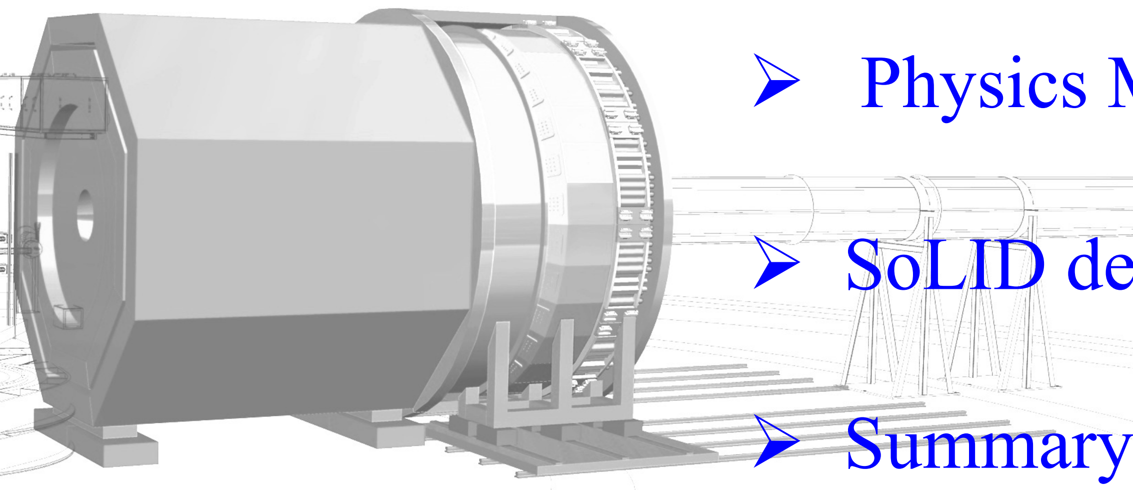
Parity Violation in DIS Region with SoLID at 12 GeV JLab



- Physics Motivation
- SoLID detector for PVDIS
- Summary

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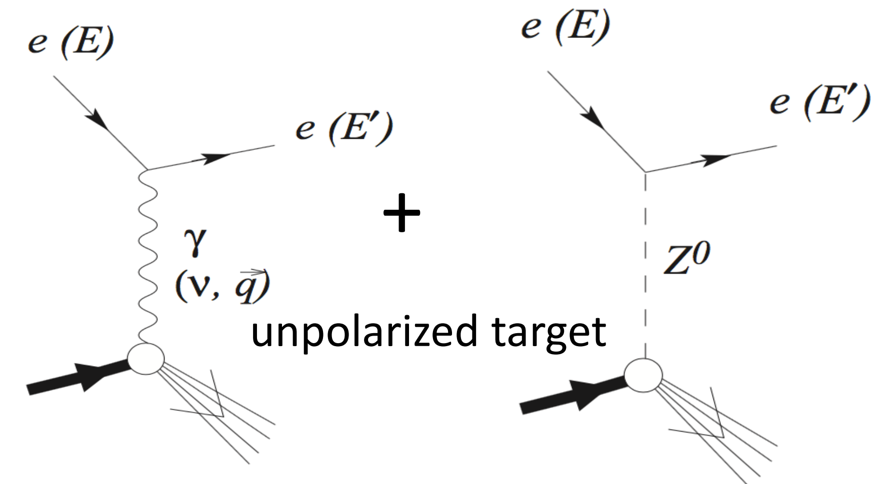
For the SoLID Collaboration

Supported by the U.S. Department of Energy under Grant : DE-FG02-84ER40146

Parity Violation in Electron Scattering (PVES)

longitudinally polarized



$$\sigma \;\; \alpha \; | \, A_\gamma + A_{weak} \, |^2$$

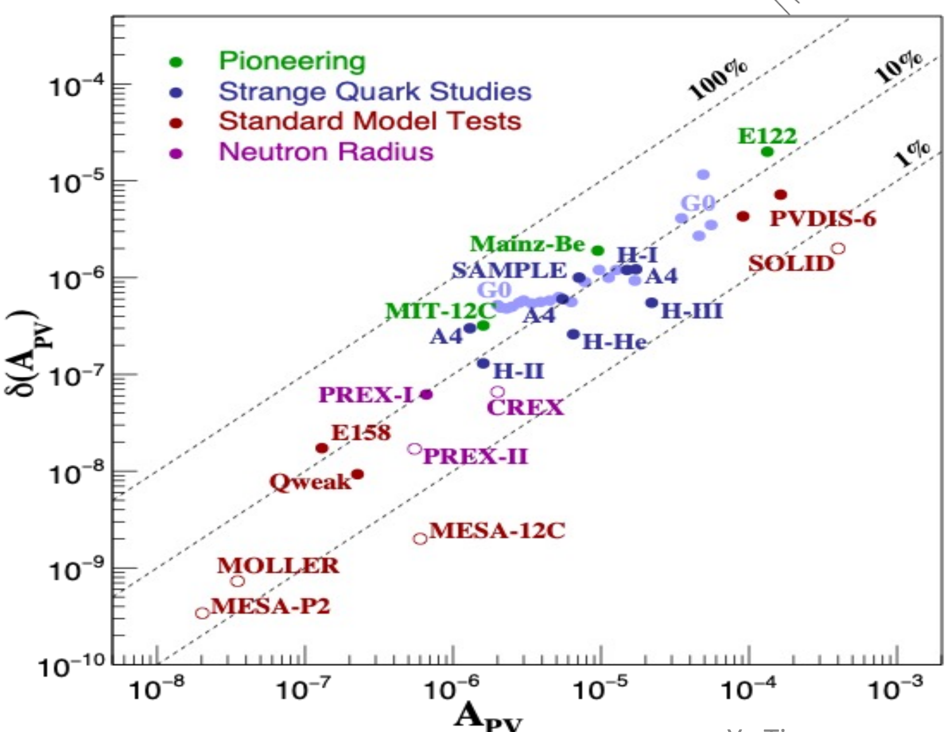
$$-A_{LR} = A_{PV} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \sim \frac{A_{weak}}{A_\gamma} \sim \frac{G_F Q^2}{4\pi\alpha} g$$

$$g = g_A^e g_V^T + \beta \, g_V^e g_A^T$$

- g_V and g_A are functions of $\sin^2\theta_W$

-g^T affected by QCD physics

In the DIS region, the interaction vertex provides the unique information on effective electron-quark couplings while the quarks probed by the neutral current reveal the internal structure of the nucleon.



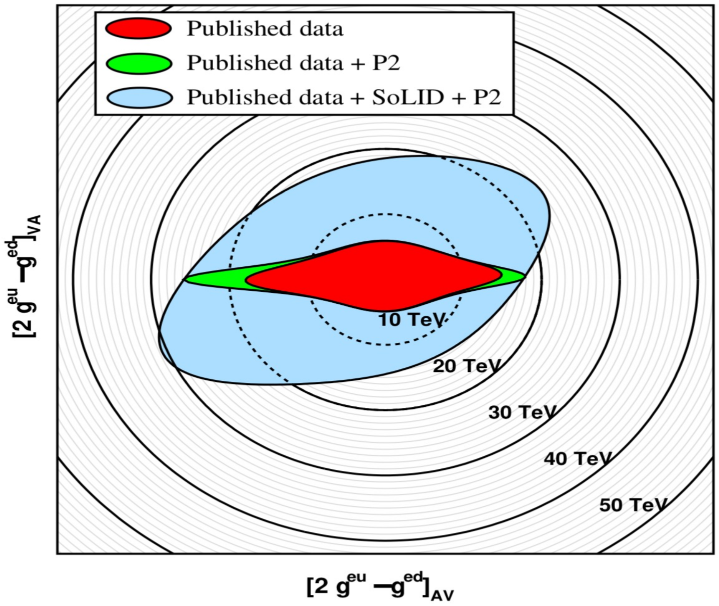
	A ppm	A ppm	A/A(%)
SoLID	500	3	0.6
MOLLER	0.035	0.0008	2.2
P2	0.020	0.0004	2.0

- SoLID, MOLLER, and P2 all improve precision

PVDIS with SoLID

A_{pv} with deuterium:

- Measure electroweak parameters
- Search for BSM physics at a high E scale
- Search for CSV at the quark level
- Search for quark-quark higher twist effects



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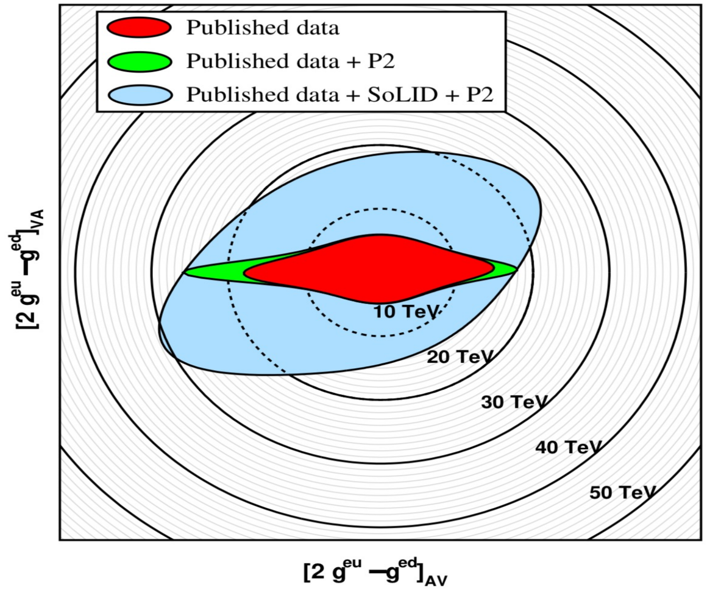
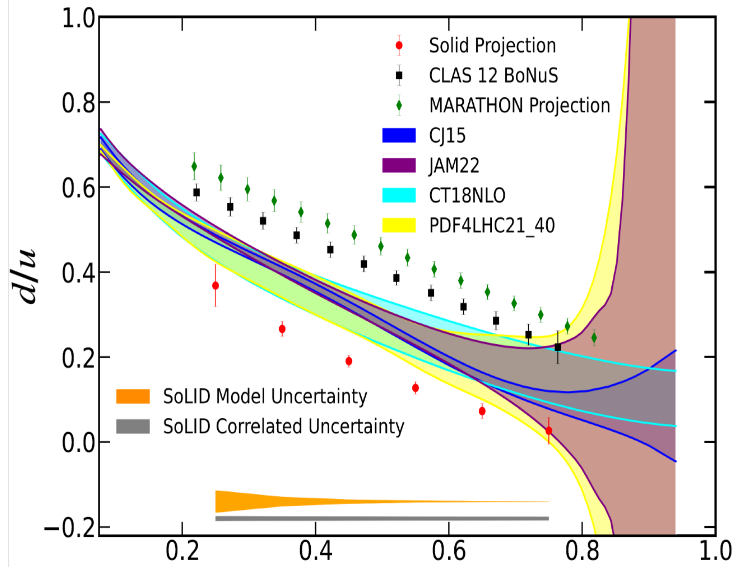
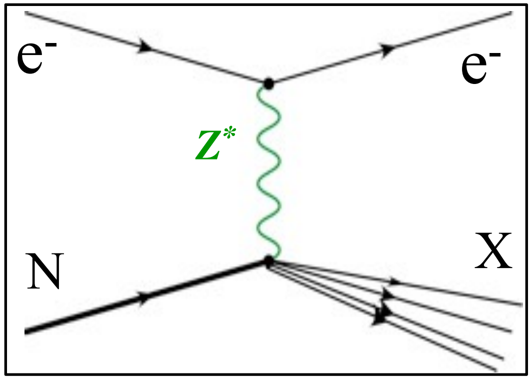


Apv with the proton:

- Help determine d/u PDF's
- Insight into nuclear effects at high x



Parity Violating DIS on Deuteron



- Scattering off the simplest isoscalar nucleus and at high *x*

$$A_{LR}^{DIS} \approx -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[a_1(x) + a_3(x)\frac{1-(1-y)^2}{1+(1-y)^2}\right]$$

$$x \equiv x_{Bjorken} = \frac{Q^2}{2M\nu}, y = 1 - \frac{E'}{E}$$

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

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

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

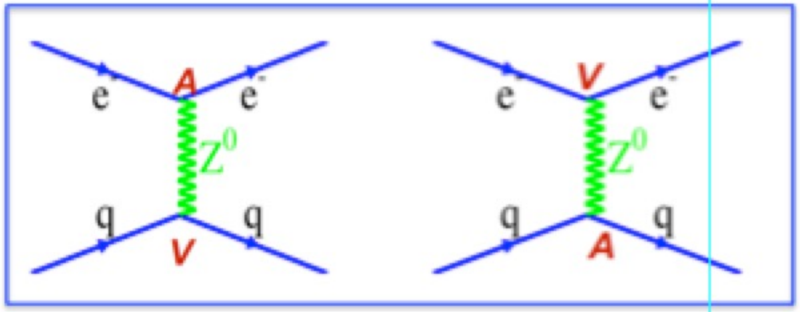
$$R_s(x) = \frac{2S(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 0$$

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

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

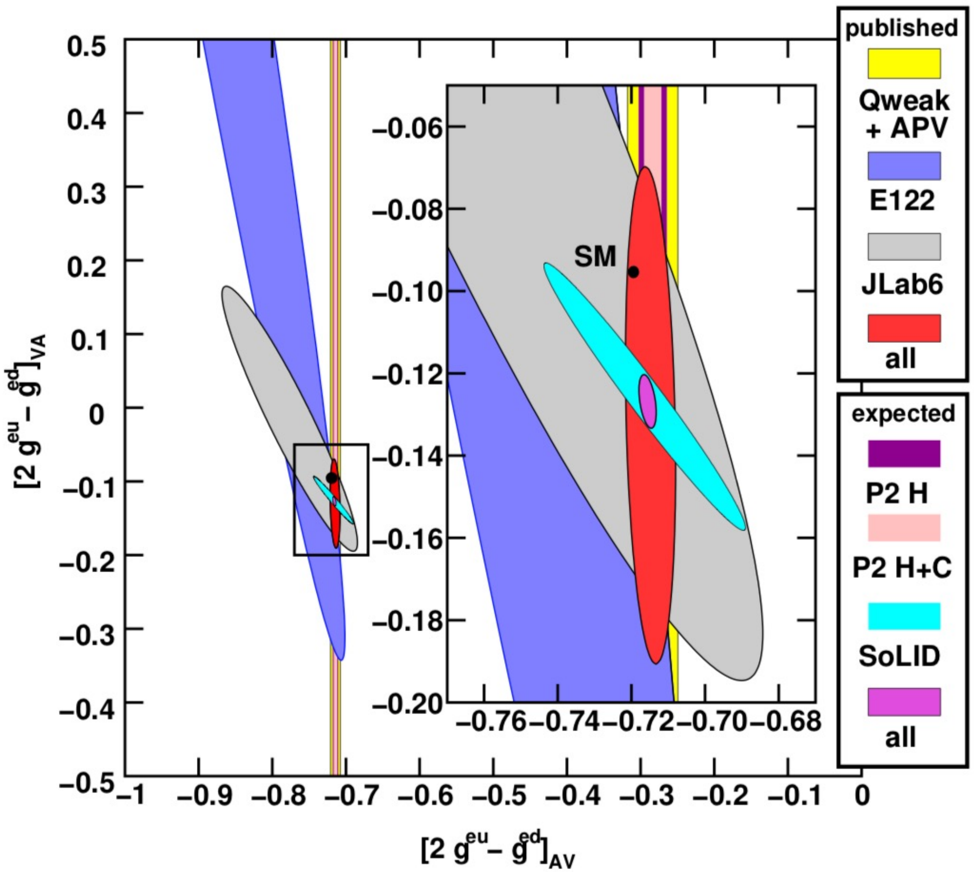
$$R(x,Q^2) = \sigma^l/\sigma^r \approx 0.2$$

EW neutral current interaction



$C_{1q} = 2g_A^e g_V^q$ $C_{2q} = 2g_V^e g_A^q$

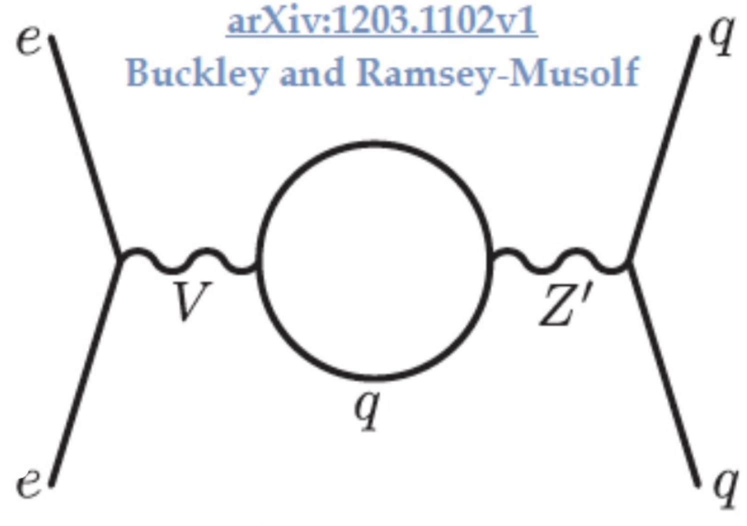
New Physics



- The phase-space of the linear combinations of axial-vector and vector-axial electron-quark effective coupling constants

Leptophobic Z'

arXiv:1203.1102v1
Buckley and Ramsey-Musolf

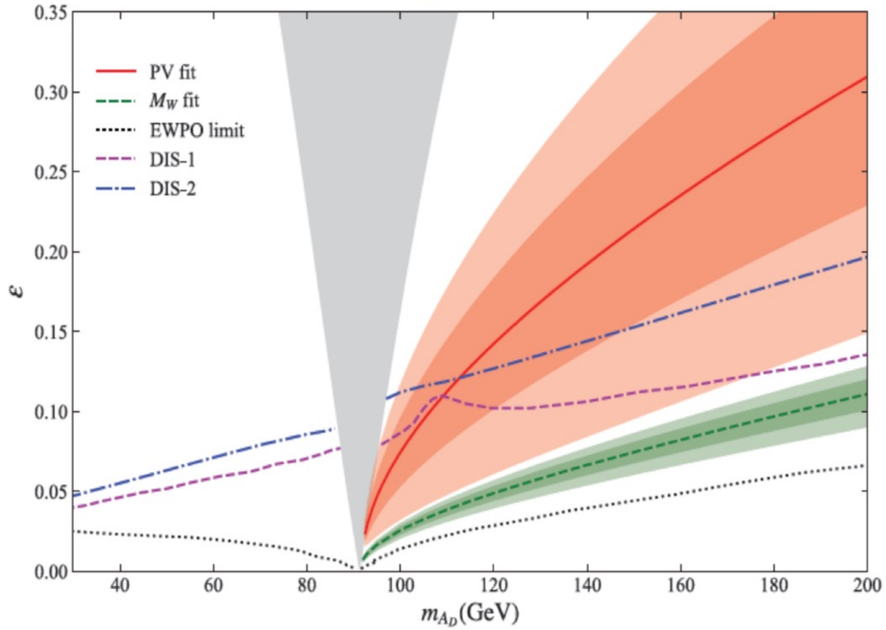


Since electron vertex must be vector, the *Z'* cannot couple to the C_{1q}'s if there is no electron coupling: can only affect C_{2q}'s

New Physics Beyond Stand Model

Constraints of new W mass versus PV

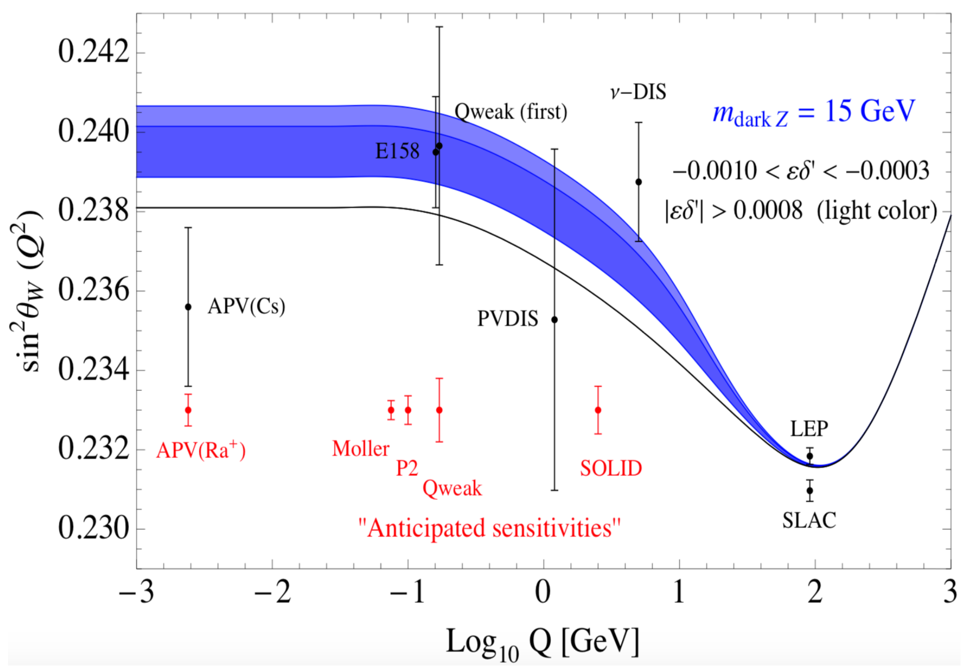
Thomas and Wang, arXiv: 2205.01911



- Constraints on the dark photon from parity violation and the W mass: https://arxiv.org/abs/2205.01911
- Sensitivity of Parity-violating Electron Scattering to a Dark Photon https://arxiv.org/pdf/2201.06760.pdf

- Running of $\sin^2 \theta_W$ with Q^2

From HD, Lee, Marciano, Phys. Rev. D **92**, no. 5, 055005 (2015)



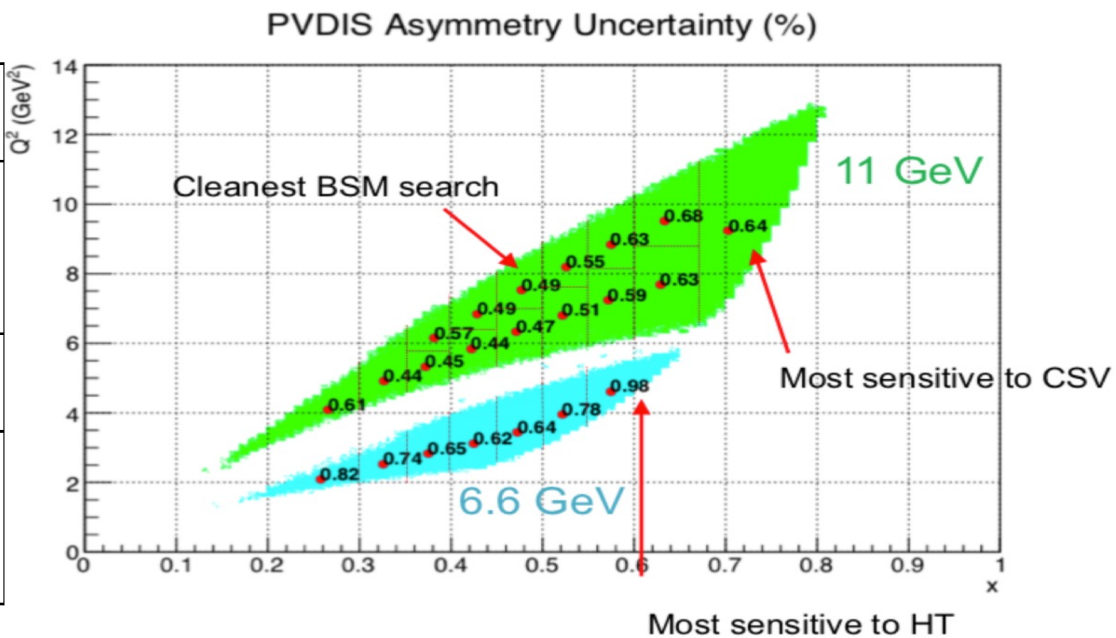
Hadron Physics with PVDIS

- Precision tool to study Hadron Physics
- Sensitive to Partonic Charge Symmetry Violation at large X
- Clean probe to study Higher-Twist effects from q-q correlations
- Broad kinematic coverage allows clean separation of different Physics

$$A_{DIS}^{D} = A_{SM}\left[1 + \frac{\beta_{HT}}{(1-x)^3}Q^2 + \beta_{CSV}x^2\right]$$

Kinematic dependence of physics topics

	x	y	Q^2
New Physics	no	yes	small
CSV	yes	small	small
Higher Twist	large?	no	large



Parity Violating DIS on Proton

$$A_{LR}^{P} \sim -\frac{1}{4\pi\alpha}\frac{Q^2}{\upsilon^2}\left[\frac{6C_{1u} - 3C_{1d}\,{}^{d(x)}\!/_{u(x)}}{4 + {}^{d(x)}\!/_{u(x)}}\right]$$

- Measurement of d(x)/u(x) ratio for the proton at high x
- The d/u extraction is made directly from PVDIS on proton: no nuclear corrections

- PVDIS is complementary to the rest of the JLab d/u program
- The MARATHON Data on d/u has different interpretations. Hence as many targets as possible should be studied: PVDIS, BoNus (D), and MARATHON

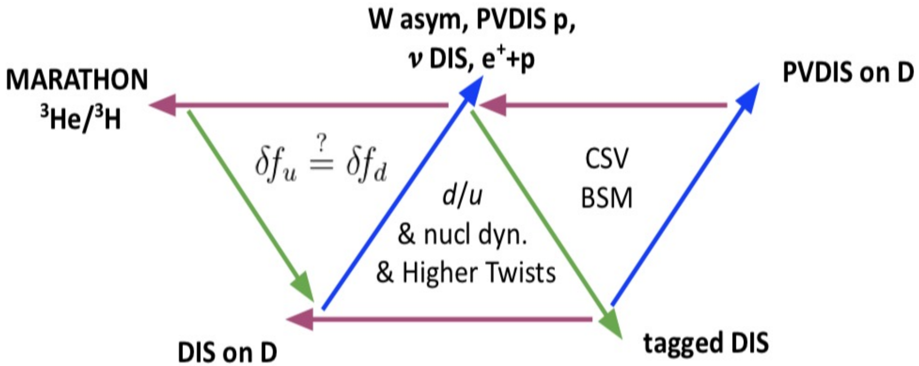
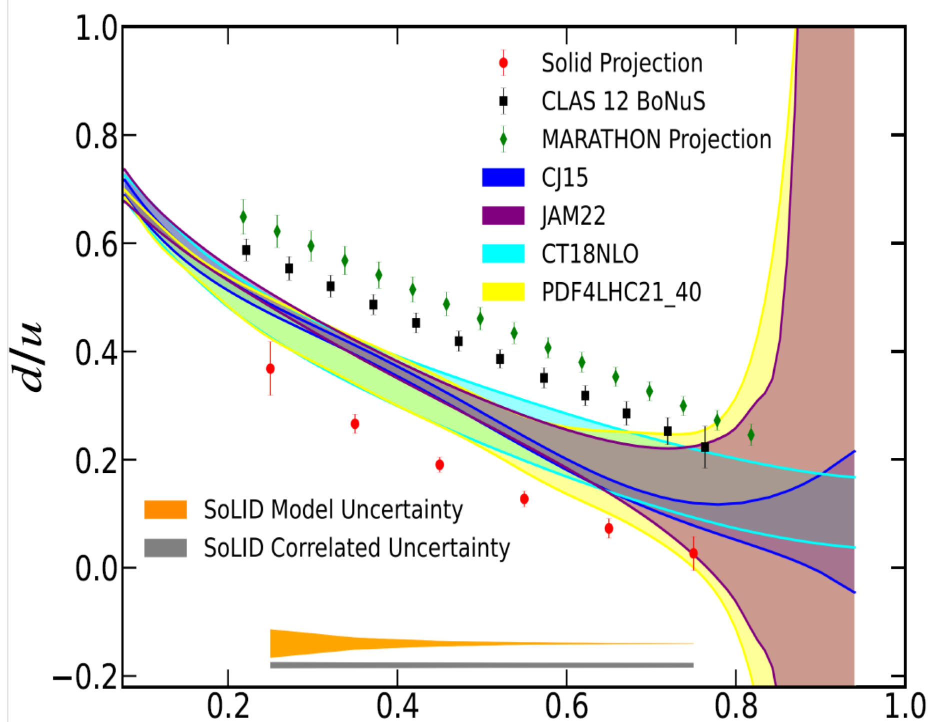
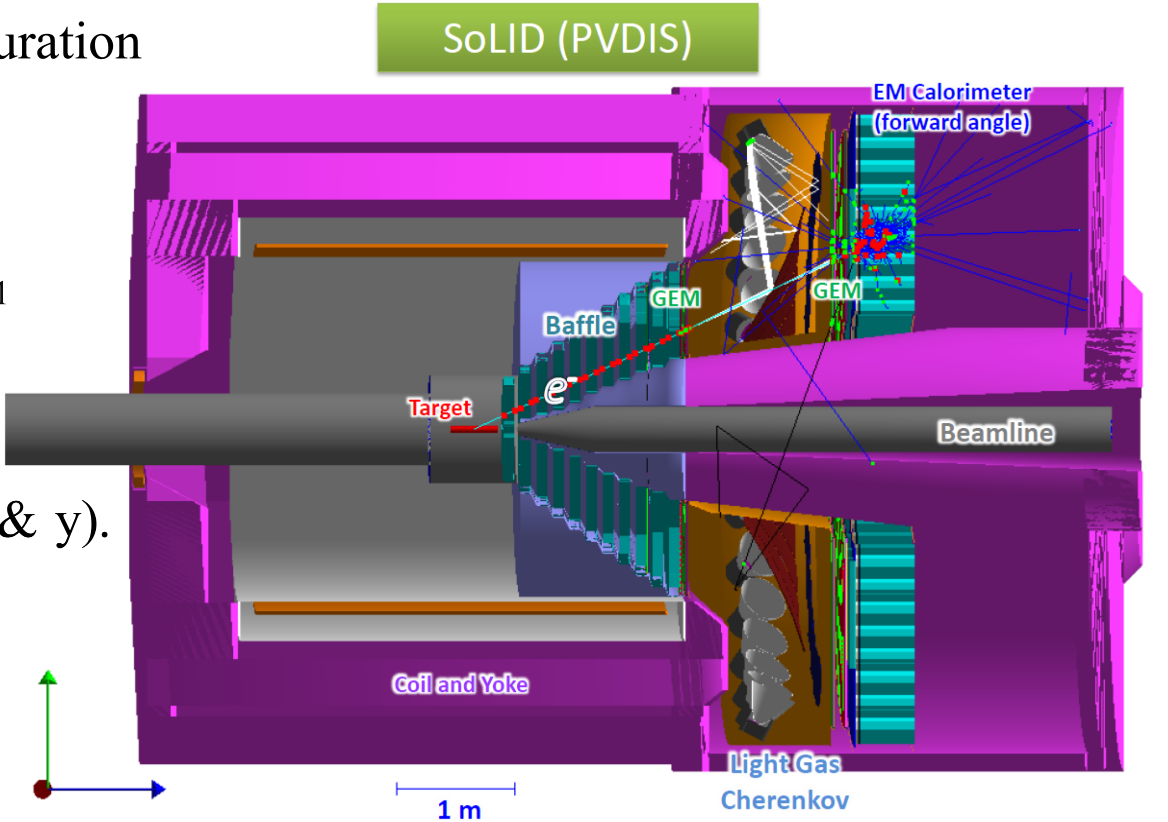


Figure courtesy of A. Accardi



SoLID PVDIS Proposed Setup

- Solenoidal Large Intensity Device – Hall A at Jlab
- SoLID-PVDIS detector configuration



- High Luminosity: 10^{39} cm^{-2}s^{-1}
- Large azimuthal acceptance.
- Large scattering angles
  ~22° < θ < ~35° (for high x & y).

Kinematic Requirements

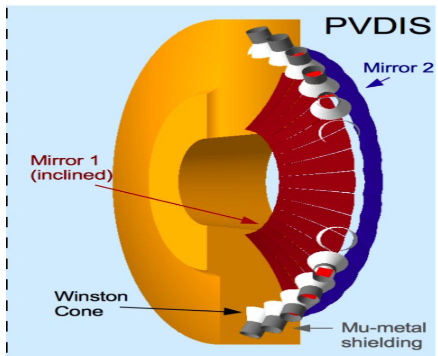
- 2 GeV < E'< 6 GeV: Low background
- 2GeV^2 <Q^2 <10GeV^2
- Wide x-range: 0.25-0.75
- Momentum resolution: ~2%
- W^2> 4 GeV: Isolate DIS events.
- Polar angle resolution ~ 1mrad

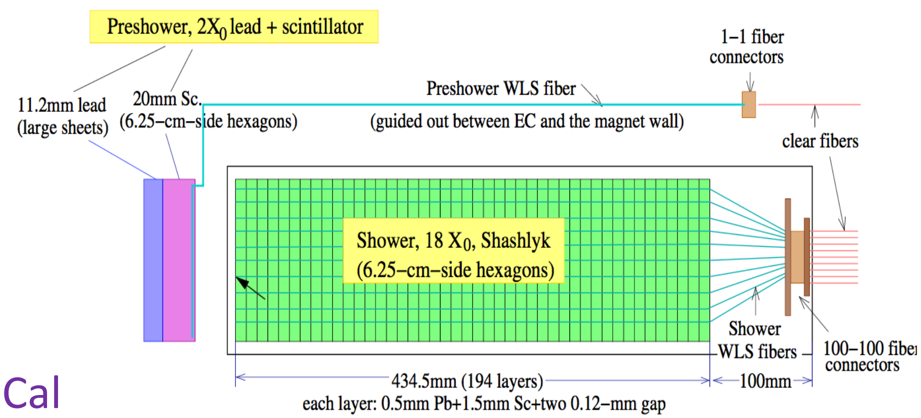
- CLEO magnet with the 40 cm LD_2 or 40 cm LH_2 target in the center provides the desired acceptance.

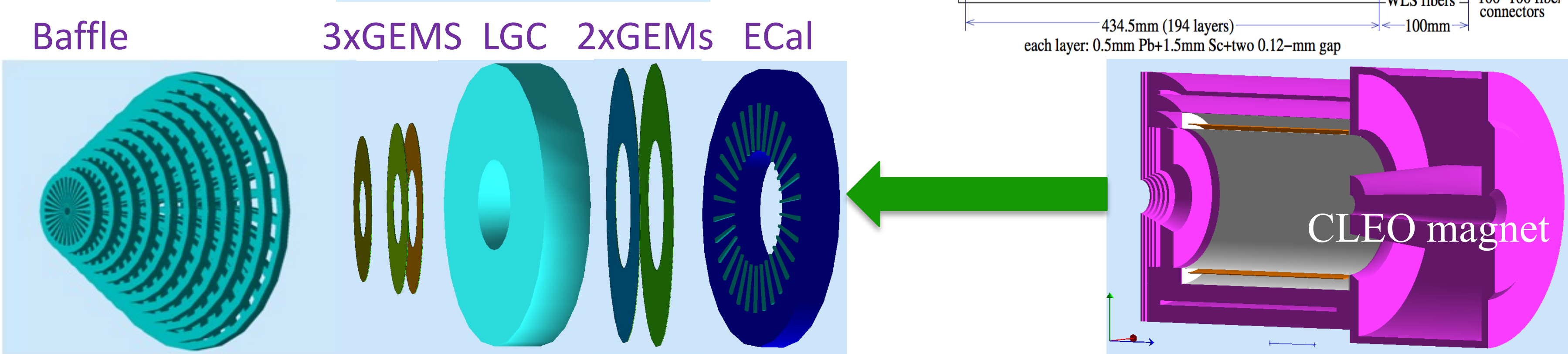
SoLID PVDIS Detector Subsystems

Requirements for Particle Identification and Trigger

- Light Gas Cherenkov (LGC): identify electrons for trigger; reject pions.
- Shashlyk electromagnetic calorimeter (ECal) : coincident trigger with LGC and further particle identification.
- With tracking, tight E/p cuts reduce pion backgrounds.





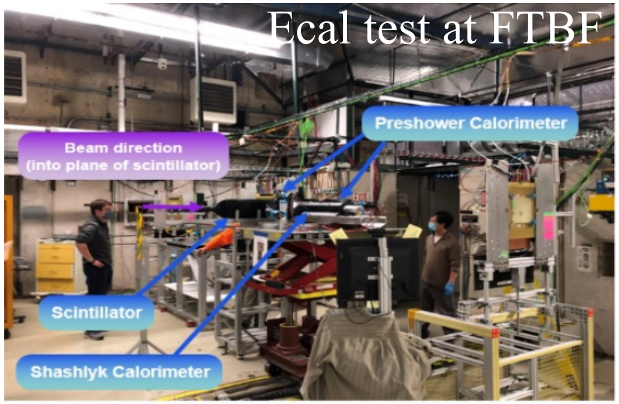


- **Baffle:** ~40% azimuthal coverage with baffles which provide curved channels that block positive and neutral background particles

SoLID Beam Test

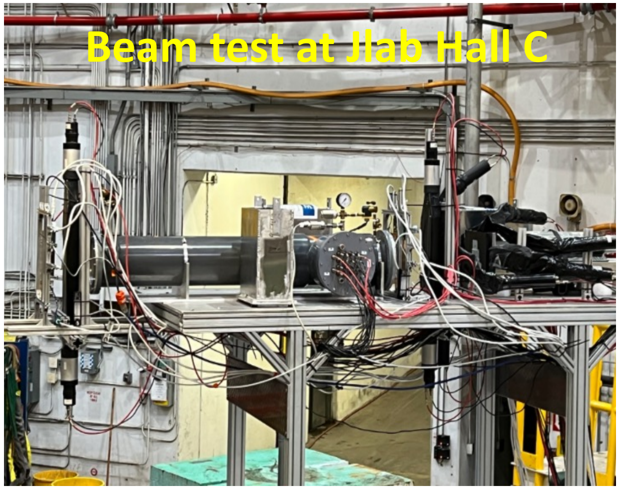
- ➢ Beam test of Cherenkov (pre-R&D in 2020) at Jlab Hall C
- ✓ Low-rate beam test of maPMTs: 3/2020
- ✓ High-rate beam test of maPMTs: 6-8/2020
  - MaPMT works well in a high-rate environment of 300 kHz per cm2
  - LAPPD exhibits a similar performance
- ✓ Low-rate beam test of LAPPD: 8-9/2020

- ➢ Beam test of Ecal at Fermilab Test Beam Facility (1/2021)
- ✓ energy resolution $\frac{\sigma_E}{E} = 4.6\% \oplus \frac{10.4\%}{\sqrt{E}}$
- ✓ position resolution dX = 0.67 cm dY = 0.56 cm

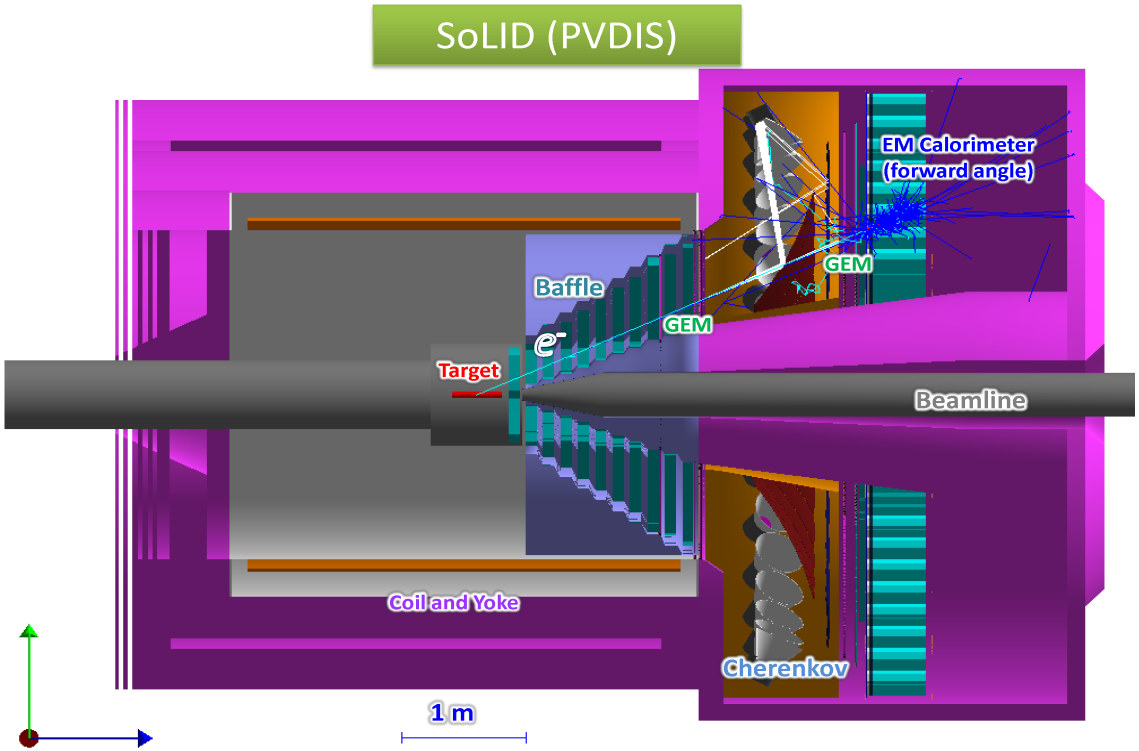


Beam test of a full set of SoLID detector prototypes – GEM, LGC, ECal, DAQ and associated electronics: (12/2022-3/2023)

- Benchmarking simulation of rate and background
- Study ECal and LASPD performance under high rate, high radiation, high background condition
- Study ECal and LASPD PID



More Physics Programs using SoLID PVDIS configuration



- ➢ Beam Normal Single Spin Asymmetry: (Approved proposal)
- • Investigate the effect of two-photon exchange in DIS.

- ➢ Flavor Dependent EMC effect: (Conditionally approved proposal)
- • Measure PVDIS on ^{48}Ca
- • Apv directly sensitive to flavor dependence of EMC

Summary

- PVDIS on deuteron: sensitive to C_{2q} weak couplings, precision test of SM, precision study of charge symmetry violation and higher-twist.
- PVDIS on proton: clean measurement of d/u at high-x without nuclear correction.
- Technical risks are assessed and addressed in the pre-R&D activities.
- Completed the DOE science review (March 2021)
- SoLID is explicit mentioned in the proposed recommendations from the recent town hall meeting for both Hot/Cold QCD and Fundamental Symmetries Long Range Plan Workshops

SoLID PVDIS Collaboration

- 247+ collaborators, 62+ institutions from 13 countries
- Large international participations and anticipate contributions
- Strong theory support

Backup

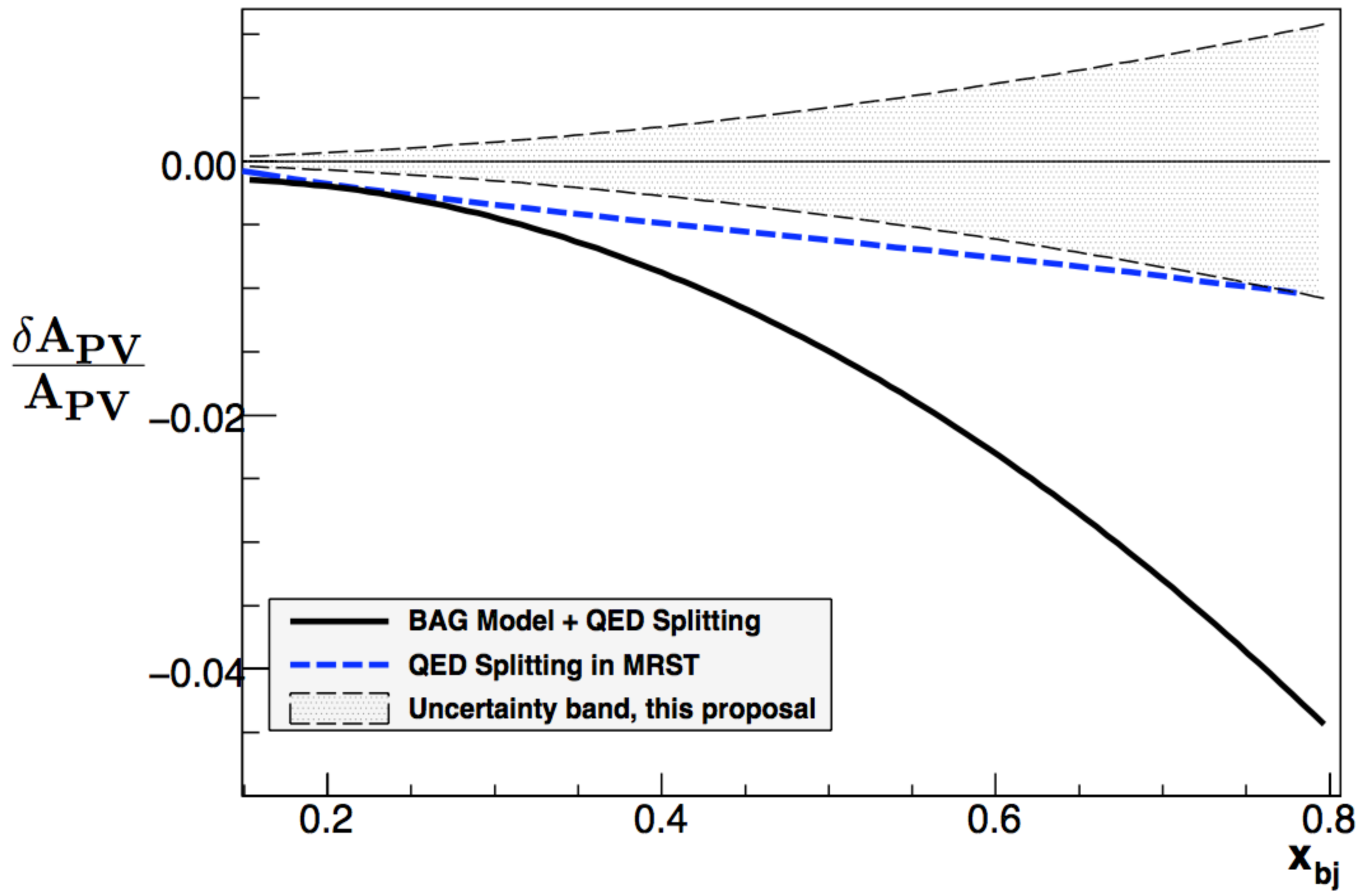


Figure 2.5: CSV predictions as a function of x. The vertical axis is the fractional change in A_{PV} due to CSV. The uncertainty band is the result of the fit discussed in Section 2.4.2. The MRST results shown here account for QED splitting in the Q^2 evolution only, and do not include non-pertubative QCD effects [24].

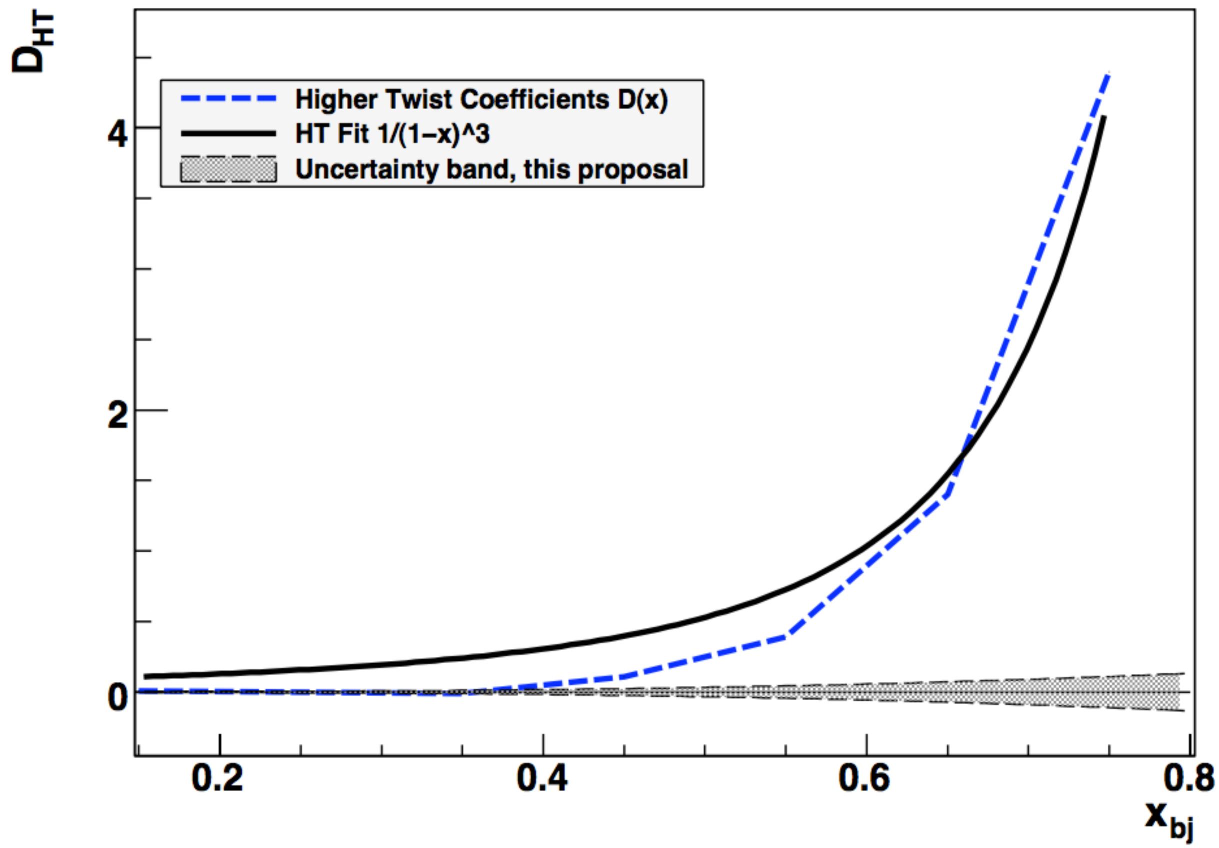
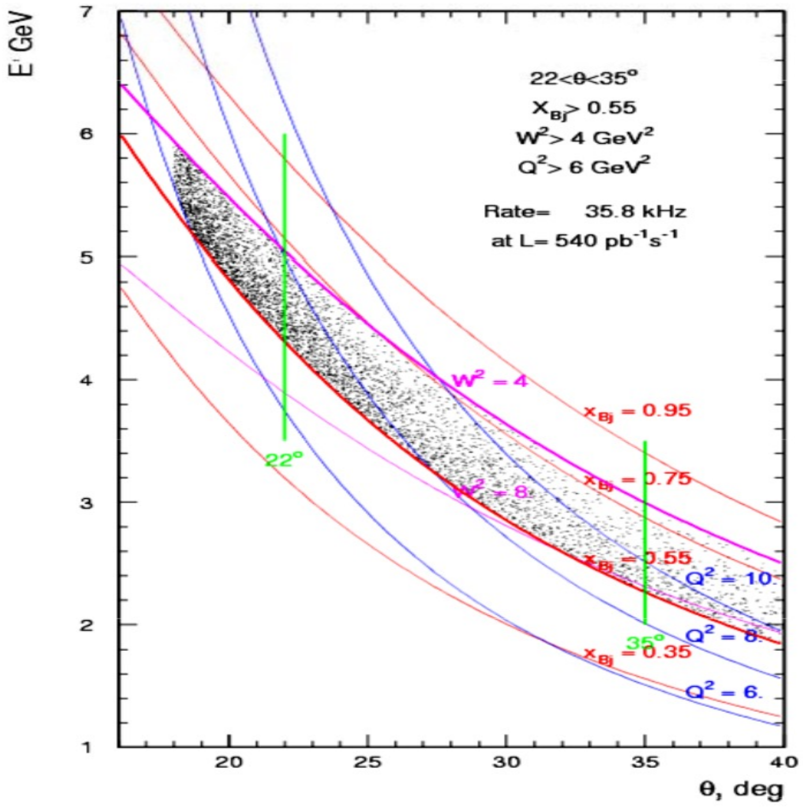
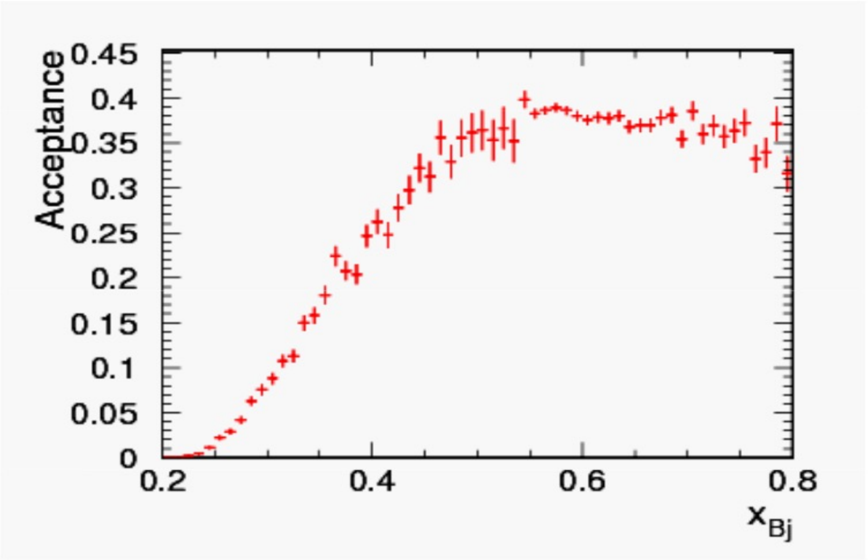


Figure 2.7: Demonstration of sensitivity to Q^2-dependent effects. Plotted are the higher-twist coefficients $D(x)$ from Ref. [21], listed in Table 2.1. Also shown is a fit to these coefficients using the form $(1-x)^{-3}$. The uncertainty band is the result of the fit discussed in Section 2.4.2.

Kinematics at large x





Parity Violation in Deep Inelastic Scattering

$$A_{LR}^{DIS} \approx -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[a_1(x) + a_3(x)\frac{1-(1-y)^2}{1+(1-y)^2}\right] \quad x \equiv x_{Bjorken} = \frac{Q^2}{2M\nu}, y = 1 - \frac{E'}{E}$$

In valence quark region:

at high x

$$a_1(x) = \frac{6}{5}(2C_{1u} - C_{1d})\left(1 + \frac{0.6s^+}{u^+ + d^+}\right), \quad a_3(x) = \frac{6}{5}(2C_{2u} - C_{2d})\left(\frac{u^+ - d^+}{u^+ + d^+}\right) + \ldots$$

0

1

SM at tree level:

$$C_{1u} = 2g_A^e g_V^u \approx -\frac{1}{2} + \frac{4}{3}sin^2\theta_W \approx -0.19$$

$$C_{1d} = 2g_A^e g_V^d \approx \frac{1}{2} - \frac{2}{3}sin^2\theta_W \approx 0.34$$

PV elastic e-p scattering,
Atomic parity violation

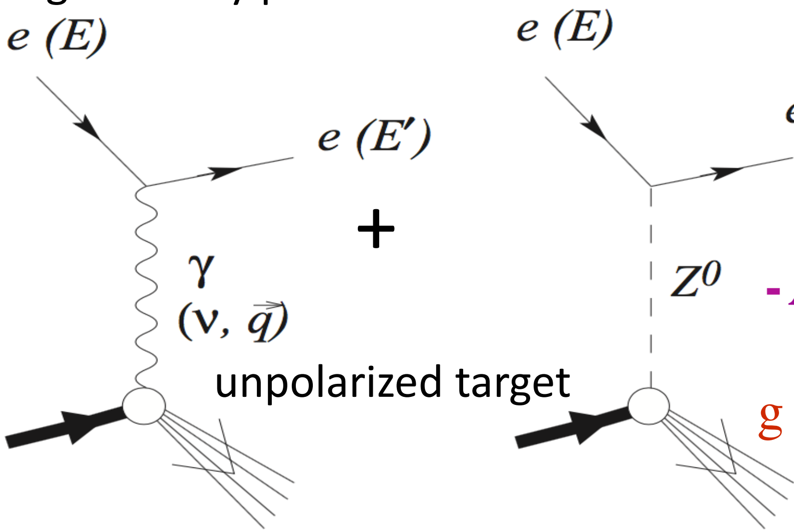
$$C_{2u} = 2g_V^e g_A^u \approx -\frac{1}{2} + 2sin^2\theta_W \approx -0.030$$

$$C_{2d} = 2g_V^e g_A^d \approx \frac{1}{2} - 2sin^2\theta_W \approx 0.025$$

PV deep inelastic scattering （PVDIS）

Parity Violation in Electron Scattering

longitudinally polarized



$$\sigma \;\alpha\; |A_\gamma + A_{weak}|^2$$

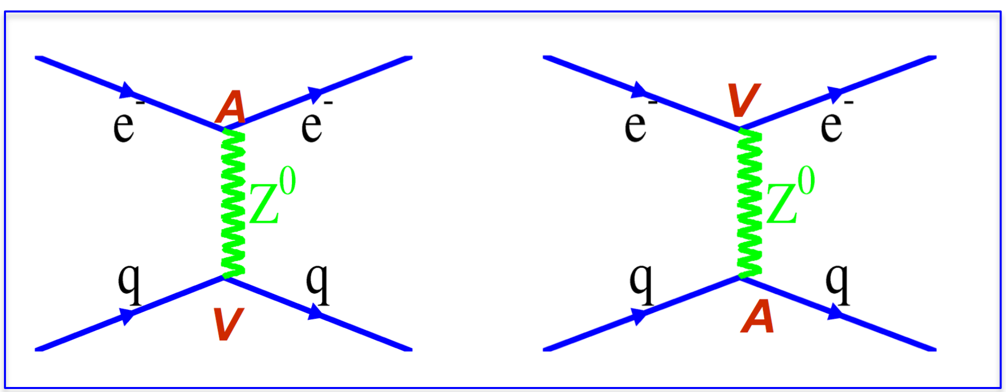
$$\sim |A_{EM}|^2 + 2A_{EM}A^*_{weak} + \ldots$$

$$-A_{LR} = A_{PV} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \sim \frac{A_{weak}}{A_\gamma} \sim \frac{G_F Q^2}{4\pi\alpha} g$$

$$g = g_A^e g_V^T + \beta\, g_V^e g_A^T \;\Rightarrow\; A_{PV} \sim 10^{-5} \cdot Q^2 \text{ to } 10^{-4} \cdot Q^2$$

- g_V and g_A are function of $\sin^2\theta_W$
- g^T affected by QCD physics

EW neutral current interaction



$$C_{1q} = 2g_A^e g_V^q \qquad C_{2q} = 2g_V^e g_A^q$$