WG6
Spin and 3D Structure
Report

XVII International Workshop on Deep Inelastic Scattering and Related Subjects

Oleg Eyser, Bakur Parsamyan, Ted Rogers

BROOKHAVEN NATIONAL LABORATORY

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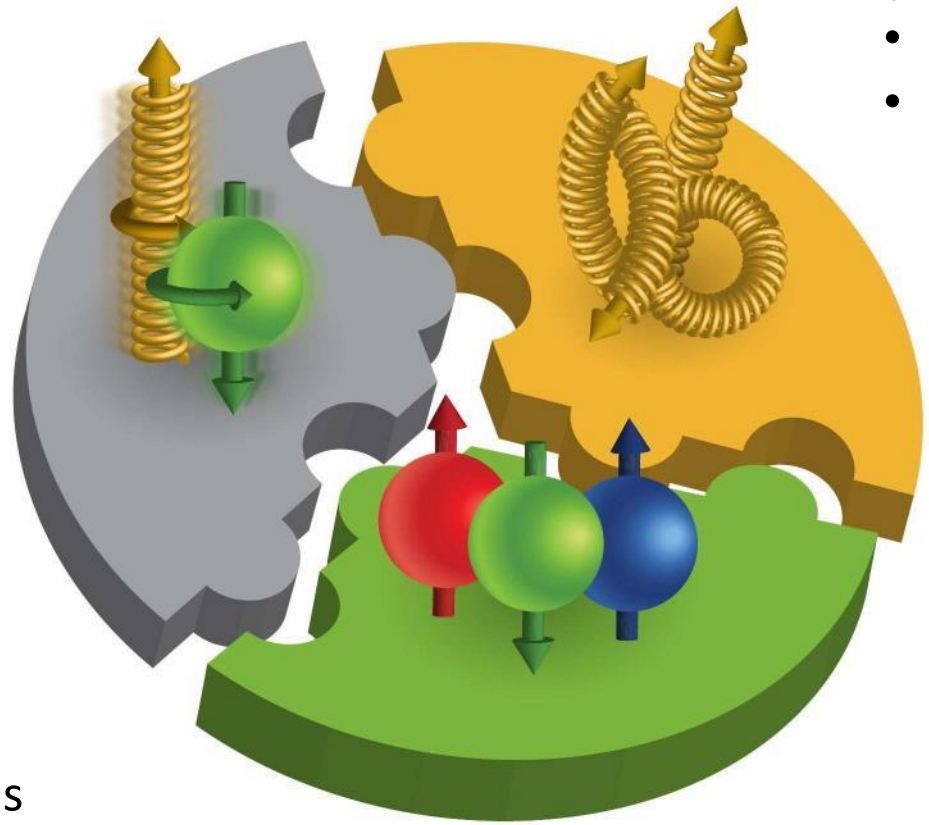
WG6: Spin and 3D Structure

The Proton



Generalized parton distribution functions
(coordinate space)
- Deeply virtual Compton scattering
- Exclusive reactions

Spin-orbit correlations
(transverse momentum)
- Particle multiplicities
- Fragmentation functions
- Transverse spin asymmetries

Polarized parton distribution functions
(longitudinal momentum)
- Helicity asymmetries
- Transverse spin asymmetries

Illustration courtesy of Brookhaven National Laboratory, https://www.bnl.gov/newsroom/news.php?a=114331

List of Speakers WG6, WG6/7

TUESDAY April 9

Gunar Schnell Matt Posik Nick Lukow Gunar Schnell Stefan Diehl	Jan Matousek Andrea Moretti Nobuo Sato J. Osvaldo Gonzalez H. Andrea Simonelli Alexey Vladimirov	Marcin Stolarski Nicolas Pierre Ralf Seidl Aram Kotzinian Alberto Accardi Christopher Dilks	Albi Kerbizi Franco Bradamante Marco Radici Nicole Lewis Ken Barish

WEDNESDAY April 10

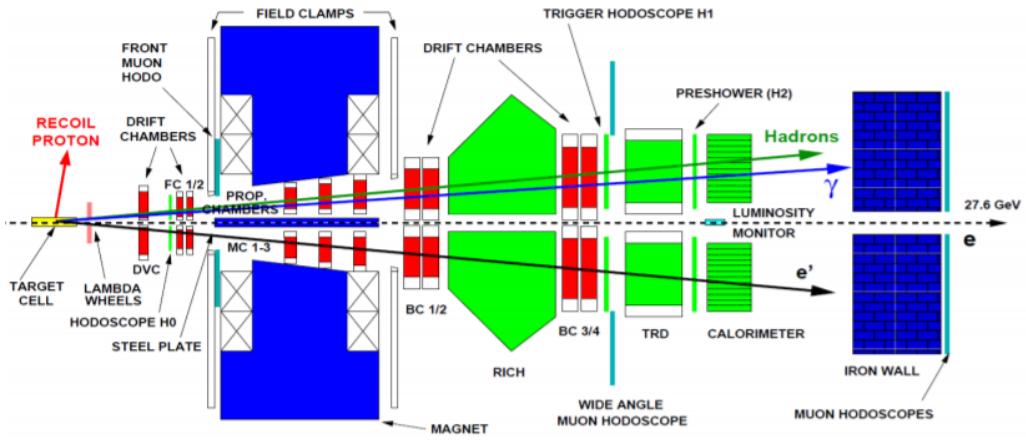
Bakur Parsamyan Xiaoyu Wang Riccardo Longo Wen-Chen Chang Maxim Nefedov Oleg Teryaev	Leonard Gamberg Ignazio Scimemi Kemal Tezgin Christian Pisano Abhiram Kaushik Elliot Leader	Piet Mulders Sergio Leal Gomez Florent Scarpa Sookhyun Lee Shohini Bhattacharya	Felix Hekhorn Chandan Mondal Wei Yang Wenjuan Mao Arturo Amor

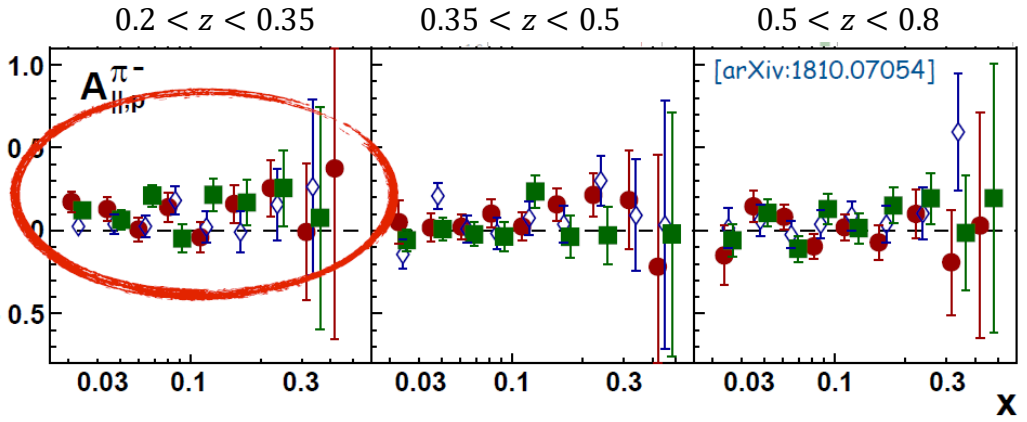
THURSDAY April 11

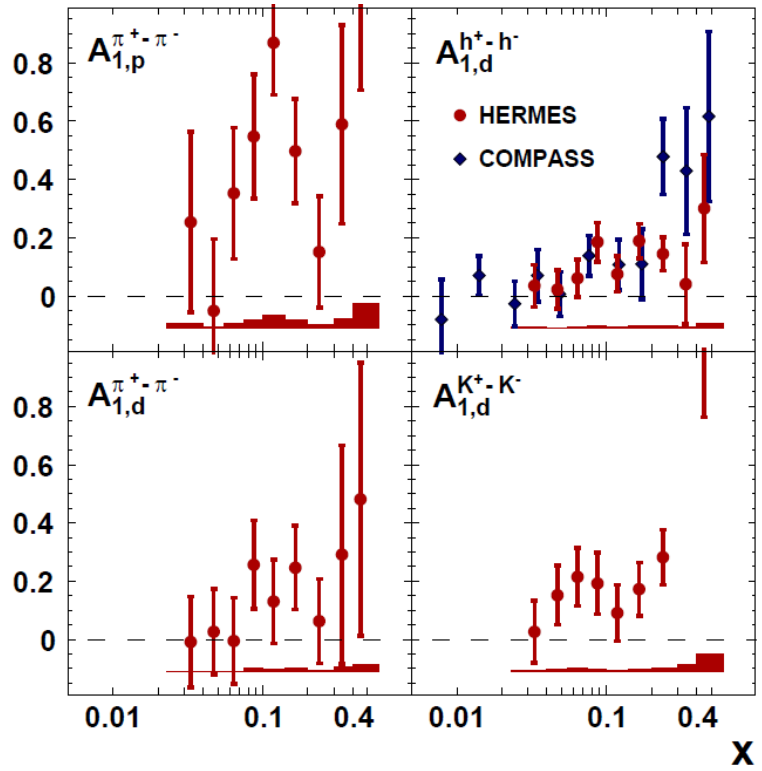
Pawel Sznajder Antoine Vidon Francesco Bossu Kemal Tezgin Aleksandra Pedrak Simone Rodini	Anna Martin Harut Avakian Yuxiang Zhao Zhenyu Ye Daniel Boer		

Helicity Asymmetries in SIDIS

Gunar Schnell







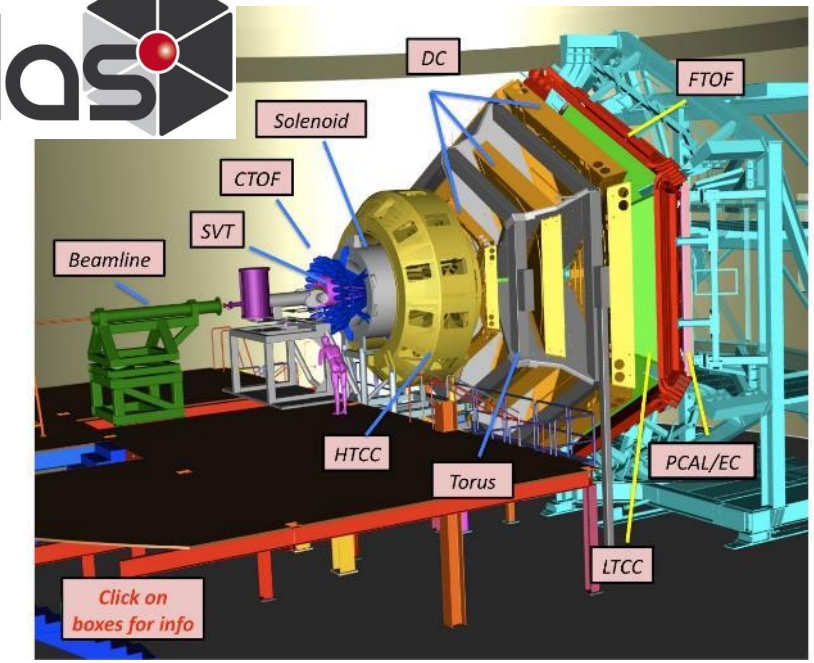
- RPD 71 (2005) 012003 → new multidimensional analysis of A_1

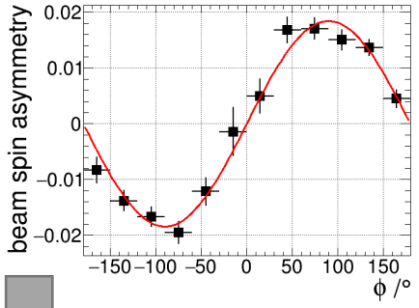
$$A_{||}^h = \frac{C_\phi^h}{f_D}\left[\frac{L_{++}N_{+-}^h + L_{+-}N_{++}^h}{L_{P,++}N_{+-}^h + L_{P,+-}N_{++}^h}\right]_B$$

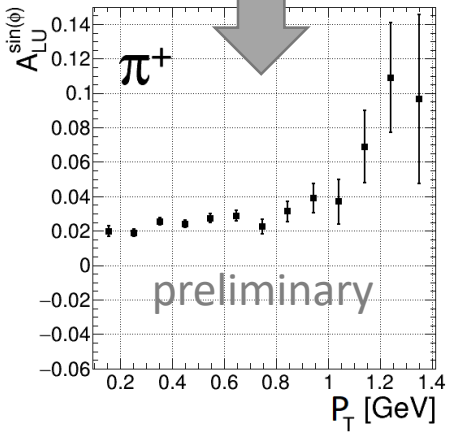
- Multidimensional analysis important, but statistically limited
- Also charge difference asymmetry and $\cos\phi$ moments (twist-3)
- arxiv:1810.07054
- Beam helicity asymmetries A_{LU}^h → arxiv:1903.08544

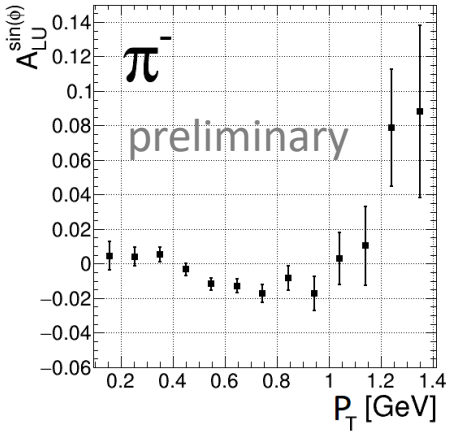
Beam Spin Asymmetries

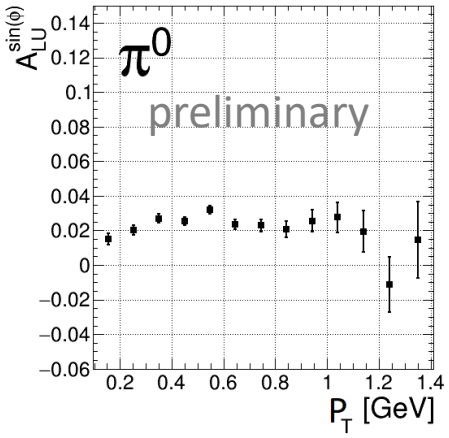
Stefan Diehl





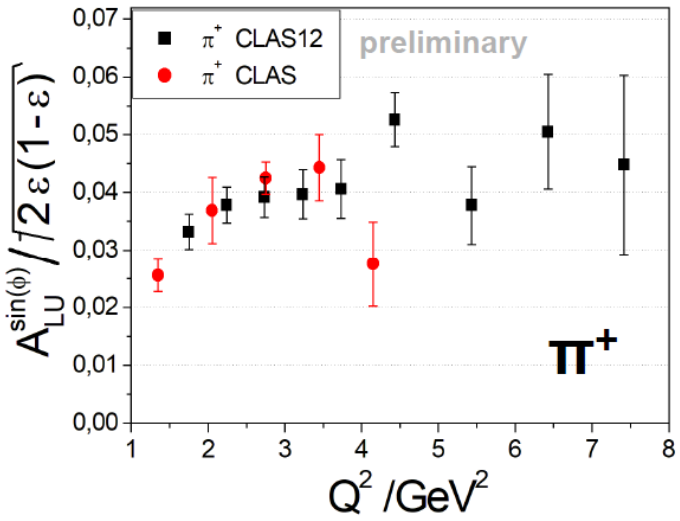






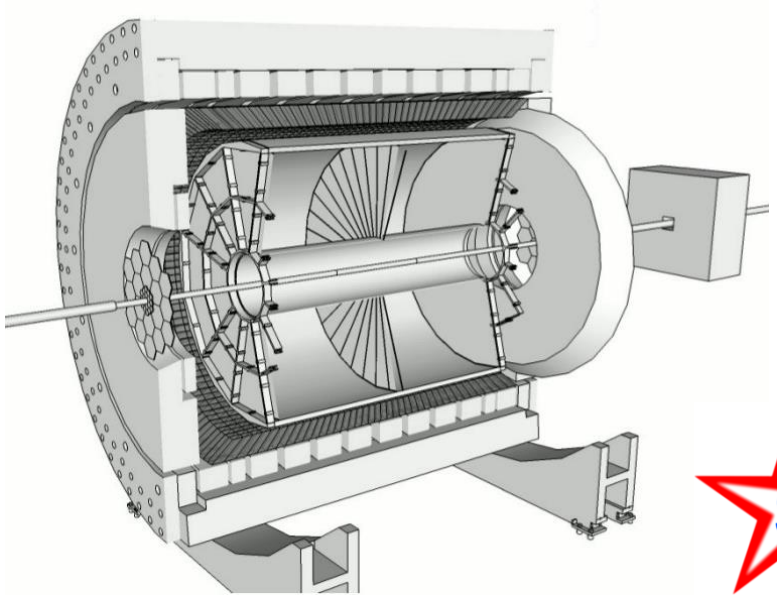
$$\frac{d\sigma}{d\sigma_0} = 1 + A_{UU}^{\cos\phi}\cos\phi + A_{UU}^{\cos 2\phi}\cos 2\phi + \lambda_e A_{LU}^{\sin\phi}\sin\phi$$

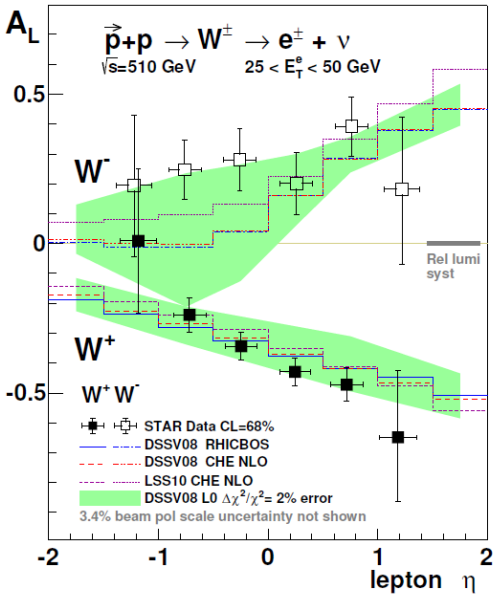
- Charged and neutral pions
- Currently only 2% of approved data analyzed
- Detailed systematics study necessary

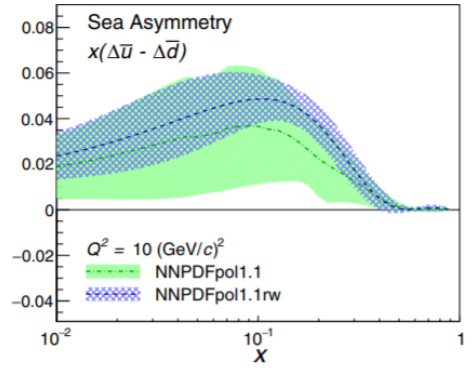


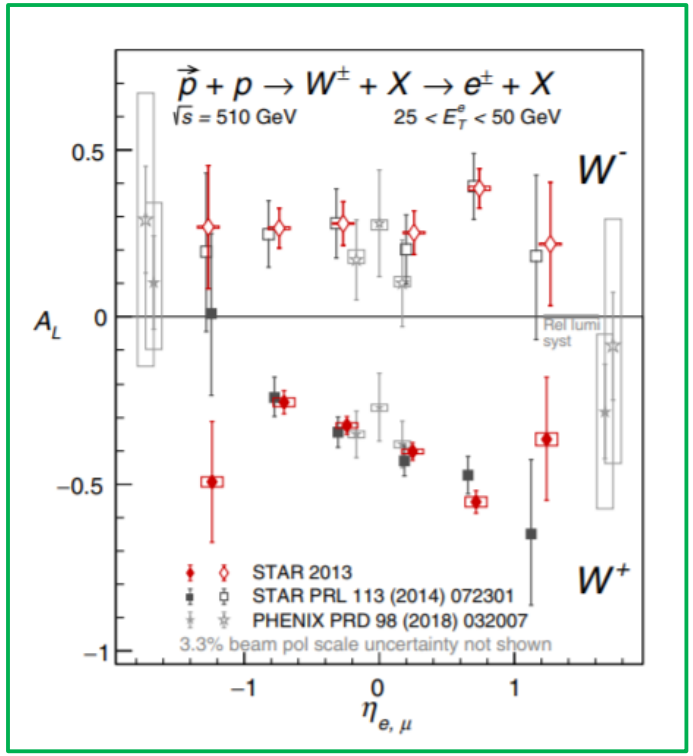
W-Boson Production and Sea Quark Polarization

Matt Posik
Nicolas Lukow









- Parity violating single-spin asymmetries

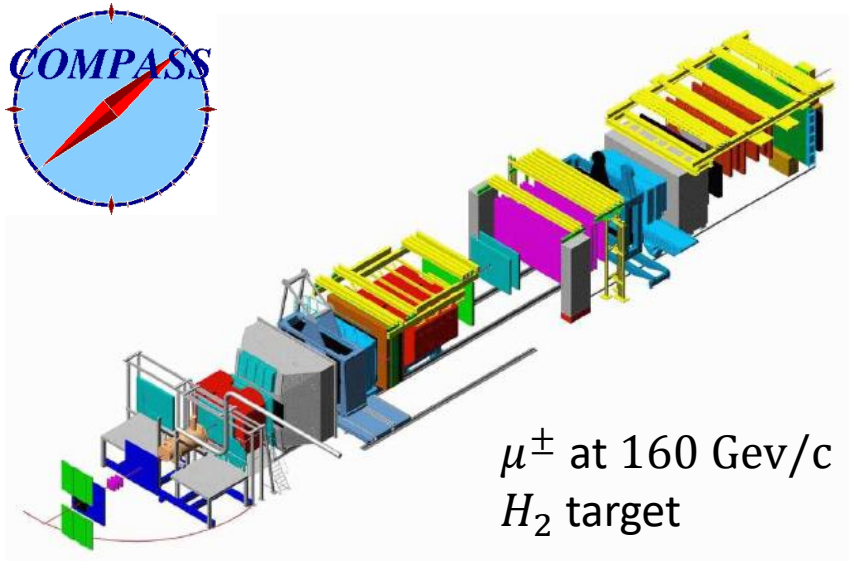
$$A_L(l^-) = \frac{\Delta\bar{u}(x_1)d(x_2)(1-\cos\theta)^2 - \Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2}{\Delta\bar{u}(x_1)d(x_2)(1-\cos\theta)^2 + \Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2}$$

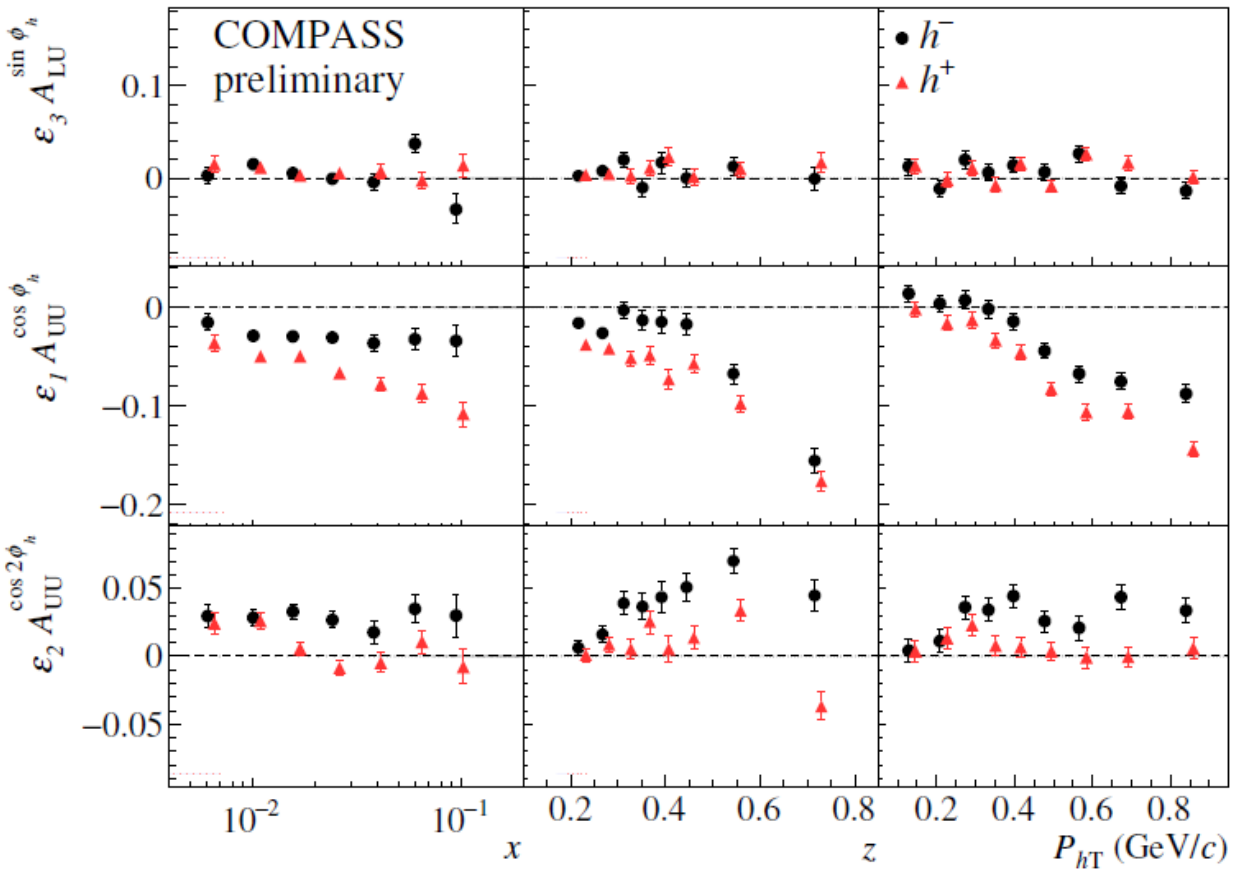
- **Final results from the RHIC W-program (2009-2013)**
  - PRD 99 (2019) 051102
  - PRD 98 (2018) 032007

- Also: status and outlook of gluon polarization from jet and dijet double helicity measurements

Unpolarized Azimuthal Modulations in SIDIS

Jan Matousek

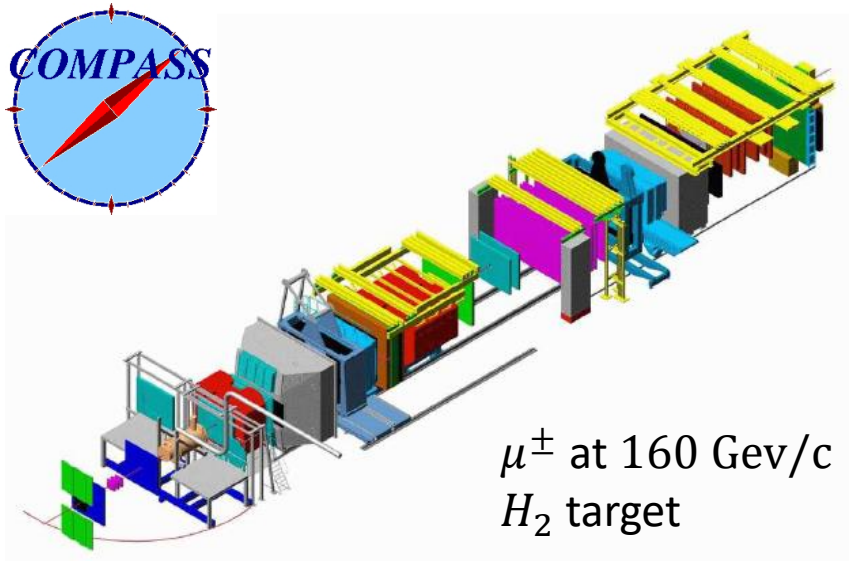




- Acceptance corrected (LEPTO)
- Significant contributions from vector meson decays
- Planned 4D binning (x, Q^2, z, p_T) and vector meson subtraction ($\rightarrow$ ^6LiD data)
- Currently only 4% of available data analyzed (2016+2017)

Charged Hadron Multiplicities

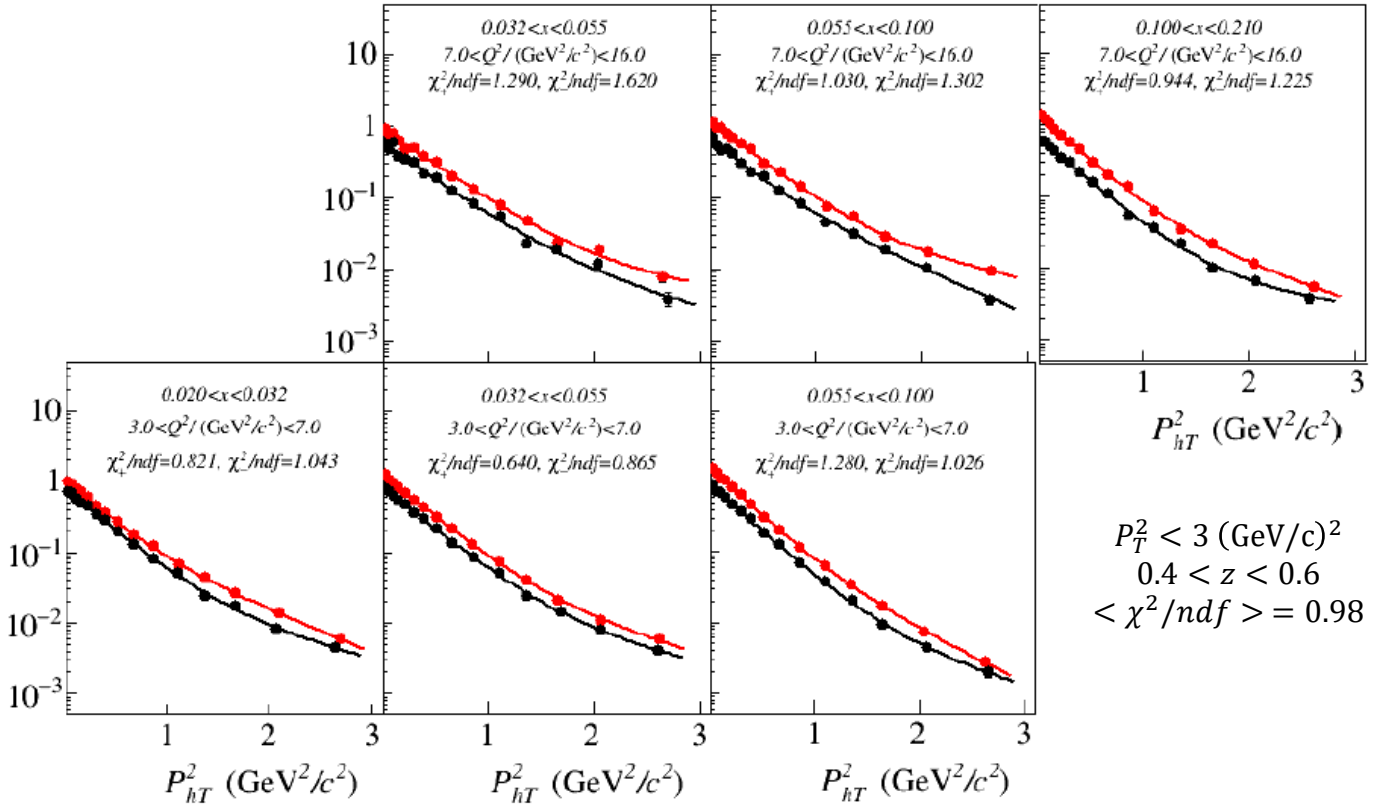
Andrea Moretti



$$\frac{d^4\sigma}{dxdQ^2dzdP_T^2} = \frac{2\pi^2\alpha^2}{(xys)^2}[1+(1-y)^2]F_{UU}(x,Q^2,z,P_T^2)$$

$$M^h_{meas}(x,Q^2,z,P_T^2) = \frac{N(x,Q^2,z,P_T^2)}{N^{DIS}(x,Q^2)\Delta z\Delta P_T^2}\frac{1}{acc(x,Q^2,z,P_T^2)}$$

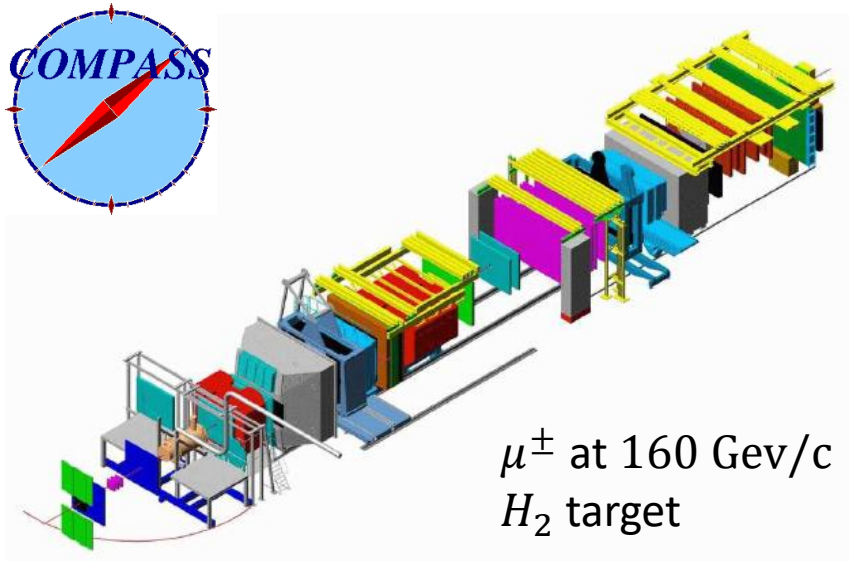
- Acceptance corrected (LEPTO, flat in P_T^2 and hadron charge)
- Diffractive vector meson contamination <2% (not corrected yet)
- No radiative corrections
- Currently only 10% of available data analyzed (2016)

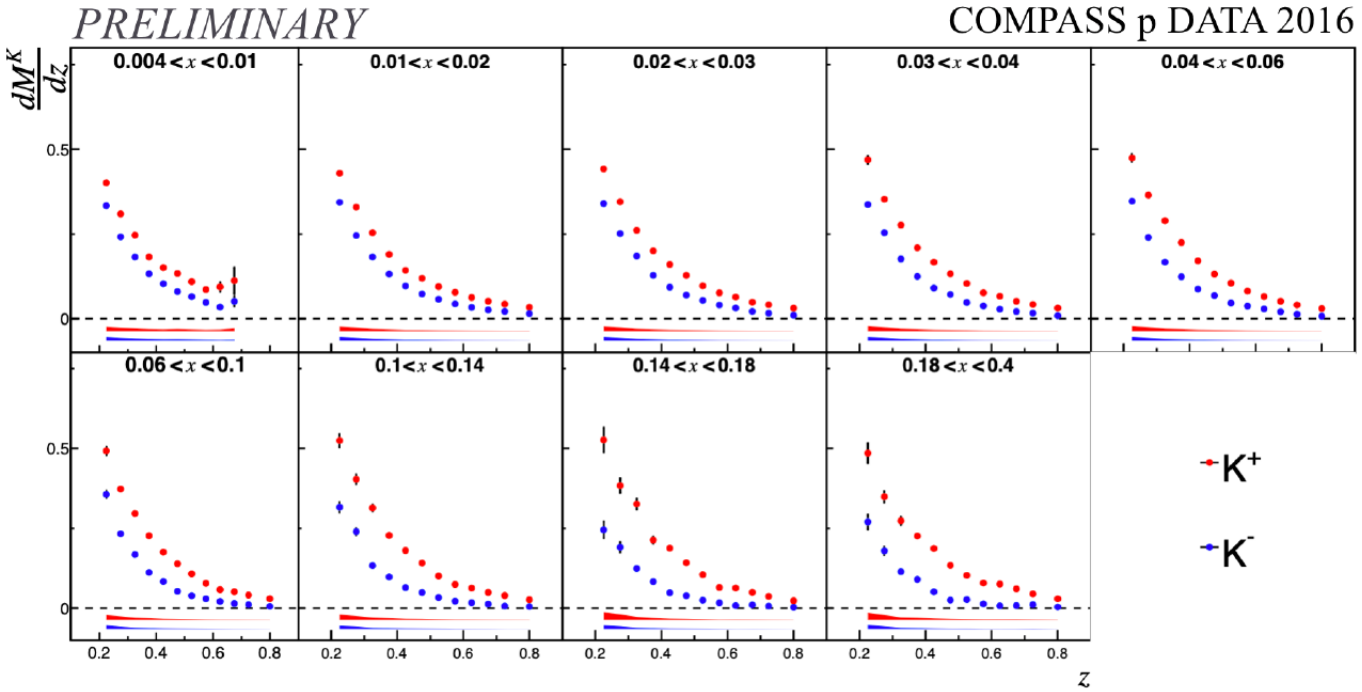


$P_T^2 < 3\ (\mathrm{GeV/c})^2$
$0.4 < z < 0.6$
$< \chi^2/ndf > = 0.98$

Kaon Multiplicities

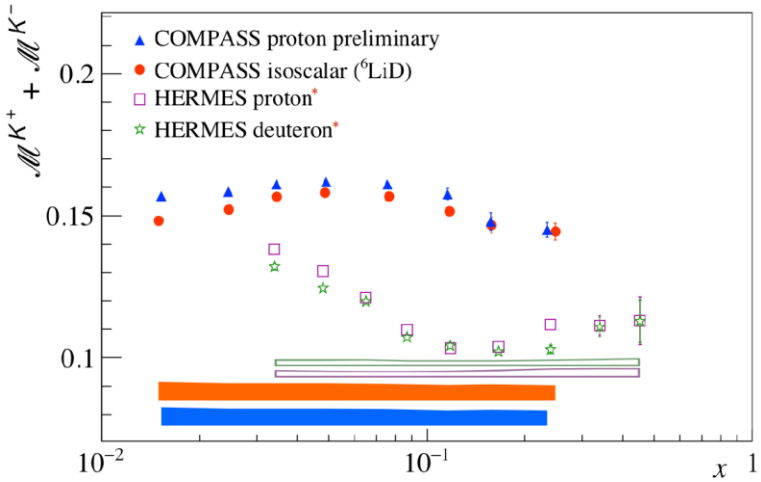
Nicolas Pierre





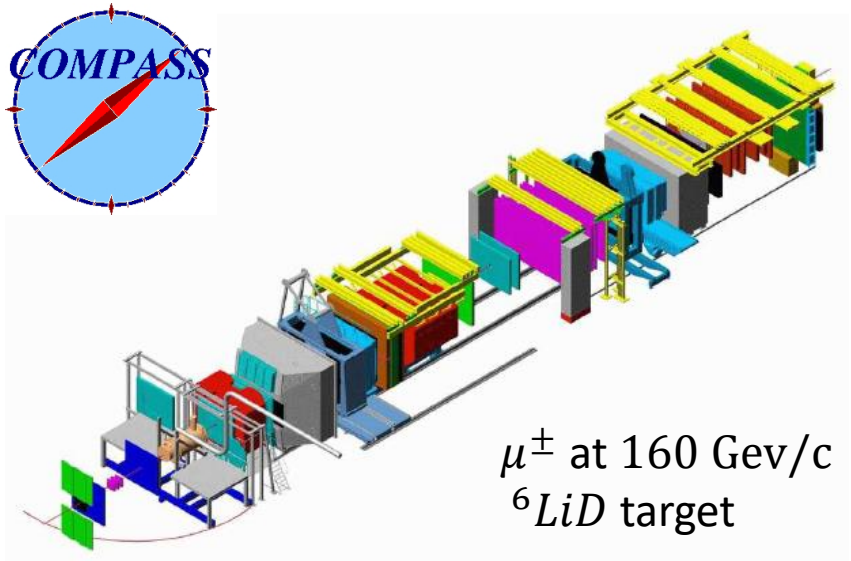
$$\frac{dM^h(x,Q^2,z)}{dz} = \frac{d^3\sigma^h(x,Q^2,z)/dxdQ^2dz}{d^2\sigma^{DIS}(x,Q^2)/dxdQ^2}$$

- 300 multidimensional bins (x, y, z)
- Fully corrected for acceptance, efficiencies, resolution and reconstruction
- Radiative corrections (DJANGOH, 0% - 20%)
- Diffractive vector meson corrections (<10% in most bins)
- ¼ of available data analyzed



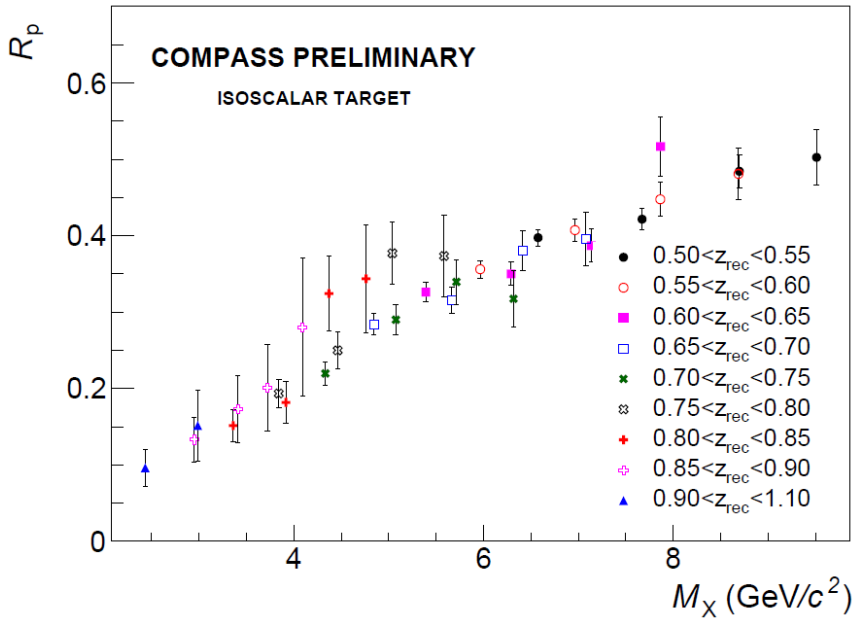
Hadron Multiplicities: Ratios

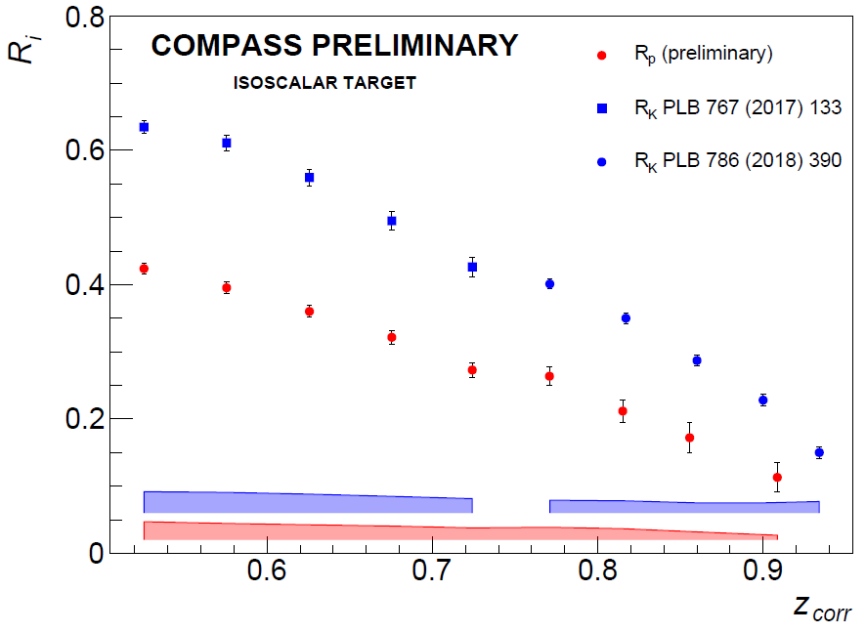
Marcin Stolarski



$$R_h = \frac{dM^{h^-}(x, Q^2, z)/dz}{dM^{h^+}(x, Q^2, z)/dz}$$

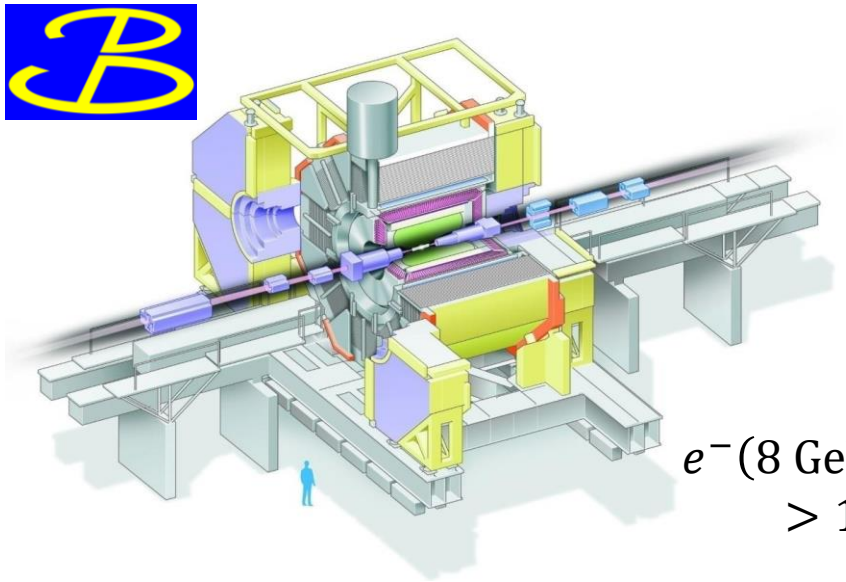
- Strong M_X dependence indicates the limited phase space can explain discrepancy with HERMES.
- PLB 786 (2018) 390
- The region of applicability of factorized pQCD in SIDIS should be revisited (high-z).





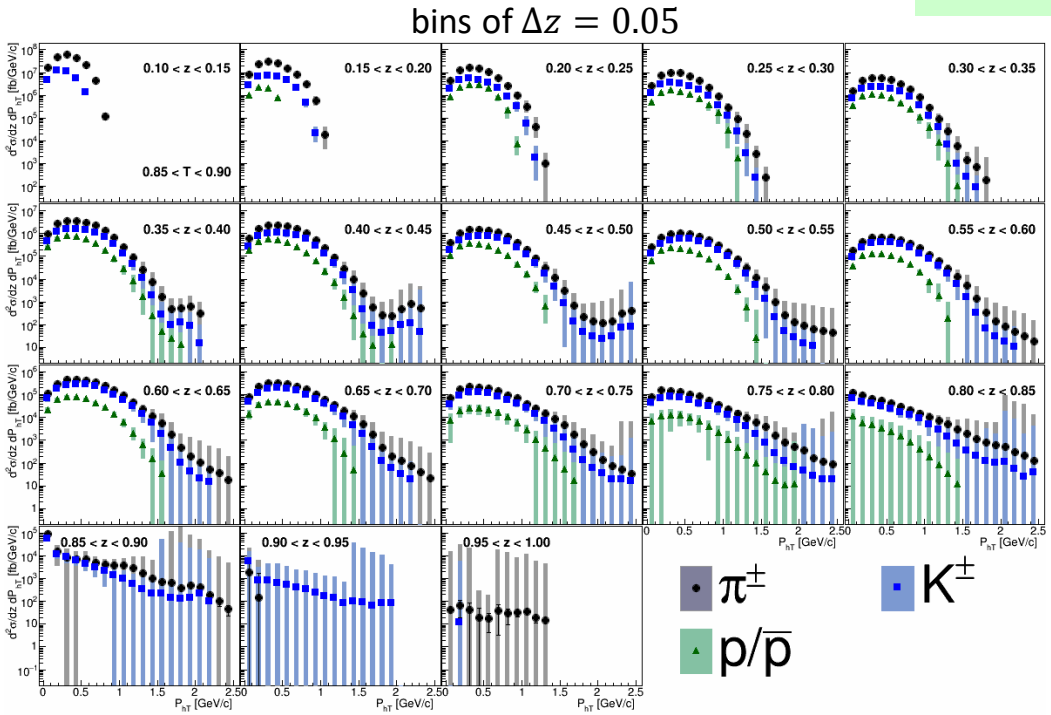
Fragmentation Functions

Ralf Seidl

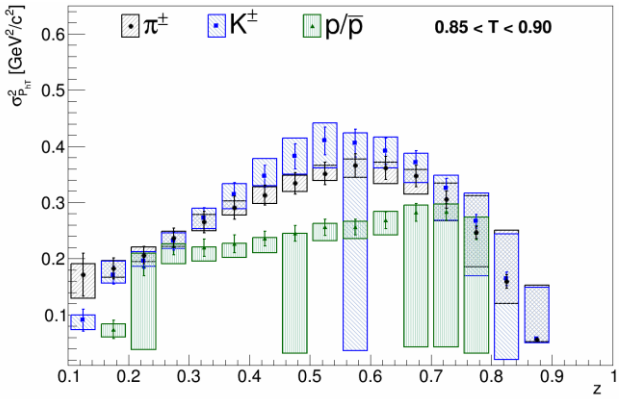


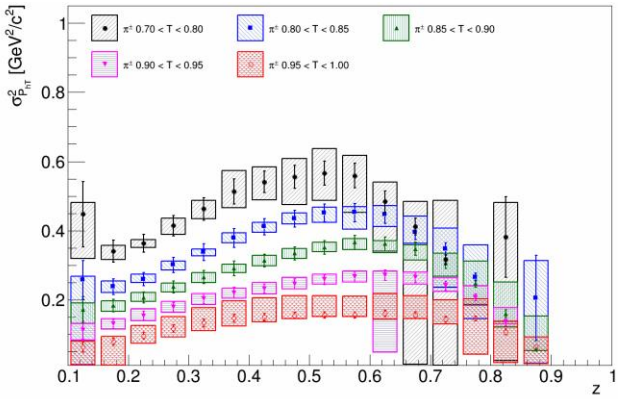
$$\frac{d^2\sigma}{dz dP_T^h}(P_T^h)$$

$e^-(8\ \mathrm{GeV})e^+(3.5\ \mathrm{GeV})$
$> 1000\ \mathrm{fb}^{-1}$



- arxiv:1902.01552
- Transverse momentum dependence from thrust axis Correction chain and systematics: particle mis-ID, p-smearing, non $q\bar{q}$ background, acceptance, weak decay, ISR
- New proposed q_T-weighted asymmetries for DiFF in SIDIS and SIA, access different STMD FF, flavor decomposition

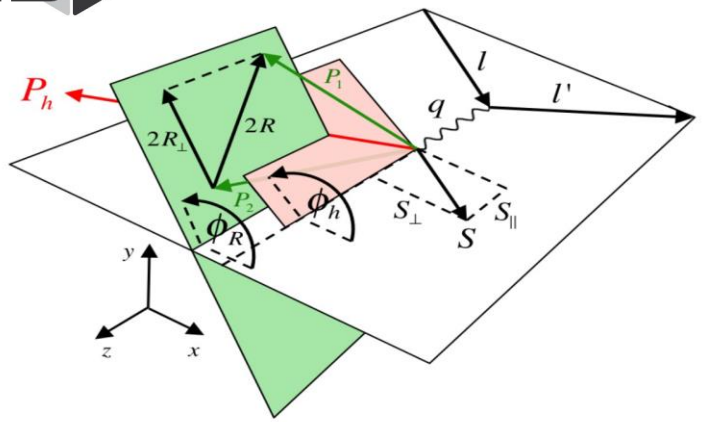




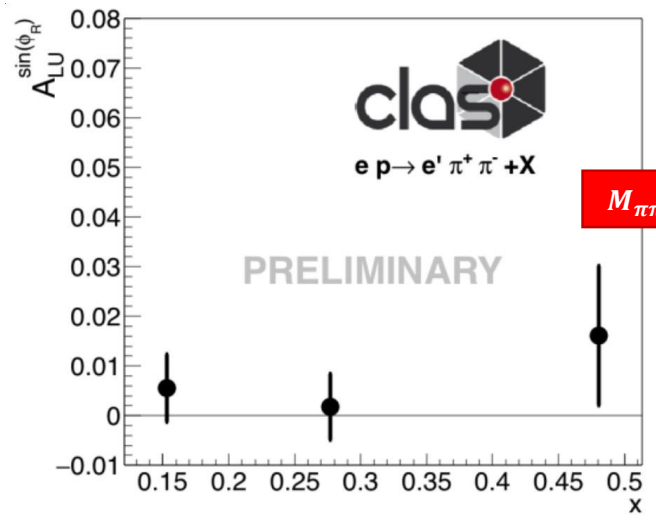
Aram Kotzinian

Dihadron Fragmentation

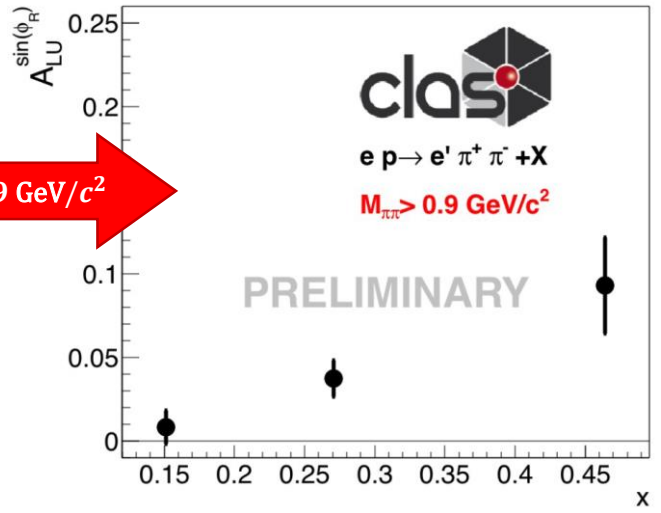
Christopher Dilks

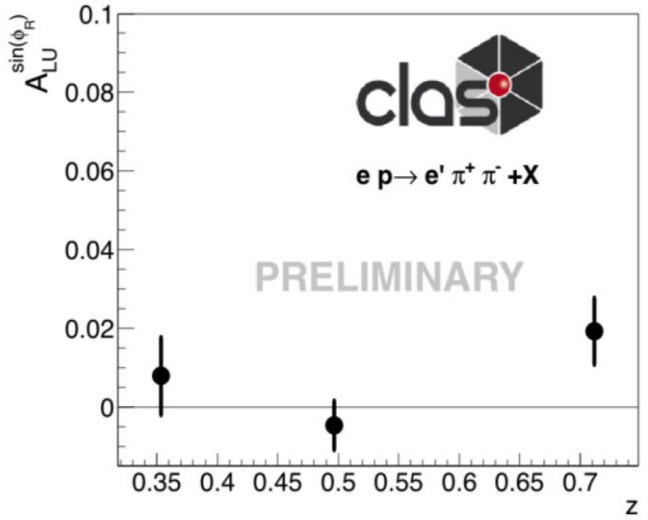


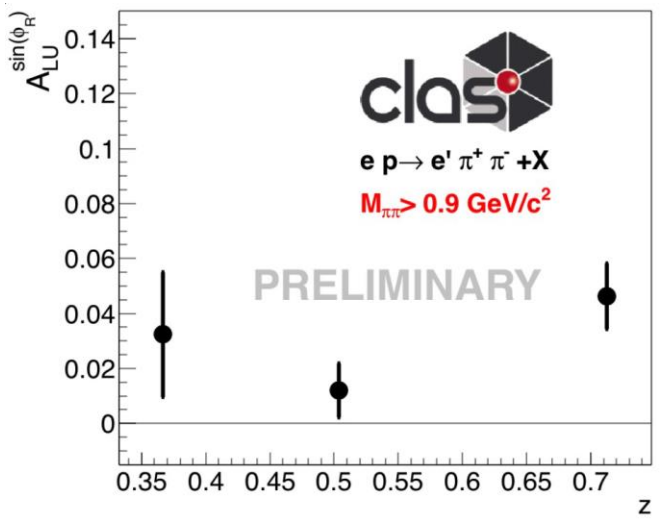
- Access $G_1^{\perp a}$ beam *and target* spin asymmetries
- Results previously shown from CLAS-6
- CLAS-12 preliminary results based on 10% of the full projected statistics



$M_{\pi\pi} > 0.9$ GeV/c^2





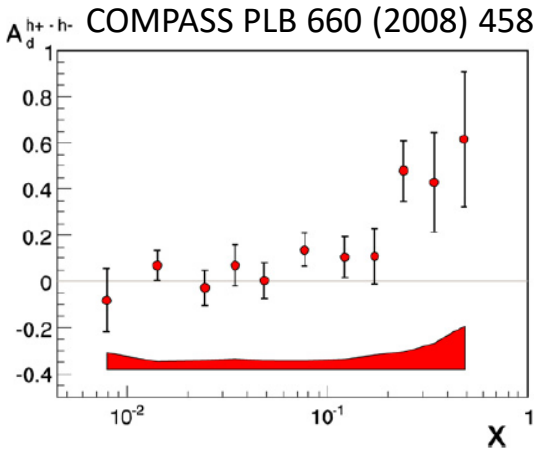


Transversity from Difference Asymmetries

Franco Bradamante

Avoid the use of FFs in the extraction of the PDFs (helicity asymmetries):

$$A^{h^+-h^-} = \frac{\left(\sigma^{h^+}_{\uparrow\downarrow} - \sigma^{h^-}_{\uparrow\downarrow}\right) - \left(\sigma^{h^+}_{\uparrow\uparrow} - \sigma^{h^-}_{\uparrow\uparrow}\right)}{\left(\sigma^{h^+}_{\uparrow\downarrow} - \sigma^{h^-}_{\uparrow\downarrow}\right) + \left(\sigma^{h^+}_{\uparrow\uparrow} - \sigma^{h^-}_{\uparrow\uparrow}\right)} \approx \frac{\Delta u_v + \Delta d_v}{u_v + d_v}$$



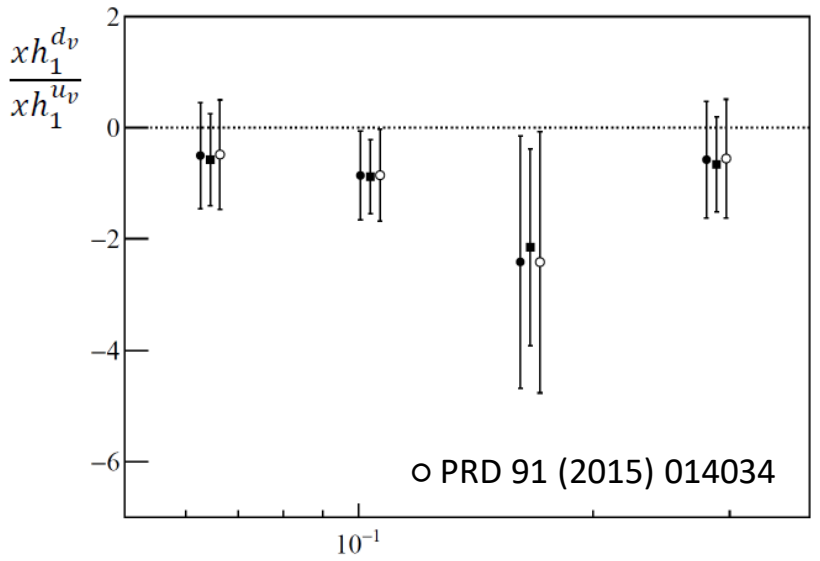
COMPASS PLB 660 (2008) 458

Transverse (Collins) asymmetries:

$$A_{D,t} = \frac{\sigma^+_{C,t} - \sigma^-_{C,t}}{\sigma^+_{0,t} + \sigma^-_{0,t}}$$

$$A'_{D,t} = \frac{\sigma^+_{C,t} - \sigma^-_{C,t}}{\sigma^+_{0,t} - \sigma^-_{0,t}}$$

$$A^{\pm}_{C,t} = \sigma^{\pm}_{C,t}/\sigma^{\pm}_{0,t}$$



○ PRD 91 (2015) 014034

"The method we applied is interesting and simple, and does not require any knowledge of the Collins fragmentation functions."

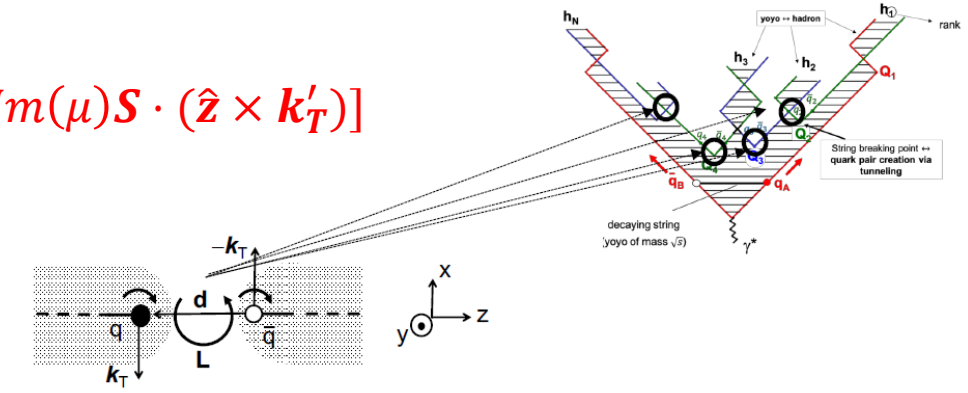
Results from $A_{D,t}$ and $A'_{D,t}$ are essentially identical with standard transversity extractions using SIDIS and e^+e^- data.

arxiv:1902.08445

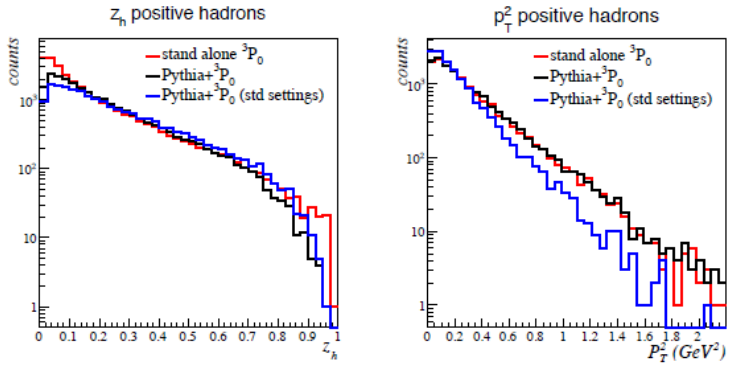
Simulating Spin Dependent Fragmentation

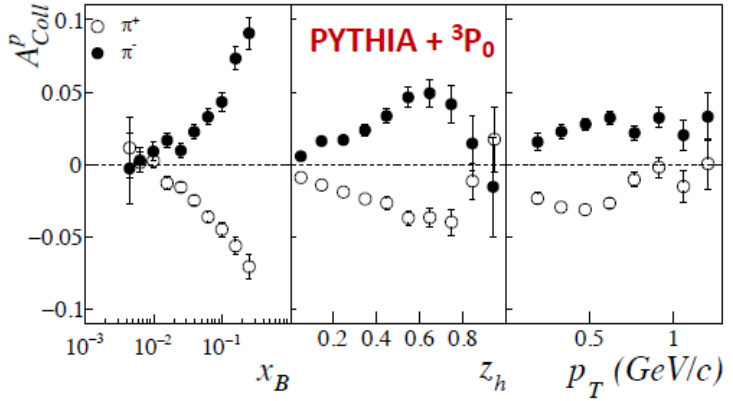
Albi Kerbizi

$$F_{q'hq} = |C_{q'hq}|^2 \left(\frac{1-Z}{\epsilon_h^2}\right)^a \frac{\exp(-b_L\epsilon_h^2/Z)}{N_a(\epsilon_h^2)} \frac{b_T^2}{\pi} \frac{\exp(-b_T \boldsymbol{k_T'}^2)}{1+b_T|\mu|^2} [|\mu|^2 + \boldsymbol{k_T'}^2 - 2Im(\mu)\boldsymbol{S}\cdot(\hat{\boldsymbol{z}}\times\boldsymbol{k_T'})]$$

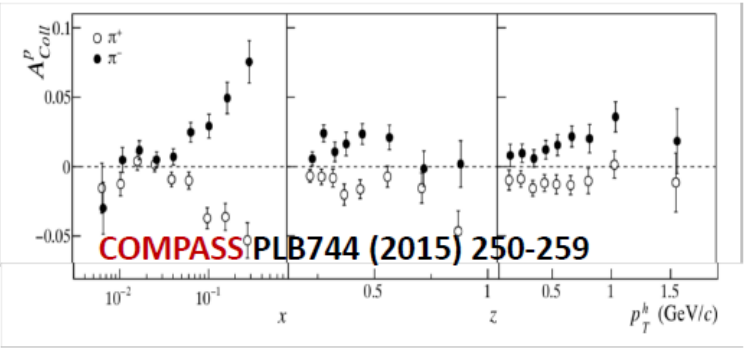


- Extension of string breaking in Lund Model: $q\bar{q}$ pair in ${}^3P_0$ $(L = 1, S = 1, J = 0)$
- Formalism defined in PRD 97 (2018) 074010 and arxiv: 1903.01736
- Implemented for DIS
- Currently:
  - Parton showers and multiple interactions switched off
  - Primordial k_T switched off
  - Only pseudoscalar mesons produced
- Comparison for COMPASS kinematics, transversity and Collins effect (p, d)



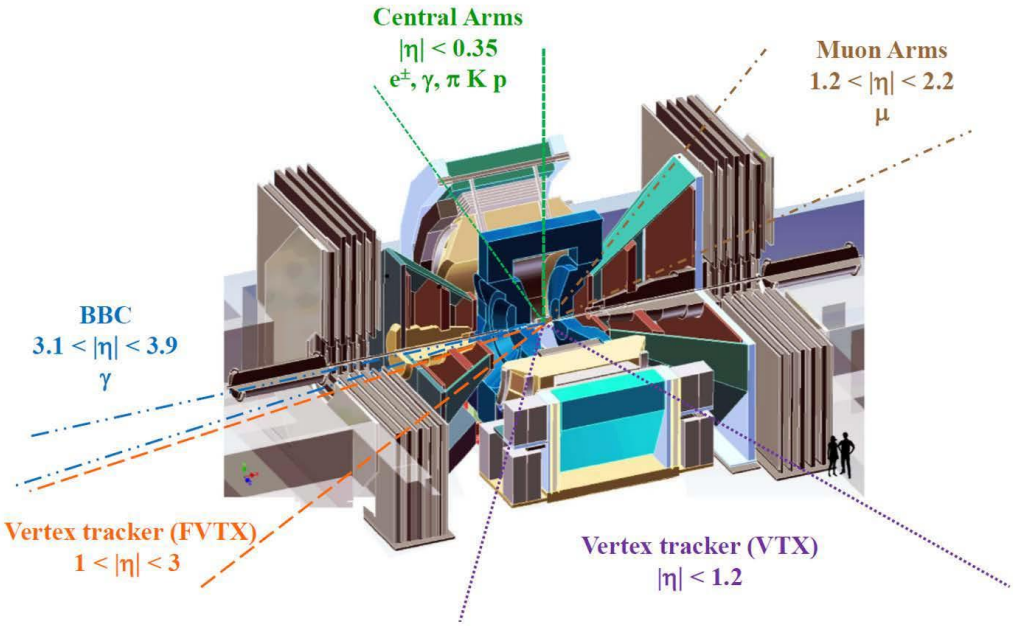


$p_T > 0.1\ GeV/c \quad z_h > 0.2$

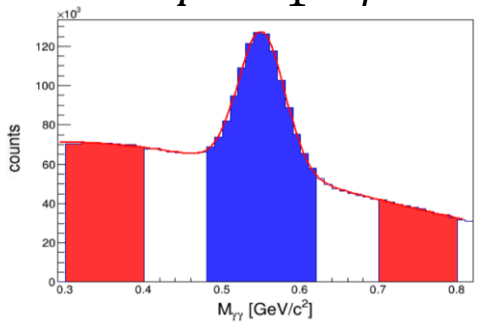


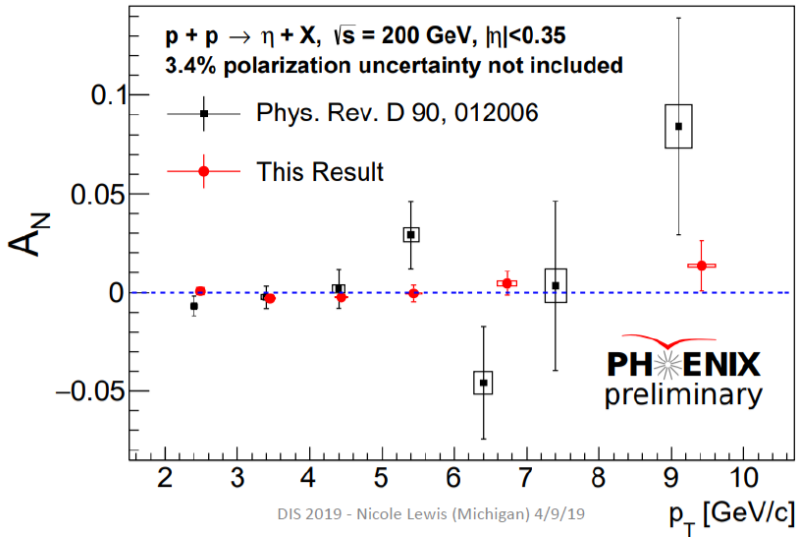
Gluon Spin-Orbit Correlations

Nicole Lewis
Sookhyun Lee



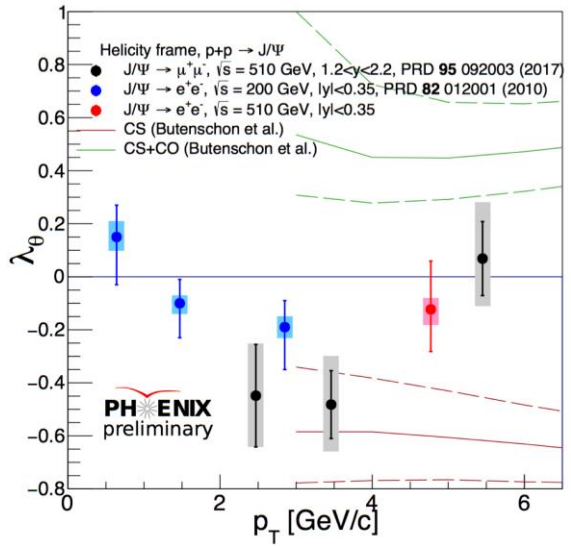
$$A_N^{\eta} = \frac{1}{P}\frac{A_N^{peak} - rA_N^{bg}}{1-r}$$





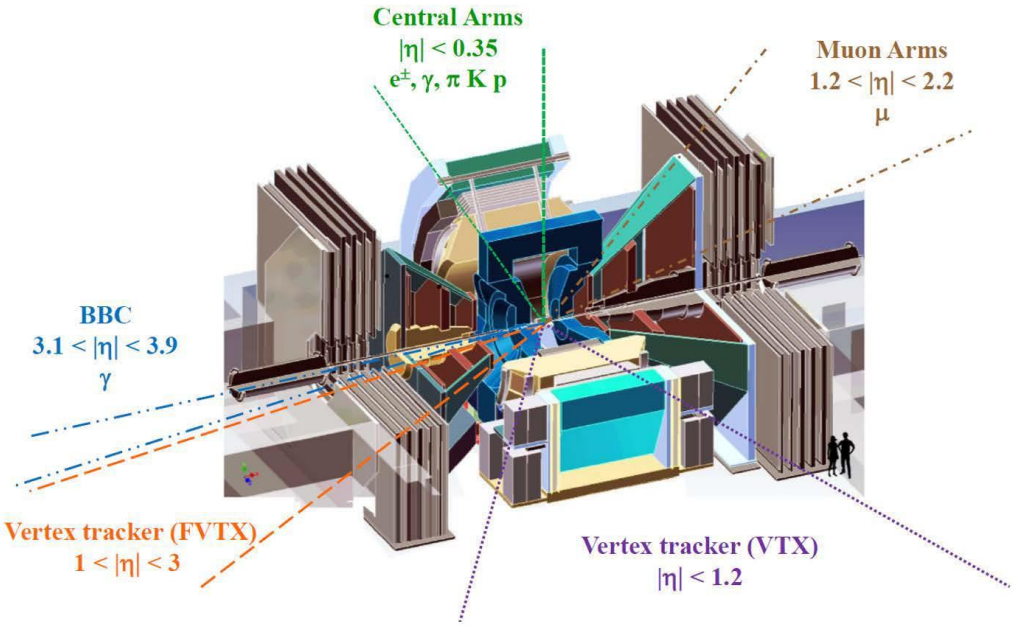
- Improved transverse asymmetries at mid-rapidity for η mesons
- Background corrected
- Consistent with zero (similar to π^0)

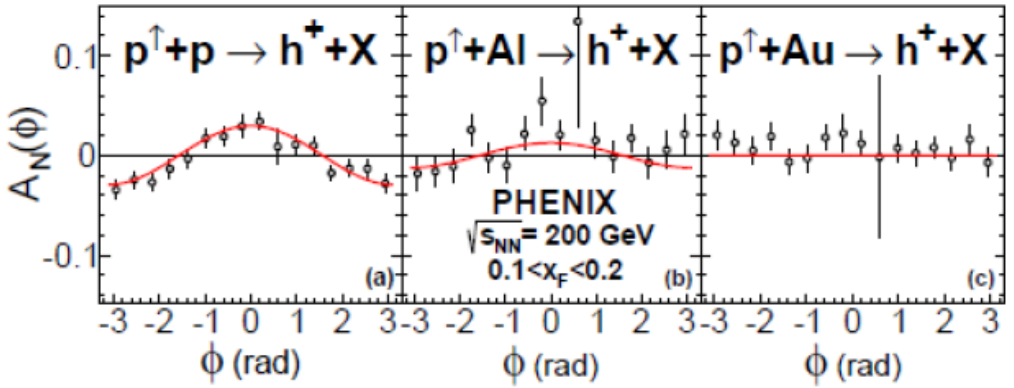
- Λ angular decay parameters consistent with previous measurements (200, 510 GeV)



Transverse Single Spin Asymmetries

Ken Barish

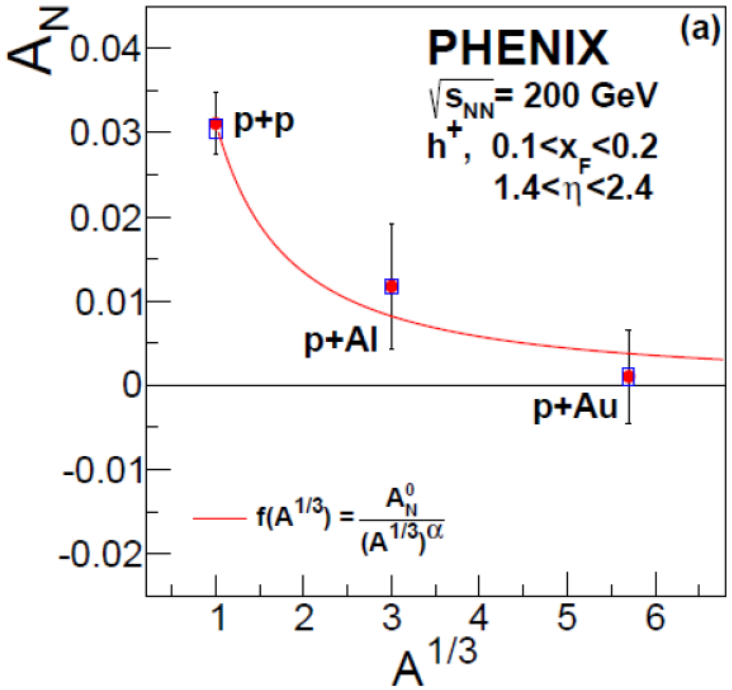




- Inclusive charged hadrons
- Observe nuclear suppression of transverse spin asymmetries
- arxiv:1903.07442

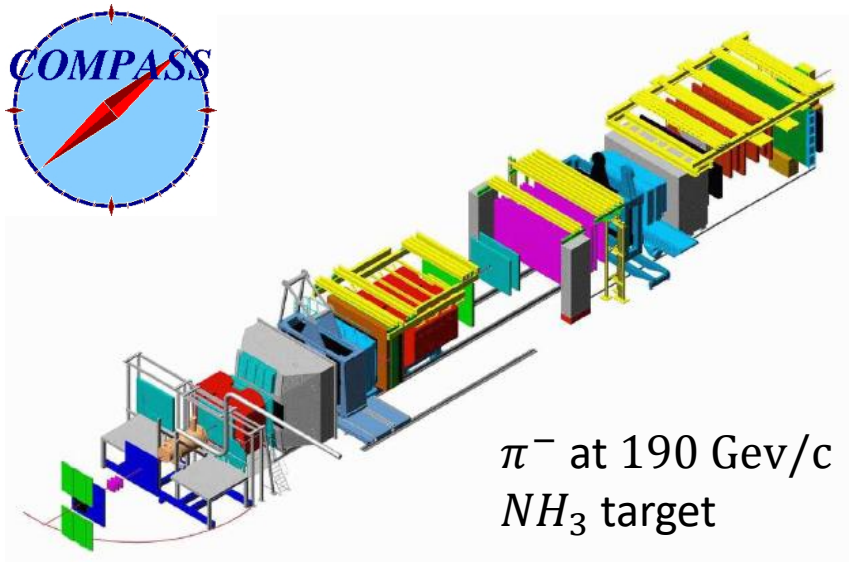
$$f\left(A^{1/3}\right) = \frac{A_N^0}{(A^{1/3})^{\alpha}}$$

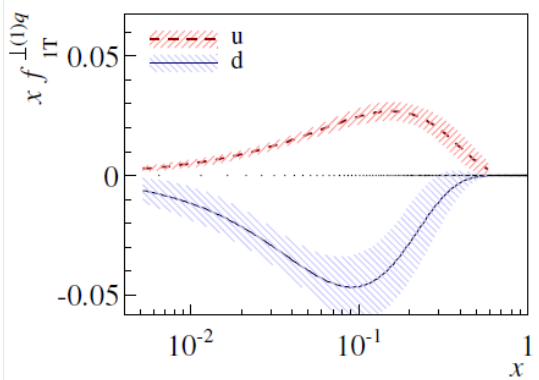
$$\alpha = 1.21^{+1.00(stat)+0.09(sys)}_{-0.42(stat)-0.07(sys)}$$



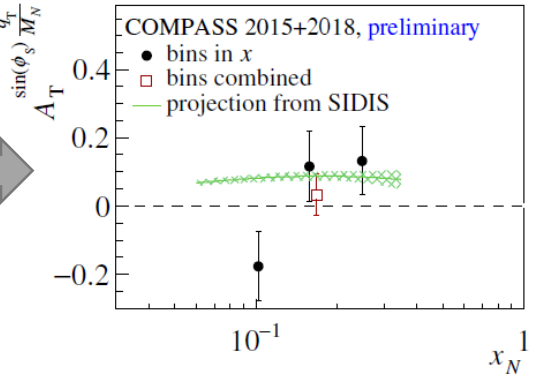
Universality of Sivers TMD

Bakur Parsamyan
Riccardo Longo

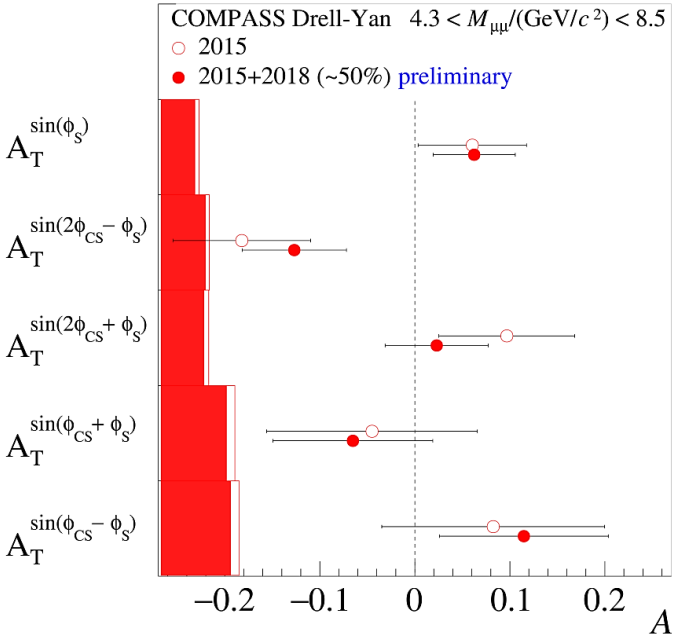




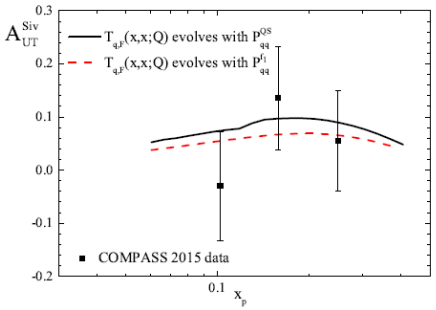
1st k_T^2 -moment of the Sivers function from SIDIS data at $Q^2 = Q^2_{SIDIS}(x)$



- First polarized DY measurements: PRL 119 (2017) 112002
- q_T weighted asymmetries consistent with extraction from SIDIS (assuming sign-change)
- 50% of 2018 data is analyzed



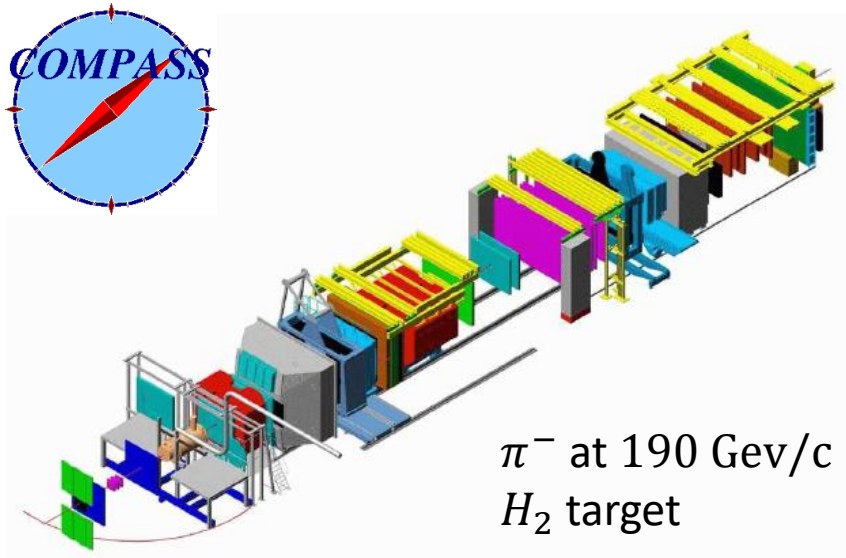
Xiaoyu Wang

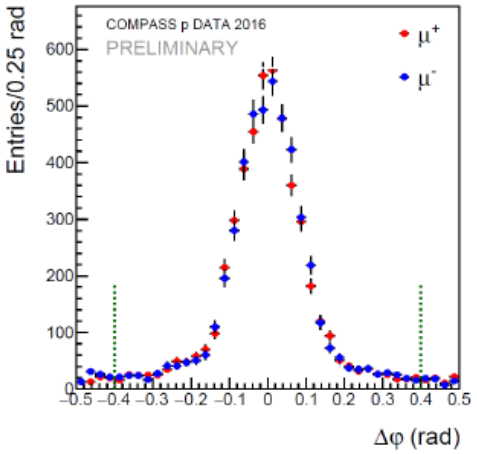


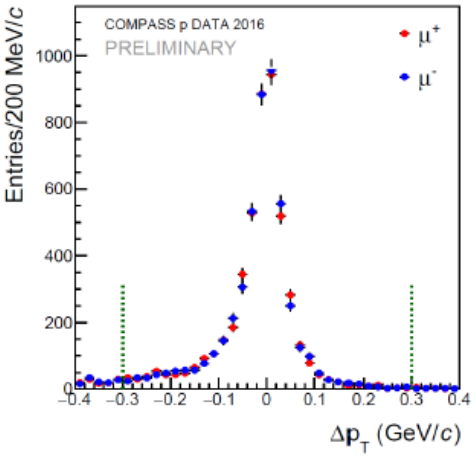
- Different evolution schemes
- Description consistent with COMPASS data
- PRD 97 (2018) 054005

Exclusive Single-Photon in Muonproduction

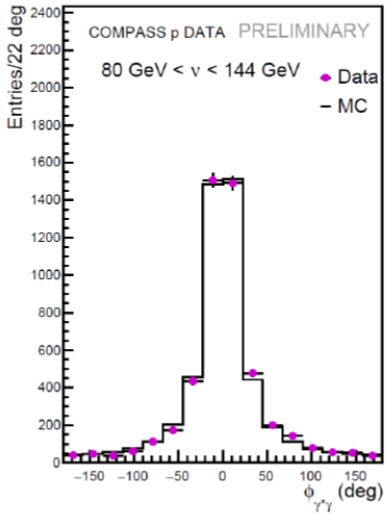
Antoine Vidon

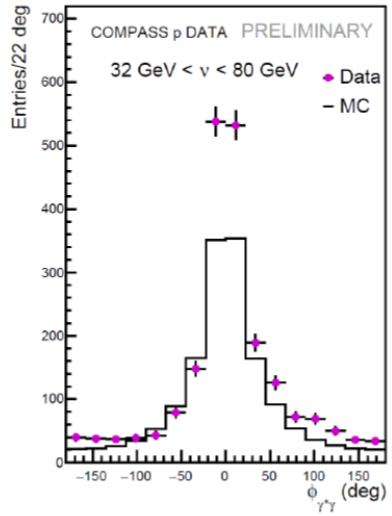


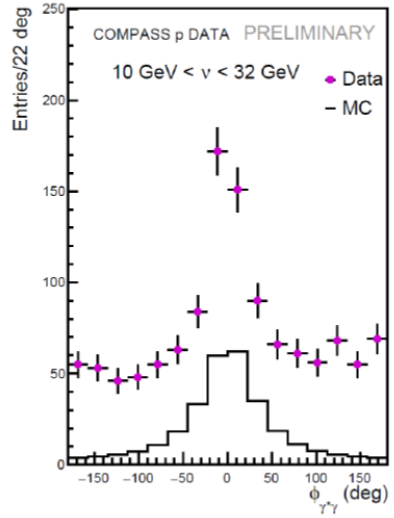




- Studied in 2012 pilot run, arxiv:1802.02739
- Combination of beam charge and helicity:
  - t-slope: $d\sigma^{\leftarrow,+} + d\sigma^{\rightarrow,-}$
  - d-term: $d\sigma^{\leftarrow,+} - d\sigma^{\rightarrow,-}$
- Invisible π^0 to be removed
- 1/8 of available 2016 data analyzed

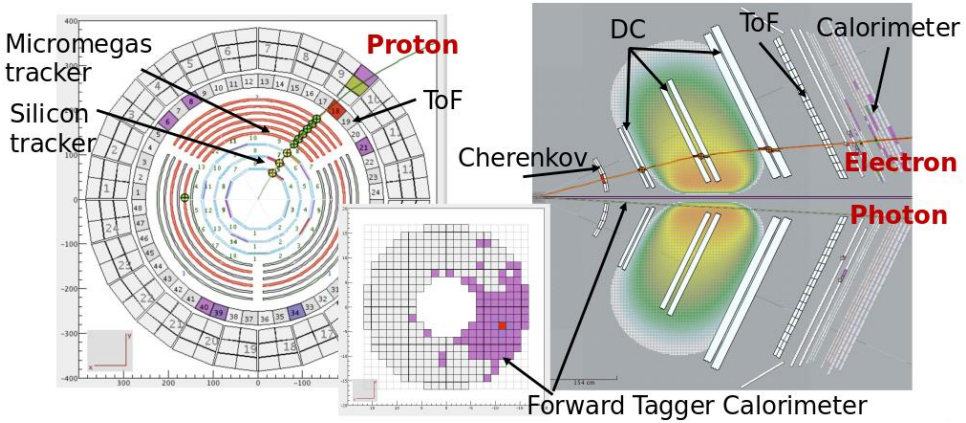


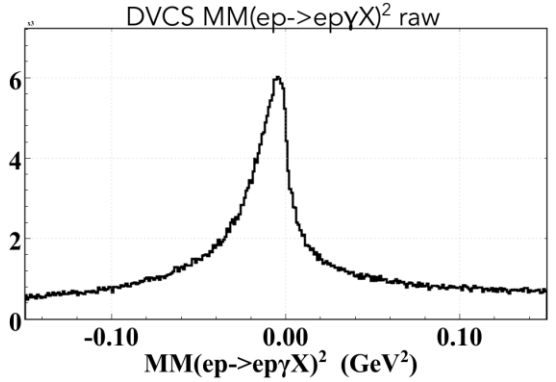


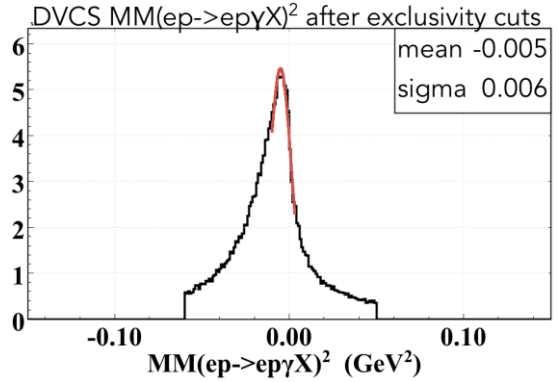


Exclusive Single-Photon in Electroproduction

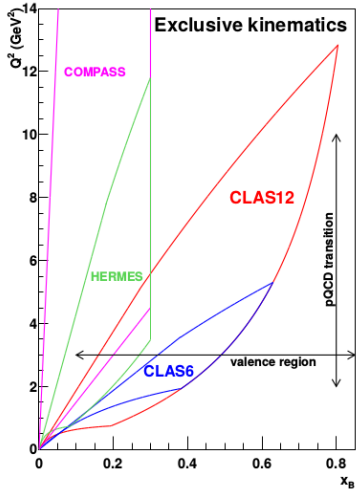
Francesco Bossu

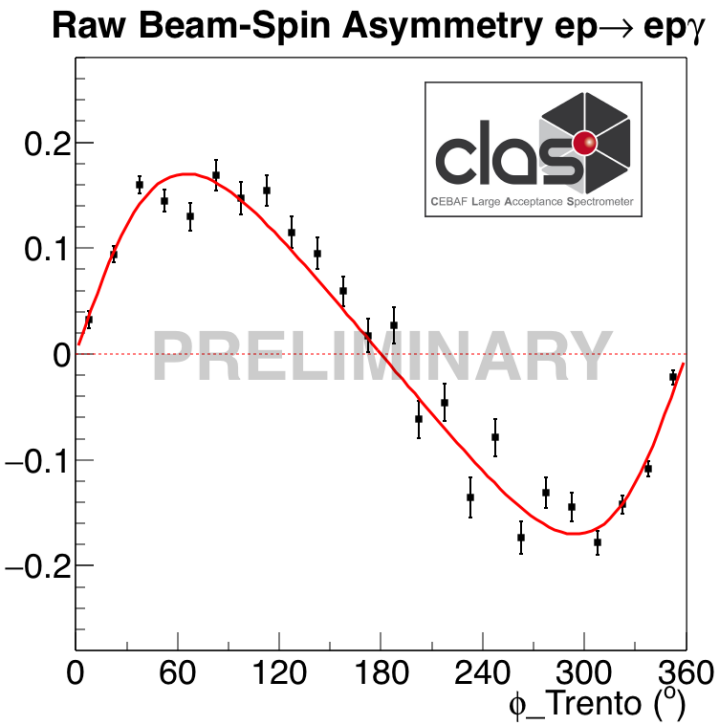






$$A_{LU} = \frac{1}{P}\frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$





- From beam spin asymmetries
- Main background from $ep \rightarrow ep\pi^0$
- Currently 2% of projected statistics (40% on disk)