Measurement of q_T-weighted transverse-spin-dependent azimuthal asymmetries at COMPASS

ILLINOIS

NSF

Riccardo Longo
On behalf of the COMPASS Collaboration

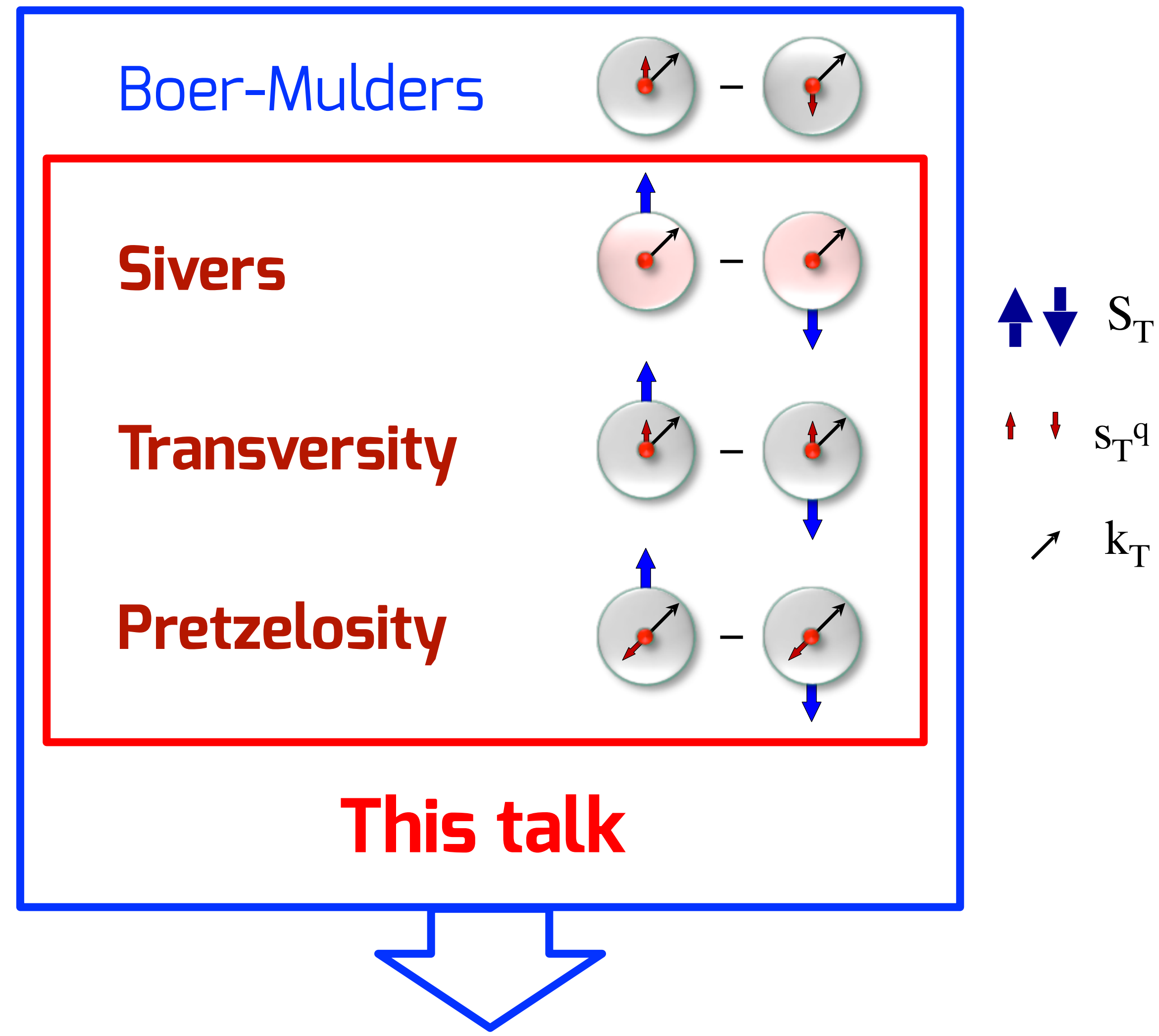
DIS 2019
TORINO
8-12 April

Transverse Momentum Dependent PDFs

In the leading order QCD parton model nucleon spin-structure can be parametrized in terms of 8 *twist-2* quark intrinsic transverse momentum (k_T) dependent TMD PDFs.

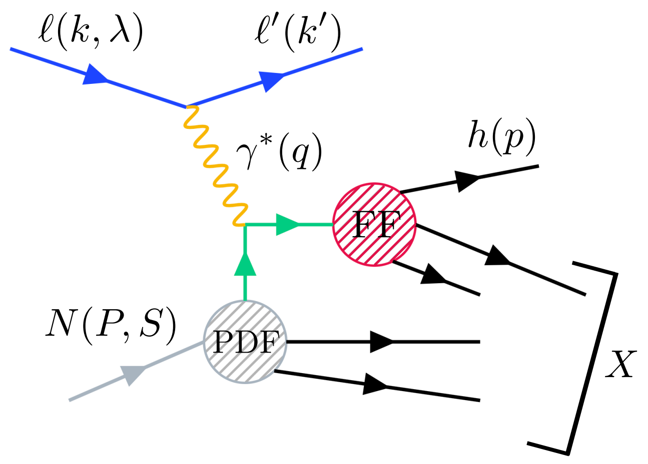
		Nucleon Polarization		
		U	**L**	**T**
Quark Polarization	**U**	$f_1^q(x, \mathbf{k_T^2})$ Number Density		$f_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Sivers
	L		$g_1^q(x, \mathbf{k_T^2})$ Helicity	$g_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear T
	T	$h_1^{q\perp}(x, \mathbf{k_T^2})$ Boer-Mulders	$h_{1L}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear L	$h_{1T}^q(x, \mathbf{k_T^2})$ Transversity $h_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Pretzelosity

Nucleon · Nucleon spin · quark · quark spin · $\mathbf{k_T}$



TMD PDFs can be accessed through measurement of target spin (in)dependent azimuthal asymmetries both in SIDIS and Drell-Yan

Probing nucleon structure via SIDIS and Drell-Yan



SIDIS on transversely polarized nucleons
COMPASS 2007, 2010

$$\mu + p^{\uparrow} \rightarrow \mu' + h + X$$

- Access to convolutions of TMD PDFs and Fragmentation Functions (FFs):

$$A_{\lambda S}^{mod} \longrightarrow F_{\lambda S}^{mod} \longrightarrow PDF_p \otimes FF_h$$

$$F_{UU}^{\cos\phi_h}, F_{UU}^{\cos 2\phi_h} \longrightarrow h_{1,p}^{\perp} \qquad F_{UT,T}^{\sin(\phi_h-\phi_S)} \propto f_{1T,p}^{\perp} \otimes D_{1,q}^{h}$$

$$F_{UT}^{\sin(\phi_H+\phi_S)} \propto h_{1,p} \otimes H_1^{\perp,h} \qquad F_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T,p}^{\perp} \otimes H_1^{\perp,h}$$

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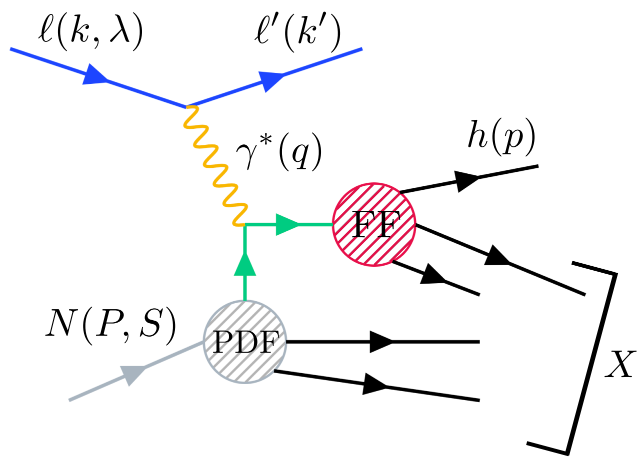

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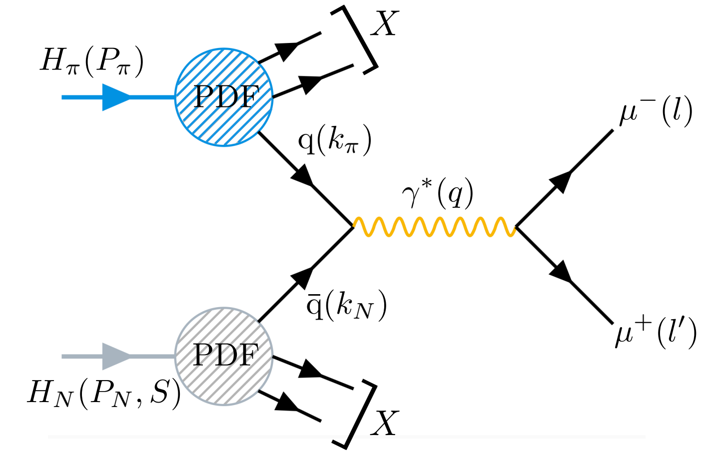
Pion induced polarized Drell-Yan
COMPASS 2015, 2018



$$\pi^- + p^{\uparrow} \rightarrow \mu^+\mu^- + X$$

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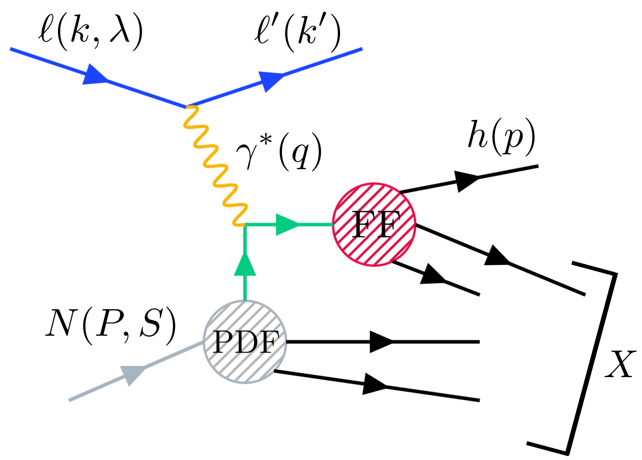

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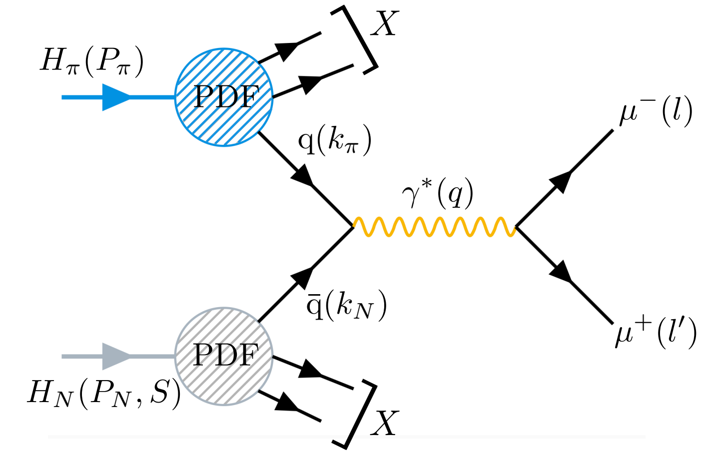

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Universality in the TMD-QCD parton model approach

$$h_{1,p}{}_{SIDIS} = h_{1,p}{}_{DY}$$

$$h_{1T,p}^{\perp}{}_{SIDIS} = h_{1T,p}^{\perp}{}_{DY}$$

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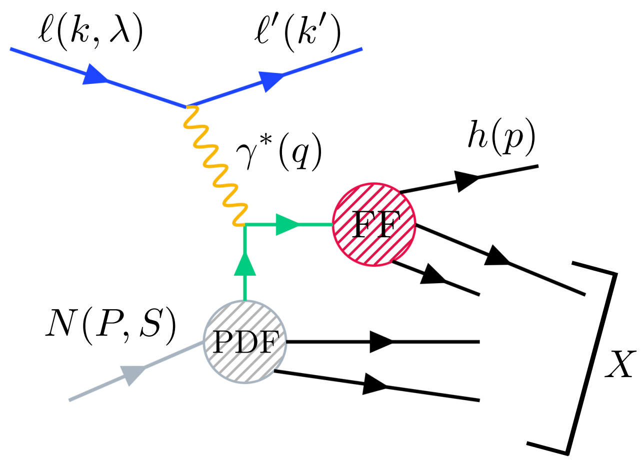

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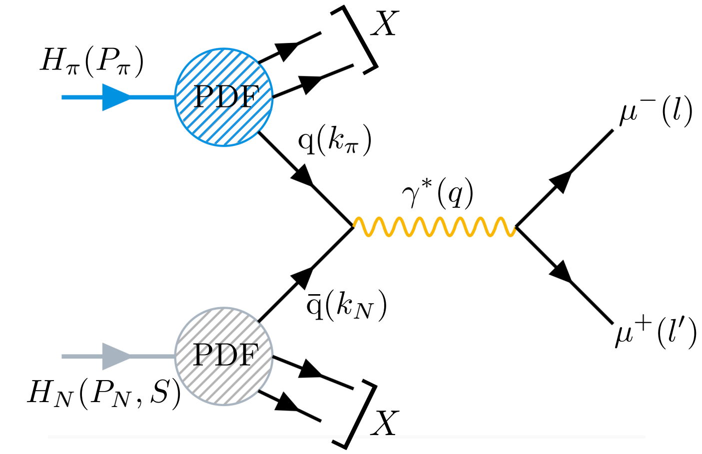

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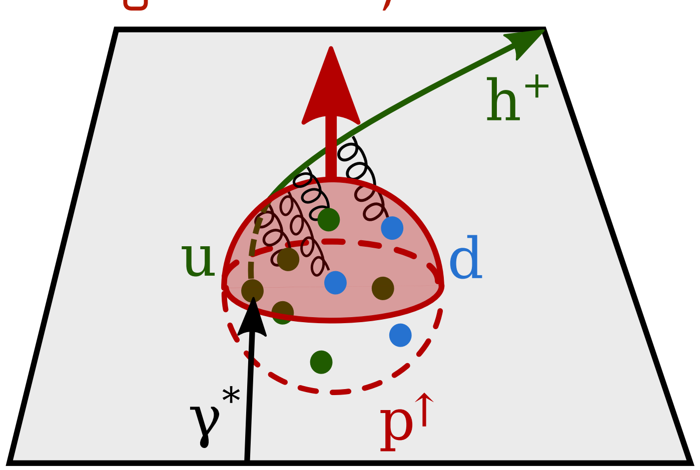
Drawings courtesy of J.Matoušek



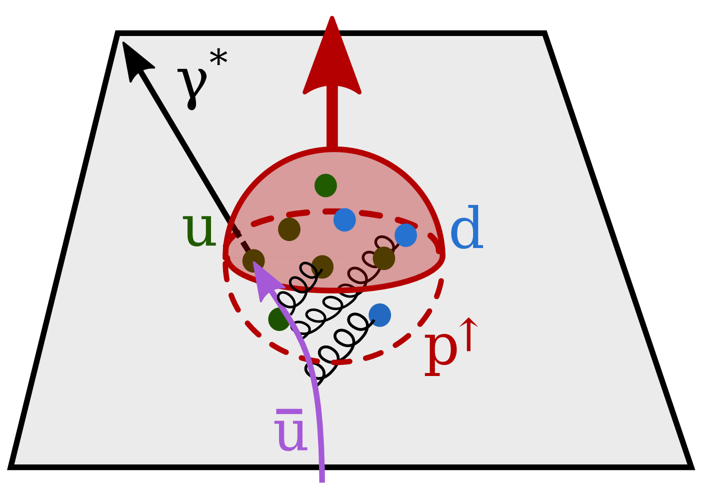
Sivers effect in SIDIS (as described by [M. Burkardt, Nucl.Phys. A735 (2004) 185]

Universality in the TMD-QCD parton model approach

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

$$h_{1,p}^{\perp}\,_{SIDIS} = -\,h_{1,p}^{\perp}\,_{DY}$$

Predicted **sign-change** for Sivers and Boer-Mulders functions



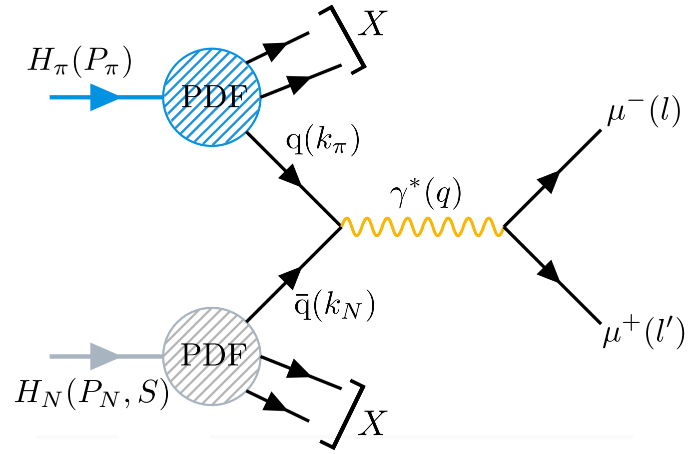
Sivers effect in Drell-Yan
Described in the same manner

Drell-Yan cross-section

General leading order QCD parton model expression of the Single Polarized DY cross-section

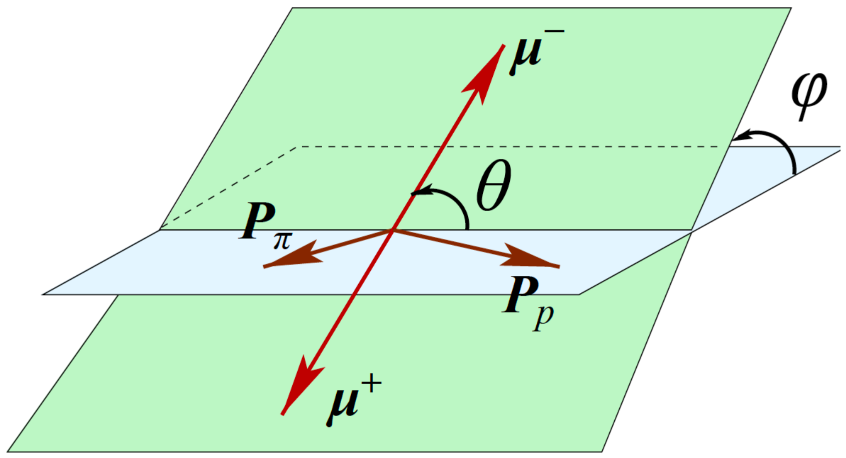
Pion induced polarized Drell-Yan
COMPASS 2015, 2018

$$\pi^- + p^\uparrow \rightarrow \mu^+\mu^- + X$$

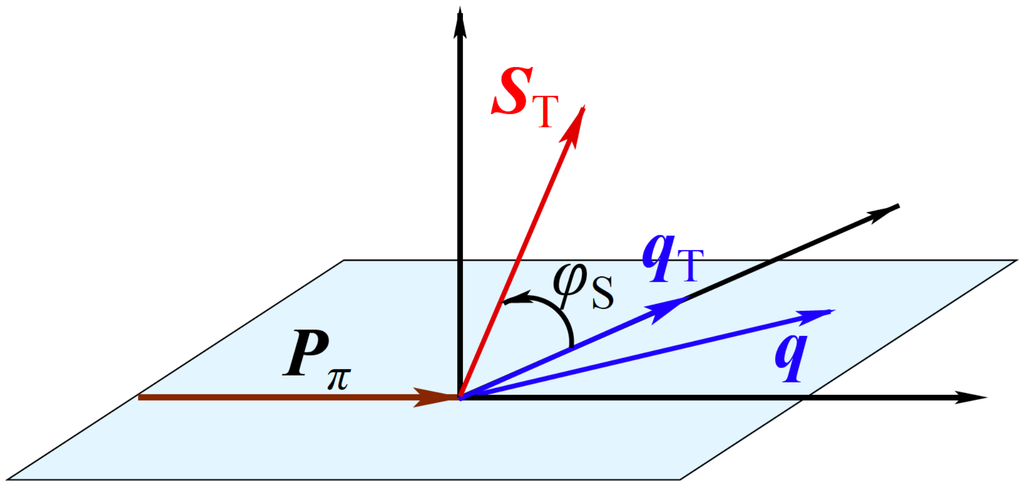


$$\frac{d\sigma_{DY}}{dx_\pi\, dx_N\, dq_T^2\, d\varphi_S d\cos\theta d\varphi} = C_0 \Big\{ (1+\cos^2\theta) F_U^1 + \sin^2\theta\cos 2\varphi F_U^{\cos 2\varphi}$$
$$+ |\mathbf{S_T}| \Big[(1+\cos^2\theta)\sin\varphi_S F_T^{\varphi_S}$$
$$+ \sin^2\theta \sin(2\varphi+\varphi_S) F_T^{\sin(2\varphi+\varphi_S)}$$
$$+ \sin^2\theta \sin(2\varphi-\varphi_S) F_T^{\sin(2\varphi-\varphi_S)} \Big] \Big\}$$

Collins - Soper frame



Target rest frame



$\mathbf{q_T}$: transverse momentum of the virtual photon in the target rest frame

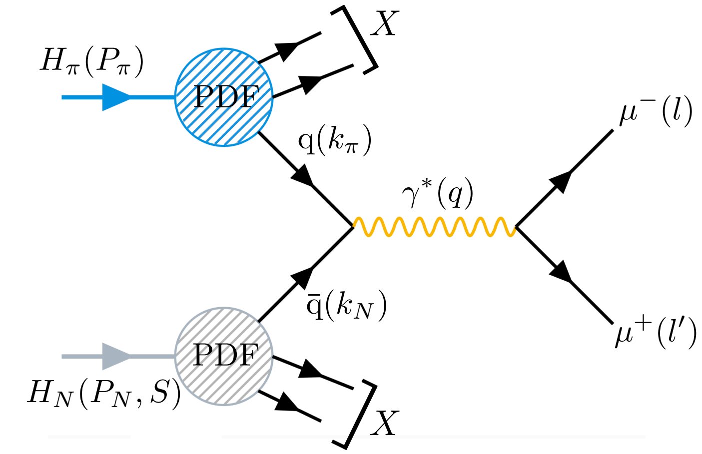
Drell-Yan cross-section

Each structure function $F_X^{[mod]}$ can be interpreted in terms of convolutions of TMD PDFs of beam and target hadrons;

Pion induced polarized Drell-Yan

COMPASS 2015, 2018

$$\pi^- + p^\uparrow \rightarrow \mu^+\mu^- + X$$



$$F_U^1 = -\mathscr{C}\left[f_{1,\pi} f_{1,p}\right],$$

Number densities

$$F_U^{\cos 2\varphi} = -\mathscr{C}\left[\frac{2(\mathbf{q_T}\cdot\mathbf{k}_{\pi\mathbf{T}})(\mathbf{q_T}\cdot\mathbf{k_{pT}}) - \mathbf{q_T^2}(\mathbf{k}_{\pi\mathbf{T}}\cdot\mathbf{k_{pT}})}{q_T^2 M_\pi M_p} h_{1,\pi}^\perp h_{1,p}^\perp\right],$$

Boer Mulders functions

$$F_T^1 = F_T^{\sin\varphi_S} = -\mathscr{C}\left[\frac{\mathbf{q_T}\cdot\mathbf{k_{pT}}}{q_T M_p} f_{1,\pi} f_{1T,p}^\perp\right],$$

Number density of the pion, Sivers of the proton

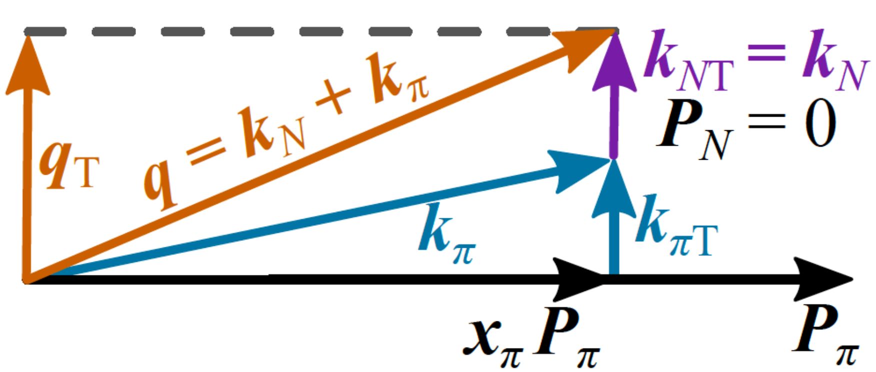
$$F_T^{\sin(2\varphi+\varphi_S)} = -\mathscr{C}\left[\left(\frac{(\mathbf{q_T}\cdot\mathbf{k_{pT}})\left[2(\mathbf{q_T}\cdot\mathbf{k}_{\pi\mathbf{T}})(\mathbf{q_T}\cdot\mathbf{k_{pT}}) - \mathbf{q_T^2}(\mathbf{k}_{\pi\mathbf{T}}\cdot\mathbf{k_{pT}})\right]}{q_T^3 M_\pi M_p^2} - \frac{k_{pT}^2(\mathbf{q_T}\cdot\mathbf{k}_{\pi\mathbf{T}})}{2q_T M_\pi M_p^2}\right) h_{1,\pi}^\perp h_{1T,p}^\perp\right],$$

Boer Mulders of the pion
Pretzelosity of the proton

$$F_T^{\sin(2\varphi-\varphi_S)} = -\mathscr{C}\left[\frac{\mathbf{q_T}\cdot\mathbf{k}_{\pi\mathbf{T}}}{q_T M_\pi} h_{1,\pi}^\perp h_{1,p}\right]$$

Boer Mulders of the pion
Transversity of the proton

The convolution $\mathscr{C}$ of the TMDs runs over the intrinsic transverse momenta



Transverse momenta in the target rest frame

Transverse Spin Asymmetries in Drell-Yan

- Transverse Spin Asymmetries (TSAs):

See talk by B.Parsamyan

$$A_T^{\sin\Phi}(x_\pi, x_N, q_T^2) = \frac{F_T^{\sin\Phi}(x_\pi, x_N, q_T^2)}{F_U^1(x_\pi, x_N, q_T^2)} = \frac{\mathscr{C}\left[\omega(\mathbf{k}_{\pi\mathbf{T}}, \mathbf{k}_{\mathbf{p},\mathbf{T}}) f_\pi \, f_p\right]}{\mathscr{C}\left[f_{1,\pi} \, f_{1,p}\right]}, \quad \Phi = \varphi_S, 2\varphi_{CS} \pm \varphi_S$$

- To solve the convolution over intrinsic transverse momenta one has to assume a given dependence of the TMD on k_T (e.g. Gaussian).

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See talk by B.Parsamyan

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- To solve the convolution over intrinsic transverse momenta one has to assume a given dependence of the TMD on k_T (e.g. Gaussian).
- Example: **Sivers asymmetry** integrated over q_T in the Gaussian model

First $\mathbf{k_T}^2$ moment of the Sivers function $$f_{1T,p}^{\perp(1)q}(x_N) = \int d^2\mathbf{k_T}\left(\frac{k_T^2}{2M^2}\right) f_{1T,p}^{\perp(1)q}(x_N, k_T^2)$$

$$A_T^{\sin\varphi_S}(x_\pi, x_N) \overset{Gauss.}{=} -a_G \frac{\sum_q e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi) f_{1T,p}^{\perp(1)q}(x_N) + (q \leftrightarrow \bar{q})\right]}{\sum_q e_q^2\left[f_1^q(x_\pi) f_1^{\bar{q}}(x_N) + q \leftrightarrow \bar{q}\right]} \approx -a_G \frac{f_{1,T}^{\perp(1)u}(x_N)}{f_{1,p}^u(x_N)}$$

$$a_G = \frac{\sqrt{\pi}\, M_p}{\sqrt{\langle \mathbf{k}_{\pi\mathbf{T}}\rangle^2 + \langle \mathbf{k}_{\mathbf{pT}}\rangle}}$$

Gaussian factor

Neglecting sea quarks contribution

$$\pi^- = |\bar{u}d\rangle$$

$$p = |uud\rangle$$

q_T-weighted TSAs in Drell-Yan

- To avoid making assumptions on the $\mathbf{k_T}$ dependence of the TMDs, a popular solution is to weight the structure functions with the transverse momentum of the virtual photon ($\mathbf{q_T}$).
- **Sivers** example:

[A. Kotzinian & P. Mulders, PLB 406 (1997) 373]
[A. Efremov et al., Phys.Lett. B612 (2005) 233]
[A. Sissakian et al., Eur.Phys.J. C46 (2006) 147]
[Z. Wang et al., Phys.Rev. D95 (2017) 094004]

$$A_T^{\sin\varphi_S}(x_\pi, x_N, q_T^2) = \frac{F_T^{\sin\phi_S}(x_\pi, x_N, q_T^2)}{F_U^1(x_\pi, x_N, q_T^2)} = -\frac{\mathscr{C}\left[\frac{\mathbf{q_T}\cdot\mathbf{k_{pT}}}{q_T M_p} f_{1,\pi}\, f_{1T,p}^\perp\right]}{\mathscr{C}\left[f_{1,\pi}\, f_{1,p}\right]}$$

- Integration of F_U^1 over $d^2\mathbf{q_T}$ can be solved w/o assumptions

$$\int d^2\mathbf{q_T} F_U^1 = \int d^2\mathbf{q_T}\mathscr{C}\left[f_{1,\pi}\, f_{1,p}\right] = \frac{1}{N_c}\sum_q e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi) f_{1,p}^q(x_p) + (q \leftrightarrow \bar{q})\right]$$

- Applying the weight $\frac{q_T}{M_p}$ the integral can be solved w/o assumptions

$$\int d^2\mathbf{q_T}\frac{q_T}{M_p}F_T^{\sin\varphi_S} = -\int d^2\mathbf{q_T}\frac{q_T}{M_p}\mathscr{C}\left[\frac{\mathbf{q_T}\cdot\mathbf{k_{pT}}}{q_T M_p} f_{1,\pi}\, f_{1T,p}^\perp\right] = -\frac{2}{N_c}\sum_q e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi) f_{1T,p}^{\perp\,(1)\,q}(x_p) + (q \leftrightarrow \bar{q})\right]$$

q_T-weighted TSAs in Drell-Yan

- q_T-weighted TSAs represent a **direct measurement** of TMD PDFs k_T^2-moments;
- By q_T-weighting we are able to access **products**, not convolutions;
- For Drell-Yan pairs originated in $\pi^- + p$ collisions and in the valence quark region, one can neglect sea quarks
- q_T-weighted Sivers asymmetry

$$A_T^{\sin\varphi_S \frac{q_T}{M_p}}(x_\pi, x_N) = -2\frac{\sum_q e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi) f_{1T,p}^{\perp(1)\,q}(x_p) + (q \leftrightarrow \bar{q})\right]}{\sum_q e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi) f_{1,p}^{q}(x_p) + (q \leftrightarrow \bar{q})\right]} \approx -2\frac{f_{1T}^{\perp(1)\,u}(x_N)}{f_{1,p}^{u}(x_N)}$$

- q_T-weighted asymmetry induced by proton Transversity and pion Boer-Mulders function

$$A_T^{\sin(2\varphi-\varphi_S)\frac{q_T}{M_\pi}}(x_\pi, x_N) \approx -2\frac{h_{1,\pi}^{\perp(1)\,\bar{u}}(x_\pi)\, h_{1,p}^{\perp\,u}(x_N)}{f_1^{\bar{u}}(x_\pi) f_{1,p}^{u}(x_N)}$$

- q_T-weighted asymmetry induced by proton Pretzelosity and pion Boer-Mulders function

$$A_T^{\sin(2\varphi+\varphi_S)\frac{q_T^3}{2M_pM_\pi}}(x_\pi, x_N) \approx -2\frac{h_{1,\pi}^{\perp(1)\,\bar{u}}(x_\pi)\, h_{1T,p}^{\perp(2)\,u}(x_N)}{f_1^{\bar{u}}(x_\pi) f_{1,p}^{u}(x_N)}$$

The COMPASS collaboration

- SPS North Area
- Fixed target experiment
- First data taking in 2002

Phase I

- 2002 – 2011
- Hadron spectroscopy
- Nucleon spin structure (L/T P/D Targets)

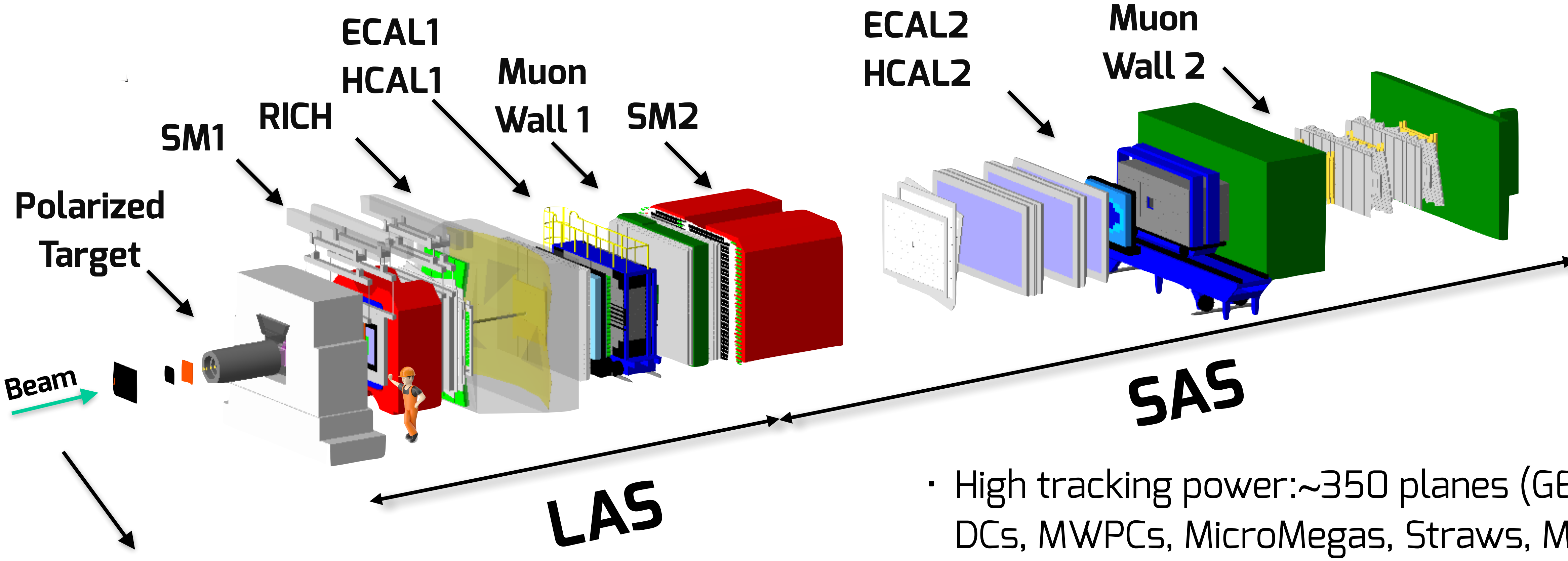
See talk by M.Stolarski

Phase II

- 2012 – 2018
- Primakoff + DVCS pilot run (2012)
- **Drell-Yan (2015, 2018)**
- DVCS + Unpolarized SIDIS(2016-2017)
- T-polarized SIDIS (D target) (2021)

See talks by B.Parsamyan, A.Martin J.Matoušek, N.Pierre, A.Vidon, A, Moretti

Drell-Yan measurements at COMPASS



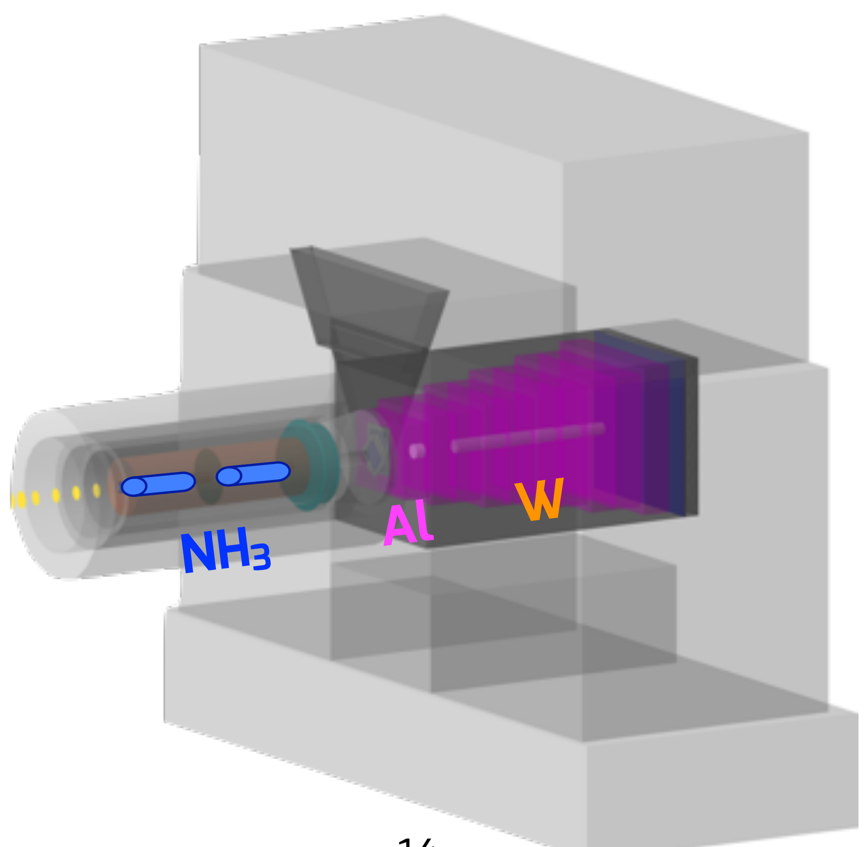
- High tracking power:~350 planes (GEMs, SciFis, DCs, MWPCs, MicroMegas, Straws, Muon Walls...)

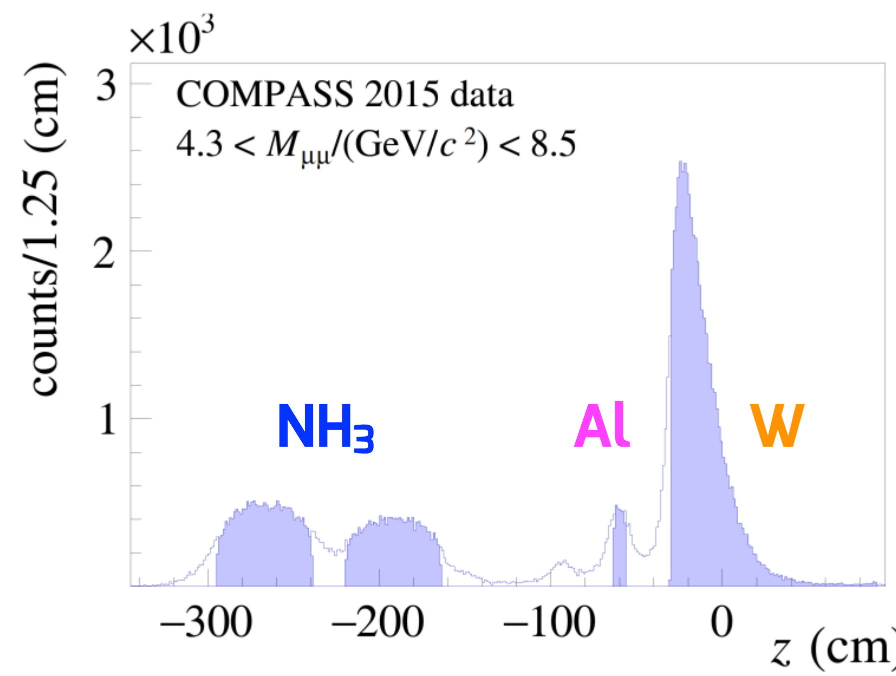
π^- beam

- P_{π^-} : 191 GeV/c, intensity $10^8\ \pi^-$/s

Target	# of cells	Polarization
NH_3	2	T, ~73 % (2015)
		T, ~75 % (2018)

- 2015 ~4 months of data taking;
- 2018 ~5 months of data taking;
- The NH_3 target polarization was **reversed** after each week;





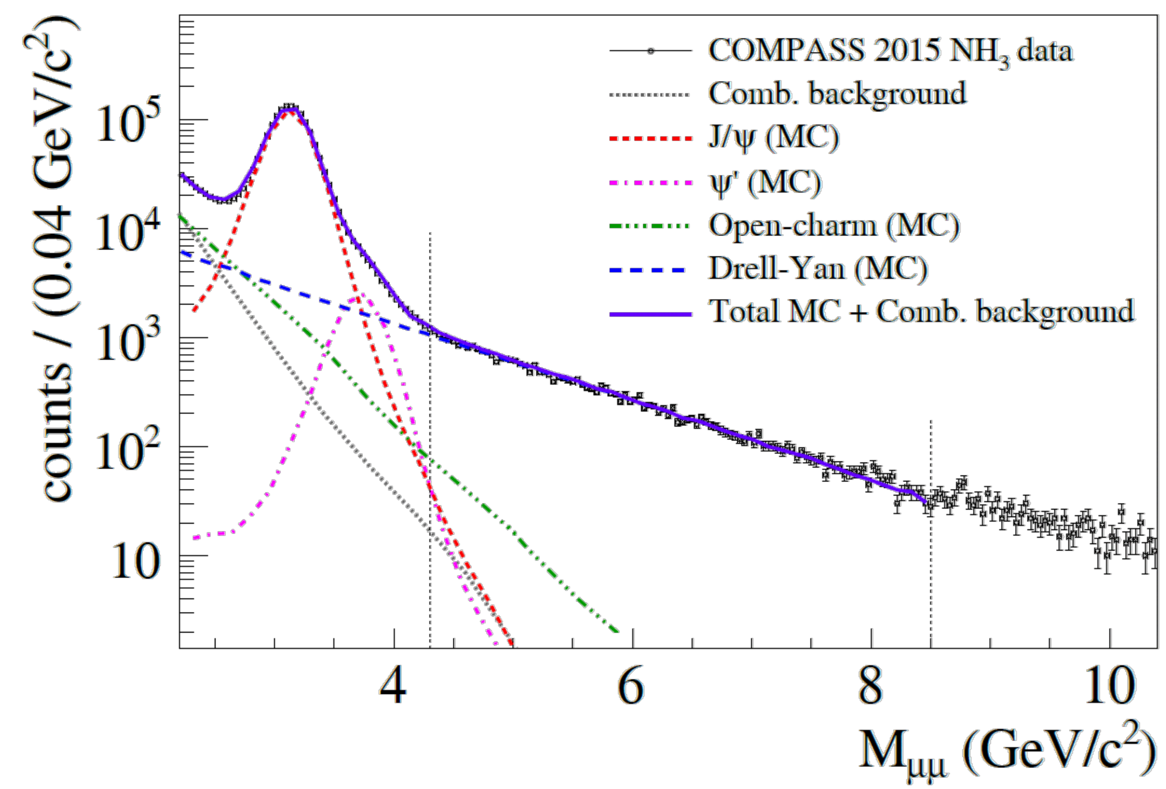
Drell-Yan measurements at COMPASS

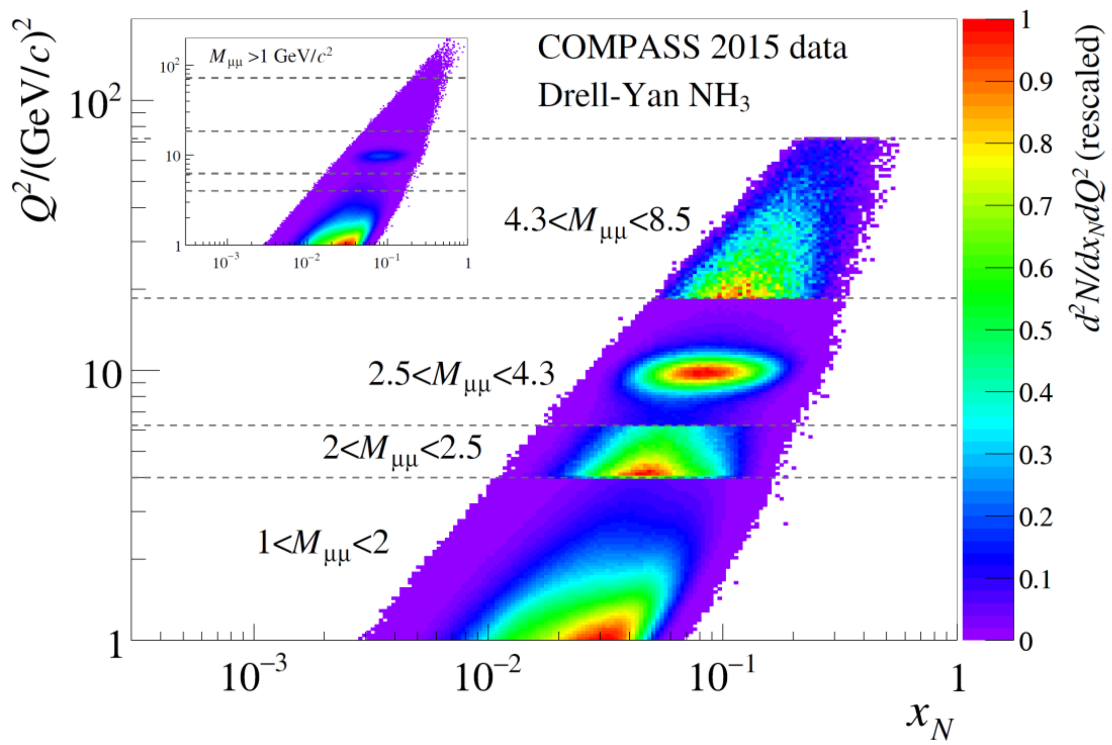
I. **$1 < M_{\mu\mu}/(GeV/c^2) < 2$, "Low mass"**
   - Large background contamination

II. **$2 < M_{\mu\mu}/(GeV/c^2) < 2.5$, "Intermediate mass"**
   - High DY cross section.
   - Still low DY-signal/background ratio.

III. **$2.5 < M_{\mu\mu}/(GeV/c^2) < 4.3$, "Charmonia mass"**
   - Strong J/ψ signal → Studies of J/ψ physics.
   - Good signal/background.

IV. **$4.3 < M_{\mu\mu}/(GeV/c^2) < 8.5$, "High mass"**
   - Beyond J/ψ and ψ' peak, background < 4%.
   - Valence quark region → Largest asymmetries!
   - Low DY cross-section





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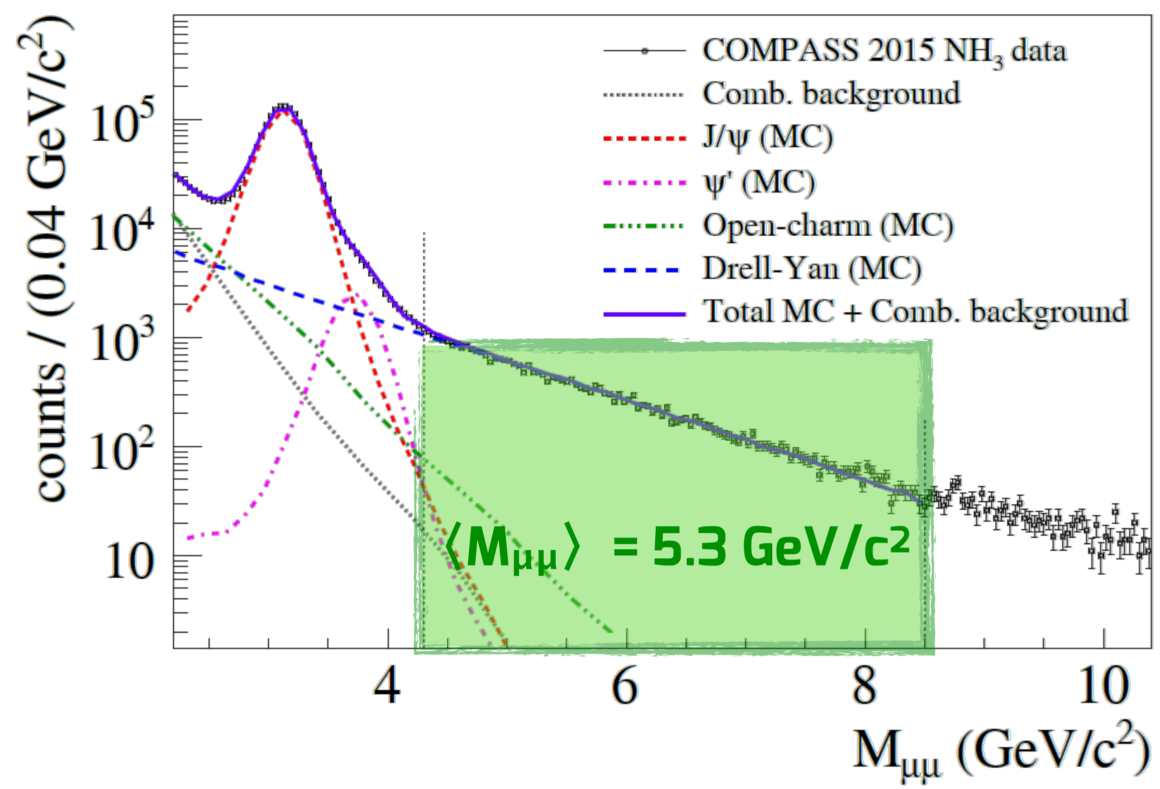
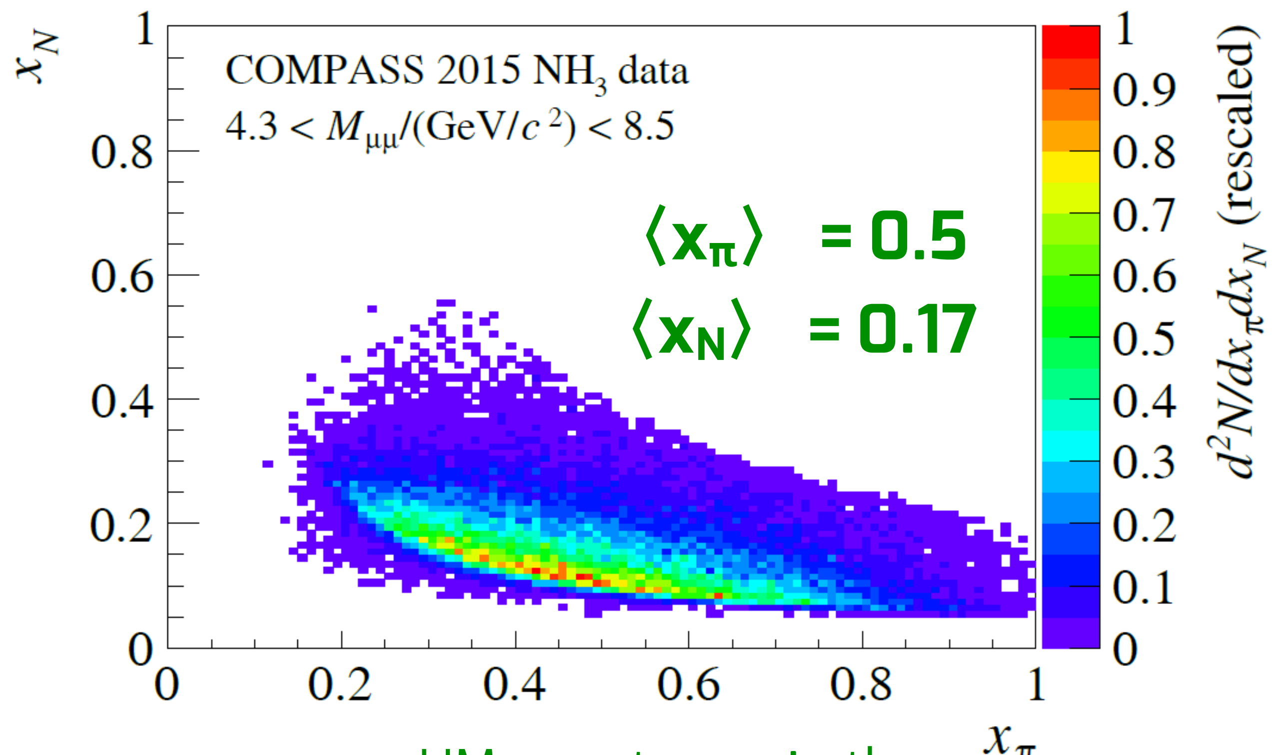
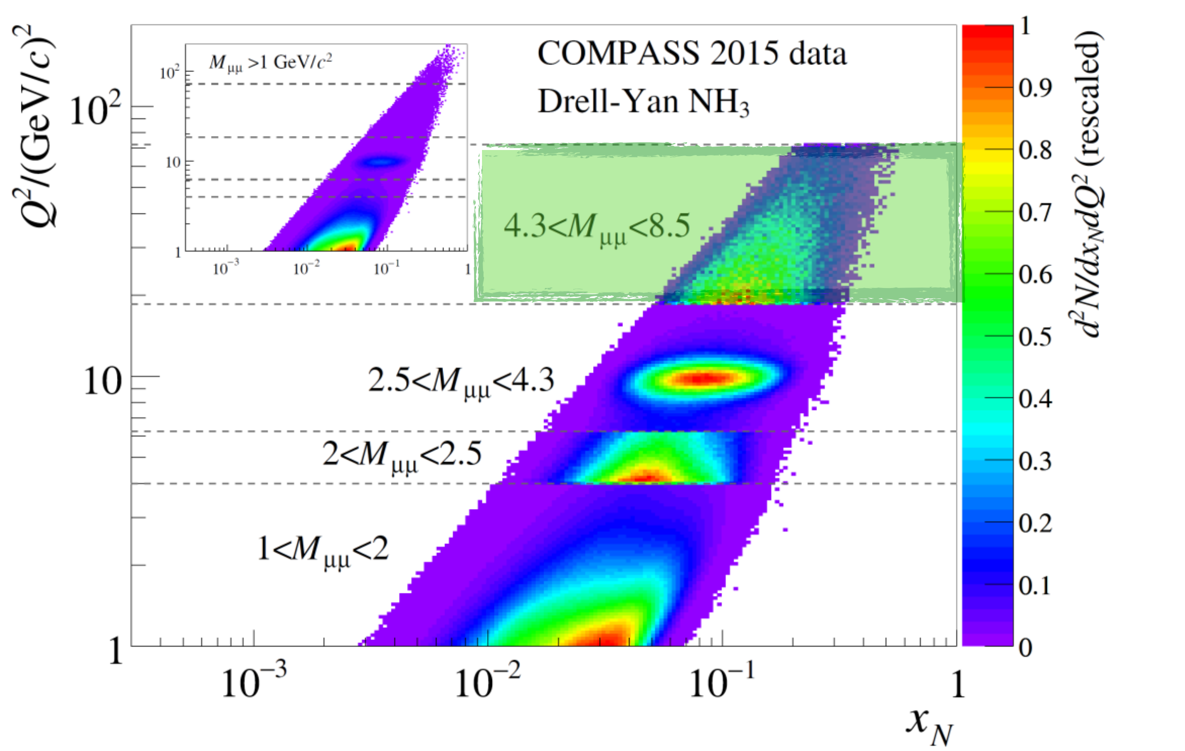
- Valence quark region → Largest asymmetries!
- Low DY cross-section

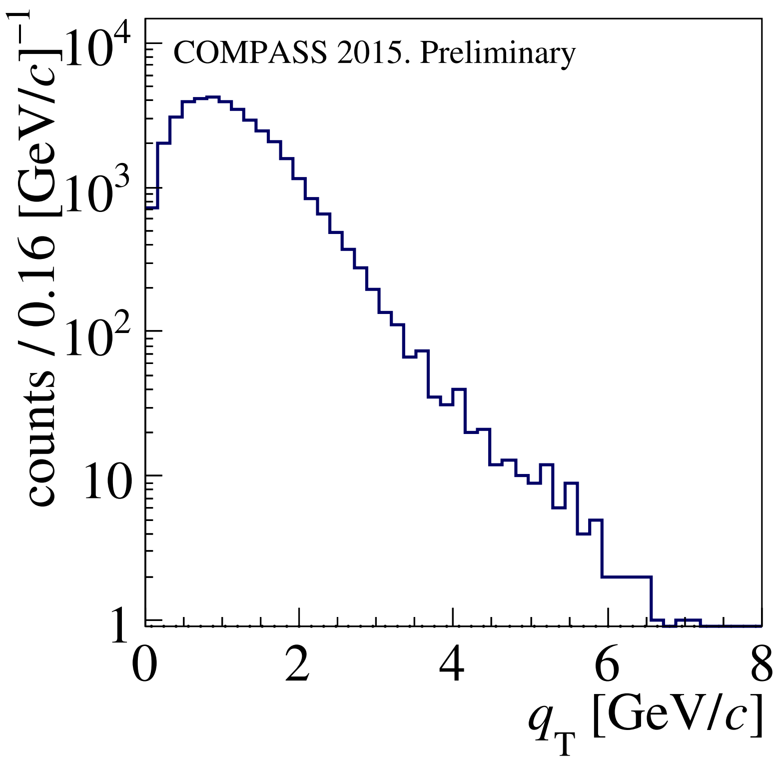


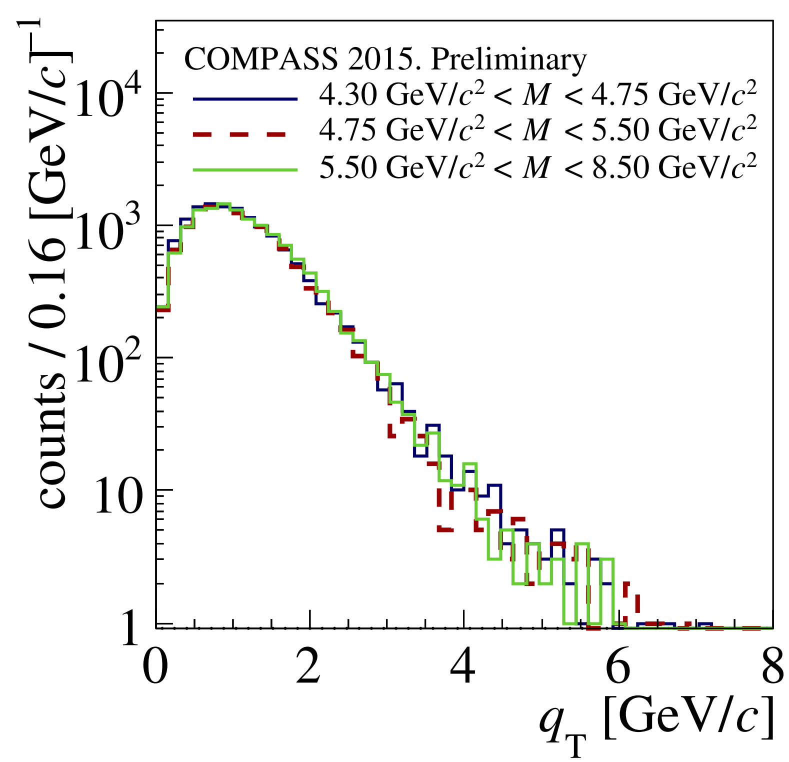


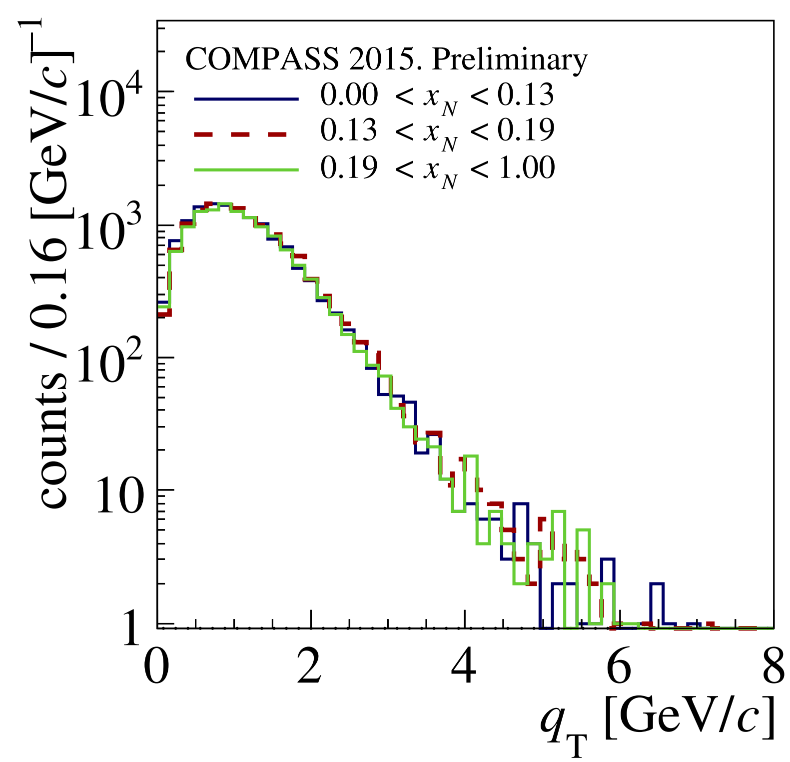


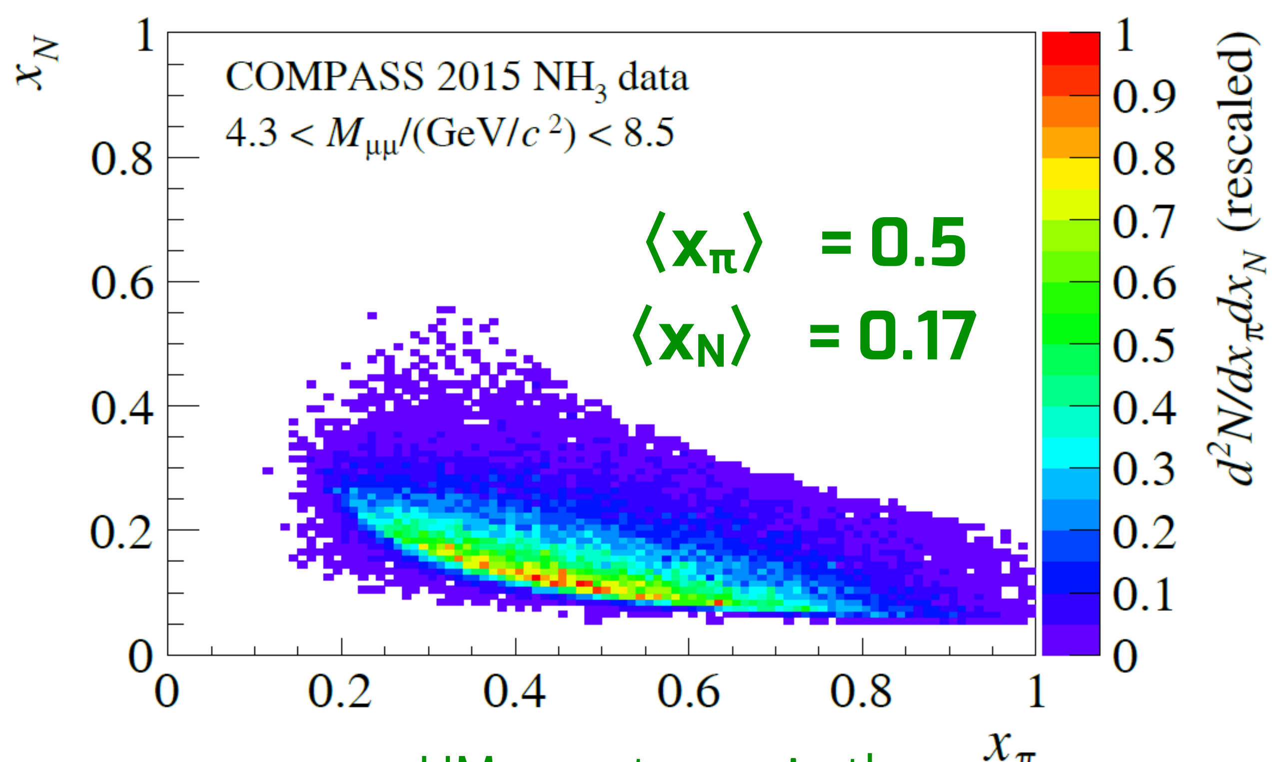
HM events are in the valence quark region

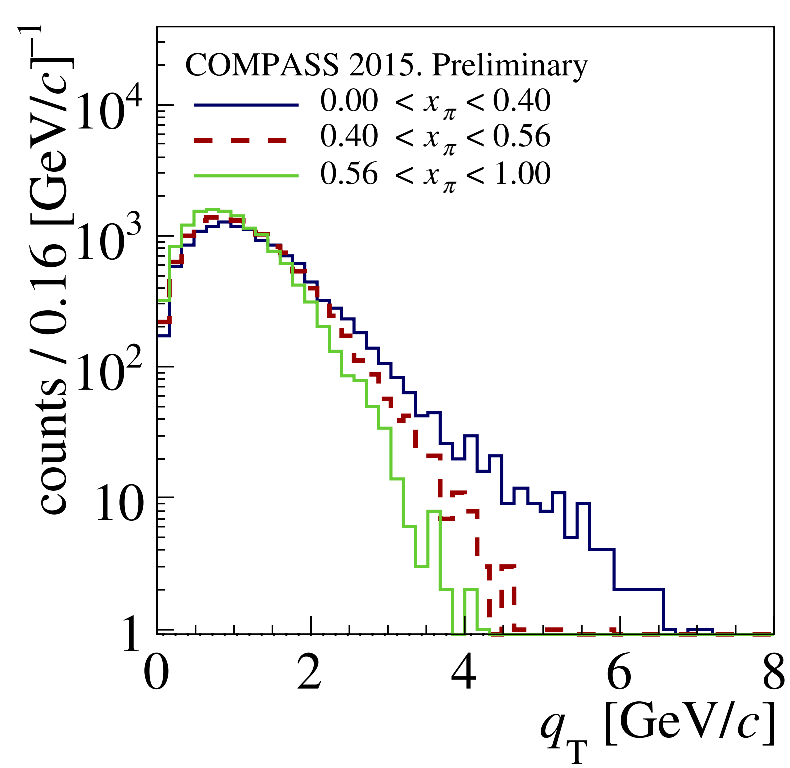
Drell-Yan measurements at COMPASS





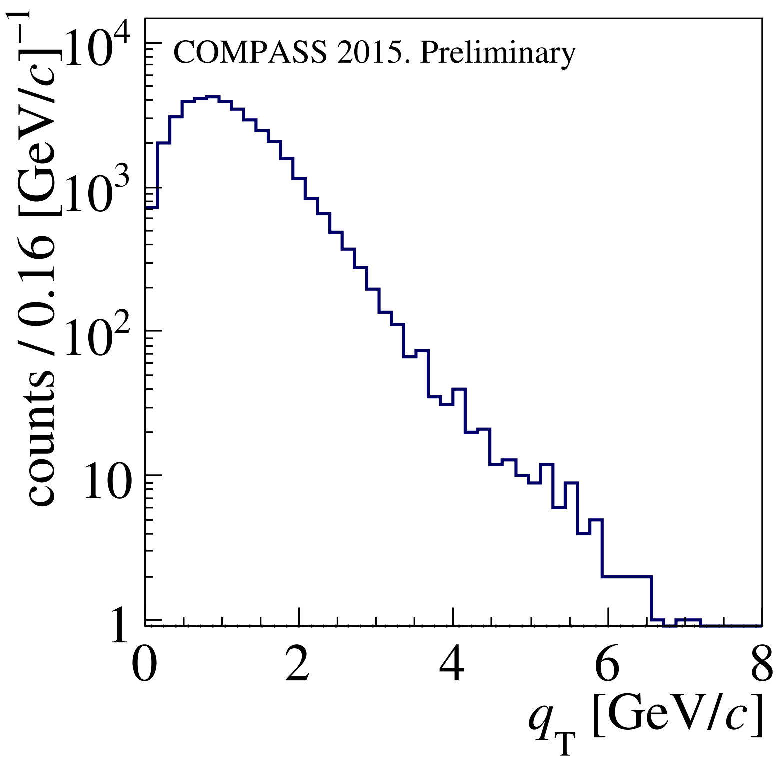


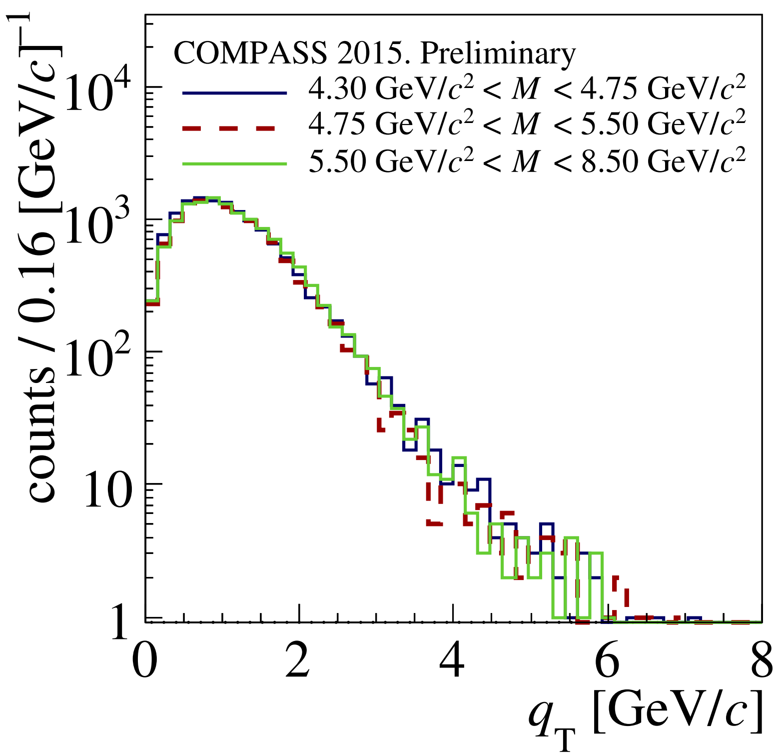


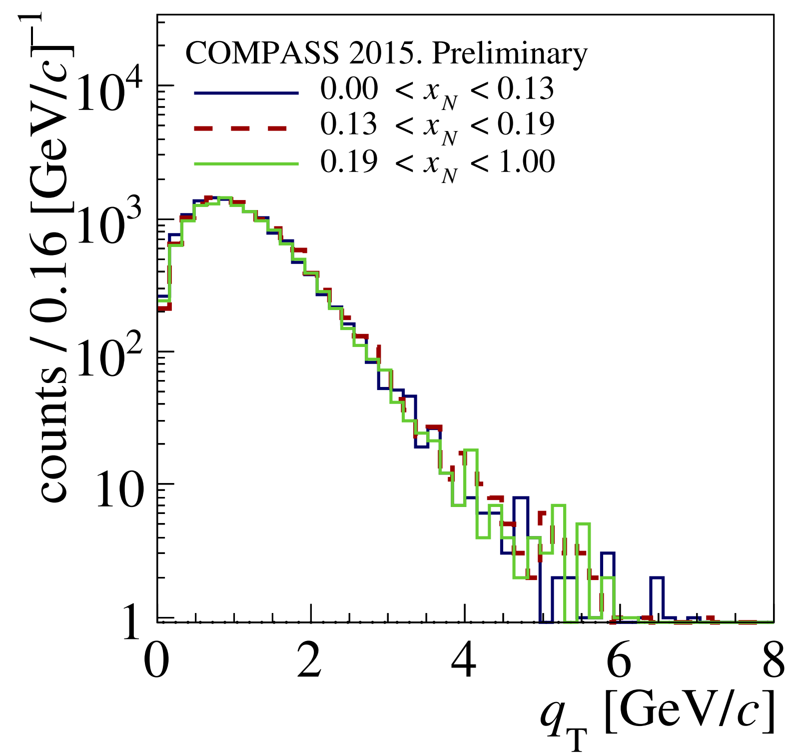


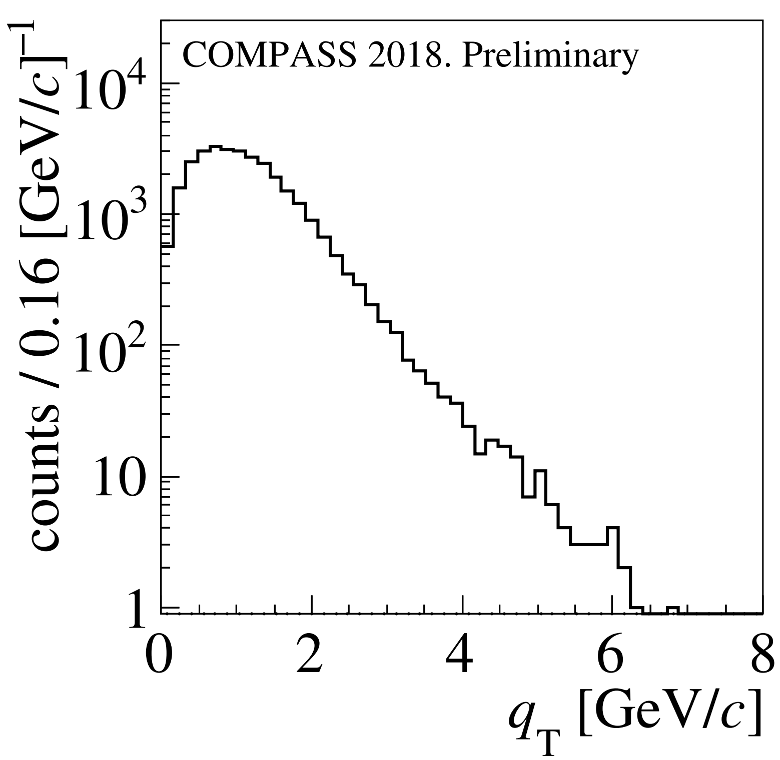
HM events are in the valence quark region

Drell-Yan measurements at COMPASS

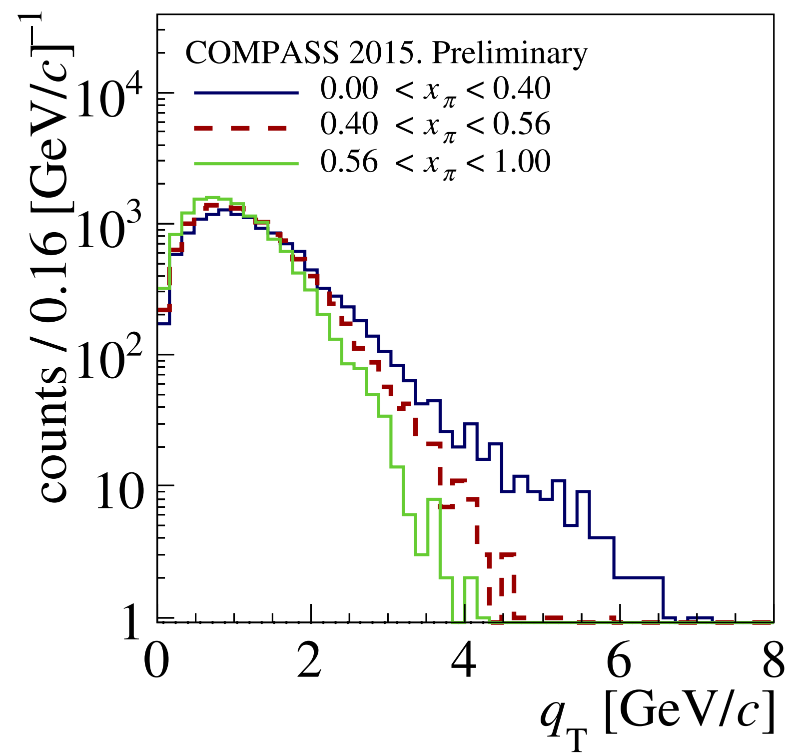




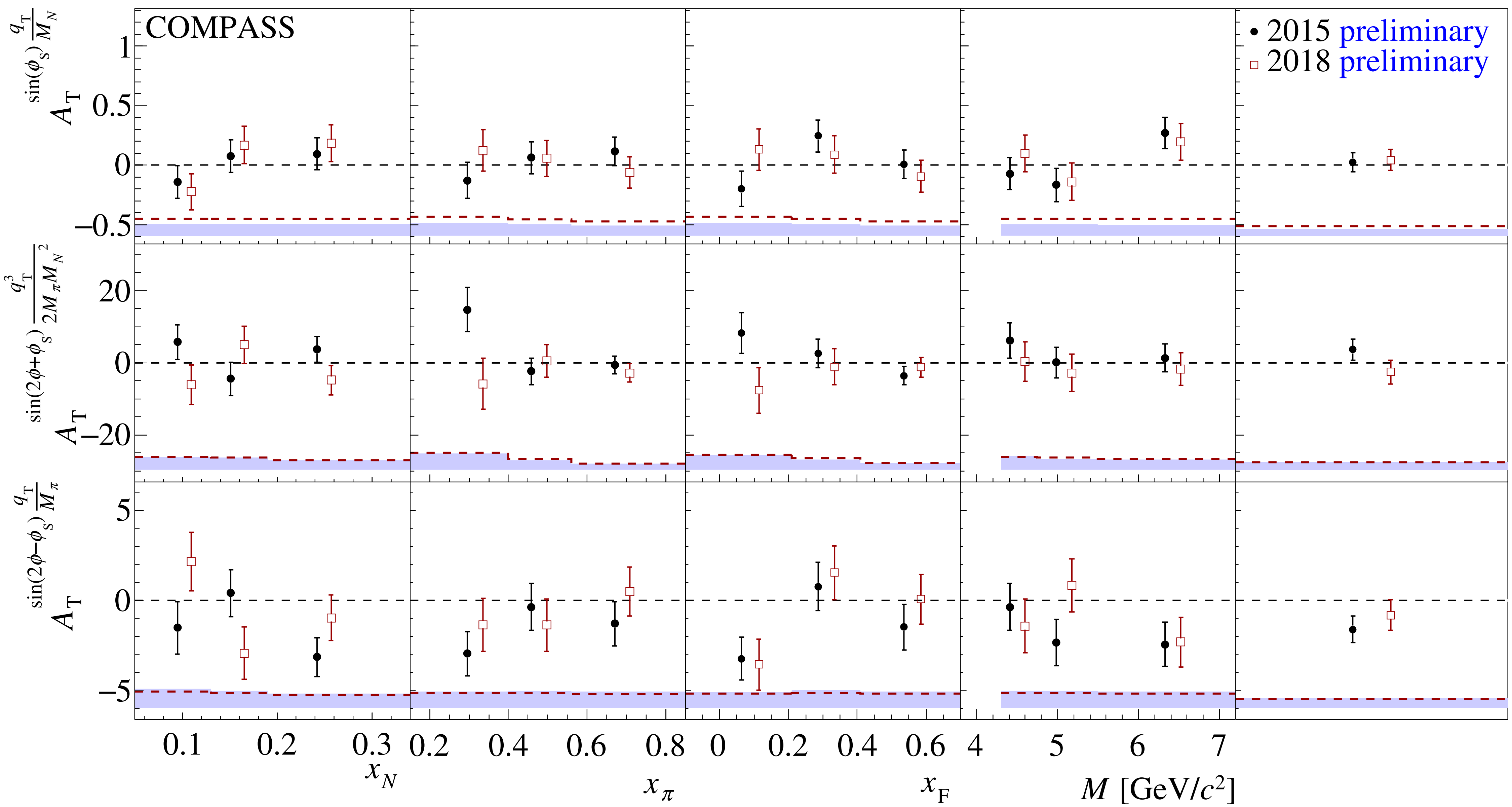




The q_T distribution of selected HM events is fully compatible in the two years (2015-2018).

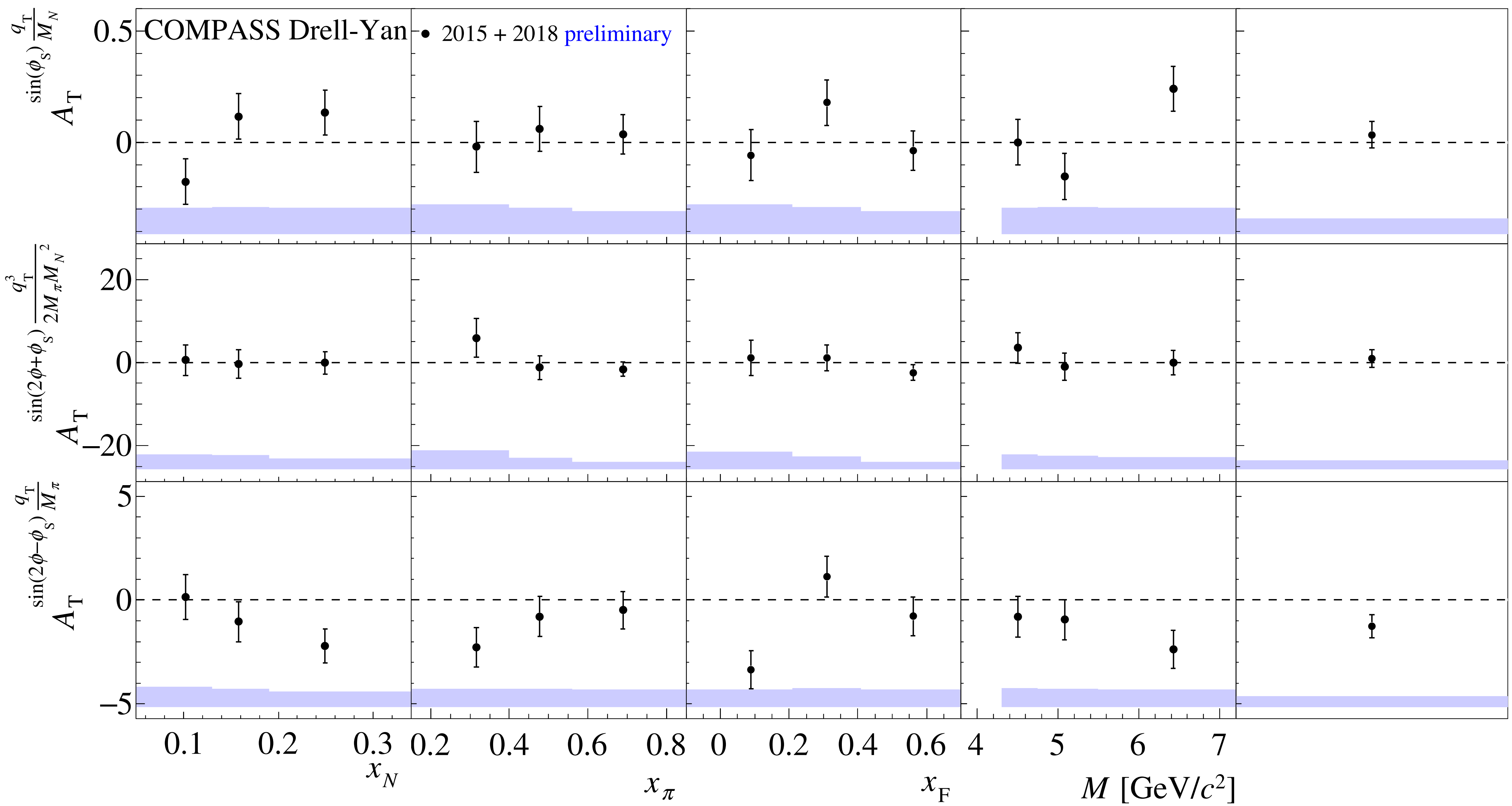


q_T weighted asymmetries: 2015 vs 2018



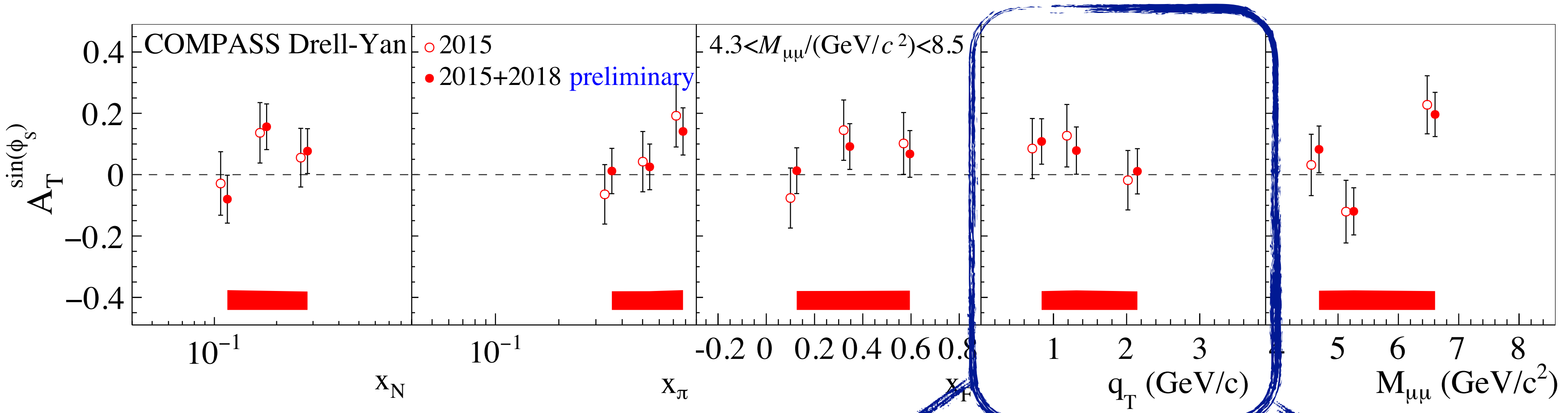
- The q_T-weighted asymmetries extracted in the **HM range** from the COMPASS Drell Yan da collected in 2015 and 2018 (~**50%**) ;
- Additional uncertainties of about 5 % from the polarization and 8 % from dilution factor calculation have to be added to the systematic errors in both the years.

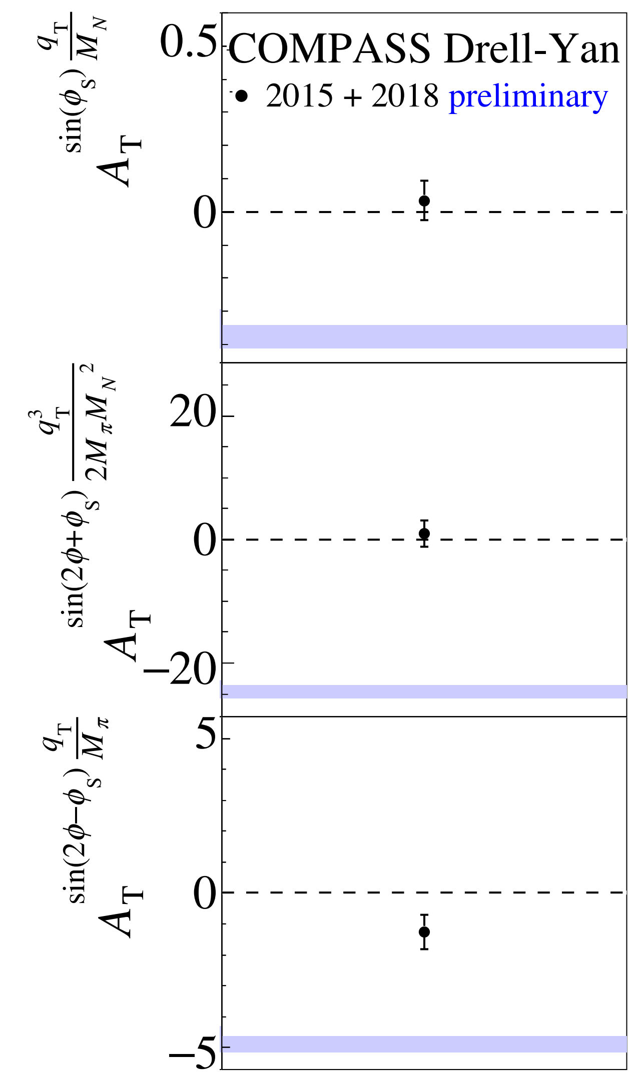
q_T weighted asymmetries: 2015+2018



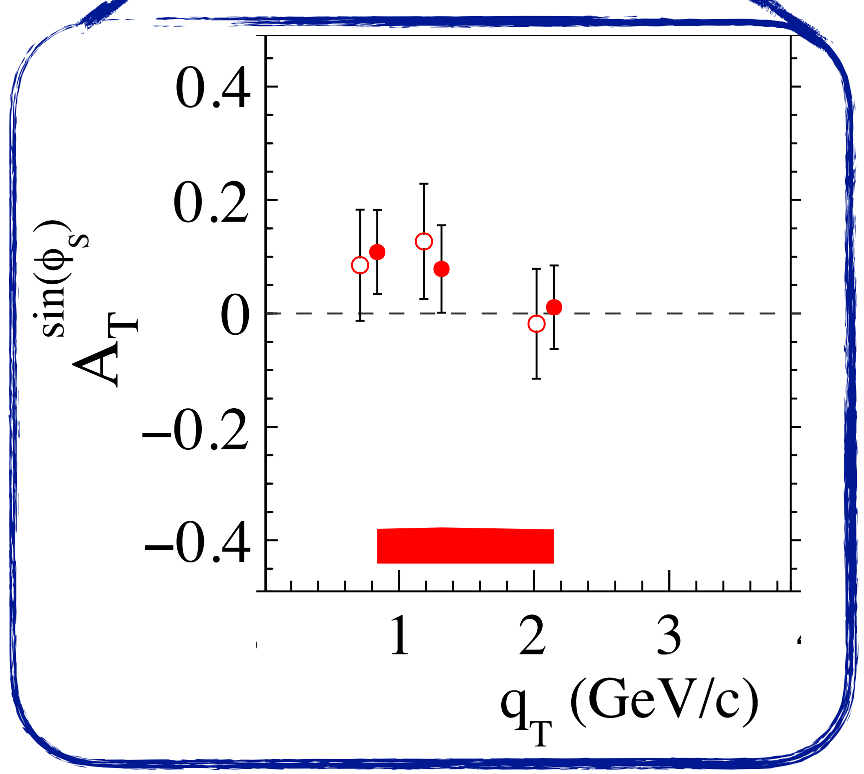
- The q_T-weighted asymmetries extracted in the **HM range** from the combined 2015-2018 Drell Yan data samples. For 2018, only **50%** of the data have been used.
- Additional uncertainties of about 5 % from the polarization and 8 % from dilution factor calculation have to be added to the systematic errors.

q_T weighted asymmetries: 2015+2018





- Standard Sivers TSA smaller in the last q_T bin;



- The q_T-weighted asymmetries extracted from the combined 2015-2018 Drell Yan data samples. For **2018**, only **50%** of the data have been used.
- Additional uncertainties of about 5 % from the polarisation and 8 % from dilution factor calculation have to be added to the systematic errors.

p_T weighted asymmetries in SIDIS

COMPASS
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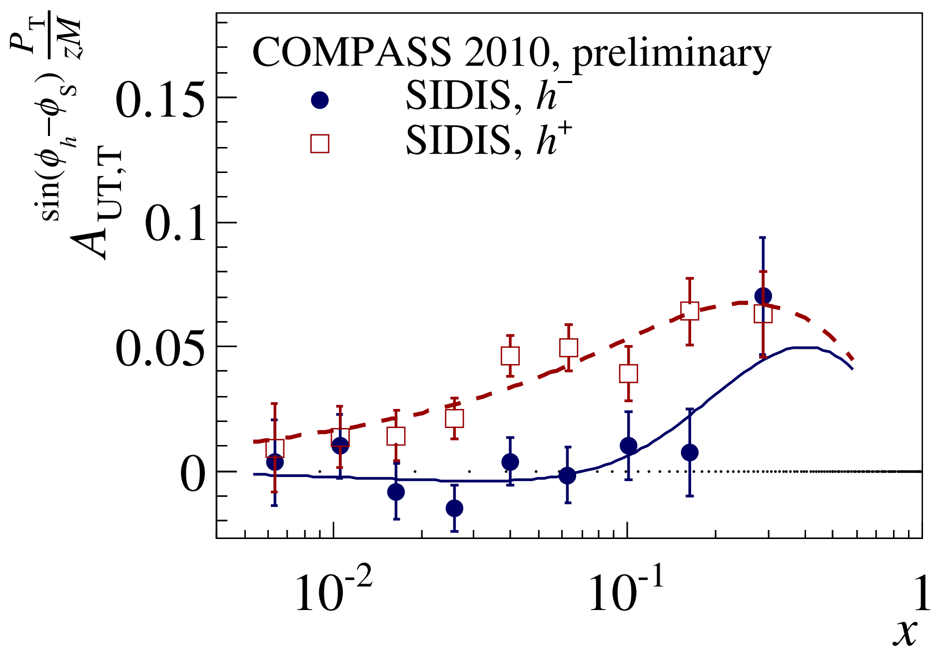
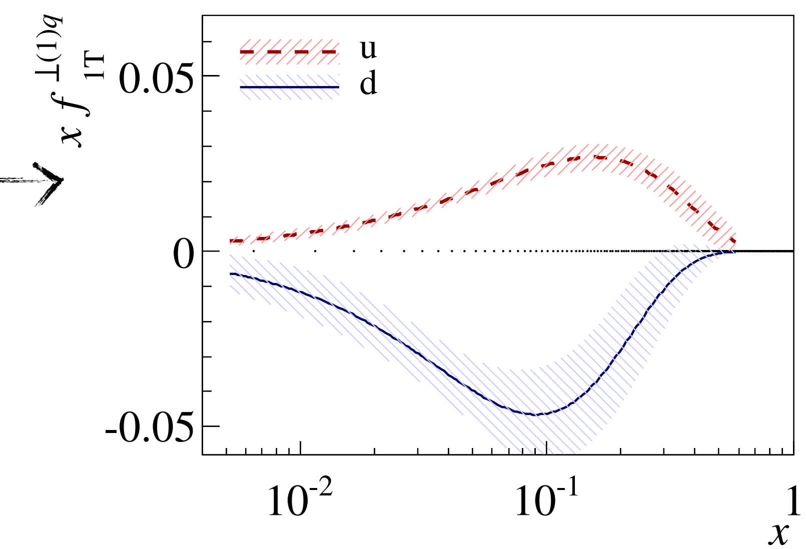


- COMPASS has also measured the p_T weighted TSAs in SIDIS;
- Alternative way to compare TMD PDFs from SIDIS and DY;

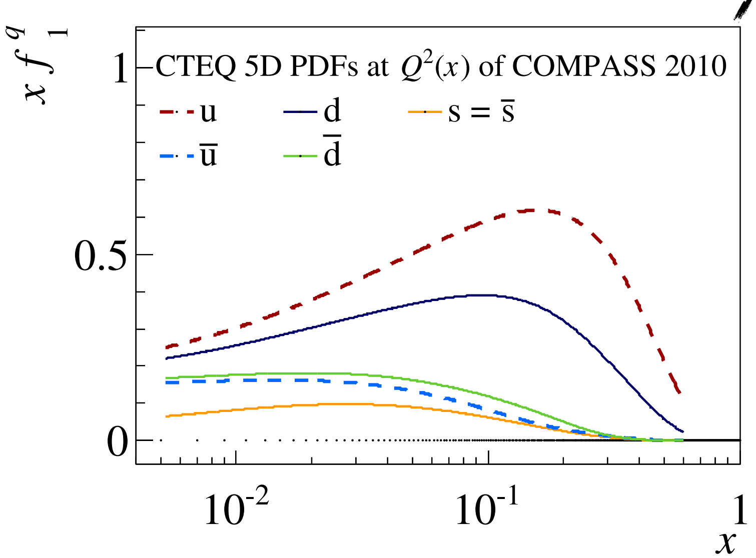
- Sivers TSA in SIDIS $\quad A_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp q} \otimes D_{1q}^h$
- Sivers wTSA in SIDIS $\quad A_{UT}^{\sin(\phi_h-\phi_S)\frac{P_T}{zM}} \propto f_{1T}^{\perp q(1)} \times D_{1q}^h$

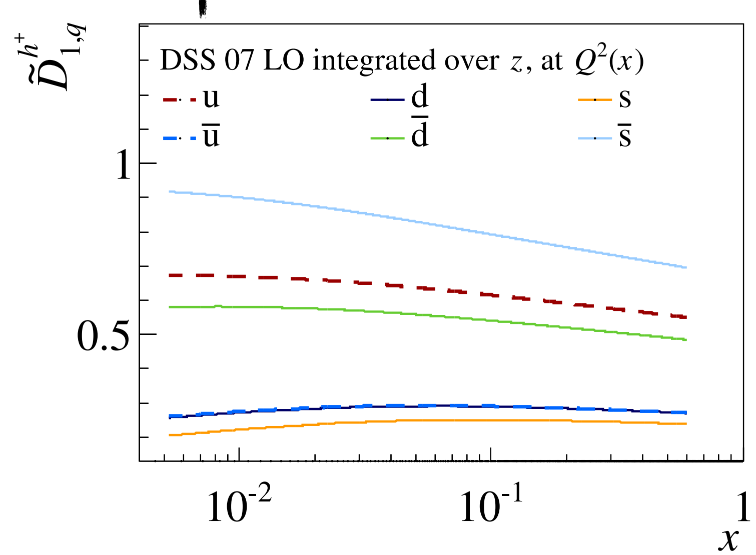
$$A_{UT}^{\sin(\phi_h-\phi_S)\frac{P_T}{zM}}(x,z) = 2\frac{\sum_q e_q^2 f_{1T}^{\perp q(1)}(x) D_1^q(z)}{\sum_q e_q^2 f_1^q(x) D_1^q(z)}$$

$$x f_{1T}^{\perp(1)q}(x) = a_q x^{b_q}(1-x)^{c_q}$$

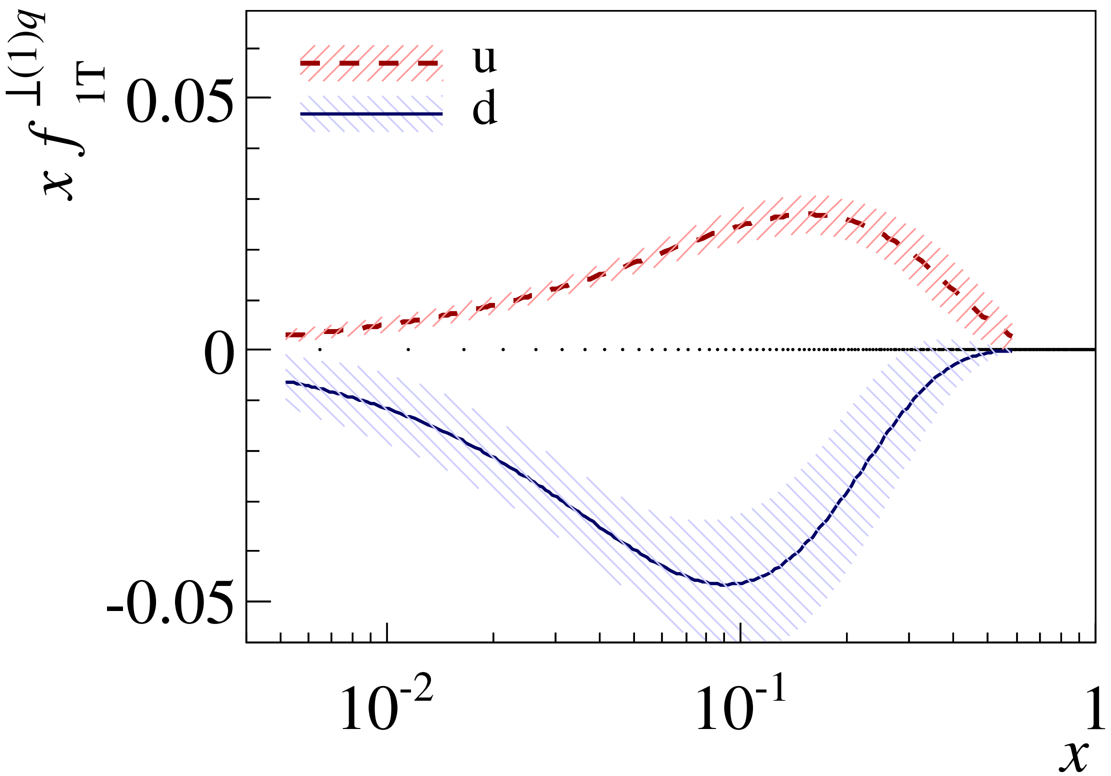


1st k_T^2 -moment of the Sivers function at $Q^2 = Q^2_{SIDIS}(x)$





Weighted asymmetries: from SIDIS to DY



1^{st} k_T^2 -moment of the Sivers function from SIDIS data at $Q^2 = Q^2_{SIDIS}(x)$

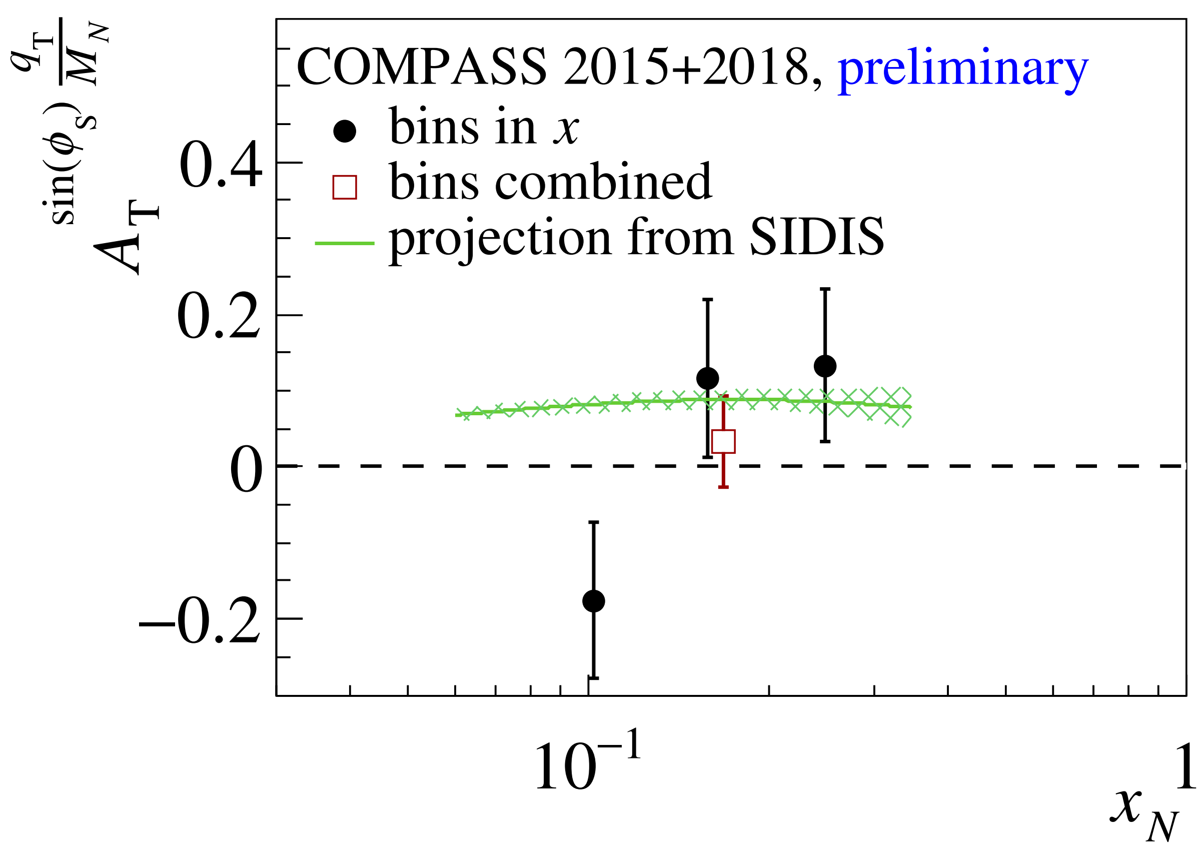
Assuming:

- *u* quark dominance

$$A_T^{\sin\varphi_S \frac{q_T}{M_N}} \sim \frac{f_{1T,p}^{\perp u(1)}}{f_{1,p}^{u}}$$

- No Q^2 evolution for Sivers
- Sivers sign-change

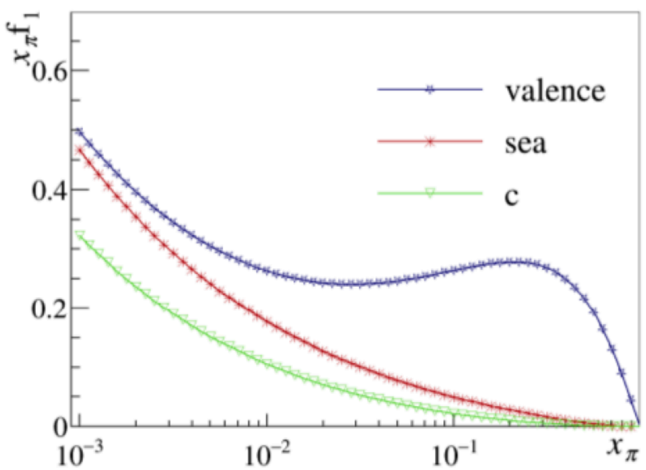
$$f_{1T,p}^{\perp u}|_{SIDIS} = -f_{1T,p}^{\perp u}|_{DY}$$



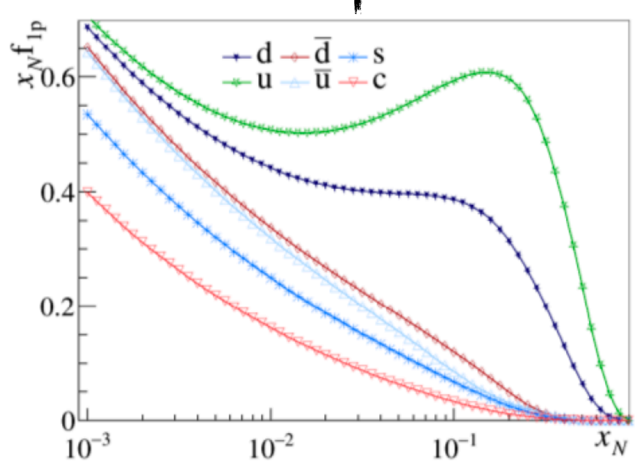
- Preliminary 2015 results, full data sample;
- Preliminary 2018 results, 50% of the sample;
- Ongoing analysis;
- What about the other asymmetries?

First k_T-moment of pion Boer-Mulders

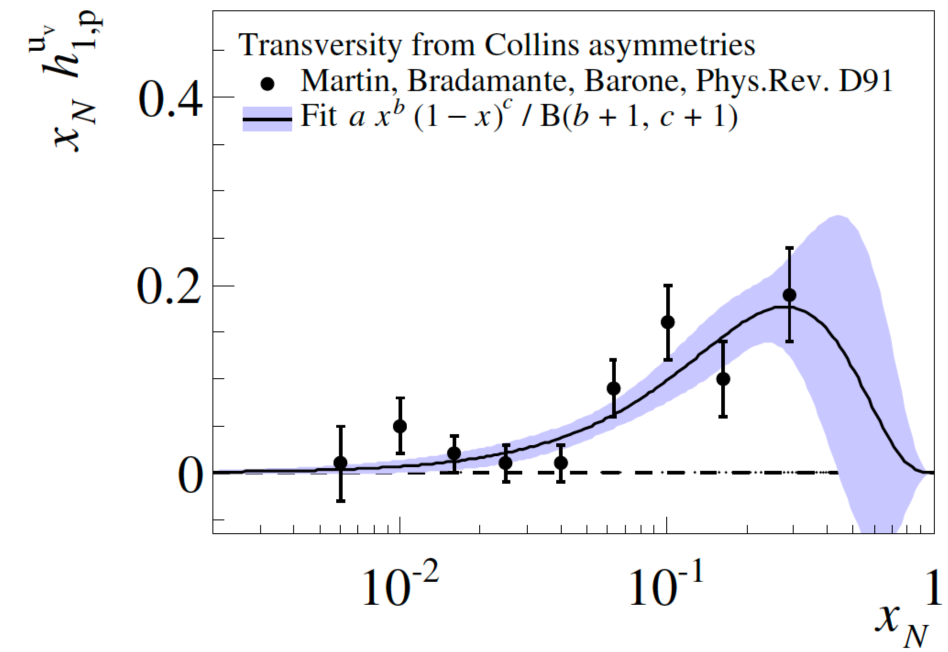
$$A_T^{\sin(2\varphi-\varphi_S)\frac{q_T}{M_\pi}}(x_\pi, x_N) \approx -2\frac{h_{1,\pi}^{\perp(1)\bar{u}}(x_\pi)\, h_{1,p}^{u}(x_N)}{f_1^{\bar{u}}(x_\pi)\, f_{1,p}^{u}(x_N)}$$



GRV-PI pion PDF
at Q^2 = 25 $(GeV/c^2)^2$

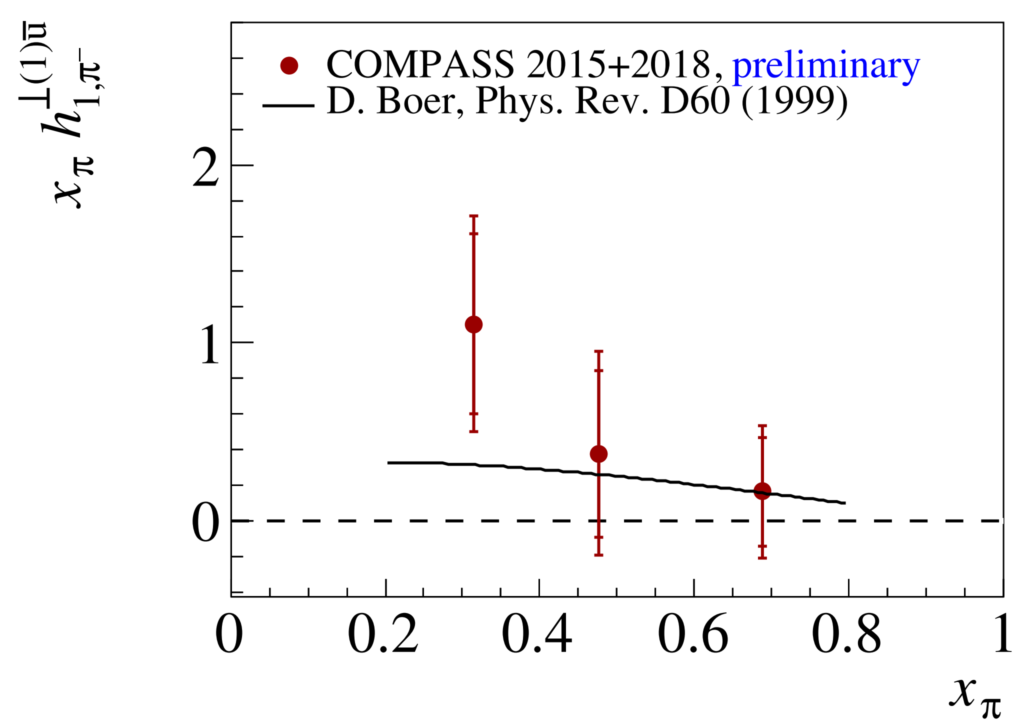


CTEQ proton PDF
at Q^2 = 25 $(GeV/c^2)^2$



Assuming:

- *u* quark dominance
- no Q^2 evolution



- Different pion PDFs tested (GRV-Pi, JAM);
- Transversity from different asymmetries (Collins, Dihadron);

Conclusions

- COMPASS is investigating the TMD PDFs in SIDIS and DY also using weighted asymmetries;
- q_T-weighted asymmetries in Drell-Yan have been extracted from the full 2015 dataset and from ~50% of 2018 data;
- 2018 analysis is ongoing, final results are expected to be released by autumn;

Thank you for your attention!

This research is part of the Blue Waters sustained-petascale computing project, which is supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois. Blue Waters is a joint effort of the University of Illinois at Urbana-Champaign and its National Center for Supercomputing Applications. This work is also part of the "Mapping Proton Quark Structure using Petabytes of COMPASS Data" PRAC allocation supported by the National Science Foundation (award number OCI 1713684).

BLUE WATERS

BACKUP SLIDES

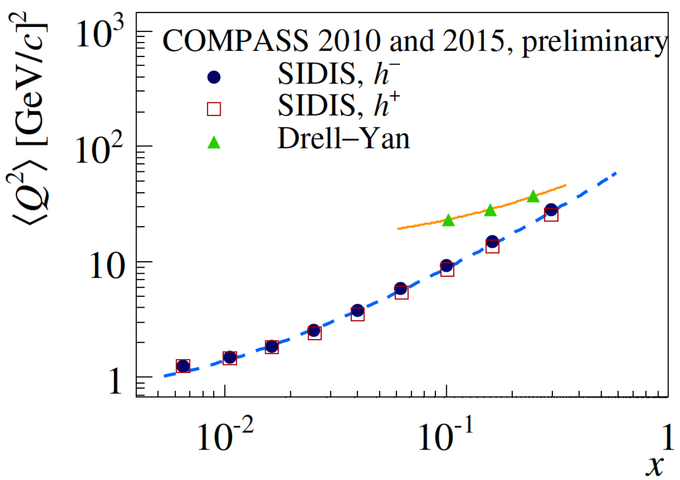
Extraction of qT-weighted asymmetries

- SIDIS events as function of x, standard event selection, z > 0.2;
- Neglecting the Sivers function of the sea quarks we can write

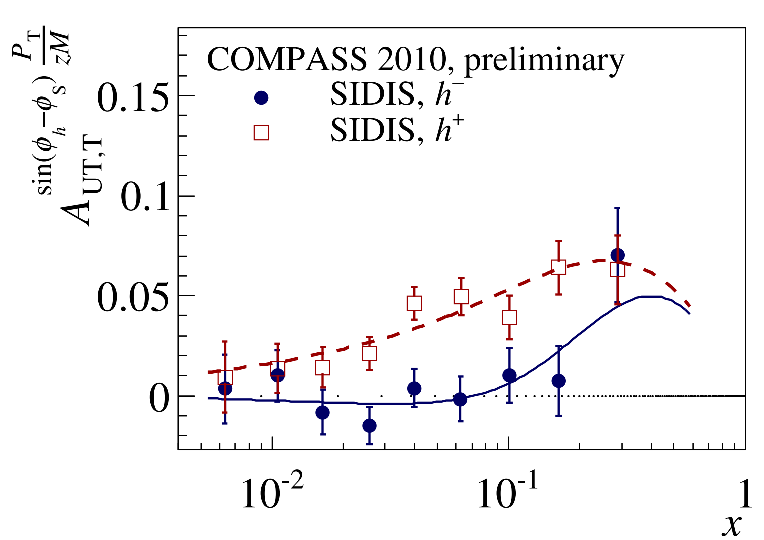
$$A_{\mathrm{UT,T},h^\pm}^{\sin(\phi_h-\phi_S)\frac{P_T}{zM}}(x,Q^2) = 2\,\frac{\frac{4}{9}\, f_{1T}^{\perp(1)u}(x,Q^2)\,\tilde{D}_{1,u}^{h^\pm}(Q^2) + \frac{1}{9}\, f_{1T}^{\perp(1)d}(x,Q^2)\,\tilde{D}_{1,d}^{h^\pm}(Q^2)}{\sum_{q=u,d,s,\bar{u},\bar{d},\bar{s}} e_q^2\, f_1^q(x,Q^2)\,\tilde{D}_{1,q}^{h^\pm}(Q^2)},$$

- For the first k_T^2-moment of Sivers we use a parametrization

$$x f_{1T}^{\perp(1)q}(x) = a_q\, x^{b_q}\,(1-x)^{c_q}$$

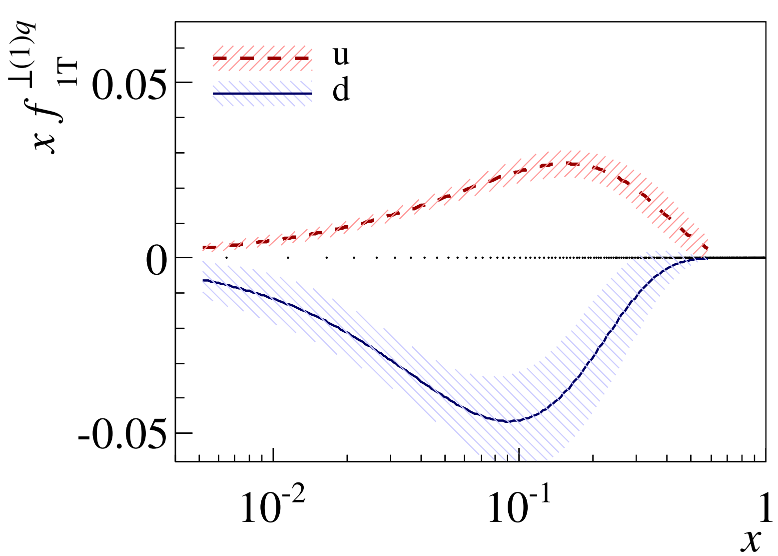


- PDFs and FFs from global it results
  [CTEQ, Eur.Phys.J. C12 (2000) 375]
  [D. de Florian et al.,Phys.Rev. D75 (2007) 114010],
  collinear evolution with $Q^2 = \langle Q^2 \rangle(x)$.



- Asymmetries are simultaneously fitted for h+ and h-

- Error bands 1 σ, only statistical error of the data and the fit



1st moment of the pion BM: assumptions

$$A_{\mathrm{T}}^{\sin(2\phi-\phi_S)\frac{q_{\mathrm{T}}}{M_\pi}}(x_\pi, x_N) = -2\frac{\sum_q e_q^2\left[h_{1,\pi}^{\perp(1)\bar{q}}(x_\pi)\, h_{1,\mathrm{p}}^{q}(x_N) + (q \leftrightarrow \bar{q})\right]}{\sum_q e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi)\, f_{1,\mathrm{p}}^{q}(x_N) + (q \leftrightarrow \bar{q})\right]}$$

$$\approx -2\frac{e_{\mathrm{u}}^2\, h_{1,\pi}^{\perp(1)\bar{\mathrm{u}}}(x_\pi)\, h_{1,\mathrm{p}}^{\mathrm{u}}(x_N)}{\sum_{q=\mathrm{u,d,s}} e_q^2\left[f_{1,\pi}^{\bar{q}}(x_\pi)\, f_{1,\mathrm{p}}^{q}(x_N) + (q \leftrightarrow \bar{q})\right]}$$

$$\approx -2\frac{h_{1,\pi}^{\perp(1)\bar{\mathrm{u}}}(x_\pi)\, h_{1,\mathrm{p}}^{\mathrm{u}}(x_N)}{f_{1,\pi}^{\bar{\mathrm{u}}}(x_\pi)\, f_{1,\mathrm{p}}^{\mathrm{u}}(x_N)},$$

Assumptions:

- Boer Mulders and Transversity of sea quarks are zero. For transversely what's available is indeed compatible with 0. For BM is a full assumption.
- We consider only u, d and s quarks in the denominator.

If we go further and we neglect also the d and s, we get the last formula (Differences <= 4%)

- Transversity: we utilize a point-by-point extraction from COMPASS data. The Q^2 of the transversity obtained in this way is different from point to point. It raises with x_N and in our range of 0.1 : 0.3 it lies between 8 and 23 $(\mathrm{GeV}/c)^2$
- We have neglected the difference with respect to the Drell-Yan kinematics.
- Two set of transversity from the article:
    - From the Collins asymmetries using the TMD formalism with the Gaussian assumption;
    - Based on dihadron asymmetries, which can be described in collinear formalism;

$$h_{1,\mathrm{p}}^{\mathrm{u}}(x_N) = a\frac{x_N^b(1-x_N)^c}{B(b+1, c+1)}$$

Final errors take into account only the statistical uncertainties of transversity PDF and the uncertainty of the weighted asymmetry.