Measurement of the Collins and Sivers asymmetries on transversely polarisedprotons

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Introduction

- Λ hyperons produced in pN interactions exhibited an anomalously large transverse polarization(Phys. Rev. Lett. 36 (1976) 1113.)
- the quark spin contributes only a small fraction to the proton spin(Phys. Lett. B 206 (1988) 364)
- the significance of the quark transversity distribution
- In this article: Collins and Sivers Mechanism
    - Collins Mechanism: transverse spin distributions $\Delta_T q(x)$ must be added to the momentum distributions $q(x)$ and the helicity distributions $\Delta q(x)$
    - Sivers Mechanism: a correlation between the transverse momentum $\overrightarrow{k_T}$ of an unpolarized quark in a transversely polarized nucleon and the nucleon polarization vector

SSA(Single Spin Asymmetry)

- In a more general formalism(TMD)

$$d\sigma \sim \sum_q e_q^2 \cdot \left\{ \frac{1}{2} [1 + (1-y)^2] \; x \left[q \otimes D_q^h + |\vec{S}_\perp| \sin(\Phi_S) \Delta_0^T q \otimes D_q^h \right] + \right.$$
$$\left. +(1-y) \; |\vec{S}_\perp| \; \sin(\Phi_C) \, x \, \Delta_T q \otimes \Delta_T^0 D_q^h \right\} .$$

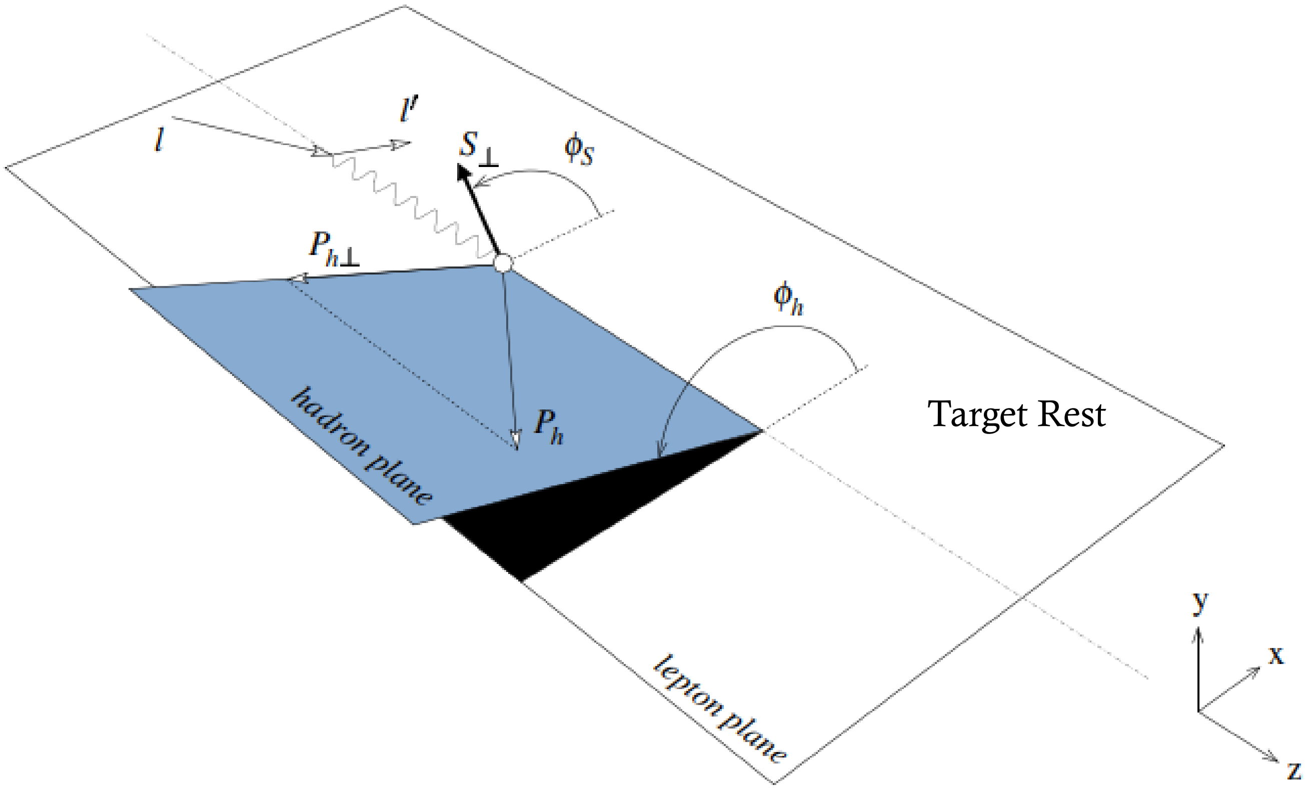
- The transverse spin asymmetry is then given by

$$A_T^h \equiv \frac{d\sigma(\vec{S}_\perp) - d\sigma(-\vec{S}_\perp)}{d\sigma(\vec{S}_\perp) + d\sigma(-\vec{S}_\perp)}$$
$$= |\vec{S}_\perp| \cdot D_{NN} \; A_{Coll} \cdot \sin \Phi_C + |\vec{S}_\perp| \cdot A_{Siv} \cdot \sin \Phi_S$$

$$D_{NN} = \frac{1-y}{1-y+y^2/2} \qquad y = \frac{(l - l').p}{l.p}$$

$$\Phi_C = \phi_h + \phi_S - \pi$$

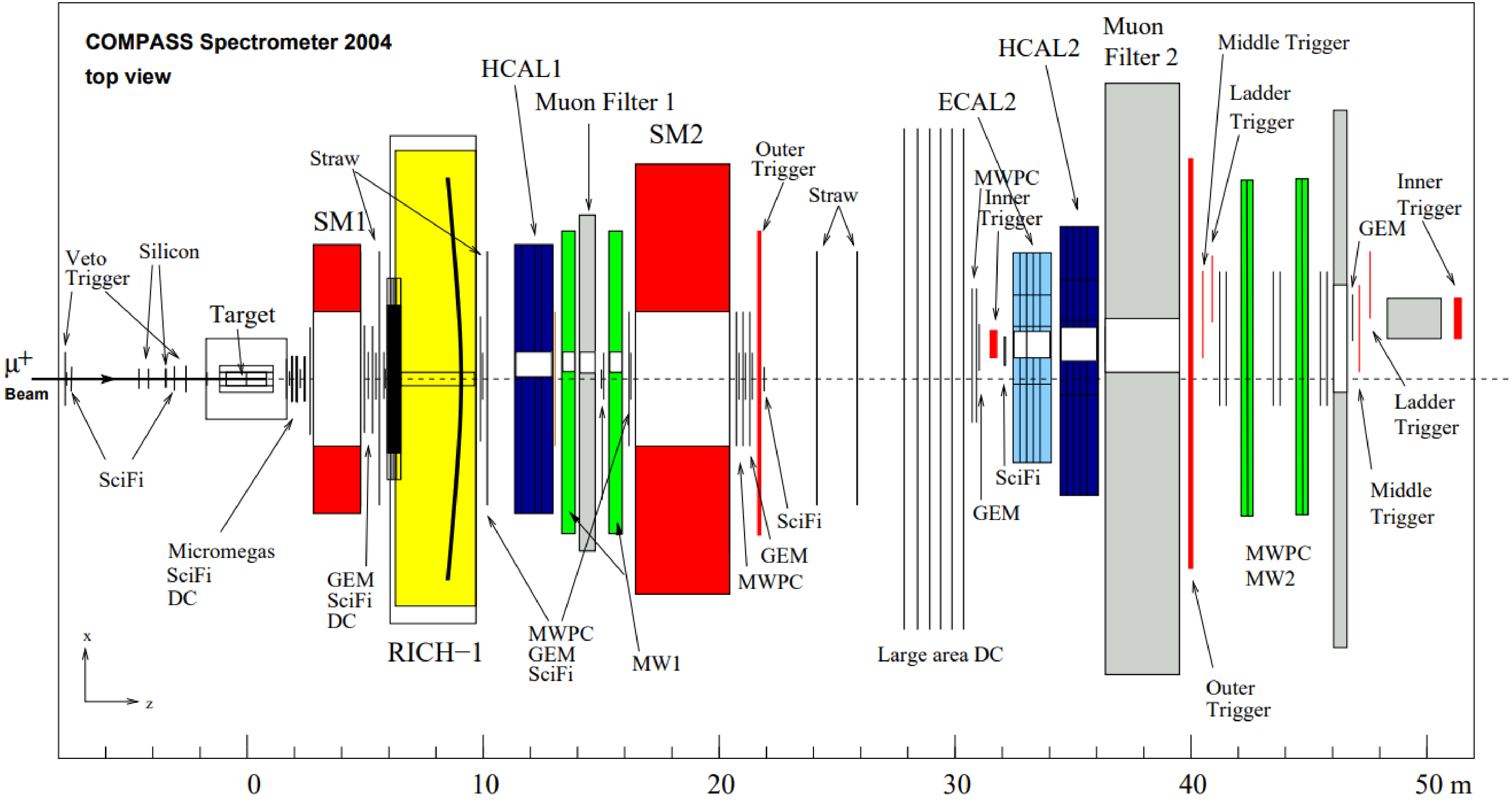
$$\Phi_S = \phi_h - \phi_S$$



TMDs		Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally polarized (L)	Quark polarization: Transversely polarized (T)
Nucleon polarization	U	f_1 Unpolarized		$h_1^{\perp}$ Boer–Mulders
	L		g_{1L} Helicity	$h_{1L}^{\perp}$ Longi-transversity
	T	$f_{1T}^{\perp}$ Sivers	g_{1T} Trans-helicity	h_1 Transversity $h_{1T}^{\perp}$ Pretzelosity

Nucleon spin   Quark spin

Detector



COMPASS Spectrometer 2004
top view
μ+
Beam
Veto
Trigger
Silicon
SciFi
Target
Micromegas
SciFi
DC
SM1
Straw
GEM
SciFi
DC
RICH−1
HCAL1
Muon Filter 1
MWPC
GEM
SciFi
MW1
SM2
Outer
Trigger
Straw
SciFi
GEM
MWPC
Large area DC
ECAL2
MWPC
Inner
Trigger
GEM
SciFi
HCAL2
Muon
Filter 2
Middle Trigger
Ladder
Trigger
Outer
Trigger
MWPC
MW2
GEM
Inner
Trigger
Ladder
Trigger
Middle
Trigger
x
z
0
10
20
30
40
50 m

Detector Setup

- Tracker
- PID: RICH, calorimeters and muon filter
- Trigger System:
  - Scintillator hodoscopes: Scattered muon
  - Calorimeters: produced hadrons
- Muon Beam
  - 160 $GeV/c,\ \Delta\mathrm{p}/\mathrm{p} = \pm 5\%$
  - 80% longitudinal polarization: π-decay mechanism
- Polarized Proton Target
  - NH_3(cooled in He3-He4 dilution refrigerator): polarization achievement with 0.6 T vertical field and microwave
  - Multiple cells: three targets where neighboring cells were polarized in opposite directions
- Polarization reversal to minimize the effects due to different spectrometer accepatance

Data Selection(12×10^9 events total)

Event Selection

- At least one "primary vertex" are reconstructed and are required to be inside a target cell
- The extrapolated beam track had to traverse all the three target cell.
- χ^2 cuts were applied to assure the quality of track reconstruction.
- Tracks from the primary vertex which traversed more than 30 radiation lengths were identified as scattered muons.
- $Q^2 > 1\ (GeV/c)^2$, $0.1 < y < 0.9$, $W > 5\ GeV/c^2$, $0.004 < x_{bj} < 0.7$

Hadron Requirements

- Emerging from the primary vertex
- Traversing less than 10 radiation lengths of material
- Requirement of the amount of deposited energy in the cluster reconstructed in hadronic calorimeters
- Tracks reconstructed only in the fringe field of the first analyzing magnet of the spectrometer were rejected.(roughly a cut at 1.5 GeV/c)
- $p_T^h > 0.1\ GeV/c$, $z > 0.2$

Raw Asymmetries

- $\mathcal{L} = \left(e^{-I^{+}} \prod_{i=0}^{N^{+}} p^{+}(\phi_{h,i}, \phi_{S,i})\right)^{\frac{1}{N^{+}}} \cdot \left(e^{-I^{-}} \prod_{i=0}^{N^{-}} p^{-}(\phi_{h,i}, \phi_{S,i})\right)^{\frac{1}{N^{-}}}$
- + and – signs refer to the orientation of the target polarization.
- $N^{\pm}$ is the corresponding total number of hadrons.
- $I^{\pm}$ are the integrals of the probability densities over ϕ_s and ϕ_h.
- $p^{\pm}$are the product of the two parts.
    - the acceptance description: various parametrizations of the acceptance part were tested.
    - the SIDIS cross section
        - Unpolarized part
        - Polarized part: $\sin(\phi_h + \phi_S - \pi)$, $\sin(\phi_h - \phi_S)$, $\cos(\phi_h - \phi_S)$, $\sin(2\phi_h - \phi_S)$, $\cos(2\phi_h - \phi_S)$, $\sin(\phi_S)$, $\cos(\phi_S)$, $\sin(3\phi_h - \phi_S)$
- The target polarization, the D_{NN} factor should be divided to get exact asymmetries: dilution factor(0.15 average,0.14 to 0.17)

Systematic Error

- Largest Part: residual acceptance variations: Collins(0.5 σ_{stat} for positive hadrons, 0.6 σ_{stat} for negative hadrons), Sivers(0.8 σ_{stat} for positive hadrons, 0.4 σ_{stat} for negative hadrons)
  - Using the external cells and the internal cell divided in two parts, and assuming wrong sign polarization for one of the two
  - Extracting the physical asymmetries with only the first and only the second half of the target
- Further ± 0.01 for Sivers asymmetry:
  - Difference in the mean value of the asymmetries extract in the first two and in the second two periods of data taking

Results

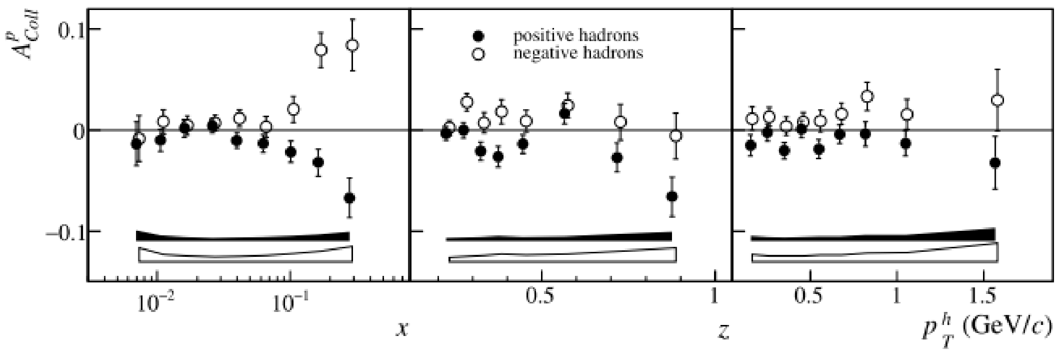


Fig. 1. Collins asymmetry as a function of x, z, and p^h_T, for positive (closed circles) and negative (open circles) hadrons. The bars show the statistical errors. The point to point systematic uncertainties have been estimated to be 0.5 σ_{stat} for positive and 0.6 σ_{stat} for negative hadrons and are given by the bands.

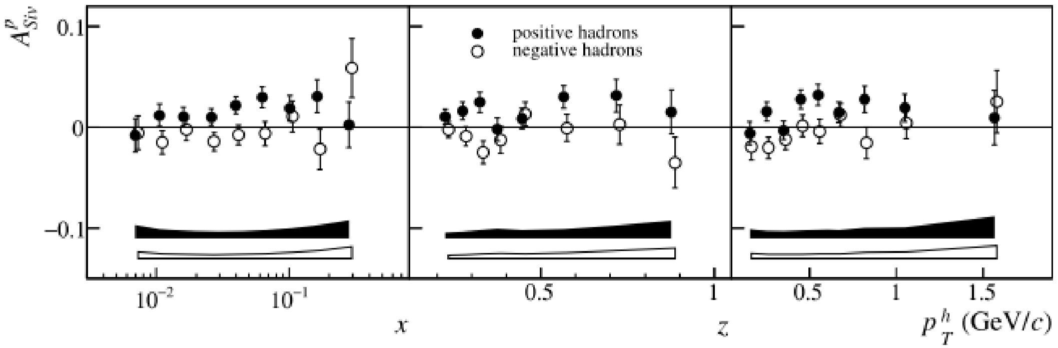


Fig. 2. Sivers asymmetry as a function of x, z, and p^h_T, for positive (closed circles) and negative (open circles) hadrons. The bars show the statistical errors. The point to point systematic uncertainties have been estimated to be 0.8 σ_{stat} for positive and 0.4 σ_{stat} for negative hadrons and are given by the bands. For positive hadrons only, an absolute scale uncertainty of ±0.01 has also to be taken into account.

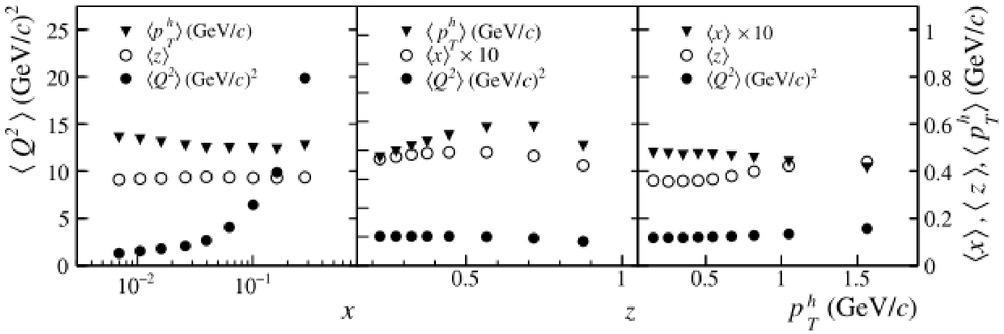


Fig. 3. Mean values of some kinematic variables in the final data sample. From left to right: mean values of p^h_T, z and Q^2 as functions of x; mean values of p^h_T, x and Q^2 as functions of z; mean values of x, z and Q^2 as functions of p^h_T.

Results

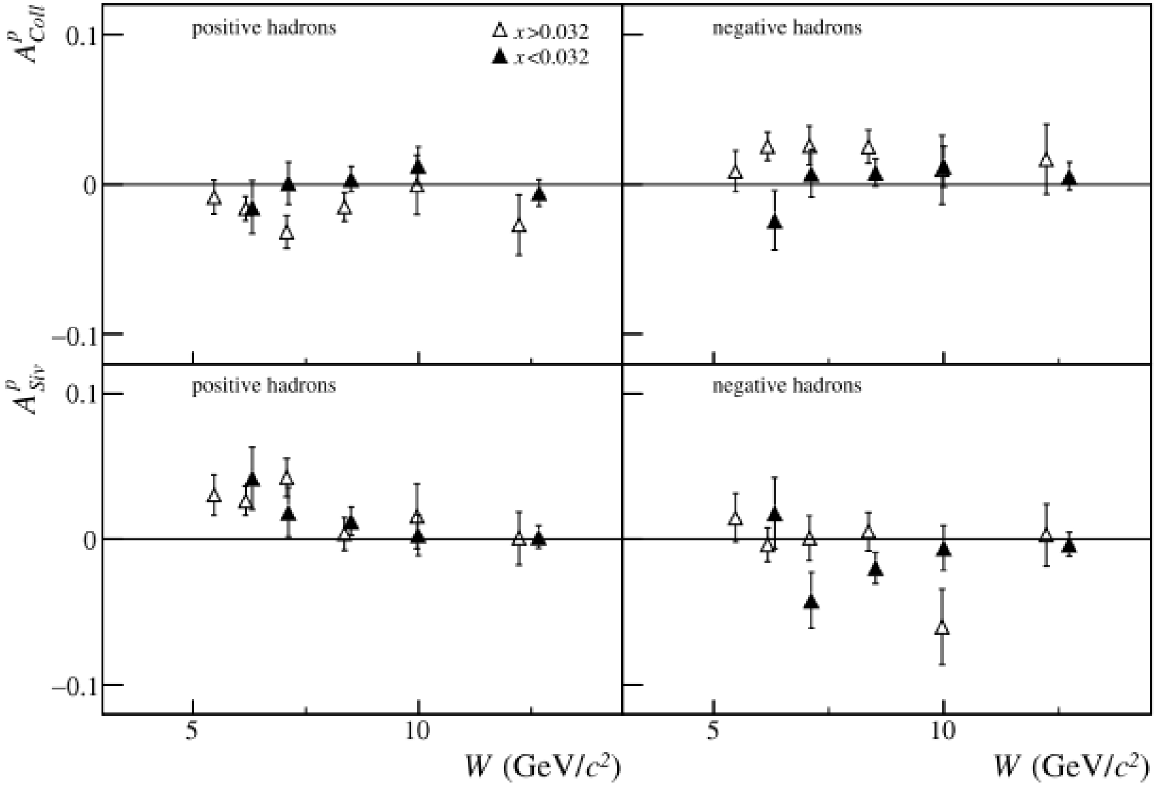


Fig. 4. Collins (upper row) and Sivers (lower row) asymmetry as a function of W, for positive (left) and negative (right) hadrons. The open and closed triangles give the values for the $x > 0.032$ and $x < 0.032$ ranges respectively. The errors are statistical only.

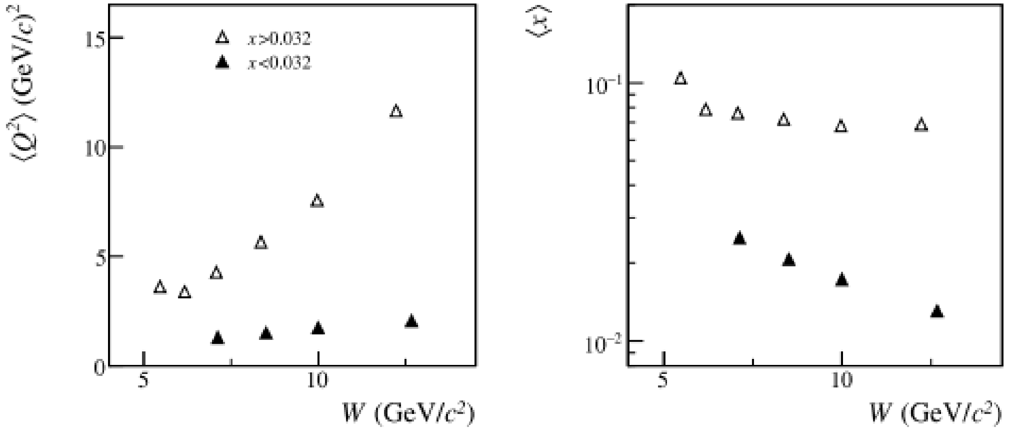
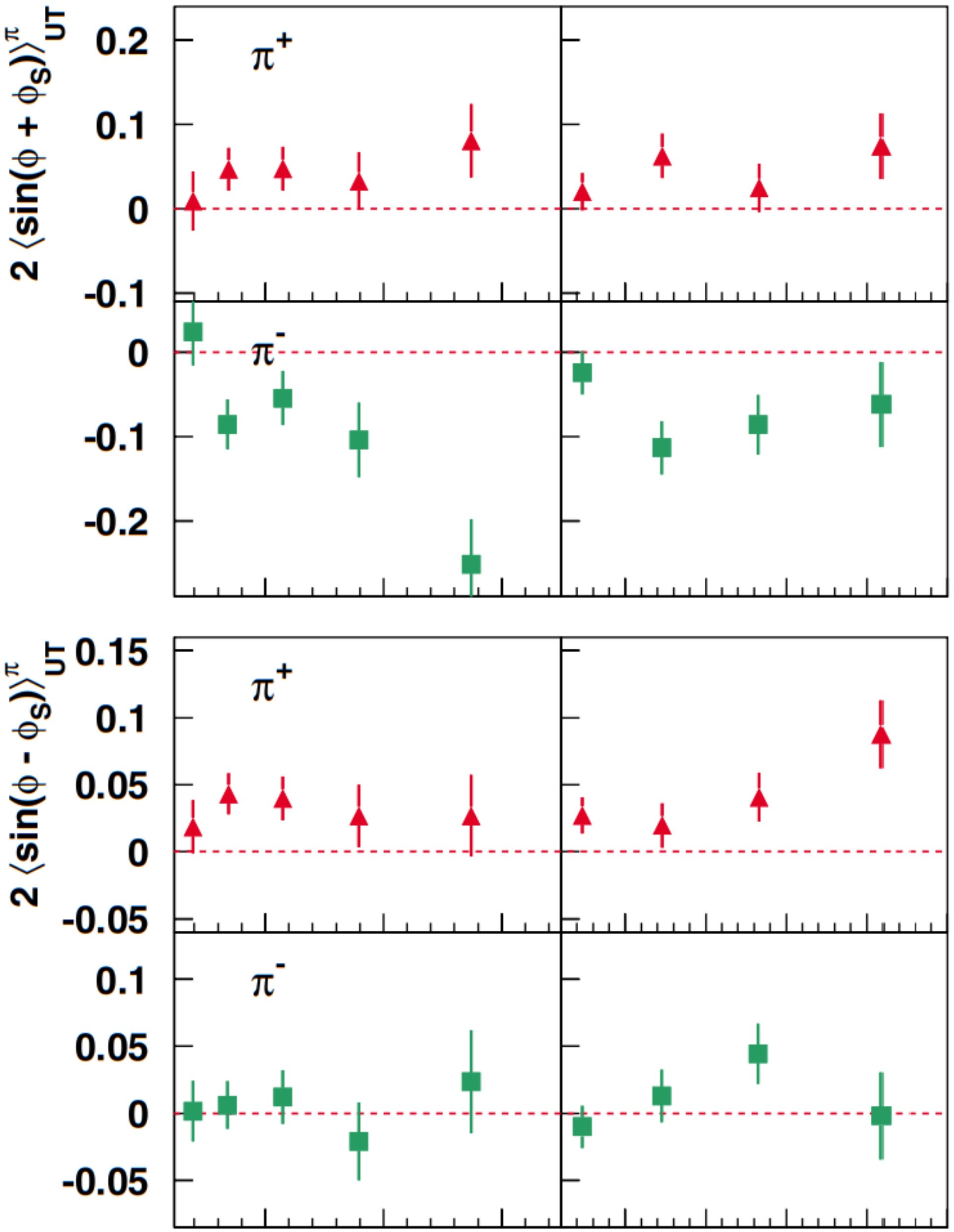


Fig. 5. Mean values of Q^2 (left) and x (right) as functions of W. The open and closed triangles give the values for the $x > 0.032$ and $x < 0.032$ ranges respectively.

HERMES Results



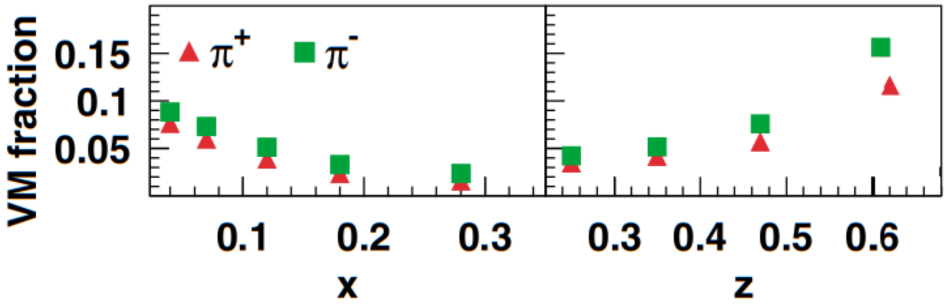


FIG. 2 (color online). Virtual-photon Collins (Sivers) moments for charged pions as labeled in the upper (middle) panel, as a function of x and z, multiplied by two to have the possible range ± 1. The error bars represent the statistical uncertainties. In addition, there is a common 8% scale uncertainty in the moments. The lower panel shows the relative contributions to the data from simulated exclusive vector meson production.