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Exclusive Hard Reactions with the Neutral Particle Spectrometer in Hall C at Jefferson Lab

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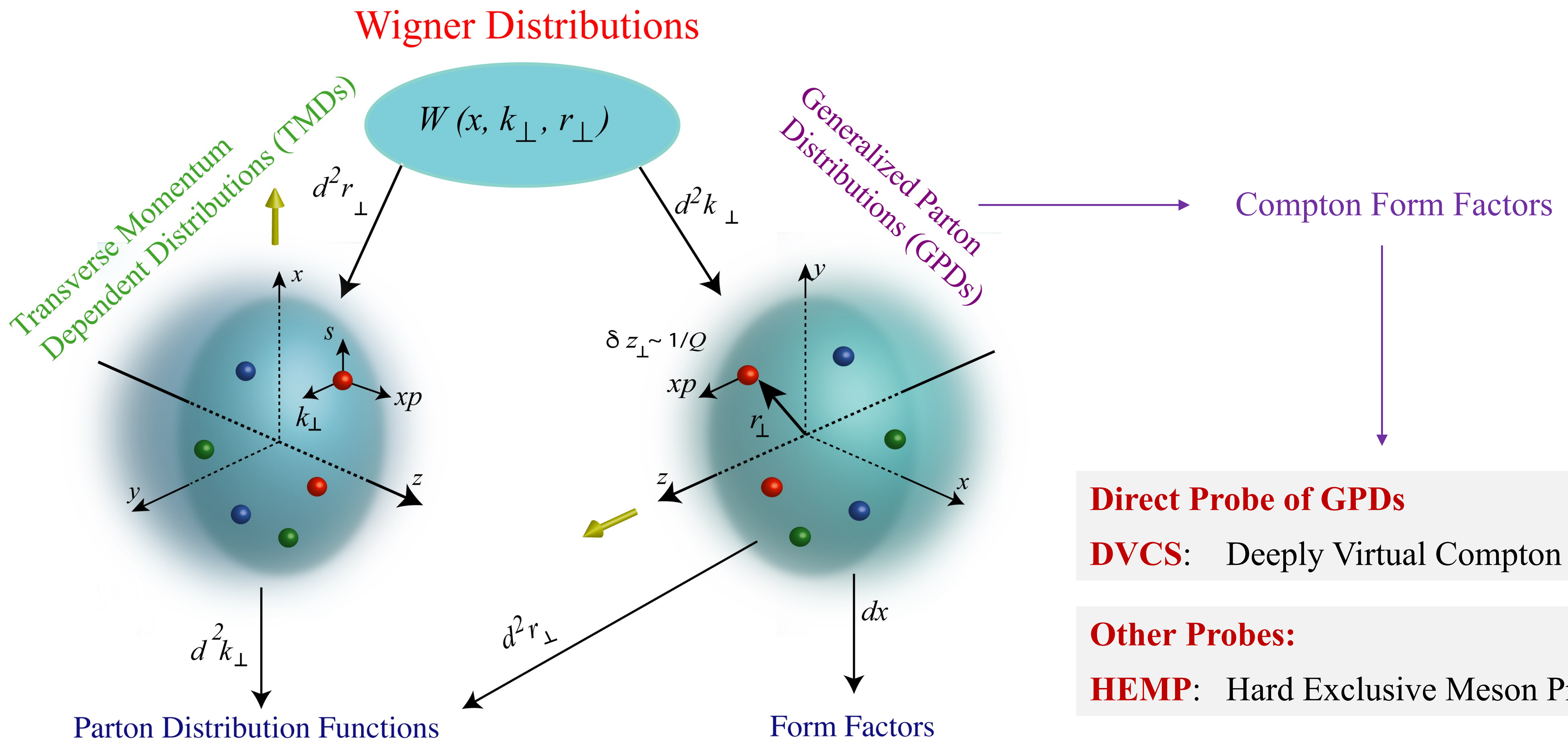
26th International Symposium on Spin Physics (SPIN2025), Qingdao, China, September 2025

Tsinghua University

■ **Toward a more complete description of the nucleon**

Figure: Dudek et al. Eur. Phys. J. A 48 (2012)



Longitudinal quark distribution in momentum space

Transverse quark distribution in coordinate space

Direct Probe of GPDs

DVCS: Deeply Virtual Compton Scattering

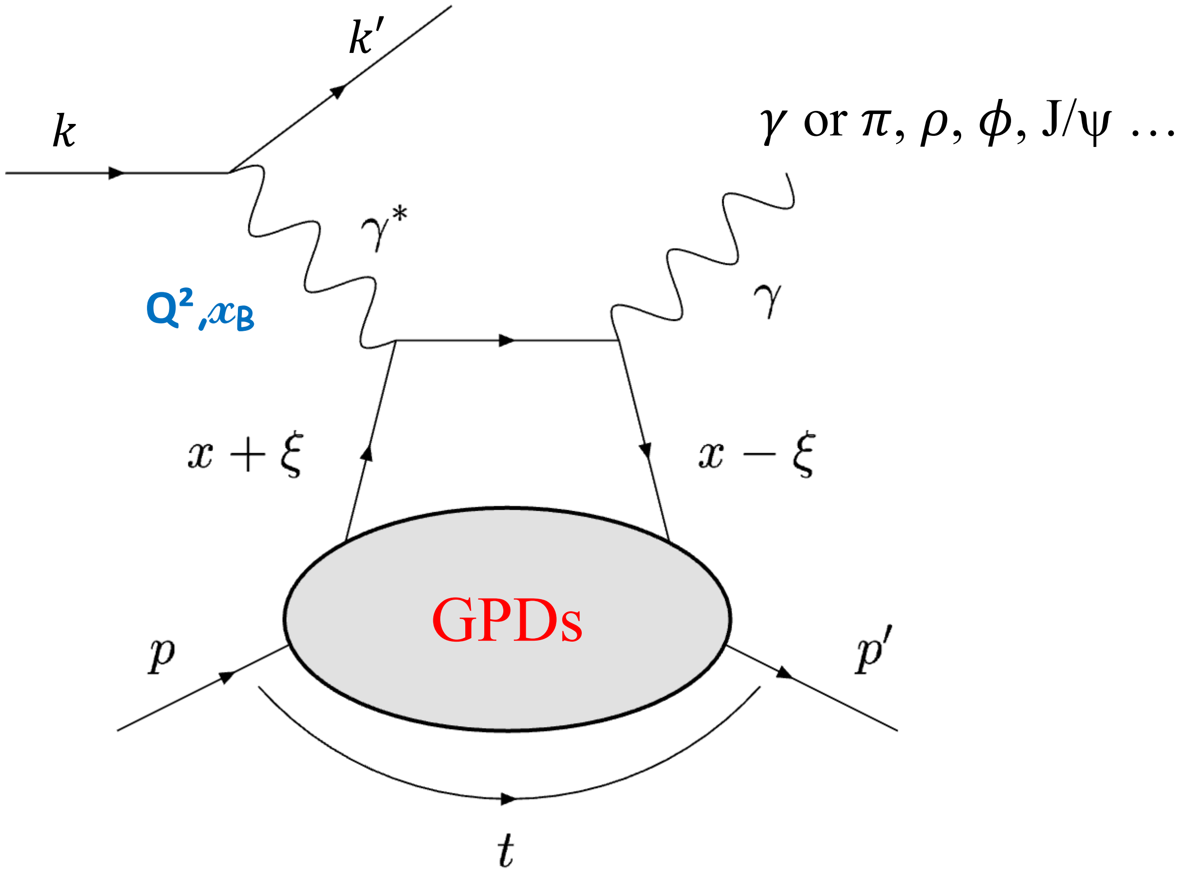
Other Probes:

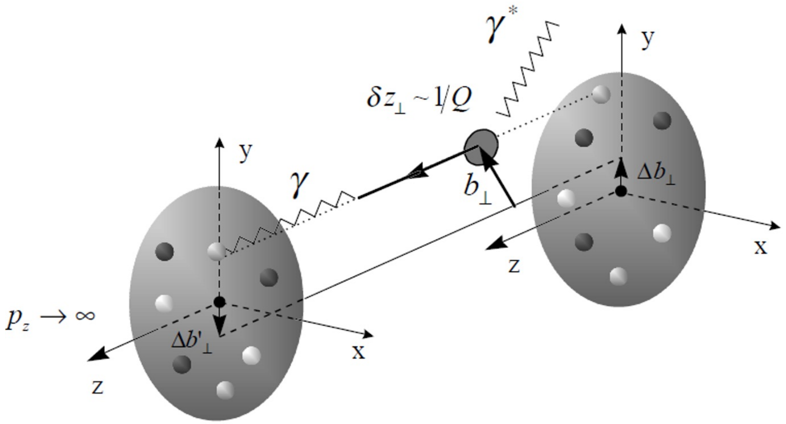
HEMP: Hard Exclusive Meson Production

Exclusive Hard Reactions

Exclusive hard reactions: handbag diagram

DVCS: **ℓp→ ℓ' p' γ** (golden channel)
HEMP: **ℓp→ ℓ' p' π or ρ or ϕ or J/ψ,…**





Definition of variables:

- x: average longitudinal momentum (NOT ACCESSIBLE)
- ξ: longitudinal momentum difference $\simeq x_B/(2-x_B)$
- t: four-momentum transfer

  related to impact parameter $b_\perp$ via Fourier transform
- $Q^2 = -(k-k')^2$
- $x_B = Q^2/2M\nu, \quad \nu = E_e - E_e'$

GPDs and DVCS factorization

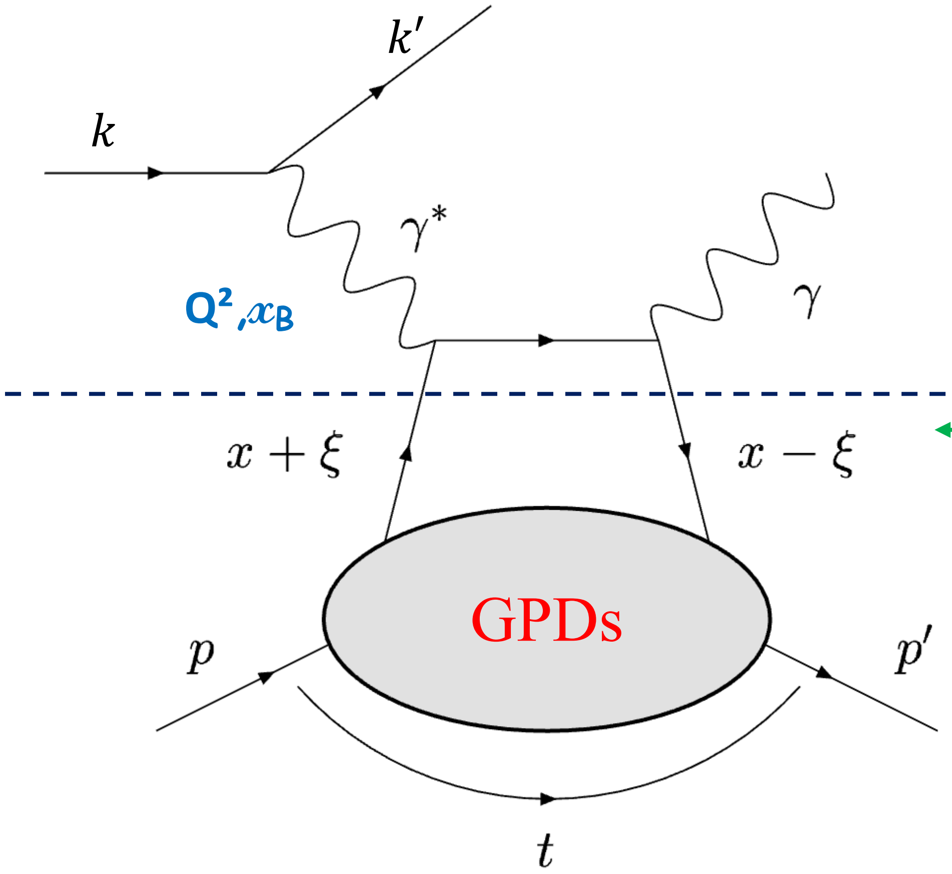
D. Mueller *et al*, Fortsch. Phys. 42 (1994)
X.D. Ji, PRL 78 (1997), PRD 55 (1997)
A. V. Radyushkin, PLB 385 (1996), PRD 56 (1997)

The minimal Q^2 at which the factorization holds must be tested and established by **experiments**

Bjorken limit:

$$\left.\begin{array}{ccc} Q^2 = -q^2 & \to & \infty \\ \nu & \to & \infty \end{array}\right\} \quad x_B = \frac{Q^2}{2M\nu} \quad \text{fixed}$$

One parton per collision



Hard process

QCD perturbative

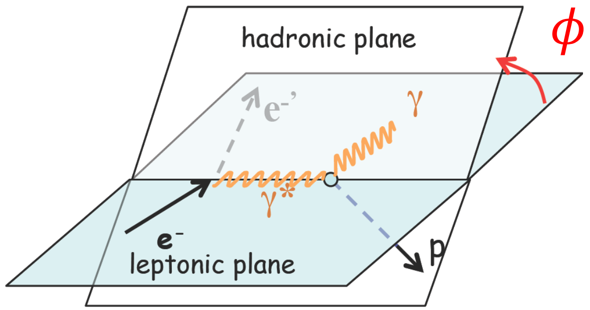
Soft process

Non perturbative QCD described by GPDs

Exclusive Hard Reactions

How to parametrize the measured cross-sections?

$$\frac{d^4\sigma(lp \to lp\gamma)}{dx_B dQ^2 d|t| d\phi} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_l \quad d\sigma^{DVCS}_{pol} + e_l\left(\mathrm{Re}(I) + P_l \mathrm{Im}(I)\right)$$



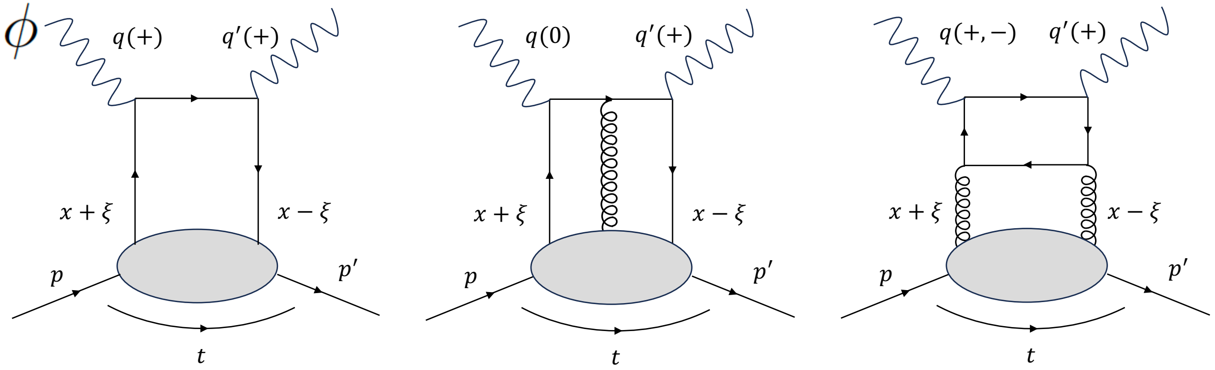
$$d\sigma^{BH} \propto c_0^{BH} + c_1^{BH}\cos\phi + c_2^{BH}\cos 2\phi$$

$$d\sigma^{DVCS}_{unpol} \propto c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi$$

$$d\sigma^{DVCS}_{pol} \propto s_1^{DVCS}\sin\phi$$

$$\mathrm{Re}\, I \propto c_0^I + c_1^I\cos\phi + c_2^I\cos 2\phi + c_3^I\cos 3\phi$$

$$\mathrm{Im}\, I \propto s_1^I\sin\phi + s_2^I\sin 2\phi$$



LT/LO HT NLO

$$s_1^I = F_1\mathcal{H} + \xi(F_1 + F_2)\tilde{\mathcal{H}} + kF_2\mathcal{E}$$

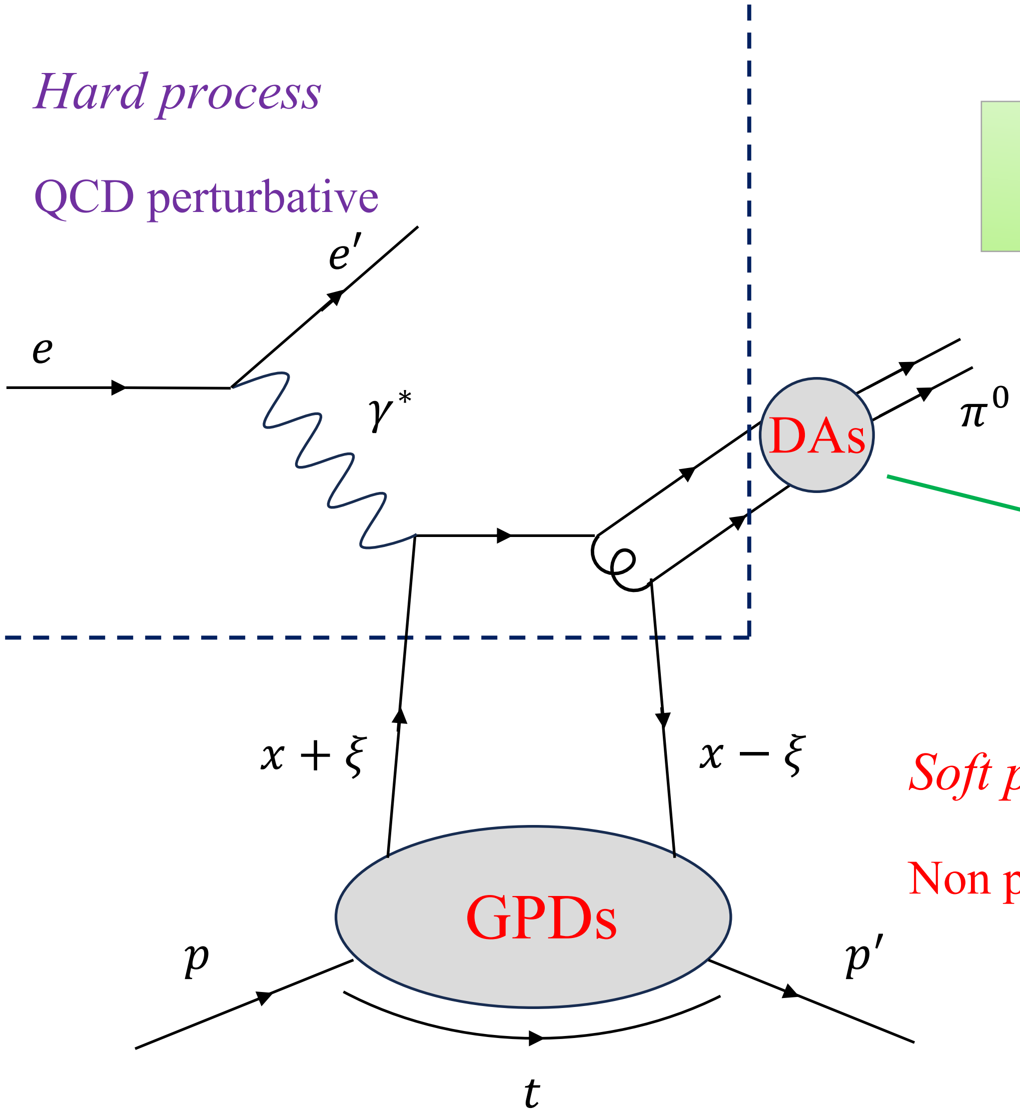
$$F \in \{H, E, \tilde{H}, \tilde{E}\} \xrightarrow{dx} \mathcal{F} \in \{\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \tilde{\mathcal{E}}\}$$

GPDs CFFs

Cross-sections analysis include more or less terms: both in terms of harmonics (c_i's and s_i's) and In term of GPD/CFFs.

■ HEMP: Hard exclusive π^0 electroproduction

John C. Collins *et al*, Adv. Ser. Direct. High Energy Phys. (1989) PRD (1997)



Factorization has been demonstrated only for **longitudinally** polarized virtual photons in this type of reaction.

Distribution amplitude describes the structure of the produced meson (non-perturbative object).

Soft processes

Non perturbative QCD described by GPDs and DAs

Exclusive Hard Reactions

■ Hard exclusive π^0 cross-sections

D. Dreschsel and L. Tiator, J. Phys. G: Nucl. Part. Phys. (1992)

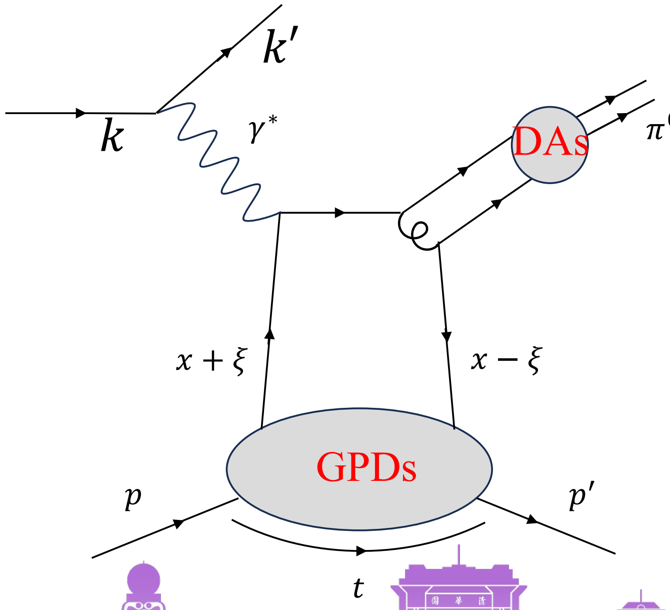
- For longitudinally polarized beam and unpolarized target:

$$\frac{d^2\Gamma_{\gamma^*}}{dQ^2 dx_B}(Q^2, x_B, E_e) = \frac{\alpha}{8\pi}\frac{Q^2}{M^2E_e^2}\frac{1-x_B}{x_B^3}\frac{1}{1-\epsilon^*}$$

$$\epsilon^* = \frac{1-y-\frac{Q^2}{4E_e^2}}{1-y+\frac{y^2}{2}+\frac{Q^2}{4E_e^2}} \qquad y = \frac{q\cdot p}{k\cdot p}$$

$$\frac{d^4\sigma}{dt\,d\phi\,dQ^2dx_B} = \frac{1}{2\pi}\frac{d^2\Gamma_{\gamma^*}}{dQ^2dx_B}(Q^2,x_B,E)\left[\frac{d\sigma_T}{dt}+\epsilon^*\frac{d\sigma_L}{dt} + \sqrt{2\epsilon^*(1+\epsilon^*)}\frac{d\sigma_{TL}}{dt}\cos(\phi)+\epsilon^*\frac{d\sigma_{TT}}{dt}\cos(2\phi)+h\sqrt{2\epsilon^*(1-\epsilon^*)}\frac{d\sigma_{TL'}}{dt}\sin(\phi)\right]$$

- ϕ is still the opening angle between the lepton plane and the hadronic plane
- T/L represents the polarization of the virtual photon
- $d\sigma_{TL}$, $d\sigma_{TT}$, $d\sigma_{TL'}$ are interference terms ($d\sigma_{TT'}$ is not included)
- Each harmonic component has ϕ and beam energy dependence
- According to handbag factorization, σ_L scales as $\frac{1}{Q^6}$ and σ_T scales as $\frac{1}{Q^8}$



Worldwide Experimental Measurement

Overview of the past experiments

- Experimental timeline

  - Pioneering results from non-dedicated experiments:

    Hall B and HERMES ~2001

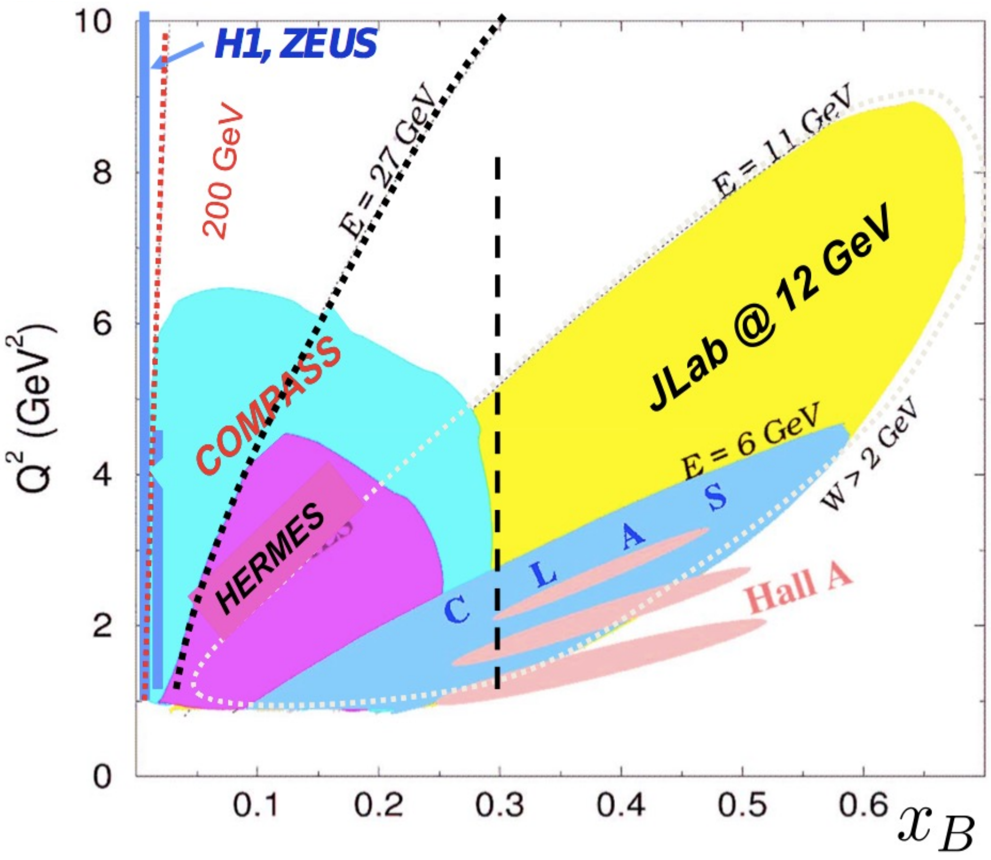
  - First round of dedicated experiments:

    Hall A/B, HERMES, H1&ZEUS ~ 2005

  - Second round of dedicated experiments:

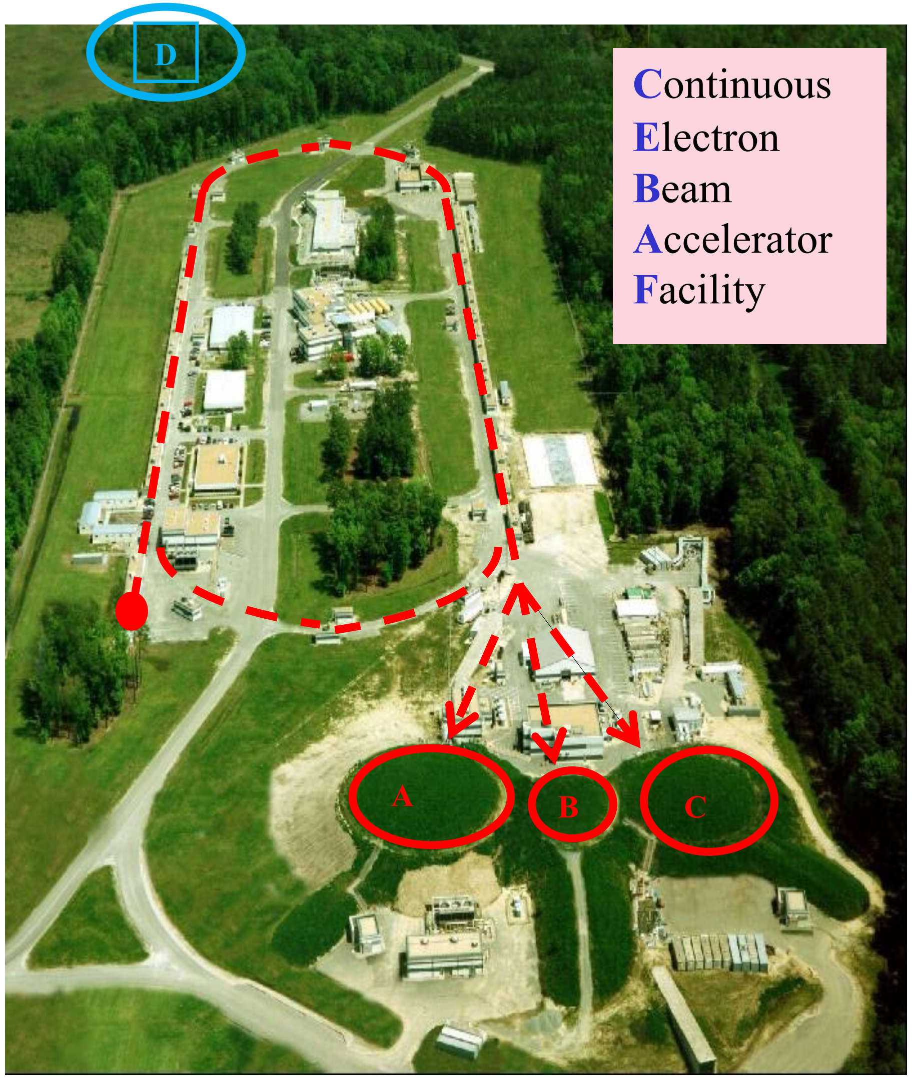
    Hall A/B ~2010

  - Compelling programs at JLab-12 GeV and COMPASS: 2015~

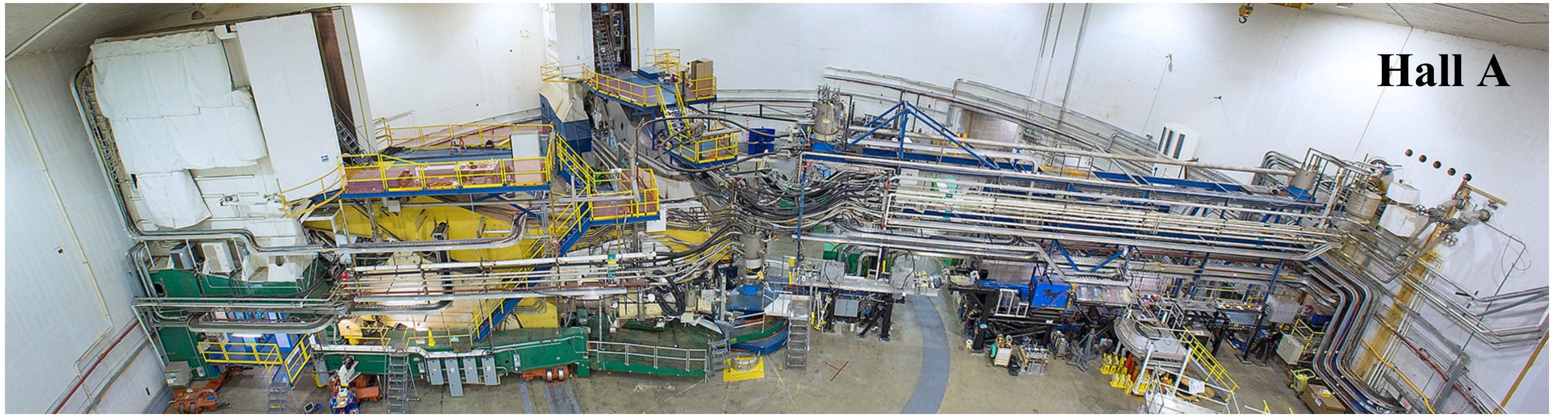


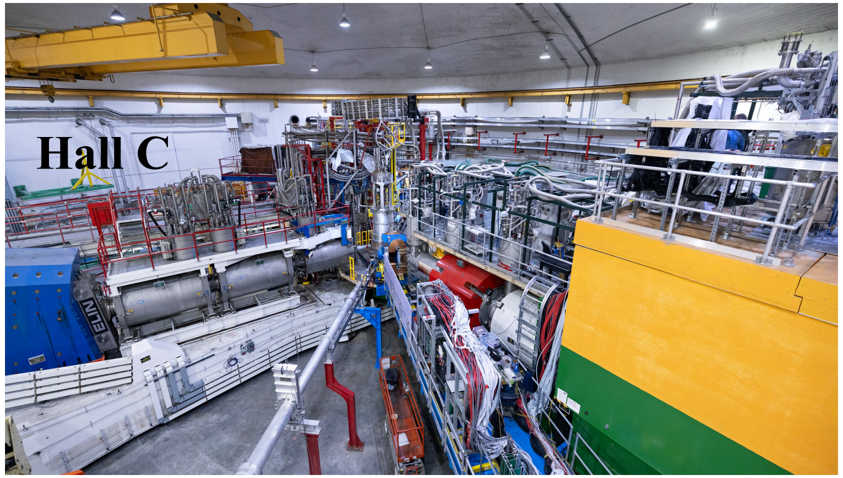
Measurements at Jefferson Lab

■ Overview of Hall-A/C and Hall-B



Continuous
Electron
Beam
Accelerator
Facility



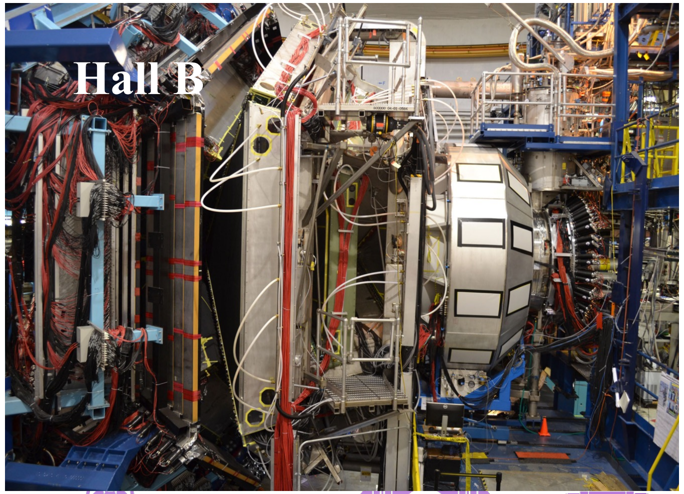


➢ Hall A/C:

- High accuracy (~5%)
- High Luminosity (~ $10^{37}/cm^2/s$)
- Limited kinematic
- Test the validity of the formalism

➢ Hall B:

- Limited accuracy (~15% +)
- Limited Luminosity (~ $10^{34}/cm^2/s$)
- Wide kinematic range
- Map the GPDs



DVCS Experiments at JLab

Hall-A DVCS experiments

Target: LH2 and LD2

- 1st Generation (2004, 5.75 GeV)

C. Muñoz Camacho et al., Phys. Rev. Lett. 97(2006) and M. Mazouz et al. Phys. Rev. Lett. 99 (2007)

- ✓ Q^2 dependence study (of red terms)
- ✓ 1st neutron DVCS experiment
  - ❑ constraint band on quark angular momenta J_u, J_d (proof of principle)

$$d\sigma^{BH} \propto c_0^{BH} + c_1^{BH}\cos\phi + c_2^{BH}\cos 2\phi$$

$$d\sigma^{DVCS}_{unpol} \propto c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi$$

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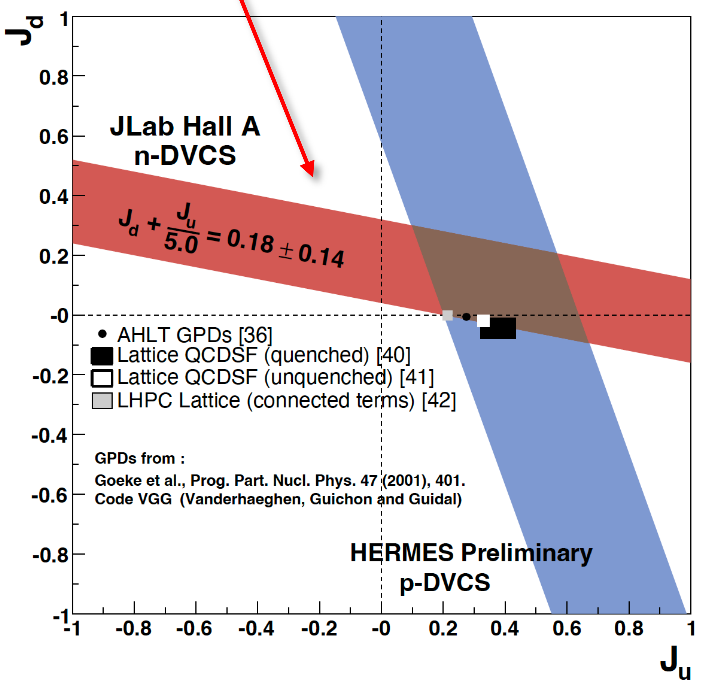

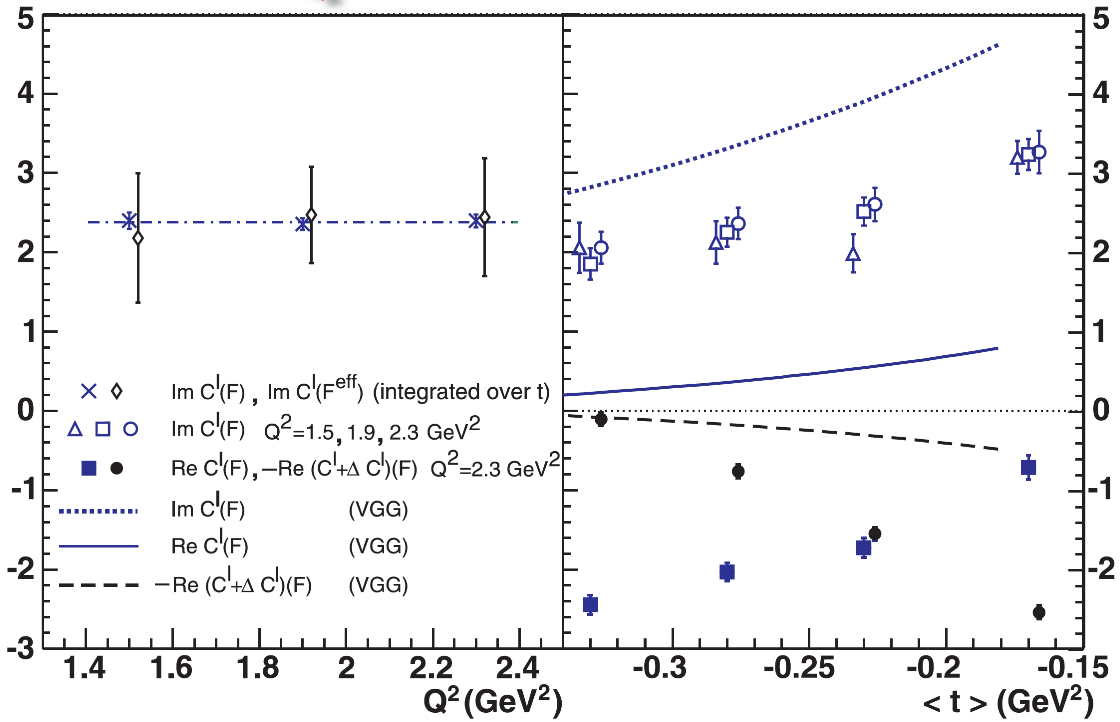

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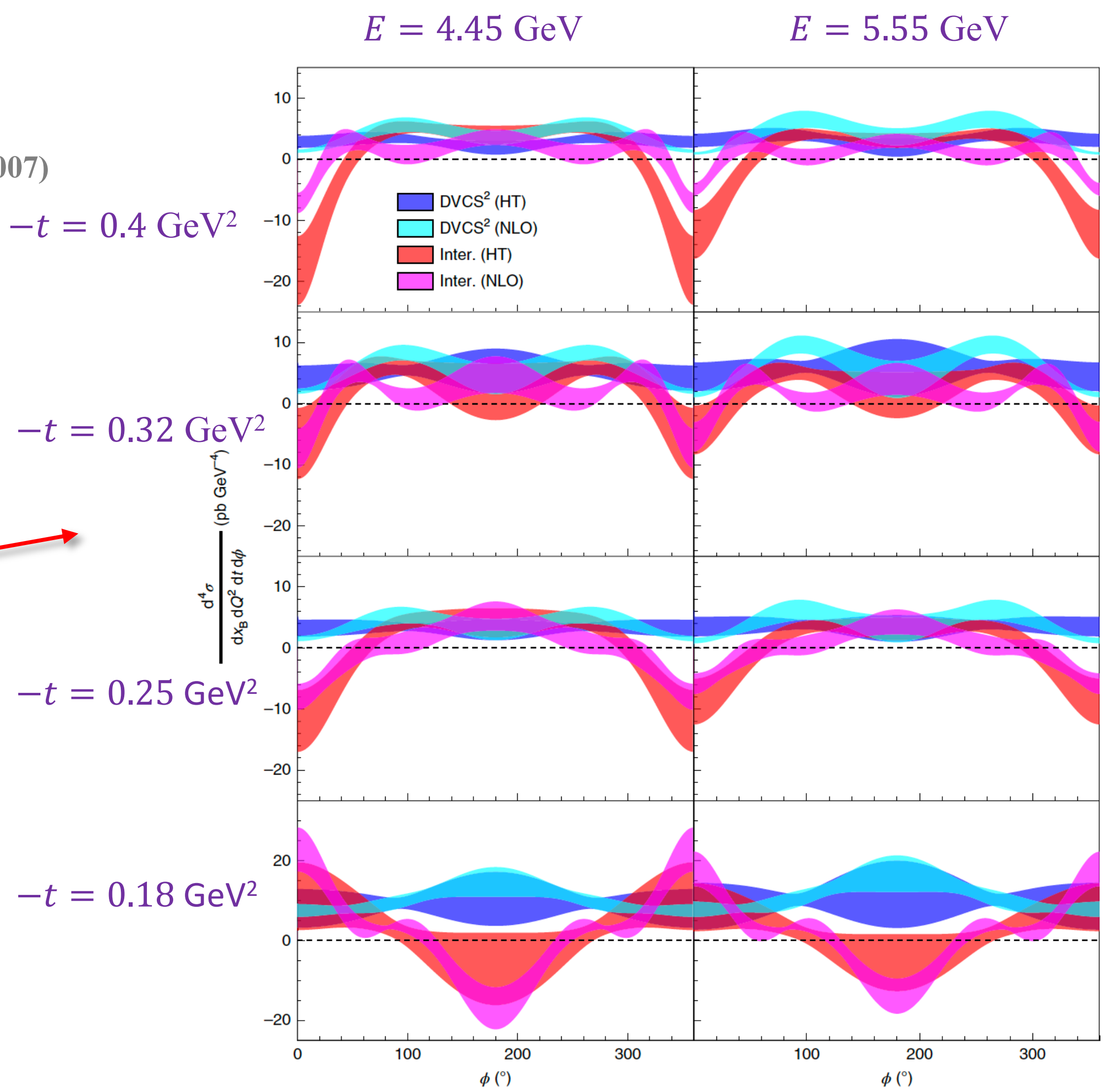
- 2nd Generation (2010, 4.45 and 5.55 GeV)

Defurne, M. et al. Nat Commun 8 (2017) and Benali, M. et al. Nat. Phys. 16 (2020)

  - ✓ Beam energy dependence study
  - ✓ DVCS Rosenbluth-like separation:
    - ❑ Separate C_0^{DVCS} from C_0^I
    - ❑ Separate HT and NLO coefficients
  - ❑ Extraction of the 3 helicity-conserving CFFs



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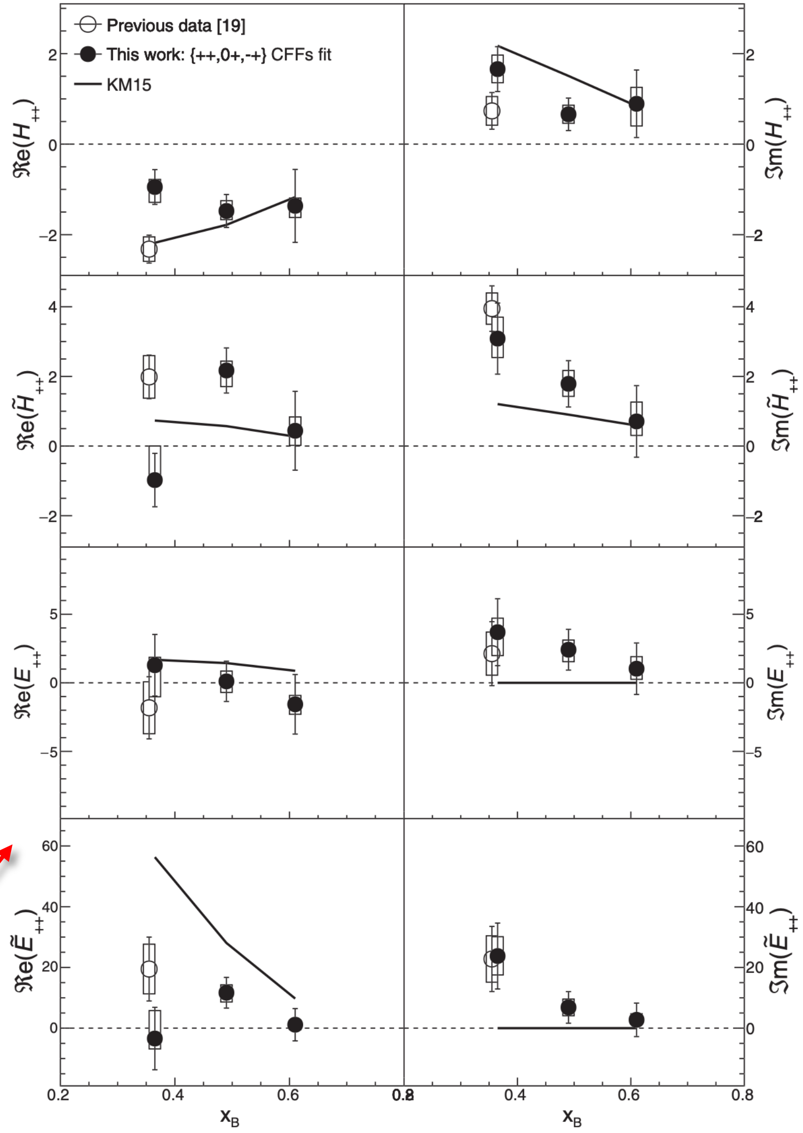
  - ❑ Extraction of the 3 helicity-conserving CFFs
- ➢ 3rd Generation (2014-2016, 4.5 to 11 GeV)

F. Georges et al. Phys. Rev. Lett. 128 (2022)

  - ✓ Helicity-independent and helicity-dependent DVCS cross sections for multiple x_B and Q^2
  - ✓ 1st Experimental extraction of all the 4 helicity-conserving CFFs

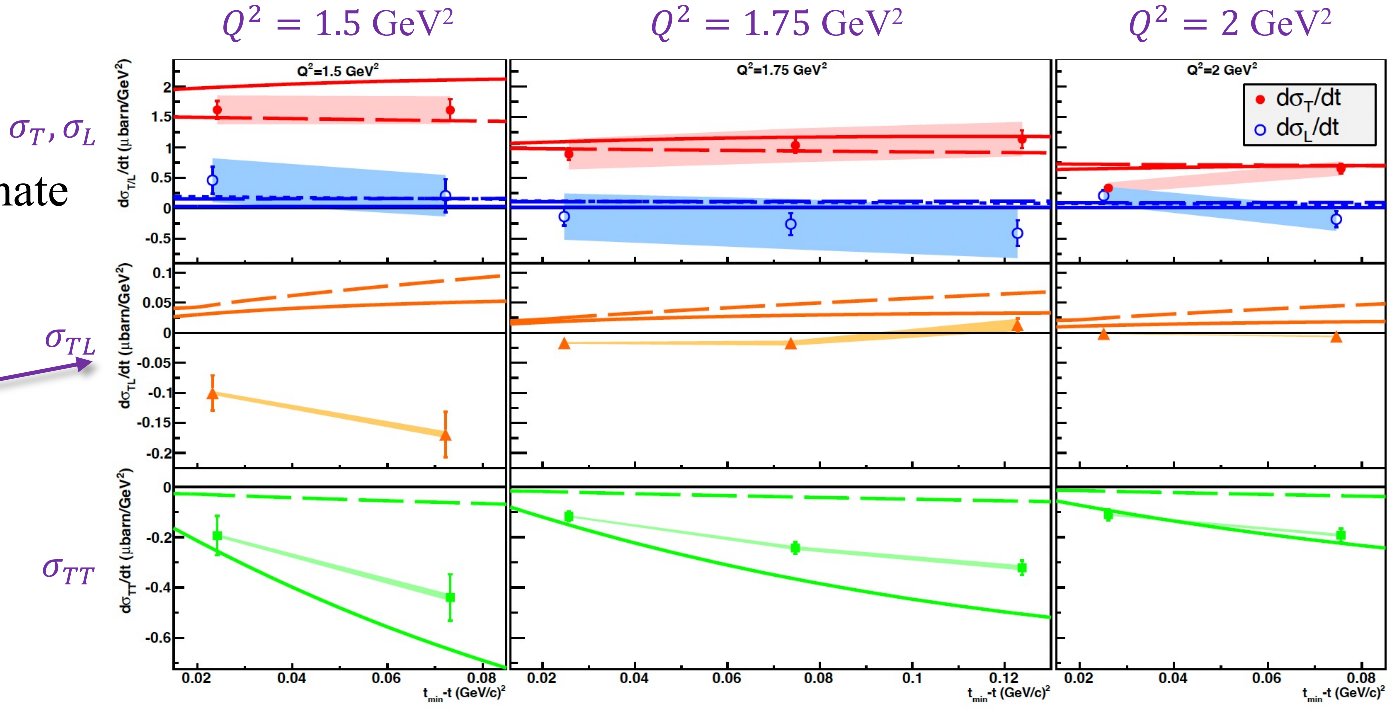


Hard Exclusive Pion Production Measurements at JLab

■ Hall-A DVMP experiments

E. Fuchey *et al*, Phys. Rev. C (2011)
M. Defurne *et al*, Phys. Rev. Lett. (2016)
M. Mazouz *et al*, Phys. Rev. Lett. (2017)
M. Dlamini *et al*, Phys. Rev. Lett. (2021)

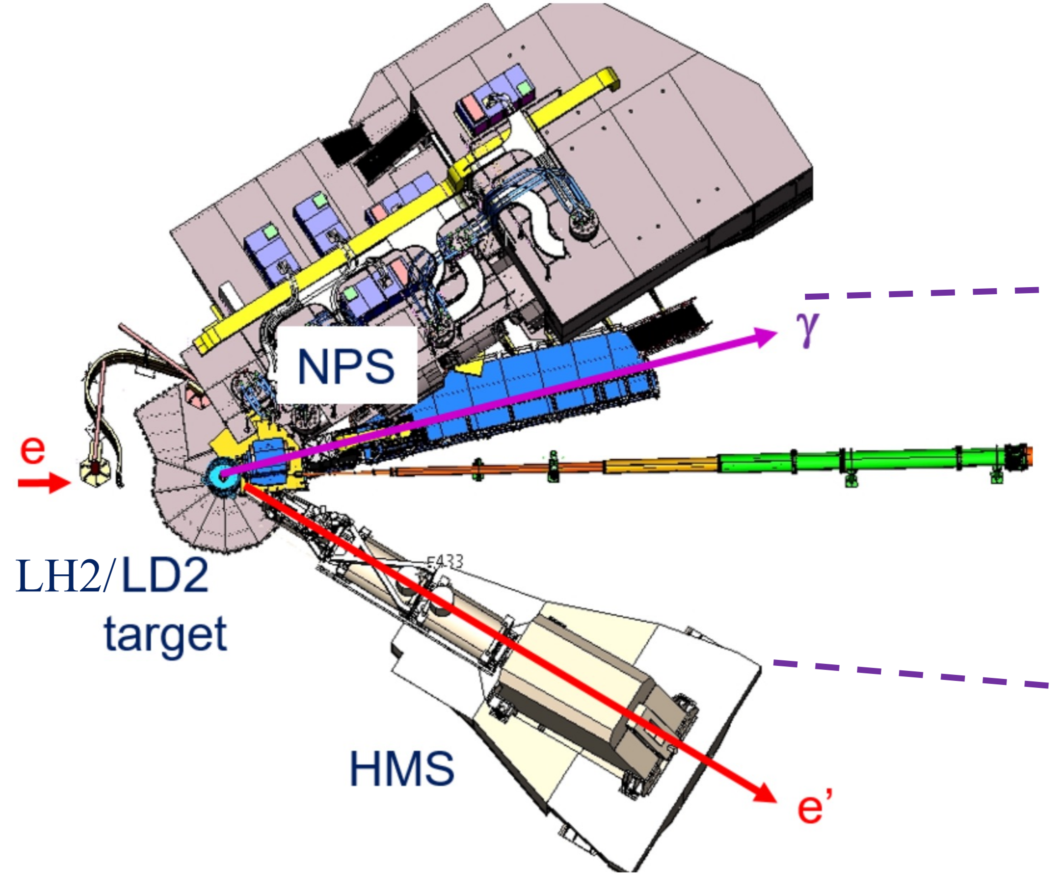
- 1st Generation (2004, 5.75 GeV)
  - ✓ 1st cross section measurement for exclusive π^0 electroproduction in the valence region
  - ✓ Results for $\sigma_0 = \sigma_T + \epsilon\sigma_L$, σ_{TL}, $\sigma_{TL'}$ and σ_{TT}:
    - ❑ Q^2 and x_B dependence
    - ❑ Transverse cross section is likely to dominate
- 2nd Generation (2010, 4.45 and 5.55 GeV)
  - ✓ Rosenbluth-like separation (both p and n):
    - ❑ Separate σ_T and σ_L
    - ❑ Seprate σ_{TL} and σ_{TT}
  - ✓ **The cross section is dominated by σ_T**
  - ✓ Non-zero longitudinal contribution σ_{TL}
- 3rd Generation (2014-2016, 4.5 to 11 GeV)
  - ✓ Results for $\sigma_0 = \sigma_T + \epsilon\sigma_L$, σ_{TL}, $\sigma_{TL'}$ and σ_{TT} for large $x_B(\leq 0.6)$ and $Q^2(\leq 8.4\ \text{GeV}^2)$
  - ✓ **Transverse cotribution continues to dominate the cross section throughout this kinematic range**
  - ✓ Data are still well described by GK model

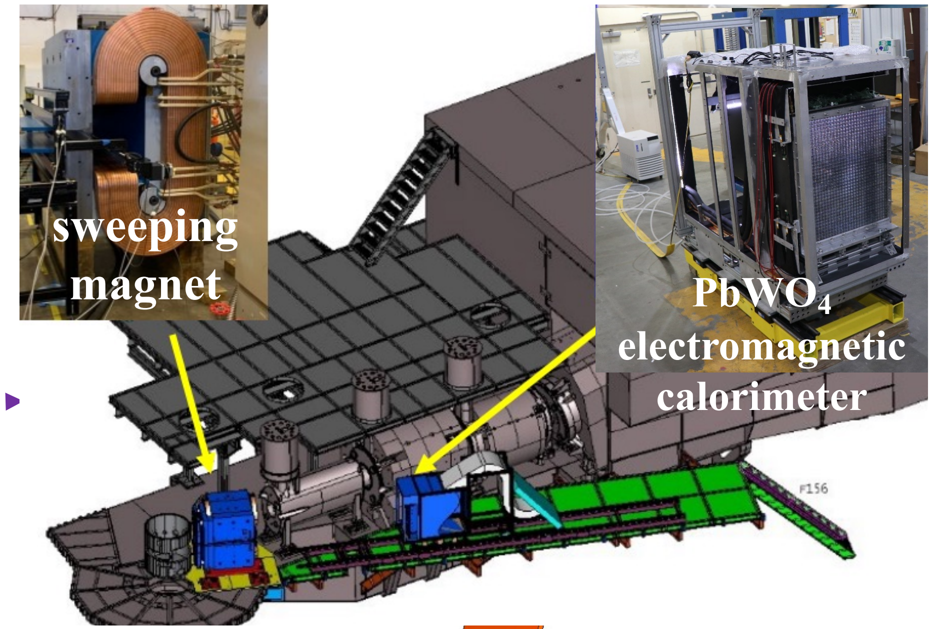


Goloskokov-Kroll (solid) and Goldstein (dashed) models

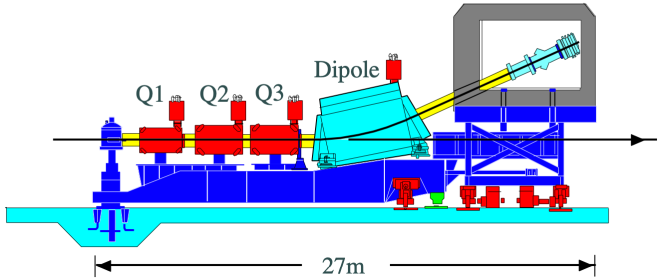
NPS Experiment in JLab Hall-C

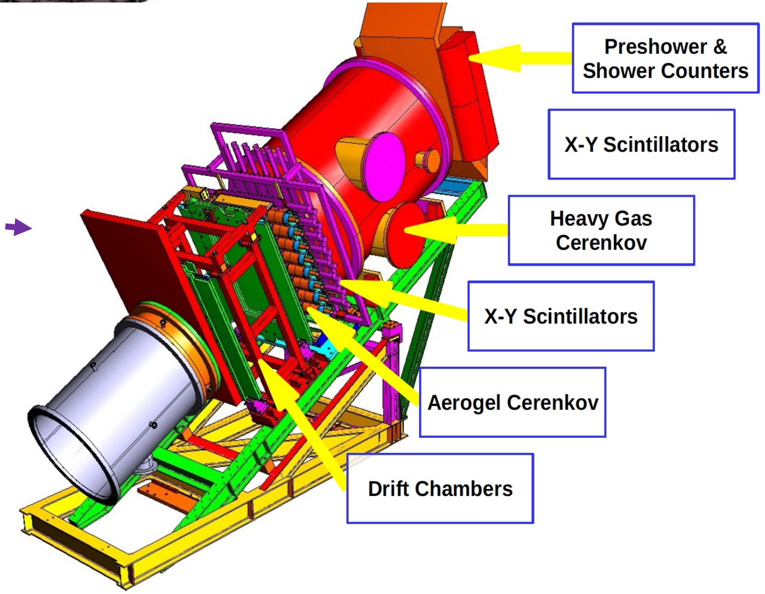
- **Latest Hall-C experiment (September 2023 - May 2024)**





$$\text{DVCS:} \quad H(e, e'_{HMS}, \gamma_{Calo})X$$
$$\text{DVMP:} \quad H(e, e'_{HMS}, \pi^0 \rightarrow \gamma\gamma)X$$

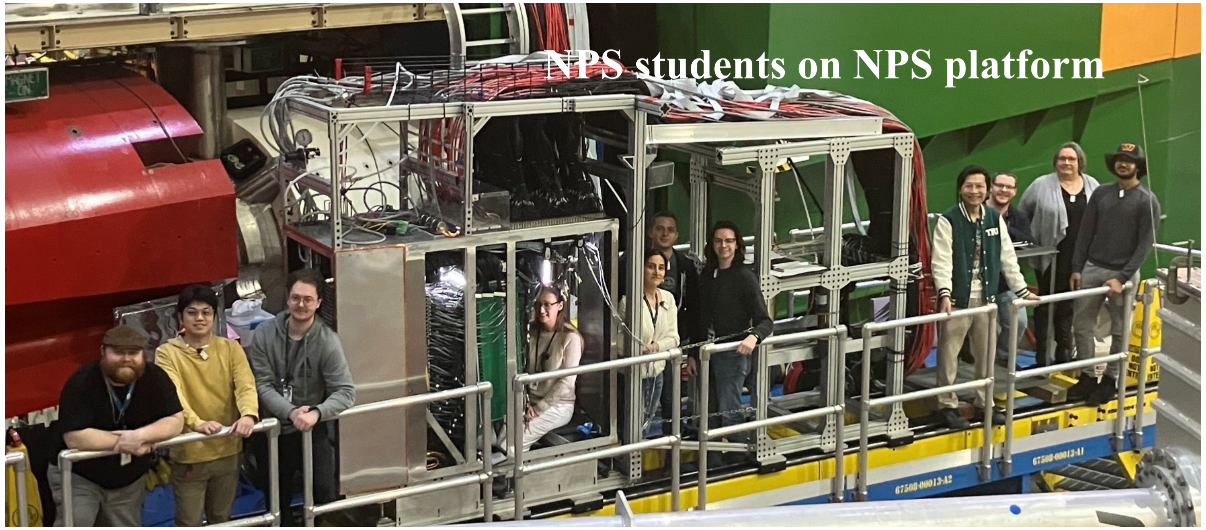


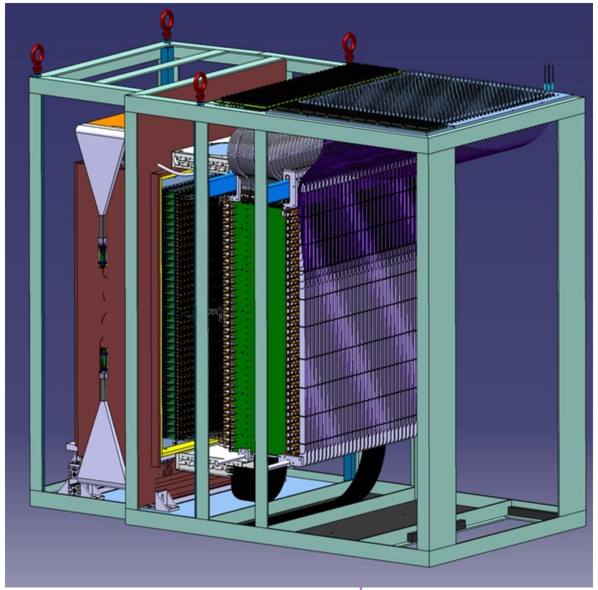


NPS Experiment in JLab Hall-C

NPS Calorimeter

- 1,080 $PbWO_4$ ($2x2cm^2$) blocks in 30x36 array
- 0.5mm carbon fiber grid to hold crystals
- 0.3 T·m sweeping magnet
- F250ADC sampling electronics for high data rate



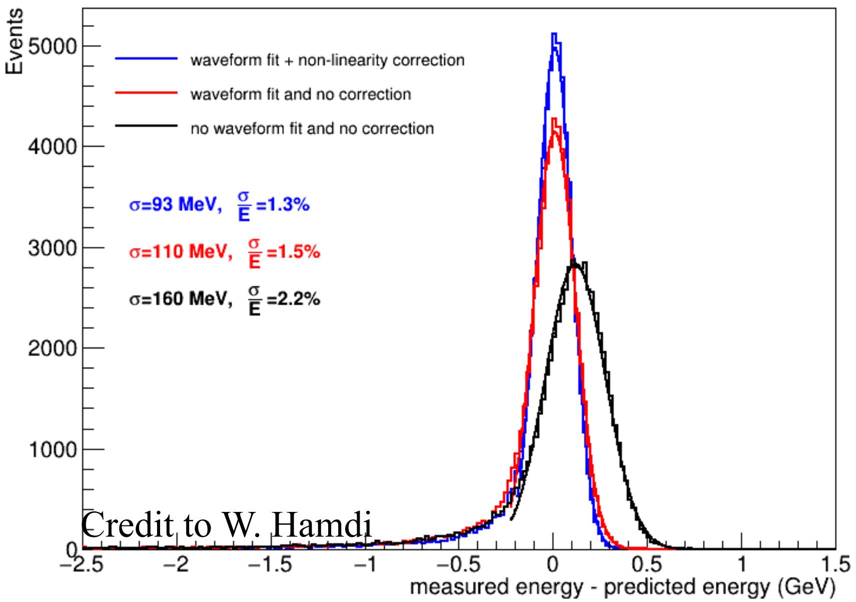


NPS Experiment in JLab Hall-C

Features and goals of this experiment

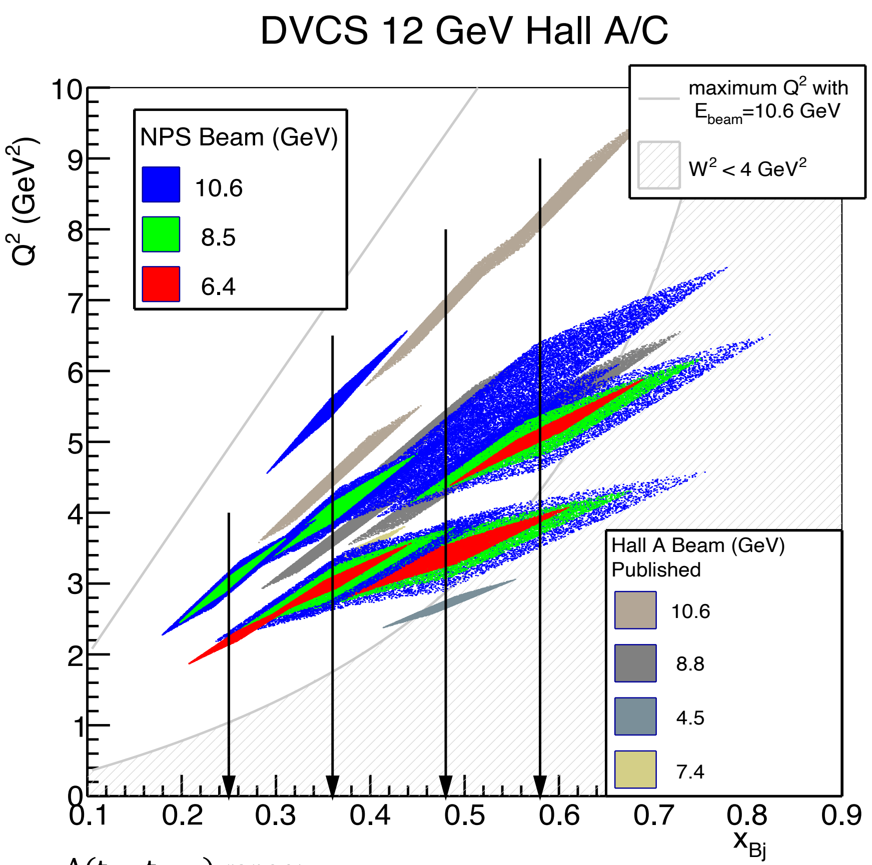
- High precision in cross-section measurement
- Expanded kinematic coverage to smaller values of x_B (0.25, 0.36, 0.48, 0.58)
- Multiple beam energies for most kinematic settings (6.4, 8.5, 10.5 GeV)
- DVCS:
  - Isolate all Fourier moments of the cross-section (E and ϕ dependence)
  - Quantify the size of higher-twist corrections (Q^2 dependence)
  - Isolate the imaginary and real part of the DVCS amplitude (helicity dependence)
- Exclusive π^0 electroproduction:
  - Separate the longitudinal and transverse contributions to the π^0 cross section
  - Measure the relative contribution of σ_L and σ_T to the cross section as a function of Q^2

NPS Energy Resolution



NPS Experiment in JLab Hall-C

Analysis status



$\Delta(t - t_{min})$ range:

- depends on the electron kinematics and NPS-target distance
- from 0.08 ($x_B = 0.25$) to 0.7 ($x_B = 0.58$) GeV^2

➢ Completed:

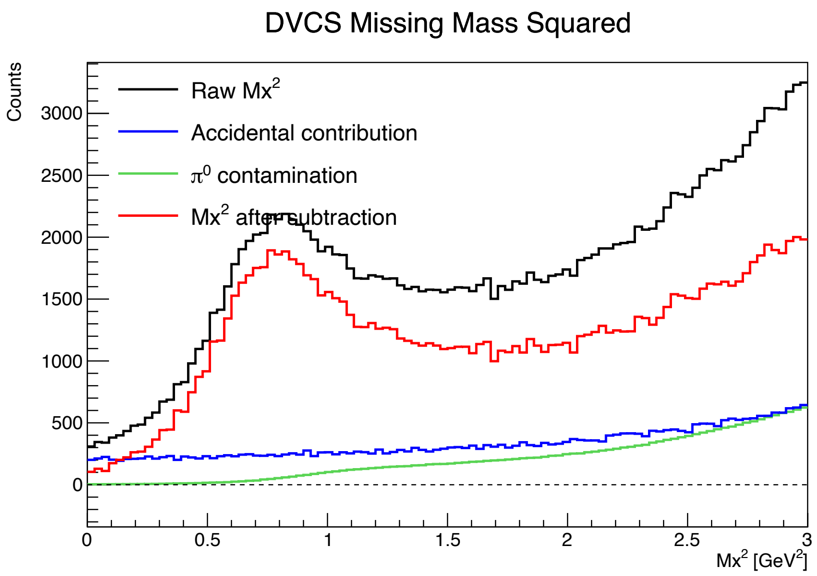
- beam line charge, energy, and polarization
- HMS detectors
- HMS optics (momentum above 5.5 GeV)

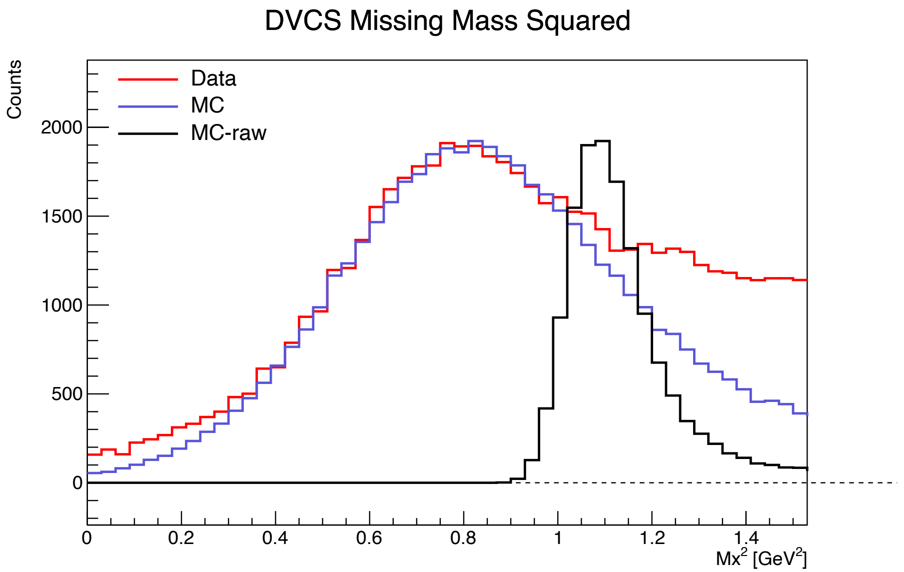
➢ In progress:

- NPS wave form fitting (multi threading)
- NPS energy calibration
- Match of NPS simulation with data
- Benchmarking against DIS cross sections (LH2 target issue)

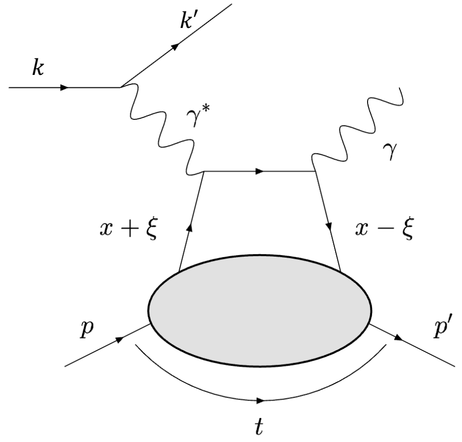
NPS Experiment in JLab Hall-C

Preliminary results





- DVCS missing mass distribution



$$p' = k + p - k' - \gamma$$

- ❑ Electron cuts, geometric cut
- ❑ Photon energy cut: 1.4 GeV
- ❑ Accidental coincidence subtraction
- ❑ π^0 contamination subtraction
- • The position of the peak is slightly off (calibration in progress)

- Simulation calibration and smearing
  - ❑ Energy leak: raw simulated missing mass is higher than 0.88 GeV^2
  - ❑ Simulation energy resolution is better than the data

$$\begin{pmatrix} q_x \\ q_y \\ q_z \\ E \end{pmatrix} \rightarrow \text{Gauss}(\mu, \sigma) \times \begin{pmatrix} q_x \\ q_y \\ q_z \\ E \end{pmatrix}$$

Summary

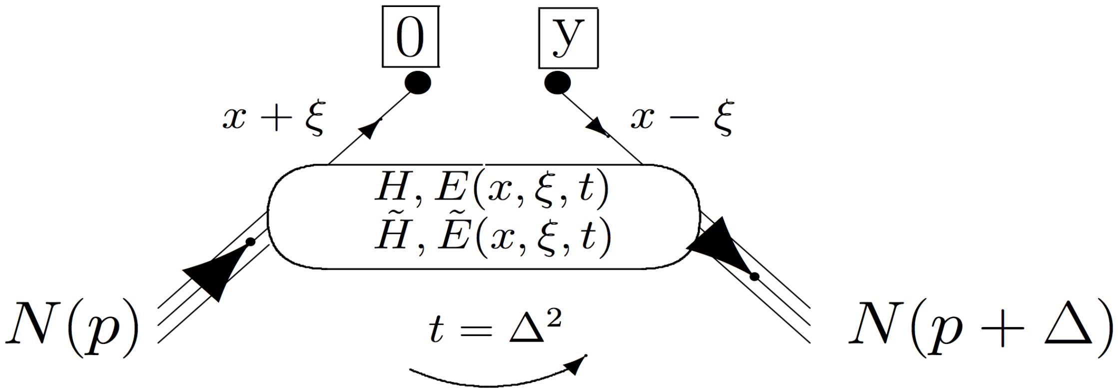
- **Introduction**
  - GPDs, DVCS and DVMP
- **Past experimental measurements**
  - H1 and ZEUS, HERMES, COMPASS, JLab (CLAS, Hall-A/C)
  - JLab Hall-A programs for DVCS
  - JLab Hall-A programs for hard exclusive pion electroproduction
- **The recent NPS experiment in JLab Hall-C**
  - Setup: HMS + NPS
  - Features and goals of this experiment
  - Analysis status & preliminary results
- **Outlook**
  - The NPS waveform fitting and energy calibration
  - Extract the cross sections and the CFFs soon

THANKS!

清華大學
Tsinghua University

Introduction to DVCS

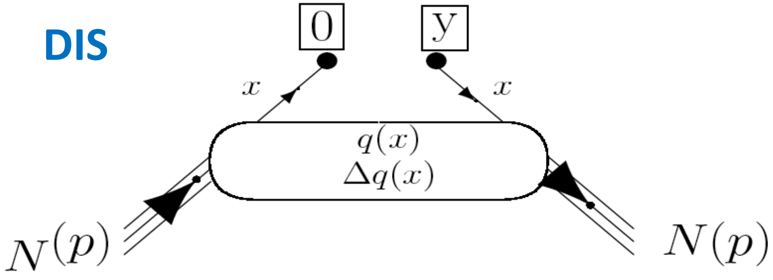
GPDs through DVCS



	Nucleon Helicity conserving	Nucleon Helicity non-conserving
unpolarized GPD	H	E
polarized GPD	H̃	Ẽ

$$\lim_{t\to 0}(GPD) \to PDF$$

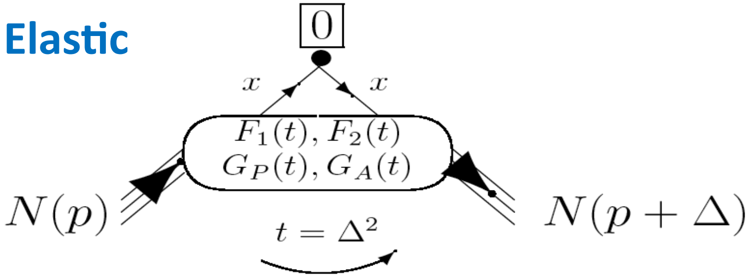
DIS



$$H^i(x,0,0) = q_i(x)$$
$$\tilde{H}^i(x,0,0) = \Delta q_i(x)$$

GPD first moments $\to$ Form Factors

Elastic

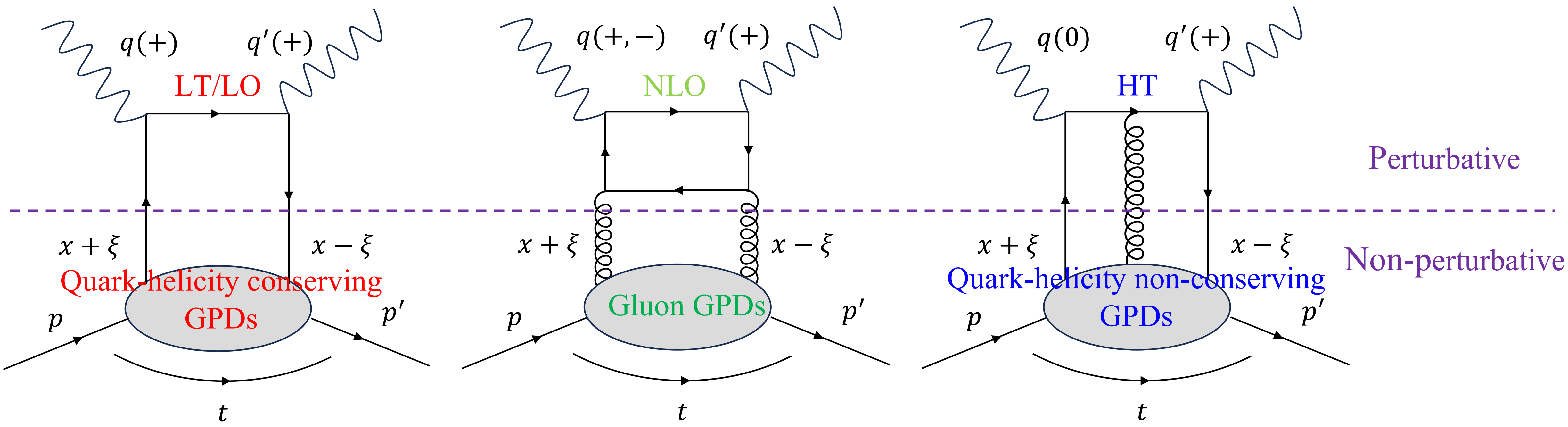


$$\int_{-1}^{1} dx H^i(x,\xi,t) = F_1^i(t) \quad \forall\xi$$
$$\int_{-1}^{1} dx E^i(x,\xi,t) = F_2^i(t) \quad \forall\xi$$
$$\int_{-1}^{1} dx \tilde{H}^i(x,\xi,t) = G_A^i(t) \quad \forall\xi$$
$$\int_{-1}^{1} dx \tilde{E}^i(x,\xi,t) = G_p^i(t) \quad \forall\xi$$

Introduction to DVCS

Order, twist: examples for DVCS

Leading order, leading twist | Next-to-leading order, leading twist | Leading order, higher twist (twist 3)

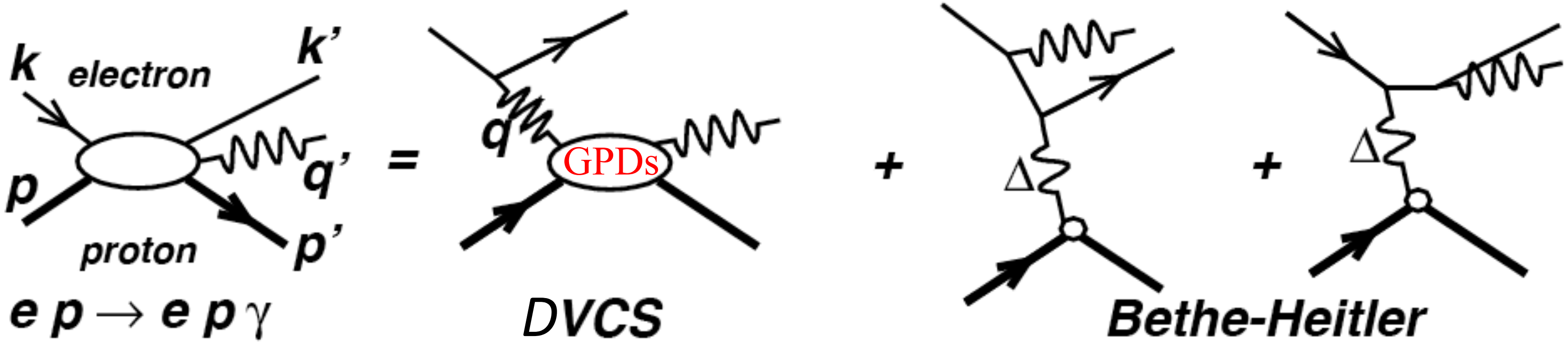


- Order appears as powers of α_s
- Twist appears as powers of $1/\sqrt{Q^2}$ in the DVCS amplitude
- General definition of twist of an operator: $\tau = d - s$
- Leading twist: twist = 2

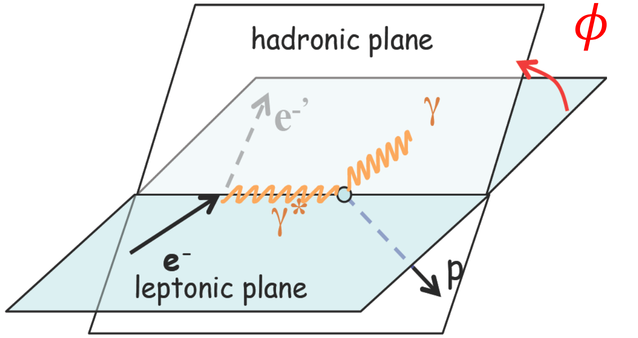
twist dimension spin

Introduction to DVCS

Measuring DVCS to access GPDs information



$$\frac{d^4\sigma(lp \to lp\gamma)}{dx_B dQ^2 d|t| d\phi} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_l \; d\sigma^{DVCS}_{pol} + e_l\,(Re(I) + P_l Im(I))$$



Known if Nucleon FFs are known

Bilinear combinations of CFFs

Linear combinations of CFFs and FFs

P_l : polarization target or beam

e_l : charge of the lepton beam

Compton Form Factors:

GPDs

CFFs → $\mathcal{F}(\xi,t) = \sum_f \left[\frac{e_f}{e}\right]^2 \left\{ i\pi\left[F_f(\xi,\xi,t) \mp F_f(-\xi,\xi,t)\right] + \mathcal{P}\int_{-1}^{+1} dx \left[\frac{1}{x-\xi} \mp \frac{1}{x+\xi}\right] F_f(x,\xi,t) \right\}$

$\xi \simeq x_B/(2 - x_B)$

Introduction to DVMP

■ Measuring DVMP to access GPDs information

M. Diehl,. Phys. Rept. (2003)
J. P. Lansberg *et al*, PRD (2007)
S. V. Goloskokov *et al*, Eur. Phys. J. A (2011)
G. R. Goldstein *et al*, PRD (2015)
L. Favart *et al*, Eur. Phys. J. A (2016)

➢ Longitudinal amplitude for π^0 electroproduction (involves the chiral-even GPDs)

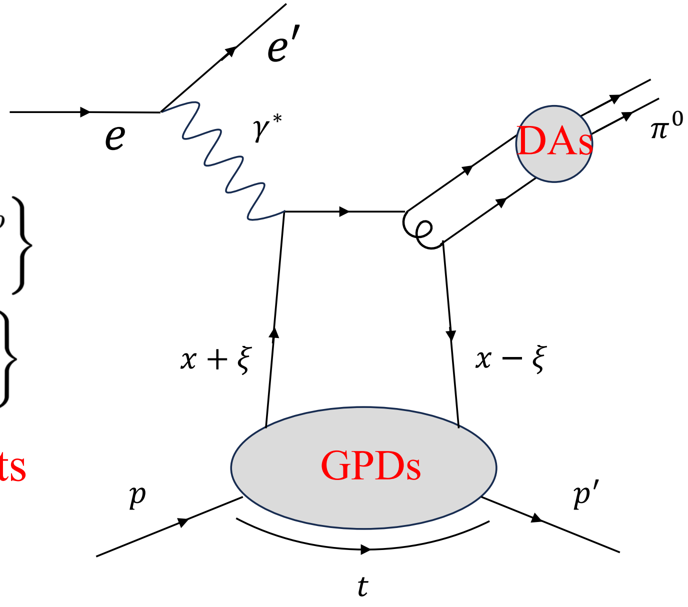
At leading order and twist: chiral-even twist-2 DA

$$\mathcal{M}^L_{\pi^0} = -ie\frac{4}{9}\frac{1}{\sqrt{Q^2}}4\pi\alpha_S\left[\int_0^1 dz\frac{\Phi_{\pi^0}(z)}{z}\right]\times\frac{1}{2}\int_{-1}^{1}dx\left[\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi+i\epsilon}\right]$$

$$\left\{\tilde{H}^p_{\pi^0}(x,\xi,t)\bar{N}(p')\not{n}\gamma^5 N(p)+\frac{\xi}{2M}\tilde{E}^p_{\pi^0}(x,\xi,t)\bar{N}(p')\gamma^5 N(p)\right\}$$

$$\tilde{H}^p_{\pi^0}(x,\xi,t)=\frac{1}{\sqrt{2}}\left\{\frac{2}{3}\tilde{H}^{u/p}_{\pi^0}-\left(-\frac{1}{3}\right)\tilde{H}^{d/p}_{\pi^0}\right\}$$

$$\tilde{E}^p_{\pi^0}(x,\xi,t)=\frac{1}{\sqrt{2}}\left\{\frac{2}{3}\tilde{E}^{u/p}_{\pi^0}-\left(-\frac{1}{3}\right)\tilde{E}^{d/p}_{\pi^0}\right\}$$



➢ Twist-3 DA and transversity GPDs

❖ Handbag factorization (L dominates) conflicts with the experimental measurements

❖ New models involving transversity GPDs (couple with twist-3 DAs):

- Twist-3 contributions are kinematically suppressed compared to the twist-2 ones
- Twist-3 DAs include a mass parameter $\mu_\pi = \frac{m_\pi^2}{m_u+m_d} \approx 2.67$ GeV

$$\frac{d\sigma_T}{dt}=\frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\left[(1-\xi^2)\left|\langle H_T\rangle\right|^2-\frac{t'}{8m^2}\left|\left\langle 2\tilde{H}_T+E_T\right\rangle\right|^2\right] \qquad \frac{d\sigma_{TT}}{dt}=\frac{4\pi\alpha}{2k'}\frac{\mu_\pi^2}{Q^8}\frac{t'}{16m^2}\left|\left\langle 2\tilde{H}_T+E_T\right\rangle\right|^2$$

Backup

Hall-C NPS DVCS Experiment Kinematics

- Data taken in 2023

x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)
0.36	KinC_x36_3	5	3.0
	KinC_x36_5	5	4.0
	KinC_x36_2	4	3.0
0.50	KinC_x50_2	5	3.4
	KinC_x50_3	5	4.8
	KinC_x50_1	4	3.4
0.6	KinC_x60_3	5	5.1
	KinC_x60_2	4	5.1

- Data taken in 2024

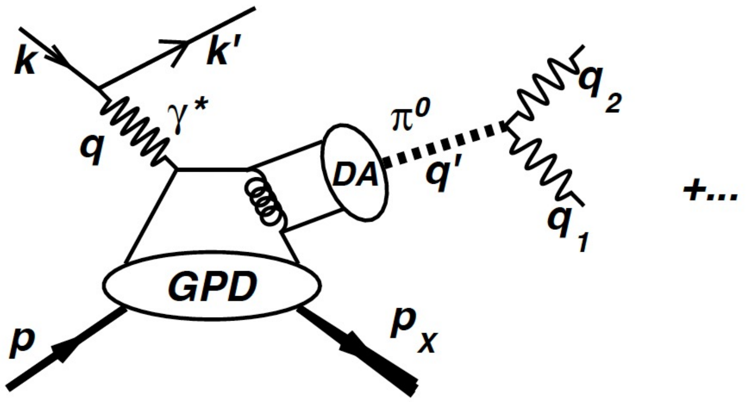
x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)
0.25	KinC_x25_1	5	2.1
	KinC_x25_2	5	2.4
	KinC_x25_3	4	2.4
	KinC_x25_4	3	3.0
0.36	KinC_x36_6	5	5.5
	KinC_x36_4	4	4.0
	KinC_x36_1	3	3.0
0.5	KinC_x50_0	3	3.4
0.6	KinC_x60_4	5	6.0
	KinC_x60_1	3	5.1

Backup

Hall-A DVCS experiments

M. Defurne *et al*, Phys. Rev. Lett. (2016)

- Definition of t_{min}



Invariants

$$Q^2 = -(k - k')^2$$

$$x_B = Q^2/(2q \cdot P)$$

$$W^2 = (q + P)^2$$

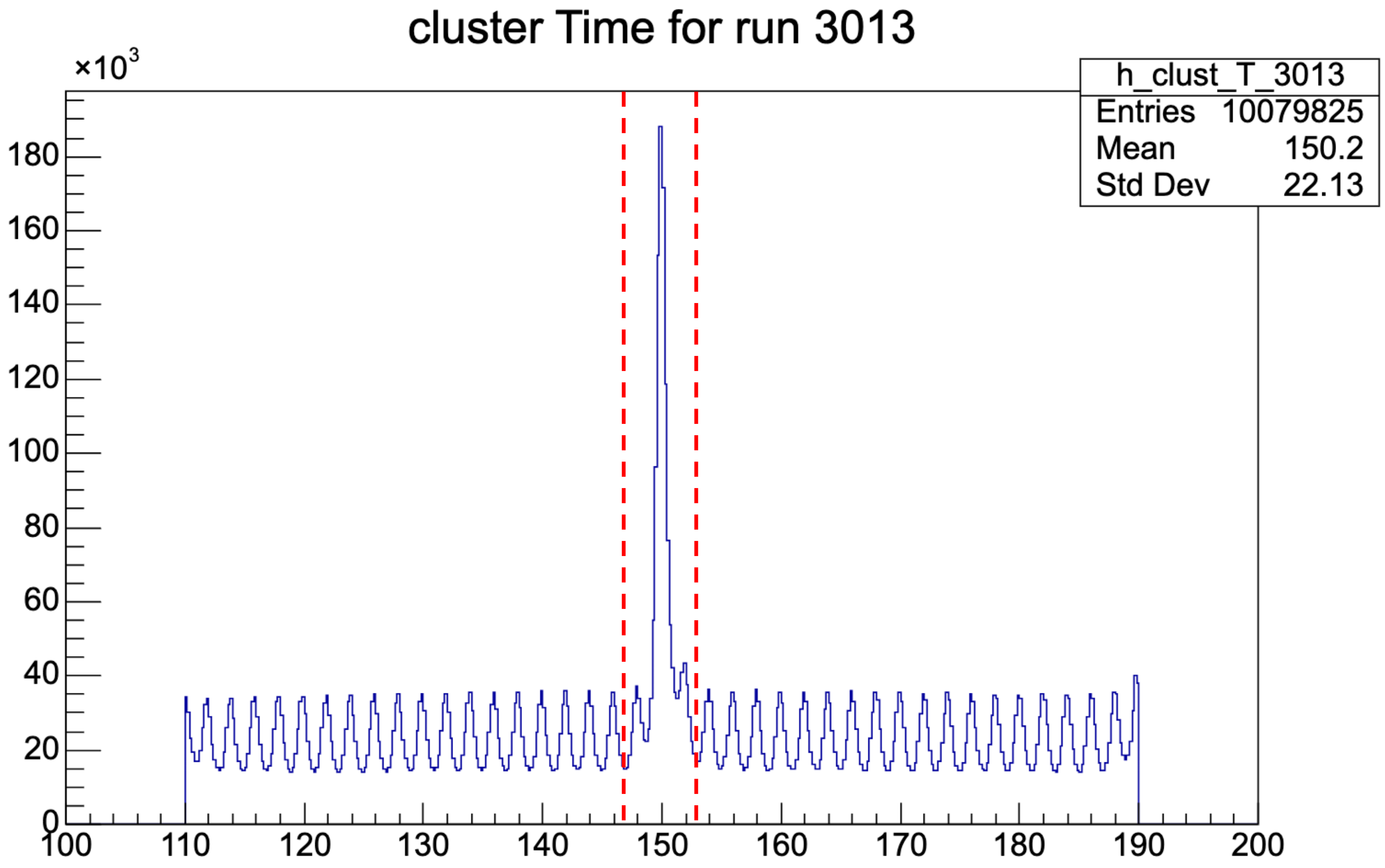
$$t = (q - q')^2$$

FIG. 1. Diagram of the exclusive π^0 electroproduction reaction, identified by the $\pi^0 \to \gamma\gamma$ decay mode. The value of t with minimal $|t|$ can be evaluated as $t_{\min} = (Q^2 + m_\pi^2)^2/(4W^2) - (|q^{\mathrm{c.m.}}| - |q'^{CM}|)^2$, with $|q^{\mathrm{c.m.}}|$ and $|q'^{CM}|$ the norms of $\vec{q}$, $\vec{q'}$ in the $p\pi^0$ final state center-of-mass frame.

DVCS Missing Mass Reconstruction

All the applied cuts

- BCM4A beam current > $2\mu A$
- EDTM TDC time < 10.
- dp/p $\in [-8, 8]$
- vertex_z $\in [-4, 4]$
- npesum > 2
- etracknorm $\in [0.7, 1.3]$
- cluster time $\in [146.8, 152.8]$

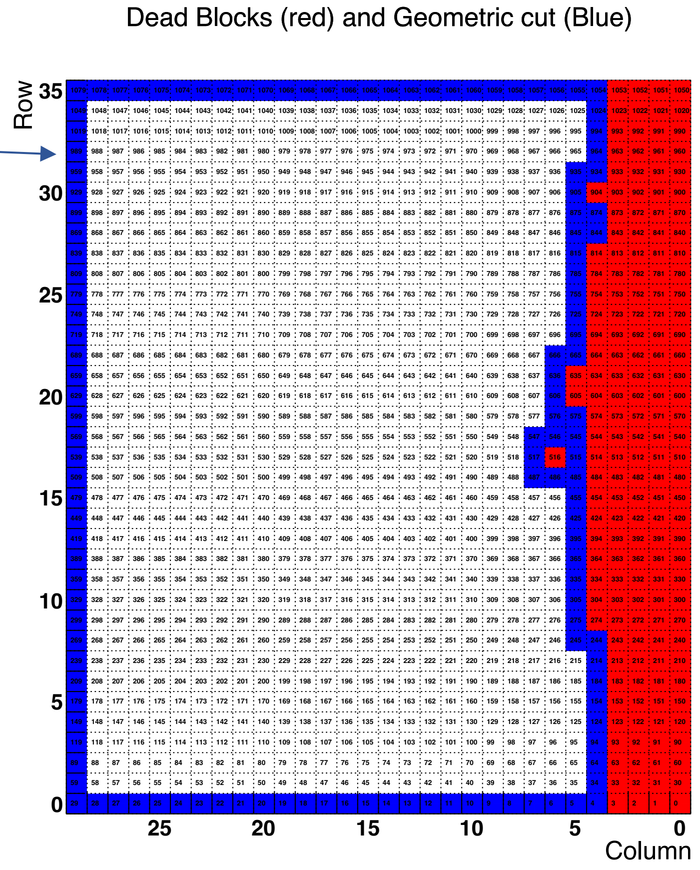


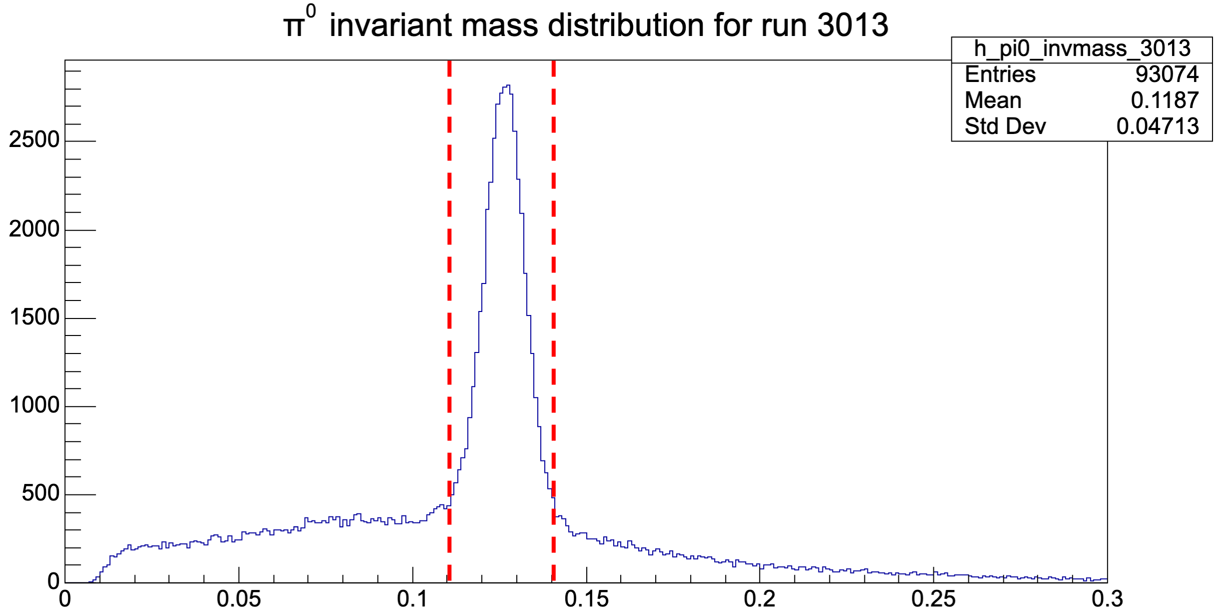
Run 3013, LH2 production, 30 μA

DVCS Missing Mass Reconstruction

DVCS event selection

- geometrical cut on the calorimeter
- cluster time ∈ [146.8, 1.52.8]
- DVCS cluster energy > 1.4 GeV
- Ignore the events with correct π^0 invariant mass (∈ [0.11,0.14])
  - π^0 reconstruction: (same geometrical cut, same cluster time cut) both of the photons > 0.65GeV





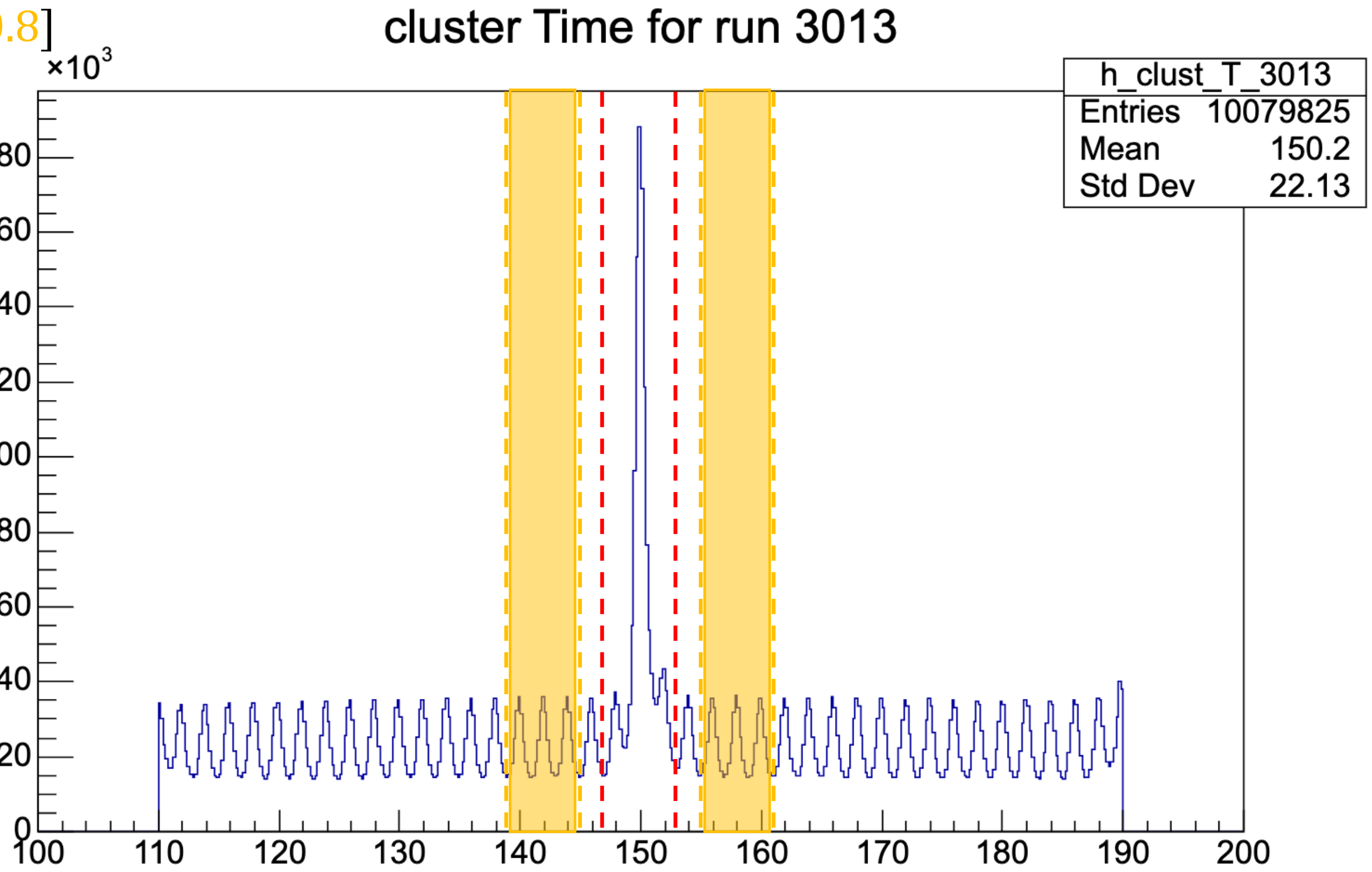
Run 3013		
clus_thresh	sing_phot_thresh	two_clus_thresh
500 MeV	1400 MeV	650 MeV

DVCS Missing Mass Reconstruction

Accidental contribution subtraction

- cluster time selection
  - cluster time ∈ [146.8, 152.8]
  - left accidental cluster time ∈ [138.8, 144.8]
  - right accidental cluster time ∈ [154.8, 160.8]
- Fill the histograms for subtraction
  - histogram: DVCS missing mass squared
  - 3 histograms:
    - ✓ h = Mx2_raw
    - ✓ h1 = Mx2_random_left
    - ✓ h2 = Mx2_random_right
  - The histogram after subtraction is:
    - ✓ h − (h1 + h2) * 0.5

Run 3013, LH2 production, 30 μA

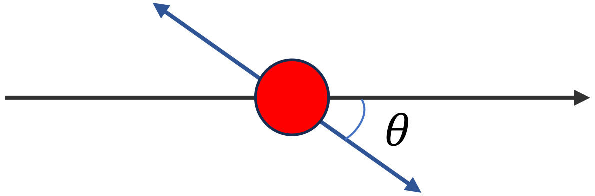


DVCS Missing Mass Reconstruction

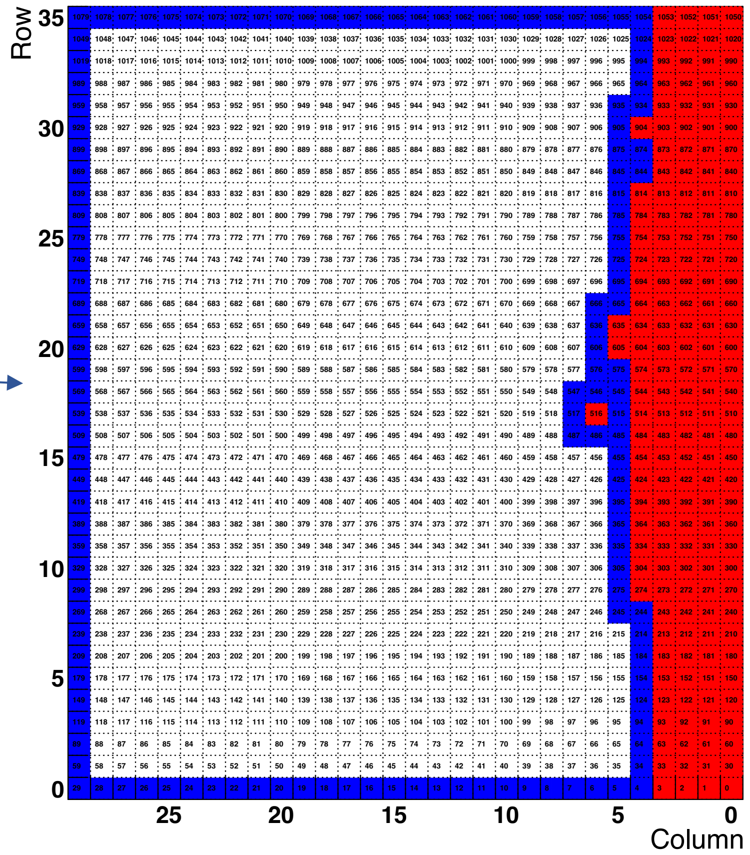
π^0 contamination subtraction

- reconstructed π^0 event selection:
  - geometrical cut on the calorimeter
  - energy threshold of the two photons
  - invariant mass cut ([0.11,0.14] GeV)
- For each selected π^0 event, do the following simulation:
  - boost the four-momentum of the two photons to their rest frame
  - simulate the 2-photon decay randomly in the solid angle 5000 times
    - $\cos\theta \in [0, 1]$
    - $\varphi \in [0, 2\pi]$
  - boost two photons to the lab frame and determine how many photons are received by the calorimeter
    - geometrical cut on the calorimeter
    - NPS_target_distance in “standard_coin.kinematics”
  - Fill the missing mass histogram:
    - only one photon is accepted by the calorimeter
    - the photon energy is larger than the DVCS photon threshold
    - weight the whole histogram with the factor: 1/N

    (N = number of the simulated events that 2 photons are in acceptance)



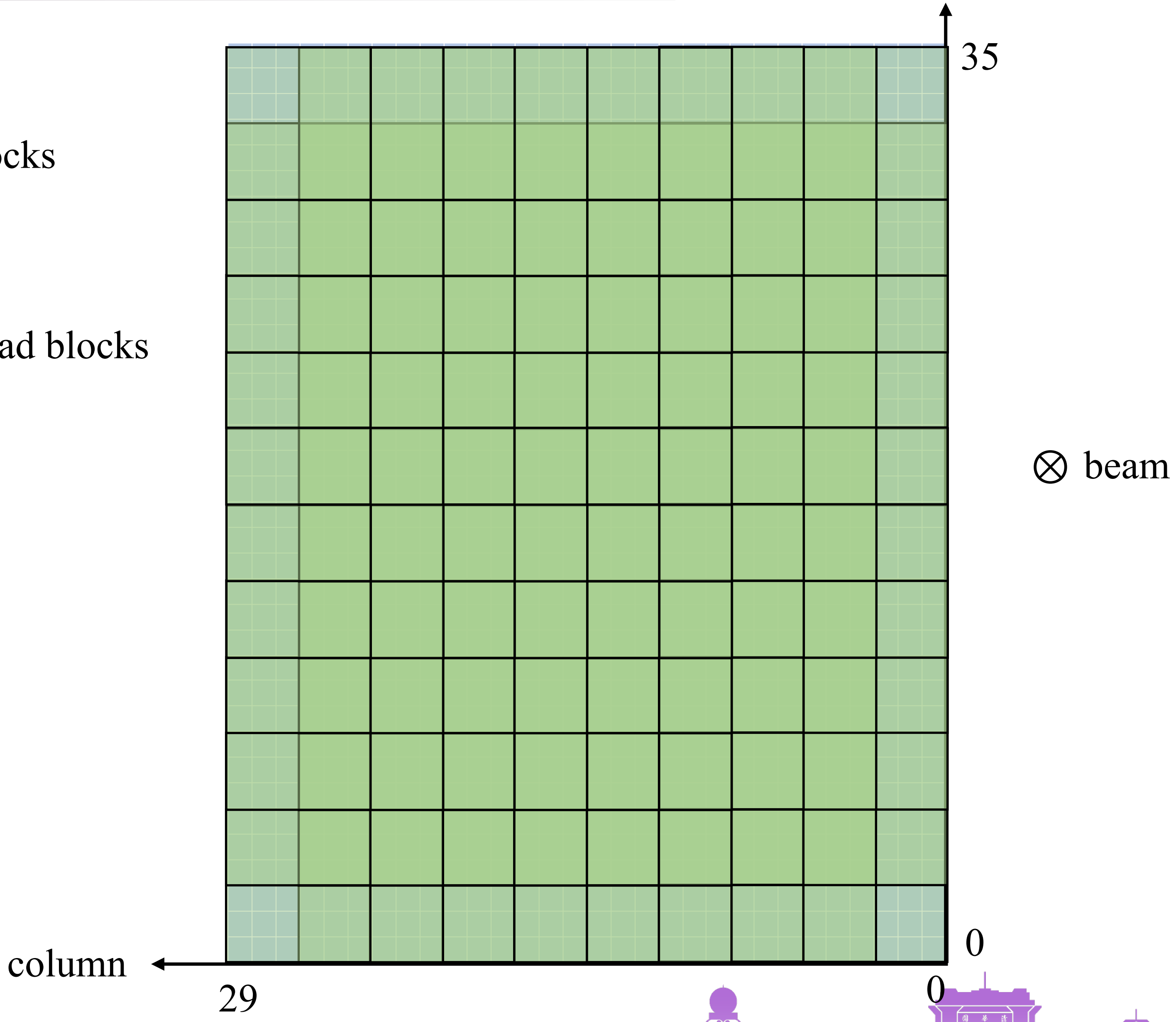
Dead Blocks (red) and Geometric cut (Blue)



Divide NPS into Square Regions

Front view of the NPS calorimeter

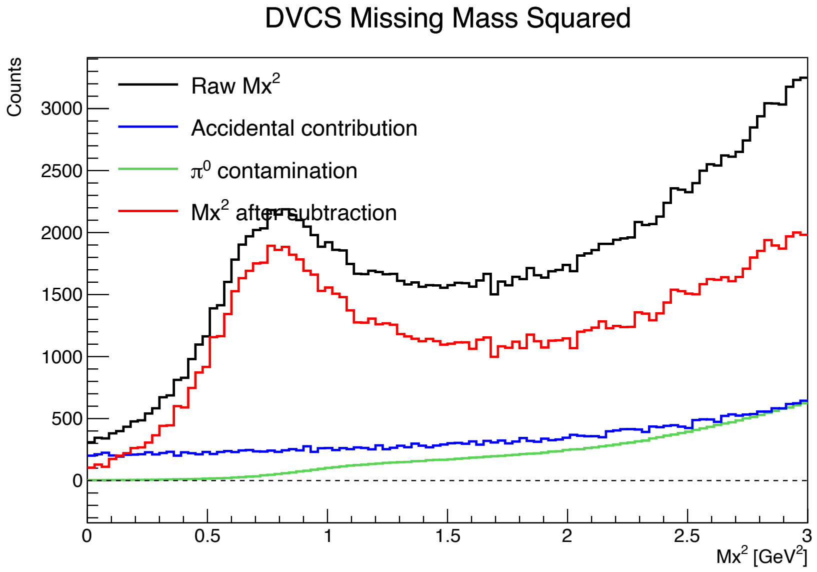
- Divide NPS into 99 square regions
  - ✓ Each single square region contains 6×6 blocks
  - ✓ Adjacent regions have overlapping area
  - ✓ There are 9 different columns of regions
  - ✓ There are 11 different rows of regions
- The regions are decided independently of the dead blocks

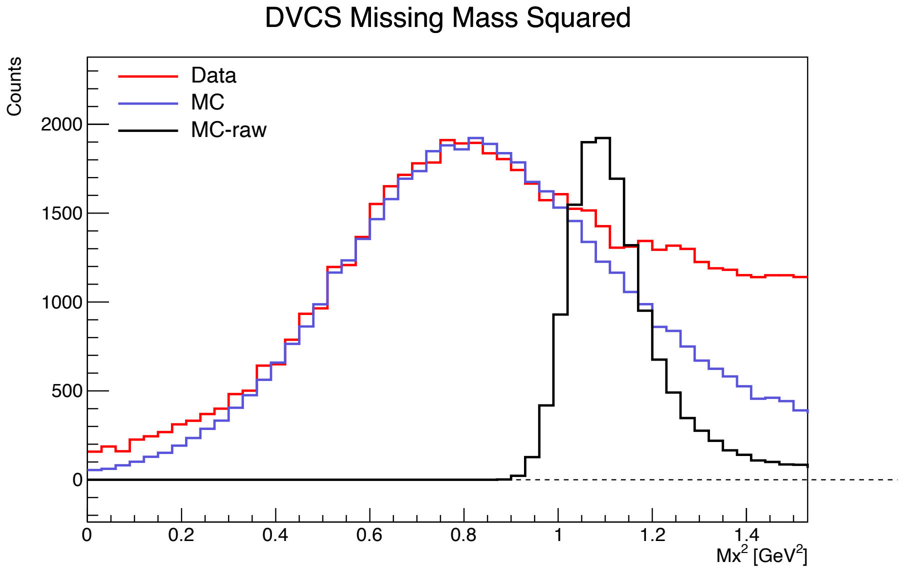


Simulation smearing

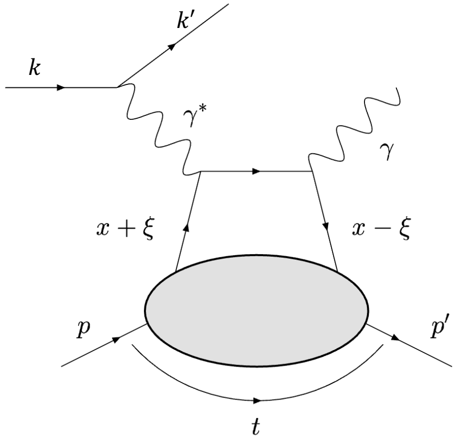
Tsinghua University

Preliminary results





- DVCS missing mass distribution



$$p' = k + p - k' - \gamma$$

- ❑ Electron cuts, geometric cut
- ❑ Photon energy cut: 1.4 GeV
- ❑ Accidental coincidence subtraction
- ❑ π^0 contamination subtraction
- The position of the peak is slightly off (calibration in progress)

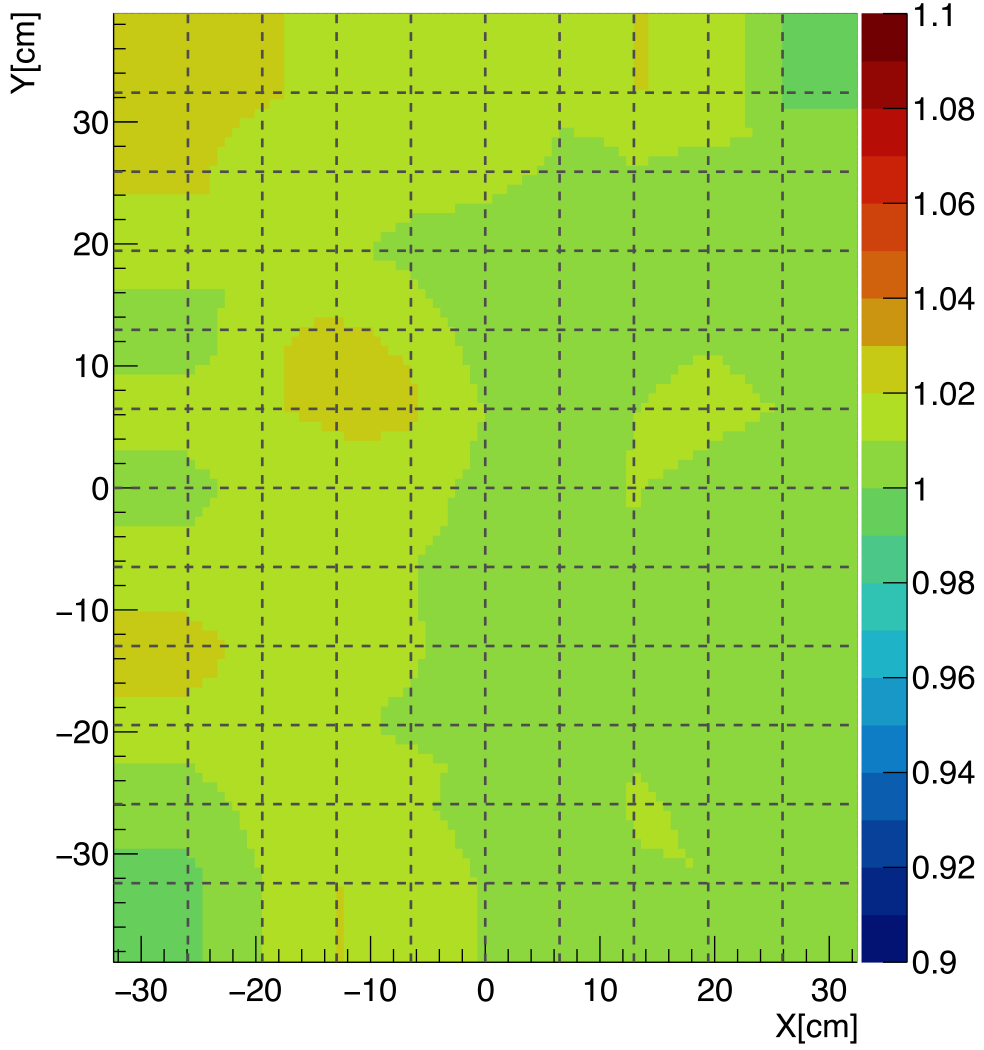
- Simulation calibration and smearing
  - ❑ Energy leak: raw simulated missing mass is higher than 0.88 GeV^2
  - ❑ Simulation energy resolution is better than the data

$$\begin{pmatrix} q_x \\ q_y \\ q_z \\ E \end{pmatrix} \rightarrow \text{Gauss}(\mu, \sigma) \times \begin{pmatrix} q_x \\ q_y \\ q_z \\ E \end{pmatrix}$$

Simulation smearing

Preliminary results

Smearing mean



Smearing sigma