Neutron DVCS Cross Section Extraction at the CLAS12 Experiment

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Outline

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- nDVCS event selection
- Extraction of cross section
- Systematic uncertainties
- Preliminary cross section
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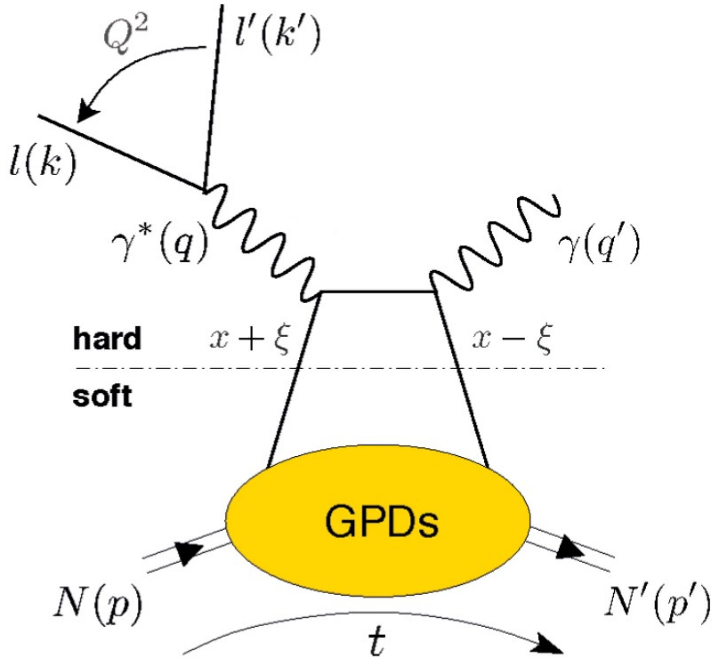
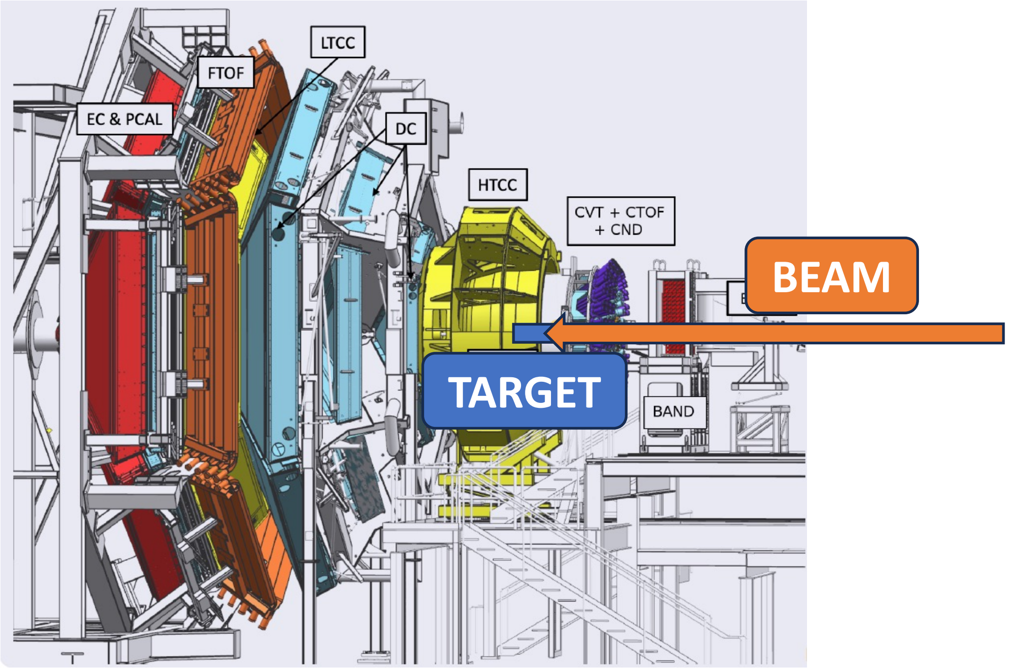
Motivation: probe nucleon structure

- Generalized Parton Distributions (GPDs)
  - Relate transverse position of partons to their longitudinal momentum
  - Give access to the angular momentum of quarks and gluons, the missing ingredient for understanding the nucleon spin composition
- Deeply Virtual Compton Scattering (DVCS)
  - Access to GPDs-related quantities: Compton Form Factors (CFFs)
- The measurement of DVCS cross-section from the neutron can provide unique information on GPDs
  - GPD E is largely unknown so far
  - The unpolarized cross-section of nDVCS is sensitive mainly to the real CFF of E
  - The polarized cross-section difference of nDVCS is sensitive to the imaginary CFF of E



Data and MC samples

- Data
  - RGB data, collected in 2019 spring and 2020 spring (inbending)
  - 10.6/10.4/10.2 GeV electron beam
    - With an average polarization of 86%
    - Scattering off an unpolarized liquid deuterium target of 5 cm length
- MC
  - Generator: genepi
  - 210M DVCS events
    - 70M for each energy
    - nDVCS: 50M events
    - pDVCS: 160M events

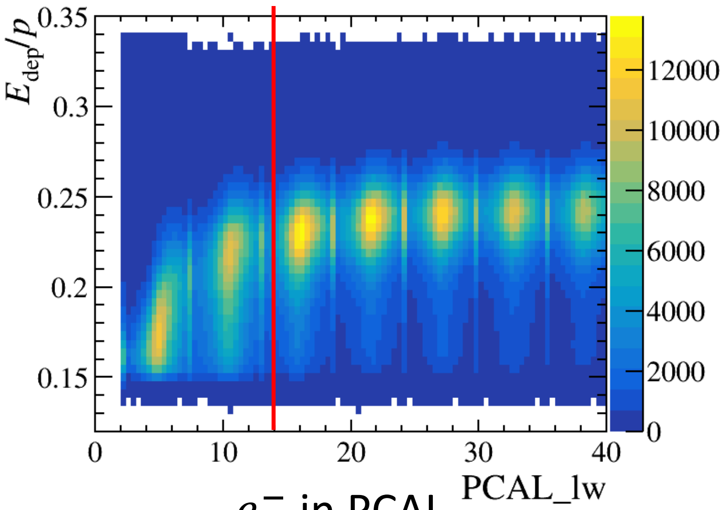


Run period	Beam energy	Accumulated charge	Luminosity	Fraction of total
2019 spring	10.6 GeV	20.91 mC	$31.7 \times 10^3\,\mathrm{pb}^{-1}$	23.6%
2019 spring	10.2 GeV	39.34 mC	$59.6 \times 10^3\,\mathrm{pb}^{-1}$	44.4%
2020 spring	10.4 GeV	28.32 mC	$42.9 \times 10^3\,\mathrm{pb}^{-1}$	32.0%

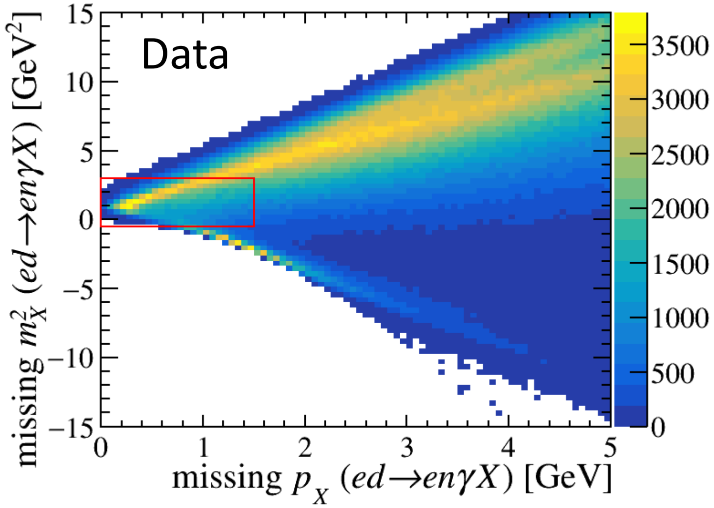
Select nDVCS data

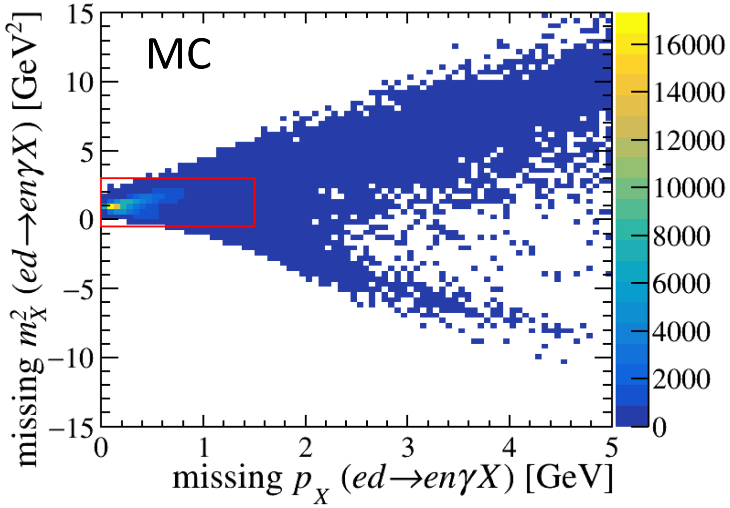
- Select $en\gamma$ final states
  - $p_e > 1$ GeV, $p_n > 0.35$ GeV, $p_\gamma > 2$ GeV
  - Fiducial cuts
- Reaction kinematics: $Q^2 > 1$ GeV^2 , $W > 2$ GeV
- Pre-selection on missing m_X^2 and p_X of $ed \to en\gamma X$
  - Reduce events from other channels

Electron	Photon	Neutron
In FD: PCAL: lv(lw) > 14 DC: edge > 6	In FD: PCAL: lv(lw) > 14	In CD: $40° < \theta_n < 140°$
	In FT: $x^2 + y^2 > 72$	
Pre-selection	$-0.5 < m_X^2 < 3$ GeV^2 $0 < p_X < 1.5$ GeV	



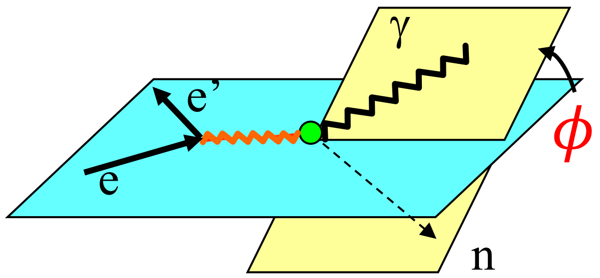
e^- in PCAL



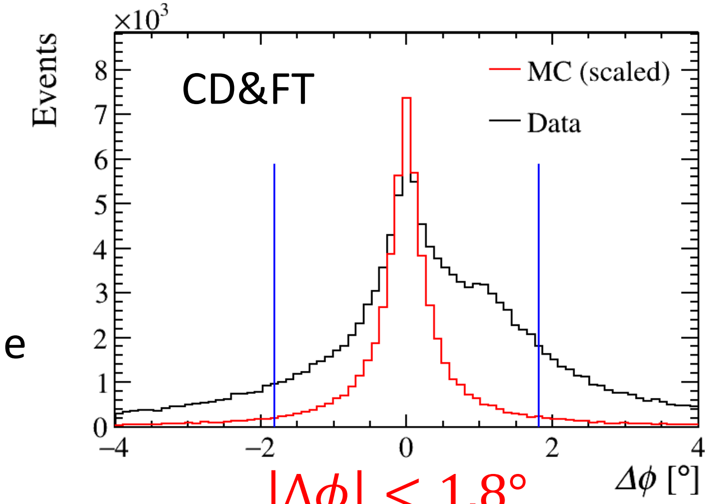


Exclusivity selection

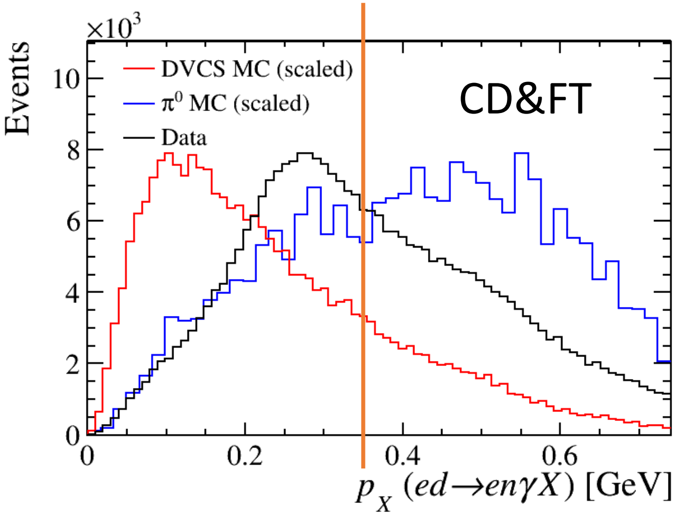
- Exclusivity variables
  - $\Delta\phi$, missing m_X^2 of $en \rightarrow en\gamma X$, m_X^2 and p_X of $ed \rightarrow en\gamma X$, etc.
- Selection criteria determined from MC
  - Separately for CD&FT (n in CD & γ in FT) and CD&FD (n in CD & γ in FD)



ϕ: angle between leptonic plane and hadronic plane



$|\Delta\phi| < 1.8°$



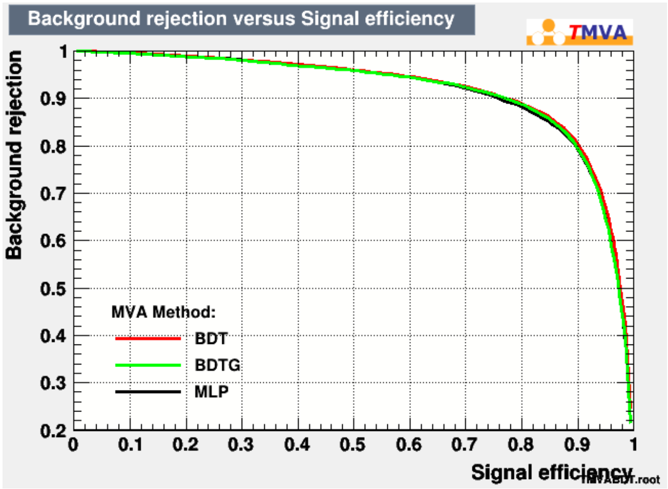
- $\Delta\phi$: difference in ϕ between
  - hadronic plane formed by the neutron and the virtual photon
  - hadronic plane formed by the neutron and the outgoing photon

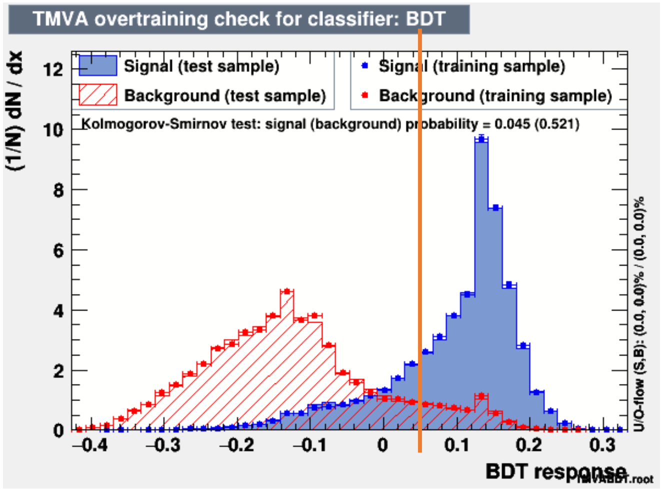
- $p_X < 0.35$ GeV for $ed \rightarrow en\gamma X$
  - The π^0 background $ed \rightarrow en\pi^0(\rightarrow \gamma\gamma)$ contributes to larger p_X

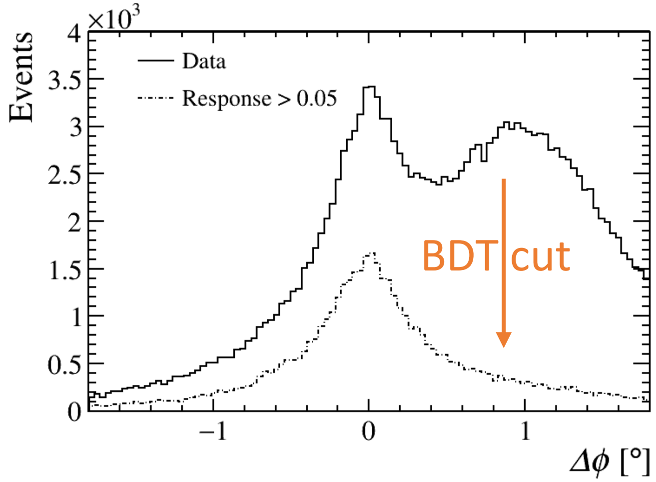
➢ The data and MC distributions are different at this stage
  ➢ Mainly due to backgrounds in data: fake neutrons and π^0 contamination

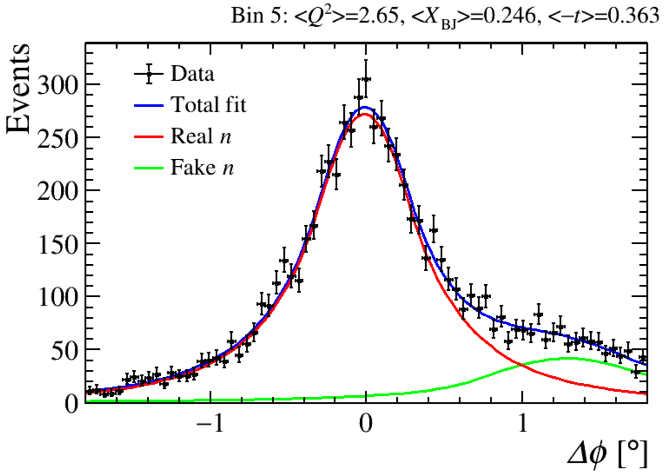
Use BDT to reduce fake neutrons

- Fake neutron background
  - The tracking system (CVT) in CD has dead or low-efficiency regions
  - Protons having no tracks in CVT but hits in CND will be misidentified as neutrons
- Boosted Decision Tree (BDT)
  - Training sample:
    - MC with n/p target
  - Training variables:
    - Info at CTOF, CVT and CND
  - Selection:
    - BDT response > 0.05
- The remaining fake neutrons after the BDT cut is subtracted by the $\Delta\phi$ fit in kinematic bins









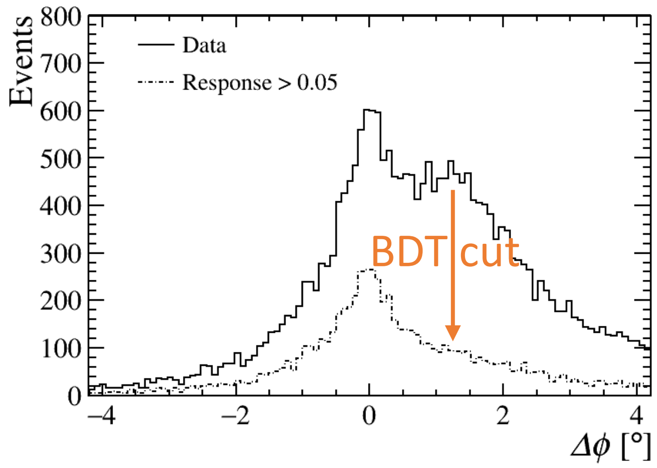
Study of π^0 production contamination

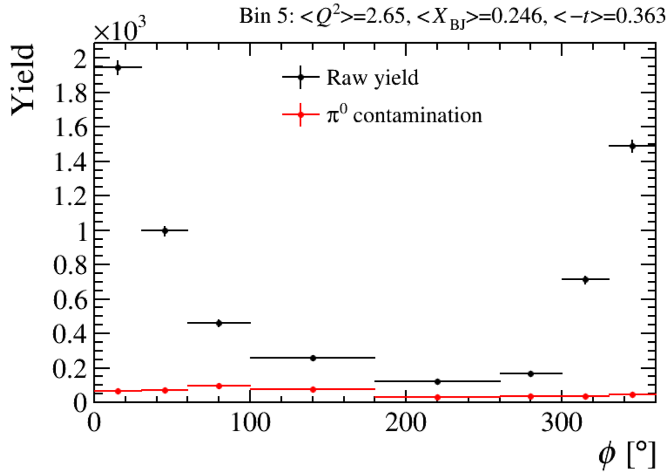
- $en \rightarrow en\pi^0(\rightarrow \gamma\gamma)$ background subtraction:
  - $N_{\mathrm{DVCS}} = N_{\mathrm{en}\gamma} - N_{en\pi^0} \times f^{\mathrm{MC}} = N_{\mathrm{en}\gamma} - N_{en\pi^0} \times \frac{N^{\mathrm{MC}}_{en\pi^0(1\gamma)}}{N^{\mathrm{MC}}_{en\pi^0(2\gamma)}}$

Partially reconstructed $en\pi^0(1\gamma)$ passing DVCS selection

Fully reconstructed $en\pi^0(2\gamma)$ passing π^0 production selection

- Select π^0 production data
  - Select $en\gamma\gamma$ final states
    - $p_e > 1$ GeV, $p_n > 0.35$ GeV, $p_\gamma > 0.6$ GeV, $0.10 < m_{\gamma\gamma} < 0.17$ GeV
  - Apply fiducial cuts and exclusivity cuts
  - Use BDT and $\Delta\phi$ fit to reduce fake neutrons
- π^0 contamination
  - Overall: 4.4%
  - It is still significant in some kinematic bins





Extraction of nDVCS cross section

- Unpolarized cross section

$$\frac{d^4\sigma_{en\to en\gamma}}{dQ^2 dx_{\mathrm{BJ}} dt d\phi} = \frac{N_{en\to en\gamma}}{L \cdot \varepsilon_{acc} \cdot V}$$

  - $N_{en\to en\gamma}$ is the yield obtained after the background subtraction in each $(Q^2, x_{\mathrm{BJ}}, -t, \phi)$ bin
  - Luminosity $L = 134.1\times 10^3\ \mathrm{pb}^{-1}$
  - Acceptance ε_{acc} determined from MC
    - Neutron detection efficiency is corrected using the RGB $ep \to en\pi^+$ data
    - BDT cut efficiency is corrected by data (performing the $\Delta\phi$ fit)
  - V is the bin volume

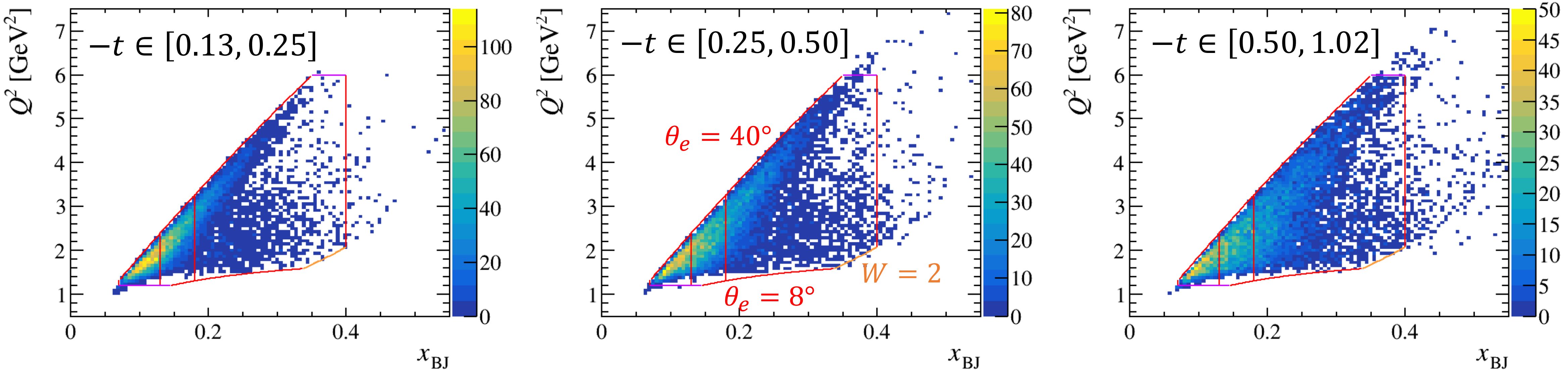
- Polarized cross-section difference

$$\frac{d^4\vec{\sigma}_{en\to en\gamma}}{dQ^2 dx_{\mathrm{BJ}} dt d\phi} - \frac{d^4\overleftarrow{\sigma}_{en\to en\gamma}}{dQ^2 dx_{\mathrm{BJ}} dt d\phi}$$
$$= \frac{N_+ - N_-}{L_{+(-)} \cdot P \cdot \varepsilon_{acc} \cdot V}$$

  - N_+ is the yield for positive beam helicity
  - N_- is the yield for negative beam helicity
  - Luminosity $L_{+(-)} = 64.5\times 10^3\ \mathrm{pb}^{-1}$
  - Beam polarization $P = 86\%$

Binning scheme

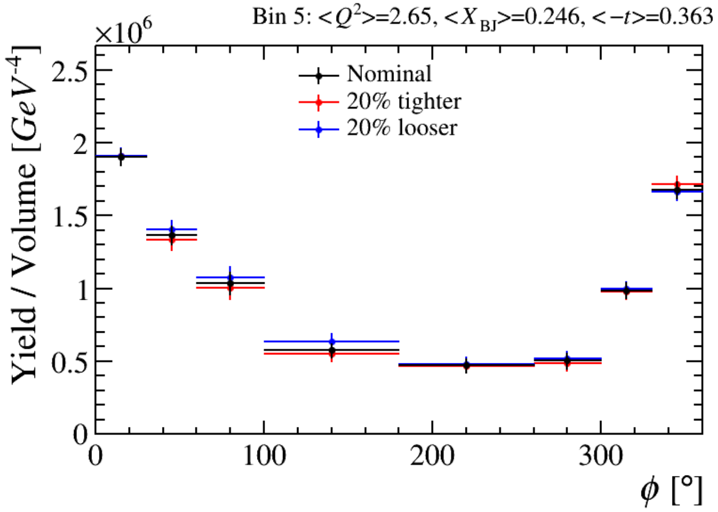
- nDVCS cross section is extracted as a function of ϕ in 9 $(Q^2, x_{\mathrm{BJ}}, -t)$ bins
- 3 bins for $-t$: $[0.13, 0.25], [0.25, 0.50], [0.50, 1.02]\ \mathrm{GeV}^2$
- 3 bins for (Q^2, x_{BJ})
  - $1.2 < Q^2 < 6.0\ \mathrm{GeV}^2,\ 8° < \theta_e < 40°,\ W > 2\ \mathrm{GeV}$
  - x_{BJ} bins: $[0.07, 0.13], [0.13, 0.18], [0.18, 0.40]$

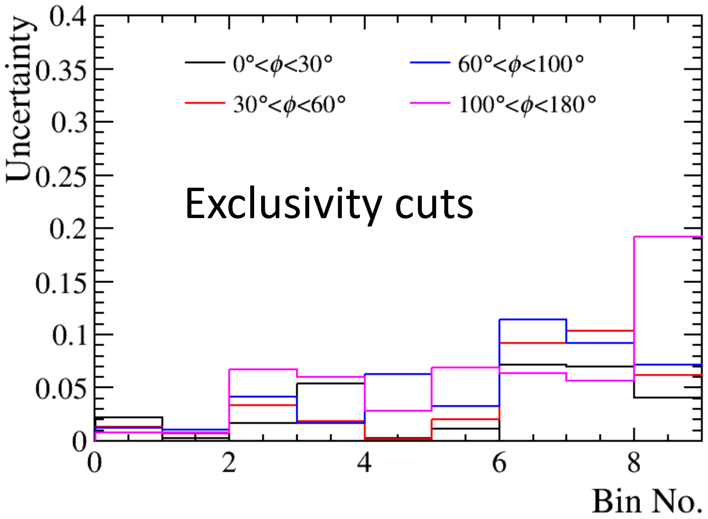


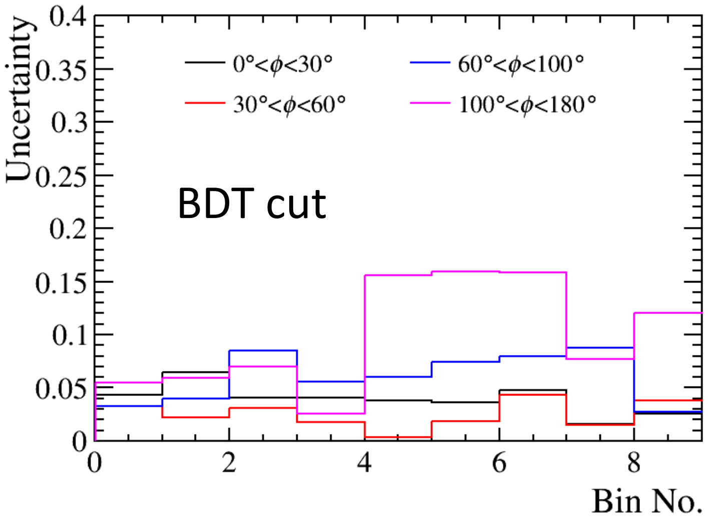
Systematic uncertainties

- Exclusivity cuts
  - Alternative: 20% tighter or 20% looser
  - The relative difference of the cross section is taken as the uncertainty in each bin
    - For two alternatives, choose the larger one
    - ϕ and $(360° - \phi)$ bins are combined in the estimation
  - Results: 0.2% - 19.2%

- BDT cut
  - Nominal:
    - BDT response > 0.05
  - Alternative:
    - BDT response > 0.08 or 0.02
  - Results: 0.4% - 15.9%

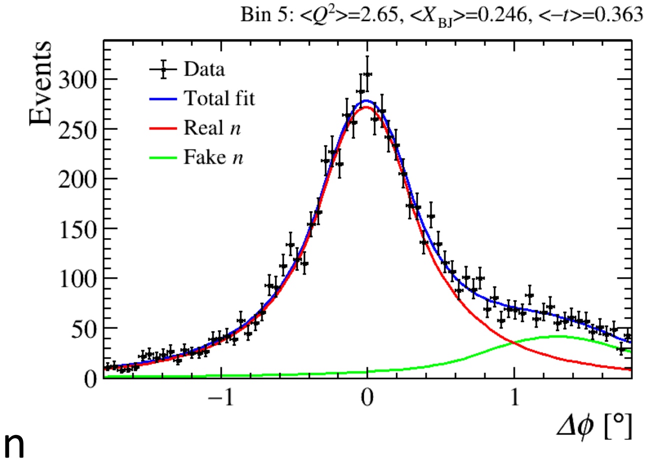


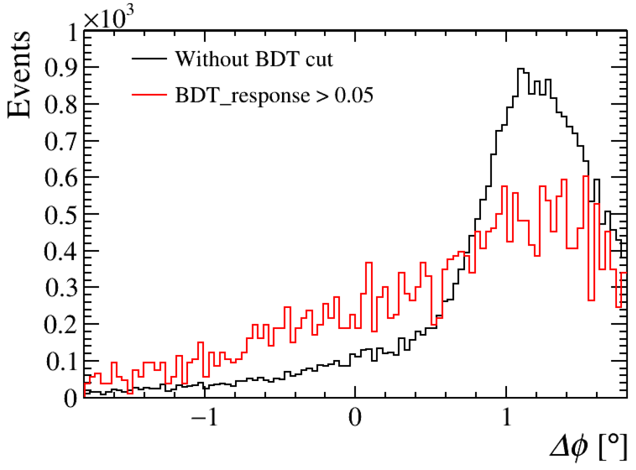


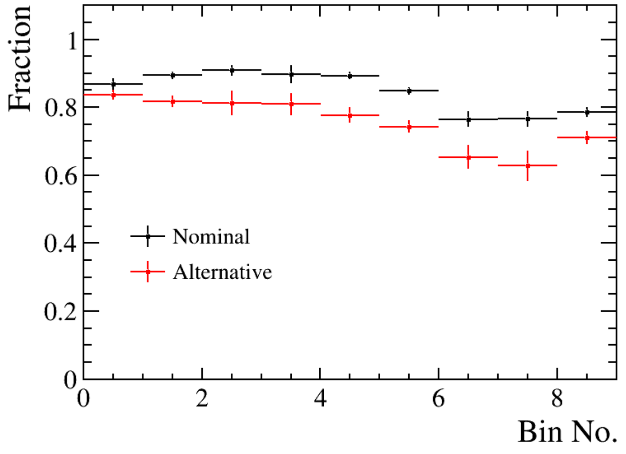


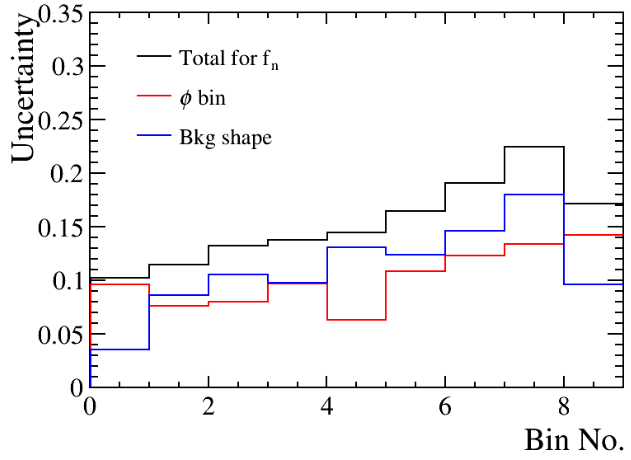
Systematic uncertainties

- $\Delta\phi$ fit to subtract remaining fake neutrons after the BDT cut
  - Real neutron fraction:
    - $f_n = N_n/(N_n + N_p)$
  - Background shape:
    - Nominal: RGA $\Delta\phi$ shape before BDT cut, separatly for each $(Q^2, x_{\mathrm{BJ}}, -t)$ bin
    - Alternative: RGA $\Delta\phi$ shape after BDT cut, integrated over all bins
  - ϕ dependence of f_n is studied using RGA data
    - The standard deviation of f_n for 8 ϕ bins is taken as another uncertainty
  - Results: 10.2% - 22.4%



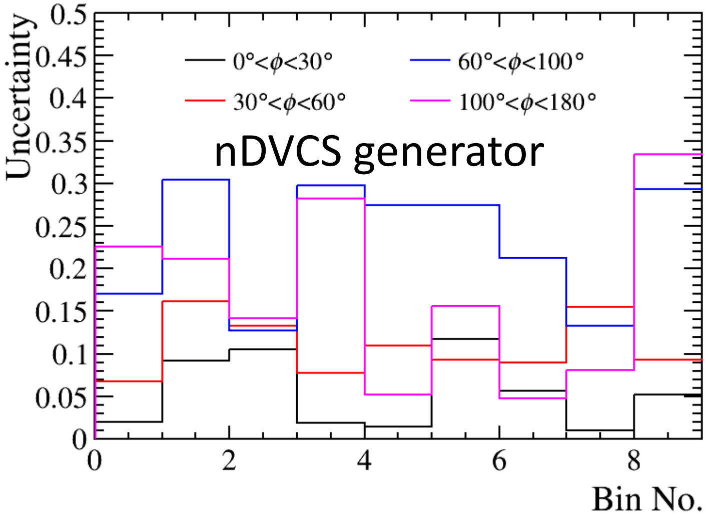


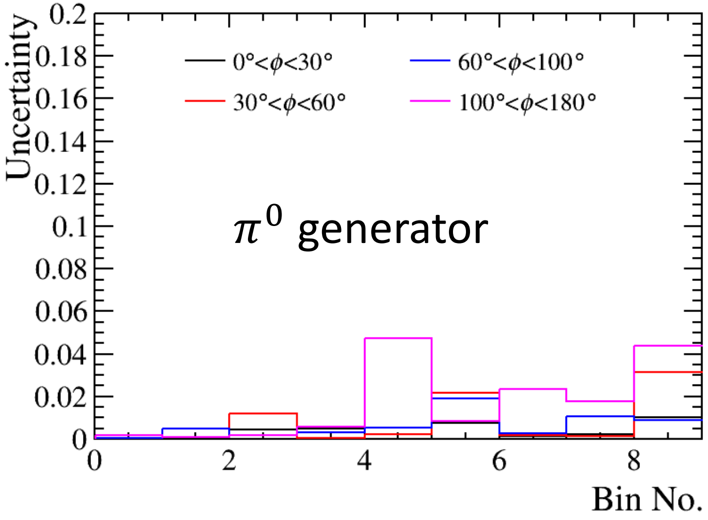


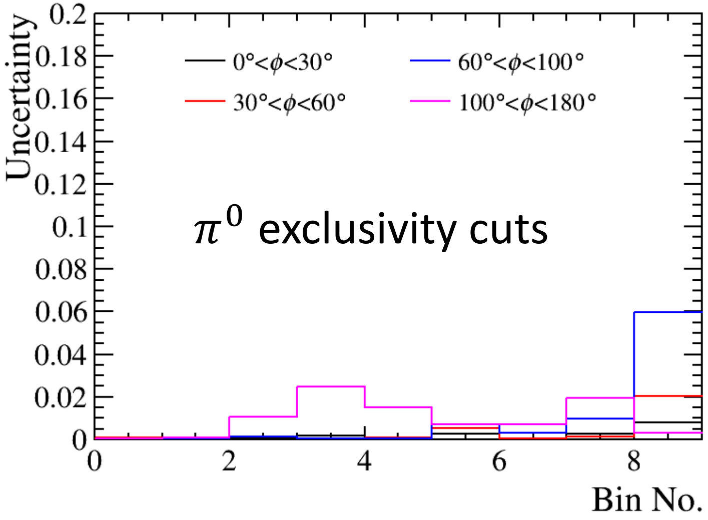


Systematic uncertainties

- nDVCS generator
    - Nominal:
        - Genepi nDVCS+BH
    - Alternative:
        - Only BH
    - Results: 1.0% - 33.4%
- π^0 generator
    - Nominal:
        - Genepi π^0 production
    - Alternative:
        - Phase-space with exponential $-t$ distribution
    - Results: 0.0% - 4.7%
- π^0 exclusivity cuts
    - Alternative:
        - 20% tighter or looser
    - Results: 0.0% - 4.2%

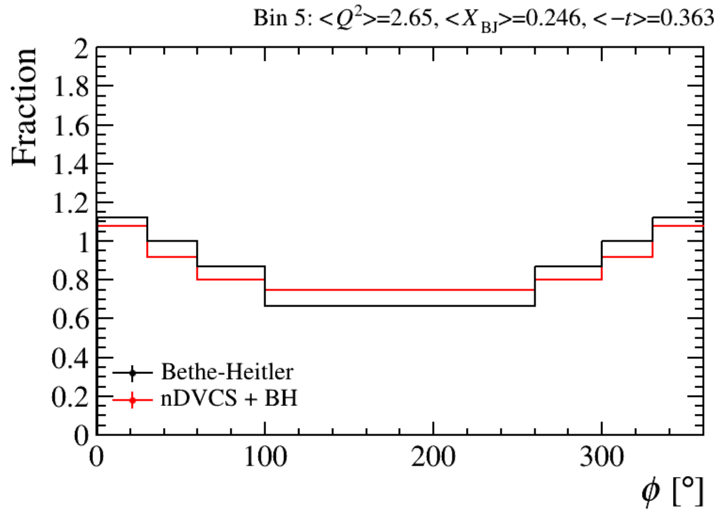


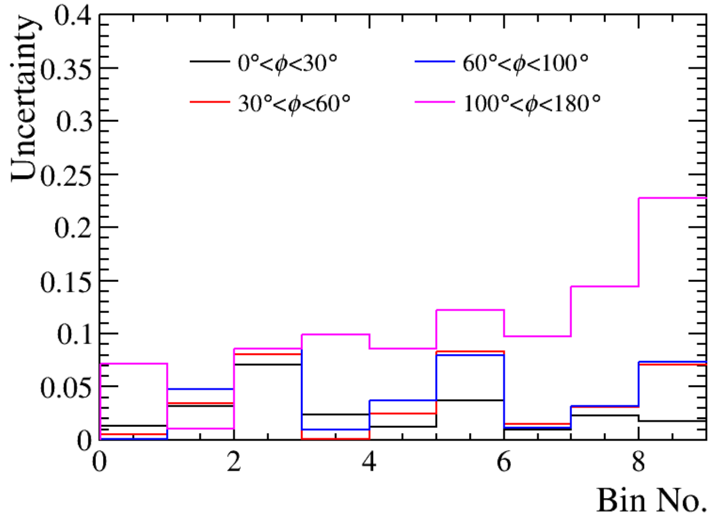




Systematic uncertainties

- Bin integral correction
  - Correct the integral cross-section in each bin to the cross-section at fixed $(Q^2, x_{\mathrm{BJ}}, -t, \phi)$ (set as mean values obtained from the generator-level MC)
  - Nominal: $\sigma_{en\gamma}^{\mathrm{fixed}} = \sigma_{en\gamma}^{\mathrm{inte}} \times (\sigma_{\mathrm{BH}}^{\mathrm{fixed}} / \sigma_{\mathrm{BH}}^{\mathrm{inte}})$
  - Alternative: BH+DVCS (VGG model with $J_u = 0.3$ and $J_d = 0.1$)
  - Results: 0.1% - 22.7%

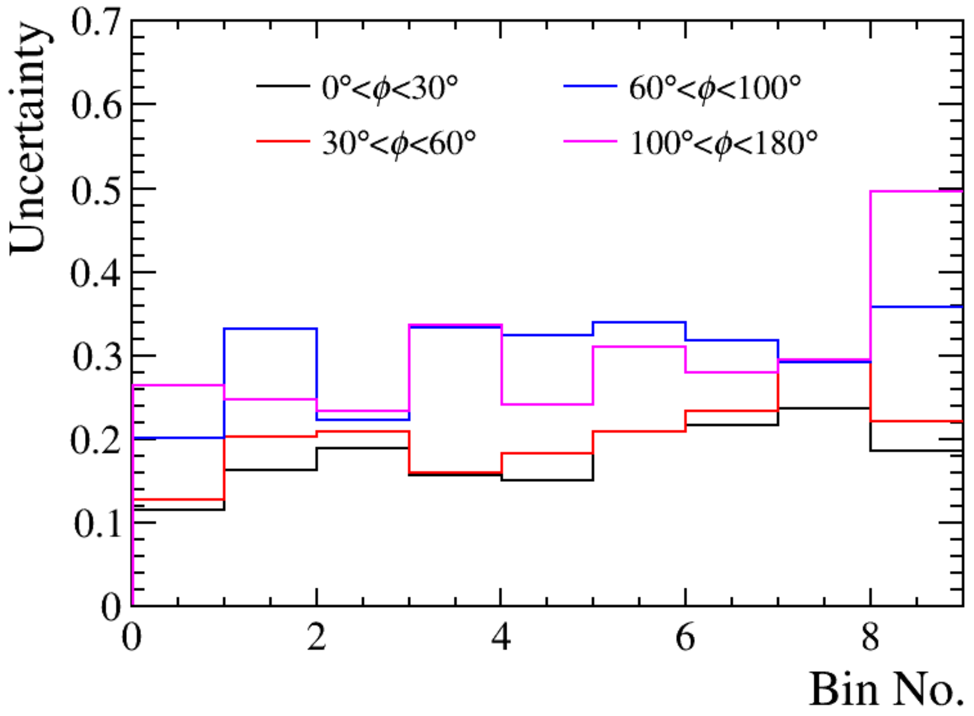




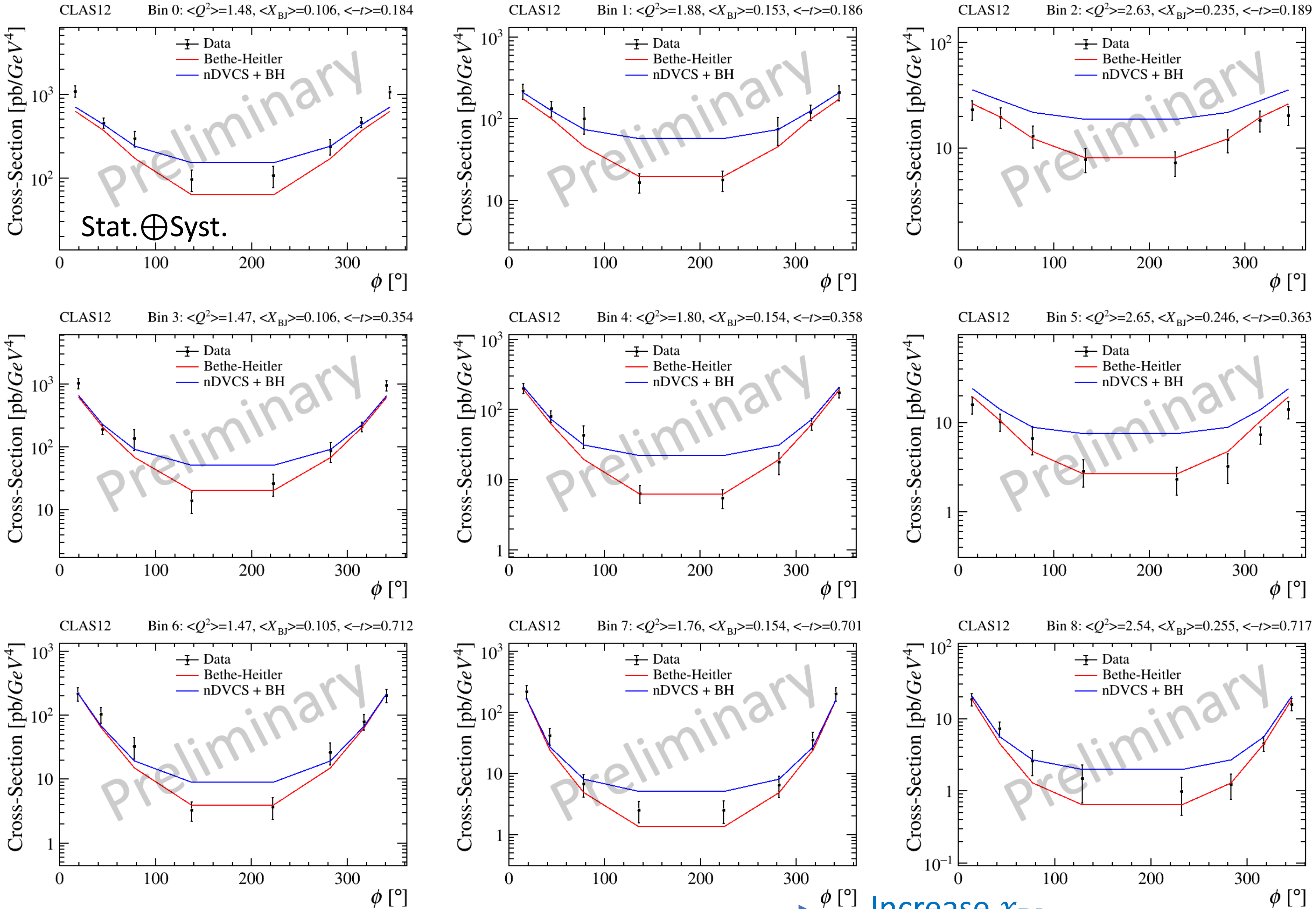
Systematic uncertainties

- Total systematic uncertainty
  - Systematic uncertainties from different sources are combined in quadrature
  - Results: 11.5% - 49.6%

Exclusivity cuts	0.2% - 19.2%
BDT cut	0.4% - 15.9%
$\Delta\phi$ fit	10.2% - 22.4%
nDVCS generator	1.0% - 33.4%
π^0 generator	0.0% - 4.7%
π^0 exclusivity cuts	0.0% - 4.2%
Bin integral correction	0.1% - 22.7%
Total	**11.5% - 49.6%**



Unpolarized cross section

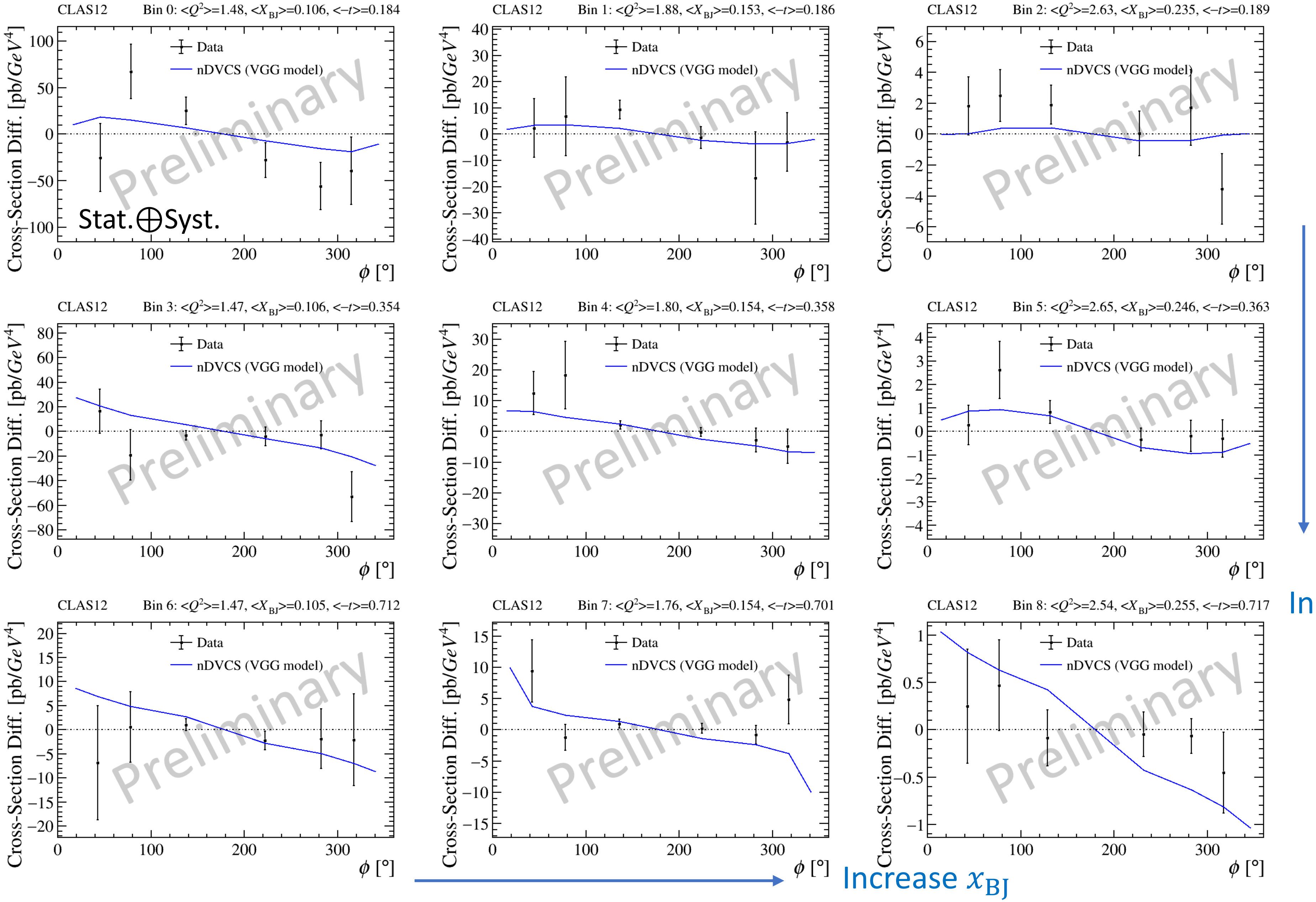


Increase $-t$

Increase x_{BJ}

- Linked mainly to the real CFF of GPD E
- Predictions are provided at the mean values of $(Q^2, x_{\mathrm{BJ}}, -t, \phi)$
- $(Q^2, x_{\mathrm{BJ}}, -t)$ mean values vary with ϕ
- nDVCS predictions: VGG model with particular parameters $J_u = 0.3$ and $J_d = 0.1$
- The measured results are at the same level with the BH calculations

Polarized cross-section difference



- Linked to the imaginary CFF of GPD E
- Predictions are provided at the mean values of $(Q^2, x_{\mathrm{BJ}}, -t, \phi)$
- $(Q^2, x_{\mathrm{BJ}}, -t)$ mean values vary with ϕ
- nDVCS predictions: VGG model with particular parameters $J_u = 0.3$ and $J_d = 0.1$
- The measured results are consistent with the predictions given the large uncertainties

Summary

- The nDVCS cross section is measured with a ~10.4 GeV electron beam scattering off a liquid deuterium target
- Both unpolarized cross section and polarized cross-section difference are extracted
  - The measured unpolarized cross sections are compatible with the BH calculations
  - The polarized cross-section differences are consistent with the VGG model predictions given the large uncertainties
- The analysis note will be completed soon

Thank you!