PVDIS Physics Case

Main Bullets

- BSM Physics via C_2's
- CSV in deuterium
- CSV in ^{48}Ca?
- d/u in the proton

Perspective

- Important new results in the field have been released: LHC, Qweak.
- Physics motivation is more important for Science Review than PCDR.
- We plan to produce updated document about the SoLID PVDIS physics case.

Standard Model Test: Couplings

This has
not changed

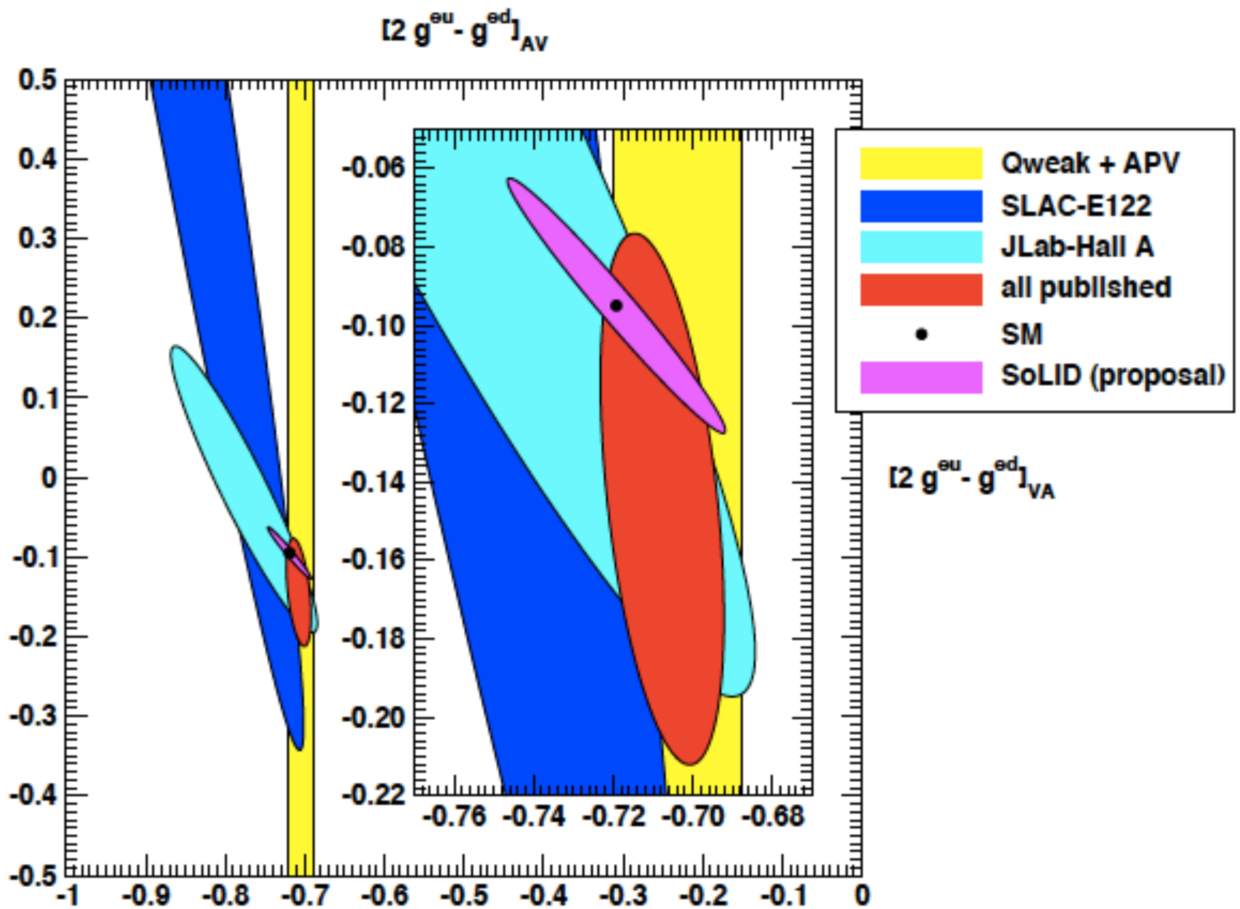


Figure 7: Results form the JLab PVDIS collaboration together with the projected results from the SoLID PVDIS experiment.

LHC pp->e^+e^- and SoLID PVDIS

- LHC has confirmed no new physics: Z', etc.
- Both measure the same contact interactions.
- For the LHC, Q^2 is 10^5-10^6 times larger.
- LHC systematics are large: >10%.
- Much LHC sensitivity comes where square of contact interactions are significant.
- LHC sets bounds on sum of squares of all couplings.

Contact Interactions: Compositeness

CI Lagrangian: $$\mathcal{L}_{eff} = \frac{g^2}{\Lambda^2} \sum_{i,j=L,R} \eta_{ij}^f \bar{e}_i \gamma_\mu e_i \bar{f}_j \gamma^\mu f_j$$

e^+e^- at LHC:

E&M Z CI

$$\frac{d\sigma}{d\Omega}\left(q_L\bar{q}_R \to e_L^- e_R^+\right) = \frac{\alpha^2}{4s}(1+\cos\theta)^2 \left|Q_q - rL_qL_e - \zeta\eta_{LL}^{qe}\right|^2$$

$$r = \frac{1}{4\sin^2\theta_W \cos^2\theta_W} \sim 1.4$$

$$\zeta = \frac{M^2}{\alpha\Lambda^2}$$ ~1 for LHC

	e^-	u	d
Q	-1	0.67	-0.33
L	-0.53	0.69	-0.84
R	0.47	-0.31	0.16

At large M, σ_T~ $\zeta^2(\eta_{LL}^2 + \eta_{LR}^2 + \eta_{RR}^2 + \eta_{RL}^2)$ Sensitive to C_2's

Comment From ATLAS

The relative impact of the interference and pure CI terms depends on both the dilepton mass and Λ. For example, the magnitude of the interference term for dilepton masses above 600 GeV is about twice as large as that of the pure CI term at $\Lambda = 14$ TeV; the interference becomes increasingly dominant for higher values of Λ.

ATLAS 8 TeV

Process	m_{ee} [GeV]					
	400–550	550–800	800–1200	1200–1800	1800–3000	3000–4500
Total SM	1260 ± 100	404 ± 35	82 ± 9	10.8 ± 1.6	0.91 ± 0.21	0.014 ± 0.005
Data	1262	388	84	7	0	0
SM+CI ($\Lambda_{LL}^{-} = 14$ TeV)	1310 ± 110	440 ± 40	108 ± 10	20.9 ± 1.9	4.2 ± 0.4	0.141 ± 0.028
SM+CI ($\Lambda_{LL}^{-} = 20$ TeV)	1290 ± 110	430 ± 40	90 ± 10	14.4 ± 1.7	2.01 ± 0.25	0.045 ± 0.012
SM+CI ($\Lambda_{LR}^{-} = 14$ TeV)	1340 ± 110	460 ± 40	118 ± 10	26.3 ± 2.1	6.0 ± 0.5	0.28 ± 0.05
SM+CI ($\Lambda_{LR}^{-} = 20$ TeV)	1290 ± 110	420 ± 40	98 ± 10	15.7 ± 1.7	2.58 ± 0.28	0.078 ± 0.018

Contact Interactions appear above systematics only at large M_{ee}

ATLAS 13 TeV

m_{ee} [GeV]	80–120	120–250	250–400	400–500	500–700
Drell–Yan	11 800 000 ± 700 000	216 000 ± 11 000	17 230 ± 1000	2640 ± 180	1620 ± 120
Top quarks	28 600 ± 1800	44 600 ± 2900	8300 ± 600	1130 ± 80	560 ± 40
Dibosons	31 400 ± 3300	7000 ± 700	1300 ± 140	228 ± 25	146 ± 16
Multi-jet & W+jets	11 000 ± 9000	5600 ± 2000	780 ± 80	151 ± 21	113 ± 17
Total SM	11 900 000 ± 700 000	273 000 ± 12 000	27 600 ± 1100	4150 ± 200	2440 ± 130
Data	12 415 434	275 711	27 538	4140	2390
Z'_χ (4 TeV)	0.00635 ± 0.00021	0.0390 ± 0.0015	0.0564 ± 0.0025	0.0334 ± 0.0027	0.064 ± 0.004
Z'_χ (5 TeV)	0.00305 ± 0.00012	0.0165 ± 0.0006	0.0225 ± 0.0010	0.0139 ± 0.0007	0.0275 ± 0.0015

m_{ee} [GeV]	700–900	900–1200	1200–1800	1800–3000	3000–6000
Drell–Yan	421 ± 34	176 ± 17	62 ± 7	8.7 ± 1.3	0.34 ± 0.07
Top quarks	94 ± 8	27.9 ± 2.8	5.1 ± 0.7	< 0.001	< 0.001
Dibosons	39 ± 4	16.9 ± 2.1	5.8 ± 0.8	0.74 ± 0.11	0.028 ± 0.004
Multi-jet & W+jets	39 ± 6	16.1 ± 2.0	7.9 ± 2.3	1.6 ± 1.2	0.08 ± 0.27
Total SM	590 ± 40	237 ± 17	81 ± 7	11.0 ± 1.8	0.45 ± 0.28
Data	589	209	61	10	0
Z'_χ (4 TeV)	0.0585 ± 0.0035	0.074 ± 0.005	0.121 ± 0.011	0.172 ± 0.017	2.57 ± 0.27
Z'_χ (5 TeV)	0.0218 ± 0.0013	0.0295 ± 0.0021	0.040 ± 0.004	0.040 ± 0.004	0.280 ± 0.030

Obsolete Plot?

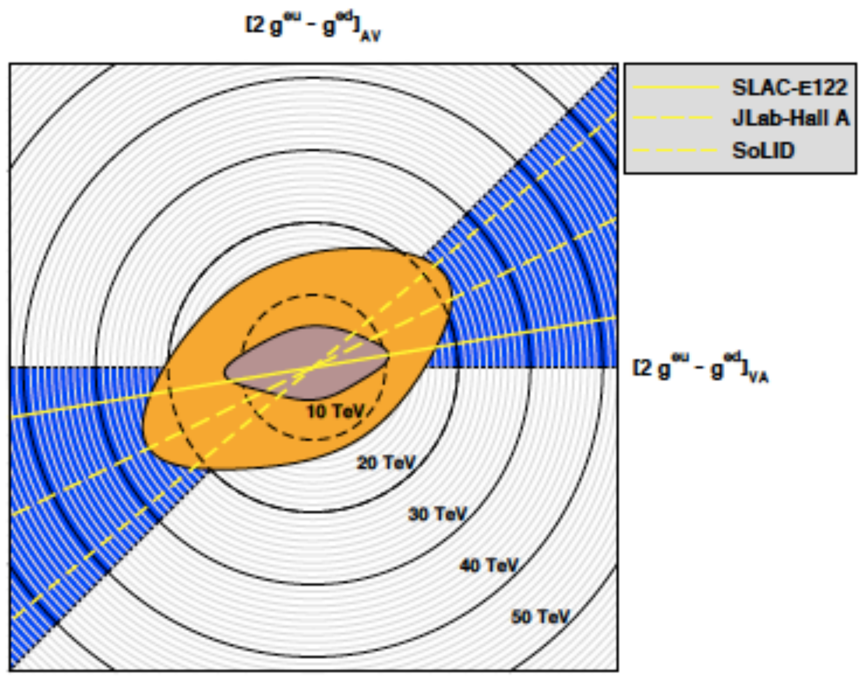


Figure 10: Polar plot for limits on composite models. The gray ellipse includes the published results form the PVDIS and Qweak collaborations. The orange ellipse gives the projected limits with the full Qweak statistics and the SoLID data.

Physics Unaffected by the LHC

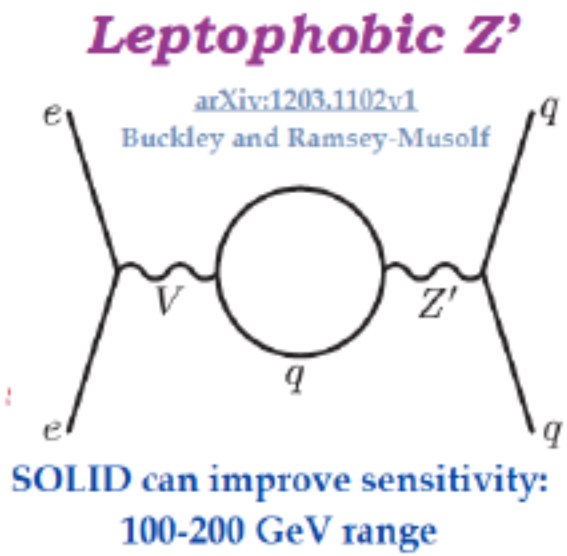
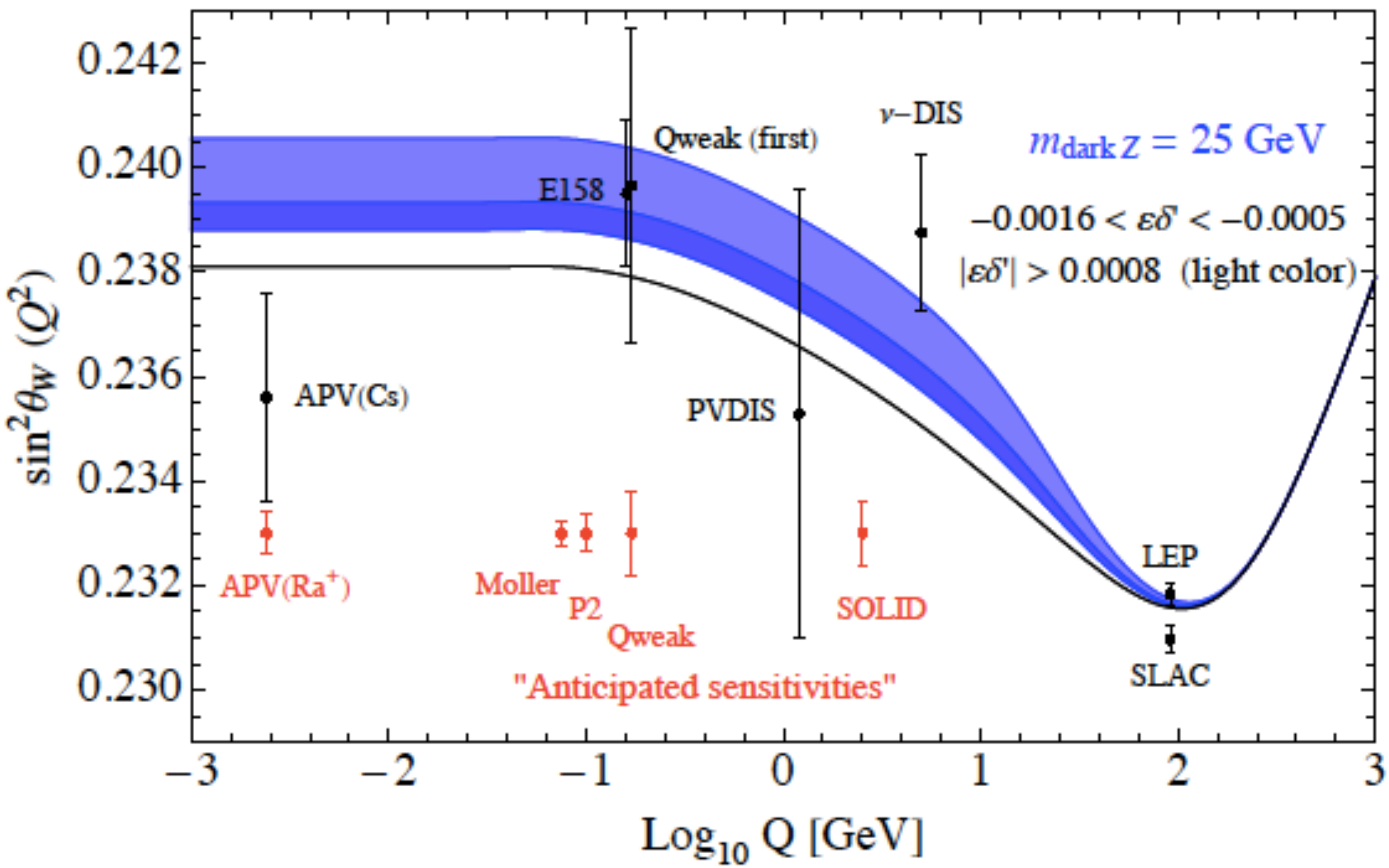


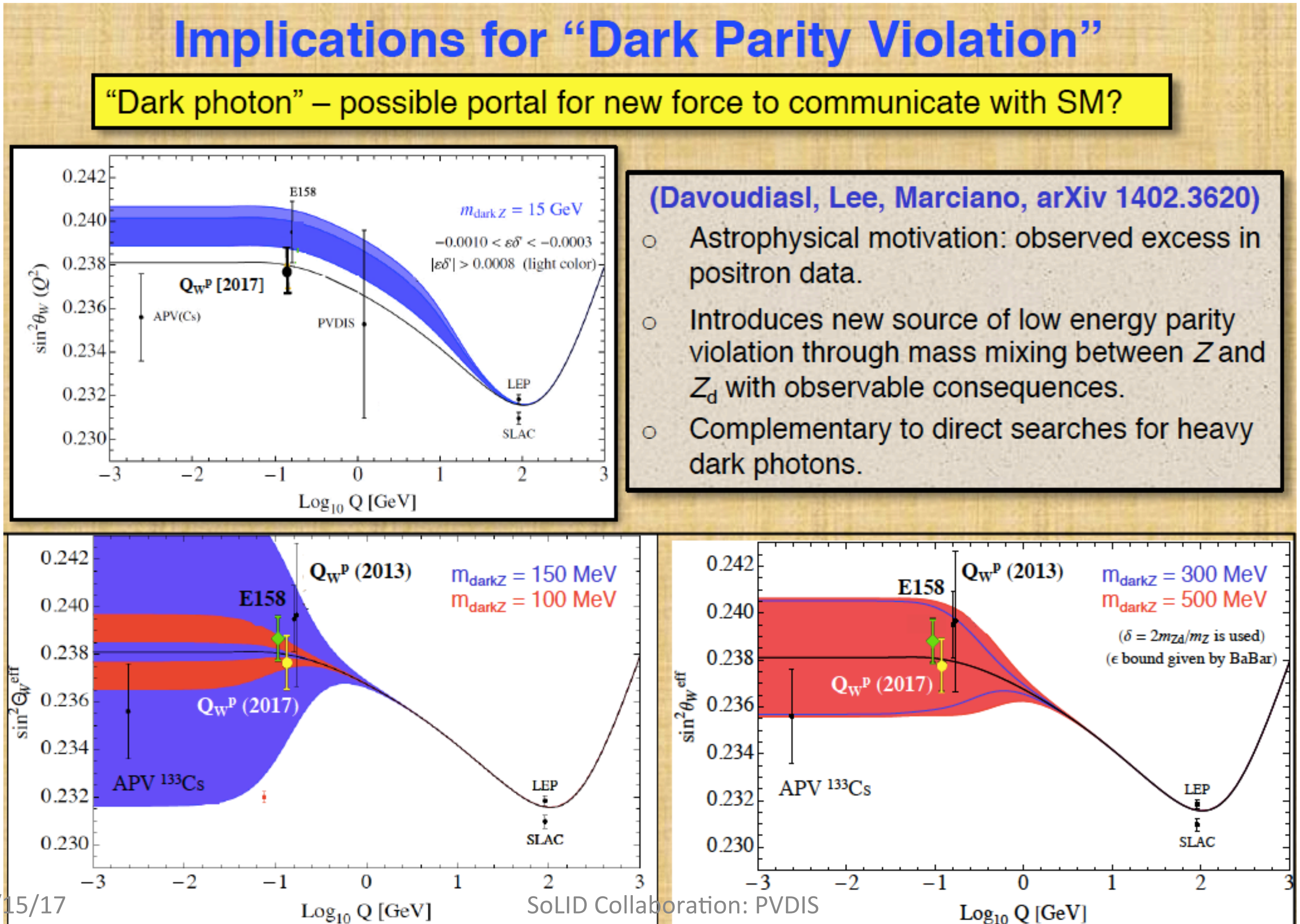
Figure 9: Diagram of a leptophobic Z' that can contribute to the C_{2q} and few other observables.

ATLAS rules out Leptophobic Z' between 1.1 and 1.5 TeV

New Idea: Dark Light



New Results from Qweak



d/u: Old

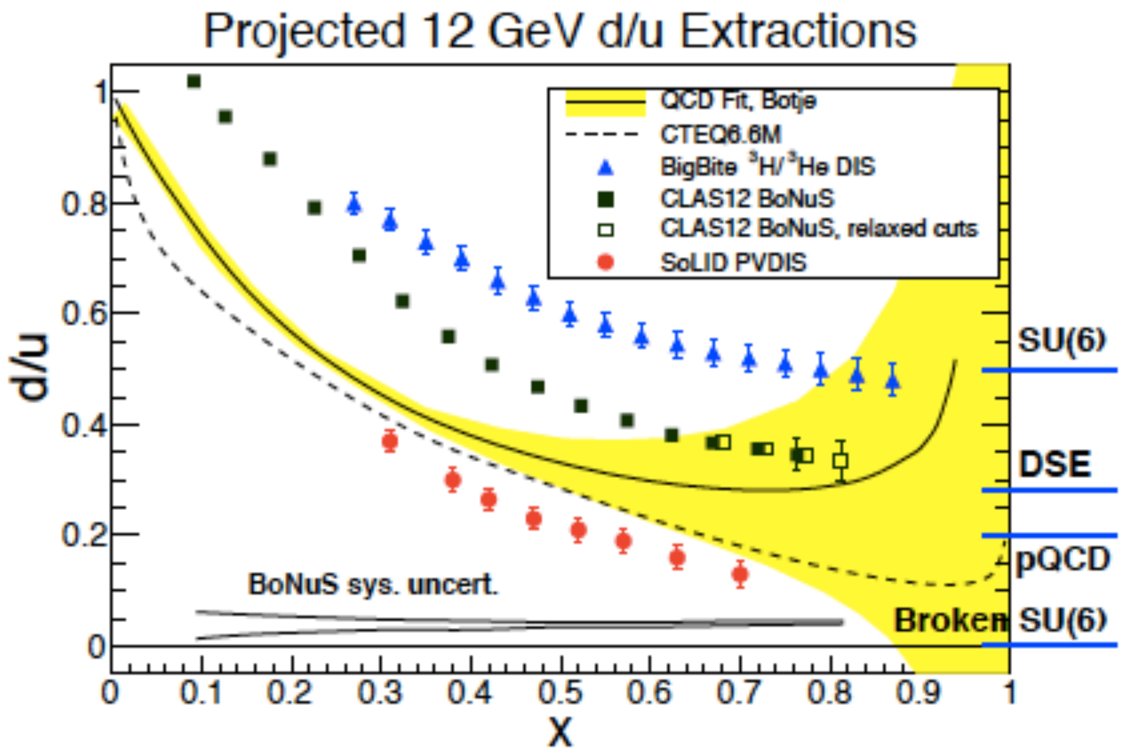
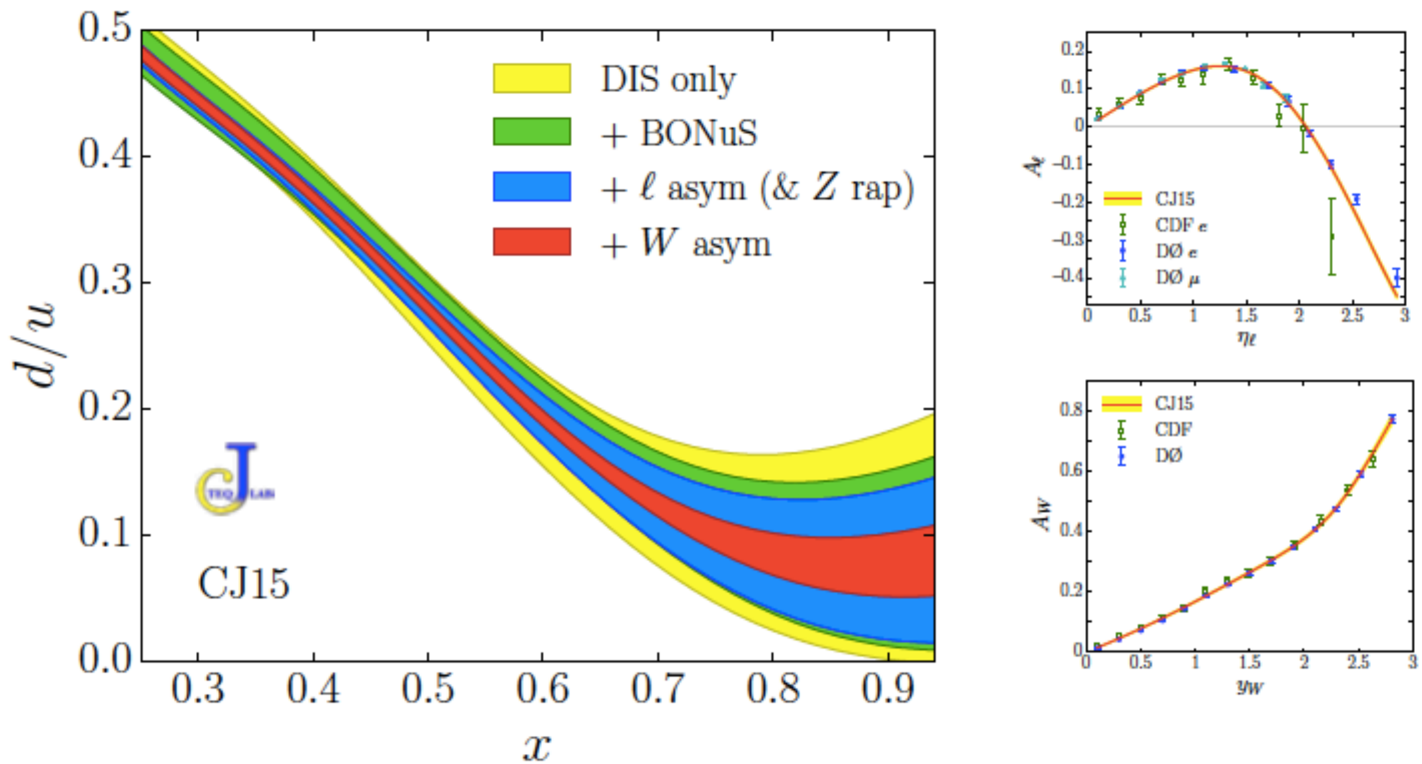


Figure 13: Anticipated precision for d/u measurement with Solid as well s other proposed experiments.

■ At large x proton asymmetry sensitive to d/u ratio

$$a_1 = \frac{12C_{1u} - 6C_{1d}\, d/u}{4 + d/u}$$

$$a_3 = \frac{12C_{2u} - 6C_{2d}\, d/u}{4 + d/u}$$



→ error reduced by recent W asymmetry data

– but rely on reconstruction from $W \to \ell\, \nu$ decays

1 Measurement of d/u for the Proton

1.1 Main Bullets

1. Interplay and complementary of the different experiments: There are four complementary precision experiments:

   (a) PVDIS is the most direct measurement of d/u

   (b) BONUS: some nuclear corrections.

   (c) Marathon: short-range correlations.

   (d) Fermilab collider: less direct, $Q^2 \sim M_W^2$

   PVDIS provides low Q^2 measure of d/u free of any nuclear corrections. It is the most direct method.

2. Possible Plots

   (a) Plot showing impact of projected PVDIS data on global fits for d/u.

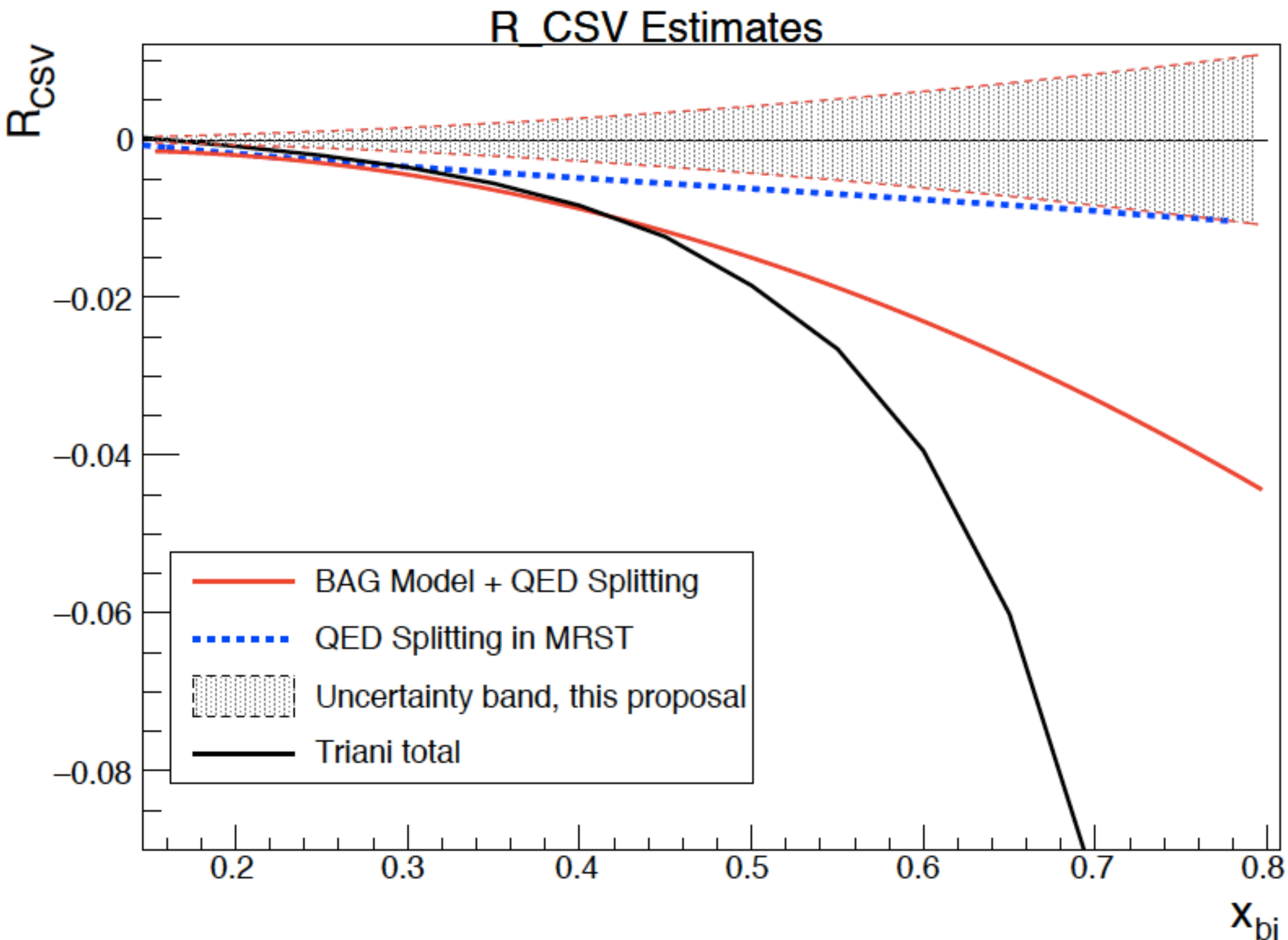
   (b) Show experiments on the plot in the CJ15 paper showing nuclear correction for deuteron.

   (c) Plot showing Fermilab collider data on the d/u plot?

3. Physics impact of d/u:

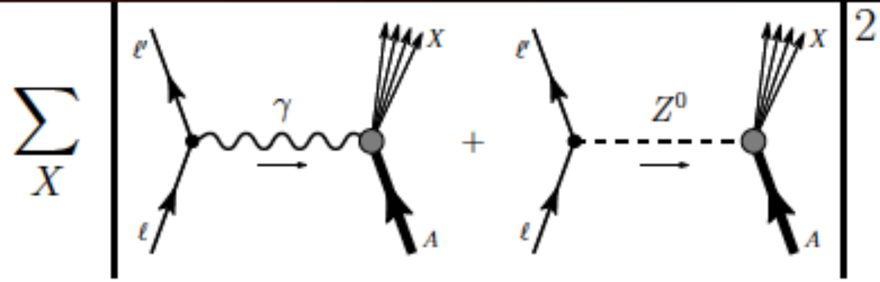
   (a) Quark models as $x \to 1$

CSV: Found New Model



Measuring CSB using PVDIS

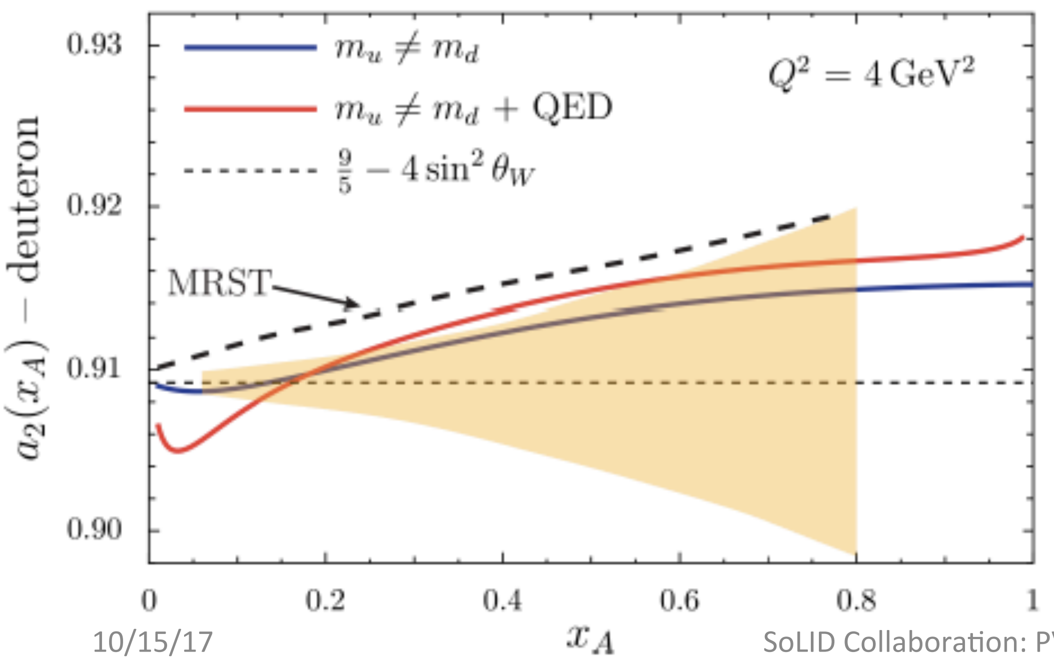
- Consider the deuteron where nuclear effects are well known



- Construct the PVDIS asymmetry

$$a_2(x) \overset{N\sim Z}{\simeq} \frac{9}{5} - 4\sin^2\theta_W - \frac{12}{25}\frac{u_D^+(x) - d_D^+(x)}{u_D^+(x) + d_D^+(x)}; \qquad \Delta a_2 = -\frac{6}{25}\frac{\delta u^+ - \delta d^+}{\delta u^+ + \delta d^+}$$

- PVDIS on $N = Z$ target – excellent way to access CSB in nucleon PDFs



- Our result likely too small to be measured in proposed JLab 12 GeV experiment
  - QED splitting does increase CSB effects but not significantly

New CSB Results from Quark Masses

Argonne National Laboratory

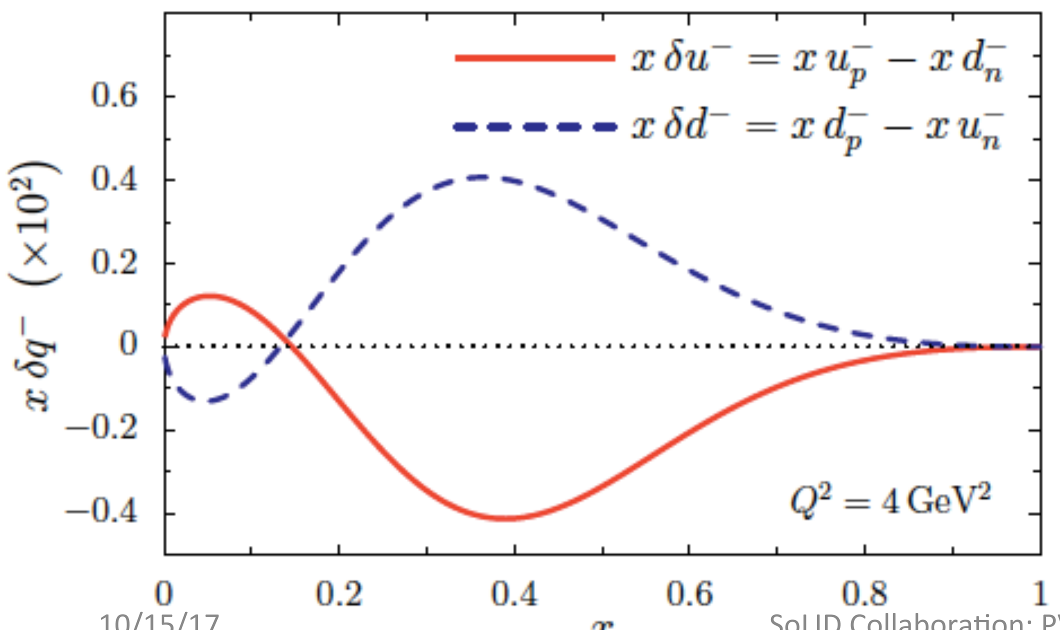
- Our dressed quark mass is $M_0 = 400\,\text{MeV}$ in the charge symmetry limit
  - define: $M_u = M_0 - \delta_M$ & $M_d = M_0 + \delta_M$; $\delta_M \mid M_n - M_p = 3\,\text{MeV}$

$$M_u = 397\,\text{MeV} \;\; \& \;\; M_d = 403\,\text{MeV} \implies \frac{M_d - M_u}{M_d} \simeq 1.5\%; \quad \frac{m_u}{m_d} = 0.58$$

- For the CSB PDFs we find, at $Q^2 = 4\,\text{GeV}^2$:

$$\langle x\,\delta u^- \rangle = -0.0019 \qquad \langle x\,\delta d^- \rangle = \;\; 0.0019$$

  - therefore a small amount of momentum is shifted from the u to the d quarks



- Recent lattice QCD analysis at $Q^2 = 4\,\text{GeV}^2$ find:

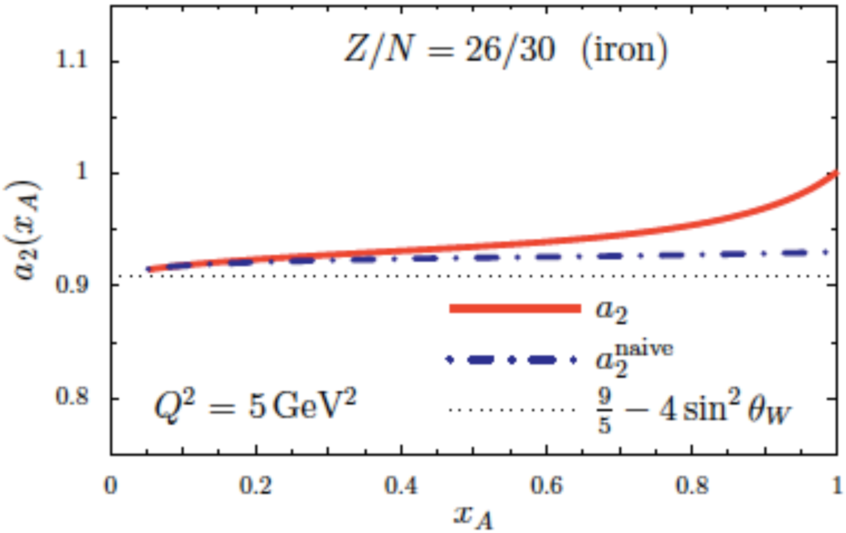
[R. Horsley *et al.*, PRD **83**, 051501 (2011)]

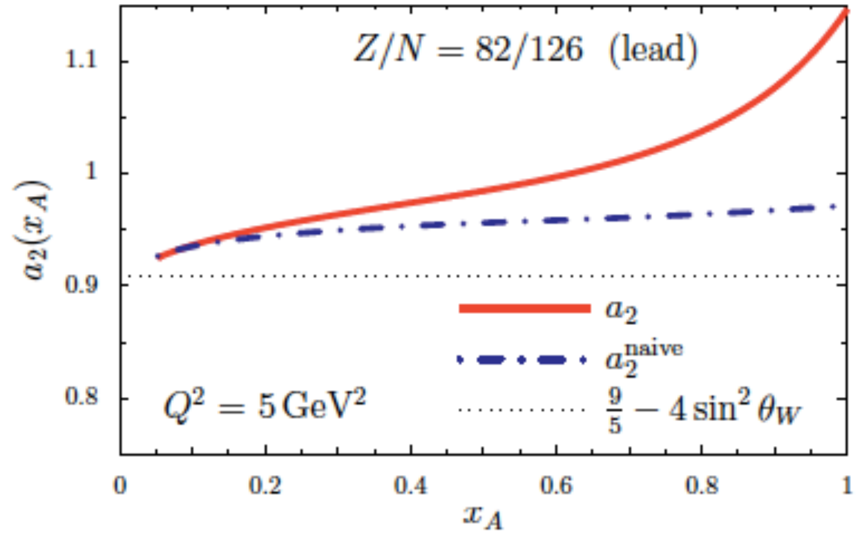
$$\langle x\,\delta u \rangle = -0.0023(6)$$
$$\langle x\,\delta d \rangle = \;\; 0.0020(3)$$

- Therefore our results are consistent with Lattice

Isovector Effects in Nuclei

[ICC, W. Bentz and A. W. Thomas, Phys. Rev. Lett. **109**, 182301 (2012)]





- PVDIS – γZ interference:

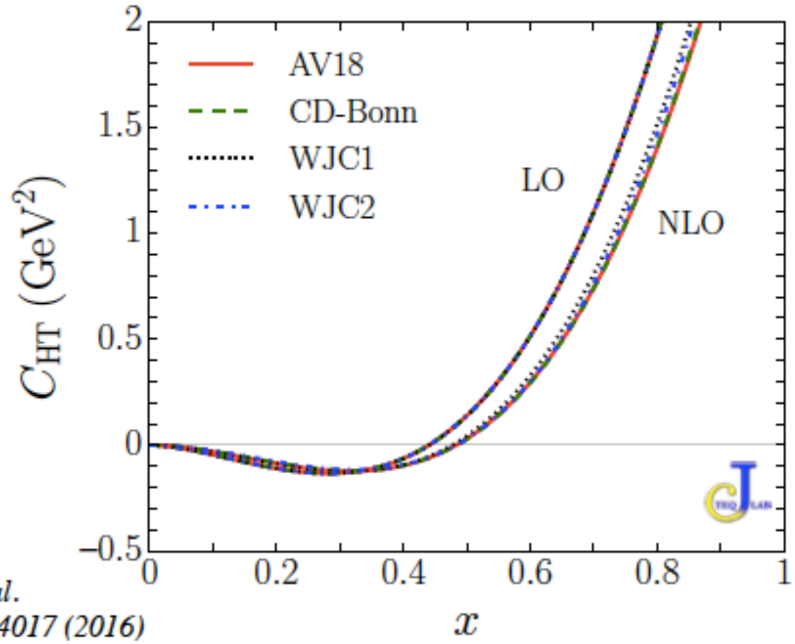
$$a_2(x) = -2\, g_A^e \frac{F_2^{\gamma Z}(x)}{F_2^{\gamma}(x)} \overset{N \sim Z}{\simeq} \frac{9}{5} - 4\sin^2\theta_W - \frac{12}{25}\, \frac{u_A^+(x) - d_A^+(x)}{u_A^+(x) + d_A^+(x)}$$

- Deviation from naive expectation: momentum shifted *from u to d quarks*
- $F_2^{\gamma Z}(x)$ has markedly different flavour dependence compared with $F_2^{\gamma}(x)$
  - a measurement of both enables an extraction of $u(x)$ and $d(x)$ separately
- Proposal to measure $a_2(x)$ of ^{48}Ca was deferred twice …

Dynamical higher twists

- In global QCD analyses parametrize structure function as

$$F_2(x,Q^2) = F_2^{(\mathrm{LT})}(x,Q^2)\left(1+\frac{C_{\mathrm{HT}}(x)}{Q^2}\right)$$



Accardi et al.
PRD 93, 114017 (2016)

$$C_{\mathrm{HT}} = h_0\, x^{h_1}(1+h_2 x)$$

→ cannot accommodate Q^2 dependence of data without power corrections

→ crucial for extracting correct PDFs at high x

→ can do the same with PVDIS data, especially with sufficient Q^2 coverage – isolate isospin dependence of higher twists vs. x!

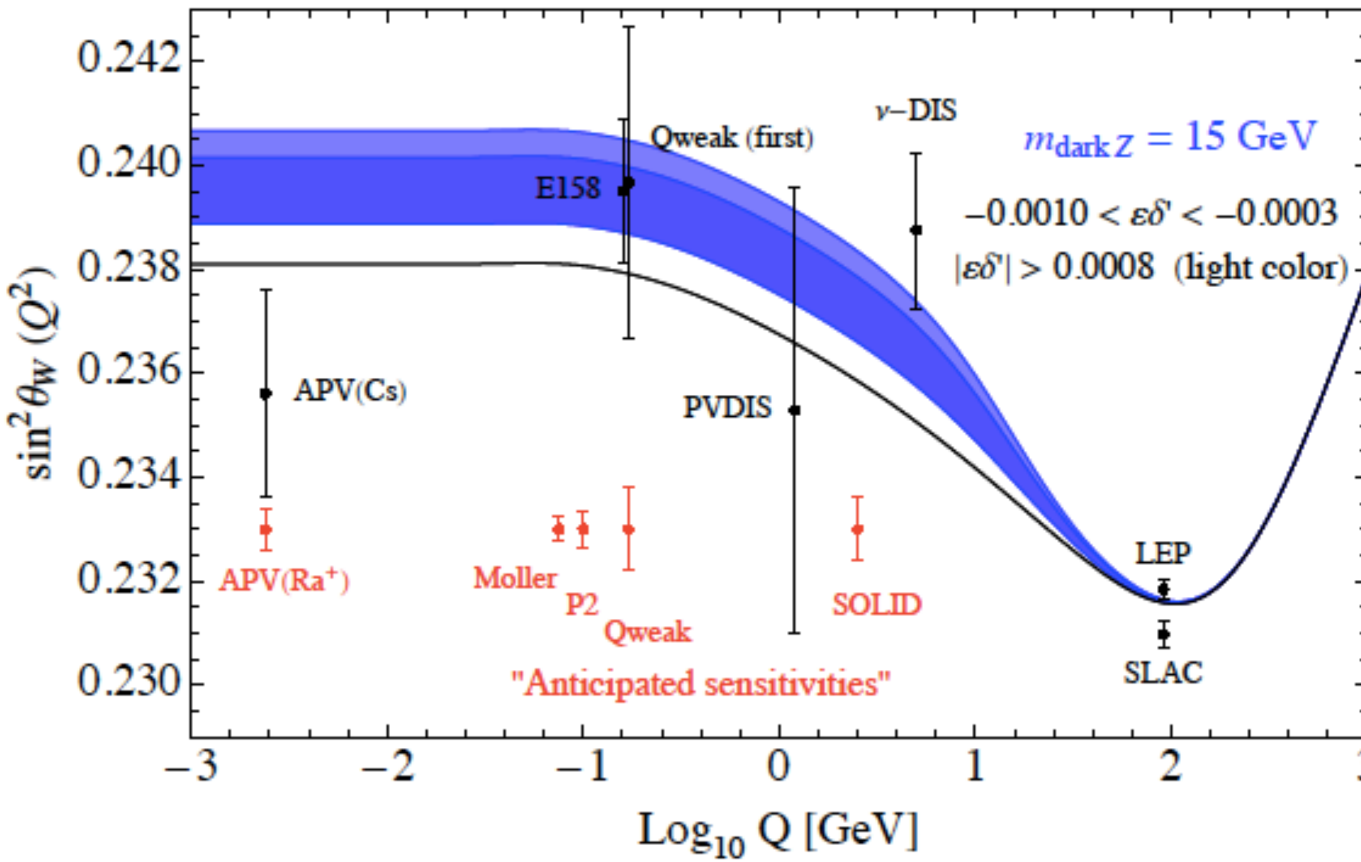


FIG. 1: Running of $\sin^2\theta_W(Q^2)$ with Q^2 due to a Z_d with $m_{Z_d} = 15$ GeV for a 1-sigma fit to $\varepsilon\delta'$ from Eq. (12), shown here as the blue band. The lighter part of the band corresponds to parameters that are in some tension with precision constraints indicated by Eq. (15) (see text for details). The black curve represents the running of $\sin^2\theta_W(Q^2)$ in the SM [14–17]. The sizes of the red error bars only represent the anticipated sensitivities of various experiments. This figure is taken from Ref. [1].