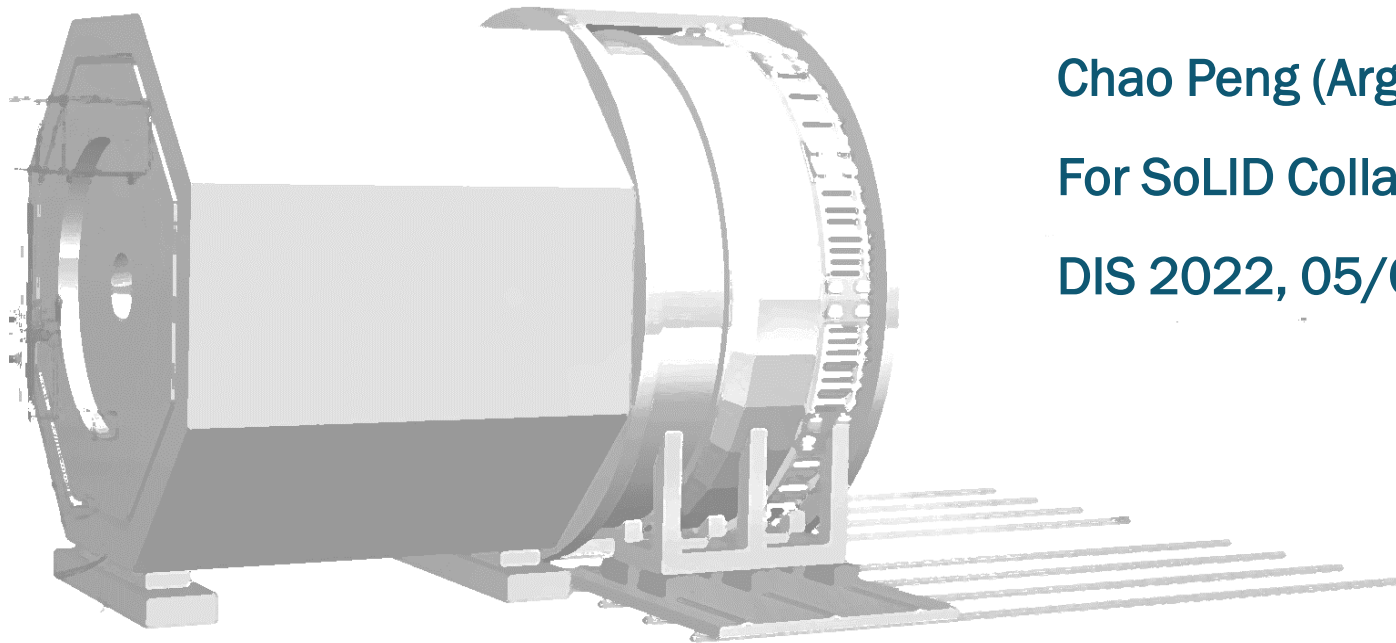# 3D Nucleon Structure with SoLID

Chao Peng (Argonne National Laboratory)

For SoLID Collaboration

DIS 2022, 05/04/2022

Solenoidal Large Intensity Detector (SoLID)

- Maximize scientific outcome of JLab 12 GeV upgrade
  - Intensity frontier (high luminosity $10^{37\text{-}39}$/cm^2/s)
  - Large detector acceptance with full azimuthal coverage

- Rich physics programs
  - Search of new physics by pushing the limit of phase space
  - 3D momentum imaging of nucleon spin
  - Precision J/ψ production near the threshold

- Complementary and synergistic with the EIC science
  - Proton spin and mass
  - Valence quark tomography and precision J/ψ production near threshold

Strong Collaboration

- ▪ 270+ collaborators, 70+ institutions from 13 countries

- - Strong theory support

- - Active development for pre-R&D and physics programs

SoLID Physics Program

- SIDIS program
  - E12-10-006: Single Spin Asymmetry in SIDIS on Transversely Polarized ^{3}He (90 days)
  - E12-11-007: Single and Double Spin Asymmetries in SIDIS on Longitudinally Polarized ^{3}He (35 days)
  - E12-11-108: Single Spin Asymmetry in SIDIS on Transversely Polarized Proton (120 days)
  - Run groups: Dihadron (E12-10-006A), Ay (E12-11-108A/E12-10-006A), Kaon Production (E12-11-108B/E12-10-006D), g2n (E12-11-007A/E12-10-006E)

- PVDIS experiments
  - E12-10-007: Parity Violating Asymmetry in DIS with LH_2 and LD_2 (169 days)

- J/psi program
  - E12-12-006: Near Threshold Electroproduction of J/psi at 11 GeV (60 days)
  - Run group: Time-Like Compton Scattering (E12-12-006A)

- GPD program
  - Run group: Deep Exclusive pion production with polarized ^{3}He target and SIDIS configuration (E12-10-006B)
 - Under development: DDVCS on proton, DVMP

SoLID SIDIS Program

E12-10-006: Single Spin Asymmetry in SIDIS on Transversely Polarized ^{3}He (90 days), **rating A**

E12-11-007: Single and Double Spin Asymmetries in SIDIS on Longitudinally Polarized ^{3}He (35 days), **rating A**

E12-11-108: Single Spin Asymmetry in SIDIS on Transversely Polarized Proton (120 days), **rating A**

- Pion Semi Inclusive DIS experiments

- Highly rated

- 4D precision mapping of asymmetries

- Physics impact on TMDs, tensor charge, …
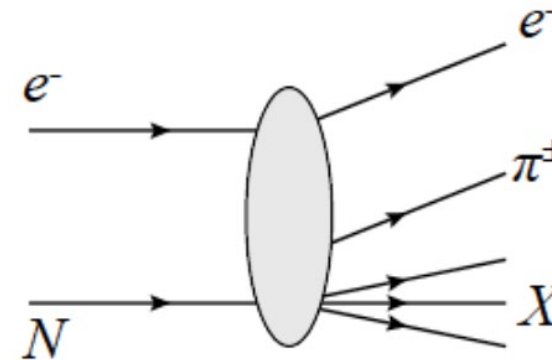
SoLID SIDIS & J/Psi Configuration

- 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)
  - Kaon maximum momentum depends on TOF resolution
  - $\delta p/p \sim 2\%, \delta\theta \sim 0.6\ mrad, \delta\phi \sim 5\ mrad$
- High luminosity, high data rate
- New Technologies
  - GEM's
  - Shashlyk ECal
  - Pipeline DAQ
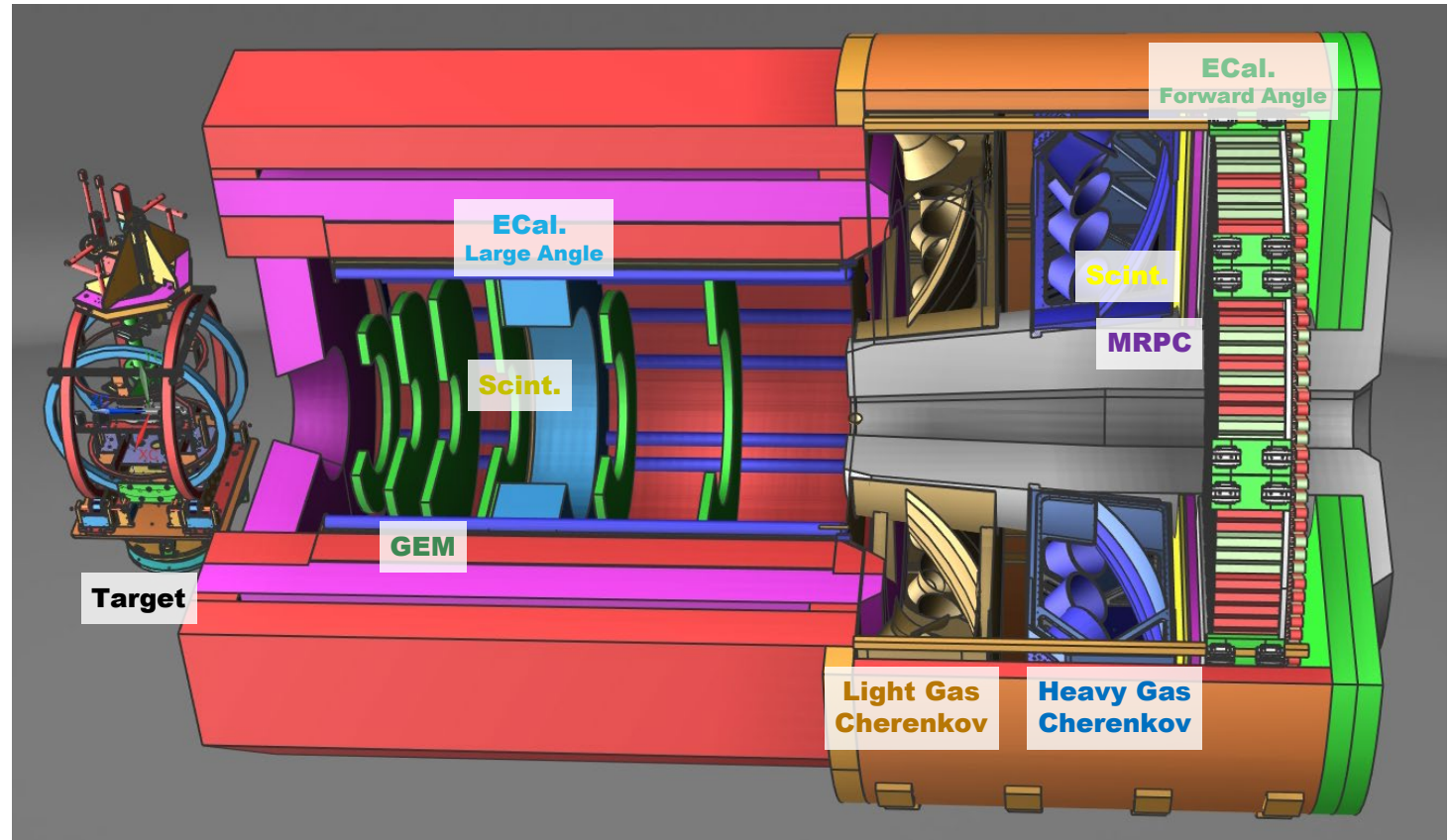
Leading Twist TMDs

- Access all 8 leading twist terms through SIDIS differential cross section $\dfrac{d\sigma}{dxdydzdP_T^2 d\phi_h d\phi_S}$

→ quark spin   → nucleon spin

		Quark polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	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

E12-10-006, E12-11-008:

Target Single Spin Asymmetry:

$$A_{UT} = \frac{1}{P}\frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$

$$= A_{UT}^{Collins}\sin(\phi_h + \phi_S) \qquad \propto h_1 \otimes H_1^\perp$$
$$+ A_{UT}^{Sivers}\sin(\phi_h - \phi_S) \qquad \propto f_1^\perp \otimes D_1$$
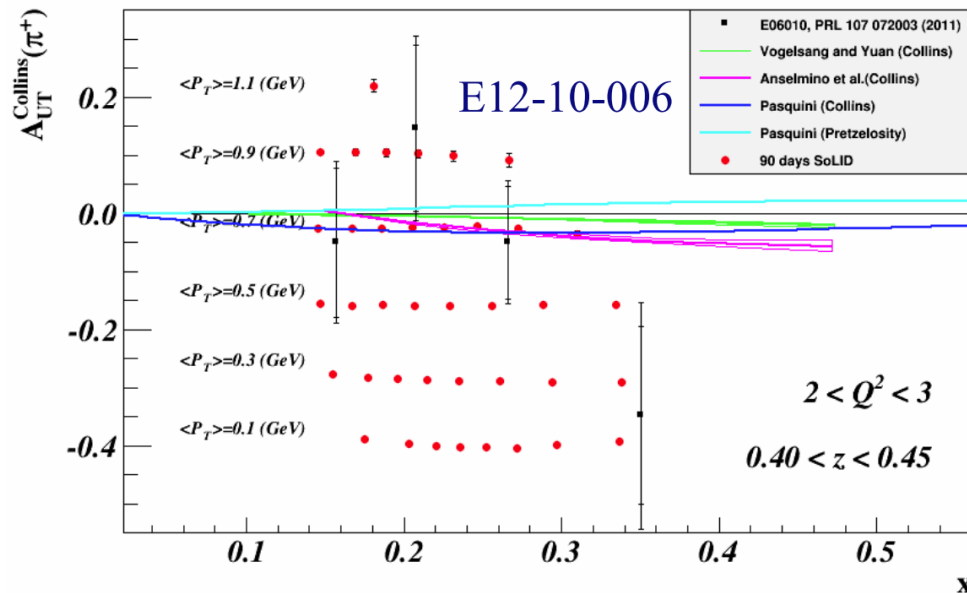$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h - \phi_S) \propto h_{1T}^\perp \otimes H_1^\perp$$

E12-11-007:

Single Spin Asymmetry and Double Spin Asymmetry:
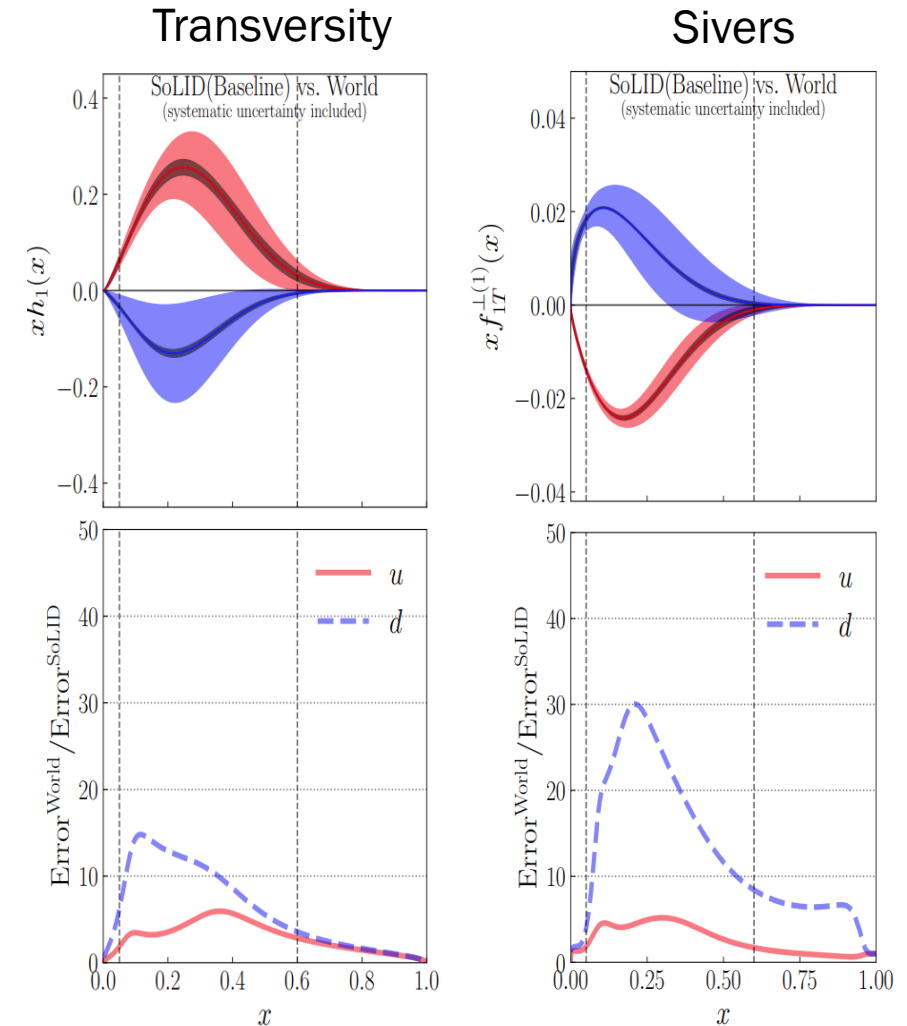
$$A_{UL}^{sin2\phi_h} \propto h_{1L}^\perp \otimes H_1^\perp \qquad A_{LT}^{\cos(\phi_h - \phi_S)} \propto g_{1T} \otimes D_1$$

Large acceptance and precision measurement of asymmetries in 4D phase space is essential
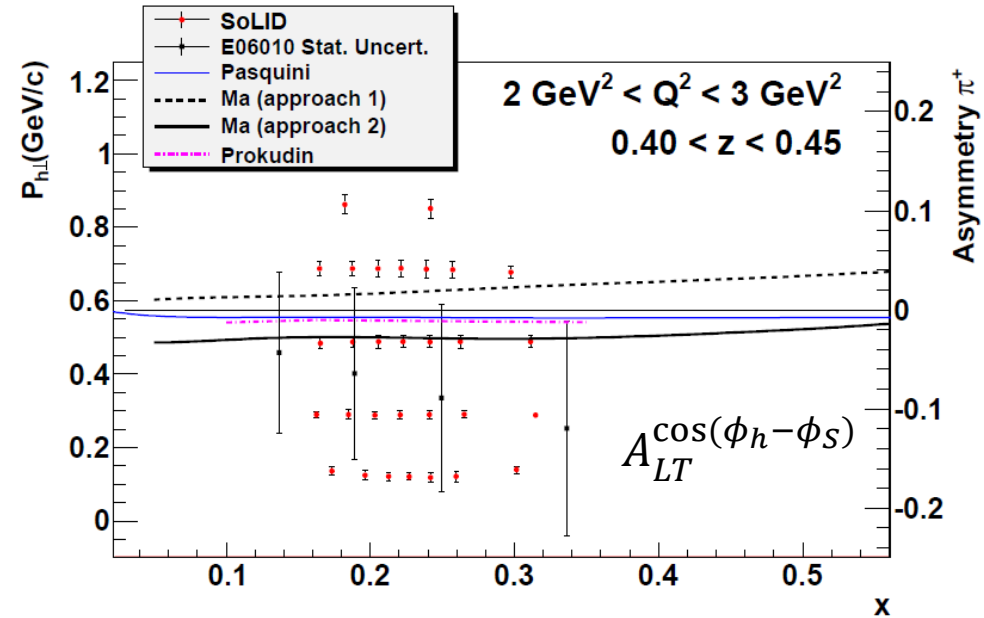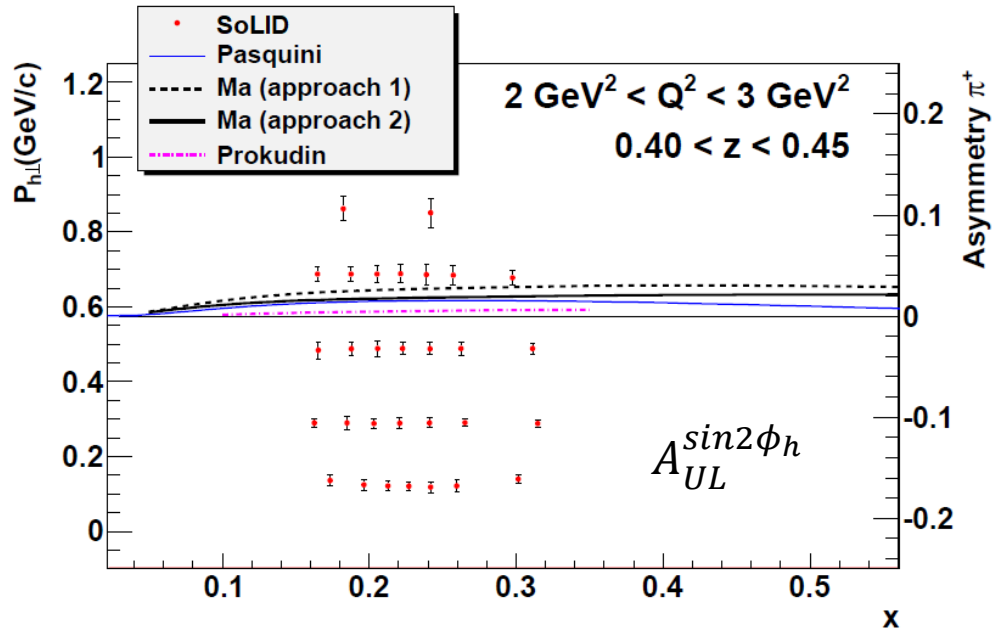
SoLID Impact on TMDs

Transversity

Sivers

- Comparison of SoLID projection with world data (HERMES, COMPASS, JLab-6GeV)

- Fit asymmetries with e⁺e⁻ annihilation data (BELLE, BABAR)

- Both stat. and syst. errors included

Z. Ye *et al*, Phys. Lett. B767, 91 (2017)

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SoLID Impact on TMDs

- Access to "worm-gear" TMD PDFs (E12-11-007)

- Test relation $g_{1T}^q = -h_{1L}^{\perp q}$ at identical kinematics with high statistics

- Investigate nucleon spin structure in terms of orbital motion of quarks and gluons
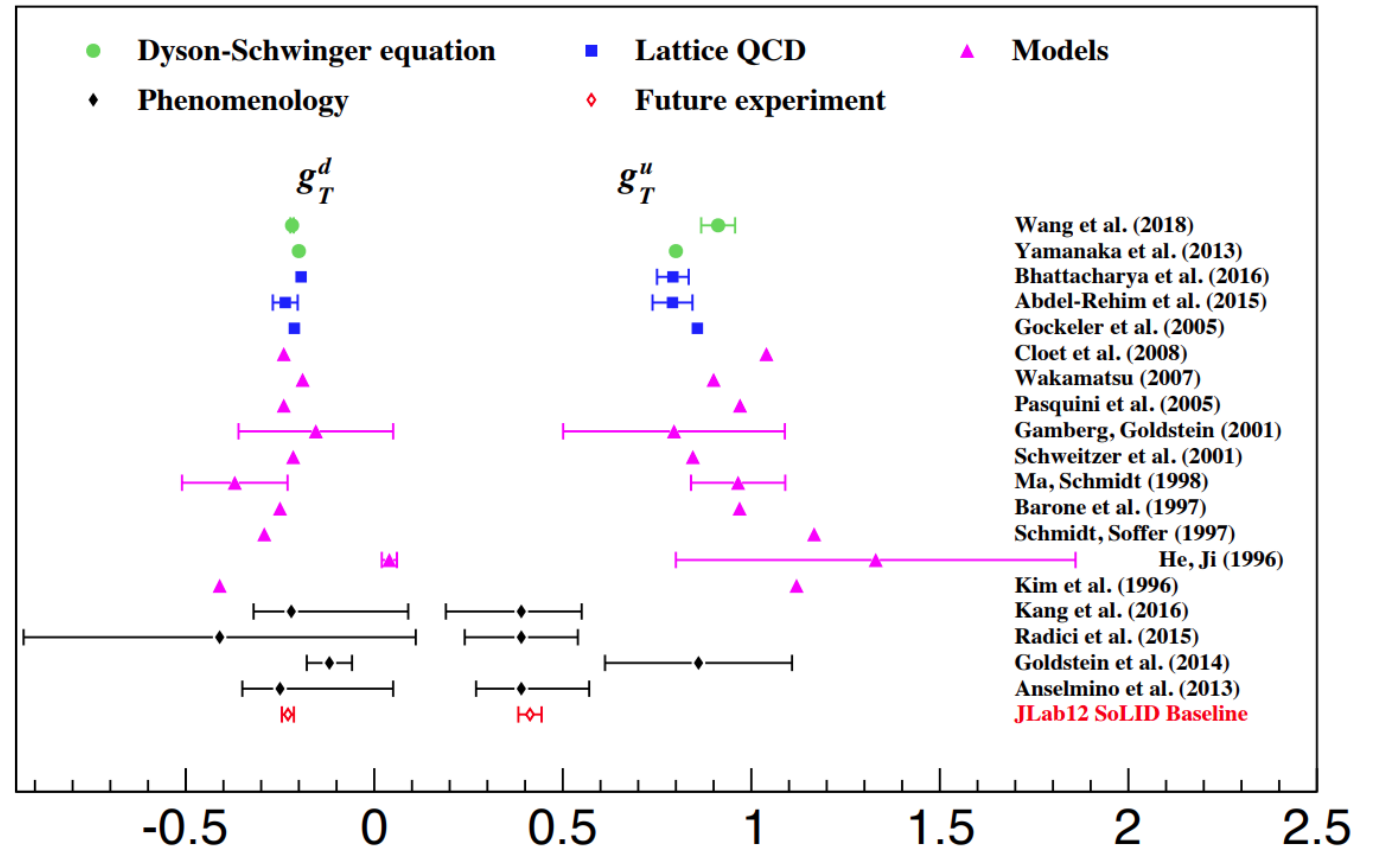
Nucleon Tensor Charge

- A fundamental QCD quantity

  - Matrix element of tensor current

$$\langle P,S|\bar{\psi}_q i\sigma^{uv}\psi_q|P,S\rangle = \delta_T^q \bar{u}(P,S)i\sigma^{uv}u(P,S)$$

  - Lowest moment of transversity

$$\delta_T^q = \int_0^1 \left(h_1^q(x) - h_1^{\bar{q}}(x)\right) dx$$

  - Can be tested in Lattice QCD

Legend:
- ● Dyson-Schwinger equation
- ◆ Phenomenology
- ■ Lattice QCD
- ◇ Future experiment
- ▲ Models

g_T^d g_T^u

Wang et al. (2018)
Yamanaka et al. (2013)
Bhattacharya et al. (2016)
Abdel-Rehim et al. (2015)
Gockeler et al. (2005)
Cloet et al. (2008)
Wakamatsu (2007)
Pasquini et al. (2005)
Gamberg, Goldstein (2001)
Schweitzer et al. (2001)
Ma, Schmidt (1998)
Barone et al. (1997)
Schmidt, Soffer (1997)
He, Ji (1996)
Kim et al. (1996)
Kang et al. (2016)
Radici et al. (2015)
Goldstein et al. (2014)
Anselmino et al. (2013)
JLab12 SoLID Baseline

SoLID J/psi Program

- Electro- and photo-production of Charmonium near threshold
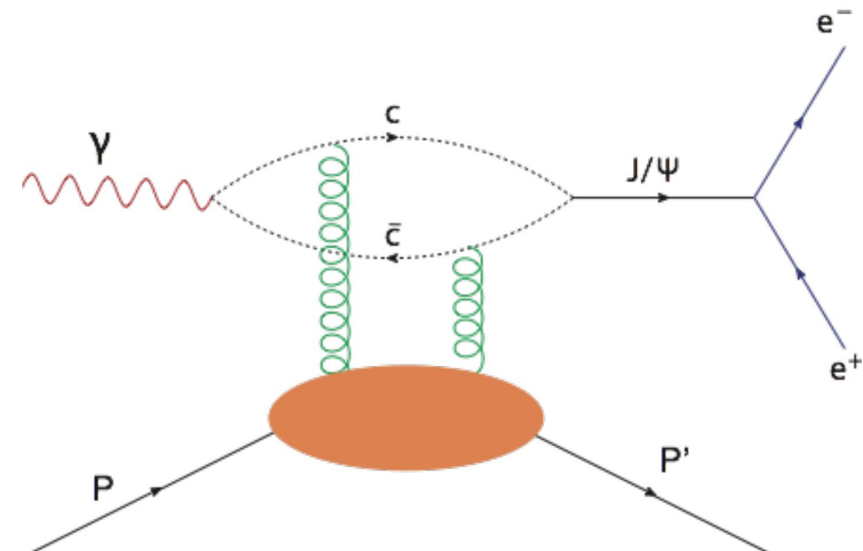
$$ep \rightarrow e'p'J/\psi(e^-e^+)$$

$$\gamma p \rightarrow p'J/\psi(e^-e^+)$$

- Probing strong color field in the nucleon
  - Color Van der Waals force?
  - Pentaquarks existence?
  - Bound states of charmonium-nuclei?

- Real part contains the QCD trace anomaly
  - Important to understand the origin of proton mass
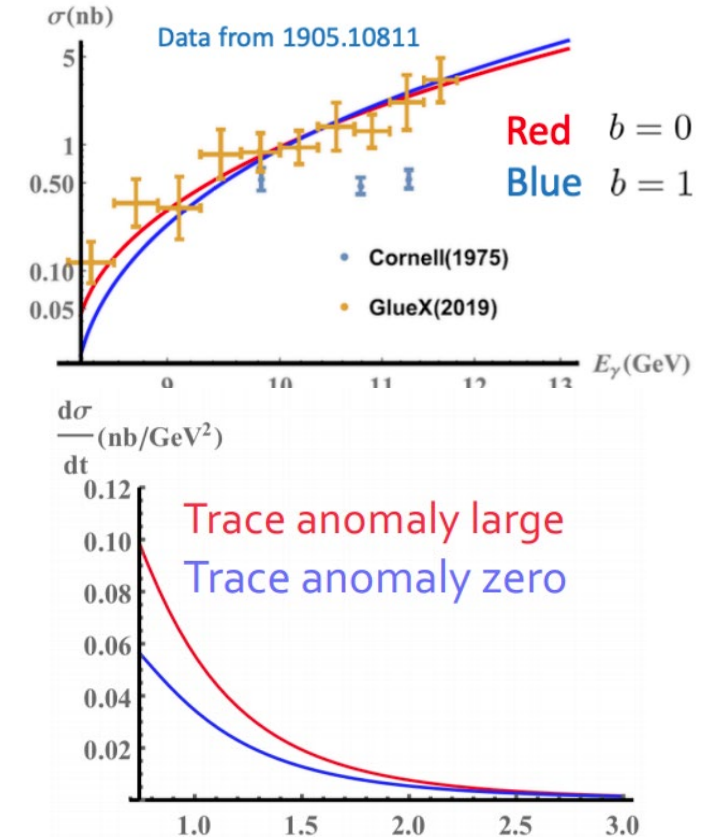
Trace Anomaly

- Ji's mass decomposition

$$H_{QCD} = \int d^3x \, T^{00}(0, \vec{x}) = H_q + H_m + H_g + H_a$$

$$H_q = \int d^3x \, \psi^\dagger(-i\mathbf{D}\cdot\alpha)\psi \qquad \text{Quarks kinetic and potential energy}$$

$$H_m = \int d^3x \, \psi^\dagger m\psi \qquad \text{Quarks masses}$$

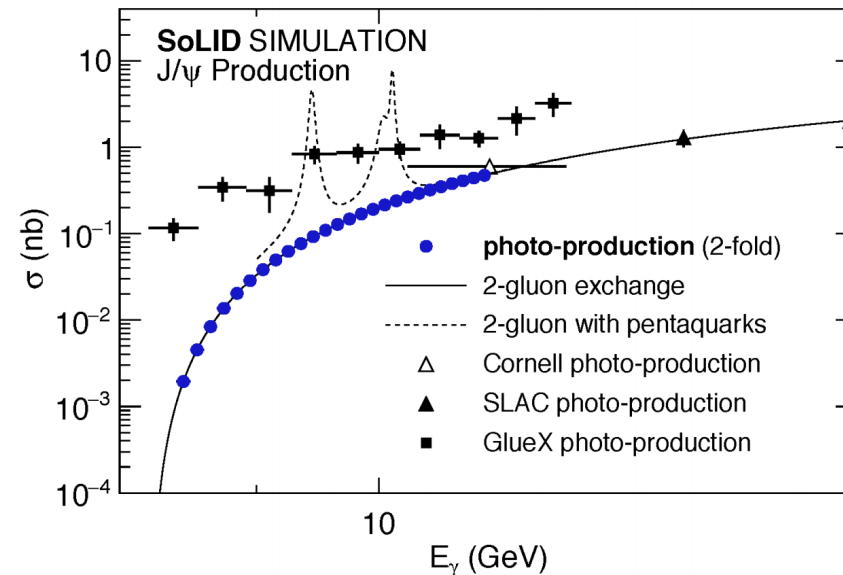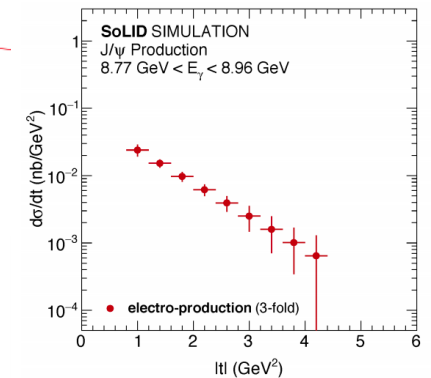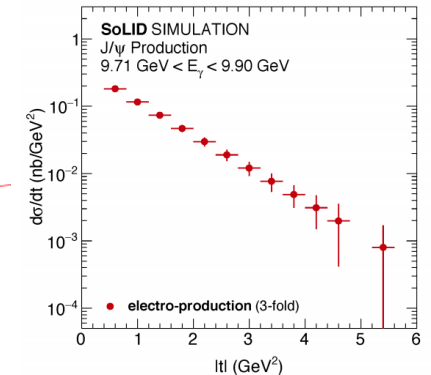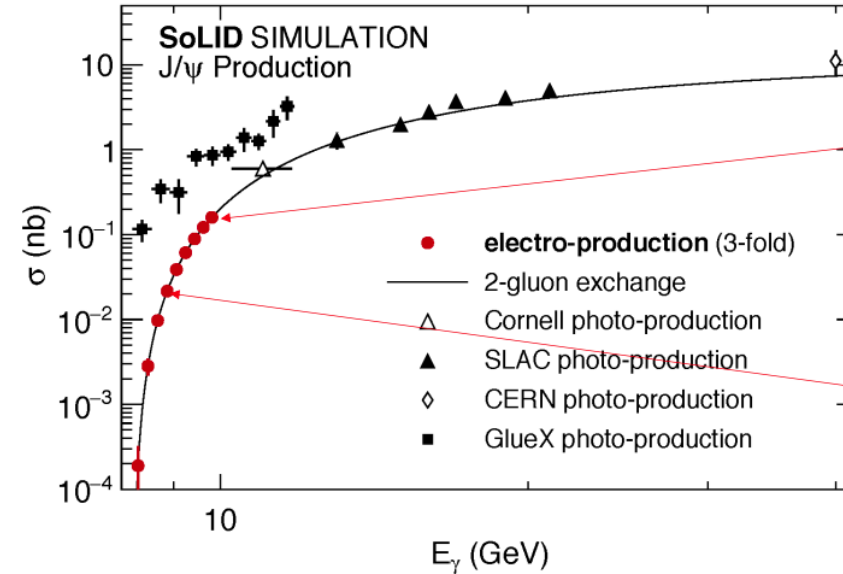$$H_g = \int d^3 \frac{1}{2}(\mathbf{E}^2 + \mathbf{B}^2) \qquad \text{Gluons kinetic and potential energy}$$

$$H_a = \int d^3 \frac{1}{2}(\mathbf{E}^2 + \mathbf{B}^2) \qquad \text{Trace anomaly}$$
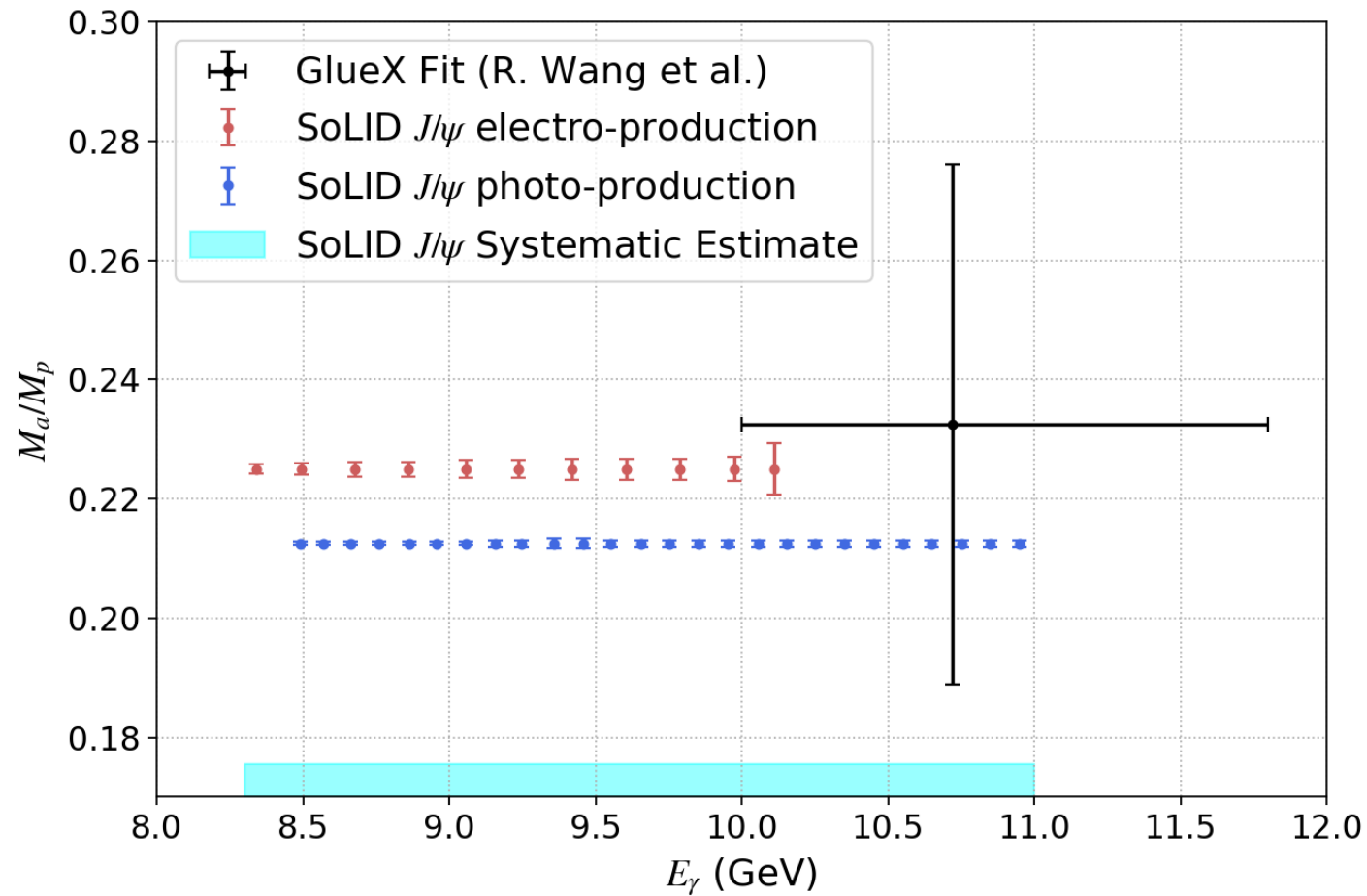

Sensitive to J/psi production near threshold

SoLID J/psi Projections

- Near threshold measurement with JLab 12 GeV upgrade

  - Test the production mechanism

- SoLID provides

  - High Intensity, large acceptance

  - Precise t-distribution for each photon energy bin

Trace Anomaly Impact

Summary

- SoLID is at the intensity frontier with JLab 12 GeV upgrade
    - Rich, highly rated physics programs
    - Address important questions in Nuclear Physics
    - Complementary and synergistic to EIC program

- 3D imaging of nucleon structure with SIDIS program

- Investigating the origin of proton mass with J/psi program

- Other high impact programs (PVDIS, GPD, …)

THANK YOU