Beyond the Standard Model: Experiment

Electroweak Physics: Moller and DIS Parity

Thanks to Bosted, Brodsky, Kumar,
Londergan, Meziani, Michaels,
Reimer, Ramsey-Musolf,
Paschke, Pitt, Zheng

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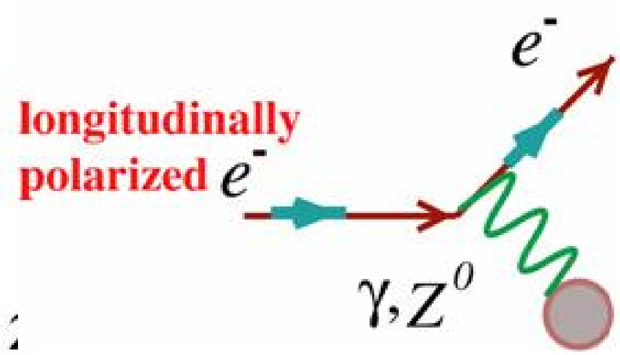
Outline

- Parity-Violating Electron Scattering
  - Brief Overview
  - Weak Neutral Current Interactions at $Q^2 << M_Z^2$
- Parity-Violating Møller Scattering
  - Ultimate Precision at $Q^2 << M_Z^2$: 25 TeV Reach
  - Complementary to Q_{weak}
- Parity-Violating Deep Inelastic Scattering
  - New Physics at 10 TeV in Semileptonic Sector
  - Charge Symmetry Violation
  - d/u at High x
  - Higher Twist Effects

PV Asymmetries

Weak Neutral Current (WNC) Interactions at $Q^2 << M_Z^2$

Longitudinally Polarized
Electron Scattering off
Unpolarized Fixed Targets



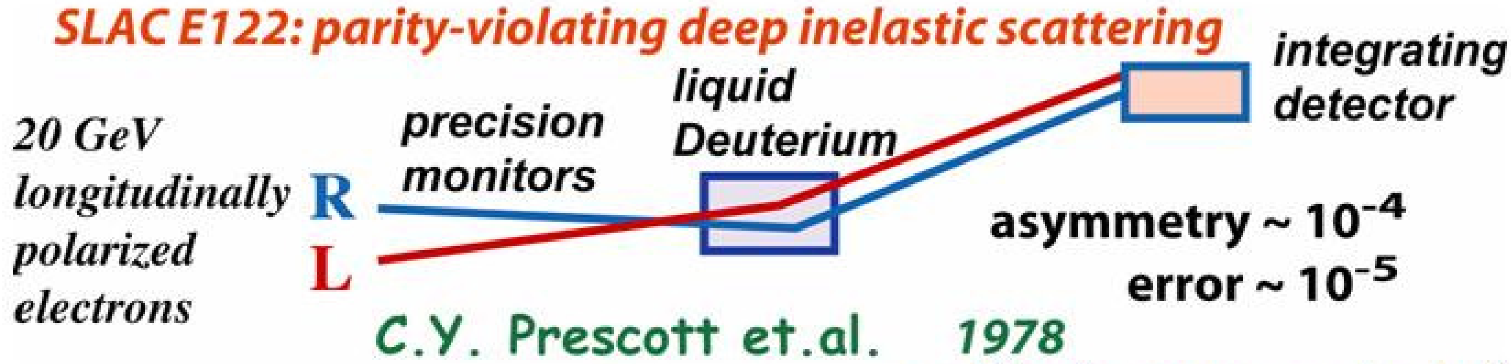
$$\sigma \propto | A_\gamma + A_{weak} |^2$$

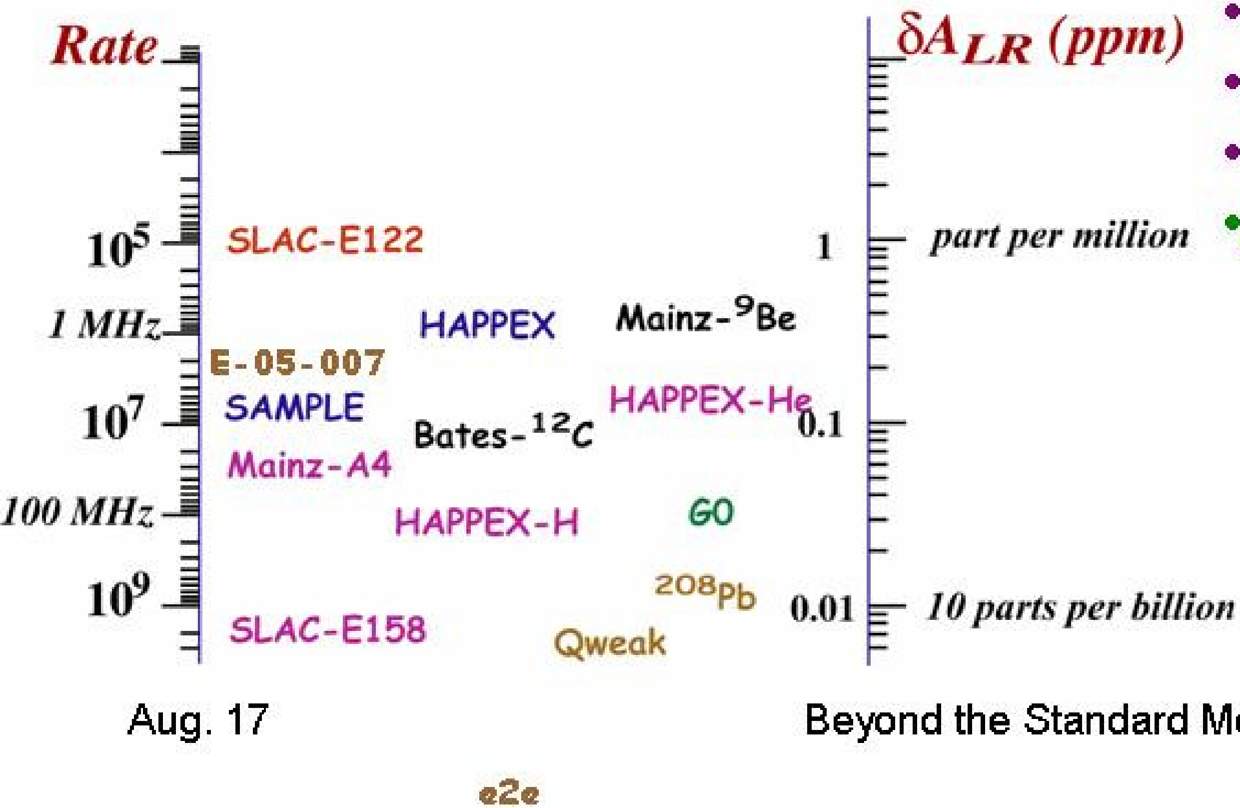
$$-A_{LR} = A_{PV} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \sim \frac{A_{weak}}{A_\gamma} \sim \frac{G_F Q^2}{4\pi\alpha} \left(g_A^e g_V^T + \beta g_V^e g_A^T\right)$$

- *The couplings g depend on electroweak physics as well as on the weak vector and axial-vector hadronic current*
- *With specific choice of kinematics and targets, one can probe new physics at high energy scales*
- *With other choices, one can probe novel aspects of hadron structure*

A_{PV} Measurements

$$A_{PV} \sim 10^{-5} \cdot Q^2 \;\; \text{to} \;\; 10^{-4} \cdot Q^2 \;\; \Rightarrow \;\; 0.1 \text{ to } 100 \text{ ppm}$$

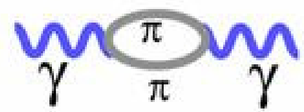


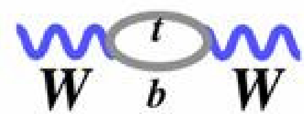


- Steady progress in technology
- part per billion systematic control
- 1% normalization control
- JLab now takes the lead
  - -New results from HAPPEX
  - -Photocathodes
  - -Polarimetry
  - -Targets
  - -Diagnostics
  - -Counting Electronics

The Standard Model

How the Standard Model (and Beyond) Works

Input α_{QED} G_F 



M_Z

Output G_0 σ_Z M_W A_f

Nuclear Physics Long Range Plan:
What is the new standard model?

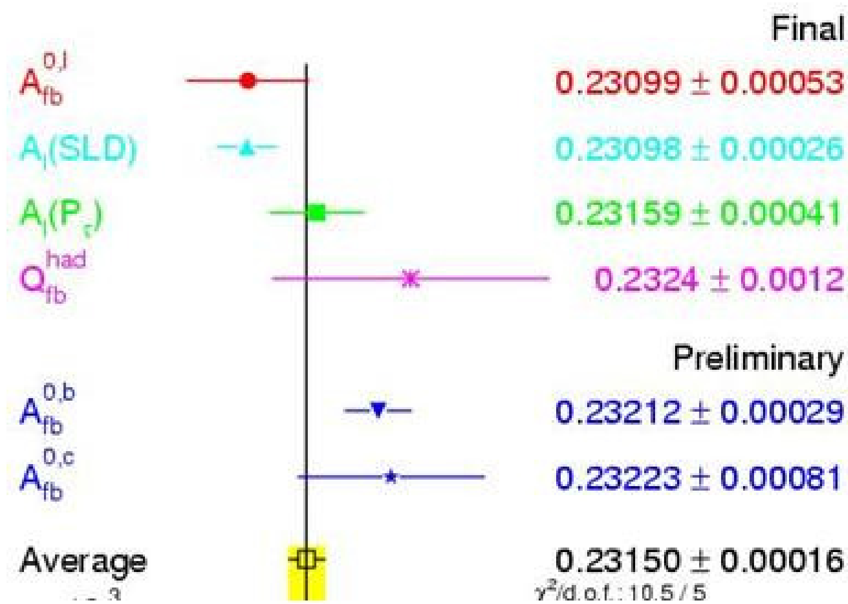
- Precise predictions at level of 0.1%
- Indirect access to TeV scale physics

- *Rare or Forbidden Processes* - *Double beta decay..*
- *Symmetry Violations* - *neutrinos, EDMs..*
- *Electroweak One-Loop Effects* - *Muon g-2, beta decay..*

Low Q^2 offers unique and complementary probes of new physics

World Electroweak Data on $\sin^2\theta_W$

Most experts see the precision data as remarkably consistent

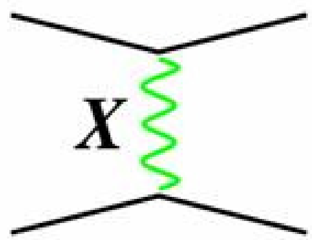


Will discoveries at the LHC imply observable deviations?

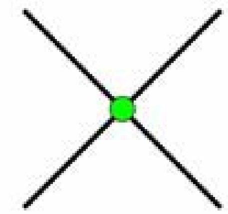
Electroweak Physics at Low Q^2

$Q^2 \ll$ scale of EW symmetry breaking

consider



$$A_X \;\alpha\; \frac{1}{Q^2 - M_X^2} \longrightarrow \quad \sim \frac{4\pi}{\Lambda^2}$$



Contact interaction

$Q^2 \sim M_Z^2$ **on resonance:** A_Z *imaginary* $\longrightarrow A_Z^2 \left[1 + \frac{A_X^2}{A_Z^2} \right]$

no interference!

Logical to push to higher energies, away from the Z resonance

LHC access scales greater than $\Lambda \sim 10\,TeV$

$$\frac{\delta A_Z}{A_Z} \;\alpha\; \frac{\pi/\Lambda^2}{g\,G_F} \longrightarrow \begin{array}{l} \delta(g)/g \sim 0.1 \\ \Lambda \sim 10\,TeV \end{array}$$

$$\frac{\delta(\sin\theta_W)}{\sin^2\theta_W} \lesssim 0.01$$

***Complementary:* Parity Violating vs Parity Conserving**

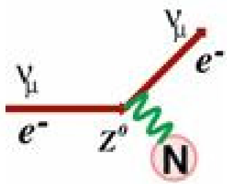
WNC Low Q^2 Processes

Atomic Parity Violation (APV) → series of isotopes

APV on Cs •*Limited by theory: Atomic structure; Neutron Halo*

Semi-Leptonic → PV Elastic electron-proton scattering at JLab Q_{weak}

PV Deep Inelastic Scattering at 6 and 11 JLab

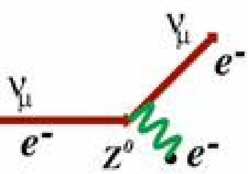


NuTeV
- *High luminosity makes high precision in PVDIS possible.*
- *Unique, complementary probes of New Physics*
- *Theoretical issues are interesting in themselves:*

Unique, outstanding opportunity for a dedicated apparatus with JLab upgrade

Leptonic → ν-e scattering in reactor

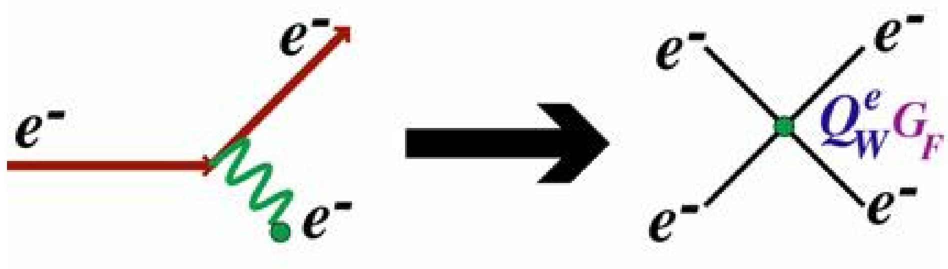
Møller scattering at upgraded JLab



E158
- *Reactor experiment cannot do better than SLAC E158*
- *Dedicated new apparatus at upgraded JLab can do significantly better:*

Best low energy measurement until Linear Collider or ν-Factory

Fixed Target Møller Scattering



Purely leptonic reaction

Weak charge of the electron:

$Q_W^e \sim 1 - 4\sin^2\theta_W$

$$A_{PV} \propto m_e E_{lab} (1 - 4\sin^2 \vartheta_W) \Rightarrow \frac{\delta(\sin^2 \vartheta_W)}{\sin^2 \vartheta_W} \cong 0.05 \frac{\delta(A_{PV})}{A_{PV}}$$

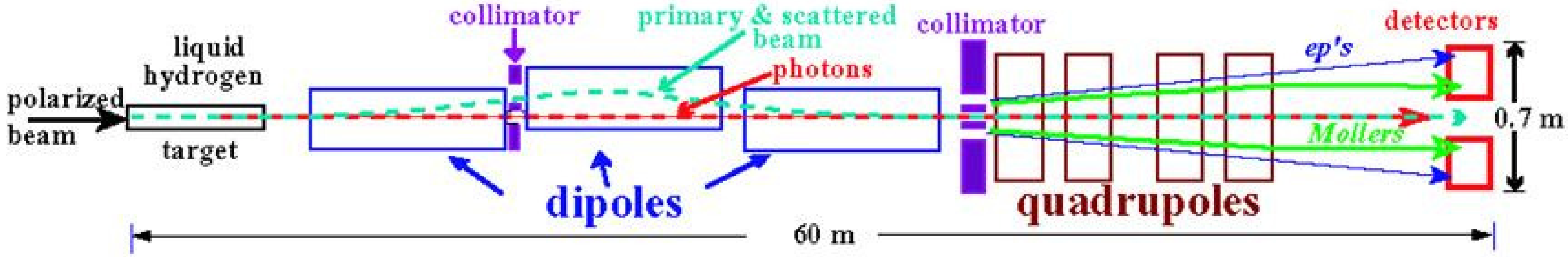
$$\sigma \propto \frac{1}{E_{lab}} \Rightarrow$$ ***Figure of Merit rises linearly with E_{lab}***

- Maximal at 90° in COM ($E' = E_{lab}/2$)
- Highest possible E_{lab} with good P^2I ← SLAC E158
- Moderate E_{lab} with LARGE P^2I ← Jlab at 12 GeV

Unprecedented opportunity: The best precision at $Q^2 << M_Z^2$ with the least theoretical uncertainty until the advent of a linear collider or a neutrino factory

Present Results and Future Experiments

Q^e_{weak} : Electron Weak Charge - SLAC E158 Experiment



Parity-violating Moller scattering

$Q^2 \sim .026\ GeV^2$

$\theta \sim 4 - 7$ mrad

$E \sim 48\ GeV$

at SLAC End Station A

Final results: hep-ex/0504049

$A_{PV} = -131 \pm 14\ (stat) \pm 10\ (syst)$ ppb

$\sin^2\theta_{eff}(Q^2{=}0.026\ GeV^2) = 0.2397 \pm 0.0010 \pm 0.0008$

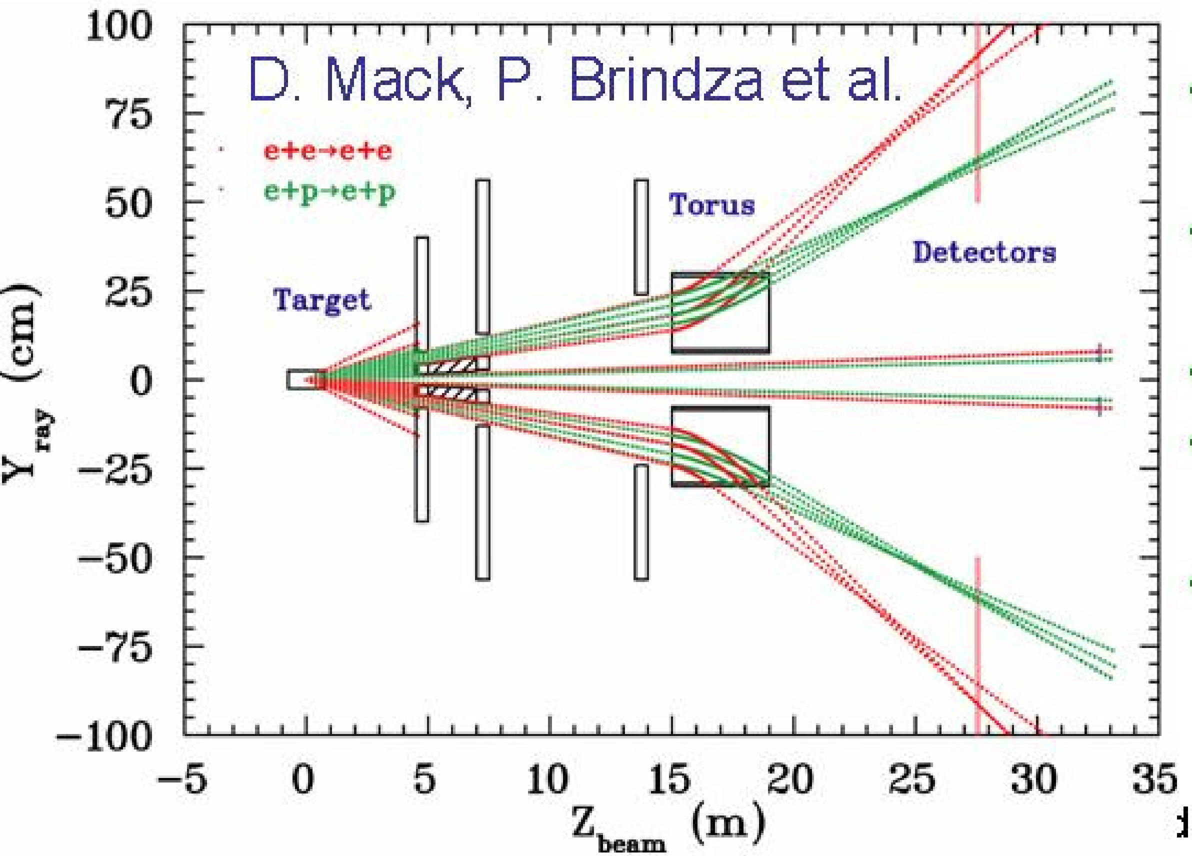
Running of $\sin^2\theta_{eff}$ established at 6σ level in pure leptonic sector

Design for 11 GeV

E': 3-6 GeV — $\theta_{lab} = 0.53^o$-0.92^o — $A_{PV} = 40$ ppb

$I_{beam} = 90\ \mu A$ — *150 cm LH_2 target* — *4000 hours*

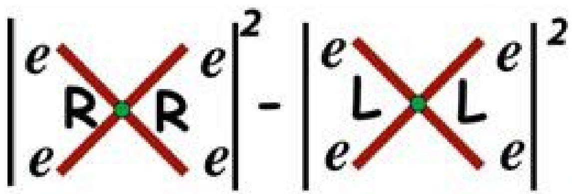
Toroidal spectrometer → **ring focus** — $\delta(A_{PV})=0.58$ ppb



- *Beam systematics: steady progress (E158 Run III: 3 ppb)*
- *Focus alleviates backgrounds:*
  $ep \rightarrow ep(\gamma)$, $ep \rightarrow eX(\gamma)$
- *Radiation-hard integrating detector*
- *Normalization requirements similar to other planned experiments*
- *Cryogenics, density fluctuations and electronics will push the state-of-the-art*

d Model

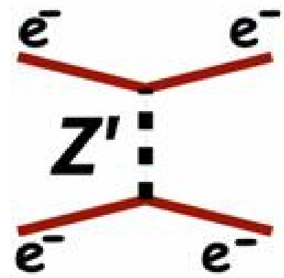
New Physics Reach

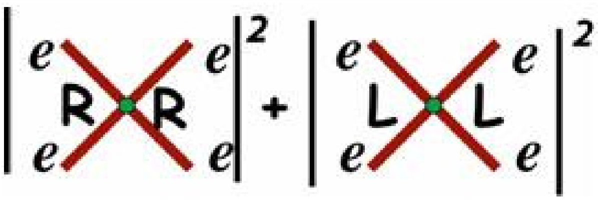


JLab Møller

$\Lambda_{ee} \sim 25$ TeV

New Contact Interactions

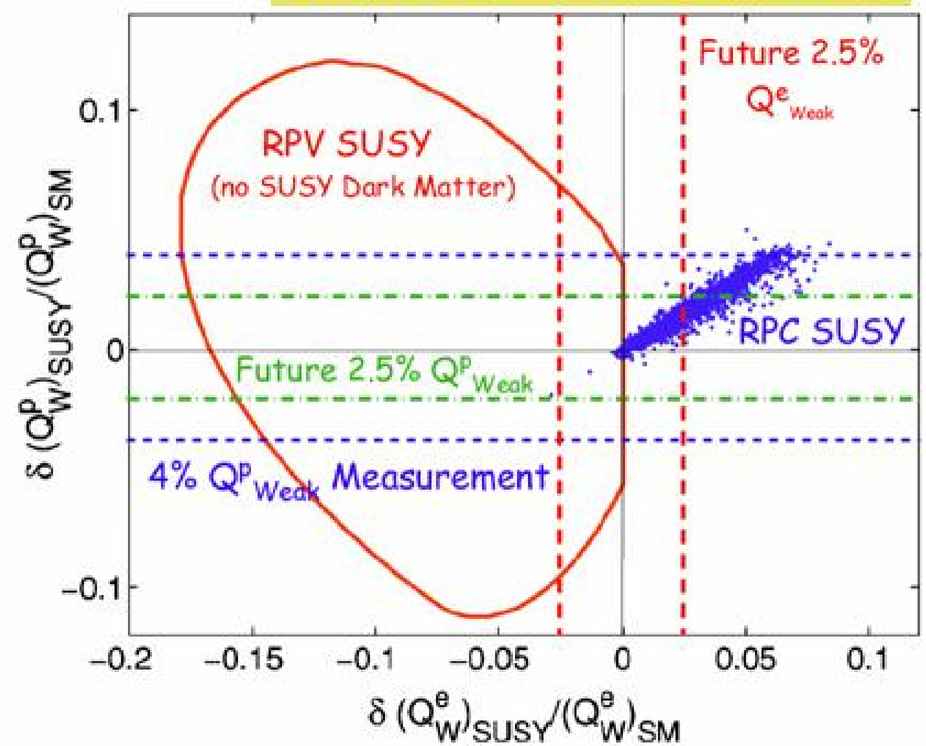




LEP200

$\Lambda_{ee} \sim 15$ TeV

Kurylov, Ramsey-Musolf, Su



Does Supersymmetry (SUSY) provide a candidate for dark matter?

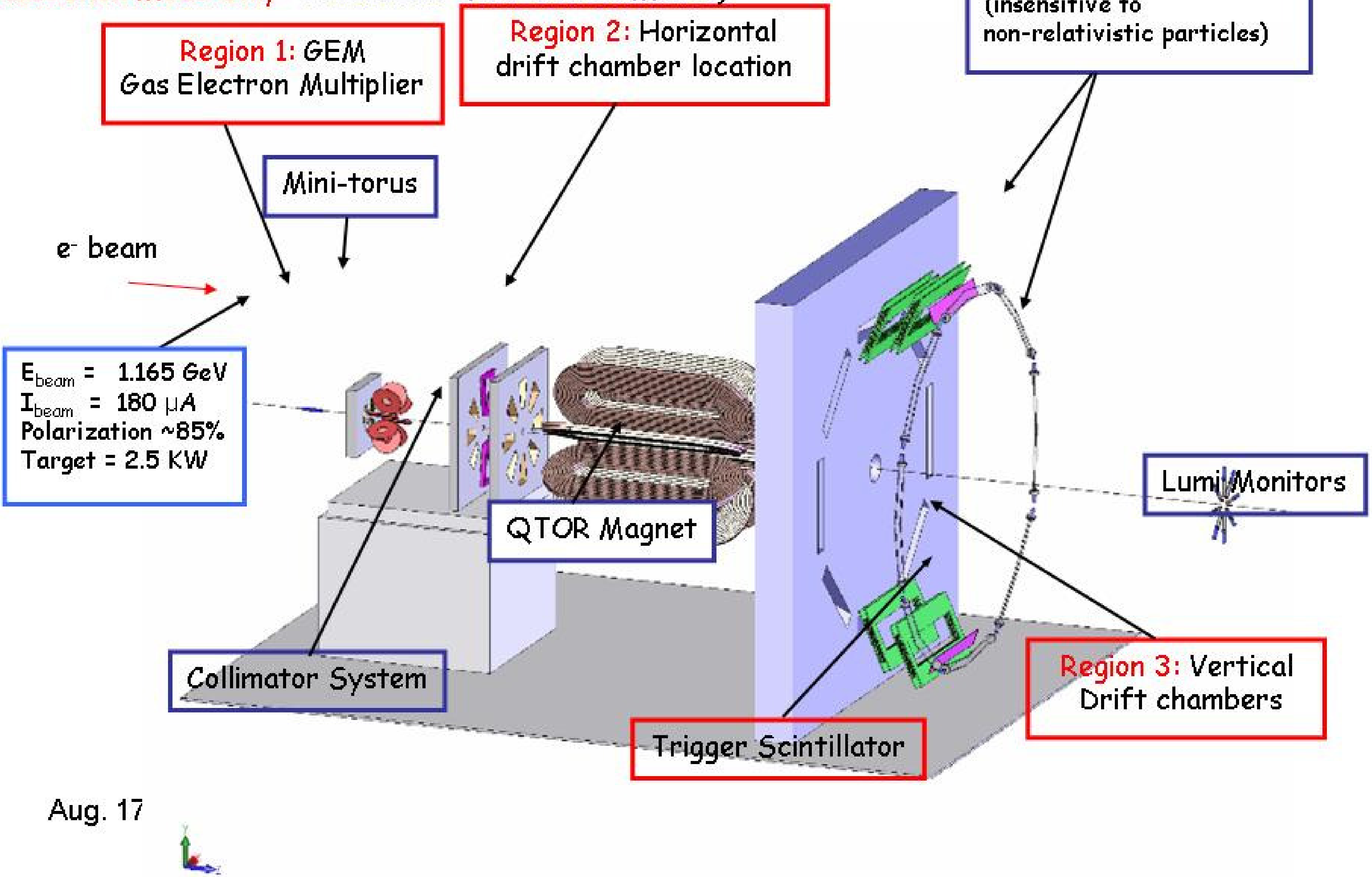
- Lightest SUSY particle (neutralino) is stable if baryon (B) and lepton (L) numbers are conserved

- However, B and L need not be conserved in SUSY, leading to neutralino decay (RPV)

Q_{weak} is good practice for e2e

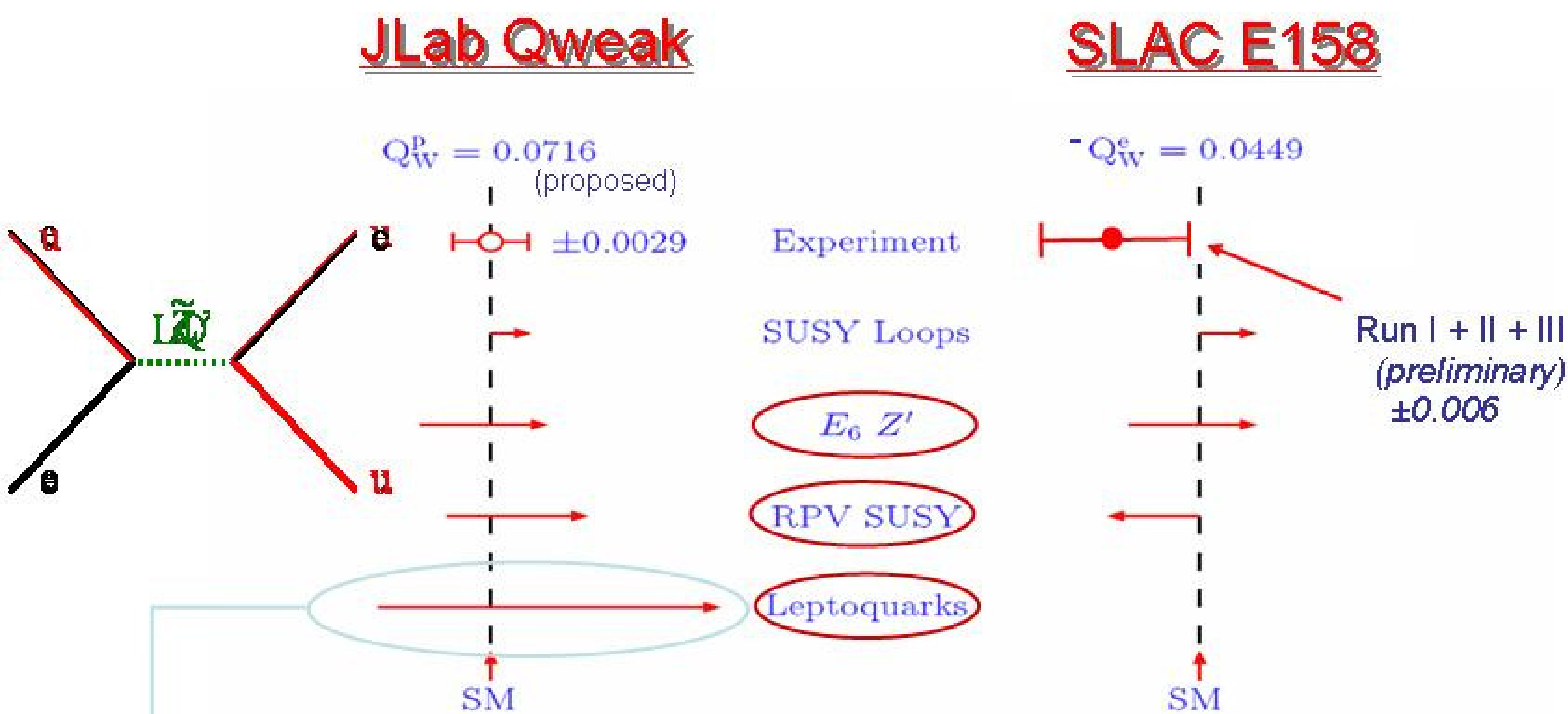
The Qweak Apparatus

(Calibration Mode Only - Production & Calibration Modes)



Aug. 17

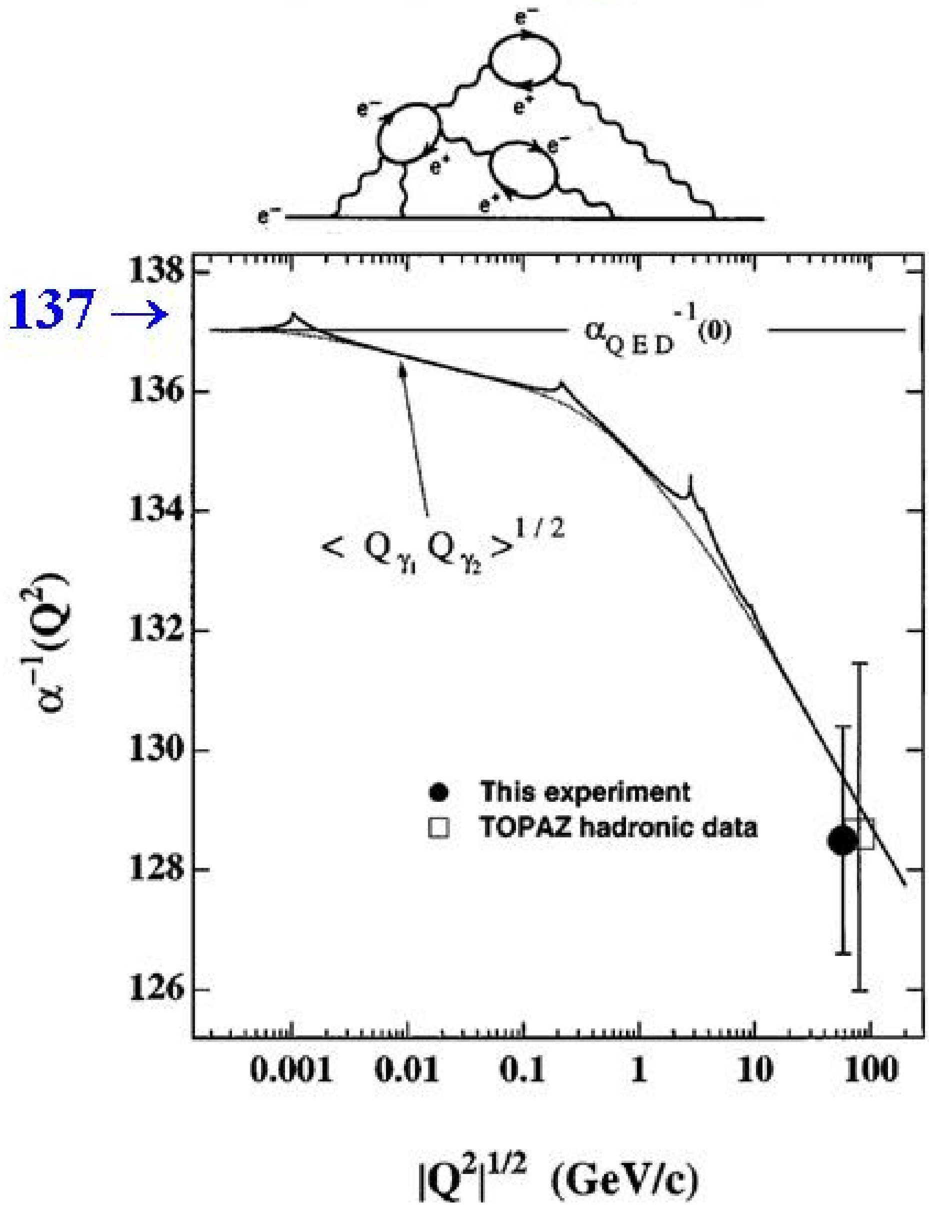
Q^p_{weak} & Q^e_{weak} – Complementary Diagnostics for New Physics



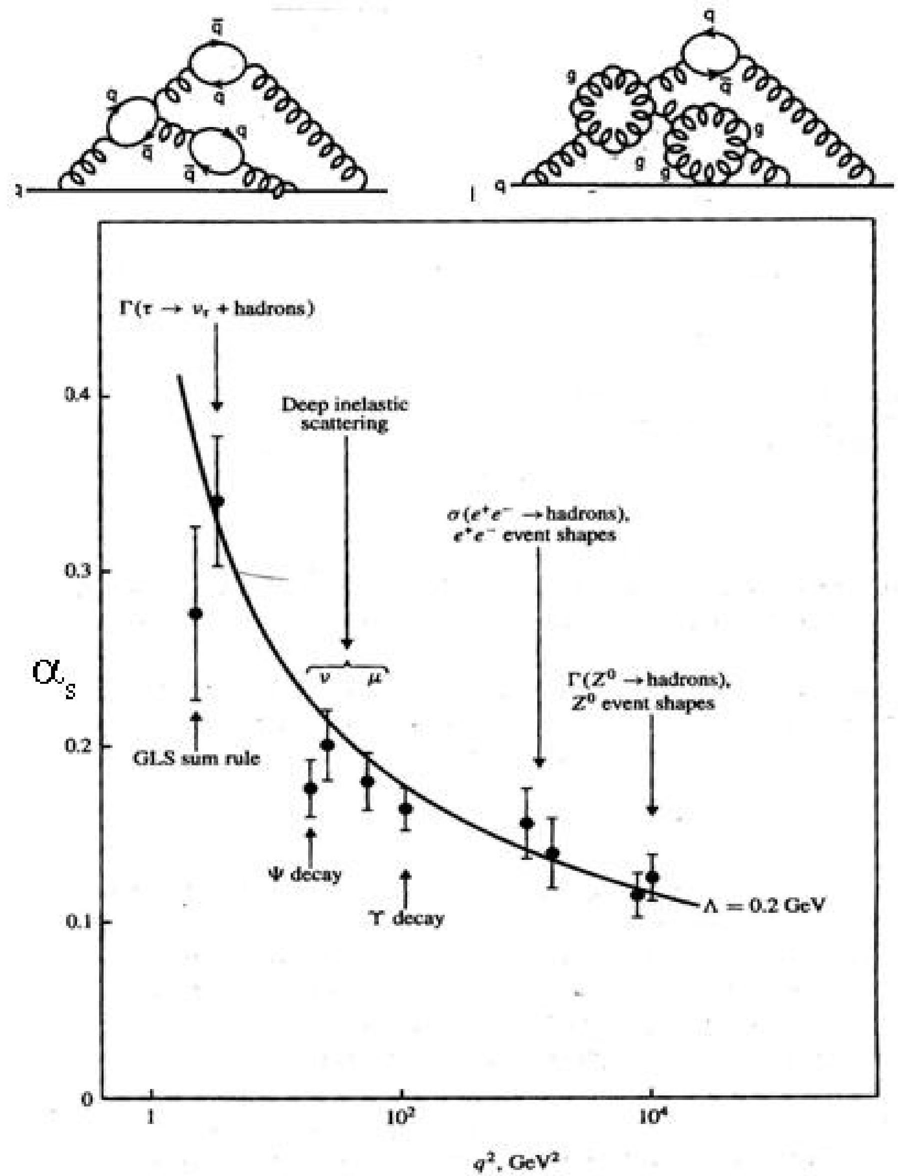
- Qweak measurement will provide a stringent stand alone constraint on Lepto-quark based extensions to the SM.
- Q^p_{weak} (semi-leptonic) and E158 (pure leptonic) together make a powerful program to search for and identify new physics.

Running coupling constants in QED and QCD

QED (running of α)

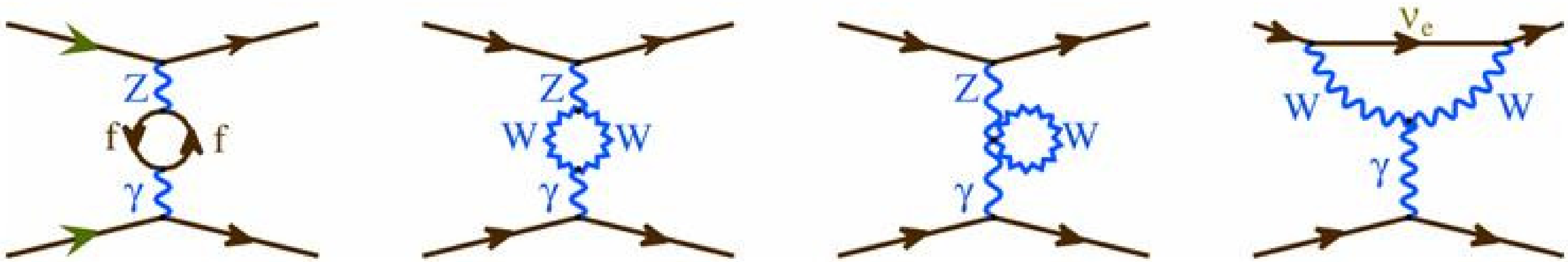


QCD(running of α_s)



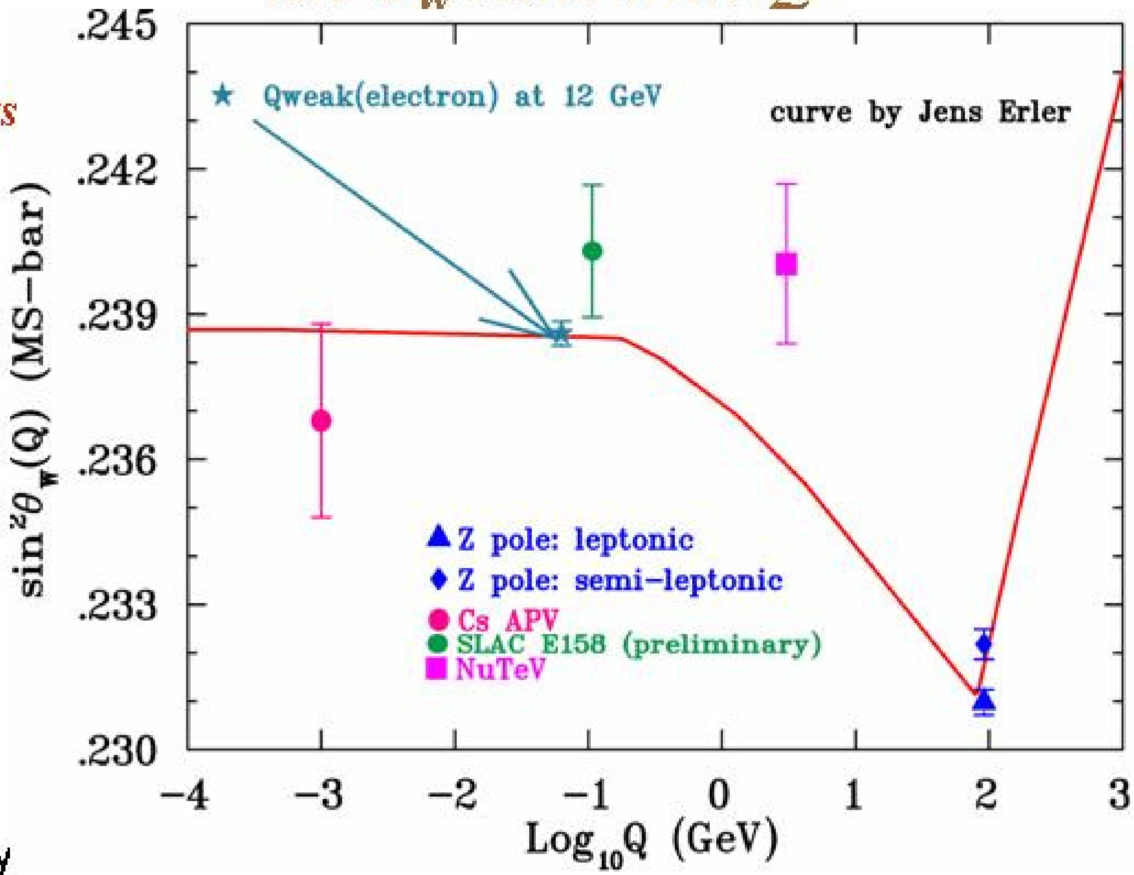
What about the running of $\sin^2\theta_W$?

Running of $\sin^2\theta_W$



Q_W^e *modified*

$\sin^2\theta_W$ *runs with* Q^2



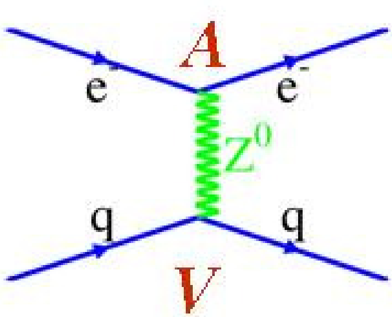
$\delta(\sin^2\theta_W) \sim 0.0003$

Comparable to single collider measurements

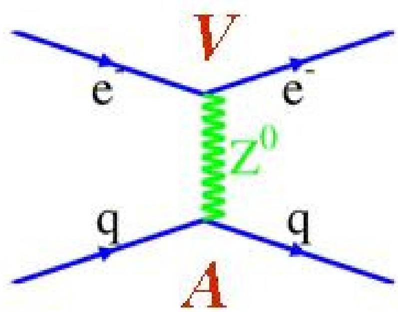
- *JLab measurement would have impact on discrepancy between leptonic and hadronic Z-pole measurements*

Parity Violation in Deep Inelastic Scattering

Electron-Quark Phenomenology



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



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

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

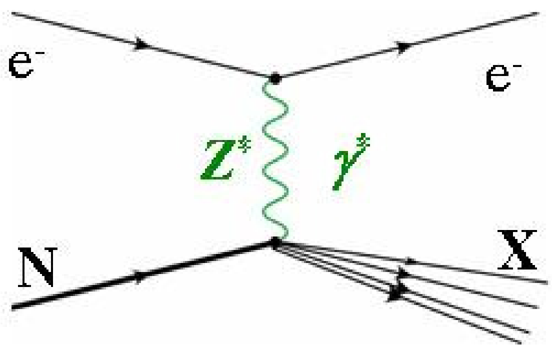
C_{1u} and C_{1d} will be determined to high precision by Q_{weak}, Cs

C_{2u} and C_{2d} are small and poorly known:
one combination can be accessed in PV DIS

New physics such as compositeness, new gauge bosons, leptoquarks:
Deviations to C_{2u} and C_{2d} might be fractionally large

Approved (concept) JLab experiments at 6(11) GeV will improve knowledge of $2C_{2u}$-C_{2d} by more than a factor of 8(20).

Parity Violating Electron DIS



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

$$a(x) = \frac{\sum_i C_{1i} Q_i f_i(x)}{\sum_i Q_i^2 f_i(x)} \qquad b(x) = \frac{\sum_i C_{2i} Q_i f_i(x)}{\sum_i Q_i^2 f_i(x)} \qquad y \equiv 1 - E'/E$$

$f_i(x)$ are quark distribution functions

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

Provided $Q^2 >> 1$ GeV^2 and $W^2 >> 4$ GeV^2 and $x \sim 0.2 - 0.4$

$$a(x) = \frac{3}{10}\left[(2C_{1u} - C_{1d})\right] + \cdots \qquad b(x) = \frac{3}{10}\left[(2C_{2u} - C_{2d})\frac{u_v(x) + d_v(x)}{u(x) + d(x)}\right] + \cdots$$

Must measure A_{PV} to fractional accuracy on the order of 1%

- *11 GeV at high luminosity makes very high precision feasible*
- *JLab is uniquely capable of providing beam of extraordinary stability*
- *Systematic control of normalization errors being developed at 6 GeV*

E05-007: Start PVDIS at 6 GeV (Approved)

R. Michaels (JLab), P. Reimer (ANL), X. Zheng (ANL)
and the Hall A Collaboration

- Asymmetry to be measured:

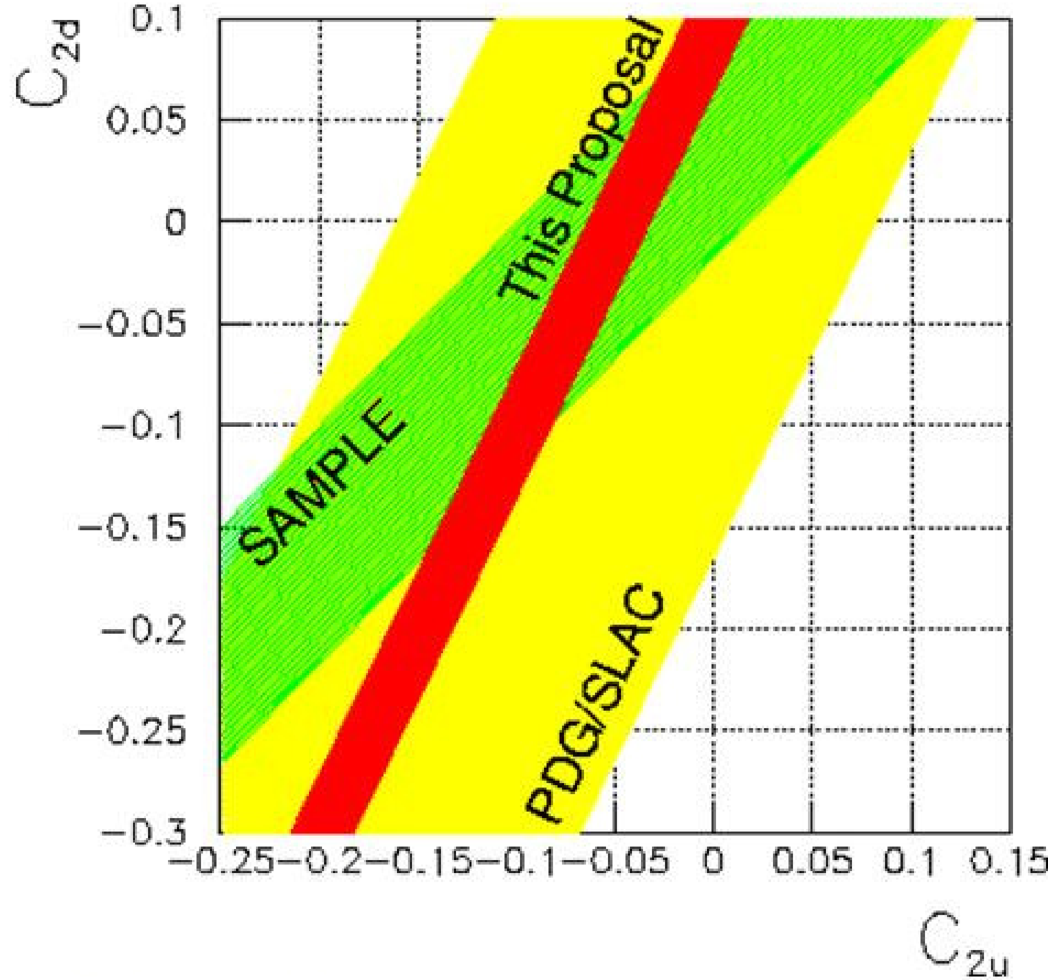
$$A_d = \left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\frac{2C_{1u}[1+R_c(x)] - C_{1d}[1+R_s(x)] + Y(2C_{2u} - C_{2d})R_v(x)}{5 + R_s(x) + 4R_c(x)}$$

- Experimental Setup:
  - 85uA, 6 GeV, “parity-quality” 80% pol. beam;
  - 25-cm LD2 target;
  - Two HRS detect scattered electrons.

- Measure A_d at Q^2=1.10 and Q^2=1.90 (GeV/c)^2 to 2% (stat.);

Goals at 6 GeV

- From A_d at Q^2=1.90 (GeV/c)^2, can extract ($2C_{2u}$-C_{2d}) to an uncertainty of 0.03 (factor of 8 improvement compared to PDG);
  - provide constraints on new physics & test of the Standard Model up to 1 TeV mass limit;
- Z' Searches:
- Compositeness (4-fermion contacts)
- Leptoquarks.



- The A_d at Q^2=1.10 (GeV/c)^2 will help to investigate if there are significant hadronic (higher-twist) effects: (12 GeV, NuTeV…)

^{2}H Experiment at 11 GeV

E': 5.0 GeV ± 10%

$\theta_{lab} = 12.5^o$

$I_{beam} = 90\ \mu A$

60 cm LD_2 target

- Use both HMS and SHMS to increase solid angle
- ~2 MHz DIS rate, π/e ~ 2-3

$A_{PV} = 217$ ppm

$x_{Bj} \sim 0.235$, $Q^2 \sim 2.6\ GeV^2$, $W^2 \sim 9.5\ GeV^2$

1000 hours

Advantages over 6 GeV:

- *Higher Q^2, W^2, $f(y)$*
- *Lower rate, better π/e*
- *Better systematics: 0.7%*

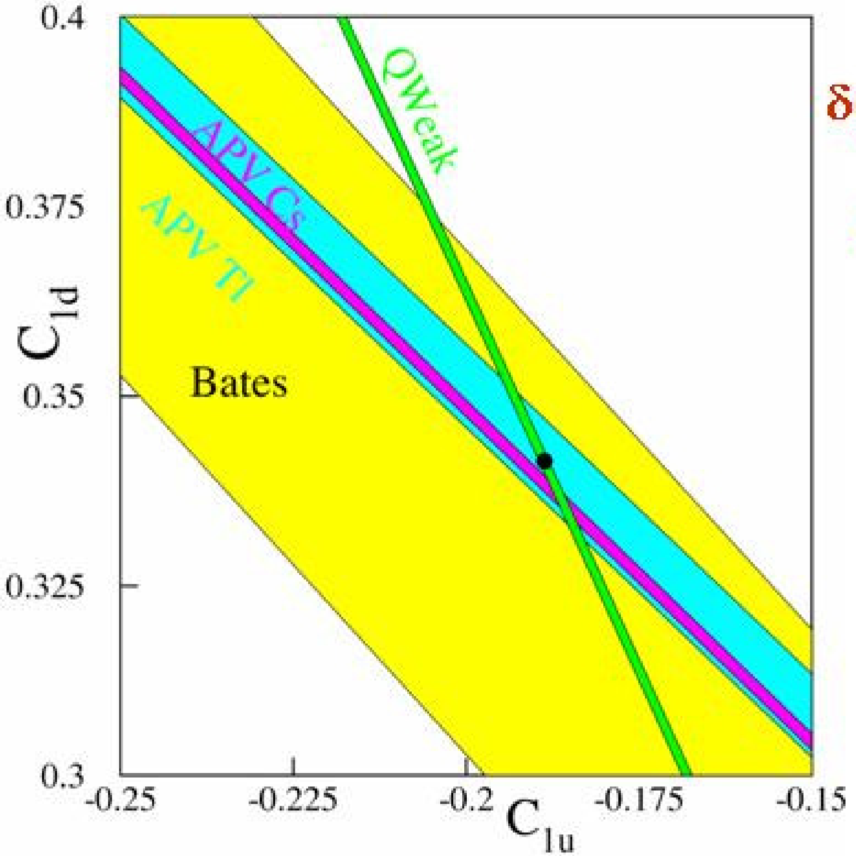
$\delta(A_{PV})$=0.65 ppm

$\delta(2C_{2u}-C_{2d}) = \pm 0.0086 \pm 0.0080$

Theory: +0.0986

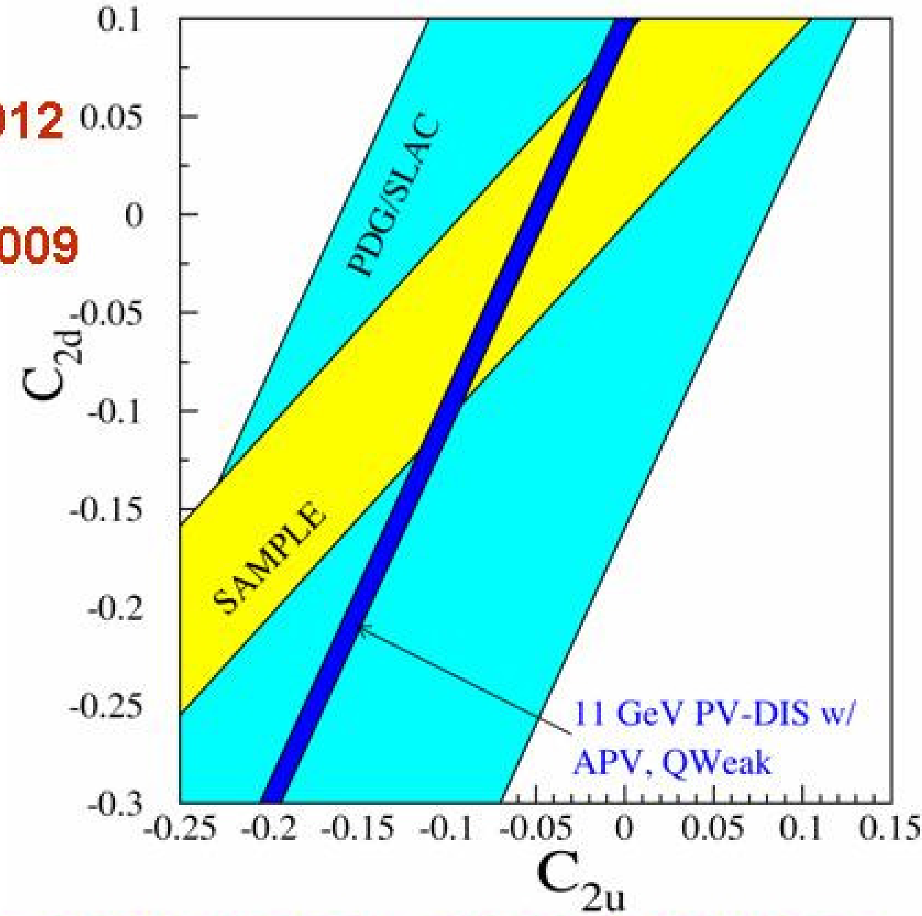
PDG (2004): -0.08 ± 0.24

Physics Implications



$\delta(2C_{2u}-C_{2d})=0.012$

$\delta(\sin^2\theta_W)=0.0009$



Unique, unmatched constraints on axial-vector quark couplings:

→ ***Complementary to LHC direct searches***

Examples:

- ***1 TeV extra gauge bosons (model dependent)***
- ***TeV scale leptoquarks with specific chiral couplings***

Why should we believe DISparity when no one Believes NuTeV?

Measuring $\sin^2\theta_W$ with NuTeV

$$R^{\nu} \equiv \frac{\sigma\langle \nu N_0 \longrightarrow \nu X\rangle}{\sigma\langle \nu N_0 \longrightarrow \mu X\rangle} = g_L^2 + r\, g_R^2 \qquad r \equiv \frac{\sigma\langle \overline{\nu} N_0 \longrightarrow \overline{\mu} X\rangle}{\sigma\langle \nu N_0 \longrightarrow \mu X\rangle}$$

$$R^{\overline{\nu}} \equiv \frac{\sigma\langle \overline{\nu} N_0 \longrightarrow \overline{\nu} X\rangle}{\sigma\langle \overline{\nu} N_0 \longrightarrow \overline{\mu} X\rangle} = g_L^2 + \frac{1}{r} g_R^2$$

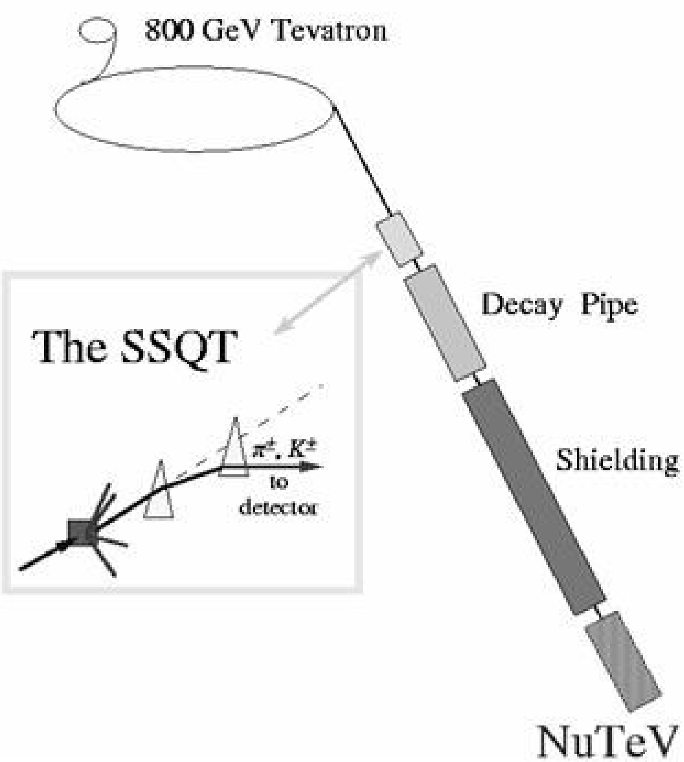
$$R^{PW} \equiv \frac{R^{\nu} - r\, R^{\overline{\nu}}}{1 - r} = \frac{\sigma\langle \nu N_0 \longrightarrow \nu X\rangle - \sigma\langle \overline{\nu} N_0 \longrightarrow \overline{\nu} X\rangle}{\sigma\langle \nu N_0 \longrightarrow \mu X\rangle - \sigma\langle \overline{\nu} N_0 \longrightarrow \overline{\mu} X\rangle} = \frac{1}{2} - \sin^2\theta_W$$

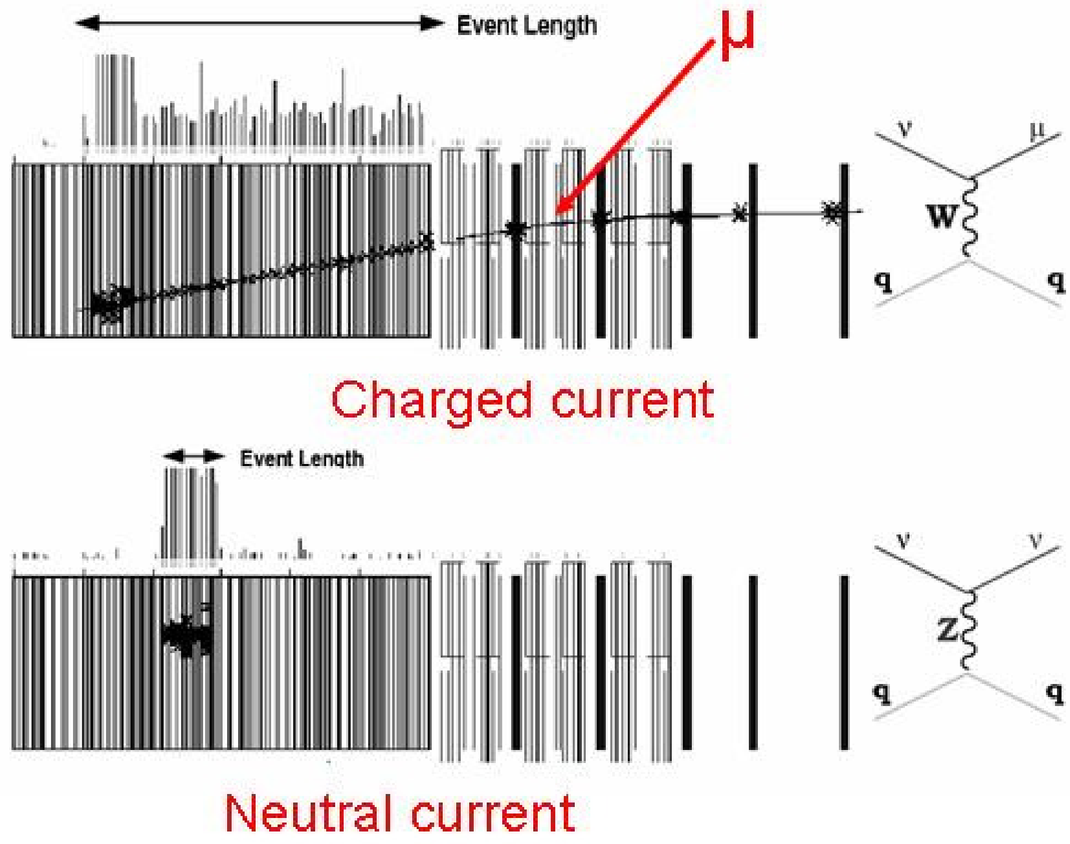
Paschos & Wolfenstein (PR **D7**, 91 (73)):
PW ratio → minimizes sensitivity to PDFs, higher-order corrections

Result is off by 2.8 σ

The NuTeV Experiment

Features very large kinematic acceptance





Assumptions for the Paschos-Wolfenstein Ratio

PW Ratio depends on the following assumptions:

JLab 12 GeV issues

- Isoscalar target (N=Z)
- include only light (u, d) quarks
- neglect heavy quark masses
- assume isospin symmetry for PDFs
- no nuclear effects (parton shadowing, EMC, ...)
- no higher twist effects
- radiative corrections OK? (γ-W boxes?)
- no contributions outside Standard Model

Nobody believes that this is the problem

PV DIS can Address Issues Raised by NuTeV

- Analysis assumed control of QCD uncertainties
  - Higher twist effects
  - Charge Symmetry Violation (CSV)
  - d/u at high x
- NuTeV provides perspective
  - Result is 3σ from theory prediction
  - Generated a lively theoretical debate
  - Raised very interesting nucleon structure issues: cannot be addressed by NuTeV
- JLab at 11 GeV offers new opportunities
  - PV DIS can address issues directly
    - Luminosity and kinematic coverage
    - Outstanding opportunities for new discoveries
    - Provide confidence in electroweak measurement

Search for CSV in PV DIS

$u^p(x) = d^n(x)$?

$d^p(x) = u^n(x)$?

- u-d mass difference
- electromagnetic effects

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

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

- *Direct observation of parton-level CSV would be very exciting!*
- *Important implications for high energy collider pdfs*
- *Could explain significant portion of the NuTeV anomaly*

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

$$\frac{\delta A_{PV}}{A_{PV}} = 0.28 \frac{\delta u - \delta d}{u + d}$$

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

Strategy:

- ***measure or constrain higher twist effects at x ~ 0.5-0.6***
- ***precision measurement of A_{PV} at x ~ 0.7 to search for CSV***

Phenomenological Parton CSV PDFs

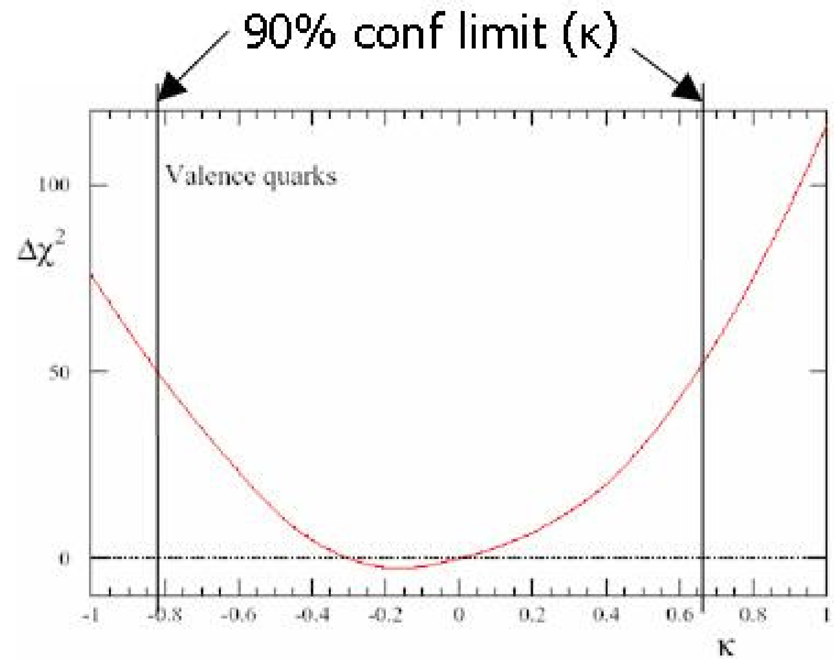
MRST Phenomenological PDFs include CSV for 1st time:

Martin, Roberts, Stirling, Thorne (03):

Choose restricted form for parton CSV:

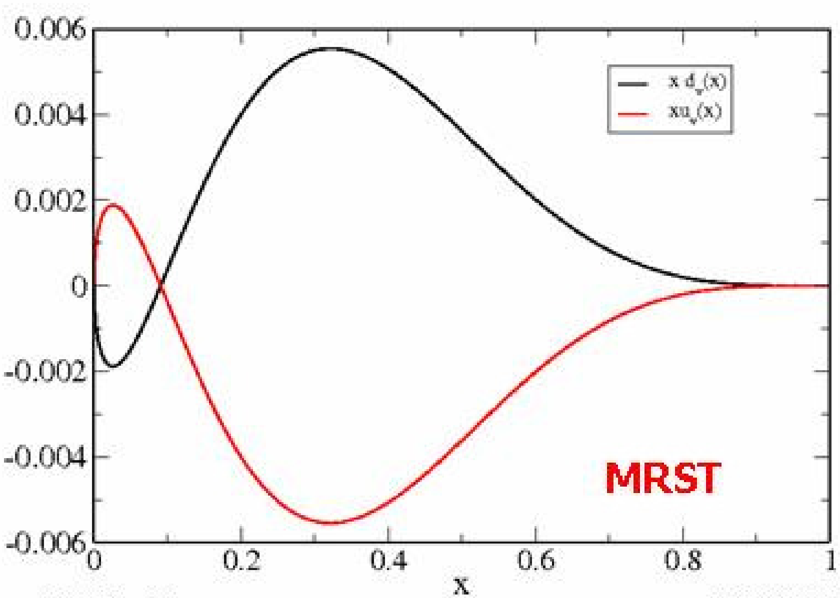
$$x\delta d_V(x) = -\kappa f(x) = -x\delta u_V(x)$$
$$f(x) = x^{0.5}(1-x)^4(x-.0909)$$

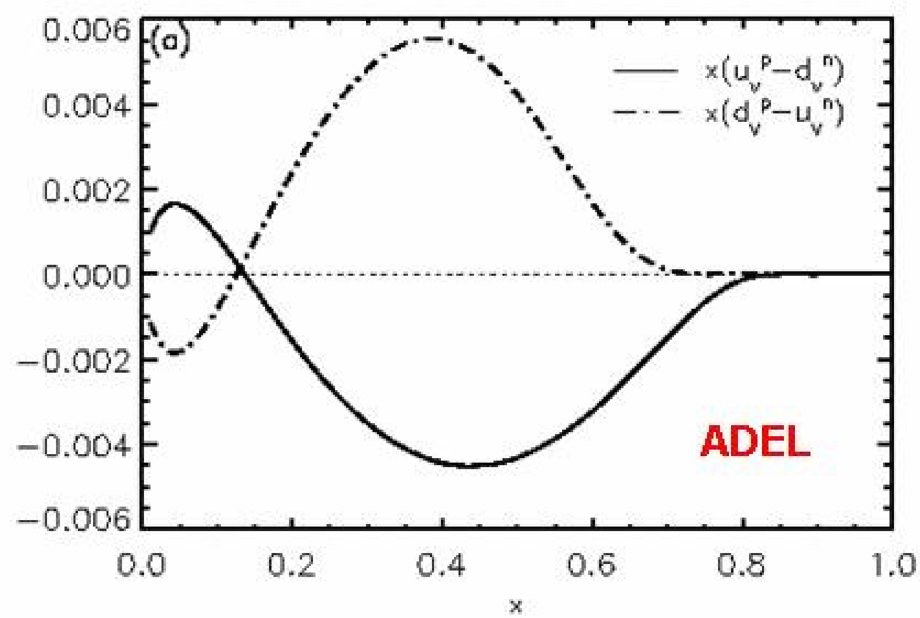
[f(x): 0 integral; matches to valence at small, large x]



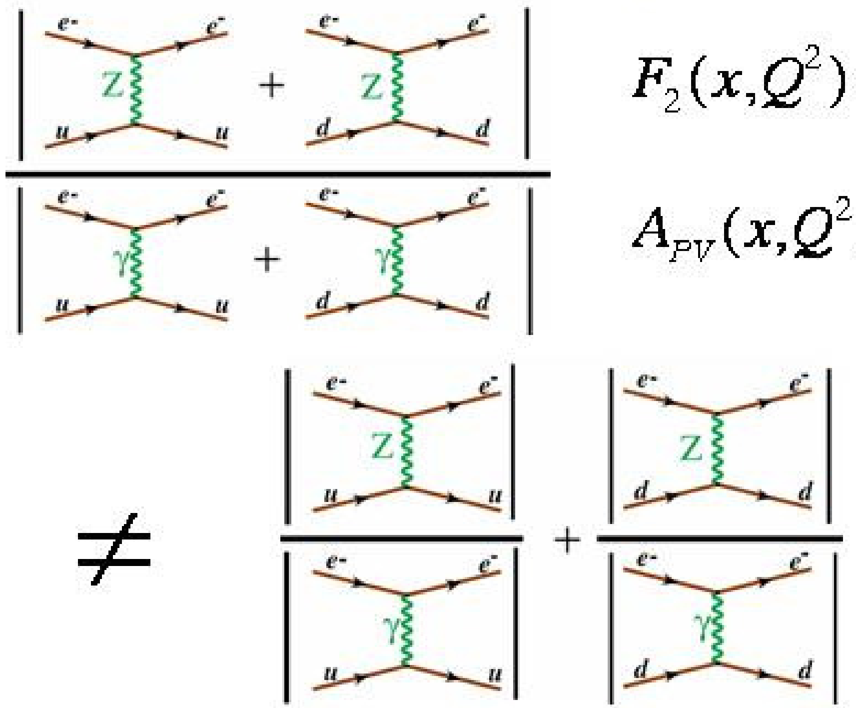
Best fit: **κ = -0.2**, large uncertainty !

Best fit remarkably similar to model CSV predictions





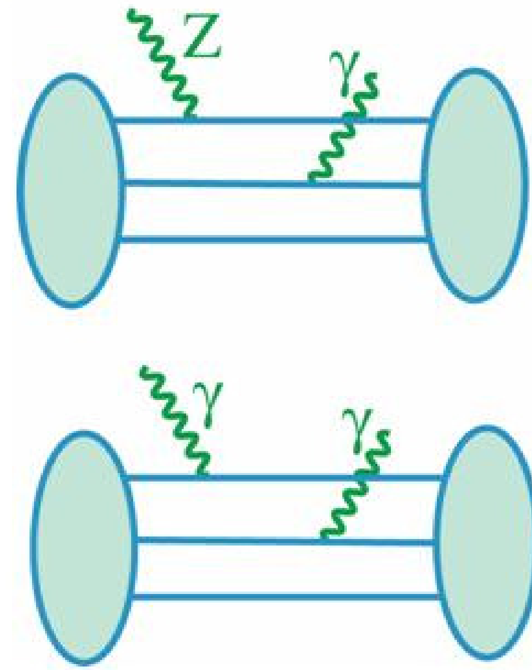
Higher Twist Coefficients in parity conserving (D_i) and nonconserving (C_i) Scattering



$$F_2(x,Q^2) = F_2(x)(1 + D(x)/Q^2)$$

$$A_{PV}(x,Q^2) = A_{PV}(x)(1 + C(x)/Q^2)$$

(Does not Evolve)



- A_{PV} sensitive to diquarks: ratio of weak to electromagnetic charge depends on amount of coherence
- If Spin 0 diquarks dominate, likely only $1/Q^4$ effects
- Some higher twist effects may cancel in ratio, so A_{PV} may have little dependence on Q^2.

Going from LO to NNNLO Greatly Reduces the Extracted Higher Twist Coefficients

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

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

If D(x)~C(x), Parity might show higher twist
At high x without needing QCD evolution.

A_{PV} in DIS on ^{1}H

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

$$a(x) = \frac{3}{2}\left[\frac{2C_{1u}u(x) - C_{1d}(d(x) + s(x))}{4u(x) + d(x) + s(x)}\right] \qquad b(x) = \frac{3}{2}\left[\frac{2C_{2u}u_v(x) - C_{2d}d_v(x)}{4u(x) + d(x) + s(x)}\right]$$

$$a(x) = \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)} + small\ corrections$$

- ***Allows d/u measurement on a single proton!***
- ***Vector quark current! (electron is axial-vector)***

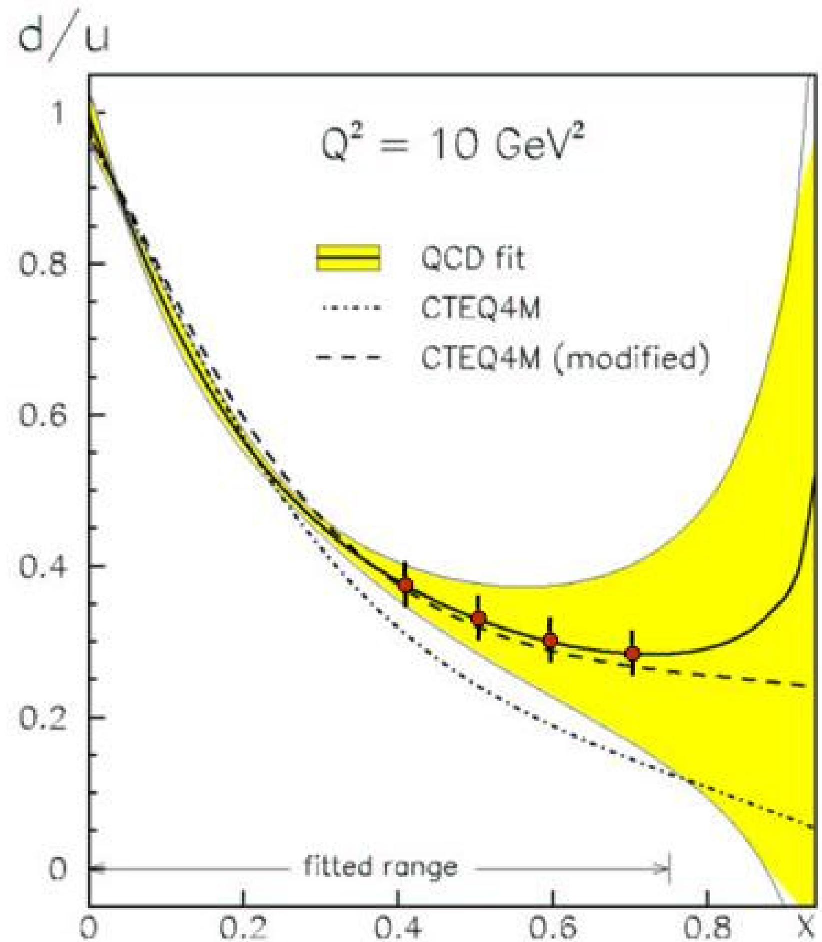
- Determine that higher twist is under control
- Determine standard model agreement at low x
- Obtain high precision at high x

Uncertainties in d/u at High x, and the Errors we Would Like to Achieve with PV Measurements

Deuteron analysis has nuclear corrections

A_{PV} for the proton has no such corrections

Must simultaneously constrain higher twist effects



The challenge is to get statistical and systematic errors ~ 2%

Complete PV DIS Program (Including 12 GeV)

- Hydrogen and Deuterium targets
- Better than 2% errors
  - It is unlikely that any effects are larger than 10%
- x-range 0.25-0.75
- W^2 well over 4 GeV^2
- Q^2 range a factor of 2 for each x point
  - (Except x~0.7)
- Moderate running times

•With HMS/SHMS: search for TeV physics
•With larger solid angle apparatus: higher twist, CSV, d/u…

Apparatus Needed for PVDIS

E05-007: Start PVDIS at 6 GeV (Approved)

R. Michaels (JLab), P. Reimer (ANL), X. Zheng (ANL)
and the Hall A Collaboration

- Asymmetry to be measured:

$$A_d = \left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\frac{2C_{1u}[1+R_c(x)] - C_{1d}[1+R_s(x)] + Y(2C_{2u} - C_{2d})R_v(x)}{5 + R_s(x) + 4R_c(x)}$$

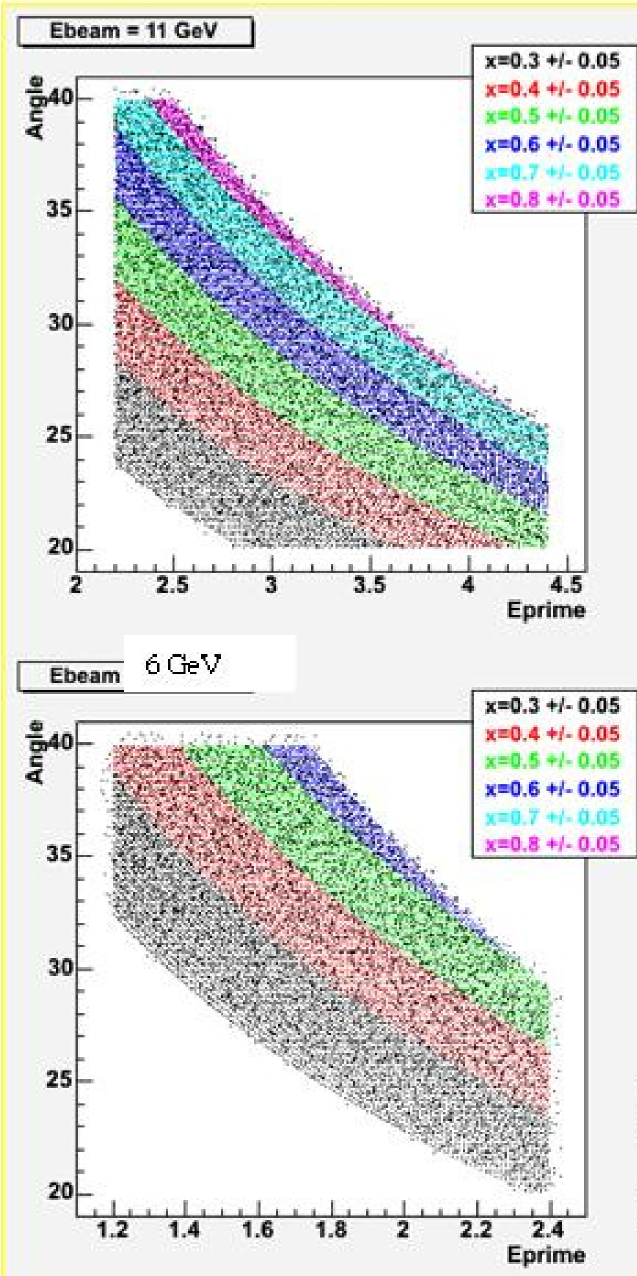
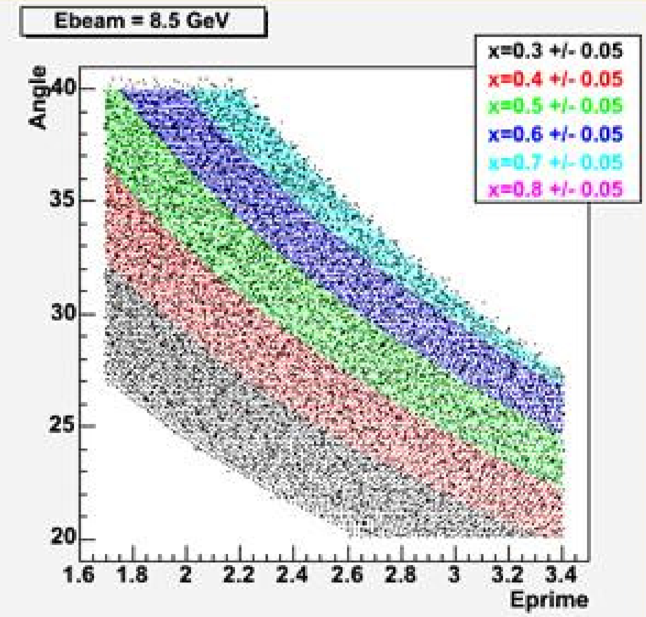
- Experimental Setup:
  - 85uA, 6 GeV, "parity-quality" 80% pol. beam;
  - 25-cm LD2 target;
  - Two HRS detect scattered electrons.

- Measure A_d at Q^2=1.10 and Q^2=1.90 $(\mathrm{GeV}/c)^2$ to 2% (stat.);

Reaching Large x and Large Q^2 at 12 GeV

Need Large θ for large x and Q^2

HMS and SHMS are fine for small θ

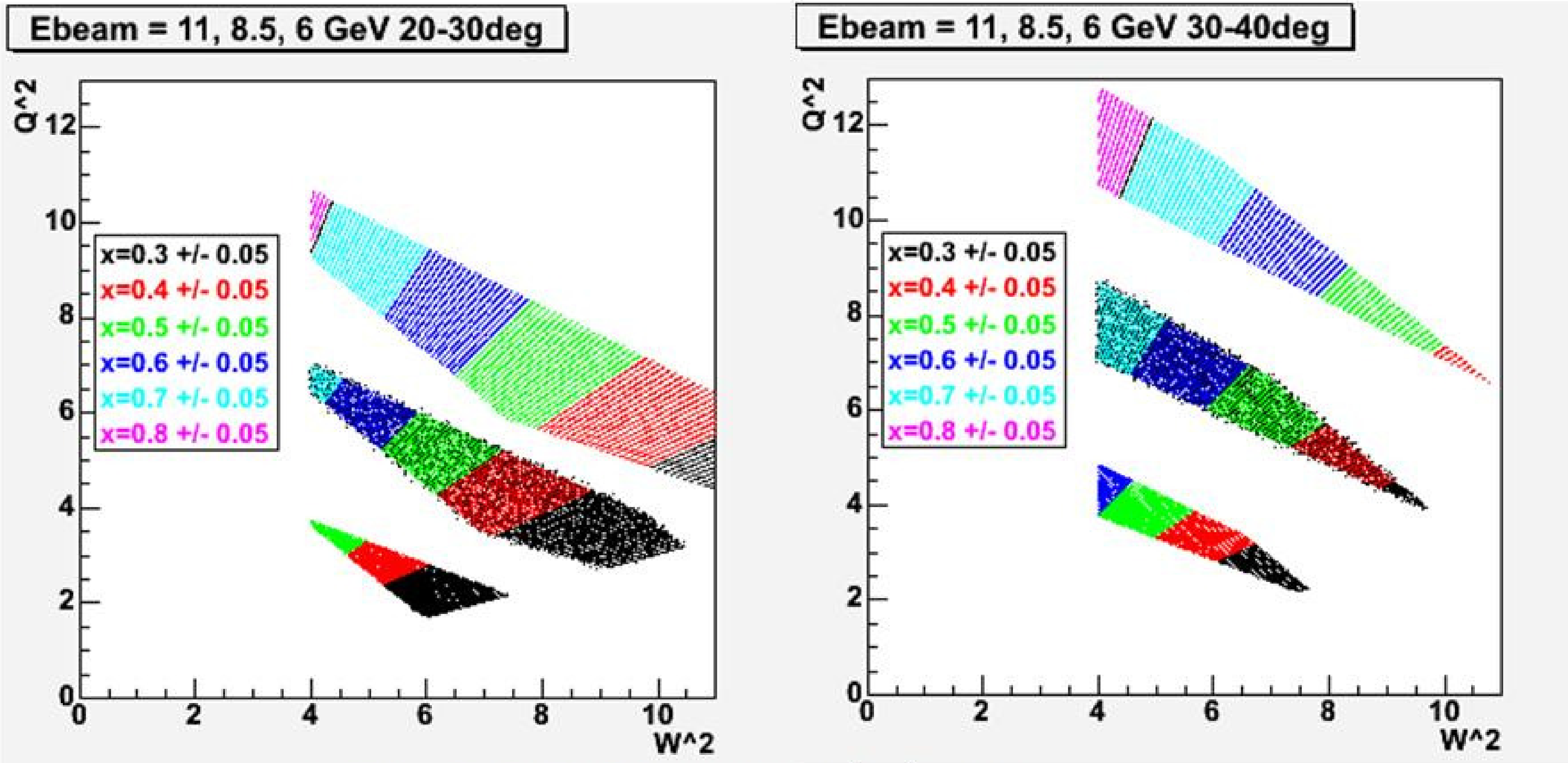
$$20 < \theta < 40$$

$$E' < 4\ GeV$$

$$0.6 < y < 0.8$$

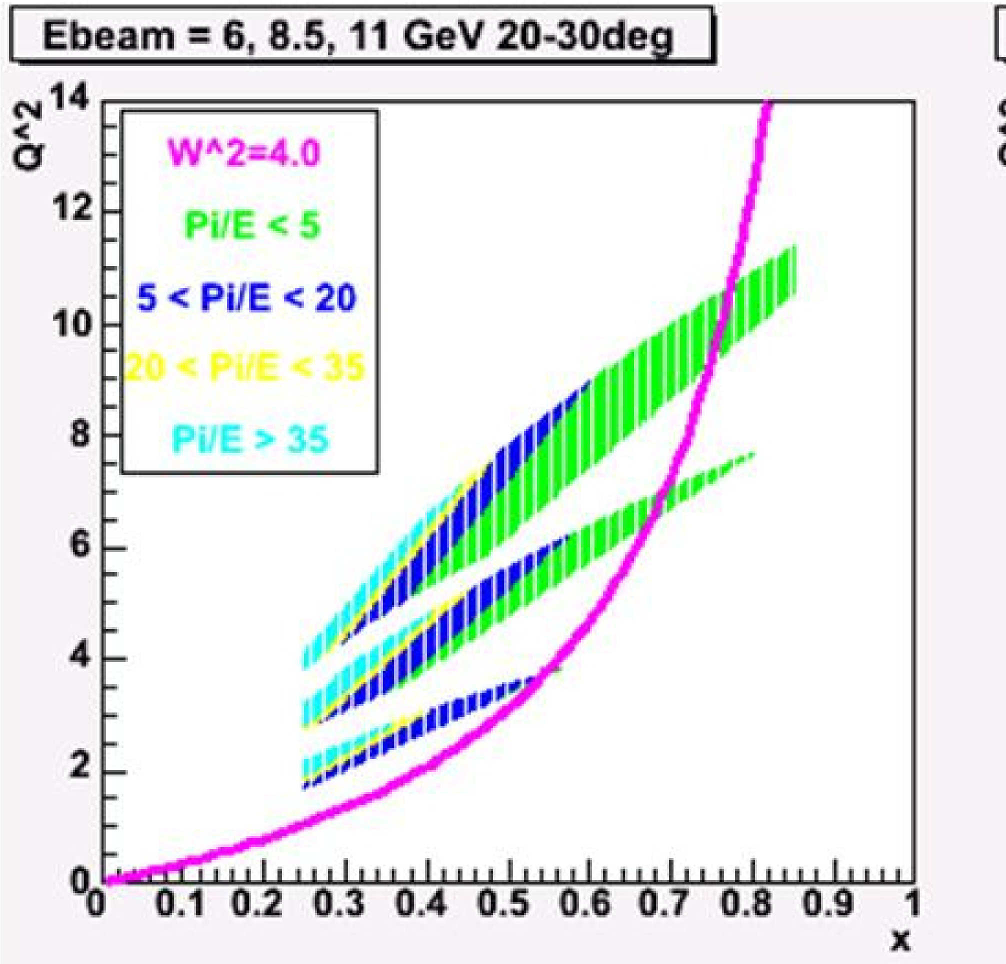
$$W^2 > 4\ GeV^2$$

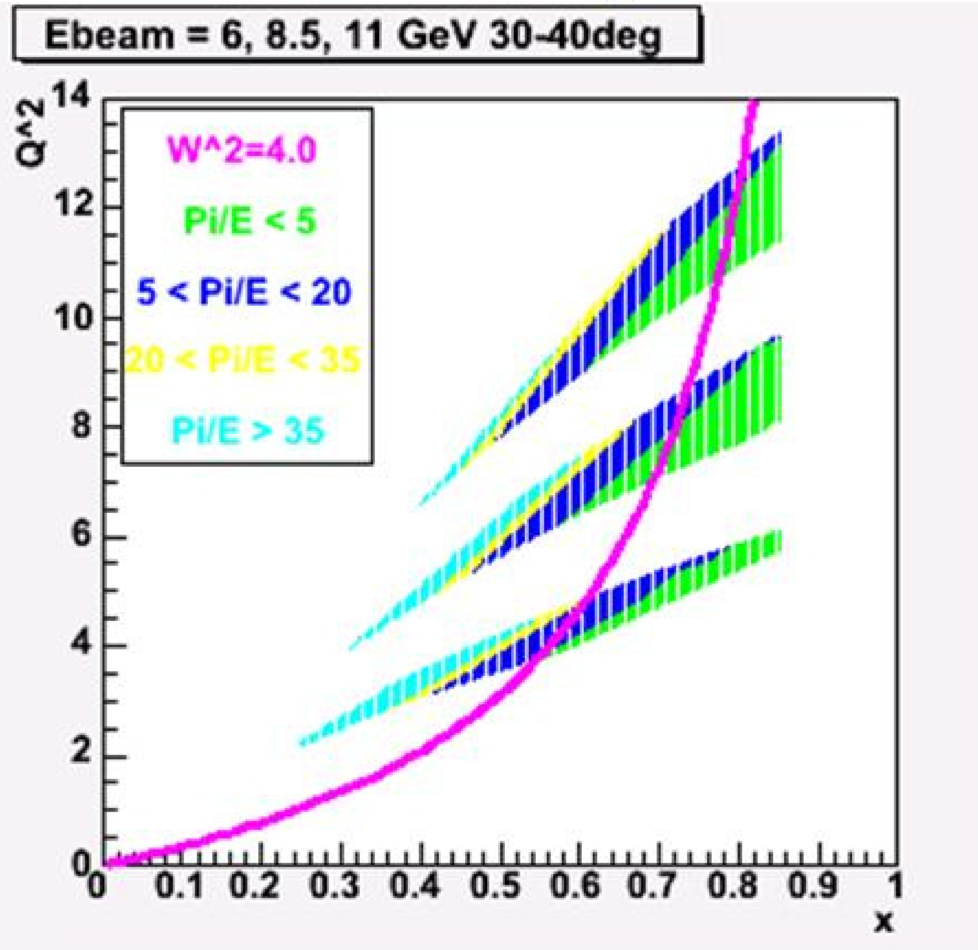
50% azimuthal coverage assumed



- *2 to 3.5 GeV scattered electrons*
- *20 to 40 degrees*
- *Factor of 2 in Q^2 range at moderate x*
- *High statistics at x=0.7, with W>2*

Details on Kinematics and π/e Backgrounds





- Large range in Q2 for HT study
- High x (>0.7) accessible with W^2>4
- Large acceptance allows feasible runtime requests
- π/e ratio is not extreme, but cannot integrate

Large Angle Large Acceptance: Concept

JLab Upgrade

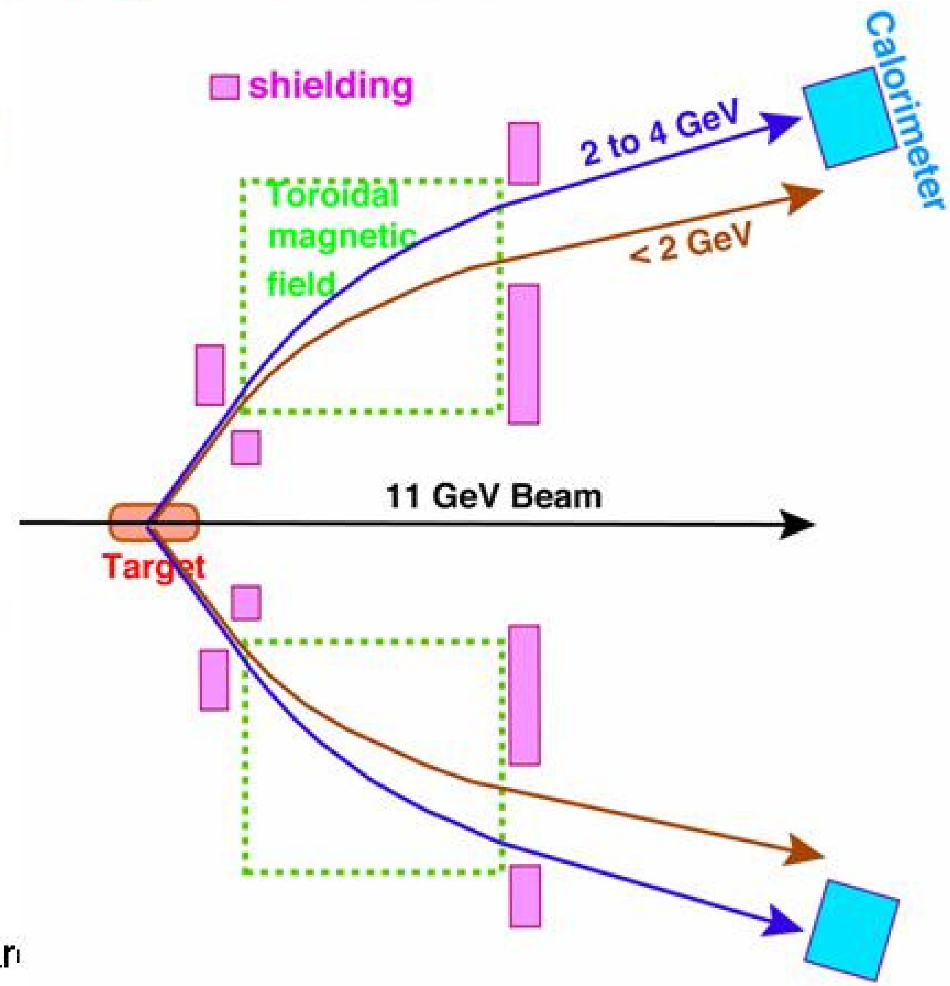
- Need high rates at high x

- *CW 90 μA at 11 GeV*
- *40-60 cm liquid H_2 and D_2 targets*
- *Luminosity > $10^{38}/cm^2/s$*

- For the first time: sufficient rates to make precision PV DIS measurements

- *solid angle > 200 msr*
- *Count at 100 kHz*
- *online pion rejection of 10^2 to 10^3*

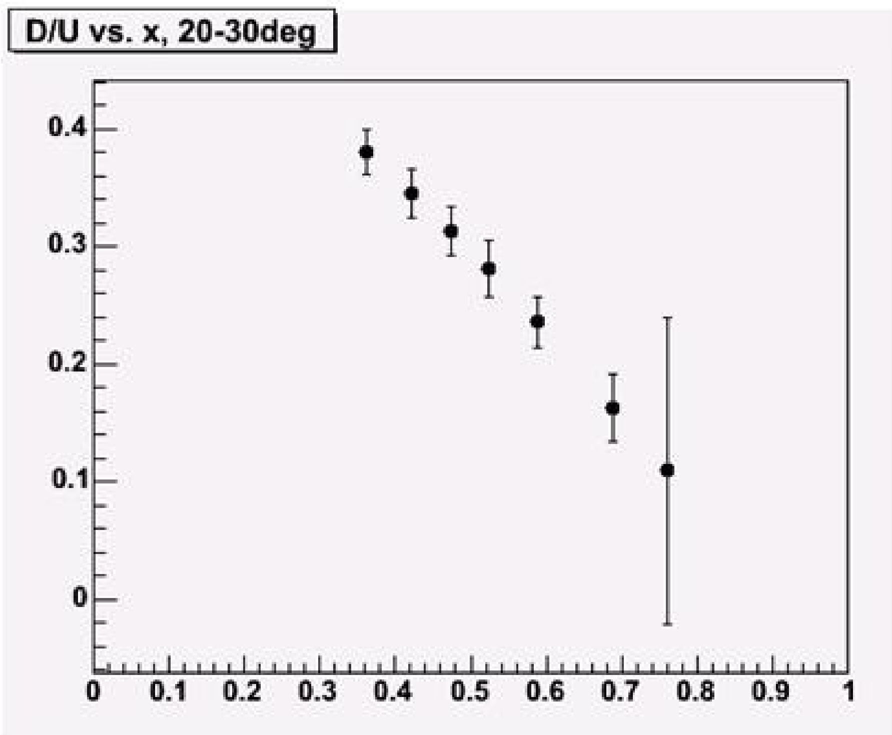
Need toroid to block γ's and low energy π's

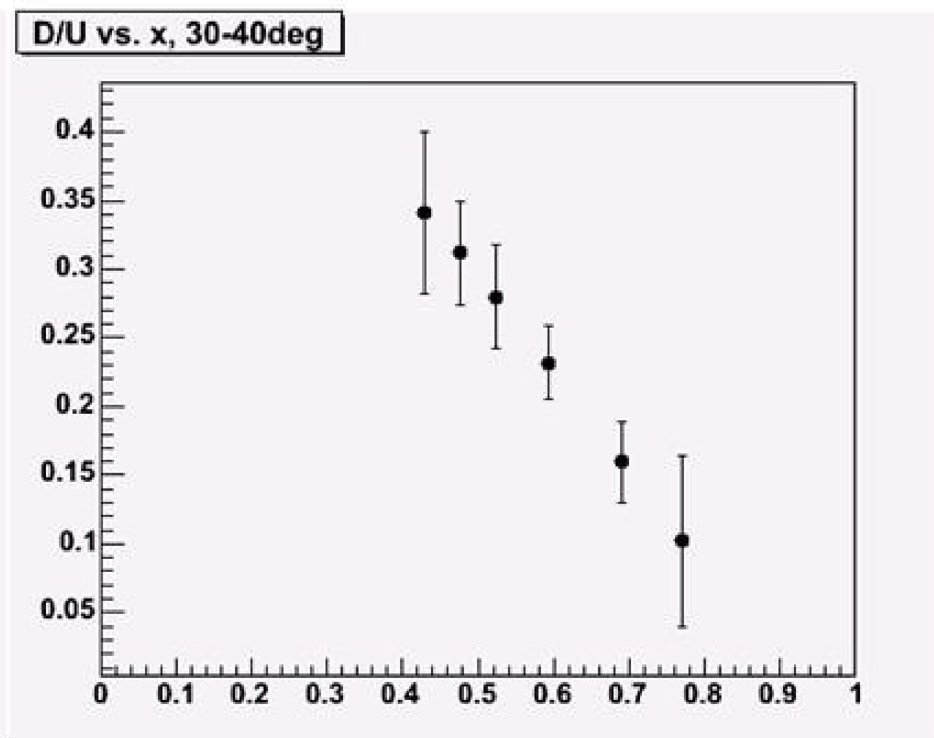


d/u Measurements for Proton

(Kent Paschke simulation)

A couple weeks of beam time with toroid spectrometer

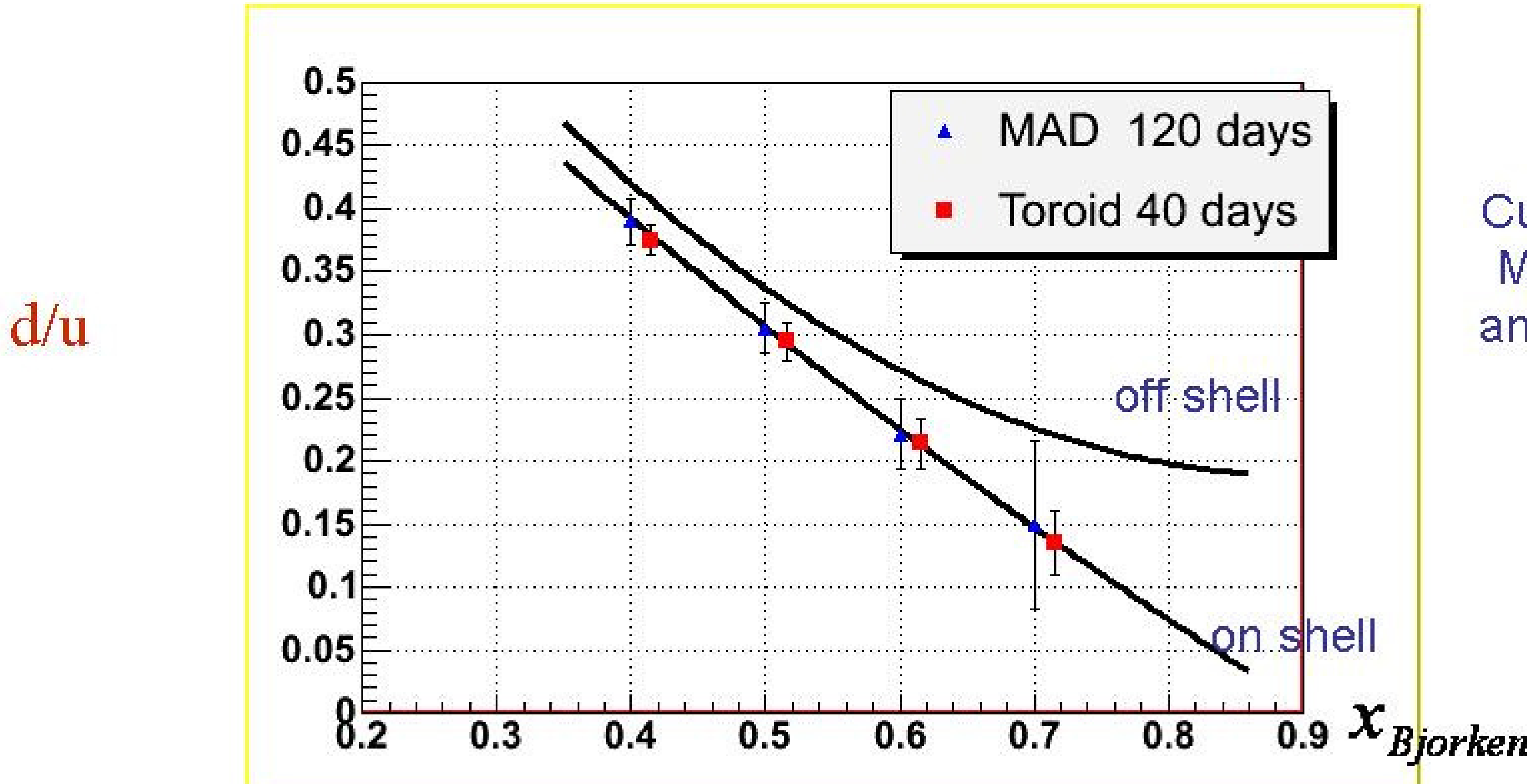




What Physics is Allowed by New Device?

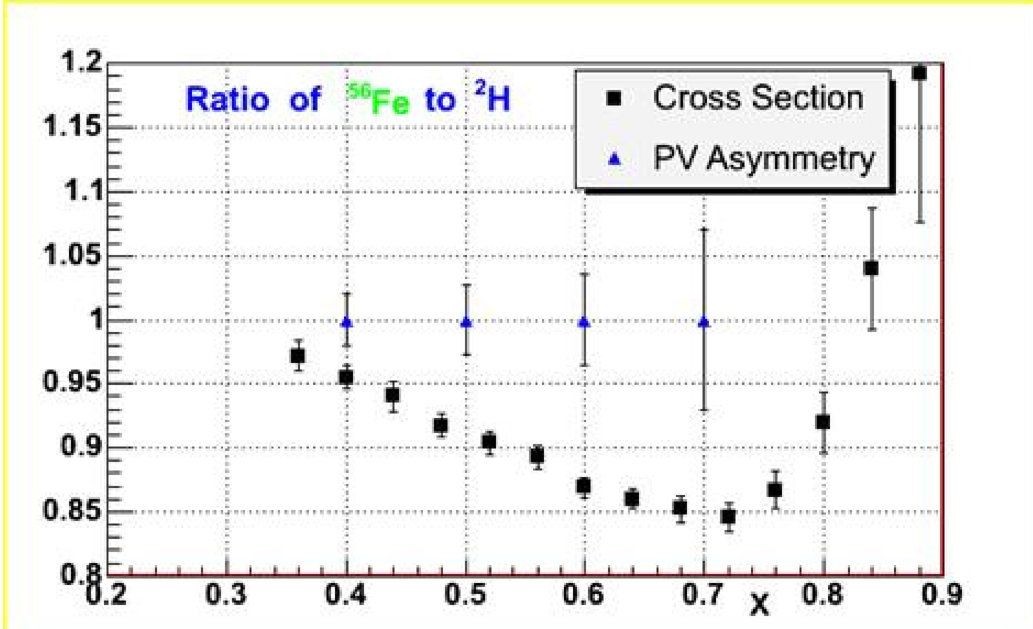
Example: d/u of Proton

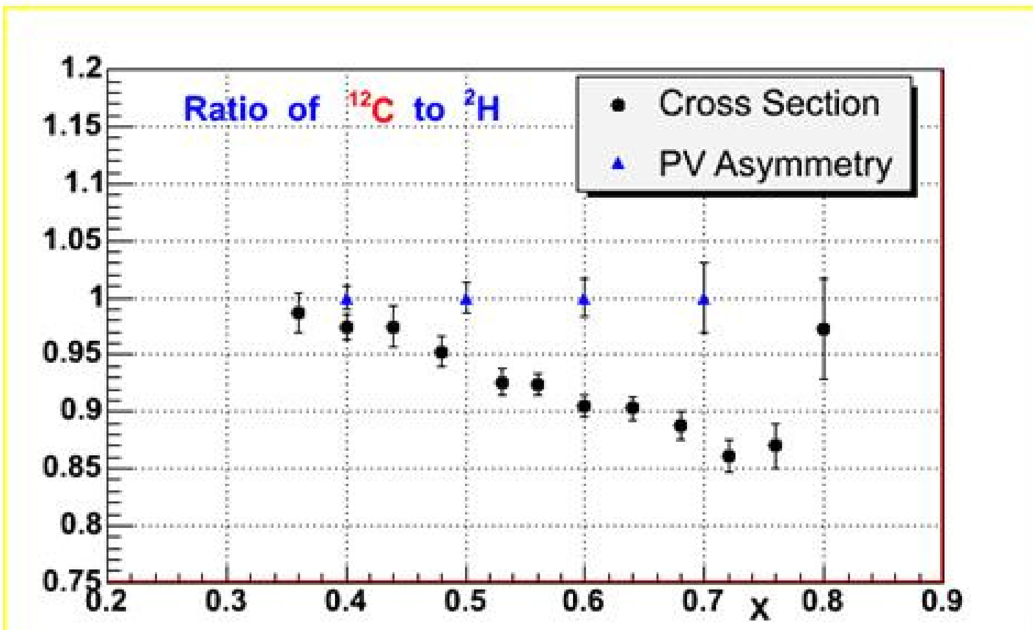
Compare MAD Spectr. to Toroid Spectr.



Curves from Melnithouk and Thomas

EMC effect in Parity Violation ?





Cross section data from J. Gomez *et.al.* PRD 49 (1994) 4348

High x Physics Outlook: Context

- Parity-Violating DIS can probe exciting new physics at high x
- One can start now (at 6 GeV)
  - Do 2 low Q^2 points (P-05-007, X. Zheng contact)
    - Q^2 ~ 1.1 and 1.9 GeV^2
    - Either bound or set the scale of higher twist effects
  - Take data for W<2 (P-05-005, P. Bosted contact)
    - Duality
    - Could help extend range at 11 GeV to higher x
- A short run to probe TeV physics in PV DIS off ^2H: Hall A or C
- The bulk of the program requires a dedicated spectrometer/detector
- CSV can also be probed via electroproduction of pions
  - 6 GeV beam can probe x ~ 0.45 (P-05-006, K. Hafidi contact)
  - Should be able to go to higher x with 12 GeV beam
- Other vital physics topics could be addressed by dedicated spectrometer:
  - Transverse (beam-normal) asymmetries in DIS
  - Polarized targets: g_2 and g_3 structure functions
  - Higher twist studies of A_1^p and A_1^n

Summary

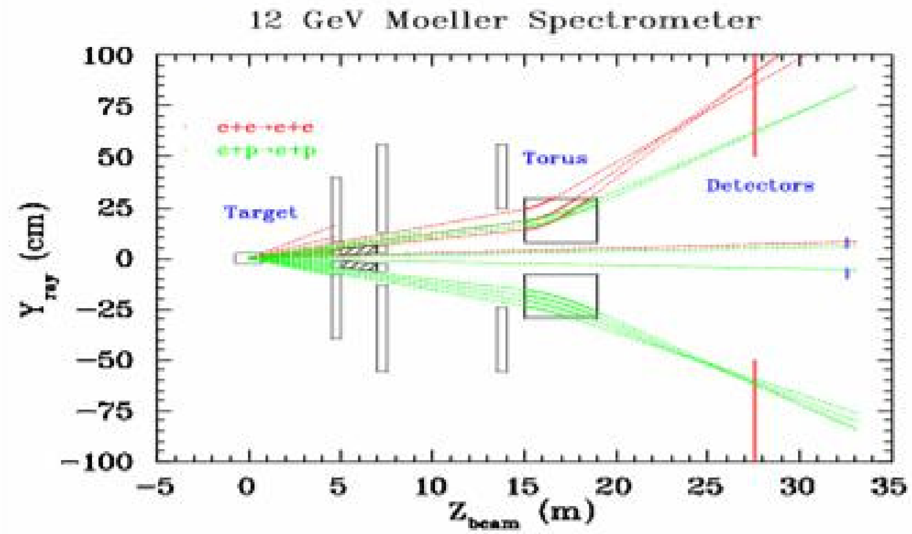
- 12 GeV Upgrade
  - Opens unique opportunities for new PV measurements
  - Hall configuration must support dedicated apparatus
    - Large solid angle toroid/calorimeter for PV DIS
    - Superconducting solenoid for Møller scattering
- Physics Highlights
  - Unique Standard Model tests
  - Unique, clean d/u for proton
  - Test Charge Symmetry at the Quark level
  - Observe clean higher twist effects

Future Directions for PV Moller and APV

e2ePV: Parity-Violating Moller scattering at 12 GeV JLAB (Mack, Reimer, *et al.*)

- Achieve Moller focus with long, narrow superconducting toroidal magnet, Radiation hard detector package
- E = 12 GeV Q^2 =.008 GeV^2 , $\theta \sim .53 - .92^\circ$, A_{PV} = - 40 ppb

In 4000 hours, could determine Q^e_W to 2.5% (compare to 12.4% for E158)

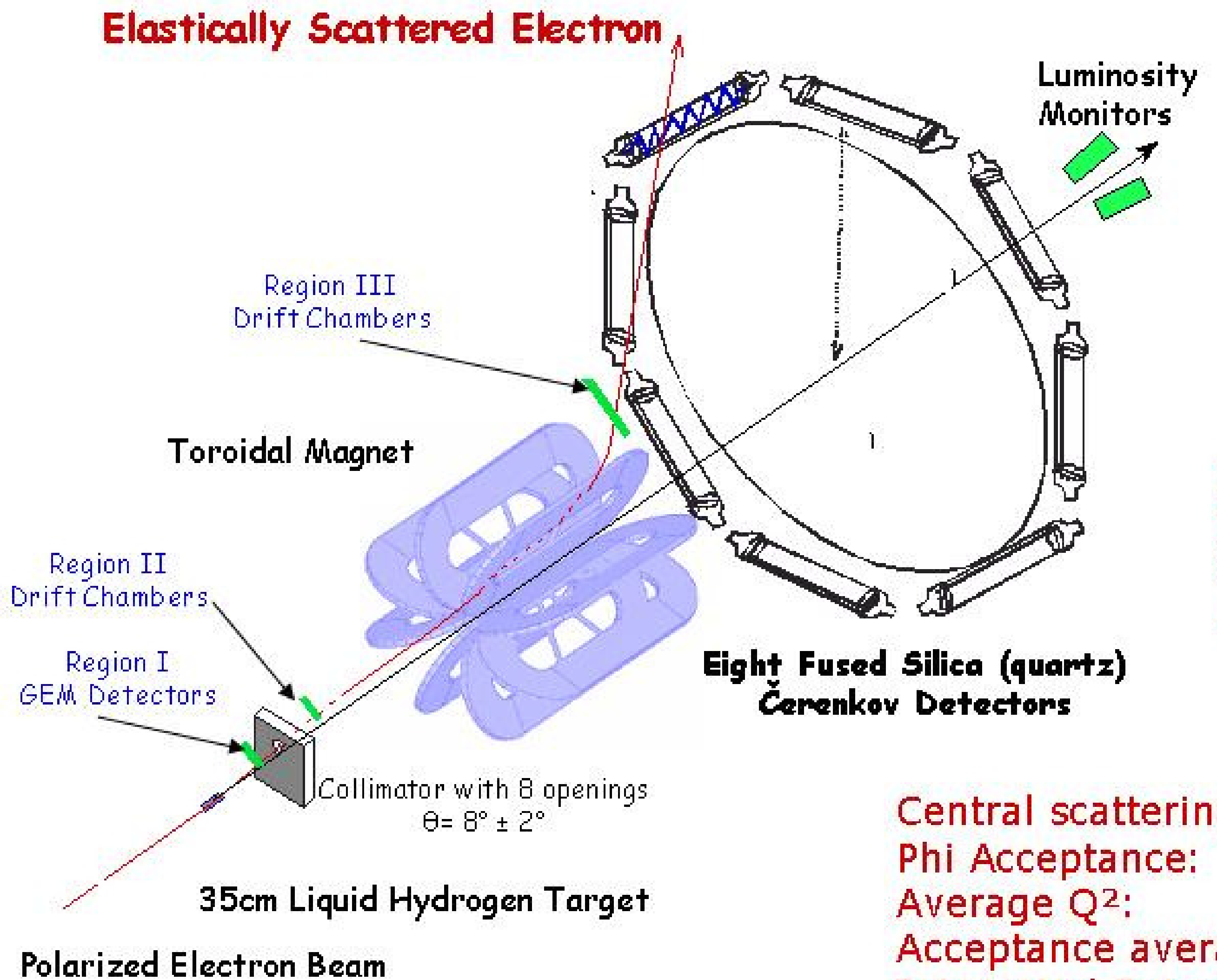


Atomic Parity Violation Future Directions

- Paris group (Bouchiat, *et al.*): more precise Cs APV
- Seattle group (Fortson, *et al.*): single trapped Ba^+ APV $6S_{1/2} \rightarrow 5D_{3/2}$
- Berkeley group (Budker, *et al.*): isotope ratios in Yb APV
- Stony Brook group (Orozco, *et al.*): isotope ratios in Fr APV

Note: isotope ratios can eliminate large atomic structure theory uncertainties

Overview of the Q^p_{Weak} Experiment

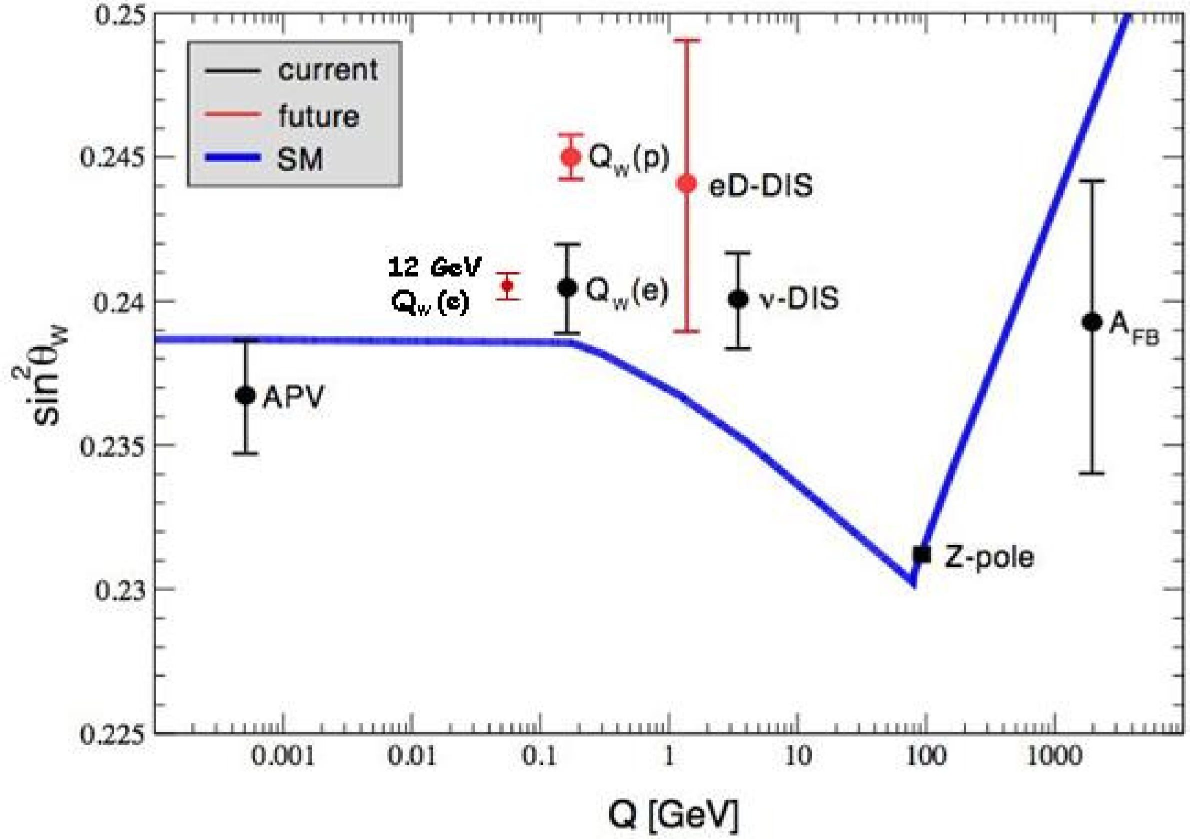


Experiment Parameters (integration mode)

Incident beam energy:	1.165 GeV
Beam Current:	180 μA
Beam Polarization:	85%
LH_2 target power:	2.5 KW

Central scattering angle:	8.4° ± 3°
Phi Acceptance:	53% of 2π
Average Q^2:	0.030 GeV^2
Acceptance averaged asymmetry:	−0.29 ppm
Integrated Rate (all sectors):	6.4 GHz
Integrated Rate (per detector):	800 MHz

"Running of $\sin^2\theta_W$" : Current Status and Future Prospects



present:

"d-quark dominated" : *Cesium APV* (Q^A_W): SM running verified at ~ 4σ level

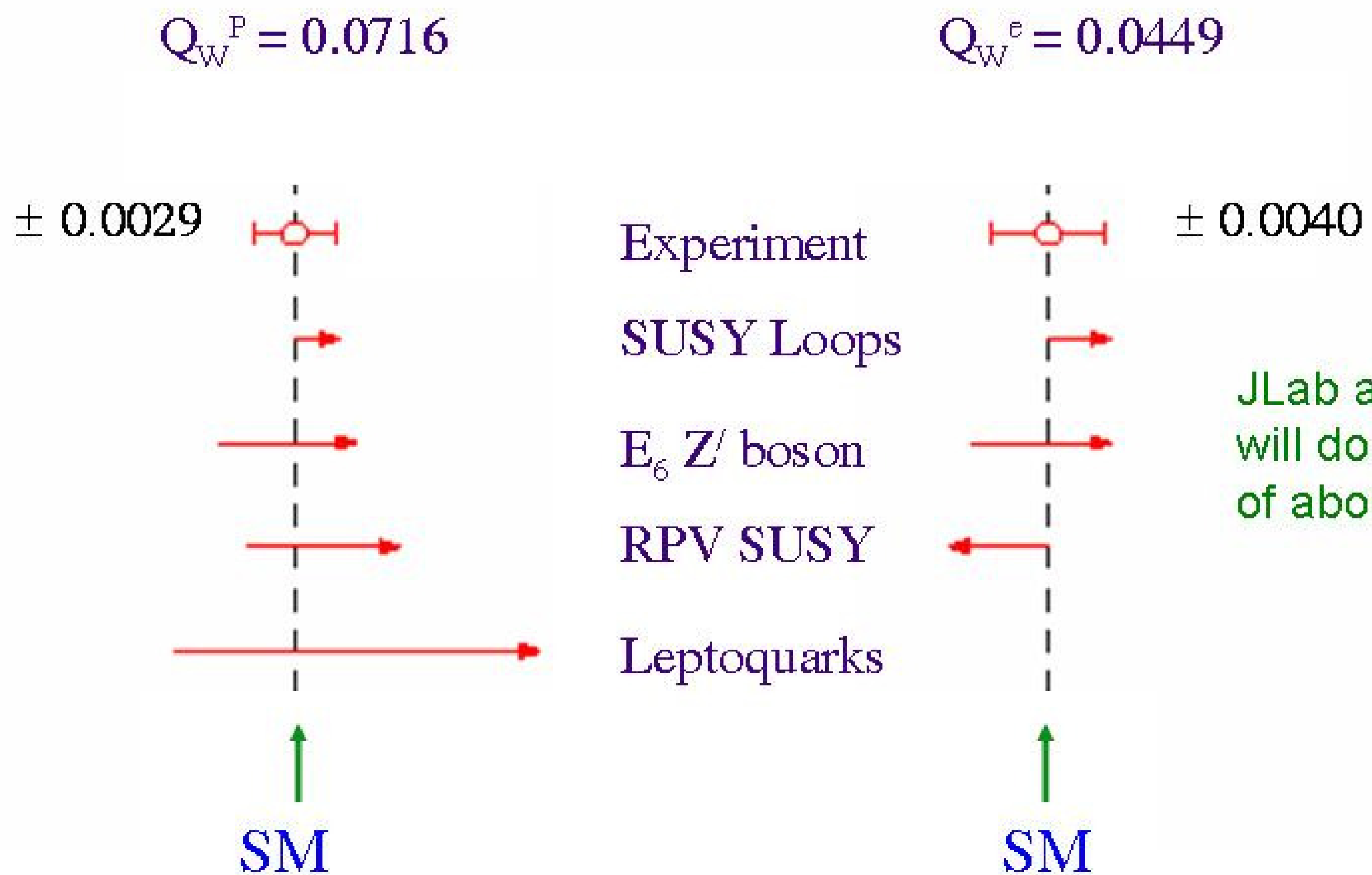
"pure lepton": SLAC E158 (Q^e_W): SM running verified at ~ 6σ level

future:

"u-quark dominated" : Q_{weak} (Q^p_W): projected to test SM running at ~ 10σ level

"pure lepton":12 GeV e2ePV (Q^e_W): projected to test SM running at ~ 25 σ level

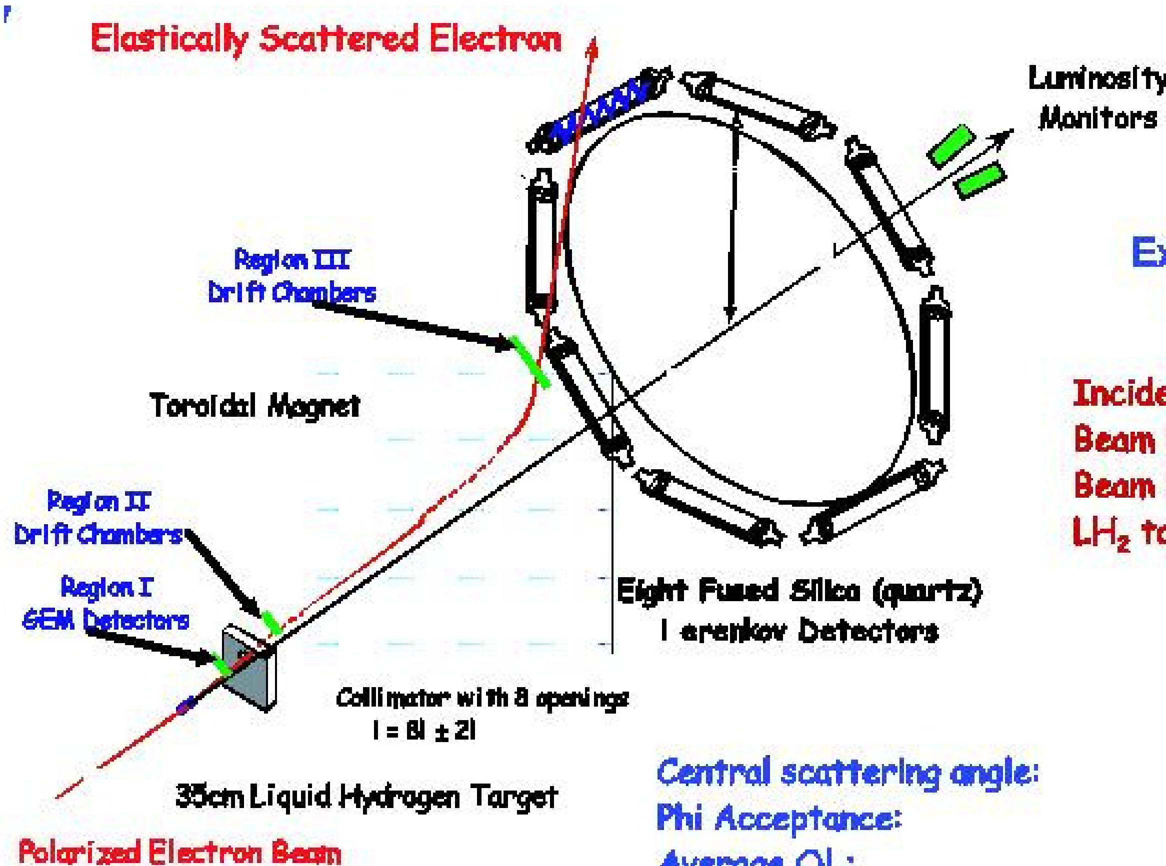
Comparing Q_W^e and Q_W^p



JLab at 12 GeV
will do a factor
of about 5 better!

Erler, Kurylov, R-M

The Qweak Experiment

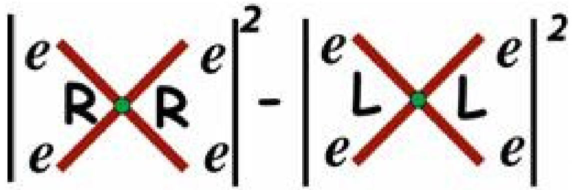


Experiment Parameters
(integration mode)

Incident beam energy:	1.165 GeV
Beam Current:	180 #A
Beam Polarization:	~80%
LH_2 target power:	2.5 KW

Central scattering angle:	8l ± 2
Phi Acceptance:	>50% of 2)
Average Ql :	0.028 GeV^2
Acceptance averaged asymmetry:	£0.28 ppm
Integrated Rate (all sectors):	~6 GHz
Integrated Rate (per detector):	~750 MHz

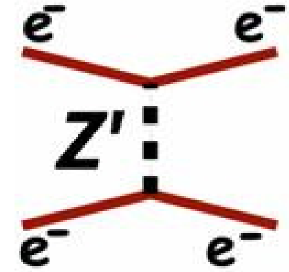
New Physics Reach

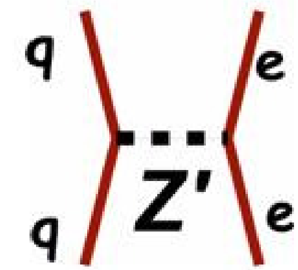


JLab Møller

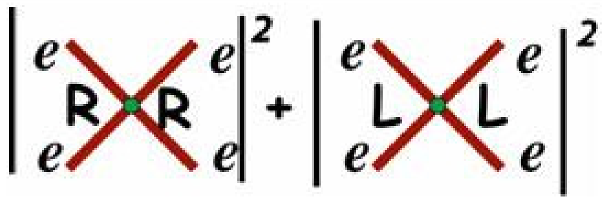
$\Lambda_{ee} \sim 25$ TeV

New Contact Interactions





LHC



LEP200

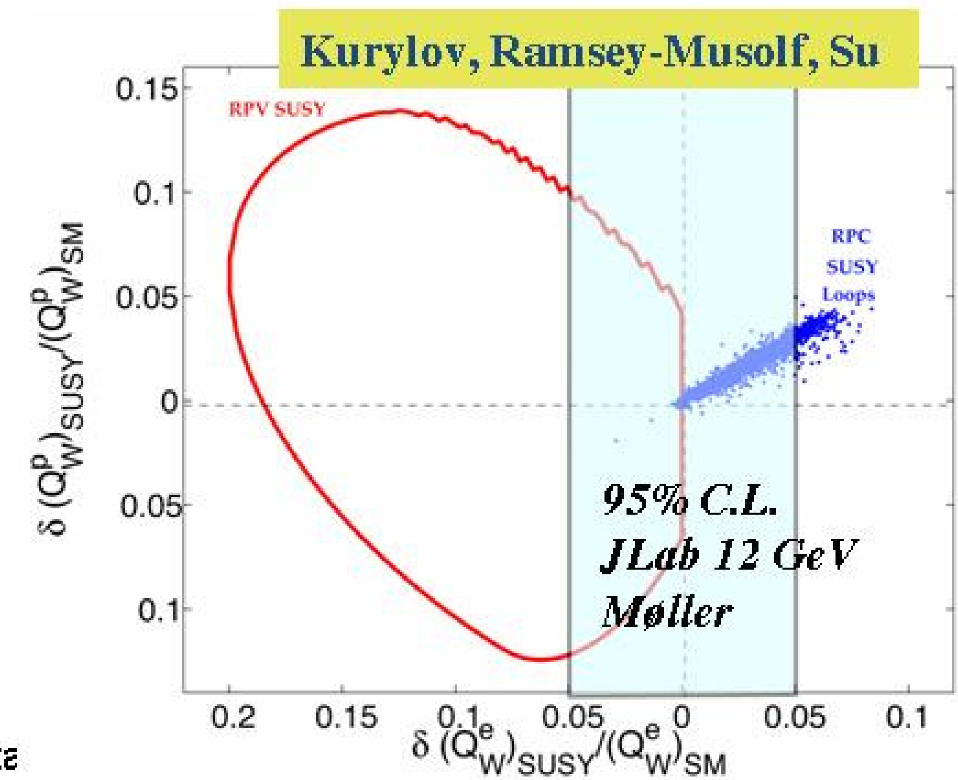
$\Lambda_{ee} \sim 15$ TeV

Complementary; 1-2 TeV reach

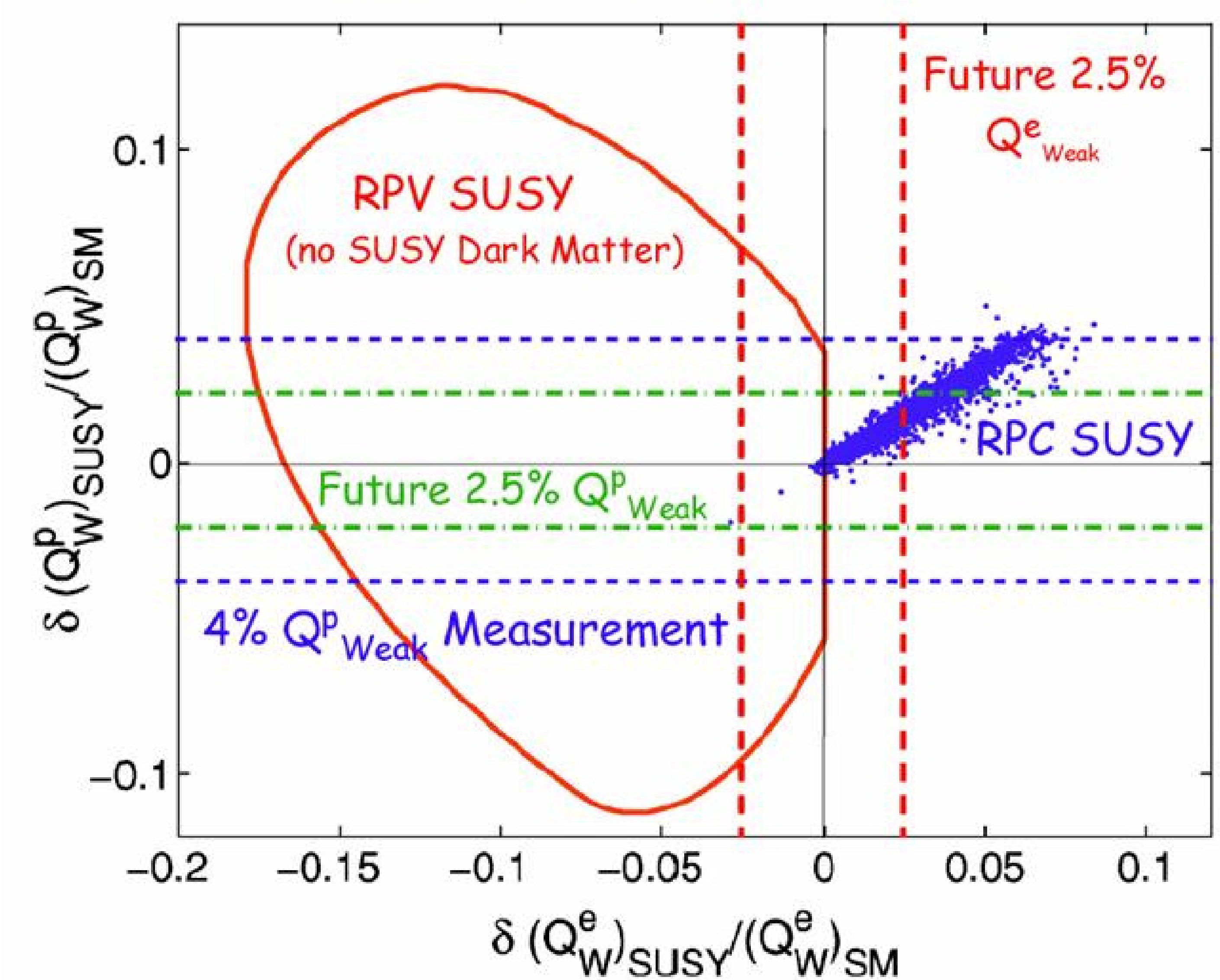
Does Supersymmetry (SUSY) provide a candidate for dark matter?

- Lightest SUSY particle (neutralino) is stable if baryon (B) and lepton (L) numbers are conserved

- However, B and L need not be conserved in SUSY, leading to neutralino decay (RPV)



Relative Shifts in Proton and Electron Weak Charges due to SUSY Effects

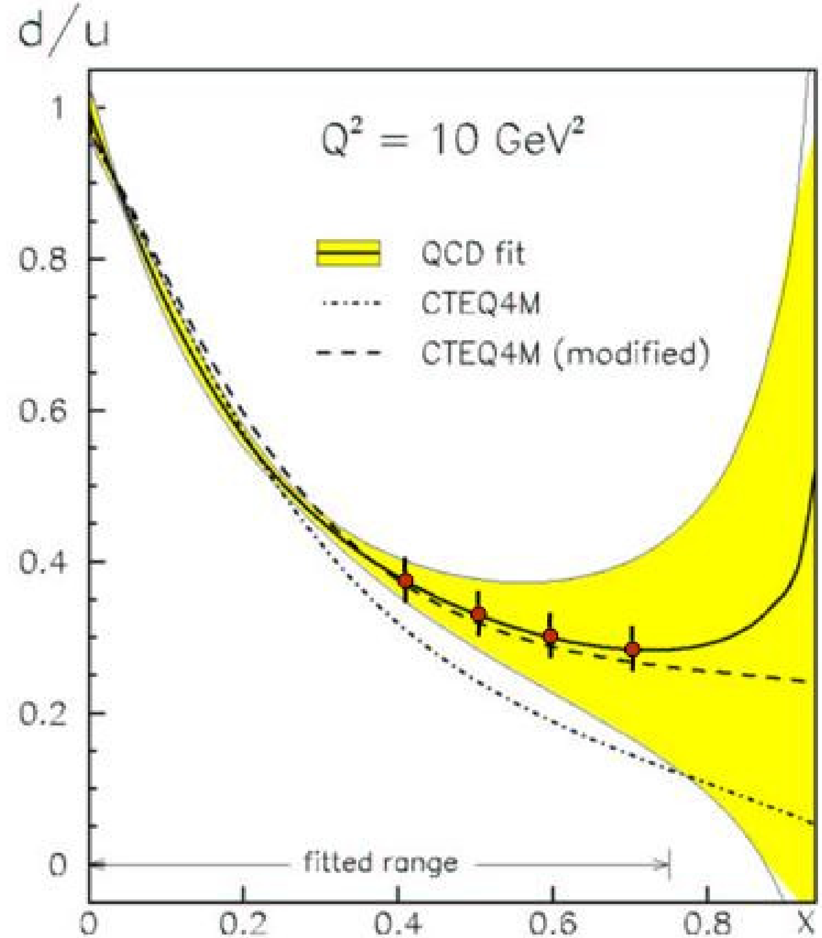


d/u at High x

Deuteron analysis has nuclear corrections

A_{PV} for the proton has no such corrections

Must simultaneously constrain higher twist effects



The challenge is to get statistical and systematic errors ~ 2%

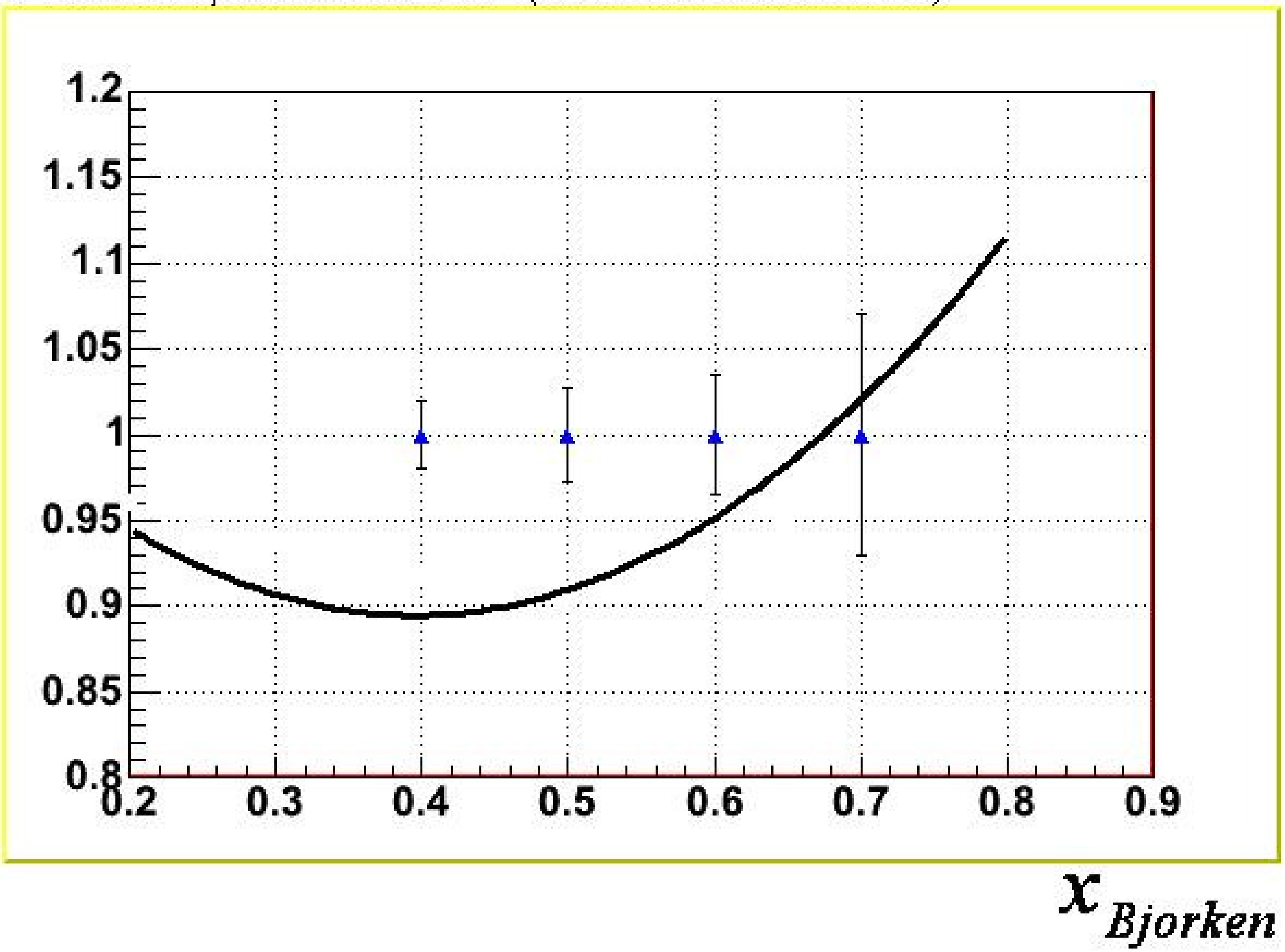
EMC Effect ?

$A(Fe)/A(^2H)$

Ratio of Asymmetries (Iron to Deuterium)

50 days running.

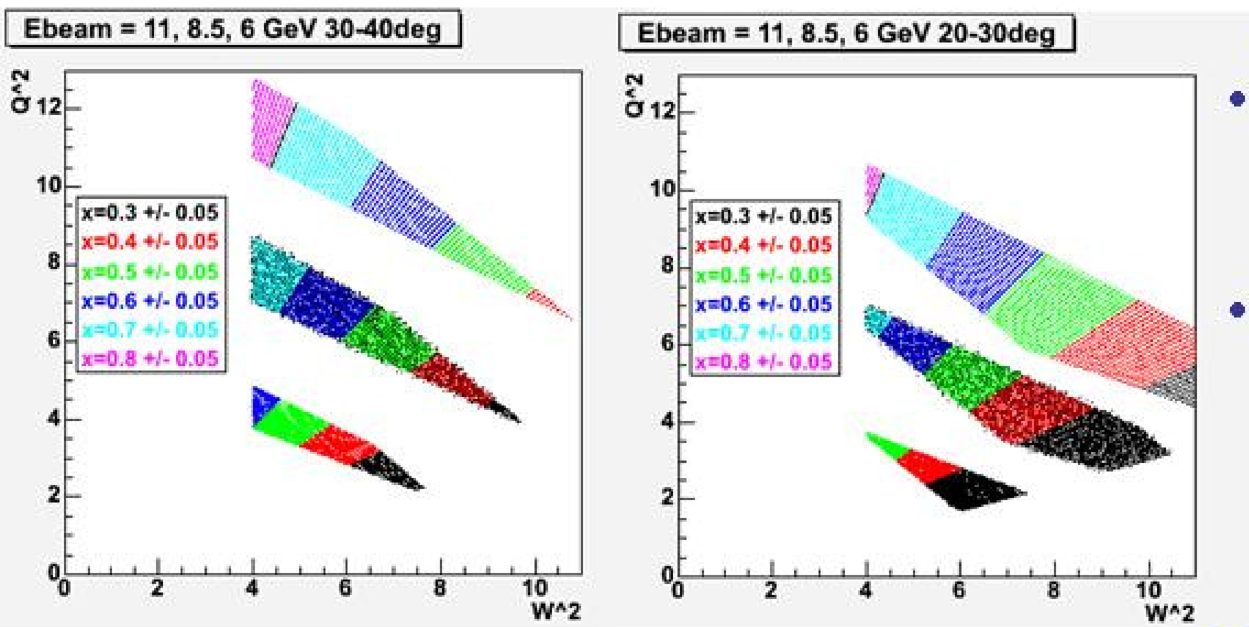
15 cm LD2 & 0.17 mm Fe Targets



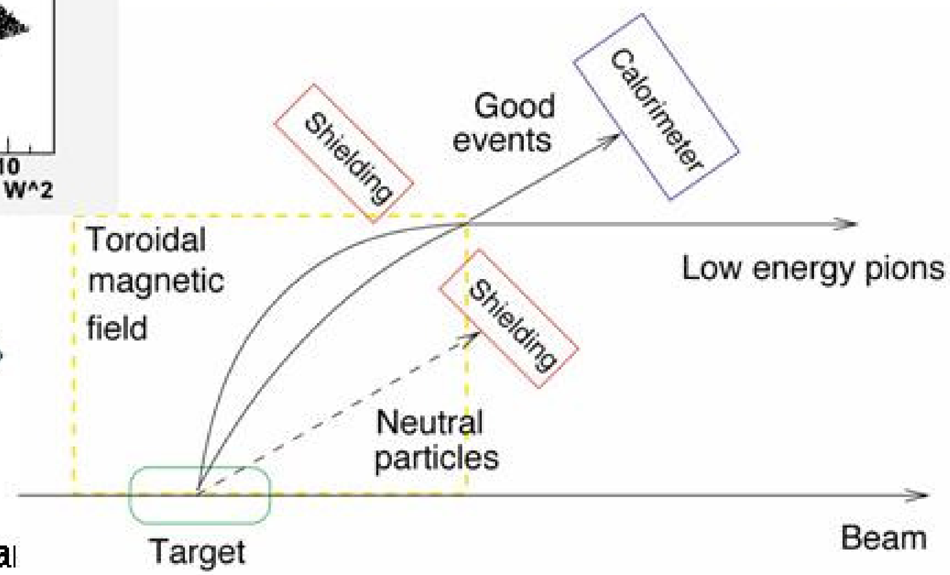
A Concept for PV DIS Studies

- *CW 100 μA at 11 GeV*
- *20 to 40 cm LH_2 and LD_2 targets*
- *Luminosity > $10^{38}/cm^2/s$*

- ***Magnetic spectrometer would be too expensive***
- ***Calorimeter to identify electron clusters and reject hadrons a la A4 at Mainz***
- ***Toroidal sweeping field to reduce neutrals, low energy Mollers and pions***
- ***Cherenkov detectors for pion rejection might be needed***

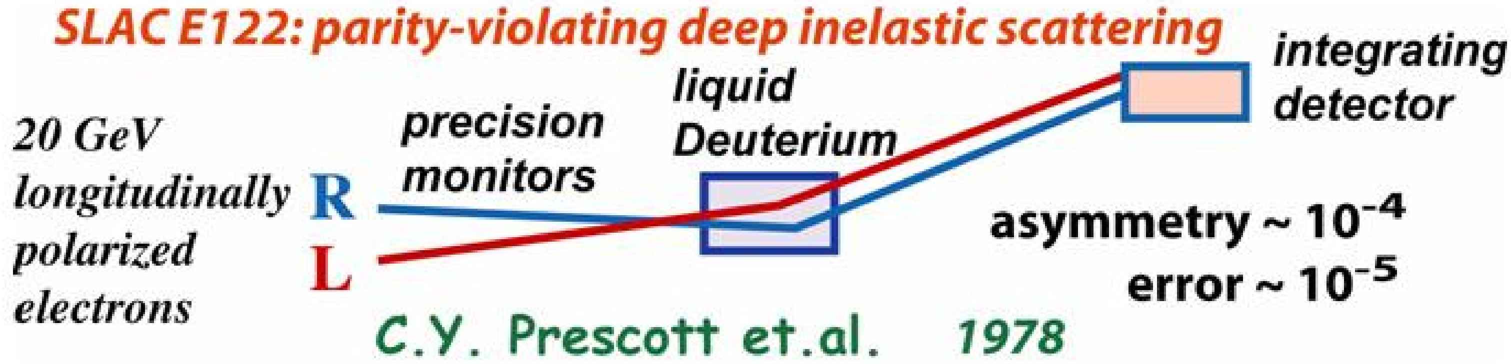


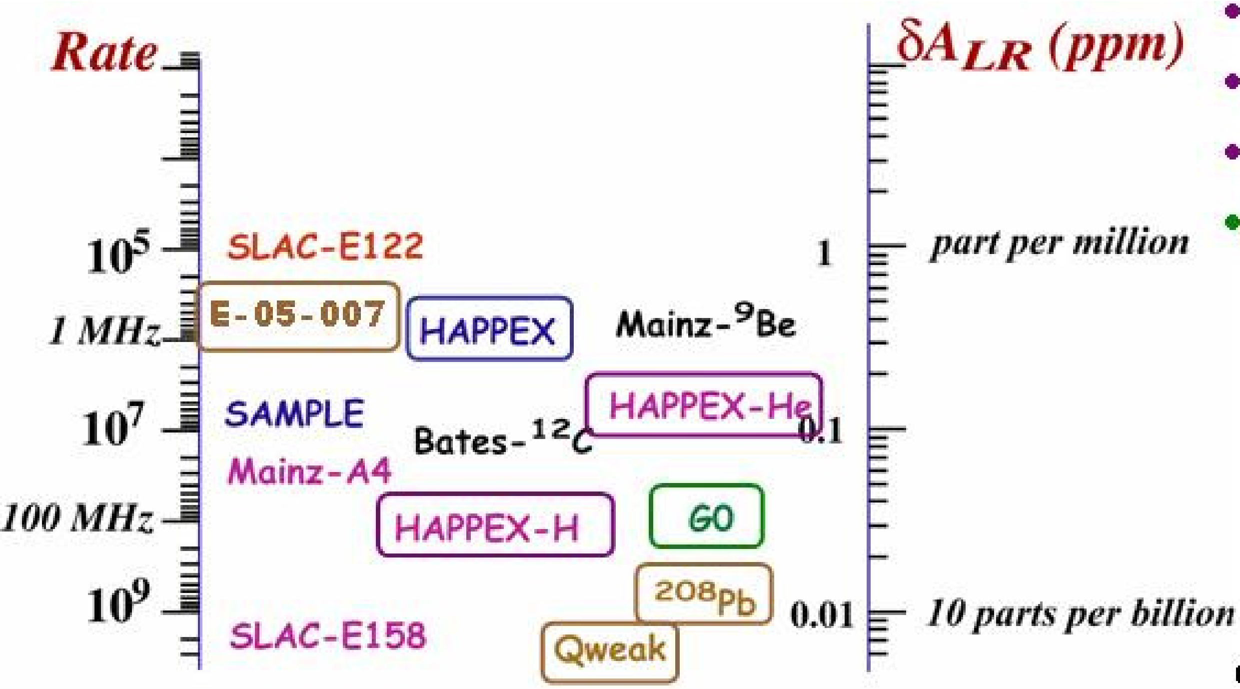
- *solid angle > 200 msr*
- *Count at 100 kHz*
- *pion rejection of 10^2 to 10^3*



A_{PV} Measurements

$$A_{PV} \sim 10^{-5} \cdot Q^2 \text{ to } 10^{-4} \cdot Q^2 \Rightarrow 0.1 \text{ to } 100 \text{ ppm}$$





odel

- *Steady progress in technology*
- *part per billion systematic control*
- *1% normalization control*
- *JLab now takes the lead*
  - *-New results from HAPPEX*
  - *-Photocathodes*
  - *-Polarimetry*
  - *-Targets*
  - *-Diagnostics*
  - *-Counting Electronics*

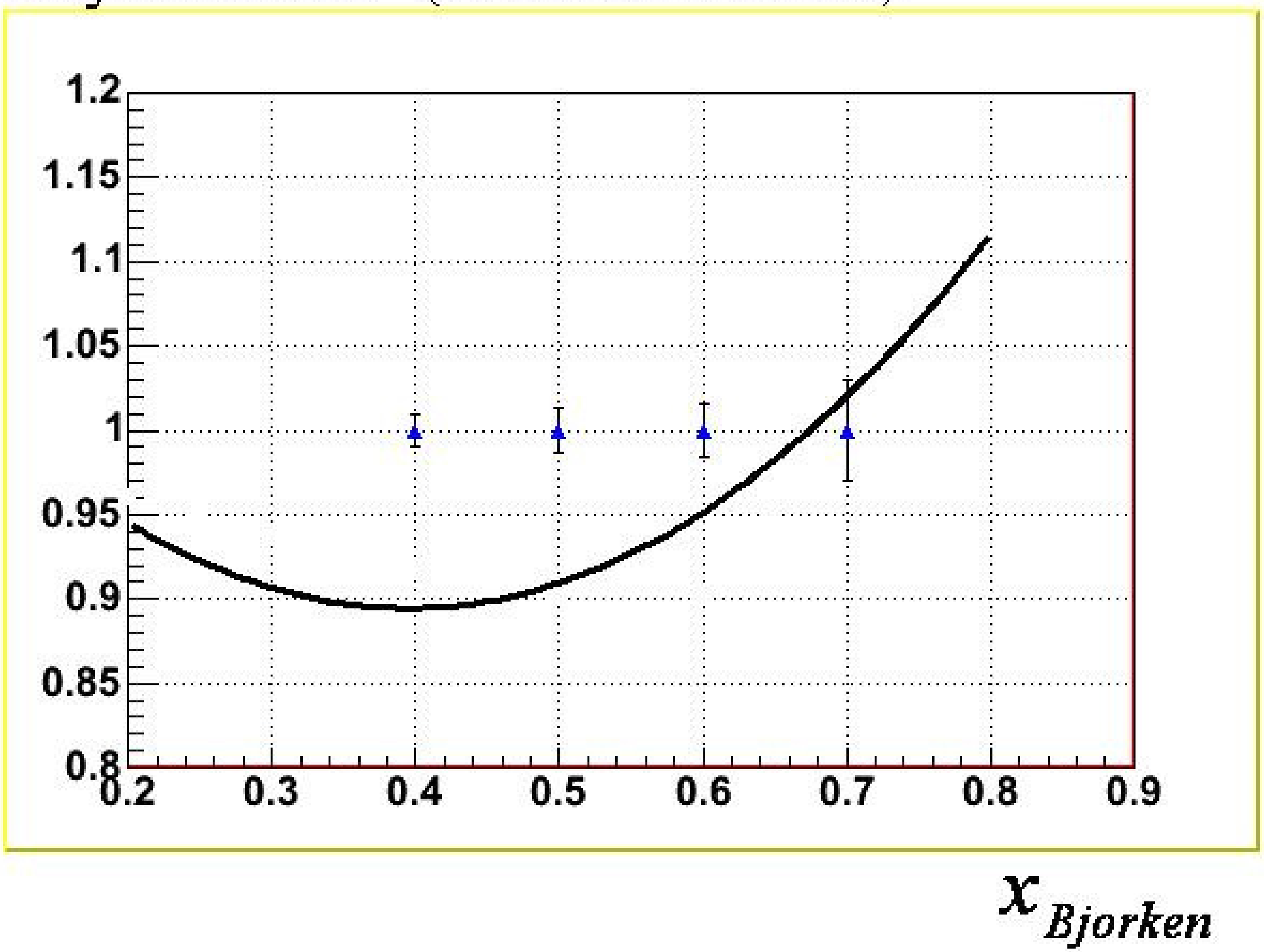
EMC Effect ?

$A(^{12}C)/A(^{2}H)$

50 days running.

15 cm LD2 & 1% RL C12 Targets

Ratio of Asymmetries (Carbon to Deuterium)



Parity Violation at Jlab

- Electron Beam Quality
  - Simple laser transport system; pioneers in PV experiments with high polarization cathodes (HAPPEX-I)
  - CW beam alleviates many higher order effects; especially in energy fluctuations
  - HAPPEX-II preliminary result: A_{raw} correction ~ 60 ppb
- High Luminosity
  - High beam current AND high polarization
  - Dense cryogenic targets with small density fluctuations
- Progression of Precision Experiments
  - Facilitates steady improvements in technology
  - Strong collaboration between accelerator and physics divisions

$\delta(A_{PV}) \rightarrow$ 1 part per billion

$\delta(A_{PV})/A_{PV} \rightarrow 1\%$