PVDIS: E05-007

- ***The Physics: Why we are here***
- ***Business details***

Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Collaboration matters/Business Details

- Spokespersons:

  Bob Michaels has agreed to join Xiaochao and myself as a co-spokesperson—Thanks!

- Communication Issues:
  - Mailing list (perhaps not yet active)
    - *pvdis@jlab.org*
  - Web site
    - *http://hallaweb.jlab.org/experiment/E05-007/*
    - Still under construction/not yet in existence
    - Please e-mail me(reimer@anl.gov)/Xiaochao a copy of your slides.

Parity Violation Experiments at JLab

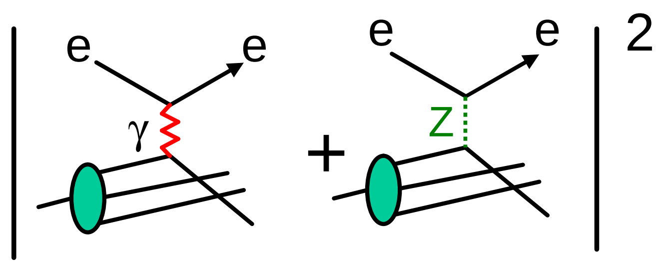
- G0
  - Strange quark form factors
  - 3-40 ppm
- HAPPEX (I, H, ^{4}He)
  - Strange quark form factors
  - 1-10 ppm
- PREX (Pb Parity)
  - RMS neutron radius
  - 0.51 ppm
- QWeak
  - Standard Model $\sin^2\theta_W$
  - 0.3 ppm

- **PV DIS**
  - Standard Model C_{2u} vs. C_{2d}, Higher Twist and more!
  - 100-200 ppm—2 orders of magnitude easier!
  - Allows for a counting expt.

PV DIS probes γ/Z – quark interaction

Total Cross section

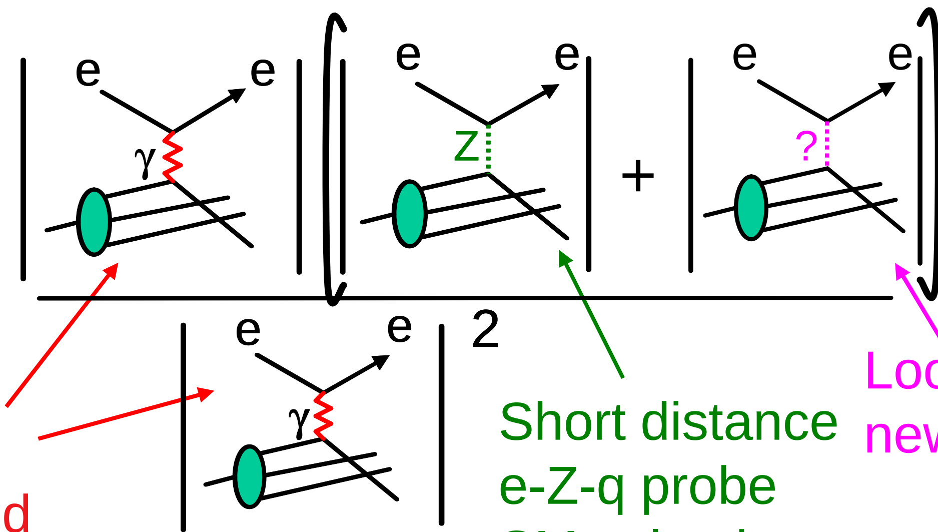
$$\sigma_L + \sigma_R \sim$$



γ-Z amplitudes interfere in SM

PV Asymmetry

$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \sim$$



γ–q large and well understood

Short distance e-Z-q probe SM value known

Look for small new physics

Thanks to Ray Arnold for graphics

PV DIS formalism

$C_{1i} = g^e_V g^i_A$

$C_{2i} = g^e_A g^i_V$

Standard Model Couplings

$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha} \frac{\sum_i q_i f_i(x) \left[C_{1i} + Y C_{2i}\right]}{\sum_i q_i^2 f_i(x)}$$

10^{-4} Q^2

Parton Distributions

- Start of PV DIS program—with different choices of target (^1H, ^2H), x, Y and Q^2 we can explore
  - The Standard Model
  - Higher Twist Effects
  - Parton distributions (CVS and d/u as $x \to 1$)

Standard Model tests

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha} \frac{\sum_i q_i f_i(x)\,[C_{1i} + Y C_{2i}]}{\sum_i q_i^2 f_i(x)}$$

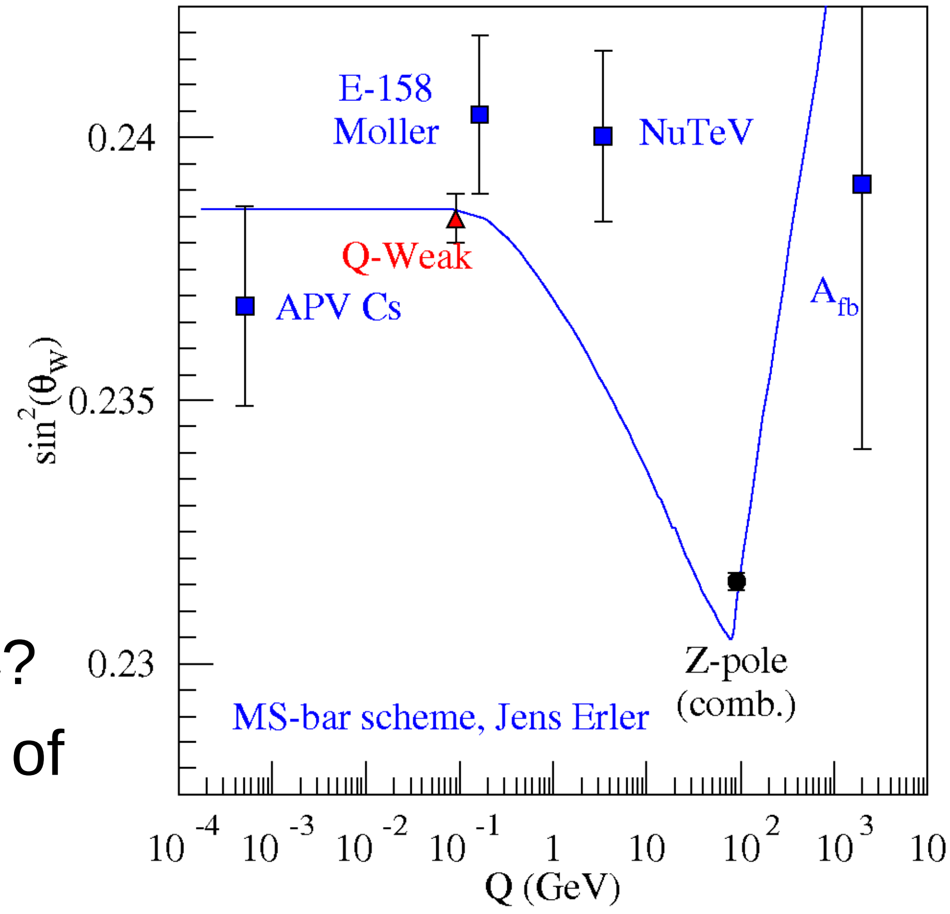
$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \approx -0.19$$

$$C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \approx 0.35$$

$$C_{2u} = -\frac{1}{2} + 2\sin^2(\theta_W) \approx -0.04$$

$$C_{2d} = \frac{1}{2} - 2\sin^2(\theta_W) \approx 0.04$$

with $\sin^2(\theta_W) \approx 0.23$

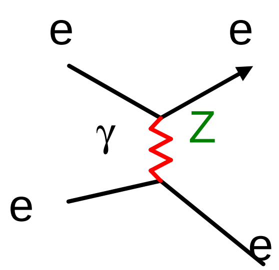


- Variation in running of $\sin^2\theta_W$?
- Process dependent variation of $\sin^2\theta_W$

How does DIS-Parity fit in?

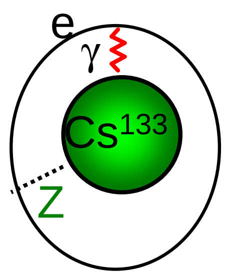
Thanks to Ray Arnold

SLAC E158/Møller



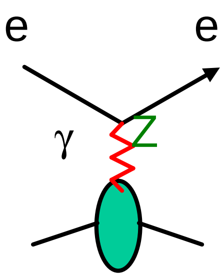
- Purely Leptonic—no quark interactions
- Complete in 2003

Atomic Parity Violation



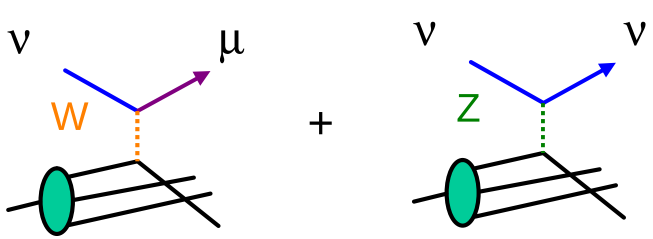
- Coherent quarks in entire nucleus
- Nuclear structure uncertainties
- $-376\ C_{1u} - 422\ C_{1d}$

Q-Weak (JLab)



- Coherent quarks in the Proton
- $2(2C_{1u}+C_{1d})$

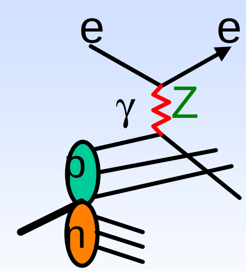
NuTeV (Fermilab)



- Quark scattering (from nucleus)
- Weak charged and neutral current difference

Expt. Probe different parts of Lagrangian

PVDIS



- Isoscaler quark scattering
- $(2C_{1u}-C_{1d})+Y(2C_{2u}-C_{2d})$

Standard Model tests

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha} \frac{\sum_i q_i f_i(x)\,[C_{1i} + Y C_{2i}]}{\sum_i q_i^2 f_i(x)}$$

$$\propto A\,(2C_{1u} - C_{2d}) + BY\,(2C_{2u} - C_{2d})$$

- C_{1i}'s are (will be) well determined
- Slope of PV DIS with Y (kinematic variable) determines $2C_{2u}$-C_{2d}

$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \approx -0.19$$

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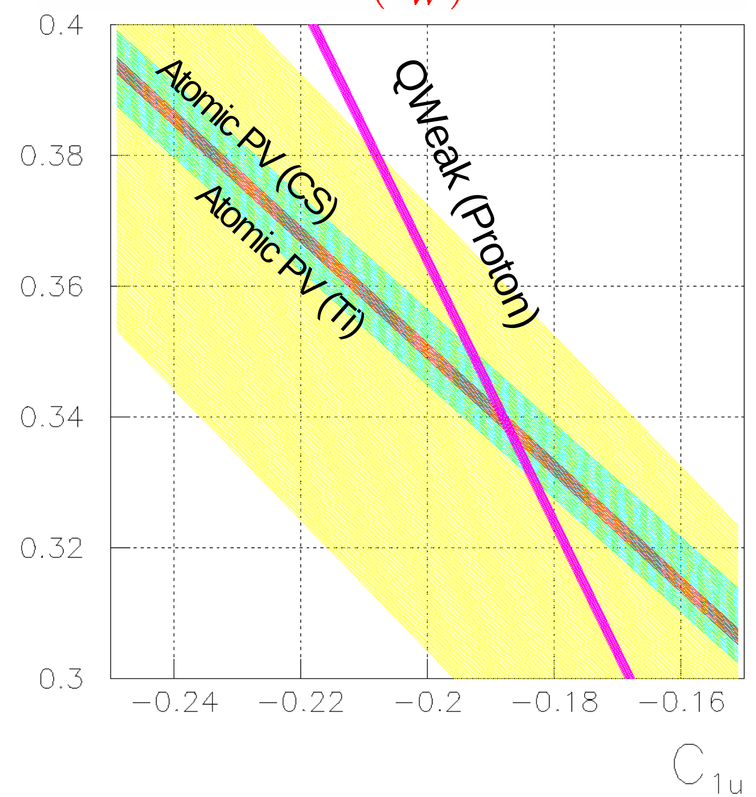


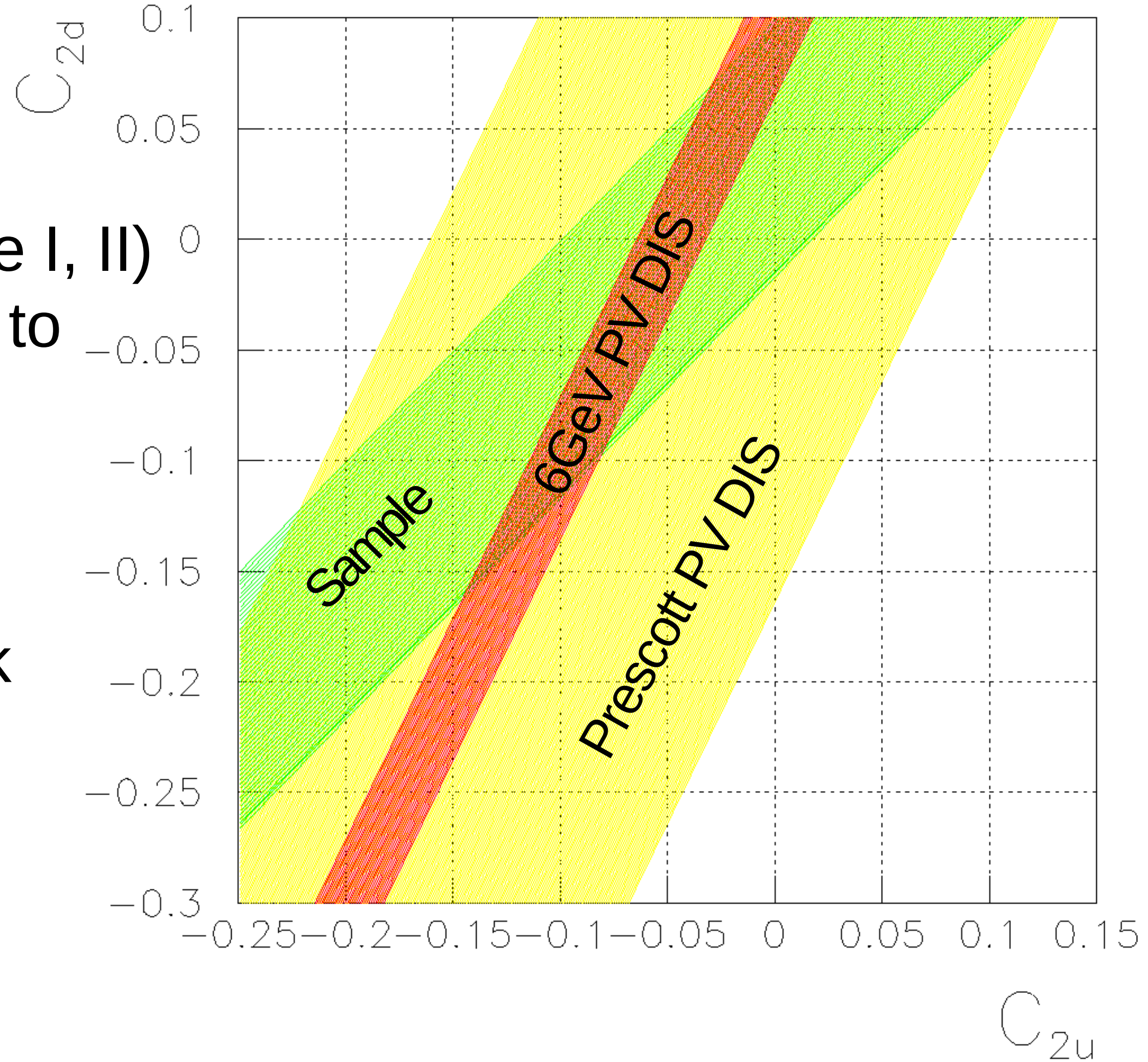
$2C_{2u}$-C_{2d}

- Present data:

  $2C_{2u}-C_{2d} = -0.8 \pm 0.24$

- This experiment (phase I, II) will reduce uncertainty to $\pm$0.03—factor of 8 improvement

- Most sensitive to quark compositeness



Higher Twist effects

- Generally not well determined theoretically—Must be explored experimentally.
- Empirically evident in DIS at $Q^2 < 5$ and $x>0.4$

$$F_2(x,Q^2) = F_2^0(x,Q^2)\left[1 + \frac{C_{HT}(x)}{Q^2} + \ldots\right]$$

- Important to understand—also may contribute to NuTeV anomaly at a level we can measure!
- In A_{PV}, sensitive to diquarks
- For our experiment:
  - Not expected to be large at $0.25 < x < 0.30$
  - 2 Q^2 points to measure this effect

$$A_{PV}(x,Q^2) = A_{PV}^0(x,Q^2)\left[1 + \frac{C_{HT}^{PV}(x)}{Q^2} + \ldots\right]$$

Parton distributions
Charge Symmetry Violation

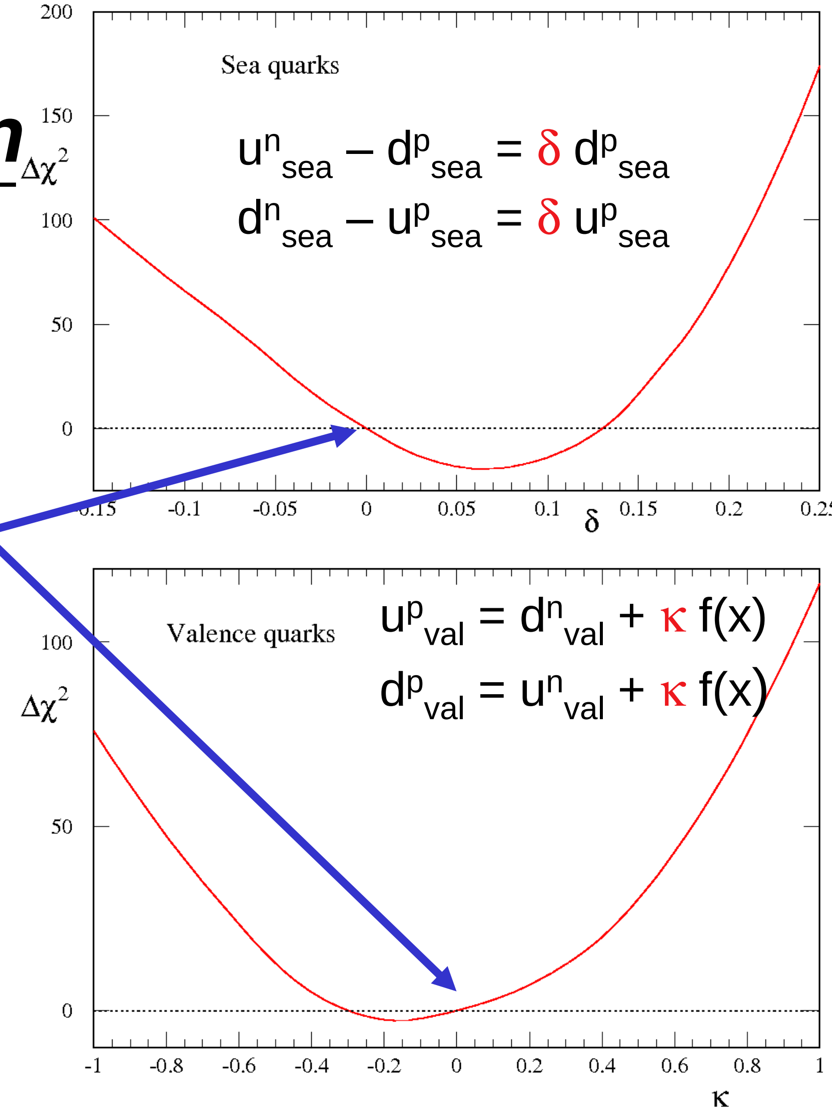
- Charge symmetry violation—everyone assumes it's small

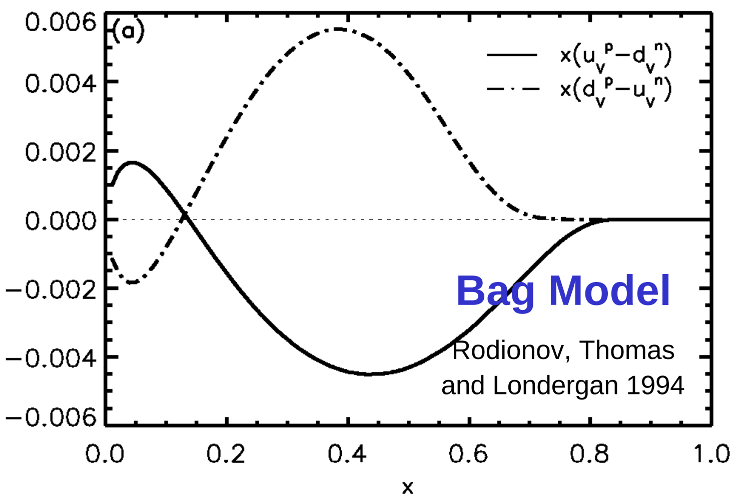
  $u^p(x) - d^n(x) \neq 0$

  $d^p(x) - u^n(x) \neq 0$

- Is it?—MRST fit
  - CSV is only loosely constrained by existing data (χ^2 space is flat)

No CSV

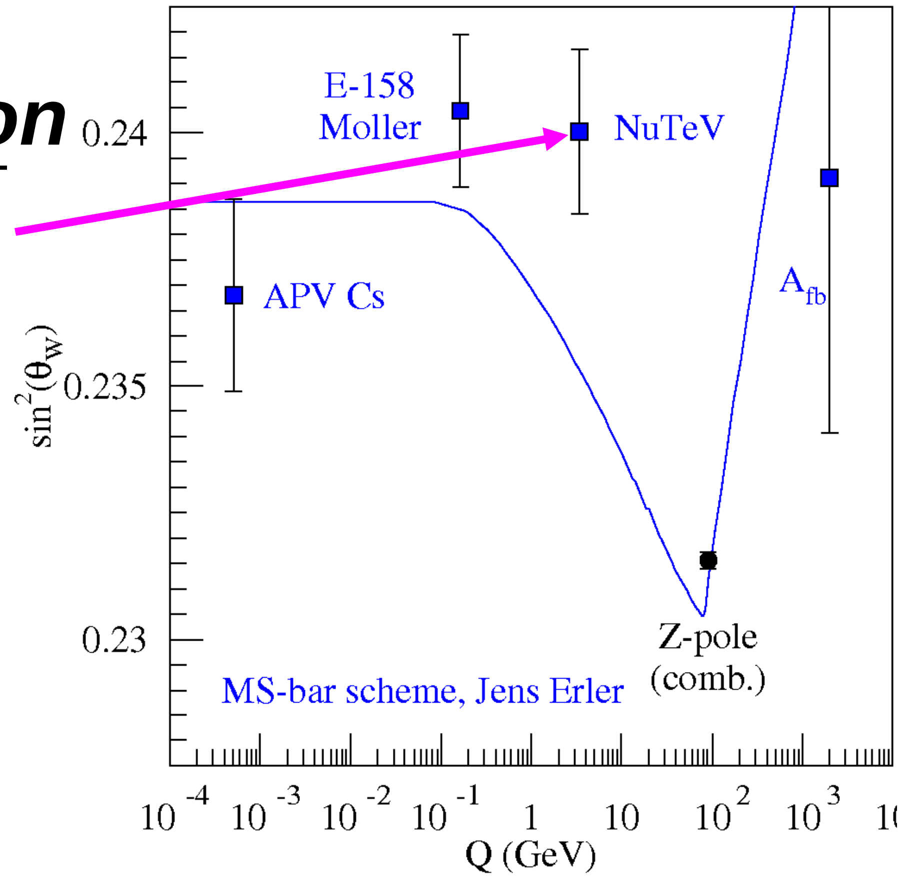




- Bag model calculation of similar shape and magnitude as χ^2 min.

Parton distributions
Charge Symmetry Violation

- NuTeV reported a 3 σ difference from the Standard Model
- At 90% CL, CSV in the sea will either explain or double the discrepancy!!!



PV DIS

$$\frac{\delta A_{PV}^{2H}}{A_{PV}^{2H}} \approx 0.28 \frac{\Delta u(x) - \Delta d(x)}{u^p(x) + d^p(x)}$$

$$\Delta u(x) = u^p(x) - d^n(x)$$

$$\Delta d(x) = d^p(x) - u^n(x)$$

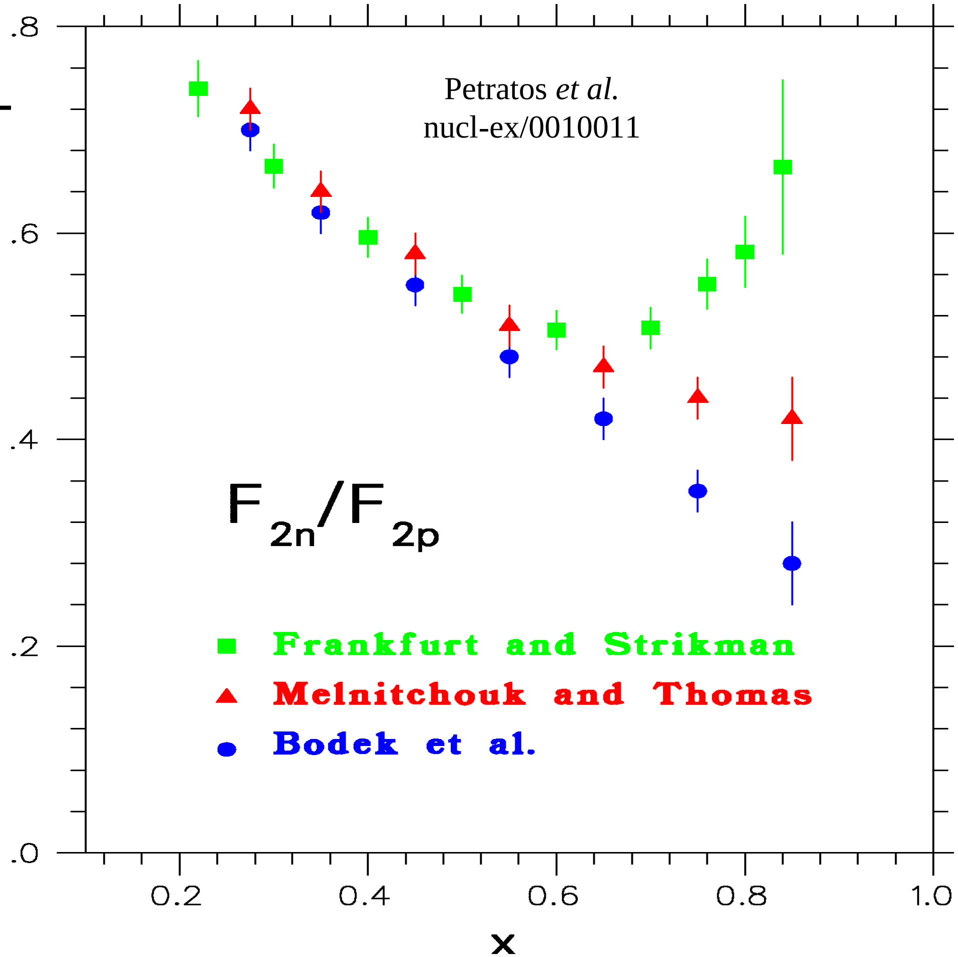
Parton distributions d/u at high-x

Theory

- Exact SU(6):
  - $d/u \to 1/2$ F2n/F2p$\to$ 2/3
- Diquark S=0 dominance:
  - $d/u \to 0$ F2n/F2p$\to$ 1/4
- pQCD:
  - $d/u \to 3/7$ F2n/F2p$\to$ 1/5

Data

- Dominated by understanding of ***nuclear corrections***



PV DIS on Hydrogen

- No Nuclear corrections!!

$$A_{PV}^{1H} \propto \frac{1+0.9\frac{d}{u}}{1+0.25\frac{d}{u}}$$

Additional Possibilities with H_2

- Asymmetry in $\sigma_d - 2\sigma_p$
  - Interpretation does not require knowledge of parton distributions.

$$A_{d2p} = \frac{\sigma_d^L - \sigma_d^R - 2\left(\sigma_p^L - \sigma_p^R\right)}{\sigma_d^L + \sigma_d^R - 2\left(\sigma_p^L + \sigma_p^R\right)}$$

$$= \left(\frac{G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\left[-\frac{1}{2} + 2\sin^2(\theta_W)\right] \times [1+Y]$$

$$\approx -0.65 \times 10^{-5} Q^2 (1+Y)$$

- Ratio of asymmetries: A_p/A_d
  - If C_{1a}'s are known, measures $r(x) \approx d(x)/u(x)$ at large x.
  - Polarization cancels out.

$$\left(\frac{A_p}{A_d}\right) = \left(\frac{2C_{1u} - r(x)C_{1d}}{2C_{1u} - C_{1d}}\right)\left(\frac{5}{4 + r(x)}\right)$$

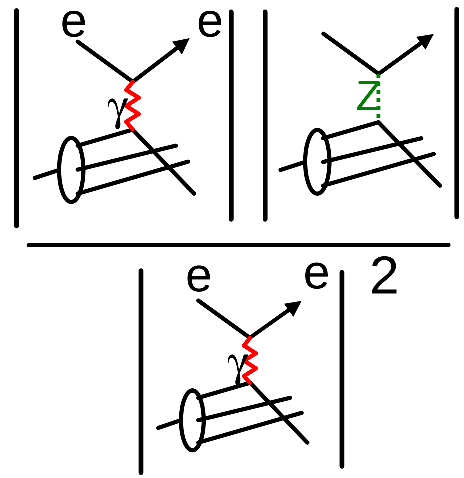
$$r(x) \approx d(x)/u(x)$$

Thanks to Peter Bosted

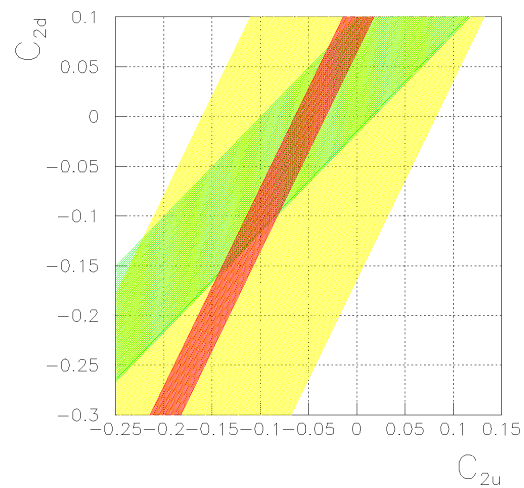
Physics Conclusions

- PV DIS is technically much less difficult that previous JLab Parity Violation experiments
- PV DIS probes both parton level questions and the Standard Model (blessing and curse).
- At 6 GeV we will use PVDIS to
  - Probe C_{2u} vs. C_{2d}
  - Check HT contributions

$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \sim$$



$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha} \frac{\sum_i q_i f_i(x)\,[C_{1i} + Y C_{2i}]}{\sum_i q_i^2 f_i(x)}$$



Factor of 8 improvement