EXPERIMENTAL RESULTS IN SIDIS ON SPIN-DEPENDENT FLAVOR STRUCTURE OF THE LIGHT QUARK SEA

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INFN Ferrara

Structure of Nucleons and Nuclei
June 10, 2013 Como

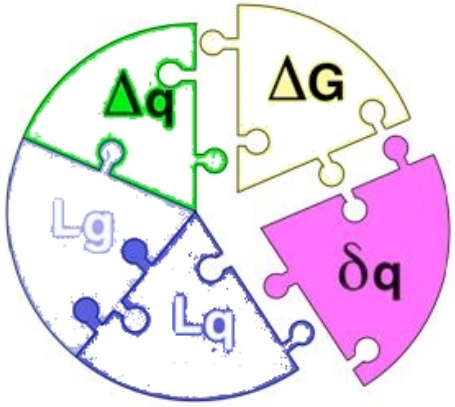
The Spin Degree of Freedom

In our exploration of the QCD micro-world

Fundamental: do not neglect spin !!

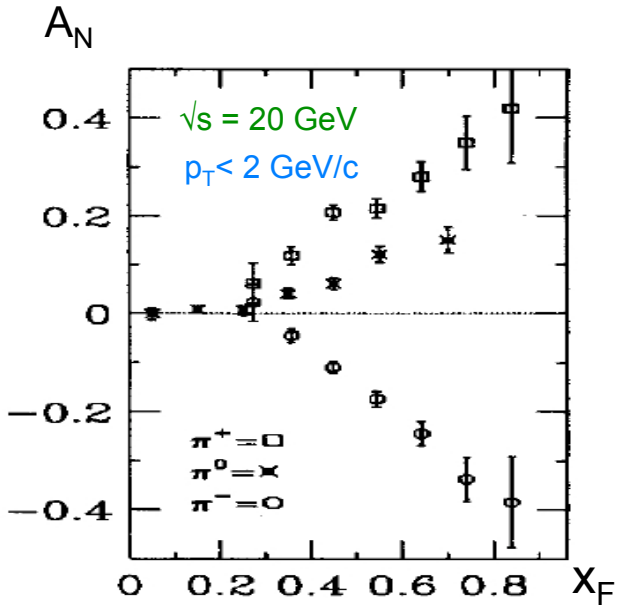
Two questions in Hadronic Physics
await explanation since too long

Proton Spin Budget



$$\frac{1}{2} = \frac{1}{2}\sum_f (q_f^+ - q_f^-) + L_q + \Delta G + L_g$$

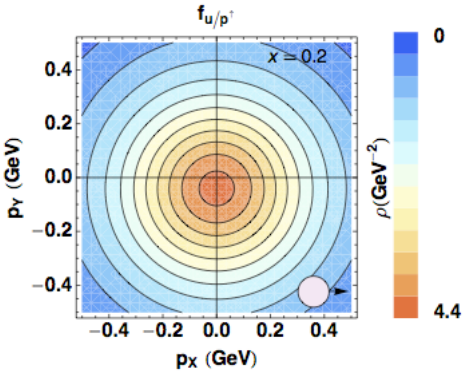
Single Spin Asymmetries



Quantum phase-space distributions of quarks

$W_p^q(x,k_T,r)$ "Mother" Wigner distributions

Probability to find a quark q in a nucleon P with a certain polarization in a position r & momentum k



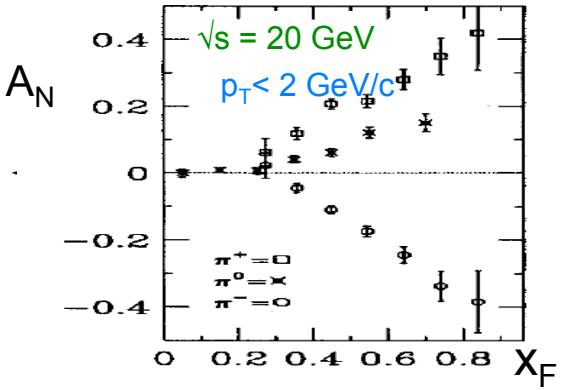
d^3r

TMD PDFs: $f_p^u(x,k_T)$,…

Semi-inclusive measurements
Momentum transfer to quark
Direct info about momentum distribution

d^2k_T

May explain SSA & Lam-Tung



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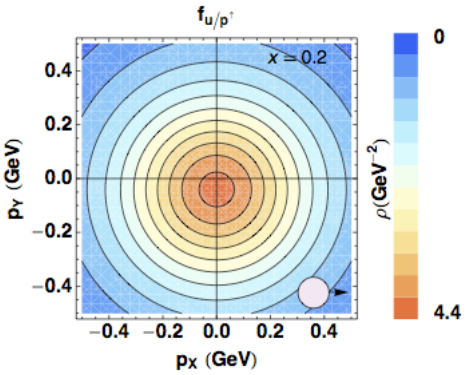
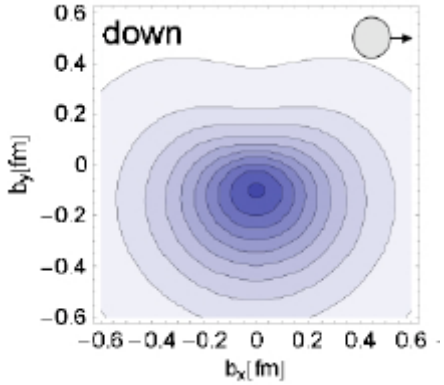


d^3r

d^2k_T (FT)



TMD PDFs: $f_p^u(x,k_T)$,…

Semi-inclusive measurements
Momentum transfer to quark
Direct info about momentum distribution

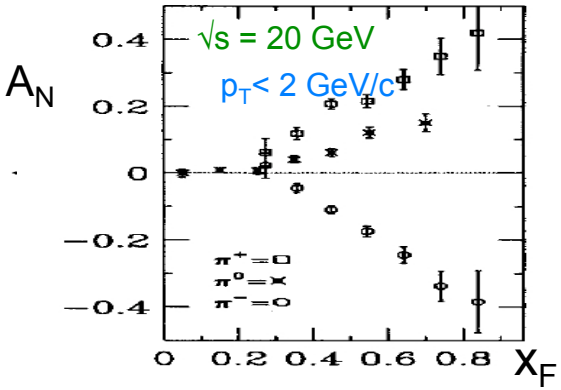
GPDs: $H_p^u(x,\xi,t)$, …

Exclusive Measurements
Momentum transfer to target
Direct info about spatial distribution

d^2k_T

$\xi=0,t=0$

May explain SSA & Lam-Tung

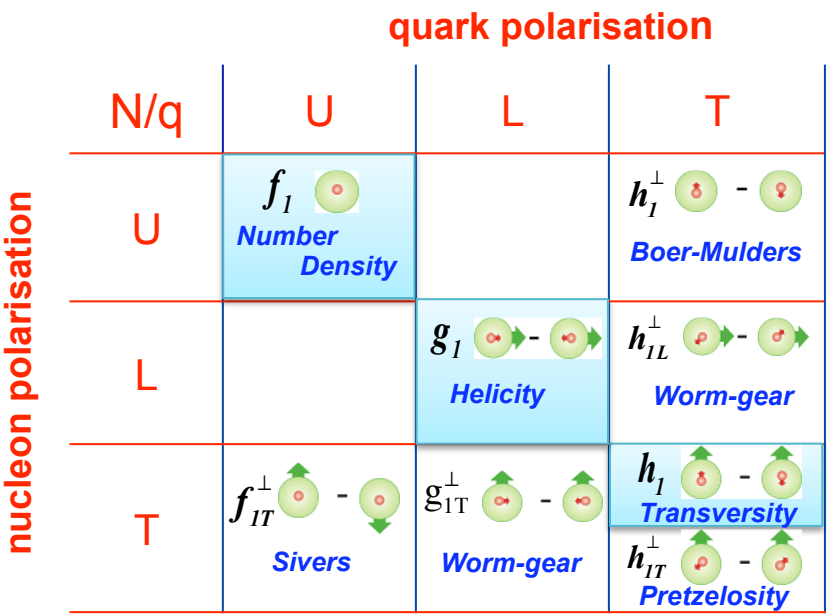


PDFs $f_p^u(x)$,…

May solve
proton spin puzzle

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \lim_{t\to 0}\int_{-1}^{1} dx\; x\left[H(x,\zeta,t) + E(x,\zeta,t)\right]$$

Leading Twist TMDs



Number density and helicity:

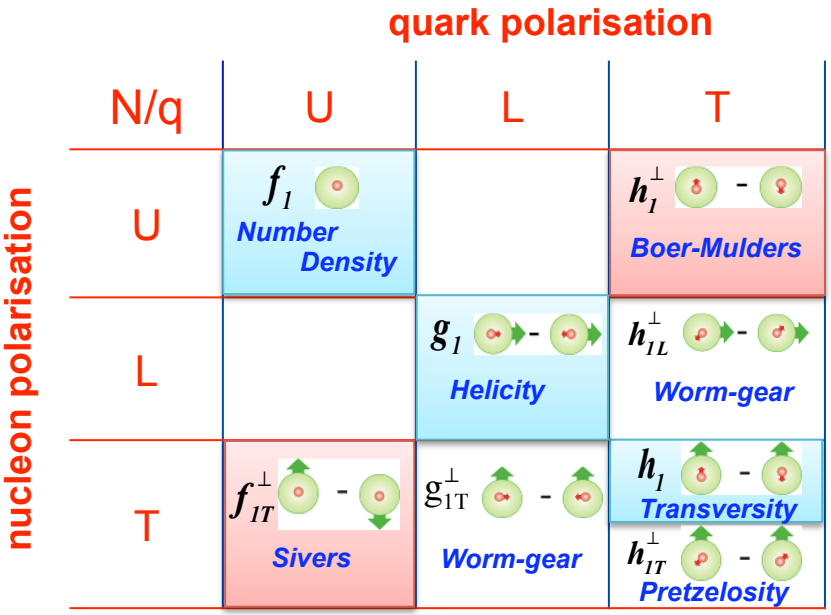
Focusing here in transverse momentum dependence

Transversity:

Survives transverse momentum integration
(missing leading-twist collinear piece)

Differs from helicity due to relativistic effects and
no mix with gluons in the spin-1/2 nucleon

Leading Twist TMDs



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Off-diagonal elements:

Interference between wave functions with different angular momenta: contains information about parton orbital angular motion and spin-orbit effects

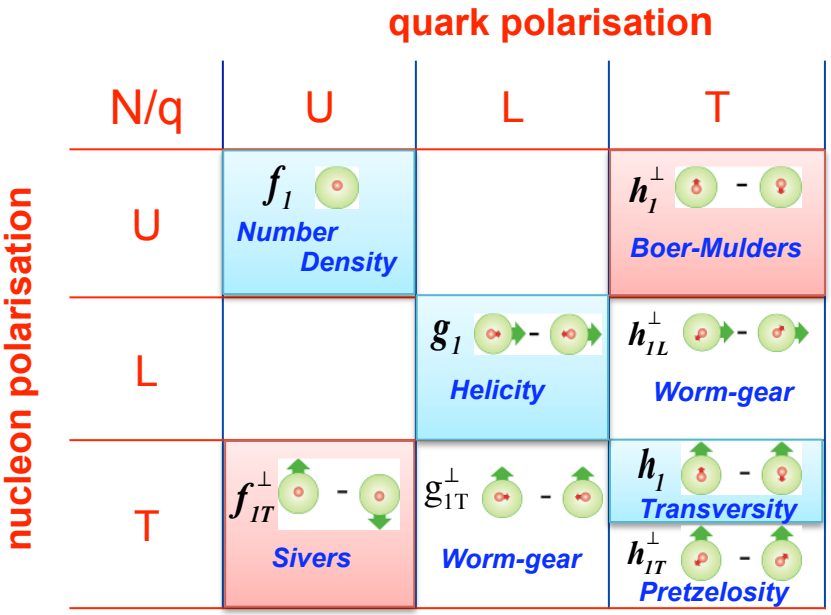
Testing QCD at the amplitude level

T-odd elements:

→ sign change between DY and SIDIS
- universality of TMDs

Strict prediction from TMDs + QCD !

Leading Twist TMDs



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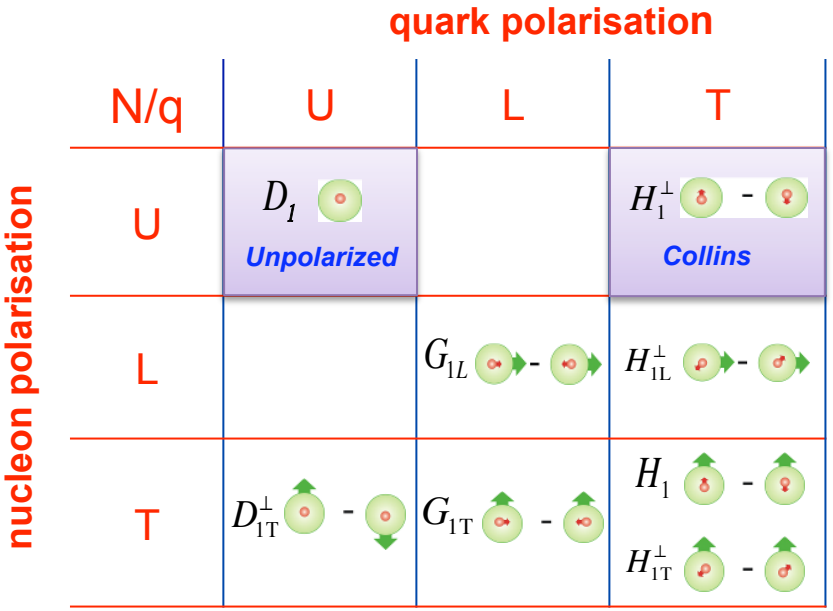
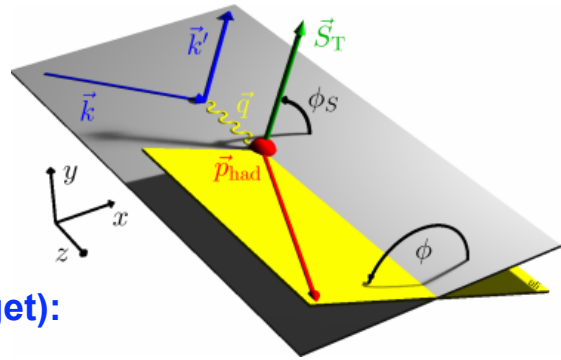


The SIDIS case

quark polarisation

nucleon polarisation

N/q	U	L	T
U	f_1 *Number Density*		$h_1^\perp$ *Boer-Mulders*
L		g_1 *Helicity*	$h_{1L}^\perp$ *Worm-gear*
T	$f_{1T}^\perp$ *Sivers*	$g_{1T}^\perp$ *Worm-gear*	h_1 *Transversity*; $h_{1T}^\perp$ *Pretzelosity*



SIDIS cross section (transversely polarized target):

$$\frac{d^6\sigma}{dx\,dy\,dz\,d\phi_S d\phi\,dP_{h\perp}^2} \underset{Twist}{\overset{Leading}{\propto}} S_T\left\{\sin(\phi-\phi_S)F_{UT,T}^{\sin(\phi-\phi_S)}\right\}$$

$$+S_T\left\{\varepsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)}+\varepsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}\right\}$$

$$+S_T\lambda_e\left\{\sqrt{1-\varepsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)}\right\}+\ldots$$

The SIDIS case

quark polarisation

nucleon polarisation

N/q	U	L	T
U	f_1 Number Density		$h_1^\perp$ Boer-Mulders
L		g_1 Helicity	$h_{1L}^\perp$ Worm-gear
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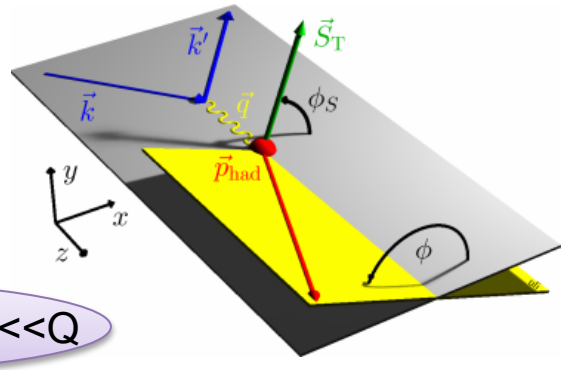
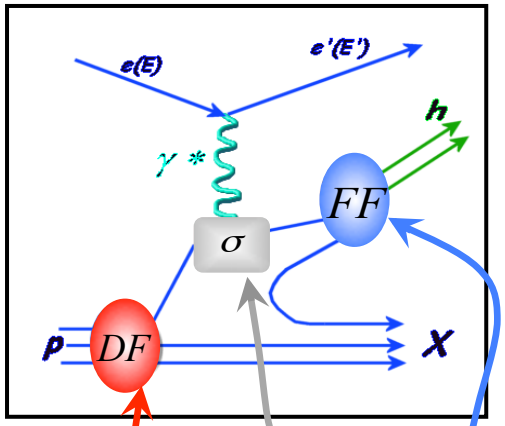


TMD factorization for $P_T \ll Q$

$$f \otimes D = \int_q e_q^2 d^2p_T d^2k_T \ldots w(k_T, p_T) f^q(x, k_T^2) D^q(z, p_T^2)$$

Involved phenomenology due to the convolution over transverse momentum



$$\sigma^{ep\to ehX} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$

$h_1 \otimes H_1^\perp$

$$\frac{d^6\sigma}{dx\, dy\, dz\, d\phi_S d\phi\, dP_{h\perp}^2} \underset{Twist}{\overset{Leading}{\propto}} S_T \left\{ \sin(\phi - \phi_S) F_{UT,T}^{\sin(\phi-\phi_S)} \right\}$$

$f_{1T}^\perp \otimes D_1$ $\qquad$ $h_{1T}^\perp \otimes H_1^\perp$

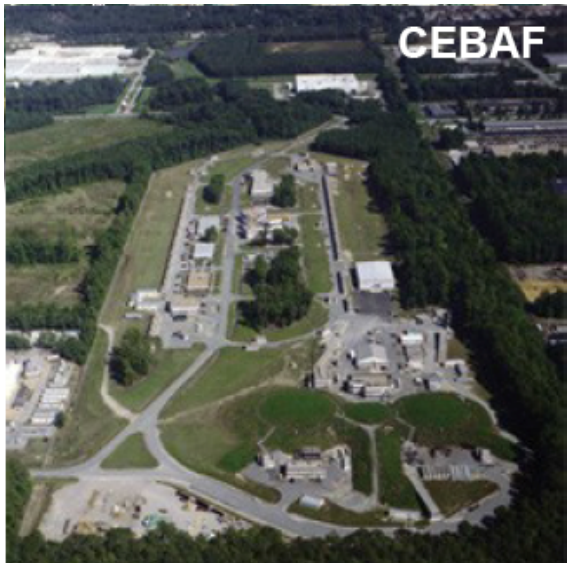
$$+ S_T \left\{ \varepsilon \sin(\phi + \phi_S) F_{UT}^{\sin(\phi+\phi_S)} + \varepsilon \sin(3\phi - \phi_S) F_{UT}^{\sin(3\phi-\phi_S)} \right\}$$

$g_{1T}^\perp \otimes D_1$

$$+ S_T \lambda_e \left\{ \sqrt{1-\varepsilon^2} \cos(\phi - \phi_S) F_{LT}^{\cos(\phi-\phi_S)} \right\} + \ldots$$

The SIDIS Factories

HERMES:
Polarized 27 GeV e+/e-
Polarized pure gaseous H&D targets
Excellent Particle ID

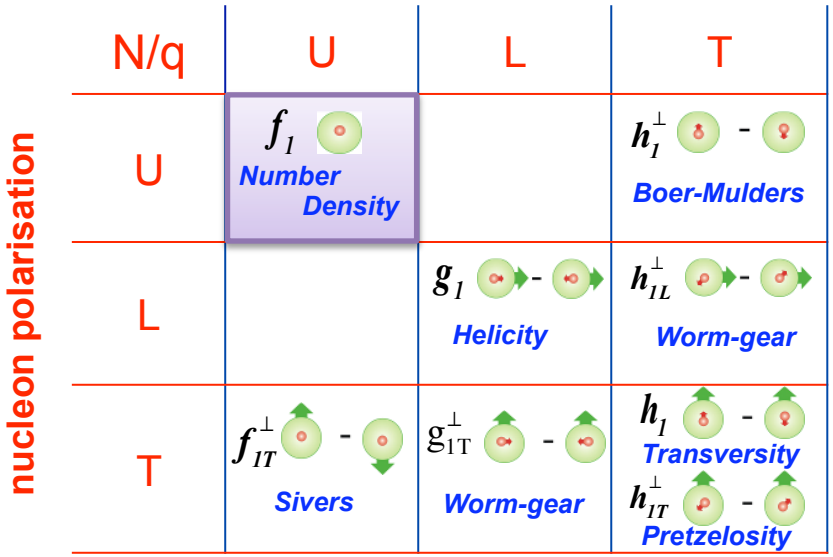


HALL-A, B , C:
Polarized 6 GeV e-
Polarized ^{3}He, NH_3 & HDice targets
High- Luminosity

COMPASS:
Polarized 160 GeV μ
Polarized ^{6}LiD & NH_3 targets
High-Energy

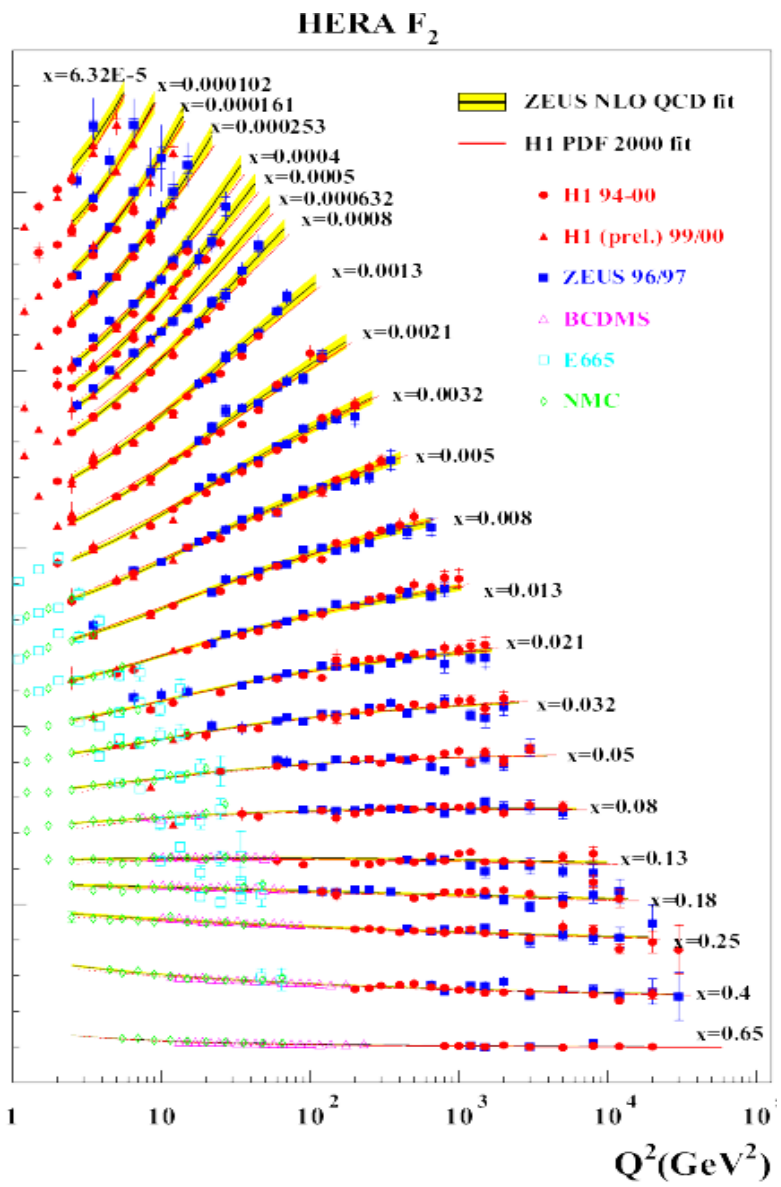
Parton Number Density

Number Density

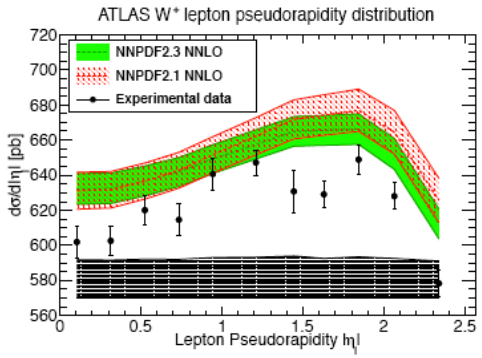


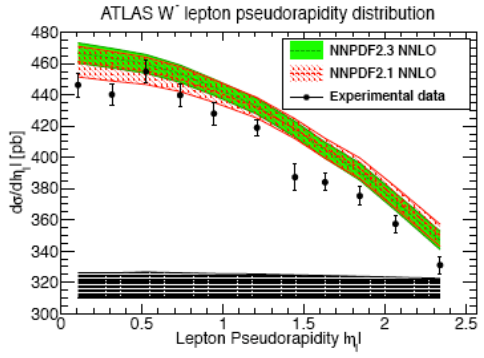
(The Baseline)

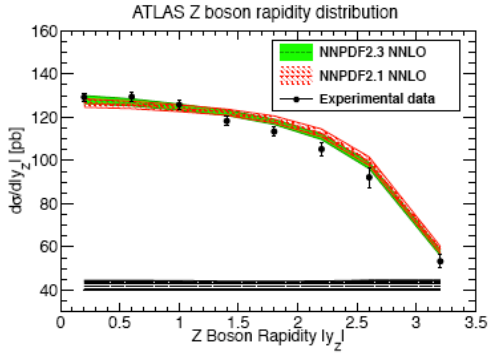
Parton Number Density

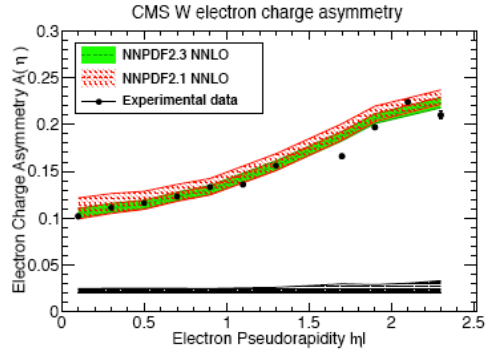


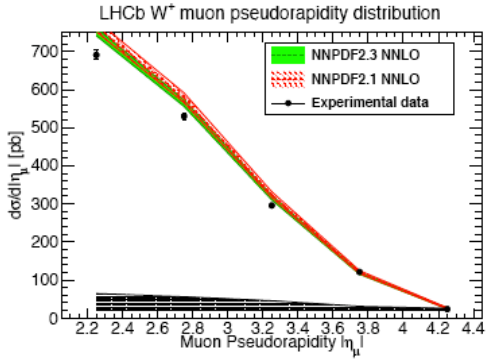
LHC gauge boson production

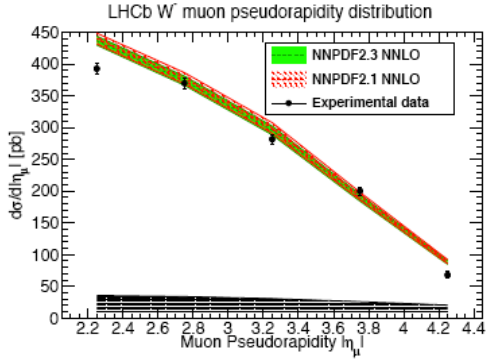












NNPDF: arXiv:1207.1303

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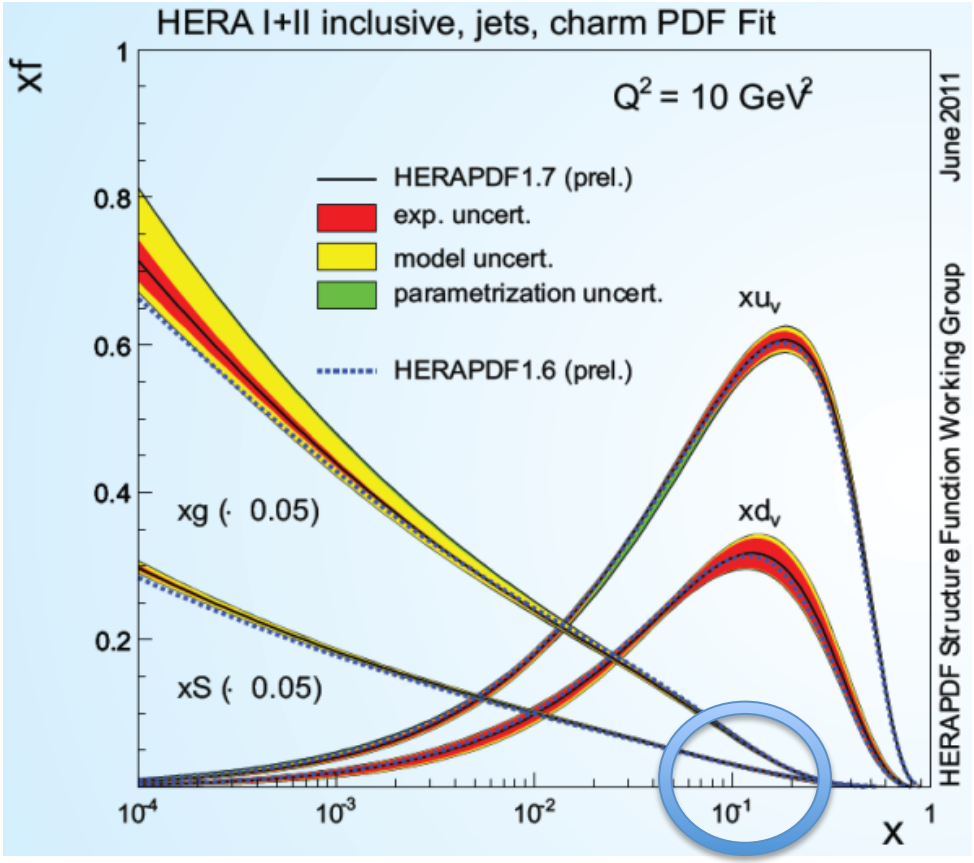
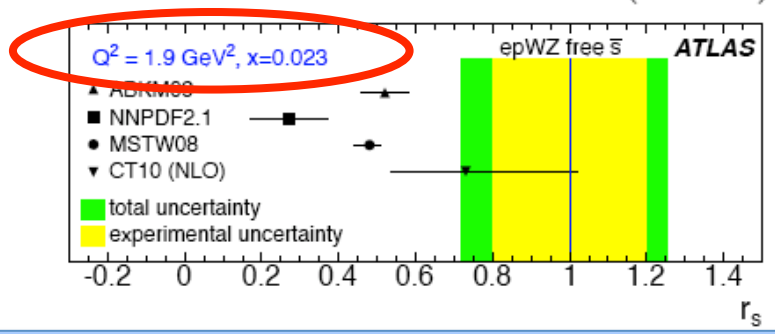


ATLAS: arXiv:1206.4051 $r_s = 0.5(s + \bar{s})/\bar{d}$



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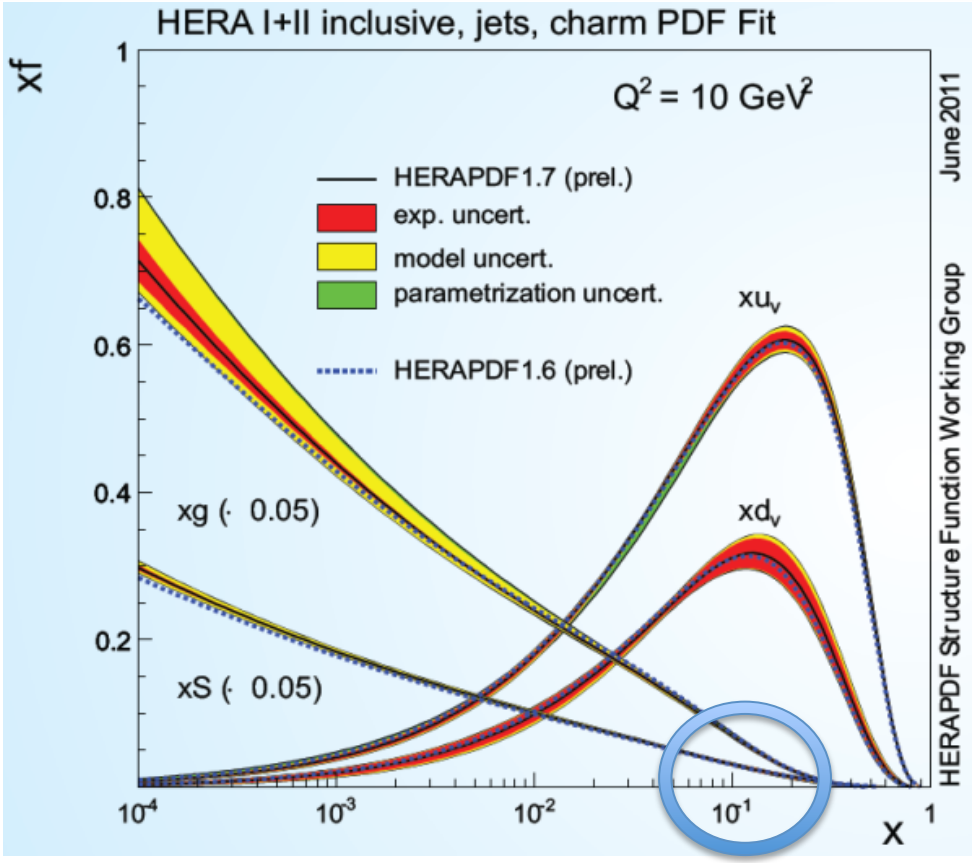
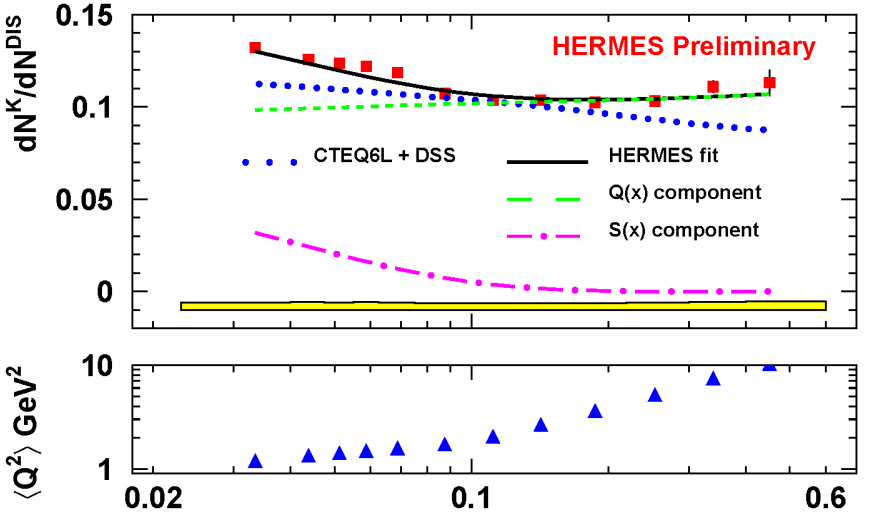
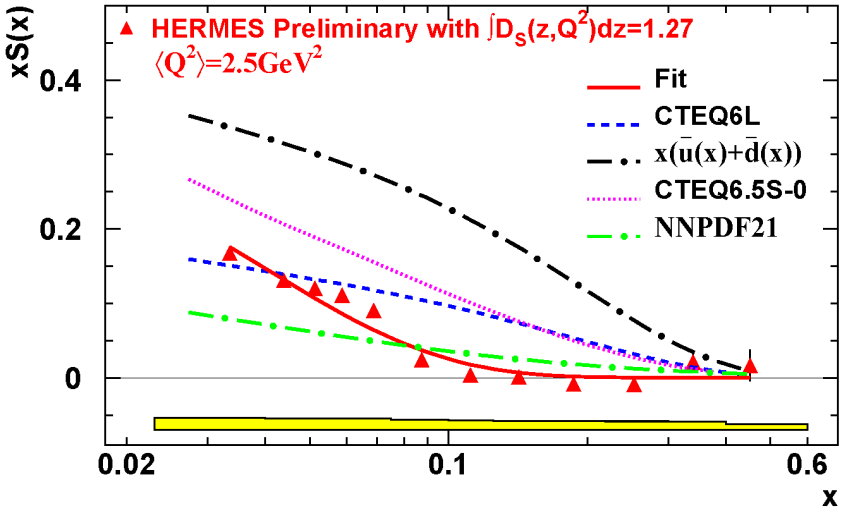


SIDIS extraction: Jackson, DIS 2013

$$\int_{0.2}^{0.85} M^{K^+ + K^-}(x,z)dz = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x)+2S(x)}$$





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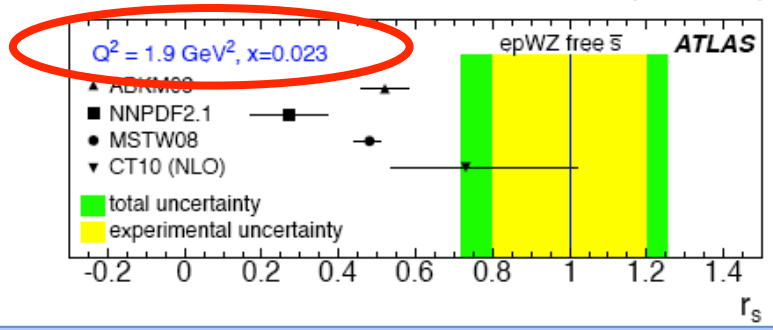

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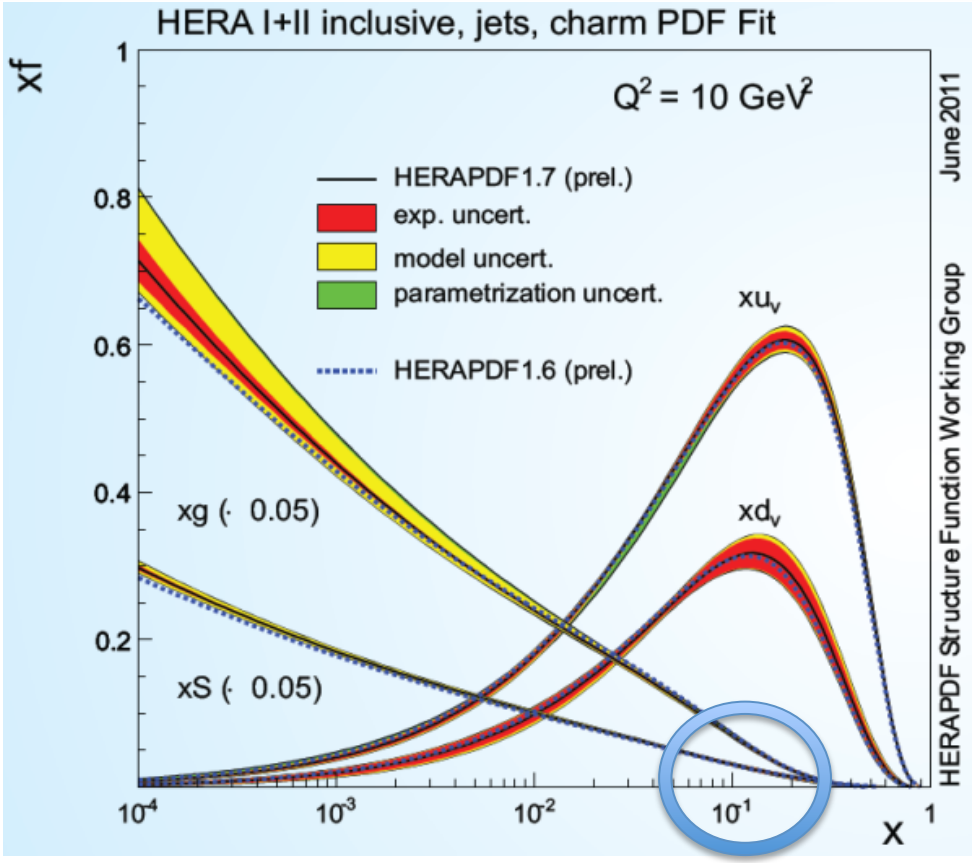

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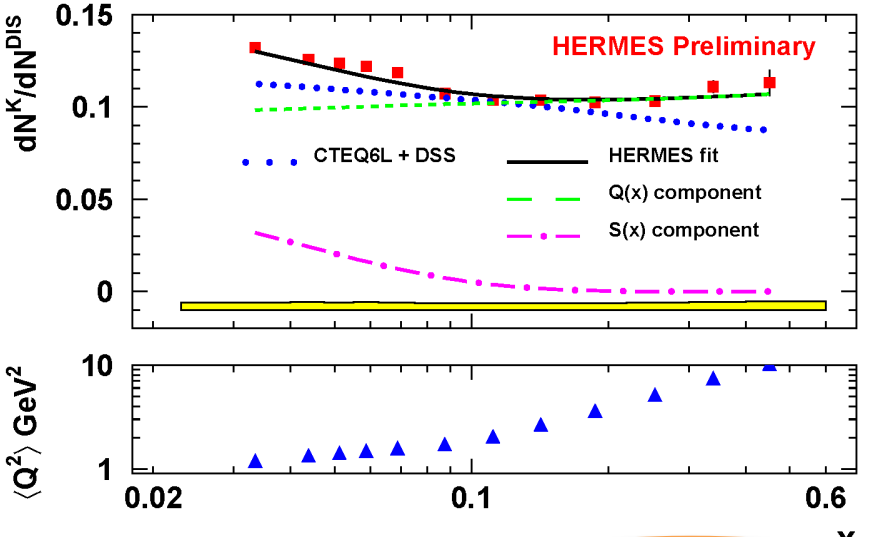

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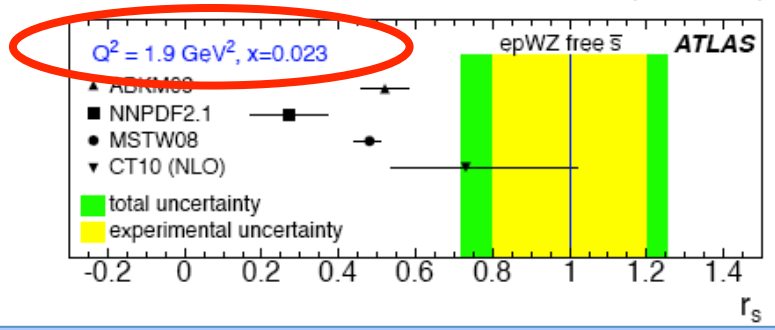
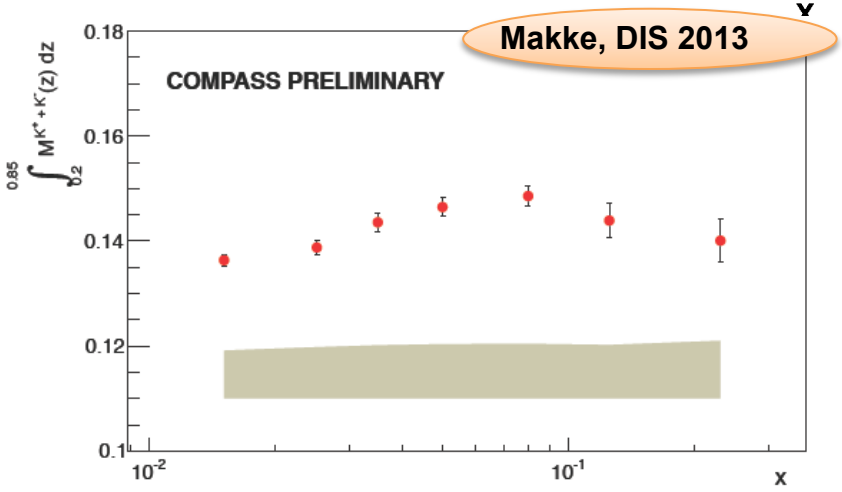
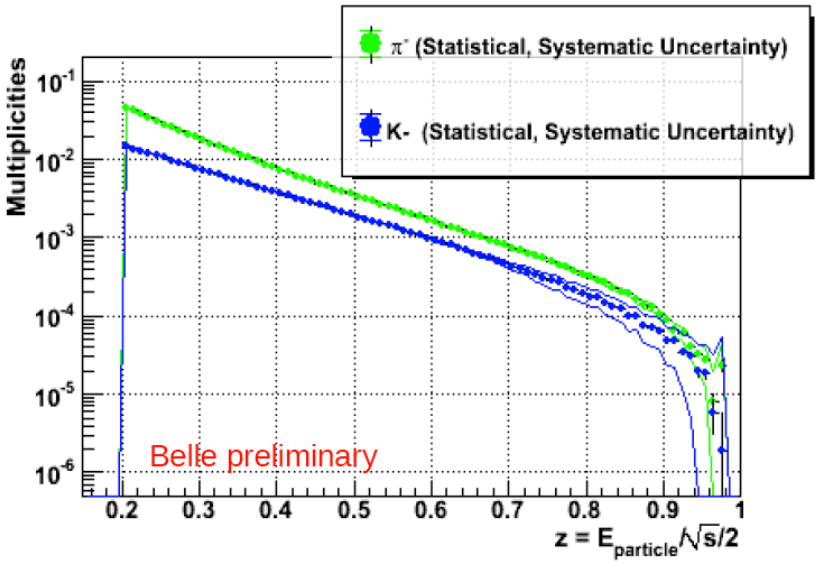


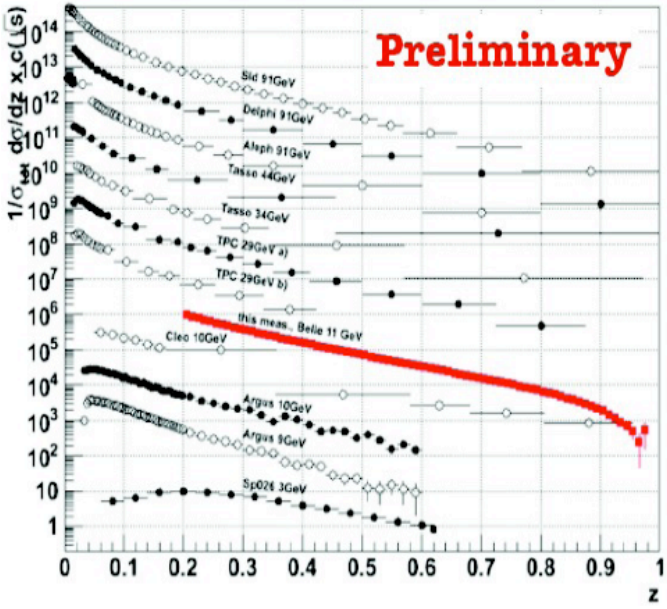
Makke, DIS 2013

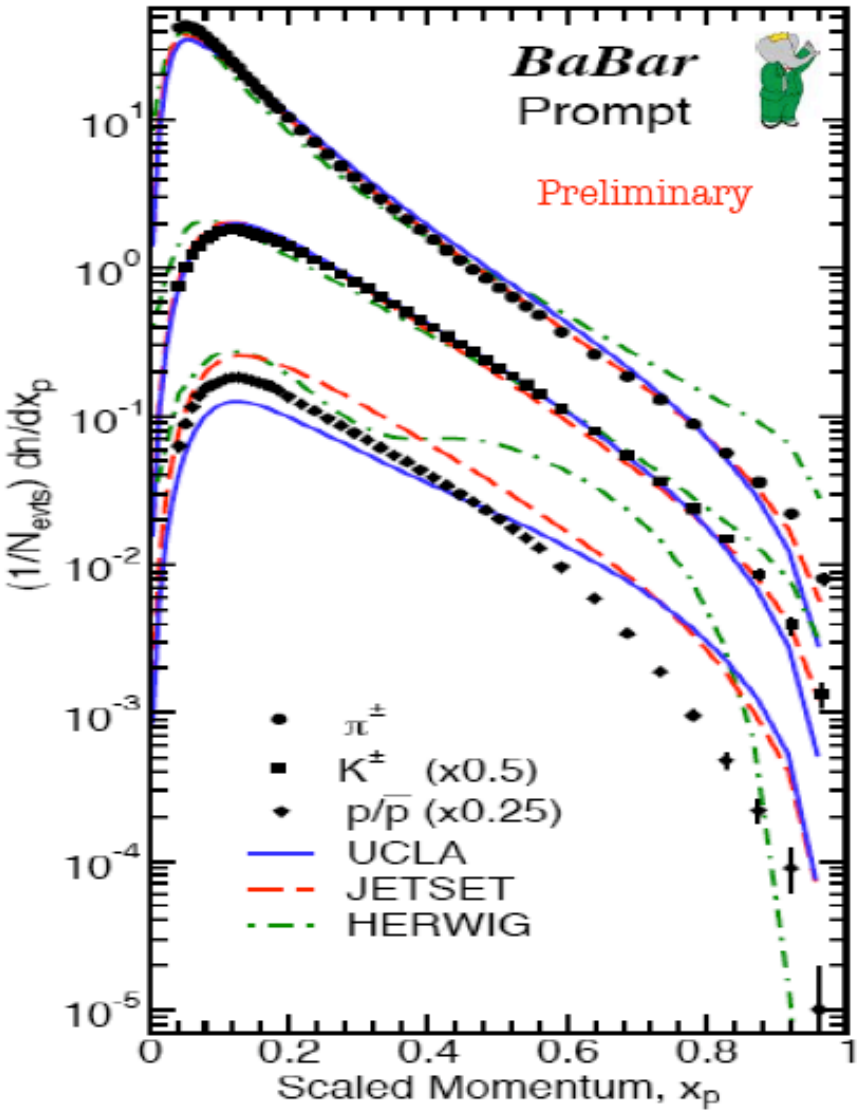


Fragmentation Functions @ B-factories



world data (sel.) for $e^+e^- \to \pi^\pm + X$ production





M. Perdekamp talk

The Hadron Multiplicities

$f_1 \cdot D_1$

LO interpretation:

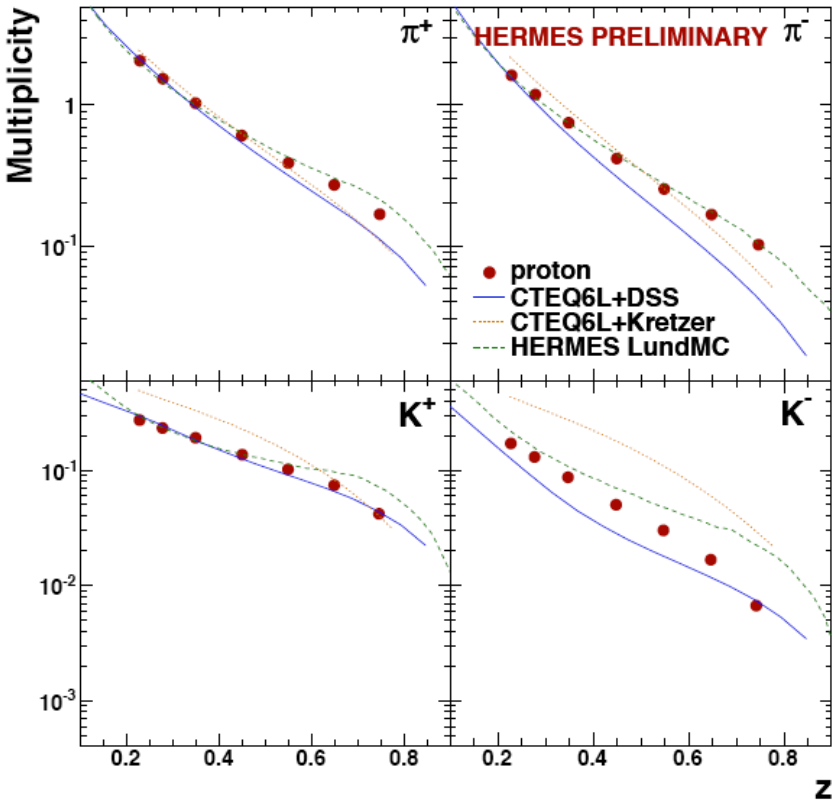
$$M_N^h = \frac{1}{N_N^{DIS}(Q^2)} \frac{dN_N^h(z,Q^2)}{dz} = \frac{\sum_q e_q^2 \int dx\, f_{1q}(x,Q^2) D_{1q}^h(z,Q^2)}{\sum_q e_q^2 \int dx\, f_{1q}(x,Q^2)}$$

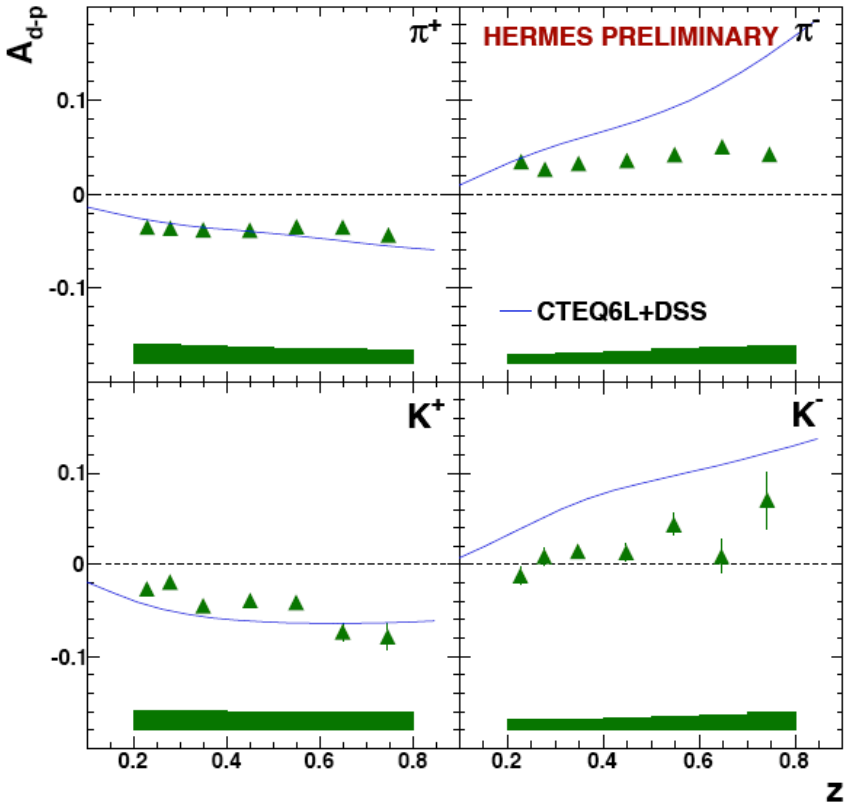
SIDIS data constrain fragmentation at low c.m. energy and bring enhanced flavor sensitivity

Proton-deuteron asymmetry:

$$A_{d-p}^h \equiv \frac{M_d^h - M_p^h}{M_d^h + M_p^h}$$

Reflects different flavor content
Correlated systematics cancels



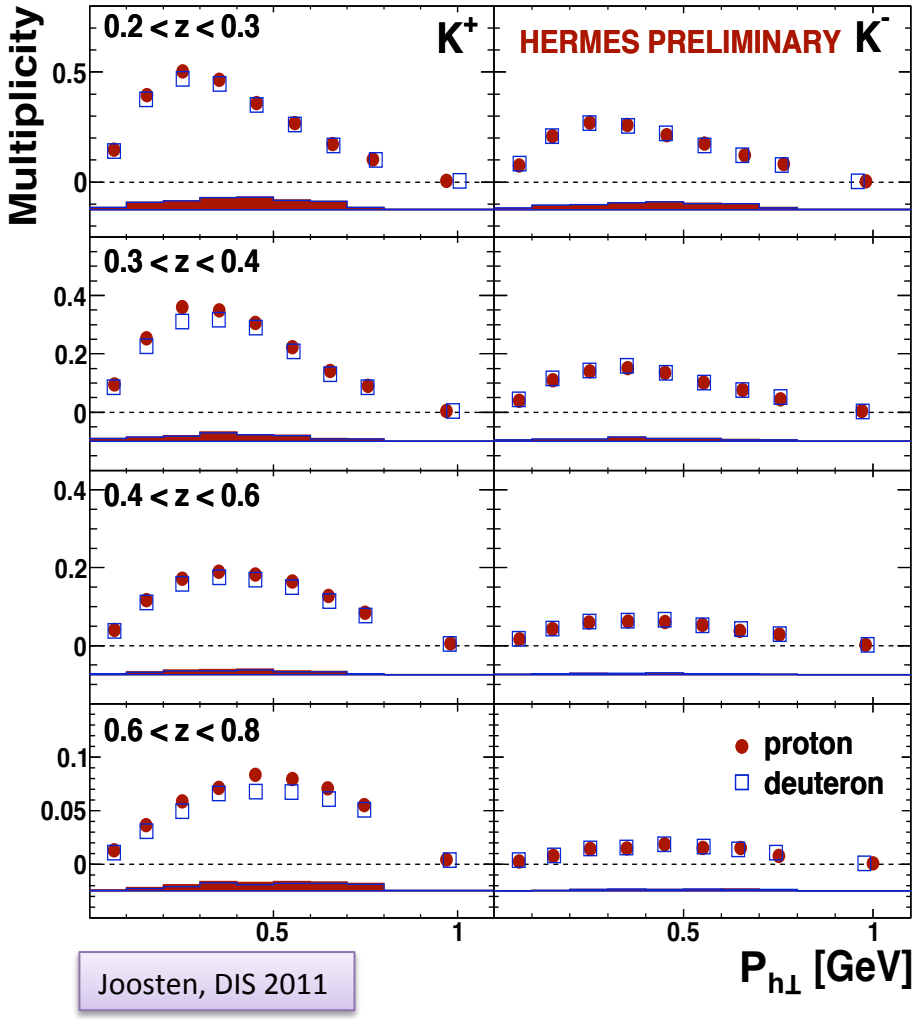


The $P_{h\perp}$-unintegrated multiplicities

$f_1 \otimes D_1$

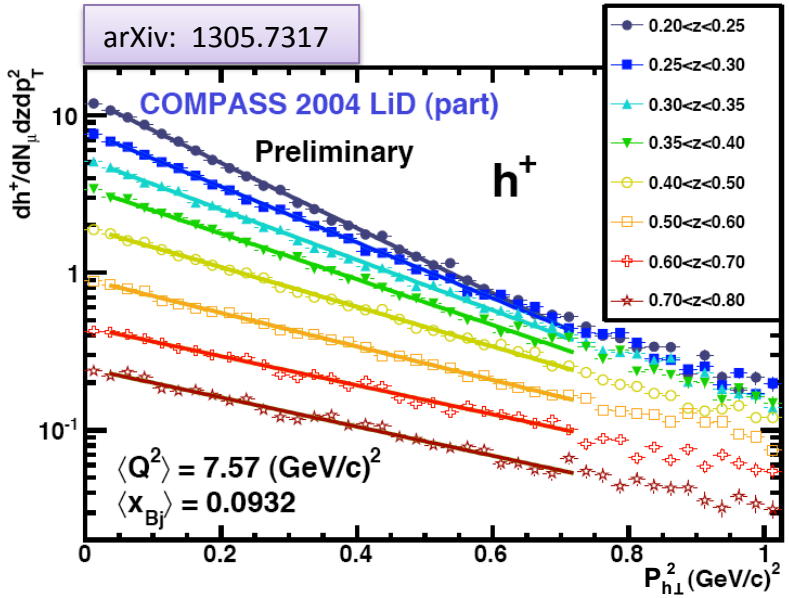
Disentanglement of z and $P_{h\perp}$: access to the transverse intrinsic quark k_T and fragmentation p_T,

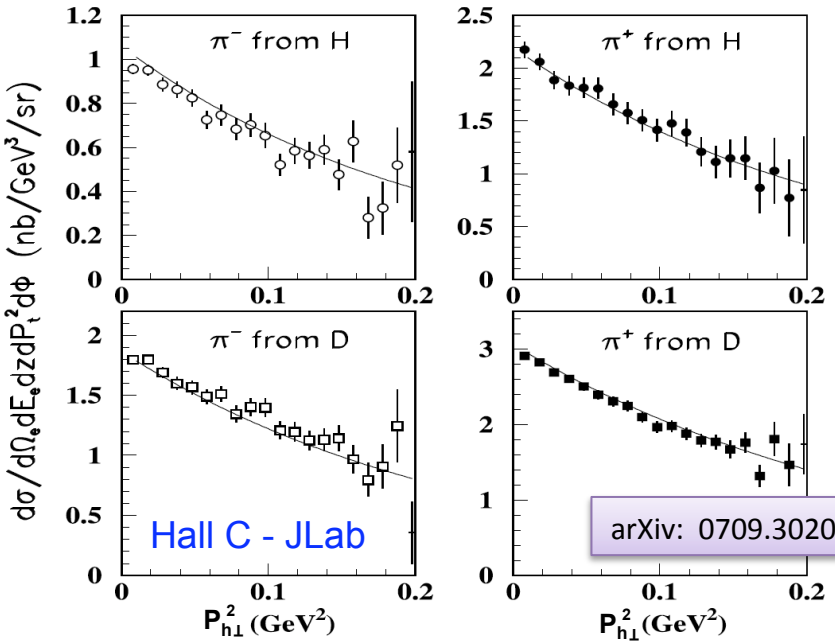
i.e. from gaussian anstaz $\left\langle P_{h\perp}^2 \right\rangle = z^2 \left\langle k_T^2 \right\rangle + \left\langle p_T^2 \right\rangle$



Joosten, DIS 2011

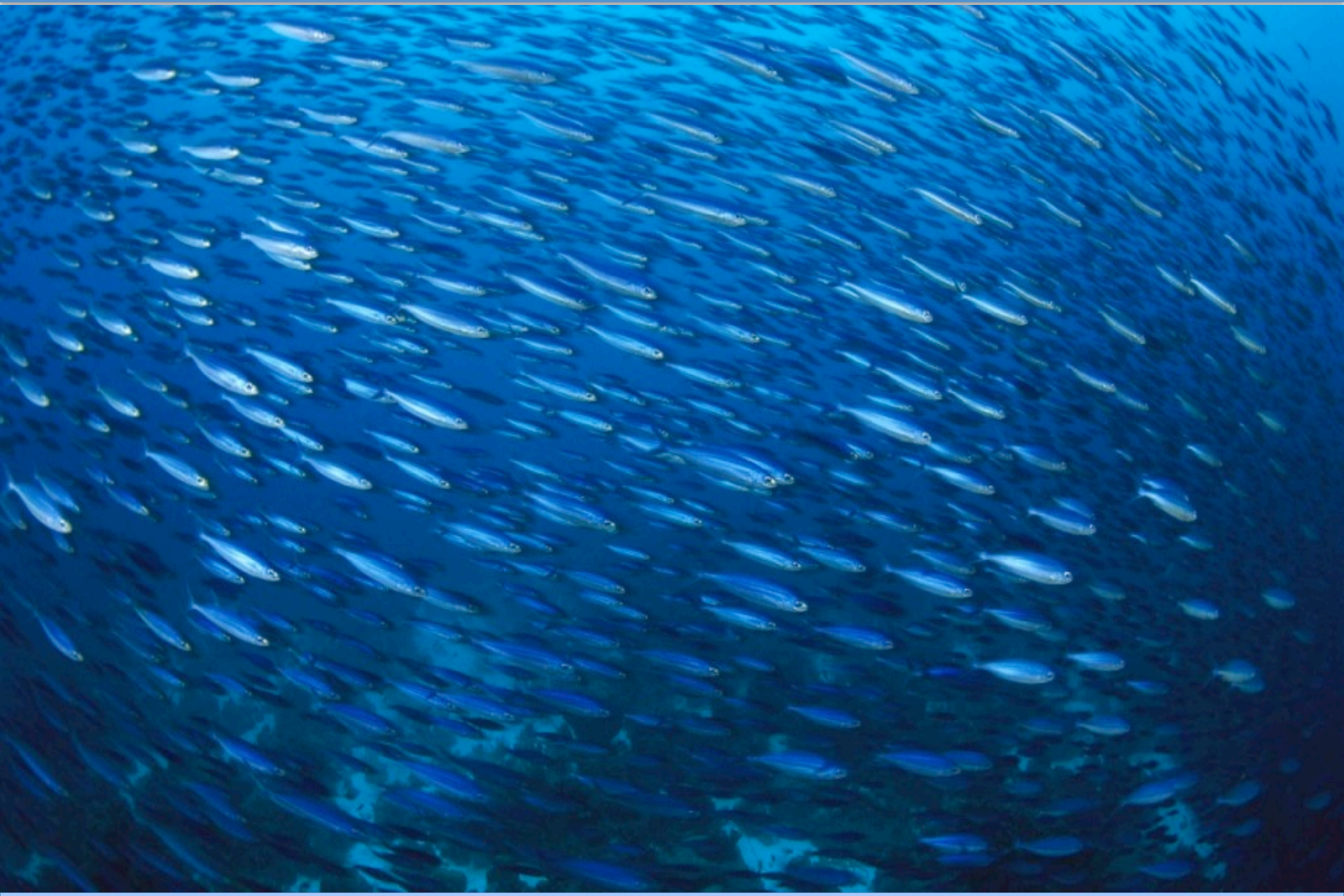
arXiv: 1305.7317



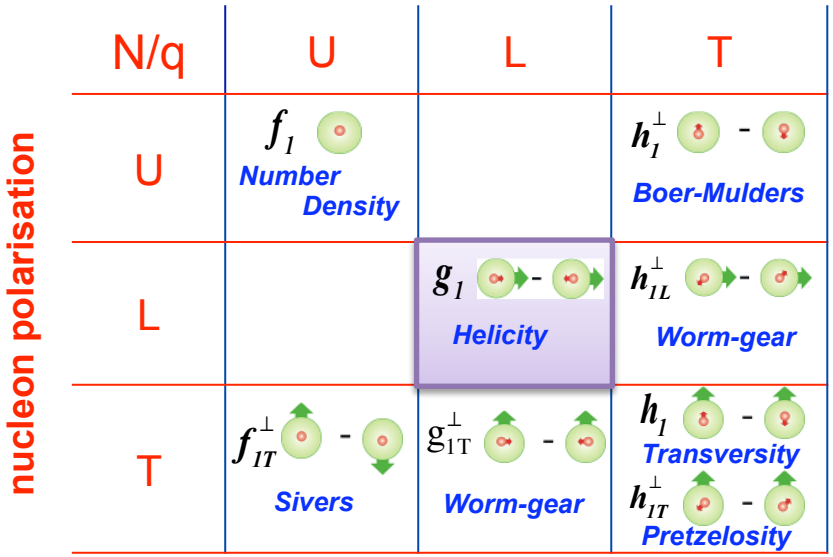


arXiv: 0709.3020

Parton Polarization

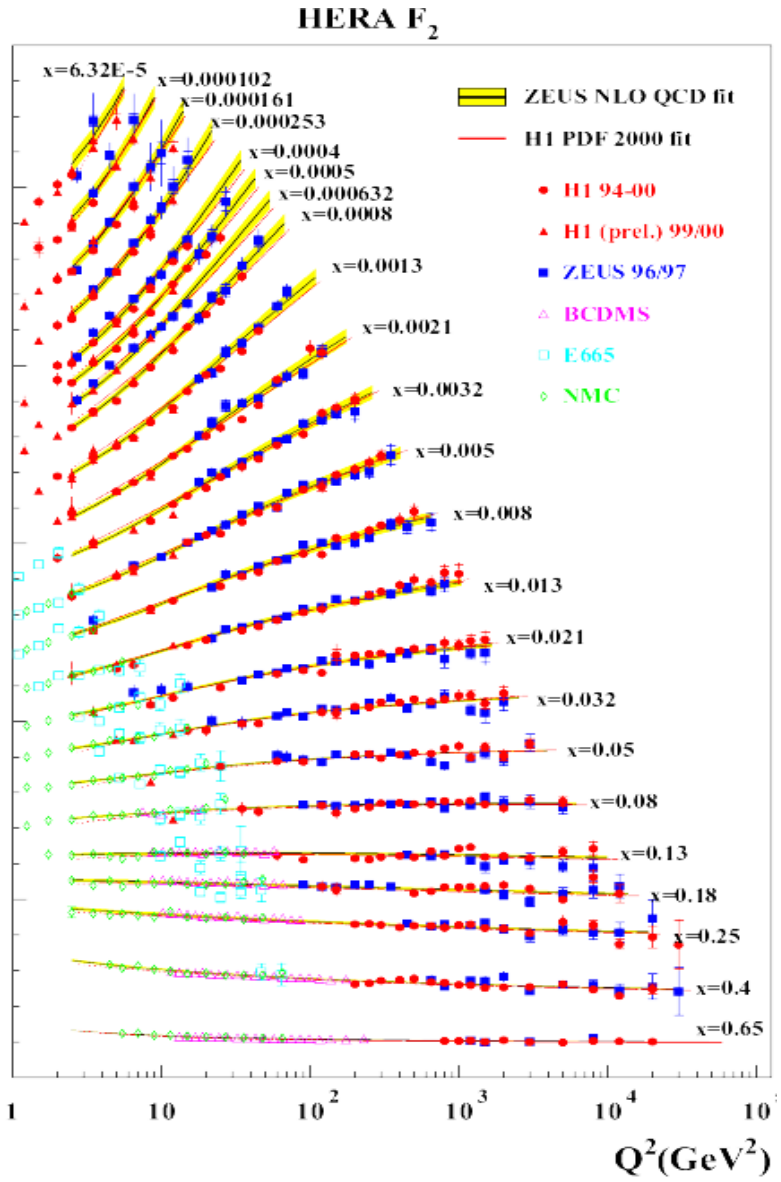


Helicity

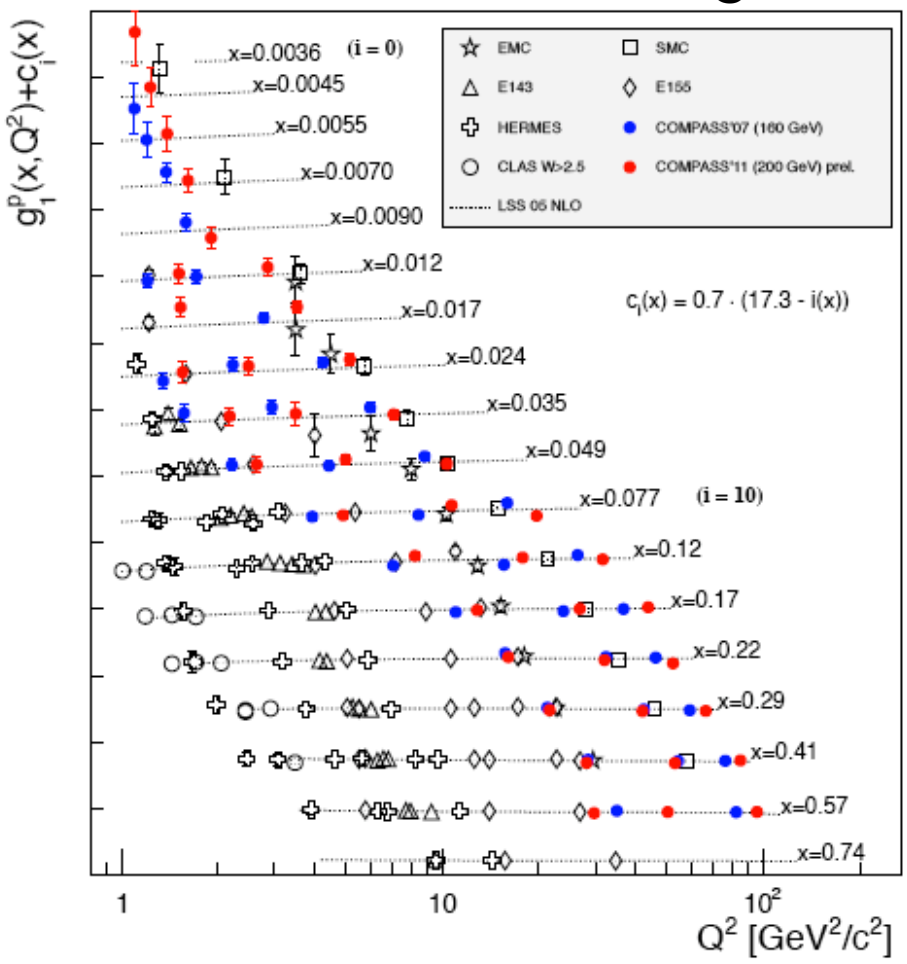


(The First Puzzle)

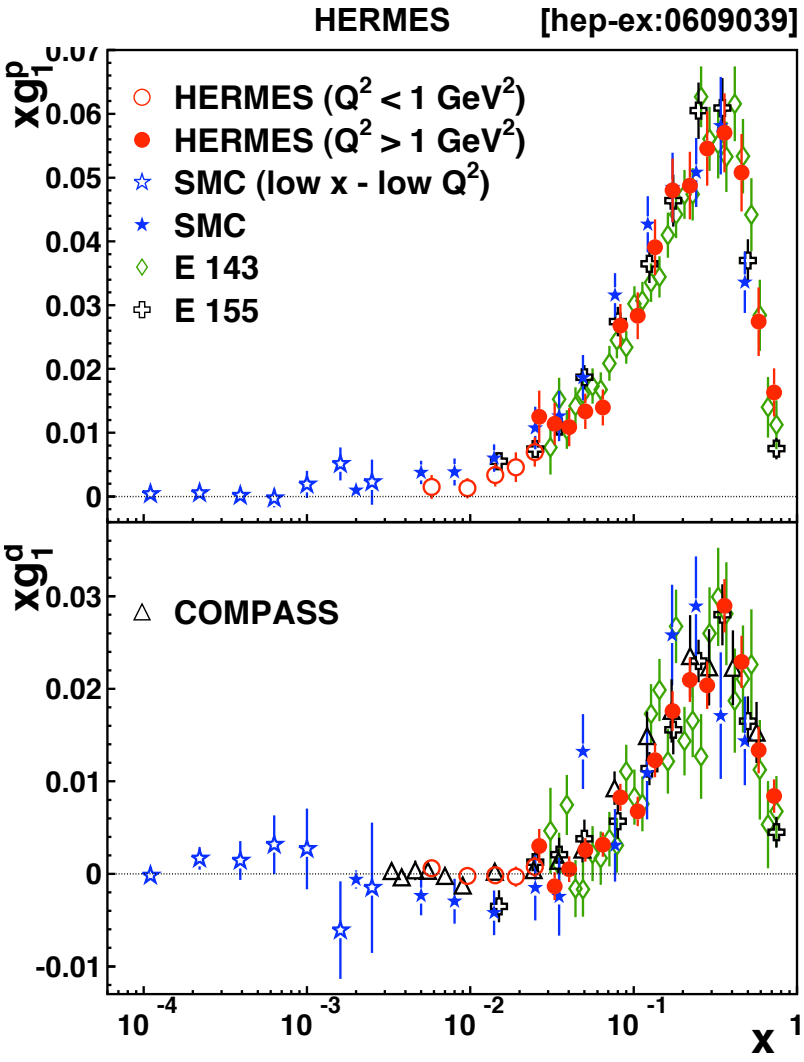
Parton Helicity from Inclusive DIS



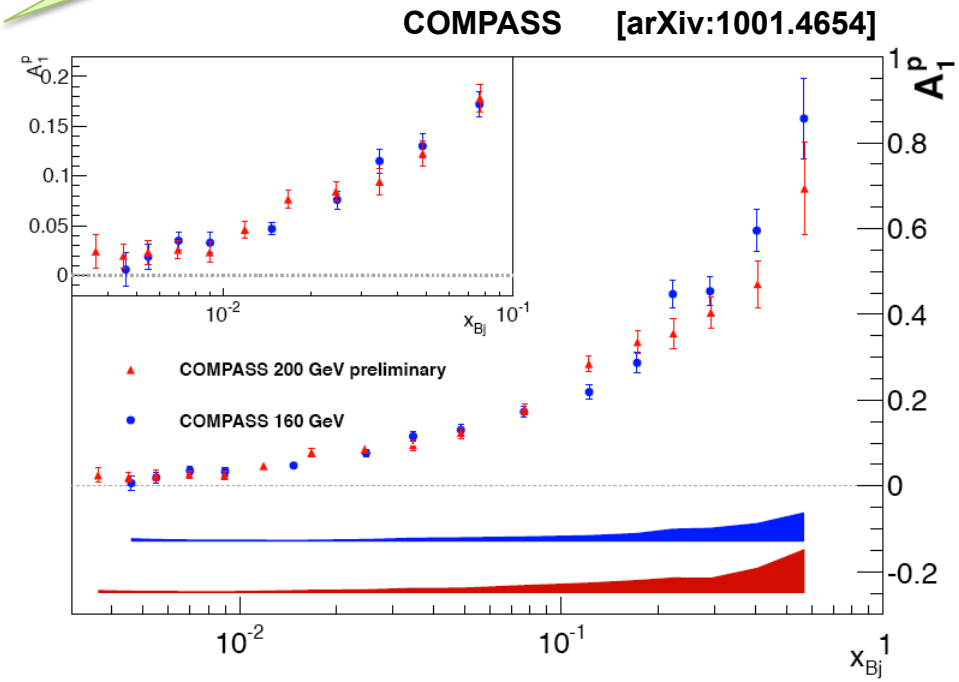
Andrieux @ DIS 2013



Parton Helicity from Inclusive DIS



DATA indicate a small net sea helicity

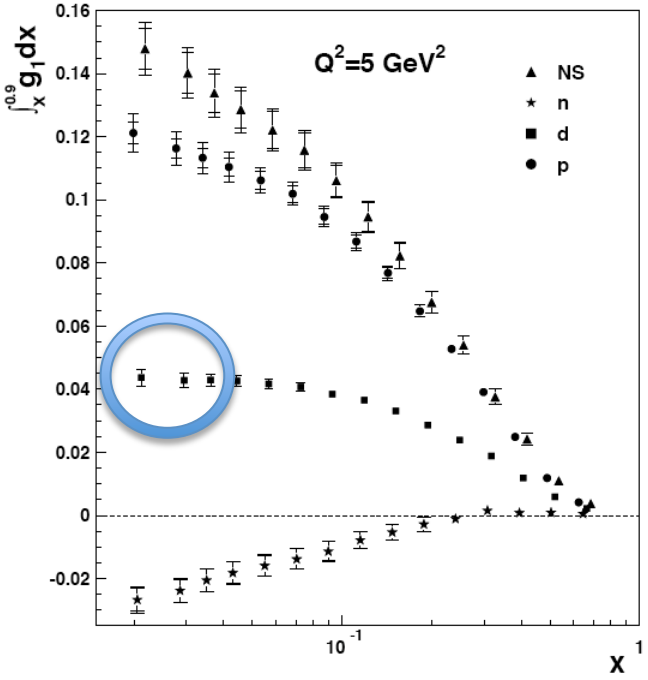


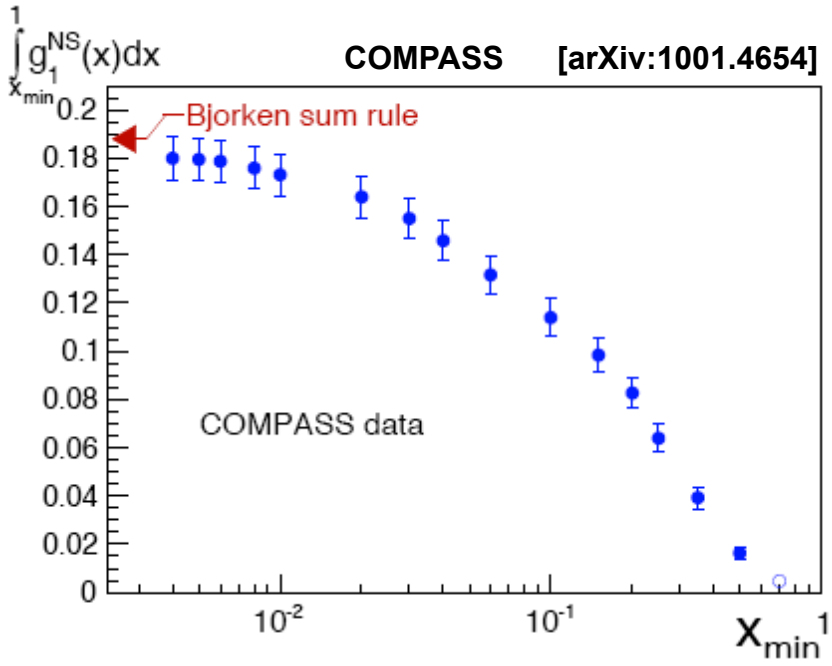
Parton Helicity from Inclusive DIS

$$\Gamma_1^d(Q_0^2) = \left(1 - \frac{3}{2}\omega_D\right)\frac{1}{36}\left[a_8 \Delta C_{NS}^{\overline{MS}} + 4a_0 \Delta C_S^{\overline{MS}}\right]$$

$$a_0 \overset{\overline{MS}}{=} \Delta\Sigma \qquad \Delta s + \Delta\bar{s} = \frac{1}{3}(a_0 - a_8)$$

$$\Gamma_1^p(Q^2) - \Gamma_1^n(Q^2) = \frac{1}{6} a_3 \Delta C_{NS}^{\overline{MS}}(\alpha_s(Q^2))$$





a_0 (3 GeV^2)= 0.35 ± 0.03 ± 0.05

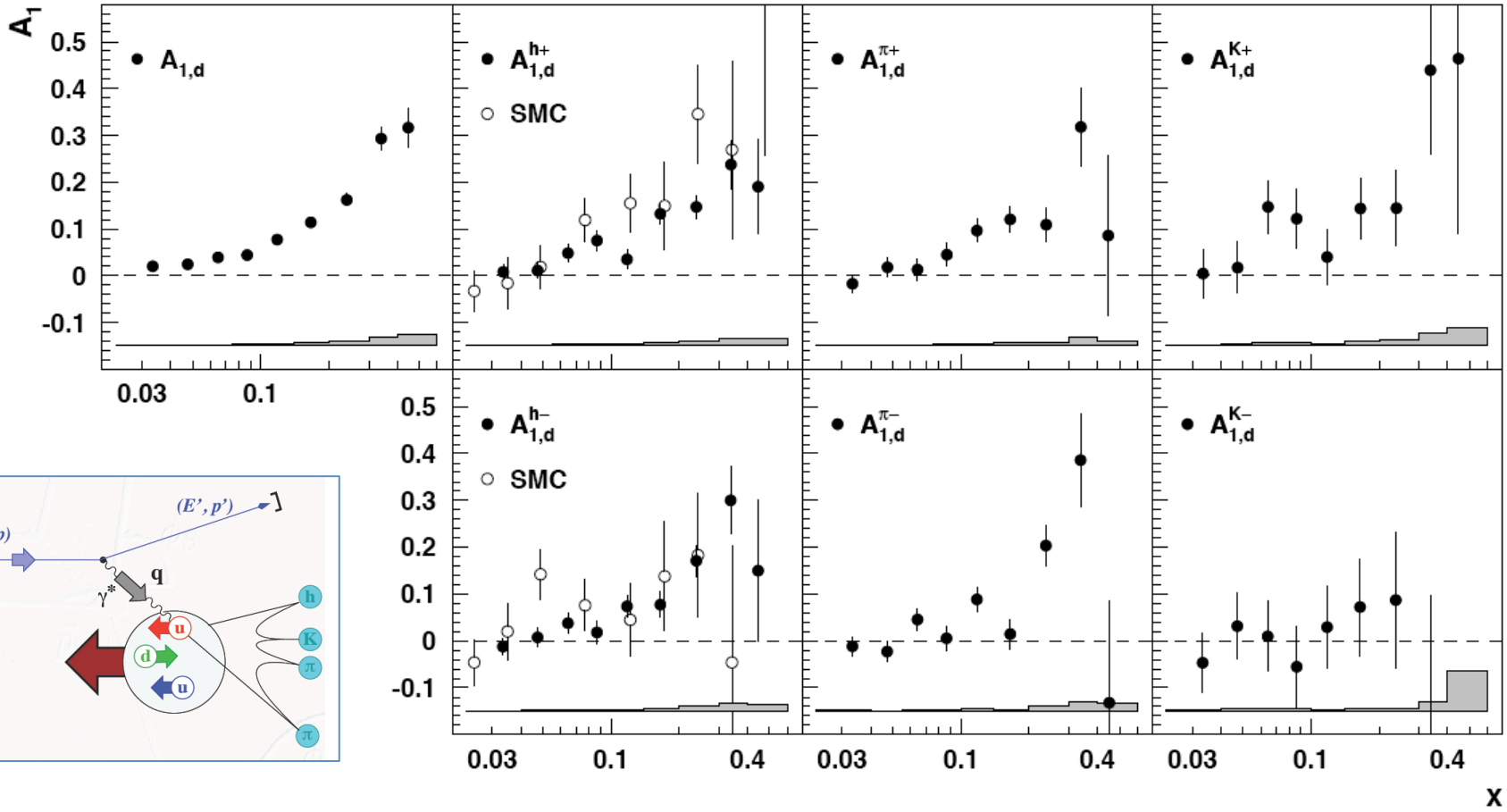
Δs= -0.08 ± 0.03 **COMPASS: arXiv:0609038**

a_0 (5 GeV^2)= 0.33 ± 0.03 ± 0.03

Δs= -0.09 ± 0.02 **HERMES: arXiv:0609039**

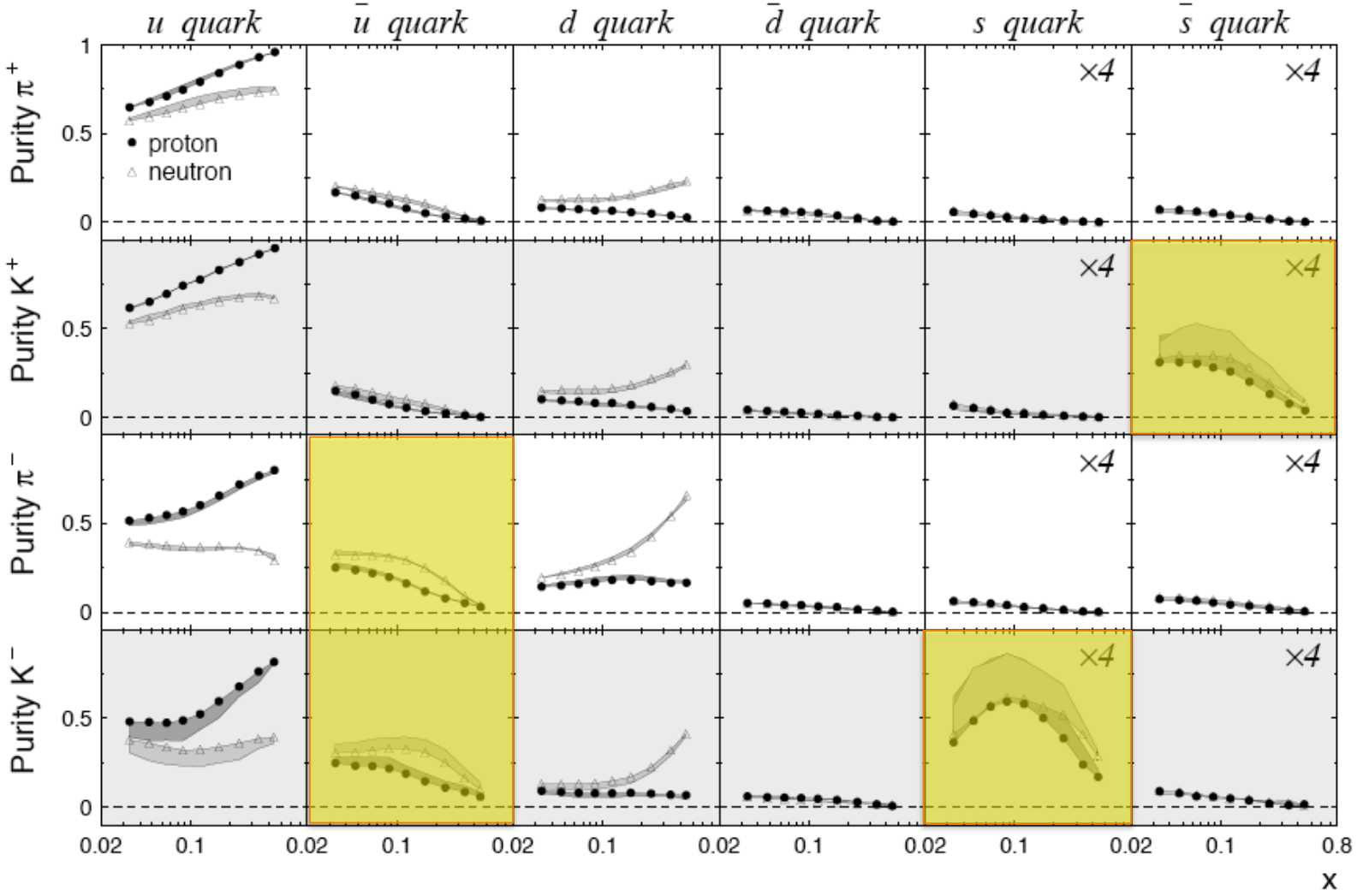
Parton Helicity from SIDIS

$$A_1^h(x,z) = \frac{\sum_q e_q^2 \Delta q(x) \int D_q^h(z)\,dz}{\sum_{q'} e_{q'}^2 q'(x) \int D_{q'}^h(z)\,dz} = \sum_q P_q^h(x,z) \frac{\Delta q(x)}{q(x)}$$

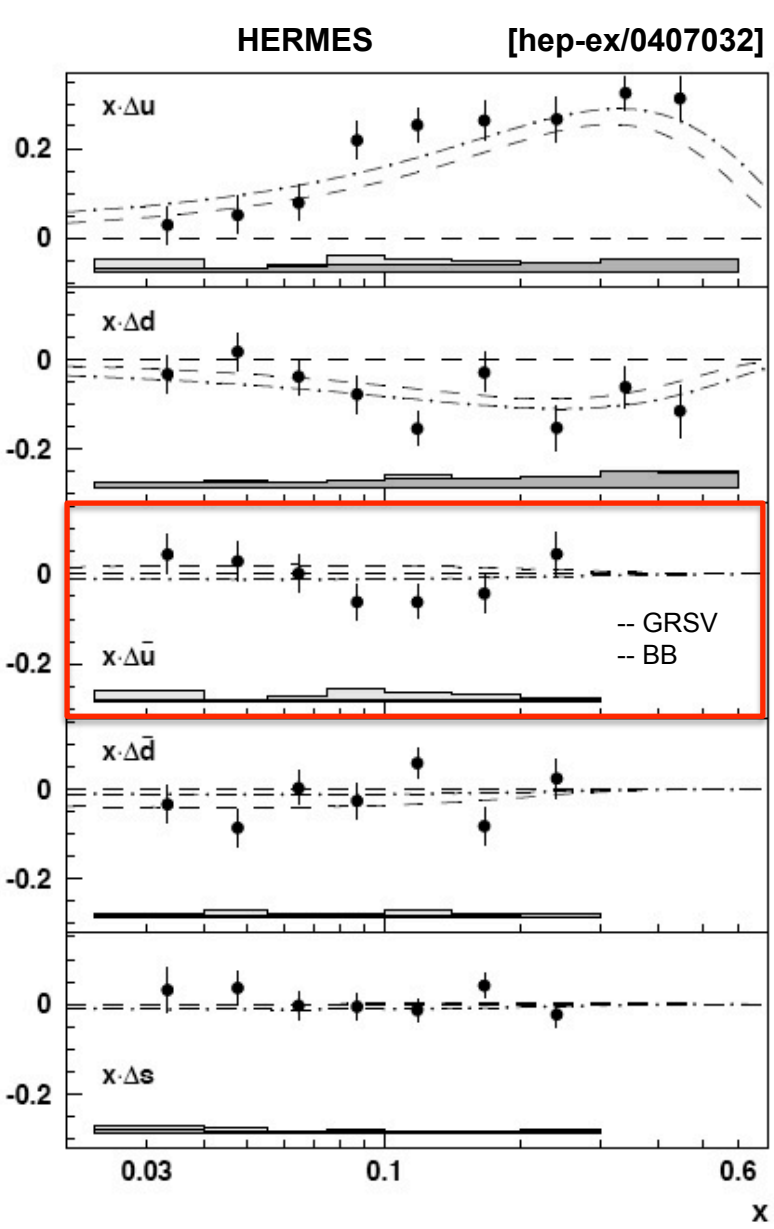


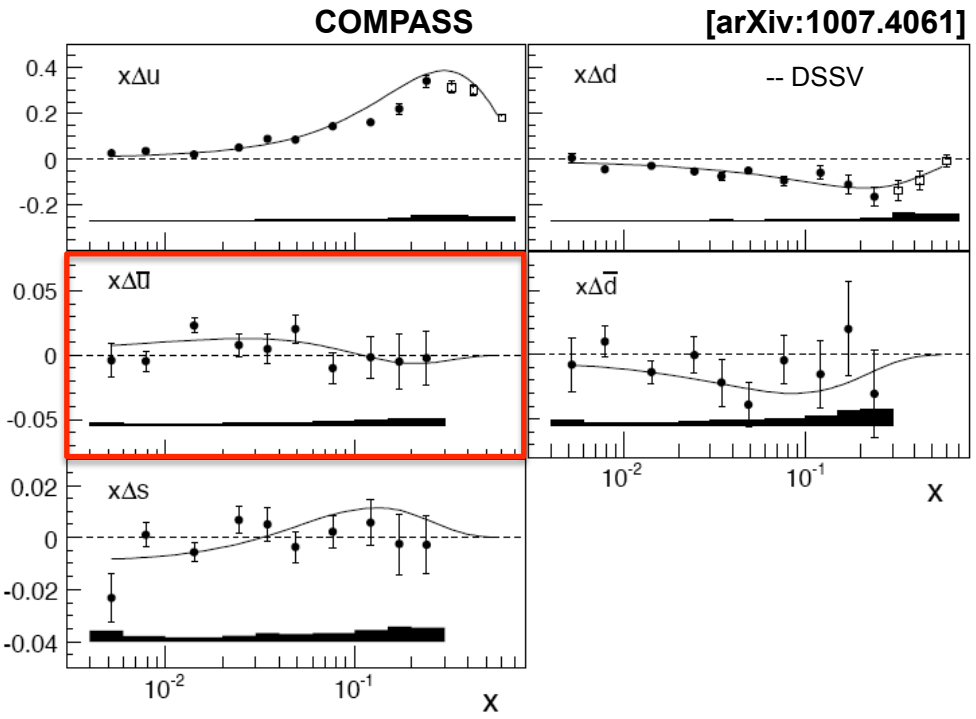
The SIDIS Flavor Probes

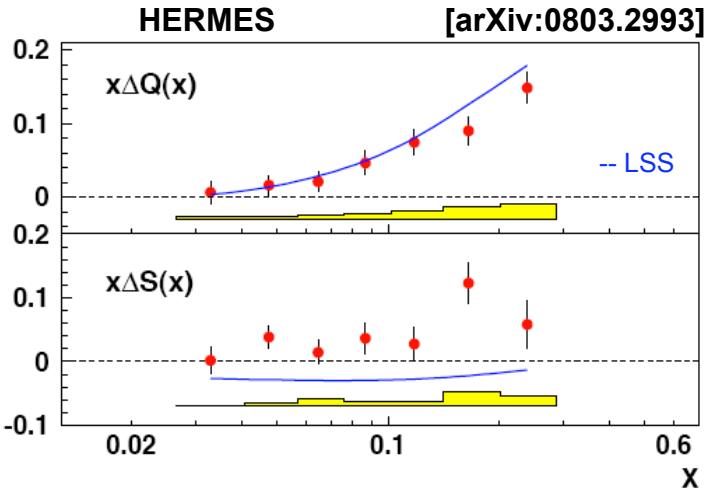
$$P_q^h(x) = \frac{e_q^2 q(x) \int D_q^h(z)\,dz}{\sum_{q'} e_{q'}^2 q'(x) \int D_{q'}^h(z)\,dz}$$



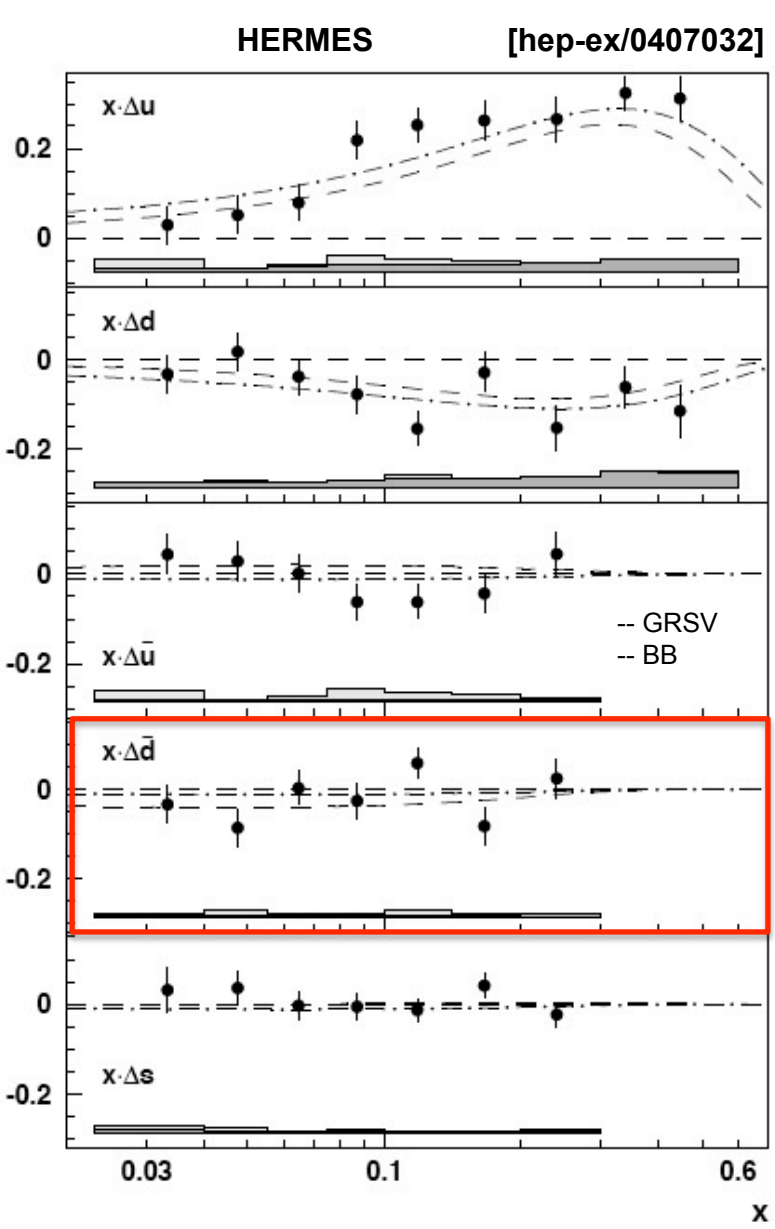
Parton Helicity from SIDIS

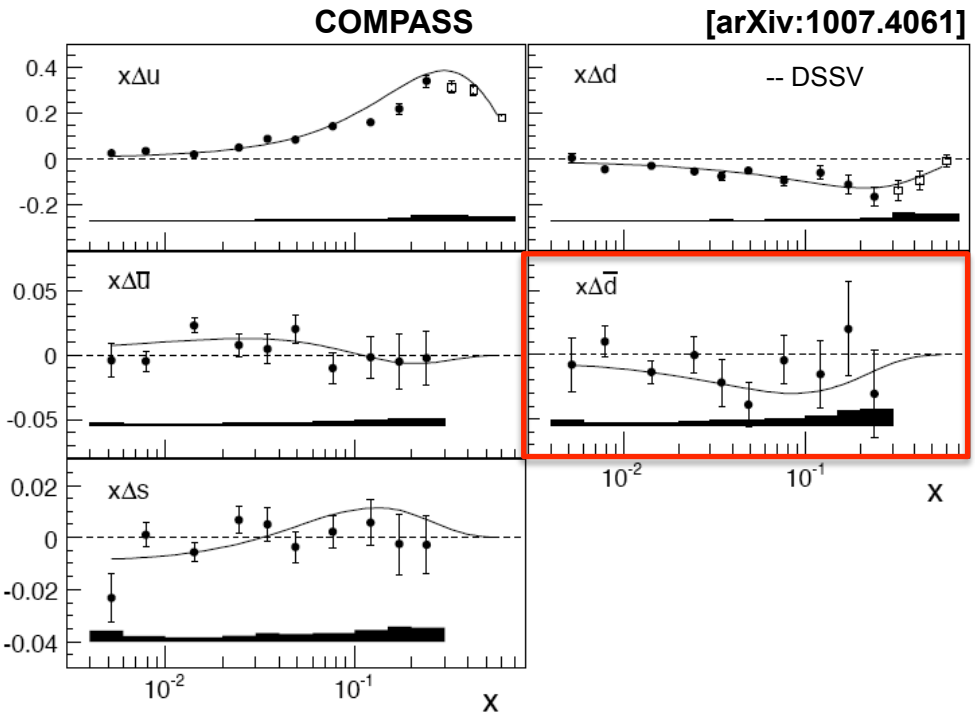


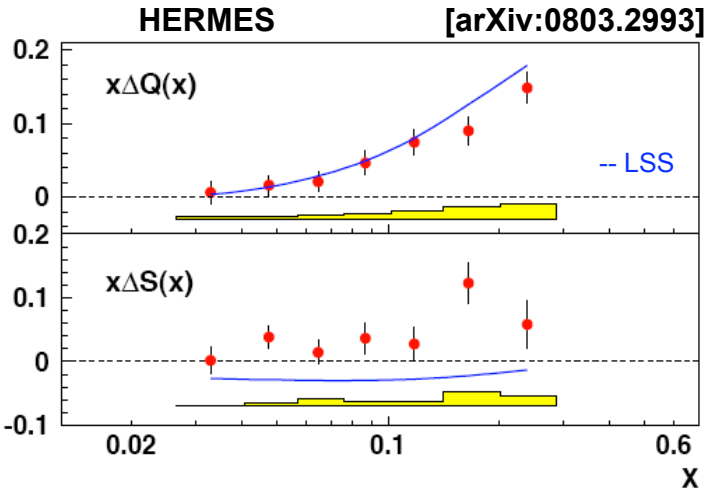




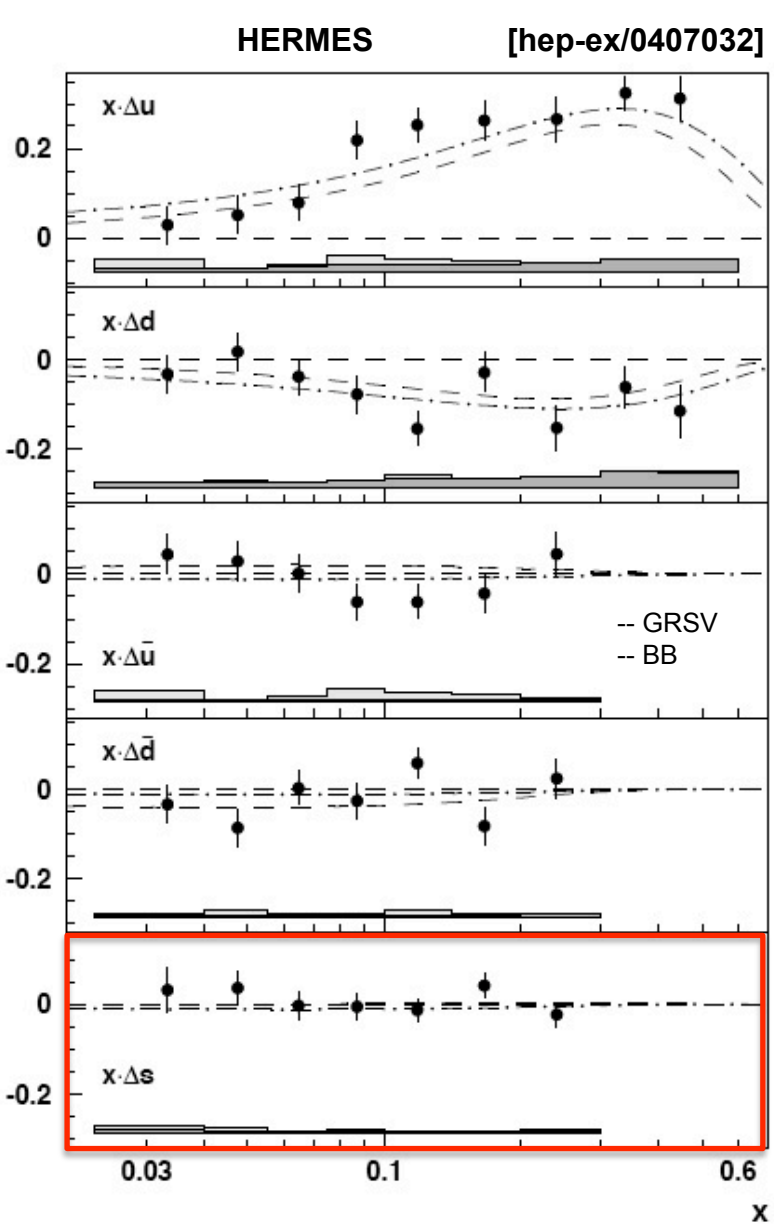
Parton Helicity from SIDIS

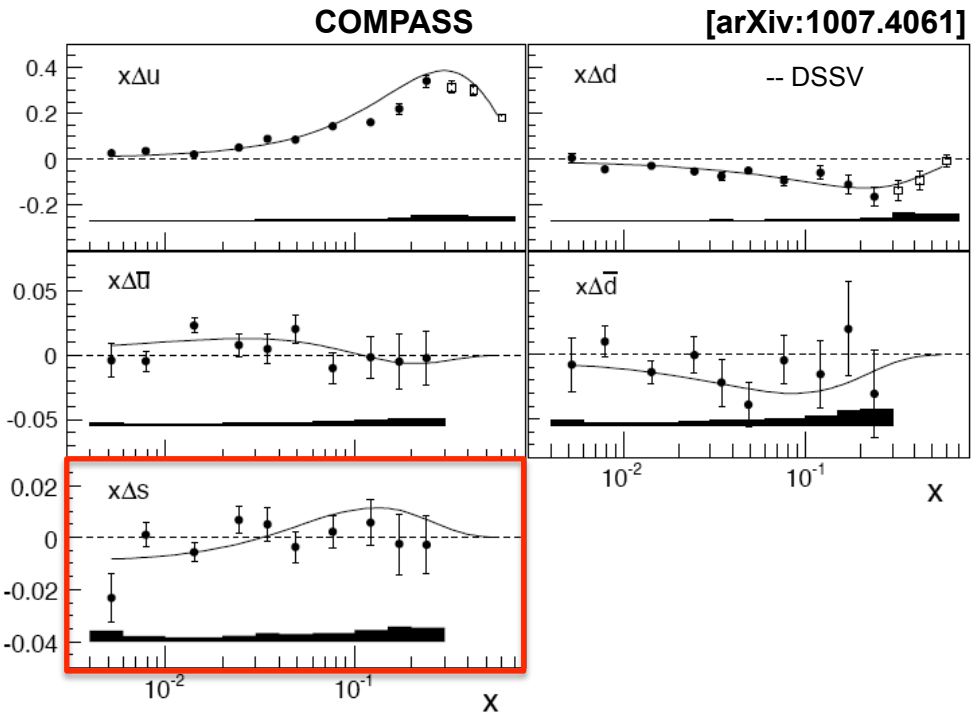


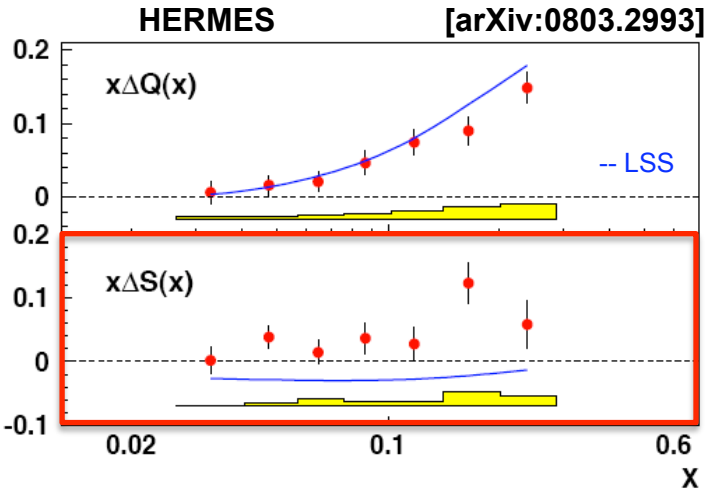




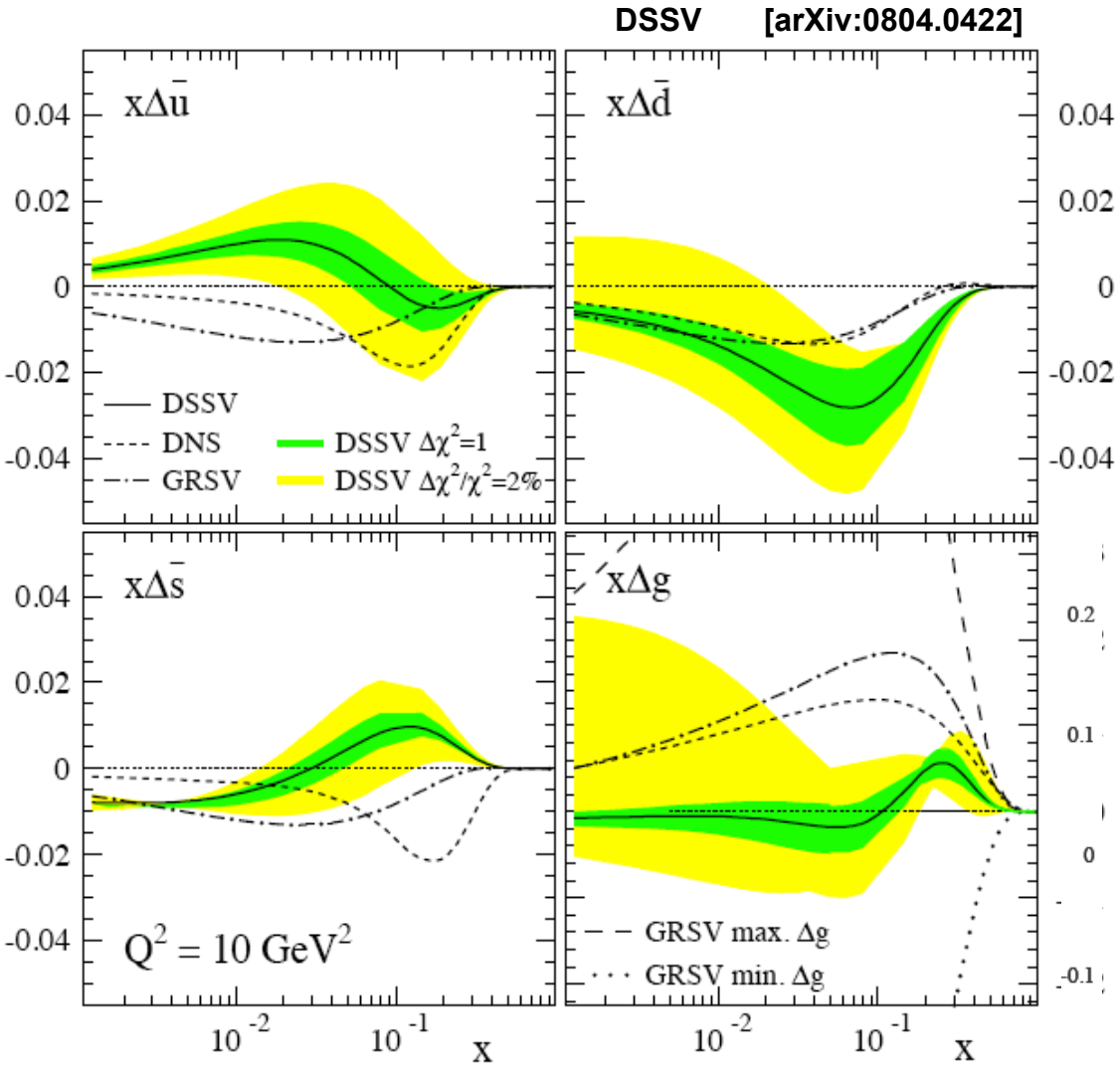
Parton Helicity from SIDIS





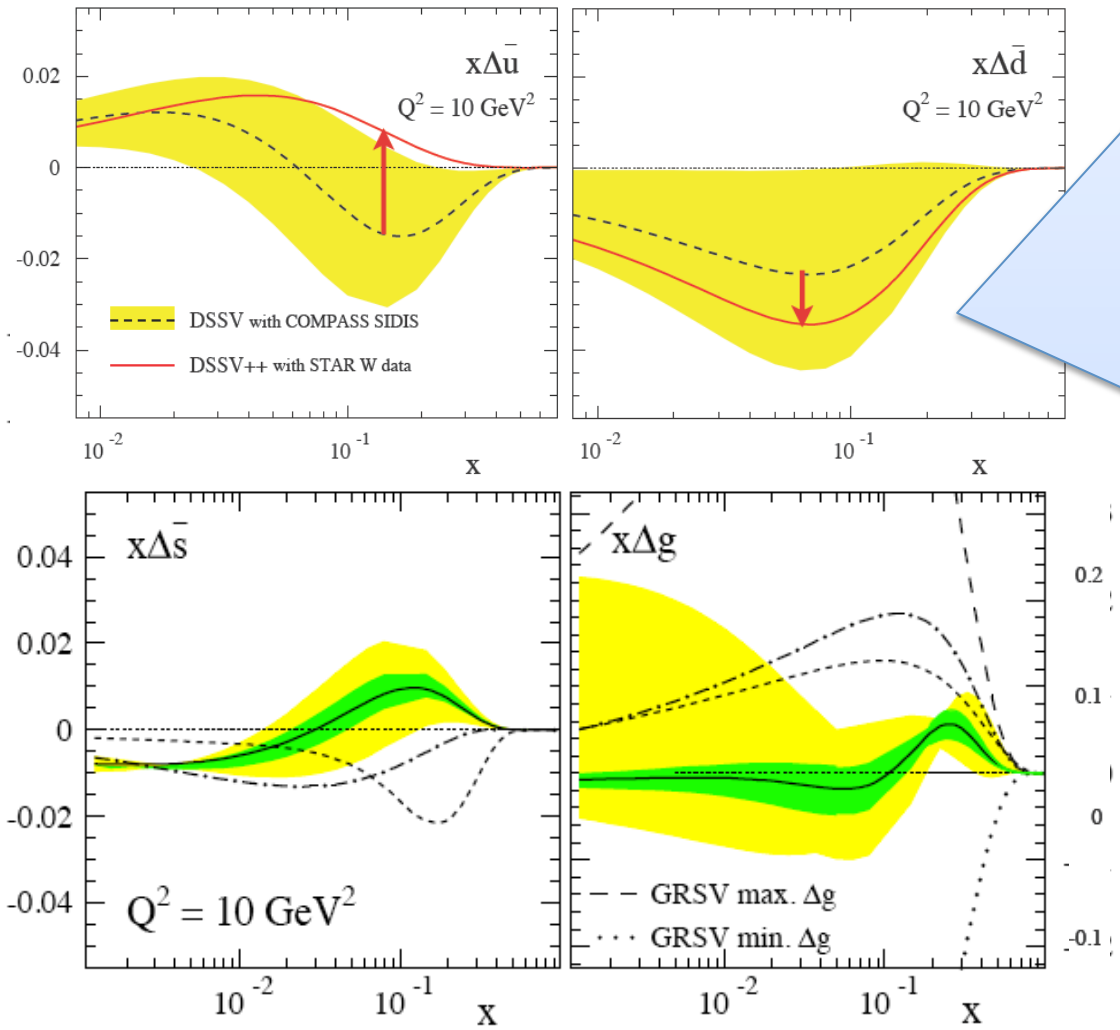


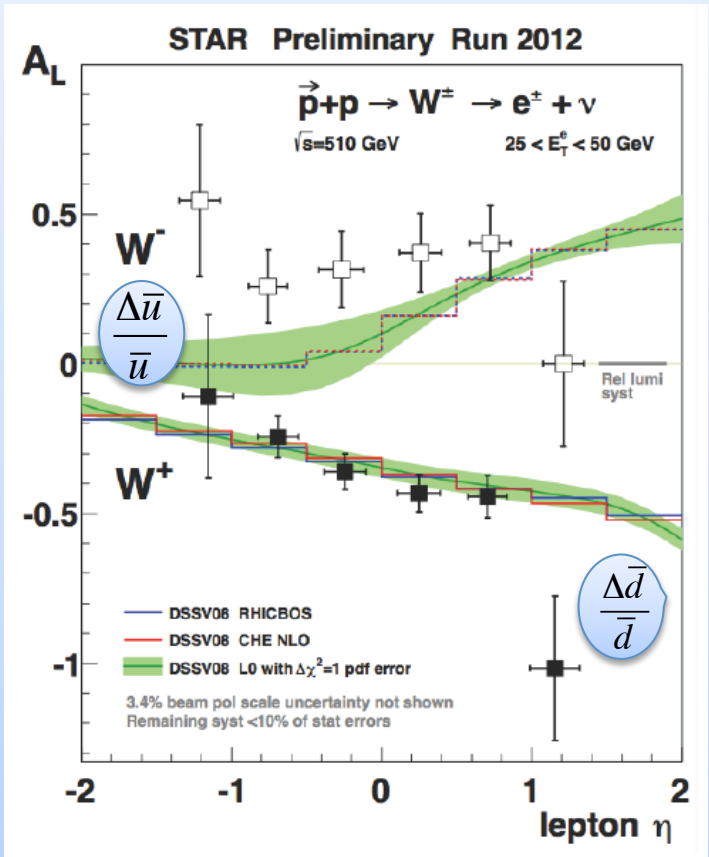
Sea Parton Helicity from RHIC



Sea Parton Helicity from RHIC

DSSV++ [arXiv:1304.0079]

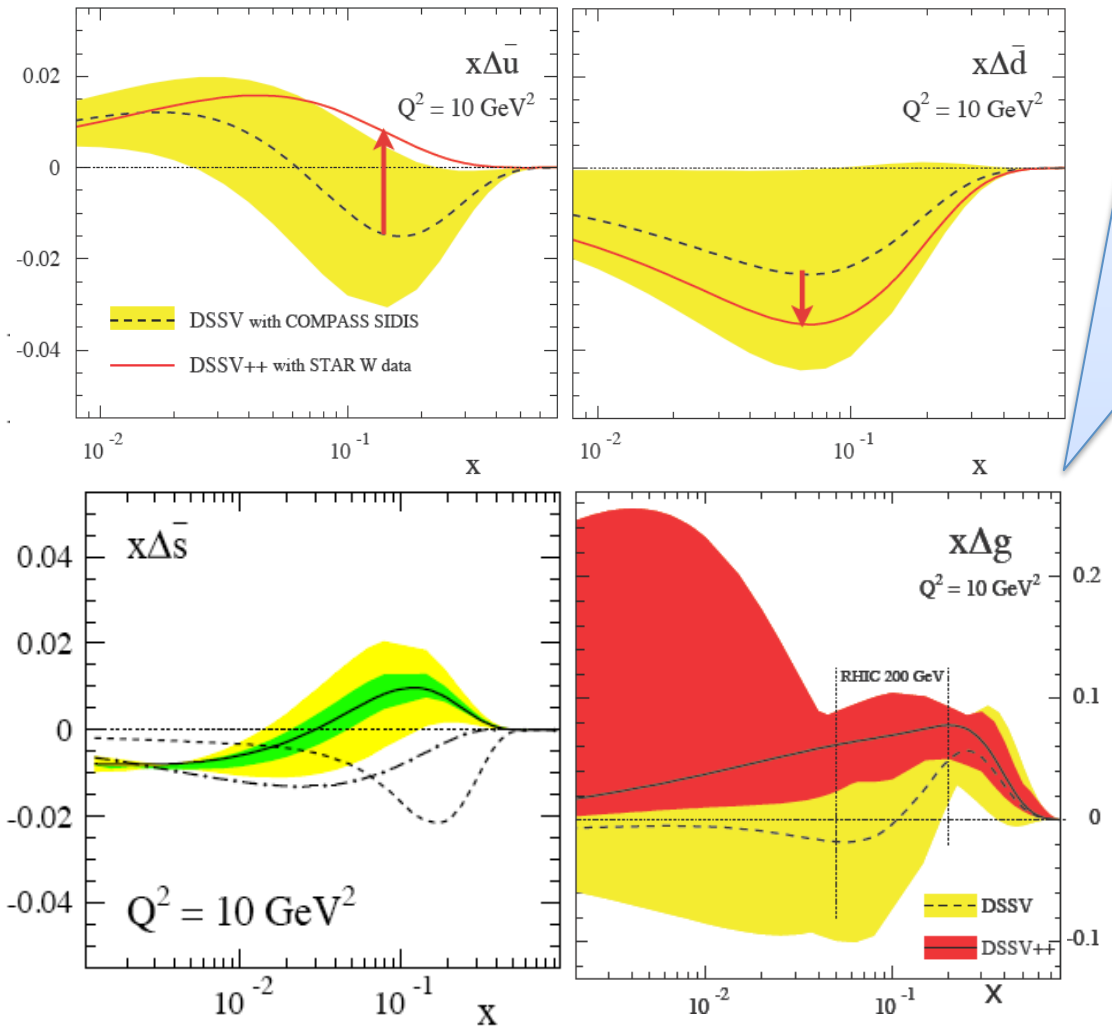


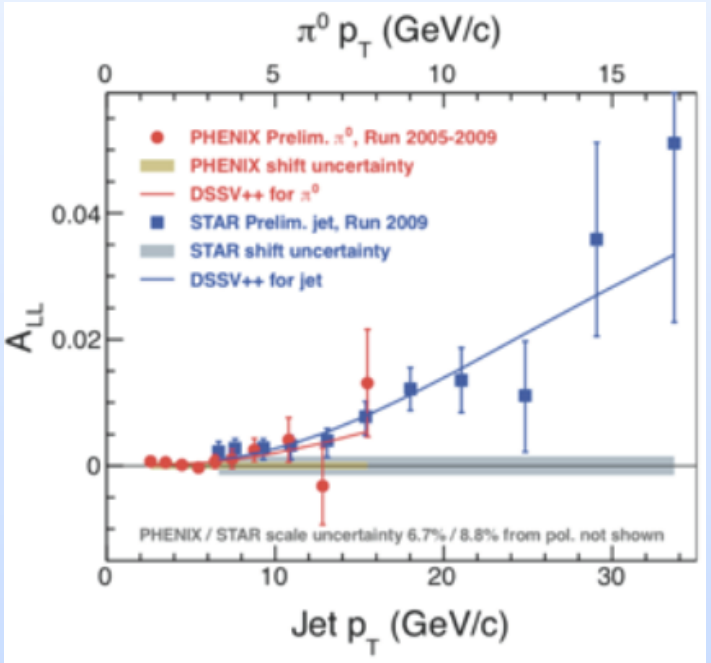


Seidl talk

Gluon Parton Helicity from RHIC

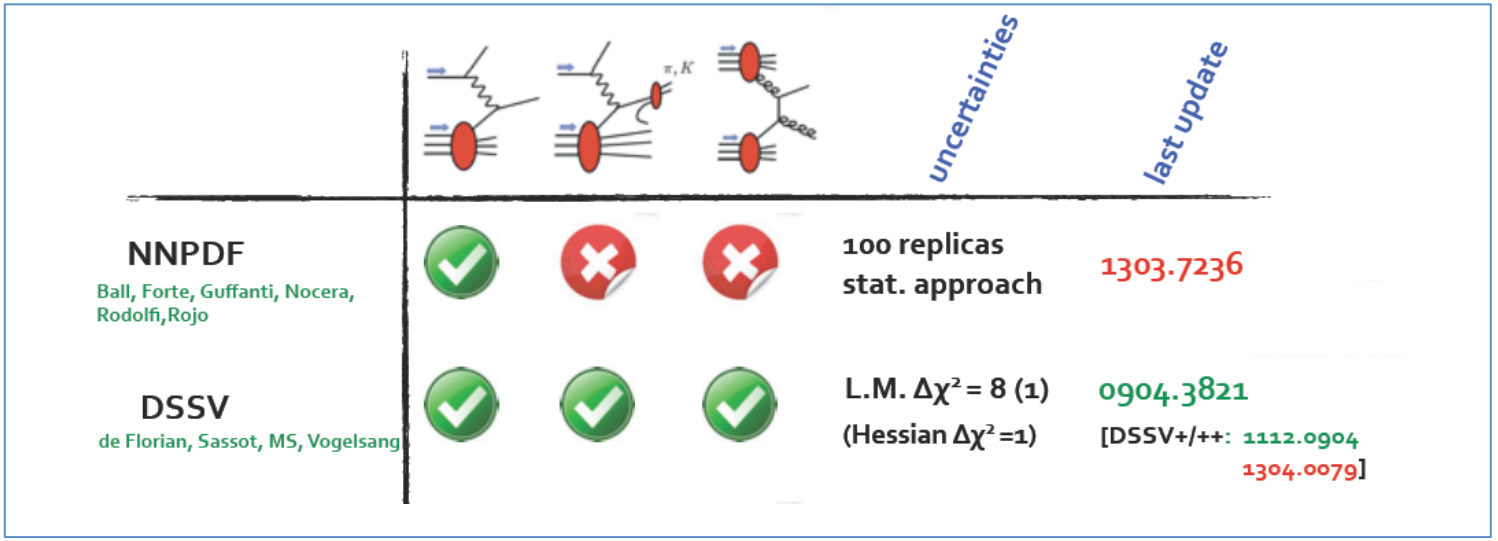
DSSV++ [arXiv:1304.0079]

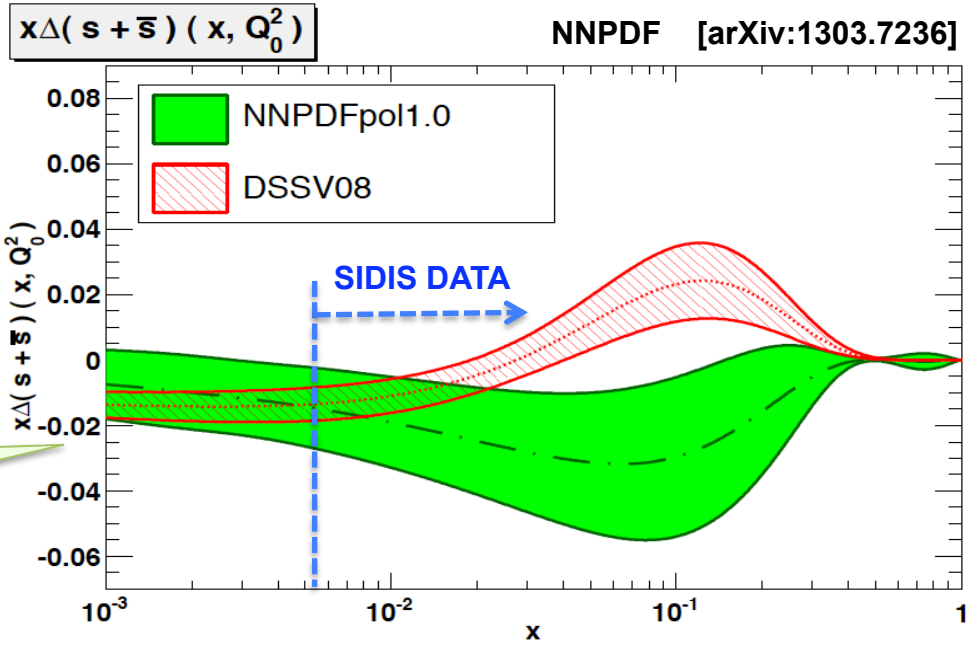




$$\int_{0.05}^{0.2} dx\, \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2) = 0.1^{+0.06}_{-0.07}$$

Parton Helicity from SIDIS



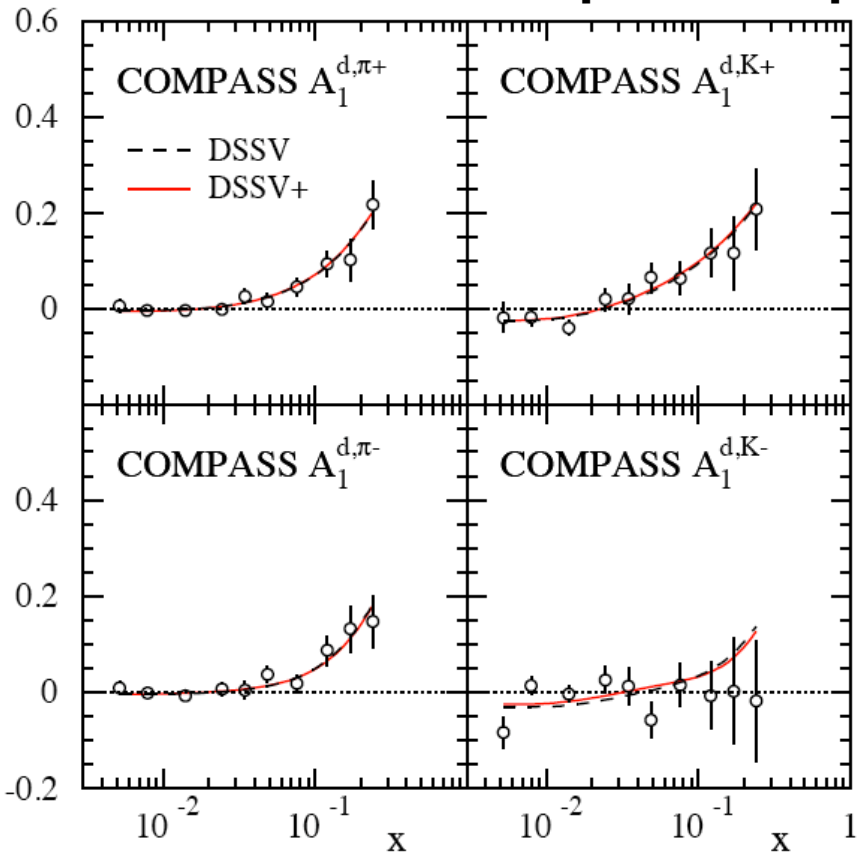


1st moment constrained by 3F-D

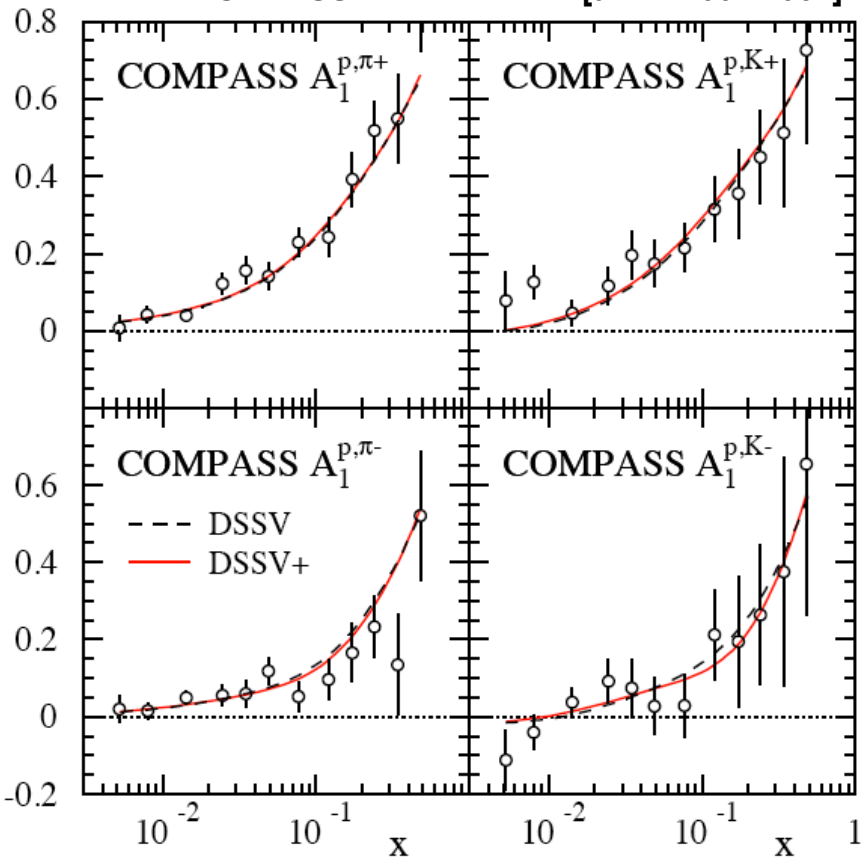
$$\int_0^1 dx\left[\Delta s + \Delta\bar{s}\right](x) \approx -0.1$$

Parton Helicity from SIDIS

COMPASS [arXiv:0905.2828]



COMPASS [arXiv:1007.4061]



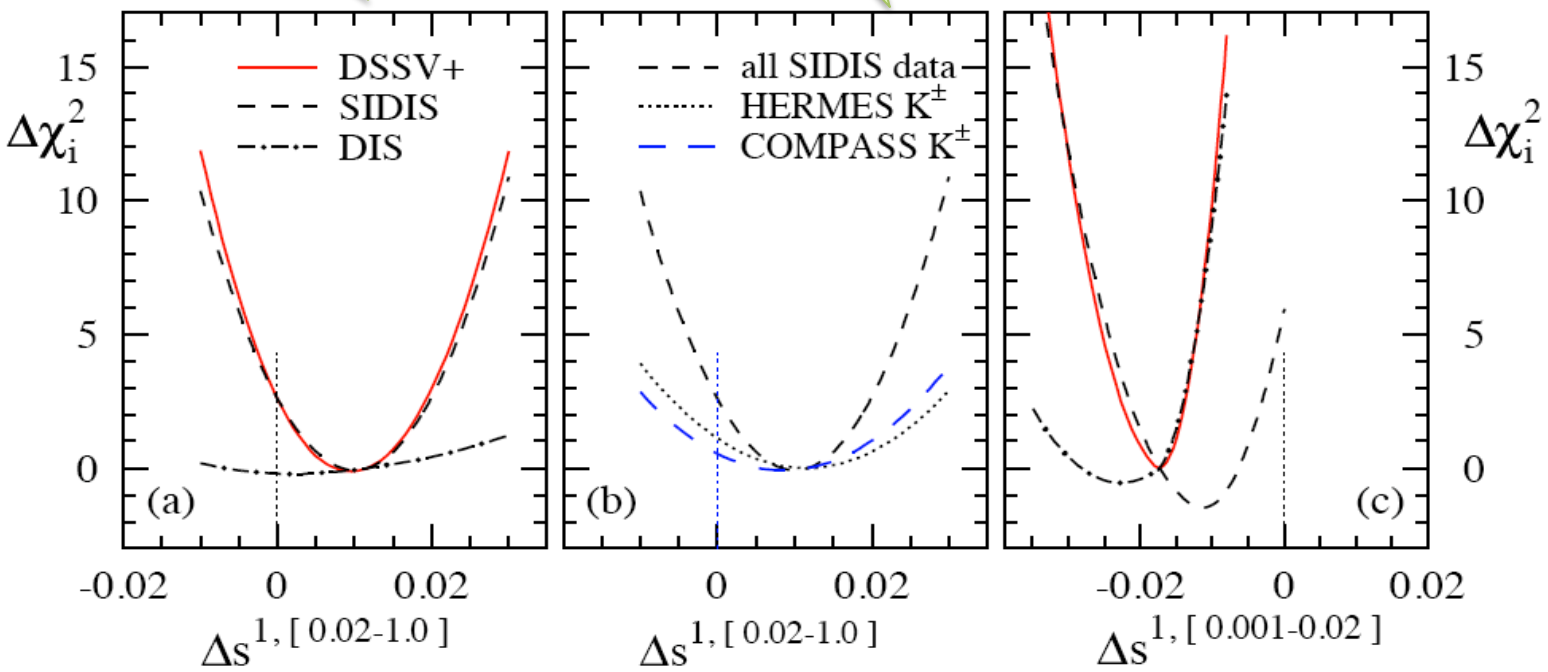
Strange Helicity from SIDIS

No real constraint from DIS

Consistency among SIDIS results

SIDIS tends to become negative

DSSV [arXiv:1108.3955]

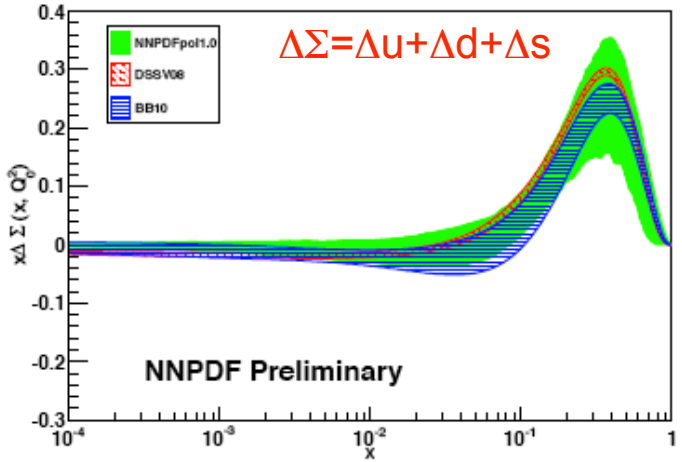


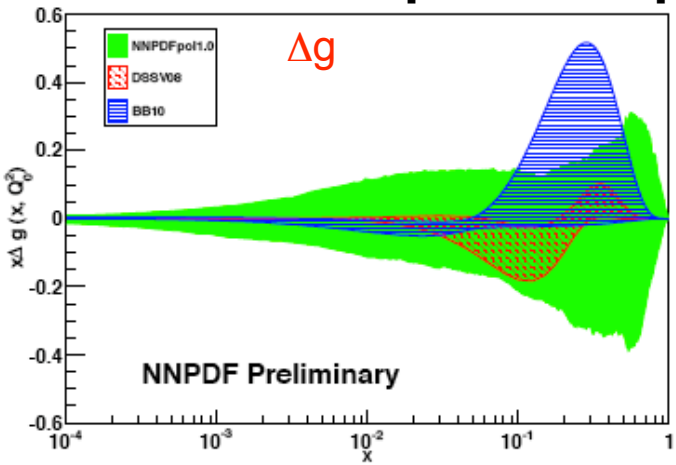
[0.02 < x < 1.0]

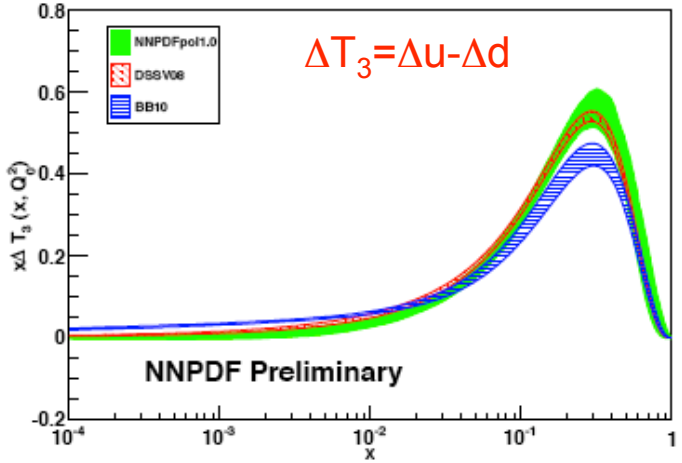
[0.001 < x < 0.02]

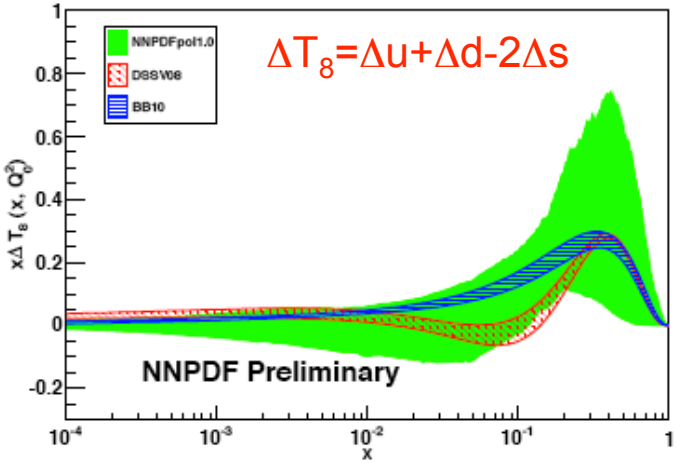
Parton Helicity from SIDIS

NNPDF [arXiv:1206.0201]



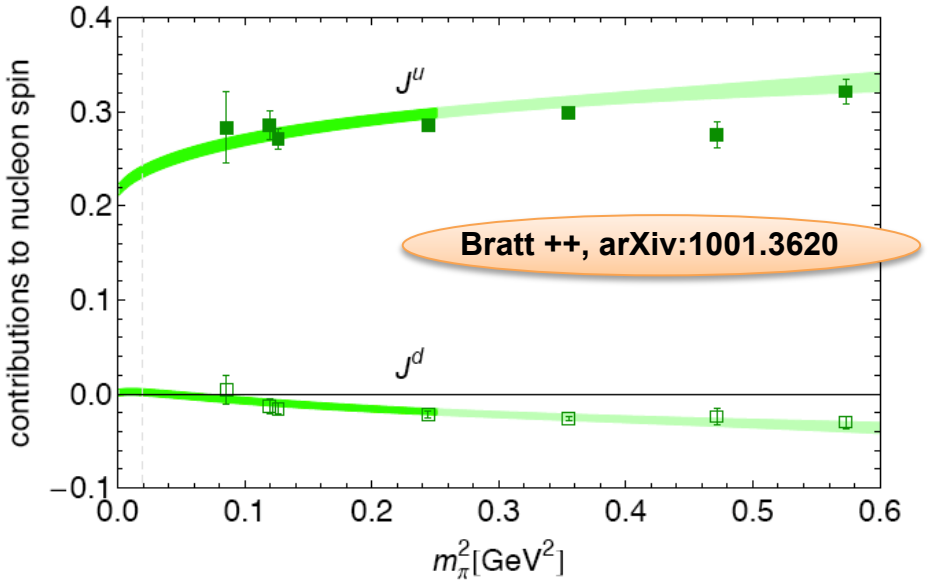


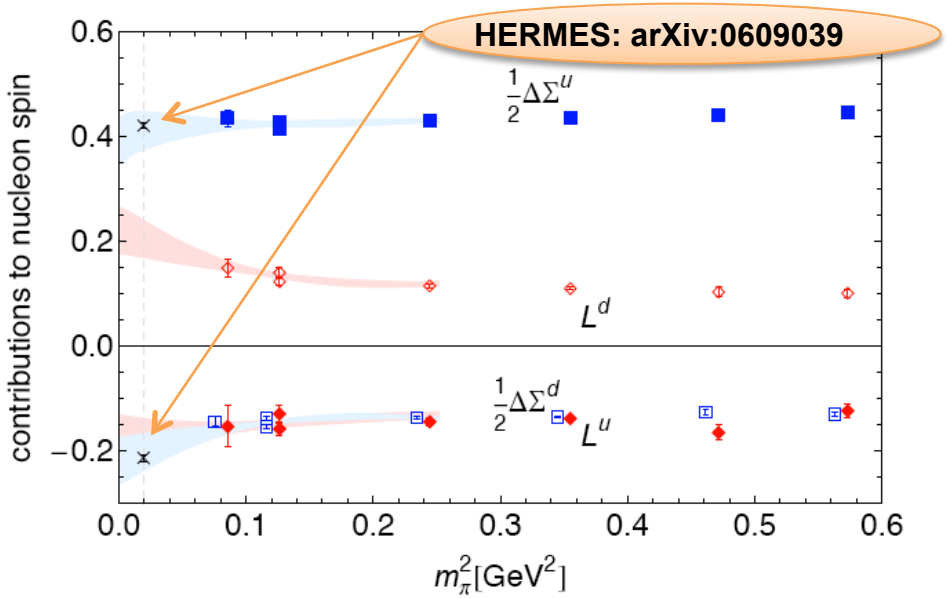




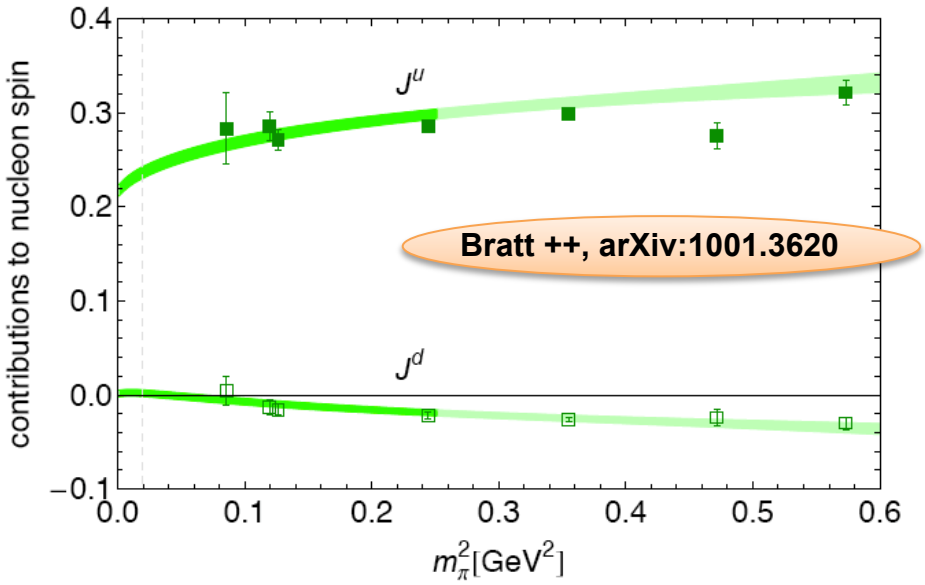
	NNPDFpol1.0	DSSV08 [5]	BB10 [2]	LSS10 [4]	AAC08 [3]
$\Delta\Sigma(Q^2)$	0.31 ± 0.10	0.25 ± 0.02	0.19 ± 0.08	0.21 ± 0.03	0.24 ± 0.07
$\Delta g(Q^2)$	-0.2 ± 1.4	-0.10 ± 0.16	0.46 ± 0.43	0.32 ± 0.19	0.63 ± 0.81

From Lattice

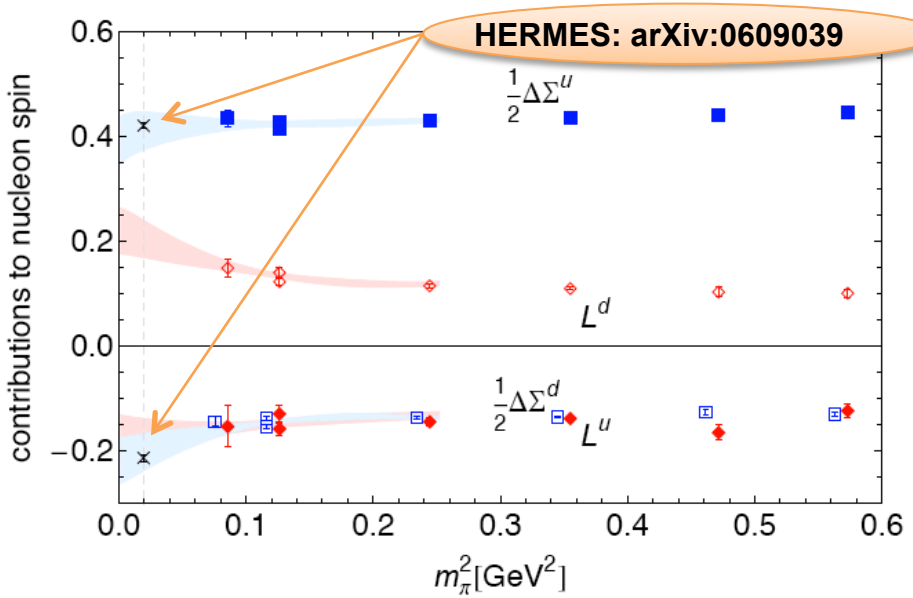




From Lattice

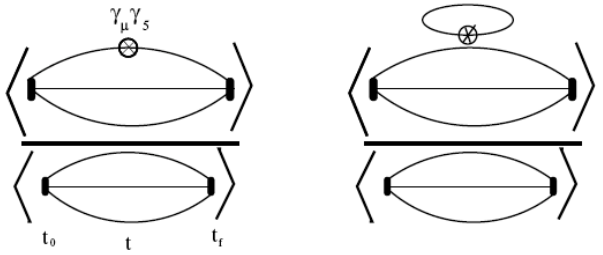


Bratt ++, arXiv:1001.3620



HERMES: arXiv:0609039

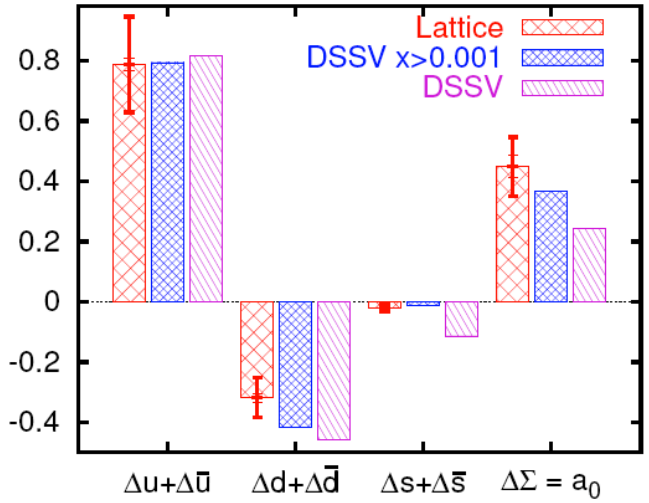
With disconnected diagrams



Bali ++,: arXiv:1112.3354

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.45(4)(9)$$

$$\Delta s = -0.020(10)(4)$$

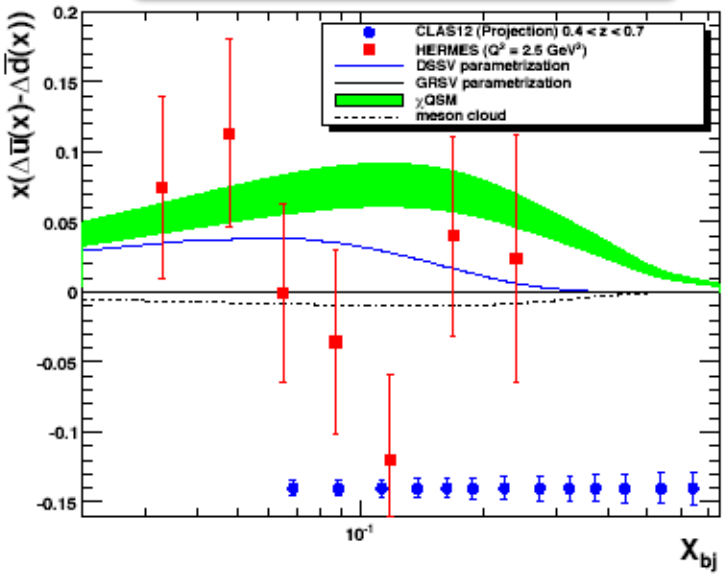


Liu ++, arXiv:1203.6388

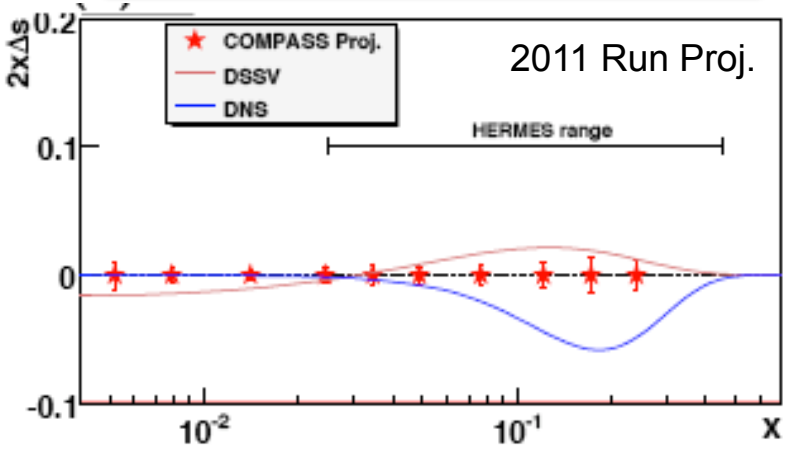
L_q mainly from sea and up to 50 % of the proton spin

Parton Helicity Landscape

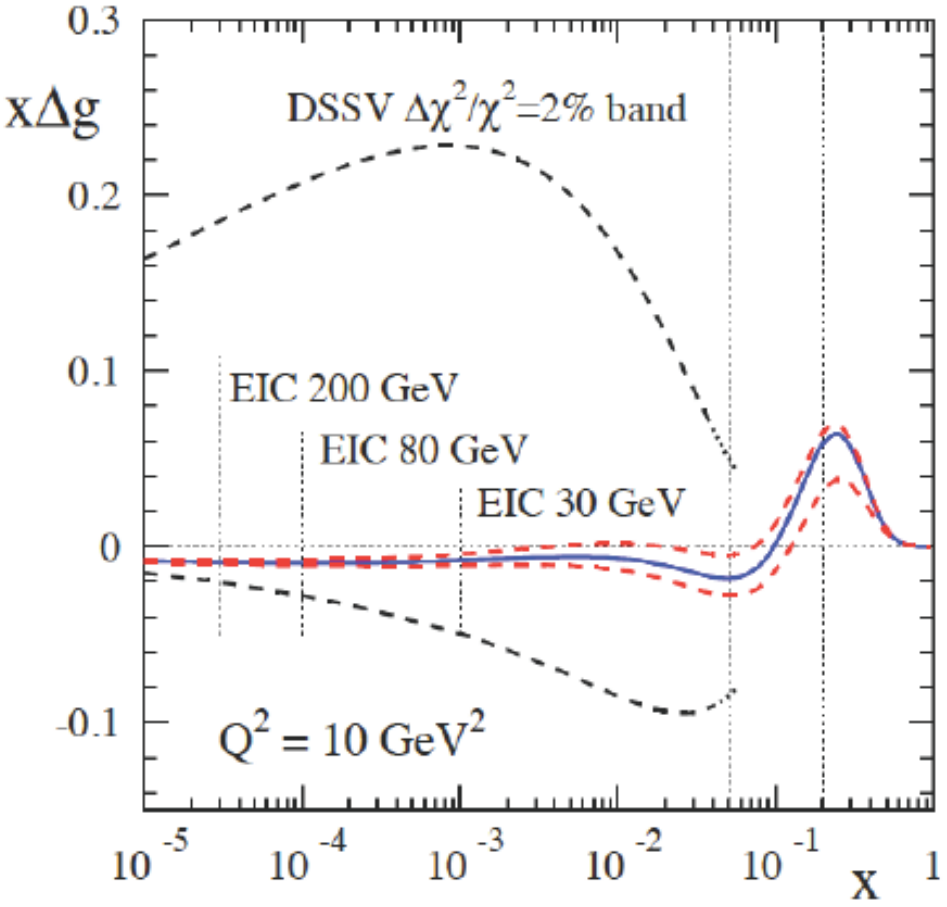
Valence Δq @ CLAS12



Middle-sea Δq @ COMPASS



Sea Δq and ΔG @ EIC

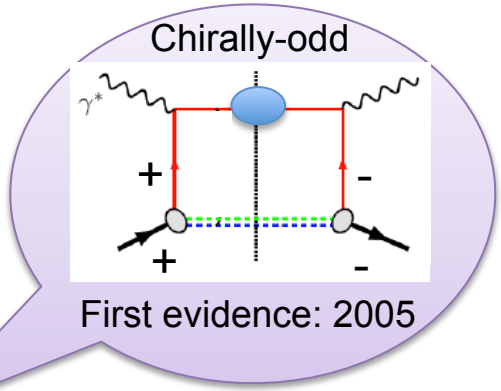


Point Transverse

TRANSVERSITY

nucleon polarisation

N/q	U	L	T
U	f_1 *Number Density*		$h_1^\perp$ *Boer-Mulders*
L		g_1 *Helicity*	$h_{1L}^\perp$ *Worm-gear*
T	$f_{1T}^\perp$ *Sivers*	$g_{1T}^\perp$ *Worm-gear*	h_1 *Transversity*; $h_{1T}^\perp$ *Pretzelosity*



(THE COLLINEAR MISSING PIECE)

First evidences

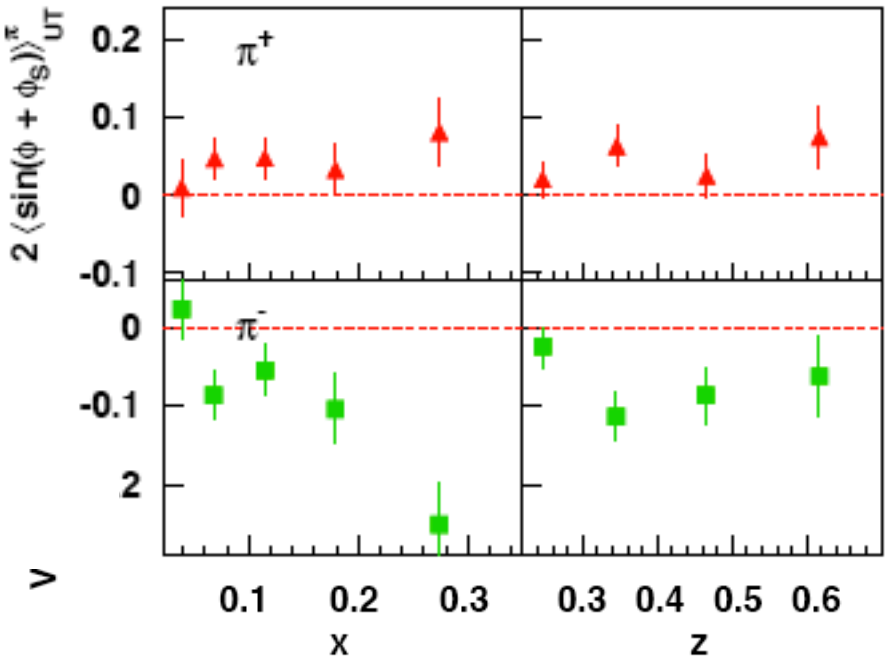
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 \otimes H_1^{\perp}$$

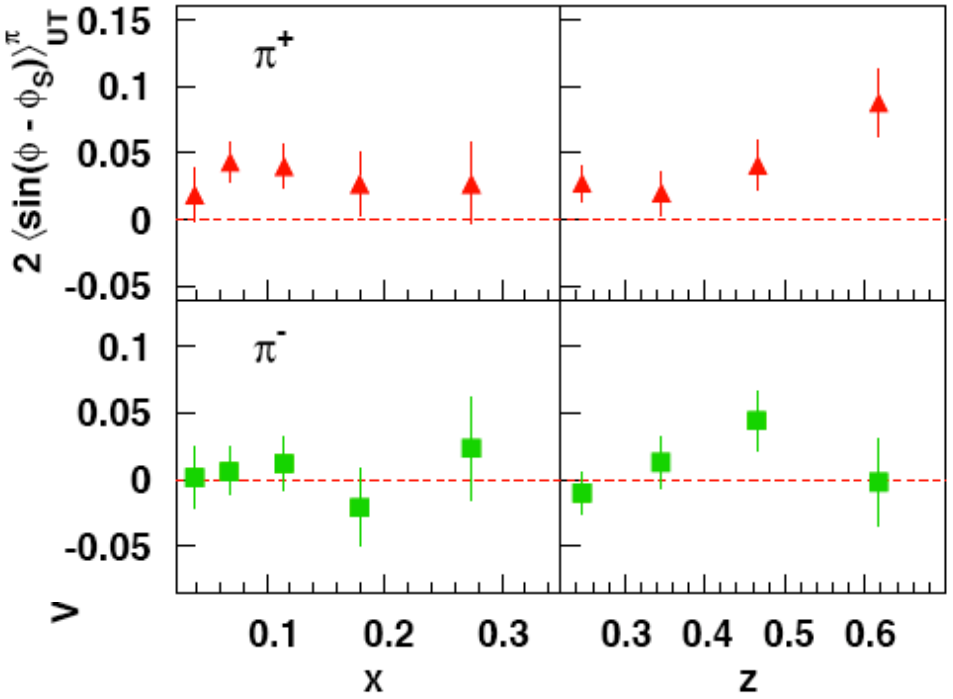
SIDIS:
ep → e'hX

$$\sigma_{UT}^{\sin(\phi-\phi_S)} \propto f_{1T}^{\perp} \otimes D_1$$

2005: First evidence from HERMES measuring SIDIS on proton

A. Airapetian et al, Phys. Rev. Lett. 94 (2005) 012002



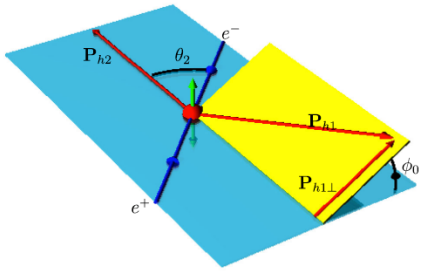


Non-zero transversity !!
Non-zero Collins function !!

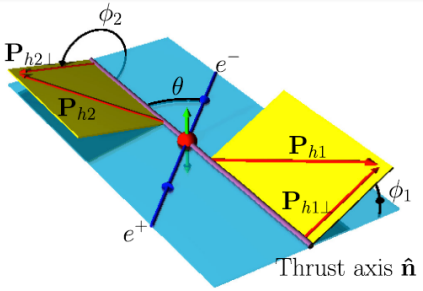
Non-zero Sivers function !!

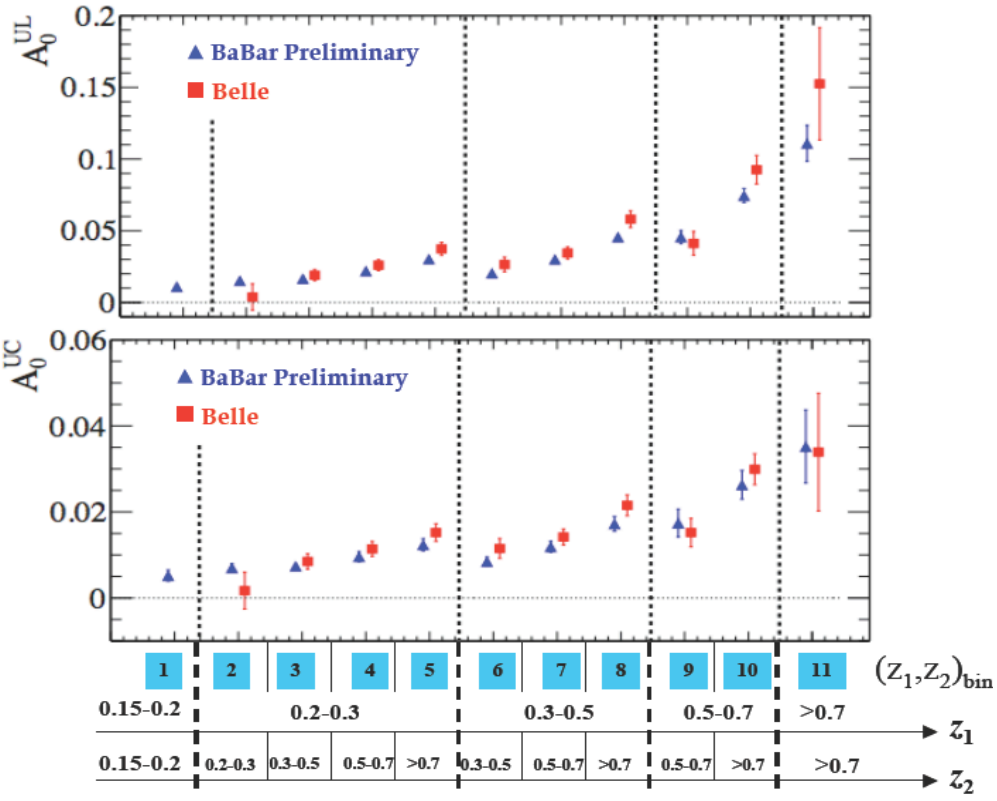
Fragmentation @ e+e- Colliders

$H_1^\perp \otimes H_1^\perp$

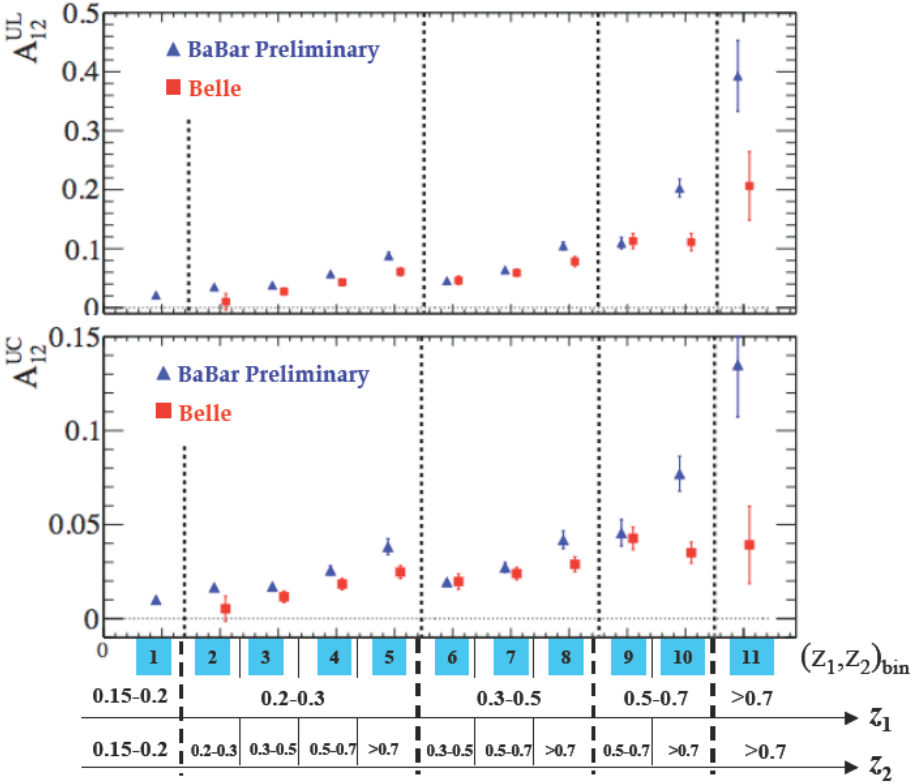


COLLINS SIGNALs





Garzia, DIS 2013



BELLE, PRD 86 (2012) 039905(E)

The Collins SIDIS amplitude

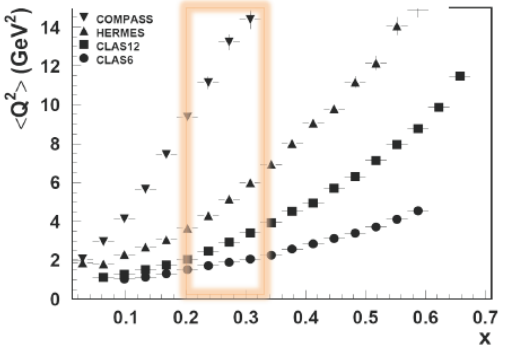
$h_1 \otimes H_1^{\perp}$

CLEAR NON ZERO SIGNALS !

$$A_{UT}^{\sin(\phi+\phi_S)} \propto \frac{\sum_q e_q^2 h_1^q(x,p_T^2) \otimes_\omega H_1^{q,\perp}(z,k_T^2)}{\sum_q e_q^2 f_1^q(x,p_T^2) \otimes D_1^q(z,k_T^2)}$$

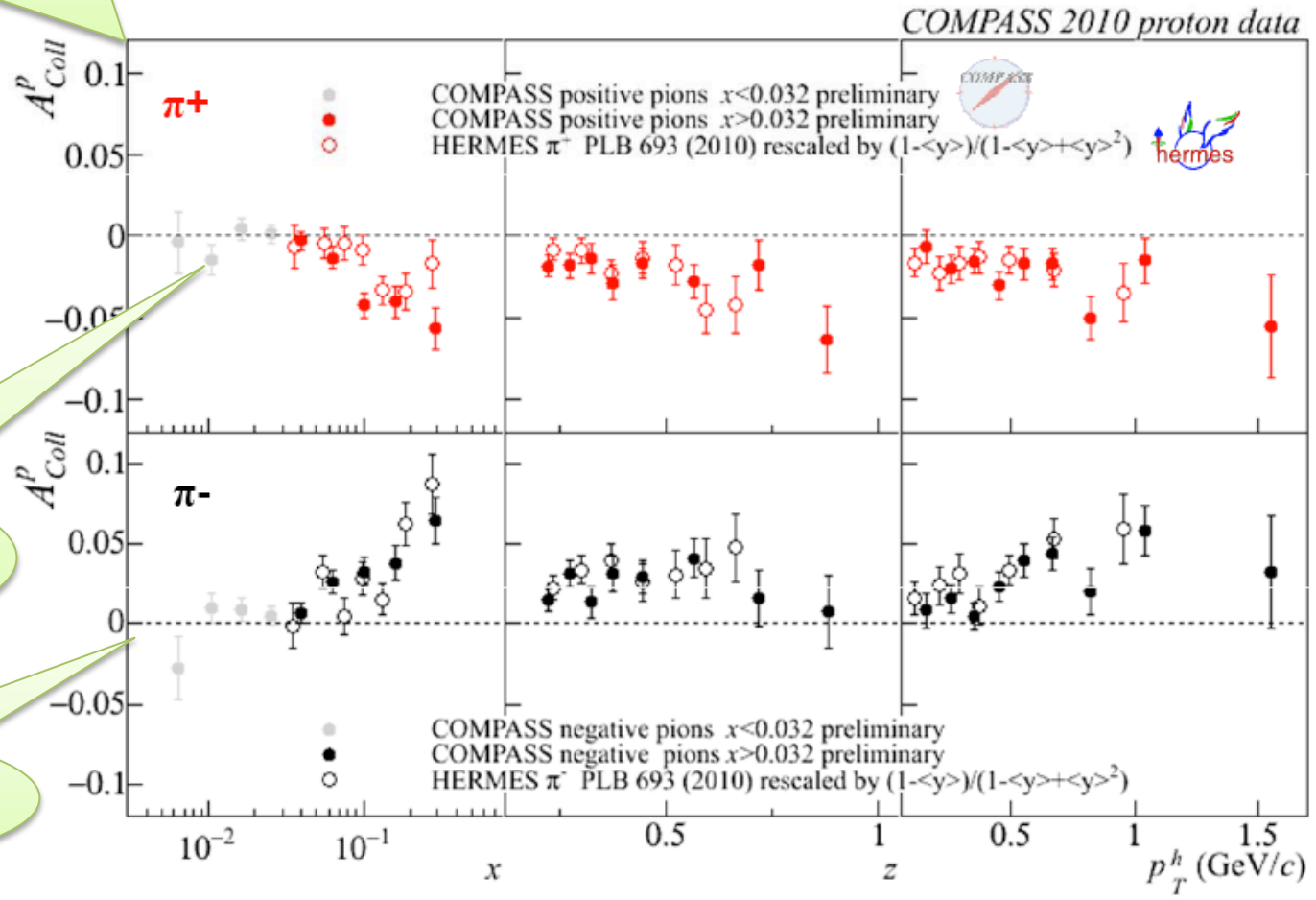
Consistent results at different Q^2
→ No higher twits
→ No strong evolution

Different Q2 for same x range



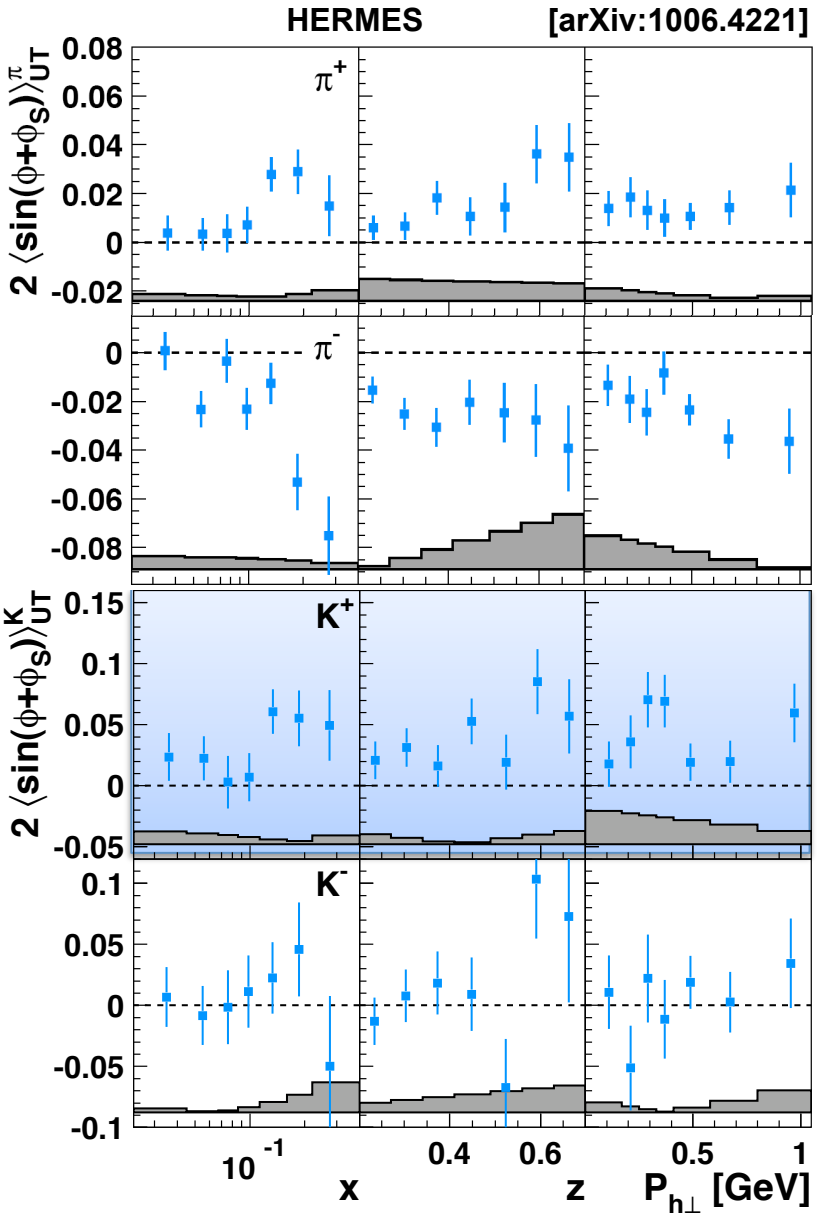
Feature of valence ?
h_1 does not couple to gluons

Opposite sign for pions reveals Collins features



The Collins Amplitude

$h_1 \otimes H_1^\perp$



K^+ signal larger than π^+ ?

role of sea quarks

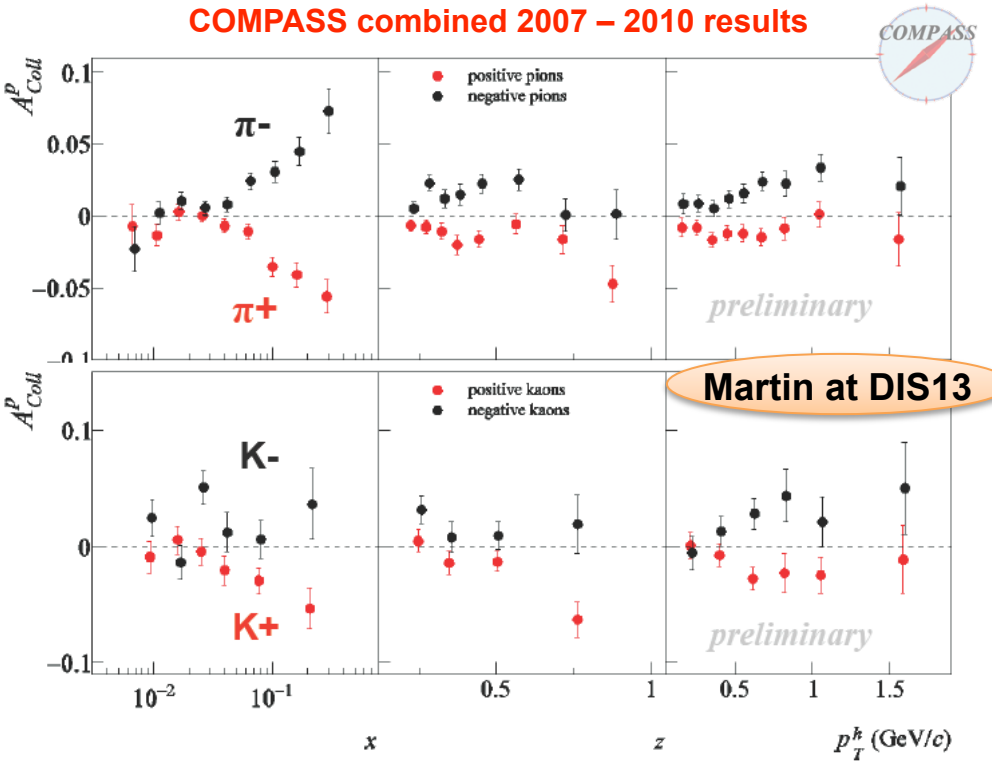
k_T dependence in FFs

higher twists effects

Peculiar K^- ?

no valence quark in common with proton

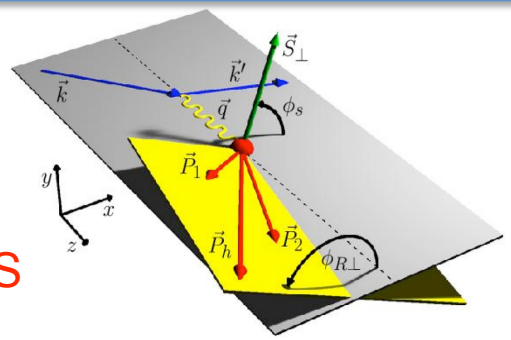
COMPASS combined 2007 – 2010 results



Martin at DIS13

Two hadron asymmetries

$h_1 \otimes H_1^{\sphericalangle}$

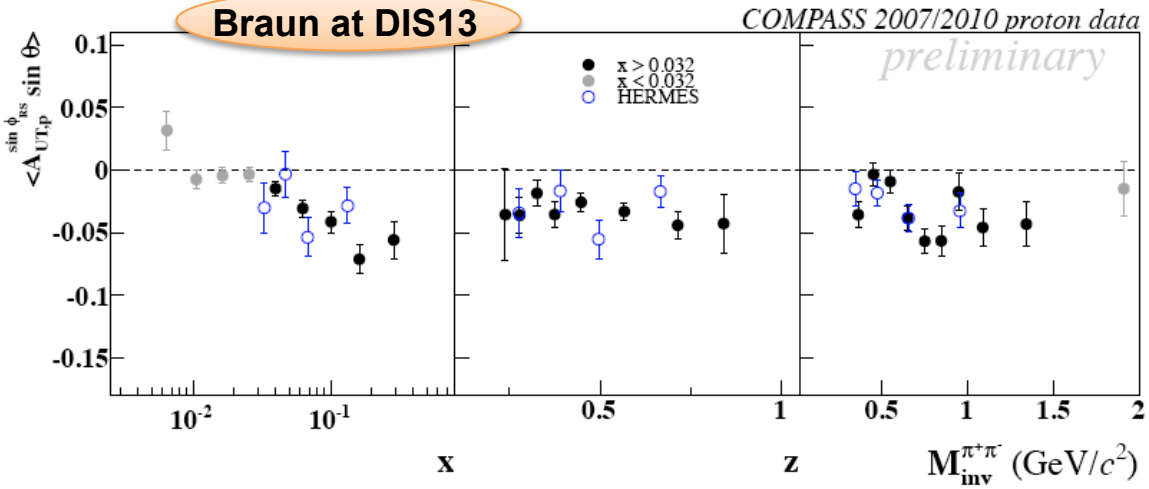


SIDIS

COMPASS, arXiv: 1202.6150

HERMES, arXiv: 0803.2367

Braun at DIS13

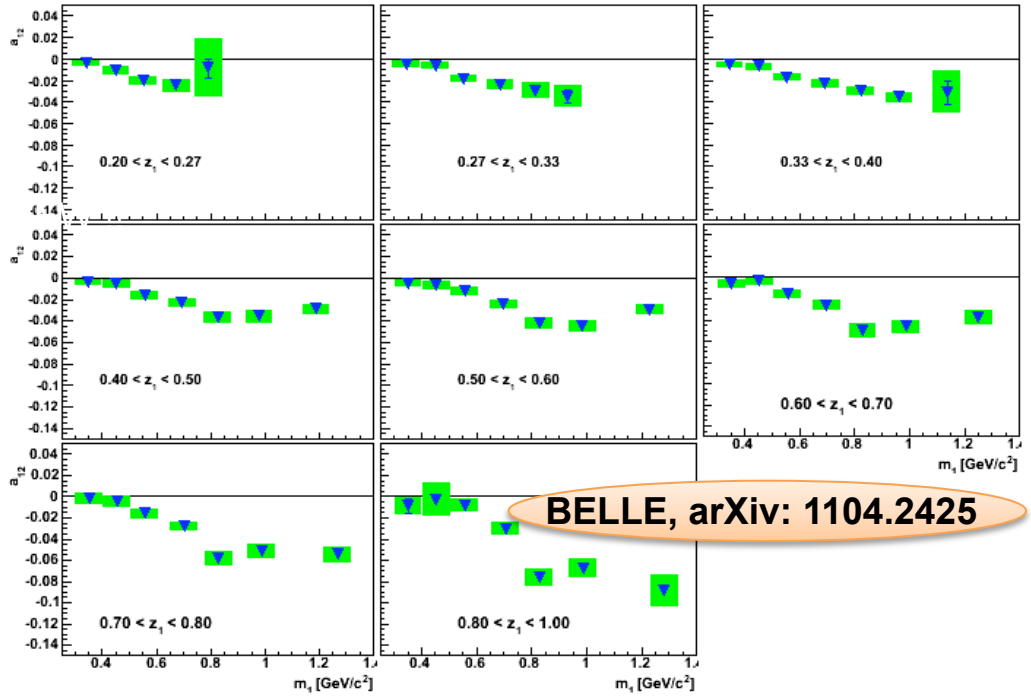


$$A_{UT}^{\sin(\phi_R+\phi_S)\sin\theta} \propto \frac{\sum_q e_q^2 h_1(x,Q^2) H_1^{\sphericalangle}(z,M_h^2,Q^2)}{\sum_q e_q^2 f_1(x,Q^2) D_1^{\sphericalangle}(z,M_h^2,Q^2)}$$

- Survives P_h integration
- Collinear factorization (simple product)
- DGLAP volution
- Universality

- Issue: unknown pp-terms in PW expansion

e+-e-



BELLE, arXiv: 1104.2425

Transversity Signals

$lp \to l' hX$ (HERMES)

$e^+e^- \to h_1 h_2 X$ (BELLE)

$lp \to l' \pi^+\pi^- X$ (HERMES, COMPASS)

$ld \to l' hX$ (COMPASS)

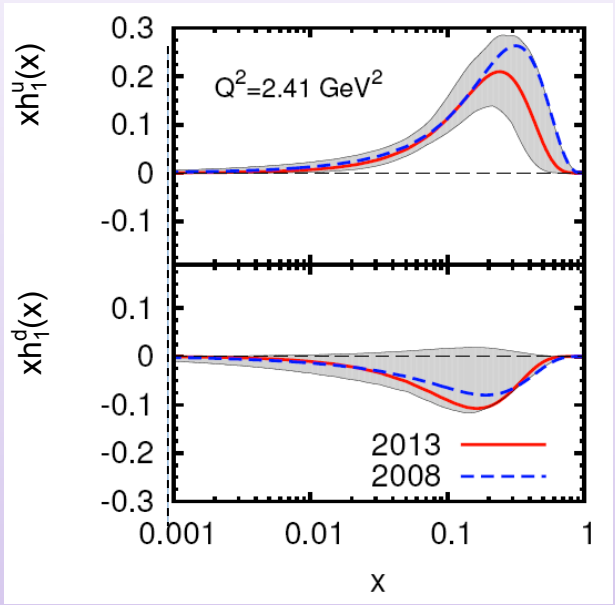
$$A_{UT}^{\sin(\phi+\phi_S)} \propto h_1(x) \otimes H_1^{\perp q}(z)$$

$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)} \propto \sin\vartheta \; h_1(x) \otimes H_1^{\sphericalangle q}(z)$$

Existing data limited to x < 0.3

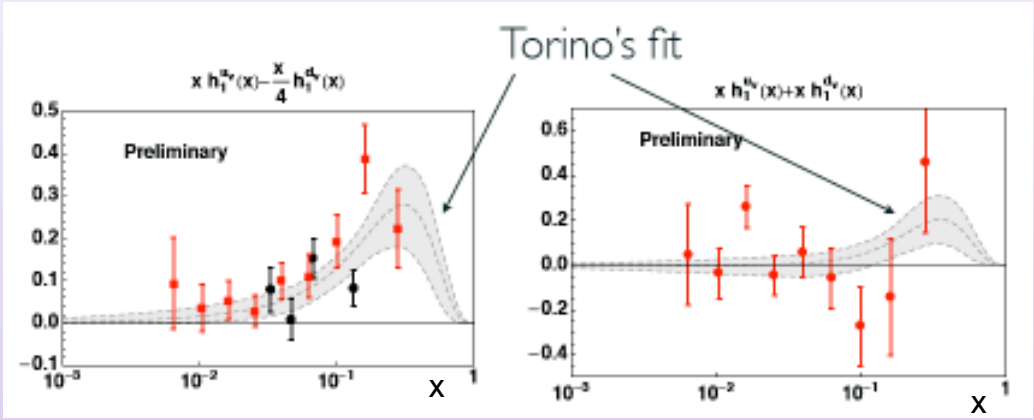
FF evol.. from high energy colliders

1st extraction of Transversity!



Anselmino ++ arXiv: 1303.3822

Collinear extraction !



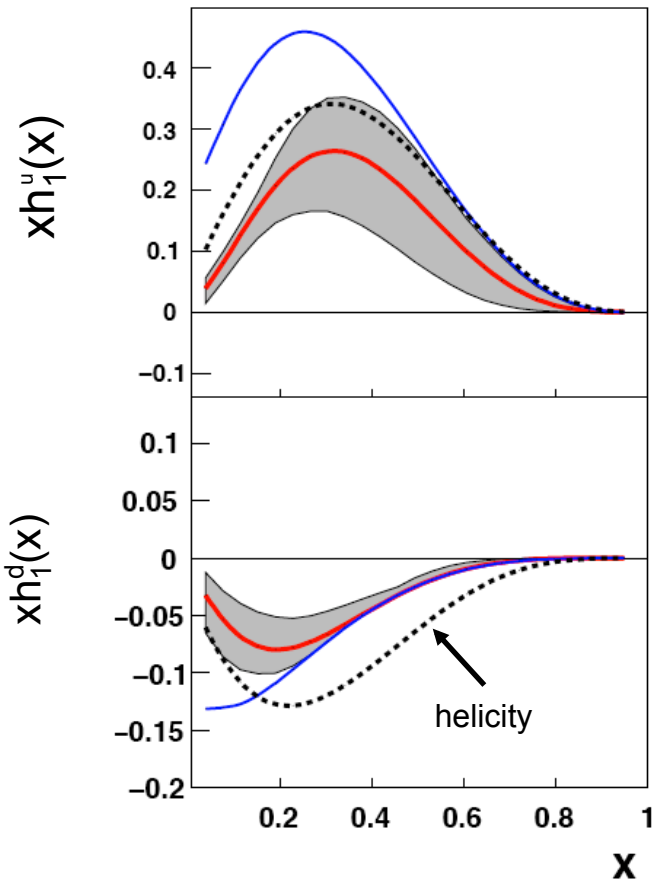
Bacchetta ++ arXiv: 1206.1836

Transversity vs Helicity

$h_1 \otimes H_1^{\perp}$

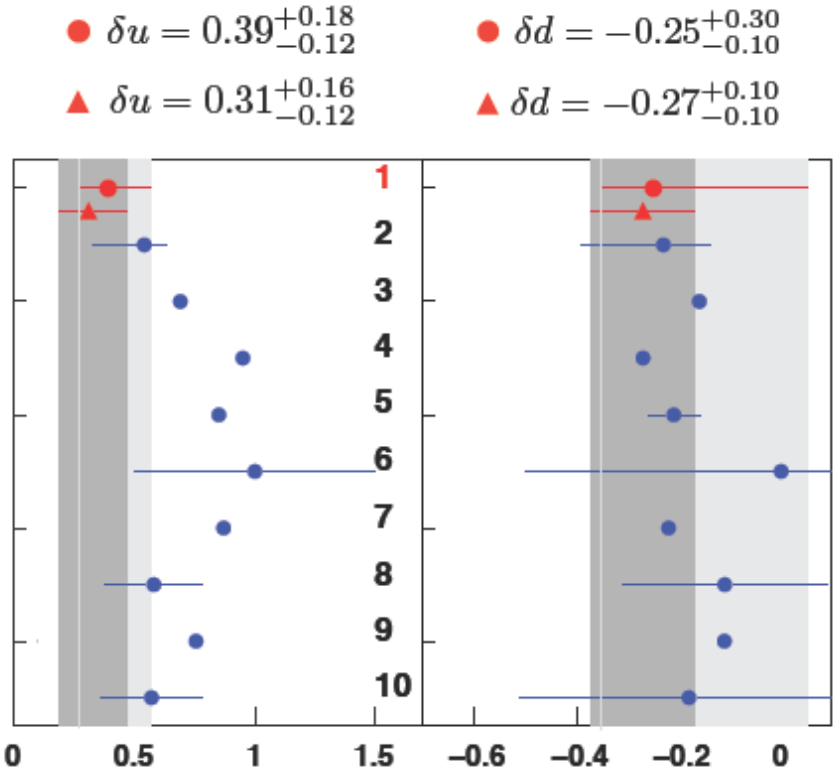
Distributions:

[arXiv:0812.4366]



Charges:

[arXiv:1303.3822]



Δu = 0.787 **Δd = -0.319**

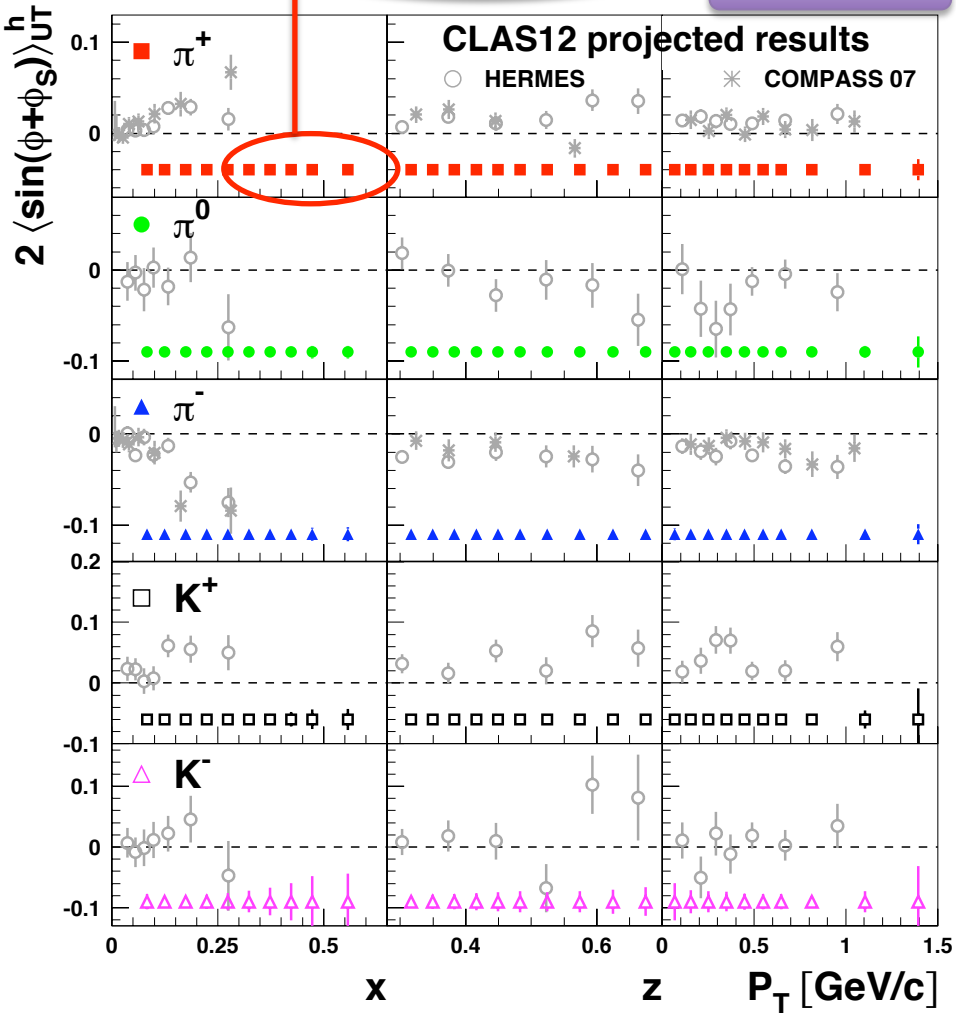
[arXiv:1303.3822]

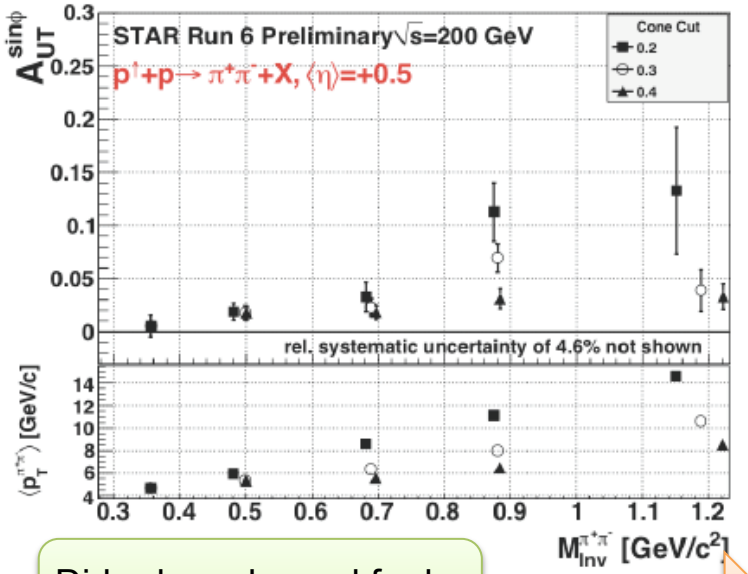
Transversity @ JLab12 2014+

Large x important to constrain the tensor charge

C12-11-111 Hall-B

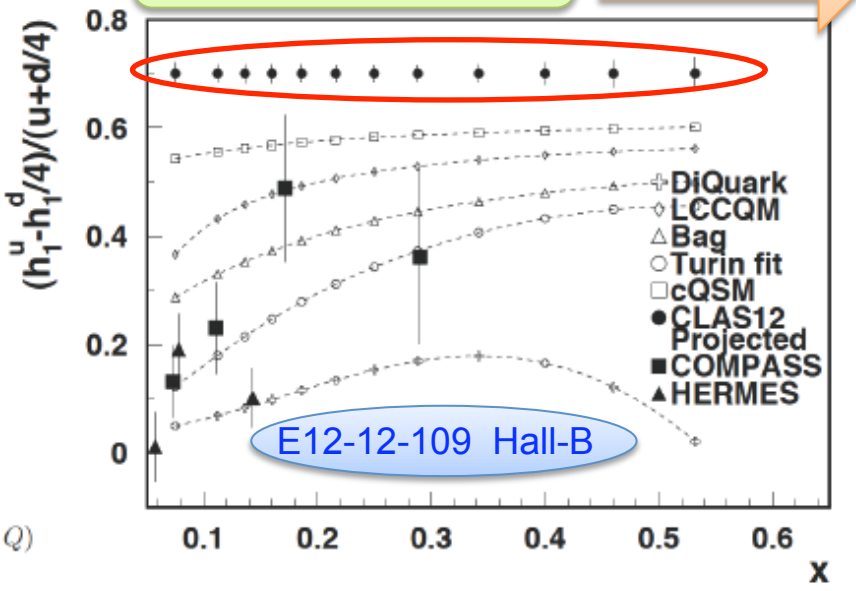
Proton



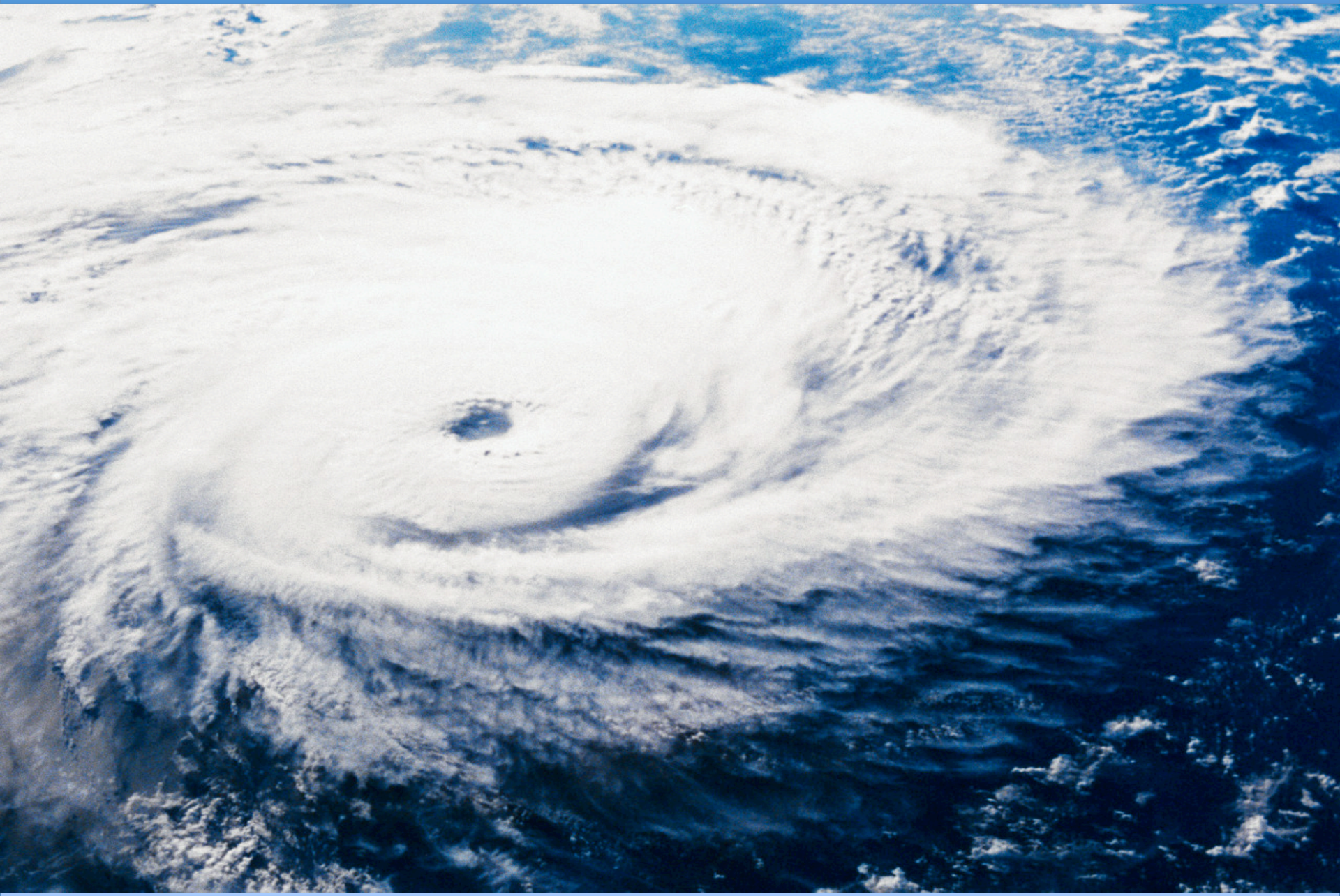


Di-hadron channel for h_1
Test of TMDs extraction

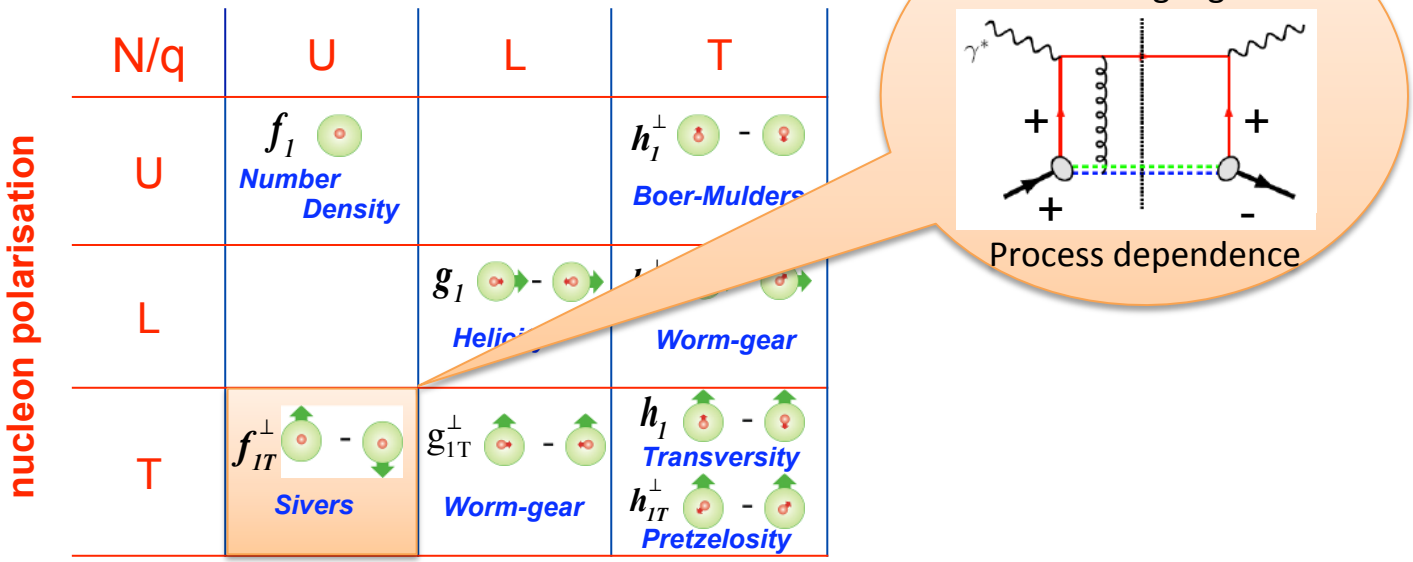
Meziani talk



Spin-Orbit Effects



SIVERS

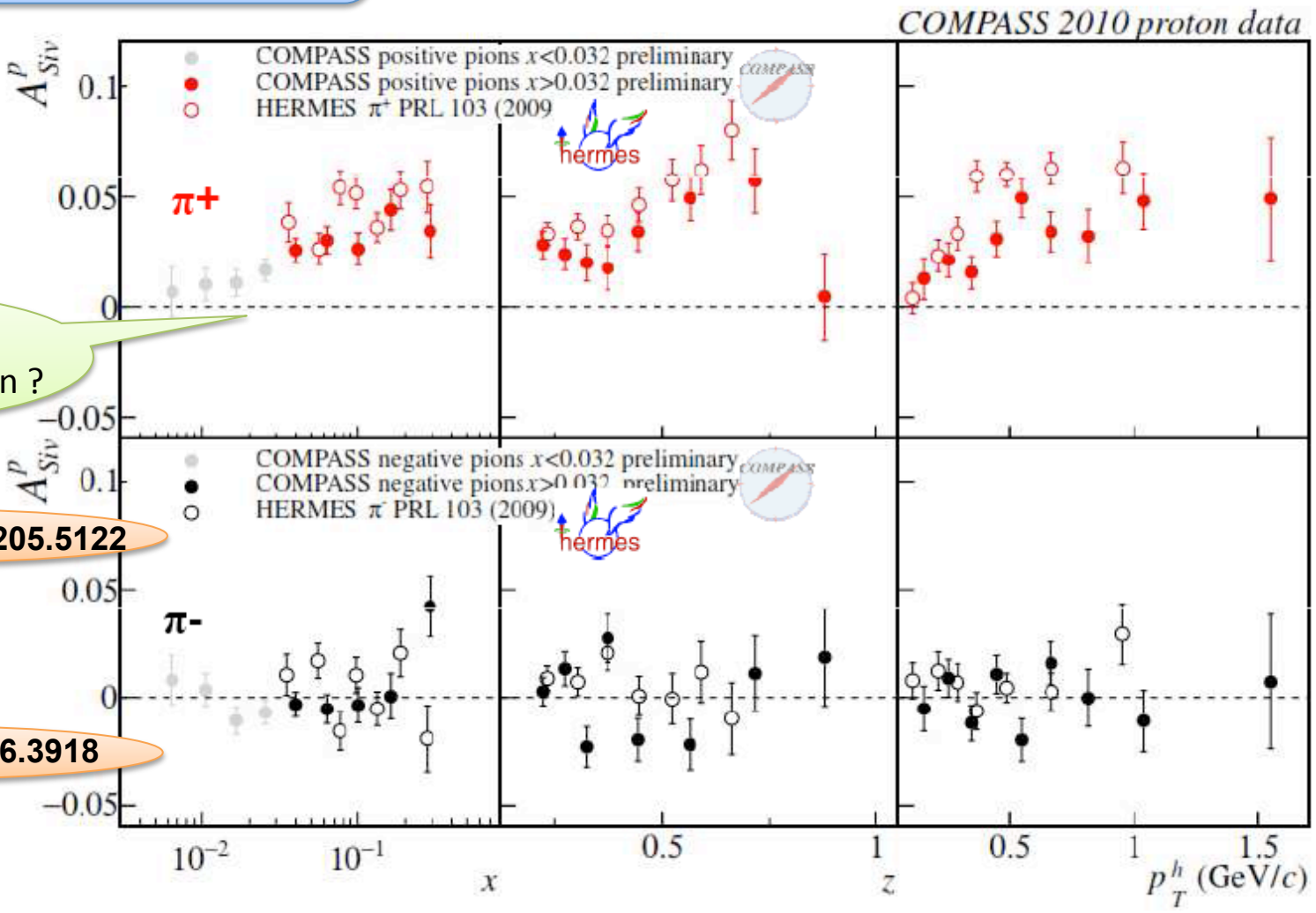


(THE TMD CHALLENGE)

The Sivers Signals

$$A_{UT}^{\sin(\phi - \phi_S)} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x, p_T^2) \otimes_\omega D_1^q(z, k_T^2)}{\sum_q e_q^2 f_1^q(x, p_T^2) \otimes D_1^q(z, k_T^2)}$$

CLEAR NON ZERO SIGNALS !



Systematic shift:
Sivers Q^2 evolution ?

COMPASS, arXiv: 1205.5122

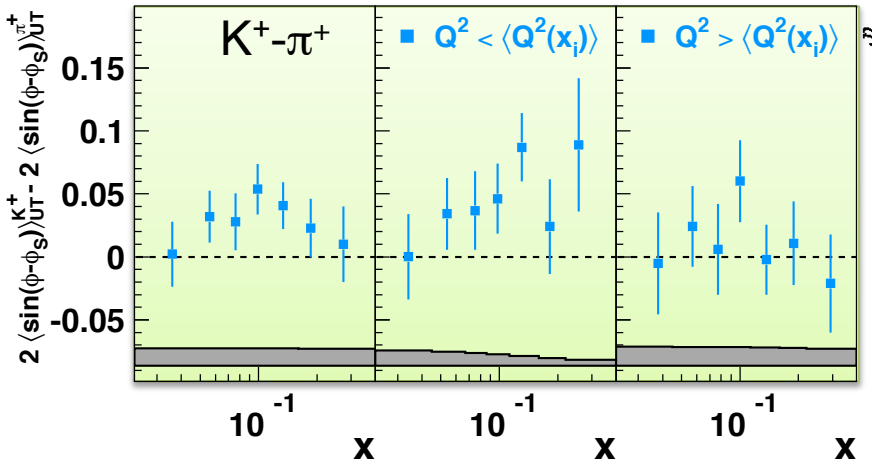
HERMES, arXiv: 0906.3918

The Sivers Signals

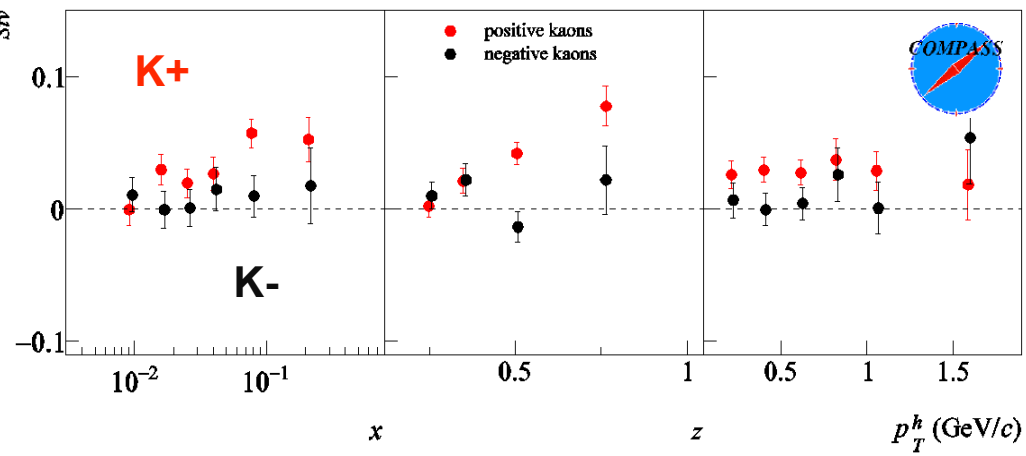
$f_{1T}^{\perp} \otimes D_1$

K+ amplitudes larger than π+:

HERMES [arXiv:0906.3918]

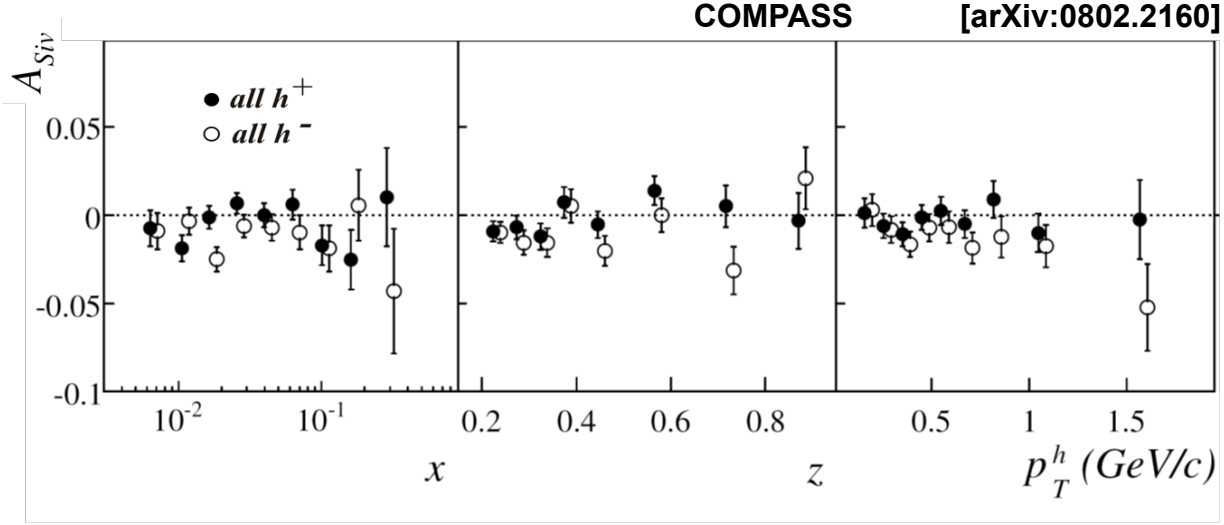


combined 2007 – 2010 results



Deuteron signal compatible with zero or slightly negative:

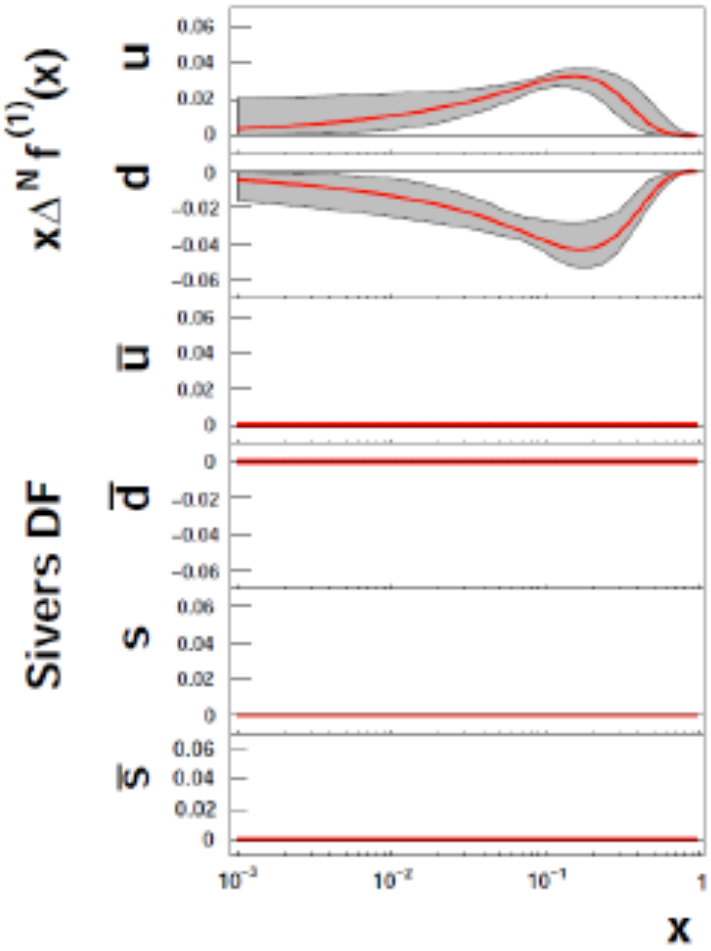
COMPASS [arXiv:0802.2160]



The Sivers Distributions

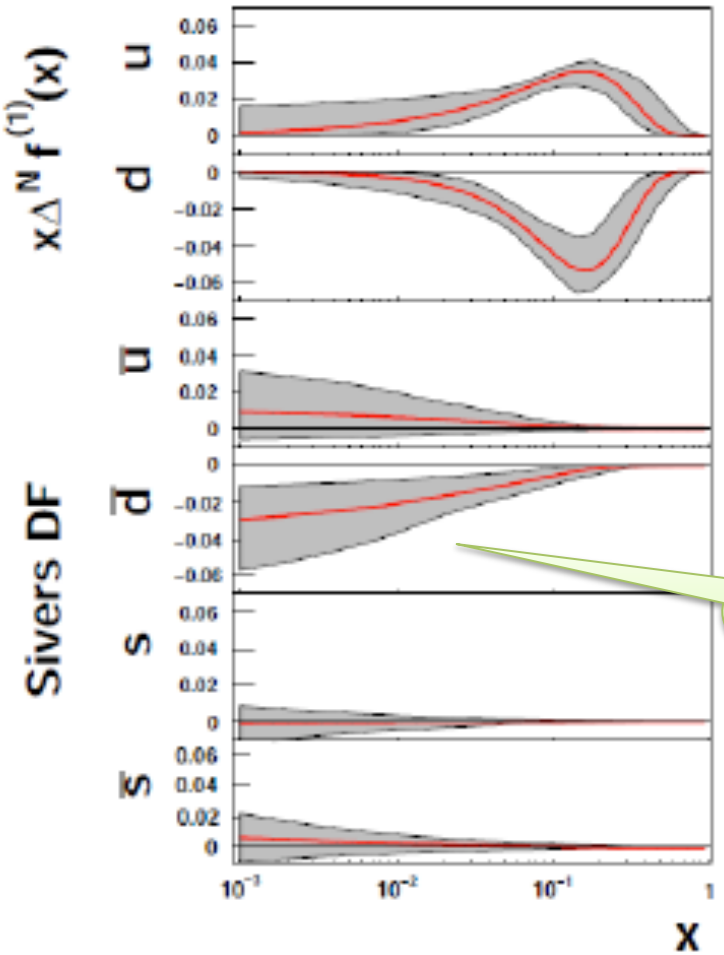
$f_{1T}^{\perp} \otimes D_1$

Without sea:



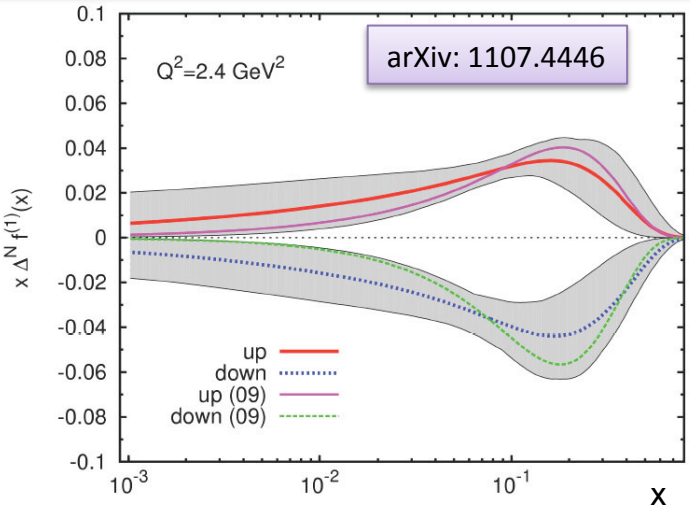
With sea:

[arXiv:1012.3565]



The Sivers Challenge

$f_{1T}^{\perp} \otimes D_1$

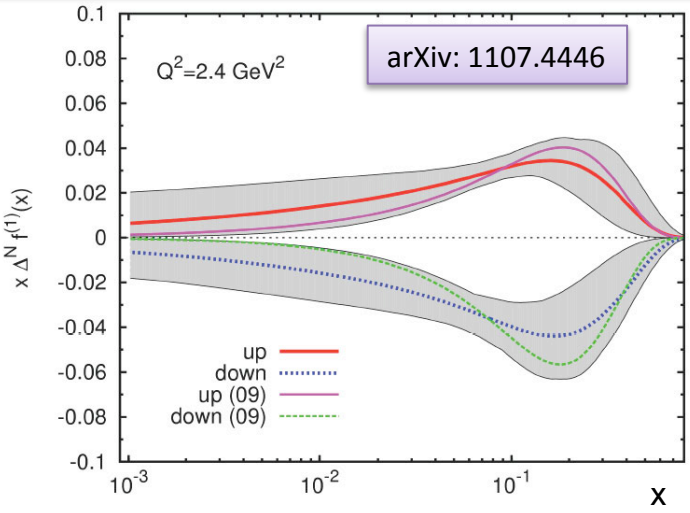


From SIDIS to Drell-Yan:

Sign change as a crucial test of TMDs factorization

The Sivers Challenge

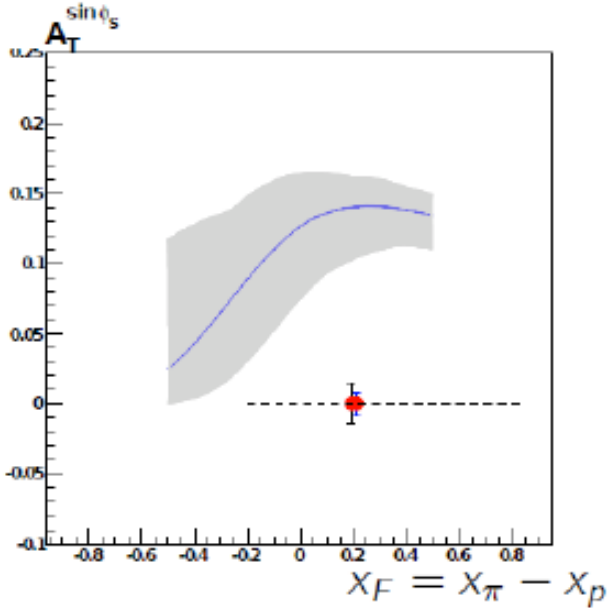
$f_{1T}^{\perp} \otimes D_1$



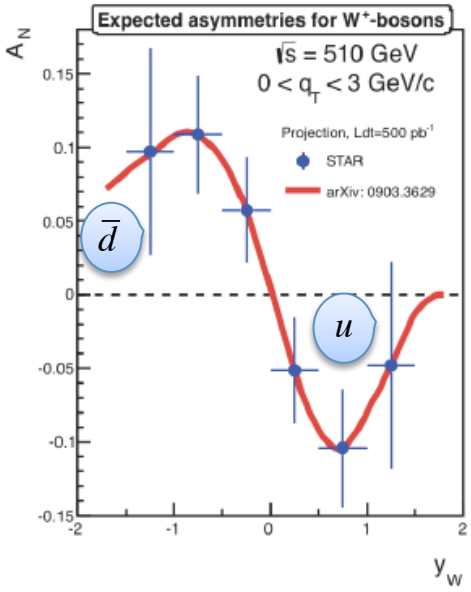
From SIDIS to Drell-Yan:

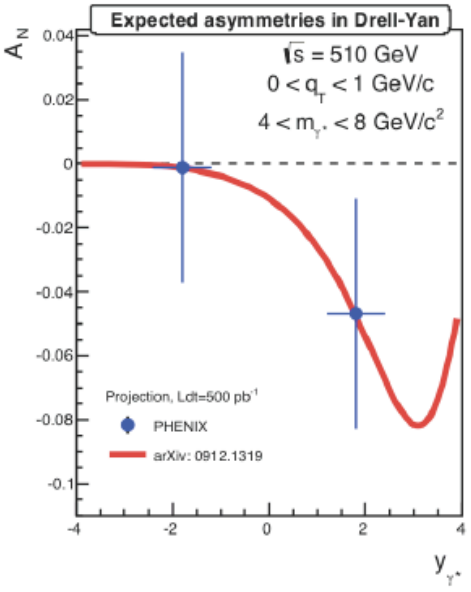
Sign change as a crucial test of TMDs factorization

π H$^{\uparrow}$ @ CERN



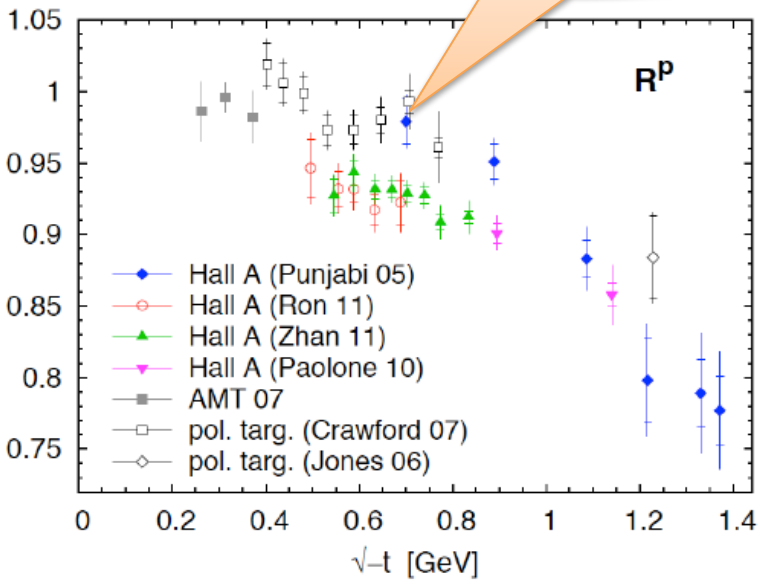
p$^{\uparrow}$p @ Brookhaven

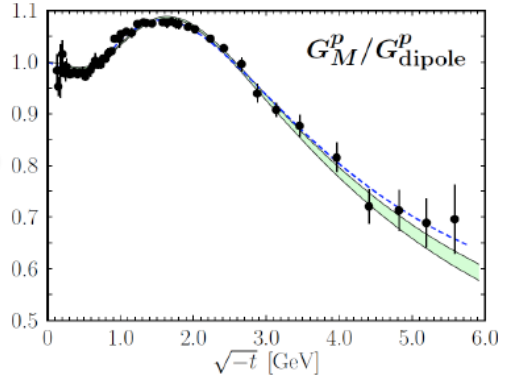


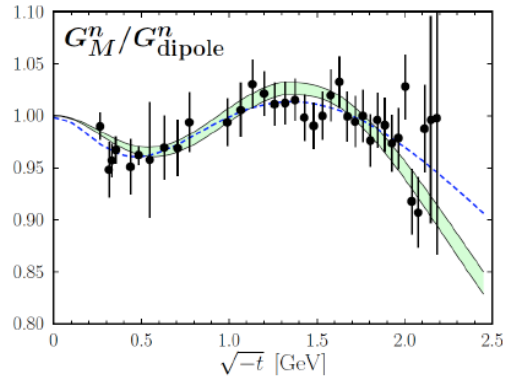


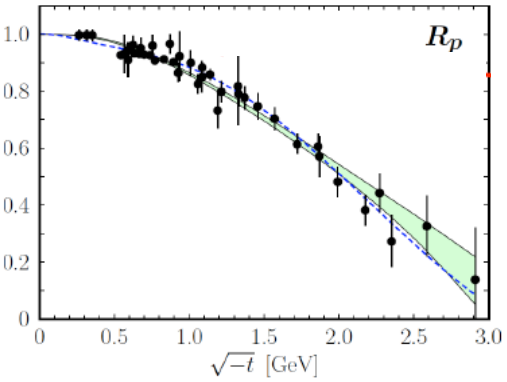
OAM Glimpses

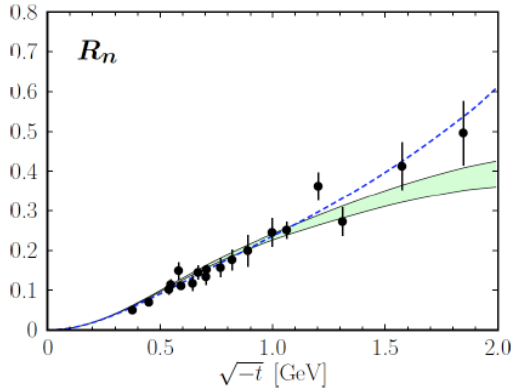
$$R^p = G_E^p / (G_M^p / \mu_p)$$











- obtain at μ = 2 GeV

$$J_v^u = 0.230^{+0.009}_{-0.024} \qquad J_v^d = -0.004^{+0.010}_{-0.016}$$

Diehl et al. arXiv: 1302.4604

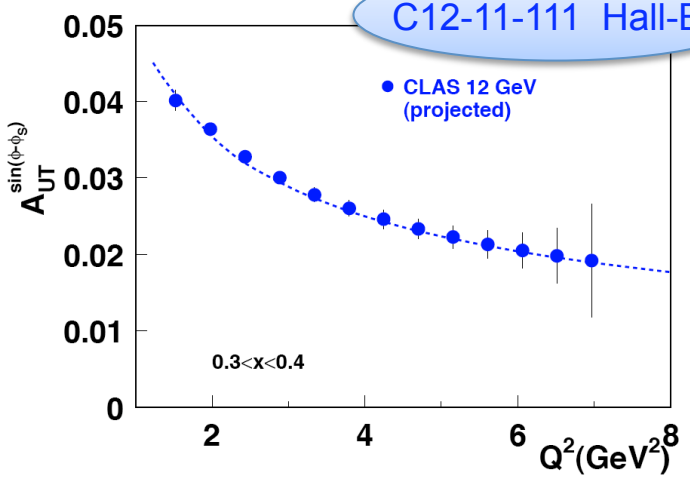
- within errors consistent with determination from Sivers distrib. and model for chromodynamic lensing:

$$J_v^u = 0.214^{+0.009}_{-0.013} \qquad J_v^d = -0.029^{+0.021}_{-0.008}$$

Bacchetta et al. arXiv: 1107.5755

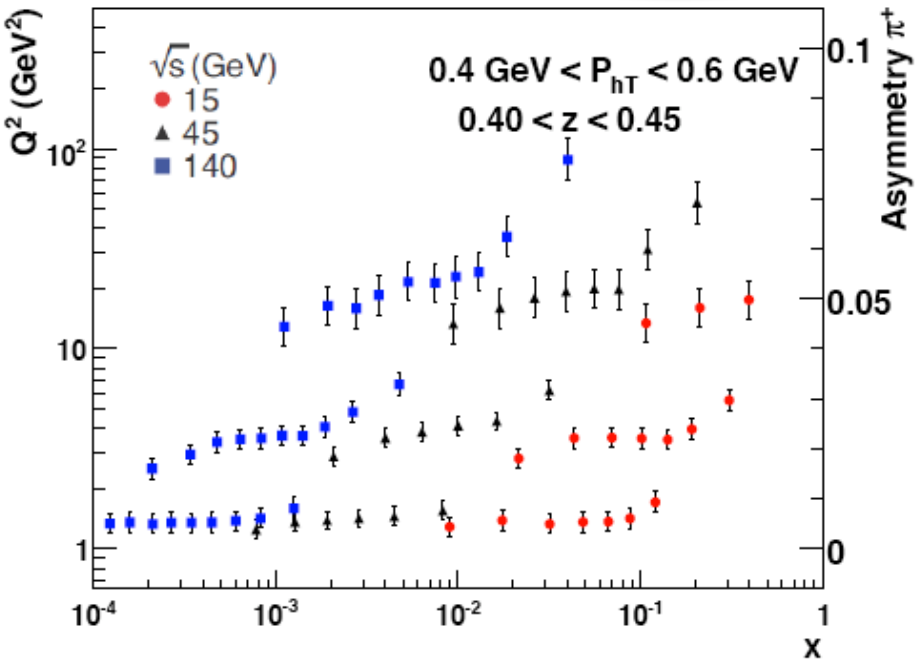
Sivers Landscape

C12-11-111 Hall-B



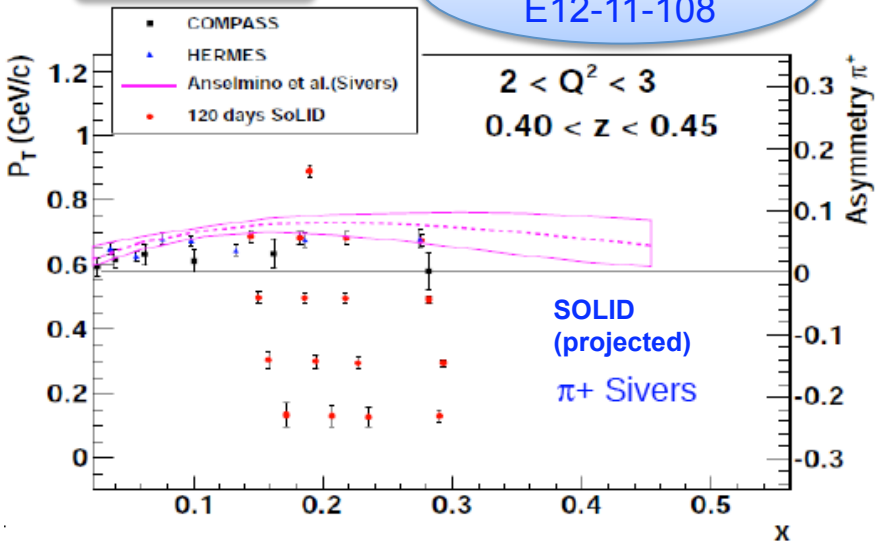
EIC

30 fb^{-1}

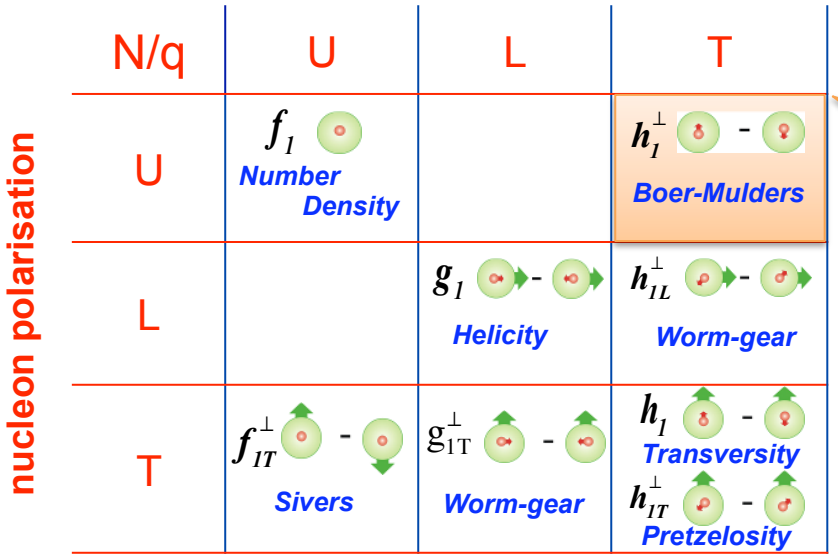


Proton & ^{3}He

E12-10-006 Hall-A
E12-11-108



Cahn & Boer-Mulders



Naïve-T-odd
Chirally-odd
Spin effect in unpolarized reactions

(The Neglected Effects)

The Azimuthal Modulation

$h_1^\perp \otimes H_1^\perp$

$$\frac{d^5\sigma^{ep\to e'hX}}{dx\,dy\,dz\,d\phi\,dP_{h\perp}^2} \propto \{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos(\phi)F_{UU}^{\cos(\phi)} + \varepsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\}$$

$(f_1 \otimes D_1)/Q$

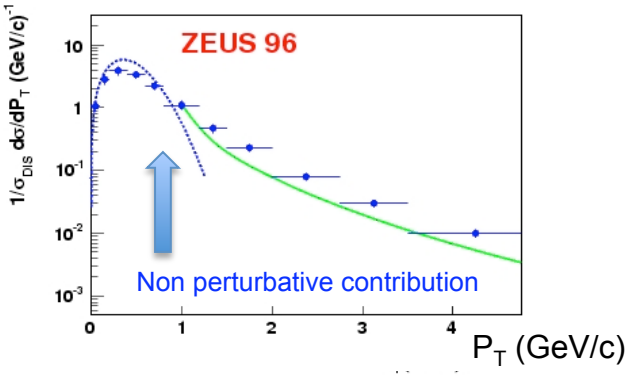
$h_1^\perp \otimes H_1^\perp$

Cahn PLB 78 (1978)

Kinematical effect predicted since 1978 by Cahn due to non-zero intrinsic k_T

Boer & Mulders PRD 57 (1998)

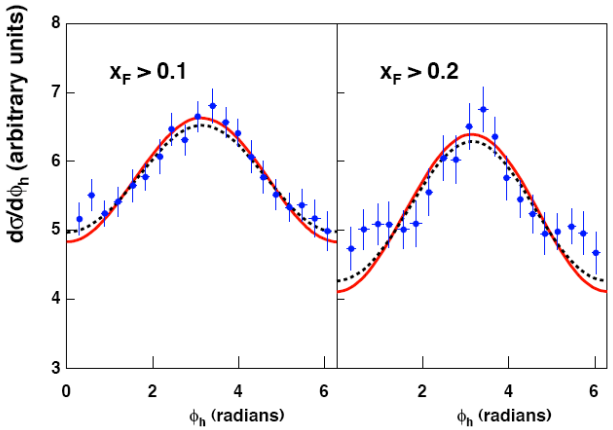
Leading-twist contribution introduced by Boer & Mulders in 1998

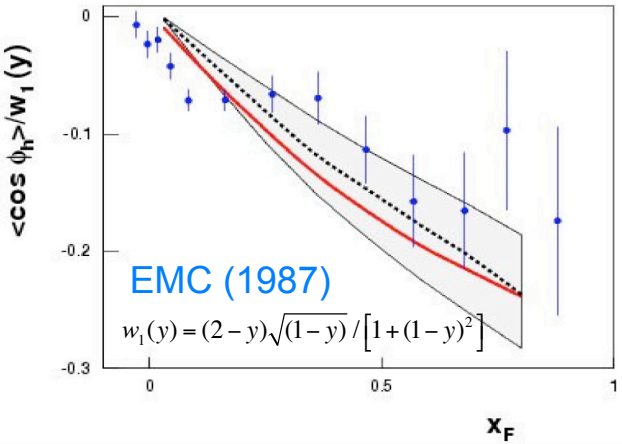


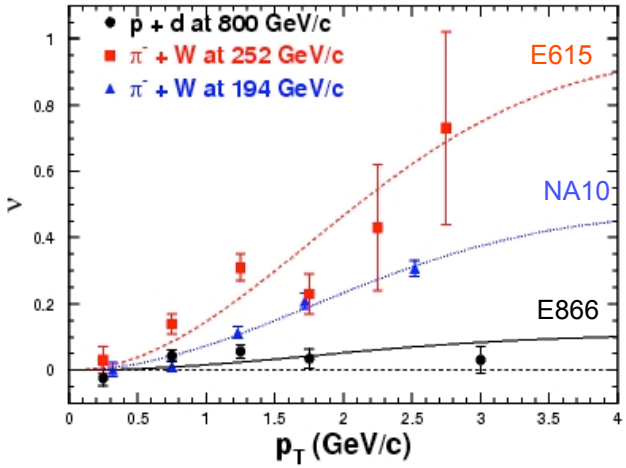
SIDIS: qualitative agreement with Cahn expectations till 2008

- No hadron identification
- No charge separation
- Poor statistics for cos2ϕ

DY: violation of Lam-Tung relation







Unpolarized Cross-section

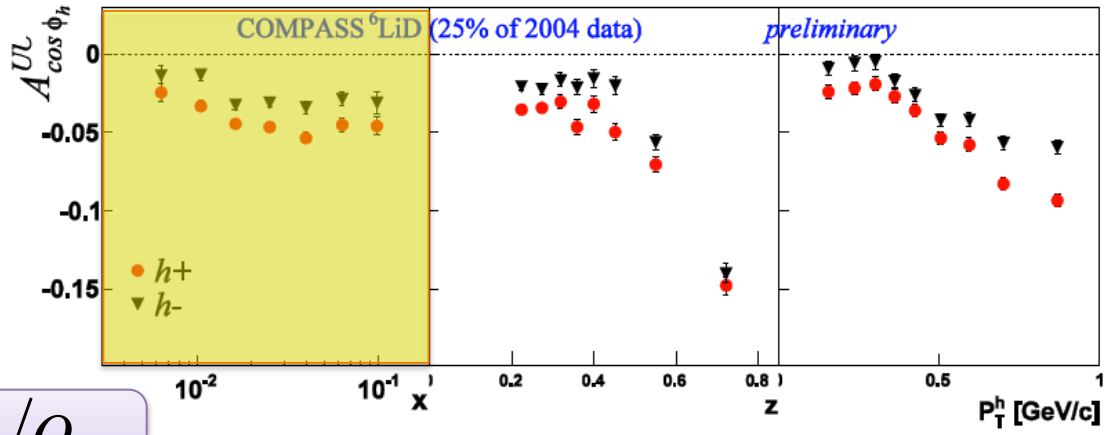
cosϕ large and negative !

Increasing with z and P_h

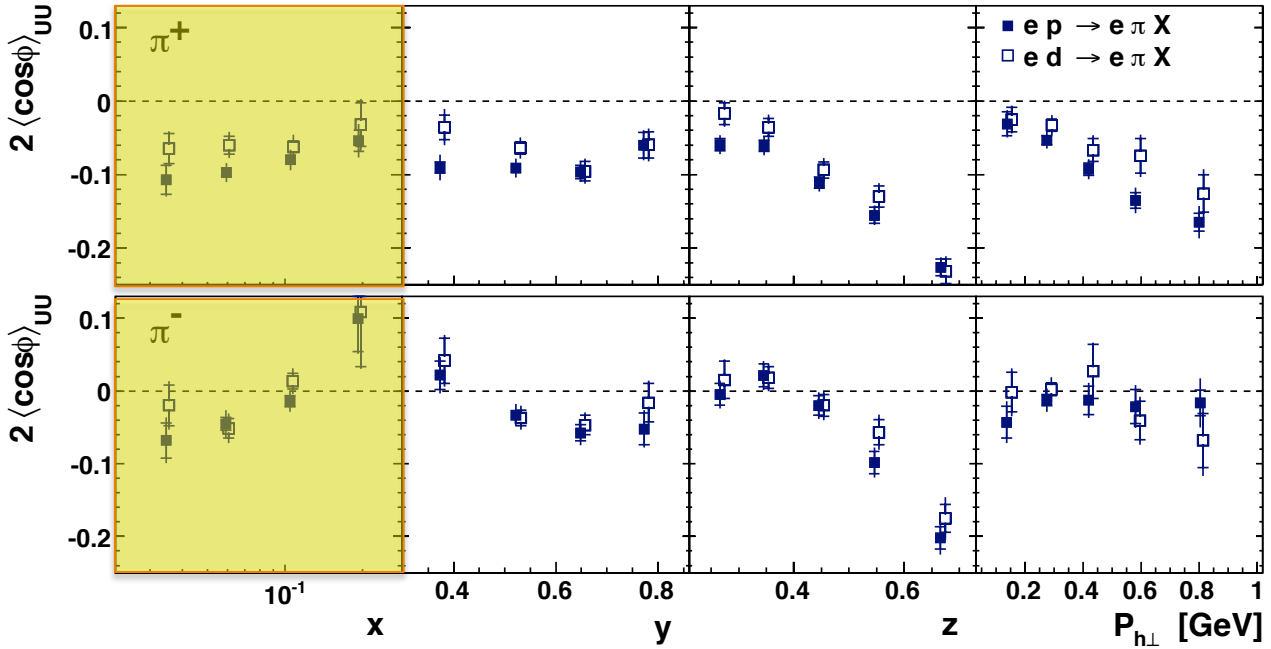
Large difference in hadron charge !

Larger in magnitude for π+

$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^{\perp} \otimes H_1^{\perp} + \ldots \right] / Q$$



HERMES H & D DATA [PRD 87 (2013) 012010]



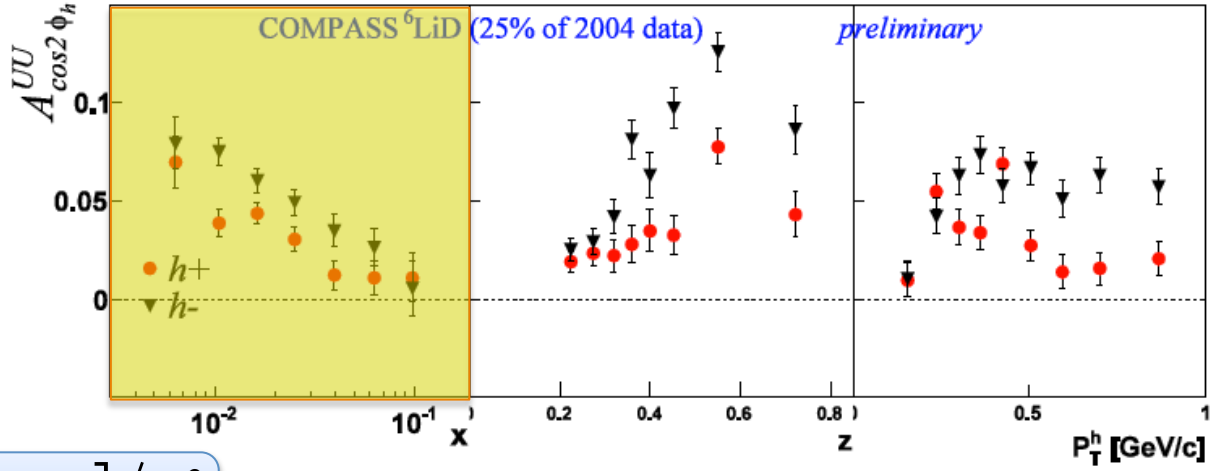
Unpolarized Cross-section

cos2ϕ non-zero !

Difference in hadron charge !

Positive for π-

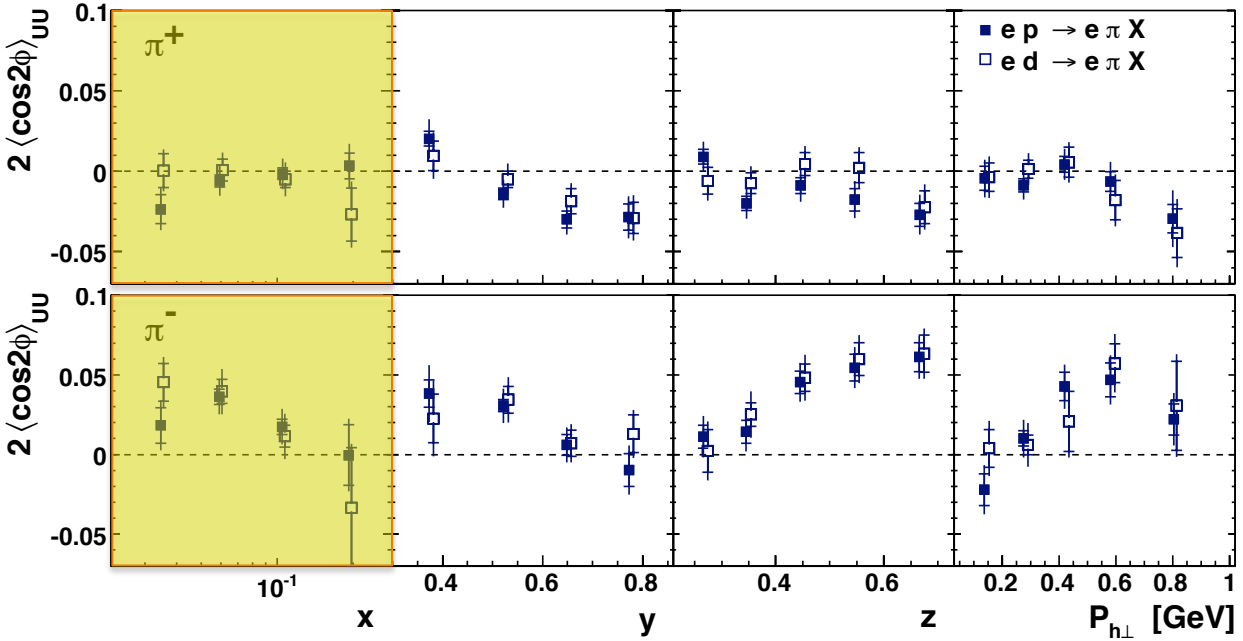
Negative for π+



$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

HERMES H & D DATA

[PRD 87 (2013) 012010]



Quark d vs u contribution ?
DATA support Boer-Mulders of same sign for u and d

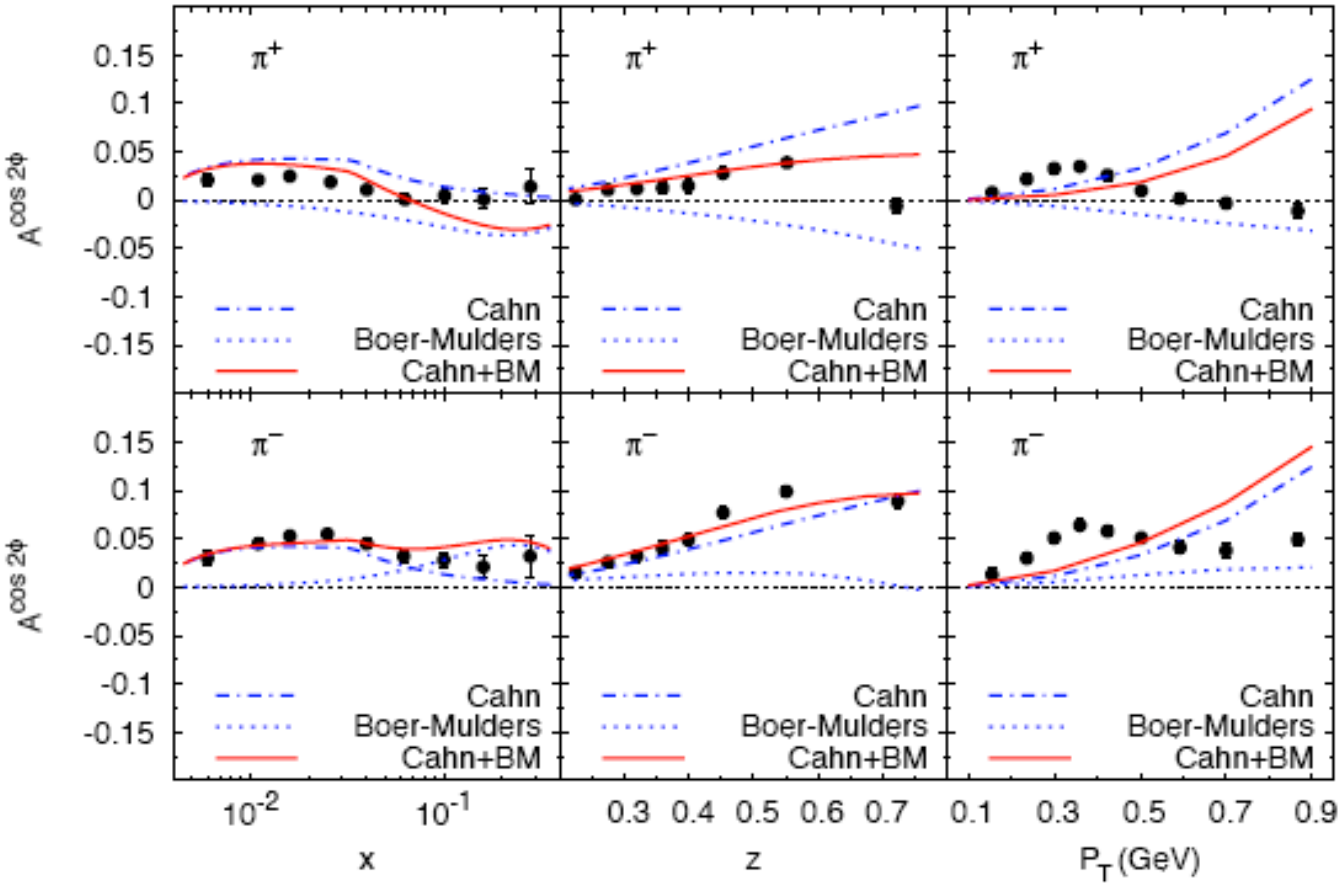
The SIDIS cos2ϕ p_T dependence

$h_1^\perp \otimes H_1^\perp$

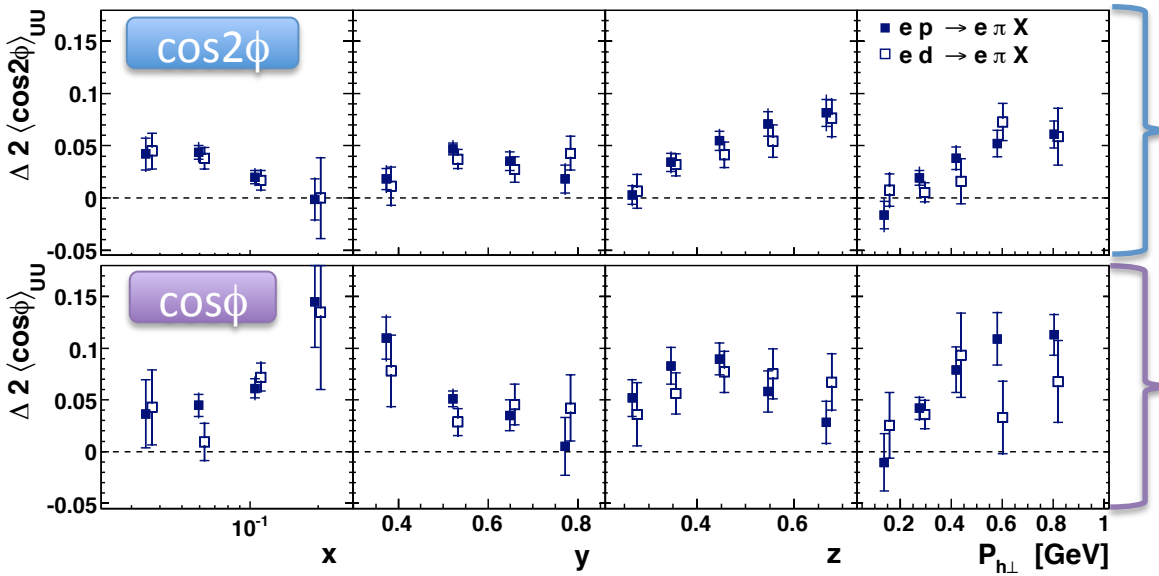
$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^\perp \otimes H_1^\perp + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

Can be explained by large uncertainty on Cahn and neglected HT effects ?

[arXiv: 0912.5194]



Difference in pion charge



$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

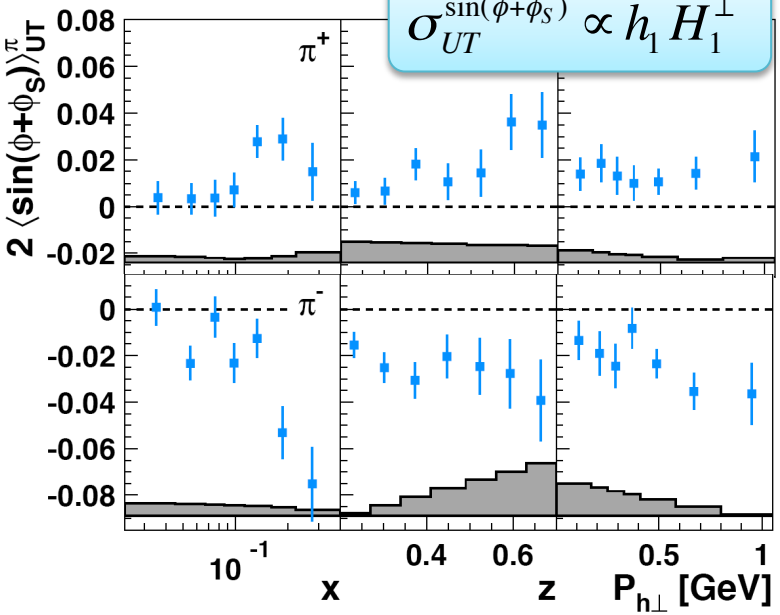
$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^{\perp} \otimes H_1^{\perp} + \ldots \right] / Q$$

Mild flavor dependence of k_T expected

From A_{UT}: Collins favored ($u \rightarrow \pi+$) and unfavored ($u \rightarrow \pi-$) fragmentation opposite in sign

With u-dominance
Collins makes the difference !
Hint of non-zero Boer-Mulders

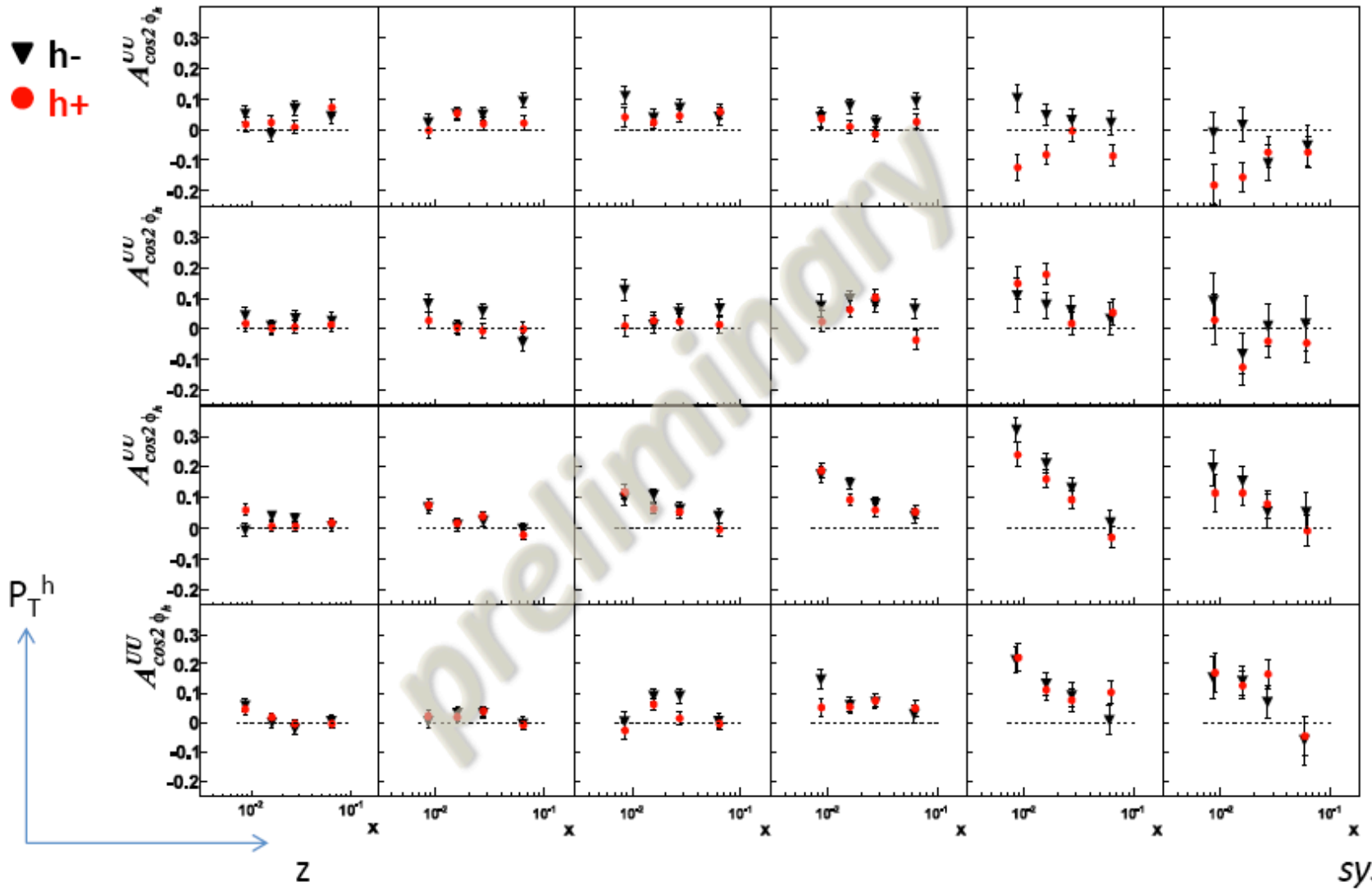
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 H_1^{\perp}$$



The SIDIS cos2ϕ dependence

$h_1^\perp \otimes H_1^\perp$

COMPASS ^{6}LiD (25% of 2004 data)



$sys \approx 2 \cdot stat$

Multidimensional analysis is mandatory: x trend changes from small z to large z values

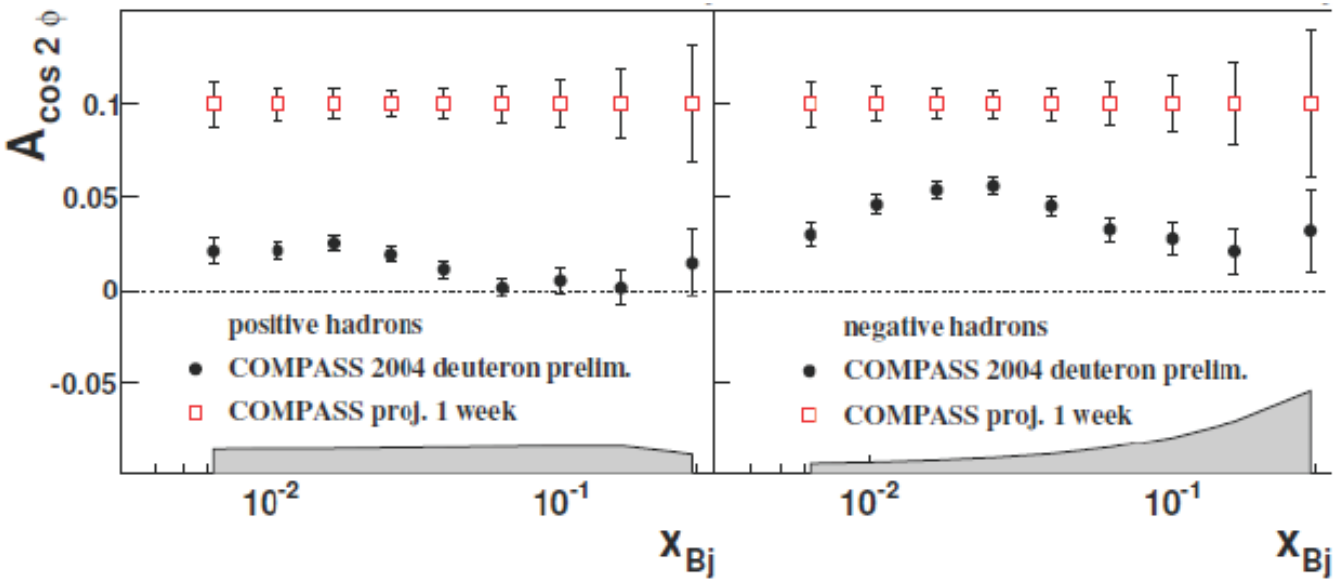
The SIDIS Landscape 2014+

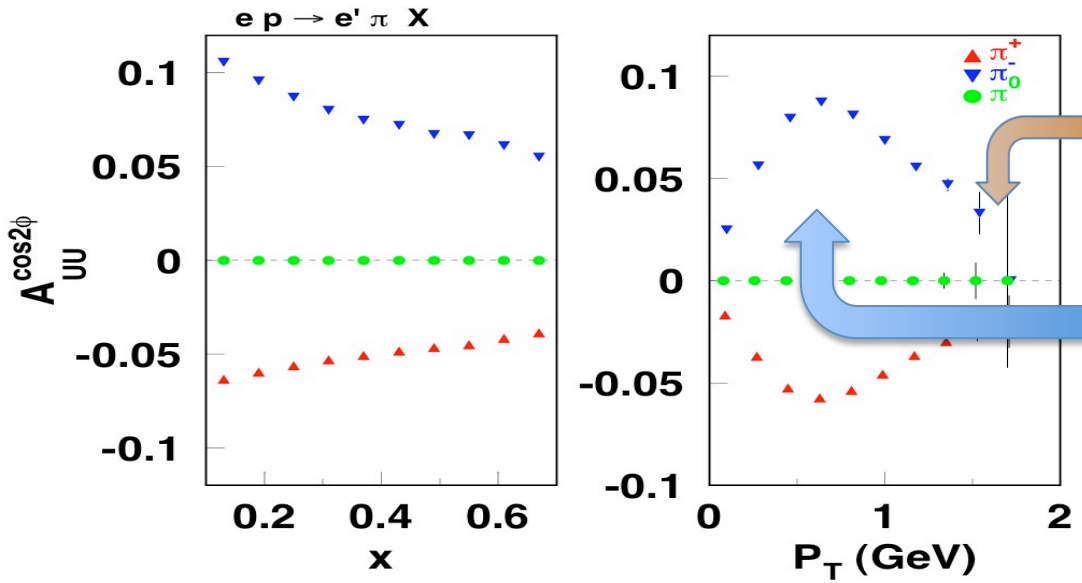
COMPASS-II:

LH_2 target
160 GeV/c muons

CLAS12:

LH2 target
12 GeV/c electrons
$L \sim 10^{35}\ cm^{-2}s^{-1}$





Perturbative region
Collinear factorization

Non-perturbative
TMD factorization

$$\Lambda_{QCD} \ll P_T \ll Q$$

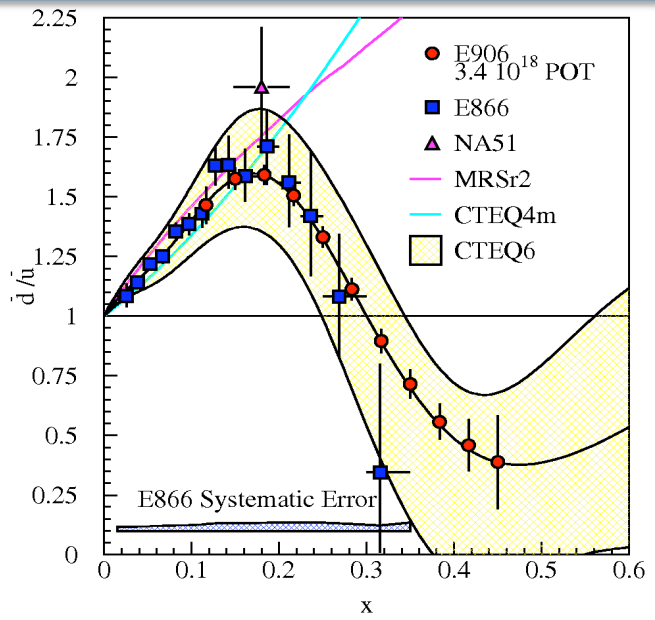
The Drell-Yan Landscape 2014+

Proton beam @ Fermilab

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

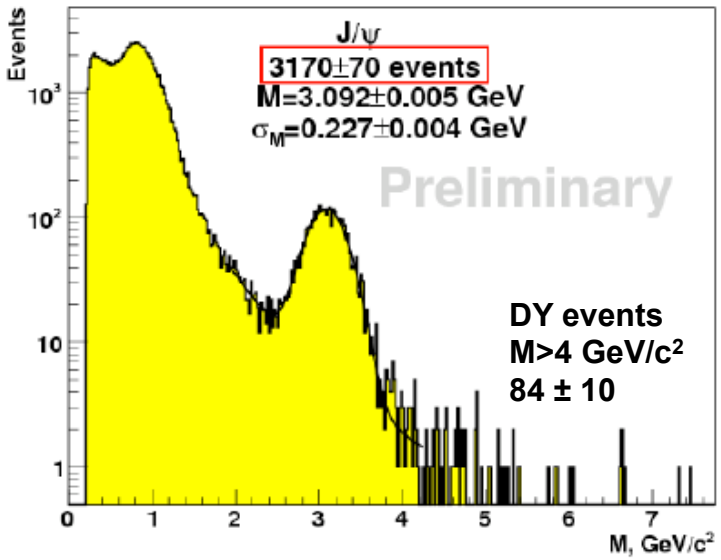
E906: test run this year

Extends E866 measurements at 120 GeV
- xsec scales as 1/s
- background scales as s.



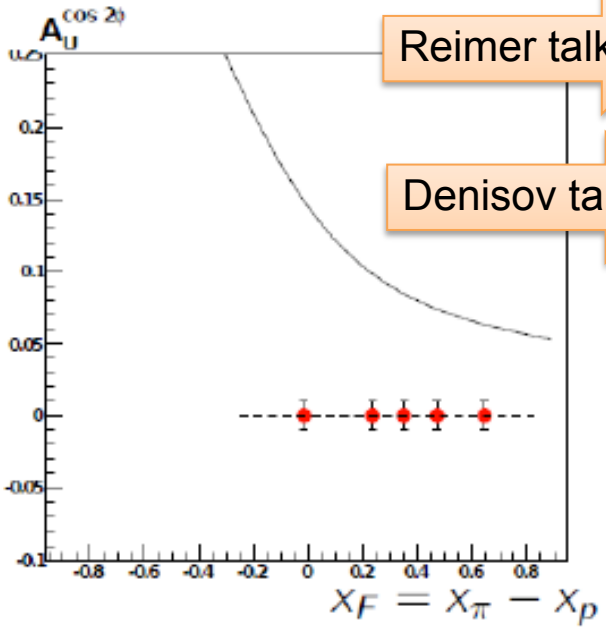
Pion beam @ CERN

2009 test

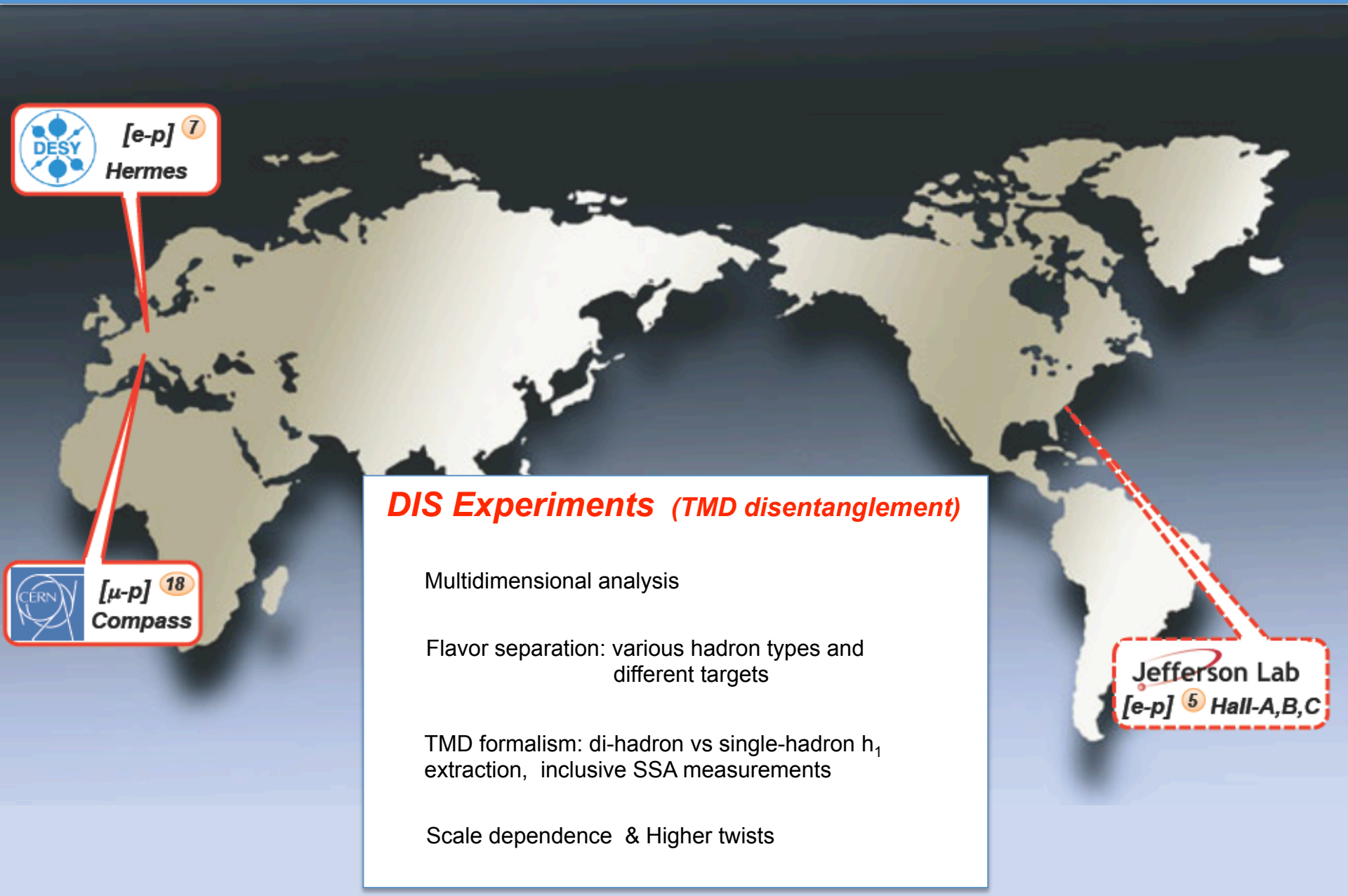


Boer-Mulders ⊗ Boer-Mulders

2 years
4 < M < 9 GeV/c²



The SIDIS Landscape



DIS Experiments (TMD disentanglement)

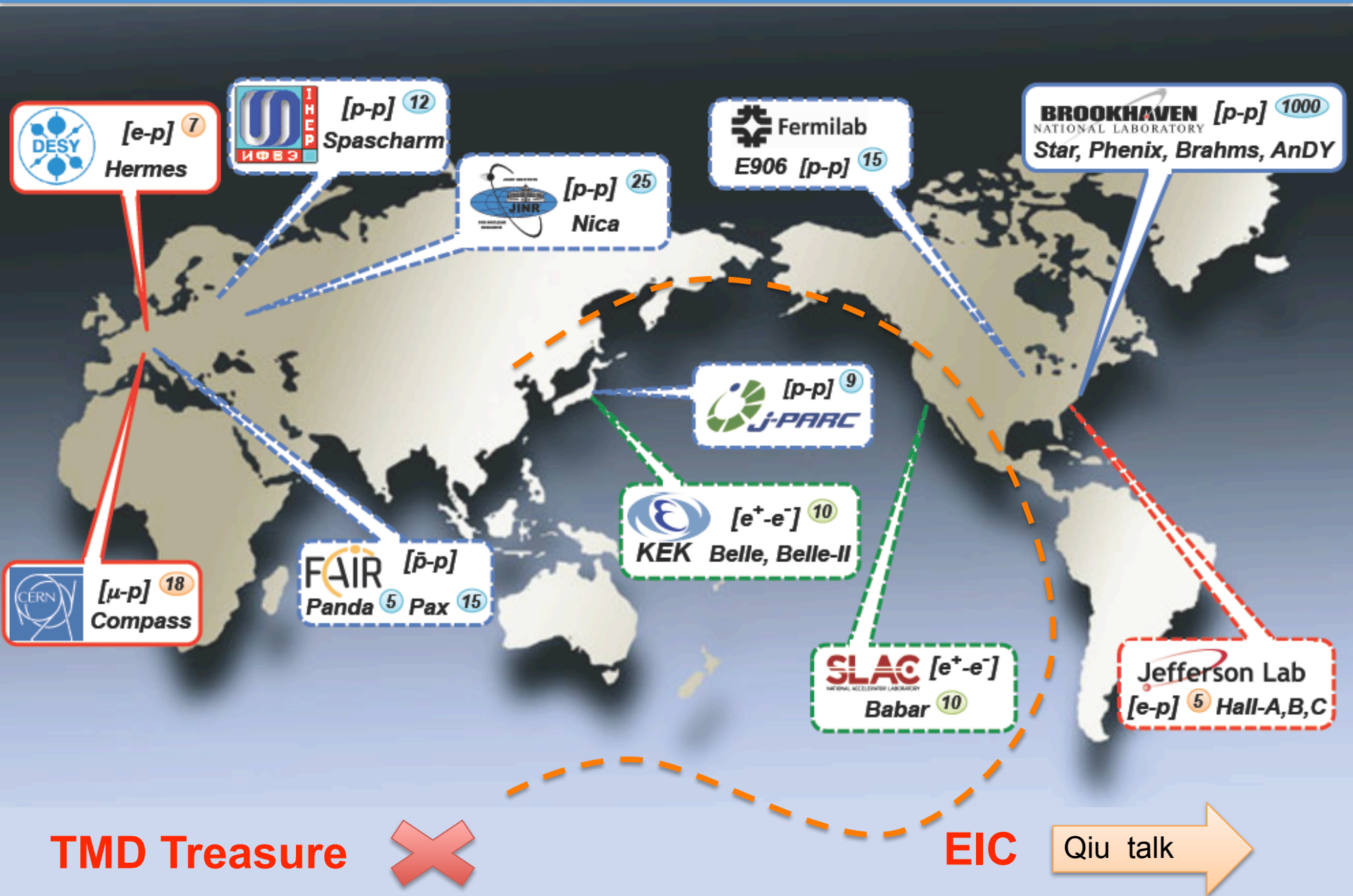
Multidimensional analysis

Flavor separation: various hadron types and different targets

TMD formalism: di-hadron vs single-hadron h_1 extraction, inclusive SSA measurements

Scale dependence & Higher twists

A World-wide Challenge



TMD Treasure ✖ **EIC**

Qiu talk