E12-11-007

Asymmetries in SIDIS (e, e'$\pi^{\pm}$) on a Long. Pol. ^{3}He Target

For SoLID Collaboration Meeting

Spokespersons

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Overview

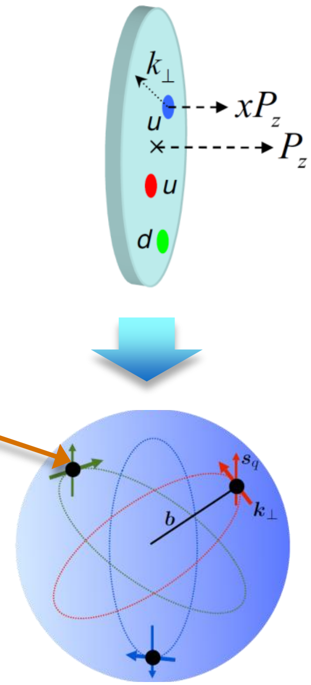
- Azimuthal Asym. in SIDIS $\pi^{\pm}$ production
  - longitudinally polarized ^3He target
  - SoLID spectrometer (Same setup as E12-10-006)
  - High precision, Multi-dimensional mapping of A_{UL}, A_{LT} , A_{LL} for neutron
- To study
  - Quark spin-orbit correlations through "worm-gear" TMD PDFs
- Beam requests
  - 35 PAC days of 11GeV and 8.8GeV Beam, 15uA
  - Beam pol. = 85%, same for E12-10-006

Transverse Momentum Dependent (TMD) Parton Distributions

- TMD PDFs link
  - Intrinsic motion of partons
  - Parton spin
  - Spin of the nucleon
- Multi-Dimension structure
  - Probes orbital motion of quarks
- A new phase of study, fast developing field
  - Great advance in theories (factorization, models, Lattice
  - Not sys. studied until recent years
    - Semi-Inclusive DIS (SIDIS): HERMES, COMPASS, Jlab-6GeV, ...
    - p-p(p_bar) process : FNAL, BNL, ...

in DIS
Nucleon -> Plate

L $\neq^{?}$ 0
→Transverse motion



Leading-Twist TMD PDFs

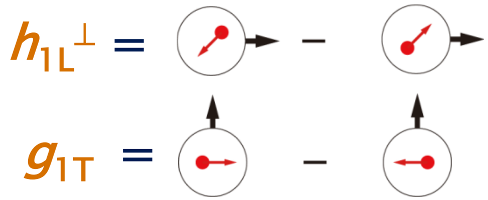
Nucleon Spin

Quark Spin

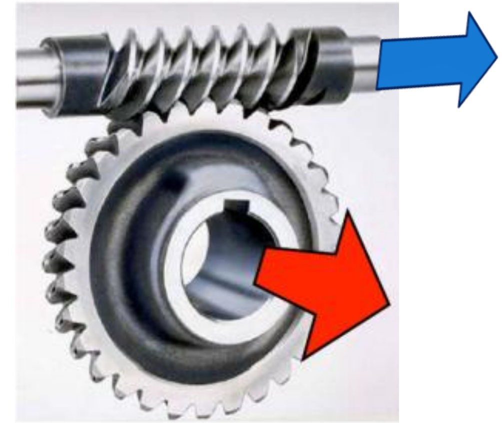
Nucleon Polarization		Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
	U	$f_1 =$		$h_1^{\perp} =$ − Boer-Mulders
	L		$g_1 =$ − Helicity	$h_{1L}^{\perp} =$ − Worm Gear (Kotzinian-Mulders)
	T	$f_{1T}^{\perp} =$ − Sivers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

: This proposal, T-even

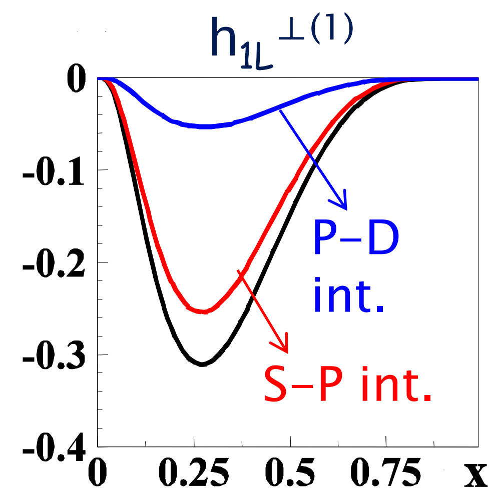
"Worm-Gear" Functions



- Leading twist TMD PDFs
- Dominated by real part of interference between L=0 (S) and L=1 (P) states
  - Imaginary part -> Boer-Mulders effect, Sivers effect
- No GPD correspondence
  - a genuine sign of intrinsic transverse motion



Worm Gear



Light-Cone CQM by B. Pasquini
B.P., Cazzaniga, Boffi, PRD78, 2008

Lattice Calculations

- So far using simplified straight gauge links
- "Worm-gear" TMDs → dipole shift @ Trans Mom.

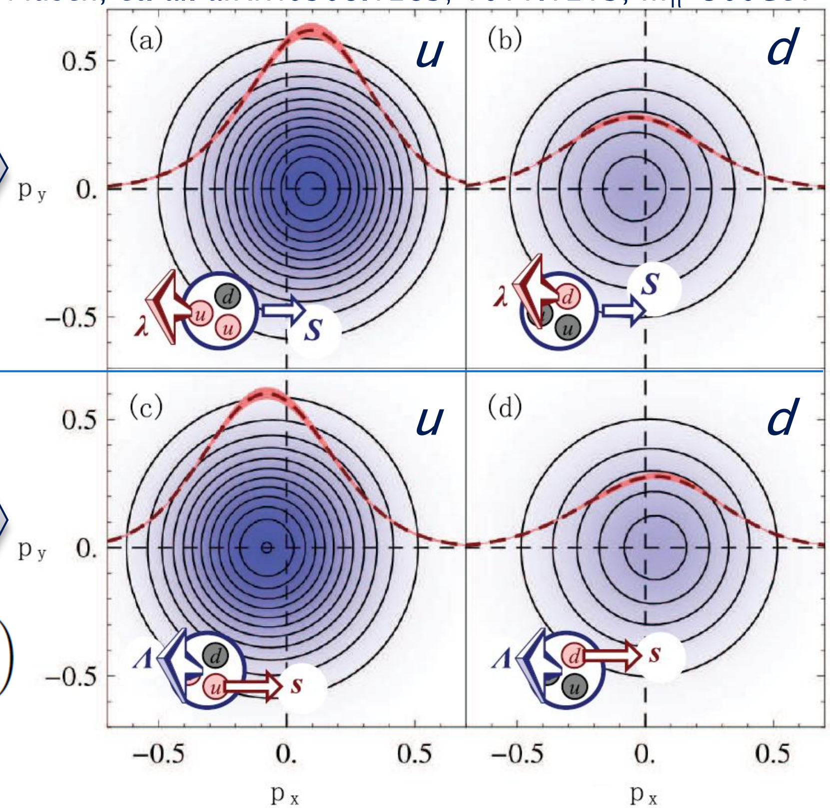
B. Musch, et. al. arXiv:0908.1283; 1011.1213, m_π~500GeV

Spin: Nucleon (T), Quark (L)

$$\langle p_x \rangle^q_{TL} = \frac{M}{n_q} \int_0^1 dx \left(g_{1T}^{q(1)}(x) - \bar{g}_{1T}^{q(1)}(x) \right)$$

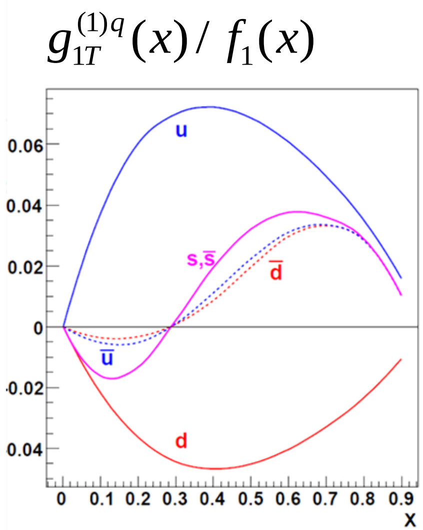
Spin: Nucleon (L), Quark (T)

$$\langle p_x \rangle^q_{LT} = \frac{M}{n_q} \int_0^1 dx \left(h_{1L}^{\perp q(1)}(x) - \bar{h}_{1L}^{\perp q(1)}(x) \right)$$

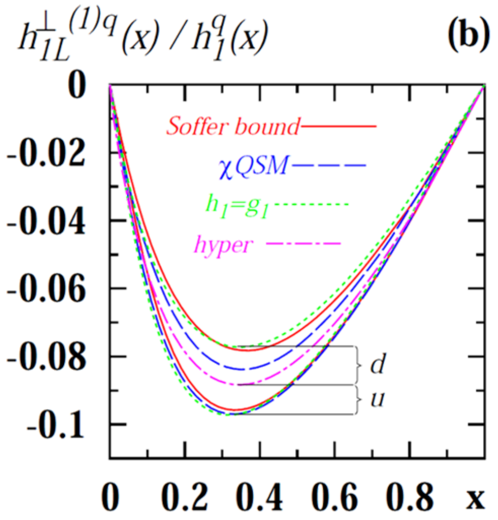


Model Predictions

- Very active theoretical studies, including modeling
- Generic features of model predictions:
  - max @ valence x region
  - ~ a few percent w.r.t. unpolarized f_1
  - *u* & *d* quarks take opposite signs
  - $h_{1L}^{\perp q}$ and $g_{1T}^{\ q}$ take opposite signs



Kotzinian, PRD73, 2006



Avakian, PRD77, 2008

$h_{1L}^{\perp} =^? -g_{1T}$

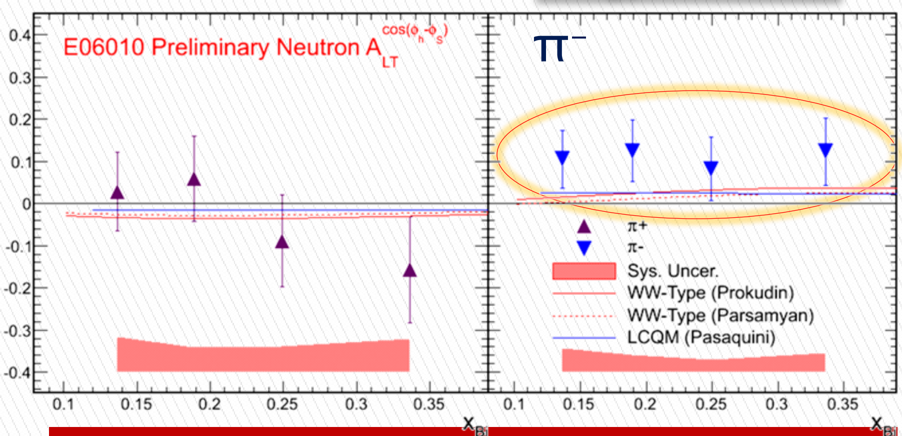
- Naive cylindrical symmetry around **y** axis
- Supported by many models w/o gluon
  - Bag model, Avakian,2010
  - Light-cone constituent QM, Pasquini, 2008
  - Chiral quark soliton model, Lorcé & Pasquini (in preparation)
  - Spectator model, Jakob,1997
  - Covariant parton model, Efremov, 2009 & 2010
- Also favored by current lattice studies
- Test at same kinematics in this experiment

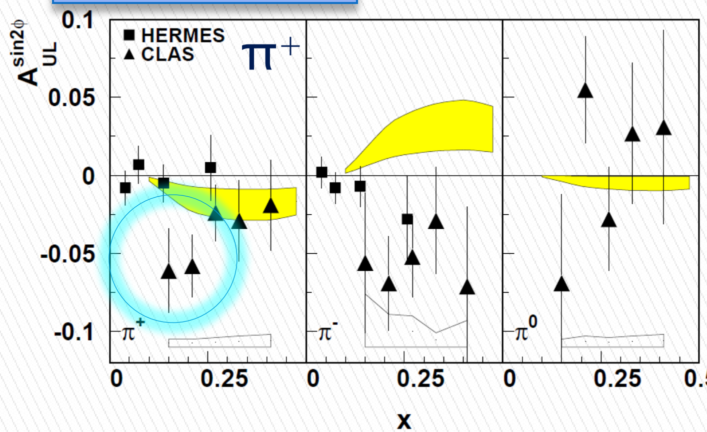
$h_{1L}^{\perp} = -g_{1T}$ favored (naively)

$g_{1T}^{u} >^{?} 0$ ← Flip Sign? → $h_{1L}^{\perp u} <^{?} 0$

d quark in neutron dominant $A_{LT}(n \rightarrow \pi^-)$

u in proton dominant $A_{LT}(n \rightarrow \pi^-)$





Hall A A_{LT} on ^3He

CLAS A_{UL} on proton

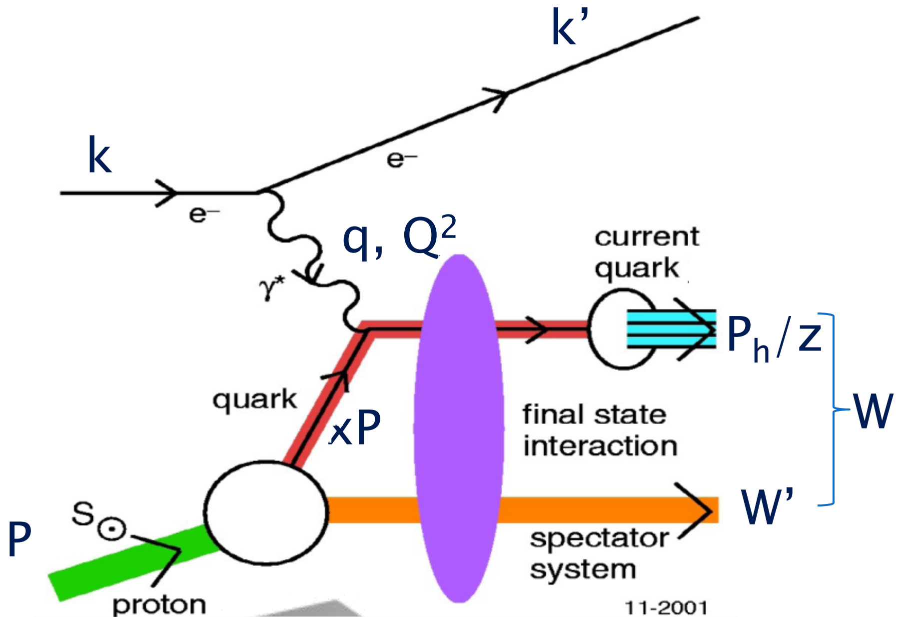
WW-type Approx.

- "Worm-gear" TMDs → collinear PDFs through
  - Lorentz Invariance Relations (LIR)
  - Wandzura-Wilczek (WW) approximation
  - Assumptions: q-g correlation small, m_q small

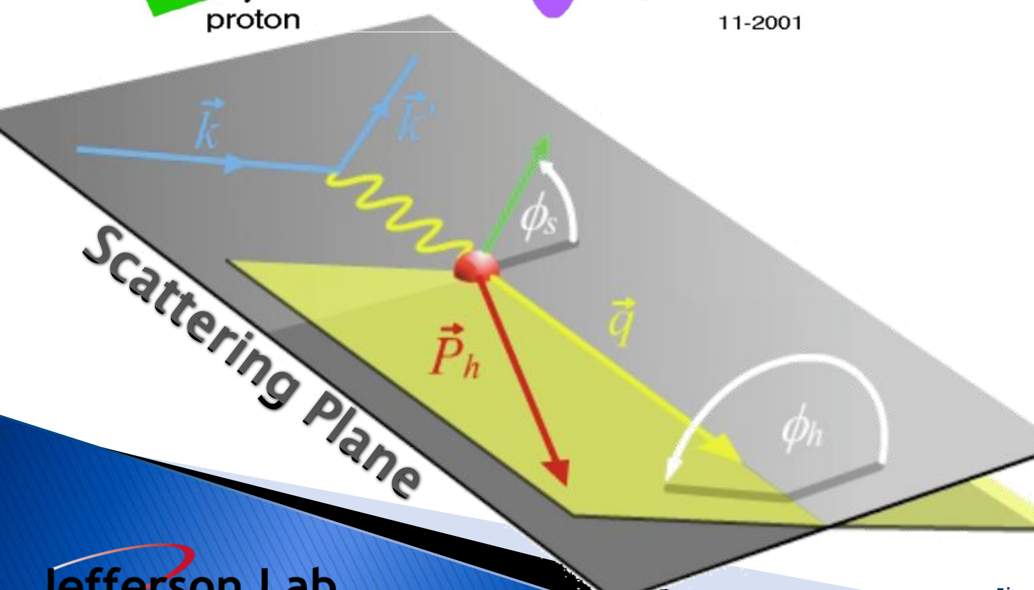
- $h_{1L}^{\perp q(1)}(x) \overset{WW-type}{\approx} -x^2 \int_x^1 \frac{dy}{y^2} h_1^q(y)$ and $g_{1T}^{q(1)}(x) \overset{WW-type}{\approx} x \int_x^1 \frac{dy}{y} g_1^q(y)$

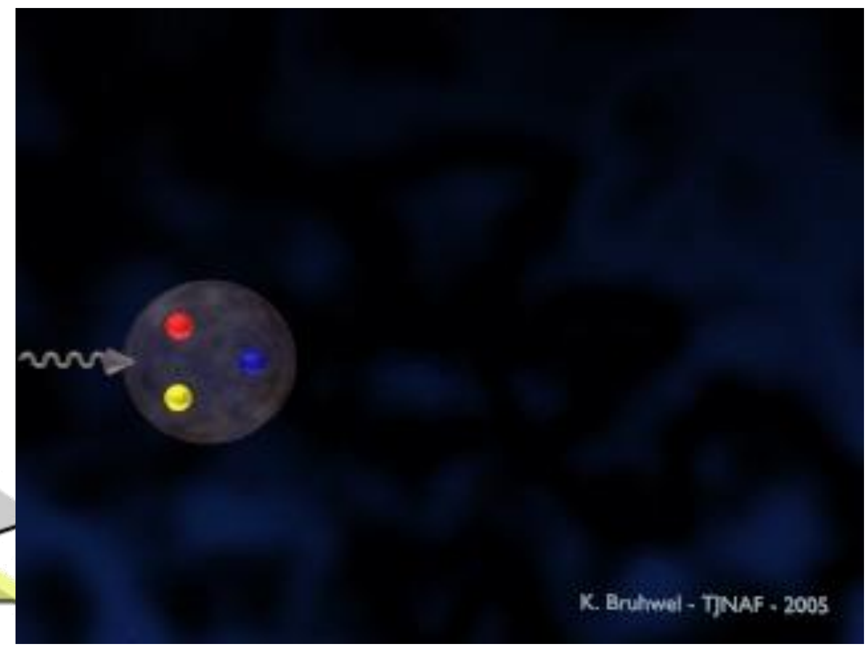
- Test with collinear PDFs to probe q-g correlation
- Indirect information on Transversity, h_1

One Tool to Study TMDs: SIDIS



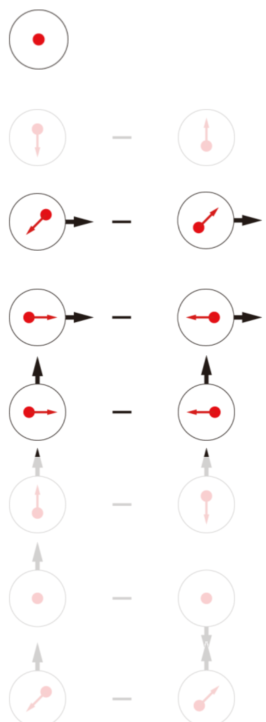
- Access new TMDs not accessible in inclusive DIS ($m_{quark}=0$)
- Variables: x, q, Q^2, z, W, W'





TMDs in SIDIS Cross Section

$$\frac{d\sigma}{dxdyd\phi_S dzd\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\cdot$$



f_1 = : $\{F_{UU,T} +$

Boer-Mulder $h_1^\perp$ = : $+\varepsilon\cos(2\phi_h)\cdot F_{UU}^{\cos(2\phi_h)} + \ldots$

Worm Gear $h_{1L}^\perp$ = : $+S_L[\varepsilon\sin(2\phi_h)\cdot F_{UL}^{\sin(2\phi_h)} + \ldots]$

Helicity g_1 = : $+S_L\lambda_e[\sqrt{1-\varepsilon^2}\cdot F_{LL} + \ldots]$

Worm Gear g_{1T} = : $+S_T\lambda_e[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\cdot F_{LT}^{\cos(\phi_h-\phi_S)} + \ldots]$

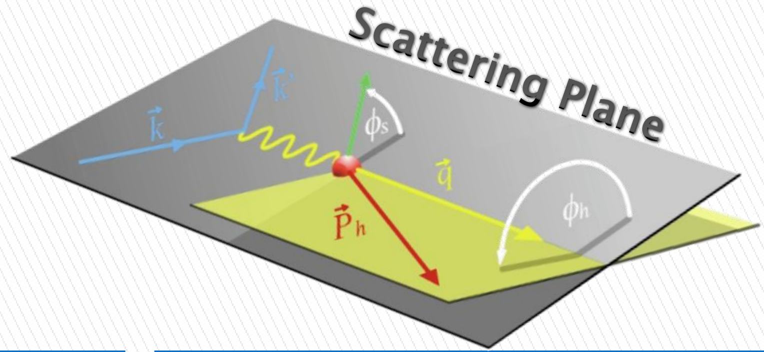
Transversity h_{1T} = : $+S_T[\varepsilon\sin(\phi_h+\phi_S)\cdot F_{UT}^{\sin(\phi_h+\phi_S)}$

Sivers $f_{1T}^\perp$ = : $+\sin(\phi_h-\phi_S)\cdot(F_{UT}^{\sin(\phi_h-\phi_S)} + \ldots)$

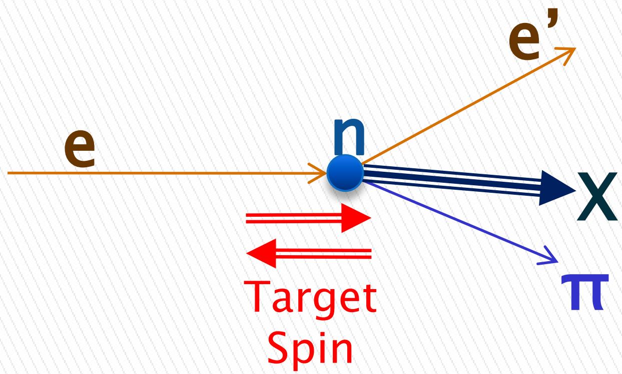
Pretzelosity $h_{1T}^\perp$ = : $+\varepsilon\sin(3\phi_h-\phi_S)\cdot F_{UT}^{\sin(3\phi_h-\phi_S)} + \ldots]\}$

S_L, S_T: Target Polarization; λ_e: Beam Polarization

Observables



$A_{UL} \rightarrow h_{1L}$

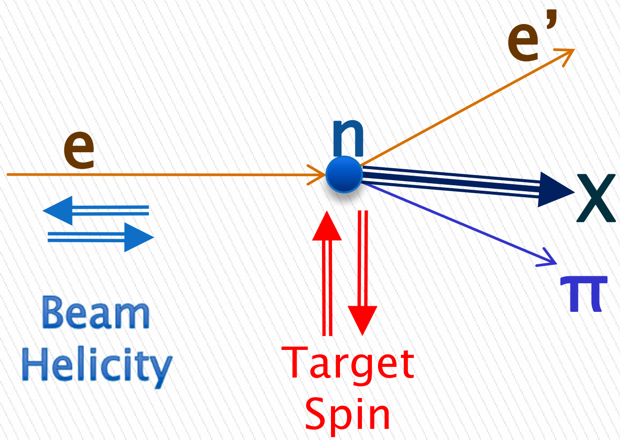


- Single Beam Asymmetry:

$$A_{UL}^{\sin 2\phi_h} \equiv 2\frac{\int d\phi_s^h \left(d\vec{\sigma} - d\overleftarrow{\sigma}\right)\sin 2\phi_h}{\int d\phi_s^h \left(d\vec{\sigma} + d\overleftarrow{\sigma}\right)}$$

$$\propto h_{1L}^{\perp} \otimes H_1^{\perp}$$

$A_{LT} \rightarrow g_{1T}$



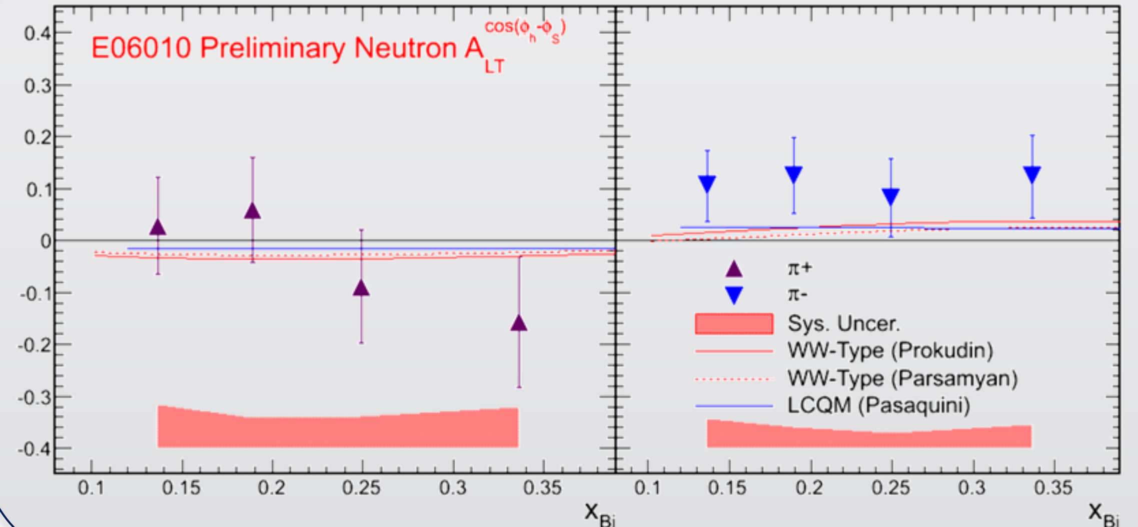
- Double Spin Asymmetry:

$$A_{LT}^{\cos(\phi_h - \phi_s)} \equiv 2\frac{\int d\phi_s^h \left(d\vec{\sigma} - d\overleftarrow{\sigma}\right)\cos(\phi_h - \phi_s)}{\int d\phi_s^h \left(d\vec{\sigma} + d\overleftarrow{\sigma}\right)}$$

$$\propto g_{1T}^{q} \otimes D_{1q}^{h}$$

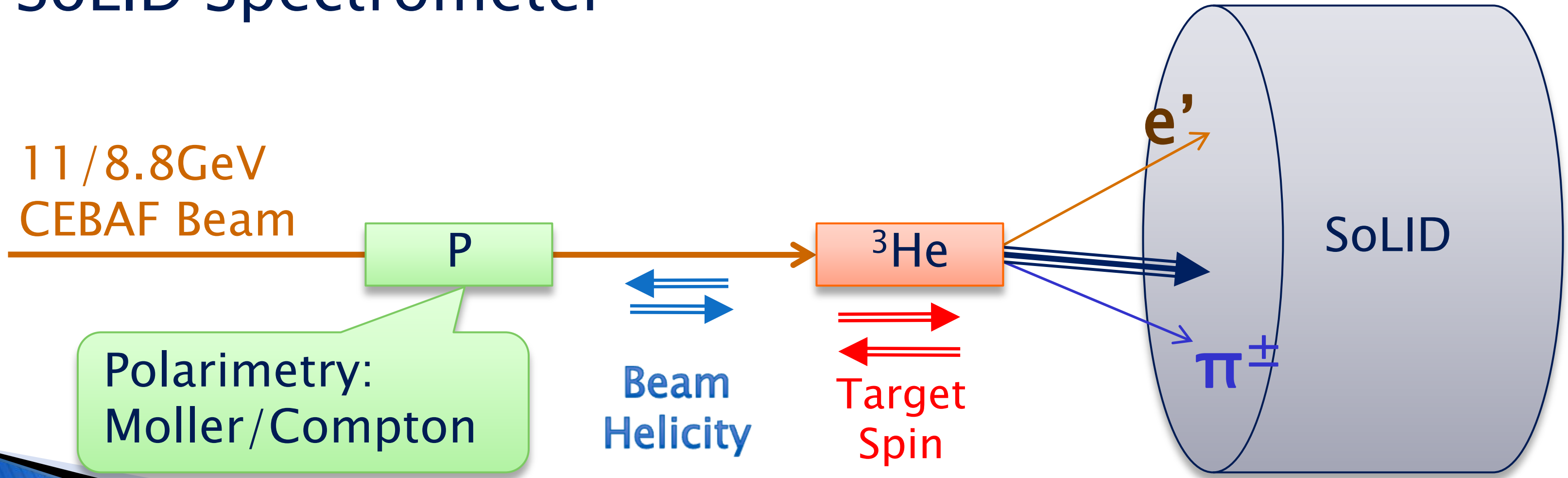
Existing data

- A_{UL} $(\to h_{1L}^{\perp})$
  - No neutron data currently
  - Proton (HERMES, CLAS)
  - Deuteron (COMPASS, HERMES)
- A_{LT} $(\to g_{1T})$
  - First Neutron A_{LT}: 6GeV Transversity
  - Deuteron A_{LT}: COMPASS



Setup Overview

- CEBAF beam
  - Energy: 11GeV & 8.8GeV
  - Polarization: 85%
    - Polarimetry: standard Hall A Moller & Compton
  - Current: 15uA
- Pol. ^{3}He Target. High luminosity, 10^{36} cm^{-2} s^{-1}
  - Support both Trans and Long. Pol.
- SoLID Spectrometer

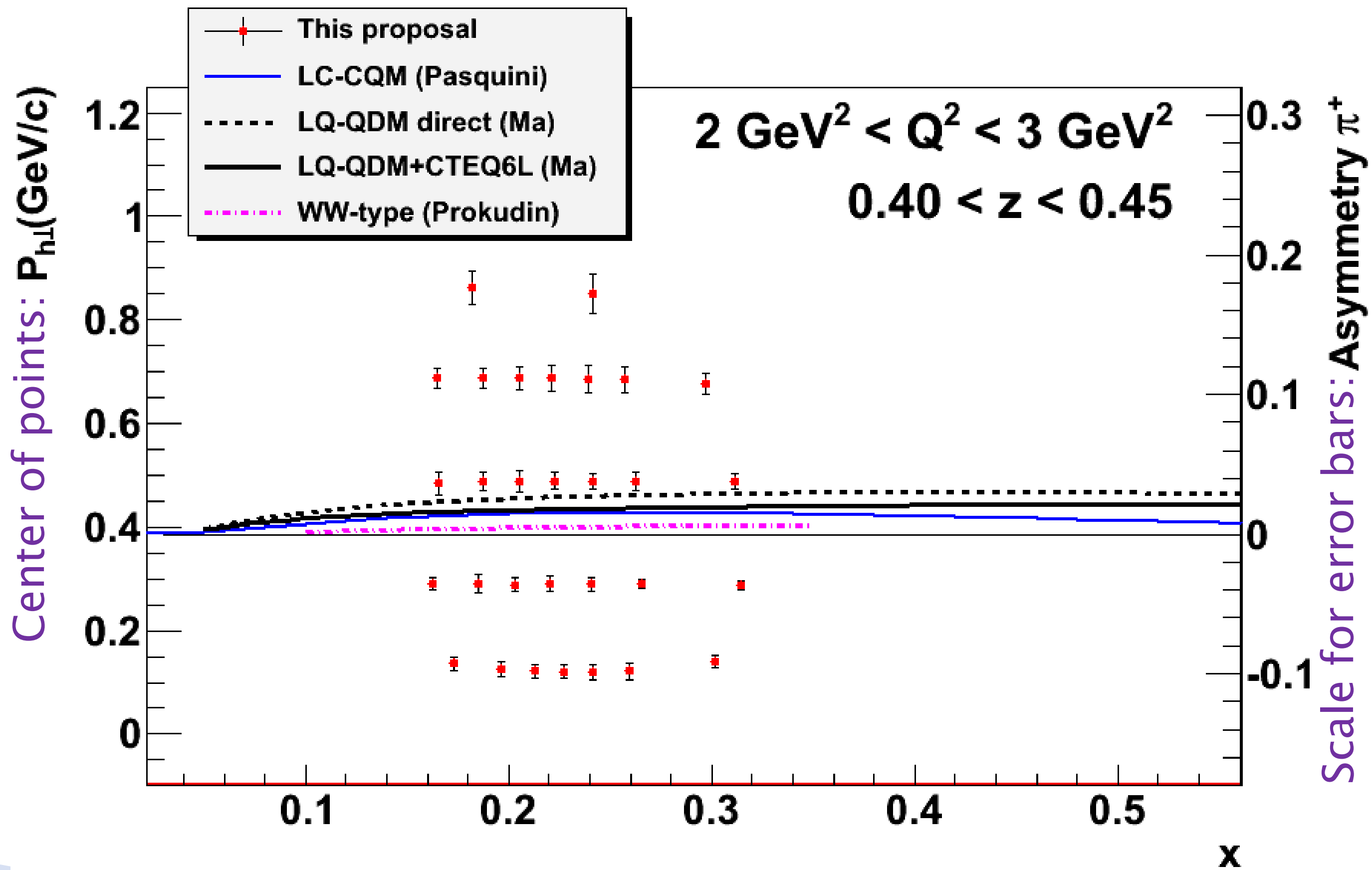


Azimuthal Asymmetry Extraction

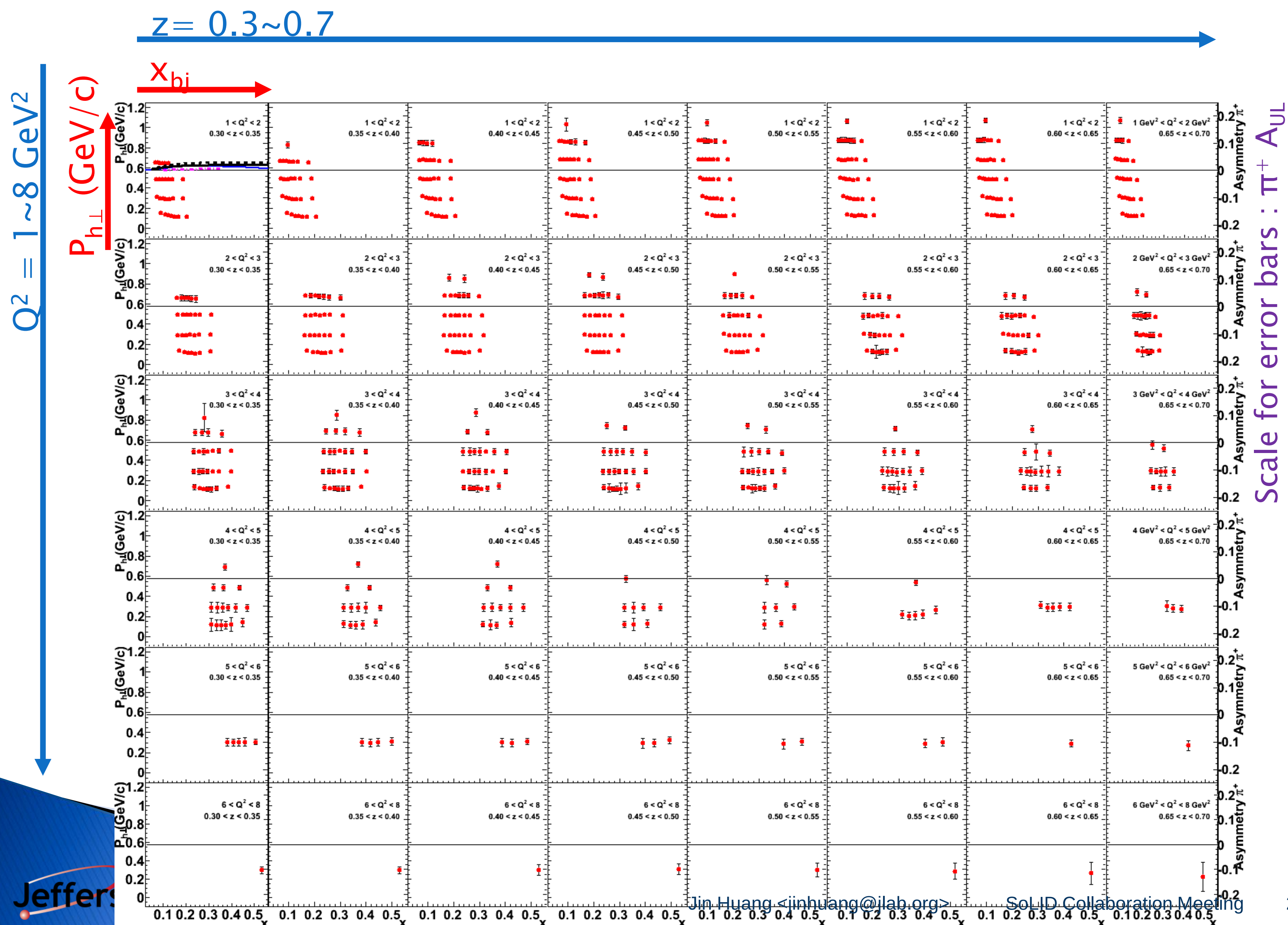
- Two methods (fitting & MLE)
  - Developed & tested at 6GeV program
- Systematic uncertainty improved by
  - Fast spin/helicity flips
    - Suppress yield drift/uncertainty on azimuthal angles/…
  - Symmetric large acceptance
  - Example: simplified asymmetry extraction
    - $$A_{UL}(\phi_h) = \frac{1}{P}\frac{\sqrt{N_1(\phi_h)N_2(-\phi_h)} - \sqrt{N_1(-\phi_h)N_2(\phi_h)}}{\sqrt{N_1(\phi_h)N_2(-\phi_h)} + \sqrt{N_1(-\phi_h)N_2(\phi_h)}} = A_{UL}^{\sin 2\phi_h} \cdot \sin 2\phi_h + \cdots$$
    - Luminosity asym. and acceptance cancel at 1^{st} order

Data Projection / A_{UL} (Partial)

- Projection of a single Q^2–z bin for π^+



>1000 bins: critical for studying multi-D structure



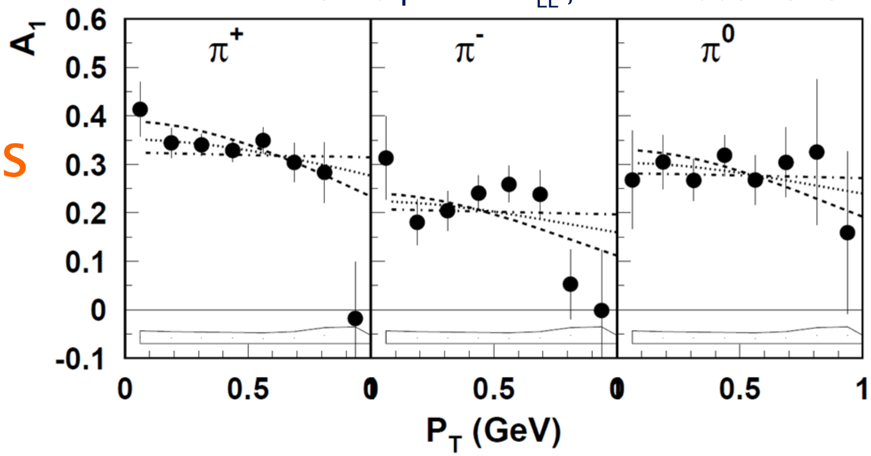
p_T Dep. Helicity Distribution

- DSA on long. pol. ^{3}He, A_{LL} → helicity $g_1(x,p_T)$
- Contribute to global analysis
  - Quark flavor tagged by detected meson
  - Significantly reduce uncertainty on Δd

$$A_1^{\pi^+-\pi^-}(^3\overrightarrow{\mathrm{He}}) \overset{LO}{\approx} \frac{4\Delta d_v - \Delta u_v}{7f_{u_V} + 2f_{d_v}}$$

- p_T dependency of A_{LL}
  - flavor dep. of p_T width
    ~ different OAM of quarks
    arXiv:0705.1553

CLAS proton A_{LL}, arXiv:1003.4549



Data Projection/A_{LL} (Partial)

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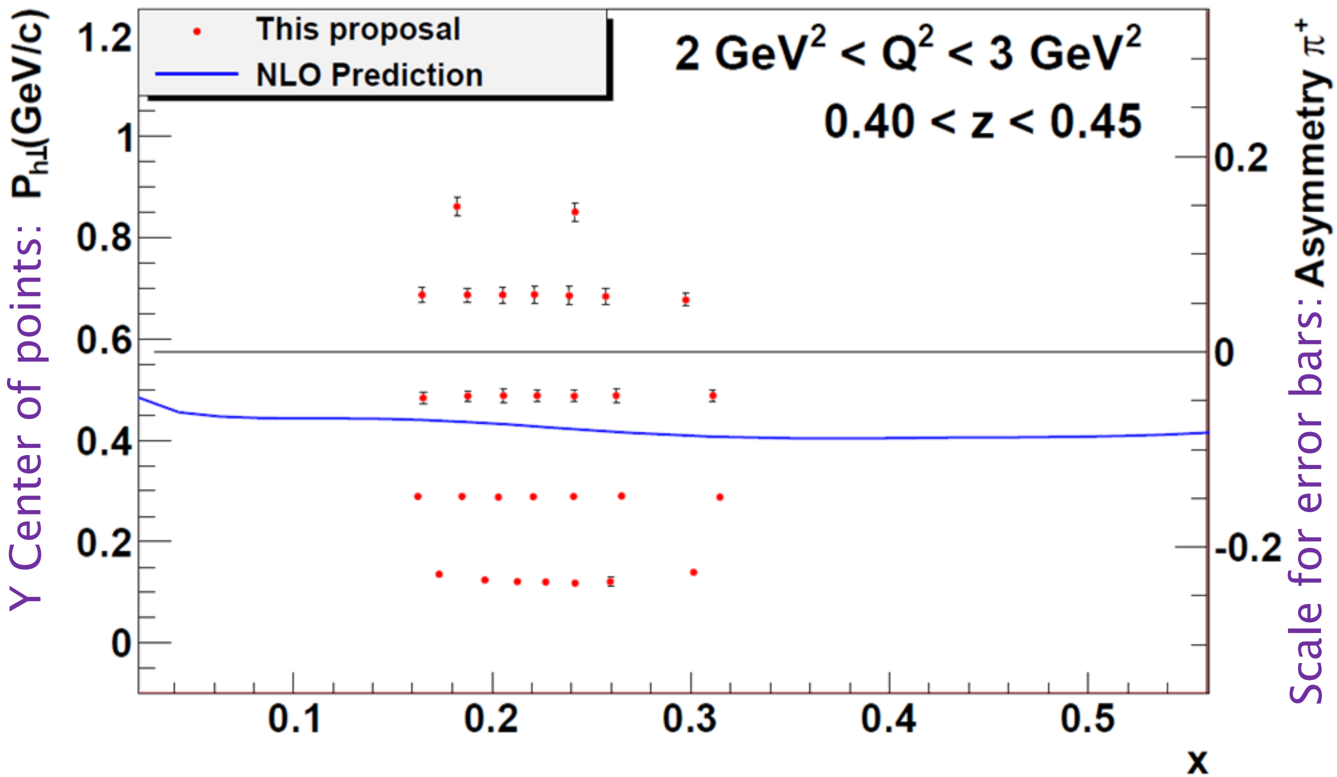
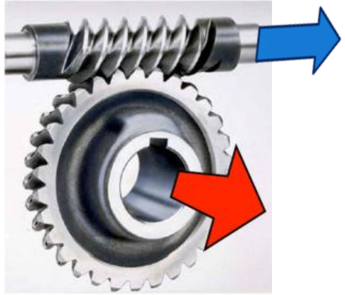


Systematic Uncertainties

Source	Type	$A_{UL}^{\sin 2\phi_h}$	$A_{LT}^{\cos(\phi_h-\phi_S)}$	A_{LL}
Raw Asymmetries	absolute	1×10^{-3}	negligible	negligible
Random Coinc. Background Subtraction	relative	1%	1%	1%
polarimetry	relative	3%	4%	4%
Nuclear Effects	relative	4%	4%	4%
Diffractive Vector Meson	relative	3%	3%	3%
Radiative Corrections	relative	2%	3%	3%
Total	**absolute**	1×10^{-3}	negligible	negligible
	relative	7%	7%	7%
Stat. Uncertainty for a Typical Bin	absolute	5×10^{-3}	4×10^{-3}	4×10^{-3}

Systematic < Statistical Uncert.

Conclusion



- SIDIS charged pion production
  ultimate precision 4D mapping of asym.
- Extraction of novel TMDs
  - $A_{UL} \rightarrow h_{1L}$ } "worm-gear" distribution, $Re[(L=0)_q \times (L=1)_q]$
  - $A_{LT} \rightarrow g_{1T}$ }
  - $A_{LL} \rightarrow g_{1L}$: p_T dep. helicity distribution, Δd
- Major role in worldwide efforts
  - Spin-orbit effects & 3D structure of nucleon
- Long. pol. ^{3}He target + SoLID
- 35-day pol. beam