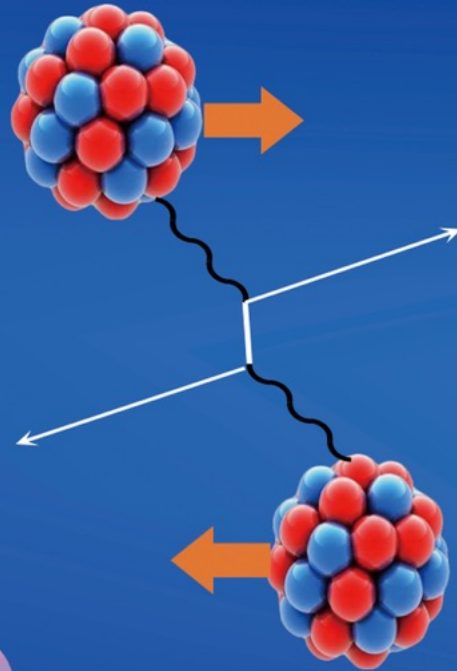


# 第二届超边缘碰撞物理研讨会

Strong Electromagnetic Fields, UPC and EIC/EicC



## Far-forward detectors and related physics at EicC

### EicC前向探测器和相关物理研究进展

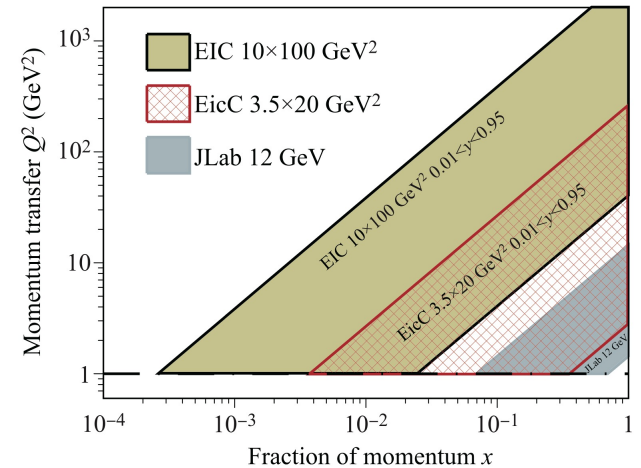
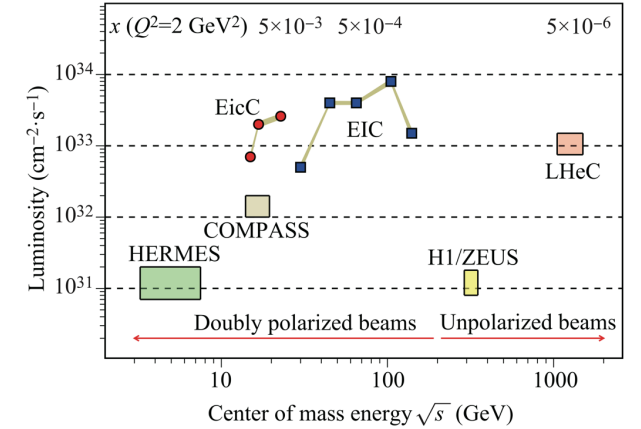
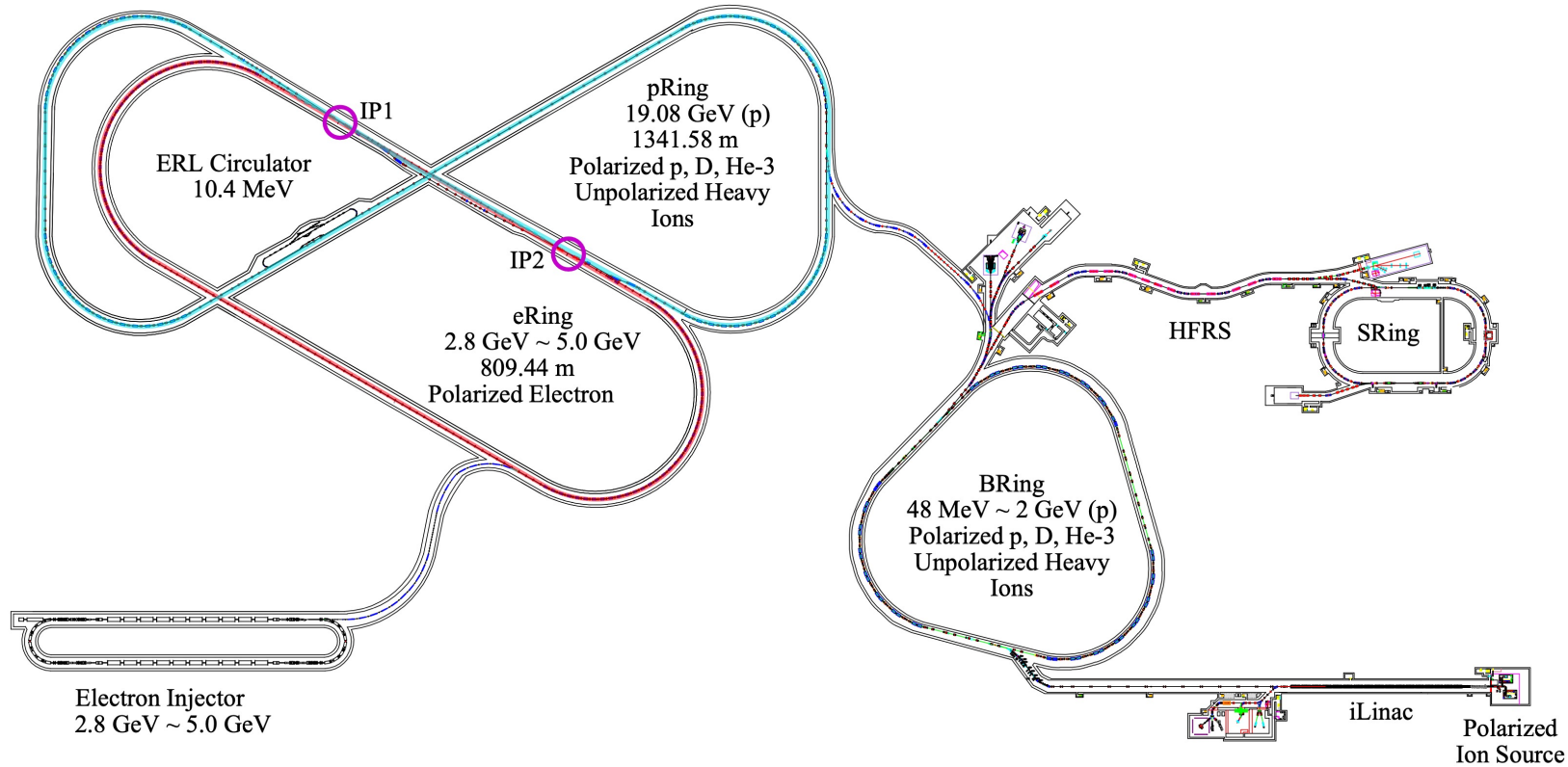
Ting Lin (林挺)

Shandong University (山东大学)

In collaboration with: Weizhi Xiong (熊伟志), Yutie Liang (梁羽铁),

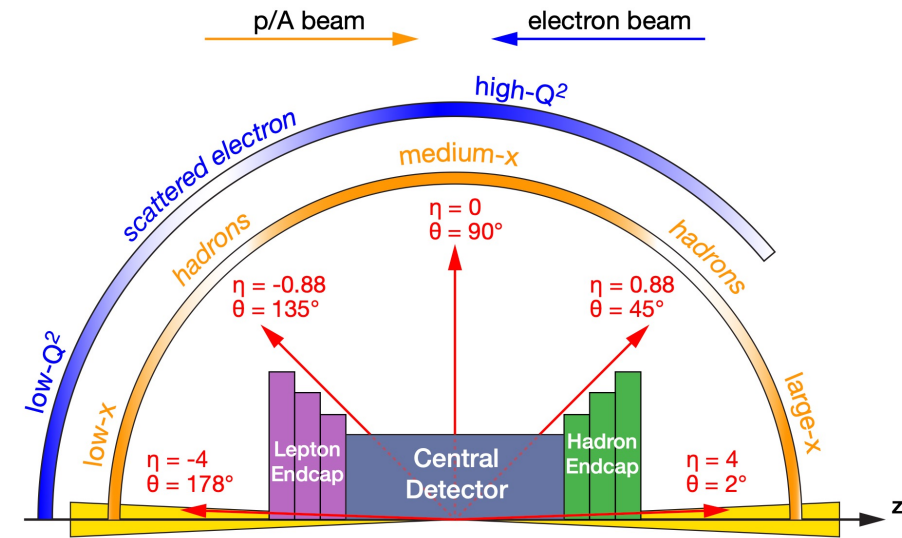
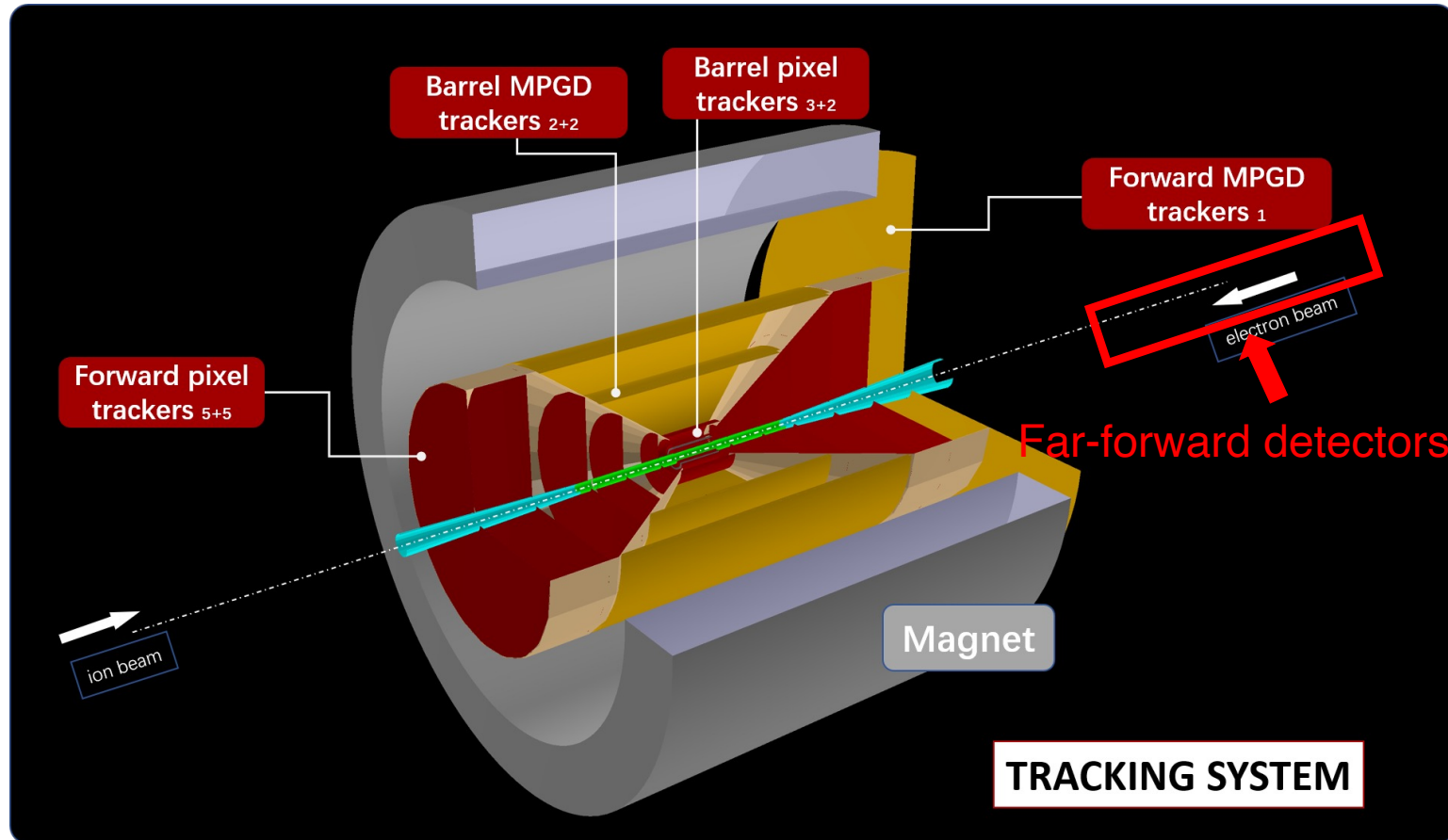
Xu Cao (曹须), Aiqiang Guo (郭爱强) .....

# Electron ion collider in China



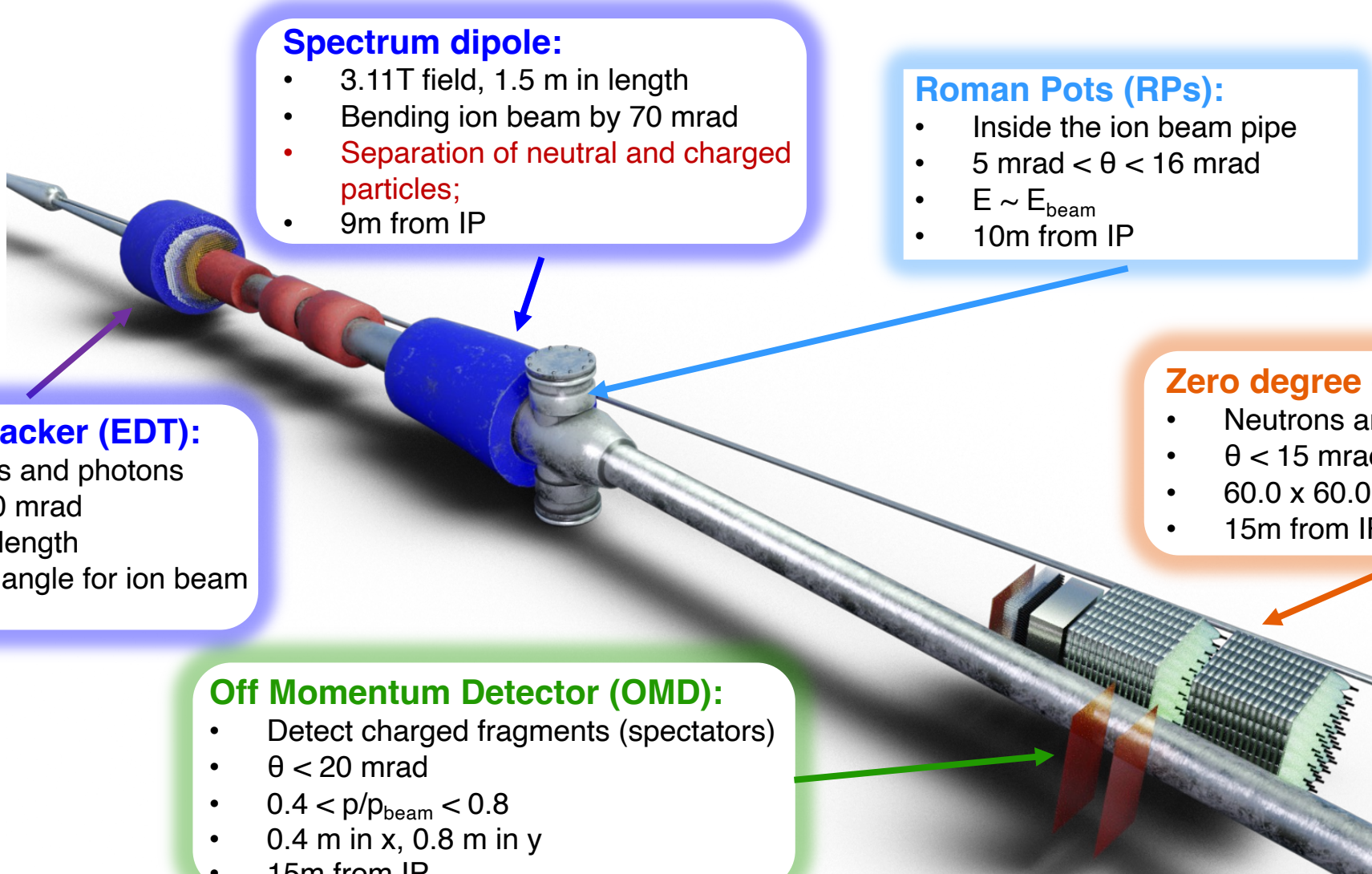
- Based on the High Intensity Heavy ion Accelerator Facility (HIAF);
- High luminosity electron-proton and electron-ion collision;
- Provide kinematic coverage to sea quark region.

# Detector Design



- Many physics processes require a detection of final-states with particles at few mrad regions ( $\eta > 4.0$ );
- Outside the acceptance of the central detector and require detectors integrated with the accelerator beamline.

# Far Forward Detector



## Spectrum dipole:

- 3.11T field, 1.5 m in length
- Bending ion beam by 70 mrad
- Separation of neutral and charged particles;
- 9m from IP

## Roman Pots (RPs):

- Inside the ion beam pipe
- $5 \text{ mrad} < \theta < 16 \text{ mrad}$
- $E \sim E_{\text{beam}}$
- 10m from IP

## Endcap Dipole Tracker (EDT):

- Charged particles and photons
- $15 \text{ mrad} < \theta < 60 \text{ mrad}$
- 2T field, 0.5m in length
- 15mrad bending angle for ion beam
- 4.8m from IP

## Zero degree calorimeter (ZDC):

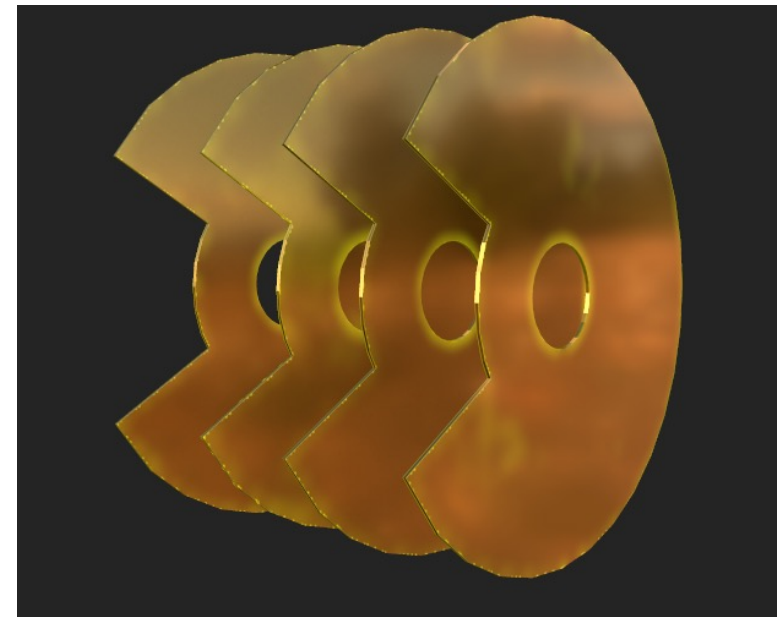
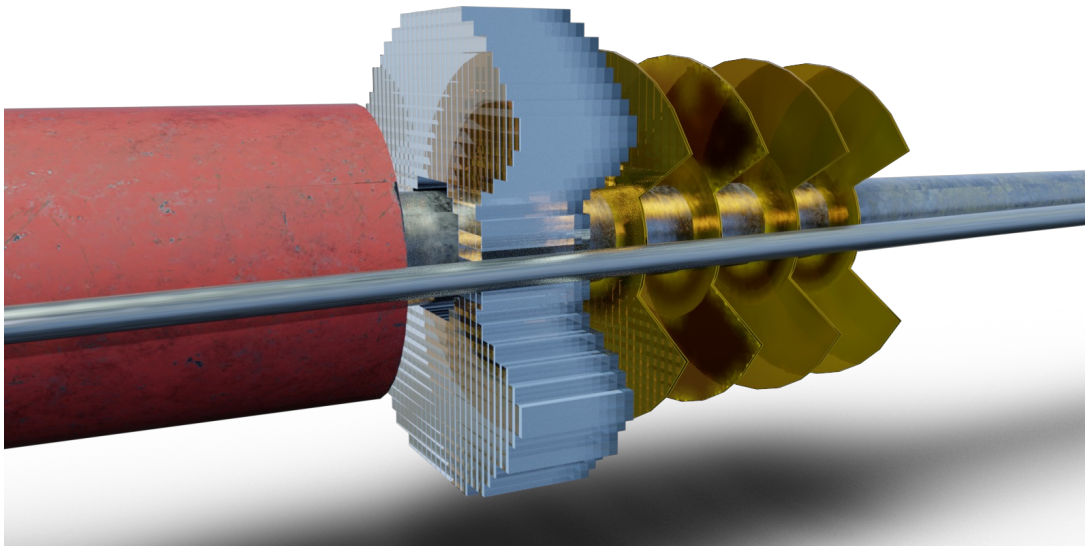
- Neutrons and photons
- $\theta < 15 \text{ mrad}$
- $60.0 \times 60.0 \times 143.5 \text{ cm}^3$
- 15m from IP

## Off Momentum Detector (OMD):

- Detect charged fragments (spectators)
- $\theta < 20 \text{ mrad}$
- $0.4 < p/p_{\text{beam}} < 0.8$
- 0.4 m in x, 0.8 m in y
- 15m from IP

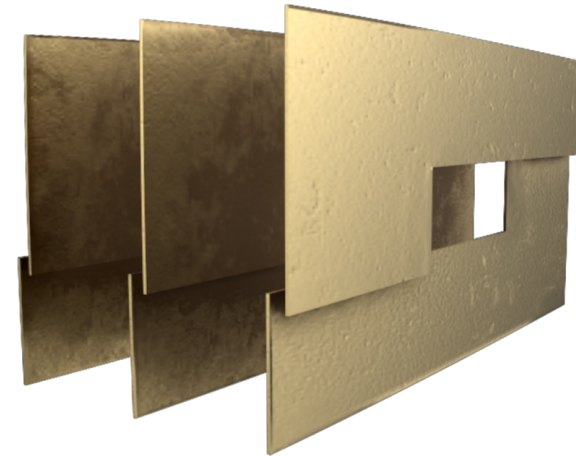
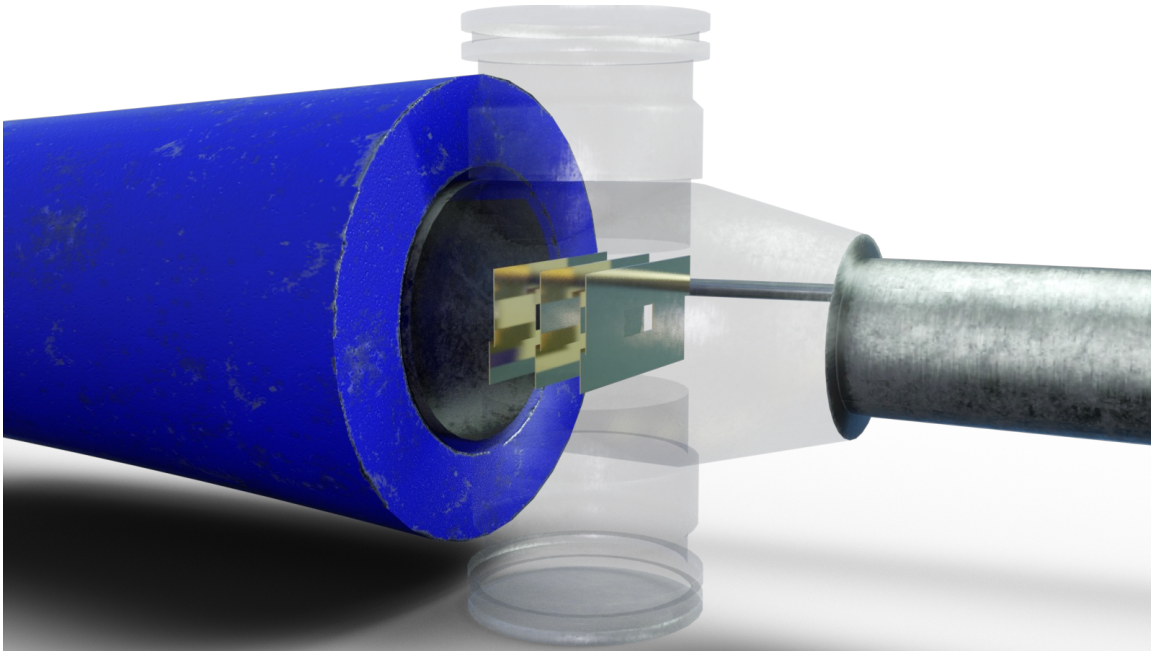
# Endcap Dipole Trackers (EDT)

- Four **silicon trackers (MAPS, AC-LGAD)**, and potential **compact EM calorimeter (PbWO<sub>4</sub>)**
- Acceptance:  $16 \text{ mrad} < \theta < 60 \text{ mrad}$
- Full  $\phi$  coverage for  $\theta < 35 \text{ mrad}$
- Require gaps for  $\theta > 35 \text{ mrad}$  and  $-30^\circ < \phi < 30^\circ$  to allow electron beam pass through



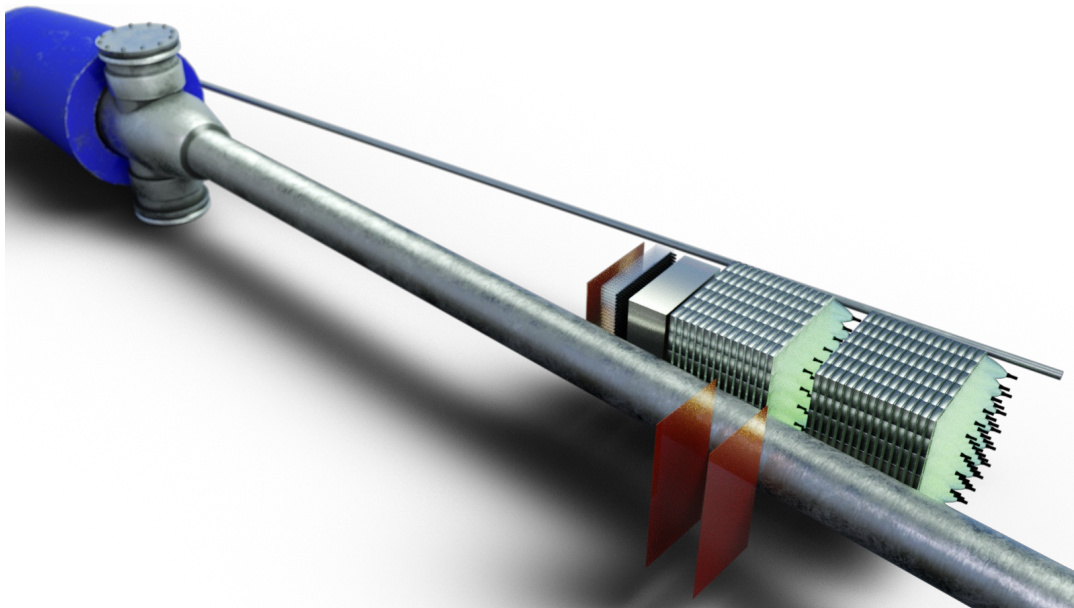
# Roman Pots (RPs)

- Roman pots: 3 **silicon trackers** (MAPS + AC-LGAD) placed inside the ion beam pipe;
- Small holes in the middle to allow ion beam passes through;
- Two movable L-shape planes, allowing for both high and low luminosity (covering down to 5 mrad).

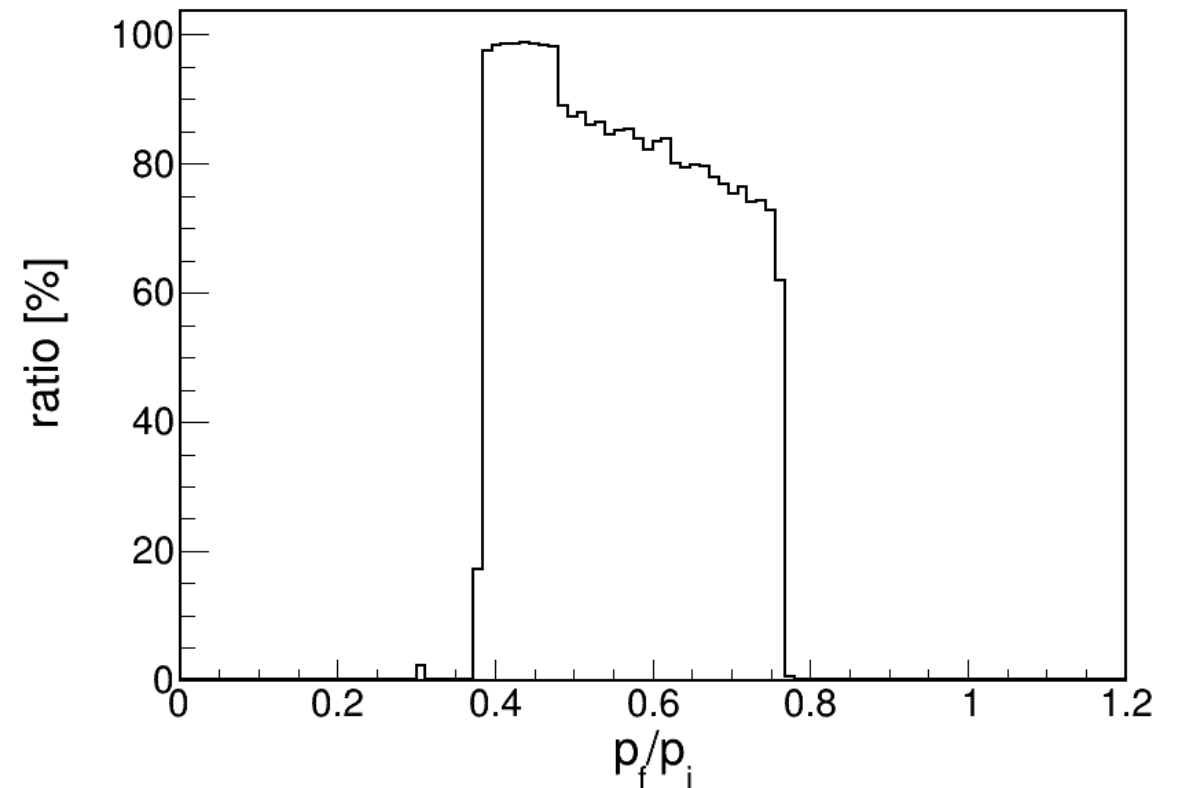


# Off Momentum Detector (OMD)

- Purpose of OMD is for charged spectator tagging
- Envisioned technology: MAPS + AC-LGAD or MPGD + AC-LGAD
- Capable of detector charge particles with  $0.4 < p_f/p_i < 0.75$



Off-momentum detectors



# Zero Degree Calorimeter

## Tungsten+Silicon detectors:

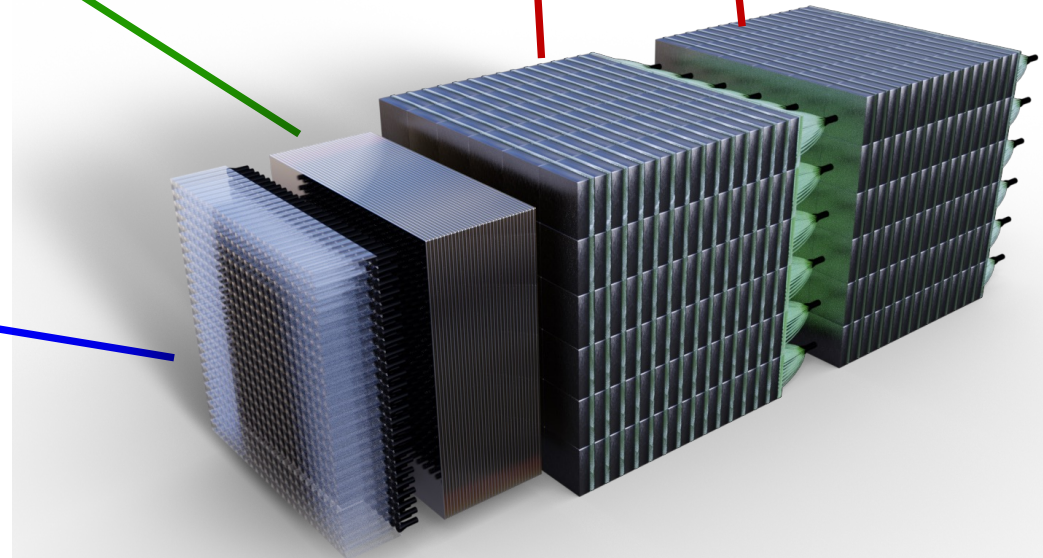
- **Imaging calo., pos recon., PID**
- 42 layers, each with 3.5mm W + 320um Si
- Si layer readout 1cm x 1cm for now
- Total size 50.6 cm x 50.6 cm x 22.5cm

## Pb+Scintillator detectors:

- **Energy measurement for neutron**
- Each layer 25.6mm lead + 6.4mm scintillator
- 15 layers with total size of 60cm x 60cm x 48cm

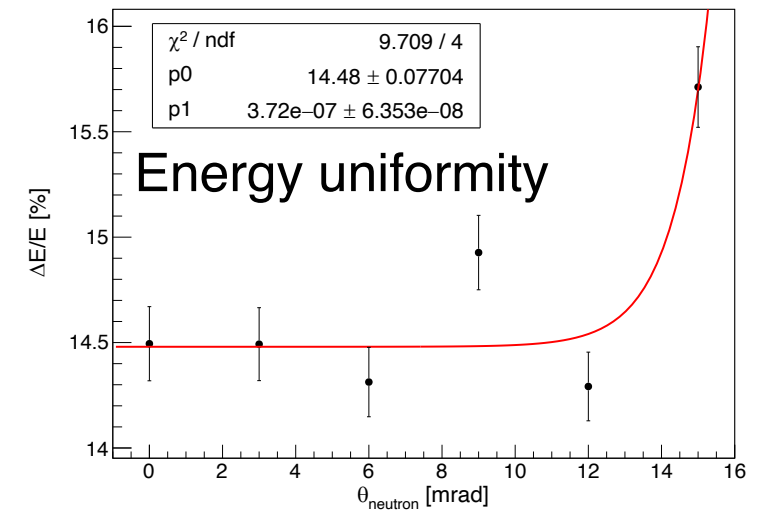
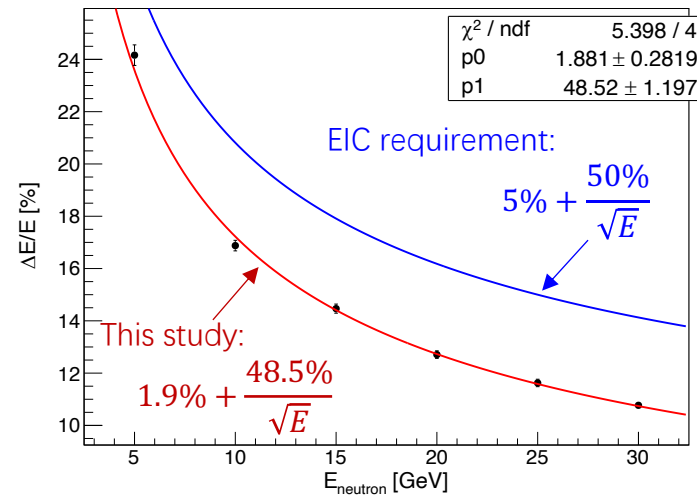
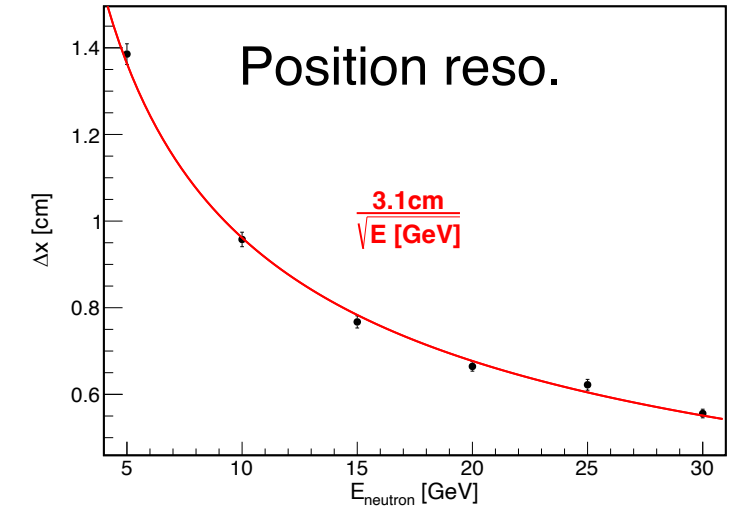
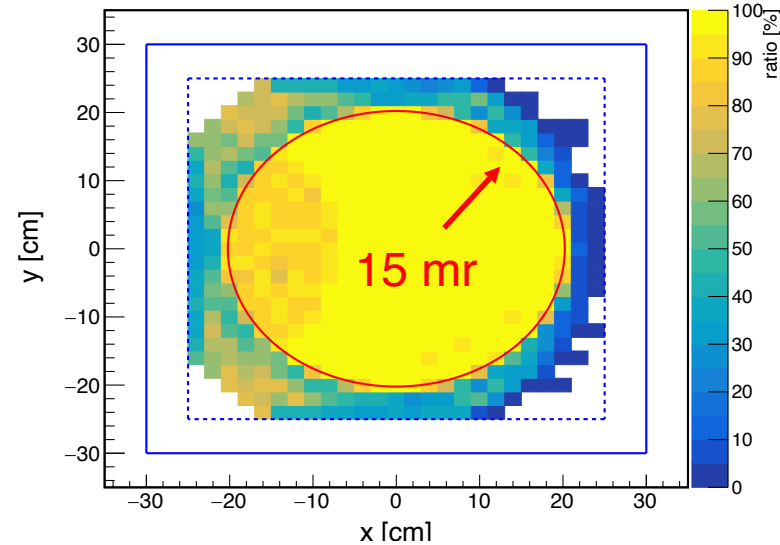
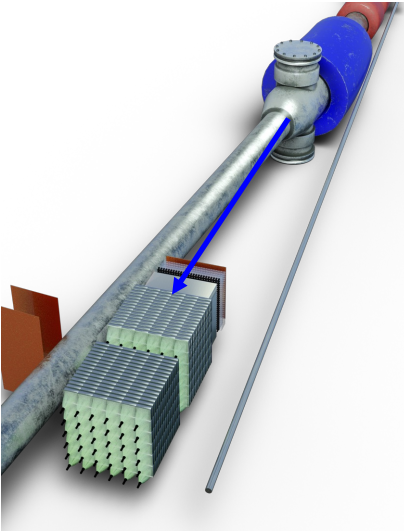
## PbWO<sub>4</sub> detectors:

- **For photon detection**
- each module 2.2 cm x 2.2 cm x 10 cm
- in total 50.6 cm x 50.6 cm x 10.0 cm





# Zero Degree Calorimeter



- Preliminary design based on the EIC ZDC;
- Pb+Sci: include simple models for light yield, trapping, attenuation, and SiPM efficiency;
- **PbWO<sub>4</sub>** use simple Gaussian smearing for edep
- No digitization for WSi yet, assume same model for PbWO4 for now;

# Similarity between UPC and EIC

TI

You

超边缘碰撞 (Ultra-peripheral collisions, UPCs) 和电子离子对撞机 (Electron-Ion Collider, EIC) 有什么相似性?

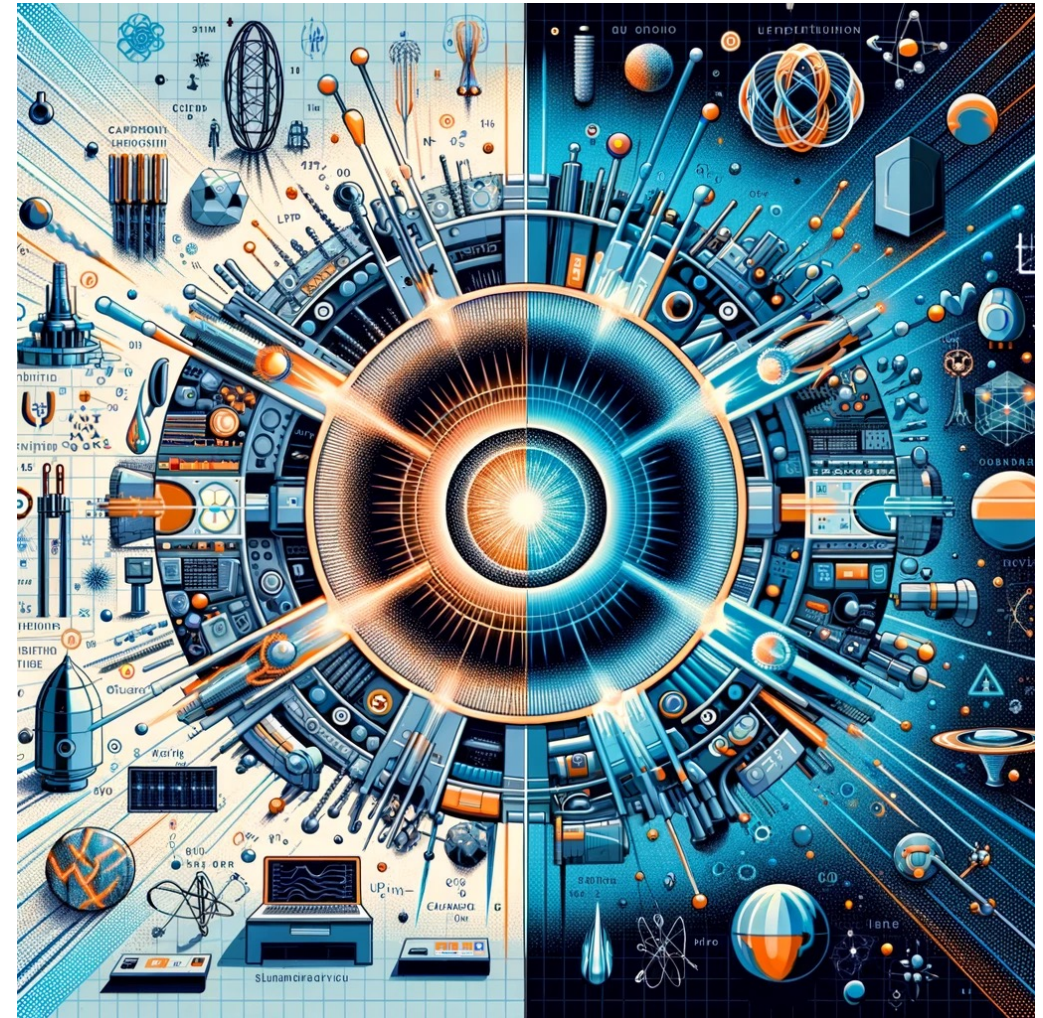
ChatGPT

ChatGPT

超边缘碰撞 (UPCs) 和电子离子对撞机 (EIC) 在探索量子色动力学 (QCD) 和强子结构方面展现了相似性, 尽管它们在实验设置和碰撞机制上有所不同。这些相似性主要包括:

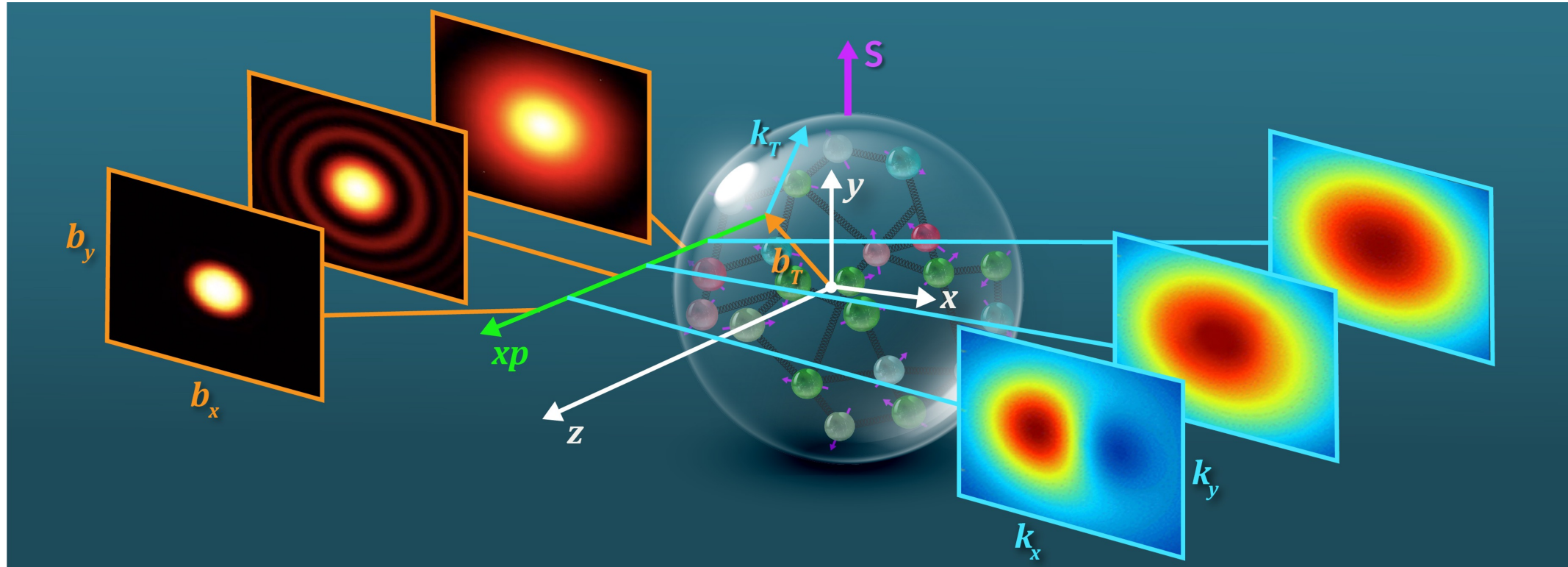
- 电磁相互作用的重点:** UPCs和EIC都利用电磁相互作用来探究强子内部的夸克和胶子分布。UPCs通过离子产生的强烈电磁场引发的虚拟光子相互作用来实现, 而EIC通过电子和离子/质子之间的直接电磁交换来探索。
- 探究QCD的现象:** 两种方法都旨在深入理解QCD的基本问题, 包括胶子动力学、强子内部的空间结构以及夸克和胶子如何贡献于强子的性质。
- 对强子结构的三维成像:** UPCs和EIC都提供了研究强子内部三维结构的手段, 尤其是通过探测不同过程中的最终态粒子来揭示夸克和胶子的分布。
- 补充性:** 虽然UPCs侧重于通过高能离子间的非接触相互作用来研究, 而EIC侧重于通过电子和离子/质子的直接碰撞来进行精确测量, 但这两种方法在理解QCD和强子结构的各个方面提供了互补的视角。

简而言之, UPCs和EIC通过不同的实验方式在电磁相互作用的框架内探索了QCD的深层次问题, 它们在强子物理学和核物理学领域的研究中都发挥着重要作用, 为我们提供了丰富的物理洞察。



# Three-Dimensional Imaging of The Proton

2023 NSAC Long Range Plan



- Generalized Parton Distribution functions (GPDs) reveal the correlation of the partons' transverse spatial distribution and longitudinal momentum density;
- Transverse-Momentum-Dependent parton distribution functions (TMDs) encode information on how the momentum of quarks and gluons are correlated with the parent hadron properties;
- GPDs and TMD distributions are intimately connected to each other and are unified under the concept of Wigner distributions.

# Three-Dimensional Imaging of The Proton

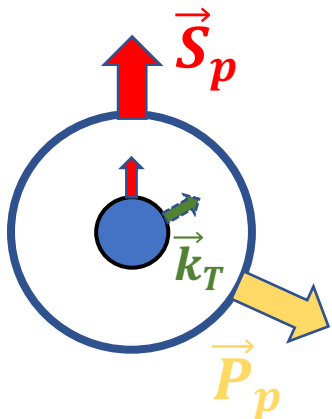
TMD Handbook, arXiv:2304.03302 [hep-ph]

Leading Quark TMDPDFs  Nucleon Spin  Quark Spin

		Quark Polarization		
		Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1 = \text{Unpolarized}$		$h_1^\perp = \text{Boer-Mulders}$
	L		$g_1 = \text{Helicity}$	$h_{1L}^\perp = \text{Worm-gear}$
	T	$f_{1T}^\perp = \text{Sivers}$	$g_{1T}^\perp = \text{Worm-gear}$	$h_1 = \text{Transversity}$ $h_{1T}^\perp = \text{Pretzelosity}$

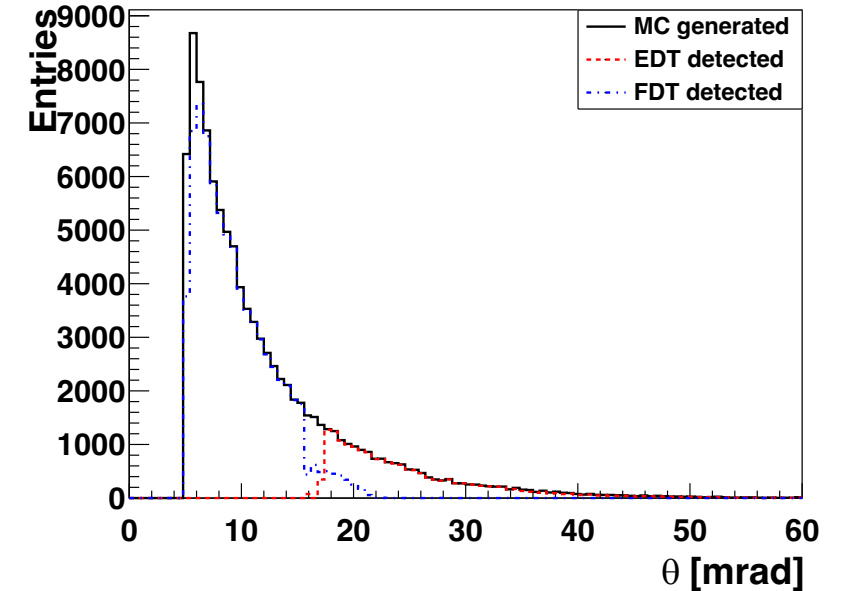
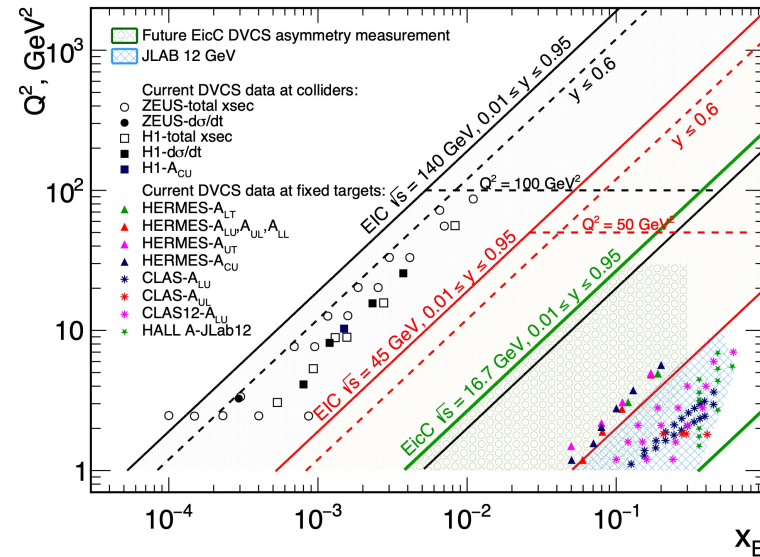
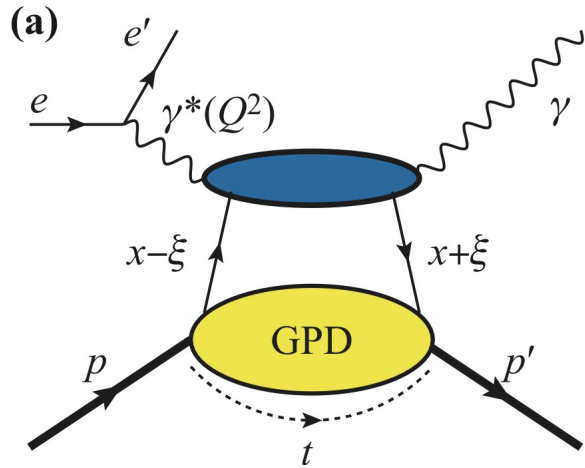
Leading Quark GPDs

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



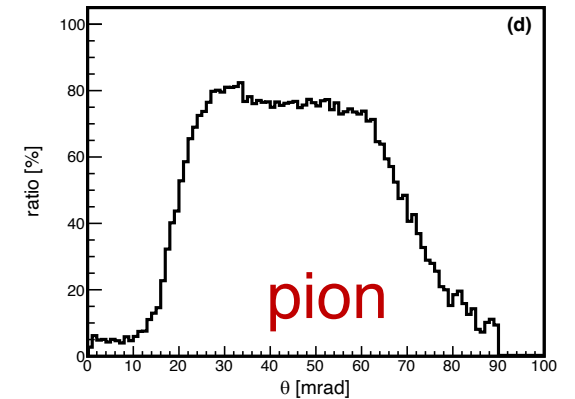
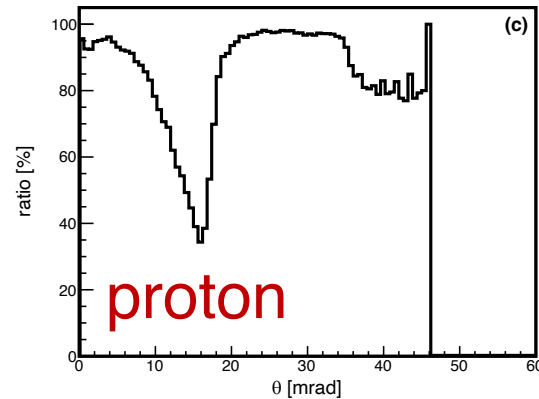
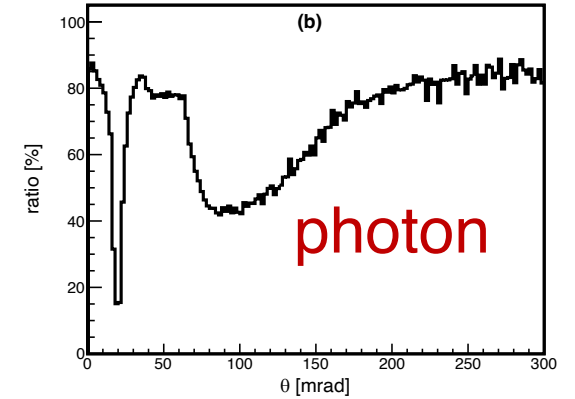
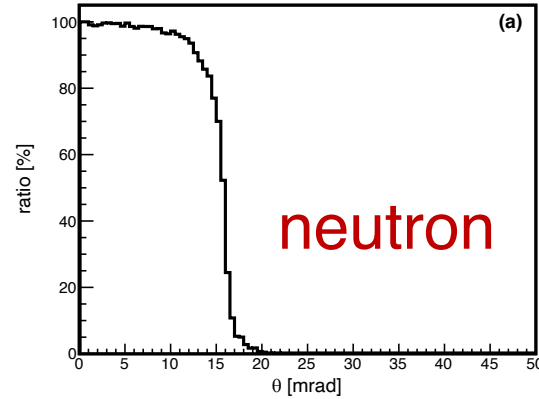
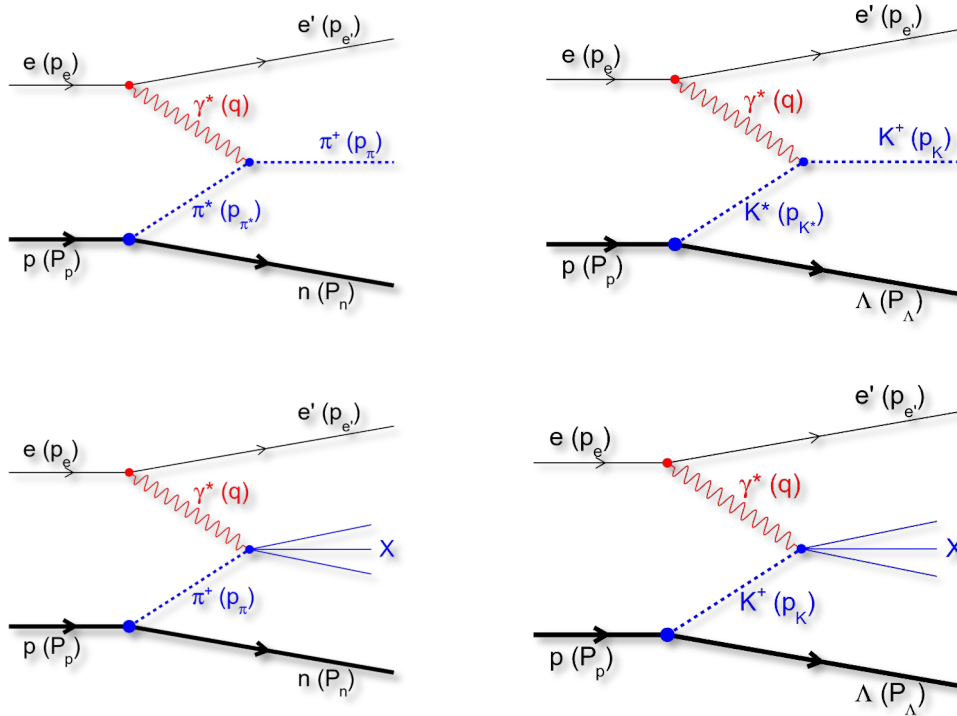
- Image the transverse and longitudinal (2+1d) structure of the nucleon and nuclei;
  - Tomography of the nucleon;
- TMD provide access to transverse momenta at non-perturbative scales;
- GPD probe nucleon tomography in the impact parameter space.

# Deeply Virtual Compton Scattering (DVCS)



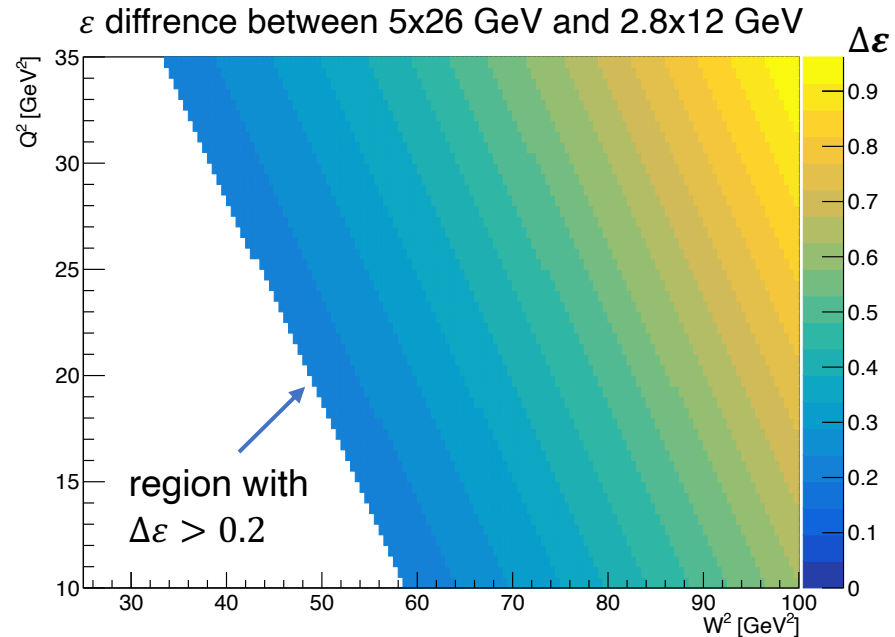
- Deeply Virtual Compton scattering (DVCS) is the golden channel measurements for GPDs;
  - Provide access to four chiral-even GPDs and Compton form factors (CFF);
- Asymmetry precision  $< 1.0 \sim 1.5 \%$  in all kinematic region of DVCS;
- A high-energy proton with small scattering angle produced in the final state
  - Mostly detected by RPs and EDT

# Meson Structure



- The Sullivan process provide access to a meson target as  $t$  becomes space-like;
- For  $ep \rightarrow e\Lambda + K^+ / X$ , require the Lambda detection, which go mostly forward;
  1. neutral channel:  $\Lambda \rightarrow n\pi^0$ , with BR 36%
  2. charged channel:  $\Lambda \rightarrow p\pi^-$ , with BR 64%
- Advantage for EicC with overall efficiency  $\sim 40\%$  (EIC 1%  $\sim 20\%$ ).

# L-T Separation



$$\frac{d^2\sigma}{dt d\phi} = \frac{1}{2\pi} \left( \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} + \epsilon \cos 2\phi \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)} \cos \phi \frac{d\sigma_{LT}}{dt} \right)$$

- Need  $\sigma_L$  to get form factor:  $\sigma_L \propto F_\pi^2$

- Measure two different  $\sigma$  at same  $Q^2$  and  $W$ 

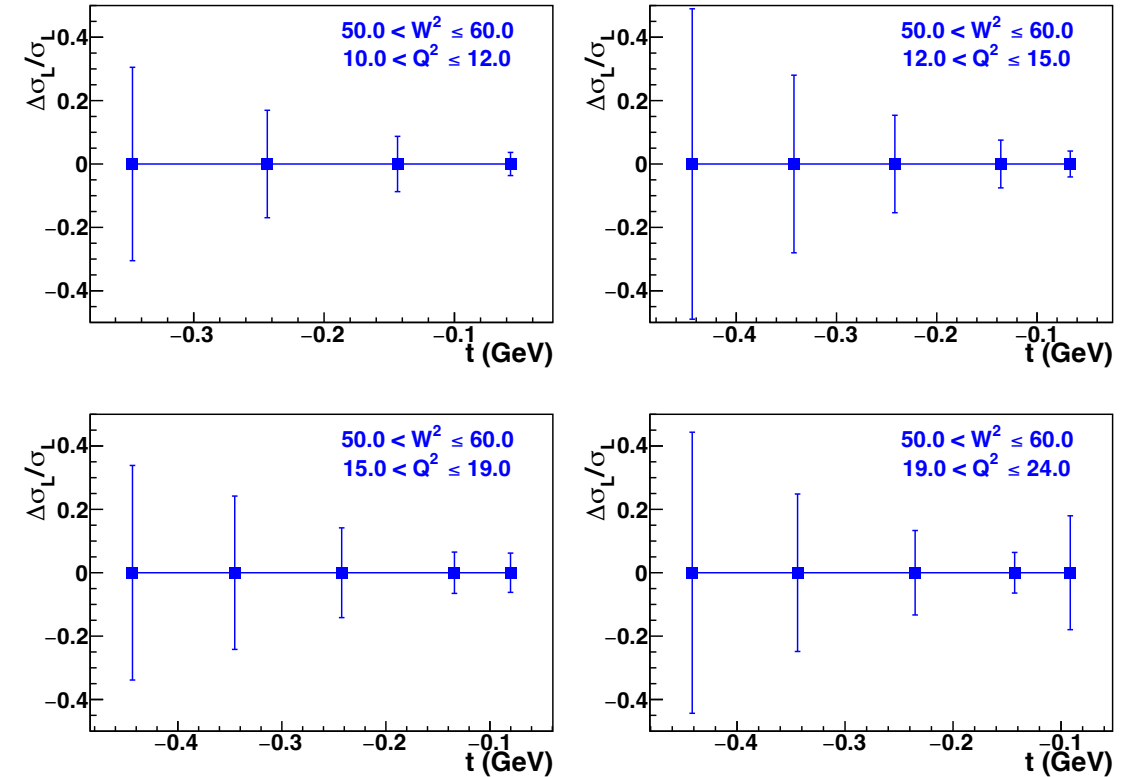
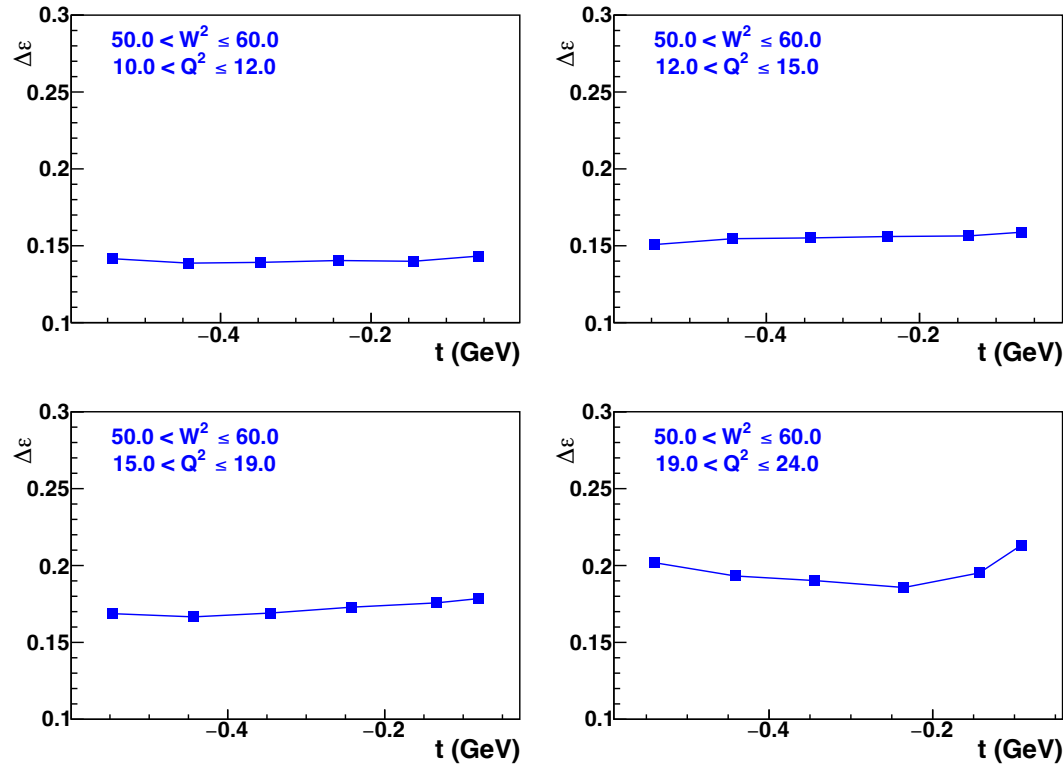
$$\sigma_1 = \sigma_T + \epsilon_1 \sigma_L$$

$$\sigma_2 = \sigma_T + \epsilon_2 \sigma_L$$

$$\sigma_L = \frac{1}{\epsilon_1 - \epsilon_2} (\sigma_1 - \sigma_2) \qquad \frac{\Delta\sigma_L}{\sigma_L} = \frac{1}{\epsilon_1 - \epsilon_2} \frac{1}{\sigma_L} \sqrt{\Delta\sigma_1^2 + \Delta\sigma_2^2}$$

- $\epsilon$ : ratio of fluxes of longitudinally and transversely polarized virtual photons;
- Need  $\Delta\epsilon > 0.2$  possible in certain kinematic to extract form factors;
- EIC likely difficult due to much higher energy

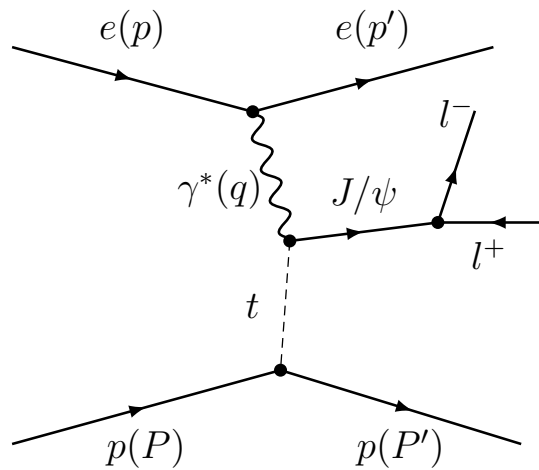
# L-T Separation



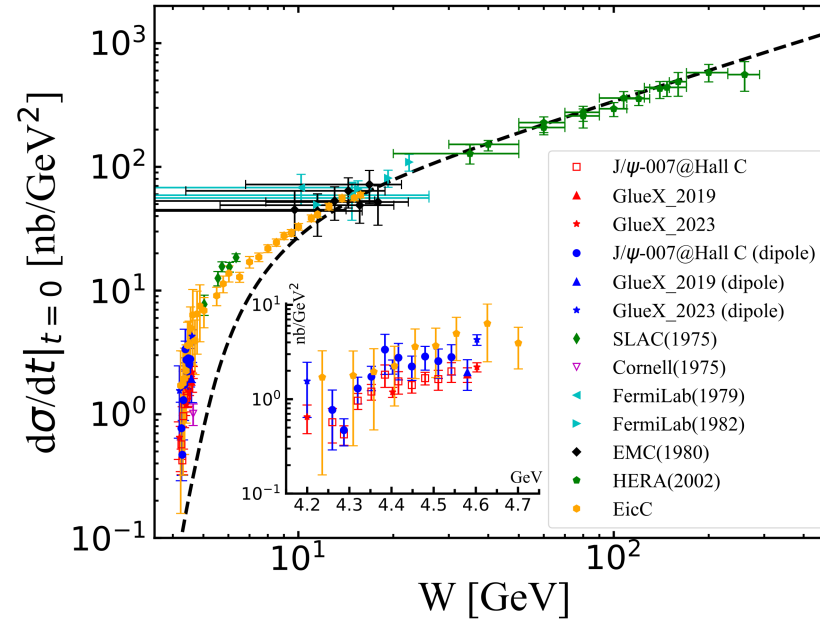
- Use DEMPgen for EIC (arXiv2403.06000);
  - Use  $2.8 \times 12 \text{ GeV}^2$  v.s.  $3.5 \times 20 \text{ GeV}^2$
  - Encounter some issues at low energy -> Still on trying to understand and test the generator
- Very preliminary estimation at this stage, need much more work.



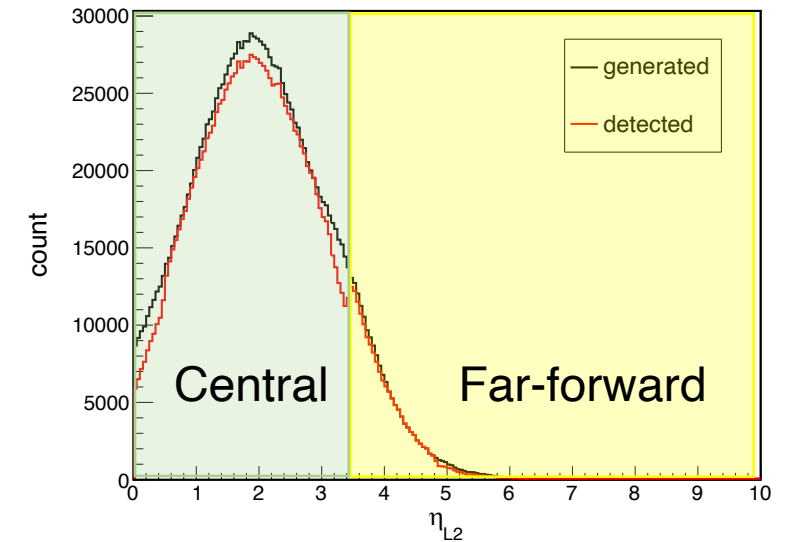
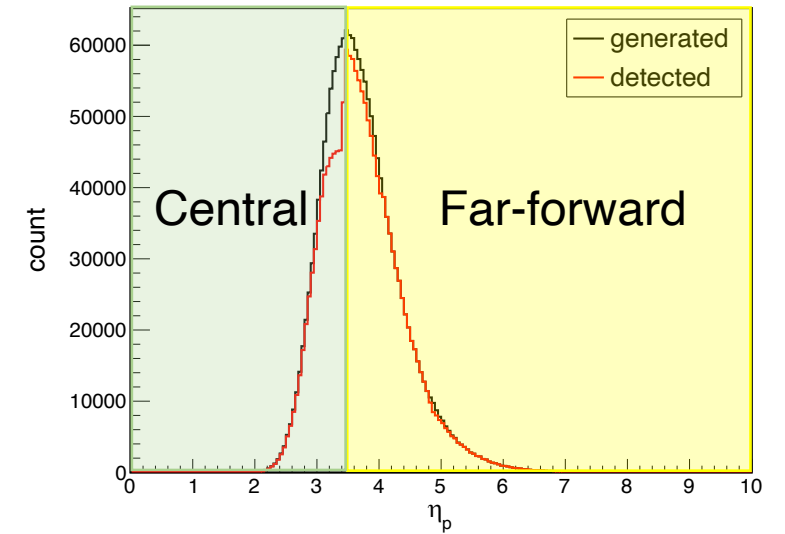
# Exclusive $J/\psi$ Production



X. Wang et al. arXiv: 2311.07008



- Exclusive  $J/\psi$  production: Gravitational form factor (GFF), proton mass, pentaquark states,  $J/\psi$  production mechanism
- The measurements at EicC fill the gap between ZEUS and JLab data;
- Excellent acceptance for p and di-leptons.



# Summary

- The first fully design of EicC far-forward detectors:
  - EDT: charged particle and photon with  $16 \text{ mrad} < \theta < 60 \text{ mrad}$
  - OMD: charged spectator with  $0.4 < \frac{p_f}{p_{beam}} < 0.8$
  - RP: charged particle with  $p_f \sim p_{beam}$  and  $5 \text{ mrad} < \theta < 16 \text{ mrad}$
  - ZDC: neutron and photon with  $\theta < 15 \text{ mrad}$
- Essential for a wide range of exclusive + diffractive physics:
  - DVCS, TCS, DVMP
  - Meson Structure
  - Exclusive  $J/\psi$  production