HAPPEX-II/^{4}He status report

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Hall A Collaboration Meeting
June 13-14, 2002

HAPPEX-II   E99-115   (Kumar, Lhuillier)

tentative schedule: March 8 → May 18 2003

^{4}He   E00-114   (Armstrong, Michaels)

tentative schedule: June 5 2003 → ??

1. Strange Quark Form Factors
2. Previous and ongoing experiments:
   - HAPPEX I   (Jlab 91-010)
   - SAMPLE   (MIT-Bates)
   - PV-A4   (Mainz)
   - G^0 (Jlab E99-016, E01-115, and E01-116)
3. Anticipated Errors
4. Preparations

Strange Quarks in The Nucleon?

1. Deep Inelastic ν Scattering

   - longitudinal momentum fraction

     $$\kappa = \frac{2\bar{s}}{\bar{u}+\bar{d}} = 0.35 \pm 0.04$$

   NuTEV PRD **64**(2001)112006; CCFR Z.Phys. C **65**(1995)189.

2. Spin-Dependent Deep Inelastic Scattering

   - spin fraction carried by s quarks

     $$\Delta s = -0.1 \pm 0.1$$

   E154 PRL **79**(1997)26; SMC PRD **56**(1997)5330

3. πN scattering (low energy)

   - scalar matrix element $< N|s\bar{s}|N >$

   $\Sigma_{\pi N}^{exp} = 70 - 80$ MeV $\qquad \Sigma_{\pi N}^{th} = 56 \pm 7$ MeV

   - implies ~ 350 MeV of M_N from $s\bar{s}$

   Pavan PiN Newslet. **15**(1999)118.; Gasser *et al.* PLB**253**(1991)260

$s\bar{s}$ provides window onto the sea

Theory

*"What is your substance, whereof are you made
That millions of strange shadows on you tend?"*

(Shakespeare, sonnets)

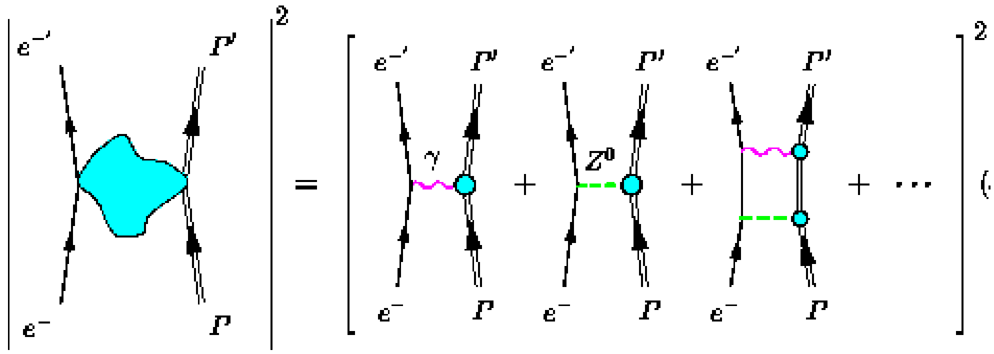
Vector strange matrix elements: $< N|\bar{s}\gamma^{\mu}s|N >$

Strange vector form factors: $G^s_{E,M}(Q^2)$

$$\rho_s = \frac{dG^s_E(\tau)}{d\tau}\Big|_{\tau=0} \qquad \tau = \frac{Q^2}{4M_P^2}$$

$$\mu_s = G^s_M(0)$$

Elastic electron scattering



$\gamma - Z$ interference term violates parity!

Measure: $A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$

Theory cont'd

For the proton:

$$A = -A_0 \tau \left(2 - 4\sin^2\theta_W - \frac{\varepsilon G_E^0 + \tau G_M^0}{\varepsilon G_E^{\gamma p} + \tau G_M^{\gamma p}} \right) - A_A$$

$$G^0_{E,M}(\tau) = \left(G^u_{E,M} + G^d_{E,M} + G^s_{E,M} \right)/3$$

$$\varepsilon = \left[1 + 2\left(1+\tau\right)\tan^2\frac{\theta}{2} \right]^{-1}$$

$$A_0 = \frac{G_F M_p^2}{\sqrt{2}\pi\alpha}$$

$A_A =$ axial vector

(small at forward scattering angles)

Use charge symmetry:

$$G^{u,p} = G^{d,n} \qquad G^{d,p} = G^{u,n} \qquad G^{s,p} = G^{s,n}$$

and known electromagnetic form factors:

$$G_E^{\gamma\ p,n} \qquad G_M^{\gamma\ p,n}$$

to extract $G^s_{E,M}$ from A.

Predictions for Strange Form Factors

Model	ρ_s	μ_s	Reference
Poles	-2.10	-0.31	Jaffe
			Phys. Lett. B **229**, 275 (1989)
SU(3) Skyrme	3.19	-0.33	Park, Schecter & Weigel
			Phys. Rev. D **43**, 869 (1991)
SU(3) Skyrme	1.64	-0.13	Park, & Weigel
			Orsay IPNO/TH 91-57 (1991)
NJL model	3.06	-0.05	Weigel, Abada, Alkofer & Reinhardt
			Phys. Lett. B **353**, 20 (1995)
Poles (update)	-2.93	-0.24	Hammer, Meisner & Dreschel
			Phys. Lett. B **367**, 323 (1996)
Quark Model	0.57	0.035	Geiger & Isgur
			Phys. Rev. D **55**, 299 (1997)
SU(3) Chiral Bag		0.37	Hong, Park & Min
			Phys. Lett. B **414**, 229 (1997)
Lattice	$1.26 \rightarrow 2.77$	$-0.56 \rightarrow -0.16$	Dong, Liu & Williams
			Phys. Rev. D **58**, 074504 (1998)
Poles + $K\overline{K}$	$-6.0 \rightarrow +2.65$	$-0.51 \rightarrow -0.26$	Hammer & Ramsey-Musolf
			Phys. Rev. C **60**, 045204 (1999)

HAPPEX I - Results

Source of Error	$\frac{\Delta A}{A}$:1998	$\frac{\Delta A}{A}$:1999
Statistics	13.3 %	7.2 %
Polarization	7.0 %	3.2 %
Q^2 Determination	1.8 %	1.8 %
Backgrounds	0.6 %	0.6 %

$$1998\text{:}\ \ A = (14.7 \pm 2.2) \times 10^{-6}$$
$$1999\text{:}\ \ A = (15.1 \pm 1.3) \times 10^{-6}$$
$$\textit{Combined}\text{:}\ \ A = (15.0 \pm 1.1) \times 10^{-6}$$

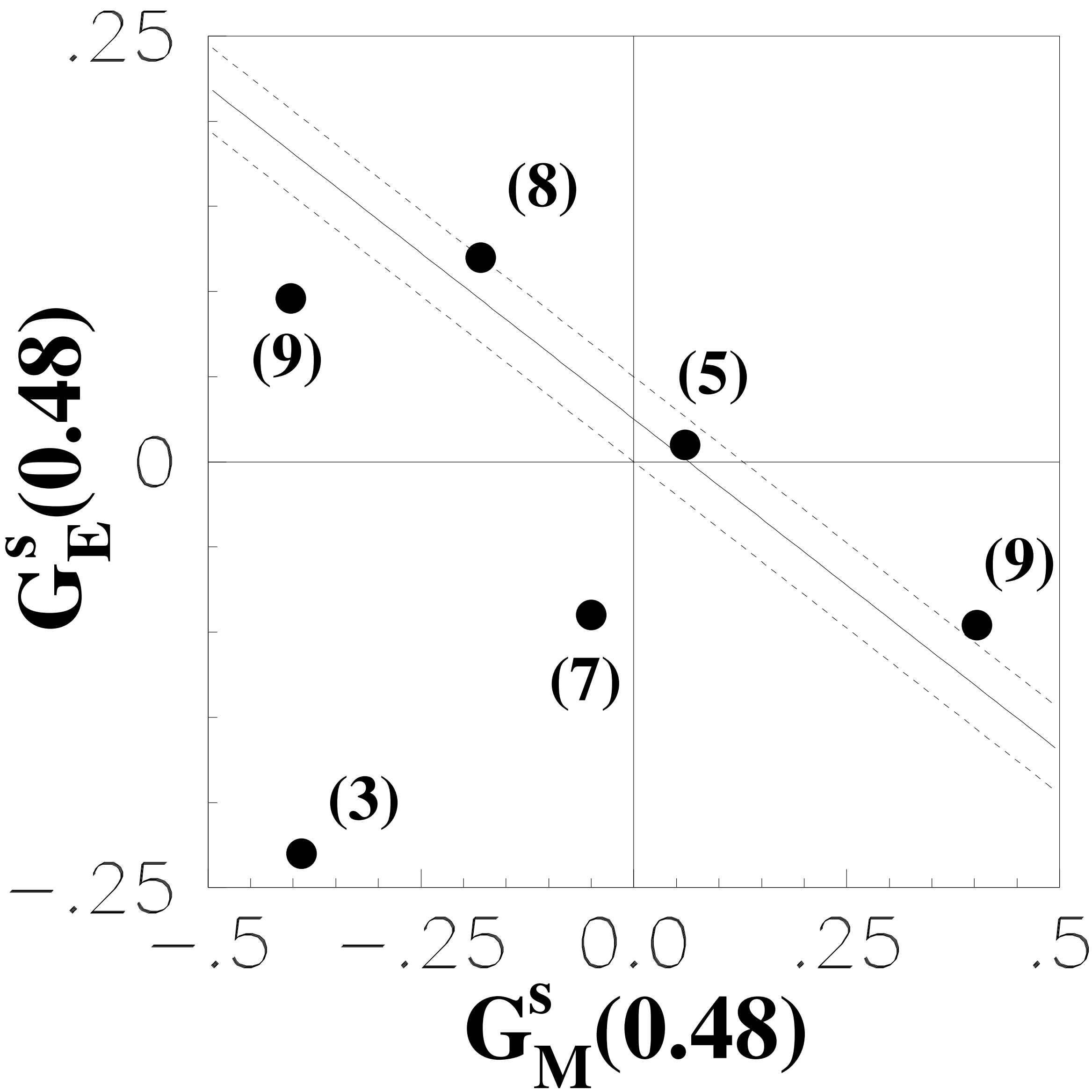
Form Factor	$\frac{\Delta A}{A}$
G_E^n	4%
G_E^p	3%
G_M^n	2%

$$G_E^s + 0.392 G_M^s = 0.025 \pm 0.020 \pm 0.014$$

K.A. Aniol *et al.*, PRL **82**(1999)1096
K.A. Aniol *et al.*, Phys. Lett. **B509**(2001)211

HAPPEX I: results

Phys. Lett. B509(2001)211.



(3) Pole Model (Hammer, Meisner, Dreschel)
(5) NJL Soliton (Weigel *et al.*)
(7) SU(3) Skyrme (Park and Weigel)
(8) Lattice (quenched) (Dong, Liu, Williams)
(9) Poles and $K\overline{K}$ (Hammer and Ramsey-Musolf)

HAPPEX II (proton) and ^{4}He

- JLab, Hall A
- Use HRS (3.7 msr$\times$2) & septum magnets $\rightarrow \theta = 6^{\circ}$
- $\langle Q^2 \rangle = 0.1\ (\mathrm{GeV}/c)^2$ $\quad [E_0 = 3.2$ GeV$]$
- 100 μA, 80% polarization, 30 ms helicity-flip
- Polarimetry: Hall A Møller & Compton (2%)
- Integrating; total absorption Cerenkov counters

	HAPPEX II	^{4}He
Rate/arm	65 MHz	11.9 MHz
$\langle A \rangle$	1.63 ppm	8.43 ppm
$\delta A/A$	5.4%	3.0%
Backgrounds ($\delta A/A$)	0.75%	0.2%

Error Budget - HAPPEX II

Source of Error	$\frac{\Delta A}{A}$ (%)
Polarization	2.0
Radiative Corrections (mainly G_A^Z)	1.0
Backgrounds	0.75
Q^2 Determination	0.6
Beam Systematics	0.2
G_E^n	1.4
Total Systematic Error	2.8
Statistics	4.6
Total Experimental Error	5.4

Measure $\rho_s + \mu_p \mu_s$ to $\pm$ 0.31
in 700 hours

Theory - ^{4}He

$$^4\mathrm{He}(\vec{e}, e') \; : \; 0^+ \rightarrow 0^+$$

$\rightarrow$ charge scattering only - no G_M^s, G_A^Z

$$A = \frac{G_F M_P^2}{\sqrt{2}\pi\alpha}\tau\left(4\sin^2\theta_W + 2\frac{G_E^s(\tau)}{[G_E^{\gamma p}(\tau)+G_E^{\gamma n}(\tau)]}\right)$$

$$\approx \quad \frac{G_F M_P^2}{\sqrt{2}\pi\alpha}\tau\left(4\sin^2\theta_W + 2\rho_s\tau\right)$$

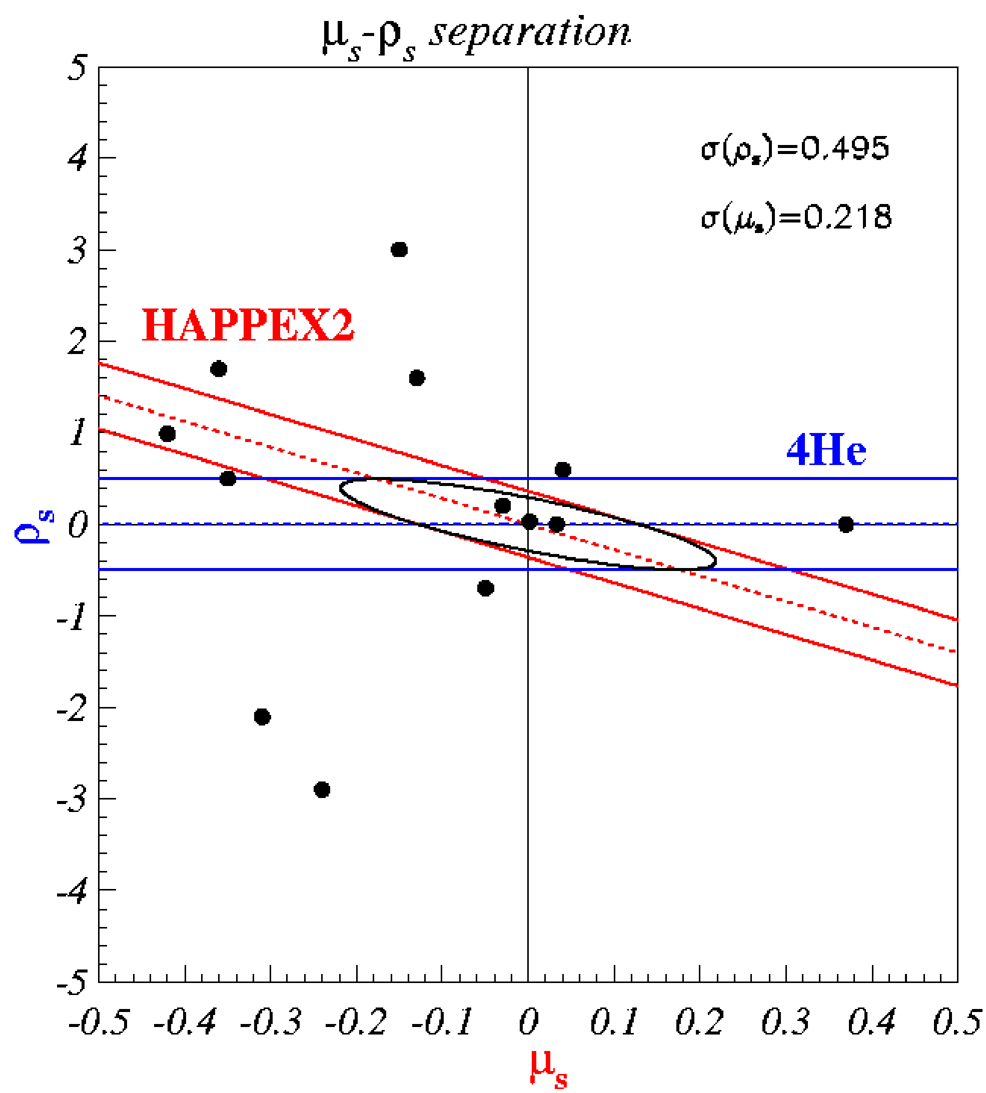
for τ small; here, $\tau = 0.03$

Error Budget - ^{4}He

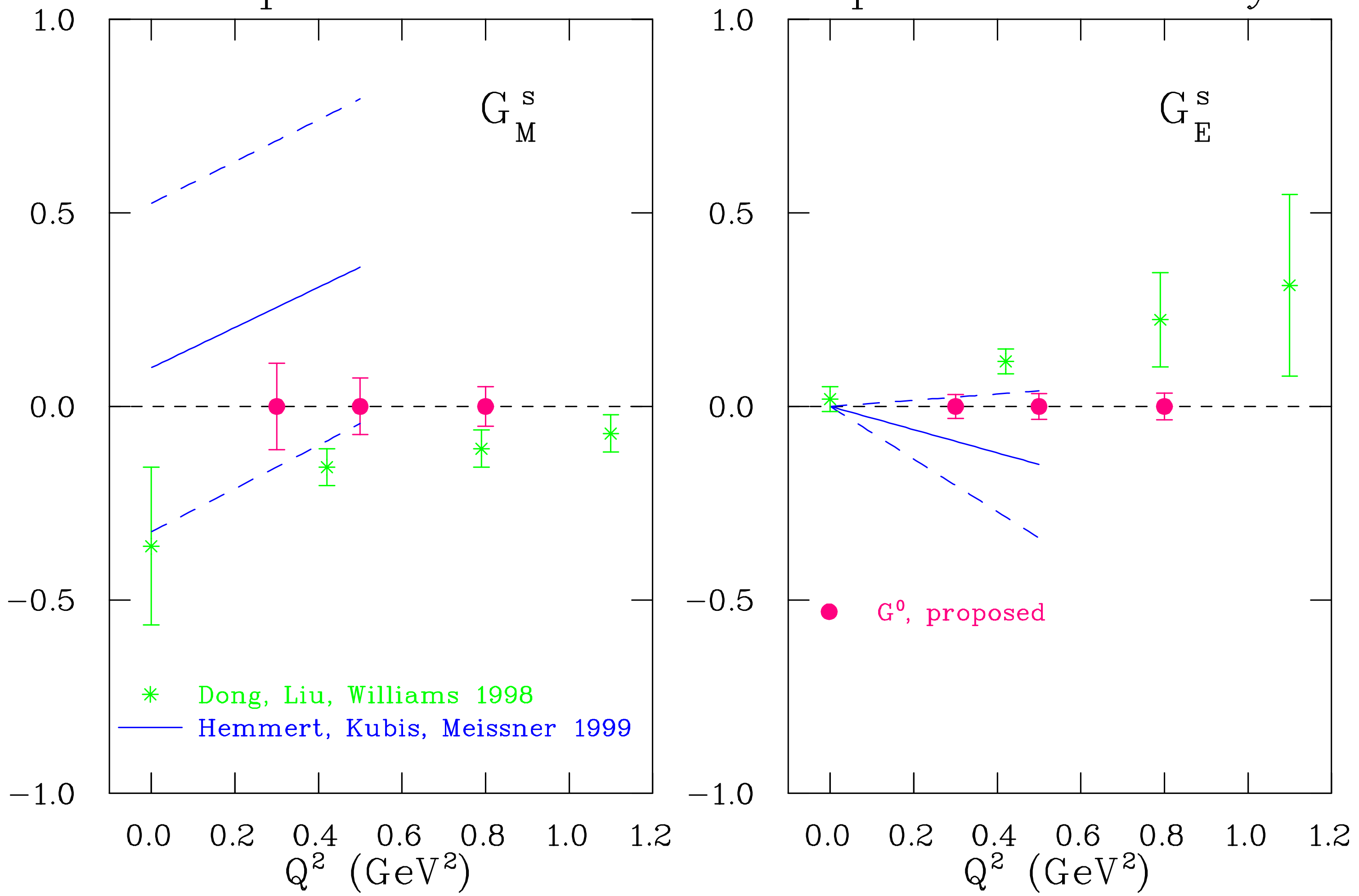
Source of Error	$\frac{\Delta A}{A}$ (%)
Polarization	2.0
Q^2 Determination	0.3
Finite Acceptance	0.3
Beam Systematics	0.2
Backgrounds	0.2
Total Systematic Error	2.1
Statistics	2.2
Total Experimental Error	3.0

Measure ρ_s to $\pm$ 0.5

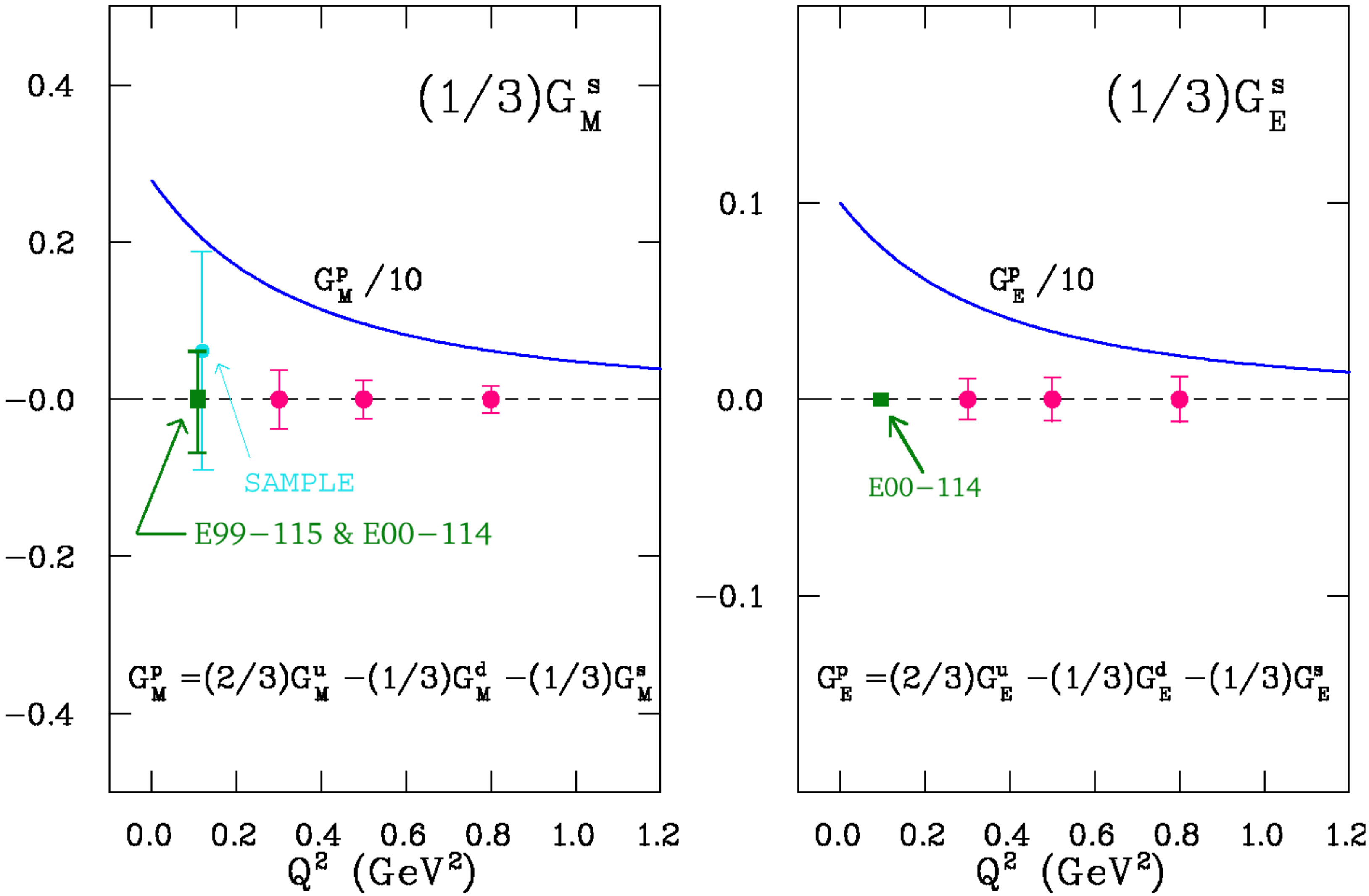
in 700 hours


μs-ρs separation
σ(ρs)=0.495
σ(μs)=0.218
HAPPEX2
4He
ρs
μs

Expected G^0 Results Compared to Theory



Expected G^0 Experiment Uncertainties



Cryotarget

HAPPEX-II: 20 cm long ℓH_2 cell, $\geq 80\mu A$
(400 W @ $100\mu A$)

^{4}He: 20 cm long ^{4}He cold gas cell $\geq 80\mu A$
$0.14\ g/cm^3 = 200$ psi
(700 W @ $100\mu A$)

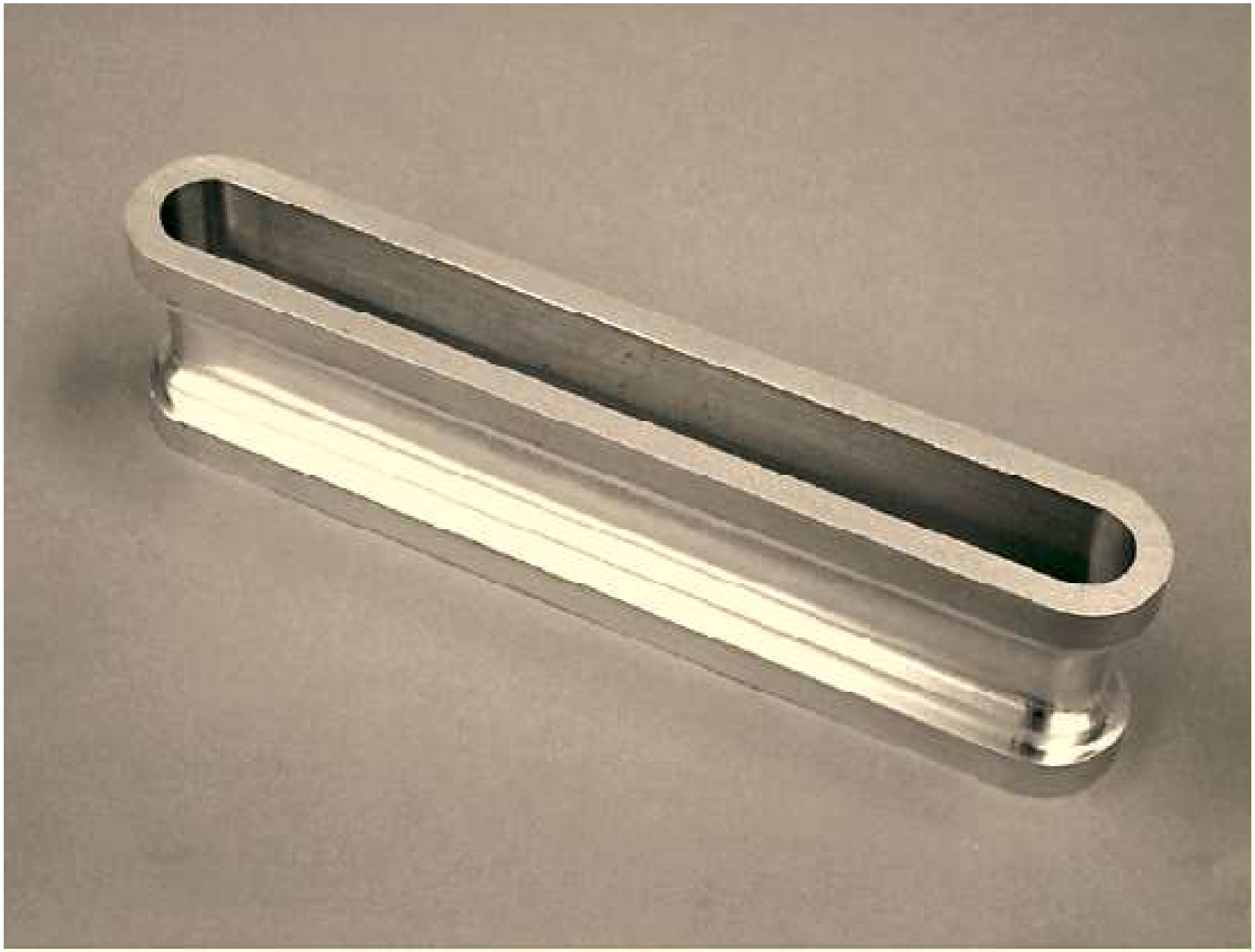
Maximize luminosity
Minimize density fluctations

Two options:

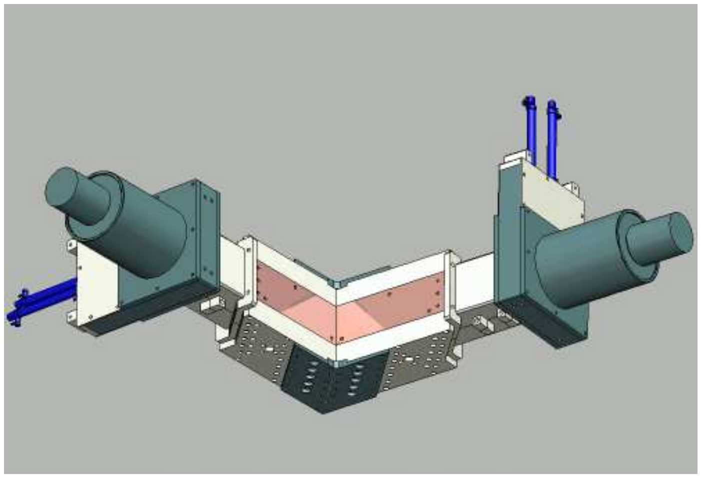
1. Racetrack-style cell (CalState LA)
   transverse flow
2. Machined 'beer-can' [Hall-C style] cell (Targets group)
   longitudinal flow with flow divertors

Unclear which will lead to minimal density fluctuations
Both options being pursued
$\rightarrow$ present plan is to have both available

‘Racetrack’ cell (Cal. State LA)



Focal Plane Detectors (Saclay)



Total Absorption Cherenkov detector

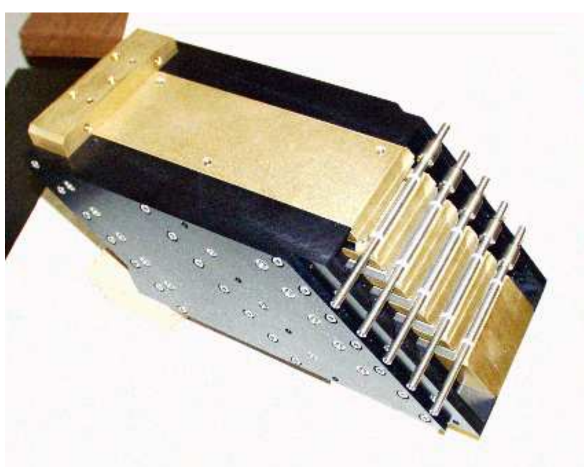
Need Radiation-hard

$\rightarrow$ 5 layer sandwich, Brass/fused amorphous silica

Two segments (for ℓH_2; for ^4He use one segment)

5" Burle PMTs

Constructed, cosmic tests done



Other Issues/Challenges

- Beam:
  - Simultaneous Charge and Position Feedback
  - Resurrect 'coil-pulsing' (beam dithering)
  - Helicity-correlated beam profile?
  - Need Beam development time
- SLAC E158 experience suggests a Luminosity monitor would be useful
- Profile scanner? (for Q^2 measurement with VDCs) (U. Mass)
- Want triangle raster (*à la* G^0/Hall-C development)
- Polarimetry $\rightarrow$ aim for 2%

Summary

- HAPPEX I
  - no *large* strange quark contributions
    $G_E^s + 0.392 G_M^s = 0.025 \pm 0.024$
    at $Q^2 = 0.48\ (\mathrm{GeV}/c)^2$.
  - Models still alive with large effects at other Q^2
- HAPPEX II and ^{4}He
  - Will measure at $Q^2 = 0.10\ (\mathrm{GeV}/c)^2$
    $\rightarrow$ provide precise values of ρ_s and μ_s
  - Schedule: *Start March 8 2003*
  - Preparations well underway
- Competition
  - SAMPLE, G^0, Mainz PV-A4

In the next few years we should have a definitive picture of the strange vector form factors of the nucleon.

$\rightarrow$ Unique view of the effect of $q\overline{q}$ sea on static nucleon properties.