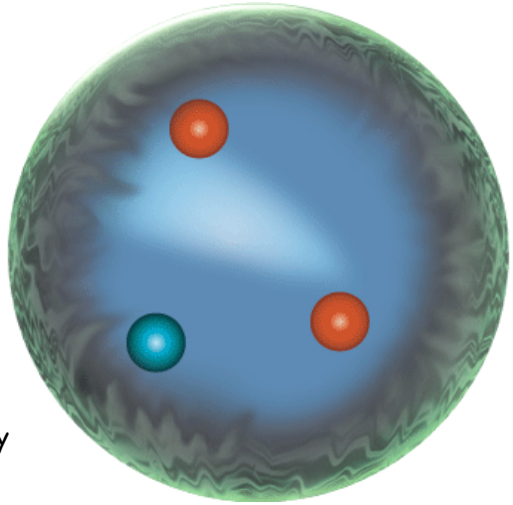
G0 experiment in Hall C @ JLab

J. Roche
Rutgers University/JLab

- Observables in parity violating electron scattering
- What the world data tell us about them so far
- Recap of the G0 forward results
- Update on the G0 backward data taking

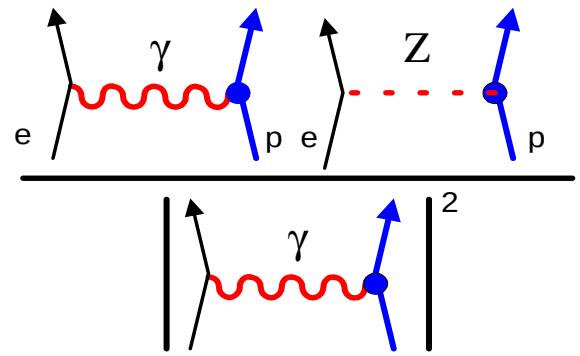


courtesy of JLab

Observables in parity violating electron scattering

longitudinally polarized electrons, unpolarized target elastic scattering

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = A(G^{\gamma}) + A(G^{\gamma} \cdot G^{Z})$$



$G^{\gamma,p}_{E,M}$, $G^{\gamma,n}_{E,M}$, $G^{Z,p}_{E,M}$ $\xrightarrow{\text{Charge symmetry}}$ $G^{u}_{E,M}$, $G^{d}_{E,M}$, $G^{s}_{E,M}$ $\xrightarrow{\text{Pick 'n Choose}}$ $G^{p}_{E,M}$, $G^{n}_{E,M}$, $G^{s}_{E,M}$

Well Measured

$\langle N|\, s\gamma^{\mu} s\, |N\rangle$

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = A_0 + \eta_E\, G_E^s + \eta_M\, G_M^s + \eta_A\, G_A^{eN}$$

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"Rosenbluth" type of separation (3 parameters)

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = A_0 + \eta_E\, G_E^s + \eta_M\, G_M^s + \eta_A\, G_A^{eN}$$

Vary both the targets (LH2, LD2, ^{4}He) and the kinematics

(selected) World data at $Q^2 \sim 0.1$ GeV^2

Exp	Target	E_{beam} (GeV)	Θ_e (deg)	A_o (ppm)	η_E (ppm)	η_M (ppm)	η_A (ppm)
SAMPLE	D	0.2	150	-7	1.6	0.8	1.8
SAMPLE	H	0.2	150	-6	2.1	3.5	1.6
HAPPEx	^{4}He	3	6	7	20.0	0	0
PVA4	H	0.6	35	-2	10.1	1.0	0.3
G0	H	3	6	-2	12.0	1.2	0.1

<u>Even simpler :</u>

use early results from SAMPLE that showed G_A^{eN} in statistical agreement with a theoretical computation : you are left only with 2 variables !

Well let's be careful

Axial form factor

tree level :

$$G_A^{eN} = \tau_3 G_A + \Delta s$$

invoke flavor symmetry between n and p

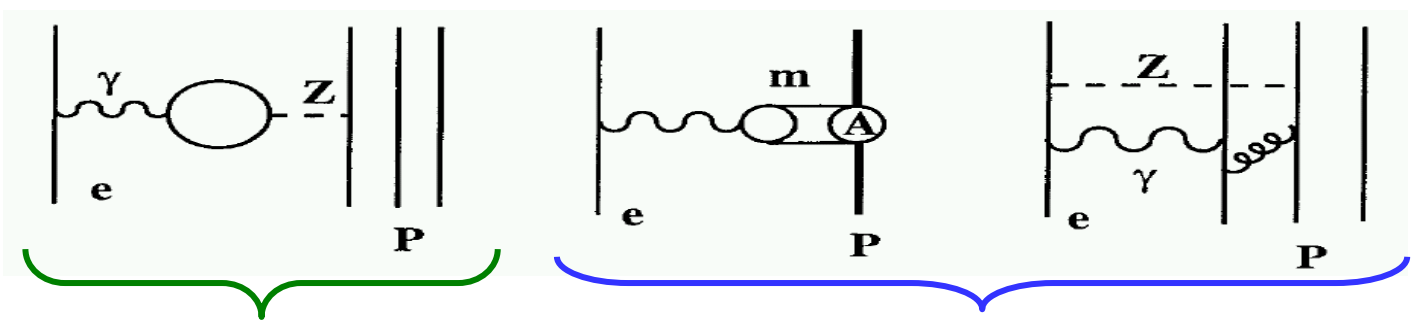
known through β decay of the neutron

known through DIS

higher order :

$$G_A^{eN} = \tau_3 (1 + R_A^{T=1}) G_A + R_A^{T=0} + (1 + R_A^{s}) \Delta s$$

for example :



electro-weak : quite precise

QCD : "not very precise"

$$R_A^{T=1} = R_A^{T=1}(1q) + R_A^{T=1}(nq) = -1.83 - 0.09\,(\pm 0.35)$$

$$R_A^{T=0} = R_A^{T=0}(1q) + R_A^{T=0}(nq) = -0.07 + 0.02\,(\pm 0.26)$$

Zhu *et al*, PRD 62 (2000) 033008

Axial form factor (cont.)

some numbers :

still using Zhu *et al*, PRD 62 (2000) 033008 for the higher orders contributions

$G_A^{T=1}$= -1.17 +/- 0.44 $G_A^{T=0}$= -0.08 +/- 0.26

Exp	Target	Θ_e (deg)	ΔA_{meas} (ppm)	$\eta_A G_A^{eN}$ (ppm)	$\Delta A(G_A^{T=1})$ (ppm)	$\Delta A(G_A^{T=0})$ (ppm)
SAMPLE	D	150	1.0	-1.6	0.61	0.08
SAMPLE	H	150	1.1	-1.6	0.57	0.34
PVA4	H	35	0.3	-0.3	0.09	0.05
G0	H	6	0.5	-0.1	0.02	0.01

With that model, one is entitled to assume $G_A^{T=0}$ and only consider $G_A^{T=1}$ as unknown *(this is what is generally done)*

BUT

For a more "naïve" analysis (no theory input) : $G_A^{T=1}$ and $G_A^{T=0}$ are unknown

$$(G_A^{T=0}, G_A^{T=1}) \Leftrightarrow (G_A^p = G_A^{T=0} + G_A^{T=1} \quad , \quad G_A^n = G_A^{T=0} - G_A^{T=1})$$

$$A_{measured} = A_0 + \eta_E G_E^s + \eta_M G_M^s + \eta_A^n G_A^n + \eta_A^p G_A^p$$

A global fit of the world PVes data at small Q^2

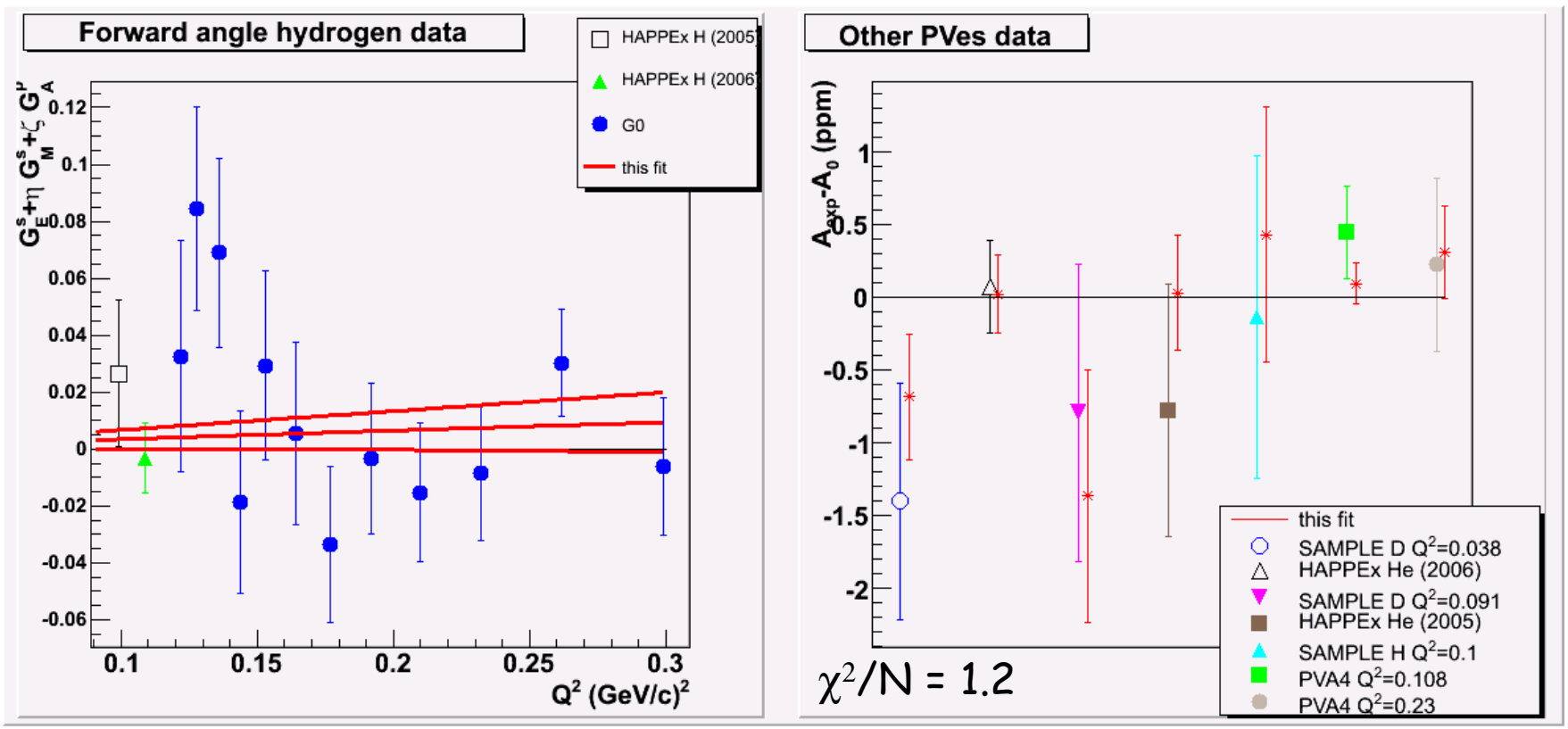
R. D. Young, JR, R. D. Carlini, and A. W. Thomas, nucl-ex/0604010

- uses published data up to $Q^2 \sim 0.3$ GeV^2 (for this talk also uses latest Happex)
- uses only data (no theory prediction for G^N_A)

$$A = A_0 + \eta_E\, G_E^s + \eta_M\, G_M^s + \eta_A^p\, G_A^p + \eta_A^n\, G_A^n$$

- parameterizes s-quark form factors with Taylor expansions at low Q^2

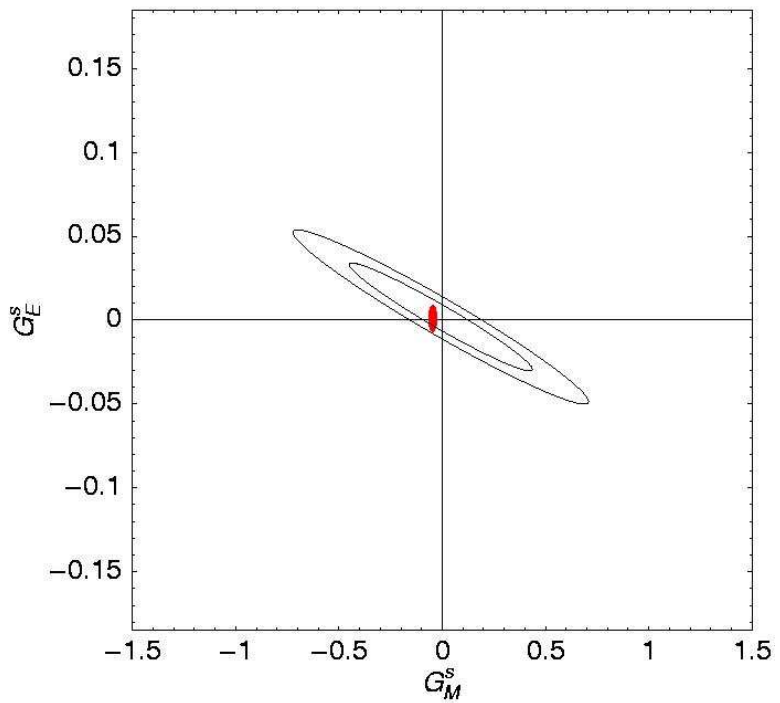
$$G_E^s = \rho_s Q^2 \qquad G_M^s = \mu_s \qquad G_A^N = g_A^N (1 + Q^2 / M_A^2)^{-2}$$

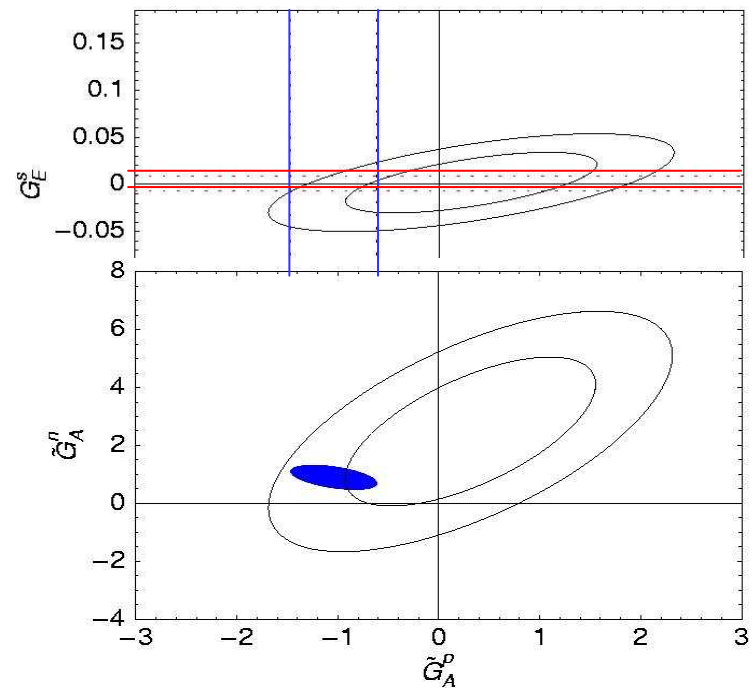


PVes global fit results

$$\rho_s = 0.02 \pm 0.21\ (GeV^{-2}) \quad \mu_s = 0.01 \pm 0.29 \quad g_A^p = 0.30 \pm 0.97 \quad g_A^n = 2.90 \pm 1.99$$

At Q^2 = 0.1 GeV^2





D.B. Leinweber *et al.* , PRL 94,212001 and hep-lat/0406002
Zhu *et al*, PRD 62 (2000) 033008

Note the large correlations between the extracted observables.

PVes global axial results

$$A_{measured} = A_0 + \eta_E G_E^s + \eta_M G_M^s + \eta_A^n G_A^n + \eta_A^p G_A^p$$

$$G_A^p = G_A^{T=0} + G_A^{T=1} \quad , \quad G_A^n = G_A^{T=0} - G_A^{T=1}$$

$$\rho_s = 0.02 \pm 0.21\ (GeV^{-2}) \quad \mu_s = 0.01 \pm 0.29 \quad g_A^p = 0.30 \pm 0.97 \quad g_A^n = 2.90 \pm 1.99$$

- now use Zhu et al. for as an additional data point for $G_A^{T=0}$

$$\rho_s = -0.10 \pm 0.19\ (GeV^{-2}) \quad \mu_s = 0.19 \pm 0.24 \quad g_A^p = 0.08 \pm 0.26 \quad g_A^n = 0.42 \pm 0.57$$

- now use Zhu at al. for as an additional data point for $G_A^{T=0}$ and for $G_A^{T=1}$

$$\rho_s = -0.15 \pm 0.18\ (GeV^{-2}) \quad \mu_s = 0.27 \pm 0.22 \quad g_A^p = 0.11 \pm 0.25 \quad g_A^n = 0.09 \pm 0.35$$

in agreement with what D. Armstrong just presented.

need more guidance on the axial form factors also
need more experimental data at backward angle

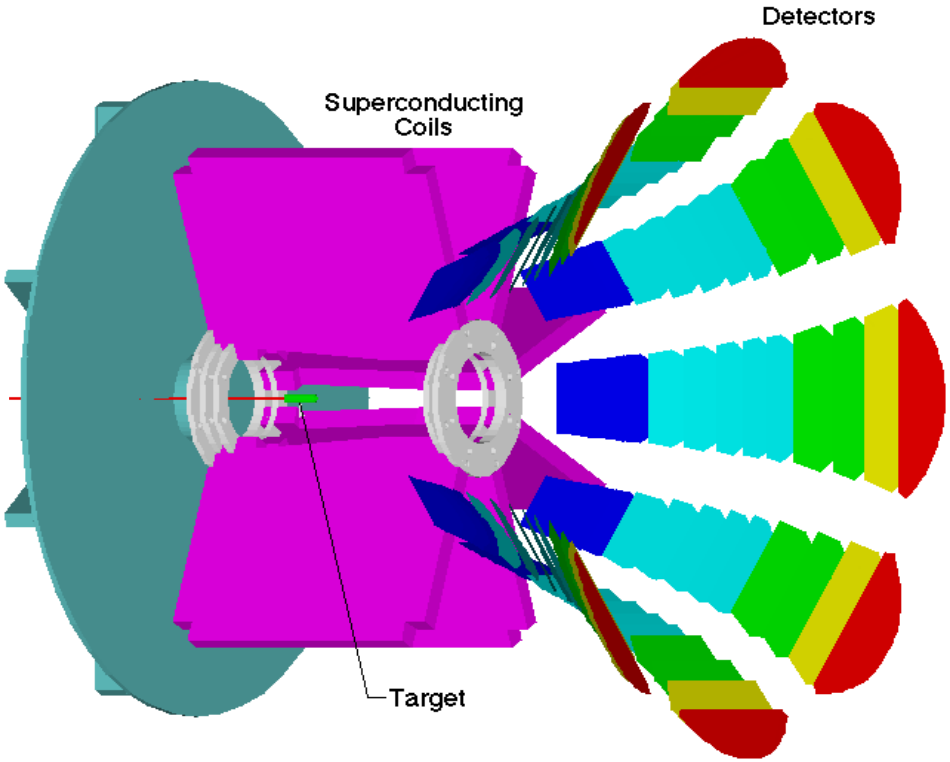
The G0 experiment

- Forward and backward angle PV e-p elastic and e-d (quasielastic) in JLab Hall C

G_E^s , G_M^s and G_A^e separated over range $Q^2 \sim 0.1-1.0\ (\mathrm{GeV/c})^2$

- superconducting toroidal magnet
- scattered particles detected in segmented scintillator arrays in spectrometer focal plane
- custom electronics count and process scattered particles

  (proton at forward angle and electrons at backward angle)



- *forward angle run completed*
- *backward angle → March 06 : February 07*

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The G0 Collaboration

College of William and Mary, Institut de Physique Nucléaire d'Orsay, Yerevan Physics Institute, Laboratoire de Physique Subatomique et de Cosmologie-Grenoble, University of Illinois, University of Maryland, Thomas Jefferson National Accelerator Facility, University of Manitoba, Carnegie Mellon University, California Institute of Technology, University of Kentucky, TRIUMF, Louisiana Tech University, Virginia Tech, University of Northern British Columbia, New Mexico State University, University of Winnipeg, Hampton University, [19]Grinnell College + Univ Zagreb (for backward angle runs)

U.S. G0 participation jointly supported by DOE and NSF. Significant additional contributions to G0 from NSERC (Canada), CNRS (FR), and our Armenian colleagues

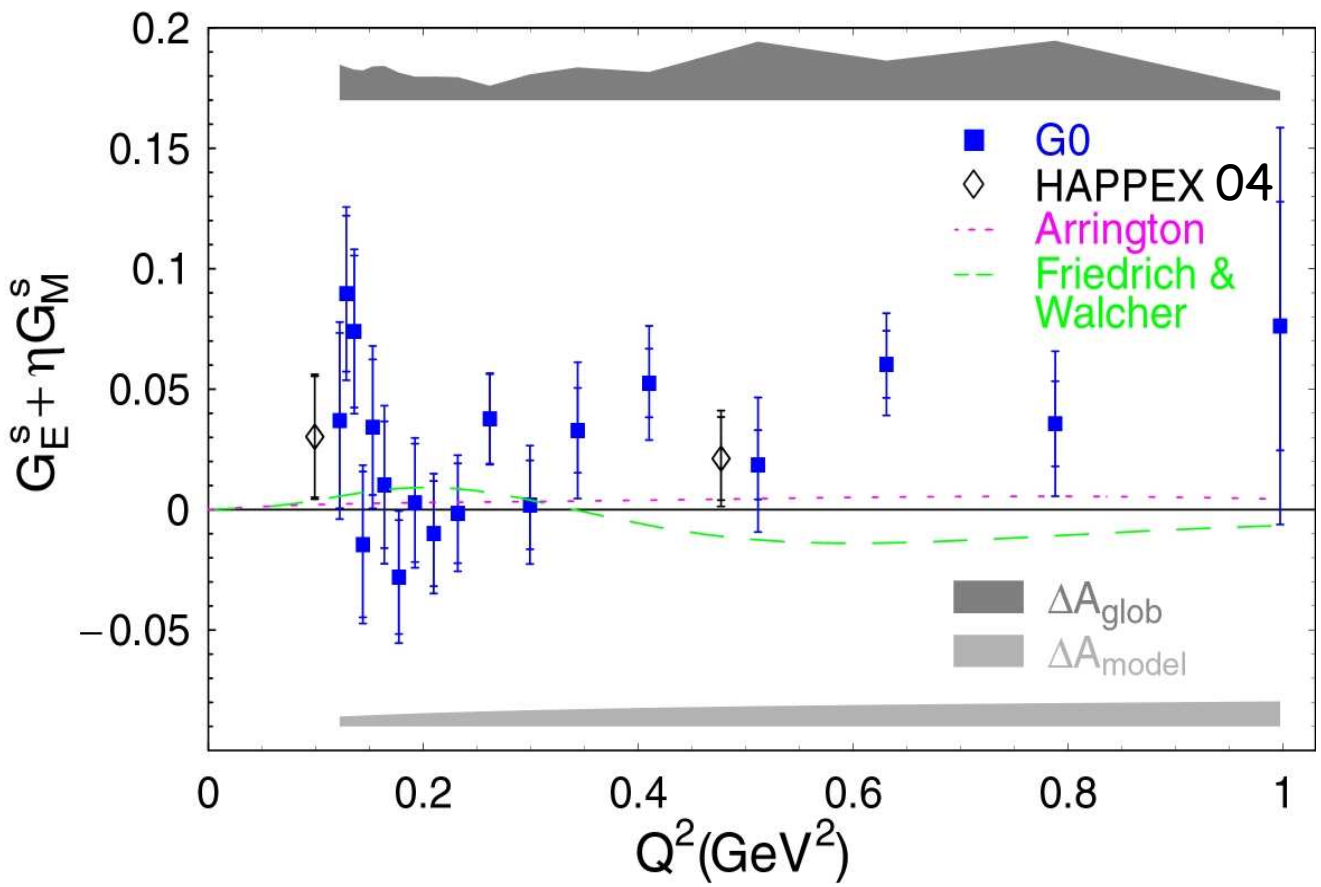
G0 Forward angle results

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

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

- Use the anapole contribution computed Zhu et al.
  Examining full data set, probability that $G_E^s + \eta G_M^s \neq 0$ is 89%

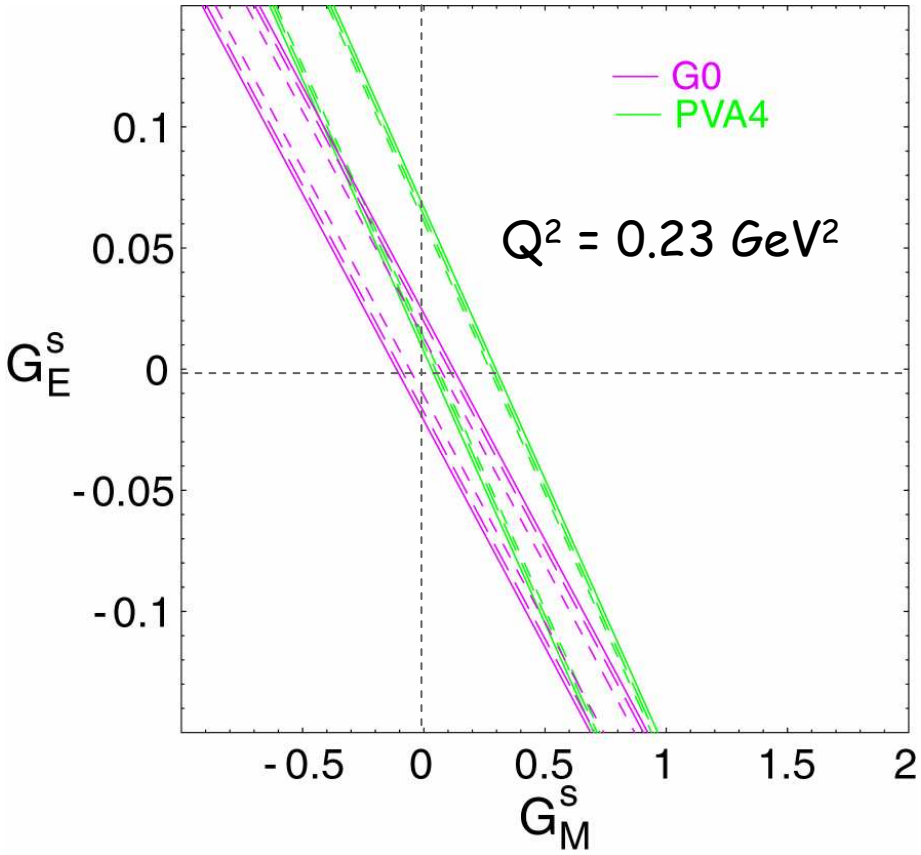
- EM form factors: J.J.Kelly, PRC **70**, 068202 (2004)

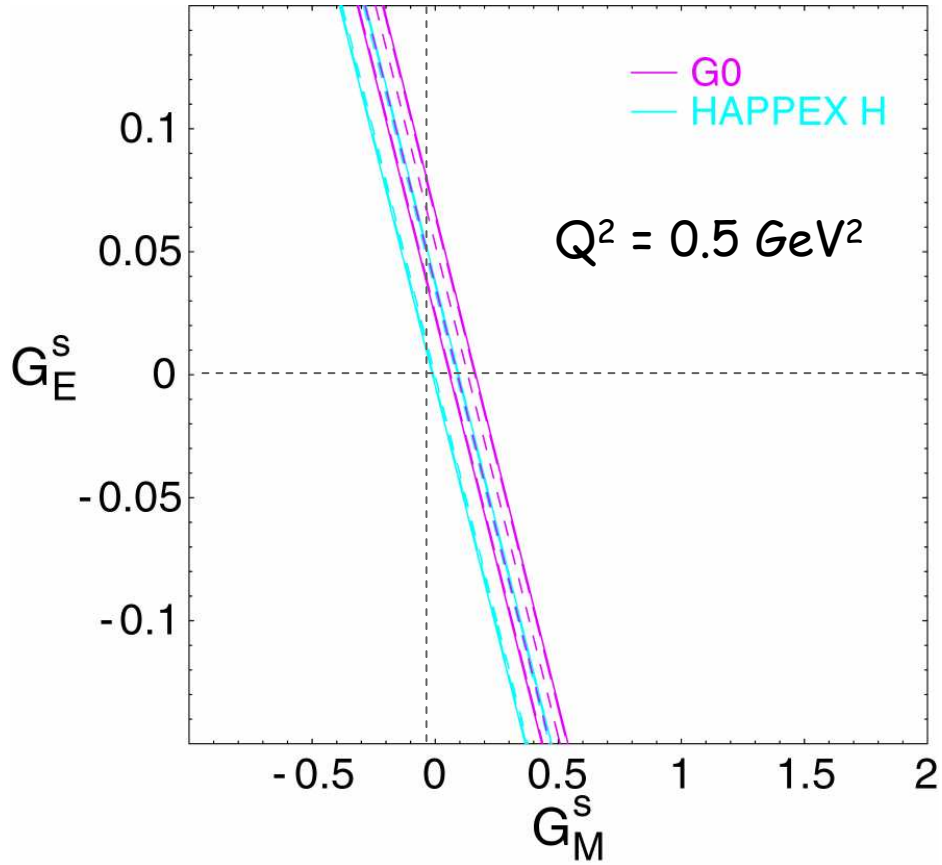


G0 Data compared with world data

The global fit at low Q^2 (including newest HAPPEx results) has already been discussed.

At high Q^2 :





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G0 Backward Angle

Electron detection: $\theta = 108°$

Both LH_2 and LD_2 targets

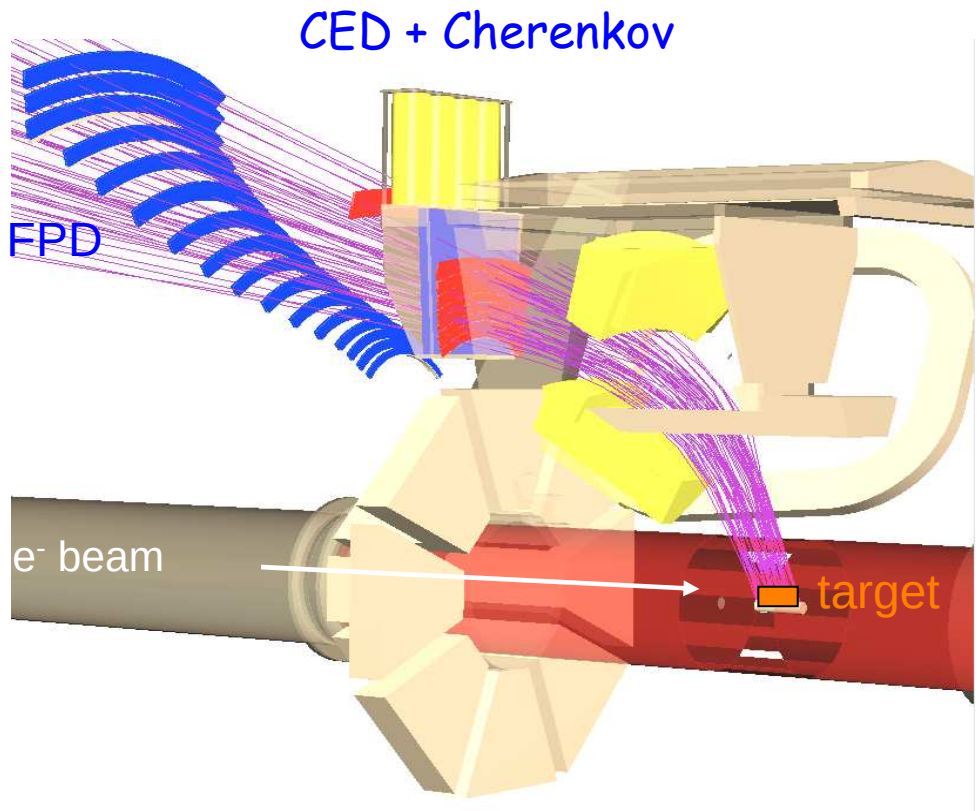
Add Cryostat Exit Detectors (CED) to define electron trajectory

1 scaler per channel FPD/CED pair

Aerogel Cerenkov detector for π/e separation ($p_\pi < 380$ MeV/c)

E_e (MeV)	Q^2 (GeV^2)
362	0.23
686	0.62

Common Q^2 with HAPPEX-III and PVA4



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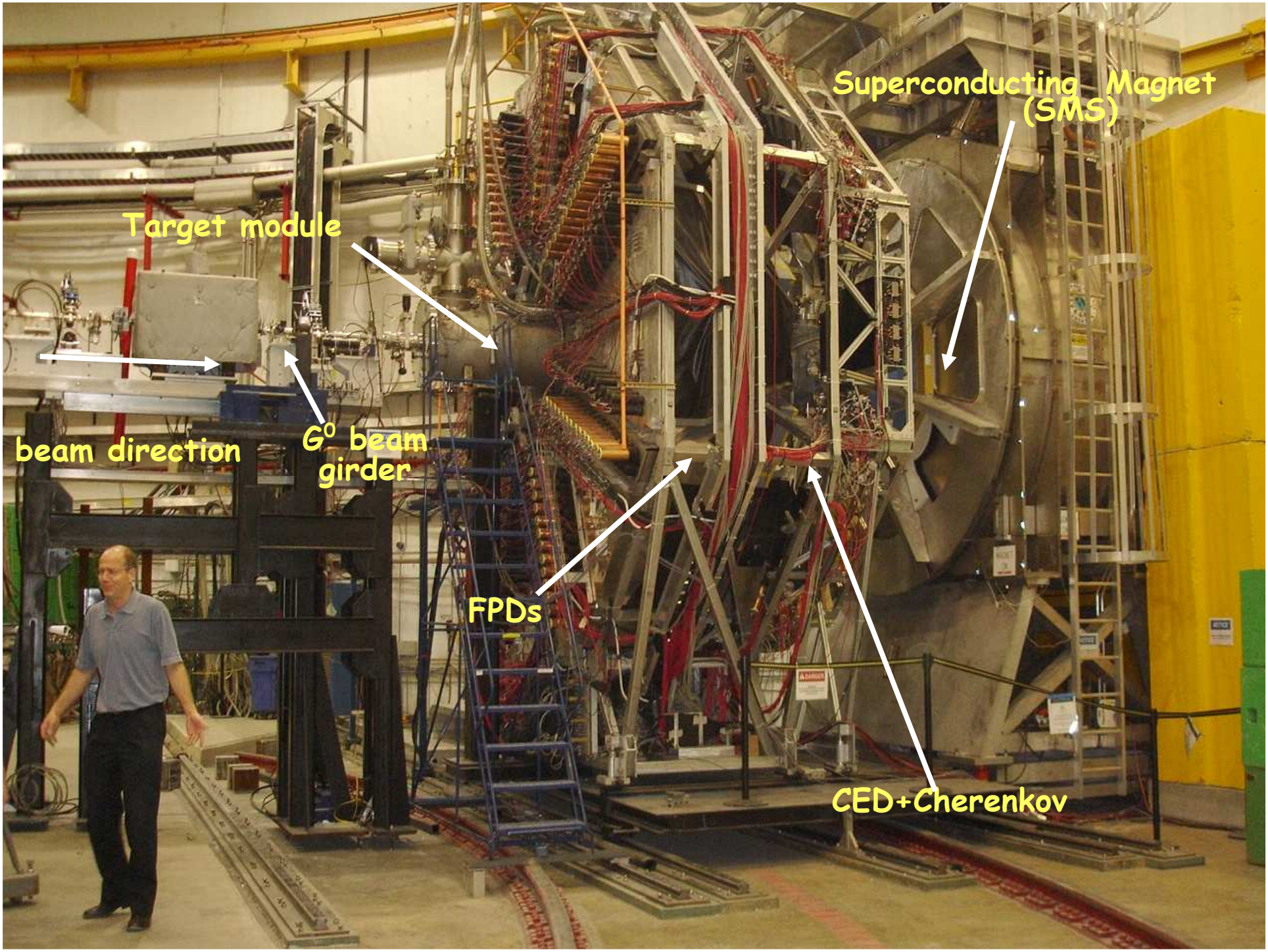

Superconducting Magnet (SMS)
Target module
beam direction
G^0 beam girder
FPDs
CED+Cherenkov

G0 first backward angle run

- March 15 – May 1 : 687 MeV
  - 200 hours LH_2, 50 hours LD_2 (at 10 μA)
  - 80 hours "parity quality" data w/ LH_2 at 60 μA
- May 15-18: 362 MeV
  - first look at LD_2 at low beam current
  - outstanding beam delivery
- July 19-Sept 1 (360 MeV) / Sept 22-Dec 22 (687 MeV) production

Synopsis from commissioning:

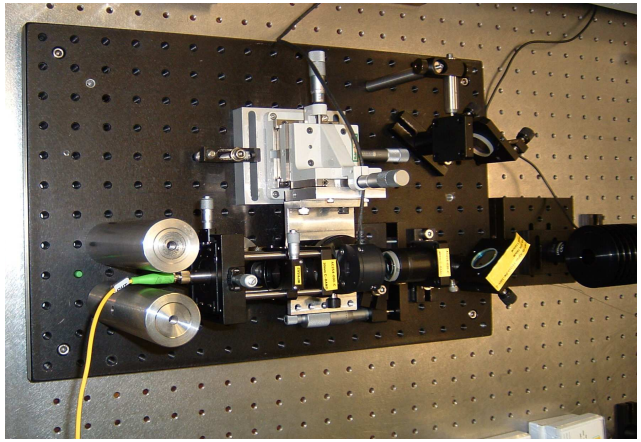
- (blinded) H elastic asymmetry near expected
- pion asymmetry smaller than elastic, same sign
- H → good elastic/inelastic electron separation
- coincidence rates not far from simulation
- D → high singles rates in Cerenkov PM tubes, improvements under study (we think it's neutrons…)

Polarized Beam Performance (687 MeV)

Polarized source: superlattice GaAs w/ new "Fiber" laser

Beam polarization 85%

Moeller modified to accommodate lower beam energy



Helicity Correlated Beam properties

Beam Param.	Achieved in G^0 (IN-OUT)	Specs
Charge asym.	-0.4 ± 0.24 ppm	2 ppm
X-Y position diff.	20-24 ± 5 nm	40 nm
X-Y angle diff.	-2 to -4 ± 2 nrad	4 nrad
Energy diff.	2 ± 4 eV	30 eV

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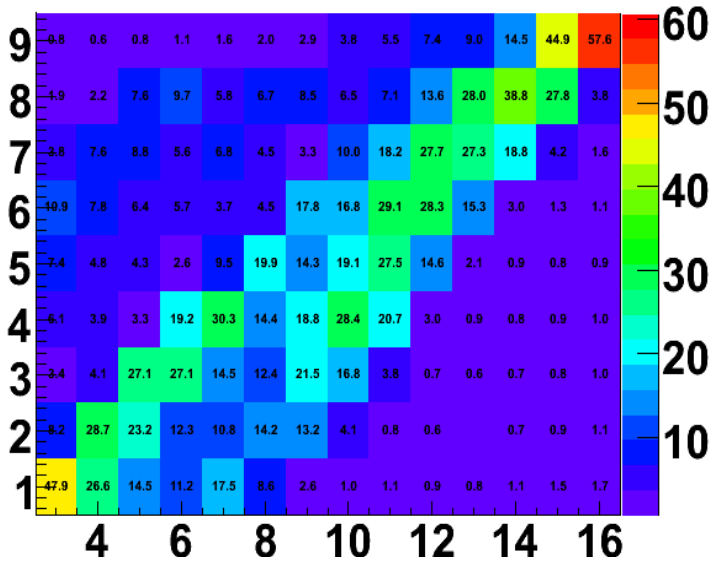
Particle ID : CED-FPD plane (687MeV)

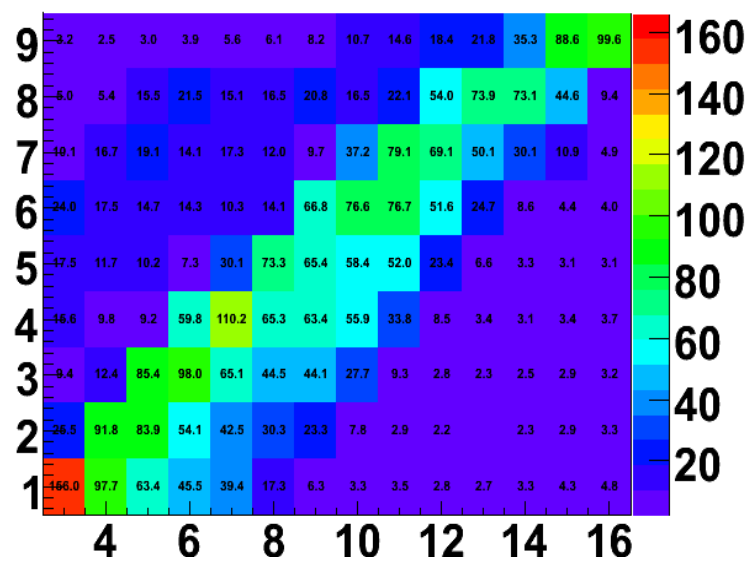
(rates in Hz/μA per octant)

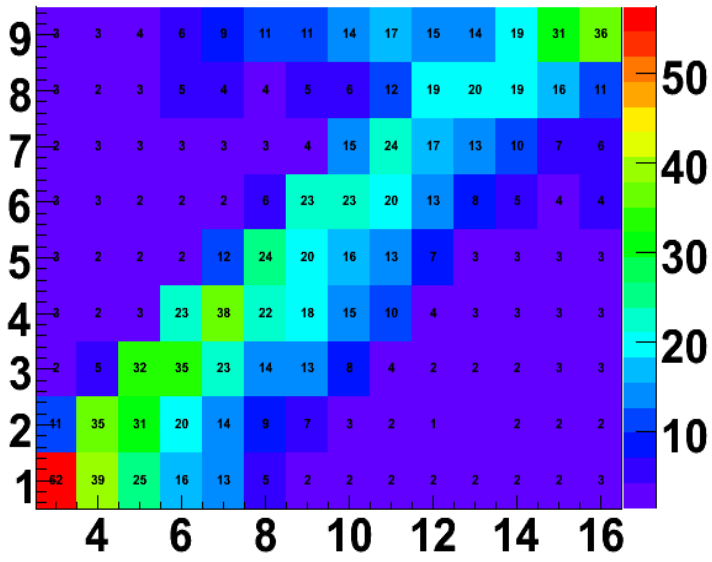
LH_2



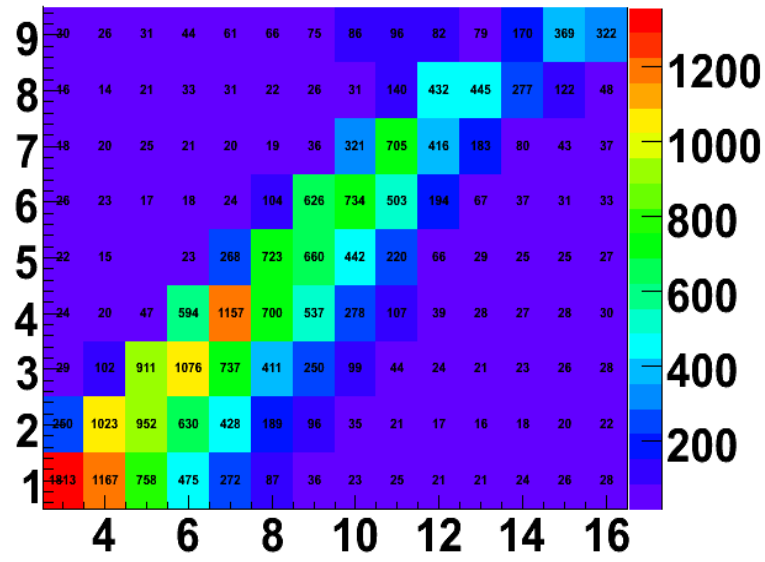
Electrons
(Cerenkov Trigger)

LD_2

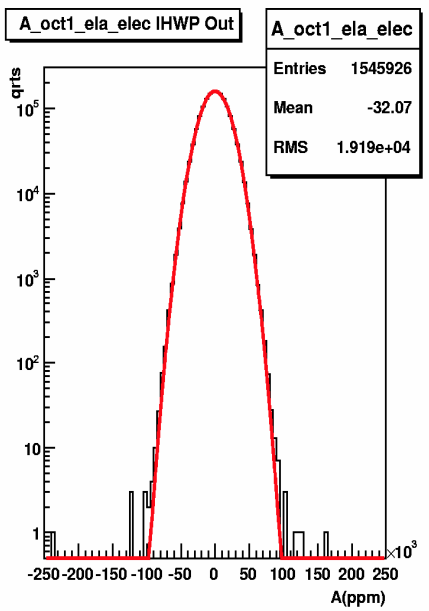


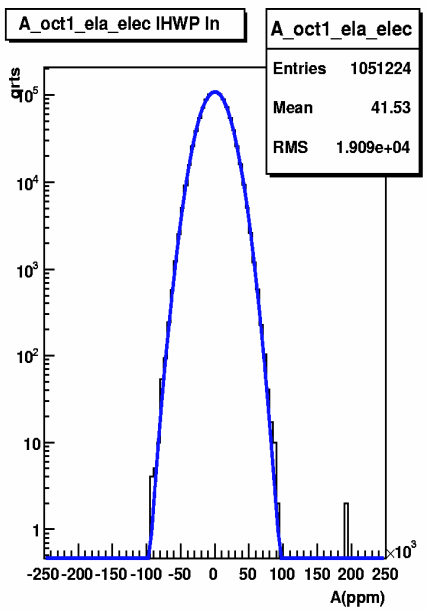


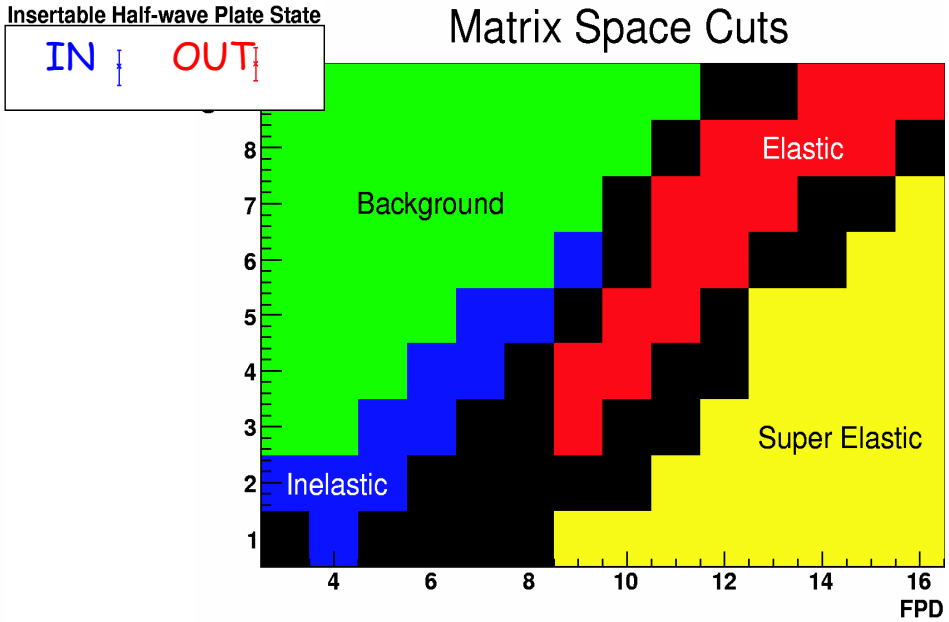
Pions
(no Cerenkov Trigger)

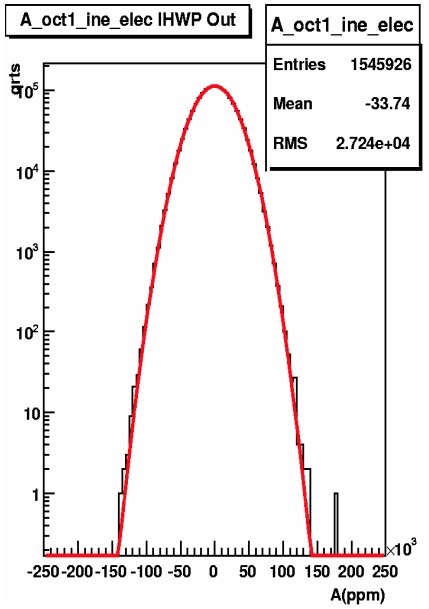


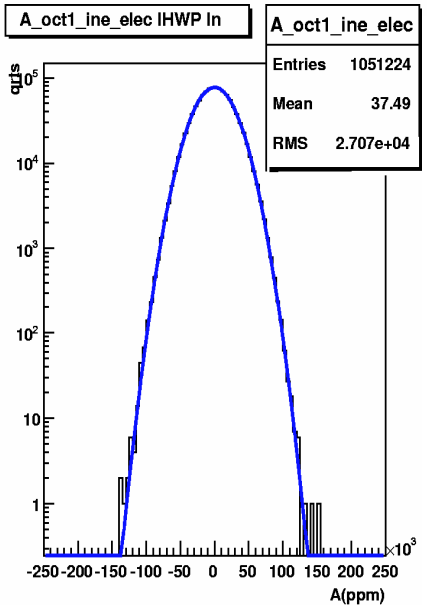
Asymmetries : Electron and LH_2 target (687 MeV)

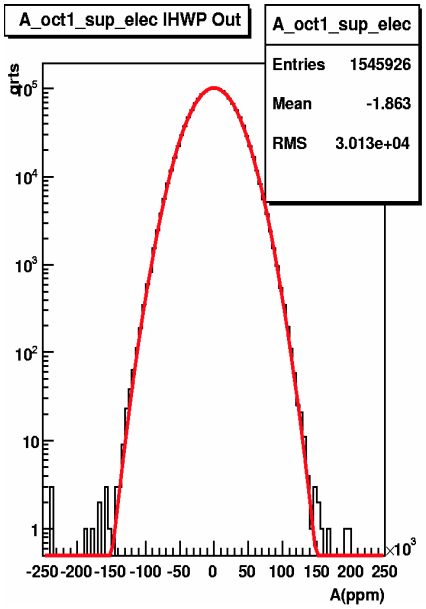


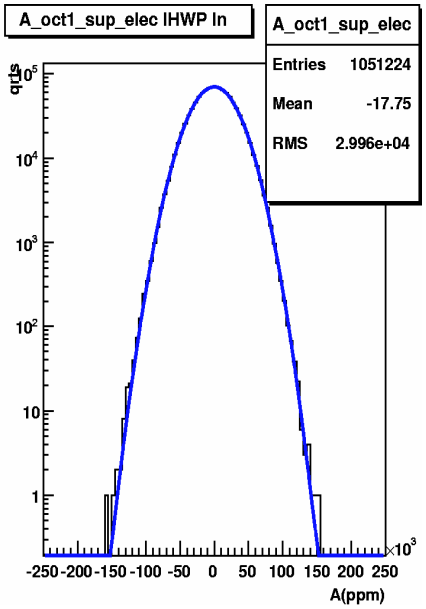












Asymmetries : background and dilution factors (687 MeV)

$$N = N_{el} + N_b = N_{el} + (N_b^e + N_b^\pi)$$

$$A_{meas}^e = \frac{N_{el}}{N} A_{el}^e + \frac{N_b^e}{N} A_b^e + \frac{N_b^\pi}{N} A_b^\pi$$

$\frac{N_{el}}{N}$	Magnet excitation scan Additional wire chambers	90%
$\frac{N_b^\pi}{N}$	31 MHz beam repetition rate	π rejection factor ~ 150 electron efficiency ~75%
A_b^π	Dedicated parallel electronic	-11 +/- 10 ppm
A_b^e	Fit the data over the whole matrix	-22 +/- 10 ppm
A_{meas}^e		-35 +/- 5 ppm

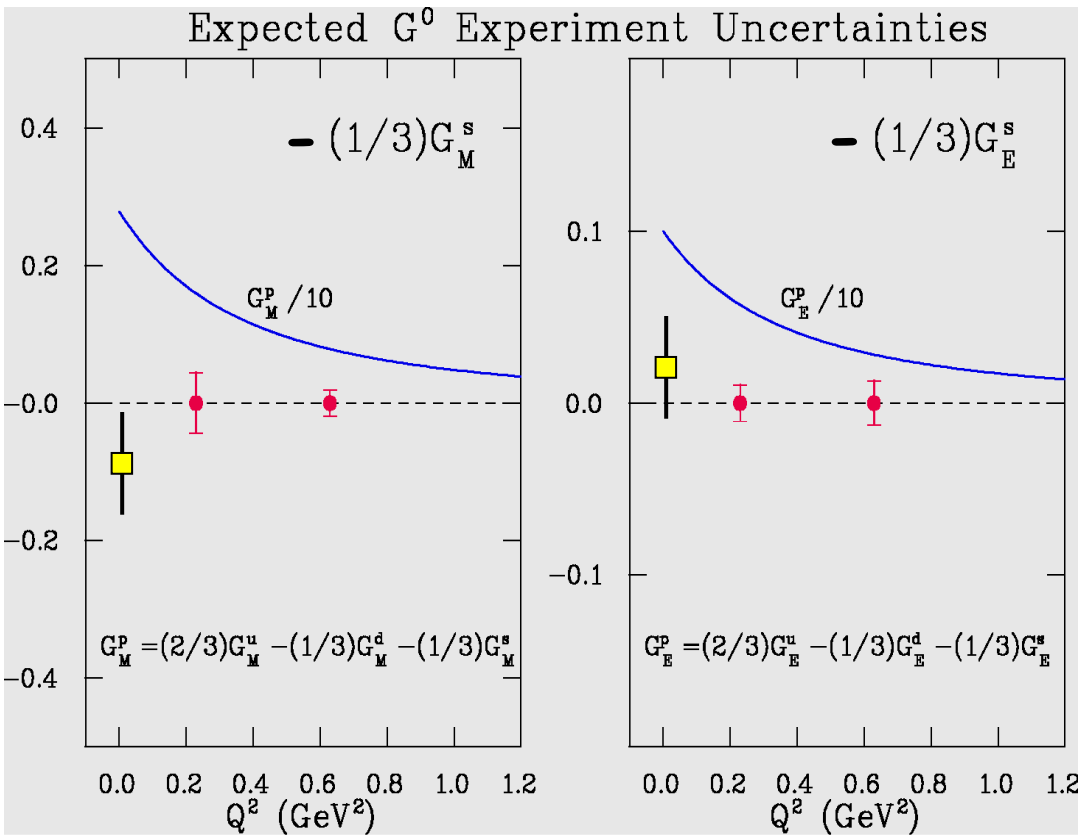
!! Preliminary !!
80 h of date at 687 MeV on LH2 case
elastic region

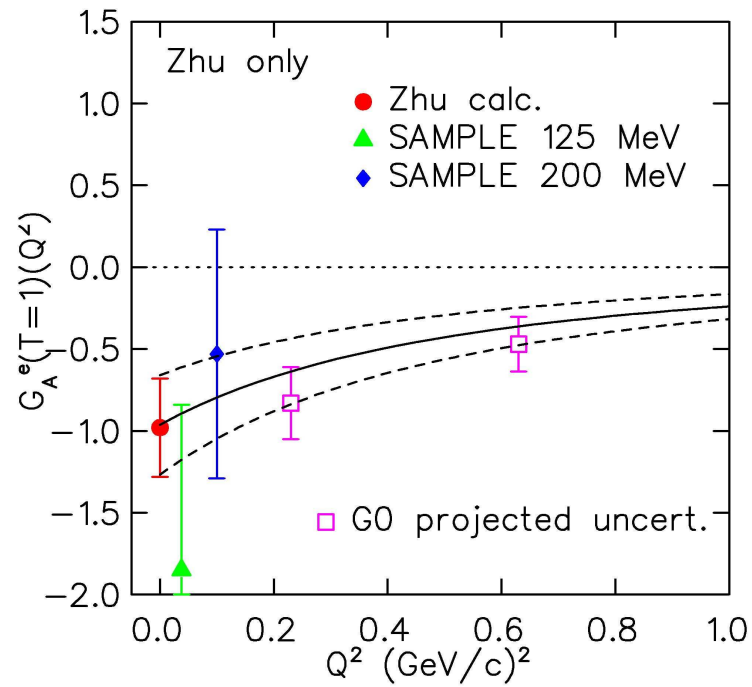
asymmetries blinded

Outlook

- Measurement of strange form factor at Q^2= 0.23 and 0.62 GeV^2 combining LH2 forward and backward data with LD2 backward
- Forward angle data published
- Backward data taking going on at this very minute and up to next year

- **Proposed precision** (using $G_A^{e(T=0)}$ from Zhu et al., pending on solving Cerenkov single rate issues : we are optimistic)





world fit '06

backup

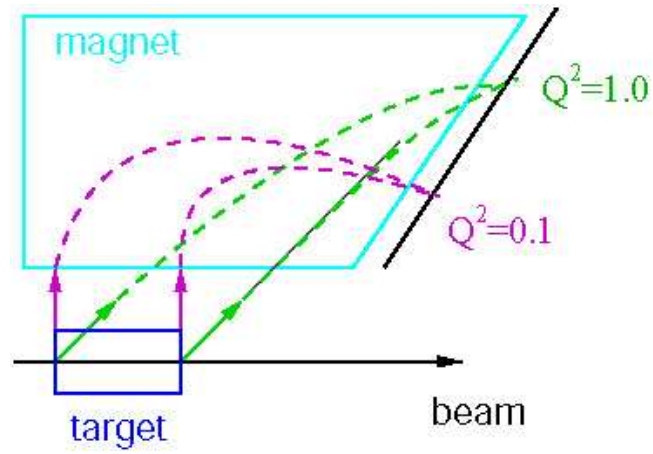
G0 Forward Detection Scheme

Detect scattered Protons

Magnet sorts protons by Q^2 at one setting

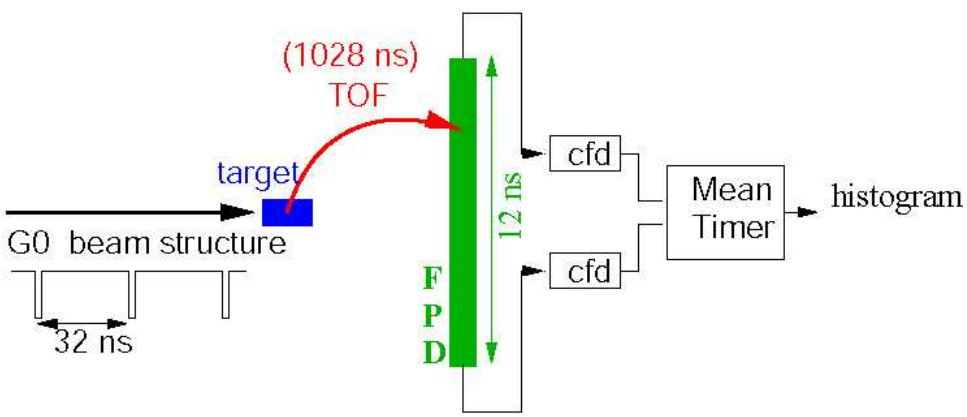
Beam bunches 32 nsec apart

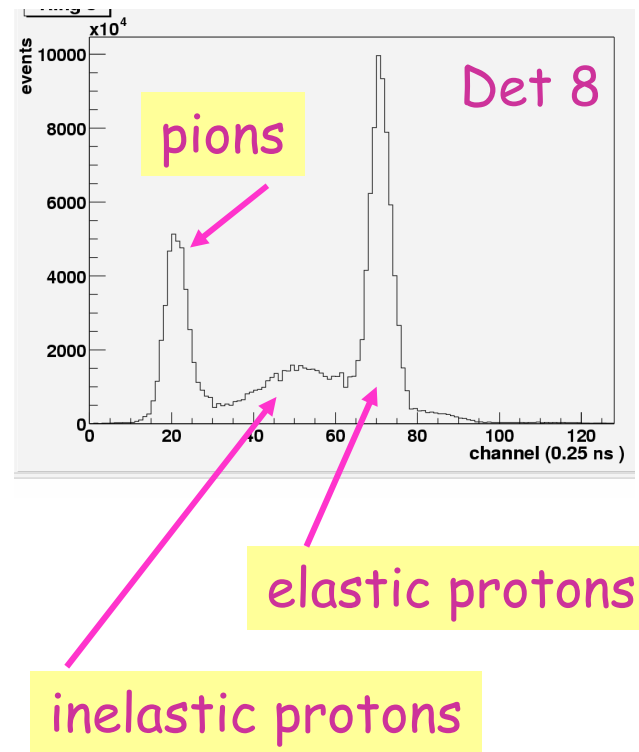
Flight time separates p and π^+



Beam spin flipped every 30 ms: + − − +

$$A = \frac{Y_1 + Y_4 - Y_2 - Y_3}{\sum Y_i}$$





G0 Forward angle analysis

Raw asymmetries (~ 4 to -13 ppm)

Source	Correction & uncertainties
deadtime	$\Delta A \approx 0.05 \pm 0.05\, ppm$
Helicity-correlated beam properties	$\Delta A \approx 0.02 \pm 0.01\, ppm$
Leakage beam	$\Delta A \approx 0.71 \pm 0.14\, ppm$
Beam polarization	$P_e = (73.7 \pm 1.0)\%$
Background (asym. & dil)	$\Delta A = (-1 \rightarrow 42) \pm (0.2 \rightarrow 9)\ ppm$

A_{phys}

Q^2 from simulation

EM form factors + Axial form factors

$A_{NVS} = A_0 + \eta_A^p G_A^p$

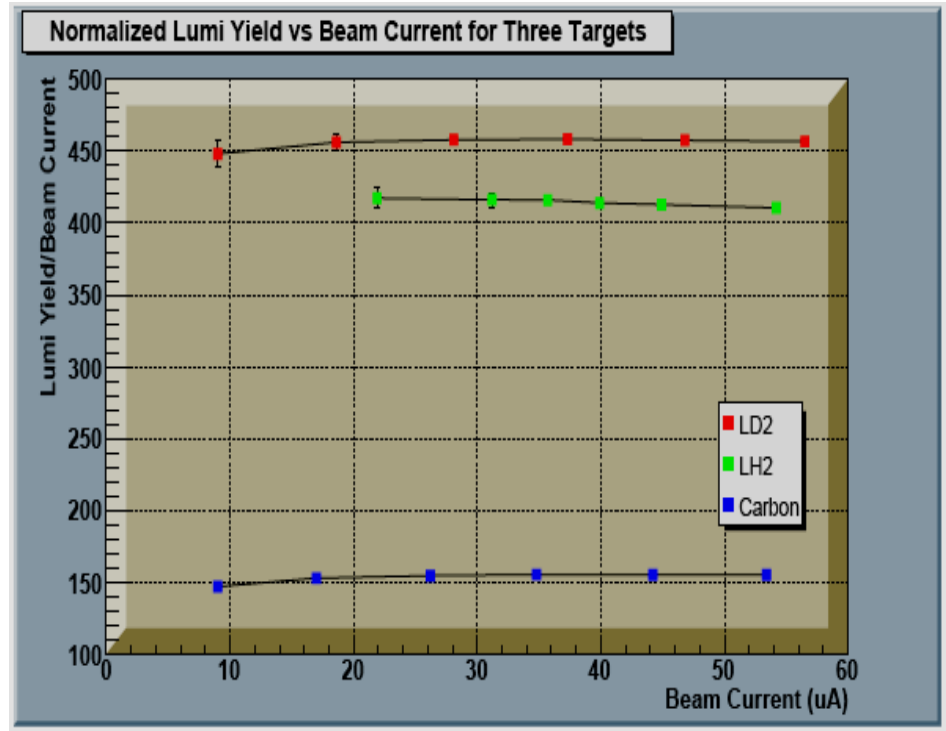
$G_E^s + \eta G_M^s$

Target and Luminosity Monitors

LH_2 and LD_2 tested up to 60 μA

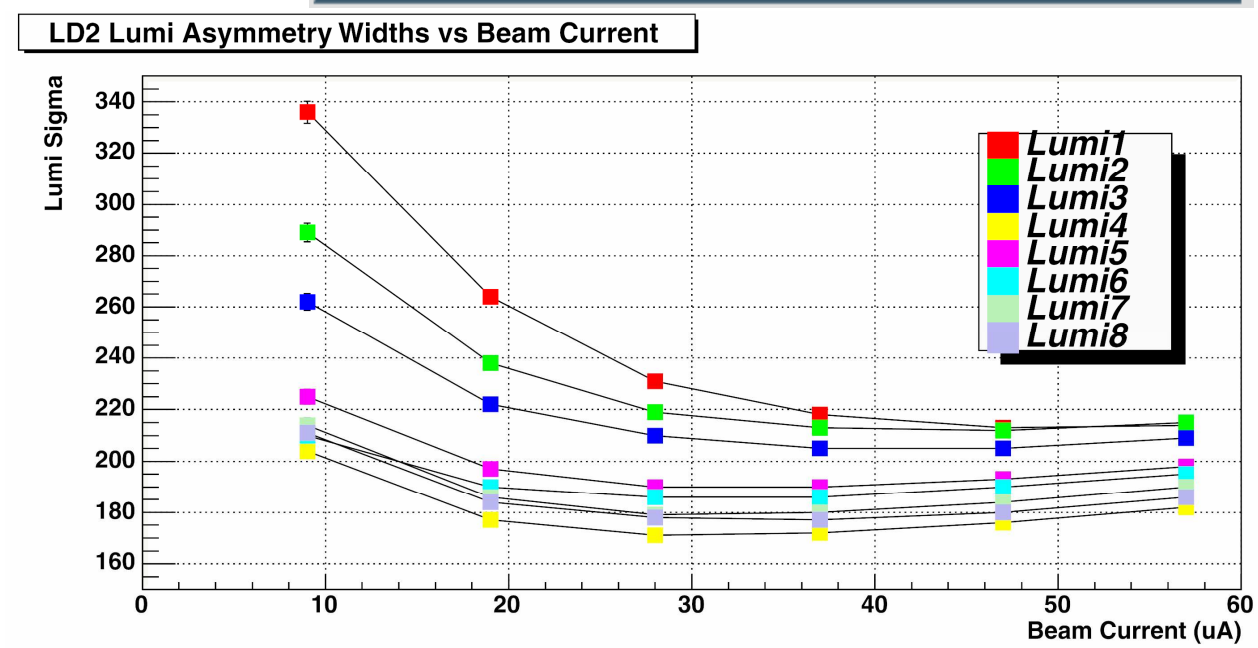
Very linear rate behavior

Ratio LD_2:LH_2:^{12}C as expected

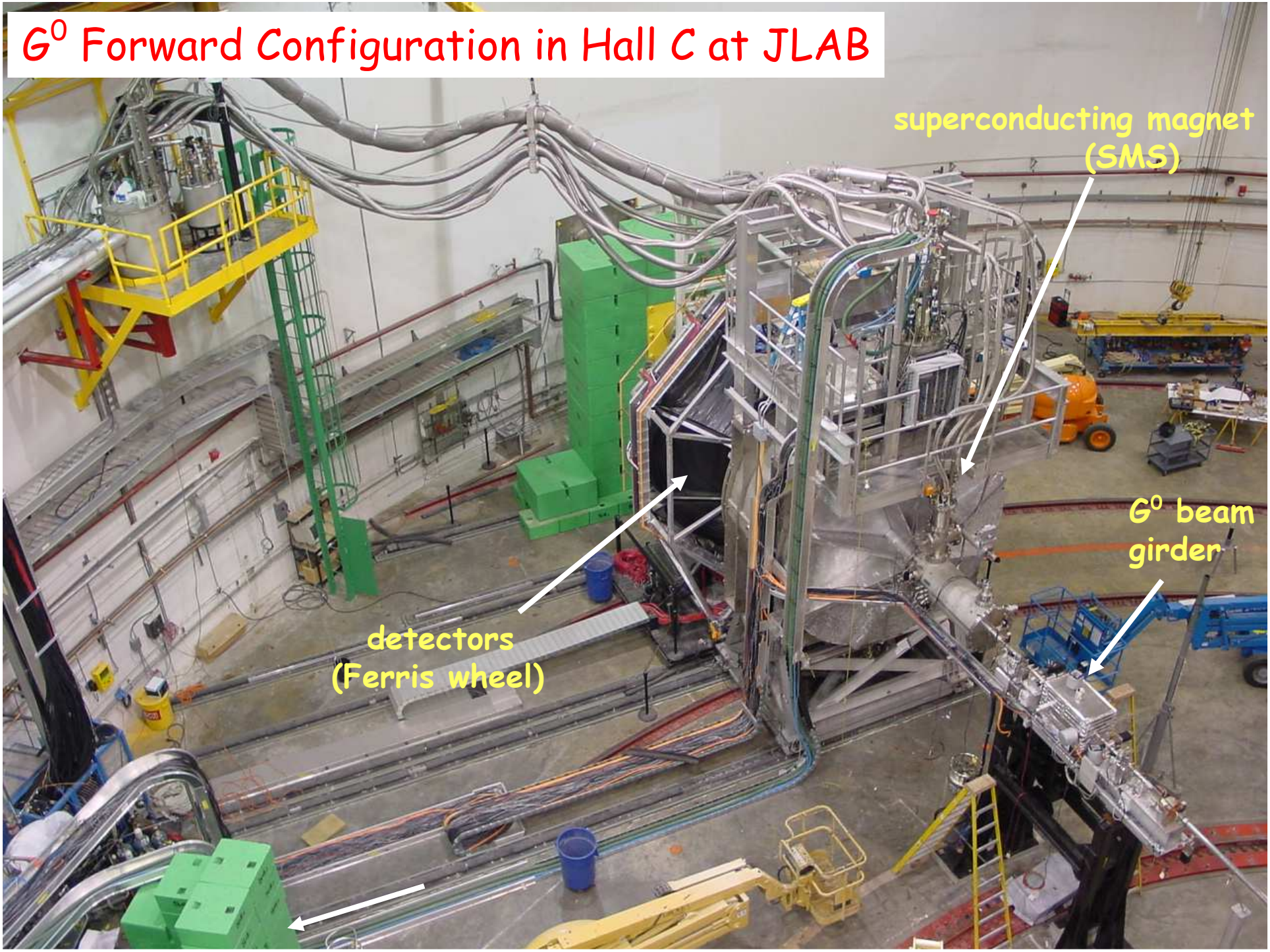


Typical LUMI asymmetry width 250 ppm -- 25 times better statistics than all detector octants combined

"boiling" contribution negligible



G^0 Forward Configuration in Hall C at JLAB



"Rosenbluth" type of separation (4 parameters)

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = A_0 + \eta_E G_E^s + \eta_M G_M^s + \eta_A^p G_A^p + \eta_A^n G_A^n$$

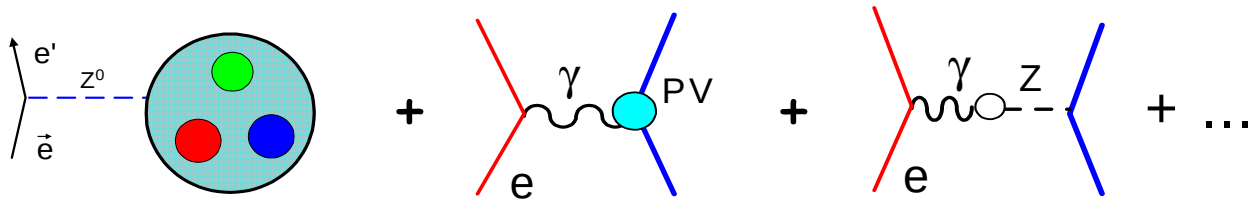
Vary both the targets (LH2, LD2, ^{4}He) and the kinematics

(selected) World data at $Q^2 \sim 0.1$ GeV^2

Exp	Target	E_{beam} (GeV)	Θ_e (deg)	A_o (ppm)	η_E (ppm)	η_M (ppm)	η^p_A (ppm)	η^n_A (ppm)
SAMPLE	D	0.2	150	-7	1.6	0.8	1.0	-0.7
SAMPLE	H	0.2	150	-5	2.1	3.5	1.6	0
HAPPEx	^{4}He	3	6	7	20.0	0	0	0
PVA4	H	0.6	35	-2	10.1	1.0	0.3	0
G0	H	3	6	-2	12.0	1.2	0.1	0

Observables in PVes (cont.)

- Axial form factor seen by PV electron scattering



$$G_A^N = \tau_3 \xi_A^{T=1} G_A + \xi_A^{T=0} a_8 + \xi_A^0 a_s + \tau_3 A_{ana}^{(T=1)} + A_{ana}^{(T=0)}$$

+1 for the proton
-1 for the neutron

- Deuterium target (quasi-elastic scattering)

$$A_d = \frac{\sigma_p A_p + \sigma_n A_n}{\sigma_d} = A_0 + \eta_E G_E^s + \eta_M G_M^s + \eta_A^n G_A^n + \eta_A^p G_A^p$$

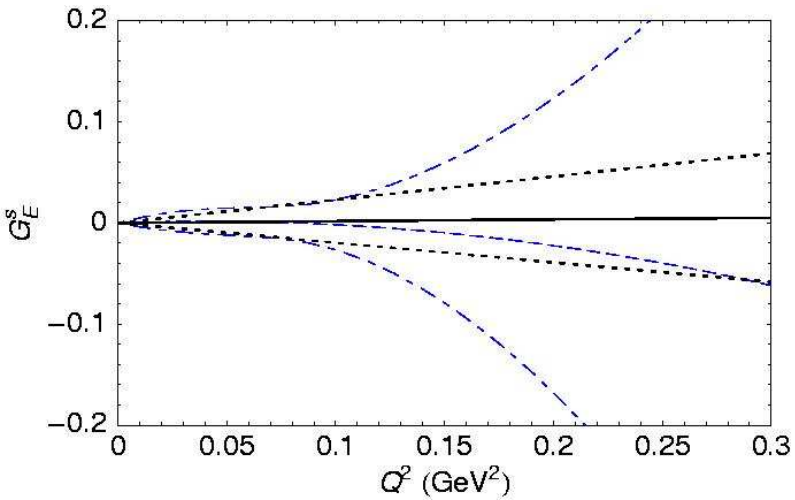
Zhu *et al*, PRD 62 (2000) 033008

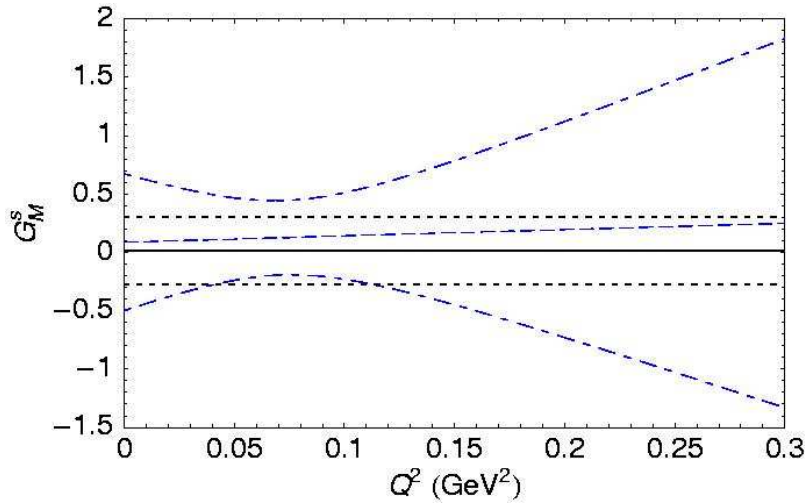
$$A_{ana}^{(T=0)} = 0.02 \pm 0.26 \qquad A_{ana}^{(T=1)} = -0.11 \pm 0.44$$

Sample experiment (LD2+LH2 at backward angle)
assumed $A_{ana}^{(T=0)}$ and found $A_{ana}^{(T=1)}$ in good agreement with their data.

A global fit of the world PVes data at small Q^2 (cont.)

- <u>Q^2 evolution below 0.3 GeV^2</u>
  from the data : no need so far for higher order terms
  (but we tried it)





- <u>high Q^2 data (larger than 0.3 GeV^2)</u> : HAPPEx, PVA4, G0
  - all of them at "forward" angle.
  - realistic limit of the break down of the Q^2 expansion ?
  - the evolution of the axial terms (anapole and others) as a function of Q^2 is unknown (S. Pate et al. , PRL 92, 082002 (2004))

need large Q^2 data at backward angle