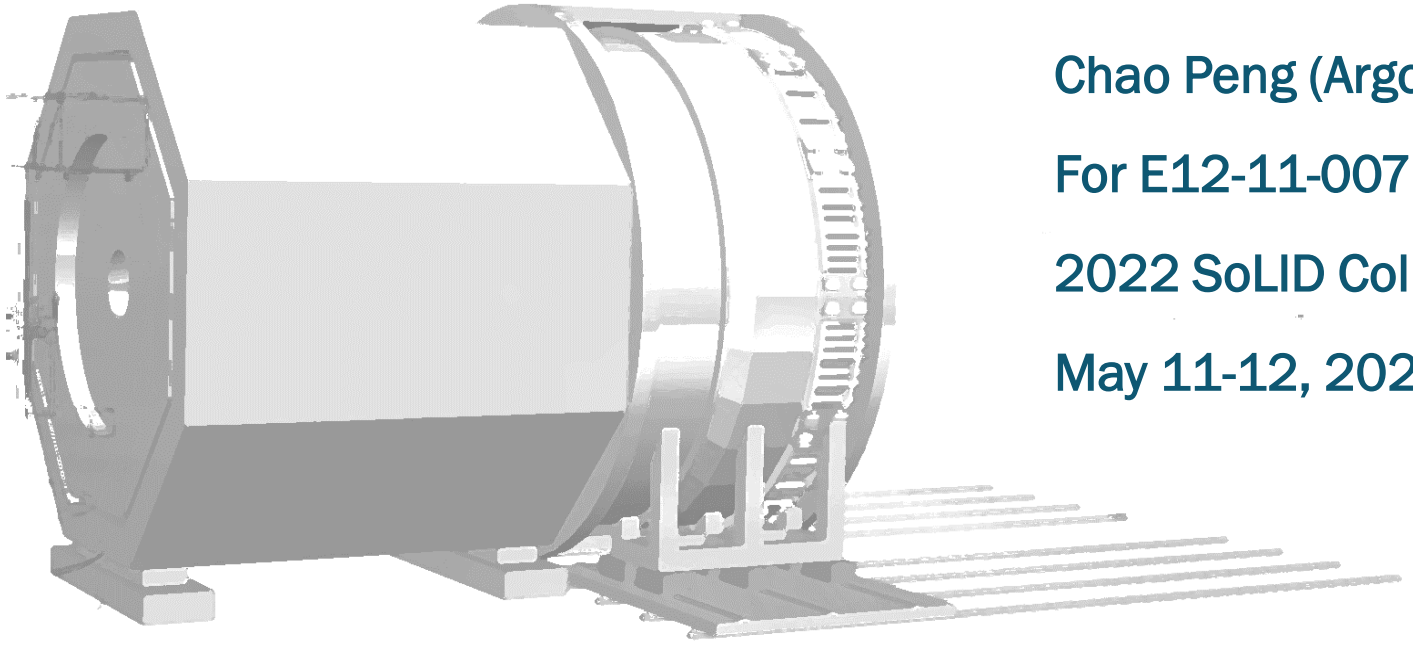
E12-11-007: SoLID-SIDIS with a Longitudinally Polarized ^{3}He Target



Chao Peng (Argonne National Laboratory)

For E12-11-007 and SoLID Collaborations

2022 SoLID Collaboration Meeting

May 11-12, 2022

Overview of E12-11-007

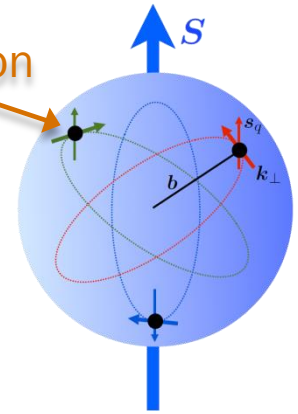
- SoLID SIDIS program: Azimuthal Asymmetries (SSA and DSAs) from SIDIS $\pi^{\pm}$
  - Longitudinally polarized ^{3}He target
  - Combined with DSA (A_{LT}) from E12-10-006
  - Access to helicity g_{1L} and "worm-gear" functions $g_{1T}, h_{1L}^{\perp}$
  - Study quark spin-orbit correlations

- Approved by PAC37
  - 35 PAC days of 11 GeV and 8.5 GeV beam at 15 μA
  - Match 50% statistics of the SSA measurements from E12-10-006
  - Precise 4D mapping of A_{UL}, A_{LT}, and A_{LL} for neutron

- Jeopardy process at PAC50

Leading Twist TMD PDFs

$L \neq^{?} 0 \rightarrow$ Transverse motion



- TMD PDFs link the intrinsic motion of partons with quark spin and nucleon spin
  - Probes orbital motion of quarks
  - Access to all leading twist terms through SIDIS differential cross sections

Nucleon Polarization	Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	f_1 =		$h_1^{\perp}$ = Boer-Mulders
L		g_1 = Helicity	$h_{1L}^{\perp}$ = Worm Gear (Kotzinian-Mulders)
T	$f_{1T}^{\perp}$ = Sivers	g_{1T} = Worm Gear	h_1 = Transversity; $h_{1T}^{\perp}$ = Pretzelosity

→ quark spin → nucleon spin

E12-11-007:

Single Spin Asymmetry and Double Spin Asymmetries:

$A_{UL}^{sin2\phi_h} \propto h_{1L}^{\perp} \otimes H_1^{\perp}$

$A_{LT}^{\cos(\phi_h - \phi_S)} \propto g_{1T} \otimes D_1$

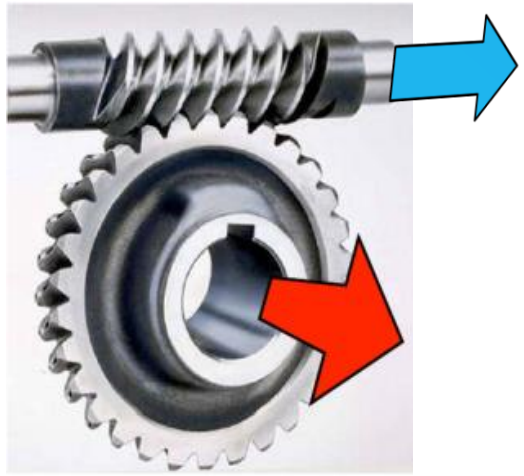
$A_{LL} \propto g_{1L} \otimes D_1$

Large acceptance, high statistics, and precision measurement with SoLID is essential for angular modulation separation and 4D mapping

“Worm-gear” Functions

$h_{1L}^{\perp}$ = –

g_{1T} = –



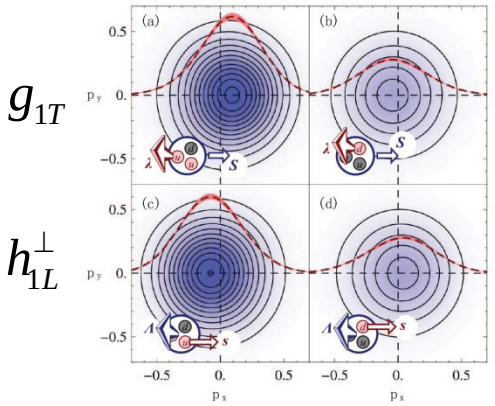
Worm Gear

- Dominated by interference between wave function components that differ by one unit of quark OAM
  - $\mathrm{Re}[(L=0)_q \times (L=1)_q]$
  - Complementary information about imaginary part from Boer-Mulders effects and Sivers effects

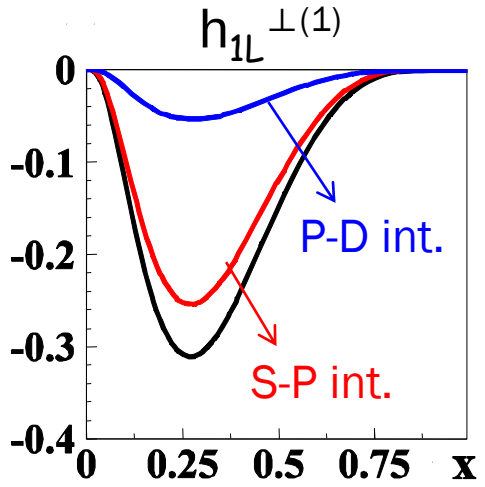
- A genuine sign of intrinsic transverse motion
  - No analogous terms in GPD
  - No dynamical generation by FSI from coordinate space densities

Test of Theoretical Predictions

- Various theoretical predictions available
  - Lattice QCD calculations
  - Quark models
- $h_{1L}^{\perp} = -g_{1T}$?
  - Cylindrical symmetry around y direction
  - Valid in many quark models
  - Favored by Lattice QCD calculations
- WW & WW-type approximations
  - Assume “pure twist-3” and quark mass terms are small
  - Indirect information on transversity



Lattice QCD, arXiv:0908.1283



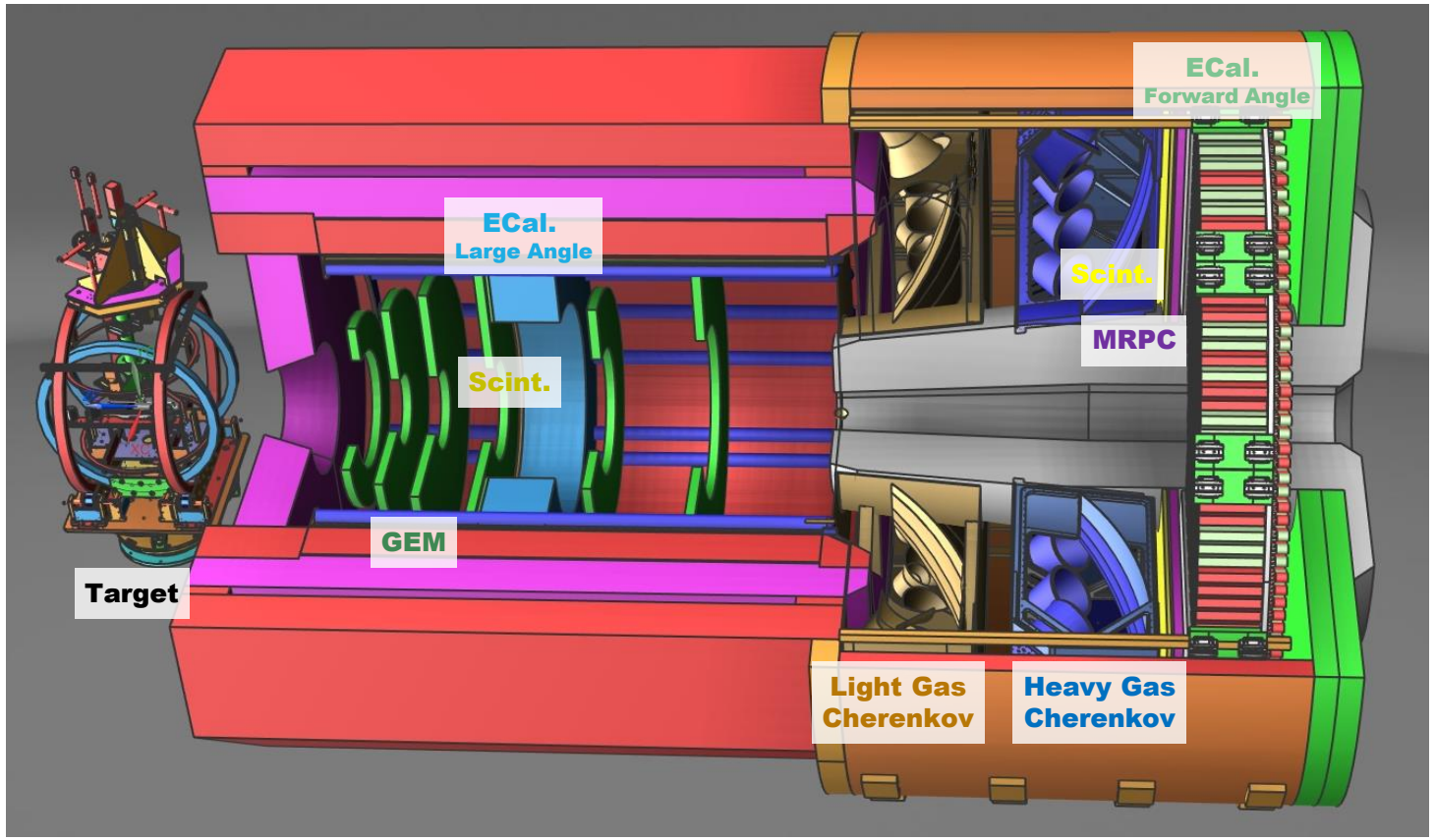
Light-Cone CQM
B. Pasquini B.P., Cazzaniga, Boffi, RD78, 2008

$$h_{1L}^{\perp q(1)}(x) \overset{WW-type}{\approx} -x^2 \int_x^1 \frac{dy}{y^2} h_1^q(y)$$

$$g_{1T}^{q(1)}(x) \overset{WW-type}{\approx} x \int_x^1 \frac{dy}{y} g_1^q(y)$$

Experimental Setup

- SoLID-SIDIS & J/ψ configuration
- Longitudinally polarized ^{3}He Target
- Full 2π coverage of polar angle from 8°-24°
  - $8° < \theta < 14.8°, 1 < P < 7$ GeV/c
  - $16° < \theta < 24°, 3.5 < P < 7$ GeV/c (electron)
  - $\delta p/p \sim 2\%, \delta\theta \sim 0.6\ mrad, \delta\phi \sim 5\ mrad$
- High luminosity, high data rate



Experimental Observables

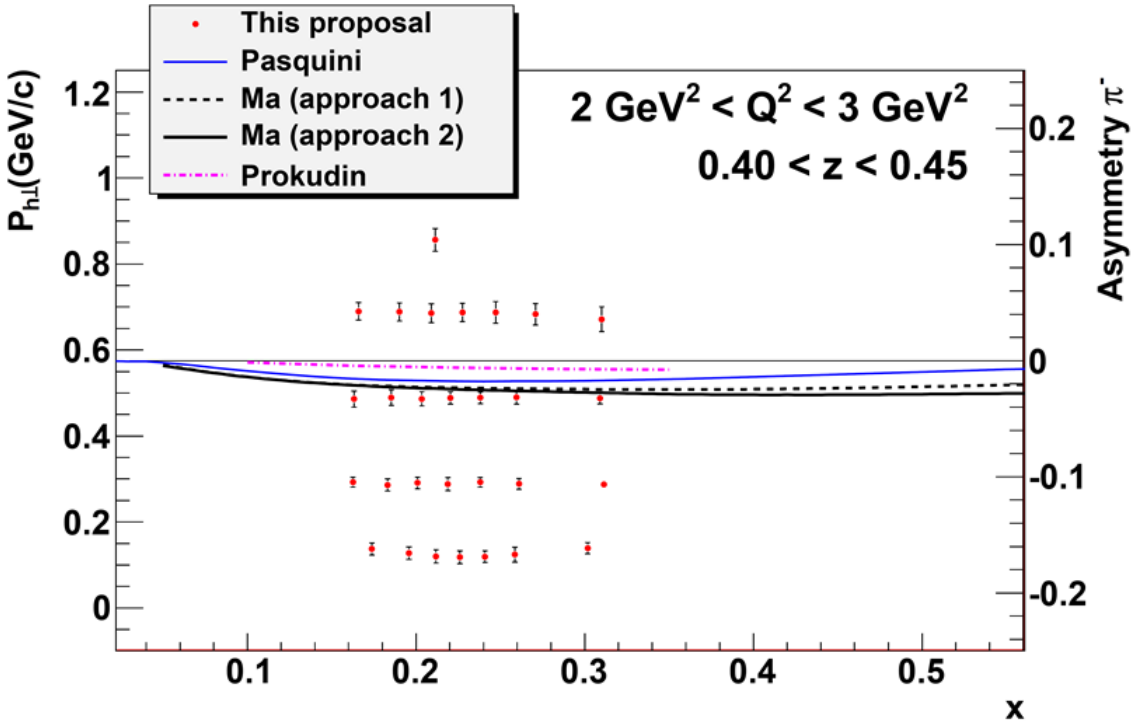
- One SSA and two DSAs: A_{UL}, A_{LT}, and A_{LL}
  - Share commissioning and A_{LT} data with E12-10-006

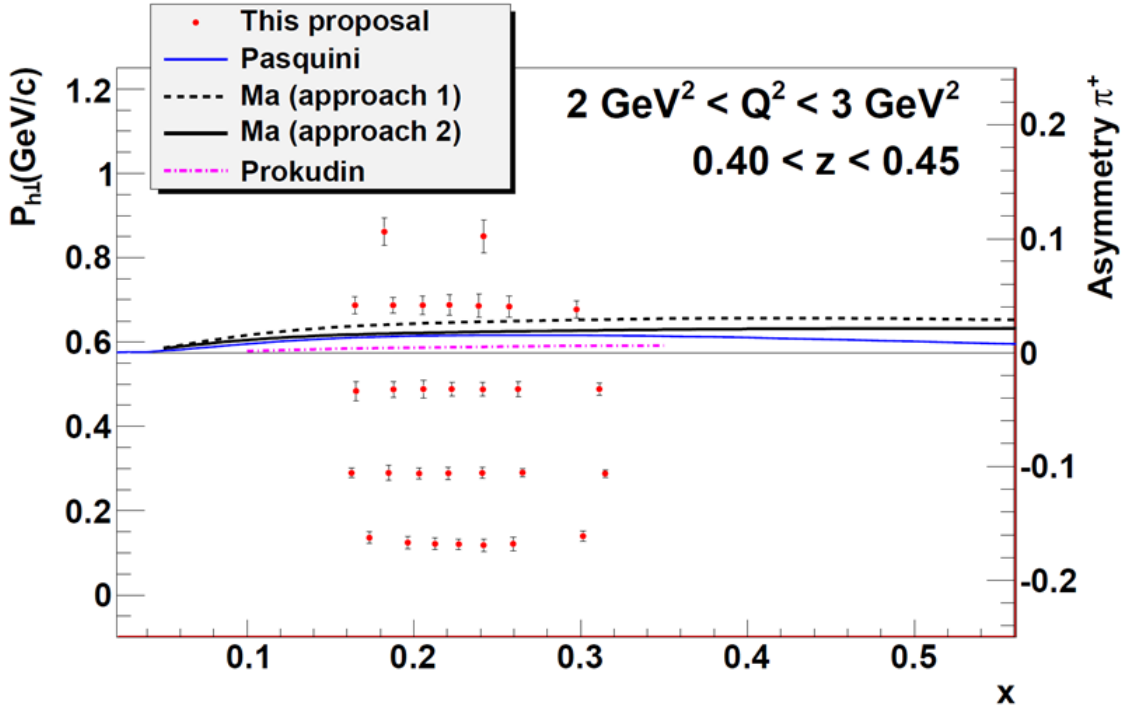
- 35 PAC days
  - 11 and 8.8 GeV beam at 15 uA
  - High beam polarization (85%)
  - High polarized luminosity 10^{36} $cm^{-2}s^{-1}$

- High statistics and well controlled systematic uncertainty
  - Precise 4D mapping with 1000-1400 bins for each asymmetry and charged pion
  - Neutron Asymmetries: $\delta A_{stat.} \approx 0.5\%$
  - Expected systematics $\delta A_{sys.}/A \approx 7\%$ with the large symmetric acceptance from SoLID

Projections: A_{UL}

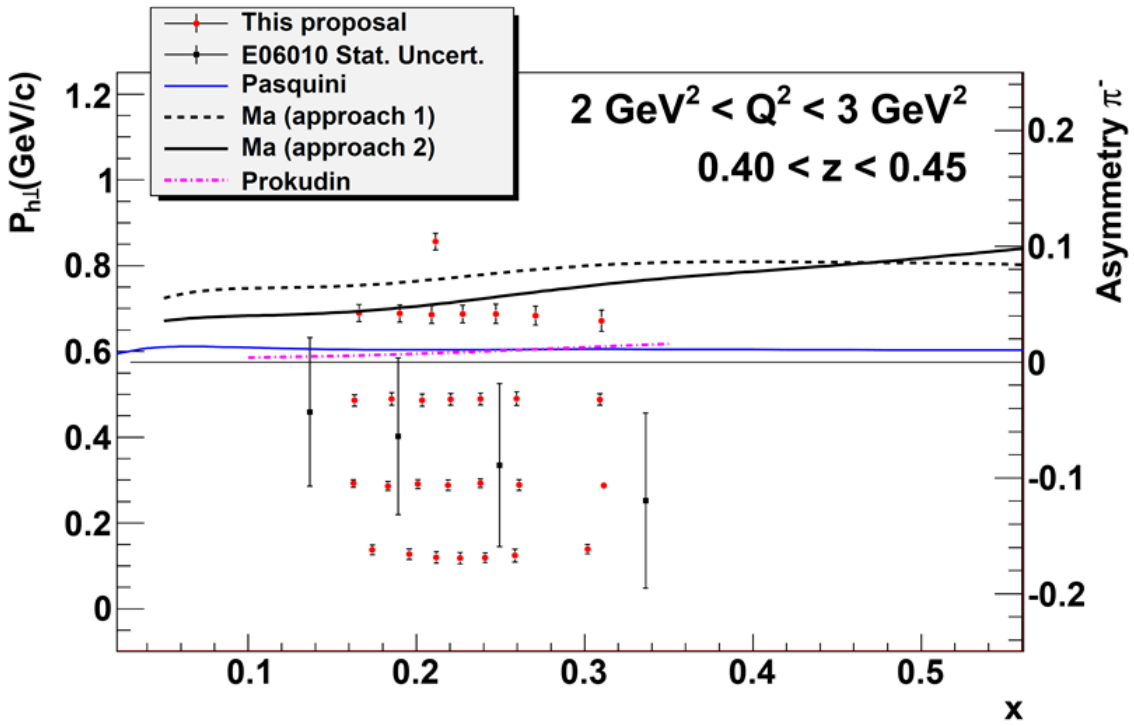
1 of 48 Z-Q^2 bins for the asymmetry of π^- and π^+

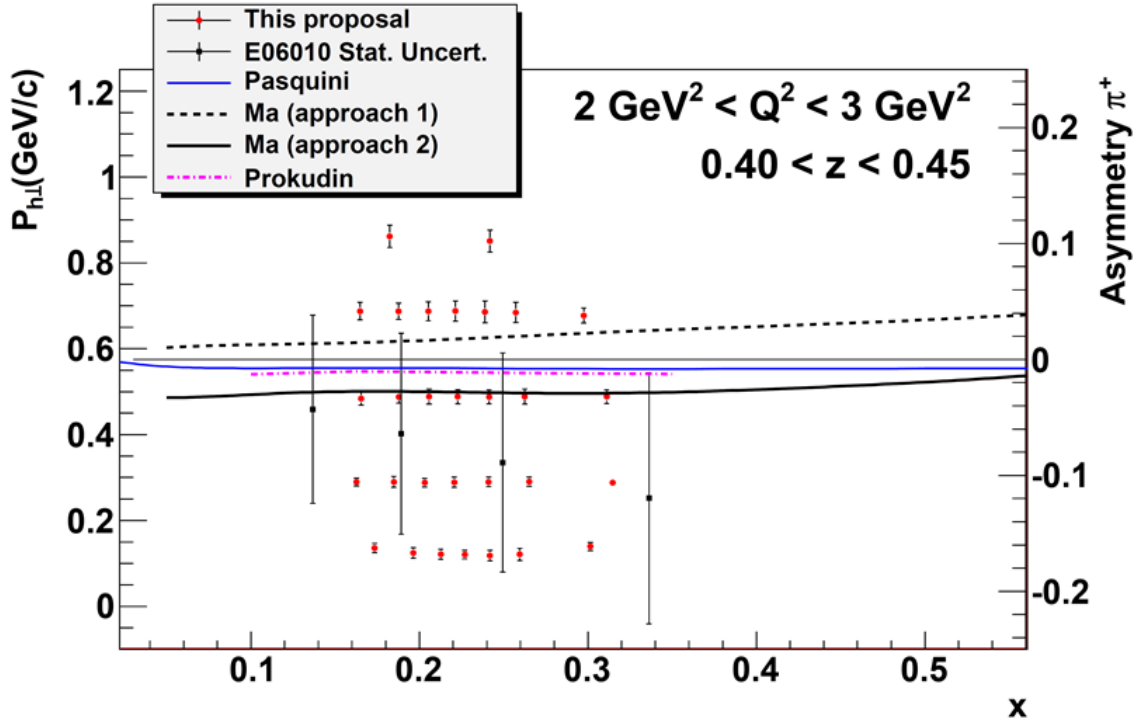




Projections: A_{LT}

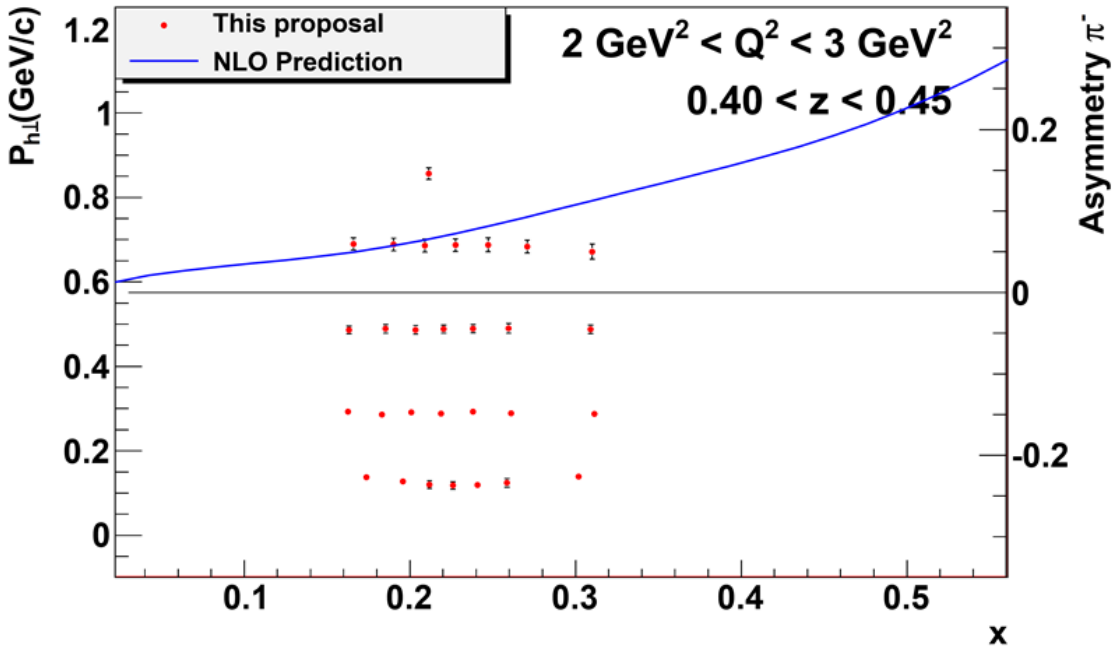
1 of 48 Z-Q^2 bins for the asymmetry of π^- and π^+

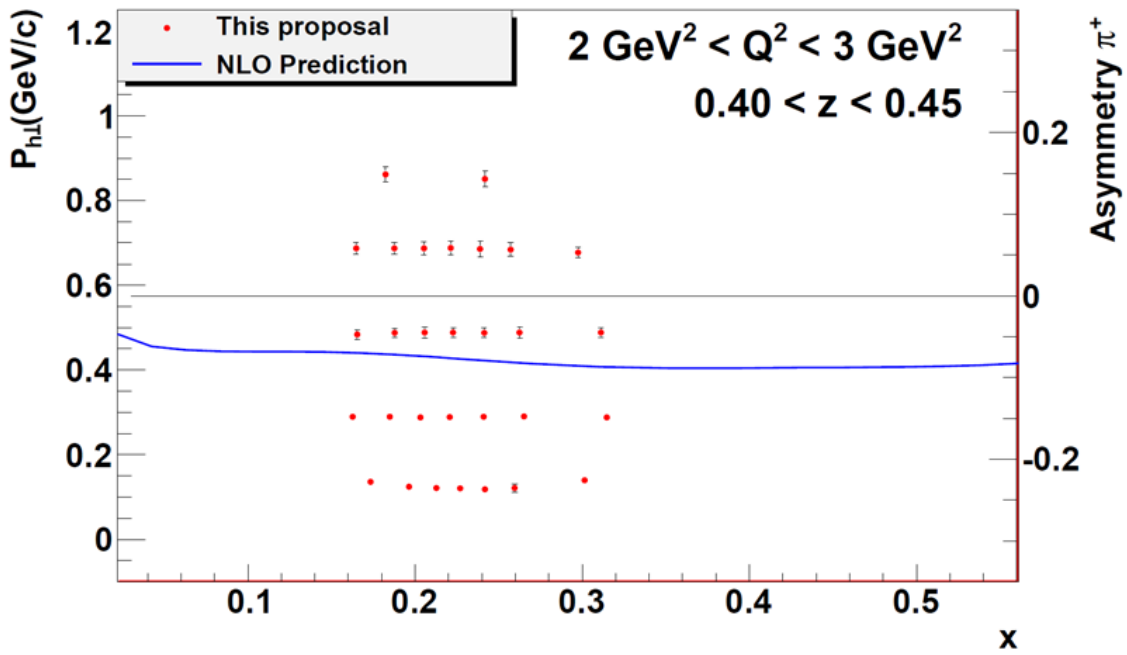




Projections: A_{LL}

1 of 48 Z-Q^2 bins for the asymmetry of π^- and π^+



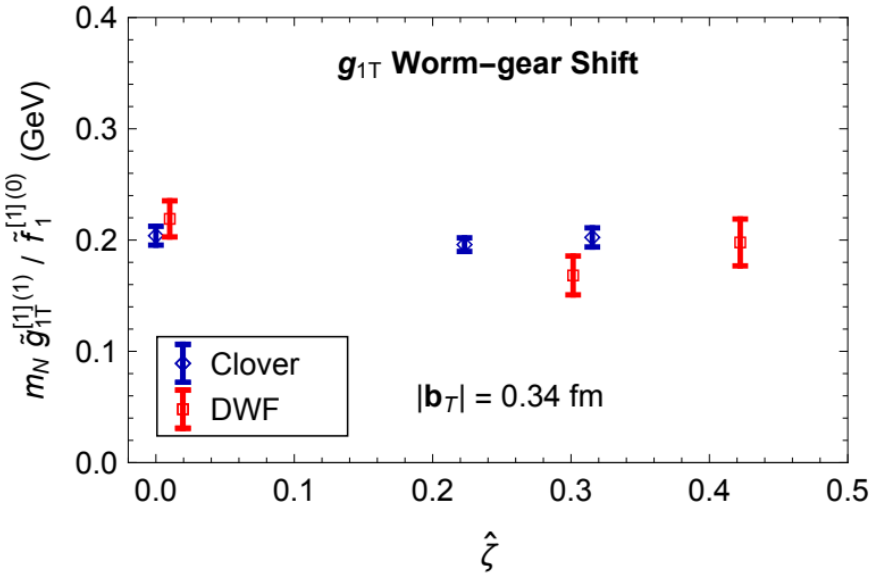


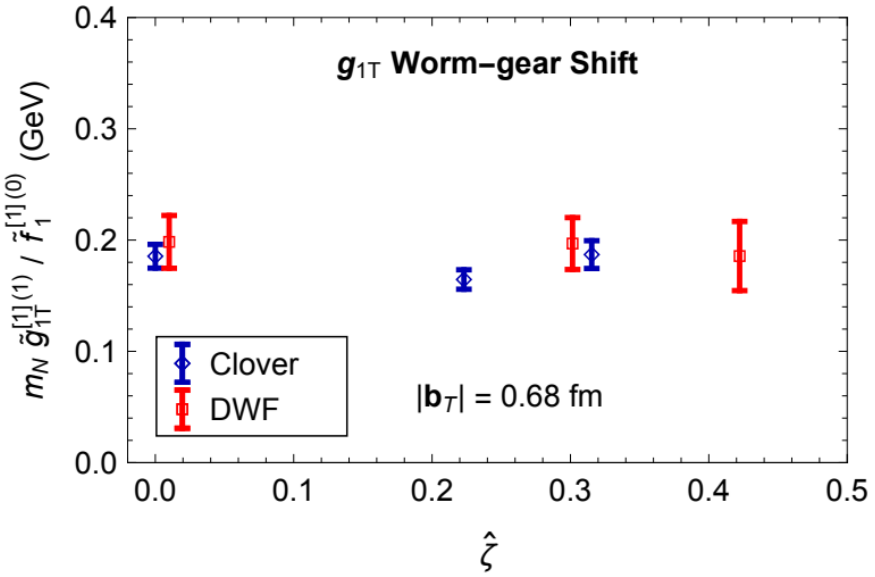
Lattice Calculation on Worm-gear Shift

- Lattice calculations on worm-gear shift

$$[\langle k_x \rangle_{TL}](Q^2) \sim \frac{\int_0^1 dx \left[g_{1T}^u(x,Q^2) - g_{1T}^d(x,Q^2)\right]}{\int_0^1 dx \left[f_1^u(x,Q^2) - f_1^d(x,Q^2)\right]}$$

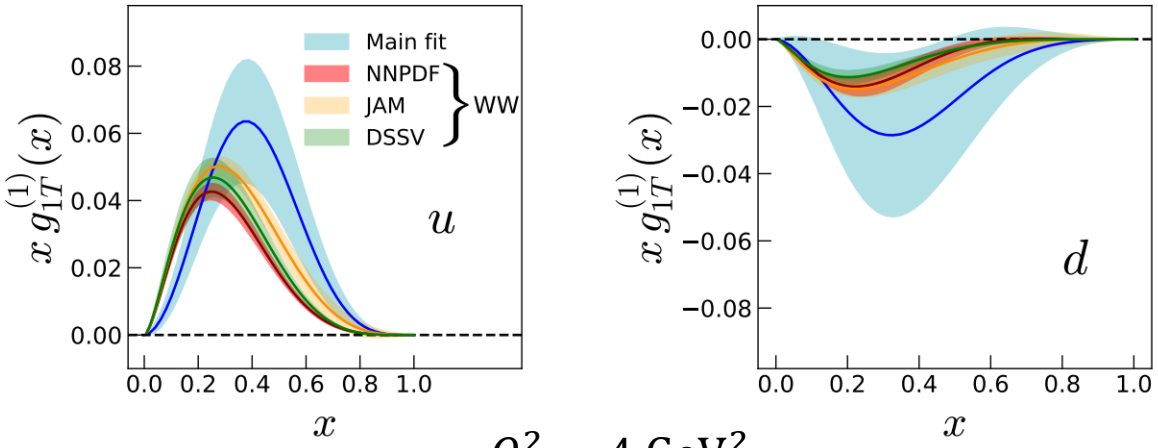
  - Yoon B. et al., Phys. Rev. D96, 094508 (2017)
  - Consistent results from two discretization schemes at quark separation $b_T > 0.3$

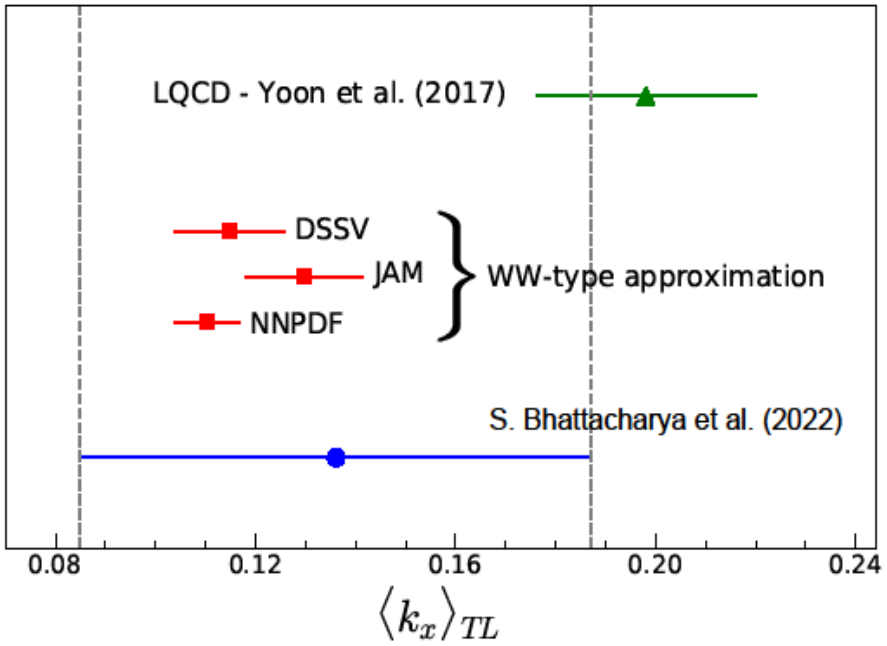




First Global Extraction of Worm-gear Function g_{1T}

- S. Bhattacharya et al., Phys. Rev. D105, 034007 (2022)
  - COMPASS, HERMES, and JLab 6 GeV data
  - Working with the authors for SoLID projections





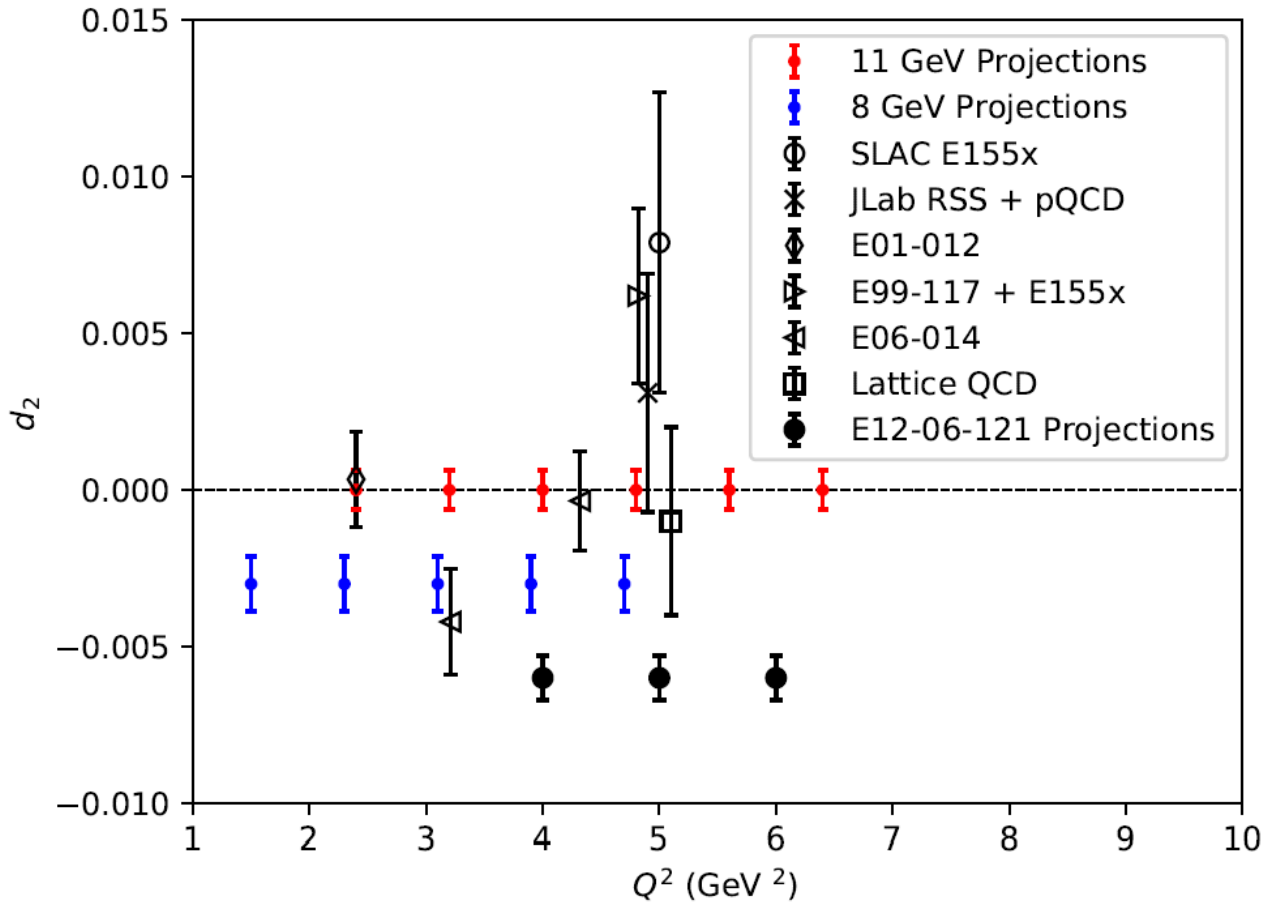
Run Group Proposal: g_2^n/d_2^n measurement

E12-11-007A/E12-10-006E, Approved in 2020. Spokesperson: T. Ye and C. Peng

- A run group proposal with E12-11-007 and E12-10-006
- Measurement of g_2^n with $1.5 < Q^2 < 10$ GeV^2 and $x > 0.1$
- Extraction of x^2 moment of $\bar{g}_2^n$

$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$

  - $1.5 < Q^2 < 6.5$ GeV^2
  - Access to twist-3 contributions
  - Carry information about quark-gluon correlations



Summary

- E12-11-007 requires 35 PAC days of 11 GeV and 8.8 GeV beam at 15 uA
  - Longitudinally polarized ^{3}He Target
  - Same setup with E12-10-006 using SoLID

- Impact on TMDs
  - $A_{UL} \rightarrow h_{1L}$
  - $A_{LT} \rightarrow g_{1T}$ } "worm-gear" distribution, Re[$(L=0)_q \times (L=1)_q$]
  - $A_{LL} \rightarrow g_{1L}$
  - 3D structure of nucleon and OAM-spin correlations
  - Test LQCD calculations and model predictions