Strange Quarks from Parity-Violating Electron Scattering: An Experimental Perspective

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Outline

- Neutral current framework
- SAMPLE measurements
- PVA4 (Mainz)
- HAPPEX

Neutral Weak Currents from Parity-Violating $(\vec{e},e')$

- $G^{Z,p}$ contributes to electron scattering

$$\sigma \propto \left| M^{\gamma} + M^{Z} \right|^2$$

- interference term: large M^{γ} x small M^{Z}

- interference term violates parity: use $(\vec{e},e')$

$$A^{PV} \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

$$\propto \frac{A_E + A_M + A_A}{2\sigma_{unp}}$$

where

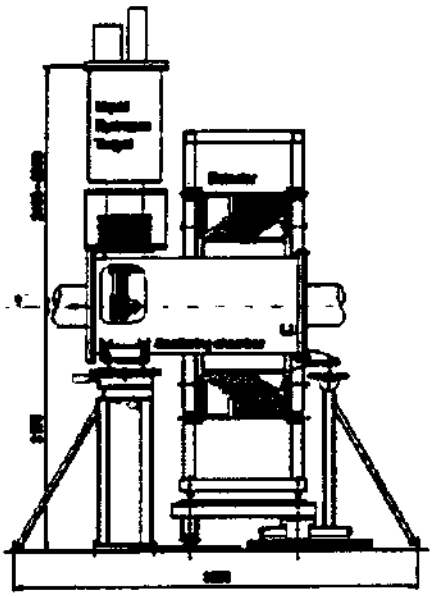
$$A_E = \varepsilon(\theta) G_E^{\gamma} G_E^{Z}$$

$$A_M = \tau G_M^{\gamma} G_M^{Z}$$

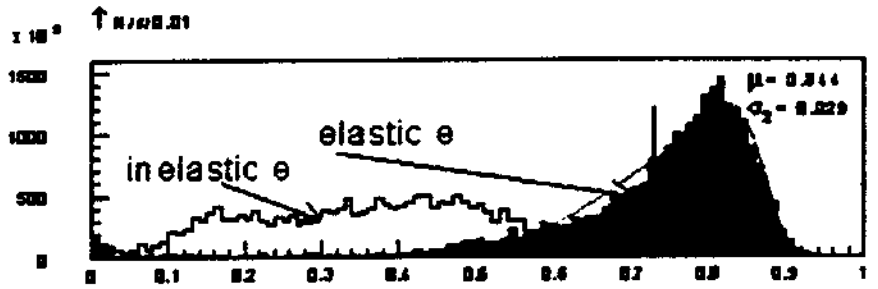
$$A_A = -\left(1 - 4\sin^2\theta_W\right)\varepsilon'(\theta)\, G_M^{\gamma} G_A^{Z}$$

Mainz PVA4 Experiment

- Measure ~ $F_1^s(Q^2 = 0.2\ GeV^2)$
  - E = 855 MeV
  - 20 μA @ 80% pol'n
  - 10 cm target
  - $\Delta\Omega$ = 0.7 (0.35) sr



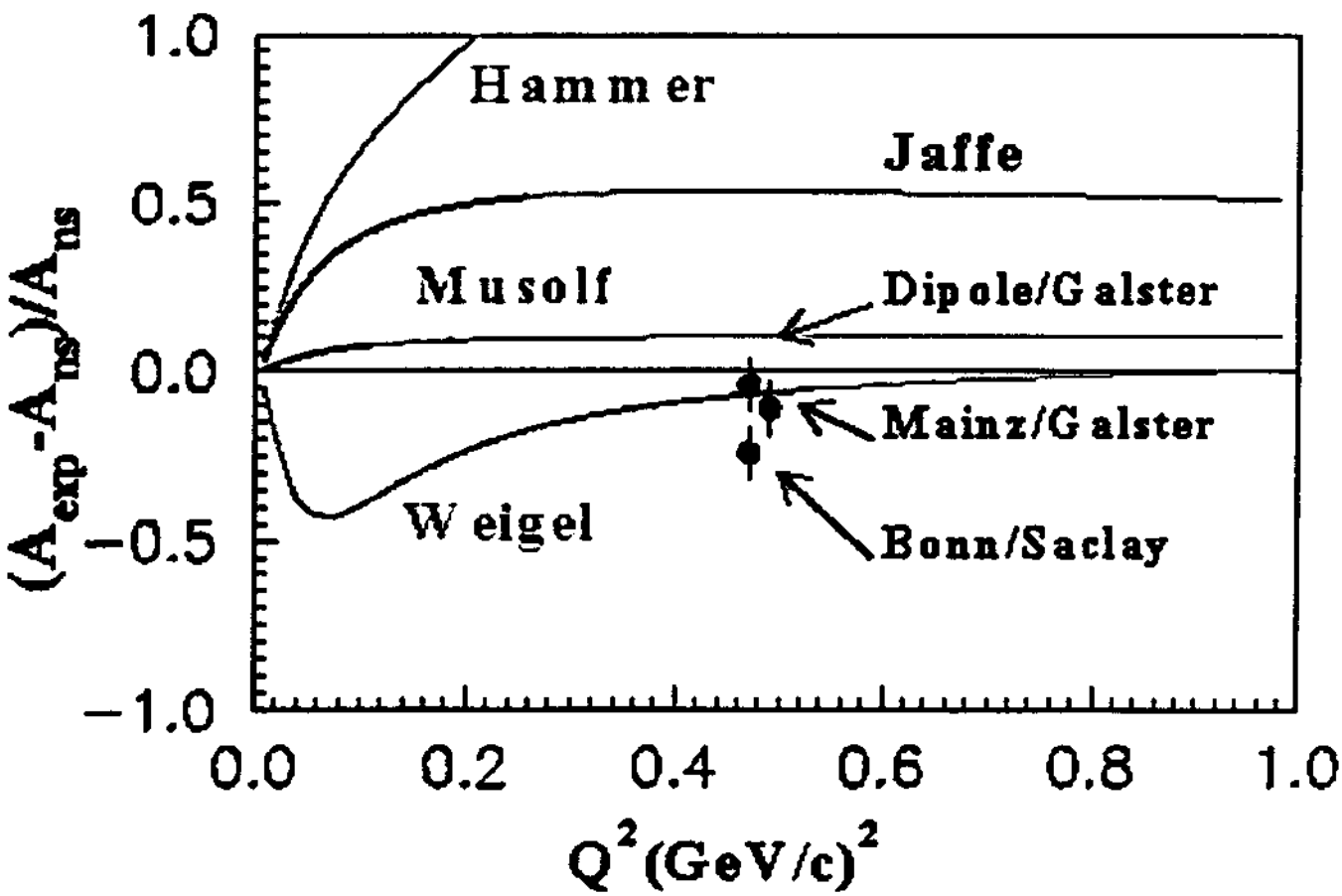
- Inelastic electron background challenge
  - $A_{inel} = 10^{-5}\ (10^{-4})$ vs. $A_{el} = 10^{-5}$
  - PbF_2 fast detector to reduce other background



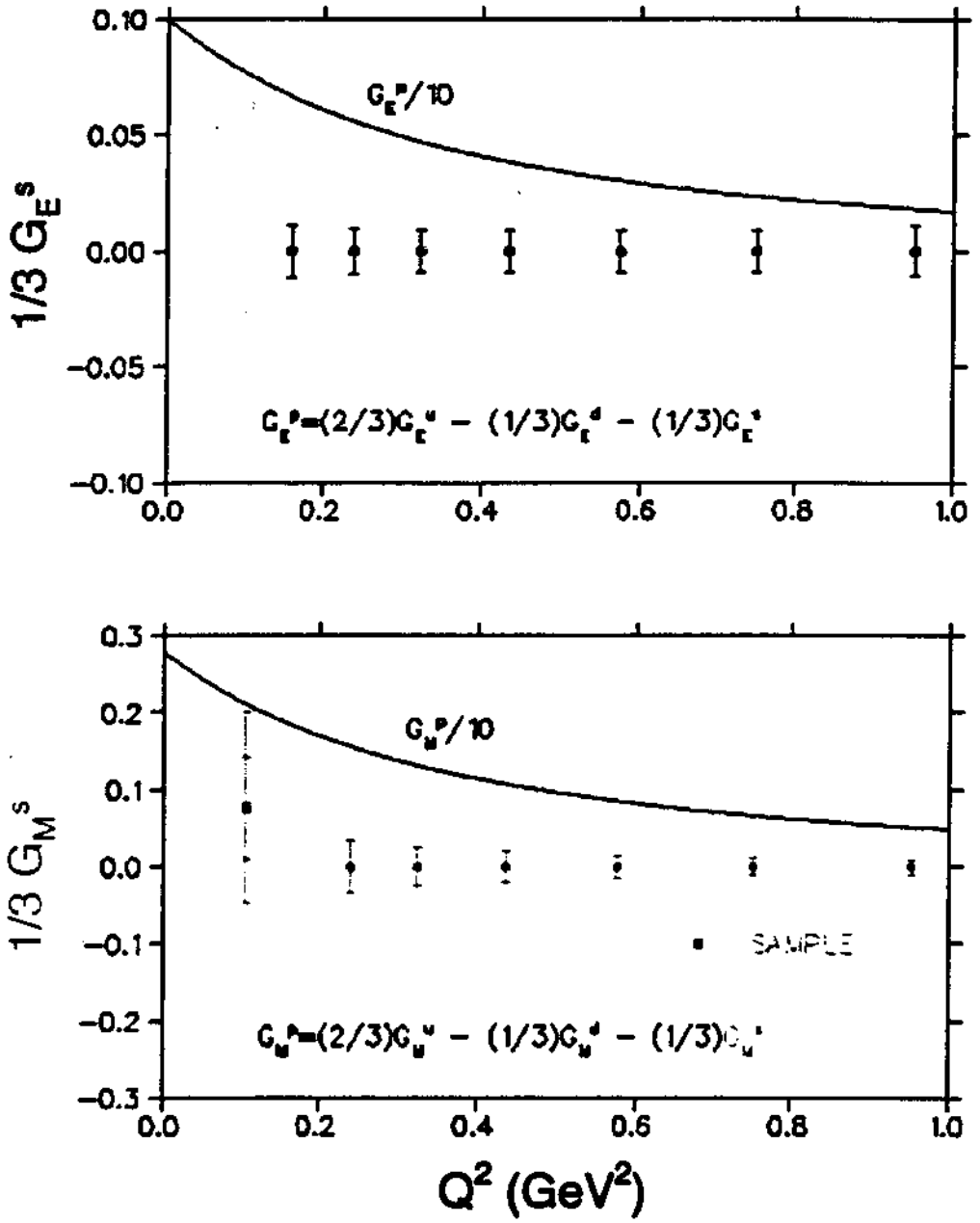
at $A_\gamma \sim 10^{-4}$: resolution 3.5 % (1 GeV) with 20ns integration gate

HAPPEX Experiment (2)

- Results
  - K. Aniol, et al. PRL **82** (99) 1096
  - preliminary combined results (98 + 99) give small deviation in same direction as SAMPLE
    - $|A_{exp}| < |A_{no\,s}|$
  - result sensitive to parameterizations of G_E^p and especially G_E^n



G0 Experiment Expected Results



- measurements of s quark contribution to G_E, G_M to a few % over range of Q^2
  - **uncertainties shown include statistical, systematic**
  - **based on HAPPEX measurements, false asymmetries expected to be very small**

SAMPLE 99: Parity-Violating Quasielastic Scattering from Deuterium

- In the "static" approximation

$$A_d = \frac{\sigma_p A_p + \sigma_n A_n}{\sigma_p + \sigma_n}$$

$$A_d = \left[\frac{0.049}{\sigma_p + \sigma_n}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 + \text{[redacted]} - 0.10 G_M^s\right]$$

$$A_p = \left[\frac{0.026}{\sigma_p}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 + \text{[redacted]} - 0.61 G_M^s\right]$$

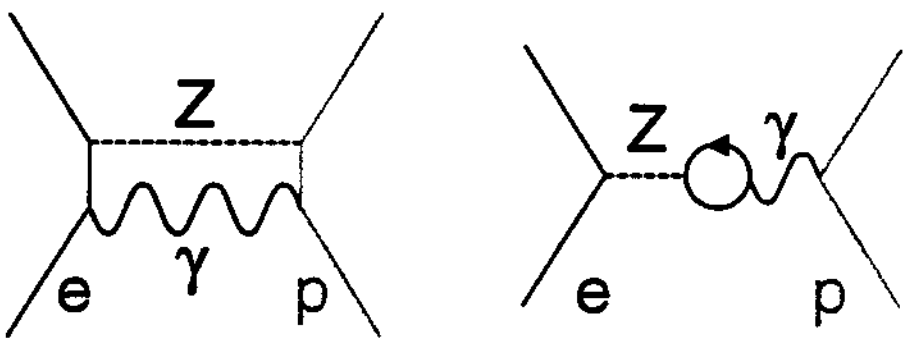
- **Then, for example,**

$$\frac{A_d}{A_p} \propto \left[1 + \text{[redacted]} - 0.51 G_M^s\right]$$

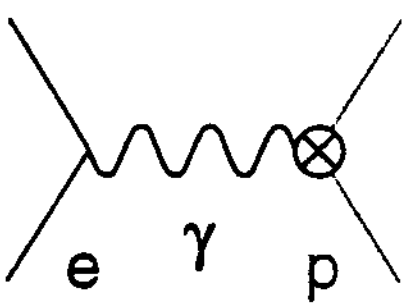
- Also get good measurement of effective axial current (including R_A)

SAMPLE 99: Parity-Violating Quasielastic Scattering from Deuterium

- Goal is to isolate G_M^s using deuterium measurement
- Also determines G_A^Z: the "effective axial current"
  - **each tree-level form factor is modified for radiative effects in the PV scattering, e.g.**

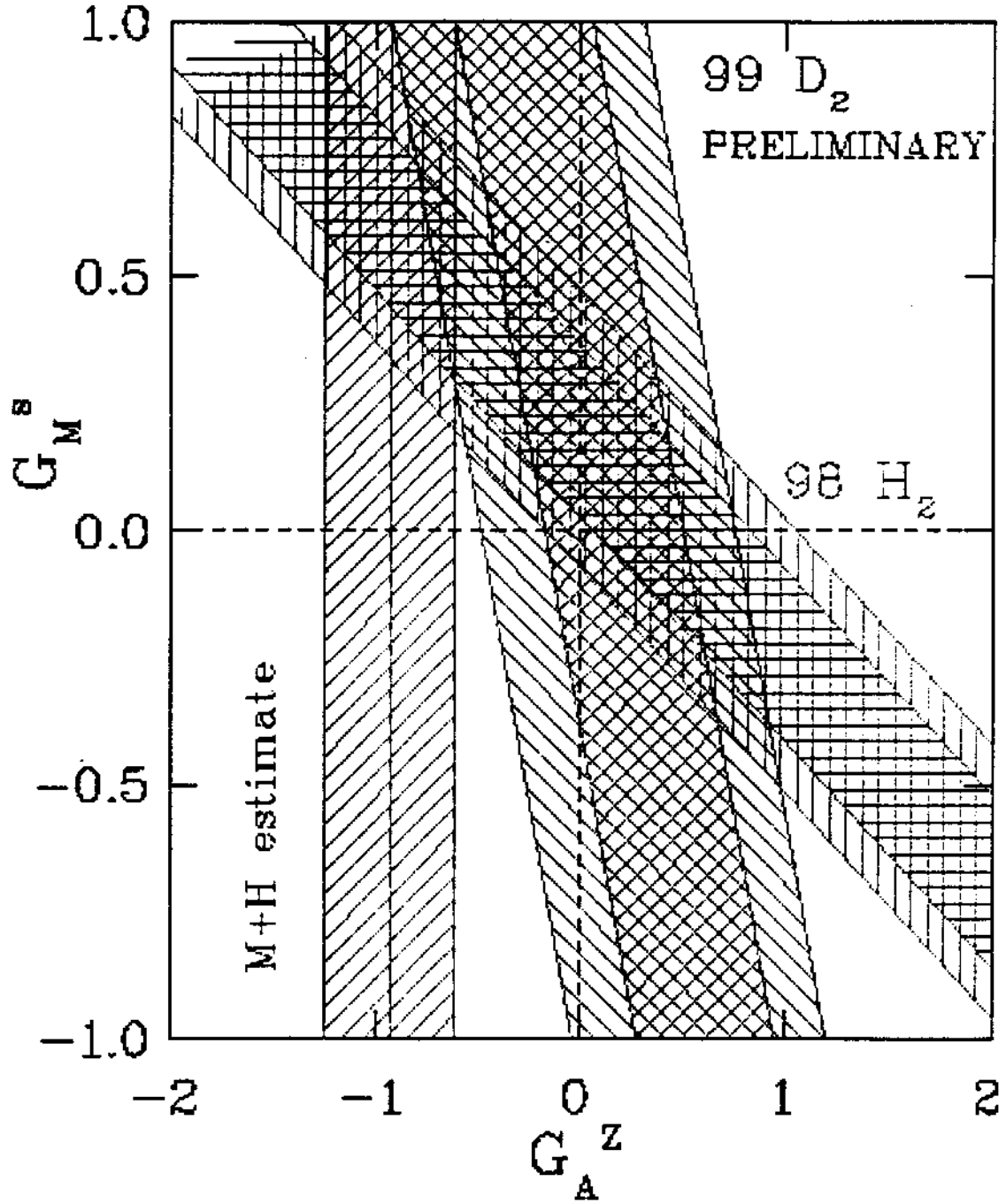


  - **for proton axial current: additional diagrams with $Z^0/W^\pm$ exchange between quarks**



  - **"effective axial coupling of the photon"**
    ~ "anapole moment" **(Zel'dovich, 58; Haxton, Henley & Musolf: 89)**

Preliminary Deuterium Result



- preliminary deuterium result indicates significant deviation from calculated G_A^Z
  - developing SAMPLE 00 experiment at 125 MeV to make 2σ determination of G_A^Z (= -1 or -0.1)
- proton results: PRL **78** (97) 3824, PRL 31 Jan 00

What is the Anapole Moment?

- As first noted by Zel'dovich (Sov. Phys. JETP **6** (58) 1184), a parity-violating coupling of the photon can occur

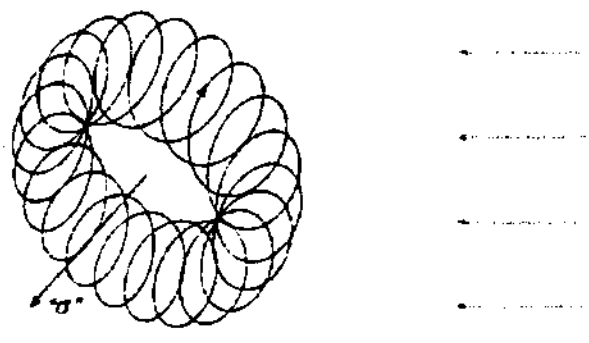
$$\langle p'|J_\mu^\gamma(Q^2)|p\rangle = \bar{u}(p')\Big(F_1(Q^2)\gamma_\mu - i\frac{F_2(Q^2)}{2M}\sigma_{\mu\nu}q^\nu + \frac{F_A(Q^2)}{M^2}\left(q^2\gamma_\mu - \not{q}q_\mu\right)\gamma_5 - i\frac{F_E(Q^2)}{2M}\sigma_{\mu\nu}q^\nu\gamma_5 \Big) u(p)$$

where F_A and F_E are the anapole (parity-violating, time-reversal conserving) and electric dipole (parity- and time-reversal- violating) moments, respectively

- At low Q^2 the corresponding interaction energy is (Musolf and Holstein, Phys. Rev. D **43** (91) 2956)

$$L_{anapole} = -e^2\frac{F_A}{M^2}\bar{\psi}\gamma_\mu\gamma_5\psi\, j_\mu \sim -e^2\frac{F_A}{M^2}\vec{\sigma}\cdot\vec{j}$$

- The classical analogy of the anapole moment is that property of a toroidal magnetic field that leads to a force (torque) in an external current field



$$U = -\vec{\sigma}_a\cdot\vec{j}$$

$$\vec{\Gamma} = \vec{\sigma}_a \times \vec{j}$$