Introduction to Parity Violation

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PREX Workshop

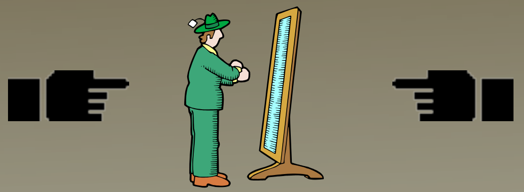
Jefferson Laboratory

Acknowledgment: Barry Holstein, Chuck Horowitz and the E158 and HAPPEX Collaborations

Definitions

parity transformation (reflection)

$$x, y, z \rightarrow -x, -y, -z$$



$$\vec{p} \rightarrow -\vec{p}, \quad \vec{L} \rightarrow \vec{L}, \quad \vec{s} \rightarrow \vec{s}$$

Definitions

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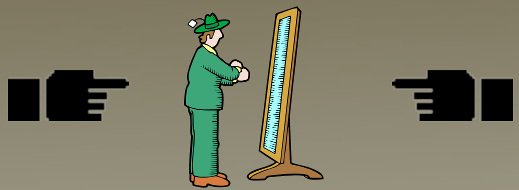

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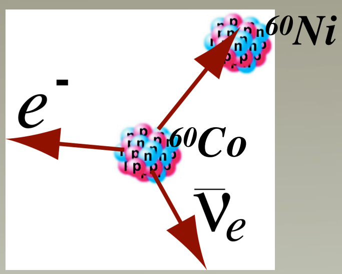
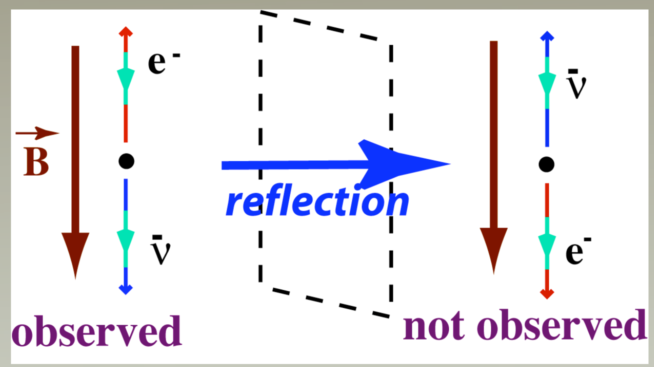
Discovery of Parity Violation (late 1950s)



Weak decay of ^{60}Co Nucleus



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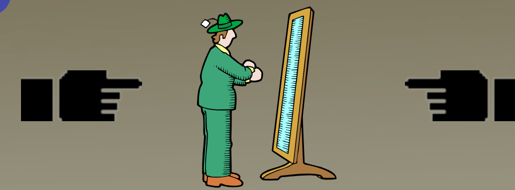

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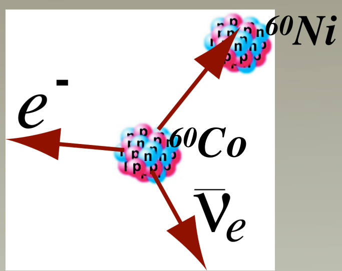

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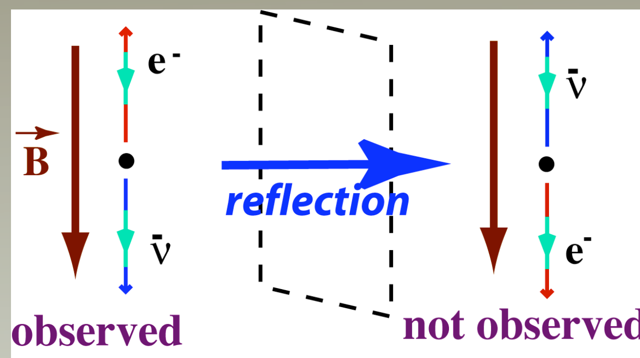

matter particles have spin = 1/2

$$h = \frac{\vec{s} \bullet \vec{p}}{|\vec{s}||\vec{p}|} = \pm 1$$

handedness or ***helicity/chirality***

Definitions

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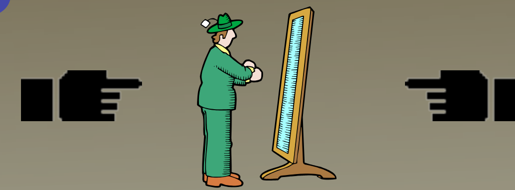

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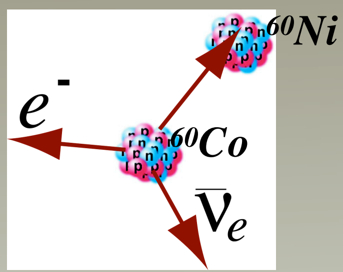
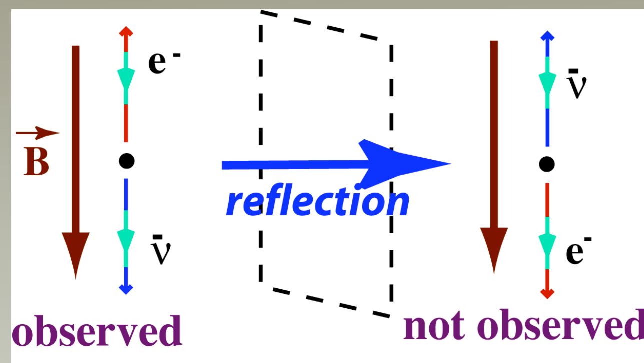


Weak decay of ^{60}Co Nucleus



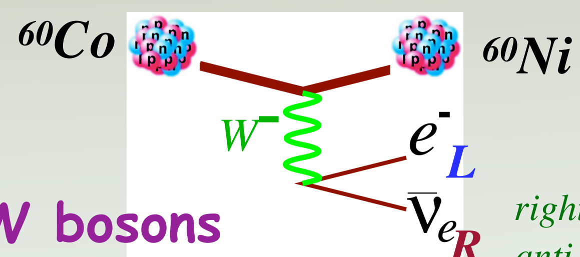
matter particles have spin = 1/2

$$h = \frac{\vec{s} \bullet \vec{p}}{|\vec{s}||\vec{p}|} = \pm 1$$

handedness or *helicity/chirality*

Mirror reflection flips sign of helicity

Left-handed ⟺ *right-handed*



right-handed anti-neutrino

Only left-handed particles can exchange W bosons

(right-handed anti-particles)

Outline

Weak Interactions without Neutrinos

- *Earliest Speculations & Measurements*
- *Parity-Violating Electron Scattering*
- *Experiments that Established the Electroweak Theory*
- *Weak Probes of Hadrons*
- *Outlook*

Disclaimer

I have developed a roughly chronological narrative. My goal here is to set the context that has made PREX feasible. I have neither attempted to be comprehensive nor taken the care to give credit to all major advances

A Classic Paper

LETTERS TO THE EDITOR

PARITY NONCONSERVATION IN THE FIRST ORDER IN THE WEAK-INTERACTION CONSTANT IN ELECTRON SCATTERING AND OTHER EFFECTS

Ya. B. ZEL' DOVICH

Submitted to JETP editor December 25, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 964–966 (March, 1959)

Parity Violation in Electron Scattering?

WE assume that besides the weak interaction that causes beta decay,

$$g\,(\bar{P}ON)\,(\bar{e}^{-}O\nu) + \text{Herm. conj.}, \qquad (1)$$

there exists an interaction

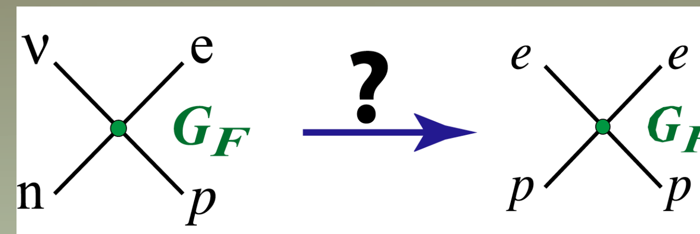
$$g\,(\bar{P}OP)\,(\bar{e}^{-}Oe^{-}) \qquad (2)$$

with $g \approx 10^{-49}$ and the operator $O = \gamma_\mu(1 + i\gamma_5)$ characteristic[1] of processes in which parity is not conserved.*

Then in the scattering of electrons by protons the interaction (2) will interfere with the Coulomb scattering, and the nonconservation of parity will appear in terms of the first order in the small quantity g. Owing to this it becomes possible to test the hypothesis used here experimentally and to determine the sign of g.

In the scattering of fast ($\sim 10^9$ ev) longitudinally polarized electrons through large angles by unpolarized target nuclei it can be expected that the cross-sections for right-hand and left-hand electrons (i.e., for electrons with $\sigma \cdot p > 0$ and $\sigma \cdot p < 0$) can differ by 0.1 to 0.01 percent. Such an effect is a specific test for an interaction not conserving parity.

Neutron β Decay → *Electron-proton Weak Scattering*

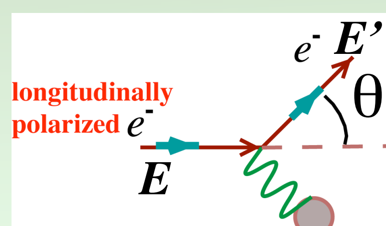


$$\sigma \;\alpha\; |A_{EM} + A_{weak}|^2$$

$$\sim |A_{EM}|^2 + 2A_{EM}A^*_{weak} + \ldots$$

Parity-violating

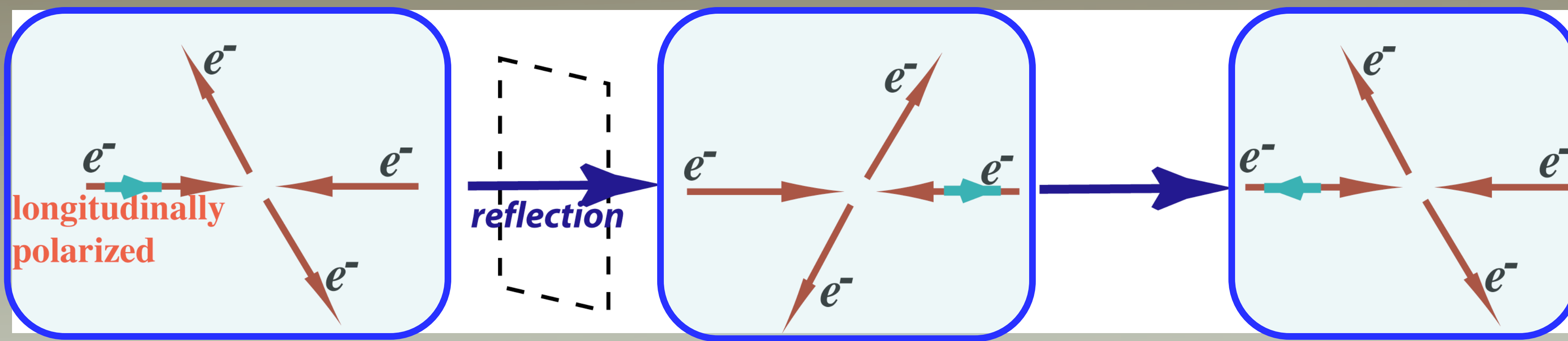
$$A_{PV} = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} = -A_{LR}$$



4-momentum transfer

$$Q^2 = 4EE'\sin^2\frac{\theta}{2}$$

Observable Parity-Violating Asymmetry



- *One of the incident beams longitudinally polarized*
- *Change sign of longitudinal polarization*
- *Measure fractional rate difference*

The matrix element of the Coulomb scattering is of the order of magnitude e^2/k^2, where k is the momentum transferred ($\hbar = c = 1$). Consequently, the ratio of the interference term to the Coulomb term is of the order of gk^2/e^2. Substituting $g = 10^{-5}/M^2$, where M is the mass of the nucleon, we find that for $k \sim M$ the parity non-conservation effects can be of the order of 0.1 to 0.01 percent.

$$A_{PV} = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} \sim \frac{A_{weak}}{A_{EM}} \sim \frac{G_F Q^2}{4\pi\alpha}$$

$$A_{PV} \sim 10^{-4} \cdot Q^2(\mathrm{GeV}^2)$$

Early Hadron-Hadron Measurements

- Longitudinal (or circular) polarization in initial or final state of one or the other particle
- Hadron-hadron interactions easier to access experimentally
- Find reactions where the denominator (electromagnetic amplitude) is small; enhancing the numerator (weak amplitude)
- In early measurements involving nuclei, connection to underlying fundamental dynamics rather tenuous

Low energy p-p elastic scattering $\vec{p} + p \longrightarrow p + p$ Tanner (1957)

$^{180}Hf^*(8^-) \rightarrow ^{180}Hf + \gamma$ $A_\gamma = -(1.66 \pm 0.18) \times 10^{-2}$ (1971)

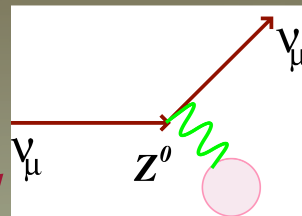
$\vec{n} + ^{139}La$ $A_z = (9.55 \pm 0.35) \times 10^{-2}$ (1991)

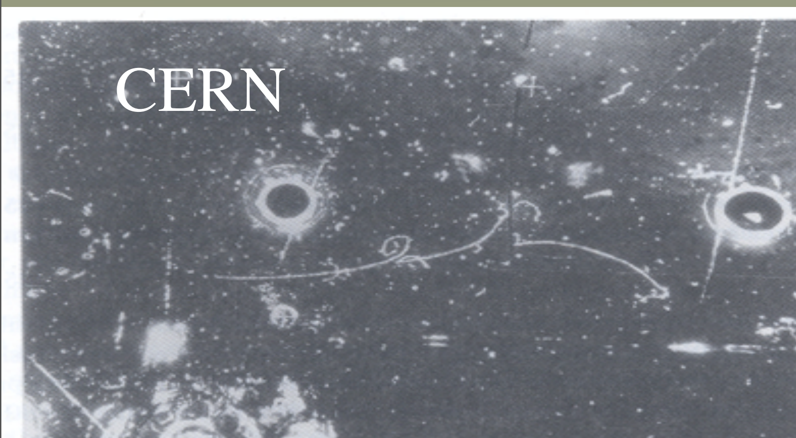
Neutral Weak Interaction Theory

A Model of Leptons

Steve Weinberg - 1967

The Z boson incorporated





	Left-	Right-
γ Charge	$0,\pm 1,\pm\frac{1}{3},\pm\frac{2}{3}$	$0,\pm 1,\pm\frac{1}{3},\pm\frac{2}{3}$
W Charge	$T=\pm\frac{1}{2}$	zero
Z Charge	$T-q\sin^2\theta_W$	$-q\sin^2\theta_W$

The weak mixing angle introduced

Gargamelle finds one ν_μ e^- event in 1973!

(two more by 1976)

electron-nucleon scattering

$\begin{pmatrix}\nu\\ e\end{pmatrix}_l \quad (e)_r$ ← *Weinberg model*

Parity is violated

or

$\begin{pmatrix}\nu\\ e\end{pmatrix}_l \quad \begin{pmatrix}E^0\\ e\end{pmatrix}_r$

Parity is conserved

Landmark experiment (late 1970s)

at Stanford Linear Accelerator Center (SLAC)

E122 at SLAC demonstrated parity-violation in electron-nucleon deep inelastic scattering

PV Deep-Inelastic Scattering

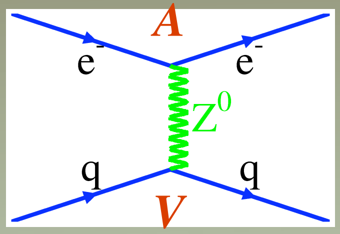
The discovery of electron-nucleon deep inelastic scattering ~ 1966 gave rise to an opportunity: large cross-section at large Q^2

Instead of left- and right-handed couplings, use g_V and g_A:

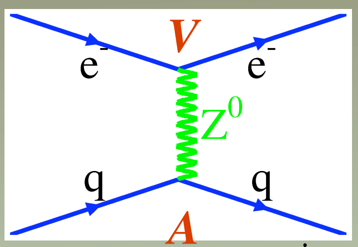
$$g_V = g_L + g_R$$

$$g_A = g_L - g_R$$

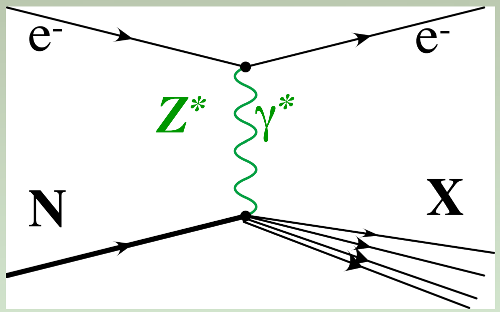
Vector and Axial-vector couplings



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



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



A_{PV} in Electron-Nucleon DIS:

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

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

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

x: struck quark's nucleon momentum fraction

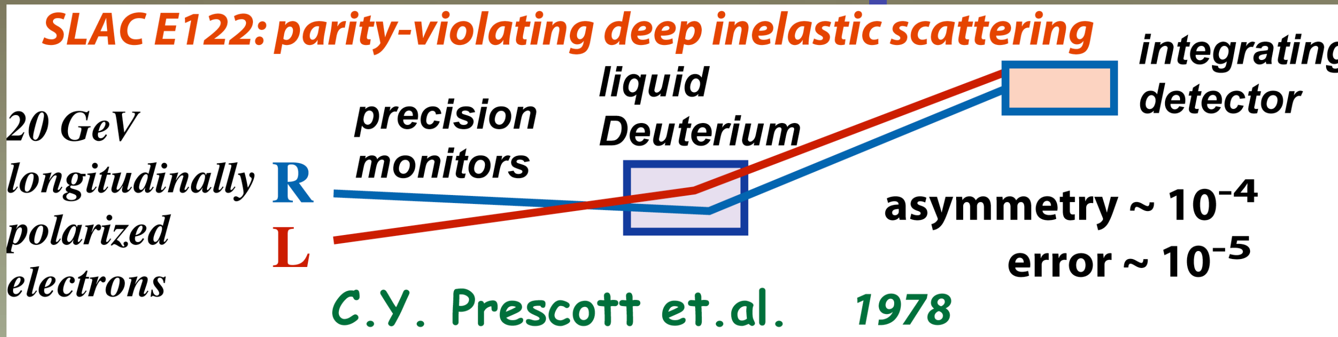
$f_i(x)$: probability distribution of i^{th} quark

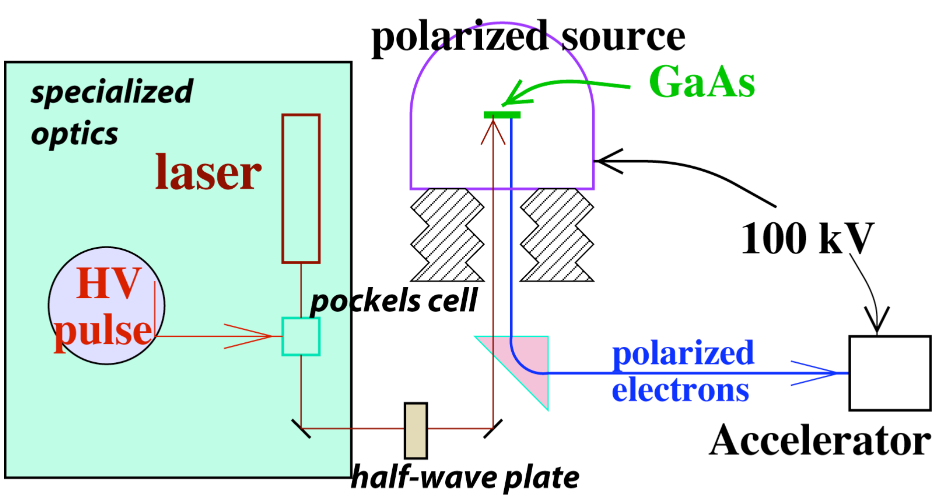
For a ^{2}H target, assuming charge symmetry, structure functions largely cancel in the ratio:

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

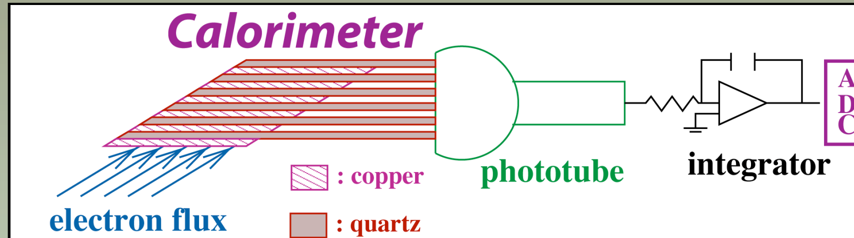
$$b(x) = \frac{3}{10}\left[(2C_{2u} - C_{2d})\frac{u_v(x) + d_v(x)}{u(x) + d(x)}\right] + \cdots$$

SLAC E122 Experiment





- Optical pumping of a GaAs wafer
- Rapid helicity reversal: polarization sign flip ~ 100 Hz to minimize the impact of drifts
- Helicity-correlated beam motion: under sign flip, beam stability at the micron level



"Flux Integration":
Allows counting at high rates

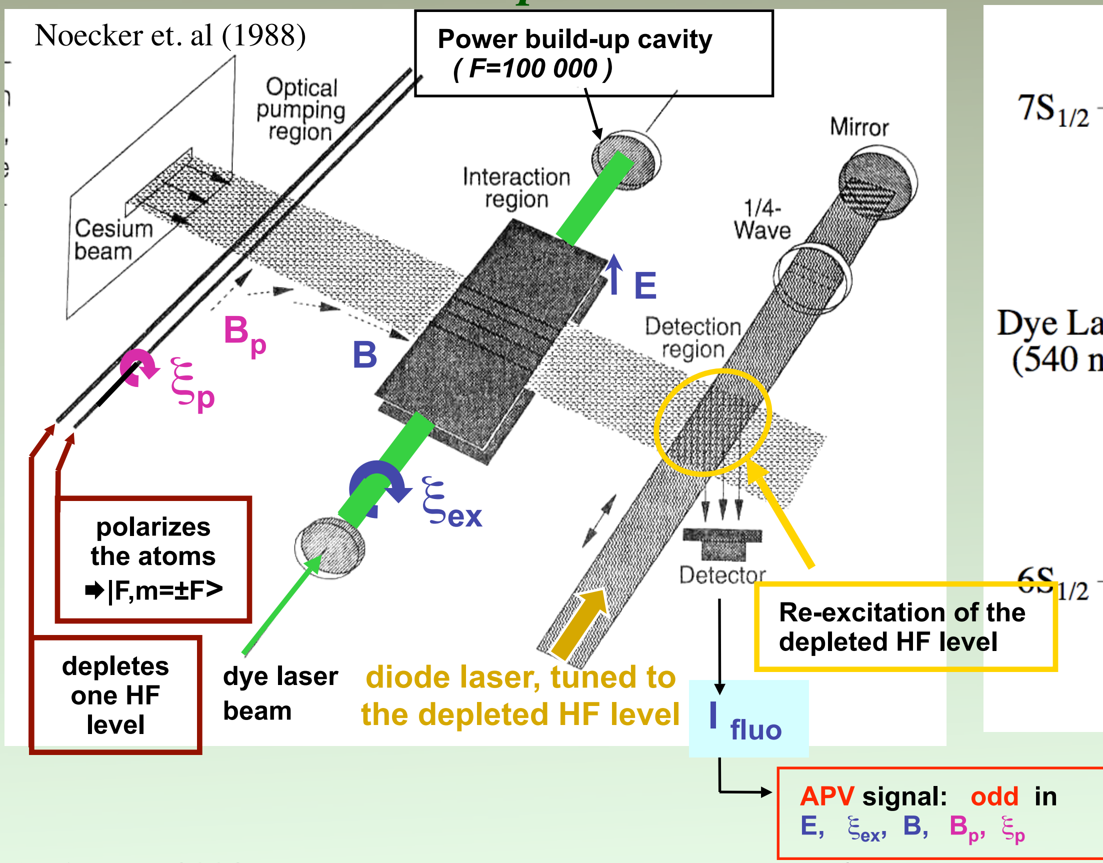
Spectrometer directs flux to background-free region

- *Parity Violation in Weak Neutral Current Interactions*
- *$\sin^2\theta_W = 0.224 \pm 0.020$: same as in neutrino scattering*

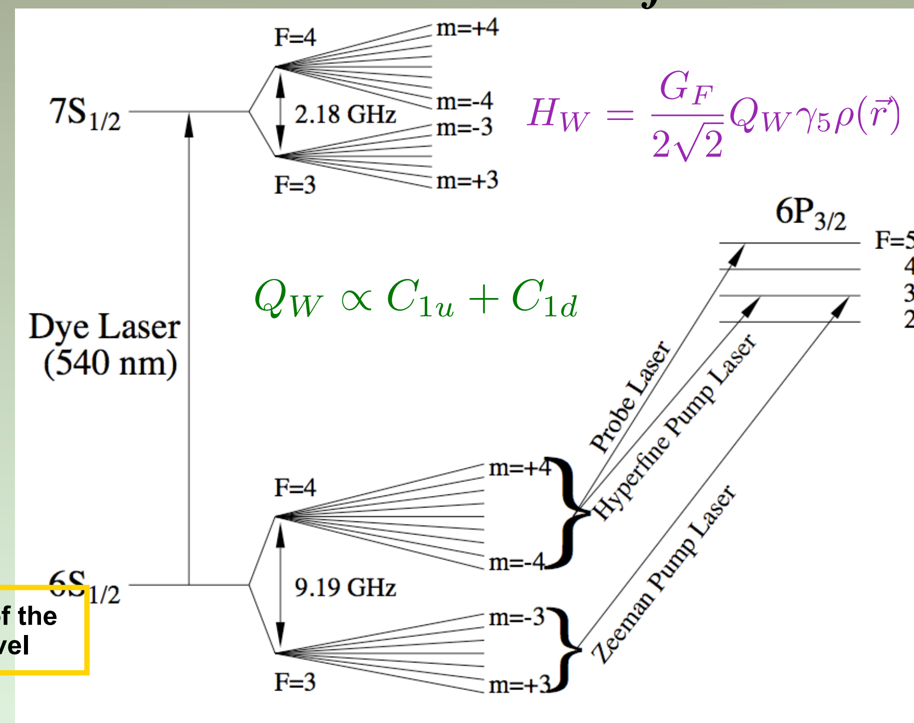
Atomic Parity Violation

- *$6S \rightarrow 7S$ transition in ^{133}Cs is forbidden within QED*
- *Parity Violation introduces small opposite parity admixtures*
- *Induce an E1 Stark transition, measure E1-PV interference*
- *5 sign reversals to isolate APV signal and suppress systematics*
- *Signal is ~ 6 ppm, measured to 40 ppb*

Boulder Experiment



Partial Level Structure of Cesium



Elastic Electron-Nuclear Scattering

Elastic scattering from $(J^\pi, T) = (0^+, 0)$ ***nuclei*** *Feinberg (1975)*

For a spinless, iso-scalar nucleus, A_{PV} in elastic scattering at forward angle insensitive to nuclear structure: clean measurement of $C_{1u} + C_{1d}$

^{12}C at MIT-Bates: $A_{PV} = (1.69 \pm 0.39 \pm 0.06) \times 10^{-6}$ *Souder (1990)*

Quasi-elastic backward angle scattering from ^{9}Be

Additional dependence on C_2 couplings

^{9}Be at Mainz: $A_{PV} = (-9.4 \pm 1.8 \pm 0.5) \times 10^{-6}$ *Heil (1989)*

- ***First measurements of electron-nuclear weak interactions***
- ***Pushed experimental technology***
- ***Low energy tests of electroweak theory***

Parity Violation at the Z Resonance

$$e^+e^- \rightarrow Z^0 \rightarrow l^+l^-, q\bar{q}$$

Polarize the electron beam and measure Z production

$$P_b = \frac{N_+ - N_-}{N_+ + N_-}$$

Fraction of electron beam polarized along or against the momentum

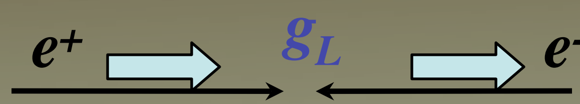
$$A_{LR} = \frac{N_{Z-} - N_{Z+}}{N_{Z-} + N_{Z+}} = \frac{(1-P_b)g_L^2 - (1+P_b)g_R^2}{(1-P_b)g_L^2 - (1+P_b)g_R^2} = P_b P_e$$

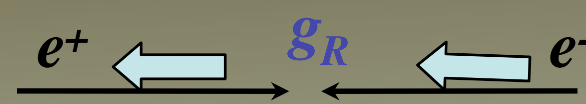
All final states can be used!

$$P_e = \frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2} = 2(1 - 4\sin^2\theta_W) \approx 0.14$$

The SLD detector at SLAC measured P_e to 1% relative precision, which has yielded the single most precise value of the weak mixing angle to date

Tau Polarization at CERN

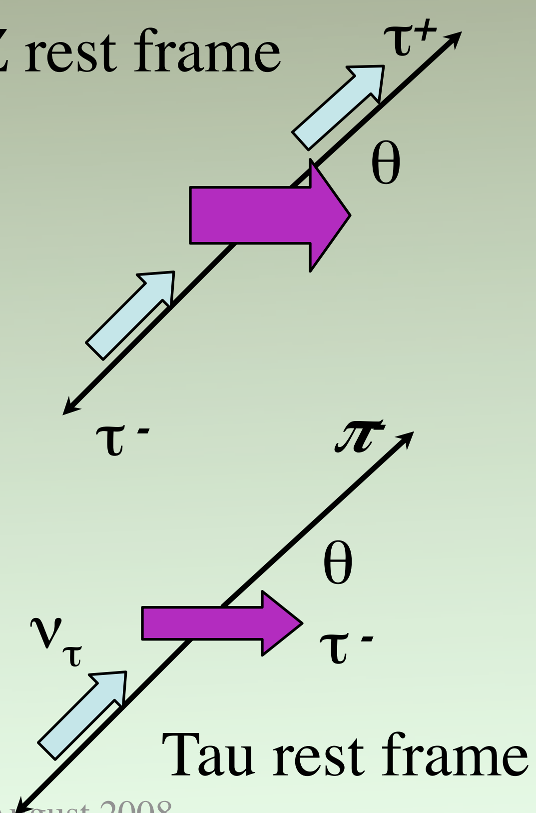




Even if electrons and positrons are unpolarized, the Z's are produced polarized

$$P_Z = \frac{N_+ - N_-}{N_+ + N_-} = \frac{g_R^2 - g_L^2}{g_R^2 + g_L^2}$$

Instead of polarizing the initial state, analyze the final state



For tau leptons, use the weak decay!

Lifetime ~ few ps

Travels a few mm

V-A interaction reveals tau polarization

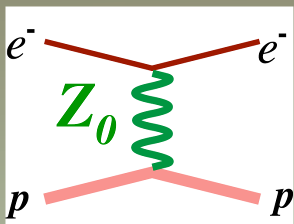
Pion lab energy distribution is related trivially to the rest frame angular distribution

Z couplings to all leptons measured precisely: firmly established the electroweak theory ~ 1990

Strange Quarks in the Nucleon

Quark Model ⟺ **?** *QCD*

Strange quarks carry nucleon momentum: Other external properties affected?

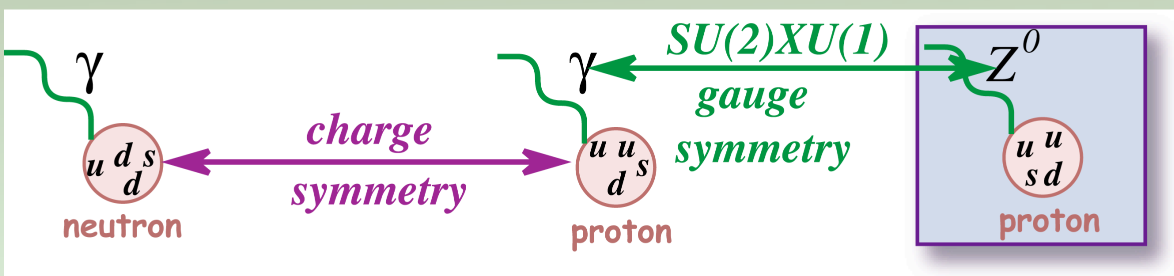


A_{PV} for elastic e-p scattering:

$$A = \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right]\frac{A_E + A_M + A_A}{\sigma_p}$$

$$A_E = \varepsilon\, G_E^p G_E^Z, \qquad A_M = \tau\, G_M^p G_M^Z, \qquad A_A = -\left(1 - 4\sin^2\theta_W\right)\varepsilon'\, G_M^p G_A^e$$

Forward angle — Backward angle



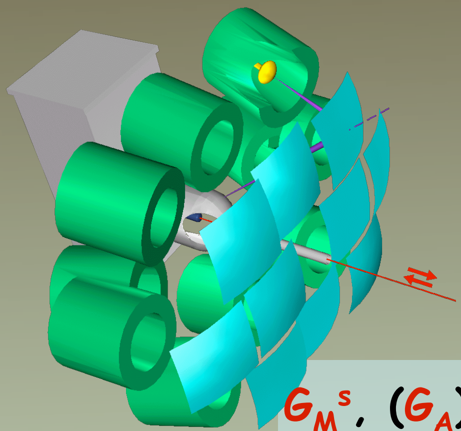
$$G_p^Z \sim (1 - 4\sin^2\theta_W)\, G_p^\gamma - G_n^\gamma - G_s$$

⇒ $G_E^s(Q^2), G_M^s(Q^2)$

Kaplan & Manohar (1988)
McKeown (1989)

^{4}He target: Unique G_E sensitivity *^{2}H: Enhanced G_A sensitivity*

World Program

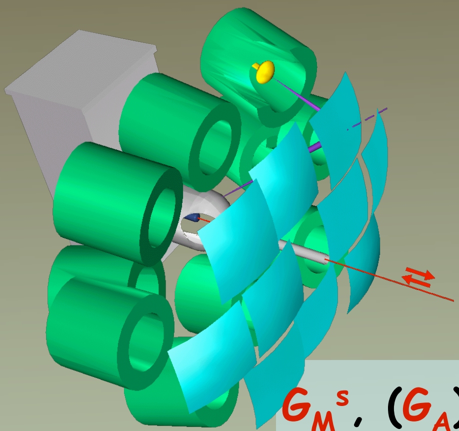


SAMPLE

open geometry,
integrating

G_M^s, (G_A) at Q^2 = 0.1 GeV^2

World Program

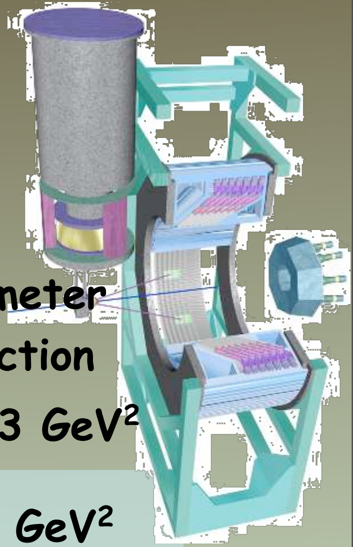


SAMPLE

open geometry, integrating

G_M^s, (G_A) at Q^2 = 0.1 GeV^2

A4



Open geometry

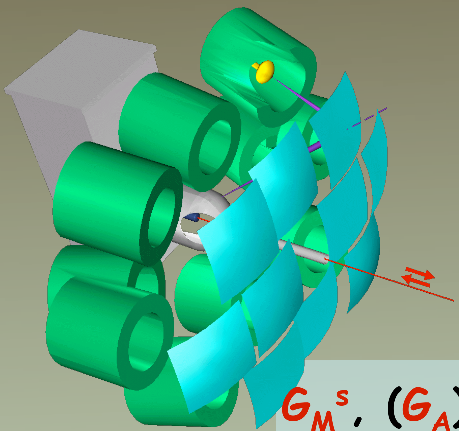
Fast counting calorimeter for background rejection

$G_E^s + 0.23\, G_M^s$ at Q^2 = 0.23 GeV^2

$G_E^s + 0.10\, G_M^s$ at Q^2 = 0.1 GeV^2

G_M^s, G_A^e at Q^2 = 0.23 GeV^2

World Program



SAMPLE

open geometry, integrating

G_M^s, (G_A) at Q^2 = 0.1 GeV^2

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Open geometry

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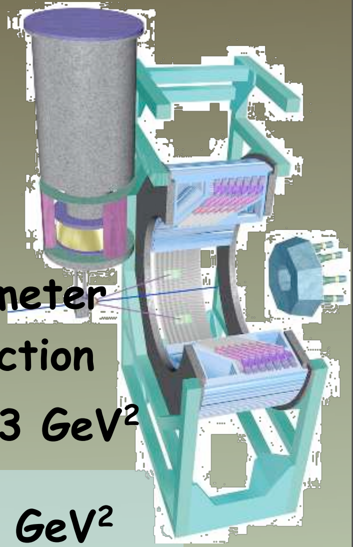
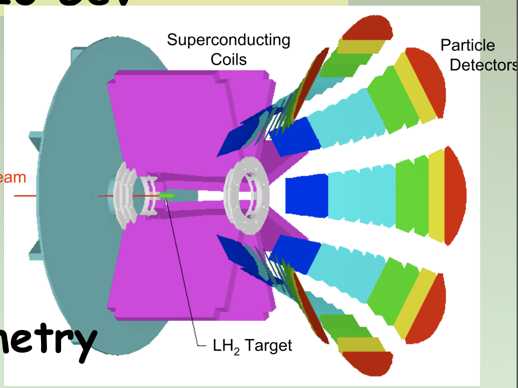


G_E^s + 0.23 G_M^s at Q^2 = 0.23 GeV^2

G_E^s + 0.10 G_M^s at Q^2 = 0.1 GeV^2

G_M^s, G_A^e at Q^2 = 0.23 GeV^2

G0



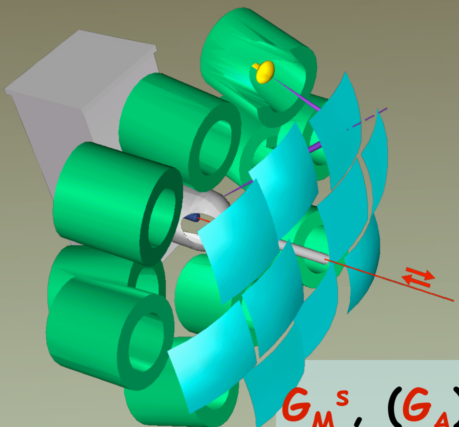
Open geometry

Fast counting with magnetic spectrometer + TOF for background rejection

G_E^s + η G_M^s over Q^2 = [0.12,1.0] GeV^2

G_M^s, G_A^e at Q^2 = 0.23, 0.62 GeV^2

World Program

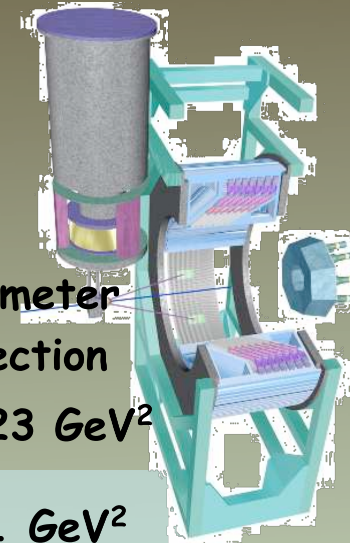


SAMPLE

open geometry, integrating

G_M^s, (G_A) at Q^2 = 0.1 GeV^2

A4



Open geometry

Fast counting calorimeter for background rejection

$G_E^s + 0.23\, G_M^s$ at Q^2 = 0.23 GeV^2

$G_E^s + 0.10\, G_M^s$ at Q^2 = 0.1 GeV^2

G_M^s, G_A^e at Q^2 = 0.23 GeV^2

HAPPEX

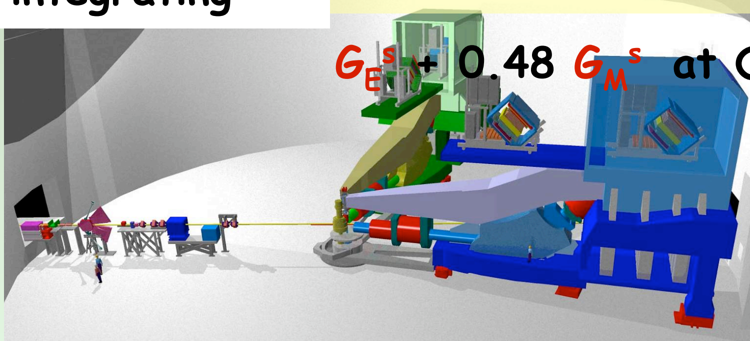
Precision spectrometer, integrating

$G_E^s + 0.39\, G_M^s$ at Q^2 = 0.48 GeV^2

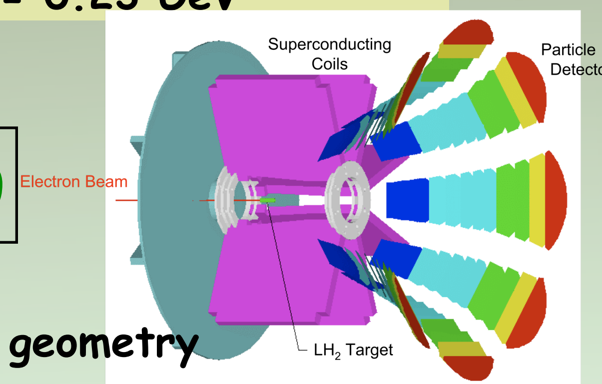
$G_E^s + 0.08\, G_M^s$ at Q^2 = 0.1 GeV^2

G_E^s at Q^2 = 0.1 GeV^2 (^{4}He)

$G_E^s + 0.48\, G_M^s$ at Q^2 = 0.62 GeV^2



G0



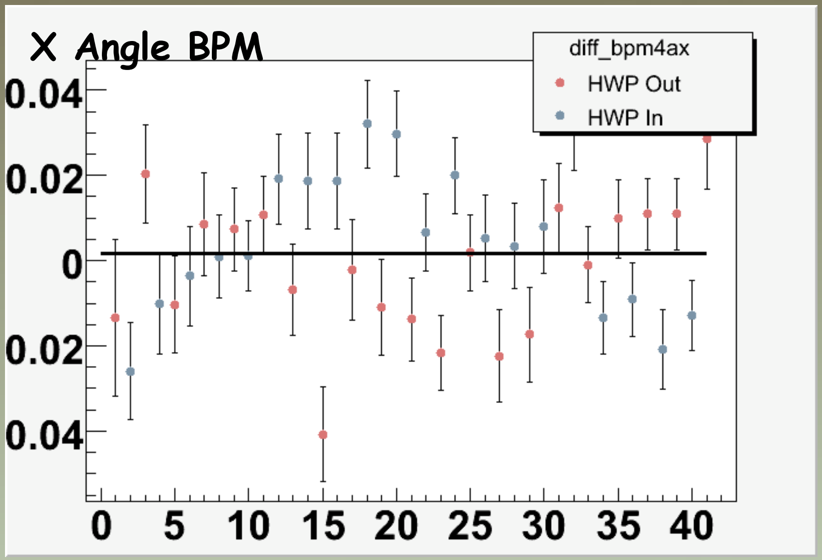
Open geometry

Fast counting with magnetic spectrometer + TOF for background rejection

$G_E^s + \eta\, G_M^s$ over Q^2 = [0.12,1.0] GeV^2

G_M^s, G_A^e at Q^2 = 0.23, 0.62 GeV^2

A_{PV} off ^{1}H & ^{4}He at Low Q^2 at JLab



Hydrogen

Systematic control ~ 10^{-8}

$A_{PV} = -1.58 \pm 0.12$ (stat) ± 0.04 (syst) ppm

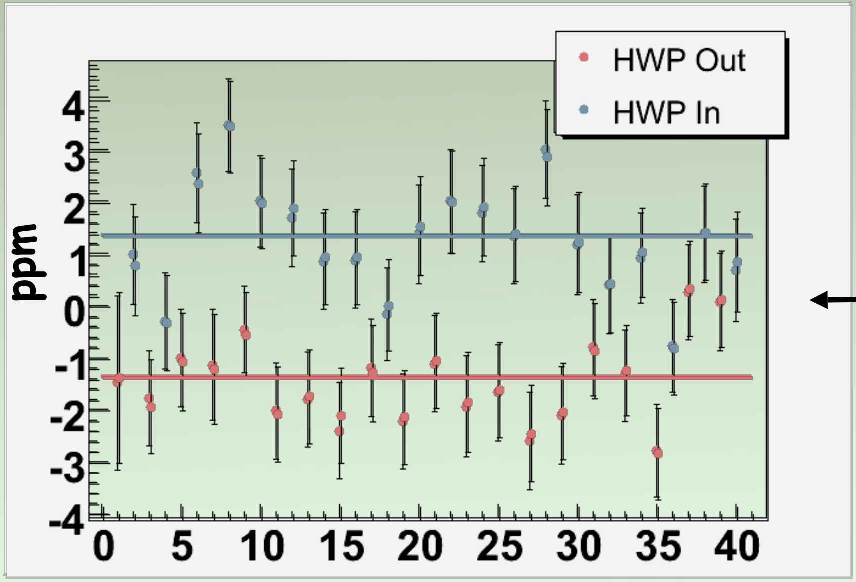
$A(G^s=0) = -1.66$ ppm $\pm$ 0.05 ppm

Helium

Normalization control ~ 2%

$A_{PV} = +6.40 \pm 0.23$ (stat) ± 0.12 (syst) ppm

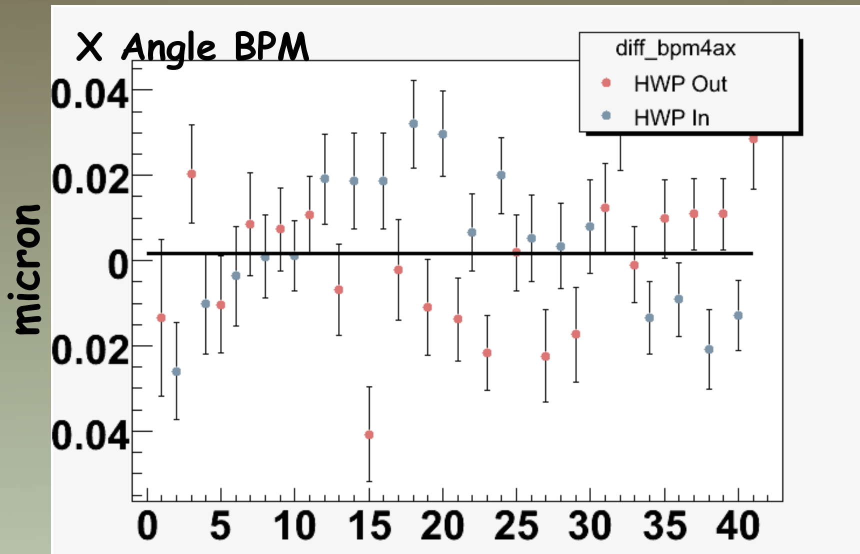
$A(G^s=0) = +6.37$ ppm



← Corrected and Raw, Left arm alone, Superimposed!

Total correction for beam position asymmetry on Left, Right, or ALL detector: 10 ppb

A_{PV} off ^1H & ^4He at Low Q^2 at JLab



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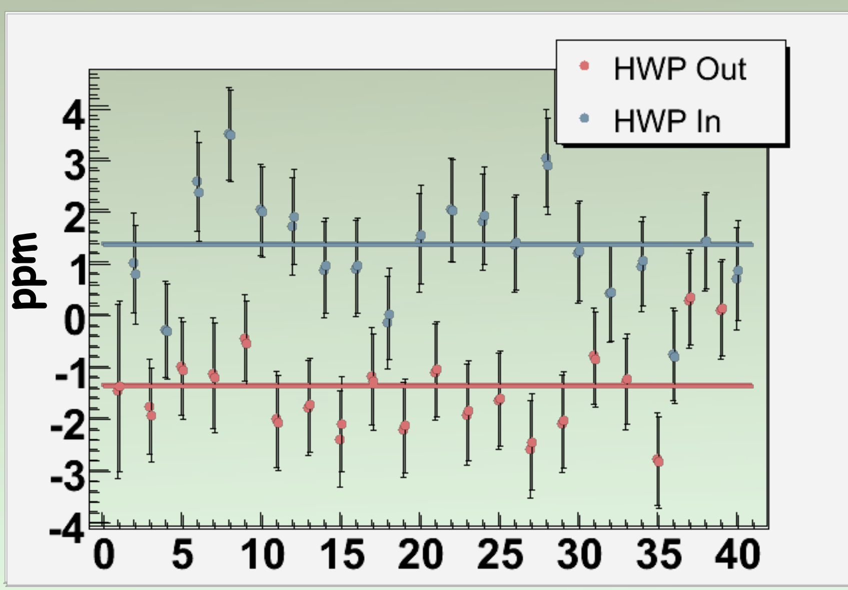
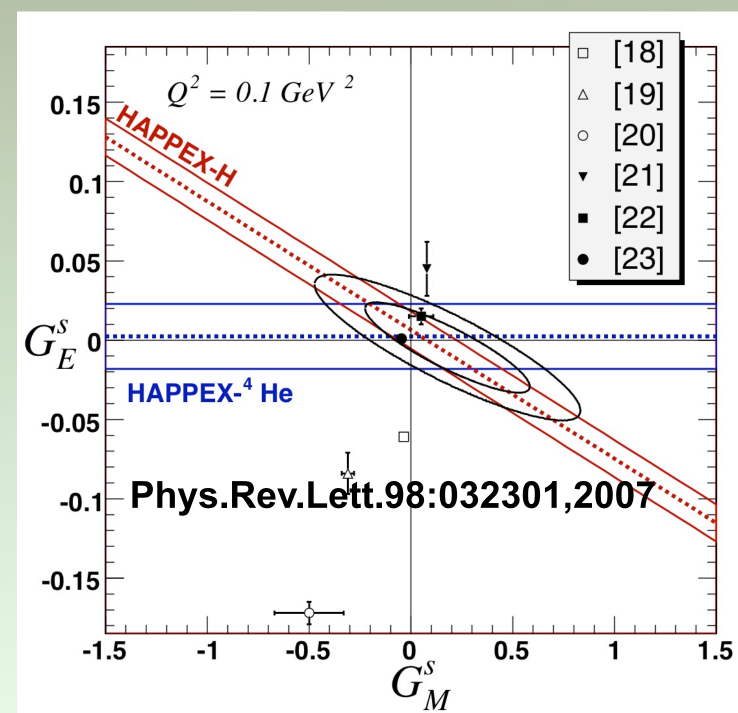
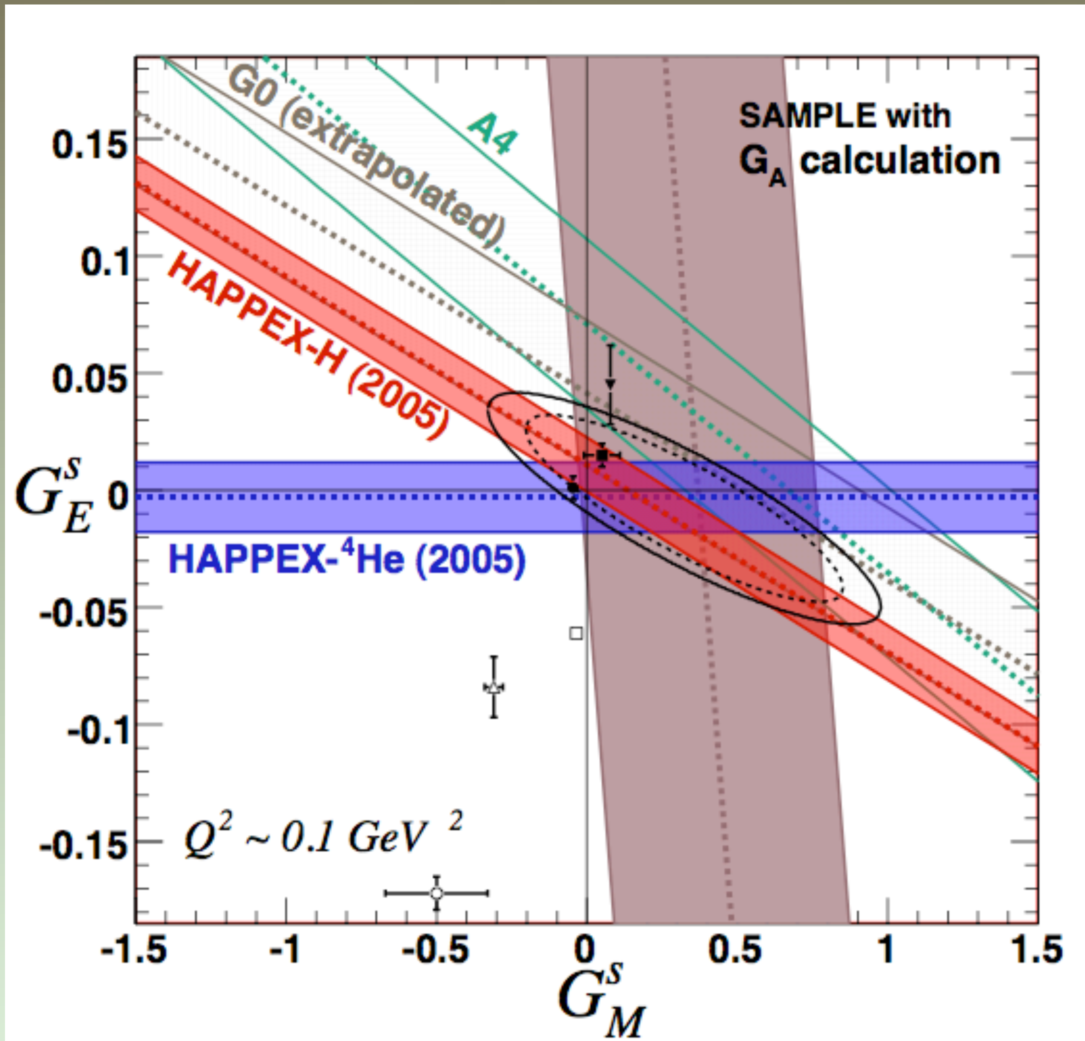




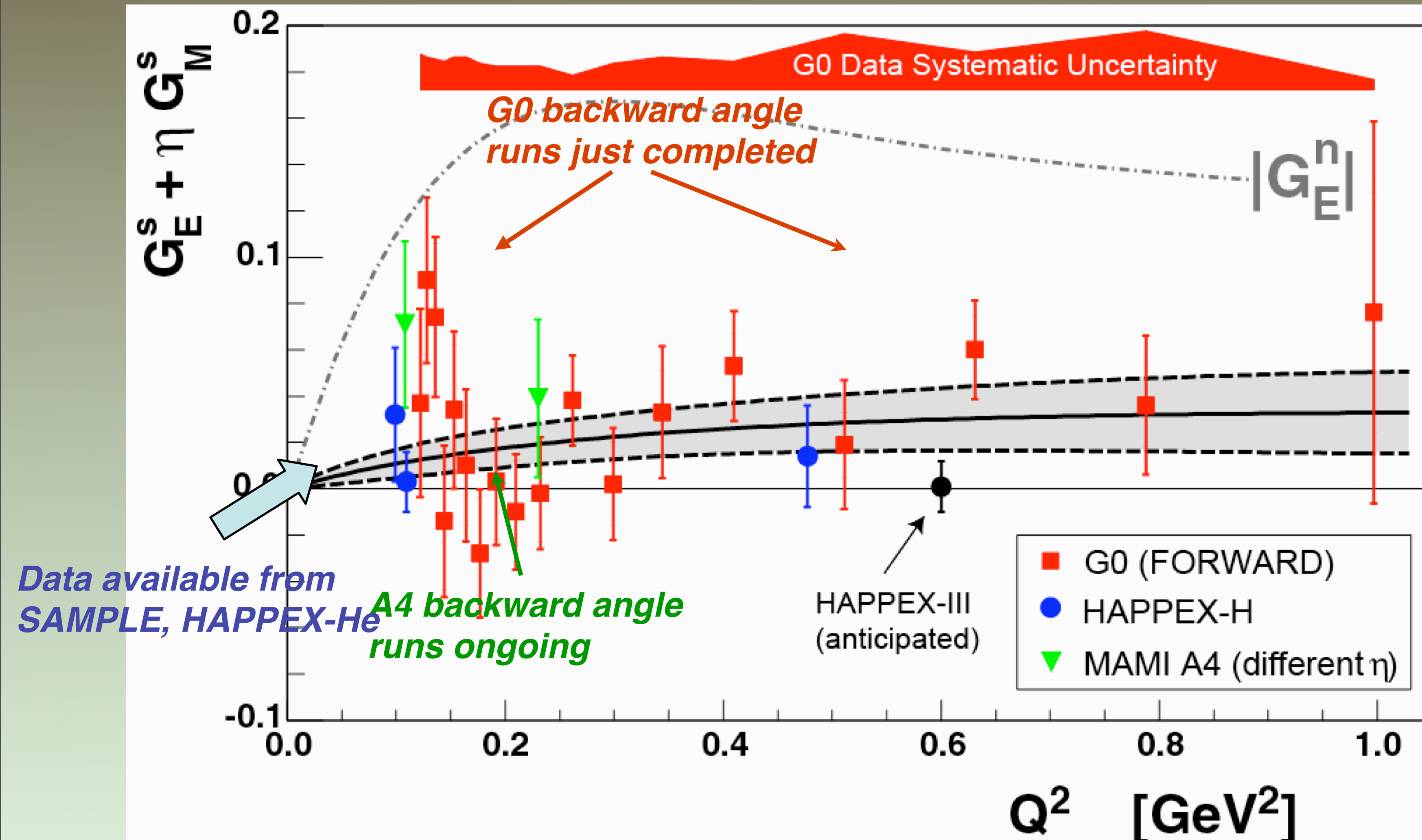
Current Status



At 95% C.L., strange quarks contribute:

< 5% of the magnetic moment, < 5% of the charge radius squared

Current Status



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< 5% of the magnetic moment, < 5% of the charge radius squared

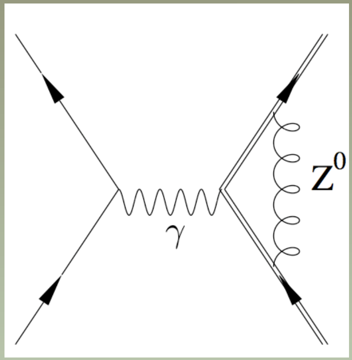
Axial Form Factor and the Anapole Moment

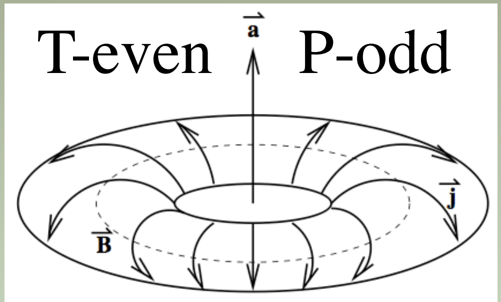
Axial-vector hadronic current has contributions from parity-violating moments

Zel'dovich (1957)

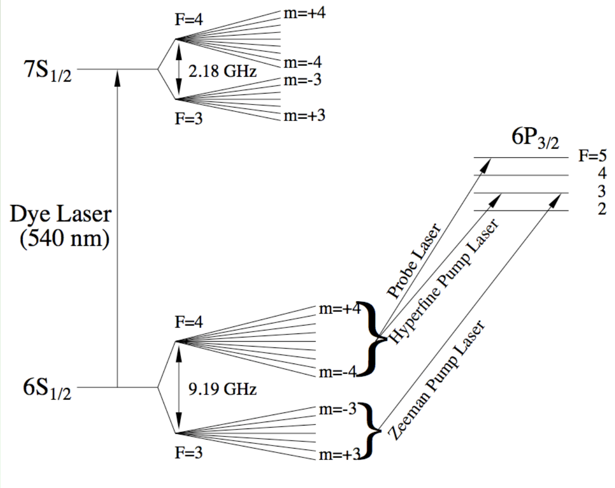
Haxton & Wieman (2001)

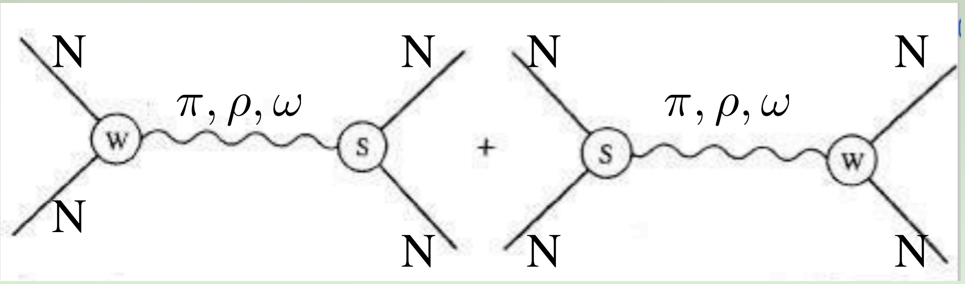
Wood et. al (1997)





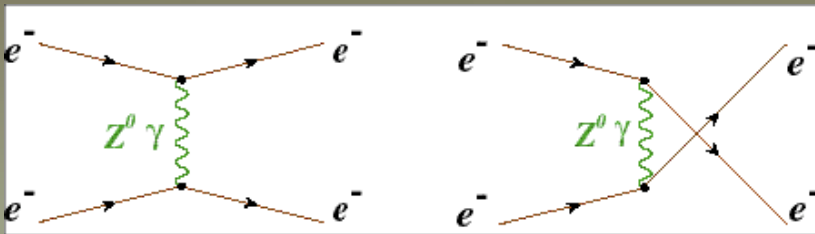
In nuclei, such moments are large enough to be observed via atomic parity violation

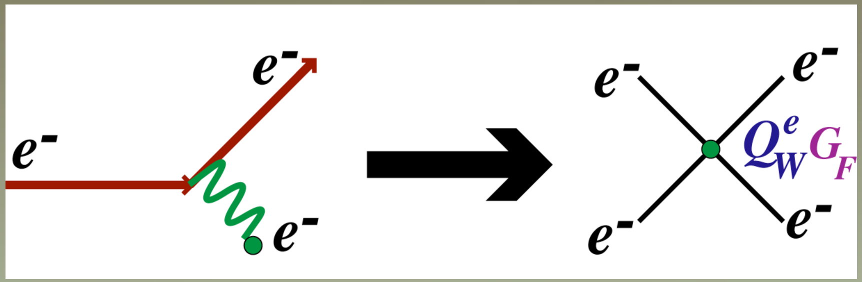




Such moments are generated by purely hadronic weak interactions, described by weak meson-nucleon couplings

Møller Scattering





Purely leptonic reaction

$$A_{PV} = -mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{16 \sin^2 \Theta}{(3 + \cos^2 \Theta)^2} Q^e_W$$

$$A_{PV} \propto m_e E_{lab} (1 - 4 \sin^2 \vartheta_W)$$

Small, well-understood dilution

$$\frac{\delta(\sin^2 \vartheta_W)}{\sin^2 \vartheta_W} \cong 0.05 \frac{\delta(A_{PV})}{A_{PV}}$$

$$\sigma \propto \frac{1}{E_{lab}} \Rightarrow$$

Figure of Merit rises linearly with E_{lab}

SLAC: Highest beam energy with moderate polarized luminosity

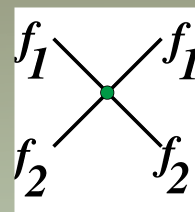
JLab 11 GeV: Moderate beam energy with LARGE polarized luminosity

Comprehensive Search for New Neutral Current Interactions

Important component of indirect signatures of "new physics"

Consider $f_1\bar{f}_1 \to f_2\bar{f}_2$ or $f_1 f_2 \to f_1 f_2$

$$L_{f_1 f_2} = \sum_{i,j=L,R} \frac{4\pi}{\Lambda_{ij}^2}\eta_{ij}\bar{f}_{1i}\gamma_\mu f_{1i}\bar{f}_{2j}\gamma^\mu f_{2j}$$



Eichten, Lane and Peskin, PRL50 (1983)

Λ's for all f_1f_2 combinations and L,R combinations

Many new physics models give rise to non-zero Λ's at the TeV scale:
Heavy Z's, compositeness, extra dimensions…

One goal of neutral current measurements at low energy AND colliders:
Access Λ > 10 TeV for as many f_1f_2 and L,R combinations as possible

LEPII, Tevatron access scales Λ's ~ 10 TeV

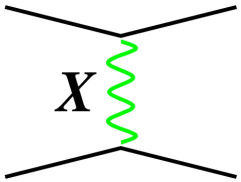
e.g. Tevatron dilepton spectra, fermion pair production at LEPII

- **L,R combinations accessed are parity-conserving**

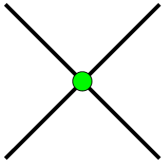
LEPI, SLC, LEPII & HERA accessed some parity-violating combinations but precision dominated by Z resonance measurements

Colliders vs Low Q^2

consider



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



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!*

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

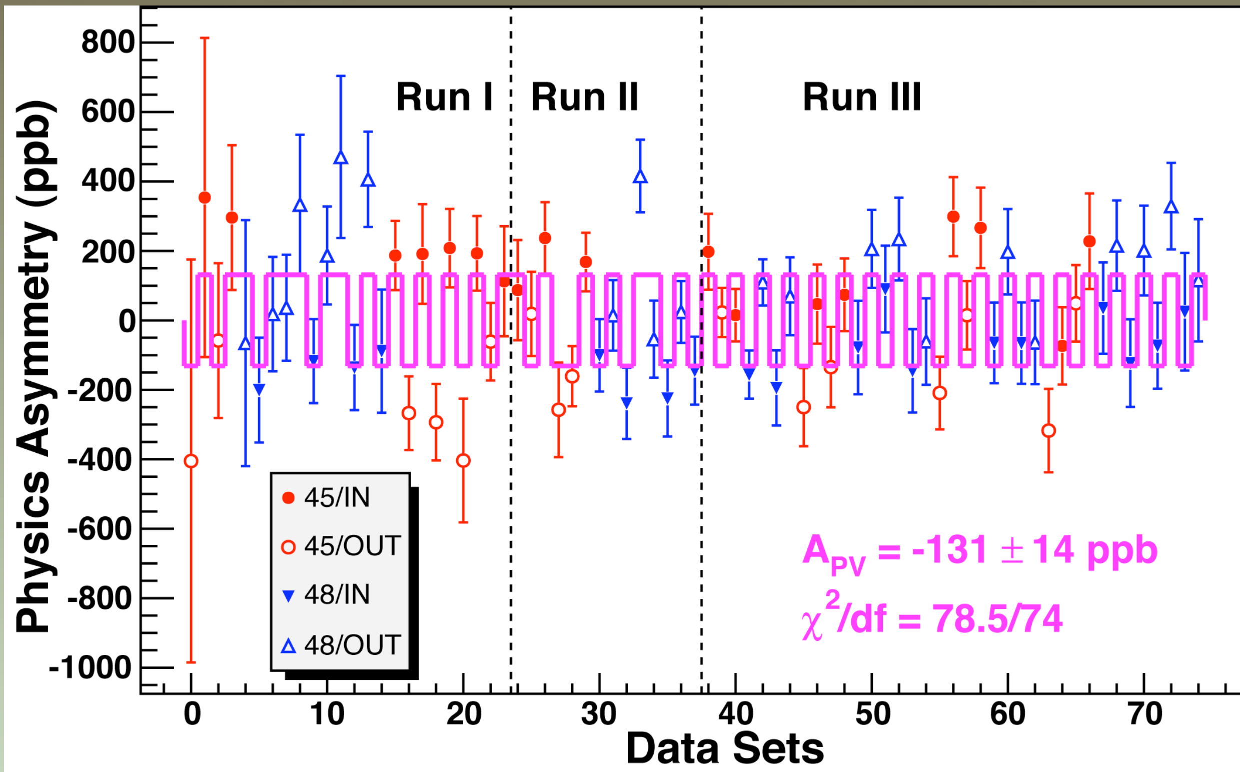
$$\frac{\delta(\sin^2\theta_W)}{\sin^2\theta_W} \lesssim 0.01$$

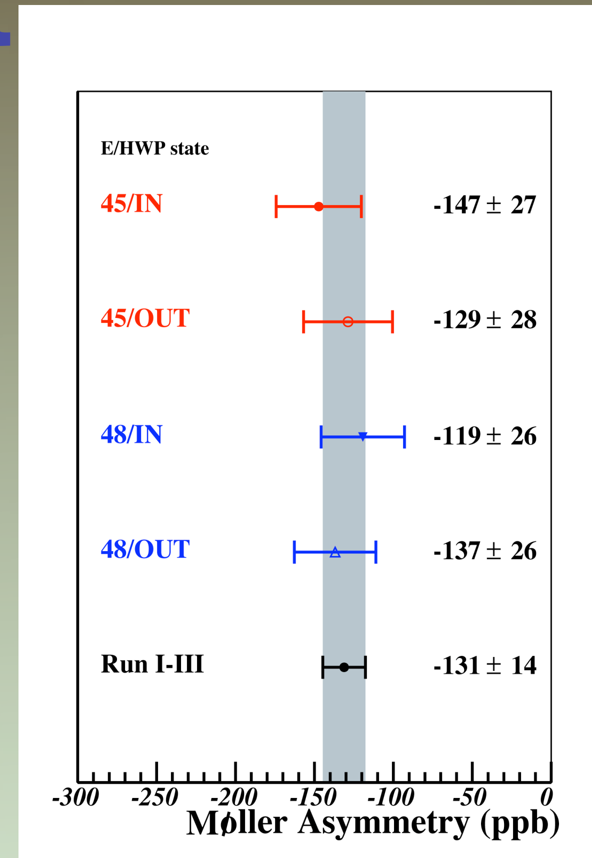
Window of opportunity for weak neutral current measurements at $Q^2 \ll M_Z^2$

Processes with potential sensitivity:

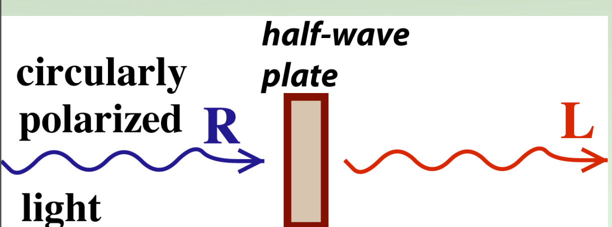
- ***neutrino-nucleon deep inelastic scattering***
- ***Atomic parity violation***
- ***parity-violating electron scattering***

E158 Result





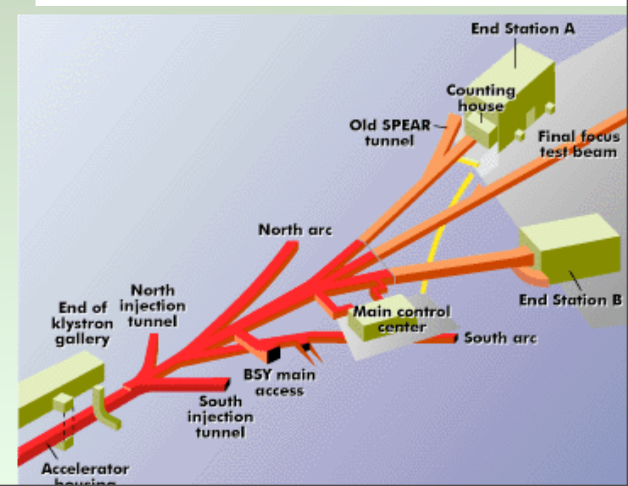
$$A_{PV} = (-131 \pm 14 \pm 10) \times 10^{-9}$$



g-2 spin precession

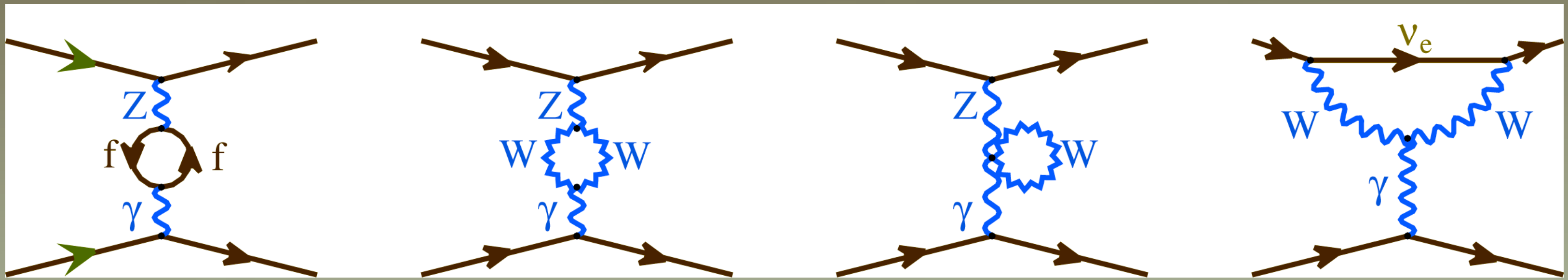
45 GeV: 14.0 revs

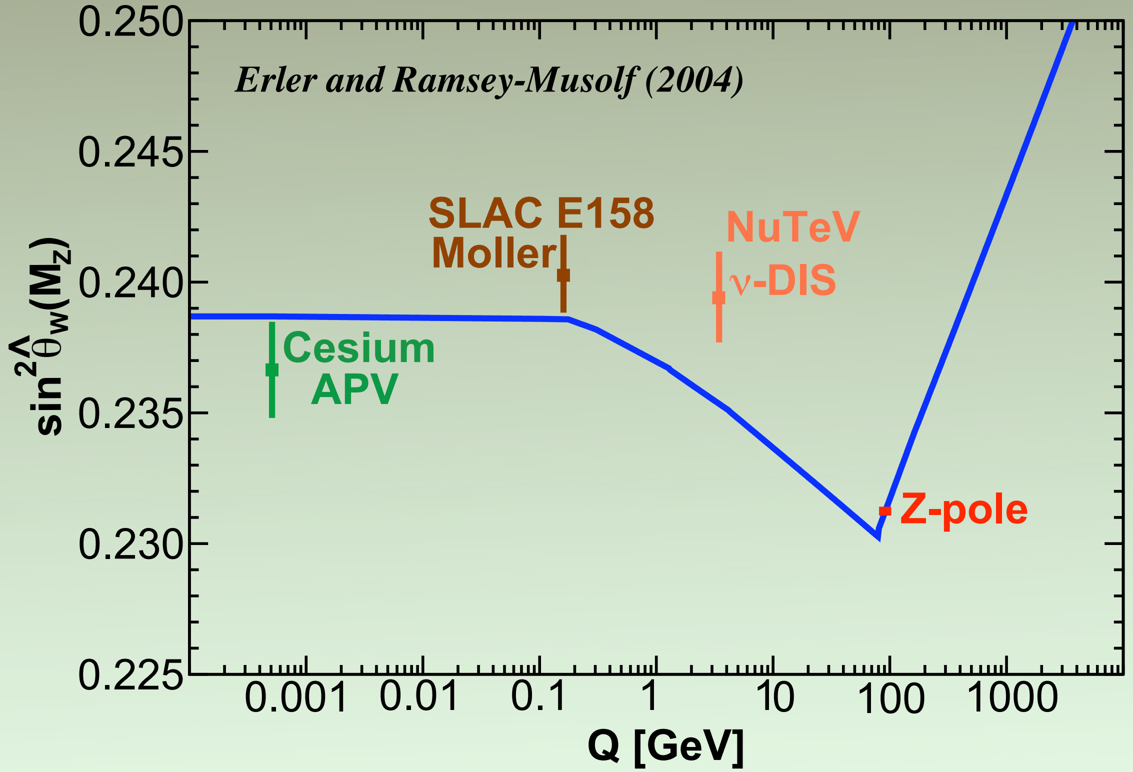
48 GeV: 14.5 revs



Phys. Rev. Lett. **95** 081601 (2005)

Physics Implications





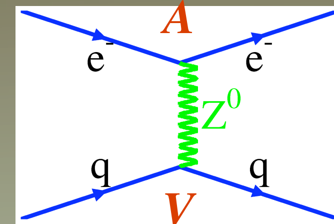
$$\Lambda^{+}_{ee} \quad > 7\ \text{TeV}$$

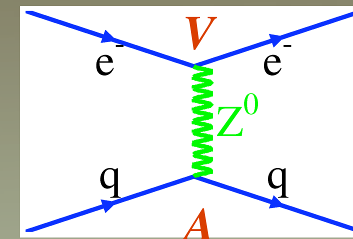
$$\Lambda^{-}_{ee} \quad > 16\ \text{TeV}$$

$$\mathbf{Z_\chi} \quad \mathbf{> 1\ TeV}$$

Lepton-Quark Couplings

- **Atomic Parity Violation**
  - ^{133}Cs 6s to 7s transition
  - Future: isotope measurements
- **Neutrino DIS: NuTeV**
  - 3 σ deviation
  - Many hadronic physics issues
  - Look at other l-q couplings?

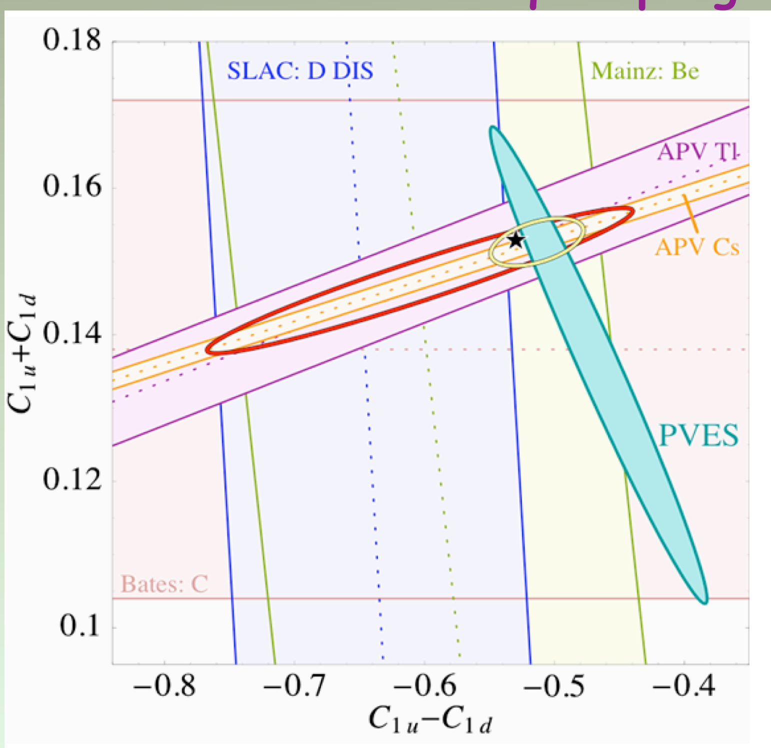




$$C_{1i} \equiv 2 g_A^e g_V^i \qquad C_{2i} \equiv 2 g_V^e g_A^i$$

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

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



A_{PV} in elastic e-p scattering: Qweak at JLab

$$A(Q^2 \to 0) = -\frac{G_F}{4\pi\alpha\sqrt{2}}\left[Q^2\, Q_{weak}^p + Q^4 B(Q^2) \right]$$

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

Data ~ 2010

Lepton-Quark Couplings

- **Atomic Parity Violation**
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  - Future: isotope measurements
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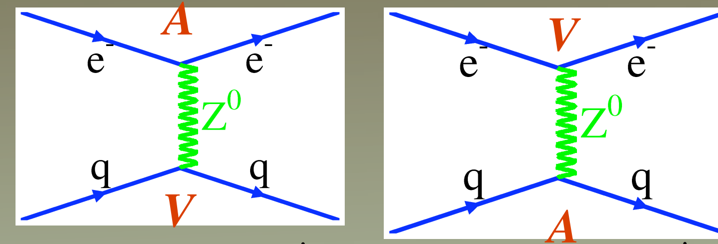

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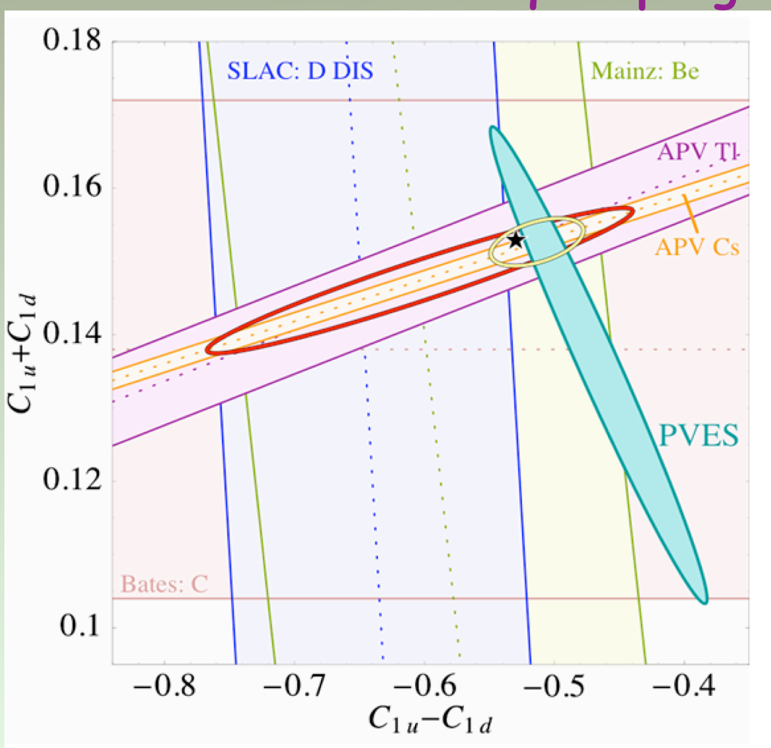
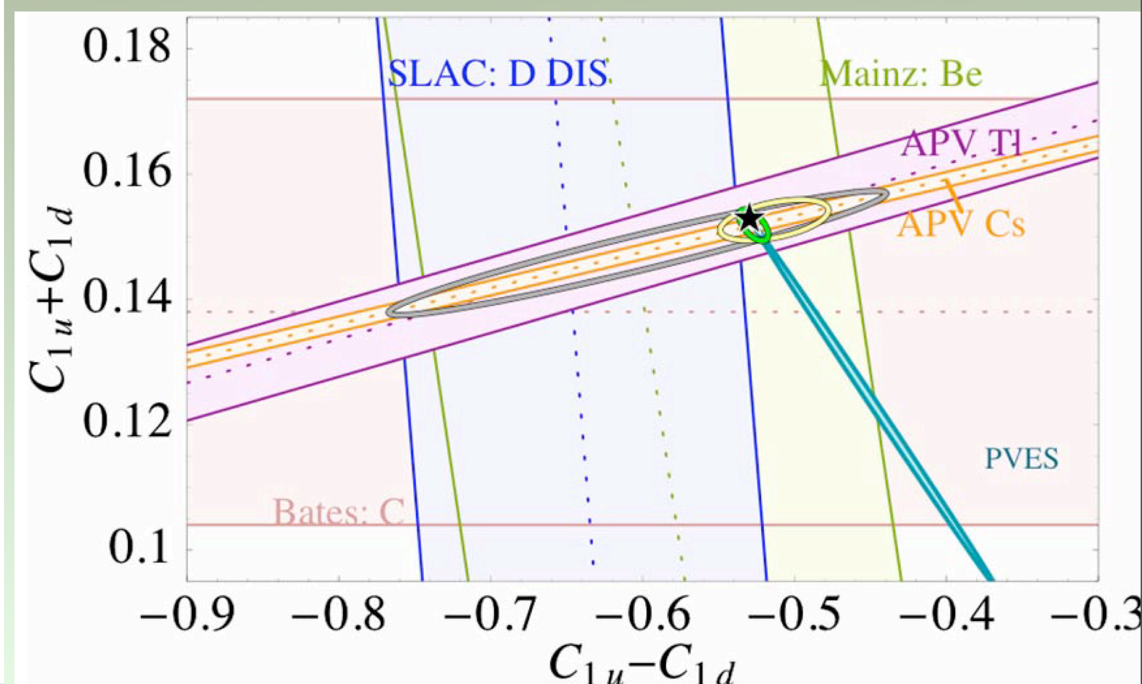
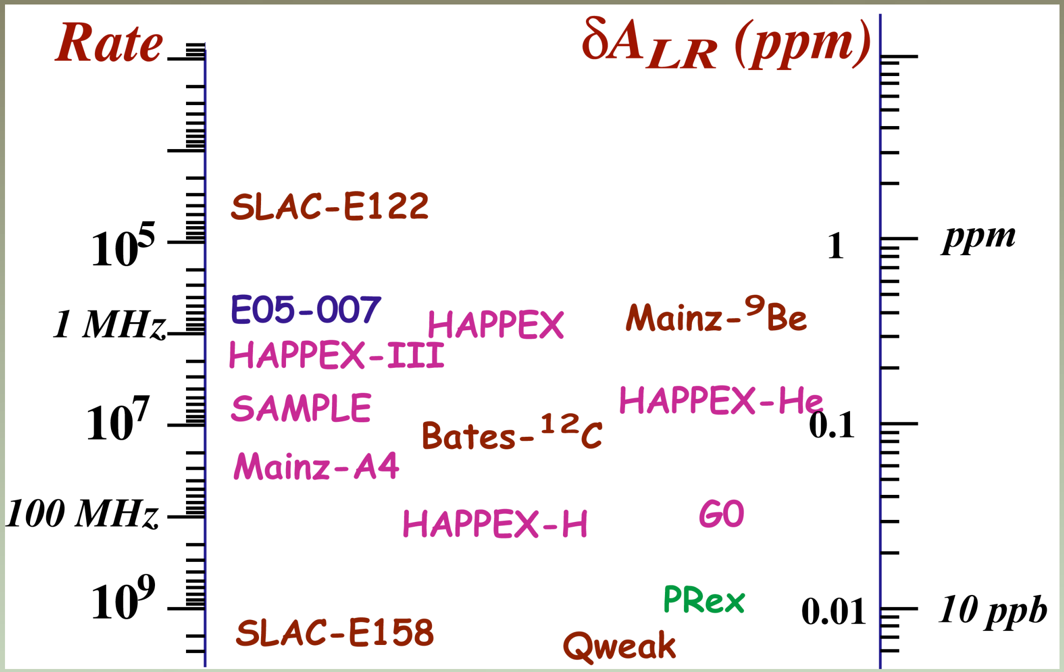




Advances in Experimental Techniques

Four electron scattering laboratories: SLAC, MIT-Bates, Mainz & JLab



- *Steady progress in technology*
- *part per billion systematic control*
- *1% normalization control*
- *Intensive R&D on:*
  - *-Photocathodes*
  - *-Polarimetry*
  - *-High Luminosity cryotargets*
  - *-Nanometer beam stability*
  - *-Precision Beam Diagnostics*
  - *-Counting Electronics*
  - *-Radiation hard detectors*

Parity-violating electron scattering has become a precision tool

Physics over a range of energy scales:

- *Nucleon structure: strangeness contribution to form factors*
- *Search for new TeV physics: Precision electroweak parameters*
- *Many-body nuclear physics: Neutron skin of ^{208}Pb*
- *Valence quark structure: Deep inelastic scattering at high-x*

Technical Achievements at Jefferson Laboratory

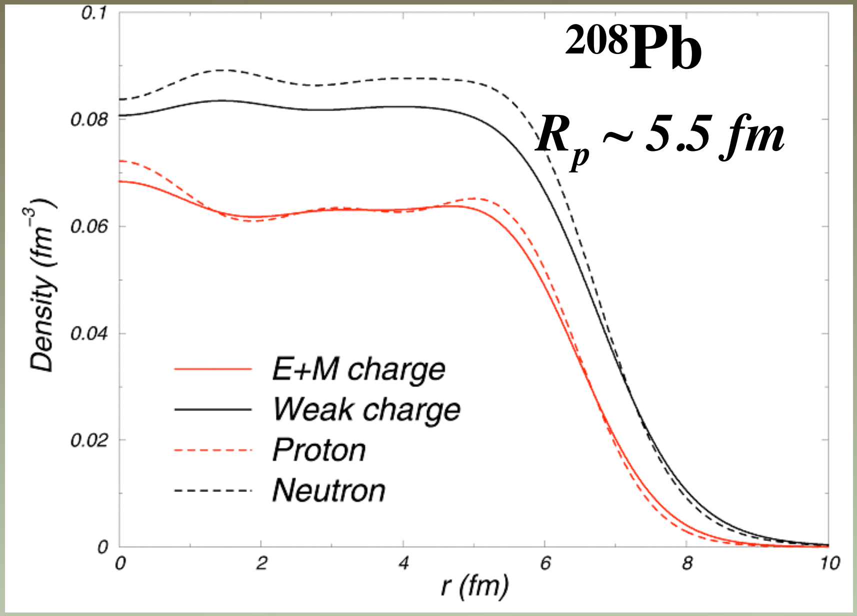
HAPPEX-II set a new benchmark precision for e^--nuclear scattering

- ~100 parts per billion (best in nuclear scattering)
- ~4% relative precision (^4He)
- statistics dominated
- ~1 nm average difference in beam position
- ~1% low-energy e^- polarimetry

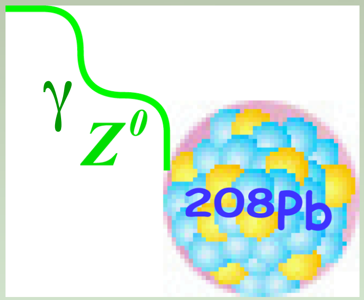
Future Program (2009-2011): 5 ppb, 3%

Future Program (12GeV): 0.5 ppb, 0.5%

PREX



- *The proton distribution of heavy nucleus: mapped via electron scattering*
- *The neutron distribution:*
  - *probed with hadrons*
  - *opportunity to measure with EW probe*
- *Neutron density a fundamental observable:*
  - *Impacts a variety of physics*



$\delta(A_{PV}) \sim 3\%$ ⟹ $\delta(R_p - R_n) \sim 0.05$

$Q^2 \sim 0.01$ GeV^2 ⟹ $A_{PV} \sim 0.5$ ppm

$Q^p_{EM} \sim 1$ $Q^n_{EM} \sim 0$

$Q^n_W \sim 1$ $Q^p_W \sim 1 - 4\sin^2\theta_W$

A technically demanding measurement:

- Rate ~ 2 GHz
- Acceptance cut off at E-E'<2.5 MeV
- Stat. Error ~ 15 ppb, Syst. Error < 2 %

Donnelly et al, 1988 R. Michaels et al, 2001

Test run: Jan 2008 Physics: Early 2010

Future 12 GeV Projects

- ***Parity-Violating Deep Inelastic Scattering***
  - C_{2i} couplings: complementary
  - partonic charge symmetry violation
  - $d(x)/u(x)$ as $x \rightarrow 1$
- ***Parity-Violating Møller Scattering***
  - Precision measurement of the weak mixing angle
  - Multi-TeV sensitivity complementary to LHC

Summary

- *Parity Violation is a critical tool to study fundamental interactions*
  - Underlying weak interaction dynamics
  - Novel aspects of strong interactions
- *Advances over several decades have made the PREX measurement feasible*
  - Theoretical understanding of strong and weak dynamics
  - Increasingly sensitive experimental techniques
- *I look forward to learning more about the impact of PREX in the larger physics community*