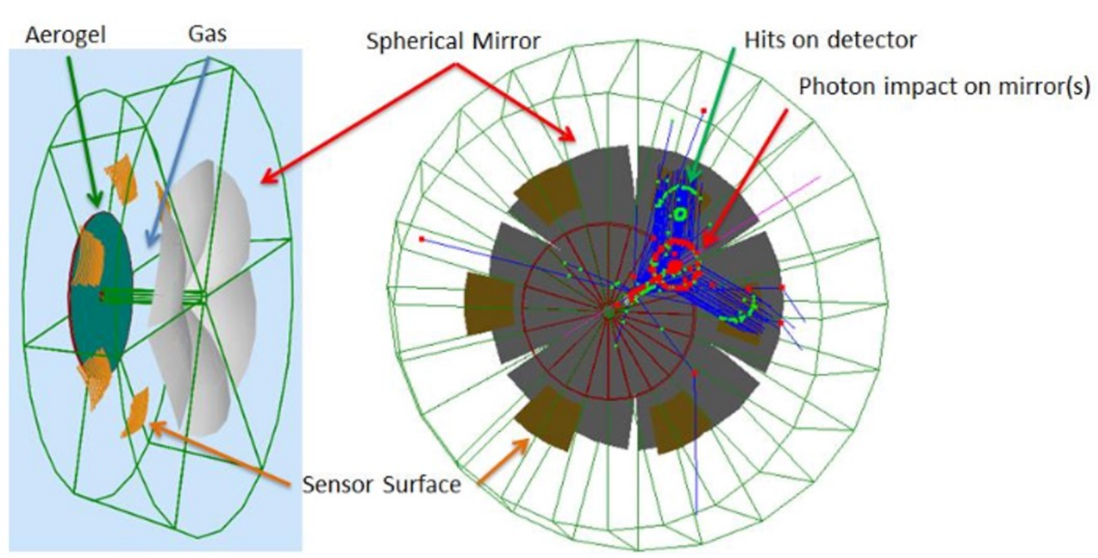
- o Tsinghua (Wang Yi's group) obtains ~16ps from sealed mRPC
- o Vs AC-LGAD: thick, less position precision

❑ What FEE to match?→ R&D needed!

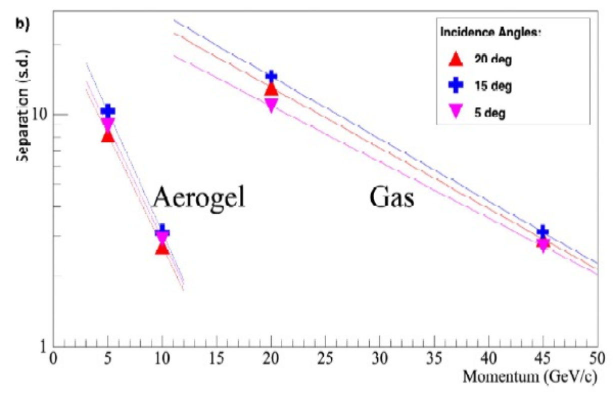
Particle Identification

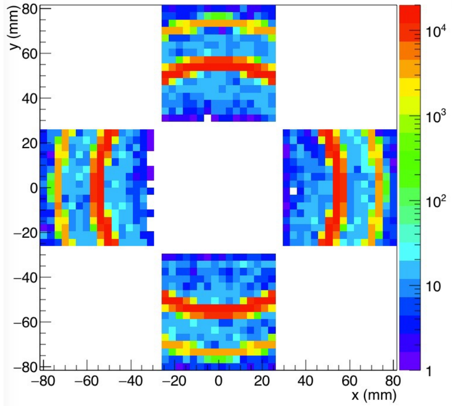
- Dual-RICH (dRICH)：

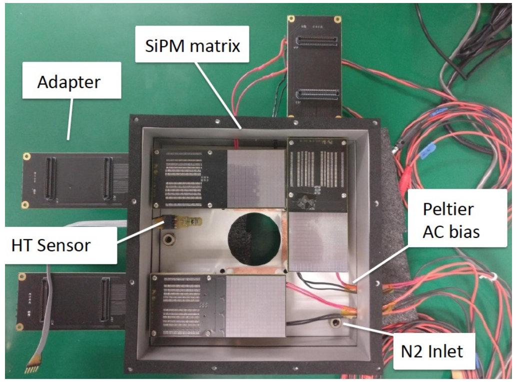




- Radiators: Aerogel (n~1.02) + C_2F_6 Gas (n~1.0008)
- Detector: 0.5 m^2/sector , 3x3 mm2 pixel
- Polar angle: 5-25 deg, π/K separation: 3-60 GeV/c
- Single-photon detection in ~1T magnetic field

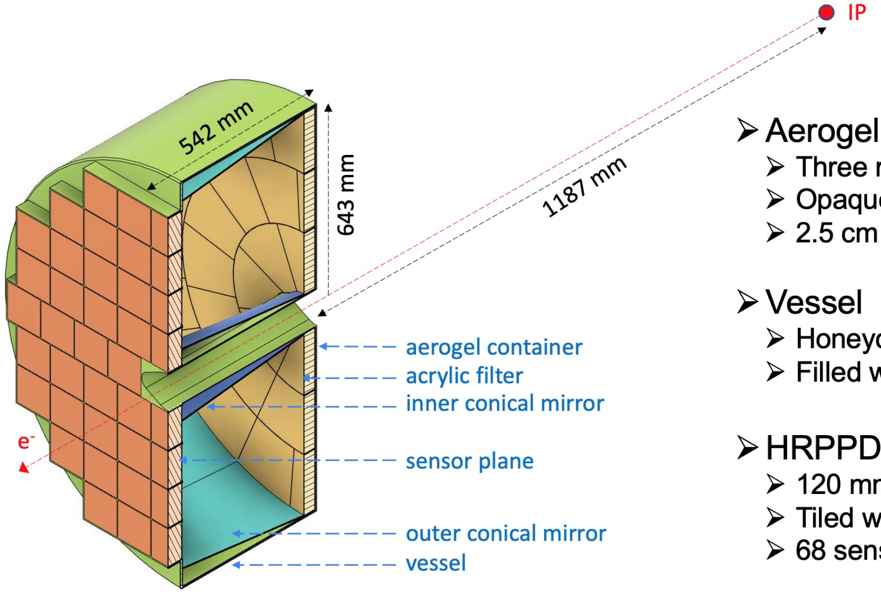




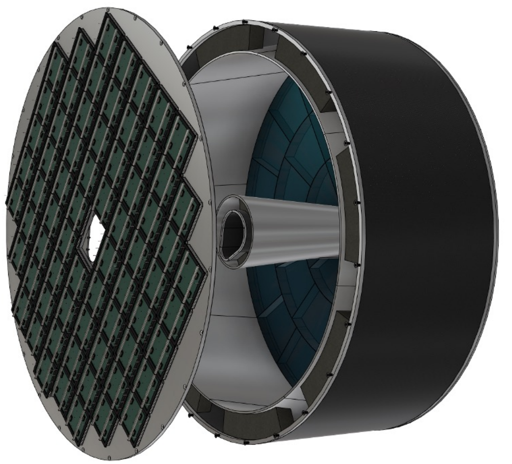


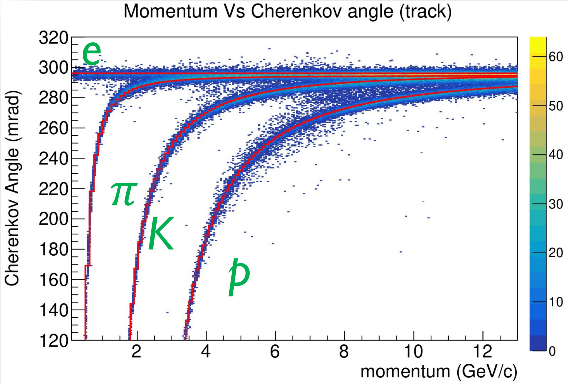
Particle Identification

➢ Proximity-focusing RICH (pfRICH):



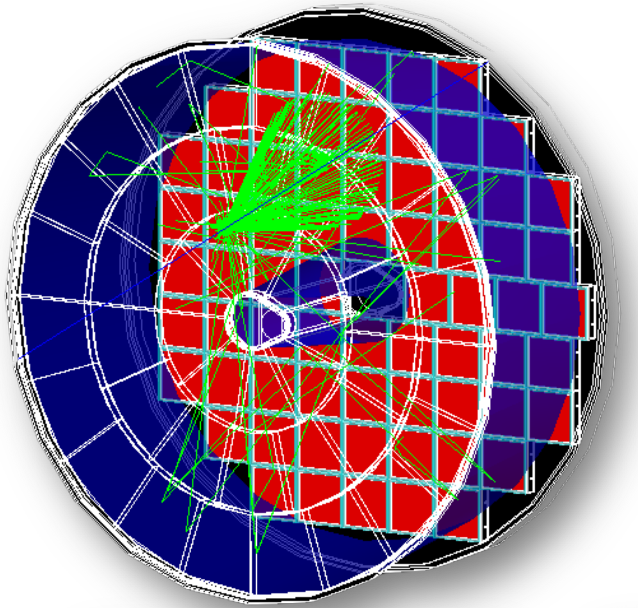
- **Aerogel**
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- **Vessel**
  - Honeycomb carbon fiber sandwich
  - Filled with nitrogen
- **HRPPD photosensors**
  - 120 mm size
  - Tiled with a 1.5mm gap
  - 68 sensors total

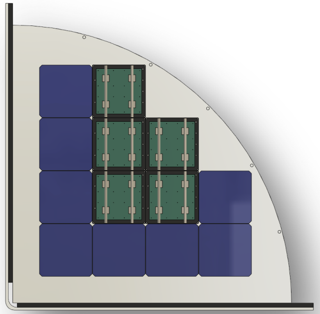


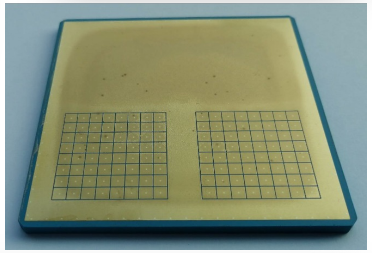


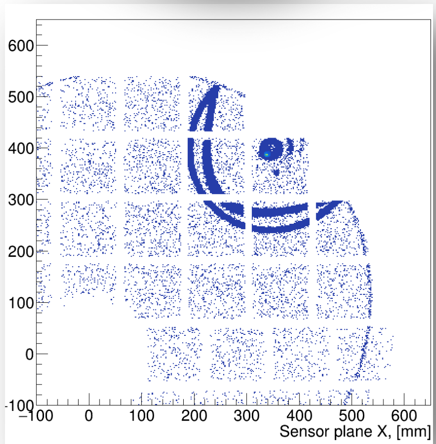
❑ Goals:

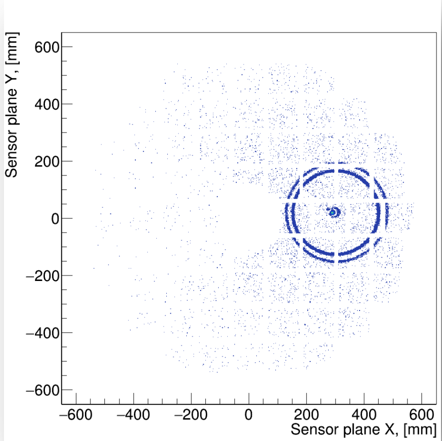
- 3σ e/π/K separation up to 7 GeV/c





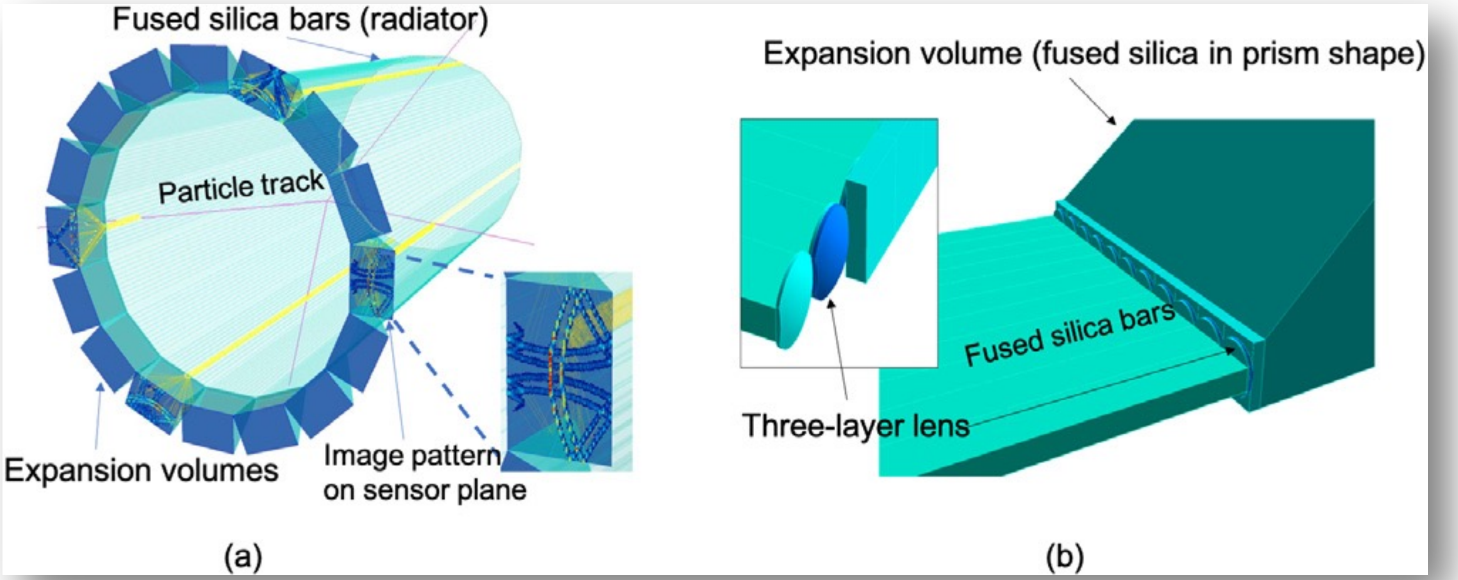






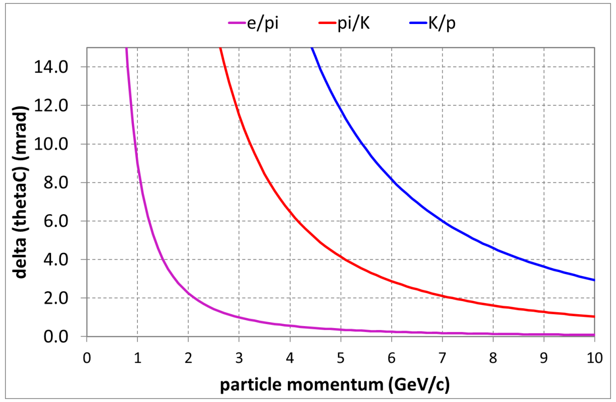
Particle Identification

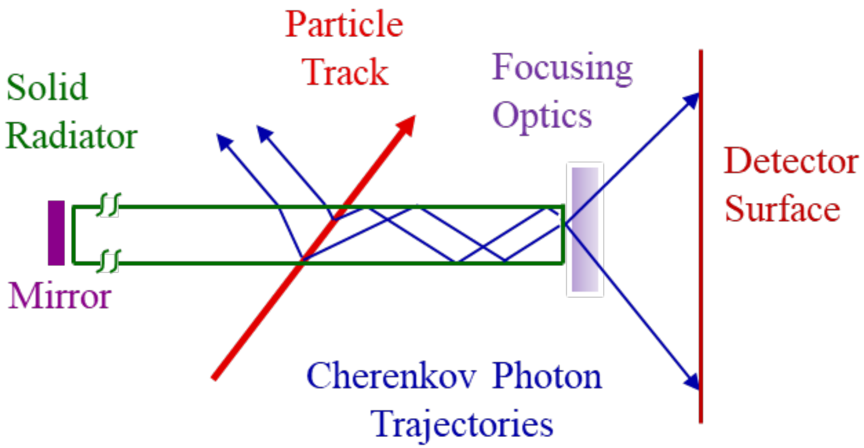
➢ High-performance DIRC (hpDIRC):

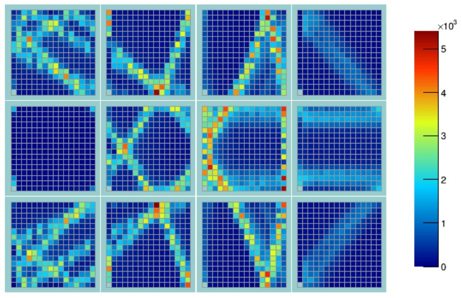


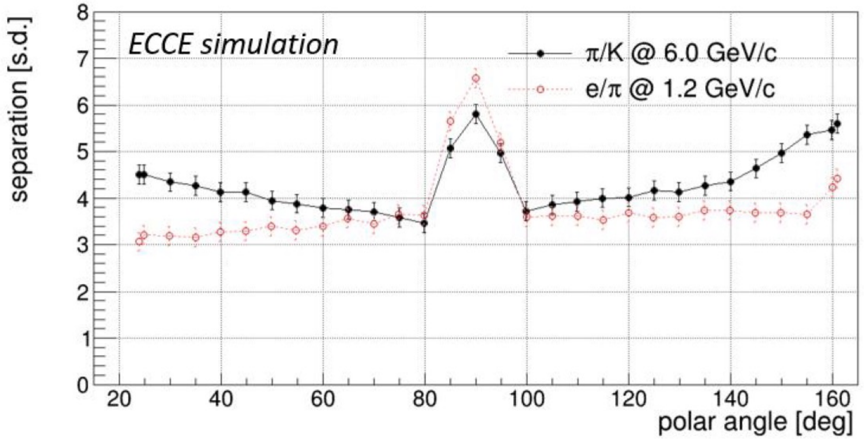
❑ Goals:

- e/π/ separation up to 1.2 GeV/c
- π/K separation up to 6 GeV/c
- Good timing









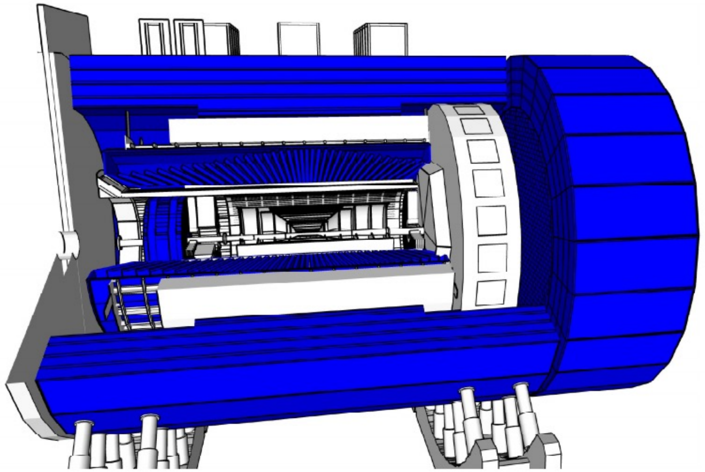
Particle Identification

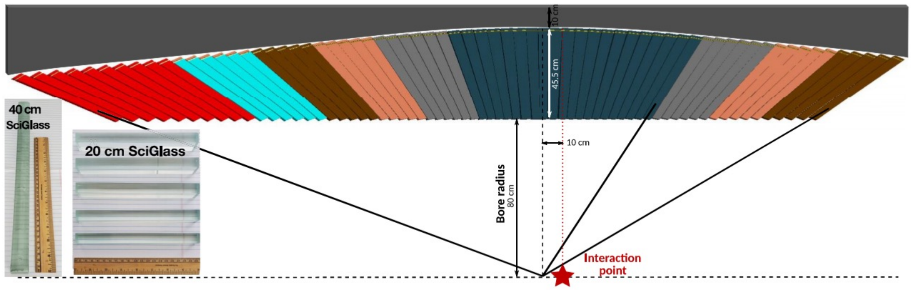
➢ Calorimeters:

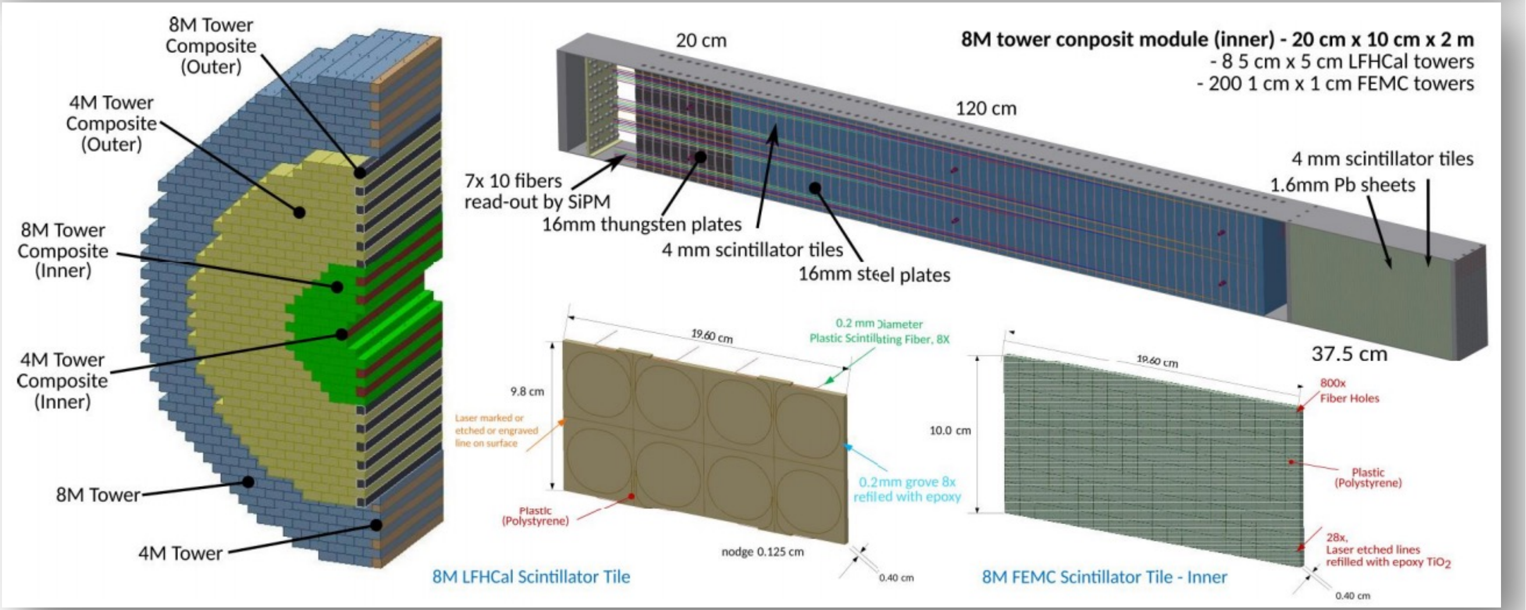
❑ Goals:

- Gamma photons' energies (up to 2%)
- Additional e/π/K separations (efficiencies)

	EEMC	BEMC	FEMC	IHCAL	OHCAL	LFHCAL
tower size	2x2x20 cm^3	4x4x45.5 cm^3 projective projective	in: 1x1x37.5 cm^3 out: 1.6x1.6x37.5 cm^3 out: 1.6x1.6x37.5 cm^3	$\Delta\eta \sim 0.1$ $\Delta\varphi \sim 0.1$ $l \sim 4.5$ cm	$\Delta\eta \sim 0.1$ $\Delta\varphi \sim 0.1$ $l \sim 88$ cm	5x5x140 cm^3
material	$PbWO_4$	SciGlass	Pb/Scintillator	Steel/ Scintillator	Steel/ Scintillator	Steel/W/ Scintillator
d_{abs}	-	-	1.6 mm	13 mm	in: 10.2 mm out: 14.7 mm	16 mm
d_{act}	20 cm	45.5 cm	4 mm	7 mm	7 mm	4 mm
N_{layers}	1	1	66	4	5	70
$N_{towers(channel)}$	2876	8960	19200/34416	1728	1536	9040(63280)
X/X_O	~ 22	~ 17	~ 19	~ 2	$36-48$	$65-72$
R_M	2.73 cm	3.58 cm	5.18 cm	2.48 cm	14.40 cm	21.11cm
f_{sampl}	0.914	0.970	0.220	0.059	0.035	0.040
λ/λ_0	~ 0.9	~ 1.6	~ 0.9	~ 0.2	$\sim 4-5$	$7.6-8.2$
η acceptance	$-3.7 < \eta < -1.8$	$-1.7 < \eta < 1.3$	$1.3 < \eta < 4$	$1.1 < \eta < 1.1$	$1.1 < \eta < 1.1$	$1.1 < \eta < 4$
resolution						
- energy	$2/\sqrt{E} \oplus 1$	$2.5/\sqrt{E} \oplus 1.6$	$7.1/\sqrt{E} \oplus 0.3$		$75/\sqrt{E} \oplus 14.5$	$33.2/\sqrt{E} \oplus 1.4$
- φ	~ 0.03	~ 0.05	~ 0.04		~ 0.1	~ 0.25
- η	~ 0.015	~ 0.018	~ 0.02		~ 0.06	~ 0.08





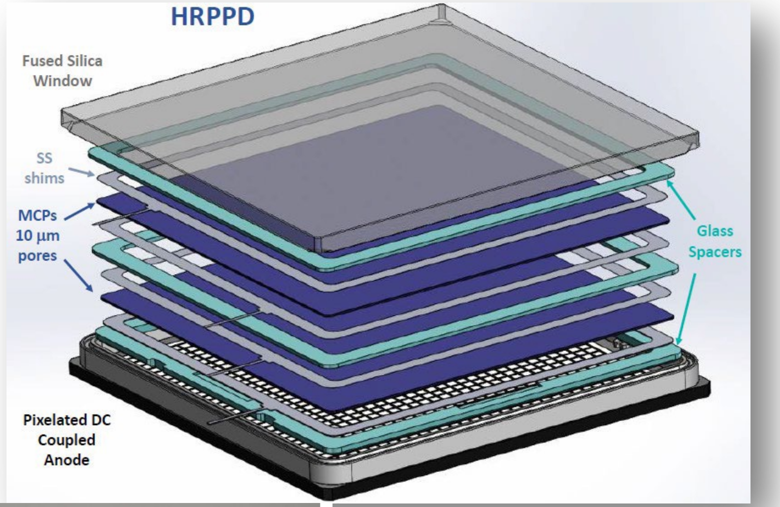


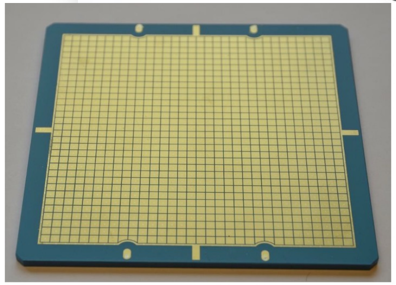
Particle Identification

➢ Photo-Sensors & Electronics:

- ❑ Requirements:
  - Work in 3T magnetic field
  - Radiation Hard
  - Highly compact & pixelized
  - Great timing resolution (<10ps)

- ❑ SiPM, MCP, LAPPD/HRPPD …





- ❑ Streaming readout (trigger less):
  - Front-end ASIC (EICROC …)
  - Wave-form sampling
  - Online reconstruction and selection

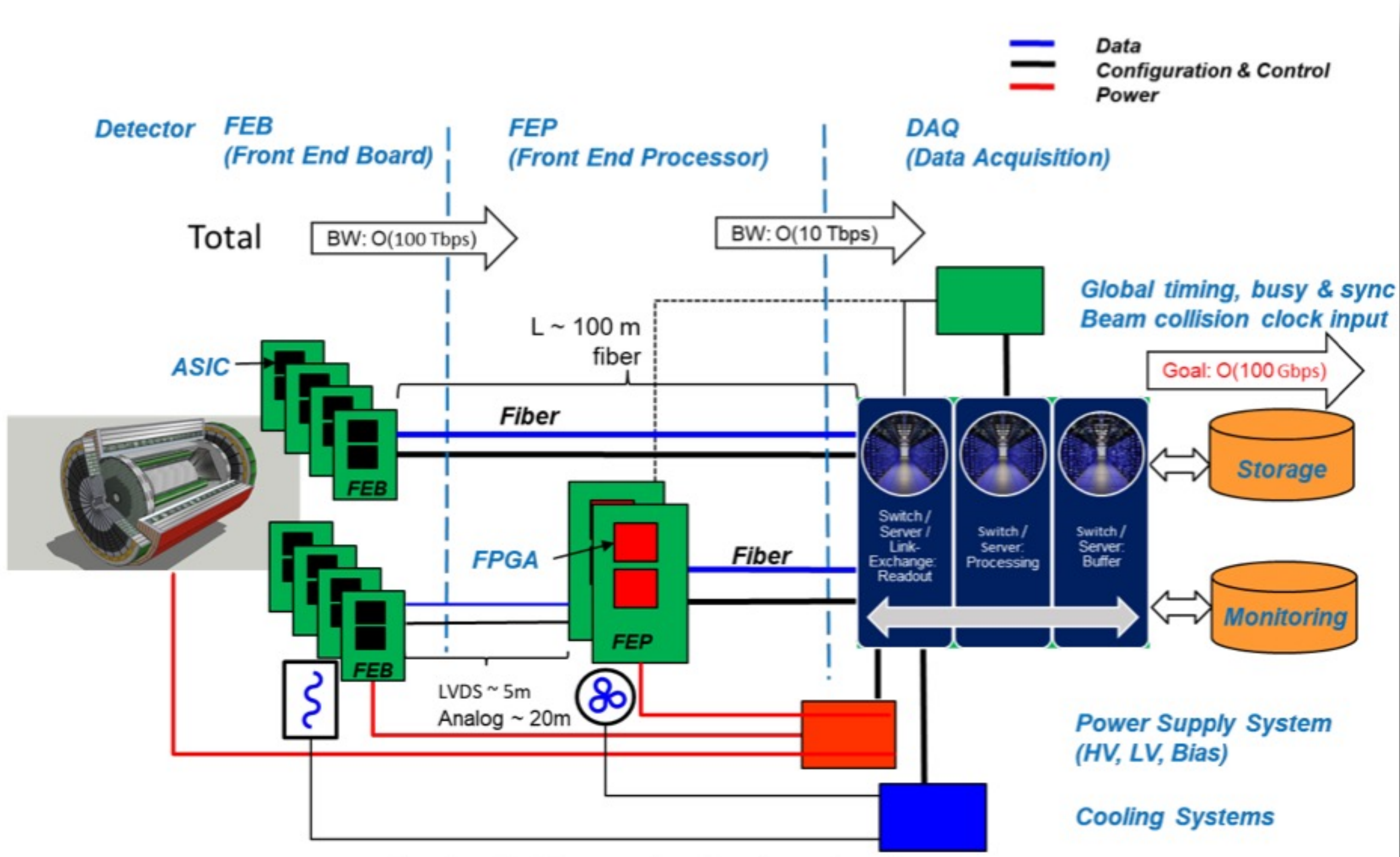


Fig. 1 – EIC Streaming Readout Architecture

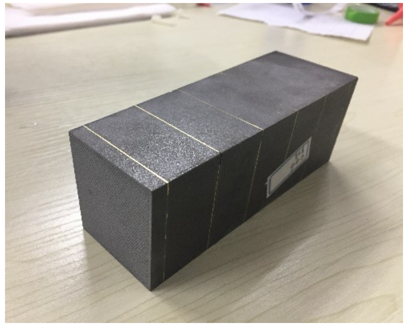
Particle Identification

➢ R&D Activities --- eRHIC, China Contributions

❑ Calorimeters

- Fudan, Shandong & Tsinghua, working with UCLA to construct 70% W-Powder HCal

W-Powder+ScFi

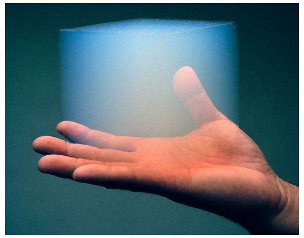


❑ Others:

- mRPC in Detector#2
- MPGD
- AC-LGAD
- Far-forward detectors

❑ RICH Detectors:

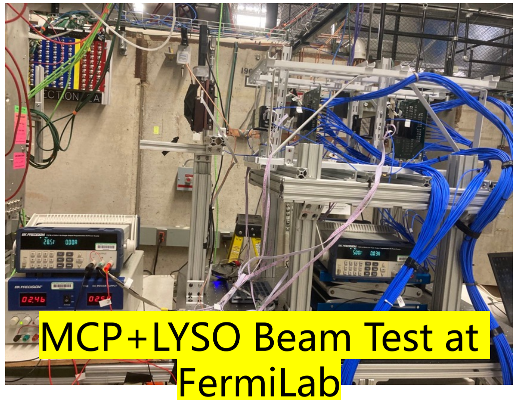
- Hydrophobic Aerogel Developments, to be tested at Temple Univ (compared with Chiba Aerogels)



First 10cm x 10cm x 2cm tiles

- To design & build a dRICH & a mRICH Prototype

- MCP Photo-sensors (w/ Qian Sen's group from IHEP, see talk by Lishuang Ma)

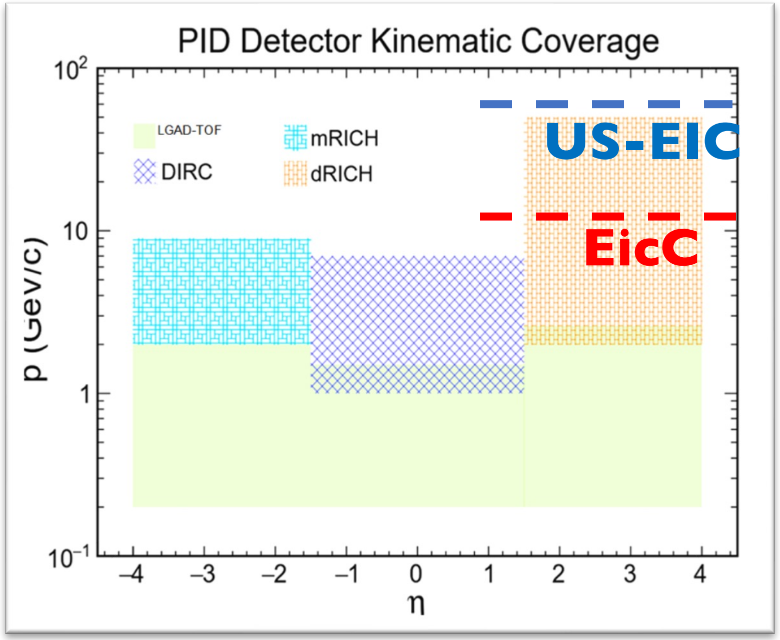


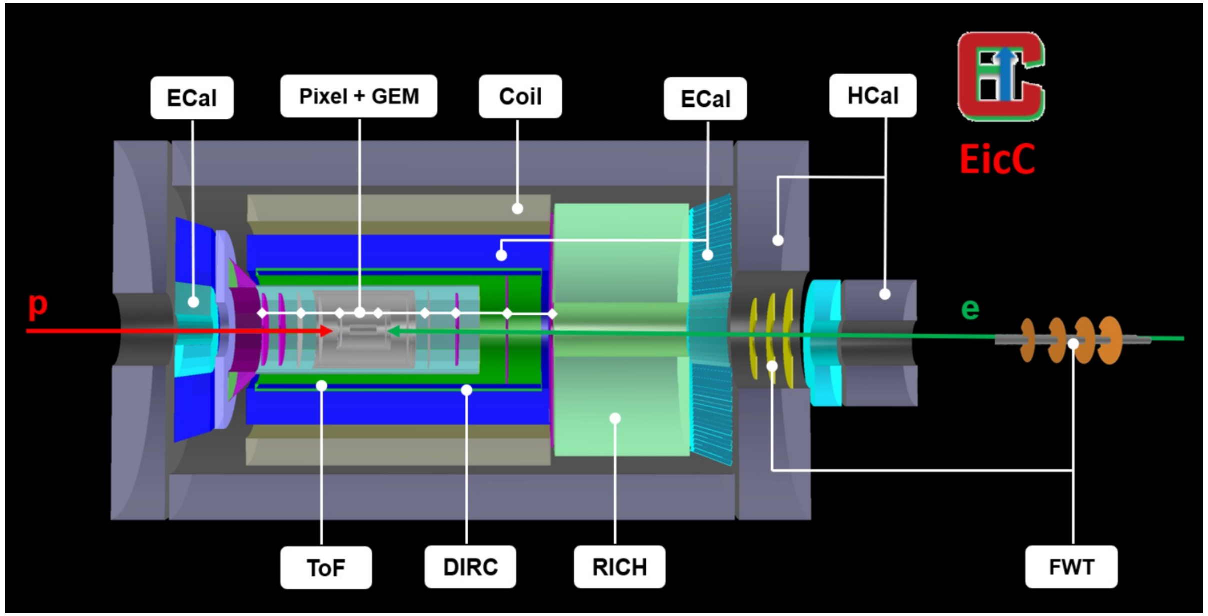
MCP+LYSO Beam Test at FermiLab

Particle Identification

➢ R&D Activities --- EicC

- ❑ EicC tentitive PID detector concepts are similar to ePIC's:
- ❑ Lower particle momenta → less challenges vs US-EIC





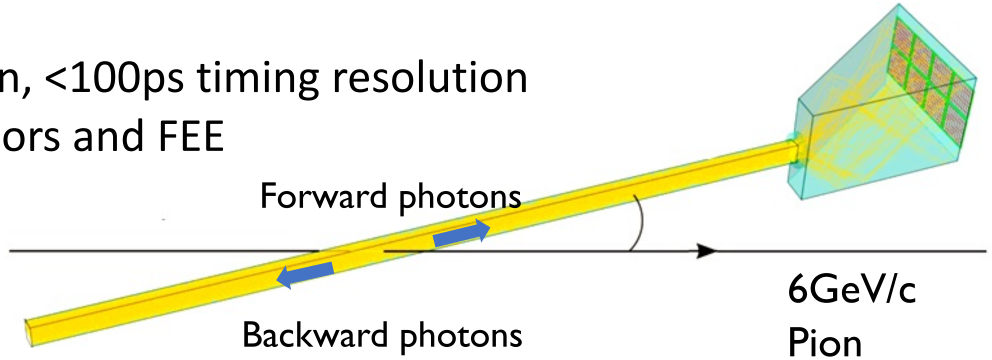
- ❑ Early phases
- ❑ Active physics simulation + detector design
- ❑ Senergistic to US-EIC and other domestic projects in China

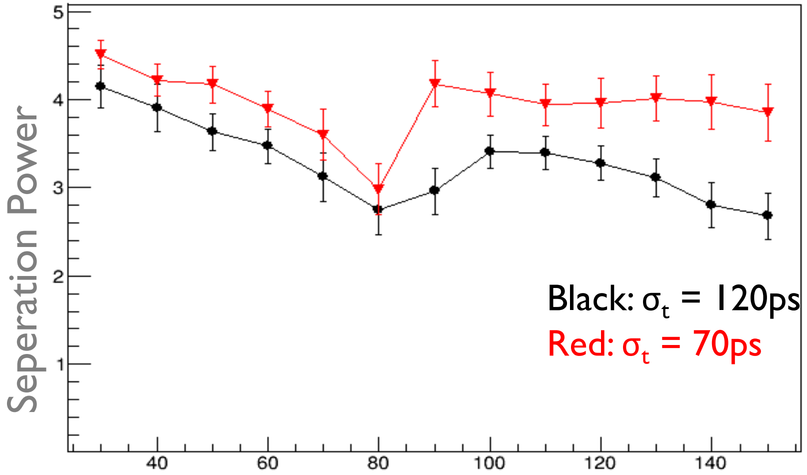
Particle Identification

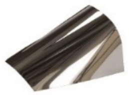
➢ R&D Activities --- EicC

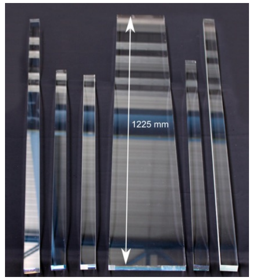
❑ hpDIRC R&D

- PID in 1~6GeV/c
- ~1mrad angular resolution, <100ps timing resolution
- Look for good photo-sensors and FEE

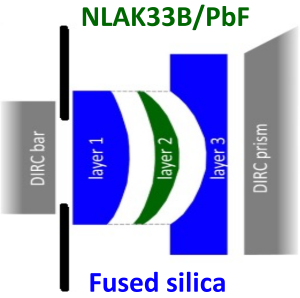






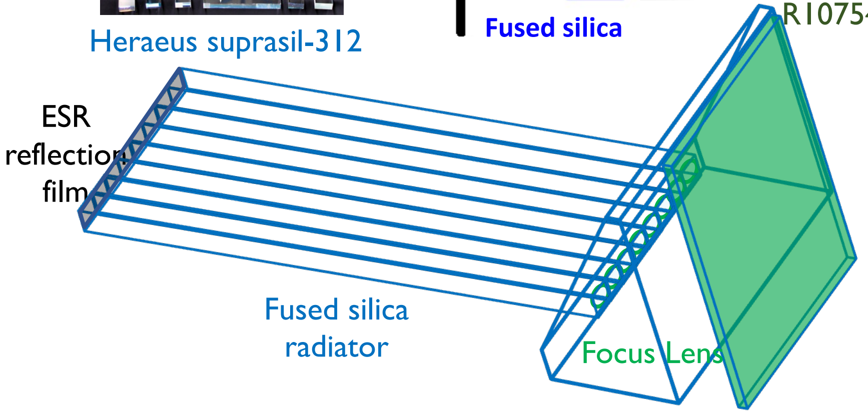


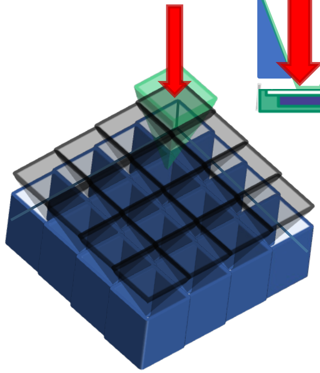
Heraeus suprasil-312

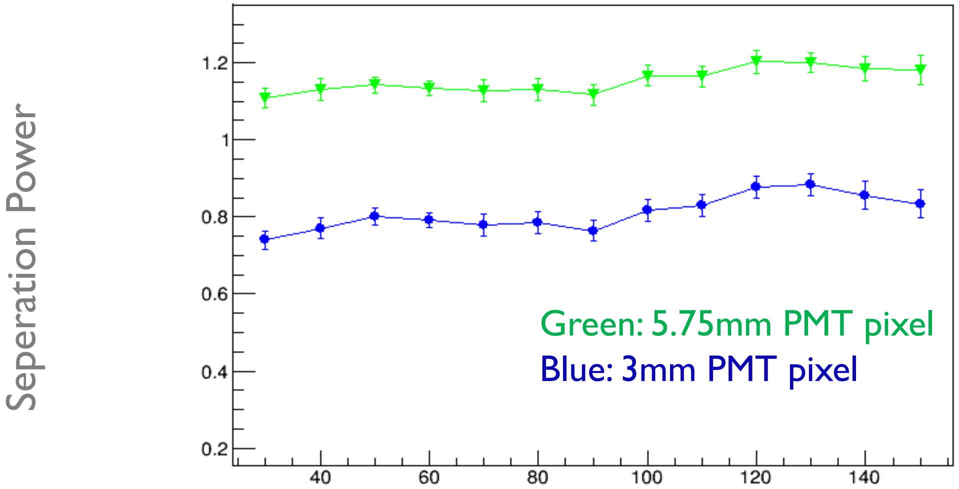


MCP-PMT array R10754/H13700

focusing



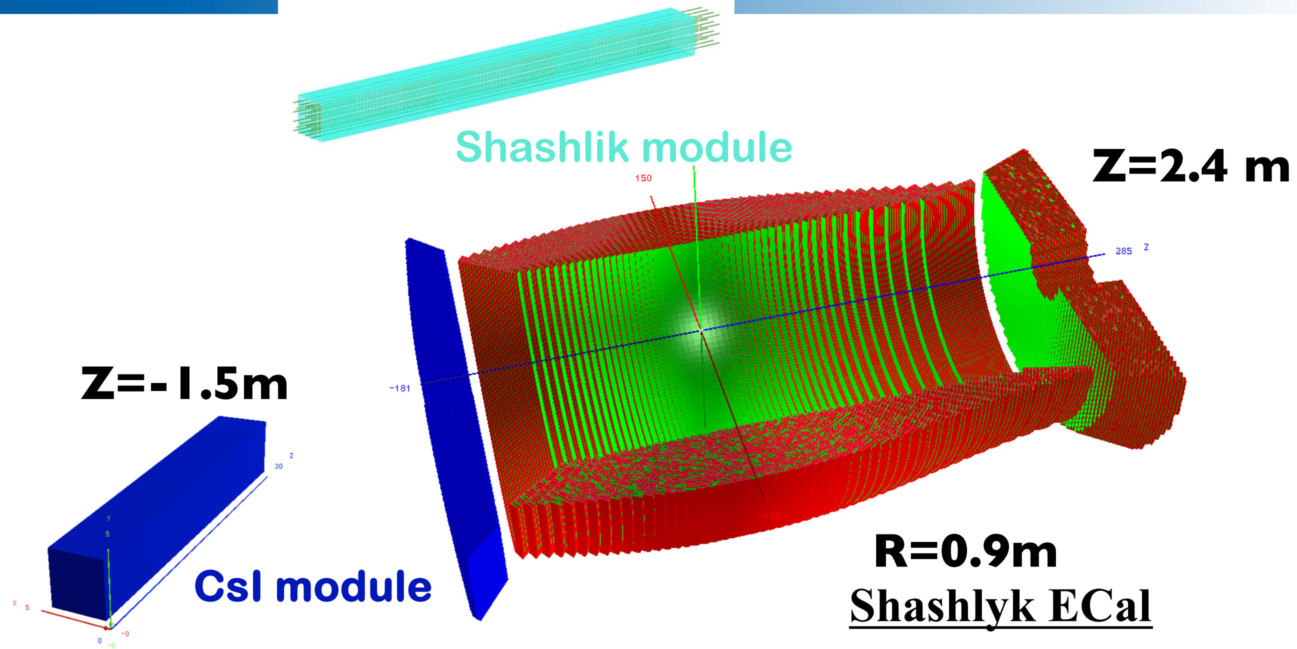




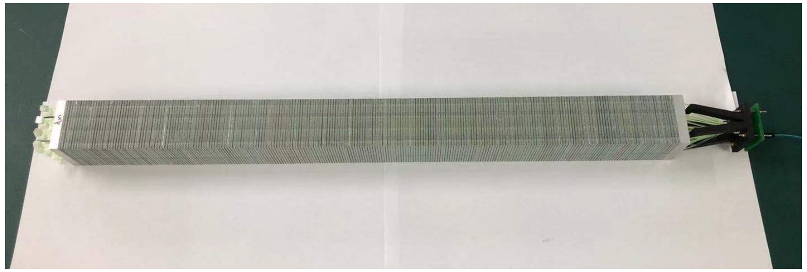
➢ R&D Activities --- EicC

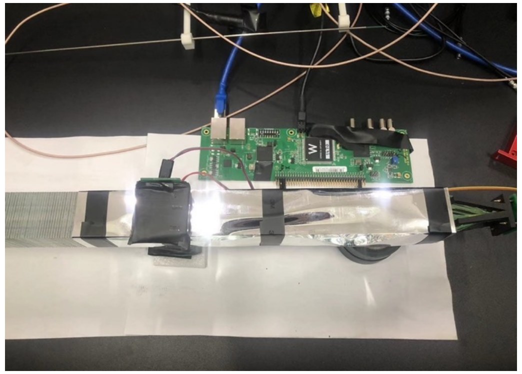
❑ Experience on Shashlyk ECAL

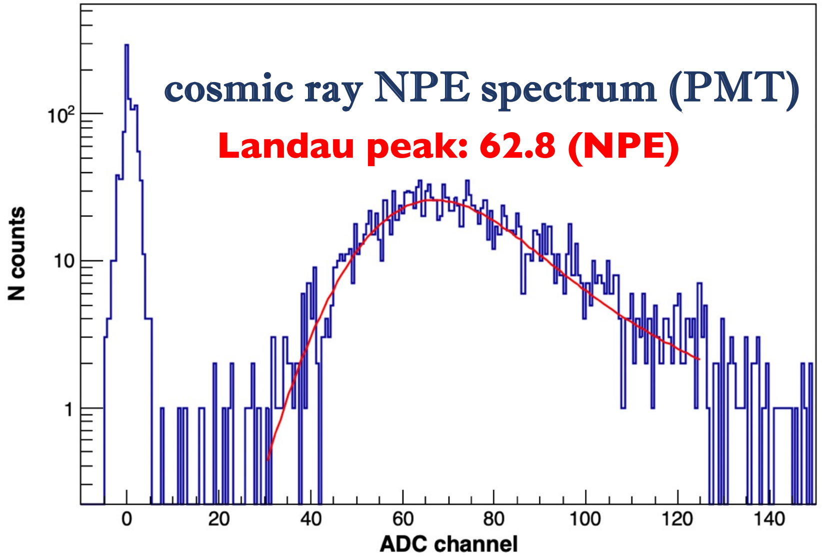
NICA ECAL



❑ Barrel Shashlyk ECAL R&D







❑ Other ECAL R&D (W-powder, CsI…)

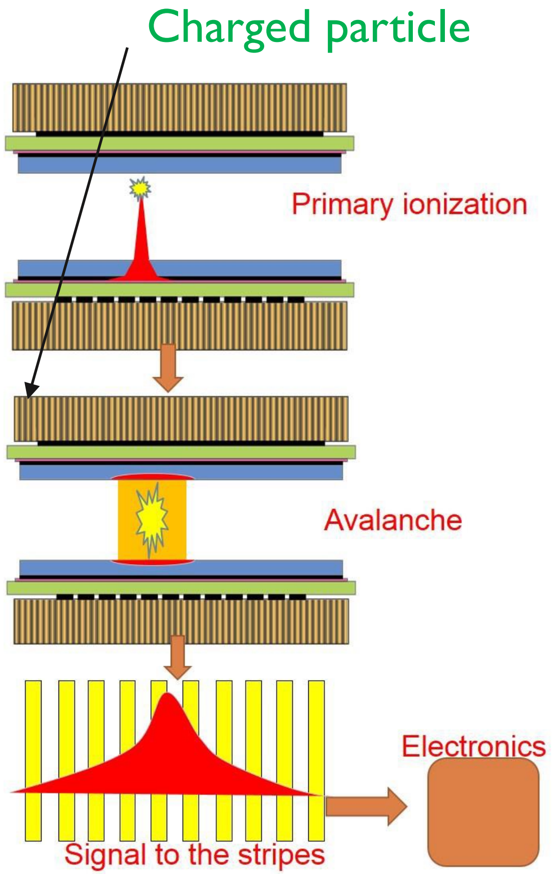
Summary

- eRHIC in US and EicC in China are designed to explore how quarks and gluons compose protons and nuclei
- Important physics reactions require identification of leptons/hadrons in a wide range of momenta and 4π coverage
- High rate, strong magnetic fields, big radiation background need good-performance PID detectors
- AC-LGAD TOF, dRICH (hadron endcap), pfRICH/mRICH (electron endcap), DIRC (barrel), and calorimeters are combined to identify e/γ/π/K/p up up to 60GeV/c in full angular coverages
- Big challenges on photo-sensors & front-end electronics, especially with trigger-less streaming readout DAQ
- Active detector designs, R&D and prototyping both in China and globally
- Great experience being shared among EICs and other projects

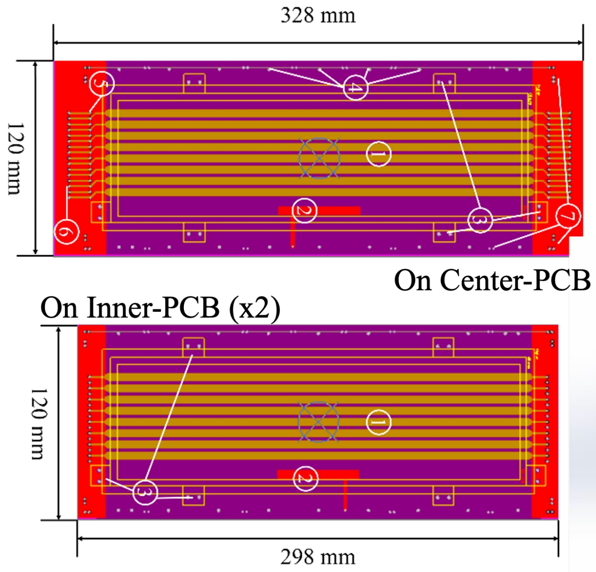
BACKUP

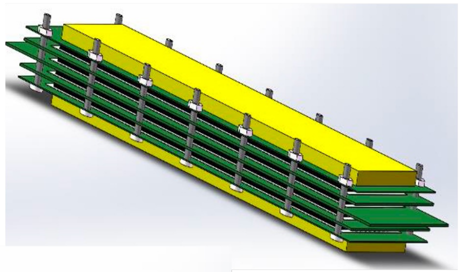
Multi-gap Resistive Plate Chamber (MRPC)

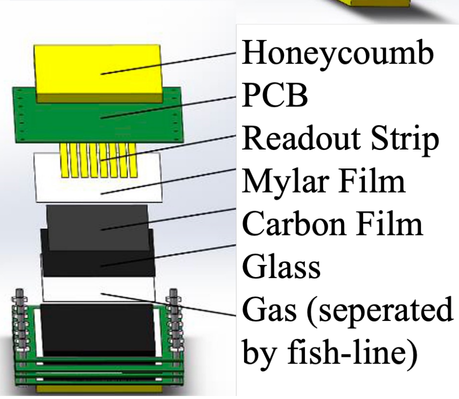
➢ General Princple

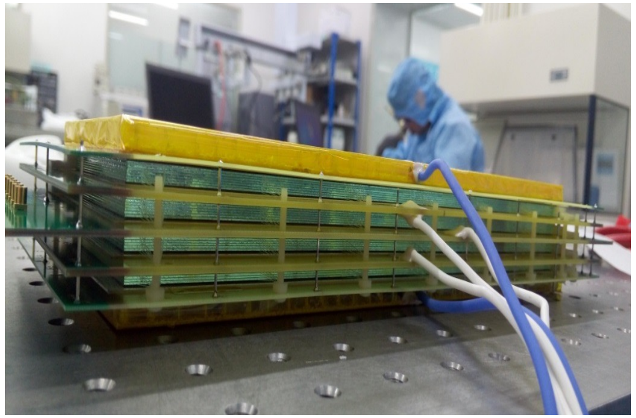


- ❑ Low-resistivity glass plates, Standard gas (95% F134a + 5% iso-butane), HV(~12kV)
- ❑ Good performances:
  time resolution, efficiency, rate capacity (>30kHz/cm^2), radiation-hard, magnet safe
- ❑ Certain spatial resolution (by strip pitch)
- ❑ Low cost, easy manufacturing, large sensitive area (up to 1.0mx0.5m)
- ❑ Used by ALICE, STAR, etc.

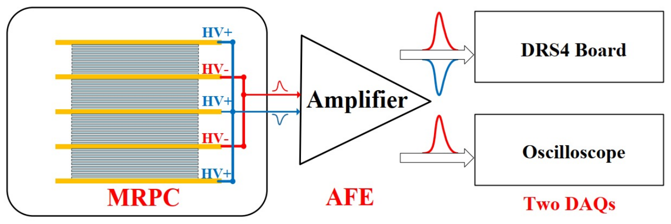








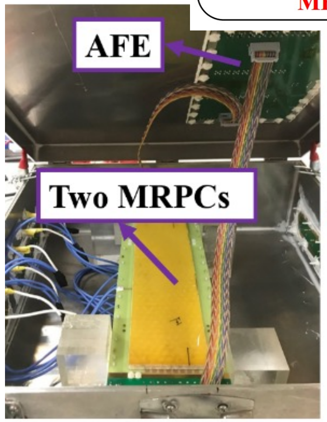
MRPC

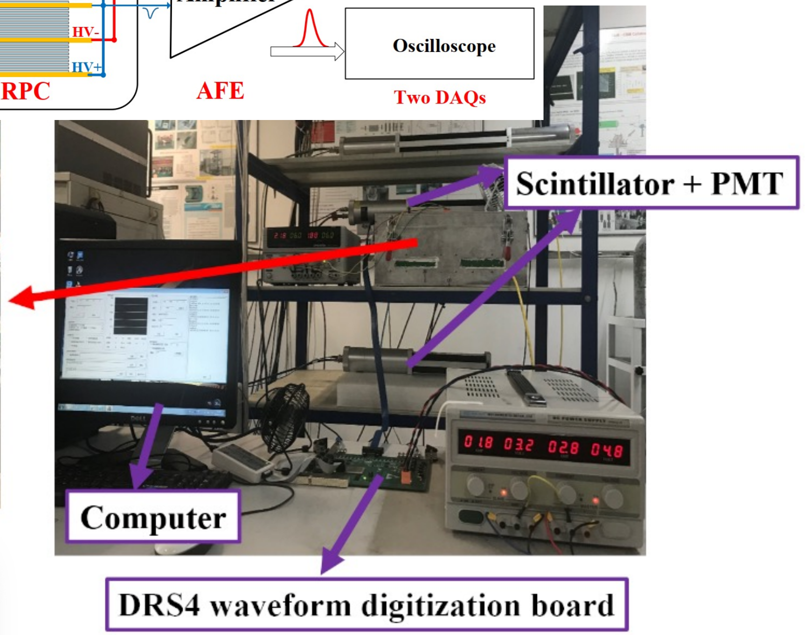


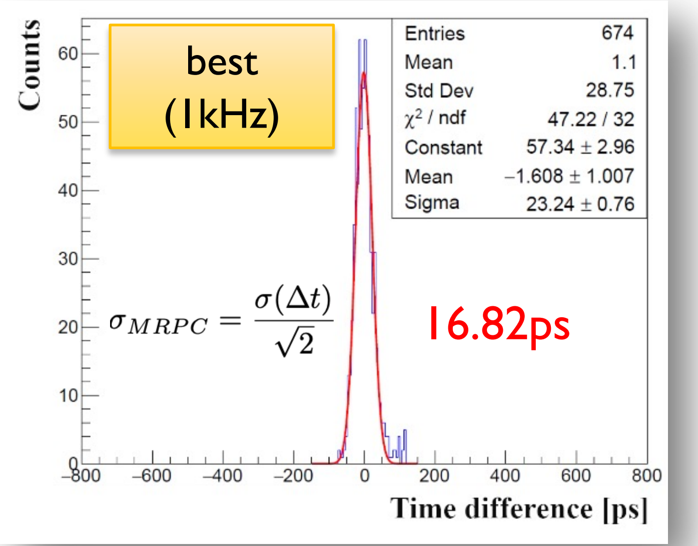
➢ Tsinghua's Sealed MRPC (sMRPC)

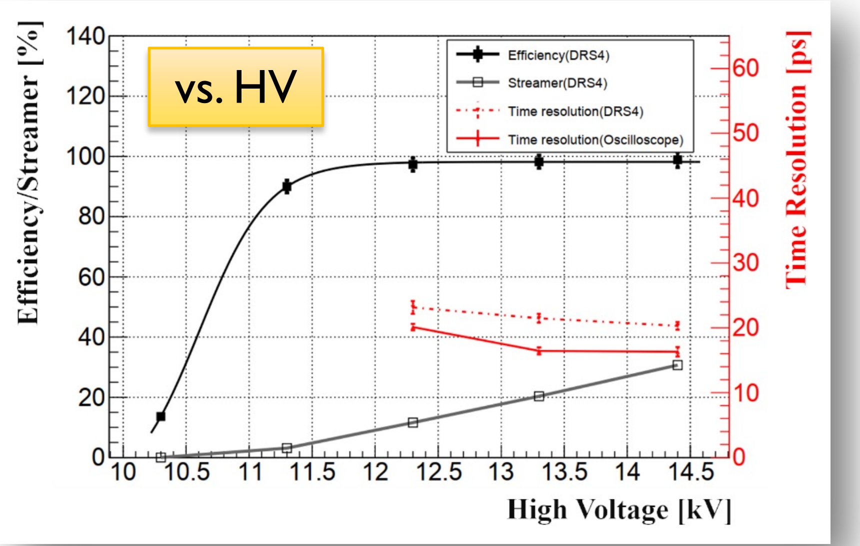
- ❑ Most recent tests: cosmic ray with x-ray background
  - ✓ 32-gaps (4 stacks), 400um thin glasses
  - ✓ 104um gas-gap + waveform-sampling → 20ps & 95% efficiency at 15kHz Y. Yu et al 2020 JINST 15 C01049
  - ✓ 128um gas-gap + ToT method → 20ps at 15kHz

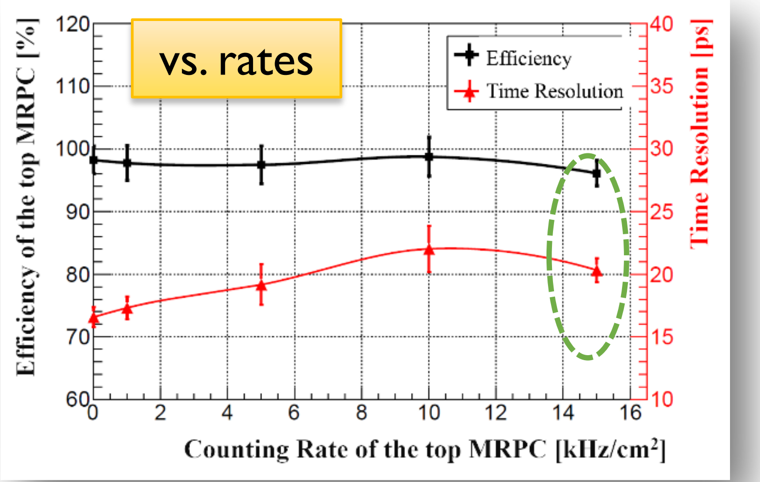
Y. Yu et al 2022 JINST 17 P02005











❑ No in-beam test yet

Deliveries#4

➢ Cosmic and Beam Test

❑ Goals:

- Validate simulation framework and machine-learning method
- Investigate different eco-friendly gas mixtures
- Study real performance with high-energy/high-rate background
- Test out front-end electronics

❑ To-dos:

- UIC local test with cosmic-ray + xray background
  - 2 planes of 16-layer sMRPC + SAMPIC
- Jlab/FermiLab beam test
  - 2 planes of 16-layer sMRPC + SAMPIC and NALU
- Tsinghua's local test with cosmic-ray + x-ray background
  - 2 planes of 32-layer sMRPC + USTC FEE
  - + DT5742 (DSR4) and DT5202 (picoTDC)


sMRPC at FermiLab (April 2022)


NALU


SAMPIC


DSR4


picoTDC