HADRON 2023

5.-9. June 2023 Genova, Italy

Exploring resonance structure with transition GPDs with CLAS12 at JLAB

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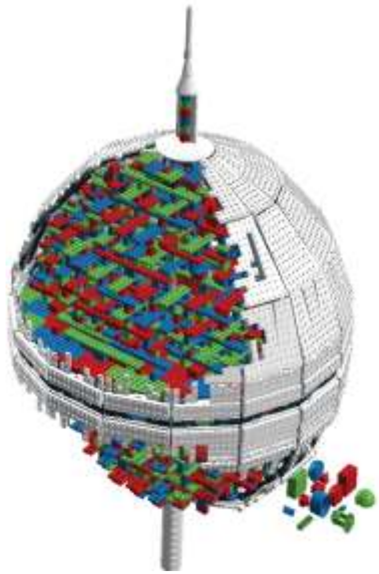
06/07/2023

QCD Science Questions

How are the quarks and gluons, and their intrinsic spins distributed in space & momentum inside the nucleon / nucleon resonance?

How can we recover the characteristics of the nucleon from the properties of its colored building blocks?

Mass? Spin? Charge? ….



What is the role of orbital angular motion?

$\boxed{\text{Classical: } L \sim \mathbf{r} \times \mathbf{p}}$

We need something three-dimensional!

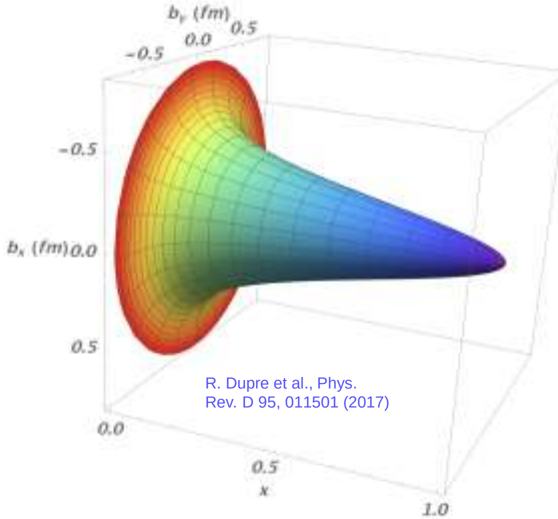
We need to investigate the 3D structure!

Generalized Parton Distributions (GPDs)

$$\rho(x, \vec{k}_T, \vec{b}_T)$$

$$\int d^2 k_T$$

GPDs: 3-D nucleon images in the transverse coordinate and longitudinal momentum space



R. Dupre et al., Phys. Rev. D 95, 011501 (2017)

www.wikipedia.de

GPDs encode information on

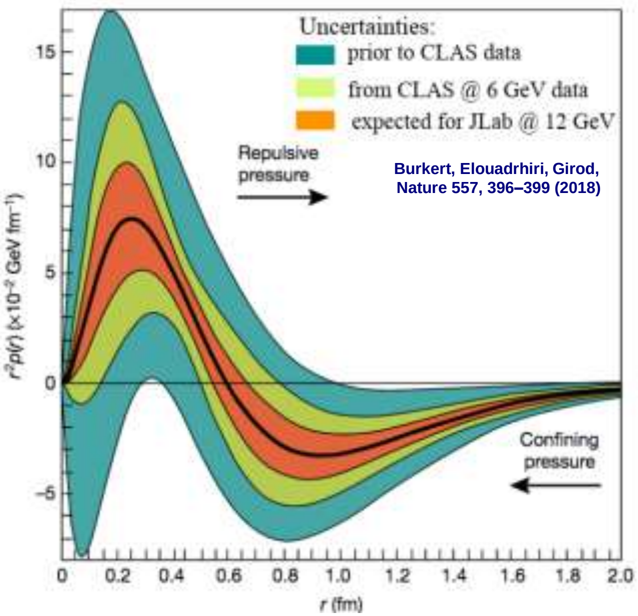
➔ the distribution of pressure and shear forces via gravitational form factors

➔ the nucleon spin via Ji‘s sum rule

➔ the tensor charge

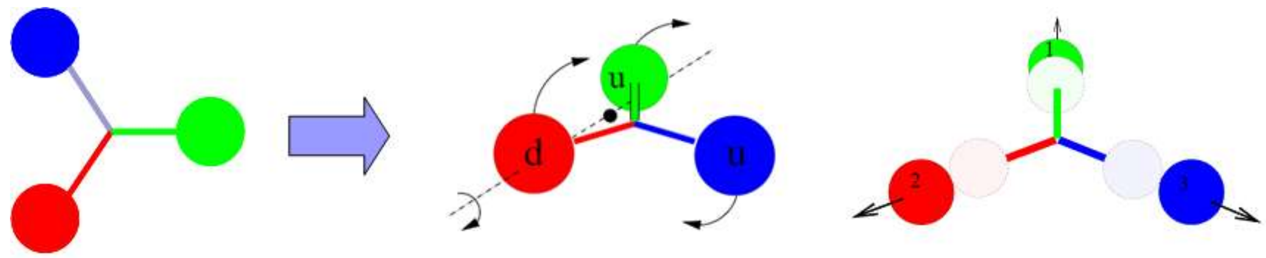
➔ the anomalous tensor magnetic moment

….



Burkert, Elouadrhiri, Girod, Nature 557, 396–399 (2018)

From the Ground State Nucleon to Resonances



How does the excitation affect the **3D structure** of the nucleon?

→ Pressure distributions, mass, tensor charge, … of resonances?

Traditional way: Study of transition form factors (**2D picture** of transv. position)

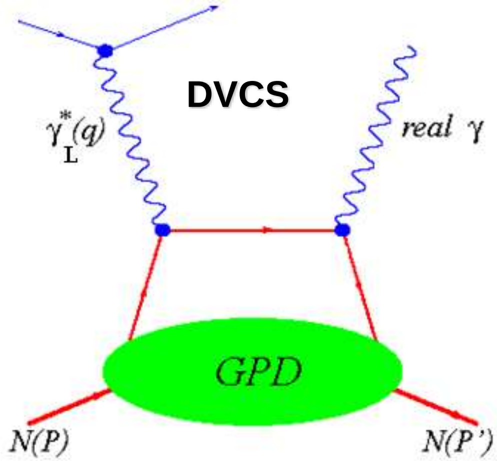
3D picture of the exitation process: Encoded in **transition GPDs**

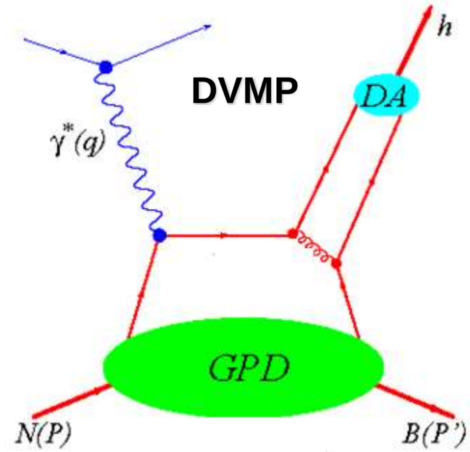
<u>**Simplest case**: N→Δ transition</u> ➔ **16 transition GPDs**

- **8 helicity non-flip transition GPDs (twist 2)**
  - Related to the Jones-Scardon and Adler EM FF for the N → Δ transition
- **8 helicity flip transition GPDs (transversity)**

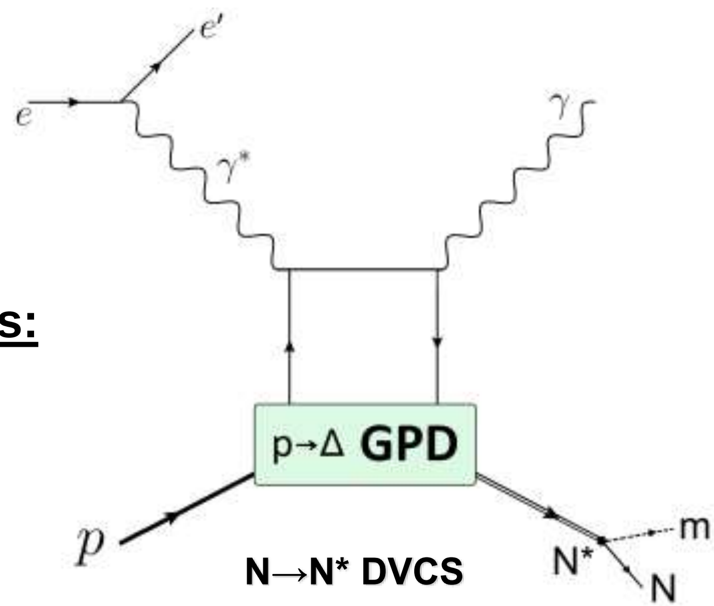
Measurement of Transition GPDs

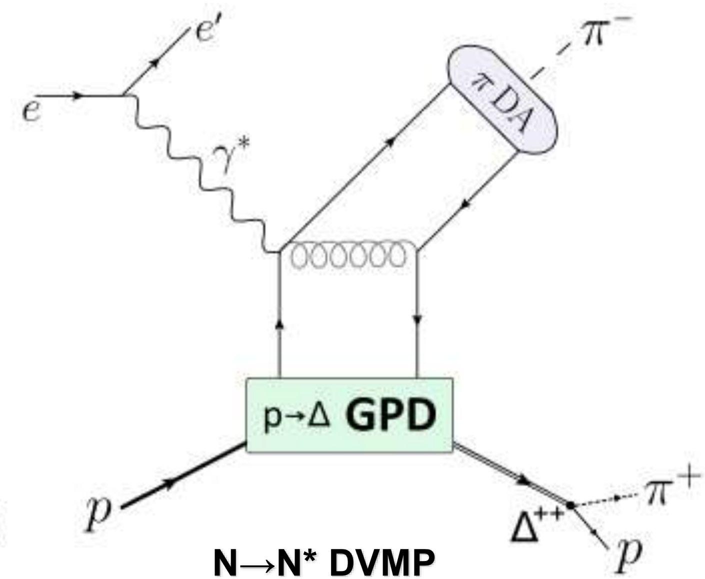
ordinary GPDs:





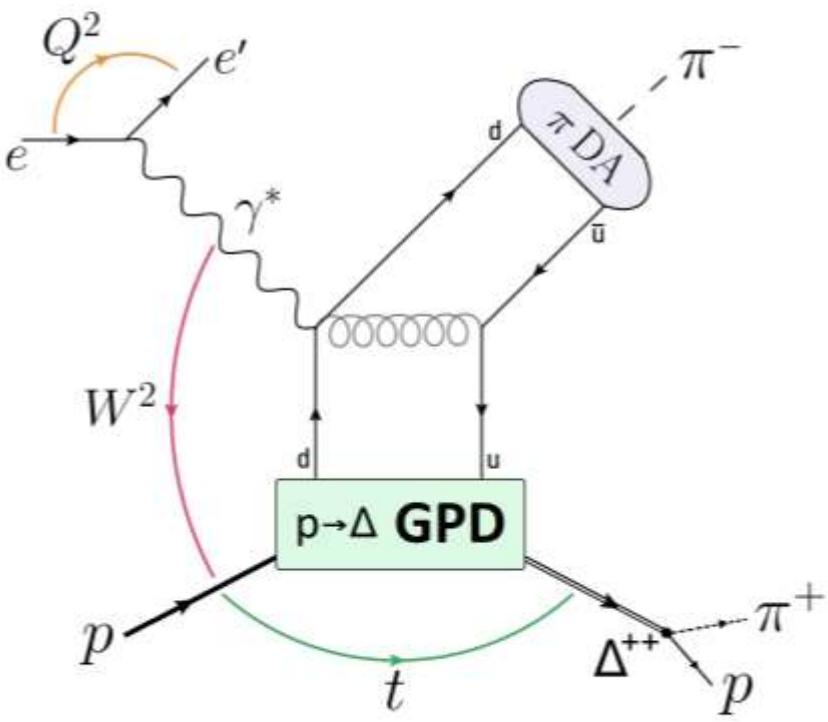
transition GPDs:





Hard Exclusive $\pi^-\Delta^{++}$ Electroproduction

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



Factorisation expected for:

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

x_B fixed

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

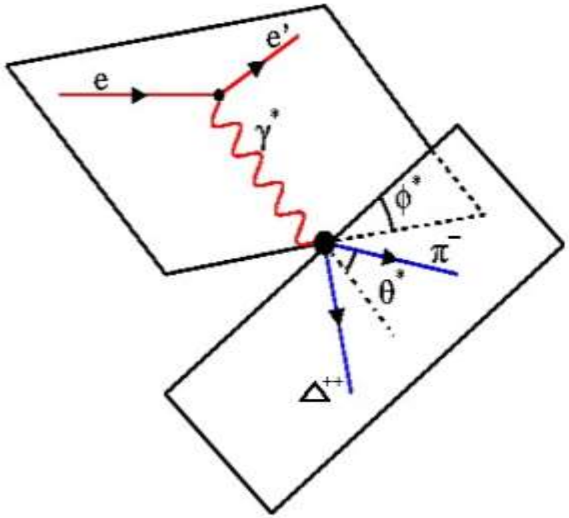
➔ Provides acess to p-Δ transition GPDs

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

Hard Exclusive $\pi^-\Delta^{++}$ Electroproduction

<u>Cross section</u> (longitudinally pol. beam and unpol. target):

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

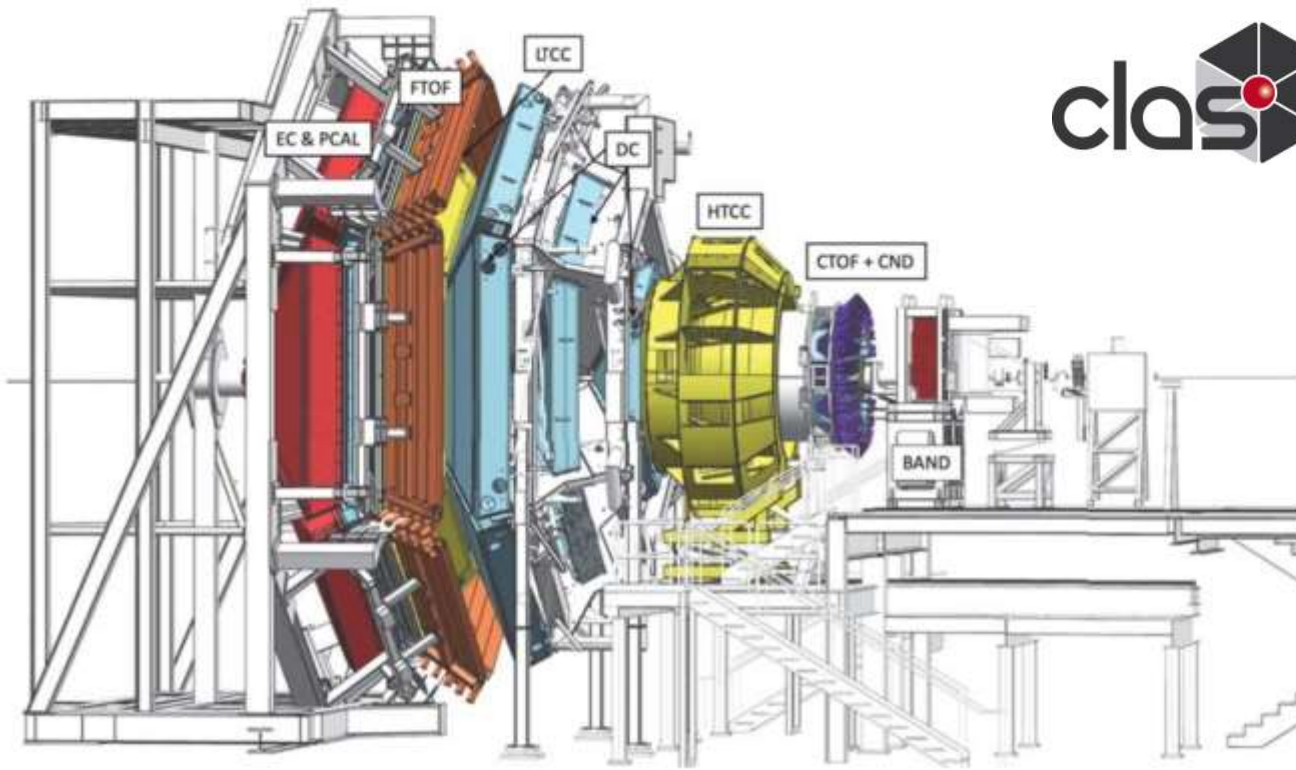


$$BSA(t, \phi, x_B, Q^2) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{\sqrt{2\epsilon(1-\epsilon)} \boxed{\frac{\sigma_{LT'}}{\sigma_0}} \sin\phi}{1 + \sqrt{2\epsilon(1+\epsilon)} \frac{\sigma_{LT}}{\sigma_0} \cos\phi + \epsilon \frac{\sigma_{TT}}{\sigma_0} \cos 2\phi}$$

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

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

CLAS12 at JLAB



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

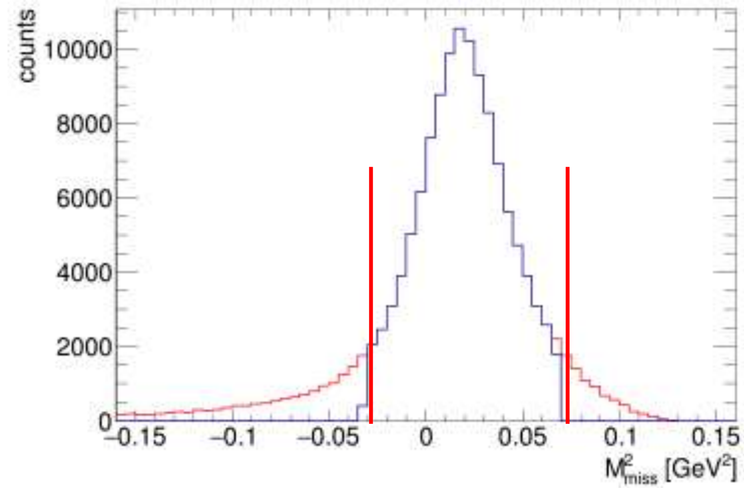
➔ liquid H_2 target

Event Selection and Kinematic Cuts

Event selection: $ep \rightarrow ep\pi^- X$

$$X = \pi^+$$

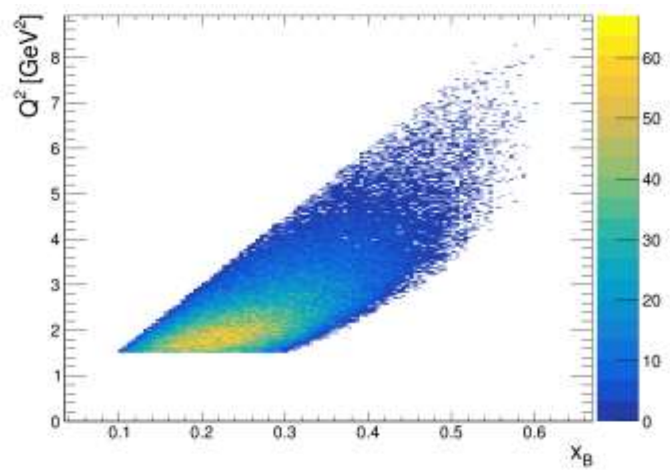
➔ 2 sigma cut around the missing π^+



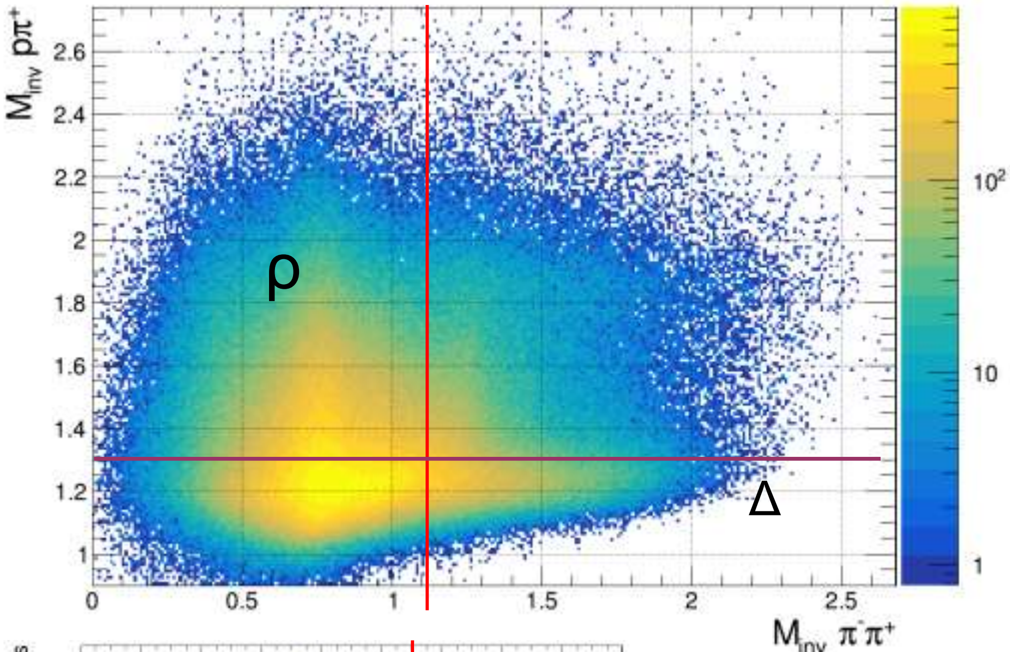
Kinematic cuts:

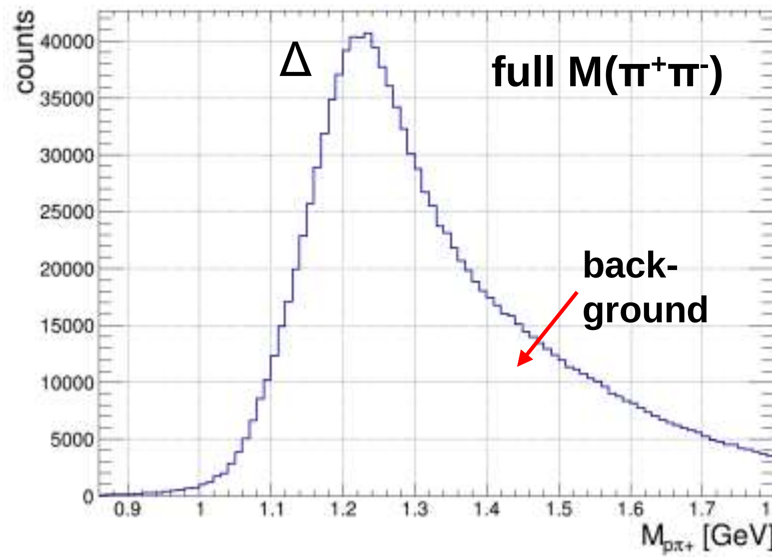
$Q^2 > 1.5$ GeV^2 $W > 2$ GeV

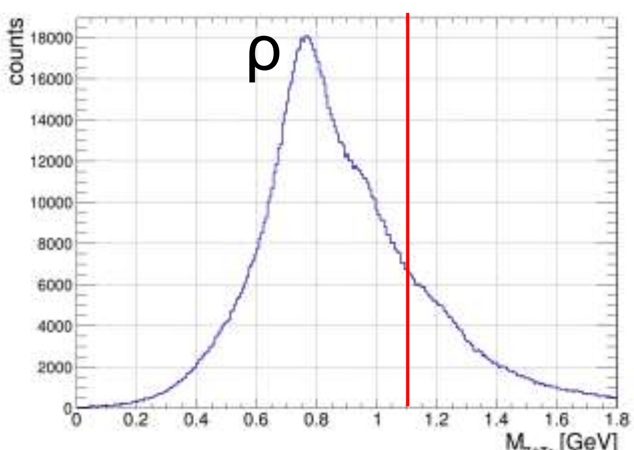
$y < 0.75$ $-t < 1.5$ GeV^2



Event Selection and Background Rejection





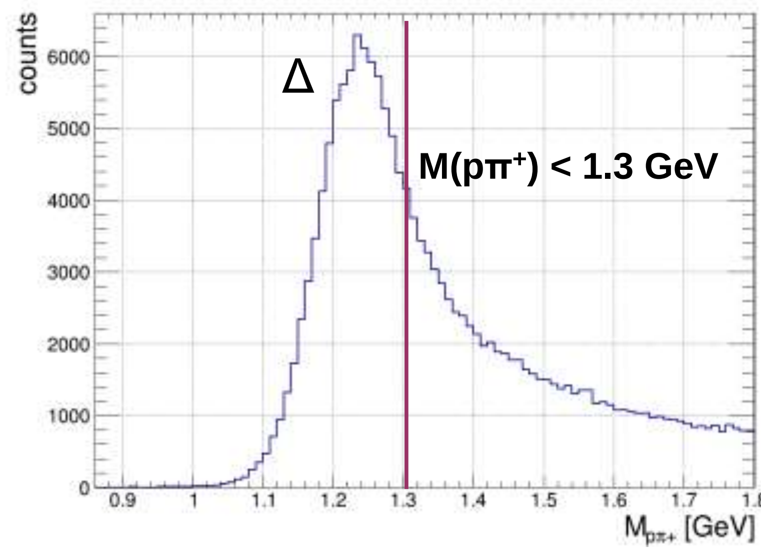


$ep \rightarrow ep\rho \rightarrow ep\pi^+\pi^-$

M(π⁺π⁻) > 1.1 GeV

ρ contamination

< 0.8 %



Monte Carlo Simulations

Background: Full deep inelastic scattering MC

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

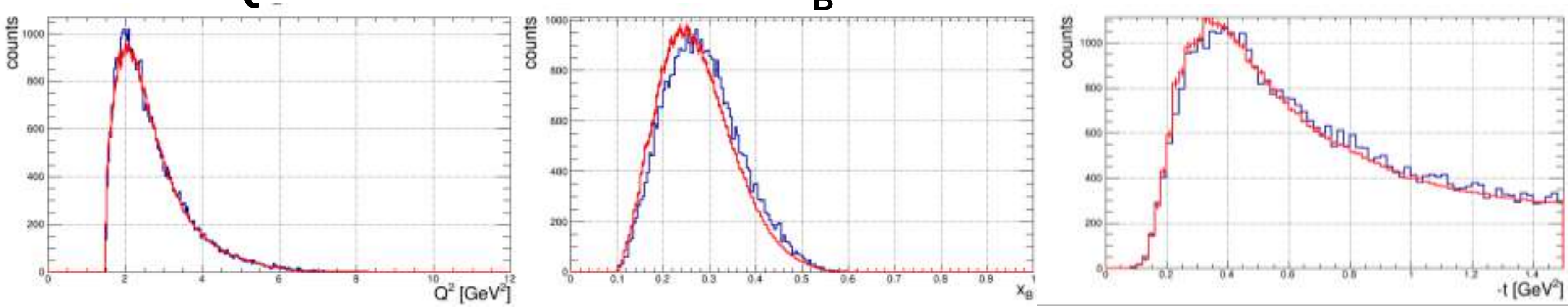
→ Contains non-resonant background as well as ρ production and other potential background channels

Signal: Exclusive $\pi^-\Delta^{++}$ MC

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

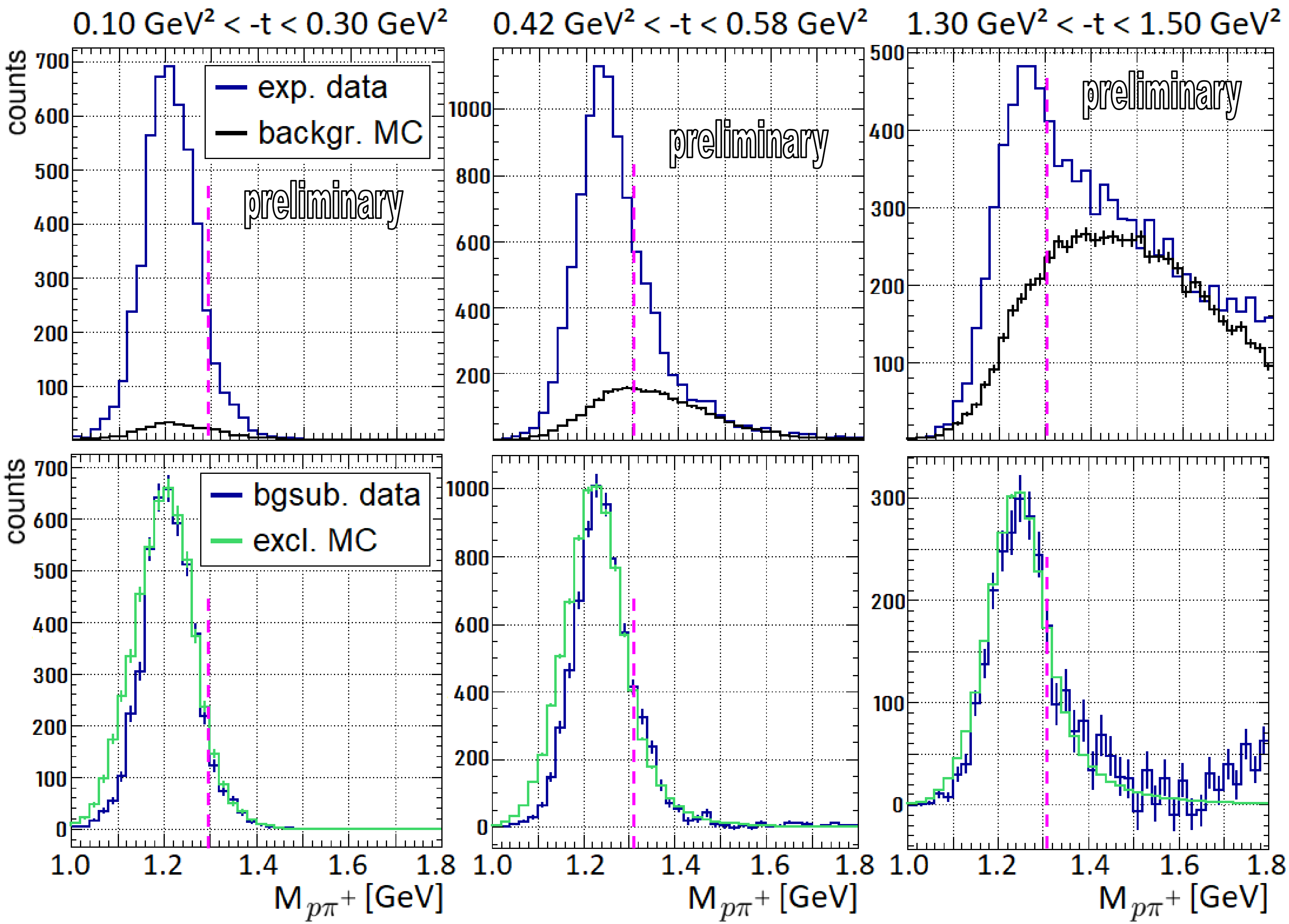
→ Δ peak with PDG mass and FWHM

Q^2 x_B $-t$



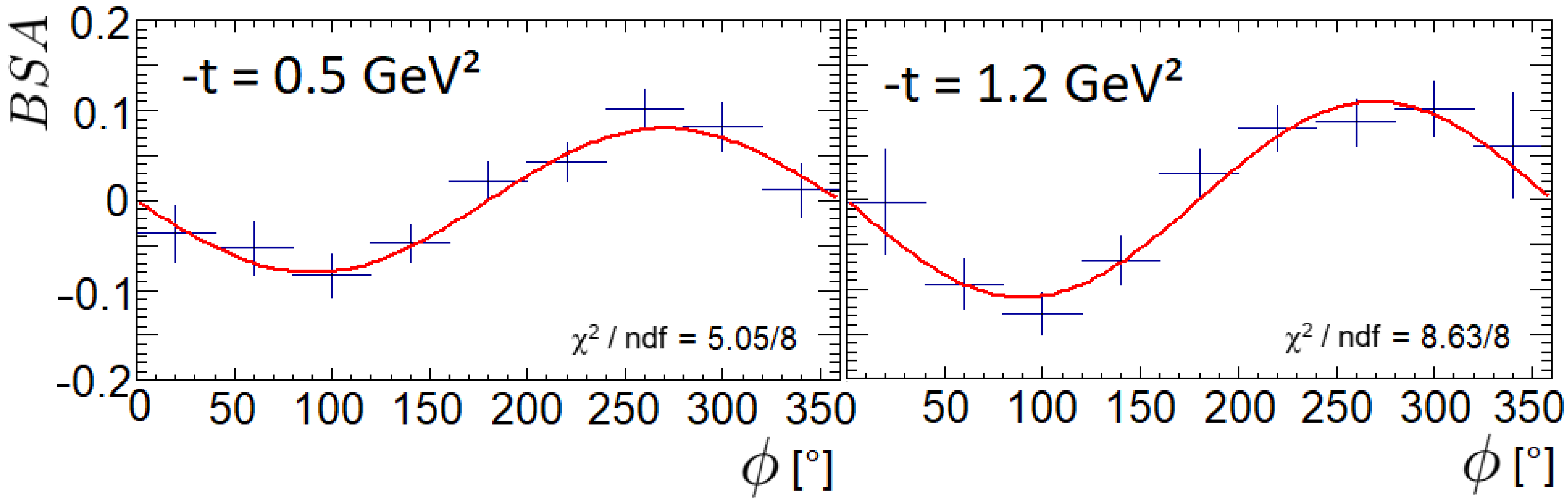
data (excl.) exclusive MC

Signal and Background Separation

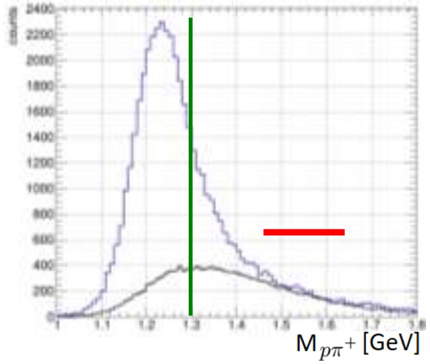


Beam Spin Asymmetries

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



Background Subtraction

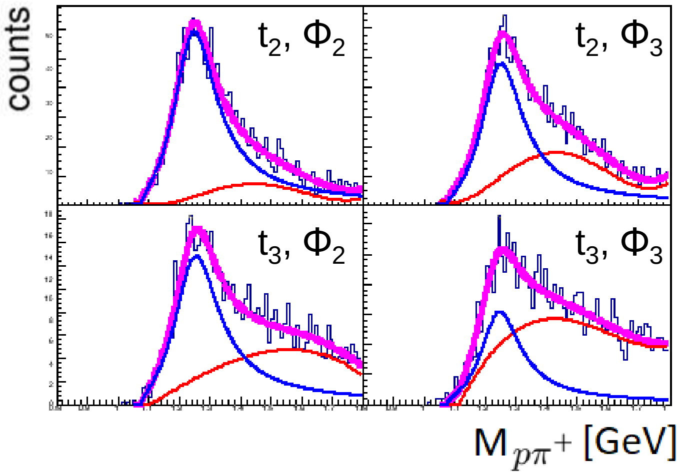


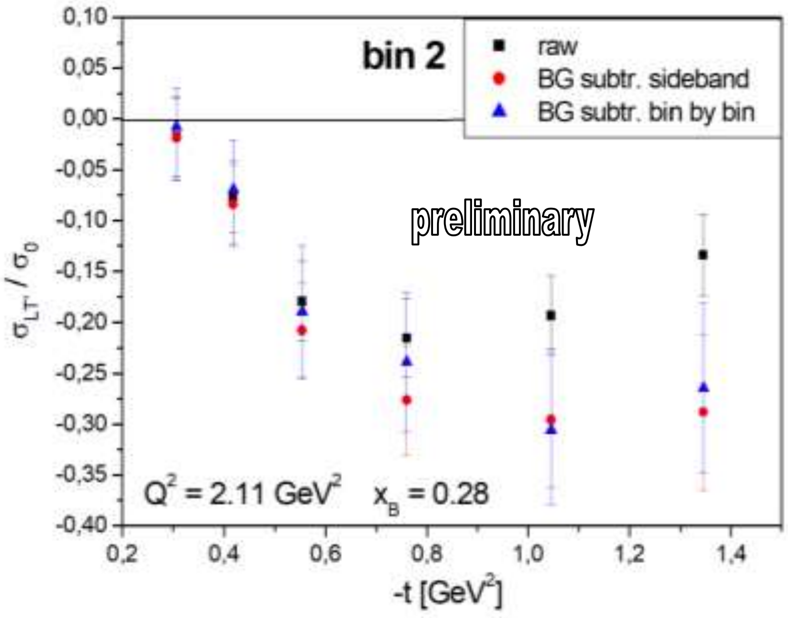
<u>Method 1</u>: A sideband based background subtraction

- S/B ratio from a fit of the signal shape and background asymmtry from the sideband

<u>Method 2</u>: A bin-by-bin background subtraction

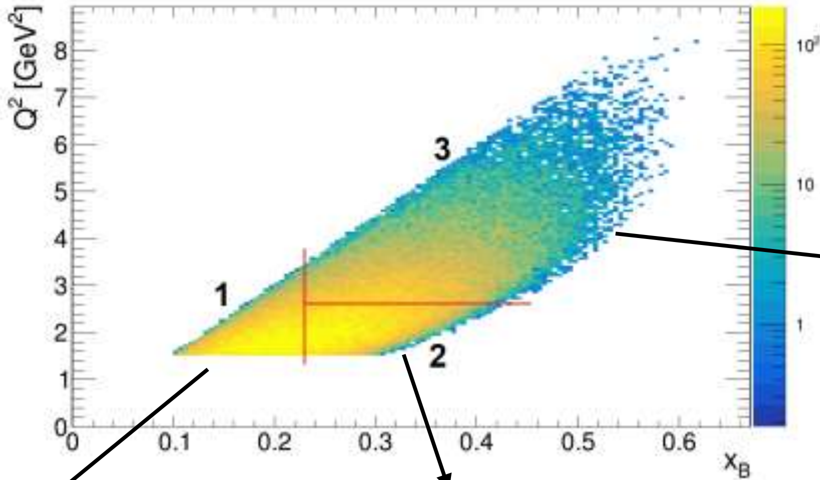
- Fit of the $p\pi^+$ inv. mass with a „Sill“ function and a 5th order polynomial in each Q^2, x_B, -t, Φ bin.





Results

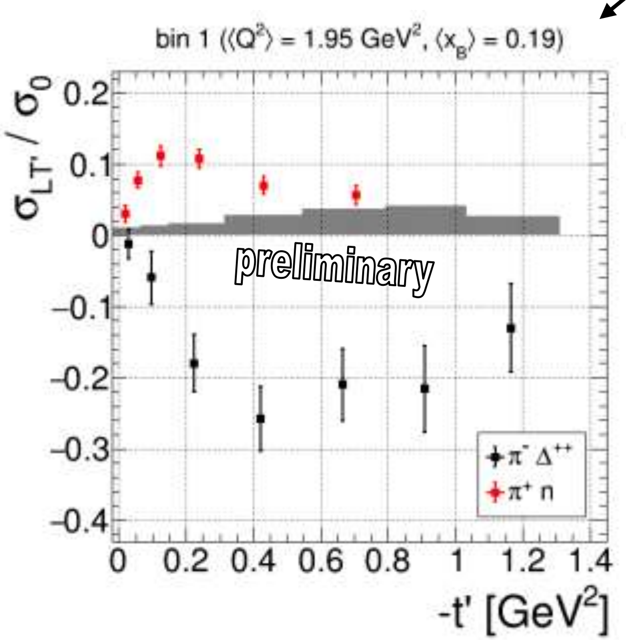
S. Diehl et al. (CLAS collab.), **submitted to Phys. Rev. Lett. (2023)** arXiv:2303.11762

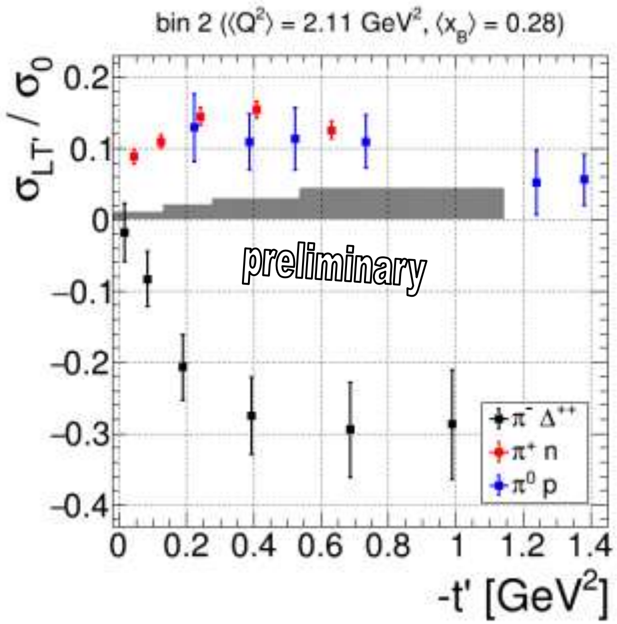


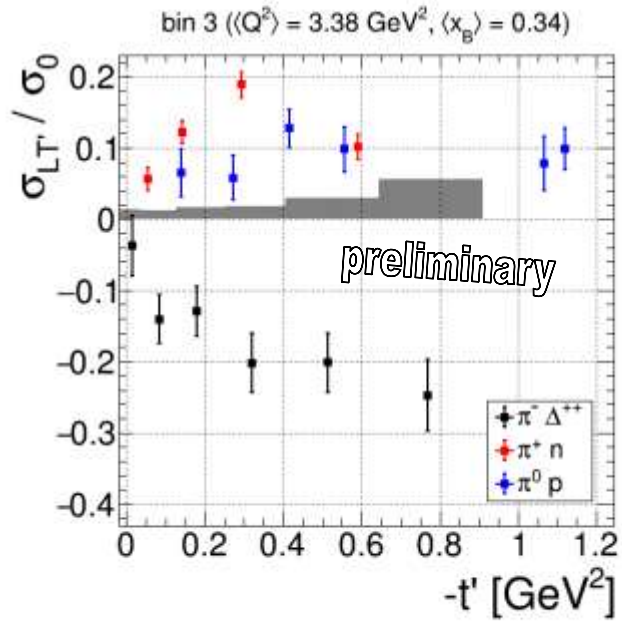
proton (uud)

$\rightarrow$ neutron (udd)
π^+ $(|u\bar{d}\rangle)$

$\rightarrow$ Δ^{++} (uuu)
π^- $(|d\bar{u}\rangle)$



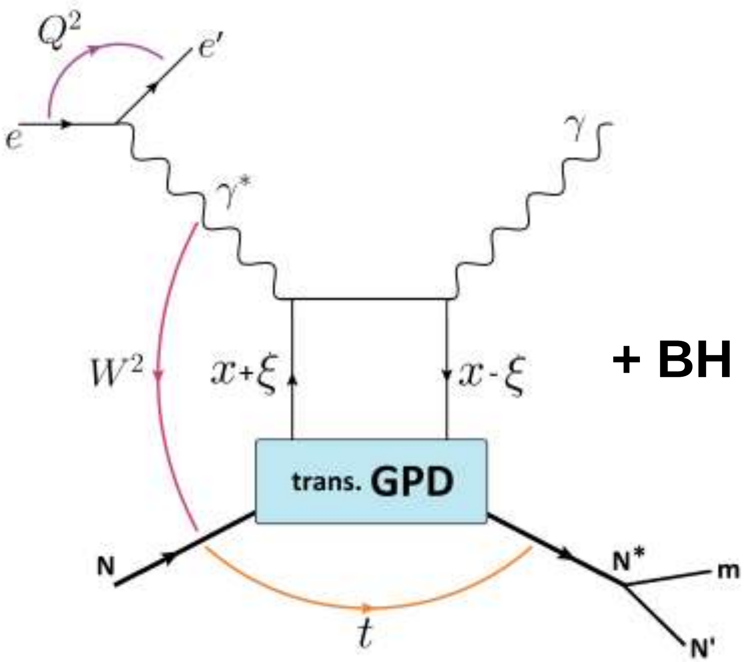




Outlook

The N→Δ DVCS process:

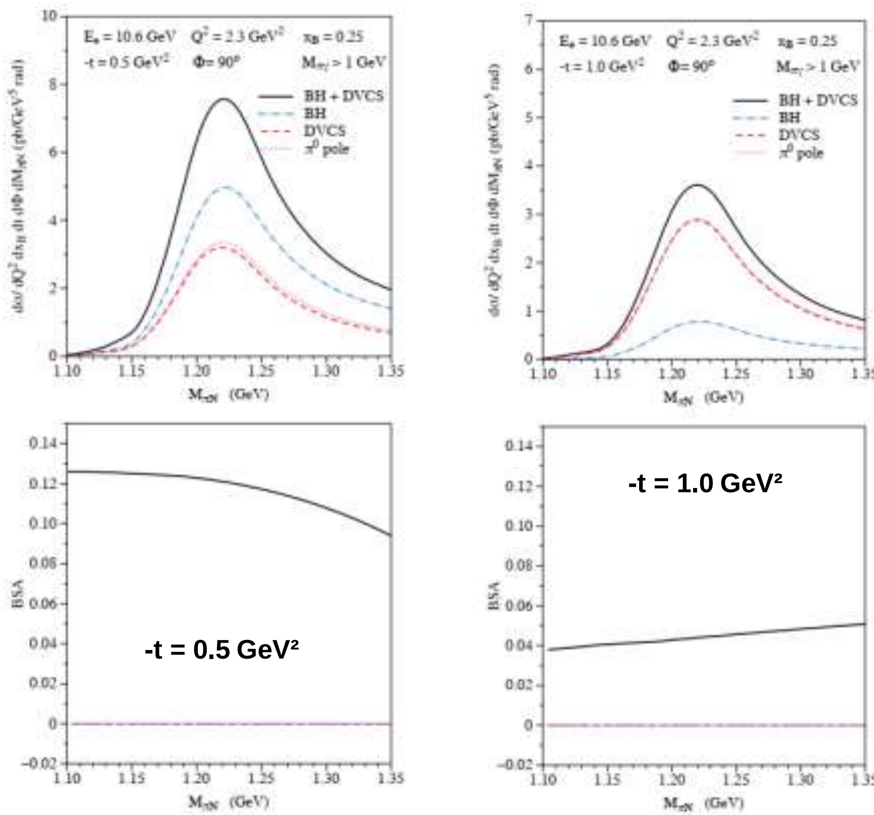
$$\gamma^* p \rightarrow N^* \gamma \rightarrow p \;\; meson \;\; \gamma$$



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**

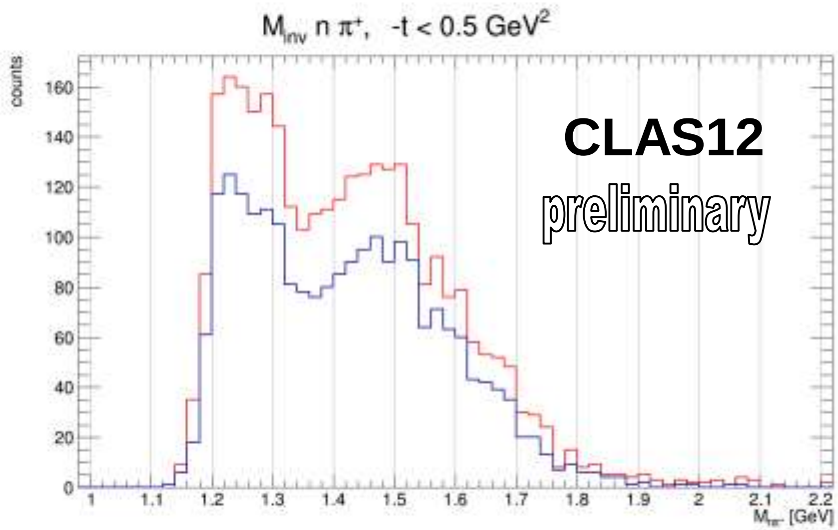
K. Semenov-Tian-Shansky, M. Vanderhaeghen, arXiv:2303.00119 (2023)

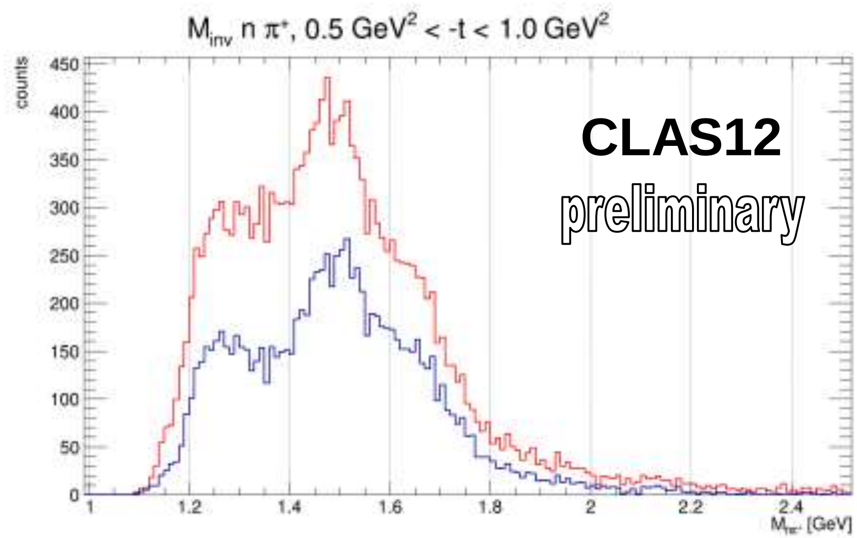


Outlook

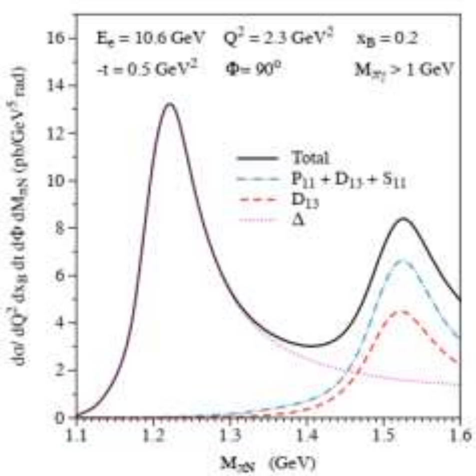
e p → e' Δ⁺ γ → e' n π⁺ γ

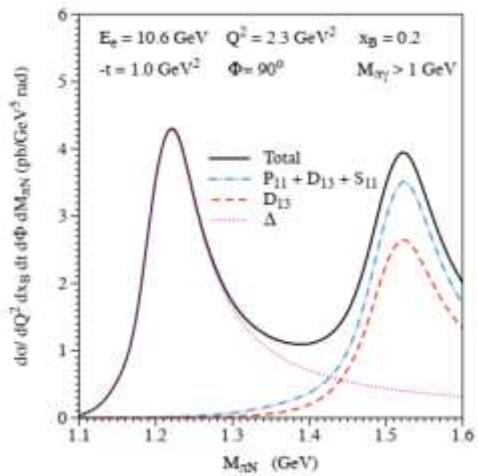
raw — $M(\pi^+\gamma) > 1.0$ GeV





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





- **More results from pass2 of RG-A will come soon**

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 π^+.
- 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

➔ Paper submitted to PRL arXiv:2303.11762

Outlook:

- Cross sections and A_{LL} of $\pi^-\Delta^{++}$ will provide further constraints to the transition GPDs.
- Other $N \rightarrow N^*$ DVMP processes are under investigation.
- The $N \rightarrow N^*$ DVCS process will further constrain the twist-2 transition GPDs.

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