Results from G0

Angela Biselli

Carnegie Mellon University

for the G0 Collaboration

Aug 20, 2004

Caltech, CMU, William & Mary, Hampton, IPN-Orsay, ISN-Grenoble, JLab, Kentucky, LaTech, NMSU, TRIUMF, U Conn, UIUC, U Manitoba, U Maryland, U Mass UNBC, VPI, Yerevan

Physics Motivation

s quark distribution is interesting since it exclusively comes from $s\bar{s}$ sea

- The proton electromagnetic form factors is weighted sum of the quark form factors

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

- Measuring $G^{\gamma,p}_{E(M)}$ not enough to separate the quark form factors

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

- Measurement of $G^{Z,p}_{E(M)}$ add 2 new eqs. Still not enough, but one can extract

$$G^{0}_{E(M)} = \frac{1}{3}(G^{u,p}_{E(M)} + G^{d,p}_{E(M)} + G^{s,p}_{E(M)})$$

$$= (2 - 4\sin^2\theta_W) G^{\gamma,p}_{E(M)} - G^{Z,p}_{E(M)}$$

Physics Motivation

- assuming that proton and neutron differ only by exchanging u and d

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

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

- quark form factors can be isolated

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

From measuring $G^{Z,p}_{E(M)}$ and using the well known $G^{\gamma,p}_{E(M)}$ and $G^{\gamma,n}_{E(M)}$ one can extract individual quark form factors

How to measure $G^{Z,p}_{E(M)}$?

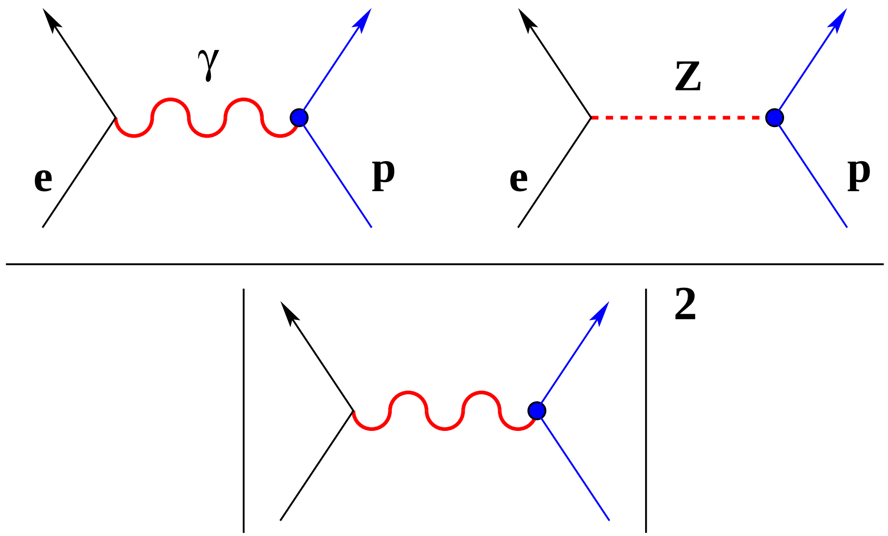
PV asymmetry for elastic electron-proton scattering $A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$

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

$$\tau = \frac{Q^2}{4M_N^2}$$

$$\epsilon = (1 + 2(1+\tau)\tan^2(\theta_2/2))^{-1}$$

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



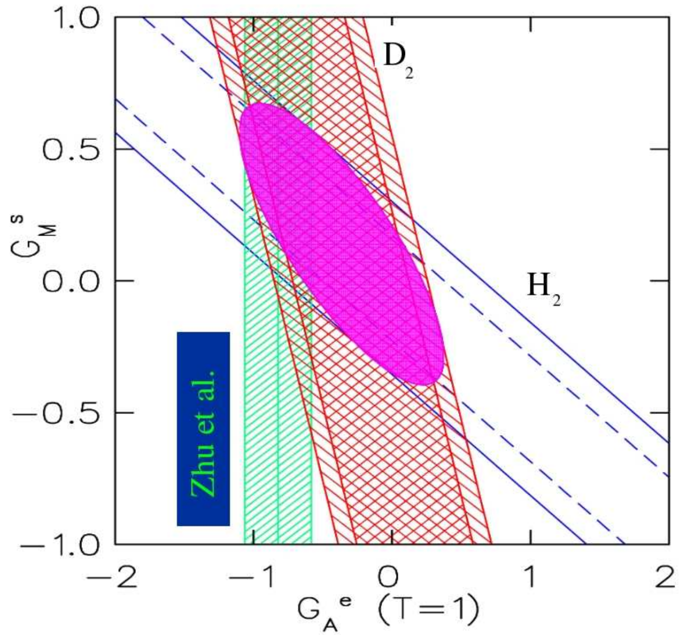
Previous measurements

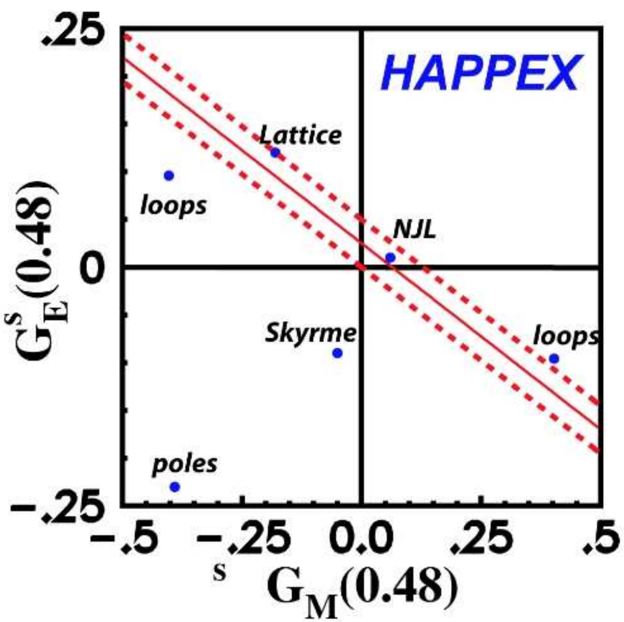
SAMPLE at MIT-Bates

$\vec{e} + p \qquad A_p = -4.92 \pm 0.61 \pm 0.73\ ppm$

$\vec{e} + d \qquad A_d = -7.55 \pm 0.70 \pm 0.60\ ppm$

$G^s_M(Q^2 = 0.1\mathrm{GeV}^2) = 0.14 \pm 0.35 \pm 0.40$





HAPPEX at JLAB

$\vec{e} + p \qquad A_p = -15.05 \pm 0.98 \pm 0.56\ ppm$

$G^s_E + 0.39 G^s_M = 0.025 \pm 0.020 \pm 0.014$

at $Q^2 = 0.48\mathrm{GeV}^2$

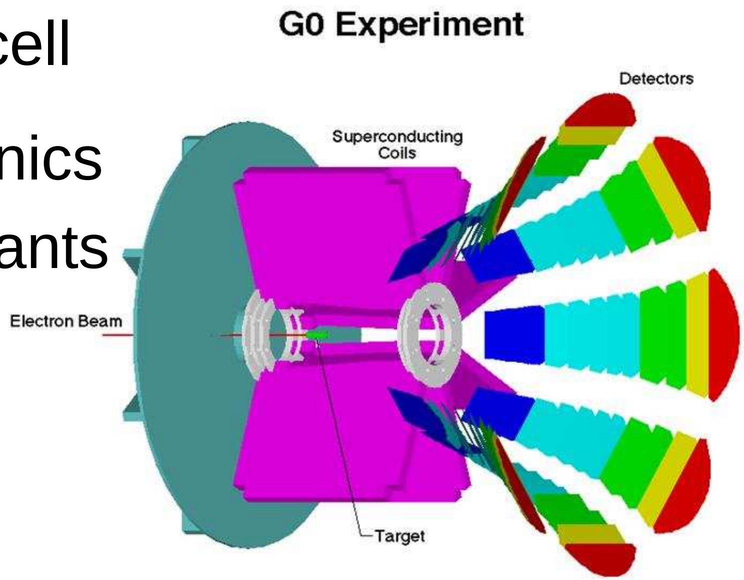
G0 experiment

Goals of the G0 experiment:

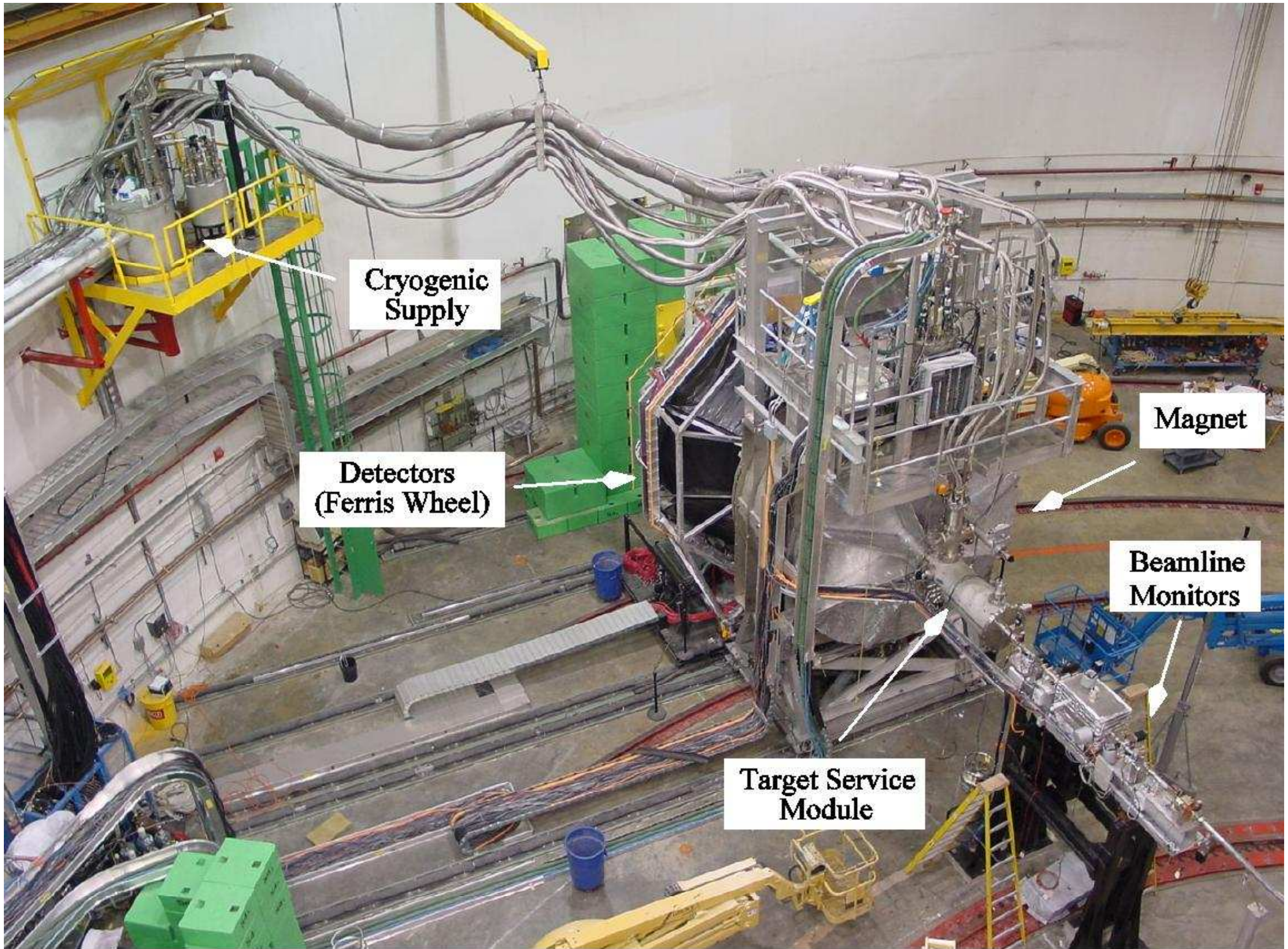
- measure the $A \sim$ -3 to -40 ppm with precision of $\sim$ 5%
  - need 10^{13} to 10^{14} events
  - high polarization, high current
  - high count rate detectors/electronics
  - small helicity correlated beam properties
  - control over sources of false asymmetries (deadtime, background, ..)
- Separate G_E^s and G_M^s
  - Forward angle elastic $\vec{e} + p$ - Full range of Q^2=0.1-1.0 GeV^2/c^2
  - Backward angle elastic $\vec{e} + p$ - Q^2=0.3, 0.5, 0.8 GeV^2/c^2
  - Backward angle quasi-elastic $\vec{e} + d$ - Q^2=0.3, 0.5, 0.8 GeV^2/c^2

Forward angle set-up overview

- superconducting toroidal magnet
- segmented large area scintillation detector array
- custom and commercial high rate electronics
- 3 GeV polarized beam in 32 ns pulses
- High power 20 cm $\mathrm{LH_2}$ target cell
- Different hardware and electronics (NA/French) for alternating octants



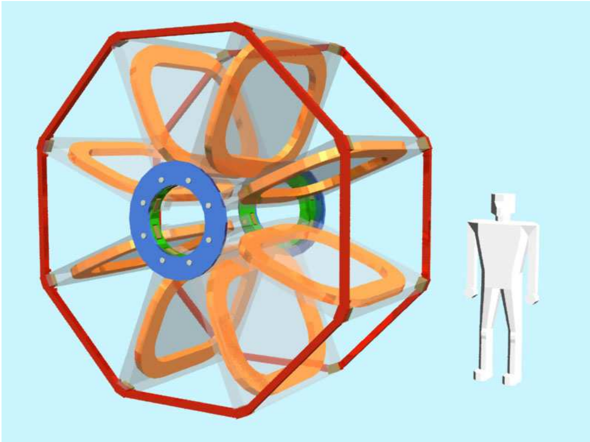
G0 experimental set-up



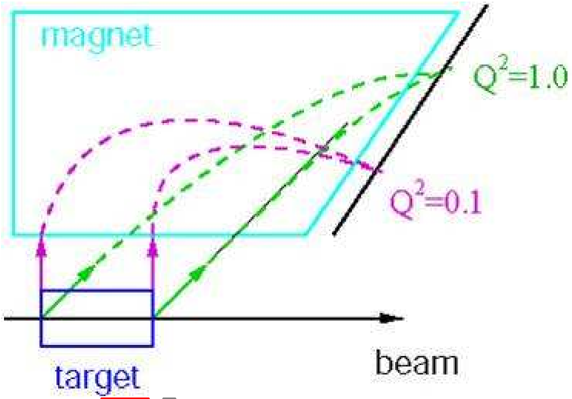
G0 magnet

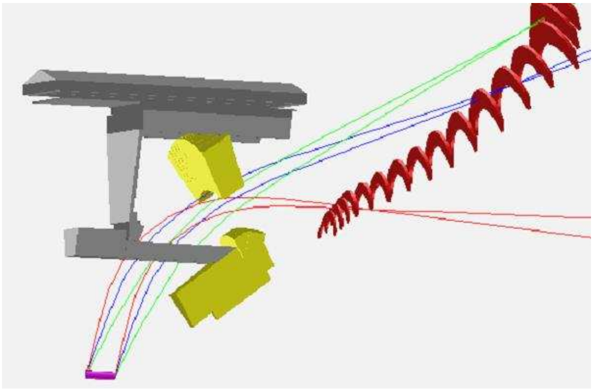
Superconducting toroidal magnet

- 8 coils
- $\int Bdl = 1.6\,Tm$
- $35° < \theta_{bend} < 86°$
- ϕ acceptance $\sim$ 0.44
- Ran at full design current (5000 A)

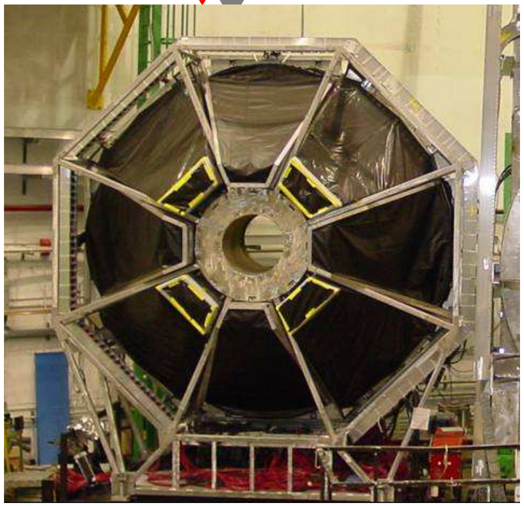


Magnet "sorts" proton by Q^2 in focal plane detector





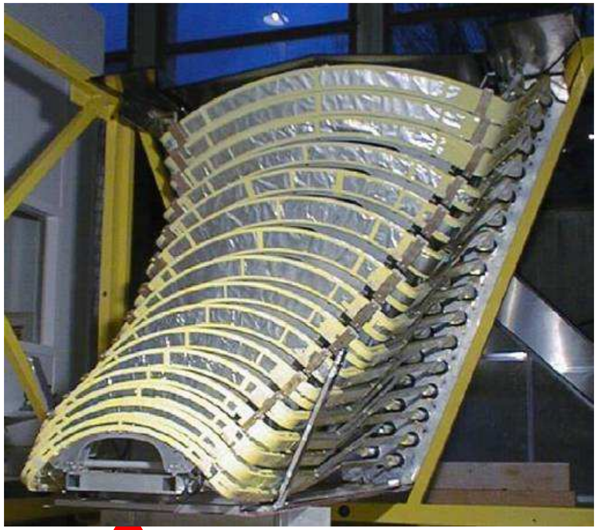
Focal plane detectors



16 pairs of arc-shaped scintillators

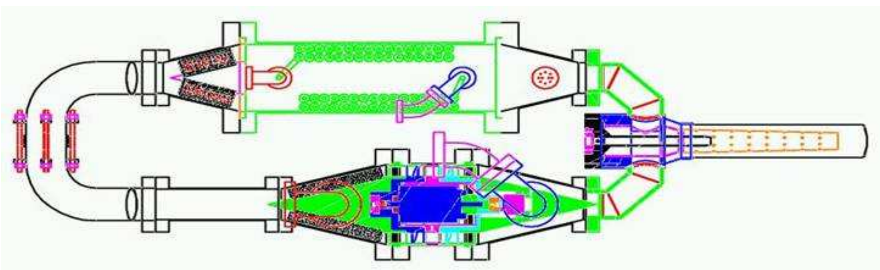
- along the focal planes of each of the toroid octants
- Back and front coincidence to eliminate neutrals
- 4 PMTs in low field region

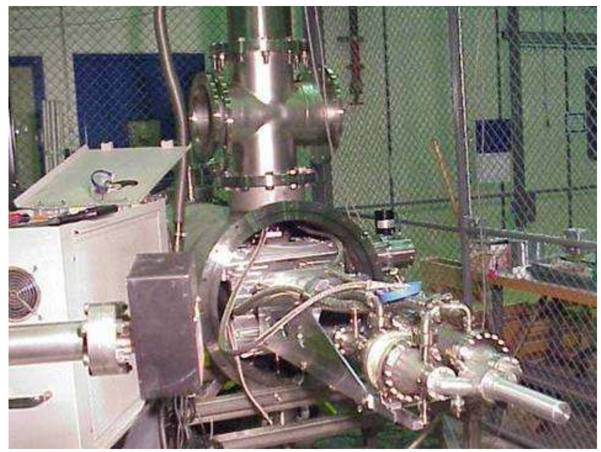
Detect recoil protons with $62^\circ < \theta < 78^\circ$



G0 target

- 20 cm LH_2 cell, 250 W heat load from beam at 40 μA
- High flow rate to minimize target density fluctuation
- magnet focal planes are independent on the point of interaction in the target



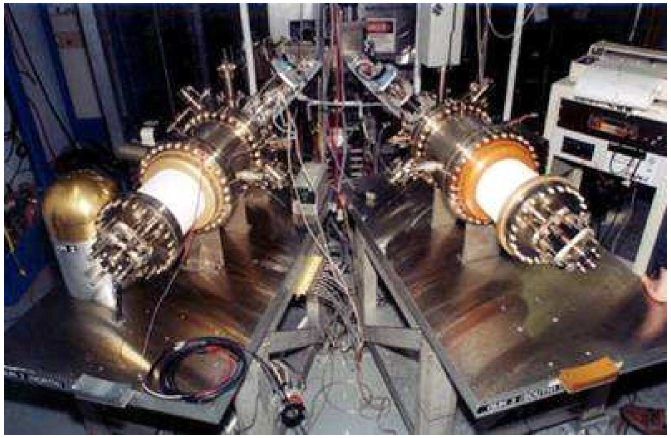


G0 beam

32 ns between pulses - 31 MHz time structure

- 1/16 of usual CEBAF 499 MHz time structure
- higher charge per bunch
- required new Ti:Sapphire laser in polarized electron gun
- Helicity reversed with a pseudo random sequence: quartet structure $+--+$ or $-++-$
- Helicity held constant every 1/30 s (MPS)

Beam quality achieved (IN-OUT):

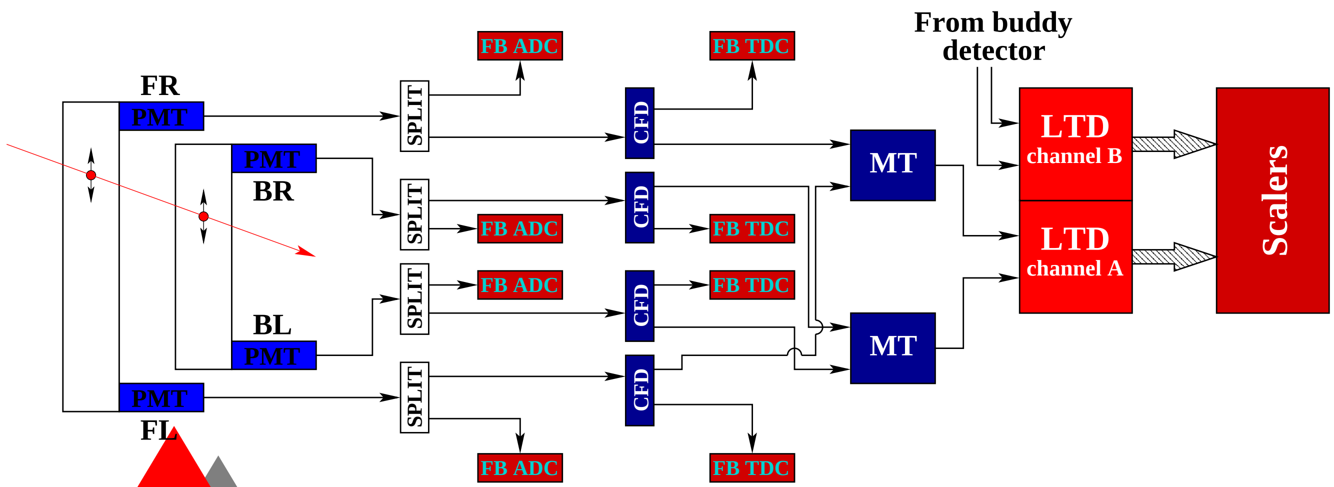


- $\Delta X = 6 \pm 4\, nm$
- $\Delta Y = 8 \pm 4\, nm$
- $\Delta x - angle = 2 \pm 0.3\, nrad$
- $\Delta y - angle = 3 \pm 0.5\, nrad$
- $\Delta I/I = -0.3 \pm 0.3\, ppm$
- Energy diff $\Delta E = 58 \pm 4$ eV

G0 Electronics

Custom electronics design to provide high rate histogramming of time-of-flight spectra

- NA: meantimer $\rightarrow$ LTD $\rightarrow$ scalers - 1 ns resolution - 24 ns window
- FR: meantimer $\rightarrow$ DMCH - 0.25 ns resolution - 32 ns window
- data read out every MPS (captured between helicity periods)
- additional Fastbus data (ADC, TDC) at lower rate (3 FB events per MPS) for systematic studies (singles rates ...)



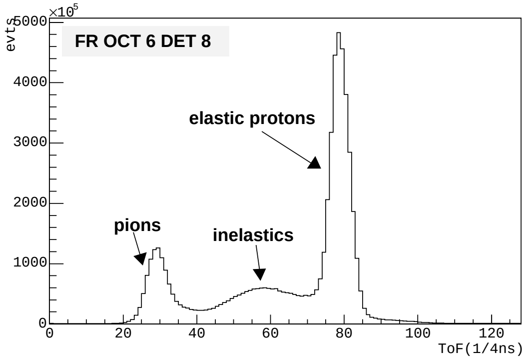
The forward angle data

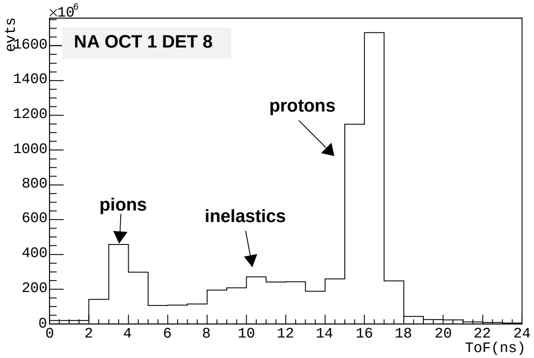
Detecting recoil protons

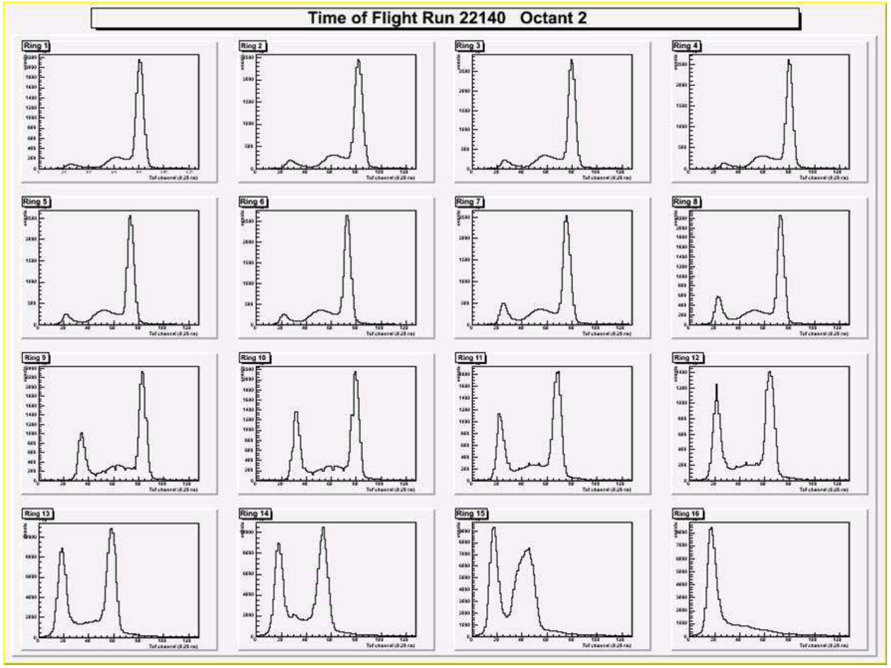
16×8 time-of-flight spectra

event rate of about 1MHz

PID by time-of-flight: p 20 ns, π^+ 8 ns







Analysis procedure

- For each helicity state (MPS) $\rightarrow Y\ [\#counts/nC]$
- For each "good" quartet (e.g. $+--+$) $\rightarrow$
  $A = \frac{Y_{1+}+Y_{2+}-Y_{1-}-Y_{2-}}{Y_{1+}+Y_{2+}+Y_{1-}+Y_{2-}}$
- Weighted average of all quartets asymmetries

Not so easy....

- Deadtime corrections $Y_c = \frac{Y_{raw}}{1-f}$, $f = 10 - 15\%$
- Correct asymmetry for helicity correlated beam properties P_i
  $A_{corr} = A_{meas} - \sum_{i=1}^{N} \frac{1}{2Y}(\frac{\partial Y}{\partial P_i})\Delta P_i$ $\quad\quad \Delta P_i = P_+ - P_-$
- Leakage correction $A'_{corr} = A_{corr} + \frac{I_L}{I_C}(1 - \frac{Y_L}{Y_C})A_{IL}$
- Background correction $A_{sig} = \frac{A'_{corr} - A_{back} f_{back}}{f_{sig}}$
- Beam polarization/radiative corrections $A_{phys} = \frac{A_{corr}}{P_{beam} R_{rad}}$

Deadtime corrections

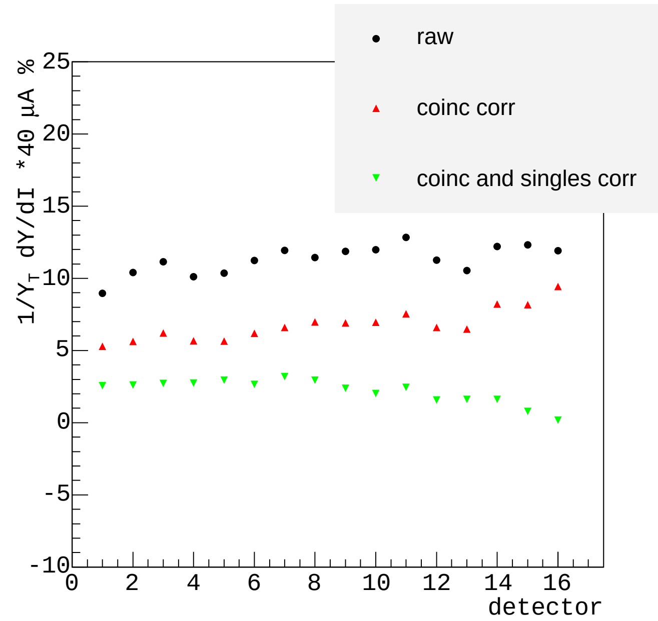
Electronic deadtime depending on rates $\rightarrow$ helicity correlated

$Y_m^{\pm} = (1 - f)Y_t^{\pm}$

$f \propto R$

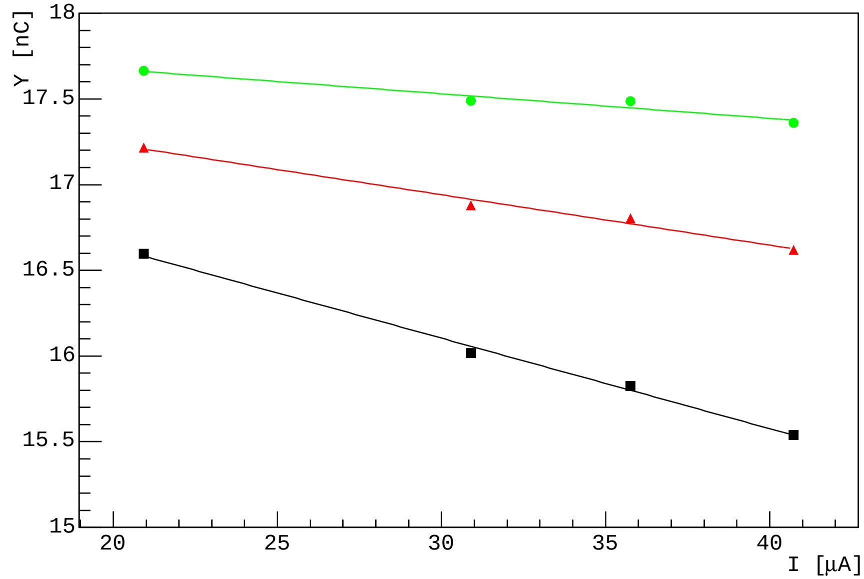
$f \sim 10\%$ before corrections

$A_{false} \sim -f(A_Q + A_{phys})$



Two "kinds" of deadtime:

- deadtime associated to coincidence rates $\rightarrow$ NPN $\rightarrow$ corrected for analytically
- deadtime due to "singles" $\rightarrow$ need to measure/estimate singles rates $\rightarrow$ FB data and/or scalers



Leakage

Unanticipated effect: Leakage from Hall A,B lasers into Hall C

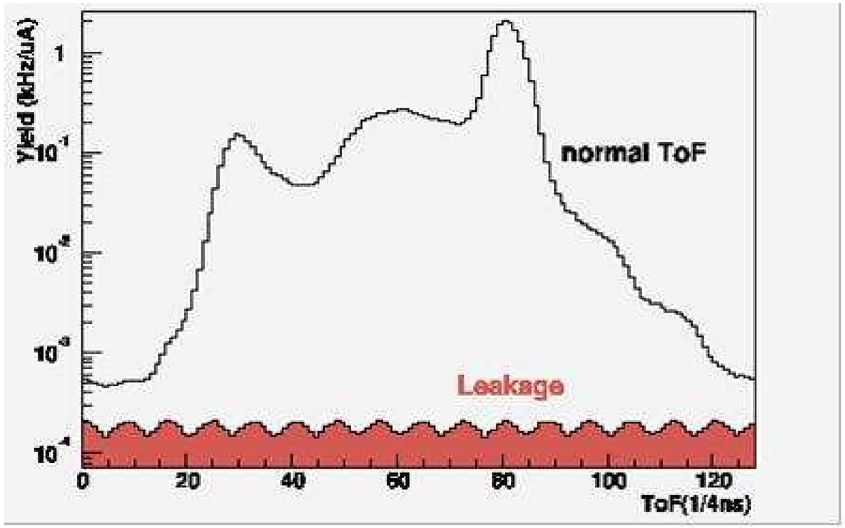
- Hall A,B beams and Hall C have different time structure (2 ns vs 32 ns)
- BCMs measure integrated (30Hz) A+B+C charge

$$A_{meas} = A_{phys} - \frac{I_L}{I_C}(1 - \frac{Y_L}{Y_C})A_{IL}$$

I_L, I_C leakage, Hall C currents

A_{IL} leakage charge asymm

Y_L, Y_C leakage, Hall C yields



Leakage

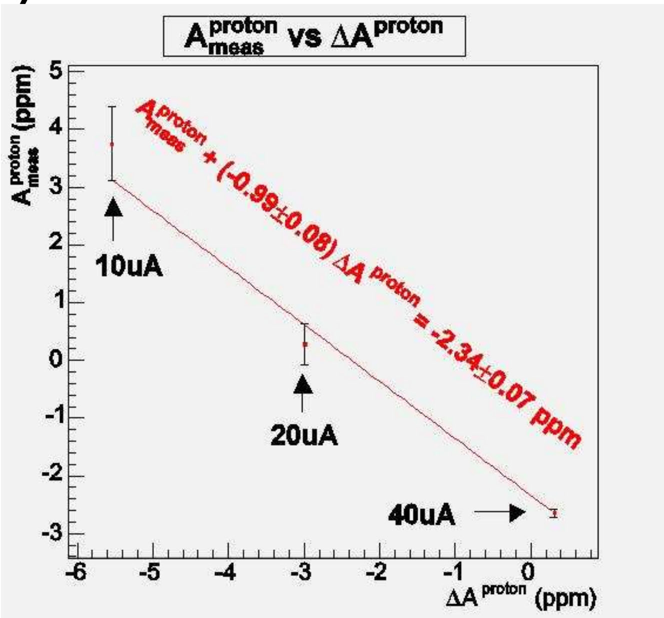
To correct for this effect:

- measure the leakage asymmetry in a "forbidden" TOF region
- verify with direct leakage measurements by turning one laser on at the time (Lumi detectors)
- verify with low rates runs

Leakage current $I_L = 40\ nA$

Charge asymmetry $A_{IL} = 500\ ppm$

net systematic 0.1 ppm



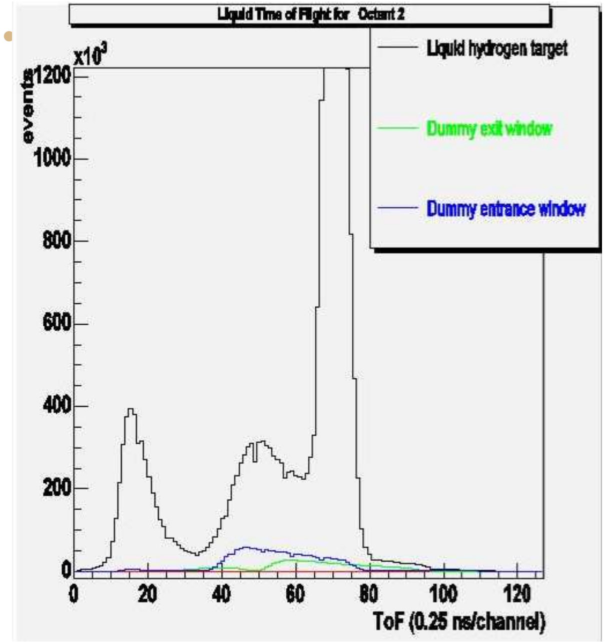
$$A_{phys} = A_{meas} + \Delta A$$

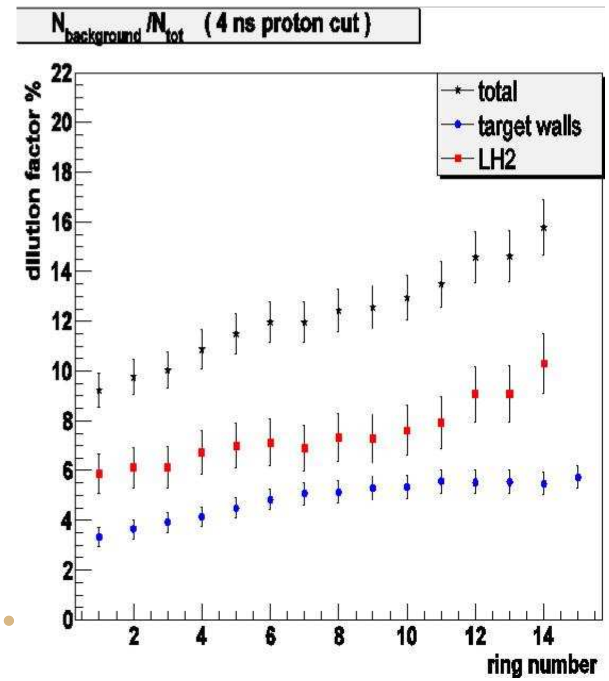
Background correction

Need to measure dilution factor of elastic peak and the asymmetry of the background

- Data with full and empty targets, different pressures
- Data with dummy entrance and exit window
- Data with W radiator and dummy windows

unfold background from target windows and the inelastic scattering from LH_2

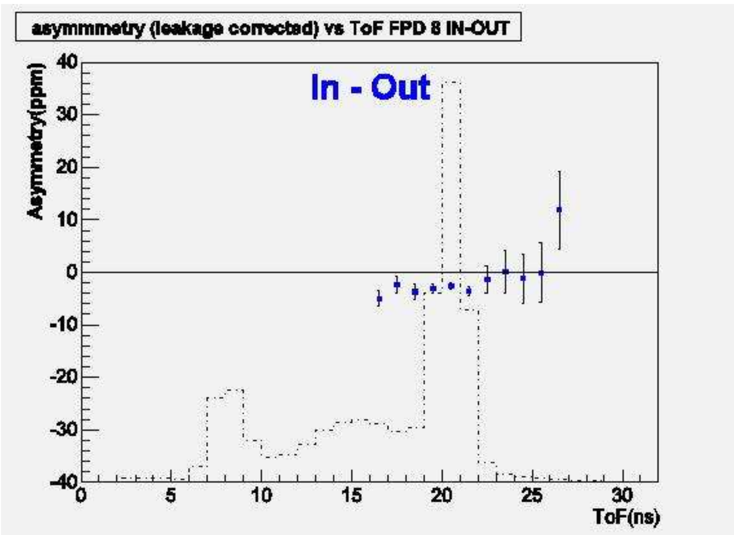


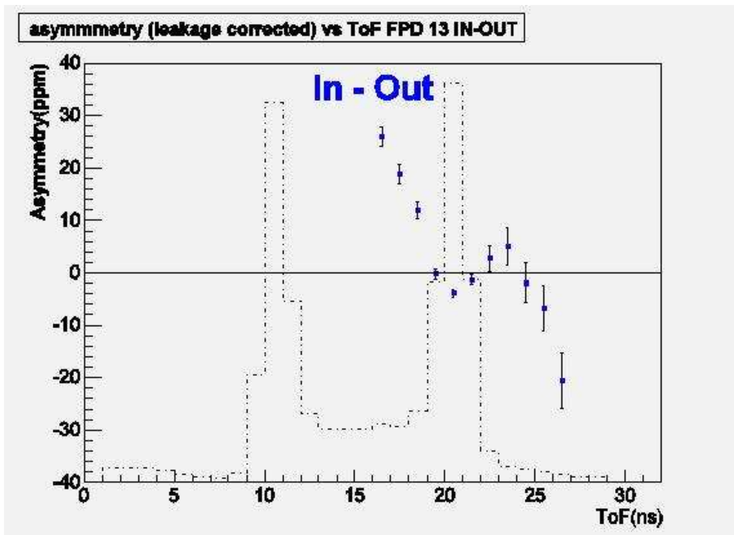


Background correction

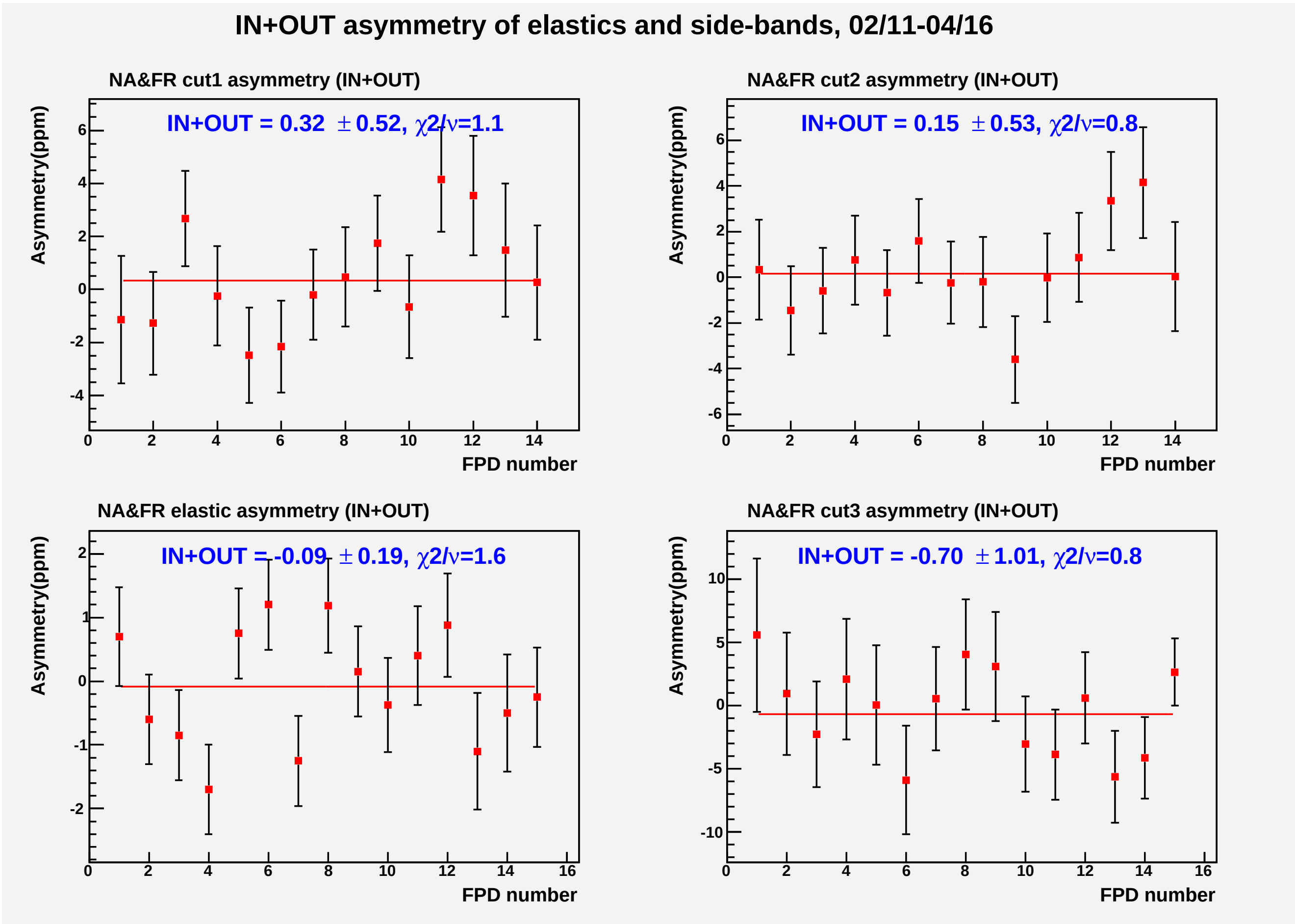
"Side-band" correction: Asymmetry and yield measured on either side of elastic peak $\Rightarrow$ interpolation

- low/mid Q^2 - error $\sim$ 2% - 5%
- high Q^2 - present estimate 7 % - 20 %





Results: IN+OUT

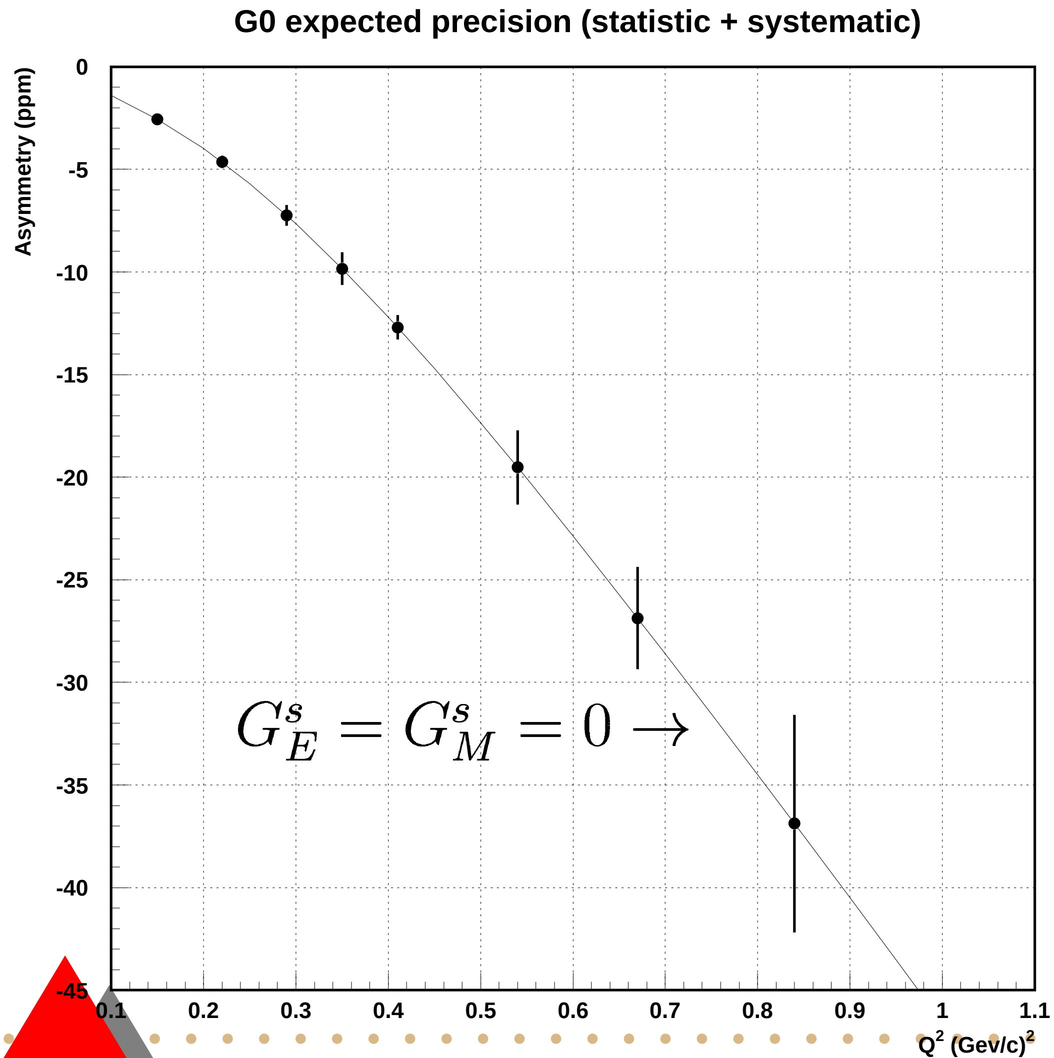


Errors

source	error
Deadtime correction	2 %
Beam param false asymm	0.01 ppm
leakage	0.10 ppm
Beam pol	2 %
Background	under study
Bin Q^2	1 %
Radiative corrections, EM form factors	to do

$G_E^s + \alpha G_M^s$ error probably dominated by background error, especially at high Q^2

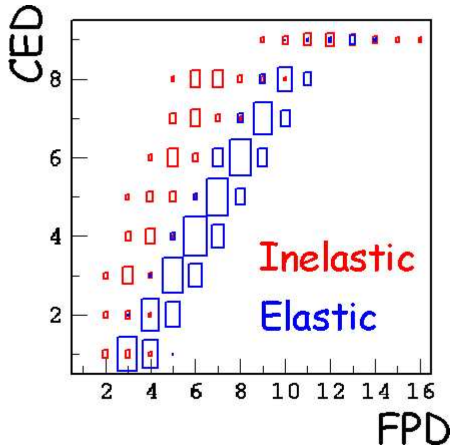
Presently estimated uncertainties (statistical + systematic)

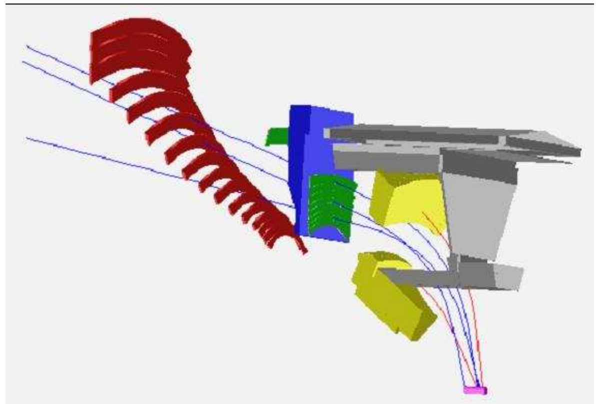


Future..

Back-angle measurement to separate G_E^s and G_M^s

- Detect scattered electron at $\theta_e \sim 110^\circ$
- Back-angle Q^2 have small variation in G0 acceptance
  - 3 energies $424,\ 576,\ 799\ \mathrm{MeV}$ for $Q^2 = 0.3,\ 0.5,\ 0.8\ \mathrm{GeV}^2/c^2$
- Need to extract G_A^e
  - all measurements on both LH_2 and LD_2
- Setup turned around + new hardware and electronics
  - Cryostat Exit Detector (CED) to separate elastic and inelastic electrons
  - Cerenkov detector for pion rejection





First run - Fall 2005

Conclusions

- G0 forward angle run complete
- Analysis well underway
- Background likely to dominate the errors
- Back angle run in Fall 2005
- In a few years we will have G^s_M and G^s_E for several Q^2