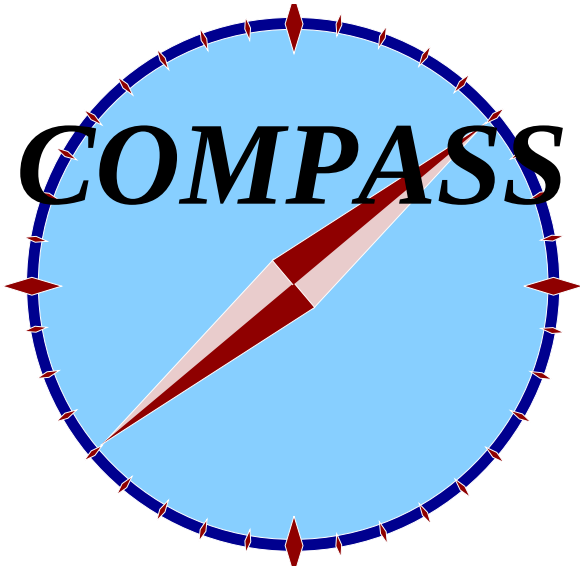
Exclusive Reactions
at High Momentum Transfer IV
Jefferson Lab, Newport News, Virginia • May 18–21, 2010

Studies of TMDs at *COMPASS*



Heiner Wollny
University of Freiburg
on behalf of COMPASS

Outline:

- Transversity: single hadrons, hadron pairs, Λ baryons
- TMDs: measured with transversely, longitudinally and unpolarized nucleons

COMPASS Detector (muon setup)

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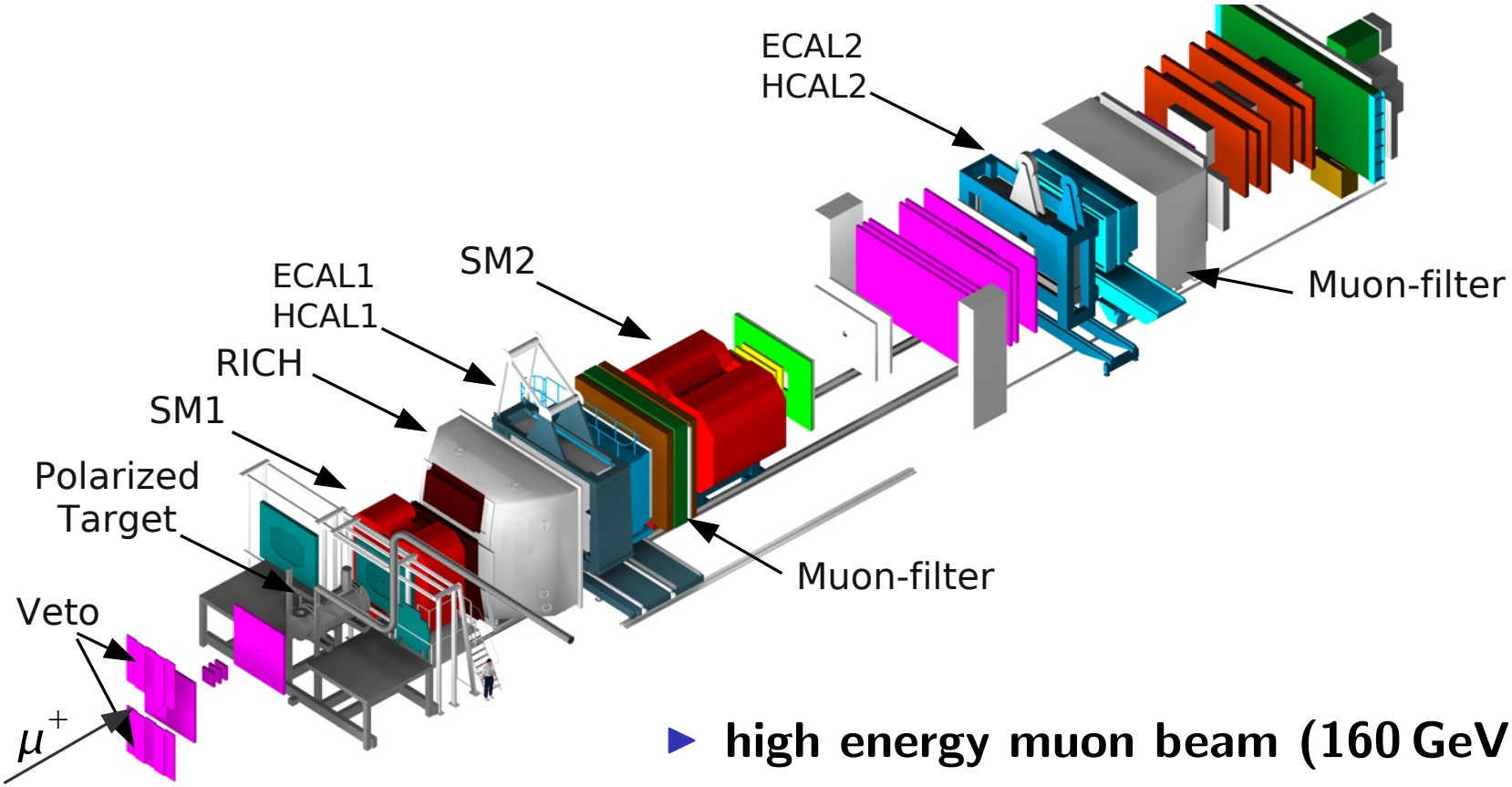

- **high energy muon beam (160 GeV)**
- **high intensity beam** ($2 \cdot 10^8 \mu^+/spill$)
- **two stages spectrometer:**
  - $\rightsquigarrow$ **large angular acceptance** ($0 \leq \theta_{lab} \leq 180\,\text{mrad}$)
  - $\rightsquigarrow$ **broad kinematical range**

COMPASS Detector (muon setup)

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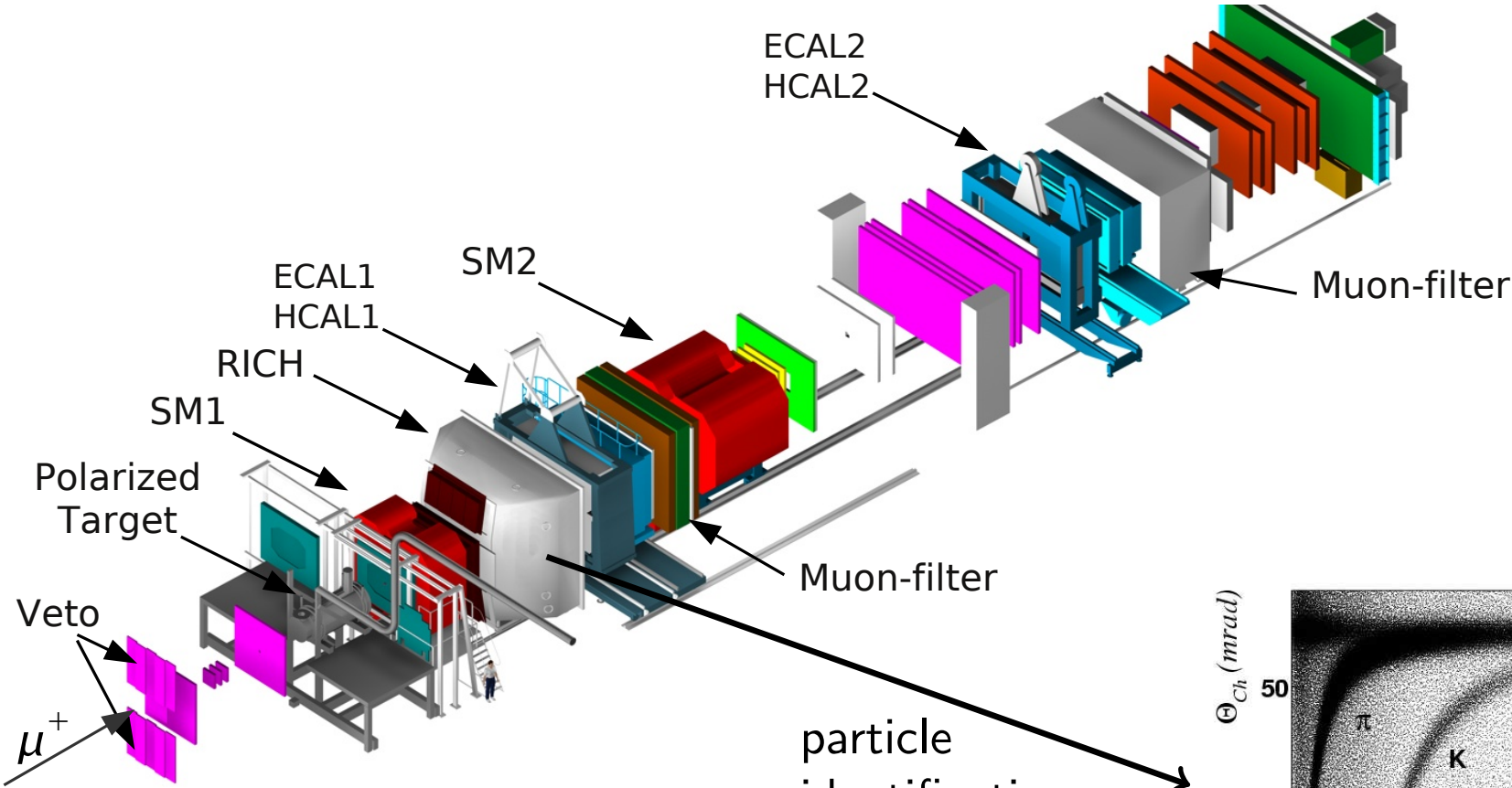
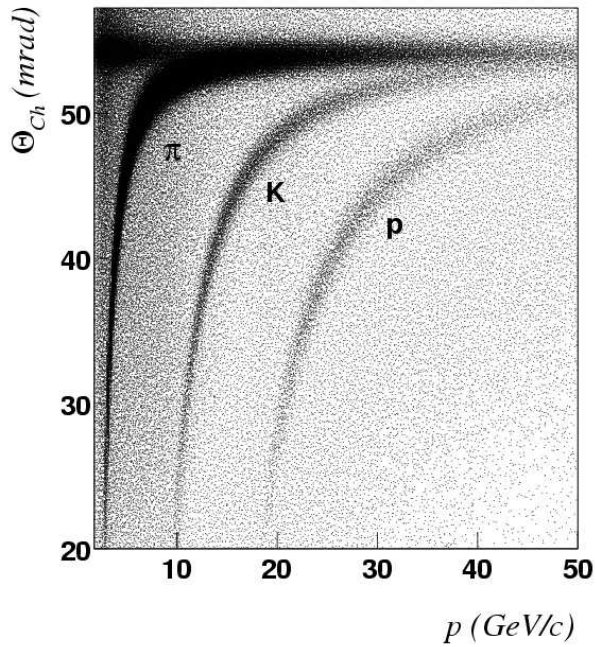




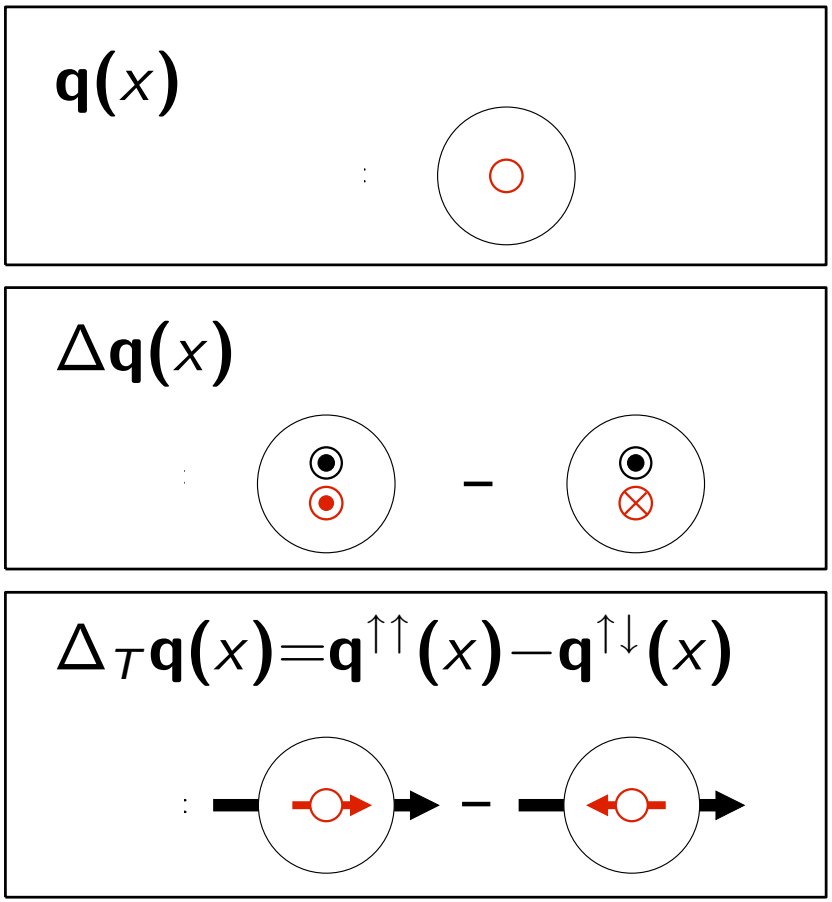
Transverse Data Taking

	Deuteron target (^{6}LiD) 2002 - 2004	Proton target (NH_3) 2007
time dedicated to transverse polarization	20 %	50 %
# charged hadrons	$\approx 15.5 \cdot 10^6$	$\approx 27 \cdot 10^6$
$1/\langle f \cdot P_T \rangle^2$ (scales σ^2_{stat}) f = target dilution P_T = target polarization	$1/(0.38 \cdot 0.48)^2 \approx 30$	$1/(0.15 \cdot 0.83)^2 \approx 64$

$\rightsquigarrow$ similar statistical precision for both data sets

Nucleon in Leading Order

In leading order three parton distributions are needed to describe the structure of the nucleon:



Courtesy of A.Bacchetta

nucleon with transverse or longitudinal spin

parton with transverse or longitudinal spin

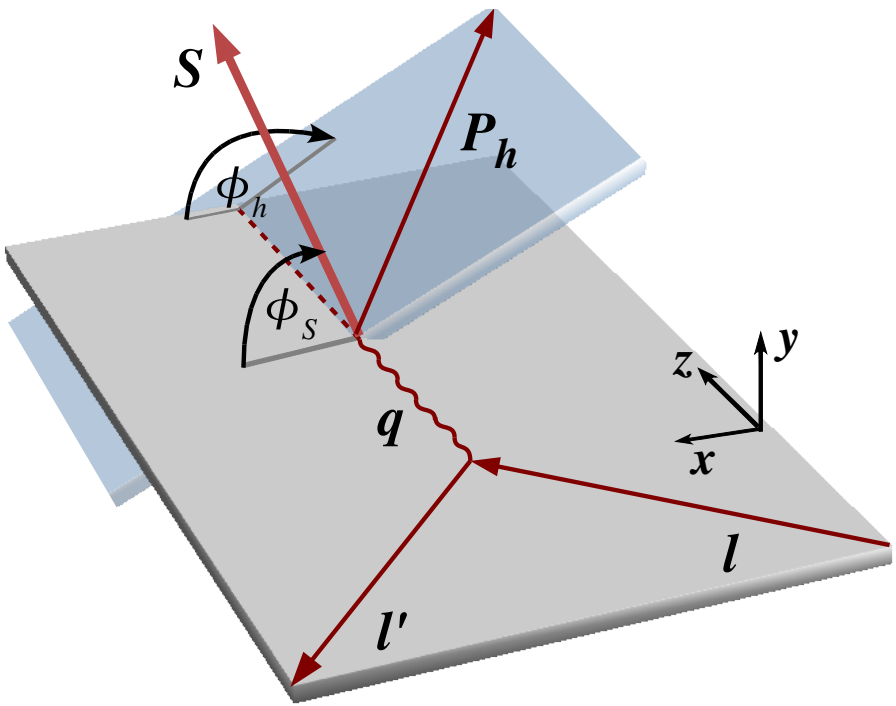
quark distribution
in unpolarized DIS
$\ell N \to \ell' X$

helicity distribution
in polarized DIS
$\vec{\ell}\vec{N} \to \ell' X$

transversity distribution
in polarized SIDIS
$\ell N^\uparrow \to \ell' h X$ Collins FF
$\ell N^\uparrow \to \ell' hh X$ Interference FF
$\ell N^\uparrow \to \ell' \Lambda^\uparrow X$ FF of $q^\uparrow \to \Lambda^\uparrow$

Collins Asymmetry

Measuring transversity with Collins-FF $\Delta_T^0 D_q^h$:



$\rightsquigarrow$ azimuthal asymmetry:

$$N_h \propto 1 \pm A \cdot \sin \phi_{Coll}$$

$$\phi_{Coll} = \phi_h + \phi_S - \pi$$

ϕ_h: azimuthal angle of hadron

ϕ_S: azimuthal angle of spin of initial quark

$$A_{Coll} = \frac{A}{f\ P_T D_{nn}} \propto \sum_q e_q^2 \cdot\ \Delta_T q \otimes \Delta_T^0 D_q^h$$

f = target dilution

P_T = target polarization

D_{nn} = transverse spin transfer

Collins Asymmetries: ^{6}LiD (2003-2004)

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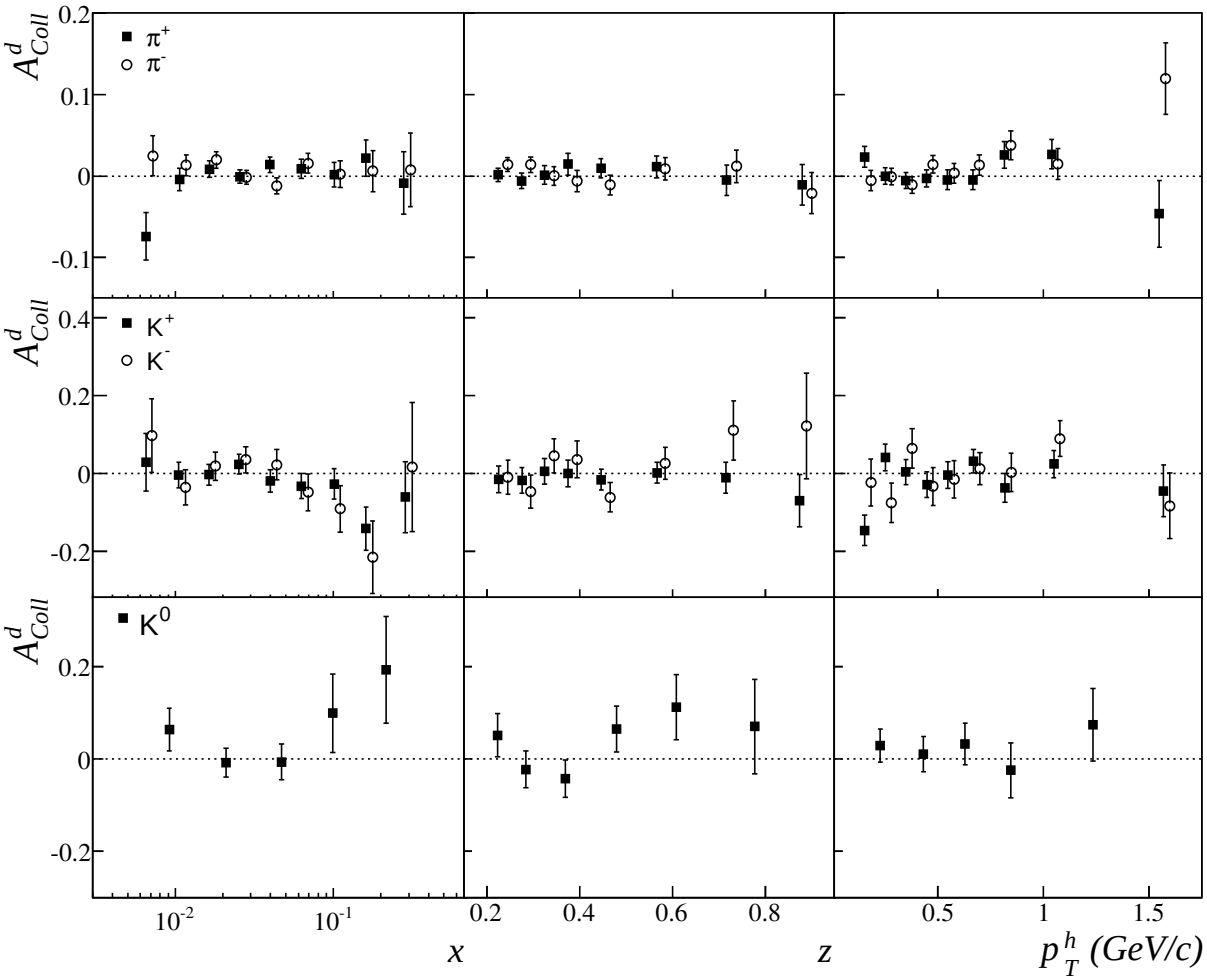
PLB 673 (2009) 127-135



all asymmetries are small, compatible with zero

systematical error: $\sigma_{sys} \leq 0.3\,\sigma_{stat}$

Collins Asymmetries: NH_3 (2007)

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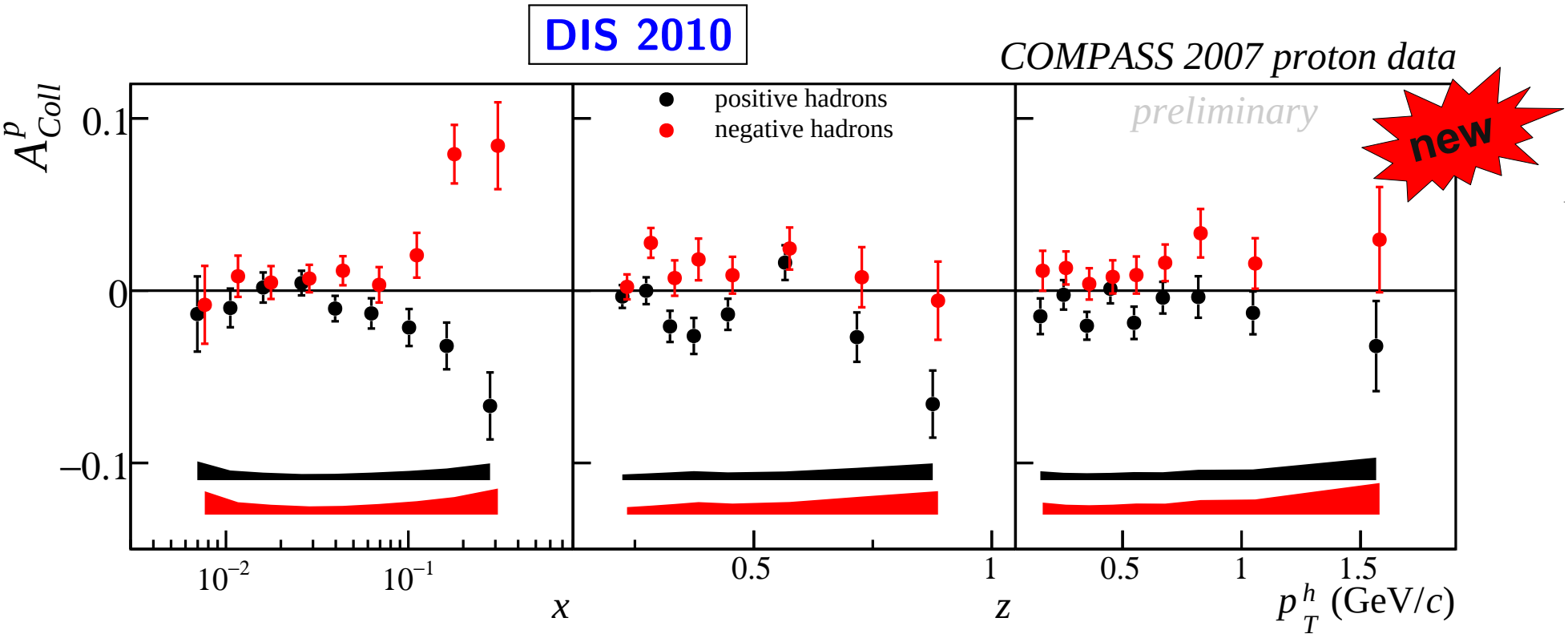
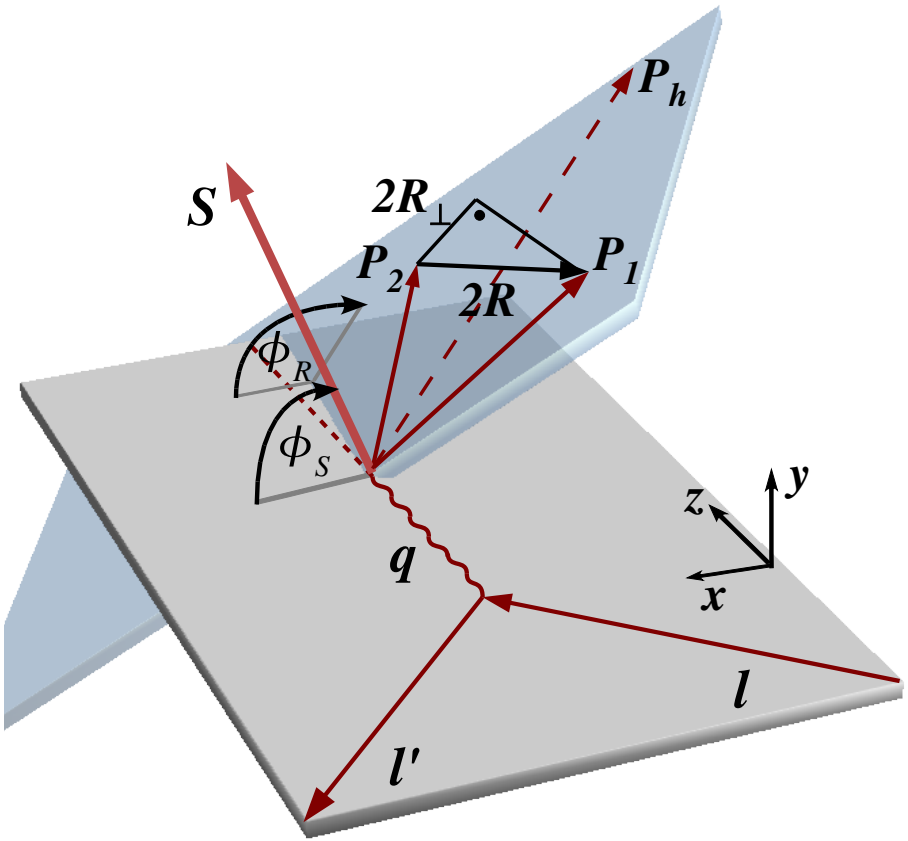


- Size and sign are compatible with HERMES results (corrected with $-1/D_{nn}$)
- Paper ready for PLB

Dihadron Interference

Measuring transversity with polarized Dihadron-Interference-FF $H_1^{\sphericalangle}$:



$\rightsquigarrow$ azimuthal asymmetry:

$$N_{h^+h^-} \propto 1 \pm A \cdot \sin\phi_{RS} \cdot \sin\theta$$

$$\phi_{RS} = \phi_R + \phi_S - \pi$$

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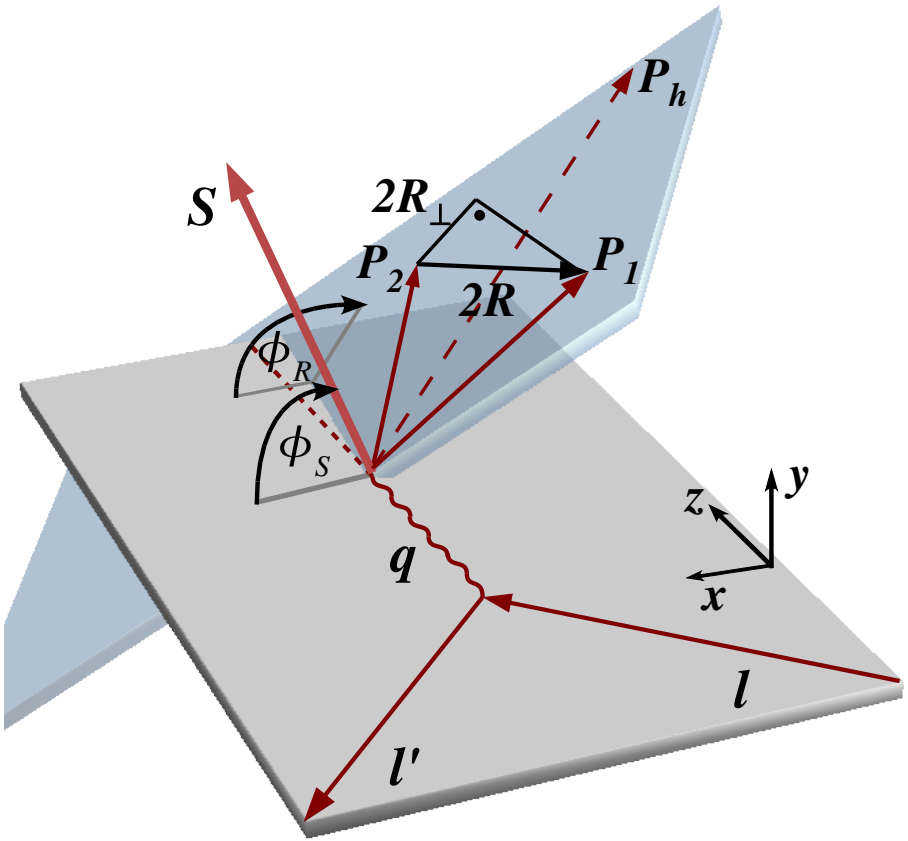

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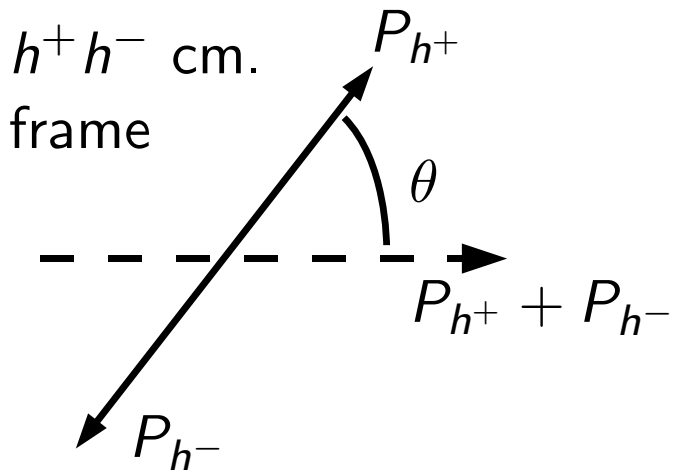

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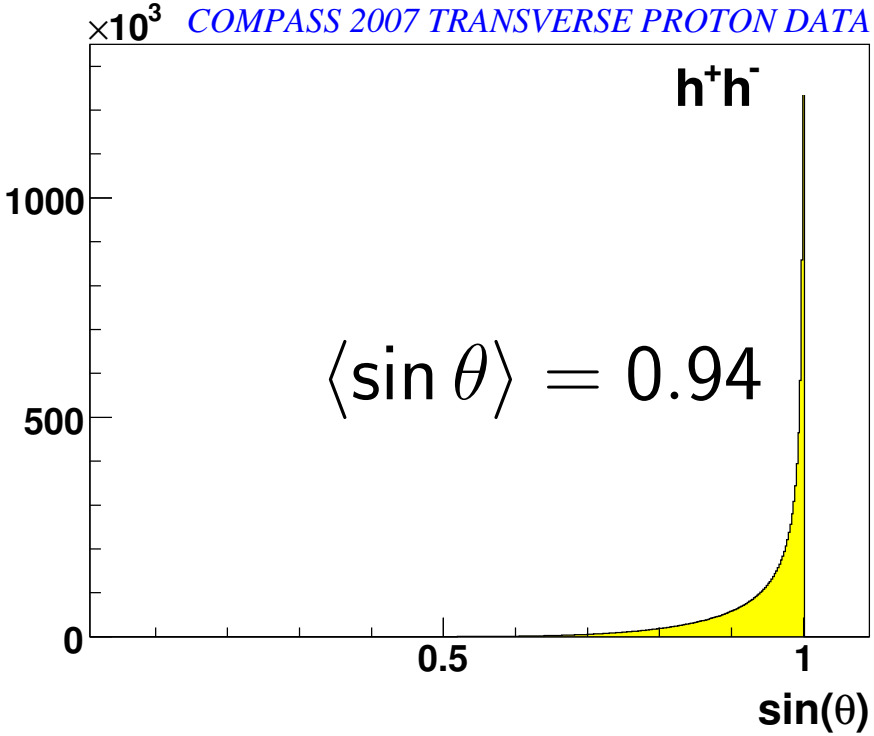

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For this analysis:
$\sin\theta$ can be neglected

Dihadron Interference

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$\rightsquigarrow$ azimuthal asymmetry:

$$N_{h^+h^-} \propto 1 \pm A \cdot \sin\phi_{RS} \cdot \sin\theta$$

$$\phi_{RS} = \phi_R + \phi_S - \pi$$

$$A_{RS} = \frac{A}{f\ P_T D_{nn}} \propto \sum_q e_q^2 \cdot \Delta_T q \cdot H_1^{\sphericalangle}$$

Dihadron Asymmetry: ^{6}LiD (2003-2004)

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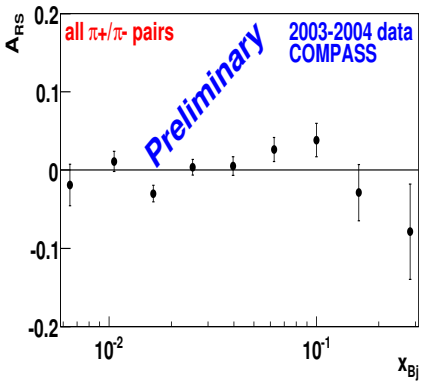

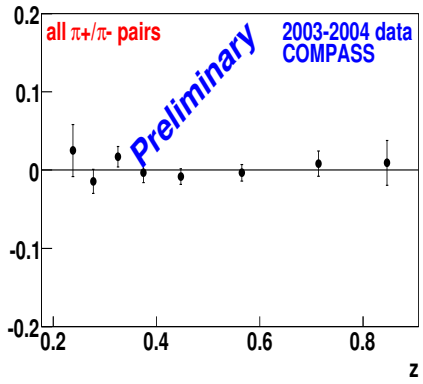

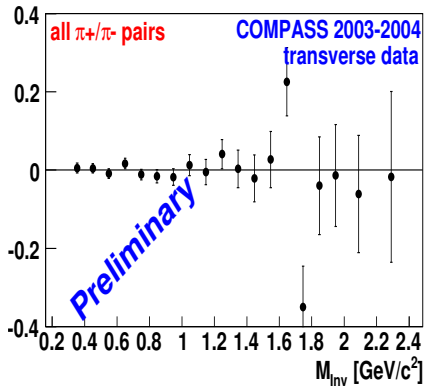

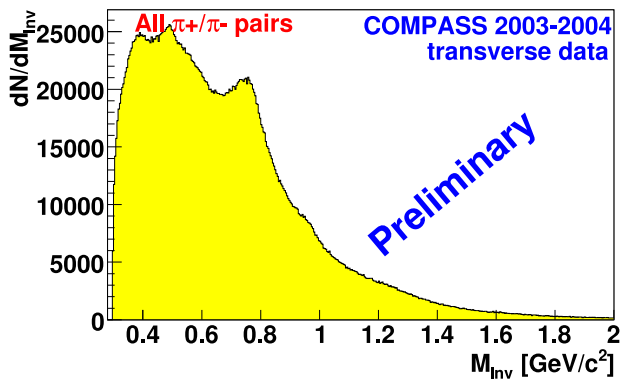

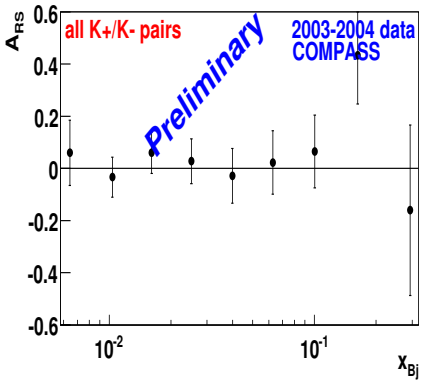

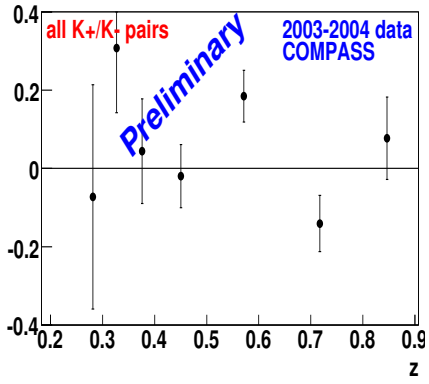

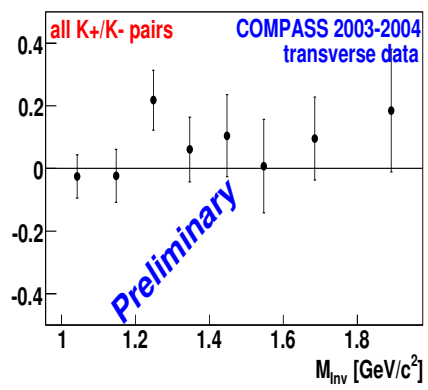

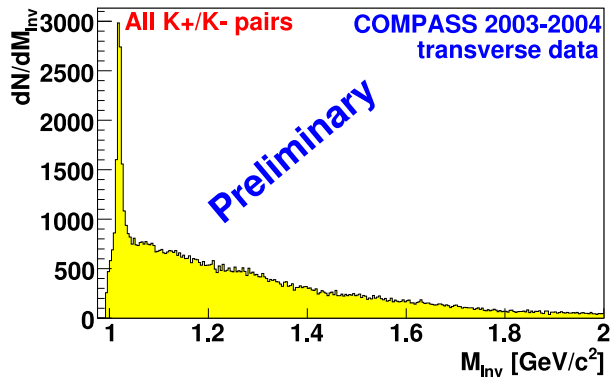

all asymmetries are small, compatible with zero

Dihadron Asymmetry: NH_3 (2007)

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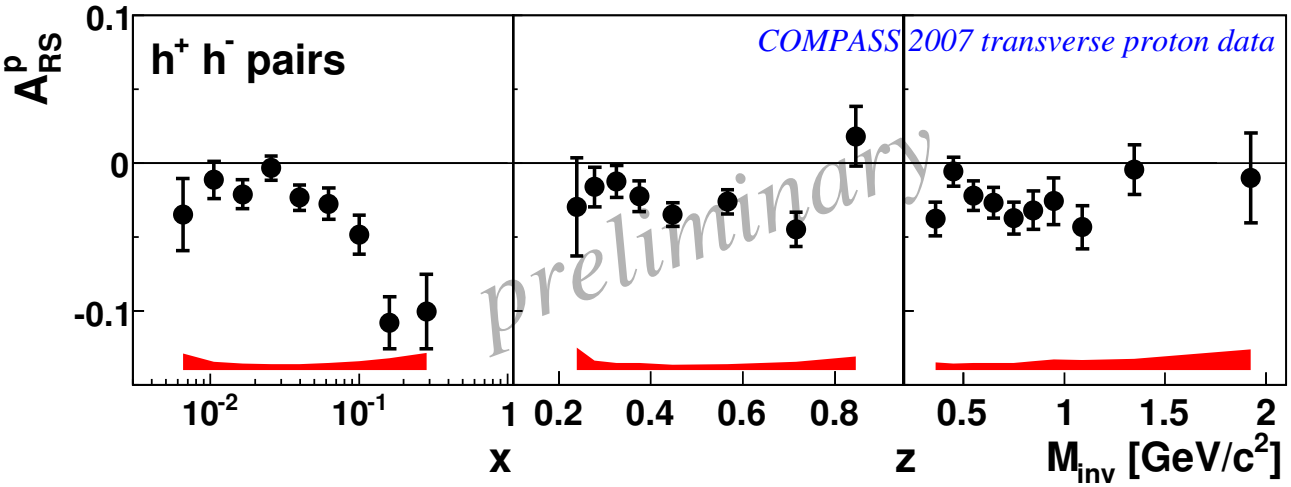
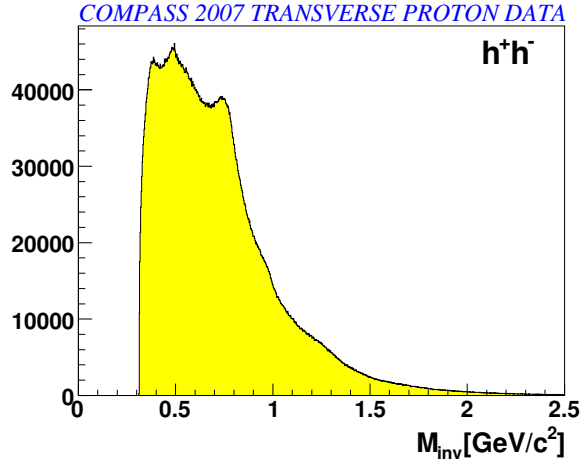
DIS 2009





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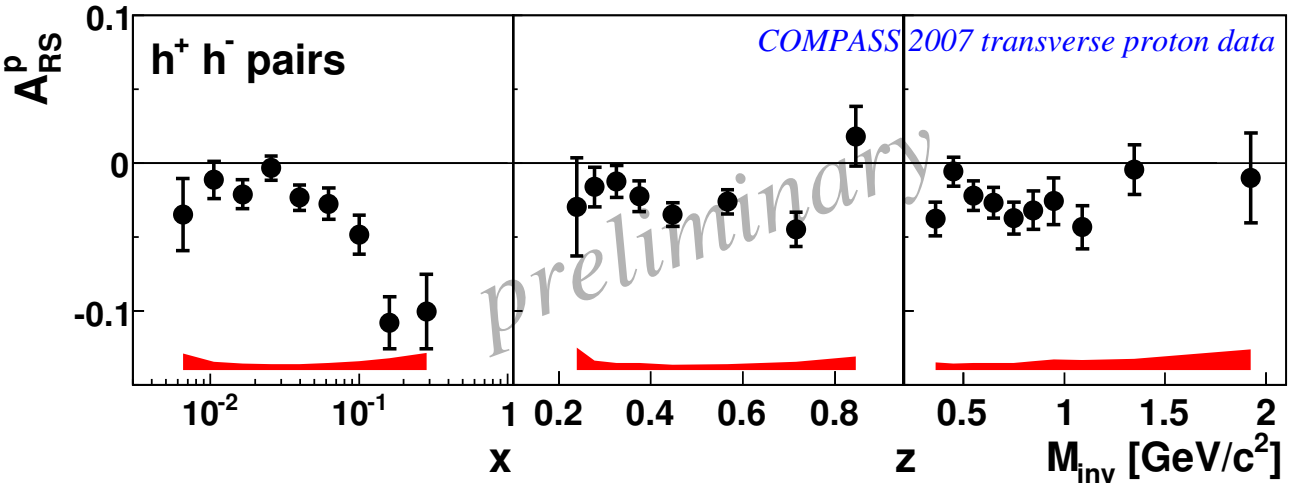

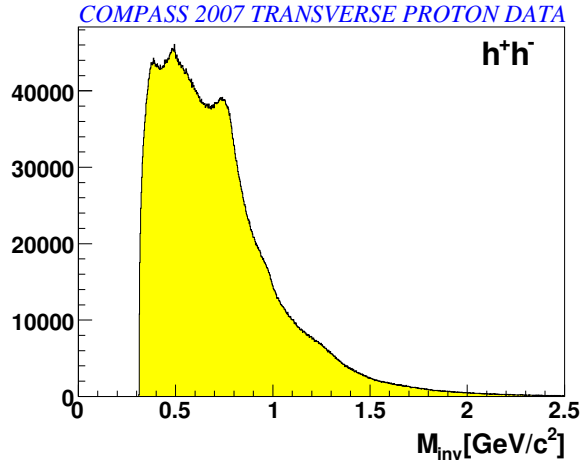

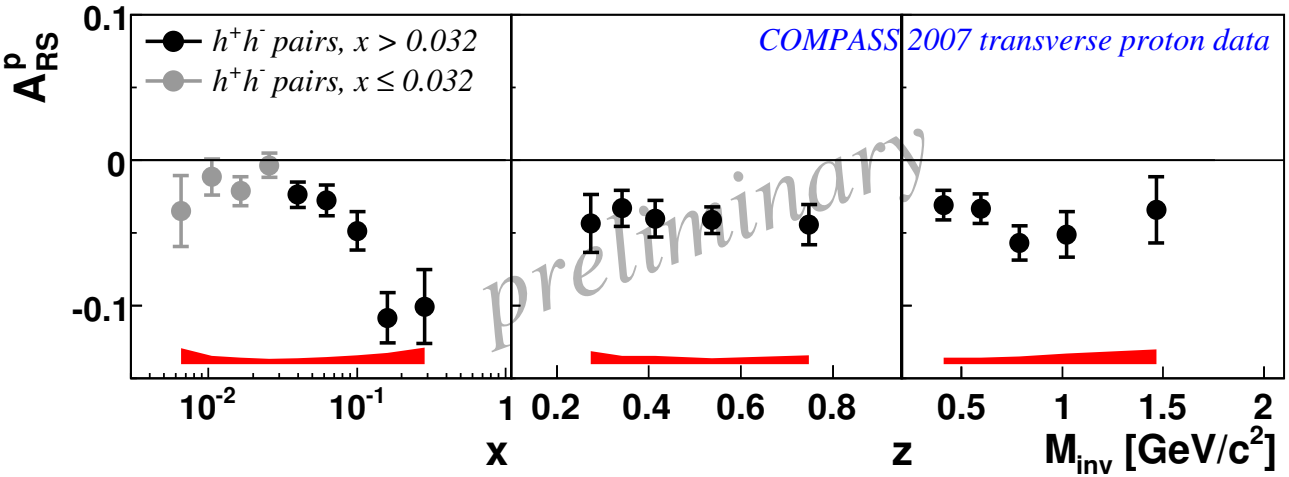

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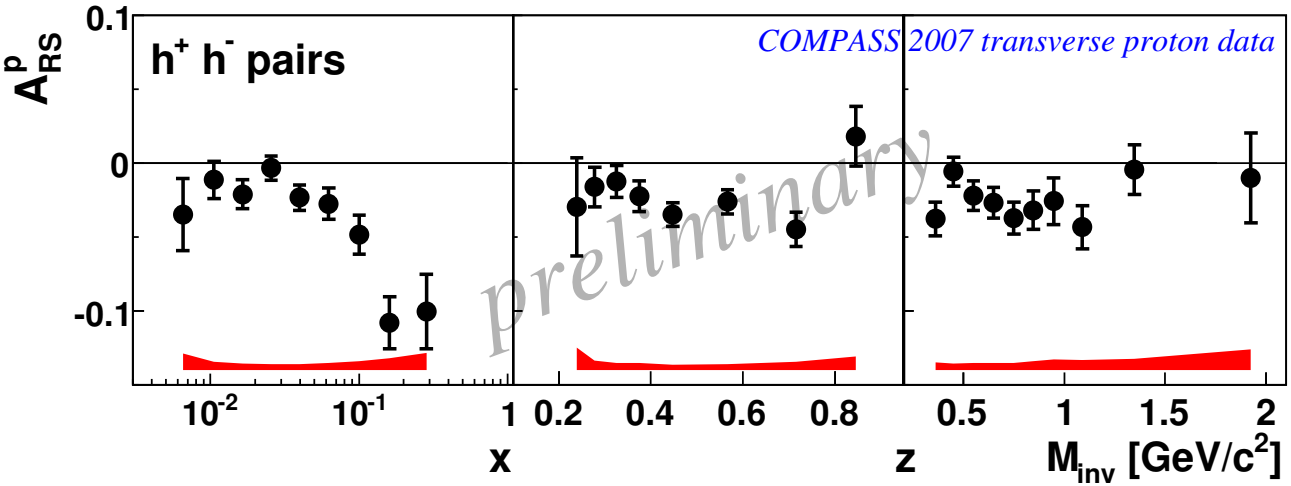

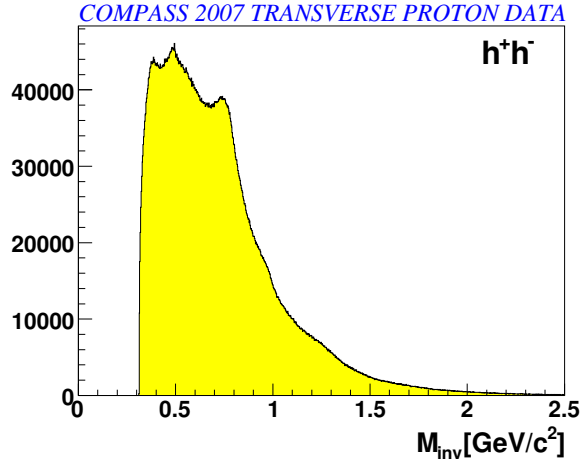

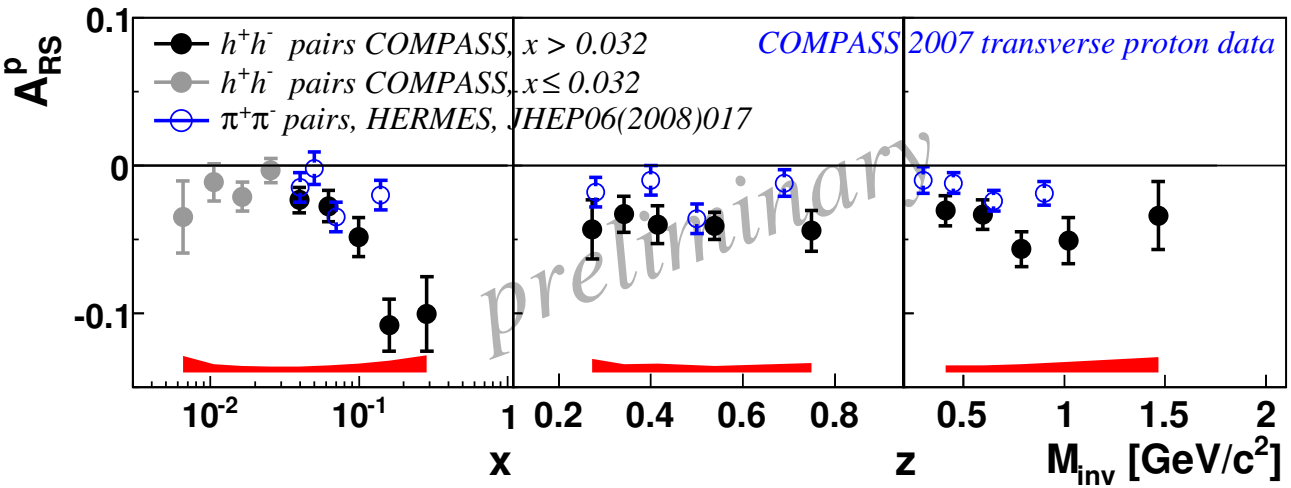

COMPASS measurement covers much larger range in x

Dihadron Asymmetry: NH_3 (2007)

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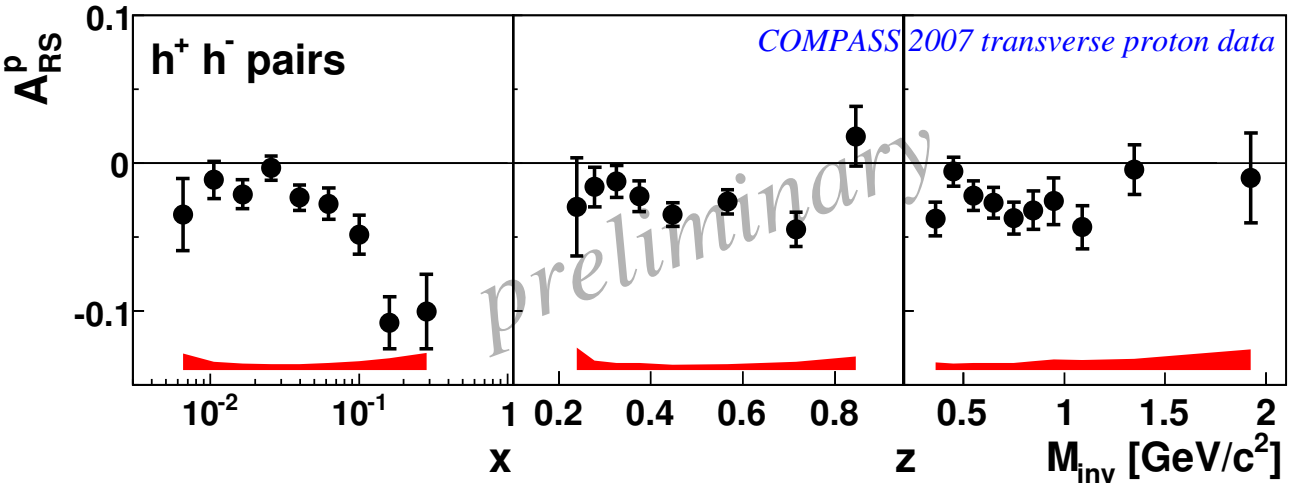

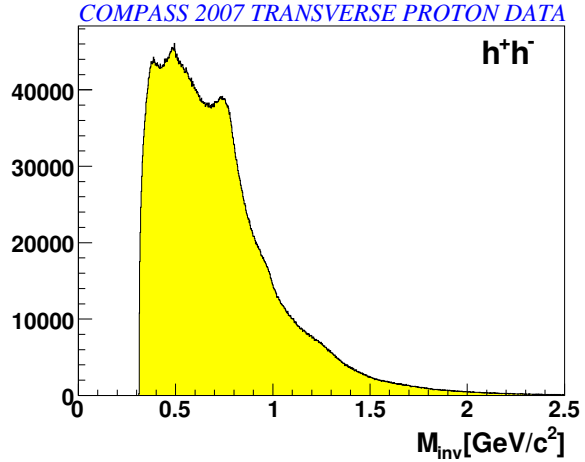

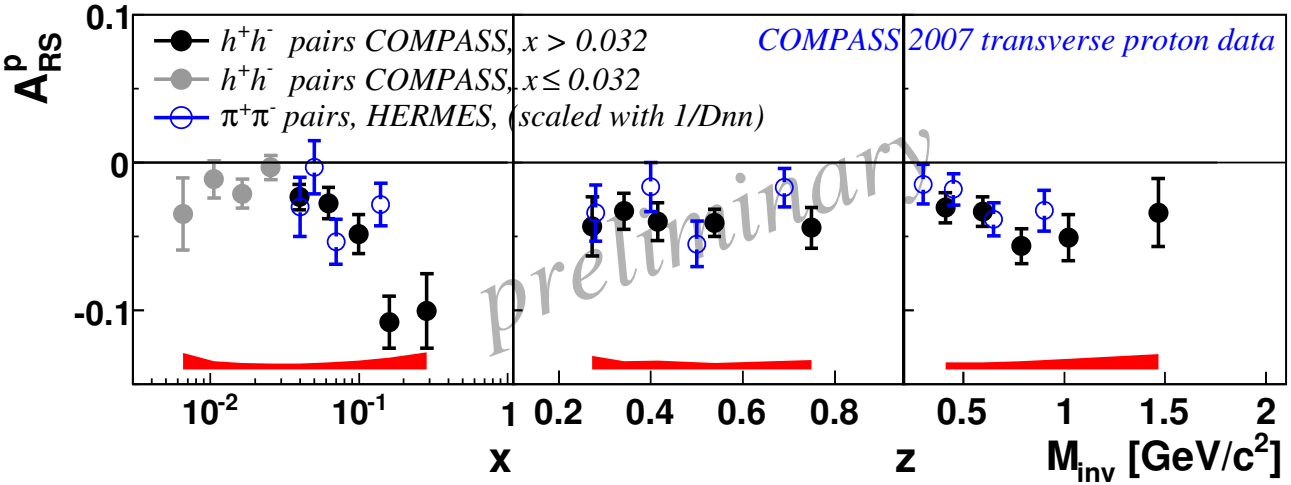

HERMES values scaled with $1/D_{nn}$

COMPASS measurement covers much larger range in x

Transverse Λ-Polarization

Measuring transversity with polarized Λ-FF $\Delta_T D_q^\Lambda$:

transversely polarized quark transfers its spin to Λ-Baryon

Λ-Polarization: $P_\Lambda \propto f\, P_T D_{nn} \sum_q e_q^2 \cdot \Delta_T q \cdot \Delta_T D_q^\Lambda$

measured via parity violating decay

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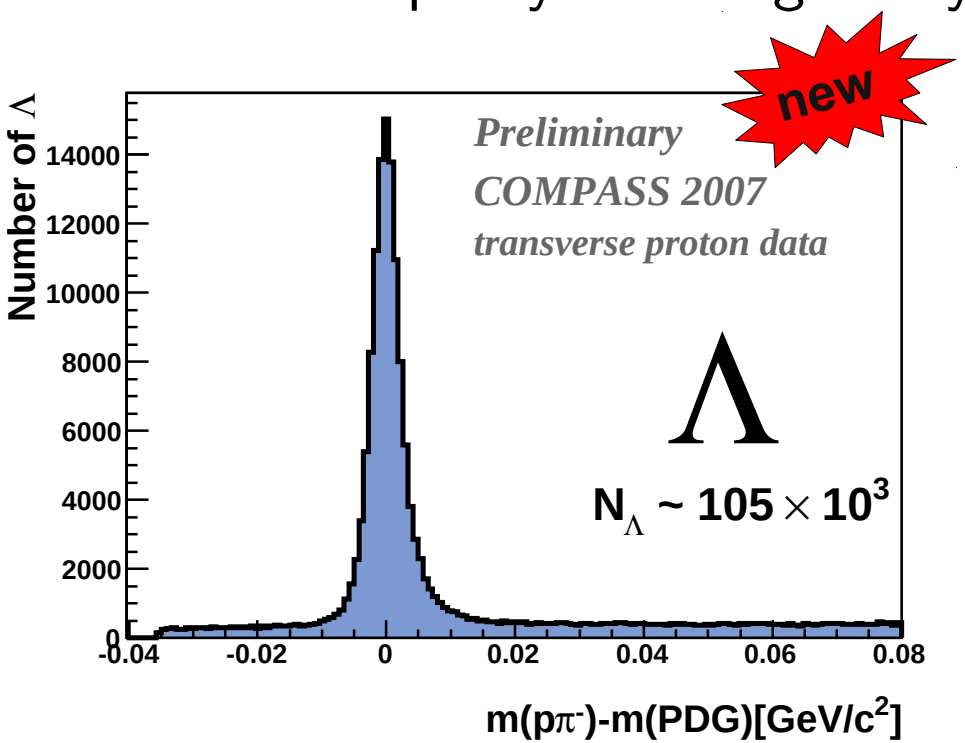
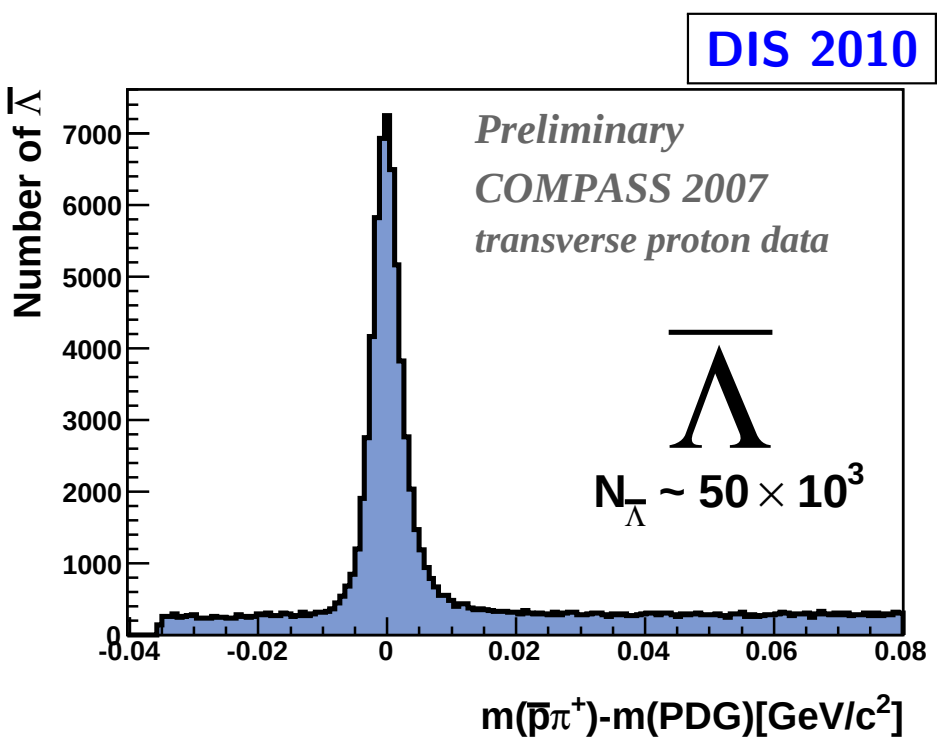


DIS 2010



Transverse Λ-Polarization: NH_3 (2007)

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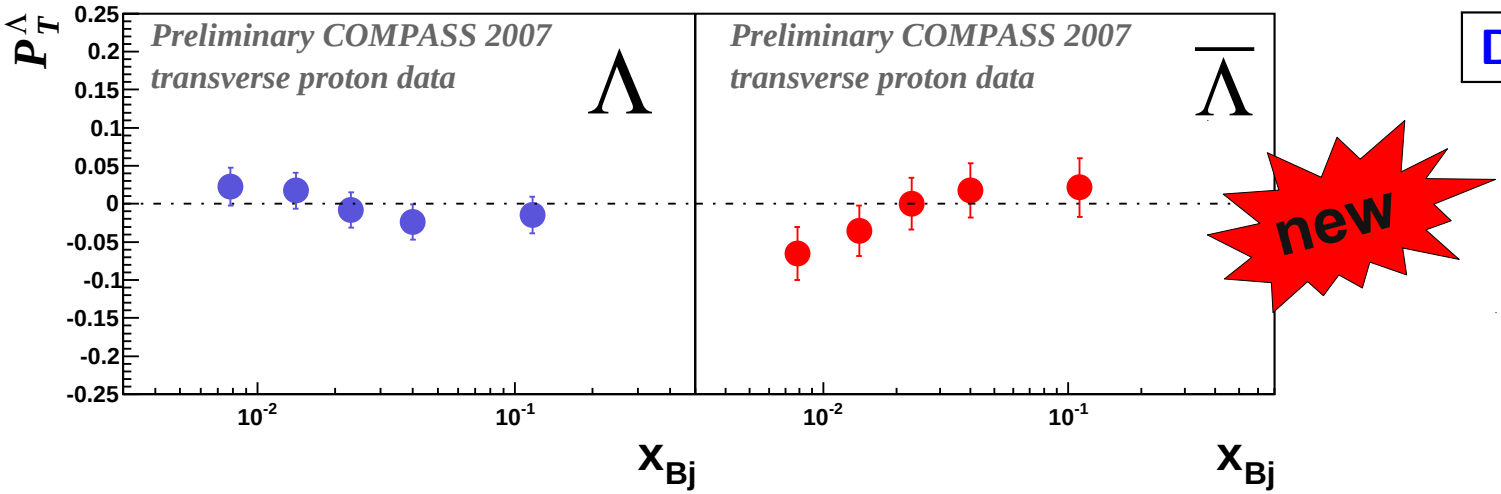

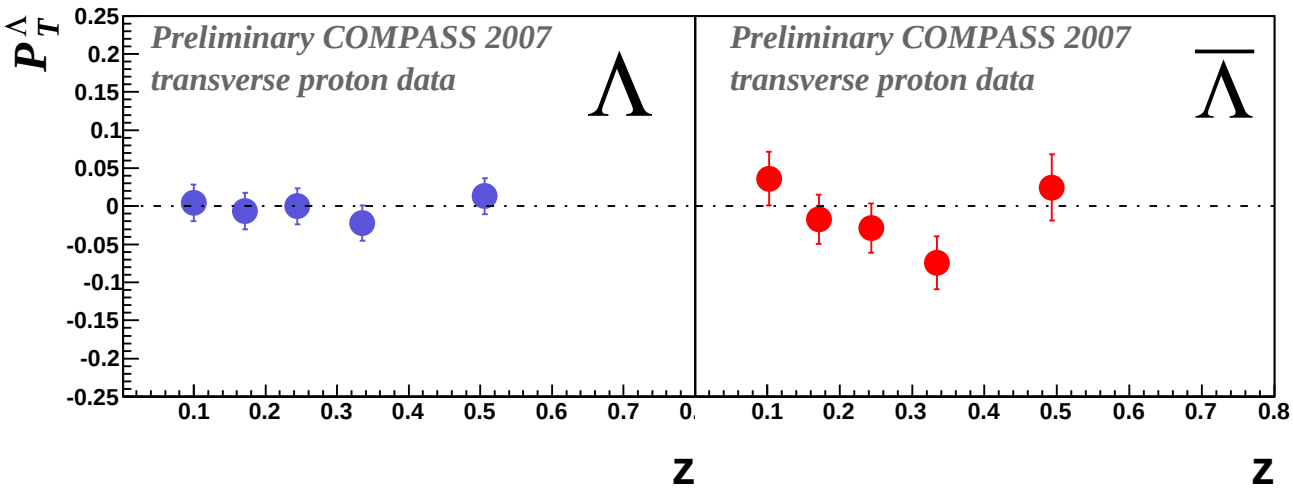

systematical error: $\sigma_{sys} \leq 0.74\,\sigma_{stat}$

P_T^Λ, $P_T^{\overline{\Lambda}}$ small, compatible with zero $\rightsquigarrow$ small analyzing power of $\Delta_T D_q^\Lambda$

P_T^Λ, $P_T^{\overline{\Lambda}}$ for deuteron also compatible with zero

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TMDs

General Expression of polarized SIDIS Cross-Section

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

$$+|\boldsymbol{S}_\perp|\left[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)\right.$$

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}$$

$$+|\boldsymbol{S}_\perp|\lambda_e\left[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}\right.$$

$$\left.\left.+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\right]\right\},$$

unpolarized target

longitudinally polarized target

transversely polarized target

A.Bacchetta et al

JHEP 0702:093,2007

E-print number: hep-ph/0611265

SIDIS Cross-Section: Transversely Polarized Target

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{\ \ldots$$

$$+\,|\boldsymbol{S}_\perp|\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},$$

twist-2

twist-3

A.Bacchetta et al

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$$+\,|\boldsymbol{S}_\perp|\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},$$

twist-2

twist-3

Collins ✓

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JHEP 0702:093,2007

E-print number: hep-ph/0611265

SIDIS Cross-Section: Transversely Polarized Target

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{\ \ldots$$

$$+\,|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

twist-2

twist-3

Sivers

Collins ✓

A.Bacchetta et al

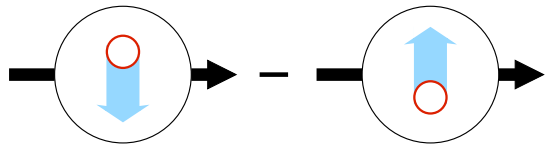
JHEP 0702:093,2007

E-print number: hep-ph/0611265

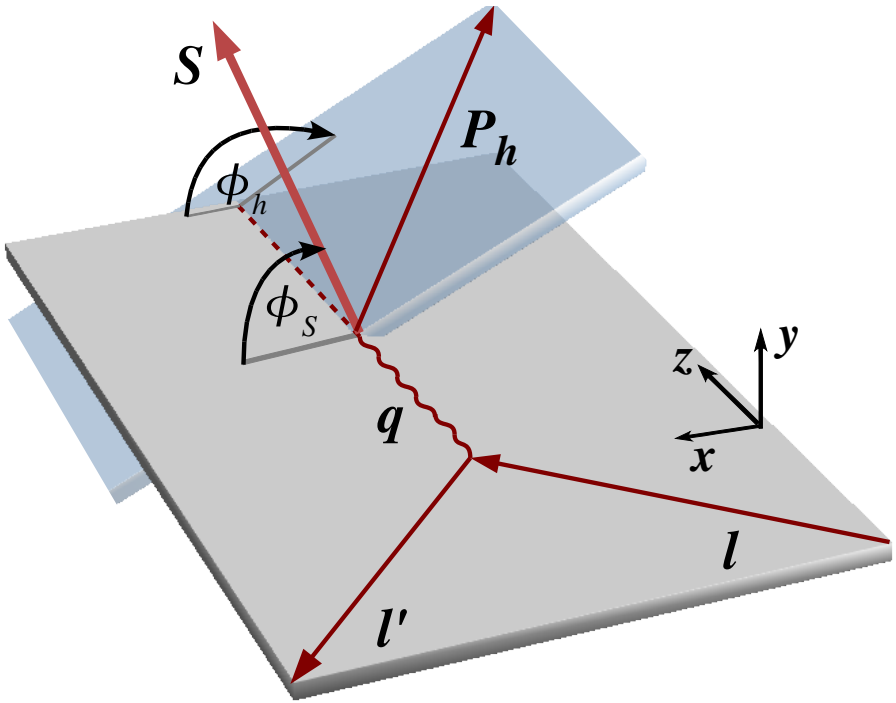
Sivers Asymmetry

$F_{UT,T}^{\sin(\phi_h-\phi_S)} \propto \Delta_0^T q \otimes D_q^h$

Sivers PDF $\Delta_0^T q$:



correlation between intrinsic transverse momentum
of the quarks and the transverse polarization of the nucleon



$\rightsquigarrow$ azimuthal asymmetry:

$$N_h \propto 1 \pm A \cdot \sin(\phi_h - \phi_S)$$

ϕ_h: azimuthal angle of hadron

ϕ_S: azimuthal angle of spin of initial quark

$$A_{Siv} = \frac{A}{f\ P_T} \propto \sum_q e_q^2 \cdot \Delta_0^T q \otimes D_q^h$$

Sivers Asymmetries: ^{6}LiD (2003-2004)

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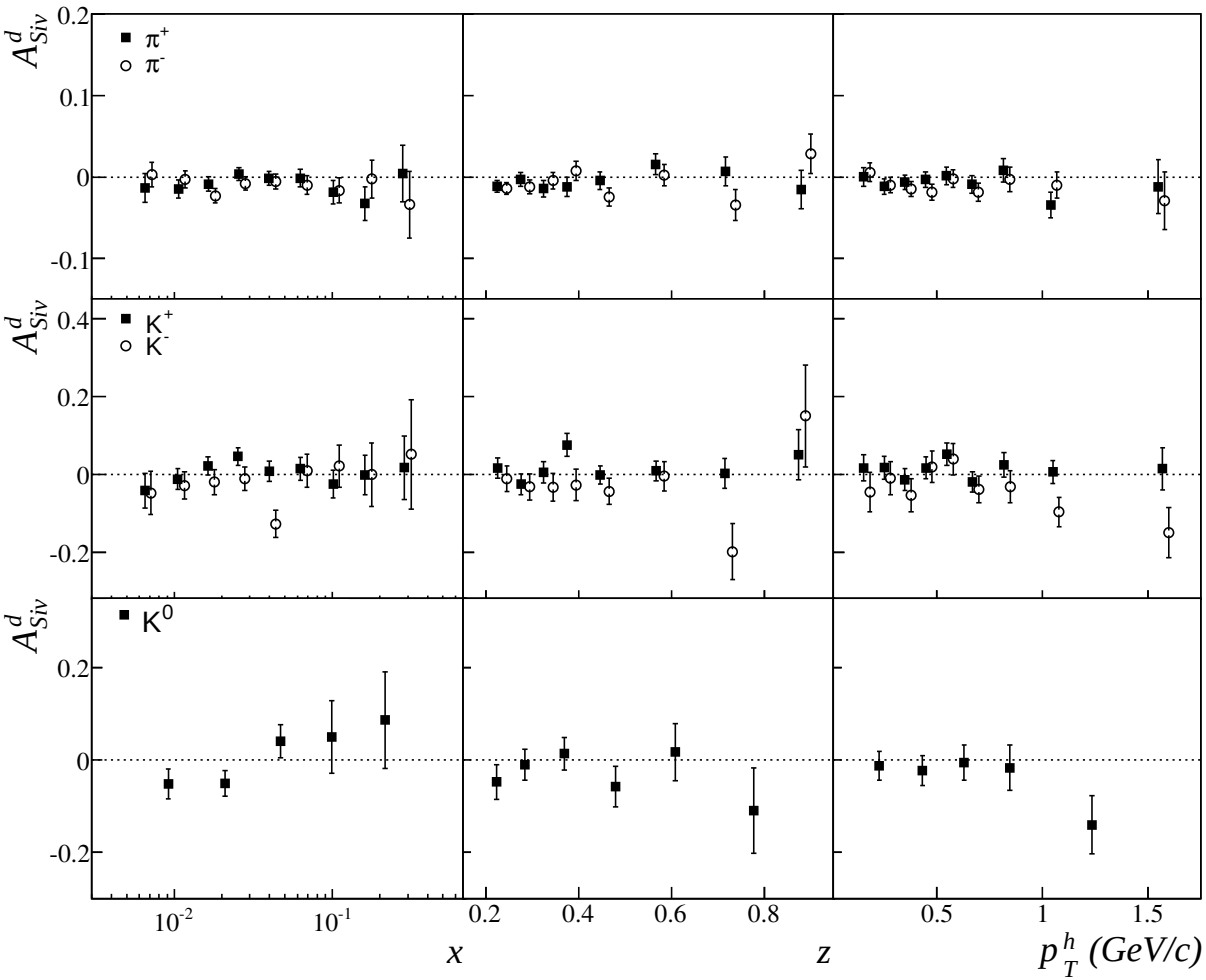
PLB 673 (2009) 127-135



all asymmetries are small, compatible with zero

systematical error: $\sigma_{sys} \leq 0.3\,\sigma_{stat}$

Sivers Asymmetries: NH_3 (2007)

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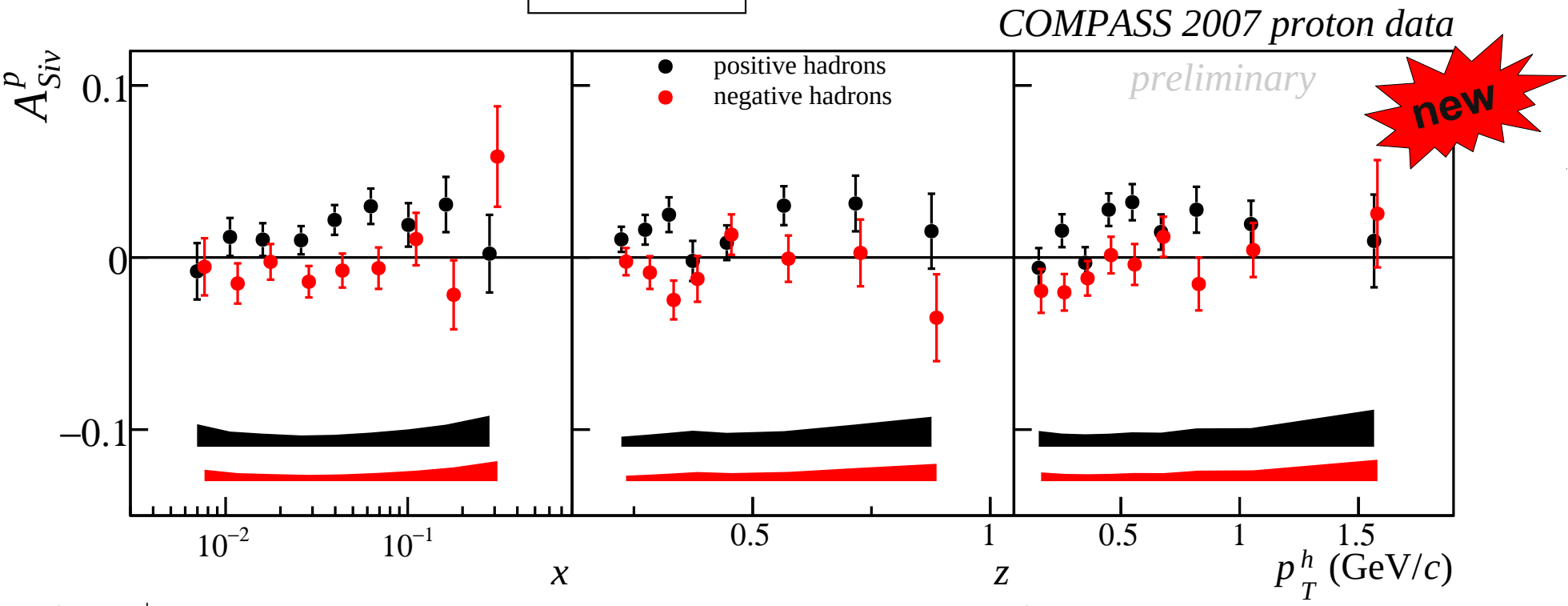
DIS 2010



for h^+ additional absolute systematical uncertainty of ± 0.01

- positive asymmetry for h^+
- asymmetry for h^- small, compatible with zero
- Paper ready for PLB

Sivers Asymmetries: NH_3 (2007)

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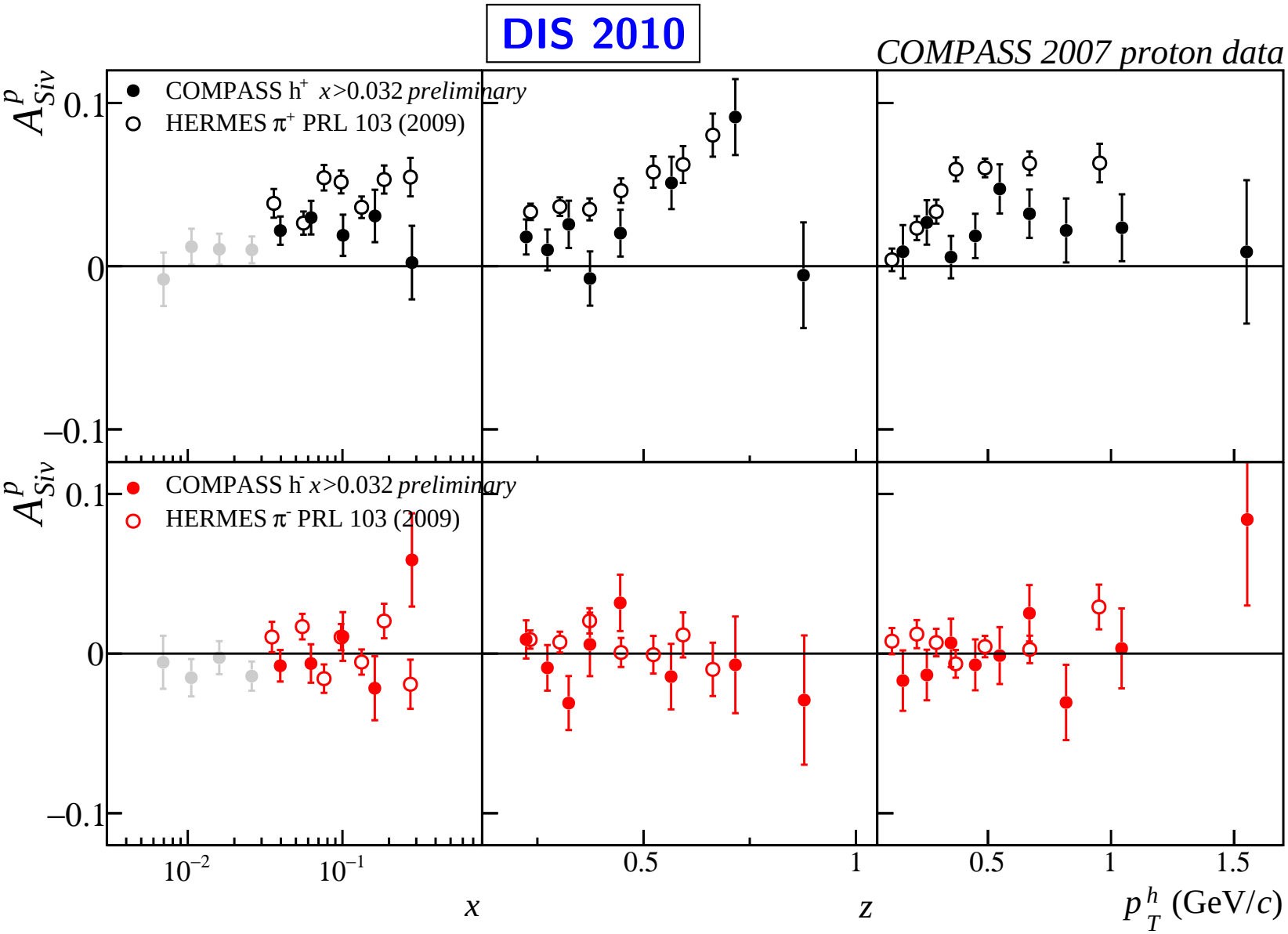

- COMPASS h^+ about factor 2 smaller than HERMES

Sivers Asymmetries: NH_3 (2007)

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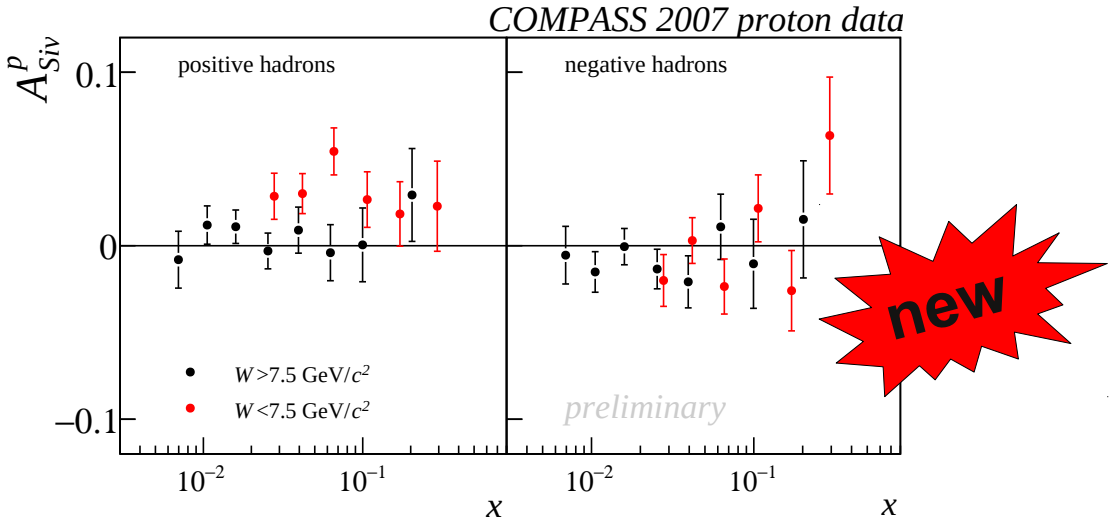
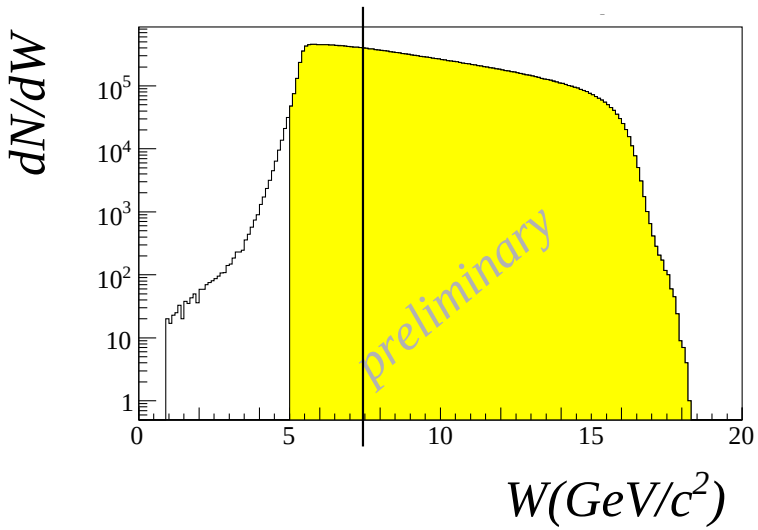
DIS 2010



possible W dependence



Sivers Asymmetries: NH_3 (2007)

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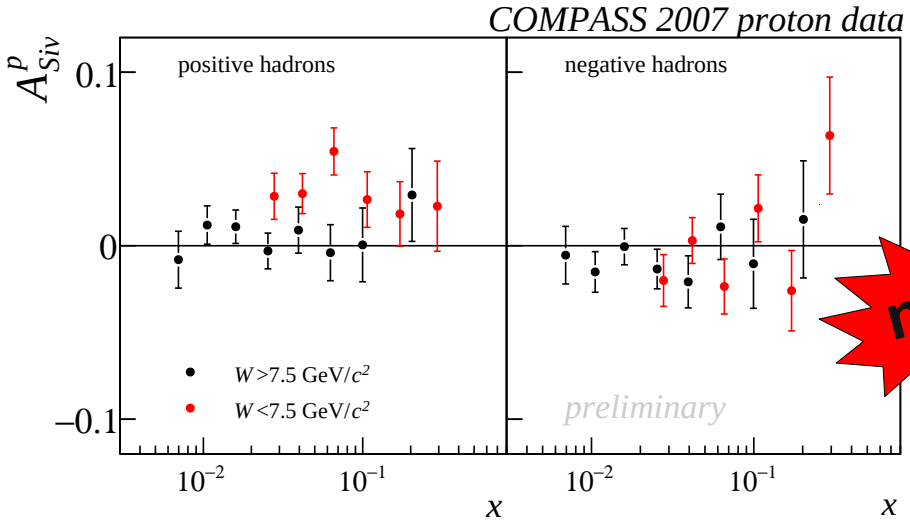
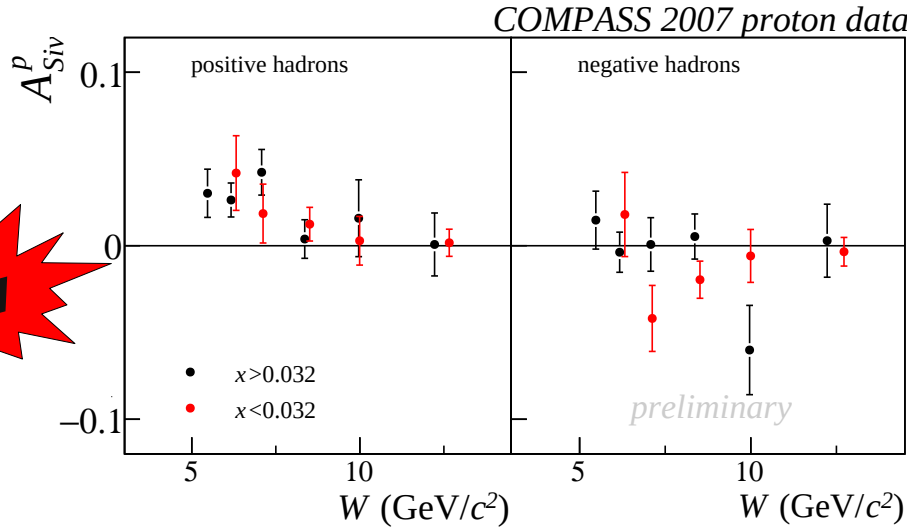
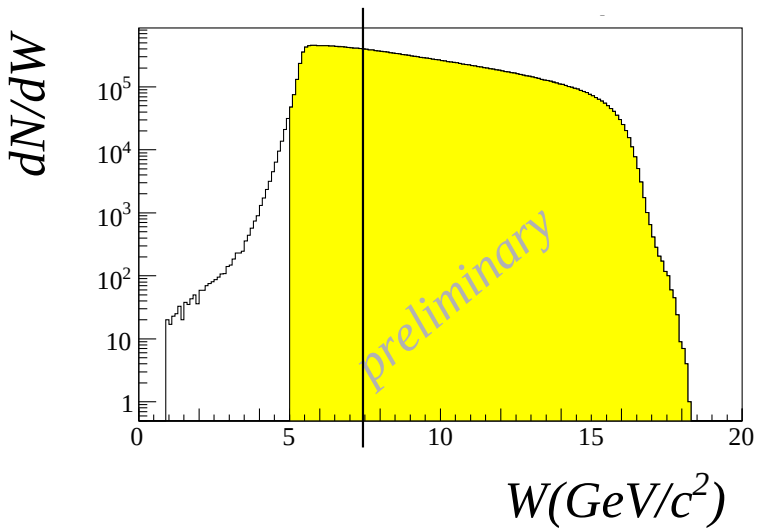
DIS 2010

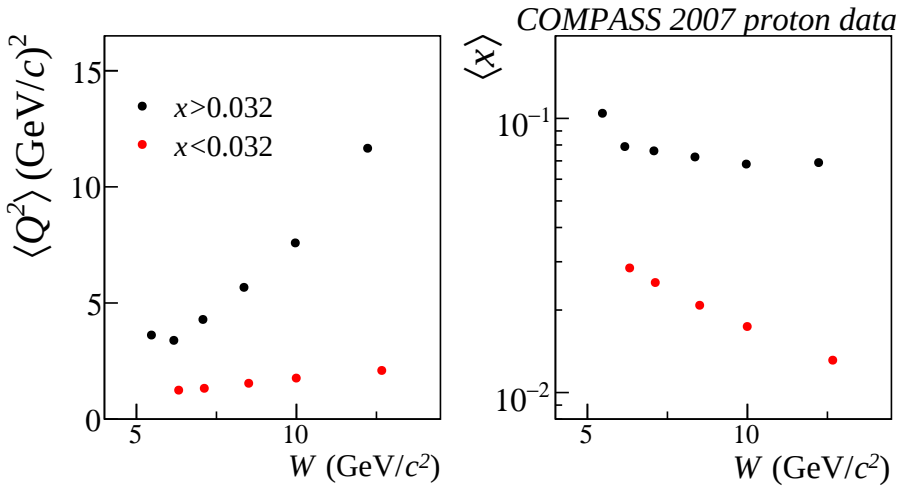


new



possible W dependence





SIDIS Cross-Section: transversely polarized target

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

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$$+\,|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},$$

twist-2

twist-3

Sivers ✓

Collins ✓

A.Bacchetta et al

JHEP 0702:093,2007

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$$+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}$$

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$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},$$

twist-2

twist-3

Sivers ✓

Collins ✓

Pretzelosity

Worm Gear

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JHEP 0702:093,2007

E-print number: hep-ph/0611265

Pretzelosity and Worm Gear: ^{6}LiD (2002-2004)

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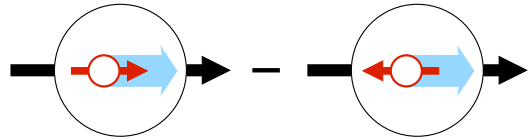
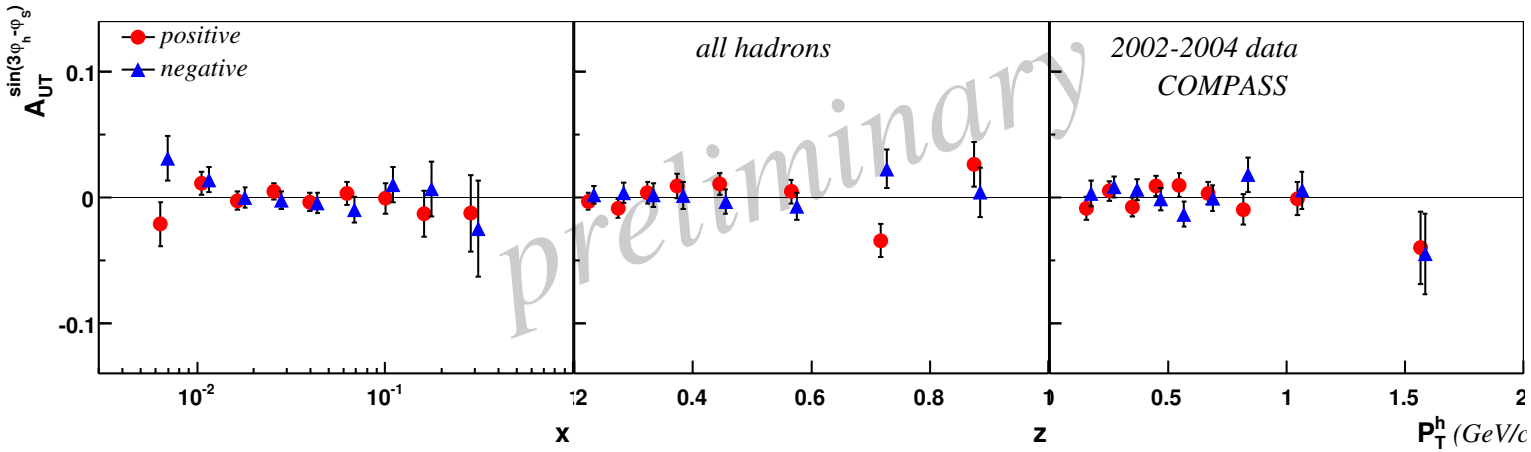
$F_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T}^{\perp,q} \otimes \Delta_T^0 D_q^h$, Pretzelosity PDF $h_{1T}^{\perp,q}$:





Pretzelosity and Worm Gear: ^{6}LiD (2002-2004)

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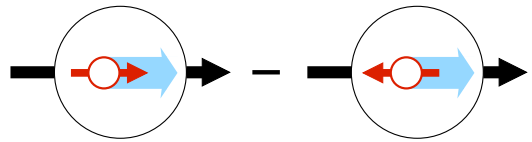
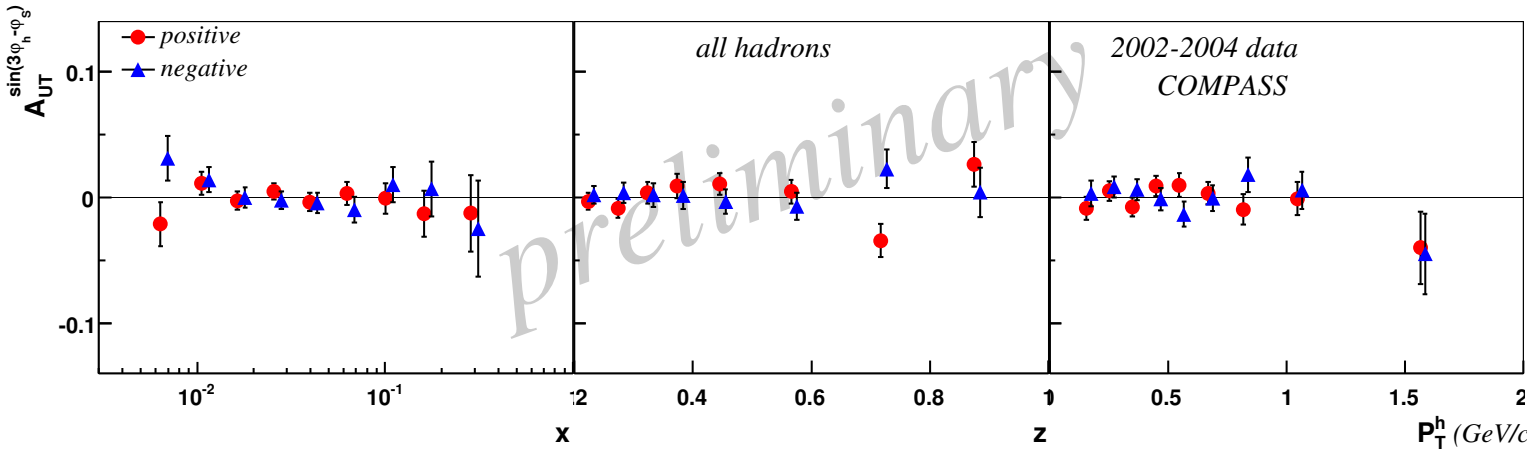
$F_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T}^{\perp,q} \otimes \Delta_T^0 D_q^h$,

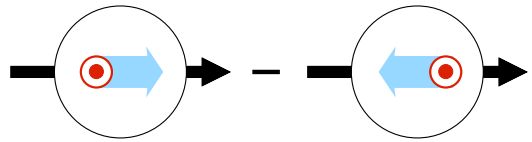
Pretzelosity PDF $h_{1T}^{\perp,q}$:

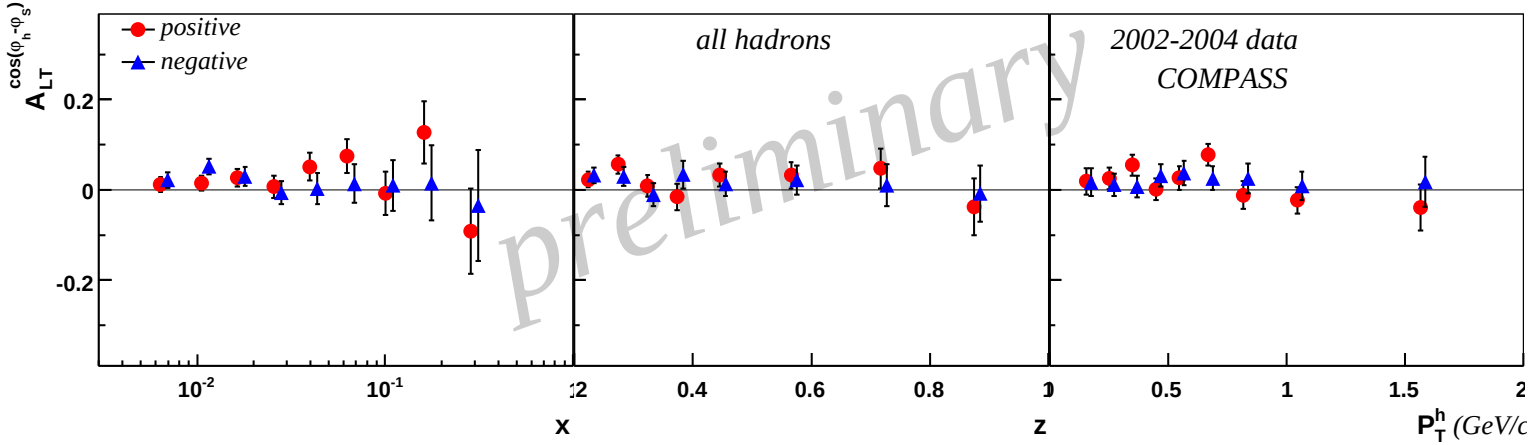




$F_{LT}^{\cos(\phi_h-\phi_S)} \propto g_{1T}^q \otimes D_q^h$,

Worm Gear PDF g_{1T}^q:





Twist-3 Structure Functions: ^{6}LiD (2002-2004)

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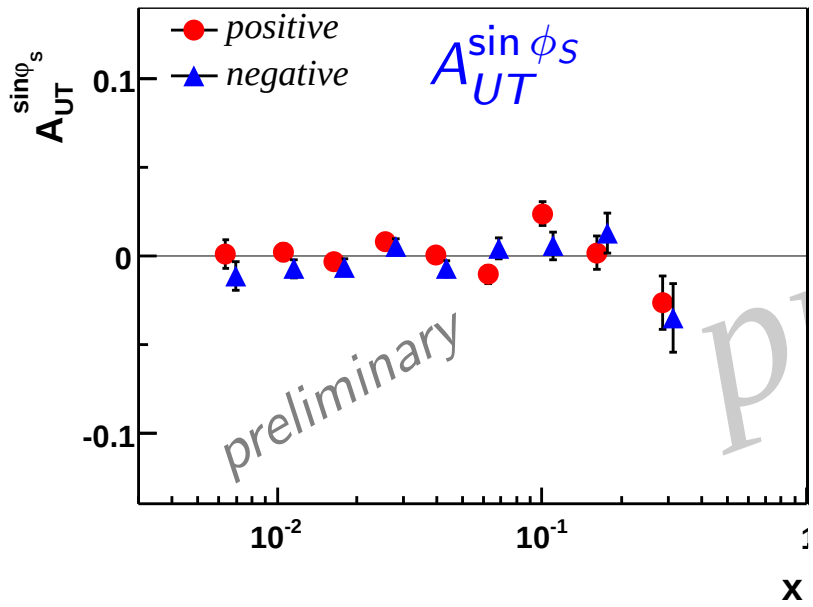

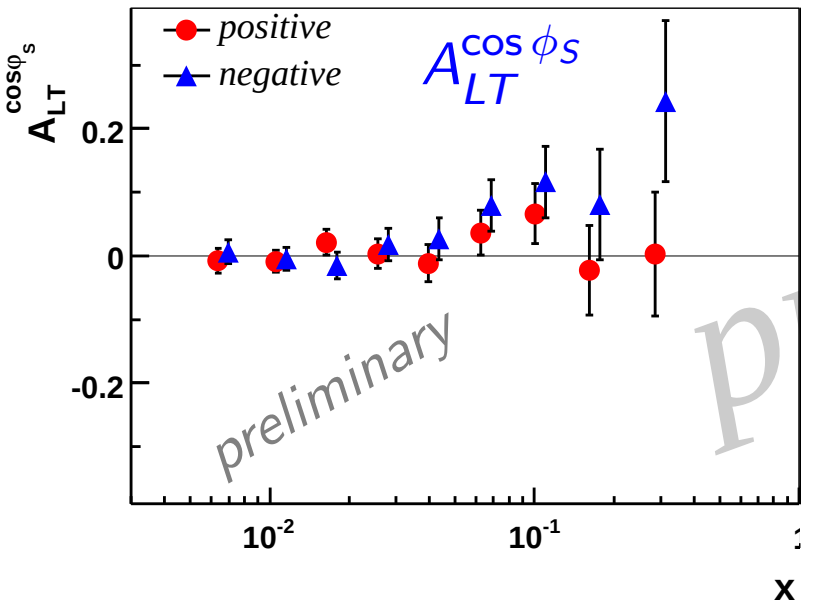

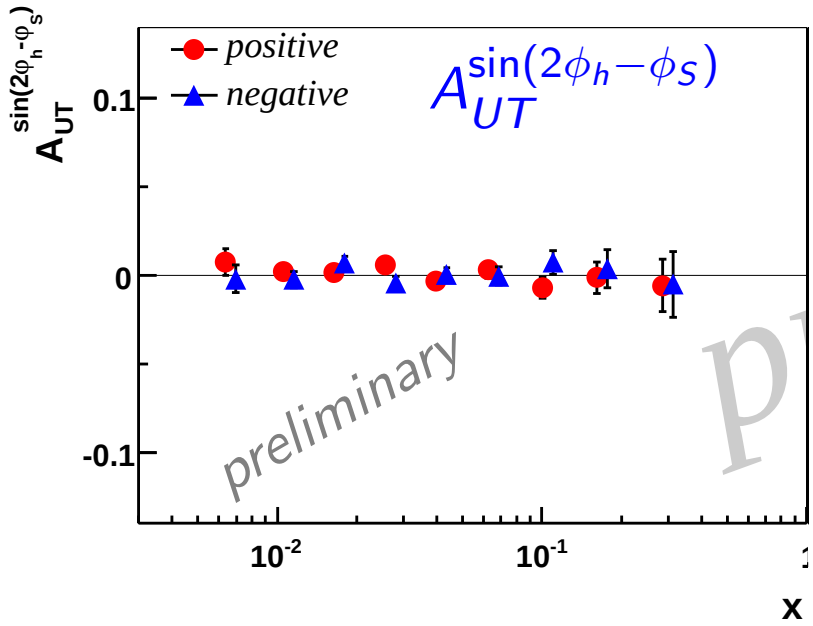

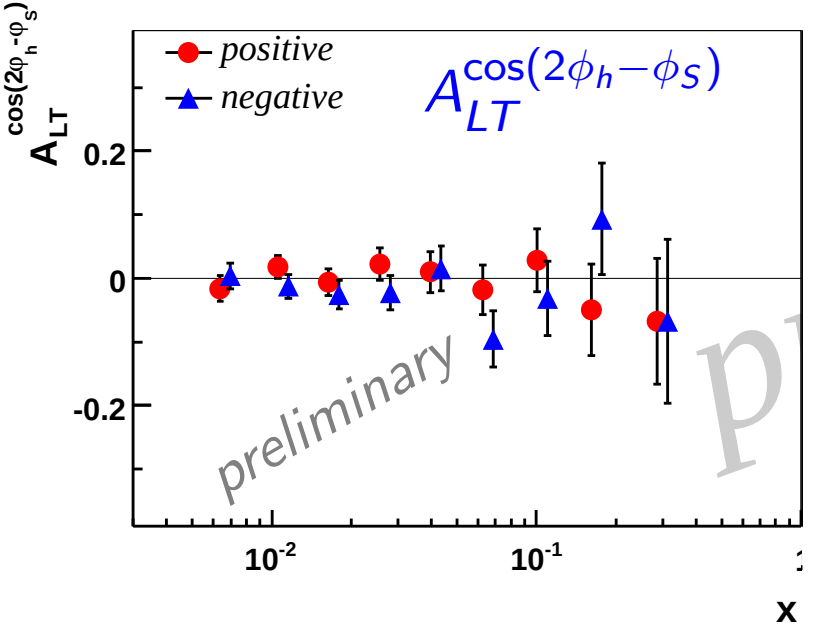

SIDIS Cross-Section: unpolarized target

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$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon\,F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\,\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

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JHEP 0702:093,2007

E-print number: hep-ph/0611265

- $F_{UU}^{\cos\phi}$ and $F_{UU}^{\cos 2\phi}$: Cahn Effect + Boer-Mulders + pQCD
- $F_{LU}^{\sin\phi_h}$: beam asymmetry (beam polarization: $P_{\mu^+} \approx -80\,\%$)

SIDIS Cross-Section: unpolarized target

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- $F_{UU}^{\cos\phi}$ and $F_{UU}^{\cos 2\phi}$: Cahn Effect + Boer-Mulders + pQCD
- $F_{LU}^{\sin\phi_h}$: beam asymmetry (beam polarization: $P_{\mu^+} \approx -80\,\%$)
- Target polarization canceled by event weighting
- Detector acceptance corrected by MC simulation

Unpolarized Asymmetries: ^{6}LiD (2004 part)

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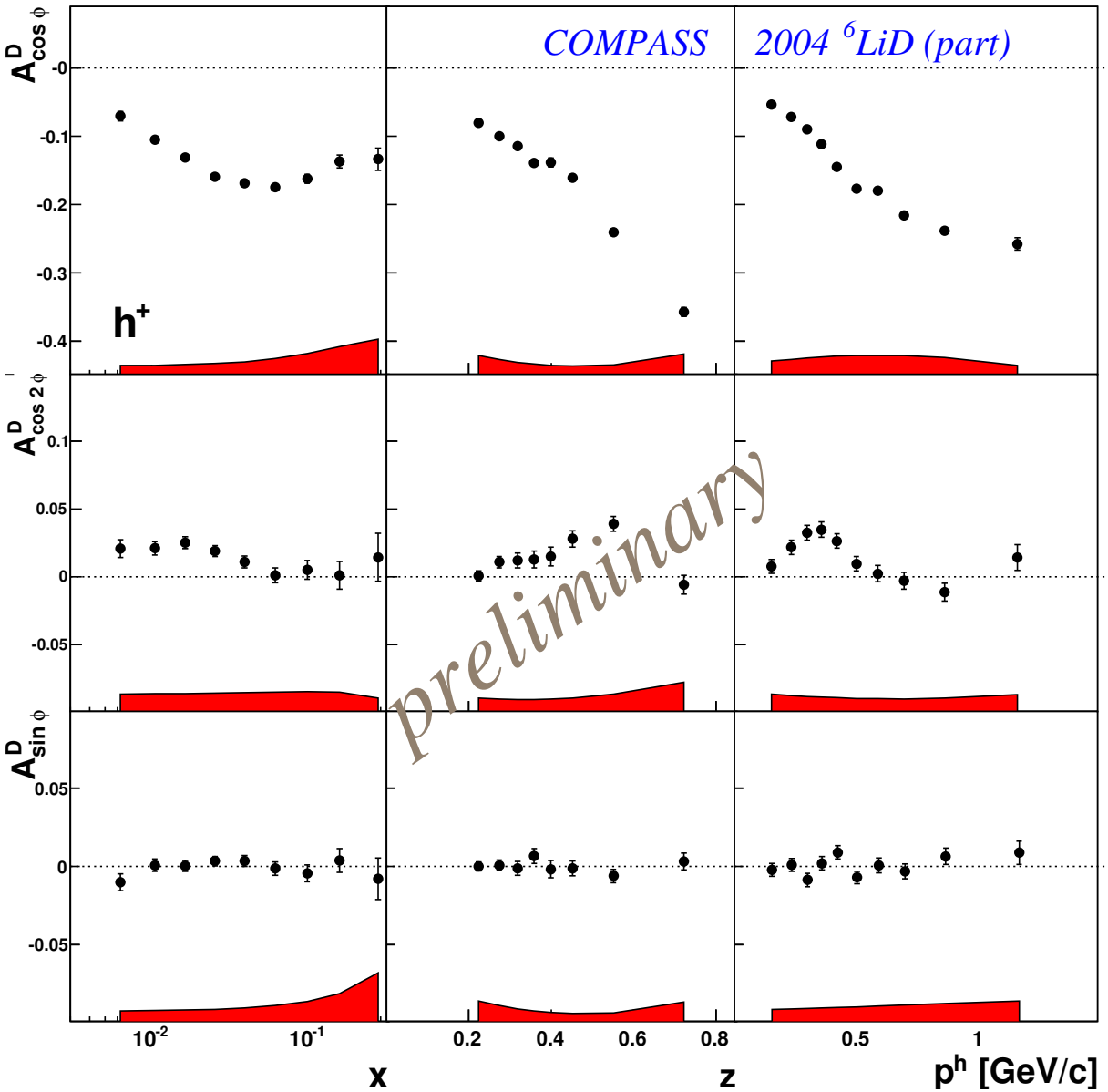
Transversity 2008



h^+

note the different y-scales

Unpolarized Asymmetries: ^{6}LiD (2004 part)

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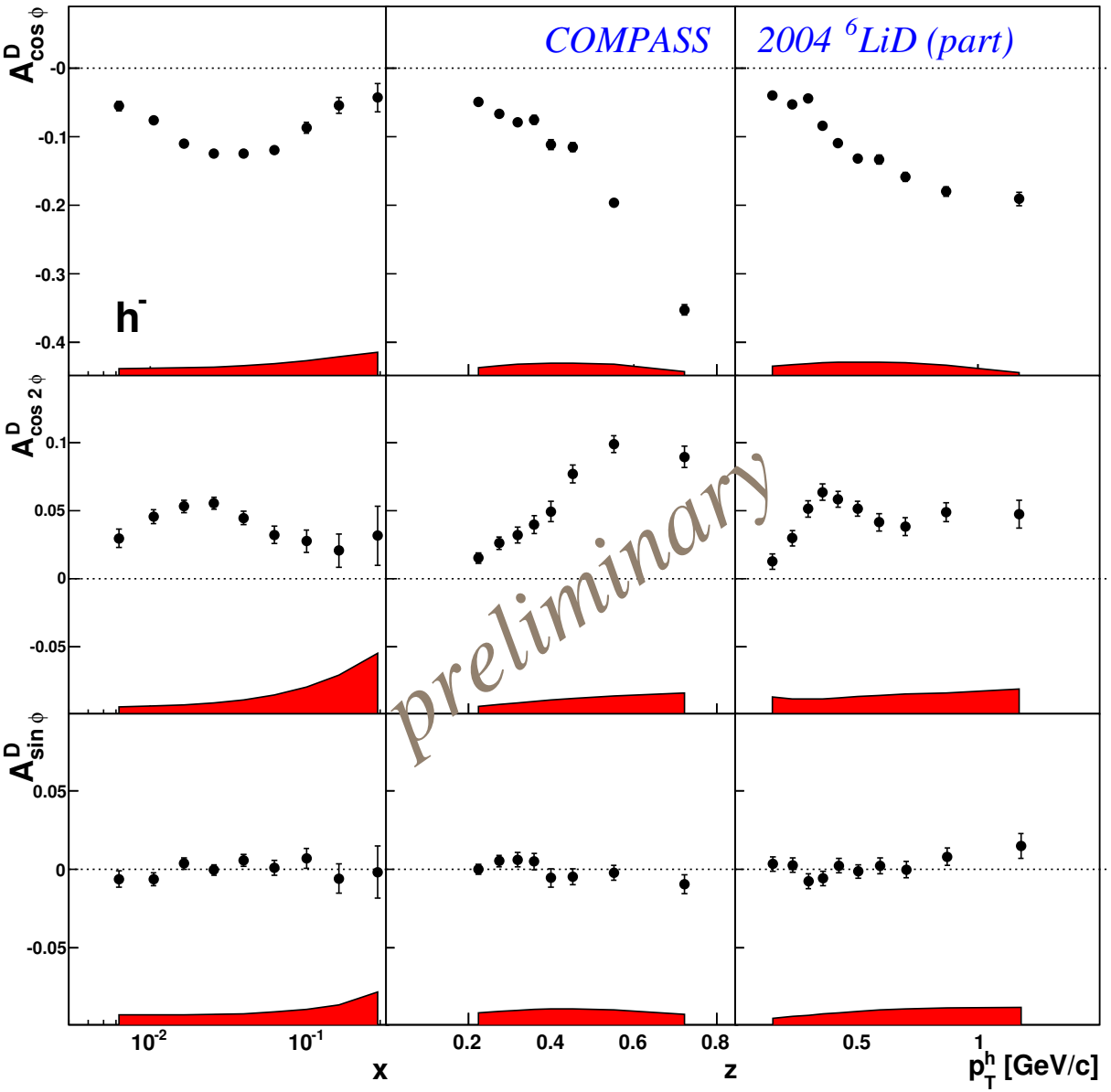
Transversity 2008



h^-

note the different y-scales

SIDIS Cross-Section: Longitudinally Polarized Target

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{\ \ldots$$

$$+\,S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\,\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+\,S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

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JHEP 0702:093,2007

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- $F_{LL} \propto \Delta q \otimes D_q^h$
- $F_{UL}^{\sin\phi_h}$, $F_{UL}^{\sin 2\phi_h}$, $F_{LL}^{\cos\phi_h}$: twist-3, complex parton picture

Longitudinally Polarized Target: ^{6}LiD (2002-2004)

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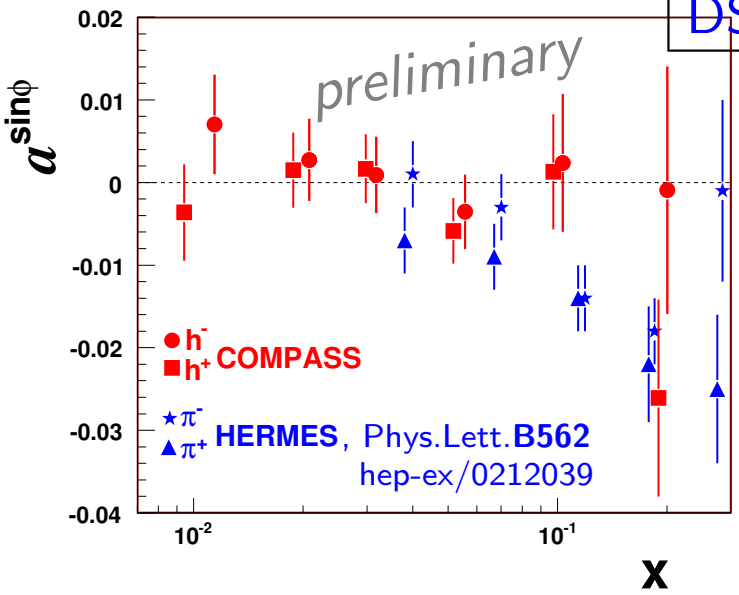
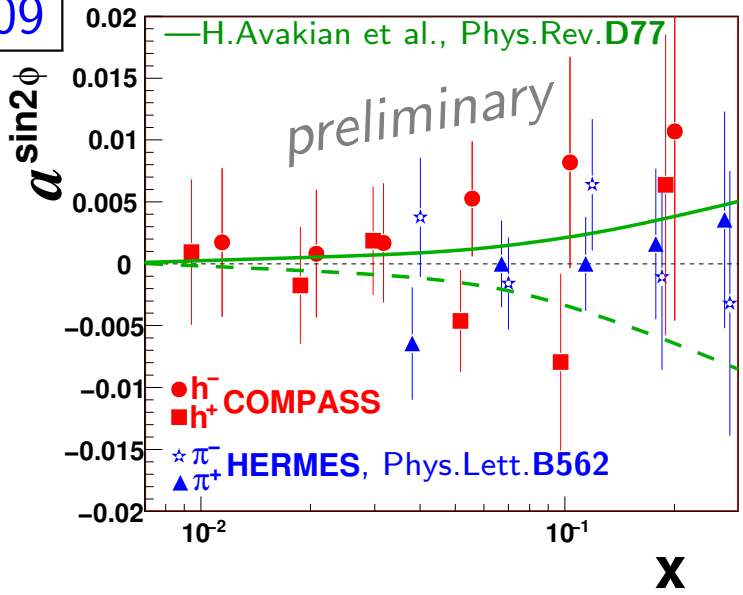
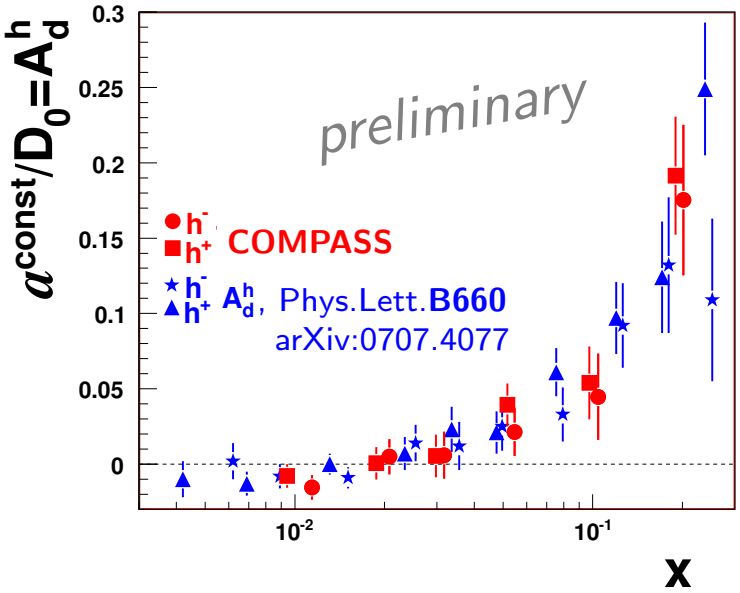
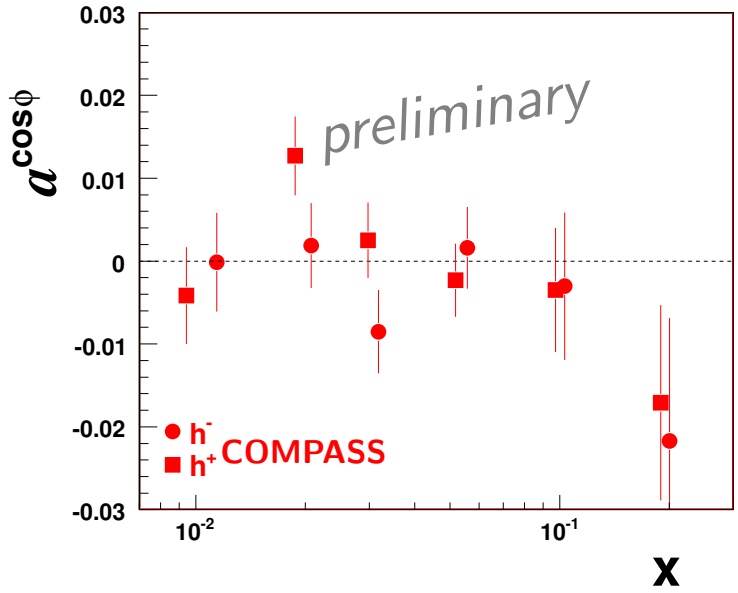
DSPIN 2009









Publication is on the way

Summary

^{6}LiD target 2002-2004:

- Transverse: all small, compatible with zero
- Longitudinal: all small, compatible with zero
- Unpolarized: large asymmetries in $\cos\phi_h$ and $\cos 2\phi_h$

NH_3 target 2007:

- Transversity:
  - Sizeable Collins and Dihadron-Interference asymmetries
  - Λ-polarization small, compatible with zero
- Sizeable positive Sivers asymmetry for positive hadrons

Summary

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NH_3 target 2007:

- Transversity:
  - Sizeable Collins and Dihadron-Interference asymmetries
  - Λ-polarization small, compatible with zero
- Sizeable positive Sivers asymmetry for positive hadrons

Outlook:

- 2010 full year of data taking with transversely polarized protons
  $\rightsquigarrow$ statistical errors are expected to improve about factor 1.5

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Thank You

email: heiner.wollny@cern.ch

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Back Up

COMPASS Experiment

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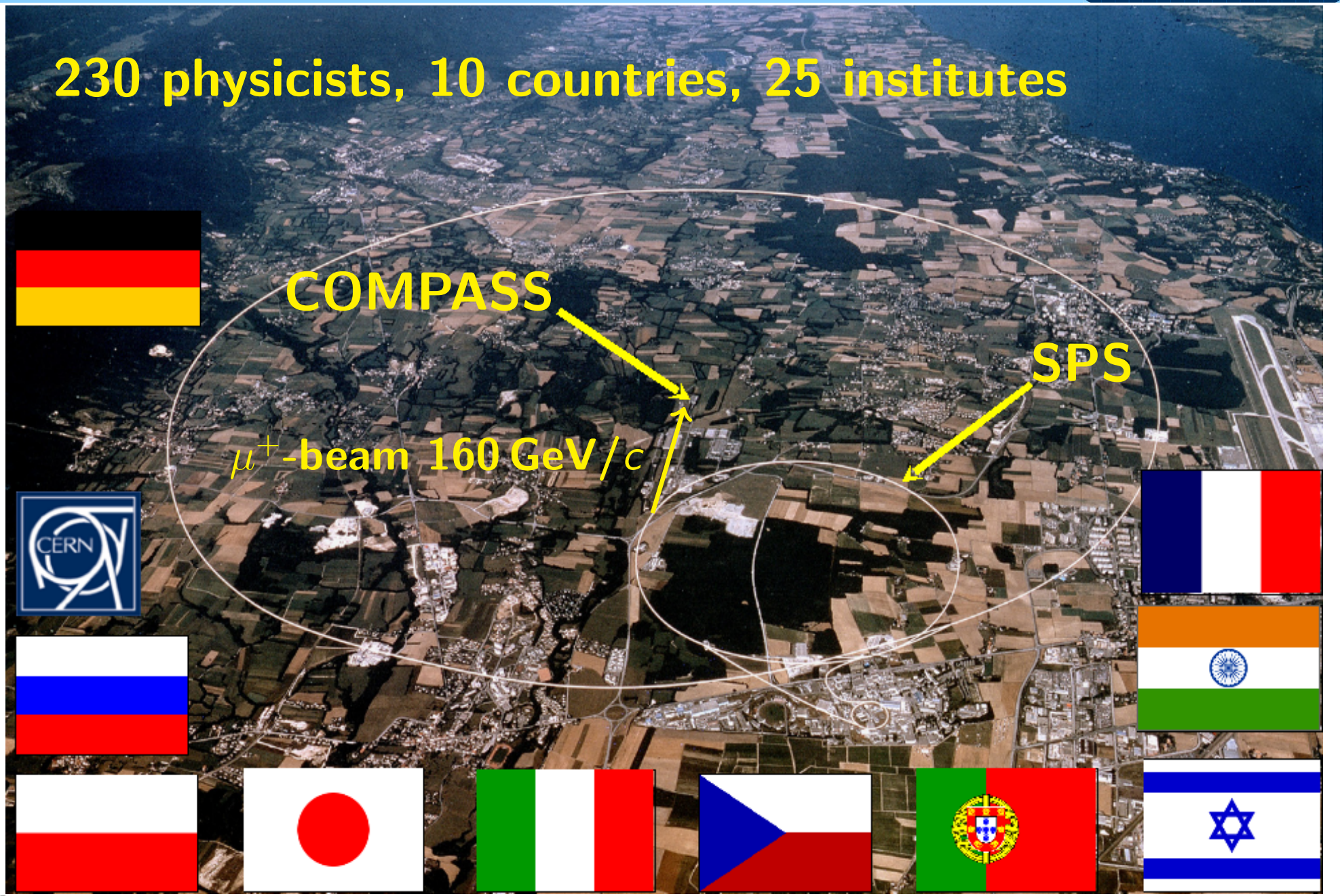
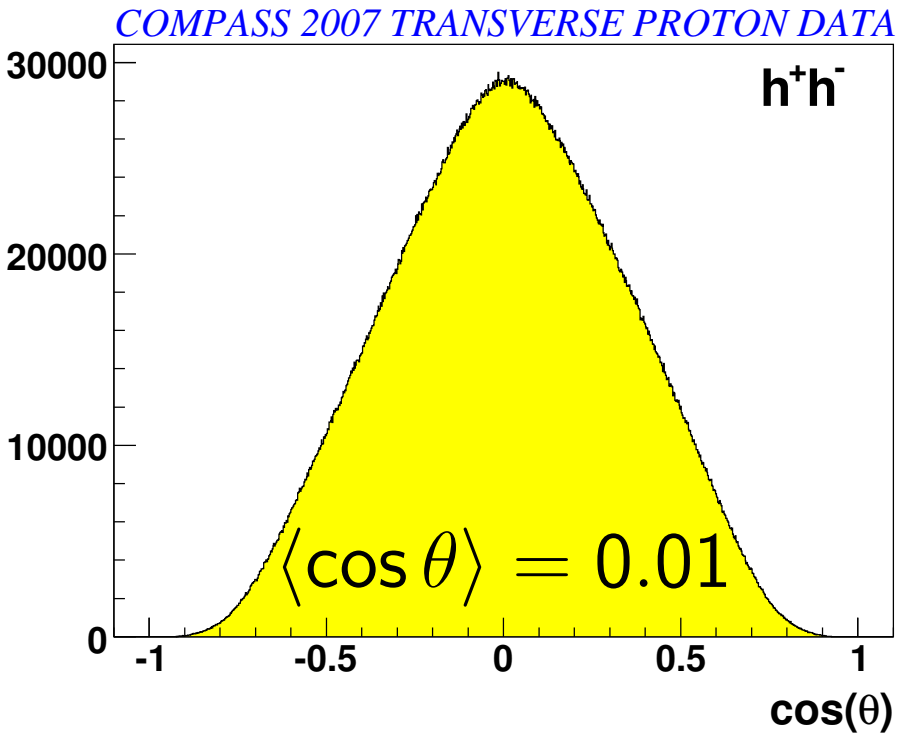


Dihadron Interference

Measuring transversity with polarized Dihadron-Interference-FF $H_1^{\sphericalangle}$:



$\rightsquigarrow$ azimuthal asymmetry:

$$N_{h^+h^-} \propto 1 \pm A \cdot \sin\phi_{RS} \cdot \sin\theta$$

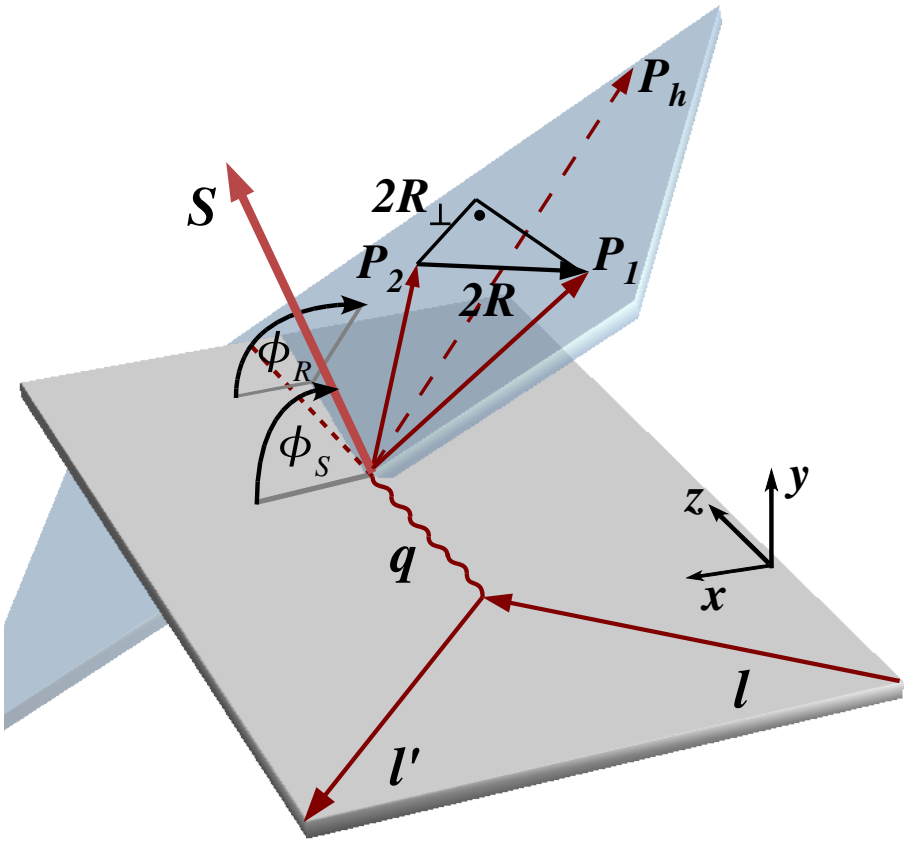
$$\phi_{RS} = \phi_R + \phi_S - \pi$$

$$A_{RS} = \frac{A}{f\ P_T D_{nn}} \propto \sum_q e_q^2 \cdot \Delta_T q \cdot H_1^{\sphericalangle}$$

$$H_1^{\sphericalangle} = H_1^{\sphericalangle,sp} + \cos\theta H_1^{\sphericalangle,pp}$$

$\rightsquigarrow$ only sensitive to $H_1^{\sphericalangle,sp}$

Definition of R_T and ϕ_R



$$\mathbf{R_T} = \frac{z_2\mathbf{P_{1T}} - z_1\mathbf{P_{2T}}}{z_1 + z_2}$$

$$\cos\phi_R = \frac{\vec{q}\times\vec{\ell}}{|\vec{q}\times\vec{\ell}|} \cdot \frac{\vec{q}\times\vec{R}_T}{|\vec{q}\times\vec{R}_T|},$$

$$\sin\phi_R = \frac{(\vec{\ell}\times\vec{R}_T)\cdot\hat{q}}{|\hat{q}\times\vec{\ell}||\hat{q}\times\vec{R}_T|}$$

Dihadron Asymmetry: NH_3 (2007)

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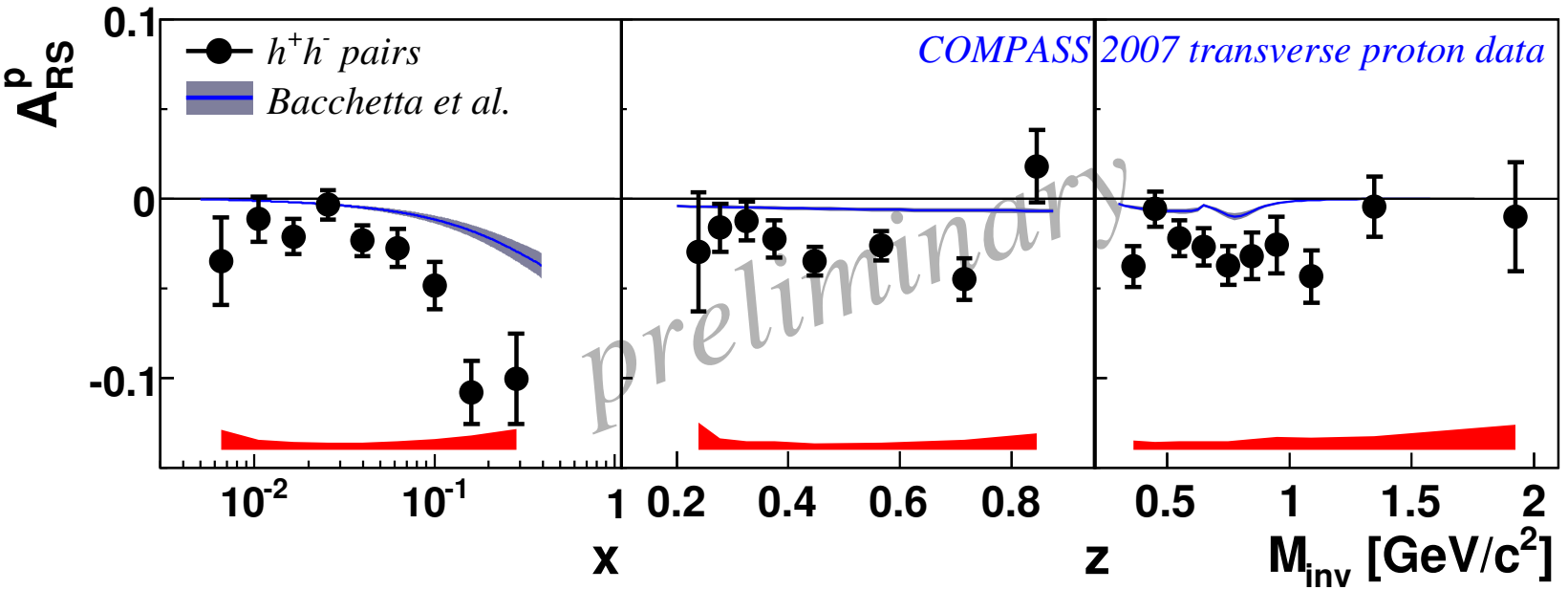

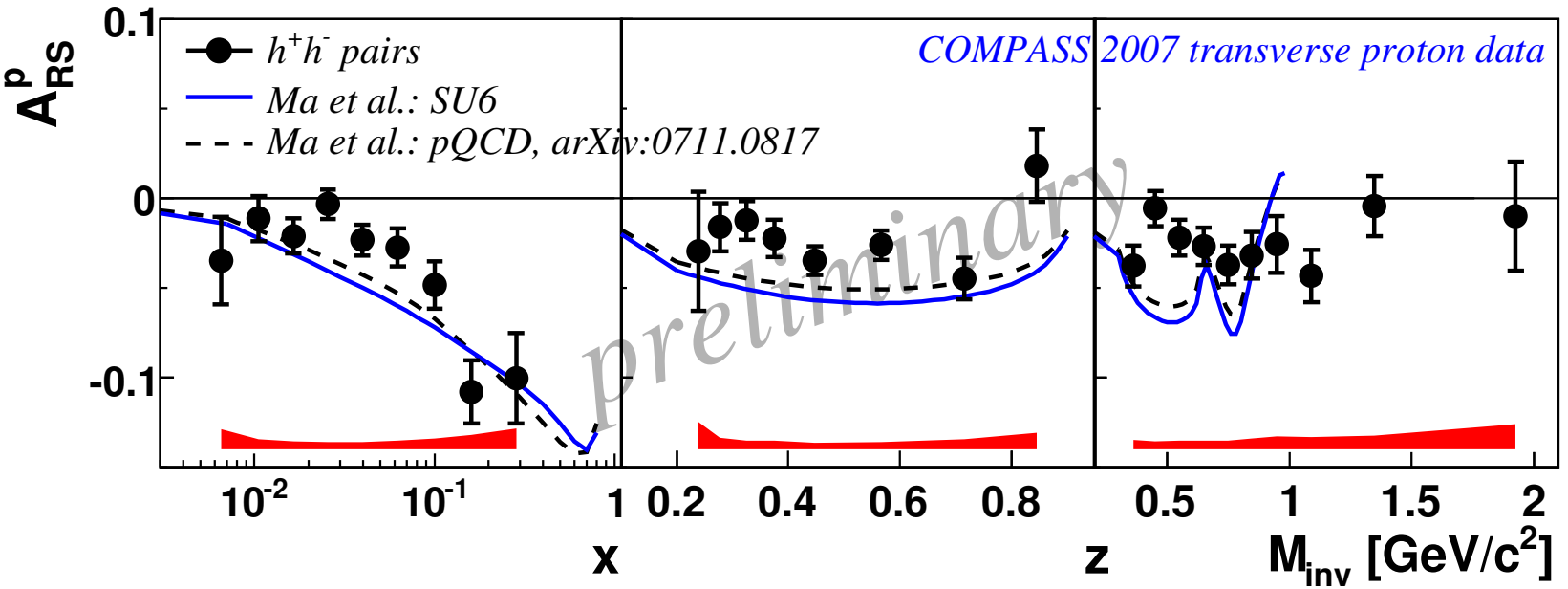

Transverse Λ-Polarization: ^{6}LiD (2002-2004)

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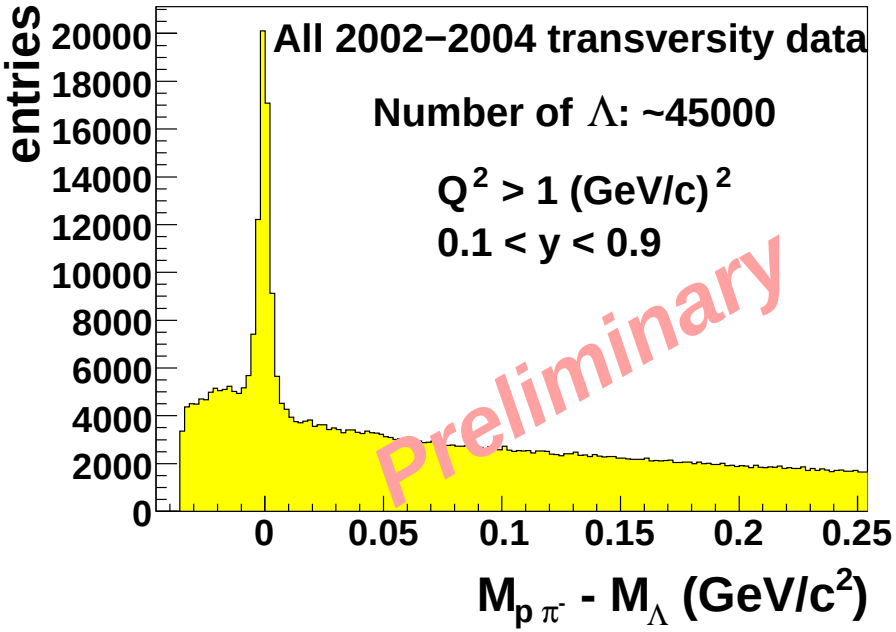
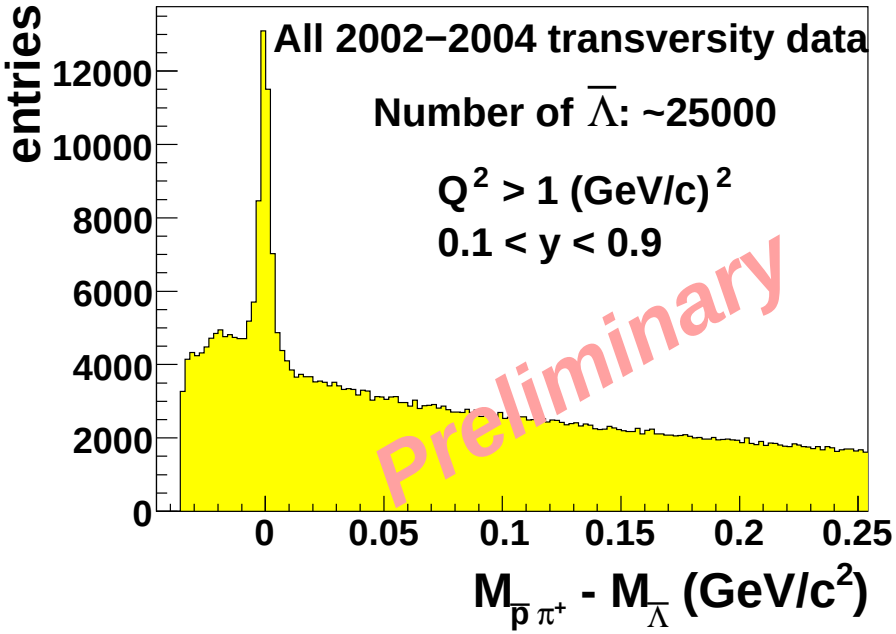
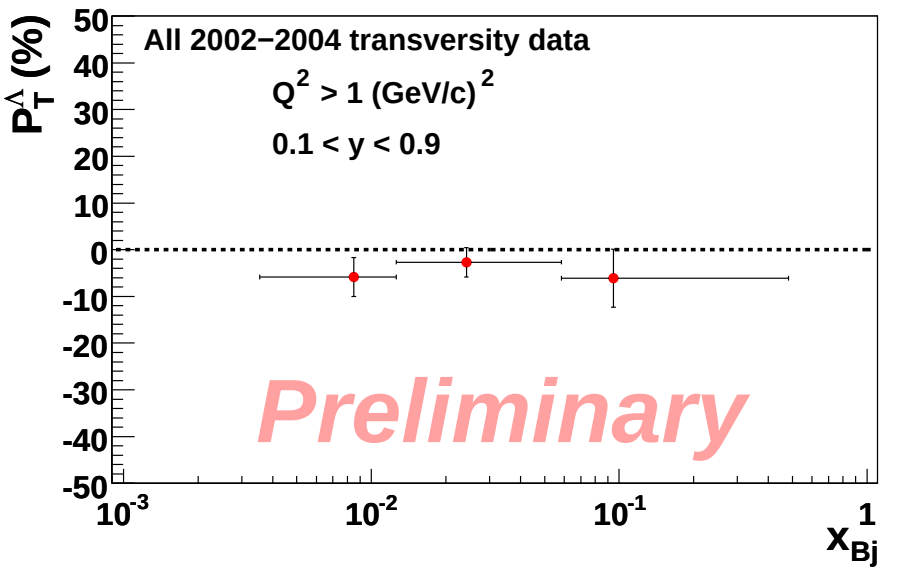
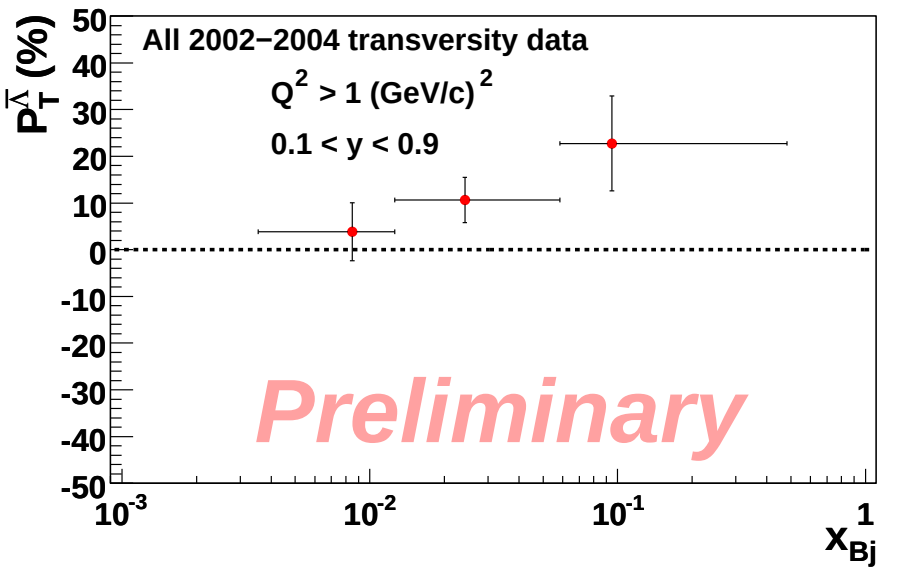




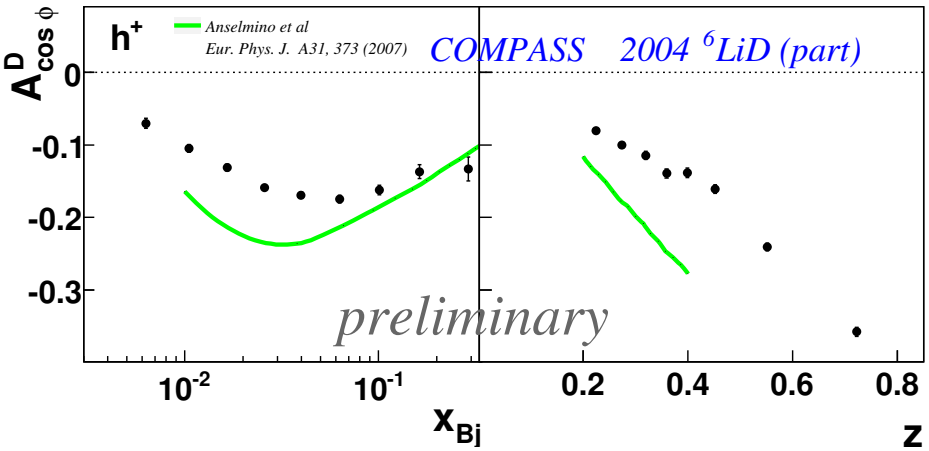




systematical errors are smaller than the statistical ones

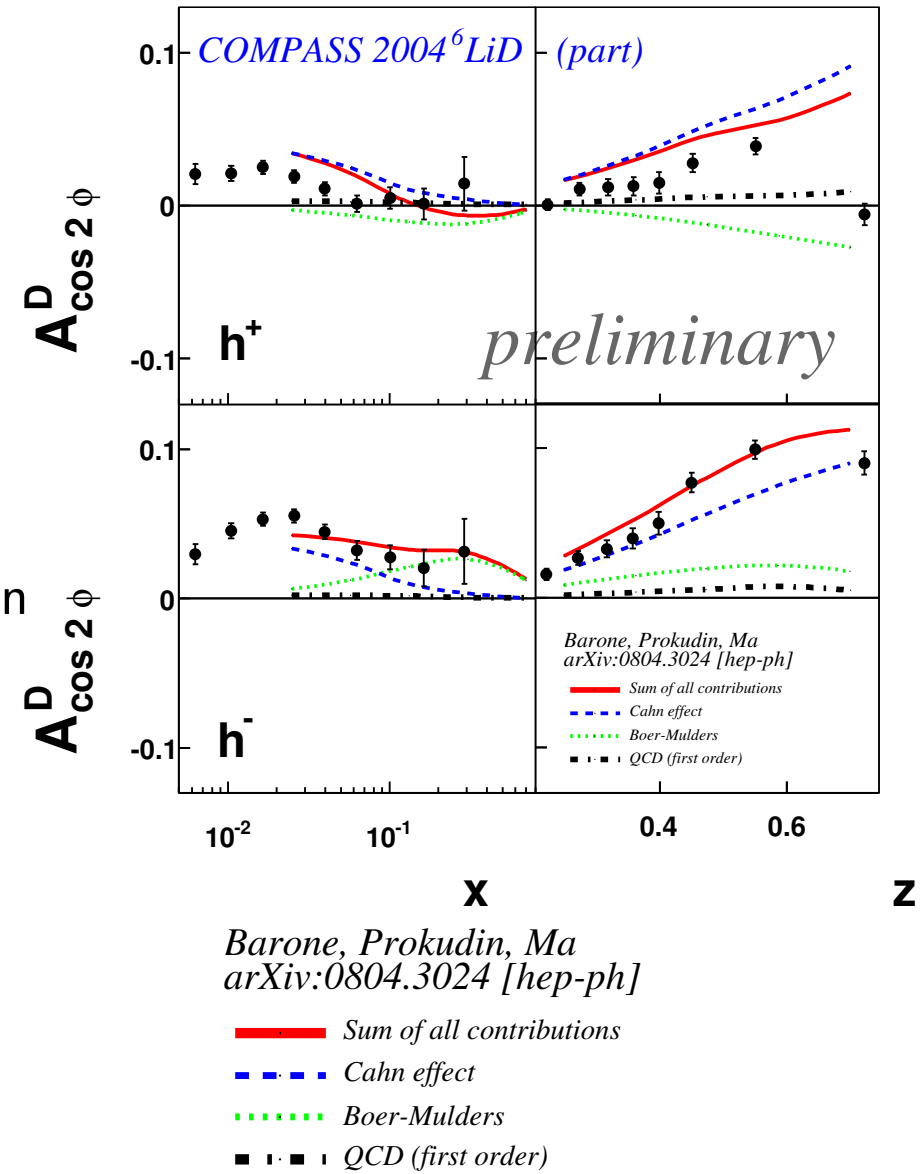
Unpolarized cosϕ and cos2ϕ: ^{6}LiD (2004 part)

Transversity 2008



Anselmino et al
Eur. Phys. J. A31, 373 (2007)

does not include Boer-Mulders contribution



Barone, Prokudin, Ma
arXiv:0804.3024 [hep-ph]

Sum of all contributions
Cahn effect
Boer-Mulders
QCD (first order)

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