Report from HERMES

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DESY Zeuthen
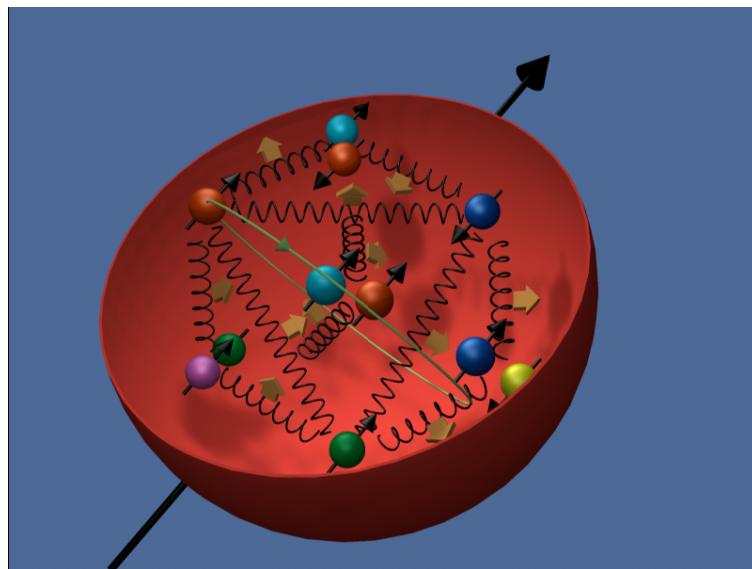
for the HERMES collaboration

68. DESY PRC Meeting, November 5, 2009

Study of spin structure of the nucleon at HERMES

- Longitudinal Spin/Momentum Structure, Hadronization

- Transverse Spin/Momentum Structure → Transversity, TMDs

- DVCS, Exclusive Meson Production → GPDs, "Nucleon Tomography"

- Strange-Baryon Production

Publications since the last PRC

- **Four papers published (accepted for publication)**
  - Spin density matrix elements in exclusive ρ^0 electroduction on ^1H and ^2H targets at 27.6 GeV beam energy, *EPJC 62 (2009) 659-694, arXiv:0901.0701 (hep-ex) and DESY-08-203*
  - Observation of the naive-T-odd Sivers effect in deep-inelastic scattering *Phys. Rev. Lett. 103 (2009) 152002, arXiv:0906.3918 and DESY-09-089*
  - Exclusive ρ^0 electroproduction on transversely polarized protons, *Phys. Lett. B679 (2009) 100-105, arXiv:0906.5160 (hep-ex) and DESY-09-094*
  - Separation of contributions from deeply virtual Compton scattering and its interference with the Bethe-Heitler process in measurements on a hydrogen target, *JHEP (in press), arXiv:0909.3587 (hep-ex) and DESY-09-143*

- **Five papers submitted to journals**
  - Transverse momentum broadening of hadrons produced in semi-inclusive deep-inelastic scattering, *submitted to Phys. Lett. B, arXiv:0906.2478 (hep-ex) and DESY-09-082*
  - Single-spin azimuthal asymmetry in exclusive electroproduction of π^+ mesons on transversely polarized protons, *submitted to Phys. Lett. B, arXiv:0907.2596 (hep-ex) and DESY-09-106*
  - Search for a two-photon exchange contribution to inclusive deep-inelastic scattering, *submitted to Phys. Lett. B, arXiv: 0907.5369 and DESY-09-117*
  - Measurement of azimuthal asymmetries associated with deeply virtual Compton scattering on an unpolarized deuterium target, *arXiv: 0911.0095 and DESY-09-189*
  - Nuclear-mass dependence of beam-helicity and beam-charge azimuthal asymmetries in DVCS, *arXiv: 0911.0091 and DESY-09-190*

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Results from transverse target running
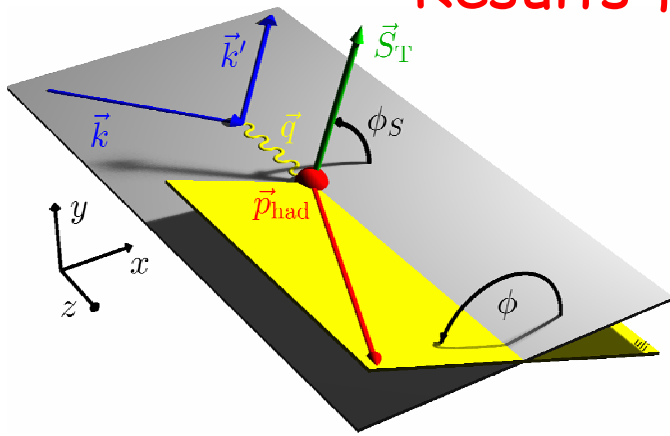
Single Spin Asymmetries in Semi-Inclusive Deep Inelastic Scattering

$$\Delta\sigma_{UT}(\phi,\phi_S) \approx 2\left\langle\sin(\phi-\phi_S)\right\rangle_{UT}^h \sin(\phi-\phi_S) + 2\left\langle\sin(\phi+\phi_S)\right\rangle_{UT}^h \sin(\phi+\phi_S) + \cdots$$
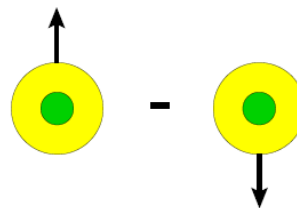
Sivers moment

Collins moment

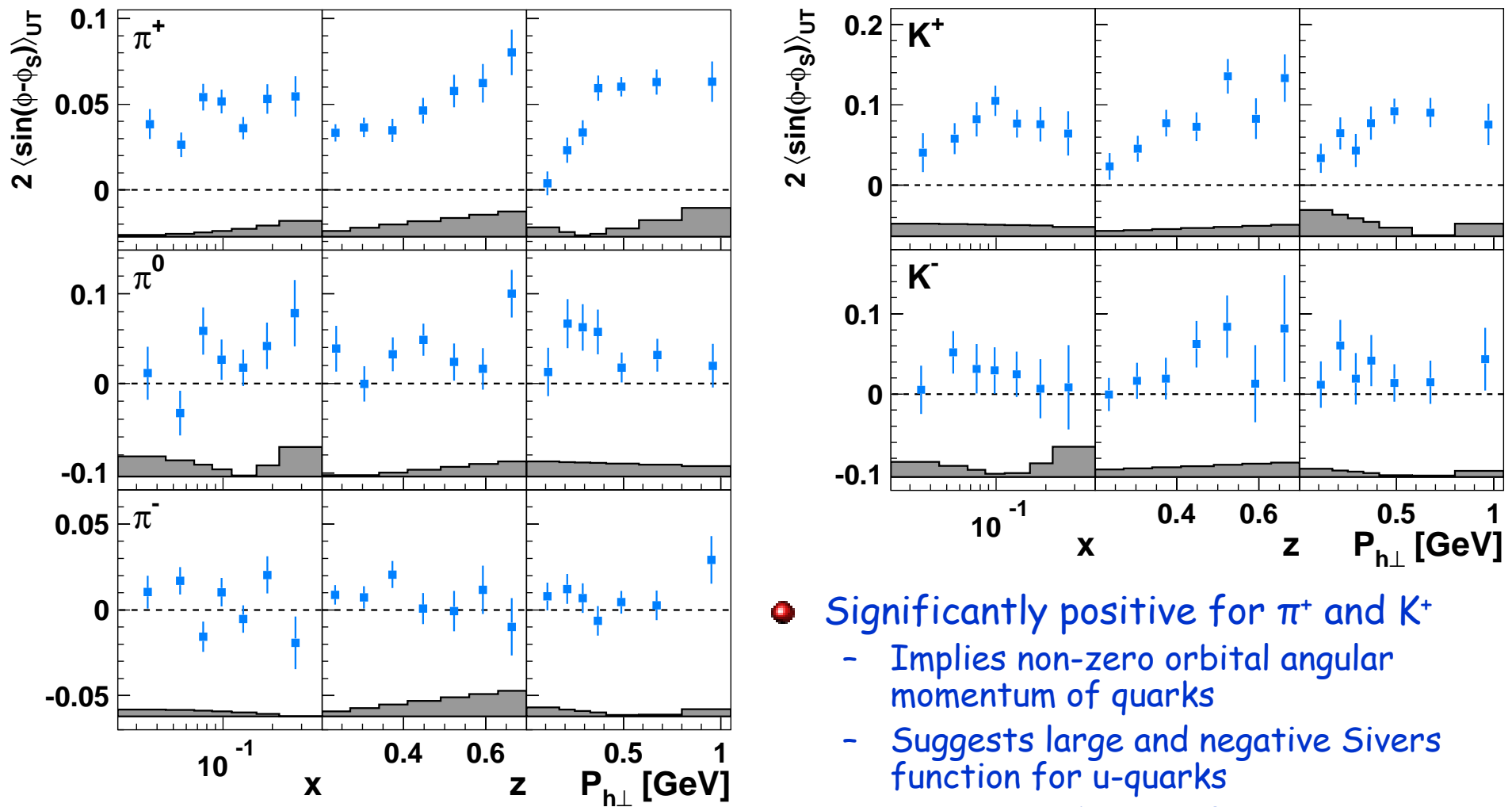$$\propto f_{1T}^{\perp q}(x)D_1^q(z)$$

$$\propto h_1(x)H_1^{\perp q}(z)$$

Sivers distribution function

- Chiral-even and naive T-odd transverse momentum dependent function
- Describes correlation between intrinsic quark p_T and transverse nucleon spin
- Non-zero Sivers DF requires non-vanishing orbital angular momentum

Sivers asymmetries for pions and kaons

Published: *Phys. Rev. Lett. 103 (2009) 152002*

- **Significantly positive for π^+ and K^+**
  - Implies non-zero orbital angular momentum of quarks
  - Suggests large and negative Sivers function for u-quarks
- **Consistent with zero for π^-**
  - Require cancellation effects, opposite sign for u- and d-quark Sivers functions

Pion-difference Sivers asymmetry and difference between K⁺ and π⁺ Sivers asymmetries
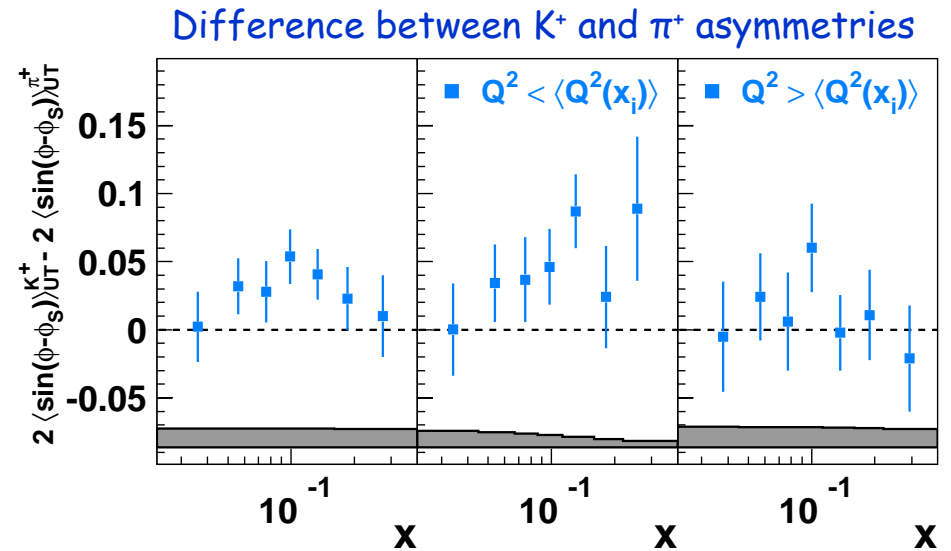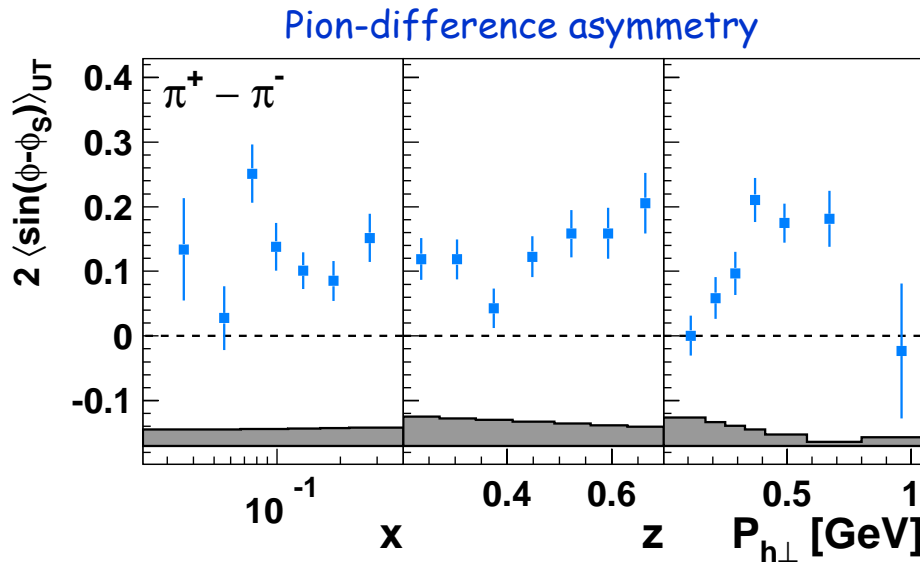
- 🔴 Pion-difference asymmetry $A_{UT}^{\pi^+ - \pi^-}(\phi, \phi_S) \equiv \dfrac{1}{|\mathbf{S_T}|} \dfrac{\left(\sigma_{U\uparrow}^{\pi^+} - \sigma_{U\uparrow}^{\pi^-}\right) - \left(\sigma_{U\downarrow}^{\pi^+} - \sigma_{U\downarrow}^{\pi^-}\right)}{\left(\sigma_{U\uparrow}^{\pi^+} - \sigma_{U\uparrow}^{\pi^-}\right) + \left(\sigma_{U\downarrow}^{\pi^+} - \sigma_{U\downarrow}^{\pi^-}\right)} \propto \left(f_{1T}^{\perp, d_v} - 4 f_{1T}^{\perp, u_v}\right)$
    - Contribution from ρ^0 mesons cancels
    - Helps to isolate the valence-quark Sivers function
    - Assumption of charge-conjugation and isospin symmetry among pion fragmentation
- 🔴 Difference between K⁺ and π⁺ asymmetries $\pi^+ = \left| u\bar{d} \right\rangle$ $K^+ = \left| u\bar{s} \right\rangle$
    - Possible significant role of sea quarks
    - Higher-twist effects in kaon production might also contribute

Access to Generalized Parton Distributions (GPDs) via Deeply Virtual Compton Scattering (DVCS)
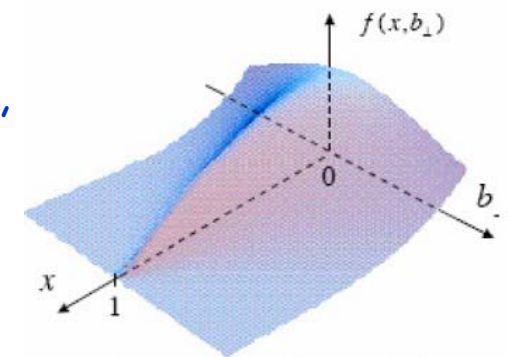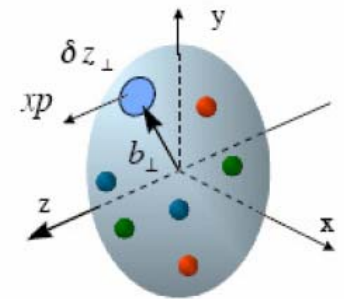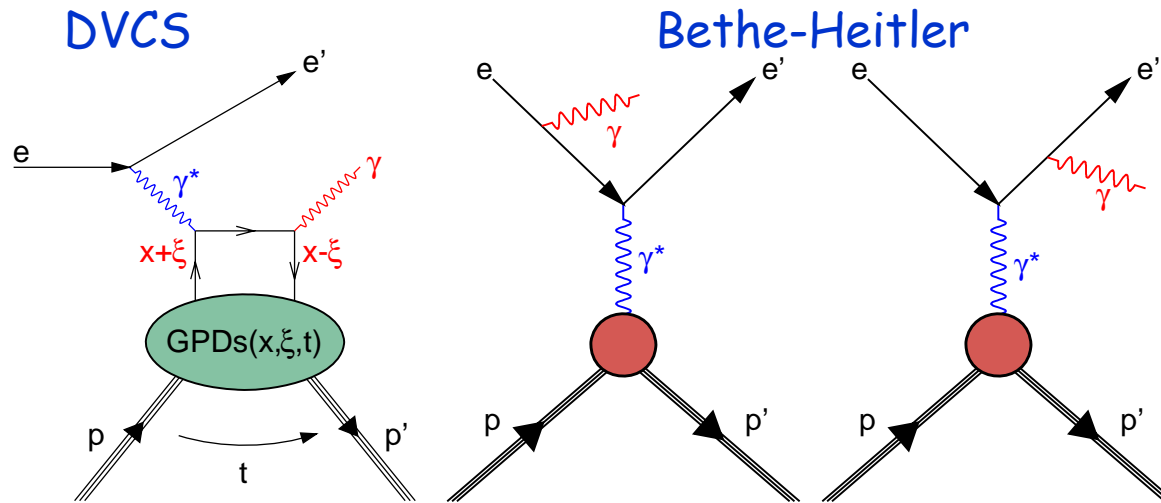
DVCS

Bethe-Heitler

- DVCS and Bethe-Heitler: the same initial and final state, Bethe-Heitler dominates at HERMES kinematics
- GPDs accessible through cross section differences and azimuthal asymmetries via interference term

- GPDs include knowledge about Parton Distribution Functions and Form Factors
- Four chiral-even GPDs for proton in leading order and leading twist for each quark flavor $H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$
- GPDs can provide access to the quark total angular momentum via Ji relation

$$J_q = \lim_{t \to 0} \int_{-1}^{1} dx\, x \left[H_q(x, \xi, t) + E_q(x, \xi, t) \right]$$

Azimuthal asymmetries in DVCS

● Cross section

$$\sigma_{LU}(\phi; P_B, C_B) = \sigma_{UU}[1 + \boxed{P_B}A_{LU}^{DVCS} + \boxed{C_B P_B}A_{LU}^{I} + \boxed{C_B}A_C]$$

● Beam-charge asymmetry

$$A_C(\phi) = \frac{\left(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}\right) - \left(\sigma^{-\leftarrow} + \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}\right) + \left(\sigma^{-\leftarrow} + \sigma^{-\rightarrow}\right)} = -\frac{1}{D(\phi)}\frac{x_B^2}{y}\sum_{n=0}^{3}\boxed{c_n^I}\cos(n\phi)$$

● Charge-difference beam-helicity asymmetry

$$A_{LU}^{I}(\phi) = \frac{\left(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}\right) - \left(\sigma^{+\leftarrow} + \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{-\leftarrow}\right) + \left(\sigma^{+\leftarrow} + \sigma^{-\rightarrow}\right)} = -\frac{1}{D(\phi)}\frac{x_B^2}{Q^2}\sum_{n=1}^{2}\boxed{s_n^I}\sin(n\phi)$$
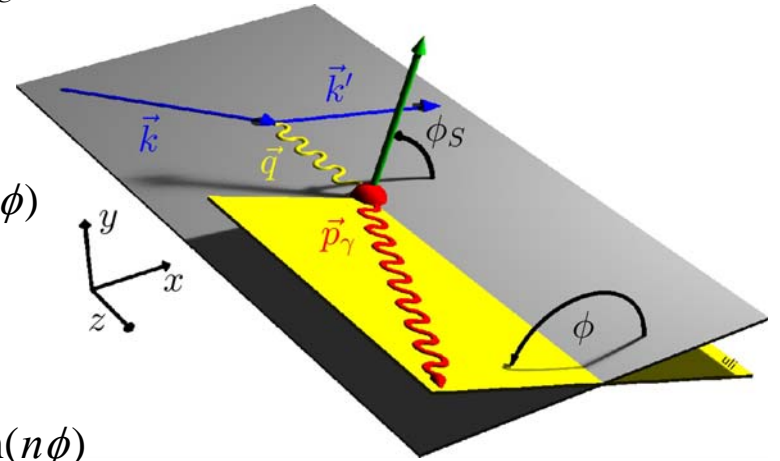
● Charge-averaged beam-helicity asymmetry

$$A_{LU}^{DVCS}(\phi) = \frac{\left(\sigma^{+\rightarrow} - \sigma^{+\leftarrow}\right) - \left(\sigma^{-\leftarrow} - \sigma^{-\rightarrow}\right)}{\left(\sigma^{+\rightarrow} + \sigma^{+\leftarrow}\right) + \left(\sigma^{-\leftarrow} + \sigma^{-\rightarrow}\right)} = \frac{1}{D(\phi)} \cdot \frac{x_B^2 t \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}{Q^2}\boxed{s_1^{DVCS}}\sin(\phi)$$

● Measurements of these beam-helicity asymmetries allow to separate contributions from DVCS and interference term
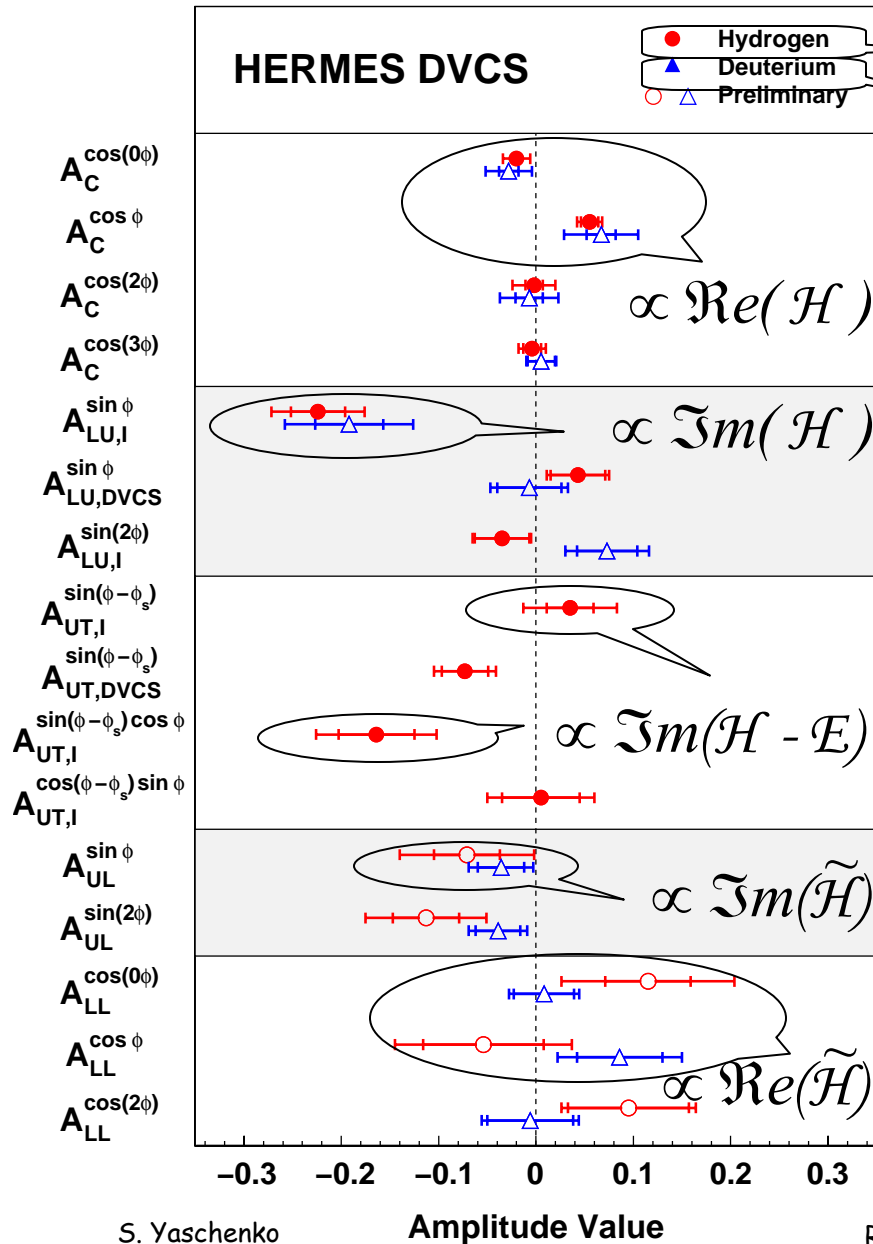
● This separation is impossible in measurements of single-charge beam-helicity asymmetry

$$A_{LU}(\phi) = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

Central analysis topic since the last PRC
## DVCS asymmetries and connections with GPDs

Accepted by JHEP, arXiv:0909.3587 (hep-ex)

Submitted, arXiv: 0911.0095 (hep-ex)

- Beam charge asymmetry
  GPD H

- Beam helicity asymmetry
  GPD H

- Transverse target spin asymmetry
  JHEP 06 (2008) 066, arXiv:0802.2499
  GPD E

- Longitudinal target spin asymmetry
  GPD H̃

- Double spin asymmetry
  GPD H̃

Results on beam-charge and beam-helicity asymmetry amplitudes in DVCS

Accepted for publication in JHEP, *arXiv:0909.3587 (hep-ex)*
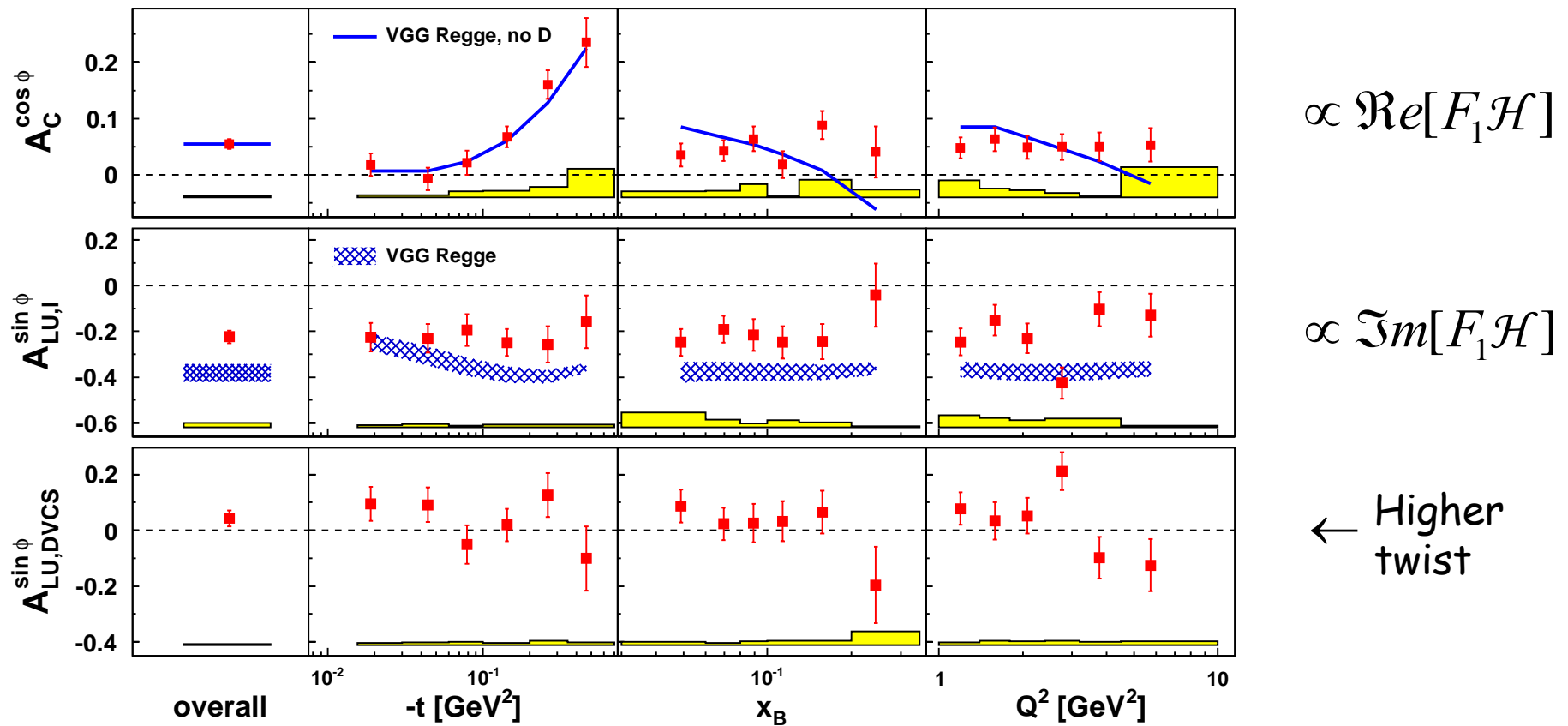
- Comparisons with GPD model, Vanderhaeghen, Guichon, Guidal
  Phys. Rev. D60 (1999) 094017, Prog. Part. Nucl. Phys. 47 (2001) 401

- Resonance fraction from $ep \rightarrow e\Delta^{+}\gamma$ is about 12%

Recoil Detector analysis

- **Technical development**
  - Calibration SSD, SFT, PD - done
  - Detector efficiency - done
  - Particle Identification - done
  - Tracking – done
  - Refinements - possible after input from physics analysis

- **Analysis tools**
  - Kinematic fitting is developed and tested on DVCS Monte Carlo and data, will be applied with modifications for other exclusive processes

- **Physics analysis**
  - Members of the Recoil group moved to physics analysis of DVCS and exclusive meson production processes

- **Recoil Detector publication in preparation**
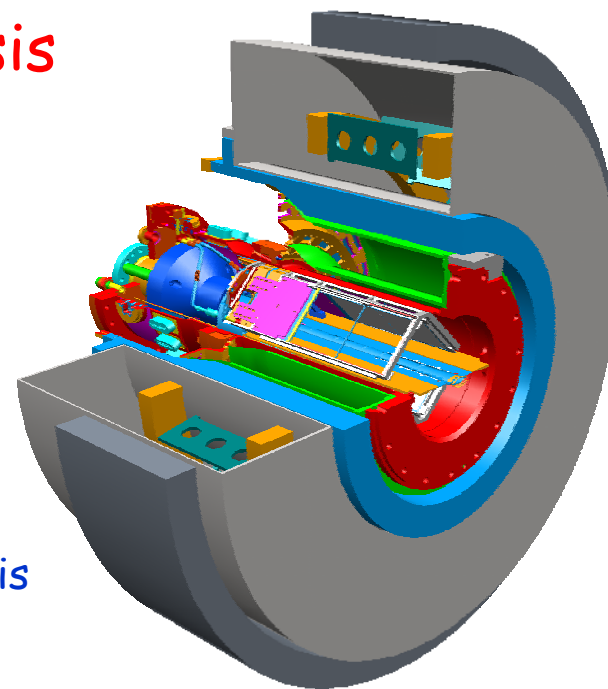
Event selection, uncertainties and corrections before the Recoil Detector installation
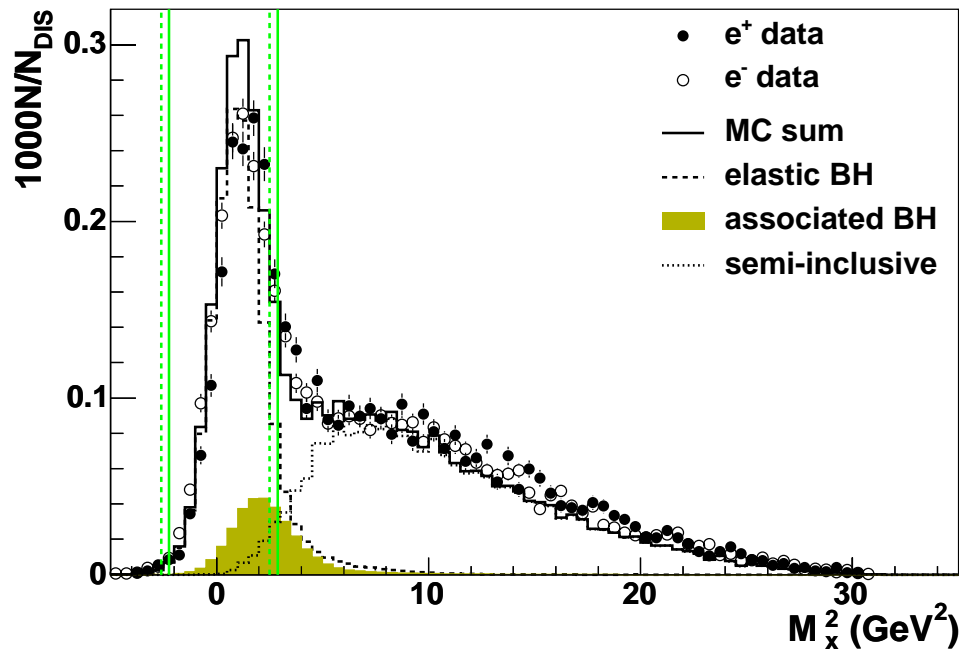
- Scattered electron and photon are detected in the Forward Spectrometer
- Recoil proton is undetected
- Identification by missing mass technique (ep $\rightarrow$ e'γX)
- Semi-inclusive corrected as dilutions for charge dependent asymmetries
- Associated Bethe-Heitler ep $\rightarrow$ e'$\Delta^+\gamma$ ~12% stays part of the signal

DVCS event selection with the Recoil detector using kinematic fitting

Monte-Carlo

M_X^2 [GeV^2/c^4]

Data

M_X^2 [GeV^2/c^4]
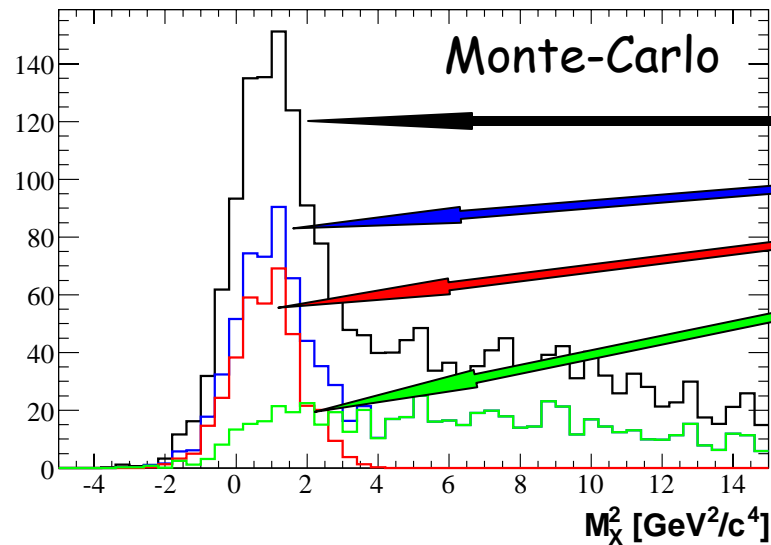
- ● **Missing mass for Monte Carlo**
  - No requirement for Recoil
  - Positively charged Recoil track
  - Kinematic fit probability > 1%
  - Kinematic fit probability < 1%

- ● **Fit works well for Monte-Carlo**
  - After chi-square cut associated Bethe-Heitler and semi-inclusive background is suppressed to negligible level

- ● **For data optimization of measurement errors of kinematic parameters is necessary**
  - Preliminary optimization done
 - Systematic studies are in progress
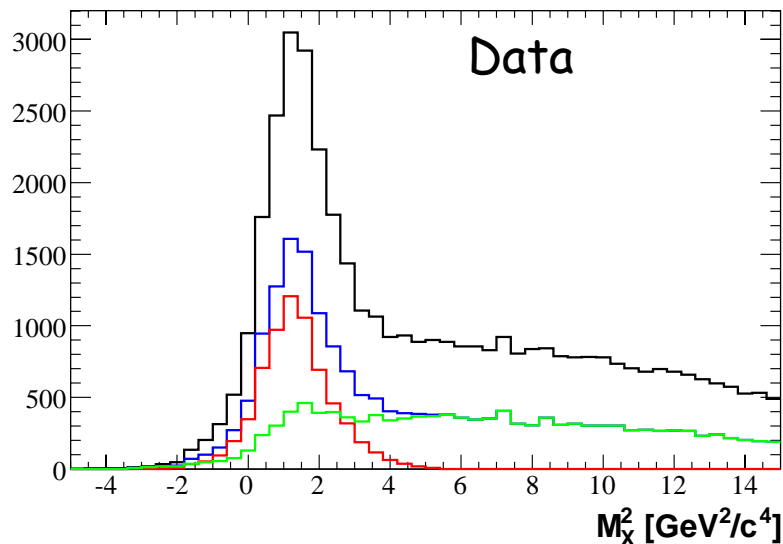
First signal of exclusive π^0 production at HERMES

- Exclusive π^0 process can provide access to chiral-even and chiral-odd GPDs
- Impossible without recoil proton detection
- After a cut on the difference between transverse momentum and φ angle of missing particle and measured Recoil proton is applied, clear signal is observed

Recoil proton required
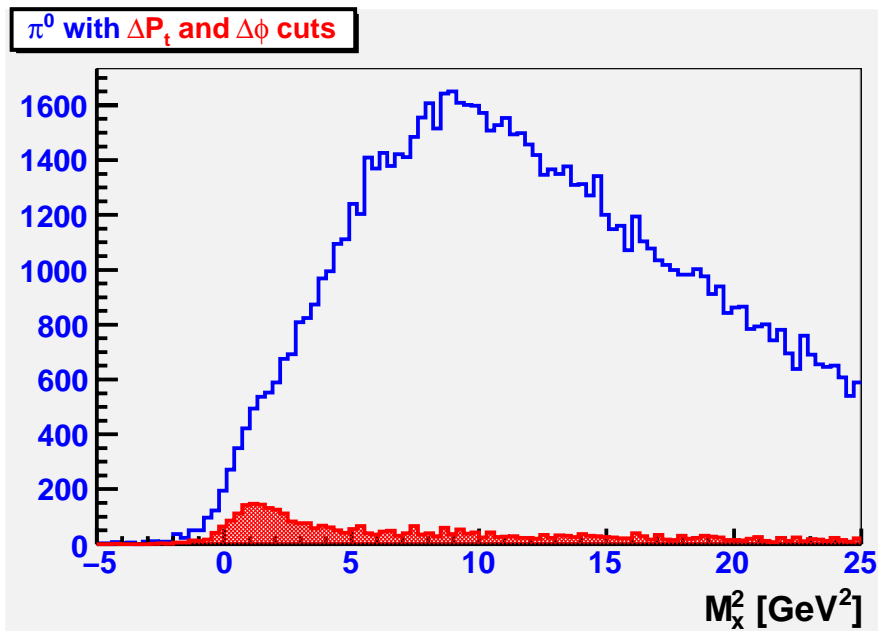
Cuts on momentum and angle difference applied

π^0 with ΔP_t and $\Delta\phi$ cuts

π^0 with ΔP_t and $\Delta\phi$ cuts

M_x^2 [GeV^2]

M_x^2 [GeV^2]
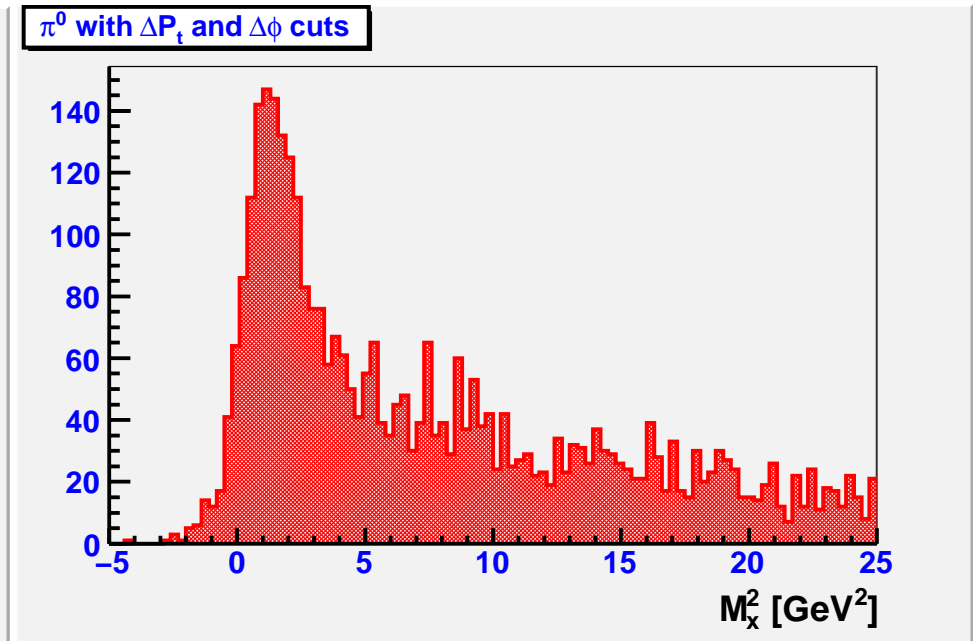
Summary

- ## Since the last PRC meeting
  - Four papers published
  - Five papers submitted
  - Four physics results released and presented at conferences

- ## Many results are expected to be finalized soon

- ## Recoil Detector physics analysis underway
  - Transition from technical development stage to physics analysis finished
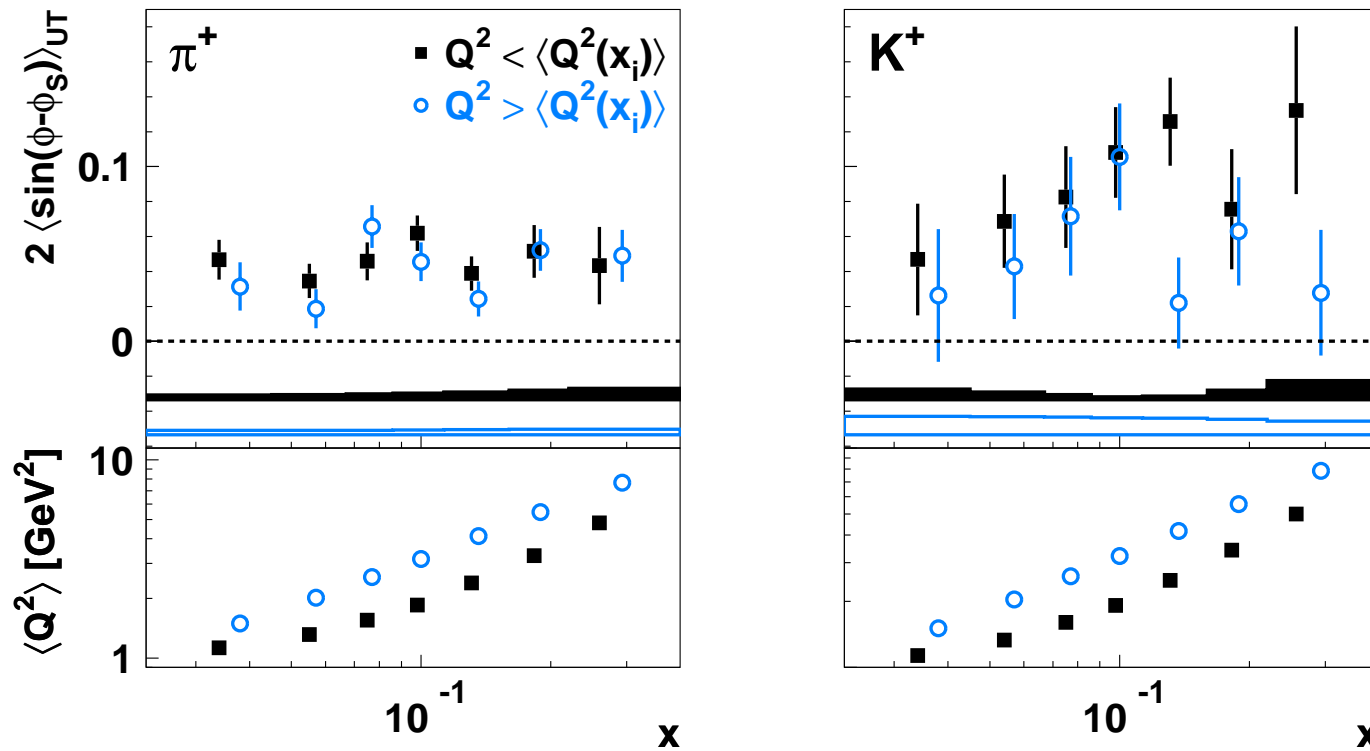 - Publication about the detector in preparation

Backup slides

Sivers amplitudes for π⁺ and K⁺ for different ranges in Q²
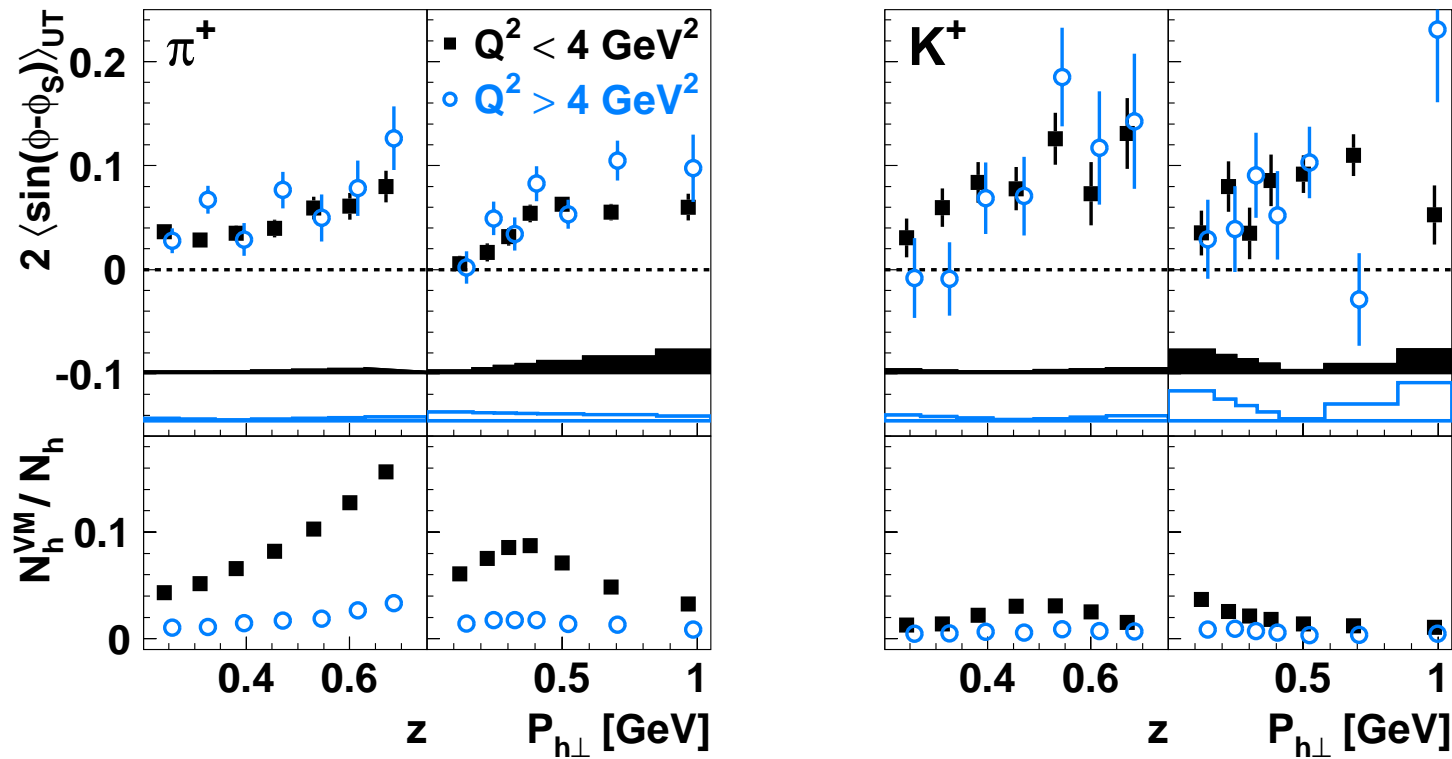
- Examine the influence of exclusive vector-meson decay and other possible $1/Q^2$ suppressed contributions
- No visible influence on the asymmetries

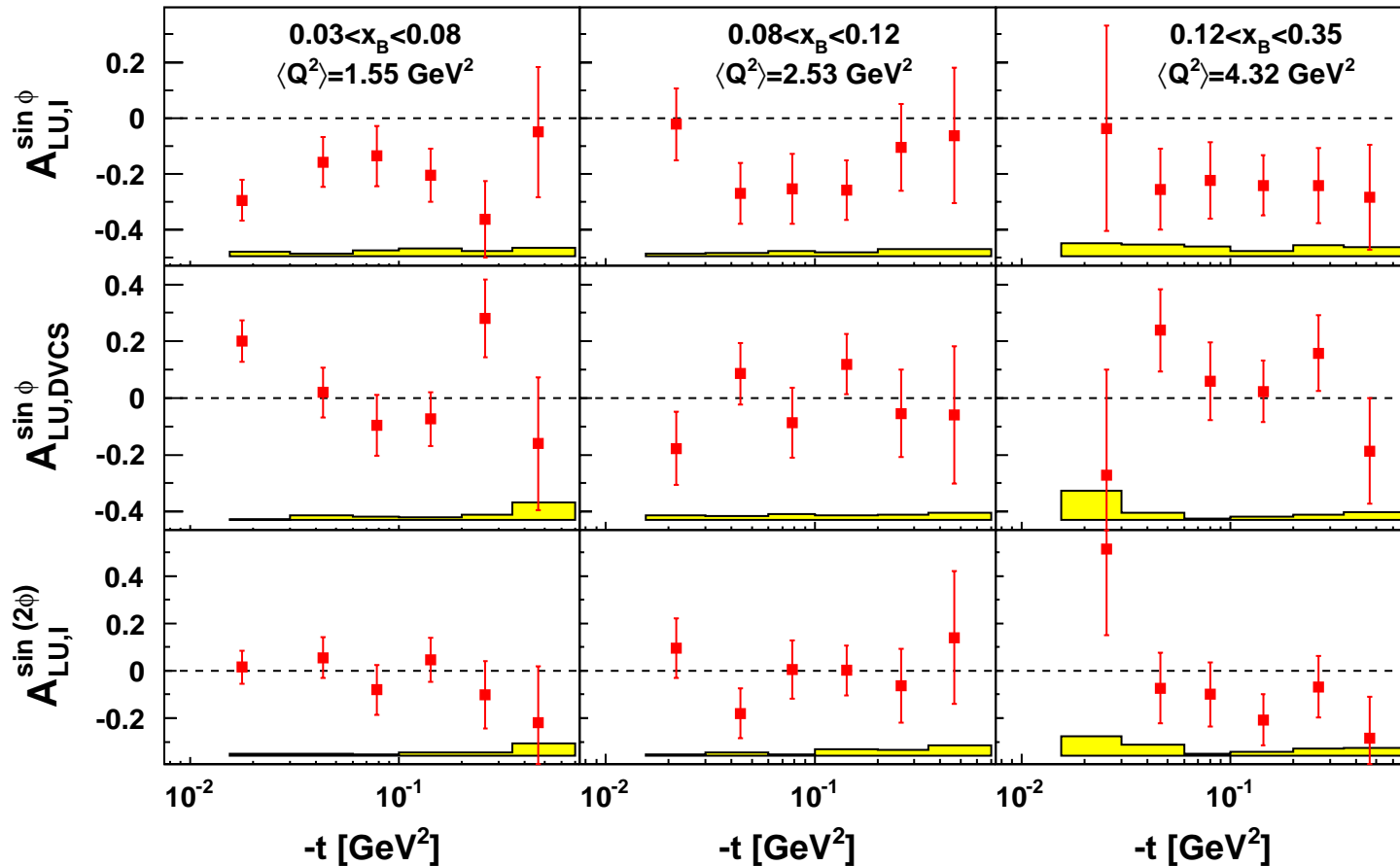# Sivers amplitudes for π^+ and K^+ for different ranges in Q^2

- No significant change of asymmetries for Q^2 ranges change by a factor of 1.7
- Fully consistent for two Q^2 regions for π^+
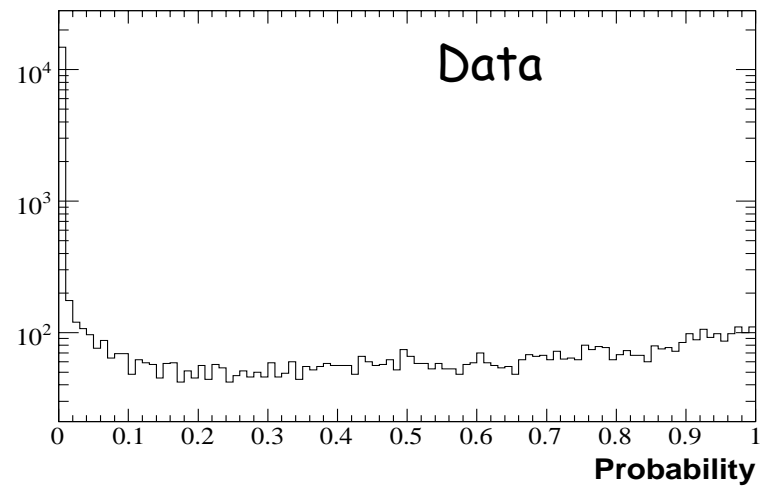- Hint of systematically smaller K^+ asymmetries in the large Q^2 region
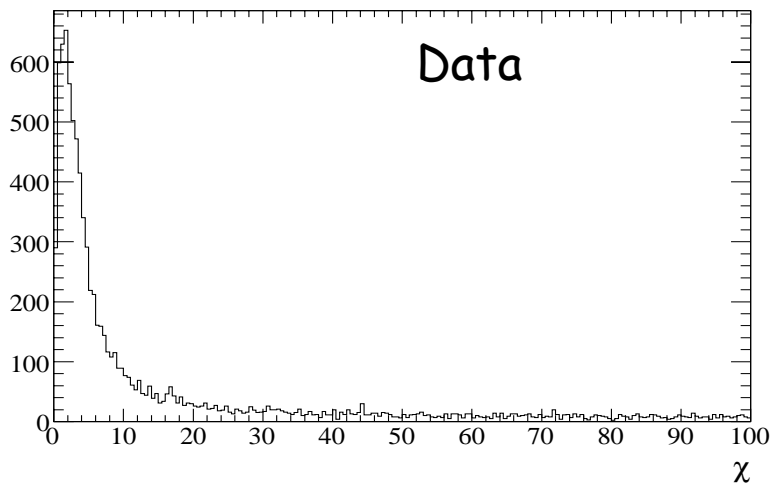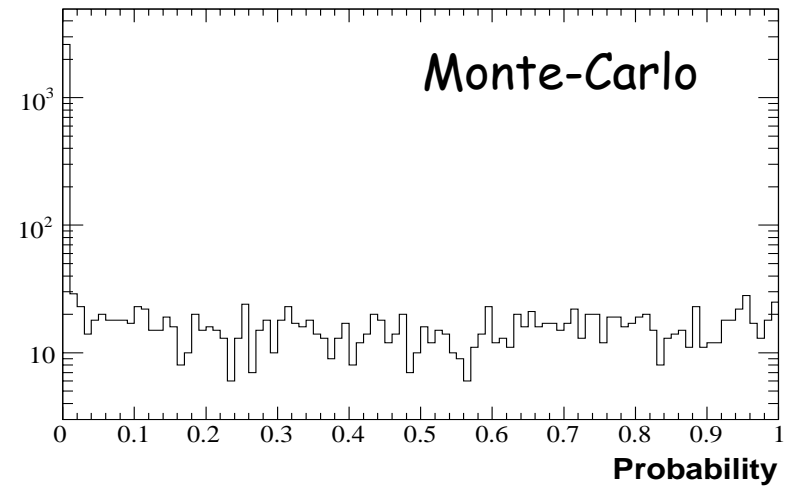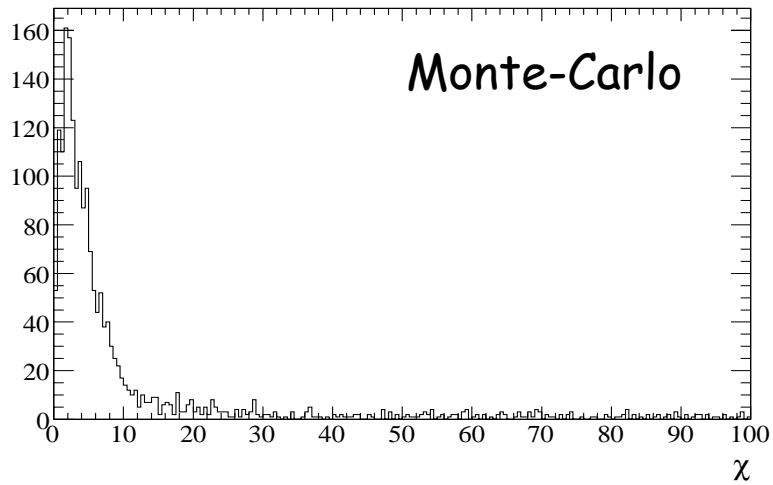
Beam charge asymmetry amplitudes in DVCS
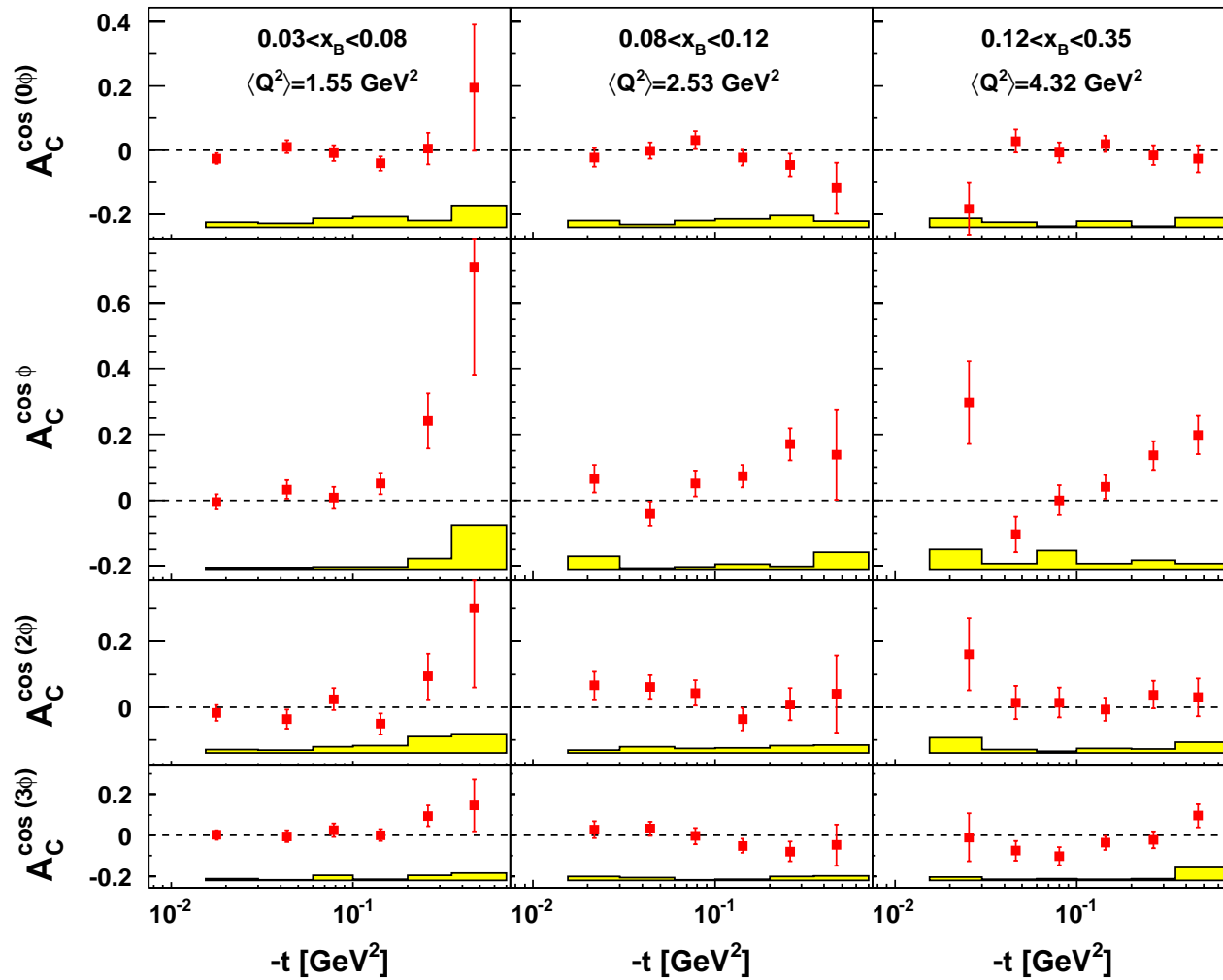
Beam helicity asymmetry amplitudes in DVCS

Kinematic fitting for DVCS

Released results since the last PRC meeting

- Direct extraction of helicity amplitude ratios in exclusive ρ^0 electroproduction

- Study of A_T, A_2 and g_2

- The other (than Sivers and Collins) amplitudes in the Fourier decomposition of the transverse single-spin asymmetry on transversely polarized protons

- Exclusive leptoproduction of real photons on a longitudinally-polarised hydrogen target