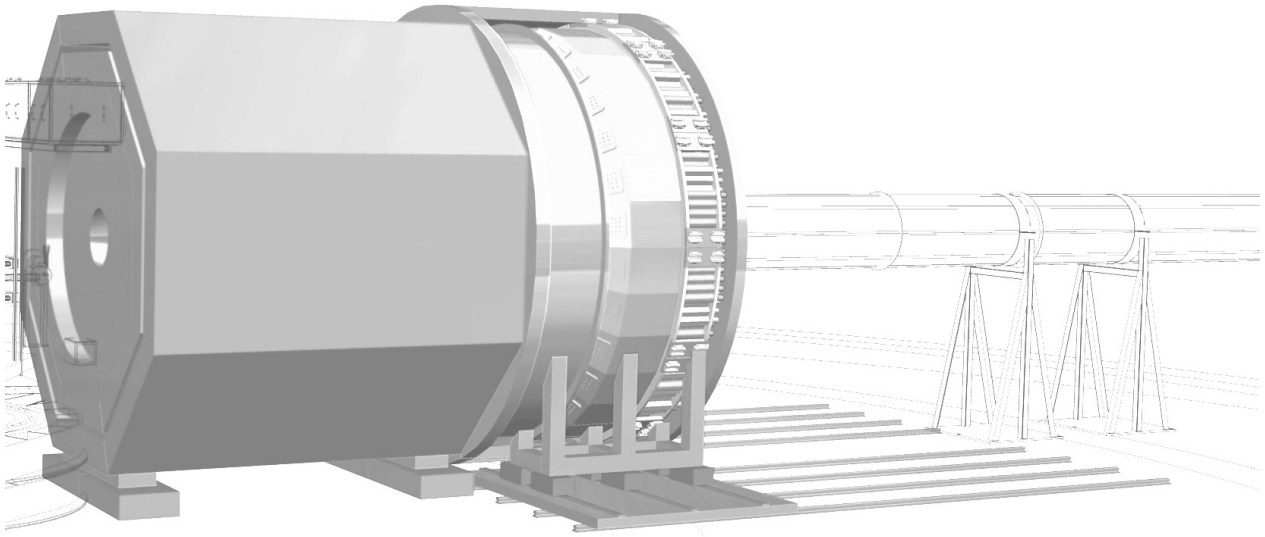
Overview and Update of Solenoidal Large Intensity Device (SoLID)



Michael Nycz
University of Virginia

JLab Hall A/C Collaboration Meeting
June 16-17, 2022

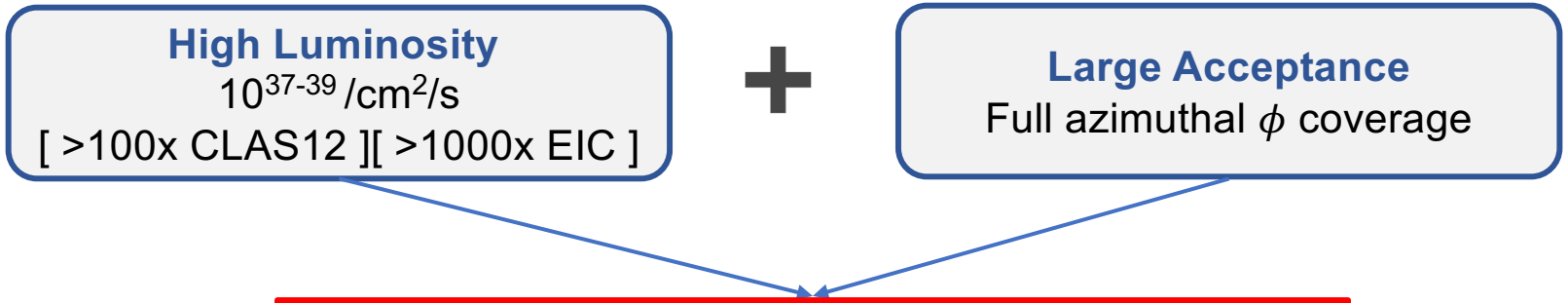
On Behalf of the SoLID Collaboration

SoLID
SOLENOIDAL LARGE INTENSITY DEVICE

Outline

- Introduction and overview of the SoLID spectrometer
- Overview of the three SoLID scientific programs
  - **SIDIS**
  - ***J / Ψ***
  - **PVDIS**
- Current status and recent activities

Introduction



- Pushing the phase space in the search of new physics and of hadronic physics
- 3D momentum imaging of a relativistic strongly interacting confined system (**nucleon spin**)
- High sensitivity to the differential electro- and photo-production cross section of J/ψ near threshold (**proton mass**)

Nucleon spin, proton mass, and beyond standard model experiments require **precision measurements of small cross sections and asymmetries:** combined with multiple particle detection

SoLID Apparatus

SoLID Requirements

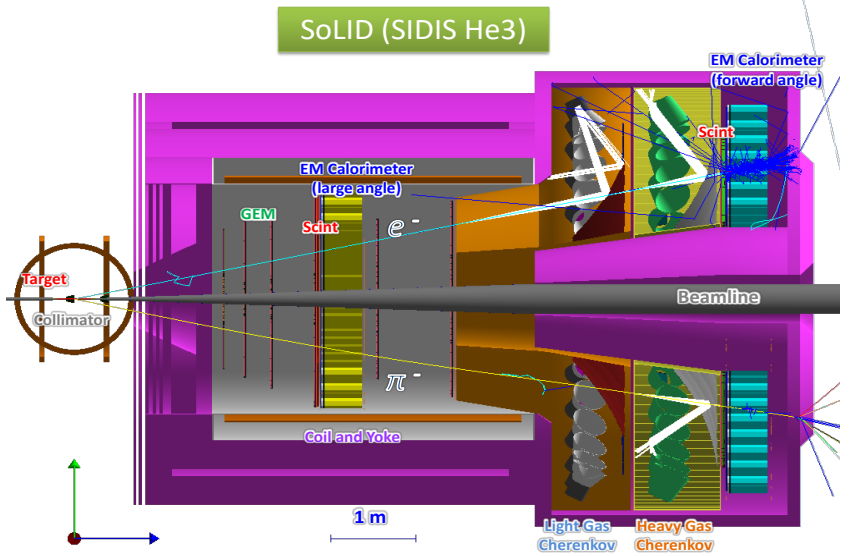
High

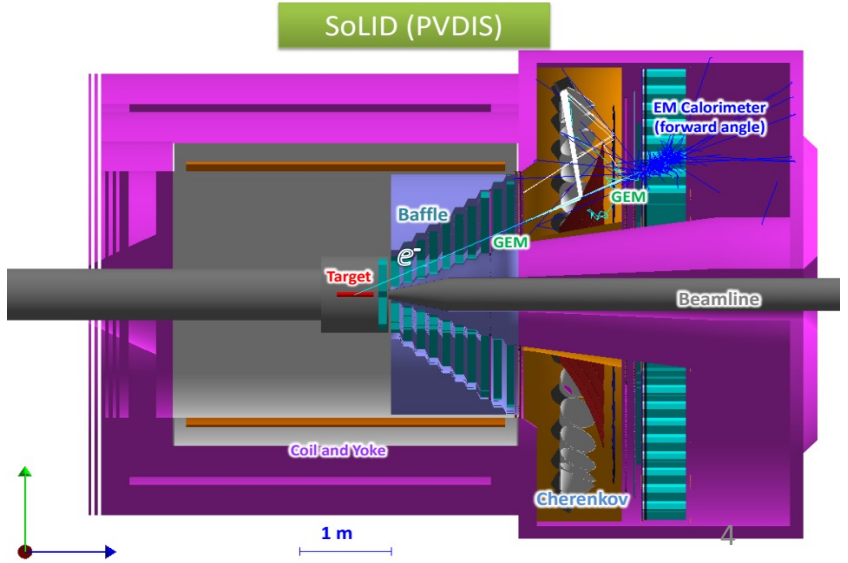
- Luminosity (10^{37}-10^{39})
- Background
- Radiation
- Data rate

- Low systematics
- Large scale

Leveraging Modern Technology

- GEM detectors
- Pipeline DAQ
- Shashlik electromagnetic calorimeter
- Baffles
- Data analysis (e.g. machine learning)
  - Jlab Data Science group



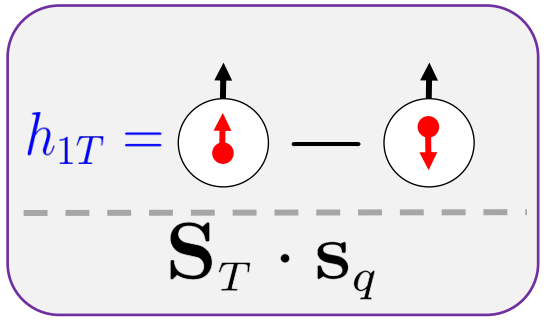


SoLID SIDIS Program

Transversely Polarized Nucleon TMDs

→ Nucleon Spin
→ Quark Spin

Transversity

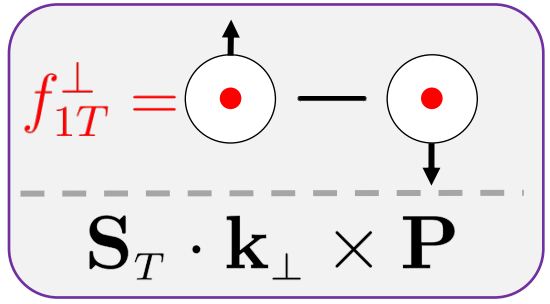


Relevant Vectors

S_T: Nucleon Spin
s_q: Quark Spin
$k_\perp$: Quark Transverse Momentum
P: Virtual photon 3-momentum (defines z-direction)

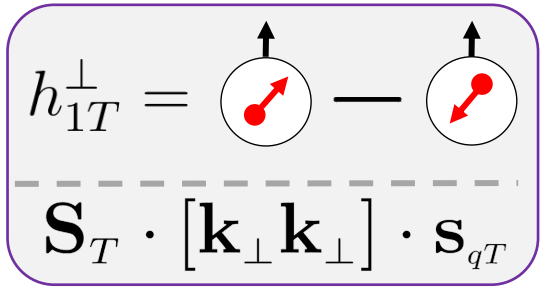
- h_{1T} (h_1) = g_1 (no relativity)
- h_{1T} → tensor charge (lattice QCD calculations)
- Connected to nucleon beta decay and EDM

Sivers



- Nucleon spin - quark orbital angular momentum (OAM) correlation – zero if no OAM (model dependence)

Pretzelosity



- Interference between components with OAM difference of 2 units (i.e., s-d, p-p) (model dependence)
- Signature for relativistic effect

Three Approved Experiments

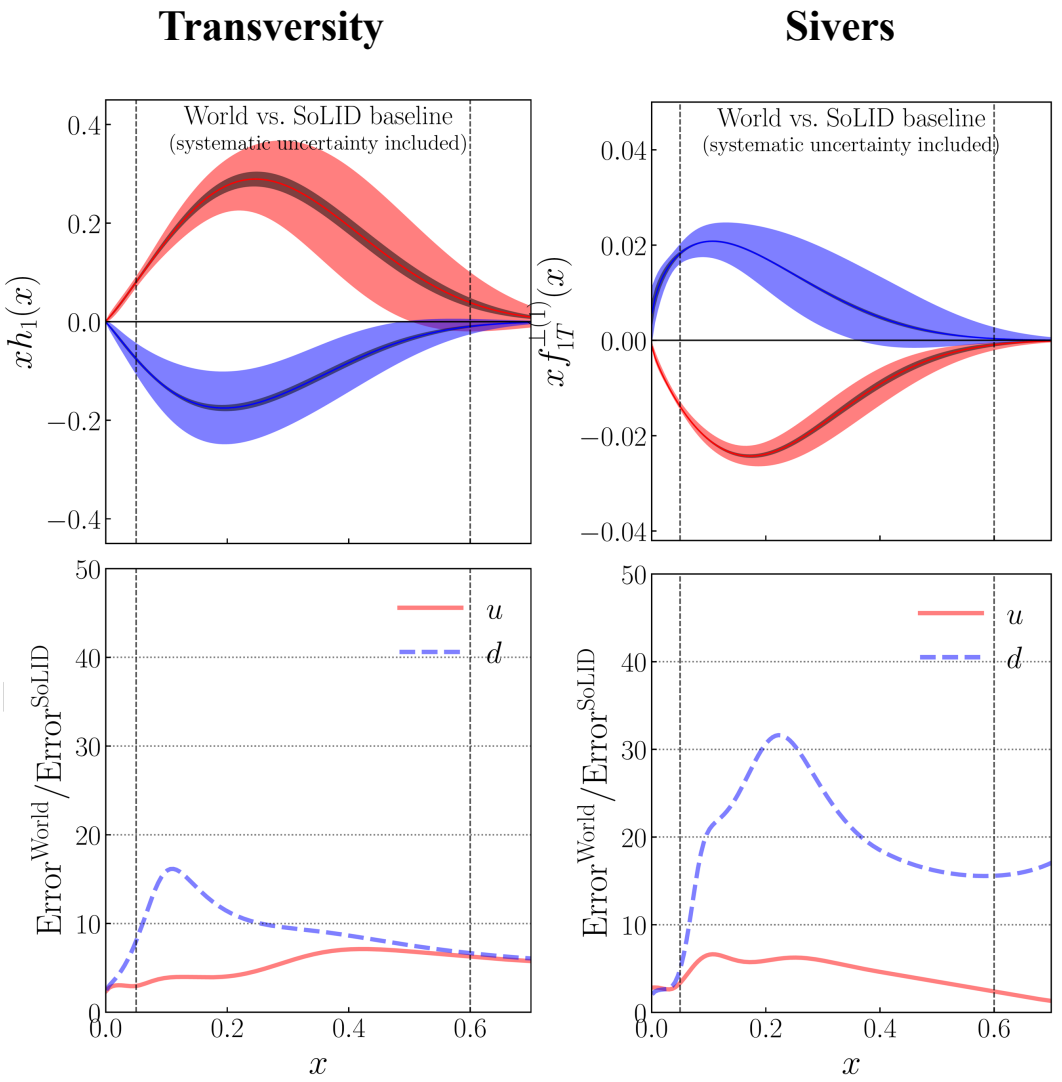
1. E12-10-006 : *Target Single Spin Asymmetry in Semi-Inclusive Deep-Inelastic (e, e'π±) Reaction on a Transversely Polarized 3He Target*
   Spokespersons: J.P. Chen, H. Gao (contact), J.C. Peng, X. Qian
2. E12-11-007 : *Asymmetries in Semi-Inclusive Deep-Inelastic (e,e'π±) Reactions on a Longitudinally Polarized 3He Target*
   Spokespersons: J.P. Chen (contact), J. Huang, W.B. Yan

1. E12-11-008 : *Target Single Spin Asymmetry in Semi-Inclusive Deep-Inelastic (e, e'π±) Reaction on a Transversely Polarized Proton Target*
   Spokespersons: J.P. Chen, H. Gao (contact), X.M. Li, Z.-E. Meziani

SoLID SIDIS Projections

Comparison of SoLID with World Data

- Perform fit of Collins and Sivers asymmetries in SIDIS and e^+e^- annihilation
- World data is from HERMES and COMPASS
- e^+e^- data is from BELLE, BABAR, and BESIII
- Monte Carlo method is applied
- Both systematic and statistical uncertainties are included

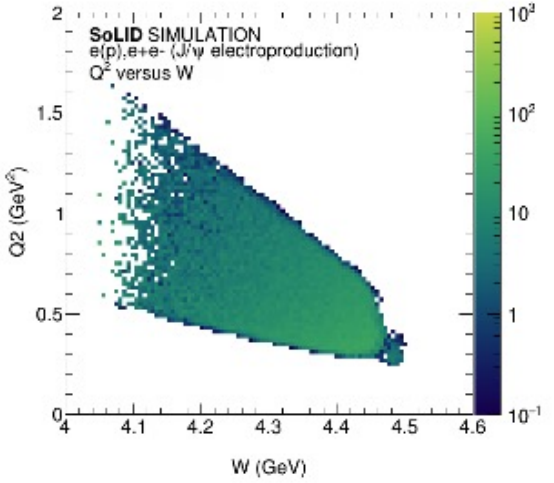


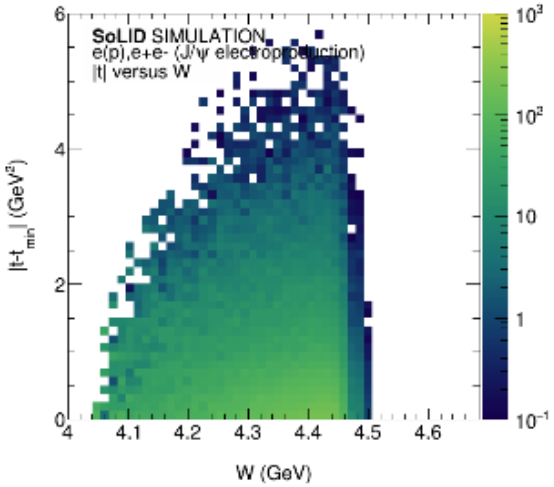
D'Alesio et al., Phys. Lett. B 803 (2020)135347
Anselmino et al., JHEP 04 (2017) 046

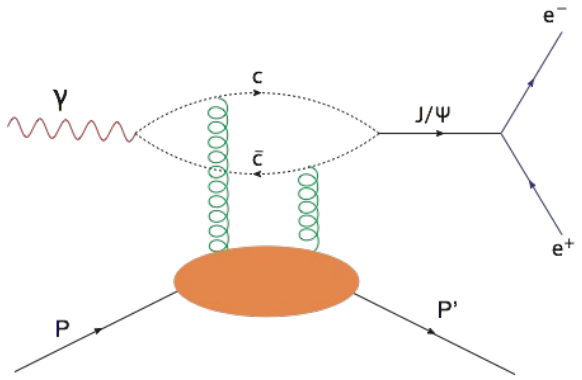
SoLID: J/Ψ Production Near Threshold

- 50 days of **3 μA** beam on a **15 cm** long LH_2 target
  - 10 days which include calibration/background run
- Compatible with SoLID SIDIS configuration
  - **Electroproduction trigger**: 3-fold coincidence of e, e^-e^+
  - **Photoproduction trigger:** 3-fold coincidence of p, e^-e^+
  - **Additional trigger:** 4-fold coincidence of ep, e^-e^+
  - And (inclusive) 2-fold coincidence e^+e^-

$1 \times 10^{37} \mathrm{cm}^{-2}\mathrm{s}^{-1}$







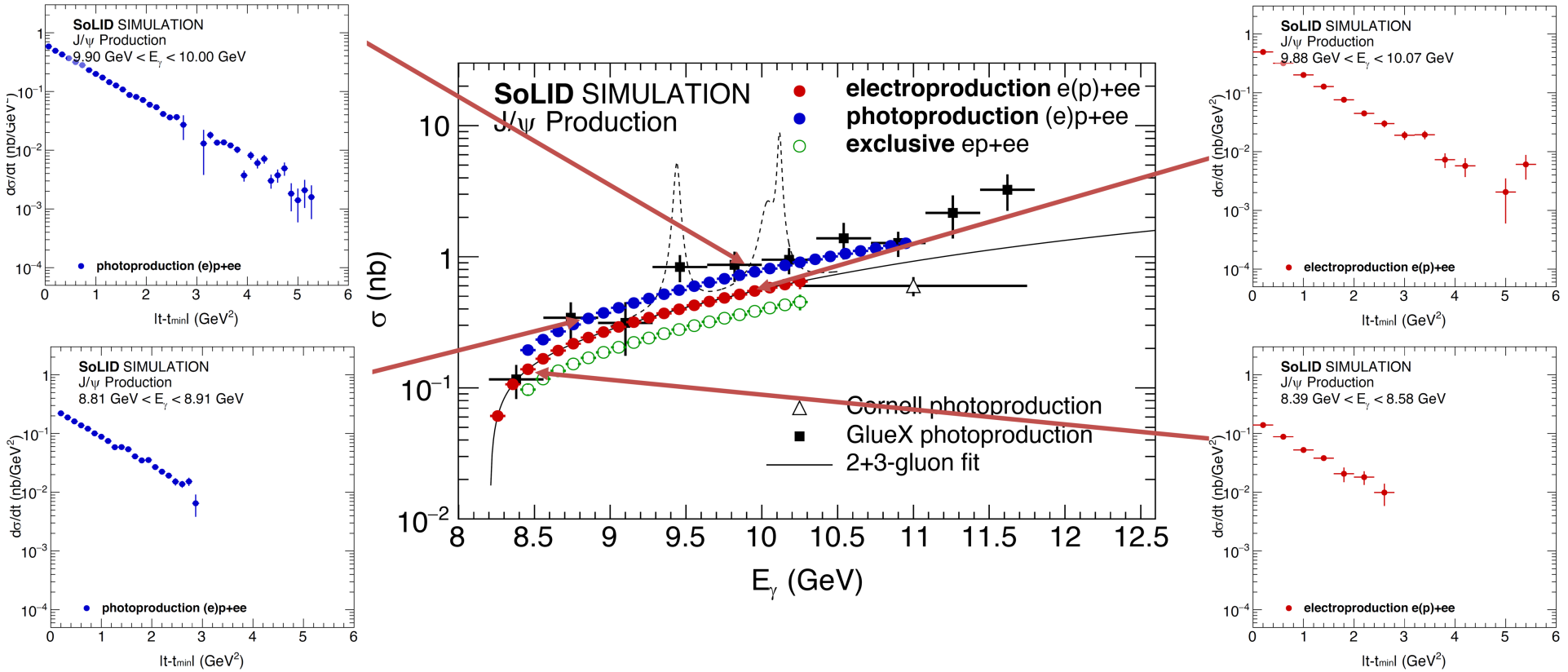
$$e^- + p \longrightarrow e^- + p + J/\psi\,(e^+ + e^-)$$

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

E12-12-006

Spokespersons: K. Hafidi, X. Qian, N. Sparveris, Z.-E. Meziani (contact), Z. Zhao

SoLID J/Ψ Projections



Sensitivity at threshold at about 10^{-3} nb!

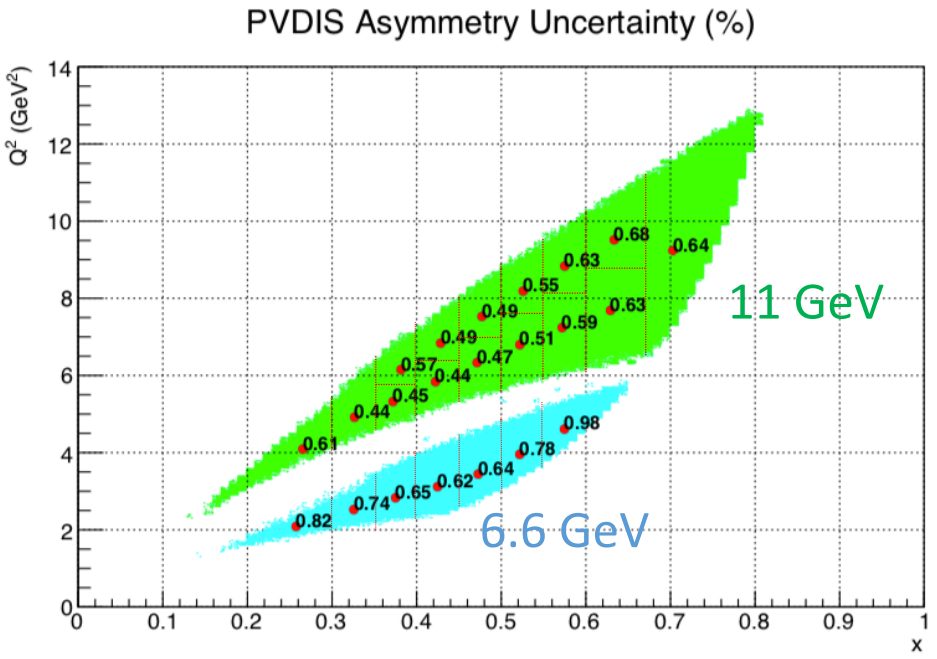
SoLID PVDIS Program

Parity Violating DIS on Isoscalar Deuteron

12 GeV JLab upgrade coupled with the high luminosity and large acceptance of SoLID provides an opportunity to perform the ultimate PVDIS experiment

Precision: sub-1% over wide kinematic range

Standard model test
Charge symmetry violation
Quark-quark correlation
d/u measurement



Achieving High Luminosity

- 50 μA (40 cm liquid ^{2}H target)
- Utilization of baffles to reduce background
- High-rate GEMs

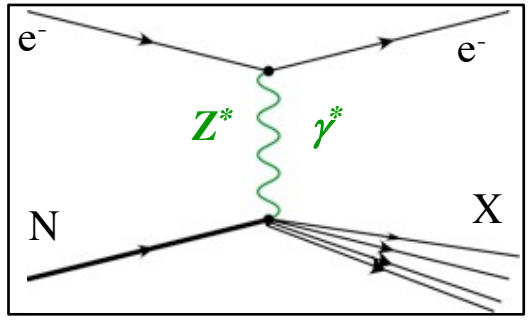
Kinematic Requirements

- x: 0.25-0.7: untangle physics
- $W^2 > 4$ GeV^2 , isolate DIS
- Q^2 range a factor of 2 for each x bin: Measure Higher Twist

E12-10-007

Spokesperson: Paul Souder

SoLID PVDIS Program



$$A_{PV} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V \frac{f(y)}{2}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

$Q^2 >> 1\ GeV^2$, $W^2 >> 4\ GeV^2$

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

$x \equiv x_{Bjorken}$

$y \equiv 1 - E'/E$

$$A_{\text{iso}} = \frac{\sigma^l - \sigma^r}{\sigma^l + \sigma^r} = -\left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\frac{2C_{1u} - C_{1d}\left(1 + R_s\right) + Y\left(2C_{2u} - C_{2d}\right)R_v}{5 + R_s}$$

At high x, A_{iso} becomes independent of pdfs, x & W, with well-defined SM prediction for Q^2 and y

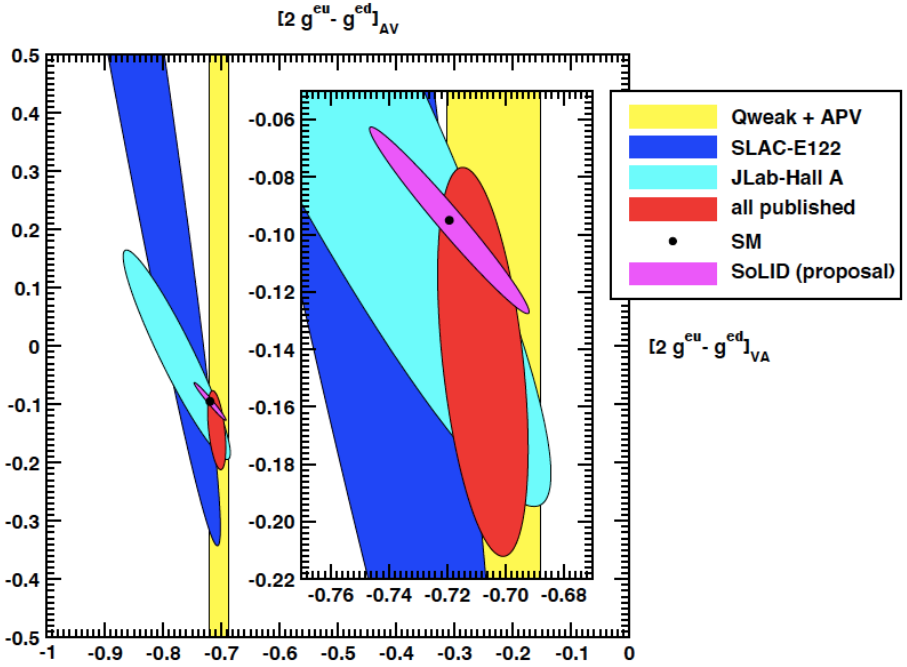
$$R_s(x) = \frac{2S(x)}{U(x) + D(x)} \xrightarrow{\text{Large } x} 0$$

$$R_v(x) = \frac{u_v(x) + d_v(x)}{U(x) + D(x)} \xrightarrow{\text{Large } x} 1$$

Interplay with QCD

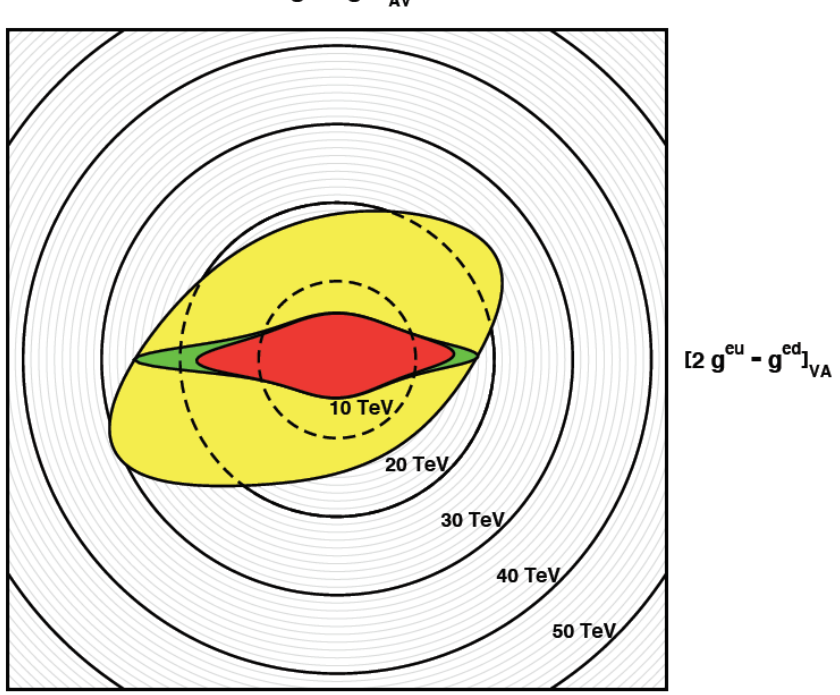
- **Parton distributions (u, d, s, c)**
- **Charge Symmetry Violation (CSV)**
- **Higher Twist (HT) – quark-quark correlation**

PVDIS Projected Results



With the expected precision, SoLID will make a unique contribution to the SMEFT program

Improvement in energy reach for electron-nucleon couplings



PVDIS: d/u Ratio for the Proton

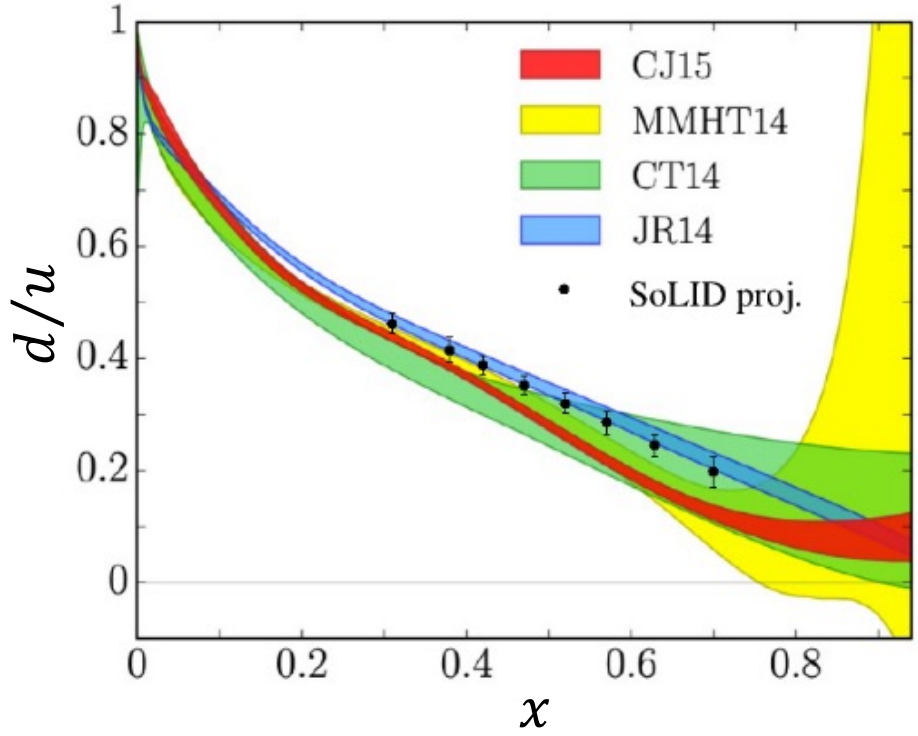
Opportunities for physics using PVDIS with other targets

Hydrogen target

By measuring A_{PV} of proton can access the d/u ratio while avoiding nuclear corrections

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

$$\boldsymbol{A^{p}_{PVDIS}(x) \approx \frac{u(x) + 0.91\, d(x)}{u(x) + 0.25\, d(x)}}$$



PVDIS is complementary to the rest of the JLab d/u program.

Approved Run Group Proposals

E12-10-006A: *SIDIS Dihadron with Transversely Polarized ^{3}He*

E12-11-108B/E12-10-006D: *SIDIS in Kaon Production with Transversely Polarized Proton and ^{3}He*

E12-11-108A/E12-10-006A: *Target Single Spin Asymmetry Measurements in the Inclusive Deep-Inelastic Reaction on Transversely Polarized Proton and Neutron (^{3}He) Targets using the SoLID Spectrometer*

E12-11-007A/E12-10-006E: *Measurement of Inclusive g2n and d2n with SoLID on a Polarized ^{3}He Target*

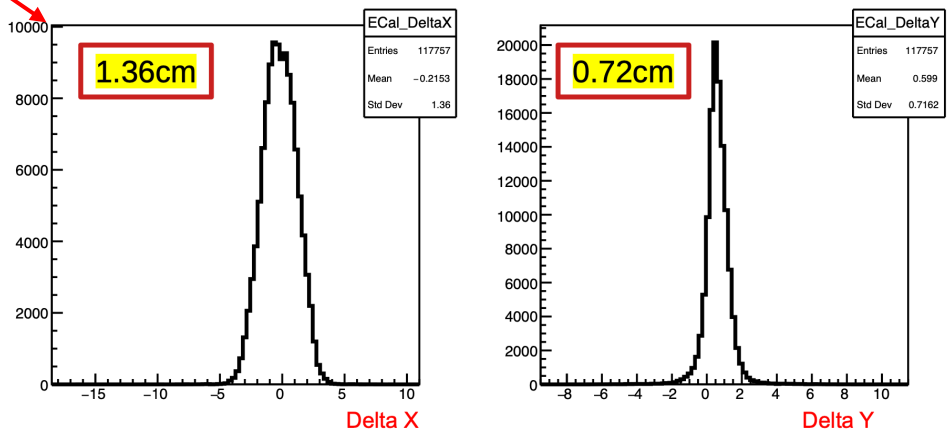
E12-10-006B: *Measurement of Deep Exclusive Pi- Production using a Transversely Polarized He3 Target and the SoLID Spectrometer*

E12-12-006A: *TCS with circular polarized beam and unpolarized LH2 target*

Recent Activities

- DOE Science Review (3/2021): waiting for report
- DOE funded pre-R&D activities: LGC and DAQ
- Magnet Cold Test
- ECal test at Fermilab Test Beam Facility
- Detector/DAQ Beam tests at high luminosity
- Detector Development
  - Cherenkov mirrors
  - HGC prototyping
  - MRPC beam test at Fermi Lab
  - ECal prototyping and tests
- Software and Simulation Development
  - Synergy with EIC software development
  - Continue AI/ML collaboration with JLab data science group
  - Update event generators
  - PID and Tracking developments
- PAC 50: All approved SoLID experiments are under jeopardy
  - Collaboration actively working to update and defend experimental proposals

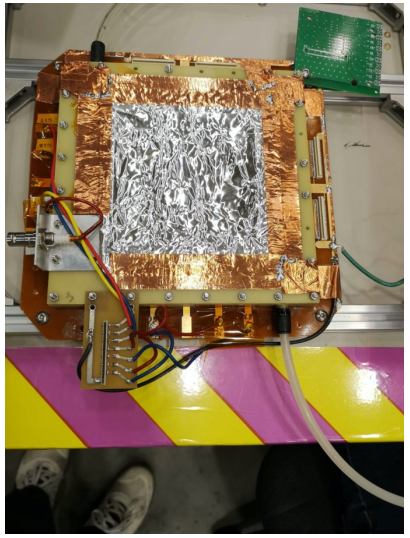
CLEO-II magnet in Test Lab

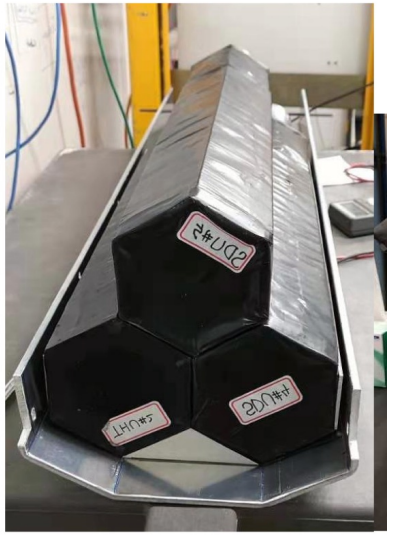


ECal position resolution

Parasitic Beam Test in Hall C

- Recent detector tests
  - Cherenkov high-rate test in Hall C (2020)
  - ECal beam test at Fermilab (2021)
- Director's Review (2021)
  - Recommendation: High-rate test with full subsystems
- Detectors
  - Ecal (preshower + shower), GEMs, cherenkov, SPDs, and scintillators
- Design and layout of current test similar to that of Cherenkov beam test
- Test stand modified by Hall C technicians to accommodate detector layout



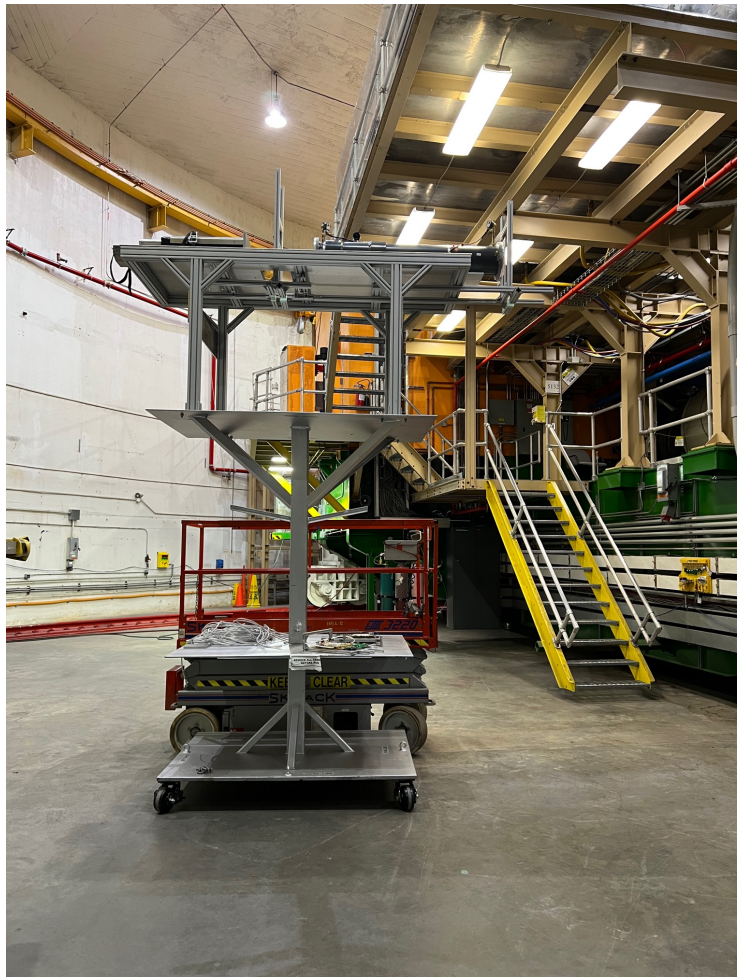


A huge thank you to Hall A/C staff for their support, especially Walter and the Hall C technicians for all their assistance in preparation and installation

Parasitic Beam Test in Hall C

Milestones

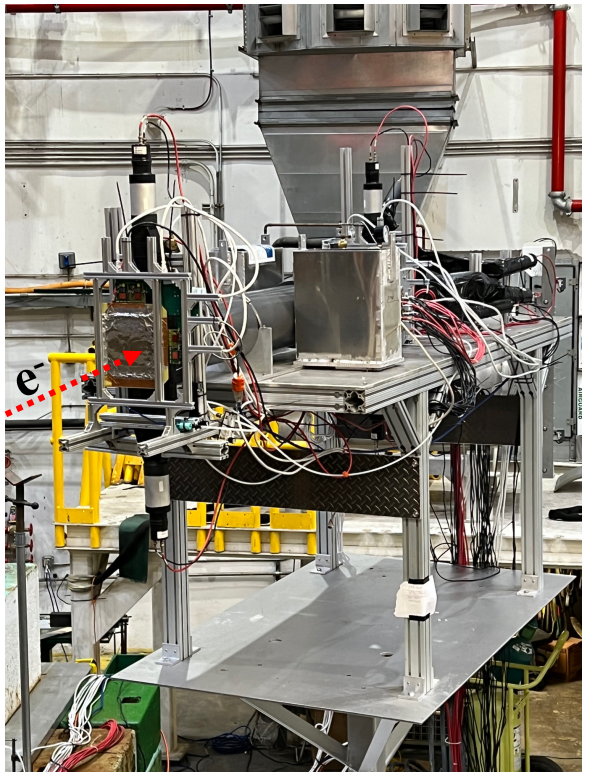
- Milestone 1: Bring all detectors to working condition and ready for beam test
  Complete: end of May 2022
  Completion criterion: All detectors are tested with cosmic data and show reasonable signals; design and completion of test stand.
- Milestone 2: Installation into experimental hall and carry out low rate test
  Complete: August 2022 + 1 month contingency
  Completion criterion: All detectors are moved to experimental hall C, tested with electron beam at the low-rate location, and show reasonable signals.
- Milestone 3: VMM high radiation components ready for testing
  Complete: January 2023 + 3 month contingency
  Completion criterion: procurement and production of radiation hard power supply and data transfer mezzanine boards based on CERN radiation hard lpGBT and bPOL components.
- Milestone 4: Low-rate test data analysis
  Complete: September 2022 + 1 month contingency
  Completion criterion: Data collected during low rate test analyzed and understood. Ideally, we will see MIP signals in SPD, Preshower and Shower detectors, see signals in Cherenkov detector and GEM trackers, and can identify tracks with GEM. GEM tracking reconstruction efficiency and accuracy will be studied. Data will also be used to optimize high-rate running condition such as trigger and PMT gain setup.

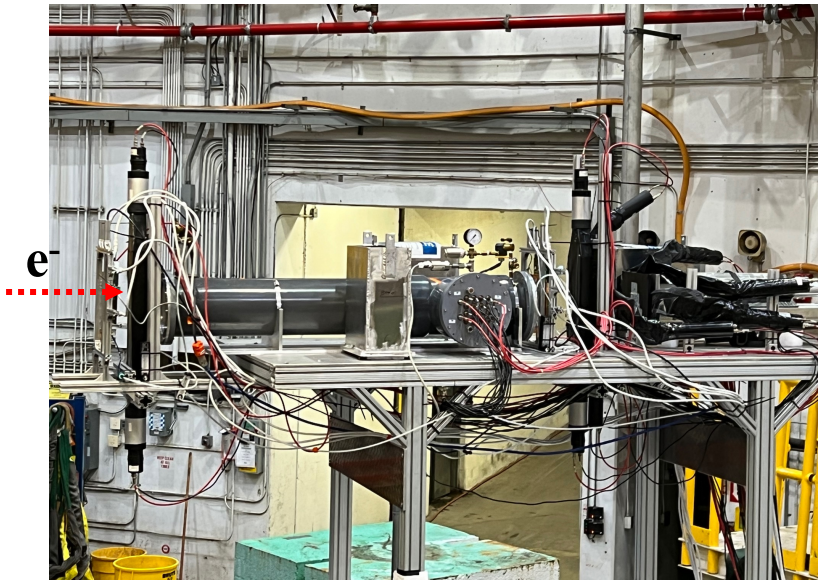


Detector test stand in Hall C

Parasitic Beam Test in Hall C

- Setup in Hall C: SHMS side
  - ~70°
- VXS crate and FADC 250 modules
  - Behind green wall
- Set up is complete
  - VME comp. died last week
  - Recovering and updating
    - (thanks Bryan Moffit)
  - Anticipate detector checkout next week
- Low-rate test (June – August)
  - Ensure all detectors are working properly
- High-rate test
  - Opportunistically move near beam line





Summary and Outlook

- SoLID: A large acceptance device which can handle very high luminosity to allow full exploitation of JLab12 potential---pushing the limit of the luminosity frontier
- SoLID has rich and vibrant science programs complementary and synergistic to the proposed EIC science program
  - Three pillars on SIDIS, PVDIS and J/ψ production
  - Along with a diverse set of approved run-group experiments including GPD program
- After a decade of hard work, we have a mature pre-conceptual design with expected performance to meet the challenging requirements for the three major science programs
- Ongoing detector and daq beam tests along with continued detector development
- Second SoLID white paper in progress
- Collaboration is working on projections for Jlab 20 GeV
- SoLID collaboration is active, international, and with many theory collaborators

New collaborators are welcomed!