3D imaging of hadrons at the EicC

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on behalf of the EicC Exclusive Physics Working Group

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

Workshop of the 3D structure of the nucleon via GPDs
Incheon, Korea, 24~28 Jun. 2024

Understanding the universe out of nothing

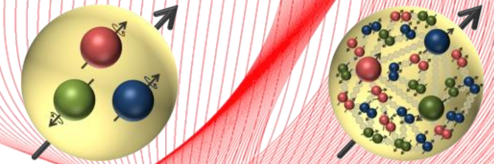
1 **Introduction**
EicC Status&Agenda

2 **3D Imaging of Nucleon**
Proton DVCS
Exclusive Heavy Flavor

3 **3D Imaging of Meson**
Meson Structure
Pion DVCS

4 **Summary**
Other Topics

Out of QCD vacuum, (anti-)quarks are born;
Out of (anti-)quarks, mass;
Out of mass, particles;
Out of particles, the created universe
--- modified from Tao Te Ching



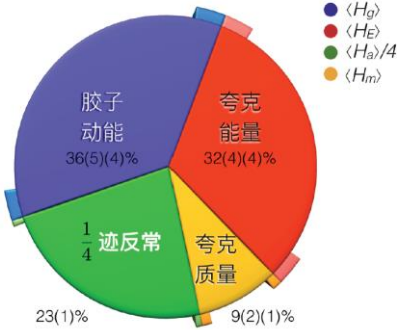
3D·Imaging@EicC
Institute of Modern Physics, Chinese Academy of Sciences

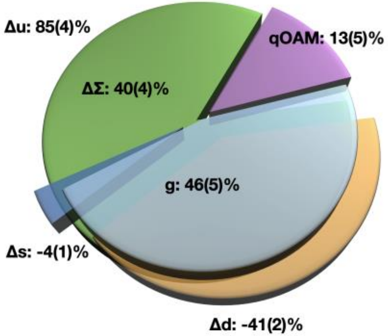
Introduction

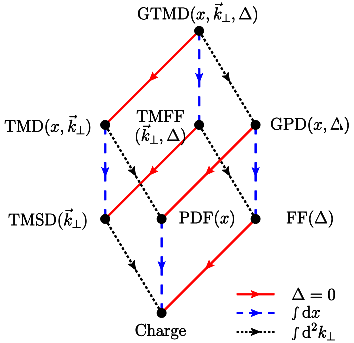
- **TMD: Transverse Momentum Distributions (k$\perp$ & longi. Momentum):**
- How is proton's spin correlated with the motion of the quarks/gluons?
- …… probed by the inclusive process

- **GPD: General Parton Distributions (trans. spatial position b$\perp$ & longi. Momentum):**
- **TDA: Transition Distribution Amplitudes (nucleon-to-photon & nucleon-to-meson):**
- How does proton's spin influence the spatial distribution of partons?
- …… probed by the exclusive process

- **From 1D to 3D picture of hadron & nuclei**
- **Origin of the Proton/Meson mass & spin**

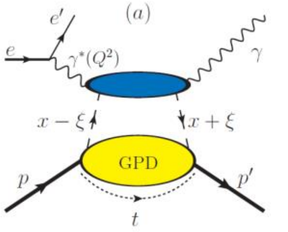




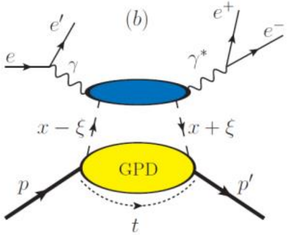


Introduction

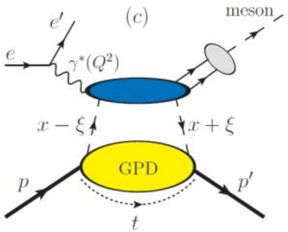
- **From 1D to 3D structure of proton & nuclei:**
  - GPD: DVCS, TCS, DVMP, DDVCS
  - TDA: backward (u-channel) meson production



- Deeply Virtual Compton Scattering $\xi = x_B/(2-x_B)$



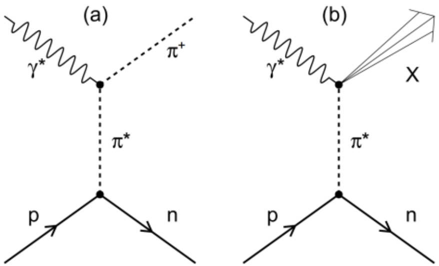
- Timelike Compton Scattering
- **share the same final states with nucleon-to-photon TDA**
- **but with backward u-channel** $\xi = \tau/(2-\tau)$



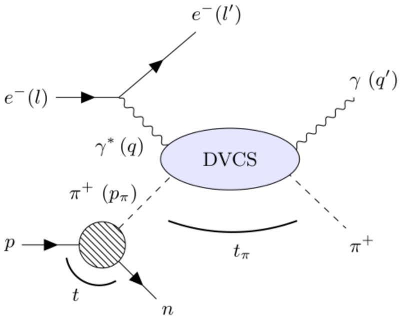
- Deeply Virtual Meson Production
- **share the same light meson with nucleon-to-meson TDA & hadron physics**
- **heavy quarkonium: gravitation form factors or proton mass?**
- **fully construction of all particles & kinematics**

Introduction

- **From 1D to 3D structure of pions & kaons:**
- Pions/Kaons as the approximate Nambu–Goldstone bosons of spontaneously broken chiral symmetries associated with the (near) masslessness of quarks
- Probed by Drell-Yan process and Sullivan process
- Detection of leading neutron/Lambda?



- Structure function
- **Sensitivity to elastic form factor and Parton Distribution Functions**

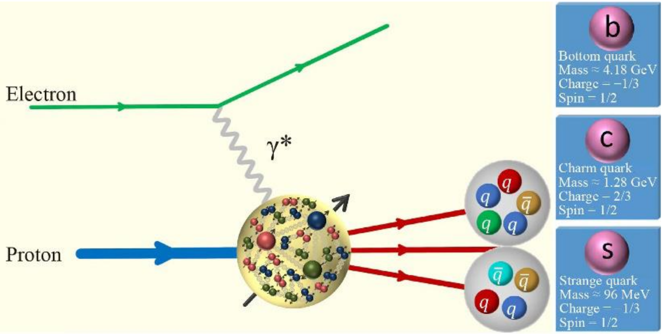


- π^+-DVCS
- **quarks and gluons interfere destructively**
- see J. M. Morgado Chávez *et al.*, Phys.Rev.Lett. 128 (2022) 202501

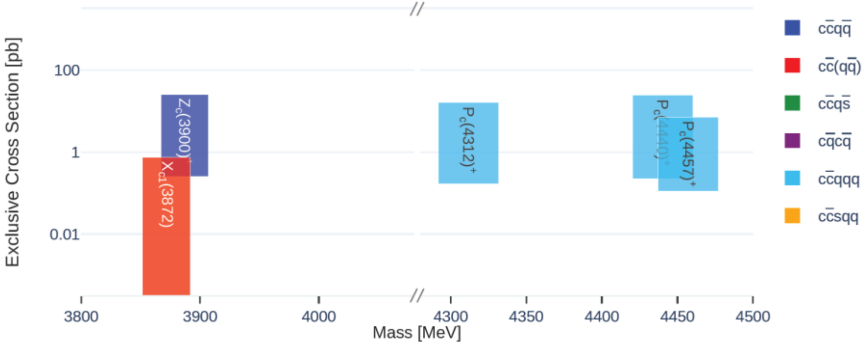
- **From conventional to exotic spectrum of Hadrons:**

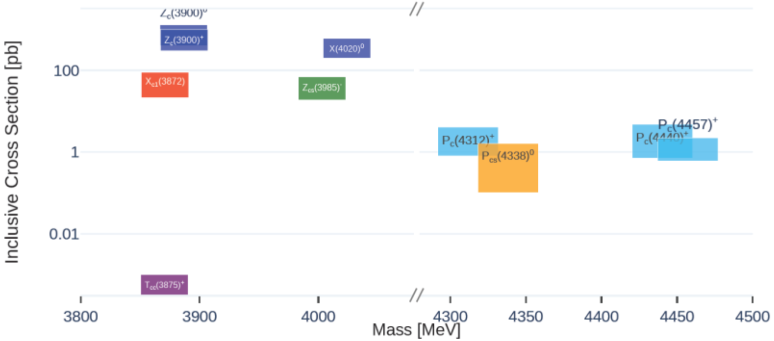
X.C, Front. Phys. 18 (2023) 44600

- Heavy Charmonium Production ≤ 1 nb
- From quasi-real to deep virtual photon
- Exotic States Production < 10pb



- Semi-inclusive electroproduction gives another upper limit of exclusive production





courtesy : Panpan Shi & Fengkun Guo

Status&Agenda of EicC

- **Energy:**

  electron + proton: 3.5 GeV × 20 GeV

  electron + ^{3}He: 3.5 GeV × 40 GeV (nucleus energy)

arXiv:2102.09222,

Front. Phys. 16, 64701 (2021)

- **Luminosity:**

  Instantaneous Lumi: 2 x 10^{33} cm^{-2} s^{-1}

  Integrated Lumi for simulation = 50 fb^{-1}

- **Polarization:**

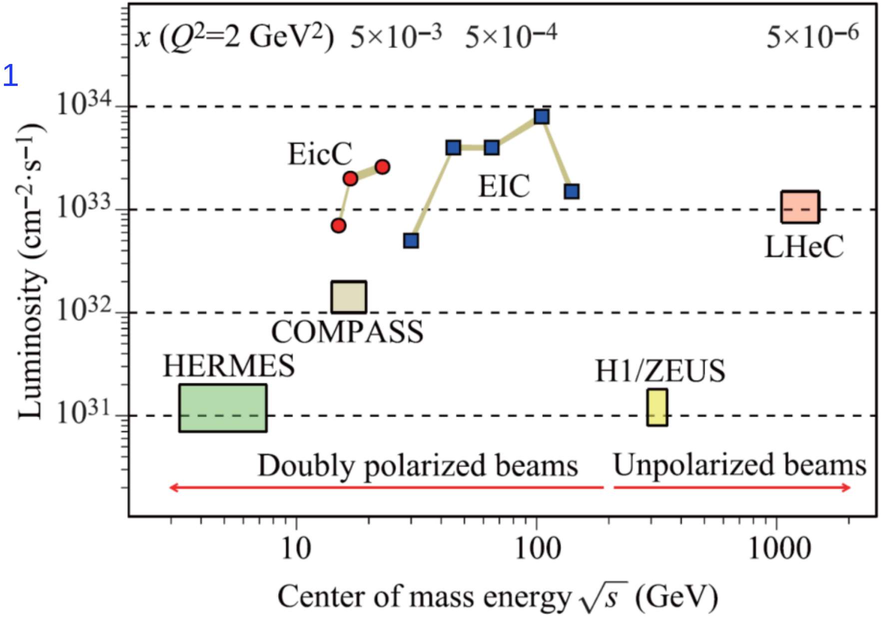
  electron: 80% L

  proton& ^{3}He: 70% L&T

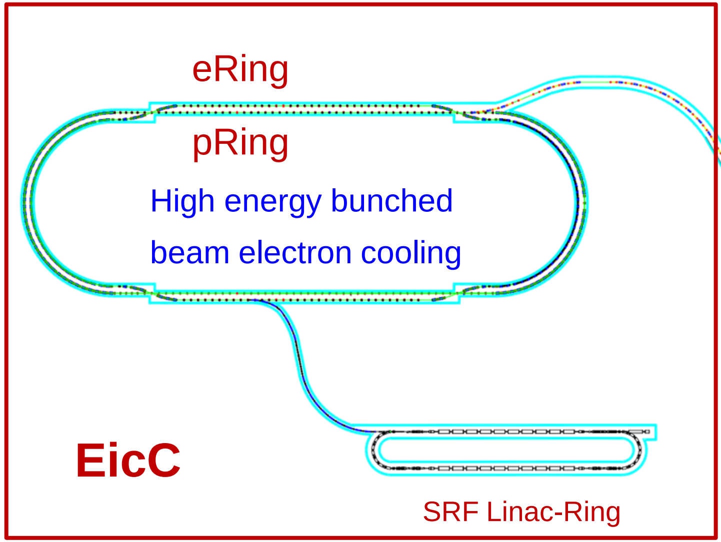
- **Phase space coverage**

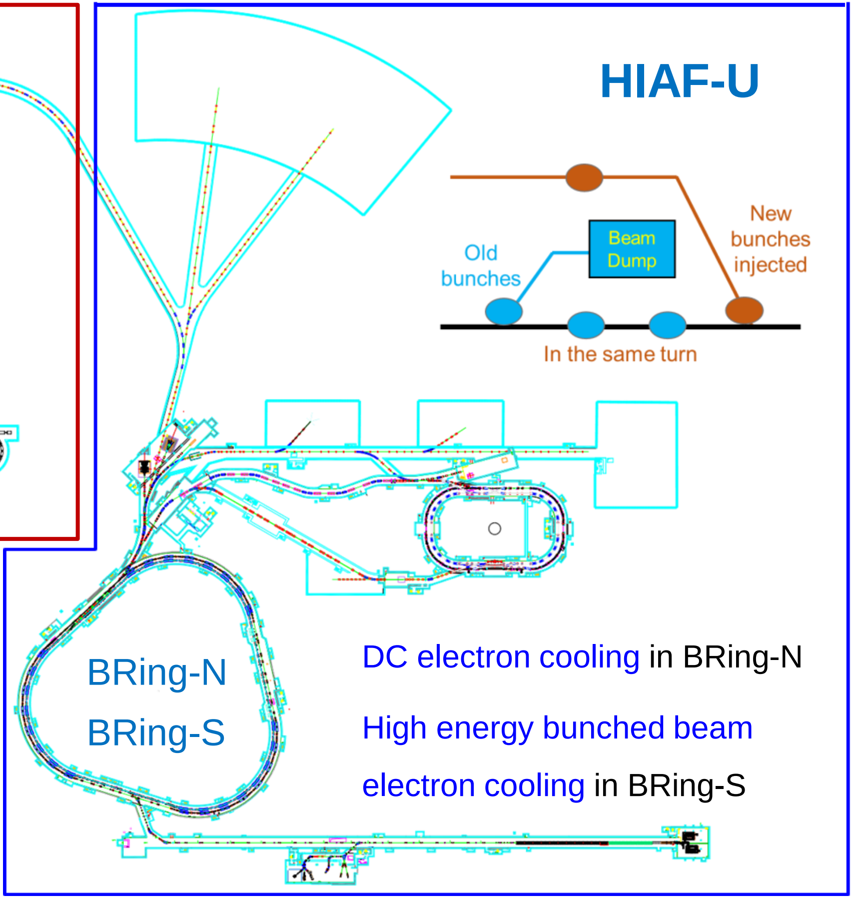
  $\sqrt{s}$ ~ 16.7 (15 ~ 20)GeV

  4×10^{-3} < x < ~ 0.1



Status&Agenda of EicC





DC electron cooling in BRing-N

High energy bunched beam electron cooling in BRing-S

Upgrade from High Intensity Heavy-ion Accelerator Facility

- ✓ Four potential interaction points
- ✓ Full energy injection for online bunch replacement
- ✓ Multi-stage electron cooling leading to smaller emittance

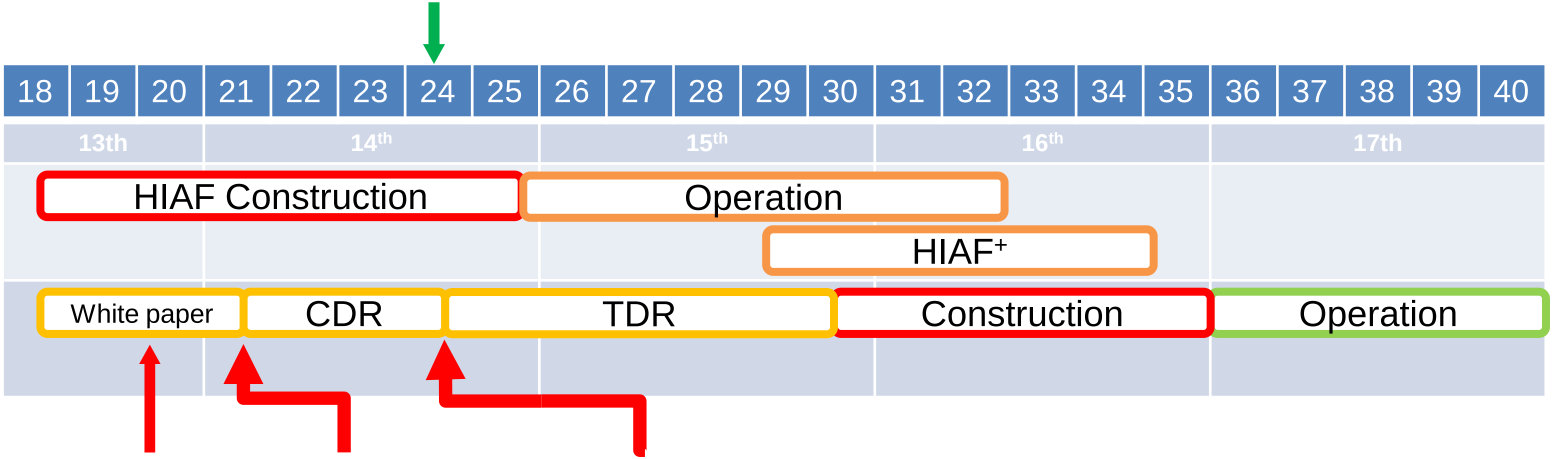
Status&Agenda of EicC

- e+p, e+d, e+^{3}He ……
- Effective tool for flavor separation

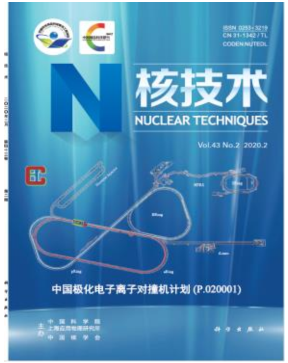
Particle	e	d	^{3}He^{++}	^{7}Li^{3+}	^{12}C^{6+}	^{40}Ca^{20+}	^{197}Au^{79+}	^{208}Pb^{82+}	^{238}U^{92+}
Kinetic energy (GeV/u)	3.5	12.00	16.30	10.16	12.00	12.00	9.46	9.28	9.09
Momentum (GeV/c/u)	3.5	12.90	17.21	11.05	12.90	12.90	10.35	10.17	9.98
Total energy (GeV/u)	3.5	12.93	17.23	11.09	12.93	12.93	10.39	10.21	10.02
CM energy (GeV/u)	–	13.48	15.55	12.48	13.48	13.48	12.09	11.98	11.87
$f_{collision}$ (MHz)	–	499.25	499.82	498.79	499.25	499.25	498.54	498.47	498.39
Polarization	80%	Yes	Yes	No	No	No	No	No	No
$B\rho$ (T·m)	11.67	86.00	86.00	86.00	86.00	86.00	86.00	86.00	86.00
Particles per bunch ($\times 10^9$)	40	6.1	3.0	2.04	1.00	0.30	0.07	0.065	0.055
$\varepsilon_x/\varepsilon_y$ (nm·rad, rms)	20	100/60	100/60	100/60	100/60	100/60	100/60	100/60	100/60
β_x^*/β_y^* (m)	0.2/0.06	0.04/0.02	0.04/0.02	0.04/0.02	0.04/0.02	0.04/0.02	0.04/0.02	0.04/0.02	0.04/0.02
Bunch length (m, rms)	0.01	0.015	0.015	0.02	0.015	0.015	0.02	0.02	0.02
Beam–beam parameter ξ_x/ξ_y	0.007	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Laslett tune shift	–	0.07	0.06	0.04	0.06	0.06	0.06	0.06	0.06
Current (A)	3.3	0.49	0.48	0.49	0.48	0.48	0.44	0.43	0.40
Crossing angle (mrad)					50				
Hourglass	–	0.94	0.94	0.92	0.94	0.94	0.92	0.92	0.92
Luminosity at nucleon level (cm^{-2}·s^{-1})	–	8.48×10^{32}	6.29×10^{32}	9.75×10^{32}	8.35×10^{32}	8.35×10^{32}	9.37×10^{32}	9.22×10^{32}	8.92×10^{32}

- The Luminosity is under optimization
- lever arm Q^2 > 30 GeV^2

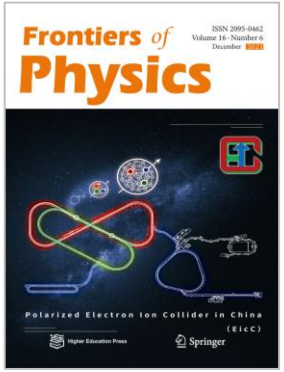
Status&Agenda of EicC



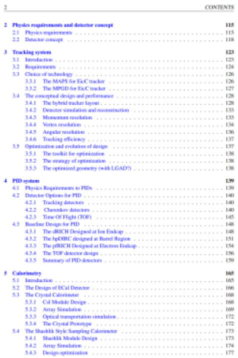
2020.02



2021.06



2024.08 CDR



2 CONTENTS

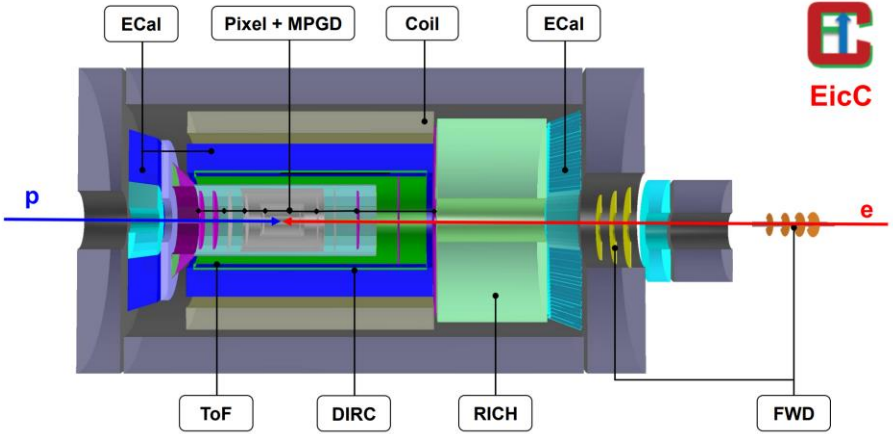
Fundings for detector and accelerator R&D:

Forward detectors: ZDC, OMD, EDT

proton polarimetry

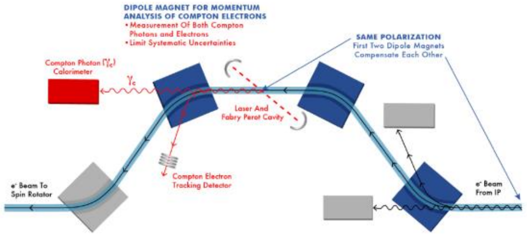
Polarized proton beam

Status&Agenda of EicC

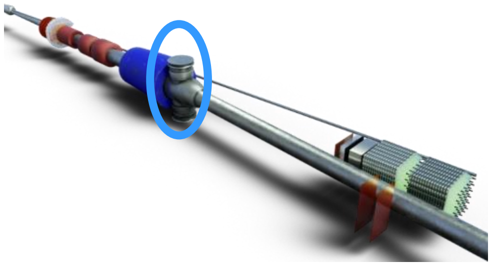


Central detector

electron far-forward detectors



Ion far-forward detectors



	High Lumi.		Low Lumi.	
Designs	HIAF-U-New, V0		V1	
Particle	e	p	e	p
Circumference(m)	1151.20	1149.07	1151.20	1149.07
Kinetic energy (GeV)	3.5	19.08	3.5	19.08
Momentum (GeV)	3.5	20	3.5	20
Total energy (GeV)	3.5	20.02	3.5	20.02
CM energy (GeV)	16.76			
$f_{\text{collision}}$ (MHz)	100			
Polarization	80%	70%	80%	70%
$B\rho$ (T·m)	11.7	67.2	11.7	67.2
Bunch intensity($\times 10^{11}$)	1.7	1.05	0.44	0.27
$\varepsilon_x/\varepsilon_y$ (nm·rad, rms)	50/15	100/50	12.5/3.75	25/12.5
β_x^*/β_y^* (cm)	10/4	5/1.2	10/4	5/1.2
RMS divergence (mrad)		1.4/2.0		0.7/1.0
6×RMS size @ BpF2 (cm)		9.3/4.6		4.6/2.3
8×RMS size @ BpF2 (cm)		12.4/6.2		6.2/3.1
10×RMS size @ BpF2 (cm)		15.5/7.7		7.8/3.9
Bunch length (cm, rms)	0.75	8	0.75	8
BB parameter ξ_x/ξ_y	0.102/0.118	0.0144/0.01	0.105/0.121	0.015/0.010
Laslett tune shift	-	0.066/0.105		0.065/0.10
Energy loss (MeV/turn)	0.32	-		
Total SR power (MW)	0.86	-		
Average Current (A)	2.7	1.68		
Crossing angle (mrad)	50			
Luminosity (cm^{-2}·s^{-1})	4.25×10^{33} (H=0.52)		1.13×10^{33} (H=0.52)	

Status&Agenda of EicC

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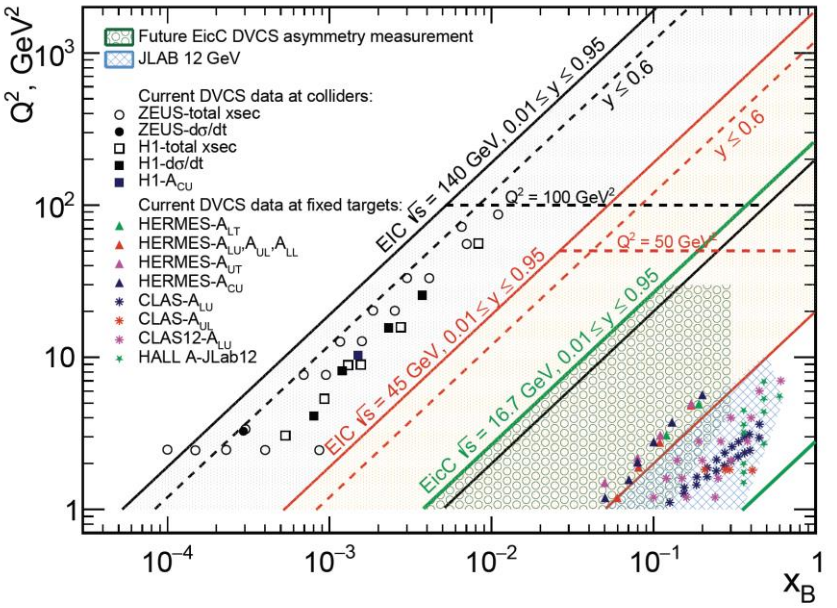
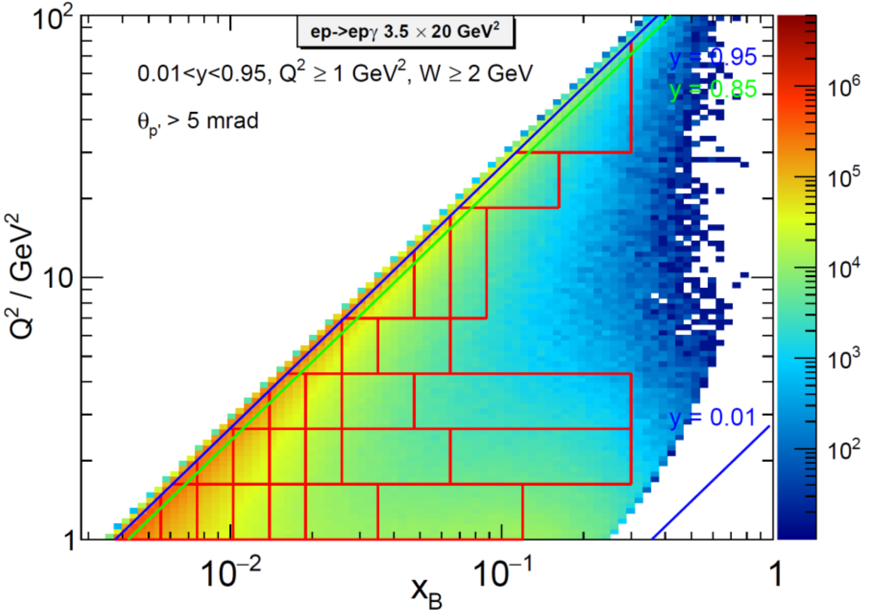
~ 100 km away from HIAF

Southern Center for Nuclear-Science Theory (SCNT), IMPCAS, Huizhou campus

Proton DVCS

- Worldwide data *VS.* pseudodata
- … generated by MILOU and filtered by the state-of-the-art detector design

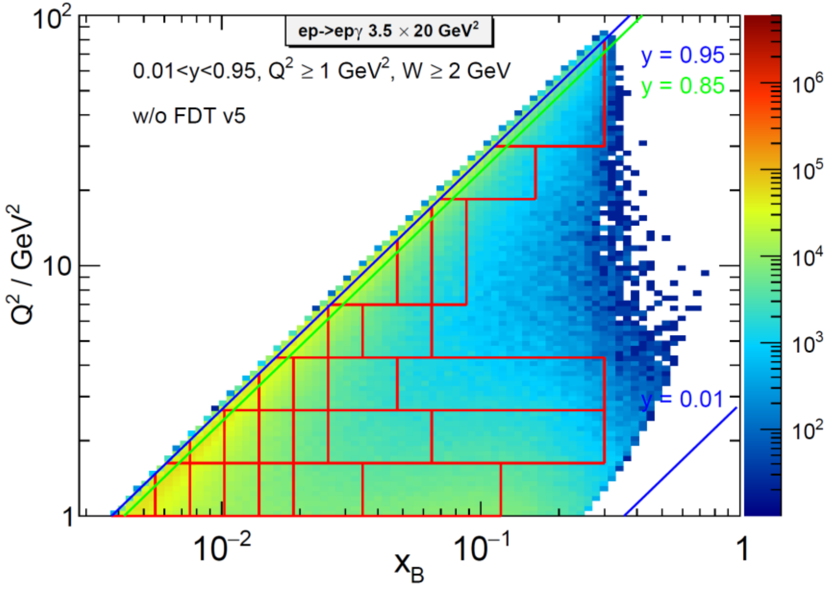


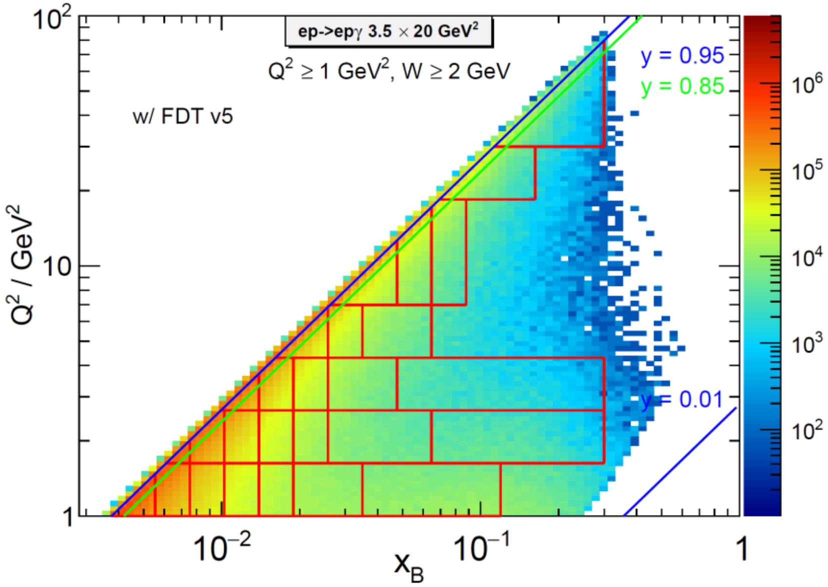


$[1.0, 1.6]$, $[1.6, 2.6]$, $[2.6, 4.3]$, $[4.3, 7.0]$, $[7.0, 18.5]$, $[18.5, 30.0]$, $[30.0, 80.0]\ \mathrm{GeV}^2$

Proton DVCS

- Detector efficiency and resolution: separately
- ¾ **High Lumi** ~7 % average ¼**Low**: ~25% average

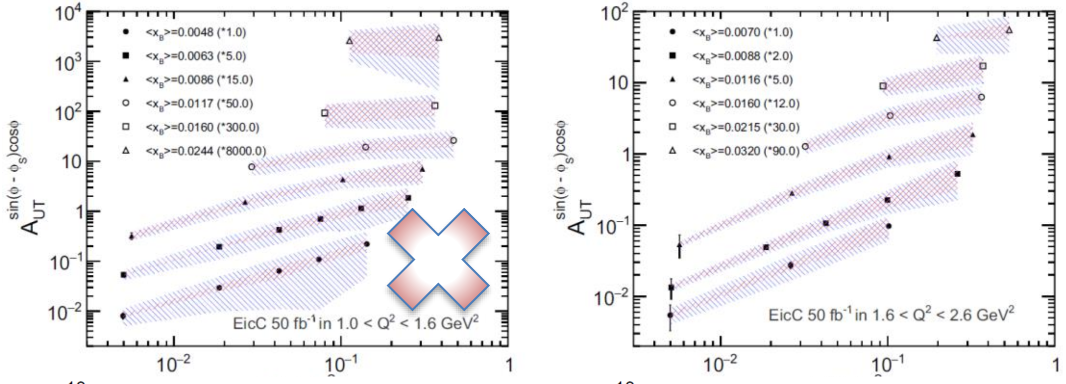




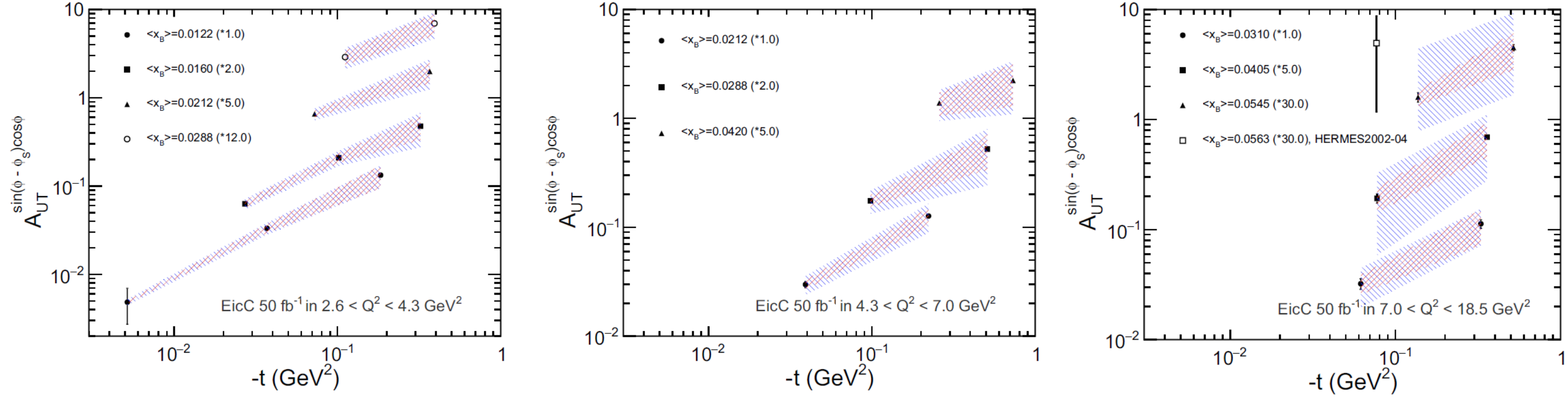
- |t|>0.01, Δt>0.02 GeV² *VS.* |t|>0.03, Δt>0.03@US-EIC

Proton DVCS

- 69 (Q^2 , x_B) bins in total



$$A_{UT,I}^{\sin(\phi-\phi_s)\cos\phi} \propto \mathrm{Im}\Big[-\frac{t}{4M^2}(F_2\mathcal{H} - F_1\mathcal{E}) + \xi^2\big(F_1 + \frac{t}{4M^2}F_2\big)(\mathcal{H}+\mathcal{E}) - \xi^2(F_1+F_2)\big(\widetilde{\mathcal{H}} + \frac{t}{4M^2}\widetilde{\mathcal{E}}\big)\Big],$$

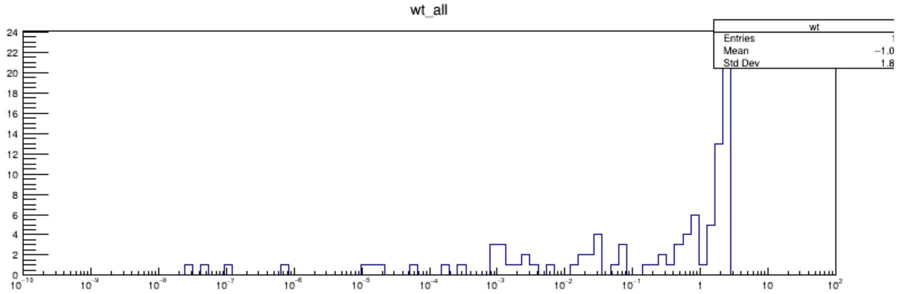


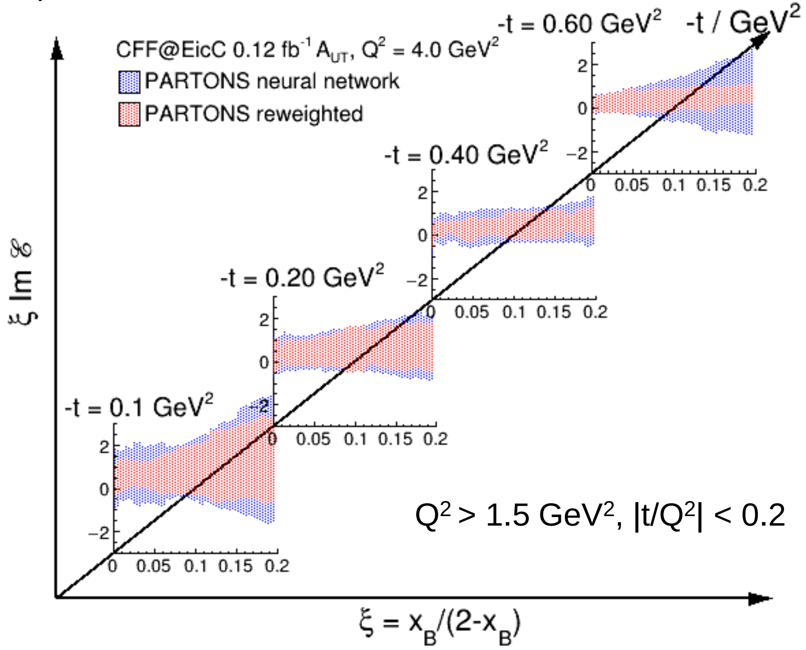
- A_{UT} in all 1.0 < Q^2 < 80.0 GeV^2 and x_B & -t bins. Cut: Q^2 > 1.5 GeV^2, $|t/Q^2|$ < 0.2

Proton DVCS

- **3D structure of nucleon (GPDs) @ EicC:** ~ 1day running surpasses old data of A_{UT}
- Accessing Compton Form Factors: An Impact study on Im$\mathcal{E}$

see X. C, Jinlong Zhang, arXiv:2301.06940, EPJC 83 (2023) 505





- NNPDF:

$$w_k = \frac{(\chi^2_k)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi^2_k}}{\frac{1}{N}\sum_{k=1}^{N}(\chi^2_k)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi^2_k}}\,.$$

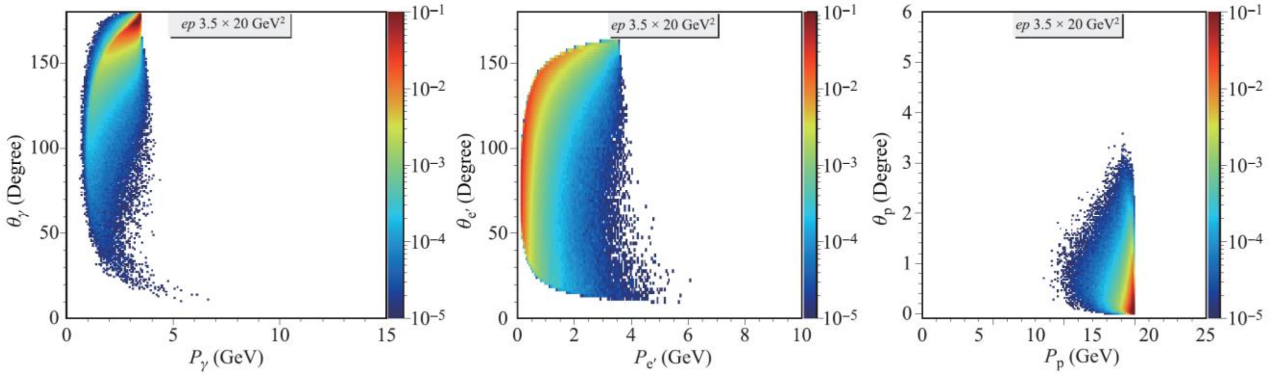
$$\langle\mathcal{O}\rangle_{\rm new} = \int \mathcal{O}[f]\,\mathcal{P}_{\rm new}(f)\,Df = \frac{1}{N}\sum_{k=1}^{N} w_k\mathcal{O}[f_k]\,.$$

- quark OAM: neutron target or a transversely polarized proton beam
- reweighting the replicas from PARTONS(EPJC79:614) by $\sin(\phi-\phi_S)\cos(\phi)$ module of A_{UT}

Proton DVCS

- Pseudo-rapidity, azimuthal angle coverage and pt coverage?
- Any requirement on far-forward detector?

- large rapidity coverage, good high momentum resolution
- DVCS&DVMP Electron ($Q^2 > 1.0$ GeV^2, $\eta > 2.0$); TCS & hadron ($Q^2 < 1.0$ GeV^2) need e-far-forward
- Proton: good far-forward detector; Photon: several to 15 GeV, 4π coverage

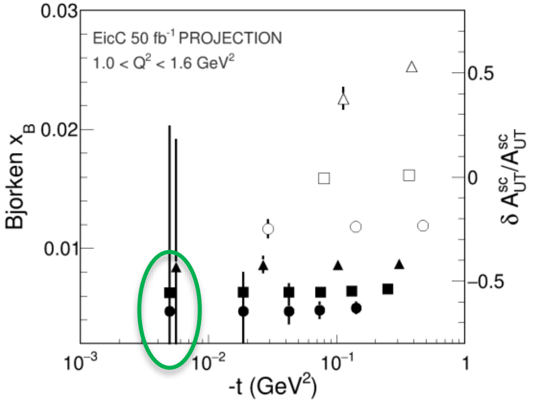
- 

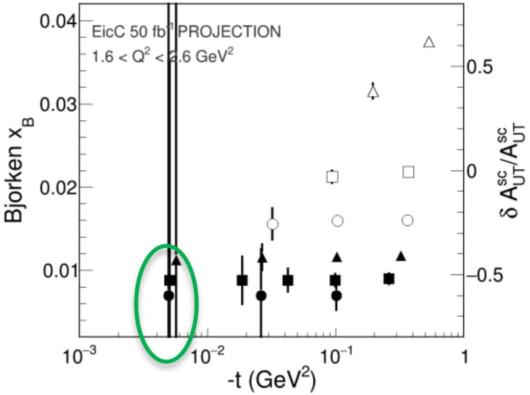
  >5mrad (previously 2mrad)

- π / K / η / η' / ω / φ separation: $\eta/\pi^0 \to \gamma\ \gamma$ required by DVMP and TDA physics

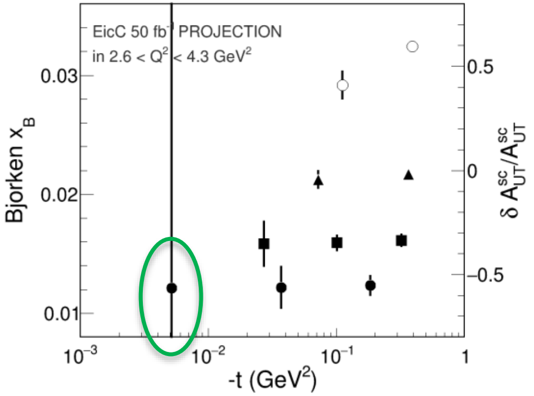
Proton DVCS

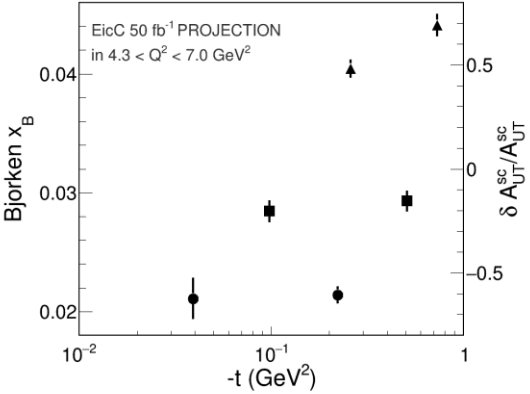
- Moderate Asymmetry precision < 1.0 ~ 1.5 % in all kinematic region

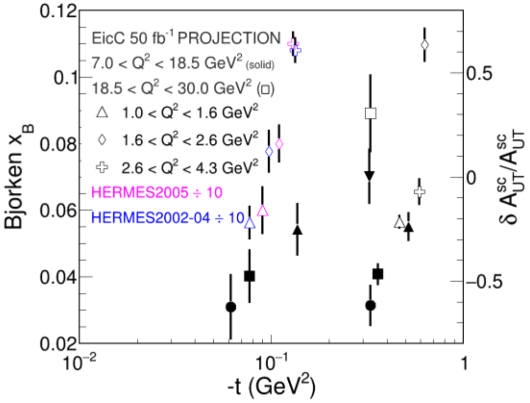




Tiny asymmetry in –t < 0.01 GeV^2 predicted by GK model with large uncertainties

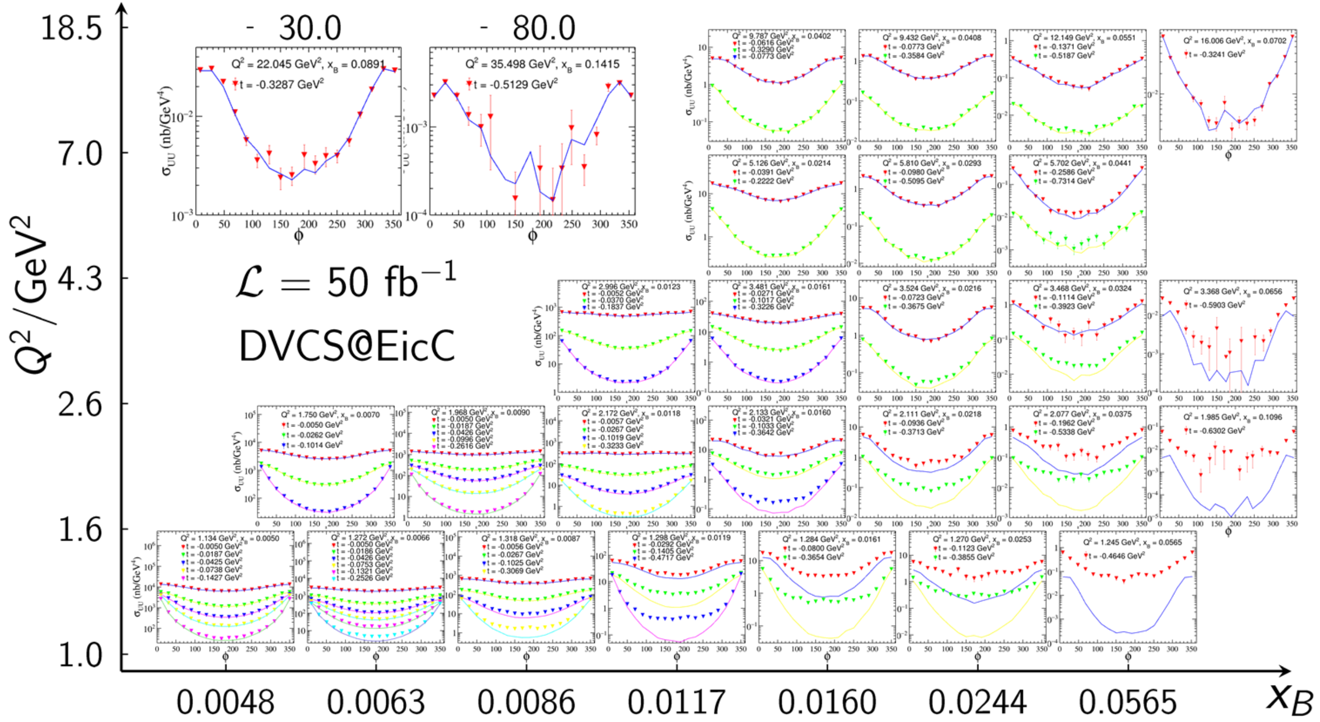






Proton DVCS

- Accessing Compton Form Factors / GPD? by all pseudo-data at the EicC

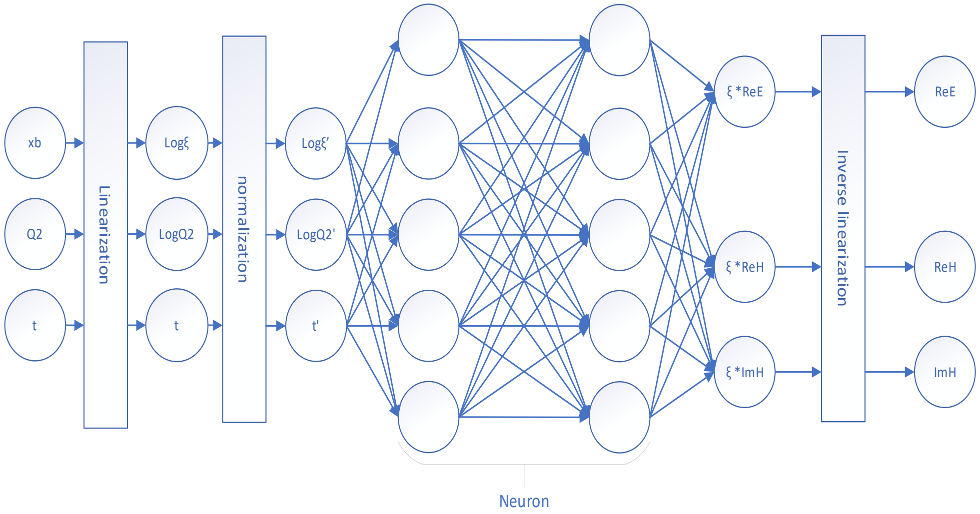


- Re-training (less-biased) within Gepard framework in collaboration with K. Kumericki

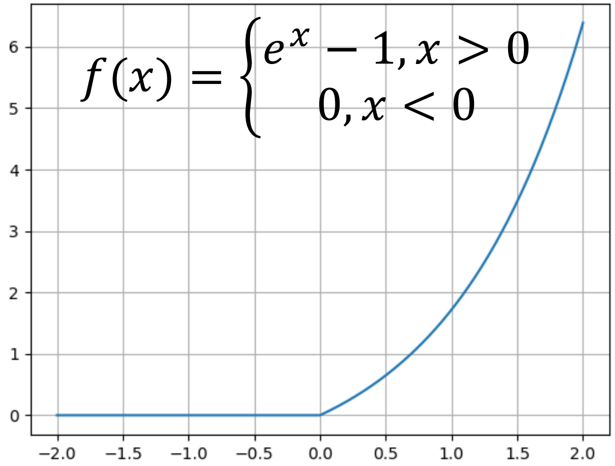
Proton DVCS

- Tool for studying the 3D quark and gluon distributions in the nucleon, encoded in terms of the so-called GEneralized PArton Distributions.
- https://gepard.phy.hr/

…… with an update of neural network architecture



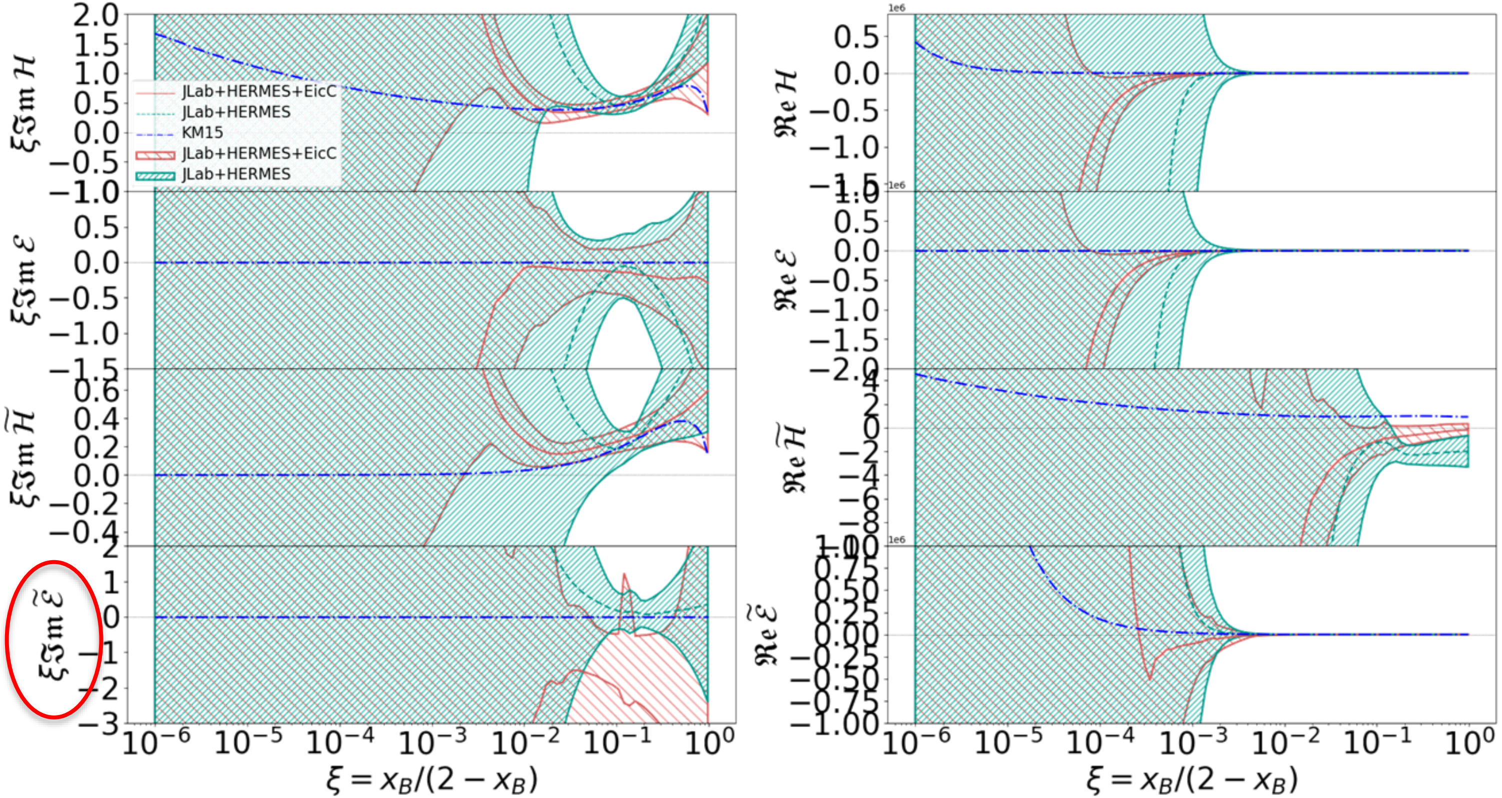
3-100-100-100-100-8



Activtion function

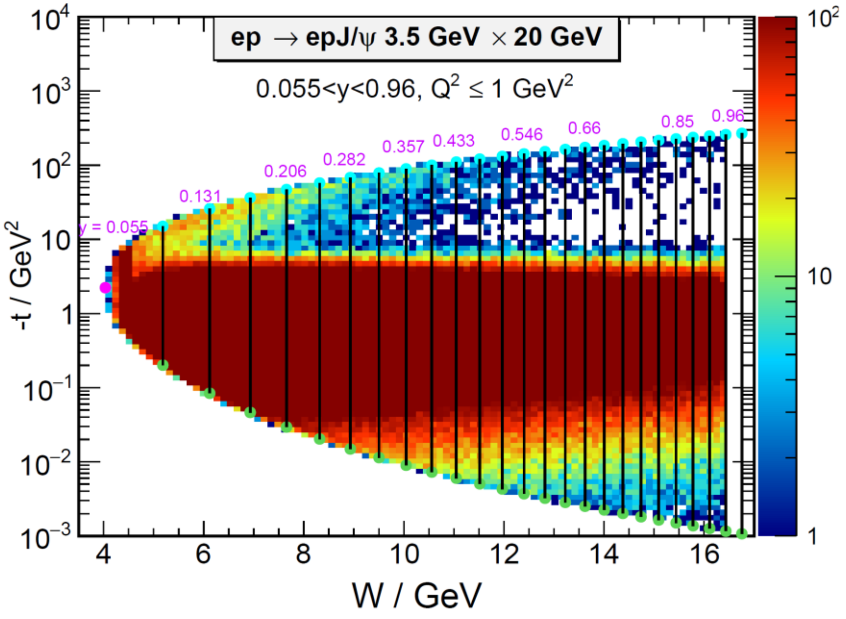
Proton DVCS

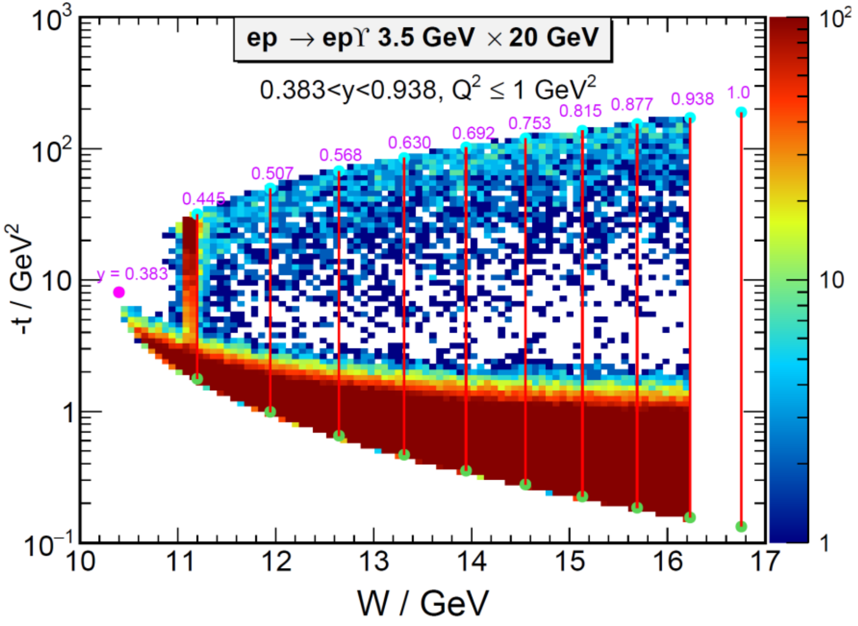
Very preliminary: trained within Gepard: dispersion relation is not enabled



Exclusive Heavy Flavor

- **From light quarks to charm and up to bottom:**
  Photo- and electro-production of narrow exotic states
- Generated by lAger and eSTARlight: X.C, Front. Phys. 18 (2023) 44600, see also PhysRevD.101.074010



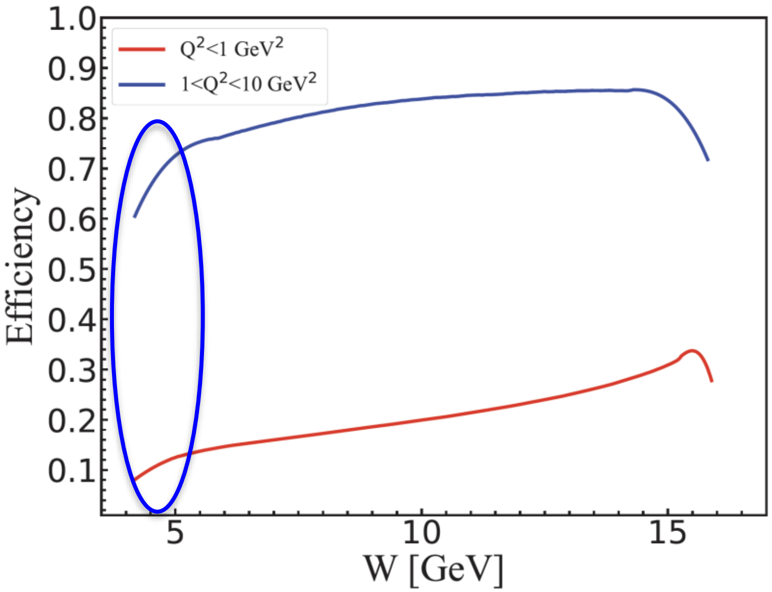


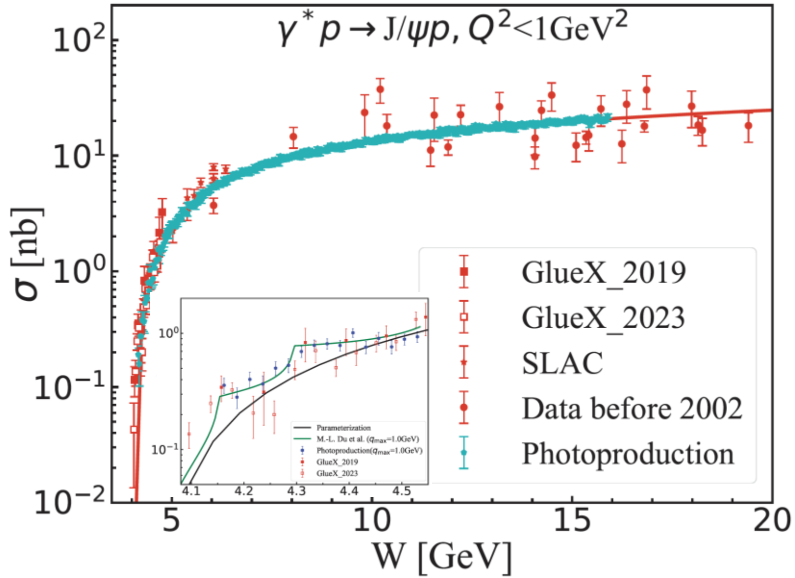
Exclusive Heavy Flavor

- **Exclusive Heavy Quarkonium Production** probes several interesting topics
- e.g. pentaquarks, cusps, Charmonium-nucleon interaction, Gravitational Form Factors …

X. Wang, X. C *et al.*, 2311.07008, EPJC (2024)

ΔW = 25 MeV, 480 bins





- Optimization the efficiency and resolution of detector
  will helpful for approaching close to the threshold region W<5.0 GeV

Exclusive Heavy Flavor

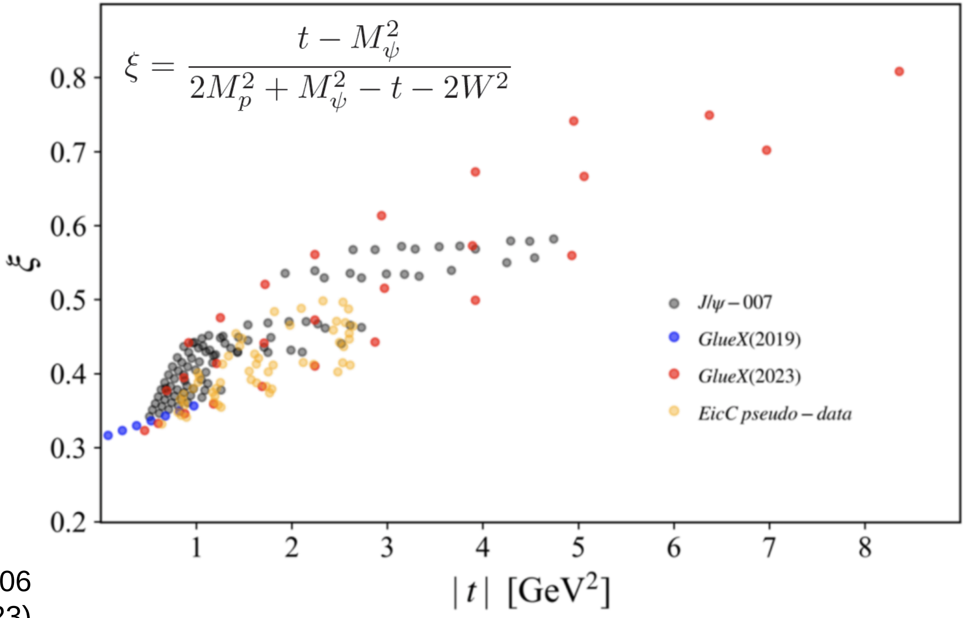
- **3D structure of nucleon (gravitation form factors & model dependence)**
- Require heavy flavor reconstruction: detect Positron & Electron from heavy quarkonium decay; approaching near-threshold: slow quarkonium need more luminosity.

$$\frac{d\sigma}{dt} = \frac{\alpha_{\rm EM} e_Q^2}{4(W^2 - M_N^2)^2} \frac{(16\pi\alpha_S)^2}{3M_V^3} |\psi_{\rm NR}(0)|^2 |G(t,\xi)|^2$$

$$|G(t,\xi)|^2 = \frac{4}{\xi^4}\left\{\left(1-\frac{t}{4M_N^2}\right)E_2^2 - 2E_2(H_2+E_2) + (1-\xi^2)(H_2+E_2)^2\right\}$$

$$\int_0^1 dx H_g(x,\xi,t) = A_{2,0}^g(t) + (2\xi)^2 C_2^g \equiv H_2(t,\xi),$$

$$\int_0^1 dx E_g(x,\xi,t) = B_{2,0}^g(t) - (2\xi)^2 C_2^g \equiv E_2(t,\xi).$$



P. Sun, X-B Tong, F. Yuan, 2111.07034, 2103.12047;
see also 2101.02395, 1808.02163, 2305.06992, 2308.13006
B. Duran, Z. -E. Meziani, S. Joosten, Nature 615, 813 (2023)

Exclusive Heavy Flavor

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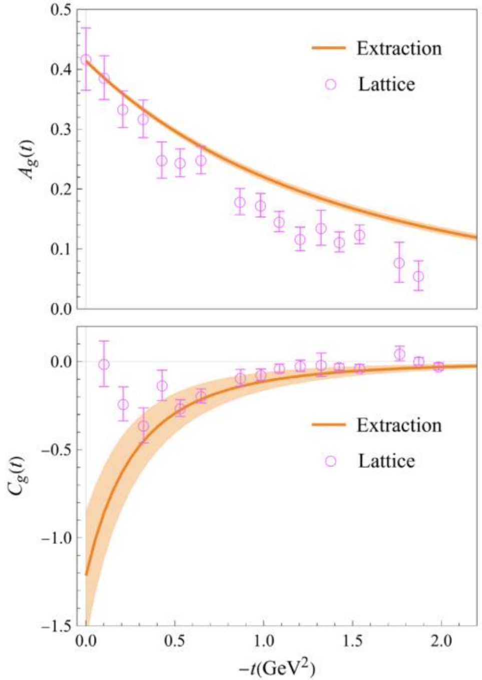
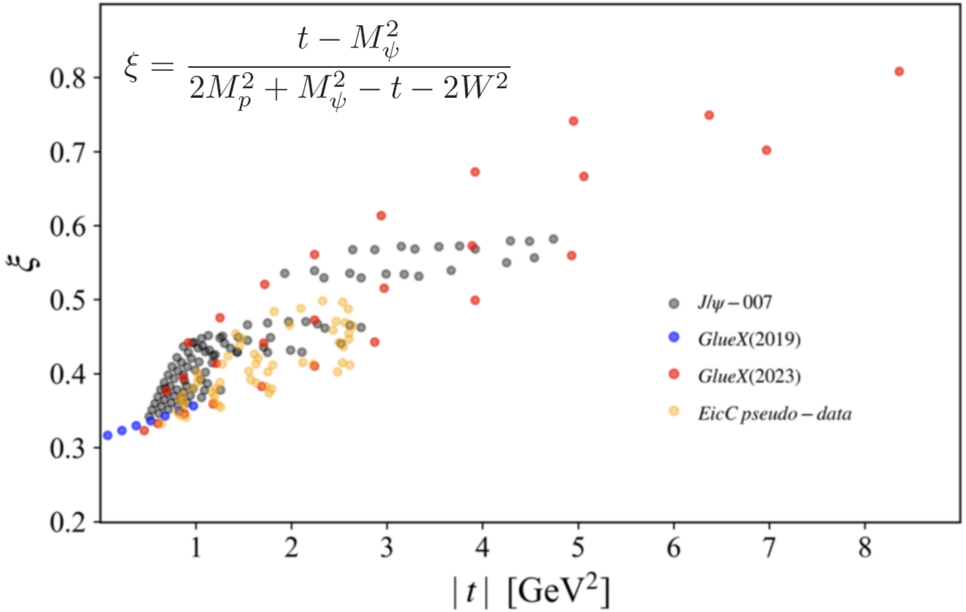
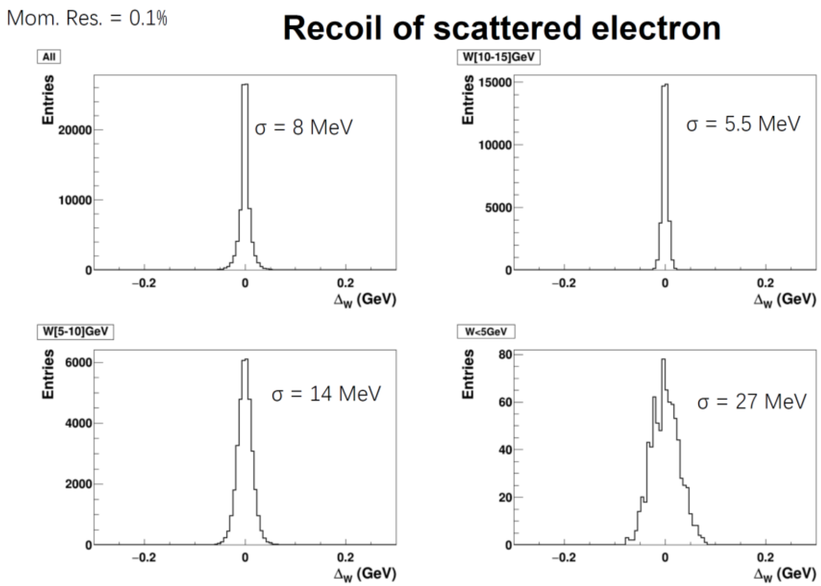




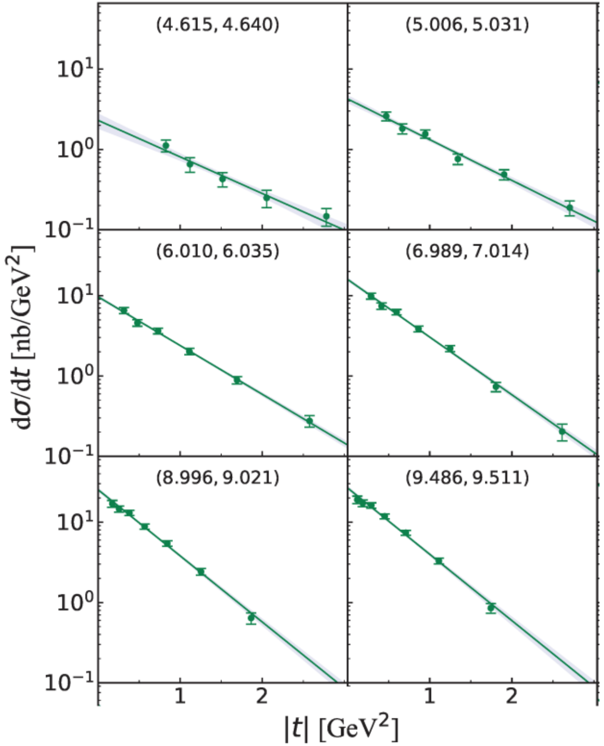
- Theorists usually ask for very low W or large-|t| or high-Q^2

Exclusive Heavy Flavor

- *W* Resolution generated by detector group:



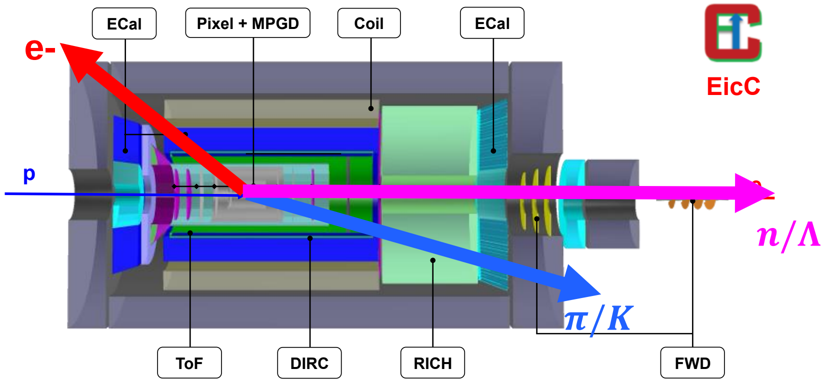
- Coverage of bigger-|*t*|

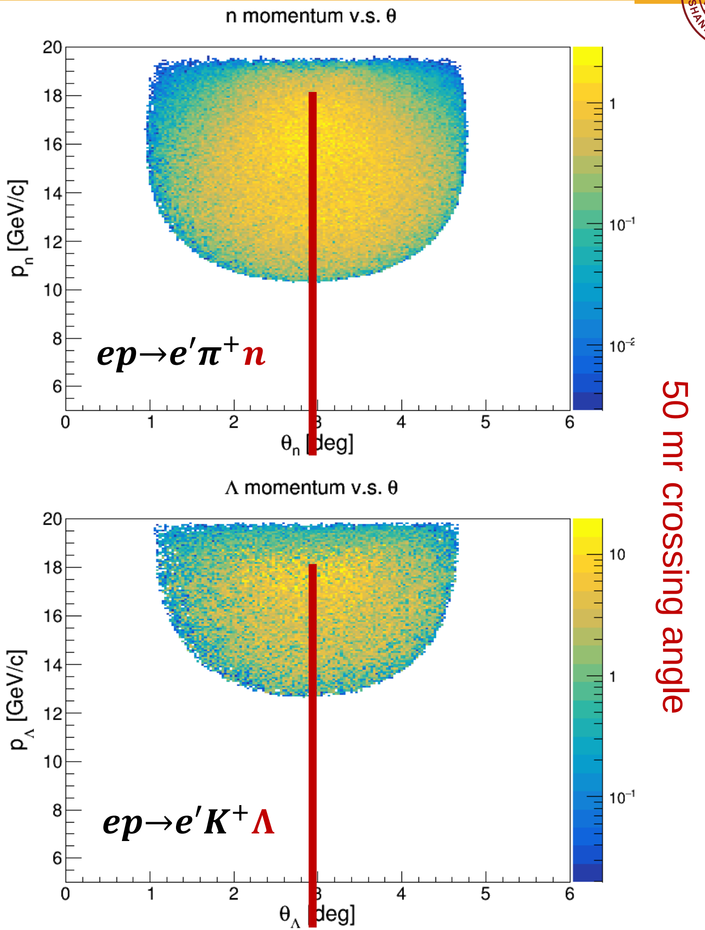


Meson Structure

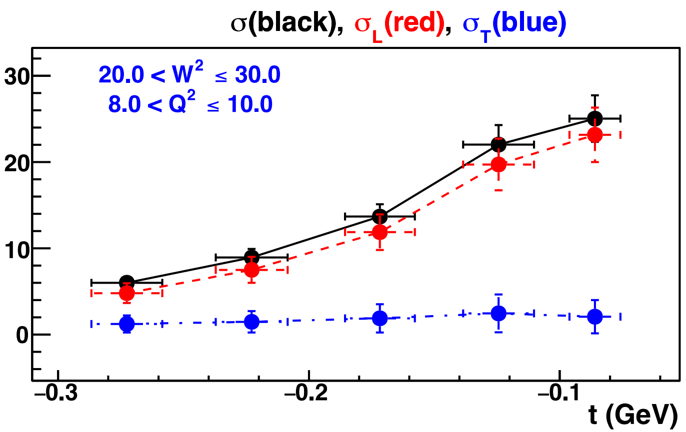
- Scattered electron and meson very well covered by central detector: Eff. > 95%
- "Spectator" neutron and **Λ** move very close to the initial p-beam: far-forward detectors

- Pion FF and SF require ZDC for neutron detection
- Kaon FF and SF need all detectors in far-forward region for **Λ** neutral & charged decay

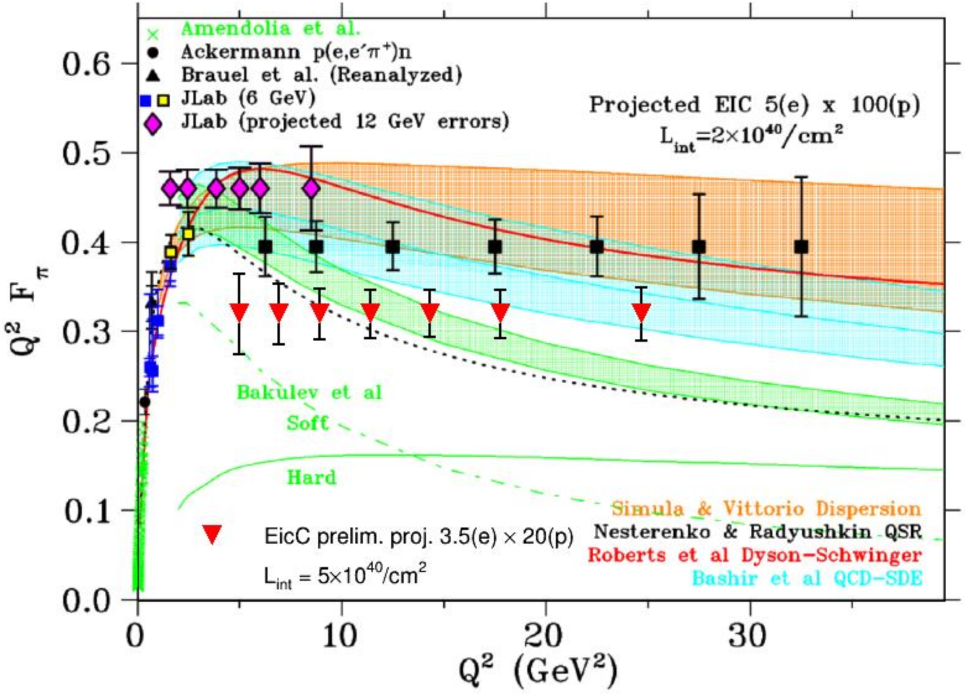




Meson Structure



- In hard scattering regime, QCD scaling predicts $\sigma_L \propto Q^{-6}, \;\; \sigma_T \propto Q^{-8}$
- 100% uncertainty in R = σ_T / σ_L from model subtraction
- 2.5% point-to-point syst. uncertainty
  12% scaling syst. uncertainty



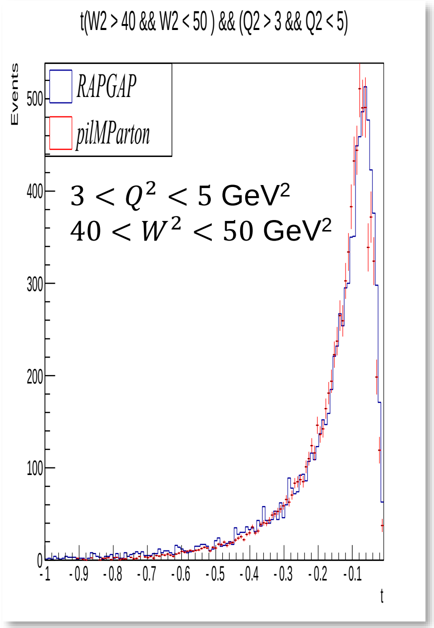
Eicc prelim. Compared to EIC(arXiv:2403.06000)

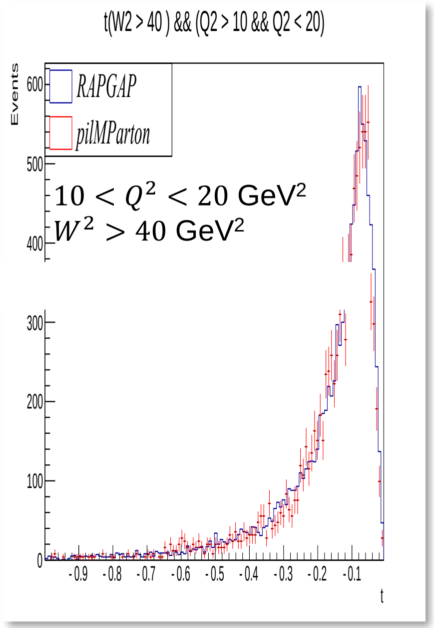
Meson Structure

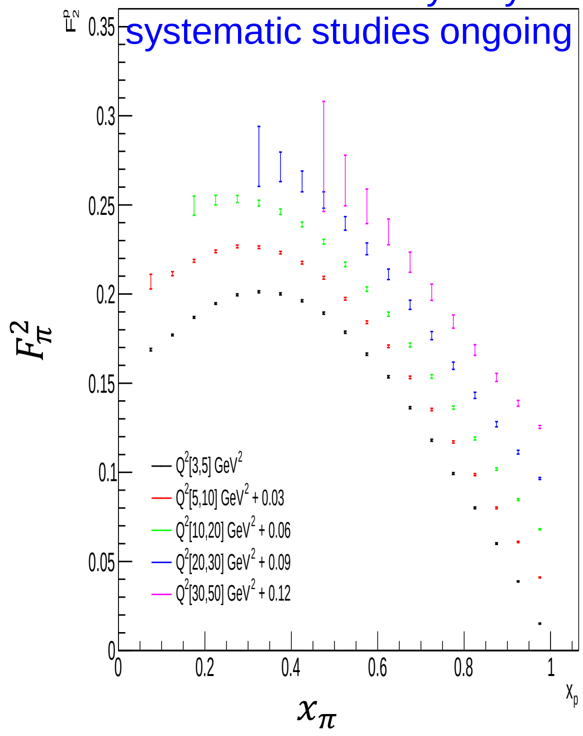
- RAPGAP generator, reasonable agreement with IMParton over a board range

$x_L > 0.75$, $P_T^n < 0.5$ GeV, θ_n<15 mrad
EicC 50 fb^{-1} $M_X > 0.5$ GeV

Stat. uncertainty only
systematic studies ongoing

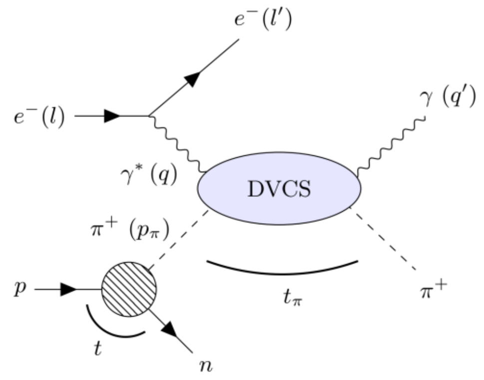


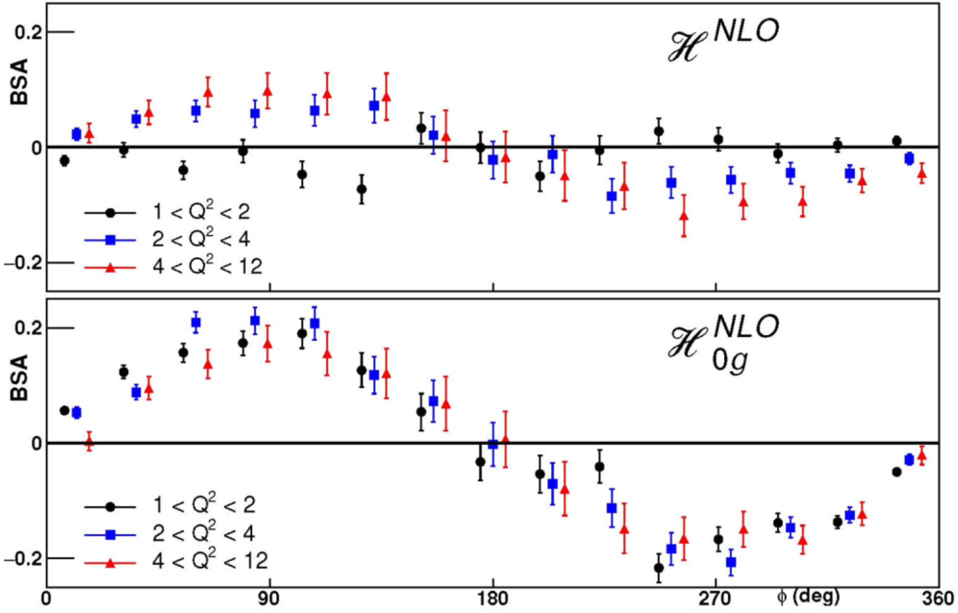


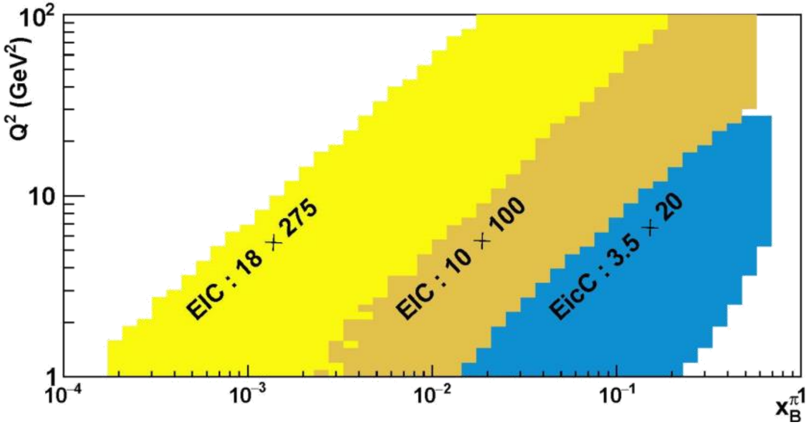


Meson Structure

- π^+-DVCS through Sullivan process
- (J. M. Morgado Chávez et al., Phys.Rev.Lett. 128 (2022) 202501)

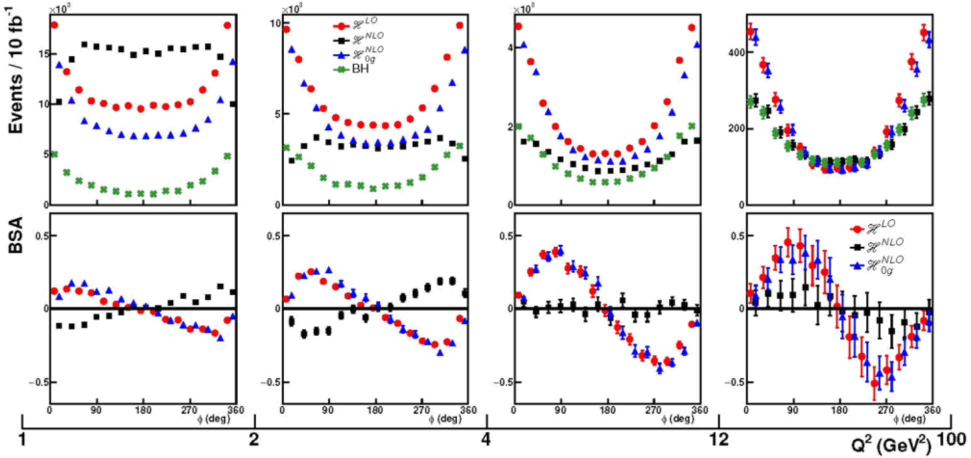


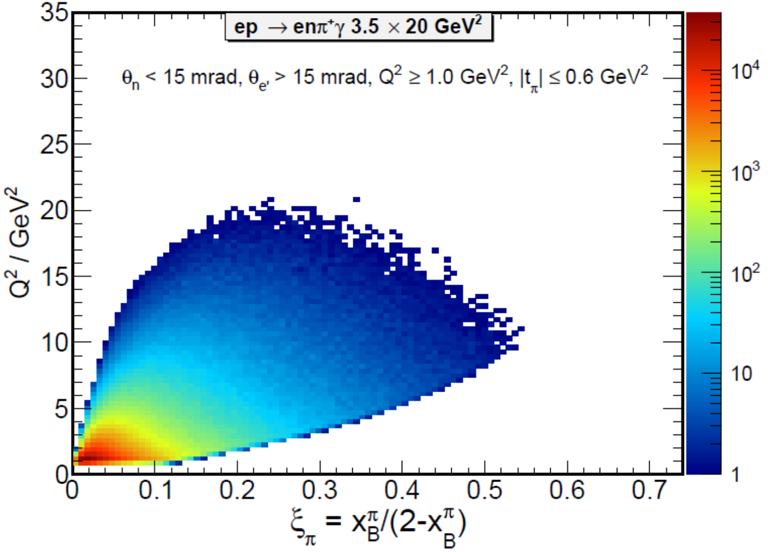




Meson Structure

- π^+-DVCS through Sullivan process (filtered by detector at EicC)
- Over eff. ~ 20.0%





Summary

- **Fruitful exclusive measurements are expected at the EicC. Selected topics are present:**
- Proton/Pion DVCS: GPD
- Heavy flavor: GFF
- Pion Form Factor & SF

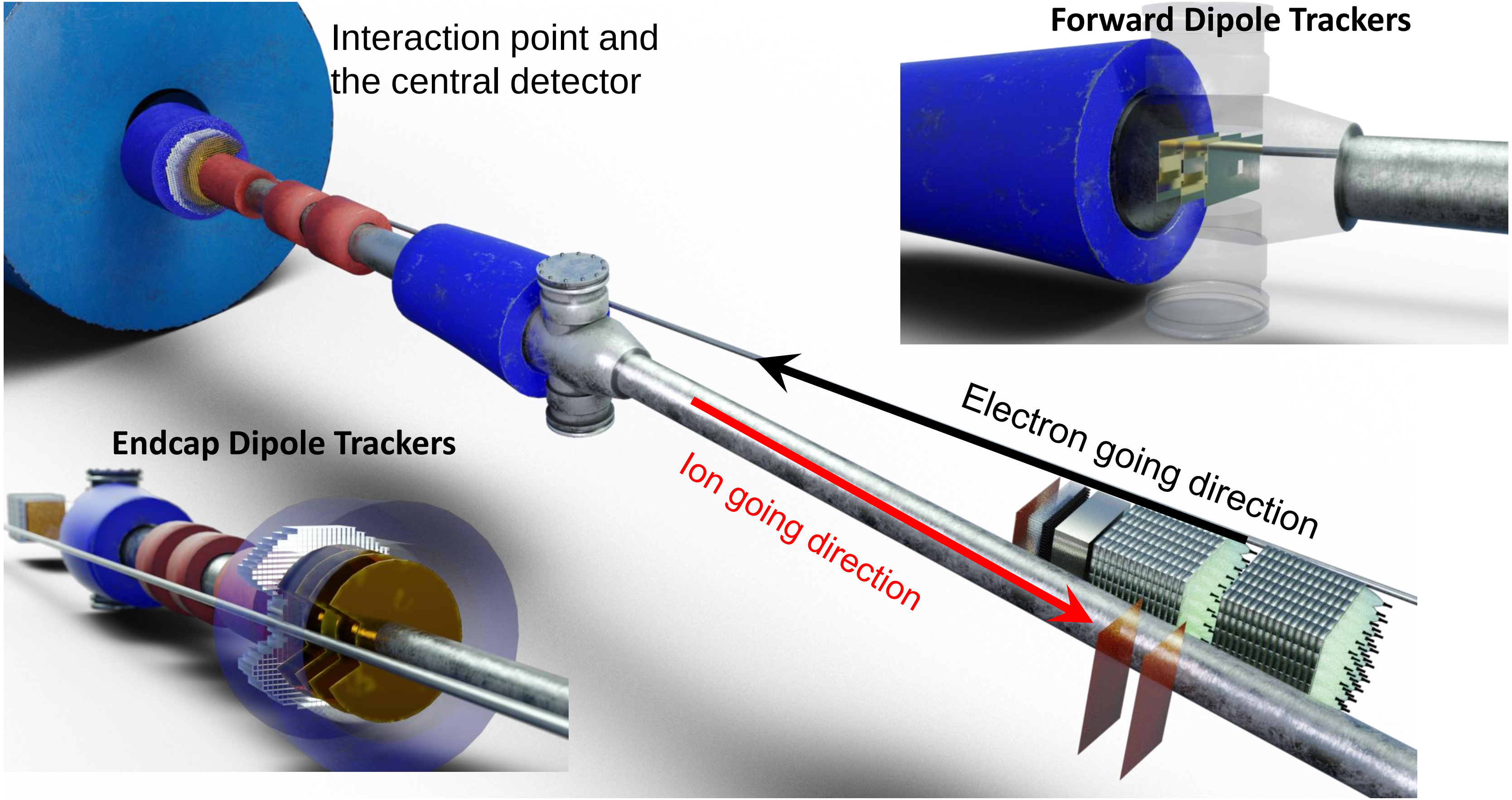
- **A lot of efforts from detector group**
- reconstruction efficiency and resolution of detector
- Far forward

Not cover here:

- TCS, DVMP, TDA
- Inclusive: TMD
- **Theoretical issue: Inverse CFF to GPD**

Special Thanks to PARTONS, Gepard, Simonetta, Pawel ……

Current Design for EicC Far-Forward (FF) Region



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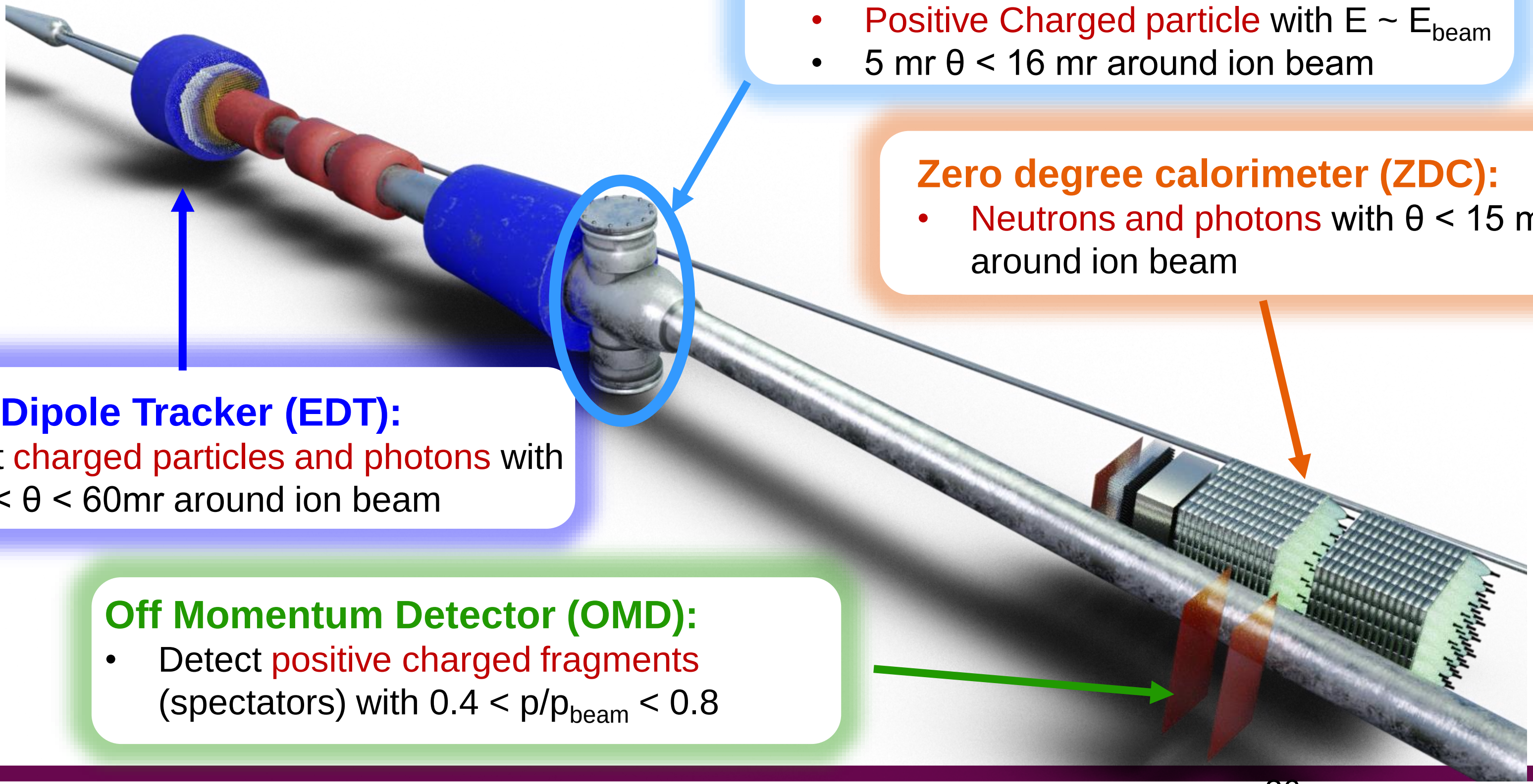


Roman Pot Station:
- Located inside the ion beam pipe
- Positive Charged particle with $E \sim E_{beam}$
- 5 mr θ < 16 mr around ion beam

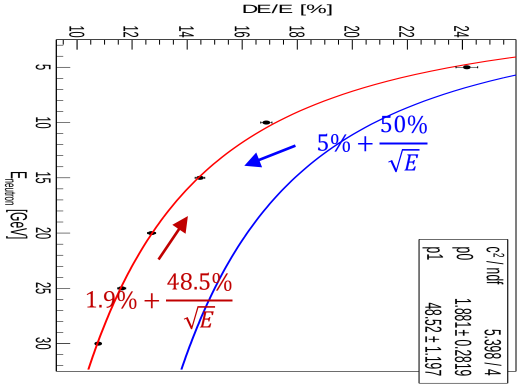
Zero degree calorimeter (ZDC):
- Neutrons and photons with θ < 15 mr around ion beam

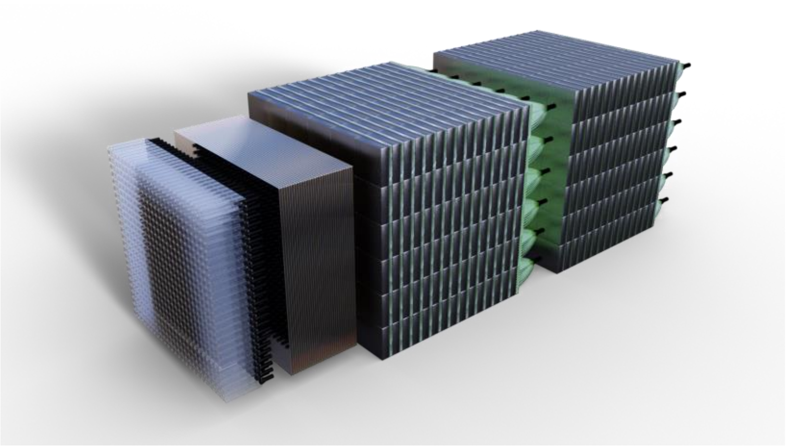
Endcap Dipole Tracker (EDT):
- Detect charged particles and photons with 15mr < θ < 60mr around ion beam

Off Momentum Detector (OMD):
- Detect positive charged fragments (spectators) with $0.4 < p/p_{beam} < 0.8$

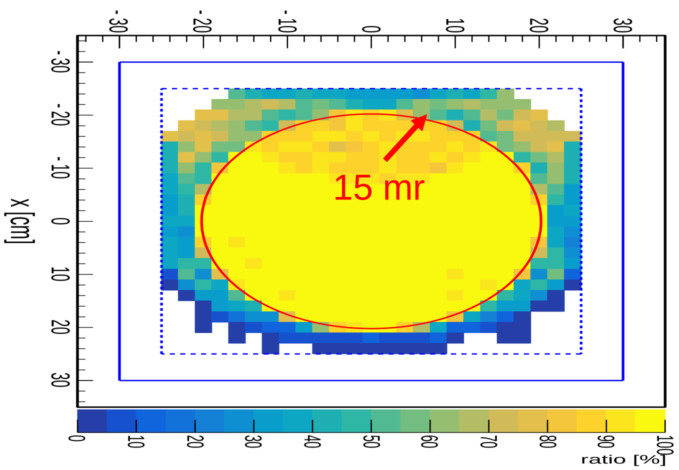
Neutron Detection for Pion FF and SF

- Main detector for neutron is ZDC:
  - 15 mrad acceptance around the ion beam
  - Nearly 100% accept rate for neutrons of interest
  - Energy resolution : 1.9% + 48.5%/sqrt(E [GeV])
  - Position resolution : 2.4 mr /sqrt(E [GeV])



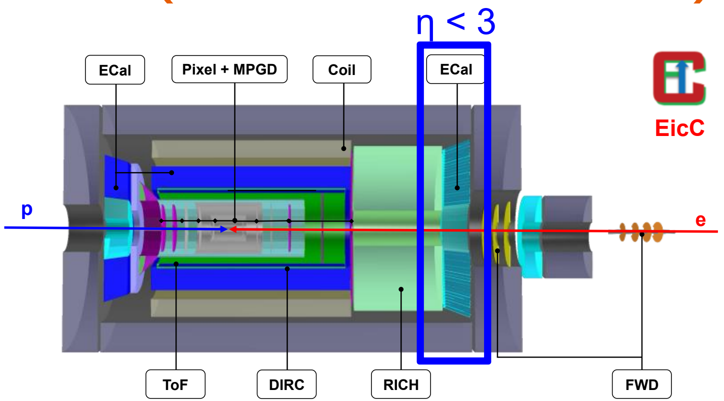


Accept/Throw Ratio for 15 GeV neutron

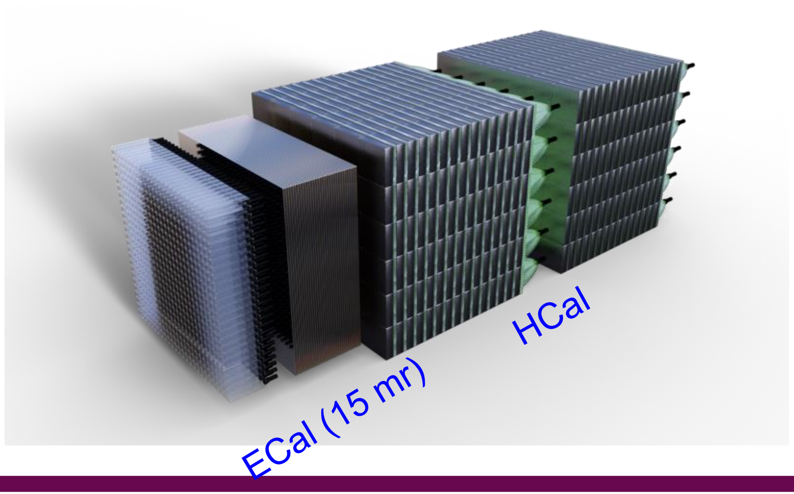


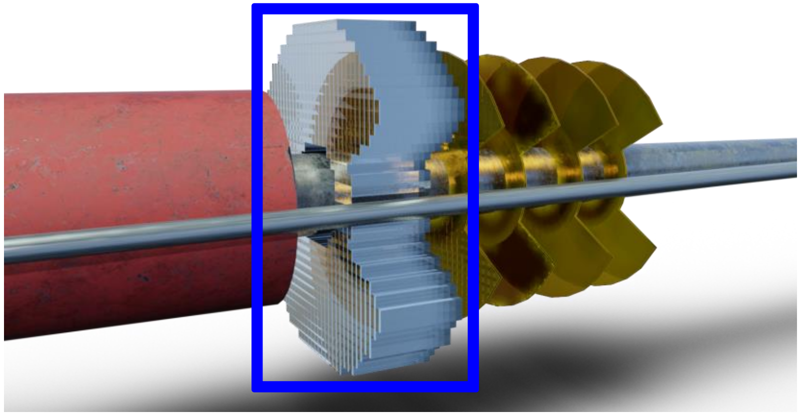
Λ Detection for Kion FF and SF (Neutral Channel)

- $\Lambda \rightarrow \pi^0 n$ with 36% branching ratio
- Neutrons only detected by ZDC (15 mr acceptance)
- Photons can be detected by ZDC, EDT-ECal and EMCal on central detector ion endcap



EicC



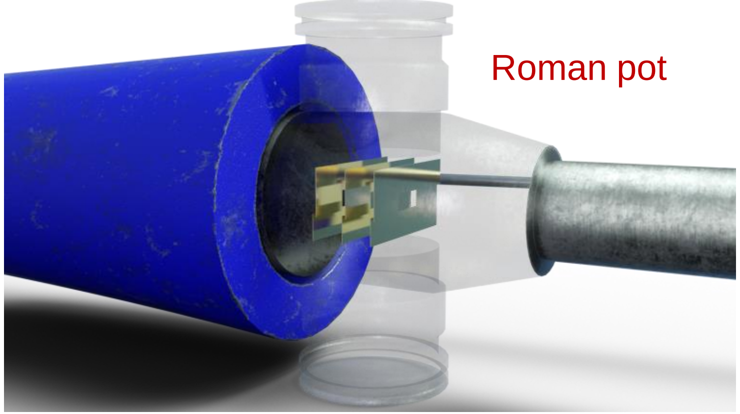


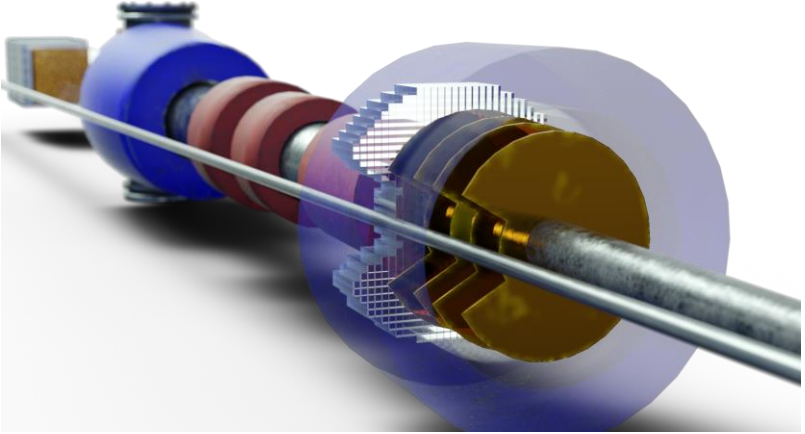
EDT-ECal (20-60 mr)

Λ Detection for Kion FF and SF (Charged Channel)

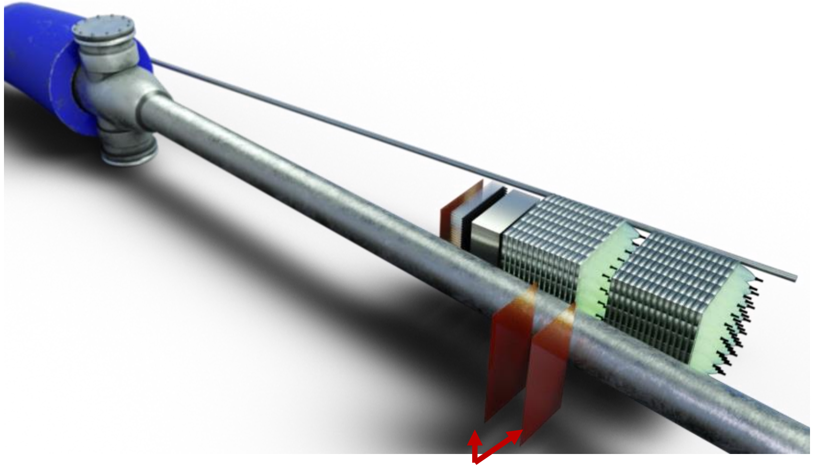
- $\Lambda \rightarrow \pi^- p$ with 64% branching ratio
- π^- can only be detected by EDT (16 – 60 mr)
- Proton will be detected by EDT, Roman pots (~5-16mrad) as well as OMD

- EDT resolution: ~0.6% for p, 0.2mr for θ
- RP resolution: ~6.0% for p, 1.2mr for θ





EDT trackers



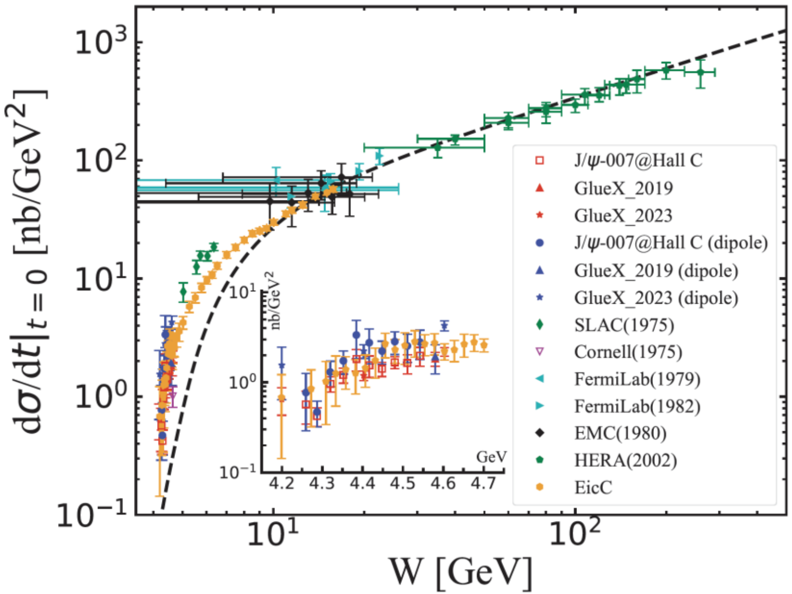
Off-momentum

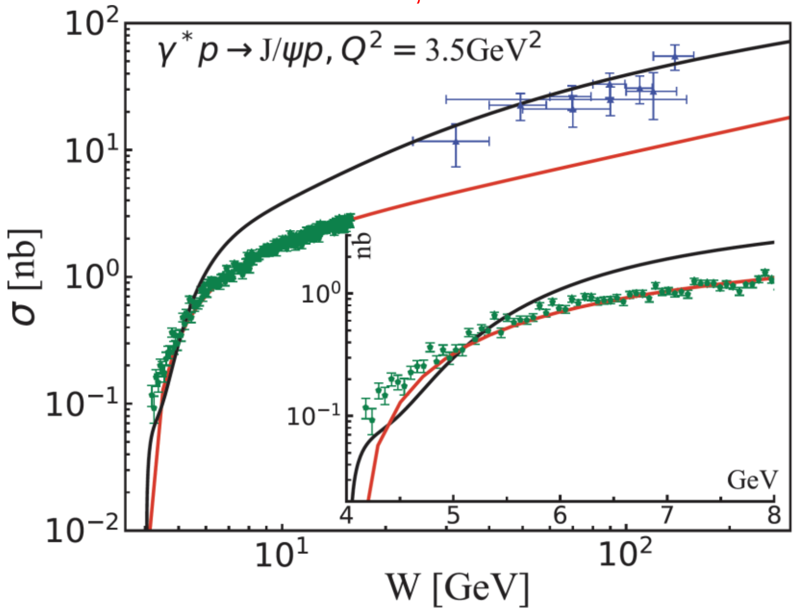
Exclusive Heavy Flavor

- **Exclusive Heavy Quarkonium Production** probes several interesting topics
- e.g. pentaquarks, cusps, Charmonium-nucleon interaction, Gravitational Form Factors …

X. Wang, X. C *et al.*, 2311.07008, EPJC (2024)

ΔW = 60 MeV, 195 bins



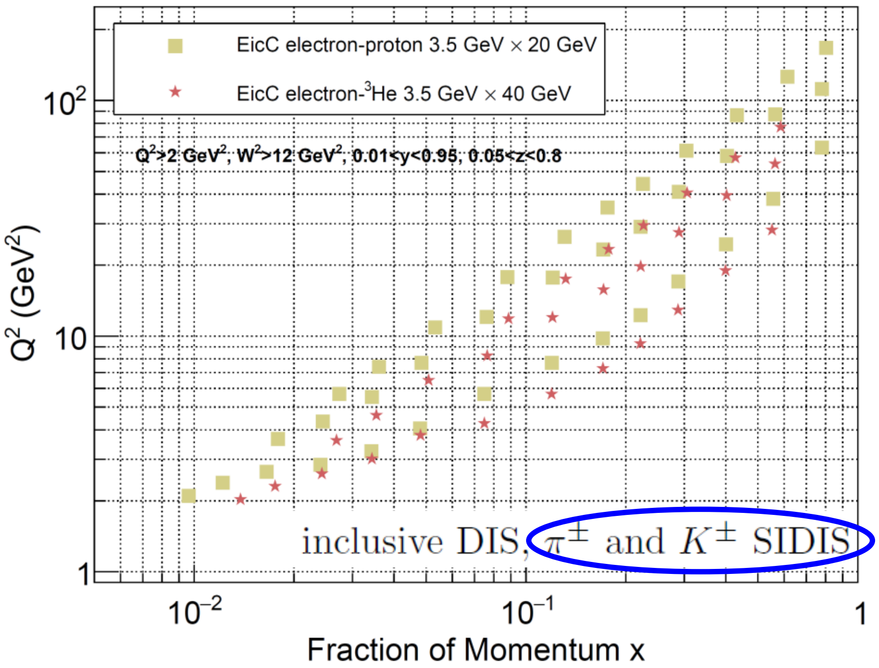


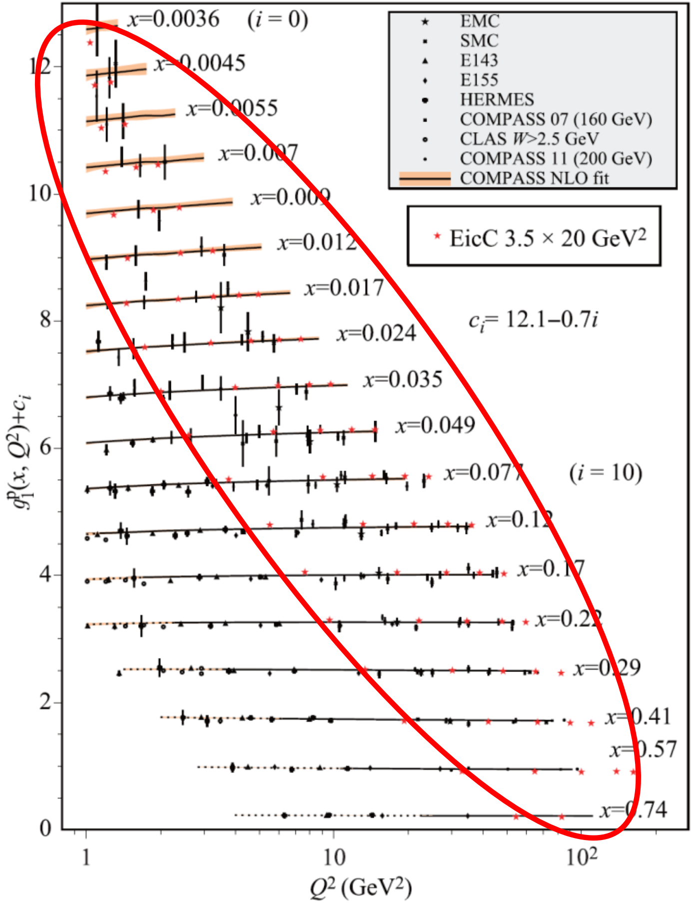
- Optimization the efficiency and resolution of detector will helpful for approaching close to the threshold region W<5.0 GeV

Inclusive Process

arXiv:2102.09222

Double-Spin-Asymmetry (DSA) $A_{LL} \propto \frac{g_1}{F_1}$

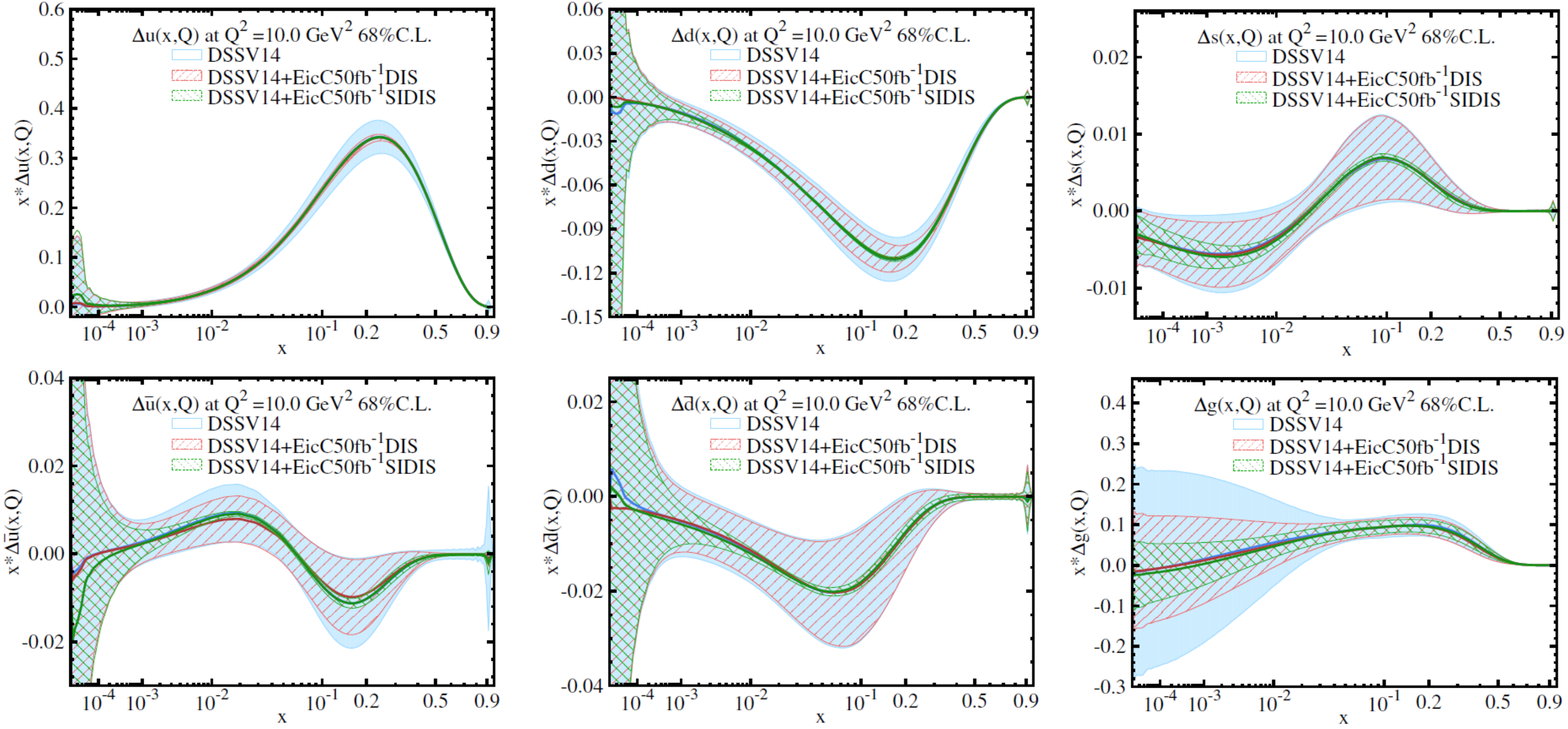




Inclusive Process

arXiv:2103.10276

Flavored Helicity PDF@EicC:
reweighting Hessian PDF sets by ePump

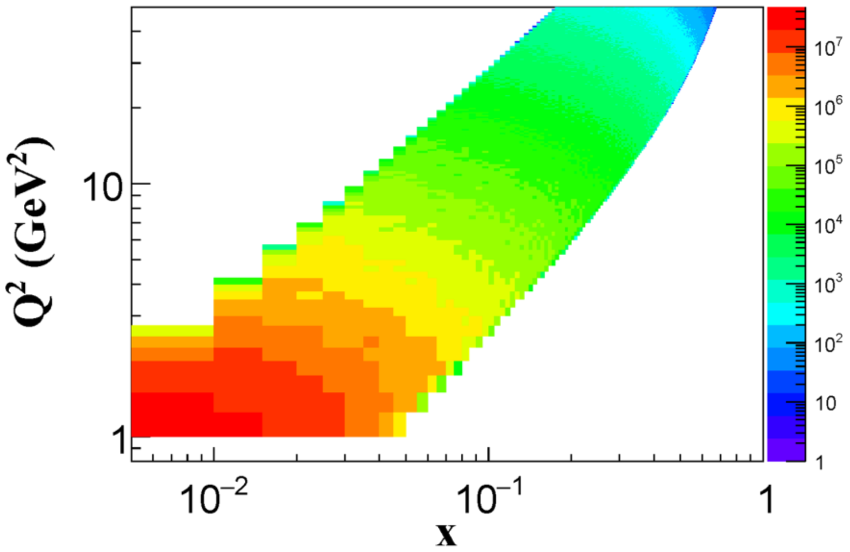


Inclusive Process

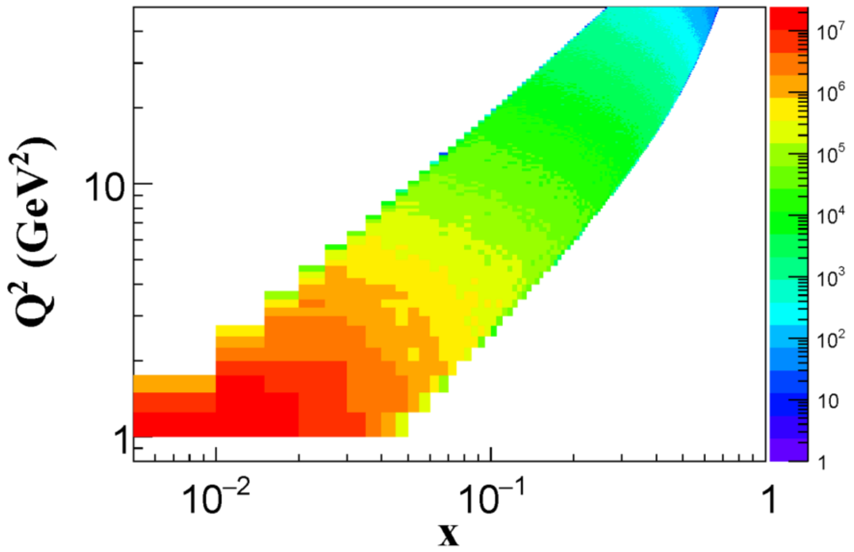
arXiv:2102.09222 SIDIS and TMD@EicC

$$Q^2 > 1\,\mathrm{GeV}^2,\ W > 5\,\mathrm{GeV},\ W' > 2\,\mathrm{GeV},\ 0.3 < z < 0.7$$

π^+ production from the proton



K^+ production from the ^{3}He beam.

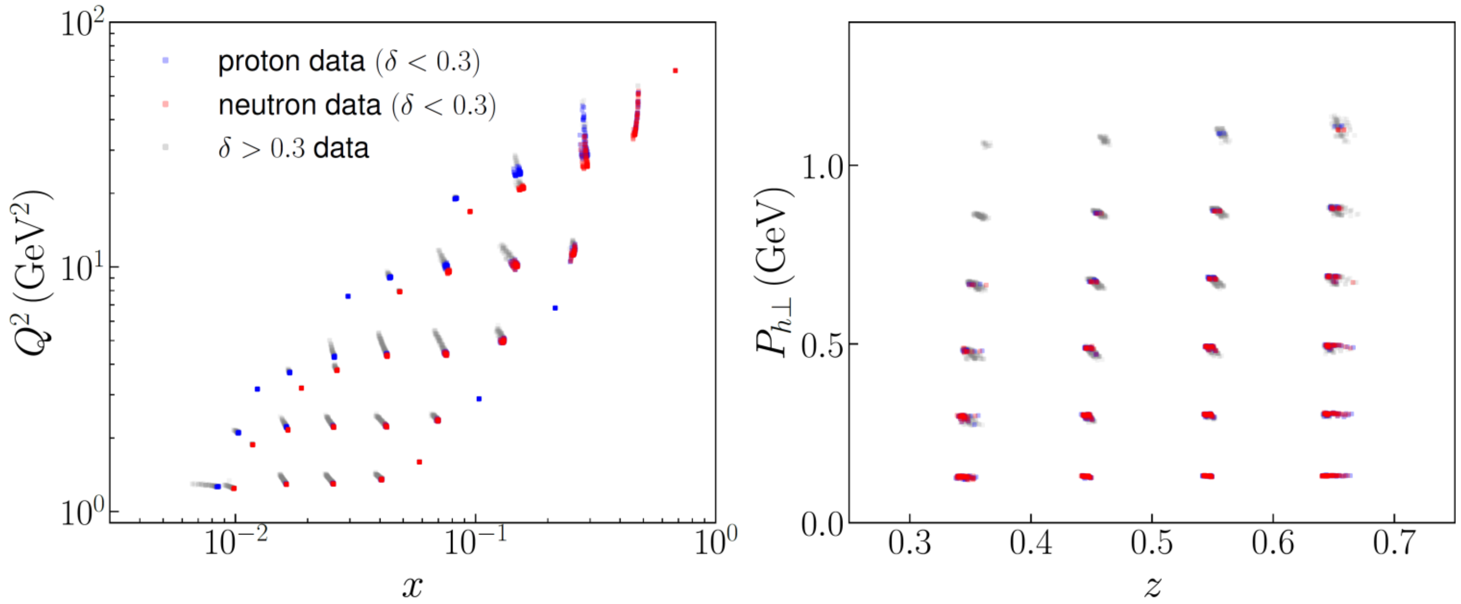


Inclusive Process

arXiv:2208.14620 SIDIS and TMD@EicC

$$Q^2 > 1\,\mathrm{GeV}^2,\ W > 5\,\mathrm{GeV},\ W' > 2\,\mathrm{GeV},\ 0.3 < z < 0.7$$

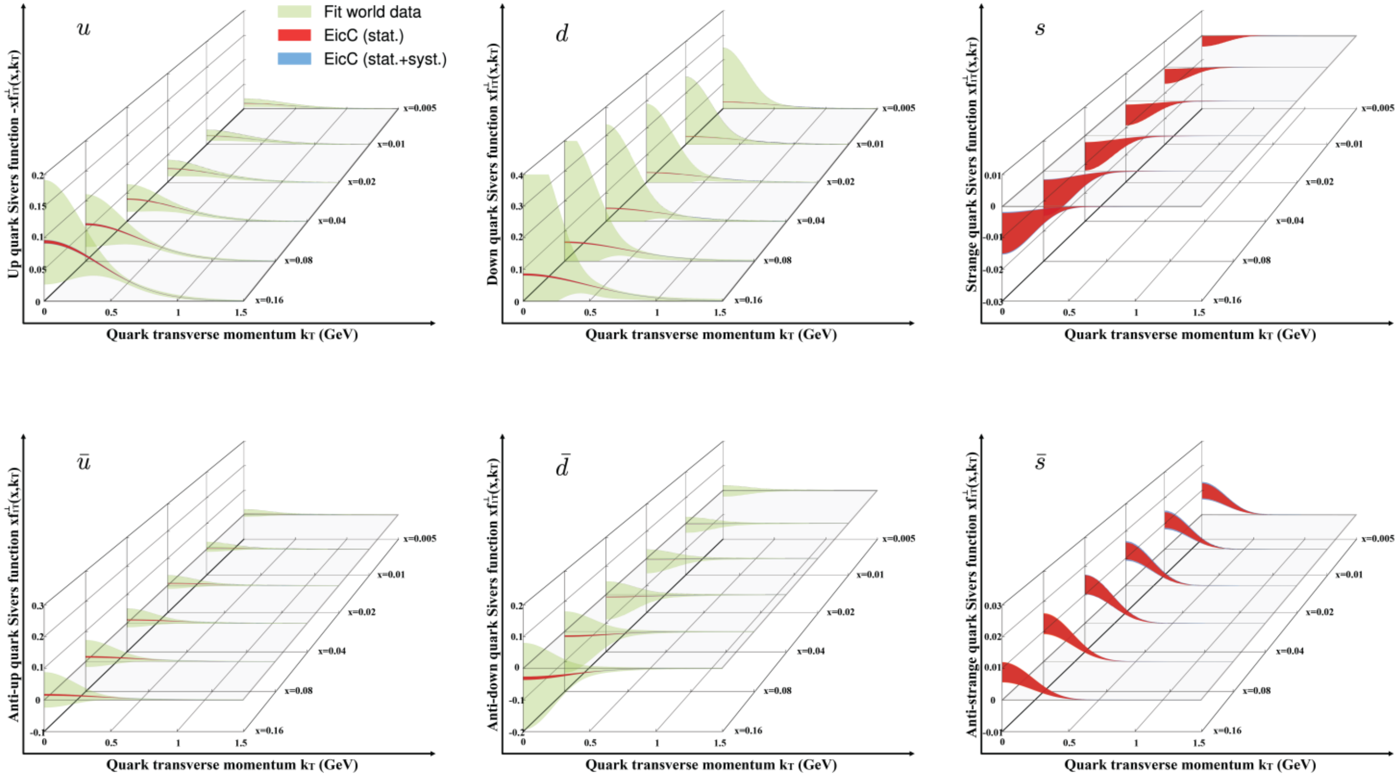
$$A_{UT}^{\sin(\phi_h-\phi_S)} \qquad \delta \equiv |P_{h\perp}|/(zQ)$$



Inclusive Process

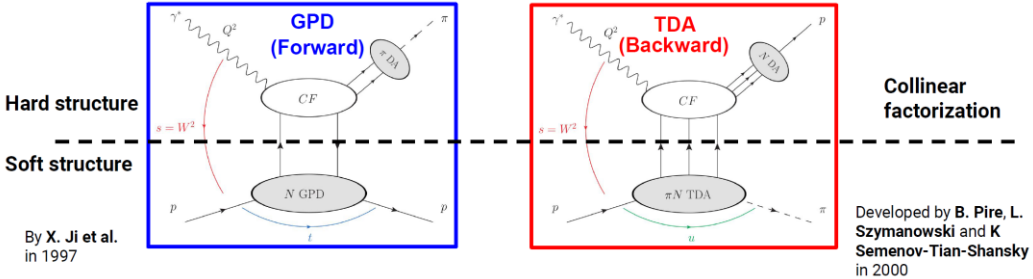
arXiv:2208.14620 The precision of extractions of Sivers functions @ EicC

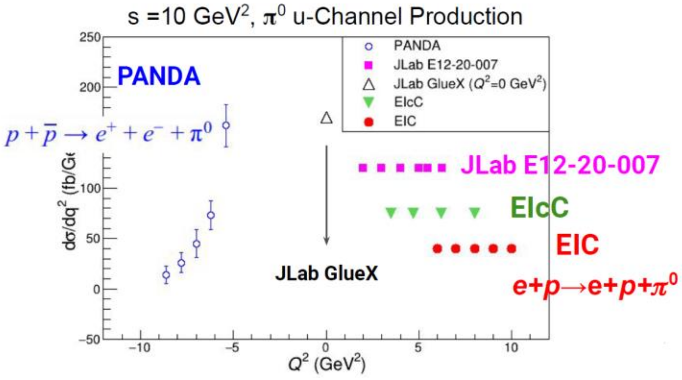
Evolution Included. Constrained by COMPASS, HERMES & Jlab data

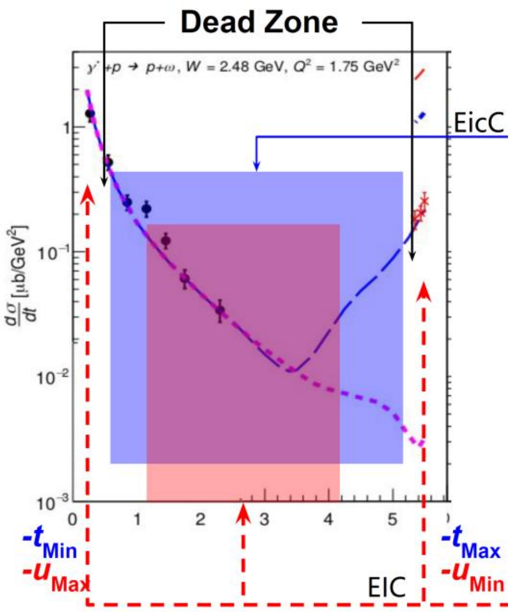


Exclusive Process

- **3D structure of nucleon (TDA)**
- *u*-channel meson production (borrowed from Bill Wenliang@WM&JLab)





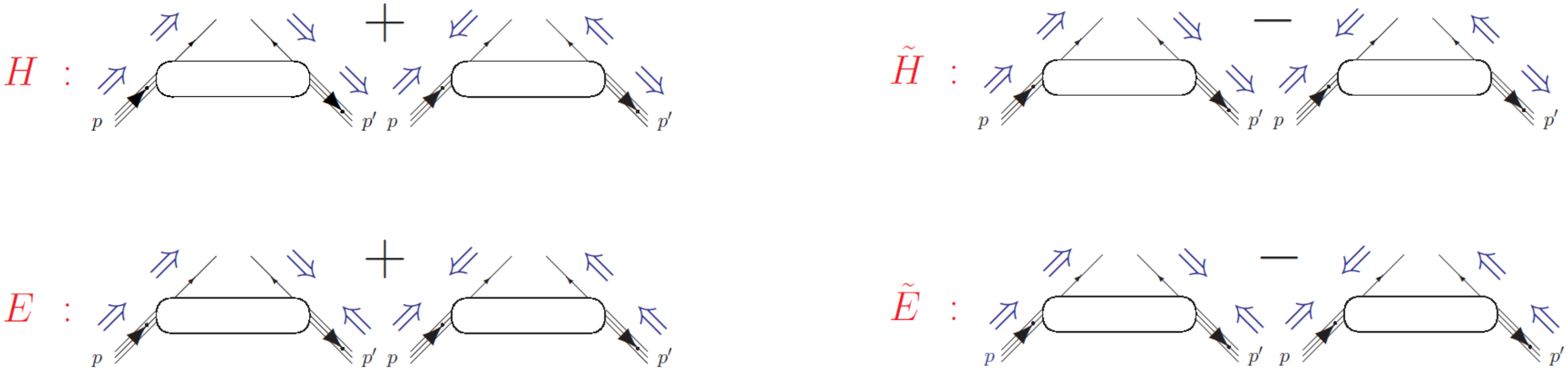


Lumi. is OK, but
15 (VS. 4.5)mRad acceptance for 2γ from π^0
other mesons: reduce the dead zone near the beamline

Deeply Virtual Compton Scattering (DVCS)

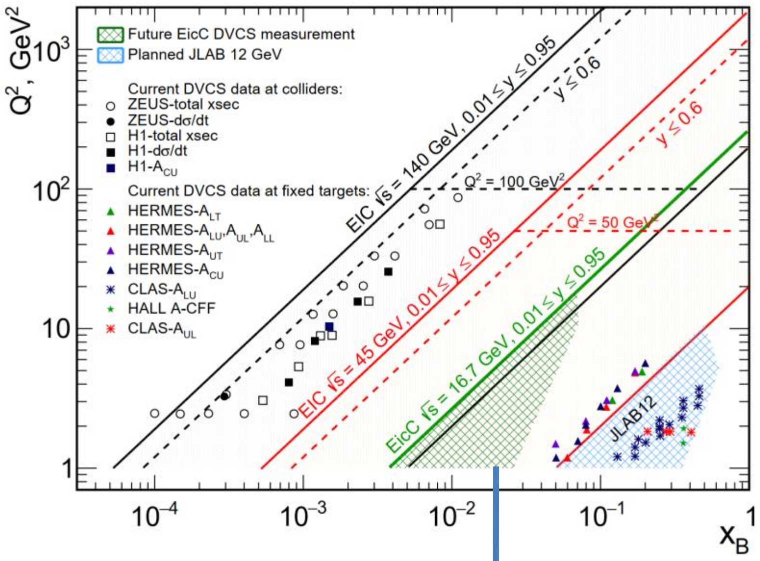
- **From 1D to 3D structure of proton & atom, and vice versa:**
- GPD: General Parton Distribution
- DVCS: Deeply Virtual Compton Scattering

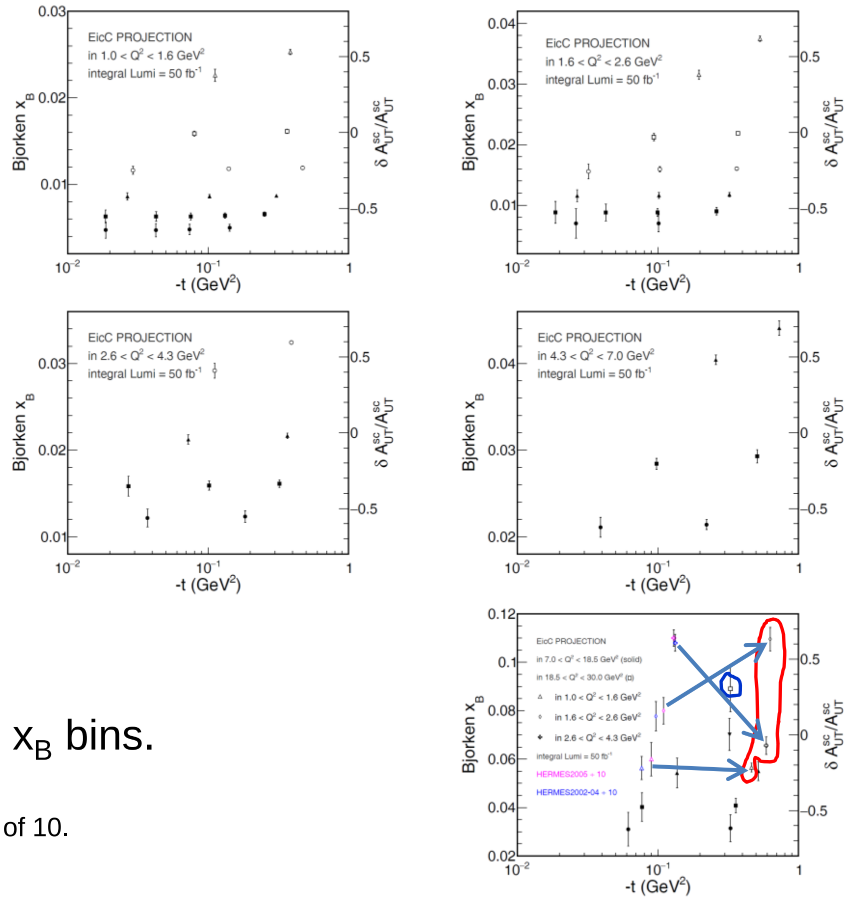
averages over the quark helicity



➢Rept. Prog. Phys. 76 (2013) 066202

Projection Bins of DVCS@EicC





- A_{UT} with -t in all $1.0 < Q^2 < 30.0$ GeV^2 and x_B bins.
- HERMES data with the relative statistical errors divided by a factor of 10.

Reweighting replicas @ PARTONS NN

- Given an PARTONS NN ensemble one can evaluate any quantity or experimental observable O[f] depending on the CFFs by computing O[f] for each of the replicas, and averaging the results:

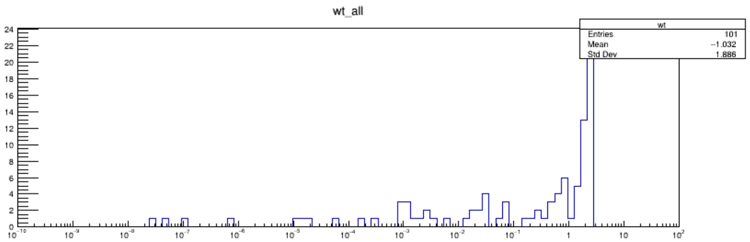
NNPDF: Nucl.Phys.B849:112,2011 (arxiv: 1012.0836)

$$\langle \mathcal{O} \rangle = \int \mathcal{O}[f]\,\mathcal{P}(f)\,Df = \frac{1}{N}\sum_{k=1}^{N} \mathcal{O}[f_k]\,.$$

(Pseudo-)data n:

$$\chi^2(y,f) = \sum_{i,j=1}^{n} (y_i - y_i[f])\sigma_{ij}^{-1}(y_j - y_j[f]).$$

$$w_k = \frac{(\chi_k^2)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi_k^2}}{\frac{1}{N}\sum_{k=1}^{N}(\chi_k^2)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi_k^2}}.$$



$$\langle \mathcal{O} \rangle_{\rm new} = \int \mathcal{O}[f]\,\mathcal{P}_{\rm new}(f)\,Df = \frac{1}{N}\sum_{k=1}^{N} w_k \mathcal{O}[f_k]\,.$$

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$$\langle \mathcal{O} \rangle_{\rm new} = \int \mathcal{O}[f]\, \mathcal{P}_{\rm new}(f)\, Df = \frac{1}{N} \sum_{k=1}^{N} w_k \mathcal{O}[f_k] \,.$$

- We can quantify this loss of efficiency by using the Shannon entropy to compute the effective number of replicas left after reweighting:

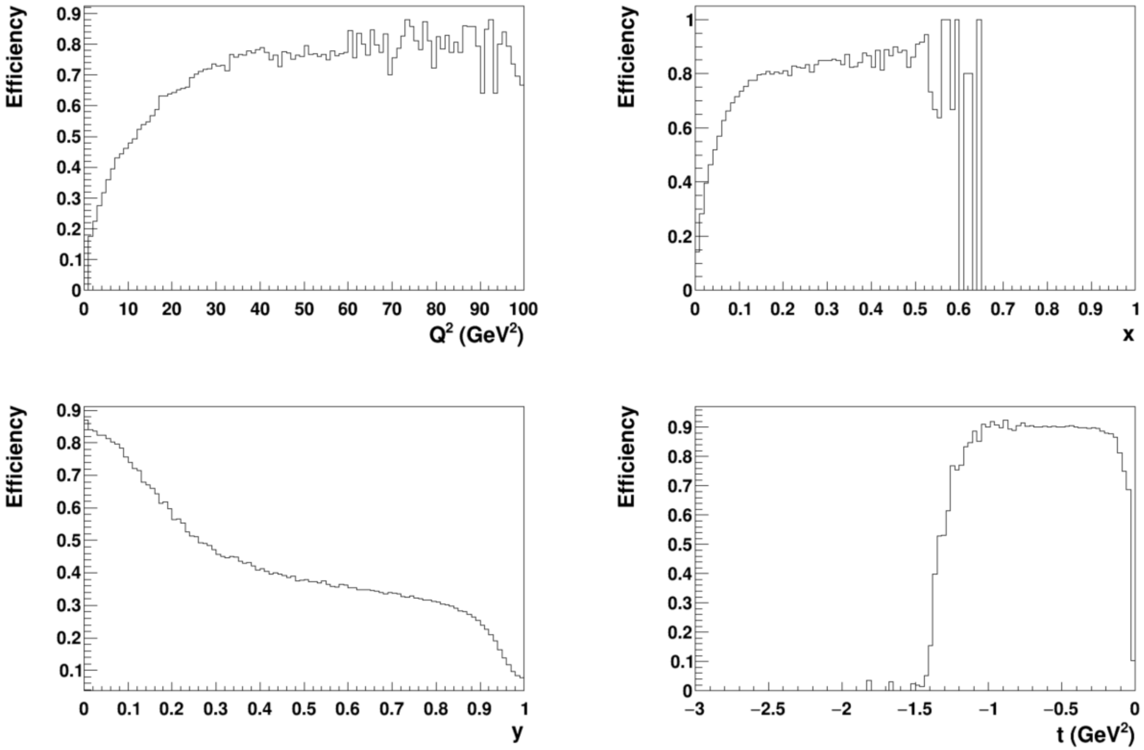
$$N_{\rm eff} \equiv \exp\left\{ \frac{1}{N} \sum_{k=1}^{N} w_k \ln(N/w_k) \right\} .$$

- If $N_{\rm eff}$ becomes too low, the reweighting procedure will no longer be reliable,

1. either because the new data contain a lot of information on the PDFs, necessitating a full refitting with more replicas. (pseudo-data：integrated luminosity)
2. or because the new data are inconsistent with the old. (pseudo-data：smeared)

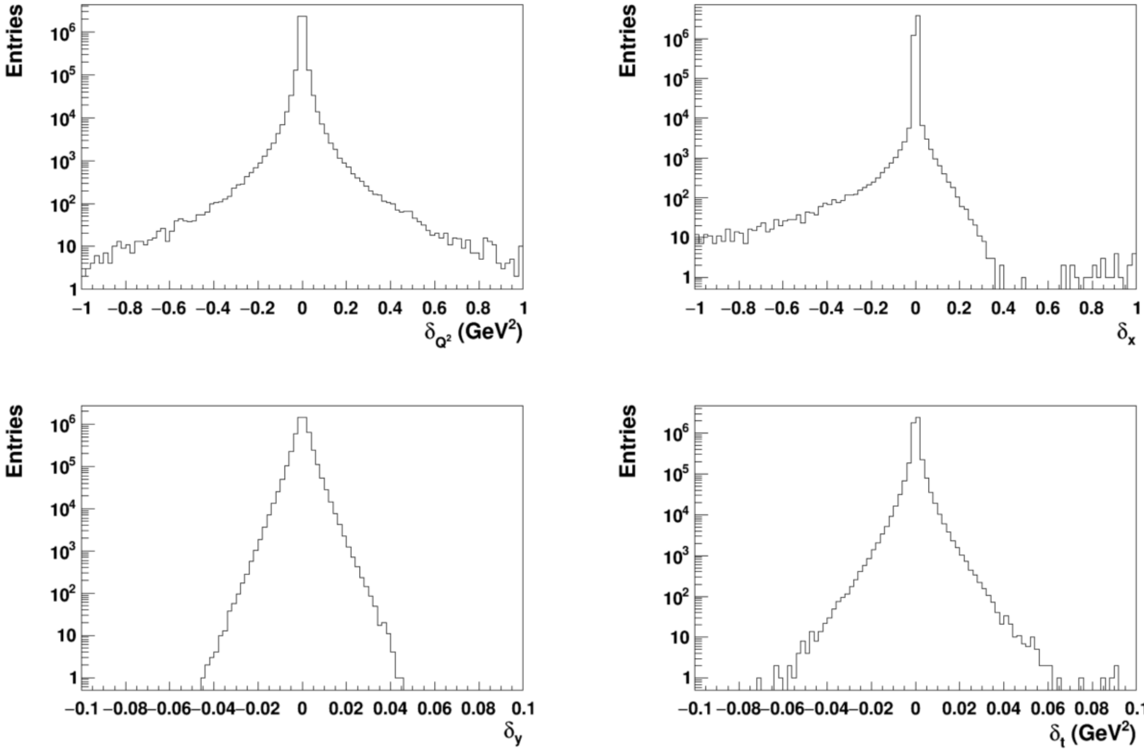
Exclusive Process

- **Detector efficiency**
- coutercy of detector group



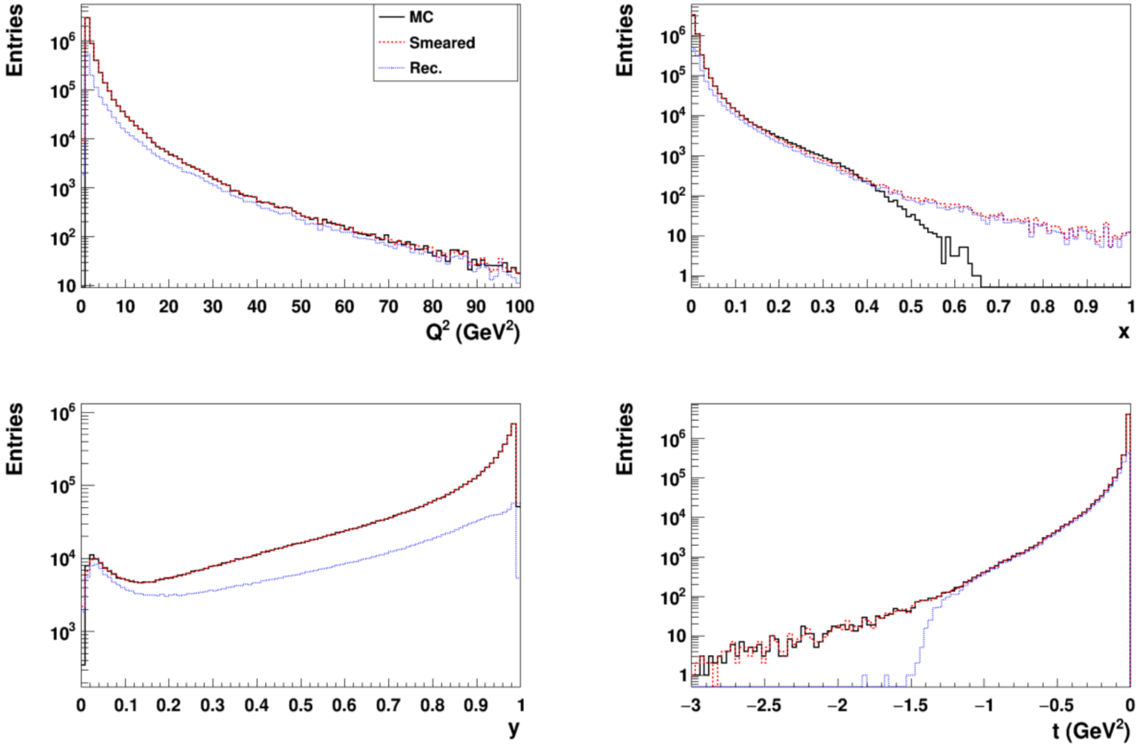
Update of DVCS

- **Detector resolution**
- coutercy of detector group



Exclusive Process

- **Detector efficiency**
- coutercy of detector group



Ultimate Goal: impact of EicC on GPD of proton

- Flavor seperation? CFF $, \; , \; \tilde{} , \; \tilde{}$ & $, \; \tilde{} , \; \tilde{} ,$

$$A_{LU,I}^{\sin\phi} \propto \mathrm{Im}\left[F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4m^2}F_2\mathcal{E}\right],$$

$$A_{UL,I}^{\sin\phi} \propto \mathrm{Im}\left[\xi(F_1+F_2)(\mathcal{H}+\frac{\xi}{1+\xi}\mathcal{E}) + F_1\widetilde{\mathcal{H}} - \xi(\frac{\xi}{1+\xi}F_1+\frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}\right]$$

$$A_{LL,I}^{\cos\phi} \propto \mathrm{Re}\left[\xi(F_1+F_2)(\mathcal{H}+\frac{\xi}{1+\xi}\mathcal{E}) + F_1\widetilde{\mathcal{H}} - \xi(\frac{\xi}{1+\xi}F_1+\frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}\right]$$

$$A_{UT,I}^{\sin(\phi-\phi_s)\cos\phi} \propto \mathrm{Im}\Big[-\frac{t}{4M^2}\big(F_2\mathcal{H}-F_1\mathcal{E}\big)+\xi^2\big(F_1+\frac{t}{4M^2}F_2\big)\big(\mathcal{H}+\mathcal{E}\big) -\xi^2\big(F_1+F_2\big)\big(\widetilde{\mathcal{H}}+\frac{t}{4M^2}\widetilde{\mathcal{E}}\big)\Big],$$

$$A_{UT,I}^{\cos(\phi-\phi_s)\sin\phi} \propto \mathrm{Im}\left(F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}\right),$$

$$A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi} \propto \mathrm{Re}\left(F_2\mathcal{H} - F_1\mathcal{E}\right),$$

$$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi} \propto \mathrm{Re}\left(F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}\right).$$

- Error propagation? CFF , , ˜, ˜ → GPD $H, \tilde{E}, \tilde{H}, E$

$$A_{LU,I}^{\sin\phi} \propto \mathrm{Im}\left[F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4m^2}F_2\mathcal{E}\right],$$

$$A_{UL,I}^{\sin\phi} \propto \mathrm{Im}\left[\xi(F_1+F_2)(\mathcal{H}+\frac{\xi}{1+\xi}\mathcal{E}) + F_1\widetilde{\mathcal{H}} - \xi(\frac{\xi}{1+\xi}F_1+\frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}\right]$$

$$A_{LL,I}^{\cos\phi} \propto \mathrm{Re}\left[\xi(F_1+F_2)(\mathcal{H}+\frac{\xi}{1+\xi}\mathcal{E}) + F_1\widetilde{\mathcal{H}} - \xi(\frac{\xi}{1+\xi}F_1+\frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}\right]$$

$$A_{UT,I}^{\sin(\phi-\phi_s)\cos\phi} \propto \mathrm{Im}\Big[-\frac{t}{4M^2}(F_2\mathcal{H}-F_1\mathcal{E}) + \xi^2(F_1+\frac{t}{4M^2}F_2)(\mathcal{H}+\mathcal{E}) \\ -\xi^2(F_1+F_2)(\widetilde{\mathcal{H}}+\frac{t}{4M^2}\widetilde{\mathcal{E}})\Big],$$

$$A_{UT,I}^{\cos(\phi-\phi_s)\sin\phi} \propto \mathrm{Im}\left(F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}\right),$$

$$A_{LT,I}^{\sin(\phi-\phi_s)\sin\phi} \propto \mathrm{Re}\left(F_2\mathcal{H} - F_1\mathcal{E}\right),$$

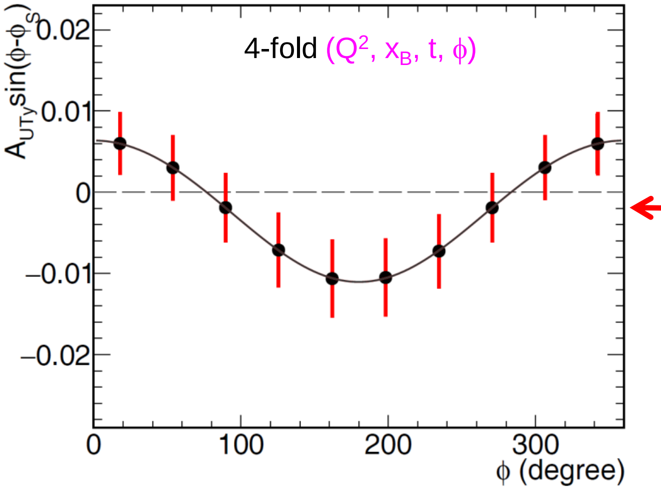
$$A_{LT,I}^{\cos(\phi-\phi_s)\cos\phi} \propto \mathrm{Re}\left(F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}\right).$$

Deeply Virtual Compton Scattering (DVCS)

➢Proejction Bins of DVCS@EicC: Assume |t|>0.01, Δt>0.02

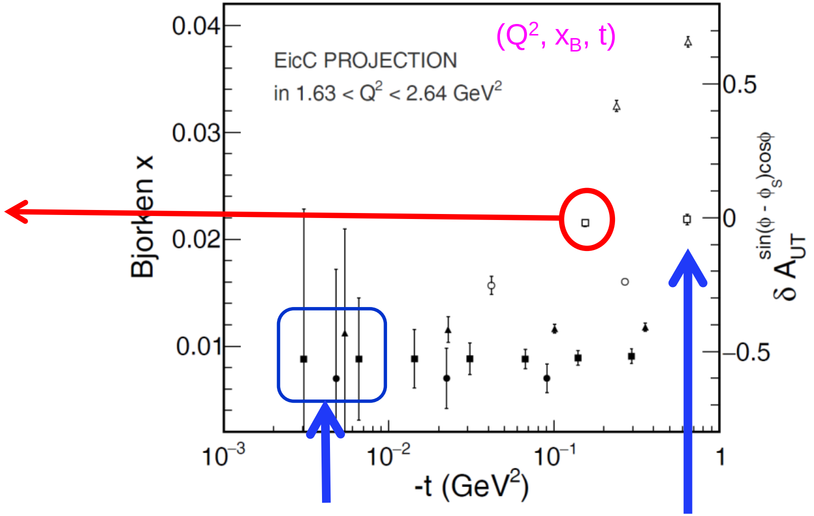
- 1. Only several projection points with |t|<0.01
- 2. Magnitude of asymmetry is tiny with |t|<0.01, so the relative errors are usually above 50% there
- 3. A big challenge for the detector design for |t|~0.002 & Δt~0.002: detector simulation?

the first t-bin in $1.63< Q^2 <2.64$ GeV^2



10 ϕ bins each

absolute asymmetry: GK model for illustration only



|t|<0.01 GeV^2 |t| ~ 1 GeV^2

Exclusive Process

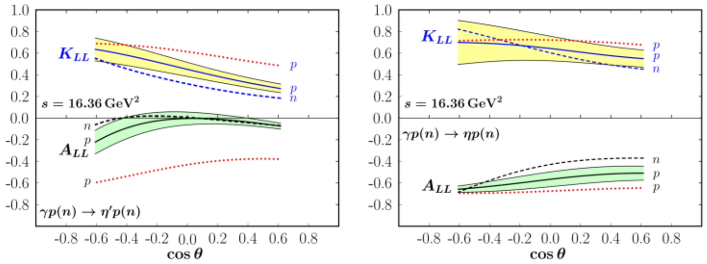
- **3D structure of nucleon (TDA)**
- *u*-channel meson production (Bill Wenliang@WM&JLab)

- Pseudo-rapidity, azimuthal angle coverage and pt coverage?
- outgoing scattered e': 0< η <3; recoiled proton: 1.5 < η < 4; π^0 : 0 < η < 3.69;
- Note: η = 3.69 is the far-forward region

- Momentum/Energy resolution?
- Energy resolution ($\sigma(\Delta E / E)$) in the far forward region and forward endcap: 0.02 + 0.077$\sqrt{E}$ for photon. minimum requirement 0.35*$\sqrt{0.35}$

- PID requirements?

Note (η' for glue, see 2111.08965):

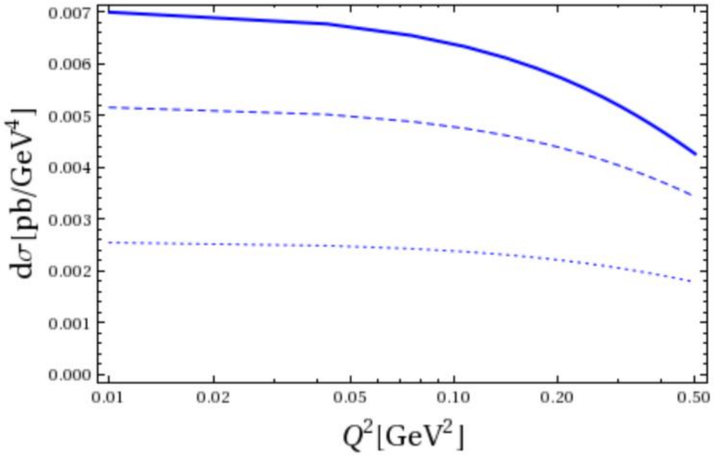


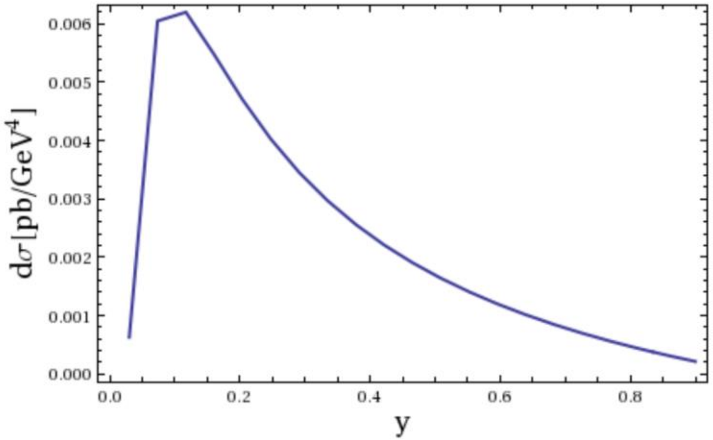
- Any requirement on far-forward detector?
- Excellent forward γ/neutron separation
- Reconstruct photon energy.
- The forward acceptance: ±7mrad, >±5 mrad

GPD physics

- 3D structure of nucleon (GPDs) @ EicC
- *Charged current electroproduction of a charmed meson* (PRD104, 094002)
- Courtesy: B. Pire, L. Szymanowski, J. Wagner

- The rates are quite small
- missing mass technique: the neutrino at final states.
- Ds reconstruction: difficult





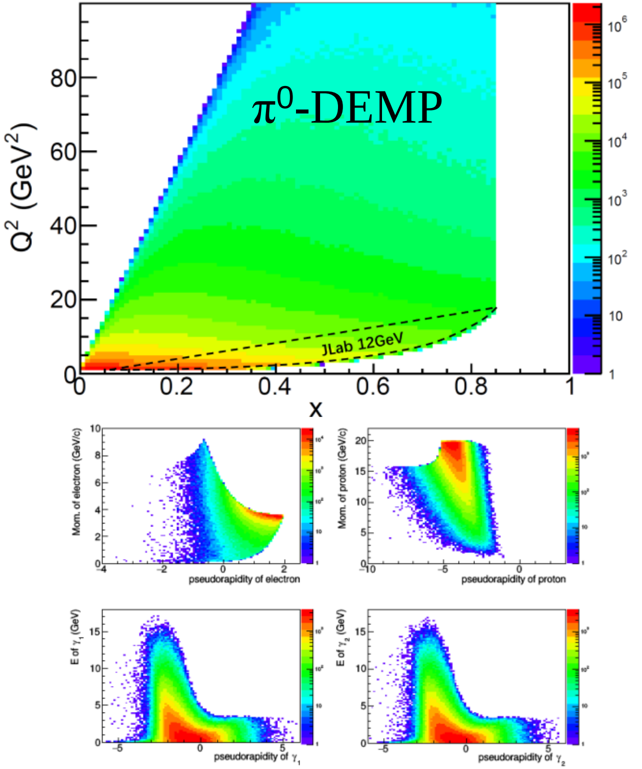
DVMP

- The exclusives of EicC (DVCS, DEMP…):

- Impact of A_{UT} is noticeable to imaginary CFF-$\mathcal{E}$ (KK);
- Present data constraining power in sea CFF-$\mathcal{E}$: ~ 0.01 fb^{-1} (PARTONS-NN);

- Future:
- Local extracting of CFF
- Feed the numerical framework and models

- … GPD impact study of electron-ion collider



Introduction

- **From 1D to 3D picture of hadron & atom:**
- TMD: Transverse Momentum Distribution (k⊥ & longi. Momentum)
- How is proton's spin correlated with the motion of the quarks/gluons?
- GPD: General Parton Distribution (trans. spatial position b⊥ & longi. Momentum)
- How does proton's spin influence the spatial distribution of partons?
- TDA: nucleon-to-photon & nucleon-to-meson Transition Distribution Amplitudes

- **Origin of the Proton spin**

$$J_{q,g} = \frac{1}{2}\int_{-1}^{1} \mathrm{d}x\, x\, [H_{q,g}(x,\xi,t=0) + E_{q,g}(x,\xi,t=0)]$$

- **Origin of the Proton mass**

- **Quark OAM?**

$$\mathcal{F}(\xi,t,Q^2) = \sum_{q=u,d,s,\cdots} e_q^2 \int_{-1}^{1} \mathrm{d}x \left[\frac{1}{\xi - x - i\epsilon} \mp \frac{1}{\xi + x - i\epsilon}\right] F^q(x,\xi,t)$$

Proton DVCS

EicC Central Detector