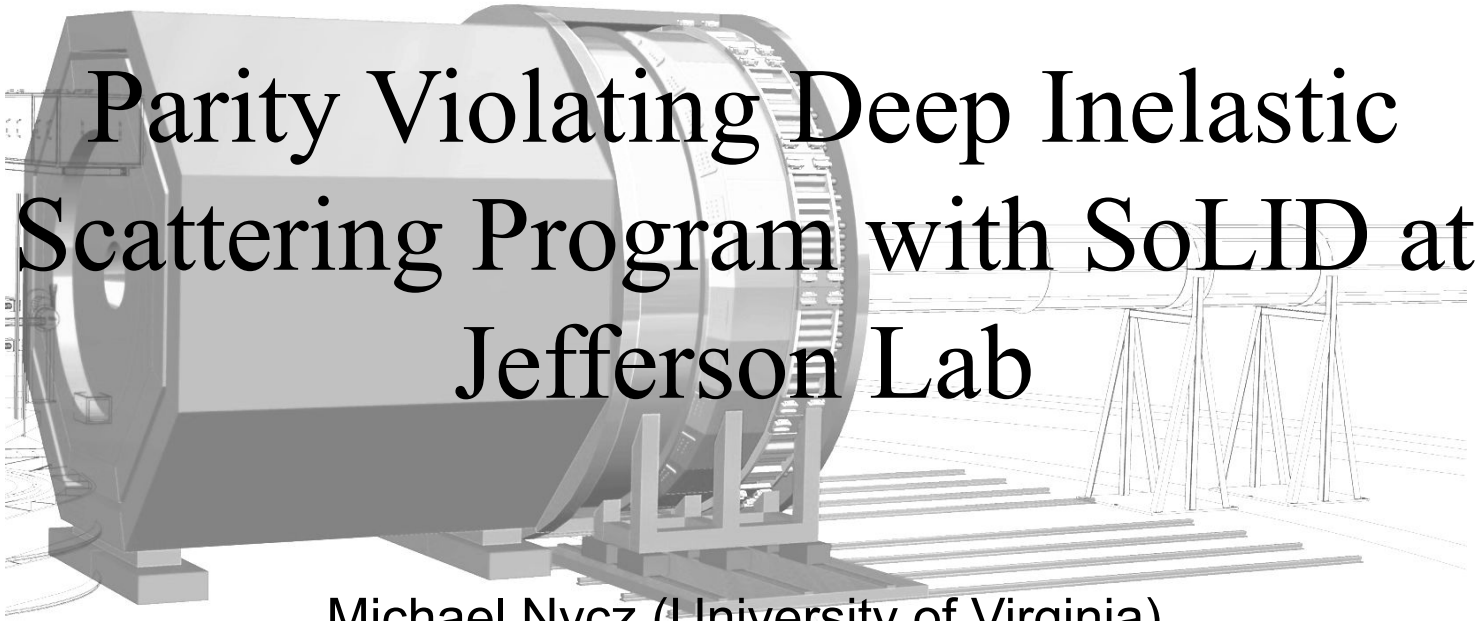


Parity Violating Deep Inelastic Scattering Program with SoLID at Jefferson Lab

Michael Nycz (University of Virginia)
2024 Fall CTEQ Meeting
November 22, 2024

*This work is supported in part by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract number DE–SC0014434.

SoLID
SOLENOIDAL LARGE INTENSITY DEVICE

(Brief) Outline

1. Overview of SoLID
2. Overview of the PVDIS (Deuteron) program with SoLID
3. PDF Uncertainty Study with PVDIS (Deuteron)
4. Overview of the PVDIS (Proton) program with SoLID
5. Summary and Outlook

Overview of SoLID

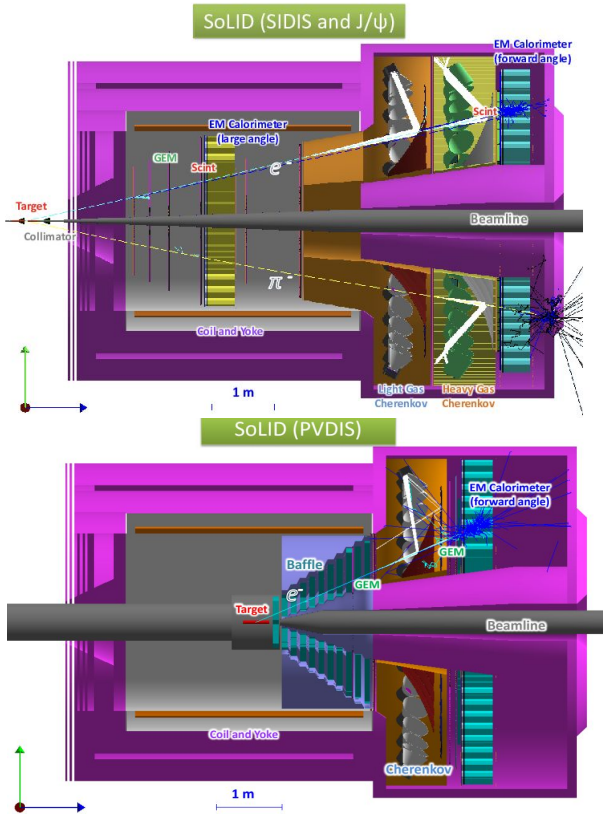
SoLID (**So**lenoidal **L**arge **I**ntensity **D**evice)

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

+

Large Acceptance
Full azimuthal ϕ coverage

SoLID will maximize the science from the
12 GeV Upgrade of CEBAF
Research at **SoLID** will have a ***unique*** capability to
explore the QCD landscape
while **complementing** the research of other key facilities



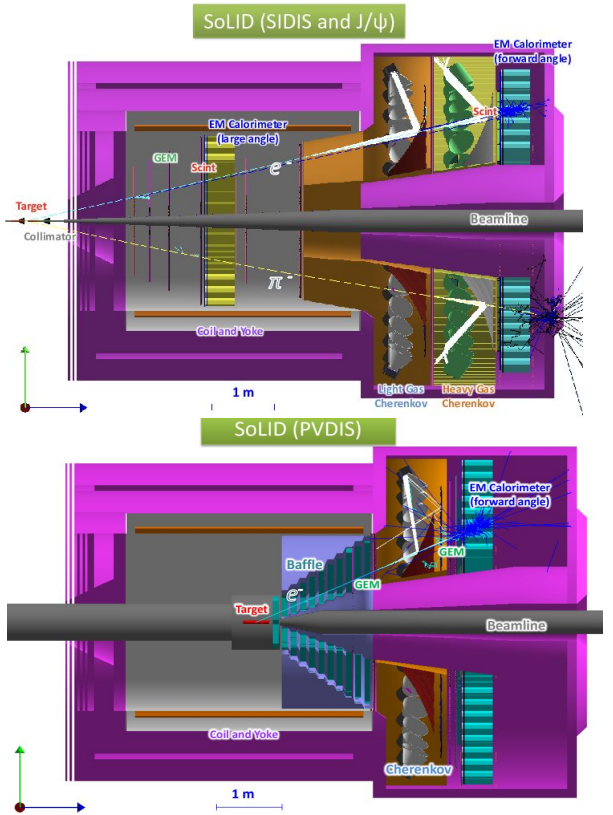
SoLID (**So**lenoidal **L**arge **I**ntensity **D**evice)

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

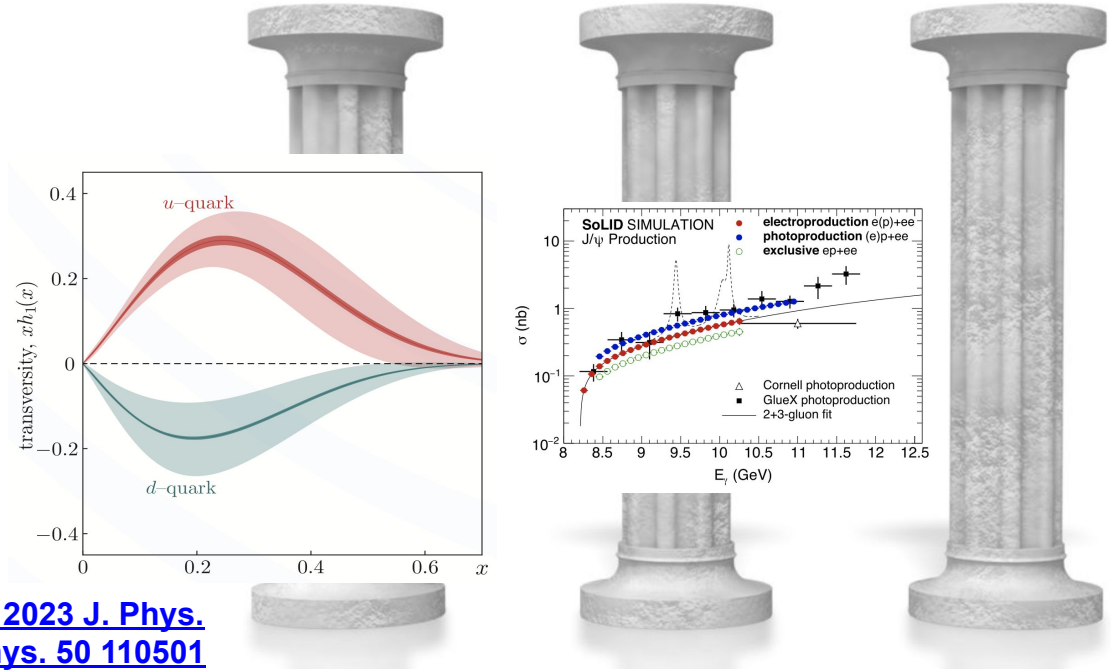


Three Pillars of the SoLID Program

SIDIS ***J / Ψ*** ***PVDIS***

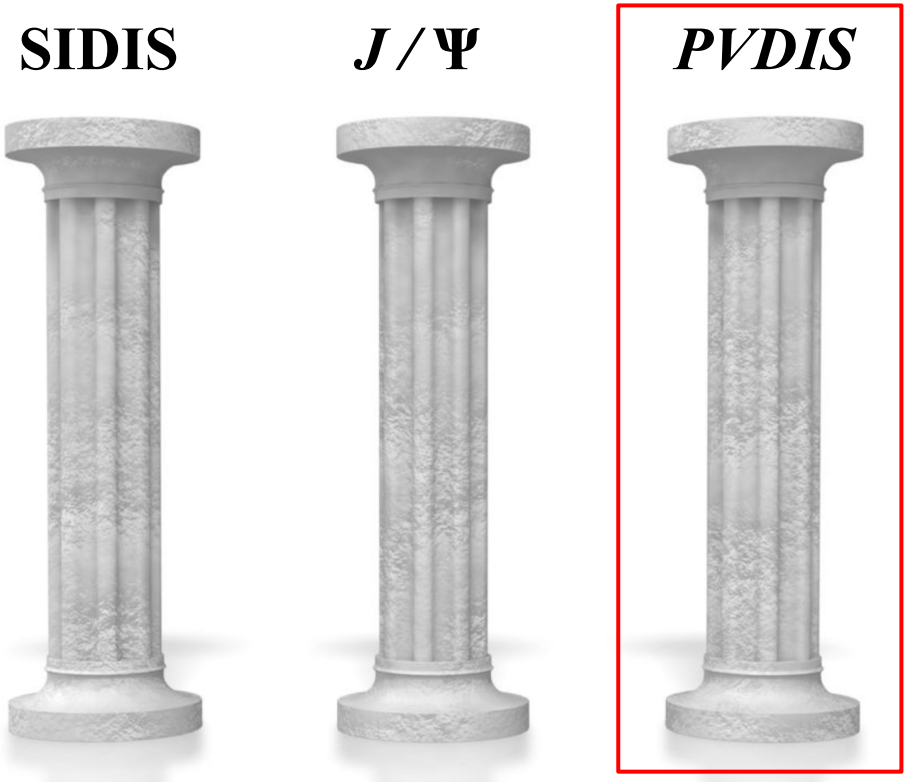
Three Pillars of the SoLID Program

SIDIS ***J / Ψ*** ***PVDIS***



[J Arrington et al 2023 J. Phys. G: Nucl. Part. Phys. 50 110501]

Three Pillars of the SoLID Program



SoLID PVDIS Program

1. **Parity Violating DIS on Isoscalar Deuteron**
   a. Precision determination of electroweak parameters
   b. Beyond-the-Standard Model (BSM) physics search
2. **Parity Violating DIS on Proton Target**
   a. *d/u* measurement
3. **Parity Violating EMC Effect**
   a. Isospin dependence of the EMC effect by the use of neutron-rich isotopes

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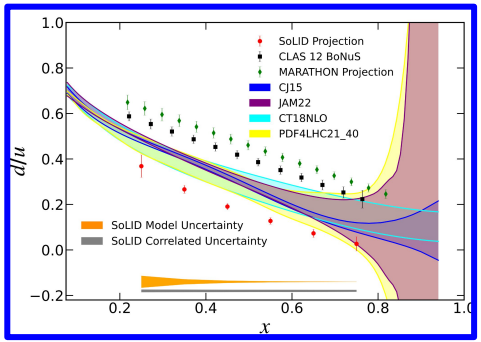
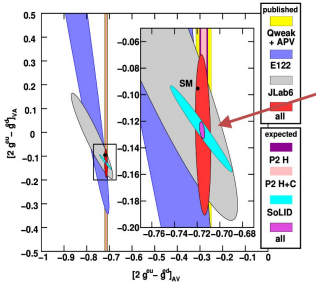
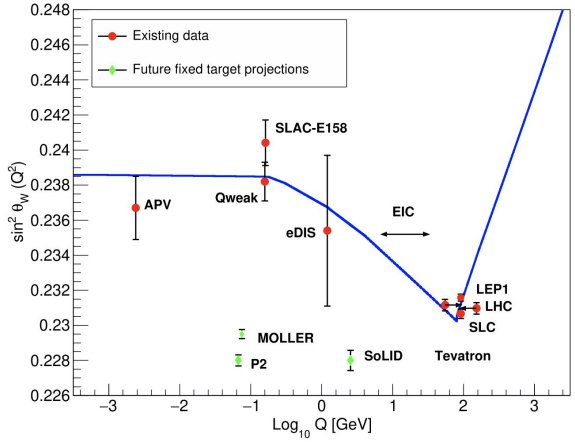




Qweak, APV, and P2 do not provide constraints in the vertical direction. Only PVDIS experiments (SLAC, Jlab 6 GeV, and Solid) constrain the C_2's

Paul Sauder (PAC 50)



Overview of PVDIS with SoLID

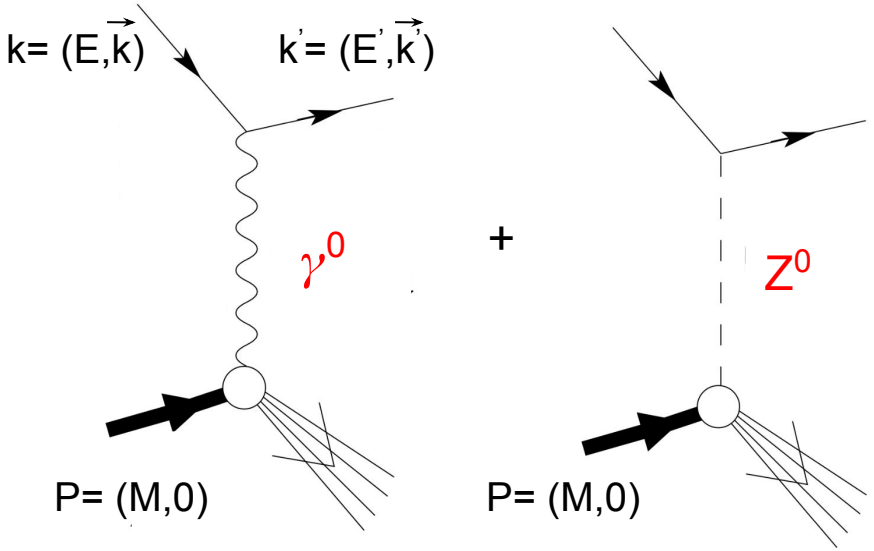
SoLID PVDIS Program: Isoscalar Deuteron

$$A_{PV}^{(e)} \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{d\sigma_e}{d\sigma_0}$$

In Deep Inelastic Scattering regime

$$A_{PV} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}[a_1 + a_3 Y]$$

$$a_1(x) = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} \qquad a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}}$$



Isoscalar Deuteron Target

$$A_{PV,(d)}^{SM} = \frac{3G_F Q^2}{10\sqrt{2}\pi\alpha}\left[(2g_{AV}^{eu} - g_{AV}^{ed}) + R_V Y(2g_{VA}^{eu} - g_{VA}^{ed})\right]$$

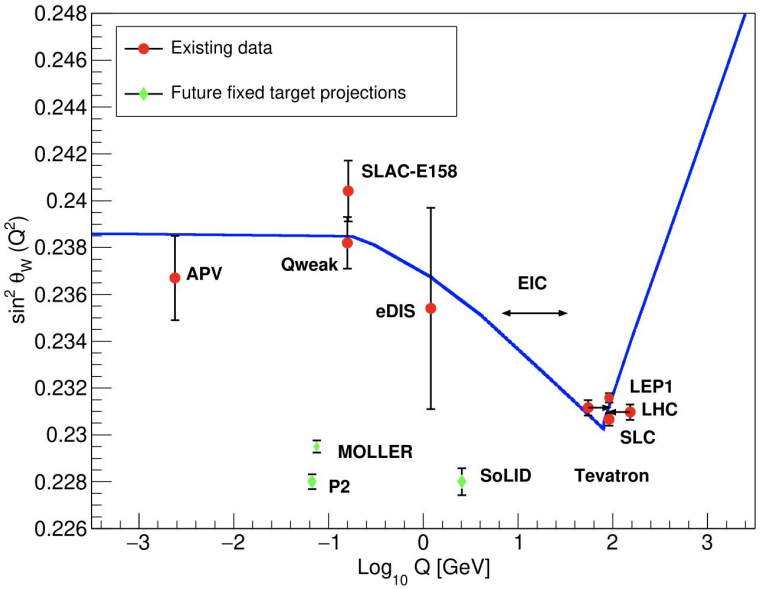
SoLID PVDIS Program: Isoscalar Deuteron

- Dominant Uncertainties: experimental systematics
  - Beam polarimetry: 0.4%
  - Q^2 determination: 0.2%
  - Radiative corrections: 0.2%
- **Able to measure A_{pv} to sub-percent level precision**

Fitting A_{pv} (with the functional form)

$$A_{PV}^{\text{data}} = A_{PV,(d)}^{\text{SM}}\left(1 + \frac{\beta_{\text{HT}}}{(1-x)^3 Q^2} + \beta_{\text{CSV}} x^2\right)$$

$\longrightarrow$ **$\sin^2\theta_w(Q^2)$**



- 120 days
- 50 μA (beam current)
- 85% (beam polarization)

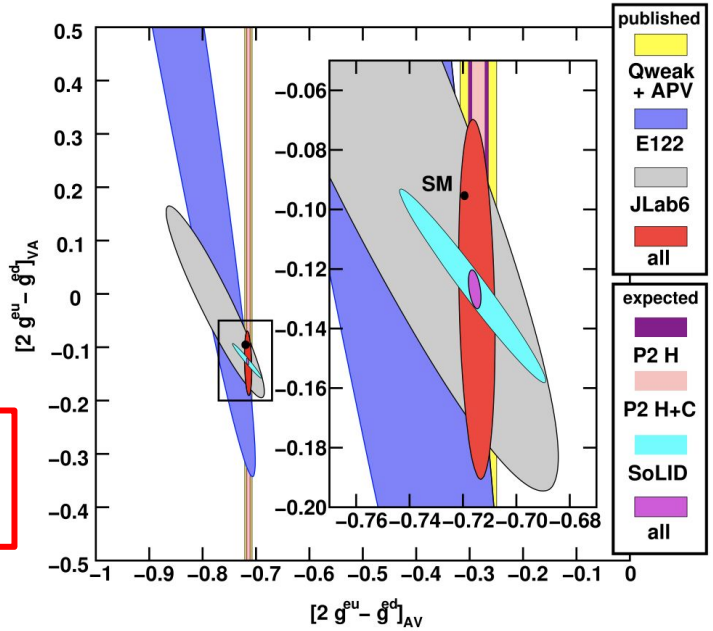
SoLID PVDIS Program: Isoscalar Deuteron

- Full exploration of BSM physics
  - need lepton-lepton or lepton-quark interactions

SoLID PVDIS

$$A_{PV}^{\text{data}} = A_{PV,(d)}^{\text{SM}}\left(1 + \frac{\beta_{\text{HT}}}{(1-x)^3 Q^2} + \beta_{\text{CSV}} x^2\right)$$

$$A_{PV,(d)}^{SM} = \frac{3G_F Q^2}{10\sqrt{2}\pi\alpha}\left[(2g_{AV}^{eu} - g_{AV}^{ed}) + R_V Y(2g_{VA}^{eu} - g_{VA}^{ed})\right]$$



Simultaneous fit of $(2g_{AV}^{eu} - g_{AV}^{ed})$ and $(2g_{VA}^{eu} - g_{VA}^{ed})$

PDF Uncertainty Study with PVDIS

General Procedure

1. Generate Pseudo data

$$(A_{\mathrm{PV}})_b^{\mathrm{pseudo}} = (A_{\mathrm{PV}})_b^{\mathrm{SM}} + r_b \sqrt{\sigma_{\mathrm{stat},b}^2 + \left[\frac{(A_{\mathrm{PV}})_b^{\mathrm{SM}} \sigma_{\mathrm{uncorr}}}{A}\right]_b^2} + r'(A_{\mathrm{PV}})_b^{\mathrm{SM}} \left(\frac{\sigma_{\mathrm{corr}}}{A}\right)_b$$

Parity Violating Asymmetry (SM)

$$(A_{\rm PV})_b^{\rm pseudo} = (A_{\rm PV})_b^{\rm SM} + r_b\sqrt{\sigma^2_{{\rm stat},b} + \left[(A_{\rm PV})_b^{\rm SM}\frac{\sigma_{\rm uncorr}}{A}\right]^2_b} + r'(A_{\rm PV})_b^{\rm SM}\left(\frac{\sigma_{\rm corr}}{A}\right)_b$$

$$A_{RL,d}^{e^-,\rm PVDIS} = \frac{3G_F Q^2}{2\sqrt{2}\pi\alpha}\frac{2(1+R_C)C_{1u}-(1+R_S)C_{1d}+Y[2C_{2u}(1+\epsilon_c)-C_{2d}(1+\epsilon_s)]R_V}{5+4R_C+R_S}$$

Where

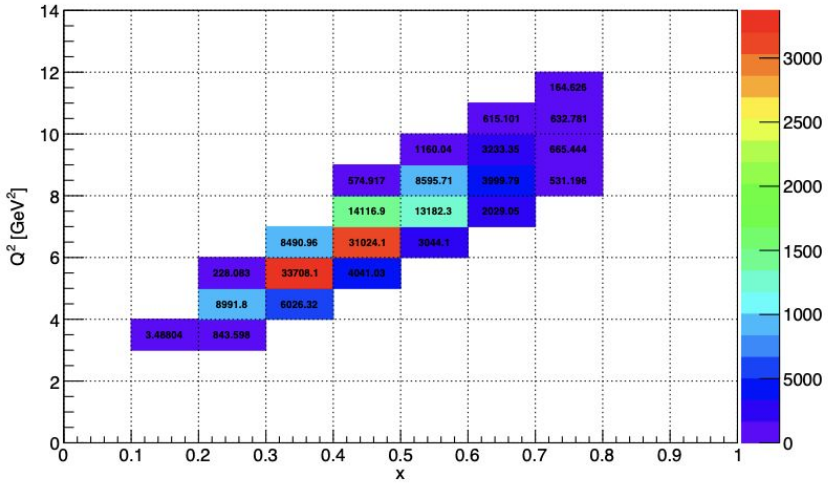
$$R_V(x) \equiv \frac{u_V+d_V}{u^++d^+}\ ,\quad R_C(x) \equiv \frac{2(c+\bar{c})}{u^++d^+}\ ,\quad R_S(x) \equiv \frac{2(s+\bar{s})}{u^++d^+}\ ,\quad \epsilon_c \equiv \frac{2(c-\bar{c})}{u^++d^+} = 0\ ,\quad \epsilon_s \equiv \frac{2(s-\bar{s})}{u^++d^+} = 0$$

Y is a kinematic factor $Y \equiv [1-(1-y)^2]/[1+(1-y)^2] \approx Y_3$

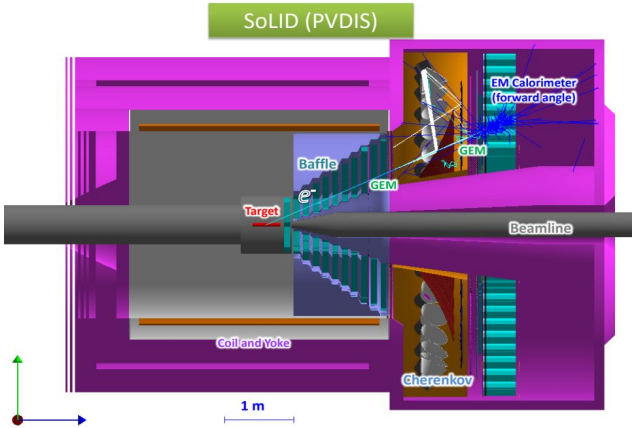
$$\Longrightarrow \quad (A_{\rm PV})_b^{\rm SM}\left[C_{1q}, C_{2q}\right]\ ,\quad (A_{\rm PV})_b^{\rm SM}\left[\sin^2\theta_W\right]$$

Event Simulation

- GEMC simulation: 50 μA e− beam incident on 40cm liquid deuterium target
- Scale by trigger efficiency
- DIS kinematic cut: W > 2
- Acceptance cut for nominal target position (z = 10cm): $22^{\circ} < \theta < 35^{\circ}$



Rates (Hz)



Estimating Uncertainties

$$\Sigma^2 = \boldsymbol{\Sigma_0^2} + \Sigma^2_{\mathrm{PDF}}$$

Total Uncertainty

Estimating Uncertainties

$$\Sigma^2 = \boldsymbol{\Sigma_0^2} + \Sigma^2_{\mathrm{PDF}}$$

$$\boldsymbol{\Sigma_0^2} = \begin{pmatrix} \sigma_1^2 & \tilde{\sigma}_1\tilde{\sigma}_2 & \cdots & \tilde{\sigma}_1\tilde{\sigma}_{N_{\mathrm{bin}}} \\ & \sigma_2^2 & \cdots & \tilde{\sigma}_2\tilde{\sigma}_{N_{\mathrm{bin}}} \\ & & \ddots & \vdots \\ & & & \sigma^2_{N_{\mathrm{bin}}} \end{pmatrix}$$

$$\tilde{\sigma}_b = (A_{\mathrm{PV}})_b^{\mathrm{SM}} \left(\frac{\sigma_{\mathrm{corr}}}{A}\right)_b$$

$$\sigma_b^2 = \sigma^2_{\mathrm{stat},b} + \left[(A_{\mathrm{PV}})_b^{\mathrm{SM}} \left(\frac{\sigma_{\mathrm{uncorr}}}{A}\right)\right]^2_b + \tilde{\sigma}_b^2$$

Uncertainties: Statistical and (Experimental) Systematics

- Statistical uncertainty

$$\longrightarrow \quad dA_{PV}^{\text{stat}} = \frac{1}{P_e\sqrt{n_b}} = \sigma_{\text{stat},b}$$

Beam polarization = 85%

120 days

- Experimental systematic uncertainties

Source	Relative Uncertainty dA/A
Beam polarization	0.4%
Q^2 determination	0.2%
Event reconstruction	0.2%
Radiative correction	0.2%

Completely correlated ($\sigma_{\text{corr}}/A = 0.45\%$)

Uncorrelated ($\sigma_{\text{uncorr}}/A = 0.28\%$)

Estimating Uncertainties

$$\Sigma^2 = \boldsymbol{\Sigma_0^2} + \Sigma^2_{\mathrm{PDF}}$$

PDF Uncertainties

- PDF uncertainties were determined following the prescription of each PDF set
- Hessian PDF Sets

$$\left(\Sigma^2_{\mathrm{PDF}}\right)_{bb'} = \frac{1}{4}\sum_{m=1}^{N_{\mathrm{PDF}}/2}\left(A_{2m,b} - A_{2m-1,b}\right)\left(A_{2m,b'} - A_{2m-1,b'}\right)$$

- Replica PDF Sets

$$\left(\Sigma^2_{\mathrm{PDF}}\right)_{bb'} = \frac{1}{N_{\mathrm{PDF}}}\sum_{m=1}^{N_{\mathrm{PDF}}}\left(A_{m,b} - A_{0,b}\right)\left(A_{m,b'} - A_{0,b'}\right)$$

Accounted for both diagonal and off-diagonal elements of PDF uncertainty

PDF Uncertainty Matrix

$$\Sigma^2_{pdf} = \begin{bmatrix} \sigma^2_{1,pdf} & \sigma_{1,pdf}\sigma_{2,pdf} & \cdots & \sigma_{1,pdf}\,\sigma_{N_{bin,pdf}} \\ & \sigma^2_{2,pdf} & \cdots & \sigma_2\sigma_{N_{bin,pdf}} \\ & & \ddots & \vdots \\ & & & \sigma^2_{N_{bin,pdf}} \end{bmatrix}$$

Fitting Procedure

1. Generate Pseudo data

$$(A_{\mathrm{PV}})_b^{\mathrm{pseudo}} = (A_{\mathrm{PV}})_b^{\mathrm{SM}} + r_b\sqrt{\sigma^2_{\mathrm{stat},b} + \left[(A_{\mathrm{PV}})_b^{\mathrm{SM}}\frac{\sigma_{\mathrm{uncorr}}}{A}\right]^2_b} + r'(A_{\mathrm{PV}})_b^{\mathrm{SM}}\left(\frac{\sigma_{\mathrm{corr}}}{A}\right)_b$$

2. Preform χ^2 minimization

$$\chi^2 = [\mathcal{A}^{\mathrm{pseudo}} - \mathcal{A}^{\mathrm{fit}}][(\Sigma^2)^{-1}][\mathcal{A}^{\mathrm{pseudo}} - \mathcal{A}^{\mathrm{fit}}]^T$$

Where

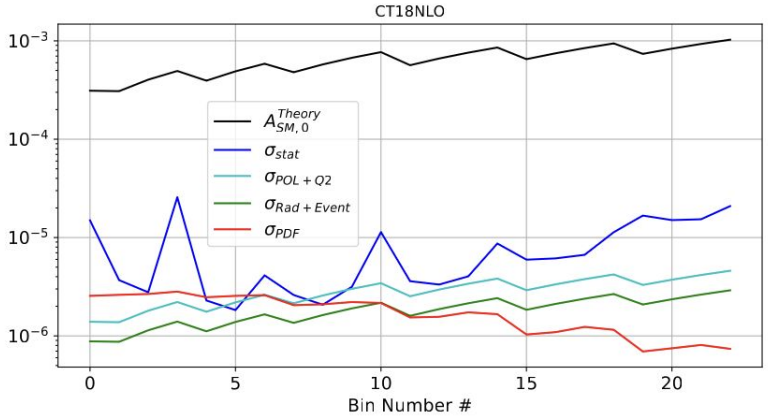
$$(A_{\mathrm{PV}})_b^{\mathrm{fit}} = (A_{\mathrm{PV}})_b^{\mathrm{SM}}\left[\sin^2\theta_W\right]\left(1 + \frac{\beta_{\mathrm{HT}}}{(1-x)^3Q^2} + \beta_{\mathrm{CSV}}x^2\right)$$

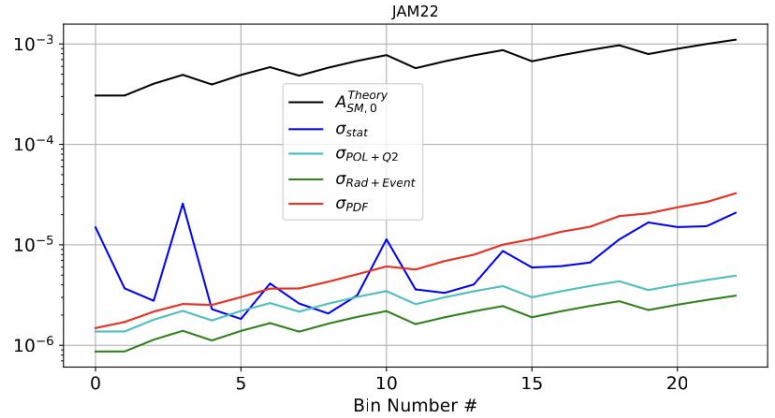
$$[C_{1q}, C_{2q}]$$

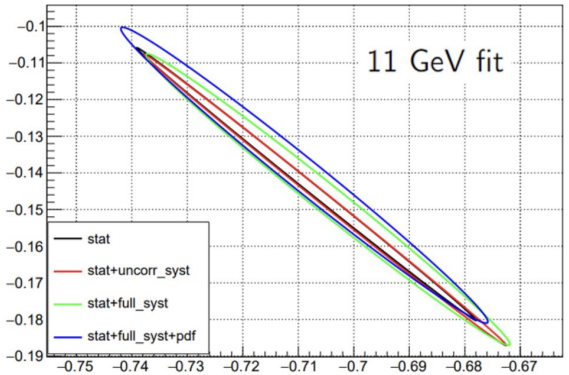
PDF Grids Used

- 12400 CJ15NLO
- 14000 CT18NNLO; 14400 CT18NLO
- 93000 (or 92900 to avoid conflict) PDF4LHC21_MC; 93100 PDF4LHC21_40
- 303400 NNPDF31_nlo_as_0118; 303600 NNPDF31_nnlo_as_01180
- 331100 NNPDf40_nnlo_as_01180; 331700 NNPDF40_nlo_as_01180
- 952000 JAM22 (private grid)

Results (a selected subset)







CJ15nlo

Work done by Alex Emmert

Results (a selected subset)

	sin2th	d(sin2th)	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-12400-sin2th-bfixed-stat	0.230706	0.000169517	0	0	0	0
11GeV-12400-sin2th-bunfixed-stat	0.230308	0.000475106	0.000853468	0.00427771	-0.0210573	0.0358759
11GeV-12400-sin2th-bfixed-statuncorrsyst	0.23069	0.000191799	0	0	0	0
11GeV-12400-sin2th-bunfixed-statuncorrsyst	0.230285	0.000529134	0.000531857	0.00448832	-0.019157	0.0386906
11GeV-12400-sin2th-bfixed-statfullsyst	0.230743	0.00048733	0	0	0	0
11GeV-12400-sin2th-bunfixed-statfullsyst	0.230342	0.000693488	0.000514219	0.00449153	-0.0190638	0.0387134
11GeV-12400-sin2th-bfixed-statfullsystpdf	0.230744	0.000488029	0	0	0	0
11GeV-12400-sin2th-bunfixed-statfullsystpdf	0.230343	0.0006953	0.000510542	0.00449385	-0.0190212	0.0387554

	sin2th	d(sin2th)	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-14000-sin2th-bfixed-stat	0.230705	0.000169785	0	0	0	0
11GeV-14000-sin2th-bunfixed-stat	0.230311	0.000471962	0.000834267	0.00427992	-0.0208128	0.0357795
11GeV-14000-sin2th-bfixed-statuncorrsyst	0.230689	0.000191977	0	0	0	0
11GeV-14000-sin2th-bunfixed-statuncorrsyst	0.230289	0.000525272	0.000513776	0.00448906	-0.0189146	0.0385654
11GeV-14000-sin2th-bfixed-statfullsyst	0.230738	0.000486725	0	0	0	0
11GeV-14000-sin2th-bunfixed-statfullsyst	0.230346	0.000687598	0.000525635	0.00449181	-0.0189992	0.0385845
11GeV-14000-sin2th-bfixed-statfullsystpdf	0.230868	0.000572799	0	0	0	0
11GeV-14000-sin2th-bunfixed-statfullsystpdf	0.230583	0.0011245	-6.08864e-05	0.00494169	-0.0095525	0.0528822

	sin2th	d(sin2th)	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-14400-sin2th-bfixed-stat	0.230705	0.00016987	0	0	0	0
11GeV-14400-sin2th-bunfixed-stat	0.230309	0.000473317	0.000833924	0.00427281	-0.0208541	0.0357585
11GeV-14400-sin2th-bfixed-statuncorrsyst	0.230689	0.000192114	0	0	0	0
11GeV-14400-sin2th-bunfixed-statuncorrsyst	0.230287	0.000526885	0.00051325	0.00448221	-0.0189546	0.038551
11GeV-14400-sin2th-bfixed-statfullsyst	0.230739	0.000487609	0	0	0	0
11GeV-14400-sin2th-bunfixed-statfullsyst	0.230343	0.00069007	0.000497034	0.0044851	-0.0188791	0.0385717
11GeV-14400-sin2th-bfixed-statfullsystpdf	0.230907	0.000556984	0	0	0	0
11GeV-14400-sin2th-bunfixed-statfullsystpdf	0.230201	0.000976653	0.00164751	0.00474962	-0.0309963	0.0452451

	sin2th	d(sin2th)	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-25300-sin2th-bfixed-stat	0.230705	0.000169564	0	0	0	0
11GeV-25300-sin2th-bunfixed-stat	0.230312	0.000471375	0.000847482	0.00428578	-0.0208571	0.0358027
11GeV-25300-sin2th-bfixed-statuncorrsyst	0.23069	0.000191824	0	0	0	0
11GeV-25300-sin2th-bunfixed-statuncorrsyst	0.230291	0.000524864	0.000517102	0.00449577	-0.0189093	0.0385983
11GeV-25300-sin2th-bfixed-statfullsyst	0.230738	0.000486622	0	0	0	0
11GeV-25300-sin2th-bunfixed-statfullsyst	0.230346	0.000687334	0.00050862	0.00449877	-0.0188841	0.0386199
11GeV-25300-sin2th-bfixed-statfullsystpdf	0.230756	0.000590617	0	0	0	0
11GeV-25300-sin2th-bunfixed-statfullsystpdf	0.230408	0.000849785	0.000321819	0.00467455	-0.0159079	0.0432267

	C1	dC1	C2	dC2	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-12400-Ciq-bfixed-stat	-0.712315	0.0302581	-0.138413	0.0367288	0	0	0	0
11GeV-12400-Ciq-bunfixed-stat	-0.715736	0.0330164	-0.138188	0.0400034	0.00157814	0.00451164	-0.0245653	0.0365027
11GeV-12400-Ciq-bfixed-statuncorrsyst	-0.708705	0.0322854	-0.142979	0.0392313	0	0	0	0
11GeV-12400-Ciq-bunfixed-statuncorrsyst	-0.712759	0.035212	-0.141997	0.0426854	0.00134166	0.00472302	-0.023064	0.039303
11GeV-12400-Ciq-bfixed-statfullsyst	-0.708201	0.0324526	-0.1429	0.0392353	0	0	0	0
11GeV-12400-Ciq-bunfixed-statfullsyst	-0.712257	0.0353663	-0.141915	0.0426902	0.00134201	0.00472627	-0.0230761	0.0393301
11GeV-12400-Ciq-bfixed-statfullsystpdf	-0.708202	0.0324582	-0.142892	0.0392475	0	0	0	0
11GeV-12400-Ciq-bunfixed-statfullsystpdf	-0.712251	0.0353669	-0.14192	0.0426939	0.00133798	0.00472819	-0.0230345	0.0393705
11GeV-12400-CiqP2-bfixed-stat	-0.714189	0.00235285	-0.13614	0.0033213	0	0	0	0
11GeV-12400-CiqP2-bunfixed-stat	-0.714208	0.00235399	-0.140028	0.00552653	0.00163877	0.00430858	-0.024827	0.0360484
11GeV-12400-CiqP2-bfixed-statuncorrsyst	-0.714171	0.00235372	-0.136345	0.00344463	0	0	0	0
11GeV-12400-CiqP2-bunfixed-statuncorrsyst	-0.714195	0.00235472	-0.140266	0.00599601	0.00128399	0.00452124	-0.0228061	0.0388703
11GeV-12400-CiqP2-bfixed-statfullsyst	-0.714168	0.00235378	-0.135741	0.00563206	0	0	0	0
11GeV-12400-CiqP2-bunfixed-statfullsyst	-0.714191	0.00235476	-0.139611	0.00745345	0.00126691	0.00452585	-0.0227564	0.0388983
11GeV-12400-CiqP2-bfixed-statfullsystpdf	-0.714168	0.00235379	-0.135734	0.00563851	0	0	0	0
11GeV-12400-CiqP2-bunfixed-statfullsystpdf	-0.714191	0.00235476	-0.139609	0.00747027	0.00126283	0.00452818	-0.0227155	0.0389405

	C1	dC1	C2	dC2	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-14000-Ciq-bfixed-stat	-0.707893	0.0302556	-0.143772	0.0366985	0	0	0	0
11GeV-14000-Ciq-bunfixed-stat	-0.713918	0.033704	-0.140019	0.0401935	0.00147384	0.00443683	-0.0224955	0.0358939
11GeV-14000-Ciq-bfixed-statuncorrsyst	-0.704598	0.0322783	-0.147961	0.0391974	0	0	0	0
11GeV-14000-Ciq-bunfixed-statuncorrsyst	-0.710992	0.0359455	-0.143702	0.0428831	0.00121058	0.00464641	-0.0206211	0.038672
11GeV-14000-Ciq-bfixed-statfullsyst	-0.704094	0.0324448	-0.147883	0.0392005	0	0	0	0
11GeV-14000-Ciq-bunfixed-statfullsyst	-0.710497	0.0360955	-0.143615	0.0428864	0.00121196	0.00464958	-0.0206521	0.0386984
11GeV-14000-Ciq-bfixed-statfullsystpdf	-0.707097	0.0331204	-0.143009	0.0401174	0	0	0	0
11GeV-14000-Ciq-bunfixed-statfullsystpdf	-0.708592	0.0365362	-0.14305	0.0429098	0.000578151	0.00504819	-0.00939356	0.0529042
11GeV-14000-CiqP2-bfixed-stat	-0.714162	0.00235285	-0.136176	0.00332177	0	0	0	0
11GeV-14000-CiqP2-bunfixed-stat	-0.714199	0.00235424	-0.139686	0.00546218	0.00146253	0.00430613	-0.0224637	0.0358477
11GeV-14000-CiqP2-bfixed-statuncorrsyst	-0.714149	0.00235372	-0.136377	0.00344525	0	0	0	0
11GeV-14000-CiqP2-bunfixed-statuncorrsyst	-0.714186	0.00235493	-0.139923	0.00592385	0.0011166	0.00451685	-0.0204985	0.0386299
11GeV-14000-CiqP2-bfixed-statfullsyst	-0.714147	0.00235378	-0.13583	0.0056304	0	0	0	0
11GeV-14000-CiqP2-bunfixed-statfullsyst	-0.714184	0.00235498	-0.139288	0.00735978	0.00109984	0.00452071	-0.0204616	0.0386543
11GeV-14000-CiqP2-bfixed-statfullsystpdf	-0.714164	0.00235403	-0.134536	0.00639466	0	0	0	0
11GeV-14000-CiqP2-bunfixed-statfullsystpdf	-0.714177	0.0023551	-0.136714	0.0113756	0.000458732	0.0049868	-0.0100404	0.052686

	C1	dC1	C2	dC2	beta-ht	d(beta-ht)	beta-csv	d(beta-csv)
11GeV-14400-Ciq-bfixed-stat	-0.708535	0.0305834	-0.143065	0.037197	0	0	0	0
11GeV-14400-Ciq-bunfixed-stat	-0.713925	0.0335577	-0.140186	0.0403131	0.00148009	0.0044315	-0.0229832	0.0359459
11GeV-14400-Ciq-bfixed-statuncorrsyst	-0.705168	0.0326347	-0.147347	0.0397315	0	0	0	0

SoLID PVDIS Program: Proton

Proton measurement

- Lack of free neutron target
  - ➢ Nuclear corrections in the deuteron (large uncertainties)
  - ➢ Measurement of $d/u \rightarrow$ challenging at high x
- BoNuS (**Barely** Off-Shell Neutron Structure)
- MARATHON (Ratio of A=3 mirror nuclei)

SoLID PVDIS Program: Proton

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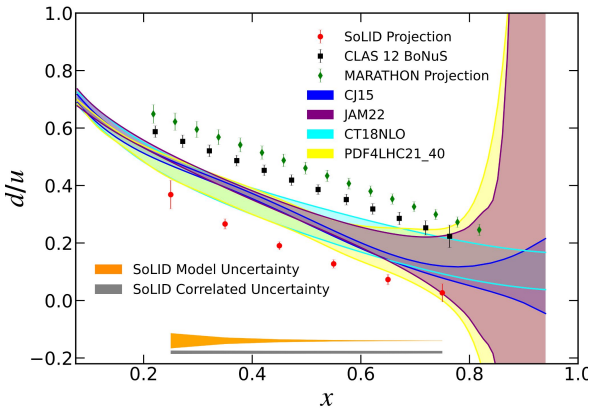
- BoNuS (**Barely** Off-Shell Neutron Structure)
- MARATHON (Ratio of A=3 mirror nuclei)
- SoLID PVDIS on the **Proton**
  - ➢ d/u obtained free nuclear effects

$$A_{PV,(p)} = \frac{3G_F Q^2}{2\sqrt{2}\pi\alpha} \frac{\left(2g_{AV}^{eu} - \frac{d}{u}g_{AV}^{ed}\right) + Y\left[2g_{VA}^{eu} - \frac{d}{u}g_{VA}^{ed}\right]}{4 + \frac{d}{u}}$$



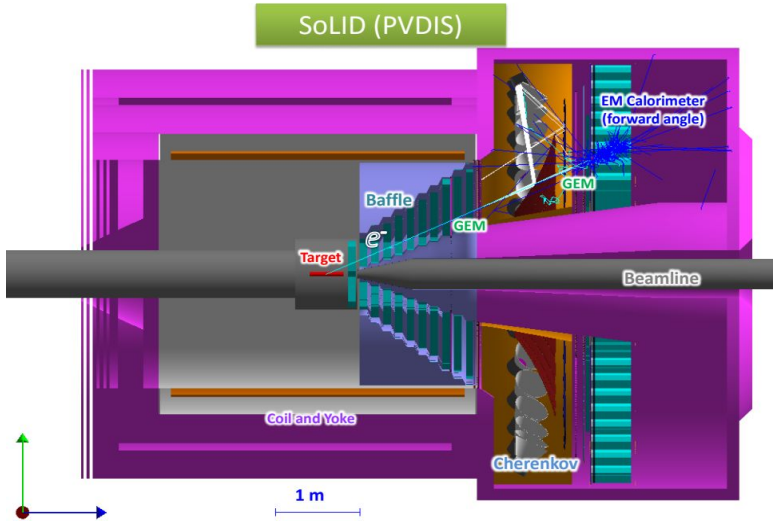
Summary and Outlook

- SoLID: A large acceptance device which can handle very high luminosity
  - Full exploitation of JLab12 potential & push the limit of the luminosity frontier
- PVDIS with SoLID: High rated physics program **(A rating)**
- SoLID has rich and vibrant science programs: SIDIS, **PVDIS** and J/ψ production
  - The SoLID program continues to grow
    - Beam-Normal SSA, Approved PAC 50 (2022)
    - PVEMC with SoLID, Conditionally Approved PAC 50 (2022)
- NSAC Long Range Plan: ***Recommendation 4***: "Opportunities to advance discovery"
  - "These projects include the 400 MeV/u energy upgrade to FRIB (FRIB400), the **Solenoidal Large Intensity Device (SoLID)** at Jefferson Lab, etc…"
- PDF uncertainties appear manageable, but….
  - Different assumptions in PDF sets
  - How reliable?

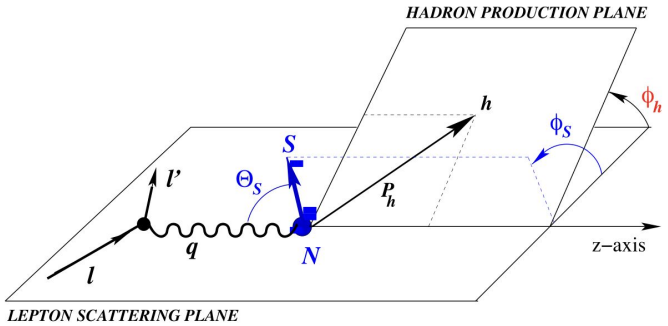
Thank You

SoLID: PVDIS Configuration

- $2\ \mathrm{GeV}^2 < Q^2 < 10\ \mathrm{GeV}^2$
- $0.3 < x_{\mathrm{Bjorken}} < 0.7$
- Scattering angle ~22° to ~35°
- Acceptance ~ 40%
- Luminosity ~ $10^{39}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Momentum resolution ~ 2%
- Polar angle resolution ~ 1mrad



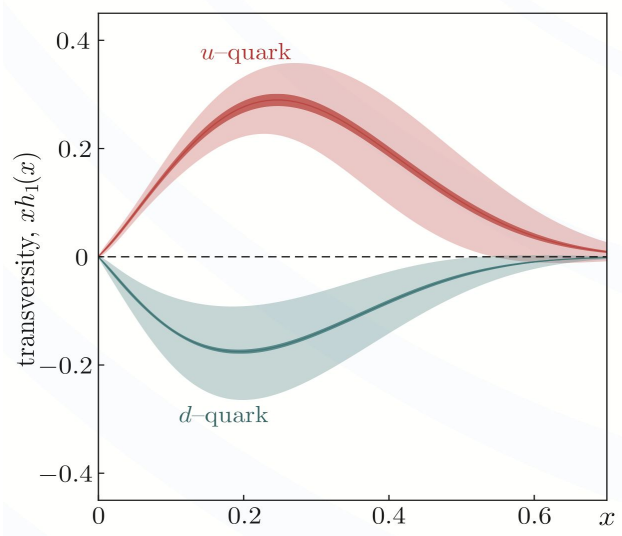
SoLID SIDIS Program



Leading Twist TMDs

: Nucleon Spin : Quark Spin

Nucleon Polarization	Quark polarization: Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = Boer-Mulder
L		g_1 = Helicity	$h_{1L}^\perp$ = Worm gear
T	$f_{1T}^\perp$ = Sivers	$g_{1T}^\perp$ = Worm gear	h_{1T} = Transversity; $h_{1T}^\perp$ = Pretzelosity



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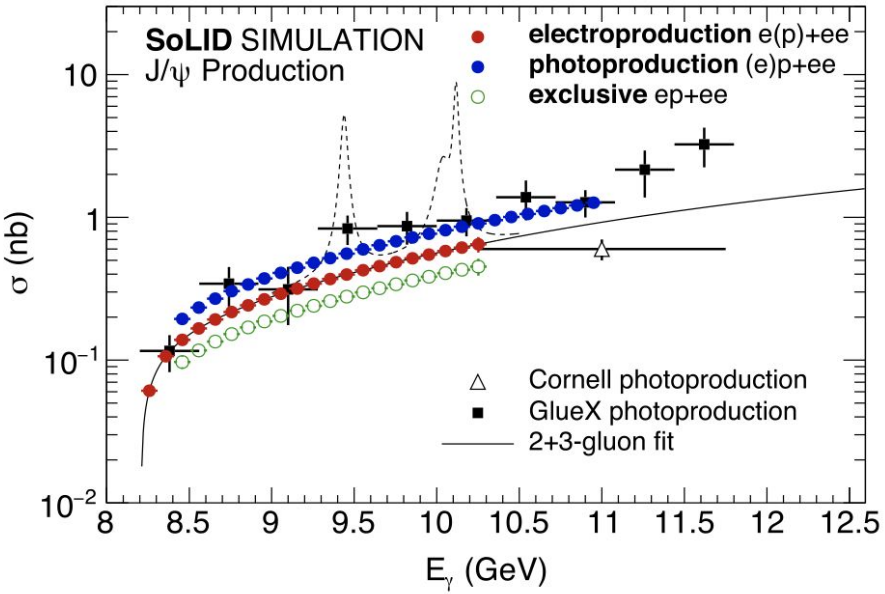
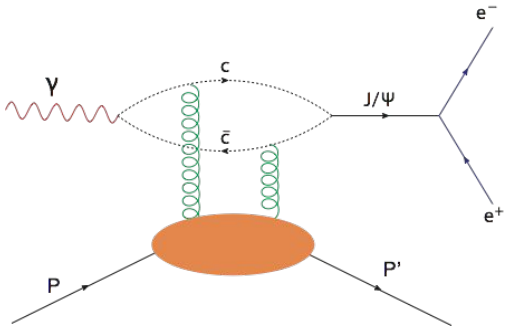
SoLID J/Ψ Program





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

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

- Precision measurement of J/Ψ production at threshold that probes the gluon field
- Understand origin of proton mass through measurements of near-threshold photo-production and electroproduction of J/Ψ

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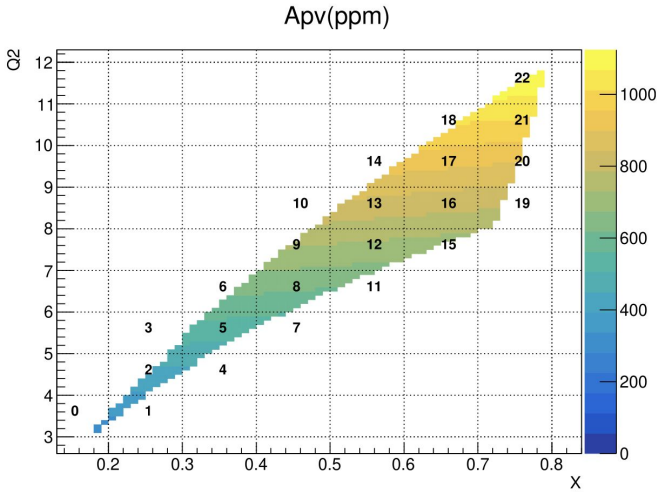
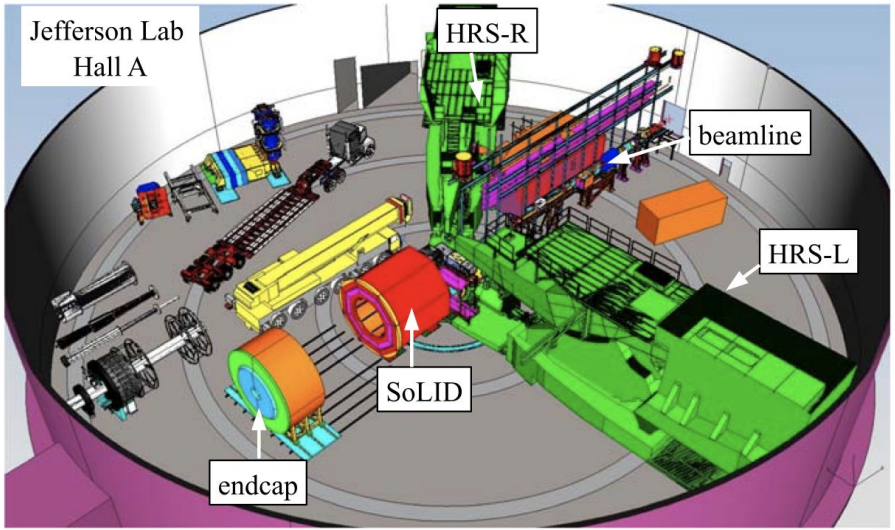
SoLID PVDIS Program

1. **Parity Violating DIS on Isoscalar Deuteron**
   a. Precision determination of electroweak parameters
   b. Beyond-the-Standard Model (BSM) physics search
2. **Parity Violating DIS on Proton Target**
   a. *d/u* measurement
3. **Parity Violating EMC Effect**
   a. Isospin dependence of the EMC effect by the use of neutron-rich isotopes



Precision: sub-1% over wide kinematic range

SoLID Magnet



Nuclear Science Outlook

Long Range Plan Science Questions

1. **Quantum Chromodynamics**
2. Nuclear Structure and Nuclear Reactions
3. Nuclear Astrophysics
4. **Fundamental Symmetries**

Recommendation 1: "Continuing effective operation of the national user facilities ATLAS, **CEBAF**, and FRIB, …"

Recommendation 4: "Opportunities to advance discovery"

- ✓ "These projects include the 400 MeV/u energy upgrade to FRIB (FRIB400), the **Solenoidal Large Intensity Device (SoLID)** at Jefferson Lab, etc…"

Recommendation 3: "We recommend the expeditious completion of the EIC as the highest priority for facility construction"

- ✓ The Science Questions: "Carrying out a targeted program of experiments,..., that reaches for **physics beyond the Standard Model**…"