The G^0 experiment @ Jefferson Lab.

Nucleon strange form factors in parity-violating experiment

G^0 Collaboration : Spokesperson: Doug Beck (UIUC)

Caltech, Carnegie-Mellon, William&Mary, Hendricks College, IPN-Orsay, Ljubljana, LPSC-Grenoble, NMSU, Illinois, JLab, Kentucky, NMSU, Manitoba, Maryland, Ohio, TRIUMF, Virginia Tech, Winnipeg, Yerevan, Zagreb

Physics case and experimental set-up

Results for the Backward Angle configuration.

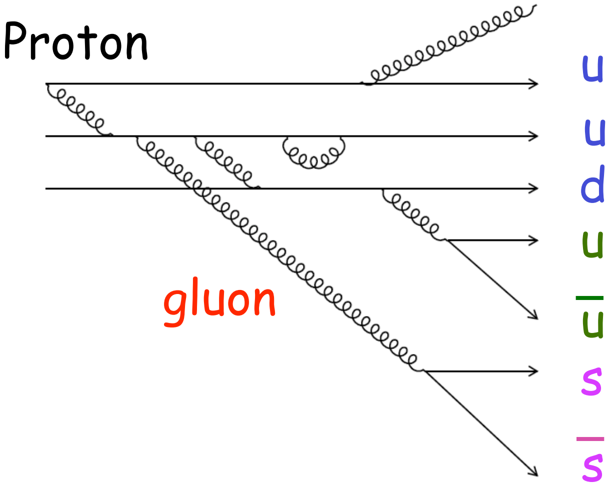
Results on vector strange form factors and isovector axial form factor

Summary

C. Furget for the G0 collab., EINN09, September 2009

Physics motivation

What role do strange (sea) quarks play in nucleon properties ?



Momentum (Global DIS analysis, Lai et al.) :

$$0.018 \leq \langle x(s+\bar{s}) \rangle \leq 0.04$$
$$-0.001 \leq \langle x(s-\bar{s}) \rangle \leq 0.005$$

Spin (DIS) : $\Delta s \approx -0.1 \; to \; 0$ $\quad (Hyp: s = \bar{s})$

Mass : $< N | \bar{s}s | N >$ ~ 0 to 30% $(\pi N \sigma \text{ - term})$

G0 goal : Determine the contribution $\langle N | \bar{s} \gamma^{\mu} s | N \rangle$ of the strange quarks to the electric and magnetic nucleon form factors

✓ Q^2 ~ 0 $(GeV/c)^2$: charge radius and magnetic moment

✓ Q^2 dependence : extraction of G_e^s and G_M^s at 0.22 and 0.63 $(GeV/c)^2$

✓ Measurement of the axial form factor G_A^e

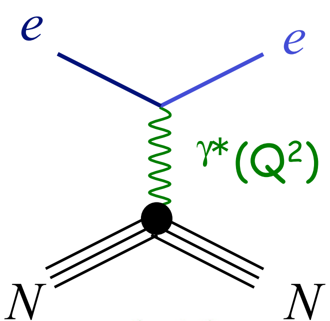
Quark decomposition of EM and Weak form factors

In elastic eN scattering, charge and current/spin distributions in the nucleon are expressed through EM and Weak nucleon form factors

Proton and Neutron Electromagnetic Form Factors :

Measured with precision of 2 – 4 %
in the 0.1 – 1 GeV² Q² range
(~15% for neutron electric F.F.)

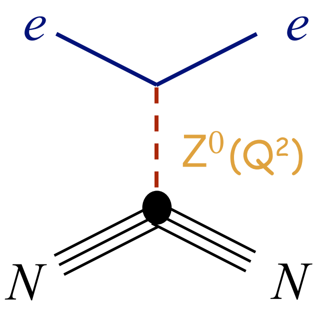
$$\boxed{\begin{aligned} G^{\gamma,p}_{E,M} &= \frac{2}{3}G^{u,p}_{E,M} - \frac{1}{3}G^{d,p}_{E,M} - \frac{1}{3}G^{s,p}_{E,M} \\ G^{\gamma,n}_{E,M} &= \frac{2}{3}G^{u,n}_{E,M} - \frac{1}{3}G^{d,n}_{E,M} - \frac{1}{3}G^{s,n}_{E,M} \end{aligned}}$$



+ proton-neutron charge symmetry reduce from 6 to 3 unknowns

Proton Weak Form Factors :

$$\boxed{G^{Z,p}_{E,M} = \left(1 - \frac{8}{3}\sin^2\theta_W\right)G^{u,p}_{E,M} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right)G^{d,p}_{E,M} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right)G^{s,p}_{E,M}}$$



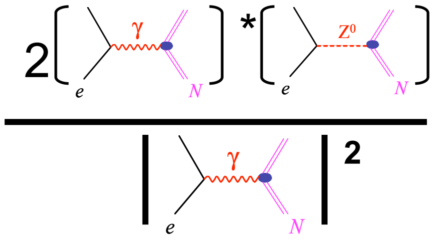
Extraction of the strange quarks contribution :

$$\boxed{G^{s}_{E,M} = \left(1 - 4\sin^2\theta_W\right)G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{Z,p}_{E,M}}$$

Parity violation asymmetry

Elastic scattering of longitudinally polarized electrons on unpolarized nucleon :

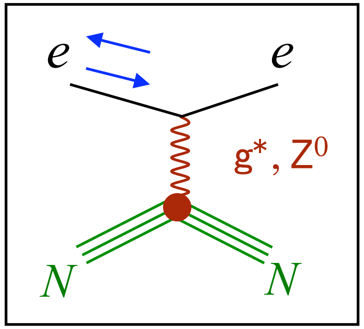
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} =$$



($M_Z << M_\gamma$ at 1 $(GeV/c)^2$)

$$= -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\,\frac{\varepsilon\, G_E^{(\gamma,p)}\, \mathbf{G}_E^{(Z,p)} + \tau\, G_M^{(\gamma,p)}\, \mathbf{G}_M^{(Z,p)} - \left(1 - 4\sin^2\theta_W\right)\varepsilon'\, G_M^{(\gamma,p)}\, \mathbf{G}_A^e}{\varepsilon\left(G_E^{(\gamma,p)}\right)^2 + \tau\left(G_M^{(\gamma,p)}\right)^2}$$

$$A_{PV} = A_0 + \alpha\, \mathbf{G}_E^s + \beta\, \mathbf{G}_M^s + \delta\, \mathbf{G}_A^e(T=1)$$



with

$\tau = Q^2/(4M_p^2)$

$\varepsilon = 1/\left(1 + 2(1+\tau)\tan^2(\theta_e/2)\right)$

$\varepsilon' = \sqrt{\tau(1+\tau)(1-\varepsilon^2)}$

G0 plan : Full separation of G_E^s, G_M^s et G_A^e (T=1) for Q^2 = 0.22 and 0.63 $(GeV/c)^2$

- ✓ Forward Angle (Θ_e = 7 – 15°), LH_2 target : $\boxed{\approx \alpha\, G_E^s} + \beta/2\, G_M^s + \gamma/10\, G_A^e$
- ✓ Backward Angle (Θ_e = 110°), LH_2 target : $\approx \alpha/3\, G_E^s \boxed{+ \beta\, G_M^s + \gamma\, G_A^e}$
- ✓ Backward Angle (Θ_e = 110°) : LD_2 target: $\approx \alpha/4\, G_E^s + \beta/4\, G_M^s \boxed{+ \gamma\, G_A^e}$

Axial form factor in electron-nucleon scattering

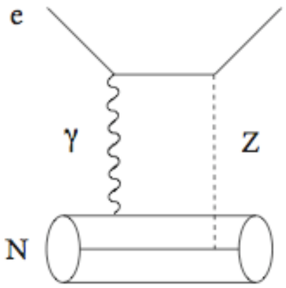
$$G_A^{e,N} = \tau_3 G_A^{e,N}(T=1) + G_A^{e,N}(T=0)$$

$$= -\tau_3\left(1+R_A^{T=1}\right)\boldsymbol{G_A^{CC}}\left(Q^2\right) + \sqrt{3}\,R_A^{T=0}\,\boldsymbol{G_A^{(8)}}\left(Q^2\right) + \left(1+R_A^{(0)}\right)\boldsymbol{G_A^{s}}\left(Q^2\right)$$

1/ $\boldsymbol{G_A^{CC}}(Q^2) = \dfrac{g_A}{\left(1+Q^2/M_A^2\right)^2}$

$$g_A = 1.2670 \pm 0.0035 \quad (neutron\ \beta\ decay)$$

$$M_A = 1.001 \pm 0.020 \quad (\nu N\ data)$$

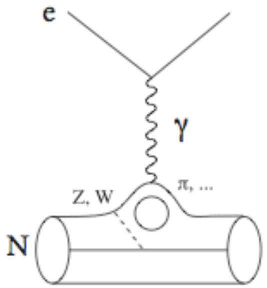


2/ $\boldsymbol{G_A^{(8)}}(0) = 0.169 \pm 0.007 \quad (from\ hyperon\ decay)$

$\boldsymbol{G_A^{s}}(0) = \Delta s \quad ranging\ from\ 0\ to -0.14 \quad (DIS\ data)$

Q2 dependence unknown

3/ Electroweak radiative corrections (including anapole effects) :



$\boldsymbol{R_A^{T=1}} \approx -0.24 \pm 0.24$ Isovector contr. poorly determined

$\boldsymbol{R_A^{T=0}} \approx -0.24 \pm 0.14$

$\boldsymbol{R_A^{(0)}} \approx -0.55$ Q2 dependence unknown

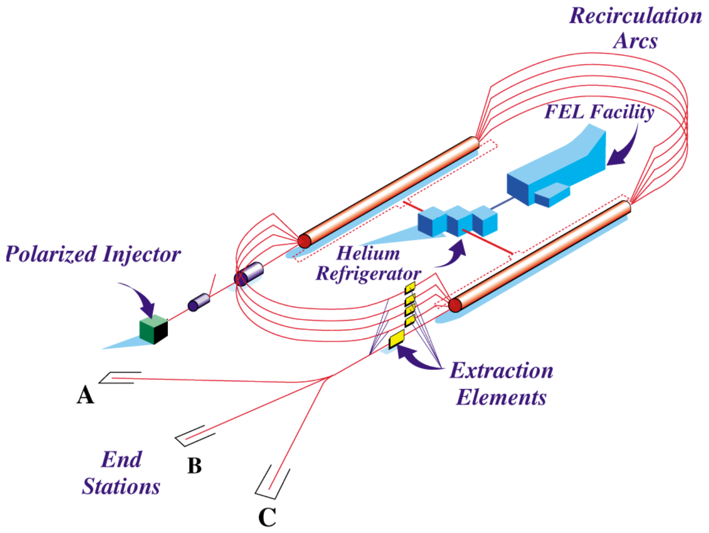
PV electron scattering experiments

Expt/Lab	Target/ Angle	Q^2 (GeV^2)	A_{phys} (ppm)	Sensitivity	Status
SAMPLE/Bates					
SAMPLE I	LH$_2$/145	0.1	-6	$m_s + 0.4G_A$	2000
SAMPLE II	LD$_2$/145	0.1	-8	$m_s + 2G_A$	2004
SAMPLE III	LD$_2$/145	0.04	-4	$m_s + 3G_A$	2004
HAPPEx/JLab					
HAPPEx	LH$_2$/12.5	0.47	-15	$G_E + 0.39G_M$	2001
HAPPEx II, III	LH$_2$/6	0.11	-1.6	$G_E + 0.1G_M$	2006, 2007
HAPPEx He	^{4}He/6	0.11	6	G_E	2006, 2007
HAPPEx	LH$_2$/14	0.63	-24	$G_E + 0.5G_M$	-2009
A4/Mainz					
PVA4	LH$_2$/35	0.23	-5	$G_E + 0.2G_M$	2004
PVA4 I	LH$_2$/35	0.11	-1.4	$G_E + 0.1G_M$	2005
PVA4 II	LH$_2$/145	0.23	-17	$G_E + \eta G_M + \eta' G_A$	2009
PVA4 III	LH$_2$/35	0.63	-25.5	$G_E + 0.64G_M$	-2009
G0/JLab					
Forward	LH$_2$/35	0.1 to 1	-1 to -40	$G_E + \eta G_M$	2005
Backward	LH$_2$/LD$_2$/110	0.23, 0.63	-12 to -45	$G_E + \eta G_M + \eta' G_A$	2009

G0 experimental setup

Measurement A_{PV} ~ -3 to -40 ppm with dA_{PV}/A_{PV} ~ 5% and separation of G_E^s and G_M^s

Two phases for Forward measurement (F) and Backward measurements (B)



CEBAF accelerator

✓ E_{beam} = 3.03 GeV (F), 362 – 687 MeV (B)

✓ L = 2 to 4 10^{38} cm^{-2} s^{-1} with I_e = 40 (F), 20-60 μA (B)

✓ High polarization : 75% (F), 85% (B)

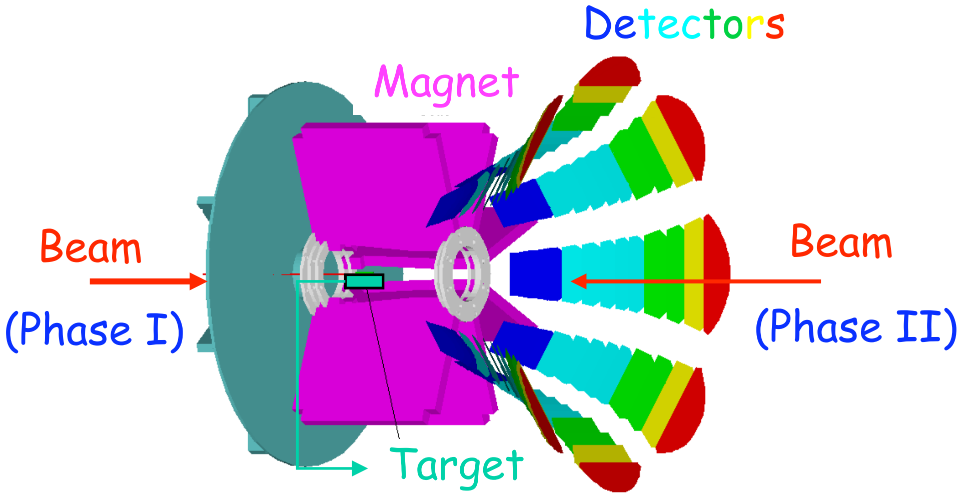
✓ Fast Helicity reversal (33 ms) + beam feedback

G0 setup (hall C)

✓ Superconducting toroidal magnet

✓ LH_2 (F,B) and LD_2 (B) targets

✓ Large acceptance ΔΩ = 0.9 sr (F), 0.5 sr (B)

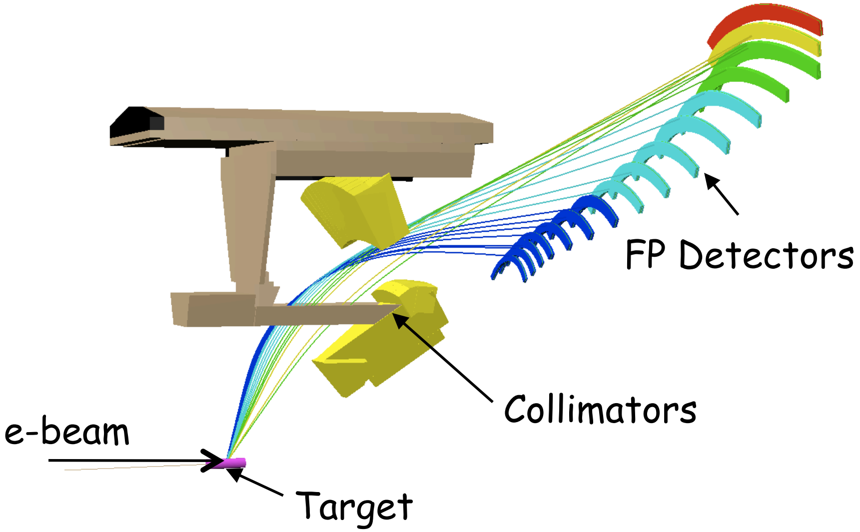


G0 Forward angle configuration

Single measurement for $Q^2 = 0.12 - 1\ (\mathrm{GeV}/c)^2$

$E_{e^-} = 3$ GeV and $\theta_p \sim 70° \rightarrow \theta_e = 7$ to $15°$

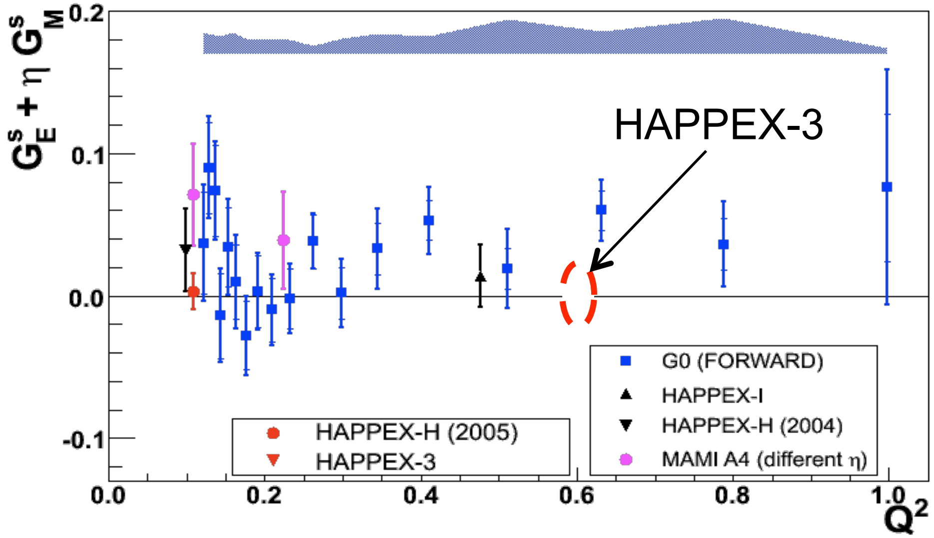
- ✓ Recoil protons detected through a toroidal magnetic field in 8 sectors of 16 Focal plane detectors (FPD).
- ✓ Time of flight discrimination between elastic and inelastic processes



Strange quark contribution :

$$\boldsymbol{G_E^s} + \eta \boldsymbol{G_M^s} = \frac{4\pi\alpha\sqrt{2}}{G_F Q^2} \frac{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}}{\varepsilon G_E^p \left(1 + R_V^{(0)}\right)} \left(A_{phys} - A_{NVS}\right)$$

A null strange quark contribution is rejected at 89 % CL



D.S. Armstrong *et al.*, PRL 95, 092001 (2005)

G0 Backward angle configuration

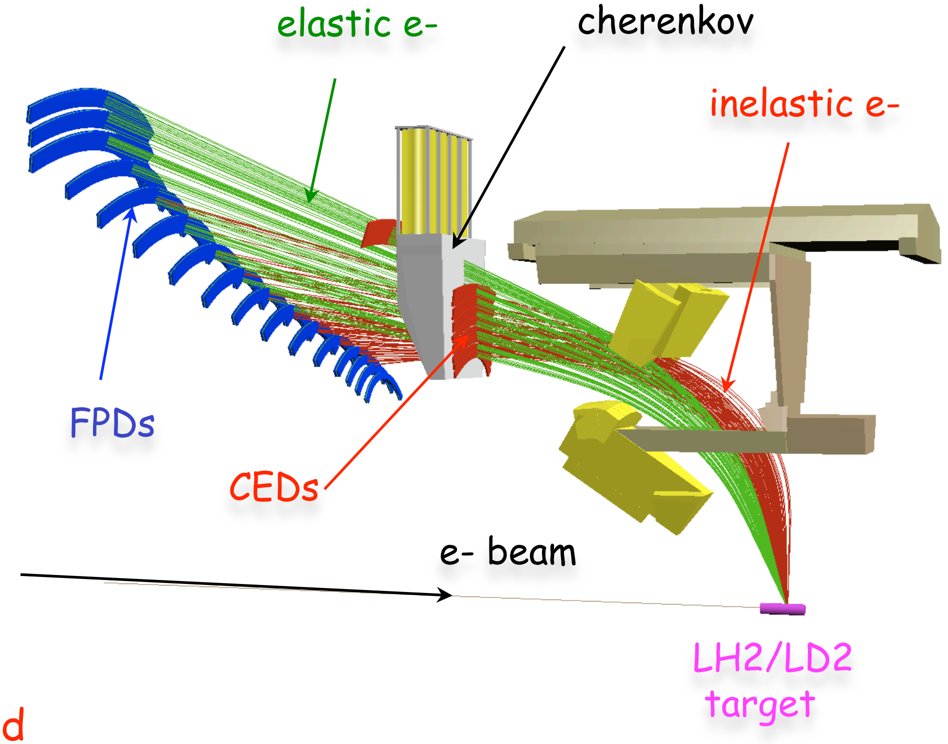
G0 backward measurements at Q^2 = 0.22 and 0.63 $(GeV/c)^2$

- Detection of the scattered electrons ($\theta_e \sim 110°$)
- Small Q^2 acceptance : 2 different beam energies required (362 and 687 MeV)
- Measurement on LH_2 and LD_2 targets

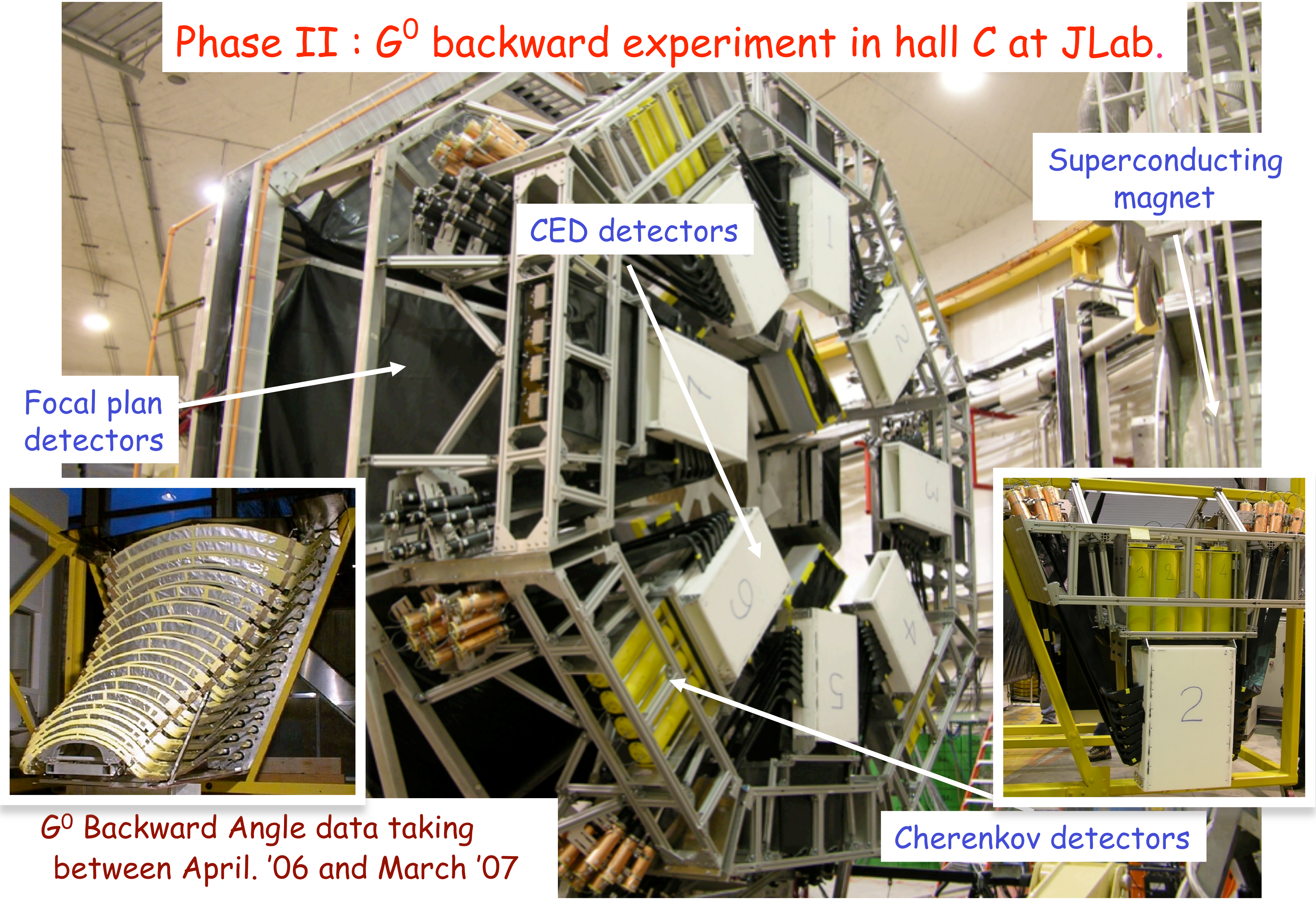
Experimental set-up

- Standard 2 ns beam structure
- Turn-around of the magnet (compared to forward configuration)
- Coincidence matrix between 9 CED and 14 FPD scintillators to separate elastic and inelastic electrons
- Cherenkov detector electron/pion separation

→ Electrons AND pions matrices have been recorded



Phase II : G^0 backward experiment in hall C at JLab.



Superconducting magnet

CED detectors

Focal plan detectors

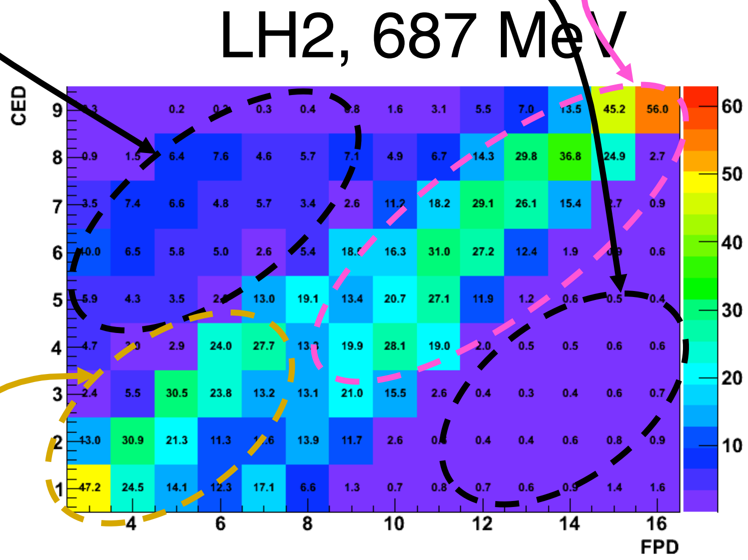
Cherenkov detectors

G^0 Backward Angle data taking between April. '06 and March '07

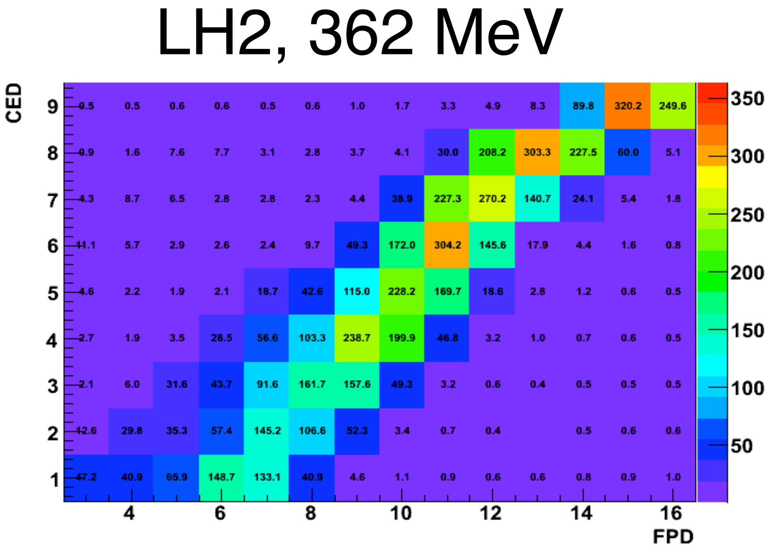
Coincidence matrix for electron only (4 settings)

background regions

(quasi) elastic electrons



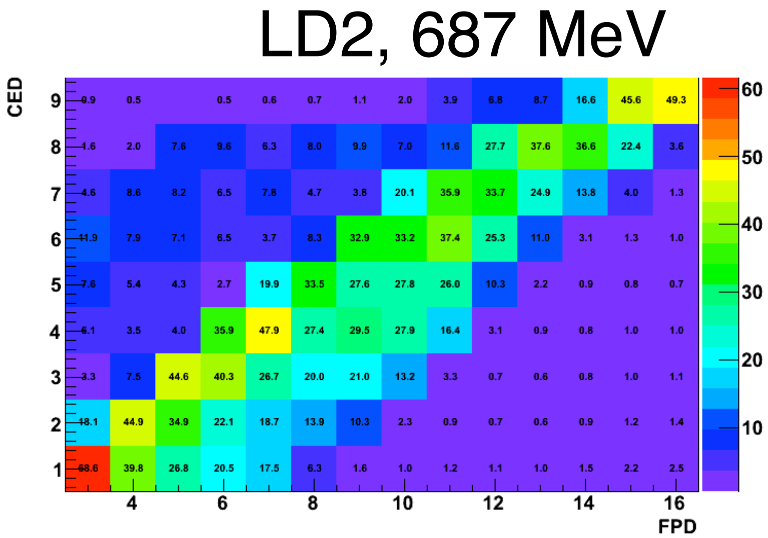
CED		4		6		8		10		12		14		16
9	0.3		0.2	[illegible]	0.3	0.4	0.8	1.6	3.1	5.5	7.0	13.5	45.2	56.0
8	0.9	1.5	6.4	7.6	4.6	5.7	7.1	4.9	6.7	14.3	29.8	36.8	24.9	2.7
7	3.5	7.4	6.6	4.8	5.7	3.4	2.6	11.2	18.2	29.1	26.1	15.4	[illegible]	0.9
6	10.0	6.5	5.8	5.0	2.6	5.4	18.6	16.3	31.0	27.2	12.4	1.9	0.9	0.6
5	5.9	4.3	3.5	[illegible]	13.0	19.1	13.4	20.7	27.1	11.9	1.2	0.6	0.5	0.4
4	4.7	[illegible]	2.9	24.0	27.7	13.3	19.9	28.1	19.0	2.0	0.5	0.5	0.6	0.6
3	2.4	5.5	30.5	23.8	13.2	13.1	21.0	15.5	2.6	0.4	0.3	0.4	0.6	0.7
2	13.0	30.9	21.3	11.3	[illegible]	13.9	11.7	2.6	[illegible]	0.4	0.4	0.6	0.8	0.9
1	47.2	24.5	14.1	12.3	17.1	6.6	1.3	0.7	0.8	0.7	0.6	0.9	1.4	1.6



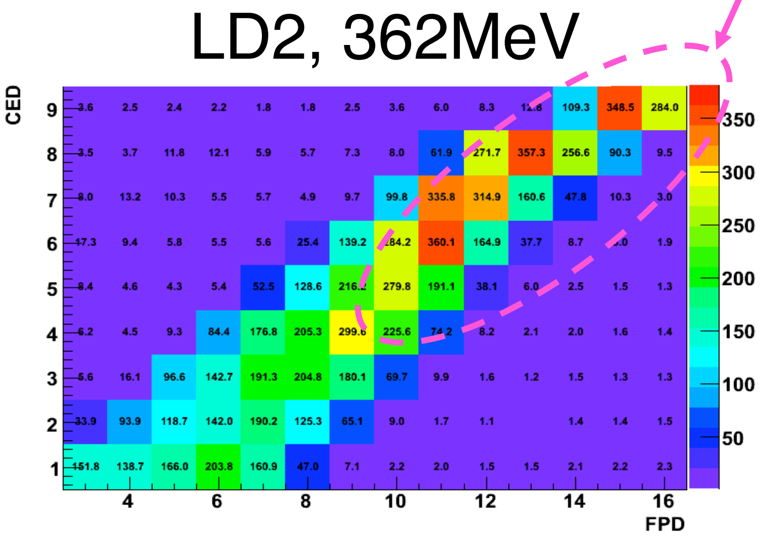
CED		4		6		8		10		12		14		16
9	0.5	0.5	0.6	0.6	0.5	0.6	1.0	1.7	3.3	4.9	8.3	89.8	320.2	249.6
8	0.9	1.6	7.6	7.7	3.1	2.8	3.7	4.1	30.0	208.2	303.3	227.5	60.0	5.1
7	4.3	8.7	6.5	2.8	2.8	2.3	4.4	38.9	227.3	270.2	140.7	24.1	5.4	1.8
6	11.1	5.7	2.9	2.6	2.4	9.7	49.3	172.0	304.2	145.6	17.9	4.4	1.6	0.8
5	4.6	2.2	1.9	2.1	18.7	42.6	115.0	228.2	169.7	18.6	2.8	1.2	0.6	0.5
4	2.7	1.9	3.5	28.5	56.6	103.3	238.7	199.9	46.8	3.2	1.0	0.7	0.6	0.5
3	2.1	6.0	31.6	43.7	91.6	161.7	157.6	49.3	3.2	0.6	0.4	0.5	0.5	0.5
2	12.6	29.8	35.3	57.4	145.2	106.6	52.3	3.4	0.7	0.4		0.5	0.6	0.6
1	47.2	40.9	65.9	148.7	133.1	40.9	4.6	1.1	0.9	0.6	0.6	0.8	0.9	1.0

inelastic electrons

With Cerenkov validation

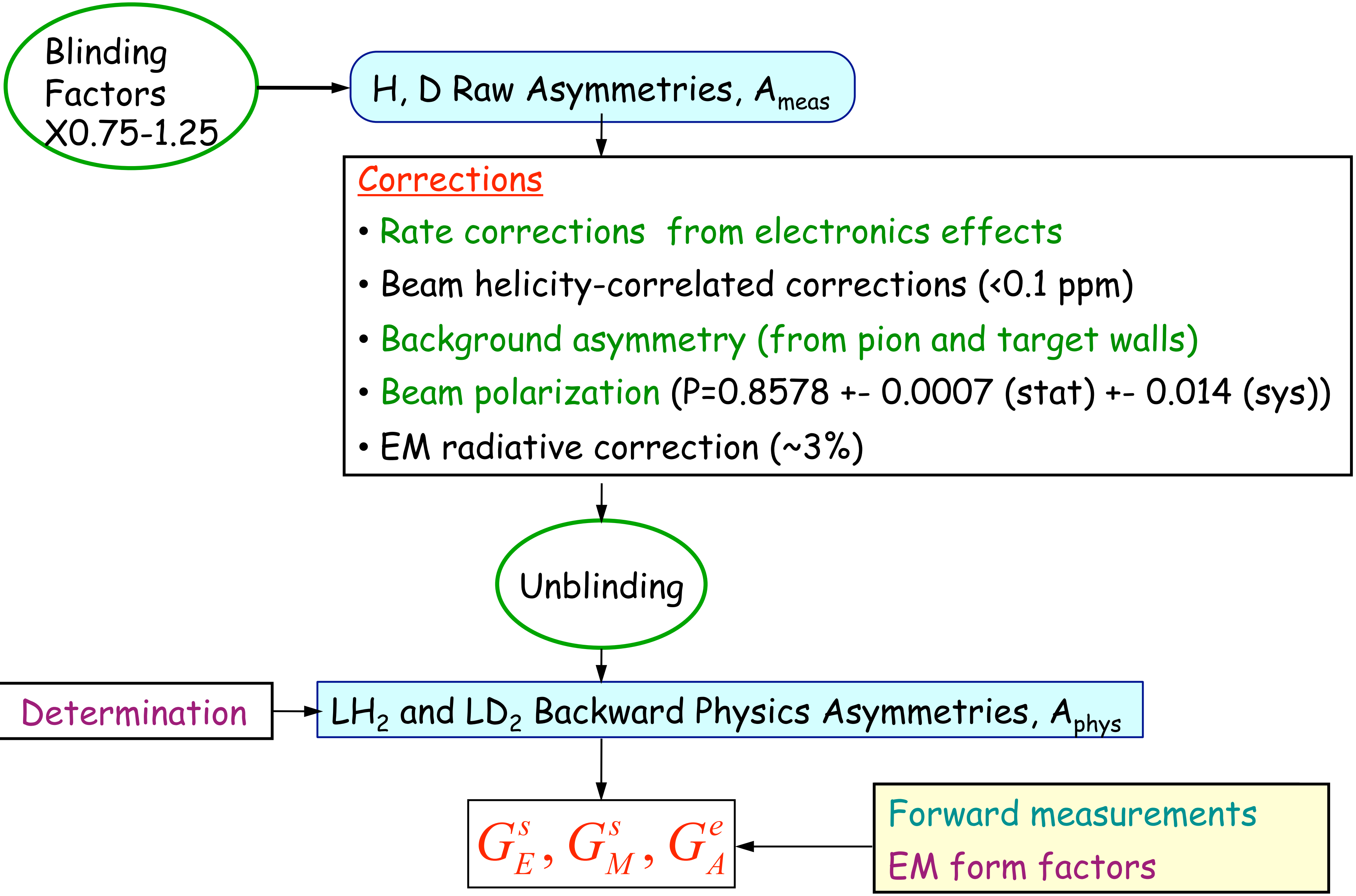


CED		4		6		8		10		12		14		16
9	0.9	0.5		0.5	0.6	0.7	1.1	2.0	3.9	6.8	8.7	16.6	45.6	49.3
8	1.6	2.0	7.6	9.6	6.3	8.0	9.9	7.0	11.6	27.7	37.6	36.6	22.4	3.6
7	4.6	8.6	8.2	6.5	7.8	4.7	3.8	20.1	35.9	33.7	24.9	13.8	4.0	1.3
6	11.9	7.9	7.1	6.5	3.7	8.3	32.9	33.2	37.4	25.3	11.0	3.1	1.3	1.0
5	7.6	5.4	4.3	2.7	19.9	33.5	27.6	27.8	26.0	10.3	2.2	0.9	0.8	0.7
4	6.1	3.5	4.0	35.9	47.9	27.4	29.5	27.9	16.4	3.1	0.9	0.8	1.0	1.0
3	3.3	7.5	44.6	40.3	26.7	20.0	21.0	13.2	3.3	0.7	0.6	0.8	1.0	1.1
2	18.1	44.9	34.9	22.1	18.7	13.9	10.3	2.3	0.9	0.7	0.6	0.9	1.2	1.4
1	68.6	39.8	26.8	20.5	17.5	6.3	1.6	1.0	1.2	1.1	1.0	1.5	2.2	2.5



CED		4		6		8		10		12		14		16
9	3.6	2.5	2.4	2.2	1.8	1.8	2.5	3.6	6.0	8.3	12.8	109.3	348.5	284.0
8	3.5	3.7	11.8	12.1	5.9	5.7	7.3	8.0	61.9	271.7	357.3	256.6	90.3	9.5
7	8.0	13.2	10.3	5.5	5.7	4.9	9.7	99.8	335.8	314.9	160.6	47.8	10.3	3.0
6	17.3	9.4	5.8	5.5	5.6	25.4	139.2	284.2	360.1	164.9	37.7	8.7	[illegible]	1.9
5	8.4	4.6	4.3	5.4	52.5	128.6	216.2	279.8	191.1	38.1	6.0	2.5	1.5	1.3
4	6.2	4.5	9.3	84.4	176.8	205.3	299.6	225.6	74.2	8.2	2.1	2.0	1.6	1.4
3	5.6	16.1	96.6	142.7	191.3	204.8	180.1	69.7	9.9	1.6	1.2	1.5	1.3	1.3
2	33.9	93.9	118.7	142.0	190.2	125.3	65.1	9.0	1.7	1.1		1.4	1.4	1.5
1	151.8	138.7	166.0	203.8	160.9	47.0	7.1	2.2	2.0	1.5	1.5	2.1	2.2	2.3

Analysis overview



Blinding Factors X0.75-1.25

H, D Raw Asymmetries, A_{meas}

Corrections

- Rate corrections from electronics effects
- Beam helicity-correlated corrections (<0.1 ppm)
- Background asymmetry (from pion and target walls)
- Beam polarization (P=0.8578 +- 0.0007 (stat) +- 0.014 (sys))
- EM radiative correction (~3%)

Unblinding

Q^2 Determination

LH_2 and LD_2 Backward Physics Asymmetries, A_{phys}

G_E^s, G_M^s, G_A^e

Forward measurements

EM form factors

Rate corrections from electronics

Correction on the yields (for each helicity) :

- ✓ electronic deadtime (full simulation)
- ✓ random coincidence pion-Cerenkov (direct measurement)

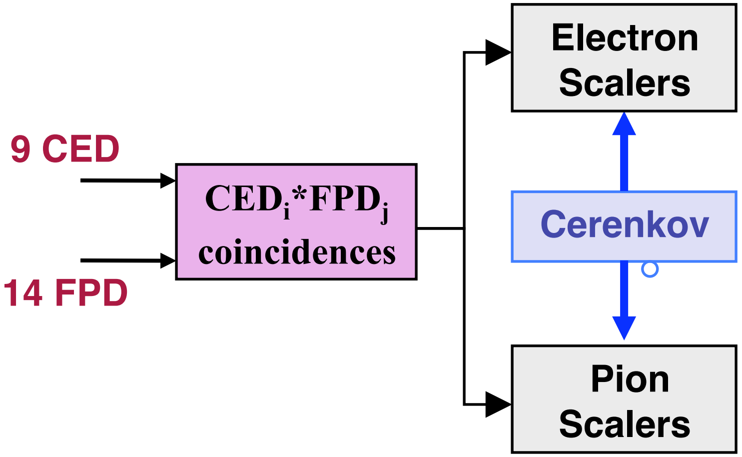
(which depend on the beam current and physics asymmetry)

Additional correction on the asymmetry :

- ✓ Residual Deadtime (<3%)
- ✓ random coincidences CED-FPD in electron matrix

(estimated from specific measurement)

Counting experiment :



9 CED

14 FPD

CED_i*FPD_j coincidences

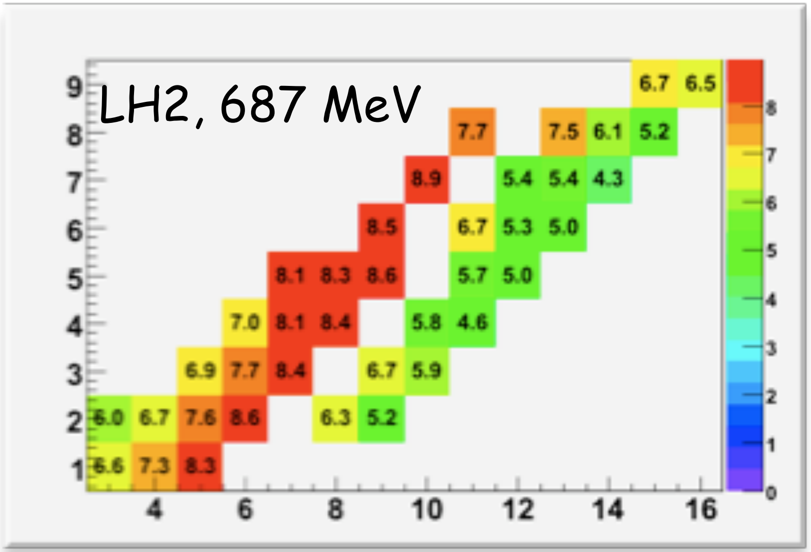
Electron Scalers

Cerenkov

Pion Scalers

Data set	Correction to Yield (%)	Asymmetry Correction (ppm)	systematic error (ppm)
LH_2 / 0.22 GeV^2	6	- 0.31	0.08
LD_2 / 0.22 GeV^2	13	- 0.58	0.21
LH_2 / 0.67 GeV^2	7	-1.28	0.18
LD_2 / 0.67 GeV^2	-9	-7.0	1.8

Deadtimes (%)



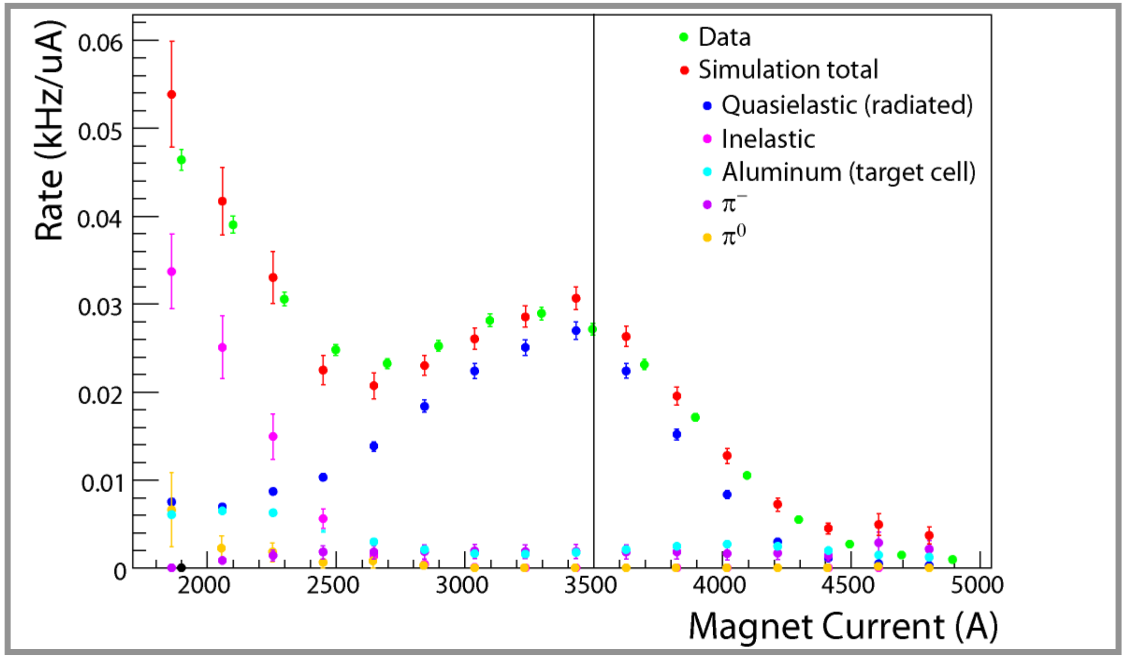
Backgrounds - Magnetic Field Scans

Magnetic field scans :

→ Use simulation Shapes to help determine dilution factors

Main contribution are :

- ✓ Aluminum Windows (~10%)
- ✓ π contamination in LD_2 at $Q^2 = 0.63\ GeV^2$



Data set	Asymmetry Correction (ppm)	systematic error (ppm)
LH2 / 0.22 GeV^2	0.5	0.11
LD2 / 0.22 GeV^2	0.07	0.04
LH2 / 0.67 GeV^2	0.13	0.62
LD2 / 0.67 GeV^2	2.03	0.38

$$A_{corr} = \frac{A_{meas} - f_{Al} A_{Al} - f_{\pi} A_{\pi}}{1 - f_{Al} - f_{\pi}}$$

Physics Asymmetries

Data Set	Asymmetry	Stat	Sys pt	Sys Global	Total
H 362	-11.416	0.872	0.268	0.385	0.990
D362	-17.018	0.813	0.411	0.197	0.932
H687	-46.14	2.43	0.84	0.75	2.68
D687	-55.87	3.34	1.98	0.64	3.92

Preliminary results (all entries in ppm, not for quotation)

Comments :

✓ Statistical errors between 4.7 to 7.6 % of the asymmetry (depending on the setting)

✓ Beam polarization error (1.6%) dominate the systematic point-to-point error except for LD_2 target at 0.63 GeV^2 where the rate correction error dominates.

✓ Main contributions to the global systematic errors are coming from polarization measurement for LD_2 setting and background correction for LH_2 setting.

Strange form-factors extraction

$$A_{phys} - a_0 = a_1\ G_E^s + a_1\ G_M^s + a_3\ G_A^e$$

Q^2	Setting	A_{phys}-a_0	a_1	a_2	a_3
0.63	F / LH_2	+3	79	43	2
	B / LH_2	-8	22	63	12
	B / LD_2	-2	12	12	9

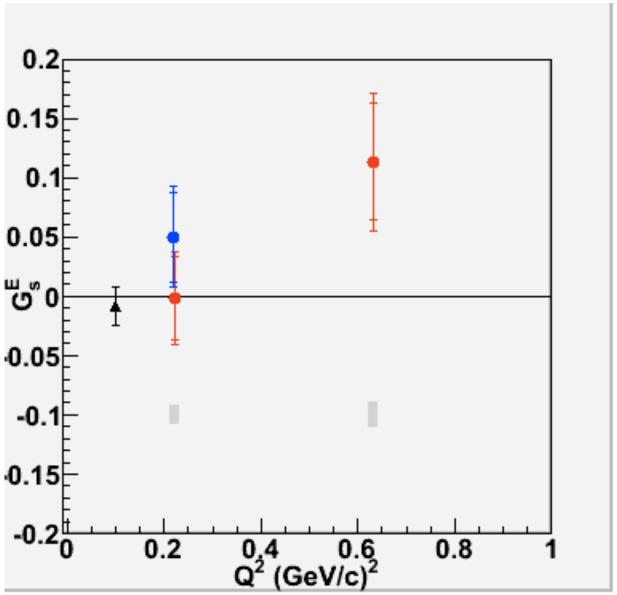
(all entries in ppm, not for quotation)

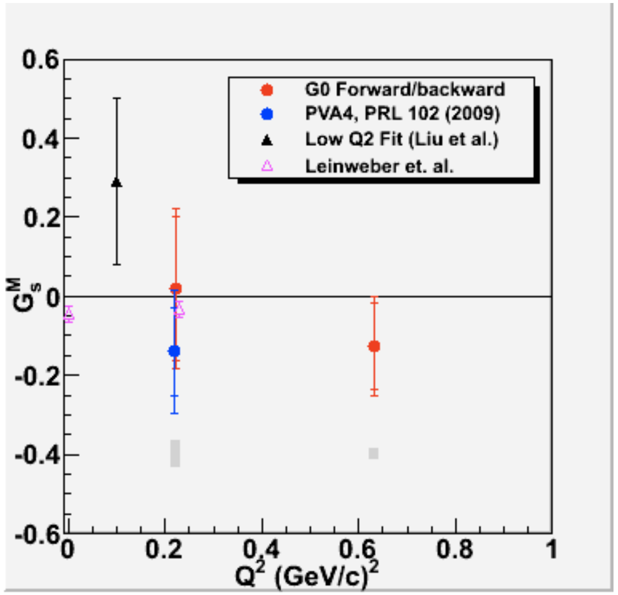
Starting from asymmetries, it requires :

- ✓ Effective Q^2 determination from simulation : Q^2= 0.2205 and 0.6279 $(GeV/c)^2$
- ✓ Interpolation of G0 forward angle data
- ✓ 2 Bosons corrections on the asymmetries : < 1.5% effect

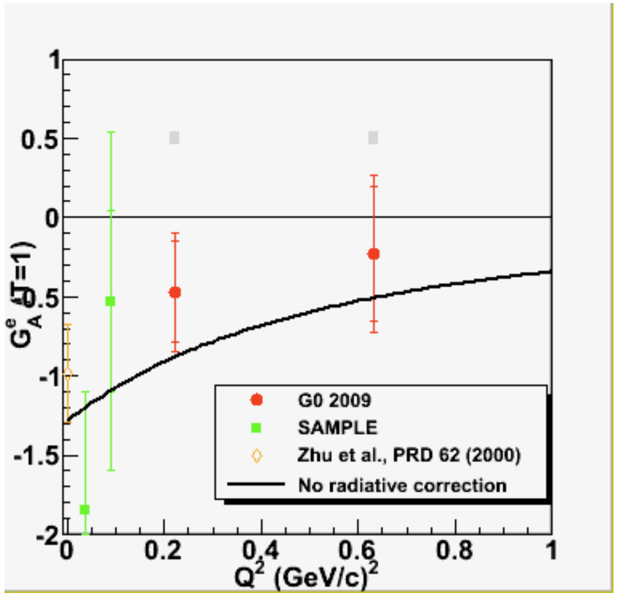
  (Tjon, Blunden, Melnitchouk, Phys. Rev. C 79, 055201 (2009))
- ✓ a_i-coefficients for LH_2 asymmetries : Kelly E.M. form factors (PRC 70 (2004))
- ✓ a_i-coefficients for LD_2 asymmetries : Use deuteron model (from Schiavilla priv. comm.)

G0 results on strange form-factors





▢ Global uncertainties



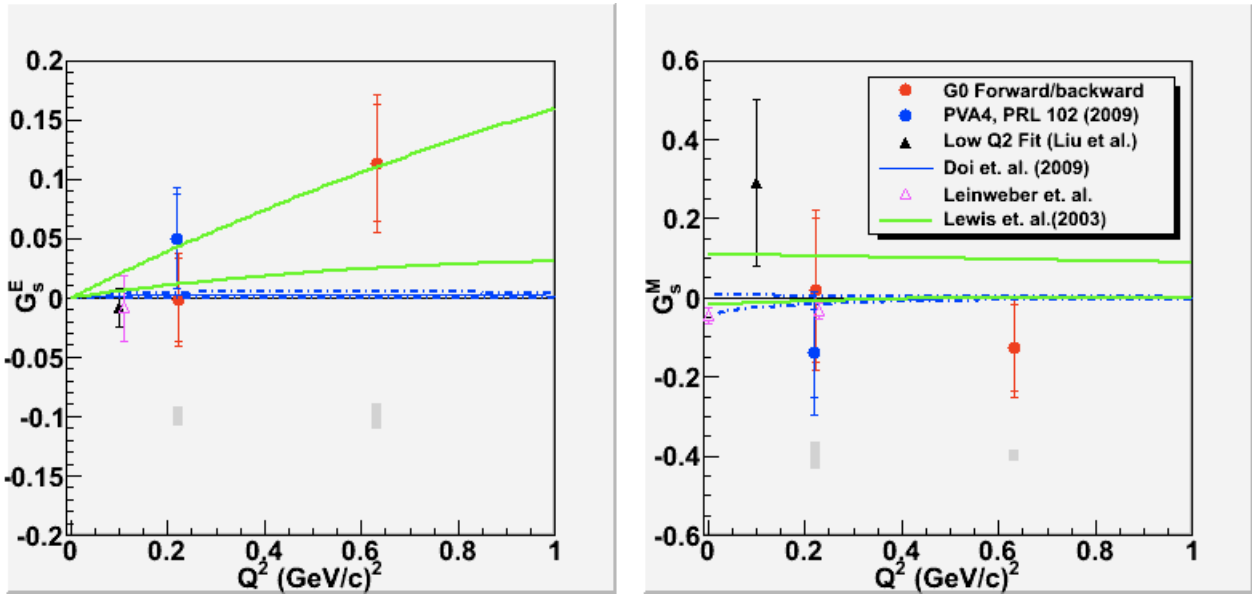
Found a good agreement between data

✓ Small positive G_E^S at Q^2 = 0.63 GeV^2

✓ G_M^S consistent with zero

✓ First Q^2 dependence on axial G_A form factor, smaller than G_a^{tree}(without radiative corrections)

G0 results on strange form-factors



Non-exhaustive comparison with theory (only small sample of models)

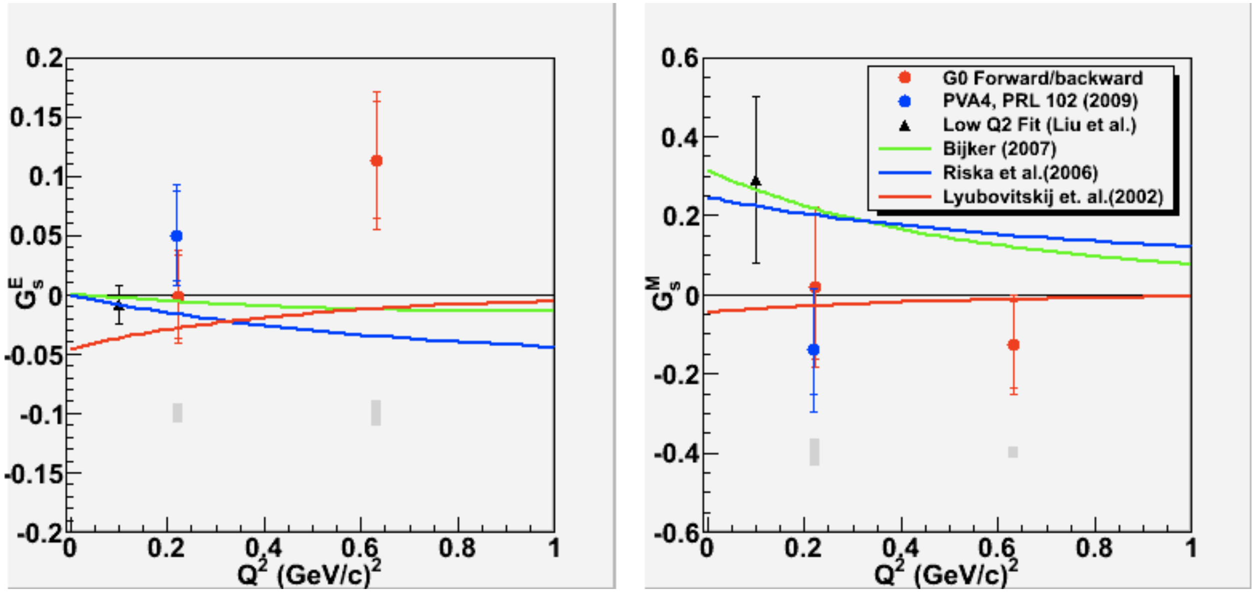
✓ Different approaches based on Lattice QCD predictions

Lewis et al. (2003), Leinweber et al. (2004, 05), Doi et al. (2009)

✓ Some other models predict small G_Es and sizeable GMs

2 component model (Bijker et al.), Pert. Chiral quark model (Lyubovitkij et al.), simple quark model (Riska et al.)

G0 results on strange form-factors



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✓ Different approaches based on Lattice QCD predictions

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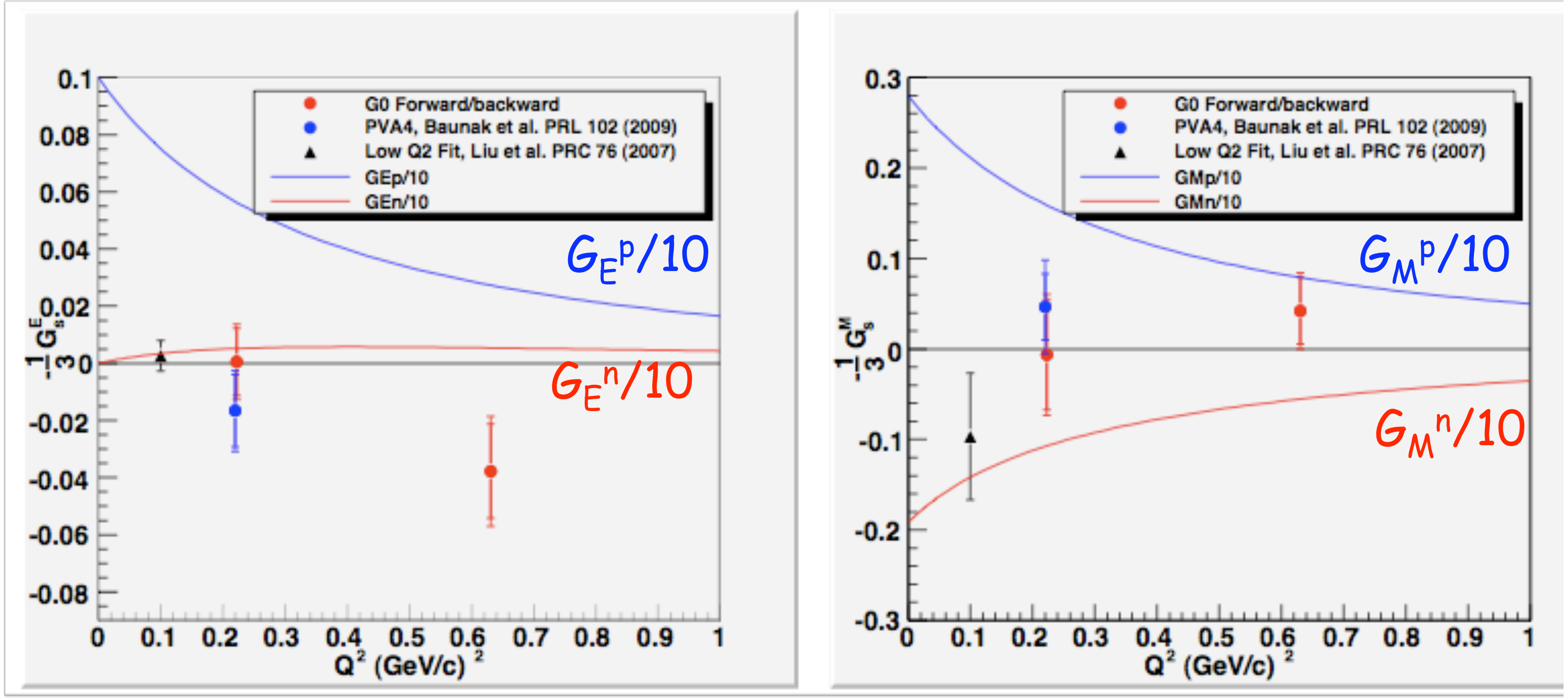
✓ Some other models predict small G_Es and sizeable GMs

VDM model (Bijker et al.), Pert. Chiral quark model (Lyubovitkij et al.), simple quark model (Riska et al.)

Contribution to overall form-factors



NEXT STEPS :

- ✓ combine G0 and PVA4 data at $Q^2 = 0.22\ (GeV/c)^2$
- ✓ Reduced uncertainties with foreseen PVA4 and Happex data at $Q^2 = 0.63\ (GeV/c)^2$
- ✓ Overall fit on 33 separate asymmetry measurements for H, D, He targets
  (prelimininary fit (including neutrino data) shown by J. Schaub et al. at PAVI09)

Summary

- ✓ New G0 measurements of Backward asymmetries for 2 energies (Q2 = 0.22 and 0.63 $(GeV/c)^2$ and 2 targets (LH_2 and LD_2)
- ✓ Full separation of strange vector G_e^s , G_M^s and isovector axial G_a^e at 0.22 and 0.63 GeV^2 when combined with G0 Forward measurements

  First look at Q^2 dependence of strange quark contribution to proton's FF

  - ➡ Small positive G_E^S at higher Q2
  - ➡ G_M^S consistent with zero
- ✓ First results for the Q^2 behavior of the Axial isovector FF

  First indication of the Q^2 dependence of the anapole contribution

◉ Other results to come soon from G0 :

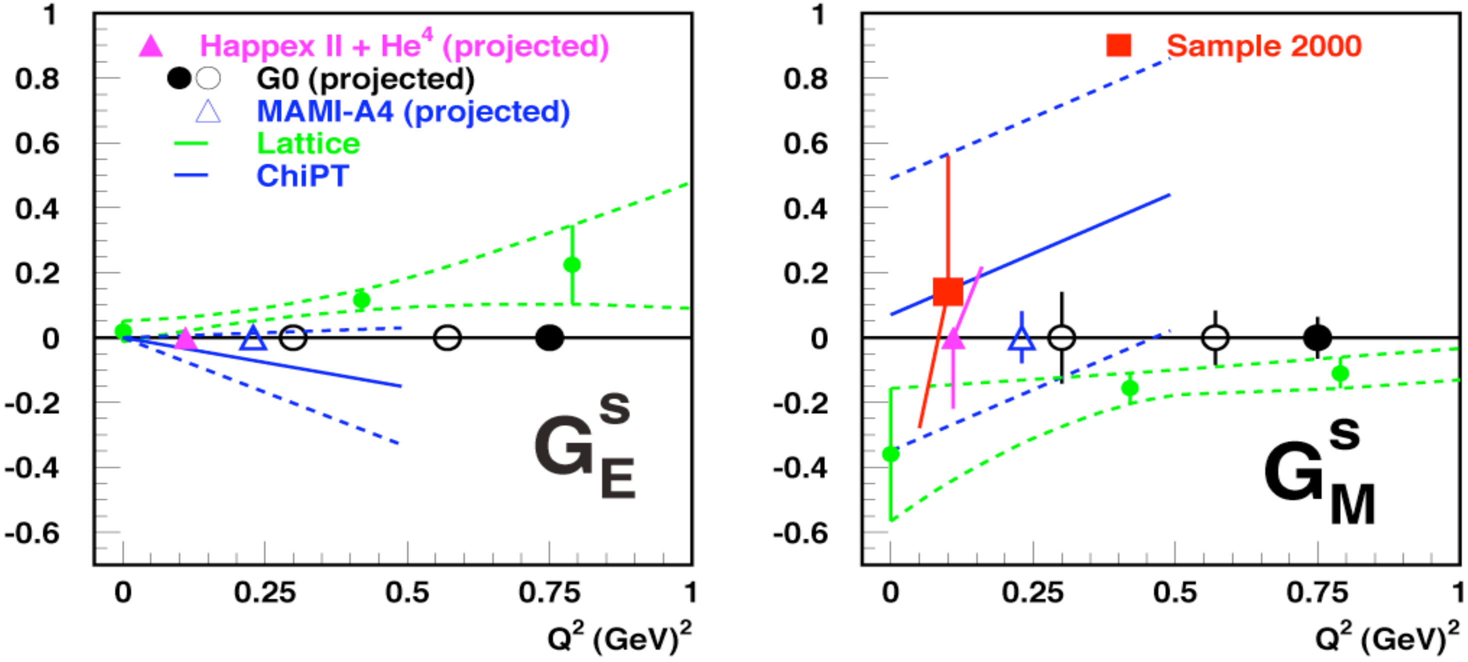
- Transverse beam spin asymmetry (2-γ exchange)
- PV asymmetry in N-Δ transition (0.3 $(GeV/c)^2$)
- PV asymmetry in inclusive π^- production

(part of) the G0 Collaboration (backward angle run)

67 physicists from Caltech, Carnegie-Mellon, William&Mary, Hendricks College, IPN-Orsay, Ljubljana, LPSC-Grenoble, NMSU, Illinois, JLab, Kentucky, NMSU, Manitoba, Maryland, Ohio, TRIUMF, Virginia Tech, Winnipeg, Yerevan, Zagreb

Graduate Students: C. Capuano (W&M), A. Coppens (Manitoba), C. Ellis (Maryland), J. Mammei (VaTech), M. Muether (Illinois), J. Schaub (New Mexico State), M. Versteegen (Grenoble); S. Bailey (W&M)

Status on vector current form factors (2005)



Important improvements from coming measurements

✓ Improved statistics of HAPPEX II (factor 6-10) at 0.1 (GeV/c)^2

✓ Separation of the 2 term (E,M) with Forward measurement (HAPPEX III) and Backward measurements (G0 and A4)

⇨ Large Q^2 domain covered (0.1, 0.23, 0.47 and 0.8 (GeV/c)^2)

Fit Uncertainty Limit Curves

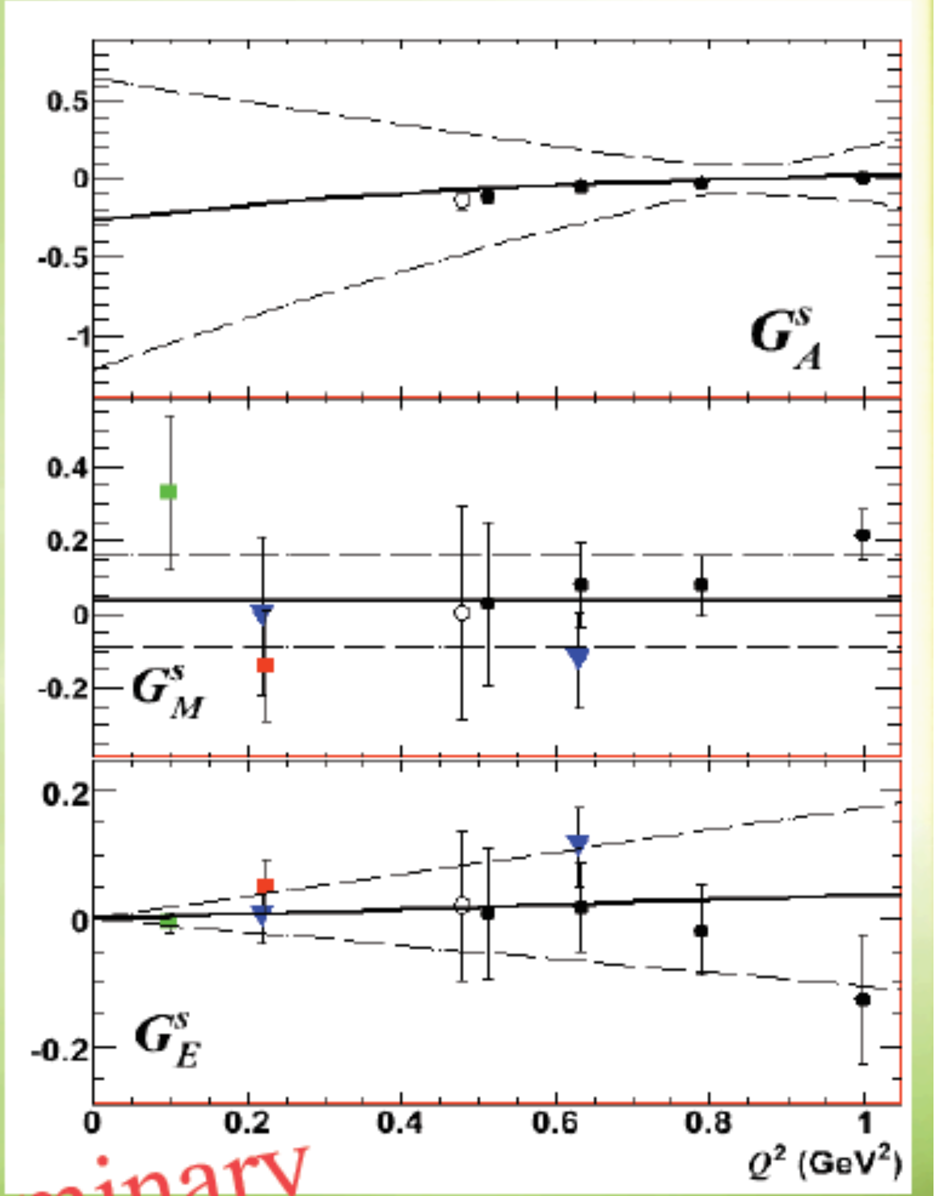
Taken from J. Schaub talk (PAVI09)

- ● G0 (forward *ep*) + E734 (νp and $\bar{\nu}p$)
- ○ HAPPEx (forward *ep*) + E734 (νp and $\bar{\nu}p$)
- 🟥 PVA4 (forward and backward *ep*)
- ▼ G0 (forward and backward *ep*, and backward *ed*)
- 🟩 HAPPEx + PVA4 + SAMPLE + G0 (0.1 GeV^2)

——— 5 parameter fit

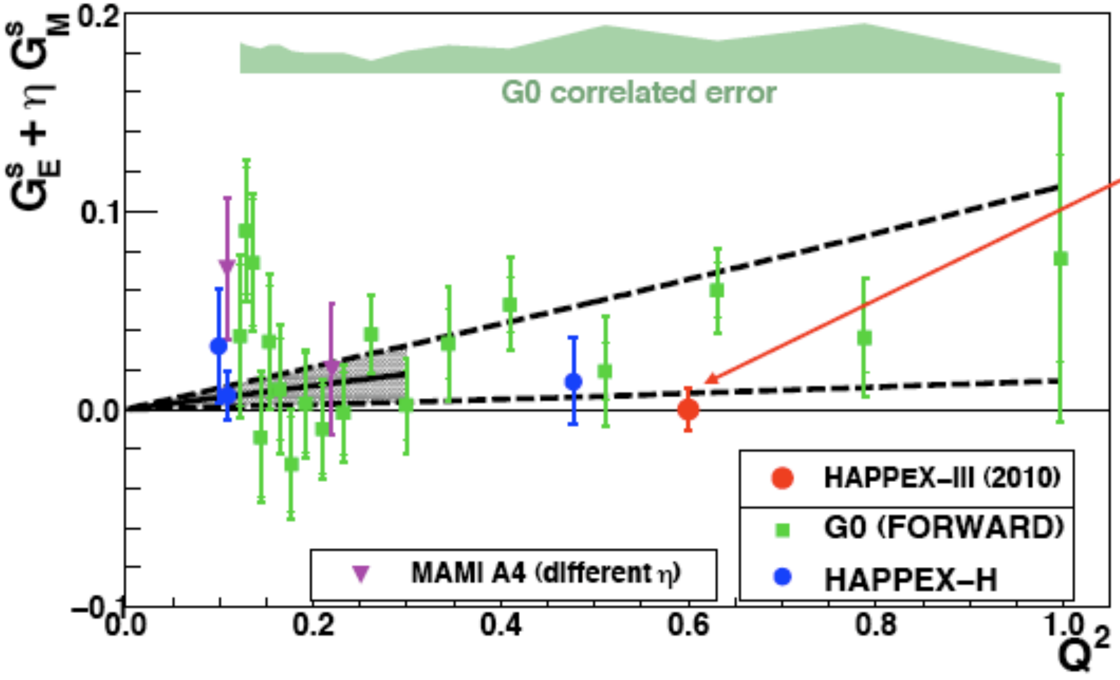
– – – – 70% confidence level

Parameter	Fit to Existing Data
ρ_s	0.13 ± 0.21
μ_s	0.035 ± 0.053
ΔS	–0.27 ± 0.41
Λ_A	1.3 ± 1.9
S_A	0.32 ± 0.48



Preliminary

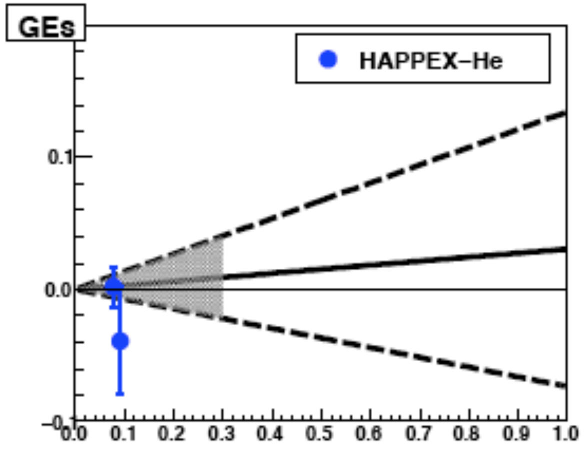
HAPPEX-III

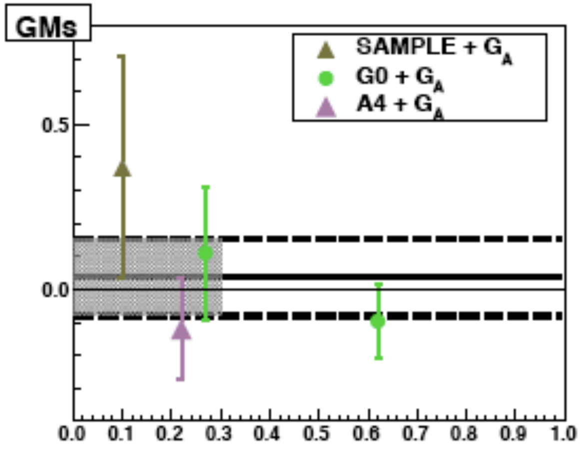


HAPPEX-III (running 2009)

$\delta(G_E^s + 0.48\, G_M^s) \sim 0.01$

World data suggests central value 4σ from zero



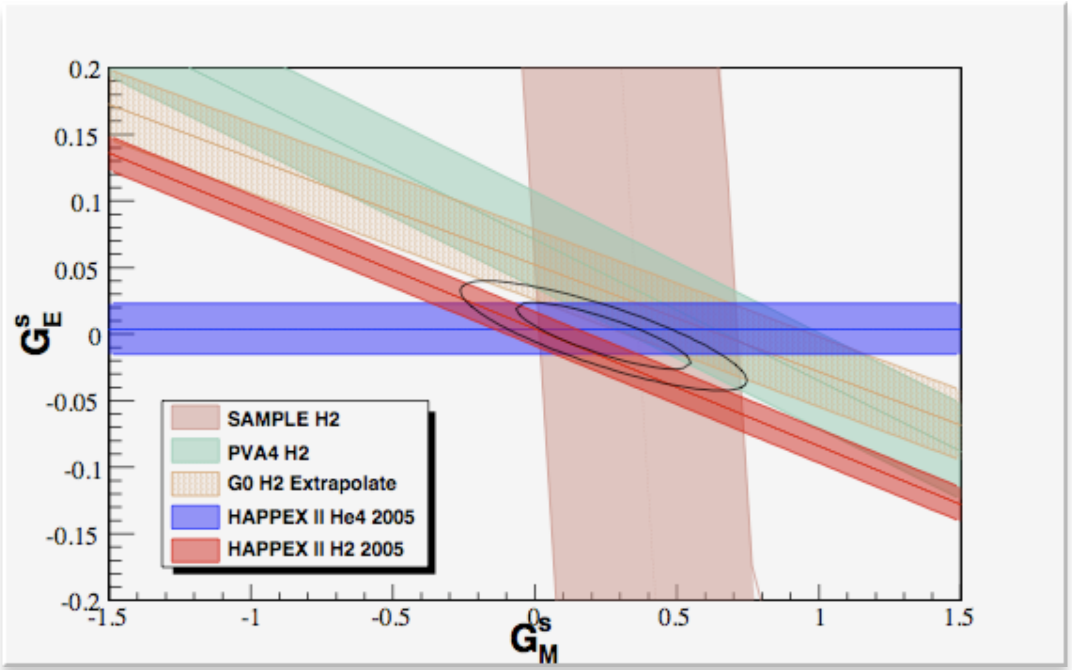


Taken from K. Paschke talk (PAVI09)

Word data at $Q^2 = 0.1\ (GeV/c)^2$

Solid Ellipse :
68.27% CL / 95.45% CL
Uses theoretical
constraints on
the axial form factor

Placement of SAMPLE
band depends on GA
calculation



From J.Liu et al. PRC 76 (2007)

G^s_E = *-0.006 + / - 0.016* *(~ 0.2% of the proton electric FF)*

G^s_M = *0.33 +/ - 0.21* *(~ 3% of the proton magnetic FF)*

Asymmetry corrections

LH2 362 MeV	Value (ppm)	Stat. (ppm)	Syst. pt (ppm)	Sys. Glo (ppm)	Total (ppm)
Measured asym.	-9.941	0.872			
Background asym.	-9.441		0.034		
Dilution correction			0.109	0.411	
Transverse correction			0.025	0.008	
Rate correction	-9.444		0.090		
Beam polarization	-11.010		0.223	0.133	
EM Radiative corr.	-11.416		0.023		
Physics asym.	-11.416	0.872	0.268	0.431	1.009

LH2 687 MeV	Value (ppm)	Stat. (ppm)	Syst. pt (ppm)	Sys. Glo (ppm)	Total (ppm)
Measured asym.	-38.141	2.443			
Background asym.	-38.272		0.405		
Dilution correction			0.467	0.888	
Transverse correction				0.008	
Rate correction	-38.393		0.173		
Beam polarization	-44.757		0.518	0.537	
EM Radiative corr.	-46.394		0.093		
Physics asym.	-46.394	2.443	0.831	1.038	2.781

LD2 362 MeV	Value (ppm)	Stat. (ppm)	Syst. pt (ppm)	Sys. Glo (ppm)	Total (ppm)
Measured asym.	-14.047	0.813			
Background asym.	-14.114				
Dilution correction			0.021	0.086	
Transverse correction			0.037	0.008	
Rate correction	-14.152		0.232		
Beam polarization	-16.498		0.331	0.197	
EM Radiative corr.	-17.018		0.061		
Physics asym.	-17.018	0.813	0.411	0.215	0.936

LD2 687 MeV	Value (ppm)	Stat. (ppm)	Syst. pt (ppm)	Sys. Glo (ppm)	Total (ppm)
Measured asym.	-44.021	3.328			
Background asym.	-46.053		0.052		
Dilution correction			0.374	0.316	
Transverse correction			0.009	0.008	
Rate correction	-46.349		1.828		
Beam polarization	-54.033		0.621	0.644	
EM Radiative corr.	-55.858		0.201		
Physics asym.	-55.858	3.328	1.977	0.717	3.936

Deuterium Model

$$A_{phys} = a_0 + a_1 G_E^s + a_2 G_M^s + a_3 G_A^e$$

calculations from R. Schiavilla, see also R.S., J. Carlson, and M. Paris, PRC70, 044007 (2004).

leading term
of the
asymmetry

axial form
factor coefficient
has ~15%
correction from
2-body effects