The G^0 experiment @ Jefferson Lab.

Measurement of the weak neutral form factors of the nucleon

G^0 Collaboration :

Caltech, Carnegie-Mellon, William&Mary, Hampton, IPN-Orsay, LPSC-Grenoble, JLab, Kentucky, LaTech, NMSU, TRIUMF, U Con, UIUC, U Manitoba, U Maryland, U Mass, UNBC, VPI, Yerevan

Physics case

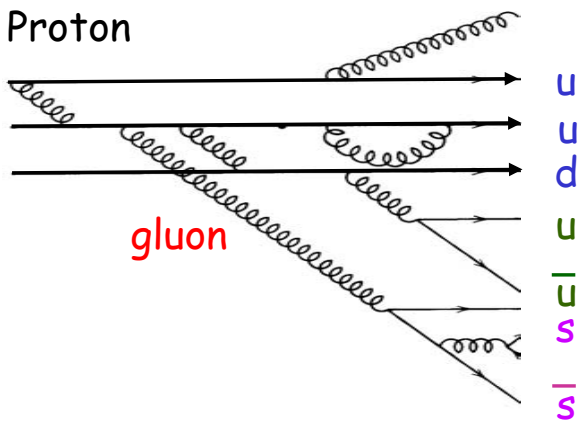
Experimental set-up

Analysis in the Forward Angle configuration.

Summary and outlook

C. Furget for the G0 collab., Grőningen, August 2004

Physics motivation



What role do strange quarks play in nucleon properties ?

Momentum: $\int_0^1 x(s+\bar{s})dx \sim 4\%$ (DIS)

Spin: $< N | \bar{s}\gamma^5 s | N > \sim -10\%$ (polarized DIS)

Mass: $< N | \bar{s}s | N > \sim 30\%$ (πN σ - 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

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

Also Q^2 dependence is required

The axial form factor G_A^e also measured

Nucleon form factors in elastic e-N scattering

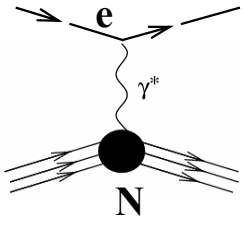
Flavor decomposition of the electric and magnetic nucleon form factors

Proton and Neutron Electromagnetic Form Factors :

Measured with precision of 2 – 4 %
in the 0.1 – 1 GeV^2 Q^2 range

$$G_{E,M}^{\gamma,p} = \frac{2}{3}G_{E,M}^{u,p} - \frac{1}{3}G_{E,M}^{d,p} - \frac{1}{3}G_{E,M}^{s,p}$$

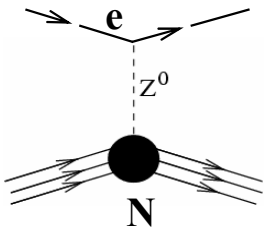
$$G_{E,M}^{\gamma,n} = \frac{2}{3}G_{E,M}^{u,n} - \frac{1}{3}G_{E,M}^{d,n} - \frac{1}{3}G_{E,M}^{s,n}$$



Proton Weak Form Factors :

Projected precision of ~ 10 %
in the 0.1 – 1 GeV^2 Q2 range

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



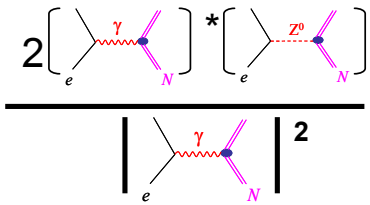
+ proton-neutron charge symmetry → 3 unknowns and 3 equations

Extraction of the strange quarks contribution :

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

Parity violation asymmetry

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



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

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 = 0.3, 0.5 and 0.8 $(GeV/c)^2$

-Forward Angle configuration : LH_2 measurement for $0.1 < Q^2 < 1$ $(GeV/c)^2$

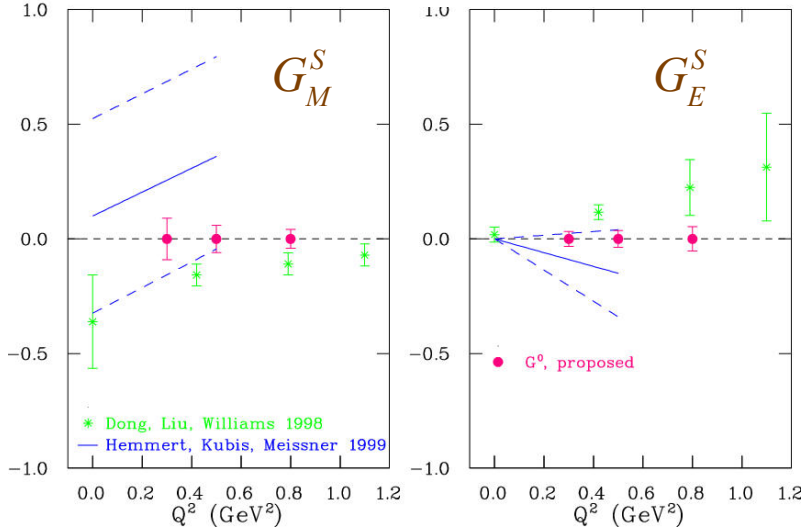
→ detect recoil protons at ~70° (electron angles 7 – 15°)

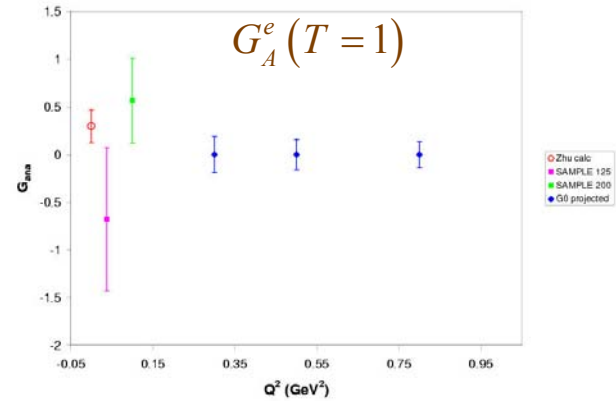
-Backward Angle configuration : LH_2 (elastic) and LD_2 (quasi-elastic) measurements for three Q^2 values

→ detect electrons at ~110°

G0 expected results

Electric, magnetic and axial form factors in e-N elastic scattering





Other experiments (see F. Maas talk) :

HAPPEX, PVA4

$\alpha \; G_E^s + \beta \; G_M^s$

SAMPLE :

$\alpha \; G_M^s + \beta \; G_A^e$

Other aspects of G0 program :

- Q^2 dependence of the N-Δ axial transition form factor (Backward angle configuration)
- Transverse spin asymmetry sensitive to the imaginary part of 2γ exchange amplitude

4 forward angle meas. at beam energy of 3 GeV & 3 backward angles at 130 °

General requirements

Measurement of A_{PV} ~ -3 to -40 ppm with precision $\delta A_{PV} / A_{PV}$ ~ 5%
AND separation of G_E^s and G_M^s

Statistics (need 10^{13} - 10^{14} events):

- Reliable high polarization, high current polarized electron source

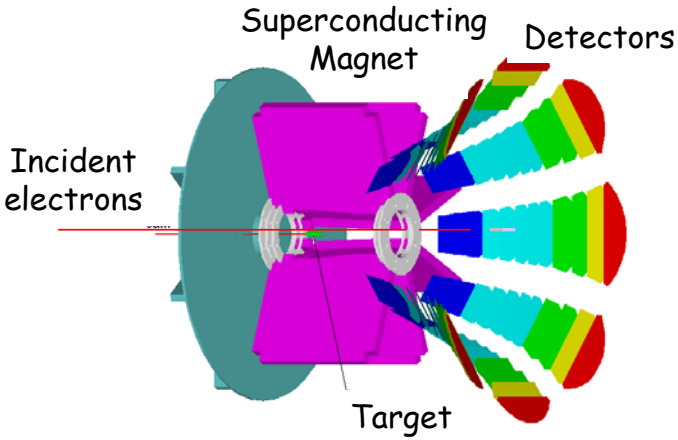
  (P_e ~ 80%, I = 40 μA, d_{target} = 20 cm, L = 2.1 ×10^{38} cm^{-2} s^{-1})
- Large acceptance detector
- High count rate capability detectors/electronics (~ 2 MHz)

Systematics (need to reduce false asymmetries):

- Small helicity-correlated beam properties
- Capability to isolate elastic scattering from other processes

  (TOF, particle trajectory, PID)

G0 Forward angle configuration

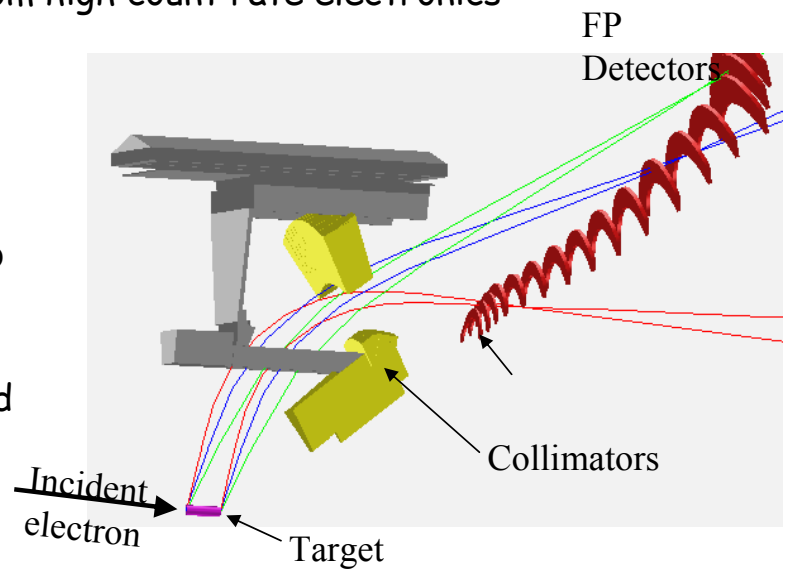


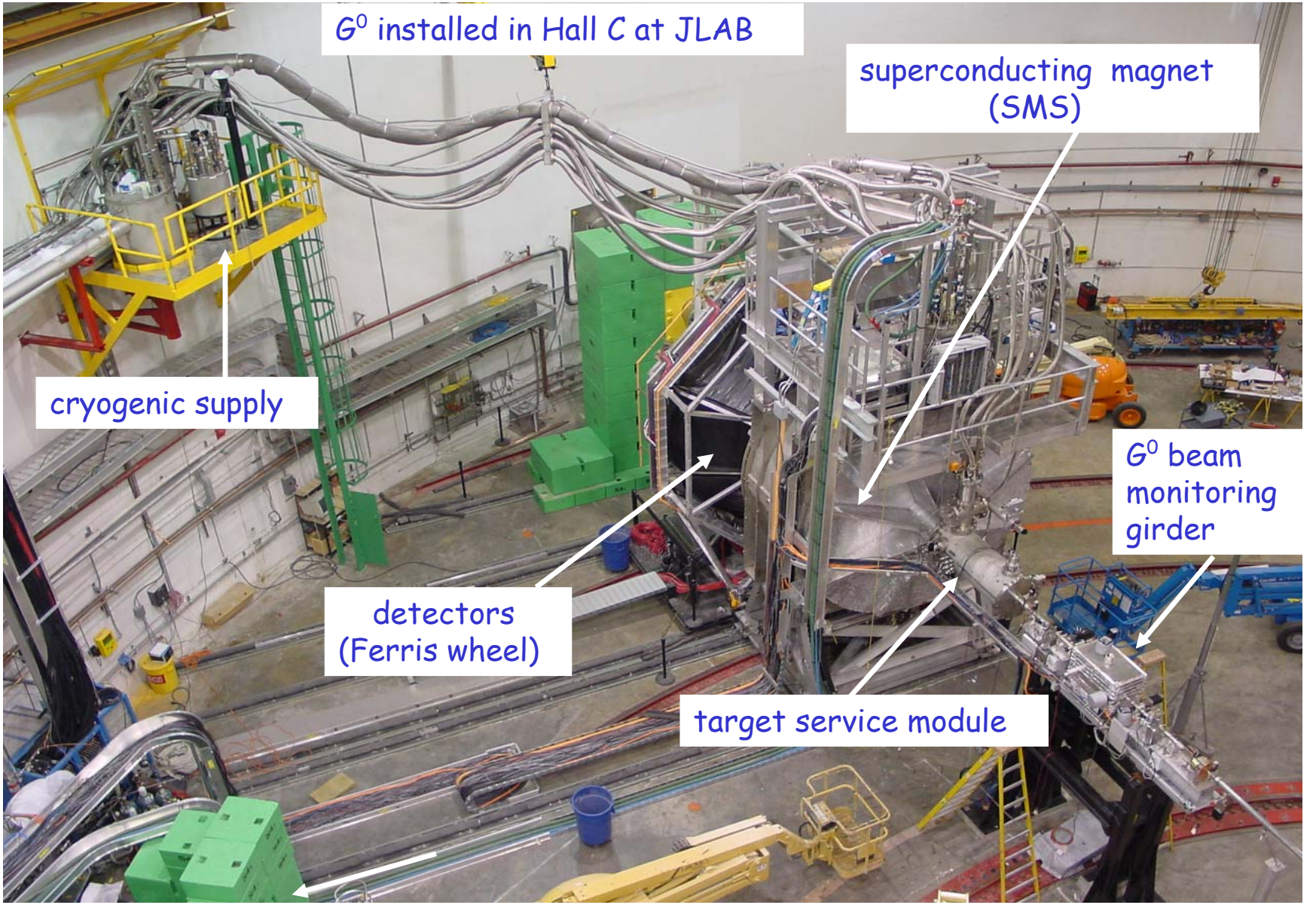
Main components:

- Jefferson Lab polarized source & CEBAF accelerator
- Superconducting toroidal magnet
- High power liquid H_2 /D_2 target
- Large acceptance scintillation detector array
- Custom high count rate electronics

G0 Forward angle configuration

- Recoil protons detected through a toroidal magnetic field and 16 Focal plane detectors (FPD) to sort protons by Q^2 in 0.1 – 1 GeV^2 range.
- Field and collimators used to stop (γ, **n**) background
- Time of flight discrimination between elastic and inelastic processes




G⁰ installed in Hall C at JLAB
superconducting magnet (SMS)
cryogenic supply
G⁰ beam monitoring girder
detectors (Ferris wheel)
target service module

Helicity correlated beam properties

Requirement for helicity-correlated beam parameters P_i

- Keep ΔP_i small so individual run-averaged corrections < $\Delta A_{stat} \sim 10^{-7}$

- Measure ΔP_i accurately so the error on the correction < 5% $\Delta A_{stat} \sim 5\times10^{-9}$

→ Use of beam feedback system (intensity attenuator cell and piezo-electric mirror) to modulate the laser intensity and position at the cathode in a helicity-correlated manner.

Beam Parameter	**Achieved (IN-OUT)**	**"Specs"**
Charge asym.	-0.28 ± 0.28 ppm	1 ppm
x position diff.	6 ± 4 nm	20 nm
y position diff.	8 ± 4 nm	20 nm
x angle diff.	2 ± 0.3 nrad	2 nrad
y angle diff.	3 ± 0.5 nrad	2 nrad
Energy diff.	58 ± 4 eV	75 eV

744 hours (103 Coulombs) of parity quality beam

Parameter	False asymmetry
Charge	10^{-8}
Position	10^{-9}
Angle	10^{-8} to 10^{-9}
Energy	10^{-9}

Results :

-All parity quality Specs achieved

- Total false asymmetry from beam parameters of the order of 10^{-8}

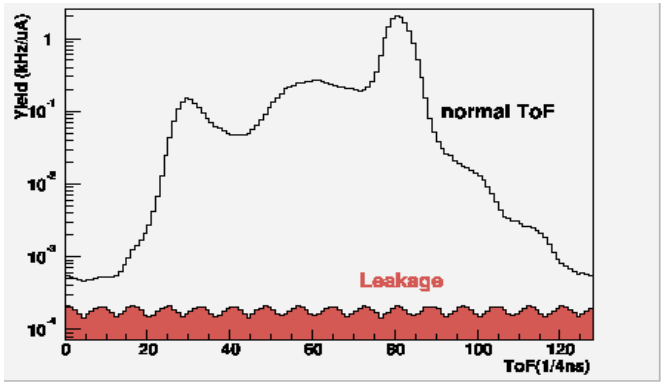
Beam leakage corrections

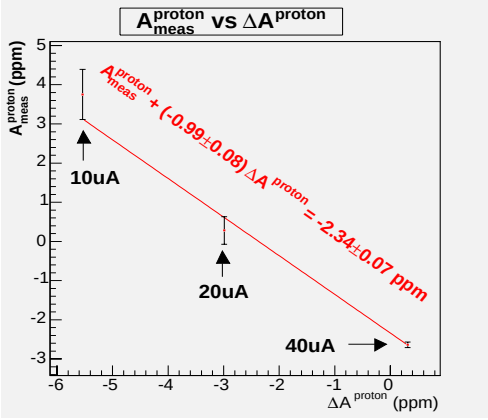
- leakage of beam from Hall A, B lasers into Hall C have been observed with large asymmetry (40 nA leakage, 40 μA main beam; leakage asymmetry ~340 ppm)
- Different beam time structure (499 MHz for Hall A,B beams and 32 MHz for Hall C)

→ Induce false asymmetry which depends on the TOF and the beam intensity

Corrected asymmetries estimated by

- measuring effect using "signal-free" region of TOF spectra;
- performing studies with other lasers turned off, high-rate luminosity monitors
- cross-checks with low-rate runs.





Systematic error on the correction :

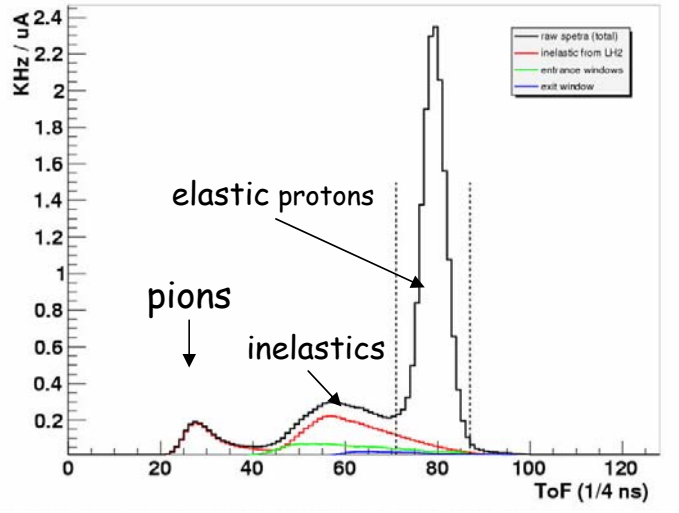
$$\delta\left(\Delta A_{cor}\right) \sim 0.1\ ppm$$

Background subtraction

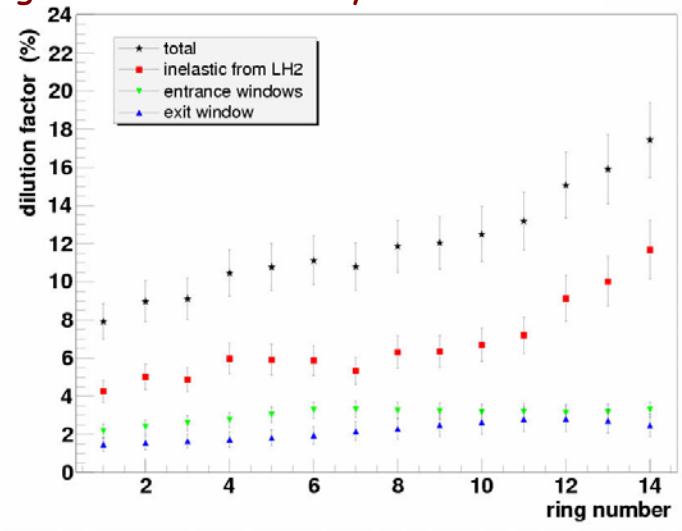
Estimate of background yield under the elastic peak is performed by using

- data with full and empty (gas H_2) targets, different pressures
- data with dummy entrance and exit windows (Al)
- Data with W radiator and dummy windows (electro/photo production)

→ Unfold backgrounds from target windows and inelastic LH_2 processes



Background over elastic yields at the elastic peak



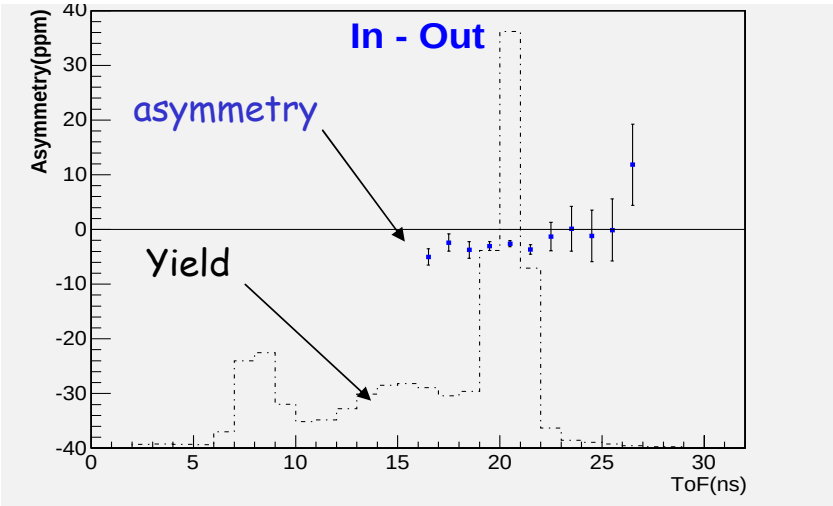
Correction of the asymmetries

The best method to be applied could depend on detectors - still under study

- For smaller detectors, yields and asymmetries are measured on each side of the elastic peak and a smooth interpolation could probably be applied.

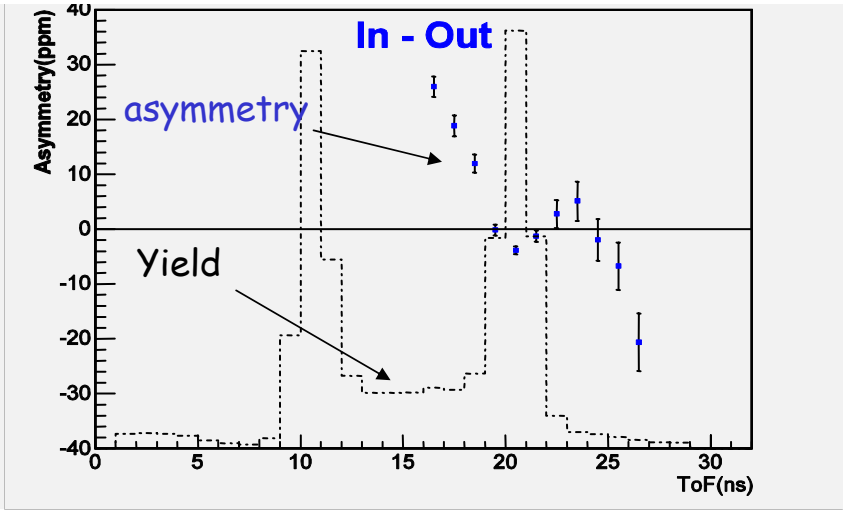
- For larger detectors, background asymmetry is large and vary significantly.

Detector 8



Small increase of the error in elastic asymmetry due to background for small detectors

Detector 13



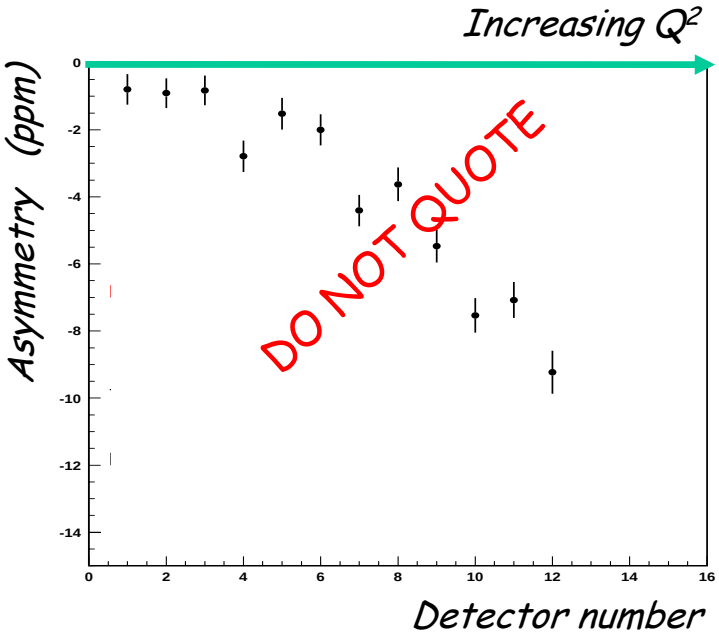
Error in elastic asymmetry due to the background will likely dominate

(depending on detectors)

Preliminary results

Forward angle asymmetries

- full statistics used and detectors 13 to 15 not shown.
- present background correction
- 25% blinding factor applied



First estimates of systematic uncertainties :

- Deadtime correction	2% error ✓
- Beam parameters correction	0.01 ppm ✓
- 'Leakage' correction	0.10 ppm ✓
- Beam Polarization	2% error ✓
- Background correction	still under study
- Q^2 determination	1% error ✓
- Rad. Corr., EM form factors	to do

Summary and outlook

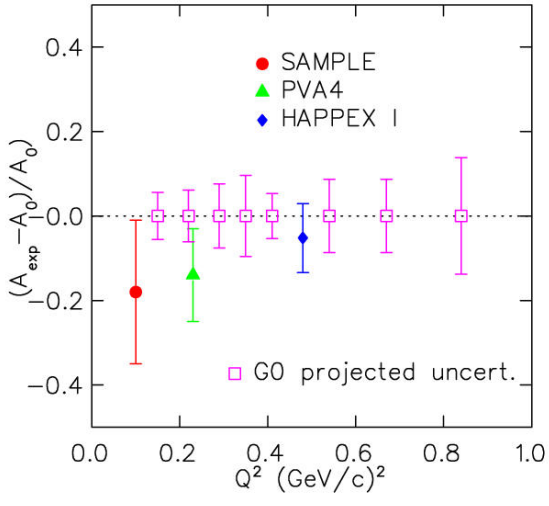
- G^0 Forward Angle run completed in May '04

  Analysis under progress …

- 2004-05 : Installation of the G0 setup for the Backward Angle run. Turnaround of the magnet and detectors frame underway. Additional detectors required (scintillators + Cherenkov) and new electronics modules.

- First backward angle in Fall 2005

- Goal : Extraction of Electric and Magnetic Weak Form factors for Q^2 = 0.3, 0.5 and 0.8 GeV^2 by 2008



G0 Forward Angle configuration

Expected Results by late 2004