G0: Results and Outlook

Goals of G0 Experiment:

- Determine Q^2 dependence of a combination of G^s_E and G^s_M over range $0.1 \leq Q^2 \leq 1.0$ GeV^2 ✓
- Determine G^s_E and G^s_M separately for 3 specific Q^2 values

Greg Smith
JLab
August 18, 2005

Outline:

- Forward Angle Experimental Setup
- " " Analysis, Background, & Uncertainties
- " " Experiment Results
- Backward Angle Experiment

Acknowledgement: Many slides originally from D. Beck

G0 Collaboration

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Legend: Students Post-docs Honchos Everyone else

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G0 Status

- **Forward Angle**
  - Experiment is done… (whew!)
  - See results, etc. at http://www.npl.uiuc.edu/exp/G0/Forward/index.html
  - PRL accepted, expect publication 9/05
  - Detailed Phys Rev C article forthcoming
  - Instrumentation papers
    - Target NIM paper: nucl-ex/0502019
    - General instrumentation paper: in progress

- **Backward Angle**
  - $Q^2 = 0.8$ experiment approved
    - Installation starts 10/05
    - Beam time starts 3/06
  - Asking for $Q^2 = 0.23$ & 0.48 at PAC next week
    - Possible summer '06 run at $Q^2 = 0.23$ (single-user)

Quark Currents in the Nucleon

- Measure $G^{\gamma,p}, G^{Z,p}, G^{\gamma,n}$: $\quad G \sim \langle N | \sum_i e_i \bar{q}_i \Gamma_\mu q_i | N \rangle$
  - e.g. $G_{E,M}^{i,p} = e^{i,u} G_{E,M}^{u,p} + e^{i,d} \left(G_{E,M}^{d,p} + G_{E,M}^{s,p} \right)$

Charges	u	d,s
g	2/3	-1/3
Z	$1-8/3\sin^2\theta_W$	$-1+4/3\sin^2\theta_W$

  - note

$$G^{u,p} = G^{d,n}$$
$$G^{d,p} = G^{u,n}$$
$$G^{s,p} = G^{s,n}$$

charge symmetry

(see G. A. Miller, PRC **57** (98) 1492.)

then

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

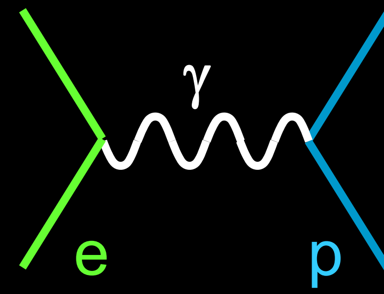
flavor decomposition

Parity-Violating Electron Scattering

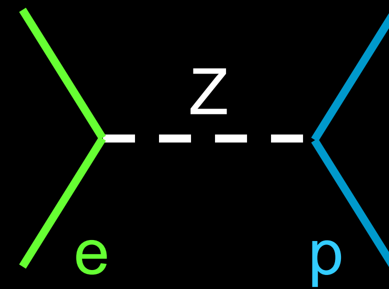
- $G^{Z,p}$ contributes to electron scattering

$$\sigma \propto \left| M^{\gamma} + M^{Z} \right|^2$$

- interference term: **large** M^{γ} x small M^{Z}



- Interference term violates parity: use $(\vec{e}, e')$



$$A^{PV} \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

$$= -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha} \frac{A_E + A_M + A_A}{\varepsilon \left(G_E^{\gamma}\right)^2 + \tau \left(G_M^{\gamma}\right)^2}$$

where

$$A_E = \varepsilon(\theta) G_E^{\gamma} G_E^{Z}, \quad A_M = \tau G_M^{\gamma} G_M^{Z}$$

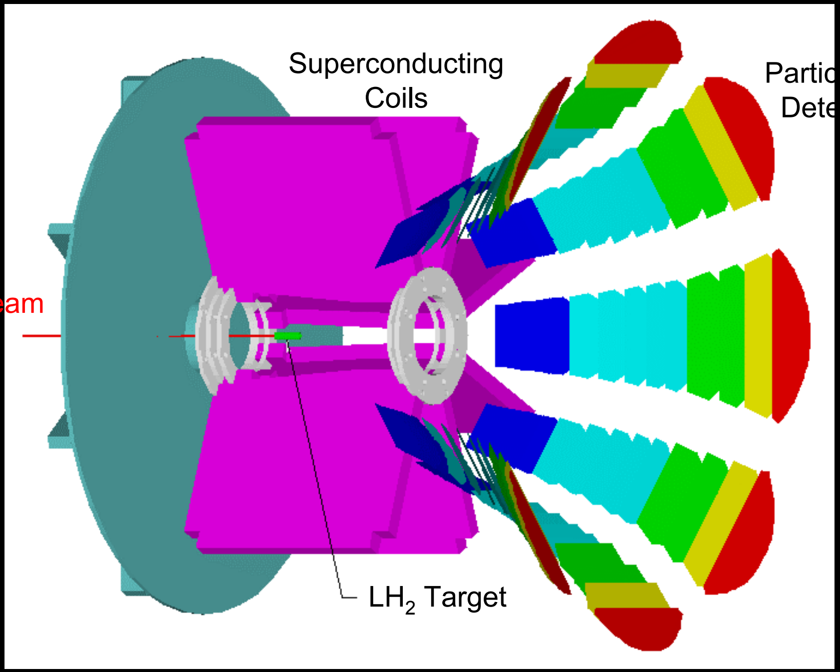
$$A_A = -\left(1 - 4\sin^2\theta_W\right) \varepsilon'(\theta)\, G_M^{\gamma} G_A^{e}$$

$$\varepsilon(\theta) = \left[1 + 2(1+\tau)\tan^2(\theta/2)\right]^{-1},$$

$$\tau = \frac{Q^2}{4M_p^2},$$

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

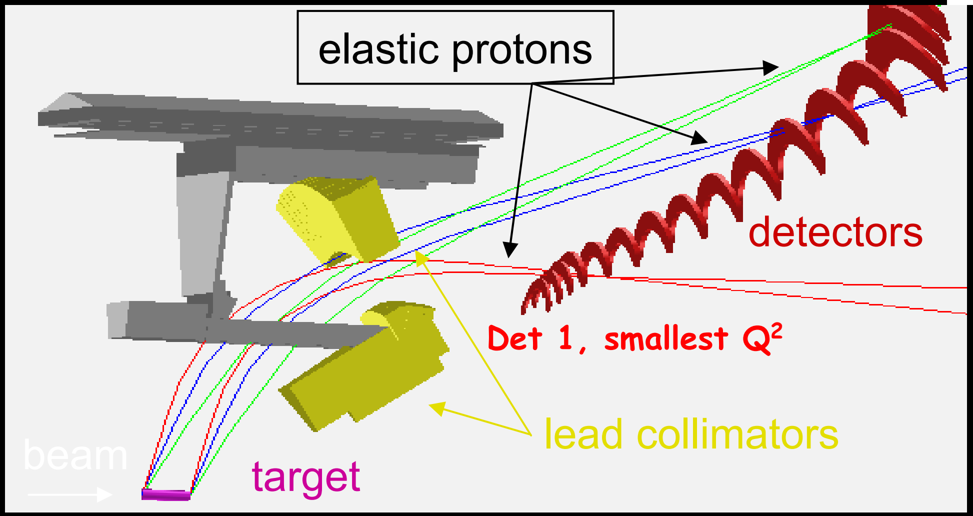
G0 Experiment Overview



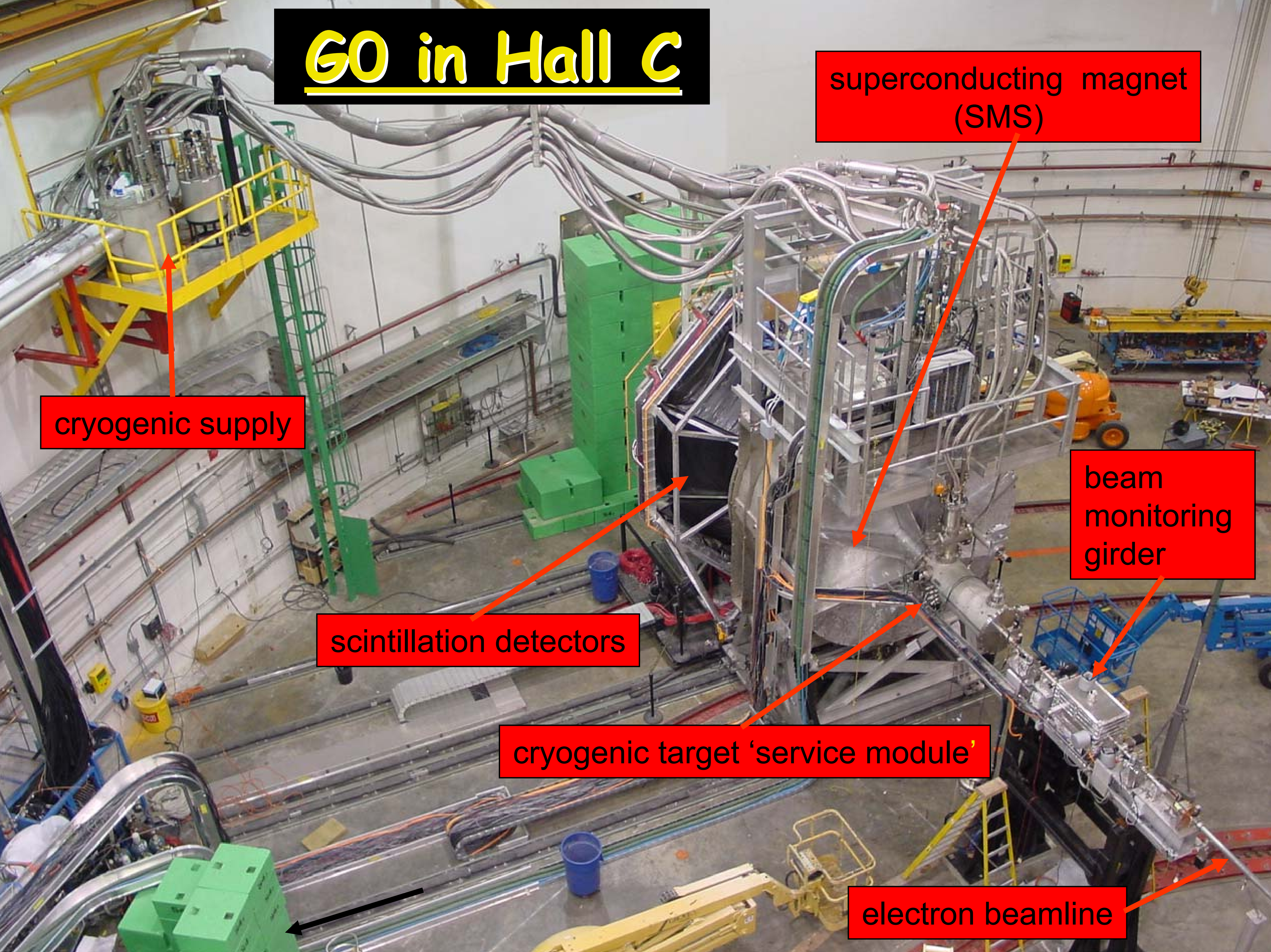
	Forward	Backward
E_{beam} (GeV)	3.03	0.36 – 0.8
I_{beam} (μA)	40	80
P_{beam} (%)	75%	80%
Θ (deg)	52°-76°	104°-116°
$\Delta\Omega$ (sr)	0.9	0.5
L_{target} (cm)	20	20
L (cm^{-2} s^{-1})	2.1×10^{38}	4.2×10^{38}
A (ppm)	-1 to -50	-12 to -70

acceptance $0.12 < Q^2 < 1.0$ GeV^2
for 3 GeV beam

- Measure forward and backward asymmetries
  - recoil protons for forward measurement
  - electrons for backward measurements
    - elastic/inelastic for ^{1}H, quasi-elastic for ^{2}H



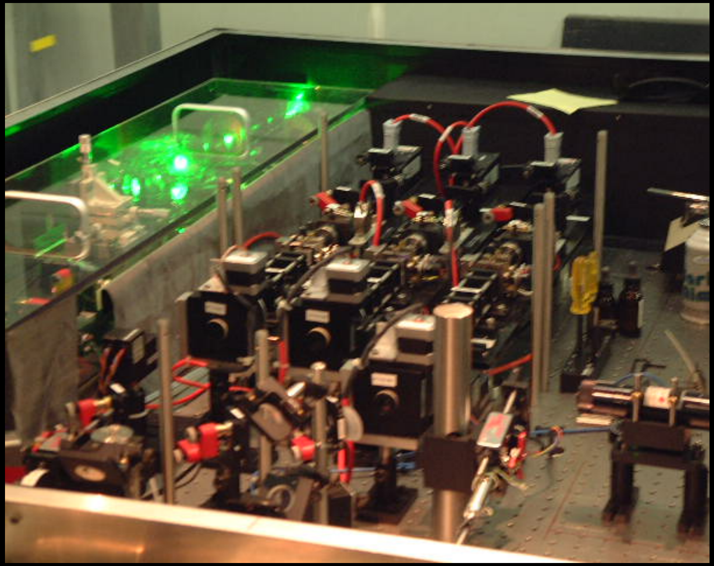
G0 in Hall C


superconducting magnet (SMS)
cryogenic supply
beam monitoring girder
scintillation detectors
cryogenic target 'service module'
electron beamline

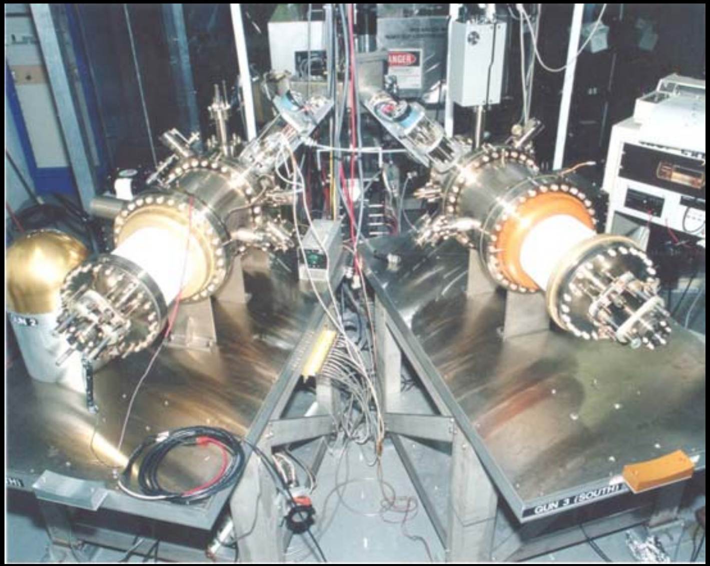
Polarized Injector/Accelerator

- Challenging specifications – all met!
  - 32 ns pulse spacing for t.o.f.
  - 40 μA beam current
    - higher bunch charge
  - Active charge & position feedback (injector)

Beam Parameter	Achieved	"Specs"
Charge asymmetry	-0.14 ± 0.32 ppm	1 ppm
x position differences	3 ± 4 nm	20 nm
y position differences	4 ± 4 nm	20 nm
x angle differences	1 ± 1 nrad	2 nrad
y angle differences	1.5 ± 1 nrad	2 nrad
Energy differences	29 ± 4 eV	75 eV



New Tiger laser system for G0

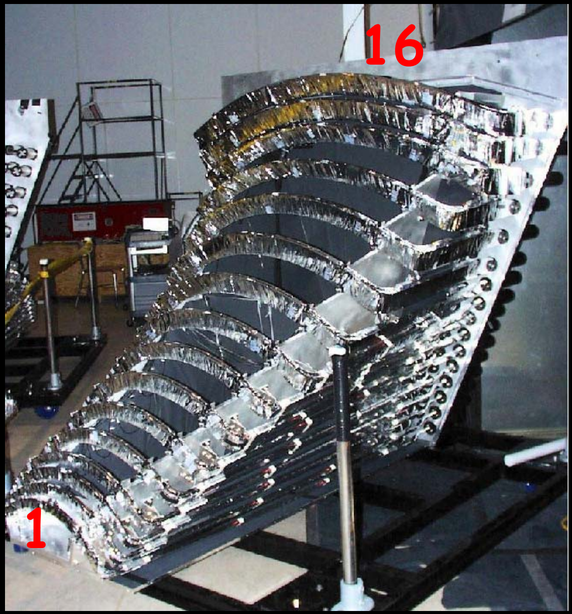


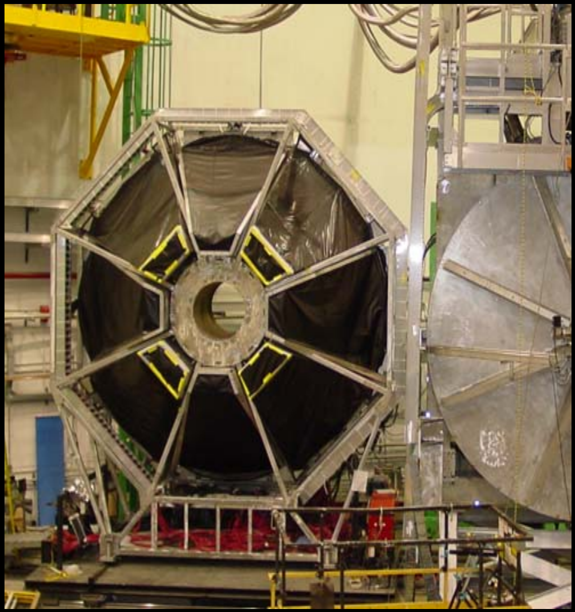
JLab polarized injector

Detectors

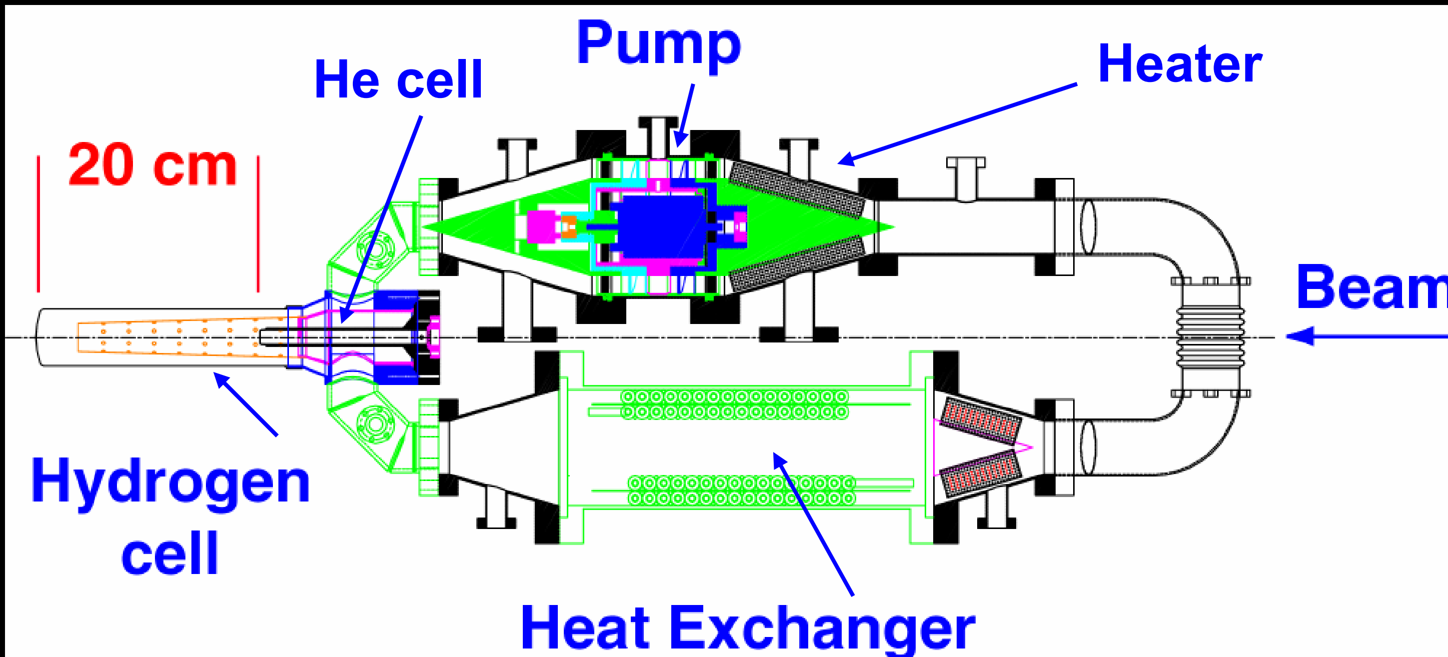
- 16 detectors per octant
- Arc shape (const. Q^2)
- Each detector: scintillator pair
  - BC408: 0.5, 1.0 cm thick
  - 1/8 in. shielding in-between
  - ≤ 4 MHz / detector pair
- PMT at each end of each scintillator
  - XP2262B (NA), XP2282B (Fr)
- Signal: mean-time-front .AND. mean-time-back
- Assembled with ~ 2 mm accuracy
- Octants in light-tight enclosures

- Essentially unshielded!





Target



CalTech

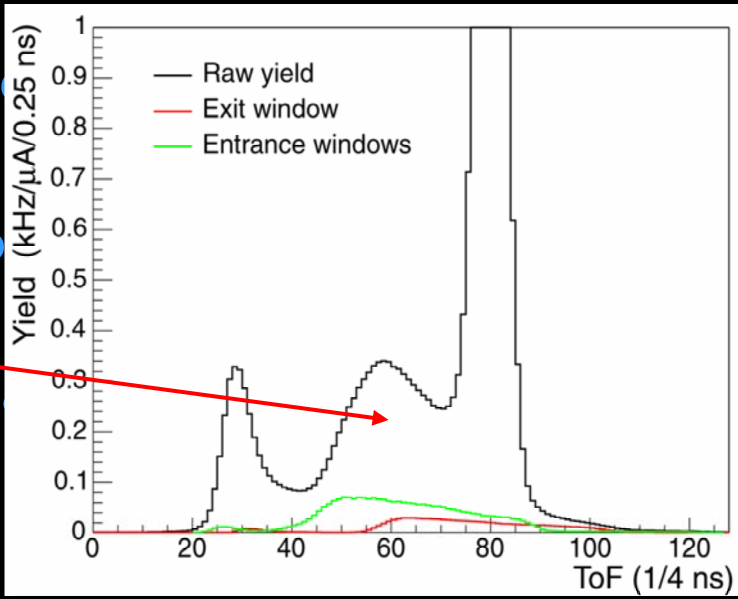
Ran 10 months without a major problem

- 20 cm LH_2, with He backing cell
- LH2 cell 7 mils Al, with 3 mil nipple
- longitudinal flow, v ~ 7 m/s, P ~ $\frac{1}{2}$ kW
- negligible $\Delta\rho/\rho$ < 1.5%
- boiling small:
  - 260 ppm/1200 ppm stat. width

Analysis

Sources of Background

- Understanding bkg was a major goal
  - It was bigger than expected → treate
- Sources (all protons in tof spectrum):
  - Quasi-elastic in Al cell windows & He b
  - Inelastic in H2 & Al cell windows & He
  - Bremsstrahlung g's interacting in LH2
  - Hyperon production & decay
- Explicit measurements:
  - Used a W radiator outside the acceptance (matched to LH2 X_0) in conjunction with a retractable Al (flyswatter) tgt
  - Used a thick (self-radiating) Al dummy tgt by itself
  - "Empty" cell with 2 different temperatures of cold H2 gas
- Monte Carlo



Bottom line: A successful description and understanding of the background was achieved

Det. 1-14 Background Uncertainty

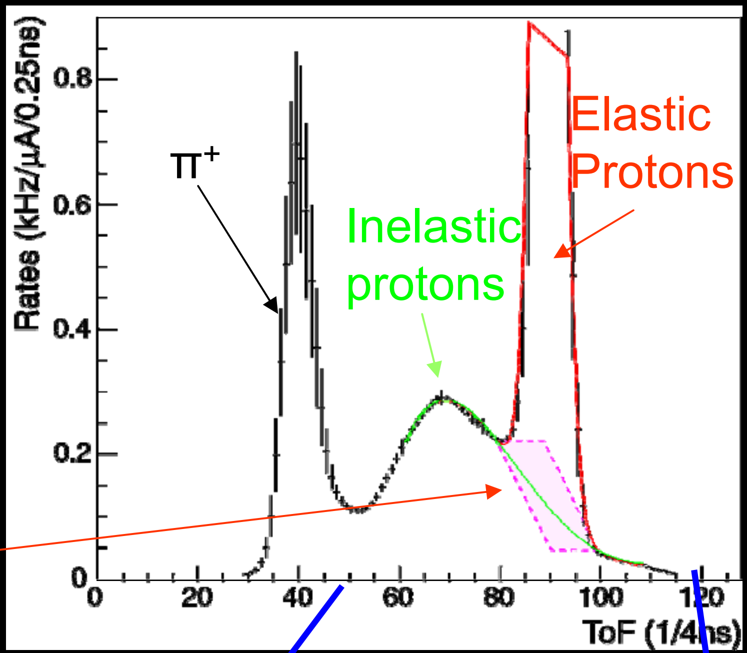
- Measure Y & A of entire spectrum
- Correct asymmetry according to

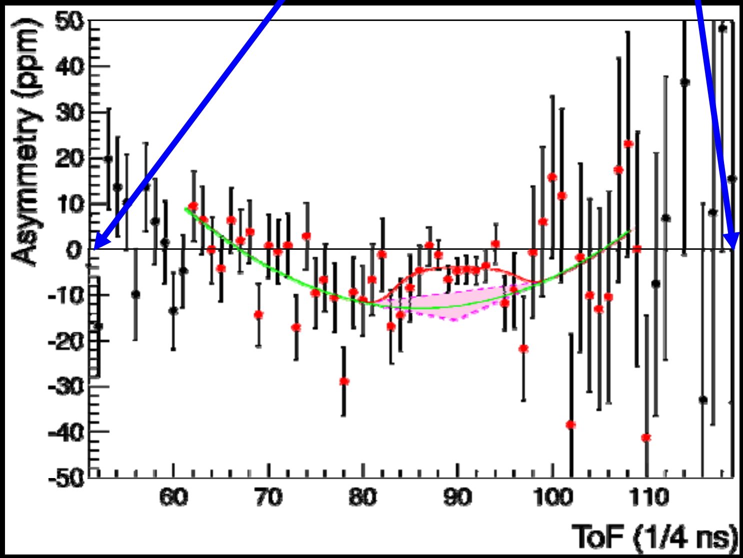
$$A_{meas} = (1 - f)A_{el} + f A_{back}$$

where A_{el} is the raw elastic asymmetry, and

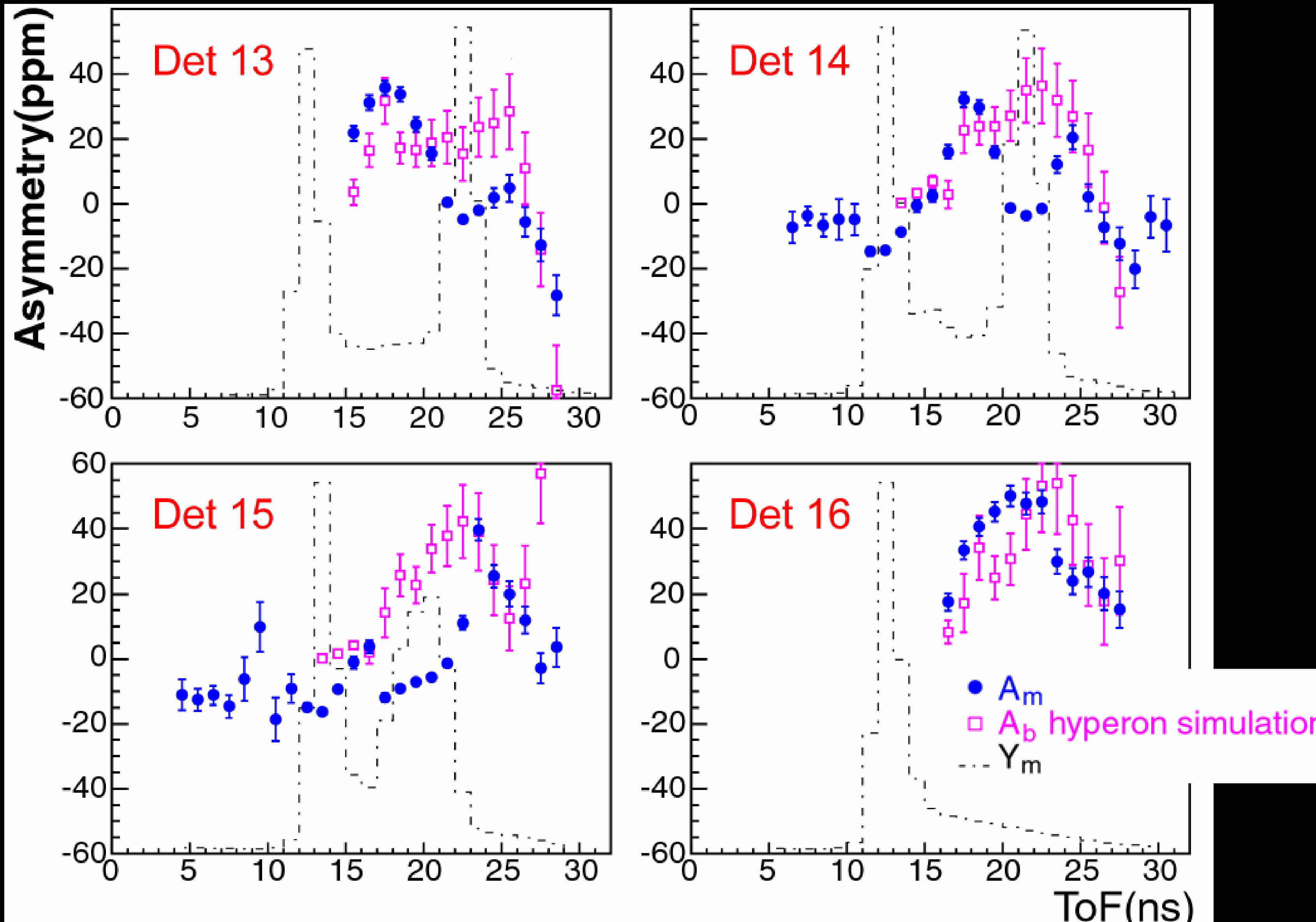
$$f = \frac{Y_{back}}{Y_{meas}}$$

- Bkg yield varied within "lozenge"
  - use a variety of shapes
  - fit Y_{back} with poly'l of degree 4, Gaussian for elastic peak
- Similar approach for asymmetry
  - vary throughout range
  - fit A_{back} *with* poly'l of degree 2, constant A_{el}
- <u>Conservative !</u>



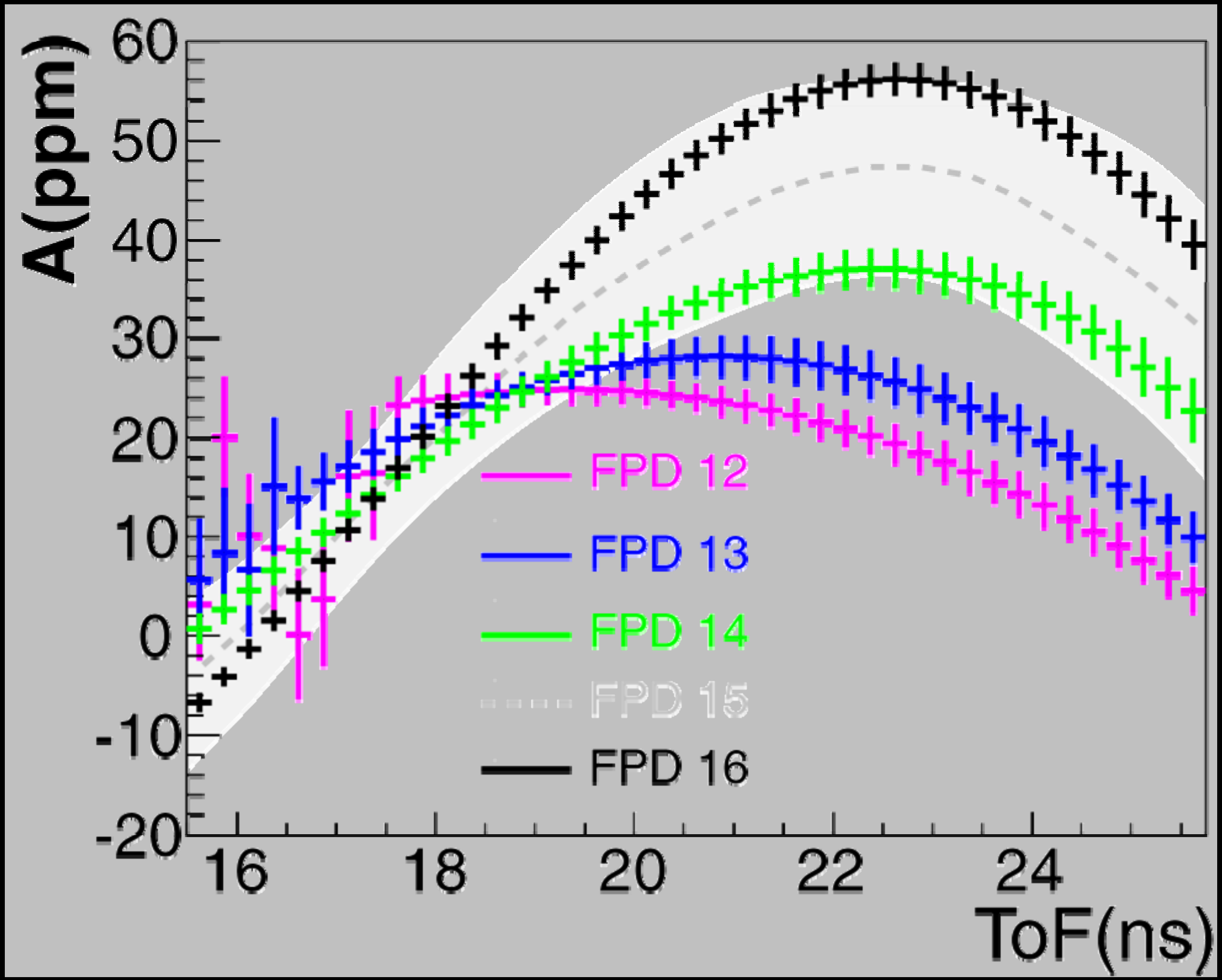


Positive Background Asymmetries: GEANT



Det. 15 Background Asymmetry

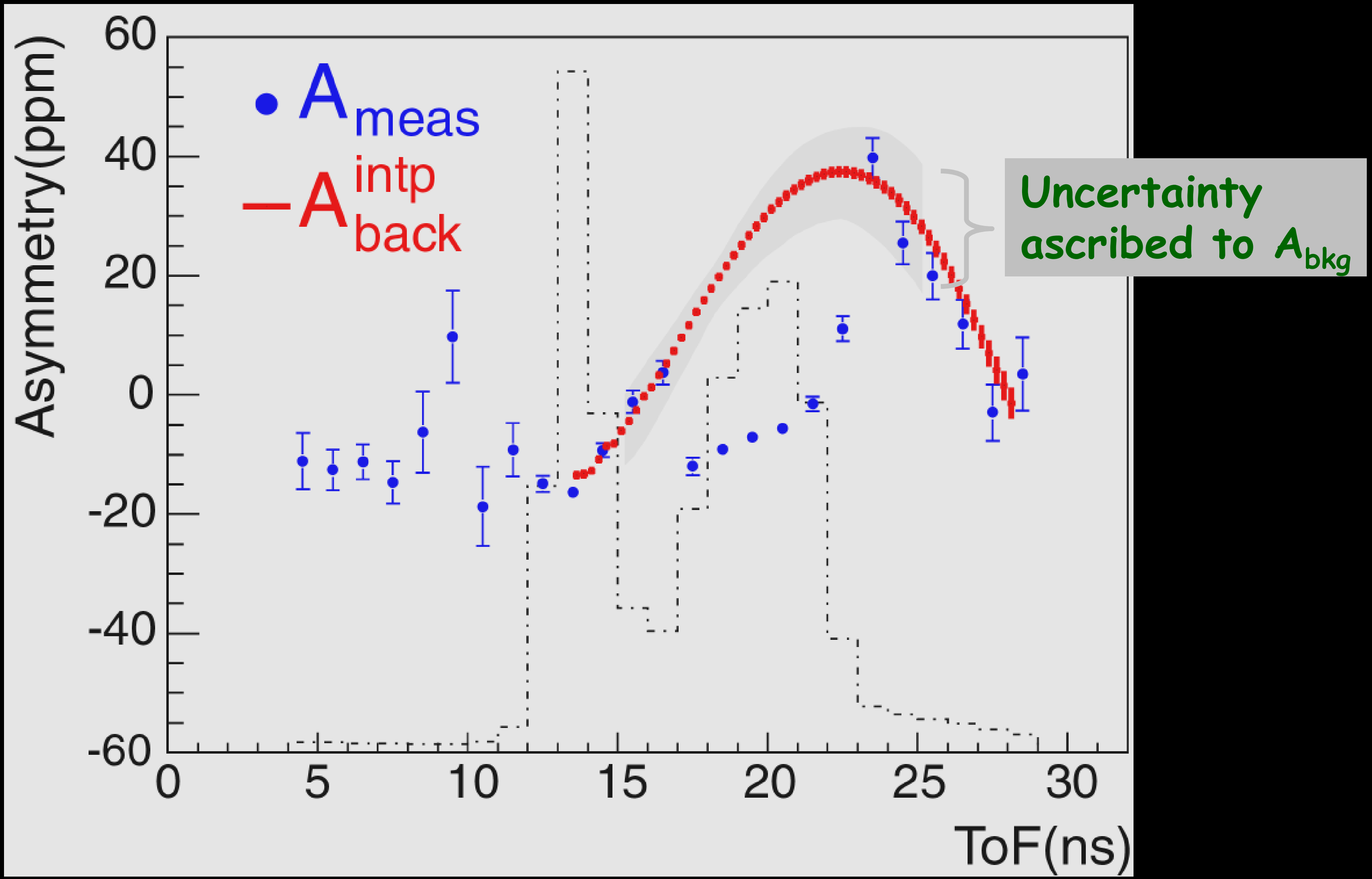
- Use smoothed interpolation of A_{back} from det. 12-14, 16
- Uncertainties are ± 1 detector AND ± 0.5 ns time shift



- Note: Det. 16 has (by design) no elastic acceptance.
- Note: G0 data above $Q^2 \sim 0.4$ come from detectors 14 & 15

Det. 15 Asymmetry

- Compare interpolated background asymmetry and data



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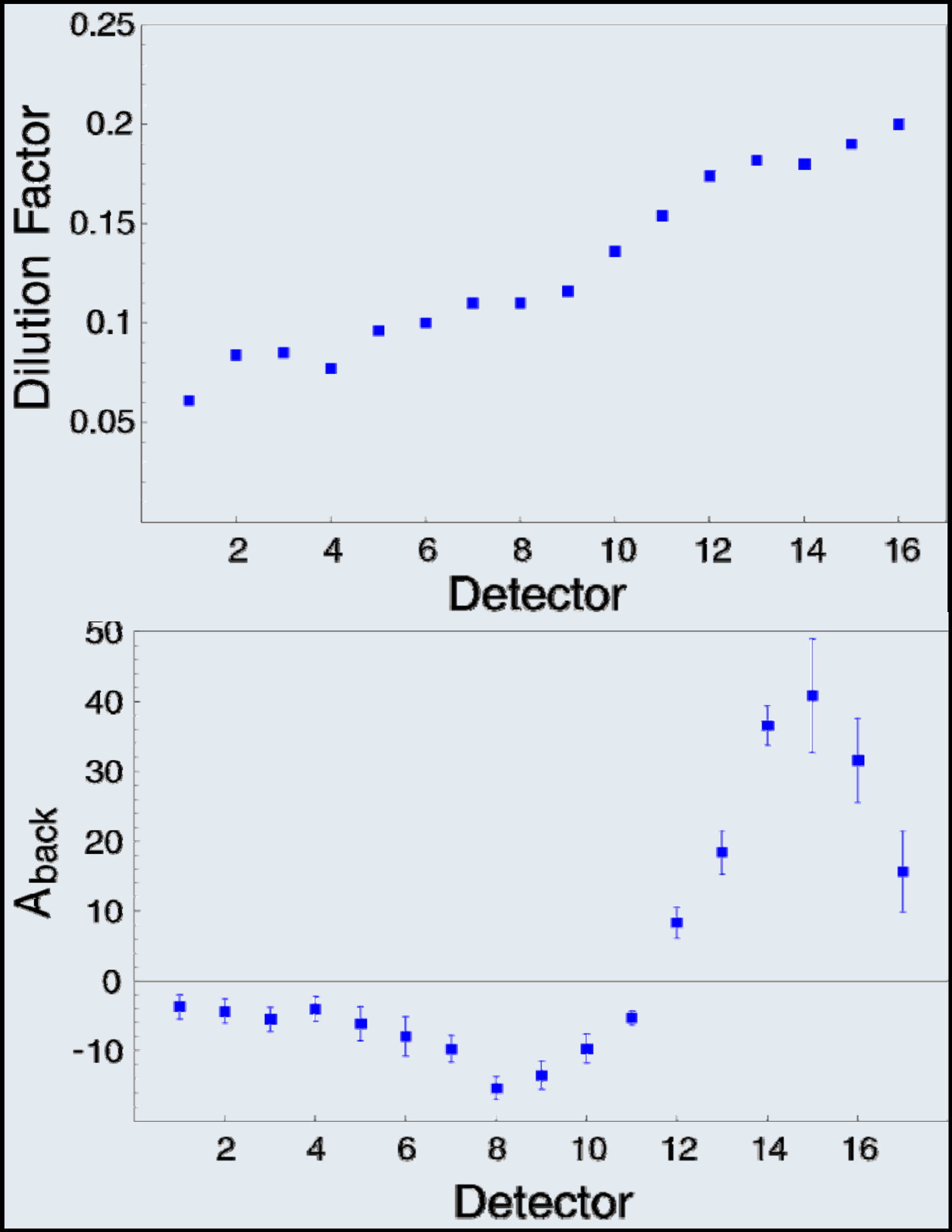
Dilution factor and Background Asymmetry

- Smooth, systematic progression
  - dilution factor
  - background asymmetry
- But, A_{bkg} pretty big…
  - Conservative errors
  - Separate point-to-point and global uncertainties
    - From, eg, different functional forms
  - Quasi-independent analyses
    - All agreed



Other Corrections

- Large (positive) bkg asymmetry from Λ & Σ decays
  - Shape well described by MC → understood
- Transverse beam polarization
  - Explicitly measured (resulting uncertainty only 0.01 ppm)
- Leakage beam
  - $\sim 10^{-3}$ of I_{beam} was (A/B/C) leakage with 2ns time structure
  - Outside scope of nominal 32 ns IA → large IA for the leakage beam (~570 ppm)
  - Measured explicitly
    - Pure leakage from each hall's laser (inter-hall cooperation!)
    - In forbidden regions of tof spectrum
  - Understood, accounted for a +0.71 ± 0.14 ppm correction
- Deadtime
  - Typically 10-15%. Corresponding ΔA ~ 0.05 ppm.

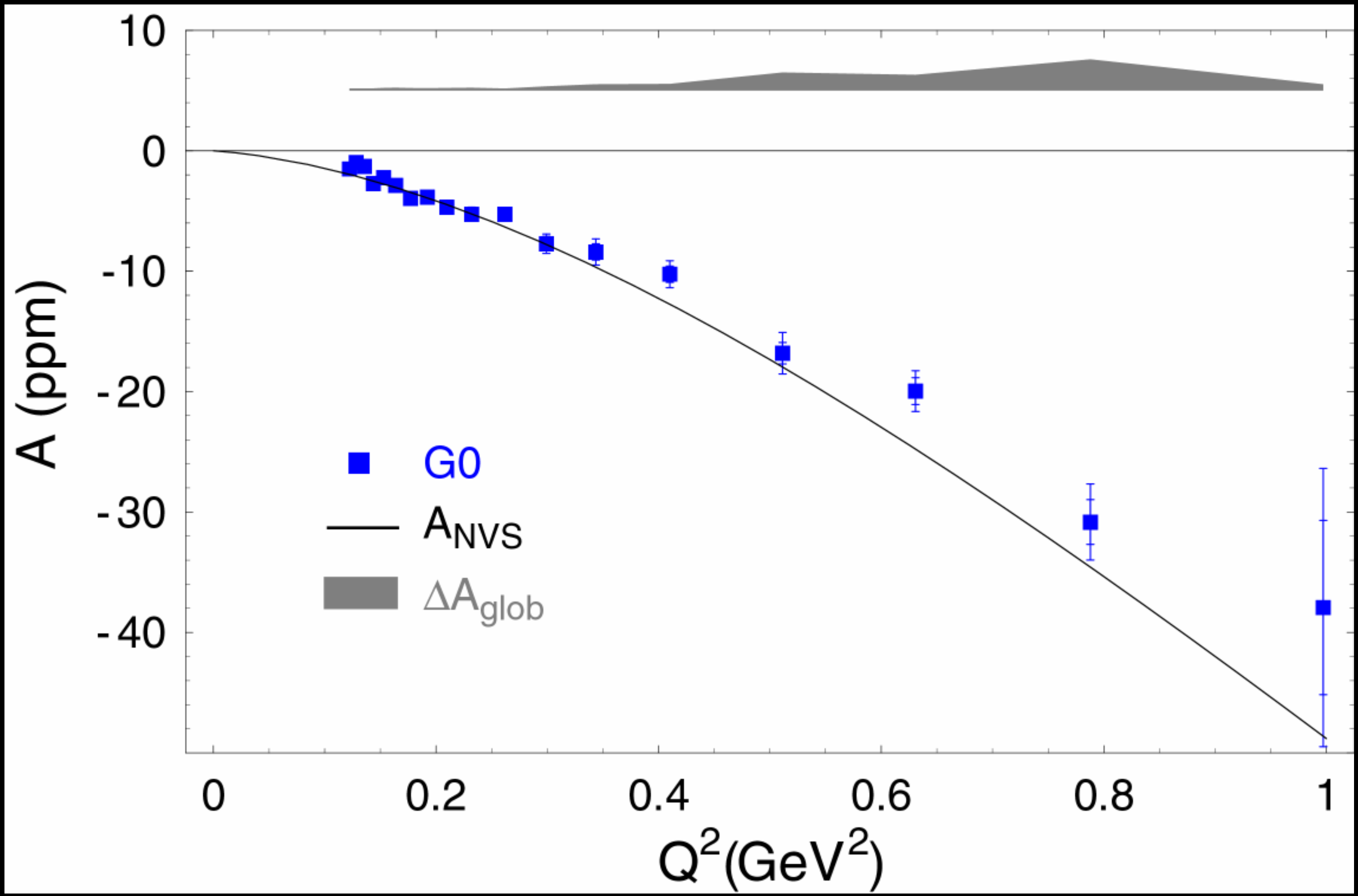
Systematic Uncertainties

Source	Uncertainty	Type
Helicity-correlated beam parameters	0.01 ppm	global
Leakage beam	0.14 ppm	global
Beam polarization	1.0%	global
Ordinary radiative corrections	0.3%	global
Transverse polarization	0.01 ppm	global
Q^2 (π-p tof)	1%	global
Background correction	0.2 – 9 ppm	Point-to-point & global
Deadtime	0.05 ppm	Point-to-point

GO results

Experimental Asymmetries

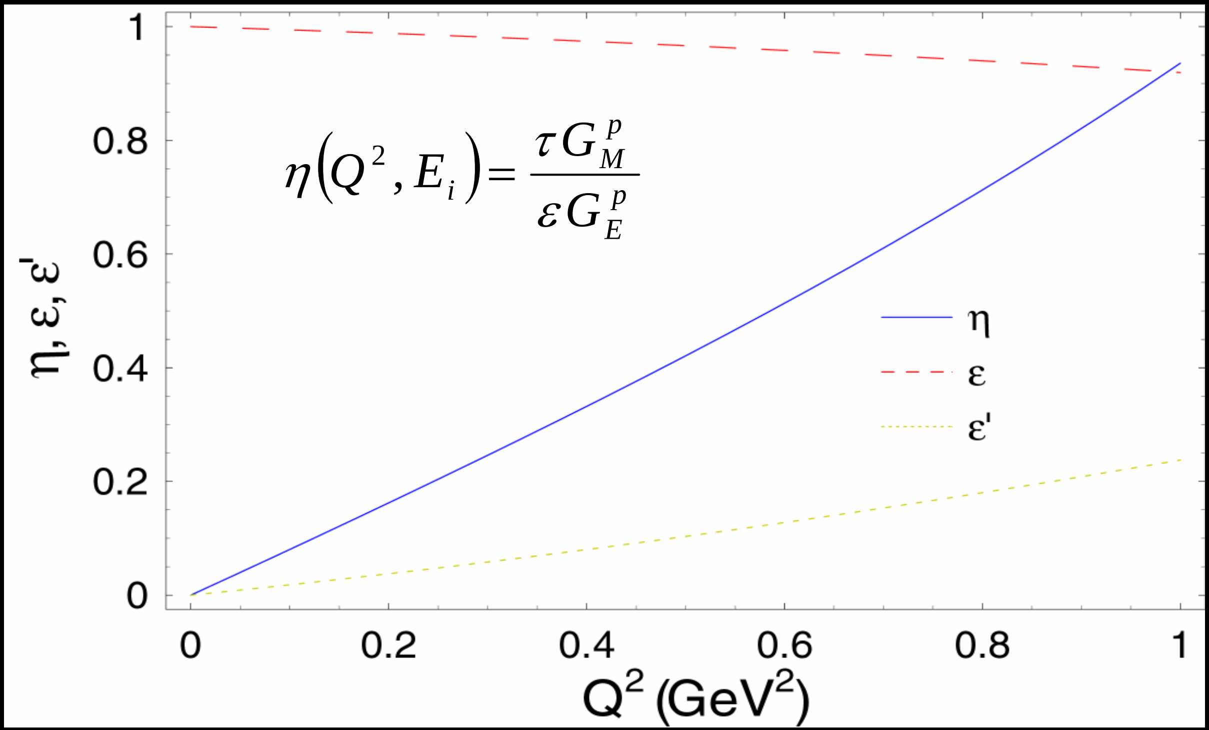
- em form factors: Kelly PRC **70** (2004) 068202
- "no vector strange" asymmetry, A_{NVS}, is $A(G^s{}_E, G^s{}_M = 0)$
- inside error bars: stat, outside: stat & pt-pt



Strange Quark Contribution

- Strange quark contribution to asymmetry:

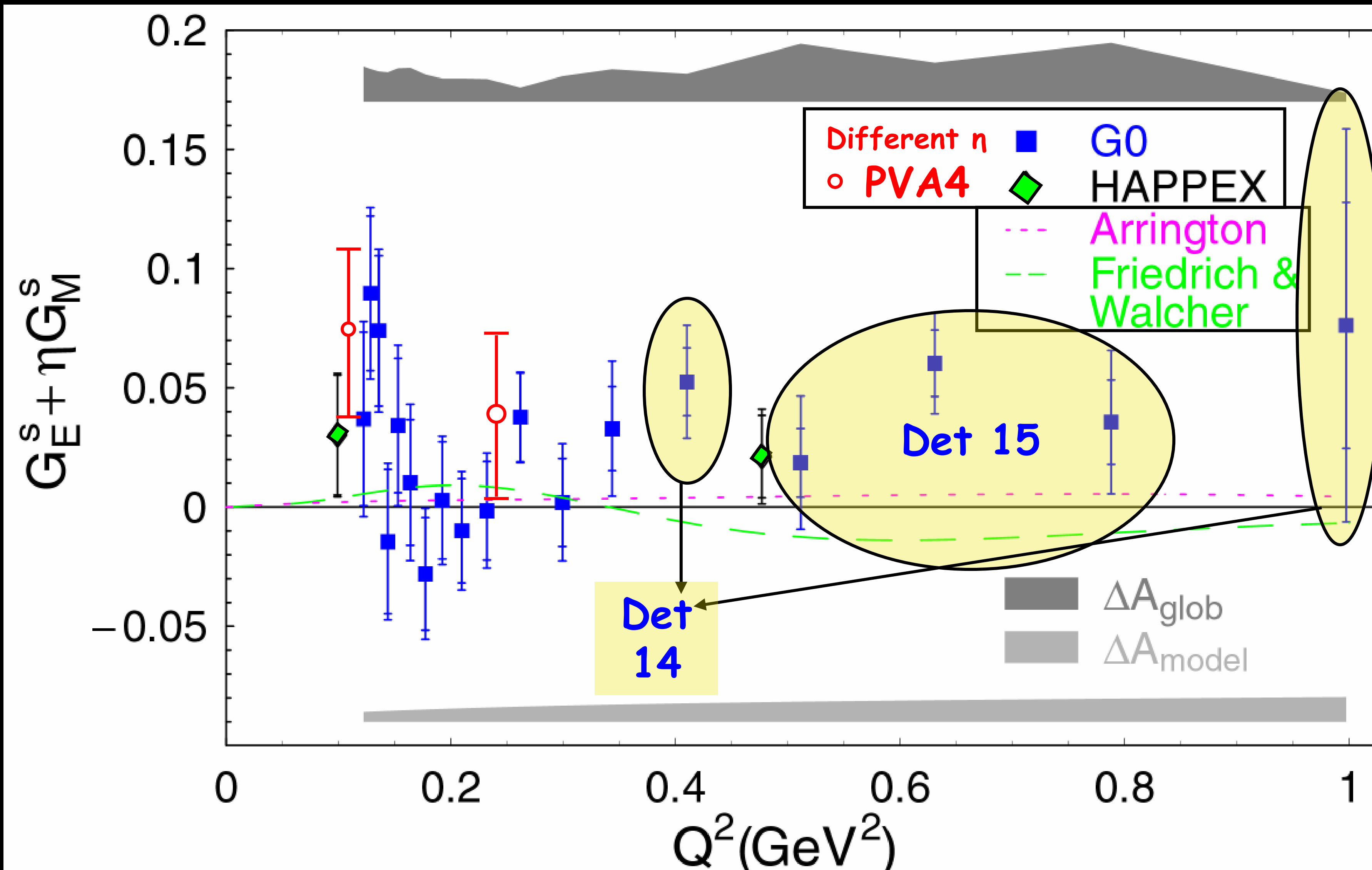
$$G_E^s + \eta G_M^s = \frac{4\pi\alpha\sqrt{2}}{G_F Q^2} \frac{\varepsilon {G_E^p}^2 + \tau {G_M^p}^2}{\varepsilon G_E^p \left(1 + R_V^{(0)}\right)} \left(A_{phys} - A_{NVS}\right)$$



$$\eta\left(Q^2, E_i\right) = \frac{\tau G_M^p}{\varepsilon G_E^p}$$

So $\eta \sim 0.94\ Q^2$ (for G0 Kinematics)

G0 Results: Intriguing Q^2 Dependence



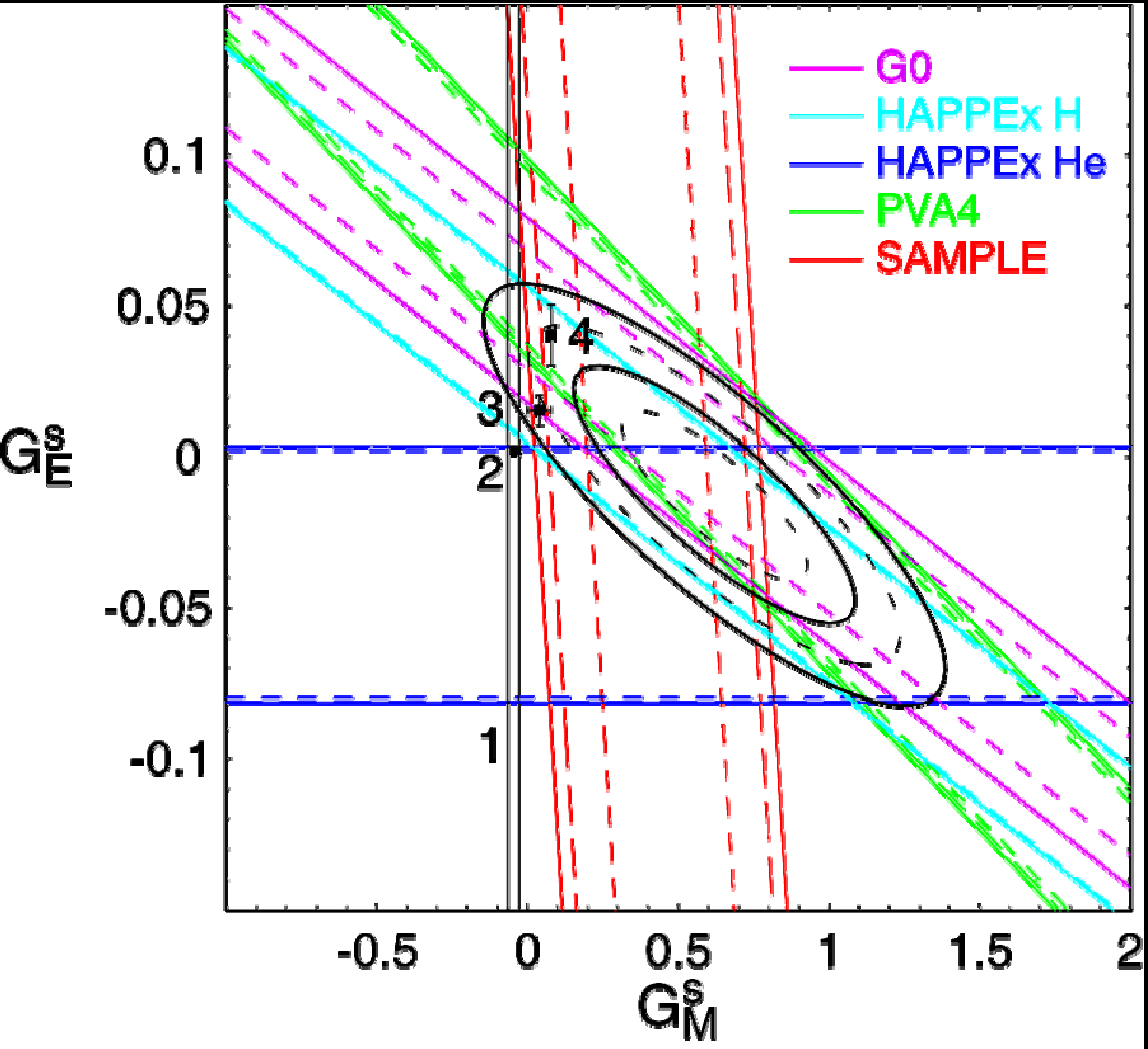
Are the G0 Data Consistent with Zero?

- Test hypothesis $G^s_E + \eta G^s_M = 0$
- Simple χ^2 incorrect because of correlated uncertainties
  - Also, depends on choice of binning
- Instead, apply a "hypothesis test"
  - see, eg, PDG 32.2.1 (Hypothesis tests)
  - let points on the zero line fluctuate according to all our uncertainties and then determine the frequency with which the resulting χ^2 is larger than that for our data
- Result
  - 11% of resulting χ^2 values for test data sets are larger than that for our data → G0 data ≠ 0 at 89% CL
  - More interesting: What are G^s_E & G^s_M doing, separately? To answer that, need G0 backward!

Combination of G0 with SAMPLE, HAPPEx, PVA4

At $Q^2 = 0.1$, 0.23, & 0.48 GeV^2

World Data @ $Q^2 = 0.1\ GeV^2$



$G_E^s = -0.013 \pm 0.028$

$G_M^s = +0.62 \pm 0.31$

$\pm 0.62\ 2\sigma$

Contours

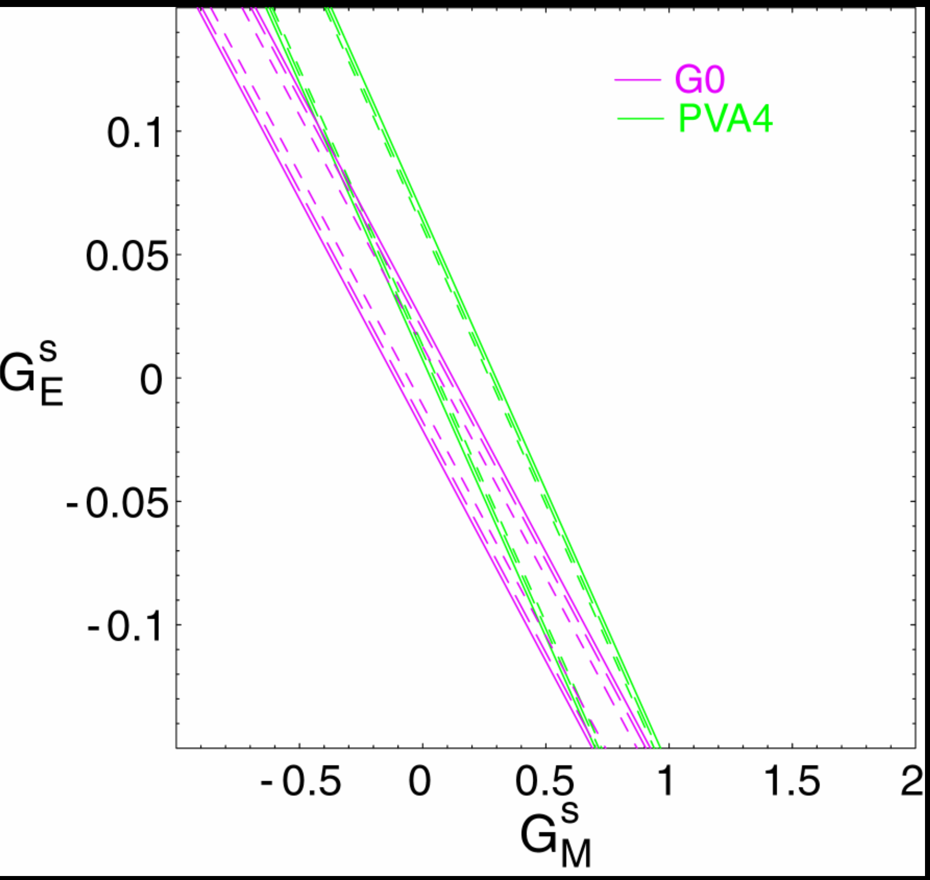
----- 1σ, 2σ

—— 68.3, 95.5% CL

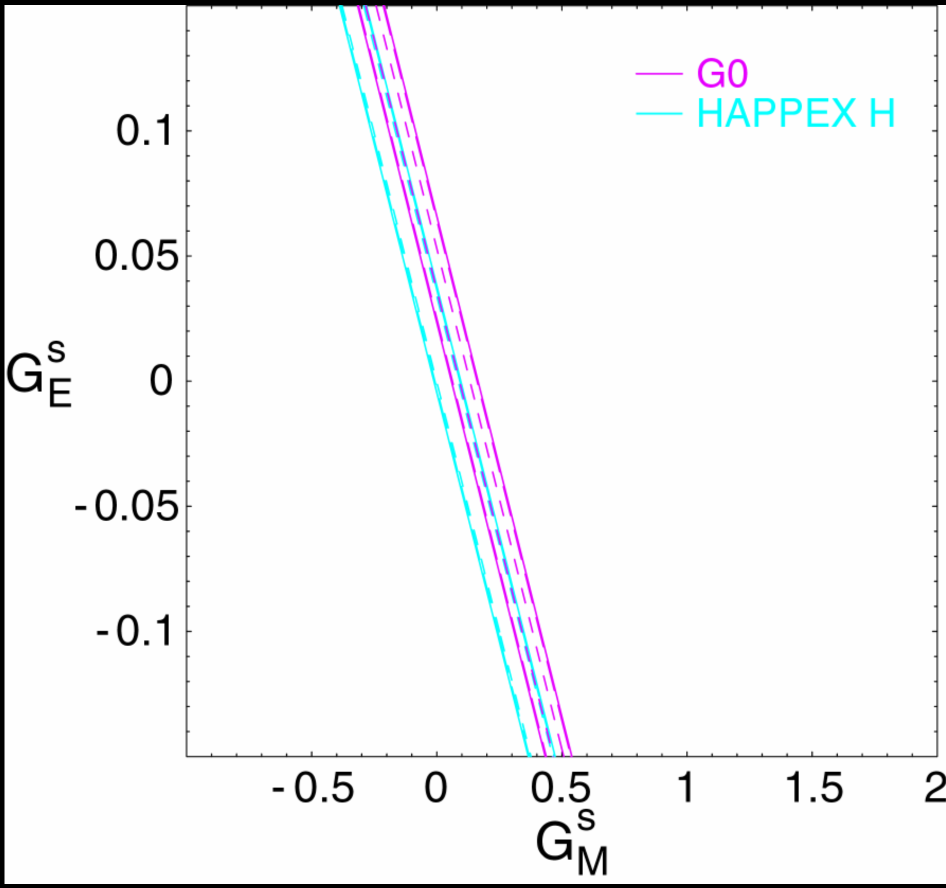
Theories

1. Leinweber, et al. PRL **94** (05) 212001
2. Lyubovitskij, et al. PRC **66** (02) 055204
3. Lewis, et al. PRD **67** (03) 013003
4. Silva, et al. PRD **65** (01) 014016

World Data @ $Q^2 = 0.23\ GeV^2$



World Data @ $Q^2 = 0.477\ GeV^2$

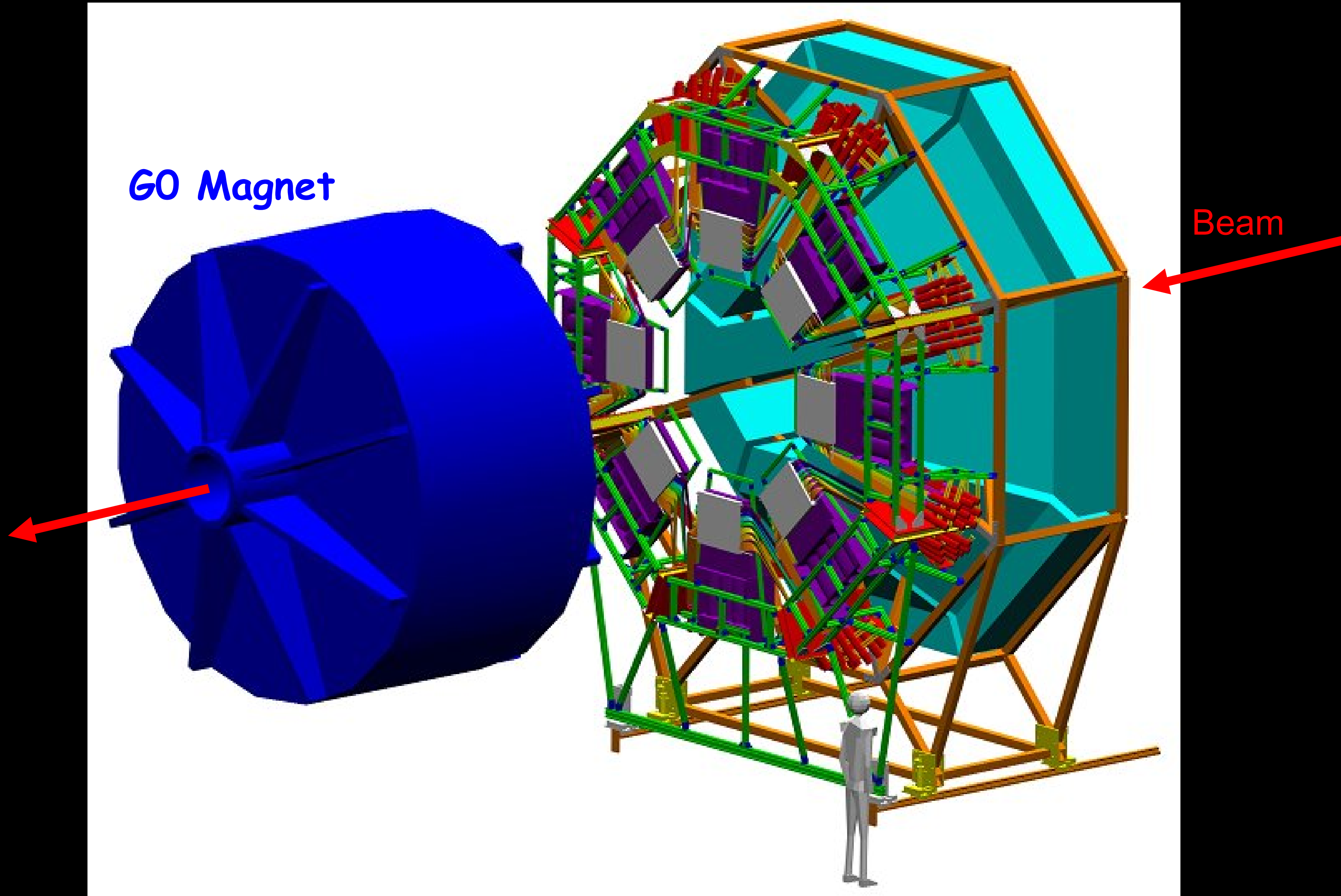


<u>GO Backward Angle Measurements</u>

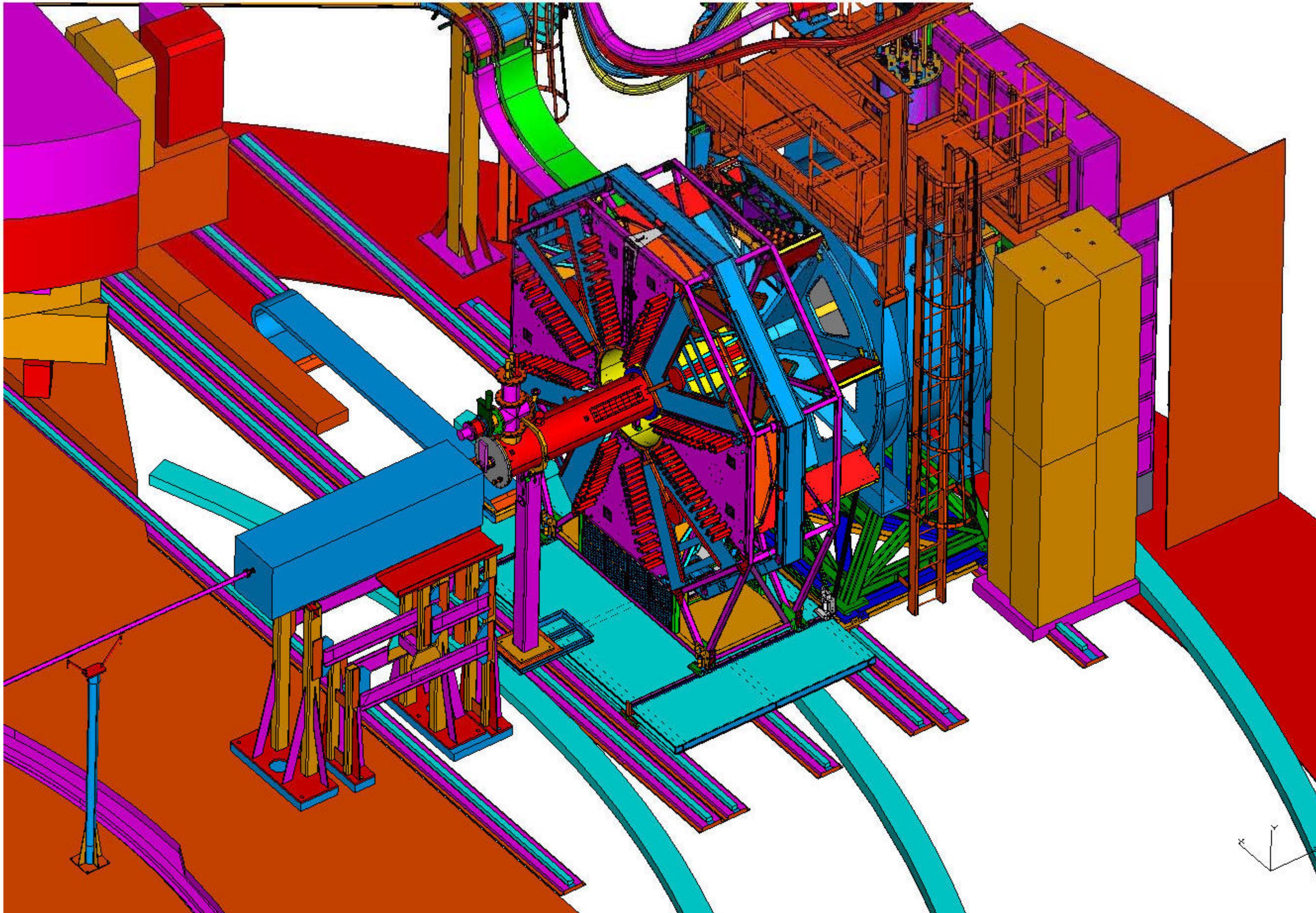
Changes

- Detect electrons now (108°) instead of protons
- Make use of D2 as well as H2
- Rotate magnet & detector package 180°
- Move magnet downstream of detectors
- New Cryostat Exit Detectors (in coinc. with old FPD's).
- New Aerogel Cerenkov detectors (π rejection)
- New Electronics. No tof.
- Use 499 MHz beam structure instead of 32 MHz
- 80 μA instead of 40 μA.
- New DAQ
- New Shielding

Ya, that's right. Basically a completely new experiment…


G0 Magnet
Beam

G0 Backward Layout



G0 Backward Angle Measurements

- Match forward angle range with measurements at 3 momentum transfers

Q^2	Beam Energy	Target	Rate	Asymmetry
(GeV^2)	(GeV)		(MHz)	(ppm)
0.3	0.424	H_2	2.03	-18
(0.23)	(0.360)	D_2	2.80	-25
0.48	0.576	H_2	0.718	-32
		D_2	1.10	-43
0.8	0.799	H_2	0.190	-54
		D_2	0.274	-72

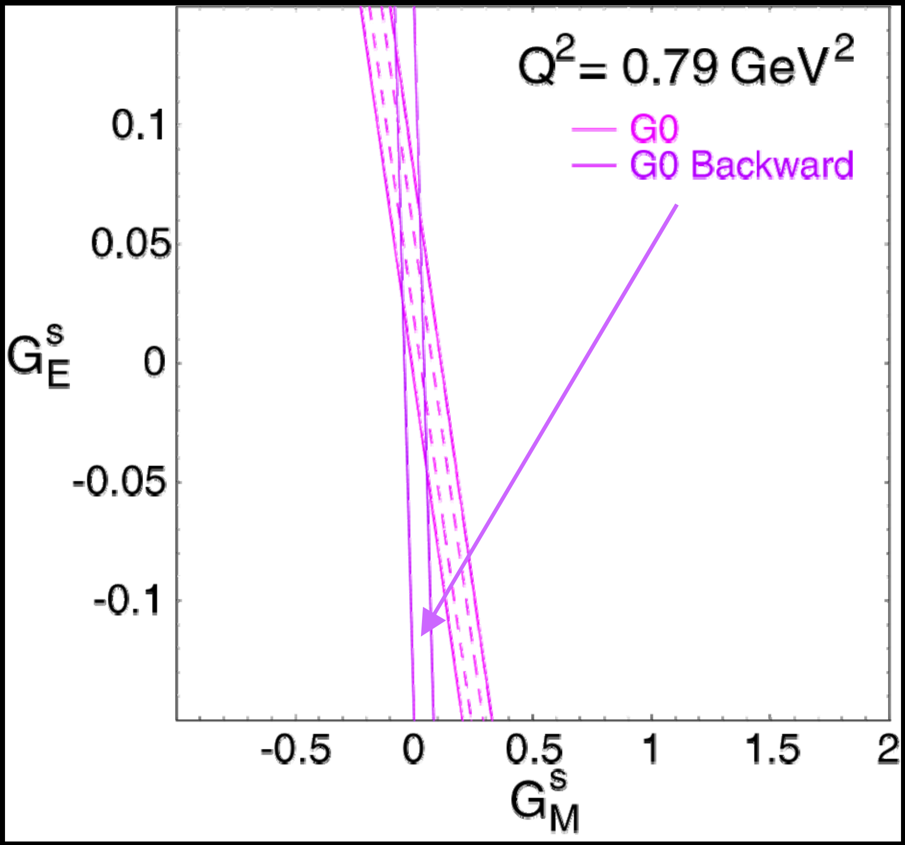
← Skip?

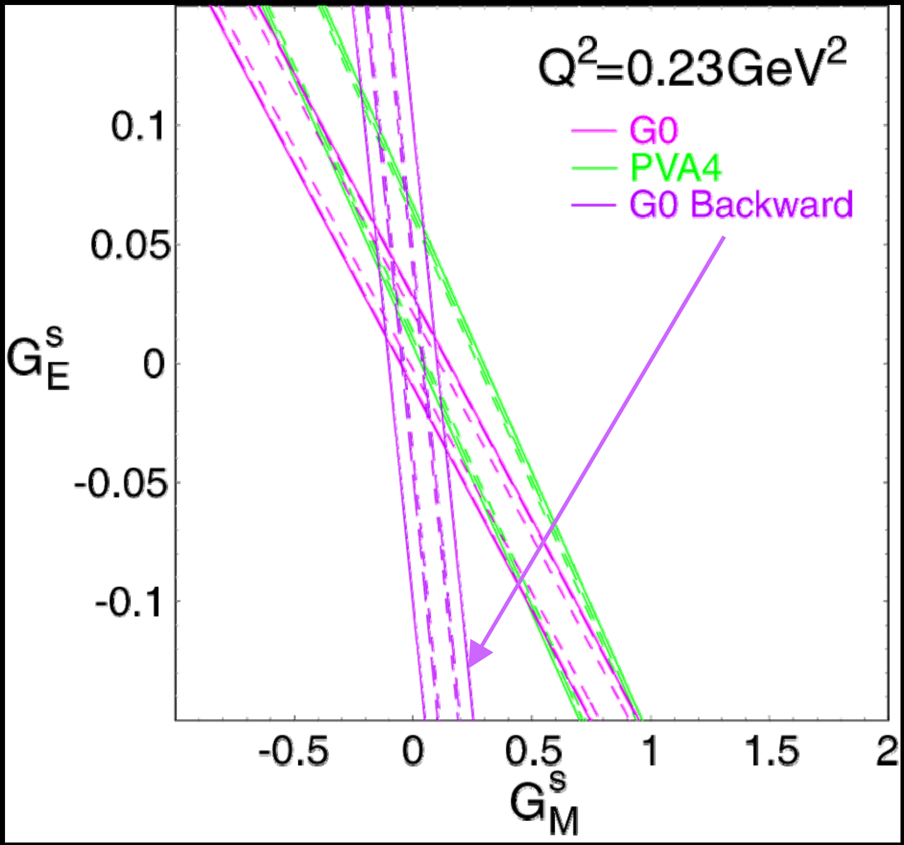
Scheduled: Mar 06 → ?

- Rates are per *octant*, for expected elastic e's & inelastic e's, π's & μ's.

Prospective G0 Data @ Q^2 = 0.8, 0.23 GeV^2

- Run in '06 at Q^2 = 0.79 GeV^2 (H and D targets)
- Possible run at Q^2 = 0.23 GeV^2 next (H alone?)





Expected Errors (Stat & Syst) on G0 Bkwrd Separated Form Factors

Assumes: 80 μA, 75% polarization, 20 cm target, …

50 days at Q^2 = 0.23, all on LH2
60 days at Q^2 = 0.48, split evenly on LH2 & LD2
} Pending (PAC28)

60 days at Q^2 = 0.80, split evenly on LH2 & LD2
10 days at Q^2 = 0.80, spent on commissioning
} approved

$Q^2 (GeV^2)$	ΔG^s_E	ΔG^s_M	$\Delta G^e_A(T=1)$
0.23	0.026	0.098	-----
0.48	0.048	0.058	0.158
0.8	0.051	0.040	0.133

Some Conclusions from G0-Forward

1. Results *consistent* with:
   1. HAPPEx-H measurements at similar Q^2 (0.1 GeV^2)
   2. PVA4 at similar Q^2
2. Hypothesis $G^s_E + \eta G^s_M = 0$ disfavored at 89% CL (including all uncertainties)
3. *By itself*, G0-Forward only constrains linear combination of G^s_E & G^s_E (hence G0-Bkwrd!). *However*, combining SAMPLE, PVA4, HAPPEx-H, HAPPEx-He, & G0 at $Q^2 = 0.1$ yields
   1. $G^s_E = -0.013 \pm 0.028$, and
   2. $G^s_M = 0.62 \pm 0.31$ at 1-σ
      ± 0.62 at 2-σ

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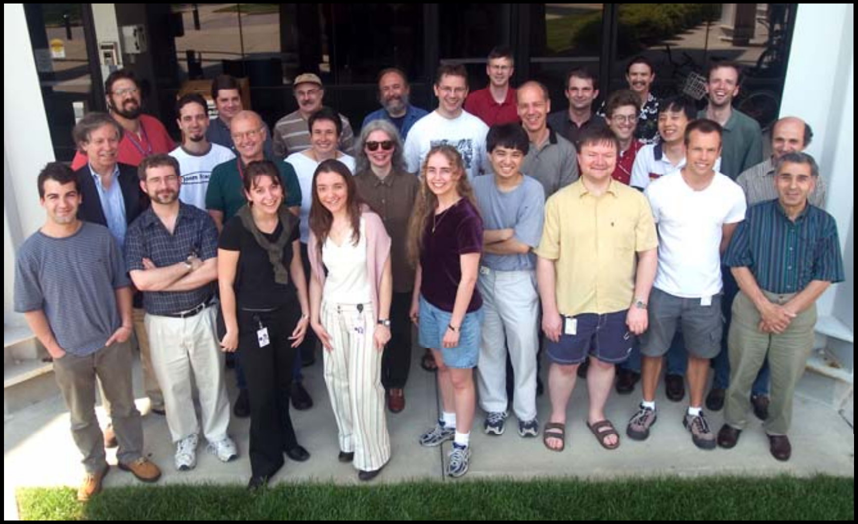

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