1st Workshop on PBT2024

Electromagnetic Calorimeter at EicC

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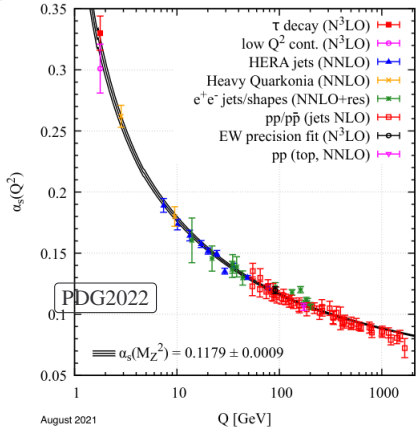
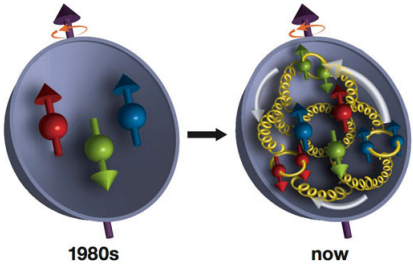
Outline

Introduction



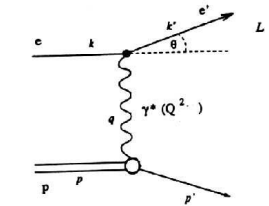
- More than 90% of visible matter in nature governed by strong interaction, which is described by QCD successfully (in general),
- pQCD (perturbative) at high energy scale vs non-pQCD in the low energy regime.



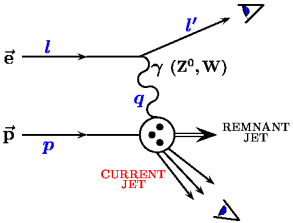
- Total mass of three valence quarks is only $\sim 10\%$ of proton mass
  $\Longrightarrow$ **origin of proton mass**?
- Only $\sim 30\%$ of proton spin from quark spin
  $\Longrightarrow$ **origin of proton spin**?

➥ **The internal structure of proton (nucleon)?**

Introduction – Nucleon Structure Research



Elastic Scattering



Deep Inelastic Scattering

Proton has internal structure (not point like particle)

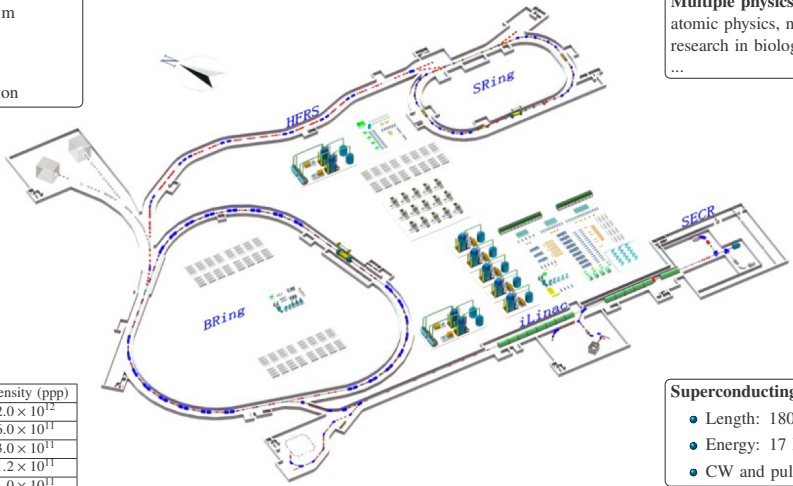
- Elastic scattering of electon-proton at low energy:
  - Electromagnetic form factors of proton,
  - Size of the proton: charge and magnetization distributions,
  - Four-momentum transfer squared: Q^2;
- Deep inelastic scattering of electron-nucleon at high energy:
  - **Parton distribution** (PDF) inside the nucleon,
  - One-dimensional **spin structure** of nucleons,
  - **Three-dimensional tomography** of nucleons,
  - .....
- Electron-Ion Collider (EIC), as a "Super Three Dimention Computed Tomography", can research the clearest structure inside the nucleon.
- EicC (Electron-Ion Collider in China) is considered, based on HIAF at IMP.

High Intensity Heavy-Ion Accelerator Facility (HIAF)

Booster Ring (BRing)

- Circumference: 569 m
- Rigidity: 34 Tm
- Accumulation
- Cooling & acceleration

Layout of the accelerator complex of HIAF



Multiple physics reseraches:
atomic physics, nuclear physics, applied research in biology and material science, ...

High intensity ion beams:

beam	E (GeV/u)	intensity (ppp)
p	9.3	2.0×10^{12}
$^{18}O^{6+}$	2.6	6.0×10^{11}
$^{78}Kr^{19+}$	1.7	3.0×10^{11}
$^{209}Bi^{31+}$	0.85	1.2×10^{11}
$^{238}U^{35+}$	0.835	1.0×10^{11}

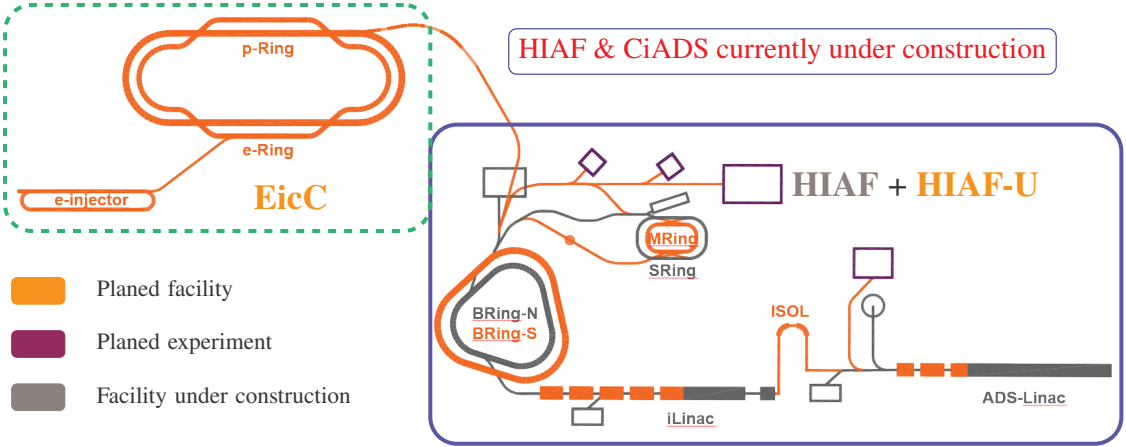
Superconducting Ion Linac:

- Length: 180 m
- Energy: 17 MeV/u (U^{35+})
- CW and pulse modes

Location of HIAF

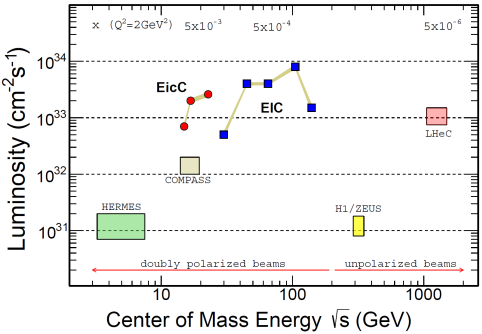
The facility is under construction at Huizhou of Guangdong Province.

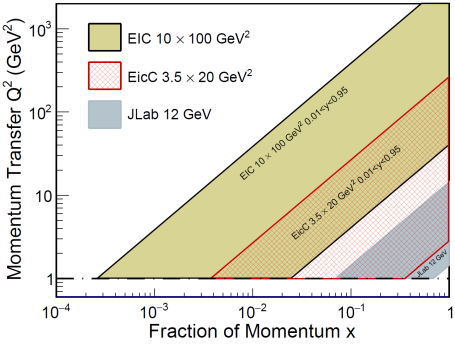
Electron-Ion Collider in China



EicC is considering based on the upgrade of HIAF
R&D for accelerator, detectors are in progress!

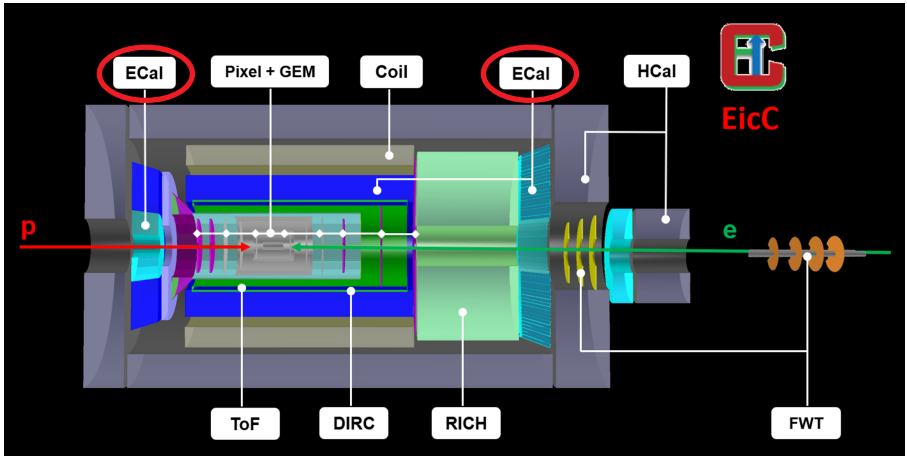
Parameters of EicC





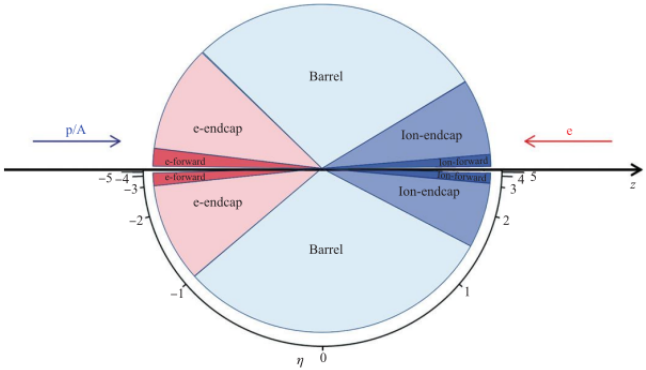
- Luminosity of EicC is up to 2.0×10^{33} cm^{-2}·s^{-1} (for proton),
- Center-of-mass energy ($\sqrt{s}$) of EicC ranged between 15 and 20 GeV,
- EicC focuses on moderate x and sea-quark regions,
- EicC covers the kinematic region between JLab experiments and us-EIC.

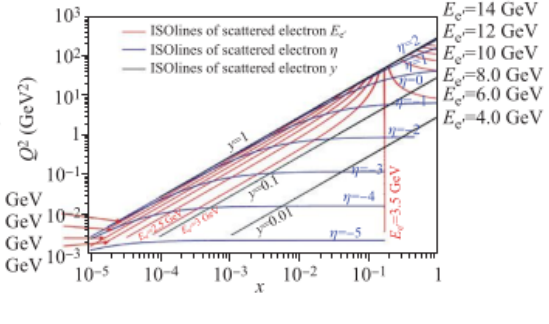
Spectrometer of EicC



- Baseline design of EicC: **3.5 GeV electron** beam and **20 GeV proton** beam,
- Mian parts of the spectrometer: Vertex, Tracking, PID, **ECal**, FWT, ...,

Physics Requirements of EicC



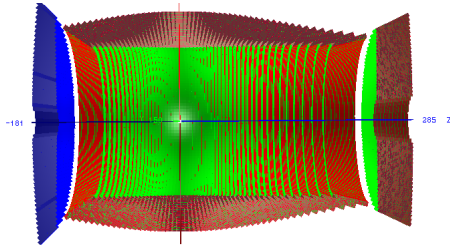


- Angular coverage: $-3.0 < \eta < 3.0$,
- Momentum coverage for scattering electron: $0.2 < p < 4$ (12) GeV/c,
- Good e/π separation power, for precise measurement of scattering electron.

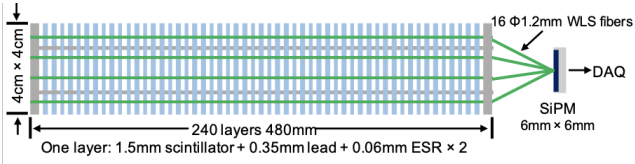
Electromagnetic Calorimeter at EicC

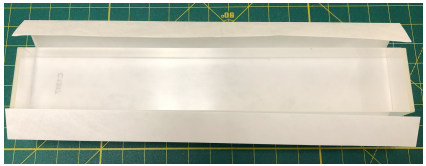
region	type	z/r [m]	L [cm]	coverage [cm]	pseudorapidity (η)	tower size [cm×cm]
ef-EMC	CsI	z=-1.5	30.0 (16.1 X_0)	15.0<r<127.6	(-3.0, -1.0) (**174.3°, 139.6°**)	4.0×4.0 (front)
br-EMC	Shashlik	r=0.9	48.0 (16 X_0)	-105.8<z<187.5	(-1.0, 1.5)	4.0×4.0 (front)
hf-EMC	Shashlik	z=2.4		24.0<r<115.2	(1.5, 3.0)	

- Calorimeter at EicC has the Shashlik and crystal (CsI) designs for different parts,
- Three parts are included: electron-forward endcap, central barrel and hadron-forward endcap,
- The actual coverage of different parts need more details from physics requirements and mechanical design,



Modules of Shashlik and CsI Crystal



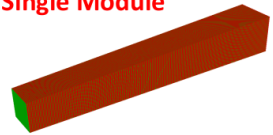


- Shashlik module for the central barrel and hadron-forward endcap,
- Each layer contains: 0.35 mm lead, 1.50 mm scintillator and 0.06×2 ESR,
- Wavelength shift fibers (16) to collect scintillation light,
- 240 layers (480 mm) corresponding with $16X_0$ radiation length.

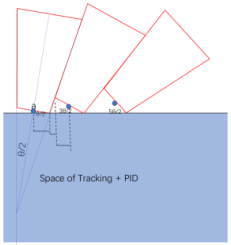
- Pure Cesium Iodide (CsI) module for the electron-forward endcap,
- Homogeneous material is sensitive material as well as absorber,
- Scintillation light collected with UV-sensitive APD at one end,
- Length 30 cm is equivalent to $16X_0$ radiation length.

Configurations of Barrel and Hadron-Forward Endcap

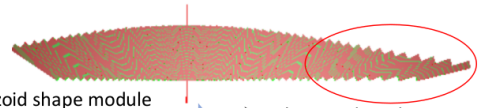
Single Module



240 layers * (1.5 mm scintillator + 0.35 mm Lead) (20 X_0)



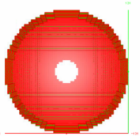
Barrel

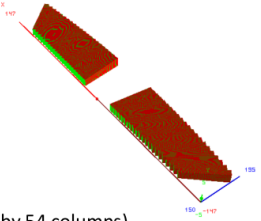


- Trapezoid shape module
  - 4.0 × 4.0 cm^2 front size
  - 5.7 × 5.7 cm^2 rear size
- Total modules: 7332 (52 modules[22+30] by 141 segments)
- Each module roughly point to the IP (Interaction Point)

➢ *Fiber Readout design*
➢ *Module with high z*

Ion-endcap





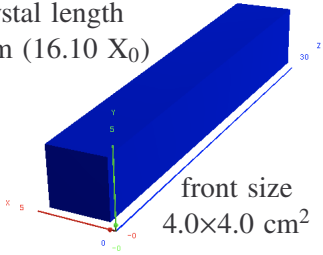
- Trapezoid shape module
  - 4.0 × 4.0 cm^2 front size
  - 4.7 × 4.7 cm^2 rear size
- Total modules: ~2300 (54 rows by 54 columns)
- Each module point to the IP (Interaction Point)

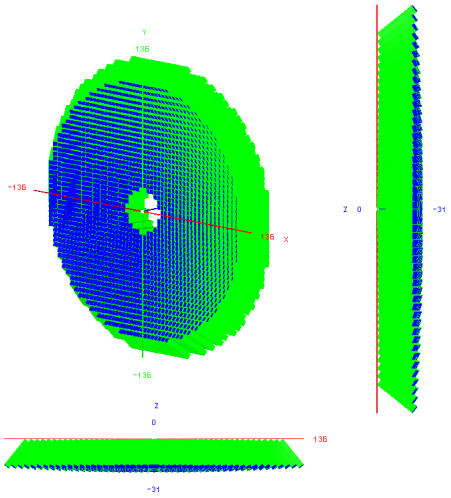
Configuration of Electron-Forward Endcap

crystal length
30 cm (16.10 X_0)

rear size
4.8×4.8 cm^2

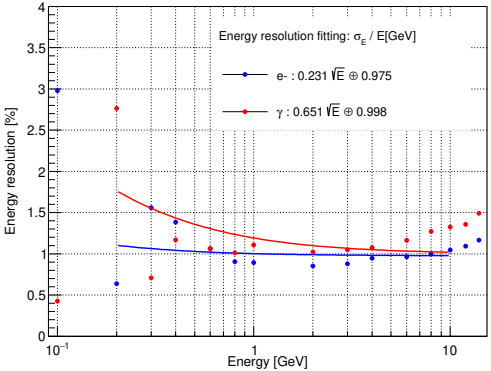
front size
4.0×4.0 cm^2

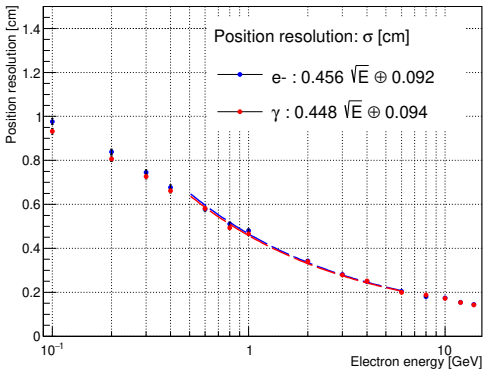




- Coverage of pseudo-rapidity: $-3.0 < \eta < -1.0$,
- Distance from the front plane to IP: 1.5 m,
- total crystals: 2648 (58 rows by 58 columns)
- Crystal is wrapped with Tyvek.

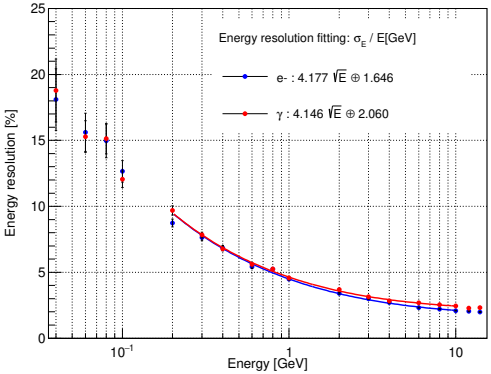
Energy and Position Resolution from Geant4 Simulations (I)

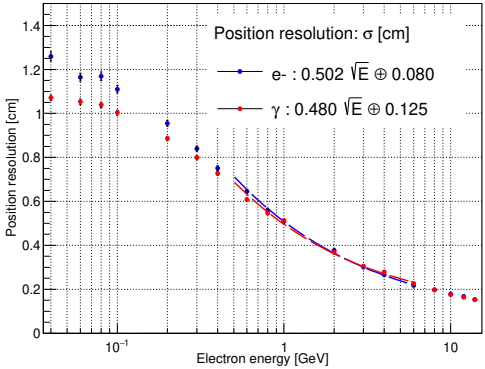




- Excellent energy resolution from the **pCsI crystal**, less than 1.5% @1.0 GeV,
- Position resolution is better than 5 mm @1.0 GeV with the logarithm weighted method.
- Only intrinsic and constant parts considered yet.

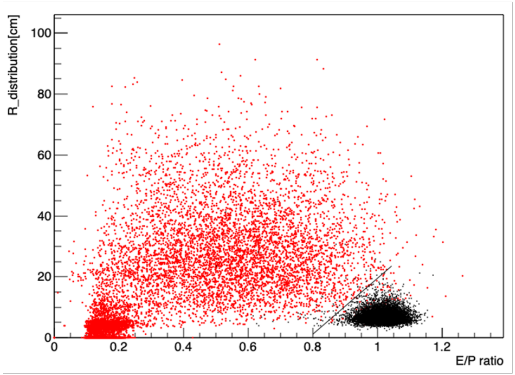
Energy and Position Resolution from Geant4 Simulations (II)

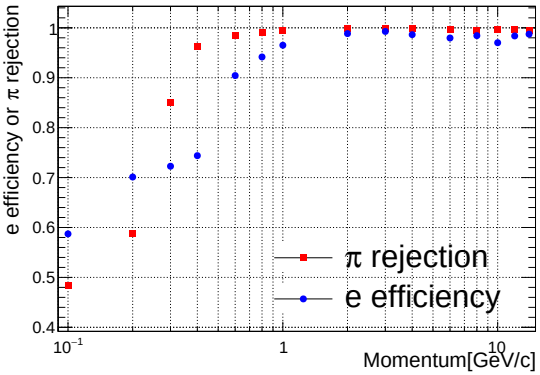




- Excellent energy resolution from the **Shashlik module**, less than 4.5% @1.0 GeV,
- Position resolution is better than 5 mm @1.0 GeV with the logarithm weighted method.
- Only intrinsic and constant parts considered yet.

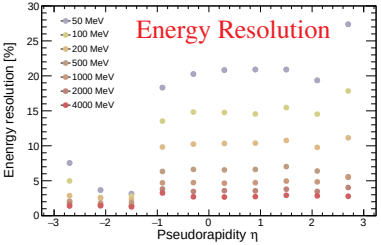
e/π Separation Study

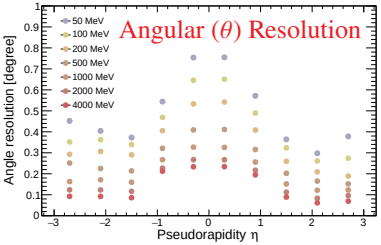


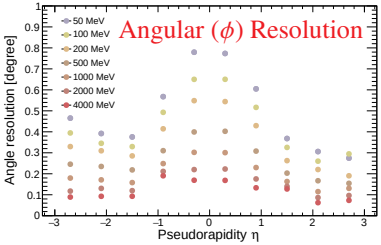


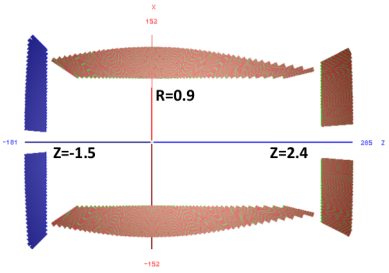
- Using the shower dispersion (second moment of position), and energy-momentum ratio,
- Good e/π separation power for particle momentum larger than 1.0 GeV/c,
- Further investigation, multi-variable analysis or machine learning, is ongoing.

Performance of the Whole EMC



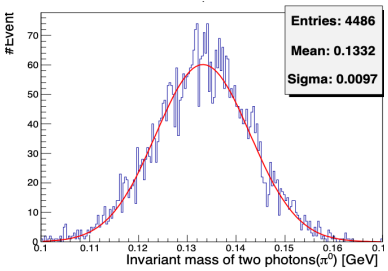


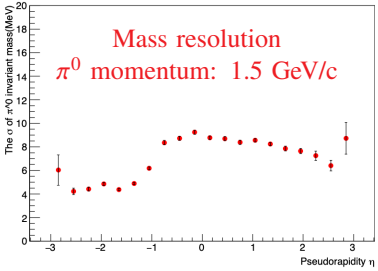


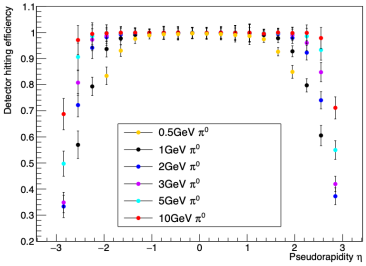


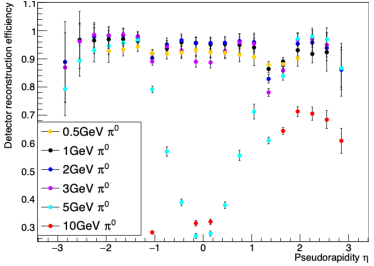
- Simulations with mono-energetic electron from IP,
- Good energy resolution for the electron-forward endcap with pCsI crystal,
- Further studies are necessary, especially the edge effects.

Reconstruction of π^0 in EMC



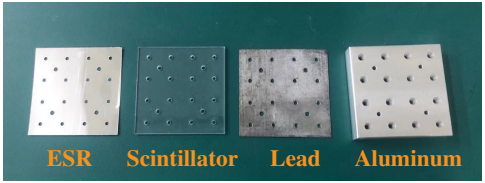


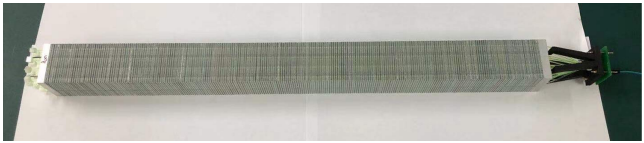




- Reconstruct π^0 by two photons: $m_{\pi^0} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - cos\theta_{\gamma_1\gamma_2})}$,
- Better mass resolution of π^0 with higher energy resolution of the crystal endcap,
- Mass resolution of π^0 varies to η,
- Efficiency of the π^0 reconstruction decreased for the high momentum.

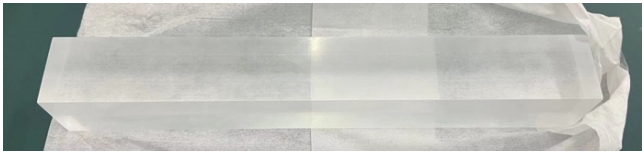
Modules of Shashlik and CsI Crystal





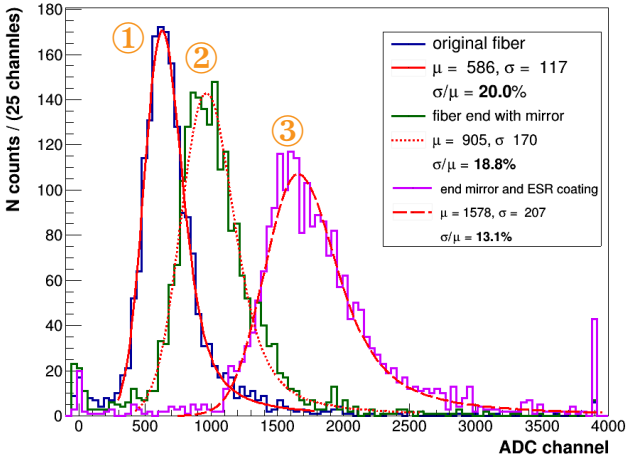
Shashlik Module

- The Shashlik module is built in our lab,
- CsI crystal module is purchased for test,
- Prototypes with both modules are ongoing.



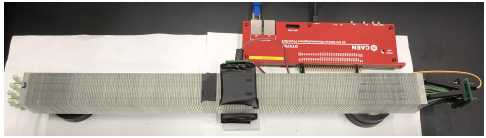
CsI crystal

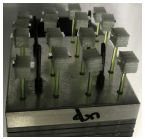
Test of Shashlik Module with Cosmic Ray



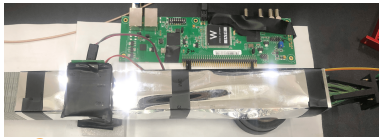
Light yield increased with additional reflective material applying

① original measurement



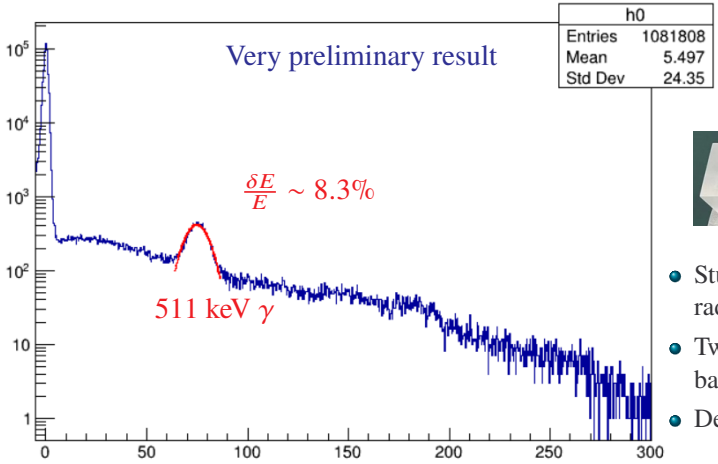


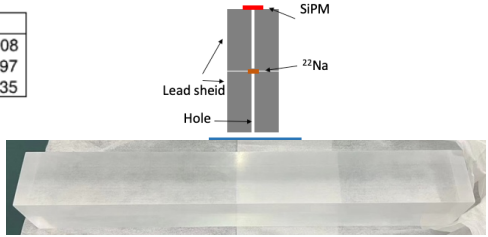
② measurement by adding mirror at ends of WLS fiber



③ measurement with ESR covered

Test of CsI Crystal with Radioactive Source





- Study the optical properties of the crystal with radioactive source (^{22}Na),
- Two gammas with 0.511 MeV energy emitted back-to-back through positron annihilation,
- Detail studies (LY, LRU, *etc*) are preparing.

Summary and Outlook

- Two types of electromagnetic calorimeter are designed for the EicC experiment,
- Sampling EMC with **Shashlik** design for the **central barrel** and **hadron-forward endcap**,
- Homogeneous EMC with **pCsI crystal** for the**electron-forward endcap**,
- Simulation and event reconstruction are available based on current design, more details is considering to meet the EicC physics requirements,
- Hardware research and development is ongoing in the laboratory,
- First goal is to build **prototypes for both Shashlik and crystal EMC**.

Thanks!

Welcome to join: dxlin@impcas.ac.cn


thank you
gracias
danke
merci
obrigado
謝謝
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ngiyabonga
go raibh maith agat
mochchakkeram
dziękuję
sukriya
kop khun krap
terima kasih
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ありがとう
arigatô
grazie
спасибо
bedankt
dank je
dakujem
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murakoze
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kia ora
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Баярлалаа
faafetai lava
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nanni
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gracie
dêkuji
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mèsi
didi madloba
sagolun
najis tuke
rahmat
kam sah hamnida