SoLID and Future Programs at JLab

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Duke University

The 26th International Symposium on Spin Physics
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Jefferson Lab

OUTLINE

- Introduction
- The SoLID Program and status
- Selected future programs at JLab
- Summary

100 YEARS SPIN 2025
26th International Symposium on Spin Physics
A Century of Spin

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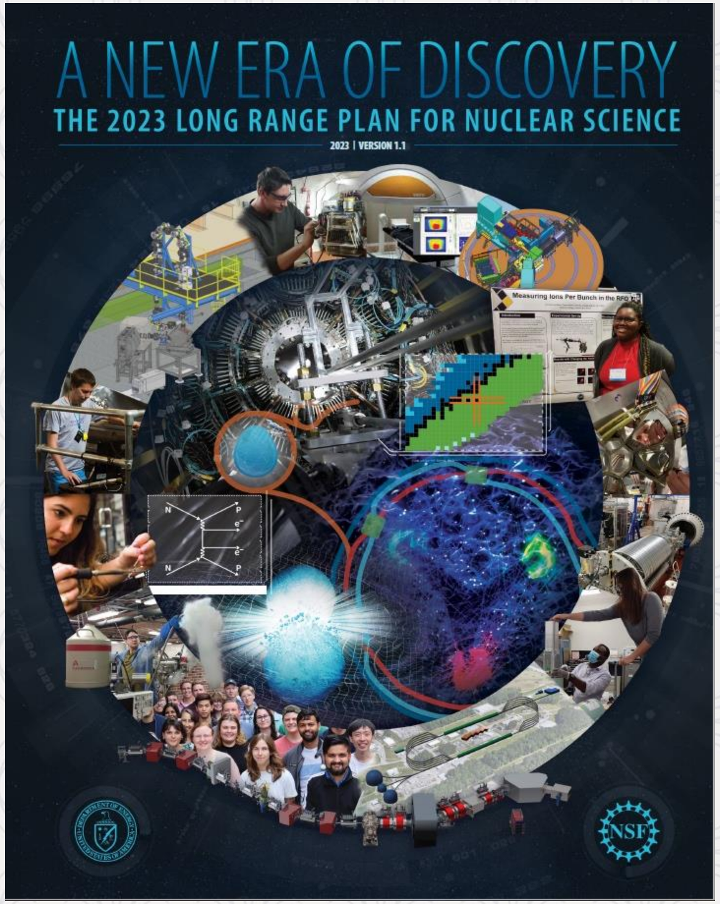
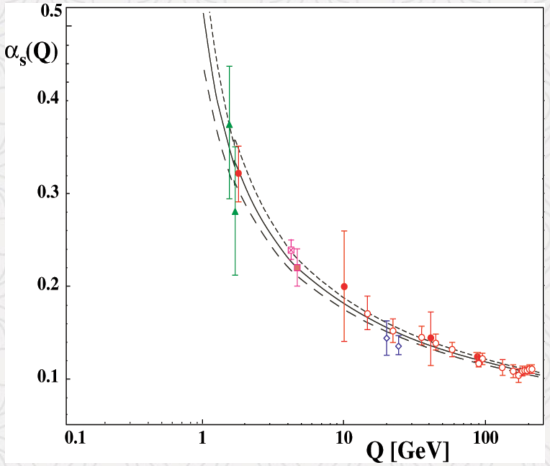
The Fundamental Structure of Visible Matter

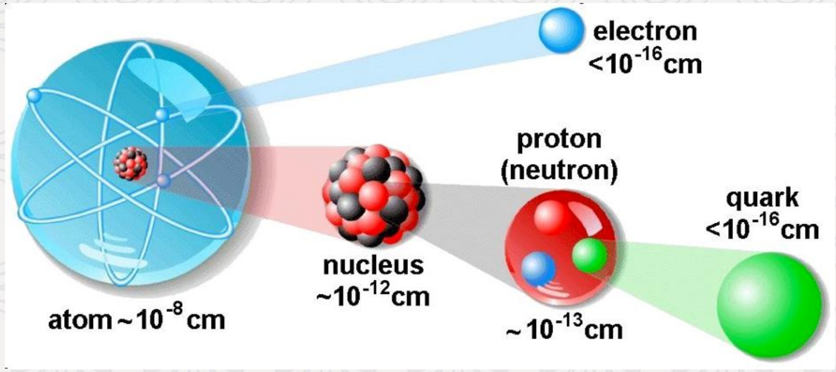


- How does QCD generate the spectrum and structure of conventional and exotic hadrons?
- How do the mass and spin of the nucleon emerge from the quarks and gluons inside and their dynamics?
- How are the pressure and shear forces distributed inside the nucleon?
- How does the quark–gluon structure of the nucleon change when bound in a nucleus?
- How are hadrons formed from quarks and gluons produced in high-energy collisions?

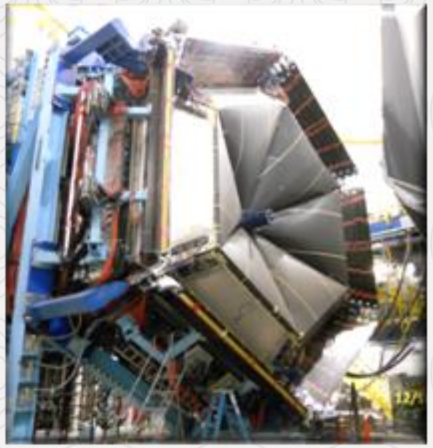
Hadron properties and structure
Nuclei and QCD
Hadronization: forming QCD bound states
Spectrum of excited hadrons



https://science.osti.gov/-/media/np/nsac/pdf/202310/NSAC-LRP-2023-v12.pdf
https://arxiv.org/abs/2303.02579



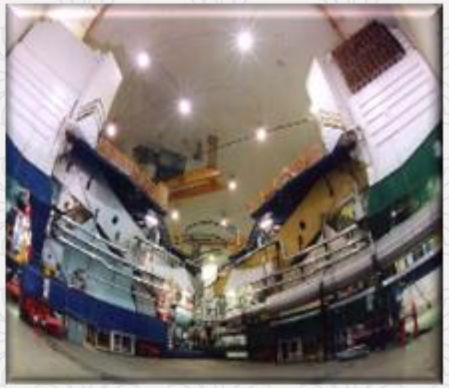
JLab 12 GeV Scientific Capabilities



Hall D – exploring origin of confinement by studying exotic mesons

Hall B – understanding nucleon structure via generalized parton distributions and transverse momentum distributions

Hall C – precision determination of valence quark properties in nucleons and nuclei



Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments (e.g., SoLID and MOLLER)

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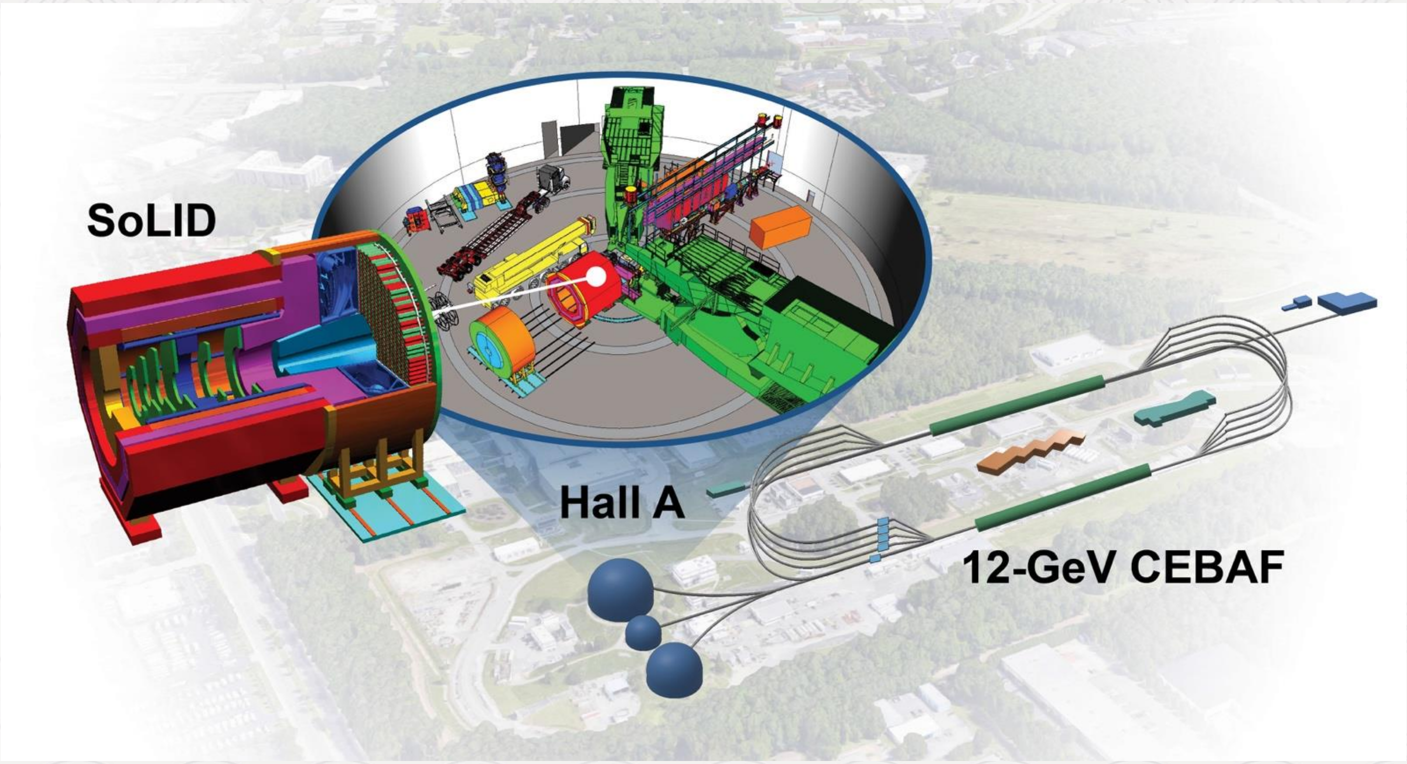
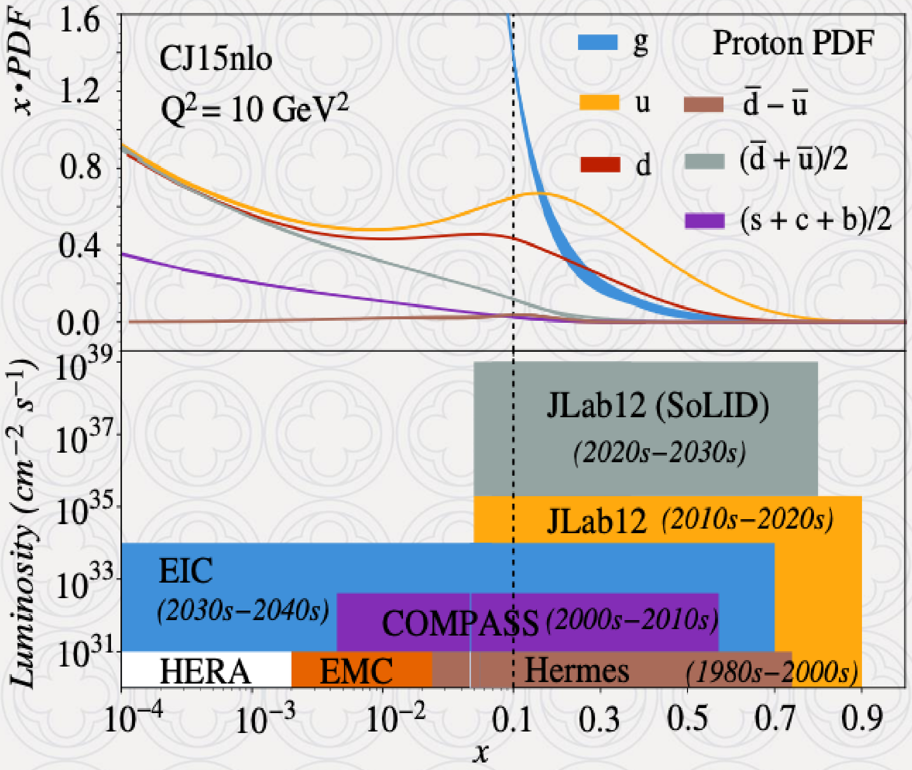
Interplay of Energy and Intensity

Structure of visible matter probed at JLab and the future EIC

Discoveries in Physics are often enabled by high-precision measurements and that is where

Solenoidal Large Intensity Device (SoLID) comes!





Haiyan Gao (Duke), Zein-Eddine Meziani (ANL)
https://www.innovationnewsnetwork.com/quantum-chromodynamics-at-the-intensity-frontier-with-a-precision-microscope/52920/

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SoLID Science and Project Development Timeline

- **Rich physics program:** (2010-now)

  6 SoLID experiments approved by PAC with high rating (5 A, 1 A-)

  3 SIDIS (3d structure), 1 PVDIS (search for new physics),

  1 threshold J/ψ (gluon force), 1 A- on BNSSA (new phenomena)

  + 2 conditional approval (1 C1 approval on DDVCS with A rating

  + 7 run-group experiments (3d/spin structure)

- **Pre-conceptual design, Pre-R&D, reviews and status**

  2014: pCDR submitted to JLab with cost estimation, updated in 2017, 2019

  Director's Reviews in 2015, 2019 and 2021

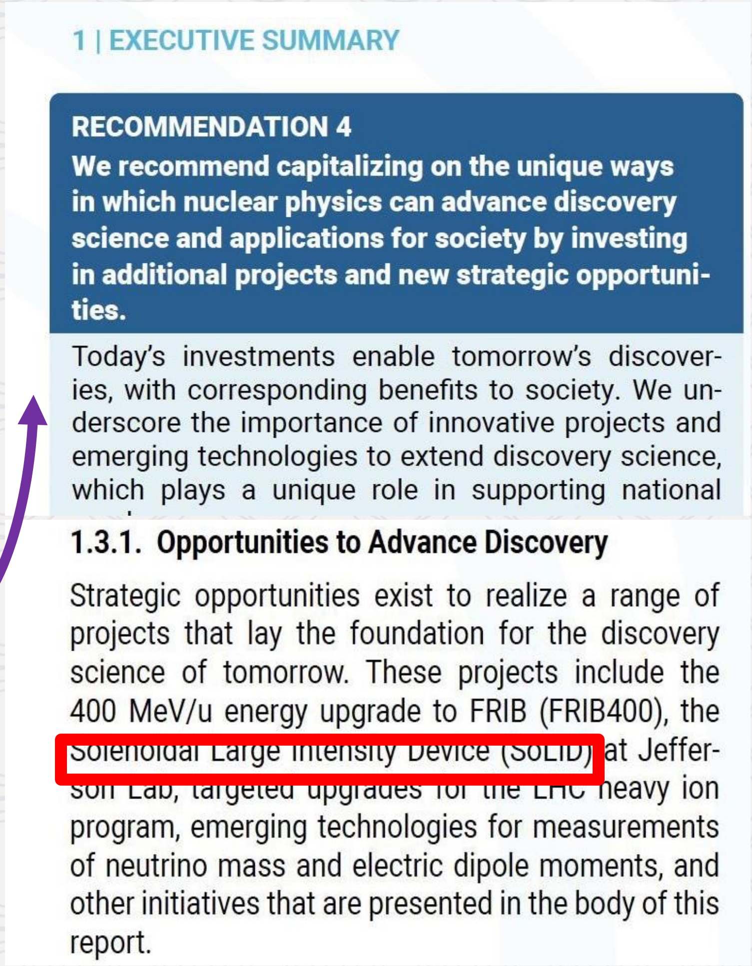
  2020: SoLID MIE (with updated pCDR/estimated cost) submitted to DOE

  2020-now: DOE funded pre-R&D activities

  2021: DOE **Science Review for SoLID, positive feedback**

  2023: **Long Range Plan, SoLID highlighted, one of the recommendations**

  2024: DOE Office of Science Facility Review: Ready to Launch



1 | EXECUTIVE SUMMARY

RECOMMENDATION 4

We recommend capitalizing on the unique ways in which nuclear physics can advance discovery science and applications for society by investing in additional projects and new strategic opportunities.

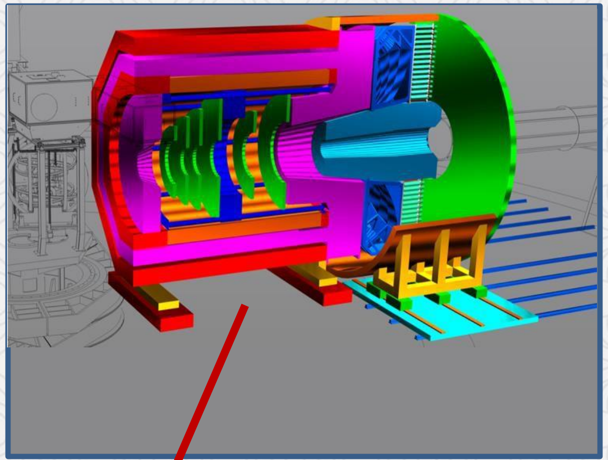
Today's investments enable tomorrow's discoveries, with corresponding benefits to society. We underscore the importance of innovative projects and emerging technologies to extend discovery science, which plays a unique role in supporting national

1.3.1. Opportunities to Advance Discovery

Strategic opportunities exist to realize a range of projects that lay the foundation for the discovery science of tomorrow. These projects include the 400 MeV/u energy upgrade to FRIB (FRIB400), the Solenoidal Large Intensity Device (SoLID) at Jefferson Lab, targeted upgrades for the LHC heavy ion program, emerging technologies for measurements of neutrino mass and electric dipole moments, and other initiatives that are presented in the body of this report.

Solenoidal Large Intensity Device (SoLID)

SoLID will ***maximize*** the science return of the 12-GeV CEBAF upgrade by **combining**

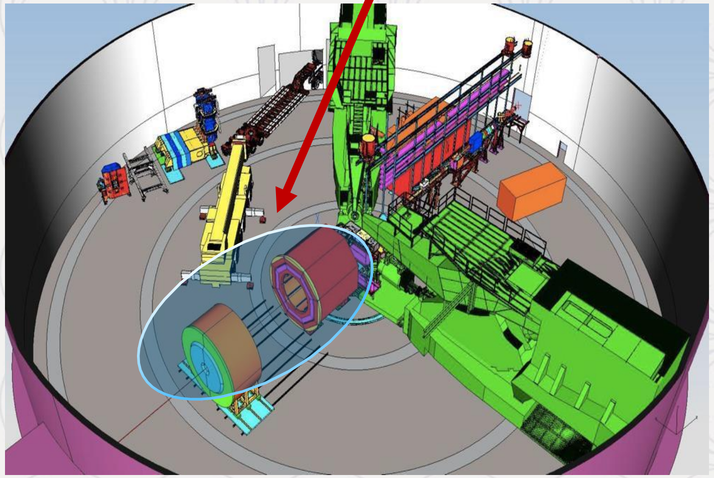


High Luminosity
$10^{37\text{-}39}$ /cm^2/s
[>100x CLAS12][>1000x EIC]

+

Large Acceptance
Full azimuthal ϕ coverage

Research at **SoLID** will have the ***unique*** capability to **explore** the QCD landscape while **complementing** the research of other key facilities including the future EIC



Two science pillars of the SoLID (**proton spin** and **mass**):
high-luminosity valence quark tomography and precision J/ψ production near threshold (EIC in the sea/gluon region, **both needed!)**
PVDIS: test of Standard Model & search for new physics

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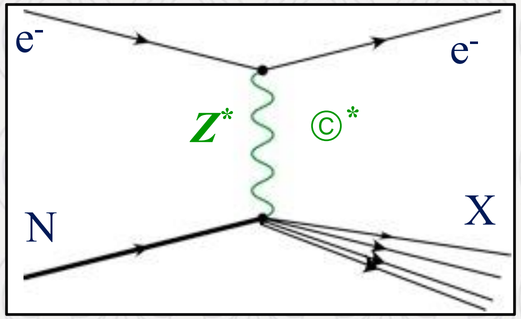
PV Deep Inelastic Scattering

Off the simplest isoscalar nucleus and at high Bjorken *x*



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

$x \equiv x_{Bjorken}$

$y \equiv 1 - E'/E$

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

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

$$Y = \frac{1-(1-y)^2}{1+(1-y)^2 - y^2\frac{R}{R+1}}$$

$$R(x,Q^2) = \sigma^l/\sigma^r \approx 0.2$$

$$A_{\rm iso} = \frac{\sigma^l - \sigma^r}{\sigma^l + \sigma^r}$$

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

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

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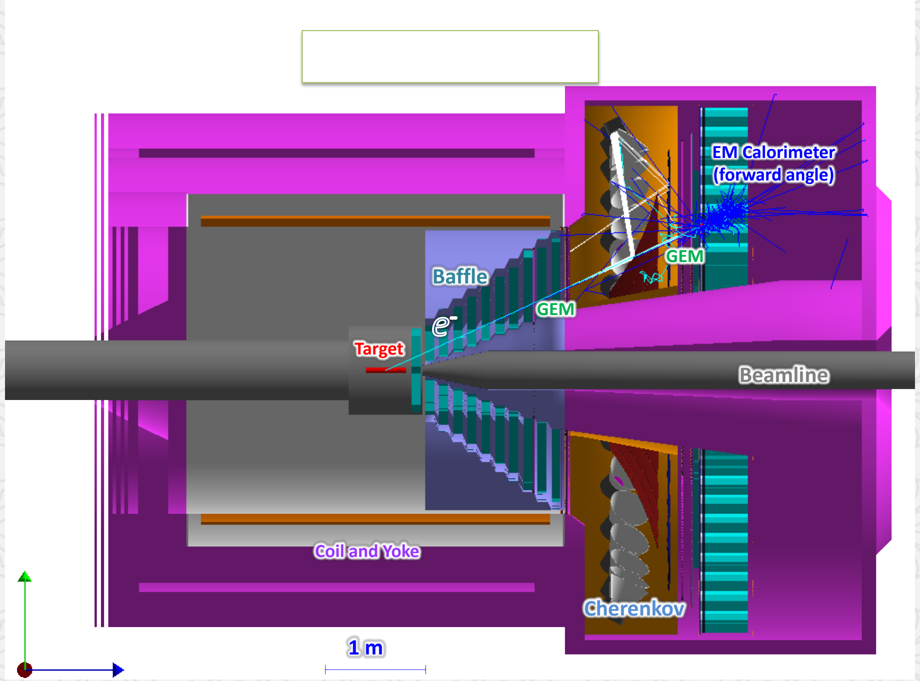
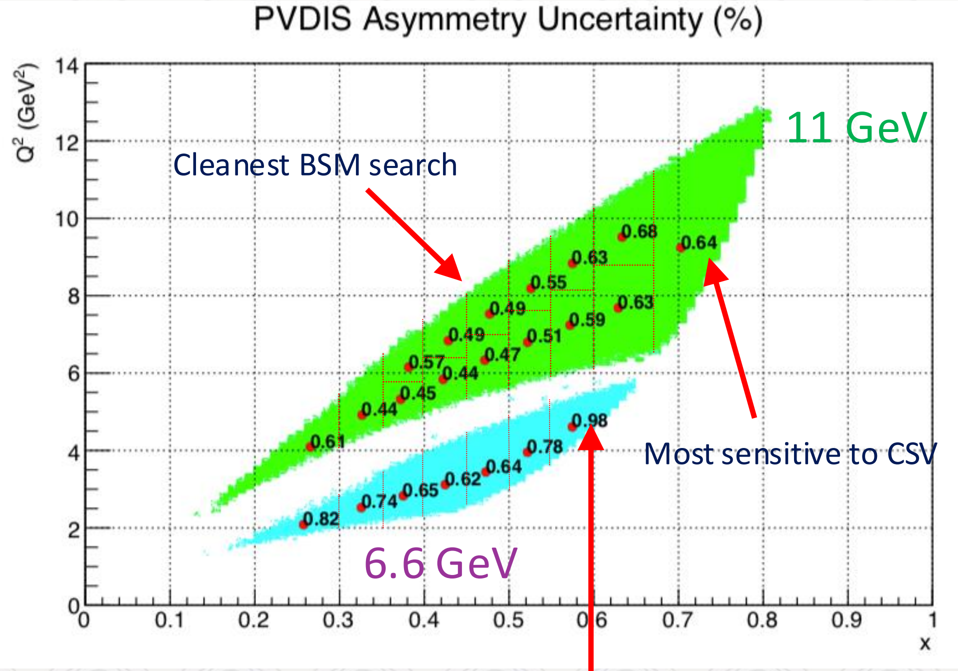
PVDIS @ SoLID: Experiment E12-10-007

12 GeV CEBAF: Extraordinary opportunity to do the ultimate PVDIS measurement

Strategy: **sub-1% precision** over broad kinematic range: **sensitive Standard Model test** *and* **detailed study of hadronic structure contributions**

Targets: deuterium and hydrogen



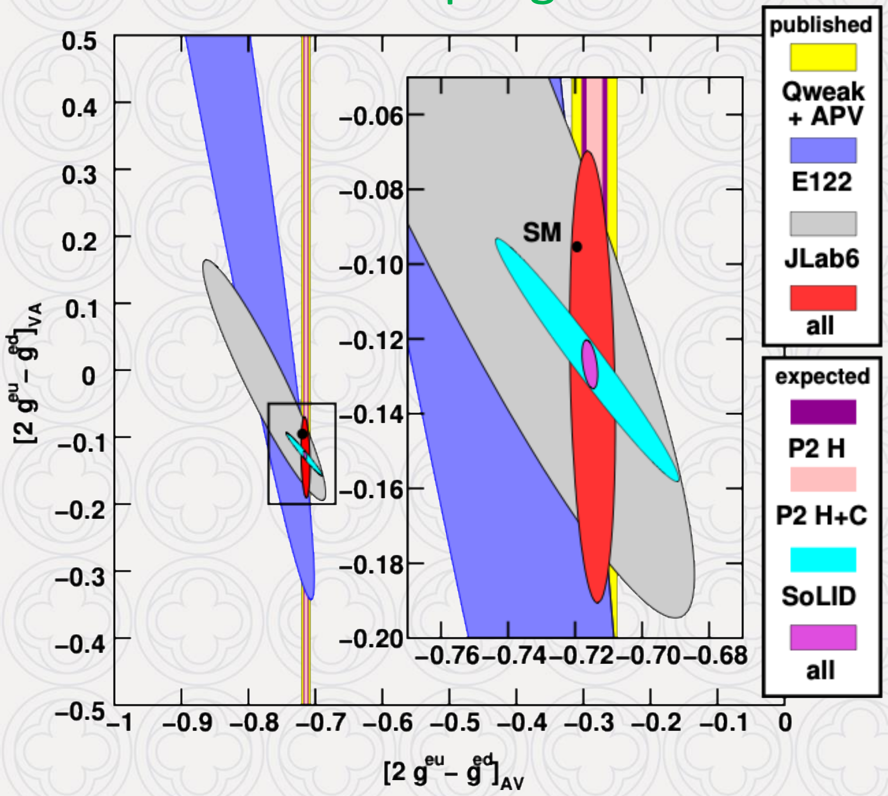


Spokespersons: Paul Souder (contact), Paul Reimer and Xiaochao Zheng

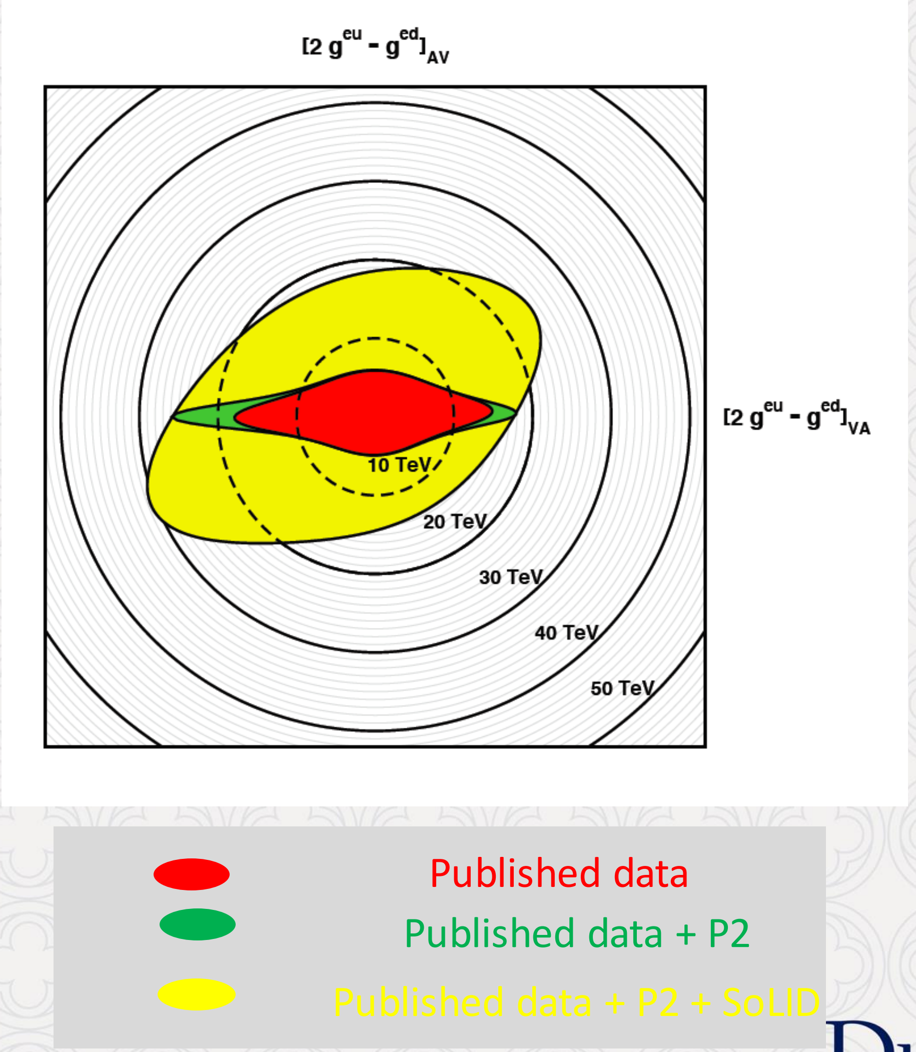
Projected Results

With this precision,
SoLID makes a unique contribution
to the Standard Model Effective Field Theory program.

Improvement in
couplings



Improvement in energy reach for
electron-nucleon couplings



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Proton Mass, Trace Anomaly/Gravitational Form Factors

- **Nucleon mass is the total QCD energy in the rest frame (QED contribution small)**

$$H_{QCD} = H_q + H_m + Hg + H_a$$

$H_q =$ Quark energy $\int d^3x\, \psi^\dagger (-i\mathbf{D}\cdot\alpha)\psi$

$H_m =$ Quark mass $\int d^3x\, \bar{\psi} m \psi$

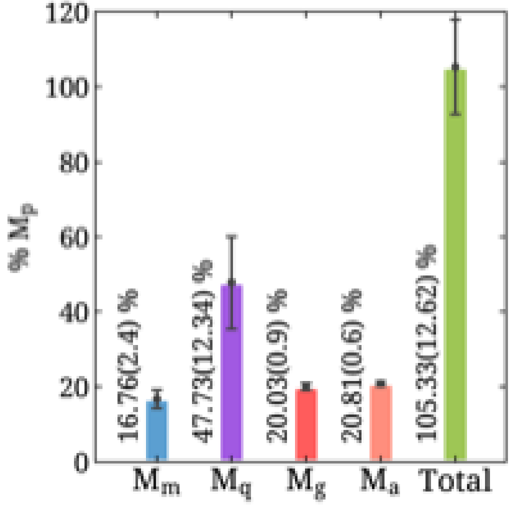
$H_g =$ Gluon energy $\int d^3x\, \frac{1}{2}(\mathbf{E}^2 + \mathbf{B}^2)$

$H_a =$ Quantum Anomalous energy $\int d^3x\, \frac{9\alpha_s}{16\pi}(\mathbf{E}^2 - \mathbf{B}^2)$

Sets the scale for the hadron mass!

X. Ji PRL 74 1071 (1995), X. Ji & Y. Liu, arXiv: 2101.04483

First three contributions can be determined from PDFs and pi-N sigma term. And from lattice QCD→



C. Alexandrou et al., (ETMC), PRL 116, 252001 (2016); PRL 119, 142002 (2017) ;
Y.-B. Yang *et al.*, (χQCD), PRL 121, 212001 (2018)

C. Lorce', EPJC 78 (2018) 2; C. Lorce', H. Moutarde and A. Trawińsk, EPJC79 (2019); Metz, Pasquini and Rodini, PRD102, 114042(2021); Lorce, Metz, Pasquini, Rodini, JHEP 11 (2021) 121; Rodini, Metz, Pasquini, JHEP 09 (2020) 067

- **Accessing trace anomaly in experiments is an important goal in the future**

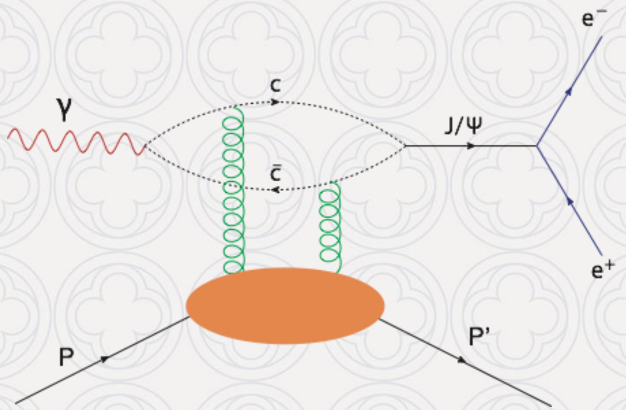
  accessed via heavy quarkonium threshold (J/psi & Upsilon) production

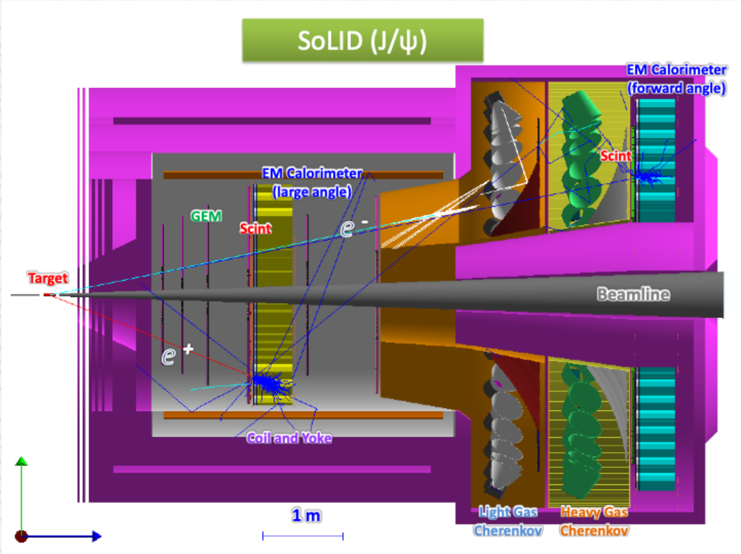
  D. Kharzeev, Proc. Int. Sch. Phys. Fermi 130, 105 (1996); Kharzeev, Satz, Syamtomov, and Zinovjev EPJC,9, 459, (1999); Gryniuk and Vanderhaeghen, PRD94, 074001 (2016); R. Wang, J. Evslin and X. Chen, Eur. Phys. J. C 80, 507 (2020); Y. Hatta, D-L Yang, PRD 98, 074003 (2018); Hatta et al., PRD 100, 014032 (2019); ……

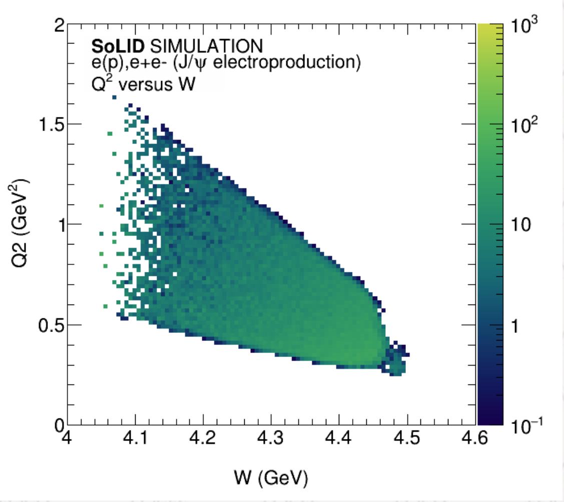
Understanding reaction mechanisms:
GlueX, PRC**108**, 025201 (2023); Tang *et al.*, arXiv:2405.17675;….

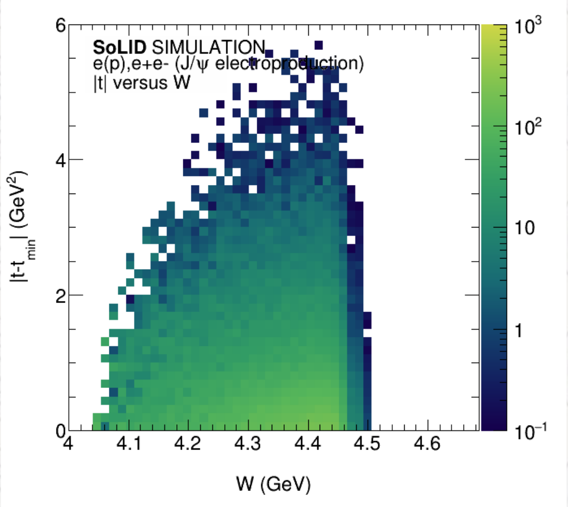
J/ψ @ SoLID: Experiment E12-12-006

- 50 days of 3 μA beam on a 15 cm long LH_2 target & 10 more days include calibration/background runs $1 \times 10^{37} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- SoLID configuration overall compatible with SIDIS
  - **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 $e^+ e^-$









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

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

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

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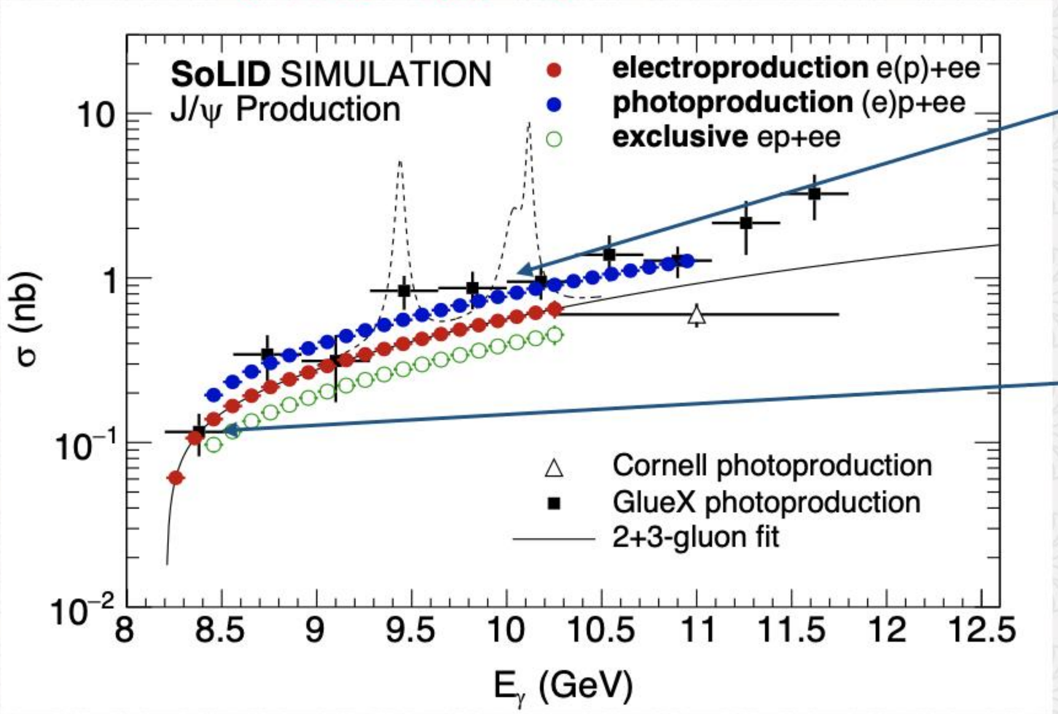
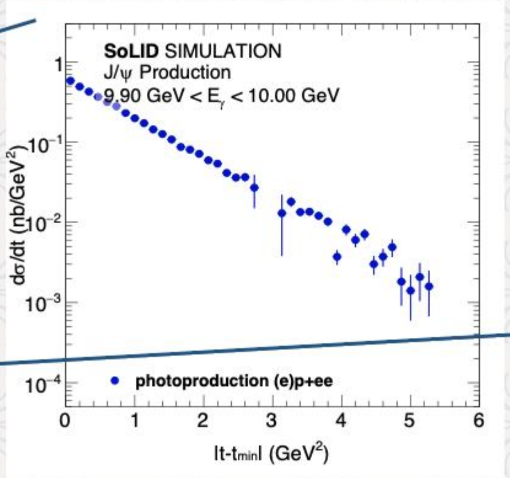
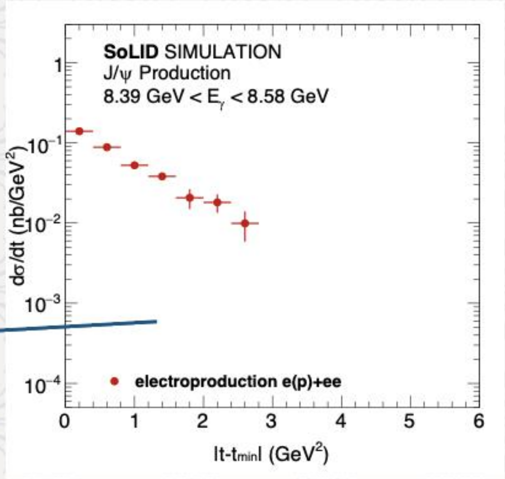
J/Ψ Experiment E12-12-006 @ SoLID

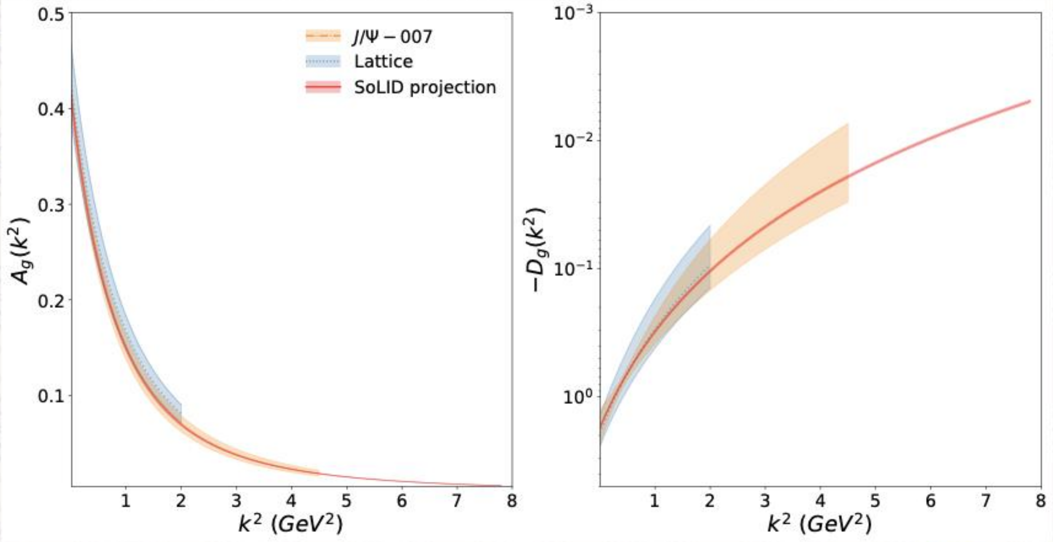
$1 \times 10^{37} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

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





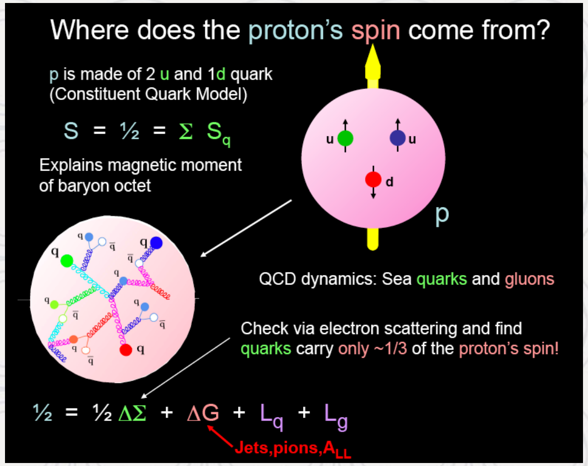




B. Duran *et al*., Nature **615**, 813 (2023)

Gravitational form factors of the proton and mass radius: Hagler *et al* (2008); Y. Hatta, A. Rajan and K. Tanaka, JHEP 12, 008 (2018); Shanahan *et al* (2018); K. Mamo & I. Zahed, Phys. Rev. D 101, 086003 (2020) & (2022); Guo, Ji, Yuan (2023); Guo, Ji, Liu and Yang (2023); D. Hackett *et al*, PRL 132, 251904 (2024); K.F. Liu; …….

Nucleon Structure from 1D to 3D & orbital motion



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + (L_q + L_g)$$

Jaffe-Manohar sum rule
Nucl. Phys. B337, 509 (1990)

Ji sum rule $\frac{1}{2} = J_q + J_g$

Ji, PRL 78, 610(1997)

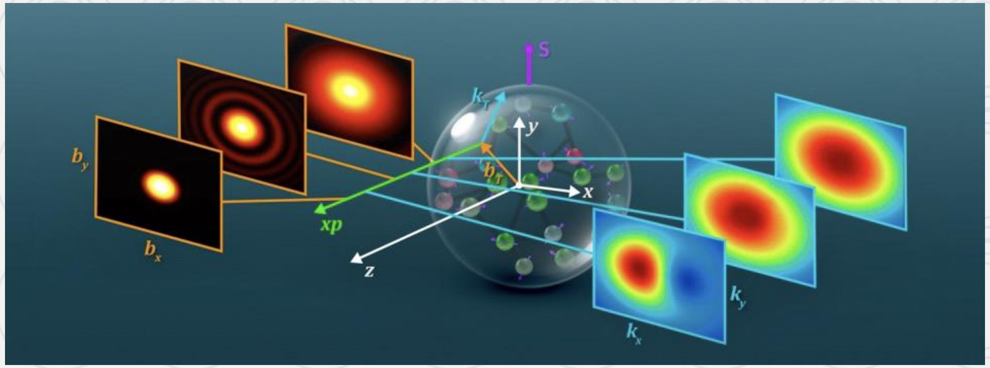
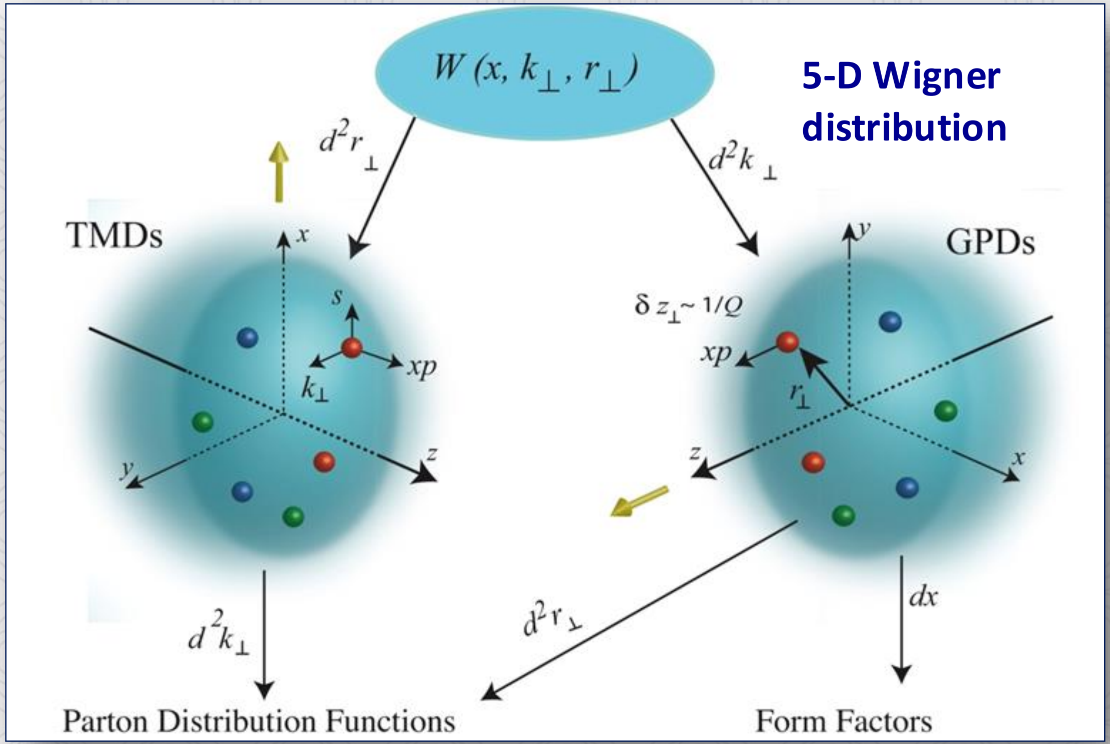


Image from 2023 NSAC LRP

Generalized parton distribution (GPD)
Transverse momentum dependent parton distribution (TMD)



X.D. Ji, PRL91, 062001 (2003);
Belitsky, Ji, Yuan, PRD69,074014 (2004)

Image from J. Dudek et al., EPJA 48,187 (2012)

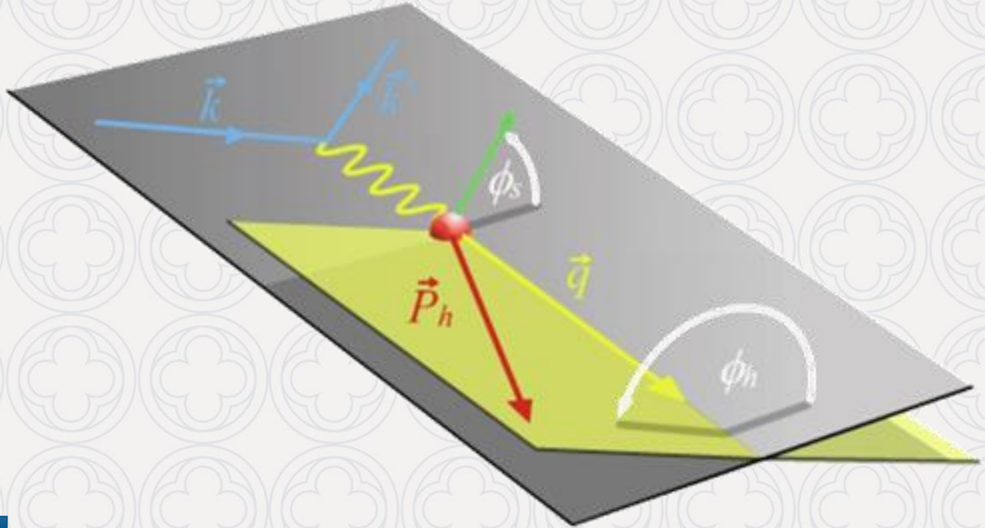
Many talks at this symposium (both plenary and parallel sessions; not listed here individually)

Separation of Collins, Sivers and pretzelocity effects through angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins}\sin(\phi_h + \phi_S) + A_{UT}^{Sivers}\sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h - \phi_S)$$



$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

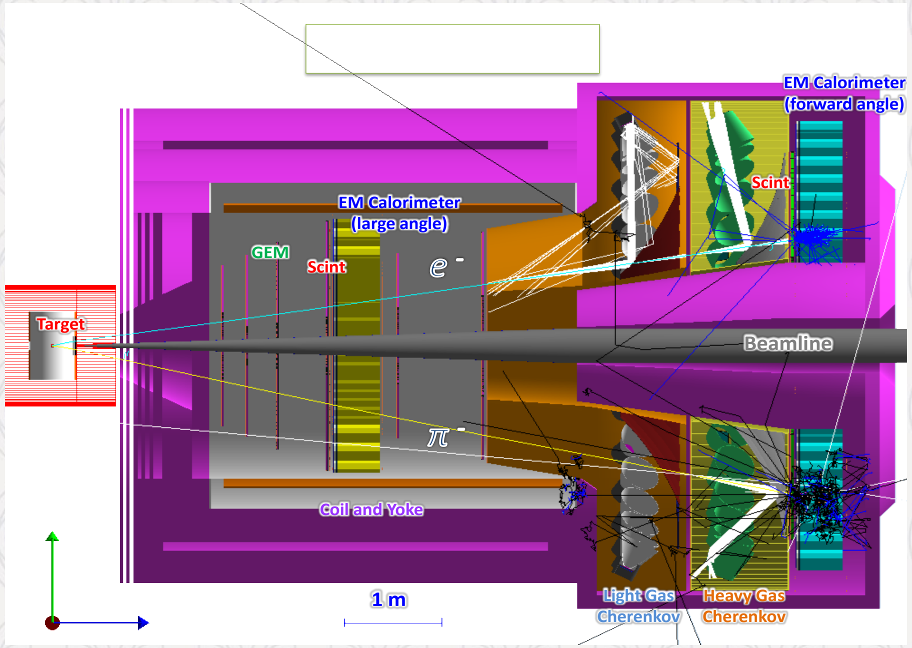
$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

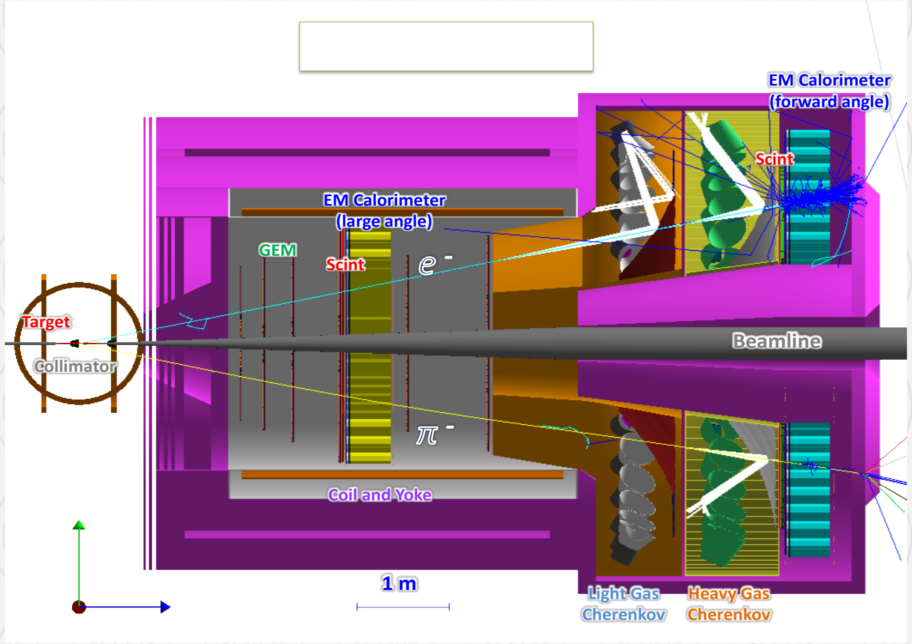
$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

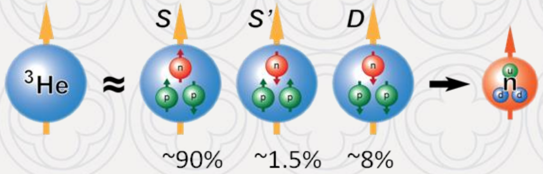
Collins frag. Func. from e^+e^- collisions

SIDIS SSAs depend on 4-D variables (x, Q^2, z and P_T)
Large angular coverage and precision measurement of asymmetries in 4-D phase space is essential.

SIDIS with polarized "neutron" and proton @ SoLID







E12-10-006: Single Spin Asymmetries on Transversely Polarized ^{3}He @ 90 days
Rating A Spokespersons: J.P. Chen, H. Gao (contact), J.C. Peng, X. Qian

E12-11-007: Single and Double Spin Asymmetries on Longitudinally Polarized ^{3}He @ 35 days
Rating A Spokespersons: J.P. Chen (contact), J. Huang, W.B. Yan

E12-11-108: Single Spin Asymmetries on Transversely Polarized Proton @ 120 days
Rating A Spokespersons: J.P. Chen, H. Gao (contact), X.M. Li, Z.-E. Meziani

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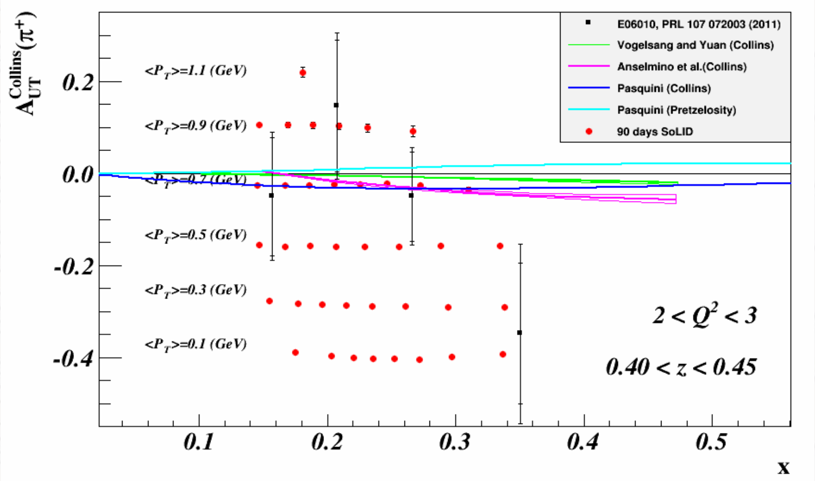
SoLID Projection and Impact

SoLID-SIDIS program: Large acceptance, Full azimuthal coverage + High luminosity

- 4-D mapping of asymmetries with precision

Δz = 0.05, ΔP_T= 0.2 GeV, ΔQ^2 = 1 GeV^2, x bin sizes vary with median bin size 0.02 (statistical uncertainty for each bin: $\delta A \leq 0.02$)

- Constrain models and forms of TMDs, Tensor charge, …
- Lattice QCD, QCD dynamics, models



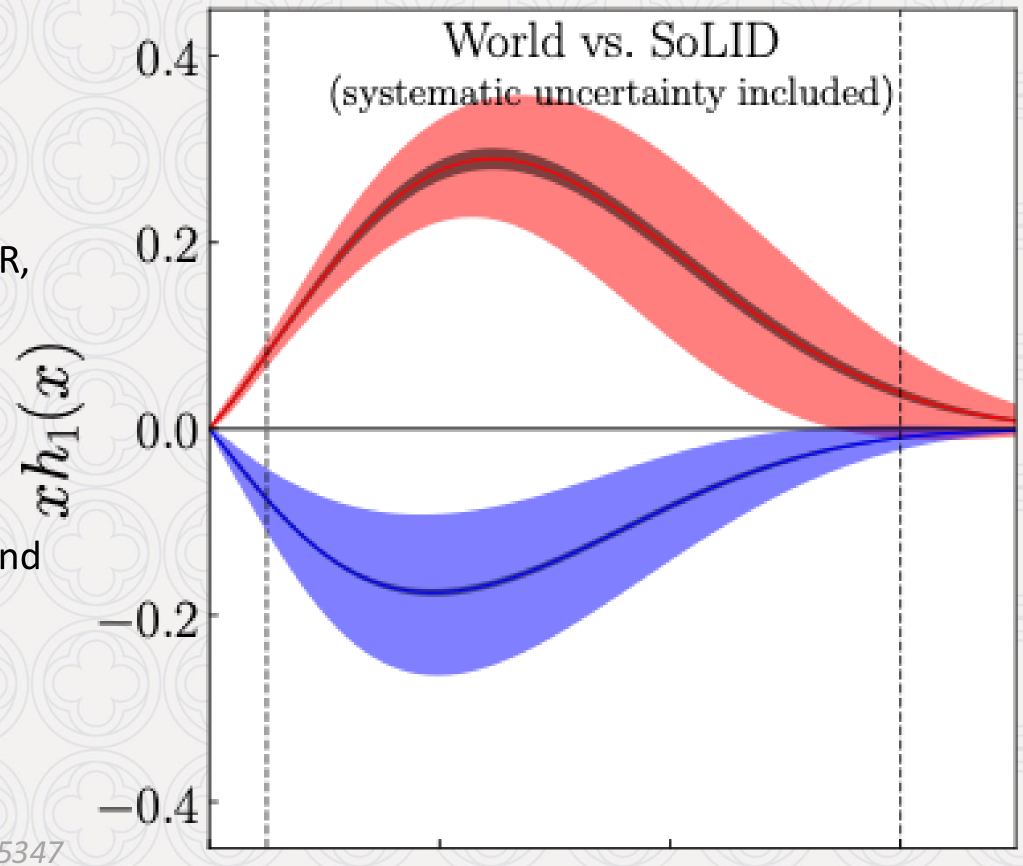
X. Qian et al., PRL107, 072003(2011), 4 points in total

- Fit Collins and Sivers asymmetries in SIDIS and e^+e^- annihilation
- World data from HERMES, COMPASS
- e^+e^- data from BELLE, BABAR, and BESIII
- Monte Carlo method is applied
- Including both systematic and statistical uncertainties

World data according to SoLID pre-CDR (2019)

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

Compare SoLID with World Data



Z. Ye et al., PLB 76, 91 (2017)

- **SoLID: Total 1400 bins in x, Q^2, P_T and z for 11/8.8 GeV beam**

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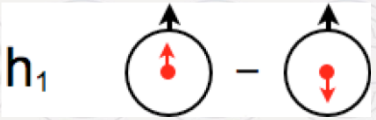
Transversity and Tensor Charge

Transversity distribution



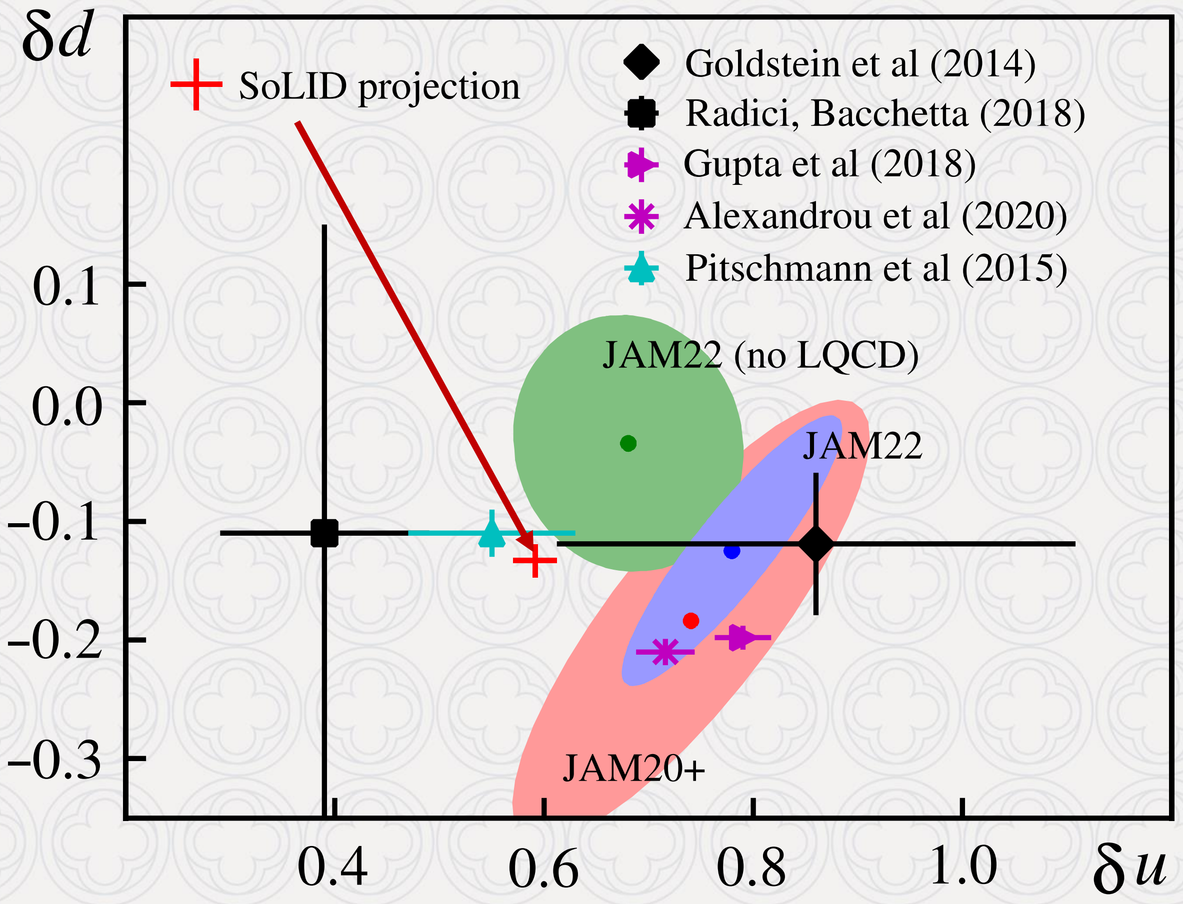
(Collinear & TMD)

- Chiral-odd, unique for the quarks
- No mixing with gluons, simpler evolution effect
- Tensor charge:

$$\langle \mathrm{P,S}|\overline{\psi}_q i\sigma^{\mu\nu}\psi_q|\mathrm{P,S}\rangle = g_T^q \overline{u}(\mathrm{P,S}) i\sigma^{\mu\nu} u(\mathrm{P,S})$$

$$g_T^q = \int_0^1 \left[h_1^q(x) - h_1^{\overline{q}}(x)\right] dx$$

- A fundamental QCD quantity dominated by valence quarks
- Precisely calculated on the lattice
- Difference from nucleon axial charge is due to relativity
- SoLID measurements allows for high-precision test of LQCD predictions
- Global analysis including LQCD (PRL 120 (2018) 15, 152502



SoLID projection: statistical and systematic uncertainties included (shifted for visibility)
Z. Ye *et al.*, PLB 767, 91 (2017)

J. Cammarota et al, PRD 102, 054002 (2020) (JAM20+)
L. Gamberg et al., PRD 106, 034014 (2022) (JAM22)

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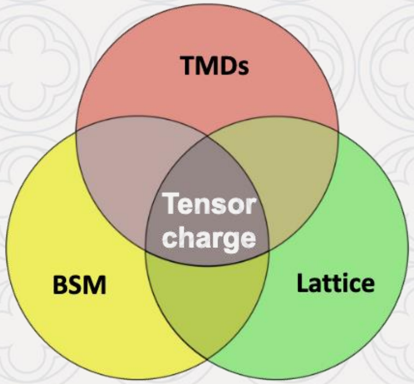
Constraint on Quark EDMs and Sensitivity on BSM

Constraint on quark EDMs with combined proton and neutron EDMs



	d_u upper limit	d_d upper limit
Current g_T + current EDMs	$1.27\times10^{-24}e$ cm	$1.17\times10^{-24}e$ cm
SoLID g_T + current EDMs	$6.72\times10^{-25}e$ cm	$1.07\times10^{-24}e$ cm
SoLID g_T + future EDMs	$1.20\times10^{-27}e$ cm	$7.18\times10^{-28}e$ cm

Include 10% isospin symmetry breaking uncertainty

Nucleon Electric Dipole Moment and Tensor Charge

$$d_n = g_T^d\, d_u + g_T^u\, d_d + g_T^s\, d_s$$

$$d_p = g_T^u\, d_u + g_T^d\, d_d + g_T^s\, d_s$$

Sensitivity to new physics

$$d_q \sim e m_q/(4\pi\Lambda^2)$$

Three orders of magnitude improvement on quark EDM limit → Probe to 30 ~ 40 times higher scale

Current quark EDM limit: $10^{-24}e$ cm → ~ 1 TeV

Future quark EDM limit: $10^{-27}e$ cm → 30 ~ 40 TeV

H. Gao, T. Liu, Z. Zhao, PRD 97, 074018 (2018)

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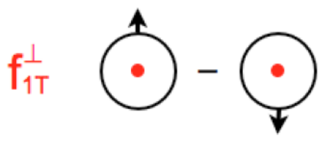
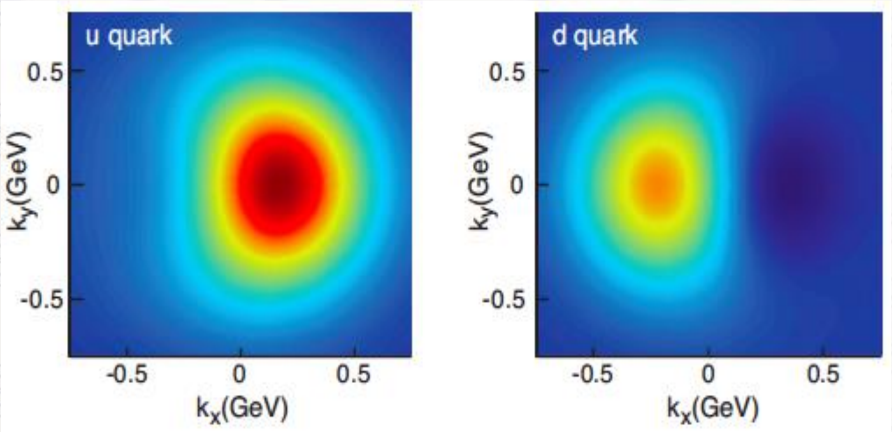
TMDs – confined motion inside the nucleon

Sivers distribution

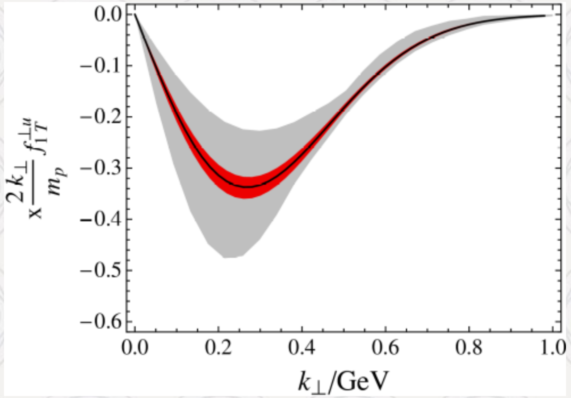


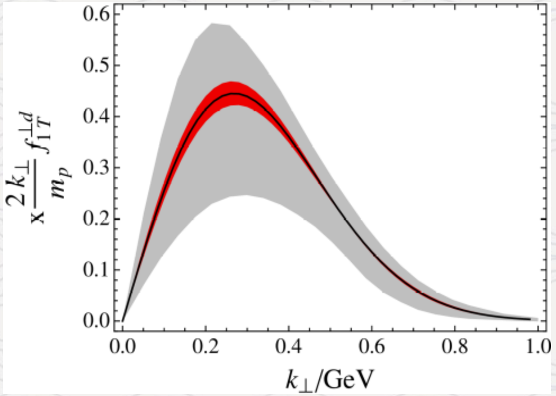
naively time-reversal odd

$$f_{1T}^{\perp q}(x, k_\perp)\Big|_{\text{SIDIS}} = -f_{1T}^{\perp q}(x, k_\perp)\Big|_{\text{DY}}$$



Nucleon spin - quark orbital angular momentum (OAM) correlation
– zero if no OAM (collinear, massless quarks)





$$f_{q/p\uparrow}(x, \mathbf{k}_\perp) = f_1^q(x, k_\perp) - f_{1T}^{\perp q}(x, k_\perp)\frac{\widehat{\mathbf{P}} \times \mathbf{k}_\perp \cdot \mathbf{S}}{M}$$

$$\langle \mathbf{k}_\perp \rangle = -M \int dx\, f_{1T}^{\perp(1)}(x)(\mathbf{S} \times \widehat{\mathbf{P}})$$

Parametrization by M. Anselmino et al., EPJ A 39, 89 (2009)

SoLID projection with transversely polarized n/p

	$\langle k_\perp \rangle^u$	$\langle k_\perp \rangle^d$
	96^{+60}_{-28} MeV	-113^{+45}_{-51} MeV
	$96^{+2.8}_{-2.4}$ MeV	$-113^{+1.3}_{-1.7}$ MeV

T. Liu (2018): https://pos.sissa.it/317/036

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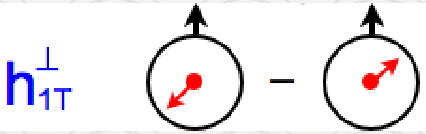
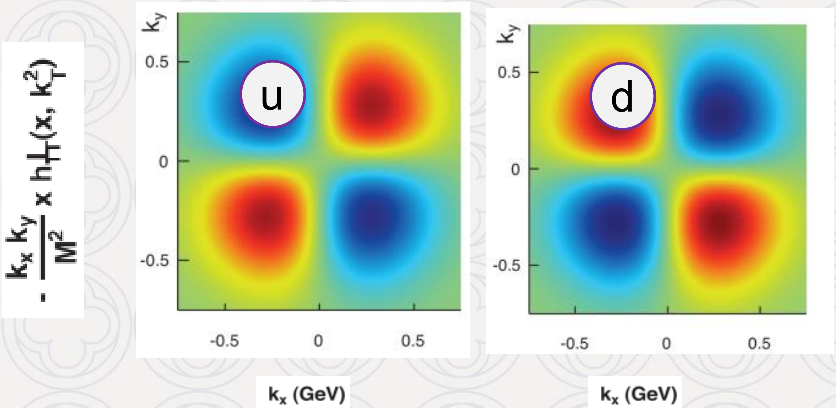
TMDs – confined motion inside the nucleon

Pretzelocity distribution



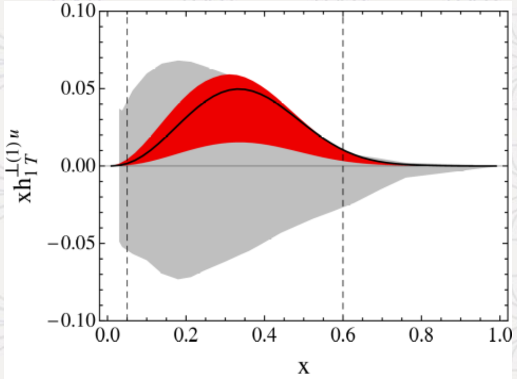
- Chiral-odd, no gluon analogy
- Quadrupole modulation of parton density in the distribution of transversely polarized quarks in a transverse polarized nucleon
- Interference of light-front wave functions differing by ΔL = 2 (seen in many models)
- Measuring the difference between helicity and transversity, i.e. relativistic effects
- Expected to be small – high luminosity-large acceptance crucial



Images from PRD 91 034010 (2015)

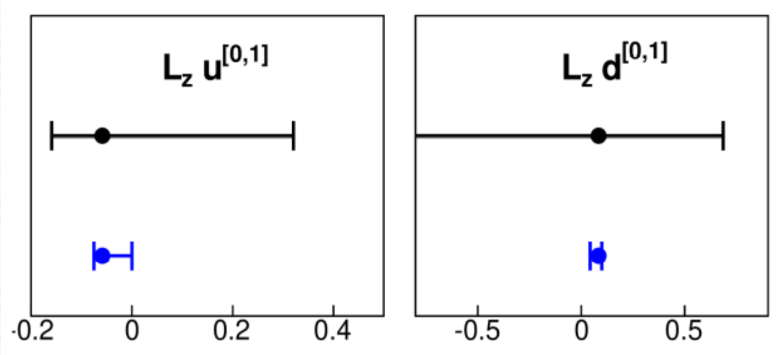
Parametrization by C. Lefky et al., PRD 91, 034010 (2015)

SoLID projection with transversely polarized n and p data



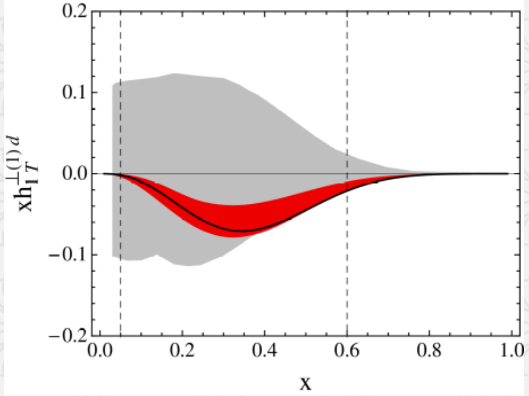
Relation to OAM (canonical)

$$L_z^q = -\int dx d^2\mathbf{k}_\perp \frac{\mathbf{k}_\perp^2}{2M^2} h_{1T}^{\perp q}(x, k_\perp) = -\int dx h_{1T}^{\perp(1)q}(x)$$



Lefky and Prokudin PRD 91, 034010 (2015)

SoLID projection



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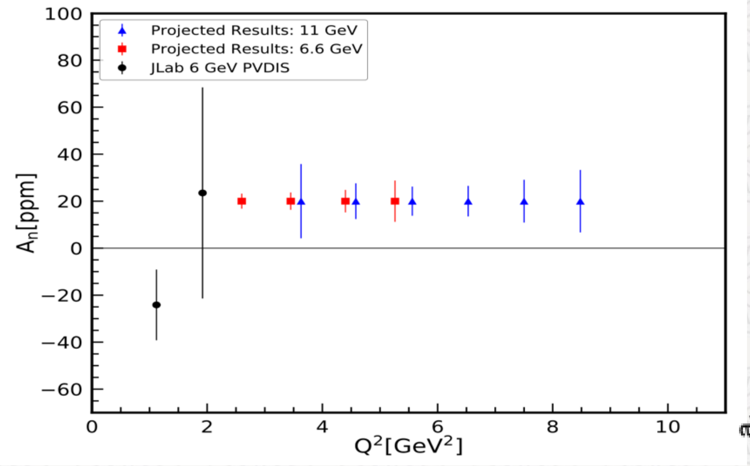
SoLID SIDIS run group experiments

- SIDIS Dihadron with Transversely Polarized ^{3}He
  - J.-P. Chen, A. Courtoy, H. Gao, A. W. Thomas, Z. Xiao, J. Zhang, Approved as run group (E12-10-006A)
- SIDIS in Kaon Production with Transversely Polarized ^{3}He
  - T. Liu, S. Park, Z. Ye, Y. Wang, Z.W. Zhao, Approved as run group (E12-10-006D)
- Ay with Transversely Polarized ^{3}He
  - T. Averett, A. Camsonne, N. Liyanage, Approved as run group (E12-10-006A)
- g_2^n and d_2^n with Transversely and Longitudinally Polarized ^{3}He
  - C. Peng, Y. Tian, Approved as run group (E12-10-006E)
- Deep exclusive π^- Production with Transversely Polarized ^{3}He
  - Z. Ahmed, G. Huber, Z. Ye, Approved as run group (E12-10-006B)
- Timelike Compton TCS circular polarized beam and unpolarized LH2 target M. Boer, P. Nadel-Turonski, J. Zhang, Z. Zhao, Approved as run group (E12-12-006A)
- Measurement of the Unpolarized SIDIS Cross Section from a ^{3}He Target with SoLID U. D'Alesio, M. Cerutti, H. Gao, S. Jia, V. Khachatryan, T. Ye, Approved as run group (E12-11-007B/E12-10-006F)

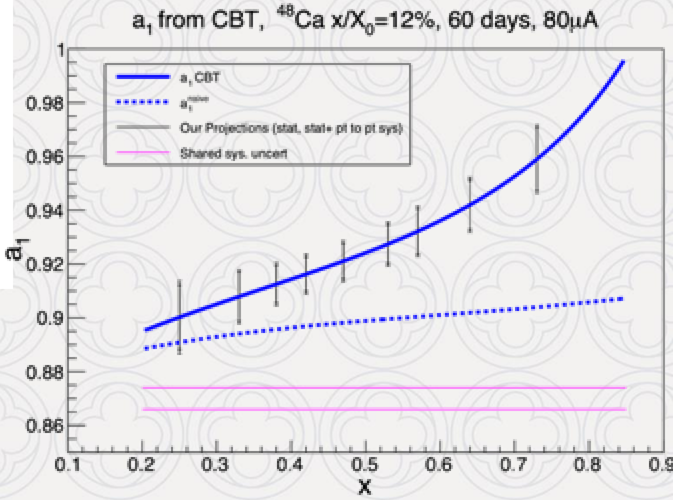
BNSSA, PVEMC, and DDVCS Experiments

- Beam Normal Single Spin Asymmetry (E12-22-004)
  - Approved with A- rating
  - Investigate the effect of two-photon exchange in DIS
  - Q2 dependence of the asymmetry

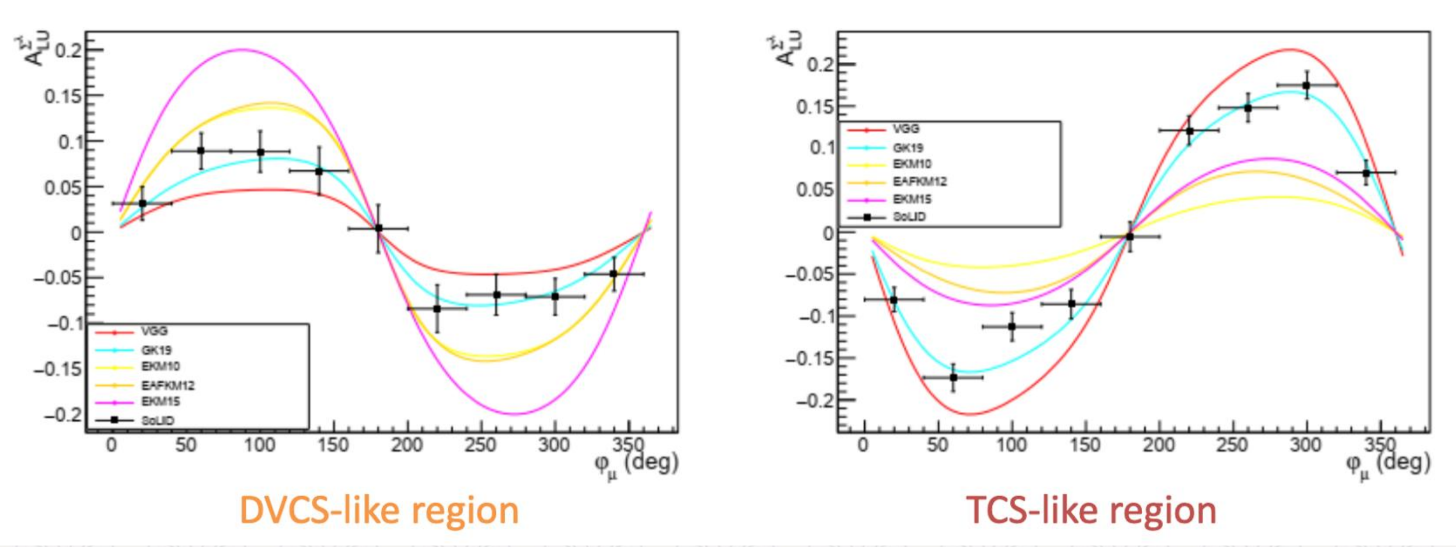


- Flavor Dependent EMC effect (PR12-22-002)
  - Conditionally approved proposal
  - Measure PVDIS on ^{48}Ca
  - A_{pv} directly sensitive to flavor dependence of EMC

$$a_1 \simeq \frac{9}{5} - 4\sin^2\theta_W - \frac{12}{25}\frac{u_A^+ - d_A^+}{u_A^+ + d_A^+}$$



- Double Deeply Virtual Compton Scattering (E12-25-010)
  - C1 Conditionally approved with A rating
  - First ever DDVCS to access the full kinematic space for extracting GPDs
  - A breakthrough physics program (from PAC53 closeout)

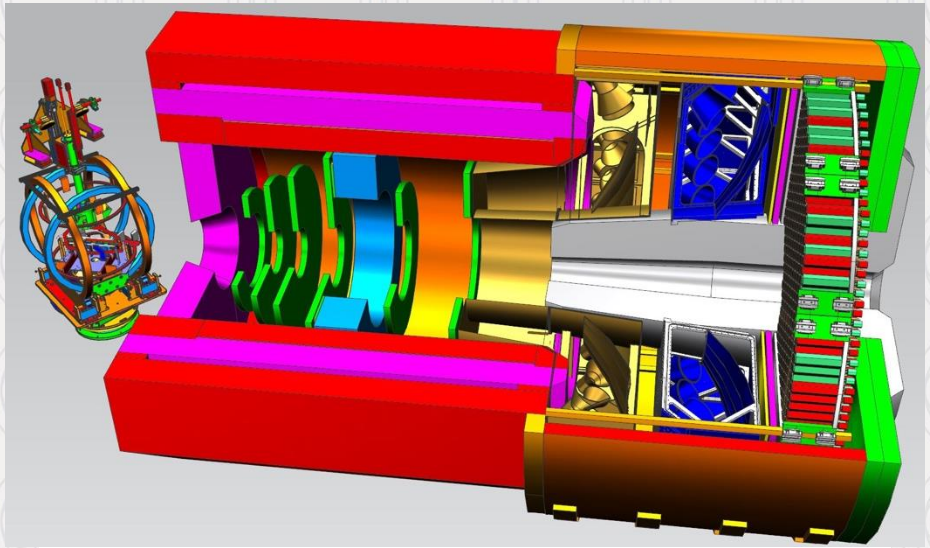


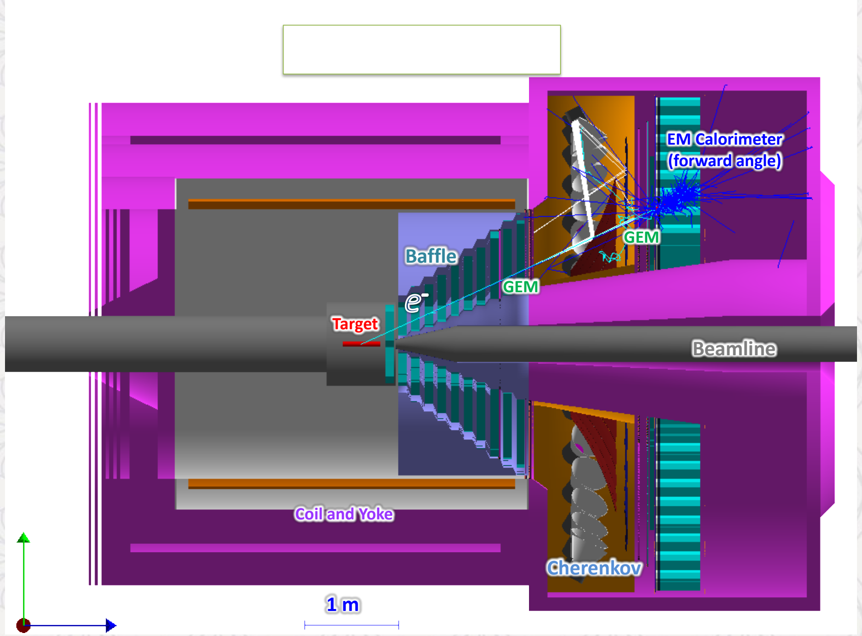
SoLID Apparatus

Requirements are Challenging

- High Luminosity (10^{37}-10^{39})
- High data rate
- High background
- Low systematics
- High Radiation
- Large scale
- Modern Technologies
  - GEM's or other MPGD detectors
  - Shashlik ECal
  - Pipeline DAQ
  - Rapidly Advancing Computational Capabilities including AI/ML
- High Performance Cherenkov
- Baffles

Polarized ^{3}He (``neutron") @ SoLID





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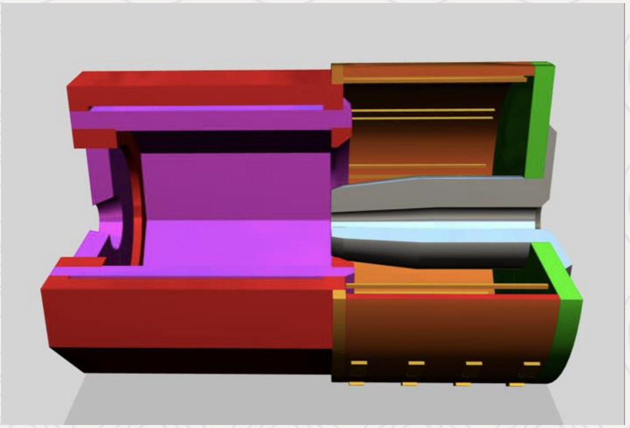
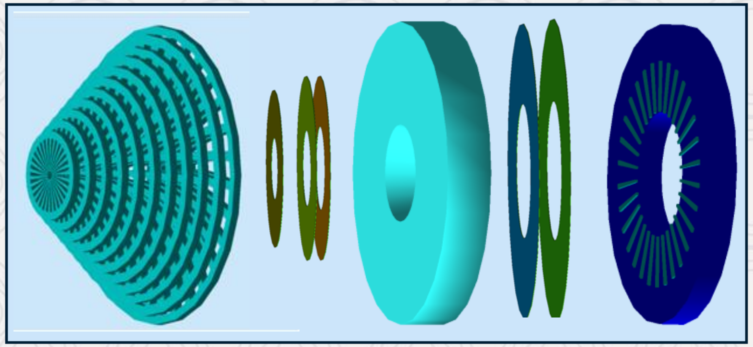
SoLID Detector Subsystems

Uses full capability of JLab electronics



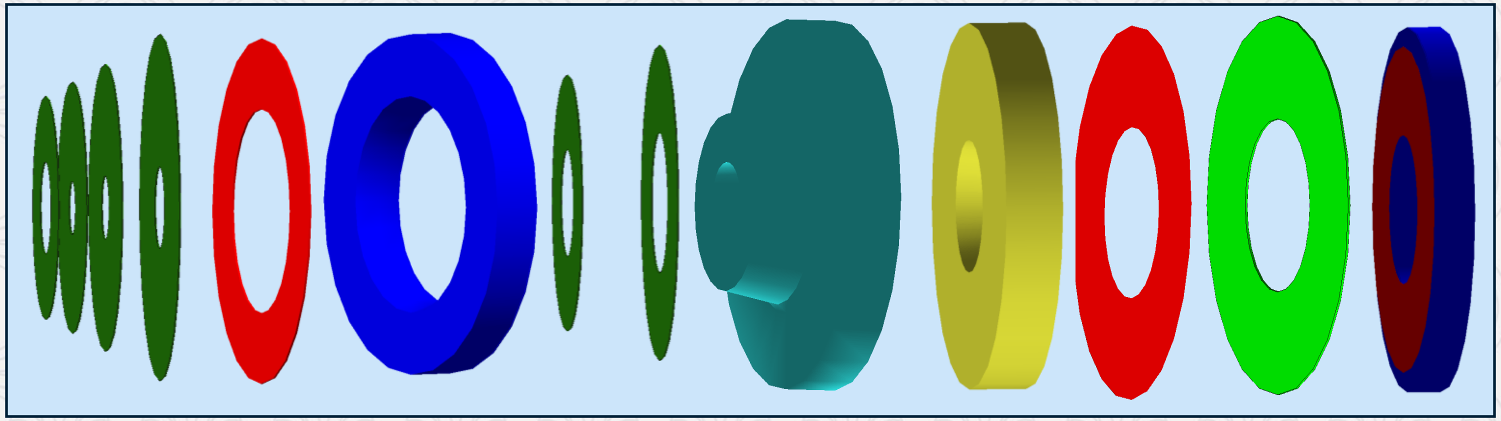
PVDIS

Baffle 3xGEMS LGC 2xGEMs EC



SIDIS-J/ψ

4xGEMs LASPD LAEC 2xGEMs LGC HGC FASPD (MRPC) FAEC



Pre-R&D items: LGC, HGC, GEM's, EC, DAQ/Electronics, Magnet

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Magnet: Requirement and Design

Requirements:

→Acceptance: P: 1.0 – 7.0 GeV/c;
Φ: 2π; θ: 8°-24° (SIDIS), 22°-35° (PVDIS)

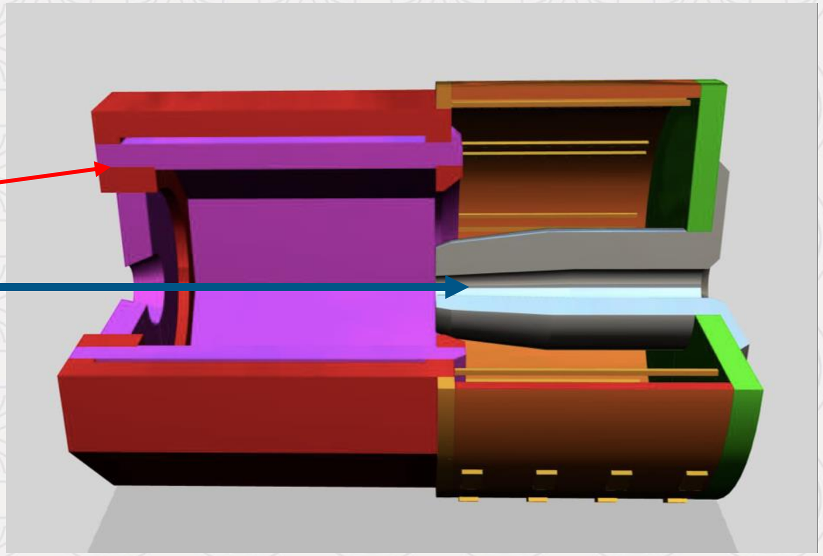
→ Resolution: δP/P ~ 2%
(requires 0.1 mm tracking resolution)

→ Fringe field at the ^{3}He target < 5 Gauss

CLEO II magnet at JLab

Use CLEO II magnet with the following modifications

- Two of three layers of return yoke needed
- Add thickness to front endcap
- Add extended endcap



Yoke for SoLID

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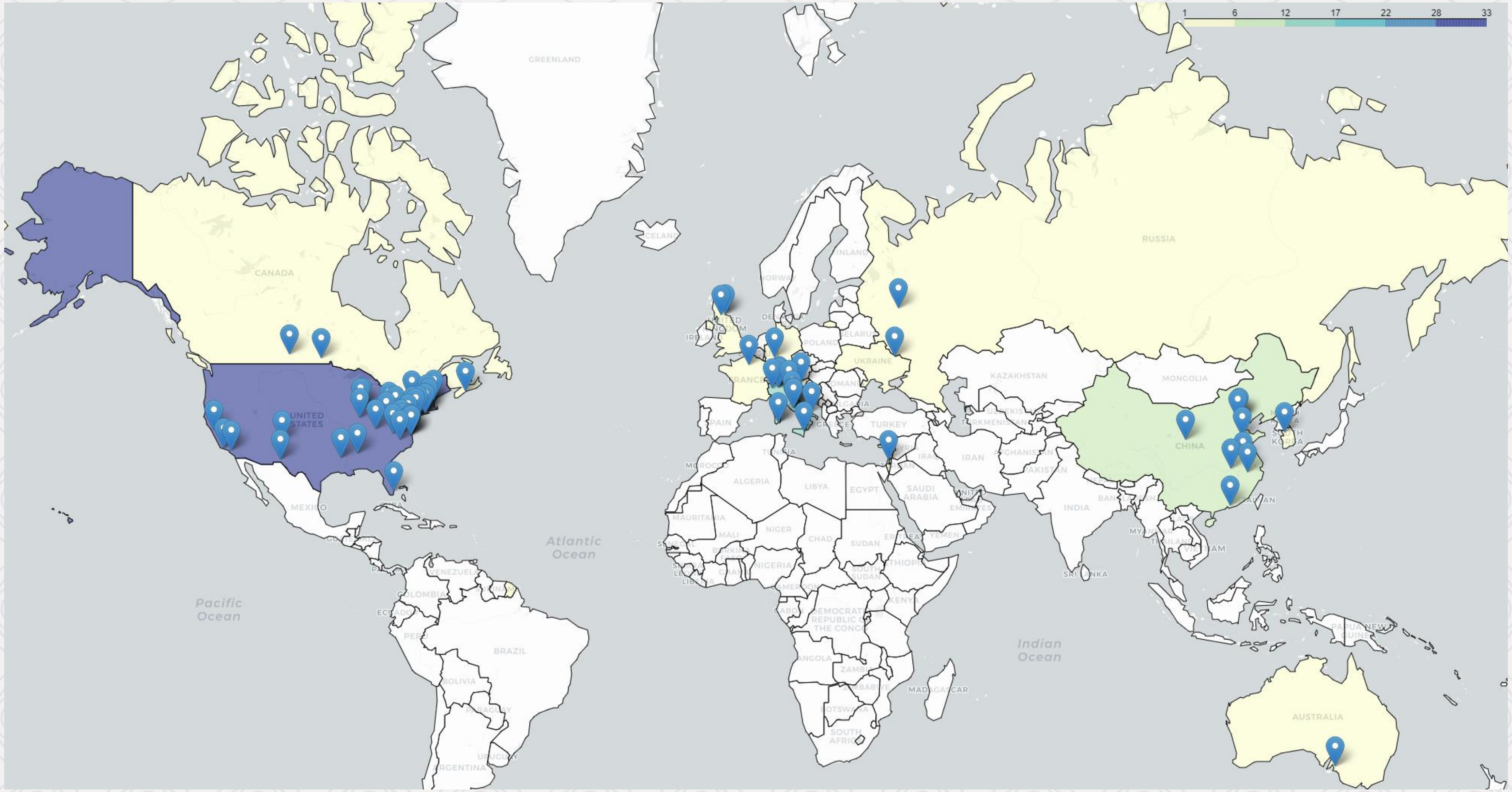
Strong Collaboration

- 270+ collaborators, 70+ institutions from 13 countries
- Large international participations and anticipated contributions
- Strong theory support



https://solid.jlab.org/

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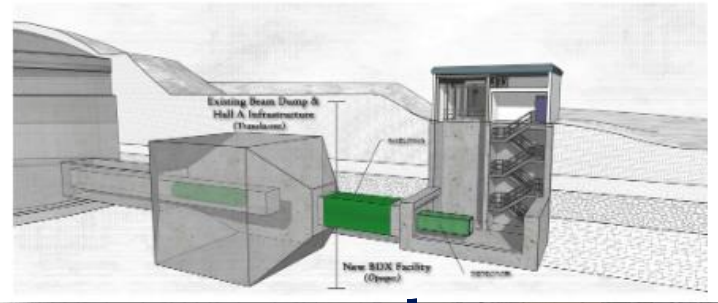
What's on the horizon?

Thia Keppel (PAC53, July2025)

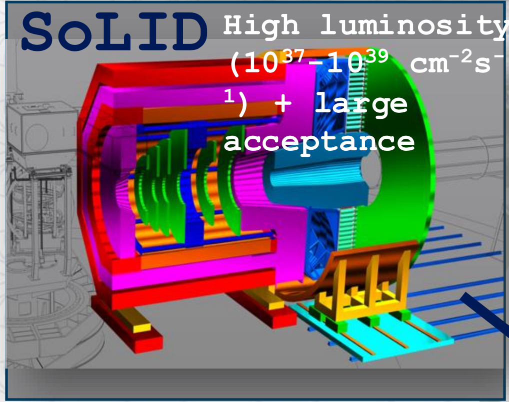
…and associated beam and detector developments

BDX: Beam Dump exp.

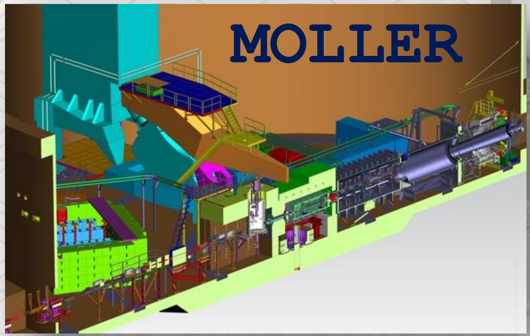
- Search for light dark matter particles
- Intense secondary μ and ν beams

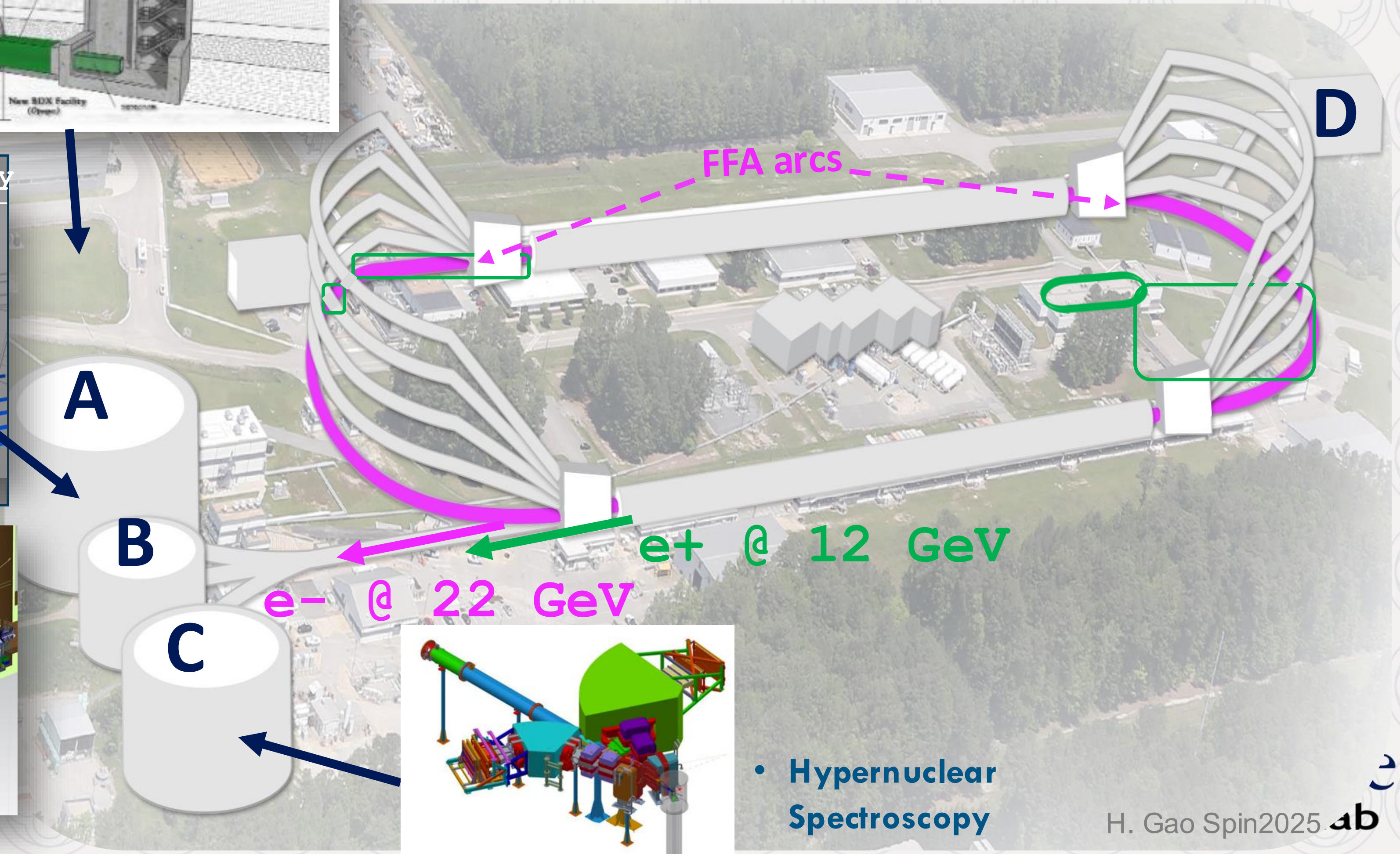


- Precision nucleon 3D imaging
- Origin of the proton mass and gluonic force
- BSM searches & nucleon structure



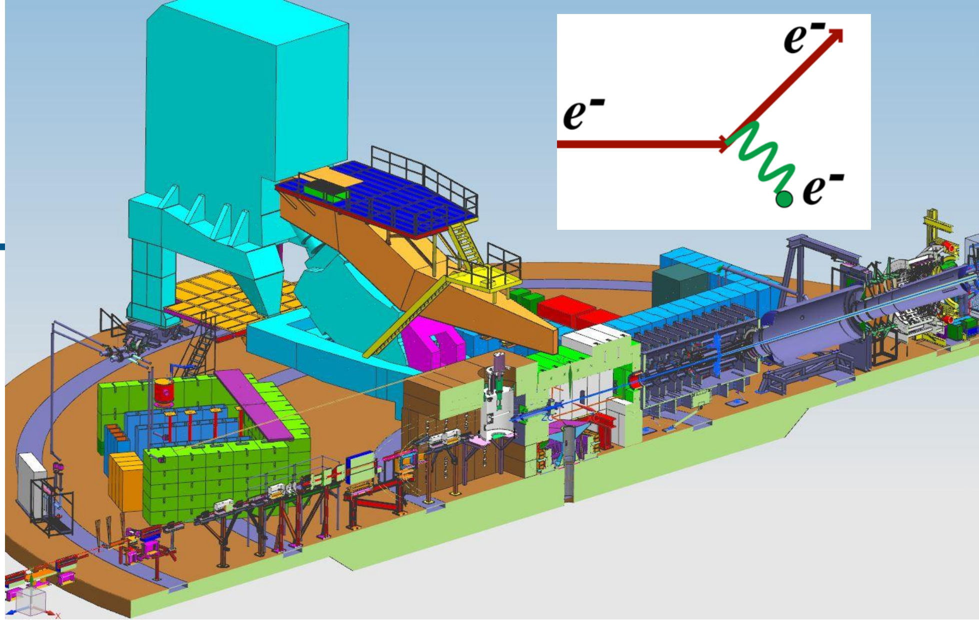
- Ultra-precise measurement of the weak charge of the electron
- Sensitive to BSM physics





- Hypernuclear Spectroscopy

MOLLER: Precision Electroweak Physics



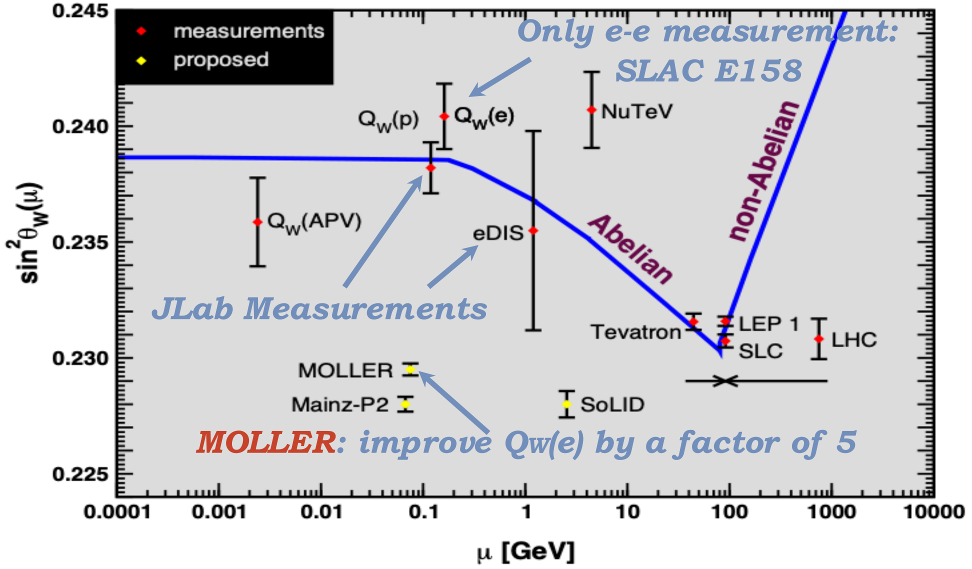
$$\delta(\sin^2\theta_W) = \pm\, 0.00023\ (stat.)\ \pm\, 0.00012\ (syst.)$$

⇨ ~ 0.1%

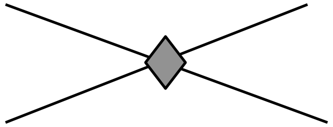
- **Unique (purely leptonic) new physics reach**
- **Special opportunity with 12 GeV high luminosity**

Search for new flavor diagonal neutral currents

Look for tiny but measurable deviations from precisely calculable predictions for SM processes



A_{new}



$$\frac{1}{\Lambda^2}\mathcal{L}_6$$

MOLLER Reach

$\Lambda^{ee}_{RR-LL} \sim 38$ TeV

- **Unique discovery space: beyond that of a 500 GeV lepton collider**
- **Precursor to HiLumi LHC $\sin 2\theta_W$ – complementary precision electroweak physics**
- **Impacts the current discrepancy on the W mass (Fermilab vs LHC)**

Thia Keppel (PAC53, July2025)

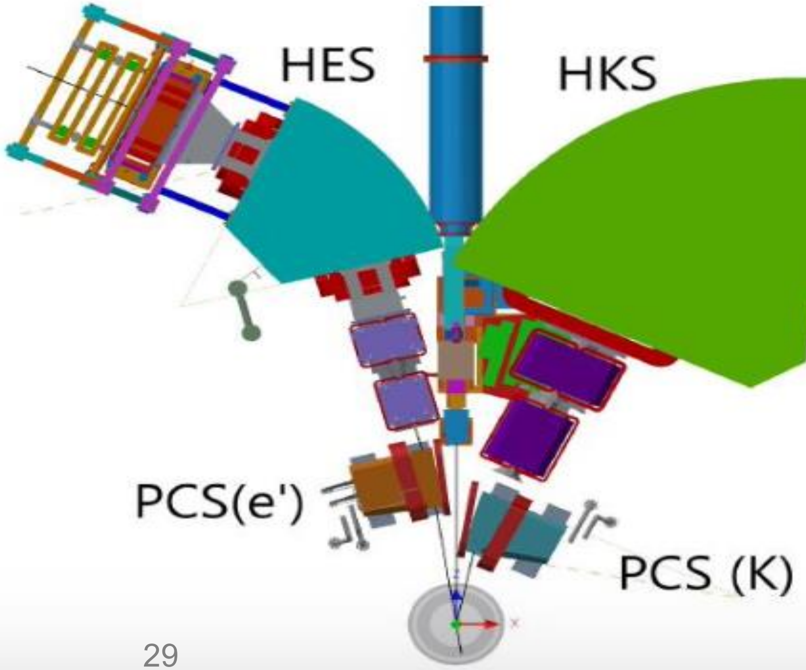
Hypernuclear Spectroscopy in Hall C

Thia Keppel (PAC53, July2025)

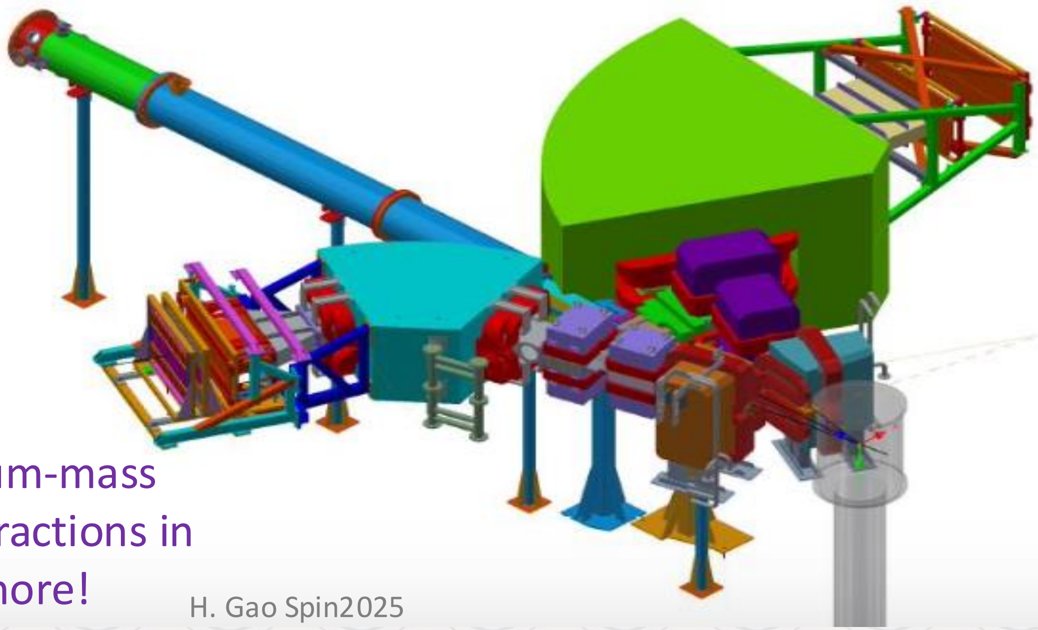
	Original	Updated
Experimental Hall	Hall-A	Hall-C
Beam Energy [/(GeV)]	4.532	2.240
Electron spectrometer	HRS	HES
Bending direction	Vertical	Horizontal
Central momentum [/(GeV/c)]	3.03	0.74
Kaon spectrometer	HKS	HKS
Bending direction	Horizontal	Horizontal
Central momentum [/(GeV/c)]	1.20	1.20

Beam	Energy E_e [/(GeV)]	2.240
	Energy stability $\Delta E_e/E_e$	3×10^{-5}
PCS + HES	Central momentum P_e [/(GeV/c)]	0.744
	Central angle $\theta_{e,e'}$ [/(deg)]	8
	Solid angle $\Delta\Omega_{e'}$ [/(msr)]	3.4
	Momentum resolution $\Delta P_{e'}/P_{e'}$	4.4×10^{-4}
PCS + HKS	Central momentum P_K [/(GeV/c)]	1.200
	Central angle θ_K [/(deg)]	15
	Solid angle $\Delta\Omega_K$ [/(msr)]	8.3
	Momentum resolution $\Delta P_K/P_K$	2.9×10^{-4}

$$Y = N_t \times N_e \times \Gamma \times \frac{d\sigma}{d\Omega_{HKS}} \times \Delta\Omega_{HKS} \times \epsilon_{HES} \times \epsilon_{HKS} \times \epsilon_{decay}.$$



Study of the isospin dependence in medium-mass hyperisotopes, Λ interactions in nuclear matter, and more!

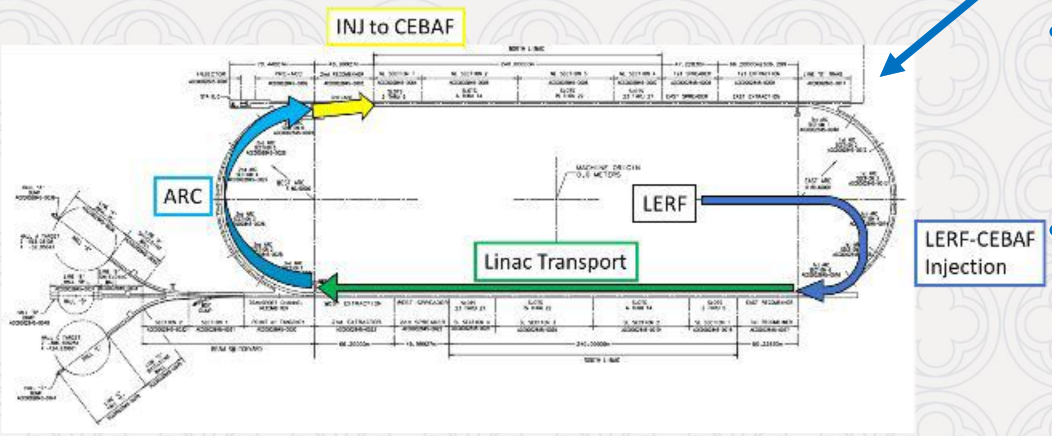


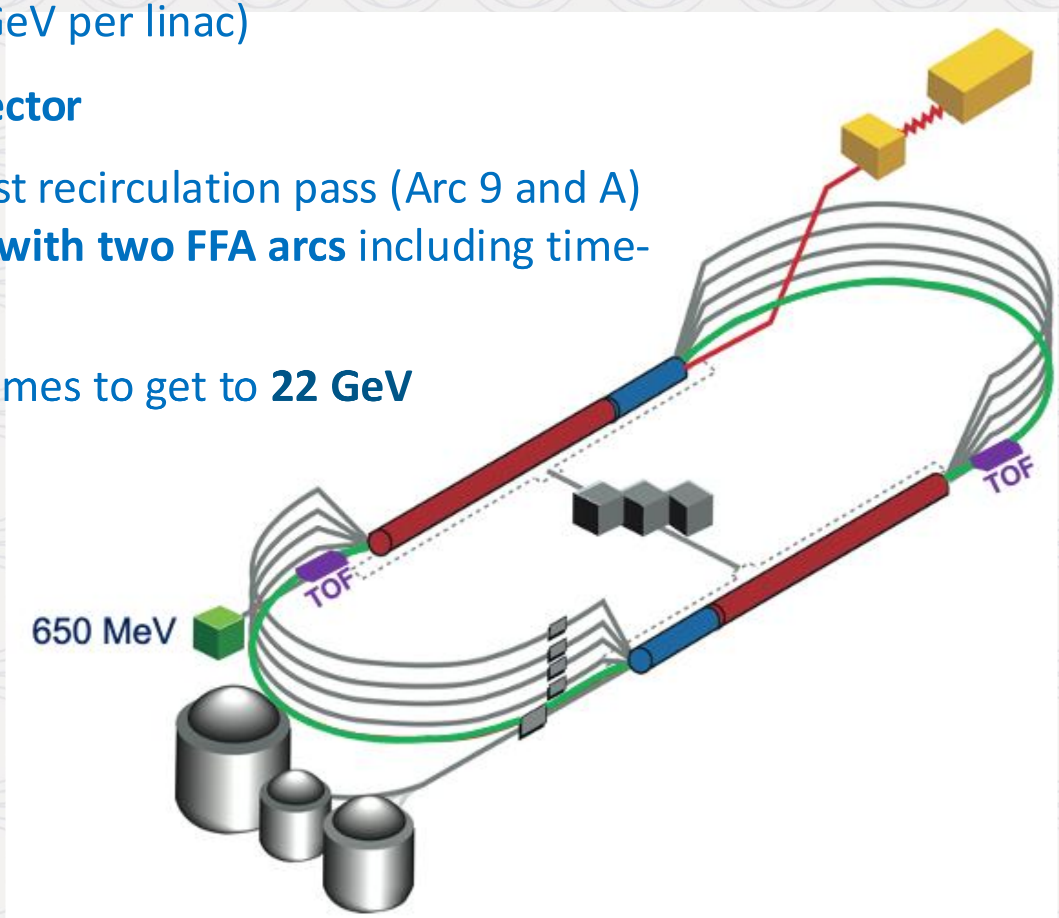
Feasible, Cost effective, Innovative Path from e+ to 22 GeV

Capitalize on recent science insights and US-led accelerator science and technology innovations to develop a **staged program at the luminosity frontier**

- CEBAF @ 22 GeV
- Positron beam

- Starting with 12 GeV CEBAF
- NO new SRF (1.1 GeV per linac)
- **New 650 MeV injector**
- Remove the highest recirculation pass (Arc 9 and A) and **replace them with two FFA arcs** including time-of-flight chicane
- Recirculate 4.5+6times to get to **22 GeV**



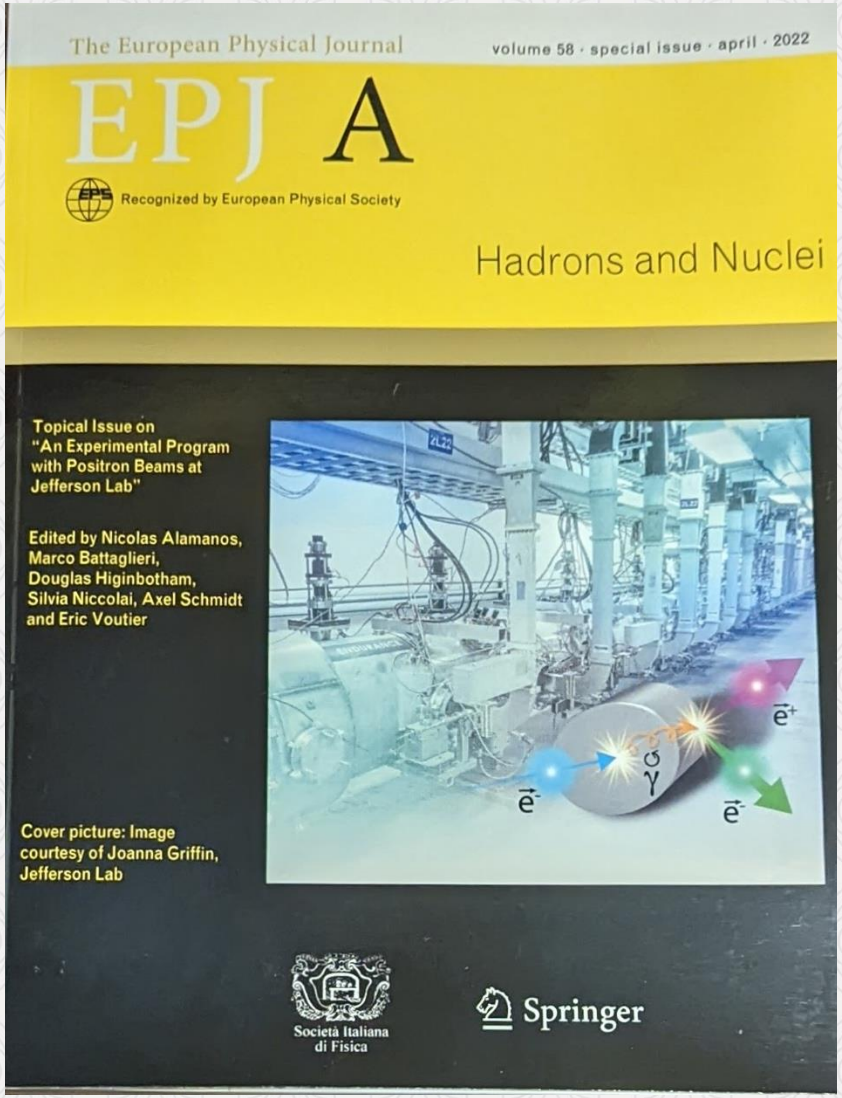


- **Positrons (e+) in the LERF with transport to CEBAF**
- Injection energy upgrade for 650 MeV Electron (e-) in LERF

The Proposed Positron Program at JLab

Experiment Label (EPJ A)	Short Name	Hall	Detector	Target	Polarity	p (GeV/c)	P (%)	I (μA)	Time (d)	PAC Grade
Two Photon Exchange Physics										
57:144	$H(e,e'p)$	B	CLAS12$^+$	H_2	$+/-_s$	2.2/3.3/4.4/6.6	0	0.060	53	
57:188	$H(\vec{e},e'\vec{p})$	A	ECAL/SBS	H_2	$+/-_p$	2.2/4.4	60	0.200	121	
57:199	r_p r_d	B	PRad-II	H_2 D_2	$+$	0.7/1.4/2.1 1.1/2.2	0	0.070 0.010	40 39	
57:213	$\vec{H}(e,e'p)$	A	BB/SBS	$N\vec{H}_3$	$+/-_s$	2.2/4.4/6.6	0	0.100	20	
57:290	$H(e,e'p)$	A	HRS/BB/SBS	H_2	$+/-_s$	2.2/4.4	0	1.000	14	
57:319	SupRos	A	HRS	H_2	$+/-_p$	0.6–11.0	0	2.000	35	
58:36	$A(e,e')A$	A	HRS	He	$+/-_p$	2.2	0	1.000	38	
Nuclear Structure Physics										
57:186	p-DVCS	B	CLAS12	H_2	$+/-_s$	2.2/10.6	60	0.045	100	C2
57:226	n-DVCS	B	CLAS12	D_2	$+/-_s$	11.0	60	0.060	80	
57:240	p-DDVCS	A	SoLID$^\mu$	H_2	$+/-_s$	11.0	(30)	3.000	100	
57:273	He-DVCS	B	CLAS12/ALERT	^{4}He	$+/-_s$	11.0	60			
57:300	p-DVCS	C	SHMS/NPS	H_2	$+$	6.6/8.8/11.0	0	5.000	77	C2
57:311	DIS	A/C	HRS/HMS/SHMS		$+/-_s$	11.0				
57:316	VCS	C	HMS/SHMS	H_2	$+/-_s$		60			
Beyond the Standard Model Physics										
57:173	C_{3q}	A	SoLID	D_2	$+/-_s$	6.6/11.0	(30)	3.000	104	D
57:253	LDM	B	PADME ECAL/HCAL	C $PbW0_4$	$+$	11.0	0	0.100	180 120	
57:315	CLFV	A	SoLID$^\mu$	H_2	$+$	11.0				
								Total (d)	**1121**	

CLAS12$^+$ ≡ CLAS12 implemented with an Electromagnetic Calorimeter in the Central Detector
SoLID$^\mu$ ≡ SoLID complemented with a muon detector
$+$ Secondary positron beam
$-_s$ Secondary electron beam
$-_p$ Primary electron beam
(30) Do not require polarization but would take advantage if available at the required beam intensity

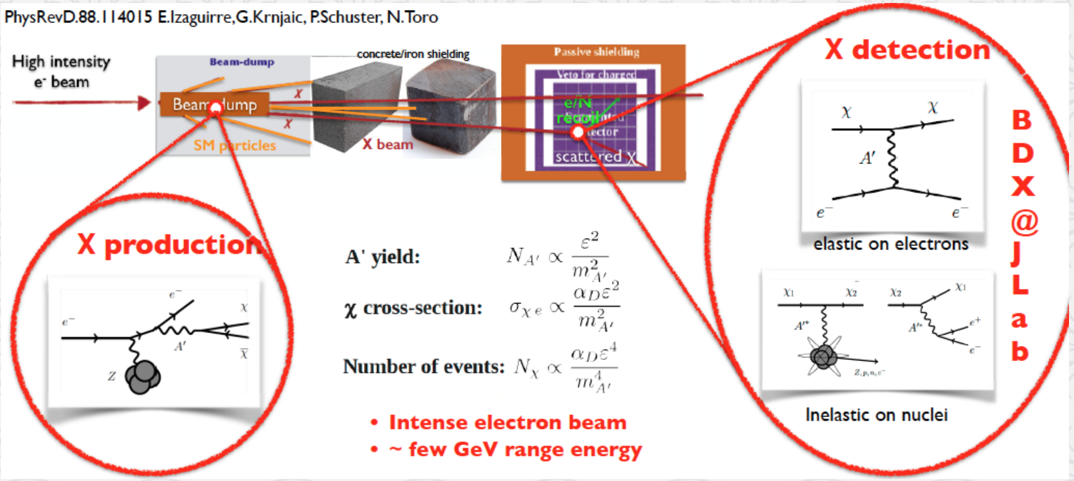


Another approved e+ exp (PAC53)

https://doi.org/10.1140/epja/s10050-022-00699-6

Beam Dump Experiment (BDX)

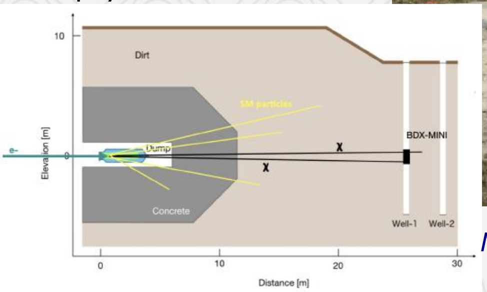
Thia Keppel (PAC53, July2025)



- A cutting-edge experiment designed to search for **light dark matter**
- Two step process
  - I) An electron radiates an A' and the A' promptly decays to a χ (DM) pair
  - II) II) The χ (in-)elastically scatters on a e-/nucleon in the detector producing a visible recoil (GeV)
- Experimental signature in the detector: **X-electron → EM shower ~GeV energy**

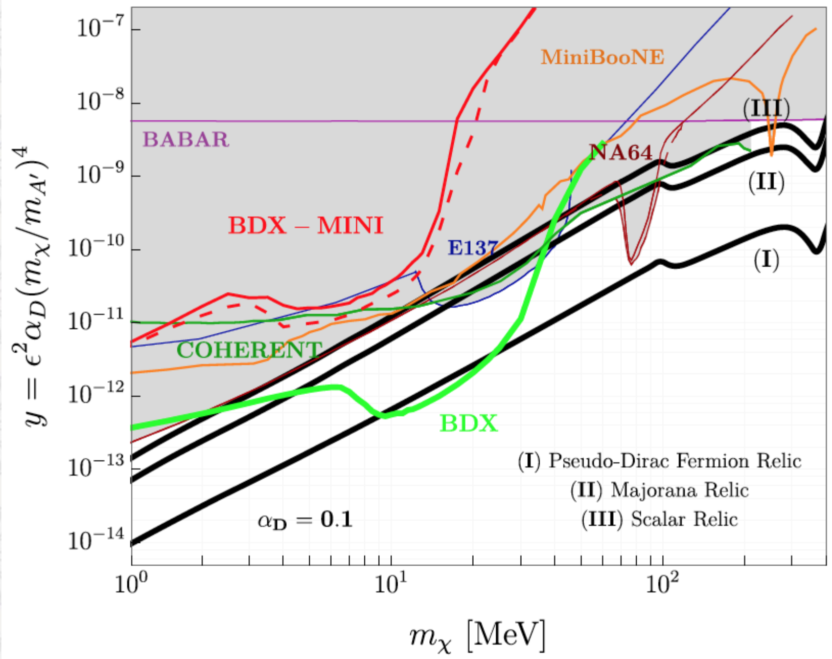
BDX-MINI: pilot experiment to prove the validity and feasibility of the BDX exp

- Two wells dug for bg muon tests
- E_{beam}=2.2 GeV, no muons
- Limited reach but first physics result!



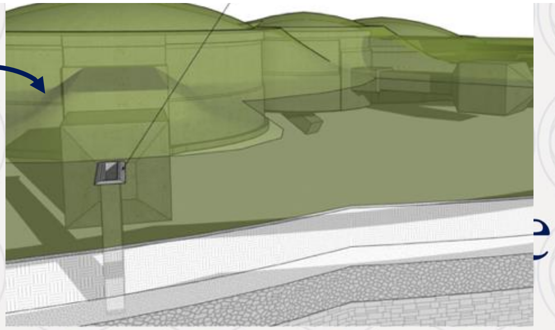
M.Battaglieri et al. PRD 106, 072011

Collected 4e21 EOT (40% BDX!) in ~4 months (+ cosmics)



- **Accumulating 10^{22} EOT in ~2y BDX sensitivity is 10-100 times better than existing limits on LDM**

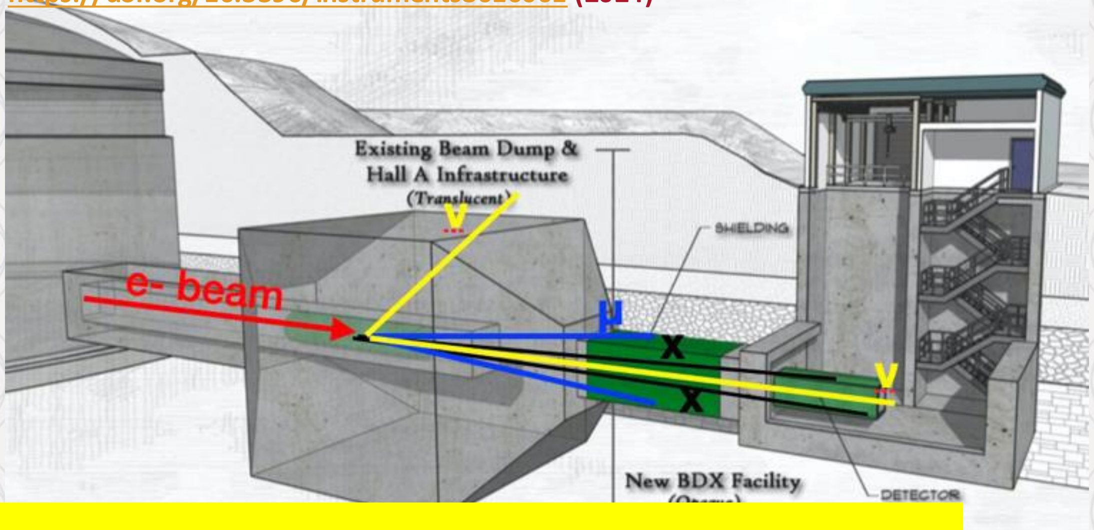
- Funds for the construction of the first module of the calorimeter secured.
- Engineering design studies for the construction of the hall are ongoing.



Secondary Beams at Jefferson Lab

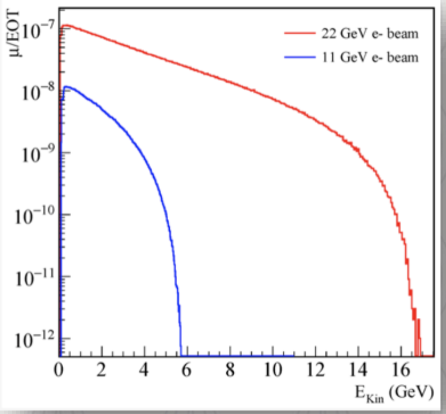
- **High-intensity secondary beams are produced in the dump(s) fully parasitically with high-intensity 10 GeV (22 GeV) electron beam**

https://doi.org/10.3390/instruments8010001 (2024)

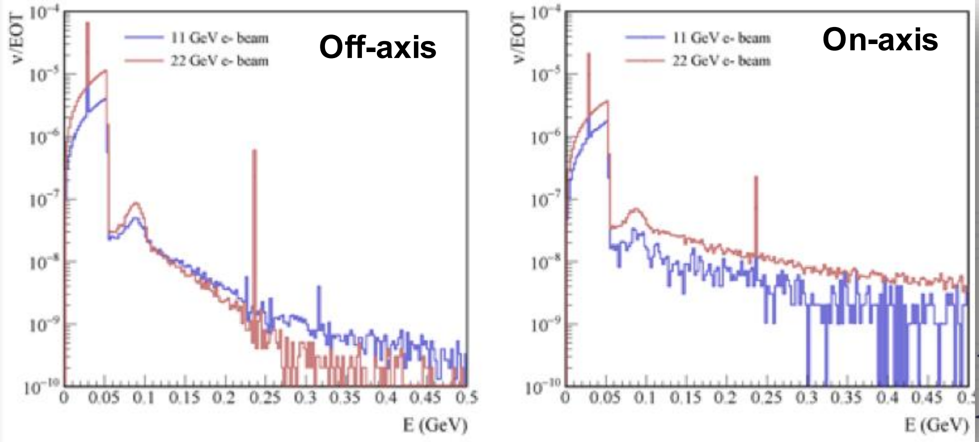


Thia Keppel (PAC53, July2025)

- A secondary **muon beam** with a bremsstrahlung-like energy spectrum extending up to 5 GeV could yield up to ~10^{-6} μ/EOT, corresponding to **10^8 μ/s for an i_e 50 μA**

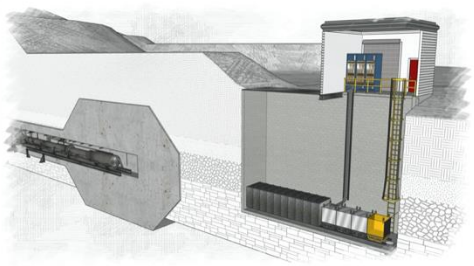


- A secondary **neutrino beam** with a typical decay-at-rest (DAR) energy spectrum could provide up to ~7×10^{-5} ν/EOT when integrated over a 1 m² detector located 10 m above the beam dump; Considering a delivered charge of 10^{22} EOT per year, the **annual neutrino flux would be in the range of 10^{18} ν**



Neutrons too

SECONDARY BEAMS AT JEFFERSON LAB WORKSHOP: BDX & BEYOND



Experimental Area Design Drawing

Conference Date
September 04, 2025 to September 05, 2025

Conference Location
Jefferson Lab, CEBAF Center rm. F113

The Secondary Beams at Jefferson Lab Workshop (BDX & Beyond) convenes scientists worldwide, will focus on optimizing the use of intense secondary beams at Jefferson Lab produced by the interaction of high-intensity electron beams with beamdumps, and it is anticipated to produce a White Paper summarizing the findings.

(2024)

Summary

- SoLID at the QCD intensity frontier is the capstone of the JLab 12-GeV science program – rich and vibrant program synergistic with EIC's, and highlighted in 2023 NSAC LRP
  - Three major science pillars: tomography in 3d momentum with SIDIS; proton mass and scalar radii and gluonic gravitational f.f. from near-threshold J/ψ production; SM test and BSM physics with PVDIS
  - Nuclear PDF from PVDIS PR12-22-002 (C2 approval); Beam normal SSA from DIS PR12-22-004 approved (A-); DDVCS C1 approval with A rating PR12-25-010
  - A diverse set of approved 7 run-group experiments
- New opportunities on the horizon with MOLLER being built and SoLID (hope) to be built soon, hypernuclear physics, secondary beams, BDX, ..
- Longer-term future of JLab may involve positron and 20+ GeV beams

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