

**DIS2023: XXX International Workshop on Deep-Inelastic Scattering and Related Subjects** 

# **Nucleon Spin Structure with SoLID-SIDIS Program**



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For SoLID Collaboration











# **Solenoidal Large Intensity Device (SoLID)**

- Maximize scientific outcome of JLab 12 GeV upgrade
  - QCD Intensity frontier (high luminosity 10<sup>37-39</sup>/cm<sup>2</sup>/s)
  - Large detector acceptance with full azimuthal coverage
- Rich physics programs
  - Precision test of SM and search of new physics
  - 3D momentum imaging of nucleon spin
  - Precision J/ $\psi$  production near the threshold
- Complementary and synergistic with the EIC science
  - Proton spin and mass
    - Spin: valence quark tomography in momentum space
    - Mass: precision  $J/\psi$  production near threshold







# **Strong Collaboration**

- 270+ collaborators, 70+ institutions from 13 countries
- Strong theory support
- Active development for pre-R&D and physics programs







# **Progresses Since Approval of SoLID Experiments**

- Since 2010: Five SoLID experiments approved by PAC with high rating
  - 3 SIDIS (including E12-11-007), 1 PVDIS, 1 threshold J/ $\psi$
  - 6 run group experiments
- CLEO-II magnet arrived at JLab in 2016, cold test on-going
- 2014: pCDR submitted to JLab with cost estimation, updated in 2017 and 2019
- Director's Reviews in 2015, 2019 and 2021
- 02/2020: SoLID MIE (with updated pCDR/estimated cost) submitted to DOE
- DOE funded Pre-R&D on Cherenkov/GEM and DAQ tests started 02/2020 and mostly completed
- 03/2021: SoLID Science Review
- Consistent effort on pre-conceptual design and pre-R&D with the support of JLab and DOE.
- New beam test to verify high luminosity (high rate/high radiation) capability of the detectors and DAQ.



CLEO II coil at JLab





# **SoLID Physics Program**

- SIDIS program
  - E12-10-006: Single Spin Asymmetry in SIDIS on Transversely Polarized <sup>3</sup>He (90 days)
  - E12-11-007: Single and Double Spin Asymmetries in SIDIS on Longitudinally Polarized <sup>3</sup>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<sub>2</sub> and LD<sub>2</sub> (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 <sup>3</sup>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 <sup>3</sup>He (90 days), **rating A** E12-11-007: Single and Double Spin Asymmetries in SIDIS on Longitudinally Polarized <sup>3</sup>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 Configuration**

- Full 2π coverage of polar angle from 8°-24°
  - $8^{\circ} < \theta < 14.8^{\circ}, 1 < P < 7 \text{ GeV/c}$
  - $16^{\circ} < \theta < 24^{\circ}, 3.5 < P < 7 \text{ GeV/c}$  (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



![](_page_7_Picture_0.jpeg)

![](_page_7_Picture_1.jpeg)

# Leading Twist TMDs

• Access all 8 leading twist terms through SIDIS differential cross section  $\frac{d\sigma}{dxdydzdP_T^2d\phi_h d\phi_s}$ 

![](_page_7_Figure_4.jpeg)

Large acceptance and precision measurement of asymmetries in 4D phase space is essential

![](_page_8_Picture_0.jpeg)

![](_page_8_Picture_1.jpeg)

## **SoLID Impact on TMDs**

- World: SIDIS data from the COMPASS / HERMES, e+e- annihilation data from the BELLE / BABAR / BESIII
- Top : impact on the *u* and *d* quarks' Sivers TMD extractions by the SoLID SIDIS program
- Bottom: ratios between the World and SoLID projected uncertainties shown in the top figures
- Projections from Monte-Carlo simulation at Q<sup>2</sup> = 2.4 GeV<sup>2</sup>

![](_page_8_Figure_7.jpeg)

![](_page_9_Picture_0.jpeg)

![](_page_9_Picture_1.jpeg)

#### **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

![](_page_9_Figure_6.jpeg)

![](_page_10_Picture_0.jpeg)

![](_page_10_Picture_1.jpeg)

#### **Transverse SSA Projections**

![](_page_10_Figure_3.jpeg)

- SoLID SIDIS projections of A<sub>UT</sub> in various
  4-D bins at 11/8.8 GeV
- Projections at EIC kinematics for the same observable at 29 GeV center-ofmass energy
- The scale of the SSA and uncertainties shown on the right-side axis of the figures
- SoLID and EIC projections synergistic towards each other, covering different x and Q<sup>2</sup> ranges

![](_page_11_Picture_0.jpeg)

![](_page_11_Picture_1.jpeg)

## Worm-gear Function $g_{1T}$

- First global extraction of g<sub>1T</sub>
- S. Bhattacharya et al., Phys. Rev. D105, 034007 (2022)
  - COMPASS, HERMES, and JLab 6 GeV data
  - Ongoing work for SoLID projections

![](_page_11_Figure_7.jpeg)

![](_page_11_Figure_8.jpeg)

#### More precise neutron data are needed for a better flavor separation

![](_page_12_Picture_0.jpeg)

![](_page_12_Picture_1.jpeg)

#### **Nucleon Tensor Charge**

- A fundamental QCD quantity
  - Matrix element of tensor current

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

- 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

![](_page_12_Figure_8.jpeg)

Gamberg, et al., PLB 816, 136255 (2021)

![](_page_13_Picture_0.jpeg)

![](_page_13_Picture_1.jpeg)

# **Run Group Proposal:** $g_2^n/d_2^n$ measurement

d\_2

Refer to talk from Tian Ye

- A run group proposal with E12-11-007 and E12-10-006
- Measurement of  $g_2^n$  with  $1.5 < Q^2 < 10$ GeV<sup>2</sup> and x > 0.1
- Extraction of  $x^2$  moment of  $\bar{g}_2^n$  $d_2(Q^2) = 3 \int_0^1 x^2 [g_2(x, Q^2) - g_2^{WW}(x, Q^2)] dx$ 
  - $1.5 < Q^2 < 6.5 \text{ GeV}^2$
  - Access to twist-3 contributions
  - Carry information about quark-gluon correlations

**Run Group Experiment Projection** 0.015 **11 GeV Projections** 8 GeV Projections SLAC E155x 0.010 JLab RSS + pQCD E01-012 E99-117 + E155x0.005 E06-014 Lattice QCD E12-06-121 Projections 0.000 -0.005ł -0.0102 З 7 8 10 Δ 5 q  $Q^2$  (GeV <sup>2</sup>)

![](_page_14_Picture_0.jpeg)

![](_page_14_Picture_1.jpeg)

# 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

Other high impact programs (J/psi, PVDIS, GPD, ...)

![](_page_15_Picture_0.jpeg)

![](_page_15_Picture_1.jpeg)

# **THANK YOU**