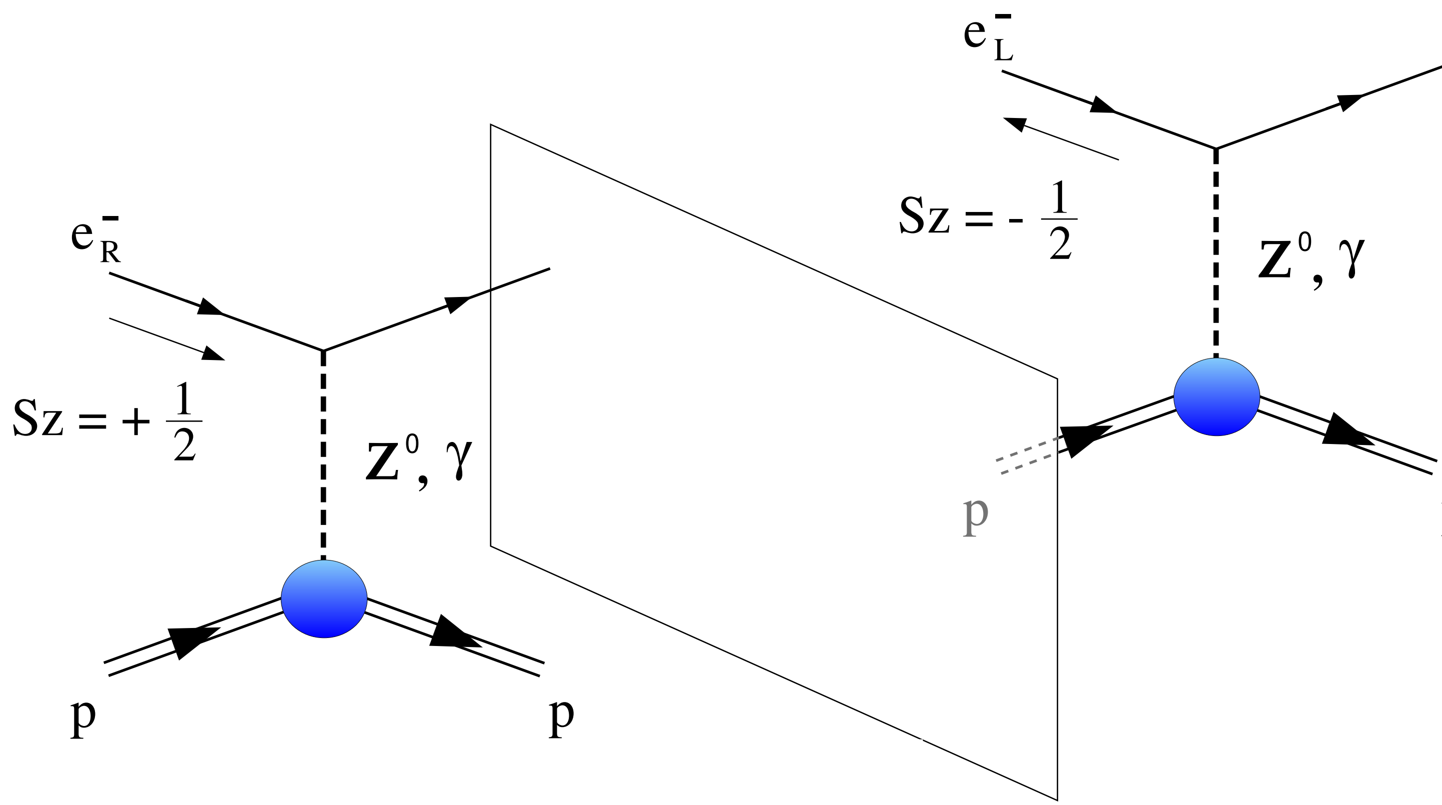
Weak Form Factors Measurements through Parity Violating Electron Scattering

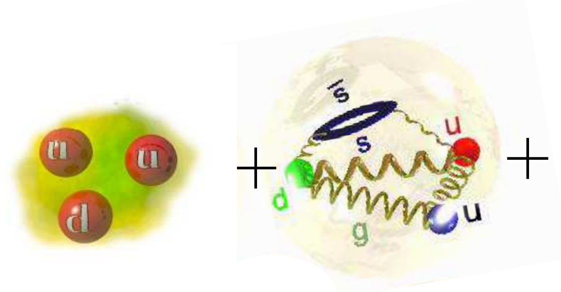


or what can we learn from the other side of the mirror ...

Outline

- Physics motivations
- Experimental status
- HAPPEX experiment @ JLab
- Prospects
- Summary

Strangeness in the nucleon

Nucleon = 

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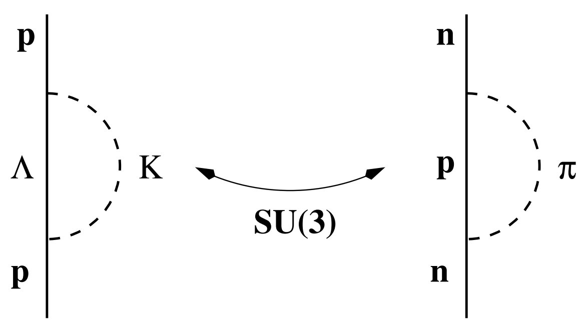
Valence + quark-gluon sea

Does strangeness play a role
in the ground state of the nucleon?

No valence contribution

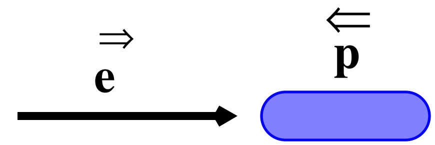
→ **Unique and pure probe of the sea**



SU(3) image of the π-loop contribution in G_E^n , decorrelated from the quarks contribution.

Strange Matrix Elements

- **Lepton deep inelastic scattering:**



$\langle N|\bar{s}\gamma_\mu\gamma_5 s|N\rangle$ **Axial vector matrix element.**

$$A = \frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\uparrow\downarrow}}$$

Sea contributes to the spin, $\Delta s \sim -10\%$ [SU(3)]

Strange sea = ?

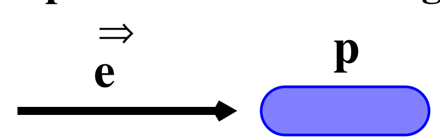
- **π-N scattering:**

$\langle N|\bar{s}s|N\rangle$ **Scalar matrix element**

s quarks = 15 % of the mass [Many assumptions]

- **Vector matrix element?** $\langle N|\bar{s}\gamma_\mu s|N\rangle$

Lepton elastic scattering



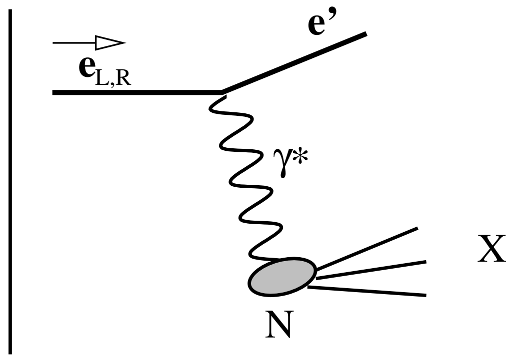
$$A = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}}$$

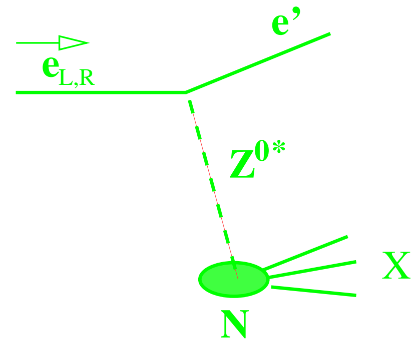
Contribution to charge and current distributions

[Assumes only isospin and Standard Model]

Clean observables of the strangeness of the nucleon

Parity Violating Electron Scattering





$$\sigma = \left|M_\gamma + M_Z\right|^2$$

$$A_{LR} = \frac{N_R - N_L}{N_R + N_L} \propto \frac{M_Z}{M_\gamma}$$

First measurement at SLAC with Deuteron target

C.Prescott, Phys. Let. 77B (1978) 347.

$$A_{LR} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}} \times \frac{9}{10}\left[\left(1 - \frac{20}{9}\underline{\sin^2\Theta_W}\right) + (1 - 4\underline{\sin^2\Theta_W})\frac{1-(1-y)^2}{1+(1-y)^2}\right] \qquad \left(y = \frac{E-E'}{E}\right)$$

Test of the Standard Model

$A_{LR} \approx 10^{-4}$ at $Q^2 = 1\ \mathrm{GeV}^2$

Major developpements: -High current from polarized source

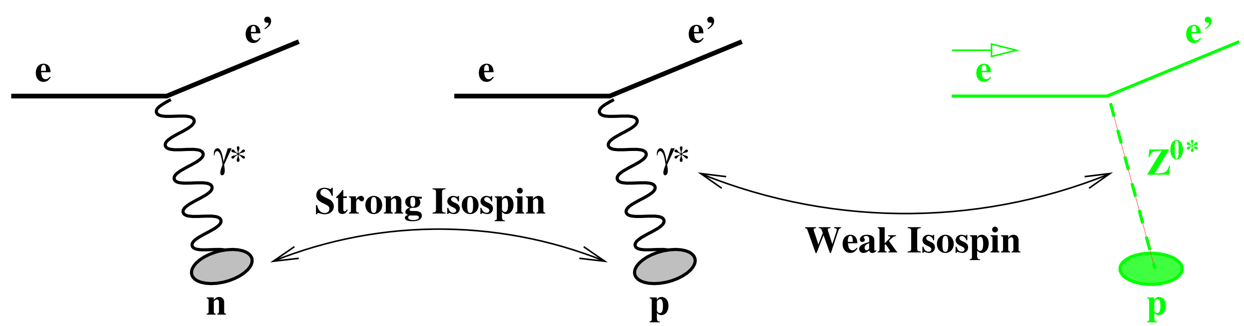
-Tricky control of the systematics

Parity Violating Electron Scattering

Parameters of the Standard Model well known from experiments with high energy colliders

→ **New generation of accurate measurements to seek deviation from s=0 predictions.**

Elastic Scattering off the Nucleon:



Assuming three flavor degrees of freedom:

$$G_p^Z = \frac{1}{4}(1 - 4\sin\Theta_W)G_p^\gamma - G_n^\gamma - \boxed{G^s}$$

Contribution of the strange quark to the charge and current distributions

$$\sigma = |M_\gamma + M_Z|^2 \qquad A = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \sim \frac{M_Z}{M_\gamma} \sim 10^{-5} \quad (Q^2 = 1\ \mathrm{GeV}^2)$$

Isospin Sym. Breaking

- Decomposition of form factors on u,d,s quarks' flavors:

$$G^{\gamma}_{E,M}(p) = \underline{\tfrac{2}{3}}G^{u}_{E,M}(p) - \underline{\tfrac{1}{3}}G^{d}_{E,M}(p) - \underline{\tfrac{1}{3}}G^{s}_{E,M}(p)$$

$$G^{\gamma}_{E,M}(n) = \underline{\tfrac{2}{3}}G^{d}_{E,M}(n) - \underline{\tfrac{1}{3}}G^{u}_{E,M}(n) - \underline{\tfrac{1}{3}}G^{s}_{E,M}(n)$$

$$G^{Z}_{E,M}(p) = \underline{\left(\tfrac{1}{4} - \tfrac{2}{3}\sin^2\theta_W\right)}G^{u}_{E,M}(p) + \underline{\left(-\tfrac{1}{4} + \tfrac{1}{3}\sin^2\theta_W\right)}G^{d}_{E,M}(p) + \underline{\left(-\tfrac{1}{4} + \tfrac{1}{3}\sin^2\theta_W\right)}G^{s}_{E,M}(p)$$

— Electric charges

— Weak charges

- Assumption of Isospin symmetry:

$$G^{u}_{E,M}(n) = G^{d}_{E,M}(p) + \varepsilon$$

$$G^{d}_{E,M}(n) = G^{u}_{E,M}(p) + \varepsilon$$

$$G^{s}_{E,M}(n) = G^{s}_{E,M}(p) + \varepsilon$$

Explicit breaking: ε ~ **1-2 %**

$$\hookrightarrow G^{Z}_{p} = \frac{1}{4}(1 - 4\sin\Theta_W)G^{\gamma}_{p} - G^{\gamma}_{n} \boxed{+\,\varepsilon} - G^{s}$$

For Happex kinematics, 1% of $G^{n}_{E} + 0.39G^{n}_{M}$

is only 10% of the statistical error bar.

Parity Violating Electron Scattering

$$A_{LR} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times \left\{ (1-4\sin^2\Theta_W) - \frac{\varepsilon G_E^p (G_E^n + G_E^s) + \tau G_M^p (G_M^n + G_M^s) - (1-4\sin\Theta_W)\varepsilon' G_M^p G_A^p}{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}} \right\}$$

τ, ε and ε' are kinematical factors, functions of Q^2 and scattering angle.

Rosenbluth separation to extract electric and magnetic contributions:

Forward angles: $\varepsilon \to 1, \tau \propto \Theta^2, \varepsilon' \propto \Theta^2$ $\Rightarrow$ Sensitive to the Electric part, G_E^S

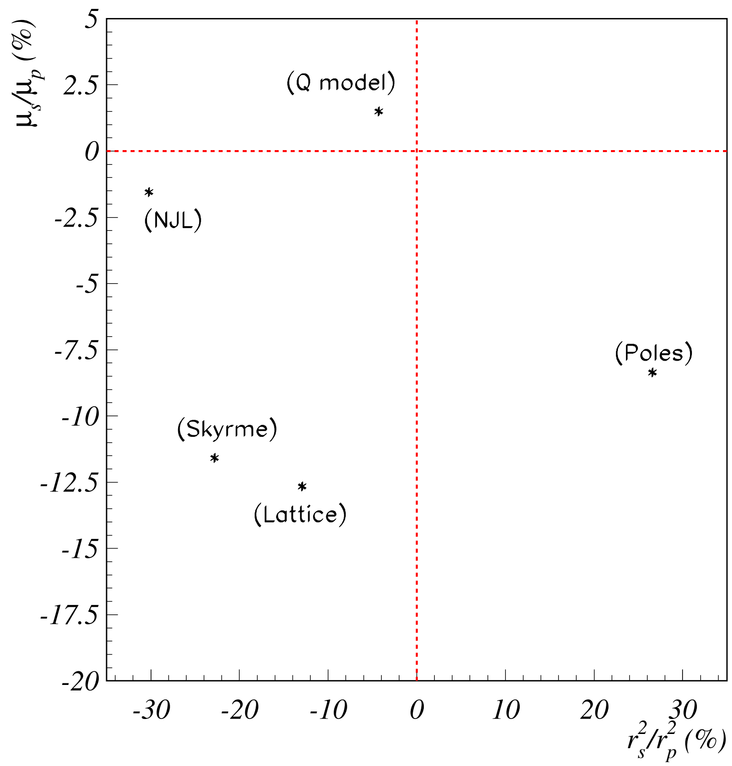
Backward angles: $\varepsilon \to 0$ $\Rightarrow$ Magnetic and Axial parts, G_M^S, G_A

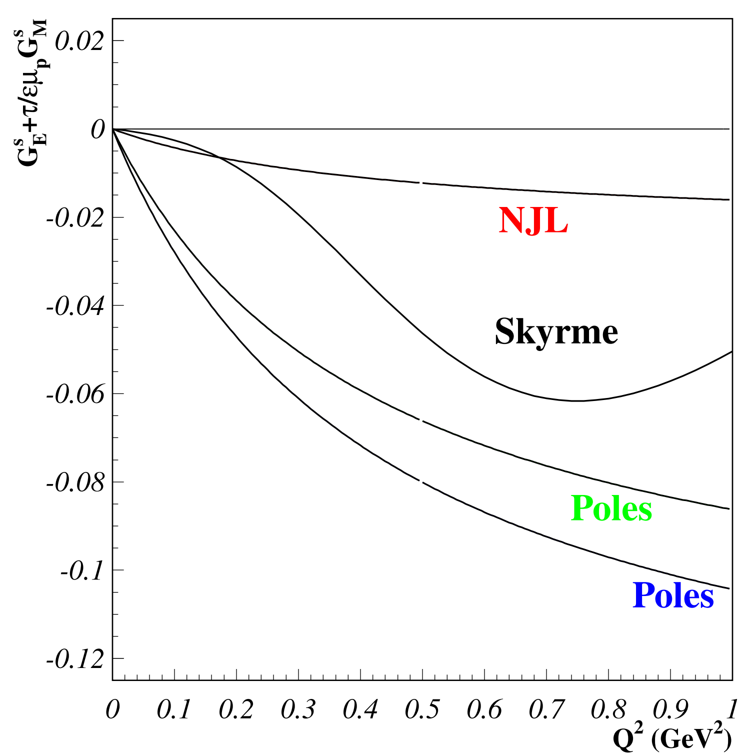
Take advantage of other targets:

$^{12}C, {}^4He$: Spin 0, Isospin 0 $\Rightarrow$ Pure monopole form factor G_E^S

^2H : Complementary to proton measurement (SAMPLE)

Models





Few predictions of the Q^2 dependence.

Usual parametrization is the Galter's one: $G_E^S = \frac{\rho_S \tau G_D}{1+\lambda_E \tau}$ $G_M^S = \frac{\mu_S G_D}{1+\lambda_M \tau}$

Experimental Status

- ^{9}Be at Mainz (Nucl. Phys. B327 (1989) 1),
  ^{12}C at Bates(PRL 65, 694 (1990)) have measured 10^{-6} asymetries !

  → Constraints on the parameters of the Standard Model

- SAMPLE at Bates: G_M^s at backward angle, E= 200 MeV, $\underline{Q^2 \sim 0.1 GeV^2}$

$$G_M^S = 0.61 \pm 0.17(stat) \pm 0.21(syst) \pm 0.17(theo)$$

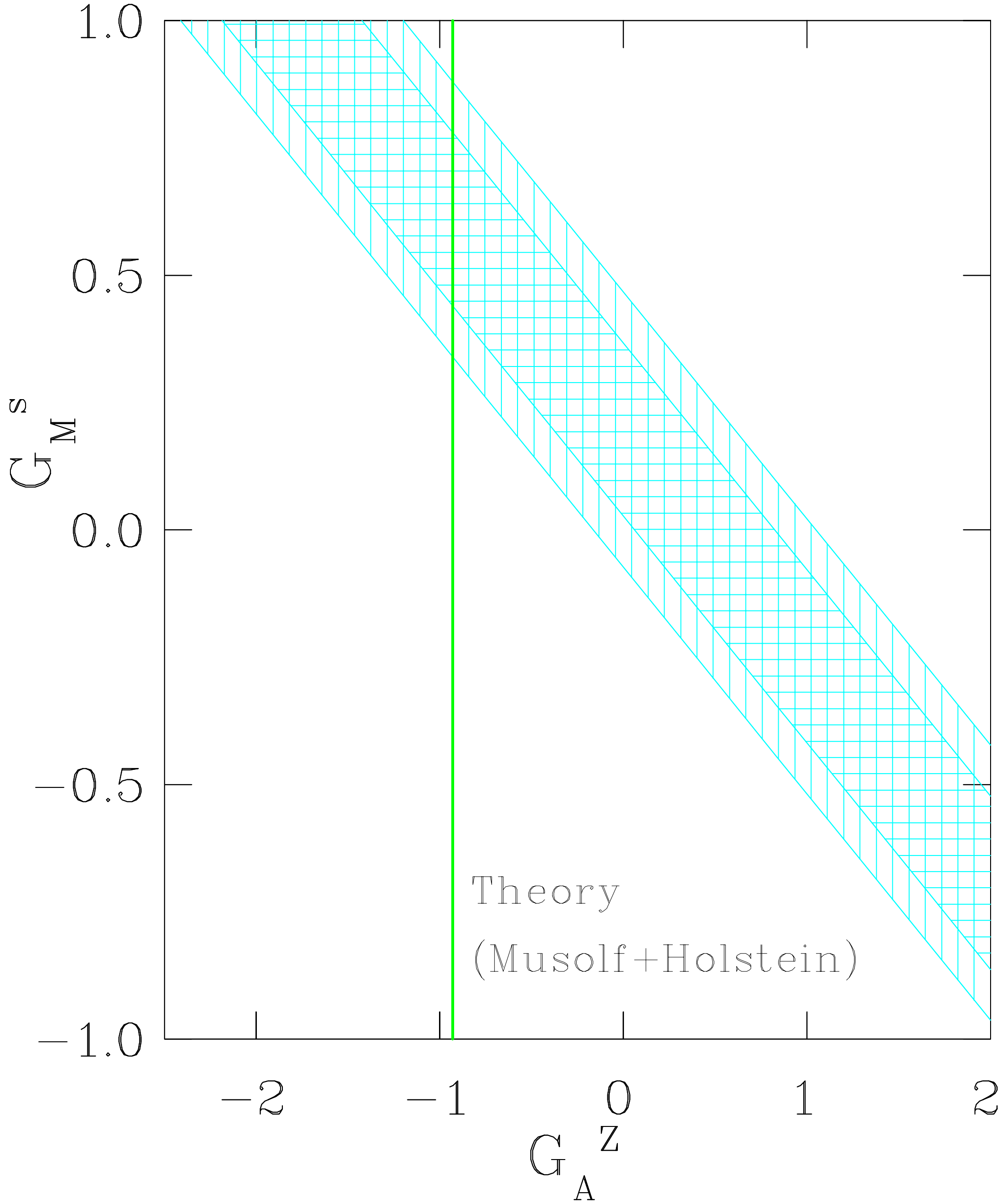
nucl-exp/9702004 New data on deuteron

- HAPPEX at Jlab: Linear combination $G_E^s + 0.39 G_M^s$ at $\underline{Q^2 \sim 0.48 GeV^2}$

$$G_E^S + 0.39 G_M^S = 0.023 \pm 0.034(stat) \pm 0.022(syst) \pm 0.026(theo)$$

PRL 82, 1096 (1999) Half of the whole data set

SAMPLE 1998 H_2 Results



→ **Positive μ_s?**

HAPPEX 1998 Results

$$A_{Exp} = -14.7 \pm 2.0(stat) \pm 1.1(syst)\,ppm$$

$$\frac{G_E^s + 0.39 G_M^s}{\frac{1}{3}G_E^p + 0.39 G_M^p} = 9.1 \pm 13.5(stat) \pm 8.7(syst) \pm 10.3(\delta G_E^n)\ \%$$

Conclusions:

- **Fast fall off with Q^2**
- **Cancellation**
- **No strangeness effect**

Source of error	ΔA/A (%)	
Statistics	13.4	→ 6.5
Beam polarization	7.0	→ 4.0
Q^2 Determination	1.0	
Background	2.0	
Radiative Corrections	1.4	
G_E^n	9.6	
Nucleon form factors	4.0	

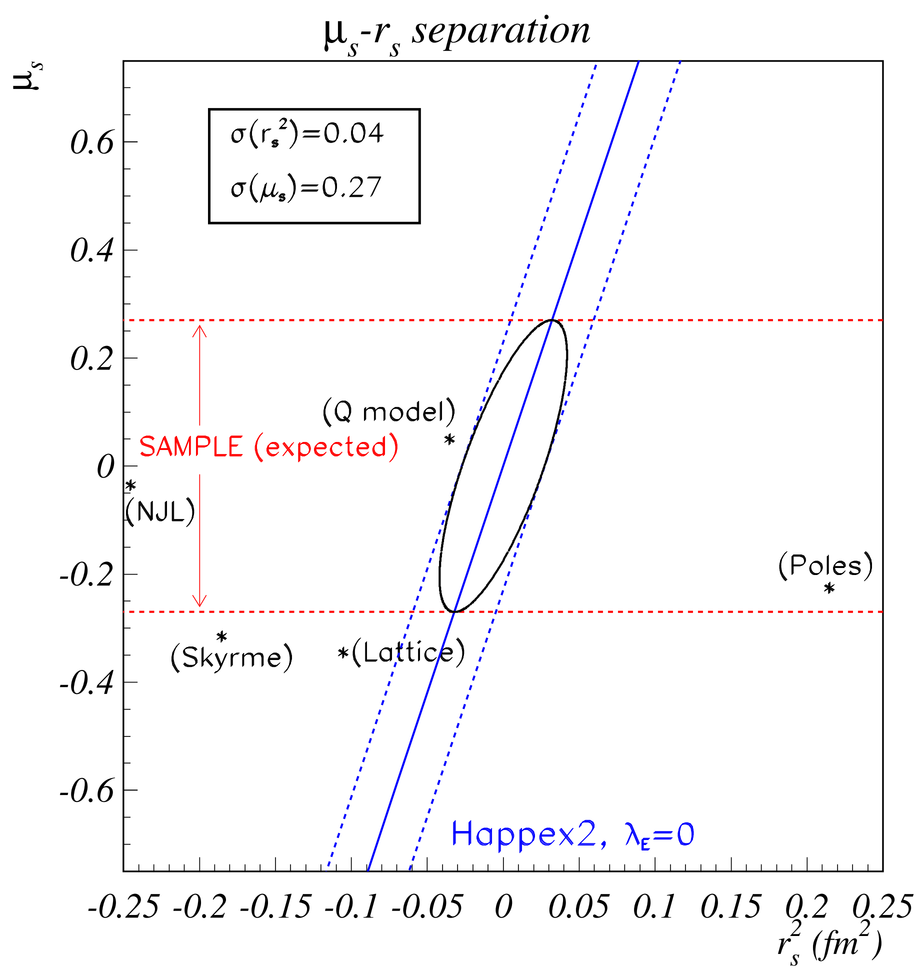
HAPPEX II

First HAPPEX measurement very successful

⟶ New experiment proposed at lower Q^2

$$A_{LR} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times \left\{(1 - 4\sin^2\Theta_W) + \tau[\mu_n(1-\mu_p) - \underline{\rho_s - \mu_p\mu_s}] + O(\tau^2)\right\}$$

Using SAMPLE result,nice E/M separation providing first constraints on r_s^2

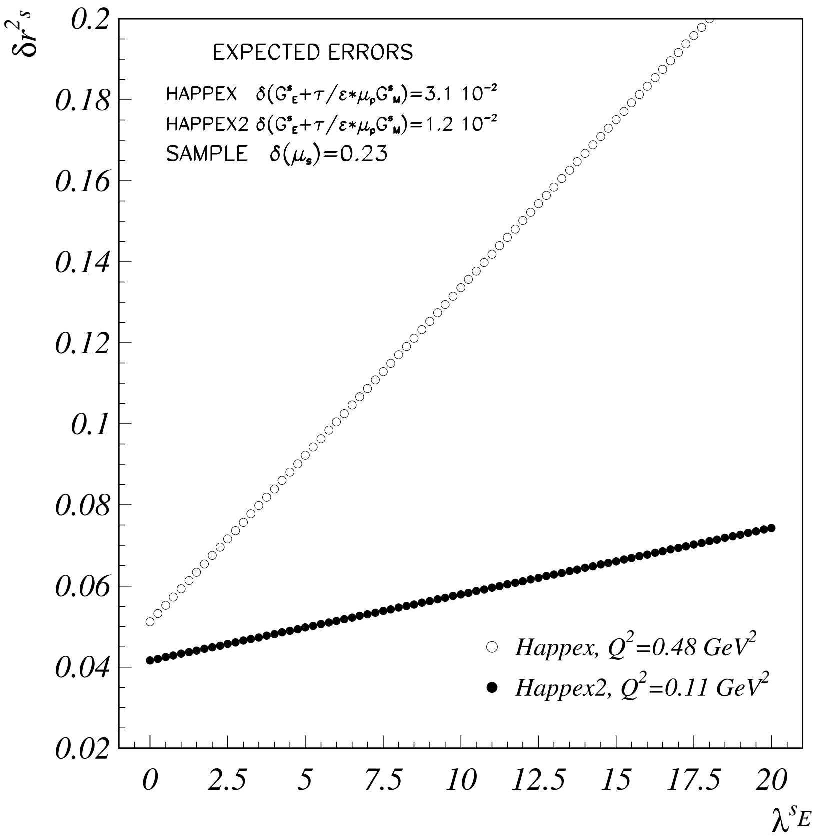


Pins down the dispersion of the theoretical predictions.

HAPPEX II

Kinematics: E = 3.2 GeV, Θ = 6 degrees (Septum magnets)

Q^2 = 0.1 GeV, good compromise between "s" signal and sensitivity to Q^2 dependence



- **Accepted with highest rating in HallA at Jlab**
- **Saclay's leadership:**
  - **Compton Polarimetry**
  - **Co-spokesperson**
  - **Charge of the new detector**

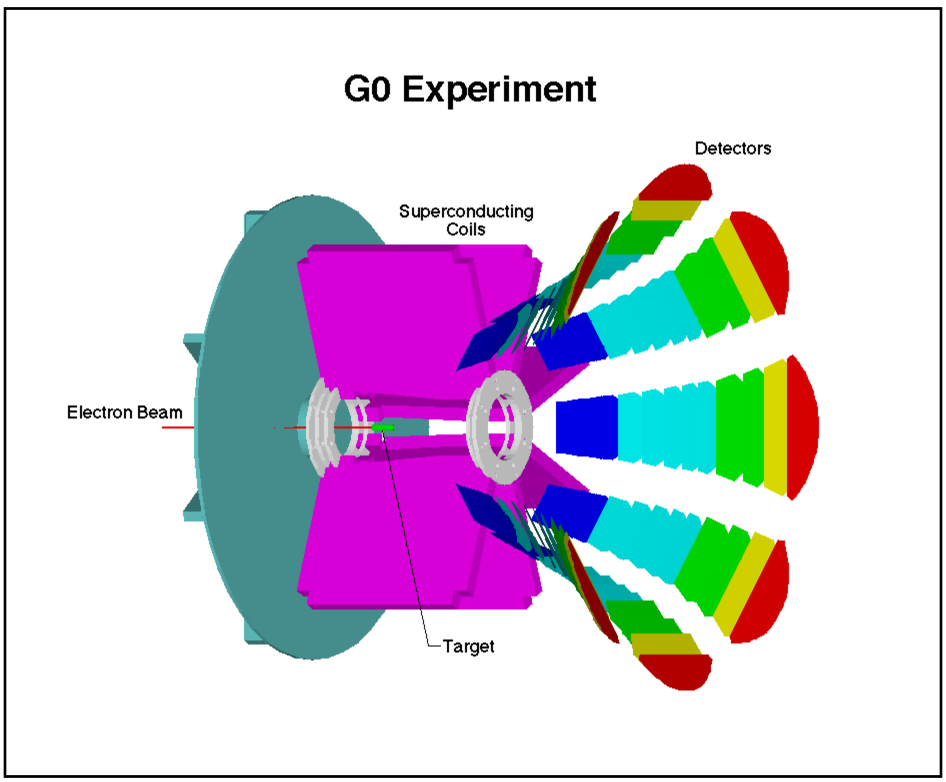
G0

G_E^s / G_M^s separation in the 0.15-1.0 GeV^2 Q^2 range

IN2P3: ISN-Grenoble, IPN-Orsay

Forward angle: proton detection using ToF technics
All Q^2 pts at the same time
1 month data taking

Backward angle with the detector reversed:
electron detection using coincidence technics



Commissionning in 2001, JLab-HallC

Summary

	Experiment	Detection	Kinematics	Q^2 (GeV^2)	Observable	Date
Completed	SAMPLE (MIT-Bates)	Cerenkov Integrating	E = 200 MeV 130< Θ < 170	0.1	G_M^s	1997-99
	HAPPEX (JLab)	Spectro+Cerenk Integrating	E = 3.355 GeV Θ = 12.5	0.47	$G_E^s + 0.39 G_M^s + 0.01 G_A^s$	1998-99
Approuved	HAPPEX II (JLab)	Spectro+Cerenk Integrating	E = 3.2 GeV Θ = 6.	0.1	$\rho_s + \mu_p \mu_s$	2002
	G0 (JLab)	Spectro+Scint Semi-Integr.	E = 0.33 - 3 GeV Θ_e = 70 (Θ_p= 7) Θ_e= 110	0.2-1.0	G_E^s / G_M^s separation	2001-06
	PV-A4 (MAMI)	Cerenkov array event/event	E = 855 MeV Θ = 35	0.225	$G_E^s + 0.08 G_M^s + 0.01 G_A^s$	1999-00
To be proposed	Pb (JLab)	Spectro+Cerenk Integrating	E = 850 MeV Θ = 6.	0.004	R_n / R_p	?
	He4 (JLab)	Spectro+Cerenk Integrating	E = 3.2 GeV Θ = 6.	0.1	ρ_s	?

Letter of intent in Hall C for an experiment using the G0 detector:

→ new constraints on the standard model, complementary to E158.

Conclusion

- Happex has demonstrated that Cebaf was a nice machine for PV measurements

- Large program undertaken by Jlab

- Important french participation

- Complete covering of Q   dependence of the form factors up to 1 GeV