Experimental overview of Transverse Momentum Distributions and Momentum Effects

Spin 2018

INTERNATIONAL SPIN SYMPOSIUM
FERRARA - ITALY

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INFN

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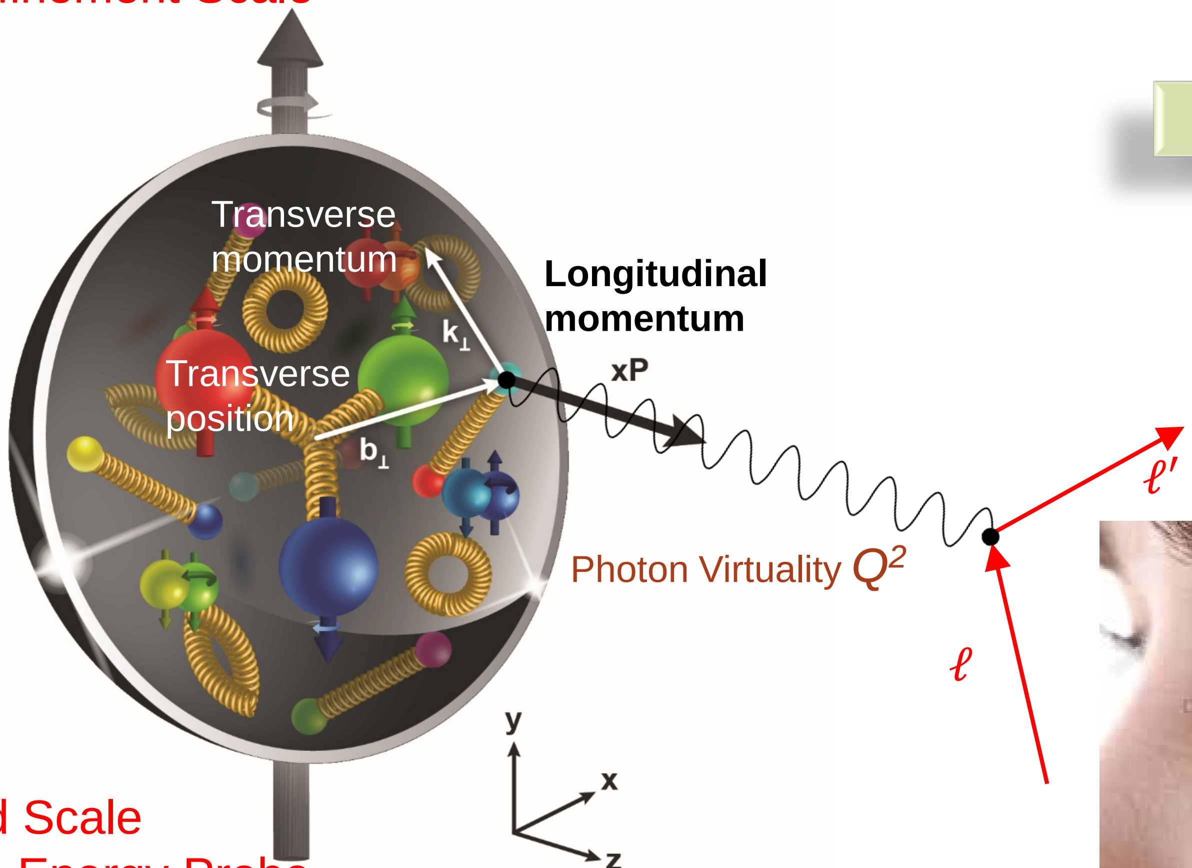
SEPTEMBER 10-14, FERRARA ITALY.

Transverse structure of the Nucleon

Confinement Scale

$$W_p^q(x, \vec{k}_\perp, \vec{b}_T)$$

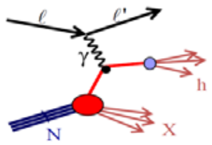


Hard Scale

High Energy Probe

Accessing TMD PDFs and FFs

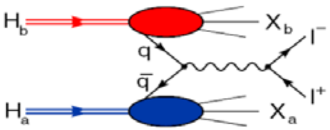
- TMD factorization works in the domain where there are two observed momenta in the process, such as SIDIS, DY, e^+e^-. $Q \gg q_T$: Q is large to ensure the use of pQCD, q_T is much smaller such that it is sensitive to parton’s transverse momentum
- SIDIS off polarized p, d, n targets



HERMES
COMPASS
JLab
future: ***EIC***

$$\sigma^{\ell p\to\ell' hX} \sim q(x) \otimes \hat{\sigma}^{\gamma q\to q} \otimes D_q^h(z)$$

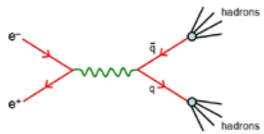
- polarised Drell-Yan



COMPASS
RHIC
FNAL
future: ***FAIR, JPark, NICA***

$$\sigma^{hp\to\mu\mu} \sim \bar{q}_h(x_1) \otimes q_p(x_2) \otimes \hat{\sigma}^{\bar{q}q\to\mu\mu}(\hat{s})$$

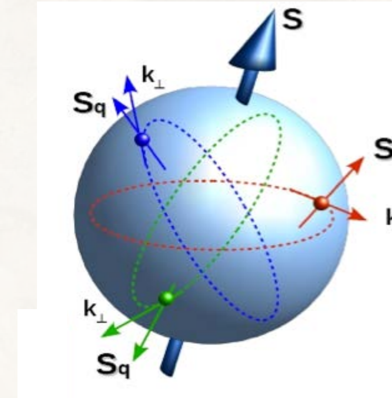
- $e^+e^- \to h_1 h_2$



BaBar
Belle
Bes III

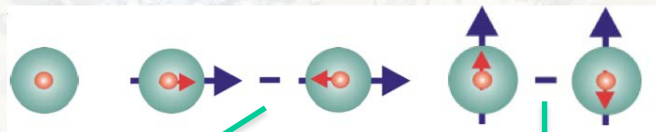
$$\sigma^{e^+e^-\to h_1h_2} \sim \hat{\sigma}^{\ell\ell\to\bar{q}q}(\hat{s}) \otimes D_q^{h_1}(z_1) \otimes D_q^{h_2}(z_2)$$

The spin of the proton



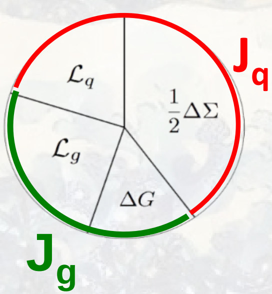
Three twist-2 quark DF's in collinear approximation ($\int d\boldsymbol{k}_\perp$)

$$\Phi_{\text{Coll}}^{\text{Tw}-2}(x) = \frac{1}{2}\{q(x) + S_L\gamma_5 g_1(x) + S_T\gamma_5\gamma^1 h_1(x)\}n^+$$



helicity **transversity**

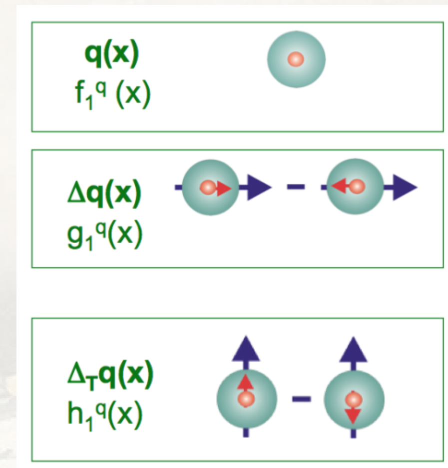
$$\frac{S_z^N}{\hbar} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$



≈30% : **Spin puzzle**

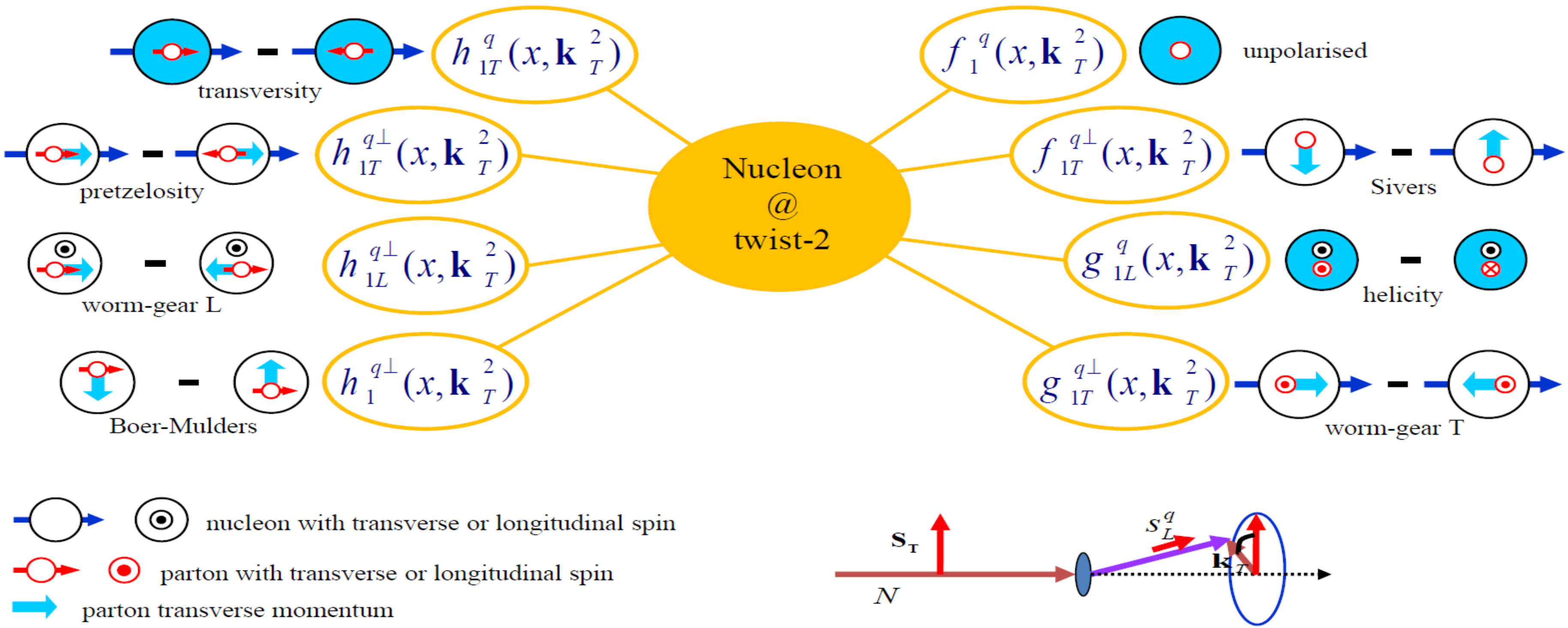
NR limit
[boost, rotat.]=0

➡ $h_1(x, Q^2) = g_1(x, Q^2)$



When $\boldsymbol{k}_\perp$ is taken into account …

TMD Distribution Functions



Proton goes out of the screen. Photon goes into the screen

$\mathbf{k}_T$ – intrinsic transverse momentum of the quark

TMD evolution:

- QCD evolution of TMDs in Fourier space (solution of equation)

$$F(x,b;Q) \approx C \otimes F(x,c/b^*) \exp\left\{-\int_{c/b^*}^{Q_f} \frac{d\mu}{d}\left(A \ln \frac{Q_f^2}{\mu^2} + B\right)\right\} \times \exp\left[-S_{\text{non-pert}}(b,Q)\right]$$

Evolution of longitudinal/ collinear part

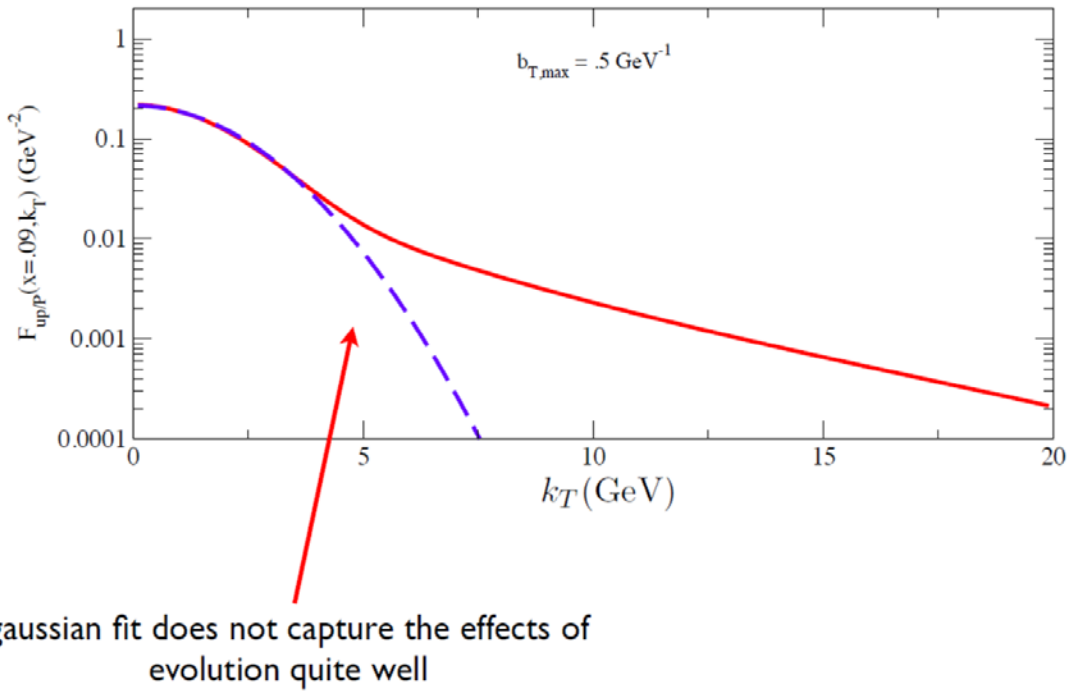
Evolution of transverse part (Sudakov form factor)

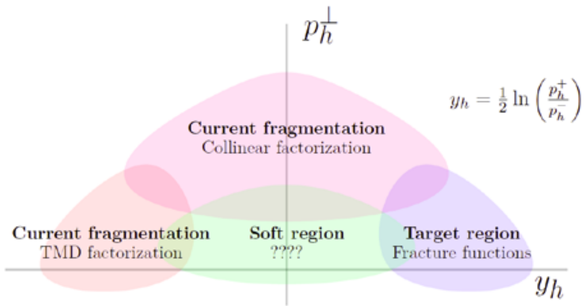
Non-perturbative part has to be fitted to experimental data
The key ingredient is spin-independent

- Polarized scattering data comes as ratio: e.g. $A_{UT}^{\sin(\phi_h-\phi_s)} = F_{UT}^{\sin(\phi_h-\phi_s)}/F_{UU}$
- Unpolarized data is very important to constrain/extract the key ingredient for the non-perturbative part

Effect of QCD evolution

- What evolution does
  - Spread out the distribution to much larger $k_\perp$. At low $k_\perp$, the distribution decreases due to this spread

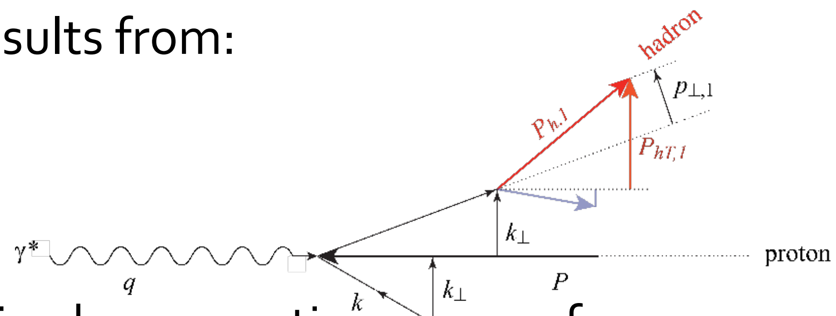




Echevarria, Idilbi, Kang, Vitev. Kang, Prokudin, Sun, Yuan

Importance of unpolarized SIDIS

- The cross section dependence from P_{hT} results from:
  - intrinsic $k_\perp$ of the quarks
  - $p_\perp$ generated in the quark fragmentation



- The azimuthal modulations in the unpolarised cross sections comes from:
  - Intrinsic $k_\perp$ of the quarks
  - The Boer-Mulders PDF

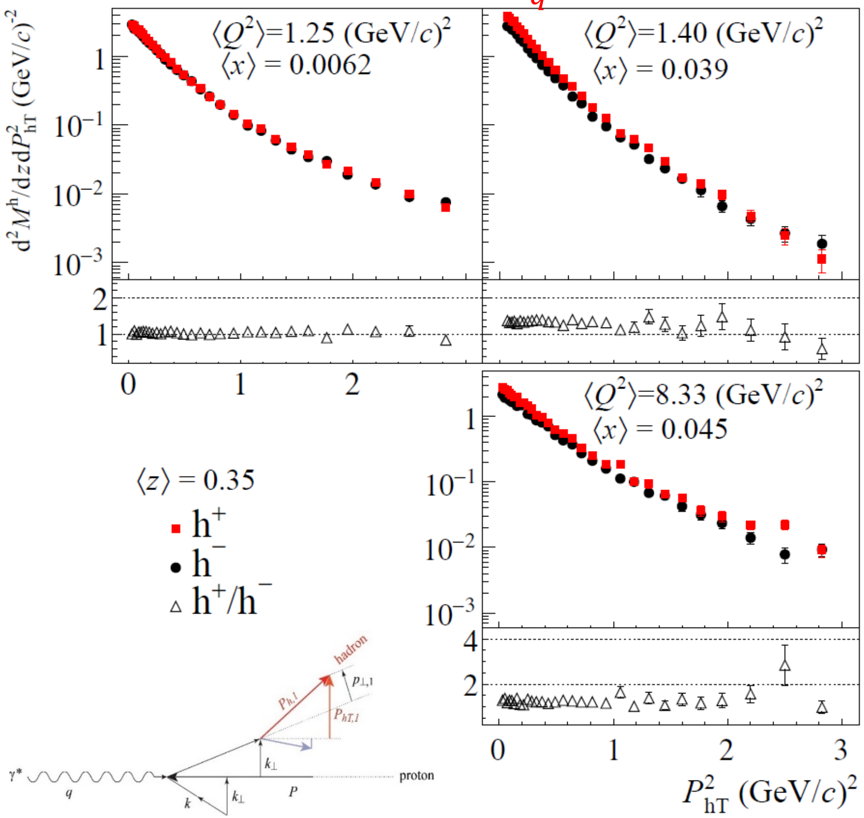
- Difficult measurements were one has to correct for the apparatus acceptance

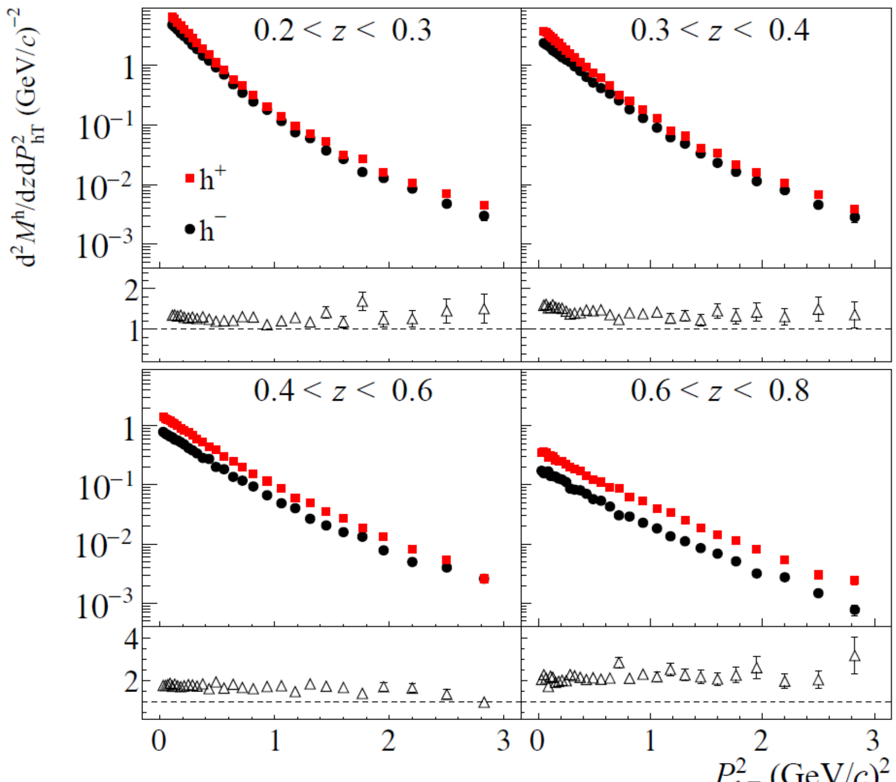
- COMPASS and HERMES have
  - results on ^6LiD $(\sim d)$ and d and on p (Hermes only)
  - No COMPASS measurements on p since on NH_3 $(\sim p)$ nuclear effects may be important

- ⇒COMPASS-II, measurements on LH_2 in parallel with DVCS

Positive vs Negative charged hadrons

$$F_{UU}^{h}(x,z,P_{hT}^{2};\,Q^{2}) = x\sum_{q} e_q^2 \int d^2\vec{k}_\perp d^2\vec{p}_\perp \delta(\vec{p}_\perp + z\vec{k}_\perp - \vec{P}_{hT})\; f_1^q(x,k_\perp^2;Q^2) D_1^{q\to h}(z,p_\perp^2;Q^2)$$



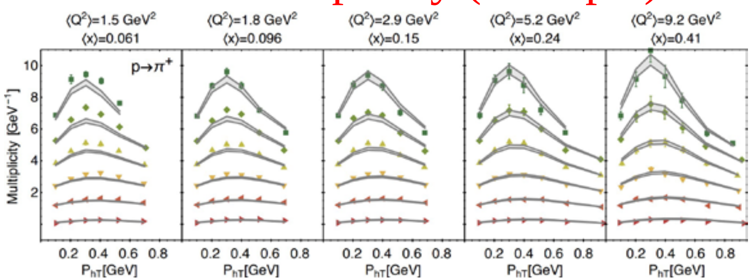


$\langle Q^2\rangle = 9.78\ (\mathrm{GeV}/c)^2$ and $\langle x\rangle = 0.149$

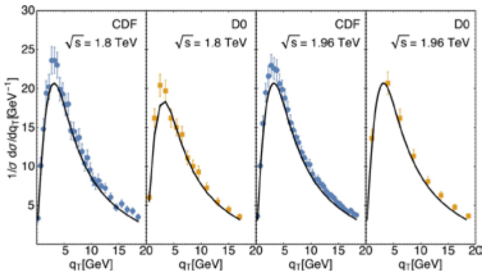
Global Analysis: Unpolarized TMD

Global analysis of semi-inclusive DIS, Drell-Yan and Z production data with TMD evolution

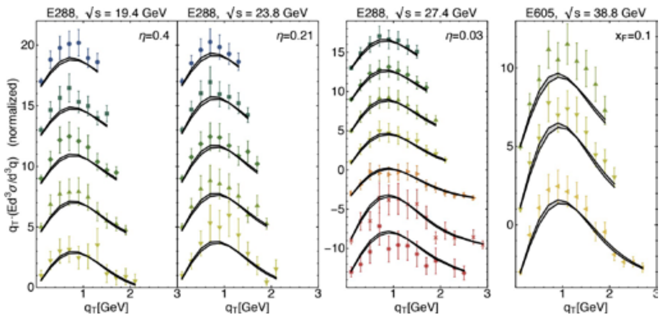
SIDIS multiplicity (example)



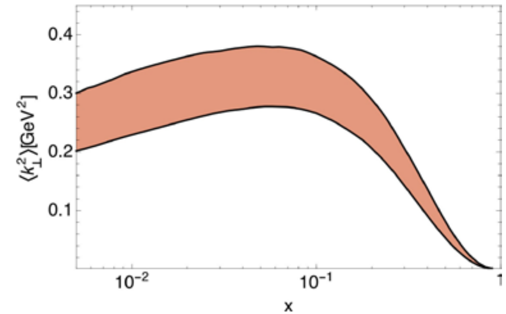
Z production



Drell-Yan cross section



Transverse momentum distribution



A. Bacchetta *et al.*, J. High Energy Phys. 06 (2017) 081.

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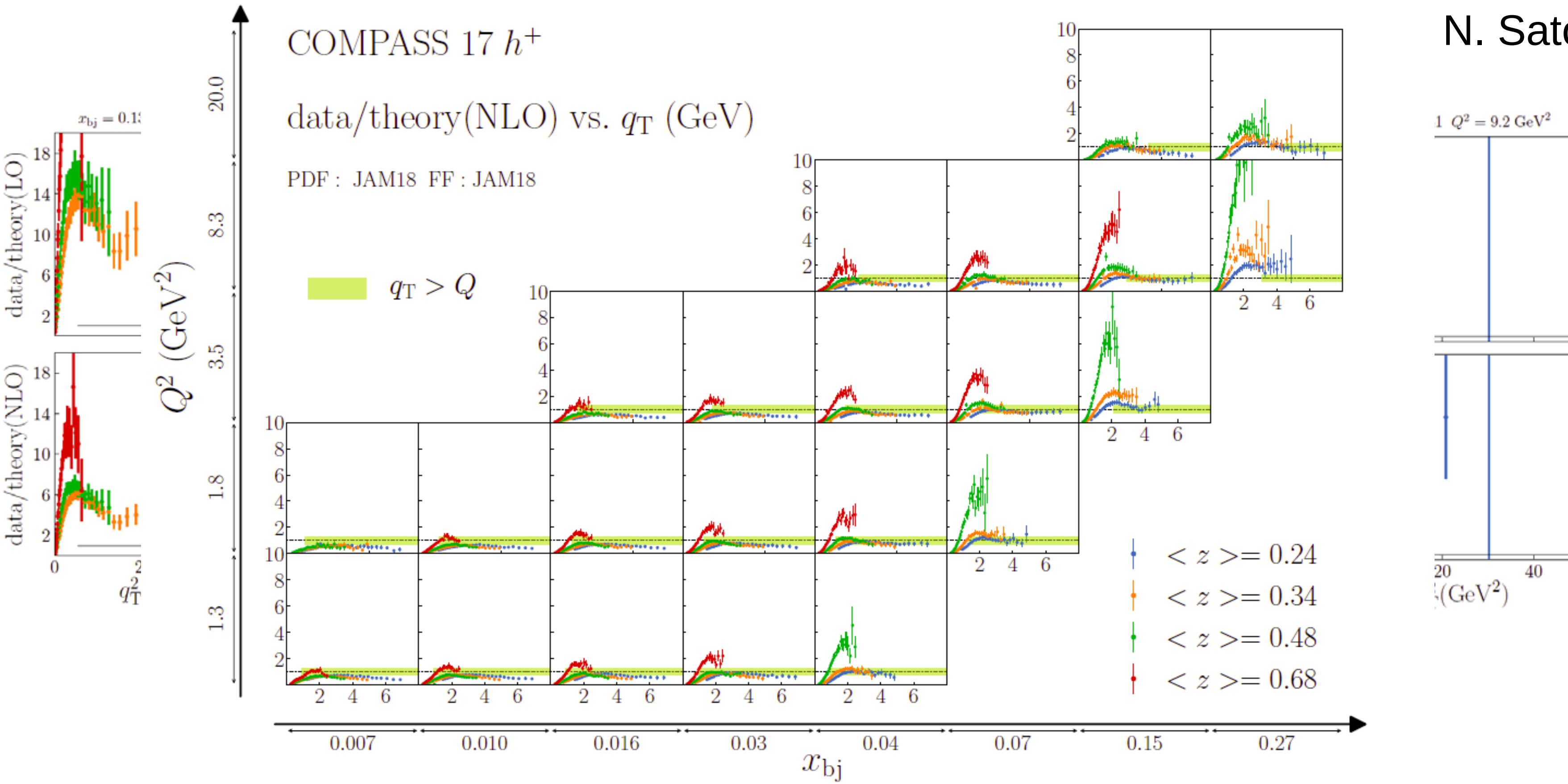
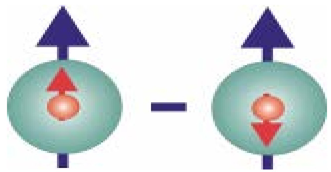
The matching problem ($q_T/Q > 1$ region)

N. Sato



Transversity PDF

$$\boldsymbol{h_1^q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)}$$



$\boldsymbol{q = u_v, d_v, q_{sea}}$

quark with **spin** parallel to the nucleon spin in a transversely polarised nucleon

- probes the relativistic nature of quark dynamics
- no contribution from the gluons $\rightarrow$ simple Q^2 evolution
- Positivity: Soffer bound……………… $2|h_1^q| \leq f_1^q + g_1^q$ *Soffer, PRL 74 (1995)*
- first moments: tensor charge………. $\delta q(Q^2) = \int_0^1 dx\left[h_1^q(x) - h_1^{\bar{q}}(x)\right]$
- is chiral-odd: decouples from inclusive DIS *Bakker, Leader, Trueman, PRD 70 (04)*

Transversity

is chiral-odd:

observable effects are given only by the product of h_1^q (x) and an other chiral-odd function

can be measured in SIDIS on a transversely polarised target via "quark polarimetry"

$\ell N^{\uparrow} \rightarrow \ell'\, h\, X$ — **"Collins" asymmetry**

"Collins" Fragmentation Function

$\ell N^{\uparrow} \rightarrow \ell'\, h\, h\, X$ — **"two-hadron" asymmetry**

"Interference" Fragmentation Function

$\ell N^{\uparrow} \rightarrow \ell'\, \Lambda\, X$ — **Λ polarisation**

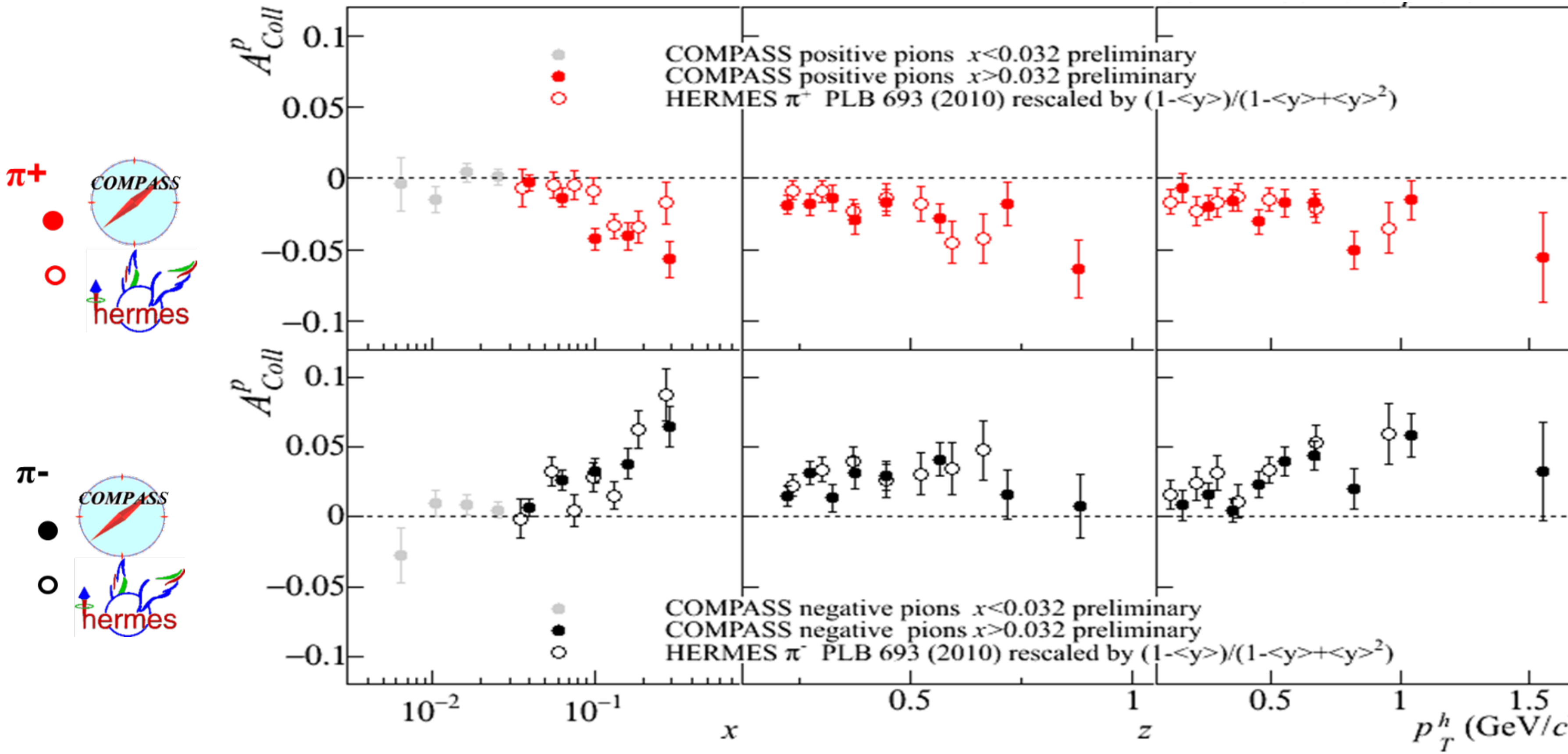
Fragmentation Function of q↑→Λ

Collins asymmetry on proton

x > 0.032 region

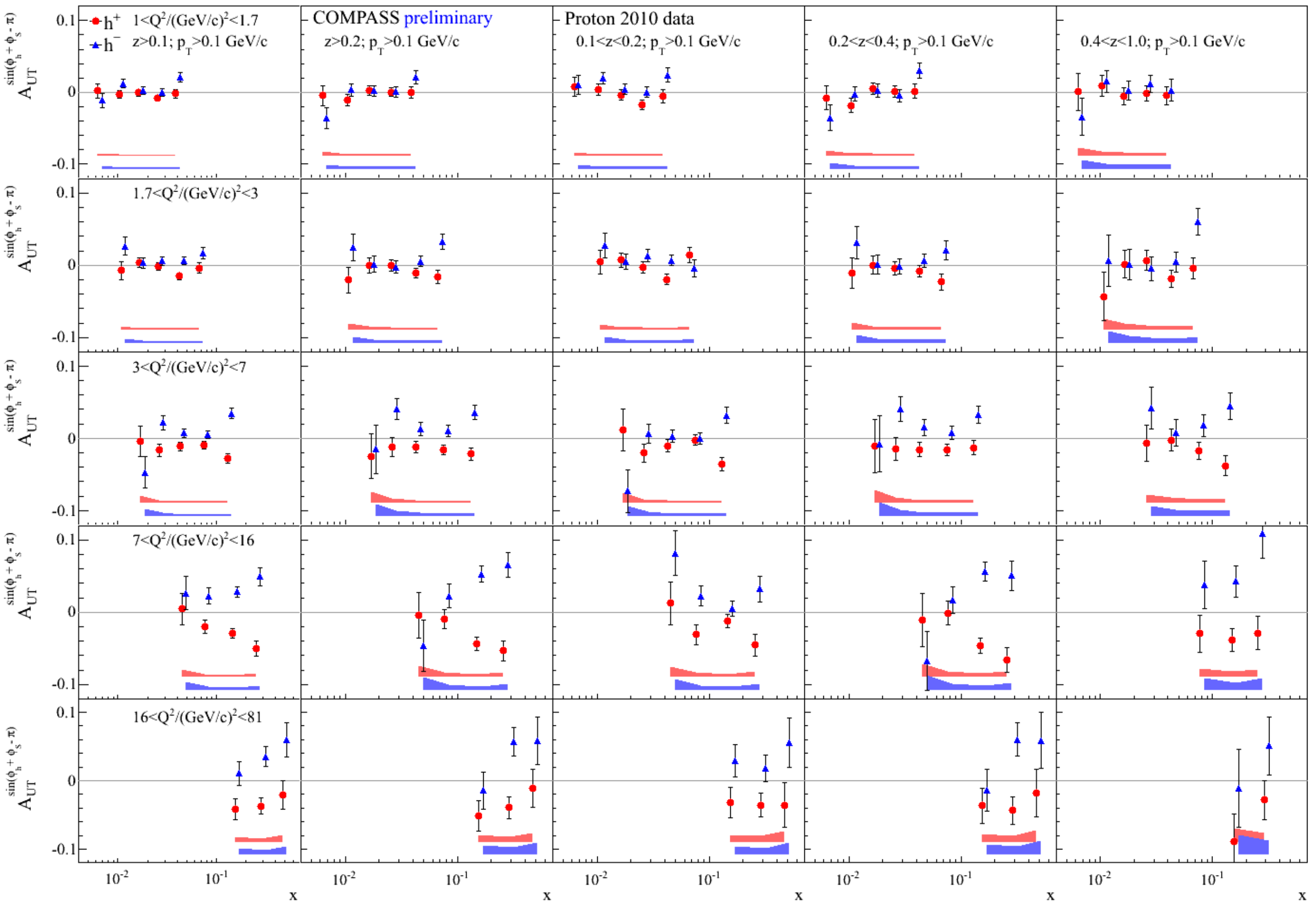
charged pions

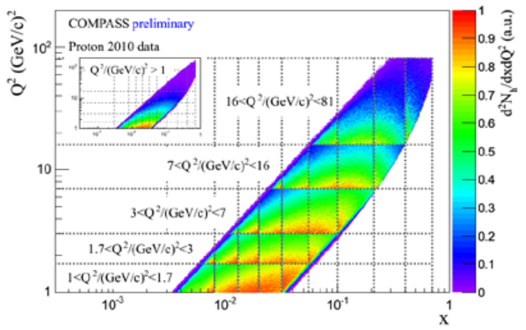
COMPASS and HERMES results



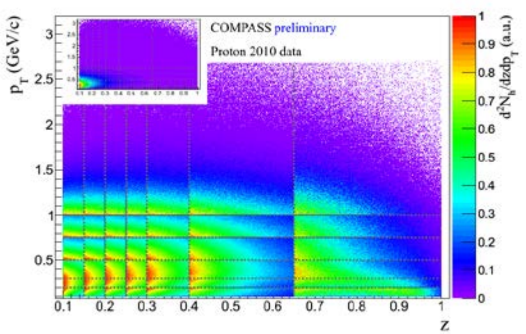
Collins asymmetry on proton. Multidimensional

Extraction of TSAs with a Multi-D $(x{:}\,Q^2{:}\,z{:}\,p_T)$ approach

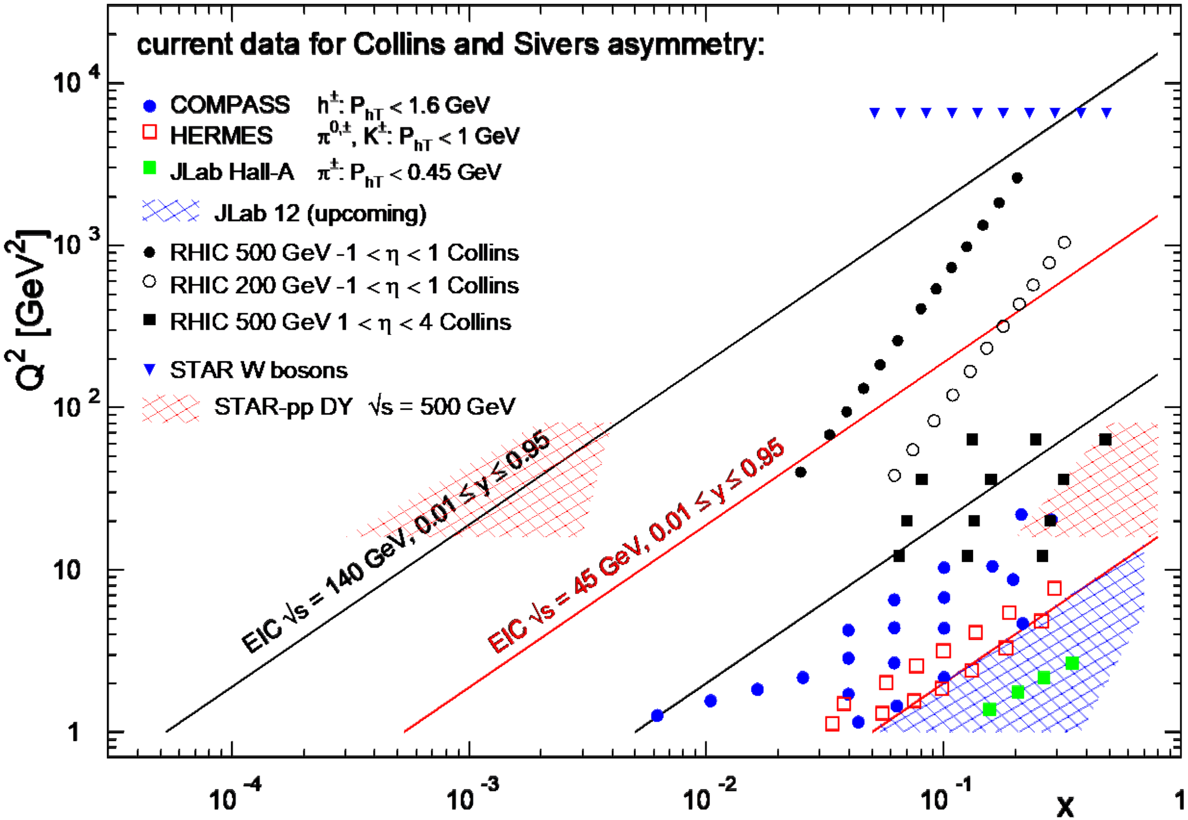




One dense plot out of many



TMDs at STAR



Before STAR TMDs came only from fixed target data → high x @ low Q^2

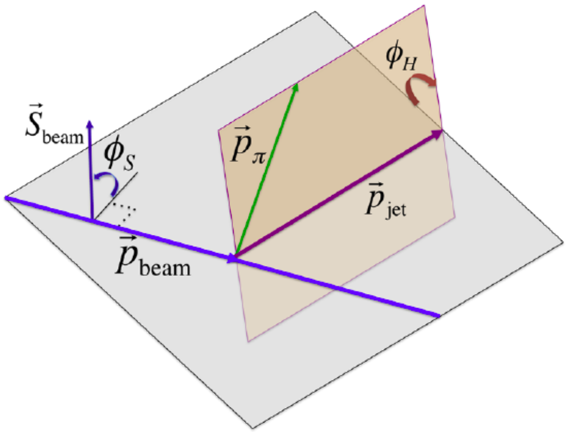
needed to establish concept at high Q^2 and wide range in x

polarised pp at RHIC

STAR unique kinematics: from high to low x at high Q^2

TSA of inclusive jets and $\pi^{\pm}$ within jets from STAR

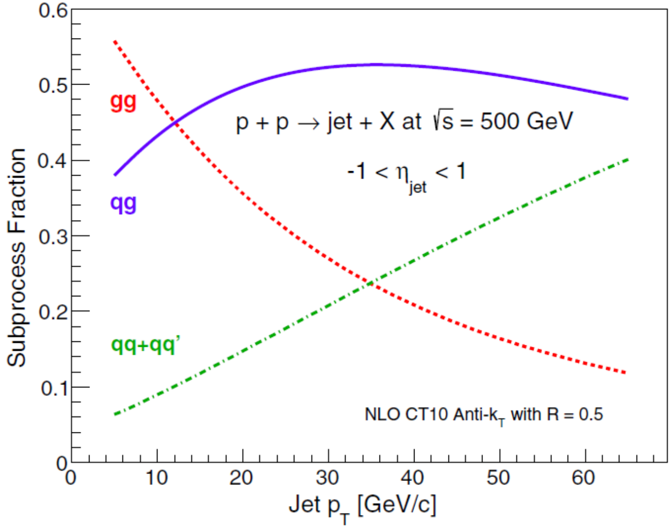
- The $P_{\mathbf{jet}\,T}$ of the jet and the $P_{\pi^{\pm}T}$ momentum transverse to the jet axis provide the hard and soft scales for TMD factorization.
- These measurements extend the kinematic reach in both x and Q^2 beyond the existing SIDIS measurements
- Different mixing of flavors, and stronger gluon content

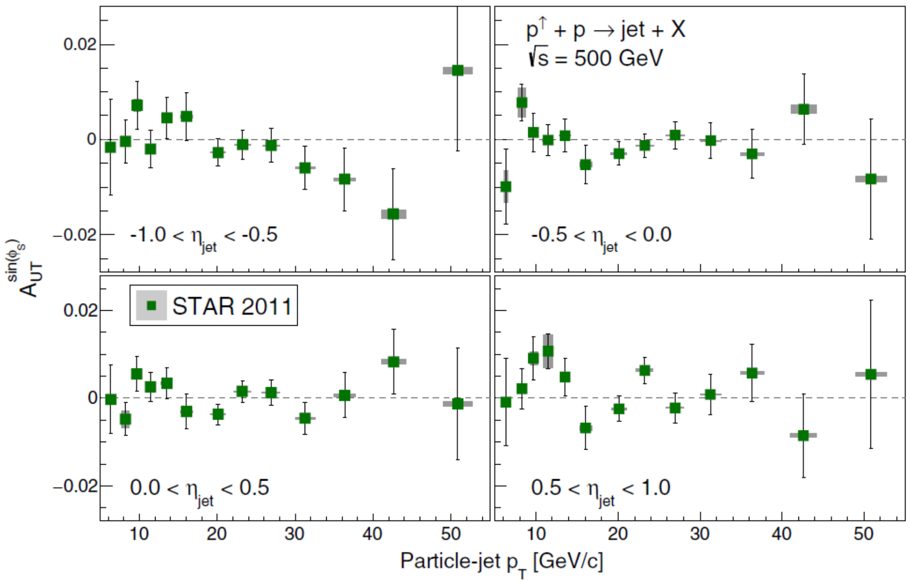


$$d\sigma^{\uparrow}(\phi_S,\phi_H) - d\sigma^{\downarrow}(\phi_S,\phi_H)$$
$$\sim d\Delta\sigma_0 \, sin\, \phi_S$$
$$+d\Delta\sigma_1^{-}\sin(\phi_S-\phi_H) + d\Delta\sigma_1^{+}\sin(\phi_S+\phi_H)$$
$$+d\Delta\sigma_2^{-}\sin(\phi_S-2\phi_H) + d\Delta\sigma_2^{+}\sin(\phi_S+2\phi_H)$$

L. Adamczyk et al. (STAR Collaboration), Phys. Rev. D 97, 032004 (2018).

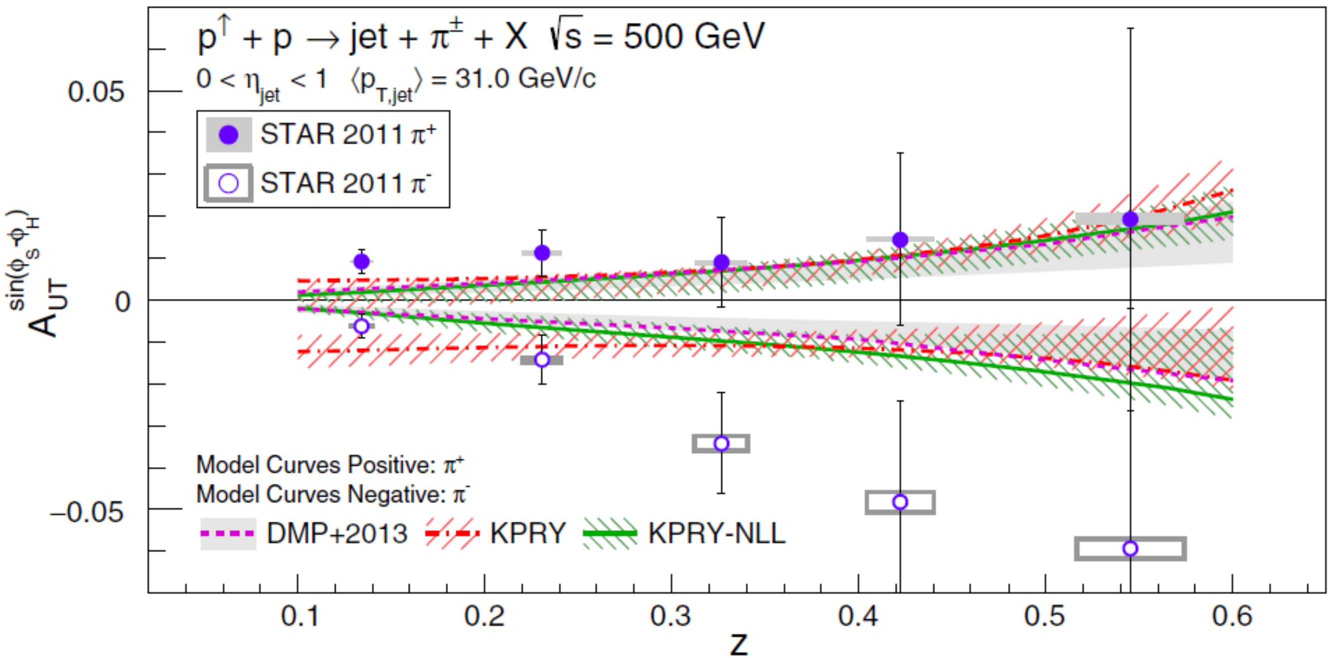
TSA of inclusive jets and $\pi^{\pm}$ within jets from STAR





A_N asymmetries consistent with zero in all rapidity intervals and over the full $P_{\pi^{\pm}T}$ range

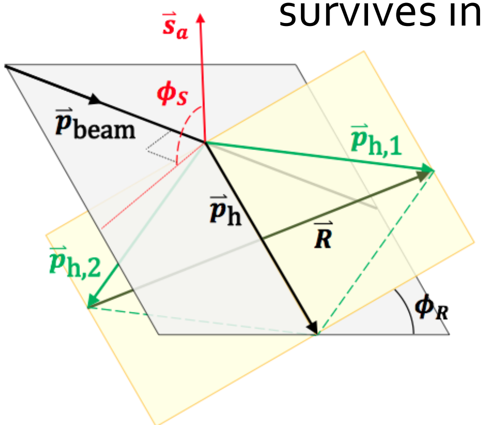
TSA of inclusive jets and $\pi^{\pm}$ within jets from STAR

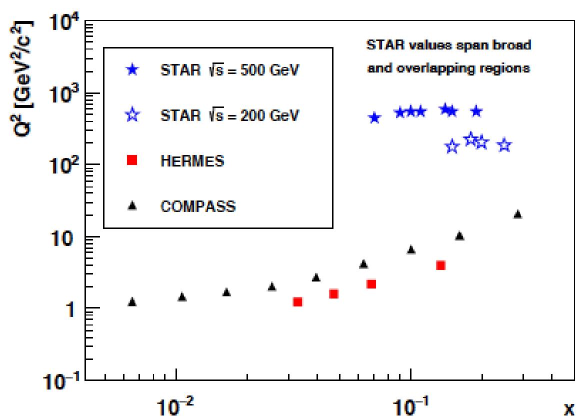


COLLINS asymmetries: general agreement between data and predictions from SIDIS consistent with TMD factorization and universality of the Collins function

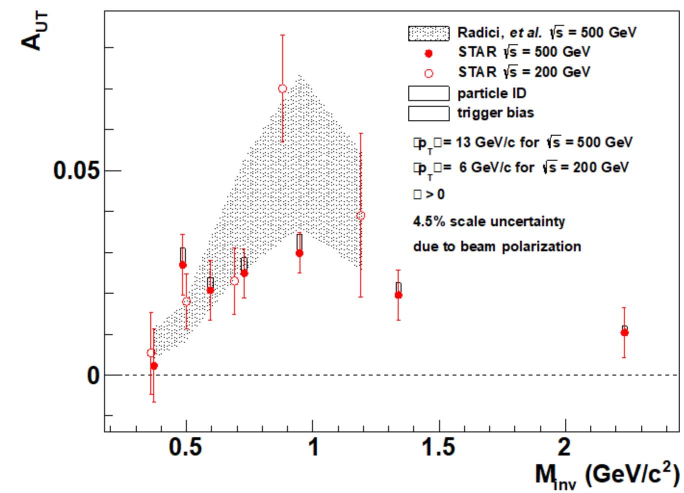
Interference fragmentation functions in pp

$p^{\uparrow}p \longrightarrow \pi^{+}\pi^{-}X \rightarrow h_1 \cdot H_1^{\sphericalangle}$ survives in collinear framework





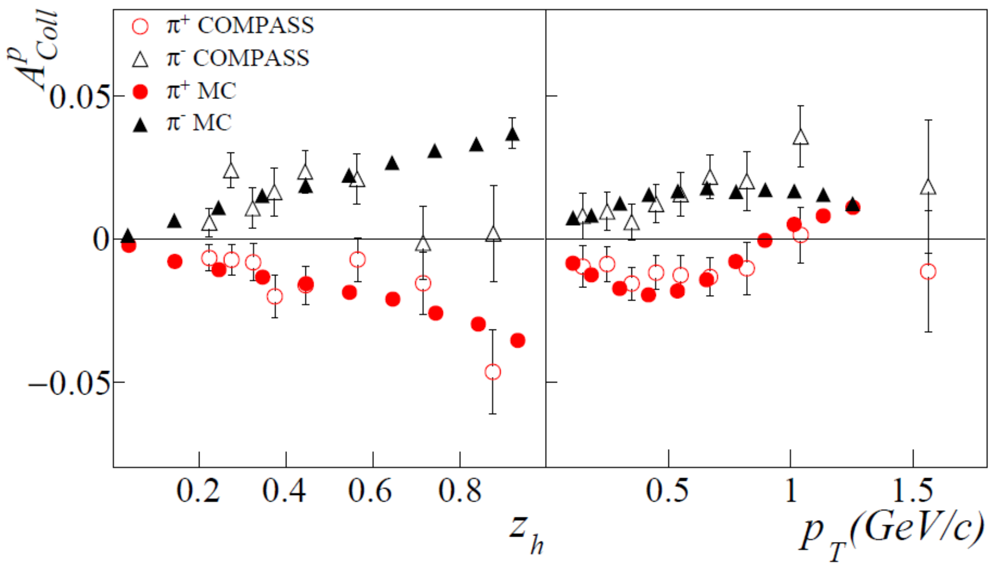
$$A_{UT}\sin(\phi_{RS}) = \frac{1}{Pol}\frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$



- Significant di-hadron asymmetries both at √s=200GeV and √s=500GeV (arXiv:1710.10215)
- Increasing with p_T
- Access to transversity with a collinear observable

A^p_{Coll} on proton and $^3P_0$ model for FF

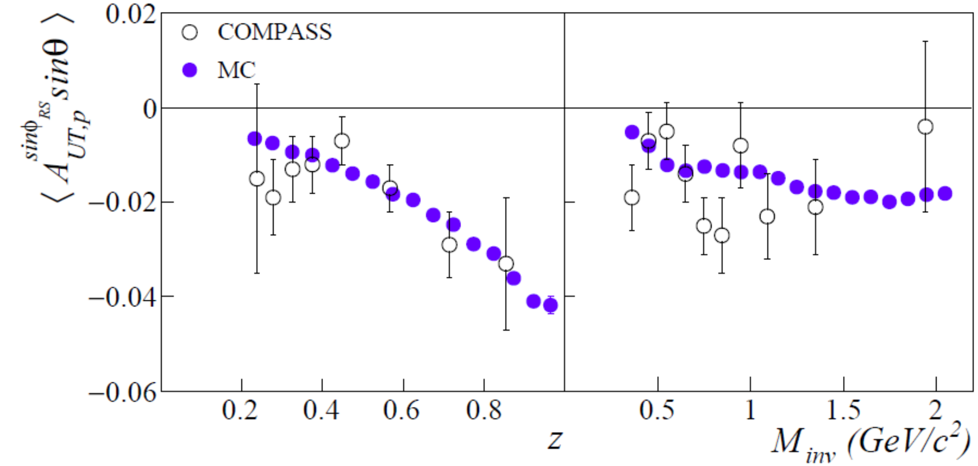
Albi Kerbizi et al. @ DSPIN17 http://theor.jinr.ru/~spin/2017/
Phys. Rev. D 97, 074010 (2018)/**arXiv:1802.00962**

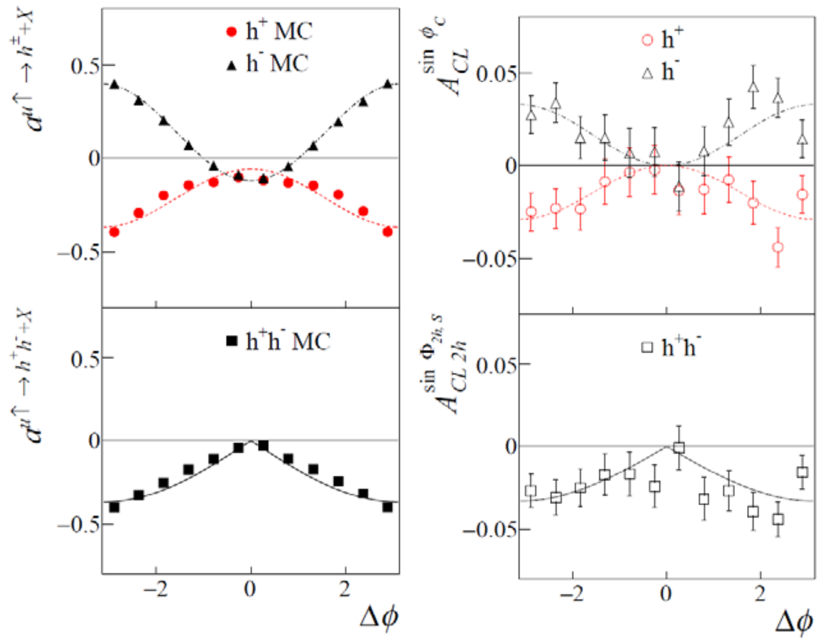


- The curves are fits of the Monte Carlo data, scaled by $\lambda \sim \langle h_1^u / f_1^u \rangle \sim 0.055$
- Agreement with the measured Collins asymmetry is quite satisfactory

2h asymmetries on p and $^3P_0$ model for FF

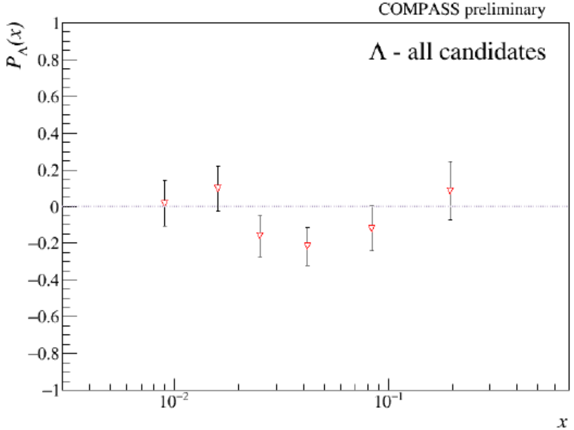
$$A_{UT}^{\sin(\phi_R+\phi_S-\pi)} = \frac{\sum_q e_q^2 h_1^q(x) H_{q\to h_1h_2}^{\measuredangle}\left(z,\mathcal{M}_{h_1h_2}^2\right)}{\sum_q e_q^2 q(x) D_q^{h_1h_2}\left(z,\mathcal{M}_{h_1h_2}^2\right)}$$

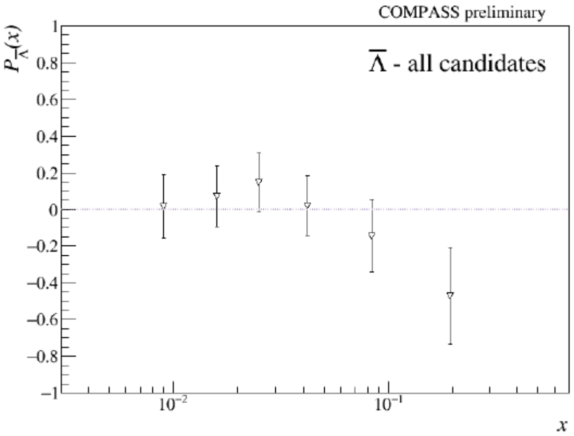




$a_P^{u\uparrow\to h^+h^-X} = \langle \sin(\phi_R+\phi_S-\pi)\rangle$ and $\vec{R} = \frac{z_2\vec{P}_{h1}-z_1\vec{P}_{h2}}{z_1+z_2}$ and as before $\lambda\sim\langle h_1^u/f_1^u\rangle\sim 0.055$

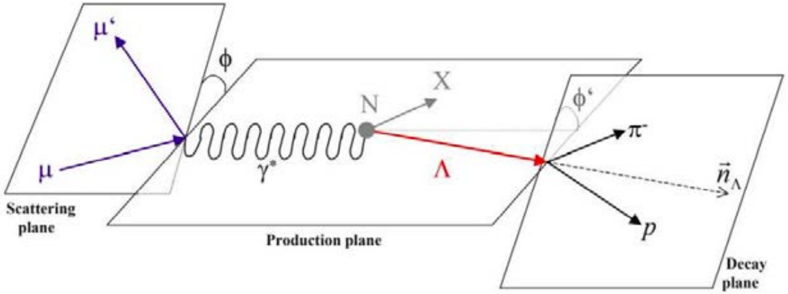
Λ transverse spin transfer from COMPASS



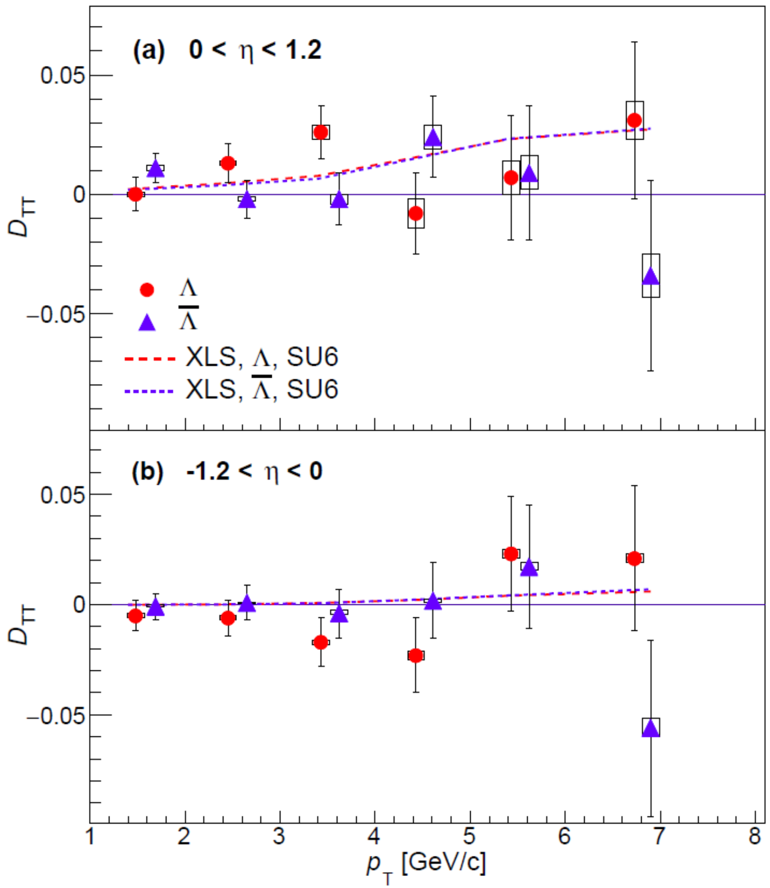


$$P_{\Lambda(\bar{\Lambda})}(x,z) = \frac{\sum_q e_q^2 h_1^q(x)\, H_1^{\Lambda(\bar{\Lambda})}(z)}{\sum_q e_q^2 f_1^q(x)\, D_1^{\Lambda(\bar{\Lambda})}(z)}$$

$$\frac{dN}{d\cos\theta^*} \propto A\left(1 + \alpha P_{\Lambda(\bar{\Lambda})} \cos\theta^*\right)$$



Λ transverse spin transfer from STAR



$$D_{TT} = \frac{d\sigma^{p^{\uparrow}p\to\Lambda^{\uparrow}X} - d\sigma^{p^{\uparrow}p\to\Lambda^{\downarrow}X}}{d\sigma^{p^{\uparrow}p\to\Lambda^{\uparrow}X} + d\sigma^{p^{\uparrow}p\to\Lambda^{\downarrow}X}}$$

$$D_{TT} = -\frac{1}{\alpha P_B \langle\cos\theta^*\rangle} \frac{\sqrt{N^{\uparrow}_{\cos\theta^*} N^{\downarrow}_{-\cos\theta^*}} - \sqrt{N^{\downarrow}_{\cos\theta^*} N^{\uparrow}_{-\cos\theta^*}}}{\sqrt{N^{\uparrow}_{\cos\theta^*} N^{\downarrow}_{-\cos\theta^*}} + \sqrt{N^{\downarrow}_{\cos\theta^*} N^{\uparrow}_{-\cos\theta^*}}}$$

$$\frac{dN}{d\cos\theta^*} \propto A\left(1 + \alpha P_{\Lambda(\bar{\Lambda})}\cos\theta^*\right)$$

About 60% of Λ or $\bar{\Lambda}$ are not primary particles, but are from heavier hyperons decay.

$$D_{TT}(\Lambda) = +0.031 \pm 0.033_{stat} \pm 0.008_{sys}$$
$$D_{TT}(\bar{\Lambda}) = -0.034 \pm 0.040_{stat} \pm 0.009_{sys}$$

Sivers Asymmetry

Sivers: correlates nucleon spin & quark transverse momentum k_T /T-ODD

at LO:

$$A_{Siv} = \frac{\sum_q e_q^2 f_{1Tq}^{\perp} \otimes D_q^h}{\sum_q e_q^2 q \otimes D_q^h}$$

$$\boxed{\mu p^{\uparrow} \rightarrow \mu X h^{\pm}}$$

The Sivers PDF	
1992	Sivers proposes $f_{1T}^{\perp}$
1993	J. Collins proofs $f_{1T}^{\perp} = 0$ for T invariance
2002	S. Brodsky, Hwang and Schmidt demonstrate that $f_{1Tq}^{\perp}$ may be $\neq 0$ due to FSI
2002	J. Collins shows that $(f_{1T}^{\perp})_{DY} = -(f_{1T}^{\perp})_{SIDIS}$
2004	HERMES on p: $A_{Siv}^{\pi^+} \neq 0$ and $A_{Siv}^{\pi^-} = 0$
2004	COMPASS on d: $A_{Siv}^{\pi^+} = 0$ and $A_{Siv}^{\pi^-} = 0$
2008	COMPASS on p: $A_{Siv}^{\pi^+} \neq 0$ and $A_{Siv}^{\pi^-} = 0$

Sivers Asymmetry

$$A_{Siv}(x,z) = \frac{F_{UT}^{sin\Phi_{Siv}}(x,z)}{F_{UU}(x,z)} = \frac{\sum_q e_q^2 x f_{1T}^{\perp q}(x, k_\perp^2) \otimes D_{1q}^h(z, \ p_\perp^2)}{\sum_q e_q^2 x f_1^q(x, \ k_\perp^2) \otimes D_{1q}^h(z, \ p_\perp^2)}$$

- To evaluate it we need to solve the convolutions (i.e. make hypothesis on the transverse momenta dependences of the TMDs)
- Gaussian ansatz: $f_{1T}^{\perp q}(x) \frac{e^{-k_\perp^2/\langle k_\perp^2\rangle_S}}{\pi\langle k_\perp^2\rangle_S}$ $\quad D_{1q}^h(z) \frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}$
- Leading to: $A_{Siv,G}(x,z) = \frac{\sqrt{\pi}M}{\sqrt{z^2\langle k_T^2\rangle_S + \langle p_T^2\rangle}} \frac{\sum_q e_q^2 \, x f_{1T}^{\perp(1)q}(x) z D_{1q}^h(z)}{\sum_q e_q^2 x f_1^q(x) D_{1q}^h(z)}$ with $f_{1T}^{\perp(1)q}(x) =$

$\int d^2\vec{k}_T \frac{k_T^2}{2M^2} f_{1T}^{\perp q}(x, k_T^2)$

TMD PDFs

- The theoretical expression of TMDs has a more complicated structure of the gauge link, connecting two space-time points with a transverse separation

$$f_{q/N}(x, k_\perp) = \frac{1}{8\pi}\int dr^- \frac{dr_\perp^2}{(2\pi)^2} e^{-iMxr^-/2+ik_\perp\cdot r_\perp}$$

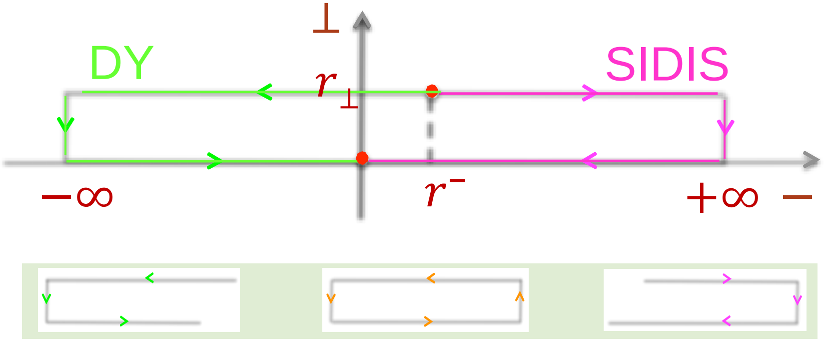
$$\langle N(P)|\bar{q}(r^-, r_\perp)\gamma^+ W[r^-, r_\perp; 0]q(0)|N(P)\rangle|_{r^+\sim 1/\nu\to 0}$$

- The Wilson line W is no longer on the light-cone axis and may introduce a **process dependence**

Parity and Time reversal invariance ⇒

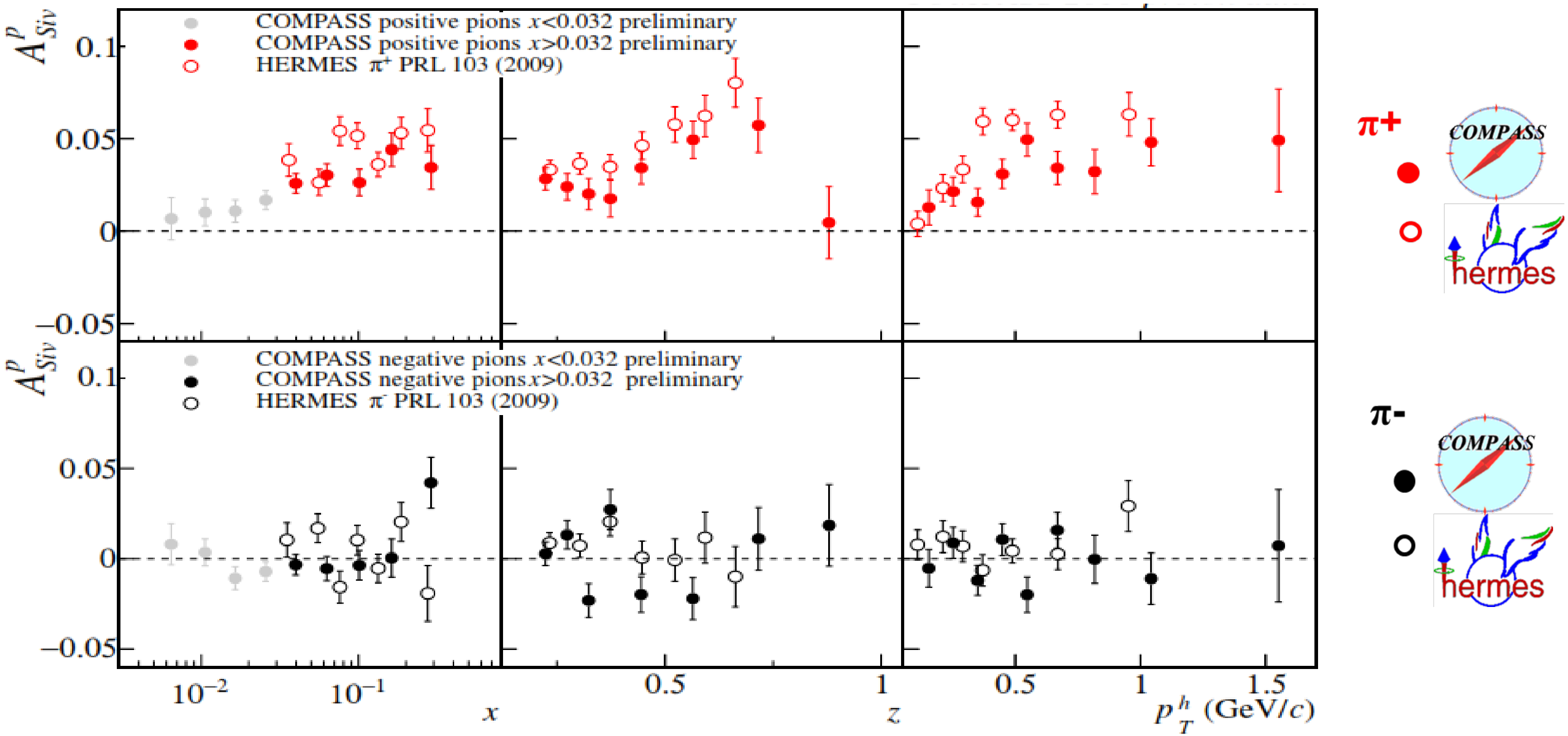
$$\left(f_{1Tq}^\perp\right)_{DY} = -\left(f_{1Tq}^\perp\right)_{SIDIS}$$

Most critical test to TMD approach to SSA



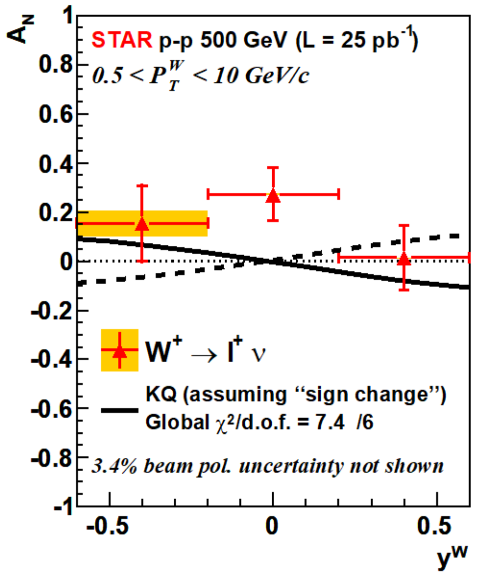
Sivers asymmetry on p

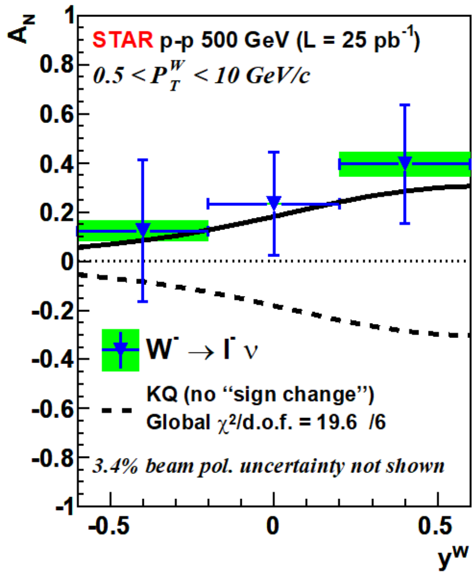
charged pions (and kaons), HERMES and COMPASS



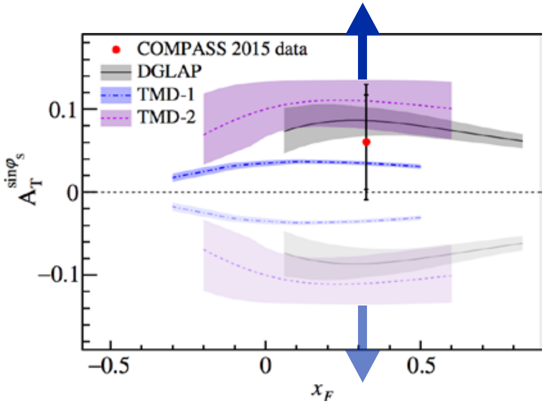
Transverse Spin Asymmetry in Drell-Yan

190 GeV/c π^- beam, transversely polarized NH_3 target





$$f_{1T,\mathrm{DY}}^{\perp} = -f_{1T,\mathrm{SIDIS}}^{\perp}$$



PRL119, 112002 (2017).

The weighted Sivers asymmetry

- If we weight the spin dependent part of the cross-section

$$F_{UT}^{\sin\Phi_{Siv}}(x,z) = \Sigma_q\ e_q^2 \int d^2\vec{P}_T P_T F_q(x,z,P_T^2)$$

- with $w = P_T/zM$, i.e.

$$F_{UT}^{\sin\Phi_{Siv},w}(x,z) = \Sigma_q\ e_q^2 \int d^2\vec{P}_T \frac{P_T^2}{zM} F_q(x,z,P_T^2) = 2\ \Sigma_q\ e_q^2 x f_{1T}^{\perp(1)q}(x) D_{1q}^h(z)$$

and $F_q(x,z,P_T^2) = \int d^2\vec{k}_T \int d^2\vec{p}_T\ \delta^2(\vec{P}_T - z\vec{k}_T - \vec{p}_T) \frac{\vec{P}_T \cdot \vec{k}_T}{MP_T^2} x f_{1T}^{\perp q}(x,k_T^2)\ D_{1q}(z,p_T^2)$

- we have no longer a convolution but a product of two integrals and we can write

$$A_{Siv}^{w}(x,z) = \frac{F_{UT}^{\sin\Phi_{Siv},w}(x,z)}{F_{UU}(x,z)} = 2\frac{\Sigma_q\, e_q^2 x f_{1T}^{\perp(1)q}(x) D_{1q}^h(z)}{\Sigma_q\, e_q^2 x f_1^q(x) D_{1q}^h(z)}$$

with $f_{1T}^{\perp(1)q}(x) = \int d^2\vec{k}_T \frac{k_T^2}{2M^2} f_{1T}^{\perp q}(x,k_T^2)$

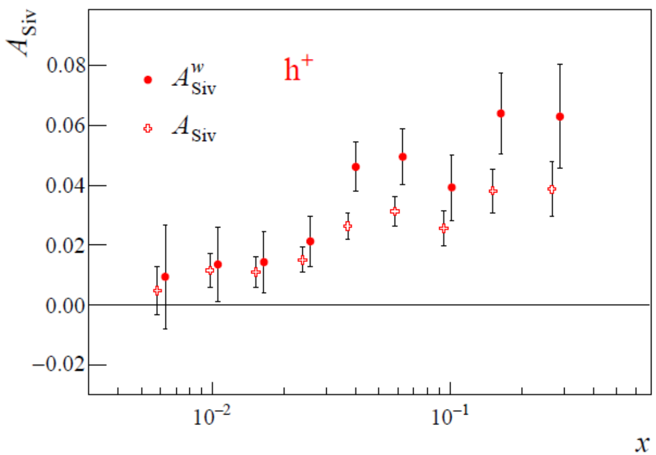
arXiv:1809.02936 A.Martin/this conf

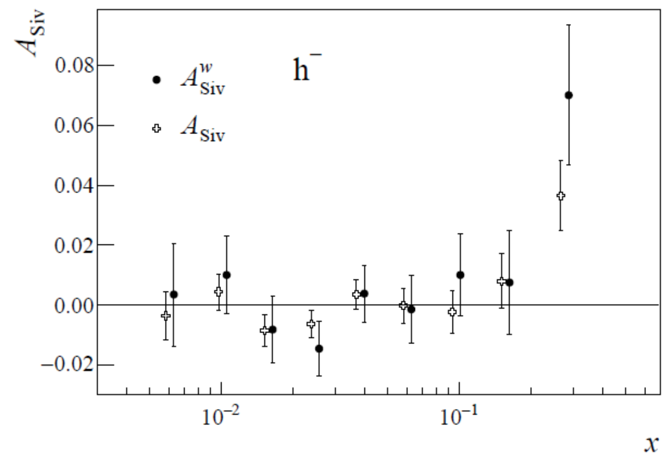
The weighted Sivers asymmetry

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

$w = P_T/zM$

standard cuts
z>0.2





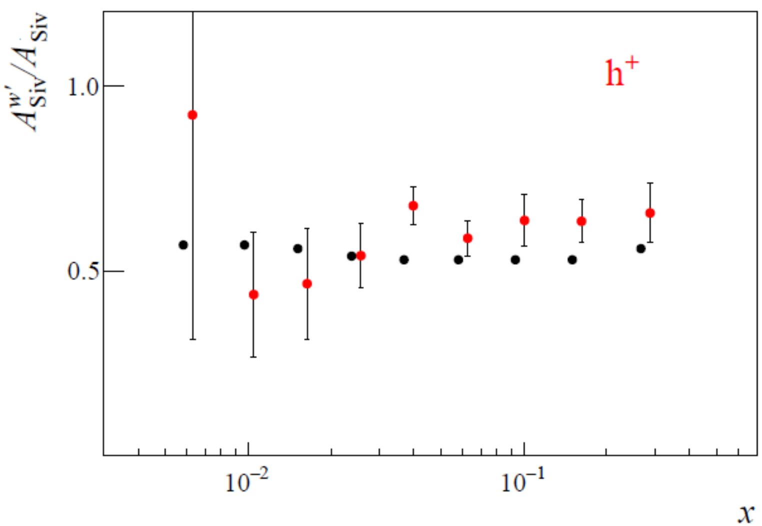
$$\sim 2\,\frac{f_{1T}^{\perp(1)u}(x)}{f_1^{u}(x)}$$

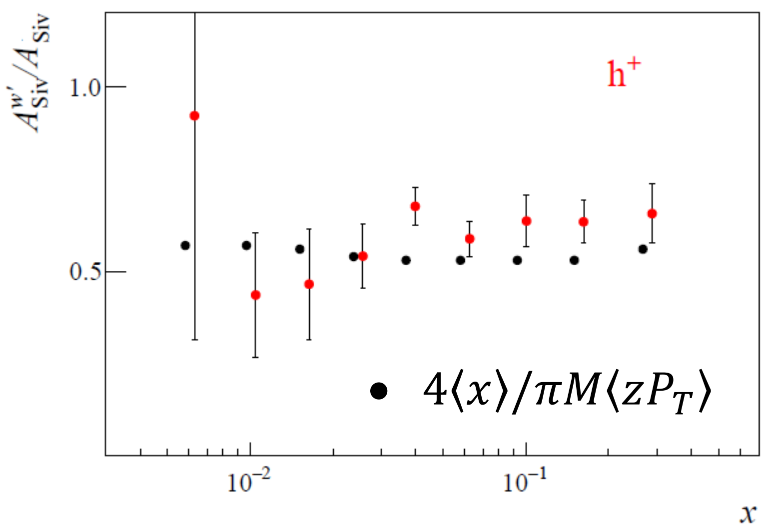
both $f_{1T}^{\perp(1)u}$ and $f_{1T}^{\perp(1)d}$ contribute

The weighted Sivers asymmetry

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

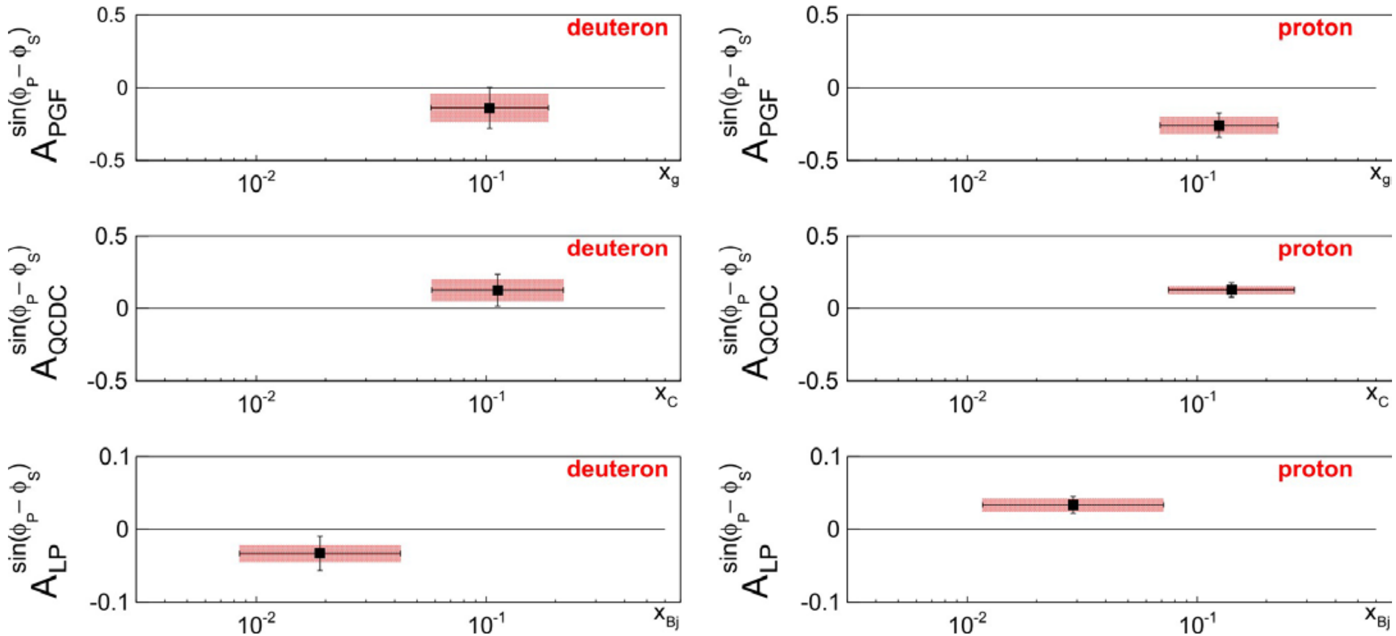
standard cuts
z>0.2





The ratio between weighted and unweighted Sivers asymmetries follows the average of $4\langle x\rangle/\pi M\langle zP_T\rangle$ of the unpolarised sample

Sivers Asymmetry for Gluon from SIDIS



$$A_{PGF}^{Siv,d} = -0.14 \pm 0.15(\text{stat.}) \pm 0.10(\text{syst.})$$
$$\langle x_g \rangle = 0.13$$

$$A_{PGF}^{Siv,p} = -0.26 \pm 0.09(\text{stat.}) \pm 0.06(\text{syst.})$$
$$\langle x_g \rangle = 0.15$$

C. Adolph et al. (COMPASS Collaboration), Phys. Lett. B 772, 854 (2017).

WHAT WILL COME NEXT

Already on tape

- COMPASS @ CERN:
  - 2016-17 DVCS and SIDIS on $\mathrm{LH_2}$
  - 2018 DY run
- STAR @ RHIC
  - 2017 350 pb^{-1} 14 times Run-11 for $-1 < \eta < 1.8 \longrightarrow \ A_N, W^{\pm}/Z^0$, Collins, ……
- 2018 RUN @ Jlab 12
  - HALL A
  - HALL B
  - HALL C

JLab 12: valence maping of TMDs and GPDs

- HALL A
  - Ongoing GPDs: E12-06-114: Deeply Virtual Compton Scattering
  - Future SOLID experiment
- HALL B
  - Ongoing GPDs: E12-06-108 (hard exclusive electro-production of π^0 and η,
  - Ongoing SIDIS: E12-06-112/A/B (SIDIS production of π, Λ in target region, nucleon structure at twist-3)
  - And much more in future
- HALL C
  - Ongoing TMDs E12-09-017 (range $0.02 < x < 0.5$, $2\ (\mathrm{GeV}/c)^2 < Q^2 < 5\ (\mathrm{GeV}/c)^2$ and $P_{hT} < 0.5\mathrm{GeV}/c$; $\sim 60\%$ of data acquired, remainder in late 2018).
  - A_1^n (E12-06-110) in late 2019

Physics in 2021+

Objective:

unique program addressing several fundamental questions in QCD

→ essential to

- ❑ the mission of the RHIC physics program in cold and hot QCD
- ❑ fully realize the scientific promise of the EIC
  - ➢ lay the groundwork for the EIC, both scientifically and by refining the experimental requirements
  - ➢ Test EIC detector technologies under real conditions, i.e SiPMs

pp, pA and AA program based on two pillars

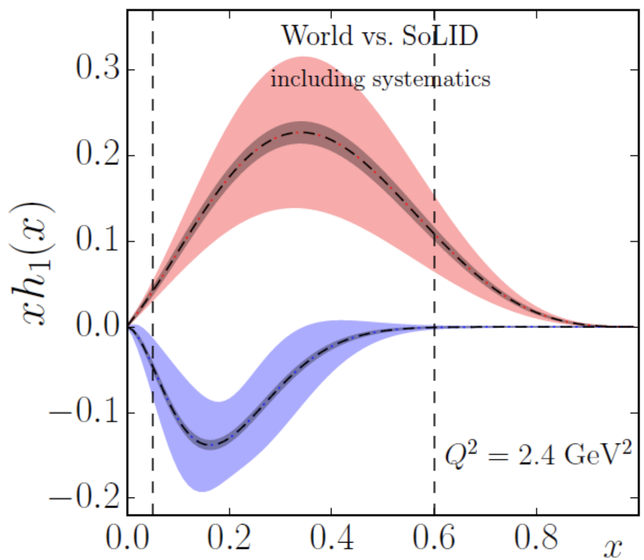
→ midrapidity program based on existing STAR detector utilizing iTPC, eToF and EPD upgrades

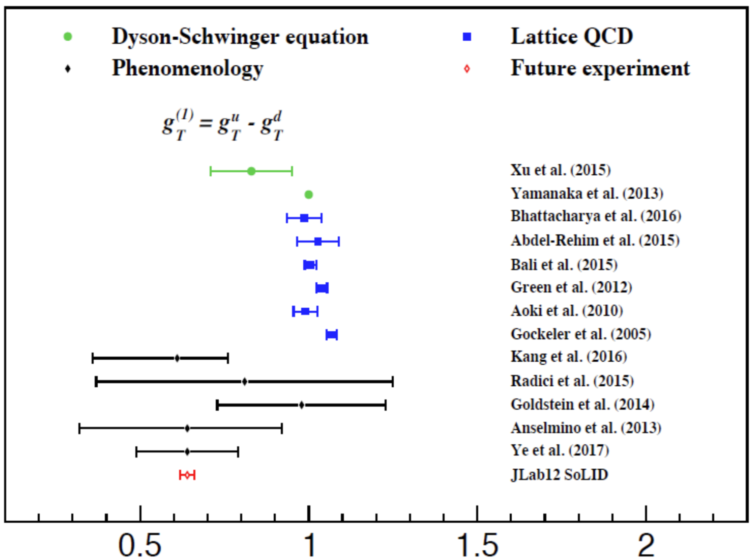
→ forward rapidity program based on unique upgrade of STAR
Upgrade consisting of Hcal + ECal + tracking (Si +sTGCs) at $2.5 < \eta < 4$

Goal:

Have the forward upgrade operational for a polarized pp@500 GeV run in 2021 and run during the sPHENIX data taking campaign (≥ 2023)

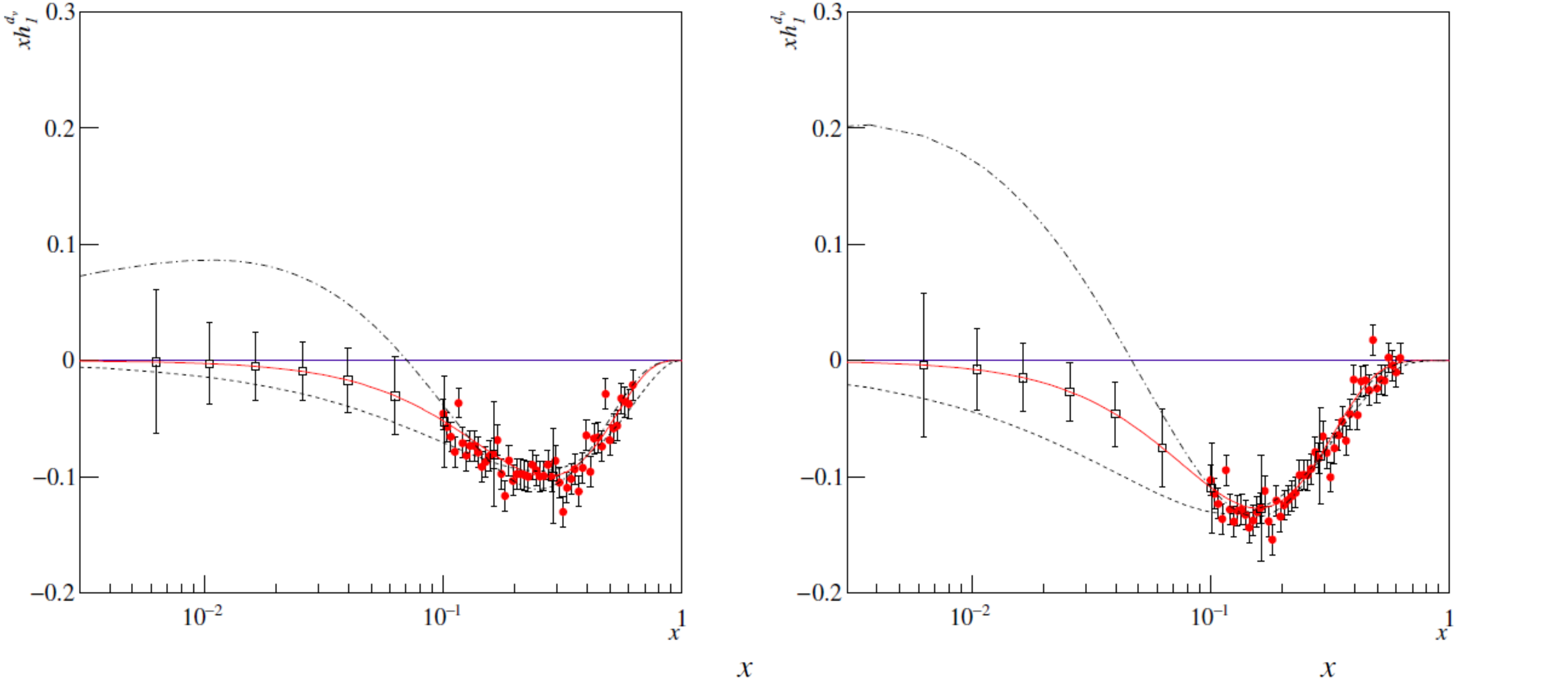
SoLID Impact on h_1 and Tensor Charges





COMPASS deuteron data in 2021

- Expected gain in precision on u- and d-quark transversity



F. Bradamante/this conf.

To conclude

- Many important results both for the spin structure and the internal 3D structure of the nucleon have been provided by experiments at hera, cern, rhic and jlab
- And many will come in the future: Jlab will map the valence region with high precision; compass and rhic will complete their programs

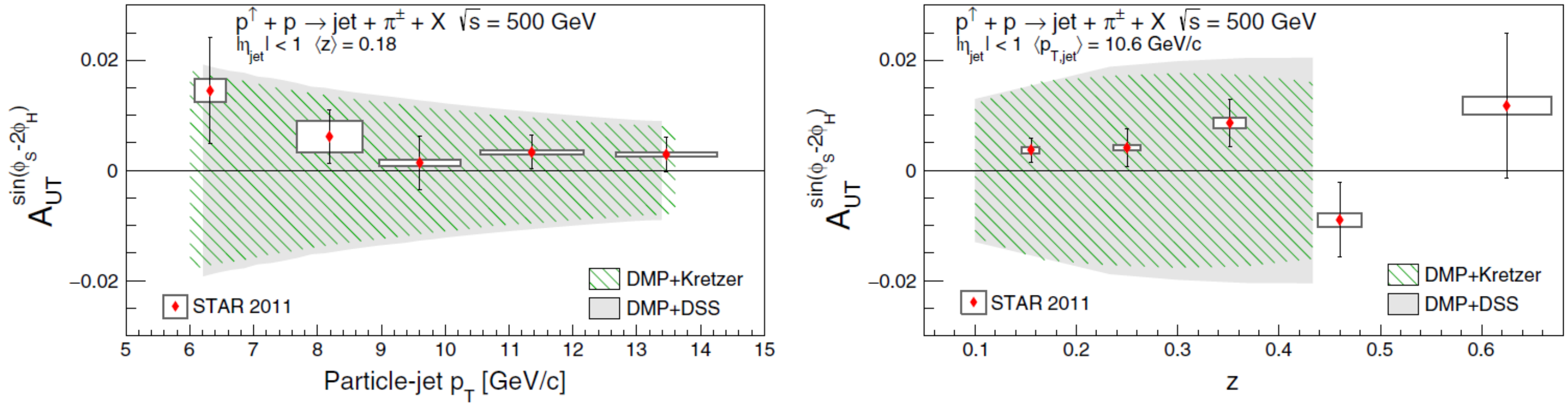
The science

Finding 1: An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms

FINALLY, WE WILL NEED A DEDICATED POLARISED eN MACHINE GIVING ACCECC TO BOTH P AND N WITH HIGH INTENSITY AND LARGE PHASE SPACE COVERAGE TO MOVE FROM EXPLORATION TO PRECISION ALLOWING US TO ANSWER THE VERY CHALLENGING QUESTIONS WE ARE FACING

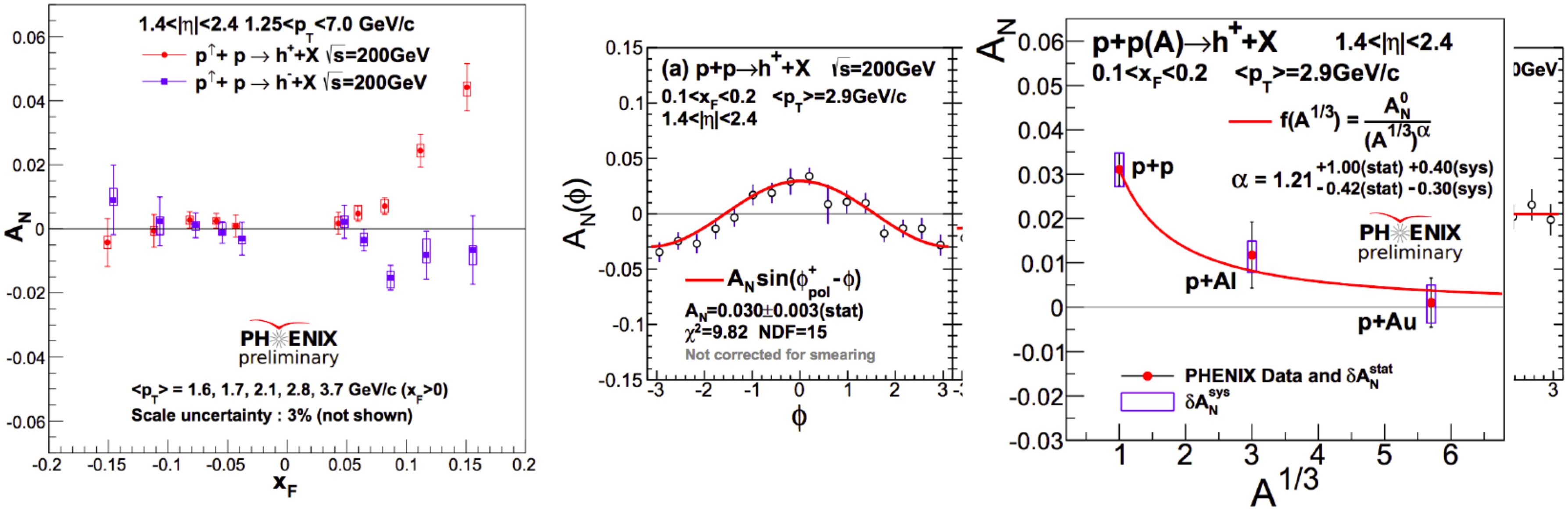

Thank you

TSA of inclusive jets and $\pi^{\pm}$ within jets from STAR



COLLINS LIKE asymmetries: sensitive to linearly polarized gluons in a polarized proton, are found to be small and provide the first constraints on model calculations.

TSSA A_N studies at PHENIX



Described by twist 3 collinear approach (1 scale, high p_T)
Suppresion in $p^{\uparrow}A$ expected by gluon saturation ($\propto A^{1/3}$)
Hybrid approach: twist-3 and CGC

New QCD facility at CERN M2

https://arxiv.org/abs/1808.00848

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

August 3, 2018

arXiv:1808.00848v1 [hep-ex] 2 Aug 2018

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS

O.Yu. Denisov
on behalf of the working group:
"A New QCD Facility at the M2 beam line of the CERN SPS"*

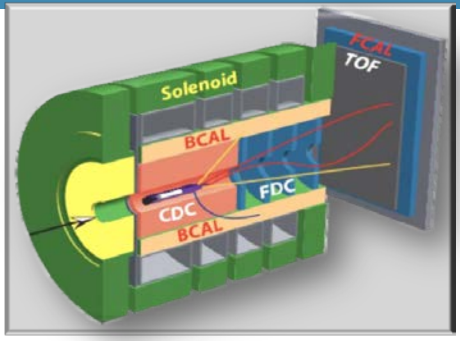
Contents

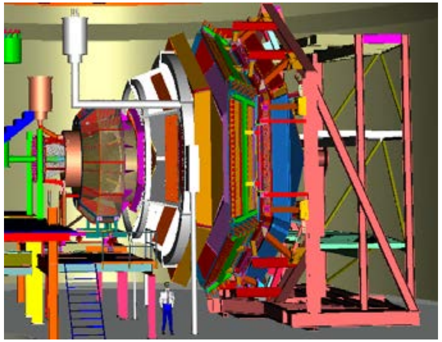
*The final author list of the LoI will be finished in October 2018. Please send e-mail to NQF-M2@cern.ch for questions and requests.

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware Additions
μp elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pr. H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2 \cdot 10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified PT magnet
Input for DMS	$\overline{p}$ production cross section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	LHe target
$\overline{p}$-induced Spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectr.: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	$\sim$100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex det.
Primakoff (RF)	Kaon polarisability & pion life time	$\sim$100	$5 \cdot 10^6$	> 10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	$\geq$ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

12 GeV Upgrade Physics Instrumentation

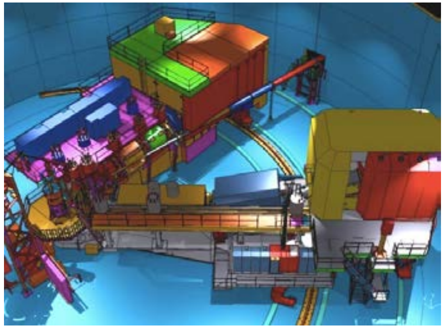
GLUEx (Hall D): exploring origin of confinement by studying hybrid mesons

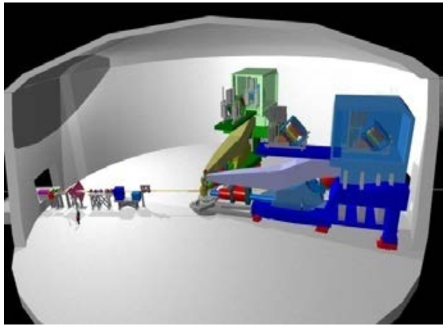




CLAS12 (Hall B): understanding nucleon structure via generalized parton distributions

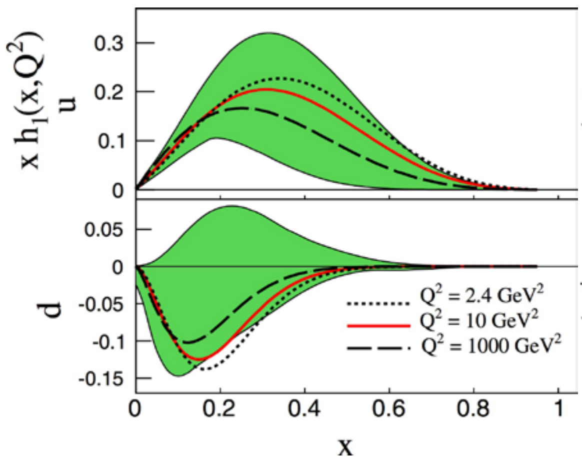
SHMS (Hall C): precision determination of valence quark properties in nucleons and nuclei

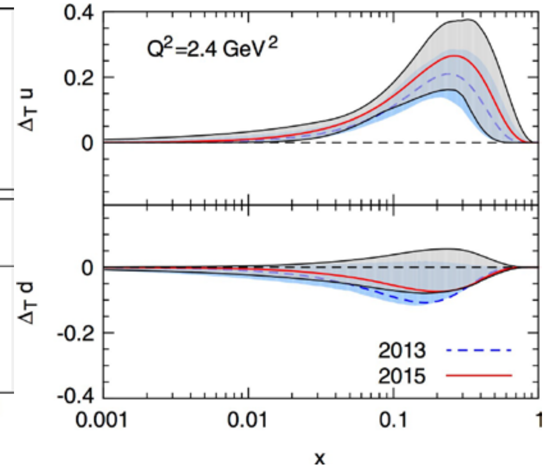


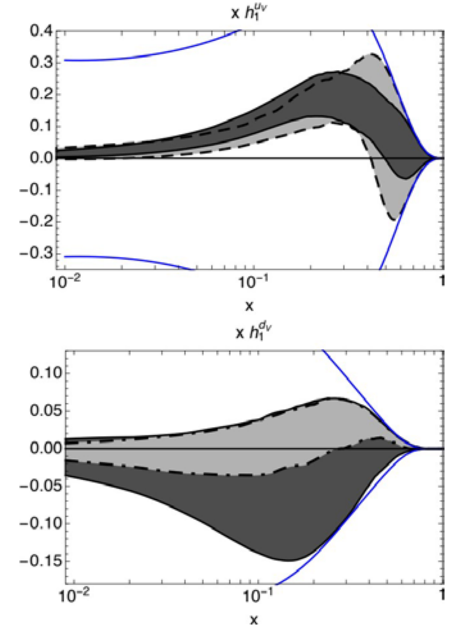


Hall A: nucleon form factors
& future new experiments like Moller & SOLID

Global Analysis: Transversity







Z.-B. Kang et al., Phys. Rev. D 93, 014009 (2016).

M. Anselmino et al., Phys. Rev. D 92, 114023 (2015).

M. Radici and A. Bacchetta, arXiv: 1802.05212[hep-ph]

Kinematic coverage