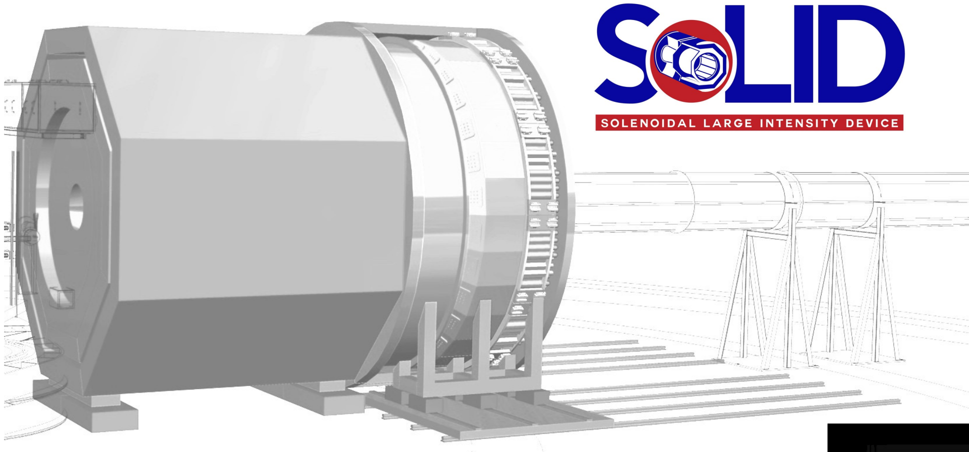
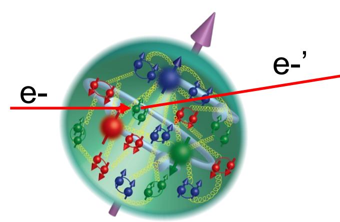
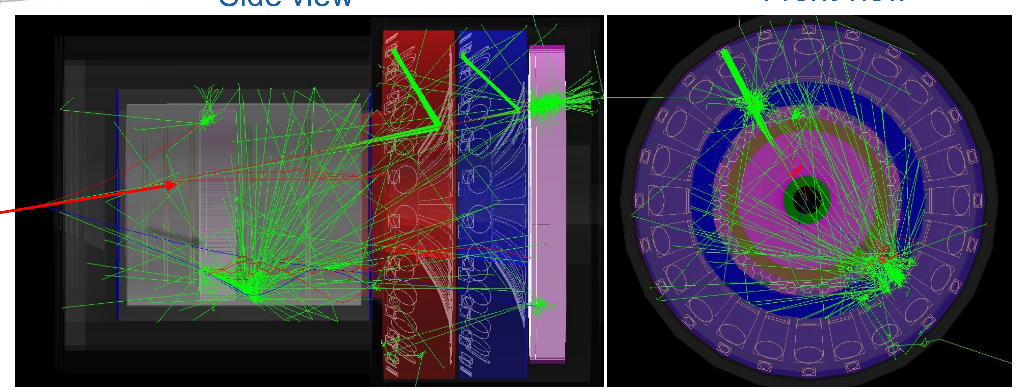
The SoLID Science Program at 12 GeV and Beyond





A charmonium production and decay event in SoLID



Zein-Eddine Meziani
For the SoLID collaboration
Argonne NATIONAL LABORATORY

With thanks to the SoLID team

U.S. DEPARTMENT OF ENERGY | Office of Science
Jefferson Lab SoLID Argonne NATIONAL LABORATORY

OUTLINE

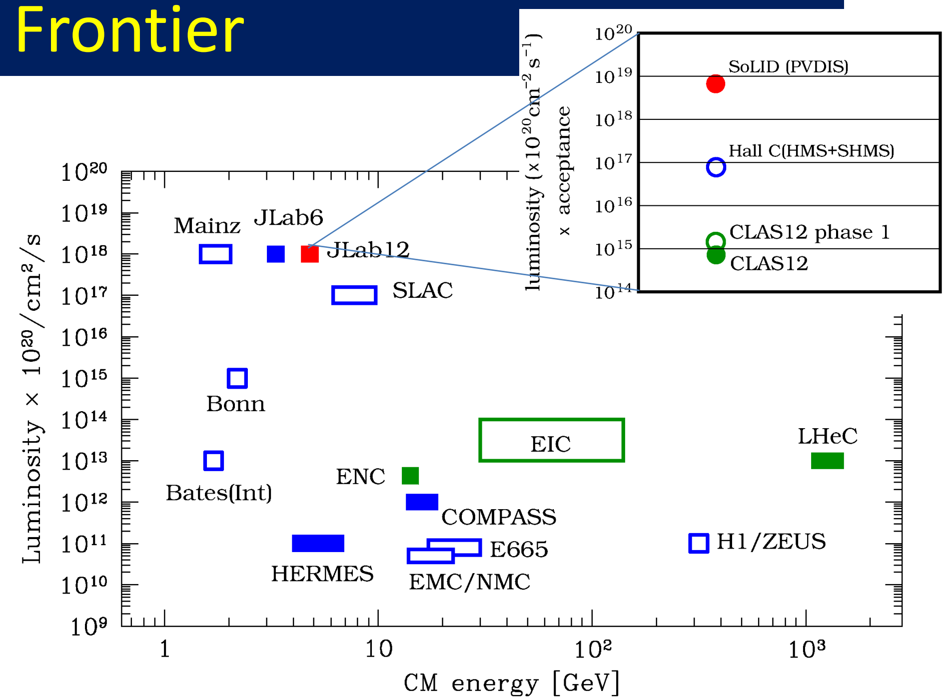
1. Introduction
   - Why a **Solenoidal Large Intensity Device** (SoLID)?
2. Parity Violation in Deep Inelastic Scattering (PVDIS):
   - Test of Standard Model and Precision Hadron Structure
3. Semi-Inclusive Deep Inelastic Program (SIDIS):
   - Transversity and Transverse Momentum Dependent Distributions (TMDs)
4. J/ψ Program: Near threshold Electro- & Photoproduction and GFFs
   - Gravitational Form Factors, Mass and Scalar radii
5. Beyond 12 GeV: Example of ψ' threshold Electron- & photoproduction
6. Summary

Why SoLID in Hall A?

SoLID@12-GeV JLab Enables QCD at the Intensity Frontier

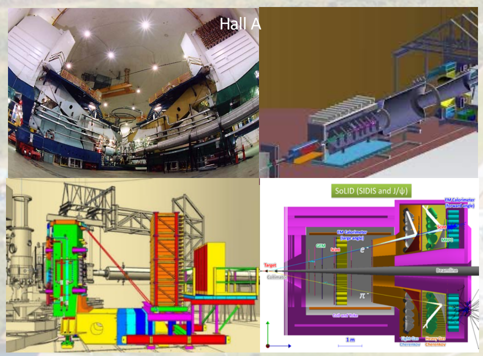
- Nucleon spin, proton mass, beyond standard model experiments require precision measurements of small cross sections and asymmetries, combined with multiple particle detection

- There is a critical need for high luminosity (10^{36}-10^{39} $cm^{-2}s^{-1}$) and large acceptance working in tandem



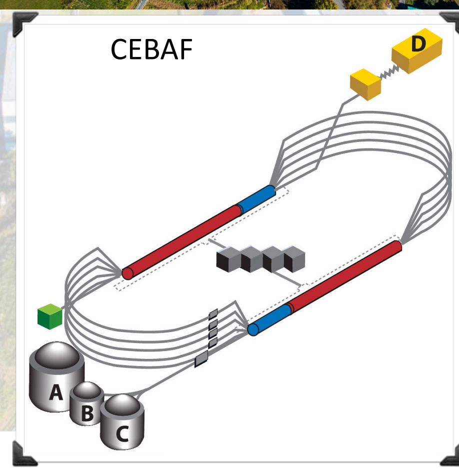
SoLID@12-GeV Enables QCD at the Intensity Frontier. This should extend to 20+ GeV

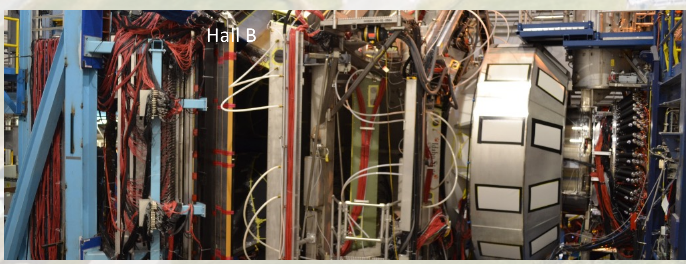
12 GeV experimental capabilities at Jefferson Lab



HRS, SBS, Moller & SoLID

Hall D (GlueX)



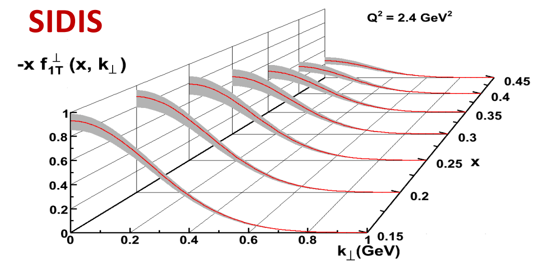


CLAS12 + (luminosity) Upgrade

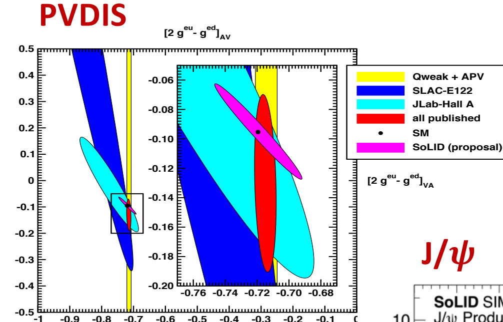
Hall C (HMS and SHMS)

Solenoidal Large Intensity Device (SoLID)

SIDIS



PVDIS



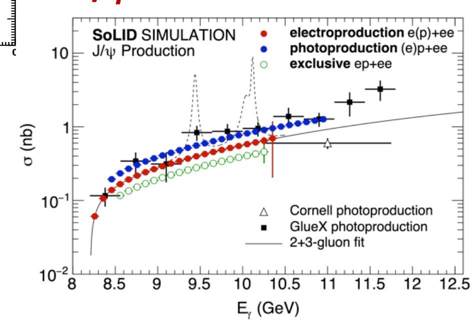
Maximize scientific outcome of JLab 12 GeV upgrade

- QCD Intensity frontier (high luminosity 10^{37-39}/cm²/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/ψ production near the threshold

J/ψ



Complementary and synergistic with the EIC science

- Proton spin and mass
  - **Spin:** valence quark tomography in momentum space
  - **Mass:** precision J/ψ production near threshold

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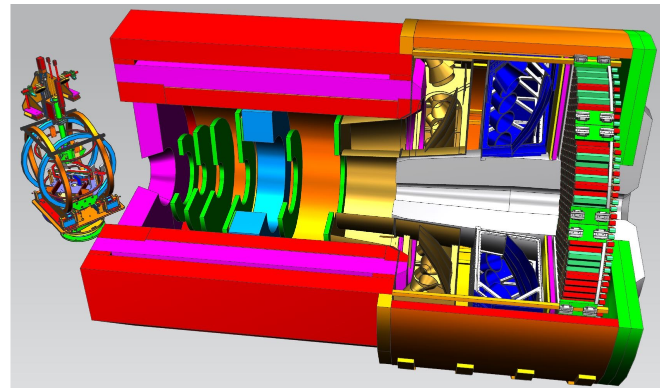
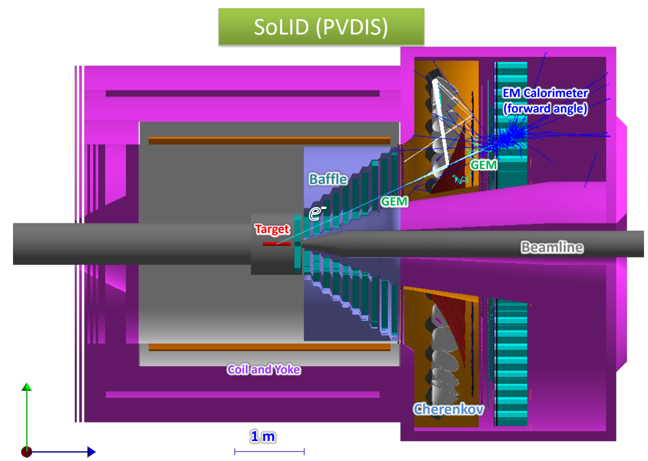
SoLID Apparatus

Requirements are Challenging

- High Luminosity (10^{37}-10^{39})
- High data rate
- High background
- Low systematics
- High Radiation
- Large scale
- Modern Technologies
  - GEM's
  - Shashlik ECal
  - Pipeline DAQ
  - Rapidly Advancing Computational Capabilities
- High Performance Cherenkovs
- Baffles

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

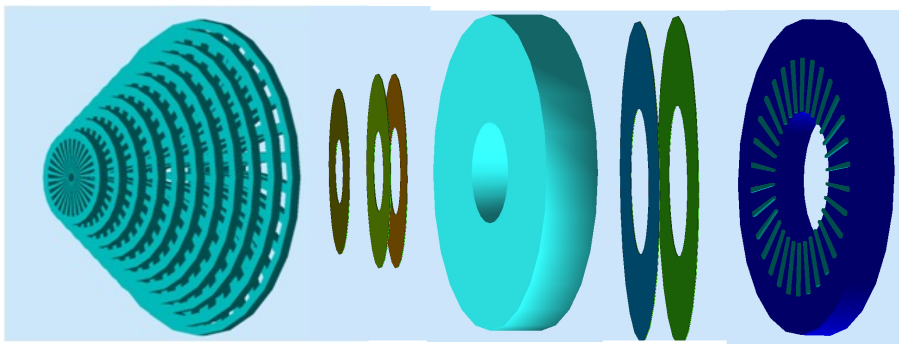


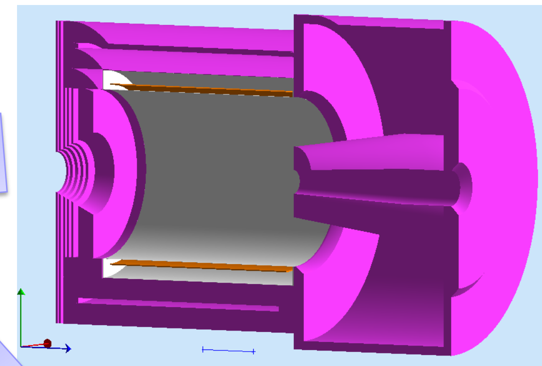


SoLID Detector Subsystems

Uses full capability of JLab electronics

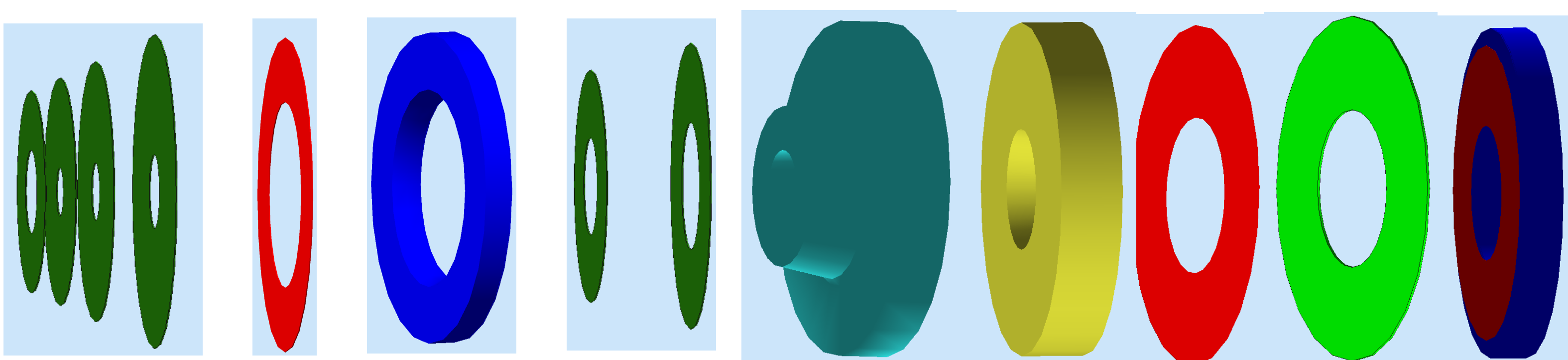
PVDIS: Baffle 3xGEMS LGC 2xGEMs EC





SIDIS& J/psi:

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



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

Progress since Approval of SoLID Experiments

- Since **2010:** Five SoLID experiments approved by PAC with high rating
  - 3 SIDIS (E12-10-006, E12-11-007, E12-11-108), 1 PVDIS(E12-10-007), 1 threshold J/ψ (E12-12-006)
  - 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, went successfully**
- **07/14/2022: All experiments re-approved by PAC50 with previous A rating but J/psi upgraded from A- to A.**
- **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

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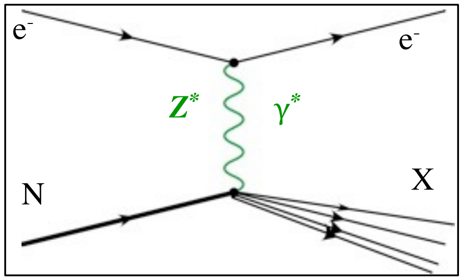
PVDIS:Test of Standard Model and Hadron Structure

Parity Violating DIS on Deuteron

Simplest isoscalar nucleus and at high Bjorken *x*



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

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

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

$$y \equiv 1 - E'/E$$

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

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

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

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

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

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

Unique feature is sensitivity to C_2's

Interplay with QCD

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

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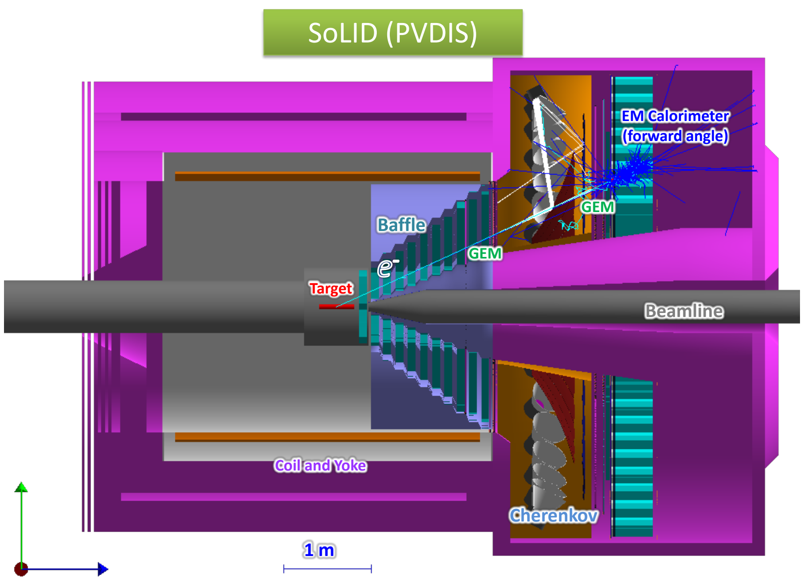
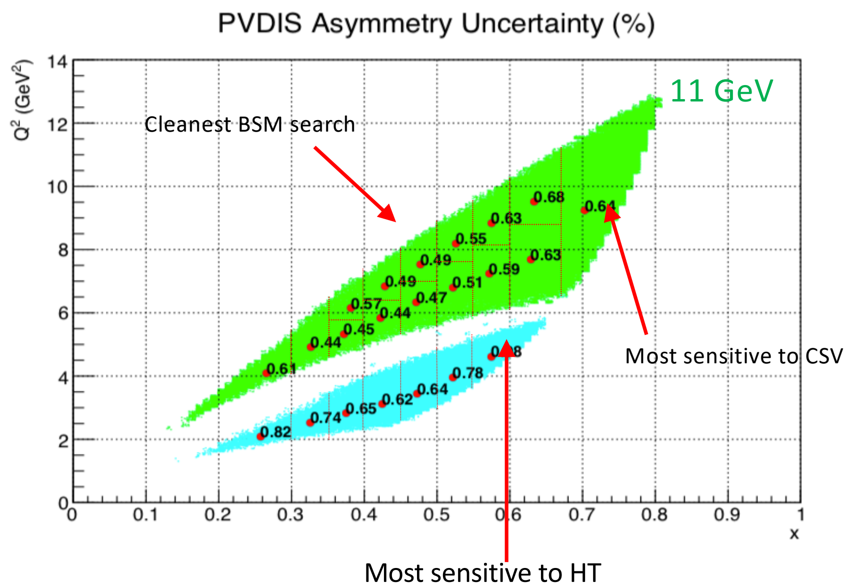
SoLID-PVDIS: Experiment E12-10-007

Spokesperson and contact: Paul Souder
Co-spokespeople: Xiaochao Zheng and Paul Reimer

12 GeV CEBAF: Opportunity to do the ultimate PVDIS measurement

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

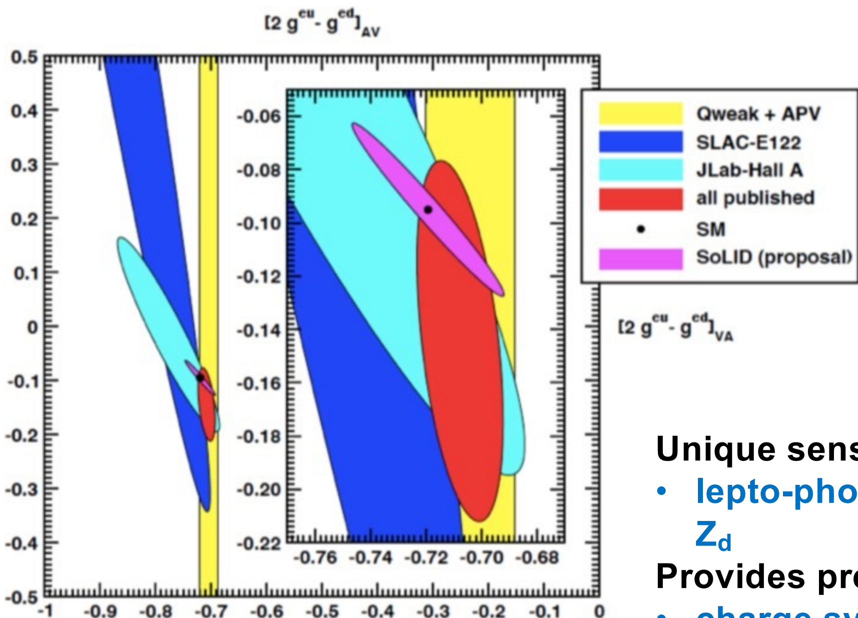




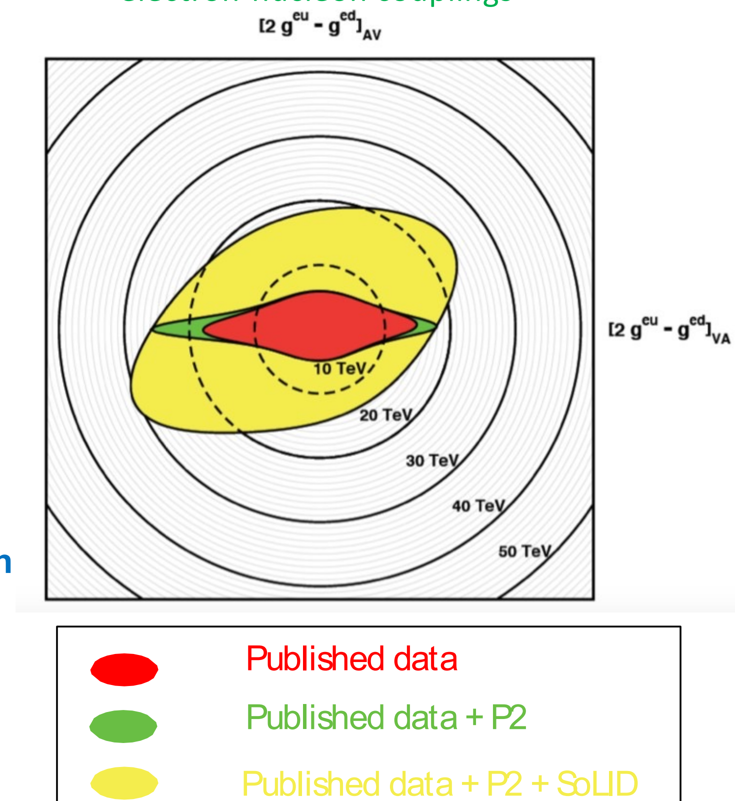
Projected Results on Coupling constants

SoLID makes a unique contribution to the SMEFT program.

Improvement in couplings



Improvement in energy reach for electron-nucleon couplings



Unique sensitivity to

- **lepto-phobic Z', dark boson Z_d**

Provides precision study of

- **charge symmetry violation**
- **high-twist effects**
- **d/u at high-x**

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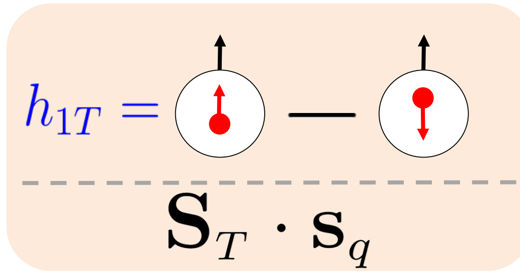
SoLID-SIDIS: Transversity/Tensor Charge and TMDs

TMDs – confined motion inside the nucleon

Transversely Polarized Nucleon TMDs

→ Nucleon Spin
→ Quark Spin



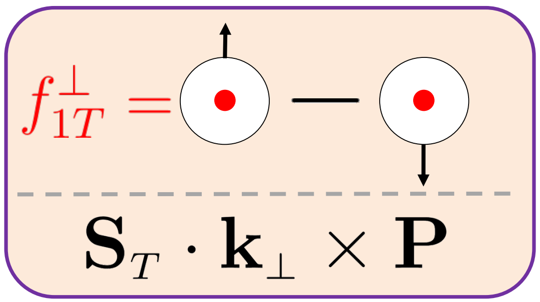
Transversity

Relevant Vectors

- $\mathbf{S}_T$: Nucleon Spin
- $\mathbf{s}_q$: Quark Spin
- $\mathbf{k}_\perp$: 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

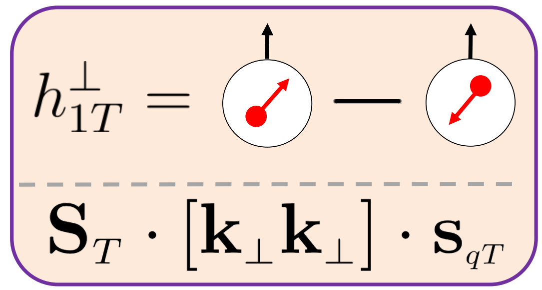
Sivers



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

Kinematic Function	TMD	Name
1	f_1	Structure Function
$\mathbf{S_L} \cdot \mathbf{s_q}$	g_1	Spin-Structure Function
$\mathbf{S_T} \cdot \mathbf{s_q}$	h_1	Transversity
$\mathbf{S_L} \cdot \mathbf{k}_\perp \times \mathbf{s}_q$	$h_{1L}^\perp$	Worm Gear
$\mathbf{S_T} \cdot \mathbf{k}_\perp \times \mathbf{s}_q$	g_{1T}	Worm Gear
$\mathbf{S_T} \cdot \mathbf{k}_\perp \times \mathbf{P}$	$f_{1T}^\perp$	Sivers
$\mathbf{k}_\perp \times \mathbf{P} \cdot \mathbf{s}_q$	$h_1^\perp$	Boer-Mulder
$\mathbf{S_T} \cdot [\mathbf{k}_\perp \mathbf{k}_\perp] \cdot \mathbf{s}_{qT}$	$h_{1T}^\perp$	Pretzelocity

Pretzelosity



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

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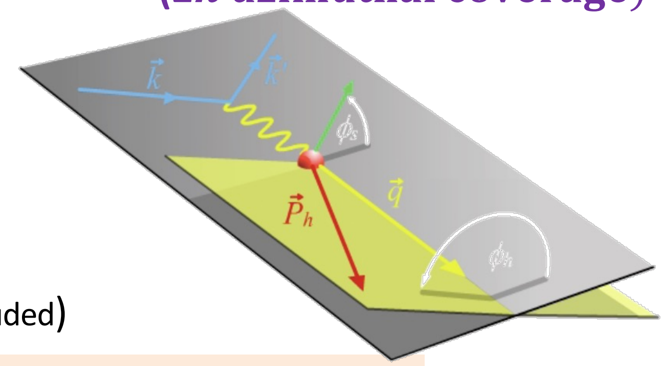
Separation of Collins, Sivers and Pretzelosity

SIDIS SSAs depend on 4-D variables (x, Q^2, z, P_T) and small asymmetries demand **large acceptance + high luminosity. A**llows precision measurements of asymmetries in 4-D binning!

(2π azimuthal coverage)



$$A_{UT}(\phi_h, \phi_S) = \frac{1}{P_{t,pol}} \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

Leading twist formalism
(higher-twist terms can be included)

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

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

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

Collins fragmentation function from e^+e^- collisions

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

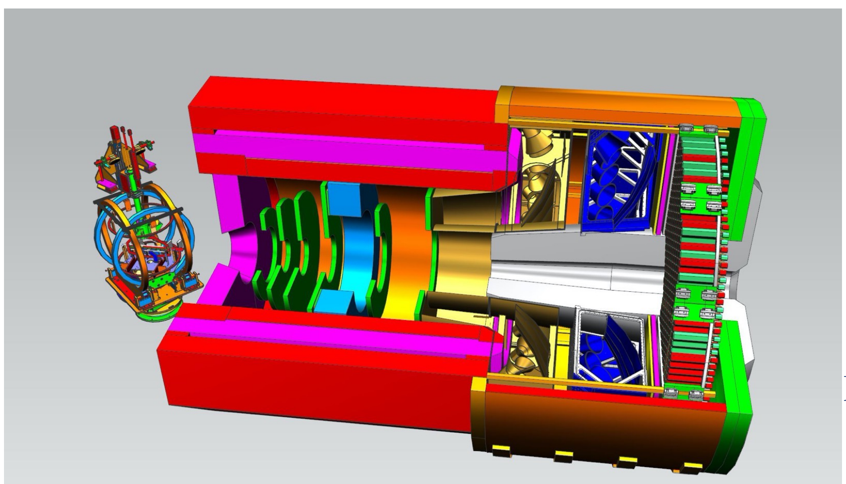
Unpolarized fragmentation function

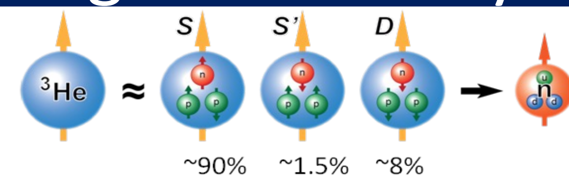
SoLID-SIDIS: Large-Acceptance & High Luminosity

Quantum leap: 4-D binning for the first time!

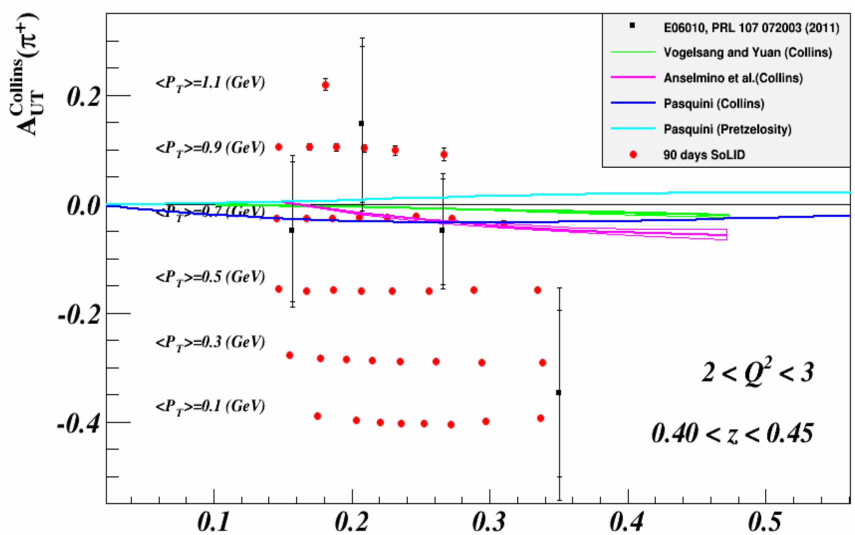
SoLID-SIDIS program: Large acceptance, Full azimuthal coverage + High luminosity

- 4-D mapping of asymmetries with precision
  - **$\Delta z = 0.05$, $\Delta P_T = 0.2$ GeV, $\Delta Q^2 = 1$ GeV2, x bin sizes vary with median bin size 0.02 (typical stat. uncertainty for each bin: $\delta A \leq 0.005$)**
- Constrain models and forms of TMDs, Tensor charge, …
- Lattice QCD, QCD dynamics



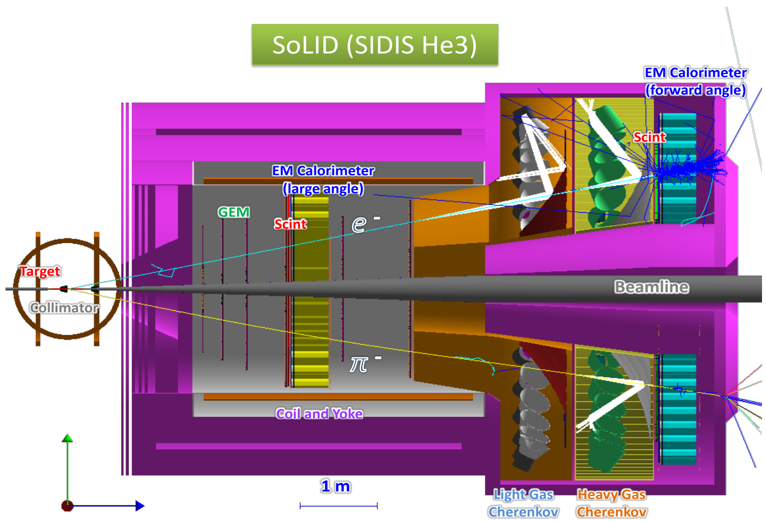


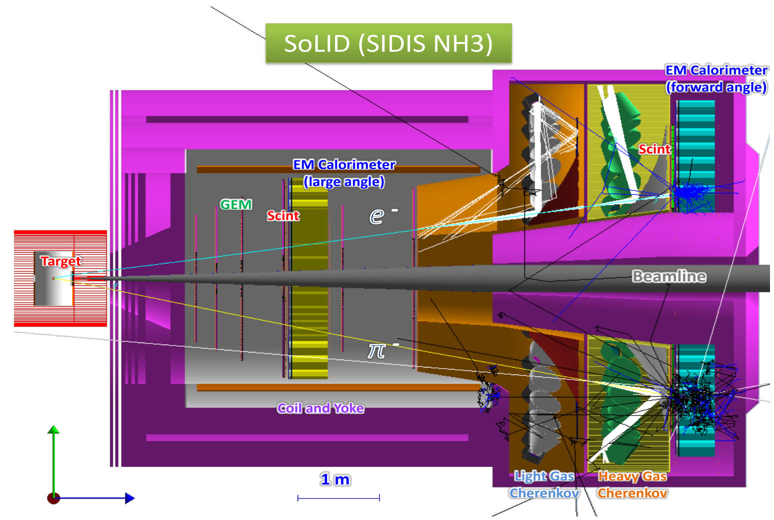
JLab 6-GeV experiment on SSA using A transversely polarized ^{3}He X. Qian et al., PRL107, 072003(2011)



More than 1400 bins in x, Q^2, P_T and z for 11/8.8 GeV beam.

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

Run group experiments approved for TMDs, GPDs, and Spin

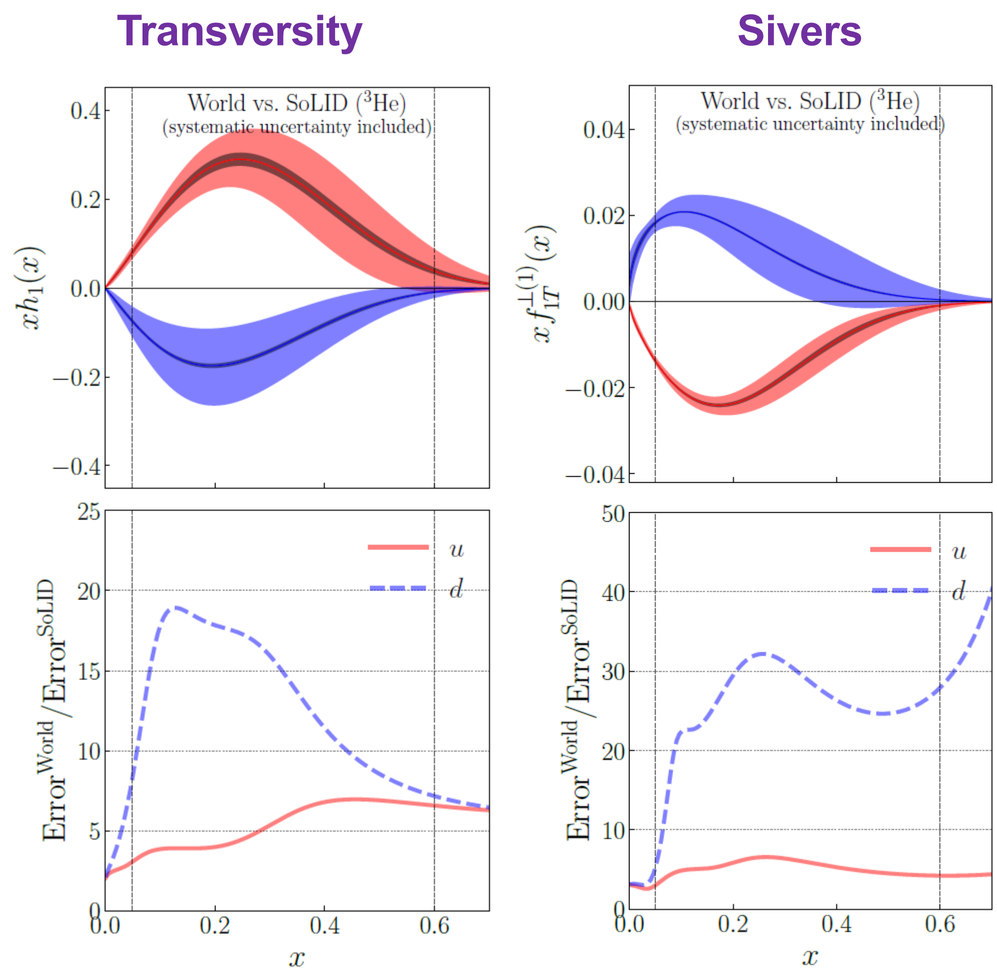
SoLID-SIDIS Projection

Impact of SoLID on World Data

- 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

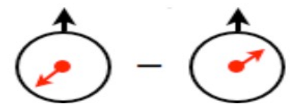
World data according to SoLID preCDR (2019)https://solid.jlab.org/experiments.html

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

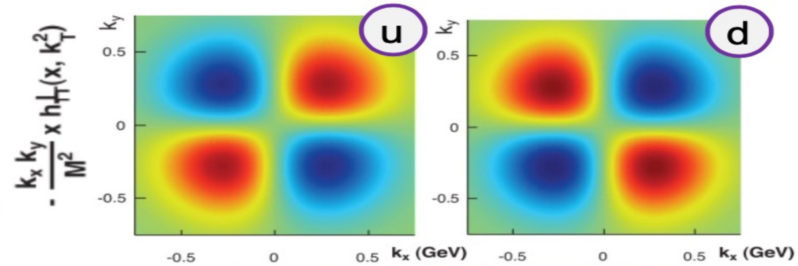


TMDs – confined motion inside the nucleon

Pretzelocity distribution $h_{1T}^{\perp}$



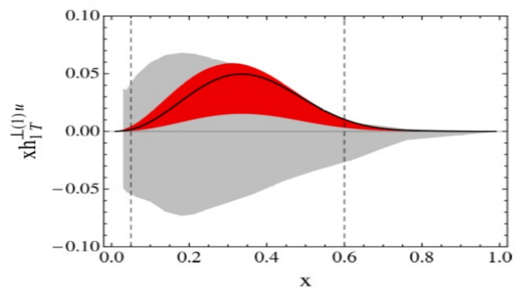
- Chiral-odd, no gluon analogy
- Quadrupole modulation of parton density in the distribution of transversely polarized quarks in a transversely polarized nucleon
- Measuring the difference between helicity and transversity (relativistic effects)



Images from PRD 91 034010 (2015)

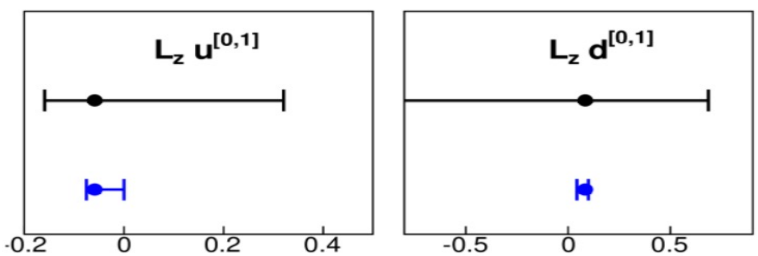
Parametrization by C. Lefky et al., PRD 91, 034010 (2015)

SoLID projection with transversely polarized n and p data



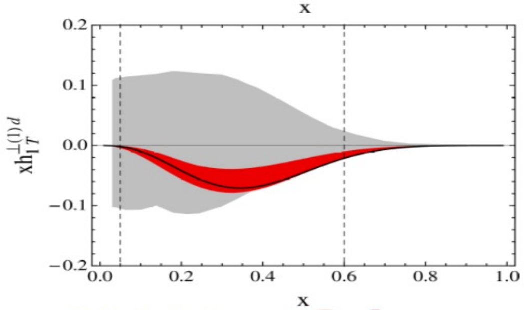
Relation to OAM (canonical)

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



Lefky and Prokudin PRD 91, 034010 (2015)

SoLID projection

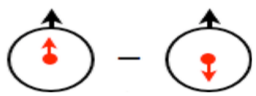


Combining E12-10-006 & E12-11-108

SoLID Jefferson Lab

Transversity and Tensor Charge

Transversity distribution

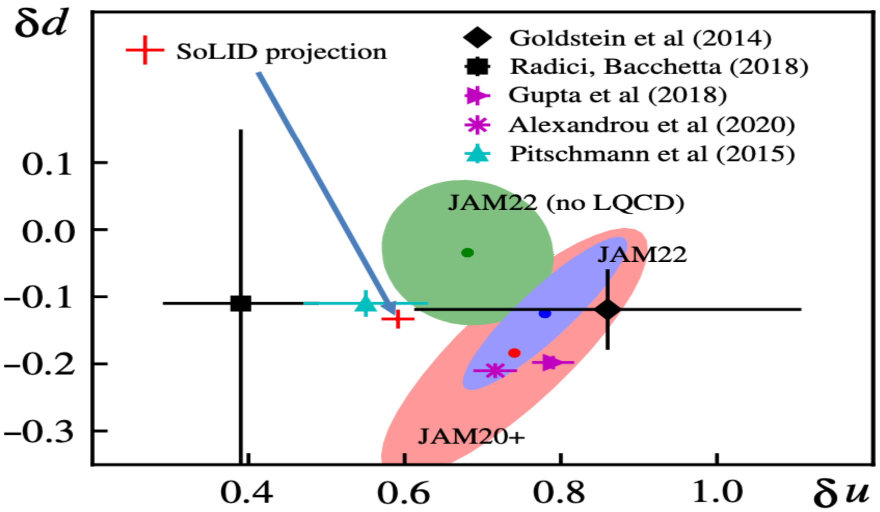
h_1  (Collinear & TMD)

- 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



Combining E12-10-006 & E12-11-108

SoLID projection: statistical and systematic uncertainties included (shifted for visibility)

J. Cammarota et al, PRD 102, 054002 (2020) (JAM20+)
L. Gamberg et al., arXiv:2205.00999 (JAM22)

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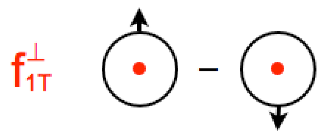
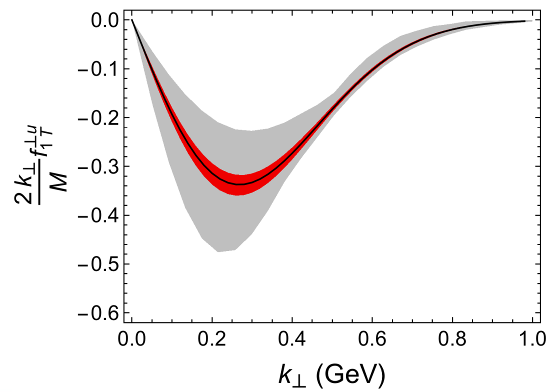
TMDs – confined motion inside the nucleon

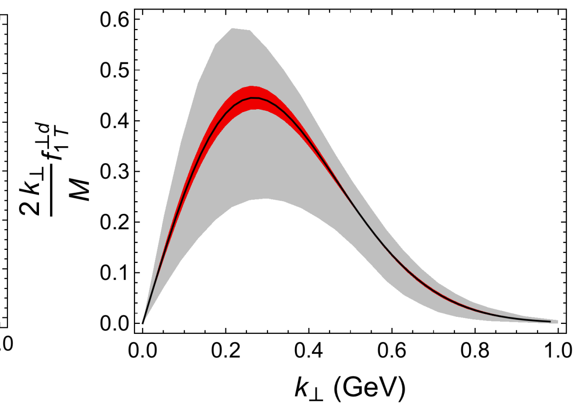
Sivers distribution

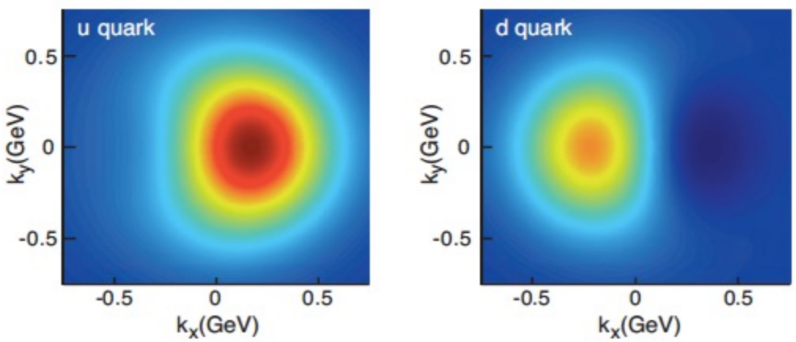


naively time-reversal odd

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







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

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

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

SoLID projection with transversely polarized n/p

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

Nucleon spin - quark orbital angular momentum (OAM) correlation

– zero if no OAM (collinear, massless quarks)

Exact finding is model dependent but SoLID impact is model-independent!

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SoLID J/ψ & (ψ') : -Near Threshold Production
-Gluonic Gravitational Form Factors
-Proton Mass and Scalar Radius

Gluonic Gravitational Form Factors

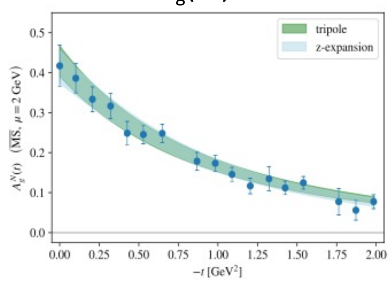
The standard decomposition of the energy-momentum tensor form factor in a nucleon state

X.-D. Ji, Phys. Rev. Lett. 78, 610 (1997)

$$\langle p_2|T_g^{\mu\nu}(0)|p_1\rangle = \bar{u}(p_2)\Big(A_g(k)\gamma^{(\mu}p^{\nu)} + B_g(k)\frac{ip^{(\mu}\sigma^{\nu)\alpha}k_\alpha}{2m_N} + C_g(k)\frac{k^\mu k^\nu - \eta^{\mu\nu}k^2}{m_N}\Big)u(p_1)$$

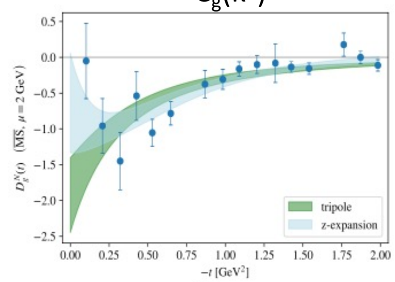
$$k^2 = (p_2 - p_1)^2 = t$$
$$a^{(\mu}b^{\nu)} = \frac{1}{2}(a^\mu b^\nu + a^\nu b^\mu)$$
$$p = (p_1 + p_2)/2$$

$A_g(k^2)$



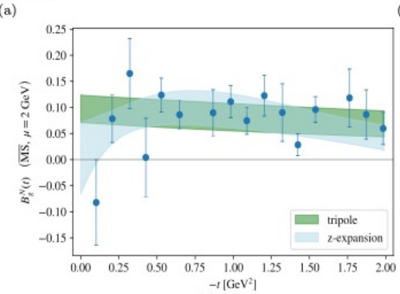
(a)

$C_g(k^2)$



(b)

Pefkou, Hackett and Shanahan
Phys. Rev. D 105, 054509



(c)

$B_g(k^2)$

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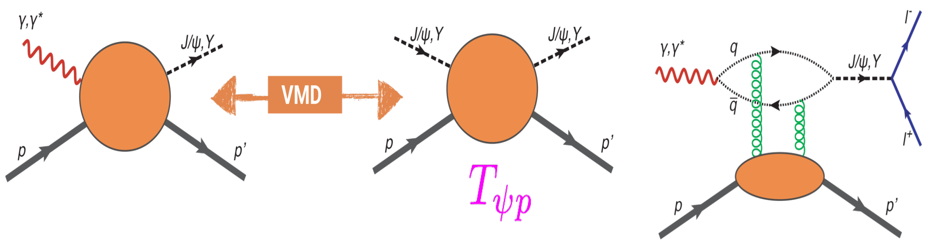
From Cross Section to the Trace Anomaly



$$\gamma^* + N \rightarrow N + J/\psi$$

Heavy quark – dominated by two gluons

$$\langle P|T^\alpha_\alpha|P\rangle = 2P^\alpha P_\alpha = 2M_p^2$$

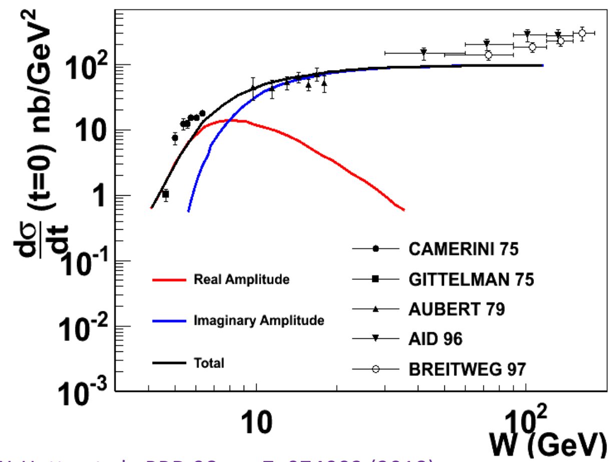
$$\frac{d\sigma_{\gamma N\to\psi N}}{dt}(s,t=0) = \frac{3\Gamma(\psi\to e^+e^-)}{\alpha m_\psi}\left(\frac{k_{\psi N}}{k_{\gamma N}}\right)^2 \frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0)$$

$$\frac{d\sigma_{\psi N\to\psi N}}{dt}(s,t=0) = \frac{1}{64\pi}\frac{1}{m_\psi^2(\lambda^2 - m_N^2)}|\mathcal{M}_{\psi N}(s,t=0)|^2$$

VMD relates photoproduction cross section to quarkonium-nucleon scattering amplitude

- **Imaginary part** is related to the total cross section through optical theorem
- **Real part contains the conformal (trace) anomaly;** Dominates the near threshold region and constrained through dispersion relation

D. Kharzeev (1995); Kharzeev, Satz, Syamtomov, and Zinovjev EPJC,9, 459, (1999); Gryniuk and Vanderhaeghen, PRD94, 074001 (2016)



Y. Hatta et al., PRD 98 no. 7, 074003 (2018)
Y. Hatta et al., 1906.00894 (2019)
K. Mamo & I. Zahed, Phys. Rev. D 101, 086003 (2020)
R. Wang, J. Evslin and X. Chen, Eur. Phys. J. C **80**, no.6, 507 (2020)

A measurement near threshold could allow access to the trace anomaly

Proton Mass and Quantum Anomalous Energy

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

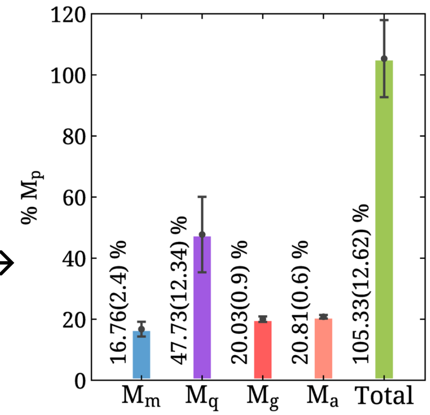
$H_m =$ Quark mass $\int d^3x\, \bar{\psi} m \psi$

$H_g =$ 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!

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



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

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

- **Measuring quantum anomalous energy contribution in experiments is an important goal in the future**

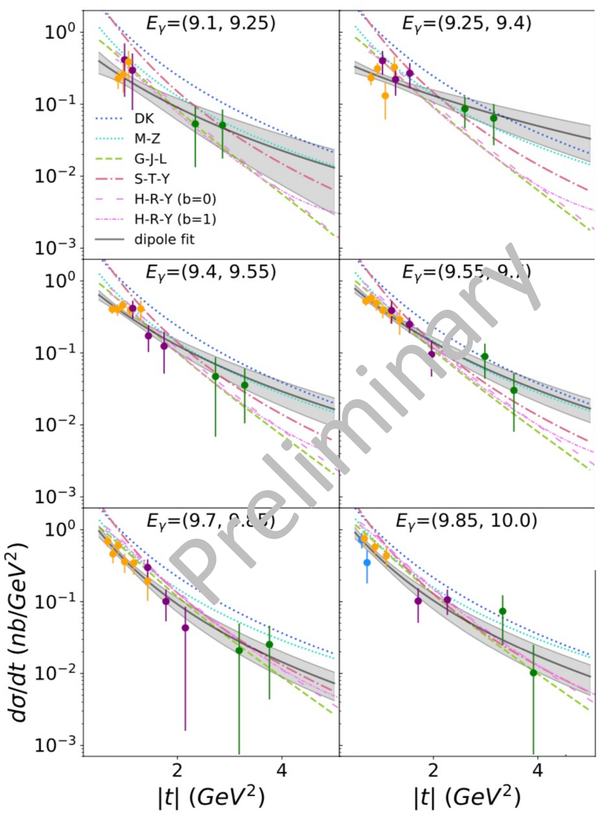
Can be accessed through heavy quarkonium threshold (J/psi & Upsilon) production,
D. Kharzeev, Proc. Int. Sch. Phys. Fermi 130, 105 (1996)
R. Wang et al, Eur.Phys.J.C 80 (2020) 6, 507

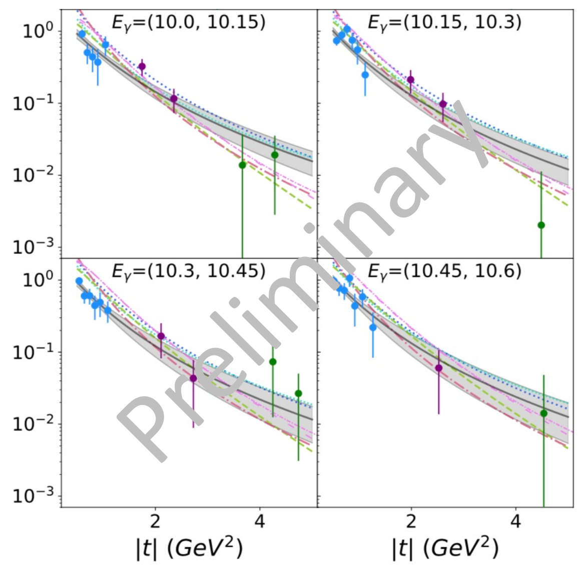
Results currently under peer-review

•e-Print: 2207.05212 [nucl-ex]

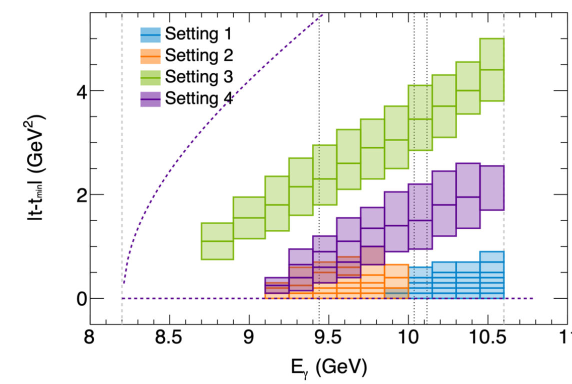
007$^{J/\psi}$

Preliminary 2D J/ψ cross section results





DK: D, Kharzeev, Phys. Rev. D 104, 054015 (2021).
M-Z: Mamo & Zahed, 2204.08857 (2022)
G-J-L: Guo, Ji & Liu, Phys. Rev. D 103, 096010 (2021)
S-T-Y: Sun, Tong & Yuan, Phys. Lett. B 822, 136655 (2021)
H-R-Y: Hatta, Rajan & Yang, Phys. Rev. D 100, 014032 (2019)
Dipole fit: Independent dipole fit to each of the t-spectra



- Unfolded 2D cross section results compared to various model predictions informed by the 1D GlueX results
- All models work reasonably well at higher energies but deviate at lower energies

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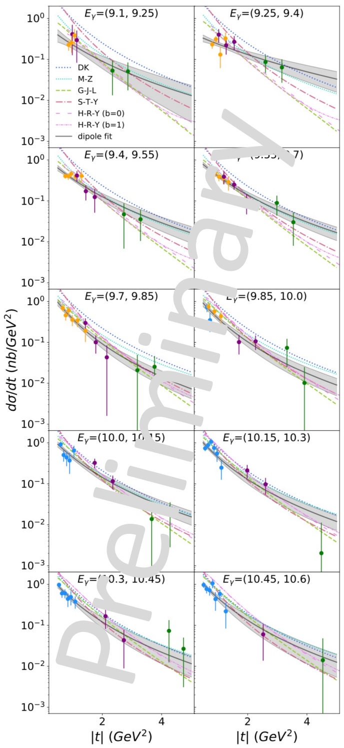
•e-Print: 2207.05212 [nucl-ex]

Extracting GFFs from the 2D profiles

007$^{J/\psi}$

First ever extraction of gluonic GFFs from purely experimental data!



- **Model dependent extractions** using the available approaches in the literature
  - Holographic QCD approach: K. Mamo & I. Zahed, PRD 103, 094010 (2021) and 2204.08857 (2022)
  - GPD+VMD approach: Y. Guo, X. Ji, Y. Liu, PRD 103, 096010 (2021)
  - In both cases assume $B_g(t)$ contributes little (supported by lattice)
- Use tripole form for $A_g(t)$ and $C_g(t)$ (differences with dipole negligible)
- Use $A_g(0) = \langle x_g \rangle$ from the CT18 global fit, fit remaining 3 parameters $(m_A, C_g(0), m_C)$ to 2D cross section results.

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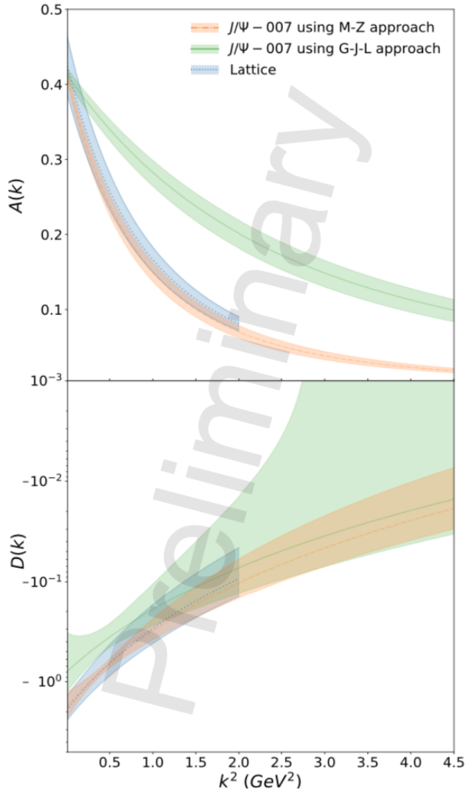
•e-Print: 2207.05212 [nucl-ex]

GLUONIC GFF RESULTS

Good agreement between Holographic QCD and Lattice results!

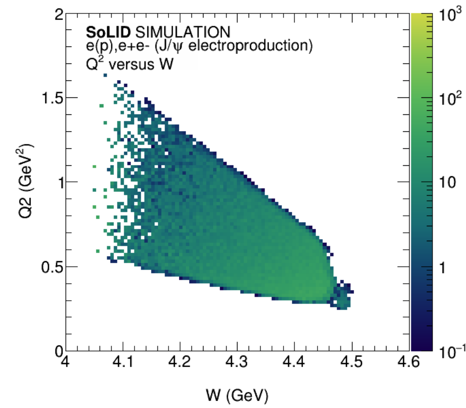


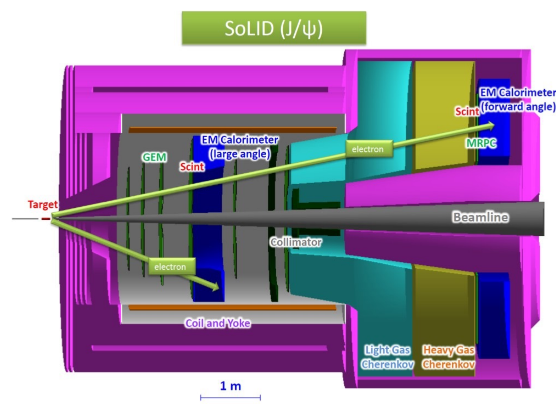
- Results from the 2D gluonic GFF fits
- Gluonic $A_g(t)$ and $D_g(t) = 4C_g(t)$ form factors
- χ^2/n.d.f. in both cases very close to 1
- M-Z (holographic QCD) approach fit to only experimental data gives results very close to the latest lattice results of the same quantities!

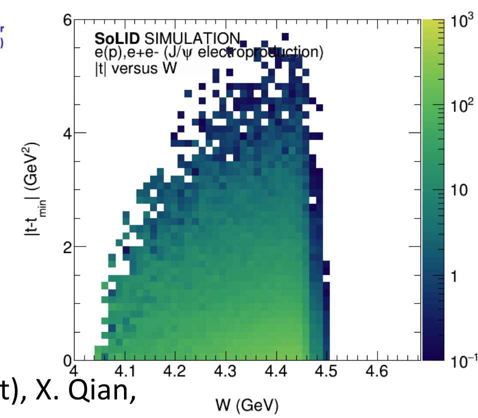
M-Z: K. Mamo & I. Zahed, PRD 103, 094010 (2021) and 2204.08857 (2022)
G-J-L: Y. Guo, X. Ji, Y. Liu, PRD 103, 096010 (2021)
Lattice: D. Pefkou, D, Hackett, P. Shanahan, Phys. Rev. D 105, 054509 (2022).

SoLID-J/ψ: Experiment E12-12-006

- 50 days of $3\,\mu$A beam on a 15 cm long LH_2 target at $1\times10^{37}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - 10 more days include calibration/background run
- 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^-







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

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

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Event Counts @ 1×10^{37} in 50 days

4-fold coincidence: ep, e^+e^-

280-400 events/day

3-fold (electroproduction): e, e^+e^-

415-594 events/day

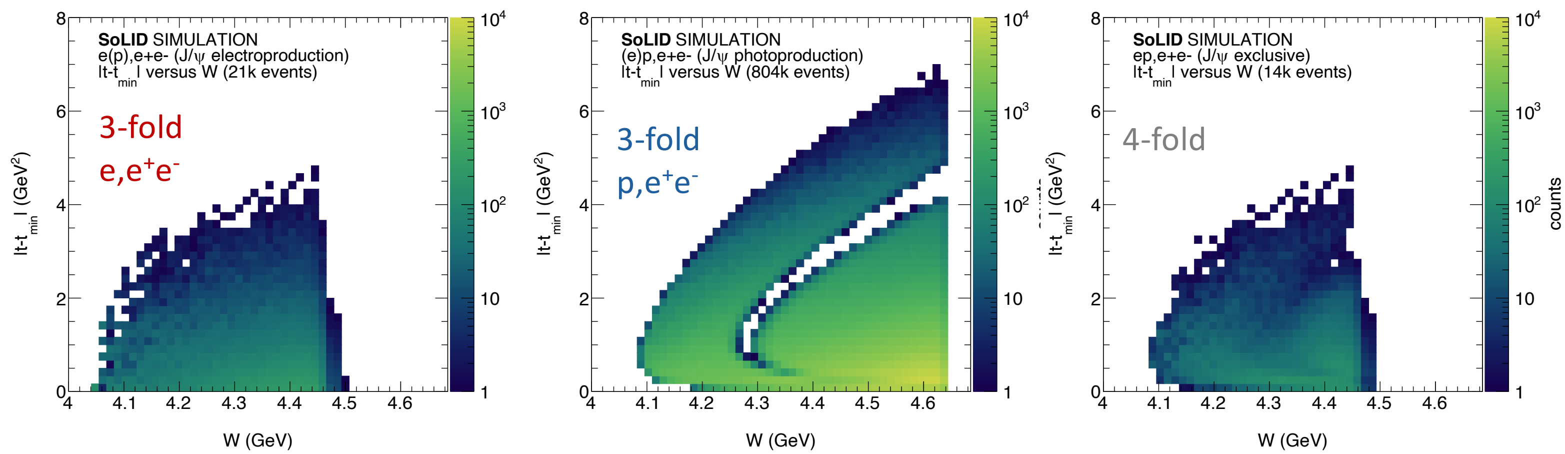
3-fold (photoproduction): p, e^+e^-

16k-23k events/day

2-fold (inclusive): e^+e^-

26k-37k events/day

	Time (Hour)	Time (Day)
LH_2 at 11 GeV	**1200**	**50**
Dedicated Al dummy run	**72**	**3**
Optics and detecto check out	**72**	**3**
Special low luminosity	**96**	**4**
Total	**1440**	**60**



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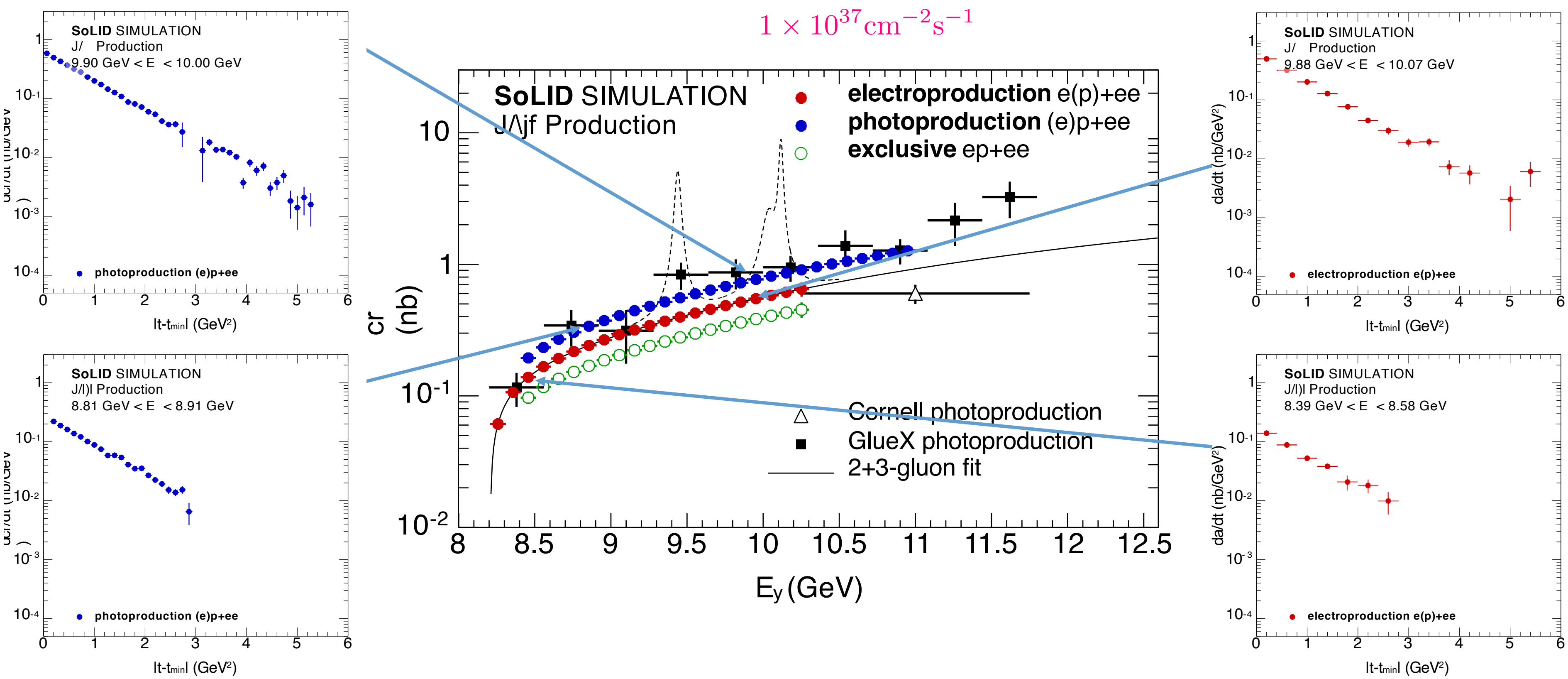
J/Psi Experiment E12-12-006 @ SoLID

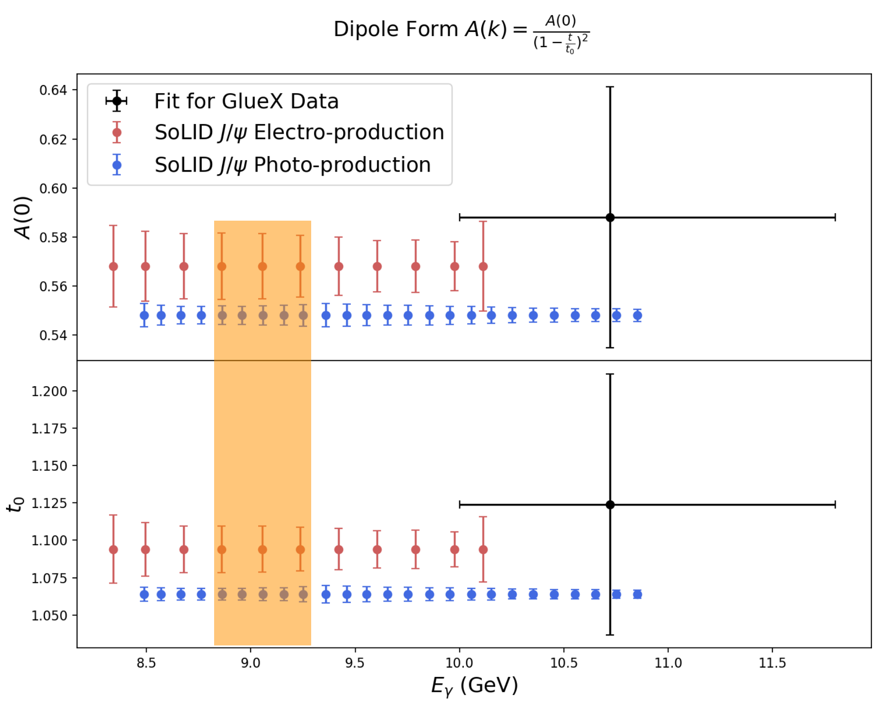


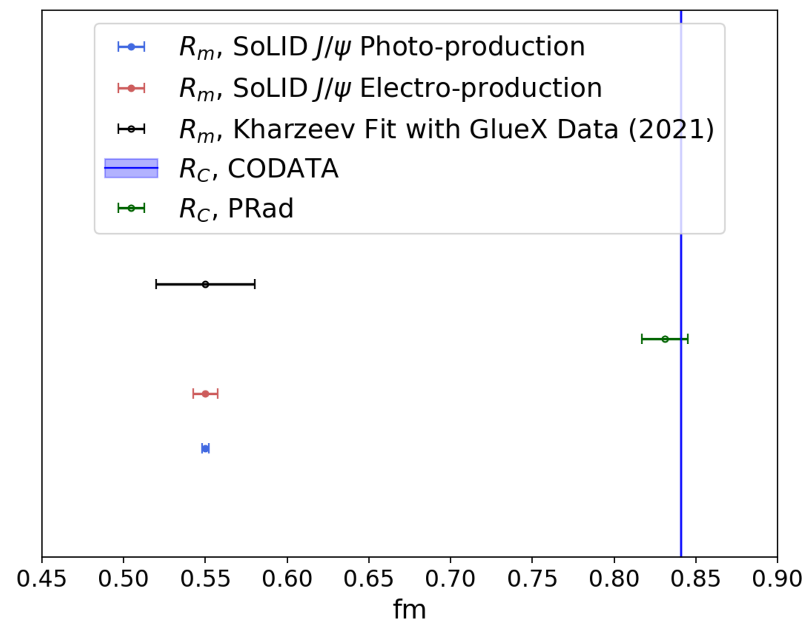
Sensitivity at threshold at about 10^{-3} nb!

SoLID

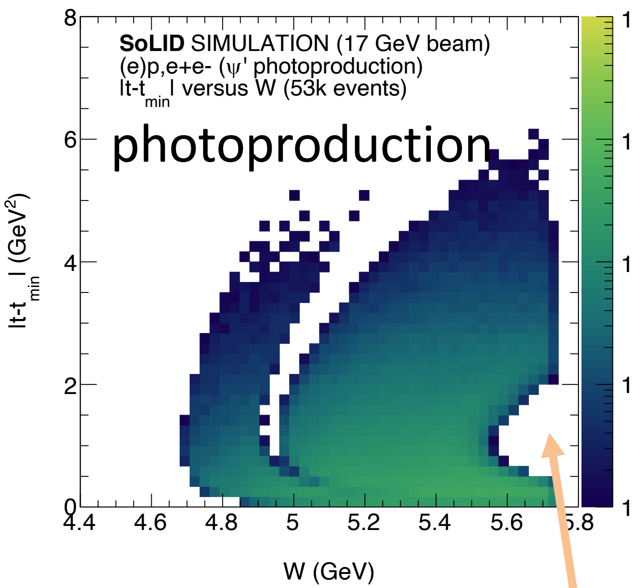
Impact on the mass radius

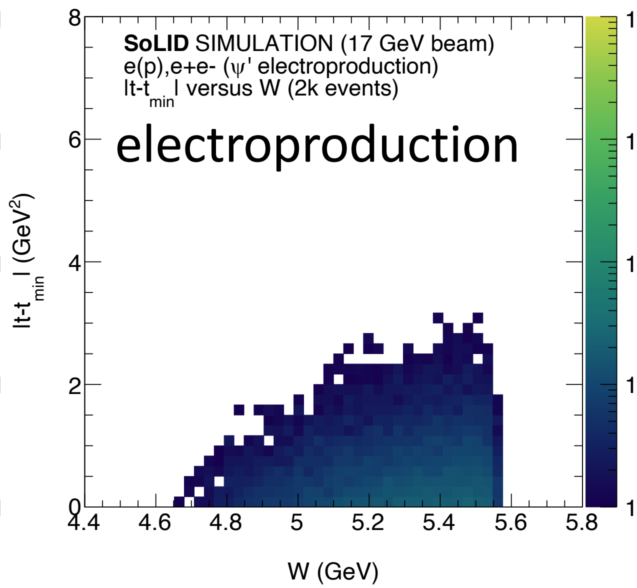
D. E. Kharzeev, ``The mass radius of the proton,"
arXiv:2102.00110 [hep-ph]

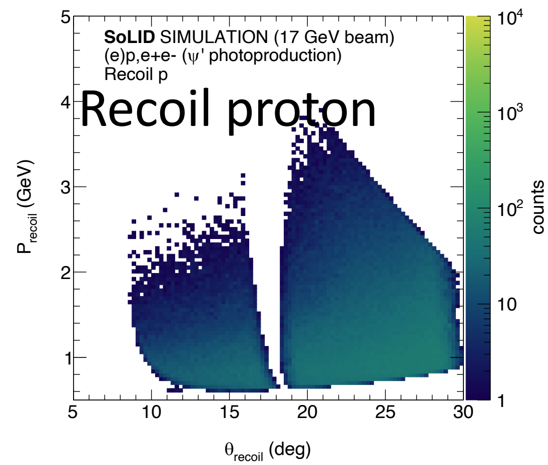


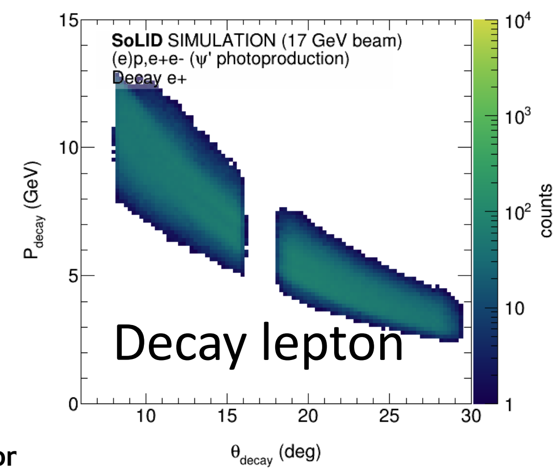


ψ(2S) triple coincidence phase space for 17 GeV









The gap on the right-hand side is due to recoil protons being lost at small angles. This makes going to higher beam energies (E>17GeV) not optimal with the current target position.

Bottom line: SoLID *J/ψ* configuration can be used without modifications to detect *ψ* (2s) with beam energies up to 17 GeV

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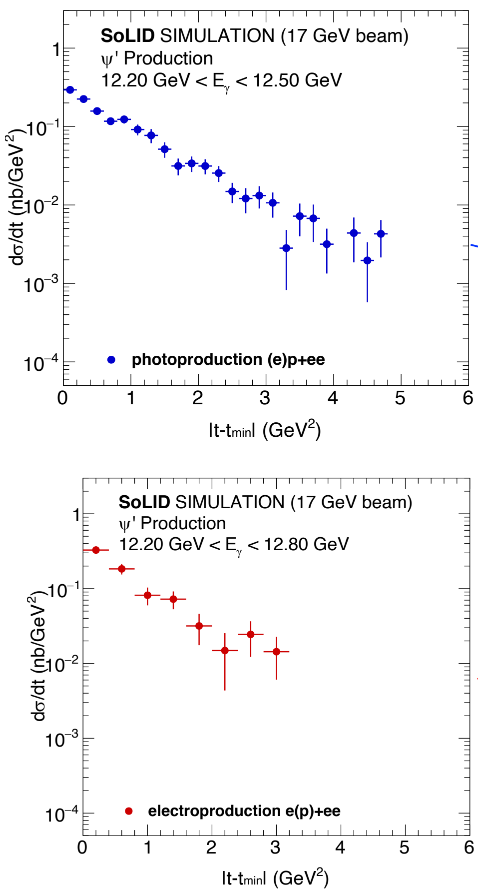
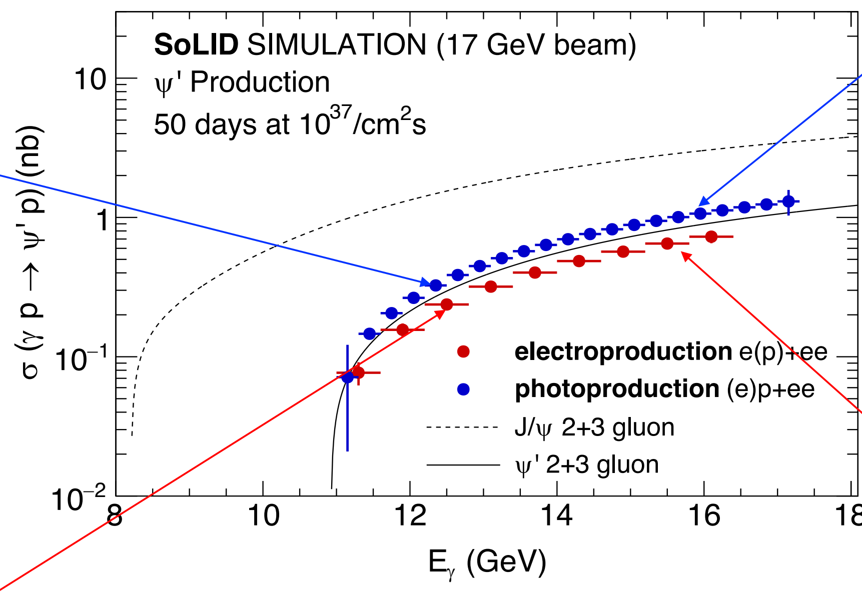
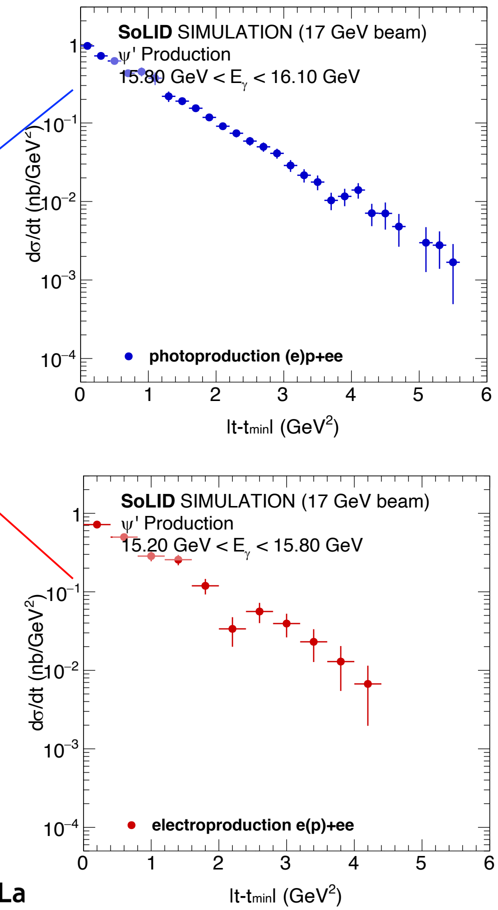
ψ(2S) production with a 17 GeV incident Electron beam







2D measurement of *ψ*(2s) cross section feasible for both photoproduction and electroproduction with the nominal SoLID-*J/ψ* setup.

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Summary

SOLID: A Science Program at the Intensity Frontier

- SoLID is a **large acceptance** device which can handle **very high luminosity** to allow full exploitation of JLab 12 GeV scientific potential by pushing the limit of the intensity frontier
- SoLID has rich and vibrant science programs complementary and synergistic to the proposed EIC science program.
  Three pillars include SIDIS, PVDIS and J/Psi threshold production
- 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 pillars
- Completed the DOE science review (March 8-10, 2021)
- There are unique opportunities with 20+ GeV upgrade and enhancement of the present science program

270+ collaborators, 70+ institutions from 13 countries

New collaborators are welcome!

https://solid.jlab.org/