First measurement of hard exclusive $\pi^- \Delta^{++}$ electro-production beam spin asymmetries off the proton

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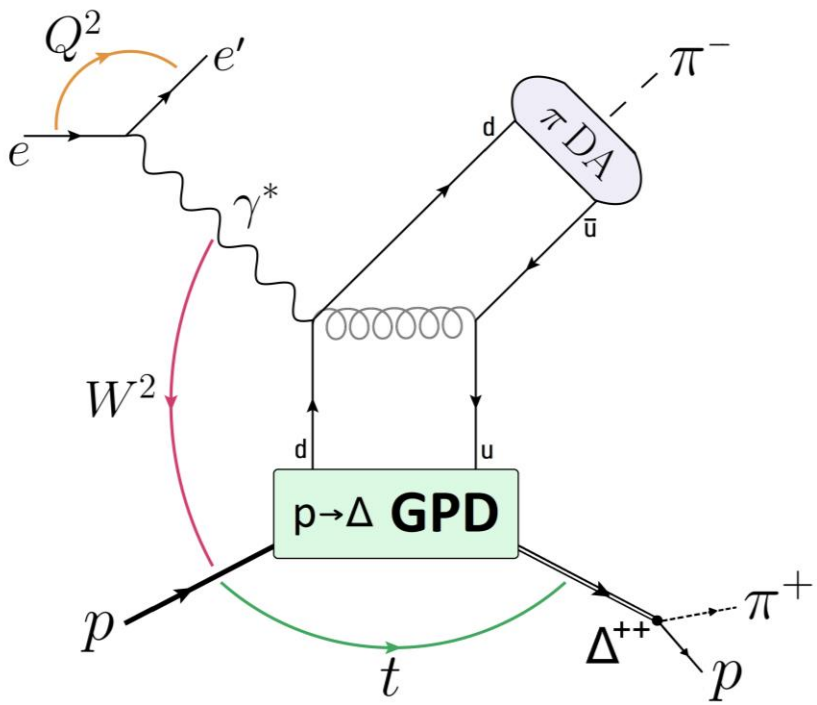
Justus Liebig University Giessen

University of Connecticut

03/24/2023

Motivation

$$ep \rightarrow e\Delta^{++}\pi^{-} \rightarrow ep\pi^{+}\pi^{-}$$



Factorisation expected for:

$-t / Q^2 << 1$ $\quad$ $Q^2 > M_\Delta^2$

x_B fixed

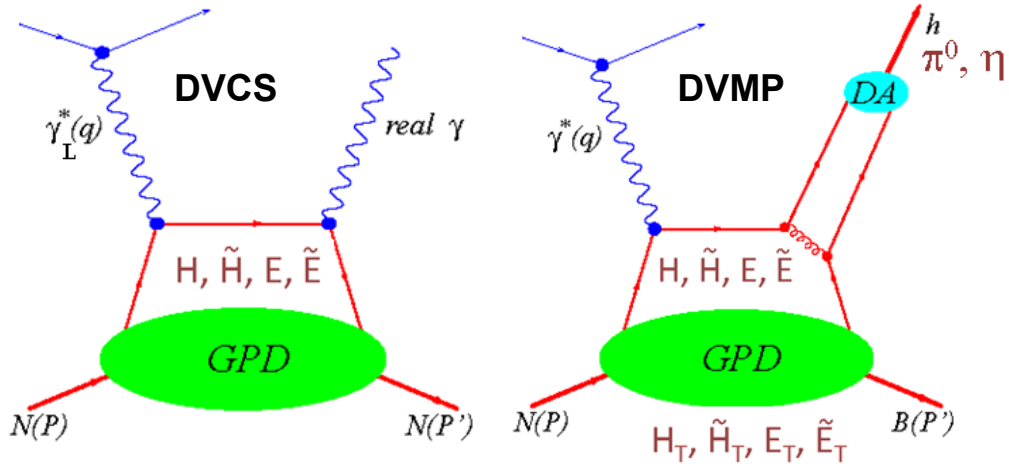
➔ Provides access to the d-quark content of the nucleon

➔ Provides acess to p-Δ transition GPDs

➔ 3D Structure of the Δ resonance and of the excitation process

➔ $\pi^\pm$ BSA is expected to be especially sensitive to the tensor charge of the nulceon / resonance (quark polarisation)

Motivation



ordinary GPDs:

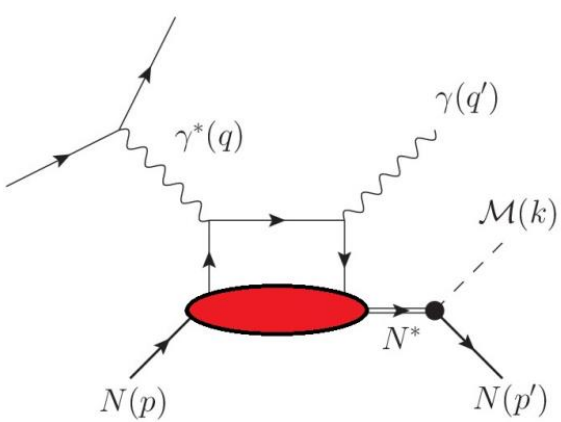
quark pol.

nucleon

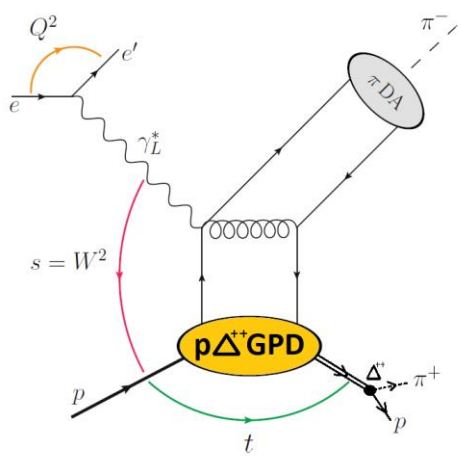
N/q	U	L	T
U	H		$\bar{E}_T$
L		$\tilde{H}$	$\tilde{E}_T$
T	E	$\tilde{E}$	$H_T, \tilde{H}_T$

4 chiral even GPDs

4 chiral odd GPDs



N→N* DVCS



N→N* DVMP

- **8 helicity non-flip trans. GPDs (twist 2)**

→ First moments related to the Jones-Scardon and Adler form factors

→ Description of N→Δ DVCS

K. Semenov, M. Vanderhaeghen, arXiv:2303.00119 (2023)

- **8 helicity flip trans. GPDs (twist-3)**

→ Impact of transversely polarized virtual photons

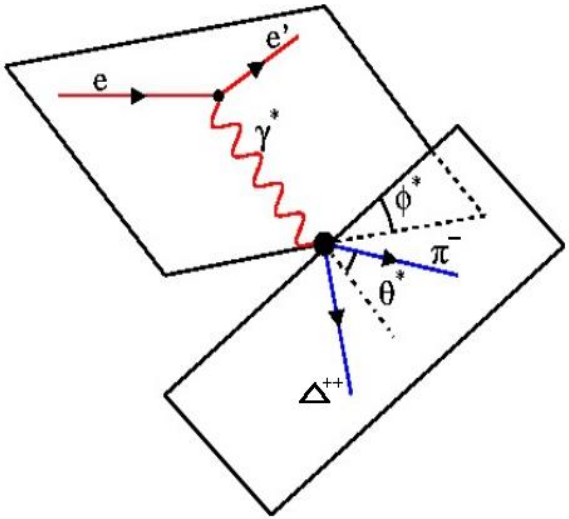
→ Needed for pseudoscalar N→Δ DVMP

P. Kroll, K. Passek-Kumericki, Phys. Rev. D 107, 054009 (2023)

Hard Exclusive π^- Electroproduction and BSA

Cross section (longitudinally pol. beam and unpol. target):

$$2\pi \frac{d^2\sigma}{dt d\phi} = \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} + \epsilon \cdot cos(2\phi) \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)} \cdot cos(\phi) \frac{d\sigma_{LT}}{dt} + h \cdot \sqrt{2\epsilon(1-\epsilon)} \cdot sin(\phi) \frac{d\sigma_{LT'}}{dt}$$

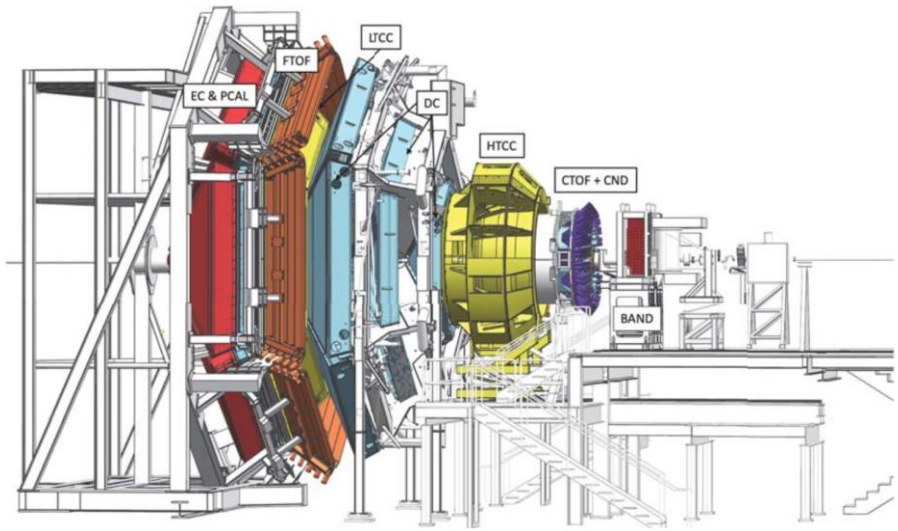


$$BSA(t, \phi, x_B, Q^2) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{\sqrt{2\epsilon(1-\epsilon)} \frac{\sigma_{LT'}}{\sigma_0} \sin\phi}{1 + \sqrt{2\epsilon(1+\epsilon)} \frac{\sigma_{LT}}{\sigma_0} \cos\phi + \epsilon \frac{\sigma_{TT}}{\sigma_0} \cos 2\phi}$$

$$\sigma_{LT'} \sim \sqrt{-t'} \;\; \Im \left[G^3_{T_5} \cdot A + c \; G^3_{T_7} \cdot A' \right]$$

$$G^{(3)}_{T5} + \frac{1}{2} G^{(3)}_{T7} = -\frac{3}{2}\left(H^u_T - H^d_T\right)$$

Experimental Setup and Run Periods



V. Burkert et al., Nucl. Instr. Meth. A 959, 163419 (2020)

- ➔ Data recorded with CLAS12 during fall 2018 and spring 2019 (RG-A)
  - ➔ 10.6 GeV / 10.2 GeV electron beam
  - ➔ ~ 86 % average polarization
  - ➔ liquid H_2 target
  - ➔ Inbending (fall 2018, spring 2019) and outbending (fall 2018) torus field configuration

Particle ID and Kinematic Cuts

Electron ID
→ eventbuilder PID
→ PCAL and DC fiducial cuts
→ PID refinements (see RG-A note)

π^- and p ID
→ eventbuilder PID
→ DC fiducial cuts
→ Δv_z cut and $|\chi^2_{pid}| < 3$ (π^-) , < 4 (p)

• Particles only detected in the FD ($5° < \theta < 35°$)

Event selection:

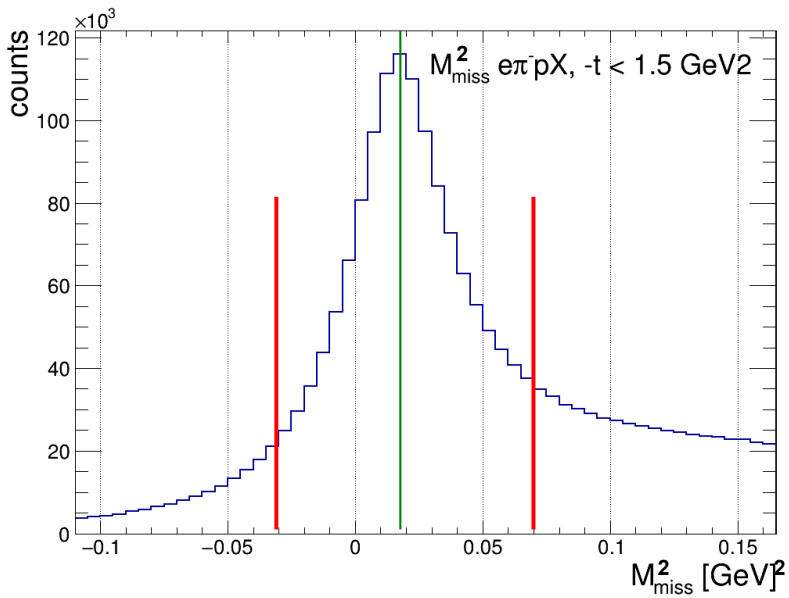
$$ep \rightarrow ep\pi^- X \qquad X = \pi^+$$

➔ 2 sigma cut around the missing π^+

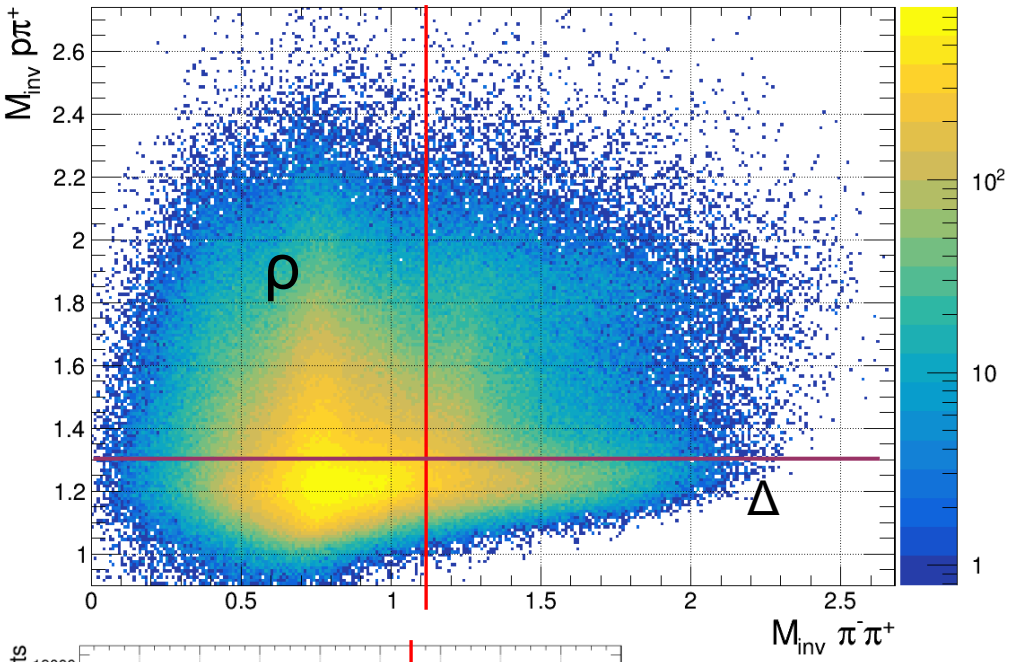
Kinematic cuts:

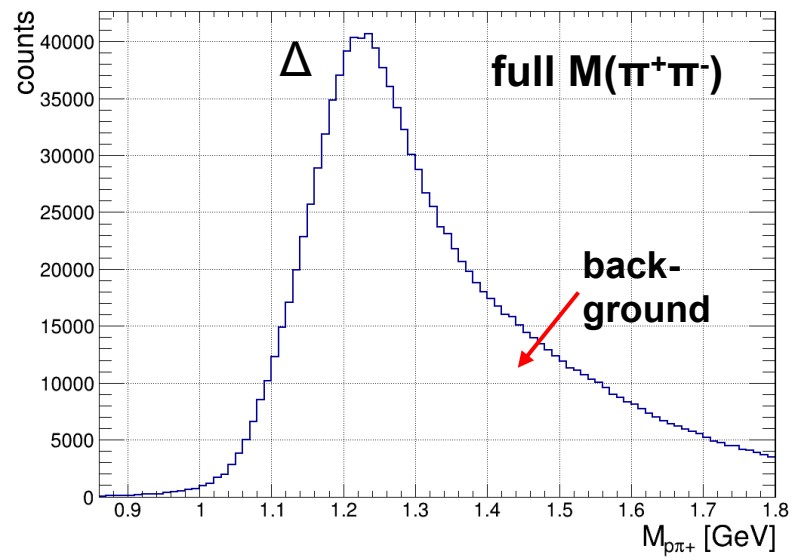
$Q^2 > 1.5$ GeV² W > 2 GeV y < 0.75

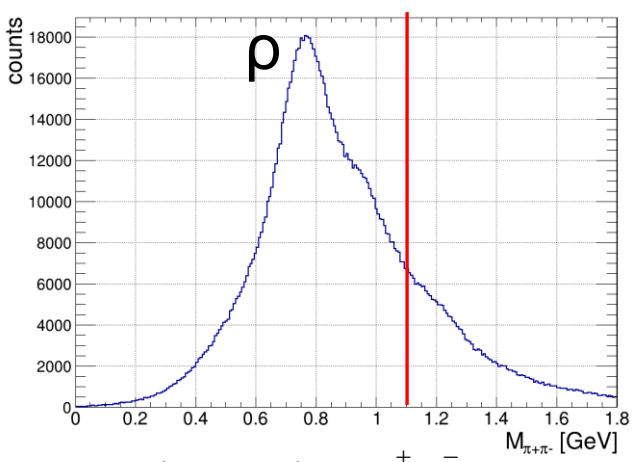
-t < 1.5 GeV² (only the forward region)



Event Selection and Background Rejection





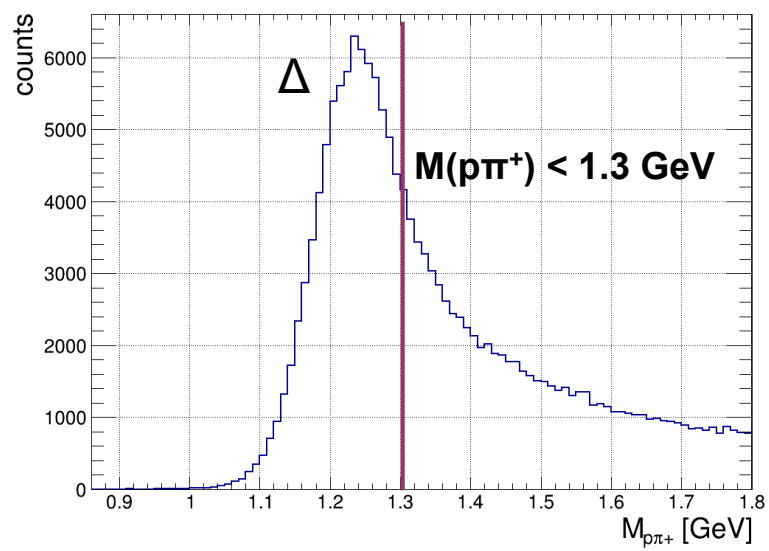


$$ep \rightarrow ep\rho \rightarrow ep\pi^+\pi^-$$

$M(\pi^+\pi^-) > 1.1$ GeV

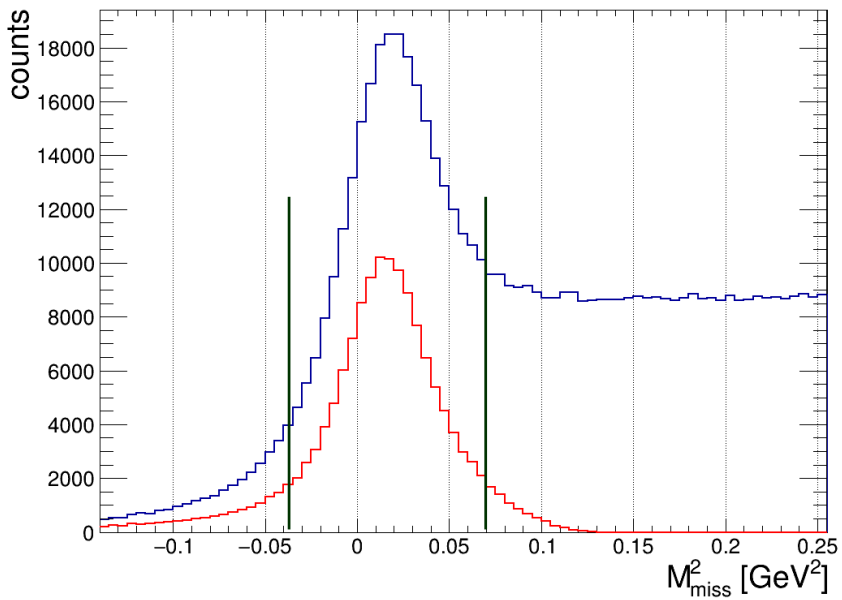
ρ contamination

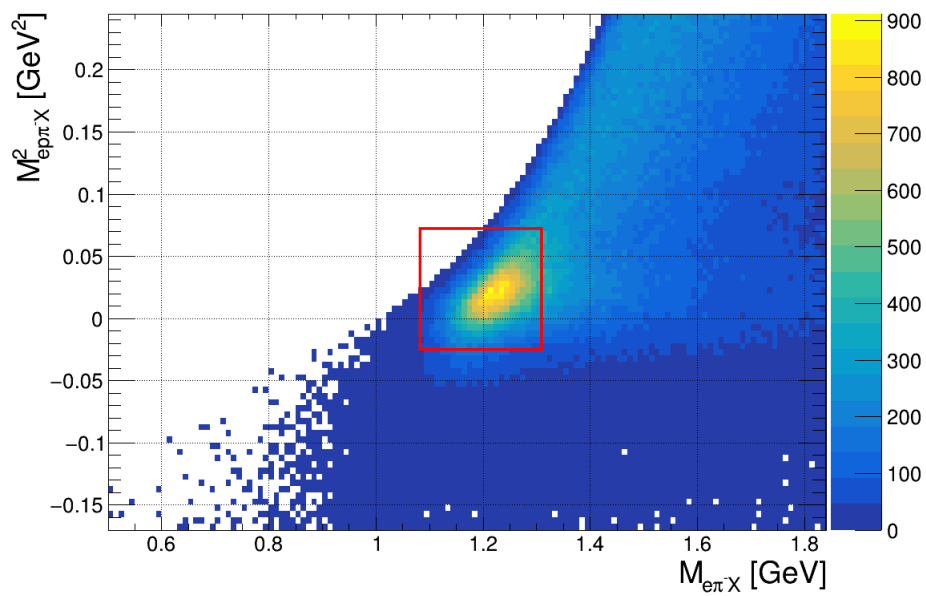
< 0.8 %



Event Selection and Background Rejection

$ep\pi^-X$ missing mass





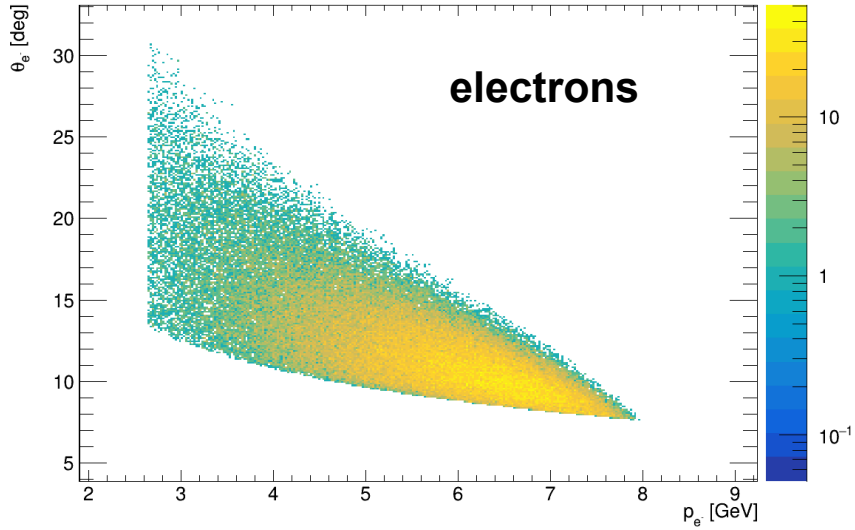
Missing π^+ after $M(\pi^+\pi^-) > 1.1$ GeV

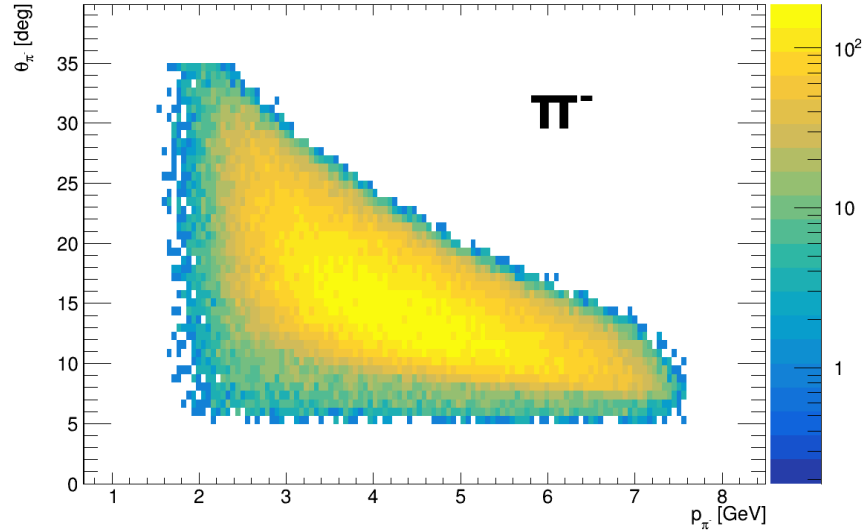
Missing π^+ after $M(\pi^+\pi^-) > 1.1$ GeV and $M(p\pi^+) < 1.3$ GeV

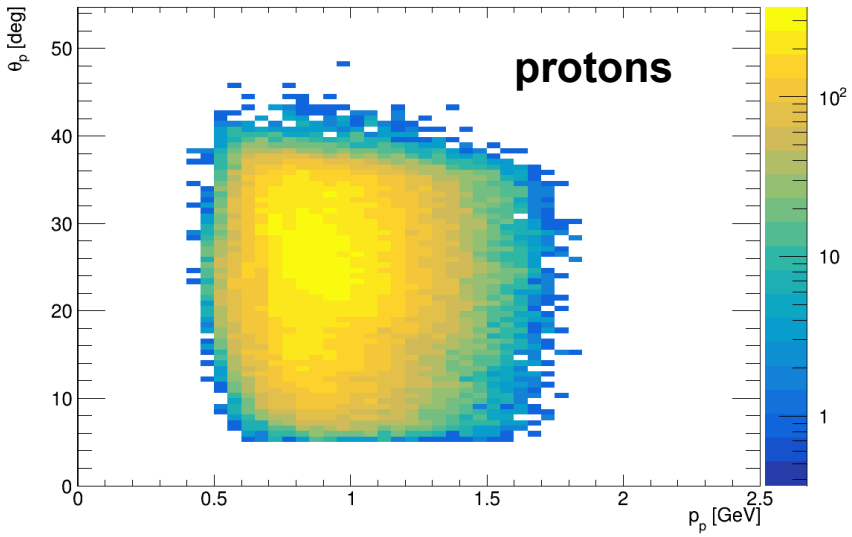
➔ **Selecting the Δ events, allows only one π^+ in addition**

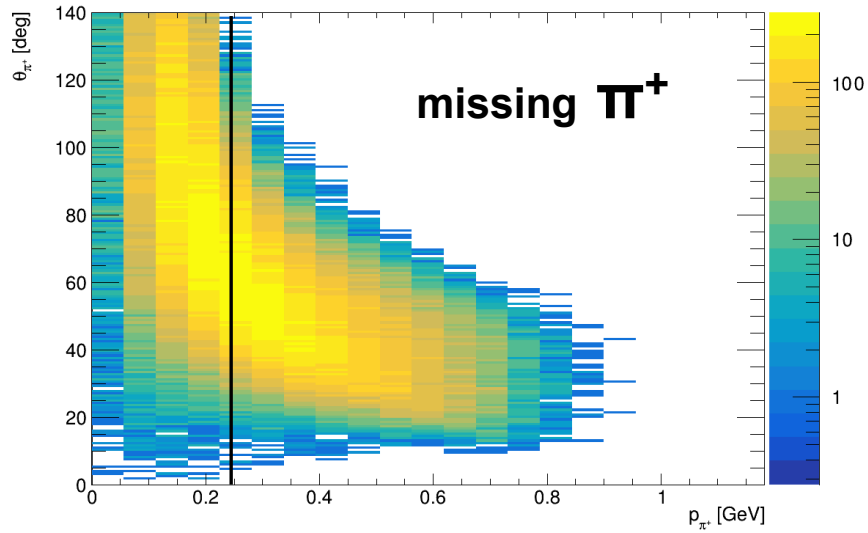
➔ **Sample is cleaned up automatically**

Particle Distributions (-t < 1.5 GeV²)









Monte Carlo Simulations

2 MC samples have been used:

a) SIDIS MC sample with background merging

→ Does not contain the exclusive $\pi^-\Delta^{++}$ production in the GPD regime ($-t < 1.5$ GeV²)

→ Contains nonresonant background as well as ρ production and other potential background channels

➔ Used to estimate background shape and contaminations

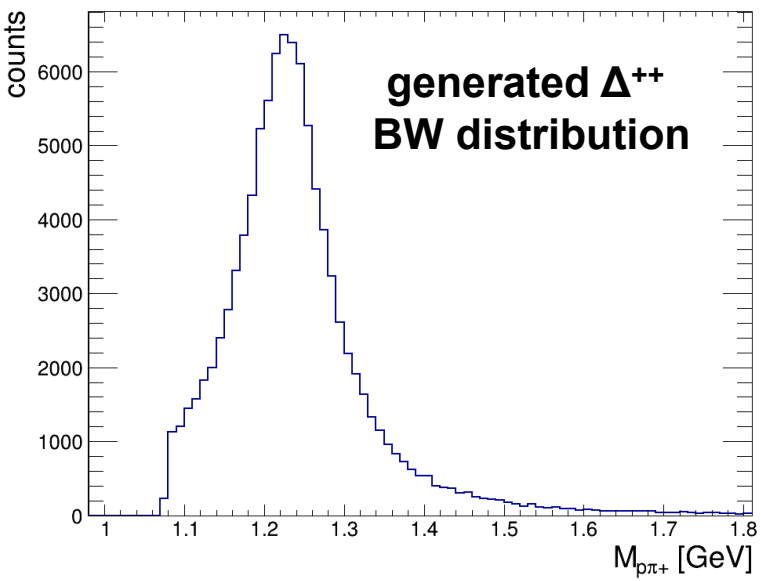
b) Exclusive $\pi^-\Delta^{++}$ MC

→ Phase space simulation with a weight added to match experimental data

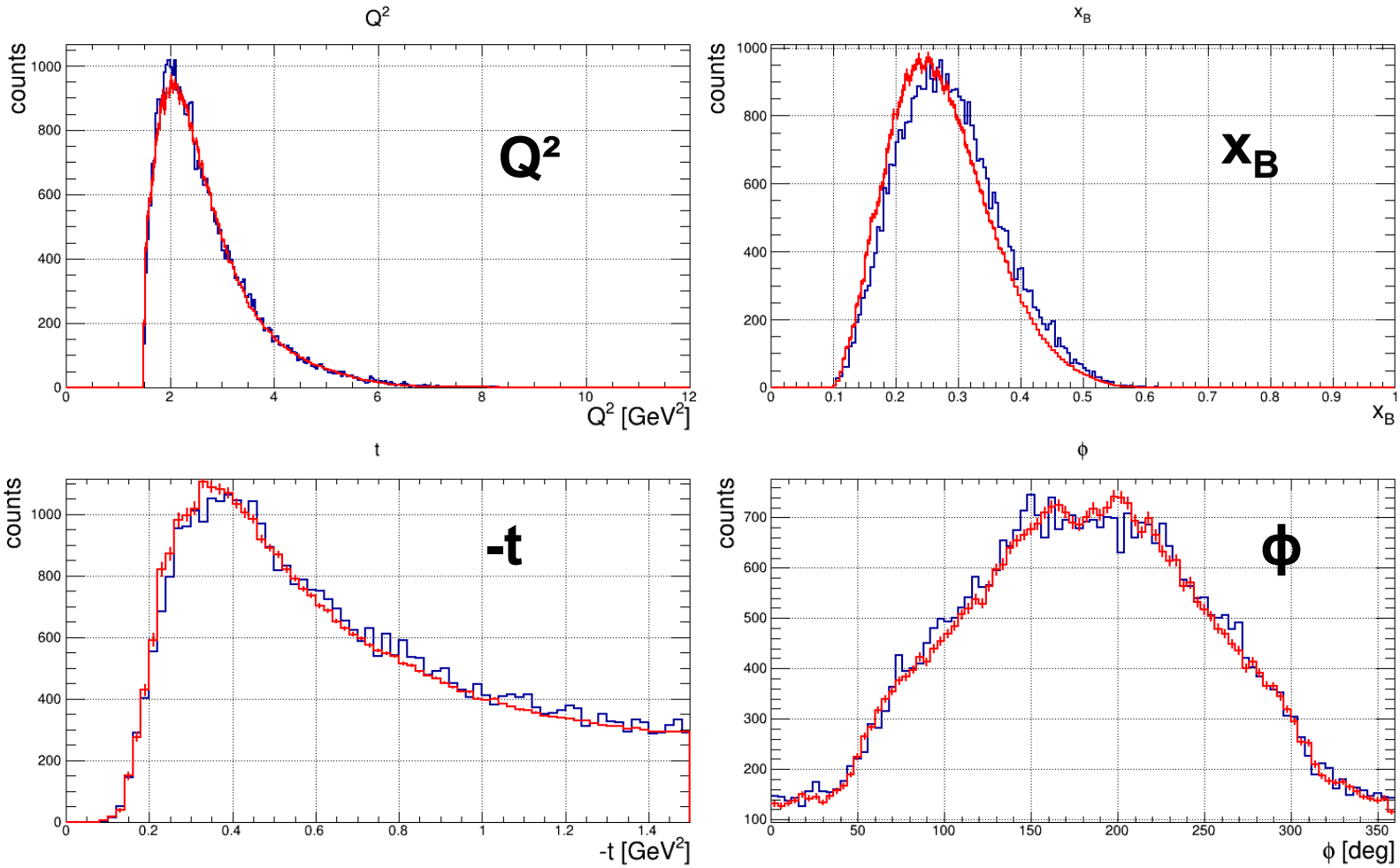
→ Δ peak with PDG mass and FWHM

➔ Both MCs are processed through gemc and reconstruction with inbending and outbending torus fields

➔ The final 4-vectors are smeared to introduce a realistic resolution

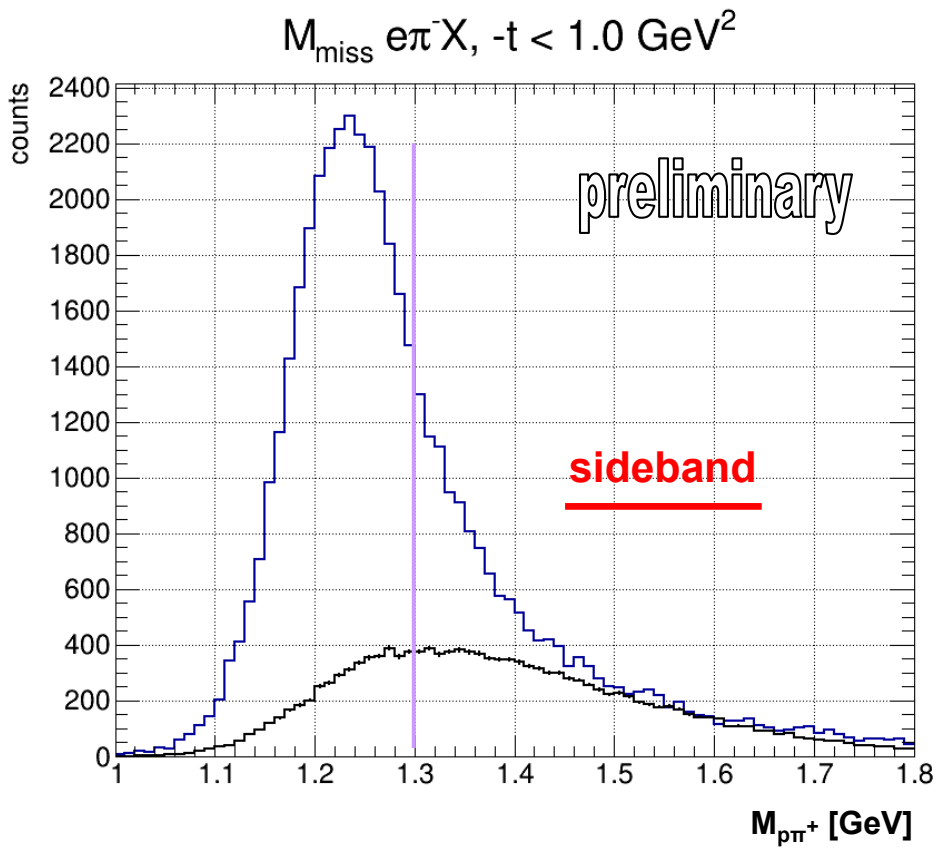


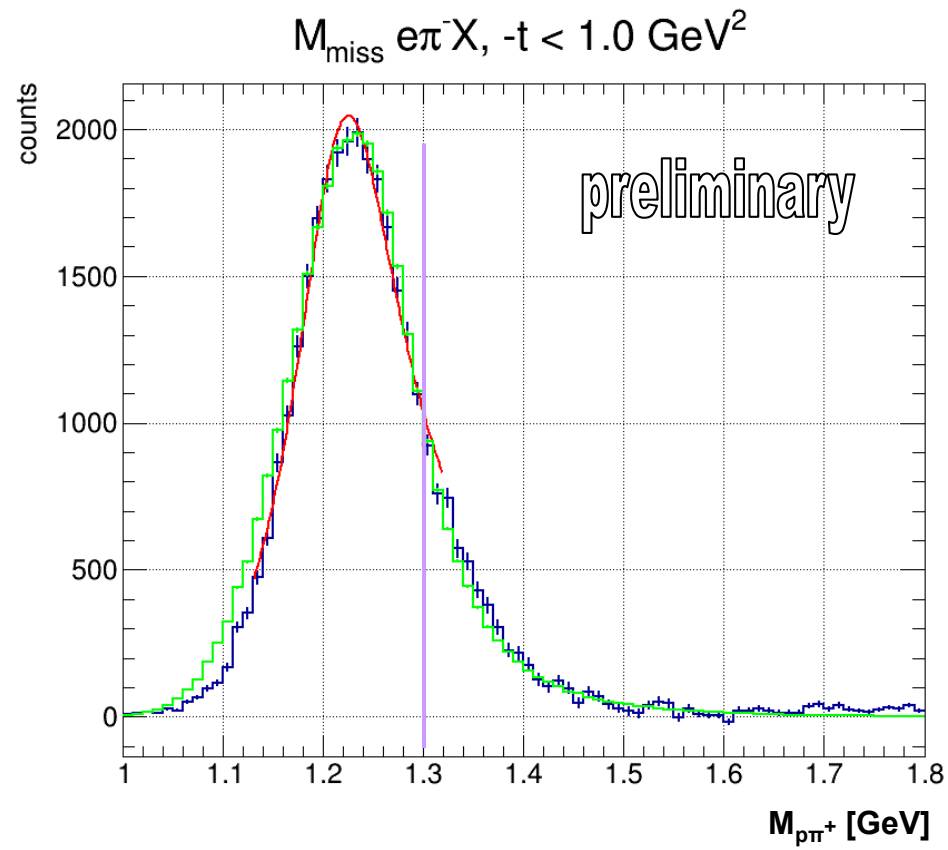
Exclusive Monte Carlo Simulations (inbending)



data (excl.) exclusive MC

Signal and Background Separation





experiemtal data

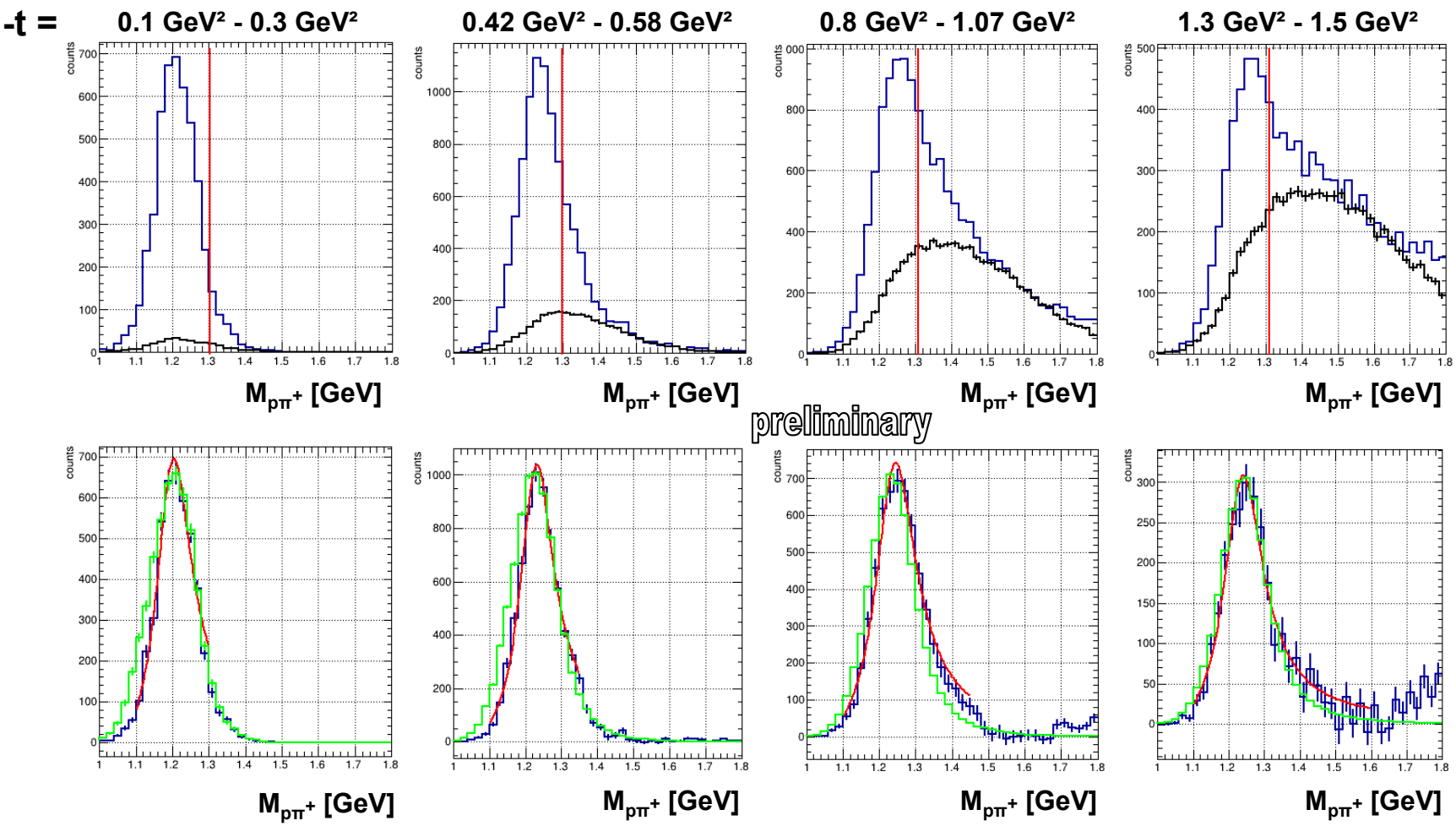
SIDIS MC (same cuts)

data after SIDIS MC subtraction

fit of a Sill function (BW with thr. effects)

exclusive MC (for comparison)

Signal and Background Separation



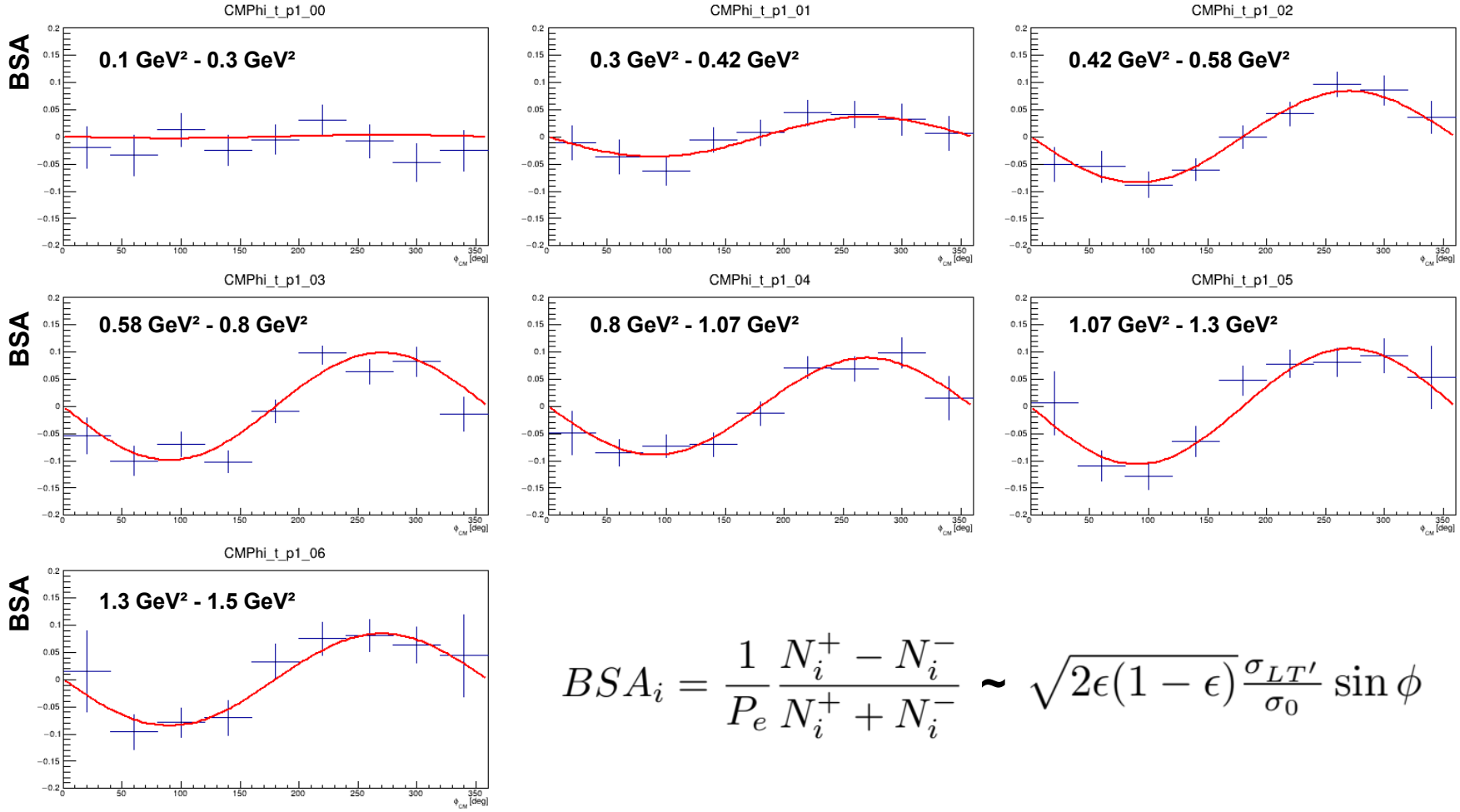
experimental data

background

data after SIDIS MC subtraction

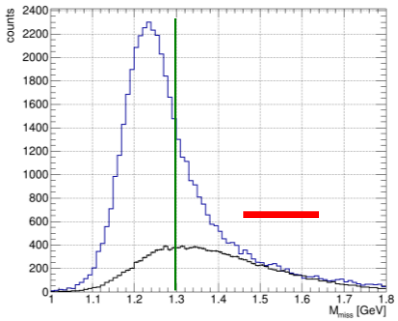
exclusive MC (for comparison)

Resulting Beam Spin Asymmetries (Q^2-x_B integrated)



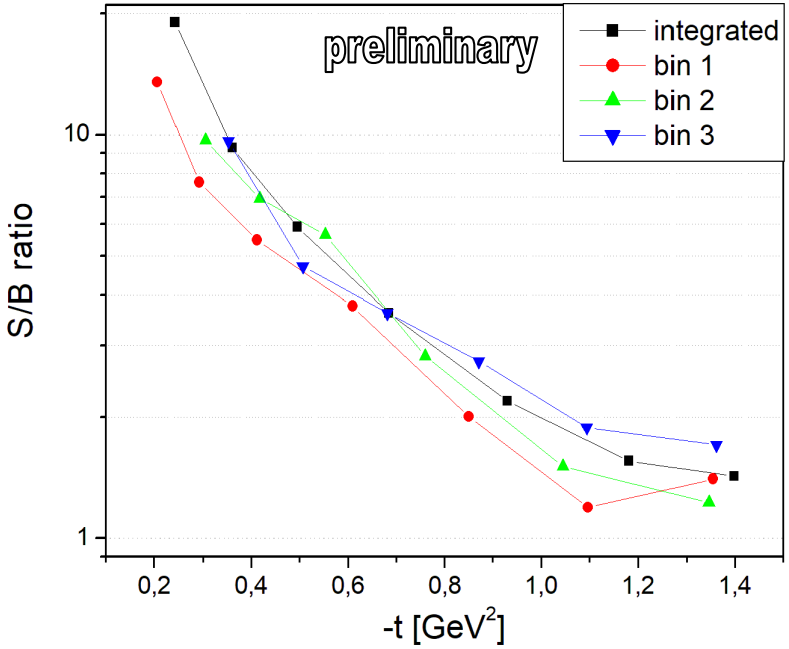
$$BSA_i = \frac{1}{P_e}\frac{N_i^+ - N_i^-}{N_i^+ + N_i^-} \sim \sqrt{2\epsilon(1-\epsilon)}\frac{\sigma_{LT'}}{\sigma_0}\sin\phi$$

Background Subtraction

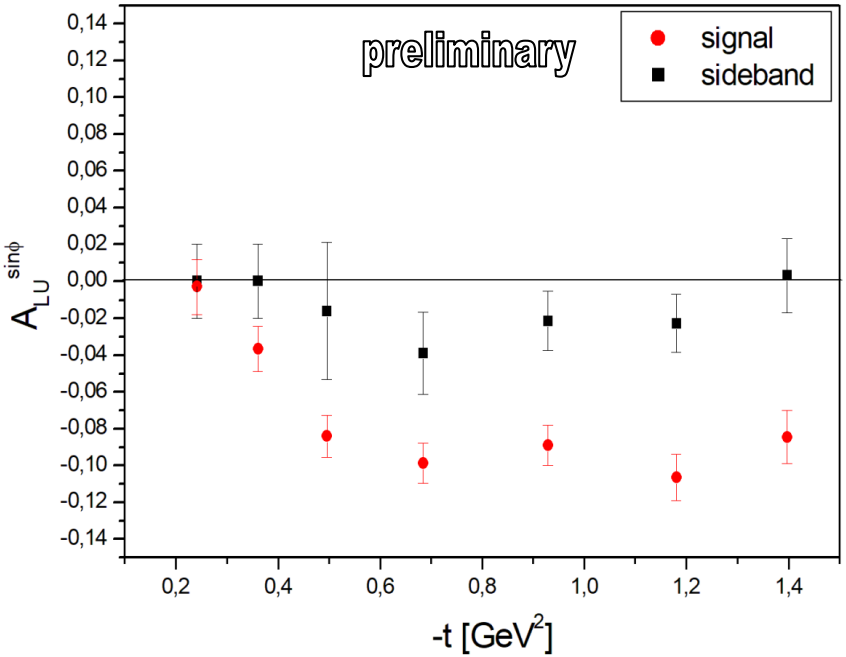


Method 1: A sideband based background subtraction

S/B ratio based on data - MC comparison



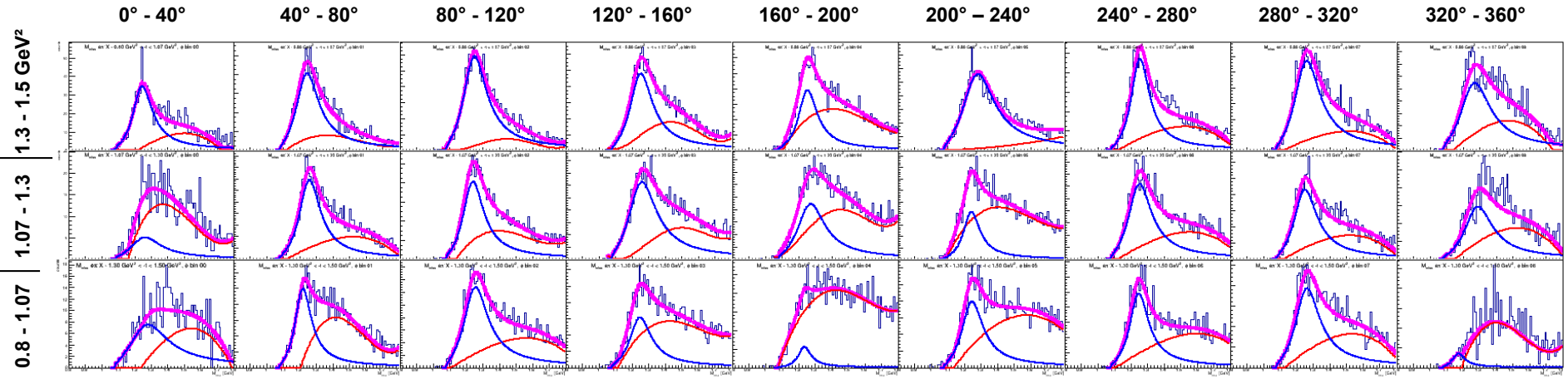
asymmetry of the sidebands

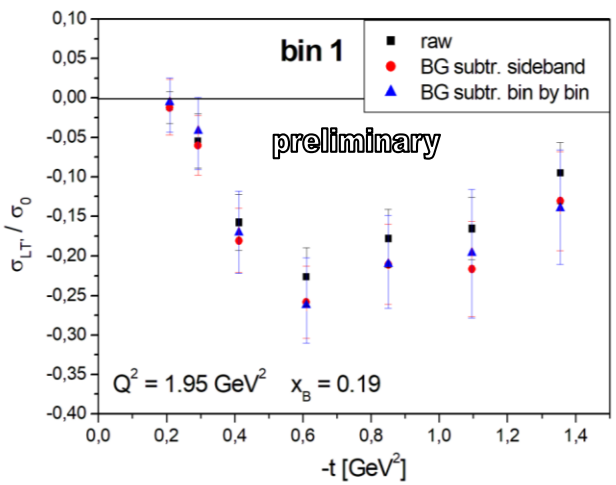


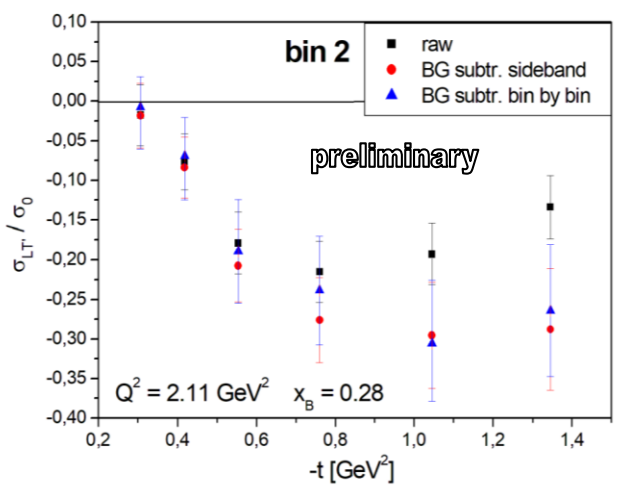
Background Subtraction

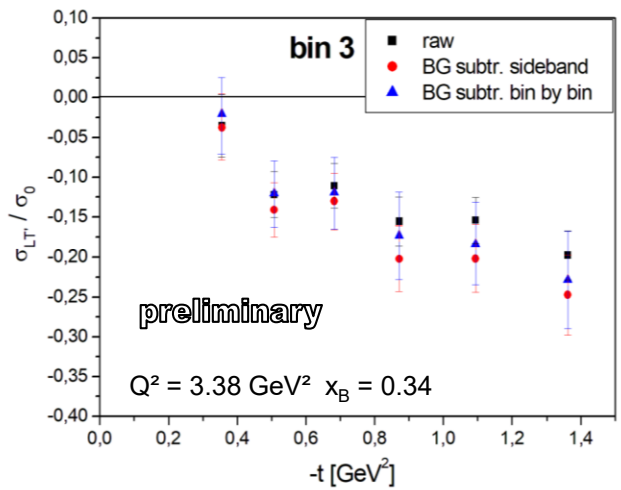
Method 2: A bin-by-bin background subtraction

- Fit of the $p\pi^+$ inv. mass with a „Sill“ function and a 5th order polynomial in each Q^2, x_B, -t, Φ bin.









Sources of Systematic Uncertainty

1. Uncertainty of the background subtraction

→ 2 sources of uncertainty: S/B ratio and sideband asymmetry

→ Both sources were varied within their uncertainty range

➔ Typically in the order of 1.5 % (low -t) - 12.5 % (high -t) (stat. ~ 12 – 25 %)

➔ Dominant sys. uncertainty for the high -t bins

2. Uncertainty of the beam polarization ~ 3.1 %

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

4. Acceptance and bin-migration effects ~ 2.9 %

→ Comparison of injected and reconstructed BSA in the MC

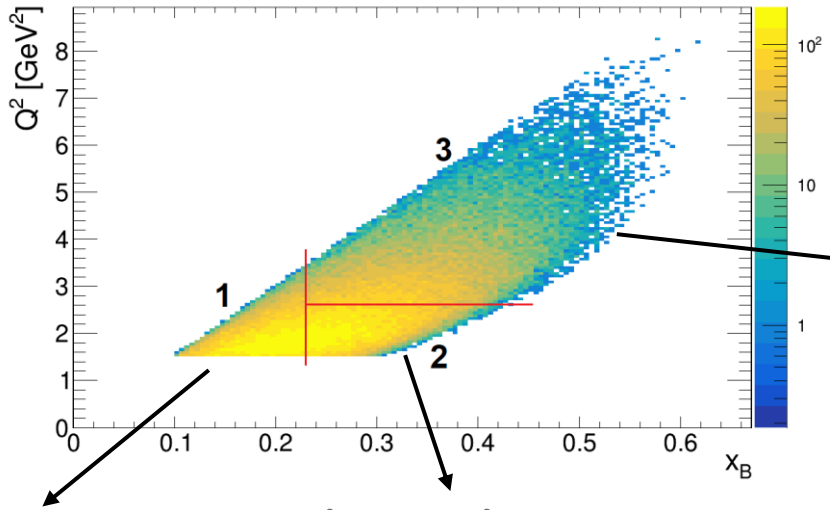
5. Radiative effects ~ 3.0 %

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

Total: 7.1 - 14.3 %

Results

S. Diehl et al. (CLAS collab.), **submitted to Phys. Rev. Lett. (2023)** arXiv:2303.11762



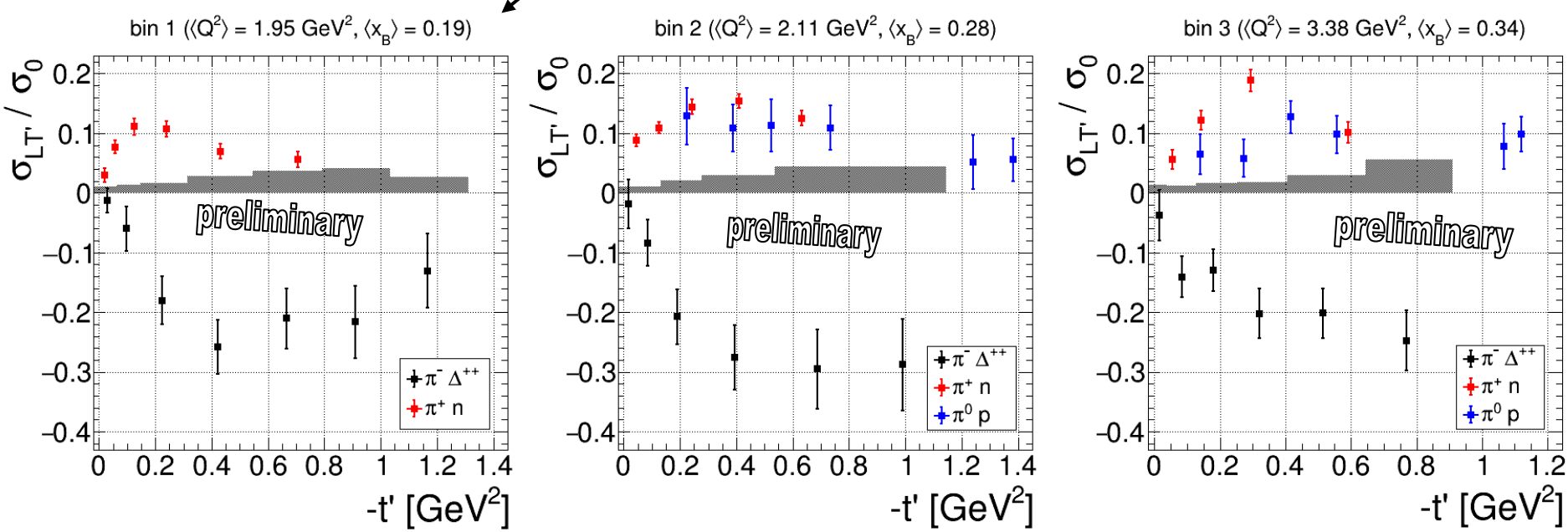
proton (uud)

$\rightarrow$ neutron (udd)

$\pi^+ \left(|u\bar{d}\rangle\right)$

$\rightarrow \Delta^{++}$ (uuu)

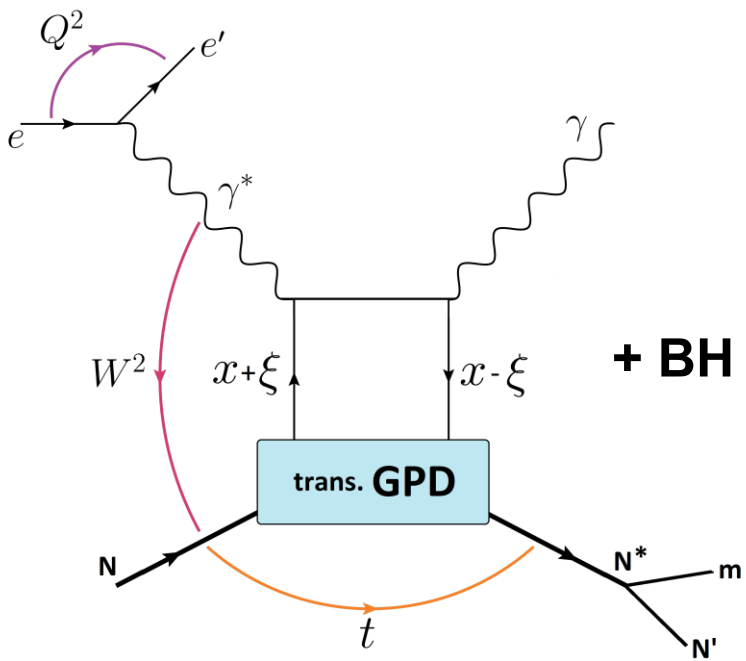
$\pi^- \left(|d\bar{u}\rangle\right)$



Outlook and Next Steps

The N→Δ DVCS process:

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

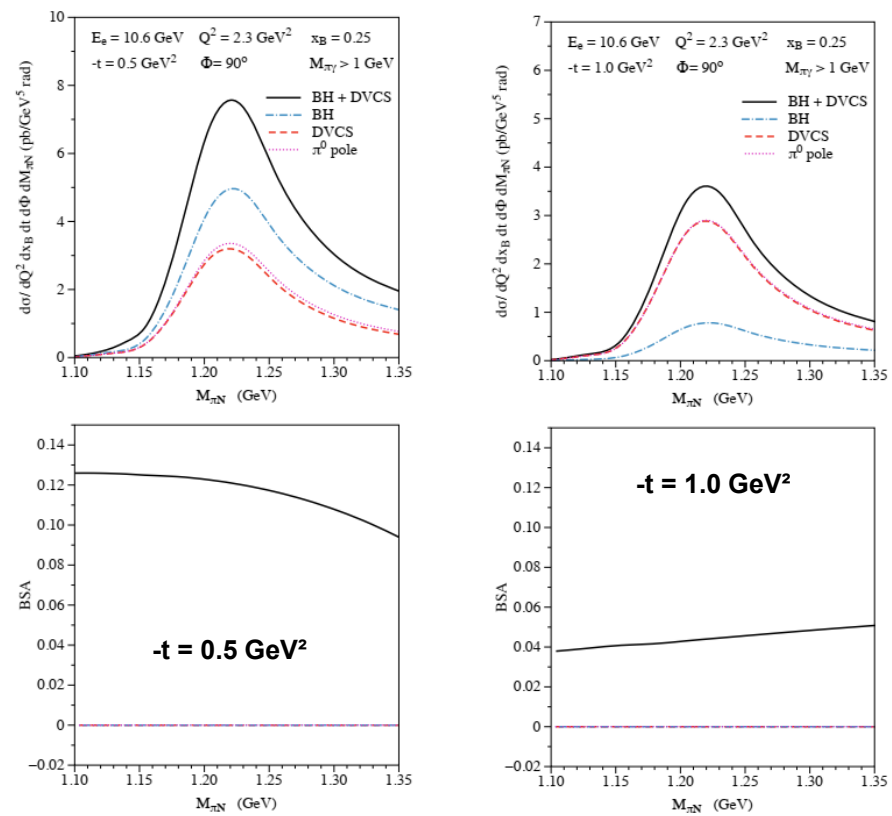


+ BH

e p → e‘ Δ⁺ γ → e‘ n π⁺ γ

- **Access to the helicity non-flip (twist-2) transition GPDs**
- **Detailed models for CLAS12 kinematics became available recently**

Semenov-Tian-Shansky, Vanderhaeghen, arXiv:2303.00119 (2023)

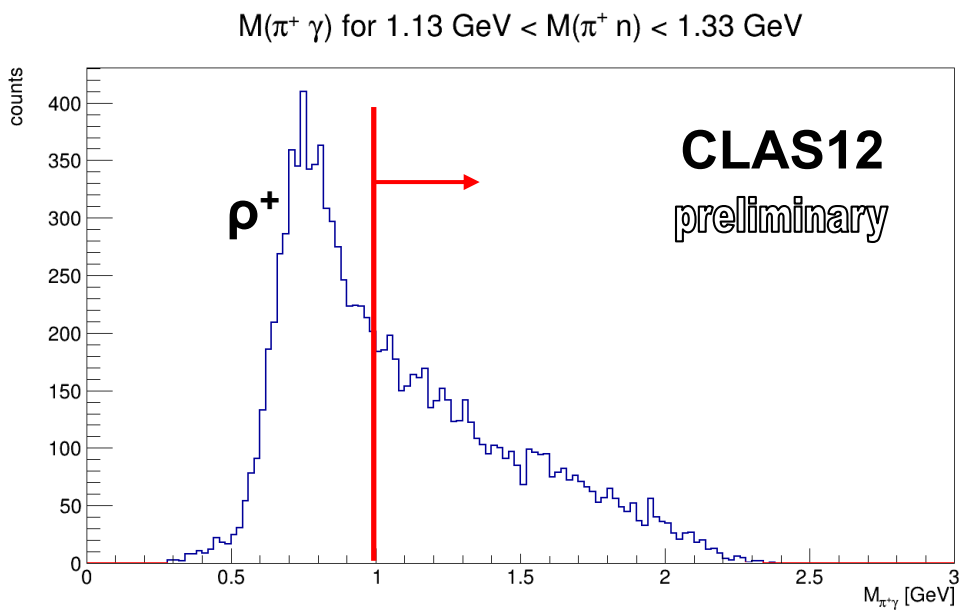


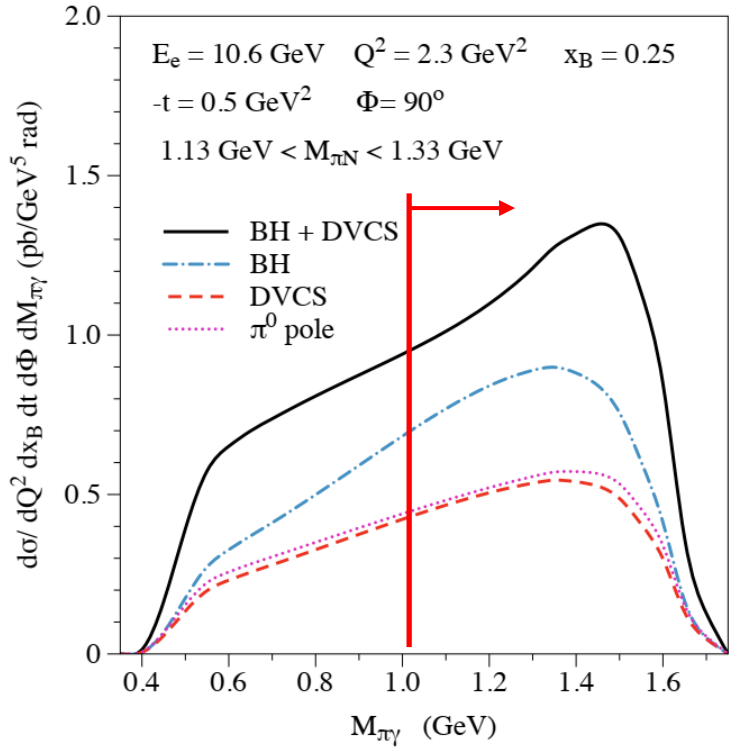
Outlook and Next Steps

$$e\ p \rightarrow e'\ \Delta^+\ \gamma \rightarrow e'\ n\ \pi^+\ \gamma$$

Kinematic cuts: $W > 2$ GeV $Q^2 > 1$ GeV² $y < 0.8$ $-t < 2$ GeV² $E_{DVCS} > 2$ GeV

Background:





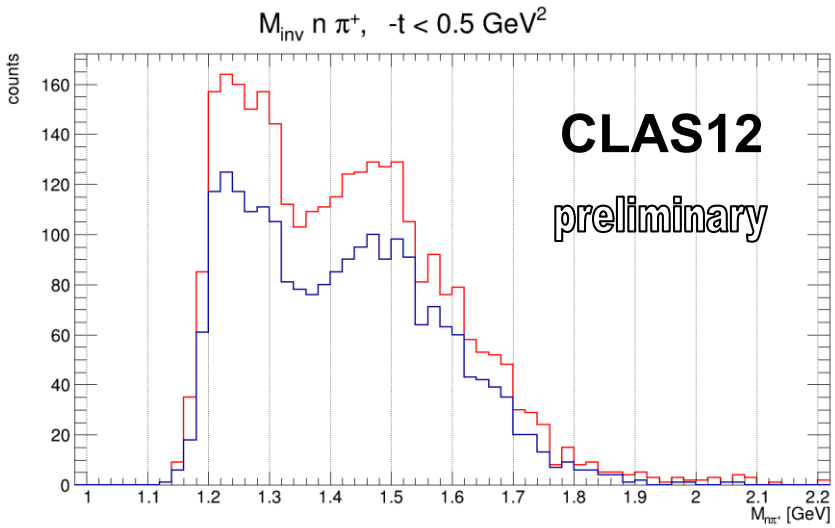
- Dominant background from $\rho^+ \rightarrow \pi^+\ \gamma$

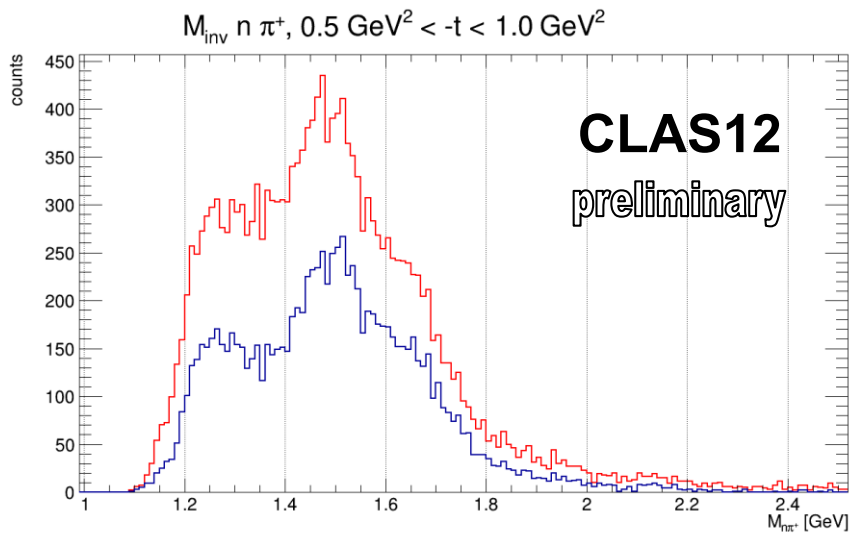
Semenov-Tian-Shansky, Vanderhaeghen, arXiv:2303.00119 (2023)

Outlook and Next Steps

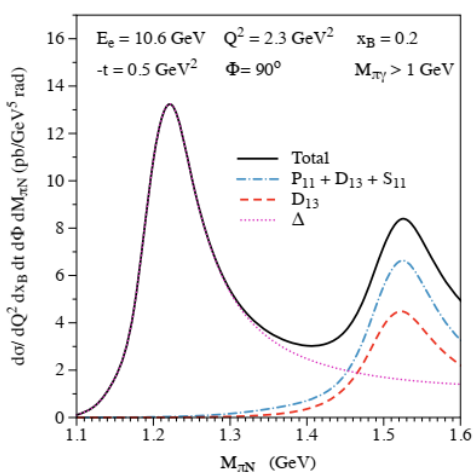
$e\,p \rightarrow e'\,\Delta^+\,\gamma \rightarrow e'\,n\,\pi^+\,\gamma$

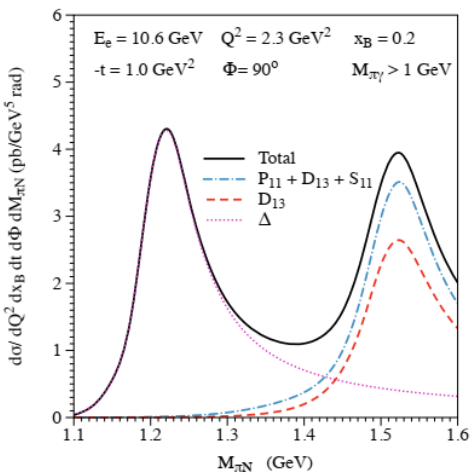
raw — $M(\pi^+\gamma) > 1.0$ GeV





Semenov-Tian-Shansky, Vanderhaeghen, arXiv:2303.00119 (2023)





- study in progress
- π^+ mainly in CD and low momentum
- Good agreement of BSA
- awaiting pass 2

Conclusion and Outlook

- Hard exclusive $\pi^- \Delta^{++}$ production can be well measured with CLAS12.
- The channel provides a first observable sensitive to $p \rightarrow \Delta$ transition GPDs and a novel access to the d-quark content of the nucleon.
- The obtained BSA is clearly negative and ~ 2 times larger than for the hard exclusive π^+ production.
- A transition GPD based description of the reaction exists by P. Kroll and K. Passek-Kumericki, but a reliable prediction of BSAs is not possible due to missing experimental constraints to the transversity transition GPDs.

P. Kroll, K. Passek-Kumericki, Phys. Rev. D 107, 054009 (2023) arXiv:2211.09474

- The paper has been submitted to PRL this Tuesday. arXiv:2303.11762

Next steps:

- Analysis of the double spin asymmetry A_{LL} of $\pi^- \Delta^{++}$ based on RG-C data.
- With RG-A pass 2, the non-diagonal DVCS process will provide additional constraints on the twist-2 transition GPDs (see theory work by K. Semenov-Tian-Shansky and M. Vanderhaegen).

K. Semenov, M. Vanderhaeghen, arXiv:2303.00119 (2023)

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Deutsche Forschungsgemeinschaft
German Research Foundation

project number: 508107918

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apctp asia pacific center for theoretical physics