Dihadrons from a Longitudinally Polarized Target

– A Run Group C Addition Proposal for PAC48 –

Speaker: Christopher Dilks

CLAS Collaboration Meeting

24 July 2020

Duke UNIVERSITY

clas

Proposal Details

Co-spokespersons: Harut Avakian, Christopher Dilks*, Orlando Soto
*contact

- Update to PR12-11-109, which was deferred in favor of higher priority measurements during initial 12 GeV operations
- Measurement planned to run during approved PAC time for Run Group C SIDIS experiments, e.g., E12-07-107
  - 120 PAC days with NH_3 target → polarized protons
  - 60 PAC days with ND_3 target → polarized deuterons

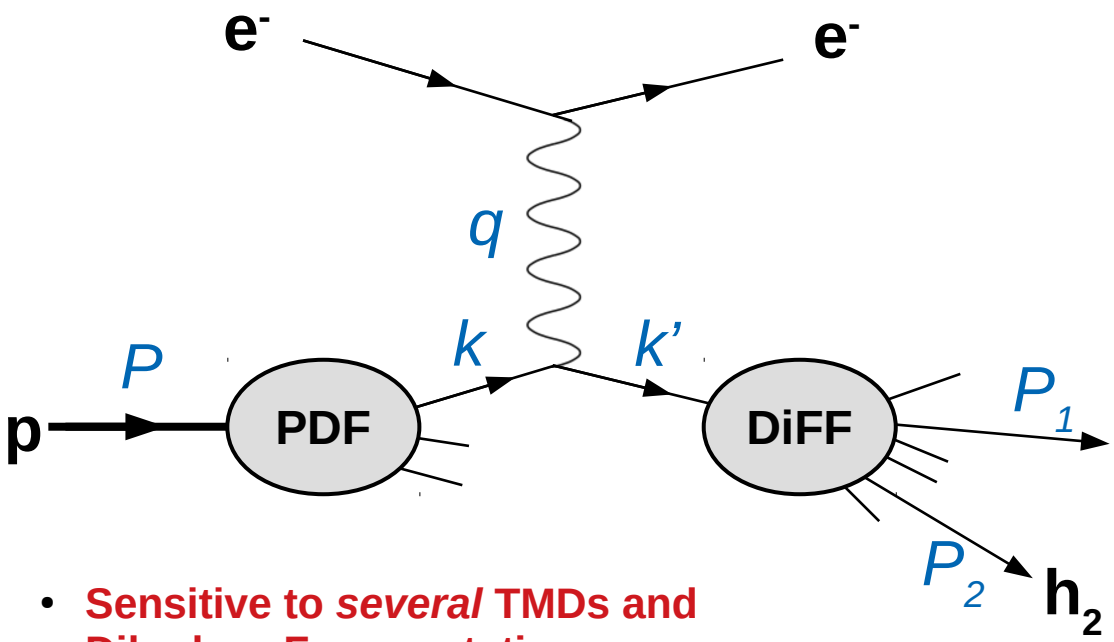
Primary Goal:

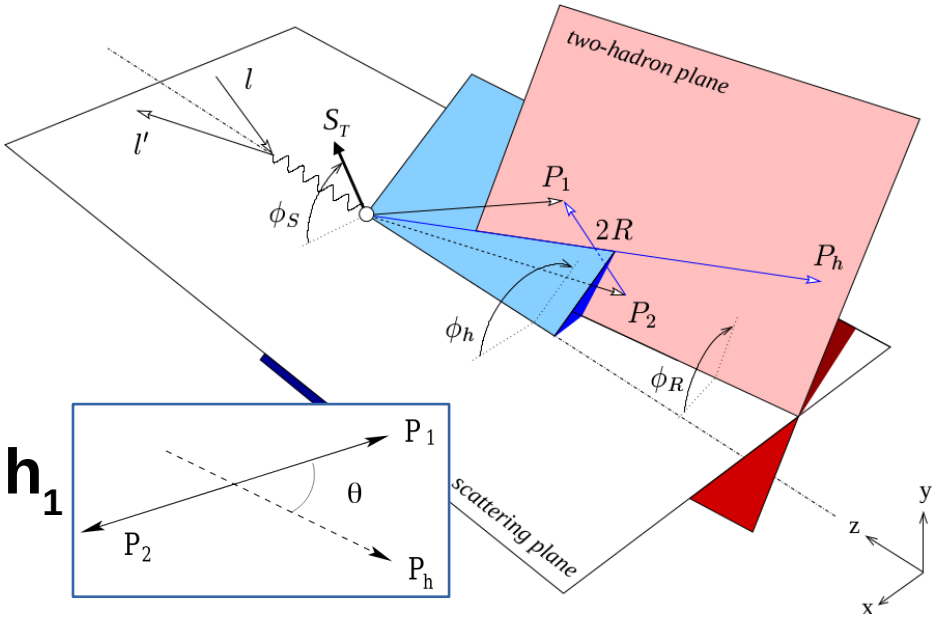
With the longitudinal target, extend the SIDIS dihadron measurements to:

– Target Spin Asymmetries

– Double Spin Asymmetries

SIDIS Dihadron Production: $e^- p \rightarrow e^- h_1 h_2 X$





- **Sensitive to *several* TMDs and Dihadron Fragmentation Functions (DiFFs)**
- **Spin-momentum correlations in hadronization**
- **Complement single-hadron SIDIS, with the advantage of another degree of freedom**

Momenta and Angles

$P_h = P_1 + P_2 \rightarrow \phi_h$

$R = \frac{1}{2}(P_1 - P_2) \rightarrow \phi_R$

Kinematic Variables:

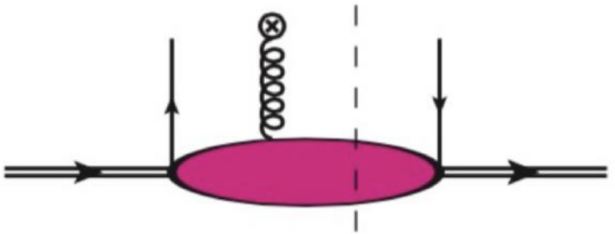
- DIS: Q^2, x, W, y
- Momenta, e.g. P_1, P_2, $P_h^{\perp}$
- Invariant Mass: M_h
- Fragmentation fraction: z
- Missing Mass: M_X
- Dihadron CoM Decay Angle: θ

Twist-3 Collinear PDFs

Collinear PDFs
– Twist-2
– Twist-3

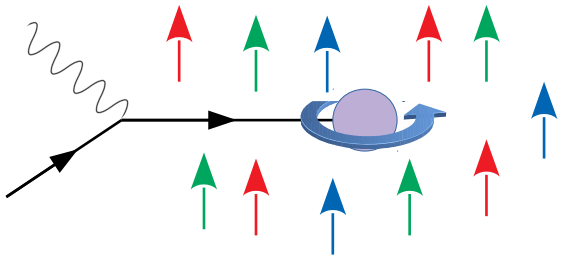
Nucleon Polarization \ Quark Polarization	U	L	T
U	f_1		e
L		g_1	h_L
T		g_T	h_1

- Twist-3 TMDs are expressible in terms of multi-parton correlators
- Fundamental to understanding TMDs in general
- Physical interpretation through *x-moments*



Beam Spin Asymmetry A_{LU}

- Ongoing measurements in Run Group A of single hadrons and dihadrons
- Physical interpretation via moments:
  - Pion-nucleon σ term: $m_q \rightarrow m_N$
  - "Boer-Mulders Force":Transverse force exerted by color field on q↑ after scattering, in an unpolarized nucleon



Target Spin Asymmetry A_{UL}

A proposed measurement for Run Group C

Twist-3 Collinear PDF $h_L(x)$

Components:

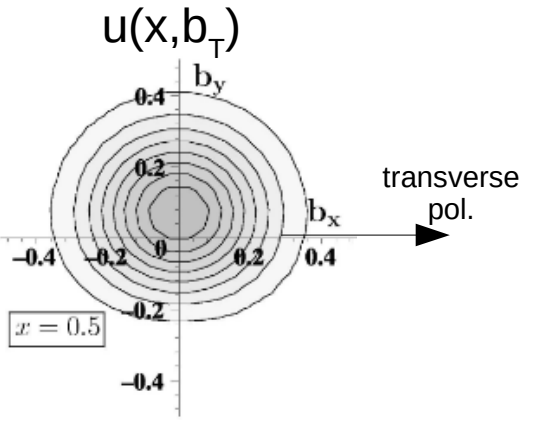
twist 2 PDFs — **pure twist 3**

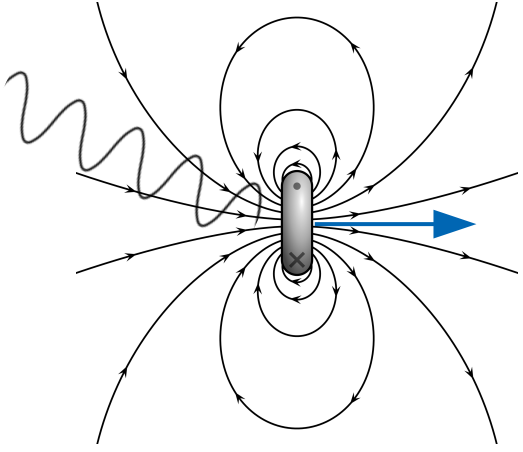
$$h_L(x) \equiv \int d^2\boldsymbol{p}_T\, h_L(x, \boldsymbol{p}_T^2) = -2\,\frac{h_{1L}^{\perp(1)}(x)}{x} + \frac{m}{M}\frac{g_1(x)}{x} + \tilde{h}_L(x)$$

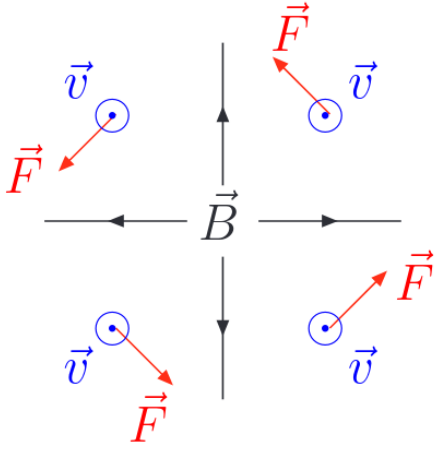
$$\int dx\, x^3$$

"Average longitudinal gradient of the transverse force that acts on transversely polarized [struck] quark"

– M. Abdallah and M. Burkardt







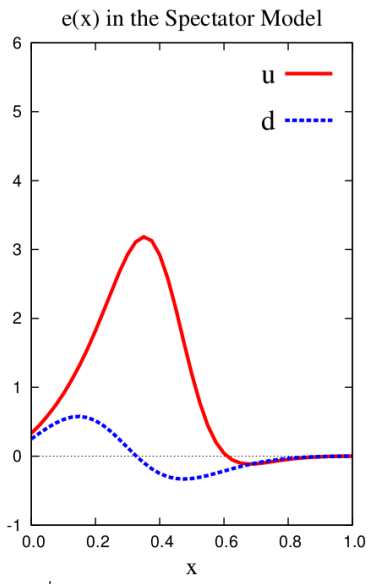
$$\mathcal{L}^q_{\rm JM} - L^q_{\rm Ji} = \Delta L^q_{\rm FSI}$$

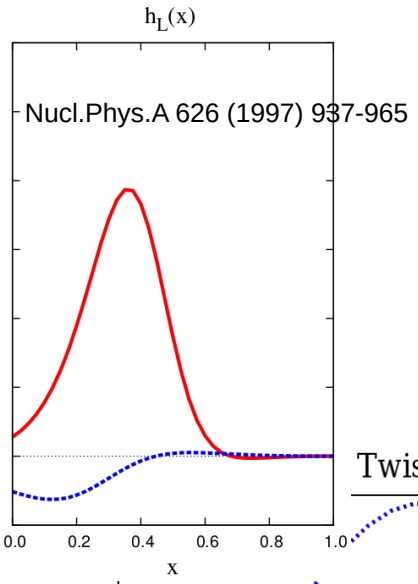
Expressible in terms of the change in quark OAM as it leaves the target

- Phys.Rev.D 94 (2016) 9, 094040
- Phys.Rev.D 66 (2002) 114005
- Nucl.Phys.B 461 (1996) 197-237

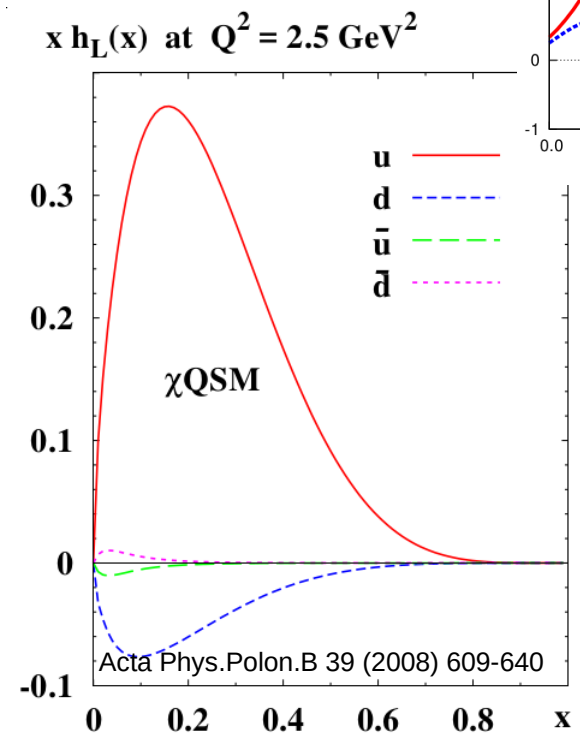
Models of $h_L(x)$

- Model predictions comparable to e(x)
- d-quark $h_L(x)$ much smaller, opposite in sign

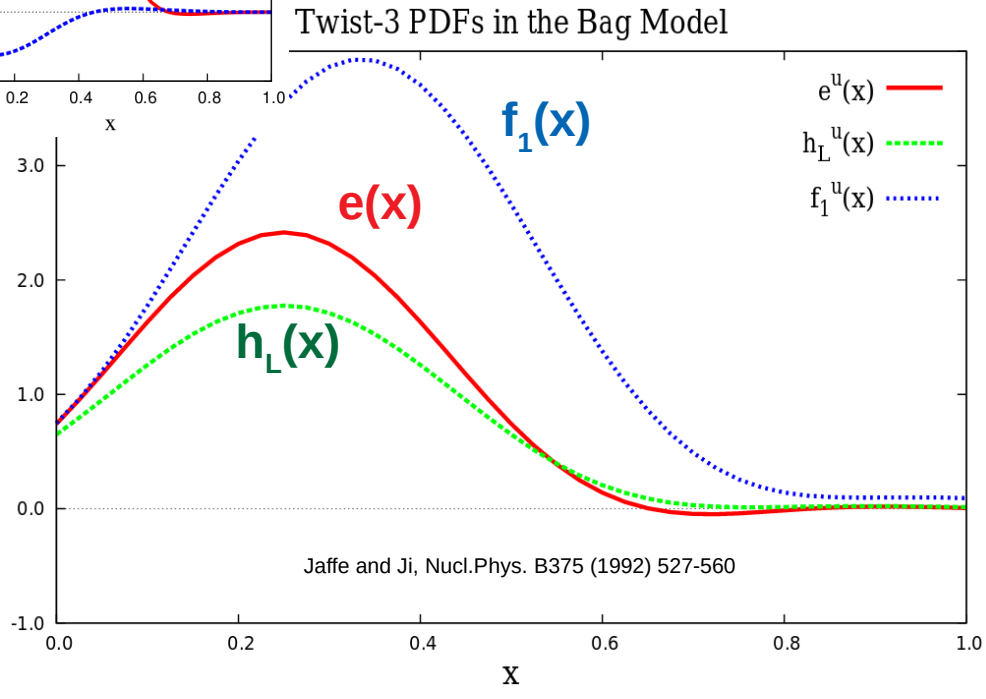




Nucl.Phys.A 626 (1997) 937-965

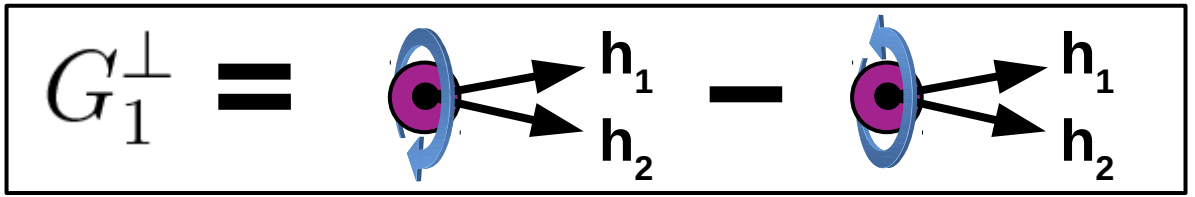


Acta Phys.Polon.B 39 (2008) 609-640



Jaffe and Ji, Nucl.Phys. B375 (1992) 527-560

Helicity Dependent DiFF: $G_1^\perp$



- **Accessible in the $\sin(\Phi_h - \Phi_R)$ modulation of dihadron A_{LU} and A_{UL}, weighted by $P_h^\perp / M_h$**

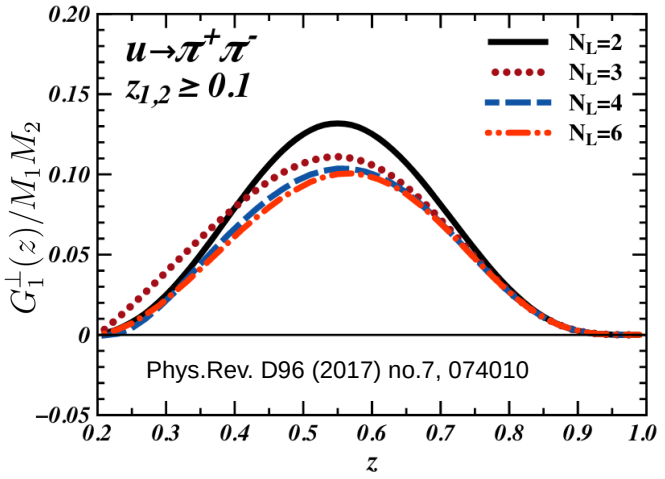
$$A_{LU}(x,y,z,M_h) = \frac{\langle P_h^\perp \sin(\phi_h - \phi_R)/M_h \rangle_{LU}}{\langle 1 \rangle_{UU}} = \lambda_l \frac{C'(y)}{A'(y)} \frac{\sum_a e_a^2 \, f_1^a(x) \, z \, G_1^{\perp a}(z,M_h^2)}{\sum_a e_a^2 \, f_1^a(x) \, D_1^a(z,M_h^2)}$$

Matevosyan, et al.
- Phys.Rev. D96 (2017) no.7, 074010
- PoS DIS2018 (2018) 150

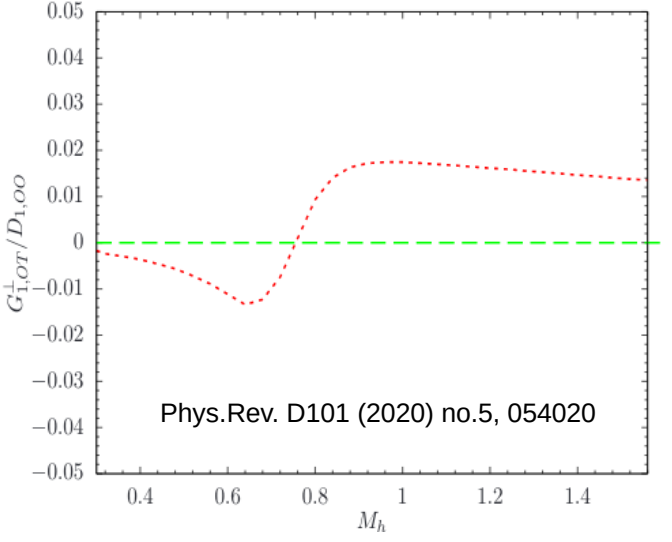
- **Sensitive to spin-orbit correlations in hadronization; no analogue in single-hadron SIDIS**
- **Not yet constrained by data; quark-jet hadronization model predicts sizable $G_1^\perp$**
- **Recent spectator model calculation predicts sign change at the ρ mass**

Luo, et al., Phys.Rev. D101 (2020) no.5, 054020

Quark-jet hadronization model prediction



Spectator Model Prediction



Double Spin Asymmetries

$$d^7\sigma_{LL} = \frac{\alpha^2}{2\pi Q^2 y}\,\lambda\, S_L \sum_a e_a^2 \left\{ C(y)\, g_1(x)\, D_1\left(z,\zeta,M_h^2\right) - W(y)\,\cos\phi_R\,\frac{|\vec{R}_T|}{Q}\left[\frac{1}{z}\, g_1(x)\,\widetilde{D}^{\sphericalangle}\left(z,\zeta,M_h^2\right) - \frac{M}{M_h}\, x\, e_L(x)\, H_1^{\sphericalangle}\left(z,\zeta,M_h^2\right)\right]\right\}$$

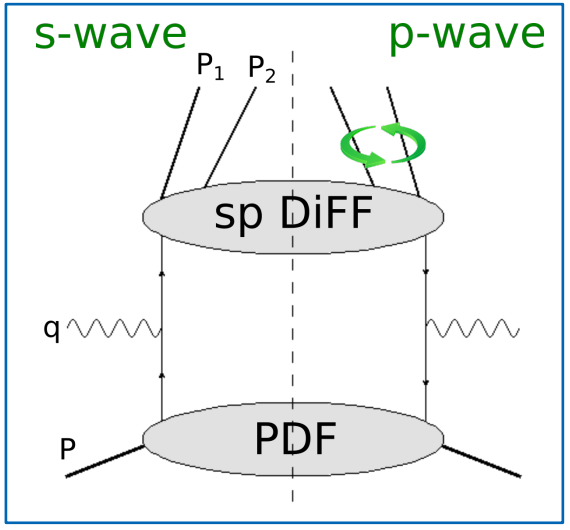
Unpolarized DiFF D_1 → Partial Waves

– Constant modulation: $D_{1,ss+pp}$

– General modulation: $P_{\ell,m}(\cos\theta)\cos[m(\phi_h-\phi_R)] \rightarrow D_1^{|\ell,m\rangle}$

– helps understand asymmetry denominators

Ongoing studies of multiplicities in RGA and RGB



N.B. Partial waves of other DiFFs are also accessible in A_{UL} (and A_{LU})

Subleading Twist Contribution

– Twist-3 DiFF $\widetilde{D}^{\sphericalangle}$

e(x) and $h_L(x)$ extractions require knowledge of $\tilde{G}^{\sphericalangle}$, another twist-3 DiFF

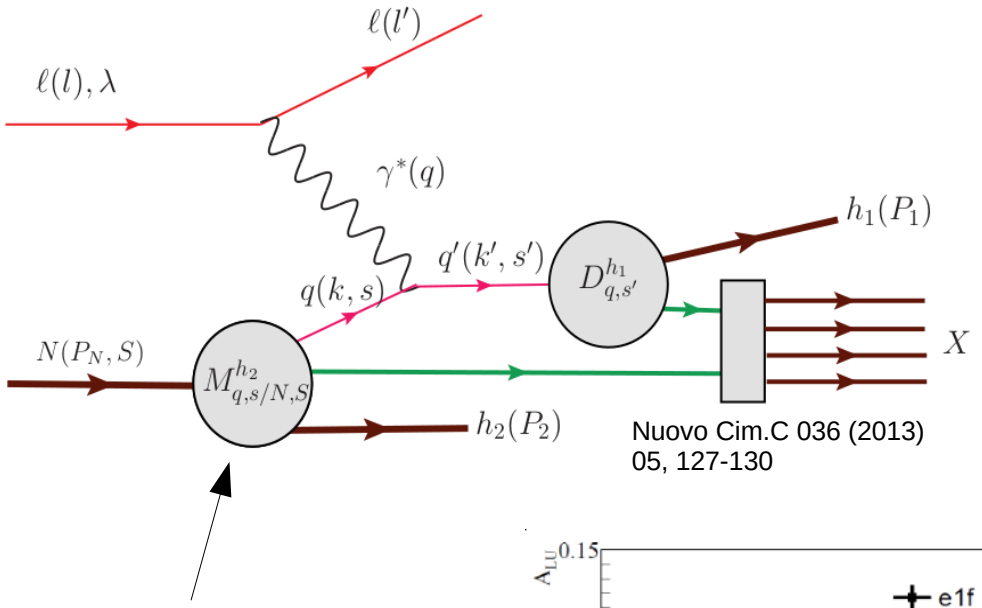
- Twist-3 DiFFs vanish in WW approximation
- Constraining $\widetilde{D}^{\sphericalangle}$ constrains $\widetilde{G}^{\sphericalangle}$
- Additional leverage from A_{LU}/A_{UL}
- A_{LL}^{const} / $A_{LL}^{\cos\phi R}$, cancels σ_{UU} denominator

– Twist-3 PDF $e_L(x)$

vanishes if T-odd behavior only from gauge link

Phys.Rev.D 69 (2004) 074026
Phys.Rev.D 90 (2014) 11, 114027

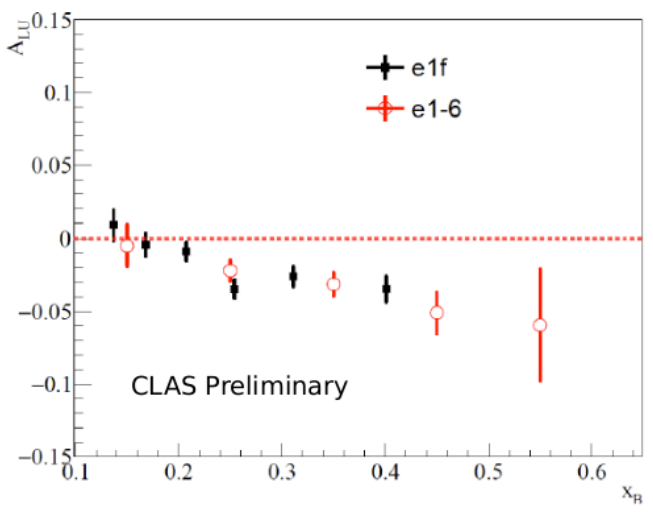
Target and Current Fragmentation



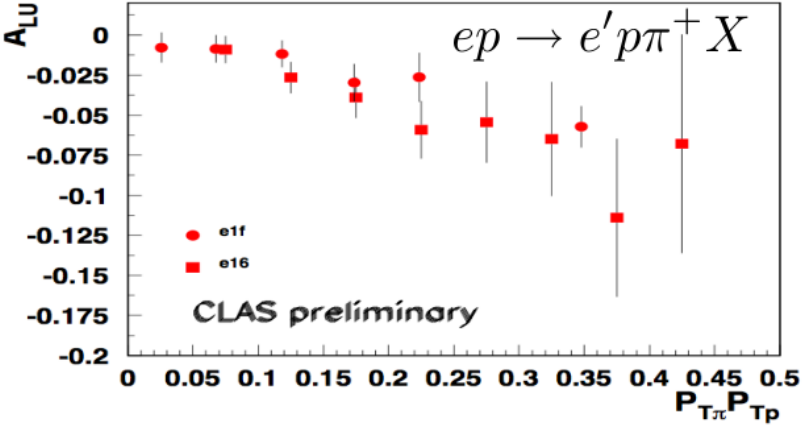
Nuovo Cim.C 036 (2013) 05, 127-130

- Fracture functions are accessible in "Double SIDIS" process:
  - One hadron in CFR
  - Other hadron in TFR
- A_{LU} only accesses one fracture function
- **A_{UL} and A_{LL} access several more**

Fracture Functions: conditional probability to produce a TFR hadron



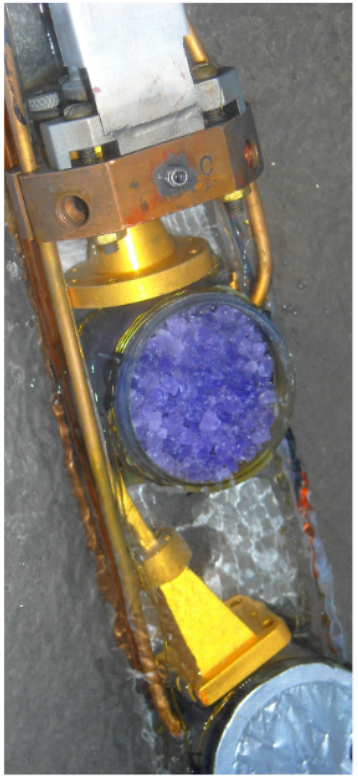
H. Avakian and S. Pisano DIS2016

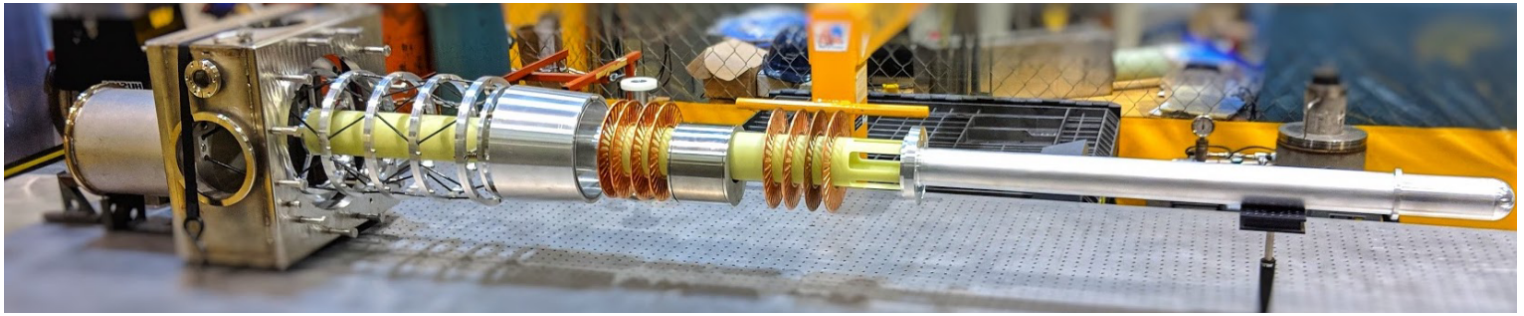


C. Dilks

Experimental Details

Target Sample





Run Group C: Longitudinally Polarized Targets

- NH_3 – polarized proton
  - ~85% polarization*

120 PAC Days

- ND_3 – polarized deuteron (neutron)
  - ~35% polarization*

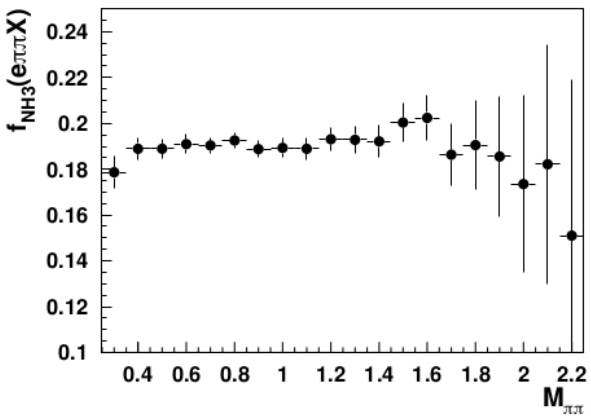
60 PAC Days

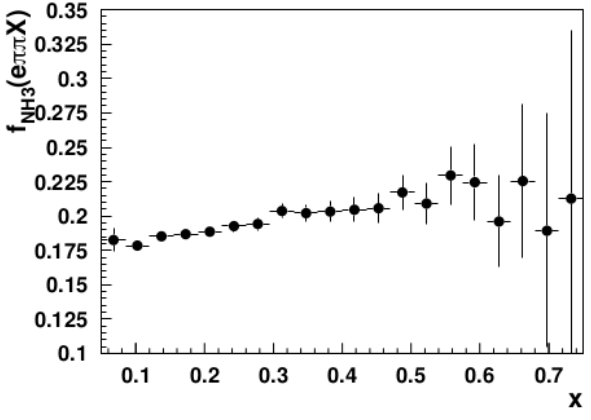
* assumed values for asymmetry projections, from design specifications

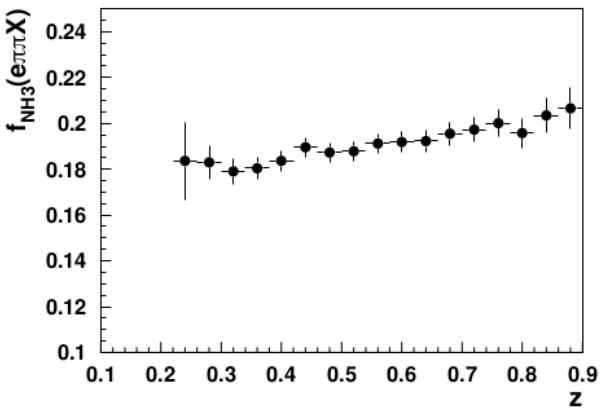
Photos from ERR presentations by S. Kuhn and C. Kieth

Dilution Factors for ππ Production

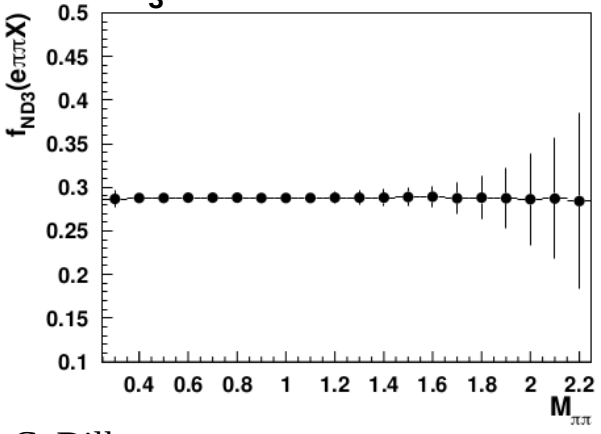
NH_3 Proton Dilution Factor

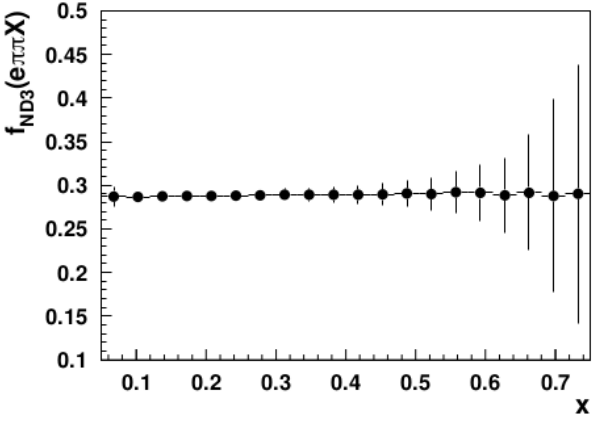


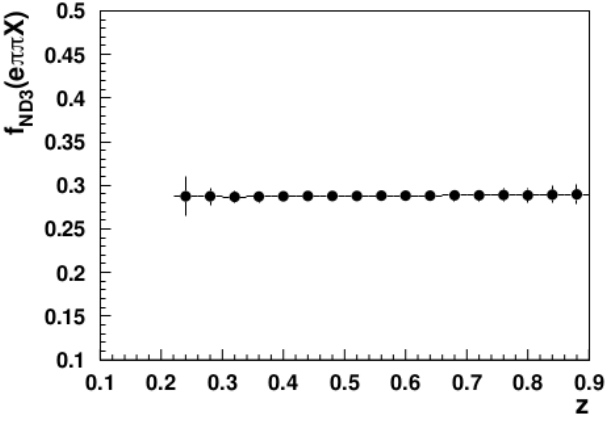




ND_3 Deuteron Dilution Factor







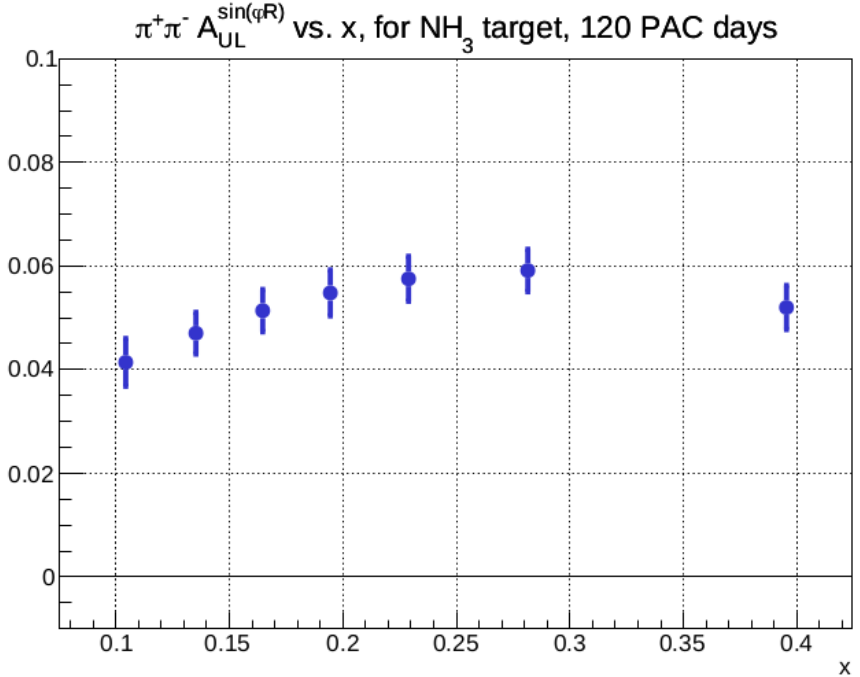
Asymmetry Projections

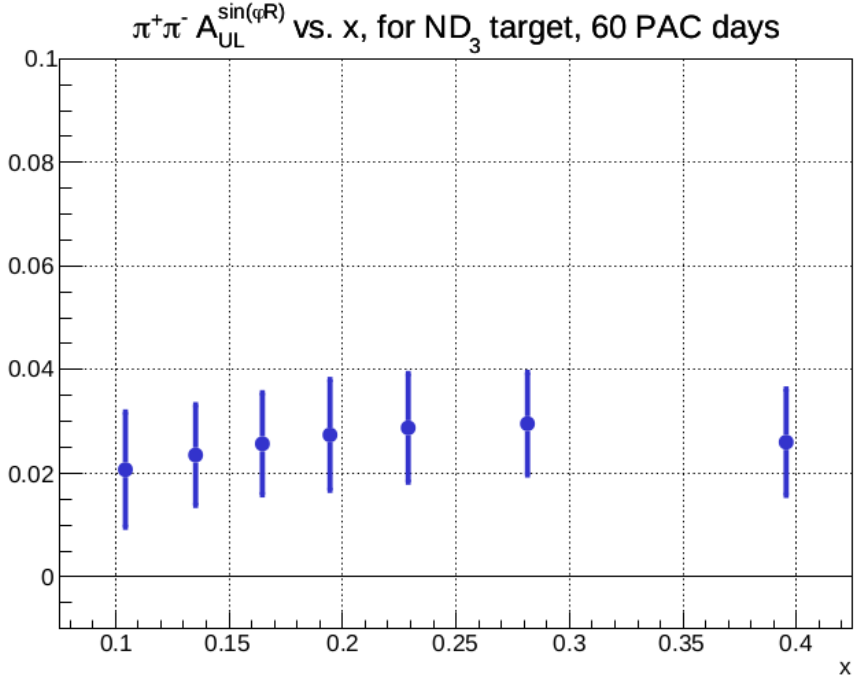
Asymmetry	Physics Goal	<K(ε,y)>
$A_{UL}^{\sin\phi_R}$	$h_L(x)$	1.3
$A_{UL}^{\sin(\phi_h-\phi_R)}$	$G_1^{\perp}$	1.0
$A_{LL}^{\cos\phi_R}$	$\tilde{D}^{\sphericalangle}$	0.7

K = kinematic depolarization factor ratio

- Projections are scaled by aforementioned polarization, dilution, and depolarization factors
- Average dihadron acquisition rate in Run Group A data: 5.1 Hz
- Extrapolate yield to PAC-approved beam time (assuming comparable luminosity)

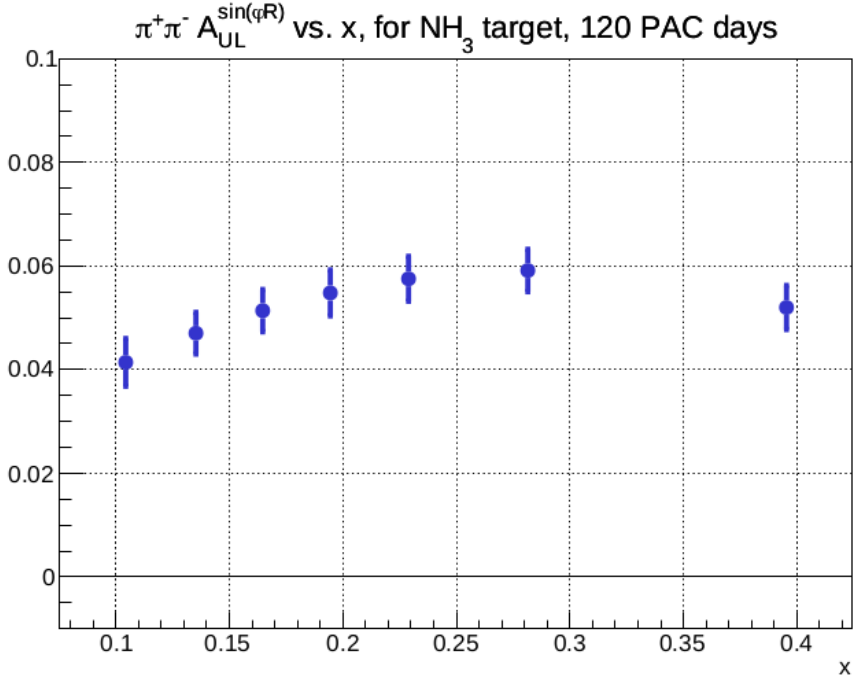
Asymmetry Projections $h_L(x)$



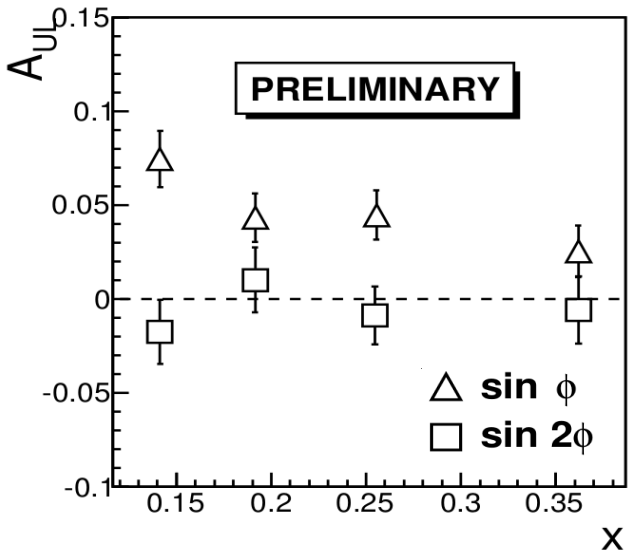


- Asymmetry plotted along polynomial curve assuming:
  - model prediction comparisons of e(x) and h_L(x)
  - similar behavior to A_{LU}, but rescaled
  - quantile binning in *x*
- Plotted A_{UL} magnitude is just a “back of the envelope” estimate; more important message is the statistical precision
  - Sufficient for a measurement of h_L(x)

Asymmetry Projections $h_L(x)$



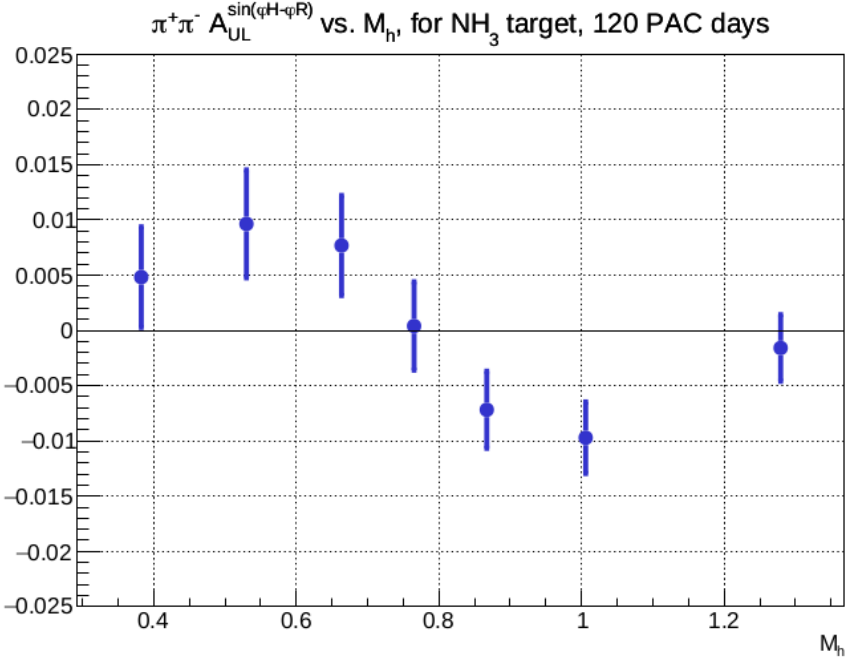
Compare to CLAS6 Measurement

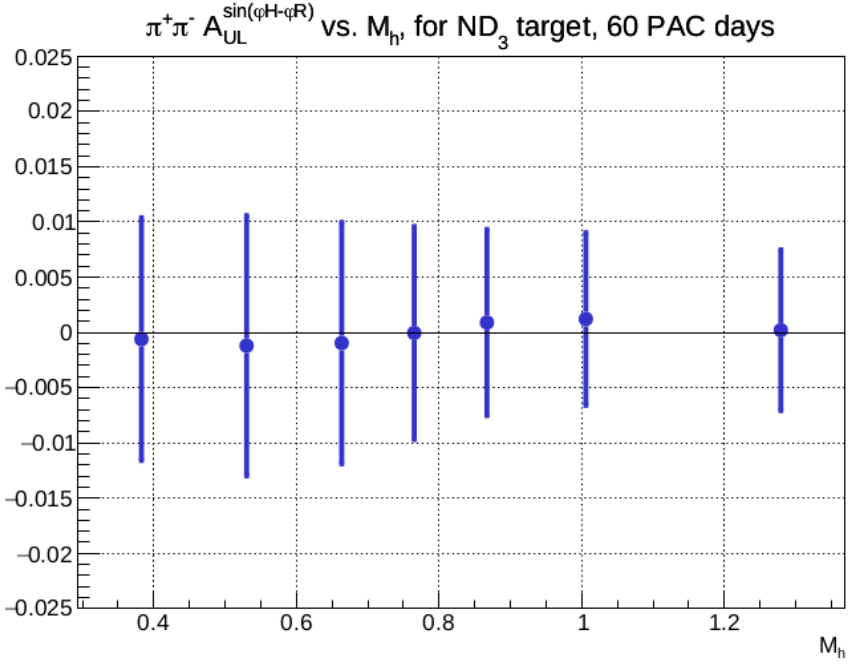


Compare projected statistical uncertainties to the CLAS6 measurements (6 GeV electrons on polarized NH_3)

Higher statistics in proposed measurement → multidimensional binning

Asymmetry Projections $G_1^\perp$

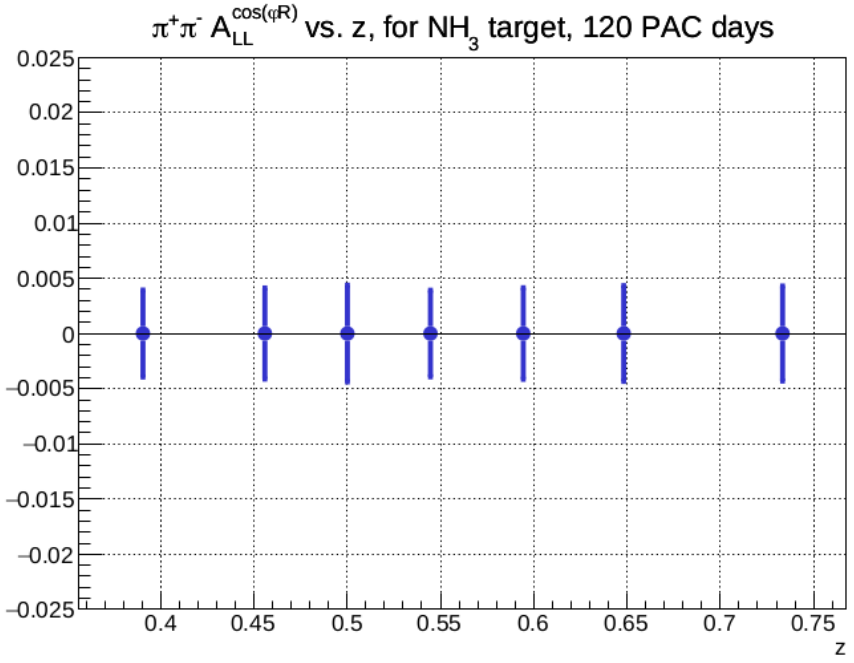


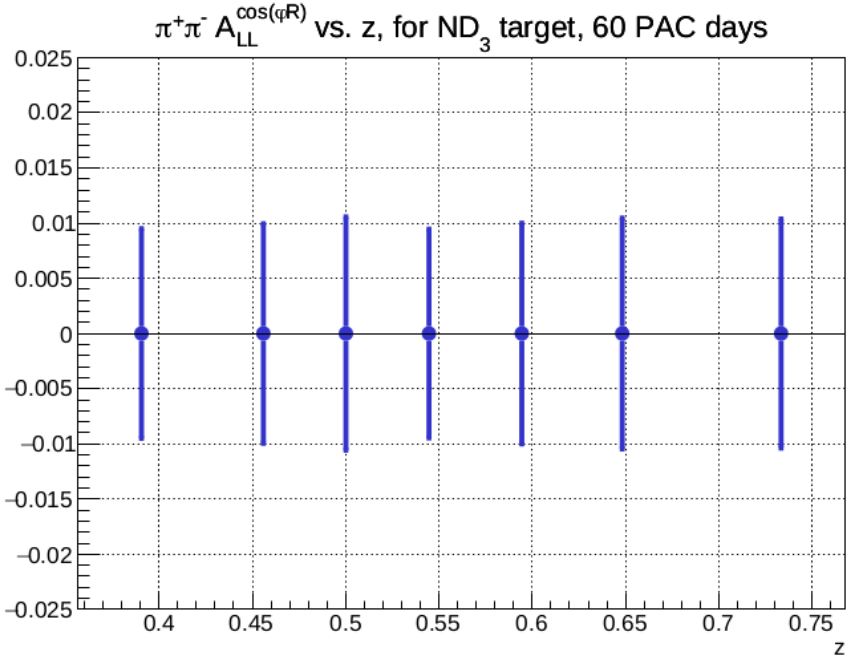


Asymmetry plotted along curve motivated by spectator model predictions (and rescaled, i.e., an estimate)

- Complement Run Group A measurements
- Asymmetry from ND_3 may be too small to see

Asymmetry Projections $\tilde{D}^{\sphericalangle}$

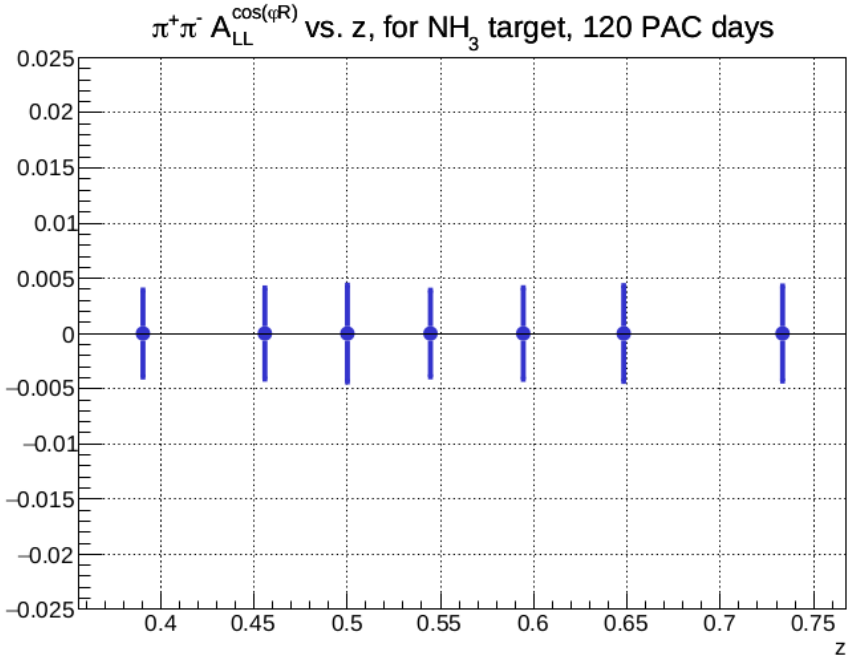




Asymmetry plotted at zero (i.e., only showing uncertainty)

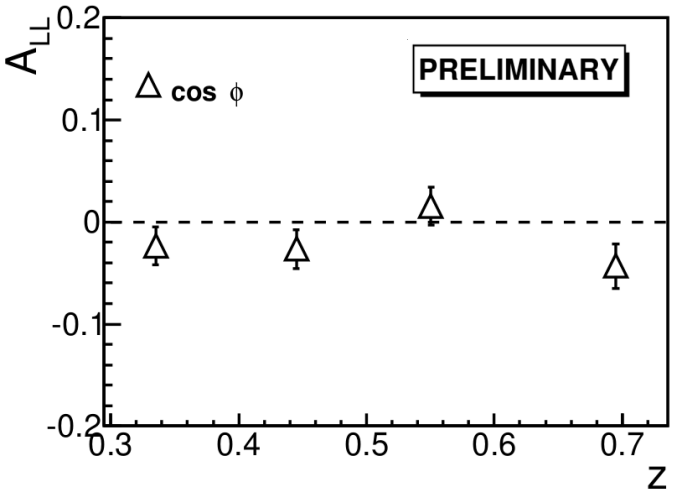
- This asymmetry is expected to be small
- This measurement will at least provide upper bounds
- Similar statistical precision expected in partial wave analysis
  - These amplitudes might be rather significant…

Asymmetry Projections

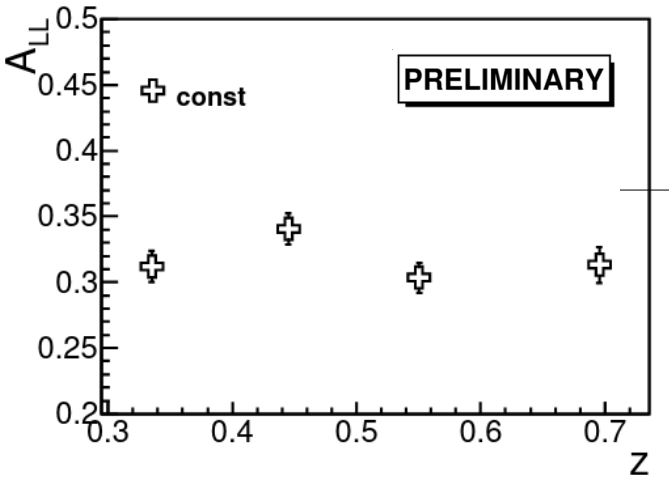


Compare projected statistical uncertainties to the CLAS6 measurements (6 GeV electrons on polarized NH_3)

Compare to CLAS6 Measurement



$\rightarrow \tilde{D}^{\sphericalangle}$



$\rightarrow \frac{g_1 D_{1,ss+pp}}{f_1 D_{1,ss+pp}}$

Summary

- Dihadrons in SIDIS provide access to several parton distribution functions and dihadron fragmentation functions, at leading and subleading twist
- **Beam spin asymmetries** in Run Group A show **significant effects**, sensitive to the twist-3 PDF **e(x)** and the helicity-dependent DiFF $\mathbf{G_1^\perp}$
- Longitudinally polarized target in **Run Group C** allows for the extension of this program to **target spin asymmetries** and **double spin asymmetries**
  - Sensitivity to twist-3 PDF $\mathbf{h_L(x)}$ → final state quark OAM effects
  - Complementary measurement sensitive to $\mathbf{G_1^\perp}$
  - Unpolarized DiFF $\mathbf{D_1}$ partial waves
  - Leverage on twist-3 DiFFs → important for e(x) and $h_L(x)$ extractions
  - Fracture functions
- Approved Run Group C PAC time is sufficient to resolve significant asymmetries, especially those sensitive to $h_L(x)$