CLAS Collaboration Meeting, JLAB

November 20 2025

Update on Beam-Spin Asymmetry Extraction from the N $\rightarrow$ N* DVCS Process with RG-A Data

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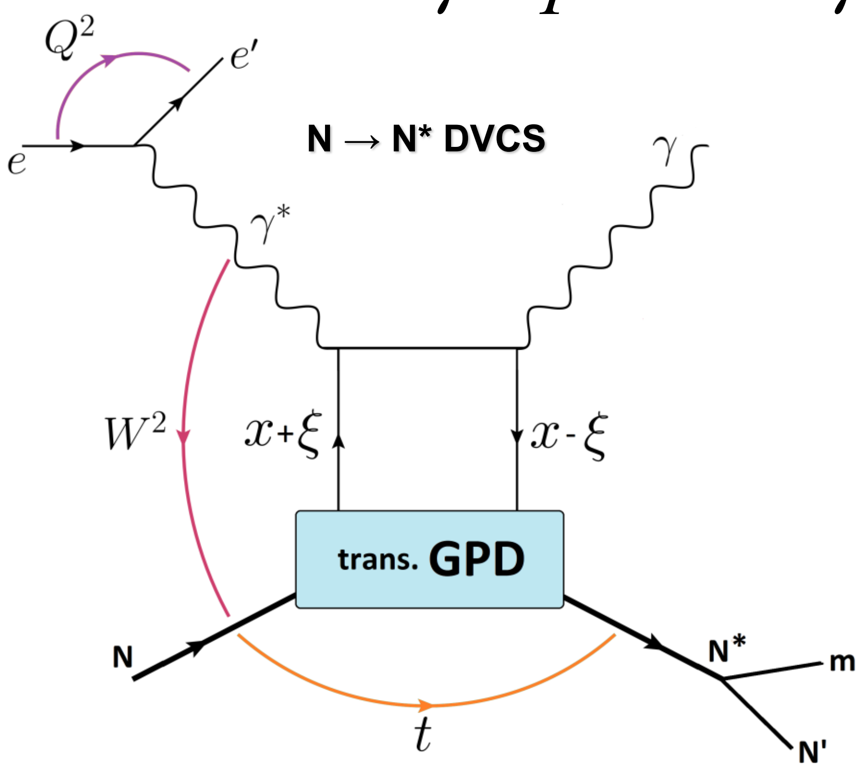
11/20/2025

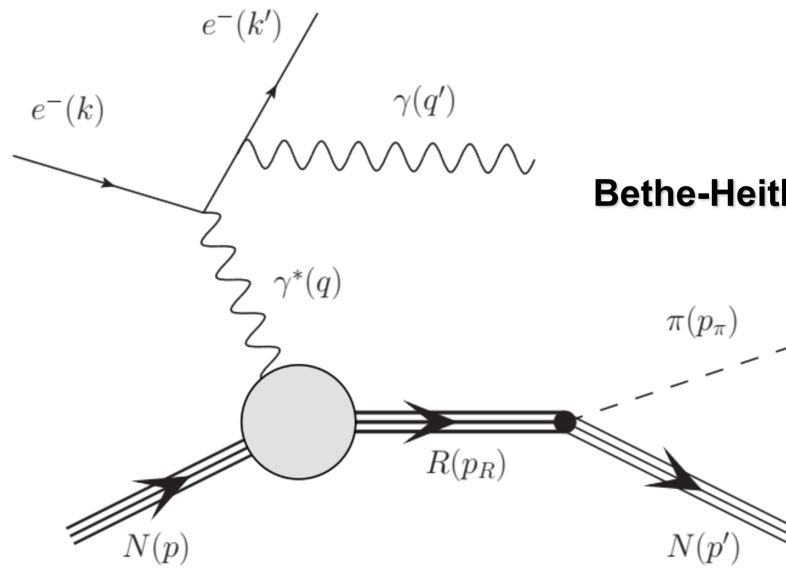
The N → N* DVCS and the Bethe-Heitler process

$$\gamma^* p \to N^* \gamma \to N \ meson \ \gamma$$

N → N* DVCS



Bethe-Heitler



factorisation for: $-t/Q^2$ small, x_B fixed, $Q^2 > M^2_{N^*}$

➔ **Sensitive to twist-2 transition GPDs**

Theory: K. M. Semenov-Tian-Shansky, M. Vanderhaeghen, Phys. Rev. D **108**, 034021 (2023)

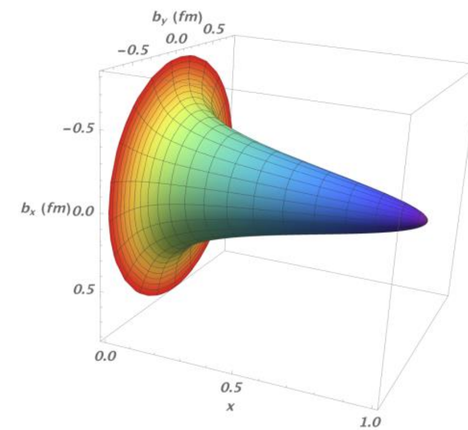
Whitepaper: S. Diehl et al., Eur. Phys. J. A 61, 131 (2025) https://doi.org/10.1140/epja/s10050-025-01552-2

Physics content of transition GPDs

N→Δ transition: 16 transition GPDs

N→N* DVCS: 8 twist-2 **helicity non-flip** transition GPDs

→ Related to the Jones-Scardon and Adler EM FF
of the N→Δ transition



➔ 3D (x-dependent) imaging of the excitation process

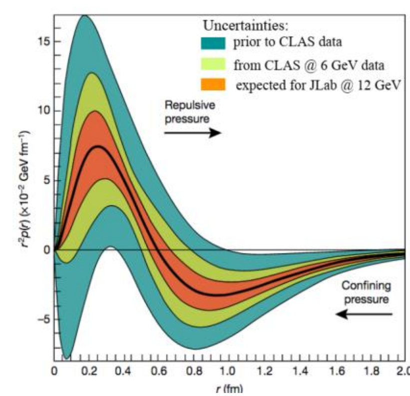
➔ N→N* transition charge / magnetization densities

➔ Transition GPDs connect the spin and angular momentum of resonances to the motion and distribution of the partons within the exited baryon

C. C. Granados, C. Weiss, Phys. Lett. B **797**, 134847 (2019), J.Y. Kim, H.Y. Won, J. Goity, C. Weiss, Phys.Lett. B **844**, 138083 (2023)

➔ Access to pressure distributions and shear forces within nucleon resonances via gravitational form factors

$$\int dx\ x\ H(x,\xi,t) = M_2(t) + \frac{4}{5}\xi^2 d_1(t)$$



V.D. Burkert, L. Elouadrhiri, F.X. Girod, Nature **557**, 396 (2018)

Dataset and event selection

CLAS12 RG-A: (pass 2) **fall 2018 inbending** / **fall 2018 outbending** } E_{beam} **= 10.6 GeV**

spring 2019 inbending } E_{beam} **= 10.2 GeV**

spring 2018 inb + outb: Impact has been investigated (see talk at RG-A meeting)

→ Limitted resolution esp. for low momentum π^+ was found to be problematic for excl. cuts + resonance spectra

→ Statistics gain in the order of only 20 – 40 %

➔ Data will not be included in the final analysis

Event selection: $e\ p \rightarrow e'\ N^{*+}\ \gamma \rightarrow e'\ n\ \pi^+\ \gamma$

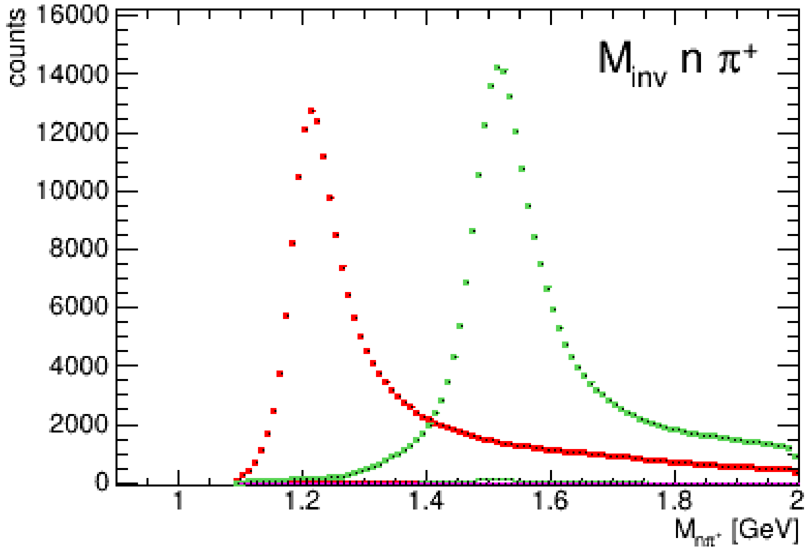
- One electron in the FD $p > 2.1$ GeV
  → Fiducial cuts for DC and PCAL + v_z cut + PID refinements + momentum corrections
- One π^+ in the FD or CD (no other charged particles) $p > 0.2$ GeV
  → Fiducial cuts for the DC + Δv_z cut + |chi2PID| < 3 + momentum corrections in the FD
- At least one neutron in the FD or CD $0.2\ \text{GeV} < p < 3.3\ \text{GeV}$
- At least one photon in the FT or FD $E > 2$ GeV
  → Fiducial cuts for the PCAL (v,w > 14 cm) and FT + $0.9 < \beta < 1.1$ + energy corrections

Kinematic cuts: $W > 2$ GeV $Q^2 > 1.5\ \text{GeV}^2$ $-t < 2\ \text{GeV}^2$

MC simulations

Signal events: Event generator based on the predicted resonance mass distributions

K. M. Semenov-Tian-Shansky, M. Vanderhaeghen, Phys. Rev. D **108**, 034021 (2023)



generated Δ(1232)

generated 2nd res region

➔ Radiative effects for the incoming and outgoing electron

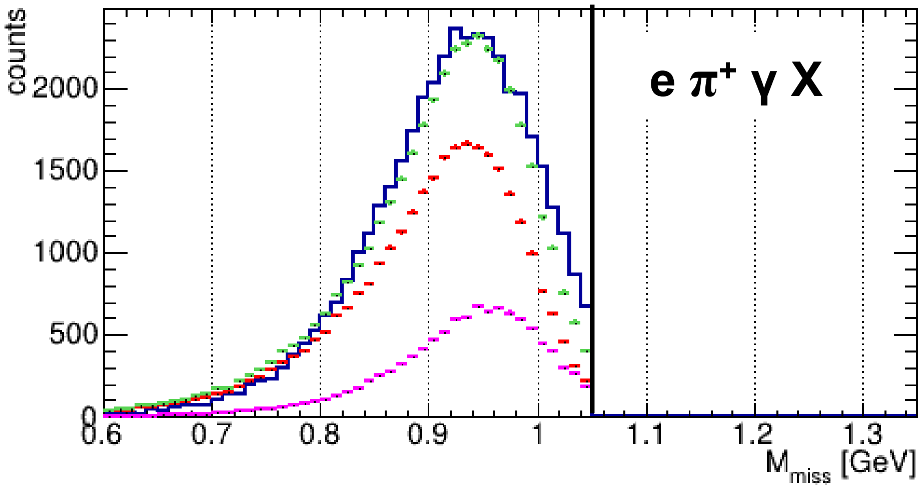
➔ Cross section of the p→p DVCS process (from dvcsgen) as a weight in x_B, Q^2, $-t$ and ϕ

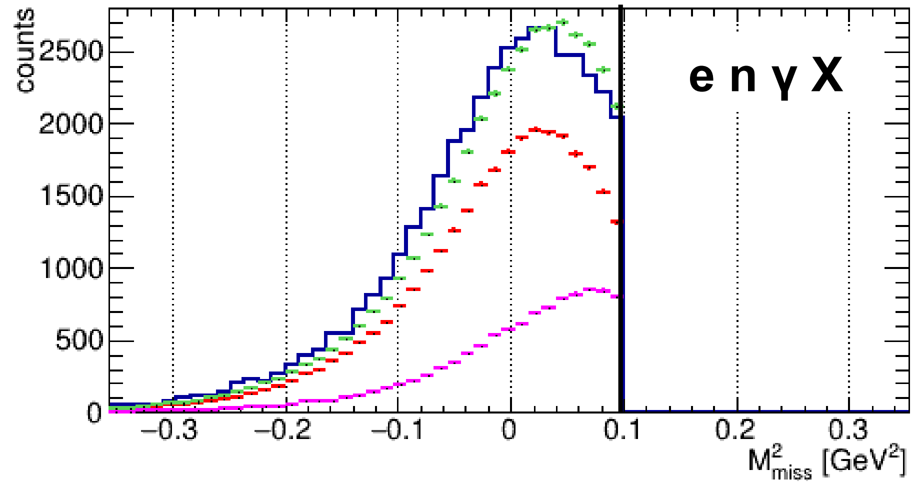
Background events:

- A phase space generator for **$N \rightarrow N^* \pi^0$ DVMP** (full N* spectrum) with added weight
- A phase space generator for **e p** $\rightarrow$ **e n ρ^+** $\rightarrow$ e n $\pi^+ \pi^0$
- CLASDIS for a general background estimate
- e p $\rightarrow$ e n $\pi^+ \gamma$ with a unifrom resonance spectrum for non-resonant background

Event selection

Missing masses:





data — MC for N→N* DVCS — MC for N→N* π^0 DVMP — sum

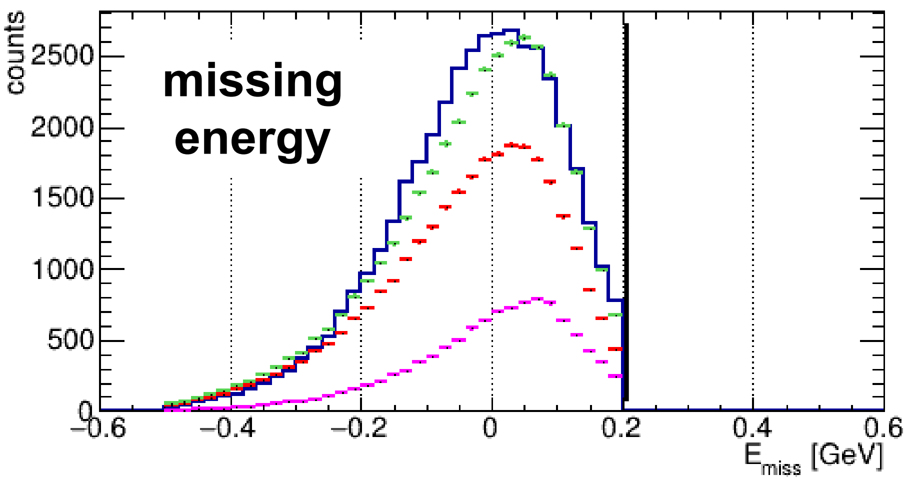
0.5 GeV < $M_{miss}(e\pi^+\gamma X)$ < 1.05 GeV

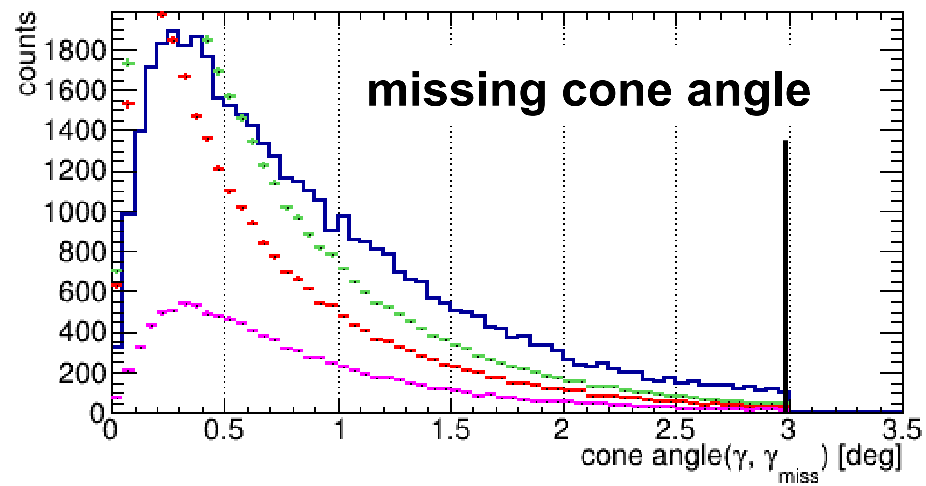
-0.4 GeV² < $M^2_{miss}(en\gamma X)$ < 0.1 GeV²

-0.04 GeV² < $M^2_{miss}(en\pi^+\gamma X)$ < 0.015 GeV²

Event selection

Missing energy, P_T and cone angle:





data — MC for N→N* DVCS — MC for N→N* π^0 DVMP — sum

-0.5 GeV < $E_{miss}(en\pi^+\gamma X)$ < 0.2 GeV

Cone(γ_{miss}, γ_{DVCS}) < 3.0°

$P_{T\text{-}miss}(en\pi^+\gamma X) < 0.2$ GeV

Background rejection

Signal: $e\ p \rightarrow e'\ N^{*+}\ \gamma \rightarrow e'\ n\ \pi^+\ \gamma$

Physics background: $e\ p \rightarrow e'\ n\ \rho^+ \rightarrow e'\ n\ \pi^+\ \gamma$ (very rare)

➔ Also radative decays of other mesons (e.g. f_2) and nucleon resonances are very rare!

Event selection background: $e\ p \rightarrow e'\ n\ \rho^+ \rightarrow e'\ n\ \pi^+\ \pi^0 \rightarrow e'\ n\ \pi^+\ \gamma\ (\gamma)$ (I)

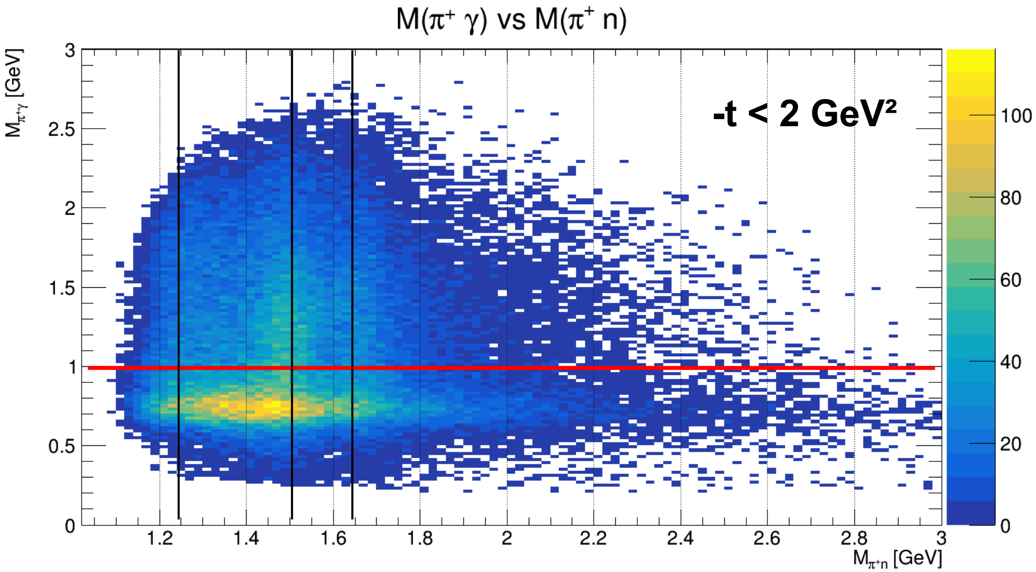
$e\ p \rightarrow e'\ N^{*+}\ \pi^0 \rightarrow e'\ n\ \pi^+\ \pi^0 \rightarrow e'\ n\ \pi^+\ \gamma\ (\gamma)$ (II)

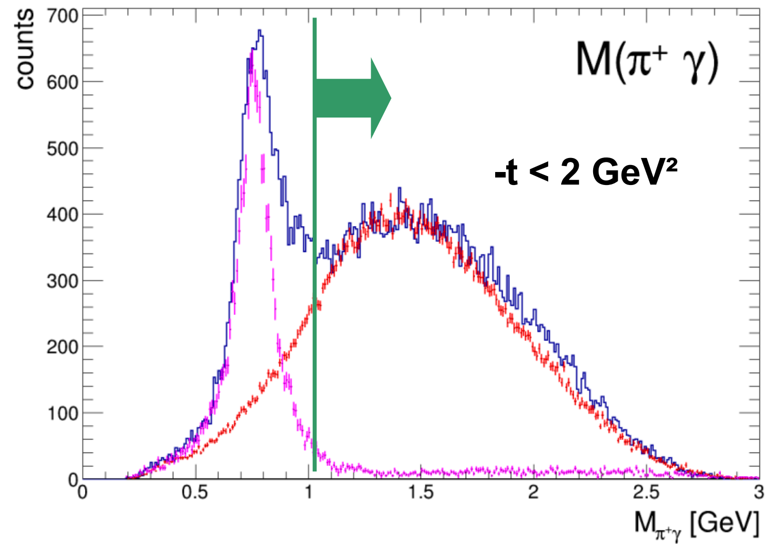
➔ **These are the main background channels**

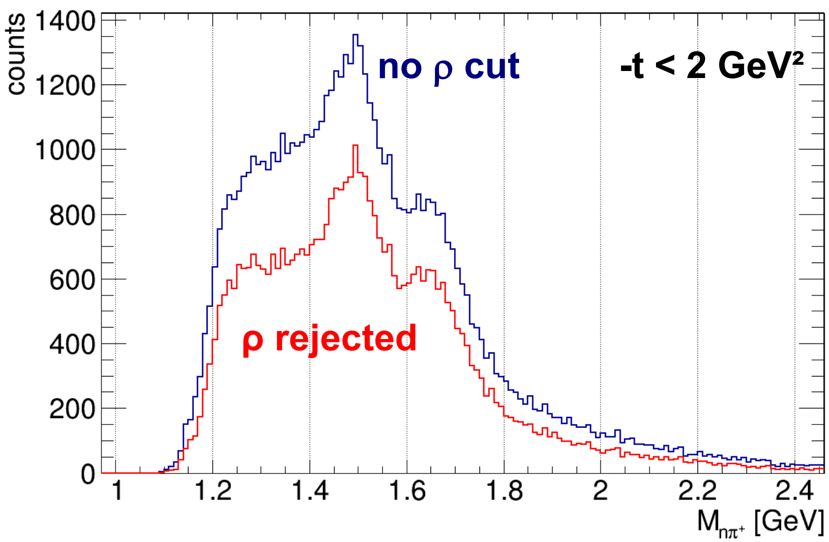
I: Can be suppressed (next slide)

II: Needs to be subtracted on a bin by bin basis

ρ background rejection







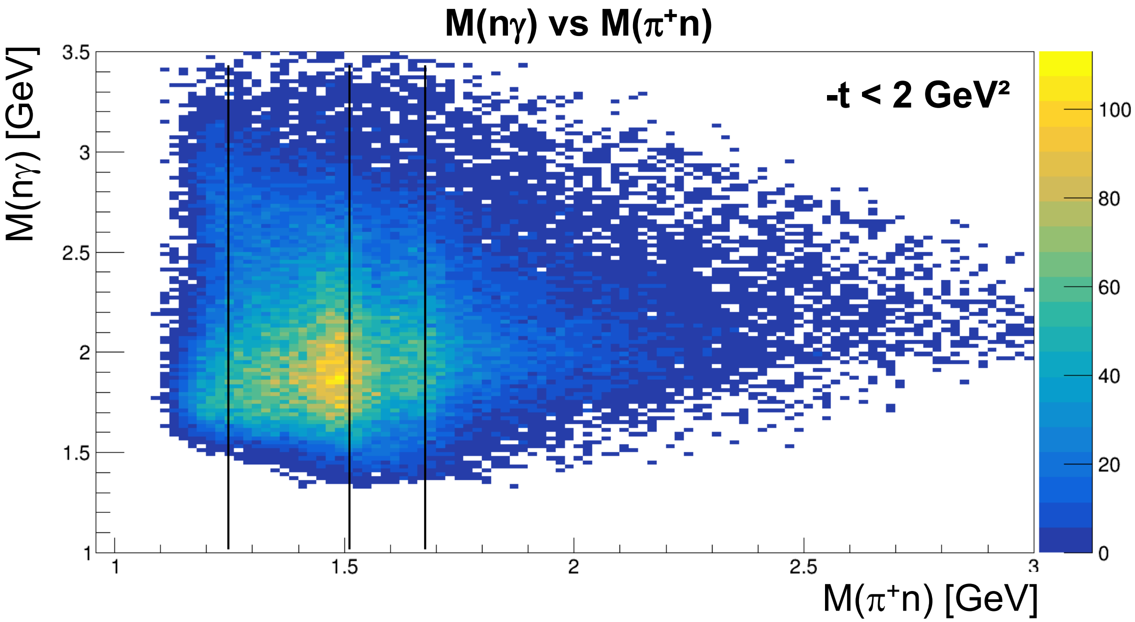
exp. data

sim N→N* DVCS

sim ρ

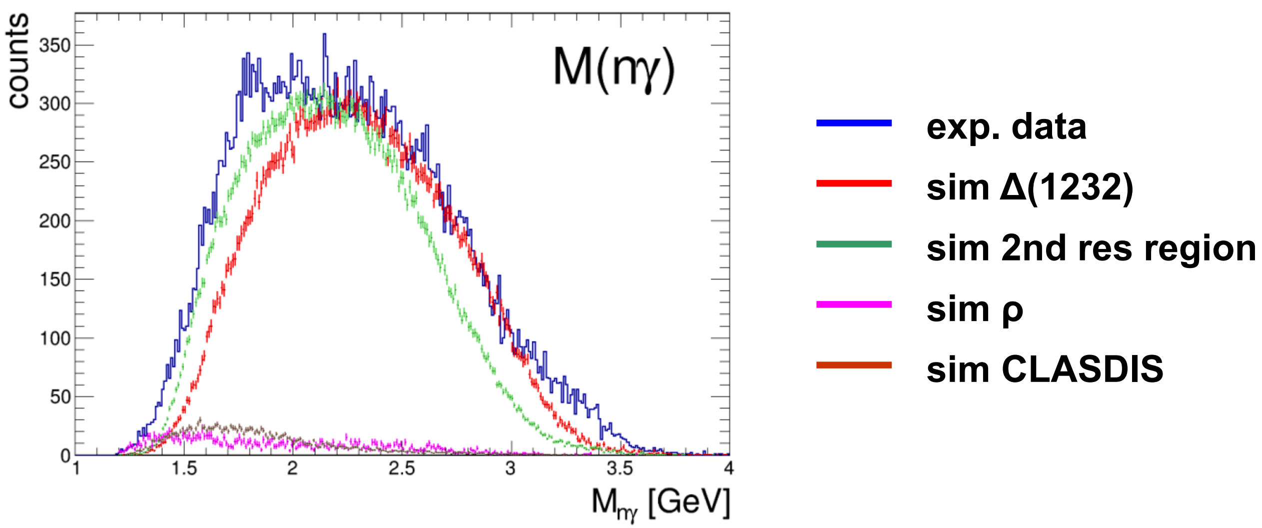
$$M(\pi^+\gamma) > 1 \text{ GeV}$$

Potential background from neutral resonances

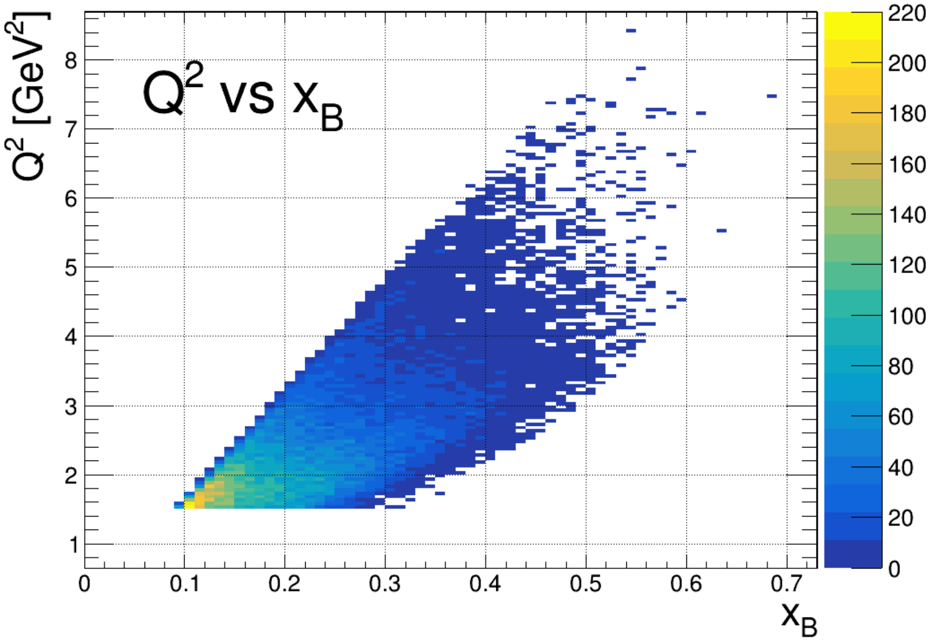


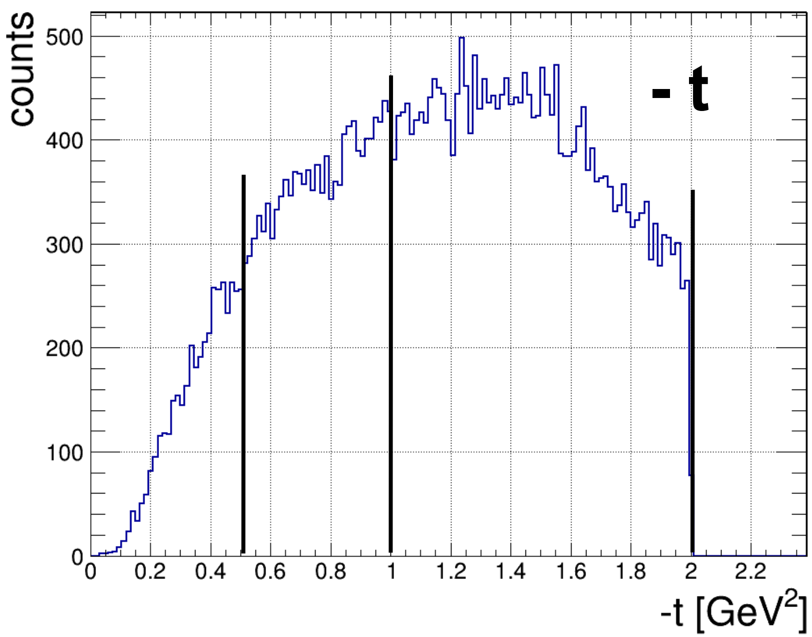
$e\, p \rightarrow e'\, N^{0*}\, \pi^+$
$\rightarrow e'\, n\, \pi^0\, \pi^+$
$\rightarrow e'\, n\, \pi^+\, \gamma\, (\gamma)$

➔ Such background is also kinematically strongly suppressed due to the cut on small -t



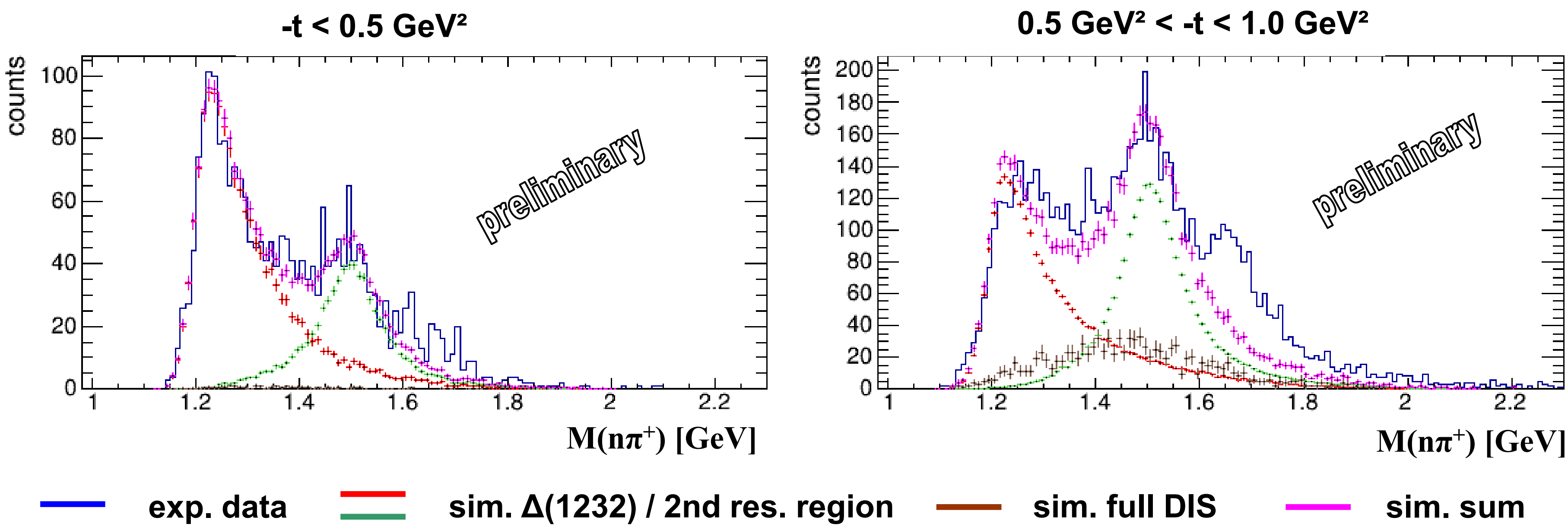
Kinematic distributions of the final sample

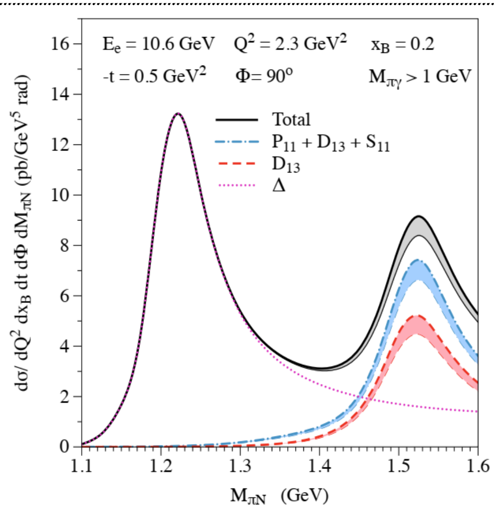




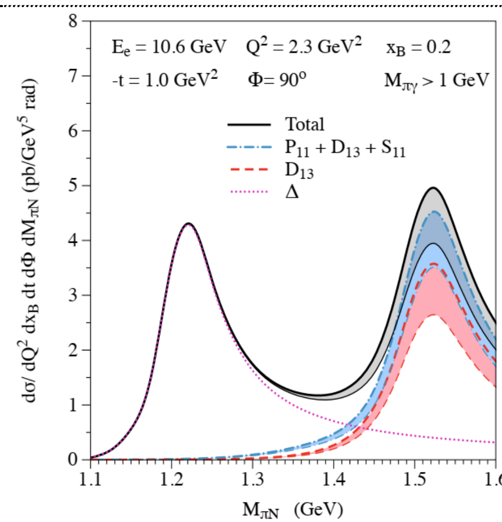
$\langle x_B \rangle \sim 0.23$ $\langle Q^2 \rangle \sim 2.5$ GeV^2

Resonance mass spectra



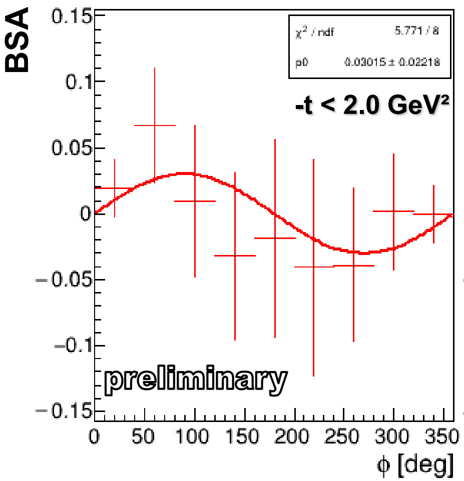


K. Semenov-Tian-Shansky, M. Vanderhaeghen, Phys. Rev. D 108, 034021 (2023)

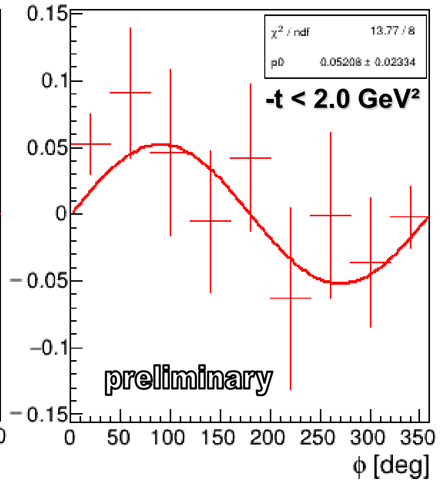


Beam spin asymmetries

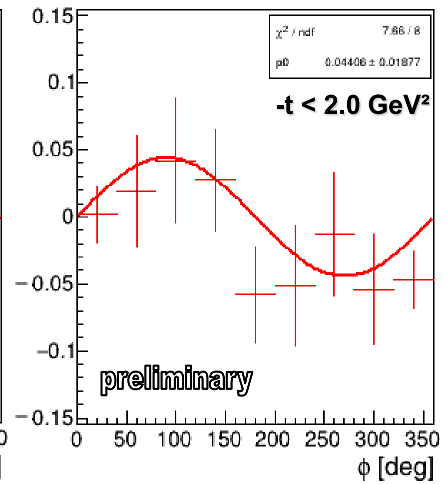
1.13 GeV < M(nπ+) < 1.33 GeV



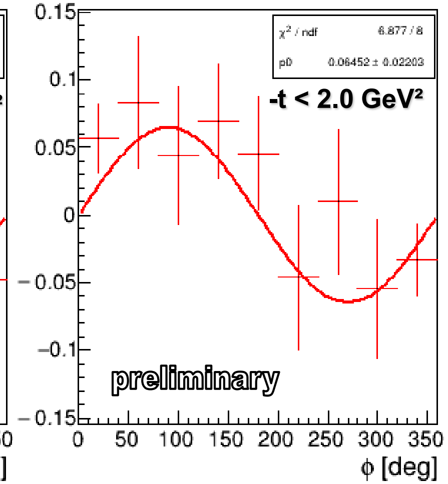
1.33 GeV < M(nπ+) < 1.45 GeV



1.45 GeV < M(nπ+) < 1.60 GeV

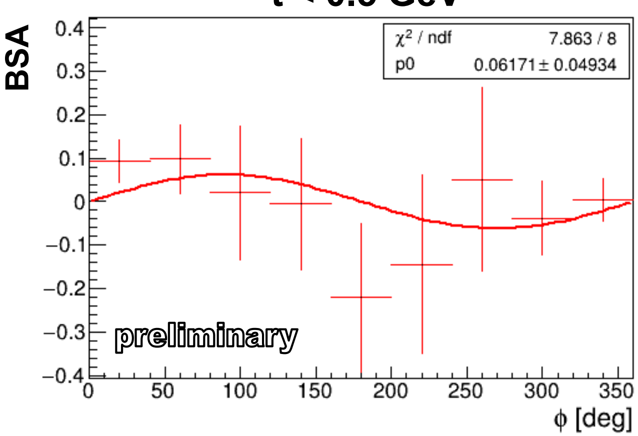


1.60 GeV < M(nπ+) < 1.77 GeV

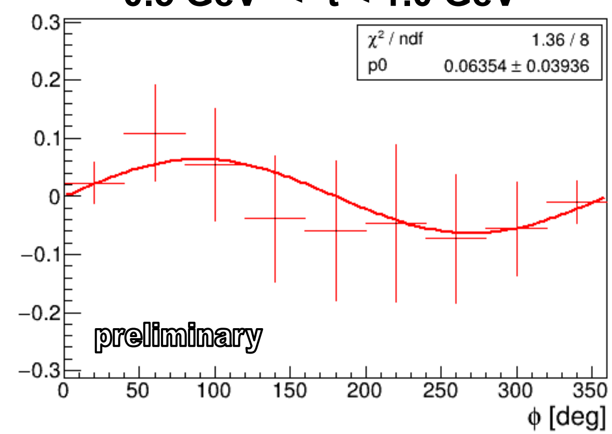


$\Delta^+(1232)$ (1.13 GeV < M($n\pi^+$) < 1.33 GeV):

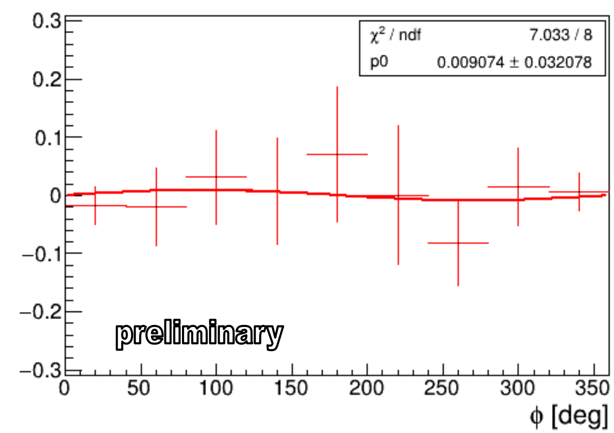
-t < 0.5 GeV²



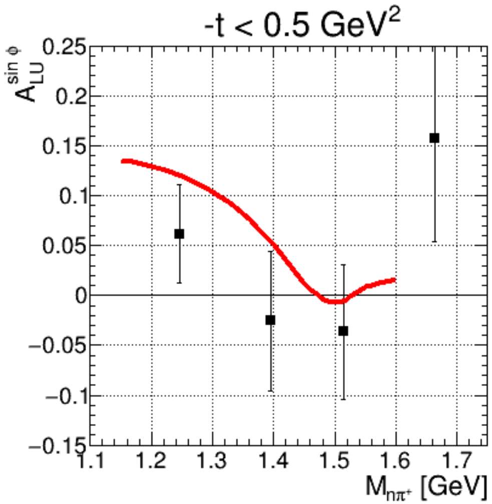
0.5 GeV² < -t < 1.0 GeV²

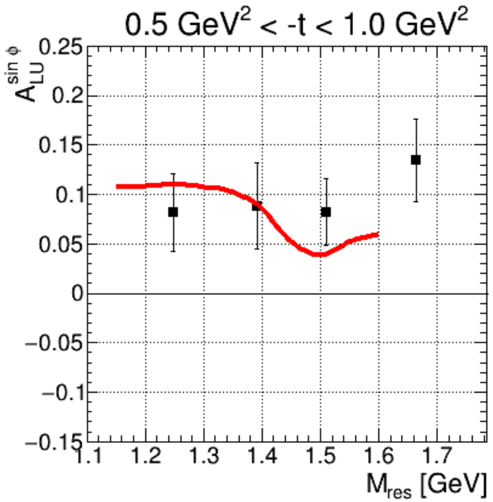


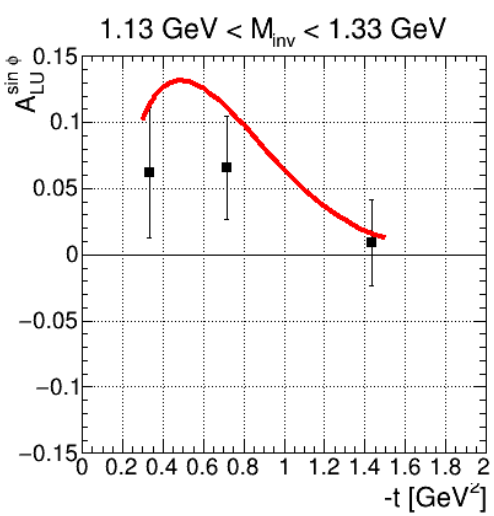
1.0 GeV² < -t < 2.0 GeV²

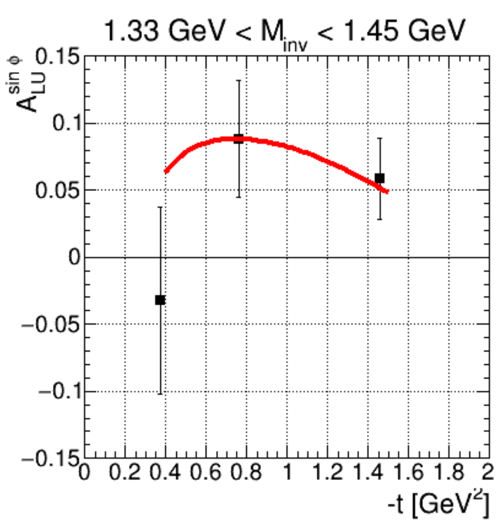


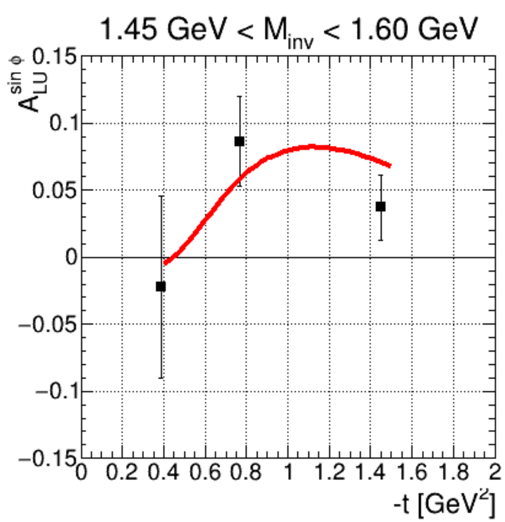
$A_{LU}^{\sin\phi}$ results ($\langle Q^2\rangle$ = 2.5 GeV², $\langle x_B\rangle$ = 0.23)











Theory curves in CLAS12 kinematics from:
K. M. Semenov-Tian-Shansky, M. Vanderhaeghen, Phys. Rev. D **108**, 034021 (2023)

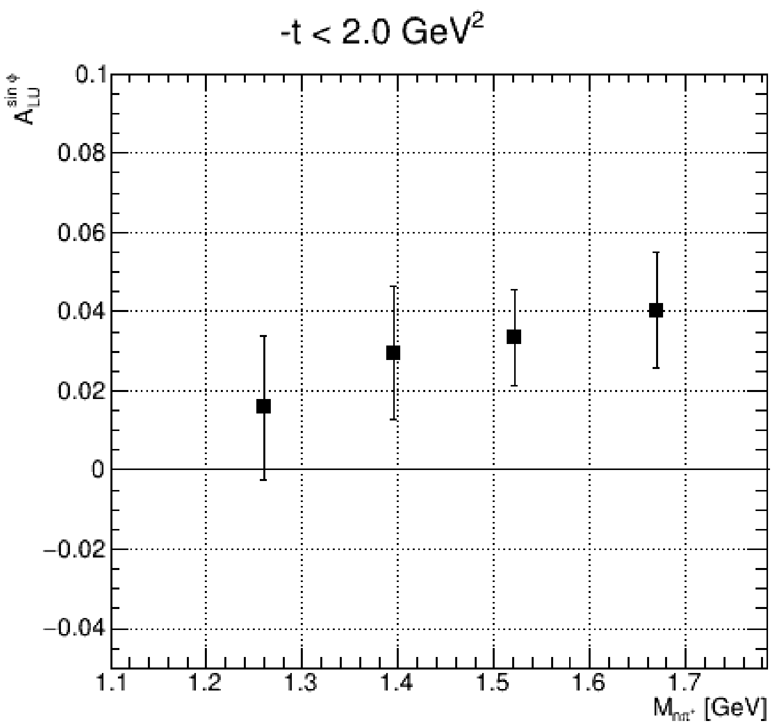
$$BSA \sim A_{LU}^{\sin(\phi)} \cdot \sin(\phi)$$

Data: No π^0 background subtraction so far!

π^0 subtraction

Asymmetry of N→N* π^0 DVMP

$e\,p \rightarrow e'\,N^{*+}\,\pi^0 \rightarrow e'\,n\,\pi^+\,\gamma\,\gamma$



N→N* π^0 DVMP asymmetry is also positive but smaller than N→N* DVCS asymmetries

Very similar for $e\,p \rightarrow e'\,N^{*+}\,\pi^0 \rightarrow e'\,n\,\pi^+\,\gamma\,(\gamma)$

π^0 subtraction methods:

$$N_{\mathrm{DVCS/BH}} = N_{eN^*_\gamma}(1 - B_{\pi^0})$$

with $$B_{\pi^0} = \frac{N_{eN^*_{\pi^0}(1\gamma)}}{N_{eN^*_\gamma}}$$

$$N_{eN^*_{\pi^0}(1\gamma)} = N^{\mathrm{DATA}}_{eN^*_{\pi^0}} * R_{\mathrm{Acc}}(1\gamma/2\gamma)$$

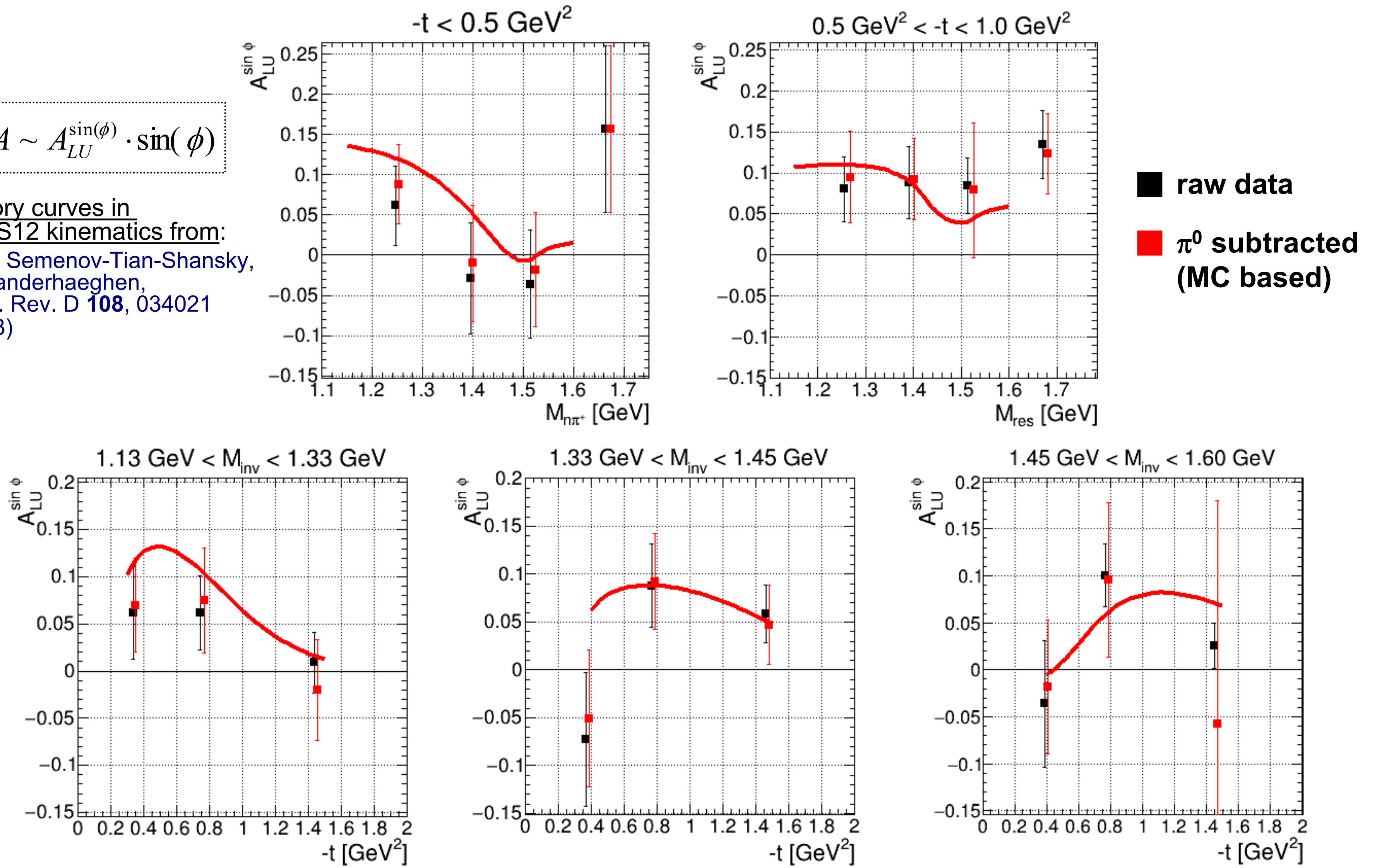
→ R can be extracted from a („realistic") π^0 MC (implemented) or from a toy MC based on reconstructed π^0 (work in progress)

→ π^0 background ~ 20 – 25 %

Final result after π^0 subtraction

$$BSA \sim A_{LU}^{\sin(\phi)} \cdot \sin(\phi)$$

Theory curves in CLAS12 kinematics from:
K. M. Semenov-Tian-Shansky, M. Vanderhaeghen, Phys. Rev. D **108**, 034021 (2023)



Sources of systematic uncertainty

1. **Uncertainty of the π^0 subtraction ~ 10 %**

    → Comparison of different subtraction methods / rejection cuts

2. **Uncertainty from other minor backgrounds ~ 1 - 5 %**

    → BSA scans over invariant masses

3. **Uncertainty of the beam polarization ~ 3.1 %**

4. **Effect of the extraction method and the denominator terms ~ 2.8 %**

5. **Acceptance and bin-migration effects ~ 2.9 %**

    → Comparison of injected and reconstructed BSA in the MC

6. **Radiative effects ~ 3.0 %**

7. **Other sources (particle ID, fiducial cuts, …) < 2.0 %**

<u>Total</u>: 11.8 - 12.8 %

Conclusion and Outlook

➔ The N→N* DVCS process can be well measured with CLAS12

➔ The results show a good agreement with the theory predictions within the uncertainties

Next steps (in progress):

➔ Finalization of the π^0 subtraction procedure (different methods)
+ Corresponding systematic checks

➔ Better quantify the systematic uncertainty due to potential further background contributions

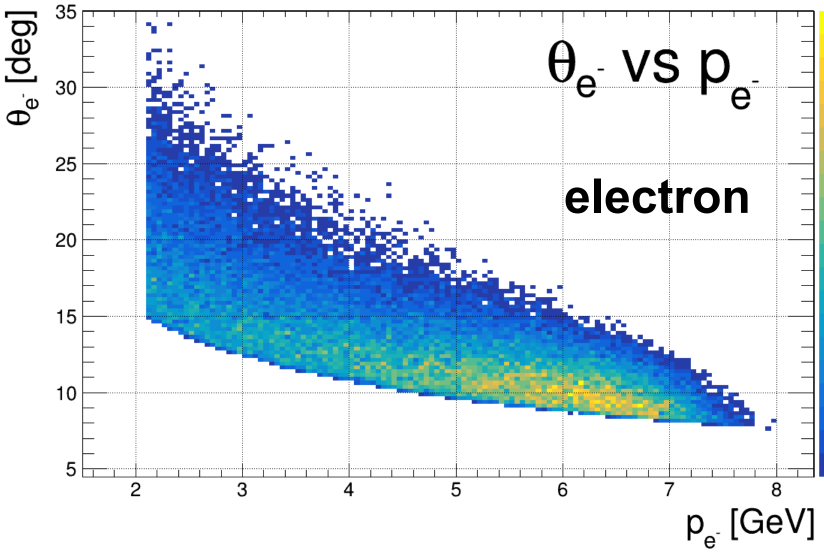
➔ Additional systematic checks and cut optimizations

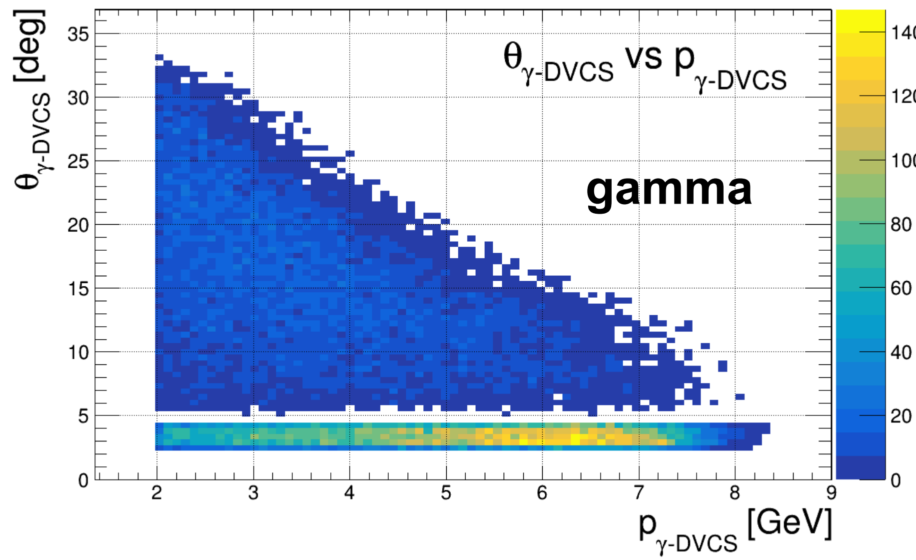
Whitepaper with a full overview on the research field:
S. Diehl et al., Eur. Phys. J. A 61, 131 (2025) https://doi.org/10.1140/epja/s10050-025-01552-2

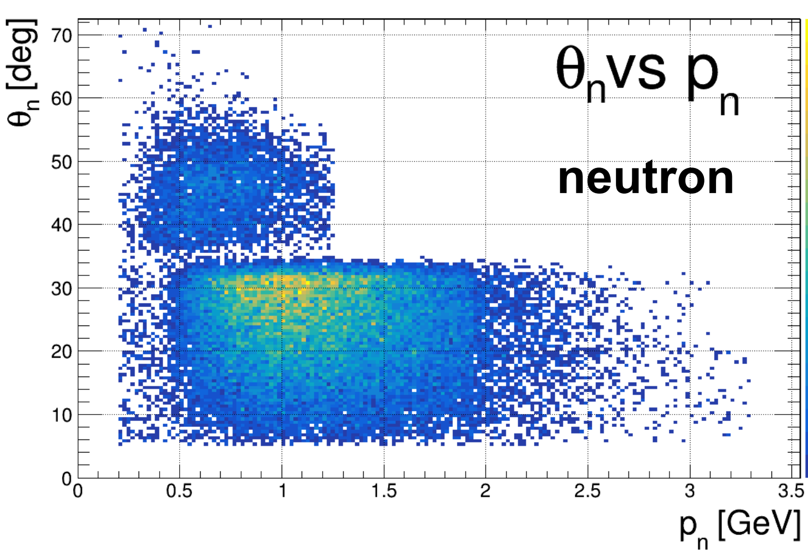
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

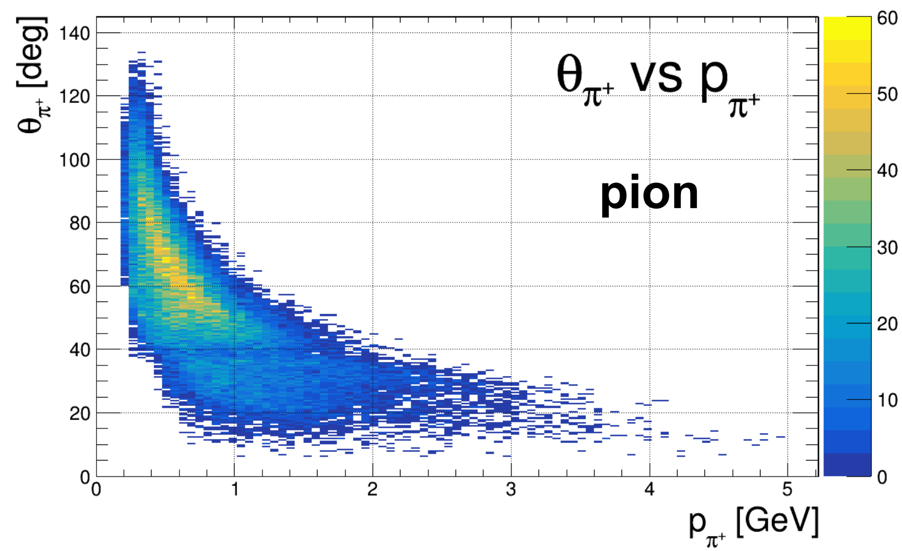
Deutsche Forschungsgemeinschaft
German Research Foundation
project number: 508107918

Experimental particle distributions of the final sample

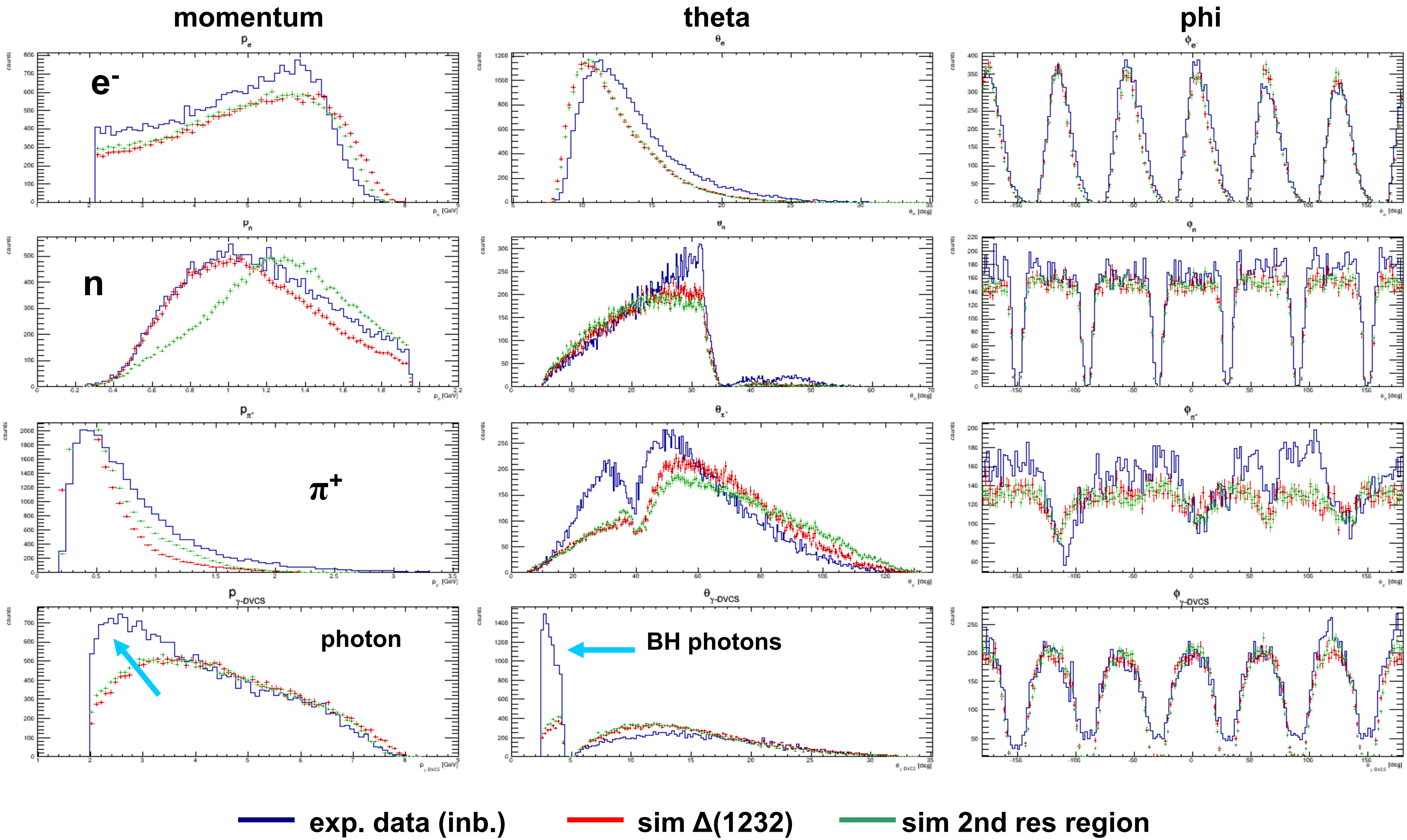




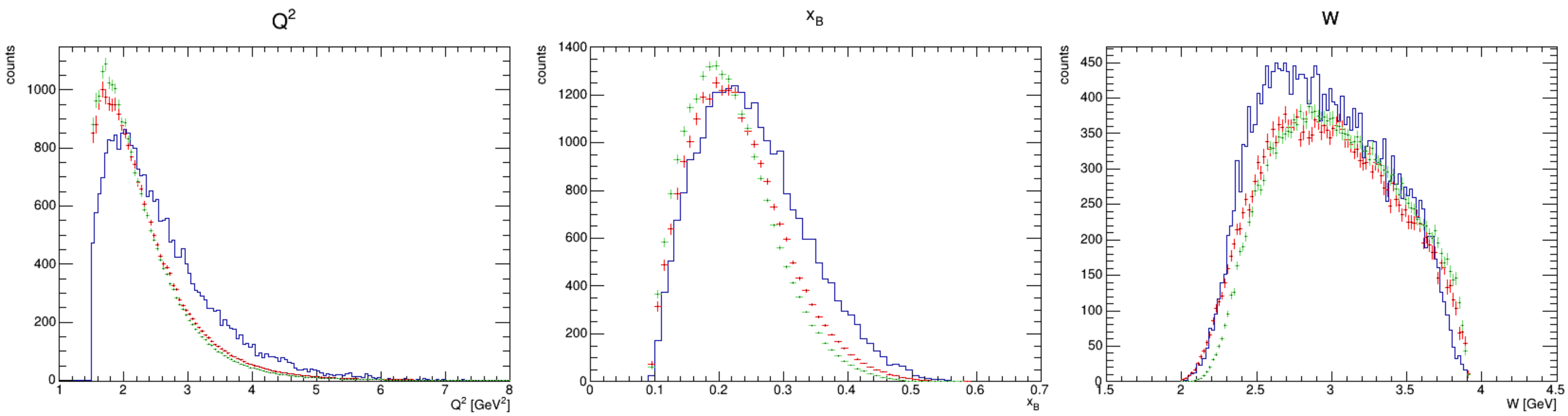




Particle distributions: Data vs MC

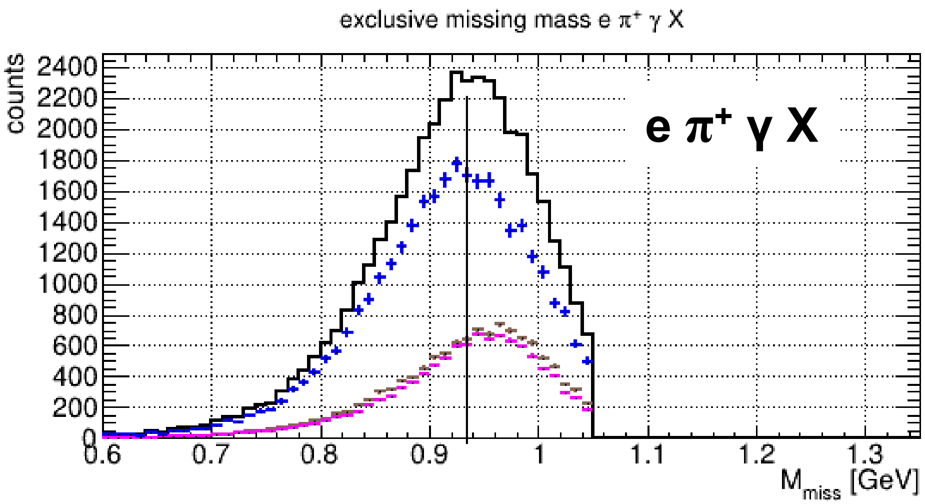


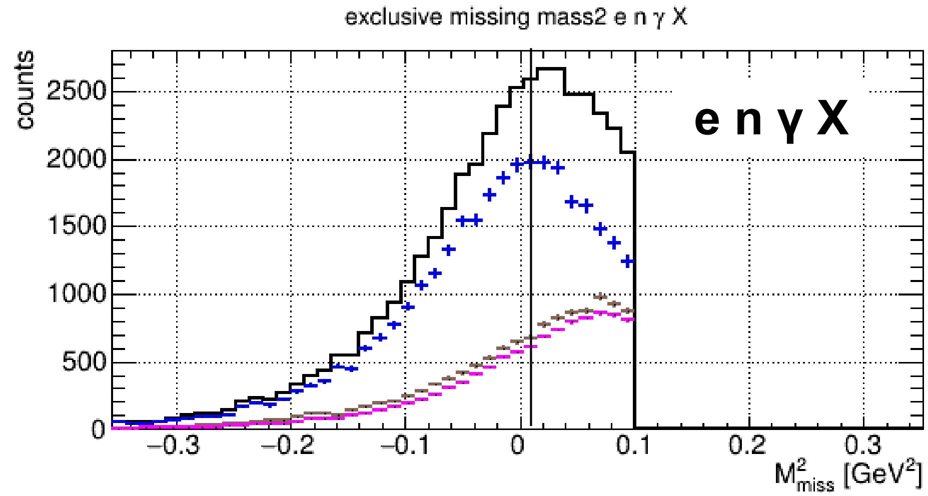
Kinematic distributions: Data vs MC

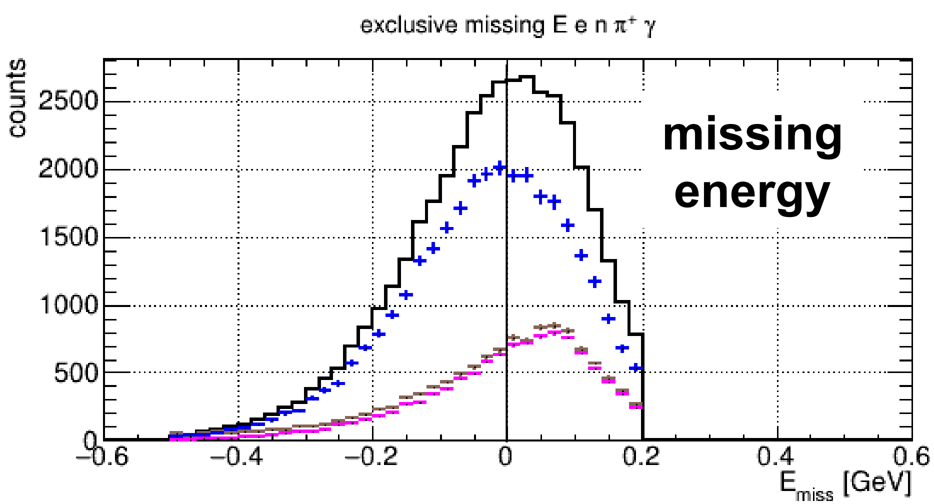


exp. data (inb.) sim Δ(1232) sim 2nd res region

π^0 background in the exclusivity distributions







- data
- MC for N→N* π^0 DVMP
- N→N* π^0 DVMP estimate based on data
- π^0 subtracted data

➔ Background ~ 20 – 25 %

➔ Peaks move to the expected position after π^0 subtraction