Salamanca

HADRON 2017

XVII International Conference on Hadron Spectroscopy and Structure

Experimental status of transverse nucleon structure (news & selected results)

Oleg Denisov, CERN / INFN section of Turin

Outline

Introduction

Transverse Momentum Dependent PDFs (FFs)

TMD PDFs and FFs – how to access

Unpolarised SIDIS:

- TMD multiplicities

Polarised SIDIS:

- Transversity
- Sivers function

Crucial nQCD test – T-odd TMD universality

First ever polarised Drell-Yan data

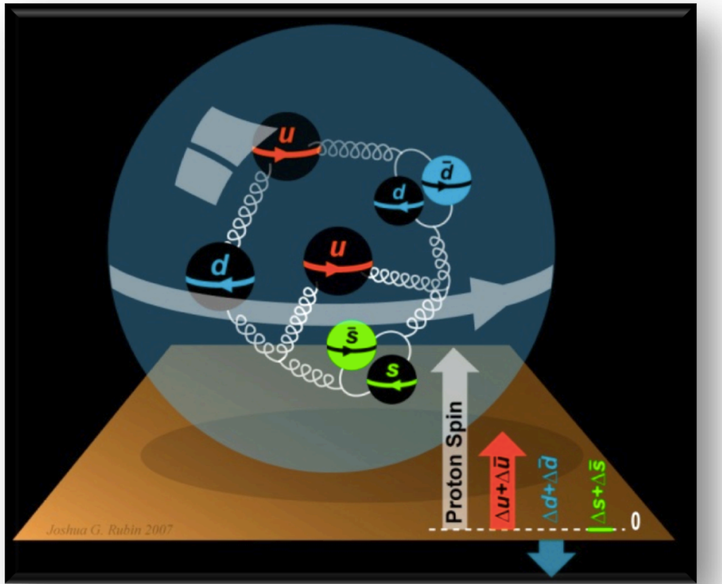
Prospectives

Summary

Introduction to the Spin I

Almost all visible matter of the universe we are able to observe consists of nucleons.

SPIN is a fundamental quantum number (Pauli principle), to some extent define a rules on how the atomic/nuclear matter is made of.

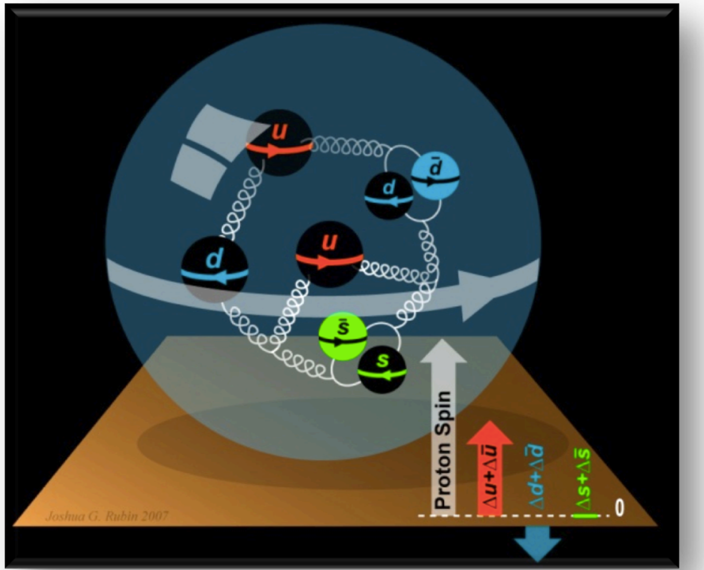


Thus we better understand well how the spin of the nucleon (and hadron in general) is "constructed".

Oleg Denisov

29-09-2017

Introduction to the Spin I



Nucleon spin ½ = ½ ΔΣ + ΔG + L

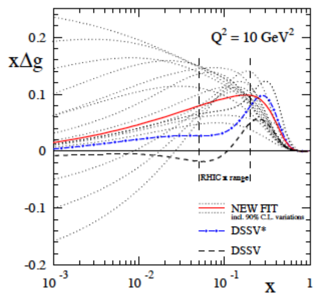
quark gluon orbital mom.

ΔΣ : sum over u, d, s, $\bar{u}$, $\bar{d}$, $\bar{s}$
Can take any value: superposition of several states

$\Delta q = \vec{q} - \overleftarrow{q}$
Parton spin parallel or anti parallel to nucleon spin

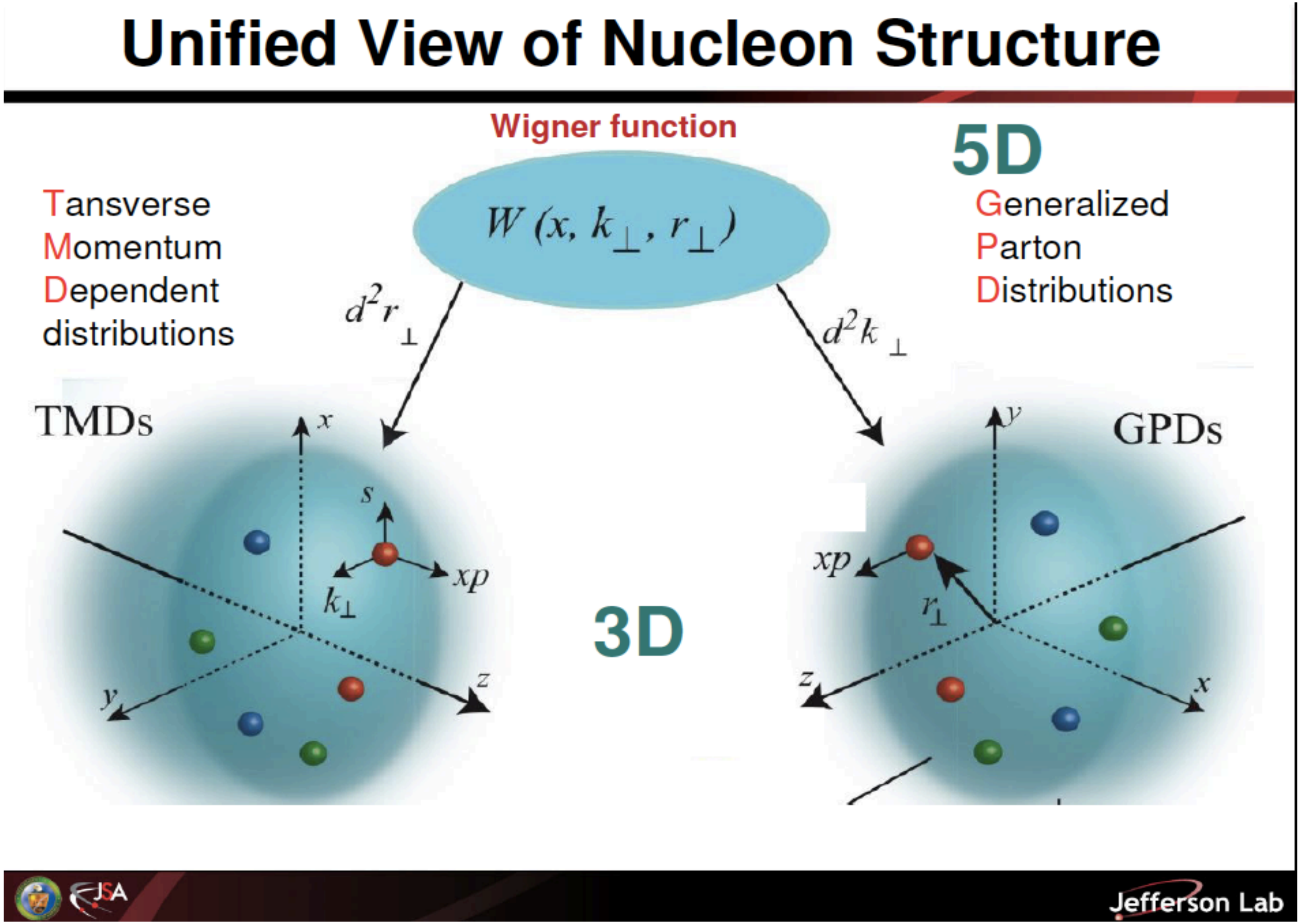
First two component were extensively studied in the SIDIS experiments with the longitudinally polarised target (collinear case approach): spin fraction carried by quarks and gluons is not sufficient to describe ½ nucleon spin (Spin Crisis, continued):

- Quark spin contribution ΔΣ=0.24 (Q^2=10 (GeV/c)^2 DSSV *arXiv:0804.0422)*
- RHIC and COMPASS Open charm measurement and other direct measurements ➔ ΔG/G is not sufficient ➔

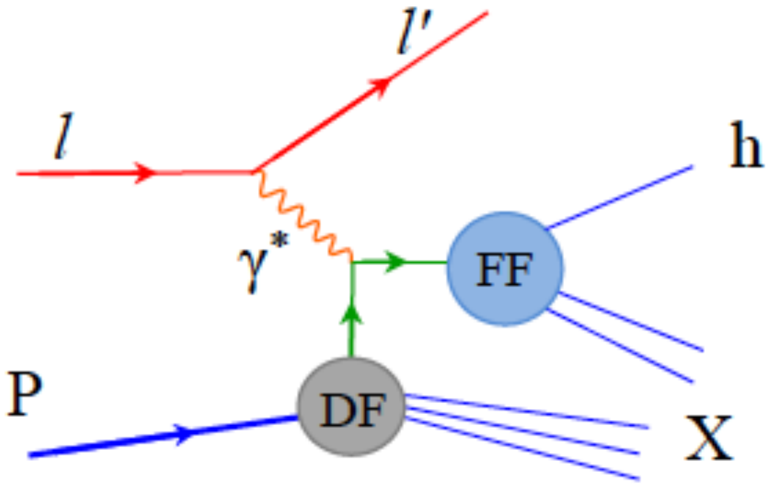


In order to create Angular Momentum of partons spin-orbit correlation has to be taken into account ➔ transverse momentum of the quark k_T appears ➔ **3D structure of the Nucleon has to be studied**

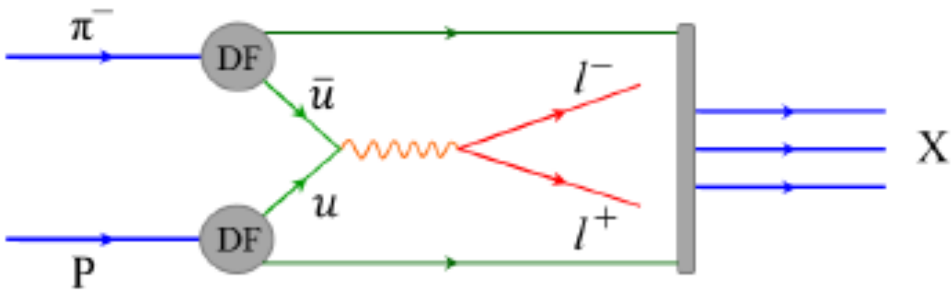
3D structure of nucleon II



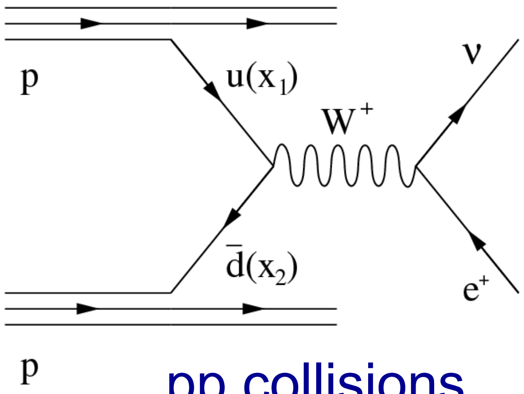
Four probes to access transverse hadron structure (TMD PDFs)



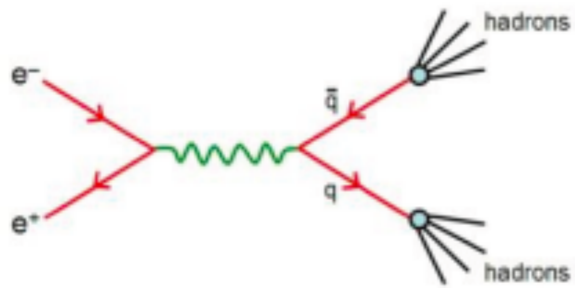
SIDIS



Drell-Yan

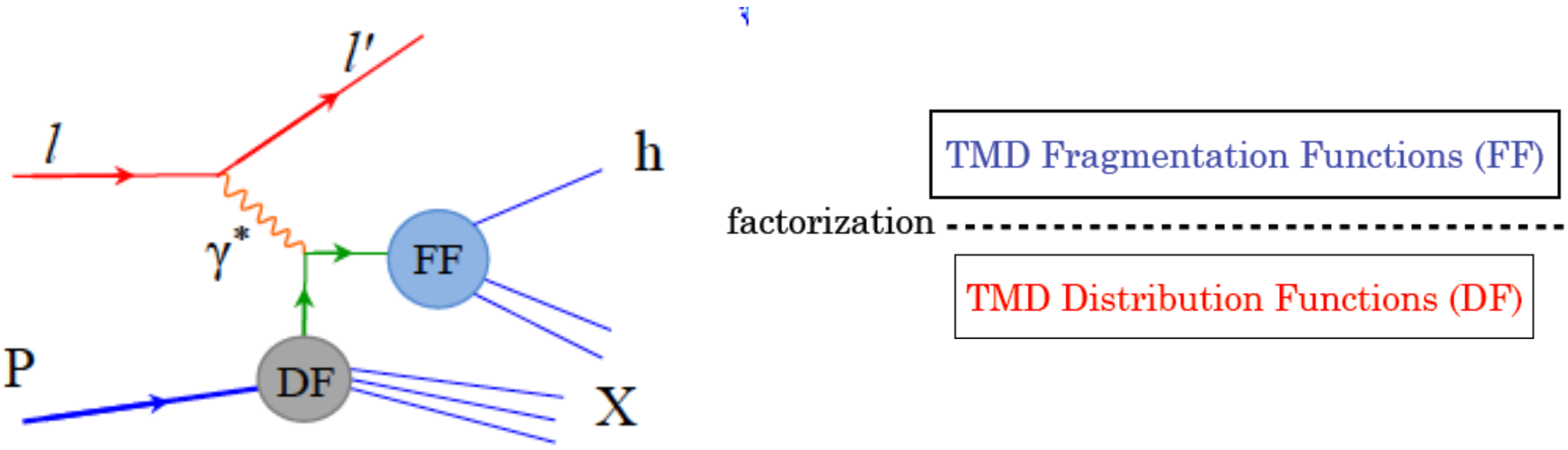


pp collisions



e^+e^- collisions

SIDIS ➔ access to TMD PDFs and FFs



$$\sigma^{\ell\, p \to \ell\, hX} = \Sigma_q \left(\mathrm{DF} \otimes \sigma^{\ell\, q \to \ell\, q} \otimes \mathrm{FF} \right)$$

(Un)polarized SIDIS process allows to probes both TMD PDFs and FFs

Unpolarised SIDIS
Access to TMD-FFs via hadron multiplicities

TMD multiplicity – ratio of hadron yields and the number of DIS events in multi-dimensional space is the most relevant experimental observable to investigate spin-averaged TMD-PDFs and TMD-FFs
^{6}LiD (deuteron) isoscalar target

$$\frac{\mathrm{d}N^h}{\mathrm{d}N^{\mathrm{DIS}}} \propto \sum_q e_q^2 q D_q^h$$

the cross-section dependence on $\boldsymbol{p_{Th}}$ comes from:

- intrinsic k_T of the quarks
- $p_\perp$ generated in the quark fragmentation

$$\left\langle \boldsymbol{p_{Th}}^2 \right\rangle = \left\langle p_\perp^2 \right\rangle + \boldsymbol{z}^2 \left\langle k_T^2 \right\rangle$$

The small P^2_{hT} region (< 1 (GeV/c)^2) - hadron transverse momenta are expected to arise from non-perturbative effects
Larger P^2_{hT}, - contributions from higher-order perturbative QCD are expected to dominate.

NEW!! TMD hadron multiplicities in SIDIS (multidimensional (x, Q^2, z, P_{hT}^2) space) COMPASS ^{6}LiD (deuteron) isoscalar target

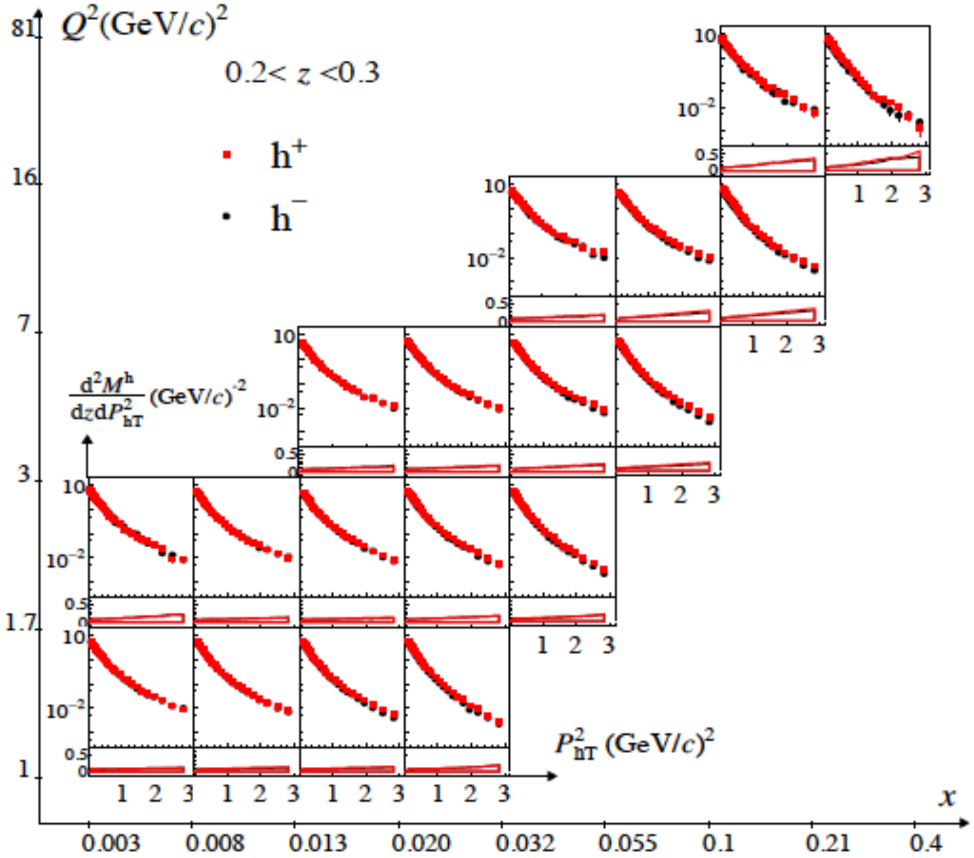
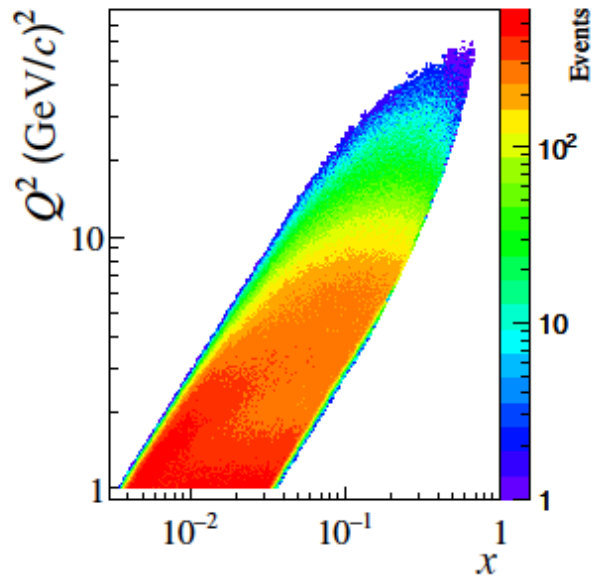


Fig. 5: Multiplicities of positively (full squares) and negatively (full circles) charged hadrons as a function of P_{hT}^2 in (x, Q^2) bins for $0.2 < z < 0.3$. Error bars on the points correspond to the statistical uncertainties. The systematic uncertainties (σ_{sys}/M^h) are shown as bands at the bottom.

COMPASS:
arXiv:1709.07374v1



NEW!! TMD hadron multiplicities in SIDIS
(multidimensional (x, Q^2, z, P^2_{hT}) space)
COMPASS ^{6}LiD (deuteron) isoscalar target

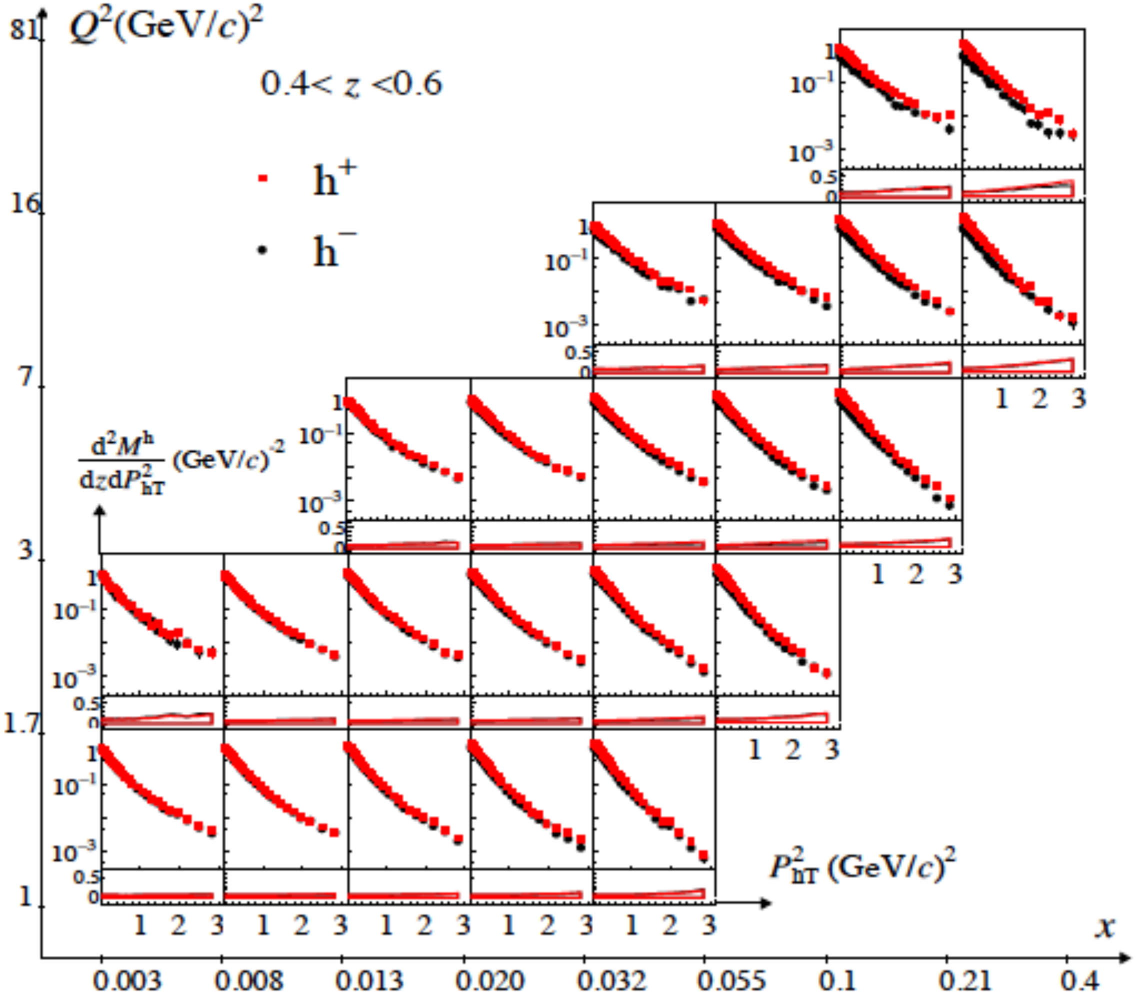
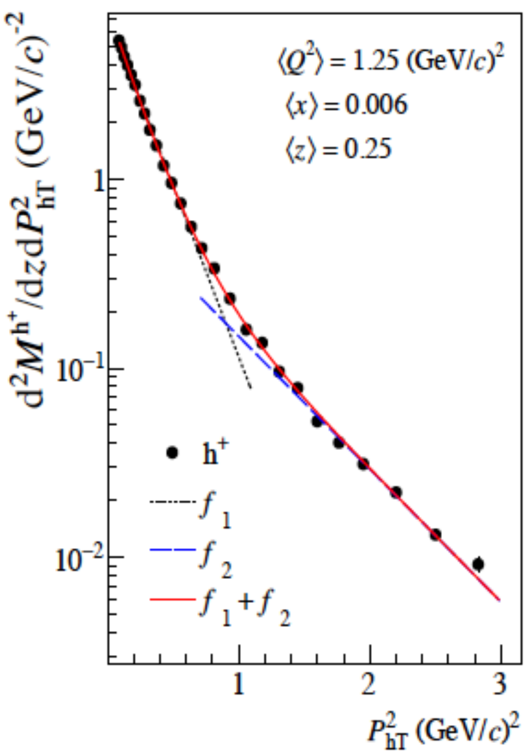


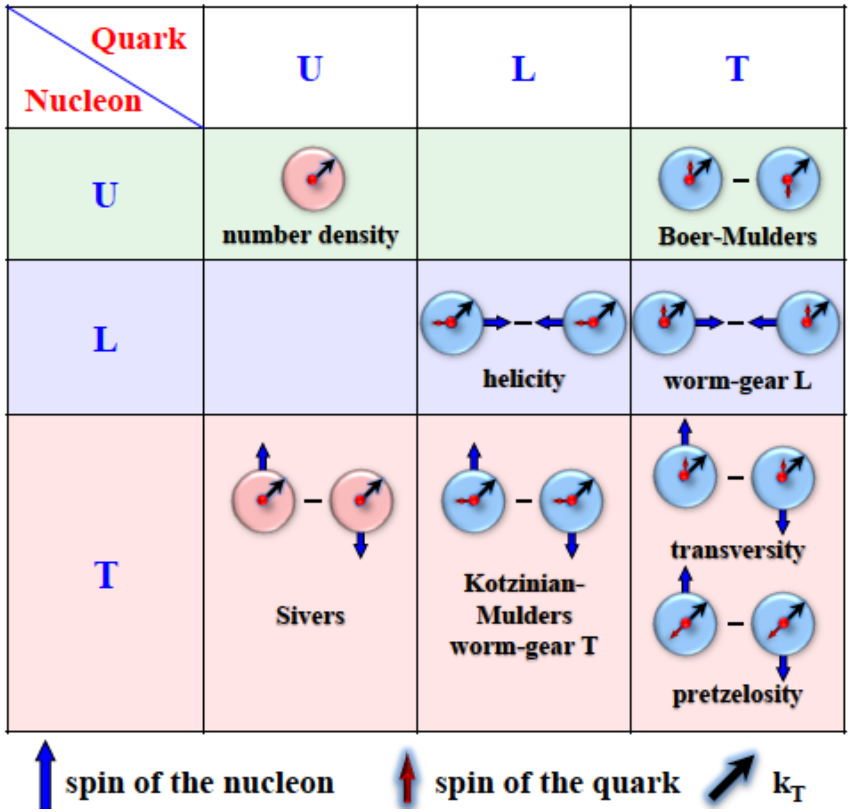
Fig. 7: Same as Fig. 5 for $0.4 < z < 0.6$.



total:
4918 data points

Leading Order (TMD) PDFs
Polarised SIDIS

At leading order, three PDFs are needed to describe the nucleon in the collinear case.
If one admit a non-zero transverse quark momentum k_T in the nucleon five more PDFs (TMD PDFs) are needed.

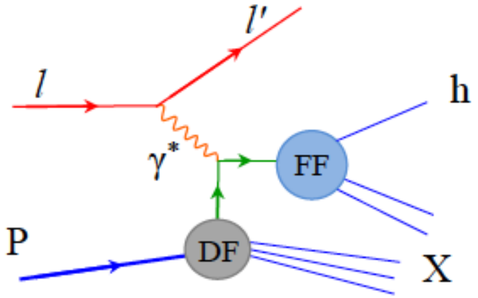


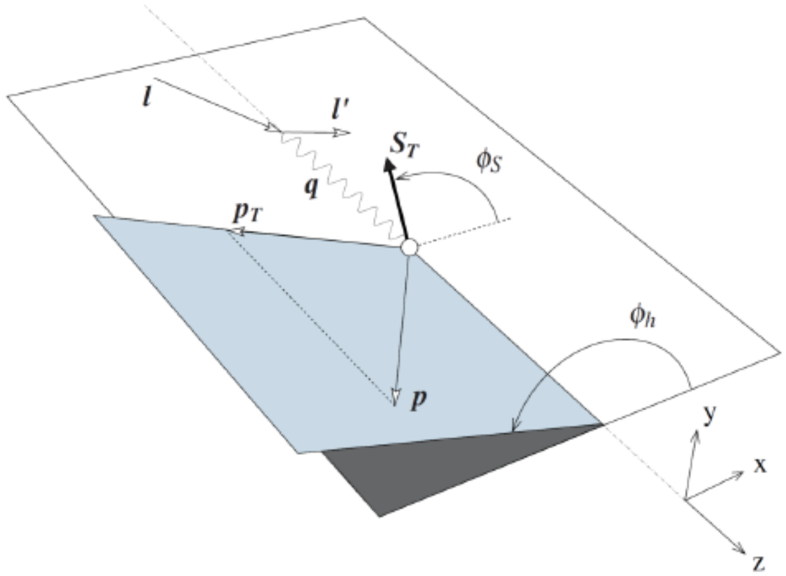
In this talk dedicated attention to two non zero structure functions:
- Transversity $h^1(x)$ (similar the helicity distribution $g^1(x)$) describing the difference between the number densities of quarks with spin parallel and anti-parallel to the spin of the transversely polarised parent hadron
- Sivers function $f^{L}_{1T}(x, k_T)$ describes the influence of the transverse spin of the nucleon onto the quark transverse momentum distribution

SIDIS → 18 structure functions, 14 azimuthal modulations

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right](F_{UU,T}+\varepsilon F_{UU,L})$$

$$\times\Big\{1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h$$
$$+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h$$
$$+S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right]$$
$$+S_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right]$$
$$+S_T\left[\begin{array}{l}A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)\\+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)\\+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)\\+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S\\+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\end{array}\right]$$
$$+S_T\lambda\left[\begin{array}{l}\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)\\+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S\\+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\end{array}\right]\Big\}$$





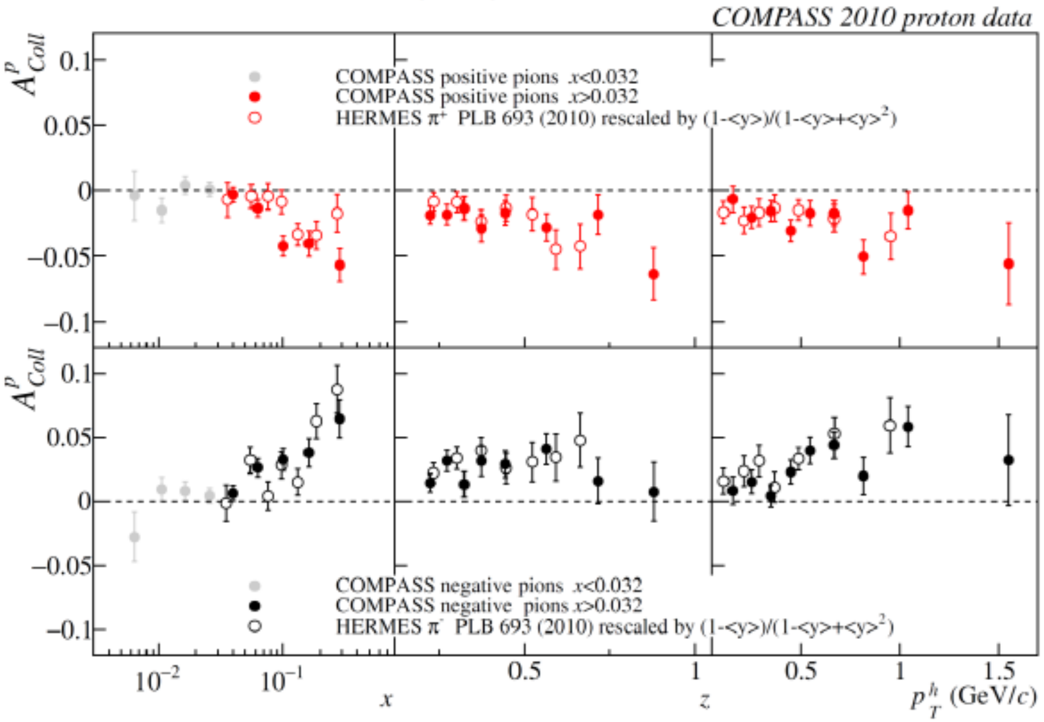
$$A_{U(L),T}^{w(\varphi_h,\varphi_s)}=\frac{F_{U(L),T}^{w(\varphi_h,\varphi_s)}}{F_{UU,T}+\varepsilon F_{UU,L}};\quad \varepsilon=\frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2},\quad \gamma=\frac{2Mx}{Q}$$

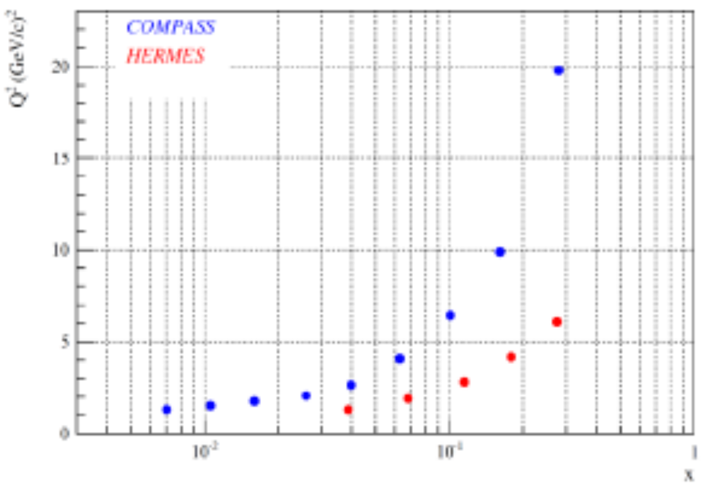
Collins asymmetry (transvesrsity)
zero knowledge ~10 years ago
First seen non zero asymmetry by HERMES on p in 2004

COMPASS:
- Measured on p/D in SIDIS and in di-hadron SIDIS
- Compatible results COMPASS/HERMES
- No (or very slow) QCD evolution? Very intriguing result!

$$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$$

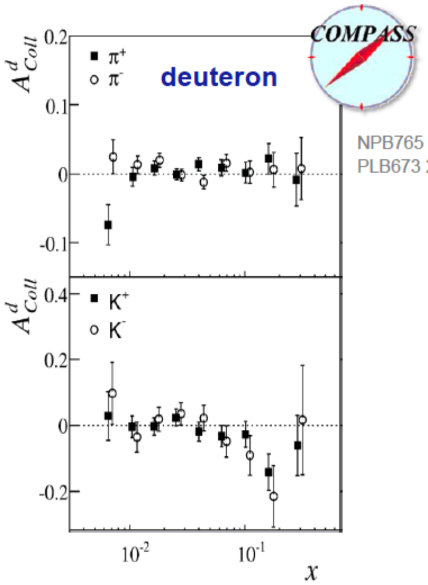
COMPASS PLB 744 (2015) 250



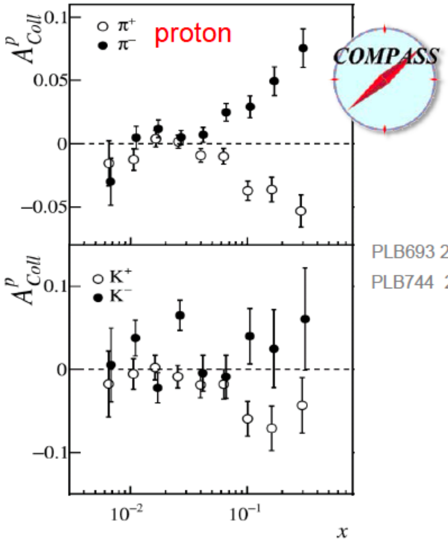


Collins asymmetry (transvesrsity)
Deuteron data – flavour separation possible

COMPASS:



NPB765 2007
PLB673 2009

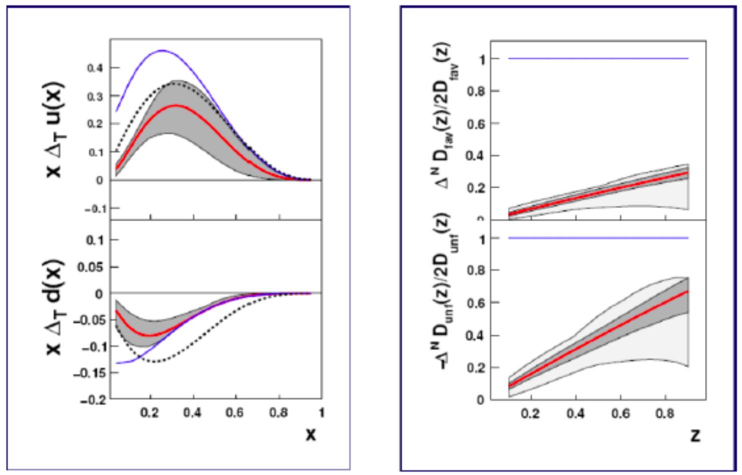


PLB693 2010
PLB744 2015

Flavour dependent

M. Anselmino et al., Nucl. Phys. Proc. Suppl. 2009

fit to HERMES p, COMPASS d, Belle e+e- data



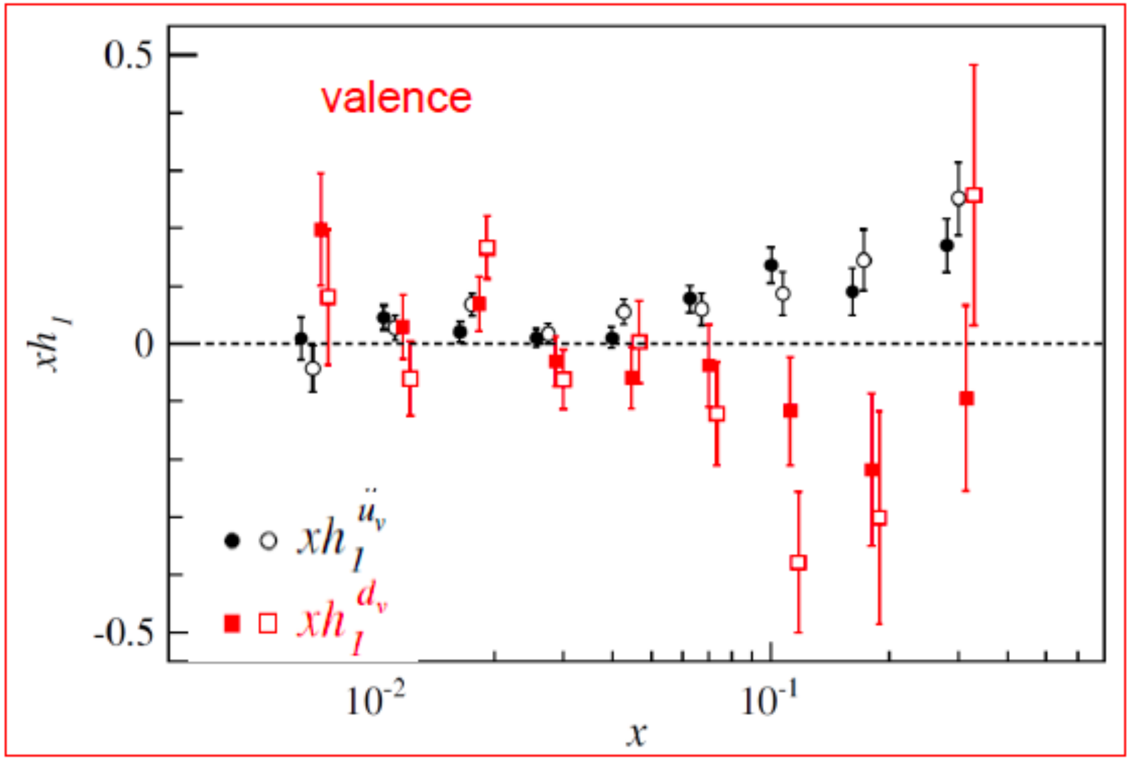
Reasonably well constrained using Belle & Hermes & COMPASS data

NEW!! Collins and di-hadron production asymmetry (transversity extraction)

point by point extraction

one can use directly the COMPASS p and d asymmetries,
and the Belle data to evaluate the analysing power
(with some "reasonable" assumptions)

advantage: no MC nor parametrisation is needed



open points: dihadron

closed points: Collins

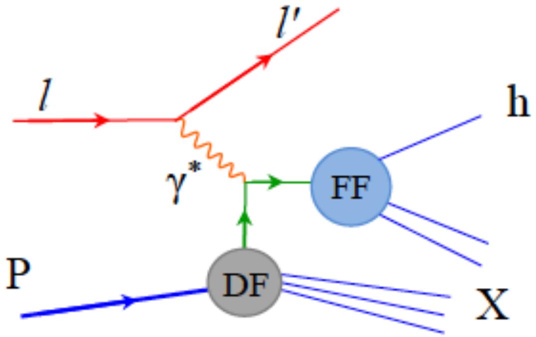
large uncertainties on the d distribution due to the poor deuteron/neutron data

A. Martin F. B. V. Barone PRD91 2015

SIDIS → **18 structure functions**
14 azimuthal modulations

$$\frac{d\sigma}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right]\left(F_{UU,T}+\varepsilon F_{UU,L}\right)$$

$$\times\left\{\begin{array}{l}
1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\
+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\
+S_L\left[\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right] \\
+S_L\lambda\left[\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right] \\
+S_T\left[\begin{array}{l}
A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S) \\
+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S) \\
+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S) \\
+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S \\
+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)
\end{array}\right] \\
+S_T\lambda\left[\begin{array}{l}
\sqrt{(1-\varepsilon^2)}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S) \\
+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S \\
+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)
\end{array}\right]
\end{array}\right\}$$



Quark / Nucleon	U	L	T
U	$f_1^q(x,\boldsymbol{k}_T^2)$ number density		$h_1^{\perp q}(x,\boldsymbol{k}_T^2)$ Boer-Mulders
L		$g_1^q(x,\boldsymbol{k}_T^2)$ helicity	$h_{1L}^{\perp q}(x,\boldsymbol{k}_T^2)$ worm-gear L
T	$f_{1T}^{\perp q}(x,\boldsymbol{k}_T^2)$ Sivers	$g_{1T}^q(x,\boldsymbol{k}_T^2)$ Kotzinian-Mulders worm-gear T	$h_1^q(x,\boldsymbol{k}_T^2)$ transversity $h_{1T}^{\perp q}(x,\boldsymbol{k}_T^2)$ pretzelosity

+ two FFs: $D_{1q}^h(z,P_\perp^2)$ and $H_{1q}^{\perp h}(z,P_\perp^2)$

Sivers asymmetry: first round (earlier 2000):
Sivers 2004 – first Hermes data at proton – non zero asymmetry, COMPASS at deuteron - zero

COMPASS Results of 2005

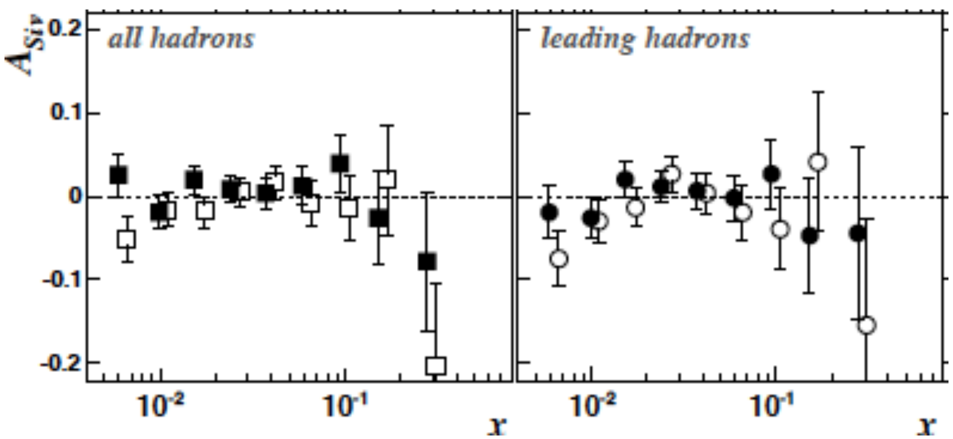
Hep-ex/0503002

Solid state ^{6}LD polarised target

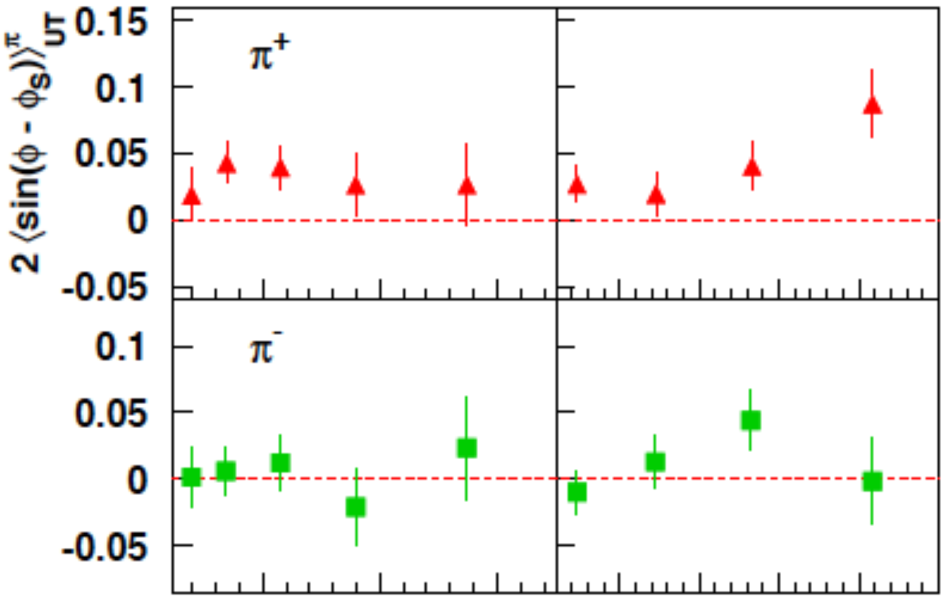
Hermes Results of 2004

hep-ph/0408013

Gaseous H_2 polarized target



Full points – positive hadrons,
Open points – negative hadrons

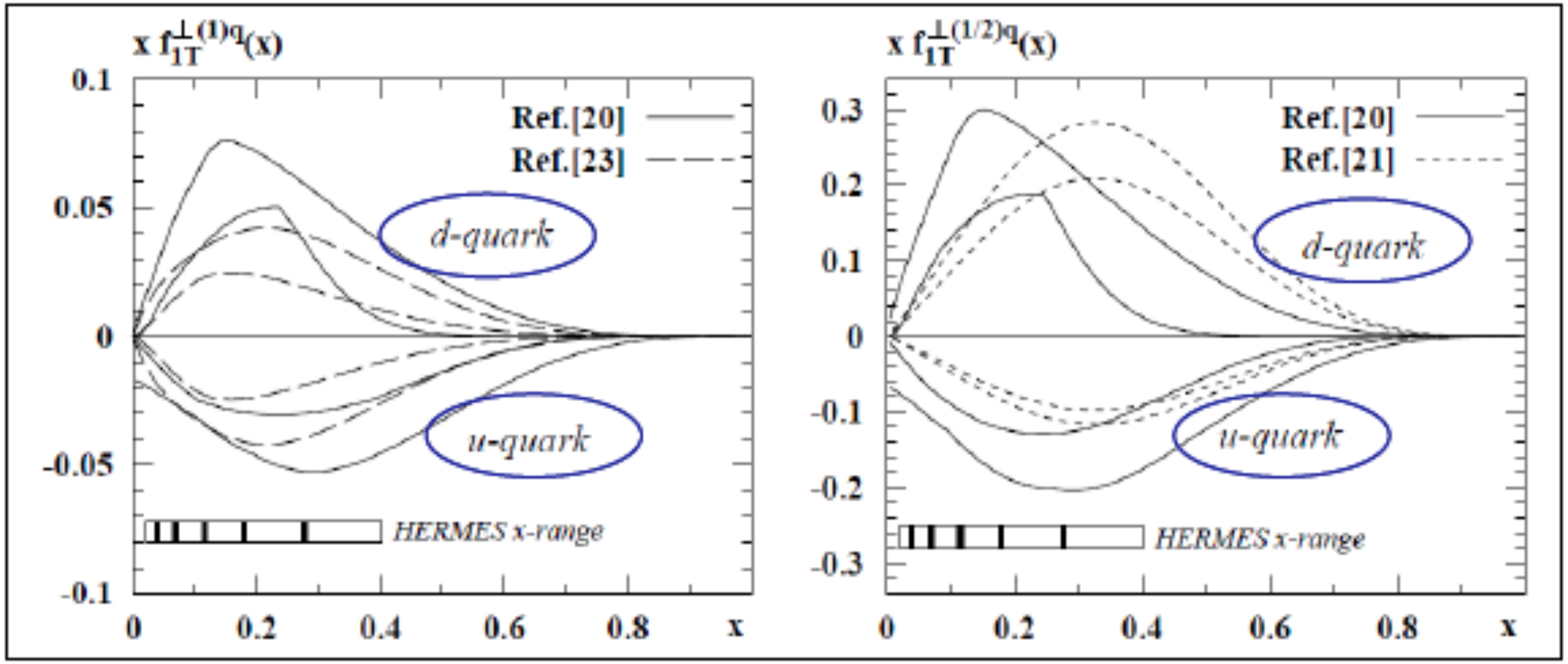


DOUBTS…..

$$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$$

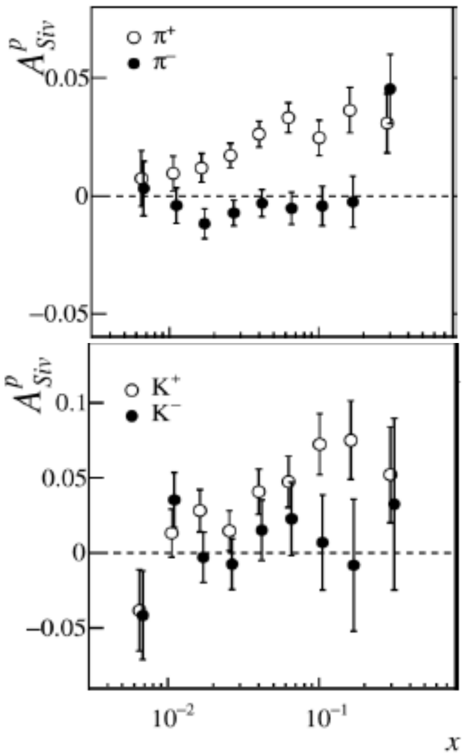
Joint data analysis form Hermes and COMPASS – no contradictions

As it was shown by Mauro Anselmino and Colleagues (second half of 2005) when first extraction of Sivers function has been performed from Hermes and COMPASS data (Transversity'2005, hep-ph/051101)) that the contributions from u- and d-quarks are opposite

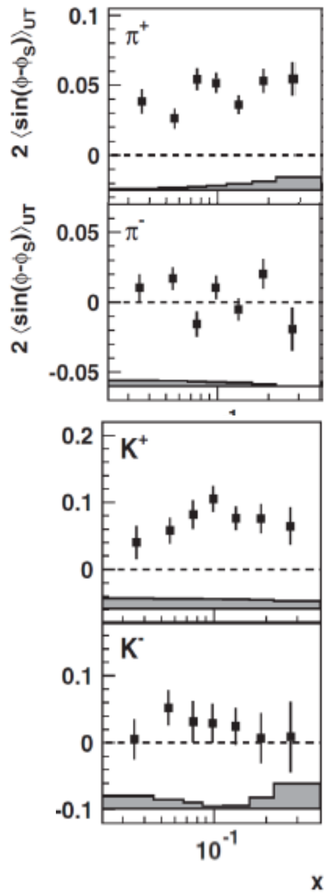


Second round:
COMPASS ←→ Hermes proton data

COMPASS final results on proton (data 2007, 2010) PLB 744 (2015)

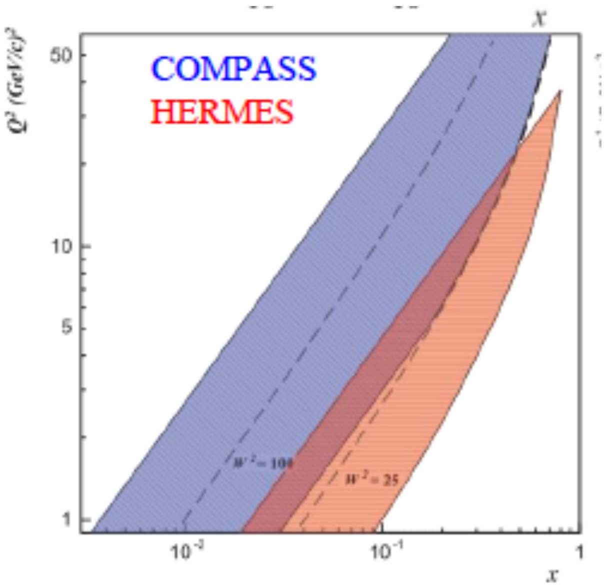


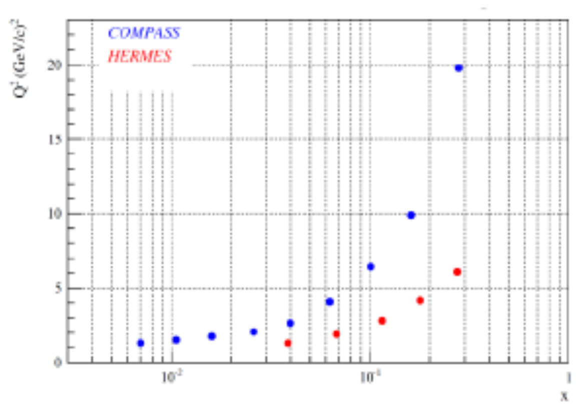
Hermes Final results on proton PRL 103 (2009)

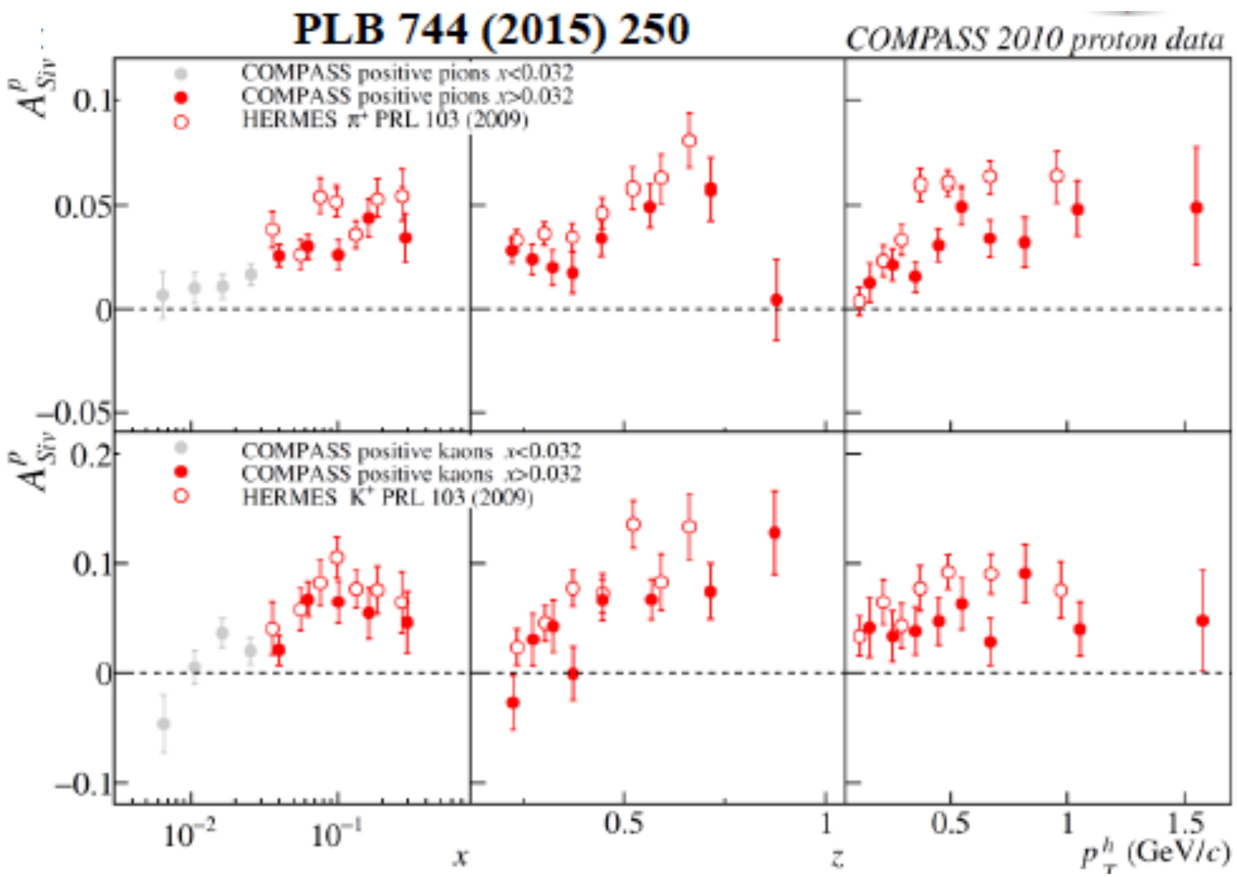


COMPASS ←→Hermes proton data
COMPASS Sivers is smaller – QCD evolution eff.?

Even if exist evolution has to be rather slow







TMDs universality SIDIS←→DY

The time-reversal odd character of the Sivers and Boer-Mulders PDFs lead to the prediction of a sign change when accessed from SIDIS or from Drell-Yan processes:

↪ Check the predictions:

$$f_{1T}^{\perp}(DY) = -f_{1T}^{\perp}(SIDIS)$$

$$h_1^{\perp}(DY) = -h_1^{\perp}(SIDIS)$$

Its experimental confirmation is considered a crucial test of non-perturbative QCD.

Universality test includes not only the sing-reversal character of the TMDs but also the comparison of the amplitude as well as the shape of the corresponding TMDs

SIDIS←→DY – QCD test

Andreas Metz (Trento-TMD'2010):

Sign reversal of the Sivers function

- Prediction based on operator definition (Collins, 2002)

$$f_{1T}^{\perp}\big|_{DY} = -\, f_{1T}^{\perp}\big|_{DIS}$$

- What if sign reversal of $f_{1T}^{\perp}$ is not confirmed by experiment ?
  - Would not imply that QCD is wrong
  - Would imply that SSAs not understood in QCD
  - Problem with TMD-factorization
  - Problem with resummation of large logarithms

  → Resummation relevant if more than one scale present

  → CSS resummation in Drell-Yan (Collins, Soper, Sterman, 1985); resum logarithms of the type

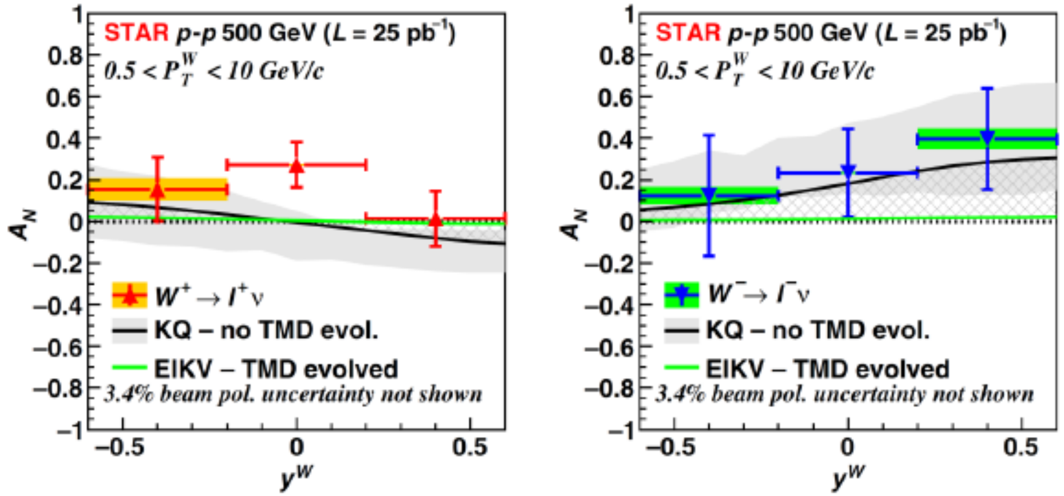
$$\alpha_s^k \ln^{2k} \frac{\vec{Q}_T^2}{Q^2}$$

  → Has also implications for Fermilab and LHC physics

Sivers in SIDIS and pp collisions

Very important STAR (RHIC) result:
- First experimental investigation of Sivers-non-universality in pp collision (W/Z production)
- Very different hard scale (Q^2) compared to the available SIDIS (FT) data
- QCD evolution effects may play a substantial role

STAR collaboration: **PRL 116, 132301 (2016)**



P. Sun and F. Yuan, **PRD 88 11, 114012 (2013)**

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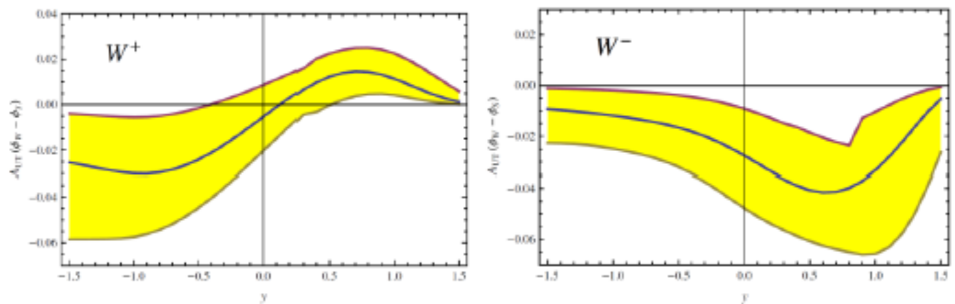
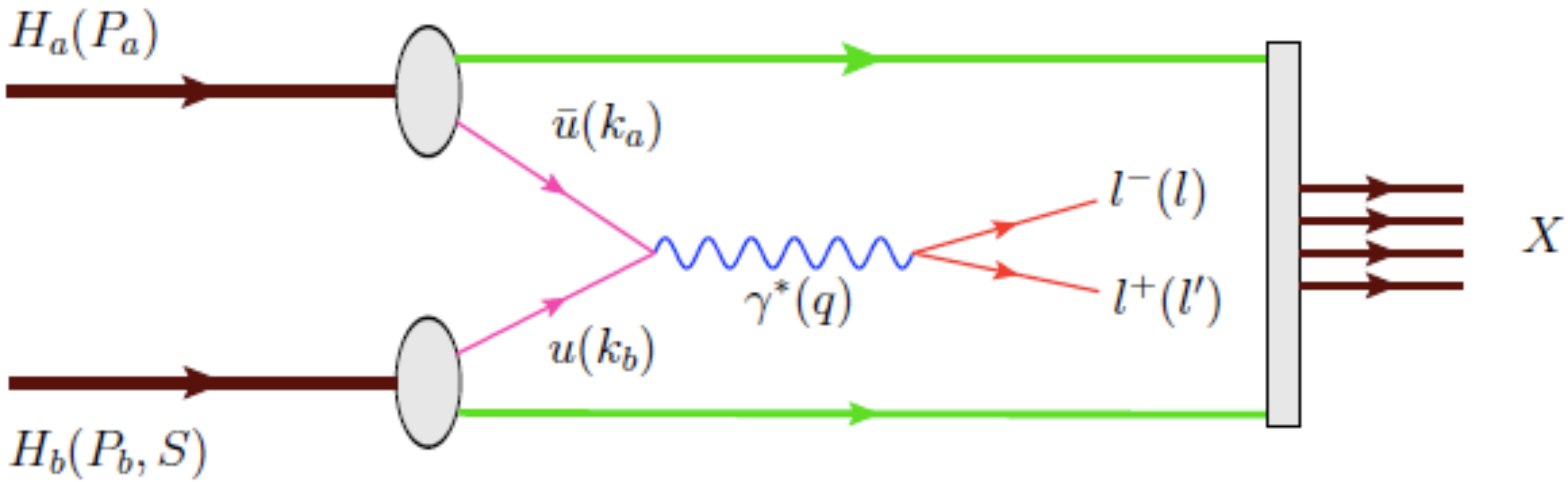


Drell-Yan process



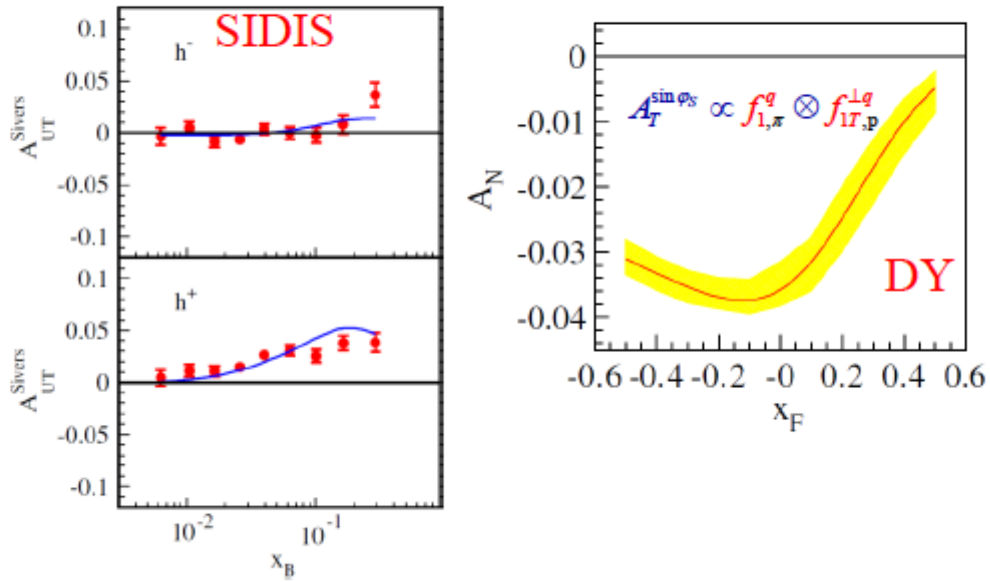
$P_{a(b)}$	the momentum of the beam (target) hadron,
$s = (P_a + P_b)^2,$	the total centre-of-mass energy squared,
$x_{a(b)} = q^2/(2P_{a(b)} \cdot q),$	the momentum fraction carried by a parton from $H_{a(b)}$,
$x_F = x_a - x_b,$	the Feynman variable,
$M_{\mu\mu}^2 = Q^2 = q^2 = s\ x_a\ x_b,$	the invariant mass squared of the dimuon,
$\mathbf{k}_{Ta(b)}$	the transverse component of the quark momentum,
$\mathbf{q}_T = \mathbf{P}_T = \mathbf{k}_{Ta} + \mathbf{k}_{Tb}$	the transverse component of the momentum of the virtual photon.

Sivers in SIDIS and Drell-Yan

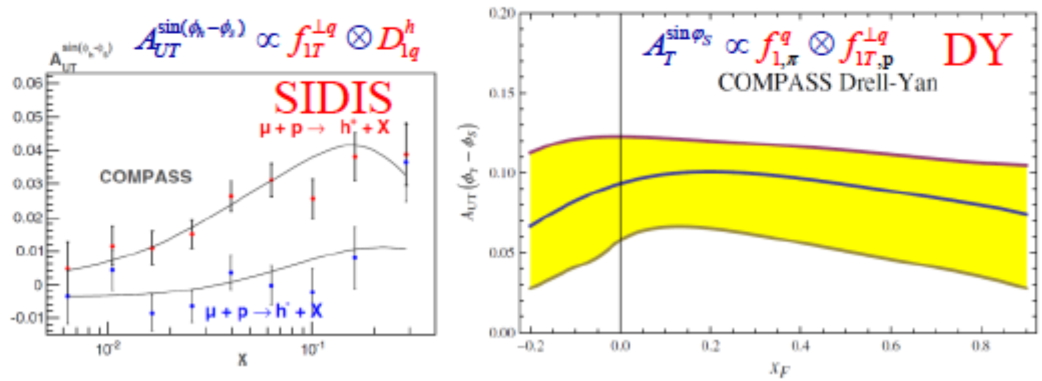
SIDIS data:
- Global fits of available 1-D SIDIS data
- Different TMD evolution schemes
- Different predictions for Drell-Yan

- Extremely important to extract Sivers in SIDIS in Drell-Yan Q^2 range

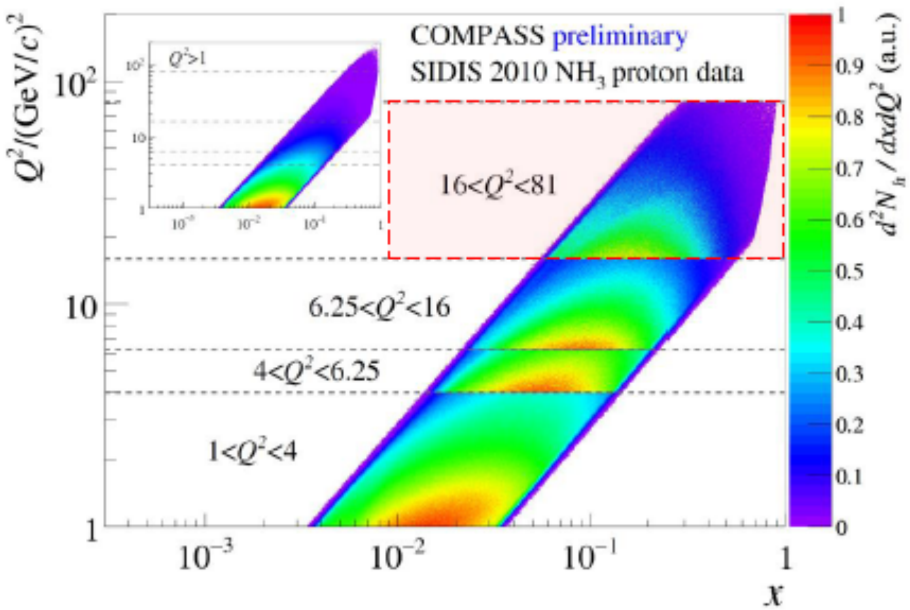
M.G. Echevarria, A.Idilbi, Z.B. Kang and I. Vitev, **PRD 89 074013 (2014)**

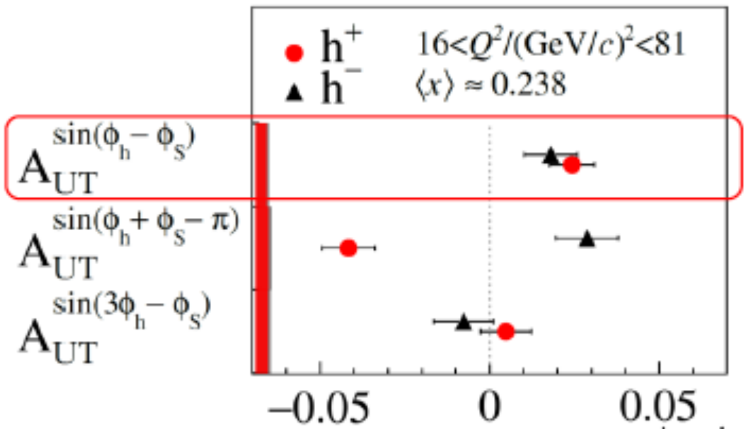


P. Sun and F. Yuan, **PRD 88 11, 114012 (2013)**



NEW!! Sivers in SIDIS in Drell-Yan kinematic range





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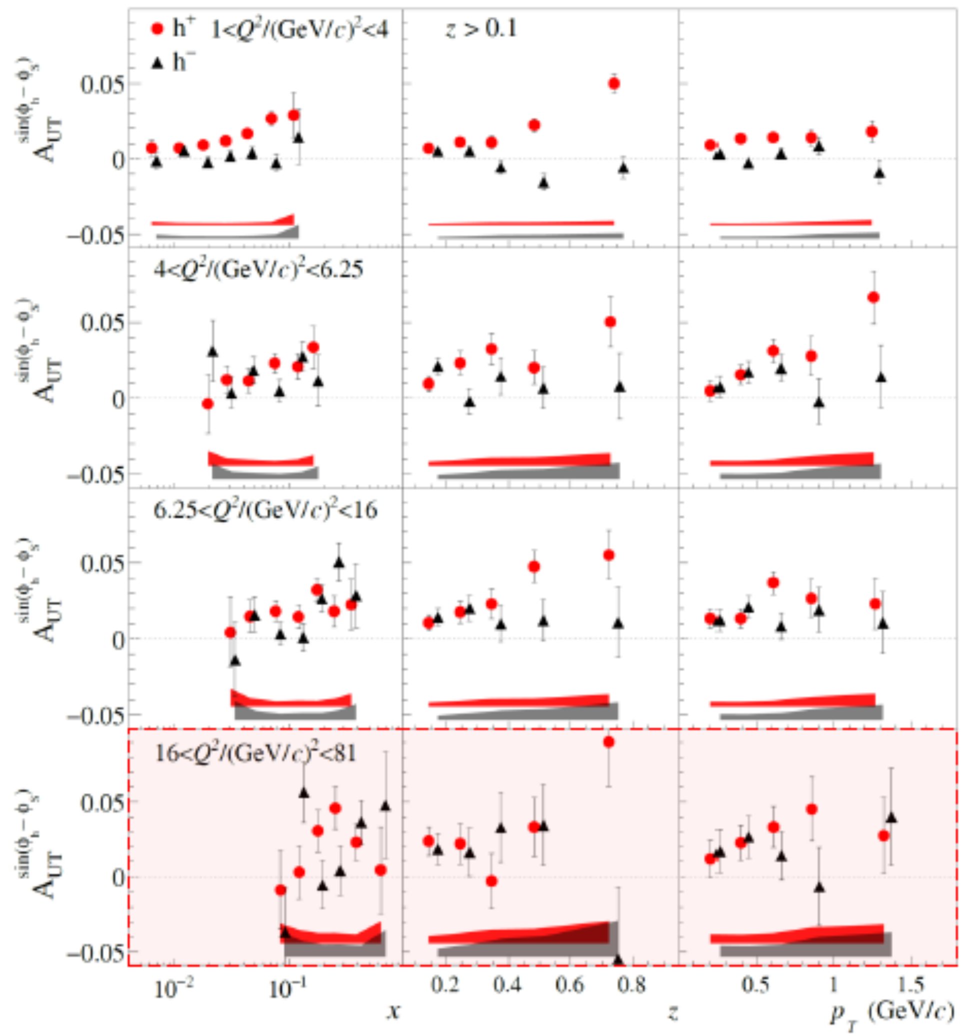
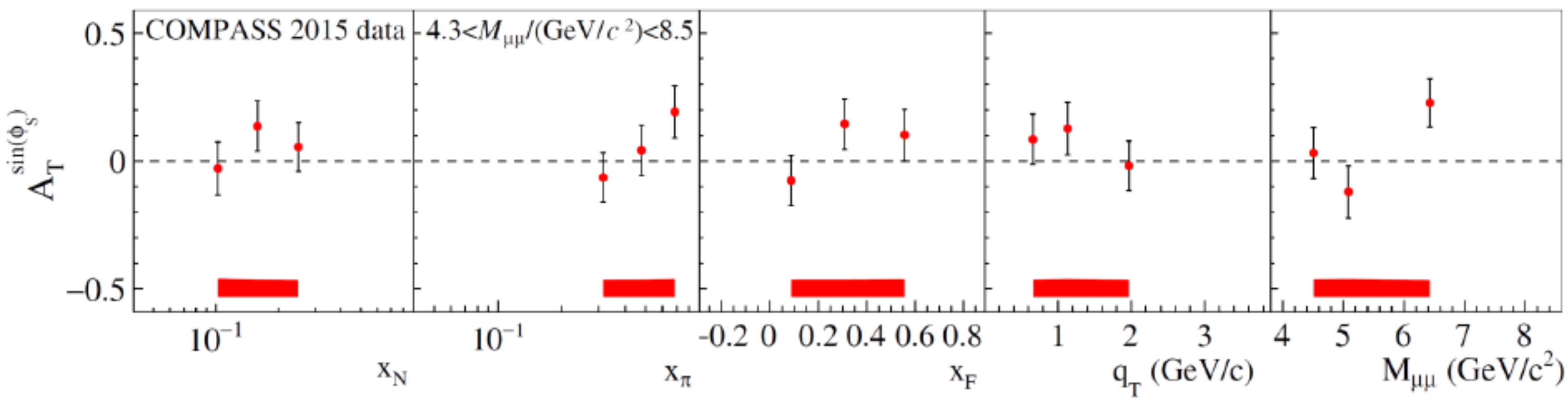


NEW!! First ever polarised DY
Sivers in Drell-Yan

New! COMPASS Phys.Rev.Lett. 119 (2017) no.11, 112002

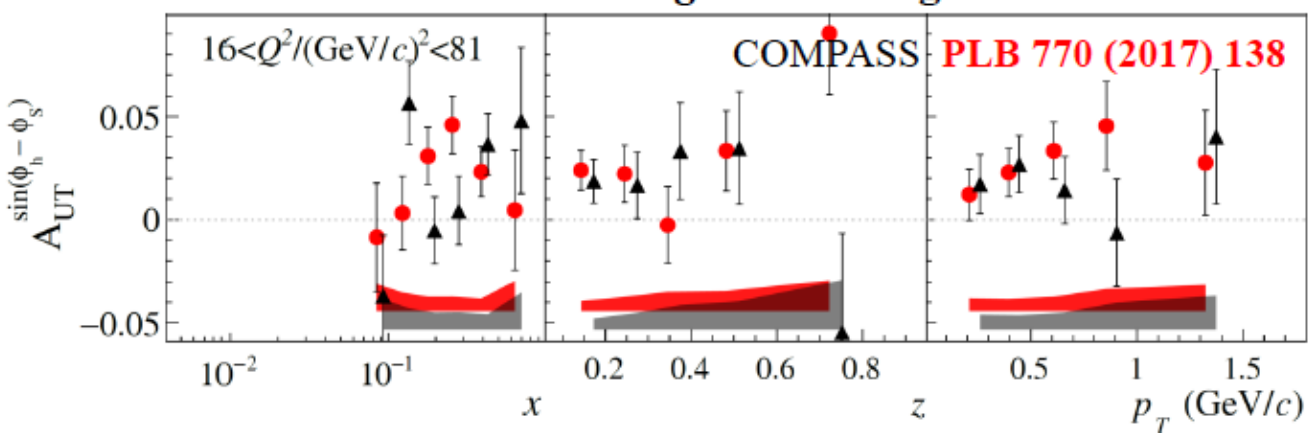
$A_T^{\sin\varphi_S} \propto f_{1,\pi}^q \otimes f_{1T,p}^{\perp q}$



Sivers SIDIS TSA

$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^h$

SIDIS in Drell-Yan *high-mass* range

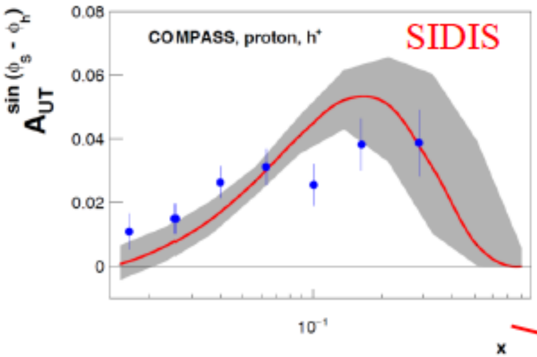


Oleg Denisov

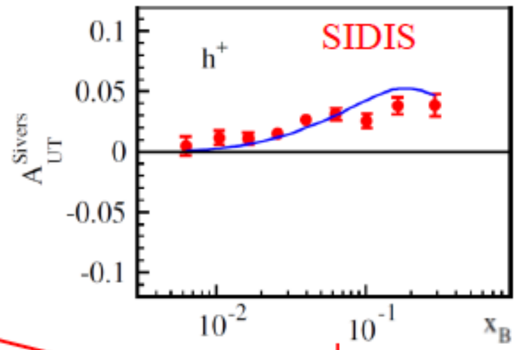
NEW!! First ever polarised DY

Sivers in Drell-Yan

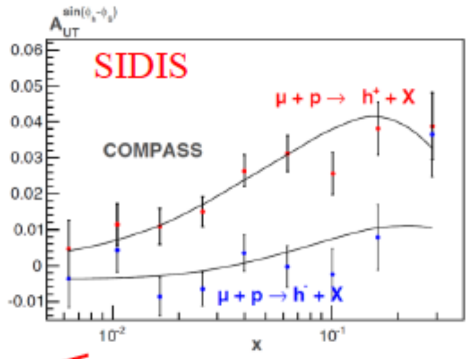
DGLAP (2016)
M. Anselmino et al., **arXiv:1612.06413**



TMD-1 (2014)
M. G. Echevarria et al. **PRD89,074013**

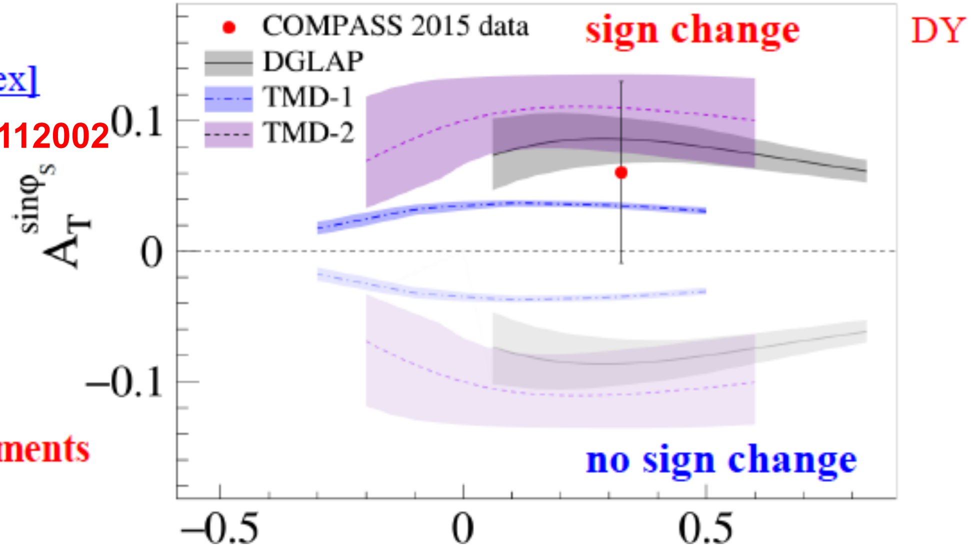


TMD-2 (2013)
P. Sun, F. Yuan, **PRD88, 114012**



New! COMPASS
[CERN-EP-2017-059]
[arXiv:1704.00488[hep-ex]]

Phys.Rev.Lett. 119 (2017) no.11, 112002

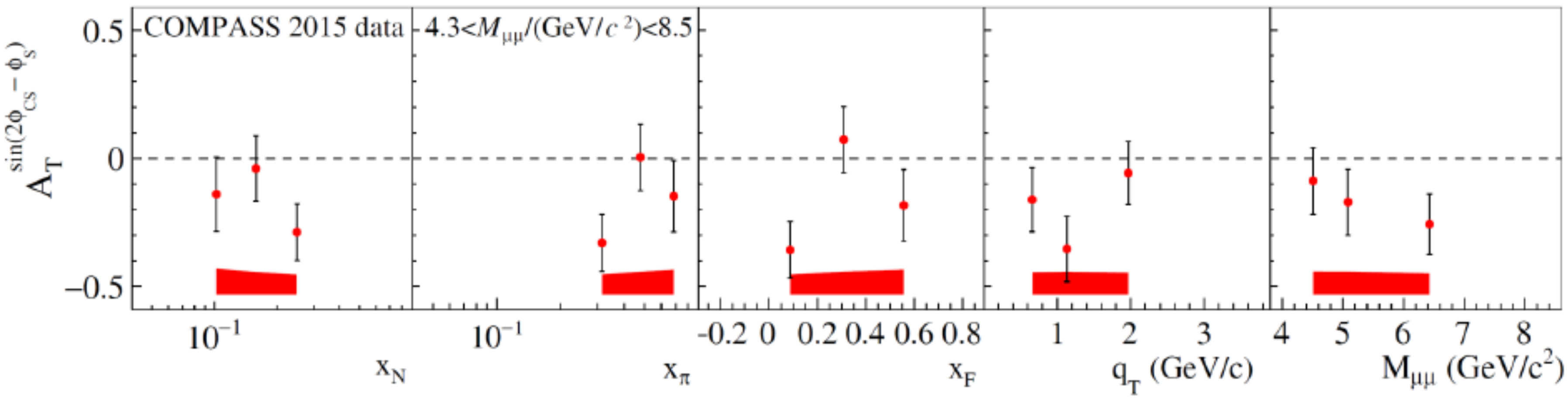


In 2018 – 2nd round of polarized DY measurements at COMPASS

NEW!! First ever polarised DY
Transversity in Drell-Yan

New! COMPASS Phys.Rev.Lett. 119 (2017) no.11, 112002

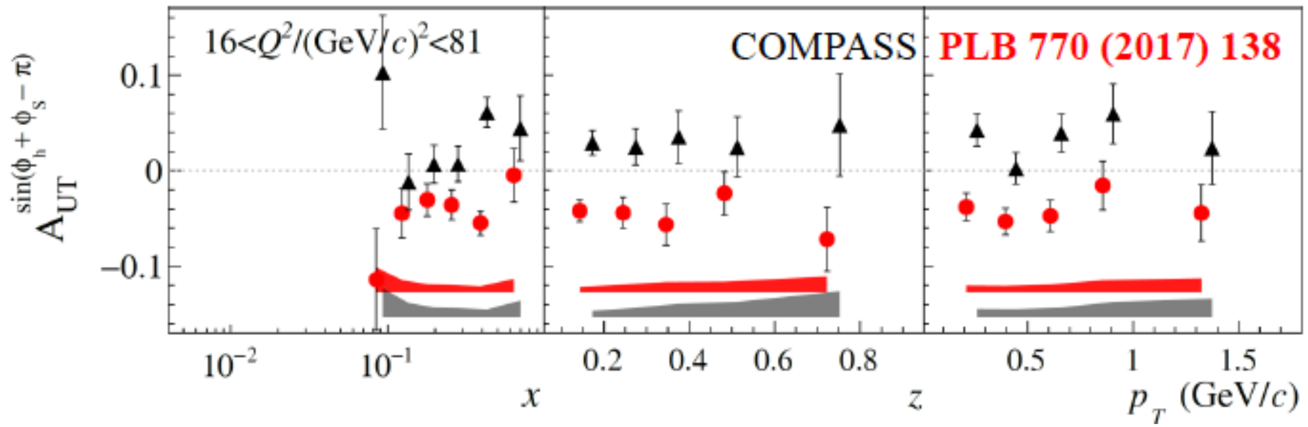
$A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$



SIDIS in Drell-Yan *high-mass* range

Collins SIDIS TSA

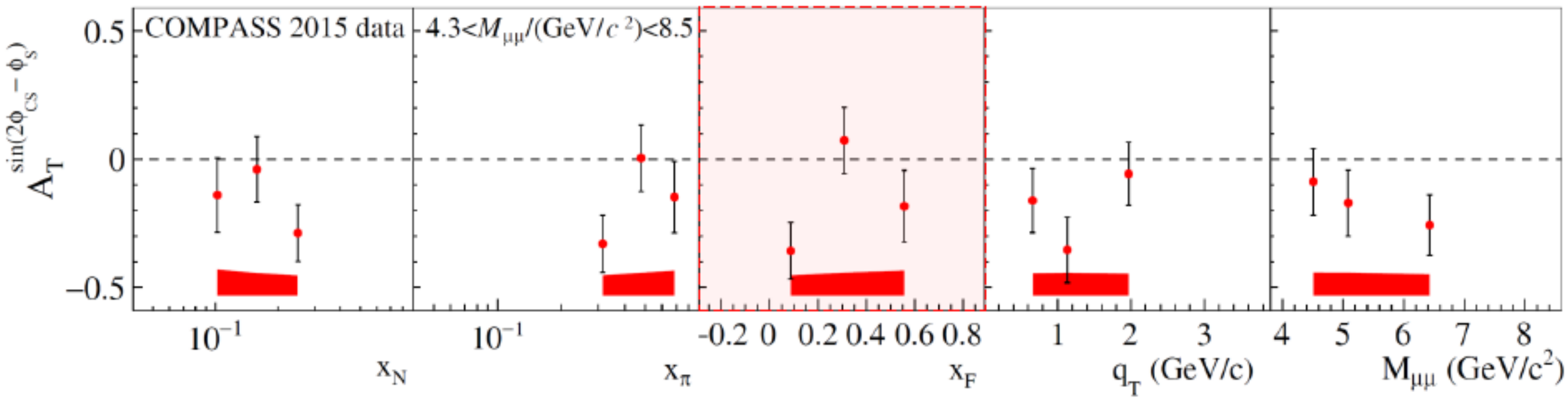
$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$

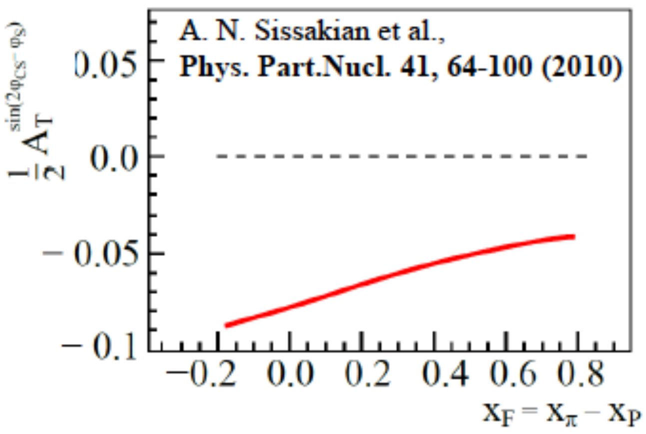


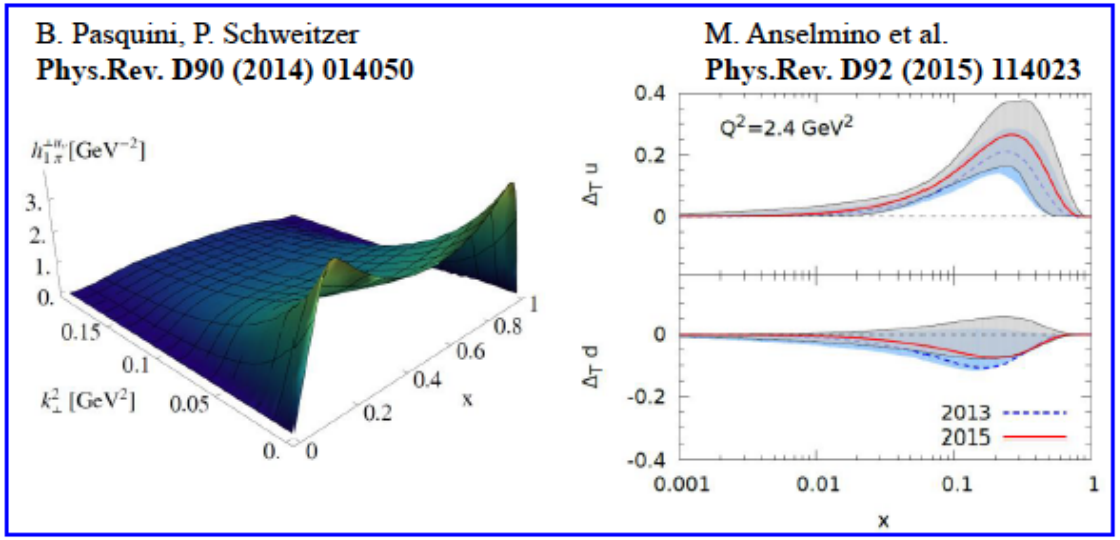
NEW!! First ever polarised DY
Transversity in Drell-Yan

New! COMPASS Phys.Rev.Lett. 119 (2017) no.11, 112002

$A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$







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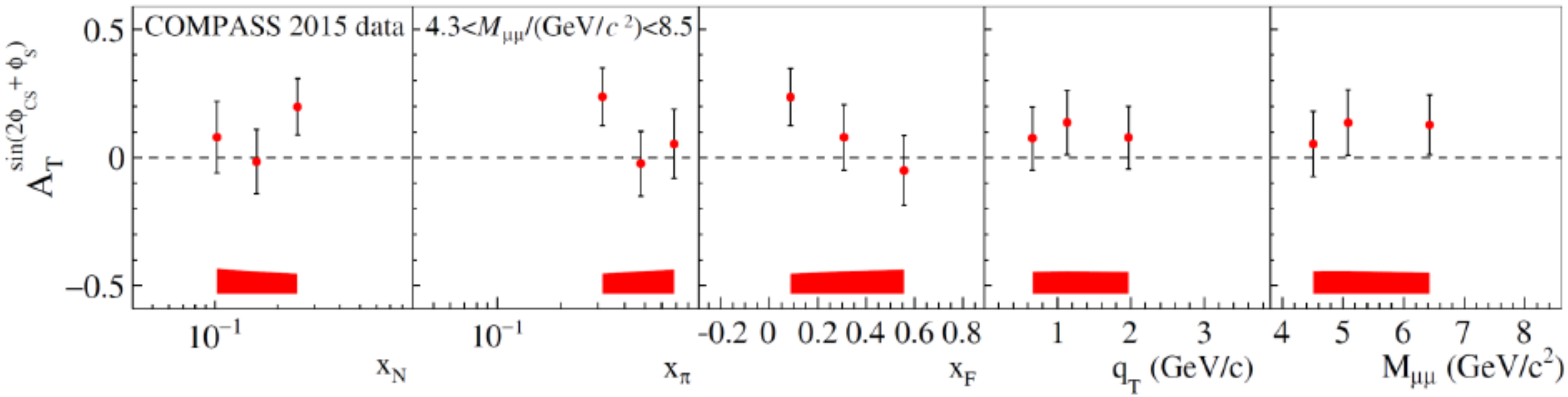
NEW!! First ever polarised DY
Pretzelosity in Drell-Yan

New! COMPASS Phys.Rev.Lett. 119 (2017) no.11, 112002

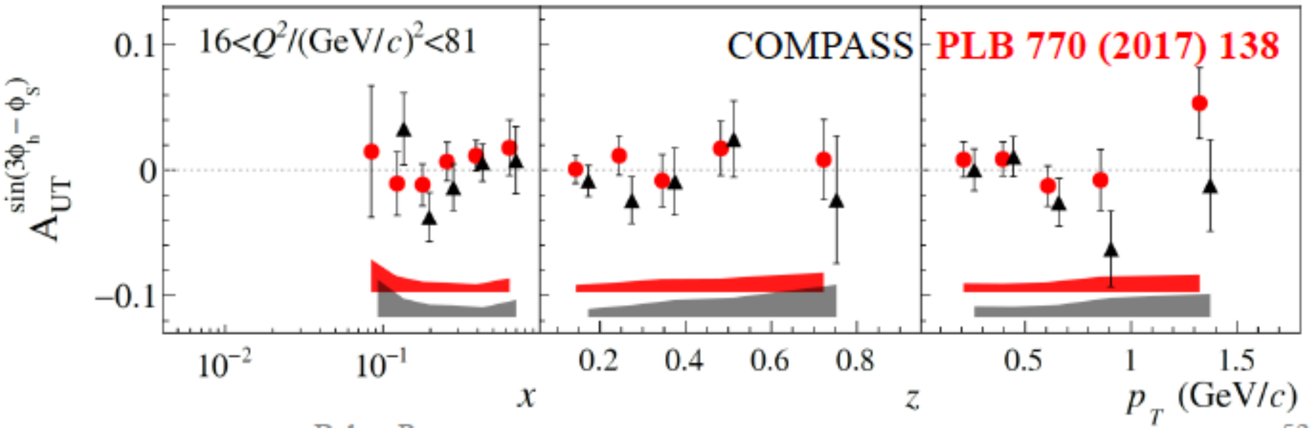
$A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp q}$



SIDIS in Drell-Yan *high-mass* range

Pretzelosity SIDIS TSA

$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$



Oleg Denisov

29-09-2017

NEW!! First ever polarised DY

TSAs in Drell-Yan compared to SIDIS

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\left\{ 1 + \ldots \right.$$

$$+ S_T \left[\begin{array}{l} A_{UT}^{\sin(\phi_h - \phi_S)} \sin(\phi_h - \phi_S) \\ + \varepsilon A_{UT}^{\sin(\phi_h + \phi_S)} \sin(\phi_h + \phi_S) \\ + \varepsilon A_{UT}^{\sin(3\phi_h - \phi_S)} \sin(3\phi_h - \phi_S) \\ + \sqrt{2\varepsilon(1+\varepsilon)} A_{UT}^{\sin\phi_S} \sin\phi_S \\ + \sqrt{2\varepsilon(1+\varepsilon)} A_{UT}^{\sin(2\phi_h - \phi_S)} \sin(2\phi_h - \phi_S) \end{array} \right] \left. \right\}$$

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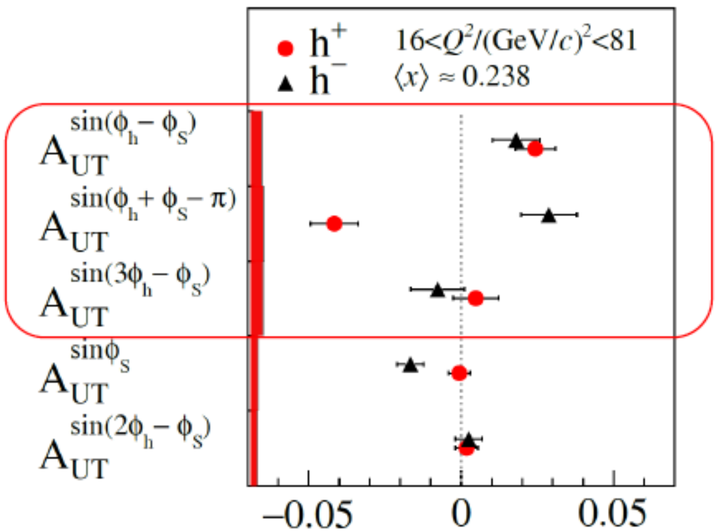
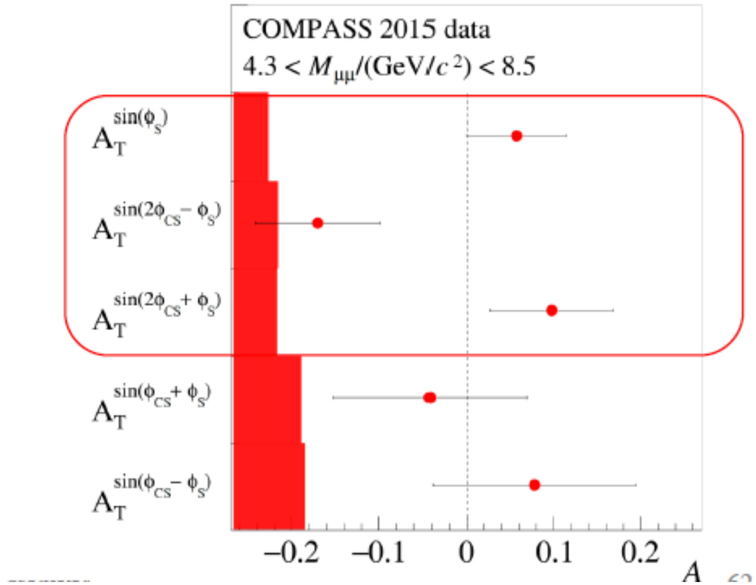


$$\frac{d\sigma^{LO}}{d\Omega} \propto F_U^1\left(1 + \cos^2\theta_{CS}\right)\left\{ 1 + \ldots \right.$$

$$+ S_T \left[\begin{array}{l} A_T^{\sin\varphi_S} \sin\varphi_S \\ + D_{[\sin^2\theta_{CS}]} \left(\begin{array}{l} A_T^{\sin(2\varphi_{CS} - \varphi_S)} \sin(2\varphi_{CS} - \varphi_S) \\ + A_T^{\sin(2\varphi_{CS} + \varphi_S)} \sin(2\varphi_{CS} + \varphi_S) \end{array} \right) \\ + D_{[\sin 2\theta_{CS}]} \left(\begin{array}{l} A_T^{\sin(\varphi_{CS} - \varphi_S)} \sin(\varphi_{CS} - \varphi_S) \\ + A_T^{\sin(\varphi_{CS} + \varphi_S)} \sin(\varphi_{CS} + \varphi_S) \end{array} \right) \end{array} \right] \left. \right\}$$

COMPASS arXiv:1704.00488 [hep-ex]



Progress

We did enormous progress over past 10-15 years:

Multiplicities: started many years ago (SMC etc..) but only now data sets large enough to study TMD-FFs evolution etc

Transversity: Basically no knowledge 15 years ago – well constrained now, extracted in a model independent (almost) way, flavour dependent

Sivers: Expected to be equal to zero one decade ago – proved to be large in SIDIS, Drell-Yan and pp experiments are on the way to access it with relatively high precision

OUTLOOK

Plenty of new results are expected to come soon:

- Jlab -12
- RHIC 2017 Run
- COMPASS Drell-Yan on transversally polarised NH_3 2018

Summary

- Proton spin puzzle is still there
- The only way to resolve it – to move in 3-D
- TMDs study will provide essential input for 3-D structure of the hadron
- Huge progress in the field over past 10 years (Transversity, Sivers, Multiplicities…)
- More data to come soon

Summary

- Proton spin puzzle is still three
- The only way to resolve it – to move in 3-D
- TMDs study will provide essential input for 3-D structure of the hadron
- Huge progress in the field over past 10 years (Transversity, Sivers, Multiplicities…)
- More data to come soon

SPARES

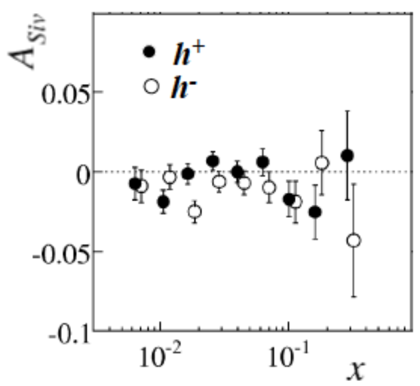
Oleg Denisov

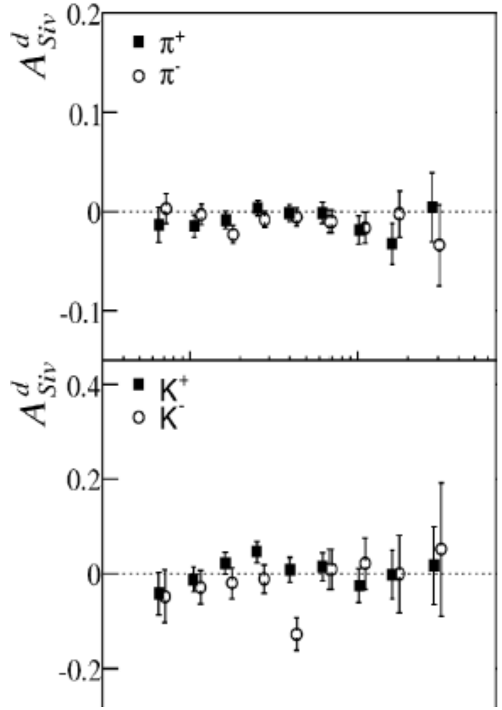
29-09-2017

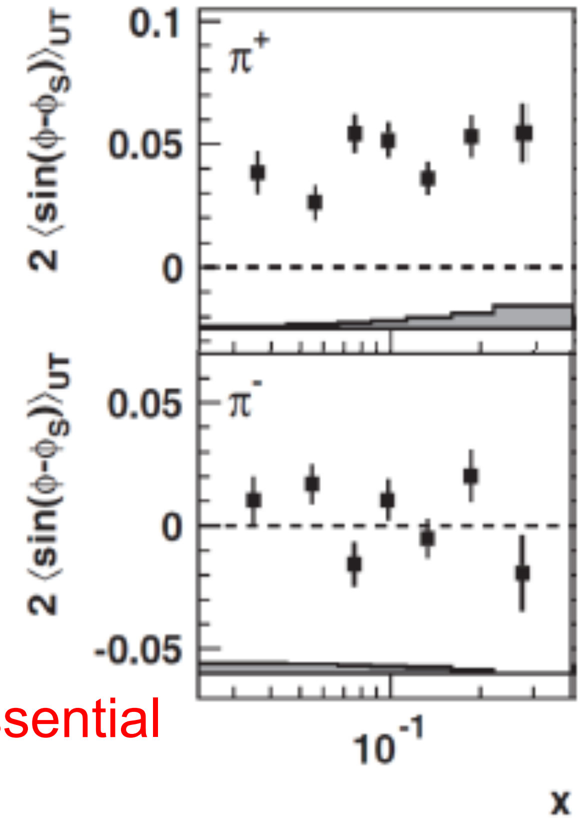
Sivers 2009 – final results Hermes&COMPASS data perfectly fits together

COMPASS Final results on deuteron (data 2002-2004) PLB 673 (2009)

Hermes Final results on proton PRL 103 (2009)







Flavour separation is essential