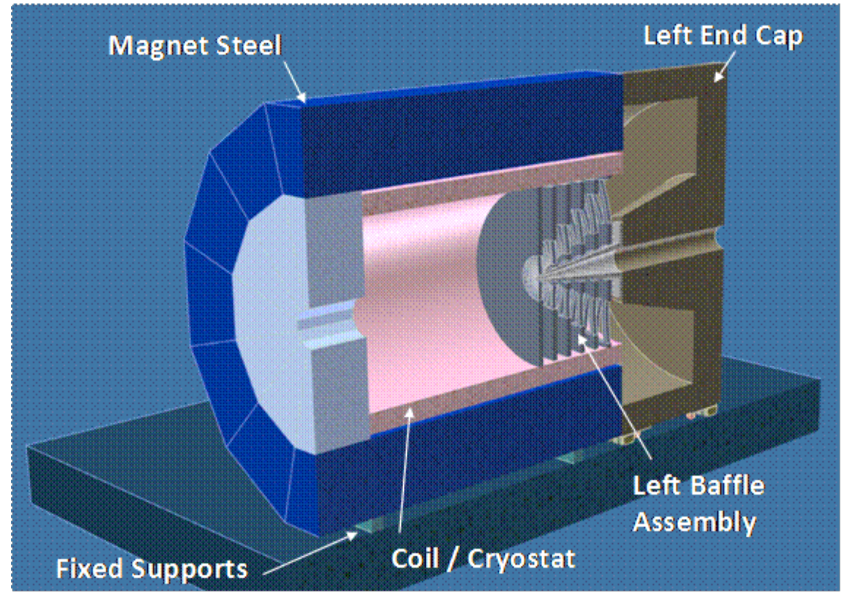
PVDIS and Solid Physics Motivation

Nilanga Liyanage

University of Virginia

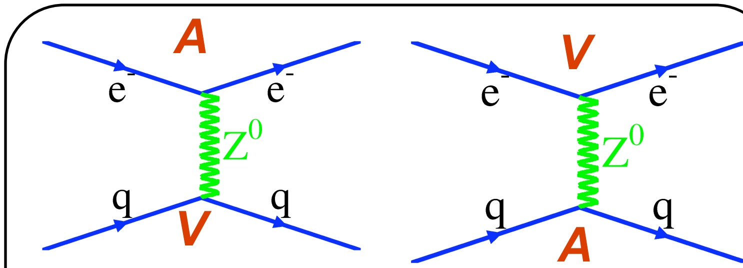
Parity Violating Deep Inelastic Scattering (PVDIS)

I. PVDIS Physics Potential
   A. Electroweak Couplings
   B. Look for new physics beyond SM
   C. Charge Symmetry
   D. Higher Twist
   E. Other Physics and Targets:
      - d_v/u_v ; Isoscaler EMC effect



II. SoLID spectrometer

PVDIS: Electron-Quark Scattering



$C_{1i} \equiv 2g_A^e g_V^i$ $\quad$ $C_{2i} \equiv 2g_V^e g_A^i$

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \frac{\tilde{A}_Z}{A_\gamma} \sim \frac{G_F Q^2}{4\pi\alpha}(g_A^e g_V^T + \beta g_V^e g_A^T)$$

$$C_{1u} = -\tfrac{1}{2} + \tfrac{4}{3}\sin^2(\theta_W) + \delta C_{1u} \approx -0.19$$
$$C_{1d} = \tfrac{1}{2} - \tfrac{2}{3}\sin^2(\theta_W) + \delta C_{1d} \approx 0.35$$
$$C_{2u} = -\tfrac{1}{2} + 2\sin^2(\theta_W) + \delta C_{2u} \approx -0.030$$
$$C_{2d} = \tfrac{1}{2} - 2\sin^2(\theta_W) + \delta C_{2d} \approx 0.025$$

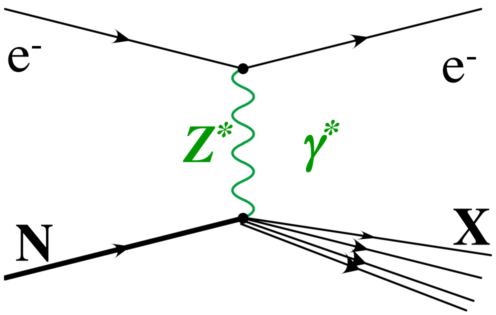
Moller PV is insensitive to the C_{ij}

C_{1u} and C_{1d} will be determined to high precision by Q_{weak}, APV Cs

$$Q_{weak}^p = 2C_{1u} + C_{1d} \propto 1 - 4\sin^2\vartheta_W$$

But C_{2u} and C_{2d} are small and poorly known :
in nucleon PV experiments large theoretical uncertainty due to electroweak radiative corrections, but in PVDIS scattering is off isolated quarks and these corrections are calculable.

Deep Inelastic Scattering



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

a(x) and b(x) contain quark distribution functions $f_i(x)$

$$x \equiv x_{Bjorken}$$

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

$$f_i^{\pm} \equiv f_i \pm \overline{f}_i$$

$$a(x) = \frac{\sum_i C_{1i} Q_i f_i^{+}(x)}{\sum_i Q_i^2 f_i^{+}(x)}$$

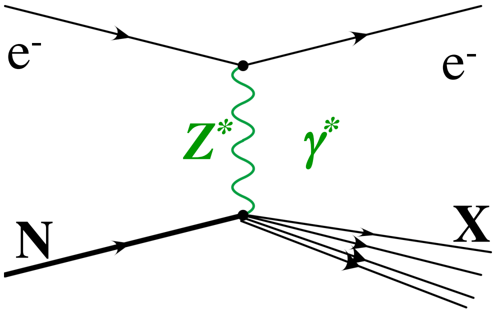
$$b(x) = \frac{\sum_i C_{2i} Q_i f_i^{-}(x)}{\sum_i Q_i^2 f_i^{+}(x)}$$

For an isoscalar target like ^{2}H, structure functions largely cancel in the ratio.

$$a(x) = \frac{3}{10}(2C_{1u} - C_{1d})\left(1 + \frac{0.6\, s^{+}}{u^{+} + d^{+}}\right)$$

$$b(x) = \frac{3}{10}(2C_{2u} - C_{2d})\left(\frac{u_v + d_v}{u^{+} + d^{+}}\right) + \cdots$$

Deep Inelastic Scattering



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

a(x) and b(x) contain quark distribution functions $f_i(x)$

$$x \equiv x_{Bjorken}$$

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

$$f_i^{\pm} \equiv f_i \pm \overline{f}_i$$

$$a(x) = \frac{\sum_i C_{1i} Q_i f_i^+(x)}{\sum_i Q_i^2 f_i^+(x)} \qquad b(x) = \frac{\sum_i C_{2i} Q_i f_i^-(x)}{\sum_i Q_i^2 f_i^+(x)}$$

For an isoscalar target like ^{2}H, structure functions largely cancel in the ratio.

At high x, $f_i^{\pm} = f_{v,i}$

at high x

$$a(x) = \frac{3}{10}(2C_{1u} - C_{1d})\left(1 + \frac{0.6\, s^+}{u^+ + d^+}\right) \quad \to 0$$

$$b(x) = \frac{3}{10}(2C_{2u} - C_{2d})\left(\frac{u_v + d_v}{u^+ + d^+}\right) + \cdots \quad \to 1$$

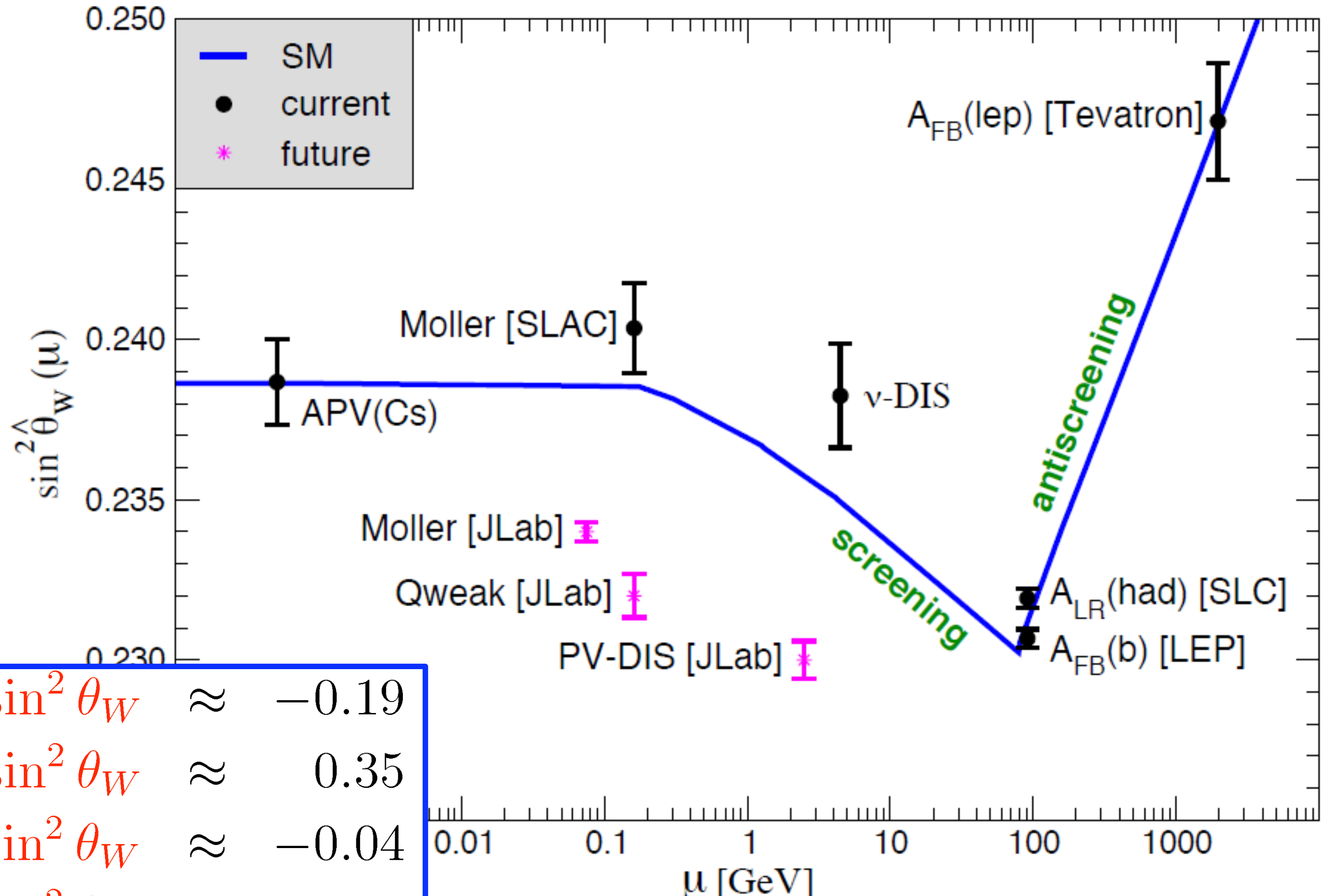
So, at high x, A_{PV} becomes independent of x, W, with well-defined SM prediction for Q^2 and y

New combination of:
Vector quark couplings C_{1q}
Also axial quark couplings C_{2q}

PVDIS: Only way to measure C_{2q}

Sensitive to new physics at the TeV scale
Deviations to C2u and C2d might be fractionally large

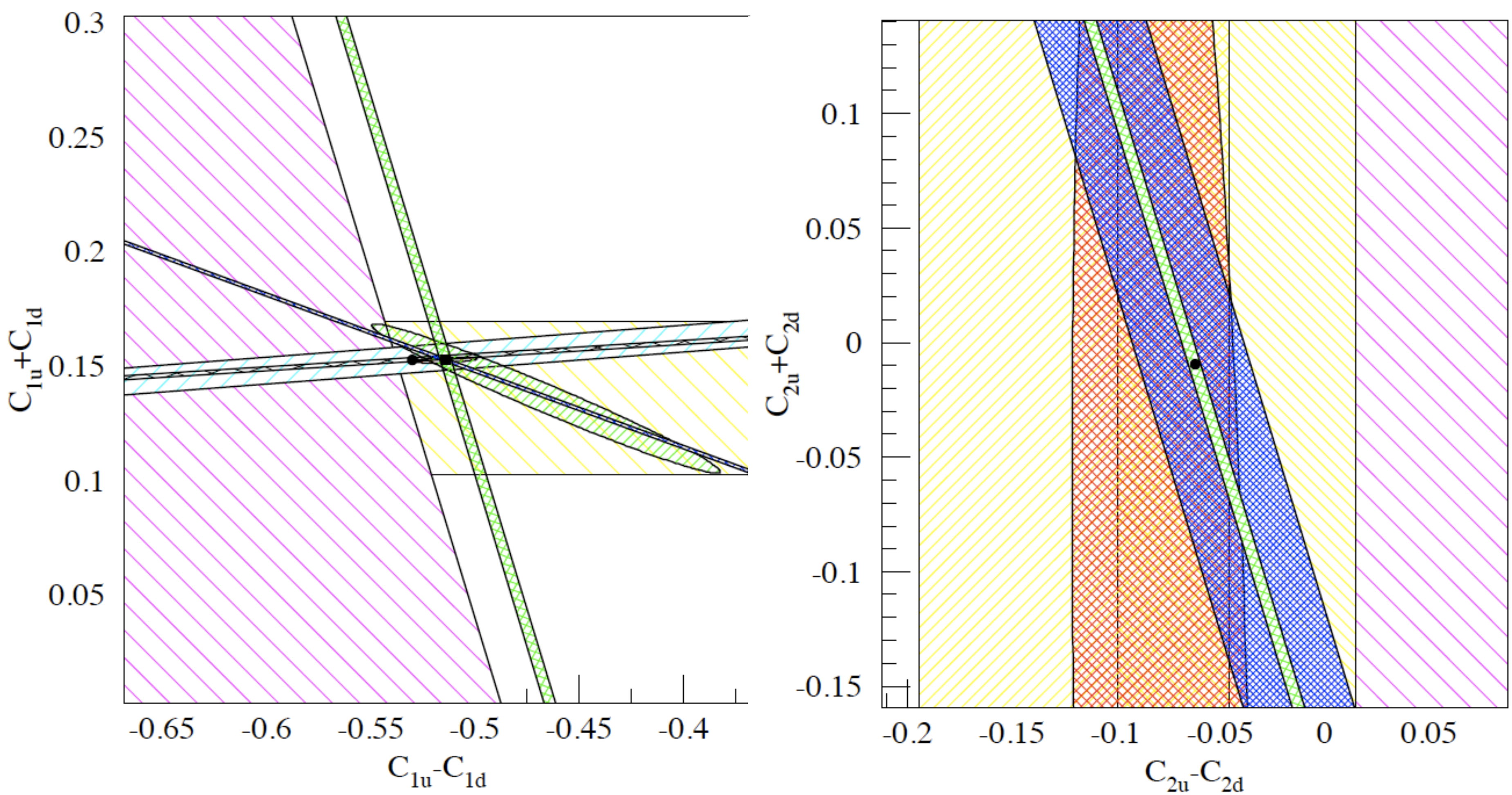
PVDIS—Electroweak couplings and $\sin^2\theta_W$



$$
\begin{aligned}
C_{1u} &= -\tfrac{1}{2}+\tfrac{4}{3}\sin^2\theta_W \approx -0.19\\
C_{1d} &= \tfrac{1}{2}-\tfrac{2}{3}\sin^2\theta_W \approx 0.35\\
C_{2u} &= -\tfrac{1}{2}+2\sin^2\theta_W \approx -0.04\\
C_{2d} &= \tfrac{1}{2}-2\sin^2\theta_W \approx 0.04
\end{aligned}
$$

Recall: $\sin^2\theta_W$ projects couplings onto Standard Model—measurements of couplings to elucidate extensions to the S.M.

Sensitivity: C_1 and C_2 Plots



However, A_{PV} at high x for a deuteron target still depends on some hadronic corrections !

- Charge Symmetry (CSV)
- Higher Twist (HT)

A set of precision measurements over a broad kinematic range can untangle the physics

QCD:
Charge Symmetry Violation

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

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

We already know CSV exists:

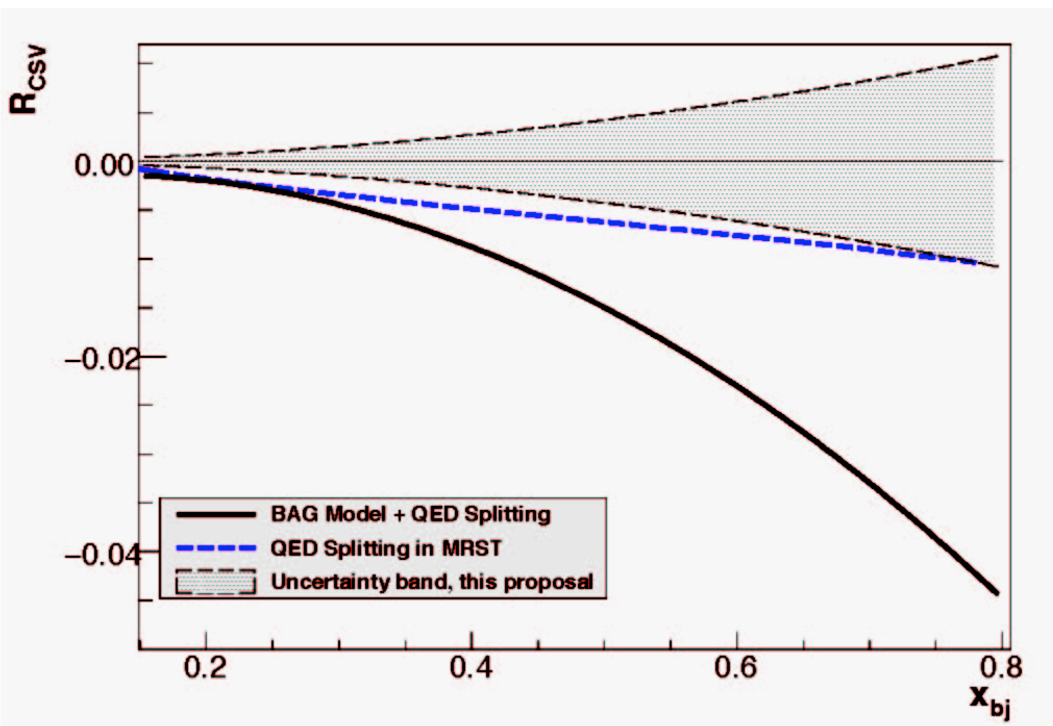
- u-d mass difference $\delta m = m_d - m_u \approx 4$ MeV
  $\delta M = M_n - M_p \approx 1.3$ MeV
- electromagnetic effects

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

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

- Direct observation of CSV—very exciting!
- Important implications for high energy collider pdfs
- Could explain significant portion of the NuTeV anomaly

MRST PDF global with fit of CSV
Martin, Roberts, Stirling, Thorne Eur Phys J C**35**, 325 (04)



Sensitivity will be further enhanced if u+d falls off more rapidly than δu-δd as x → 1

QCD:

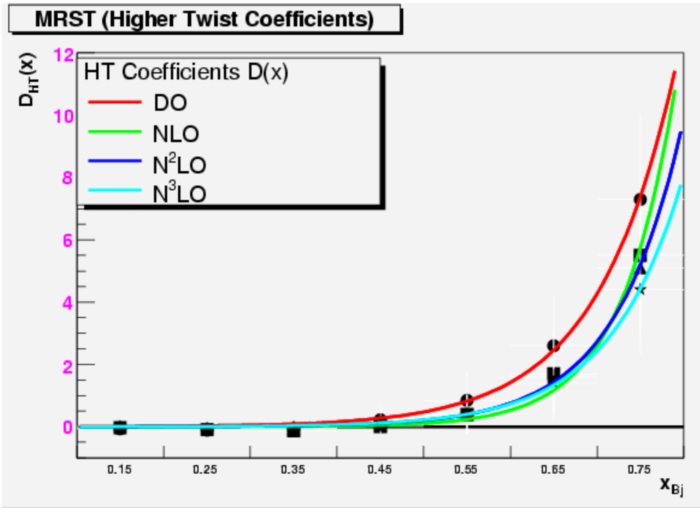
MRST, PLB582, 222 (04)

Higher Twist--MRST Fits

$F_2(x,Q^2)=F_2(x)(1+D(x)/Q^2)$ $Q^2=(W^2-M^2)/(1/x-1)$ $Q^2_{min}=Q^2(W=2)$

Order of DGLAP influences size of HT

x	Q^2_{min}	D(x)		D/Q^2_{min} (%)	
		LO	N^3LO	LO	N^3LO
0.1-0.2	0.5	-.007	0.001	-14	2
0.2-0.3	1.0	-.11	0.003	-11	0.0
0.3-0.4	1.7	-.06	-0.001	-3.5	-0.5
0.4-0.5	2.6	.22	0.11	8	4
0.5-0.6	3.8	.85	0.39	22	10
0.6-0.7	5.8	2.6	1.4	45	24
0.7-0.8	9.4	7.3	4.4	78	47



$$A_{\mathrm{meas.}} = A_{\mathrm{PV}}\left[1+\frac{C(x)}{Q^2}\right]$$

If C(x)~D(x), there is large sensitivity al large x.

Coherent Program of PVDIS Study

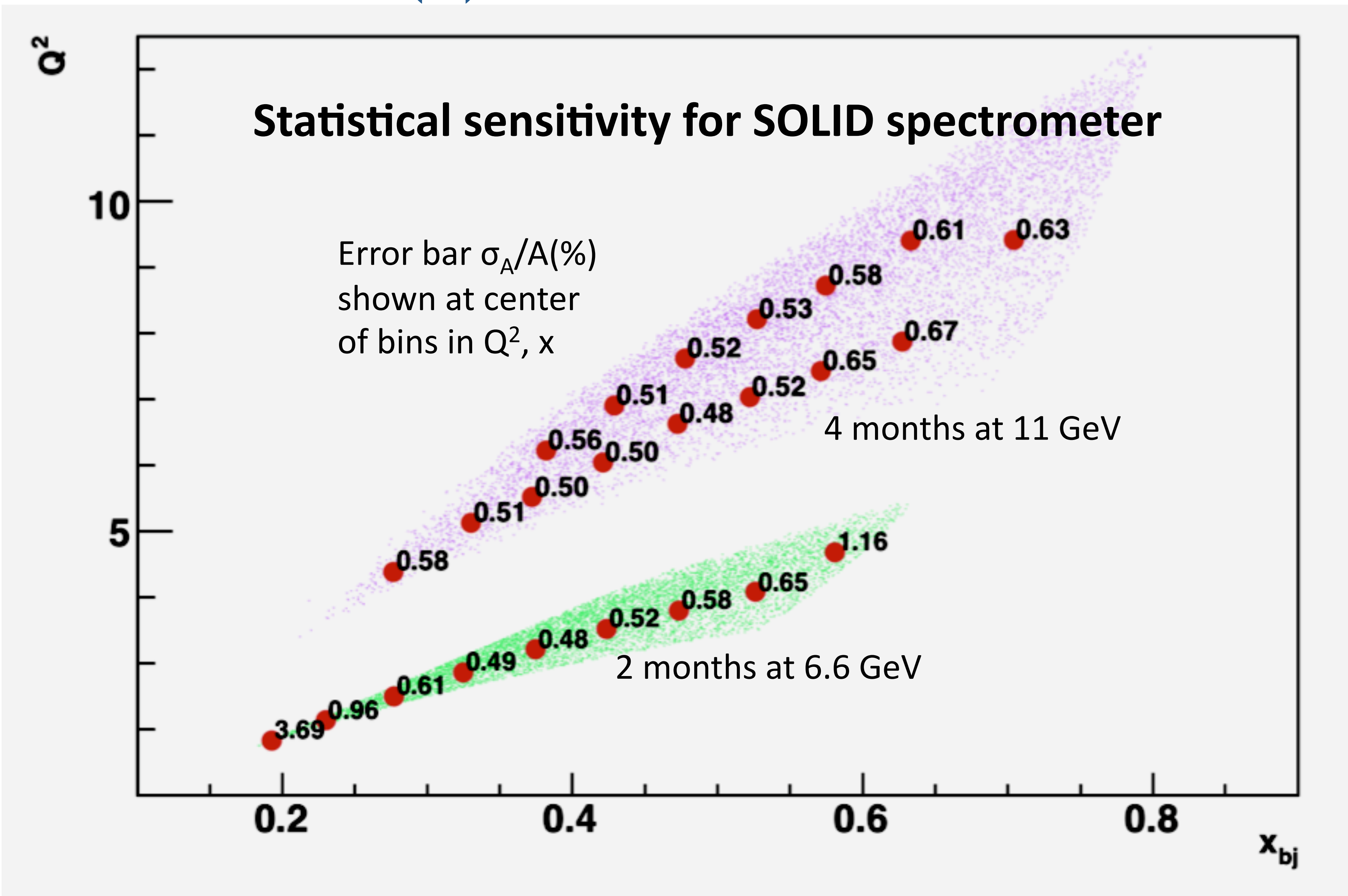
Strategy: requires precise kinematics and broad range

	x	y	Q^2
New Physics	**no**	**yes**	**no**
CSV	**yes**	**no**	**no**
Higher Twist	**yes**	**no**	**yes**

- Measure A_d in **narrow** bins of *x*, Q^2 with *0.5%* precision
- Cover broad Q^2 range for *x* in *[0.3,0.6]* to constrain HT
- Search for CSV with *x* dependence of A_d at high *x*
- Use $x > 0.4$, high Q^2 to measure a combination of the C_{iq}'s

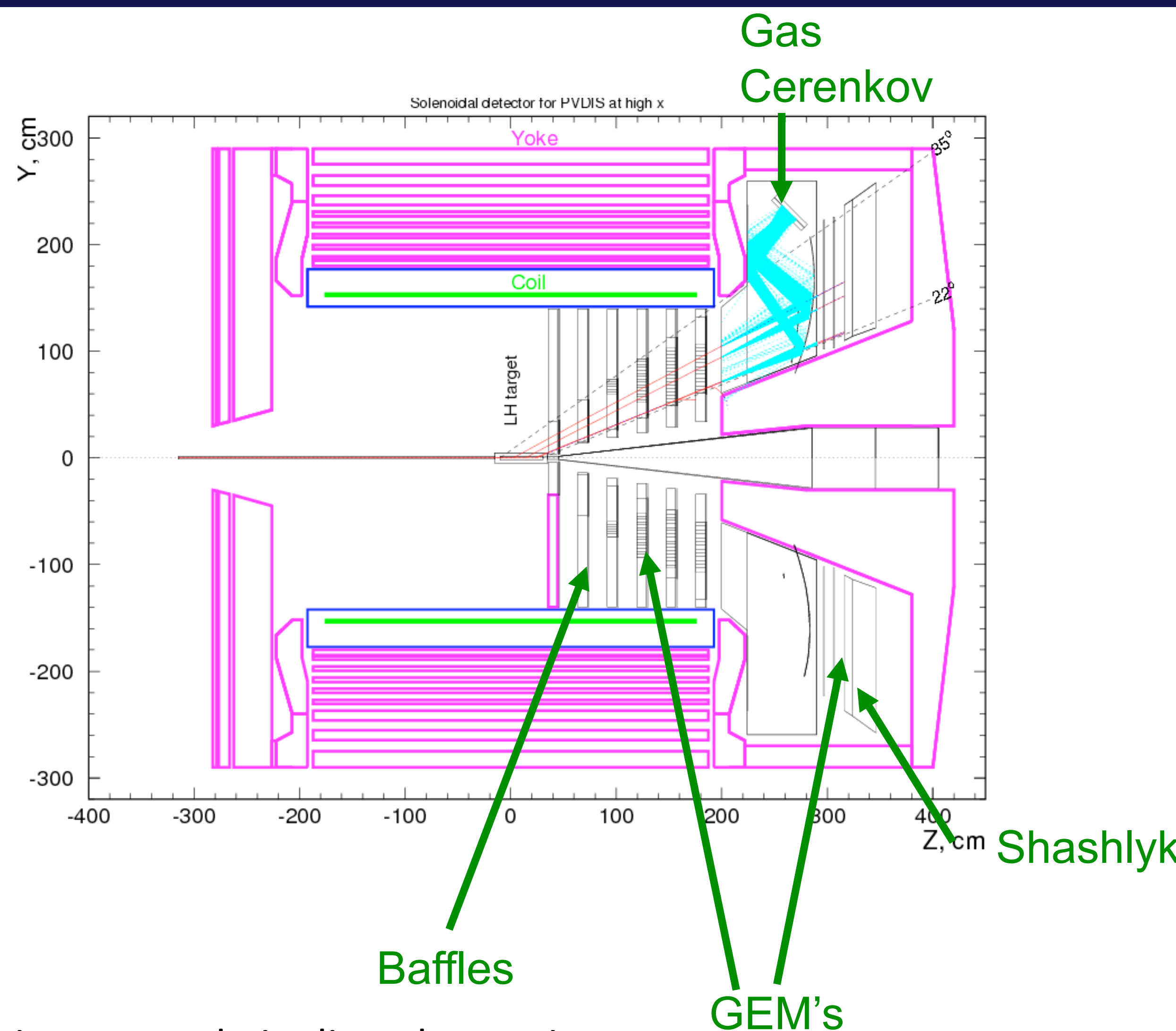
Fit data to: $$A_{\text{meas.}} = A_{\text{SM}}\left[1 + \frac{\beta_{HT}}{(1-x)^3 Q^2} + \beta_{\text{CSV}} x^2\right]$$

Statistical Errors (%) vs. Kinematics

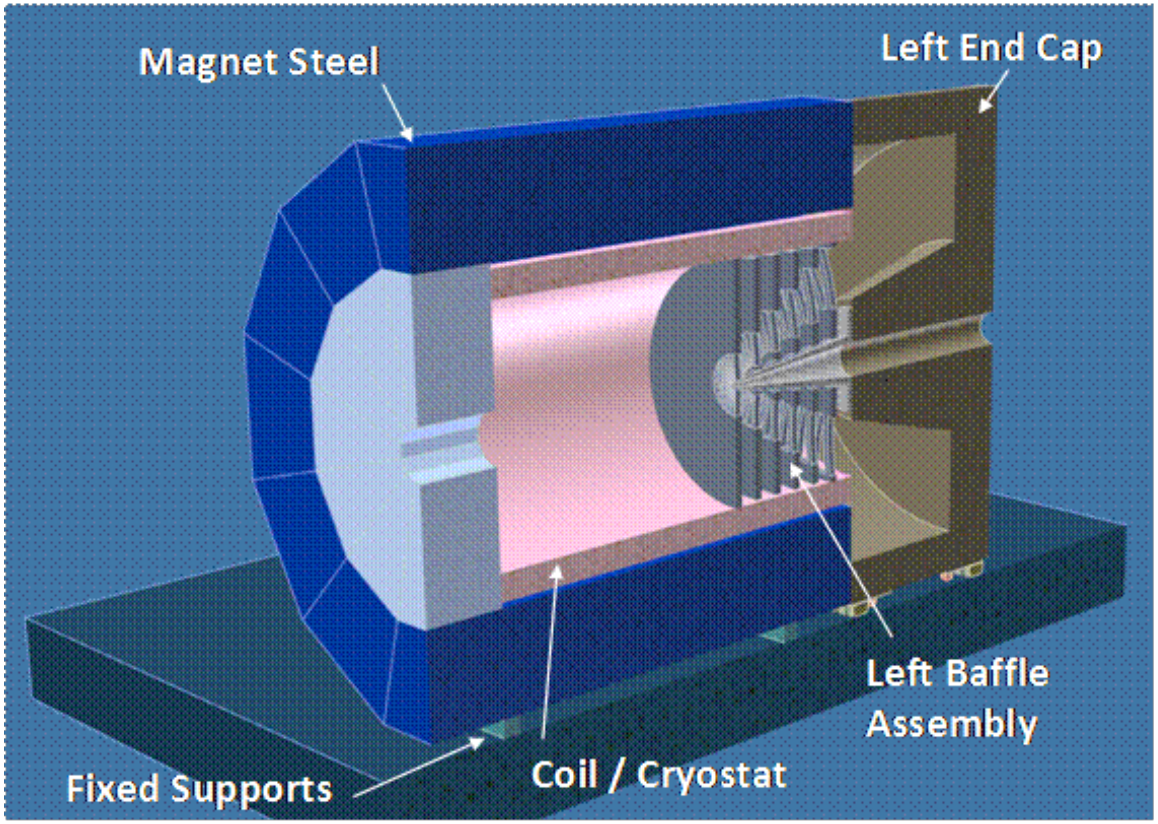


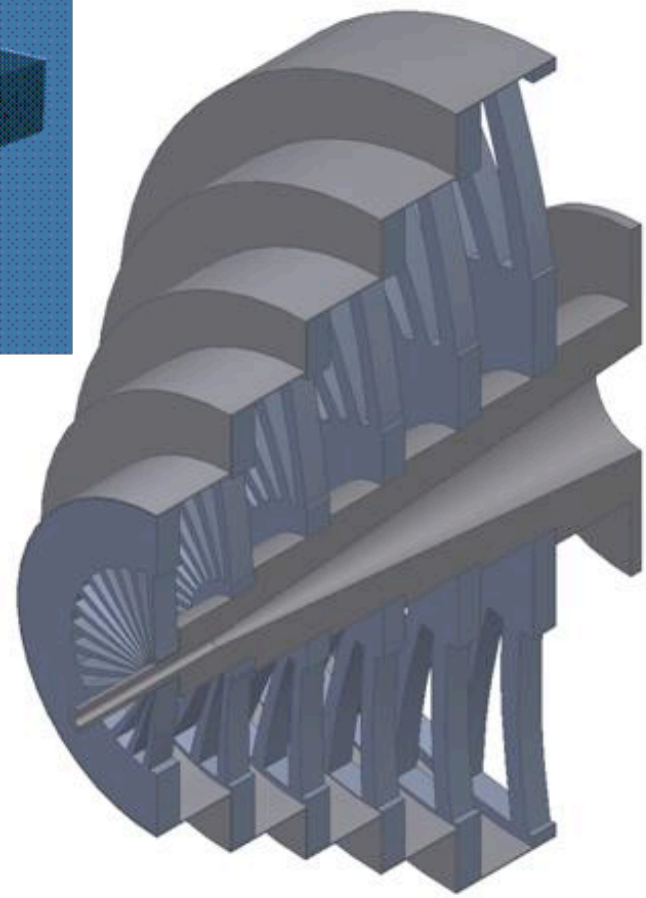
SoLID Spectrometer

- High Luminosity on LH2 & LD2
- Better than 1% errors for small bins
- Large Q^2 coverage
- x-range 0.25-0.75
- W^2 > 4 GeV^2
- **Moderate running times**
  - →**Large Acceptance**
- Solenoid (from BaBar, CDF or CLEOII) contains low energy backgrounds (Møller, pions, etc)
- Trajectories measured after baffles

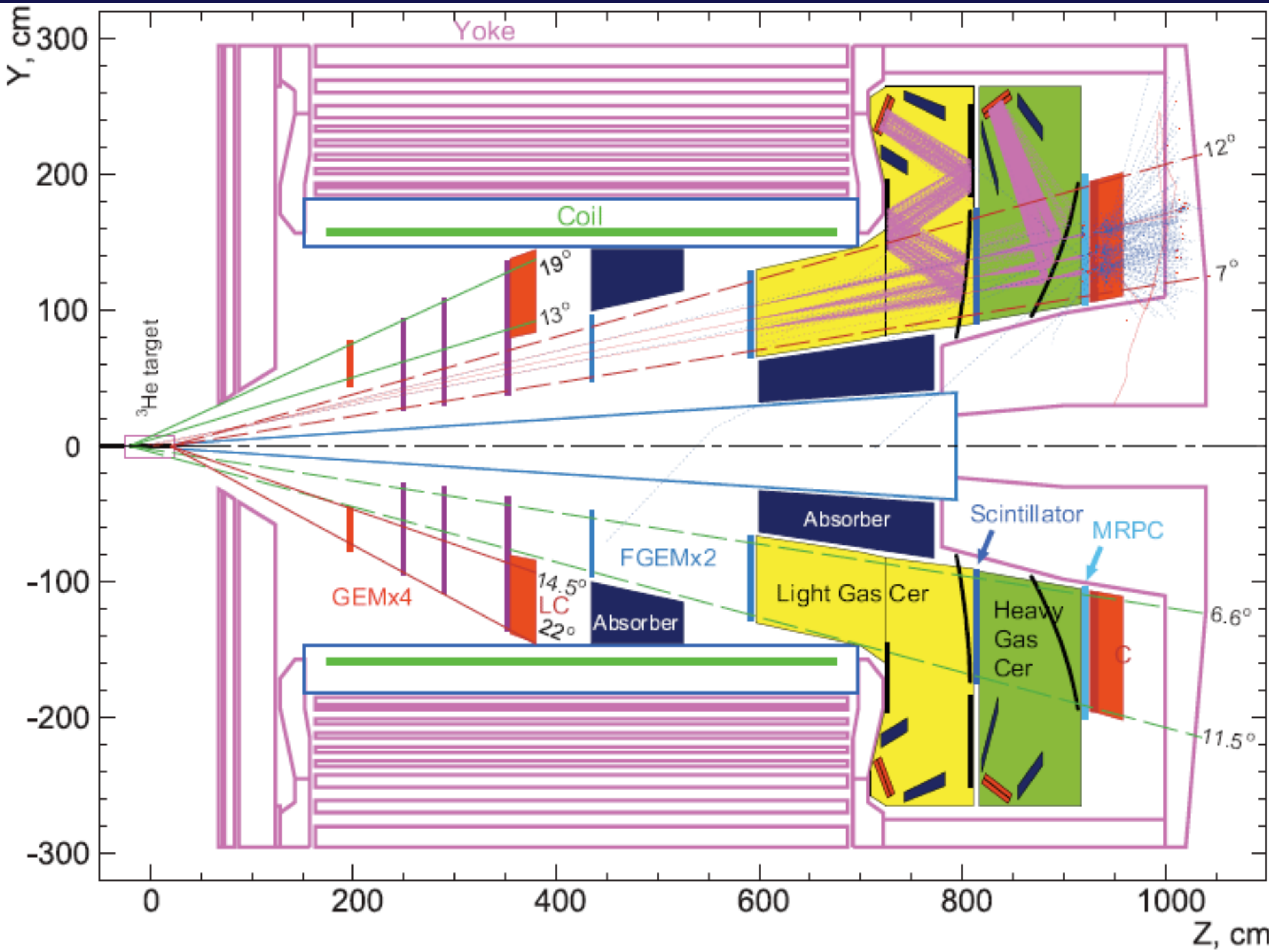


- Fast tracking, particle ID, calorimetry, and pipeline electronics
- Precision polarimetry (0.4%)


Magnet Steel
Left End Cap
Left Baffle Assembly
Coil / Cryostat
Fixed Supports



SoLID Spectrometer for SIDIS



Main Challenge: large area

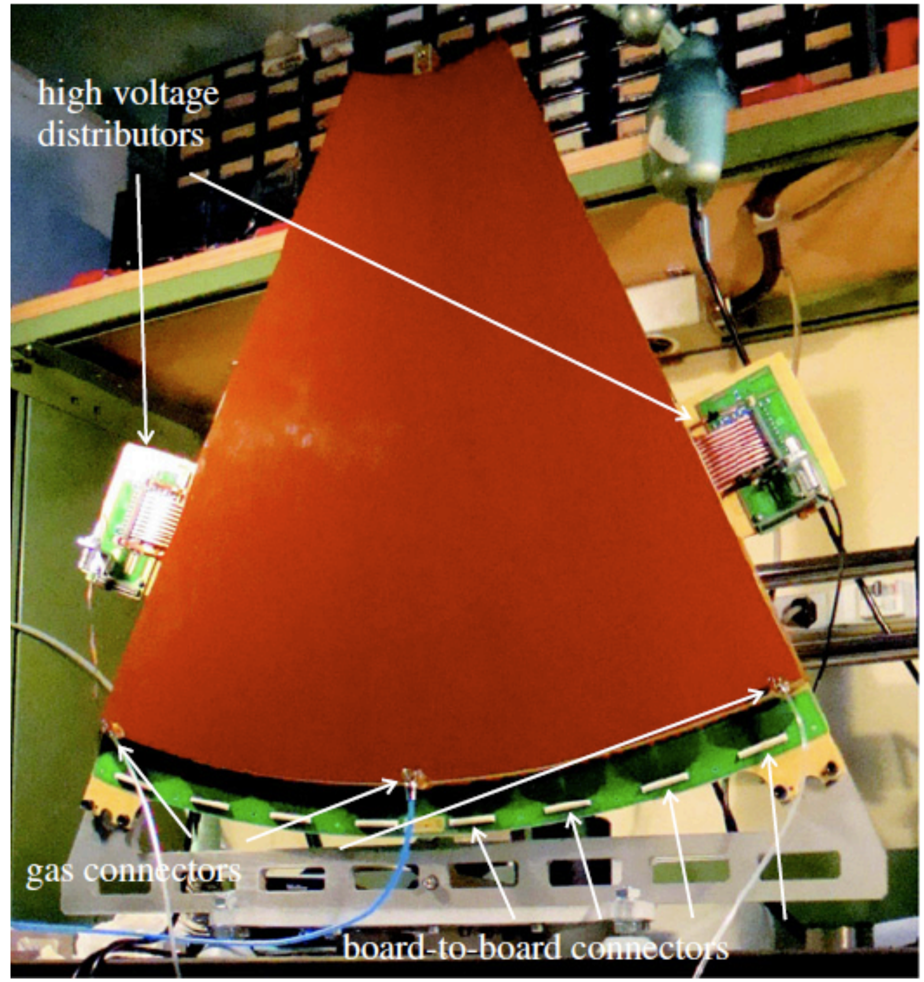
- COMPASS GEM chambers only 30 cm x 30 cm; there were total 22 chambers, total area ~ 2 m^2.
- Requirements for SOLID more than an order of magnitude larger.

Plane	Z (cm)	R_I (cm)	R_O (cm)	Total Area (m^2)	circumference (cm) Inner	outer
4	120	39.0	87.2	1.9	245	548
5	150	48.7	109.0	3.0	306	684
6	190	61.7	138.0	4.8	388	867
7	290	94.2	210.7	11.2	592	1323
8	310	100.7	225.2	12.7	633	1414
total:				33.6		

This is the bare minimum: high rates may require multiple chambers at the same location.

- Disk area larger than available GEM foil size (currently ~45 x 45 cm^2) ; need larger foil and segmentation.
- Large total area: most current GEM foil production at CERN shop: can they handle this volume ? Need new foil manufacturing

TOTEM T1 prototype chamber made with single mask GEM foils spliced together (33 cm x 66 cm)



• Base material up to 51.4 cm wide now available

• CERN is now capable of producing 200 cm x 60 cm GEM foil.

This combined with Splicing: 200 cm x 120 cm GEM foil may be possible in the next two years

M. Villa, et al., Nucl. Instr. and Meth. A (2010), doi:10.1016/j.nima.2010.06.312

M. Alfonsi et al. / Nuclear Instruments and Methods in Physics Research A 617 (2010)

Summary

•Measurements of Parity Violation in Deep Inelastic Scattering contain a wealth of information about:

- •The Standard Model
- •Charge Symmetry (CSV)
- •Higher Twist (HT)

•A program of PVDIS measurements at JLab has begun with the 6 GeV CEBAF accelerator and will continue into the 12 GeV era

•For the complete picture—to unravel the full richness of the physics reach of this process a dedicated—a large-acceptance spectrometer is needed.

• Instrument   SOLID be challenging but feasible with technology that is becoming available.

• *GEM technology:*