Overview of recent HERMES results

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DESY Zeuthen

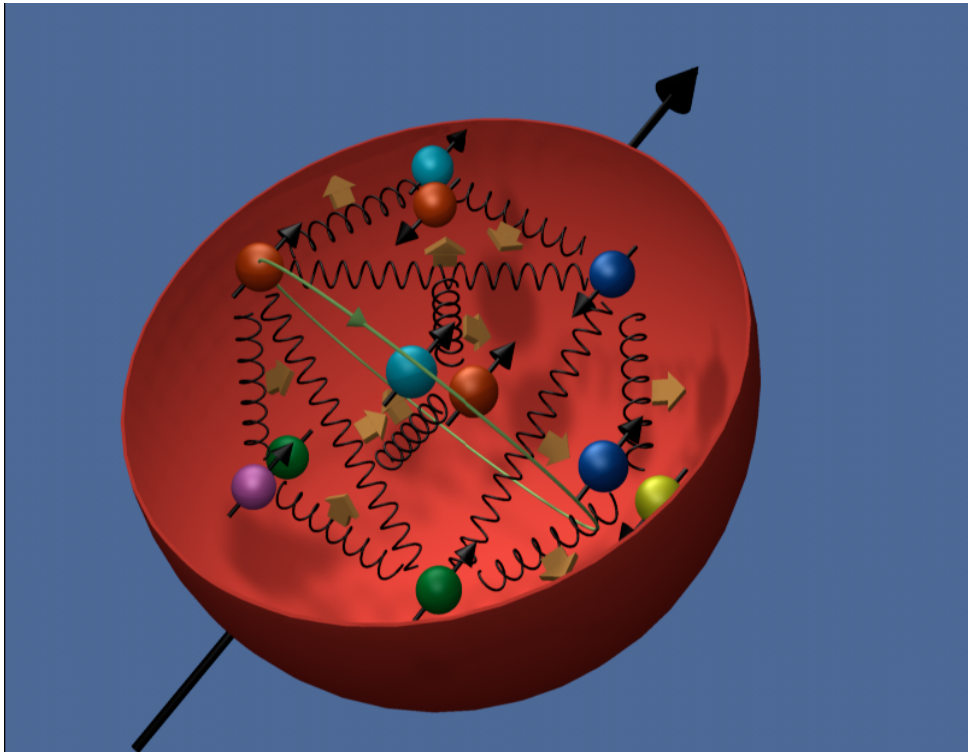
on behalf of the  collaboration

HELMHOLTZ ASSOCIATION

SPIN2010, Forschungszentrum Jülich, 1.10.2010

DESY

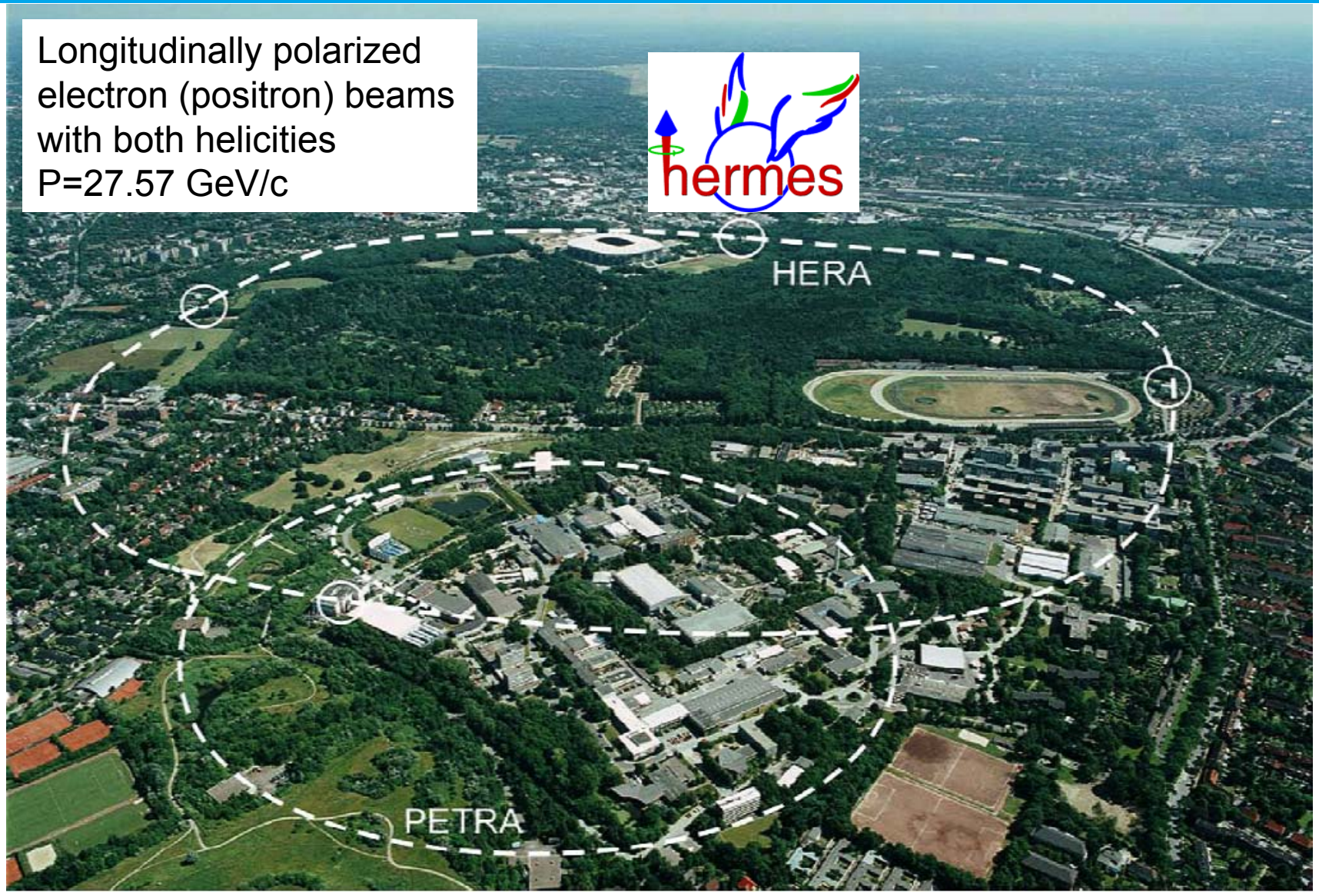
Spin structure of the nucleon at HERMES



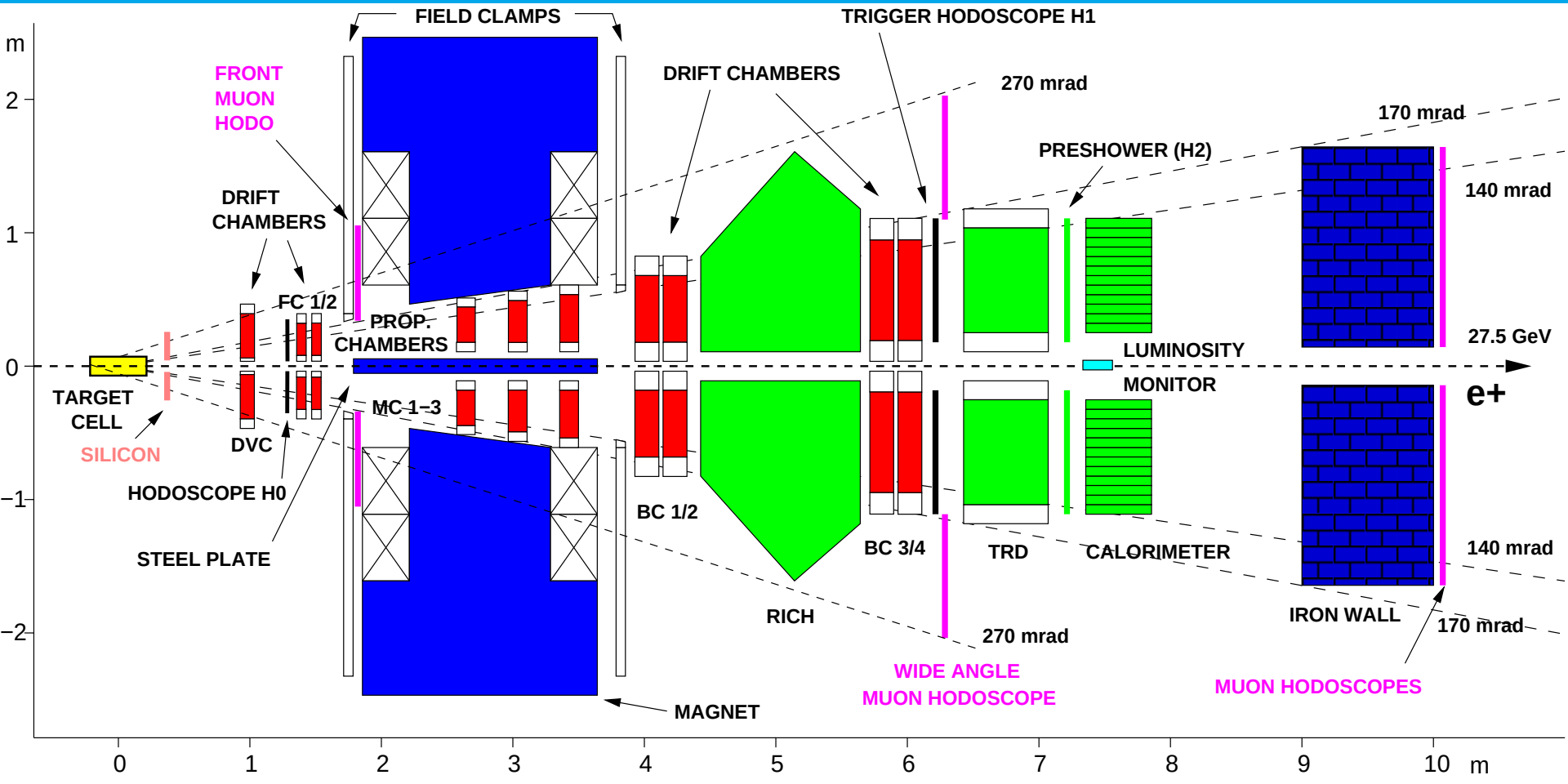
- Longitudinal spin/momentum structure, hadronization
- Transverse spin/momentum structure → transversity, TMDs
- DVCS, exclusive meson production → GPDs, “nucleon tomography”
- Strange-baryon production

HERA at DESY

Longitudinally polarized electron (positron) beams with both helicities
P=27.57 GeV/c



The HERMES spectrometer



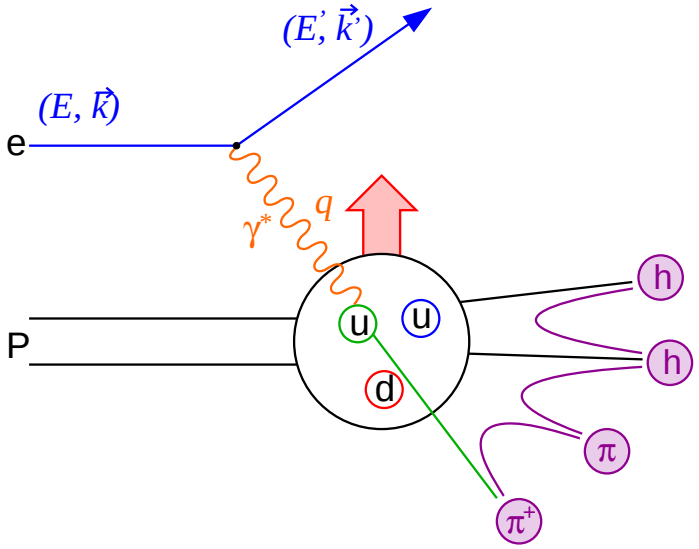
Internal gas targets:

- Longitudinally polarized *H, D*
- Transversely polarized *H*
- Unpolarized *H, D, ^{4}He, N, Ne, Kr, Xe*

Forward magnetic spectrometer

- Momentum resolution *1-2%*
- Particle identification:
  RICH, TRD, H2, calorimeter

Distribution and fragmentation functions in DIS

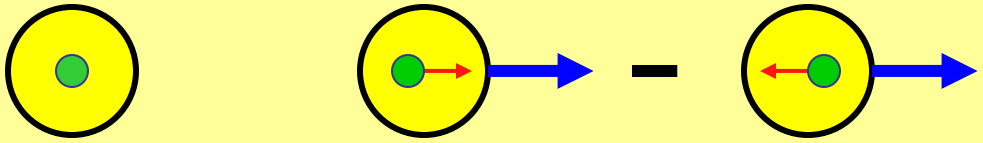


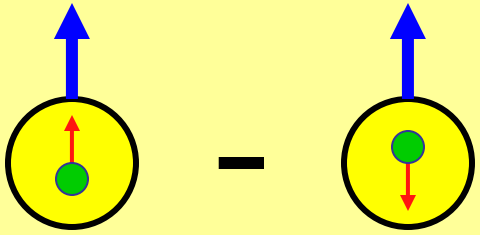
$$\sigma^{ep\to ehX} \propto \sum_q DF(x) \otimes \sigma^{eq\to eq} \otimes FF^{q\to h}(z)$$

DF: Distribution of quarks in the nucleon

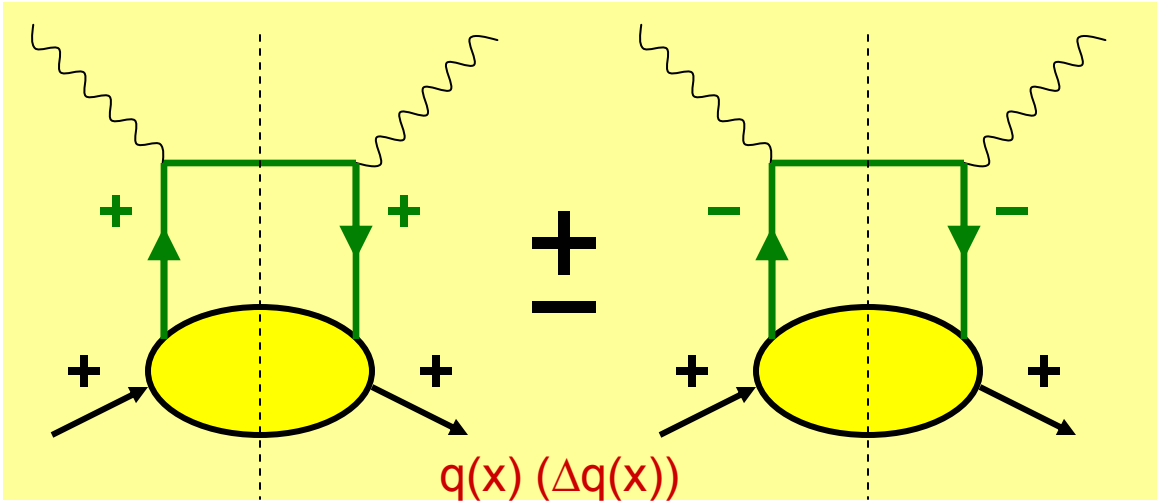
FF: Fragmentation of (struck) quark into hadronic final state

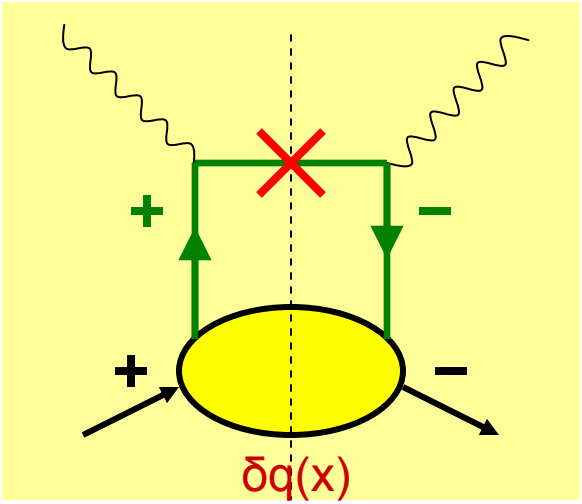
Momentum distribution	Helicity distribution	Transversity distribution
$q(x)$ $[f_1^q(x)]$	$\Delta q(x)$ $[g_1^q(x)]$	$\delta q(x)$ $[h_1^q(x)]$





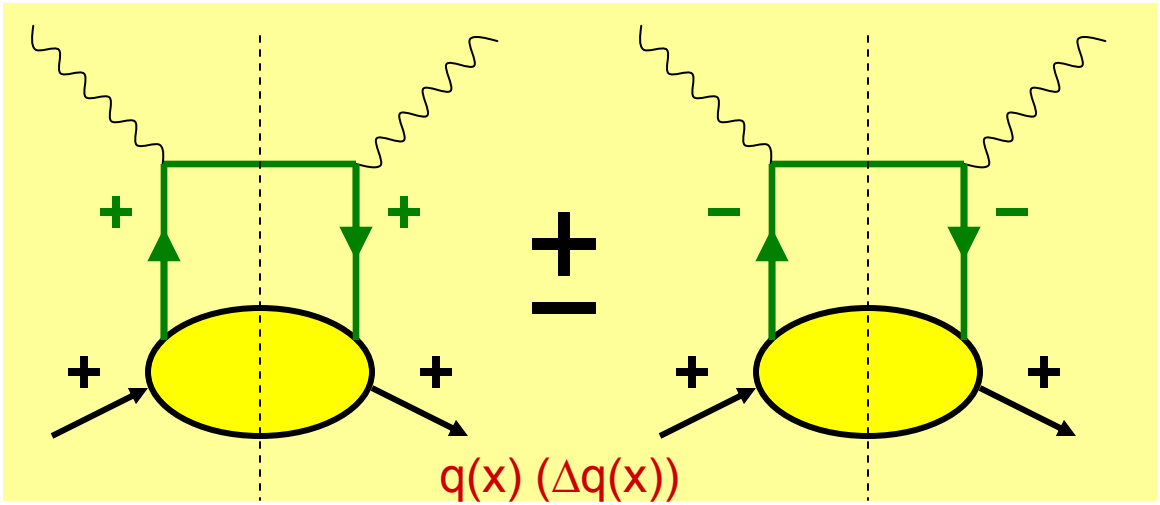
Transversity

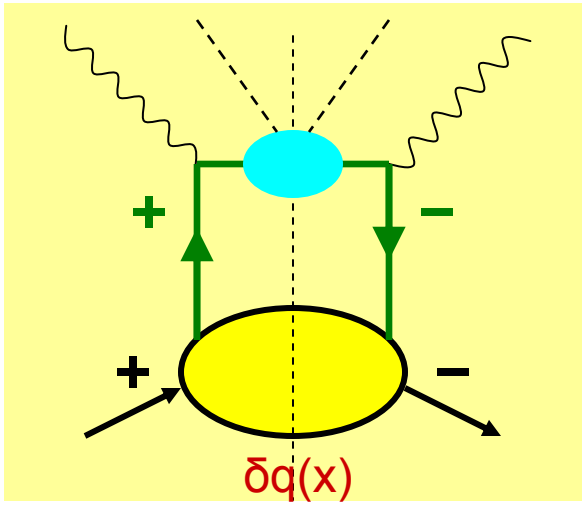




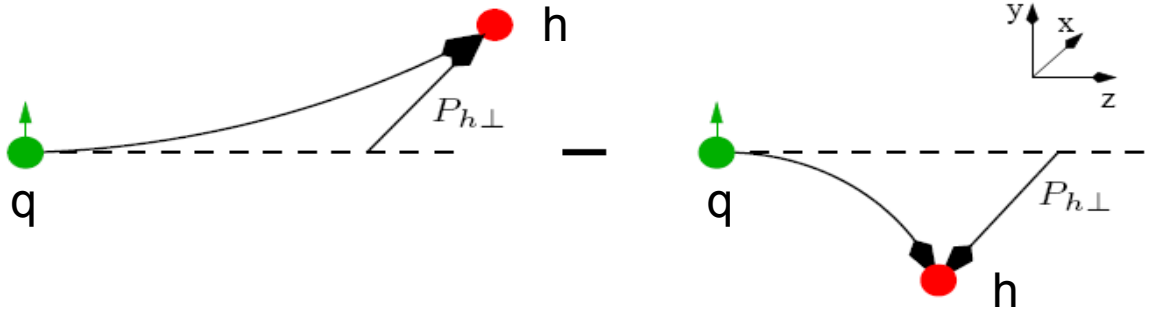
- Chiral-odd: involves quark helicity flip
- Cannot be measured in inclusive DIS
- Needs another chiral-odd partner

and Collins fragmentation function





- Collins fragmentation function $H_1^{\perp}$
- Correlation between transverse polarization of fragmenting quark and the transverse momentum $P_{h\perp}$ of the produced (unpolarized) hadron



Single spin asymmetries in semi-inclusive deep inelastic scattering

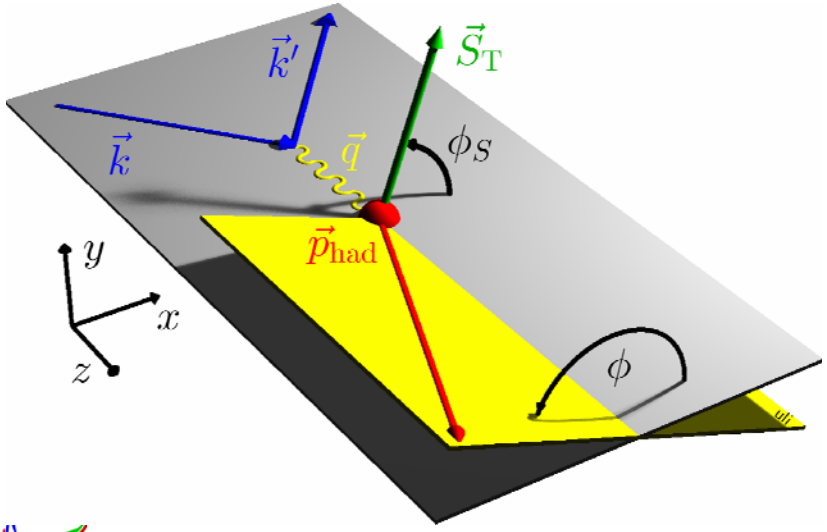
$$A_{UT}(\phi,\phi_S) \approx \boxed{2\langle \sin(\phi+\phi_S)\rangle^{h}_{UT}} \sin(\phi+\phi_S) + 2\langle \sin(\phi-\phi_S)\rangle^{h}_{UT} \sin(\phi-\phi_S) + \cdots$$

Collins moment

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

Transversity DF

Collins FF



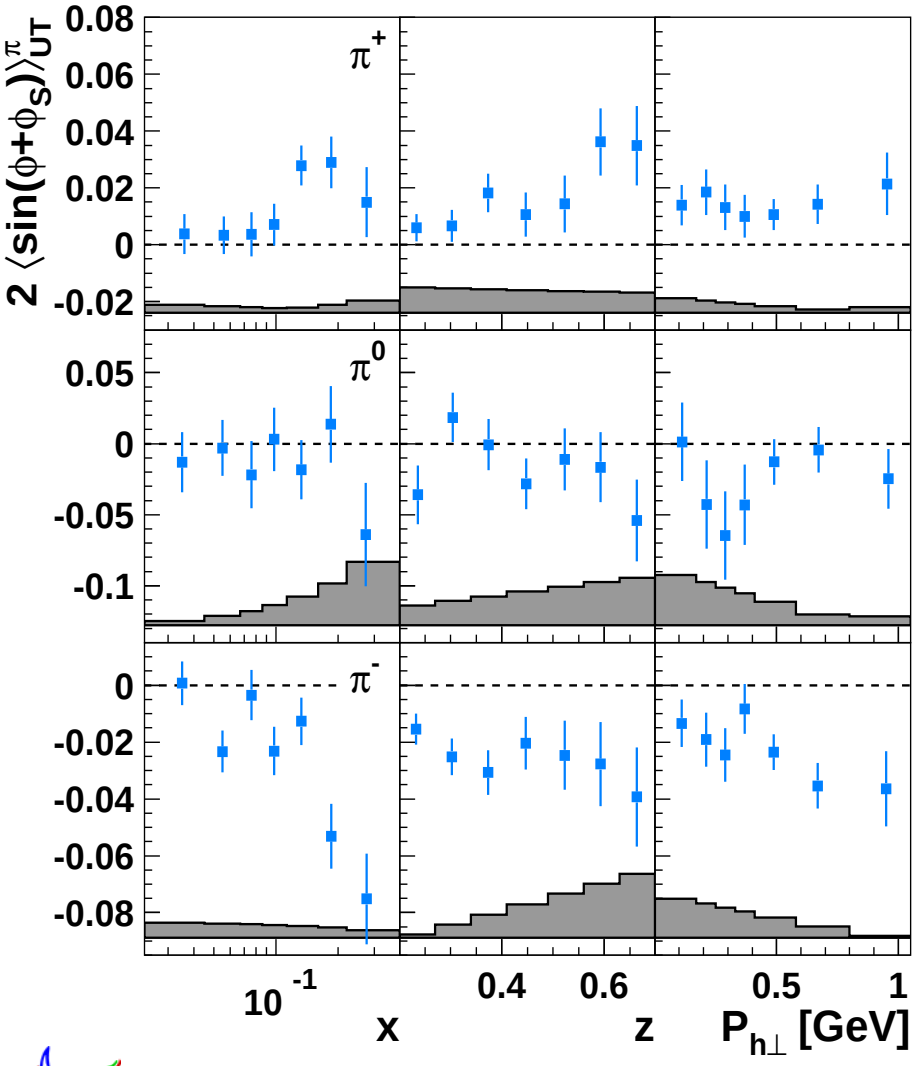
$$A_{UT}(\phi,\phi_S,\ldots) = \frac{1}{S_\perp}\frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

ϕ - angle between the lepton scattering and hadron production planes

ϕ_S -angle between the target spin direction and the lepton scattering plane

Collins results (pions)

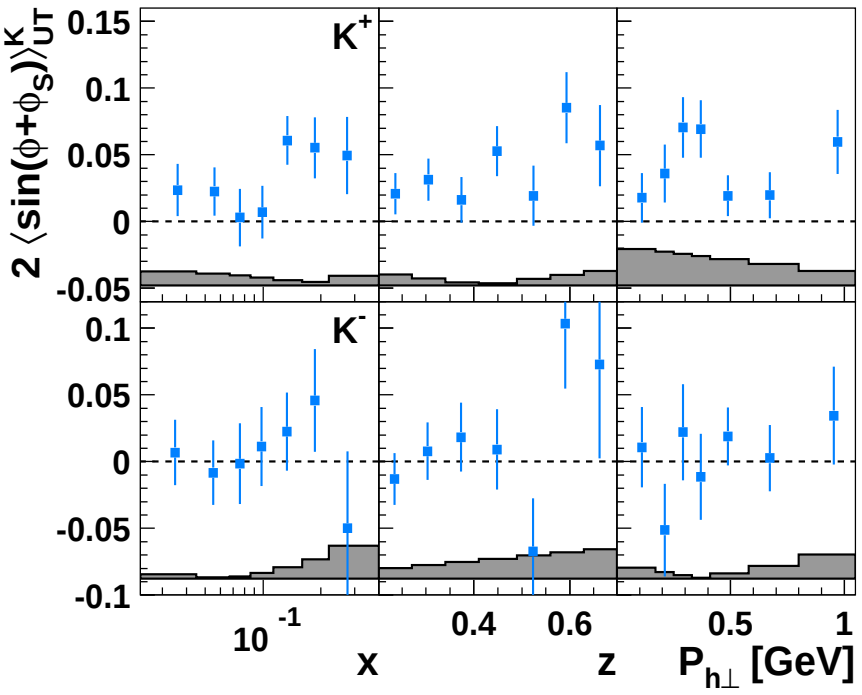
Phys. Lett. B 693 (2010) 11-16



- Positive amplitude for π^+
- Large negative amplitude for π^-
- Non-zero transversity and Collins function!
- Similar magnitude and opposite sign for favored ($u \rightarrow \pi^+$) and unfavored ($u \rightarrow \pi^-$) FF
- Isospin symmetry in π fragmentation fulfilled
- Information from another process on Collins FF (BELLE) allows extraction of δq

Collins results (Kaons)

Phys. Lett. B 693 (2010) 11-16



- Collins amplitudes for K^+ larger than for π^+
- No significant non-zero Collins amplitudes for K^-
- Collins fragmentation function for Kaons unknown
- Possible non negligible role of the sea quarks

Details: M. Diefenthaler

Single spin asymmetries in semi-inclusive deep inelastic scattering

$$A_{UT}(\phi,\phi_S) \approx 2\langle \sin(\phi+\phi_S)\rangle^{h}_{UT} \sin(\phi+\phi_S) + 2\langle \sin(\phi-\phi_S)\rangle^{h}_{UT} \sin(\phi-\phi_S) + \cdots$$

Collins moment

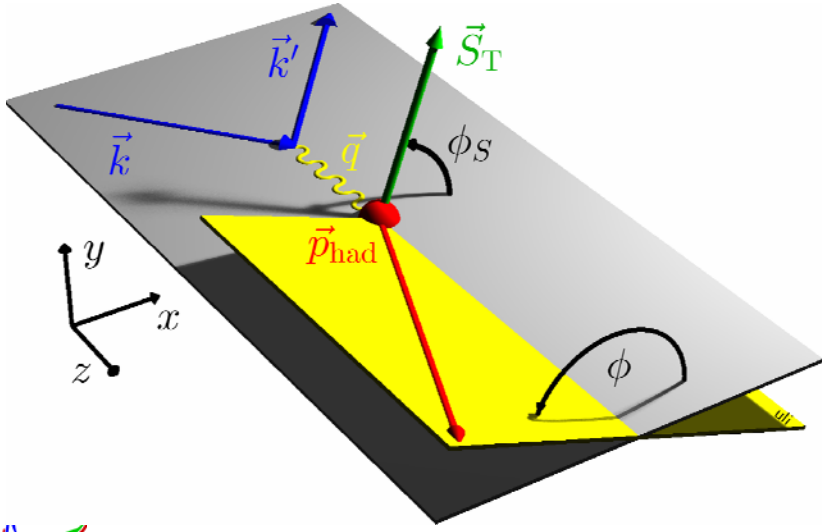
$$\propto h_1(x) \otimes H_1^{\perp q}(z)$$

Sivers moment

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

Sivers DF

Unpolarized FF

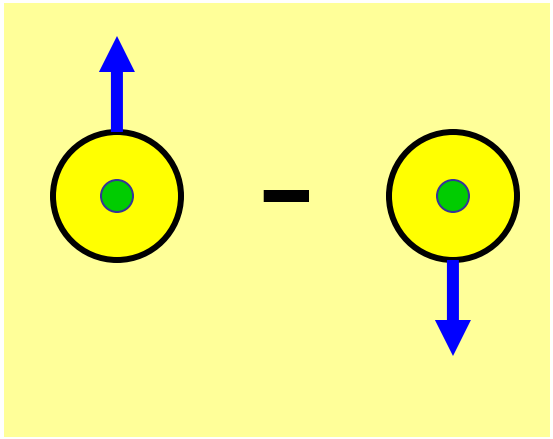


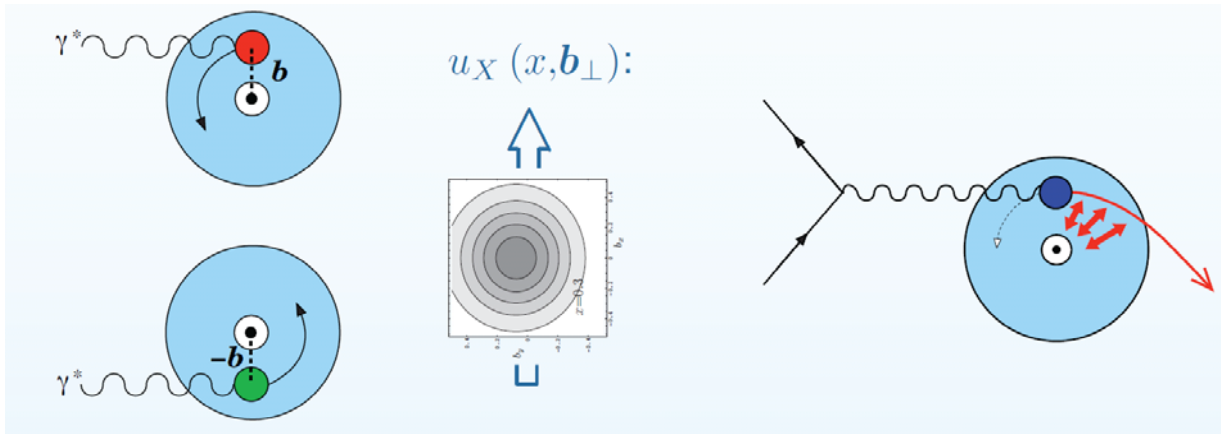
$$A_{UT}(\phi,\phi_S,\ldots) = \frac{1}{S_\perp}\frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

ϕ - angle between the lepton scattering and hadron production planes

ϕ_S -angle between the target spin direction and the lepton scattering plane

Sivers distribution function

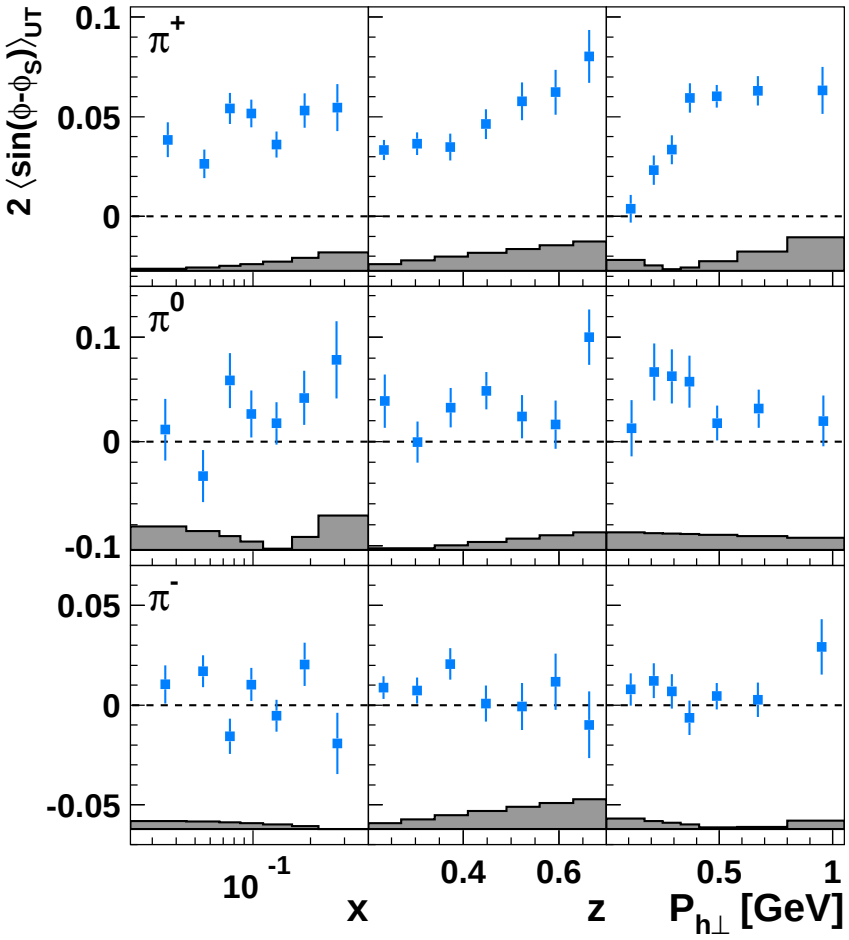


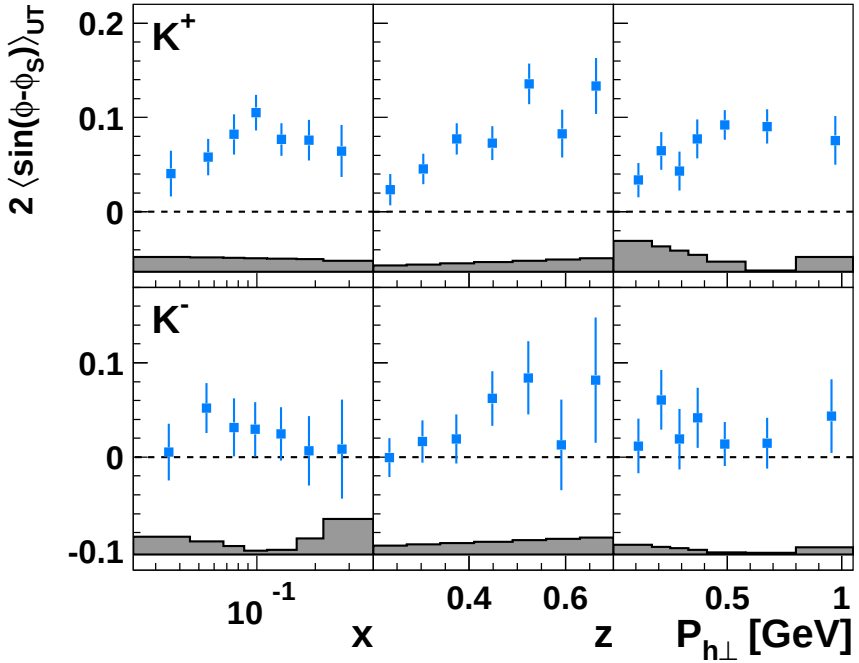


- Chiral–even and naive T–odd transverse momentum dependent function
- Allowed due to the final state interaction
- Correlation between intrinsic quark transverse momentum and transverse spin of the nucleon
- Non-zero Sivers DF requires non-vanishing orbital angular momentum of quarks in the nucleon

Sivers asymmetries for pions and Kaons

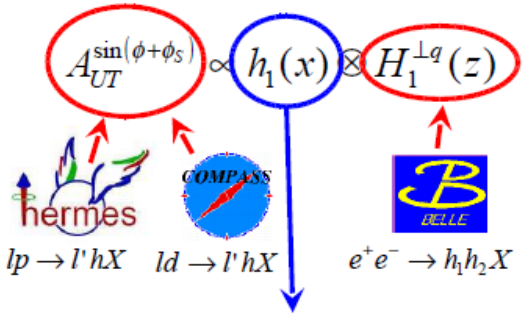
Phys. Rev. Lett. 103 (2009) 152002

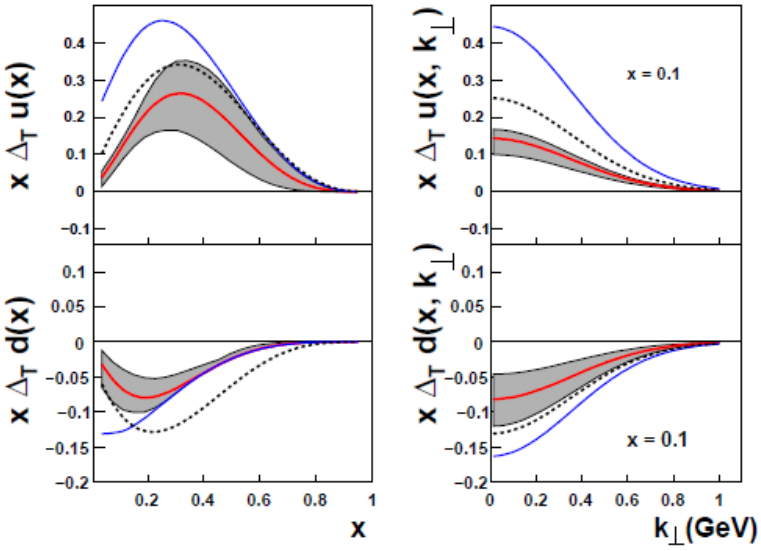




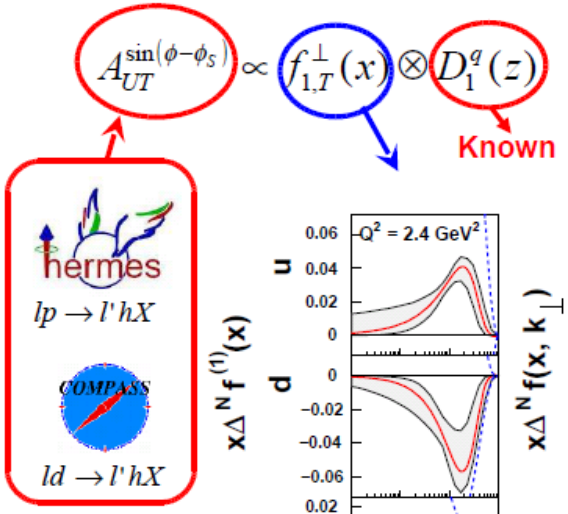
- Significantly positive for π^+ and K^+
  - Non-zero orbital angular momentum of quarks!
  - Suggests large and negative Sivers function for u-quarks
- Consistent with zero for π^-
  - Requires cancellation effects, opposite sign for u- and d-quark Sivers functions

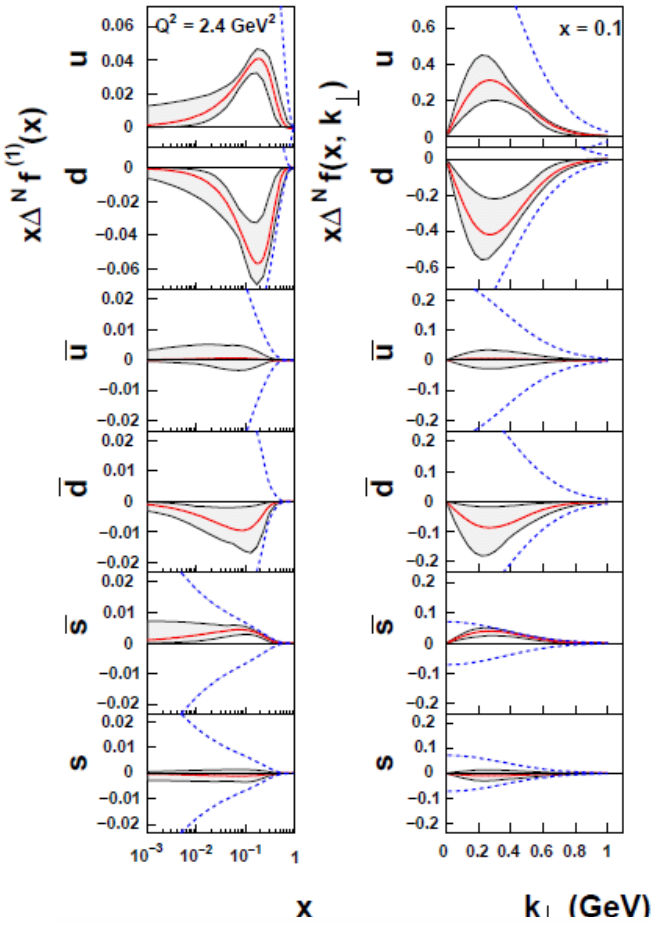
Extraction of transversity and Sivers function





-Anselmino et al. Phys. Rev. D 75 (2007)-

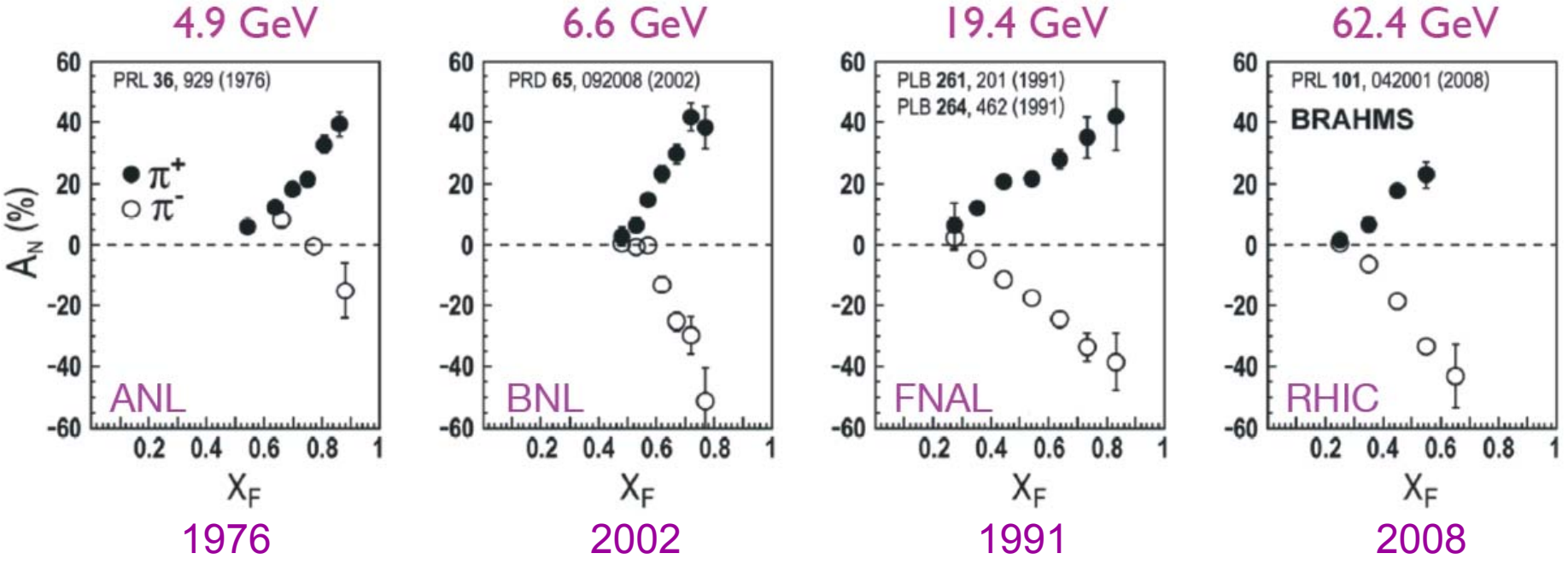




-Anselmino et al. Eur.Phys.J.A39 (2009)-

Transverse single-spin asymmetry in inclusive hadron production in pp collisions

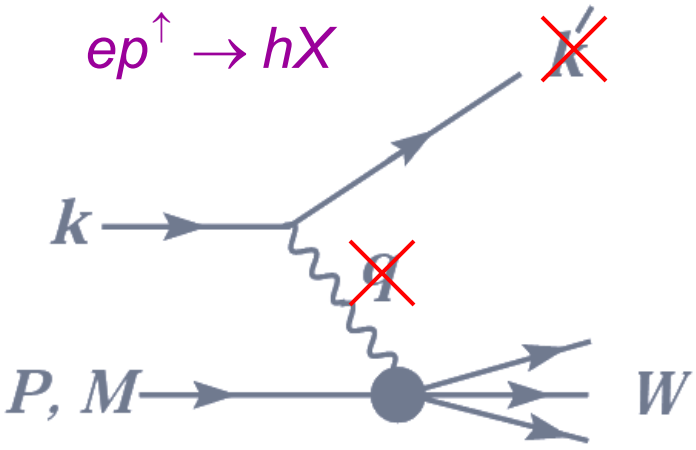
Reminder: $p^{\uparrow} p \to \pi(K) X$



- Large A_N in $p^{\uparrow} p \to \pi(K) X$
- Sivers, Collins, higher twist?

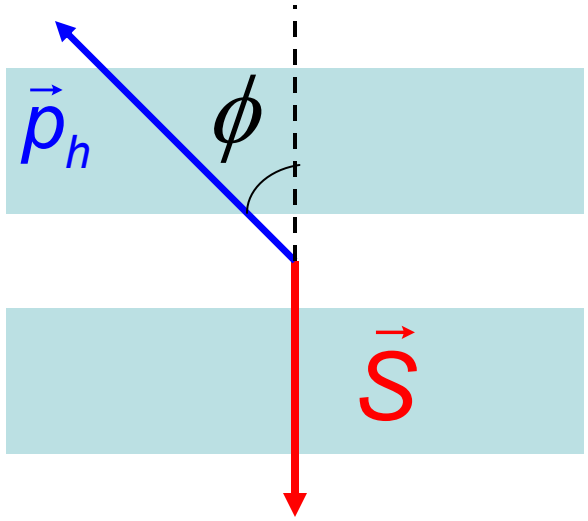
Transverse single-spin asymmetry in inclusive hadron production at HERMES

- First measurement in ep scattering
- High statistics (100 Mil hadrons)
- Inclusive measurements, only hadrons are detected → quasi-real photoproduction



$$x_F = 2p_L / \sqrt{s}$$
$$p_T = p\cos\theta$$

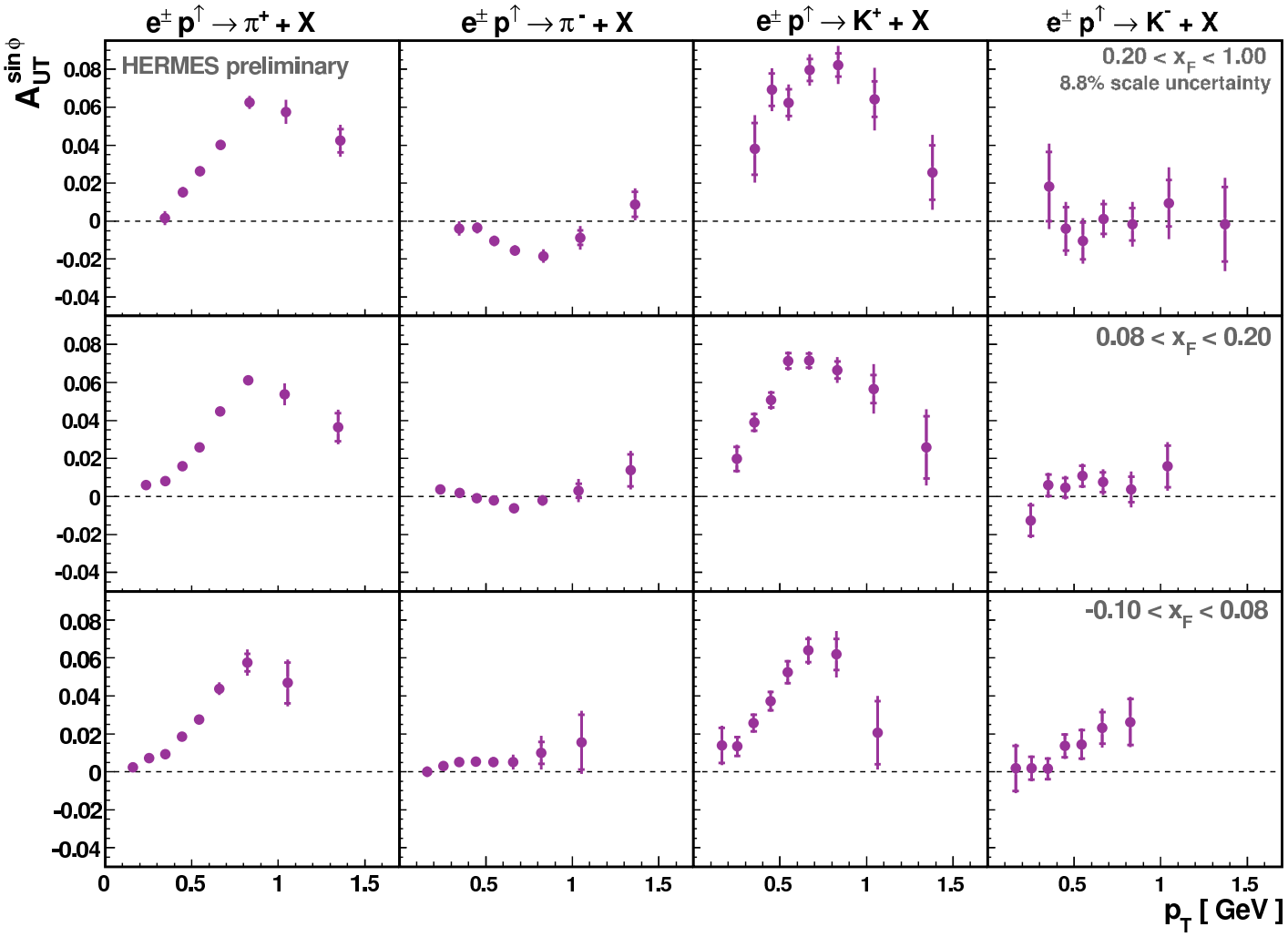
Front view of HERMES



Target spin vector

- Measure $A_{UT} = \dfrac{N_U - N_D}{N_U + N_D}$, acceptance effects cancel (target spin flip every 90s)
- Extract amplitude $A_{UT}^{\sin\phi}$ of asymmetry $A_{UT}(p_T, x_F, \phi) \approx A_{UT}^{\sin\phi}(p_T, x_F)\sin\phi$

Results on inclusive hadron TSA



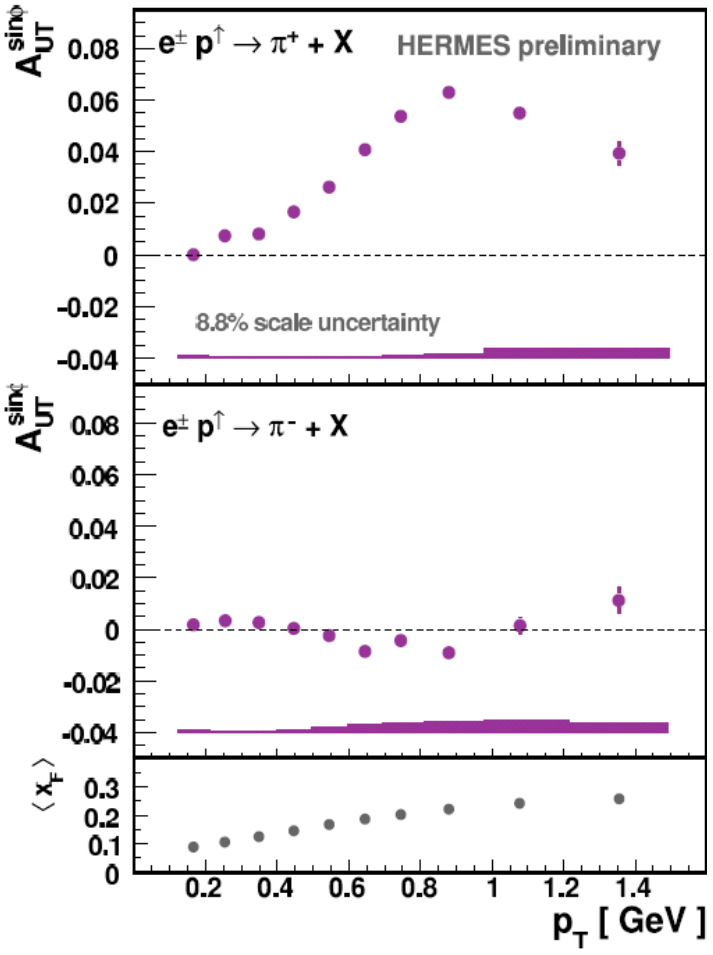
New

Details: K. Rith

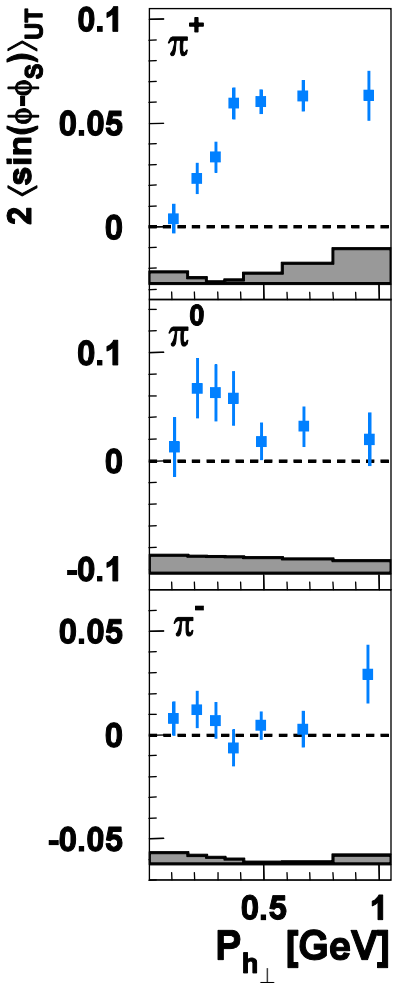
- π^+, K^+ : rise at low p_T, drop at high p_T
- π^- : sign change, K^- : positive for low x_F

Results on inclusive hadron TSA

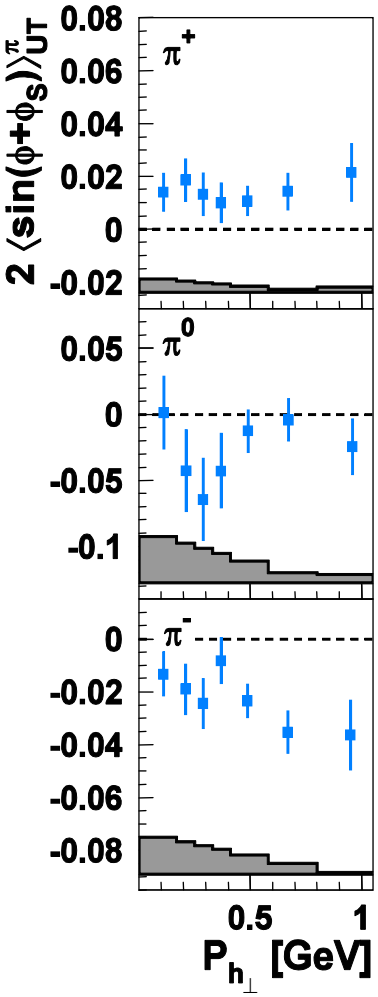
Inclusive hadrons



Sivers



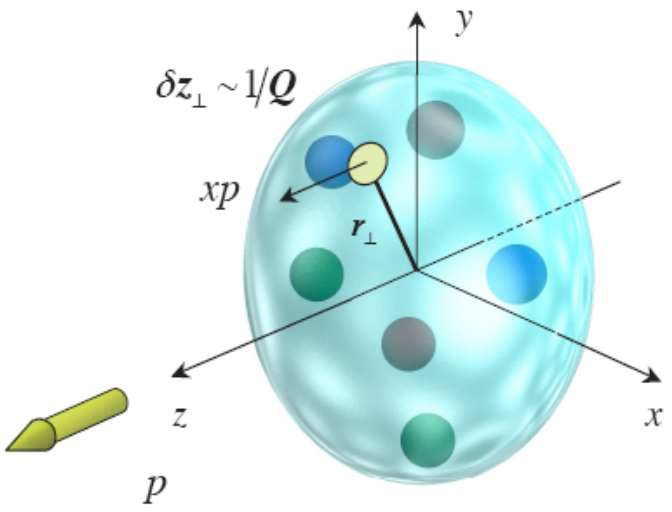
Collins

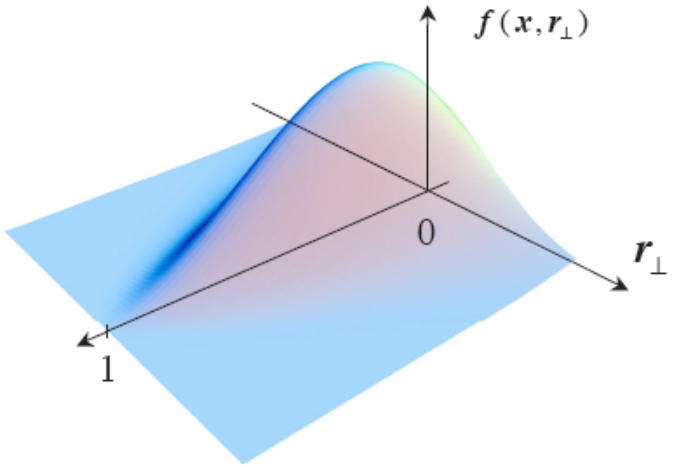


- A_N resembles Sivers effect as predicted

M. Anselmino et al., PRD 81(2010) 034007

Generalized Parton Distributions (GPDs)



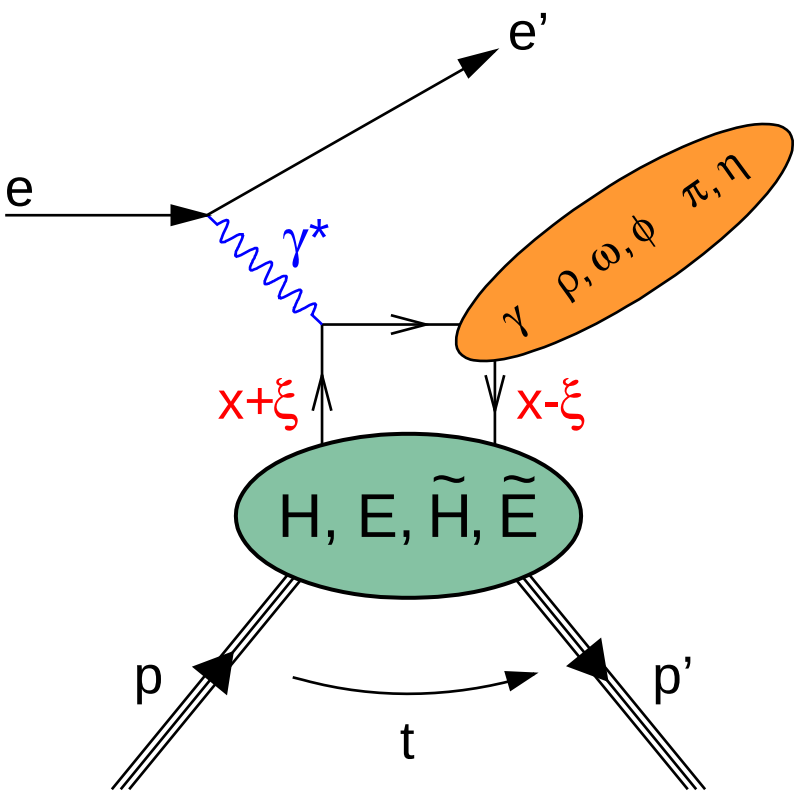


- Include Form Factors and Parton Distribution Functions as moments and forward limits
- Multidimensional description of nucleon structure
- Access to the quark total angular momentum via Ji relation

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

X. Ji, Phys. Rev. Lett. 78 (1997) 610

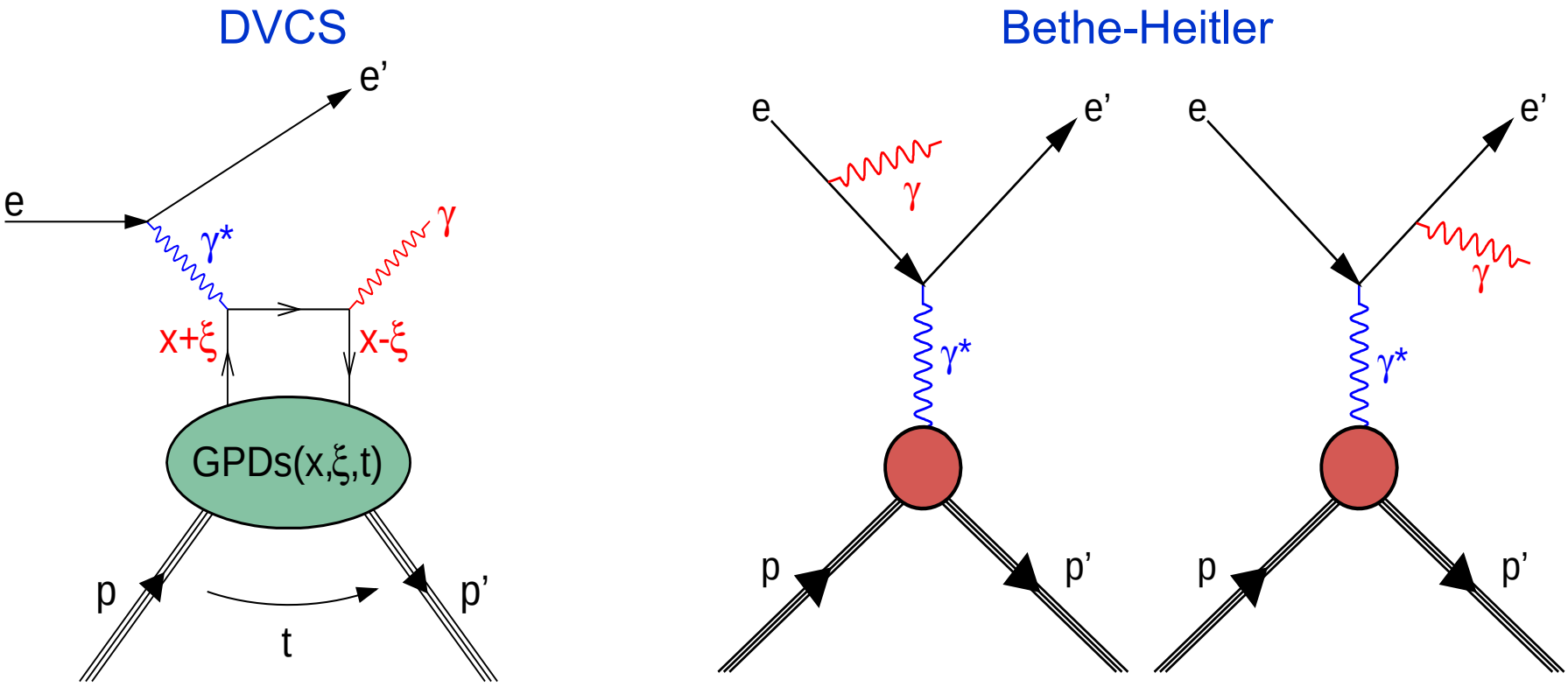
Access to GPDs via exclusive processes



- Sensitivity of different final states to different GPDs
- For spin-1/2 target 4 chiral-even leading-twist quark GPDs: $H, E, \tilde{H}, \tilde{E}$
- $H, \tilde{H}$ conserve nucleon helicity, $E, \tilde{E}$ involve nucleon helicity flip
- DVCS (γ) → $H, E, \tilde{H}, \tilde{E}$
- Vector mesons (ρ, ω, ϕ) → H, E
- Pseudoscalar mesons (π, η) → $\tilde{H}, \tilde{E}$

Details on exclusive mesons:
B. Marianski, E. Avetisyan

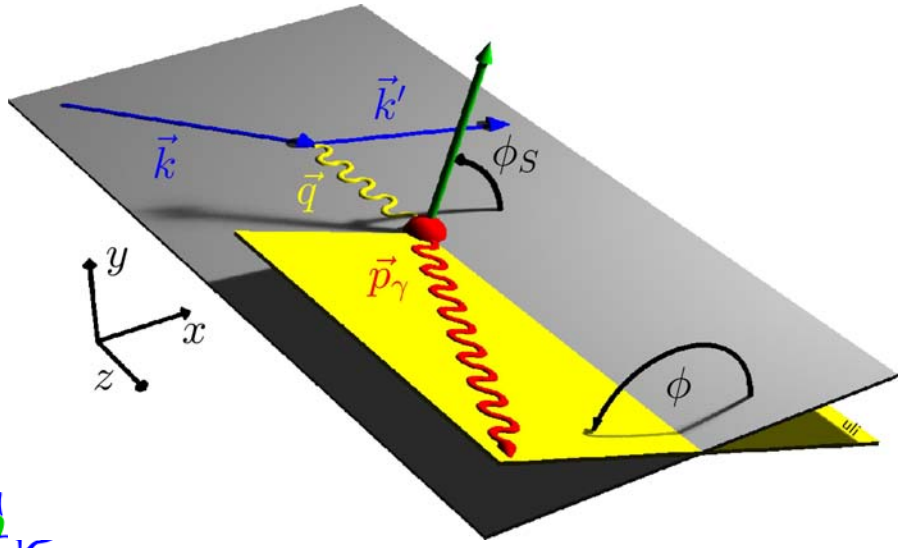
Deeply virtual Compton scattering (DVCS)



- 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

DVCS at HERMES

- Unique measurements of amplitudes in DVCS at HERMES
  - Both beam charges
  - Longitudinal beam polarization (both helicities)
  - Unpolarized H, D and nuclear targets
  - Longitudinally polarized H and D targets
  - Transversely polarized H target
  - Recoil Detector



ϕ - angle between the lepton scattering and real photon production planes

ϕ_S - angle between the target spin direction and the lepton scattering plane

Azimuthal asymmetries in DVCS

- Cross section

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

- Beam-charge asymmetry

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

- Charge-difference beam-helicity asymmetry

$$A_{LU}^{I}(\phi)=\frac{\left(\sigma^{+\rightarrow}-\sigma^{+\leftarrow}\right)-\left(\sigma^{-\rightarrow}-\sigma^{-\leftarrow}\right)}{\left(\sigma^{+\rightarrow}+\sigma^{+\leftarrow}\right)+\left(\sigma^{-\rightarrow}+\sigma^{-\leftarrow}\right)}=-\frac{1}{D(\phi)}\frac{x_B}{y}\sum_{n=1}^{2}s_n^I\sin(n\phi)$$

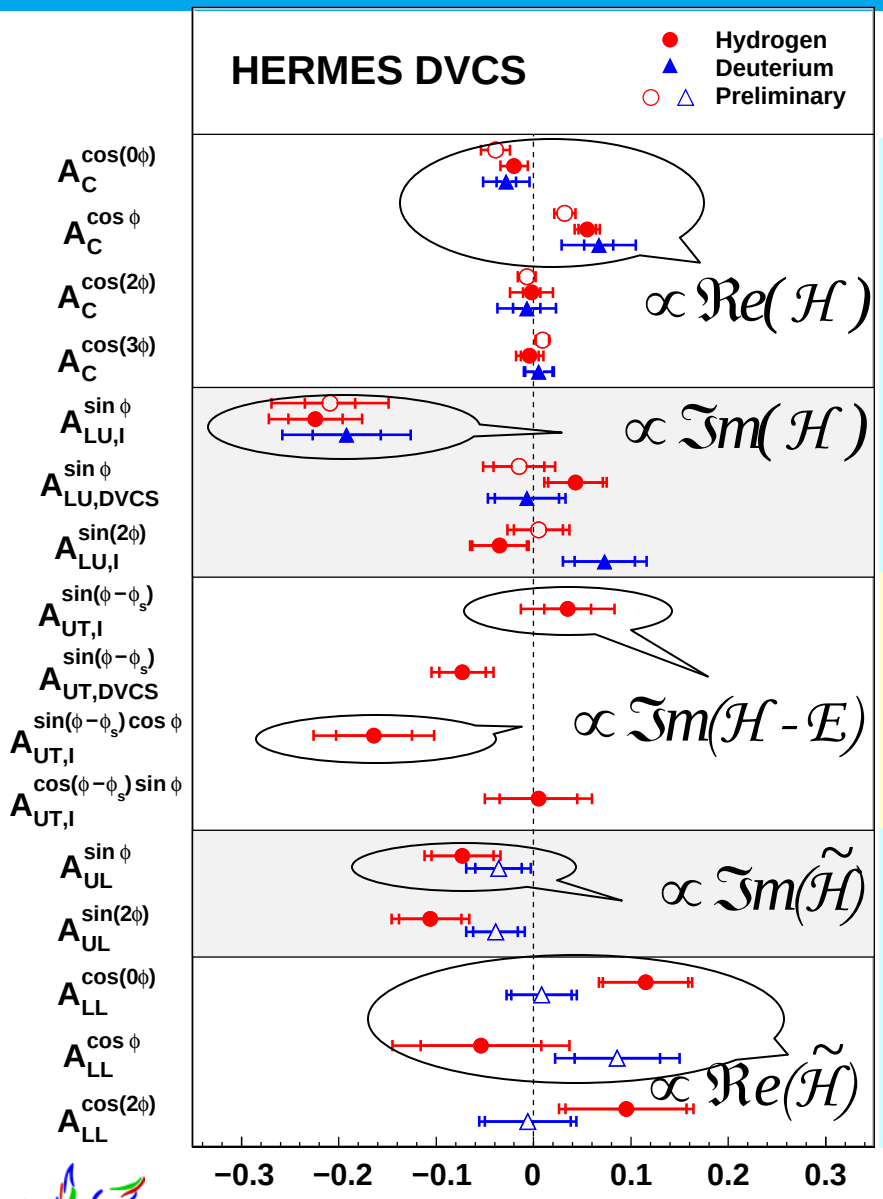
- Charge-averaged beam-helicity asymmetry

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

- Separation of contributions from DVCS and interference term
- Impossible in case of single-charge beam-helicity asymmetry

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

DVCS asymmetries and connections with GPDs



JHEP 11 (2009) 083

Nucl. Phys. B 829 (2010) 1

- Beam charge asymmetry
- Beam helicity asymmetry

GPD *H*

JHEP 06 (2008) 066

- Transverse target spin asymmetry

GPD *E*

JHEP 06 (2010) 019

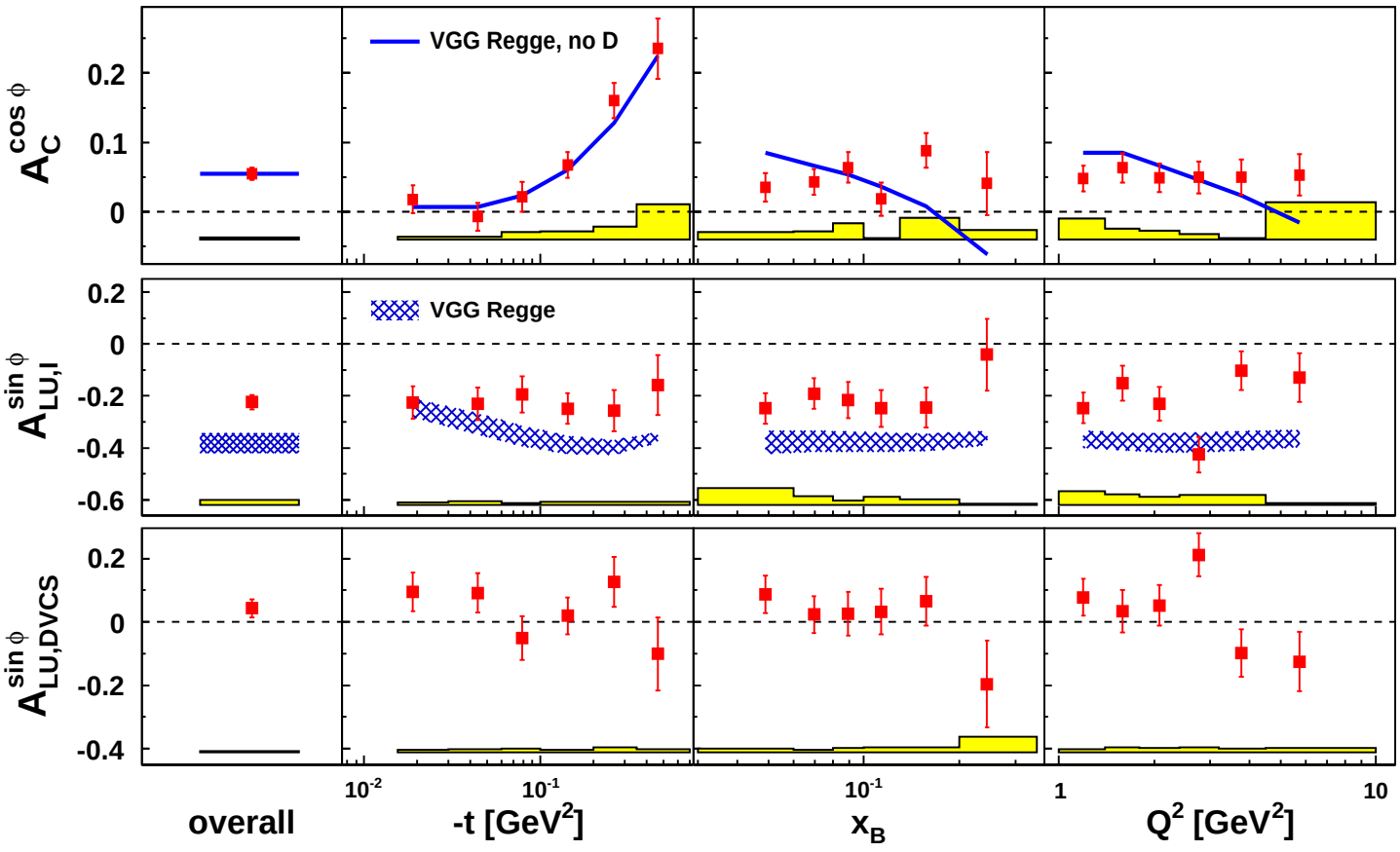
arXiv:1008.3996, in press in Nucl. Phys. B

- Longitudinal target spin asymmetry
- Double spin asymmetry

GPD $\tilde{H}$

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

JHEP 11 (2009) 083



$\propto \Re e[F_1\mathcal{H}]$

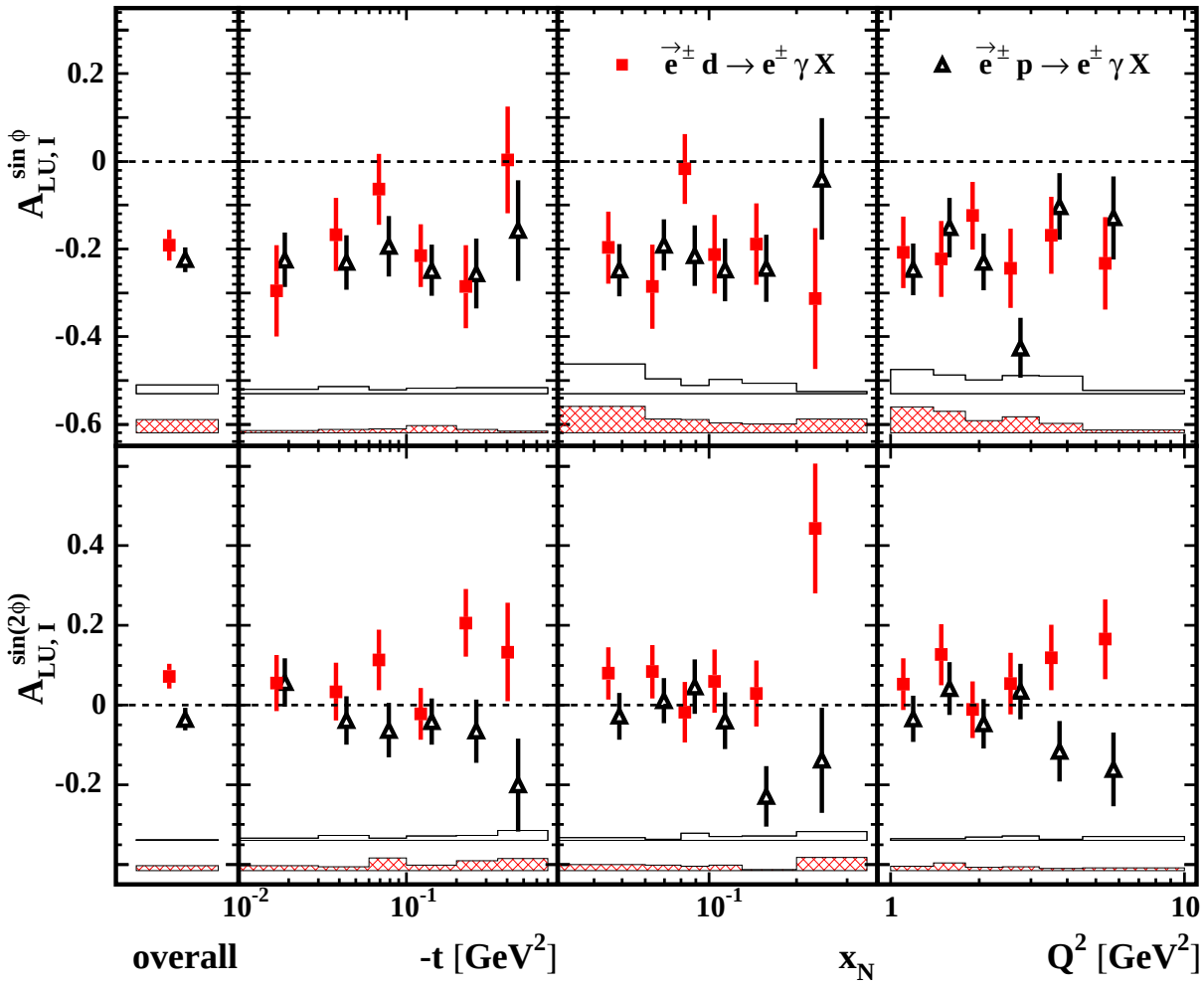
$\propto \Im m[F_1\mathcal{H}]$

← Higher twist

- Comparisons with GPD model, Vanderhaeghen, Guichon, Guidal
  Phys. Rev. D60 (1999) 094017, Prog. Part. Nucl. Phys. 47 (2001) 401
- Resonance fraction from $ep \to e\Delta^+\gamma$ is about *12%*

Comparison of deuteron and proton data

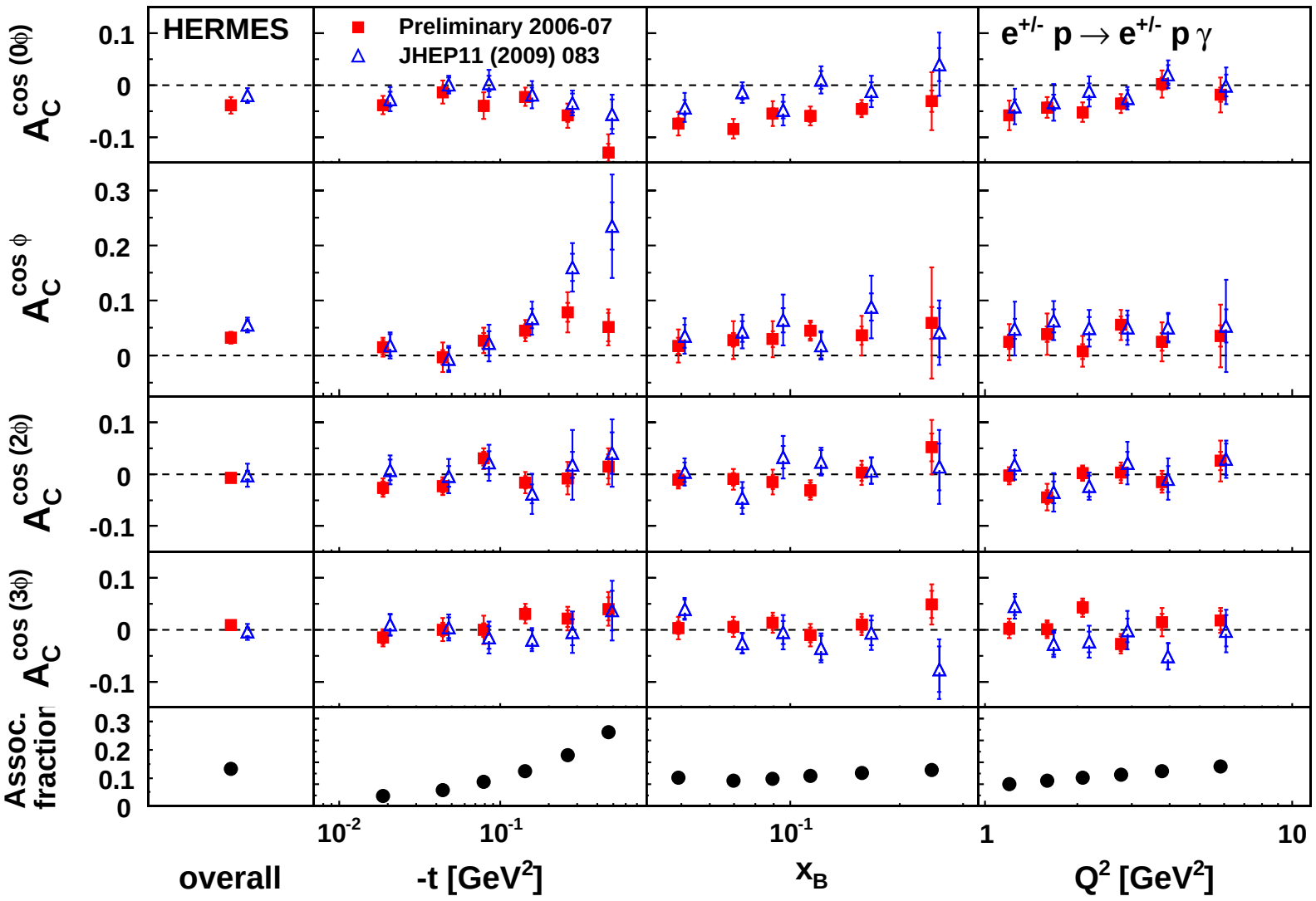
Nucl. Phys. B 829 (2010) 1



Details: C. Riedl, 16:30, Location D

- Amplitudes for proton and deuteron compatible for all leading amplitudes

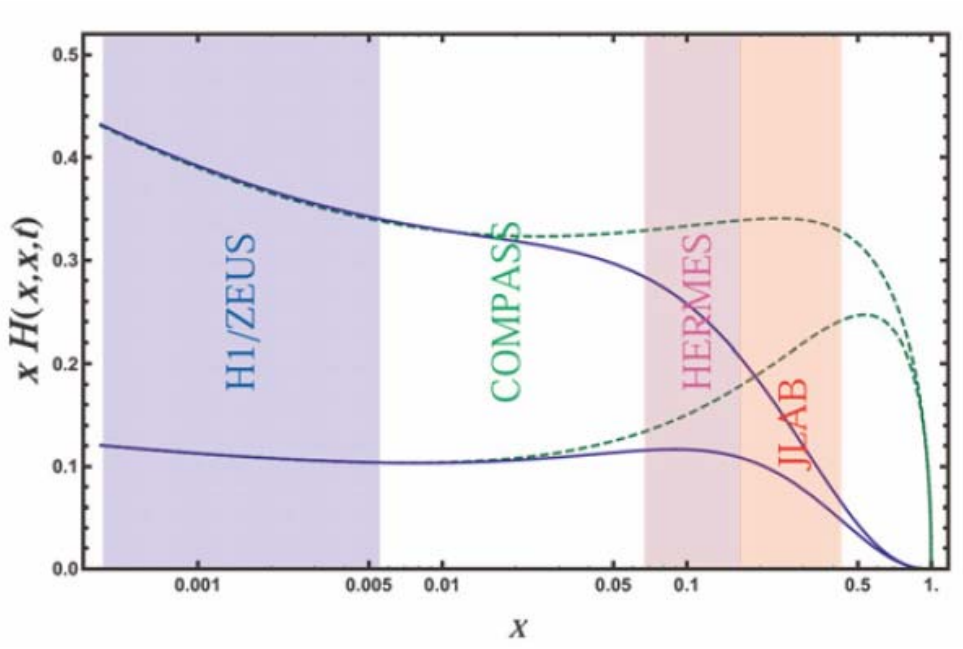
New high-statistics results from 2006-2007 data

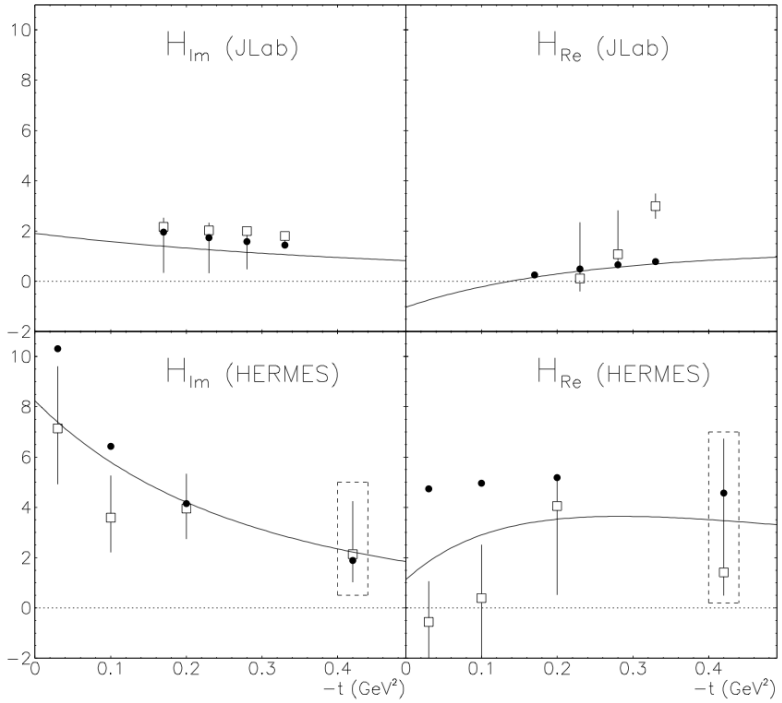


New

Details: M. Düren

Extraction of GPDs





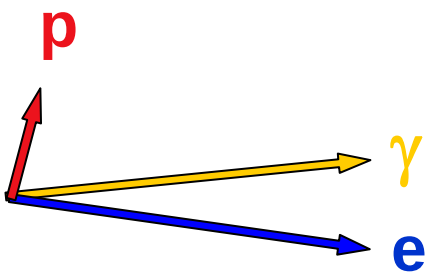
- Postulate GPDs from first principle models

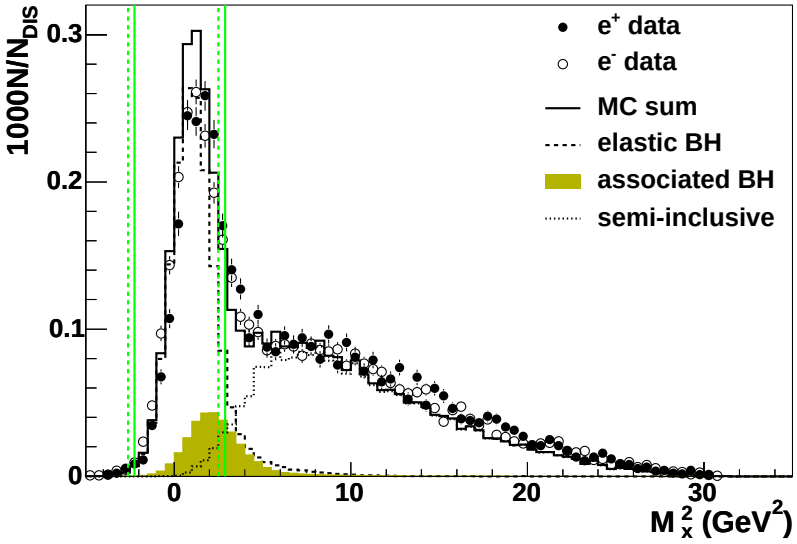
  K. Kumerički and D. Müller, Nucl. Phys. B 841, (2010) 1

- Fit Compton form factors to asymmetry data

  M. Guidal and H. Moutarde, Eur.Phys.J. A 42 (2009) 71

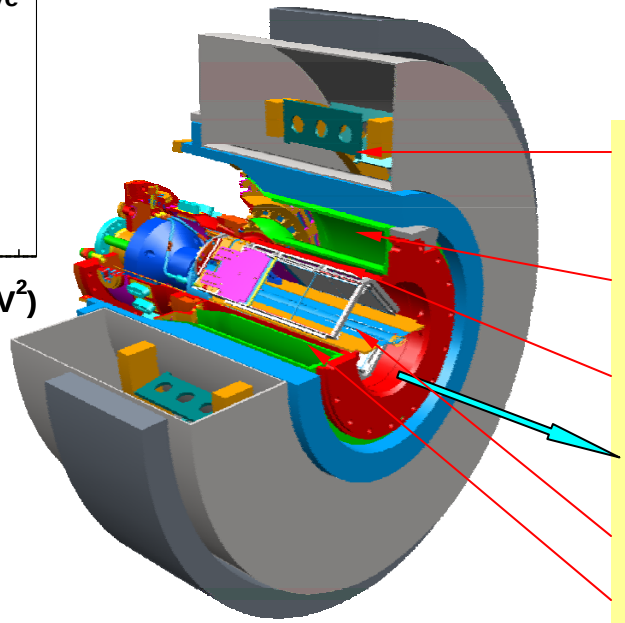
DVCS measurement with the Recoil Detector





- Recoil data
  - Detection of recoil proton
  - Suppression of the background to <1% level

- Pre-Recoil data
  - Scattered lepton and photon were detected in the forward spectrometer
  - Recoil proton was not detected
  - Exclusivity achieved via missing mass technique
  - Associated processes were not resolved (12% contribution in the signal)



1 Tesla superconducting solenoid

Photon Detector (PD)

Scintillating Fiber Tracker

Lepton beam

Silicon Strip Detector

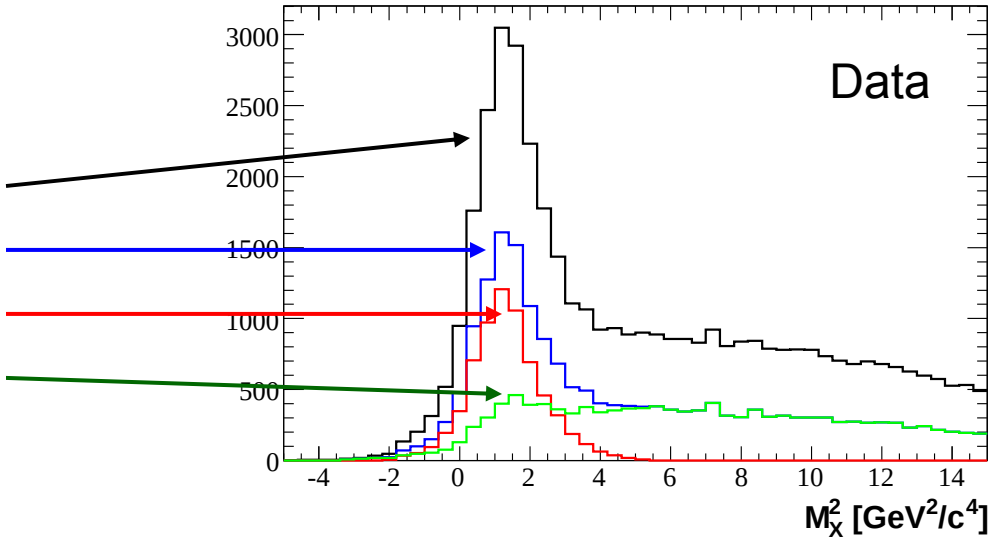
Target cell of unpolarized target

DVCS event selection with the Recoil Detector

- Kinematic fitting technique is developed and tested on Monte-Carlo
  - 3 particles detected → 4 constraints from energy-momentum conservation
  - Allows to suppress the associated Bethe-Heitler and semi-inclusive background to negligible level

- Applied for data for physics analysis
  - Systematic studies in progress
  - First physics results expected soon

- Missing mass distribution
  - No requirement for Recoil
  - Positively charged Recoil track
  - Kinematic fit probability > 1%
  - Kinematic fit probability < 1%



Summary and Outlook

- HERMES is actively producing important physics results
- Only selected results presented in this talk
  - Final results on Collins and Sivers asymmetries published
  - New preliminary data on inclusive hadron leptoproduction
  - Unique measurements of asymmetries in DVCS
- Many other interesting results presented in parallel sessions
- Physics analysis is ongoing
- New results will be presented and published soon

List of HERMES talks

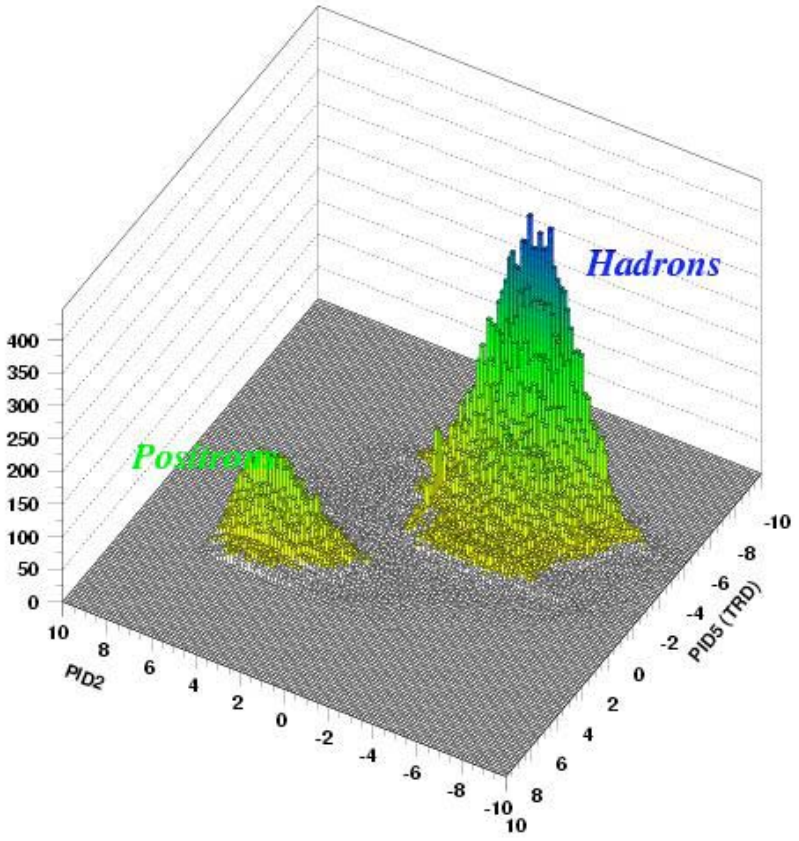
- Transverse spin/momentum effects:
  - Signals for transverse-momentum dependent quark distributions studied at the HERMES experiment, M. Diefenthaler (University of Illinois) for A. Ivanilov (IHEP, Protvino)
  - Cosine modulation of the unpolarized pion cross section at HERMES, F. Giordano (DESY)
  - Single-spin asymmeries in inclusive hadron electro-production at HERMES, K. Rith (University of Erlangen)
  - Measurement of the Proton Spin Structure Function g_2 and Asymmetry A_2 at HERMES, M. Diefenthaler (University of Illinois)
  - Transverse Target Moments of SIDIS Vector Meson Production at HERMES, S. Gliske (University of Michigan)
  - Search for a two-photon exchange contribution to inclusive deep-inelastic scattering, K. Rith (University of Erlangen) for C. Van Hulse (Gent University)
- GPDs:
  - Deeply Virtual Compton Scattering off polarised and unpolarised protons at HERMES, M. Düren (Universität Giessen)
  - Report on the HERMES Recoil Detector, S. Yaschenko (DESY Zeuthen) for C. Van Hulse (Gent University)
  - Helicity Amplitude Ratios in Exclusive Electroproduction of the rho0 meson at HERMES, B. Marianski (Institute for Nuclear Studies)
  - Hard exclusive electroproduction of vector mesons at HERMES, E. Avetisyan (DESY)
  - DVCS on the deuteron and heavier nuclear targets at HERMES, C. Riedl (DESY)

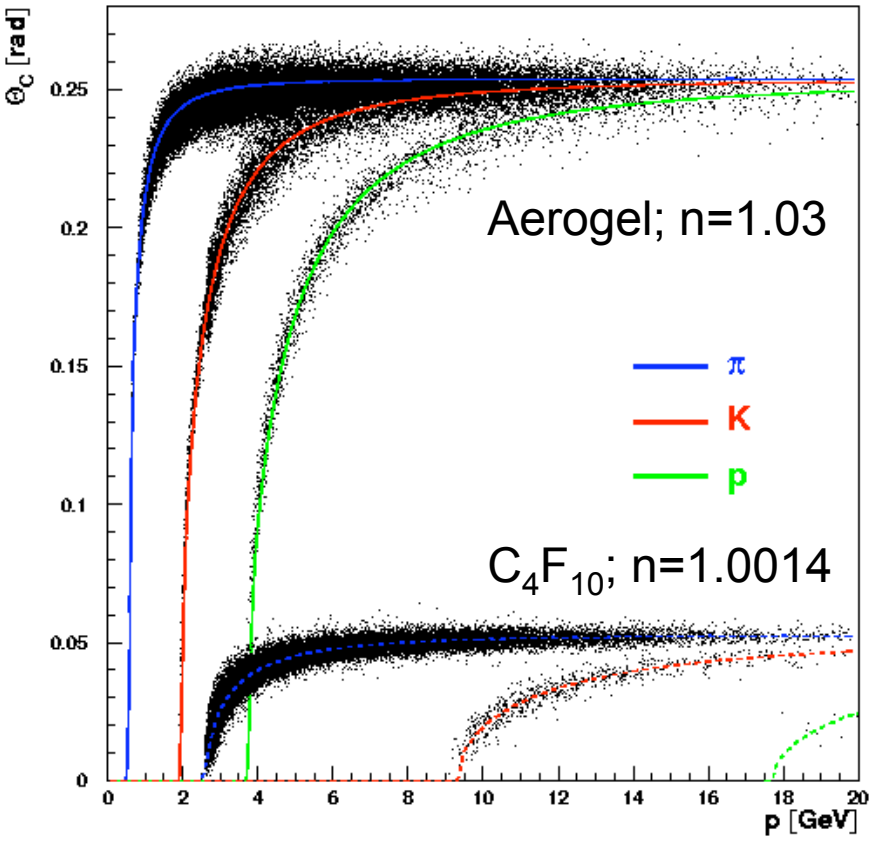
TODAY!

- Strange-baryon production
  - Spin Transfer Coefficient D_{LL} to Lambda and anti-Lambda Hyperon in Semi-Inclusive DIS at HERMES, D. Veretennikov (PNPI)
  - Measurement of the nuclear-mass dependence of transverse Lambda polarisation in quasi-real photoproduction at HERMES, Yu.Naryshkin (PNPI)

Backup slides

Particle identification

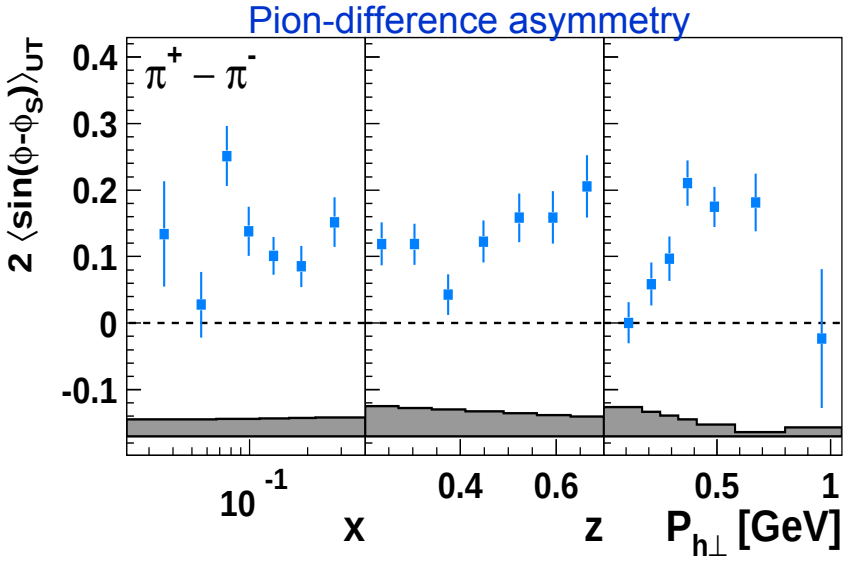


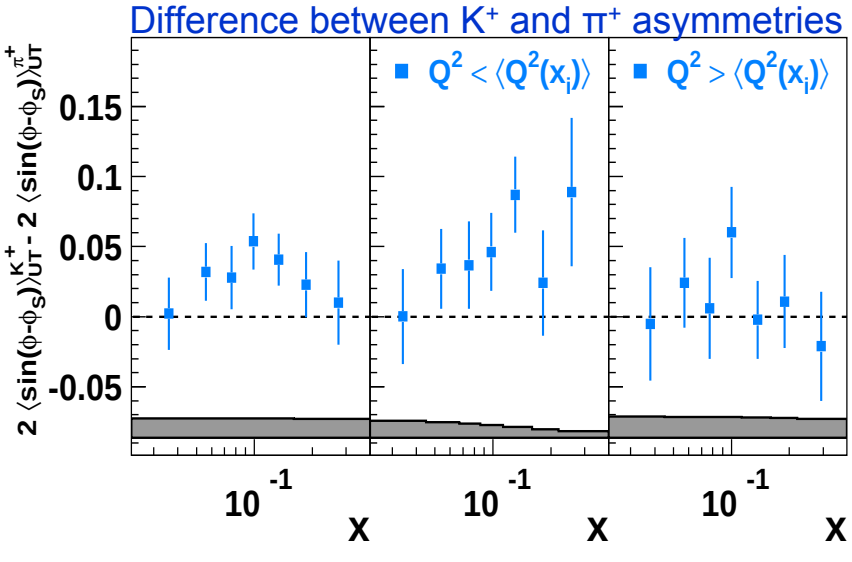


- Excellent lepton-hadron separation
- Hadron type separation with dual radiator RICH for *2-15 GeV/c*

Pion-difference Sivers asymmetry and difference between K^+ and π^+ Sivers asymmetries

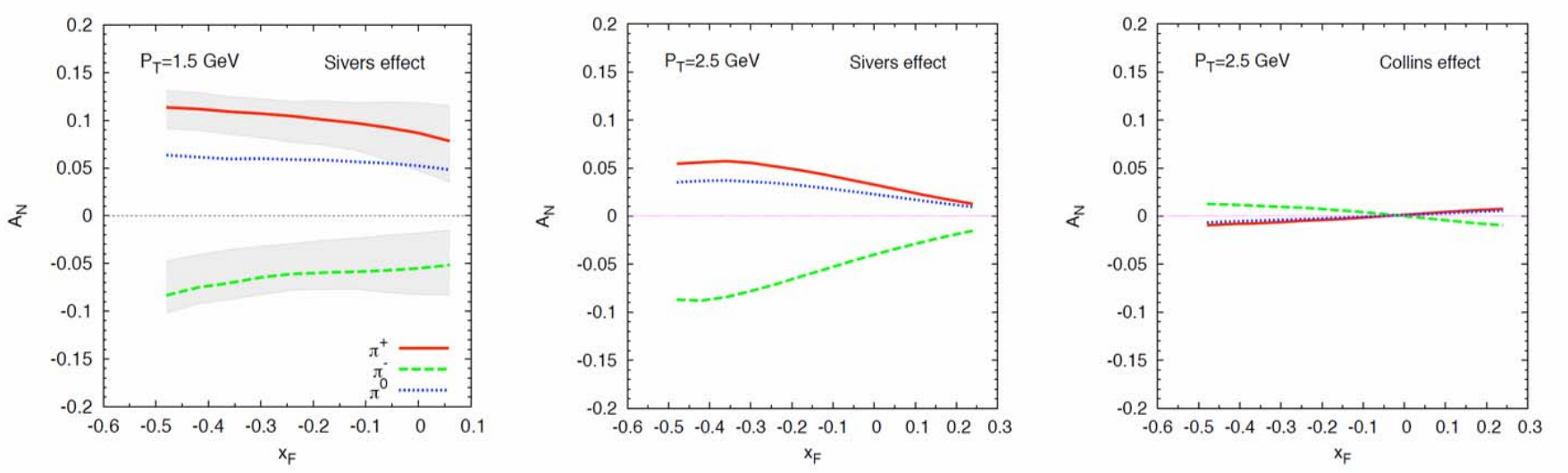
Phys. Rev. Lett. 103 (2009) 152002



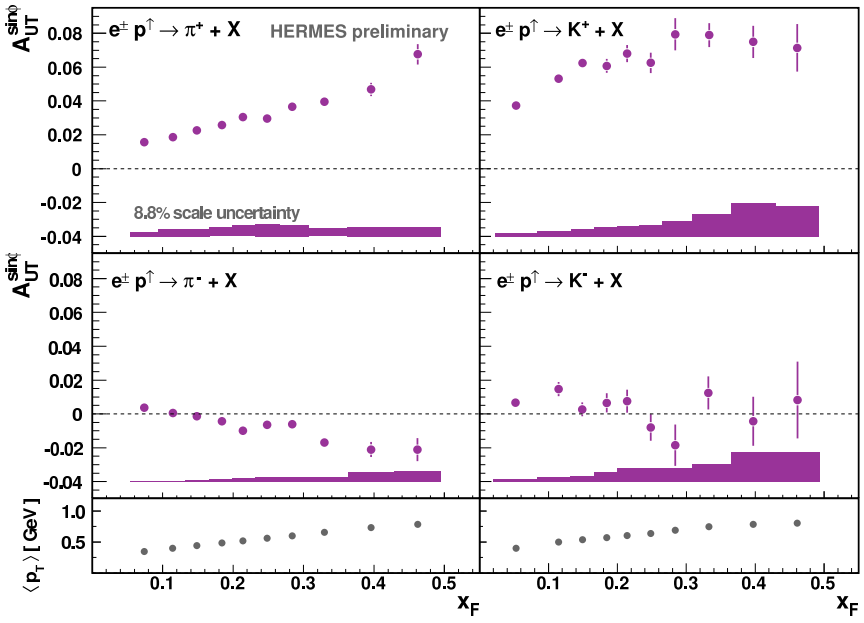


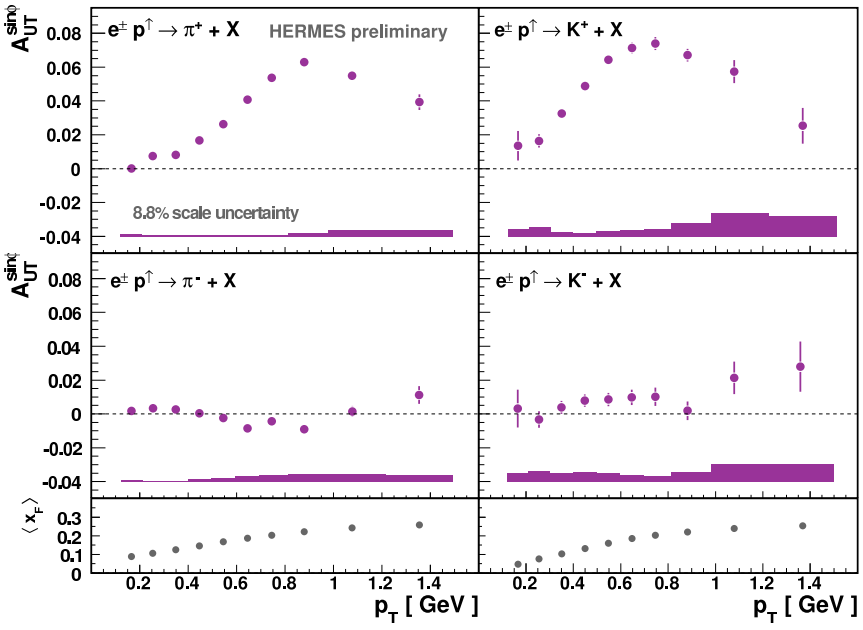
- Pion-difference asymmetry $A_{UT}^{\pi^+-\pi^-}(\phi,\phi_S) \equiv \frac{1}{|S_T|}\frac{\left(\sigma_{U\uparrow}^{\pi^+}-\sigma_{U\uparrow}^{\pi^-}\right)-\left(\sigma_{U\downarrow}^{\pi^+}-\sigma_{U\downarrow}^{\pi^-}\right)}{\left(\sigma_{U\uparrow}^{\pi^+}-\sigma_{U\uparrow}^{\pi^-}\right)+\left(\sigma_{U\downarrow}^{\pi^+}-\sigma_{U\downarrow}^{\pi^-}\right)} \propto \left(f_{1T}^{\perp,d_v} - 4f_{1T}^{\perp,u_v}\right)$
  - 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 $\pi^+ = |u\bar{d}\rangle \quad K^+ = |u\bar{s}\rangle$
  - Possible significant role of sea quarks
  - Higher-twist effects in kaon production might also contribute

Models for A_N



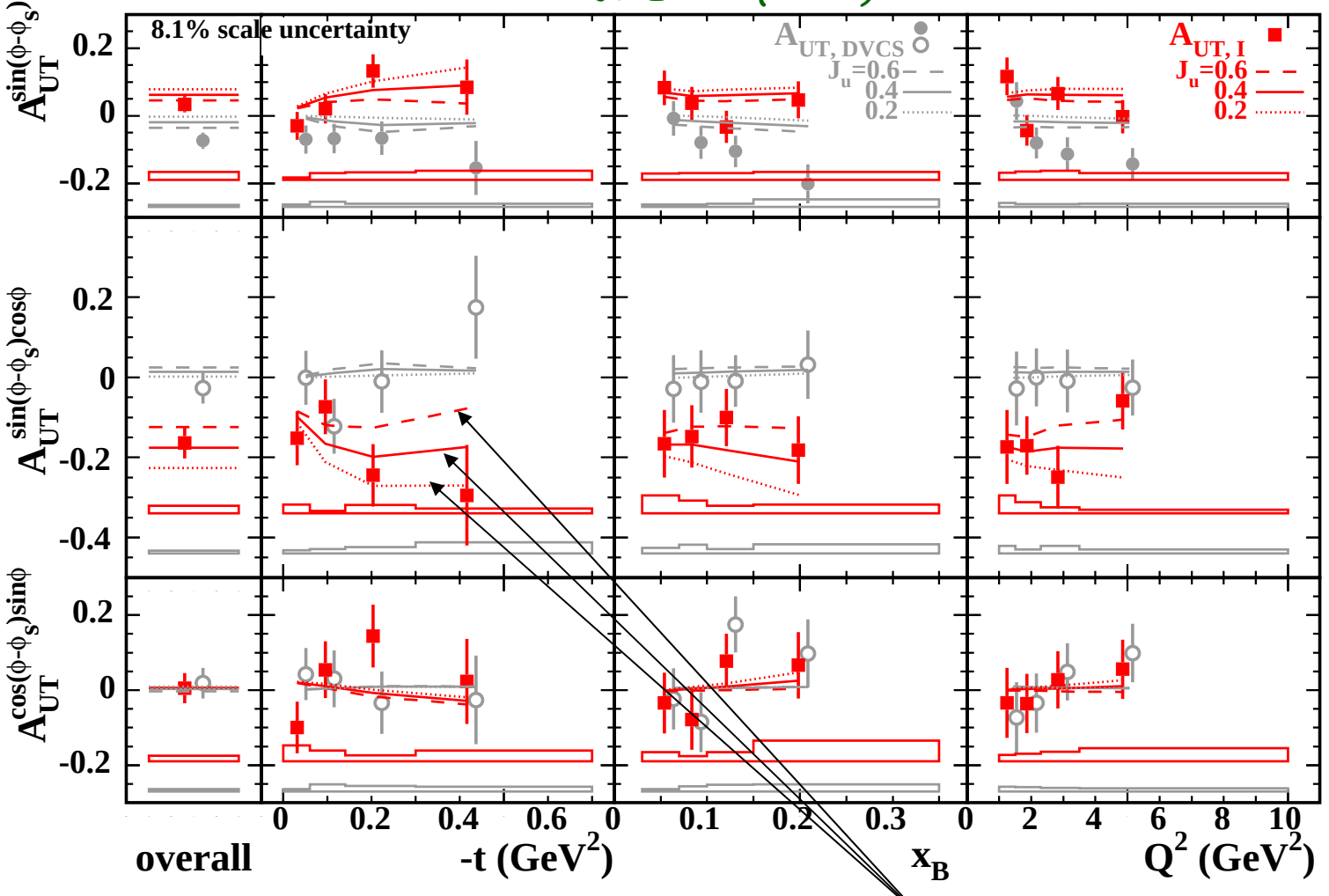
Results on Inclusive hadron leptoproduction





Transverse target spin asymmetry in DVCS

JHEP 06 (2008) 066



- Sensitivity of GPD model predictions to J_u at fixed J_d=0