ECT*-APCTP joint workshop: Exploring resonance structure with transition GPDs

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Experimental investigation of transition GPDs with CLAS12 at JLAB and future opportunities

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Generalized Parton Distributions

Generalized Parton Distributions (GPD)

↓

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

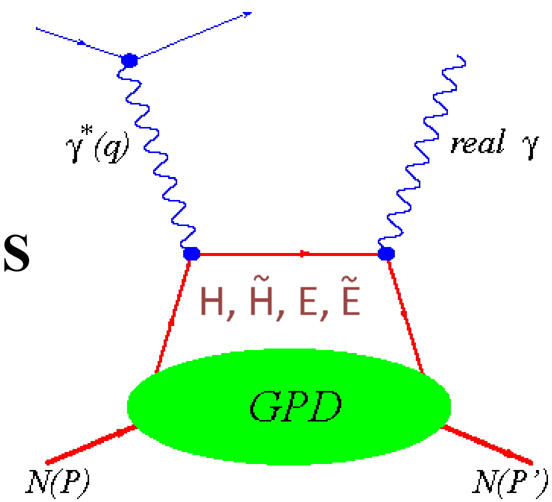
4 chiral even and 4 chiral odd GPDs

quark pol. / nucleon pol.

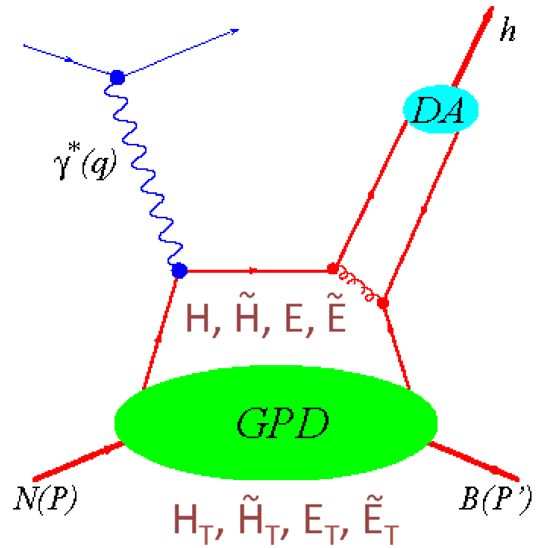
N/q	U	L	T
U	H		$\bar{E}_T$
L		$\tilde{H}$	$\tilde{E}_T$
T	E	$\tilde{E}$	$H_T, \tilde{H}_T$

$\bar{E}_T = 2\tilde{H}_T + E_T$

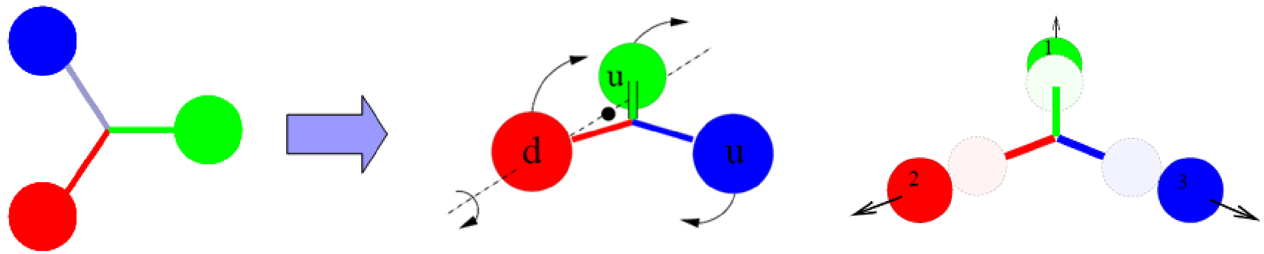
DVCS



DVMP



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?

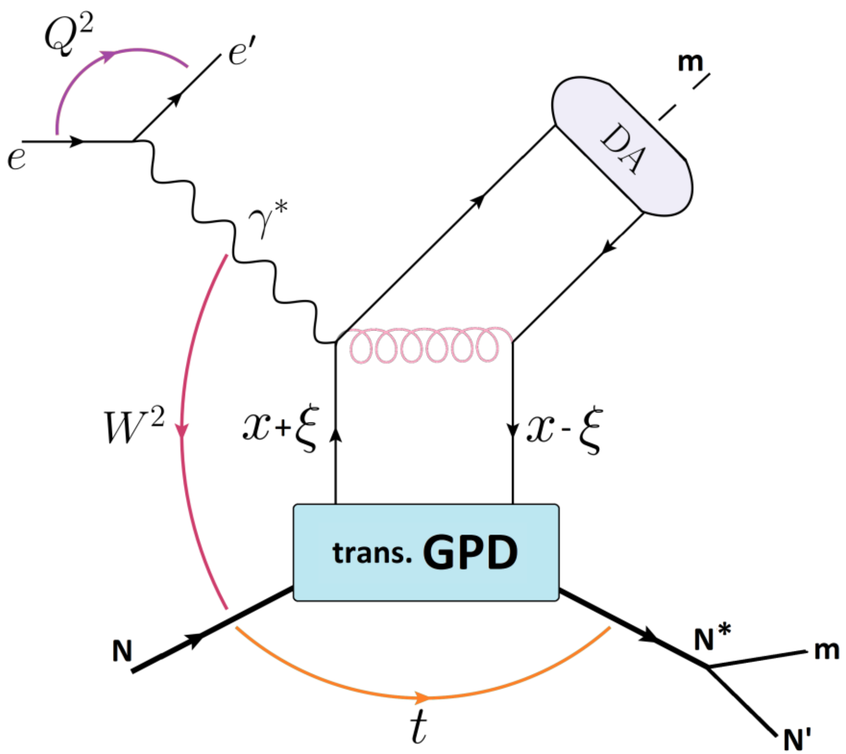
Traditional way: Study of transition form factors (**2D picture** of transv. position)

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

Simplest case: N→Δ transition ➔ **16 transition GPDs**

- **8 helicity non-flip transition GPDs (twist 2)**
  → N→N* DVCS
- **8 helicity flip transition GPDs (twist-3, transversity)**
  → N→N* DVMP

The N →N* DVMP processes



$$ep \to eN^*m \to e(Nm_2)m_1$$

<u>**p→Δ transition:**</u>

$$ep \to e\Delta^0\pi^+ \to e(p\pi^-)\pi^+$$
$$\to e(n\pi^0)\pi^+$$

$$ep \to e\Delta^+\pi^0 \to e(n\pi^+)\pi^0$$
$$\to e(p\pi^0)\pi^0$$

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

Factorisation expected for:

-t / Q² << 1, x_B fixed

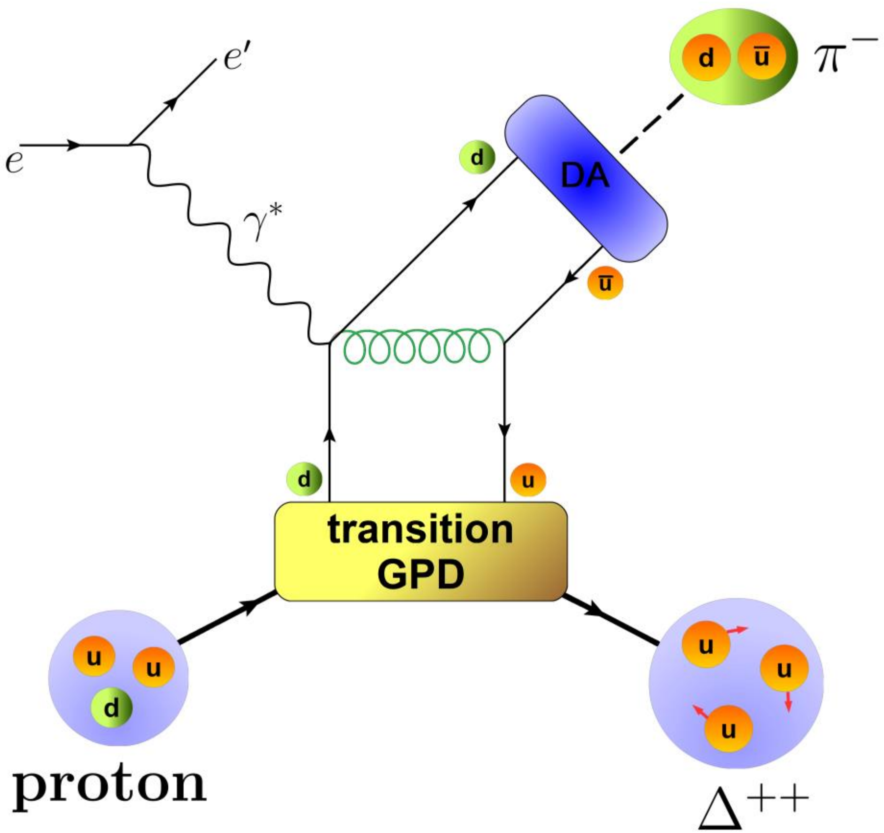
and $Q^2 > M^2_{N^*}$

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

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

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

$I_z = +3/2$



➔ The $p\pi^+$ final state can **only** be populated by **Δ-resonances**

➔ Large gap between Δ(1232) and higher resonances

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

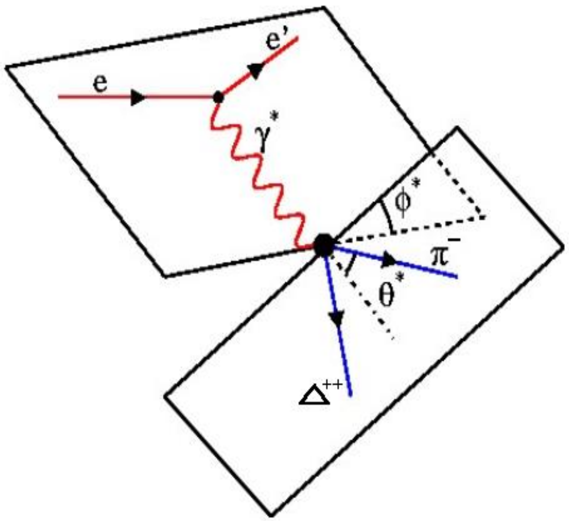
➔ Provides acess to **p-Δ transition GPDs**

S. Diehl et al. (CLAS Collaboration), Phys. Rev. Lett. 131, 021901 (2023).
https://doi.org/10.1103/PhysRevLett.131.021901

Hard Exclusive π⁻ Electroproduction and BSA

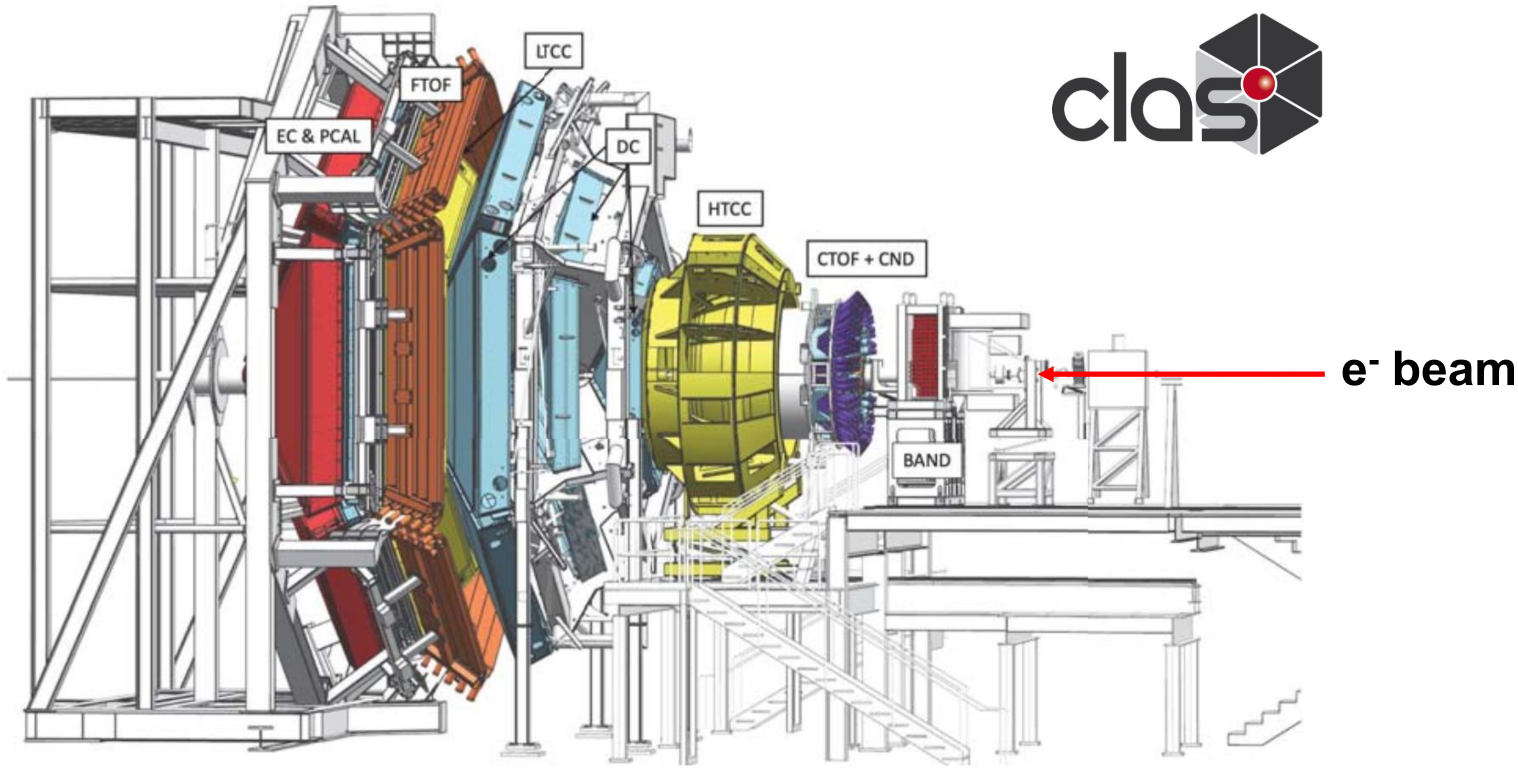
Cross section (longitudinally pol. beam and unpol. target):

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



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

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)

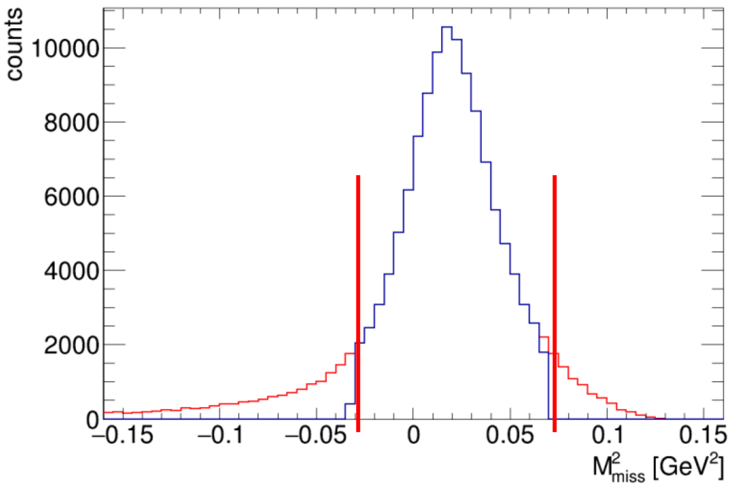
- ➔ 10.6 GeV / 10.2 GeV electron beam ~ 86 % average polarization
- ➔ liquid H_2 target

Event Selection and Kinematic Cuts

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

$$X = \pi^{+}$$

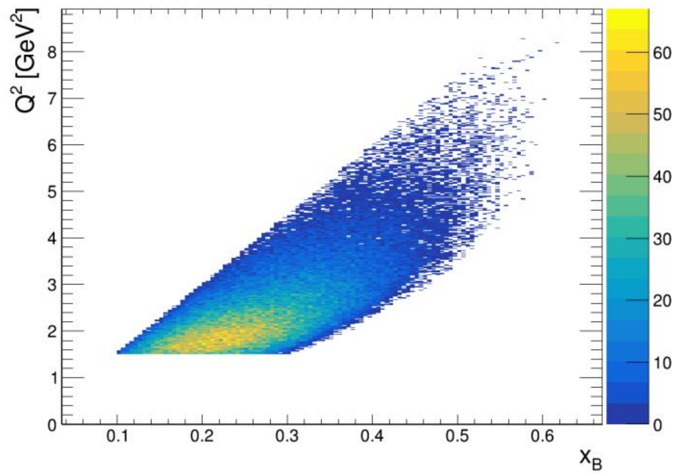
➔ 2 sigma cut around the missing π⁺



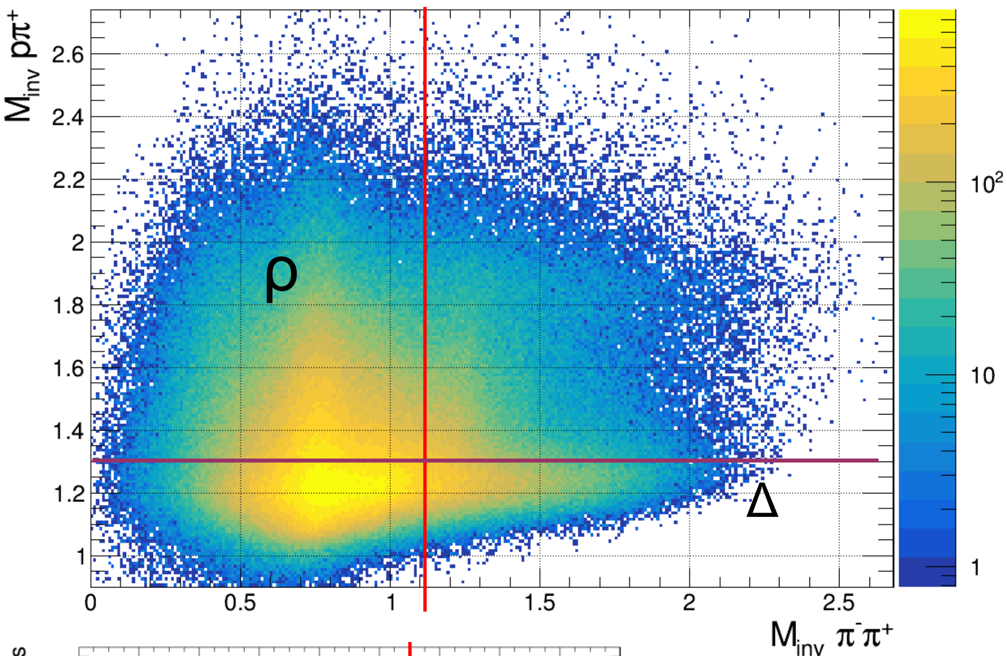
Kinematic cuts:

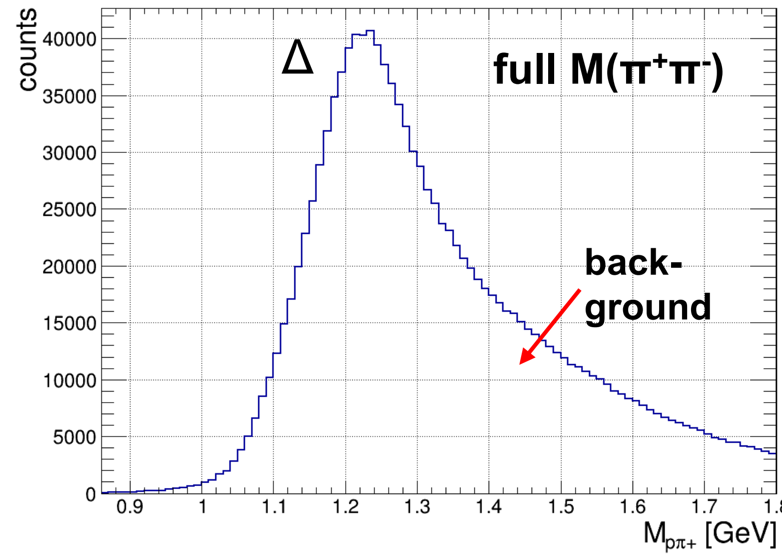
$Q^2 > 1.5$ GeV² W > 2 GeV

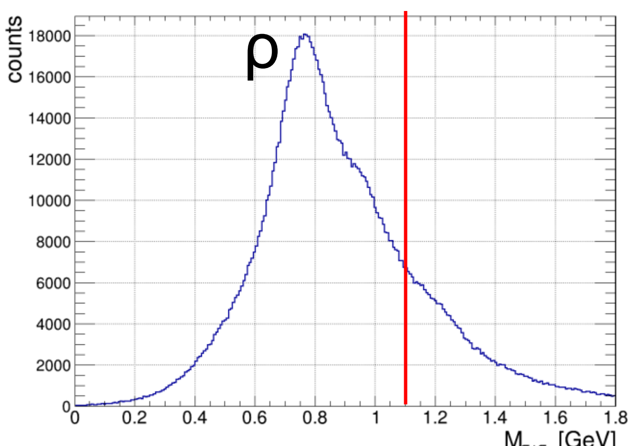
y < 0.75 -t < 1.5 GeV²



Event Selection and Background Rejection





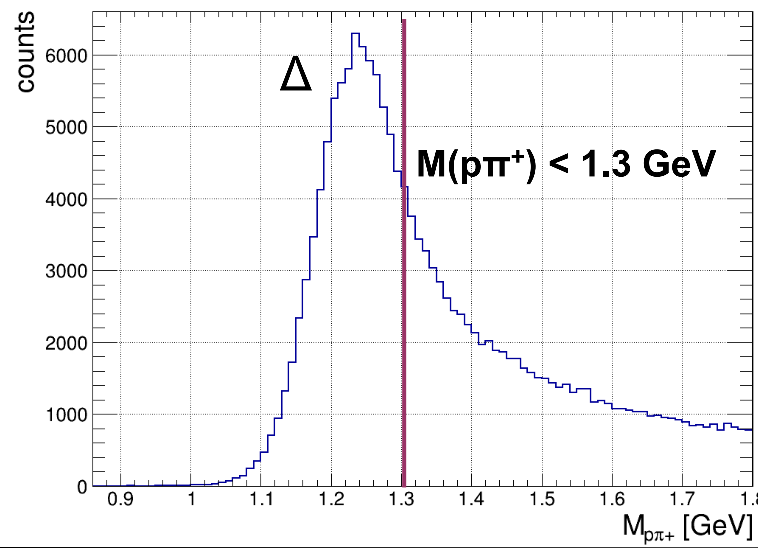


$ep \rightarrow ep\rho \rightarrow ep\pi^+\pi^-$

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

ρ contamination

< 0.8 %



Monte Carlo Simulations

Background: Full deep inelastic scattering MC

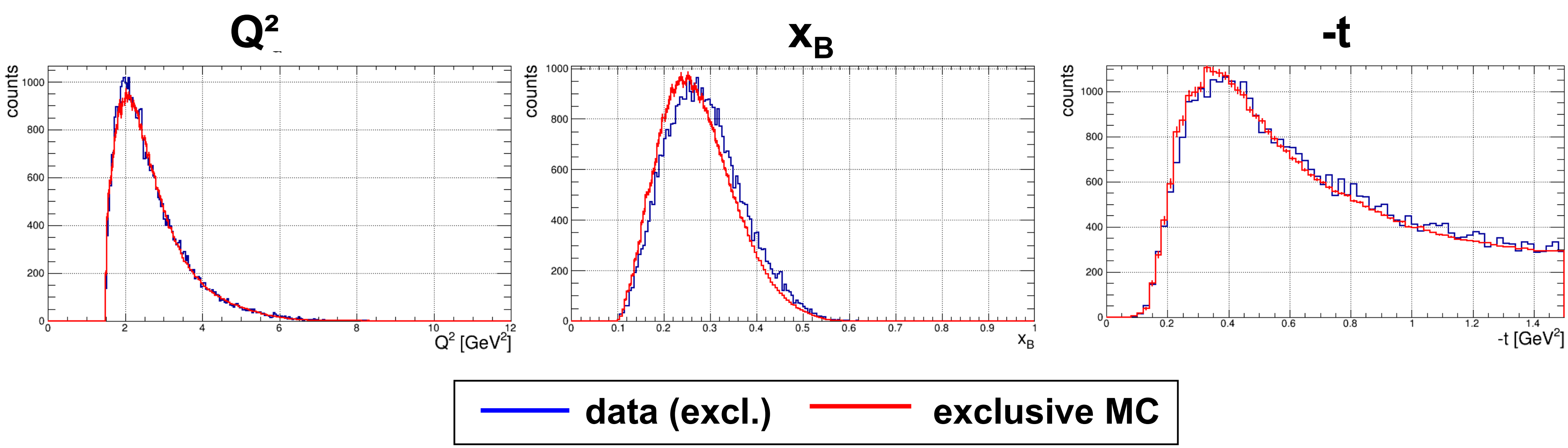
→ Does not contain the exclusive $\pi^- \Delta^{++}$ production in the GPD regime ($-t < 1.5$ GeV²)

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

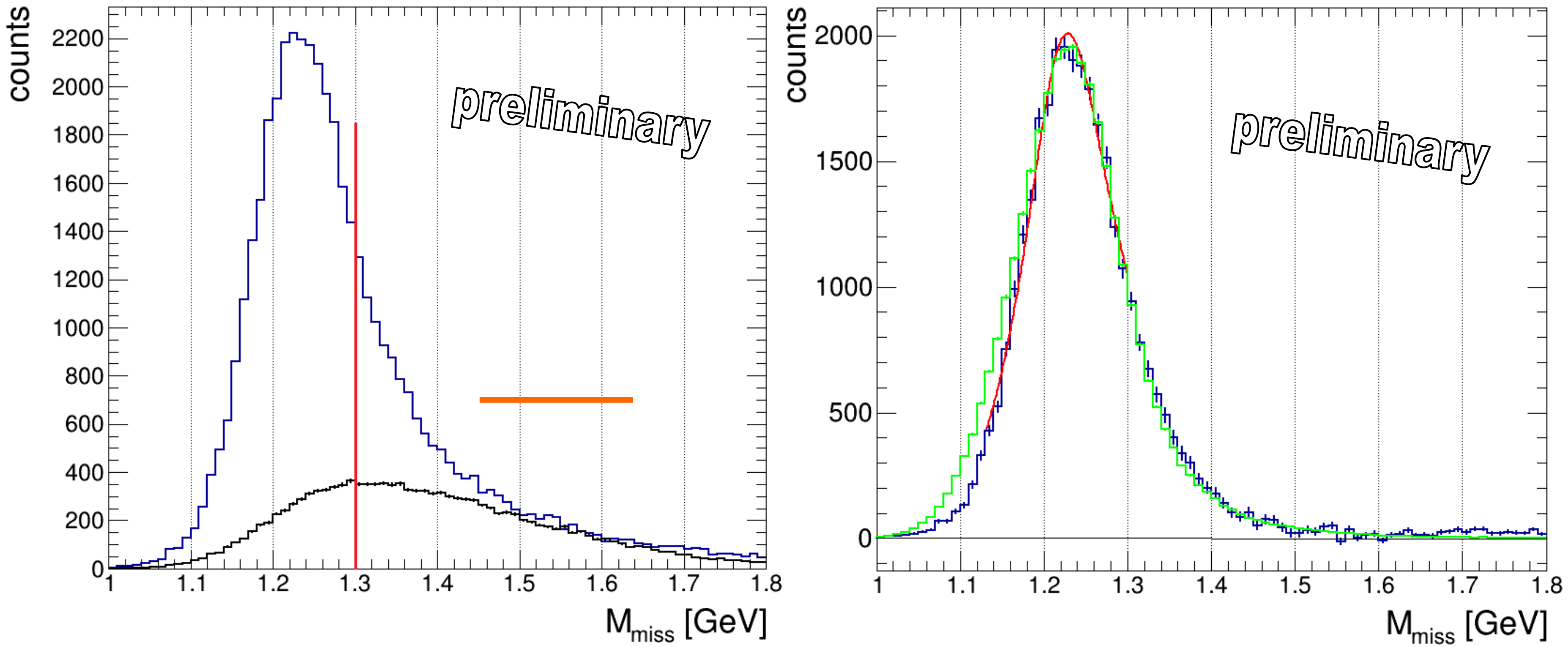
Signal: Exclusive $\pi^- \Delta^{++}$ MC

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

→ Δ peak with PDG mass and FWHM

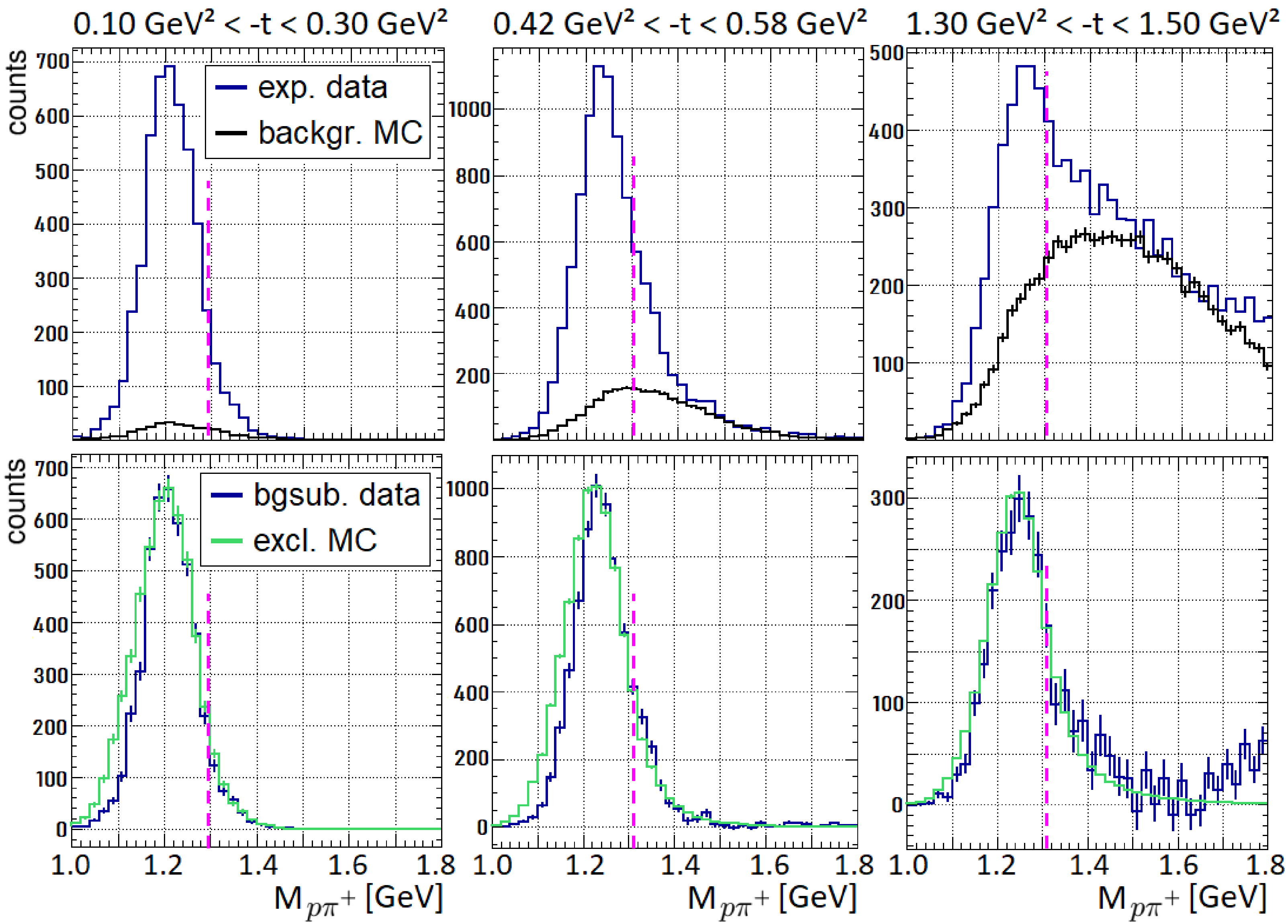


Event Selection and Background Estimate

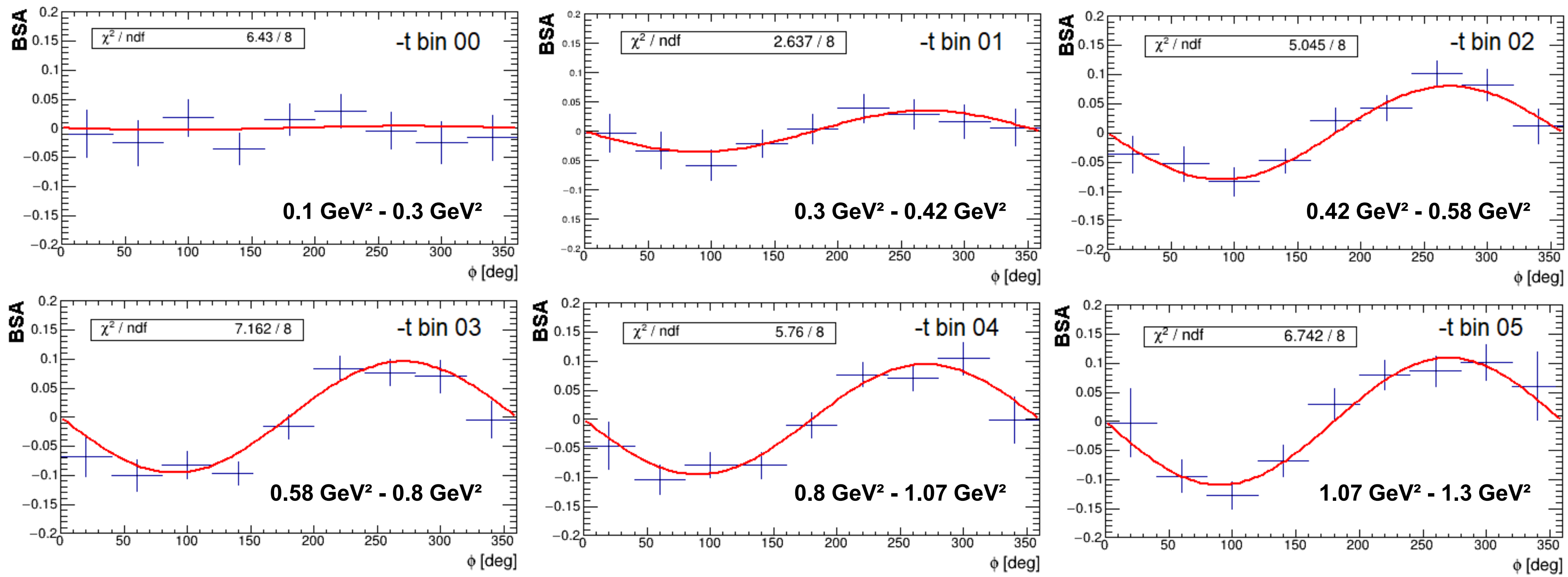


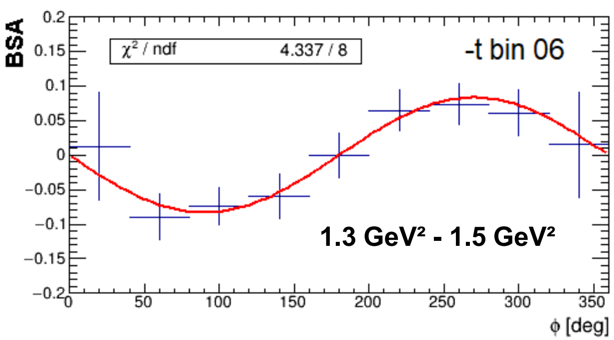
- experimental data
- SIDIS MC (same cuts)
- data after SIDIS MC subtraction
- fit of a Sill function (BW with thr. effects)
- exclusive MC (for comparison)

Signal and Background Separation



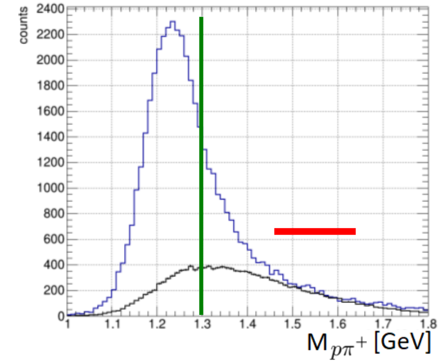
Resulting Beam Spin Asymmetries (Q²-x_B integrated)





$$BSA(t,\phi,x_B,Q^2) \sim \sqrt{2\epsilon(1-\epsilon)}\,\frac{\sigma_{LT'}}{\sigma_0}\sin\phi$$

Background Subtraction

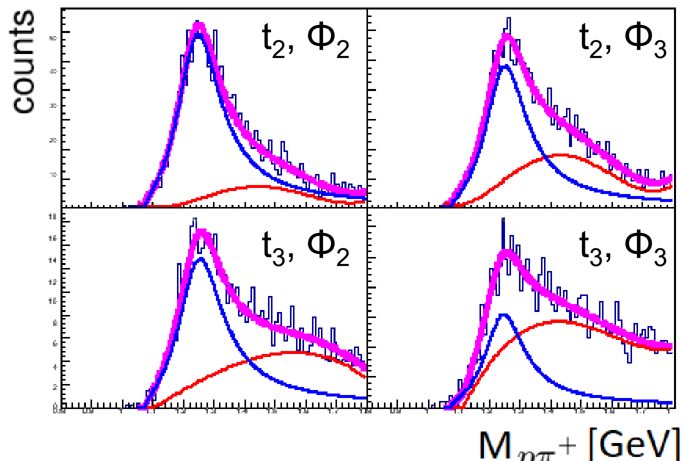


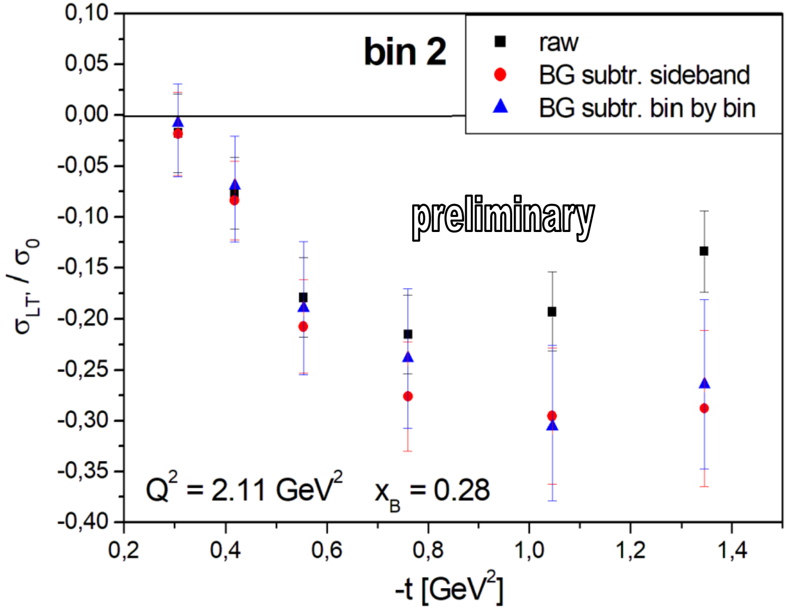
<u>Method 1</u>: A sideband based background subtraction

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

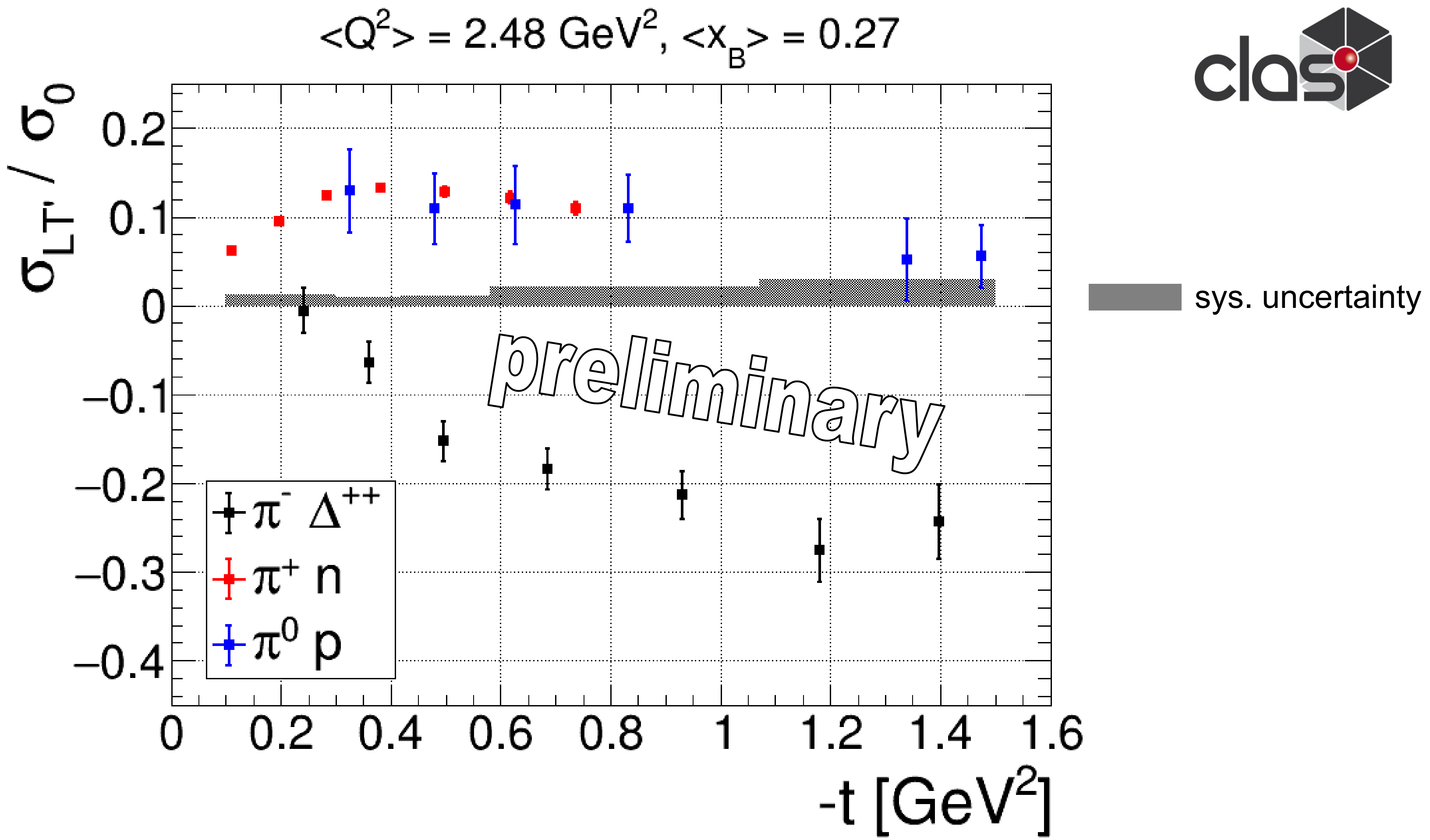
<u>Method 2</u>: A bin-by-bin background subtraction

- 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.





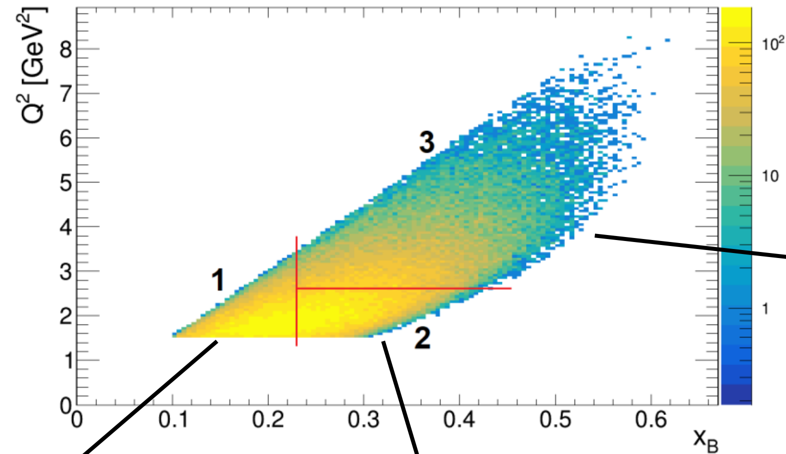
Q^2 - x_B Integrated Result



Different sources of systematic uncertainty have been studied:
beam polarisation, background subtraction, fiducial volume, extraction method, acceptance, bin migration, radiative effects

Multidimensional Results

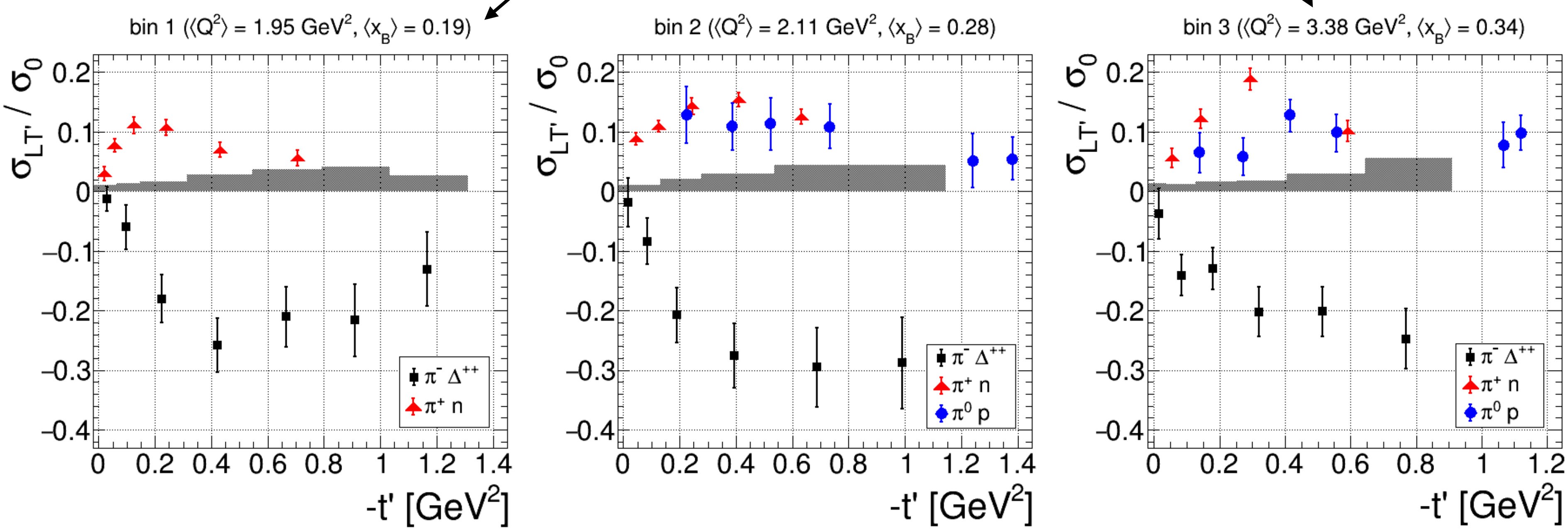
S. Diehl et al. (CLAS Collaboration),
Phys. Rev. Lett. 131, 021901 (2023).
https://doi.org/10.1103/PhysRevLett.131.021901



proton (uud)

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

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



Physics Content of the Observable

Theoretical description of the process:

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

see talk by Peter Kroll

~ helicity non-flip transition GPDs $\widetilde{G}_3$ and $\widetilde{G}_4$

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

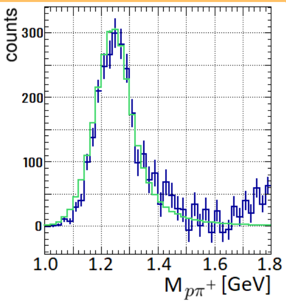
helicity flip transition GPDs

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

➔ **tensor charge of the proton / resonane:** $\delta^u_T = \int dx H^u_T(x,\xi,t=0)$

Extension to Other DVMP Channels / Why is $\pi^-\Delta^{++}$ Special?

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



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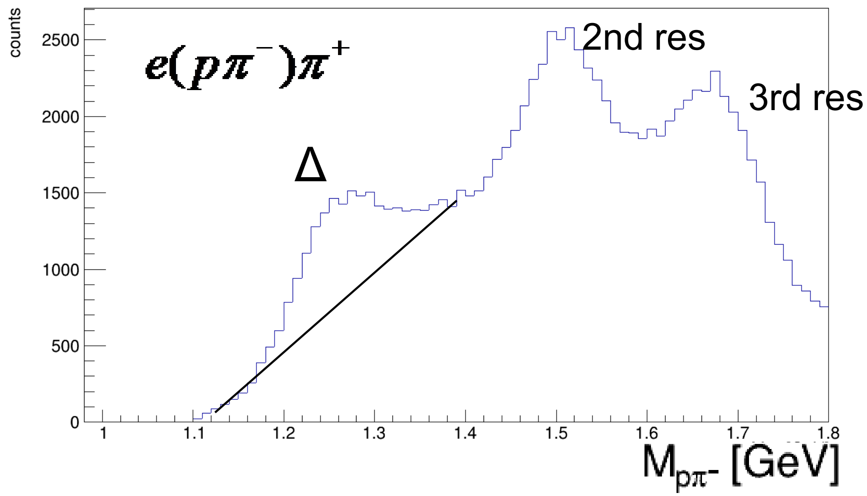
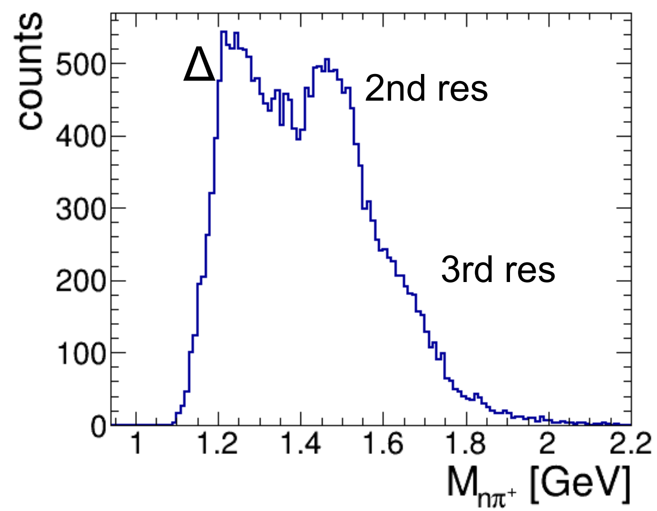
$$ep \rightarrow e\Delta^0\pi^+ \rightarrow e(p\pi^-)\pi^+ \,/\rightarrow e(n\pi^0)\pi^+$$



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

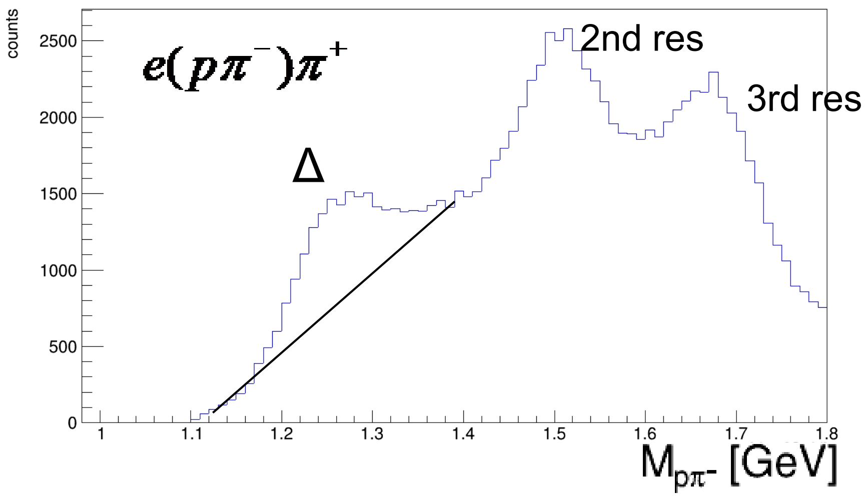


Similar picture for: $ep \rightarrow e\Delta^+\pi^0 \rightarrow e(n\pi^+)\pi^0 \;\;/\;\; \rightarrow e(p\pi^0)\pi^0$

➔ The resonances for all cases have isospin $I_z = \pm 1/2$ ➔ **N and Δ resonances possible!**

Discussion: Extension to other DVMP channels

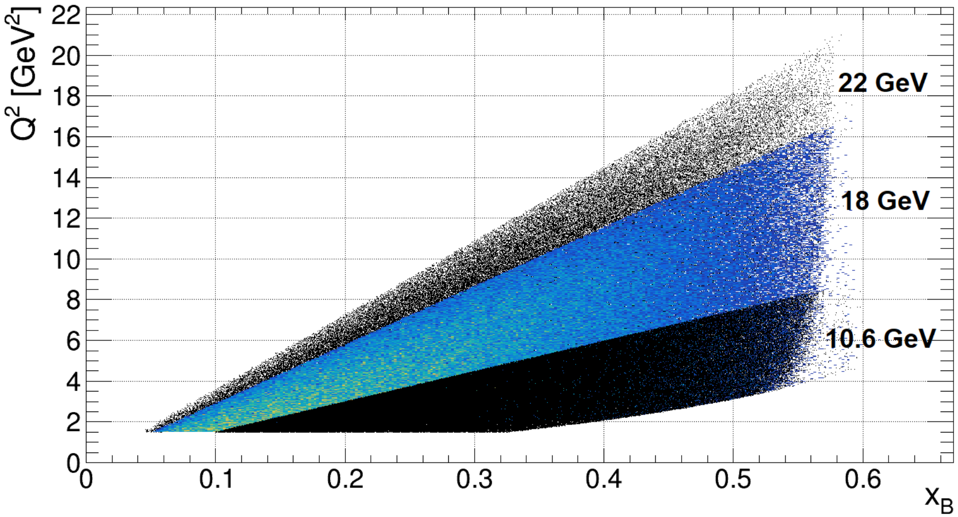
$$ep \to e\Delta^0\pi^+ \to e(p\pi^-)\pi^+ / \to e(n\pi^0)\pi^+$$



➔ **Access to higher resonances?**

➔ **Full fit?   PWA?**

Perspectives for a 22 GeV JLAB Upgrade



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

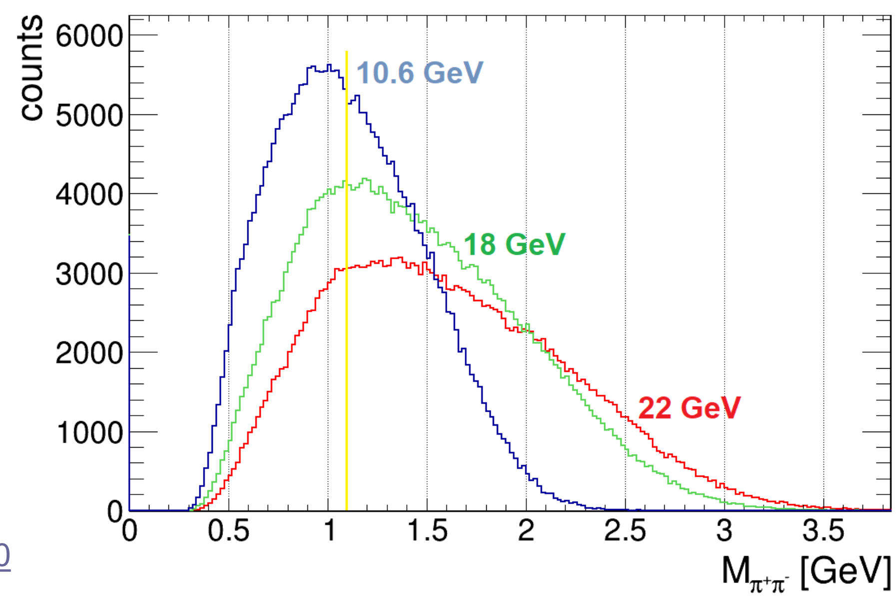
$$ep \rightarrow e\,\Delta^{+}\,\gamma \rightarrow e\,n\,\pi^{+}\,\gamma$$

Extended Q^2 range

➔ **Advantage for factorisation**

Better signal / background separation

➔ **Higher efficiency**



Transition GPDs are part of the science program for a 22 GeV JLAB upgrade:

A. Accardi, P. Achenbach, D. Adhikari et al., Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at Jefferson Lab (2023). https://doi.org/10.48550/arXiv.2306.09360

Conclusion and Outlook

- Transition GPDs can help us to better understand the 3D structure of resonances and the exitation process itself.
- Hard exclusive $\pi^- \Delta^{++}$ production can be well measured with CLAS12
- The extracted $\pi^- \Delta^{++}$ BSA is a first published observable sensitive to $p \rightarrow \Delta$ transition GPDs
- Next steps: Extract A_{LL} from the $\pi^- \Delta^{++}$ process based on CLAS12 RG-C
  → Theory predictions exist! (Kroll et al.)
- A JLAB energy and luminosity upgrade will help to significantly improve these measurements and the extraction of transition GPDs
- Feasability studies with COMPASS / AMBER are planned