COMPASS Measurements of Spin-Dependent Asymmetry Amplitudes in the Drell-Yan Process Observed from Scattering Pions off a Transversely Polarized Proton Target

Robert Heitz
on behalf of the COMPASS Collaboration

University of Illinois
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High Energy Physics Conference
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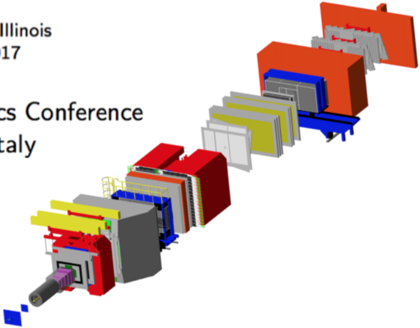
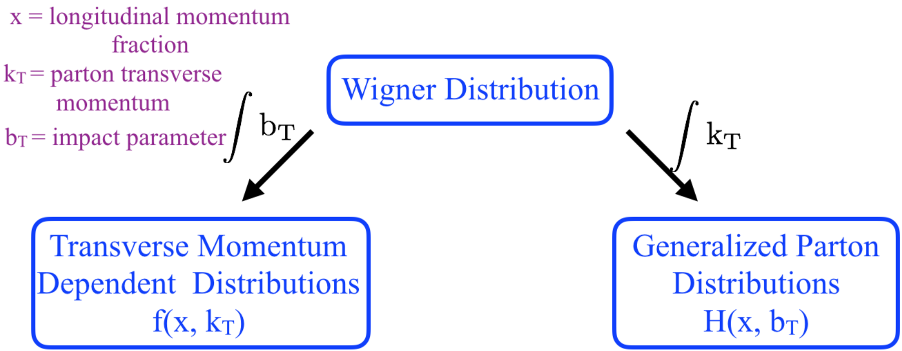


How partons are distributed in a nucleon



- COMPASS GPD measurements:
  - Deeply Virtual Compton Scattering (DVCS) reactions 2016 and 2017
- COMPASS TMD measurements:
  - Transversely polarized semi-Inclusive Deep Inelastic Scattering (SIDIS)
  - Transversely polarized Drell-Yan 2015
- Star TMD measuremnt: W and Z boson production azimuthal asymmetries in transversely polarized pp-collisions

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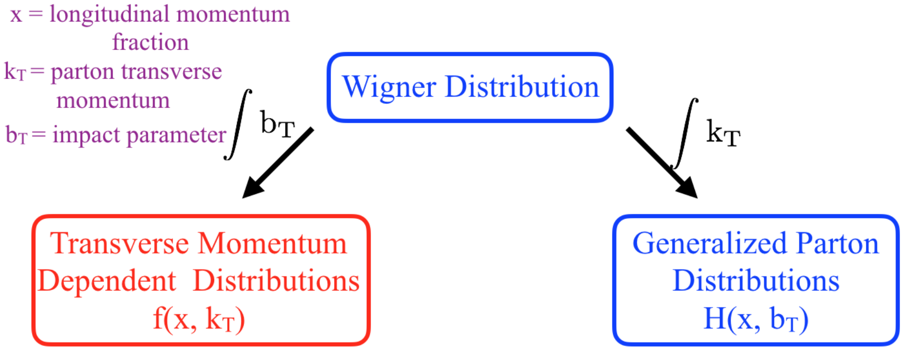

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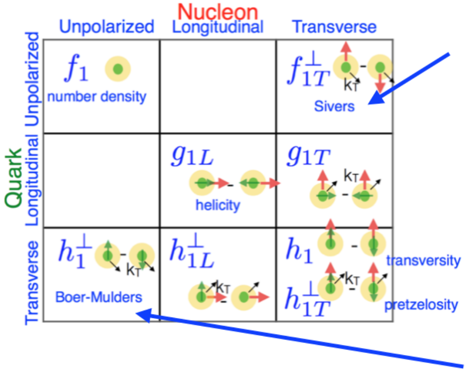
Transverse Momentum Dependent (TMD) Distributions

- Include parton k_T and parameterize non-perturbative terms of cross-section
- At leading order and leading twist, 8 TMDs are needed to describe the nucleon
- TMD description is valid for $k_T^2 \ll Q^2$



Sivers: Correlation between transverse momentum of a parton and the spin of the parent nucleon

Boer-Mulders: Correlation between transverse momentum of a parton and the transverse spin of the parton

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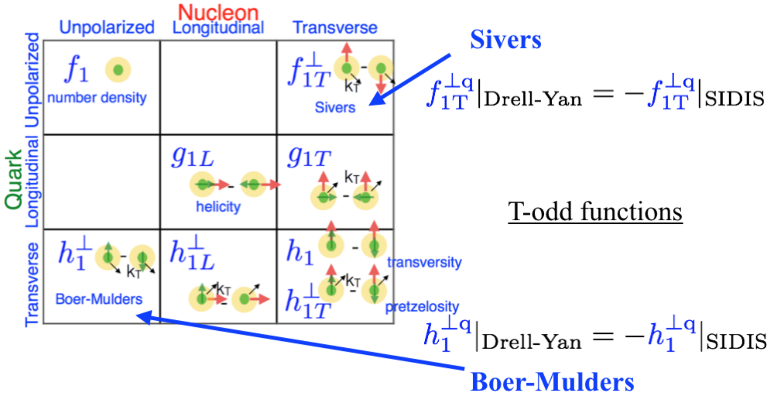
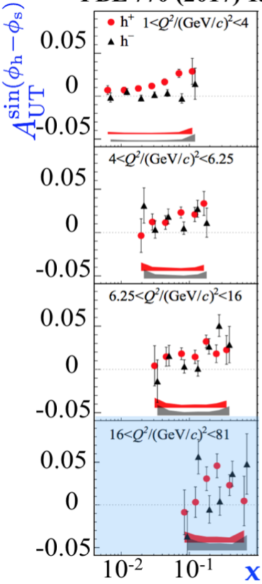


COMPASS SIDIS Sivers Results

PBL 770 (2017) 138



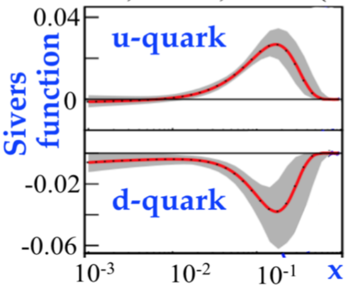
Previous Talk by Stefano Levorato

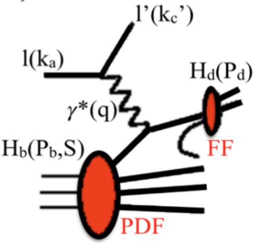
$$A_{UT}^{\sin(\phi_h - \phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$$

COMPASS found a non-zero Sivers amplitude from SIDIS over several Q^2 ranges

Comparing the sign of the Sivers function extracted from SIDIS and Drell-Yan is a fundamental test of QCD

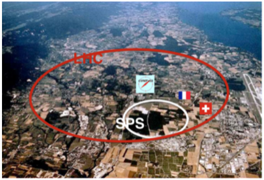
Anselmino, M., Boglione, M., D'Alesio, U. et al., JHEP04(2017)046

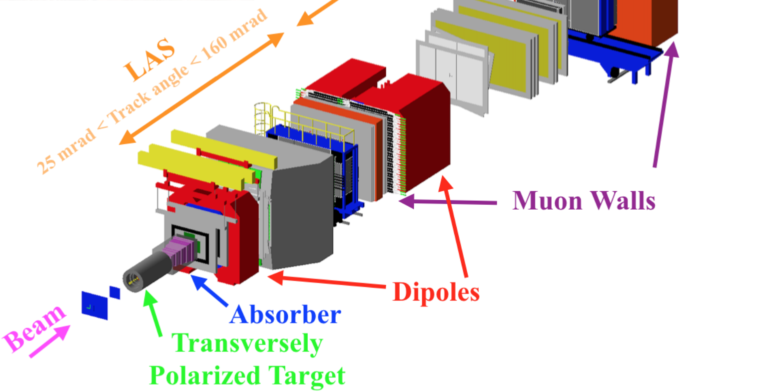




SIDIS diagram

COmmon Muon Proton Apparatus for Structure and Spectroscopy (COMPASS)





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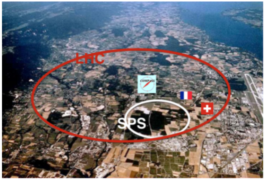
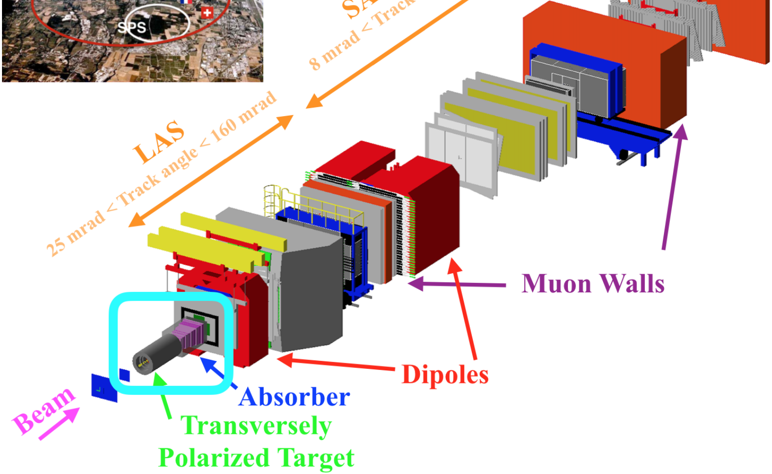
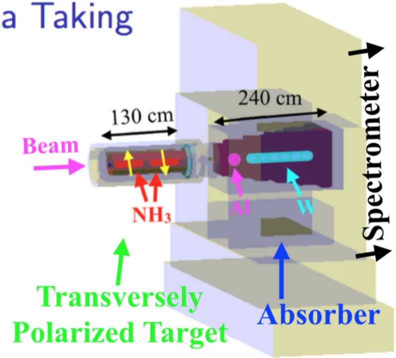
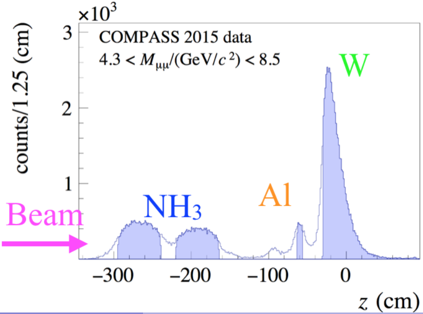




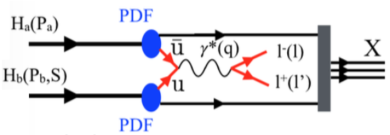
2015 COMPASS Drell-Yan Data Taking

- Recorded data for $\sim$ 18 weeks
- Two transversely polarized proton (NH_3) target cells
  - Proton polarization $\sim$ 73%
  - Target cell polarizations flipped each week
- Alumina (Al_2O_3) hadron absorber placed downstream of target cells
  - Includes Al and W beam plugs which can also be used for spin-independent analysis
- Good separation between target cells was achieved

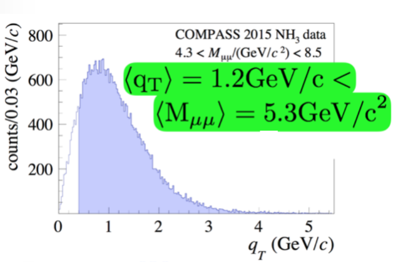




The Drell-Yan Process at COMPASS



Drell-Yan Diagram



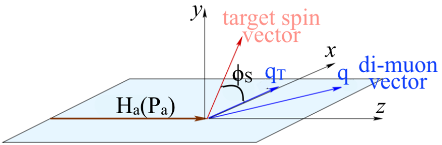
Virtual photon transverse momentum

- Negative pion beam
  - 190 GeV/c
  - 6x10^7 π^-/sec
- Negative pion beam is advantages for Drell-Yan
  - $u\bar{u}$ annihilate
- TMD description is valid at $q_T < M_{\mu\mu}$
- Lower q_T cut ensures angular variables are everywhere well defined

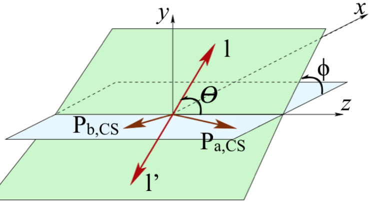
Drell-Yan Cross-Section

- The amplitudes of azimuthal modulations from the Drell-Yan cross-section give access to certain TMDs. At leading twist:

$$d\sigma^{DY} \propto \left[1 + A_U^{\cos(2\phi)} \cos(2\phi)\right] + \|S_T\| \Big\{ A_T^{\sin(\phi_S)} \sin(\phi_S) + \left[A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) + A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S) \right] \Big\}$$



Target reference frame



Collins-Soper center of momentum frame

$A_U^{\cos(2\phi)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{\perp q}$ Boer-Mulders

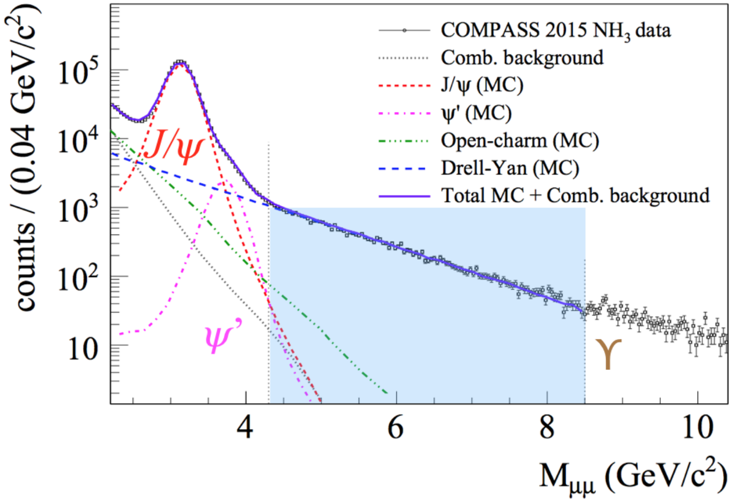
$A_T^{\sin(2\phi-\phi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$ transversity

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

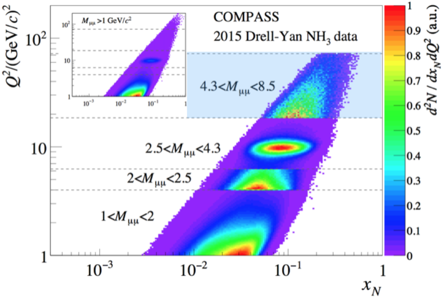
$A_T^{\sin(2\phi+\phi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp}$ pretzelosity

Di-muon Invariant Mass Spectrum

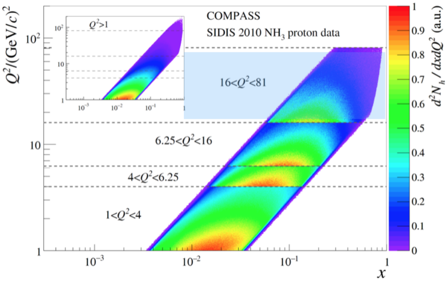
- The Drell-Yan analysis was performed in the mass range of 4.3-8.5 GeV/c^2
  - Only 4% background in this mass range
- Approximately 35 000 di-muon pairs were analyzed



COMPASS Kinematic Overlap between Drell-Yan & SIDIS



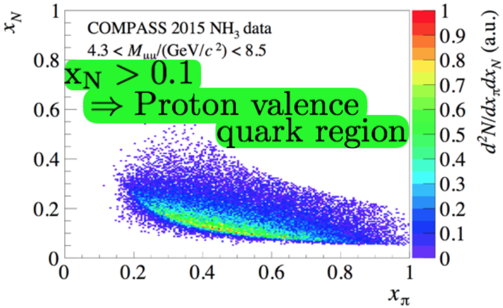
COMPASS Drell-Yan

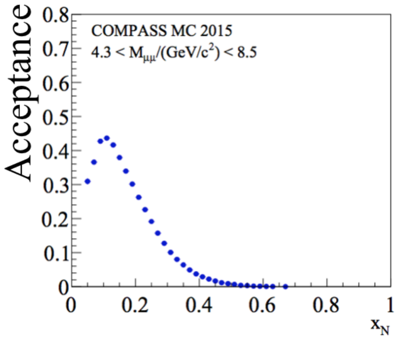


COMPASS SIDIS

- COMPASS has kinematic overlap between Drell-Yan and SIDIS
- Allows to minimize the impact of uncertainties from TMD scale evolution
- The overlap in kinematic regions of COMPASS Drell-Yan and COMPASS SIDIS data allows for direct comparisons of TMD amplitudes

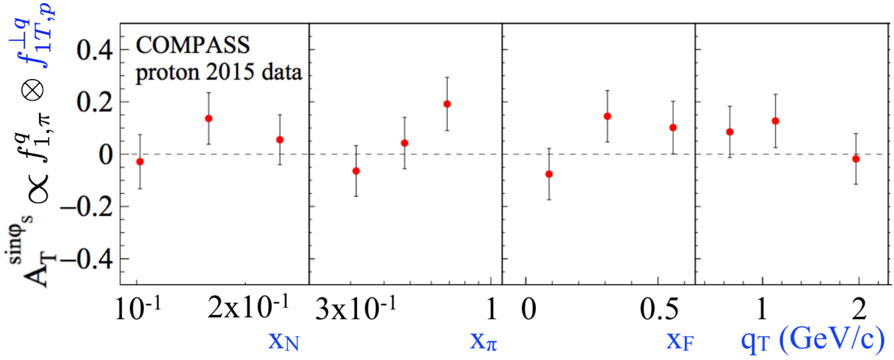
COMPASS Drell-Yan Kinematics





- The high mass range probes the proton's valence quarks
- The COMPASS spectrometer acceptance reaches a maximum in the proton valence region
  - The Sivers function extracted from SIDIS data also reaches its maximum in the proton valence region

Kinematic Dependence of the Sivers Amplitude



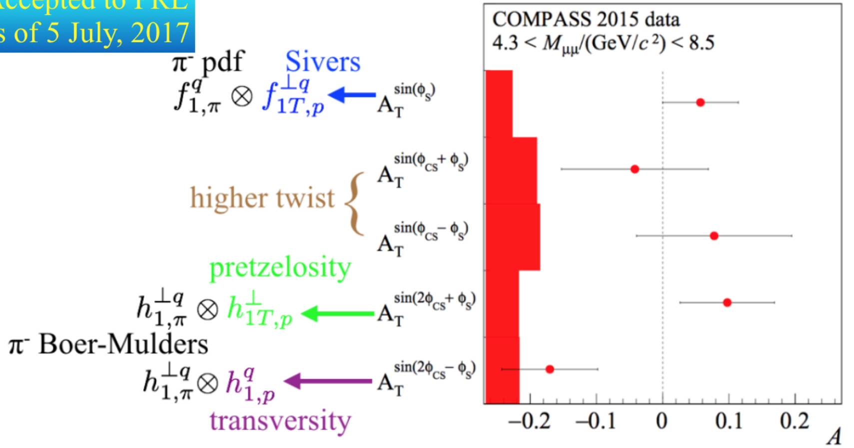
TMD Amplitudes

$$d\sigma^{DY} \propto \left[1 + A_U^{\cos(2\phi)} \cos(2\phi)\right] + \|S_T\| \left\{ A_T^{\sin(\phi_S)} \sin(\phi_S) + \left[A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) + A_T^{\sin(2\phi-\phi_S)} \sin(2\phi-\phi_S) \right] \right\}$$

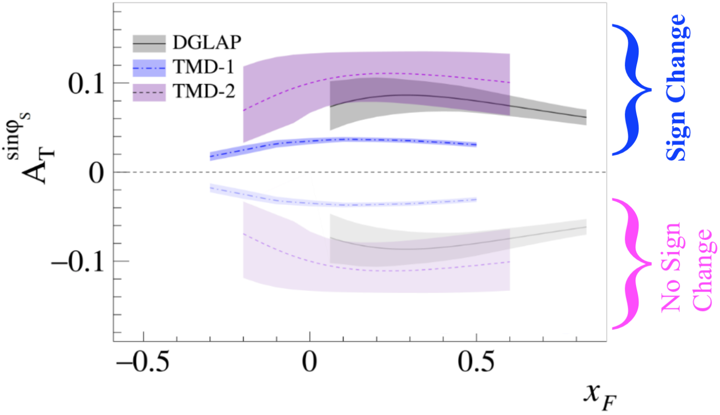
CERN-EP-2017-59

arXiv:1704.0488 [hep-ex]

Accepted to PRL as of 5 July, 2017



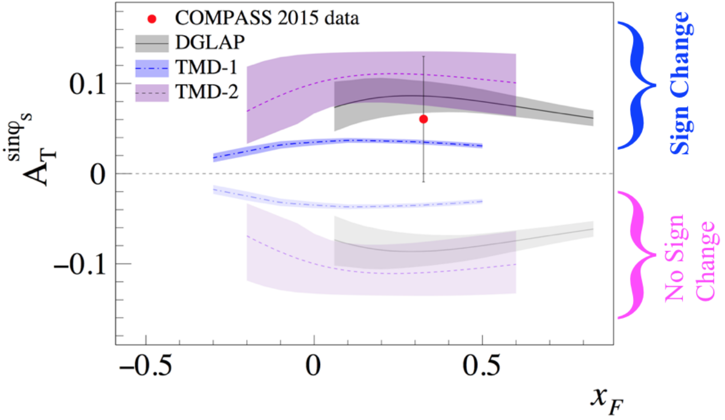
Sign Change



DGLAP
TMD-1
TMD-2
0.1
0
−0.1
$A_T^{\sin\varphi_S}$
−0.5
0
0.5
x_F
Sign Change
No Sign Change

Sign Change

- The sign of the Sivers amplitude determined from COMPASS Drell-Yan data is consistent with a sign change prediction from the Sivers TMD extracted from SIDIS!



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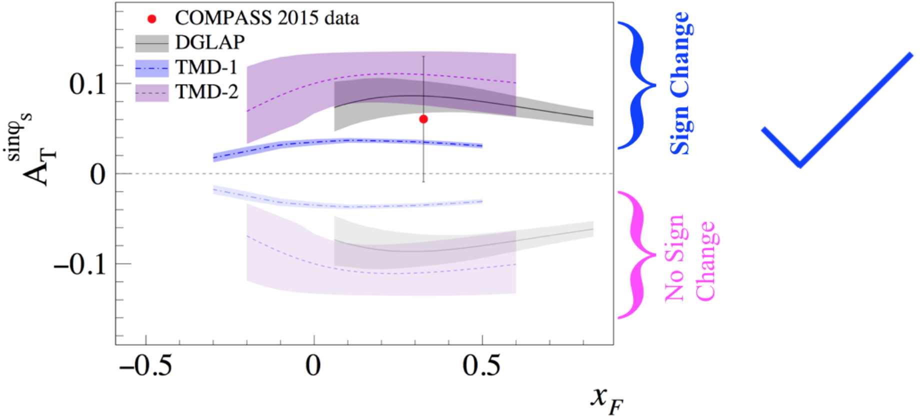
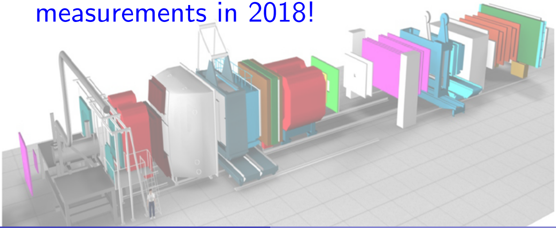


Conclusion

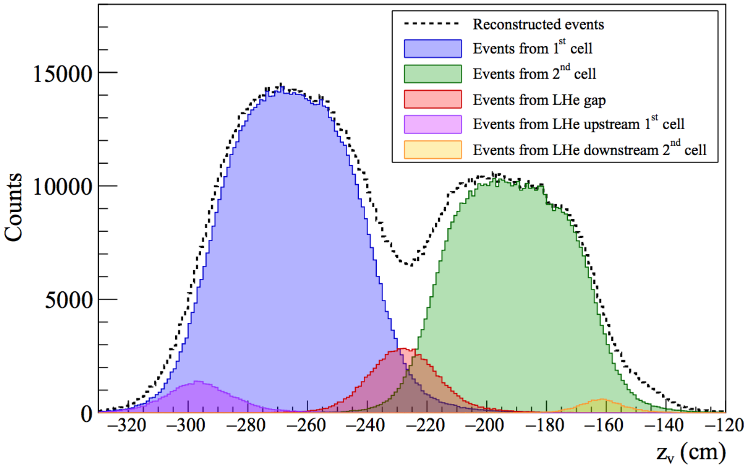
- COMPASS determined the first spin-dependent azimuthal asymmetries from transversely polarized Drell-Yan data
- COMPASS has performed the first measurements of transversely polarized SIDIS and Drell-Yan which can be compared in a similar kinematic region
- The Sivers amplitude form COMPASS Drell-Yan data and the Sivers function extracted from SIDIS data is consistent with a sign change which is a fundamental validation of quantum chromo-dynamics

- COMPASS will perform additional transversely polarized Drell-Yan measurements in 2018!



Backup

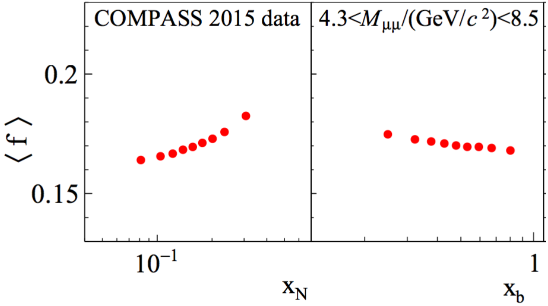
Target Cell Separation



- Monte-Carlo simulations show there is very little event migration between the two transversely polarized target cells

Dilution Factor

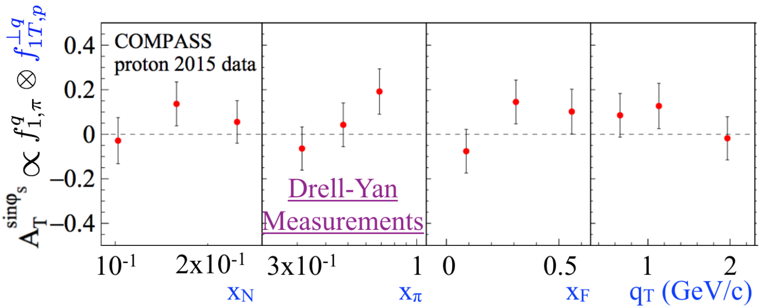
- Correction to the amount of polarizable material
  - Only protons from Hydrogen in NH_3 are assumed to be polarizable



$$f = \frac{n_H \sigma^{DY}_{\pi - H}}{n_H \sigma^{DY}_{\pi - H} + \Sigma_A n_A \sigma^{DY}_{\pi - A}}$$

- $f \sim 0.18$
  - Includes correction from event migration between target cells

Kinematic Dependence of the Sivers Amplitude



- The overlap in kinematic regions of COMPASS Drell-Yan and COMPASS SIDIS data makes the Sivers amplitude directly comparable