First Results from G^0

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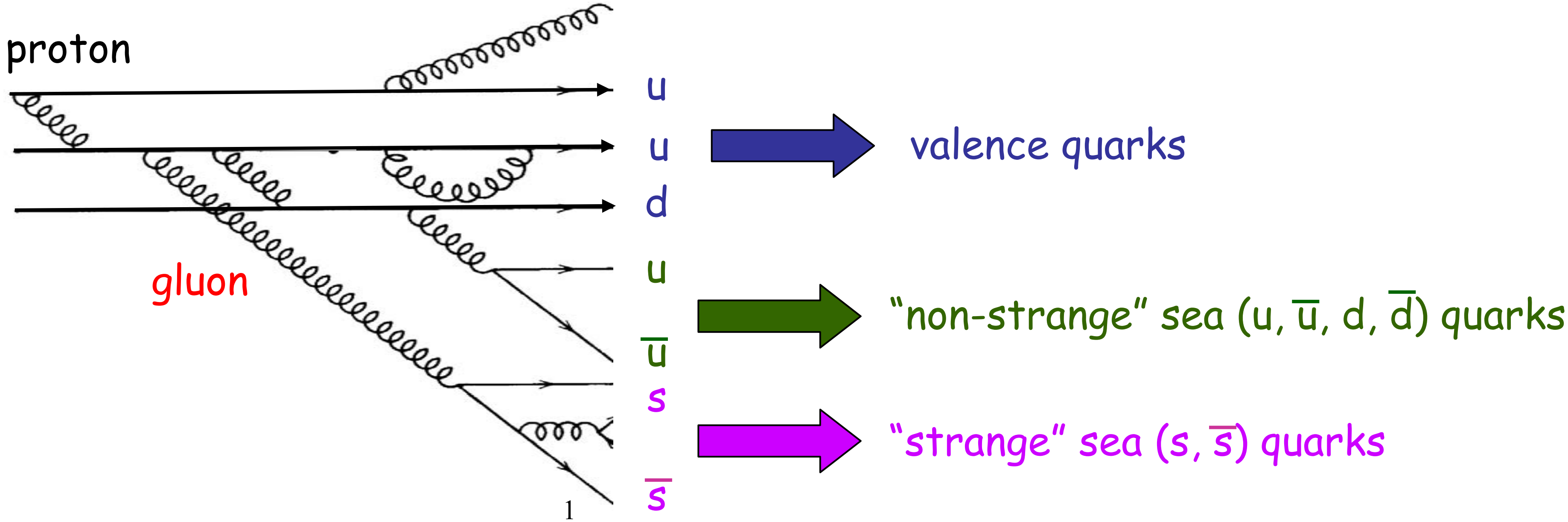
What role do strange quarks play in nucleon properties?



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

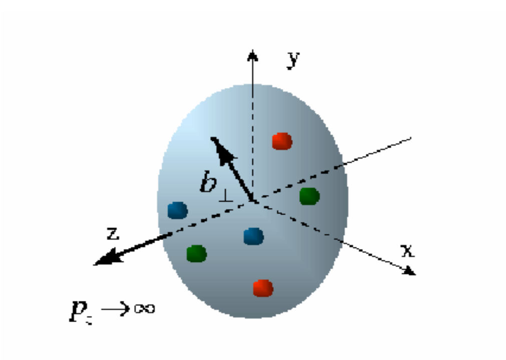
Spin: $<N|\bar{s}\gamma^5 s|N> \sim -10\%$ (polarized DIS)

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

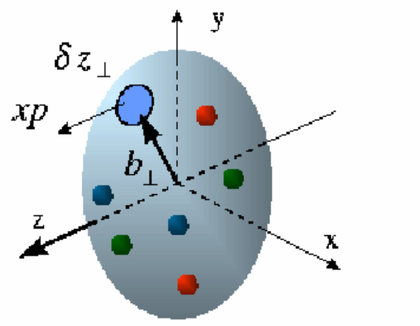
Charge and current: $<N|\bar{s}\gamma^\mu s|N> = ?? \rightarrow G_E^s \; G_M^s$

Main goal of G^0 : To determine the contributions of the strange quark sea ($s\bar{s}$) to the electromagnetic properties of the nucleon ("strange form factors").

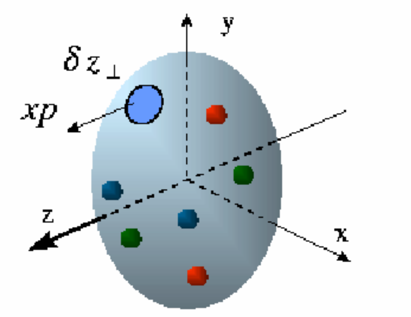
The complete nucleon landscape - unified description



Elastic scattering:
transverse quark distribution in coordinate space



Deep exclusive scattering (DES):
Generalized parton dist. (GPD):
fully-correlated quark distribution in coordinate and momentum space



Deep inelastic scattering (DIS):
longitudinal quark distribution in momentum space

Electric and magnetic form factors well-measured

$G_E \quad G_M$ for p, n

BUT quark flavor decomposition of these form factors is not yet known

$G^u_{E,M} \qquad G^d_{E,M} \qquad G^s_{E,M}$

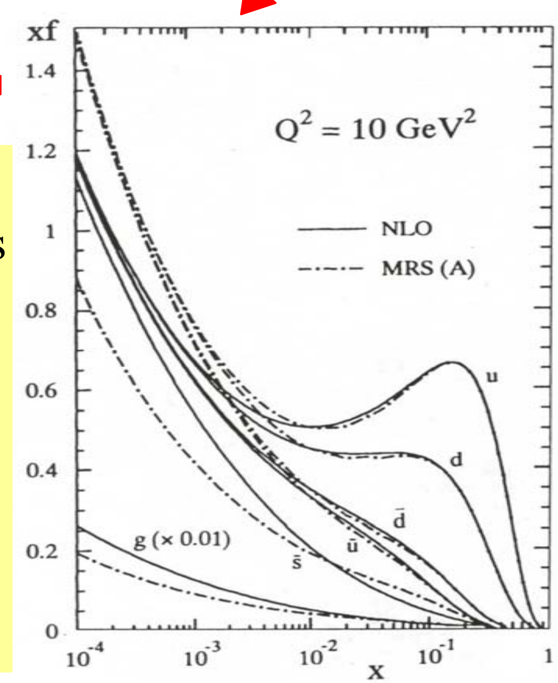
Measured nucleon momentum fractions ($Q^2 = 2\ \mathrm{GeV}^2$):

$\varepsilon_{u+\bar{u}} \sim 37\%$

$\varepsilon_{d+\bar{d}} \sim 20\%$

$\varepsilon_{s+\bar{s}} \sim 4\%$

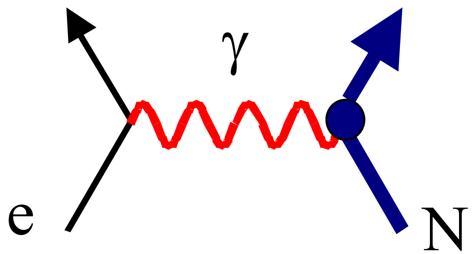
$\varepsilon_{glue} \sim 39\%$



Nucleon form factors measured in elastic e-N scattering

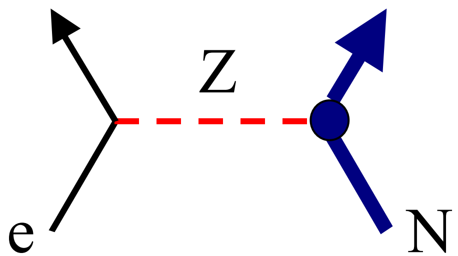
Nucleon form factors

- well defined experimental observables
- provide an important benchmark for testing non-perturbative QCD structure of the nucleon



$$< N \,|\, J_\mu^\gamma \,|\, N > \quad \rightarrow \quad G_E^\gamma, G_M^\gamma$$

electromagnetic form factors



$$< N \,|\, J_\mu^Z \,|\, N > \quad \rightarrow \quad G_E^Z, G_M^Z$$

neutral weak form factors

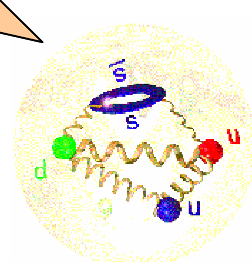
- *Measured* precision of EM form factors in 0.1 - 1 GeV^2 Q^2 range ~ 2 - 4%
- *Projected* precision of NW form factors in 0.1 - 1 GeV^2 Q^2 range ~ 10% from the current generation of experiments

Neutral weak form factors → strange form factors

STANDARD MODEL COUPLINGS

	Q^γ	Q^Z
u	+2/3	$1 - 8/3 \sin^2\theta_W$
d	−1/3	$-1 + 4/3 \sin^2\theta_W$
s	−1/3	$-1 + 4/3 \sin^2\theta_W$

$\sin^2\theta_W = 0.2312 \pm 0.0002$
weak mixing angle
key parameter of Standard Model



E158

A precision measurement of the Weak Mixing Angle in Møller Scattering

Qweak: A SEARCH FOR NEW PHYSICS

$$= \sum_i Q_i^\gamma \, \bar{q}_i \gamma_\mu q_i \qquad J_\mu^Z = \sum_i Q_i^Z \, \bar{q}_i \gamma_\mu q_i$$

Flavor decomposition of nucleon E/M form factors:

$$\langle p | J_\mu^\gamma | p \rangle: \quad G_{E,M}^{\gamma,p} = \frac{2}{3} G_{E,M}^{u,p} - \frac{1}{3} G_{E,M}^{d,p} - \frac{1}{3} G_{E,M}^{s,p}$$

$$\langle n | J_\mu^\gamma | n \rangle: \quad G_{E,M}^{\gamma,n} = \frac{2}{3} G_{E,M}^{u,n} - \frac{1}{3} G_{E,M}^{d,n} - \frac{1}{3} G_{E,M}^{s,n}$$

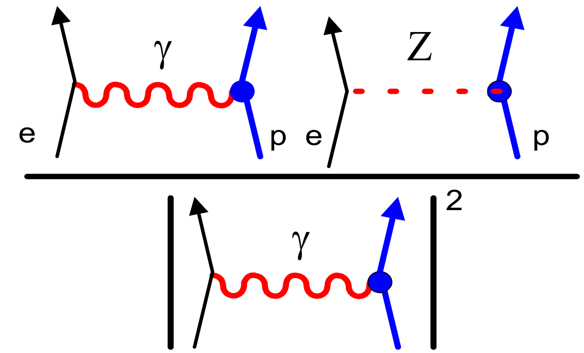
$$\langle p | J_\mu^Z | p \rangle: \quad G_{E,M}^{Z,p} = \left(1 - \frac{8}{3}\sin^2\theta_W\right) G_{E,M}^{u,p} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G_{E,M}^{d,p} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G_{E,M}^{s,p}$$

Invoke proton/neutron charge symmetry → 3 equations, 3 unknowns

$$\left(G_{E,M}^{\gamma,p}, G_{E,M}^{\gamma,n}, G_{E,M}^{Z,p}\right) \Leftrightarrow \left(G_{E,M}^{u}, G_{E,M}^{d}, G_{E,M}^{s}\right)$$

Parity Violating Electron Scattering - Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target



$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right]\frac{A_E + A_M + A_A}{2\sigma_{unpol}}$$

$$A_E = \varepsilon(\theta) G_E^Z(Q^2) G_E^\gamma(Q^2)$$
$$A_M = \tau(Q^2) G_M^Z(Q^2) G_M^\gamma(Q^2)$$
$$A_A = -(1-4\sin^2\theta_W)\varepsilon' G_A^e(Q^2) G_M^\gamma(Q^2)$$

$\rightarrow G_E^s$
$\rightarrow G_M^s$
$\rightarrow G_A^e$

Strange electric and magnetic form factors, + axial form factor

At a given Q² decomposition of $G^s{}_E$, $G^s{}_M$, $G^e{}_A$
Requires 3 measurements:

Forward angle $\vec{e} + p$ (elastic)
Backward angle $\vec{e} + p$ (elastic)
Backward angle $\vec{e} + d$ (quasi-elastic)

G^0 will perform all three measurements at three different Q^2 values - 0.3, 0.5, 0.8 GeV

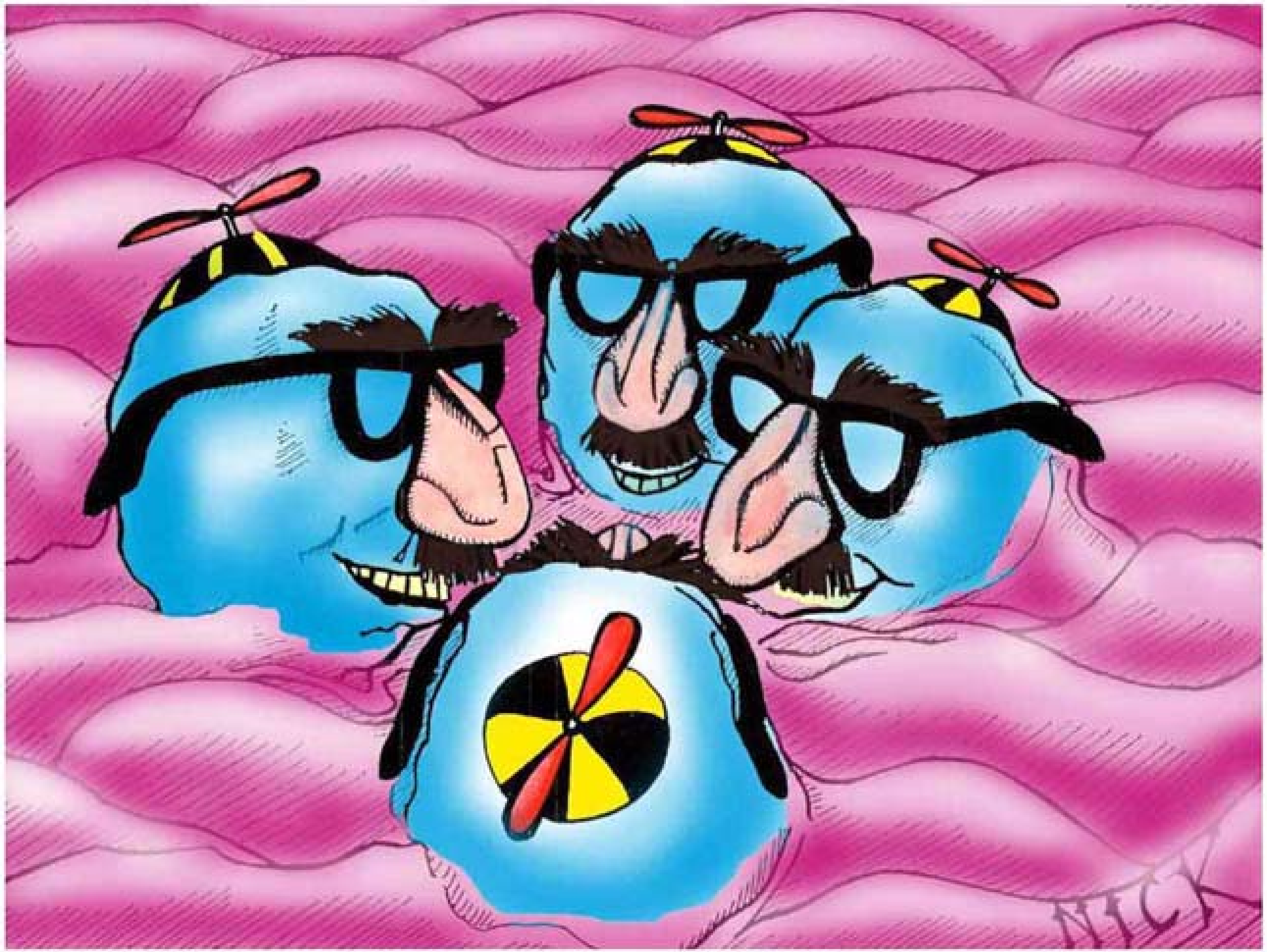
$A = -5.61 \pm 0.67 \pm 0.88$ ppm

$G_M^s = 0.37 \pm 0.20 \pm 0.26 \pm 0.07$

$Q^2 = 0.1$ GeV^2

PVA4 at MAMI: see Frank Maas' talk!

…(interlude)…



At a resolution of 10^{-24} metres, isolated clumps of Strange Matter pop briefly out of the quantum foam to debate the possible existence of Particle Physicists.

General Experimental Requirements

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

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

- Reliable high polarization, high current polarized electron source
- Large acceptance detector
- High count rate capability detectors/electronics

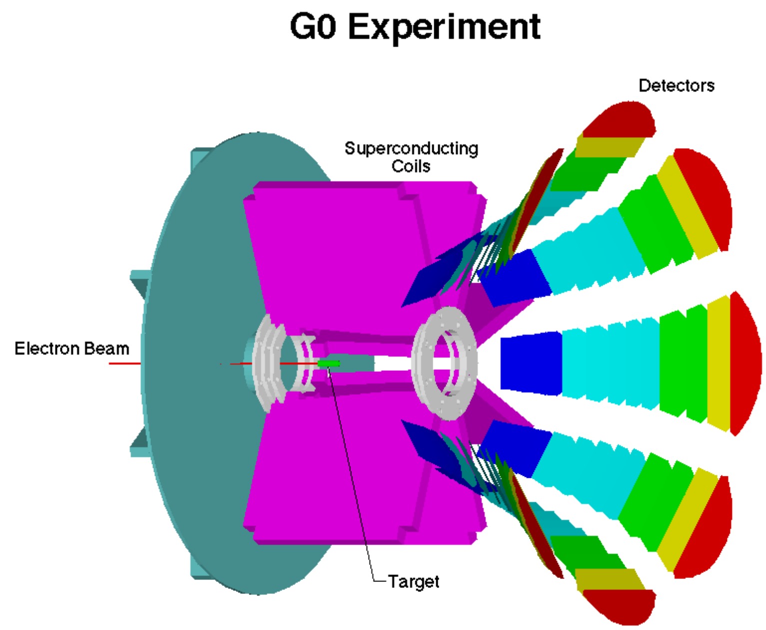
Systematics (need to reduce false asymmetries, accurately measure backgrounds):

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

The G^0 Experiment in Jefferson Lab Hall C

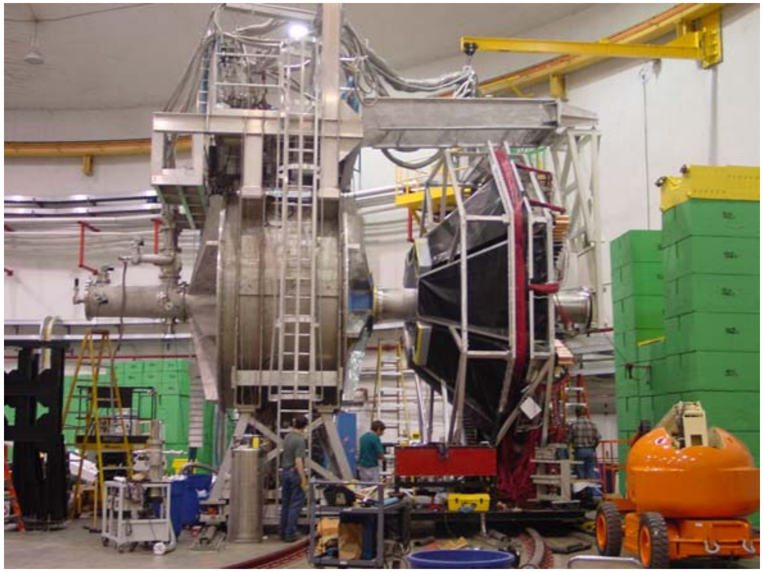
Main components:

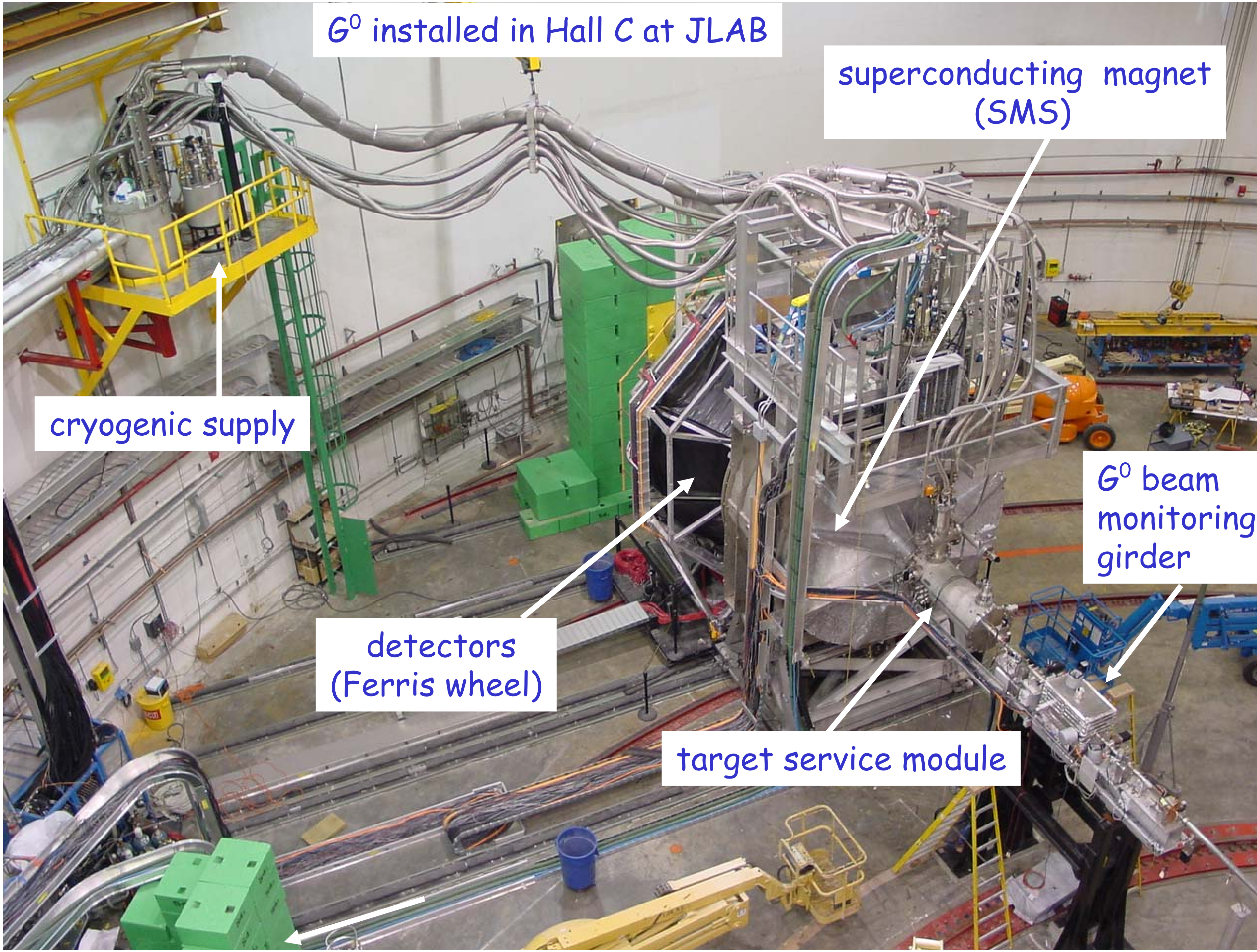
- Superconducting toroidal magnet
- Jefferson Lab polarized source
- High power H_2 / D_2 target
- Large acceptance scintillation detector array
- Custom high count rate electronics



History:

- Design and construction (1993 - 2001)
- Commissioning run (fall 2002/winter 2003)
- Finish commissioning run (fall 2003)
- Forward angle production run (spring 2004)
- Back angle production runs (2005 - ?)

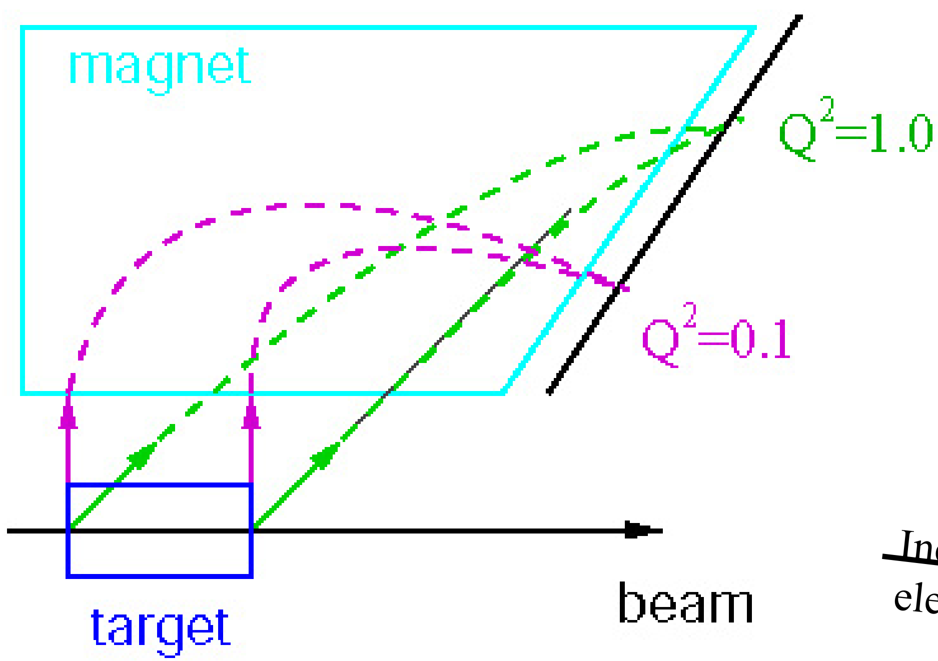


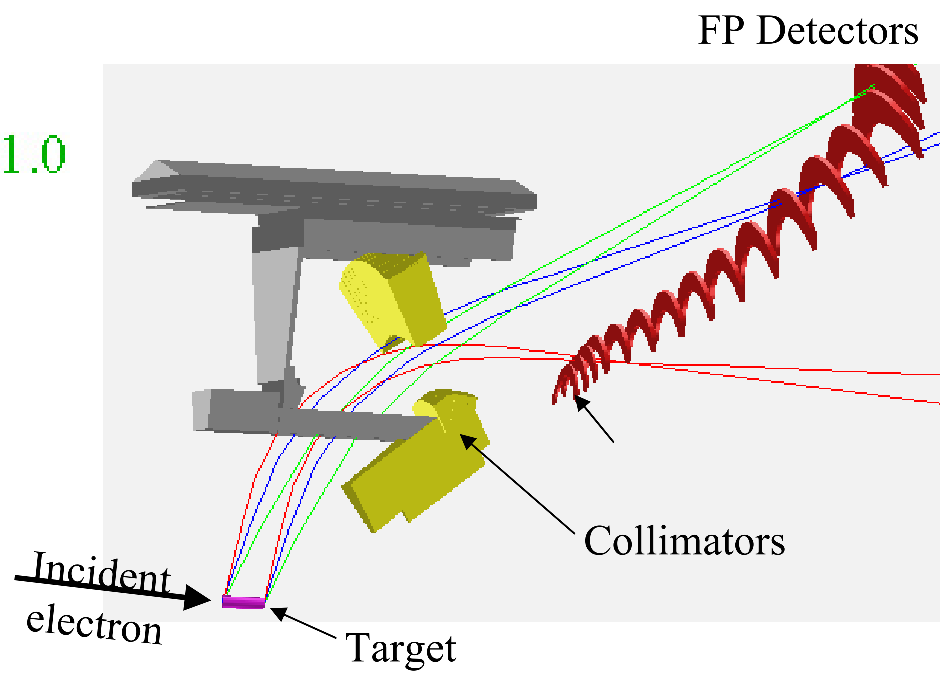


G^0 installed in Hall C at JLAB
superconducting magnet (SMS)
cryogenic supply
G^0 beam monitoring girder
detectors (Ferris wheel)
target service module

G^0 Forward Angle Mode

- Electron beam energy = 3 GeV on 20 cm LH_2 target
- Detect recoil protons ($\theta \sim 62 - 78^\circ$ corresponding to 15 - 5° electrons)
- Magnet sorts protons by Q^2 in focal plane detectors
- Full desired range of Q^2 (0.16 - 1.0 GeV^2) obtained in one setting
- Beam bunches 32 nsec apart (31.25 MHz = 499 MHz/16)
- Flight time separates p (about 20 ns) and π^+ (about 8 ns)

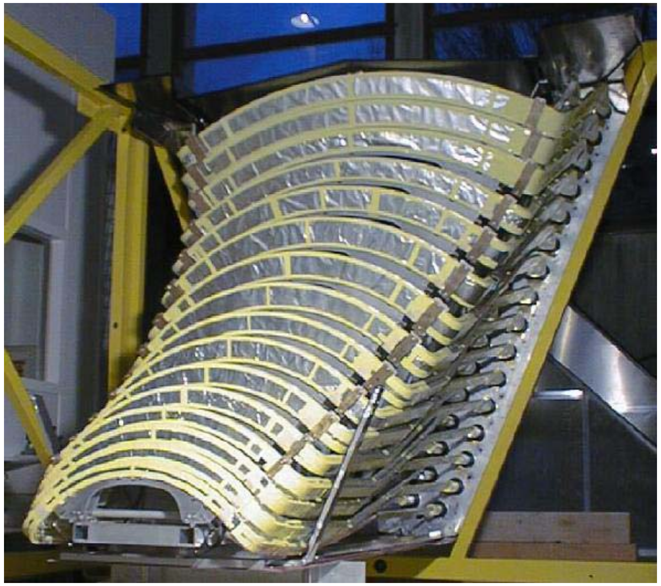




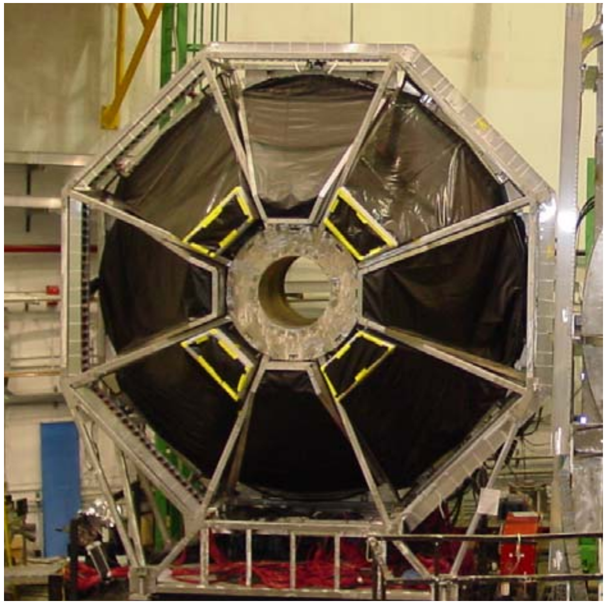
G^0 Focal Plane Detectors (FPD)

- 16 pairs of arc-shaped scintillators (iso-Q^2)
- Back and front coincidences to eliminate neutrals
- 4 PMTs (one at each end of scintillators)
- Long light guides (PMT in low B field)

French octant



North American octant

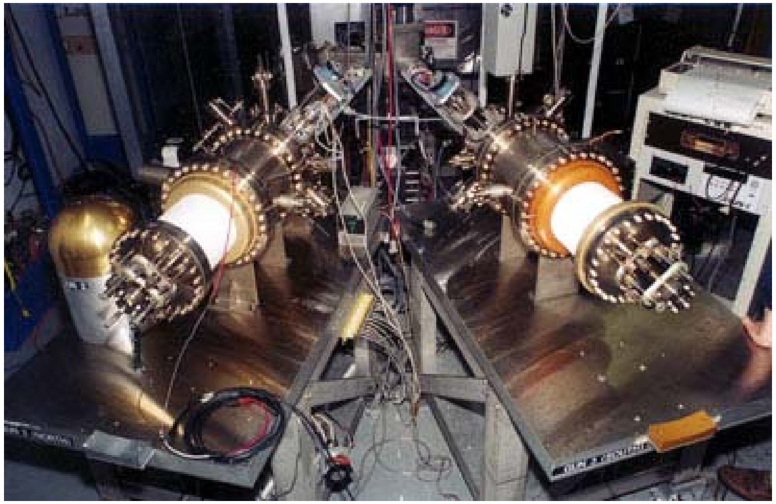


Detector "ferris wheel"

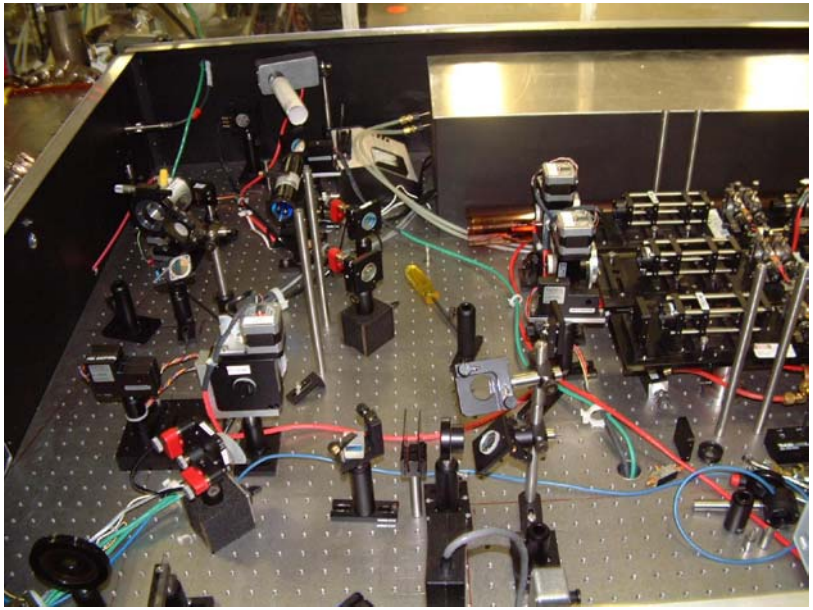
G^0 Beam

- G^0 beam requires unusual time structure: 31 MHz (32 nsec between pulses) (1/16 of usual CEBAF time structure of 499 MHz (2 nsec between pulses)
- Required new Ti:Sapphire laser in polarized electron gun
- Higher charge per bunch → space charge effects complicated beam transport in injector (challenging beam optics problem)
- JLab Accelerator Division delivered successfully (non-trivial!)
  - Beam current 40 μA
  - Beam fluctuations at (30 Hz/4) ~ $\Delta X, \Delta Y < 20\ \mu m$ $\Delta I/I < 2000$ ppm

CEBAF polarized injector

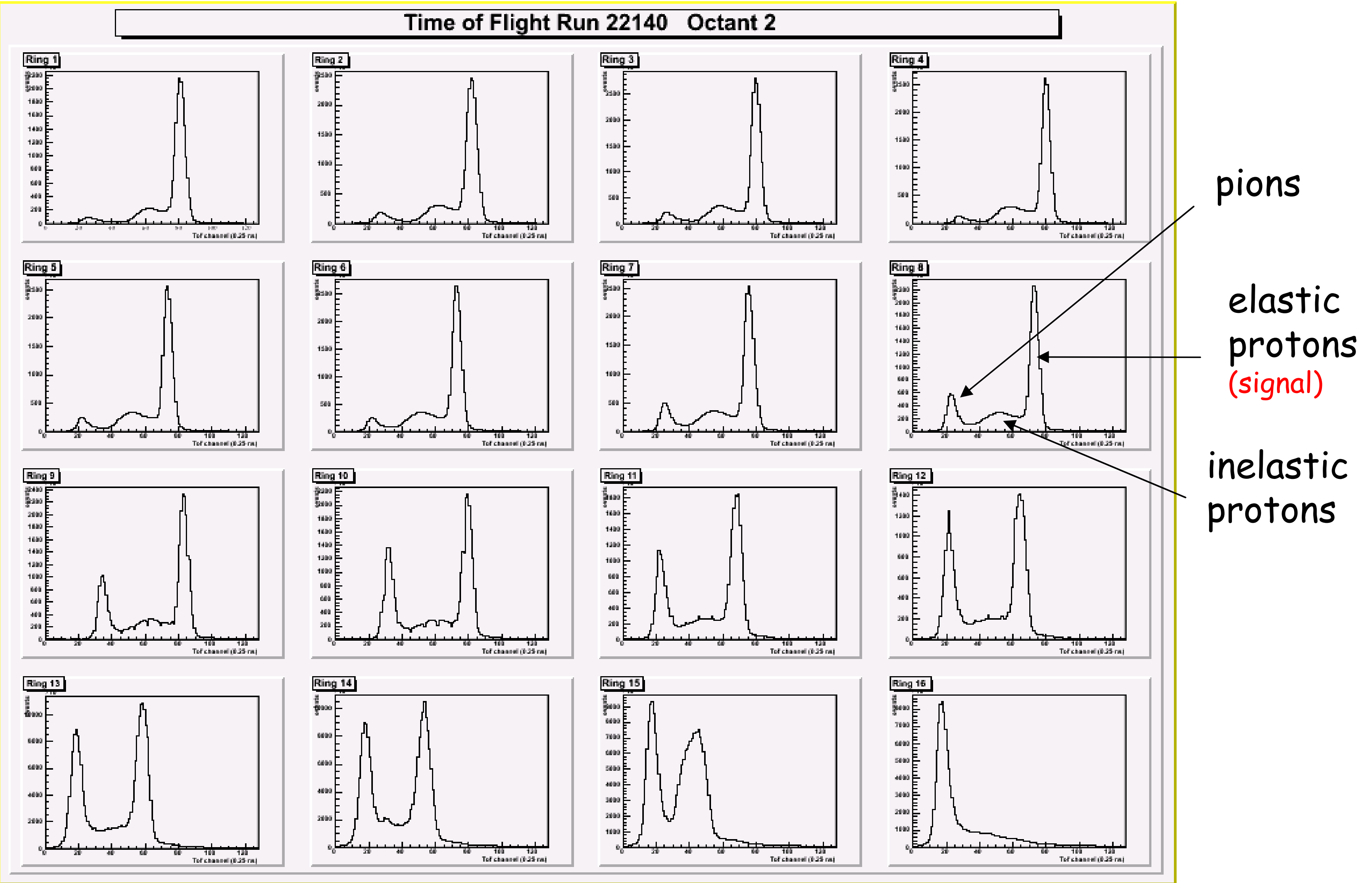


CEBAF polarized injector laser table



Time of Flight Spectra

Time of flight spectra for all
16 detectors of a single octant
- recorded every 33 ms



Forward-Angle Data

- Run: Feb. – May 2004
- 10 TByte data
- 94 Coulombs good data on LH_2 target
- Charge & position Feedback

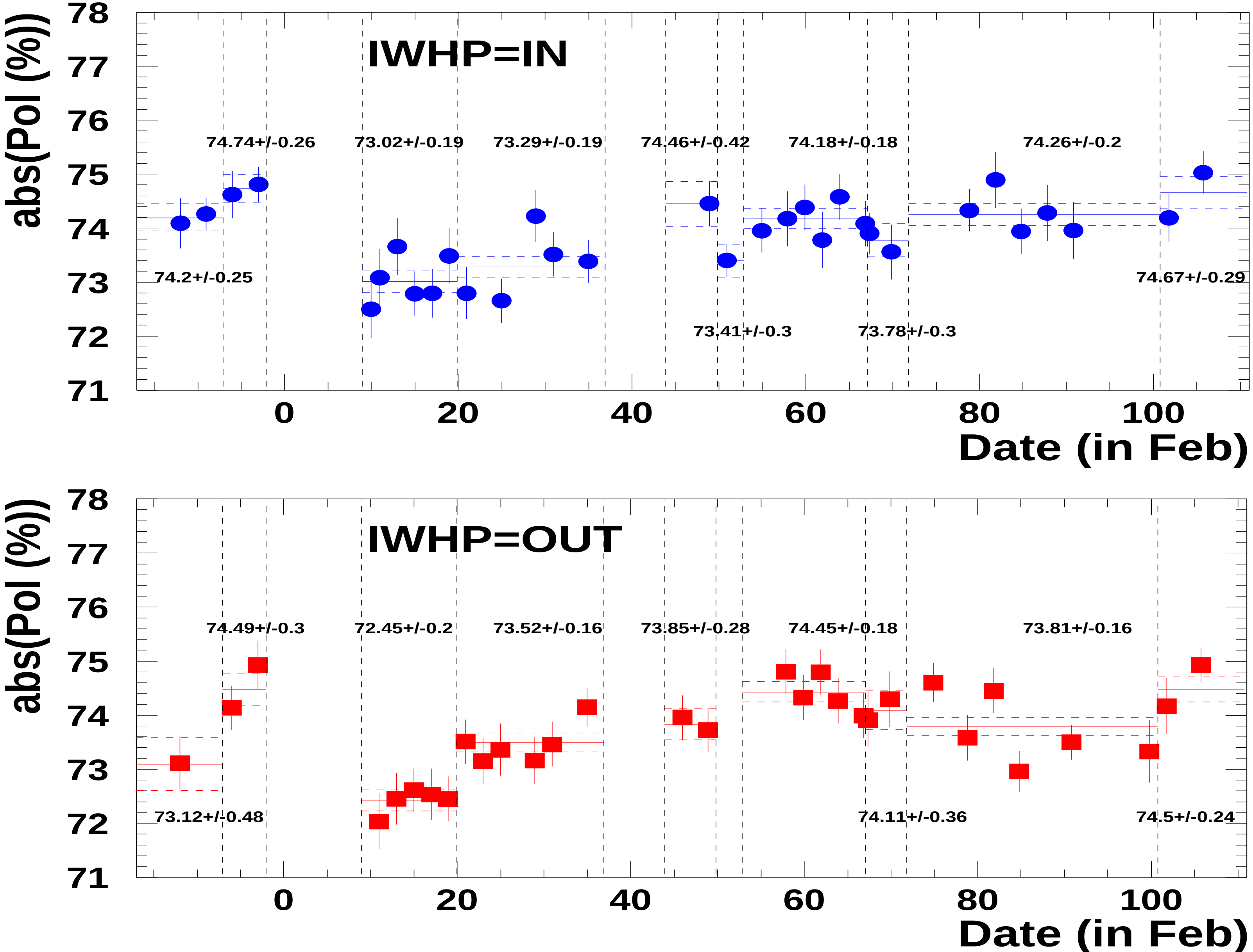
Beam Parameter	Achieved (IN-OUT)	"Specs"
Charge asymmetry	-0.3±0.3ppm	1 ppm
x position differences	6 ± 4 nm	20 nm
y position differences	8 ± 4 nm	20 nm
x angle differences	2 ± 0.3 nrad	2 nrad
y angle differences	3 ± 0.5 nrad	2 nrad
Energy differences	58 ± 4 eV	75 eV

Sensitivities stable

False Asymmetry from Helicity-correlated beam parameters: < 0.01 ppm

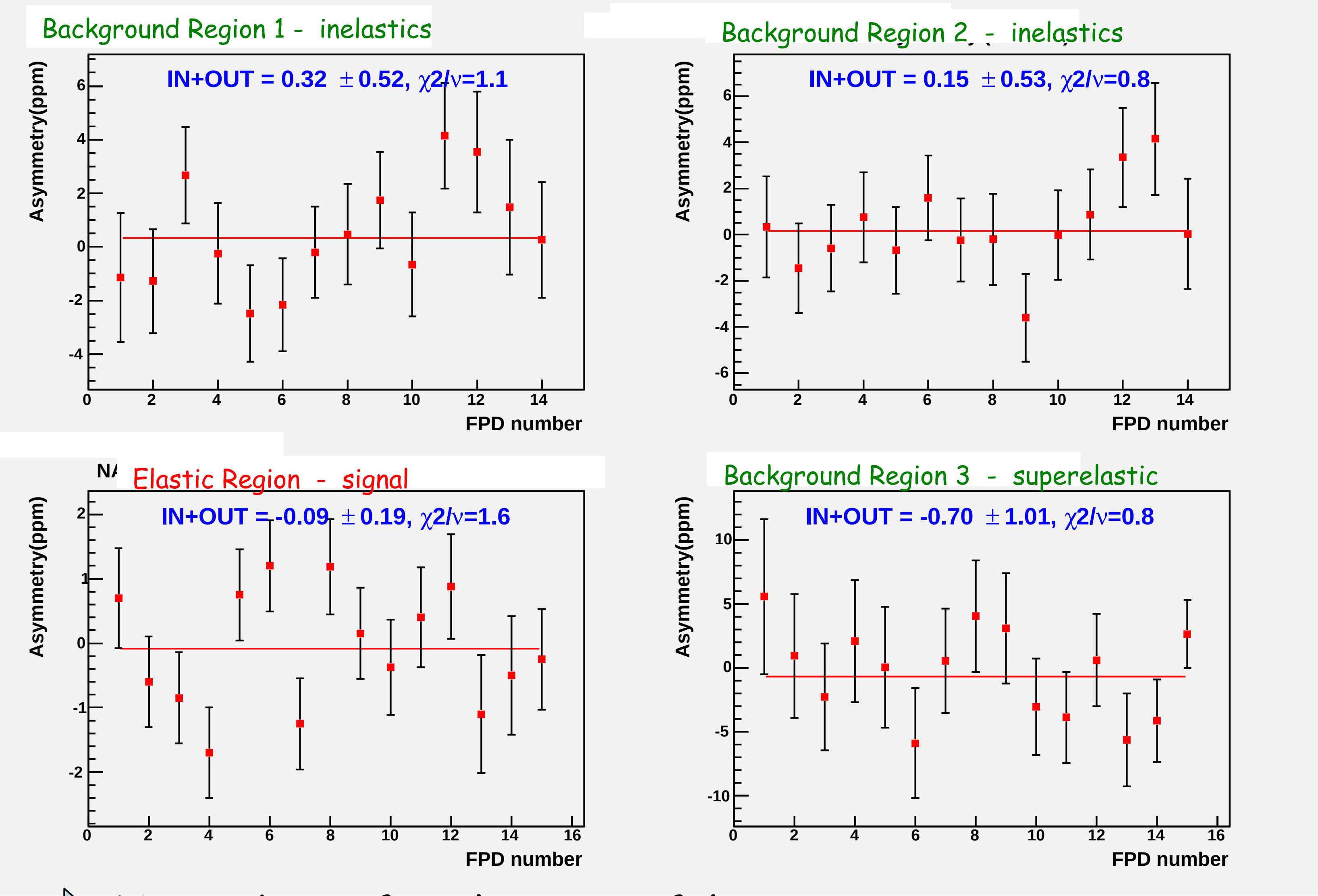
Beam Polarization: Møller Polarimeter

Average polarization: 74 ± 2 %



Behaviour of Asymmetry under half-wave plate reversal

IN + OUT should cancel to zero

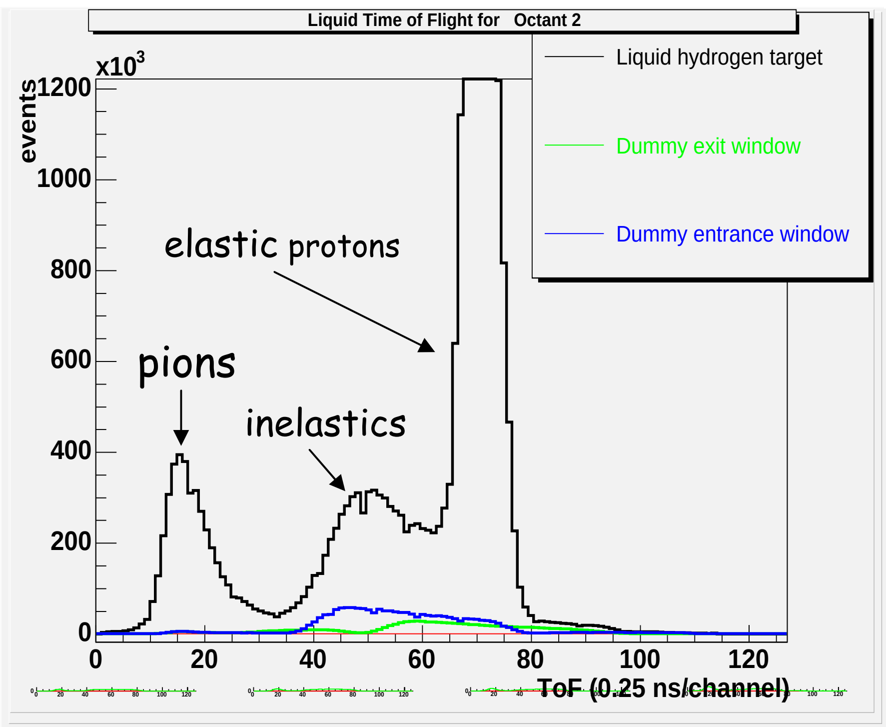


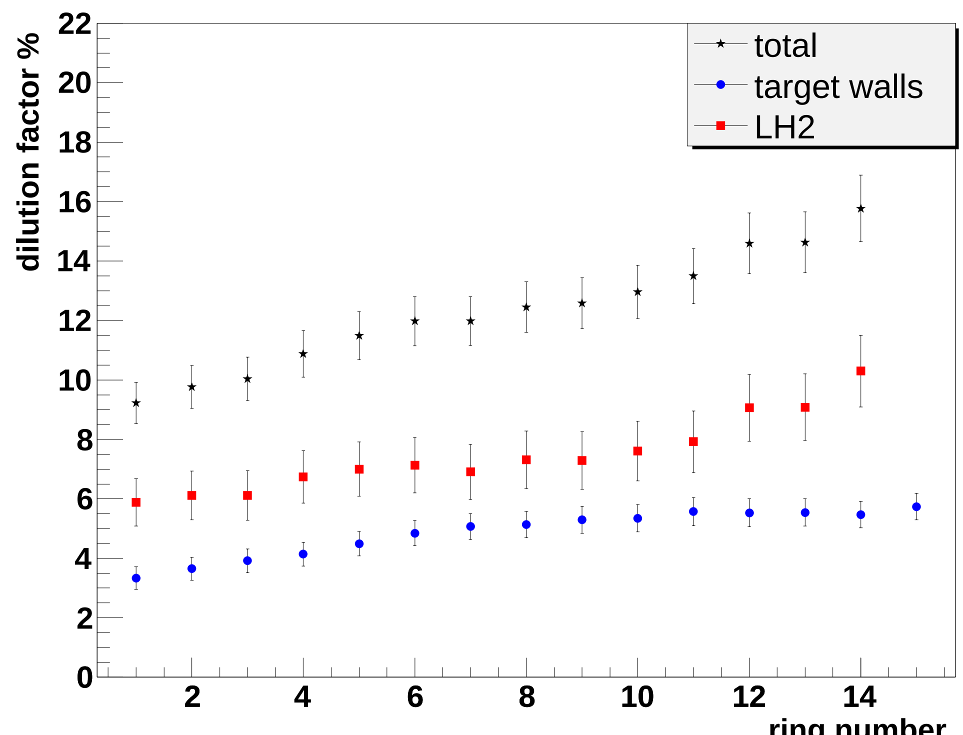
No evidence for electronic false asymmetries

Background Decomposition

- Need to measure dilution of elastic peak & asymmetry of background under peak.
- 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

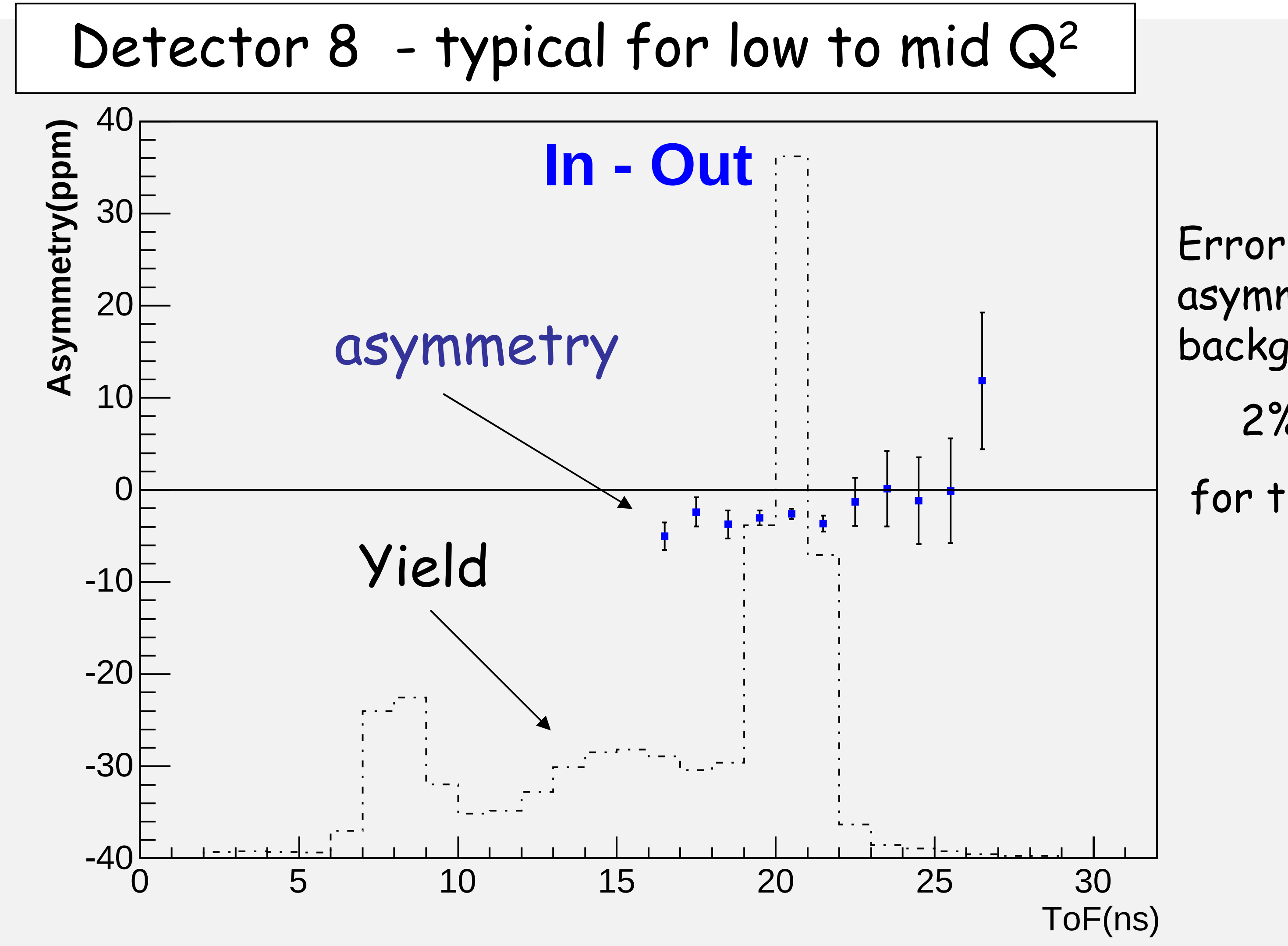




"Side-band" background correction

- Asymmetry and yield measured on either side of elastic peak

  -> smooth interpolation is simple



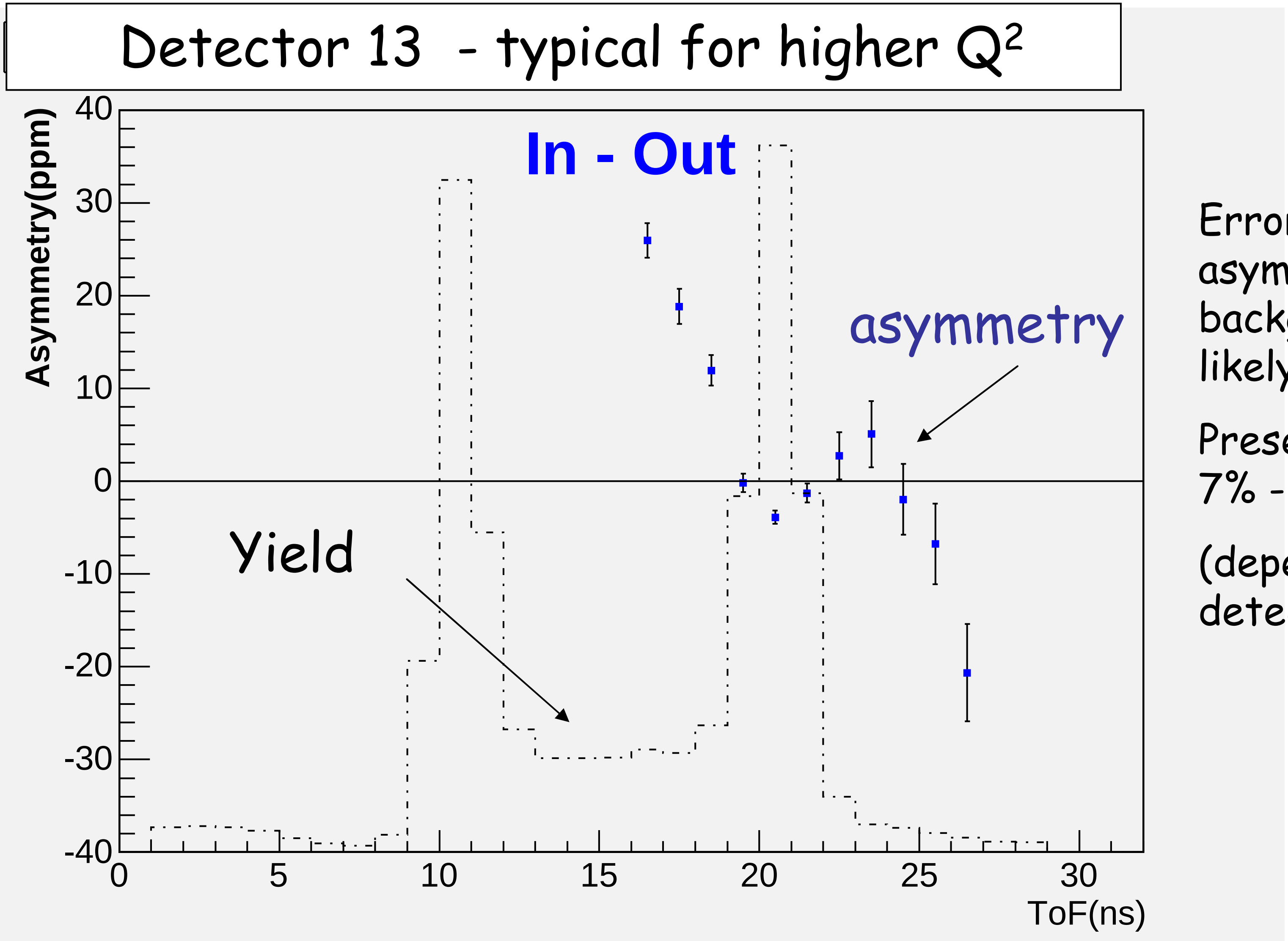
Error in elastic asymmetry due to background is

2% - 5%

for these detectors

"Side-band" background correction @ larger Q^2

- Background asymmetry 'large' & varying significantly under elastic peak



Error in elastic asymmetry due to background will likely dominate here

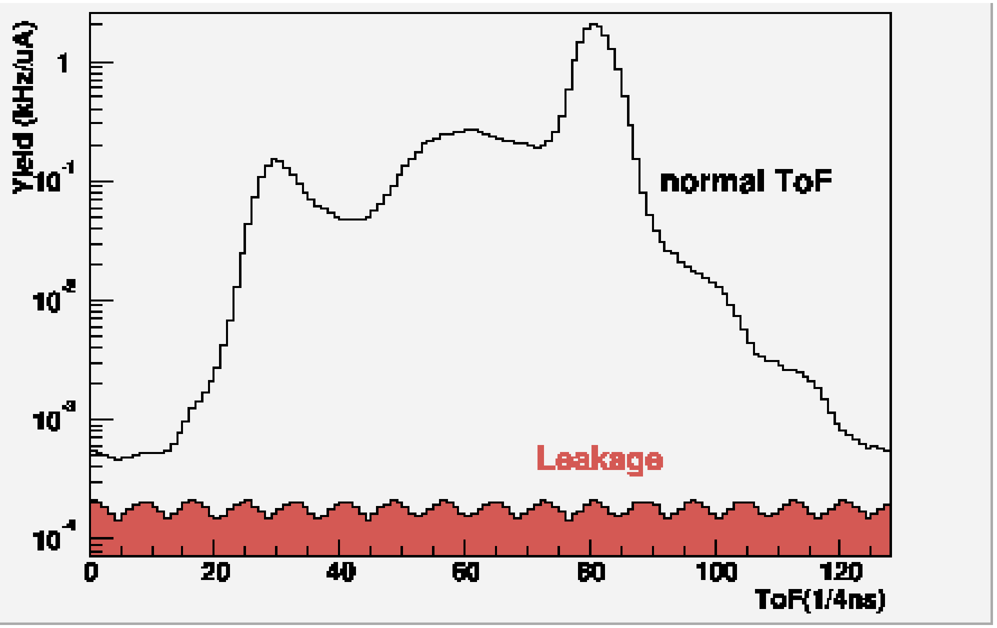
Present estimate: 7% - 20% error

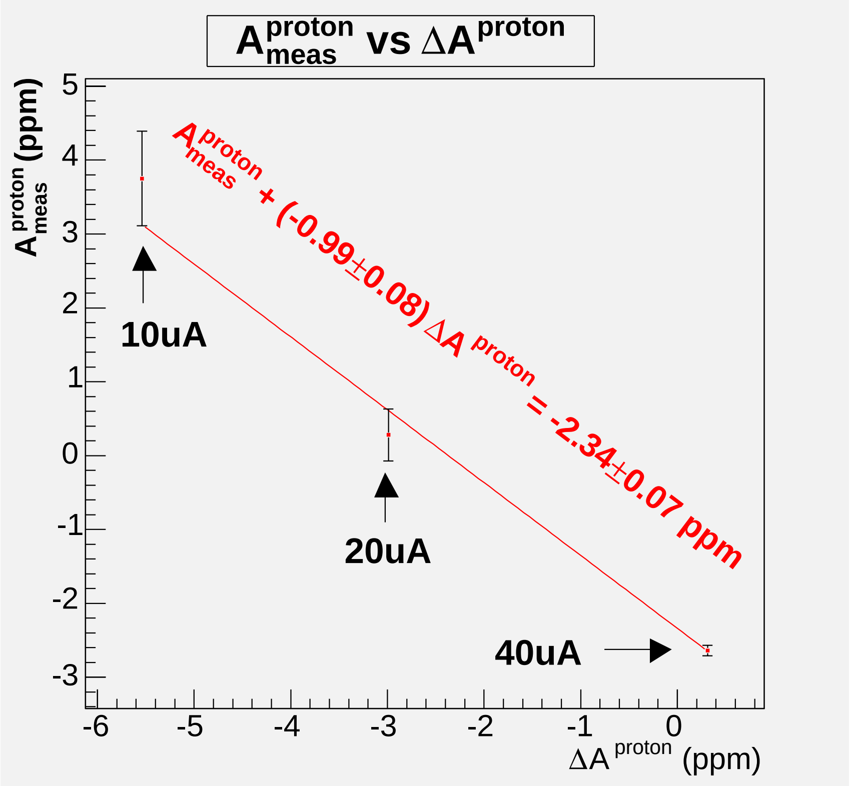
(depending on detector)

Beam 'Leakage' Correction

- unanticipated effect: leakage of beam from Hall A, B lasers into Hall C
- Hall A,B beams are 499 MHz, Hall C beam is 32 MHz
- TOF cuts means elastic signal 'sees' 32 MHz beam, but beam current monitors respond to A+B+C beam; if large current asymmetry in A, B ⟹ false asymmetry
- Measure effect using signal-free region of TOF spectra; verify with studies with other lasers turned off, high-rate luminosity monitors; also verify with low-rate runs.
- typical: 40 nA leakage, 40 μA main beam; leakage asymmetry ~500 ppm

- net systematic error: 0.1 ppm





See Jianglai Liu's poster!

Analysis Path

Start: Raw asymmetries

↓

- Correct for deadtime — 2% error ✓
- False asymmetries (beam parameters) — 0.01 ppm ✓
- 'Leakage' correction — 0.10 ppm ✓
- Beam Polarization — 2% error ✓
- Background dilution & asymmetry — (under study)
- Bin in Q^2 — 1% error ✓
- Radiative Corrections, EM form factors — (to do)

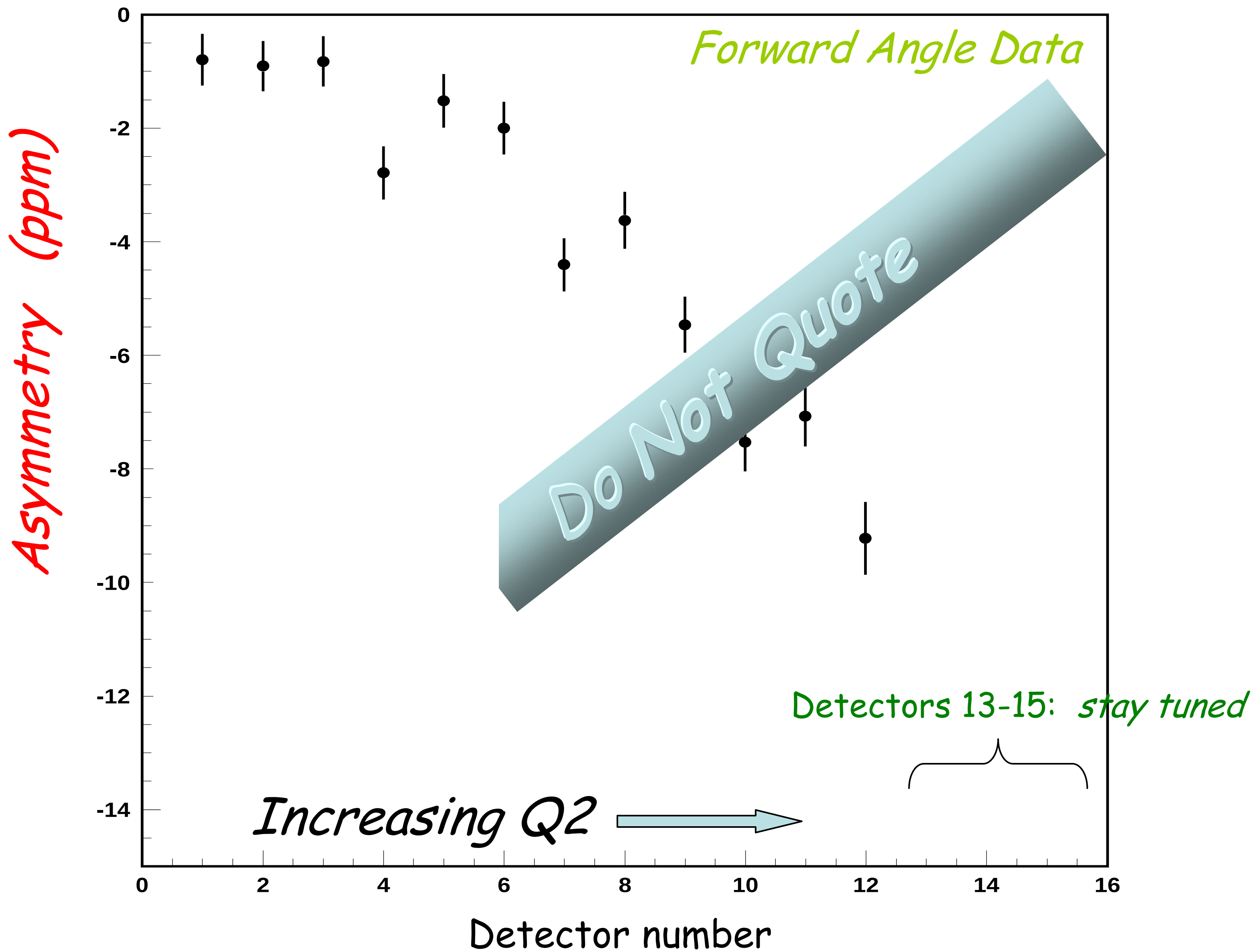
↓

Result: $G_E^s + \alpha G_M^s$

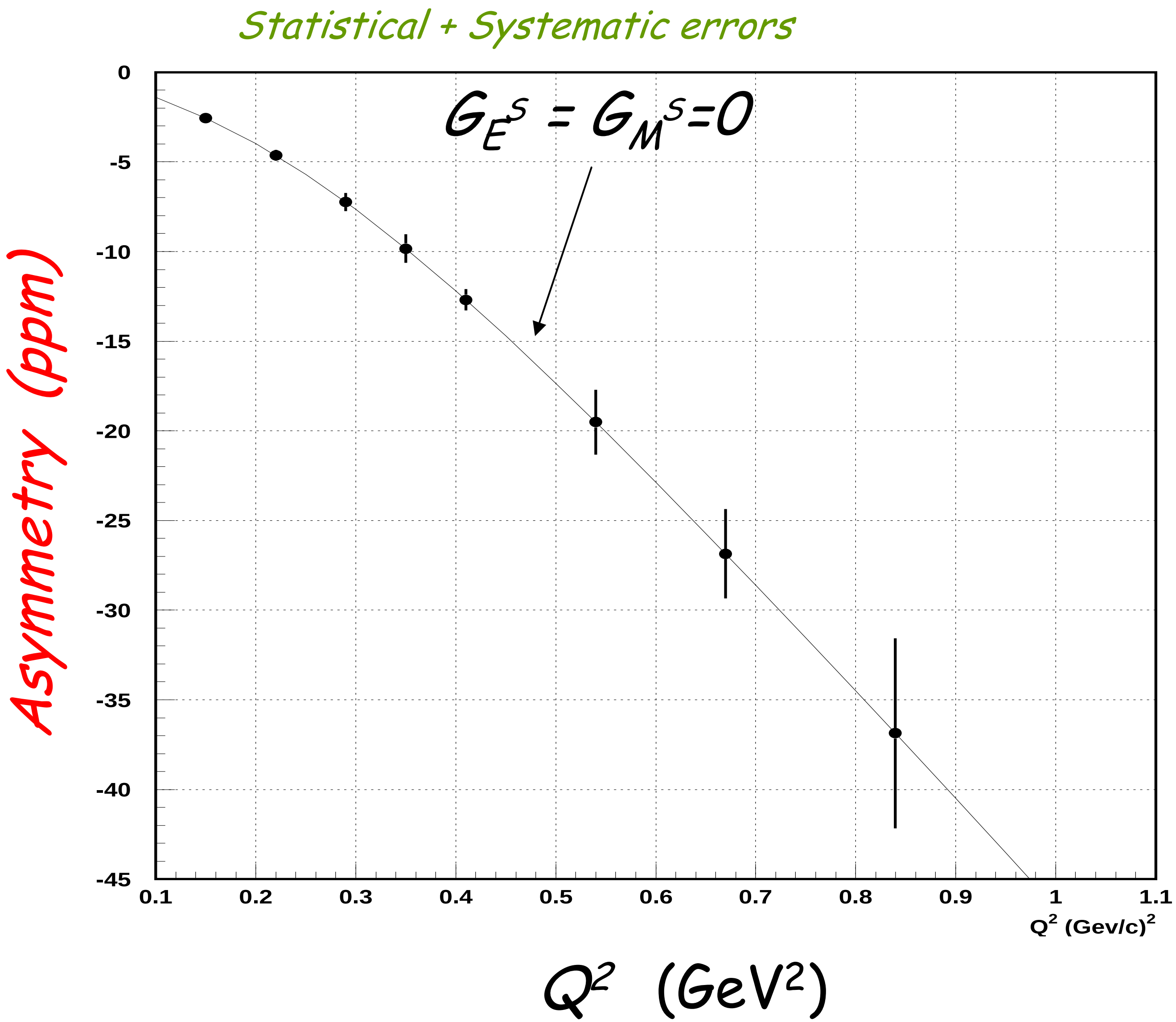
- errors likely dominated by backgrounds, esp. for large Q^2

Preliminary Results - 25% Blinding factor applied

full statistics – present best background correction



Present Precision – Forward angle data



G^0 Backward Angle Measurement

- Detect scattered electrons at $\theta_e \sim 110°$
- At back angles Q^2 only has small variation in G^0 acceptance

  → Need separate runs at E = 424, 576, 799 MeV

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

  for both LH_2 and LD_2 targets

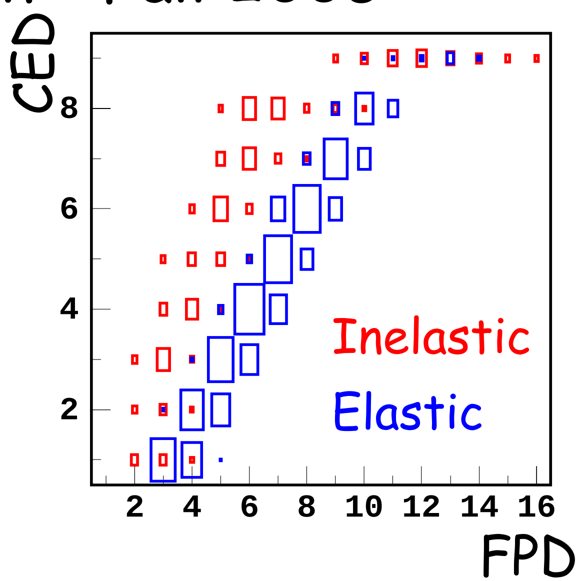
  (total of 6 runs x 700 hours)

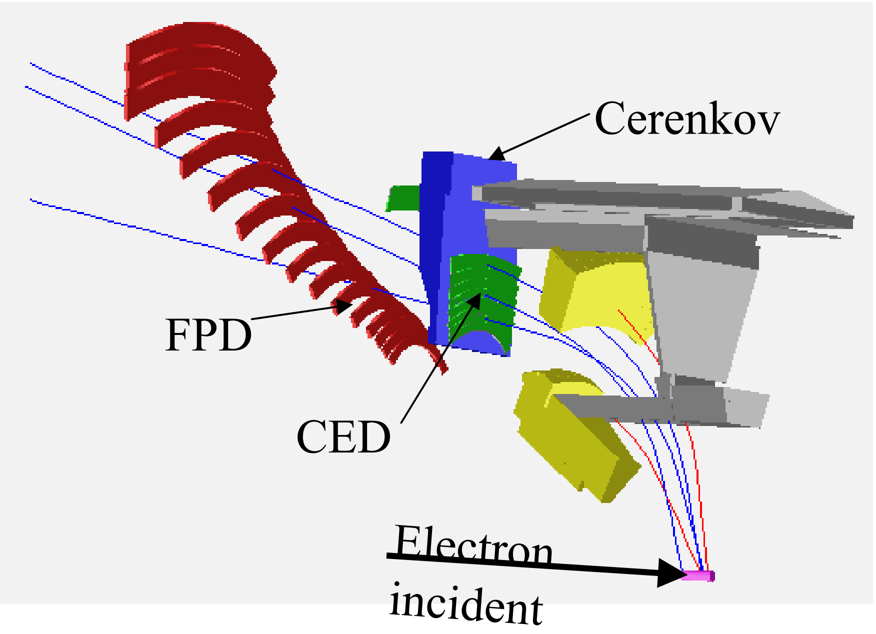
Requires additional detectors:

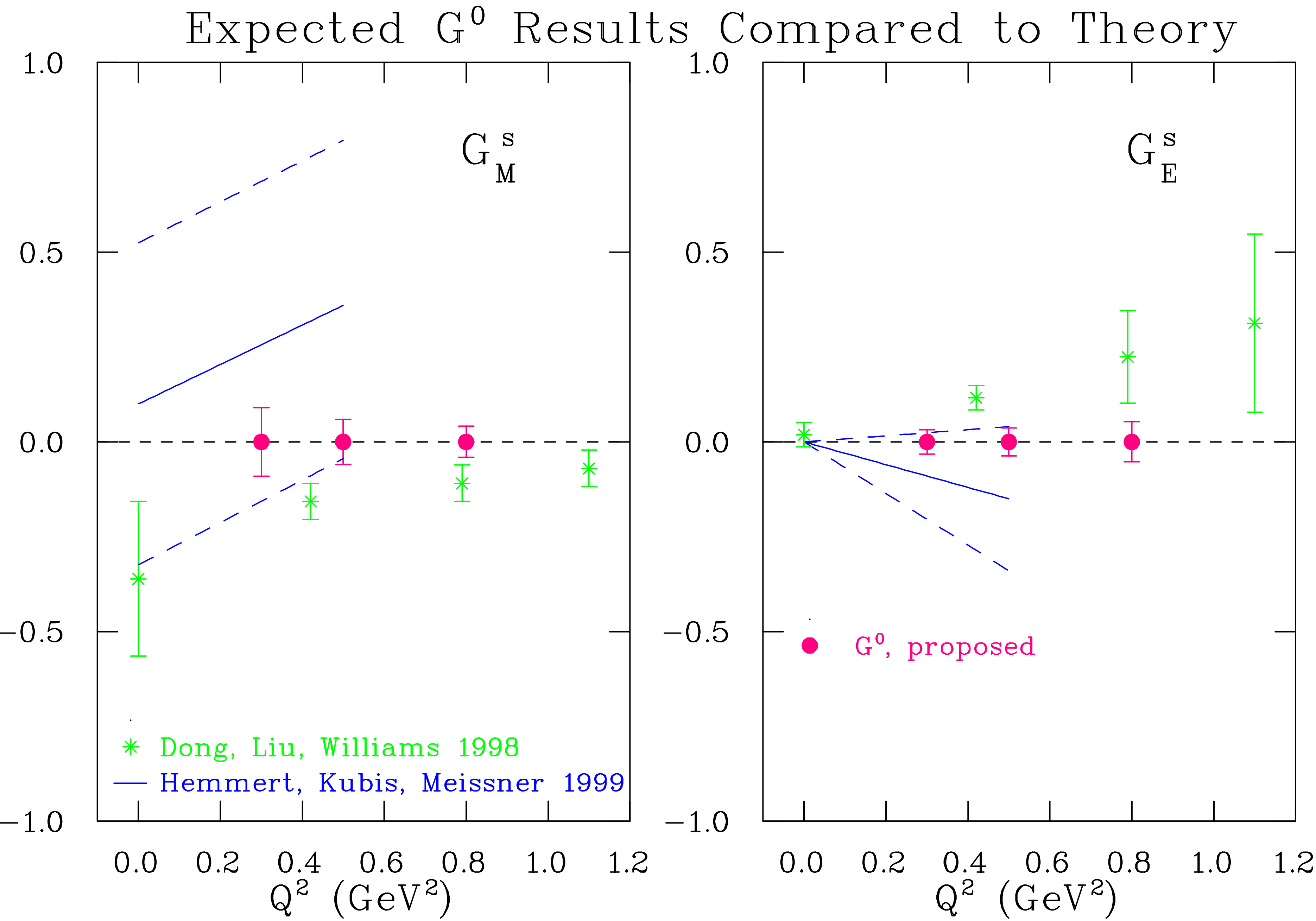
- Cryostat Exit Detectors (CED) to separate elastic and inelastic electrons
- Cerenkov detector for pion rejection (primarily for LD_2 target)

First Run – Fall 2005

CED/FPD coincidences at $Q^2 = 0.3\ GeV^2$






Expected G⁰ Results Compared to Theory
G s M
G s E
1.0
0.5
0.0
−0.5
−1.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2
Q² (GeV²)
Dong, Liu, Williams 1998
Hemmert, Kubis, Meissner 1999
G⁰, proposed

Summary and Outlook

- G^0 Forward Run Complete, analysis well underway
- Backgrounds will likely dominate errors
- First Backward angle run: Fall 2005 (tentatively)
- In a few years: separated strange form factors of nucleon vs. Q^2

Strange quark contributions at 5-10% level?

→ *still open question! (see next two talks!)*