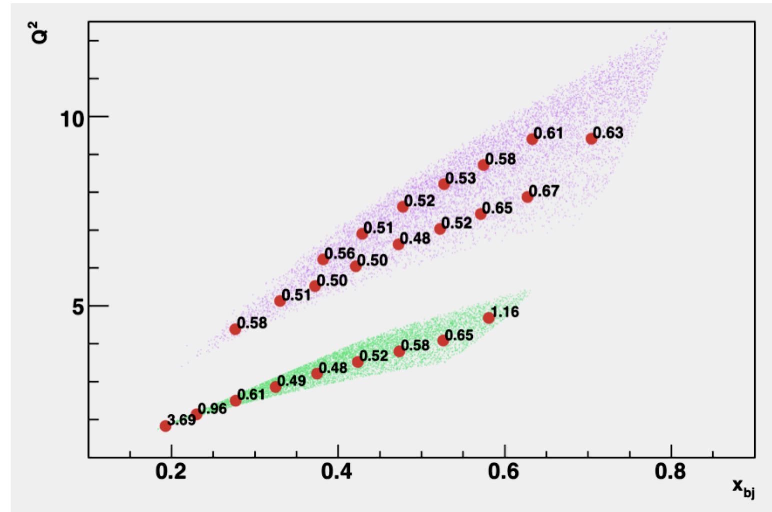
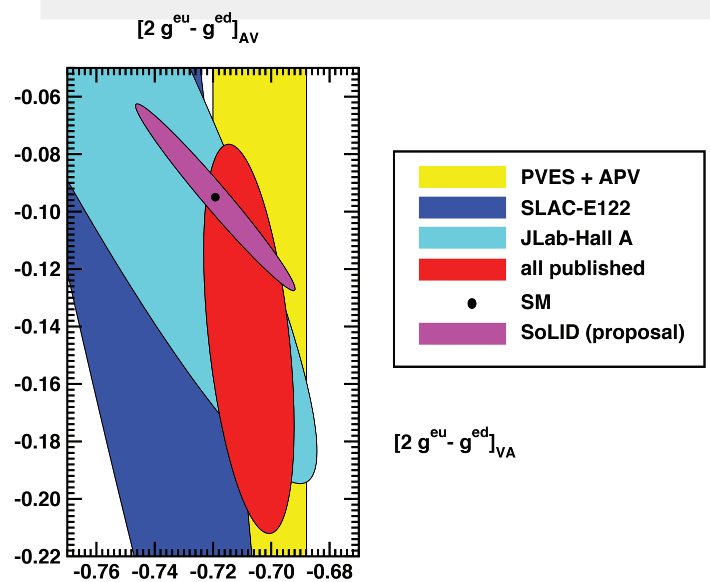
PVDIS at 11 GeV with SoLID

Primary Goals for SoLID PVDIS

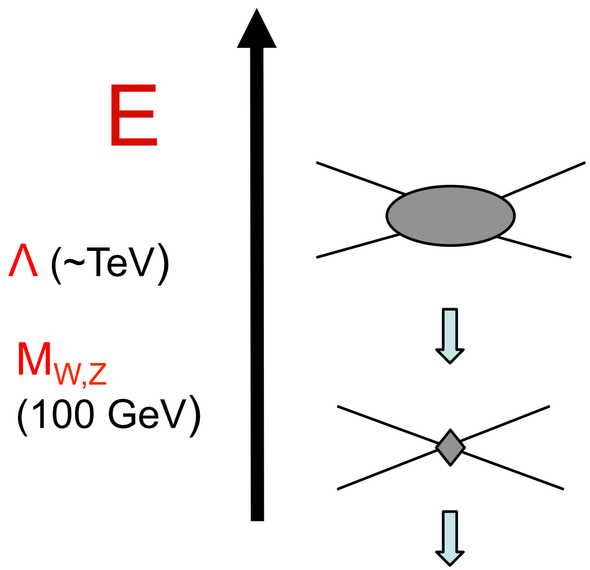
- Measurements of Parity Violation in Deep Inelastic Scattering over a broad kinematic range contain a wealth of information about:
  - The Standard Model
  - Charge Symmetry (CSV)
  - Higher Twist (HT)

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





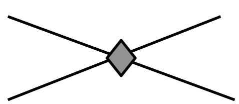
Searching for New Physics



Heavy Z's and neutrinos, technicolor, compositeness, extra dimensions, SUSY…

New Physics can be directly observed at high energies of through precision measurements at low energies

At low energies, new physics appears as new contact interactions



$$\frac{1}{\Lambda^2}\mathcal{L}_6$$

must reach Λ ~ several TeV

Consider $f_1 f_2 \rightarrow f_1 f_2$ **or** $f_1 f_1 \rightarrow f_2 f_2$

$$\mathcal{L}_{f_1 f_2} = \sum_{i,j=L,R} \frac{(g_{i\,j}^{12})^2}{\Lambda_{ij}^2} \bar{f}_{1i}\gamma_\mu f_{1i}\bar{f}_{2j}\gamma_\mu f_{2j}$$

Neutral Currents at Low Energy

Colliders AND Fixed Target

One goal of neutral current measurements at low energy AND colliders: Access $\Lambda > 10$ TeV for as many different flavor & L,R combinations as possible

Colliders access scales Λ's > 10 TeV

LHC, Tevatron, LEP, SLC, LEP200, HERA

- L,R combinations accessed are mostly parity-conserving

Z boson production accessed some parity-violating combinations but…

on resonance: A_Z imaginary

$$\left|\mathbf{A_Z} + \mathbf{A_{new}}\right|^2 \to \mathbf{A_Z^2}\left[\mathbf{1} + \left(\frac{\mathbf{A_{new}}}{\mathbf{A_Z}}\right)^2\right]$$

no interference!

Low Energy: New Physics / Weak-Electromagnetic Interference

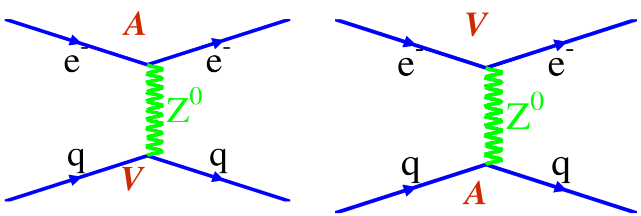
- opposite parity transitions in heavy atoms
- Spin-dependent electron scattering

Electromagnetic amplitude interferes with Z-exchange as well as any new physics

$$\left|\mathbf{A_\gamma} + \mathbf{A_Z} + \mathbf{A_{new}}\right|^2 \to \mathbf{A_\gamma^2}\left[\mathbf{1} + \mathbf{2}\left(\frac{\mathbf{A_Z}}{\mathbf{A_\gamma}}\right) + \mathbf{2}\left(\frac{\mathbf{A_{new}}}{\mathbf{A_\gamma}}\right)\right]$$

e-q coupling constants

4 phenomenological couplings: V, A & u, d combinations

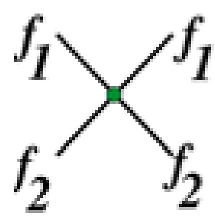


$C_{1i} \equiv 2 g_A^e g_V^i$ $\qquad$ $C_{2i} \equiv 2 g_V^e g_A^i$

$$\mathcal{L}^{PV} = \frac{G_F}{\sqrt{2}}[\bar{e}\gamma^\mu\gamma_5 e(C_{1u}\bar{u}\gamma_\mu u + C_{1d}\bar{d}\gamma_\mu d) + \bar{e}\gamma^\mu e(C_{2u}\bar{u}\gamma_\mu\gamma_5 u + C_{2d}\bar{d}\gamma_\mu\gamma_5 d)]$$

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

+ new physics



$$\mathcal{L}_{f_1 f_2} = \sum_{i,j=L,R} \frac{(g_{ij}^{12})^2}{\Lambda_{ij}^2} \bar{f}_{1i}\gamma_\mu f_{1i}\bar{f}_{2j}\gamma_\mu f_{2j}$$

$$C_{1q} \propto (g_{RR}^{eq})^2 + (g_{RL}^{eq})^2 - (g_{LR}^{eq})^2 - (g_{LL}^{eq})^2$$

→ PV elastic e-p scattering, Atomic parity violation

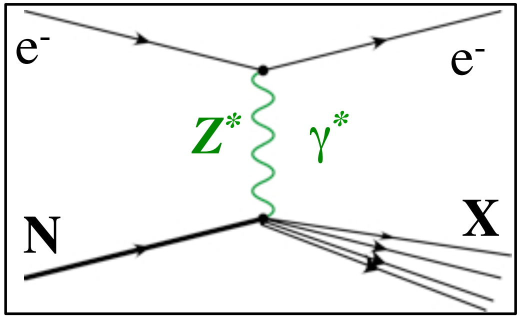
$$C_{2q} \propto (g_{RR}^{eq})^2 - (g_{RL}^{eq})^2 + (g_{LR}^{eq})^2 - (g_{LL}^{eq})^2$$

→ PV deep inelastic scattering

C_{2q}' s involve axial hadronic currents:
large theoretical uncertainties when accessed via elastic scattering

PV Deep Inelastic Scattering

off the simplest isoscalar nucleus and at high Bjorken x



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

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

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

$$x \equiv x_{Bjorken}$$

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

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

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

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

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

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

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

Interplay with QCD

- Parton distributions (u, d, s, c)
- Charge Symmetry Violation (CSV)
- Higher Twist (HT)
- Nuclear Effects (EMC)

Recent Jlab Results at 6 GeV

$$2C_{2u} - C_{2d} = -0.145 \pm 0.068$$

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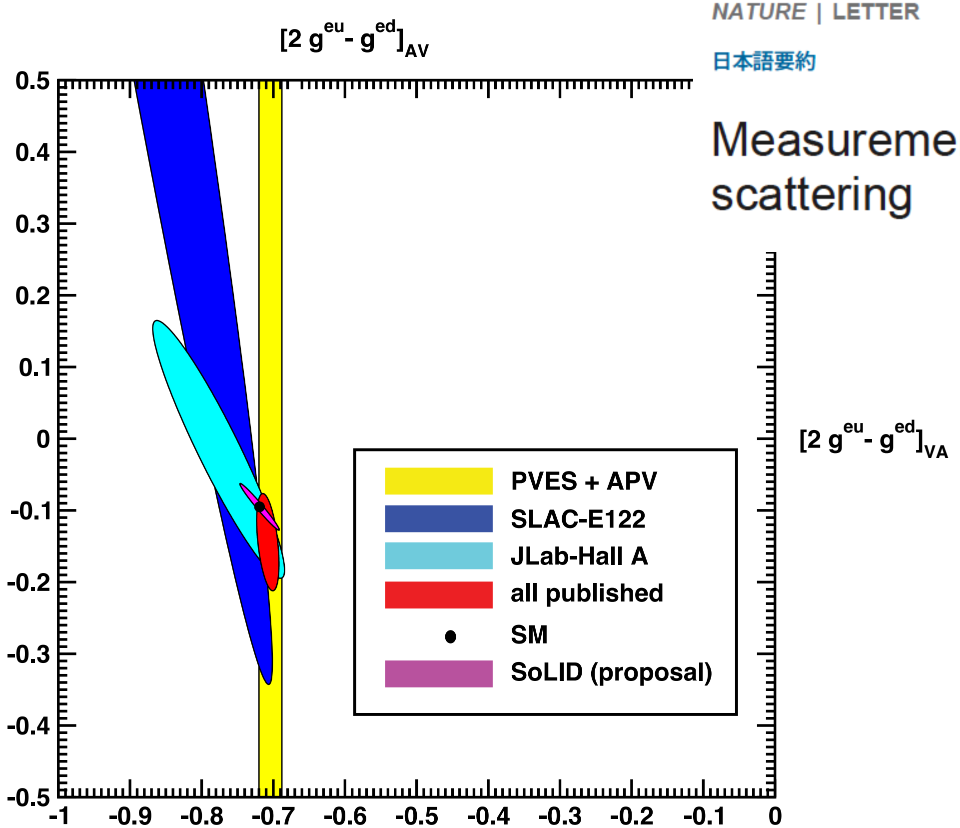
NATURE | LETTER

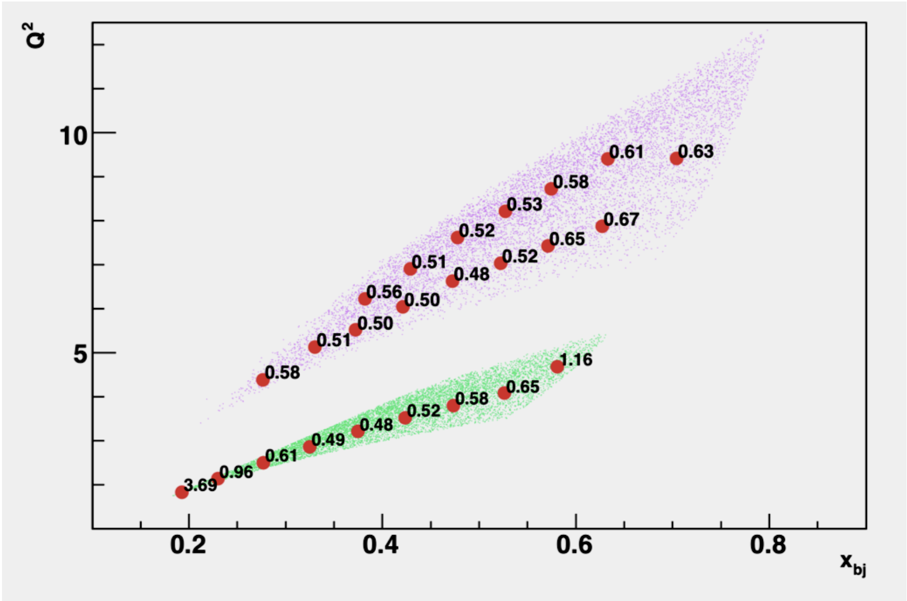
日本語要約

Measurement of parity violation in electron–quark scattering

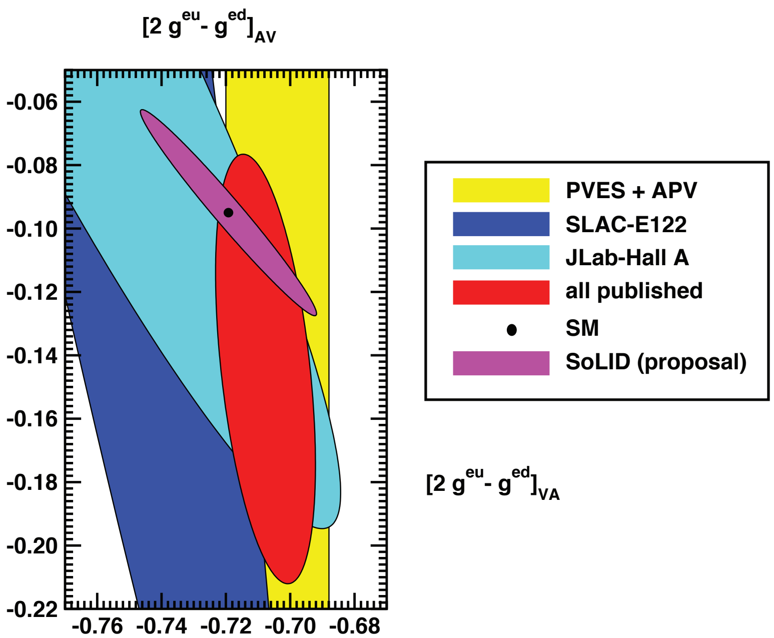


A_{PV}	x	Y
-91±4	0.24	0.43
-160±7	0.30	0.66

Projected SoLID PVDIS Data

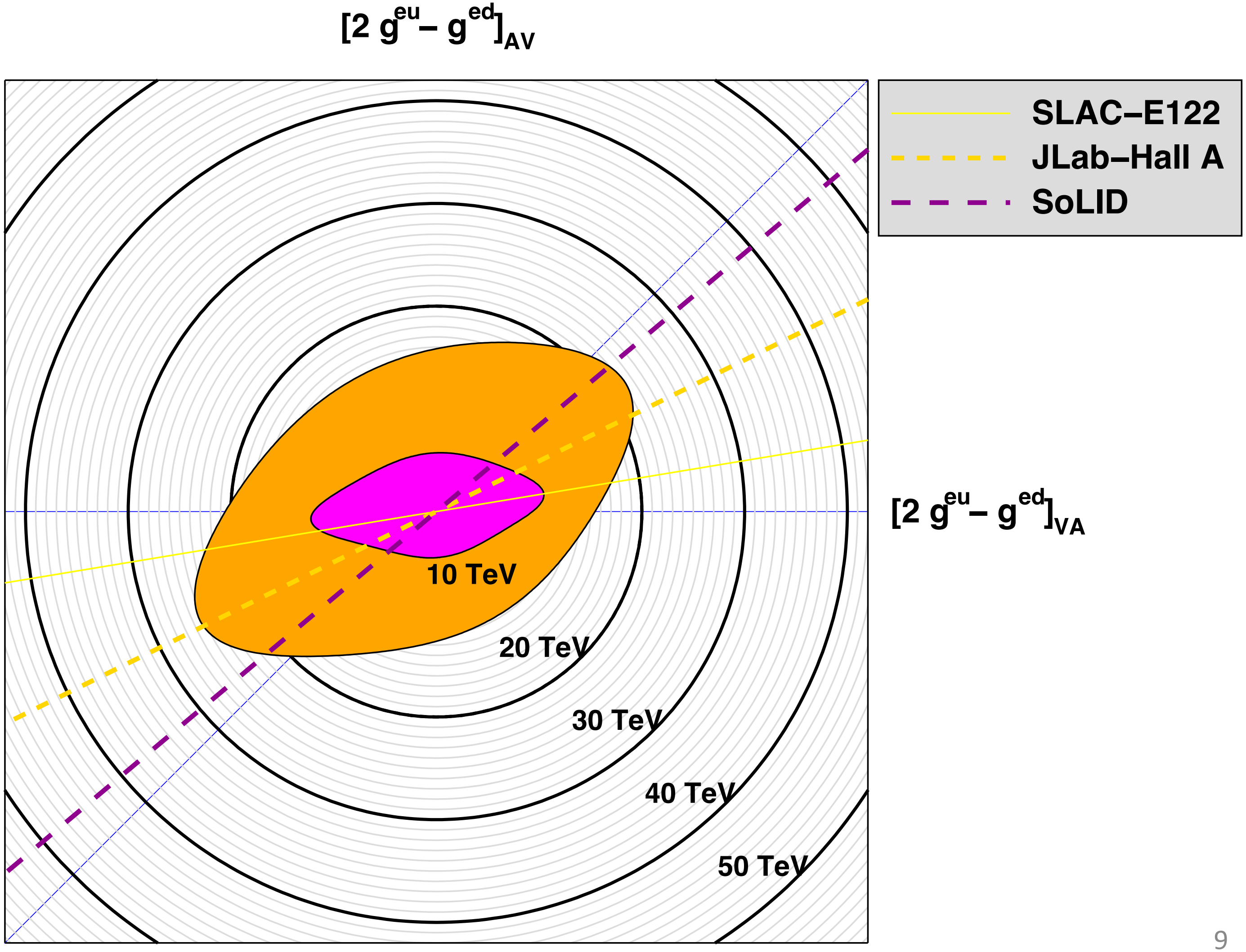


Asymmetries



Coupling constants

Projected Compositeness Limits



Particle Data Group Summary

SCALE LIMITS for Contact Interactions: $\Lambda(eeqq)$

Limits are for $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

Λ^{+}_{LL} (TeV)	Λ^{-}_{LL} (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 9.5	**>12.1**	95	[1] AAD	13E	ATLS	$(eeqq)$
> **10.1**	>9.4	95	[2] AAD	12AB	ATLS	$(eeqq)$
> 8.4	**>10.2**	95	[3] ABDALLAH	09	DLPH	$(eebb)$
> 9.4	**>5.6**	95	[4] SCHAEL	07A	ALEP	$(eecc)$
> 9.4	>4.9	95	[3] SCHAEL	07A	ALEP	$(eebb)$
>23.3	**>12.5**	95	[5] CHEUNG	01B	RVUE	$(eeuu)$
>11.1	**>26.4**	95	[5] CHEUNG	01B	RVUE	$(eedd)$

Best Limits: 2001?

TABLE IV. The best estimate on η_{LL}^{eq} and η_{VV}^{eq} for each set of data as shown. The corresponding 95% C.L. lower limits on the compositeness scale Λ are also shown.

	HERA NC		Drell-yan		LEP $\sigma_{\rm had}$		APV+eN+νN+CC	
	η (TeV^{-2})	Λ_+/Λ_- (TeV)	η	Λ_+/Λ_-	η	Λ_+/Λ_-	η	Λ_+/Λ_-
η_{LL}^{eu}	$-1.18\,^{+0.53}_{-0.56}$	5.3/2.4	$-0.19\,^{+0.24}_{-0.21}$	5.1/4.9	$-0.22\,^{+0.086}_{-0.084}$	12.3/5.9	-0.028 ± 0.023	20.6/13.7
η_{LL}^{ed}	$1.53\,^{+1.59}_{-1.35}$	1.6/2.9	$0.88\,^{+0.58}_{-0.73}$	2.7/2.7	$0.26\,^{+0.095}_{-0.098}$	5.6/11.4	0.054 ± 0.022	11.7/24.4
$\eta_{LL}^{eu} = \eta_{LL}^{ed}$	$-4.75\,^{+1.56}_{-1.13}$	4.7/1.4	$-0.19\,^{+0.32}_{-0.24}$	3.4/4.8	$-0.69\,^{+0.19}_{-0.16}$	3.0/3.7	0.017 ± 0.018	16.0/22.0
η_{VV}^{eu}	-0.30 ± 0.13	10.3/4.9	$-0.054\,^{+0.12}_{-0.11}$	6.7/7.4	$-0.11\,^{+0.042}_{-0.041}$	17.5/8.4	-	-
η_{VV}^{ed}	$-0.47\,^{+0.50}_{-0.48}$	4.1/3.2	$0.34\,^{+0.41}_{-1.27}$	3.7/3.0	$0.20\,^{+0.068}_{-0.072}$	6.5/2.4	-	-
$\eta_{VV}^{eu} = \eta_{VV}^{ed}$	$-0.38\,^{+0.14}_{-0.15}$	10.5/4.5	$-0.060\,^{+0.15}_{-0.11}$	5.0/7.2	$-0.19\,^{+0.068}_{-0.061}$	3.3/6.6	$-0.053\,^{+0.23}_{-0.27}$	5.8/1.9

K. Cheung, 2001

Limits form HERA: Many Models

H1 Search for General Compositeness			
	$\eta^q_{ab} = \epsilon^q_{ab}\, 4\pi/\Lambda^2$		
Model	$[\ \epsilon_{LL},\ \epsilon_{LR},\ \epsilon_{RL},\ \epsilon_{RR}]$	Λ^+ [TeV]	Λ^- [TeV]
LL	$[\ \pm1,\ 0,\ 0,\ 0]$	4.2	4.0
LR	$[\ 0,\ \pm1,\ 0,\ 0]$	4.8	3.7
RL	$[\ 0,\ 0,\ \pm1,\ 0]$	4.8	3.8
RR	$[\ 0,\ 0,\ 0,\ \pm1]$	4.4	3.9
VV	$[\ \pm1,\ \pm1,\ \pm1,\ \pm1]$	5.6	7.2
AA	$[\ \pm1,\ \mp1,\ \mp1,\ \pm1]$	4.4	5.1
VA	$[\ \pm1,\ \mp1,\ \pm1,\ \mp1]$	3.8	3.6
$LL+RR$	$[\ \pm1,\ 0,\ 0,\ \pm1]$	5.3	5.1
$LR+RL$	$[\ 0,\ \pm1,\ \pm1,\ 0]$	5.4	4.8

Table 2: Lower limits at 95% CL on the compositeness scale Λ. The Λ^+ limits correspond to the upper signs and the Λ^- limits correspond to the lower signs of the chiral coefficients $[\epsilon^q_{LL}, \epsilon^q_{LR}, \epsilon^q_{RL}, \epsilon^q_{RR}]$.

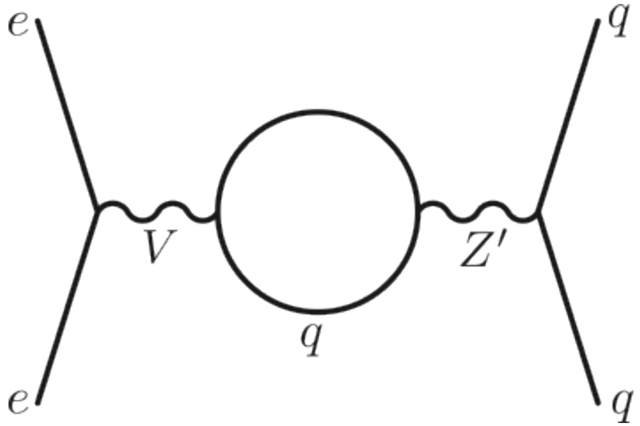
F. D. Aaron, PL B 705, 52-58 (2011)

New Physics and c_2's

Leptophobic Z'

- *Virtually all GUT models predict new Z's*
- *LHC reach ~ 5 TeV, but....*
- *Little sensitivity if Z' doesnt couple to leptons*
- *Leptophobic Z' as light as 120 GeV could have escaped detection*

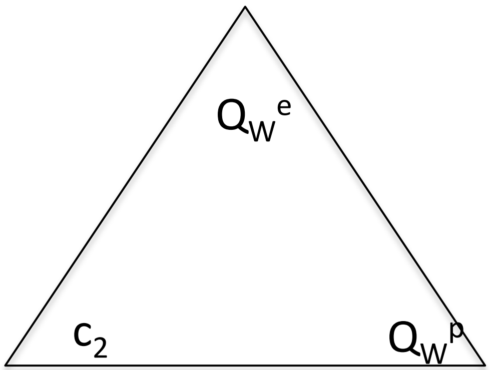
Since electron vertex must be vector, the Z' cannot couple to the C_{1q}'s if there is no electron coupling: can only affect ***C_{2q}'s***



SOLID can improve sensitivity:
100-200 GeV range

arXiv:1203.1102v1
Buckley and Ramsey-Musolf

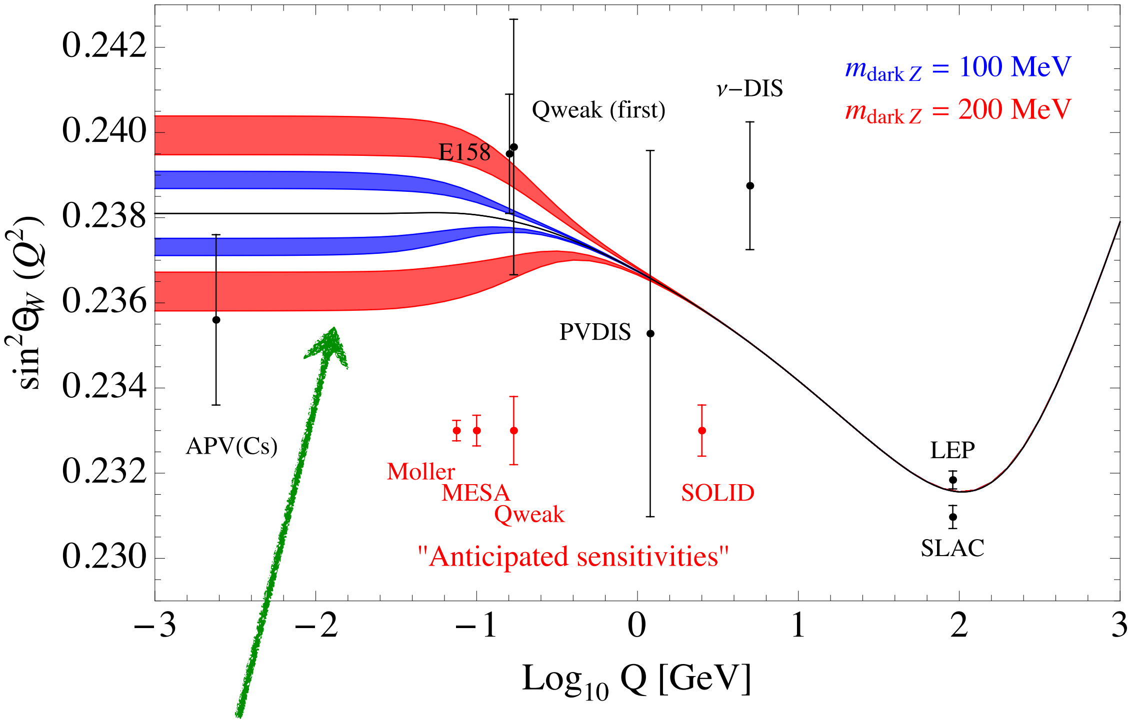
Complementarity of Measurements



SUSY Loops	**Q_W^e and Q_W^{p}:same absolute shift, smaller for others**
GUT Z'	**High for Q_w(Cs), Q_W^e(relative), smaller for others**
Leptophobic Z'	**axial-quark couplings (C_2's) only**
RPV SUSY	**Different for all four in sign and magnitude**
Leptoquarks	**semi-leptonic only; different sensitivities**
Lepton Number Violation	**Q_W^e only**

Weak angle shift for Low Q^2 due to Dark Z′

[Davoudiasl, Lee, Marciano (2014)]



Invisibly-decaying Dark Z.

Colored regions are predictions for the Weak angle due to the g-2 Δa_μ shift.

$$\Delta\ \sin^2\theta_W(Q^2) \simeq -0.42\,\varepsilon\delta\,\frac{m_Z}{m_{Z'}}\,\frac{1}{1+Q^2/m_{Z'}^2}$$

Slide adapted from Lee, PAVI-14

Deviations from the SM prediction (due to Dark Z) can appear **"only" in the Low-E experiments.**

For the Low-Q^2 Parity Test (measuring Weak angle), we can use

(i) Atomic Parity Violation (Cs, …)

(ii) Low-Q^2 PVES (E158, Qweak, MESA P2, Moller, SoLID…)

independent of Z' decay BR (good for both visibly/invisibly decaying Z').

New Models Extend Q^2 Range

Low Q^2 Weak Mixing Angle Measurements and Rare Higgs Decays

Hooman Davoudiasl,[1] Hye-Sung Lee,[2] and William J. Marciano[1]
[1] Department of Physics, Brookhaven National Laboratory, Upton, New York 11973, USA
[2] CERN, Theory Division, CH-1211 Geneva 23, Switzerland

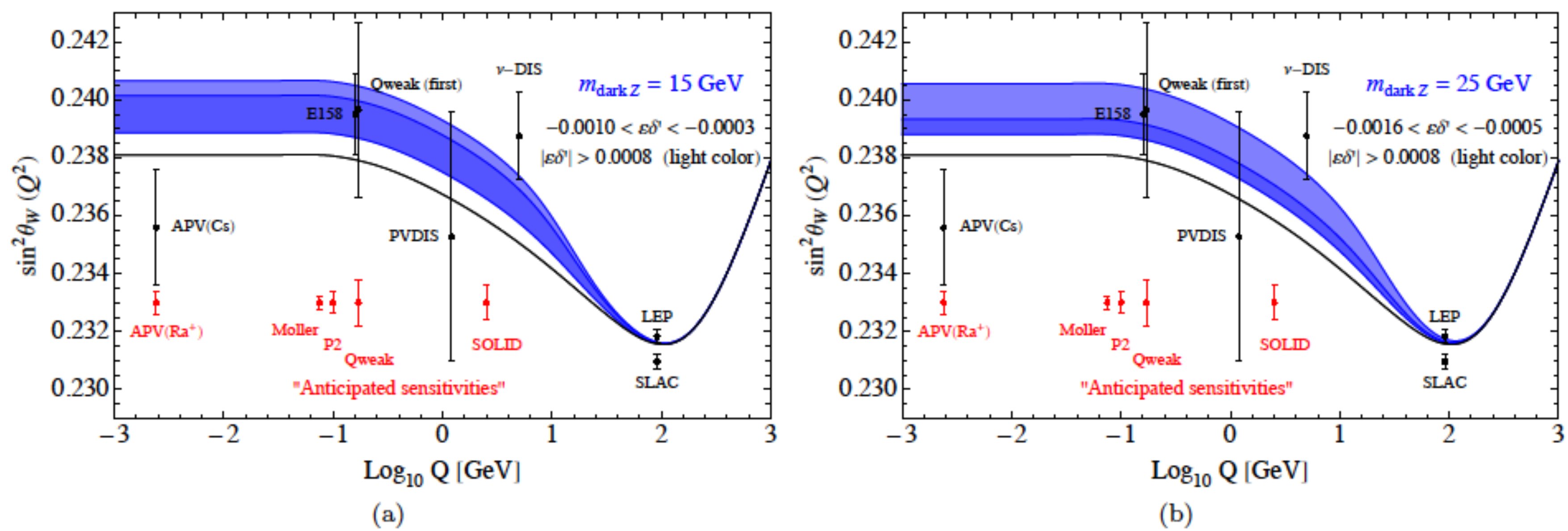


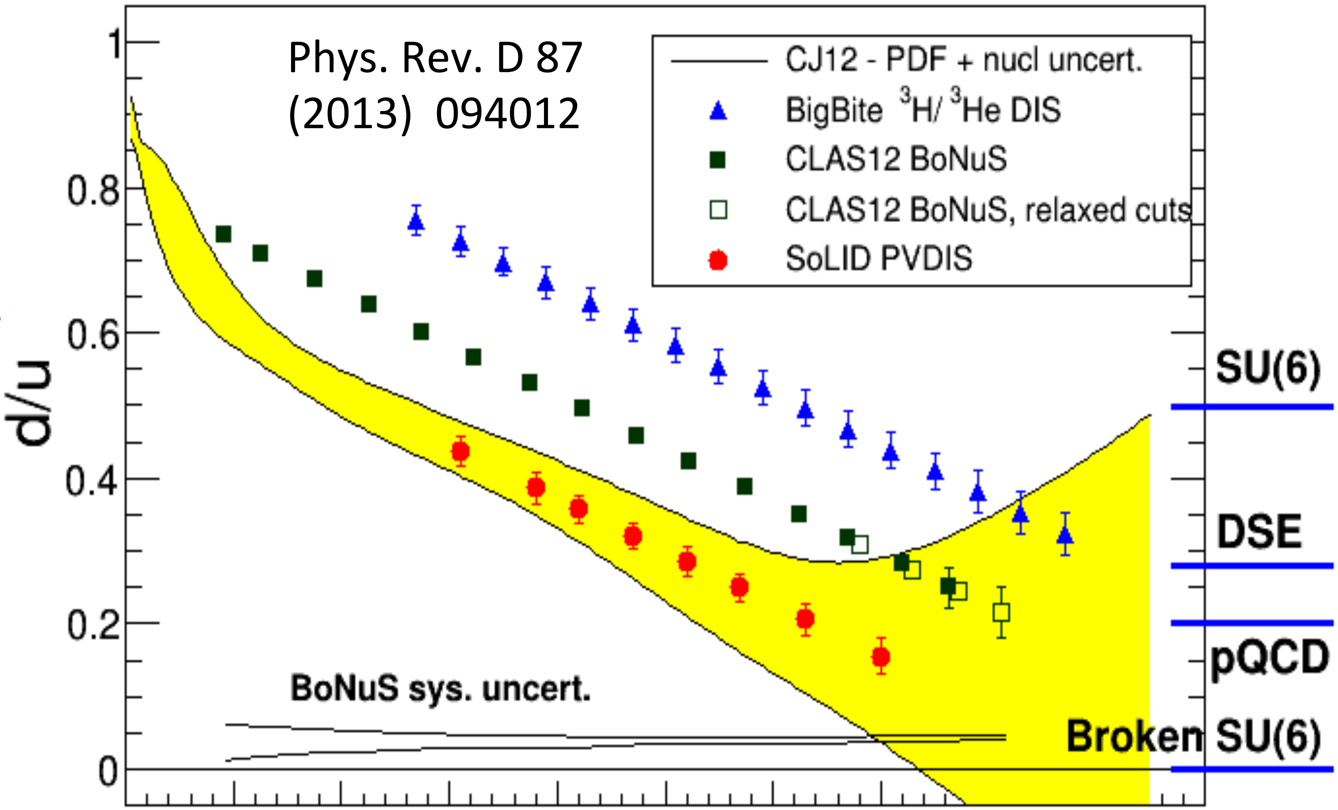
FIG. 3. Effective weak mixing angle running as a function of Q^2 shift (the blue band) due to an intermediate mass Z_d for (a) $m_{Z_d} = 15$ GeV and (b) $m_{Z_d} = 25$ GeV for 1 sigma fit to $\varepsilon\delta'$ in Eq. (12). The lightly shaded area in each band corresponds to choice of parameters that is in some tension with precision constraints (see text for more details).

PVIDS with the Proton

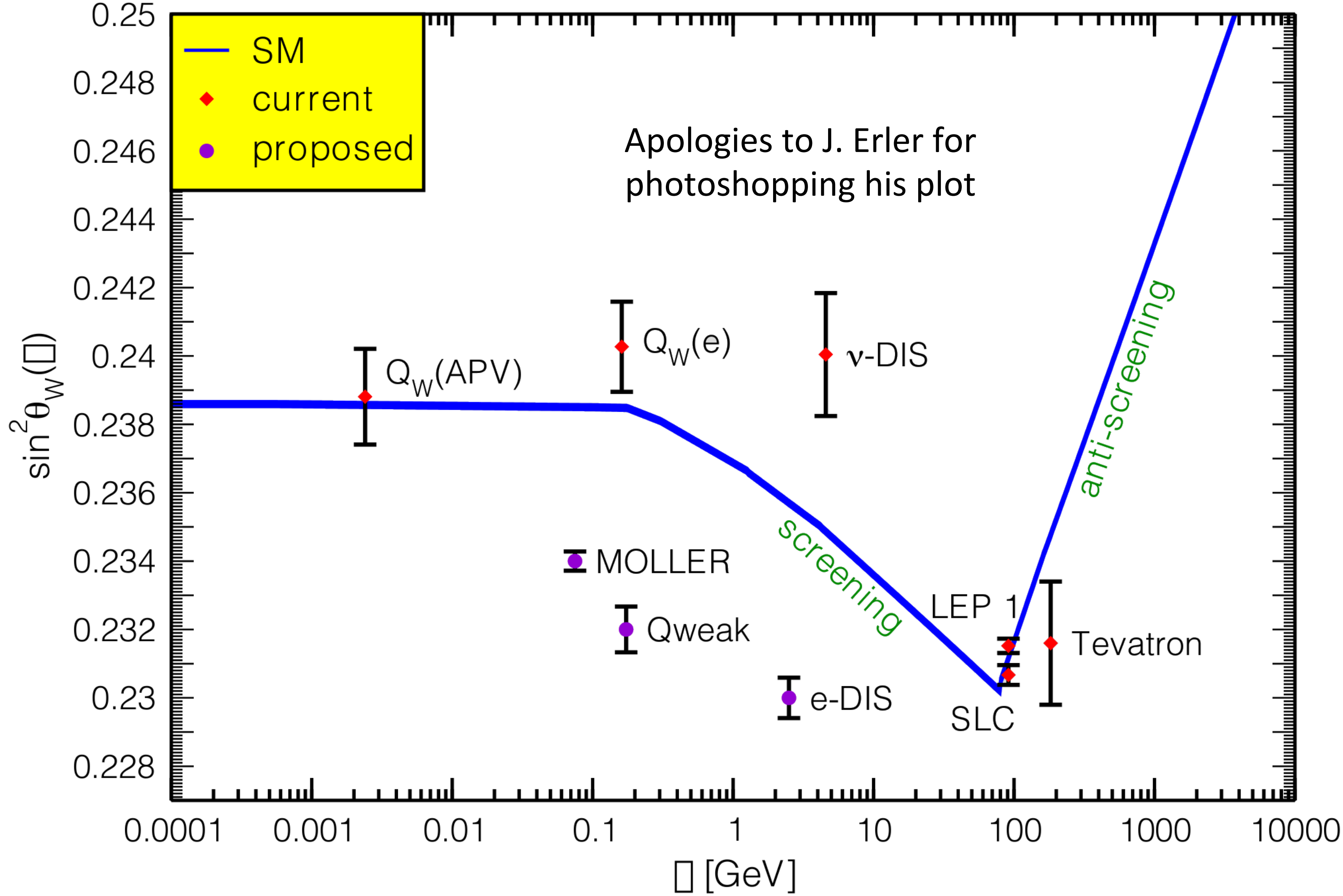
$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

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

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



What about NuTeV?



Charge Symmetry Violation

We already know CSV exists:

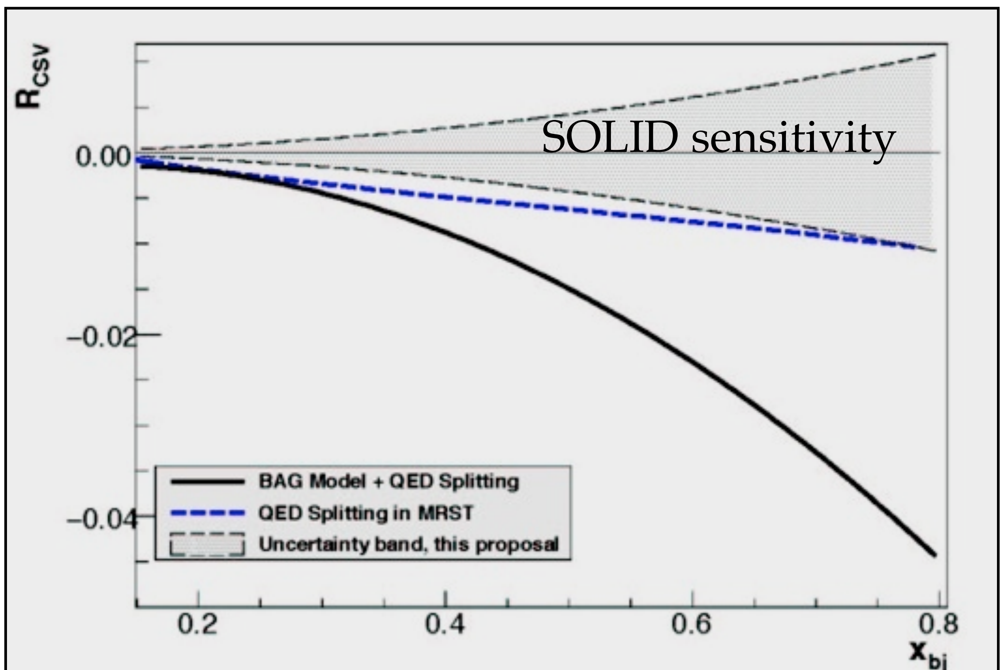
- u-d mass difference $\delta m = m_d - m_u \approx 4$ MeV
  $\delta M = M_n - M_p \approx 1.3$ MeV
- electromagnetic effects

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

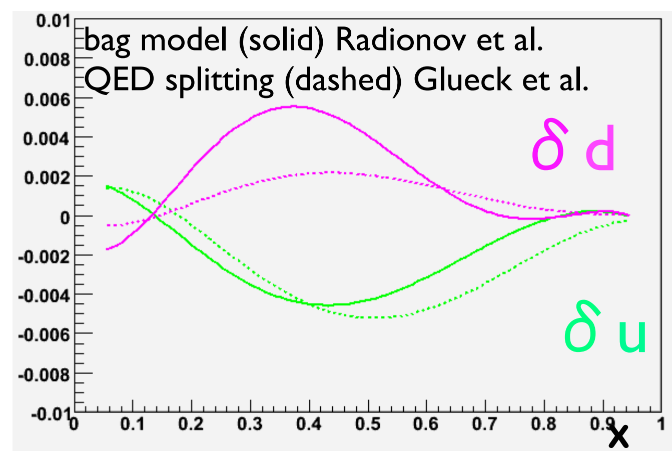
- Direct sensitivity to parton-level CSV
- Important implications for PDF's
- Could be partial explanation of the NuTeV anomaly

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

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



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



Significant effects are predicted at high x

Recent Predictions

M. Traini / Physics Letters B 707 (2012) 523–528

Progress in resolving charge symmetry violation in nucleon structure

R. D. Young*, P. E. Shanahan and A. W. Thomas

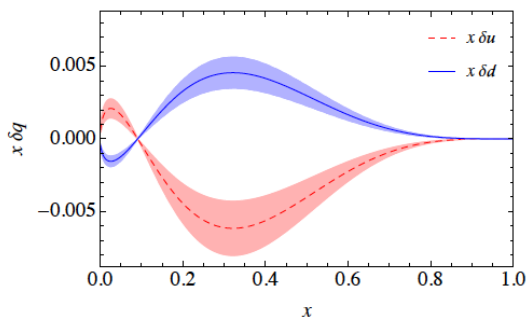


Fig. 3. Charge symmetry violating momentum fraction using simple phenomenological parameterisation $\delta q(x) = \kappa x^{-1/2}(1-x)^4(x-1/11)$ with normalisation determined from the lattice moment.[11]

Shape at large x
is very different

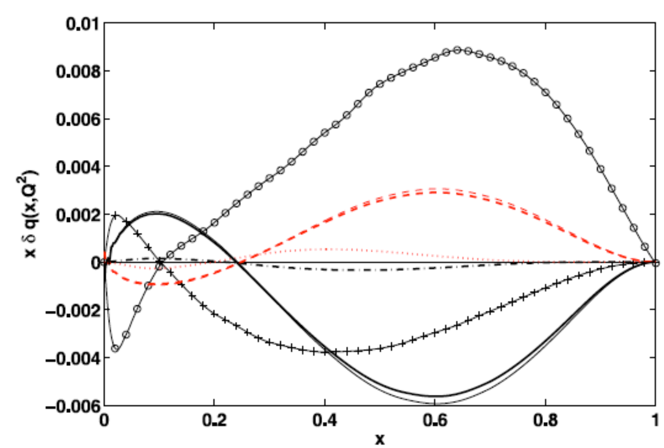
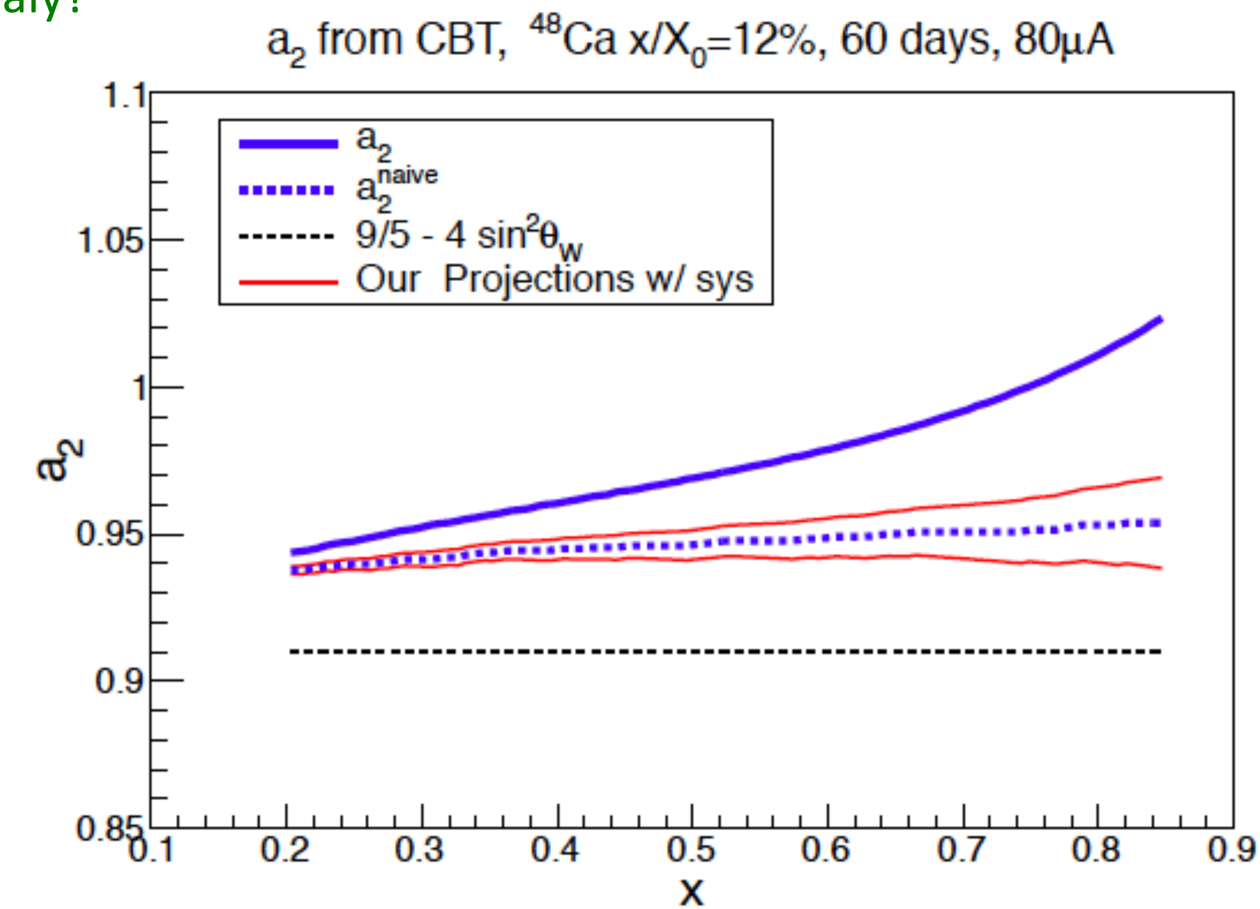


Fig. 2. Isospin symmetry violations from radiative QED effects (from Eqs. (11) at $Q^2 = 10$ GeV^2) and mass effects (from the model (9) at Q_0^2). $x\delta u_V(x,Q^2)$ (continuous lines, the tiny line does not include strange sea at the static point $Q_0^2 = 0.149$ GeV^2) and $x\delta d_V(x,Q^2)$ (dashed lines, the tiny line does not include strange sea at the static point Q_0^2). $x\delta\bar{u}$ and $x\delta\bar{d}$ are represented by the dot-dashed and dotted lines respectively, they are calculated including strange sea at the static point. The effects due to the $u-d$ mass difference ($m_d - m_u = 4$ MeV according to Ref. [34]), are shown by line-circles ($x\delta d_V(x,Q_0^2)$) and by line-pluses ($x\delta u_V(x,Q_0^2)$).

Isovector EMC Effect (New Proposal)

Additional contribution
to NuTeV anomaly?



A Special HT Effect

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)

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

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

Isospin decomposition before using PDF's

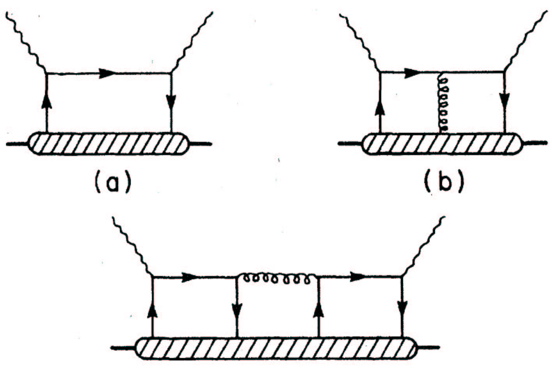
$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y) b(x)\right]$$

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

Higher-Twist valence quark-quark correlation

Zero in quark-parton model

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



Castorina & Mulders, '84

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

σ_L contributions cancel

Use ν data for small b(x) term.

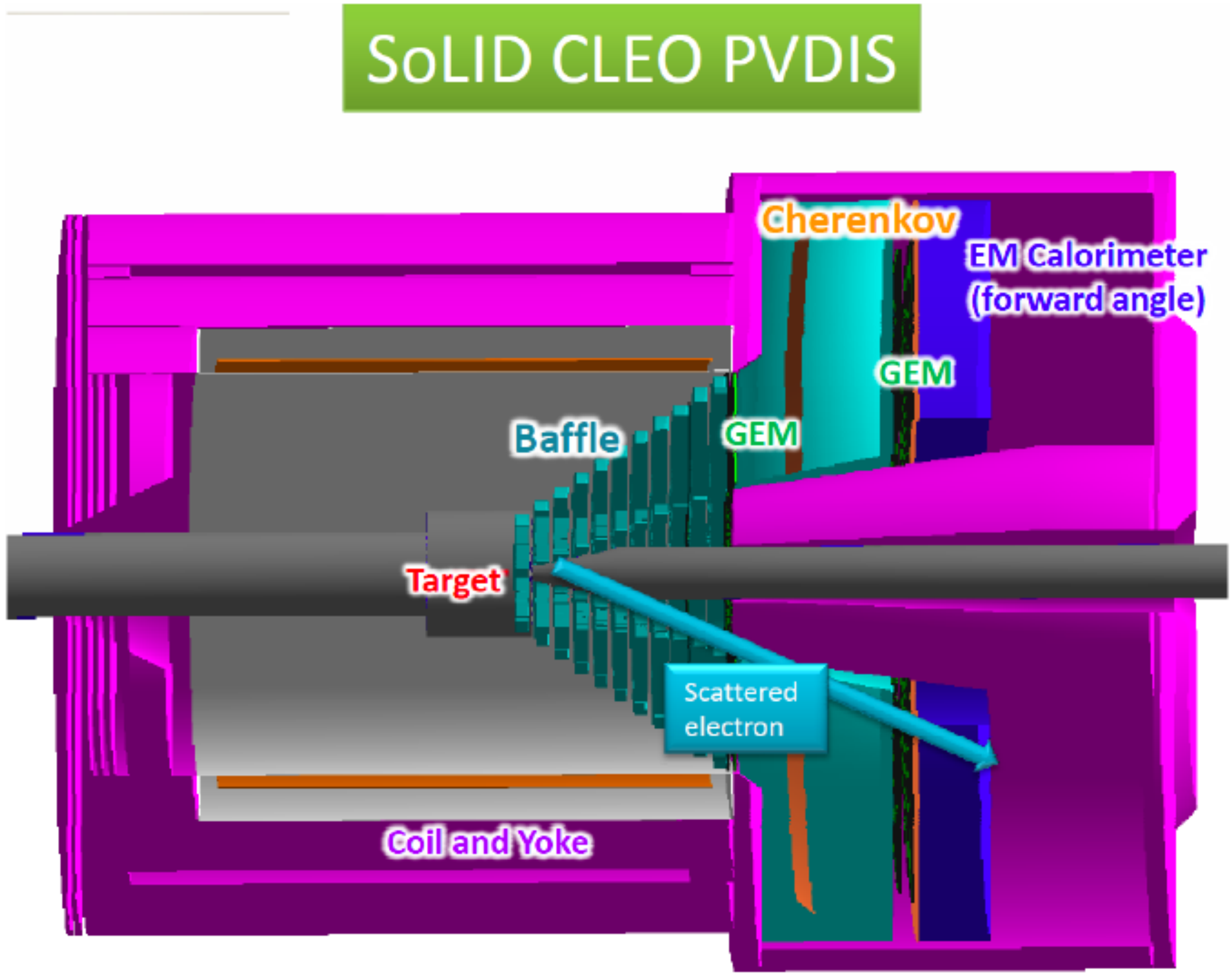
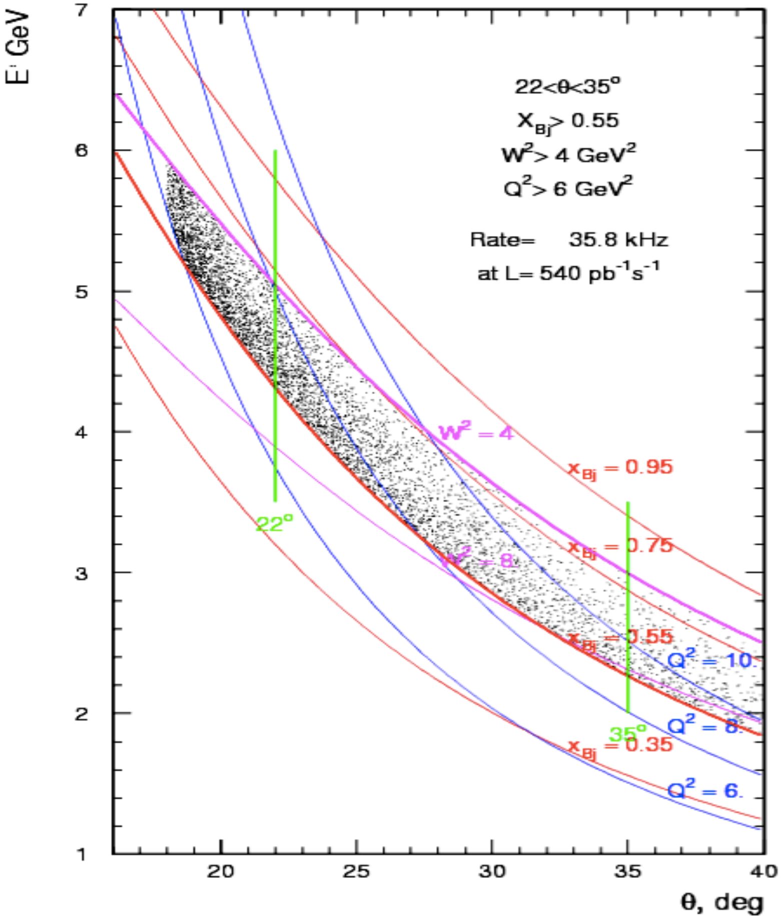
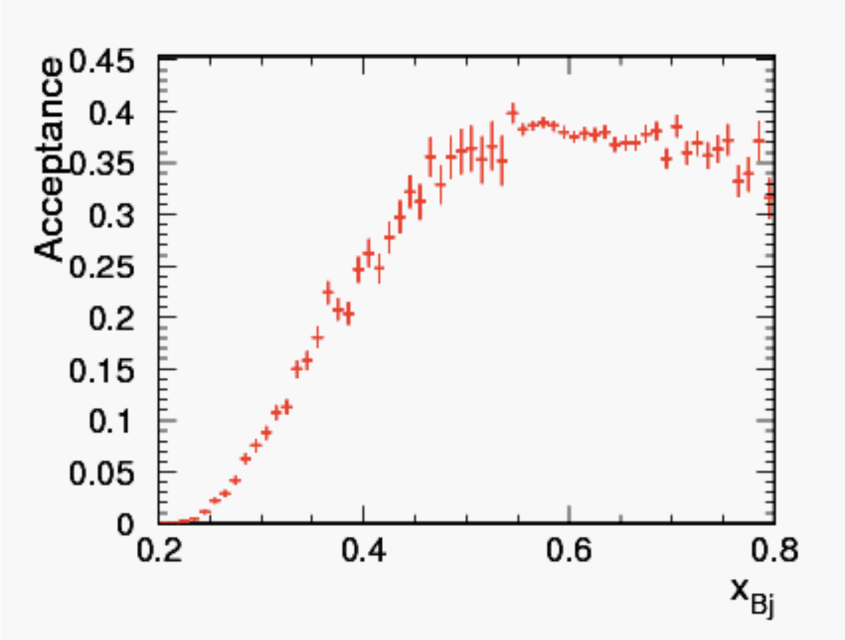


Figure 24: The experimental layout of SoLID PVDIS based on the CLEO magnet. The arrow shows a scattered electron.

Spectrometer Acceptanace





Program of Measurements

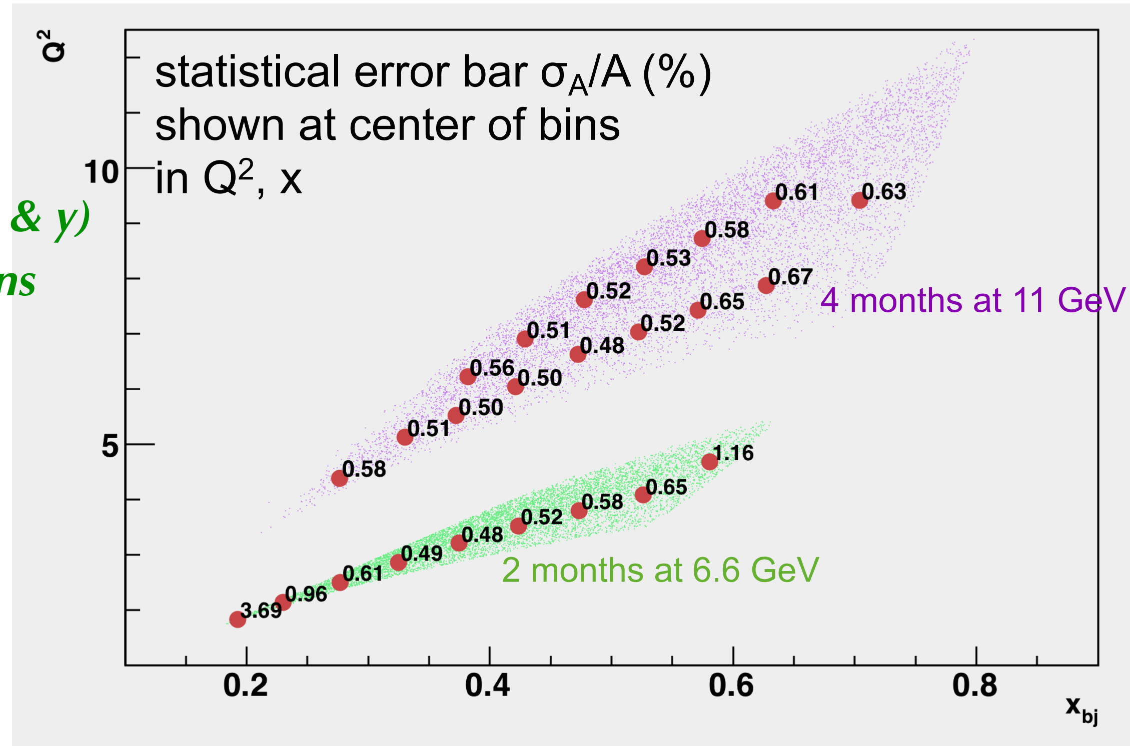
Requires 12 GeV upgrade of JLab and a large superconducting solenoid

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*



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

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

If no CSV, HT, quark sea or nuclear effects, ALL Q^2, x bins should give the same answer within statistics modulo kinematic factors!

Coherent Program of PVDIS Study

Strategy: requires precise kinematics and broad range

Kinematic dependence of physics topics

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

- 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:

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

Error Budget (%) and Running time

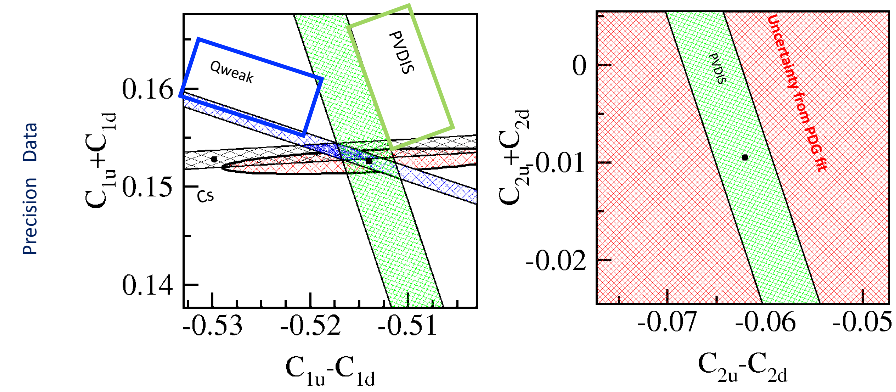
Total	0.6
Polarimetry	0.4
Q2	0.2
Radiative Corrections	0.2
Event reconstruction	0.2
Statistics	0.3

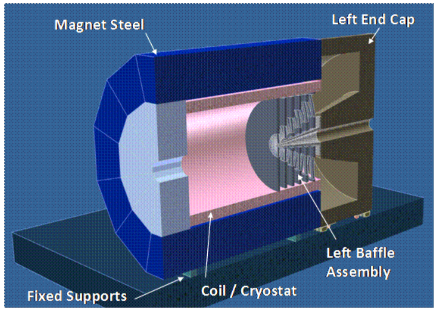
Energy(GeV)	4.4	6.6	11	Test
Days(LD2)	18	60	120	27
Days(LH2)	9	-	90	14

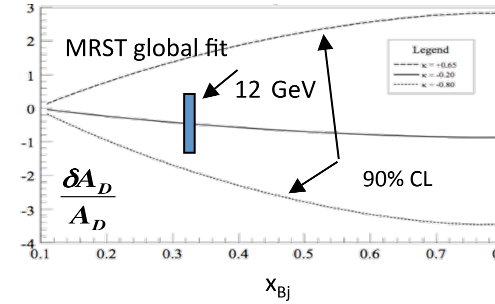
180 Days are Approved

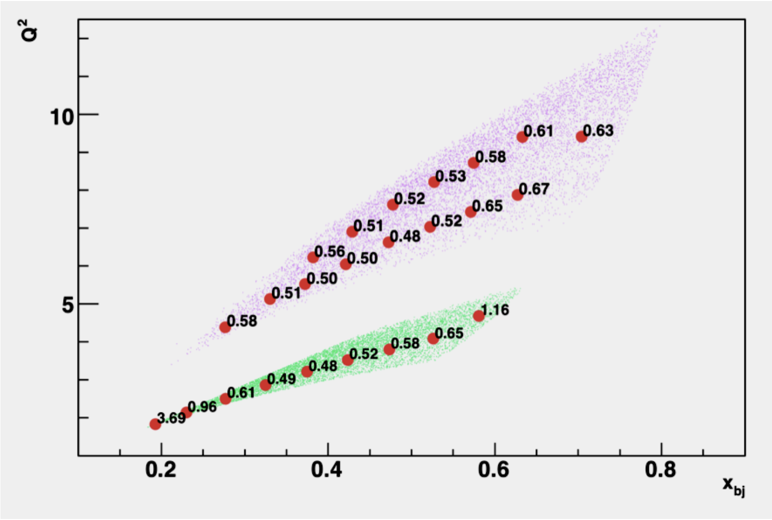
Summary

- Measurements of Parity Violation in Deep Inelastic Scattering contain a wealth of information about:
  - The Standard Model
  - Charge Symmetry (CSV)
  - Higher Twist (HT)
- For the complete picture—to unravel the full richness of the physics reach of this process a dedicated—a large-acceptance spectrometer is needed.
- SoLID will also provide critical nuclear structure test (NuTeV $\sin^2\theta_W$)
- Large additional program of SI-DIS planned for SoLID spectrometer



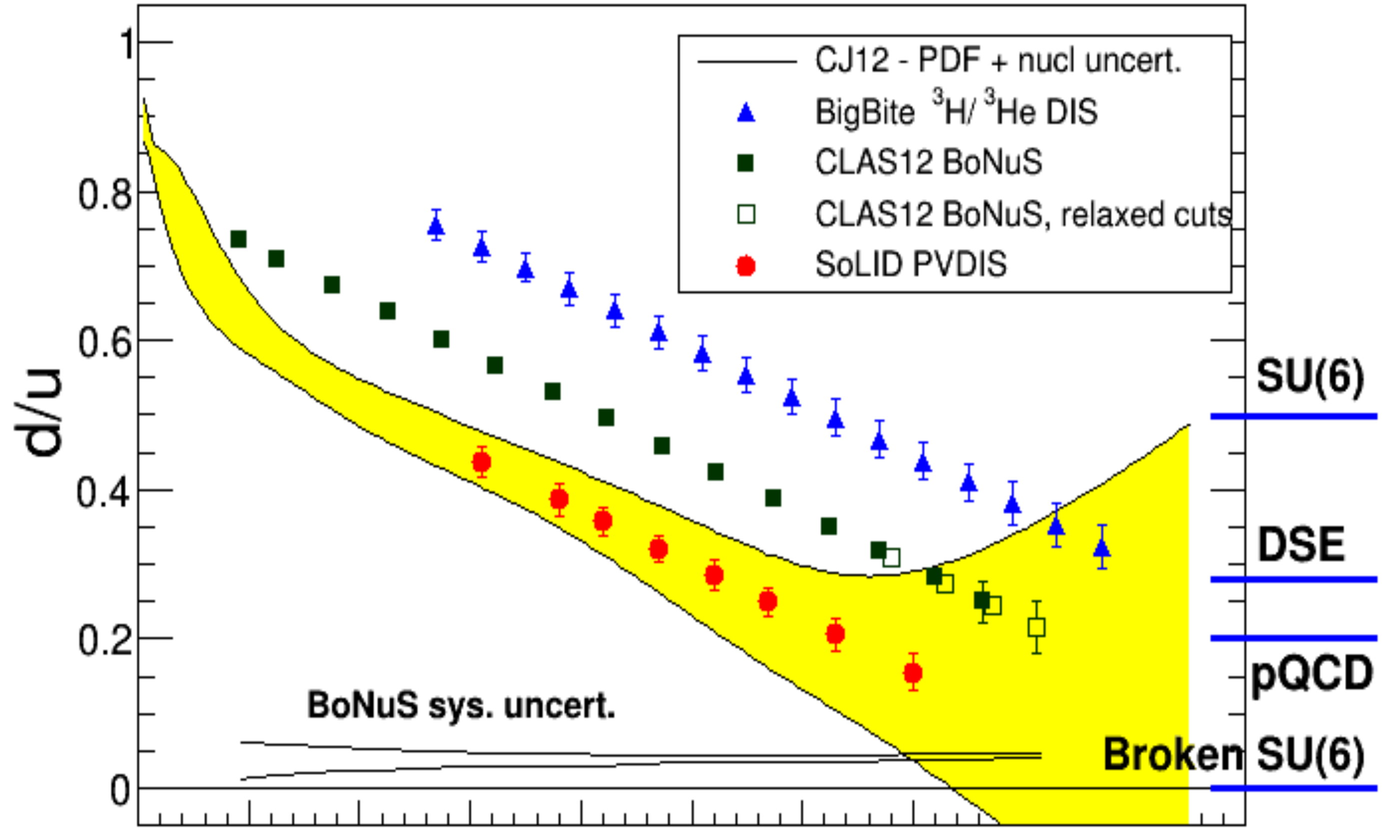






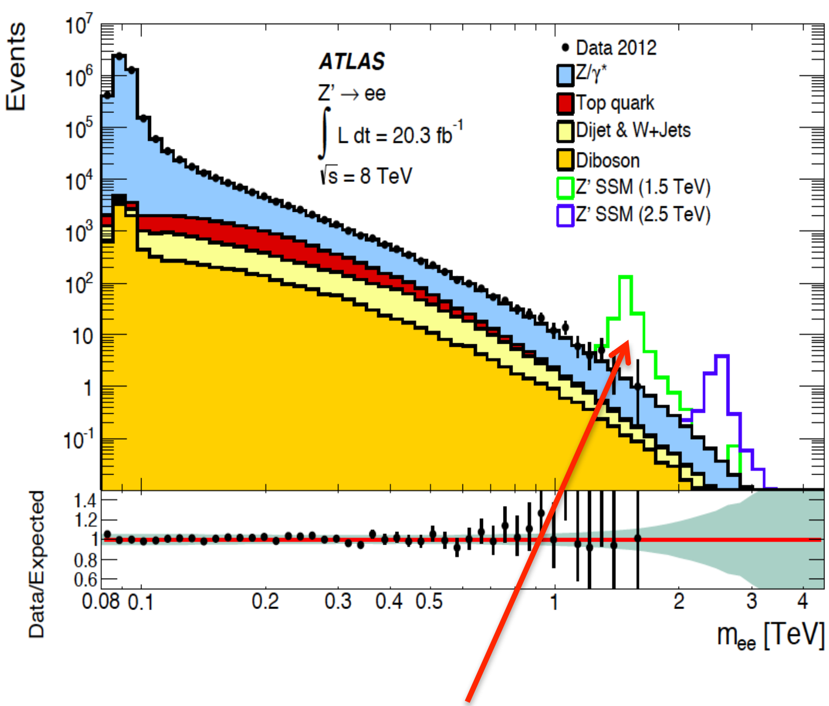
d/u: Jlab 12 GeV + World Data

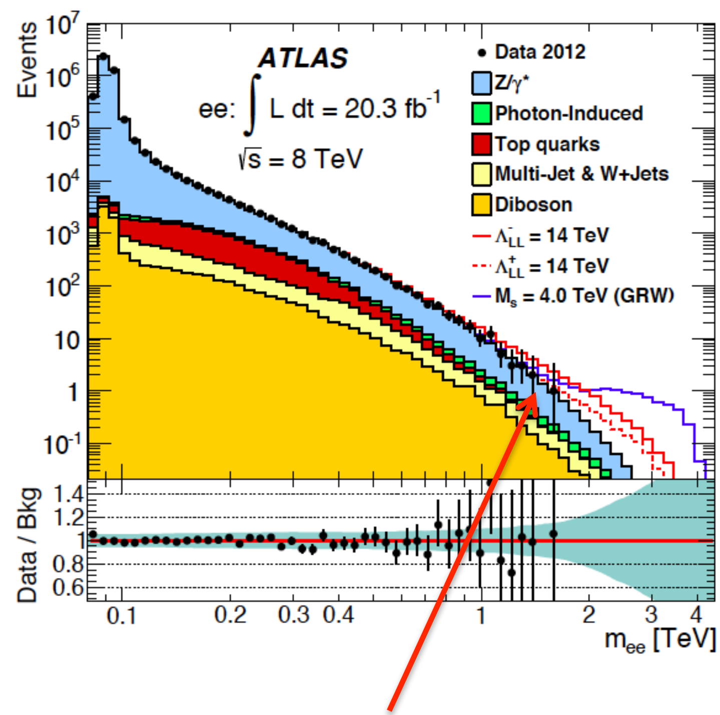
World data:
Phys. Rev. D 87
(2013) 094012



Z' versus Compositeness

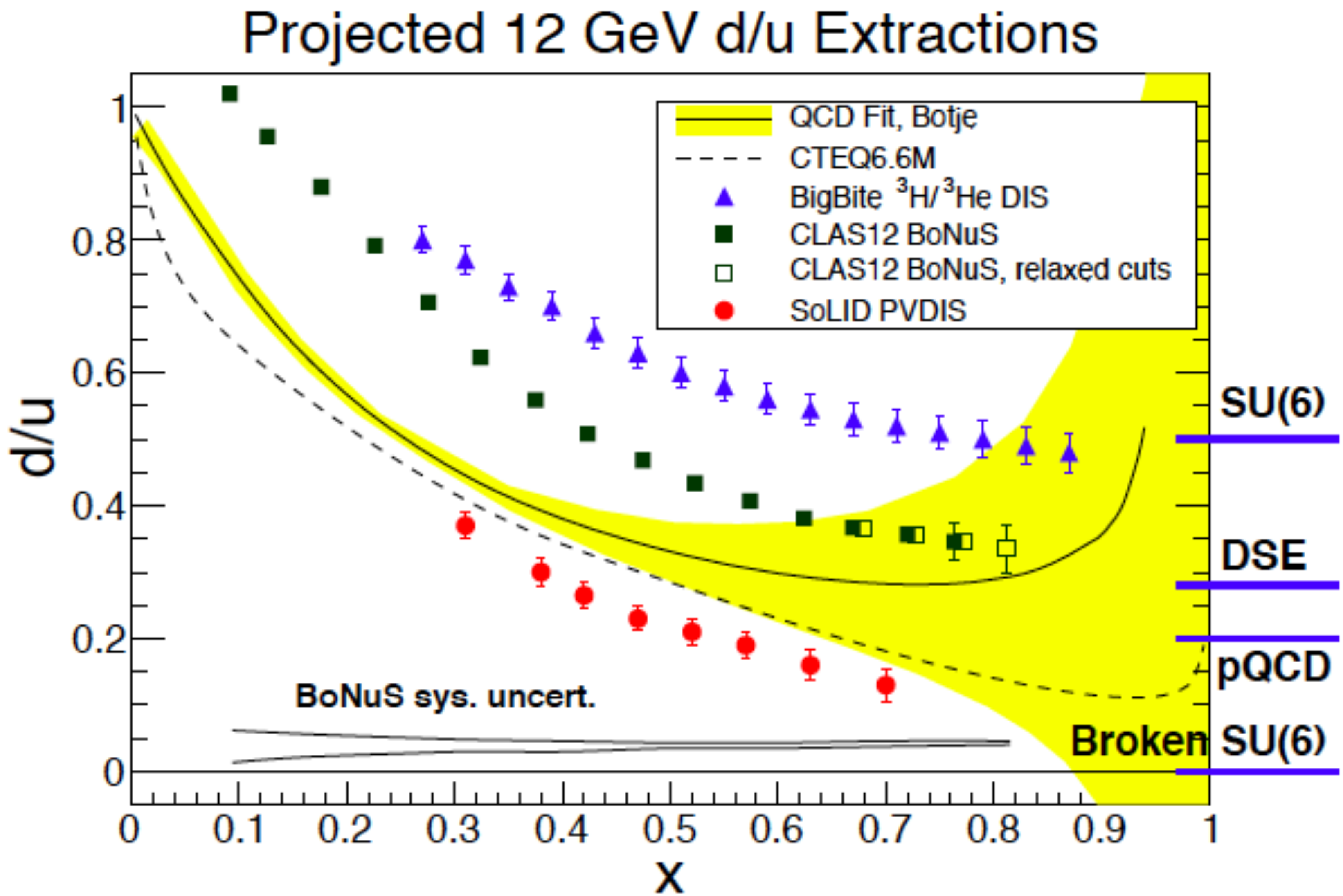
PVDIS determines g^2/Λ^2: LHC sensitivity to g^2/Λ^2 depends on Λ.





Signal dominates

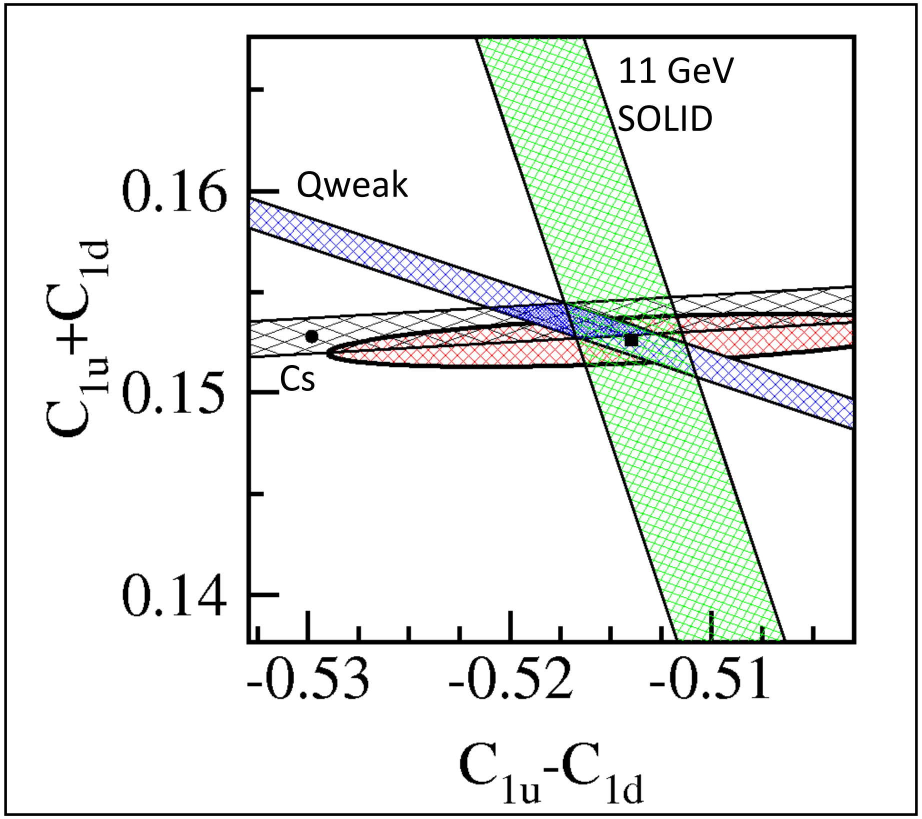
Noise dominates

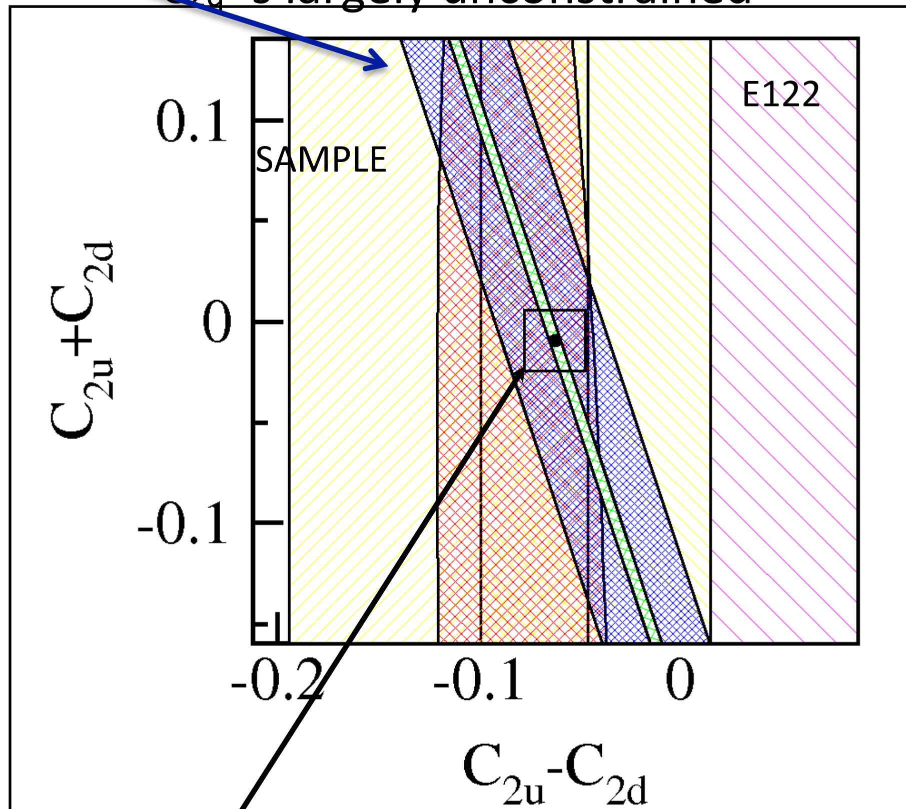

Projected 12 GeV d/u Extractions
QCD Fit, Botje
CTEQ6.6M
BigBite $^3H/^3He$ DIS
CLAS12 BoNuS
CLAS12 BoNuS, relaxed cuts
SoLID PVDIS
SU(6)
DSE
pQCD
Broken SU(6)
BoNuS sys. uncert.
d/u
x
0
0.2
0.4
0.6
0.8
1
0.1
0.3
0.5
0.7
0.9

6 GeV Result; SOLID Goal

Measure A_{PV} for e-^{2}H DIS to 0.6% fractional error (stat + syst + theory) at high x, y

C_{2q}'s largely unconstrained





Red ellipses are PDG fits

This box matches the scale of the C_{1q} plot

Green bands are the proposed measurement of SOLID

unique TeV-scale sensitivity

a_3 Term and Neutrino's

$$\frac{1-(1-y)^2}{1-y-y^2/2(1+R)}a_3(Q^2,\nu) \propto \frac{\sigma^{\nu}-\sigma^{\bar{\nu}}}{\sigma^{\nu}+\sigma^{\bar{\nu}}}$$

These hadronic corrections can be obtained from charged-current neutrino scattering data

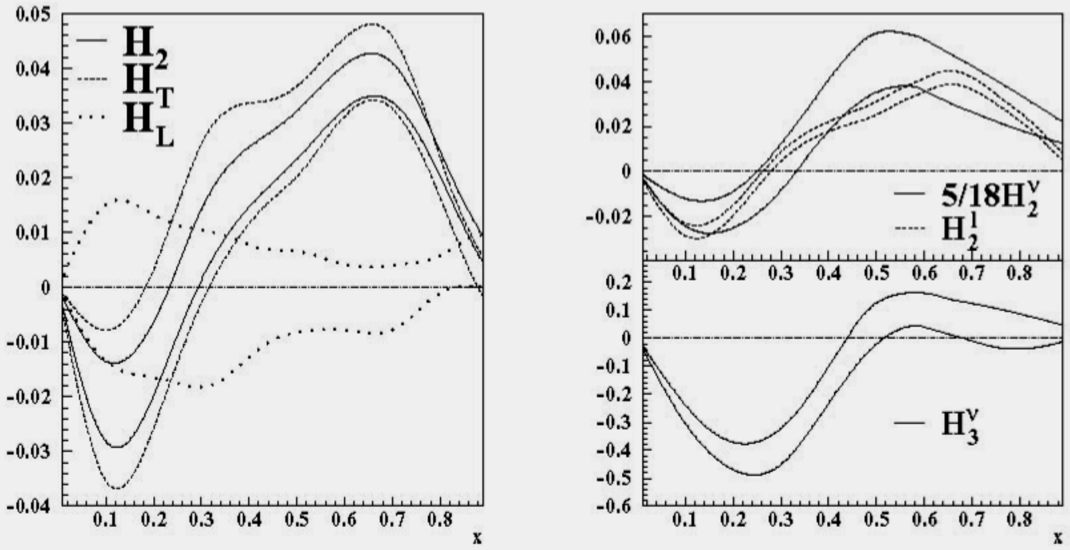
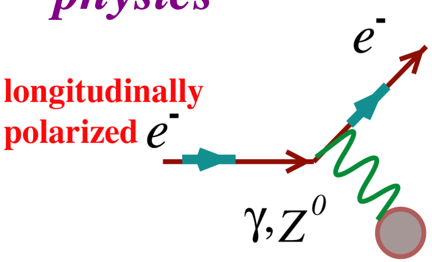


FIGURE 2. Left figure: the 1σ error bands for the high-twist terms in the isospin-symmetric combinations of different structure functions (solid lines: F_2, dashes: F_T, dots: F_L) for charged leptons. Right figure: corresponding 1σ bands for neutrino scattering off an isoscalar target (upper panel: F_2, lower panel: xF_3). The predictions for F_2 from charged leptons rescaled by the corresponding leading twist terms are also shown for comparison.

High Precision PV Electron Scattering

Continuous interplay between probing hadron structure and electroweak physics

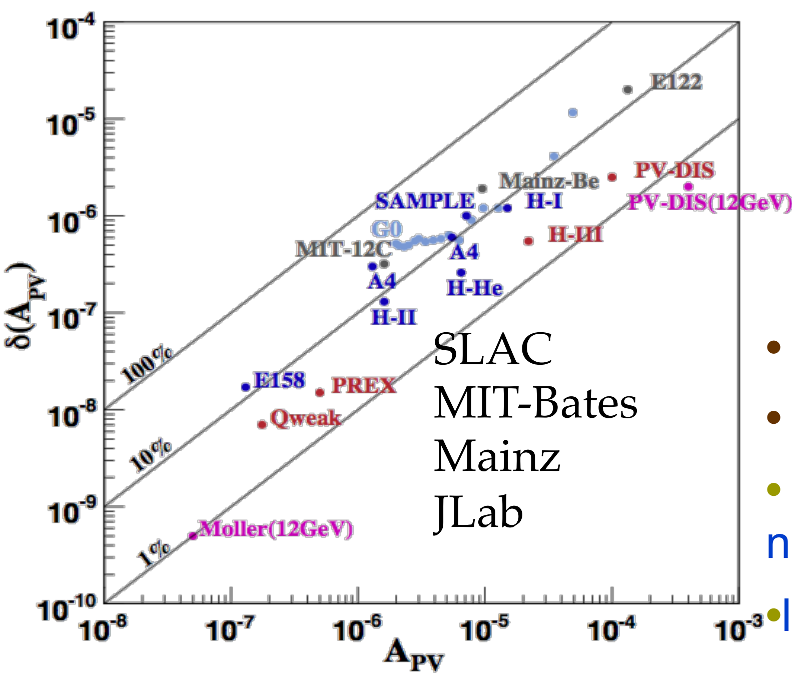


$$-A_{LR} = A_{PV} = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} \sim \frac{A_{weak}}{A_{\gamma}} \sim \frac{G_F Q^2}{4\pi\alpha}\left(g_A^e g_V^T + \beta g_V^e g_A^T\right)$$

g_V is a function of $\sin^2\theta_W$

$$A_{PV} \sim 10^{-5} \cdot Q^2 \;\; to \;\; 10^{-4} \cdot Q^2$$

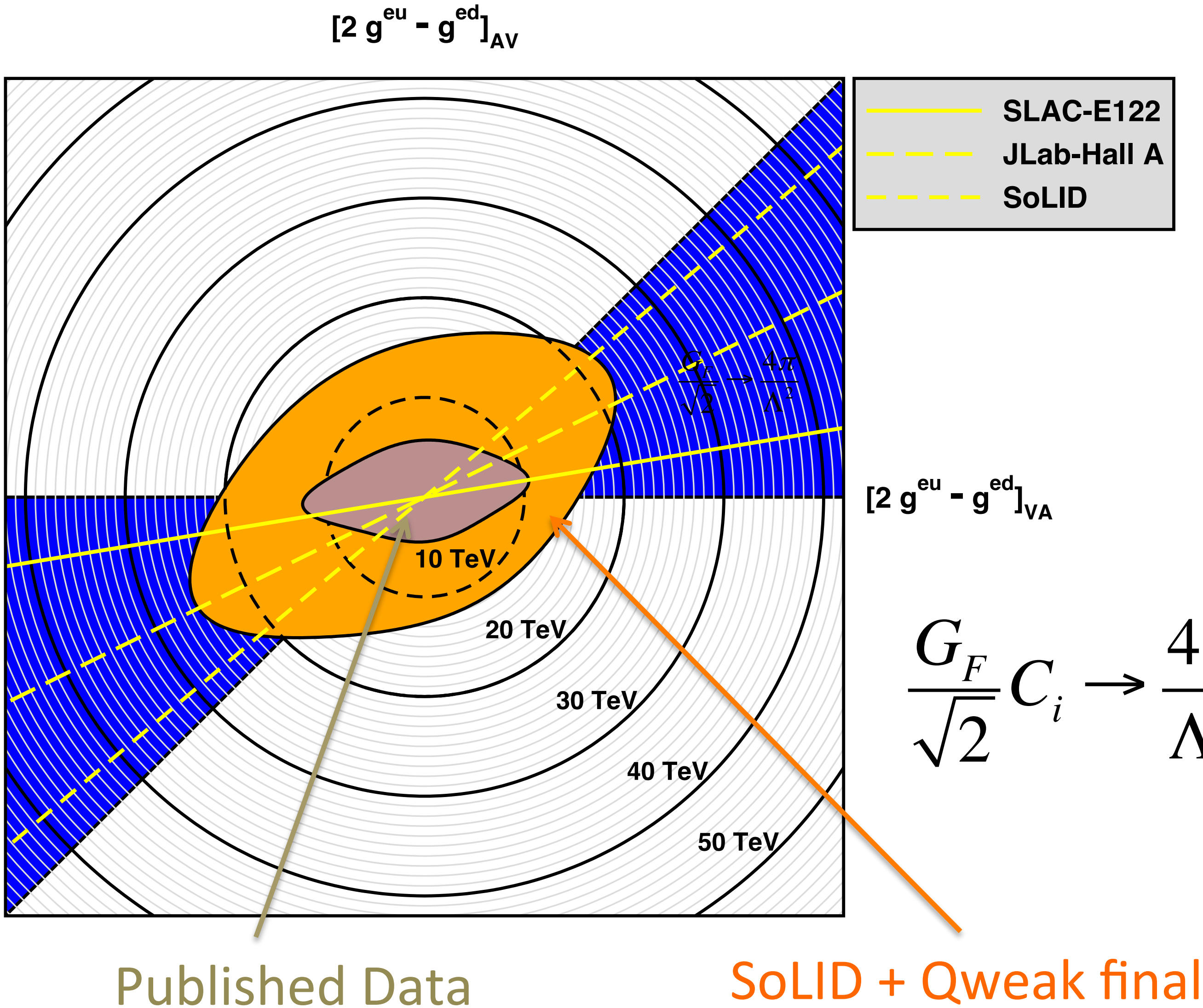
Parity-violating electron scattering has become a precision tool



- Physics beyond Standard Model
- Strange quark form factors
- Neutron skin of a heavy nucleus
- QCD structure of the nucleon in PV DIS

- part per billion systematic control
- <1% normalization control
- photocathodes, polarimetry, high power cryotargets, nanometer beam stability, precision beam diagnostics,
- low noise electronics, radiation hard detectors

Mass Limits for Composite Theories



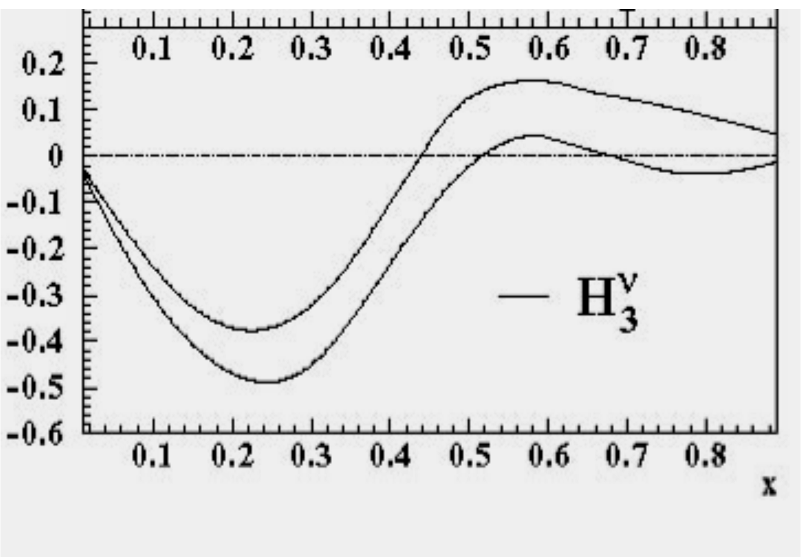
$$\frac{G_F}{\sqrt{2}} C_i \rightarrow \frac{4\pi}{\Lambda^2}$$

a_3 Term and Neutrino's

$$\frac{1-(1-y)^2}{1-y-y^2/2(1+R)}a_3(Q^2,\nu) \propto \frac{\sigma^{\nu}-\sigma^{\bar{\nu}}}{\sigma^{\nu}+\sigma^{\bar{\nu}}}$$

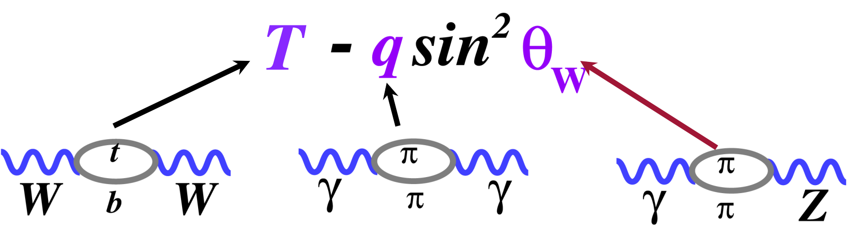
These hadronic corrections can be obtained from charged-current neutrino scattering data

Higher Twist contribution
to xF_3 from
fits to neutrino data

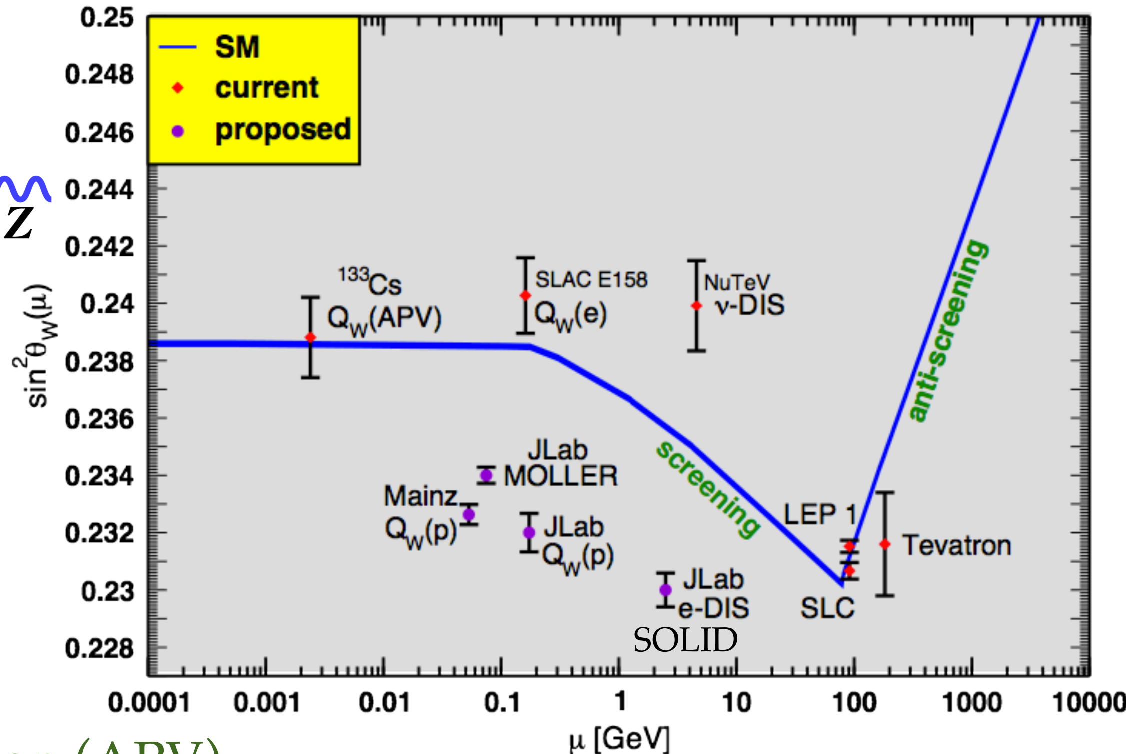


The Weak Mixing Angle

Running of θ_W : Bookkeeping to check consistency of various measurements



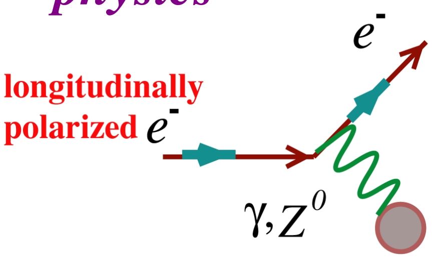
- ***γ-γ loop is the running of α_{EM}***
- ***W-W loop provides indirect m_t***
- ***γ-Z loop is the running of $\sin^2\theta_W$***



- Published Measurements
  - SLAC E158
  - ^{133}Cs Atomic Parity Violation (APV)
  - NuTeV result requires careful consideration of nuclear corrections
- Current/Future PV Electron Scattering Measurements at JLab
  - e-q measurements: QWeak (elastic e-p) and SOLID (DIS)
  - Improve on E158 by a factor of 5 (MOLLER)

PV Electron Scattering

Continuous interplay between probing hadron structure and electroweak physics



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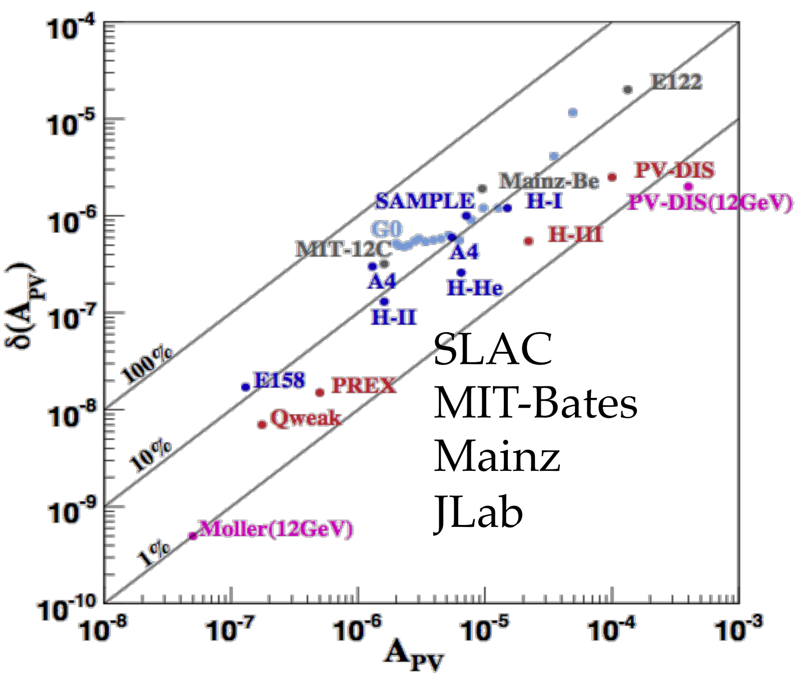
g_V is a function of $\sin^2\theta_W$

$$A_{PV} \sim 10^{-5} \cdot Q^2 \;\; \textit{to} \;\; 10^{-4} \cdot Q^2$$

Parity-violating electron scattering has become a precision tool for measuring both weak couplings (g^e, g^T) and hadronic structure (g^T).



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- <1% normalization control: small $\delta A_{PV}/A_{PV}$