Newest COMPASS results on longitudinal and transverse nucleon spin structure

Stefano Levorato INFN Trieste

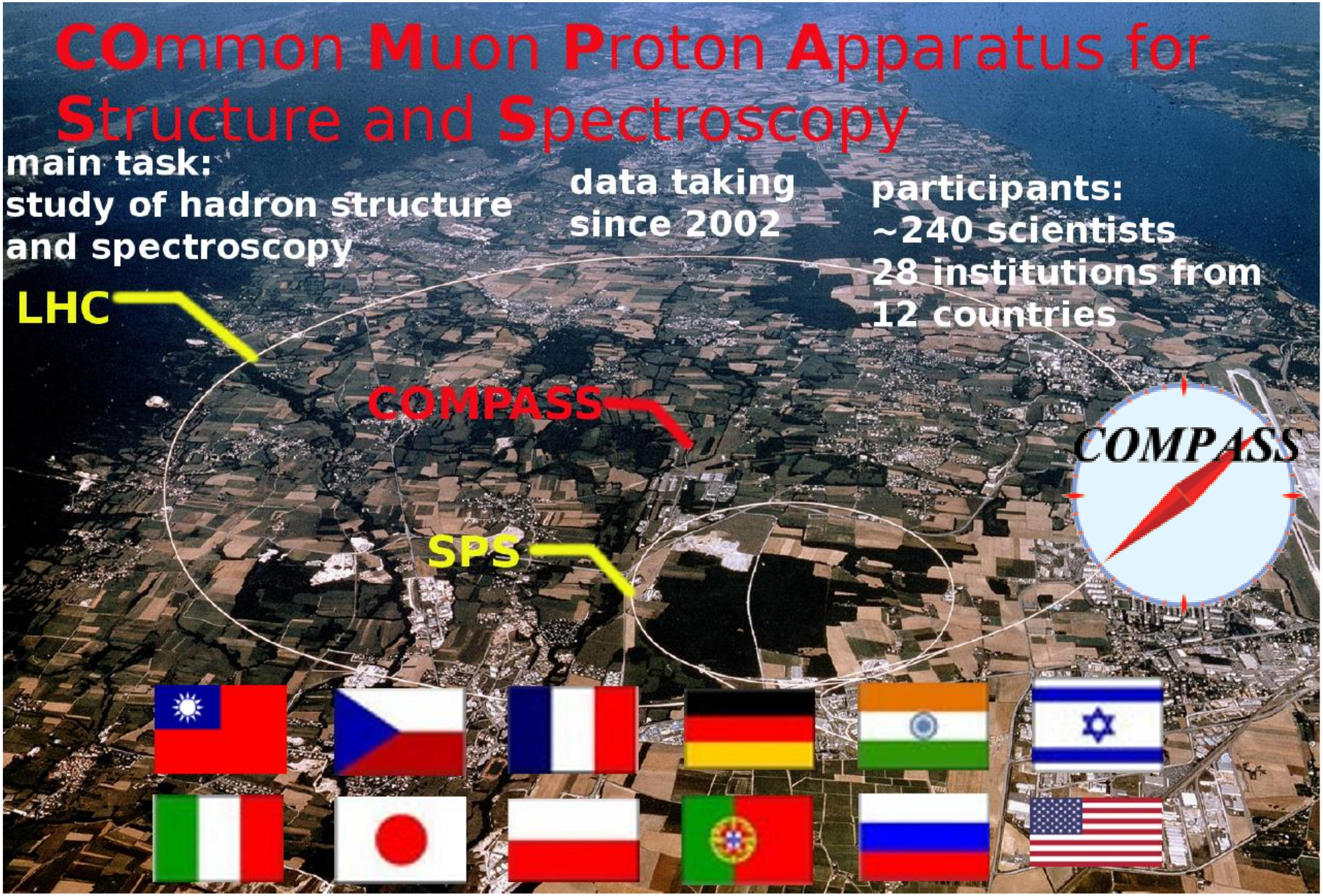
on behalf of the COMPASS collaboration

OUTLOOK

- The COMPASS experiment at CERN
- Longitudinal asymmetries in DIS
- Hadron multiplicities in SIDIS
- The Structure of the Nucleon (SIDIS): Transversity and TMD
- Unpolarized SIDIS

A selection of the many available results!

The COMPASS Fixed target experiment at CERN SPS



COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

main task:
study of hadron structure
and spectroscopy

data taking
since 2002

participants:
~240 scientists
28 institutions from
12 countries

The COMPASS Fixed target experiment at CERN SPS

Rich and diversified physics programme :

- Nucleon structure with 160 GeV μ
- Hadron Spectroscopy with 190 GeV π

On transversely, longitudinally polarized target, LH_2 or nuclei targets:

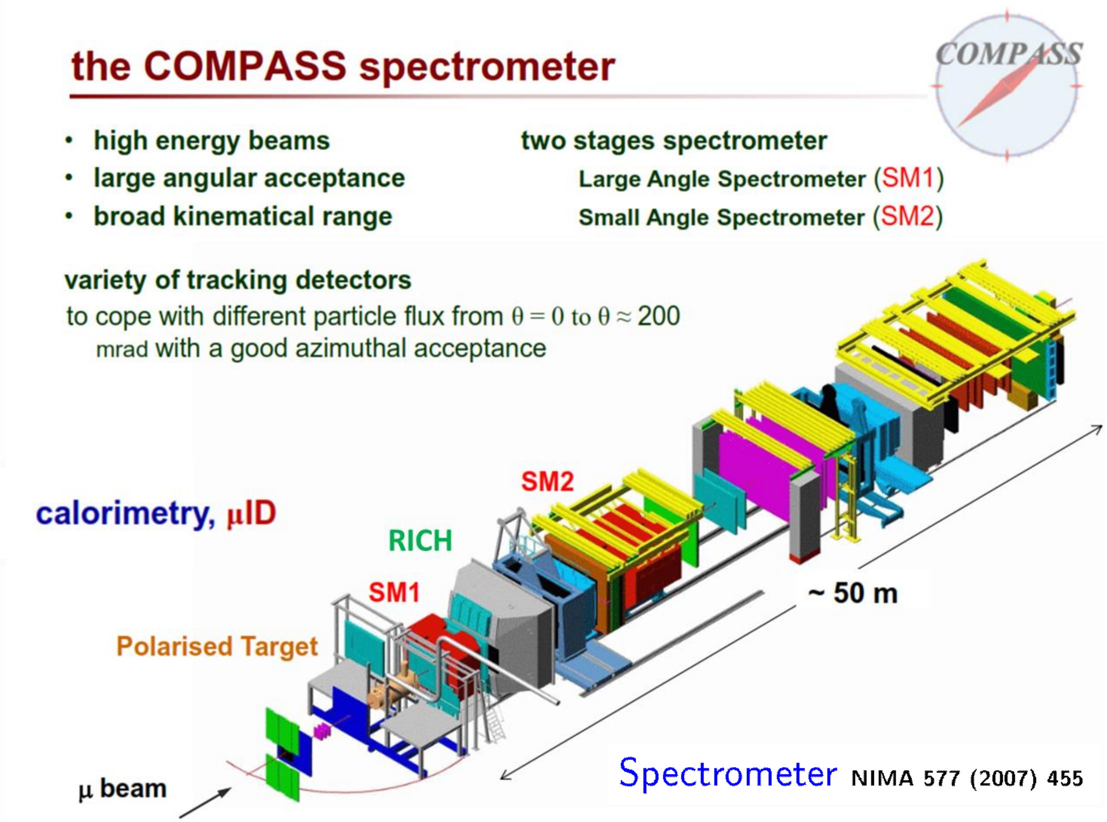
Measurement of elicity, transversity, Λ, GPD, meson spectroscopy π,K polarizabilities ….

Not all covered in this talk !!!

The COMPASS data-taking

2002	**nucleon structure with**	**160 GeV μ**	**L&T**	**polarised deuteron target**
2003	**nucleon structure with**	**160 GeV μ**	**L&T**	**polarised deuteron target**
2004	**nucleon structure with**	**160 GeV μ**	**L&T**	**polarised deuteron target**
2005	*CERN accelerators shut down*			
2006	**nucleon structure with**	**160 GeV μ**	**L**	**polarised deuteron target**
2007	**nucleon structure with**	**160 GeV μ**	**L&T**	**polarised proton target**
2008	***hadron spectroscopy***	**190 Gev π**		
2009	***hadron spectroscopy***	**190 Gev π**		
2010	**nucleon structure with**	**160 GeV μ**	**T**	**polarised proton target**
2011	**nucleon structure with**	**190 GeV μ**	**L**	**polarised proton target**
2012	**Primakoff & DVCS / SIDIS test**			
2013	*CERN accelerators shut down*			
2014	Test beam Drell-Yan process with π beam and T polarised proton target			
2015	**Drell-Yan process with π beam and T polarised proton target**			
2016	**DVCS / SIDIS with μ beam and unpolarised proton target**			
2017	**DVCS / SIDIS with μ beam and unpolarised proton target**			

The COMPASS spectrometer, an overview



the COMPASS spectrometer

- high energy beams
- large angular acceptance
- broad kinematical range

two stages spectrometer

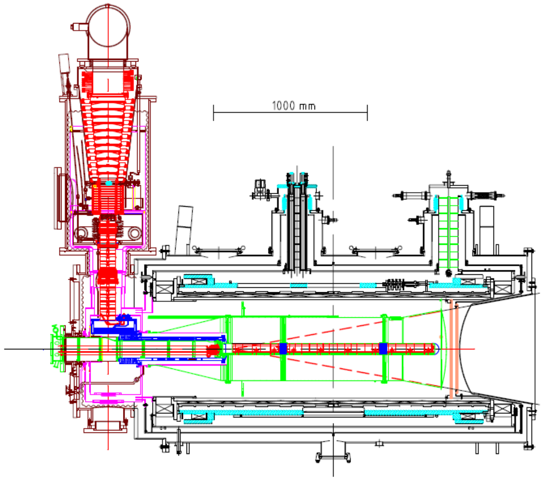
Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

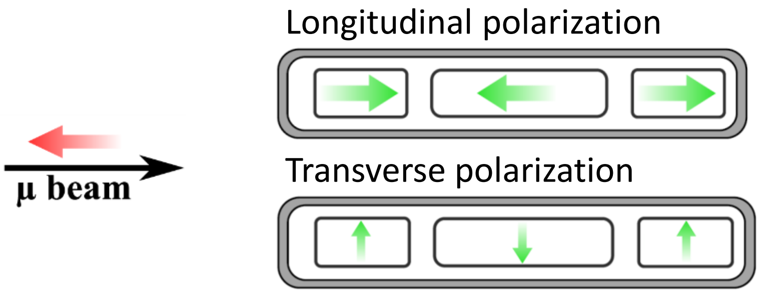
variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance

Spectrometer NIMA 577 (2007) 455



- Two/three target cells, oppositely polarized
- 180 mrad geometrical acceptance
- 2.5T solenoid field
- Low temperature 50mK
- Regular polarization reversals by field rotation
- ^{6}LiD (Longitudinal deuteron polarization: 50%)
- NH_3 (Longitudinal proton polarization: 90%)



Longitudinal polarization

Transverse polarization

μ beam

OUTLOOK

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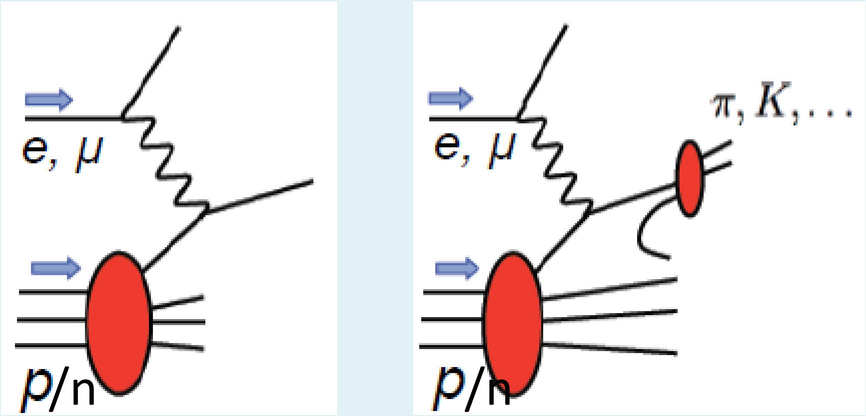
- Pion and Kaon multiplicities
- The Structure of the Nucleon : Transversity and TMD
- Unpolarized SIDIS

A selection of the many available results!

The nucleon spin structure DIS-SIDIS processes



DIS:

$\Delta q + \Delta \bar{q}$

Δg (From Q^2 evolution of g_1)

SIDIS:

$\Delta q, \Delta \bar{q}$

Δg

DIS variables

- Photon virtuality: $Q^2 = -q^2$
- Bjorken scaling variable: $x = \frac{Q^2}{2 \cdot P \cdot q}$
- Relative photon energy: $y = \frac{E - E'}{E}$

SIDIS variables

$$z = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}$$

Hadron transverse momentum p_T^h

Nucleon SPIN and helicity PDF

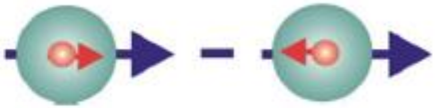
Helicity measurement in DIS process

$$\mathbf{S_N} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta\mathbf{G} + \mathbf{L_q} + \mathbf{L_g}$$

$$\Delta\Sigma(Q^2) = \int_0^1 \mathrm{d}x[\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}](x, Q^2)$$

$$\Delta G(Q^2) = \int_0^1 \mathrm{d}x \Delta g(x, Q^2)$$

Helicity PDFs: $\Delta q(x, Q^2) =$



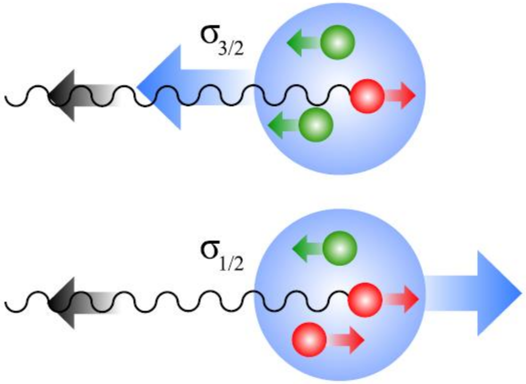
The goal is the determination of Δq (x,Q^2), ΔG

Deep inelastic scattering processes: longitudinal polarization A_1 asymmetry

- **Inclusive cross section**

$$\frac{d^2\sigma}{d\Omega dE'} \sim \underbrace{c_1 F_1(x,Q^2) + c_2 F_2(x,Q^2)}_{\text{spin independent}} + \underbrace{c_3 g_1(x,Q^2) + c_4 g_2(x,Q^2)}_{\text{spin dep. structure functions}}$$

$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \Delta q(x) \approx A_1(x,Q^2) \cdot F_1(x,Q^2)$$



Absorption of polarised photons

$$\sigma_{1/2} \sim q^+ \qquad \sigma_{3/2} \sim q^-$$

$$q(x) = q^+(x) + q^-(x)$$

$$\Delta q(x) = q^+(x) - q^-(x)$$

q(x)=Quark momentum DF

Δq(x)=Difference in DF of quarks with spin parallel or antiparallel to the nucleon's spin in a longitudinally polarized nucleon;

$$A_1(x,Q^2) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \overset{\text{LO}}{=} \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

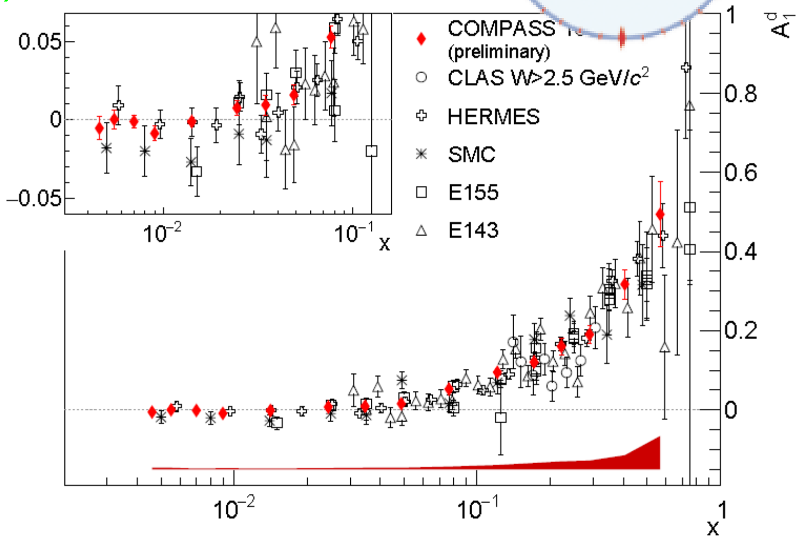
$$A_{exp} = \frac{N_u - N_d}{N_u + N_d}$$

Deep inelastic scattering processes: $A_1^d(x)$, $g^1_d(x)$ results from Deuteron Data

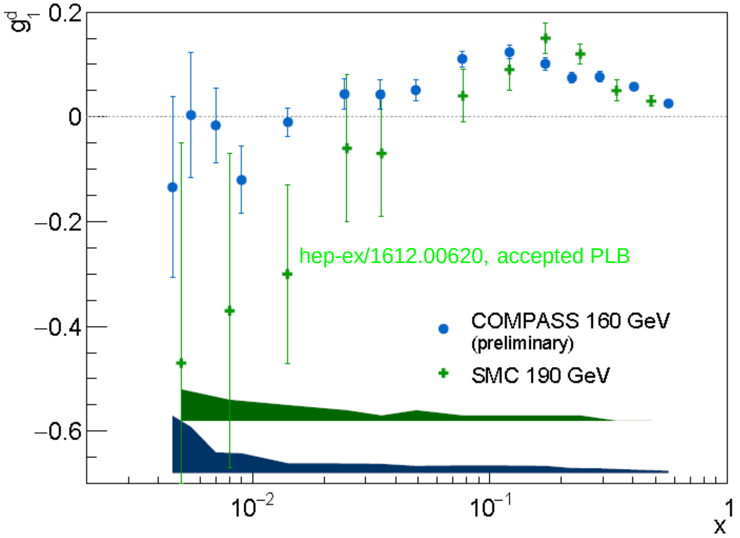
Final sample: 135 million events

Data at E = 160 GeV (from 2002–2004) published PLB 647 (2007) 8

Data at E = 160 GeV (from 2006)



- Good agreement with world data
- Small statistical uncertainty at low x
- Compatible with zero at low x
- $g_1^{\mathrm{d}}(x, Q^2) = \frac{F_2^{\mathrm{d}}(x,Q^2)}{2x(1+R(x,Q^2))} A_1^{\mathrm{d}}(x, Q^2)$
- F_2 from SMC **PRD 58 (1998) 11201**
- R1998 **PLB 452 (1999) 194**
  used with improvements



hep-ex/1612.00620, accepted PLB

Good agreement $A_1^d(x)$ and of $g^1_d(x)$ with world data

$g^1_d(x)$ compatible with zero at lowest measured values of x, contrary to hints from SMC

Deep inelastic scattering processes: $A_1^p(x)$, $g^1_p(x)$ results from Proton Data

Final sample: 85 million events @ 160 GeV + 77 million events @ 200 GeV

- 2007 results already published

  PLB 690 (2010) 466

- Increased beam energy in 2011 $160\,\mathrm{GeV} \rightarrow 200\,\mathrm{GeV}$
- Higher Q^2 and lower x reached
- ^{14}N correction applied
- Good agreement
- $g_1^{\mathrm{p}}(x, Q^2) = \frac{F_2^{\mathrm{p}}(x,Q^2)}{2x(1+R(x,Q^2))} A_1^{\mathrm{p}}(x, Q^2)$

$g^1_p(x)$ clearly positive at lowest measured values of x

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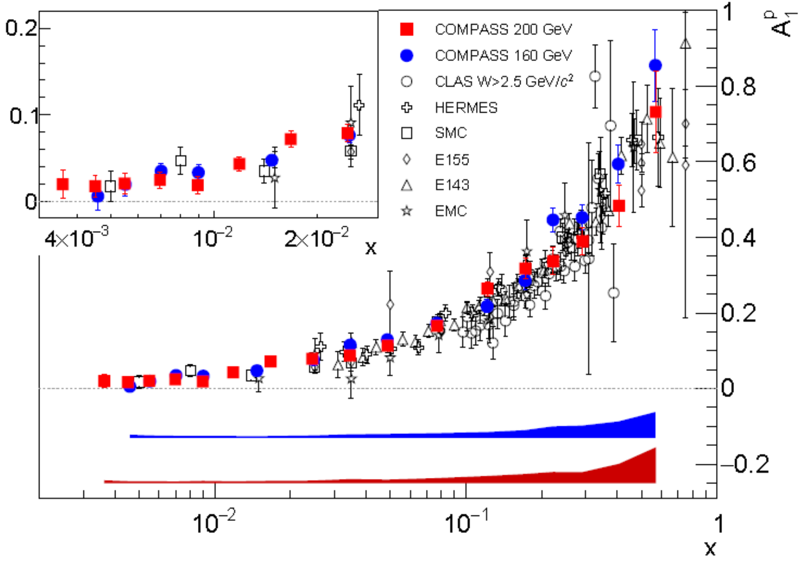
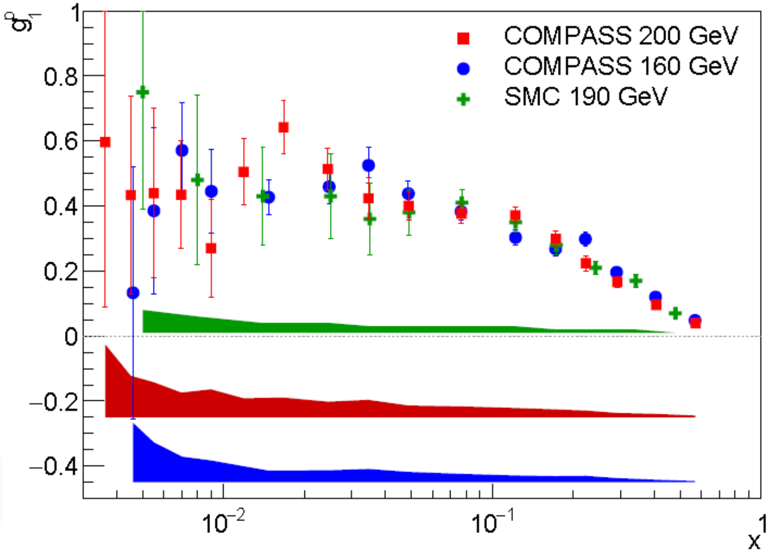




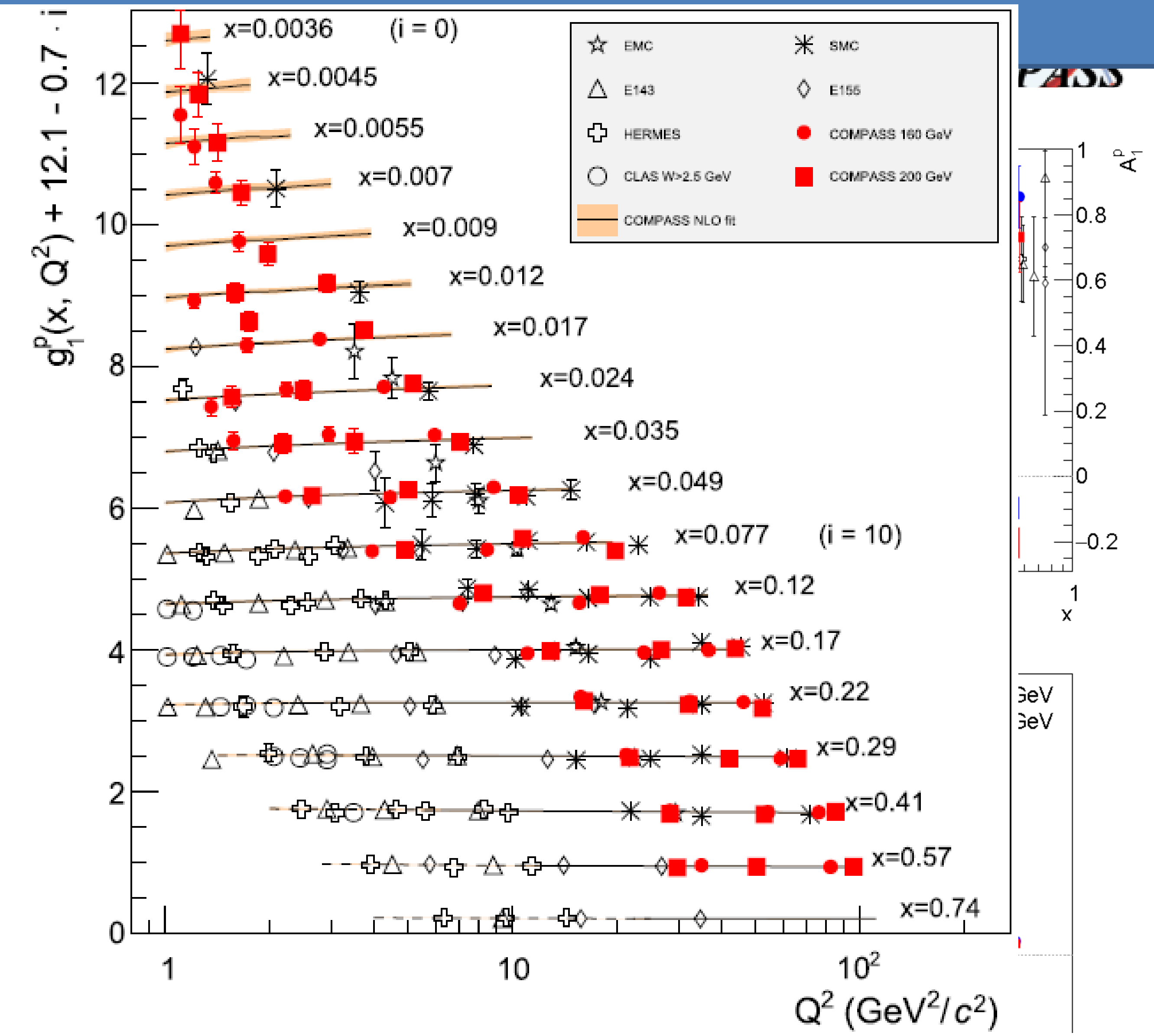
Deep inelastic scattering pr

Final sample: 85 million
+ 77 million events @ 2

- 2007 results alrea

  PLB 690 (2010) 466

- Increased beam er
  160 GeV → 200 G
- Higher Q^2 and lo
- ^{14}N correction ap
- Good agreement
- $g_1^{\rm p}(x, Q^2) = \frac{F_2^{\rm p}}{2x(1+}$



From COMPASS data alone (and a_8 from PRD 82 (2010) 114018):

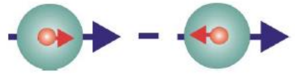
$a_0(Q_2 = 3\ (\mathrm{GeV}/c)_2) = 0.320 \pm 0.02_{stat:} \pm 0.04_{syst:} \pm 0.05_{evol:}$

(consistent with value from the COMPASS NLO QCD fit of world data).

In MS identified with total contribution of quark helicities to the nucleon spin

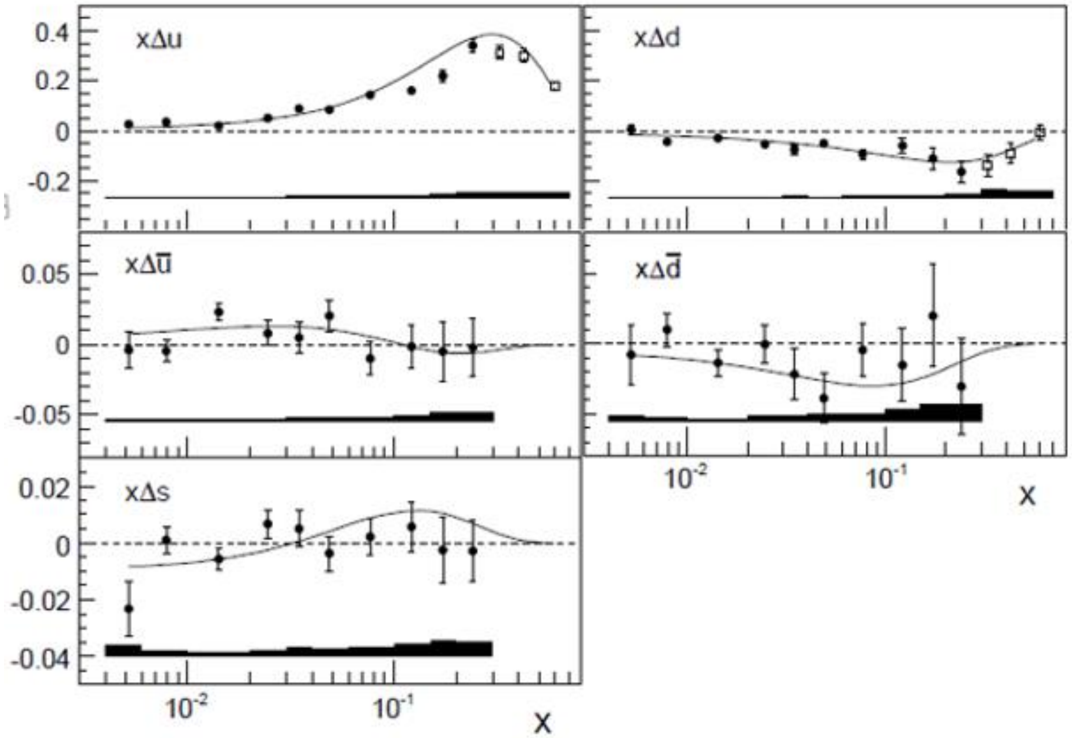
Flavour separation using SIDIS data

$\Delta q(x, Q^2) =$



To perform flavor separation SIDIS is needed

$$A_1^h = \frac{\Sigma_q e_q^2 \Delta q(x) \int D_q^h(z)\mathrm{d}z}{\Sigma_q e_q^2 q(x) \int D_q^h(z)\mathrm{d}z}$$



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Basic concept

- measured:
  A_1^{d}, $A_{1\mathrm{d}}^{K^\pm}$, $A_{1\mathrm{d}}^{\pi^\pm}$,
  A_1^{p}, $A_{1\mathrm{p}}^{K^\pm}$, $A_{1\mathrm{p}}^{\pi^\pm}$
- determined:
  Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$,
  $\Delta s = \Delta\bar{s}$
- inputs:
  unpol. LO PDFs (MRST04)
  LO FFs (DSS)
- curves: DSSV param.
- results: $\Delta s \geq 0$??

⟶ Results for Δs depend very much on the strange quark FFs used

- The COMPASS experiment at CERN
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- Hadron multiplicities
- The Structure of the Nucleon : Transversity and TMD
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A selection of the many available results!

SIDIS: Hadron multiplicities, the motivation

Fragmentation functions (FF, D^h_q) describe parton fragmentation into hadrons → needed in analyses which deal with a hadron(s) in the final state

In Leading Order QCD D^h_q describes probability density for a quark of flavour q to fragment into hadron of type h

SIDIS data are crucial to understand quark fragmentation process

Hadron multiplicities can be expressed in terms of parton distribution functions (pdfs) and fragmentation functions (FFs), in **LO pQCD** this reads:

quark pdfs quark to hadron FFs

$$\boxed{\frac{dM^h(x,z,Q^2)}{dz} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}}$$

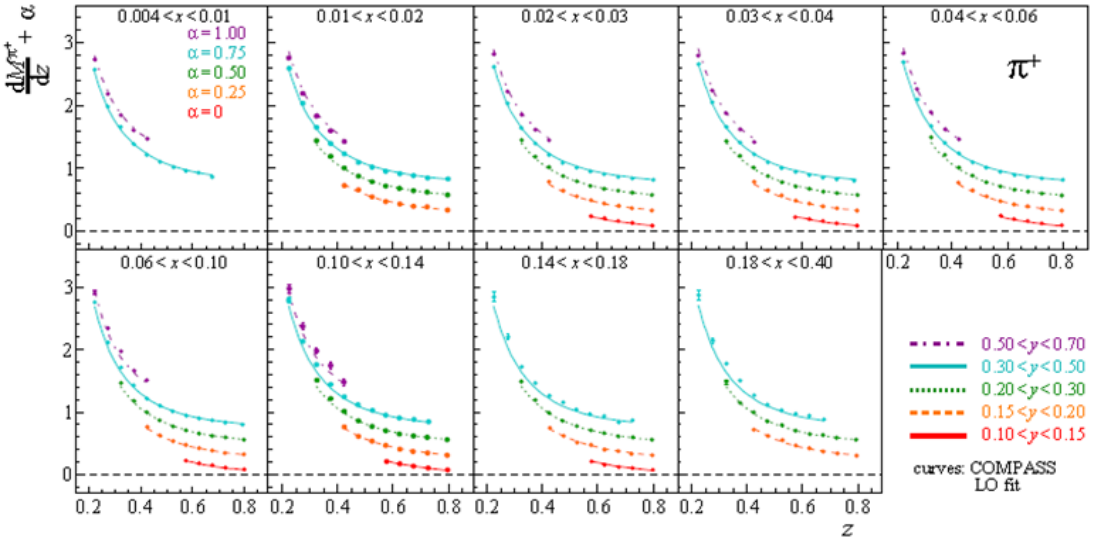
SIDIS: Multiplicities of π on Iso-Scalar Target and π^+/π^- multiplicity ratio

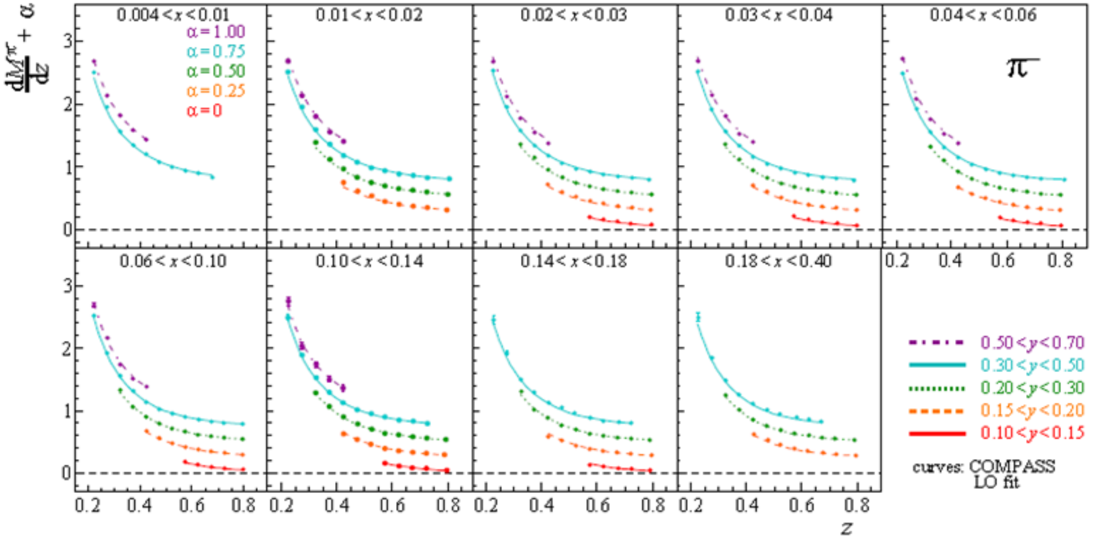
COMPASS extracted $\pi^\pm$ multiplicities

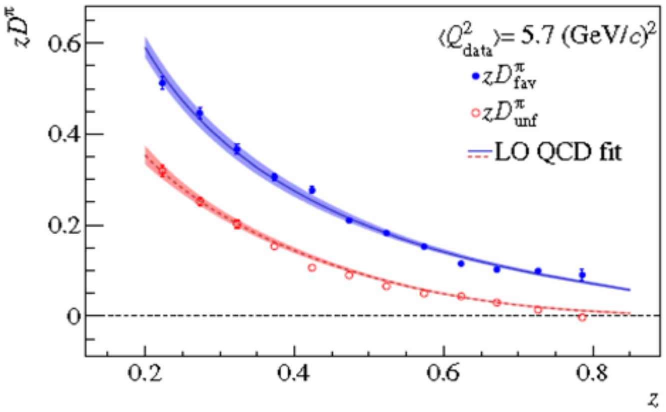
Results published in PLB 764 (2017) 001

COMPASS performed LO fit, using HKNS FF programme

Results agrees with world FFs. As expected $D_{fav} > D_{unf}$

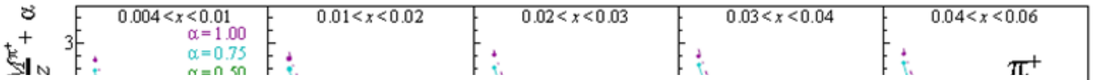






SIDIS: Multiplicities of π on Iso-Scalar Target and π^+/π^- multiplicity ratio

COMPASS extracted $\pi^\pm$

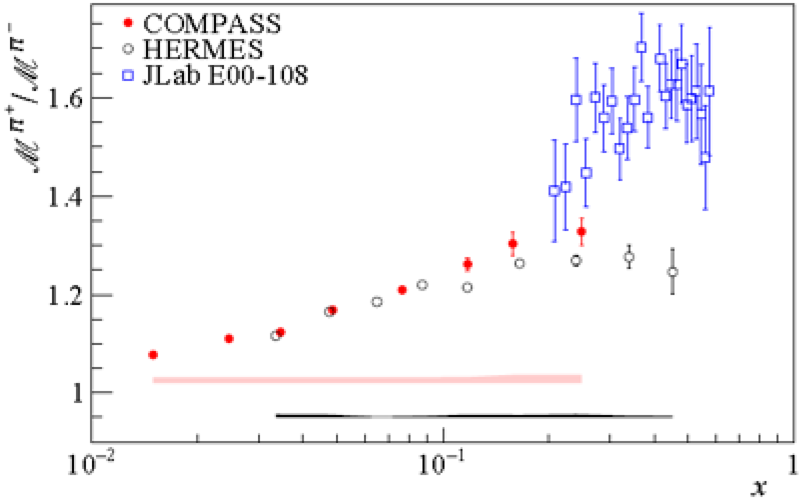


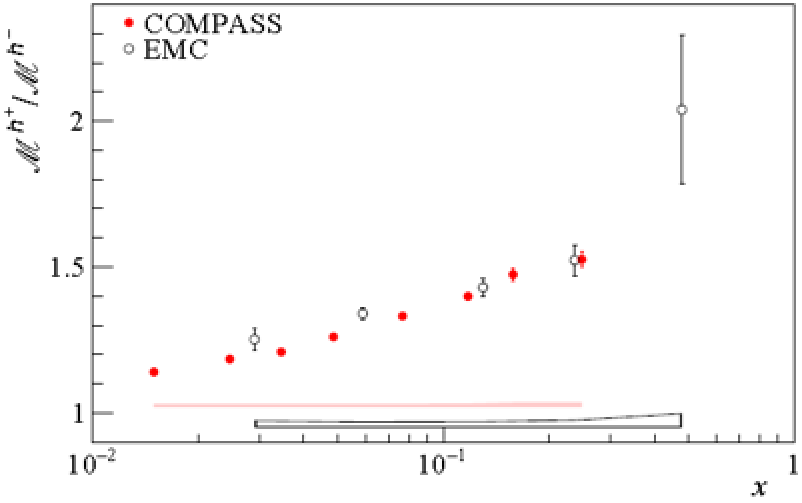
The ratio of π^+/π^- is interesting to study due to significant cancellation of experimental systematic errors

Here, a good agreement between HERMES and COMPASS

Difference between HERMES and JLab likely explained by different W

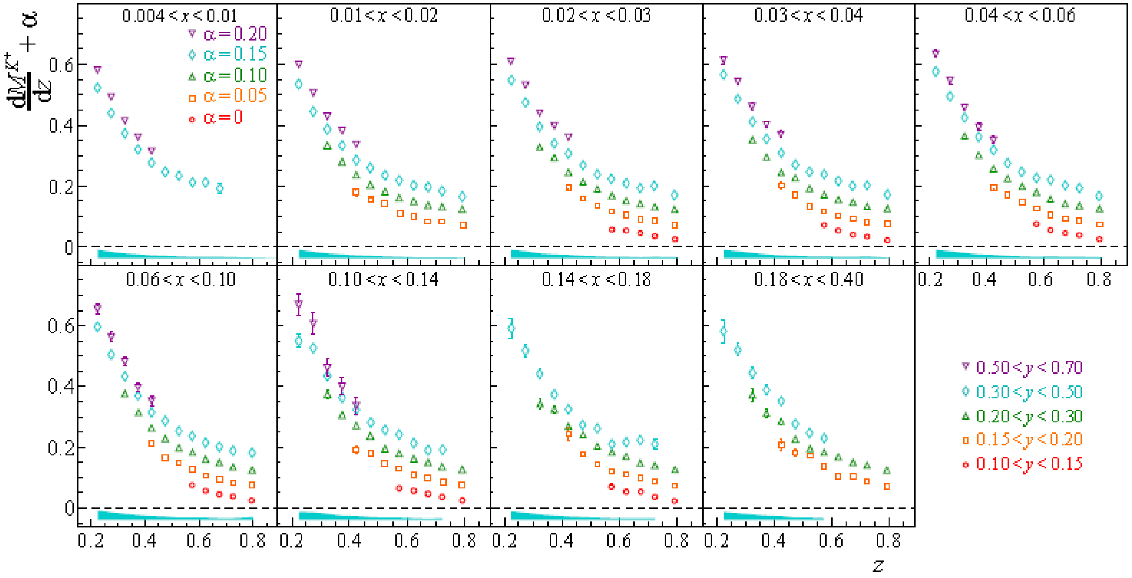
Good agreement between COMPASS and EMC data for unidentified hadrons

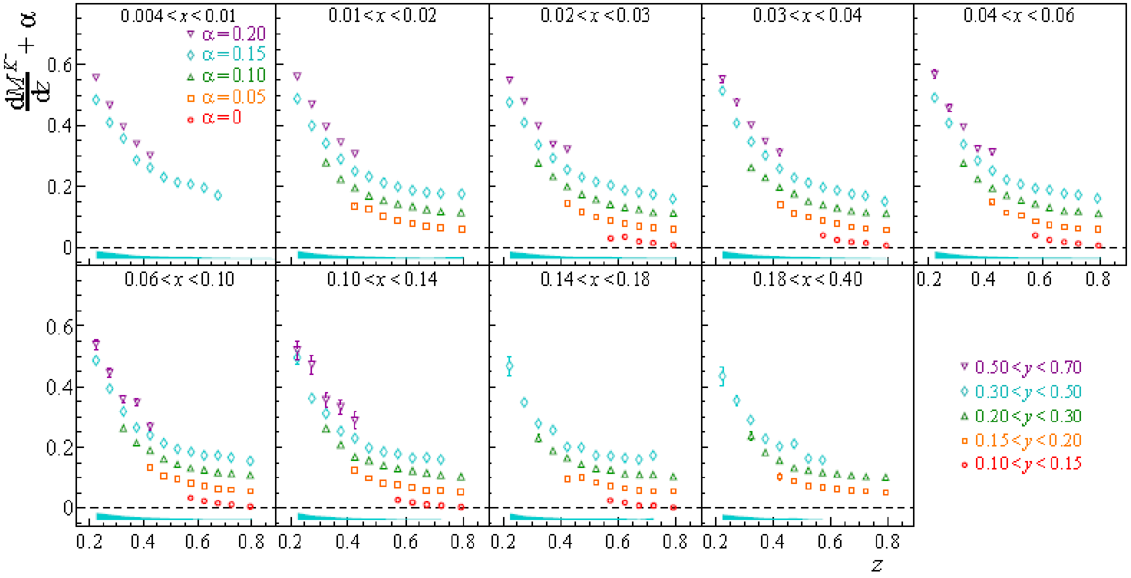




SIDIS: Multiplicities of K on Iso-Scalar Target and multiplicity ratio

- COMPASS extracted Kaon multiplicities
- More than 620 data points
- Recently published in PLB 767 (2017) 133





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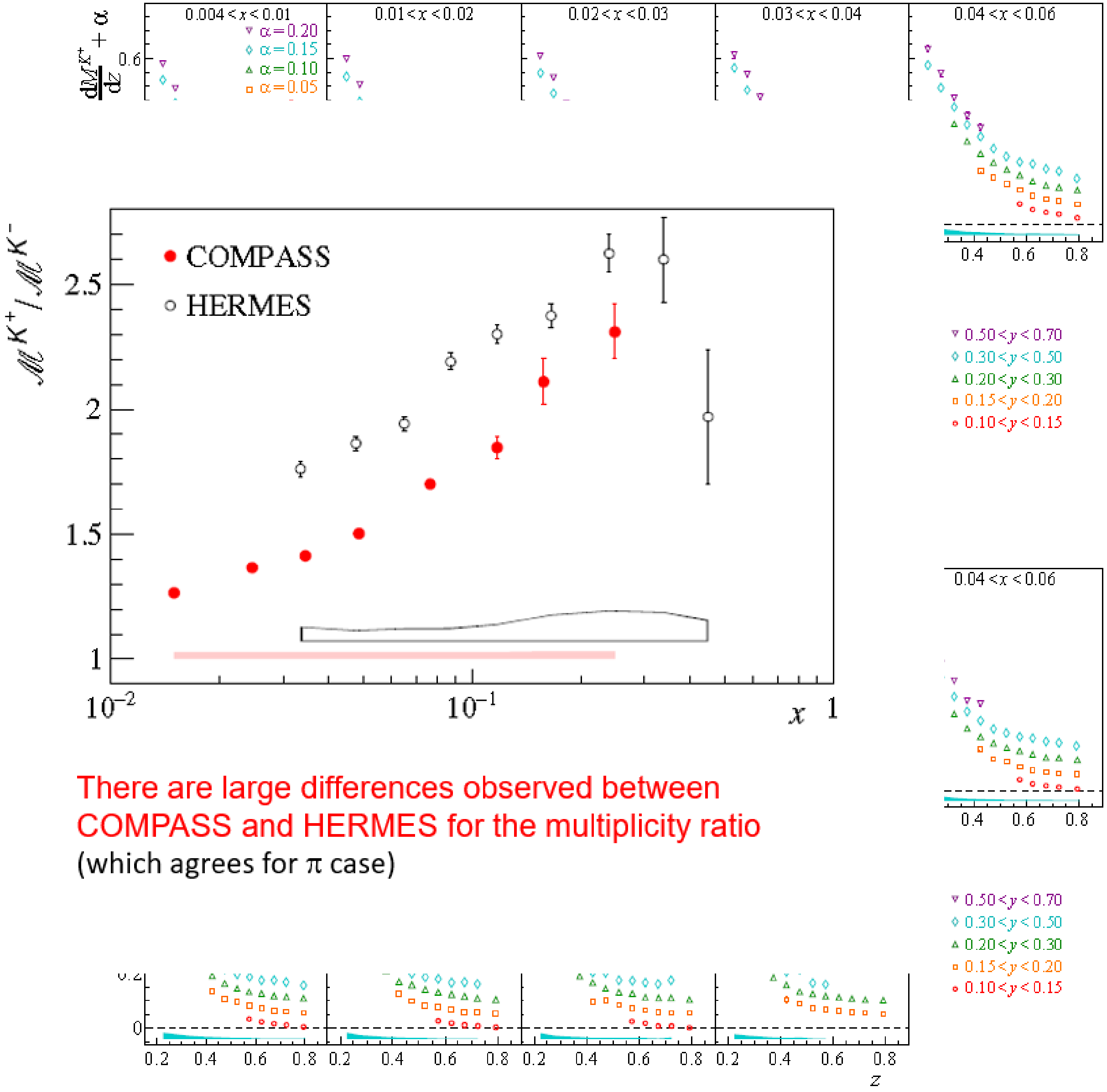
  PLB 767 (2017) 133



There are large differences observed between COMPASS and HERMES for the multiplicity ratio

(which agrees for π case)

- The COMPASS experiment at CERN
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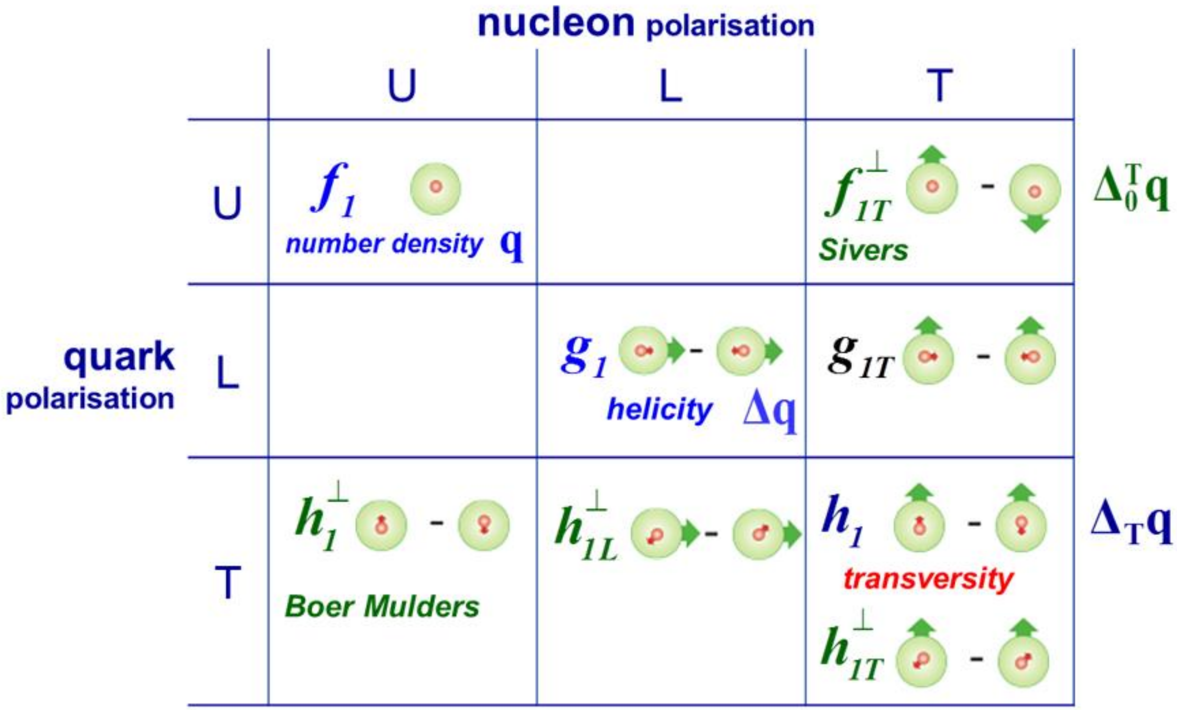
A selection of the many available results!

The structure of the nucleon

Taking into account the quark intrinsic transverse momentum k_T, at leading order other 6 TMD PDFs are needed for a full description of the nucleon structure

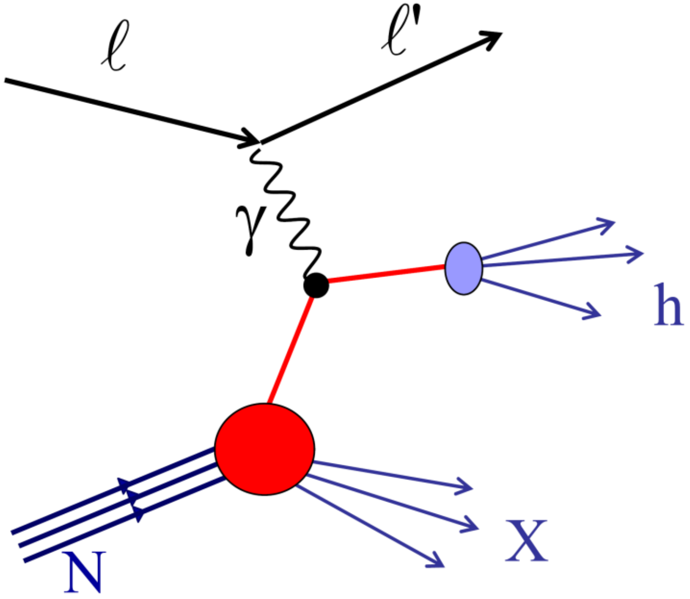


		nucleon polarisation			
		U	L	T	
	U	f_1 *number density* $\mathbf{q}$		$f_{1T}^{\perp}$ *Sivers*	$\Delta_0^T q$
quark polarisation	L		g_1 *helicity* Δq	g_{1T}	
	T	$h_1^{\perp}$ *Boer Mulders*	$h_{1L}^{\perp}$	h_1 *transversity* $h_{1T}^{\perp}$	$\Delta_T q$

SIDIS gives access to all of them

Semi Inclusive Deep Inelastic Scattering (SIDIS)

hard interaction of a lepton with a nucleon via virtual photon exchange

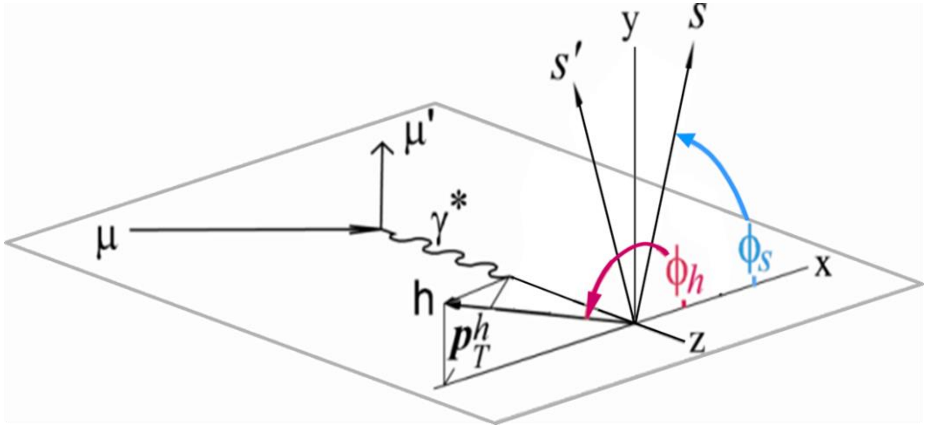


$$x = \frac{Q^2}{2P \cdot q} \qquad y = \frac{P \cdot q}{P \cdot \ell} =_{LAB} \frac{E - E'}{E}$$

$$Q^2 = -q^2 \qquad W^2 = (P + q)^2$$

$$z = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}$$

$$\sigma^{lN \to lhX} \propto \sum_q f(x) \otimes \sigma^{lq \to lq} \otimes D_q^h(z)$$



Semi Inclusive Deep Inelastic Scattering (SIDIS)

$$
\begin{aligned}
&\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \\
&\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon\,F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\boxed{\cos\phi_h}\,F_{UU}^{\cos\phi_h} \\
&\quad+\varepsilon\,\overset{h_1^\perp H_1^\perp}{\boxed{\cos(2\phi_h)}}\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\boxed{\sin\phi_h}\,F_{LU}^{\sin\phi_h} \\
&\quad+S_\parallel\Big[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\,\overset{h_{1L}^\perp H_1^\perp}{\boxed{\sin(2\phi_h)}}\,F_{UL}^{\sin 2\phi_h}\Big]+S_\parallel\lambda_e\Big[\sqrt{1-\varepsilon^2} \\
&\quad+|\boldsymbol{S}_\perp|\Big[\overset{f_{1T}^\perp D_1}{\boxed{\sin(\phi_h-\phi_S)}}\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big) \\
&\qquad+\varepsilon\,\underset{h_1 H_1^\perp}{\boxed{\sin(\phi_h+\phi_S)}}\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\overset{h_{1T}^\perp H_1^\perp}{\boxed{\sin(3\phi_h-\phi_S)}}\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
&\qquad+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\boxed{\sin\phi_S}\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\boxed{\sin(2\phi_h-\phi_S)}\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
&\quad+|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\overset{g_{1T} D_1}{\boxed{\cos(\phi_h-\phi_S)}}\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\boxed{\cos\phi_S}\,F_{LT}^{\cos\phi_S} \\
&\qquad+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\boxed{\cos(2\phi_h-\phi_S)}\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},
\end{aligned}
$$

14 independent azimuthal modulations

amplitudes of the modulations
→ TMD PDFs

Semi Inclusive Deep Inelastic Scattering (SIDIS)

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

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

$$+\,\varepsilon\,\overset{h_1^\perp H_1^\perp}{\boxed{\cos(2\phi_h)}}\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\boxed{\sin\phi_h}\,F_{LU}^{\sin\phi_h}$$

$$+\,S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\,\overset{h_{1L}^\perp H_1^\perp}{\boxed{\sin(2\phi_h)}}\,F_{UL}^{\sin 2\phi_h}\right]+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\right.$$

$$+\,|\boldsymbol{S}_\perp|\left[\overset{f_{1T}^\perp D_1}{\boxed{\sin(\phi_h-\phi_S)}}\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\right.$$

$$+\,\varepsilon\,\underset{h_1 H_1^\perp}{\boxed{\sin(\phi_h+\phi_S)}}\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon$$

$$+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\boxed{\sin\phi_S}\,F_{UT}^{\sin\phi_S}+\sqrt{}\qquad\Big]$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\left[\sqrt{1-\varepsilon^2}\,\overset{g_{1T}D_1}{\boxed{\cos(\phi_h-\phi_S)}}\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\boxed{\cos\phi_S}\,F_{LT}^{\cos\phi_S}\right.$$

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

14 independent azimuthal modulations

amplitudes of the modulations
→ TMD PDFs

SIDIS

- **allows to disentangle the effects related to the different TMD PDFs and to access all of them**
- **by identifying the final state hadrons and using different targets allows for flavour separation**

→ ***very powerful tool***

all the amplitudes (AA) have been measured in COMPASS some SIDIS results on

TRANSVERSITY and TMD PDFs

Semi Inclusive Deep Inelastic Scattering (SIDIS)

MAJOR RESULT:

in the past 10 years 2 of these new PDF's have been measured and shown to be different from zero

by COMPASS and HERMES

the Transversity PDF amplitude of the sine modulation in $\phi_h + \phi_s - \pi$

Collins asymmetry ~ $h_1 \otimes H_1^\perp$

the Sivers PDF amplitude of the sine modulation in $\phi_h - \phi_s$

Sivers asymmetry ~ $f_{1T}^\perp \otimes D_1$

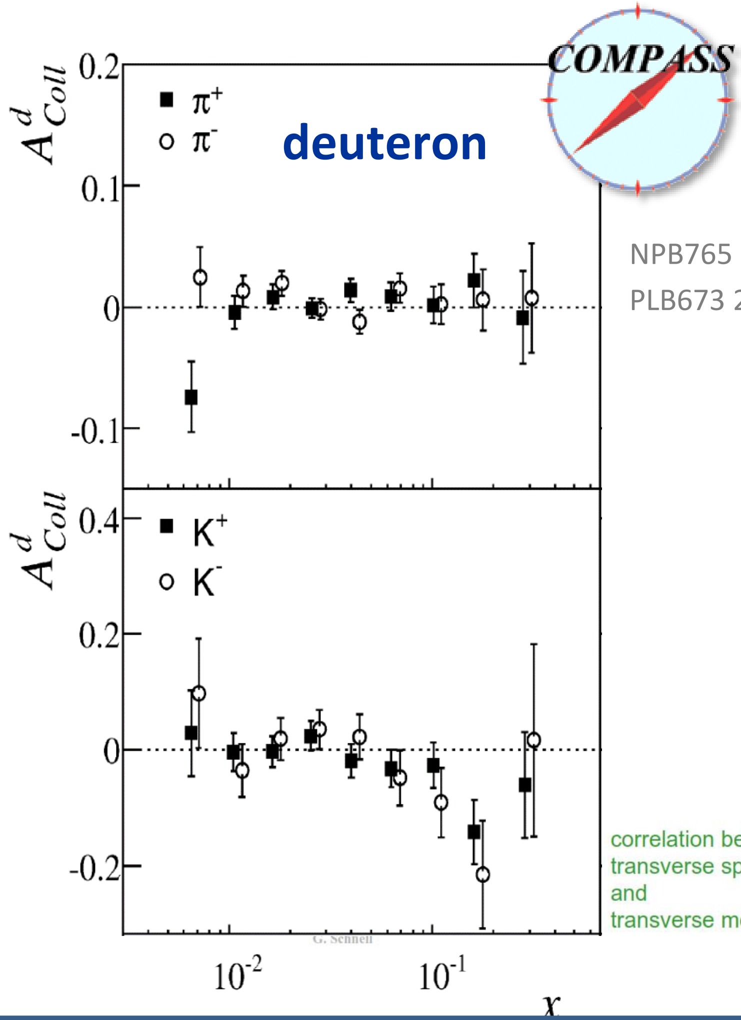
A STEP TOWARDS
THE 3-D STRUCTURE OF THE NUCLEON

SIDIS Collins Asymmetry

$$\sim \ h_1 \otimes H_1^{\perp}$$

2004: first evidence for non-zero Collins asymmetry on p from HERMES

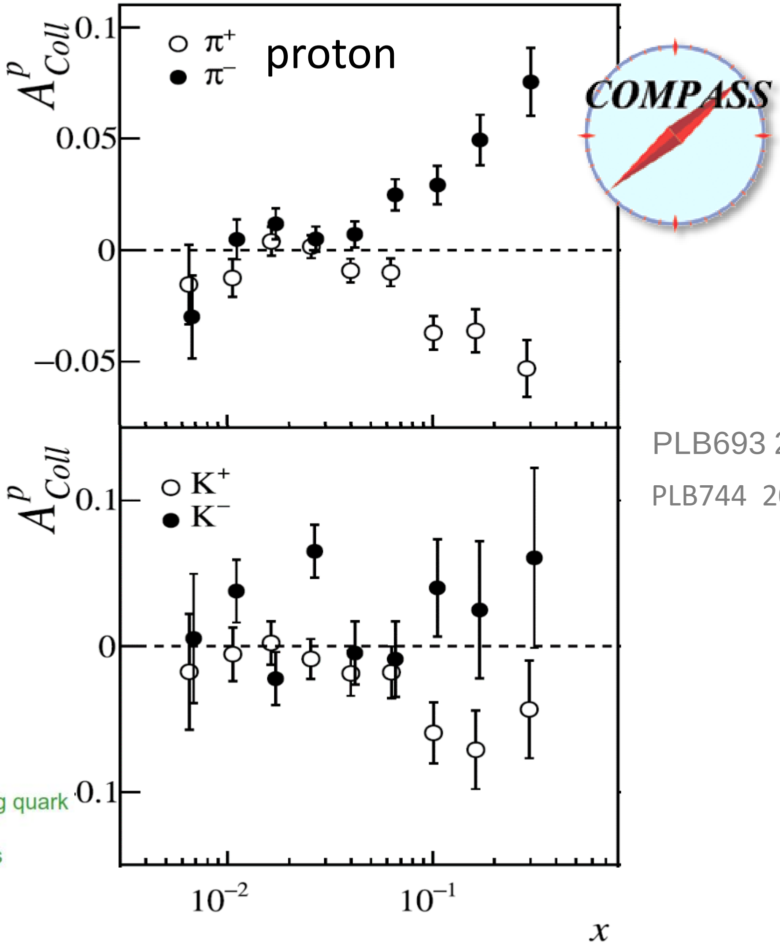
final COMPASS results



NPB765 2007

PLB673 2009

correlation between
transverse spin of the fragmenting quark
and
transverse momentum of hadrons



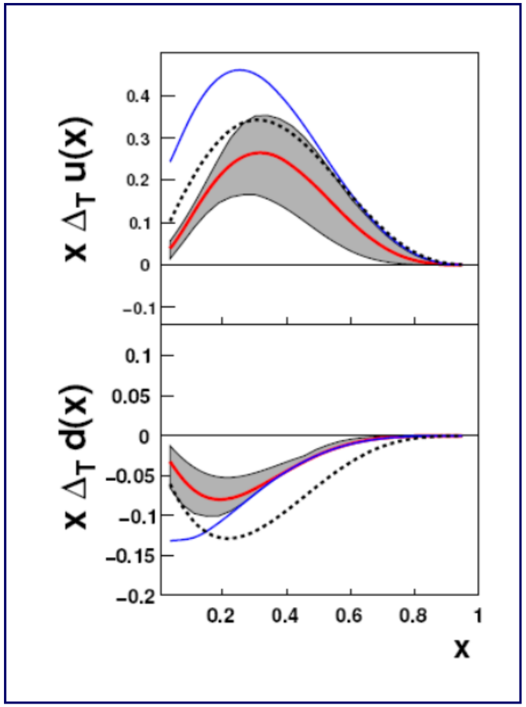
PLB693 2010

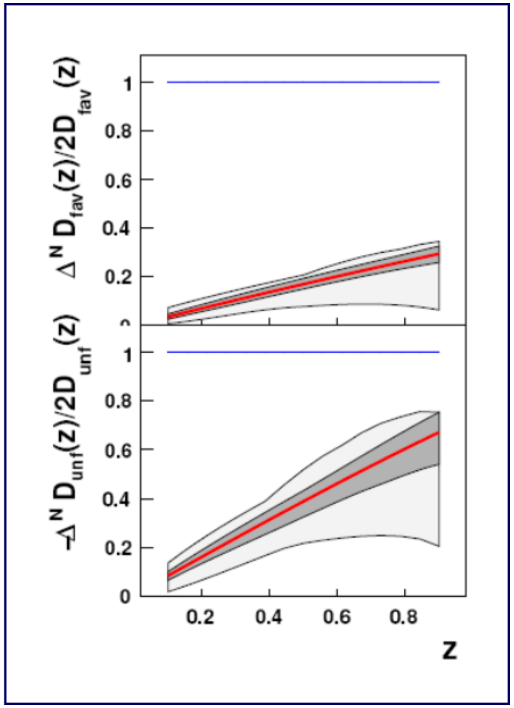
PLB744 2015

Transversity from SIDIS: Global Fit analysis

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

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





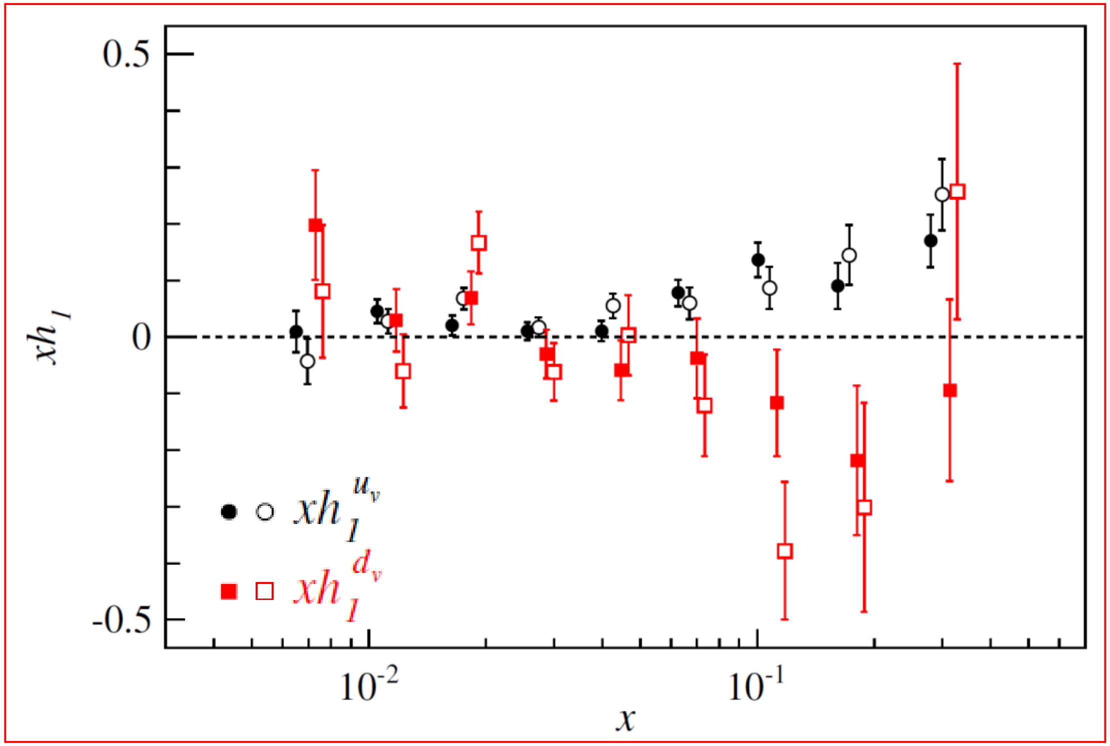
But it is not the only way→

Transversity from Collins and di-hadron asymmetries

point by point extraction

Directly use of the COMPASS p and d asymmetries, and the Belle data to evaluate the analyzing power (with some “reasonable” assumptions)

advantage: *no Monte Carlo nor parametrization is needed*



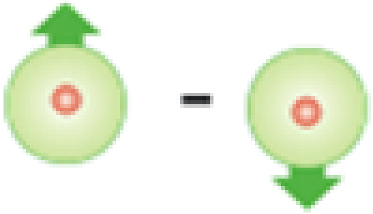
open points: di hadron

closed points: Collins

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

Semi Inclusive Deep Inelastic Scattering (SIDIS)

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



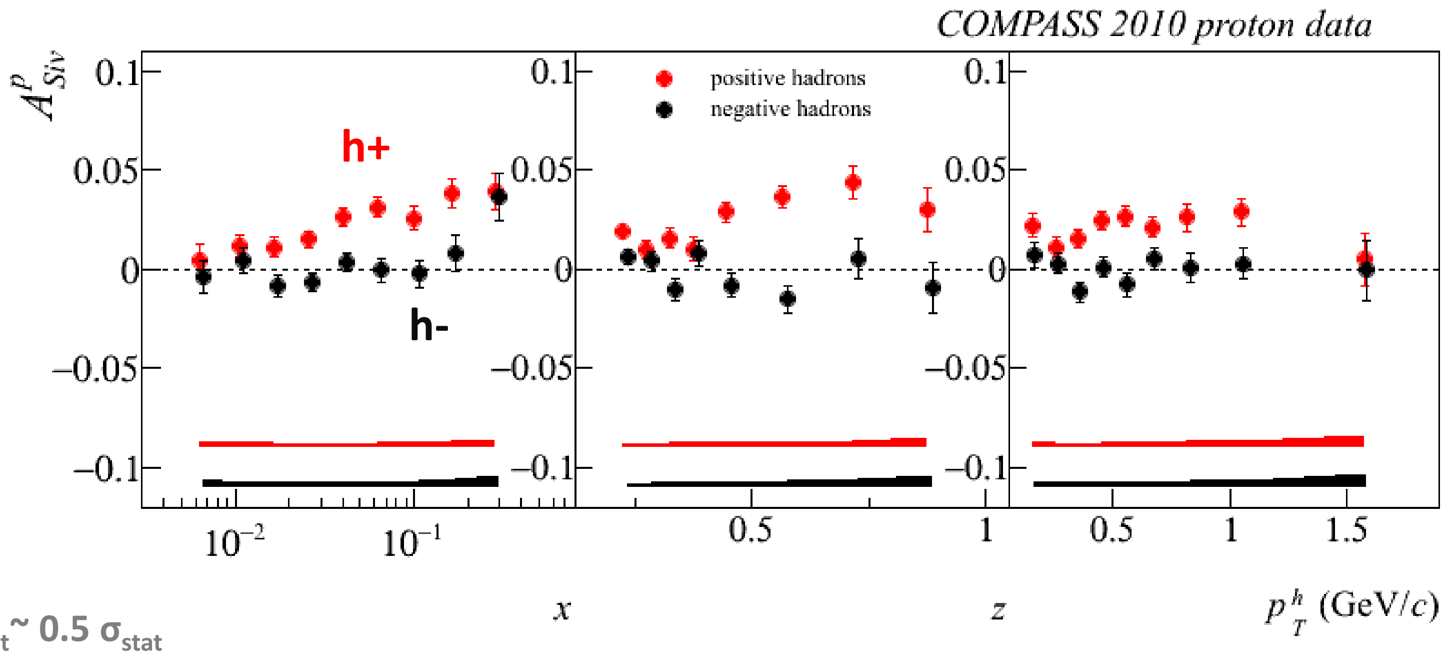
Sivers

Sivers asymmetry

correlation between the nucleon transverse polarization and the quark transverse momentum $k_{\perp}$

Sivers asymmetry on proton

charged hadrons 2010 data



σ_{syst}~ 0.5 σ_{stat}

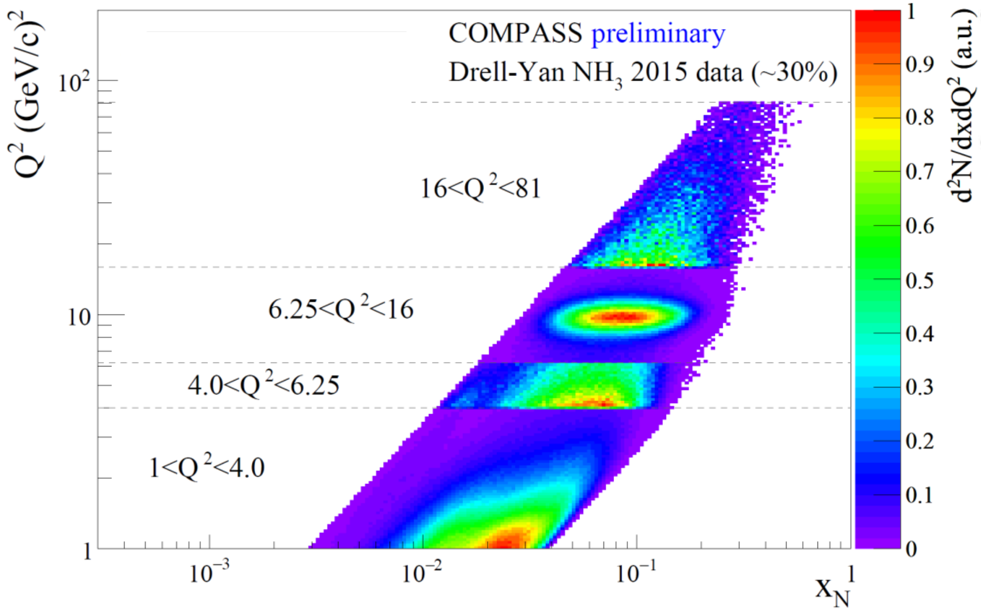
clear evidence for a positive signal for h^+, which extends to small x

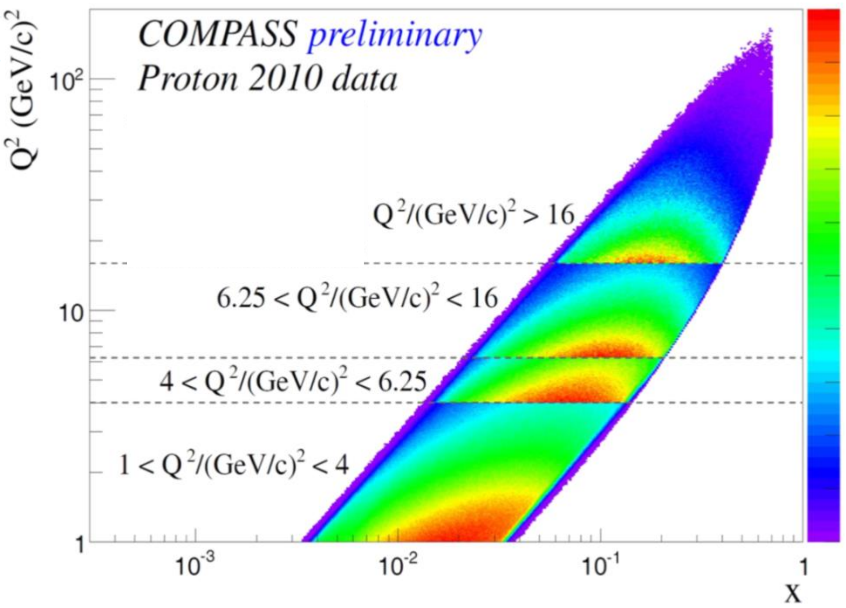
Sivers asymmetry on proton

COMPASS has measured the TSA in the 4 Q^2 ranges of the Drell-Yan experiment

Drell-Yan
190 GeV pion beam

SIDIS
160 muon beam





fundamental prediction pQCD
sign change between Sivers TMD
measured in SIDIS and in Drell-Yan

Next Talk by Robert Heitz

Sivers asymmetry on proton

multiD $(x, Q^2; z, P_T)$ analysis

an example:
Sivers
asymmetry

$P_T > 0.1\ \mathrm{GeV/c}$

COMPASS

SPIN2014

$0.1 < z < 0.2$ $0.2 < z < 0.4$ $0.4 < z < 1.0$

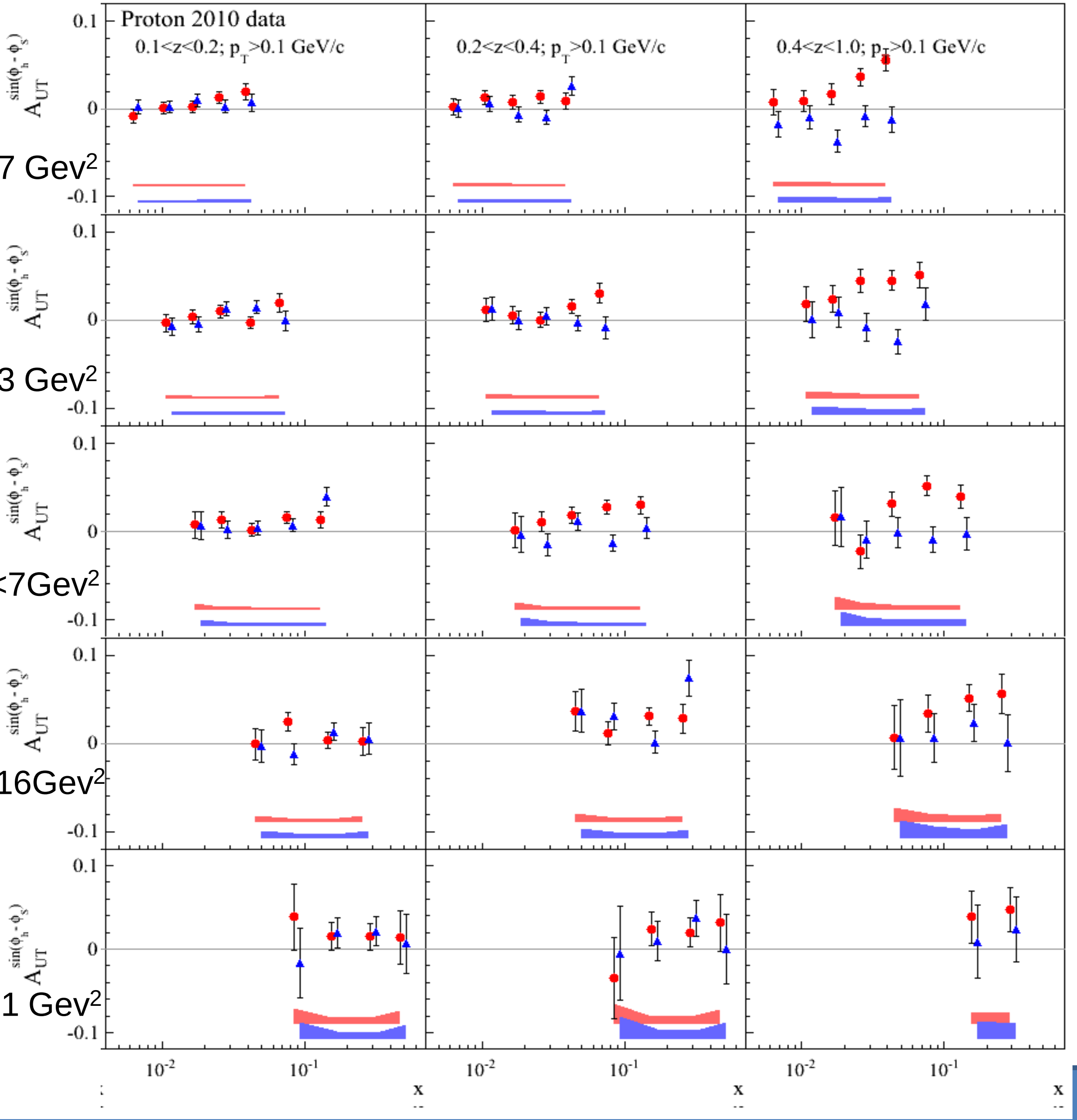
$1<Q^2<1.7$ Gev^2

$1.7<Q^2<3$ Gev^2

$3<Q^2<7$Gev^2

$7<Q^2<16$Gev^2

$16<Q^2<81$ Gev^2



The weighted Sivers asymmetry WORK in PROGRESS

Compute the Sivers Asymmetry by weighting the spin dependent part by

$$w = P_T/zM$$

Direct access to the first moment of the Sivers asymmetry!

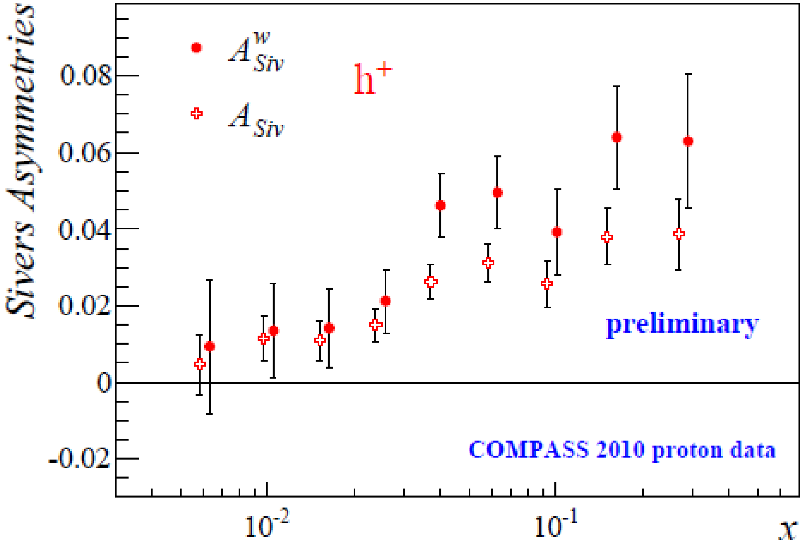
$$A^{w}_{Siv}(x) = \frac{\sigma^{w}_{Siv}}{\sigma_U} = 2\,\frac{\sum_q \boxed{e_q^2 x f_{1T}^{\perp(1)q}(x)} \int D_{1q}(z)dz}{\sum_q e_q^2 x f_1^q(x) \int D_{1q}(z)dz}$$

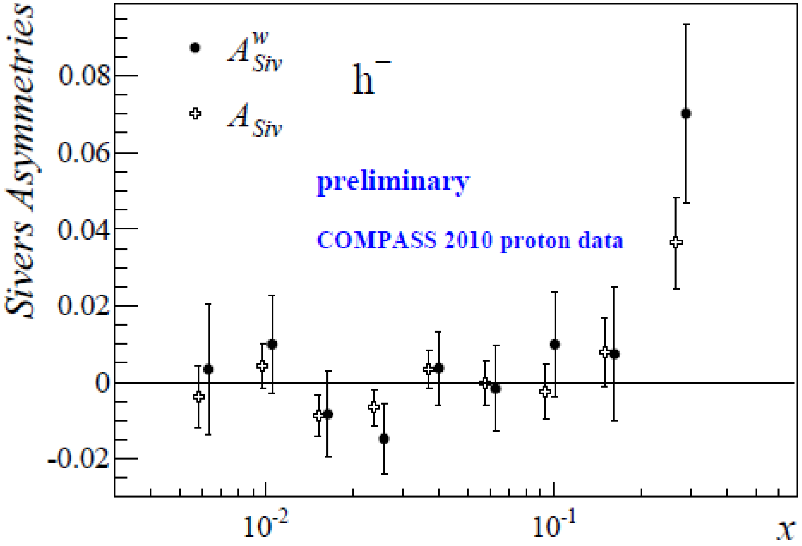
The weighted Sivers asymmetry

$$w = P_T/zM \qquad A^{w}_{Siv}(x) = \frac{\sigma^{w}_{Siv}}{\sigma_U} = 2\,\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\int D_{1q}(z)dz}{\sum_q e_q^2 x f_1^q(x)\int D_{1q}(z)dz}$$

● ✚ h^+

h^-





assuming u dominance
and for π+

$$A^{w}_{Siv}(x) \simeq 2\frac{x f_{1T}^{\perp(1)\,u}(x)}{x f_1^u(x)}$$

$A^{w}_{Siv}(x)$ SPIN2016,arXiv:1702.00621
$A^{w}_{Siv}(x)$ PLB717 (2012) 383

- The COMPASS experiment at CERN
- Longitudinal asymmetries in DIS
- Hadron multiplicities
- The Structure of the Nucleon : Transversity and TMD
- Unpolarized SIDIS

A selection of the many available results!

Unpolarized SIDIS: multiplicities

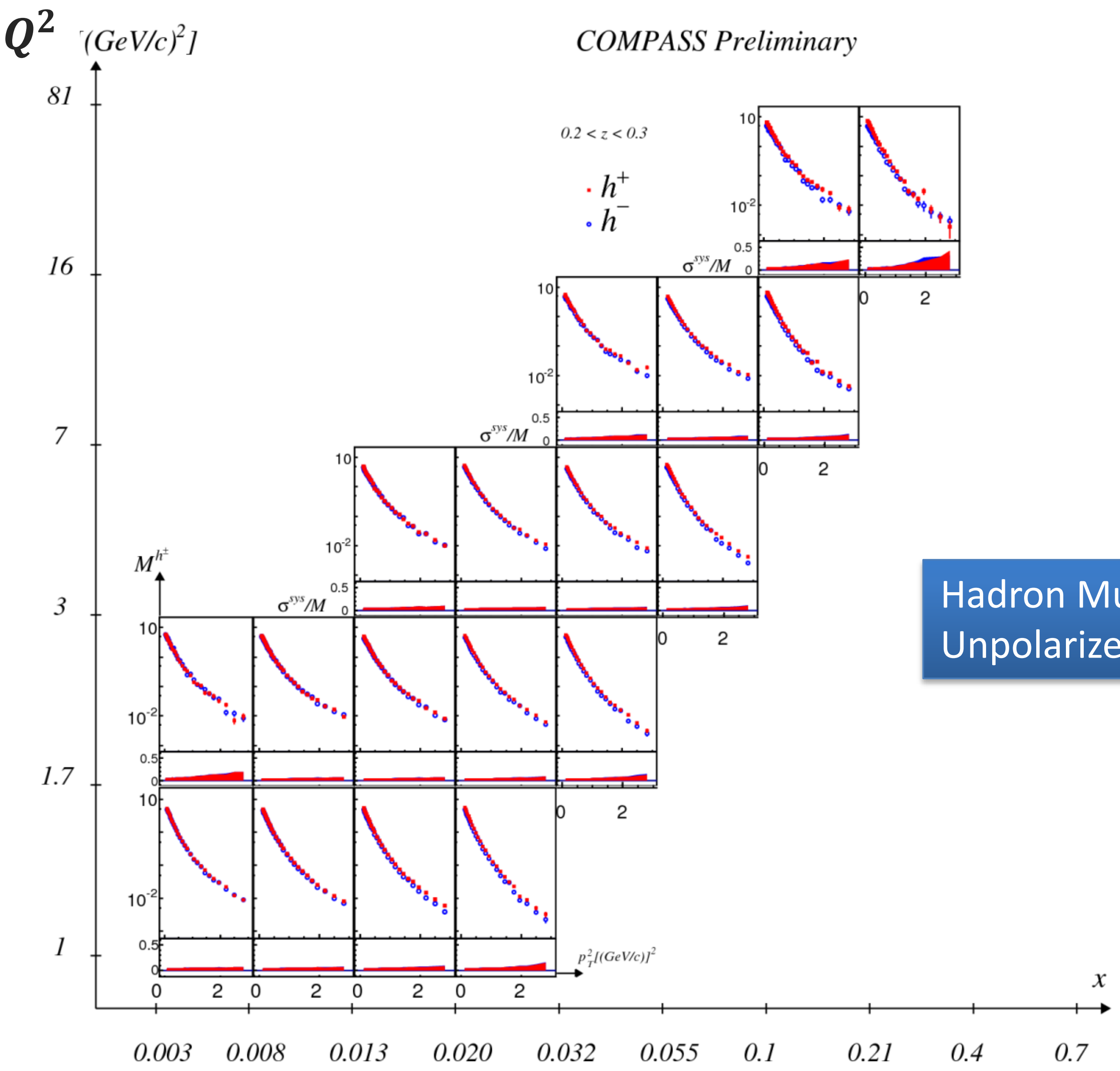
Relevance for TMDs:

- the cross-section dependence on $\boldsymbol{p_{Th}}$ comes from:
  - intrinsic k_T of the quarks
  - $p_\perp$ generated in the quark fragmentation

$$\langle \boldsymbol{p_{Th}}^2 \rangle = \langle p_\perp{}^2 \rangle + \boldsymbol{z}^2 \langle k_{\boldsymbol{T}}{}^2 \rangle$$

COMPASS
has produced results
on $\boldsymbol{{}^6LiD}$ $(\sim \boldsymbol{d})$ from
2004/6 data

Unpolarised SIDIS: multeplicities – p_{Th} distributions on deuteron



Hadron Multiplicities from Unpolarized SIDIS

Unpolarized SIDIS: multiplicities and azimuthal modulations of the cross section

Relevance for TMDs:

- the cross-section dependence on $\boldsymbol{p_{Th}}$ comes from:
  - intrinsic k_T of the quarks
  - $p_\perp$ generated in the quark fragmentation

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

COMPASS has produced results on $^6\boldsymbol{LiD}$ $(\sim\boldsymbol{d})$ from 2004/6 data

- the azimuthal modulations in the unpolarized cross-sections comes from:
  - intrinsic k_T of the quarks
  - Boer-Mulders PDF

COMPASS has produced results on $^6\boldsymbol{LiD}$ $(\sim\boldsymbol{d})$ from 2004 data

combined analysis should allow to disentangle the different effects

COMPASS

- Is measuring these observables in SIDIS on LH_2 in parallel with DVCS

Conclusions

SIDIS gave and is giving fundamental contributions to the study of the nucleon structure.

The COMPASS contribution is remarkable:

- Longitudinal spin structure→ structure function, helicity PDFs
- Transverse spin and momentum structure

  Sivers, transversity, Collins functions different from zero

to progress further

- comparison with different processes, from Drell-Yan to pp hard scattering
- more from SIDIS
  - new precise measurements at new facilities with different energies

    JLab12, EIC
  - COMPASS can still do a lot in the “consolidation” phase

    from existing data,

    with the LH2 data and hopefully in the future d↑

still a long way, a lot to be learned, and a lot of fun!