CLAS collaboration meeting, JLAB

March 8, 2019

Extraction of $A_{LU}^{\sin(\varphi)}$ from the hard exclusive π^+ channel in a wide range of kinematics – A first simultaneous experimental access to GPDs and TDAs with CLAS

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

UNIVERSITY OF CONNECTICUT 1881

Stefan Diehl

Justus Liebig University Giessen

University of Connecticut

Physics motivation

3 dimensional nucelon structure

spatial distribution

distr. in momentum space

GPDs

TMDs

DVCS

+ Clean process
- Only sensitive to chiral even GPDs

DVMP

- Distribution Amplitude (DA) is involved as an additional soft non pert. quantity
+ Enables flavour decomposition of GPDs
+ Access to transversity degrees of freedom described by chiral-odd GPDs

SIDIS

Physics motivation

exclusive pion electroproduction

colinear factorization theorems

GPD based description
- large Q^2 and s
- small -t values

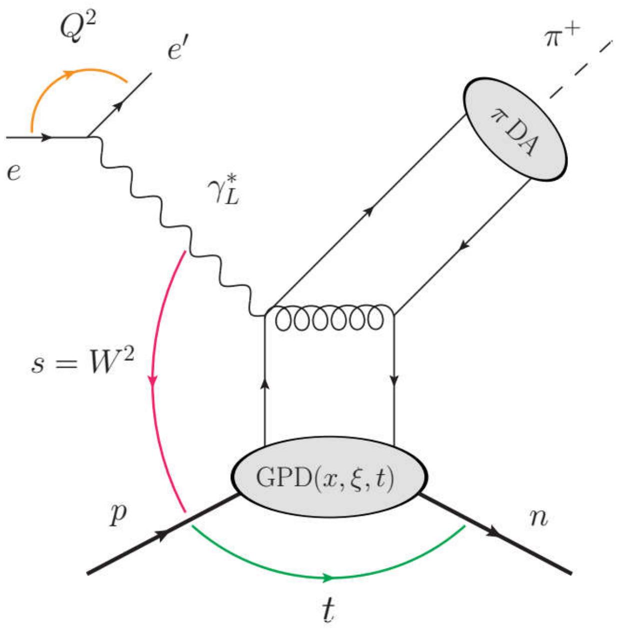
π produced in forward region

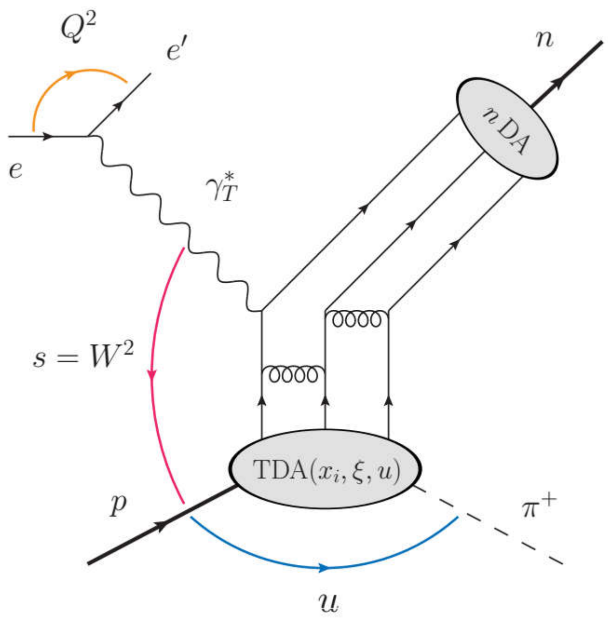
TDA based description
- large Q^2 and s
- small u channel transfer

π produced in backward region

Physics motivation: Hard exclusive π⁺ electroproduction

$$ep \rightarrow en\pi^{+}$$





forward region

small t / large u channel contribution

backward region

small u / large t channel contribution

Physics motivation

Baryon to meson TDAs: Matrix elements of a three quark operator

→ Describe partonic correlations inside a baryon

→ Common features with GPDs:

→ Give access to partonic correlations inside a nucleon with the momentum distribution of the nucleon's baryon density

→ Similar to GPDs, a Fourier transformed TDA ($\Delta T \rightarrow \mathbf{b}$) allows an impact-parameter interpretation for TDAs in the transverse plane

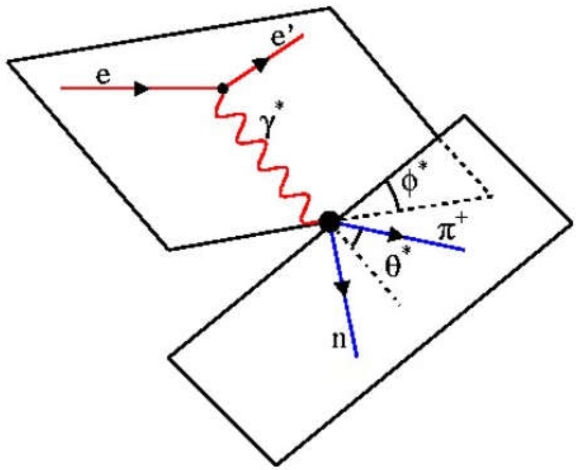
Nucleon DAs: Defined by the same operator

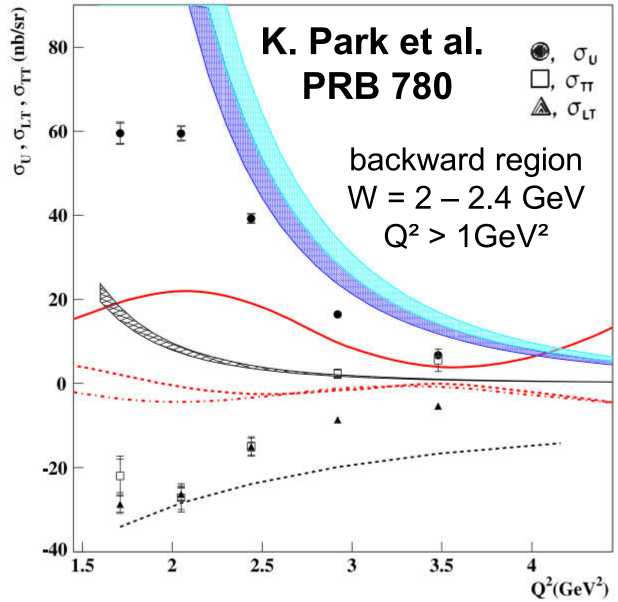
→ Limiting case of TDAs with the meson state replaced by the vacuum

Aim: Investigate the TDA kinematic regime and study the transition from the GPD to the TDA formalism

Physics motivation: Hard exclusive π+ electroproduction

$$ep \to en\pi^+$$





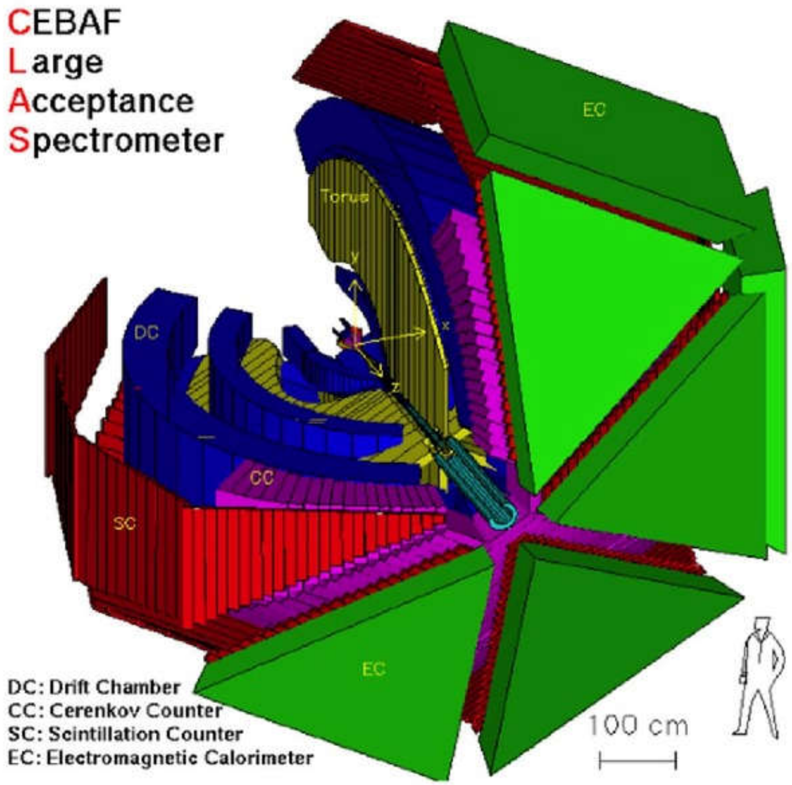
Cross section (longitudinally pol. beam and unpol. target):

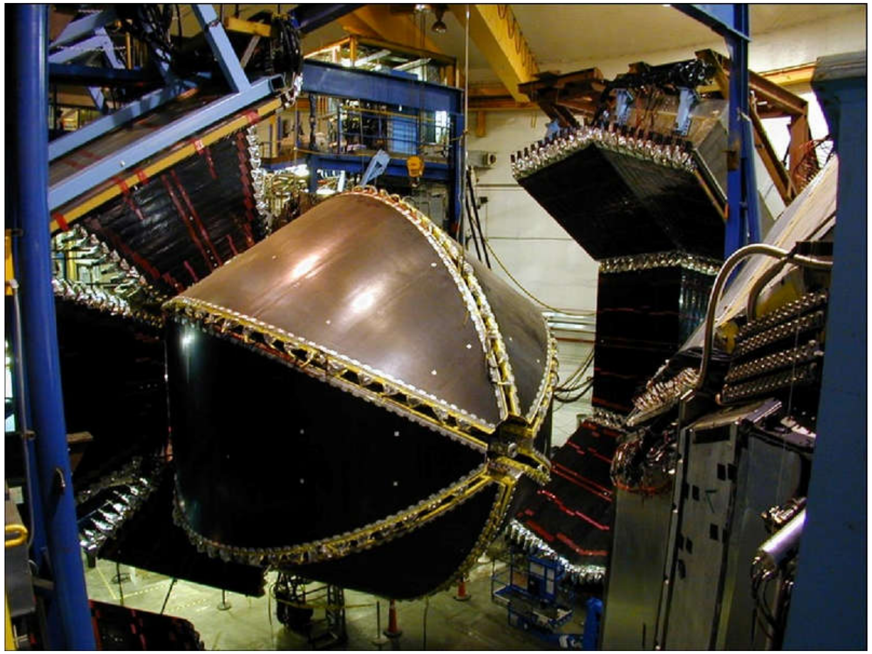
$$\frac{d^4\sigma}{dQ^2 dx_B d\phi dt} \sim \sigma_T + \varepsilon_L \sigma_L + \varepsilon \cdot \sigma_{TT} \cdot \cos(2\phi) + \sqrt{2 \cdot \varepsilon_L \cdot (1+\varepsilon)} \cdot \sigma_{LT} \cdot \cos(\phi) + h \cdot \sqrt{2 \cdot \varepsilon_L \cdot (1-\varepsilon)} \cdot \sigma_{LT'} \cdot \sin(\phi)$$

$$d\sigma = d\sigma_0 (1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi + \lambda_e A_{LU}^{\sin\phi} \sin\phi)$$

$$BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{\sin\phi} \sin\phi}{1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos(2\phi)} \cos(2\phi)}$$

Experimental Setup

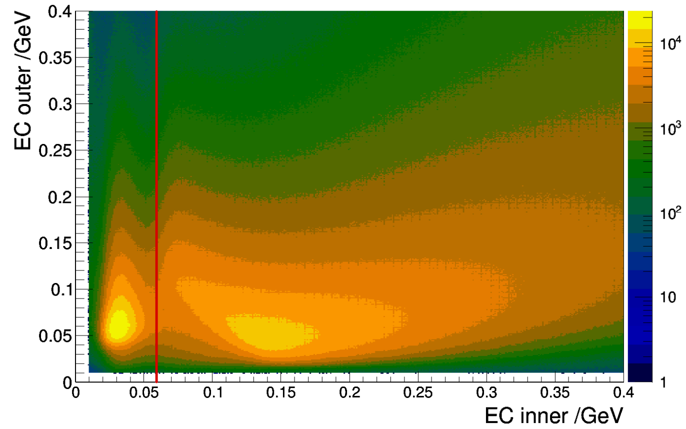


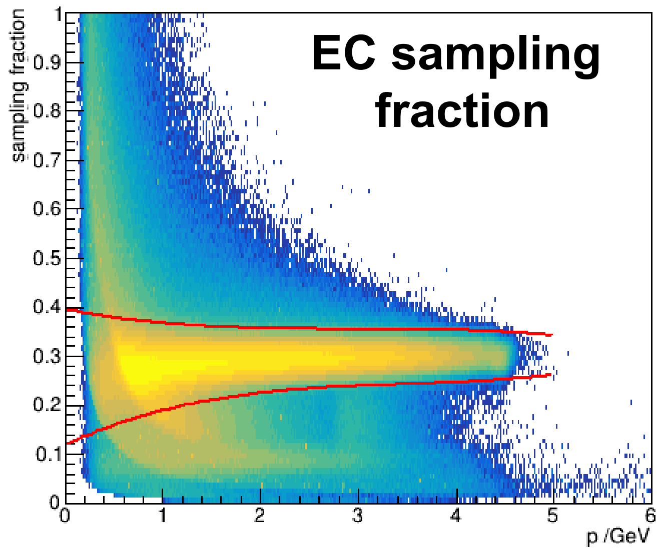


- **CLAS at 5.5 GeV (e1f run period)**
- **longitudinally polarized electron beam**
- **unpolarized hydrogen target**

Particle identification: Electron ID

- Negative charge
- Drift chamber fiducial cut
- EC fiducial cut
- EC minimum energy deposition cut
- EC sampling fraction cut
- z - vertex position cut
- Cherenkov counter geometrical matching cuts





Particle identification: π^+ ID

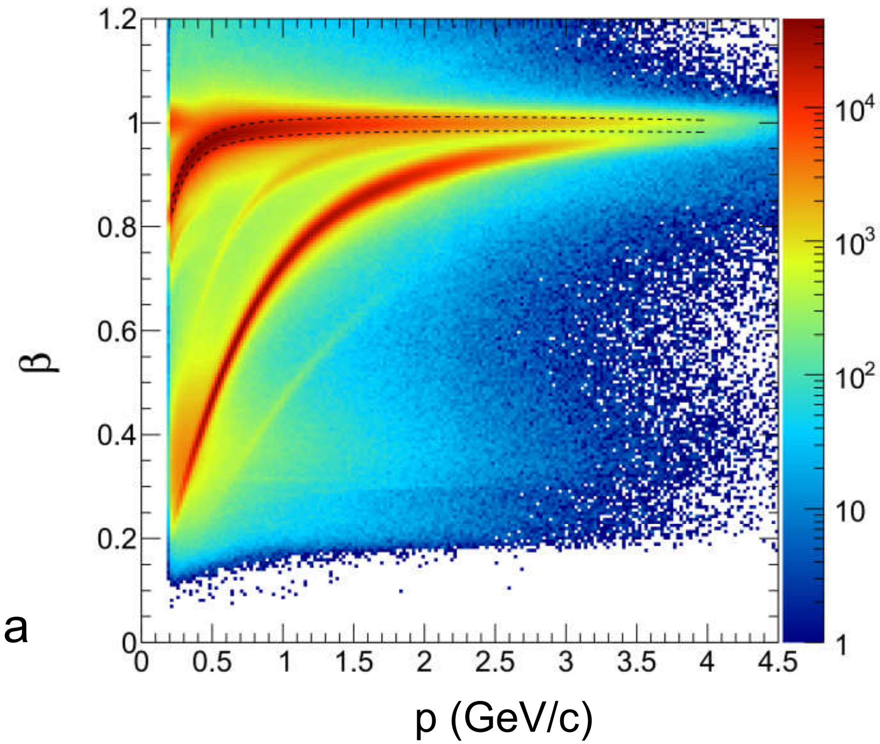
- Positive charge
- DC fiducial cuts
- Maximum likelyhood particle selection based on β vs p correlation

$$P(\beta) = \frac{1}{\sqrt{2\pi\sigma}} \cdot \exp\left(-\frac{1}{2}\left(\frac{\beta-\mu}{\sigma}\right)^2 \right)$$

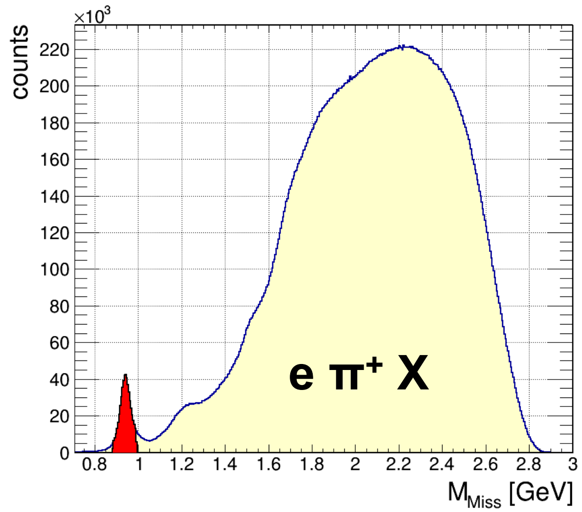
→ Assign particle to species with the highest probability

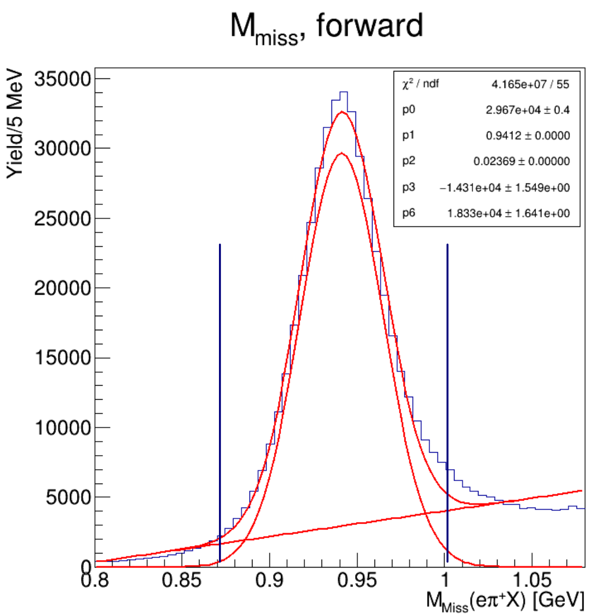
$$\alpha = 1 - \int_{\mu-\beta}^{\mu+\beta} P(\beta, p, h) d\beta$$

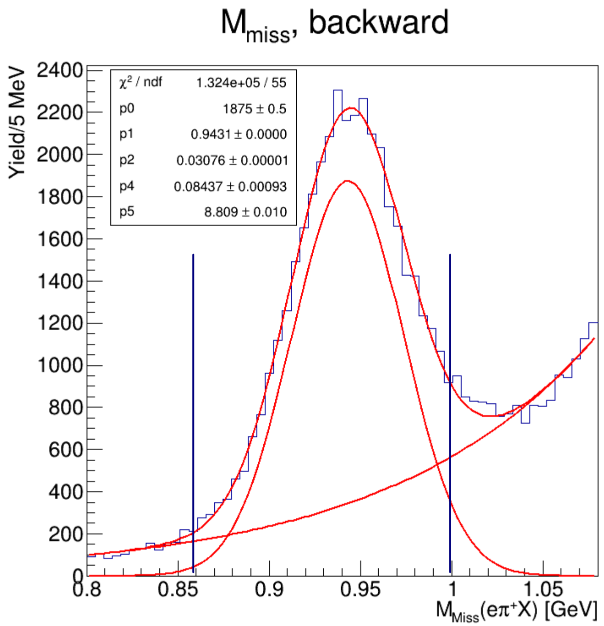
→ Check if particle is within the 3 sigma region (conf. lev. > 0.27%)



Selection of exclusive events







- Resolution and background increase in the backward region

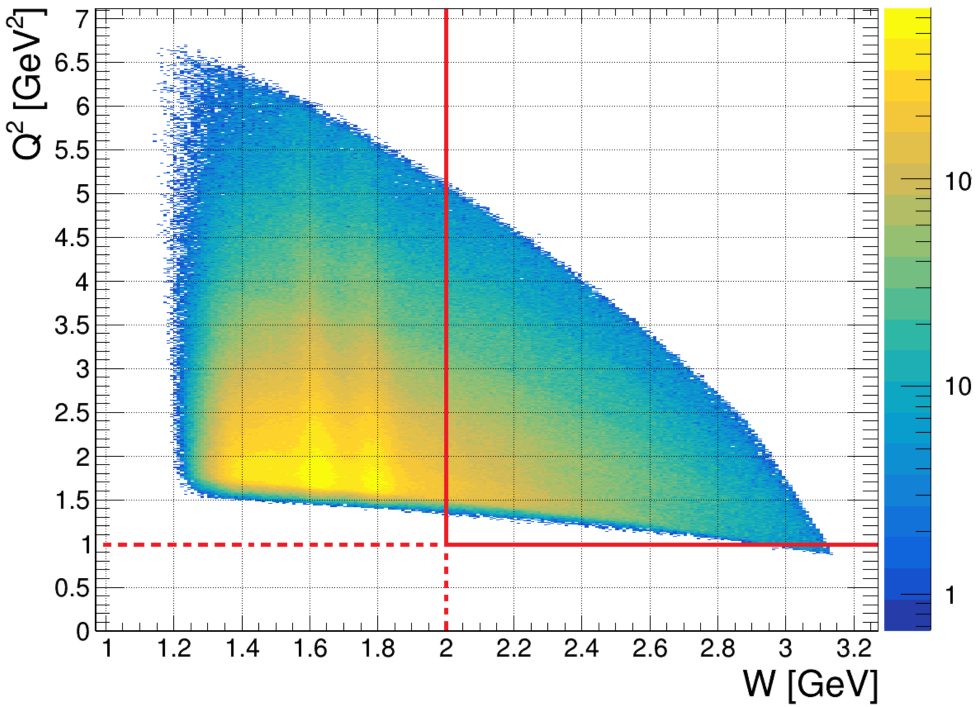
Upper limit: Background exceeds signal level at some point

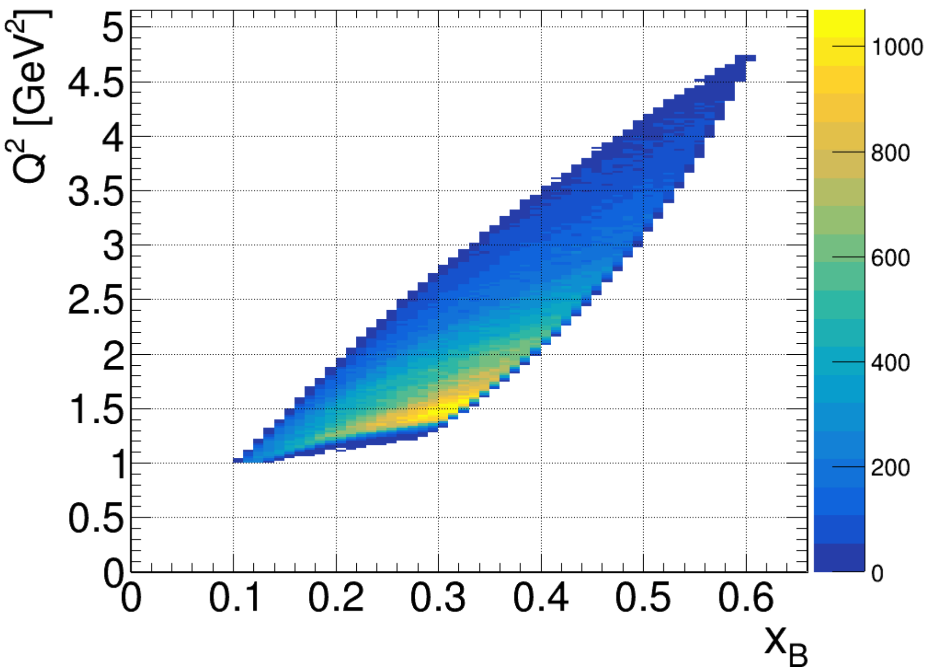
→ For most -t bins this point is at ~ 0.99 GeV

→ 1 GeV used as fixed upper limit

Lower limit: 3 sigma region is used for low t (only limitted for hight -t).

Kinematic coverage and cuts

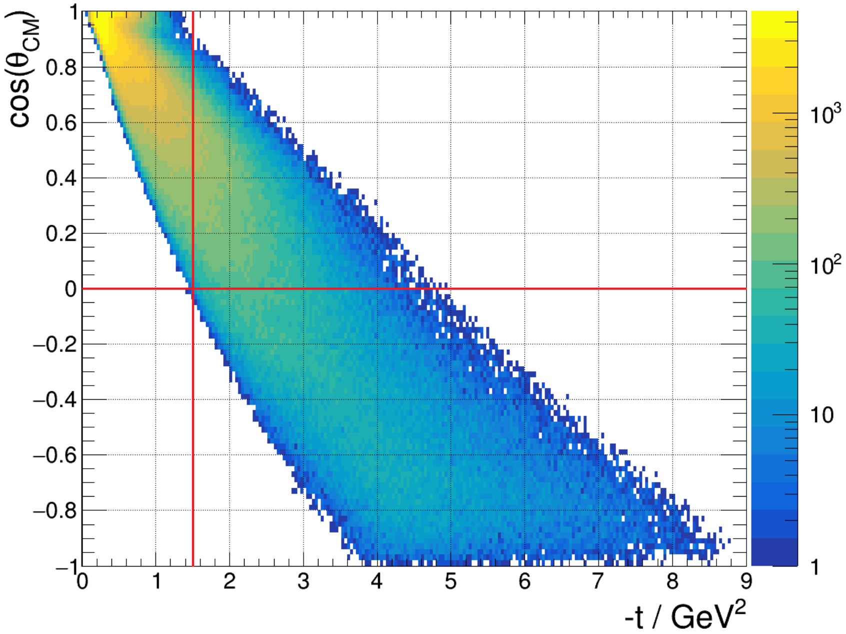




DIS cut: $W > 2$ GeV $Q^2 > 1$ GeV²

Separation of forward and backward region

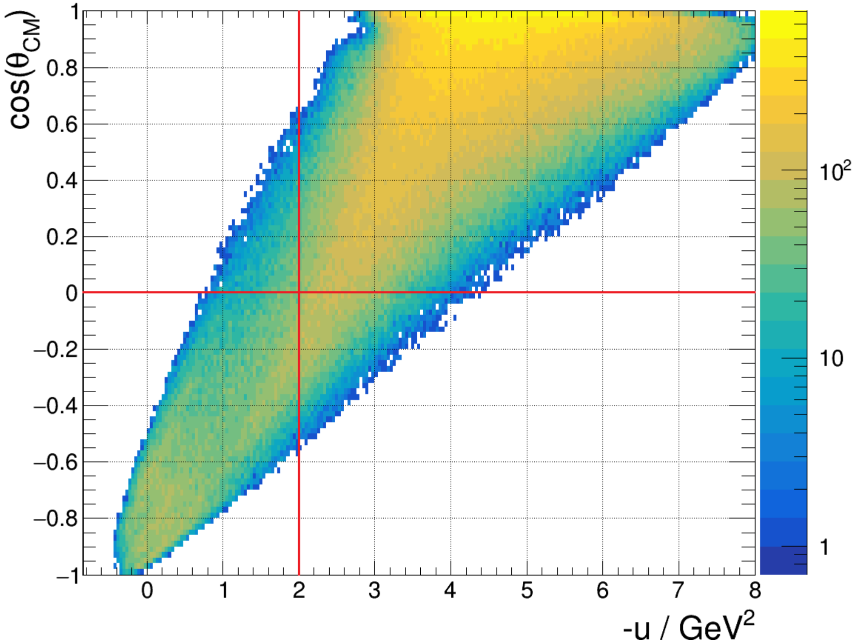
forward region
„small t“



-t < 1.5 GeV²

cos(θ) > 0

backward region
„small u“



-u < 2.0 GeV²

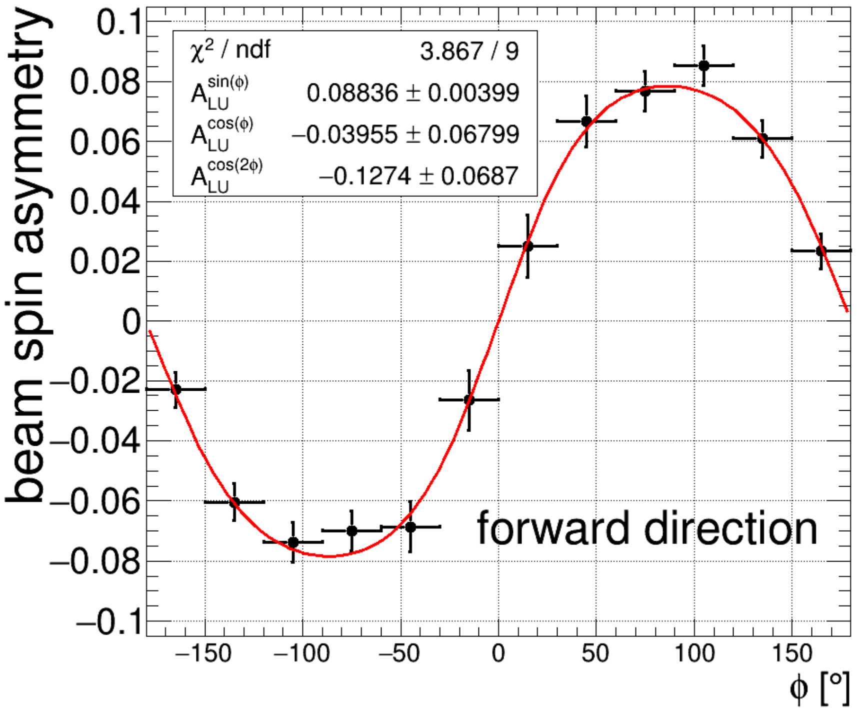
cos(θ) < 0

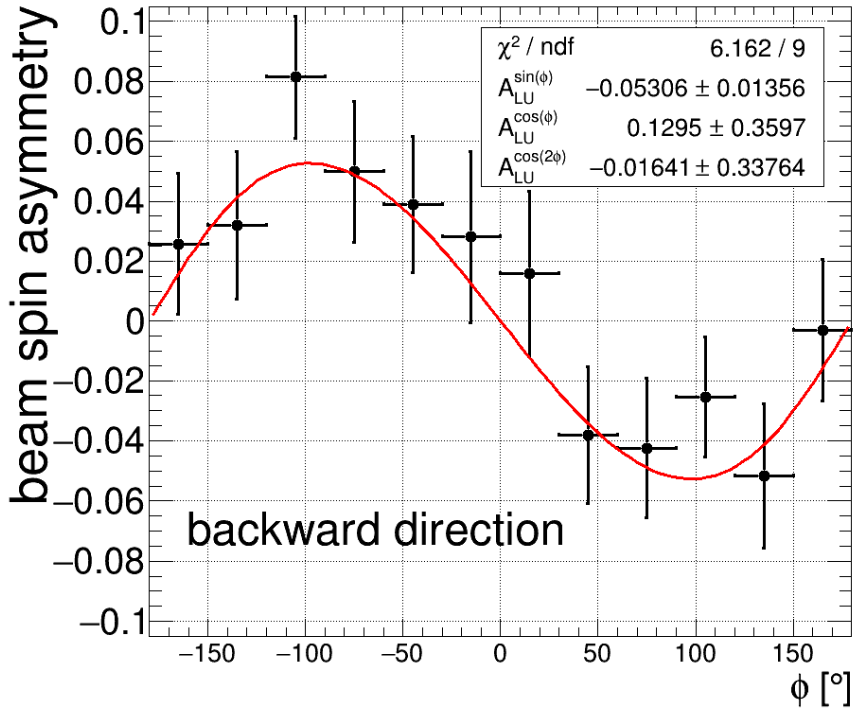
Beam spin asymmetry

$$BSA_i = \frac{1}{P_e} \cdot \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-}$$

P_e = 75 % : average e^- beam polarisation

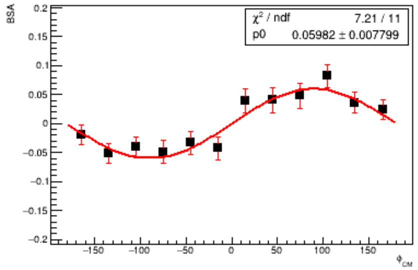
Integrated over all kinematic variables in forward / backward region:



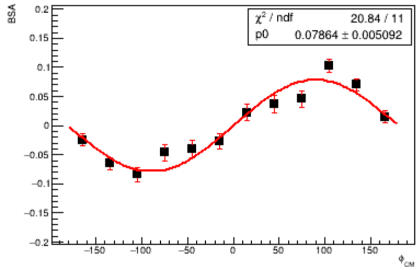


BSA for different -t bins

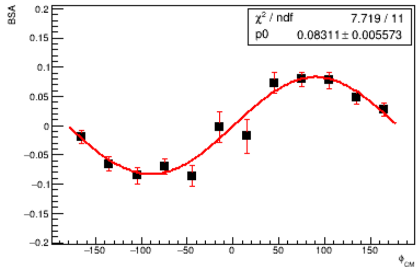
0.11 BSA t bin 00



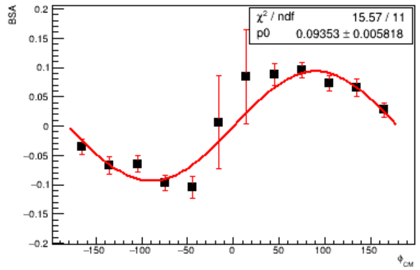
0.26 BSA t bin 01



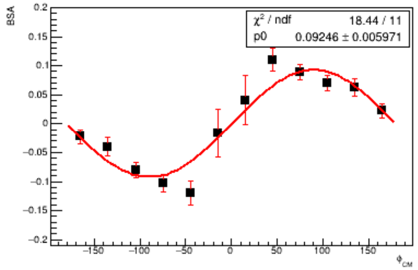
0.56 BSA t bin 02



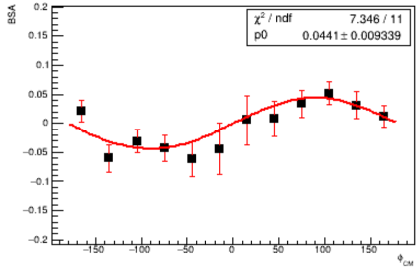
0.96 BSA t bin 03



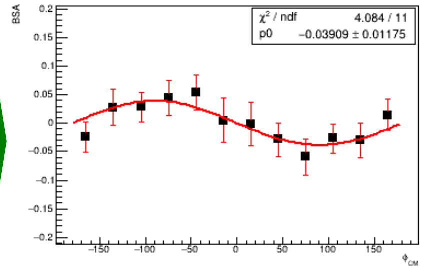
1.55 BSA t bin 04



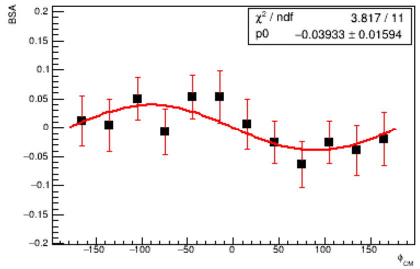
2.34 BSA t bin 05



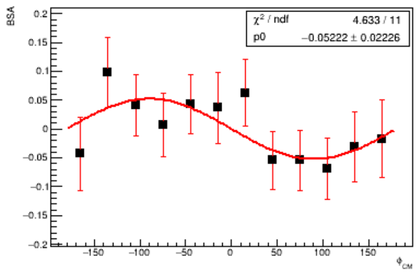
3.34 BSA t bin 06



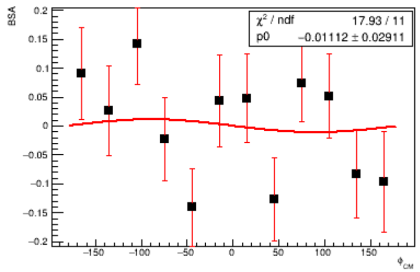
4.45 BSA t bin 07



5.44 BSA t bin 08



6.64 BSA t bin 09

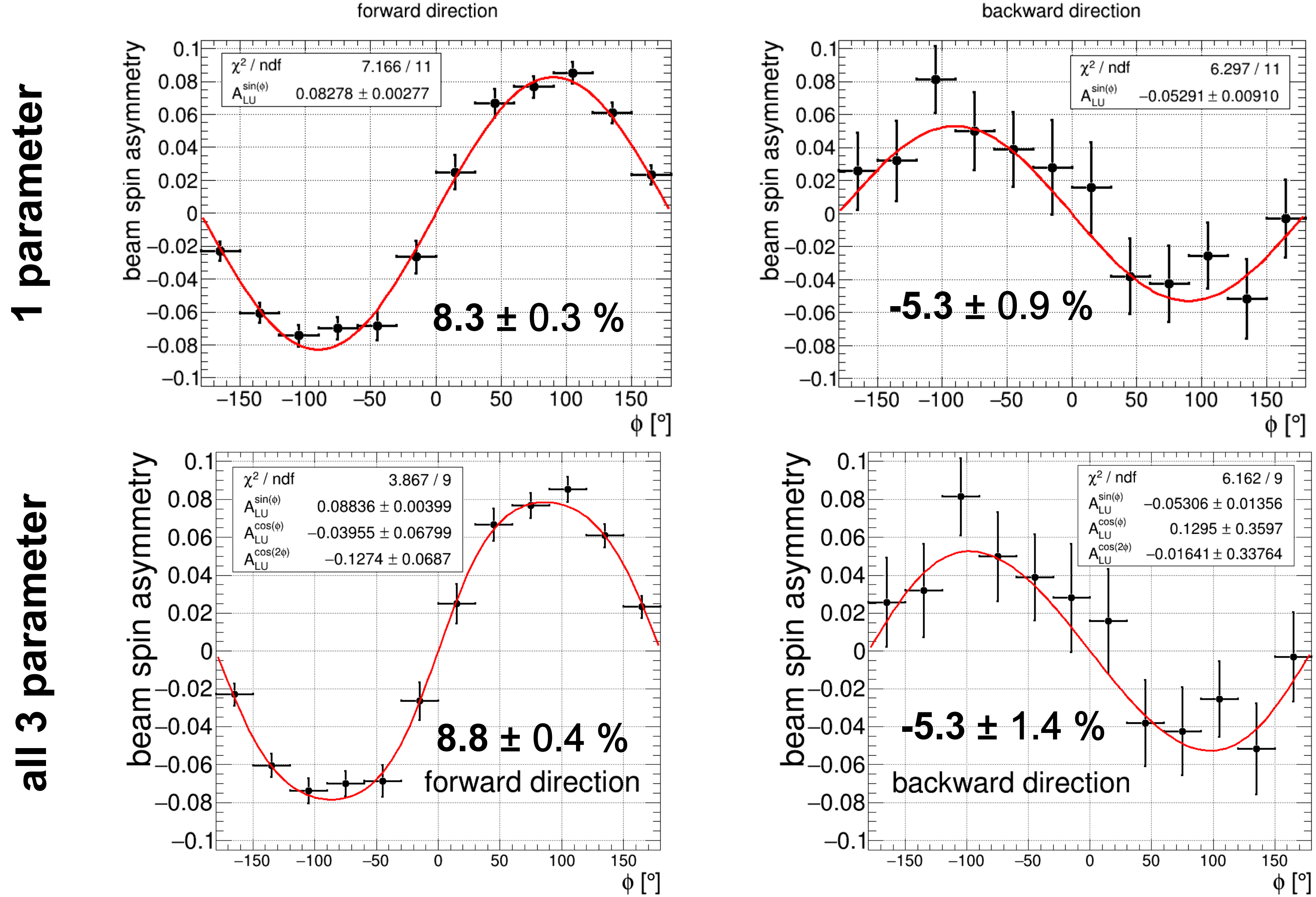


Study of systematic uncertainties

source	variation
beam polarization	$\pm$ 0.024
DC region 1 fiducial	$\pm$ 1 cm
DC region 3 fiducial	$\pm$ 3 cm
EC - w fiducial	$\pm$ 10 cm (1 bar)
EC - v fiducial	$\pm$ 10 cm (1 bar)
EC - u fiducial	$\pm$ 10 cm (1 bar)
EC sampling fraction	$\pm\ 1\sigma$
z-vertex	$\pm$ 0.5 cm
θ_{CC} matching	$\pm\ 1\sigma$
EC energy deposition	$\pm$ 0.01 (GeV)
pion confidence level (α)	0.01 - 0.07

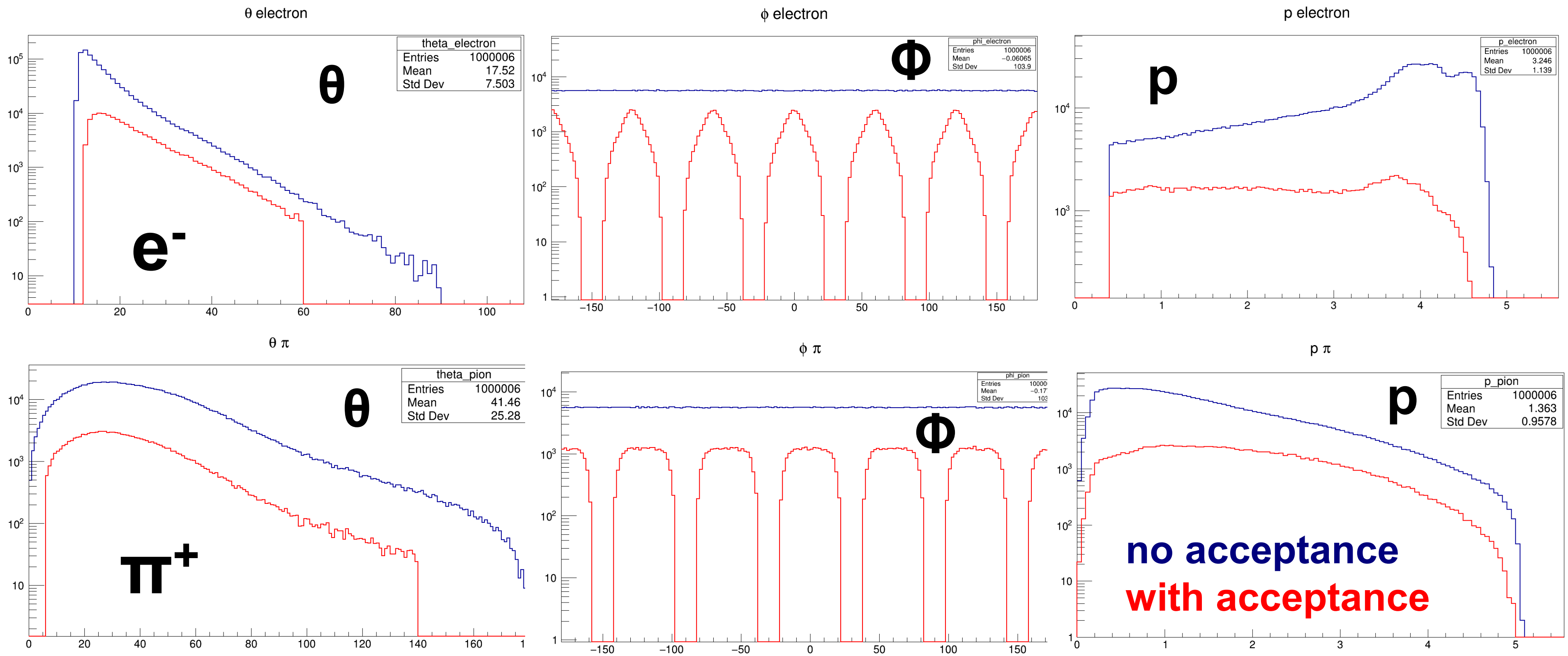
Effect of higher order moments

$$\frac{A_{LU}^{\sin\phi}\sin\phi}{1+A_{UU}^{\cos\phi}\cos\phi+A_{UU}^{\cos(2\phi)}\cos(2\phi)}$$



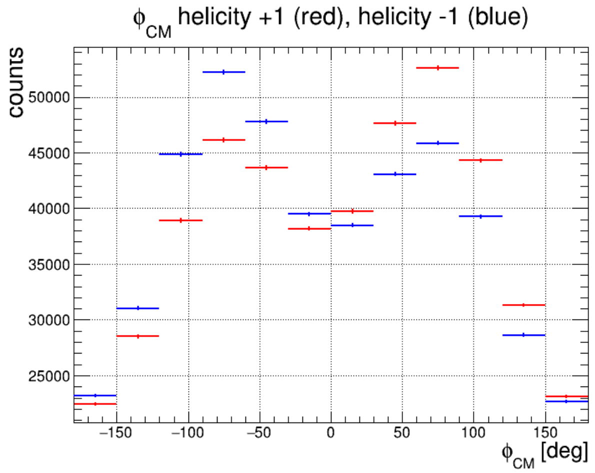
Study of acceptance effects

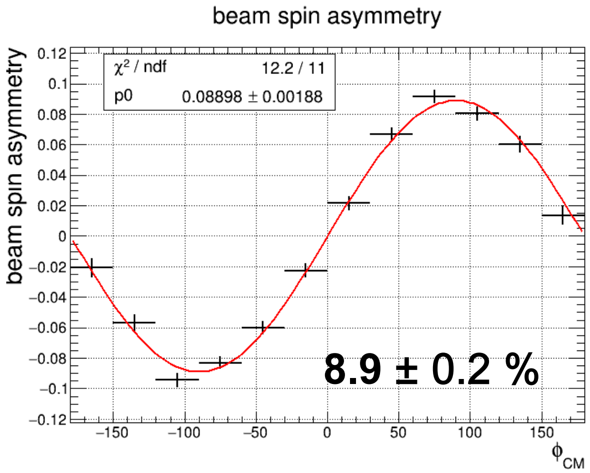
- e n π^+ events generated with a realistic event generator including radiative effects
- t-dependend beam spin asymmetry introduced according to mesured values
- Geometric acceptance simulated with formulas developed for e1-f by Daniel Carman

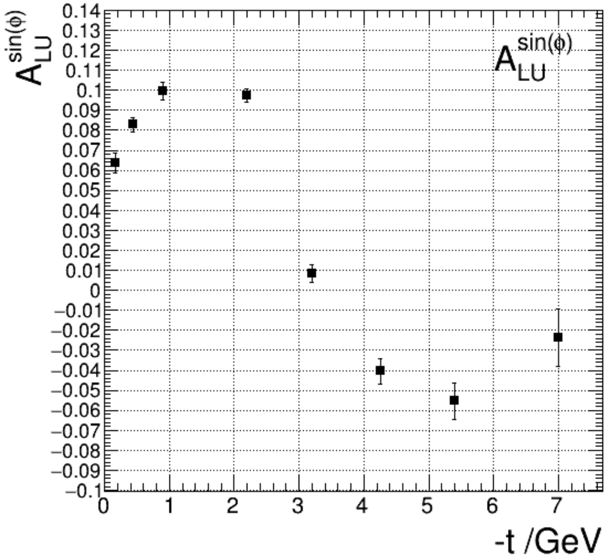


Study of acceptance effects

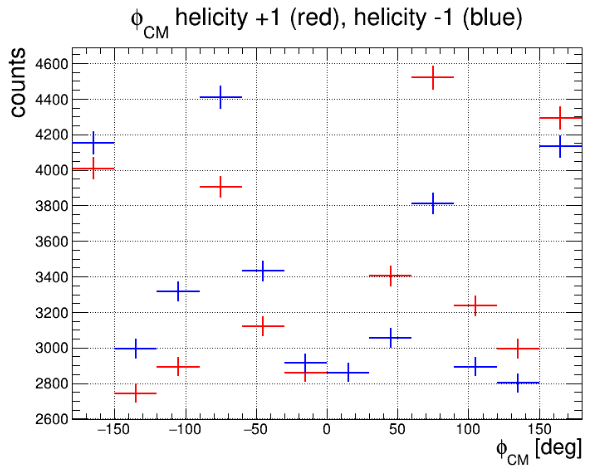
generated:

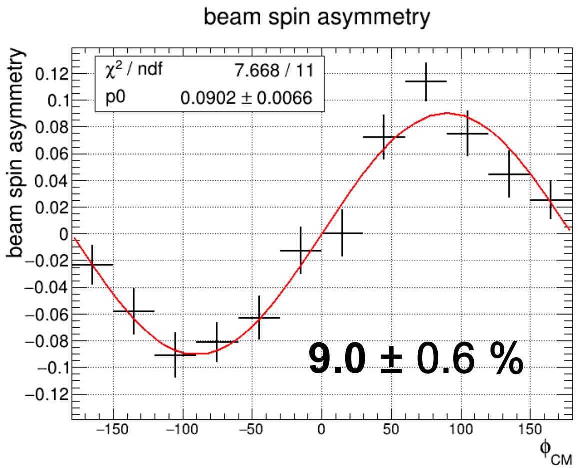


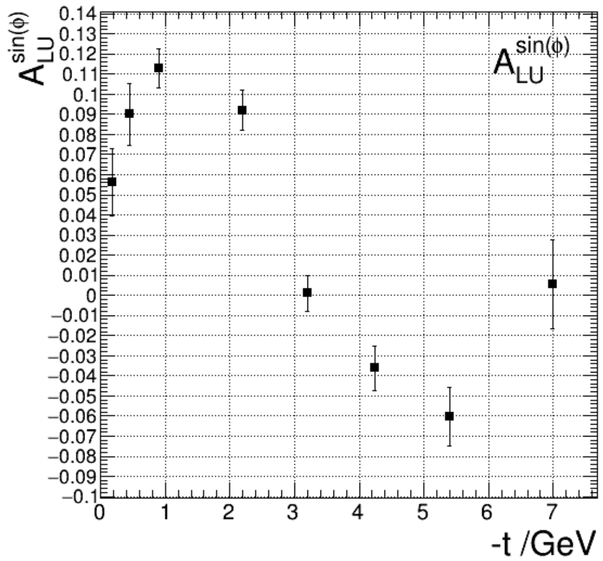




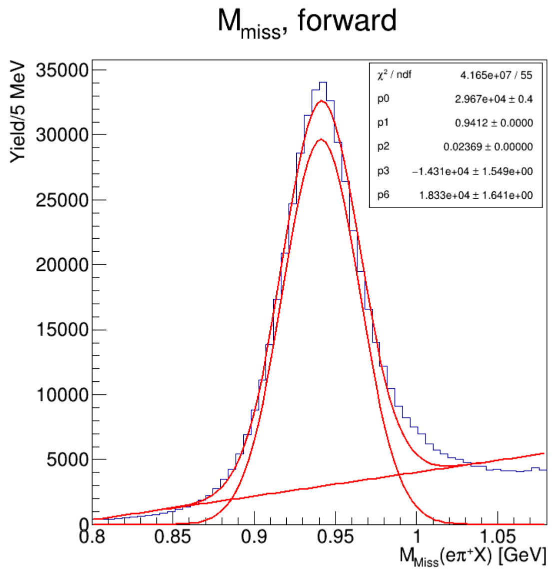
with geometrical acceptance:

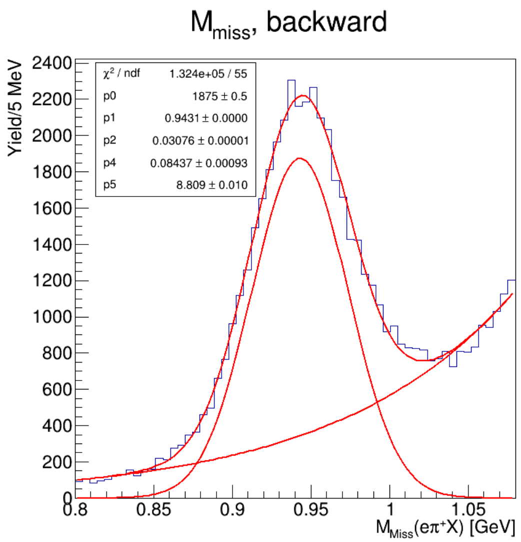


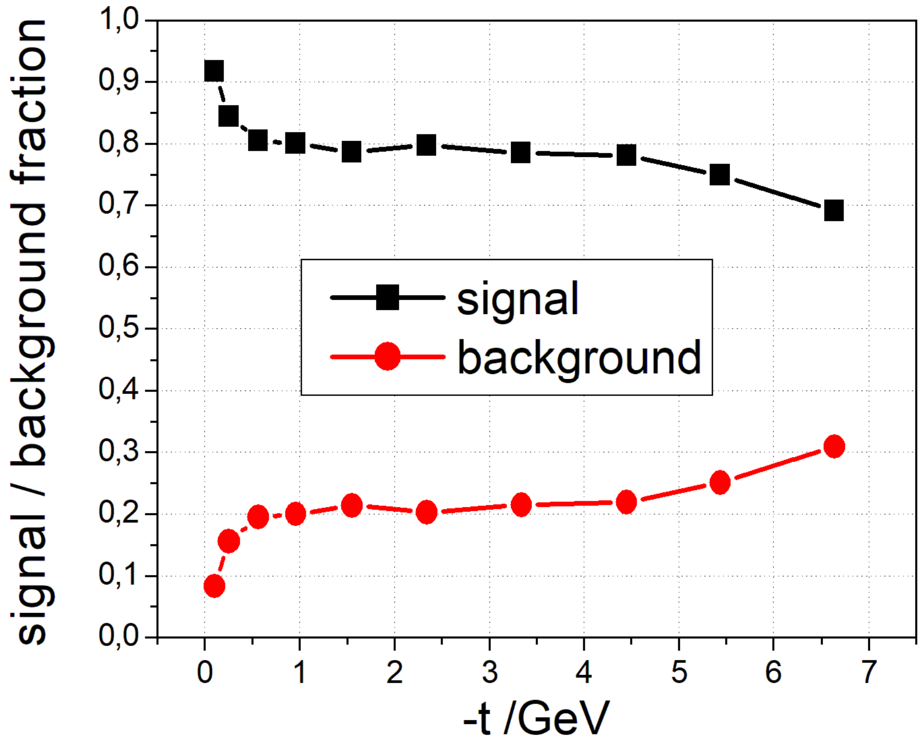




Background subtraction



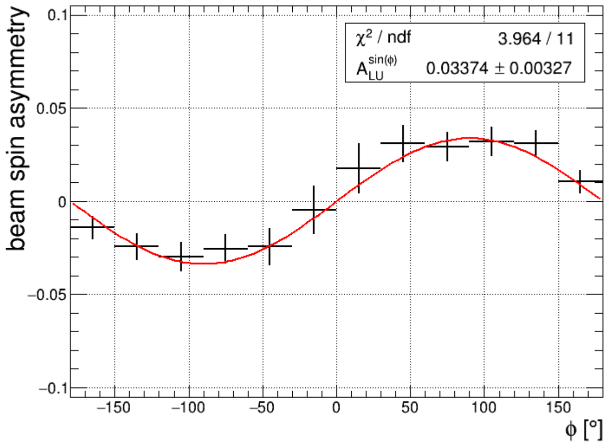




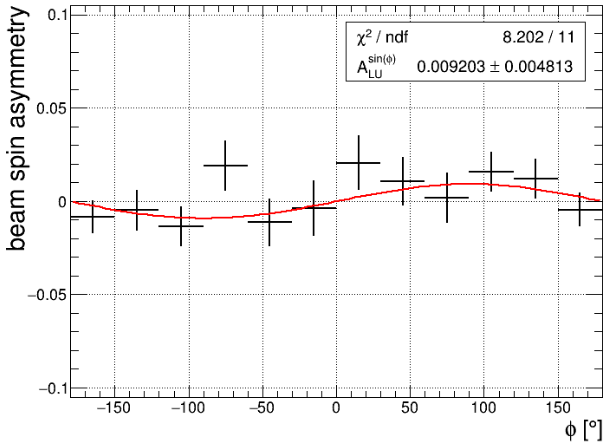
- **forward:** ~ 16 % background
- **backward:** ~ 23 % background
- Uncertainty (5 % of number of events) is considered as systeamtics

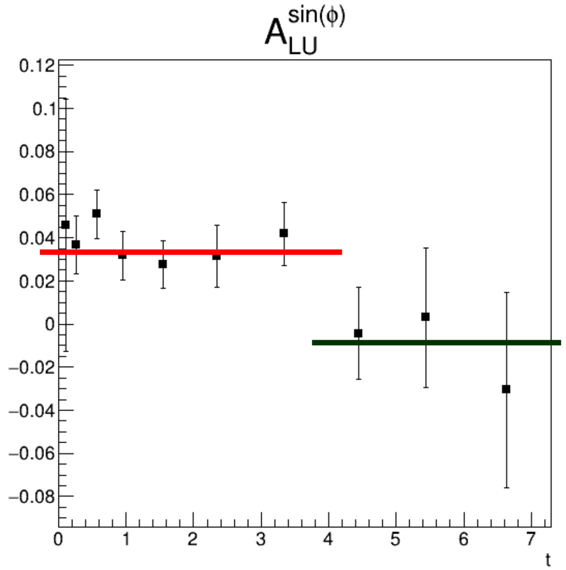
Background subtraction

forward

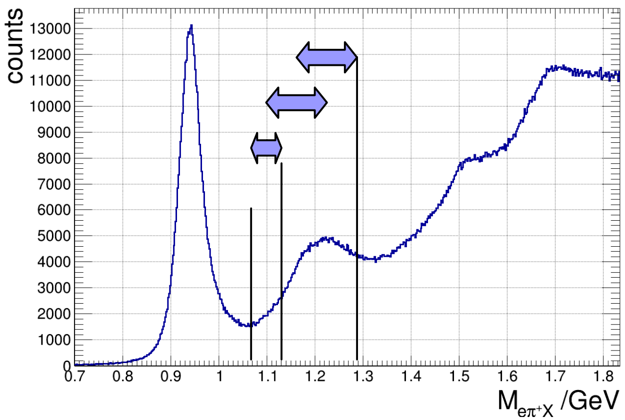


backward

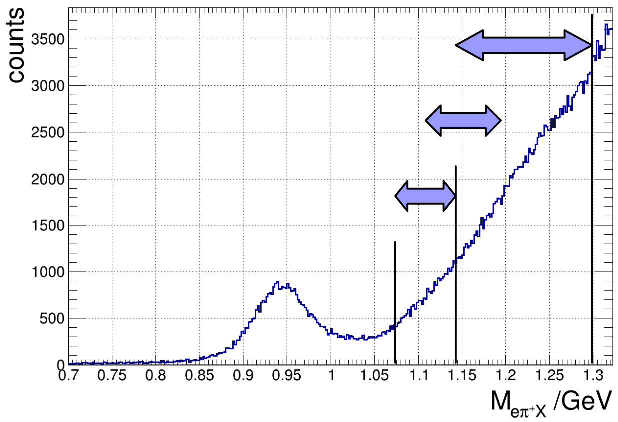




forward



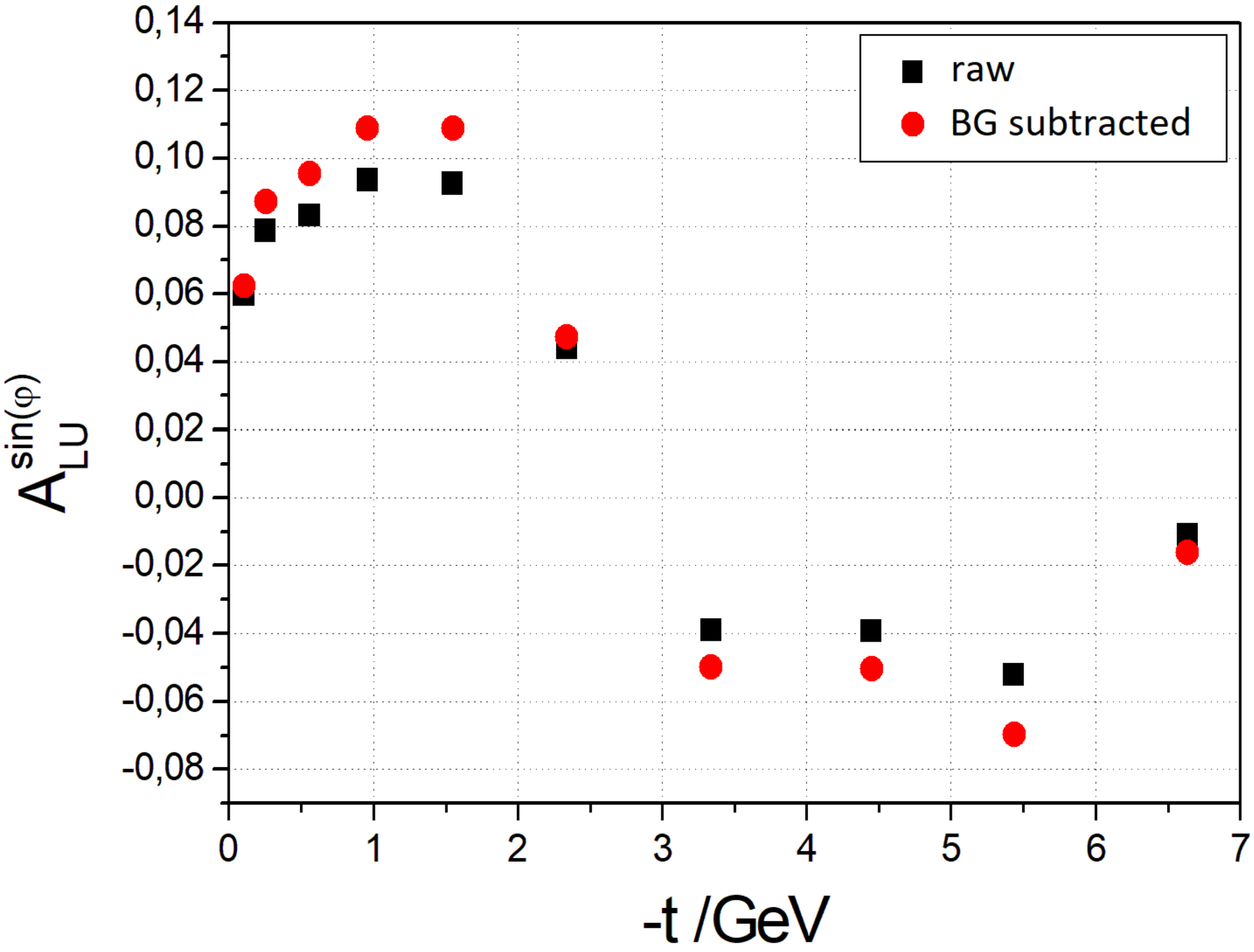
backward



Asymmetry of the background:

forward: 3.2 ± 0.6 %
backward: 0 ± 1 %

Background subtraction



Results

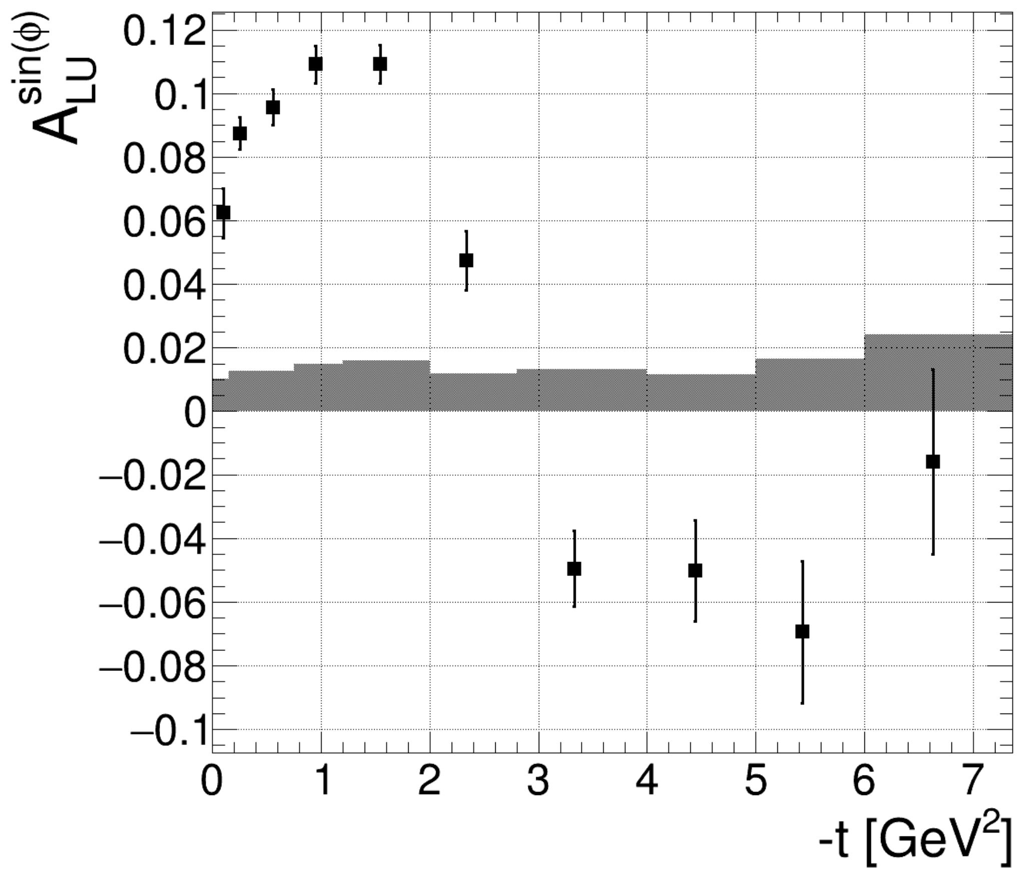
forward region:

$$A_{LU}^{\sin(\phi)} = 0.100 \pm 0.004(stat.) \pm 0.012(syst.)$$

backward region:

$$A_{LU}^{\sin(\phi)} = -0.070 \pm 0.014(stat.) \pm 0.012(syst.)$$

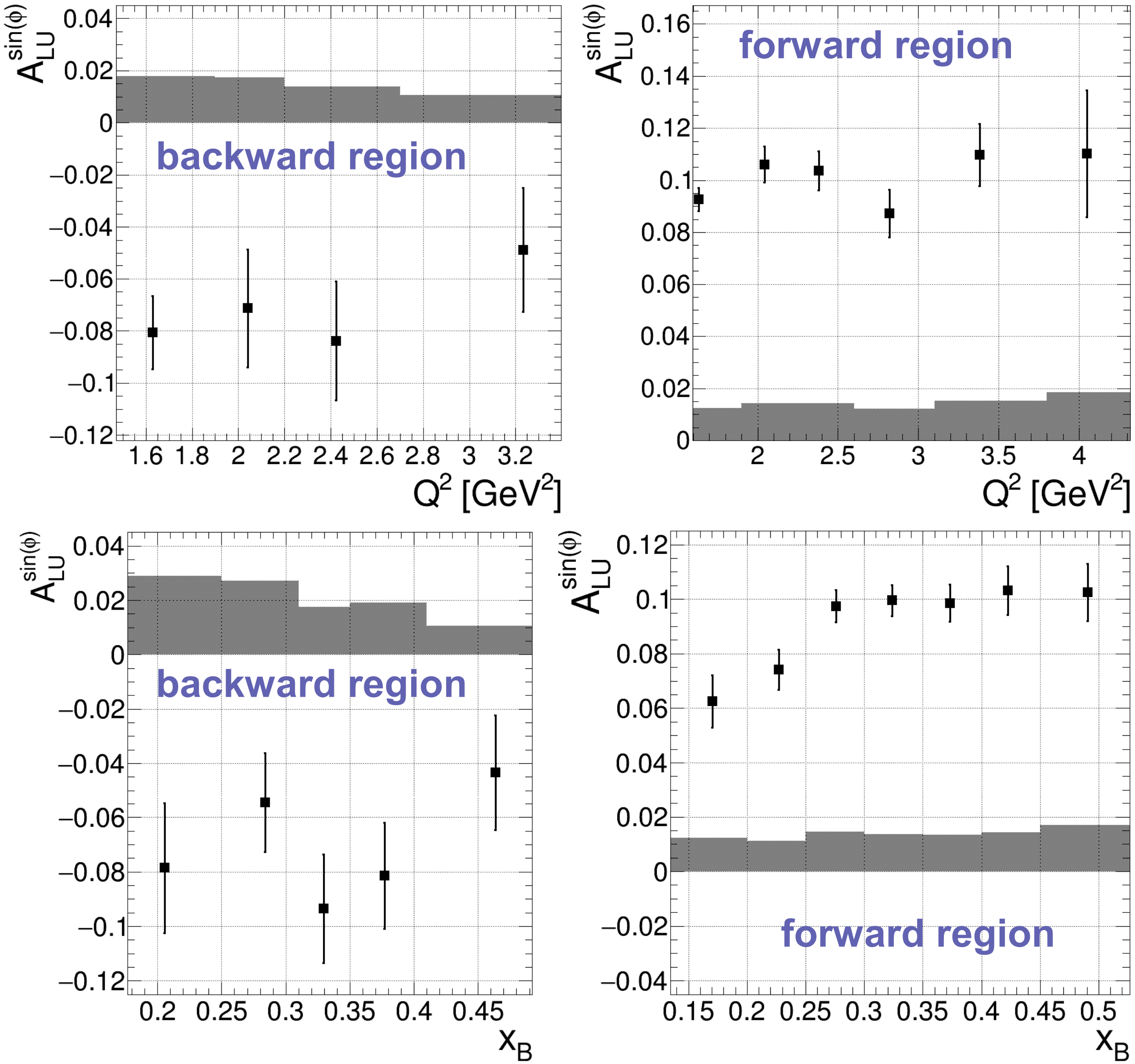
-t dependence:



Results

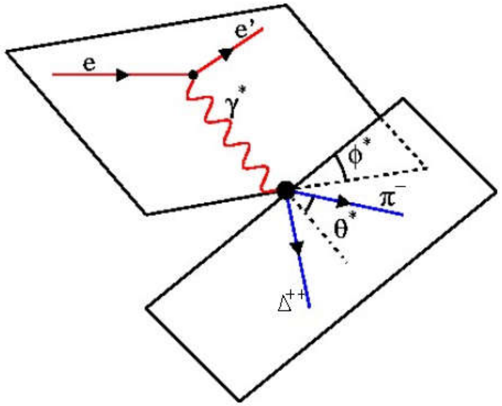
Q^2

x_B

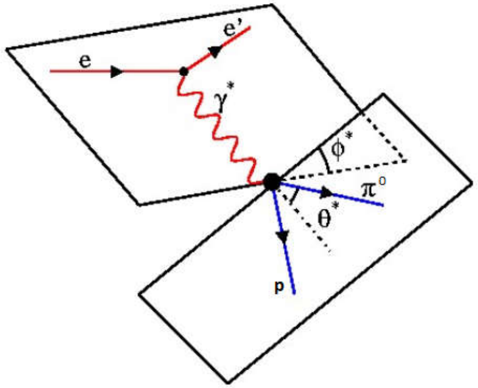


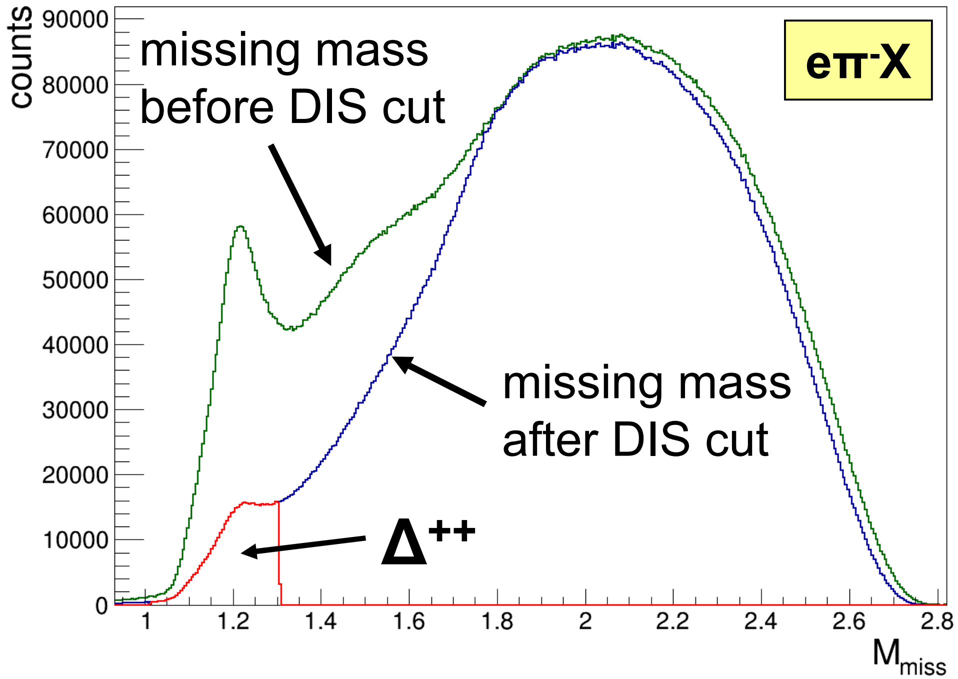
First feasbility studies for other channels

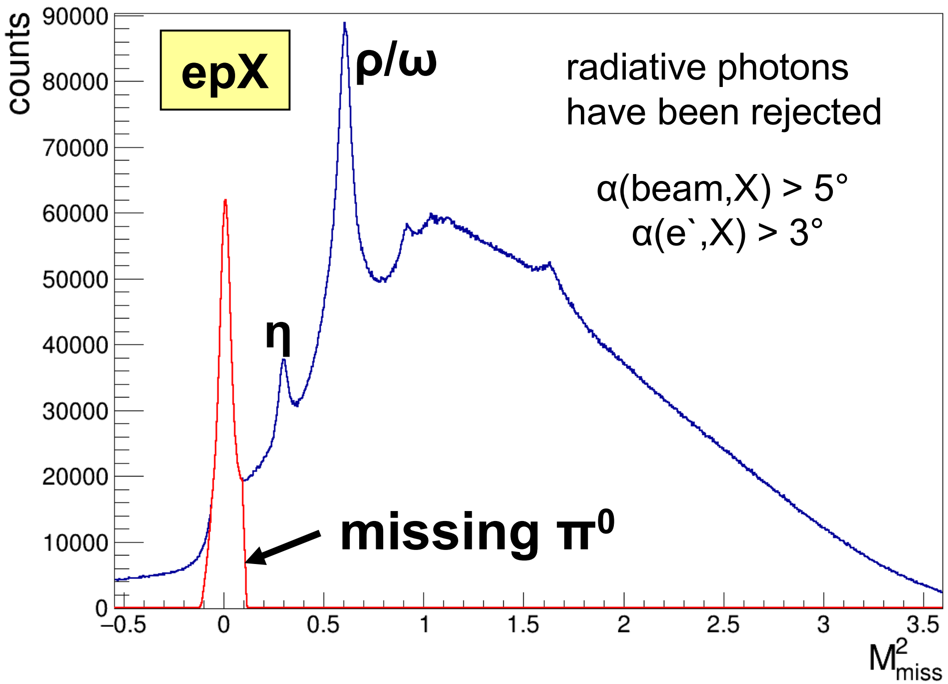
$$ep \to e\Delta^{++}\pi^{-}$$



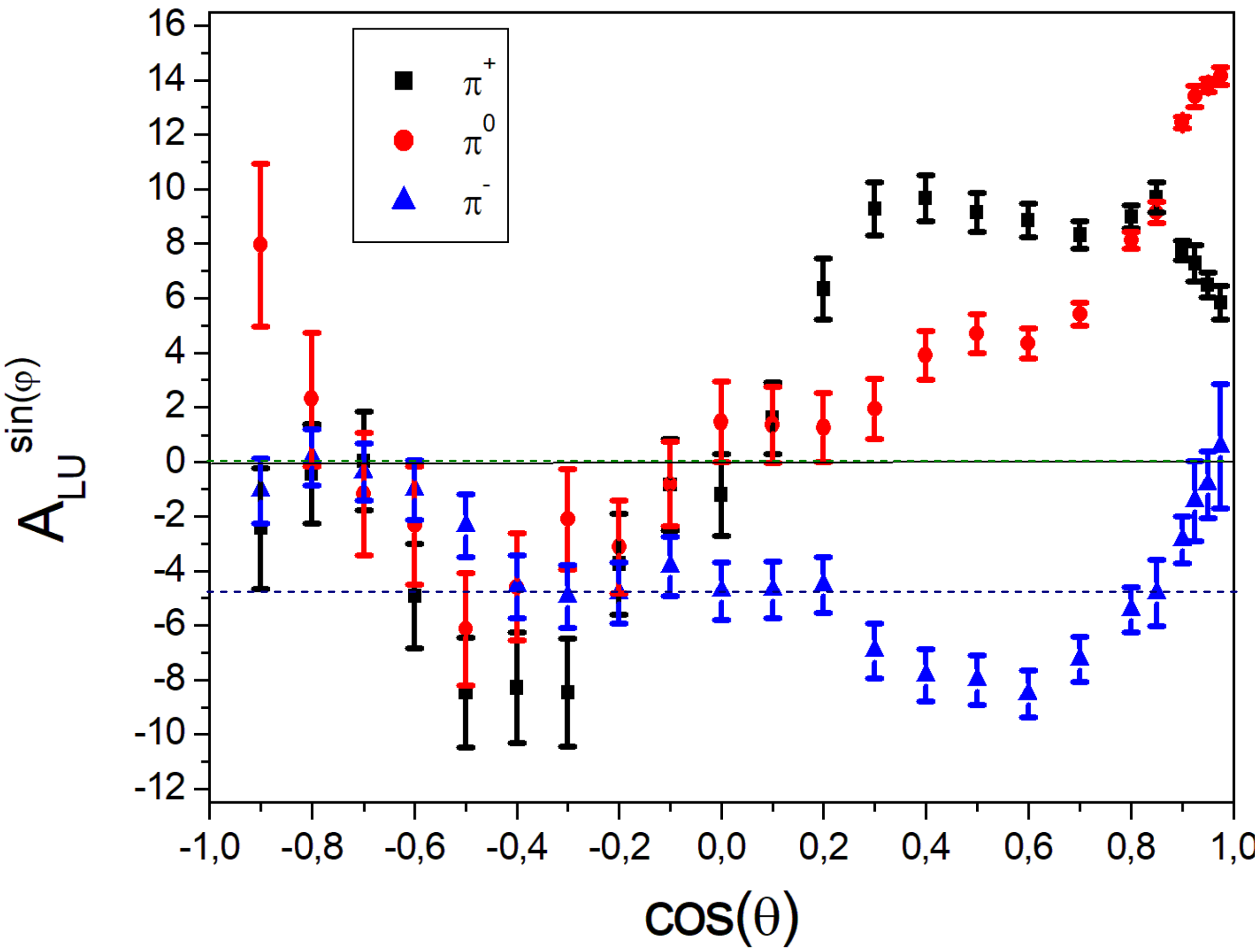
$$ep \to ep\pi^{0}$$







First feasbility studies for other channels



Future plans and ongoing work

Exprimental aspects:

- More detailed studies of cross sections and BSA will be performed with CLAS12

  → Higher statistics

  → Coverge of a larger kinematic region

  → Neutron target and neutron detection

Reactions: $e\,p \rightarrow e\,n\,\pi^+$ (RG-A)

$e\,p \rightarrow e\,p\,\pi^0$ (RG-A)

$e\,n \rightarrow e\,p\,\pi^-$ (RG-B)

- Simulations are in progress

Future plans and ongoing work

Theoretical aspects:

- Extraction of GPDs with the HepGen++ code, based on the Goloskokov-Kroll model

- Extraction of TDAs is still under development

- Development of a first realistic TDA based event generator is in progress (based on a TDA model and Mathematica code from Kirill Semenov, Bernard Pire and Lech Szimanowski [PRD85])

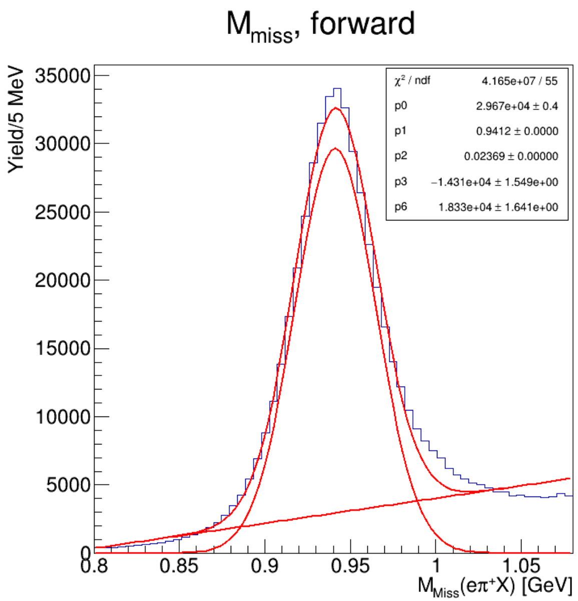
Summary and Conclusion

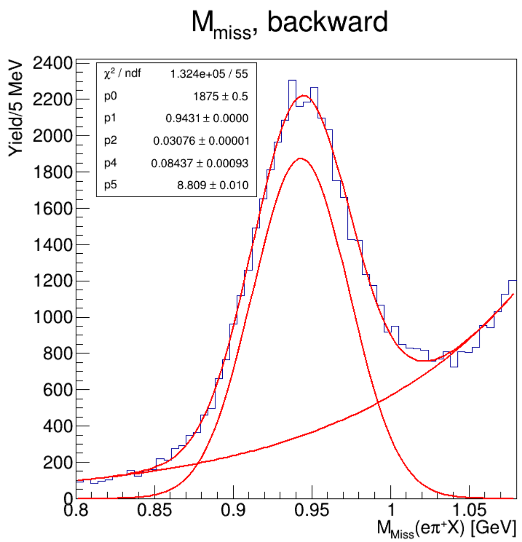
- $A_{LU}^{\sin(\Phi)}$ moment from the hard exclusive π^+ channel has been extracted for the first time over a large range of kinematics.
- The results show a clear sign change from forward to backward angles, which may indicate a transition from the GPD to the TDA regime.
- The study on π^+ is under review and a paper will be submitted soon.
- A similar effect has been observed for π^0 and π^-

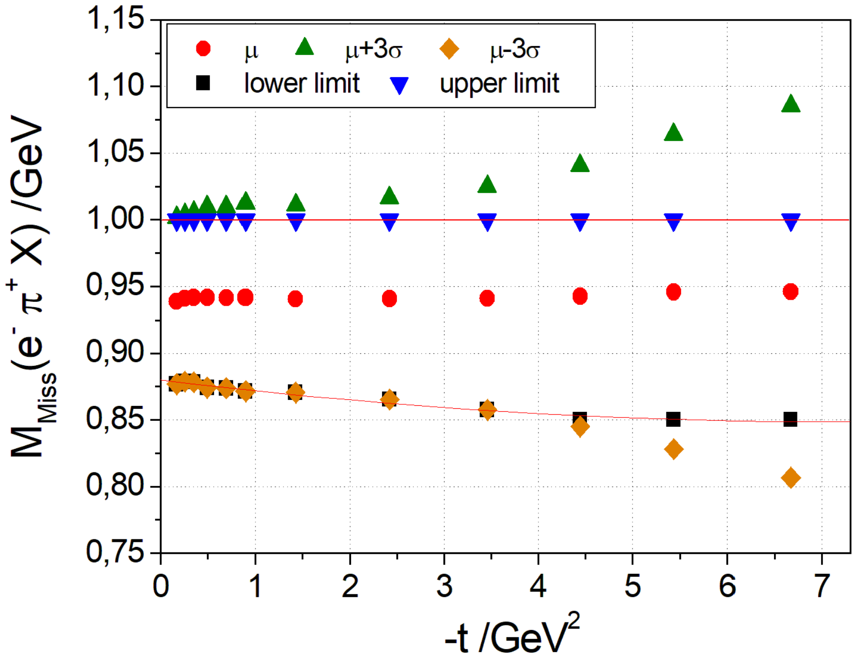
  → More detailed studies will be performed with CLAS12
- Plan to submit CAA proposal for all exclsuive pion channels from proton and neutron targets

Backup

Backup I - Cut limits for the missing mass







Upper limit: Background exceeds signal level at some point

→ In backward direction this point is at ~ 1 GeV

→ Used as fixed upper limit

Lower Limit: 3 sigma region is used for low t.

→ Reduced value at high t, due to significant background below the signal

Backup II - fit of all 3 moments

forward region:

$$A_{LU}^{\sin(\phi)} = 0.100 \pm 0.004(stat.) \pm 0.012(syst.)$$
$$A_{LU}^{\cos(\phi)} = -0.054 \pm 0.068(stat.) \pm 0.058(syst.)$$
$$A_{LU}^{\cos(2\phi)} = -0.160 \pm 0.069(stat.) \pm 0.058(syst.)$$

backward region:

$$A_{LU}^{\sin(\phi)} = -0.070 \pm 0.014(stat.) \pm 0.012(syst.)$$
$$A_{LU}^{\cos(\phi)} = 0.17 \pm 0.36(stat.) \pm 0.32(syst.)$$
$$A_{LU}^{\cos(2\phi)} = -0.02 \pm 0.34(stat.) \pm 0.19(syst.)$$