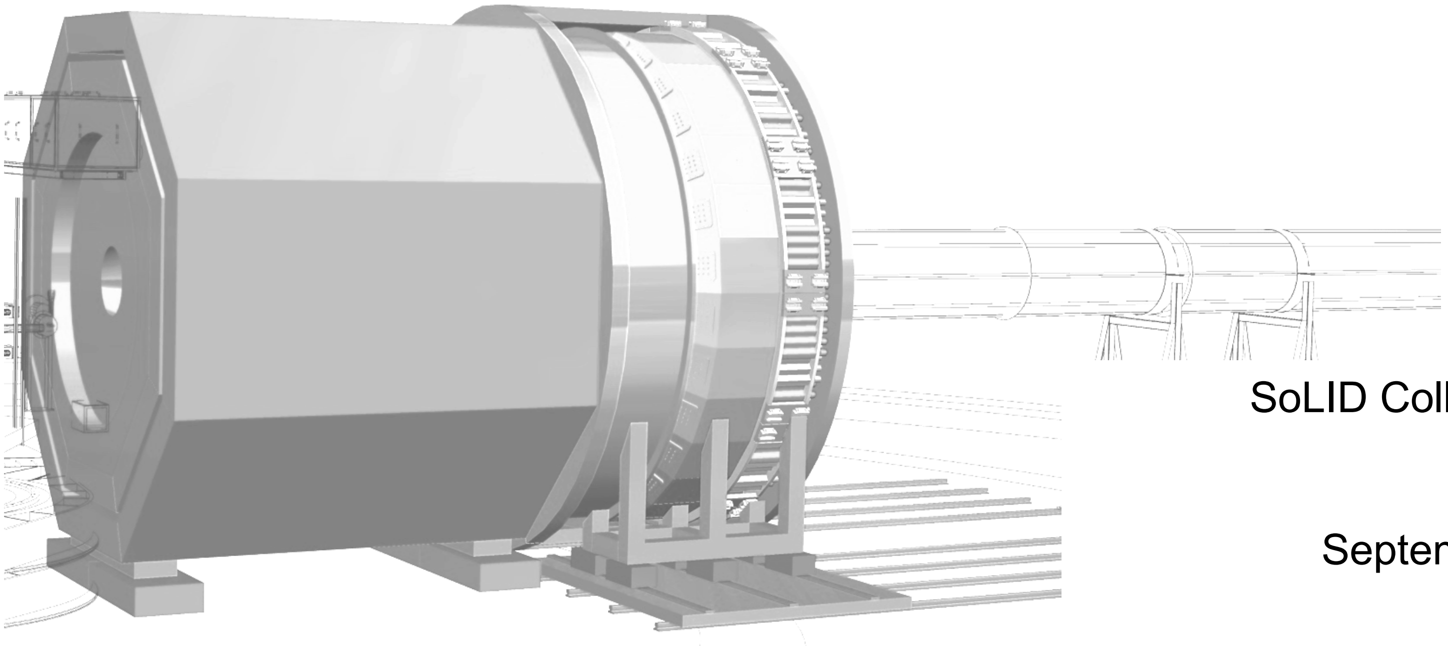
SoLID PVDIS Program



SoLID Collaboration Meeting

September 8-9, 2020

SOLENOIDAL LARGE INTENSITY DEVICE

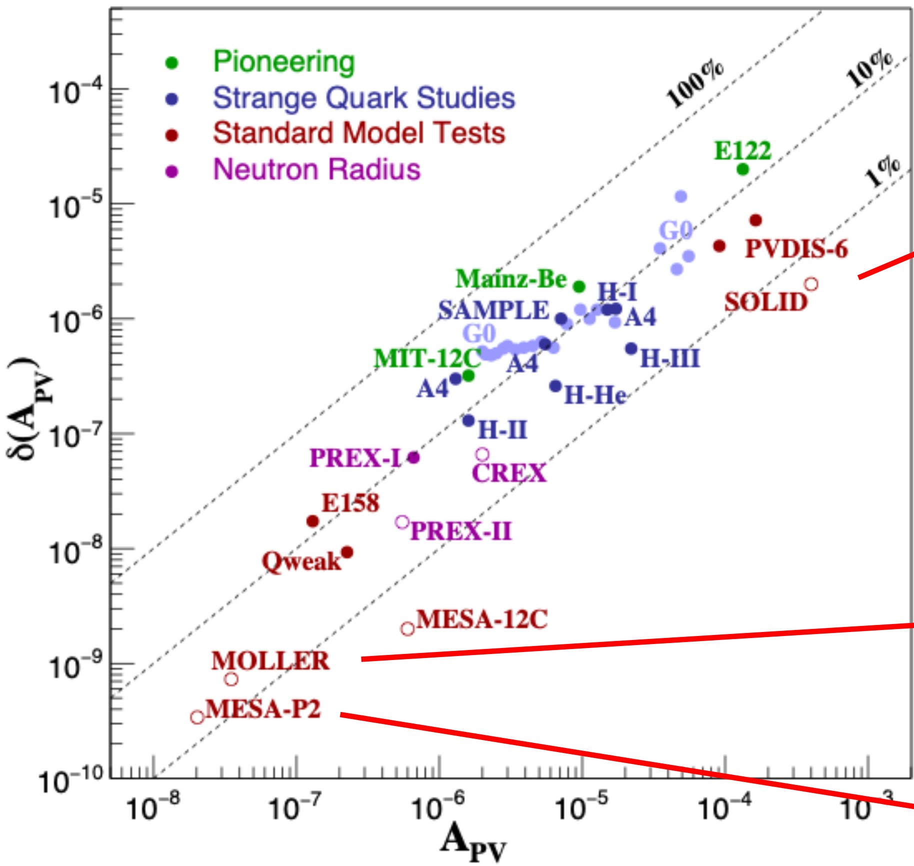
Paul Souder

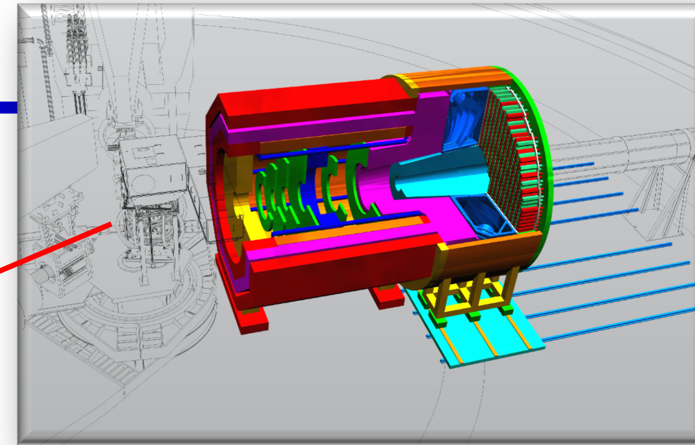
Syracuse University

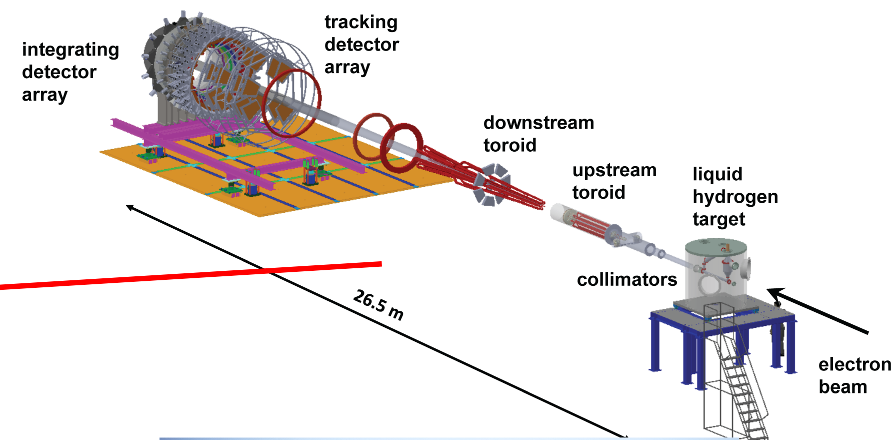
Outline

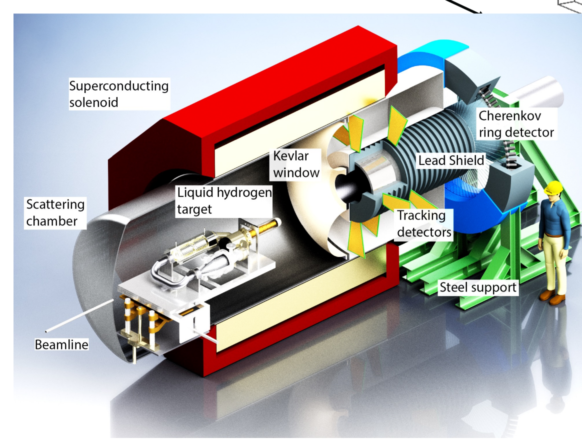
- Overview of BSM tests with PVES
- Motivation for PVDIS
- The PVDIS apparatus
- Projected results and errors

BSM PVES Experiments









	A	δA
SoLID	500 ppm	3 ppm
MOLLER	35 ppb	0.8 ppb
P2	20 ppb	0.4 ppb

MOLLER, SoLID, and P2 all improve precision

Goals of SoLID, MOLLER, and P2

$$A_{PV} = Q_W^e \frac{Q^2 G_F}{\sqrt{2}\pi} \left(\frac{1-y}{1+y^4+(1-y)^4} \right)$$

Moller (Simple formula)

$$A_{PV} = \frac{G_F Q^2}{\pi \sqrt{2}} (Q_W^p + \cancel{A_M + A_s + A_A})$$

P2: eP (Simple formula at low E and θ)

$$A^{PV} = \left(\frac{G_F Q^2}{4\sqrt{2}\pi} \right) (Y_1 a_1 + Y_3 a_3)$$

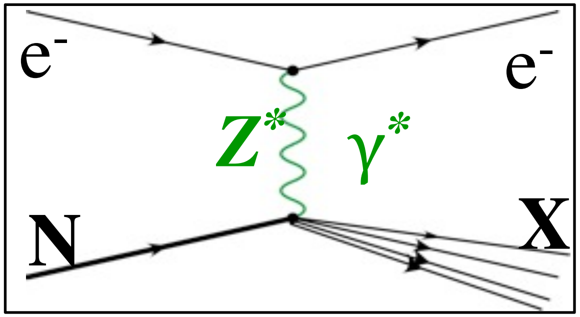
SoLID PVDIS (Simple for d at large E and θ, only way to get C_2's)

$$a_1^d = \frac{6}{5}(2C_{1u} - C_{1d}); \quad a_3^d = \frac{6}{5}(2\underline{C_{2u}} - \underline{C_{2d}})$$

$$Q_W(Z,N) = -2[\underline{C_{1u}}(2Z+N) + \underline{C_{1d}}(Z+2N)] \qquad Q_W(e) = -2\underline{C_{2e}}$$

Measure all the C's as precisely as possible

PVDIS for eD Scattering



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

$x \equiv x_{Bjorken}$

$y \equiv 1 - E'/E$

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

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

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

$$\begin{aligned} R_s(x) &= \frac{2S(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 0 \\ R_v(x) &= \frac{u_v(x)+d_v(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 1 \end{aligned}$$

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

5

Standard Model Effective Field Theory (SMEFT)

$$\mathcal{L} = \sum_d \sum_{ij} \frac{C_d^{ij}}{\Lambda^{4-d}} \mathcal{O}_d^{ij}$$

$$\mathcal{O}_d^{ij} = \bar{e}_i \gamma_\mu e_i \bar{f}_j \gamma^\mu f_j$$

$$e_{L/R} = \frac{1}{2}(1 \mp \gamma^5)\psi_e$$

$$\mathcal{O}_d^{ij} = LL_f,\ LR_f,\ RL_f,\ RR_f$$

SMEFT identifies
all possible BSM physics

61 d=6; 993 d=8 independent couplings

Goal: Measure each C_d^{ij}
as precisely as possible
(Nobody really knows where
the new physics is.)

SMEFT also identifies regions of exclusion from world data sets

$$\mathcal{A} = (\mathcal{A}_{SM} + \frac{\mathcal{A}_6}{\Lambda^2} + \frac{\mathcal{A}_8}{\Lambda^4} \ldots)$$

$$\text{For PVES :} \quad A_{PV} \sim \mathcal{A}_{EM} \times \mathcal{A}$$

$$\text{For Drell-Yan :} \quad \sigma_{BSM} \sim (\mathcal{A}_6)^2 + \mathcal{A}_{SM} \times \mathcal{A}_8$$

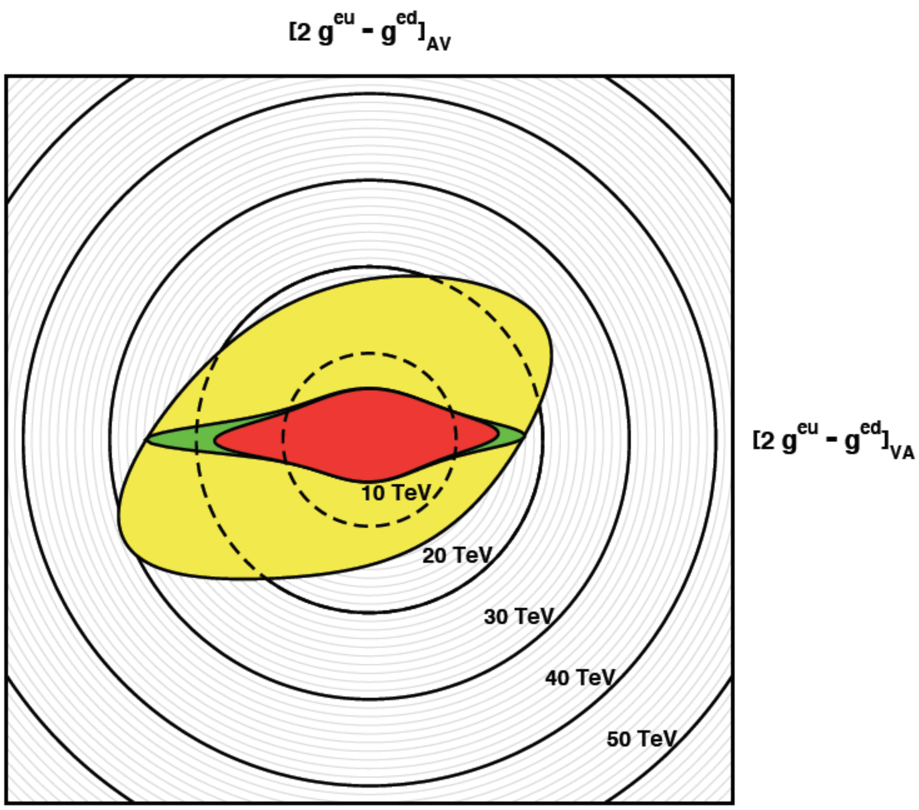
Example: LHC Drell-Yan
mainly sensitive to d=8
operator

•Alioli et al., e-Print: [2003.11615](2003.11615) [hep-ph]

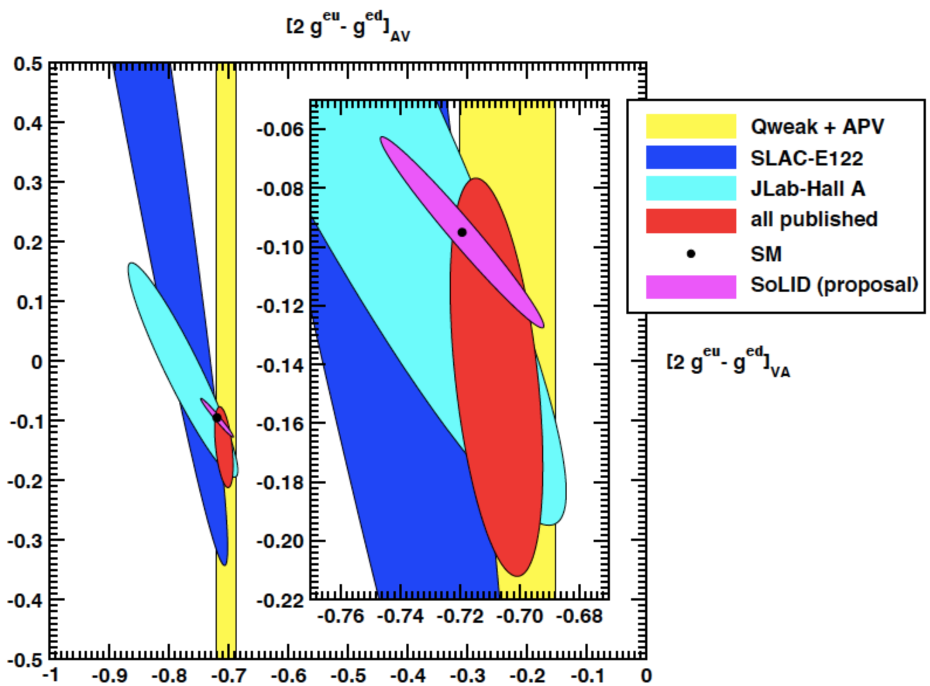
Projected Results

With this precision,
SoLID makes a unique contribution
to the SMEFT program.

Improvement in
energy reach for
electron-nucleon couplings



Improvement in
couplings

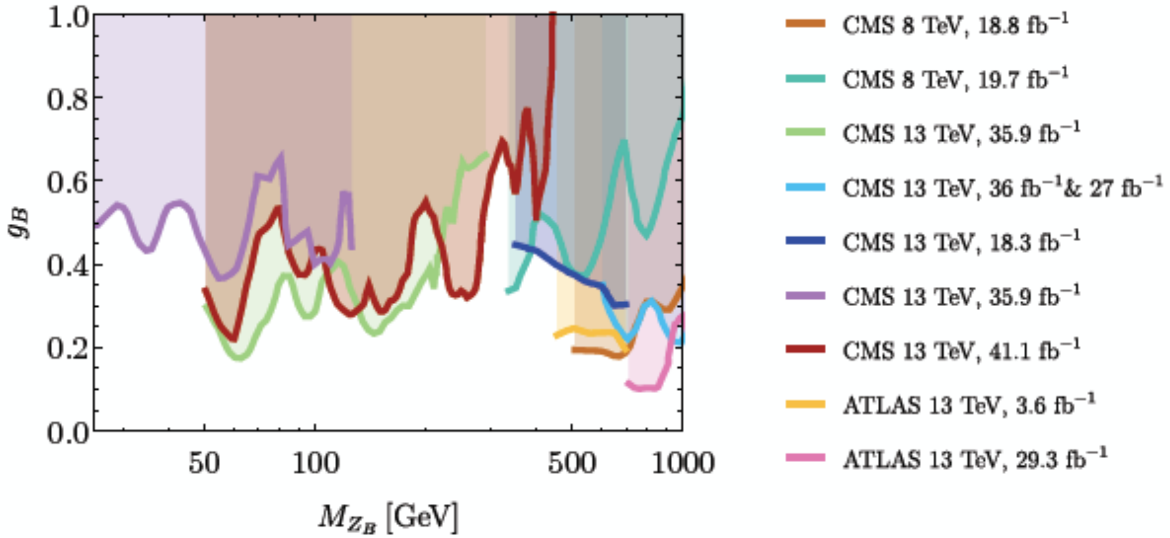


Possible Lepto-Phobic Z'; Example at lower energy

Motivation for introducing new particle:

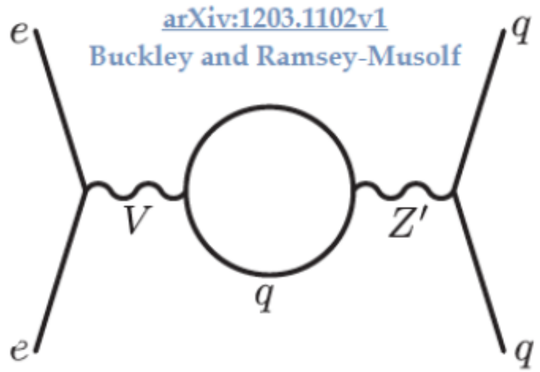
Baryon number is a global symmetry in the SM (bad).
Theories of local baryon number symmetry are attractive.
They predict a lepto-phobic boson.
They also predict a dark matter candidate.

Prerez, Phys. Rept. 597, (2015) 1-30



Prerez, et al., *JHEP* 07 (2020) 087

Leptophobic Z'

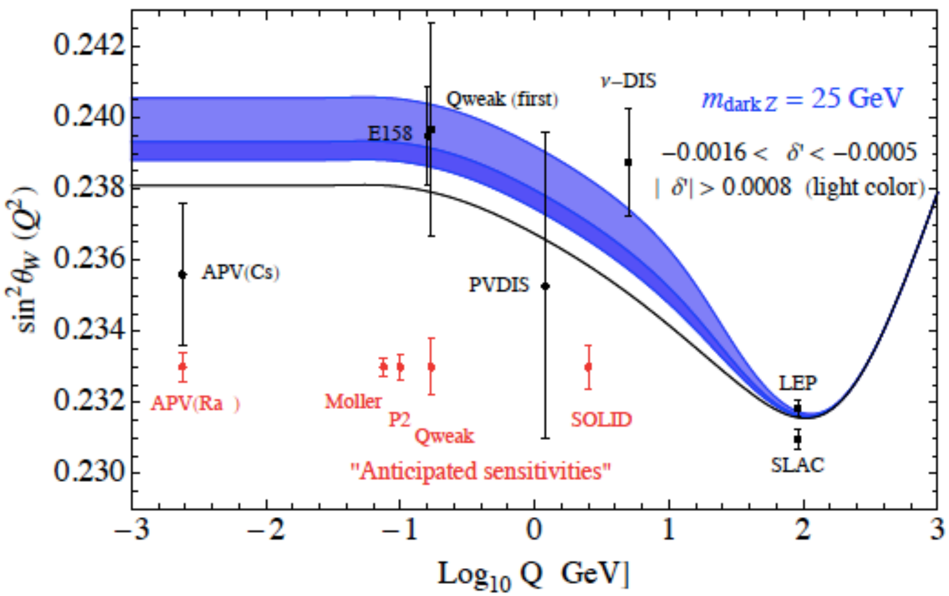


Modifies mainly C_2's in PVES

Dark Boson Z_d and $\sin^2\theta_W$

- *Davoudiasl, et al. Phys.Rev.D* 92 (2015) 5, 055005

Only effect is to change $\sin^2\theta_W$ at low Q^2



	Precision	$\delta\sin^2\theta_W$	Λ_{new}
APV CS	0.58 %	0.0019	32.3 TeV
E158	14 %	0.0013	17.0 TeV
Qweak	6.3 %	0.0011	26.3 TeV
PVDIS	4.5 %	0.005	7.6 TeV
SoLID	0.6 %	0.0006	22 TeV
MOLLER	2.3 %	0.00026	39 TeV
P2	2.0 %	0.00036	49 TeV
PVES ^{12}C	0.3 %	0.0007	49 TeV
ATLAS-2017			40 TeV

PVES is the only way to see Z_d if decay is dominated by invisible particles

Note poor correlation between $\sin^2\theta_W$ and Λ. This Is one example of why many experiments are needed.

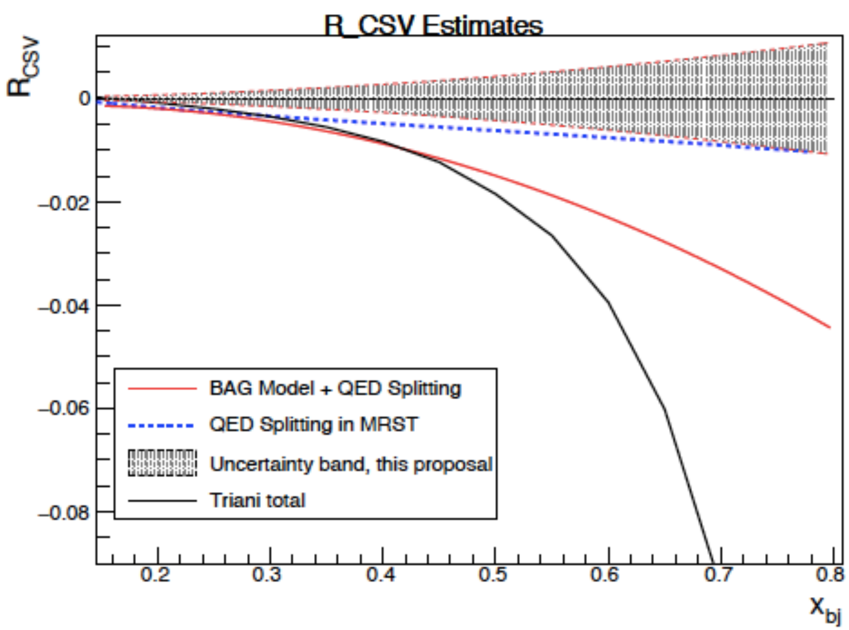
Hadronic Physics: Charge Symmetry Violation

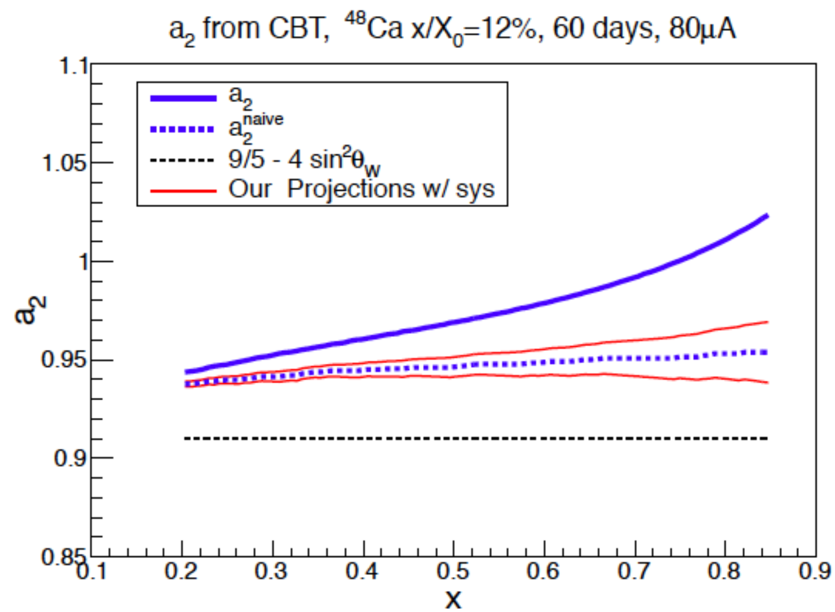
$$u^p(x) \stackrel{?}{=} d^n(x) \quad \Rightarrow \quad \delta u(x) \equiv u^p(x) - d^n(x)$$
$$d^p(x) \stackrel{?}{=} u^n(x) \quad \Rightarrow \quad \delta d(x) \equiv d^p(x) - u^n(x)$$

$$R_{CSV} = \frac{\delta A_{PV}}{A_{PV}} \approx 0.28 \frac{\delta u(x) - \delta d(x)}{u(x) + d(x)}$$

For A_{PV} in electron-^{2}H DIS

Additional contribution to NuTeV anomaly?





"The paper on PVDIS and the EMC effect highlights a way -- perhaps the best way -- to access the flavor dependent of the EIC effect using PVDIS." Ian Cloet

Unique Higher Twist Contribution

The observation of Higher Twist in PV-DIS would be exciting direct evidence for diquarks

following the approach of
Bjorken, PRD 18, 3239 (78),
Wolfenstein, NPB146, 477 (78)

$$V_\mu = \left(\bar{u}\gamma_\mu u - \bar{d}\gamma_\mu d\right) \Leftrightarrow S_\mu = \left(\bar{u}\gamma_\mu u + \bar{d}\gamma_\mu d\right)$$

Isospin decomposition
before using PDF's

$$\langle VV \rangle = l_{\mu\nu} \int \langle D | V^\mu(x) V^\nu(0) | D \rangle e^{iqx} d^4x$$

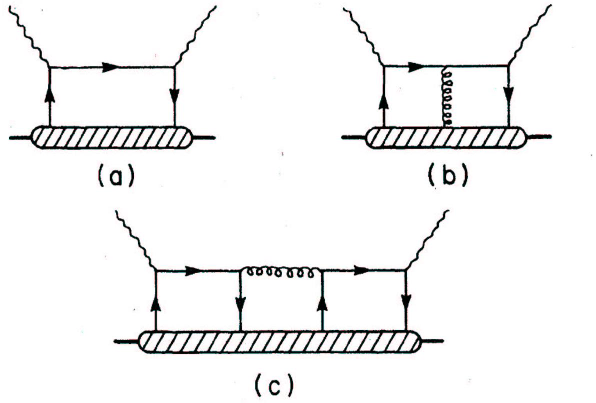
$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

$$\delta = \frac{\langle VV \rangle - \langle SS \rangle}{\langle VV \rangle + \langle SS \rangle} \qquad a(x) \propto \frac{F_1^{\gamma Z}}{F_1^{\gamma}} \propto 1 - 0.3\delta$$

Higher-Twist valence quark-quark correlation

Zero in quark-parton model

$$\langle VV \rangle - \langle SS \rangle = \langle (V-S)(V+S) \rangle \propto l_{\mu\nu} \int \langle D | \bar{u}(x)\gamma^\mu u(x) \bar{d}(0)\gamma^\nu d(0) \rangle e^{iqx} d^4x$$



(c) type diagram is the only operator that can contribute to a(x) higher twist: theoretically very interesting!

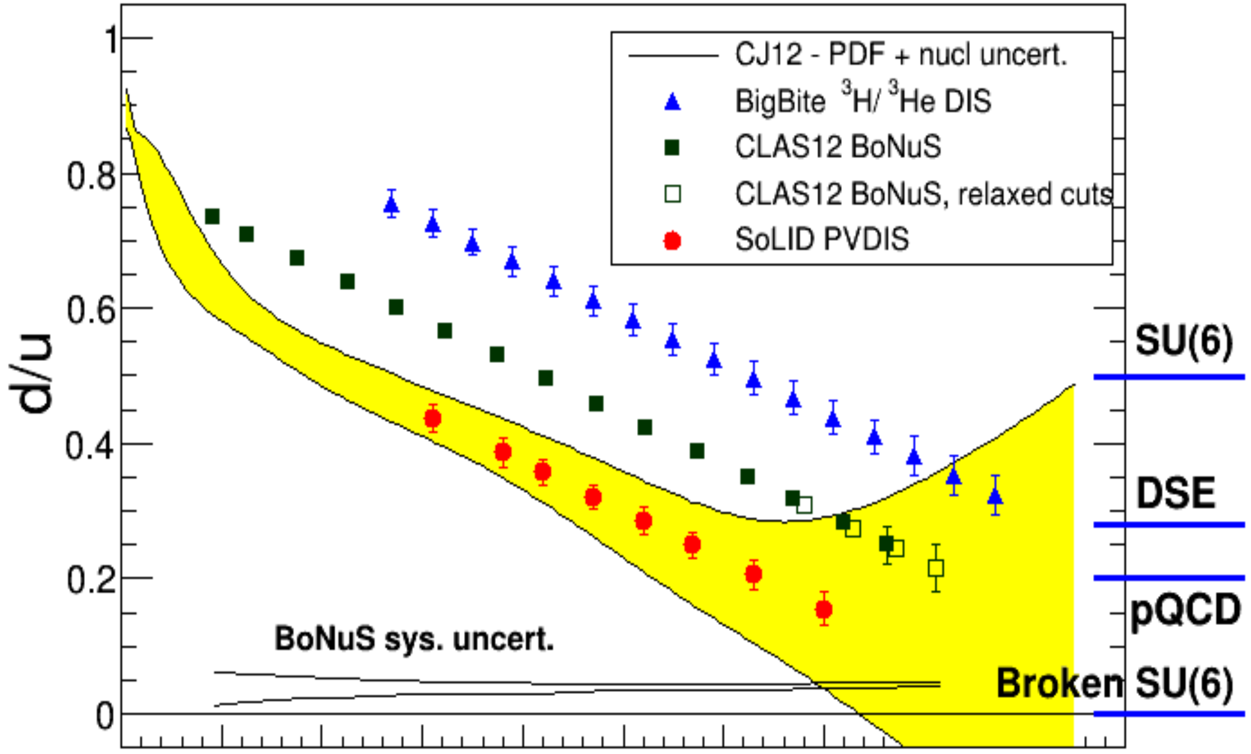
σ_L contributions cancel

Structure Function Ratio d/u for the Proton

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

$$a^P(x) \approx \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)}$$

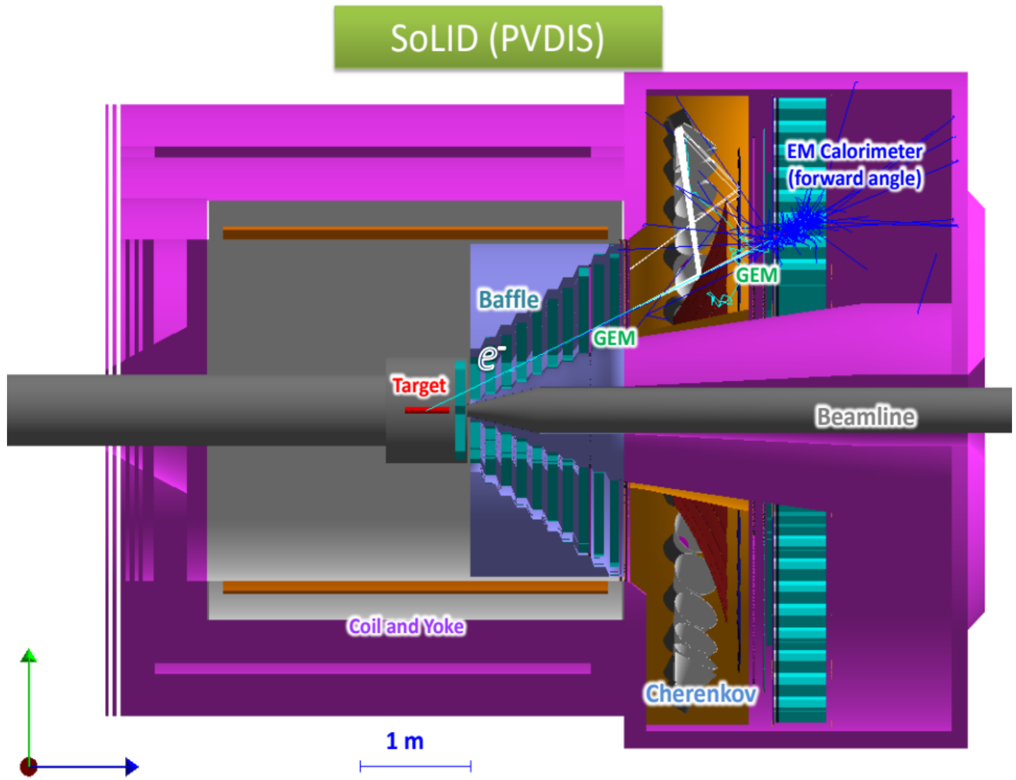
PVDIS is complementary to the rest of the JLAb d/u program: no nuclear effects



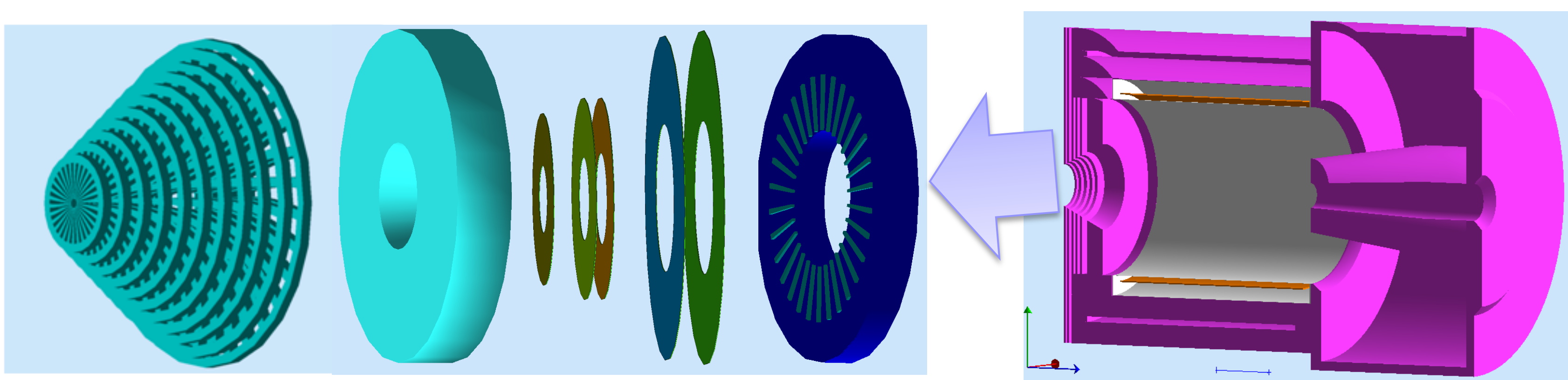
SoLID Apparatus

Requirements

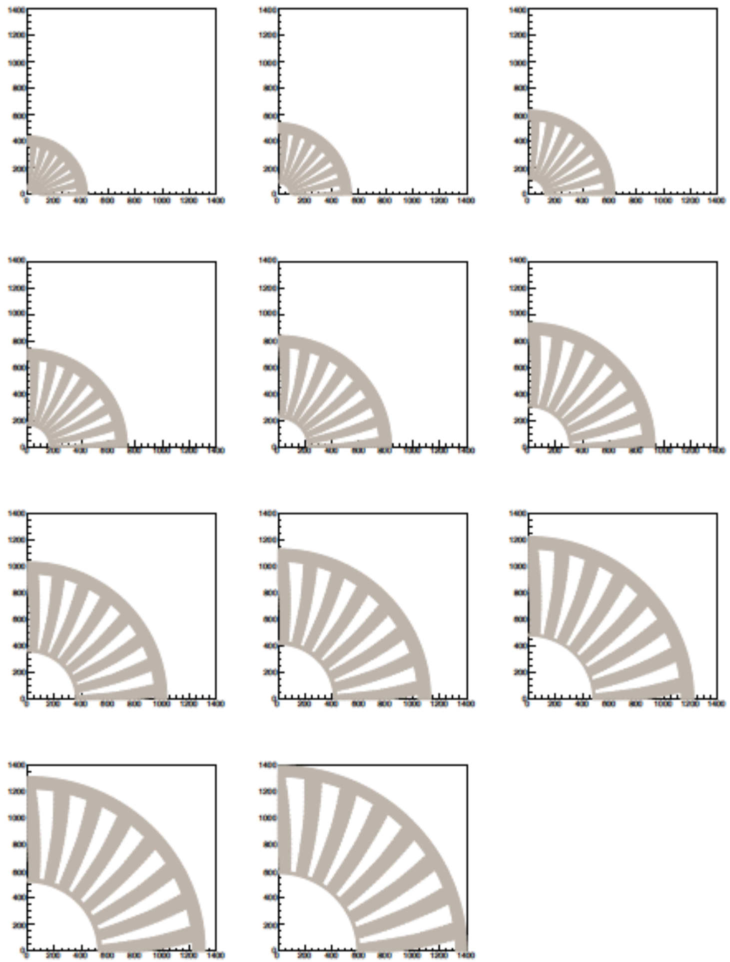
- High Luminosity with E > 10 GeV
- Large scattering angles (for high x & y)
- Better than 1% errors for small bins
- x-range 0.25-0.75
- $W^2 > 4$ GeV^2
- Q^2 range a factor of 2 for each x
  - (Except at very high x)
- Moderate running times

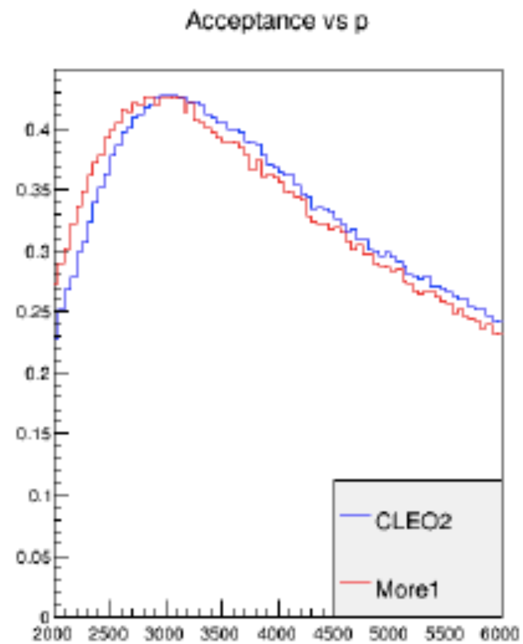


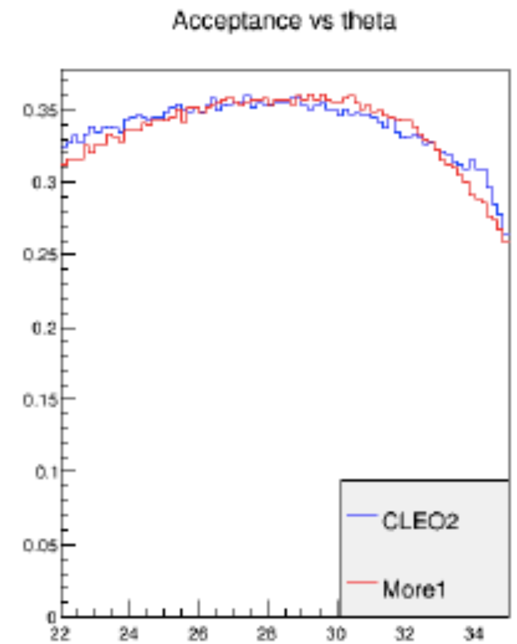
Baffle LGC 5xGEMs EC

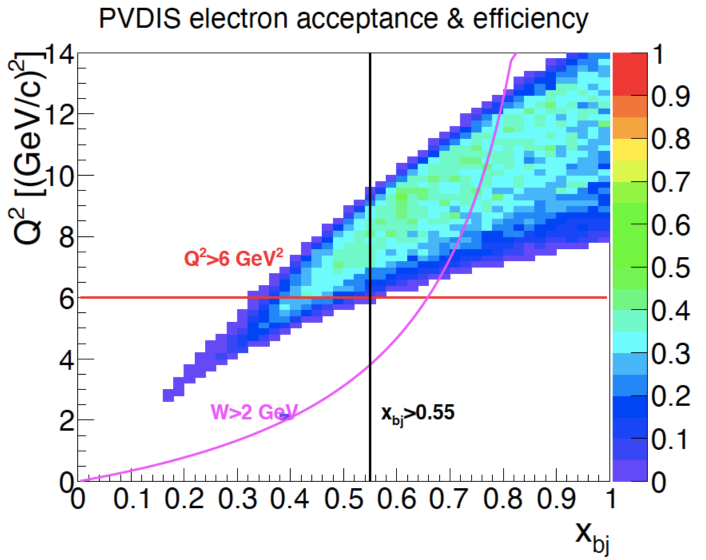


PVDIS Baffles and Acceptance

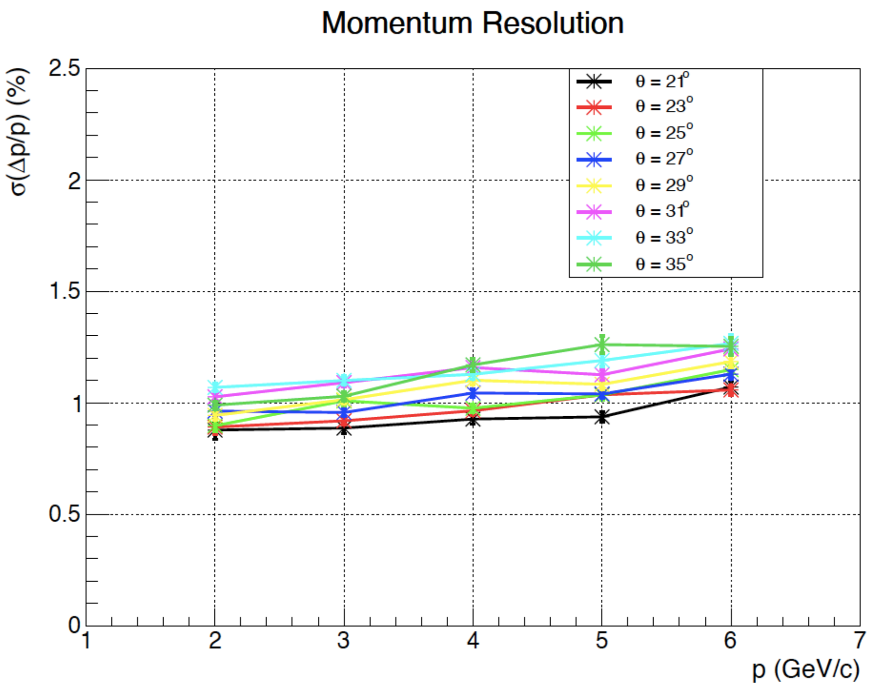


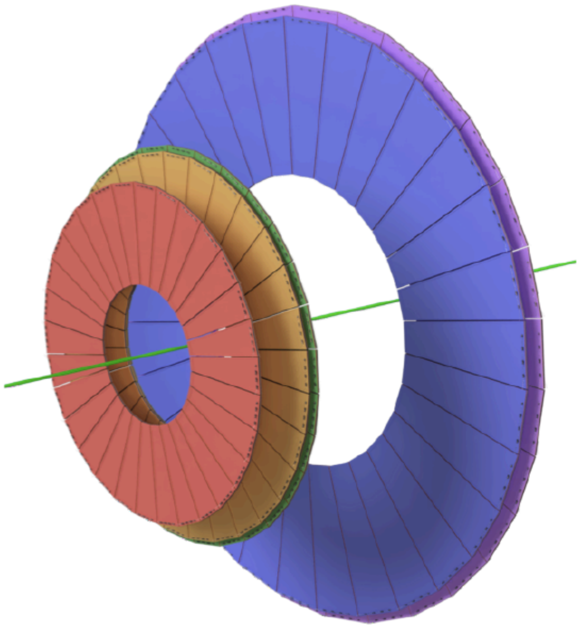


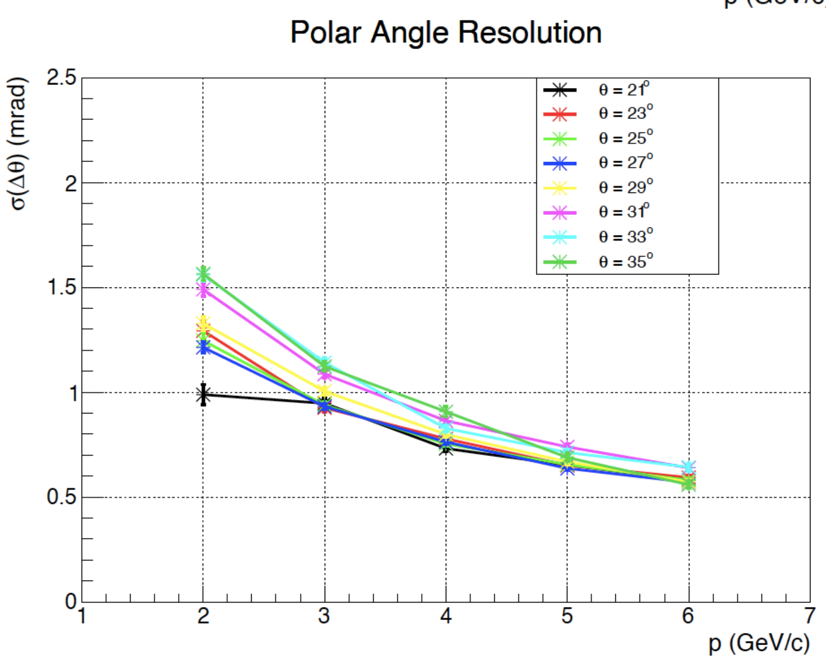


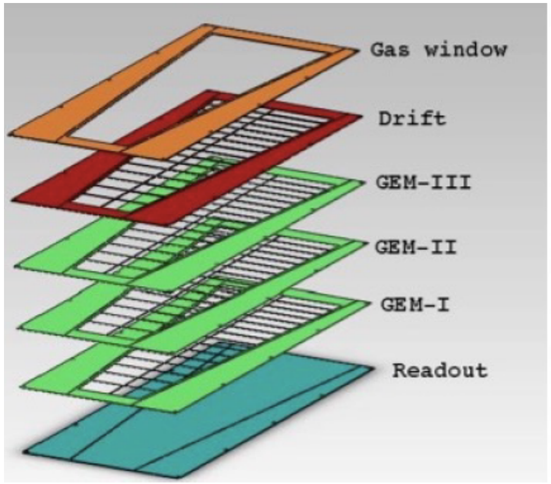


GEM Tracking and Resolution

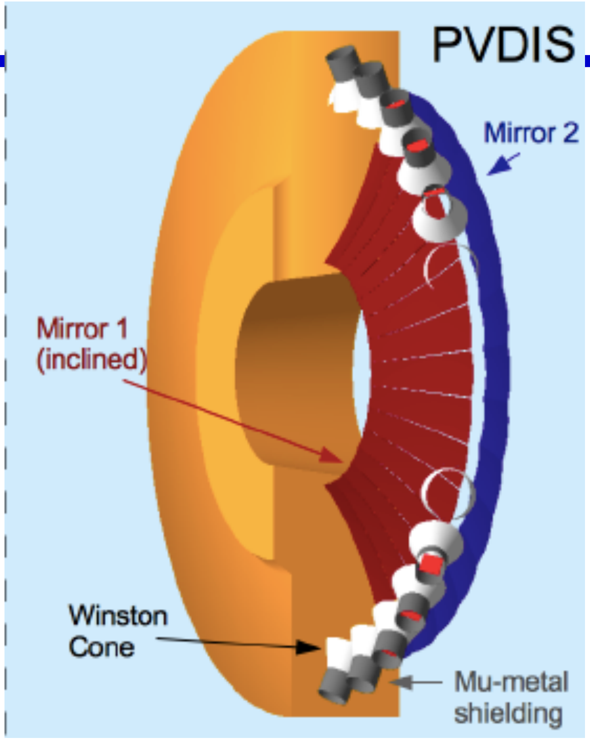






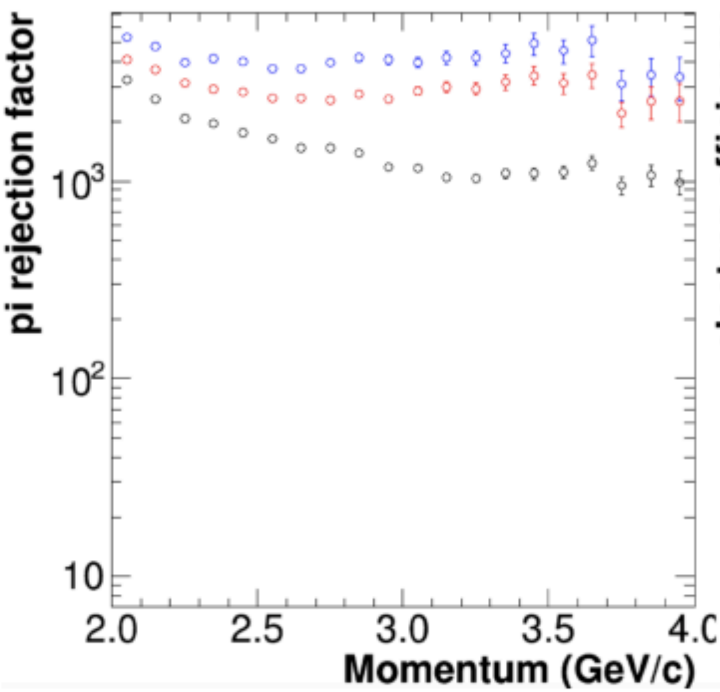


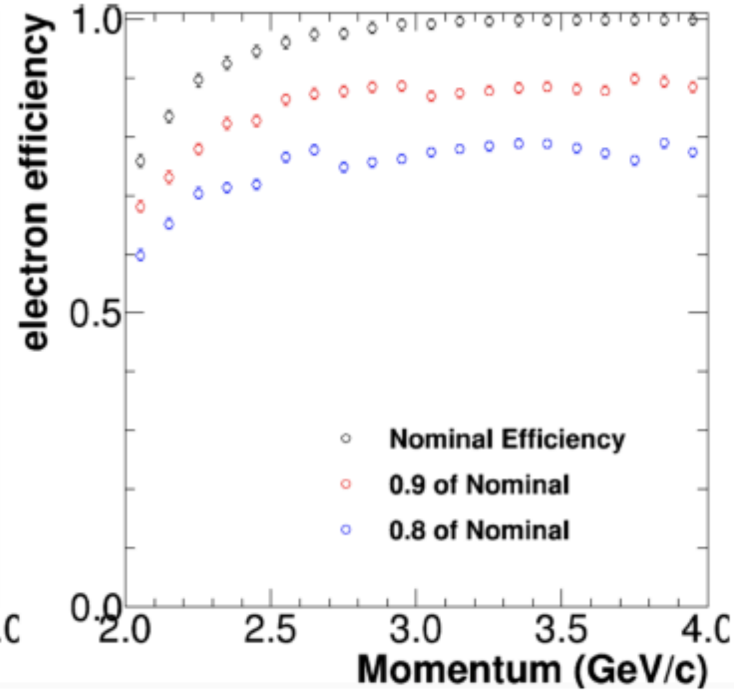
Light Gas Cerenkov for PVDIS



Together with ECal is the basis for the DAQ trigger.

Testing the performance of the Cerenkov counters, at both low and high rates, is part of the Pre-R&D plan

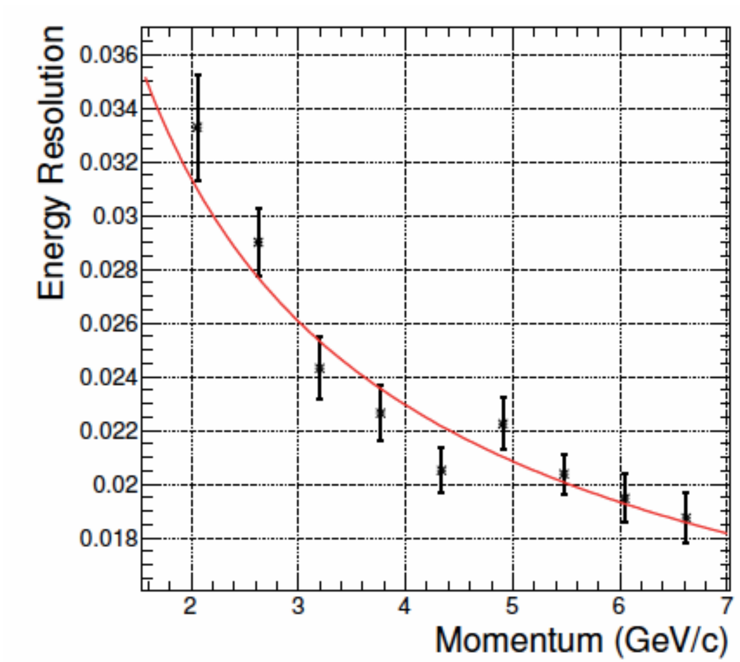


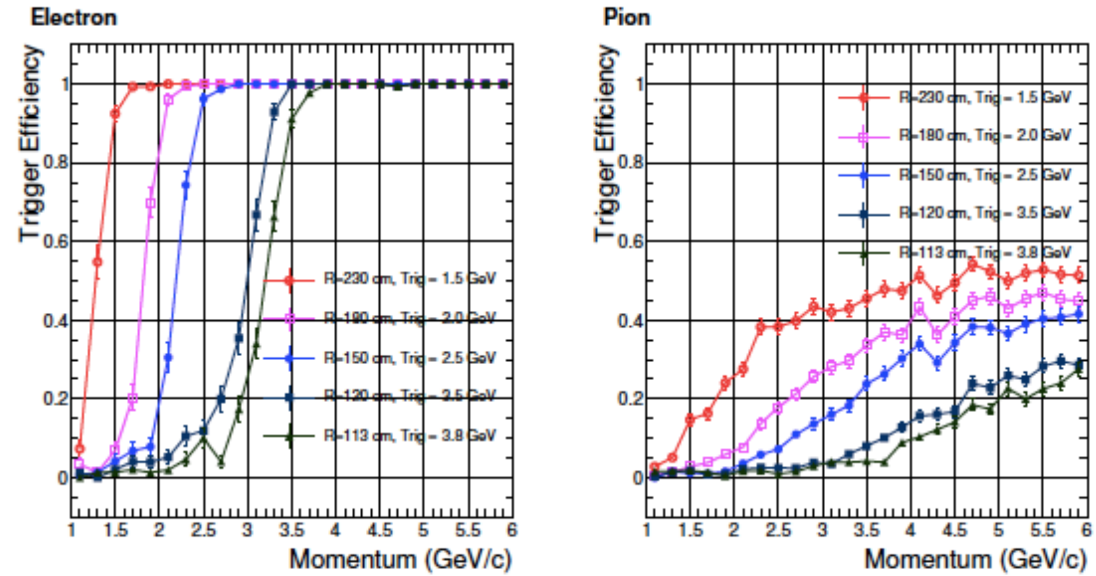


Performance of Ecal for PVDIS Trigger

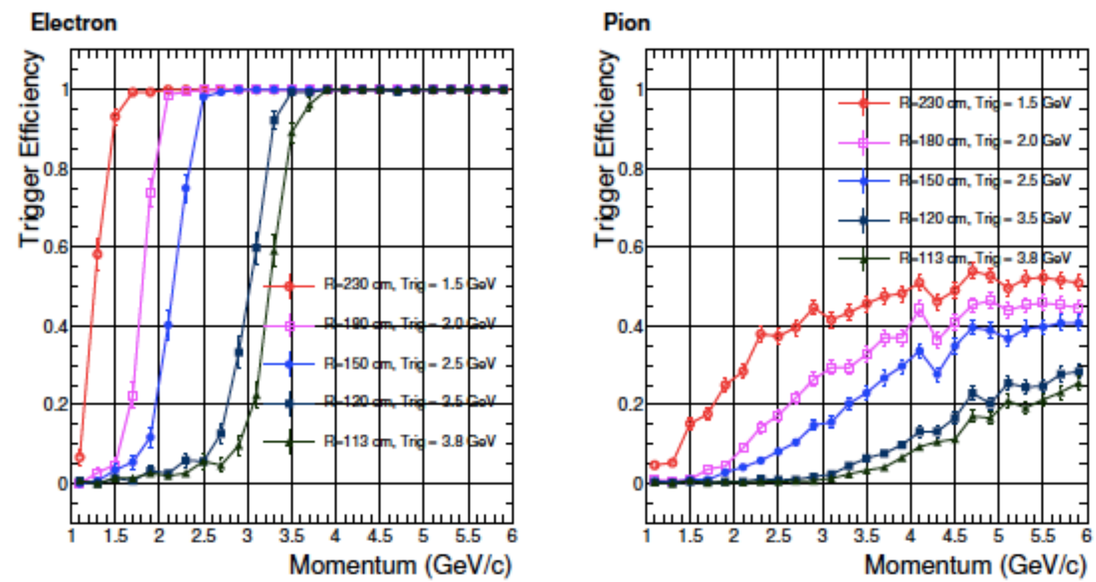
Keep trigger rate to 15 kHz/sector without tracking information

Energy Resolution



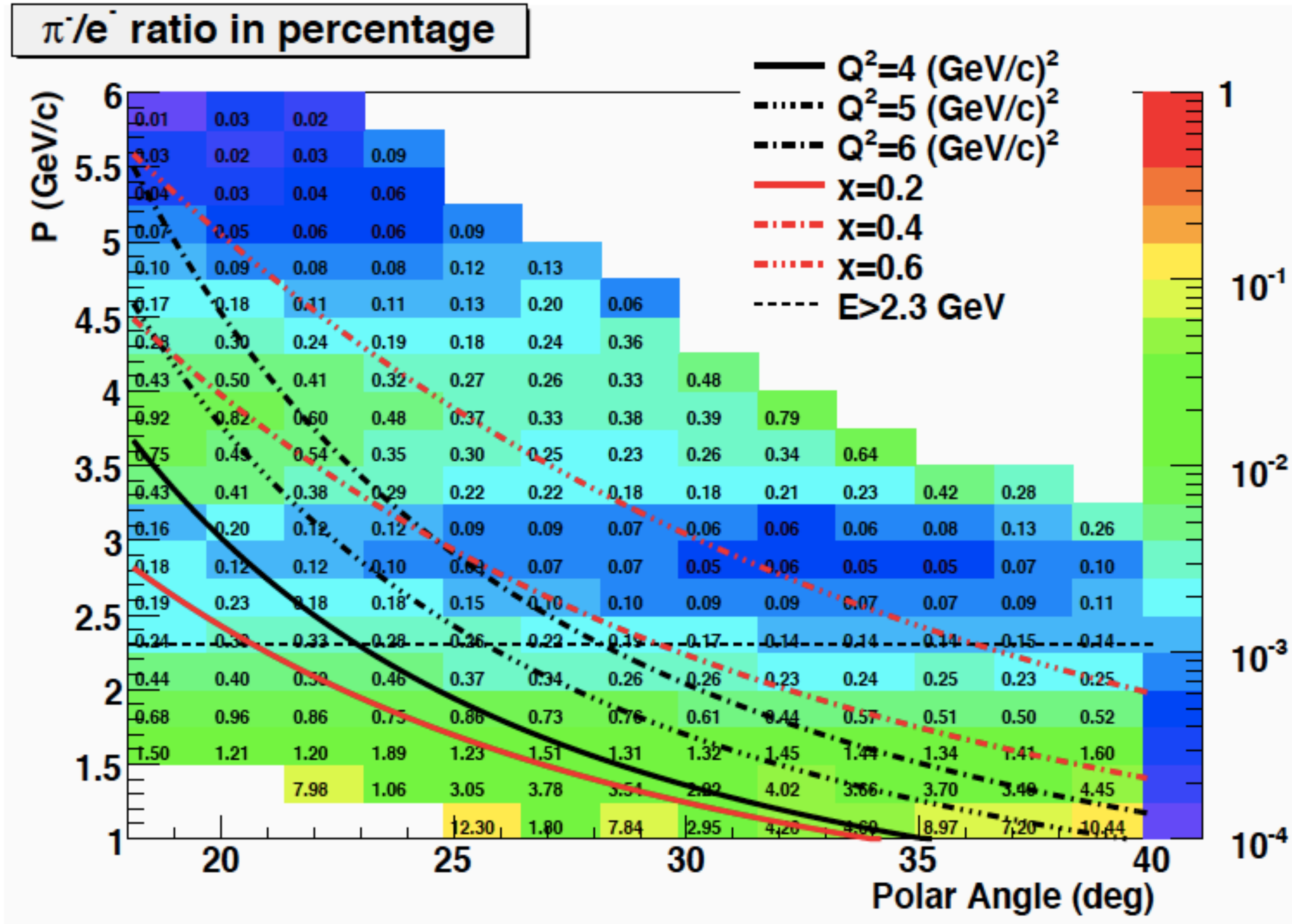


(a) Higher-radiation azimuthal region



Pion-Electron Separation After Reconstruction

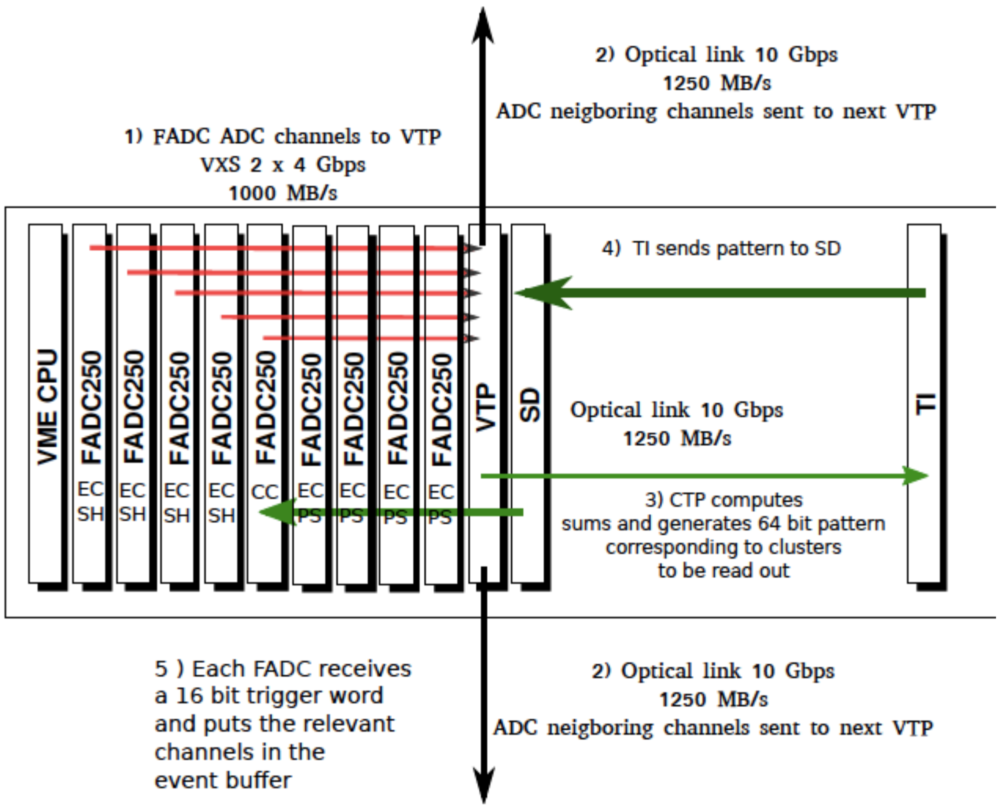
Pion contamination after tracks are reconstructed with the GEM’s

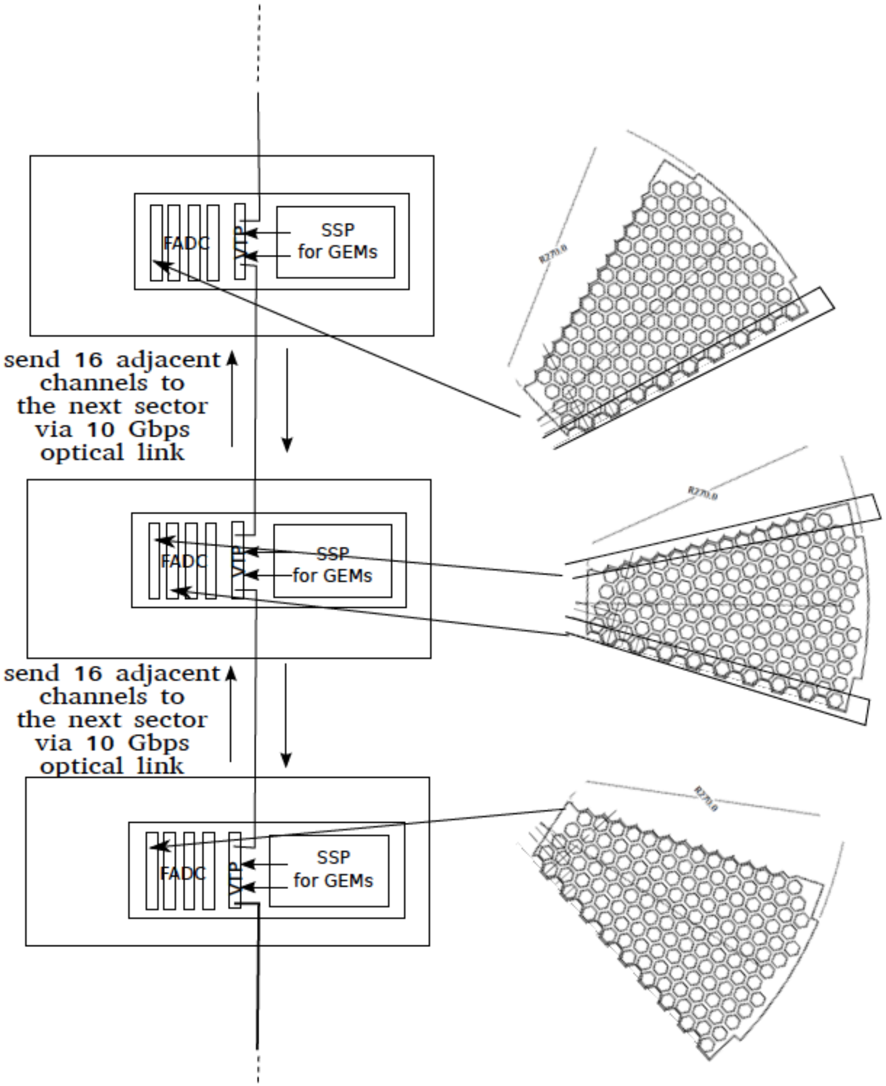


SoLID Jefferson Lab

PVDIS Electronics

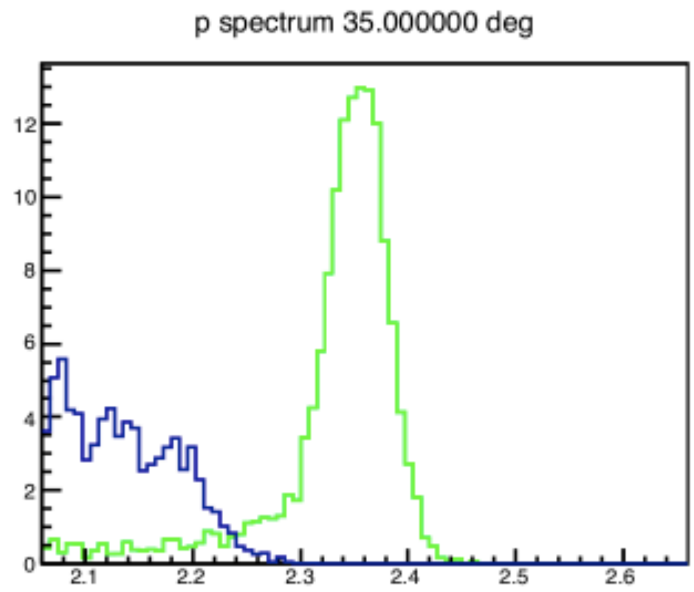
The full capabilities of the electronics
is being tested as part of the PreR&D plan.



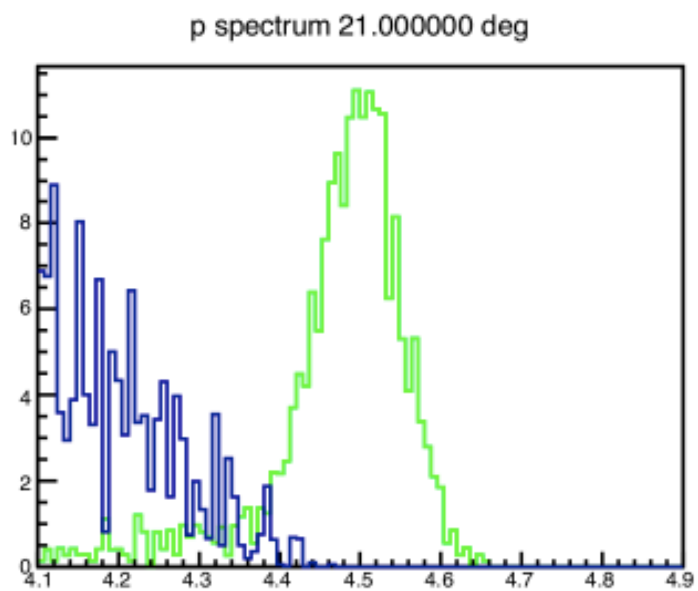


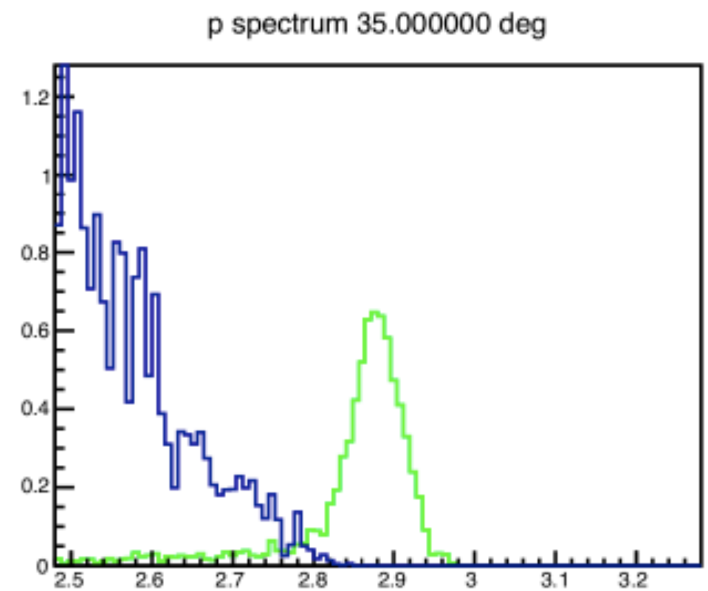
Q^2 Calibration with Elastic eP Scattering (0.2%)

1. Measure θ with geometry.
2. Align with X-rays
3. Calibrate B field with known beam energy and eP elastic scattering



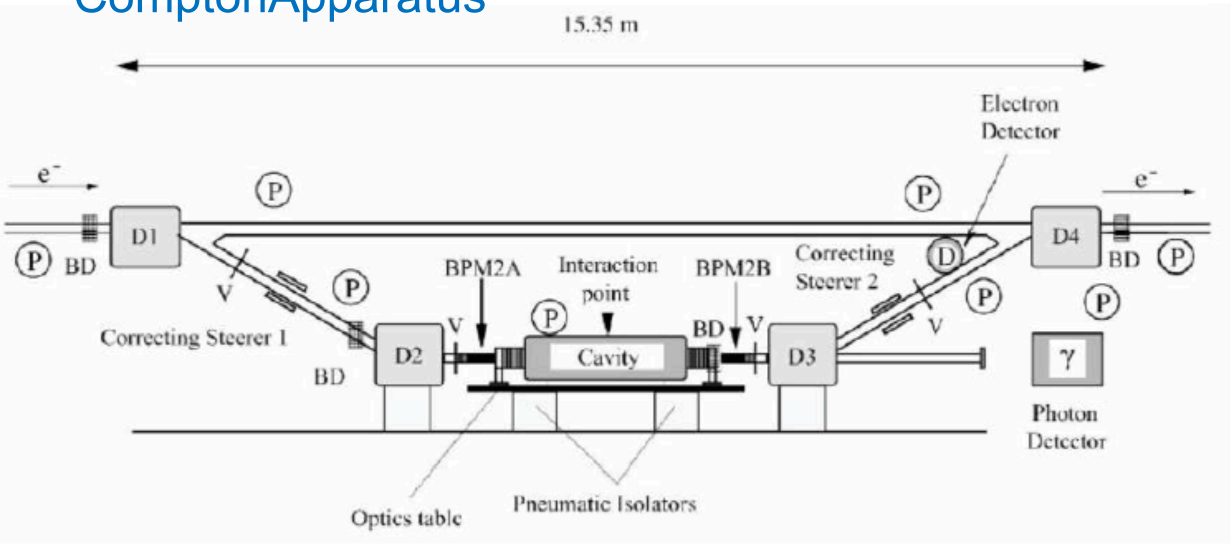
Elastic events are cleanly separated from the background.





Precision Polarimetry: 0.4% Precision

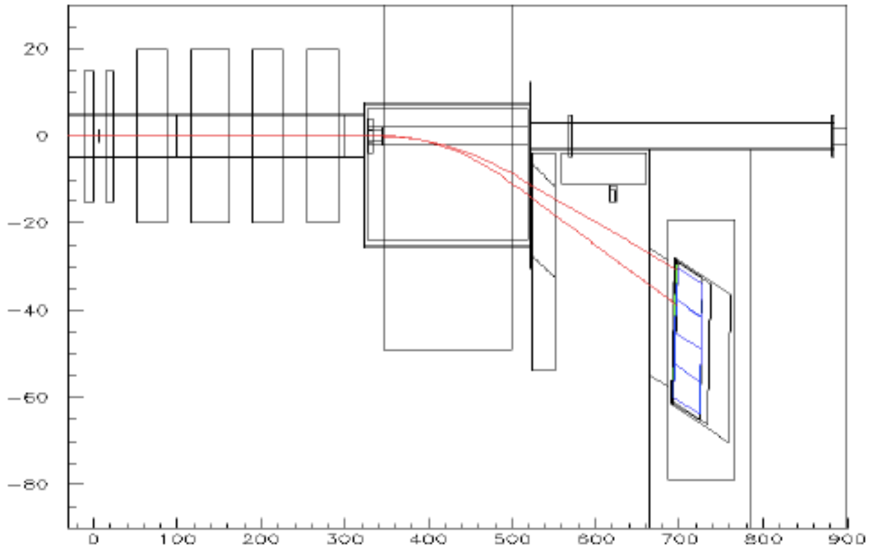
ComptonApparatus



Compton Error Budger

Relative error (%)	electron	photon
Position asymmetries*	-	-
E_{Beam} and λ_{Laser}*	0.03	0.03
Radiative Corrections*	0.05	0.05
Laser polarization*	0.20	0.20
Background / Deadtime / Pileup	0.20	0.20
Analyzing power Calibration / Detector Linearity	0.25	0.35
Total:	0.38	0.45

Moller Apparatus

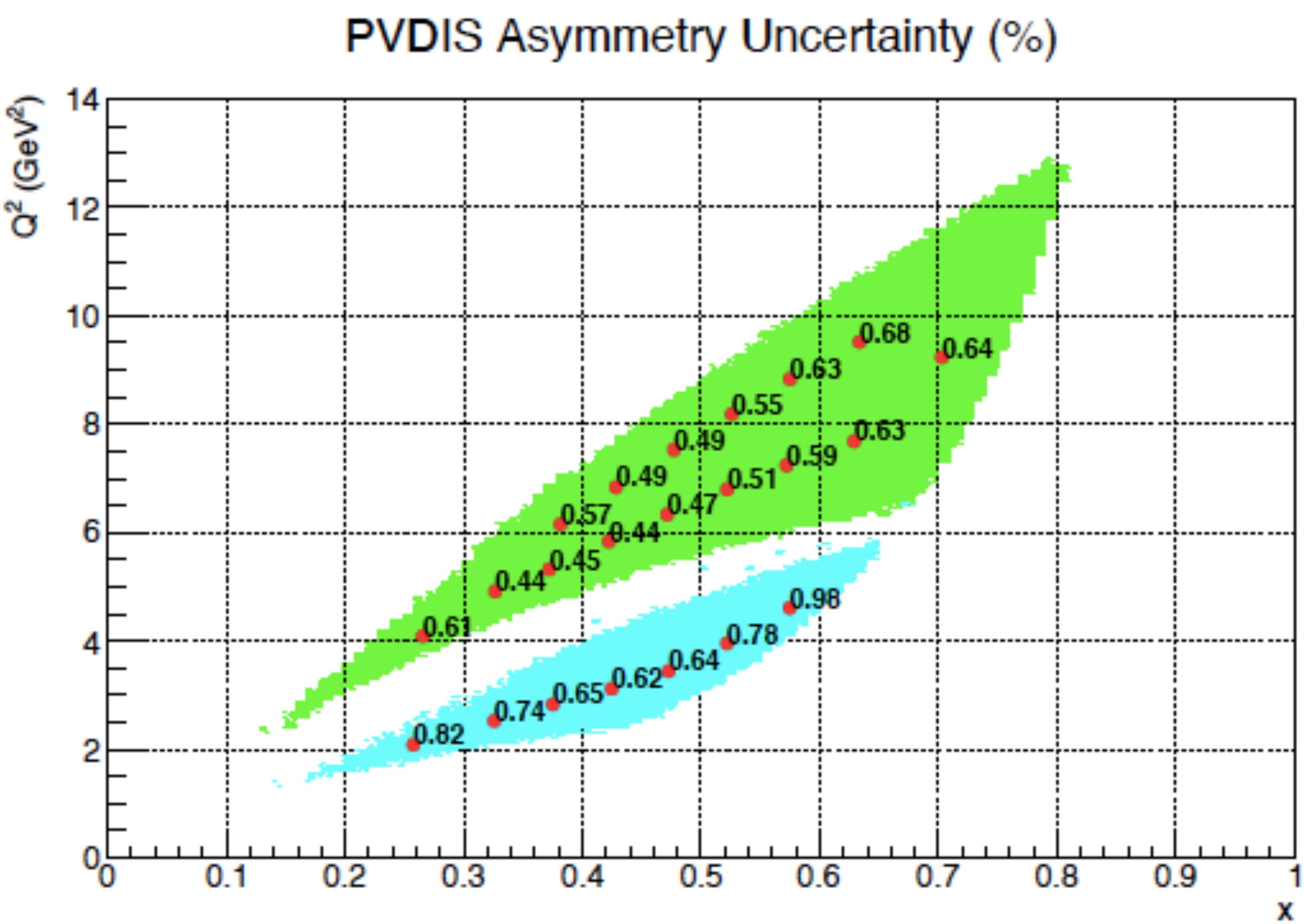


Moller Error Budget

Variable	Hall C	Hall A
Target spin polarization	0.25%	0.30%
Target angle	‡	‡
Analyzing power	0.24%	0.20%
Levchuk effect	0.30%	0.20%
Target temperature	0.05%	0.05%
Dead time	‡	0.10%
Background	‡	0.10%
Others	0.10%	0.10%
Total	0.47%	0.45%

‡: not estimated

Projected Statistics



Untangling the Physics

Kinematic dependence of physics topics:

	x	Y	Q^2
New Physics	none	yes	small
CSV	yes	small	small
Higher Twist	large?	no	large

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

Error Budget

Total	0.6
Polarimetry	0.4
Q2	0.2
Radiative Corrections	0.2
Event reconstruction	0.2
Statistics	0.3

Energy(GeV)	4.4	6.6	11	Test
Days(LD2)	18	60	120	27
Days(LH2)	9	-	90	14

180 Days are Approved

Summary

- SoLID PVDIS preforms an important BSM search.
- PDVIS also probes interesting hadronic physics.
- The SoLID spectrometer is capable of performing the measurement with the required precision.