Transverse Spin and Transverse Momentum Effects at COMPASS

Heiner Wollny
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Physikalisches Institut
Albert-Ludwigs-Universität Freiburg

Outline:

- Introduction: DIS, Parton Distribution Functions
- Transversity
- Transverse Momentum Dependent Distribution Functions (TMDs)

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- Introduction: DIS, Parton Distribution Functions
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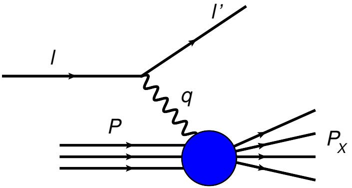
Deep-Inelastic Scattering (DIS)

Lepton-Nucleon DIS: $\ell + N \rightarrow \ell' + X$



$$Q^2 = -q^2 = -(l - l')^2$$

$$y = \frac{P \cdot q}{P \cdot l} \stackrel{\text{lab}}{=} \frac{E - E'}{E}$$

$$x = \frac{Q^2}{2P \cdot q}$$

$$W^2 = (P + q)^2$$

Deep-Inelastic Scattering (DIS)

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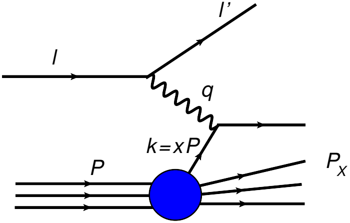

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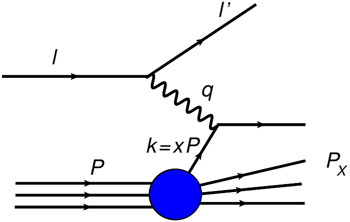

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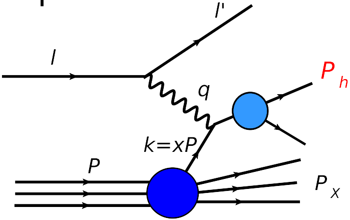
Lepton-Nucleon SIDIS: $\ell + N \rightarrow \ell' + h + X$

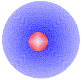


$$z = \frac{P \cdot P_h}{P \cdot l} \stackrel{\text{lab}}{=} \frac{E_h}{E - E'}$$

Nucleon in Leading Order

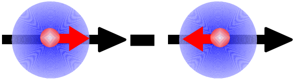
In leading order three parton distributions are needed to describe the structure of the nucleon:

$\mathbf{q}(x)$



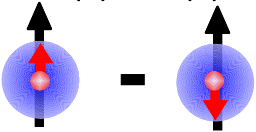
quark distribution
in unpolarized DIS
$\ell\, N \to \ell' X$

$\Delta\mathbf{q}(x)$



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

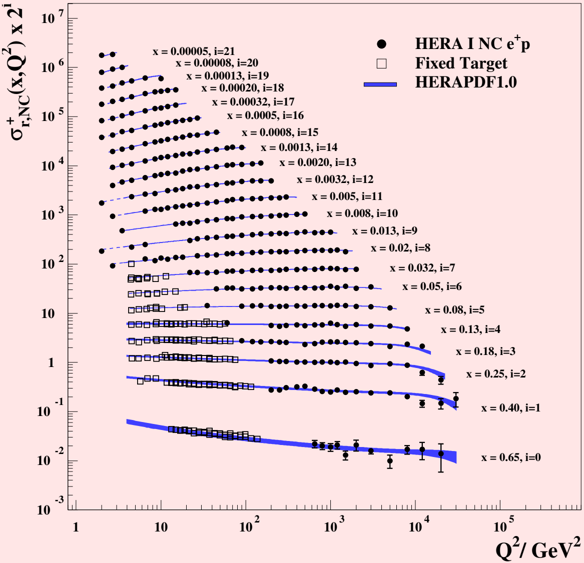
$\Delta_T\mathbf{q}(x) = \mathbf{q}^{\uparrow\uparrow}(x) - \mathbf{q}^{\uparrow\downarrow}(x)$



transversity distribution
in polarized SIDIS
$\ell\, N^{\uparrow} \to \ell' h X$
$\ell\, N^{\uparrow} \to \ell' h h X$
$\ell\, N^{\uparrow} \to \ell' \Lambda X$

Unpolarized PDFs: $q(x)$

F_2^p from lepton-proton scattering



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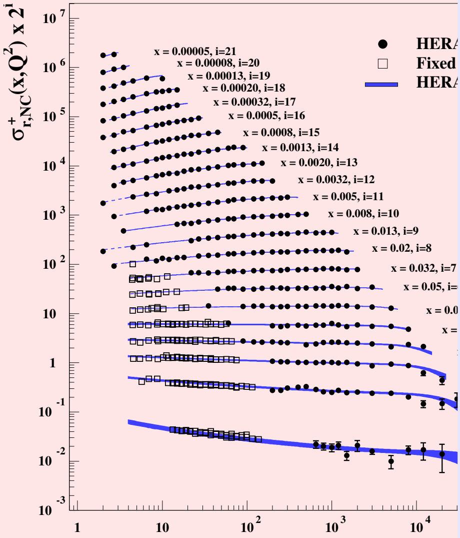
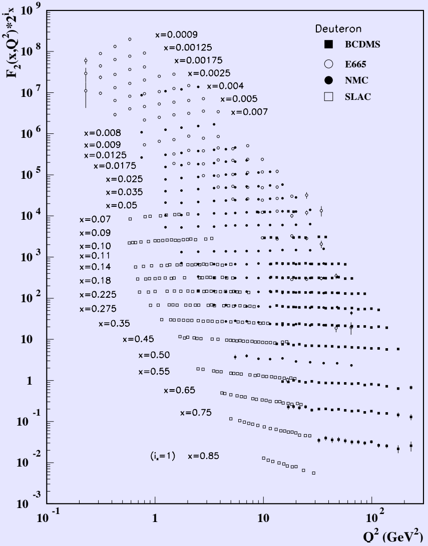


F_2^d from lepton-deuteron scattering



Unpolarized PDFs: $q(x)$

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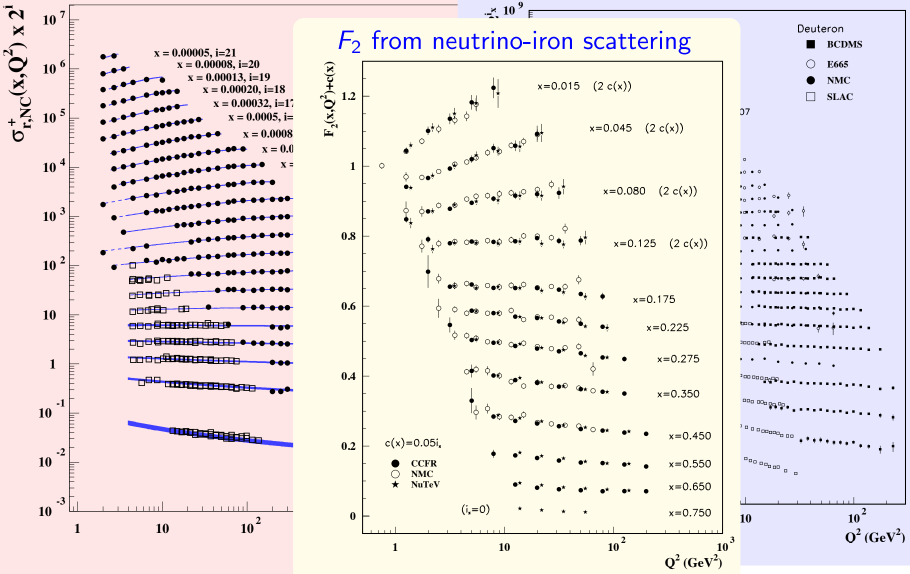
F_2^p from lepton-proton scattering

F_2^d from lepton-deuteron scattering

F_2 from neutrino-iron scattering



Unpolarized PDFs: $q(x)$

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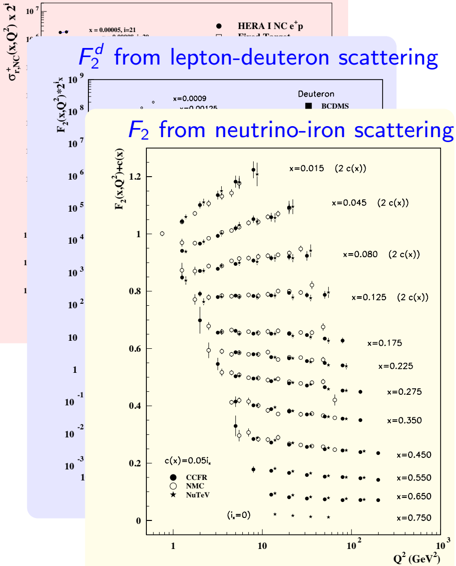
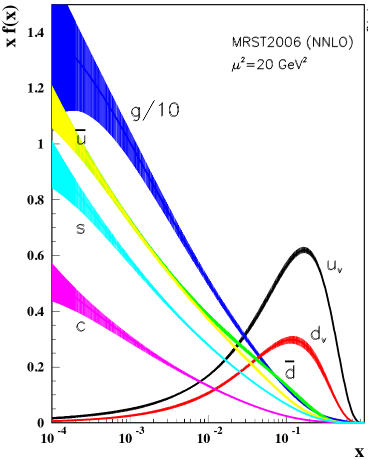
F_2 from neutrino-iron scattering



Particle Data Group Collaboration



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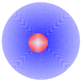
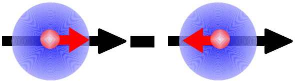


quark distribution in unpolarized DIS ← **well known**

$\ell N \rightarrow \ell' X$

$\Delta \mathbf{q}(x)$



helicity distribution in polarized DIS

$\vec{\ell}\vec{N} \rightarrow \ell' X$

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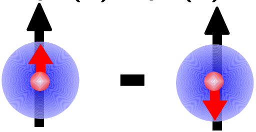

transversity distribution in polarized SIDIS

$\ell N^{\uparrow} \rightarrow \ell' hh X$

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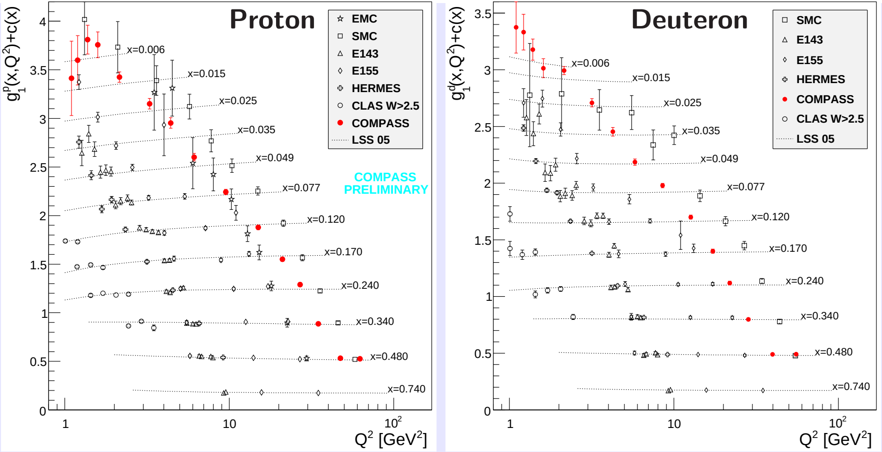
Helicity PDFs: $\Delta q(x)$



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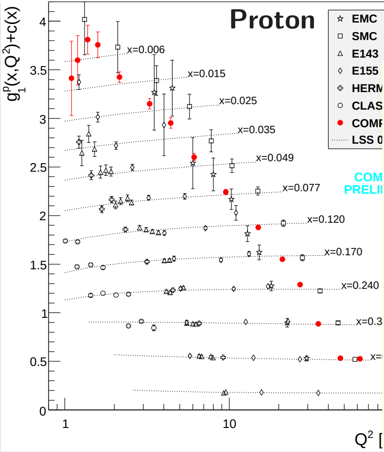
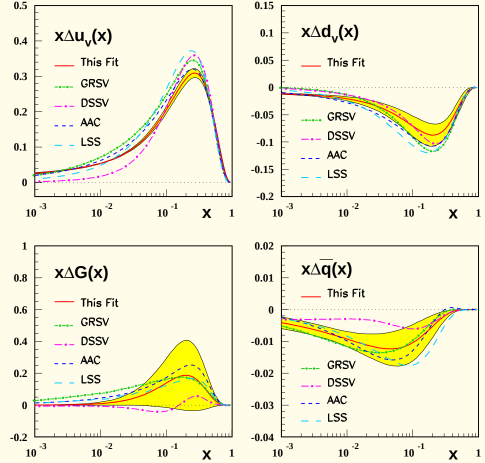


Blümlein and Böchner, arXiv:1005.3113



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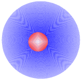

quark distribution
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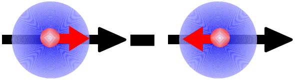
$\ell N \to \ell' X$

$\leftarrow$ **well known**

$\Delta\mathbf{q}(x)$



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

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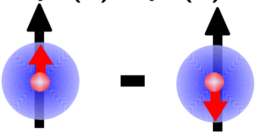

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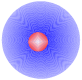
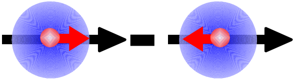


quark distribution
in unpolarized DIS
$\ell N \to \ell' X$

$\leftarrow$ **well known**

$\Delta\mathbf{q}(x)$



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

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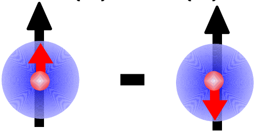
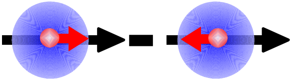


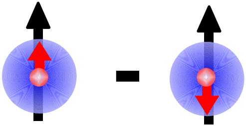
transversity distribution
in polarized SIDIS
$\ell N^{\uparrow} \to \ell' h X$
$\ell N^{\uparrow} \to \ell' h h X$
$\ell N^{\uparrow} \to \ell' \Lambda X$

Transversity: What is the challenge?

Helicity $\Delta q(x)$



Transversity $\Delta_T q(x)$



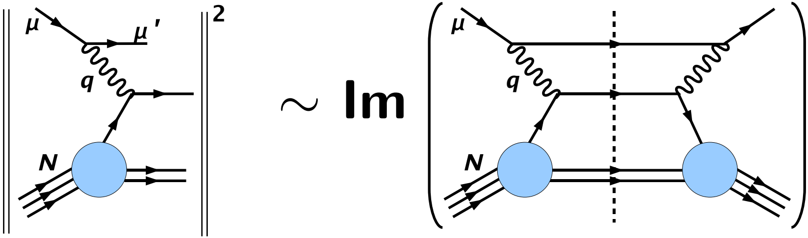
Pictures look pretty similar!

$\rightsquigarrow$ **Why is Transversity only accessible in SIDIS?**

Optical Theorem

Optical theorem:

DIS cross-section is proportional to imaginary part of compton forward scattering



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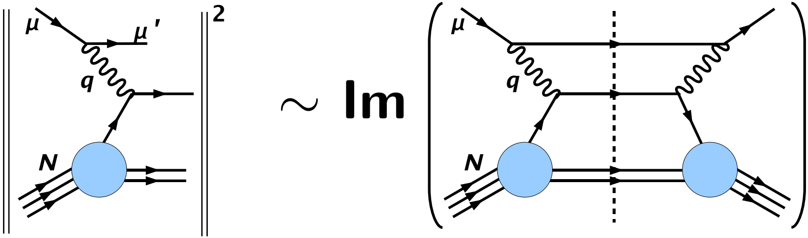
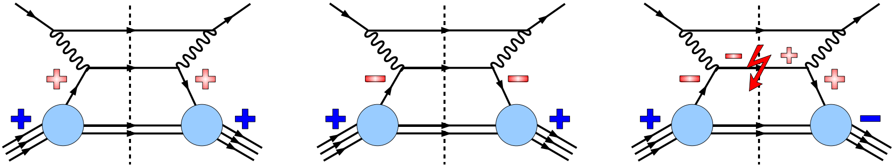
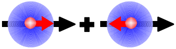


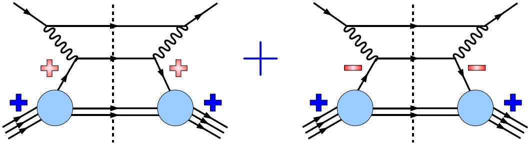
Helicity and parity conservation ⇒



PDFs in hand-bags

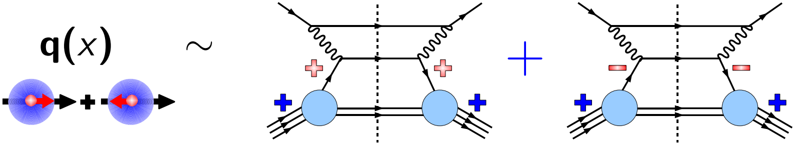
$\mathbf{q}(x)$ $\sim$



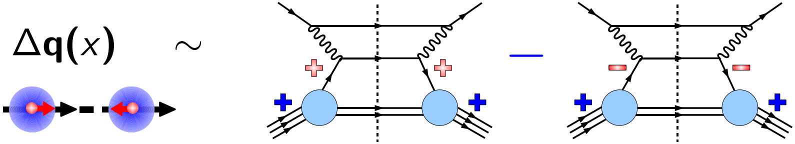


PDFs in hand-bags

$\mathbf{q}(x) \quad \sim$



$\Delta\mathbf{q}(x) \quad \sim$



PDFs in hand-bags

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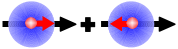

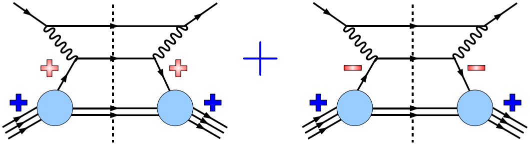

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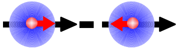
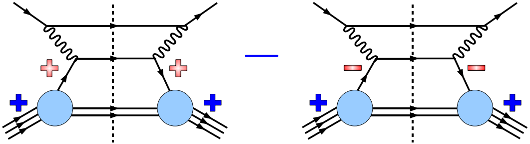
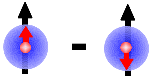
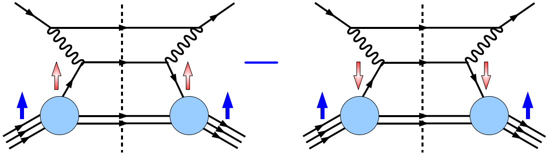




$\Delta_T\mathbf{q}(x) \sim$





PDFs in hand-bags

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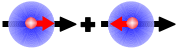

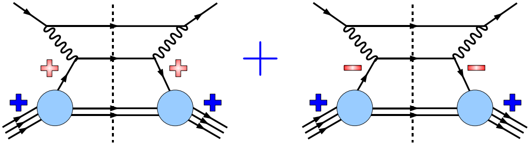

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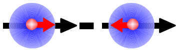

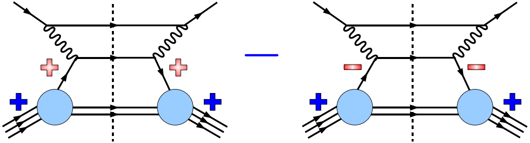

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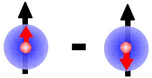
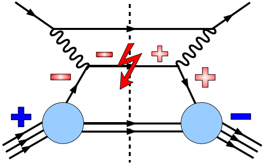


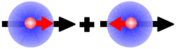


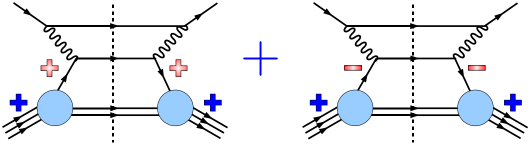
$$|\uparrow\rangle \sim |+\rangle + i|-\rangle$$

$$|\downarrow\rangle \sim |+\rangle - i|-\rangle$$

PDFs in hand-bags

$\mathbf{q}(x) \sim$





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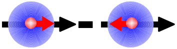
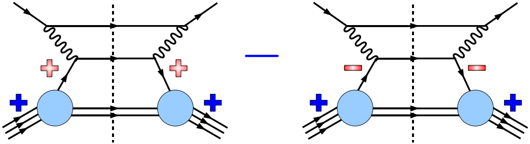
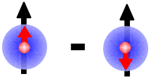
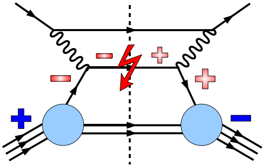




$\Delta_T\mathbf{q}(x) \sim$



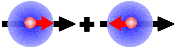


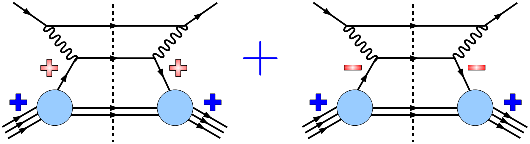
helicity-flip in inclusive DIS is suppressed with

$\mathcal{O}(m_q/Q)$

PDFs in hand-bags

$\mathbf{q}(x) \quad \sim$





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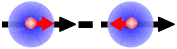

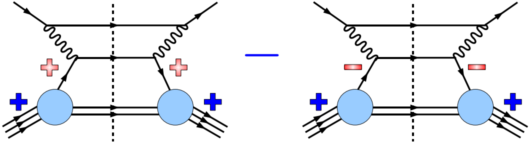

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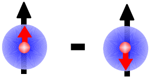

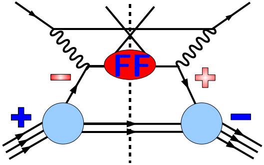

chiral-odd Fragmentation-Function balances helicity-flip

$\rightsquigarrow$ *SIDIS*

Fragmentation into single hadron:

$$\ell\, N^{\uparrow} \rightarrow \ell' h X$$

$\rightsquigarrow$ **Collins-Fragmentation Function $\Delta_T^0 D_q^h$:**

fragmentation of a transversely polarized quark into an unpolarized hadron

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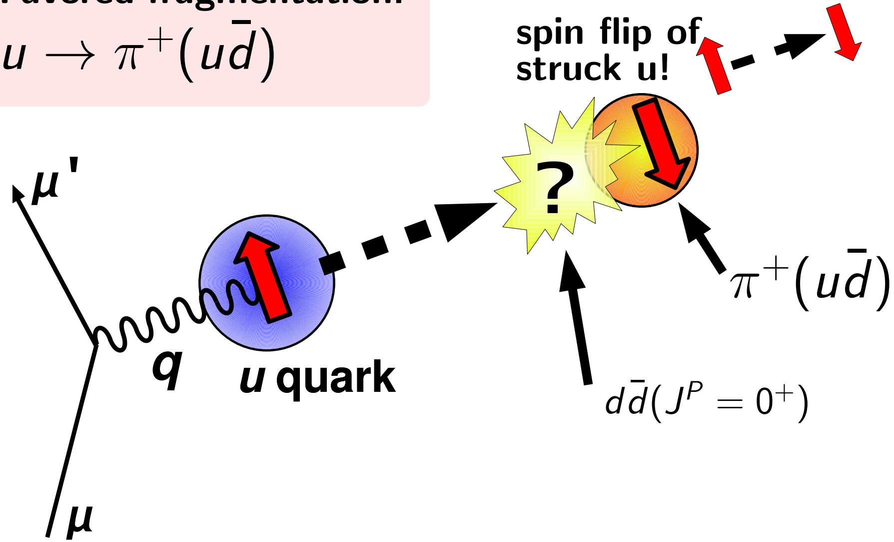
fragmentation of a transversely polarized quark into an unpolarized hadron

$\rightsquigarrow$ **azimuthal asymmetry of produced hadrons**

Favored fragmentation:

$$u \rightarrow \pi^+(u\bar{d})$$



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Favored fragmentation:

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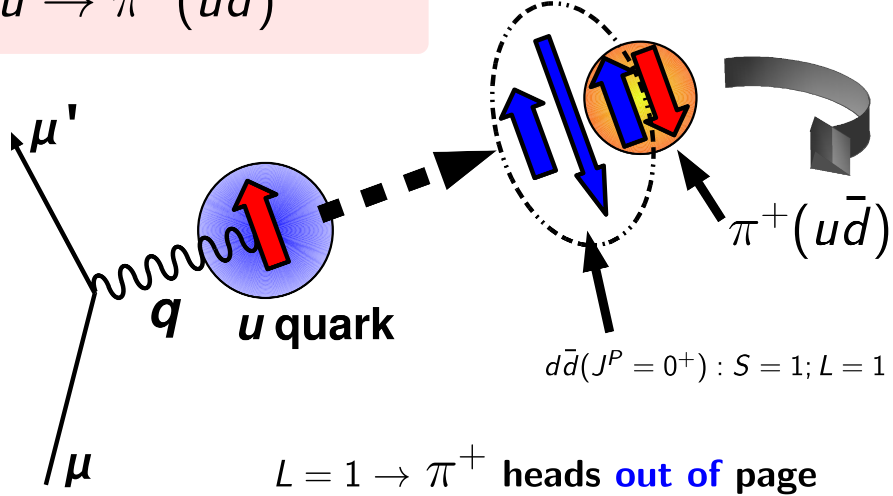

$L = 1 \rightarrow \pi^+$ **heads out of page**

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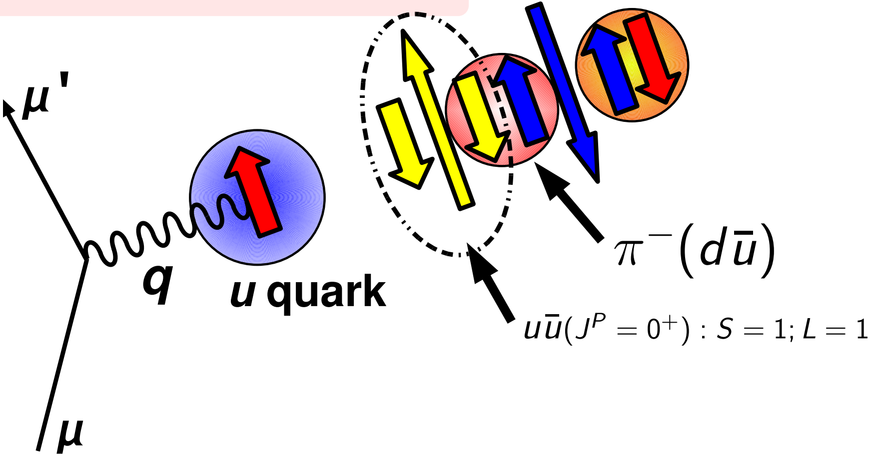
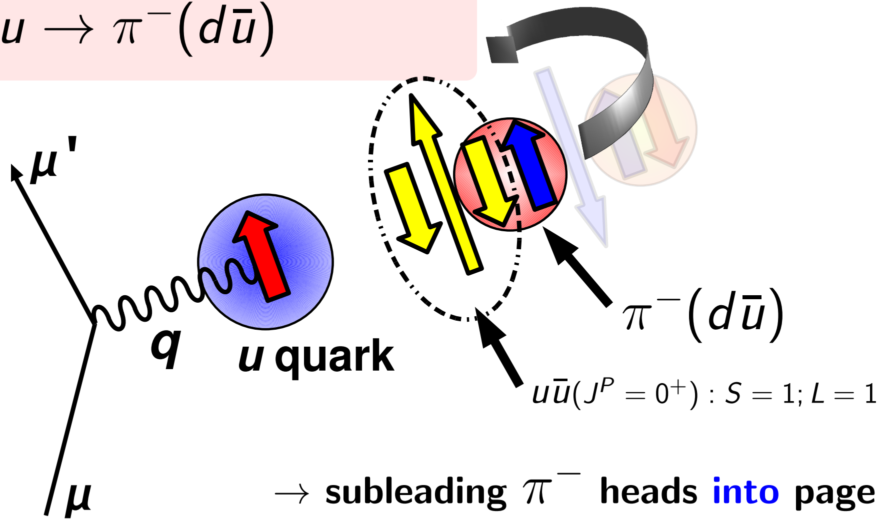
Unfavored fragmentation:
$u \rightarrow \pi^-(d\bar{u})$



Unfavored fragmentation:

$u \rightarrow \pi^{-}(d\bar{u})$



$\rightarrow$ **subleading π^{-} heads into page**

Collins-Asymmetry

Proton: $A_{Coll}^{h^+} \sim -A_{Coll}^{h^-} \neq 0$

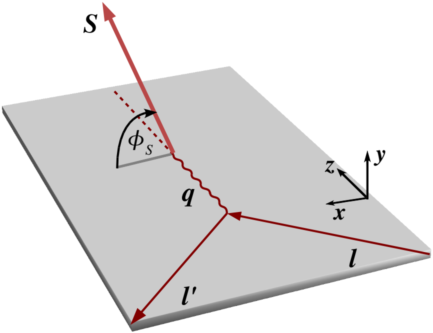
Deuteron: $A_{Coll}^{h^+} \sim A_{Coll}^{h^-} \sim 0$

(we'll keep that in mind..)

Measuring transversity with Collins-FF $\Delta_T^0 D_q^h(z, \boldsymbol{p}_T^2)$

Hadron production depends on two azimuthal angles:

ϕ_S: azimuthal angle of spin of the initial quark



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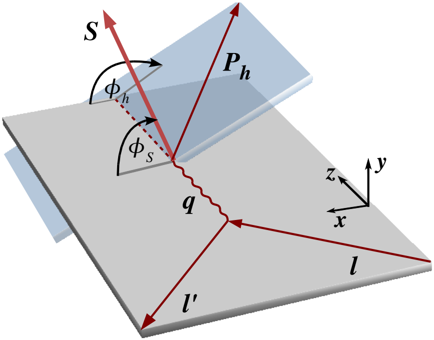

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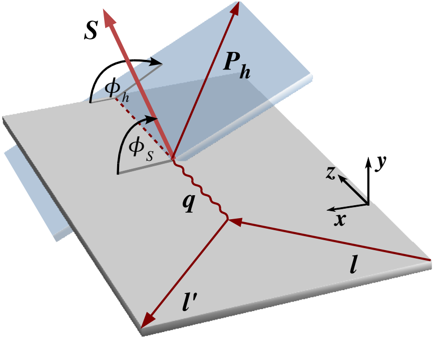

$\rightsquigarrow$ azimuthal asymmetry:

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

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

Measuring transversity with Collins-FF $\Delta_T^0 D_q^h(z, \boldsymbol{p}_T^2)$

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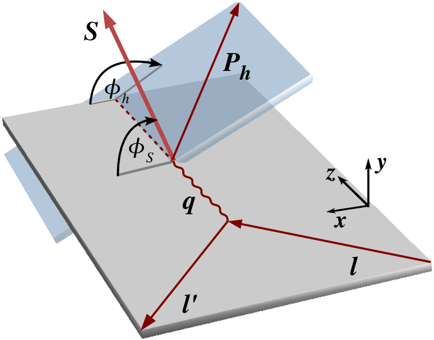


ϕ_S: azimuthal angle of spin of the initial quark

ϕ_h: azimuthal angle of hadron

$\rightsquigarrow$ azimuthal asymmetry:

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

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

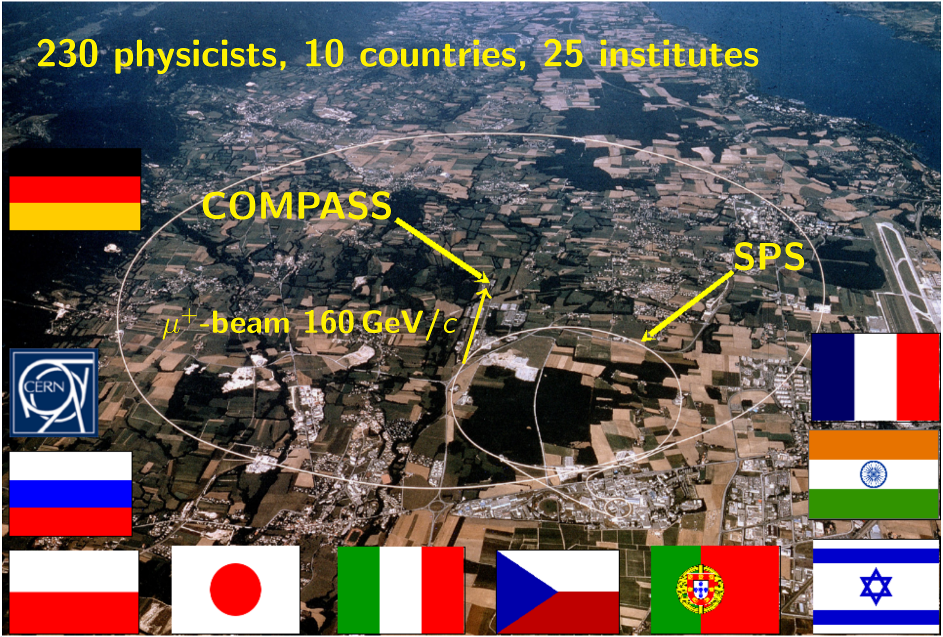
$$A_{Coll} = \frac{A}{f\ P_T D_{nn}} \propto \frac{\sum_q e_q^2 \cdot \Delta_T q(x, \boldsymbol{k}_T^2) \otimes \Delta_T^0 D_q^h(z, \boldsymbol{p}_T^2)}{\sum_q e_q^2 \cdot q(x, \boldsymbol{k}_T^2) \otimes D_q^h(z, \boldsymbol{p}_T^2)}$$

f = target dilution

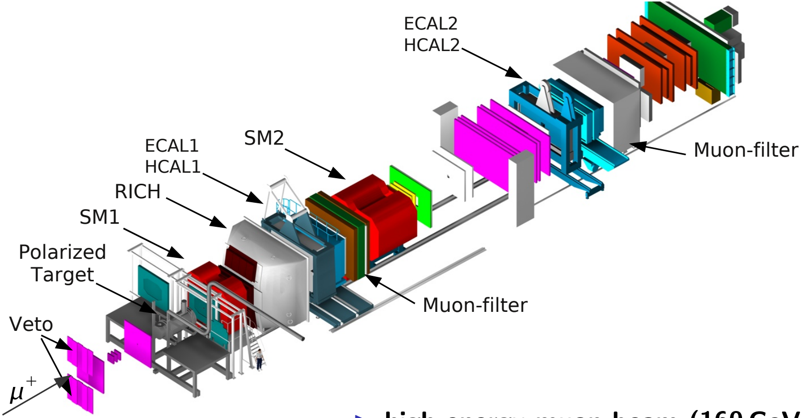
P_T = target polarization

D_{nn} = transverse spin transfer

COMPASS Experiment

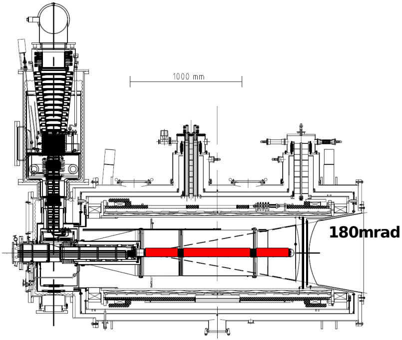


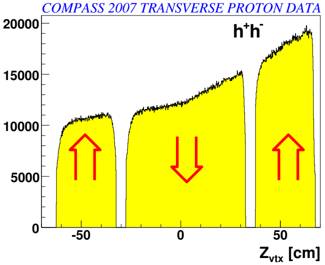
COMPASS Detector (muon setup)



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

COMPASS Polarized Target





COMPASS target ($\geq$ 2006):

- 3 target cells
- acceptance: 180 mrad
- target material: NH_3
- dilution factor: $f \simeq 15\,\%$
- polarization: $P_T \sim 90\,\%$
- reversal of polarization every 4 - 5 days

Challenge of Measurement

Measuring Collins Asymmetry is challenging:

- Asymmetries are expected to be in the order of few percents

  $\rightsquigarrow \frac{1}{f \; P_T D_{nn}} \sim 0.1 \Rightarrow$ few permille

- Coupling of data-samples with opposite target polarization

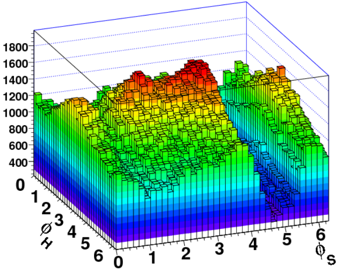
  $\rightsquigarrow$ stable working detector (timescale weeks)

  $\rightsquigarrow$ extensive data stability checks

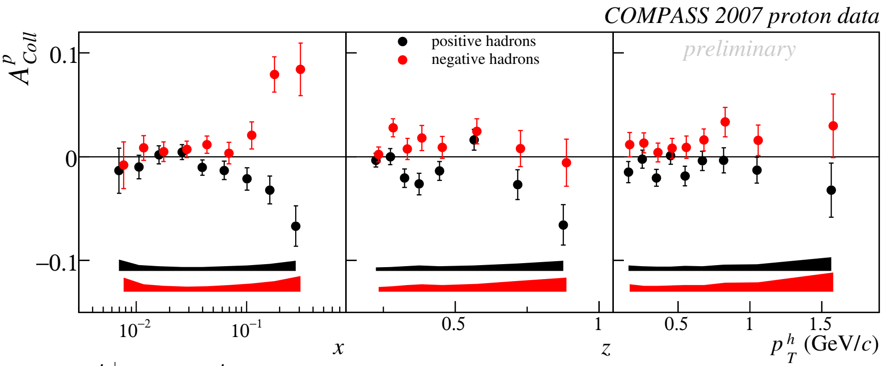
- Non-uniform angular acceptance of detector

  $\rightsquigarrow$ Orthogonal Collins- and Sivers-Modulation mixes via acceptance

  $\rightsquigarrow$ need of advanced extraction methods



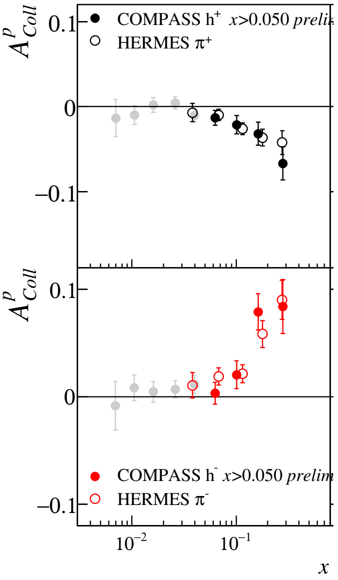
Collins: Results Proton 2007



- $A^{h^+}_{Coll} \simeq -A^{h^-}_{Coll}$
- Large asymmetries in valence-quark region

  $\rightsquigarrow$ Transversity and Collins-FF are **not** Zero
- Small asymmetries in sea-quark region
- Published in PLB 673 (2009) 127-135

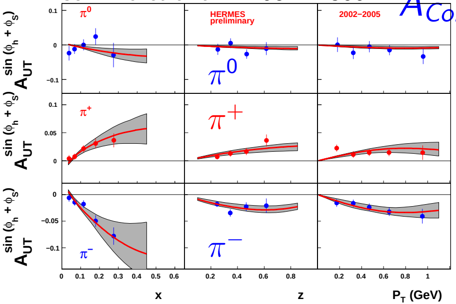
Collins: Results Proton 2007



- Nice agreement between COMPASS and HERMES data!
- Not obvious, because of different Q^2

Collins-Asymmetry: Access to Transversity

Anselmino et al arXiv:0812.4366



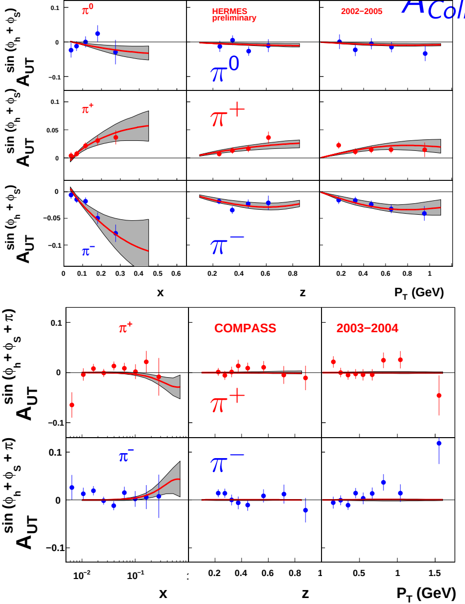
$$A_{Coll} \propto \Delta_T q(x, \boldsymbol{k}_T^2) \otimes \Delta_T^0 D_q^h(x, \boldsymbol{p}_T^2)$$

- **HERMES Proton**

  $\rightsquigarrow A_{Coll}^{\pi^+} \simeq -A_{Coll}^{\pi^-}$

Collins-Asymmetry: Access to Transversity

Anselmino et al arXiv:0812.4366



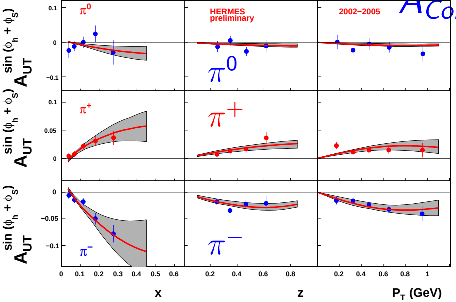
$$A_{Coll} \propto \Delta_T q(x, \boldsymbol{k}_T^2) \otimes \Delta_T^0 D_q^h(x, \boldsymbol{p}_T^2)$$

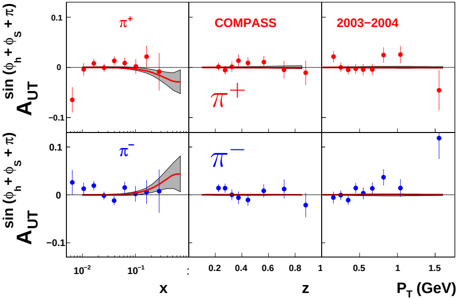
- **HERMES Proton**
  - $\rightsquigarrow A_{Coll}^{\pi^+} \simeq -A_{Coll}^{\pi^-}$
- **COMPASS Deuteron**
  - $\rightsquigarrow A_{Coll}^{\pi^+} \simeq A_{Coll}^{\pi^-} \simeq 0$

Collins-Asymmetry: Access to Transversity

Anselmino et al arXiv:0812.4366

$$A_{Coll} \propto \Delta_T q(x, \boldsymbol{k}_T^2) \otimes \Delta_T^0 D_q^h(x, \boldsymbol{p}_T^2)$$





- **HERMES Proton**

  $\rightsquigarrow A_{Coll}^{\pi^+} \simeq -A_{Coll}^{\pi^-}$

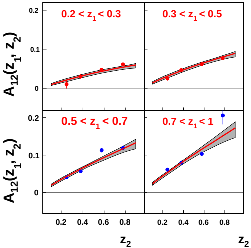
- **COMPASS Deuteron**

  $\rightsquigarrow A_{Coll}^{\pi^+} \simeq A_{Coll}^{\pi^-} \simeq 0$

- **Belle e^+e^-: Collins-FF $\Delta_T^0 D_q^h$**

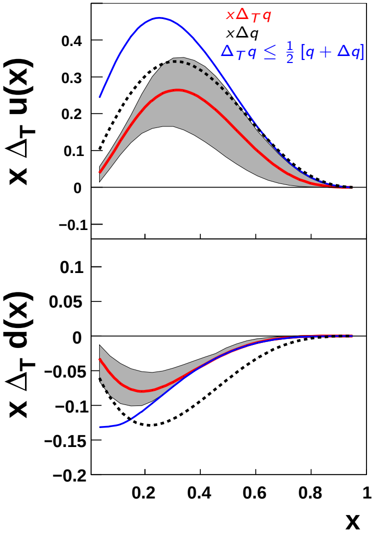
  Q^2-evolution to COMPASS

  and HERMES energies not known!



$\Rightarrow$ Transversity

$\Delta_T u > 0, \quad \Delta_T d < 0$



Collins-Asymmetry: Access to Transversity

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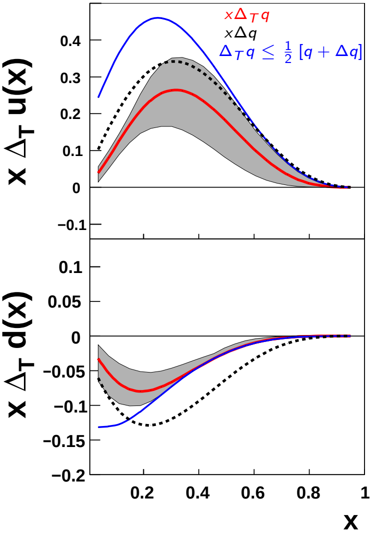
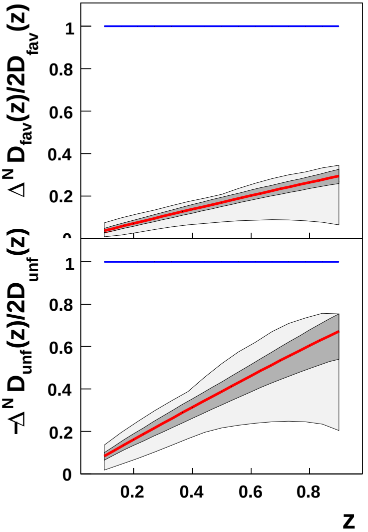


$\Rightarrow$ Collins-FF $\Delta_T^0 D_q^h$

$2\,\Delta_T^0 D_{favored} \approx -\Delta_T^0 D_{unfavored}$



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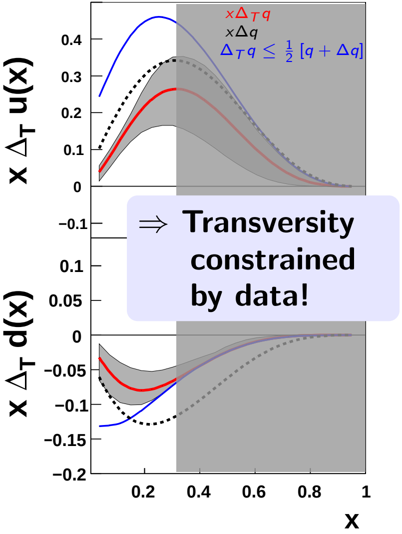

$\Rightarrow$ **Transversity constrained by data!**

$\Rightarrow$ Collins-FF $\Delta_T^0 D_q^h$

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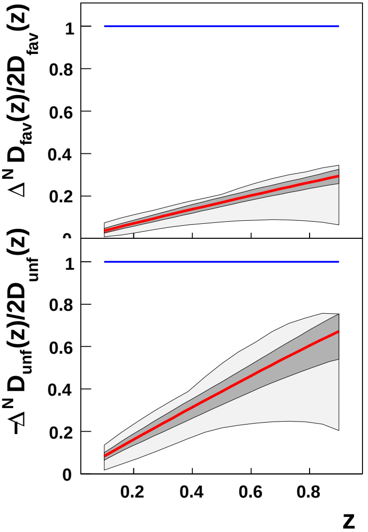

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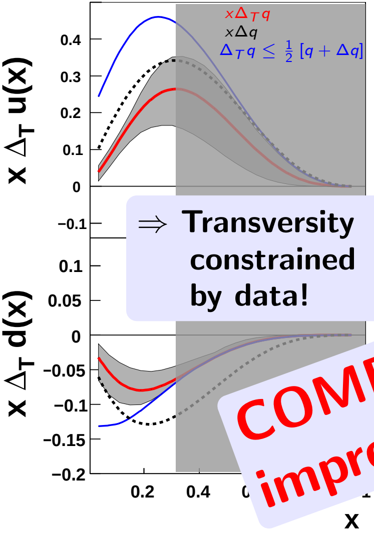

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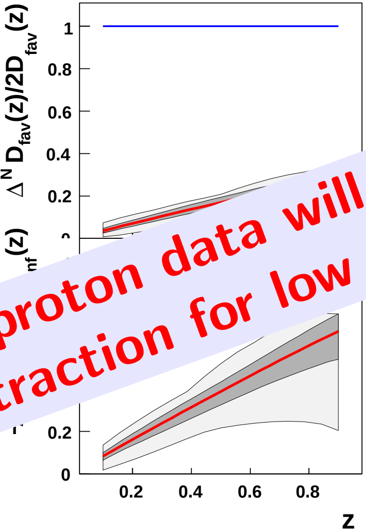


COMPASS proton data will improve extraction for low x

Fragmentation into pair of hadrons:

$$\ell\, N^{\uparrow} \rightarrow \ell' hhX$$

$\rightsquigarrow$ **Dihadron-Interference-FF** $H_1^{\sphericalangle}(z, M^2)$**:**

Fragmentation of a transversely polarized quark

into two unpolarized hadrons and rest X

Dihadron-Asymmetry

Fragmentation into pair of hadrons:

$$\ell\, N^{\uparrow} \rightarrow \ell' hh X$$

$\rightsquigarrow$ **Dihadron-Interference-FF** $H_1^{\sphericalangle}(z, M^2)$**:**

Fragmentation of a transversely polarized quark

into two unpolarized hadrons and rest X

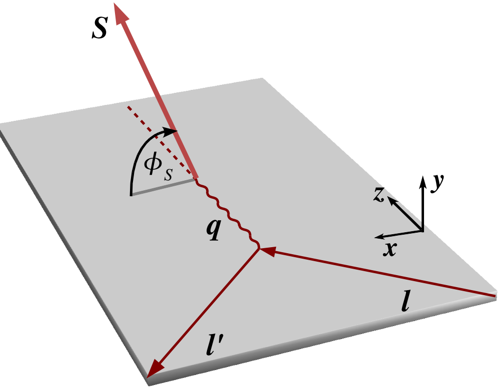
$\rightsquigarrow$ **Azimuthal asymmetry of produced hadron-pairs**

In leading order interference

between hadron pairs in relative s- and p-waves

Dihadron production depends on **two** azimuthal angles:

ϕ_S: azimuthal angle of spin of the initial quark



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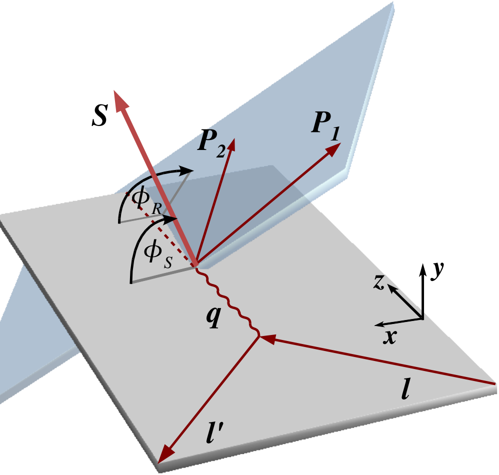

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ϕ_R: azimuthal angle of two hadron-plane

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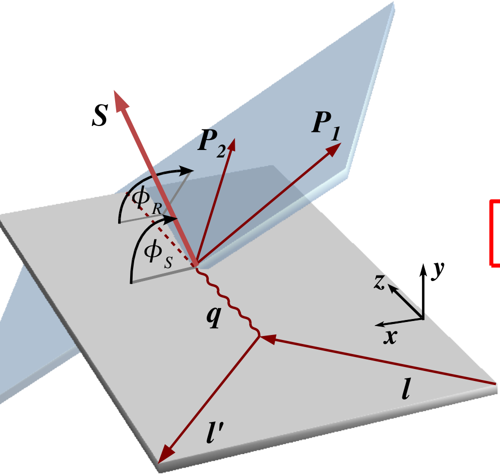

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Dihadron-Interference:

$\rightsquigarrow$ **Azimuthal asymmetry in:**

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

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

Dihadron: What to be measured

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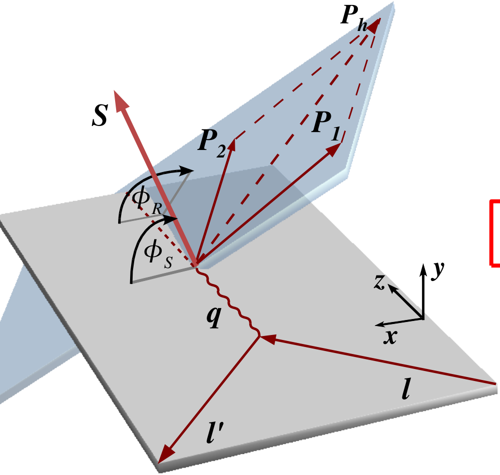

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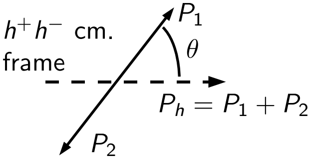

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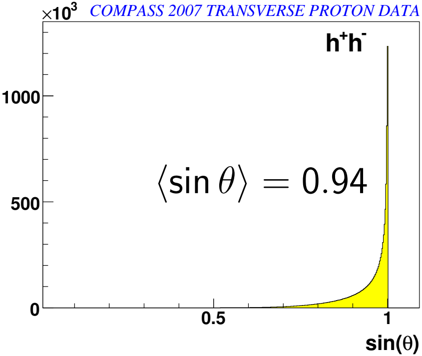

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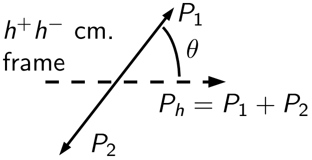

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$$\boxed{N_{h^+h^-} \propto 1 \pm A \cdot \sin\phi_{RS}}$$

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

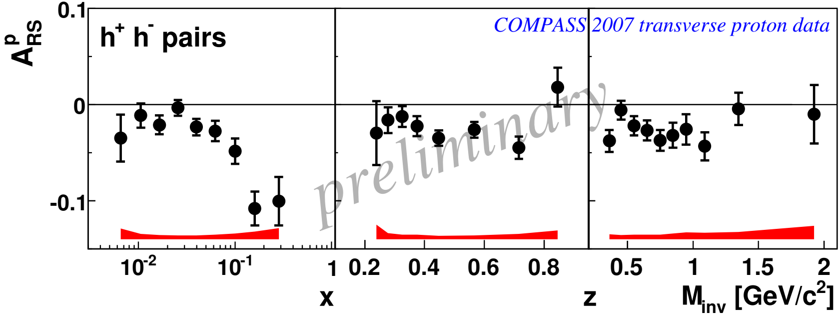
$$A_{RS} = \frac{A}{f \cdot P_T \cdot D_{nn}} \propto \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot H_1^{\sphericalangle}(z, M^2)}{\sum_q e_q^2 \cdot q(x) \cdot D_1(z, M^2)}$$

f = target dilution

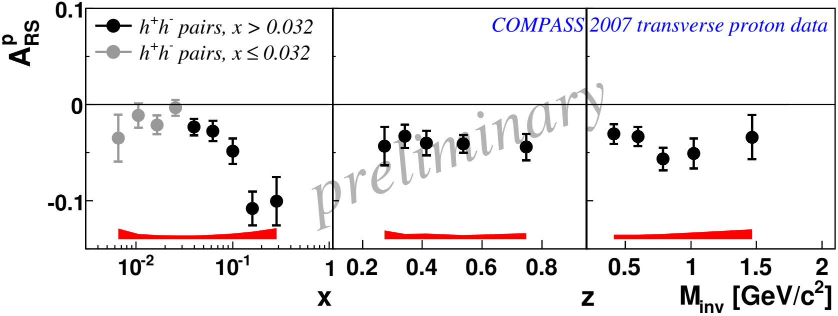
P_T = target polarization

D_{nn} = transverse spin transfer

Dihadron-Asymmetry: Results



- $\rightsquigarrow$ Polarized DiFF and Transversity are **not** Zero
- $A^p_{RS}(M_{inv}) < 0; \quad (0.4 < M_{inv} < 2\,\mathrm{GeV}/c^2)$
- Signal enhanced around ρ^0-mass ($0.77\,\mathrm{GeV}$)



- cut on $x > 0.032$ to enhance asymmetries in z and M_{inv}

$\rightsquigarrow A^p_{RS}(z) \approx A^p_{RS}(M_{inv}) \approx$ const.

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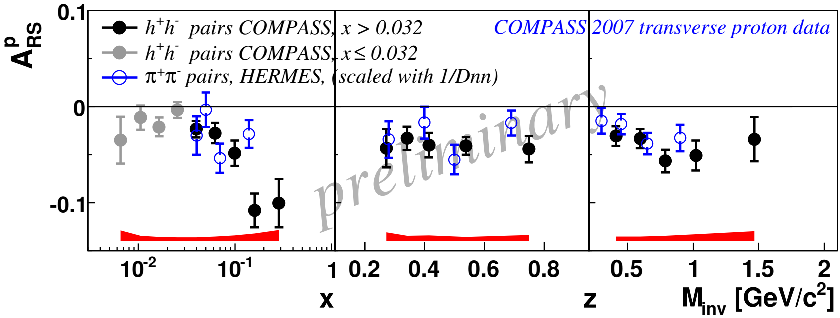
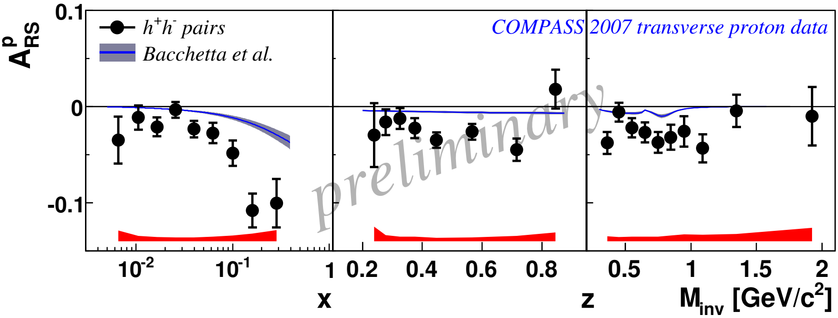


- HERMES results scaled with $-1/D_{nn}$
- COMPASS measurement covers much larger range in x
- Good agreement in overlap region

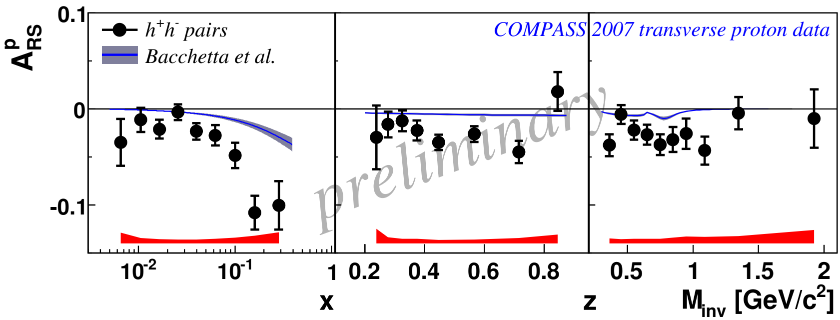
Dihadron-Asymmetry: Results



Recent prediction (Bacchetta, Radici, Phys.Rev.D79:034029,2009)

- Transversity-Distribution of Anselmino et al. (arXiv:0801.0173)
- Model for polarized DiFF

Dihadron-Asymmetry: Results



Recent prediction (Bacchetta, Radici, Phys.Rev.D79:034029,2009)

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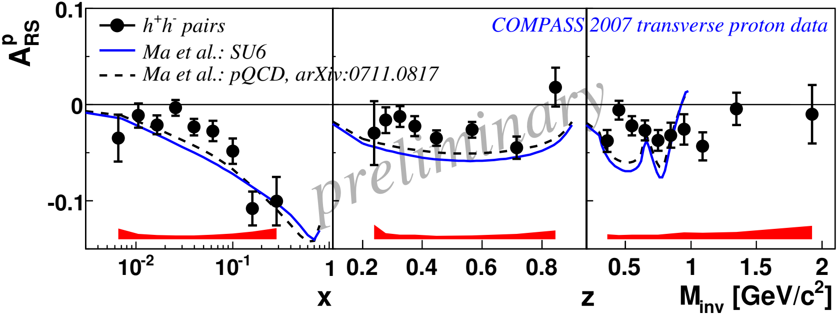
- Model for polarized DiFF

  was downscaled with factor ~ 3 ! (Fit on HERMES results!)

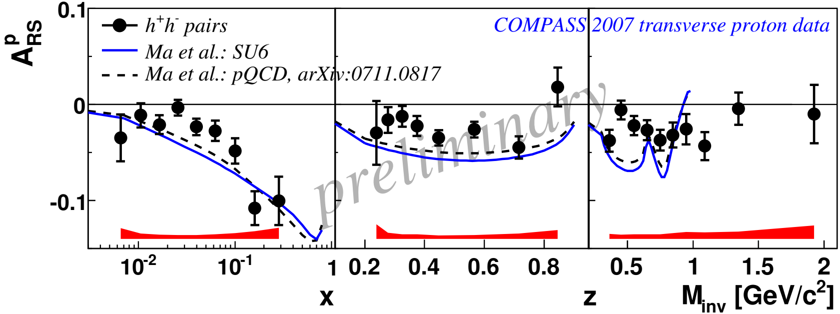
Dihadron-Asymmetry: Results



Recent prediction (Ma et al., Phys.Rev.D77:014035,2008)

- Two different Transversity models: SU6 and pQCD
- Model for polarized DiFF from Bacchetta et al (non-scaled)

Dihadron-Asymmetry: Results



Recent prediction (Ma et al., Phys.Rev.D77:014035,2008)

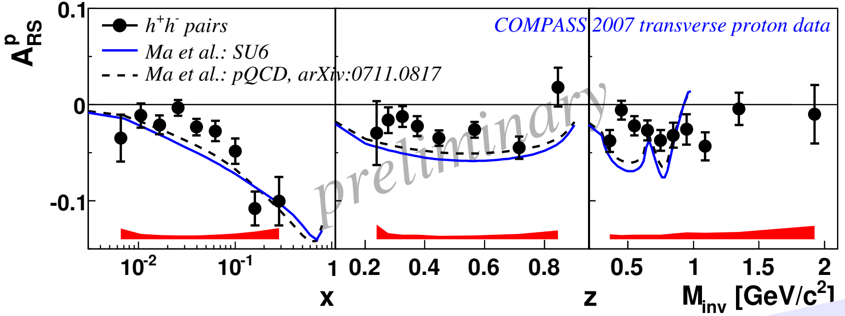
- Two different Transversity models: SU6 and pQCD
- Model for polarized DiFF from Bacchetta et al (non-scaled)

... Belle showed first results of polarized DiFF !

(A. Vossen, Dubna Spin 2009)

$\rightsquigarrow$ **significant asymmetry**

Dihadron-Asymmetry: Results



Recent prediction (Ma et al., Phys.Rev.D77:014035 200…

- Two different Transversity mo…
- Model fo…

…ized DiFF !

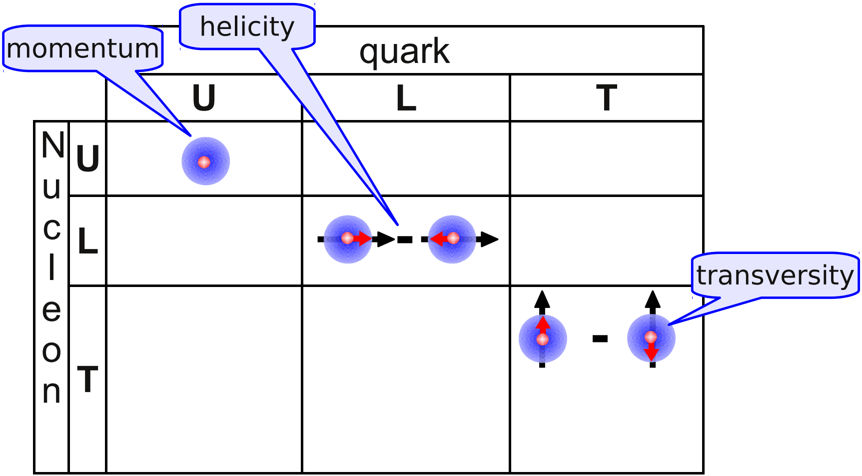
…d Spin 2009)

…gnificant asymmetry

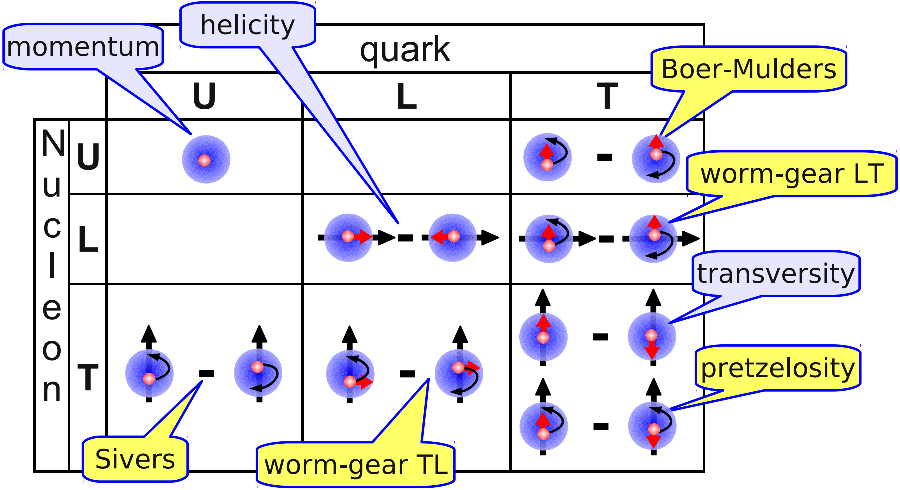
Ready for global analysis to extract Transversity $\rightsquigarrow$ Ultimate cross-check

Transverse Momentum Dependent Distributions TMDs

Three parton distribution functions when integrating over $k_\perp$

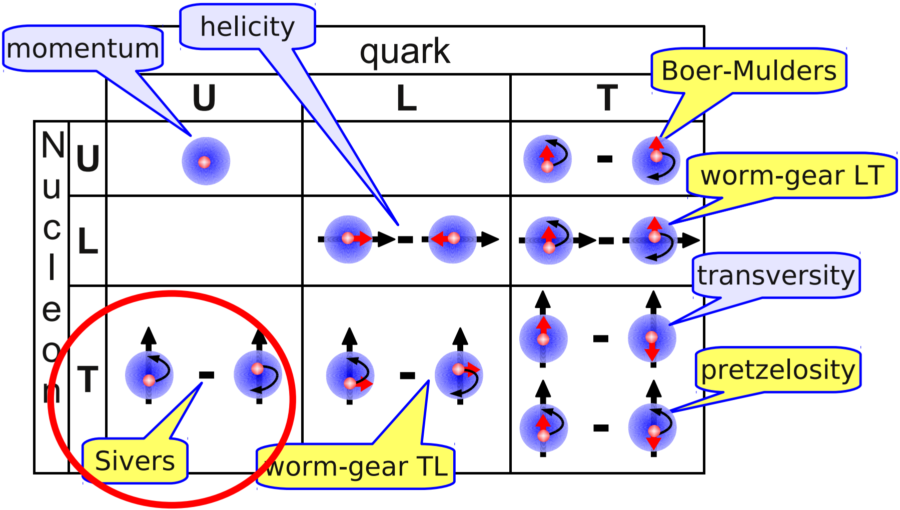


Eight parton distribution functions when taking into account $k_\perp$

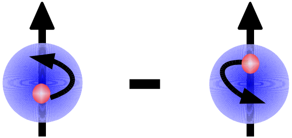


TMDs

Eight parton distribution functions when taking into account $k_\perp$



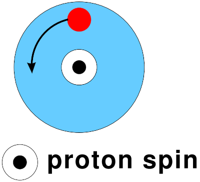
Sivers-Function $\Delta_0^T \mathrm{q}(x, \boldsymbol{k}_T^2)$**:**

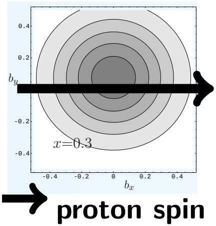


distribution of unpolarized quarks with transverse momentum k_T *in a transversely polarized nucleon*

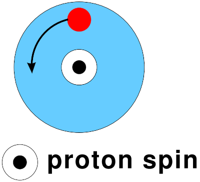
$\rightsquigarrow$ **azimuthal asymmetry of produced hadrons**

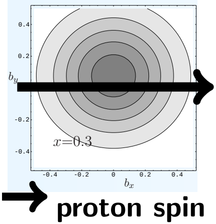
Sivers-Asymmetry: A simple interpretation





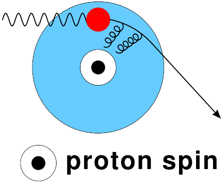
- angular momentum $\rightsquigarrow$ non-symmetric quark-density (in impact parameter space)





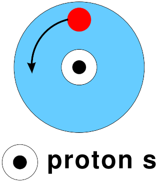
- angular momentum $\rightsquigarrow$ non-symmetric quark-density (in impact parameter space)

Chromodynamic lensing:

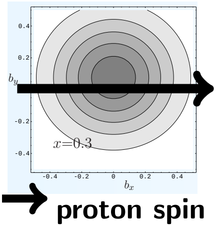


- strong force pulls fragmenting quark towards center of momentum
- more displaced quarks w.r.t center of momentum feel stronger force

Sivers-Asymmetry: A simple interpretation



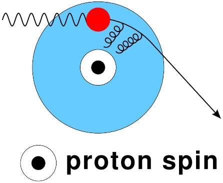
proton spin



proton spin

- angular momentum $\rightsquigarrow$ non-symmetric quark-density (in impact parameter space)

Chromodynamic lensing:



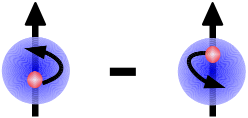
proton spin

- strong force pulls fragmenting quark towards center of momentum
- more displaced quarks w.r.t center of momentum feel stronger force

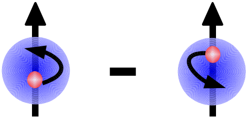
$\Rightarrow$ **More reactions in upper part of proton**

$\Rightarrow$ **More hadrons will be deflected downwards**

Sivers Asymmetry

Sivers PDF $\Delta_0^T q(x, \boldsymbol{k}_T^2)$: 

A non-zero Sivers-Asymmetry requires angular momentum of the quarks

Sivers PDF $\Delta_0^T q(x, \boldsymbol{k}_T^2)$: 

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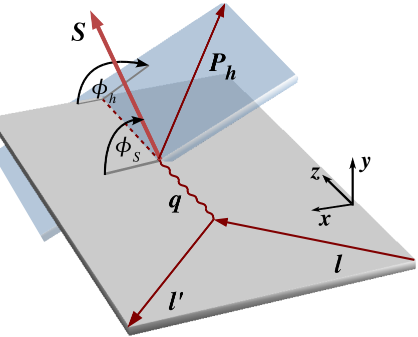


$\rightsquigarrow$ azimuthal asymmetry:

$$\boxed{N_h \;\propto\; 1 \pm A \cdot \sin(\phi_h - \phi_S)}$$

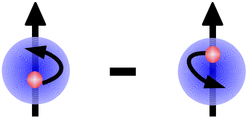
$$\phi_{Siv} = \phi_h - \phi_S$$

ϕ_h: azimuthal angle of hadron

ϕ_S: azimuthal angle of spin of initial quark

Sivers Asymmetry

Sivers PDF $\Delta_0^T q(x, \boldsymbol{k}_T^2)$:



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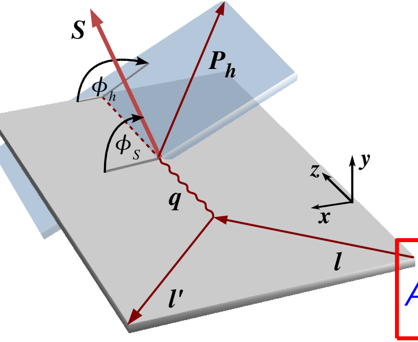

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$$\boxed{N_h \;\propto\; 1 \pm A \cdot \sin(\phi_h - \phi_S)}$$

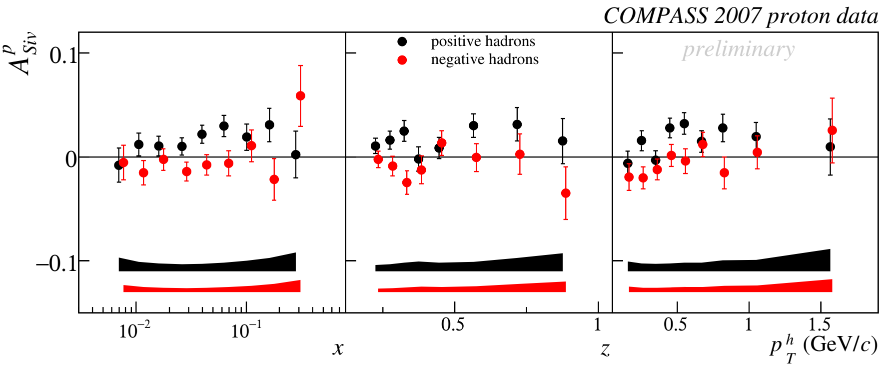
$$\phi_{Siv} = \phi_h - \phi_S$$

ϕ_h: azimuthal angle of hadron

ϕ_S: azimuthal angle of spin of initial quark

$$\boxed{A_{Siv} = \frac{A}{f\ P_T} \propto \frac{\sum_q e_q^2 \cdot \Delta_0^T q(x, \boldsymbol{k}_T^2) \otimes D_q^h(x, \boldsymbol{p}_T^2)}{\sum_q e_q^2 \cdot q(x, \boldsymbol{k}_T^2) \otimes D_q^h(z, \boldsymbol{p}_T^2)}}$$

Sivers: Results Proton 2007



for h^+ additional absolute systematical uncertainty of ± 0.01

- Positive asymmetry for h^+
- Asymmetry for h^- small, compatible with zero
- Published in PLB 673 (2009) 127-135

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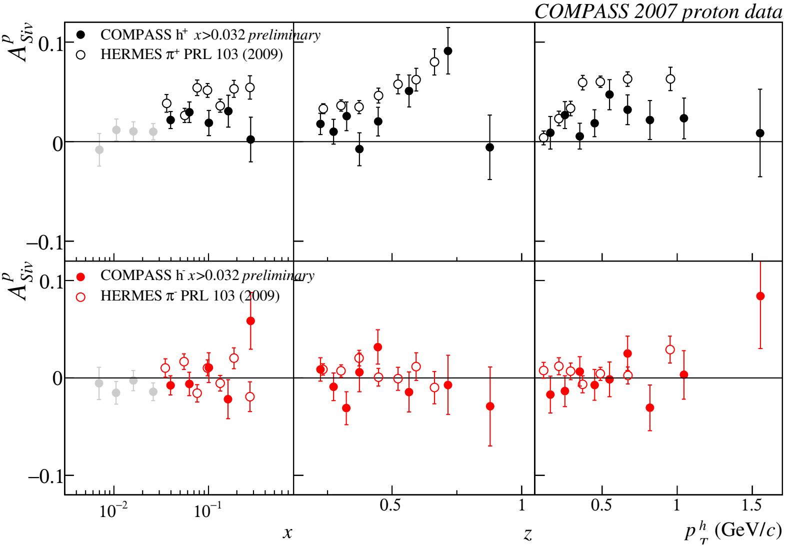
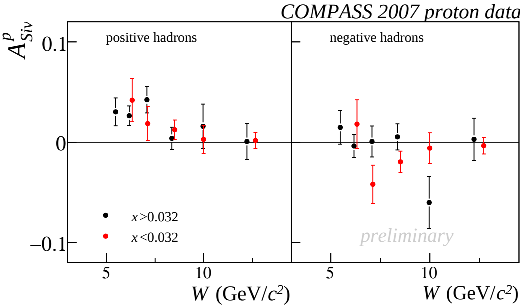


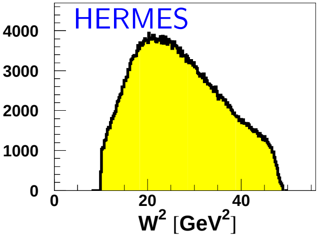
- COMPASS and HERMES data show similar trends!
- COMPASS h^+ about factor 2 smaller than HERMES

Sivers: Results Proton 2007

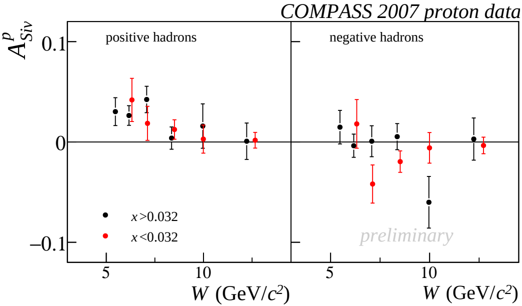


positive hadrons:

- possible W dependence
- Asymmetry only non-zero for small W, where HERMES measures



Sivers: Results Proton 2007



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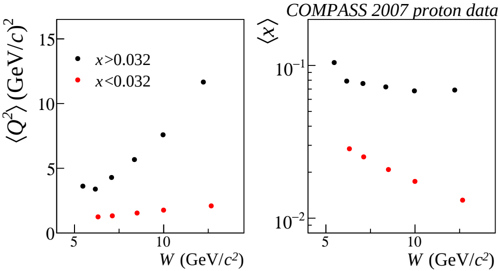
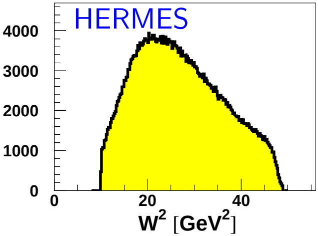
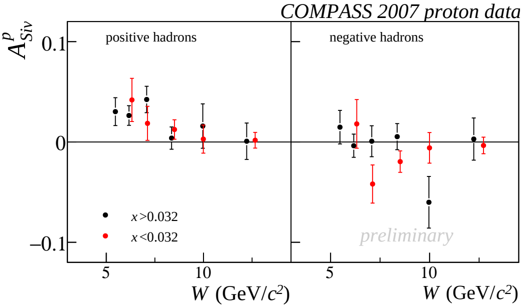




Sivers: Results Proton 2007



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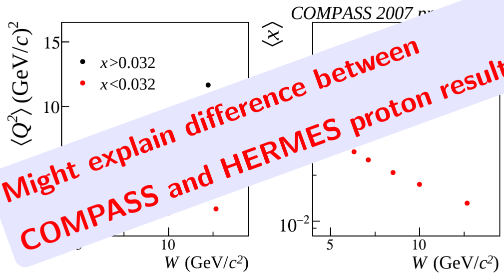
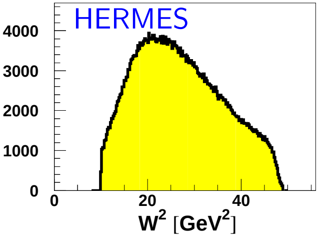


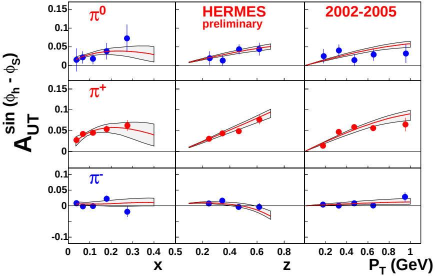
Might explain difference between COMPASS and HERMES proton results



Sivers-Asymmetry: Access to Sivers-Function

Anselmino et al. arXiv:0805.2677

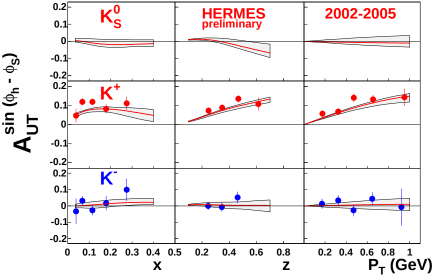
$$A_{Siv} \propto \Delta_0^T q(x, \boldsymbol{k}_T^2) \otimes D_q^h(x, \boldsymbol{p}_T^2)$$



- **HERMES Proton**

$$A_{Siv}^{\pi^0},\ A_{Siv}^{\pi^+},\ A_{Siv}^{K^+} > 0$$

$$A_{Siv}^{\pi^-},\ A_{Siv}^{K^-} \approx 0$$



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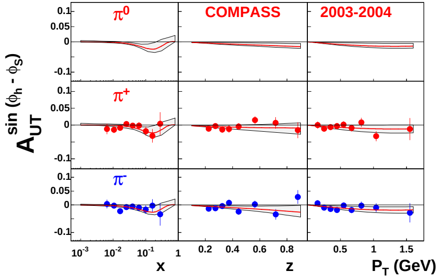
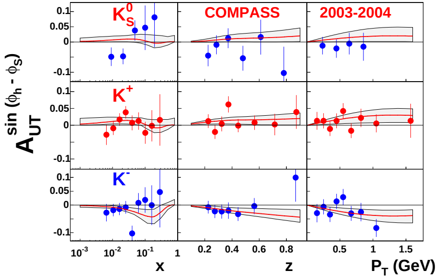




$$A_{Siv} \propto \Delta_0^T q(x, \boldsymbol{k}_T^2) \otimes D_q^h(x, \boldsymbol{p}_T^2)$$

- **HERMES Proton**

$$A_{Siv}^{\pi^0},\ A_{Siv}^{\pi^+},\ A_{Siv}^{K^+} > 0$$

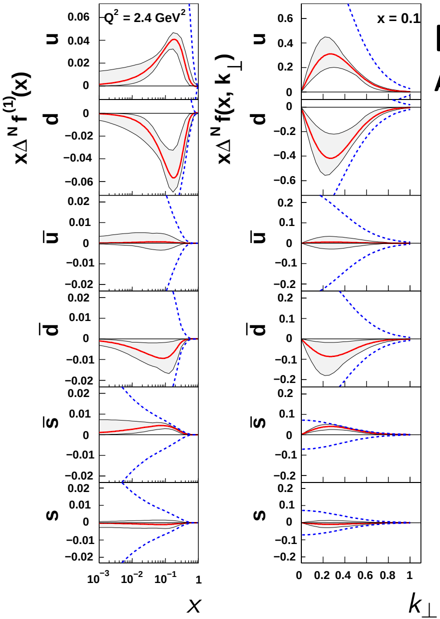
$$A_{Siv}^{\pi^-},\ A_{Siv}^{K^-} \approx 0$$

- **COMPASS Deuteron**

$$A_{Siv}^{\pi^+} \simeq A_{Siv}^{\pi^-} \simeq 0$$

$$A_{Siv}^{K^+} \simeq A_{Siv}^{K^-} \simeq 0$$

$$A_{Siv}^{K_S^0} \simeq 0$$



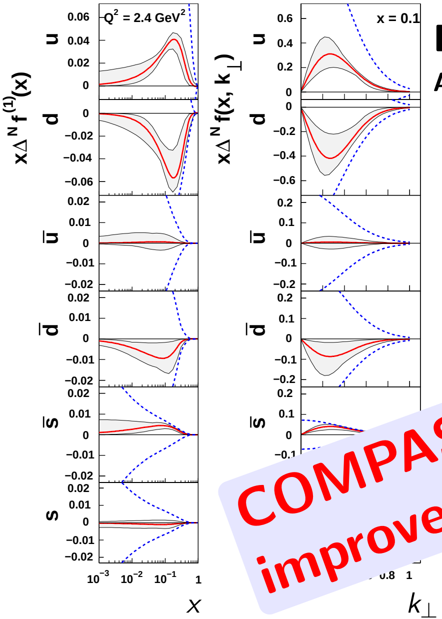
Extraction of Sivers-Function:

Anselmino et al. arXiv:0805.2677

$\Rightarrow$ **Sivers-Function**

$\Delta_0^T \mathbf{u} > 0$

$\Delta_0^T \mathbf{d} < 0$



Extraction of Sivers-Function:

Anselmino et al. arXiv:0805.2677

$\Rightarrow$ **Sivers-Function**

$\Delta_0^T \mathbf{u} > 0$

$\Delta_0^T \mathbf{d} < 0$

COMPASS proton data will improve extraction for low x

Summary

Transversity

- **Sizeable Collins asymmetries**

  First extraction of Transversity distribution and Collins Fragmenation Function

- **Sizeable Dihadron asymmetries**

  Data is ready to extract Transversity

Sivers

- **Significant asymmetry for positive hadron**

  First extraction of Sivers distribution

Summary

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Transversity

- **Sizeable Collins asymmetries**

  First extraction of Transversity distribution and Collins Fragmenation Function

- **Sizeable Dihadron asymmetries**

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Sivers

- **Significant asymmetry for positive hadron**

  First extraction of Sivers distribution

Outlook

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

End

Thank You

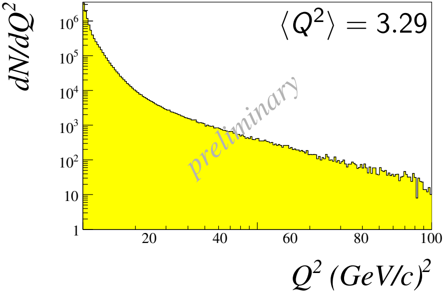
email: heiner.wollny@cern.ch

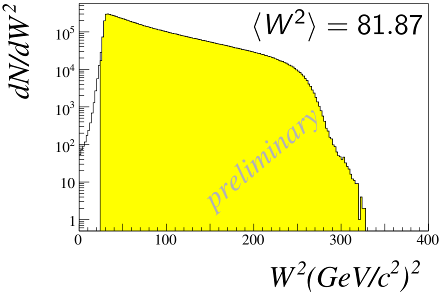
Back Up

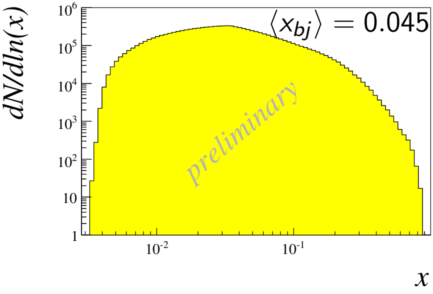
Single Hadrons: SIDIS Event Selection

DIS cuts:

- $Q^2 > 1\,(\mathrm{GeV}/c)^2$
- $0.1 < y < 0.9$
- $W^2 > 25\,\mathrm{GeV}^2/c^4$







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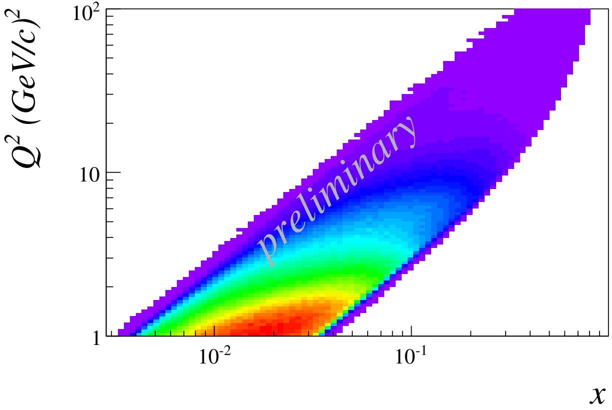
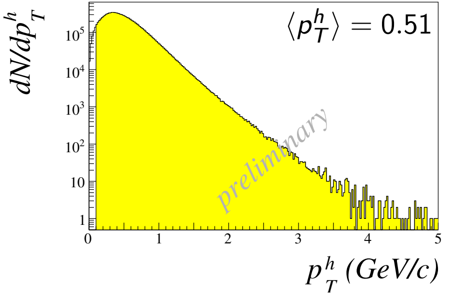


Single Hadrons: SIDIS Event Selection

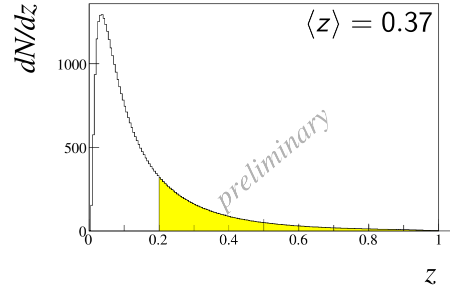
hadron cuts:

- $p_T > 0.1\,\mathrm{GeV}/c$
- $z > 0.2$



Total statistics:

pos hadrons	neg hadrons
$15 \cdot 10^6$	$12 \cdot 10^6$



General Expression of polarized SIDIS Cross-Section

$$
\begin{aligned}
&\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \\
&\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
&\quad + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
&+ S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] \\
&+ S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right] \\
&+ |\boldsymbol{S}_\perp|\bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) \\
&\quad + \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
&\quad + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\bigg] \\
&+ |\boldsymbol{S}_\perp|\lambda_e\bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
&\quad + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\bigg]\Bigg\},
\end{aligned}
$$

unpolarized target

longitudinally polarized target

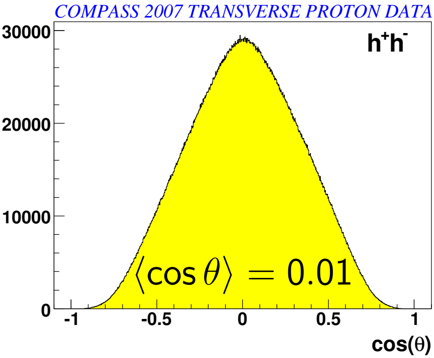
transversely polarized target

A.Bacchetta et al

JHEP 0702:093,2007

E-print number: hep-ph/0611265

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



$\rightsquigarrow$ azimuthal asymmetry:

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

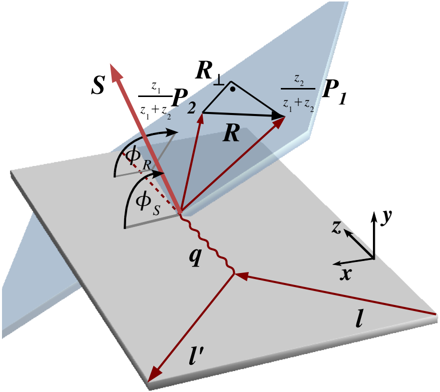
$$\phi_{RS} = \phi_R + \phi_S - \pi$$

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

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

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

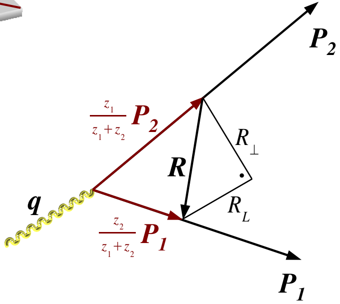
Definition of R_T and ϕ_R



$$\vec{R} = \frac{z_2\vec{P}_1 - z_1\vec{P}_2}{z_1+z_2}$$

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

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



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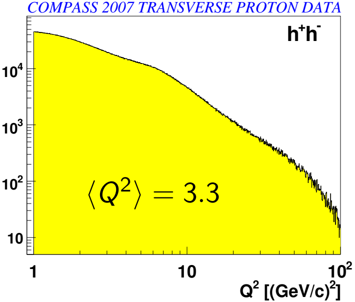
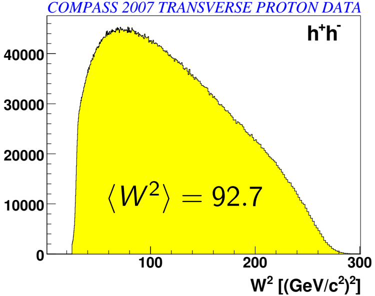
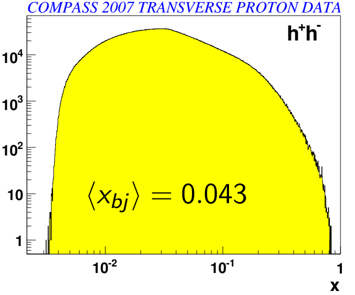
DIS cuts:

- $Q^2 > 1\,(\mathrm{GeV}/c)^2$
- $0.1 < y < 0.9$
- $W > 5\,\mathrm{GeV}/c^2$





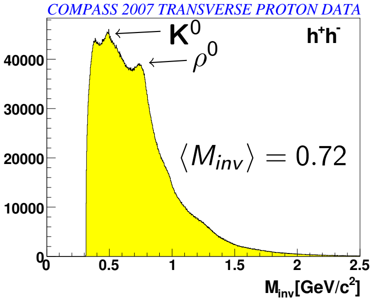


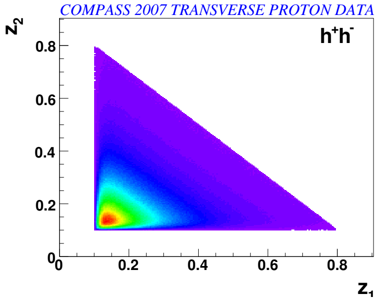
hadron cuts:

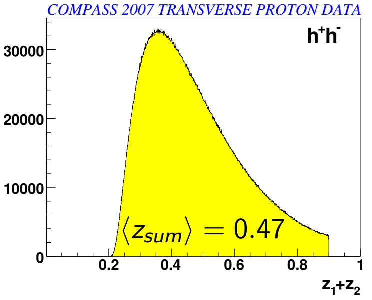
- $z_i > 0.1, \quad x_{F,i} > 0.1$
- $z_{sum} = z_1 + z_2 < 0.9$
- $R_T > 0.07\,\mathrm{GeV}/c$

Total statistics for this analysis:

$11 \cdot 10^6$ h^+h^--pairs







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