Overview of COMPASS results on spin

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on behalf of the COMPASS Collaboration

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Quy Nhon, Vietnam

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COMPASS experiment at CERN

Common Muon Proton Apparatus for Structure and Spectroscopy

$\gtrsim$ 200 collaborators

13 countries

24 institutes

Data taking since 2002

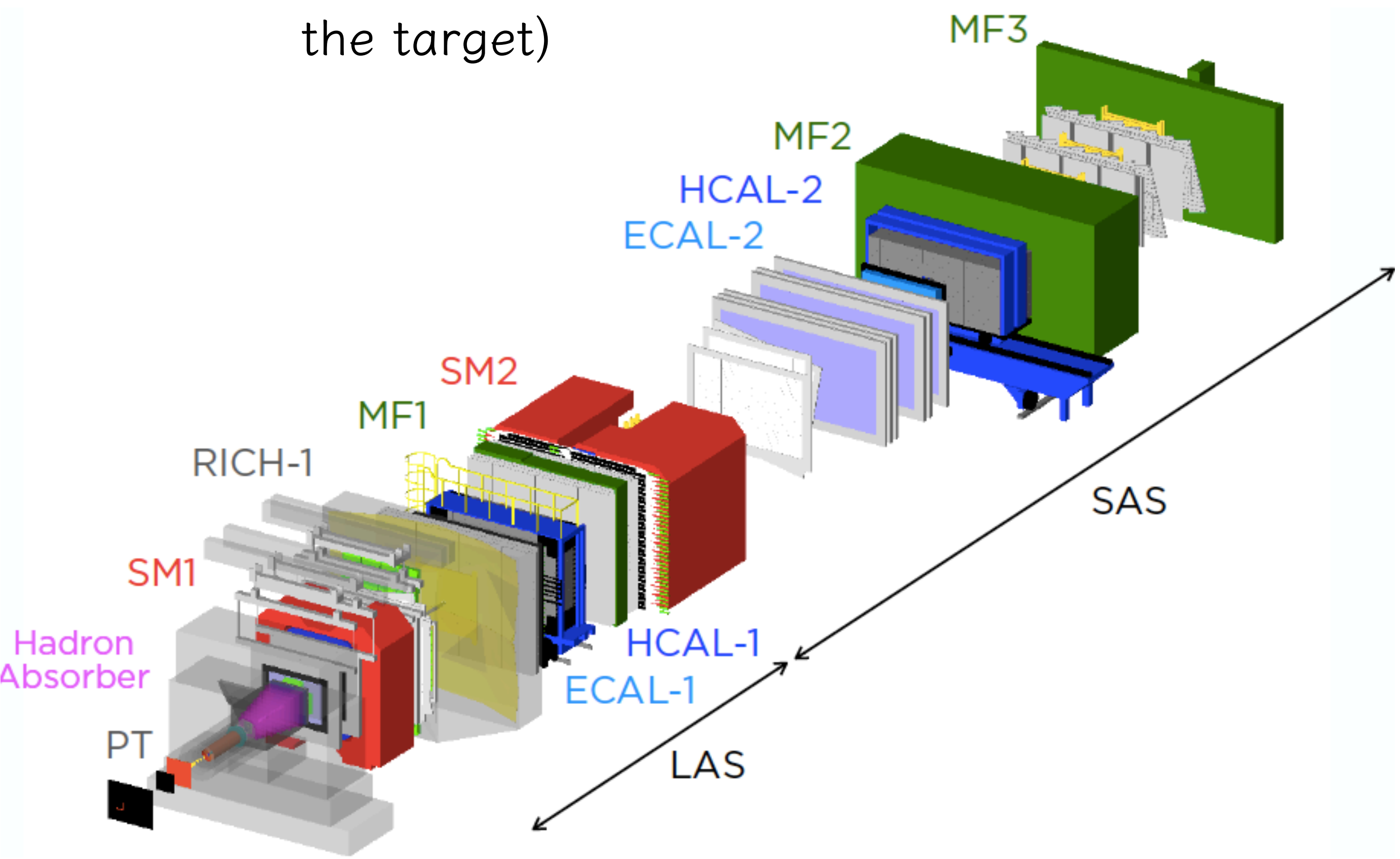
approved till 2021

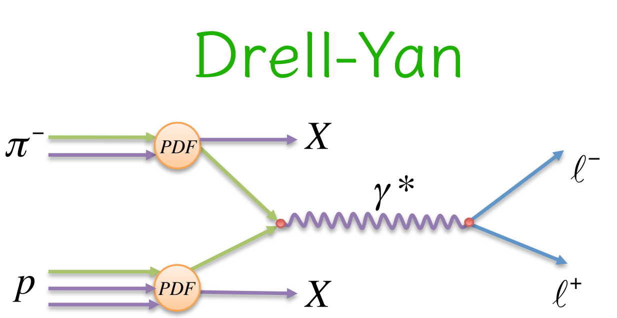
Fixed target experiment - General purpose spectrometer:

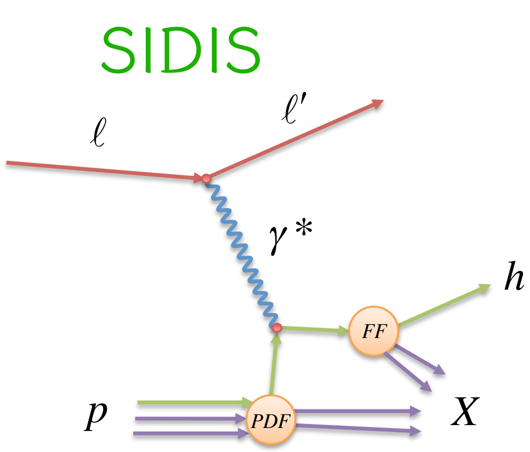
* Muon and hadron beams
* Polarised target (longitudinally and transversely polarised NH_3 and ^{6}LiD)
* Capability to identify the hadrons in final state (RICH detector)

COMPASS programmes

Drell-Yan setup (very similar to SIDIS apart from hadron absorber placed upstream of the target)







COMPASS data-takings

2002	deuteron SIDIS	20% trans., 80% long.
2003	deuteron SIDIS	20% trans., 80% long.
2004	deuteron SIDIS	20% trans., 80% long.
2005	shutdown	
2006	deuteron SIDIS	longitudinal
2007	proton SIDIS	50% trans., 50% long.
2008	Hadron run	
2009		
2010	proton SIDIS	transverse
2011	proton SIDIS	longitudinal
2012	Hadron run/DVCS run	
2013	shutdown	
2014		
2015	Drell-Yan run	transverse
2016	DVCS run, proton SIDIS	unpolarised
2017	DVCS run, proton SIDIS	unpolarised
2018	Drell-Yan run	transverse
2019	shutdown	
2020		
2021	deuteron SIDIS	transverse

COMPASS legacy on nucleon structure

Decomposition of the nucleon spin?

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

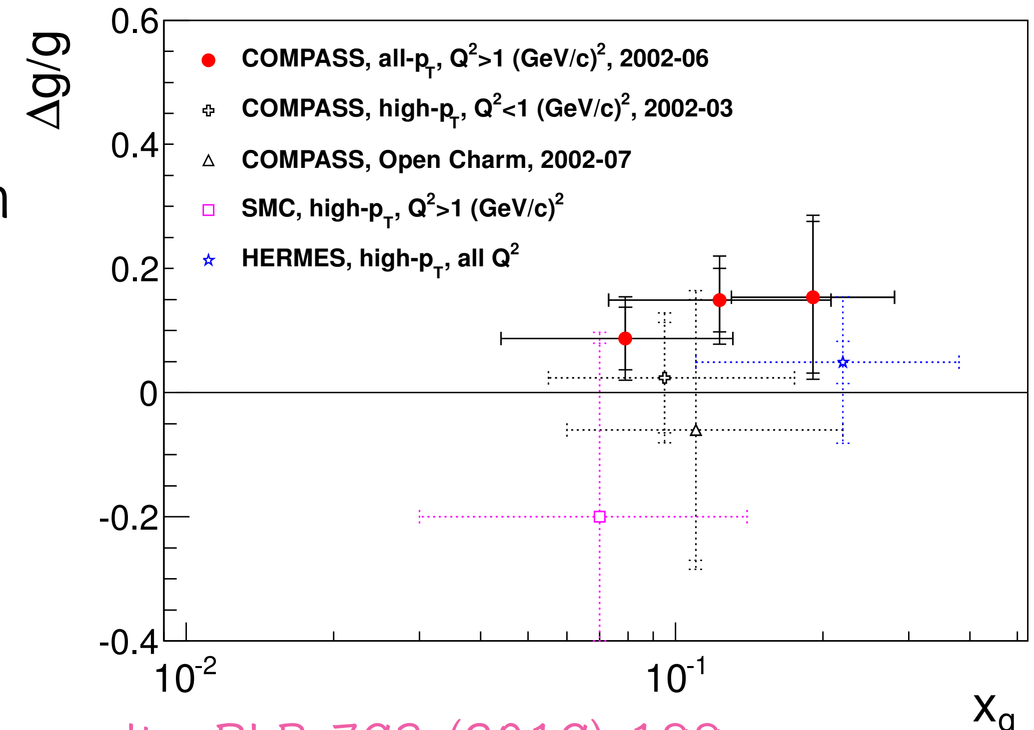
PLB 769 (2017) 34 - all d data

$$\Delta\Sigma = 0.32 \pm 0.02_{stat} \pm 0.04_{syst} \pm 0.05_{evol}$$

slightly positive in the measured region

under investigation, GPDs are the most direct way to access it

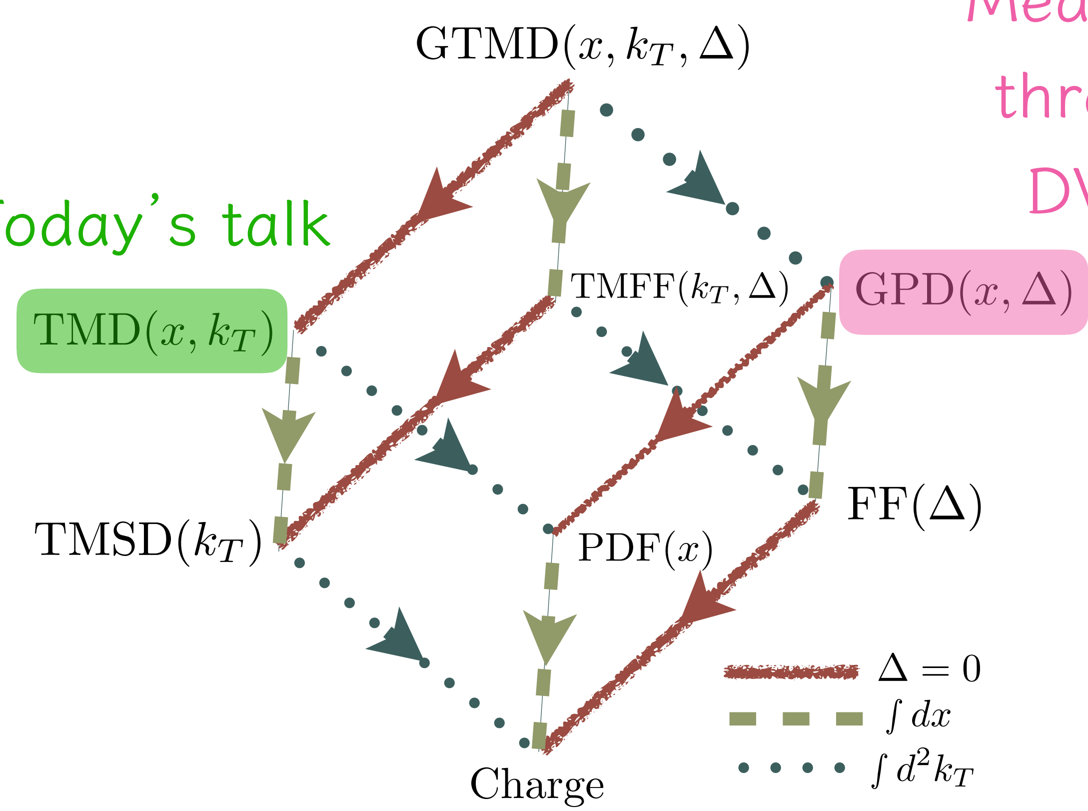
EPJC 77 (2017) 209



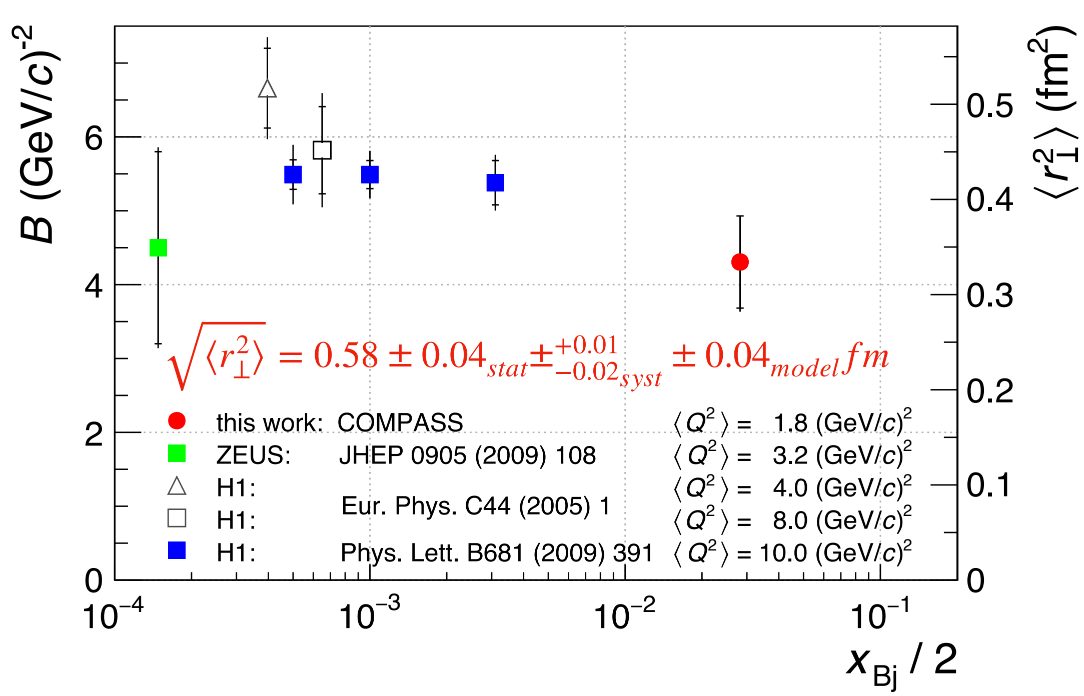
A step forward on 3D structure of the nucleon?

Today's talk

Measured through DVCS



1st DVCS result - PLB 793 (2019) 188



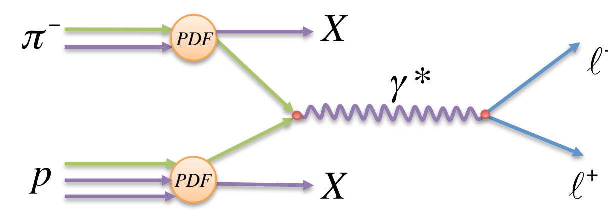
transverse extension of partons in proton

Nucleon structure

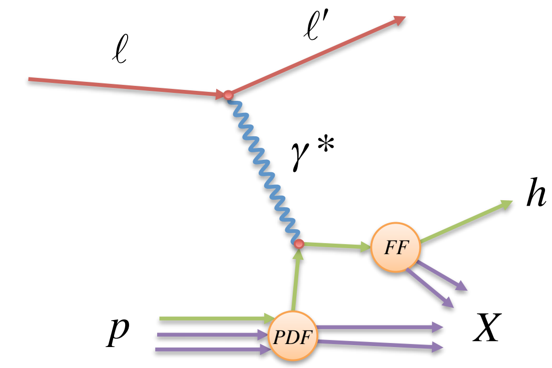
Collinear structure:

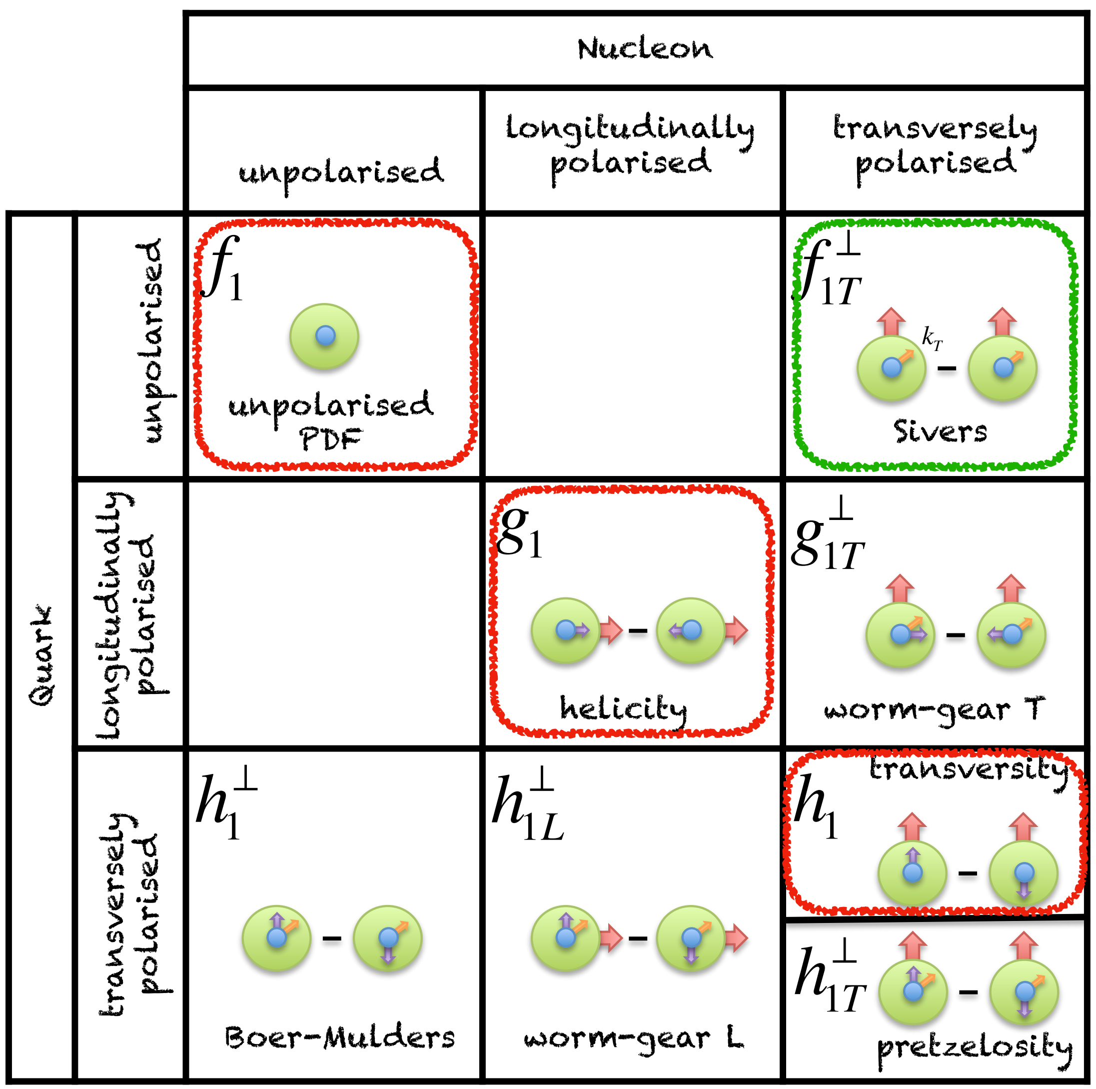
- unpolarised PDF
- helicity
- transversity (unmeasured until 2005, not accessible through DIS)
  - Can be accessed through SIDIS and Drell-Yan

Drell-Yan



SIDIS





Taking the intrinsic transverse momentum, k_T, into account:

- 8 TMD PDFs are needed to describe the nucleon
- related to nucleon spin-quark spin and/or spin-k_T correlations
- A special focus goes for Sivers TMD PDF, which sign is process dependent (has an opposite sign when accessed from Drell-Yan or SIDIS)

SIDIS cross-section

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

$$\Big[1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h$$
$$+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h$$

unpolarised target

$$+S_L\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right)$$
$$+S_L\lambda\left(\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right)$$

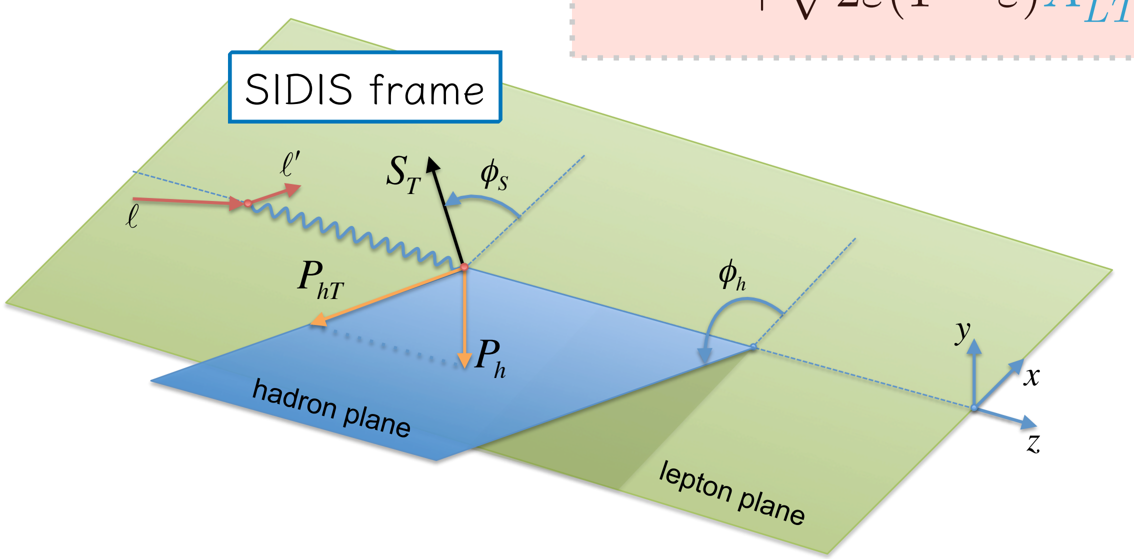
longitudinal polarised target

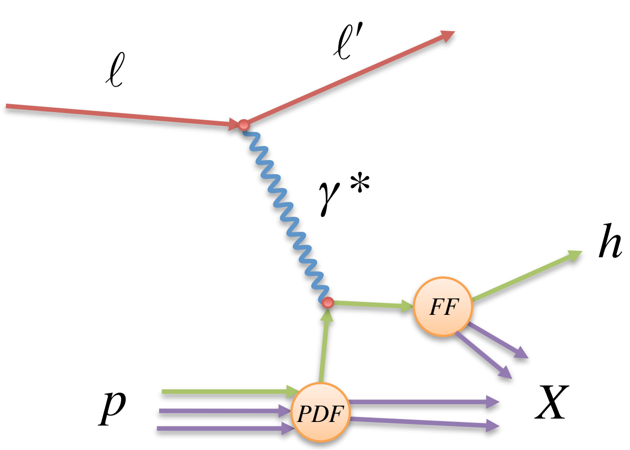
$$+S_T\left(A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)\right.$$
$$+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S$$
$$\left.+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\right)$$
$$+S_T\lambda\left(\sqrt{1-\varepsilon^2}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S\right.$$
$$\left.+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\right)\Big]$$

transverse polarised target

All these 3 target polarisation dependent parts will be mentioned on today's talk

SIDIS frame





Drell-Yan cross-section

$$A_U^1 = \lambda, A_U^{\cos\varphi_{cs}} = \mu, A_U^{\cos 2\varphi_{cs}} = \nu/2$$

$$\frac{d\sigma^{DY}}{dq^4 d\Omega} \propto (F_U^1 + F_U^2)$$

$$\Big\{1 + A_U^1 \cos^2\theta_{cs} + \sin 2\theta_{cs} A_U^{\cos\varphi_{cs}} \cos\varphi_{cs} + \sin^2\theta_{cs} A_U^{\cos 2\varphi_{cs}} \cos 2\varphi_{cs}$$

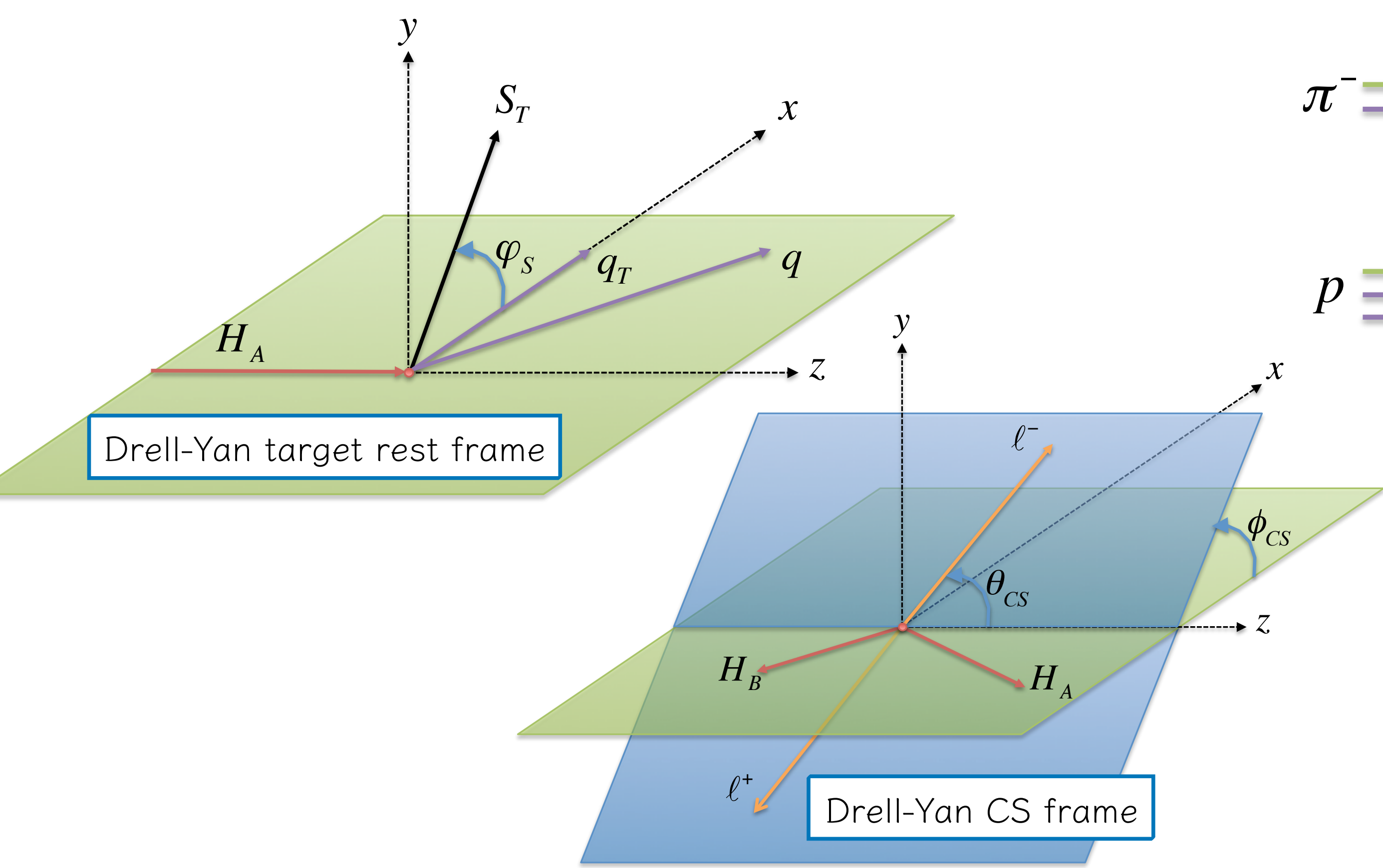
unpolarised target

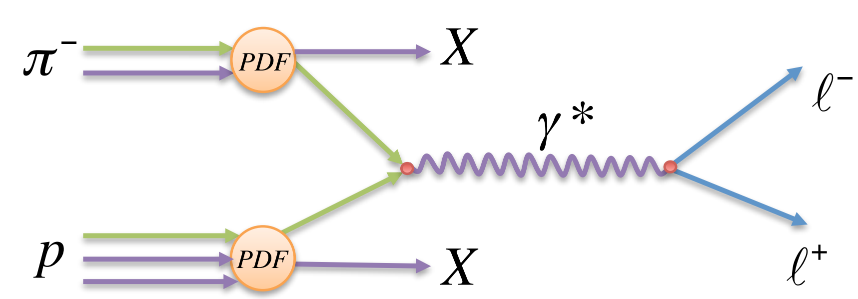
$$+S_L \left[\sin\theta_{cs} A_L^{\sin\varphi_{cs}} \sin\varphi_{cs} + \sin^2\theta_{cs} A_L^{\sin 2\varphi_{cs}} \sin 2\varphi_{cs}\right]$$

longitudinal polarised target

$$+S_T \Big[\Big(A_T^{\sin\varphi_s} + \cos^2\theta_{cs} \tilde{A}_T^{\sin\varphi_s}\Big)\sin\varphi_s$$
$$+\sin^2\theta_{cs}\Big(A_T^{\sin(2\varphi_{cs}-\varphi_s)}\sin(2\varphi_{cs}-\varphi_s) + A_T^{\sin(2\varphi_{cs}+\varphi_s)}\sin(2\varphi_{cs}+\varphi_s)\Big)$$
$$+\sin 2\theta_{cs}\Big(A_T^{\sin(\varphi_{cs}-\varphi_s)}\sin(\varphi_{cs}-\varphi_s) + A_T^{\sin(\varphi_{cs}+\varphi_s)}\sin(\varphi_{cs}+\varphi_s)\Big)\Big]\Big\}$$

transverse polarised target



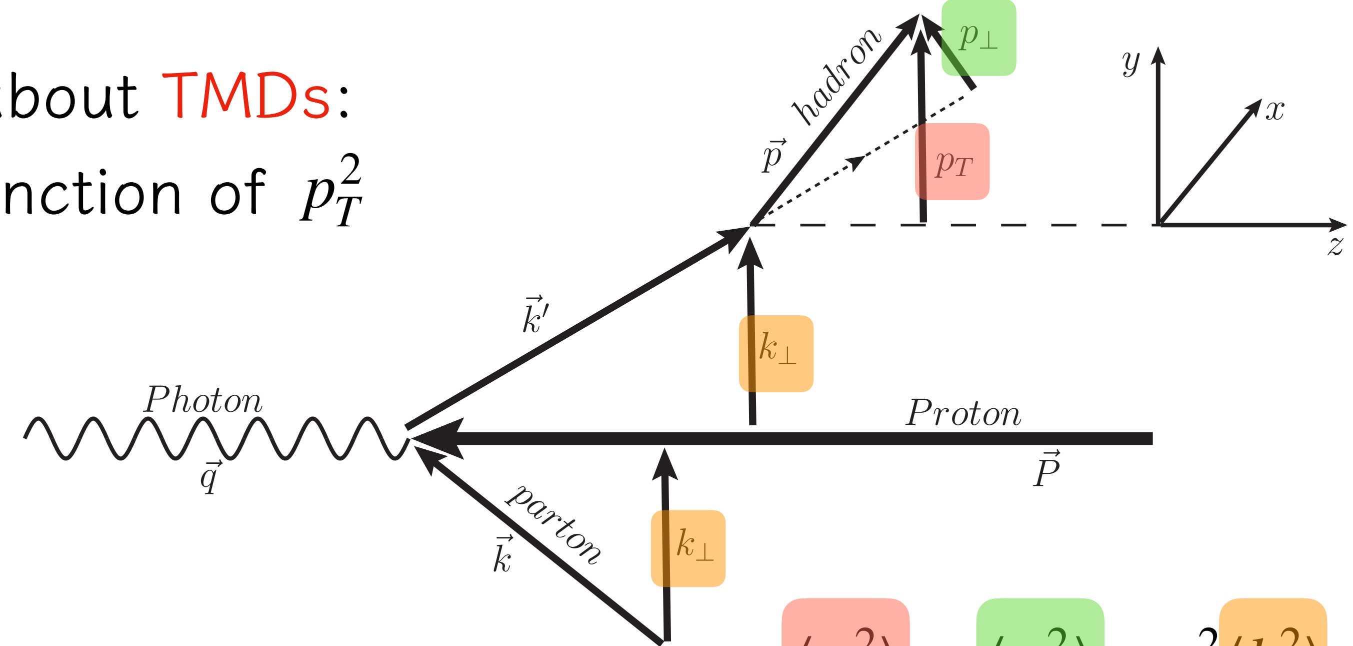


Only transverse target polarisation part will be mentioned on today's talk

Unpolarised SIDIS

Unpolarised SIDIS observables to learn about TMDs:

- differential hadron multiplicities as a function of p_T^2
- azimuthal asymmetries



$$\langle p_T^2\rangle \sim \langle p_\perp^2\rangle + z^2\langle k_T^2\rangle$$

$$\begin{aligned}
\frac{d\sigma^{SIDIS}}{dxdydzdp_T^2d\phi_h d\phi_S} = &\left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right](F_{UU,T}+\varepsilon F_{UU,L}) \\
&\Big[1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h \\
&+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h \\
&+S_L\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right) \\
&+S_L\lambda\left(\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right) \\
&+S_T\Big(A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S) \\
&\quad+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S \\
&\quad+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\Big) \\
&+S_T\lambda\Big(\sqrt{1-\varepsilon^2}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S \\
&\quad+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\Big)\Big]
\end{aligned}$$

unpolarised target

COMPASS papers/results:

Multiplicities as a function of pT^2:

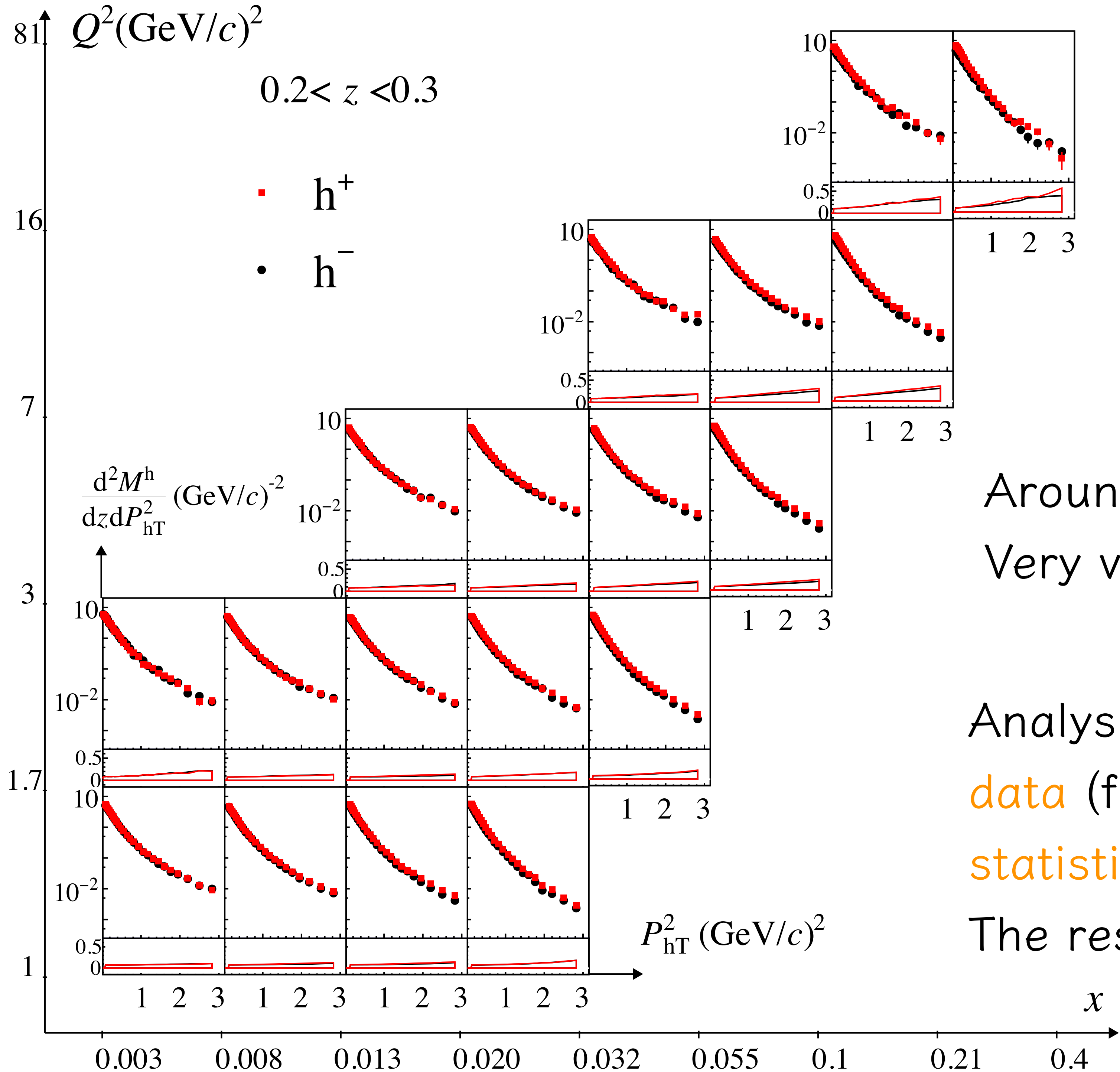
1. 2004 d SIDIS data - EPJC 73 (2013) 2531
2. 2006 d SIDIS data - PRD 97 (2018) 032006

Azimuthal asymmetries:

3. 2004 d SIDIS data - Nucl.Phys.B 886 (2014) 1046
4. 2016-2017 p SIDIS data - proceedings for SPIN2018

Unpolarised SIDIS - Multiplicities

d data - PRD 97 (2018) 032006



Compatible w/ previous measurement (EPJC 73 (2013) 2531) but w/ a wide kinematical coverage and statistical improvement

h^+ only slightly larger than h^-

Around 5000 points

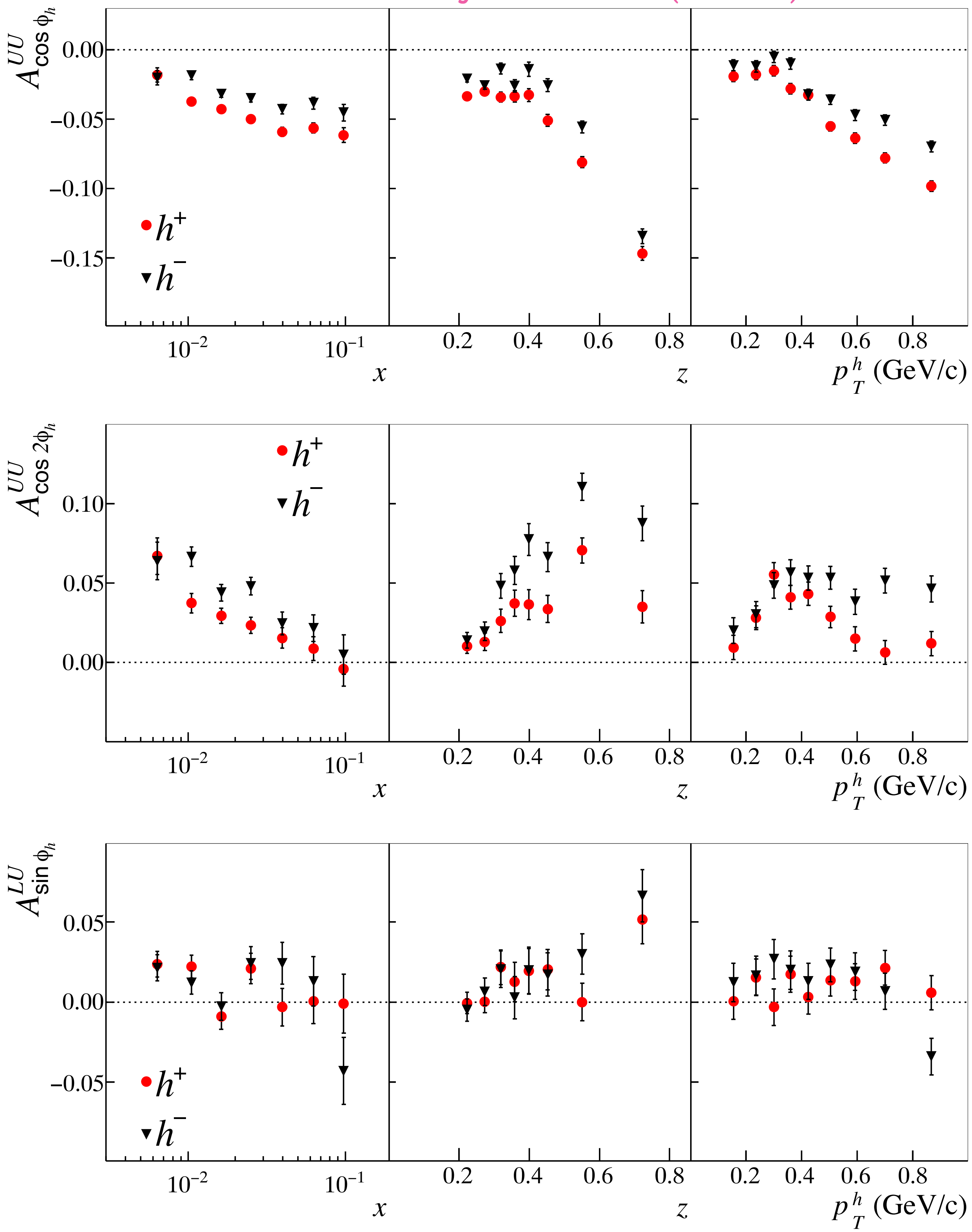
Very valuable input for global analysis

Analysis using 2016+2017 SIDIS proton data (from DVCS runs) is ongoing (higher statistics sample)

The results are consistent w/ d data

Unpolarised SIDIS - Azimuthal asymmetries from d

d data - Nucl.Phys.B 886 (2014) 1046



Higher twist effects

large asymmetries for both hadrons

larger for h^+ than for h^-

convolution between

Boer-Mulders TMD and Collins FF

large asymmetries for both hadrons

larger for h^- than for h^+

Higher twist effects

non-zero asymmetry

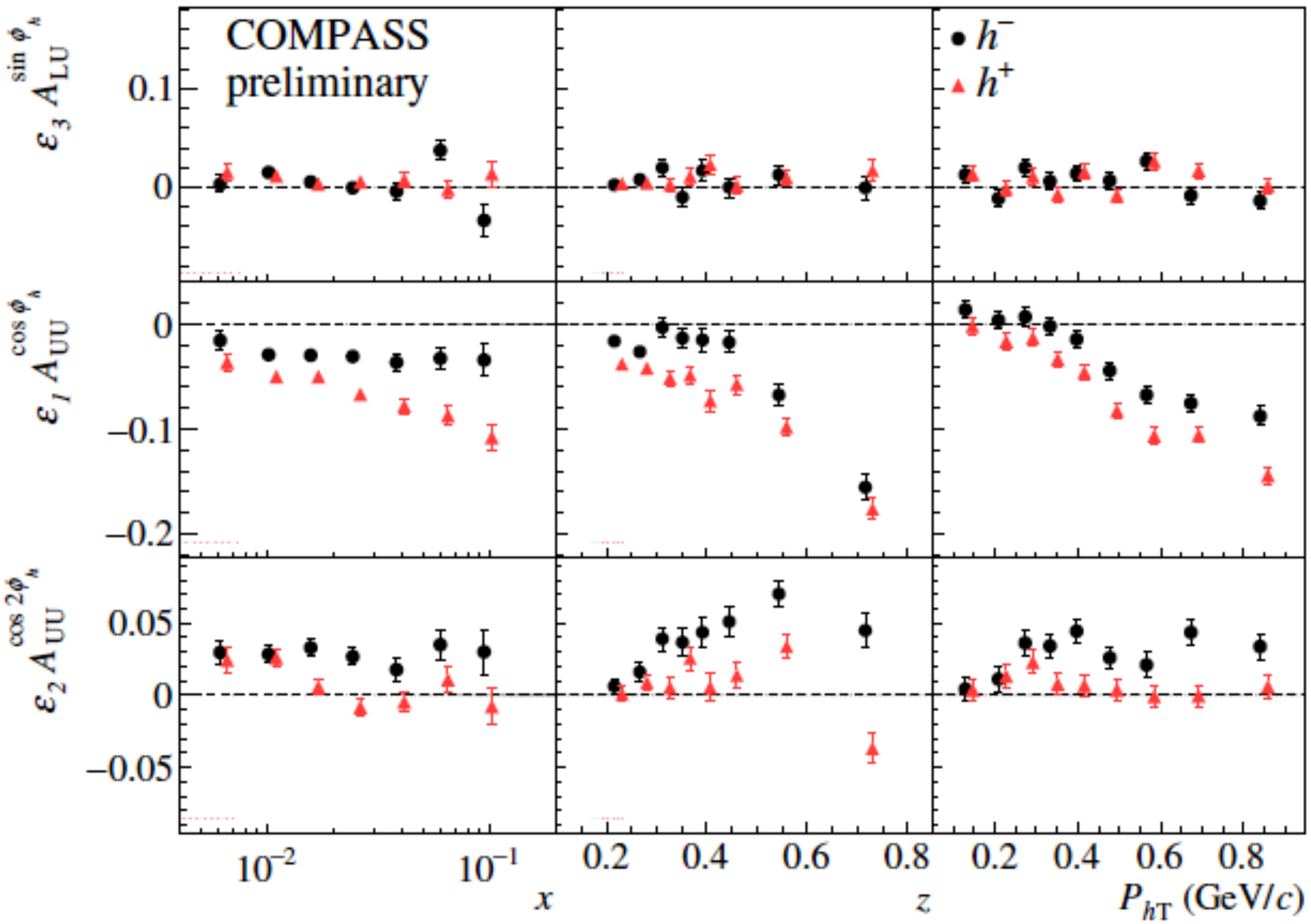
but w/ large uncertainties

Unpolarised SIDIS - Azimuthal asymmetries from p

same strong kinematic dependences

significant improvement wrt d data

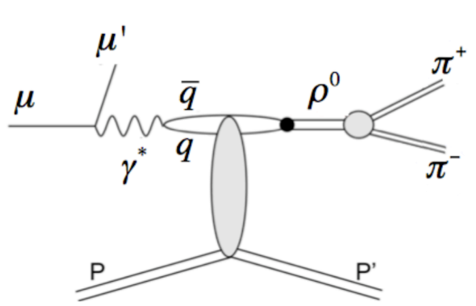
4% of statistics from 2016 data (proceedings for SPIN 2018)



Future plans:

- use full statistics from 2016+2017
- multi-dimensional analysis
- remove diffractive vector meson contributions
- hadrons identification (pions, kaons)

diffractive ρ^0 production and decay



Longitudinal target spin asymmetries

all the possible asymmetries have been measured, using:

- single hadron SIDIS on deuteron and proton

COMPASS papers/results:

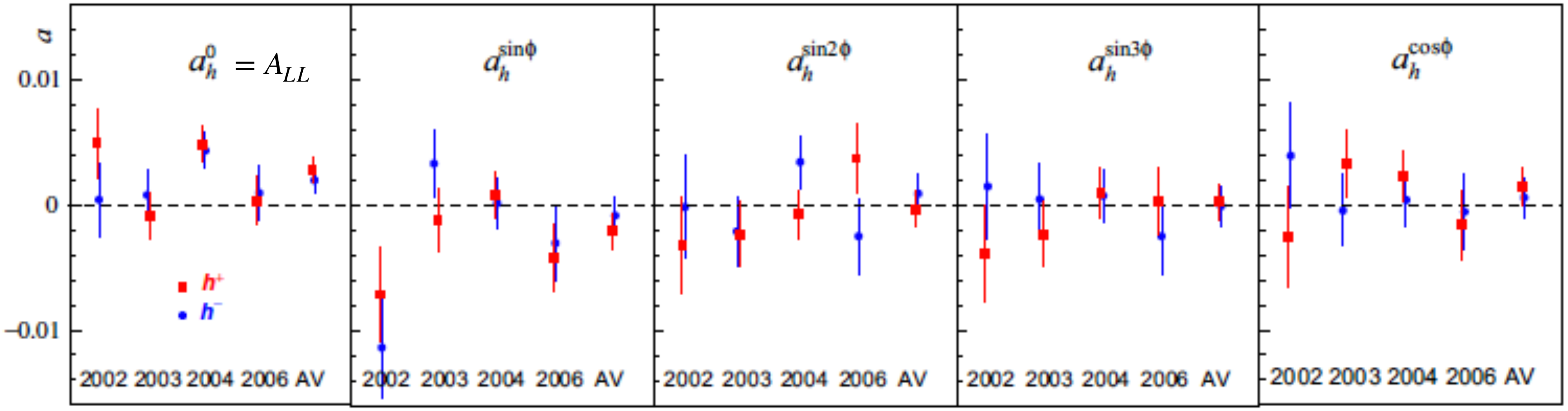
1. 2002-2004 d SIDIS data - EPJC 70 (2010) 39
2. 2002-2004 + 2006 d SIDIS data - EPJC 78 (2018) 952
3. 2007 + 2011 - p SIDIS data - proceedings for DIS2017 (arXiv:1801.01488)

$$\frac{d\sigma^{SIDIS}}{dxdydzdp_T^2d\phi_h d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right](F_{UU,T}+\varepsilon F_{UU,L})$$
$$\left[1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h\right.$$
$$+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h$$
$$+S_L\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right)$$
$$+S_L\lambda\left(\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right)$$
$$+S_T\left(A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)\right.$$
$$+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S$$
$$\left.+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\right)$$
$$+S_T\lambda\left(\sqrt{1-\varepsilon^2}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S\right.$$
$$\left.\left.+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\right)\right]$$

longitudinal polarised target

Longitudinal target spin asymmetries from deuteron

d data - EPJC 78 (2018) 952



all the asymmetries are very small and/or compatible w/ zero

Longitudinal target spin asymmetries from proton

2007 + 2011 - longitudinal proton - proceedings for DIS2017 (arXiv:1801.01488)

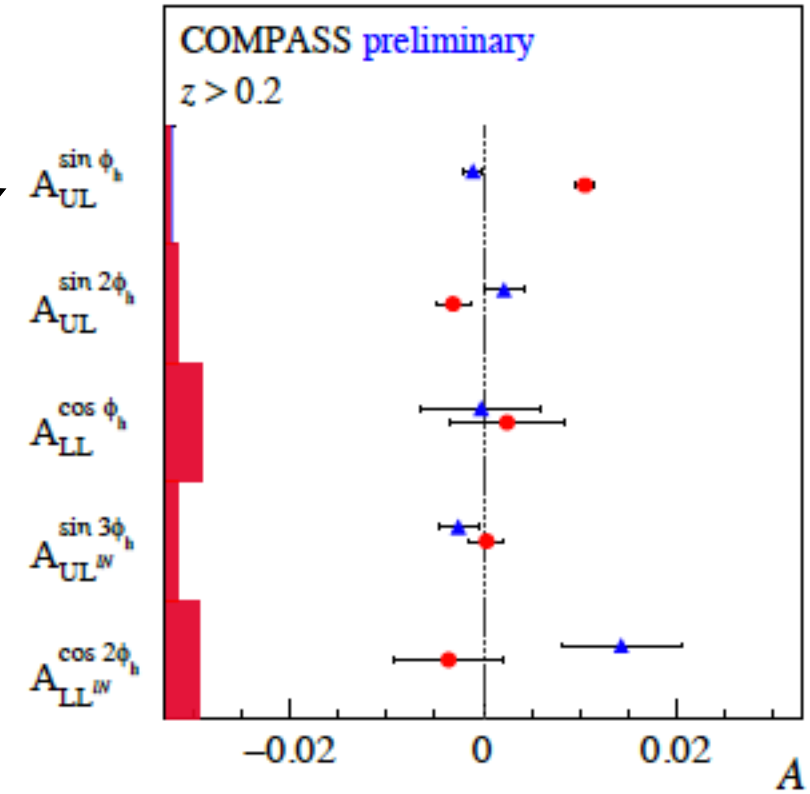
unprecedented precision when compared to HERMES and CLAS, and w/ a better kinematic coverage

positive for h^+, h^- compatible with zero

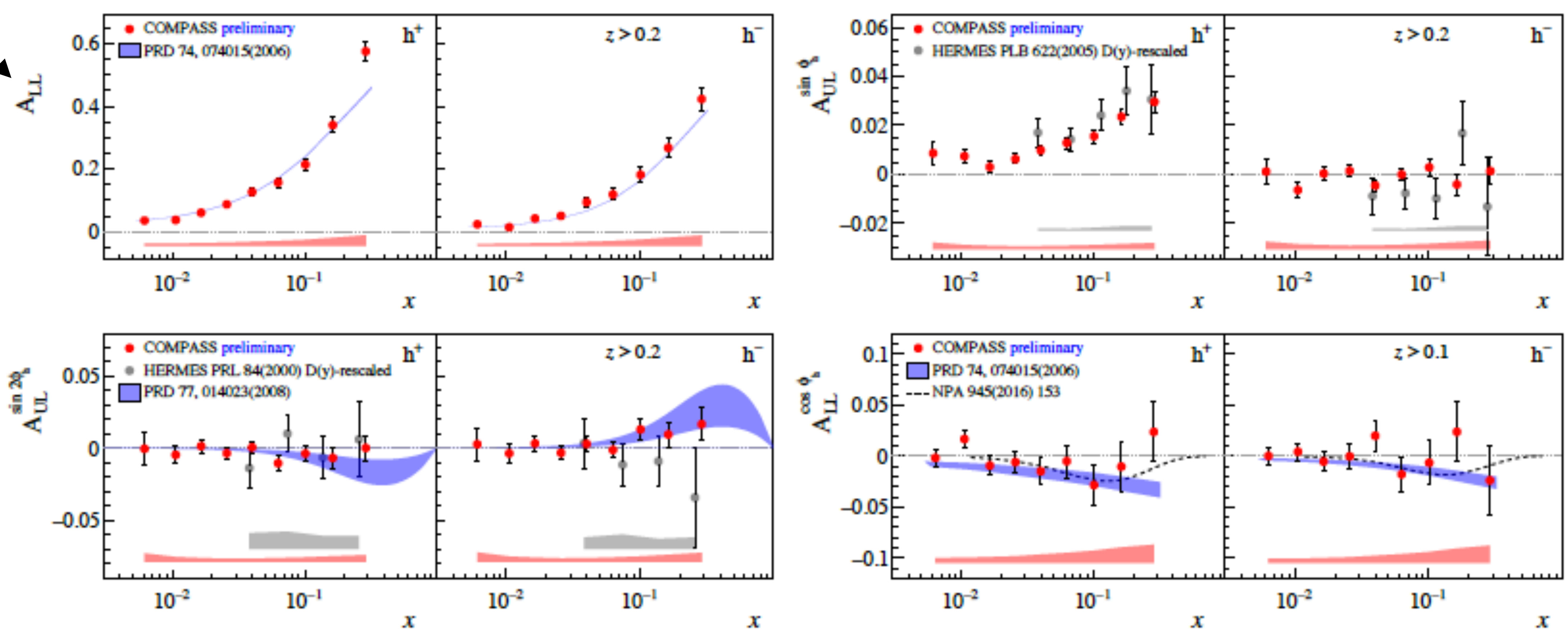
Higher twist effects

very small effects

compatible with model predictions



related to helicity PDF



Transverse target spin asymmetries

all the possible asymmetries have been measured, using:

- single hadron SIDIS on d and p
- dihadron SIDIS on d and p
- transversely polarised Drell-Yan

Today's talk

COMPASS papers/results:

single hadron SIDIS asymmetries and Drell-Yan TSAs:

1. 2002 d SIDIS data - PRL 94 (2005) 202002
2. 2003-2004 d SIDIS data - Nucl. Phys. B 765 (2007) 31
3. 2002-2004 d SIDIS data - PLB 673 (2009) 127
4. 2007 p SIDIS data - PLB 692 (2010) 240
5. 2010 p SIDIS data - PLB 717 (2012) 376 (Collins)
   PLB 717 (2012) 383 (Sivers)
6. 2007, 2010 p SIDIS data - PLB 744 (2015) 250
7. 2010 p SIDIS data - PLB 770 (2017) 138
8. 2015 Drell-Yan data - PRL 119 (2017) 112002

dihadron asymmetries (transversity):

9. 2002-2004 d SIDIS data + 2007 p SIDIS data - PLB 713 (2012) 10
10. 2007, 2010 p SIDIS data - PLB 736 (2014) 124

comparison between single hadron and dihadron transversely induced asymmetries:

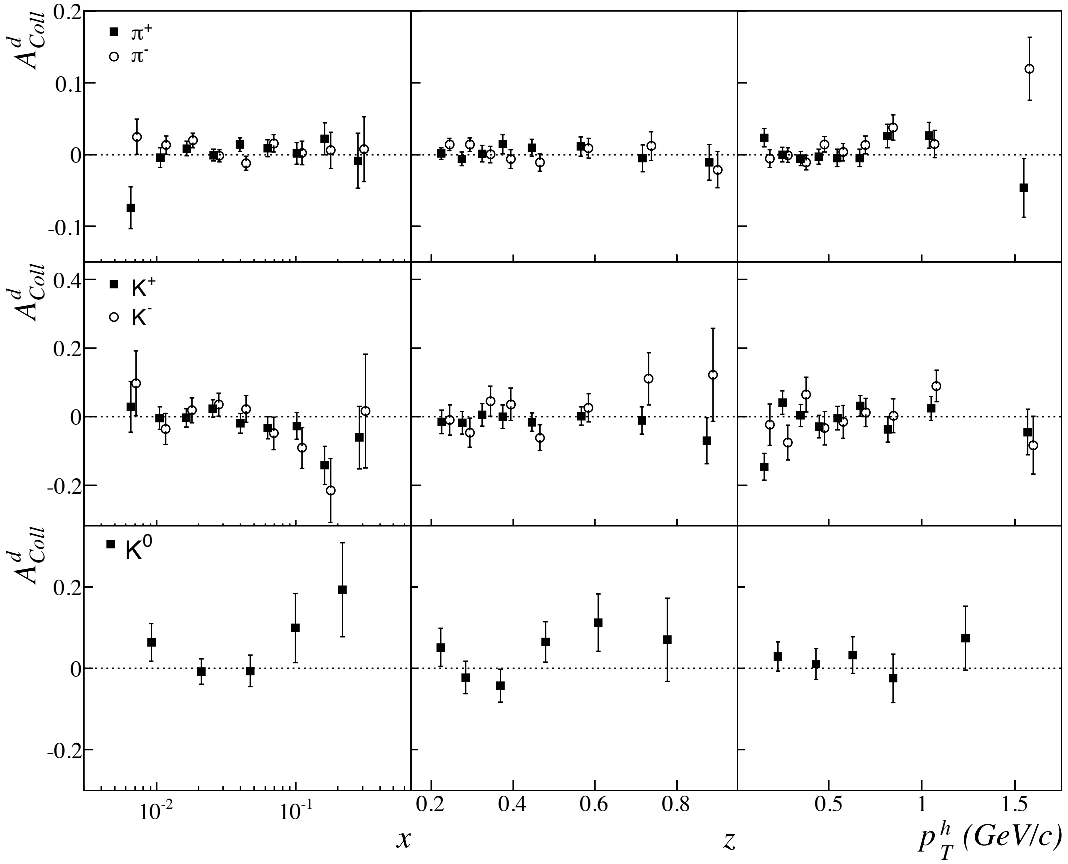
11. 2010 p SIDIS data - PLB 753 (2016) 406

$$\frac{d\sigma^{SIDIS}}{dx\,dy\,dz\,dp_T^2\,d\phi_h\,d\phi_S} = \left[\frac{\alpha}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\right](F_{UU,T}+\varepsilon F_{UU,L})$$
$$\Big[1+\sqrt{2\varepsilon(1+\varepsilon)}A_{UU}^{\cos\phi_h}\cos\phi_h+\varepsilon A_{UU}^{\cos 2\phi_h}\cos 2\phi_h$$
$$+\lambda\sqrt{2\varepsilon(1-\varepsilon)}A_{LU}^{\sin\phi_h}\sin\phi_h$$
$$+S_L\left(\sqrt{2\varepsilon(1+\varepsilon)}A_{UL}^{\sin\phi_h}\sin\phi_h+\varepsilon A_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right)$$
$$+S_L\lambda\left(\sqrt{1-\varepsilon^2}A_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}A_{LL}^{\cos\phi_h}\cos\phi_h\right)$$
$$+S_T\Big(A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)+\varepsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)$$
$$+\varepsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin\phi_S}\sin\phi_S$$
$$+\sqrt{2\varepsilon(1+\varepsilon)}A_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\Big)$$
$$+S_T\lambda\Big(\sqrt{1-\varepsilon^2}A_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos\phi_S}\cos\phi_S$$
$$+\sqrt{2\varepsilon(1-\varepsilon)}A_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\Big)\Big]$$

transverse polarised target

$$\frac{d\sigma^{DY}}{dq^4 d\Omega}\propto(F_U^1+F_U^2)$$
$$\Big\{1+A_U^1\cos^2\theta_{cs}+\sin 2\theta_{cs}A_U^{\cos\varphi_{cs}}\cos\varphi_{cs}+\sin^2\theta_{cs}A_U^{\cos 2\varphi_{cs}}\cos 2\varphi_{cs}$$
$$+S_L\left[\sin\theta_{cs}A_L^{\sin\varphi_{cs}}\sin\varphi_{cs}+\sin^2\theta_{cs}A_L^{\sin 2\varphi_{cs}}\sin 2\varphi_{cs}\right]$$
$$+S_T\Big[\left(A_T^{\sin\varphi_s}+\cos^2\theta_{cs}\tilde{A}_T^{\sin\varphi_s}\right)\sin\varphi_s$$
$$+\sin^2\theta_{cs}\left(A_T^{\sin(2\varphi_{cs}-\varphi_s)}\sin(2\varphi_{cs}-\varphi_s)+A_T^{\sin(2\varphi_{cs}+\varphi_s)}\sin(2\varphi_{cs}+\varphi_s)\right)$$
$$+\sin 2\theta_{cs}\left(A_T^{\sin(\varphi_{cs}-\varphi_s)}\sin(\varphi_{cs}-\varphi_s)+A_T^{\sin(\varphi_{cs}+\varphi_s)}\sin(\varphi_{cs}+\varphi_s)\right)\Big]\Big\}$$

TSAs: Collins from SIDIS



d data - PLB 673 (2009) 127

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

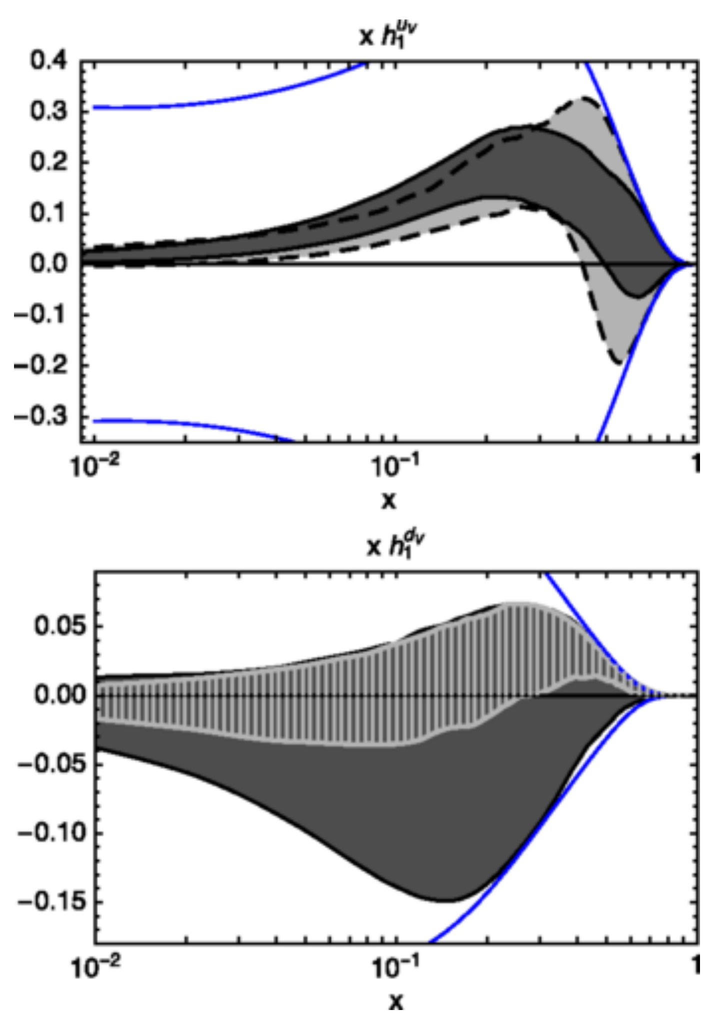
transversity Collins FF

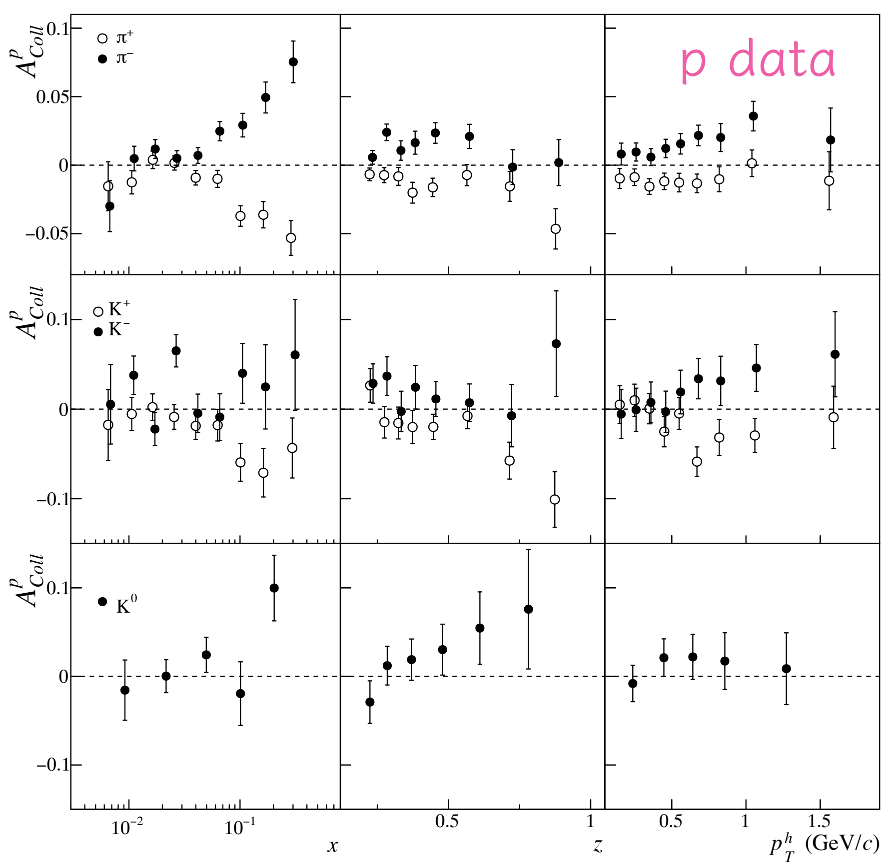
- compatible w/ zero
- only d data available on world
  - more data to come: COMPASS 2021 run
  - impact on the sign of transversity for d-quark

transversity

global analysis

PRL 120 (2018) 192001





p data

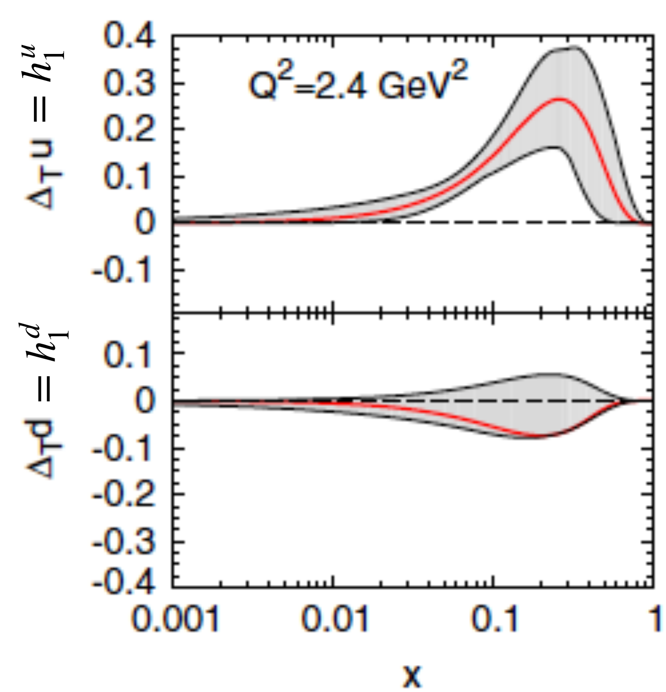
PLB 744 (2015) 250

- negative for h⁺
- positive for h⁻

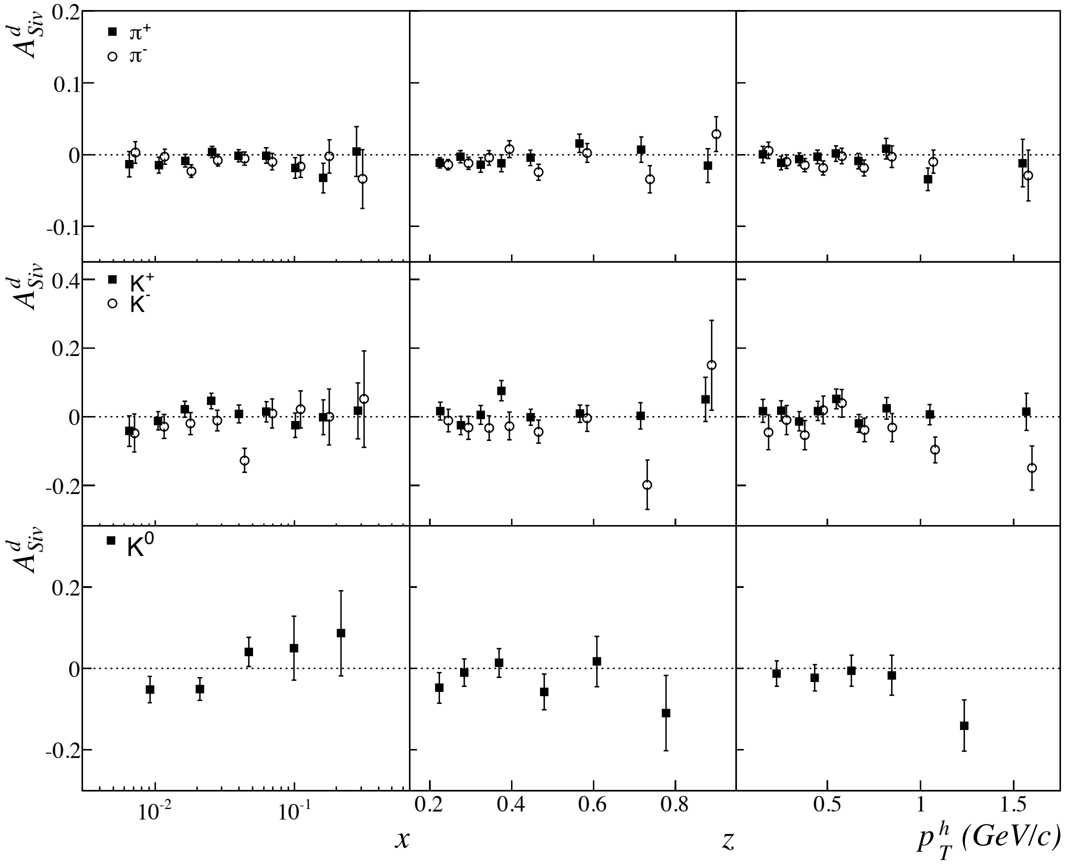
transversity

global analysis

PRD 92 (2015) 114023

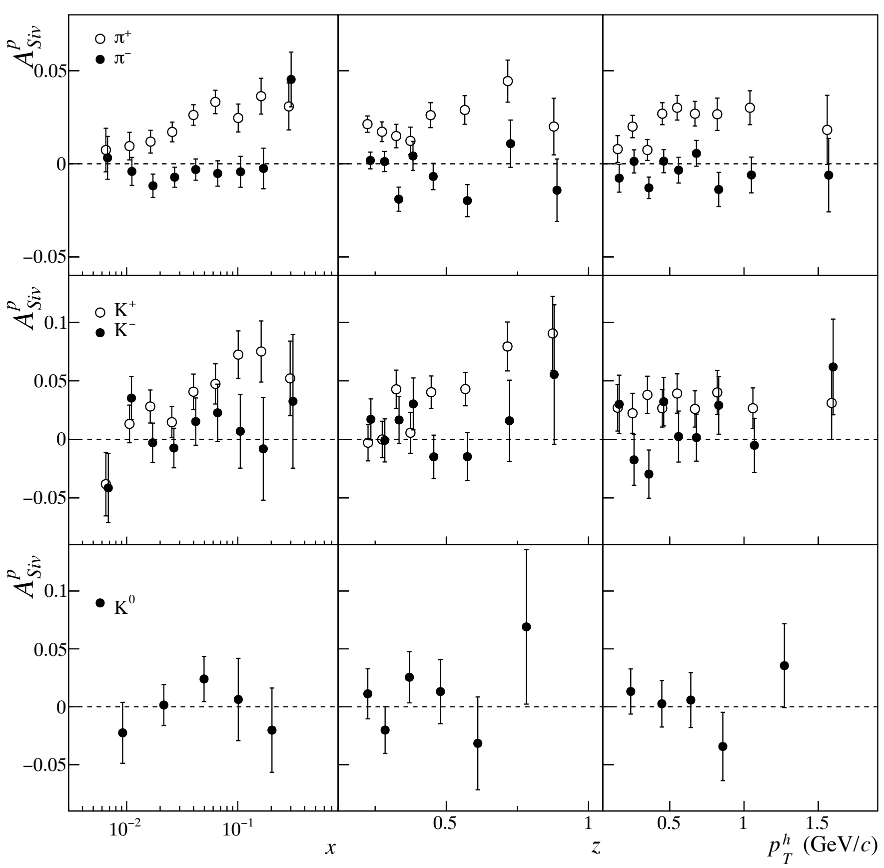


TSAs: Sivers from SIDIS



d data - PLB 673 (2009) 127

- compatible w/ zero



p data - PLB 744 (2015) 250

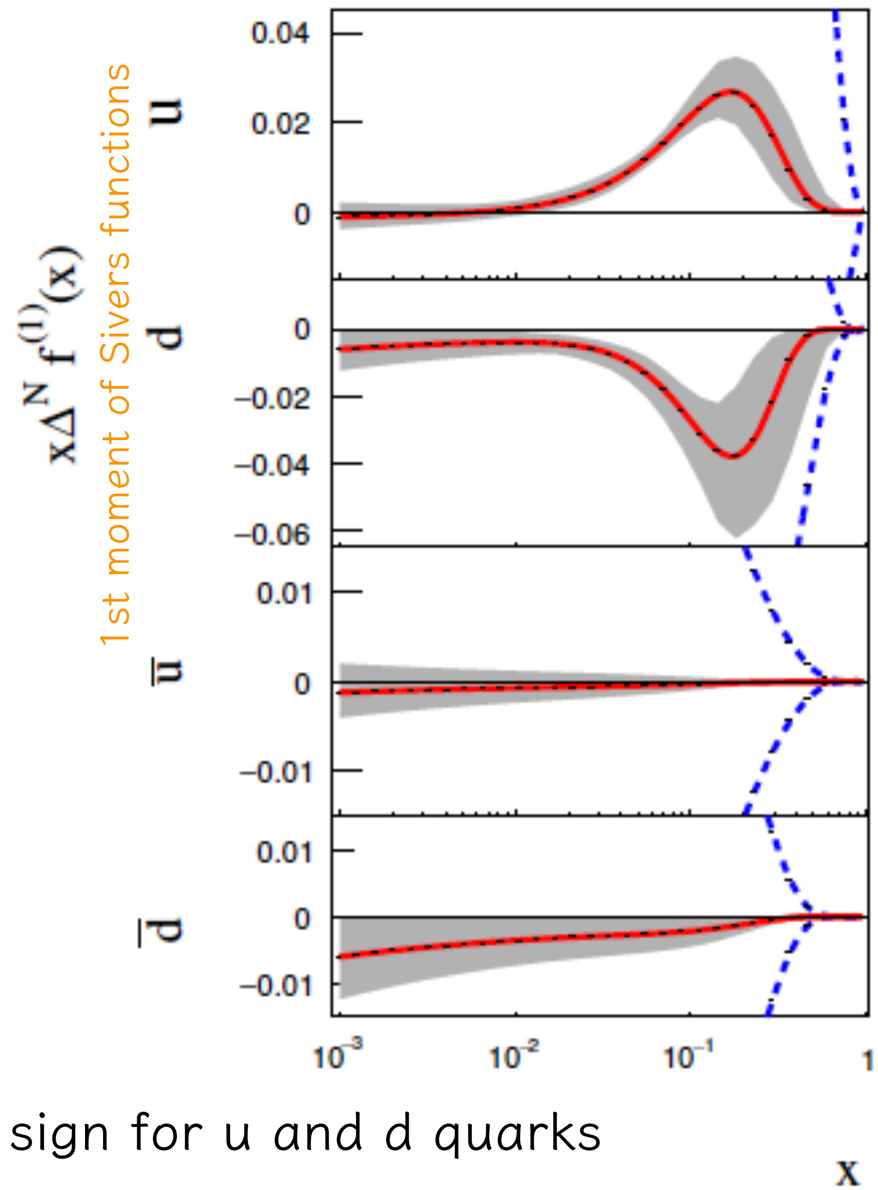
- positive for positive hadrons

Sivers unpol. FF

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

$$\Delta^N f^{(1)}(x) = \int d^2k_\perp \frac{k_\perp}{4m_p} \Delta^N f_{q/p^\uparrow}(x, k_T)$$

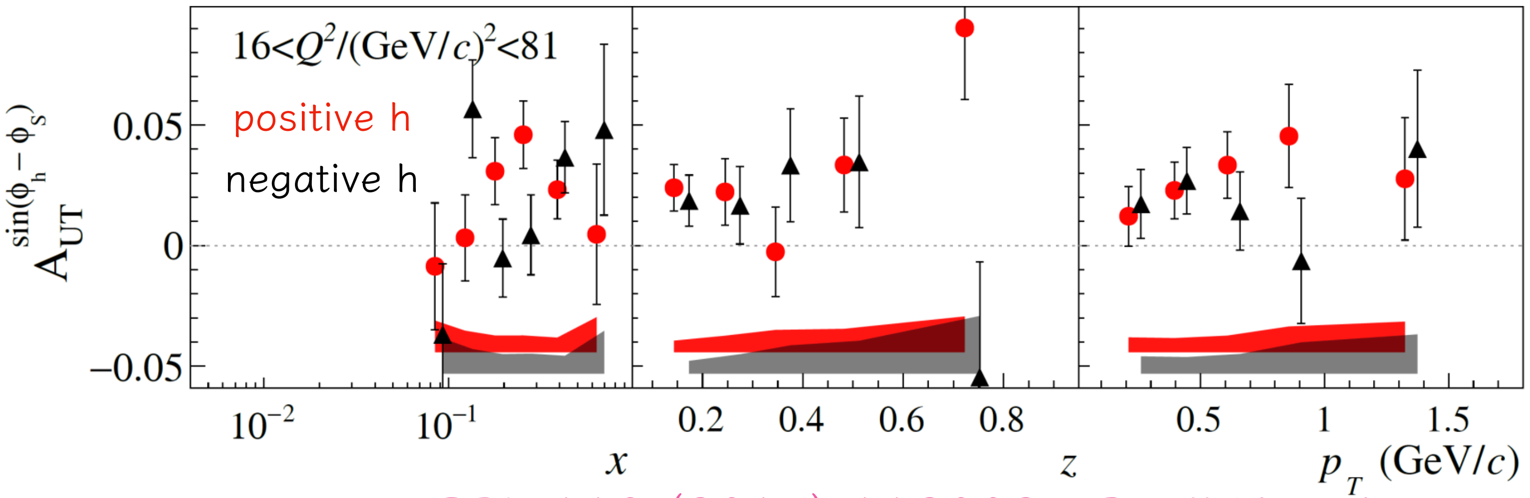
global analysis - JHEP 04 (2017) 046



- opposite sign for u and d quarks
- larger uncertainties for d quark
  - will be improved w/ 2021 COMPASS data

Sivers sign change - SIDIS vs Drell-Yan

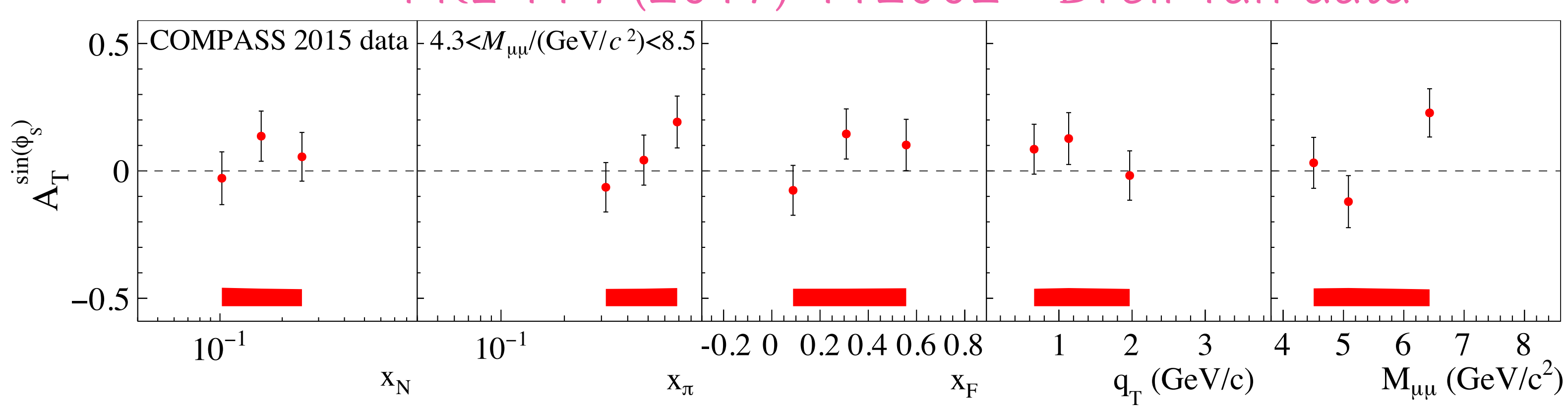
PLB 770 (2017) 138 - SIDIS data



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

Sivers unpol. FF

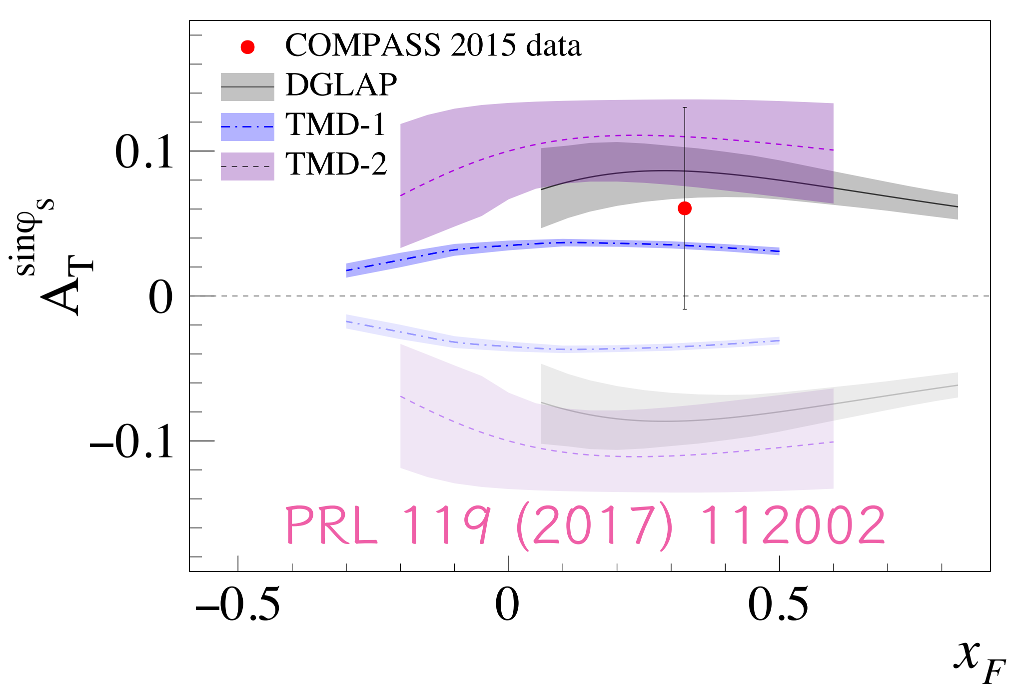
PRL 119 (2017) 112002 - Drell-Yan data



Due to the Sivers asymmetry definition in Drell-Yan and SIDIS:
The same sign of asymmetry corresponds to a sign change of the Sivers function

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

unpol. PDF Sivers

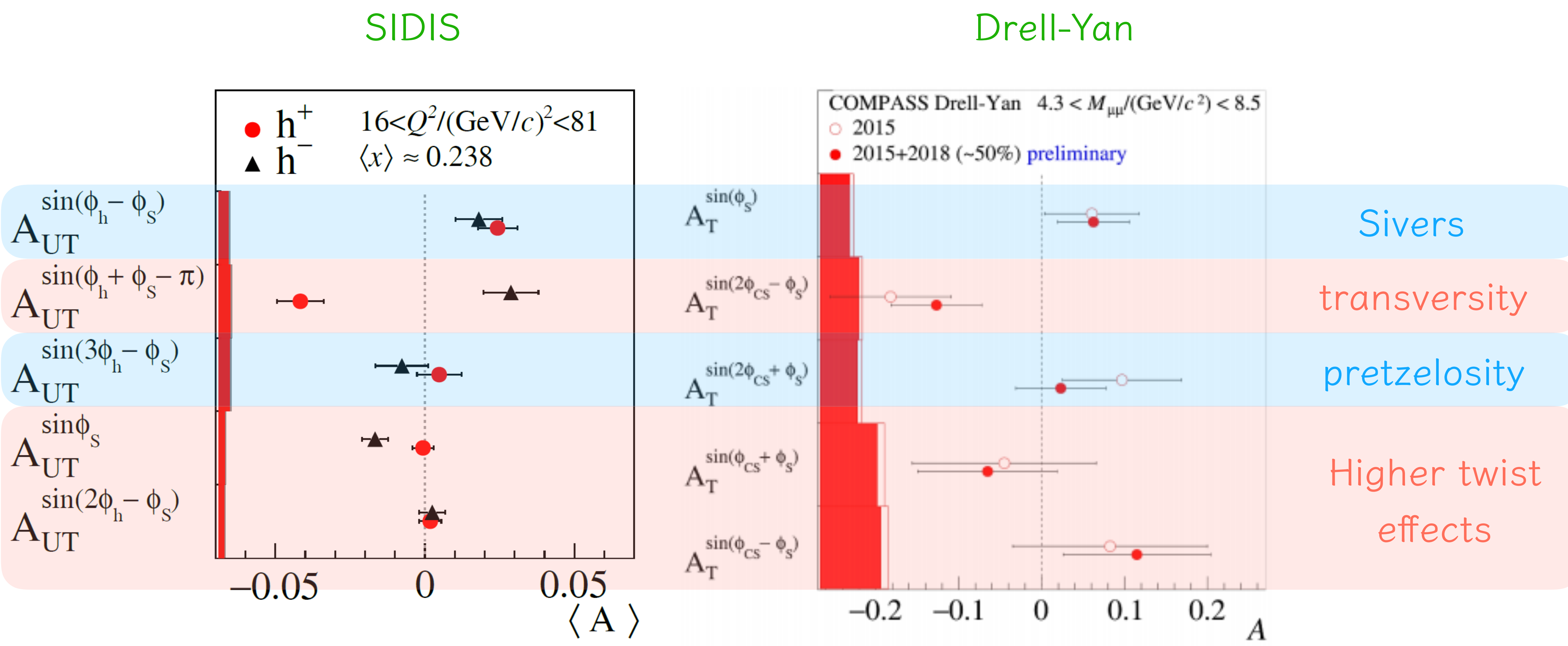


sign change

no sign change

2018 data is being analysed

Many results on TSAs from COMPASS

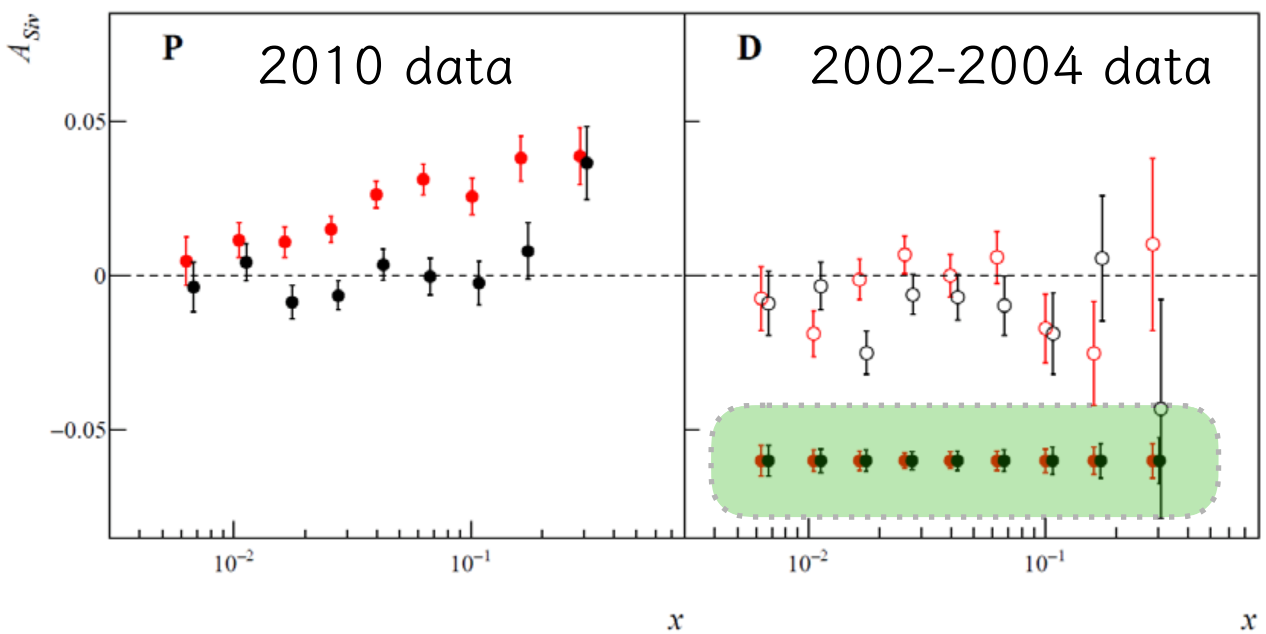


- COMPASS took a wealth amount of data
- both measuring SIDIS and Drell-Yan
- these data give access to many TMDs
- a must for global analysis

2021 run - transverse deuteron

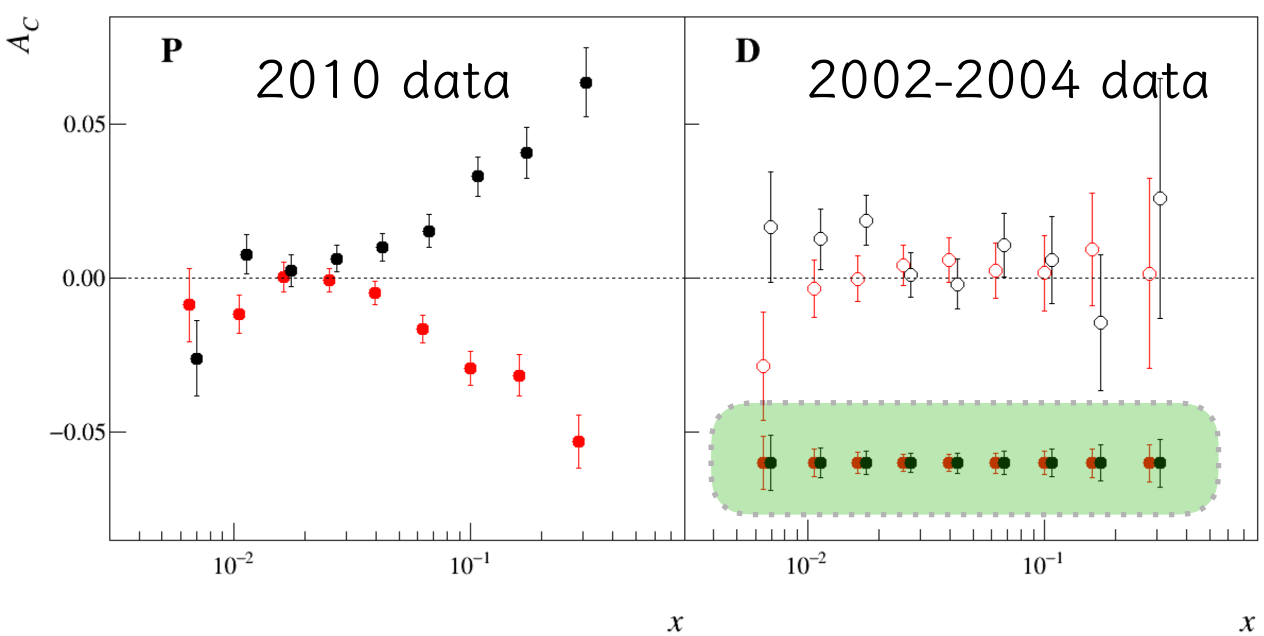
~0.6 times the statistical uncertainty of 2010 p data

Sivers asymmetry

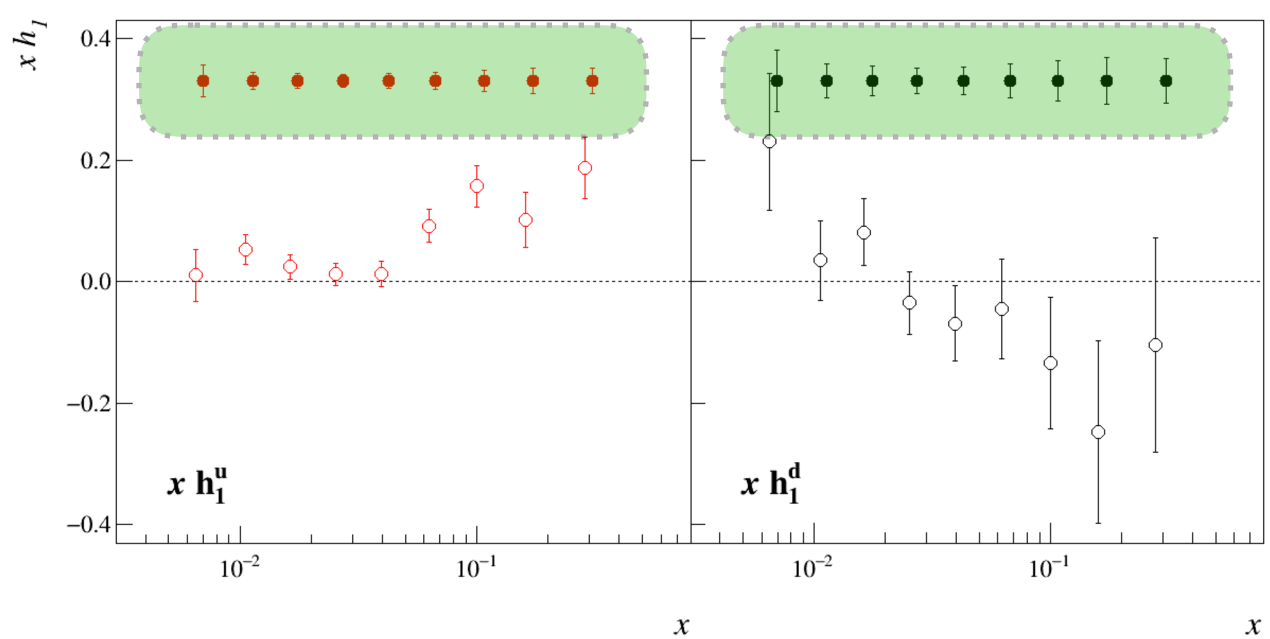


statistical projections for 2021 d data

Collins asymmetry



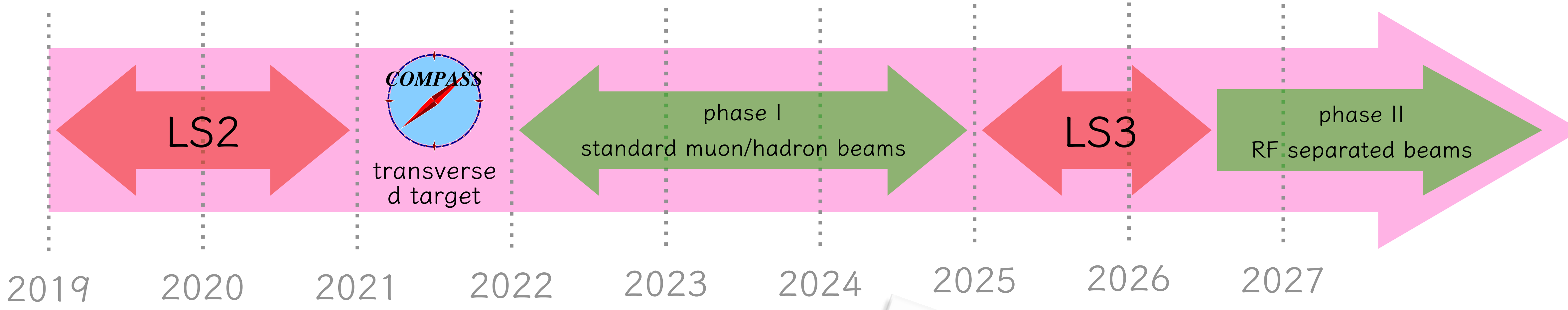
transversity PDF



Summary

* COMPASS has been taking data since 2002 w/ transverse and longitudinal polarised d and p targets
* Many data were and are being analysed to improve our knowledge on the nucleon structure and on its many degrees of freedom
* COMPASS has been the very first experiment measuring both SIDIS and Drell-Yan processes, complementary on nucleon structure studies
* This amazing journey will finish on 2021 w/ SIDIS on a transverse polarised d target

What follows COMPASS?



Letter of Intent

Available since 2nd August 2018

CERN-SPSC-2019-003 (SPSC-I-250)

arXiv:1808.00848v6

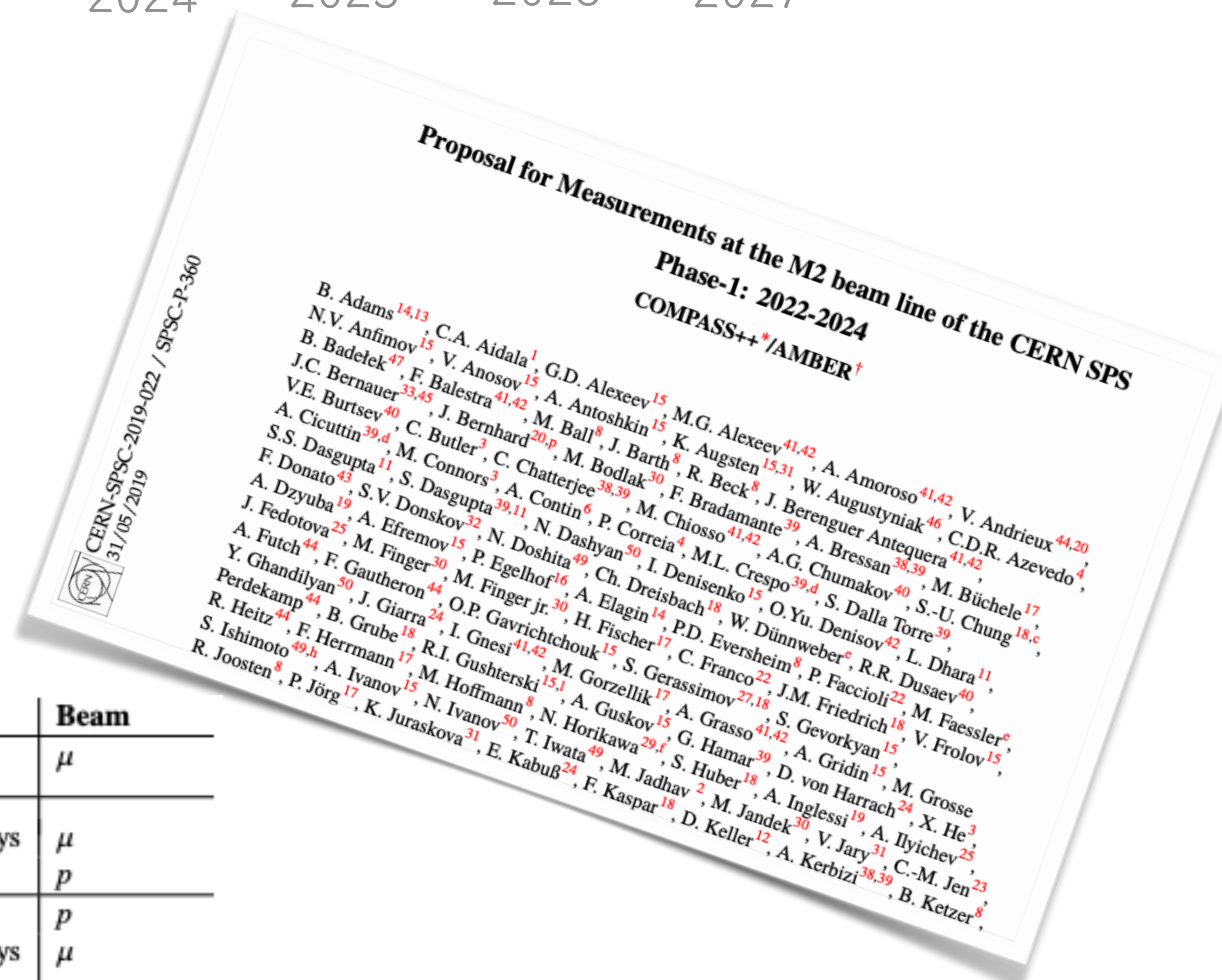
New proposal

Available since 31st May 2019

CERN-SPSC-2019-022 ; SPSC-P-360

Tentative schedule for phase I

Year	Activity	Duration	Beam
2021	Proton radius test measurement	20 days	μ
2022	Proton radius measurement Antiproton production test measurement	120 (+40) days 10 days	μ p
2023	Antiproton production measurement Proton radius measurement	20(+10) days 140 (+10) days	p μ
2024 2024+	Drell-Yan: pion PDFs and charmonium production mechanism	$\lesssim$ 2 years	$p, K^+, \pi^+,$ $\bar{p}, K^-, \pi^-$


CERN-SPSC-2019-022 / SPSC-P-360
31/05/2019

Proposal for Measurements at the M2 beam line of the CERN SPS

Phase-1: 2022-2024

COMPASS++*/AMBER†

B. Adams[14,13], C.A. Aidala[1], G.D. Alexeev[15], M.G. Alexeev[41,42], A. Amoroso[41,42], V. Andrieux[44,20], N.V. Anfimov[15], V. Anosov[15], A. Antoshkin[15], K. Augsten[15,31], W. Augustyniak[46], C.D.R. Azevedo[4], B. Badełek[47], F. Balestra[41,42], M. Ball[8], J. Barth[8], R. Beck[8], J. Berenguer Antequera[41,42], J.C. Bernauer[33,45], J. Bernhard[20,p], M. Bodlak[30], F. Bradamante[39], A. Bressan[38,39], M. Büchele[17], V.E. Burtsev[40], C. Butler[3], C. Chatterjee[38,39], M. Chiosso[41,42], A.G. Chumakov[40], S.-U. Chung[18,c], A. Cicuttin[39,d], M. Connors[3], A. Contin[6], P. Correia[4], M.L. Crespo[39,d], S. Dalla Torre[39], S.S. Dasgupta[11], S. Dasgupta[39,11], N. Dashyan[50], I. Denisenko[15], O.Yu. Denisov[42], L. Dhara[11], F. Donato[43], S.V. Donskov[32], N. Doshita[49], Ch. Dreisbach[18], W. Dünnweber[e], R.R. Dusaev[40], A. Dzyuba[19], A. Efremov[15], P. Egelhof[16], A. Elagin[14], P.D. Eversheim[8], P. Faccioli[22], M. Faessler[e], J. Fedotova[25], M. Finger[30], M. Finger jr.[30], H. Fischer[17], C. Franco[22], J.M. Friedrich[18], V. Frolov[15], A. Futch[44], F. Gautheron[44], O.P. Gavrichtchouk[15], S. Gerassimov[27,18], S. Gevorkyan[15], Y. Ghandilyan[50], J. Giarra[24], I. Gnesi[41,42], M. Gorzellik[17], A. Grasso[41,42], A. Gridin[15], M. Grosse Perdekamp[44], B. Grube[18], R.I. Gushterski[15,l], A. Guskov[15], G. Hamar[39], D. von Harrach[24], X. He[3], R. Heitz[44], F. Herrmann[17], M. Hoffmann[8], N. Horikawa[29,f], S. Huber[18], A. Inglessi[19], A. Ilyichev[25], S. Ishimoto[49,h], A. Ivanov[15], N. Ivanov[50], T. Iwata[49], M. Jadhav[2], M. Jandek[30], V. Jary[31], C.-M. Jen[23], R. Joosten[8], P. Jörg[17], K. Juraskova[31], E. Kabuß[24], F. Kaspar[18], D. Keller[12], A. Kerbizi[38,39], B. Ketzer[8],

Thank you