Strange Quark Contributions to Nucleon Structure?
Results from the Forward G0 Experiment

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Goals of G0 Experiment:

- Determine Q^2 dependence of <u>a</u> combination of G_E^s and G_M^s over range $0.1 \leq Q^2 \leq 1.0$ GeV^2 ✓
- Determine G_E^s and G_M^s separately for 3 specific Q^2 values

Results from the Forward G0 Experiment

Outline

- Quark flavor contributions from parity-violating electron scattering
- Experimental setup
- Analysis
- G0 results
- Combination with SAMPLE, HAPPEX, PVA4 measurements

G0 Collaboration

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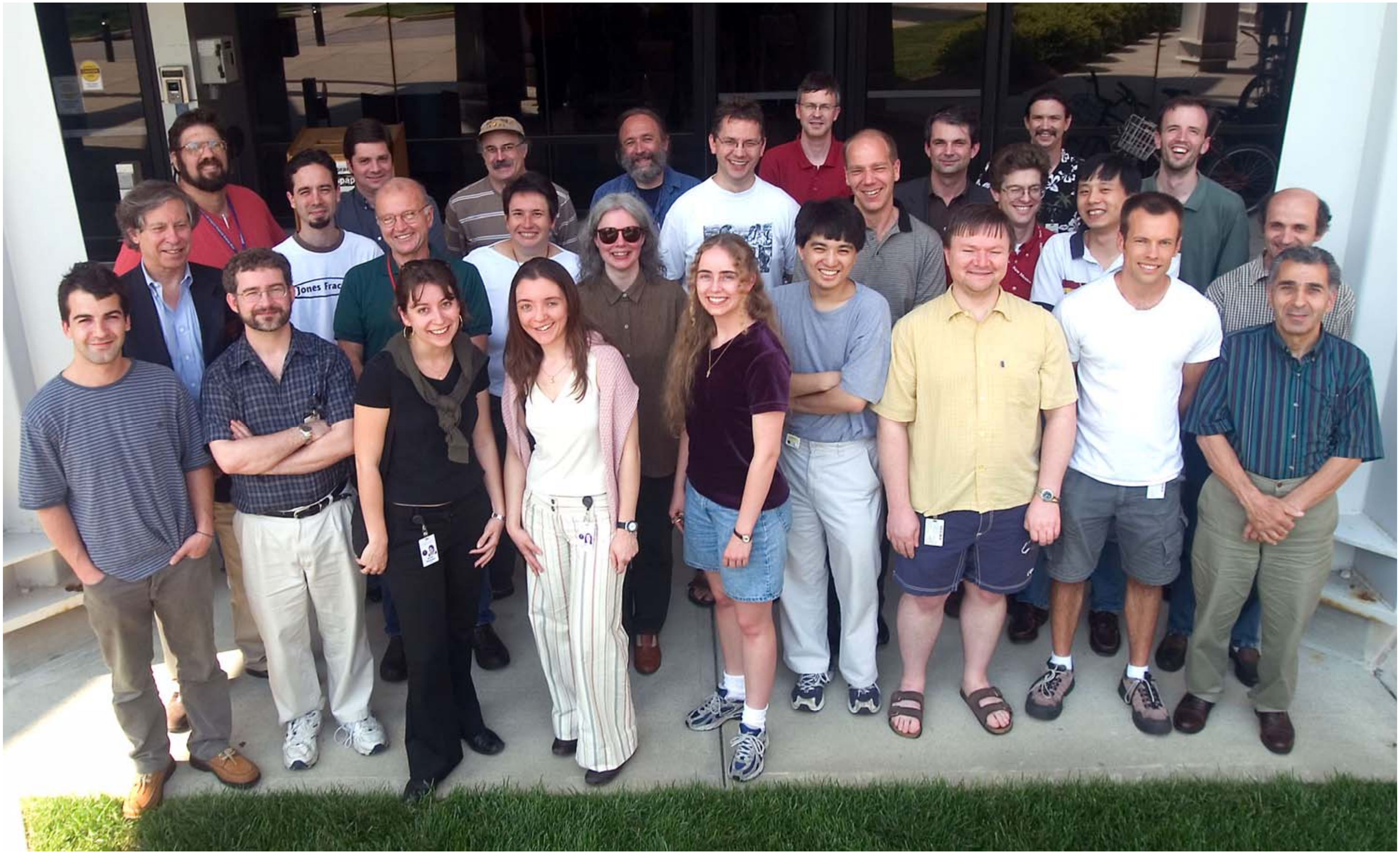

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Quark flavor contributions and parity-violating electron scattering

Quark Currents in the Nucleon

- Measure $G^{\gamma,p}, G^{Z,p}, G^{\gamma,n}$: $G \sim \langle N | \sum_i e_i \bar{q}_i \Gamma_\mu q_i | N \rangle$
  - e.g.

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

  - note

$$\left.\begin{aligned} G^{u,p} &= G^{d,n} \\ G^{d,p} &= G^{u,n} \\ G^{s,p} &= G^{s,n} \end{aligned}\right\}$$

charge symmetry

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

then

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

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

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

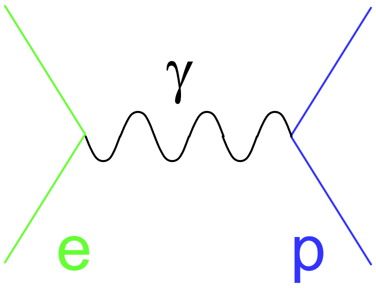
dropping the *p* superscripts on the left

Parity-Violating Electron Scattering

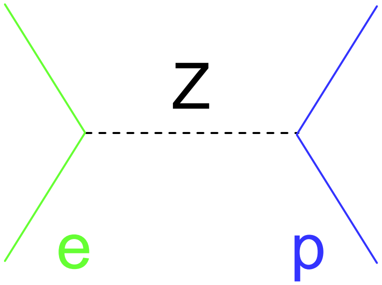
- $G^{Z,p}$ contributes to electron scattering

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

- 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

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

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

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

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

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

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Summary of PV Electron Scattering Experiments

Lab/Expt	target	Q^2 GeV^2	A_{phys} ppm	Sensitivity	Status
MIT-Bates					
- SAMPLE	H_2	0.10	8.0	$\mu_s + 0.4 G_A^Z$	published
- SAMPLE-II	D_2	0.10	8.0	$\mu_s + 2.0 G_A^Z$	published
- SAMPLE-III	D_2	0.04	3.0	$\mu_s + 3.0 G_A^Z$	published
JLab Hall A					
-HAPPEX	H_2	0.47	15.0	$G_E^s + 0.39 G_M^s$	published
-HAPPEXII	H_2	0.11	1.5	$\rho_s + \mu_p \mu_s$	publishing, running
-Helium-4	^4He	0.11	10.0	ρ_s	publishing, running
-Helium-4	^4He	0.60	50.0	G_E^s	unscheduled
-Lead-208	^{208}Pb	0.01	0.5	neutron skin	2006
Mainz					
- A4	H_2, D_2	0.1-0.25	1.0-10.0	G_E^s, G_M^s	published x2, running
Jlab Hall C					
- G0	H_2, D_2	0.1-1.0	1.0-30.0	G_E^s, G_M^s	publishing, running
- Qweak	H_2	0.03	0.3	Qw	2006
SLAC					
- E158	H_2	0.02	0.2	Qw	published

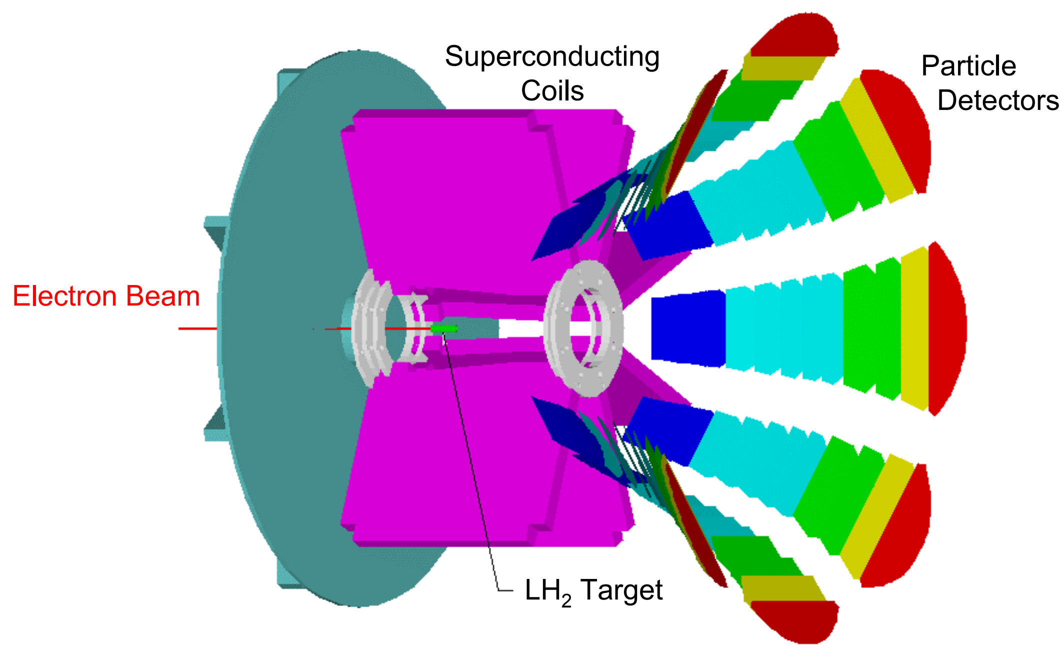
K. Kumar

Experimental setup

G0 Experiment Overview

- Measure G_E^Z, G_M^Z
  - different linear combination of *u*, *d* and *s* contributions than e.m. form factors
  - → strange quark contributions to sea
- Measure forward and backward asymmetries
  - recoil protons for forward measurement
  - electrons for backward measurements
    - elastic/inelastic for ^1H, elastic for ^2H
- Forward measurements complete (101 Coulombs)

E_{beam} = 3.03 GeV, 0.33 - 0.93 GeV
I_{beam} = 40 μA, 80 μA
P_{beam} = 75%, 80%
θ = 52 – 76^0, 104 - 116^0
$\Delta\Omega$ = 0.9 sr, 0.5 sr
l_{target} = 20 cm
L = 2.1, 4.2 x 10^{38} cm^{-2} s^{-1}
A ~ -1 to -50 ppm, -12 to -70 ppm



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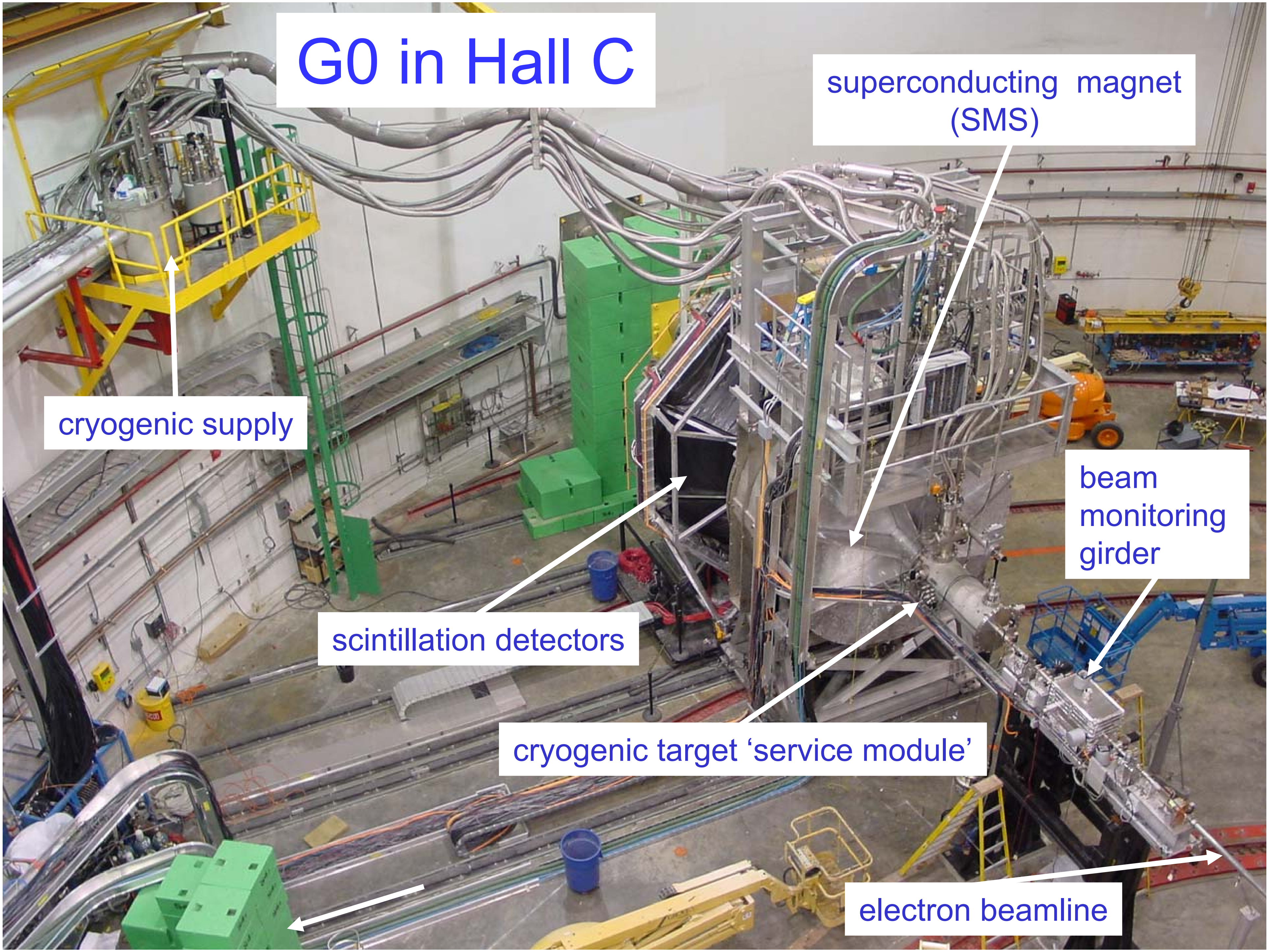
G0 in Hall C

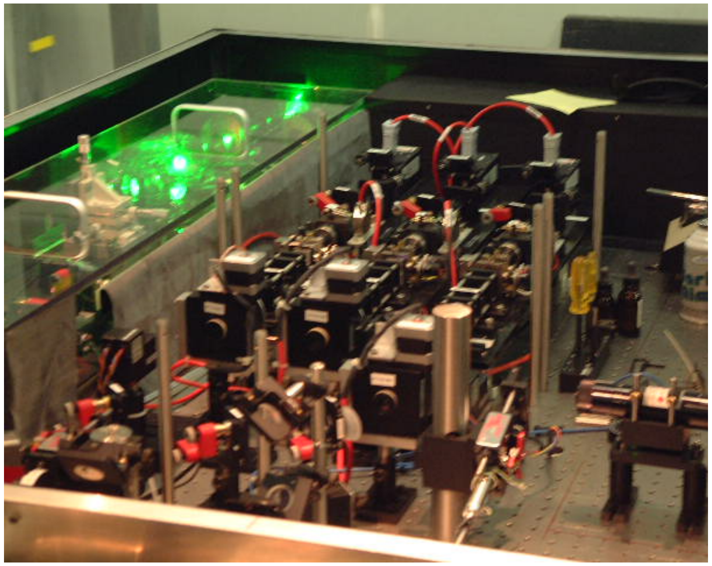


superconducting magnet (SMS)
cryogenic supply
beam monitoring girder
scintillation detectors
cryogenic target 'service module'
electron beamline

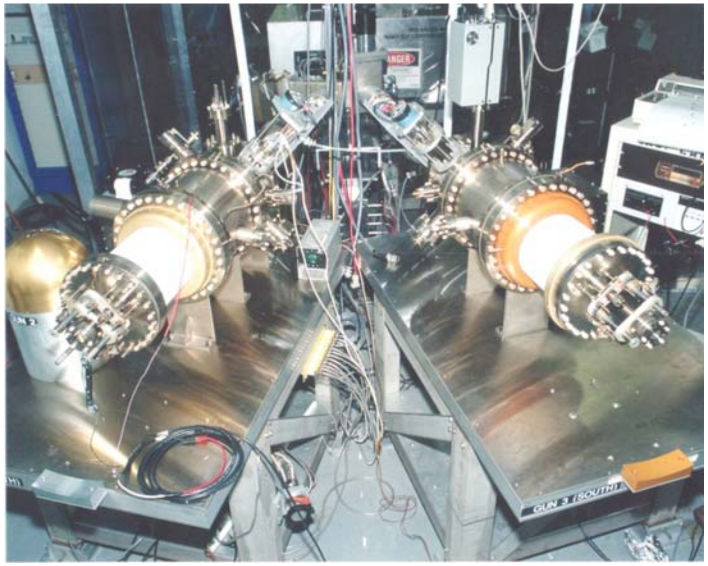
Polarized Injector/Accelerator

- Challenging specifications – all met!
  - 32 ns pulse spacing for t.o.f.
  - 40 μA beam current
    - higher bunch charge
  - run concurrently with small energy spread for Hall A

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



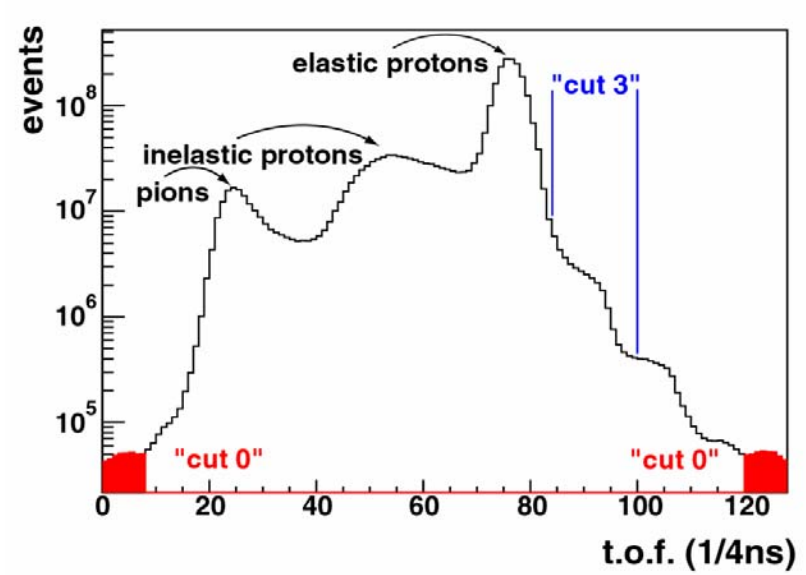
New Tiger laser system for G0



JLab polarized injector

Leakage Beam Measurement

- Use “cut0” region in actual data to measure leakage yield, asymmetry throughout run
- Cut0 certified during test runs with only leakage beam
  - uncertainty determined in 3 ways
    - compare lumi monitor (direct) measurements to cut0
    - cut3 asymmetry independent of beam current (10, 20, 40 μA)
    - variation of corrected cut3 asymmetry (should be constant over run)
  - methods consistent at 20% level
- $\delta A_{false,leak} = -0.71 \pm 0.14$ ppm



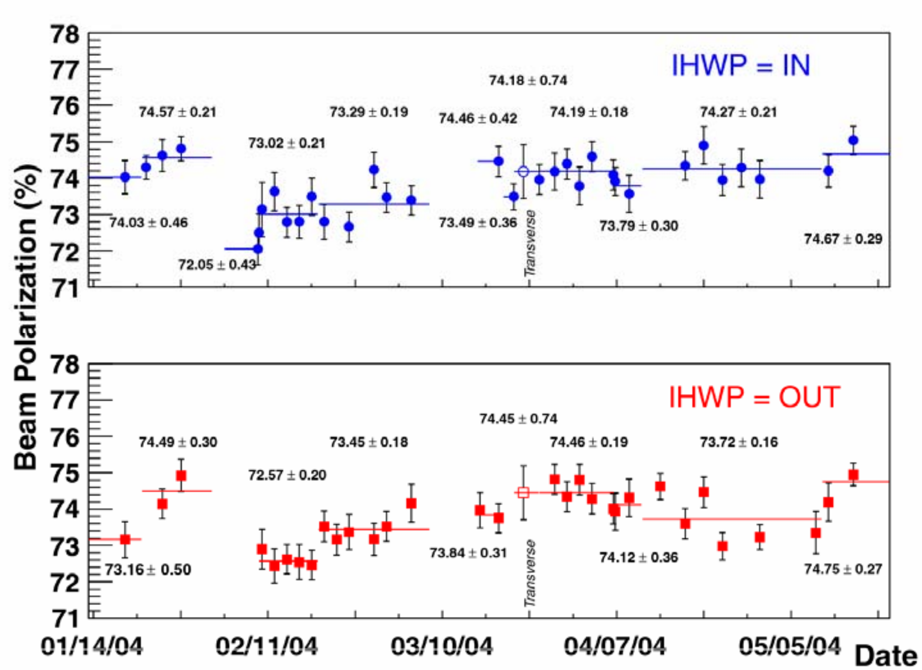
Leakage beam measurement regions

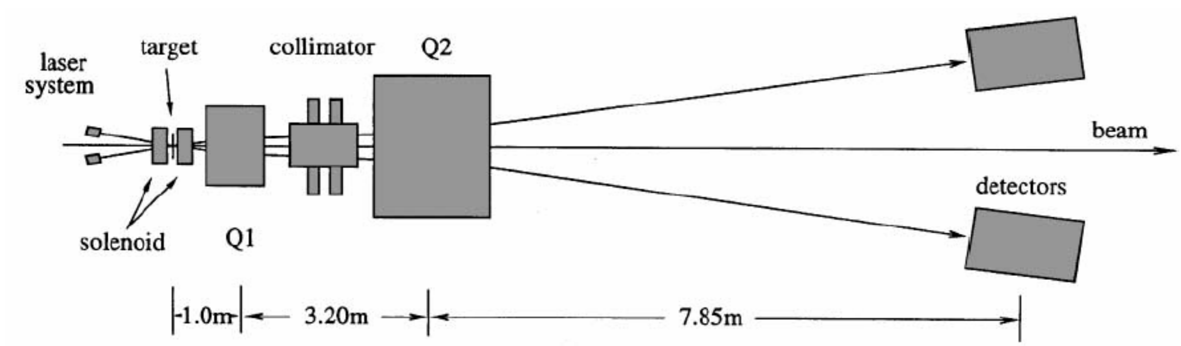
I (μA)	$A_{3,meas}$ (ppm)	$A_{3,corr}$ (ppm)
40	0.14±0.43	-2.5±0.43
20	-29.6±2.1	-7.2±2.1
10	-51.3±3.9	-9.5 ±3.9

Beam Polarization

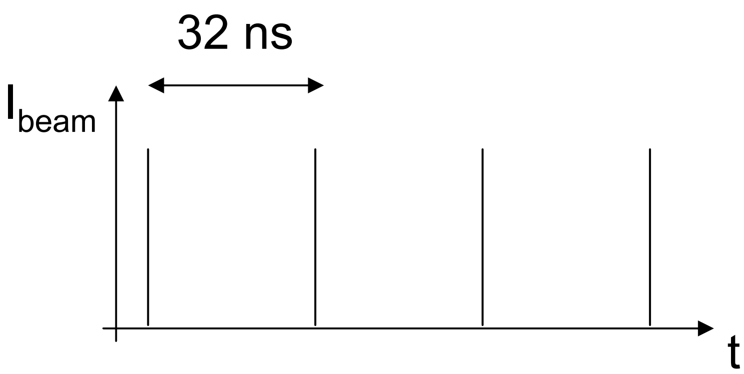
- Beam polarization measured with interleaved Møller measurements
  - std Hall C polarimeter (M. Hauger, et al. NIM **A462** (2001) 382.)
  - apply for groups of runs as shown
  - average: P = 73.7%

Source	Rel. uncertainty (%)
Target	0.42
Leakage	0.2
Current extrap'n	1
Beam	0.52
Levchuk	0.3
Detection	0.35
Total	**1.32**

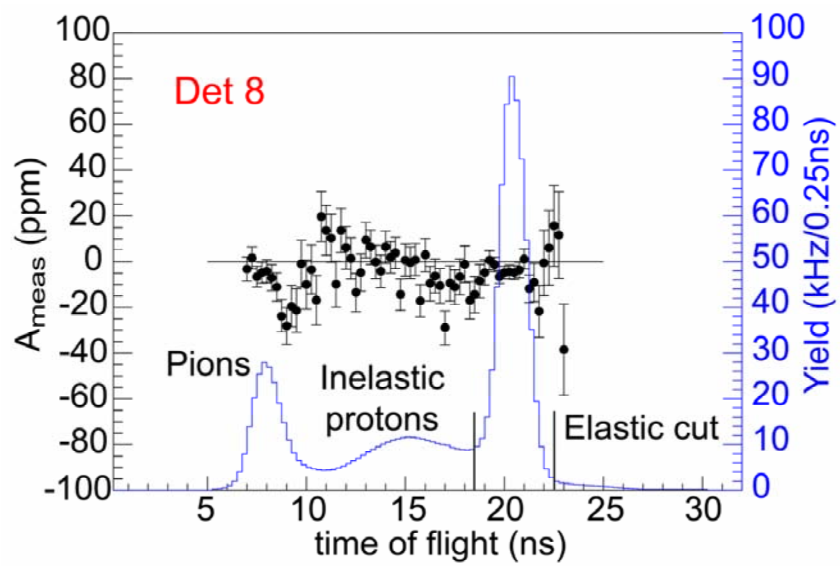




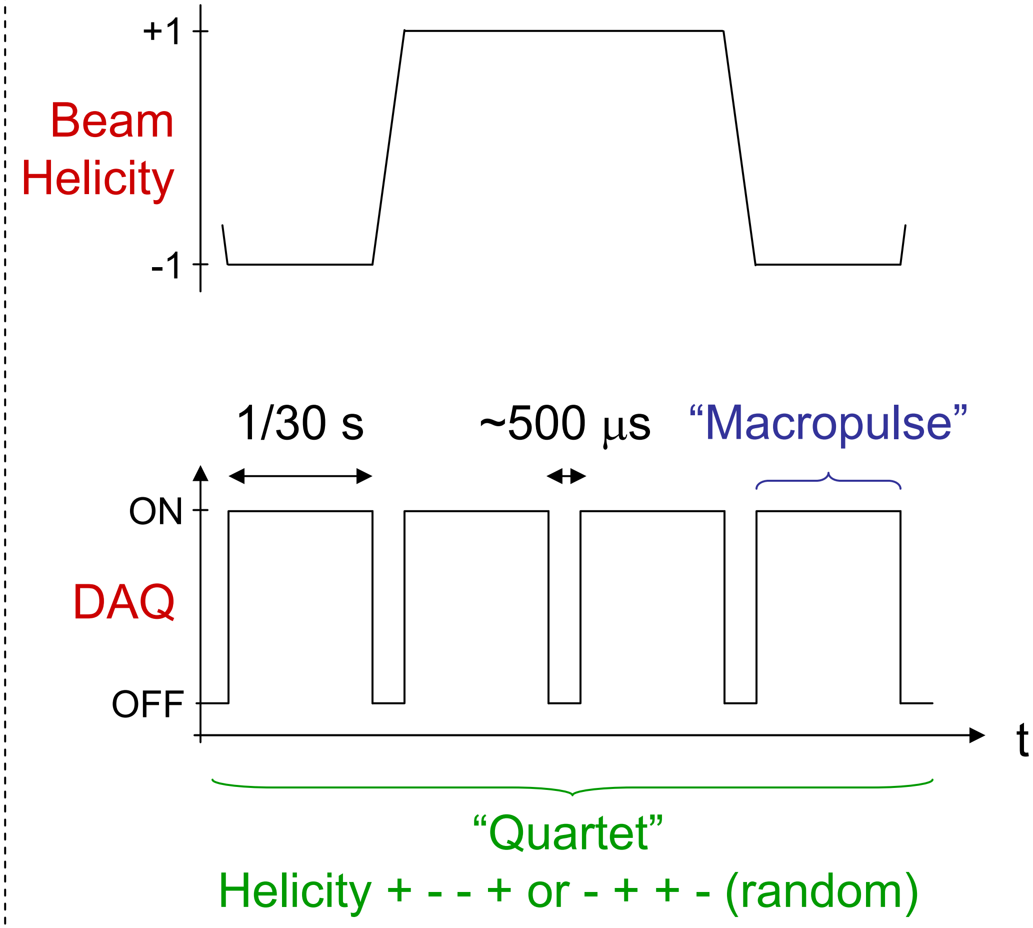
Timing in the Experiment



Accelerator pulse structure



Typical t.o.f. spectrum



Measurement timing

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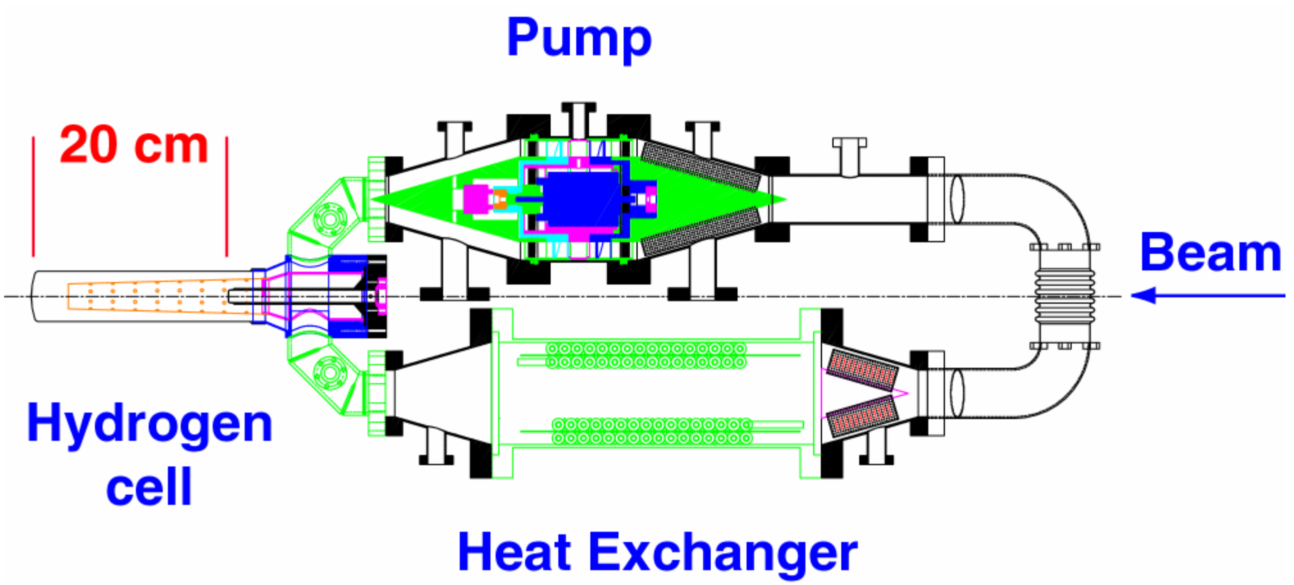
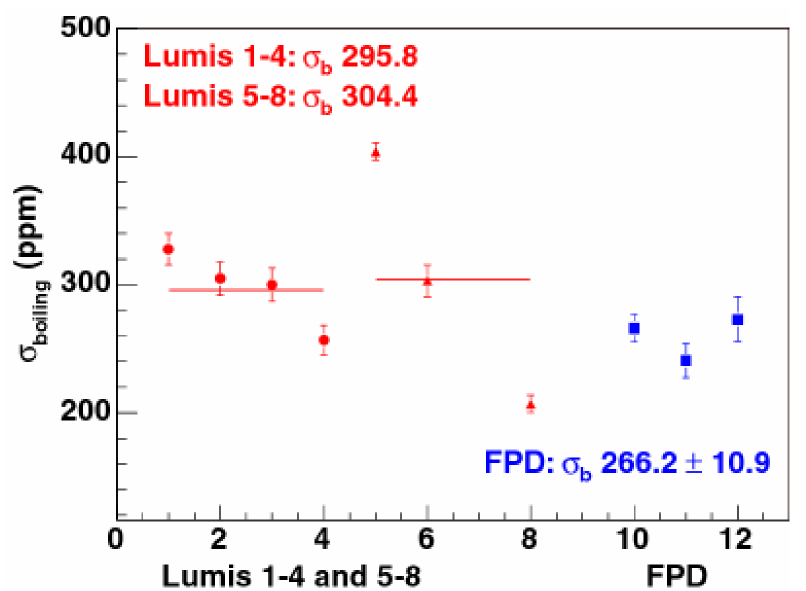
Target

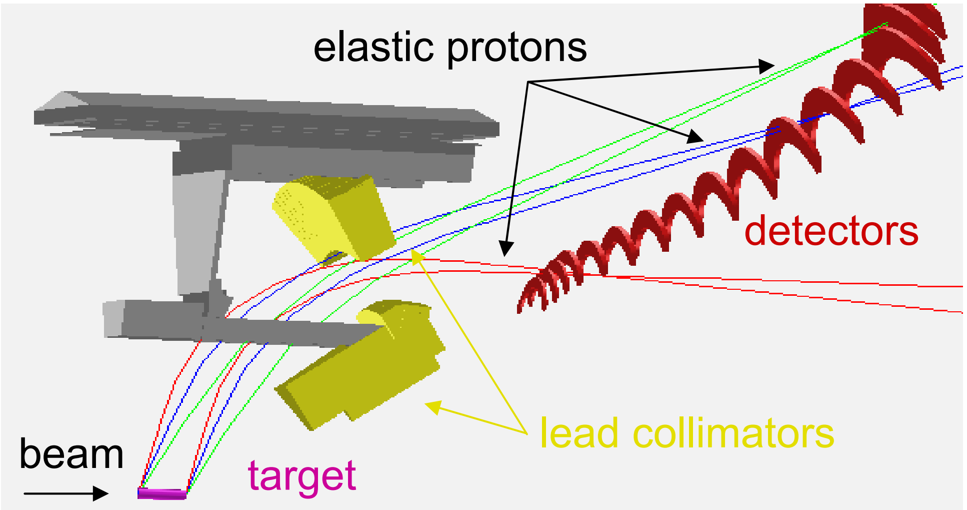


- 20 cm LH_2, aluminum target cell
- longitudinal flow, v ~ 8 m/s, P > 1000 W!
- negligible density change < 1.5%
- measured small boiling contribution
  - 260 ppm/1200 ppm statistical width



Spectrometer Optics

- zero magnification along beam axis
- elastic protons dispersed in Q^2 along focal surface



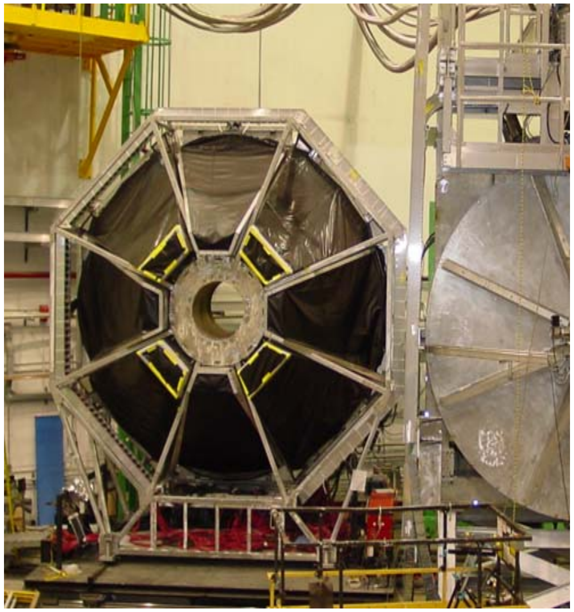
- acceptance $0.12 < Q^2 < 1.0$ GeV^2 for 3 GeV incident beam
- detector 15 acceptance: 0.44 – 0.88 GeV^2
  - 3 Q^2 bins at 0.51, 0.63 and 0.78 GeV^2
- detector 14: Q^2 = 0.41, 1.0 GeV^2
- det. 16: no elastic acceptance
  - important for measuring backgrounds

Detectors

- 16 detectors per octant
- Arc shape (const. Q^2), protons at normal incidence

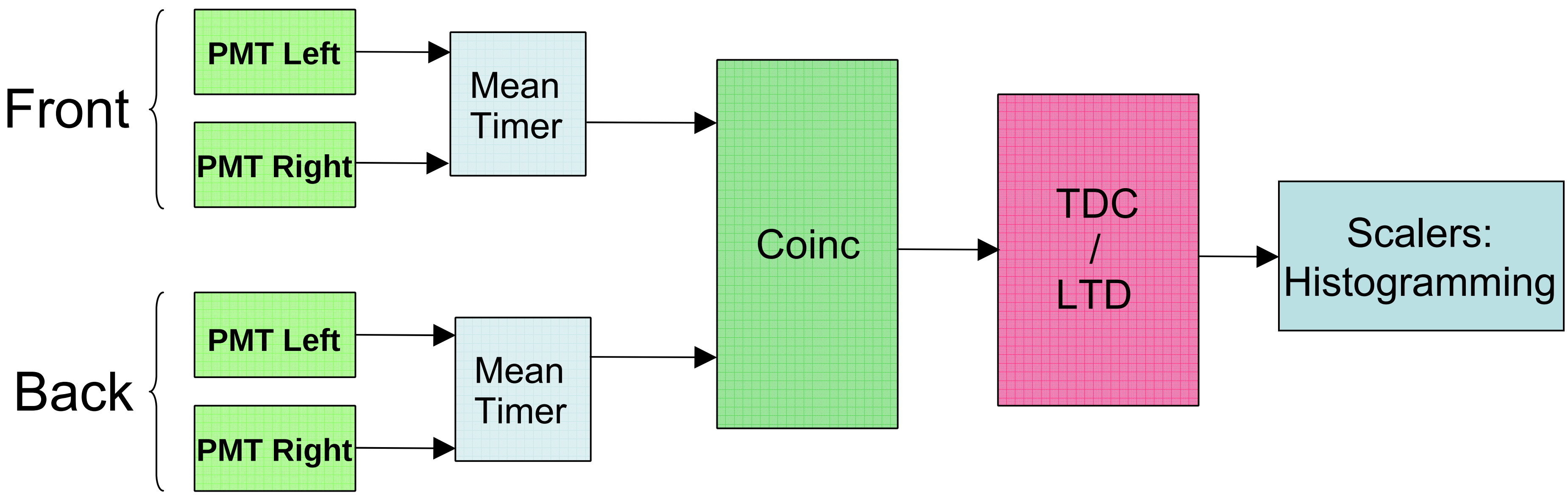
- Each detector: scintillator pair
  - BC408: 0.5, 1.0 cm thick
  - 1/8 in. shielding in-between
- PMT at each end of each scintillator
  - XP2262B (NA), XP2282B (Fr)
- Signal: mean-time-front .AND. mean-time-back

- Assembled with ~ 2 mm accuracy
- Octants in light-tight enclosures



Electronics

- Measure time-of-flight target to detectors
- Counting rates ≤ 4 MHz per scintillator pair
- Fast time encoding
  - NA: dual 500 MHz shift registers → scalers (1 ns resolution)
    - "latching time digitizer" (LTD)
  - Fr: flash TDC → DSP → scalers (1/4 ns resolution)



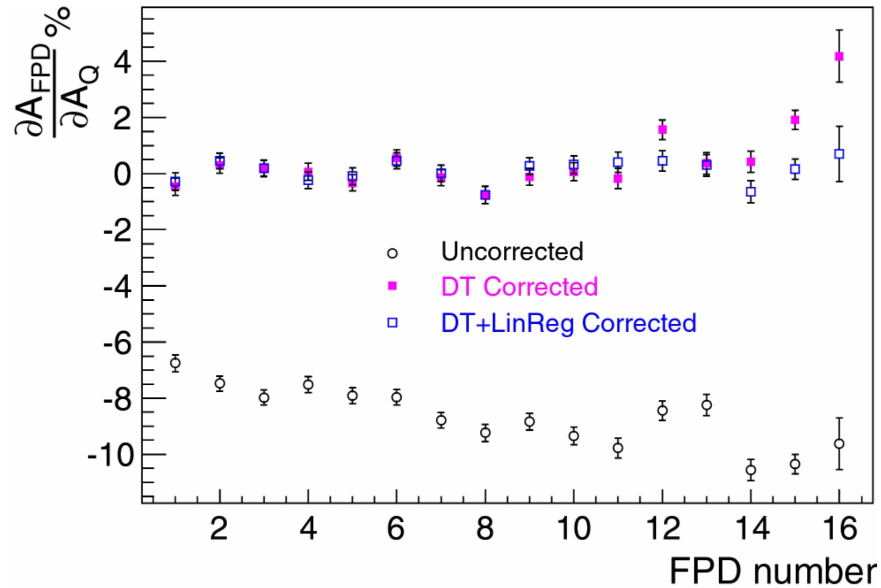
Electronics Deadtime Corrections

- Residual effect on asymmetry
  - scale factor

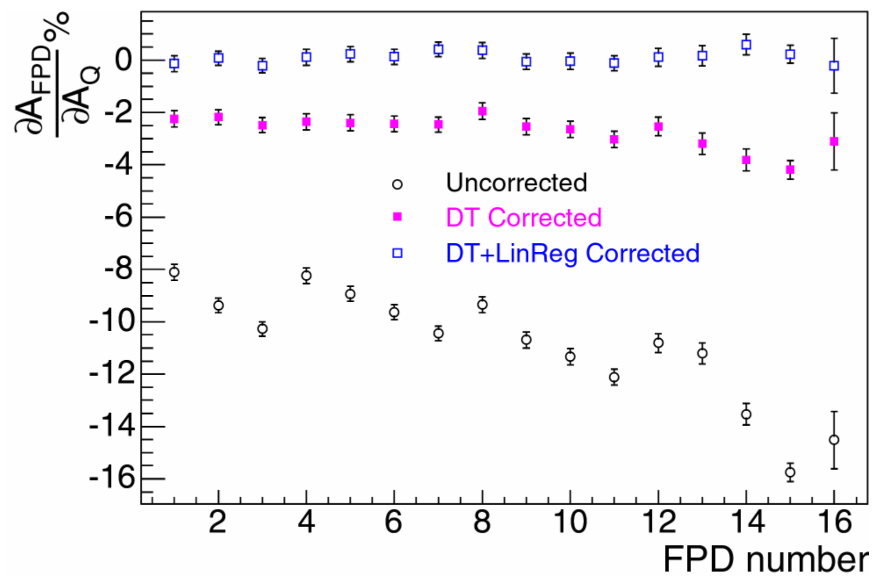
$$A_{meas} = \frac{R_+(1-\tau R_+) - R_-(1-\tau R_-)}{R_+(1-\tau R_+) + R_-(1-\tau R_-)}$$

$$\cong A\left(1-\tau\frac{R_+ + R_-}{2}\right)$$

- A is sum of physics *and* charge asymmetries
  - helicity-correlated beam current changes corrected in linear regression analysis
  - correction for residual effect ~ 0.05±0.05 ppm (pt-pt systematic unc.)



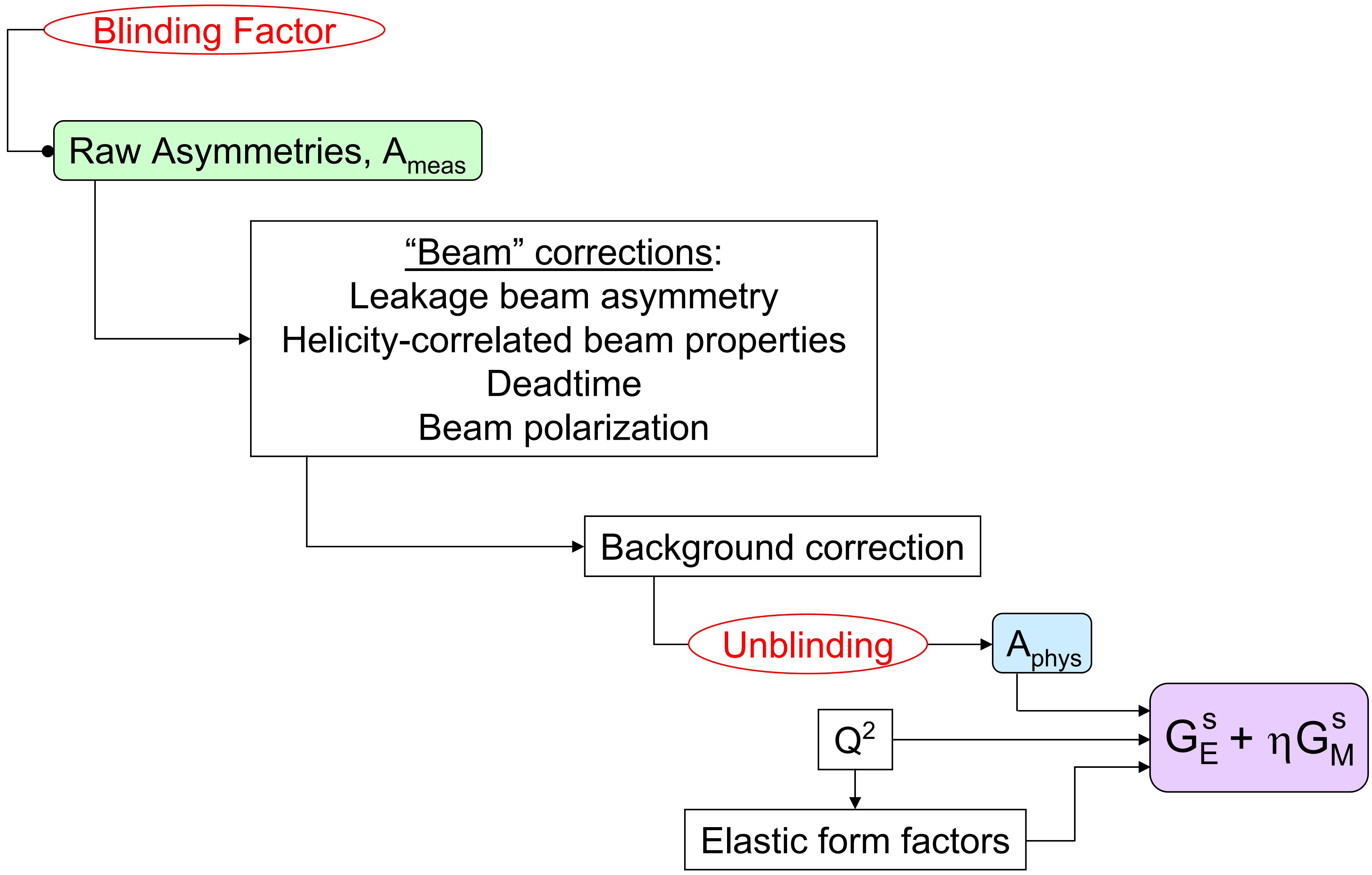
NA deadtime corrections



Fr deadtime corrections

Analysis

Analysis Overview



Forward Data Summary

- 101 Coulombs of parity-quality beam
  - cuts on helicity-correlated beam parameter are 4 x std. dev. for given run:

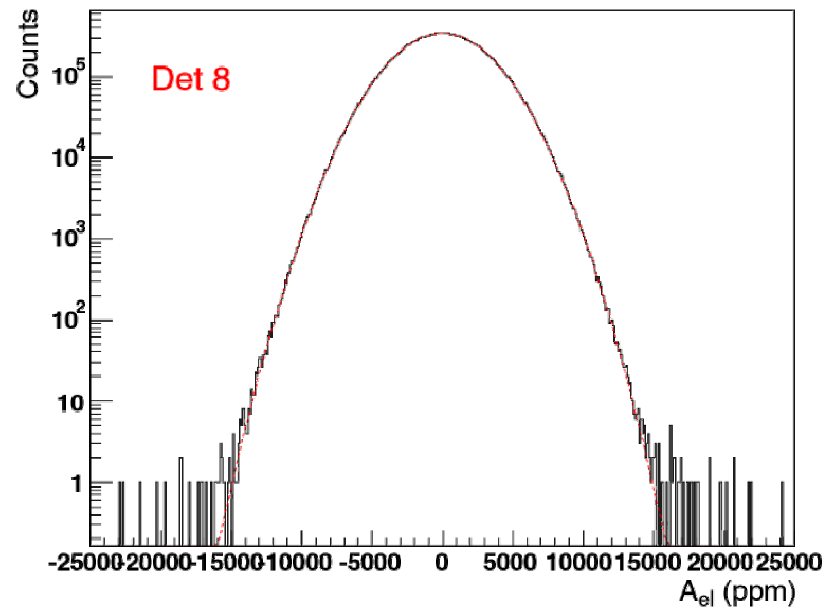
Quantity	Std. dev.
charge asymmetry	600 ppm
x, *y* position differences	8, 10 μm
x, *y* angle difference	0.6, 1.1 μrad
energy difference	7.5 keV

- Includes running with both Hall A and Hall B (leakage beam asymmetry measured satisfactorily)

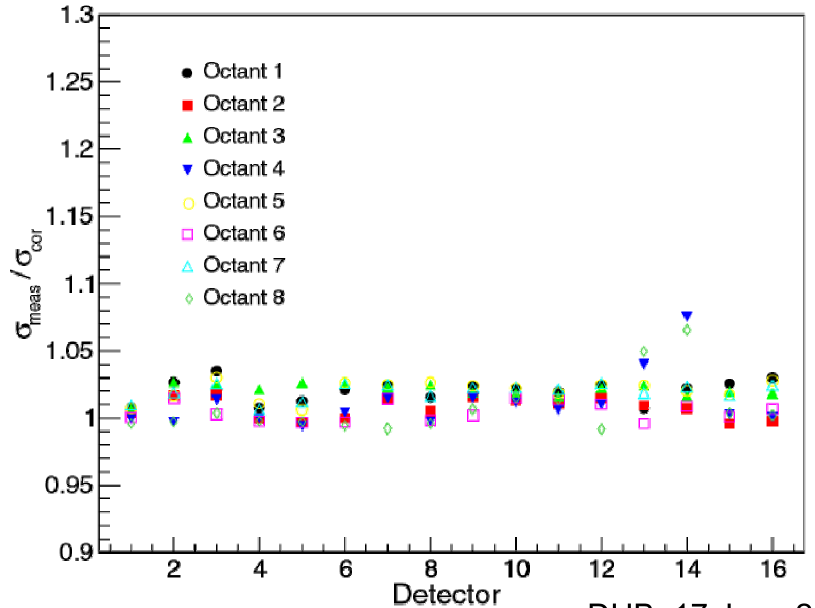
- Corresponds to: 701 h at 40 μA
  19×10^6 quartets
  76×10^6 MPS

Statistical Properties of the Data

- Asymmetry distributions very clean over range of 10^5



- Measured and expected widths agree at few % level



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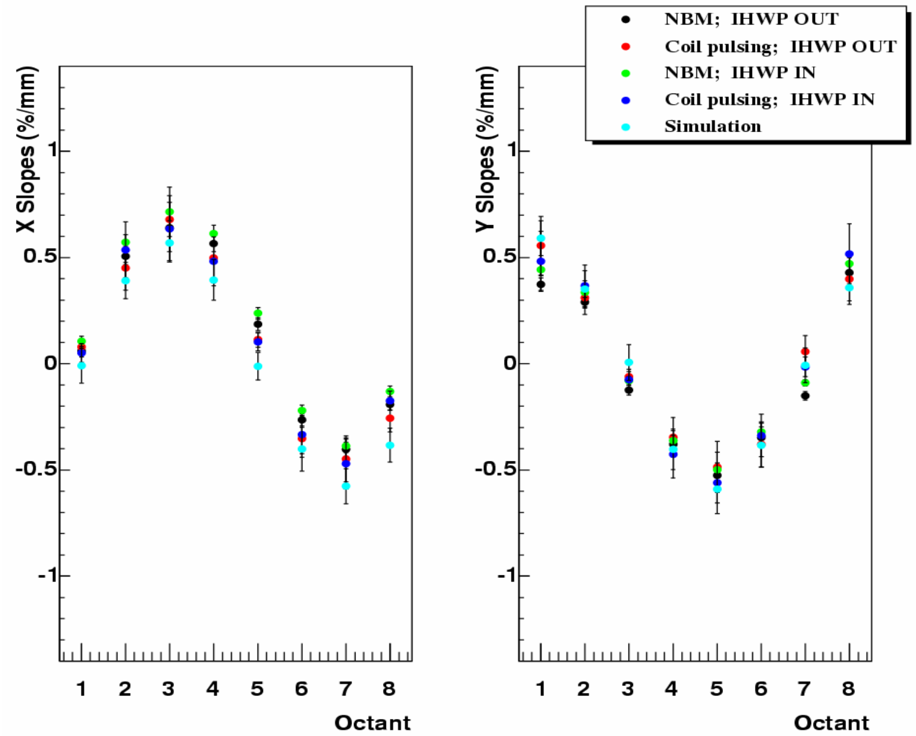
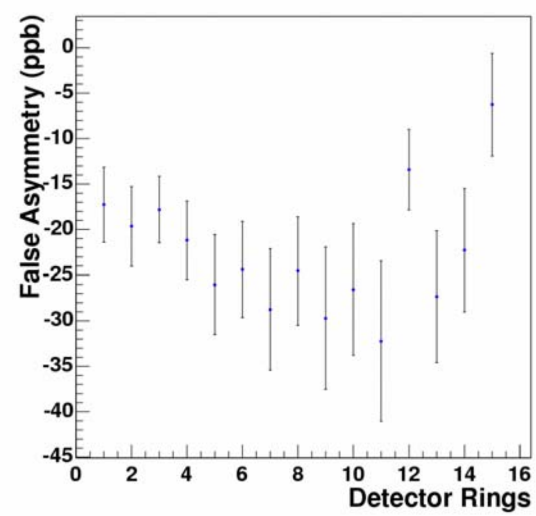
Helicity-Correlated Beam Parameters

- Response of spectrometer to beam changes well understood
- Average helicity-correlated beam parameters very small
- False asymmetries due to helicity-correlated beam parameters very small
  - overall about -0.02 ppm
  - largest is 0.01 ppm from residual charge asymmetry
  - uncertainties small as well: 0.01 ppm





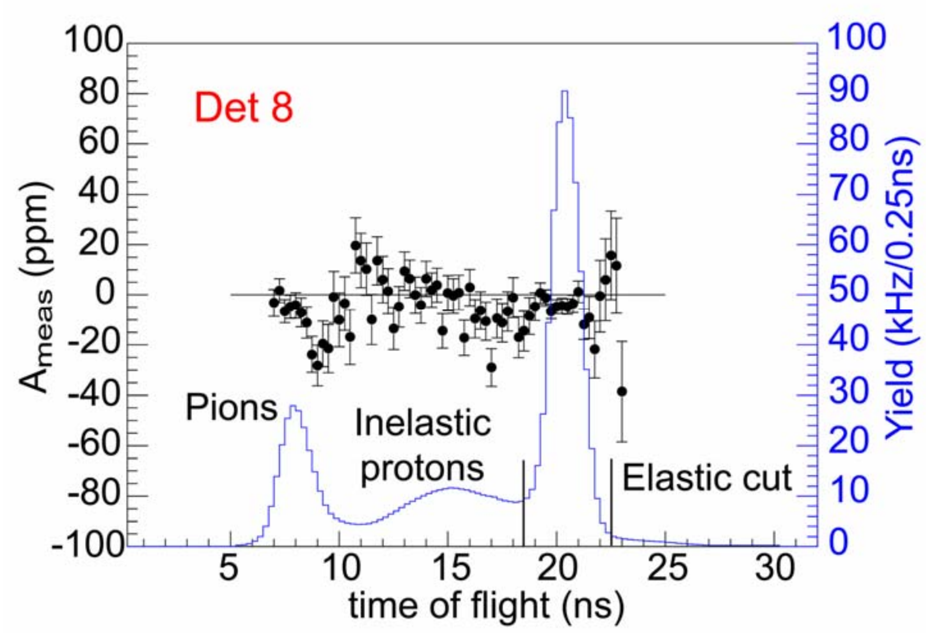
Background Overview

- Measure yield and asymmetry of entire spectrum
- Correct asymmetry according to

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

where A_{el} is the raw elastic asymmetry,

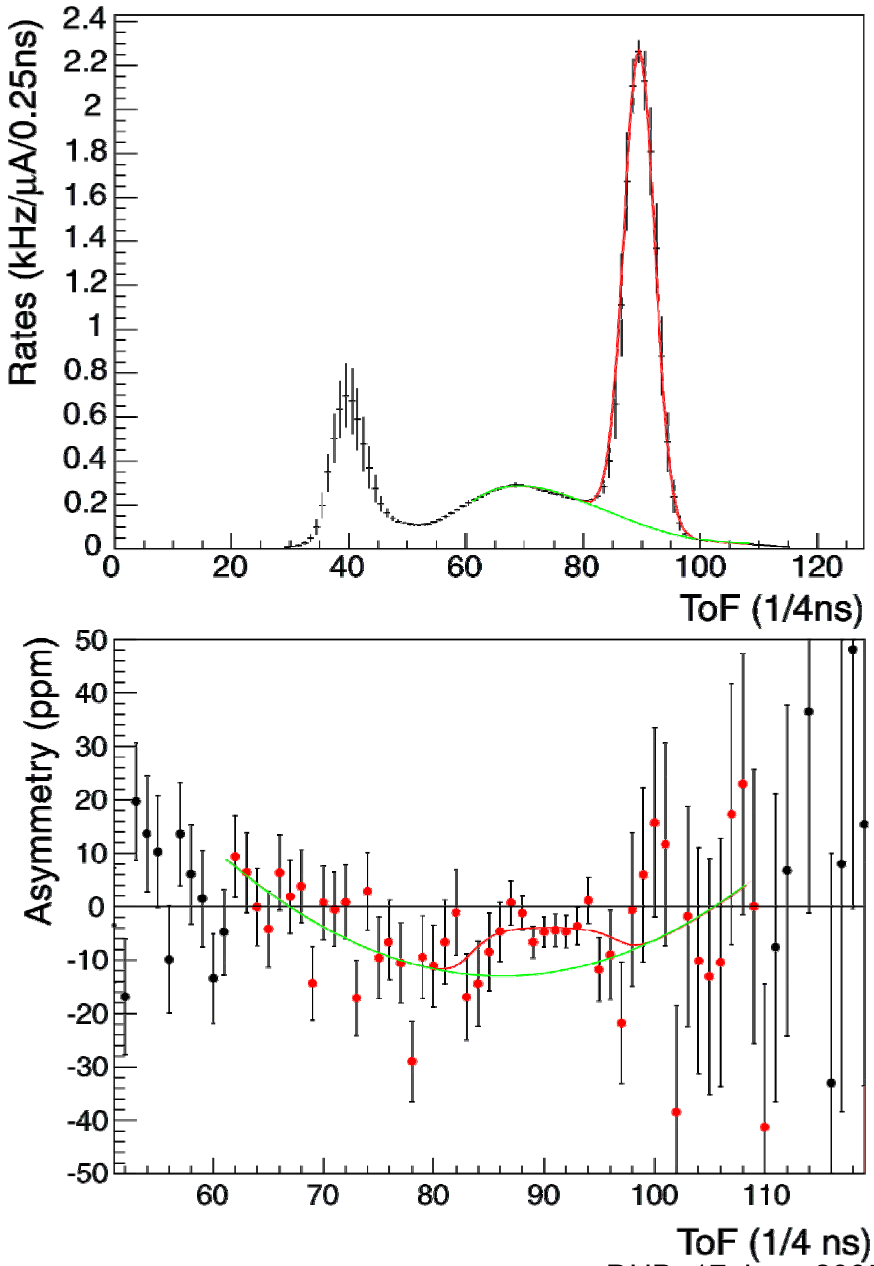
$$f = \frac{Y_{back}}{Y_{meas}}$$



- Actual analysis: *f = f(t)*
  - det. 1-14
    - fit Y_{back} (poly'l of degree 4), Gaussian for elastic peak
    - then fit A_{back} (poly'l of degree 2), constant A_{el}
  - det. 15
    - interpolate over detectors for Y_{back}, A_{back}
    - fit 3 constants for A_{el}

Det 1-14 Background

- Results of 2-step fitting procedure: det 8
  - fit Y_{back} (poly'l of degree 4), Gaussian for elastic peak
  - then fit A_{back} (poly'l of degree 2), constant A_{el}
  - example fits
    - yield: $\chi^2 = 31.1/40$
    - asym: $\chi^2 = 37.5/44$
  - f determined from Y_{back}, Y_{meas} in subsequent analysis
    - don't use detailed shape of elastic peak
- Det 14 similar except it has 2 elastic peaks
  - $Q^2 = 0.41, 1.0\ GeV^2$



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Det. 1-14 Background Uncertainty

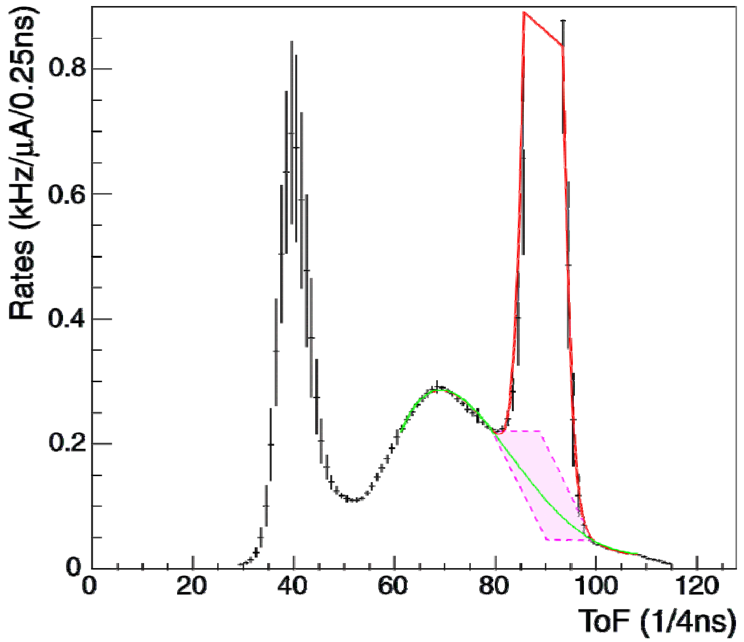
- Statistical uncertainty includes that from A_{el} and from A_{back}

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

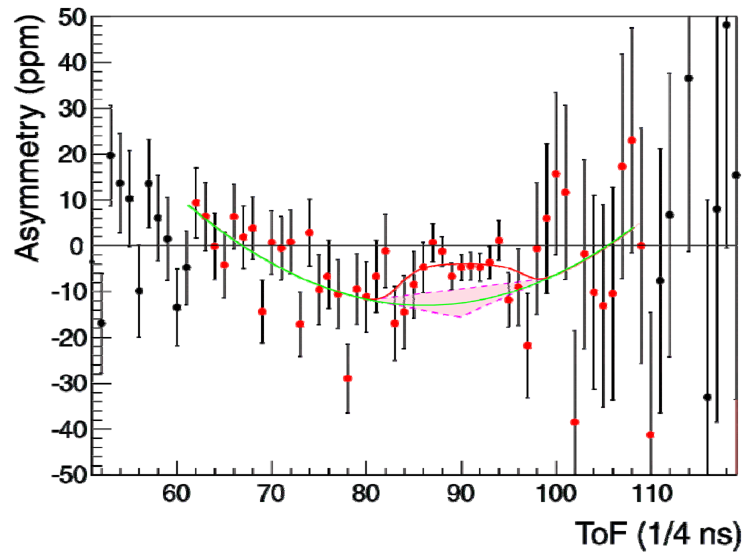
- Systematic uncertainty: general philosophy
  - vary background yield and asymmetry over plausible ranges
  - consider distributions of results for A_{el}
    - unweighted
    - weighted by χ^2
    - systematic uncertainty is average of std. dev. of these two distributions

Det. 1-14 Background Uncertainty

- Background yield varied within "lozenge"
  - use a variety of shapes



- Similar approach for asymmetry
  - vary throughout range



Correlations in Det 1-14 Backgrounds

- Separate point-to-point (pt-pt) uncertainties in background correction from global uncertainties
  - e.g. changing from linear to quadratic model for background asymmetry changes all det.1 -14 asymmetries downward on average
- Again using the distributions of results for A_{el}
  - calculate ~ correlation coefficient
  - correlated uncertainty is change in centroid of distribution for given background model compared to width of overall distribution ($\equiv$ total systematic uncertainty)
- For det. 1-14

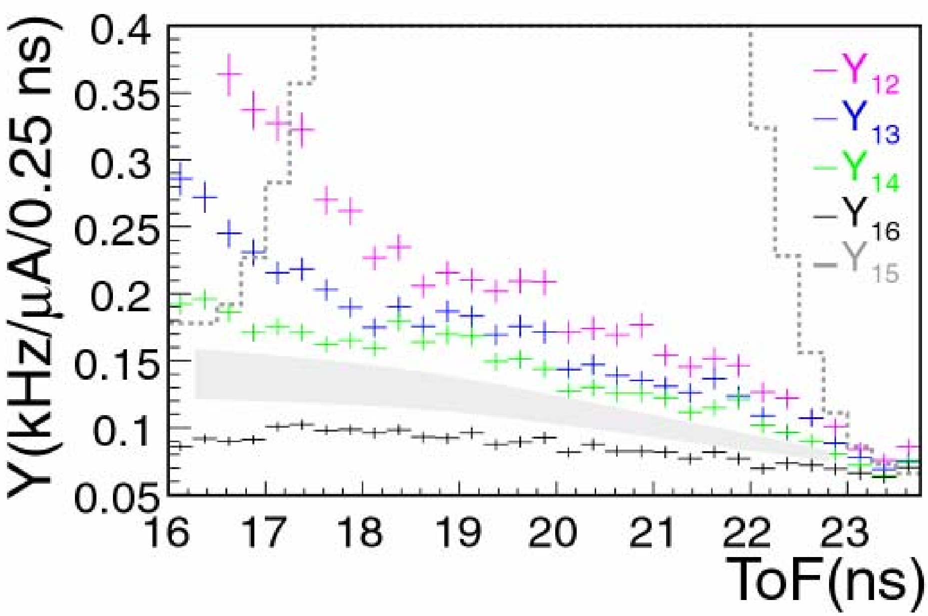
$$\Delta^2 A_{el,sys} = \Delta^2 A_{el,pt-pt} + \Delta^2 A_{el,glob}$$

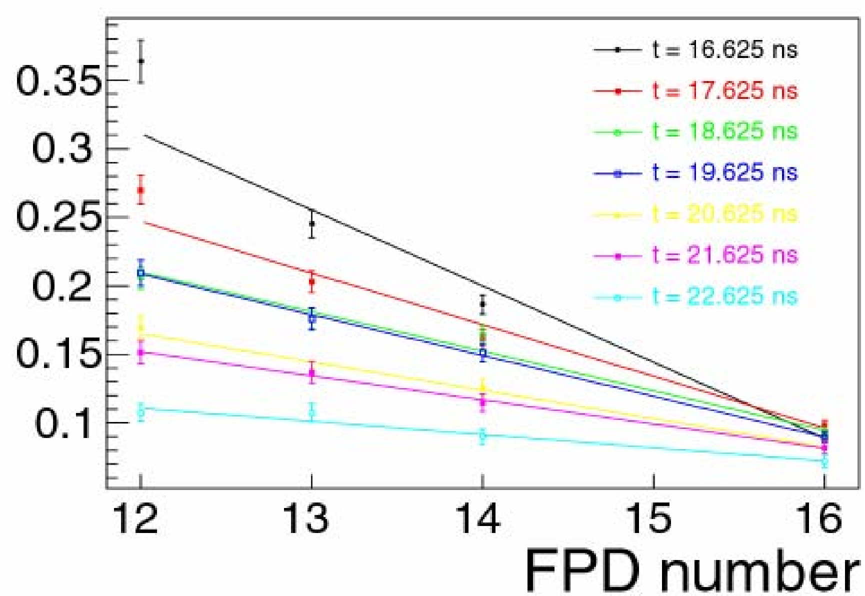
$$\Delta^2 A_{el,pt-pt} = \frac{1}{4}\Delta^2 A_{el,sys}$$

$$\Delta^2 A_{el,glob} = \frac{3}{4}\Delta^2 A_{el,sys}$$

Det. 15 Background Yields

- Elastic protons shifted to lower t.o.f.
- Elastic peak broadened because of increased Q^2 acceptance
- Interpolate over detector range 12-14, 16
  - take out changing acceptance first



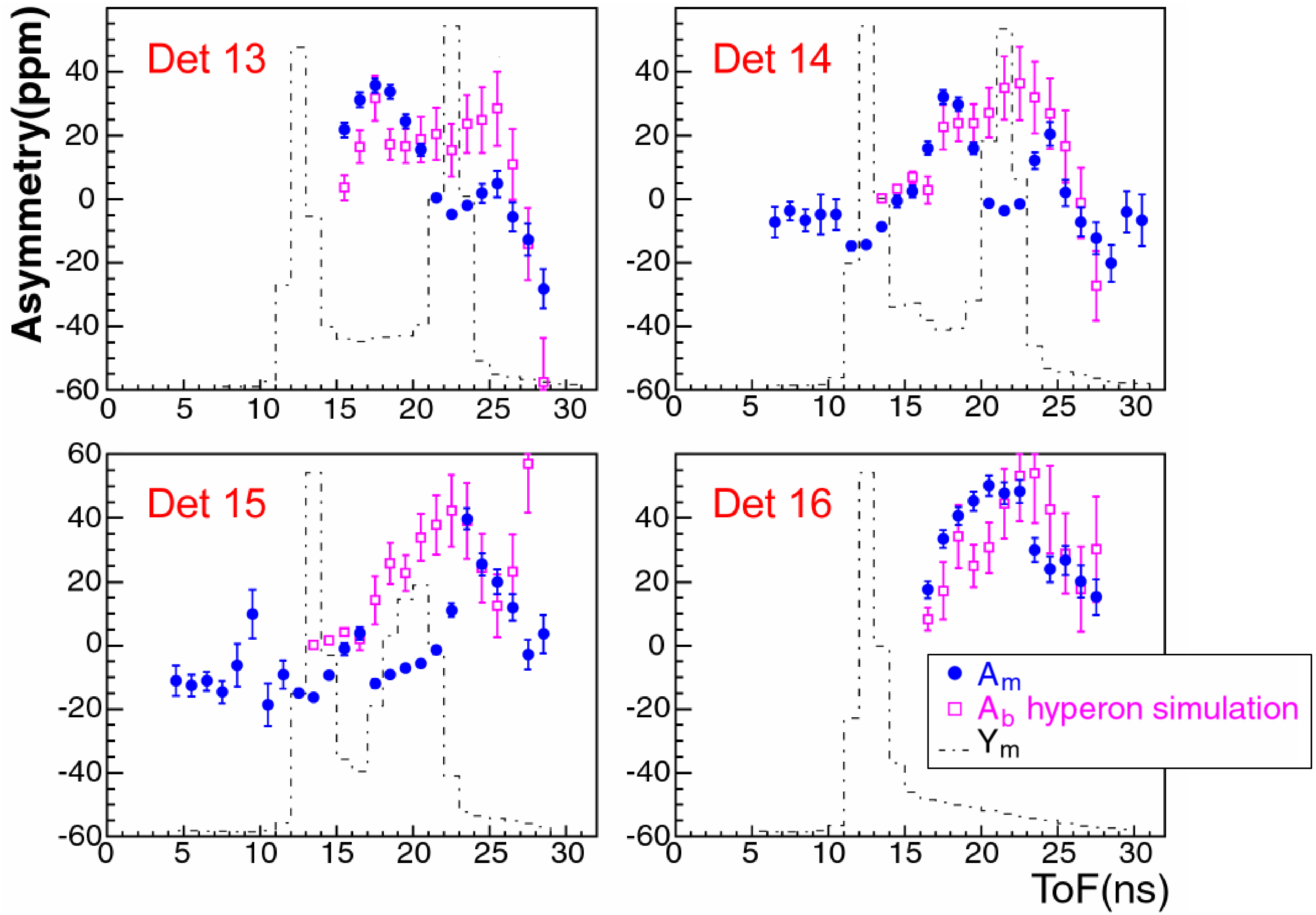


Positive Background Asymmetries

- Det. 12-16 see smoothly varying peak in background asymmetries
  - maximum magnitude ~ +45 ppm

- Source is protons from hyperon weak decay scattering inside spectrometer
  - GEANT simulation with generator for hyperon production based on CLAS data
  - simulate both Λ and $\Sigma^{+,0}$ decays
    - polarization transfer for Λ 100%
    - assume 70% for Σ^{+}
    - Σ^{0} asymmetry scaled by further factor of -1/3 (CG coefficient)
  - simulation explains source; use measured data for actual analysis

Positive Background Asymmetries: GEANT



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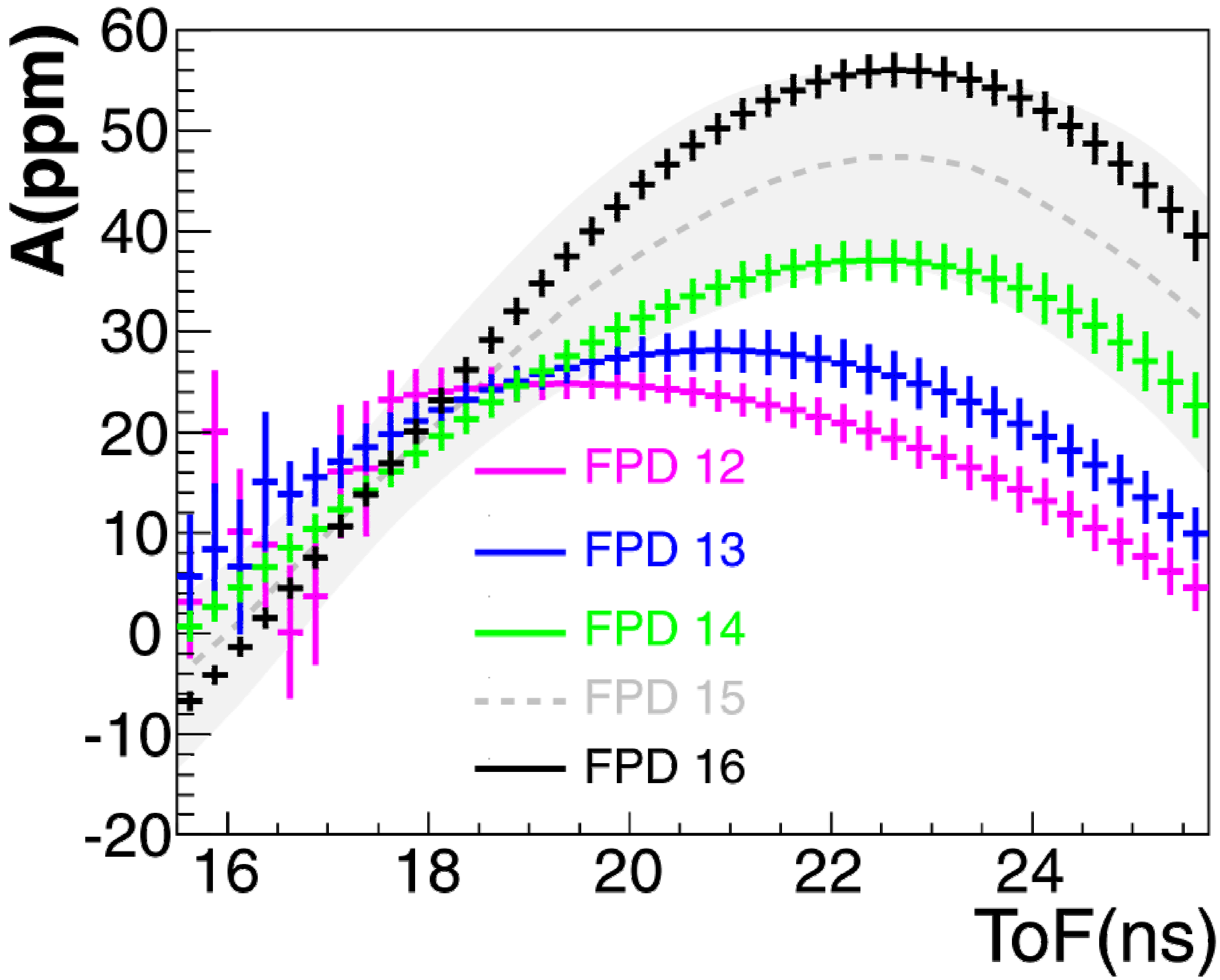
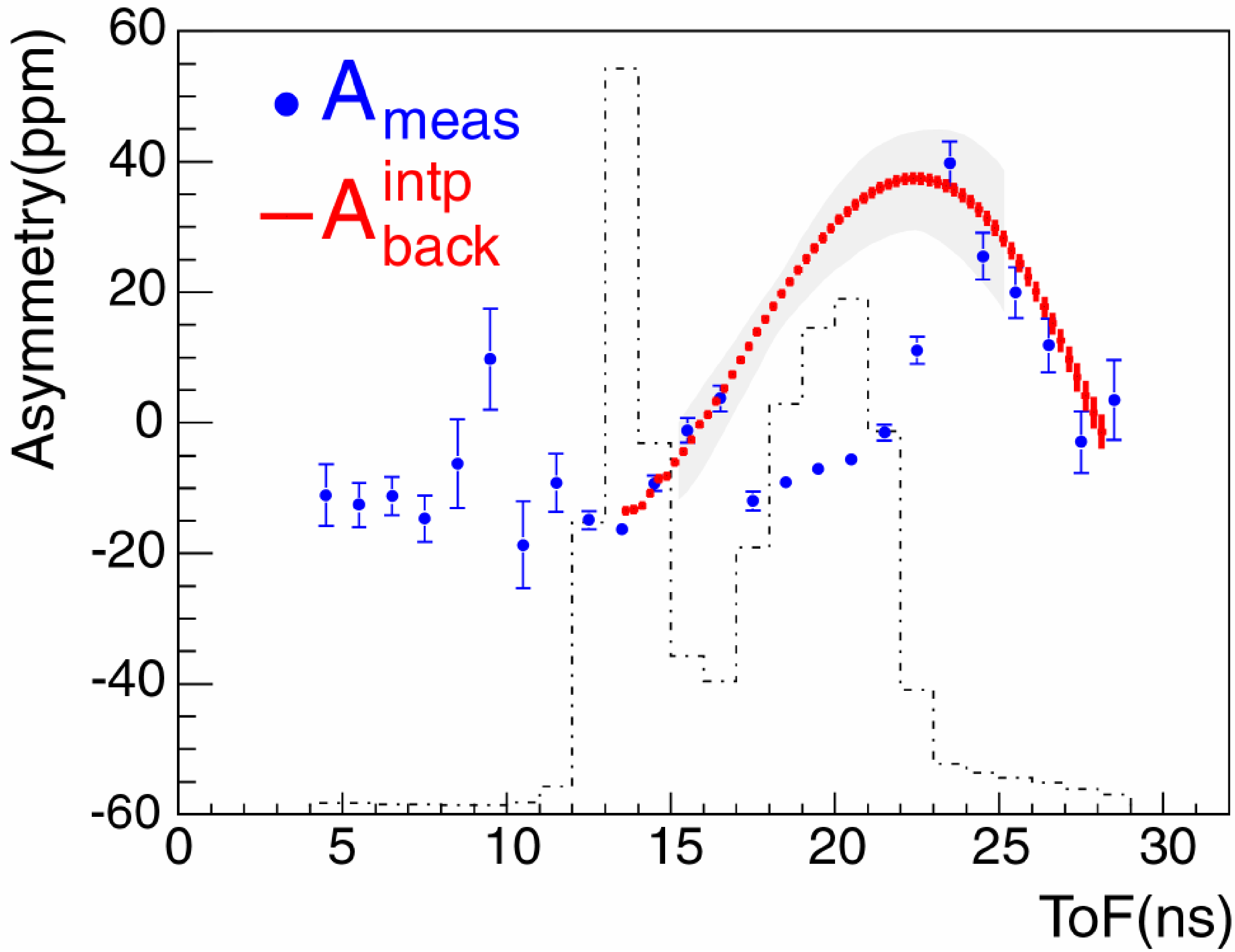
Det. 15 Background Asymmetry

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



Det. 15 Asymmetry

- Compare interpolated background asymmetry and data



Correlations in Det. 15 Backgrounds

- Separate point-to-point (pt-pt) uncertainties in background correction from global uncertainties
  – in det. 15, correlations larger because bins are contiguous
- Consider distributions of results for A_{el}
  – for variety of randomly generated models determine correlation coefficient
- For det. 15

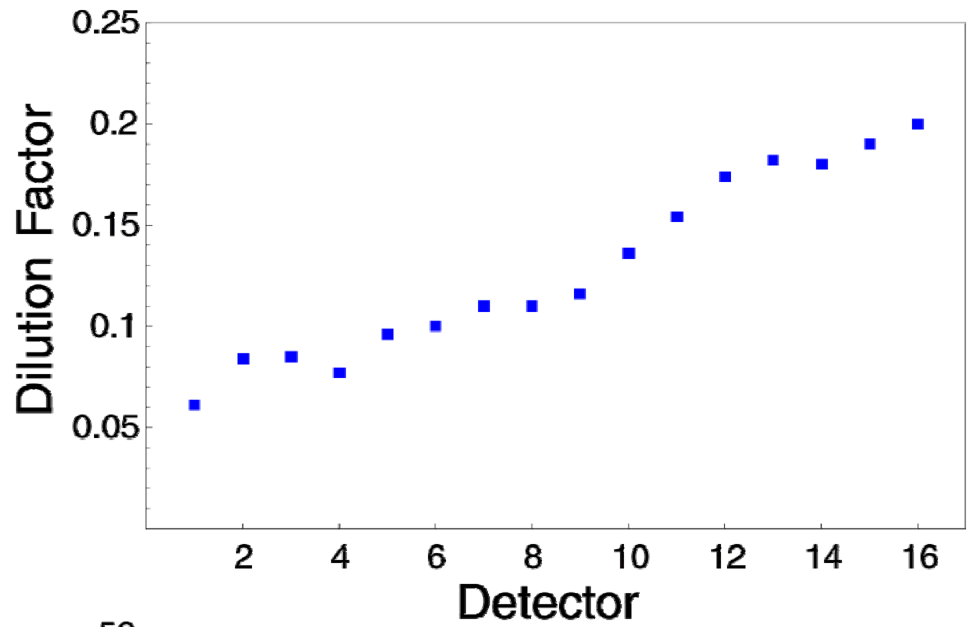
$$\Delta^2 A_{el,sys} = \Delta^2 A_{el,pt-pt} + \Delta^2 A_{el,glob}$$

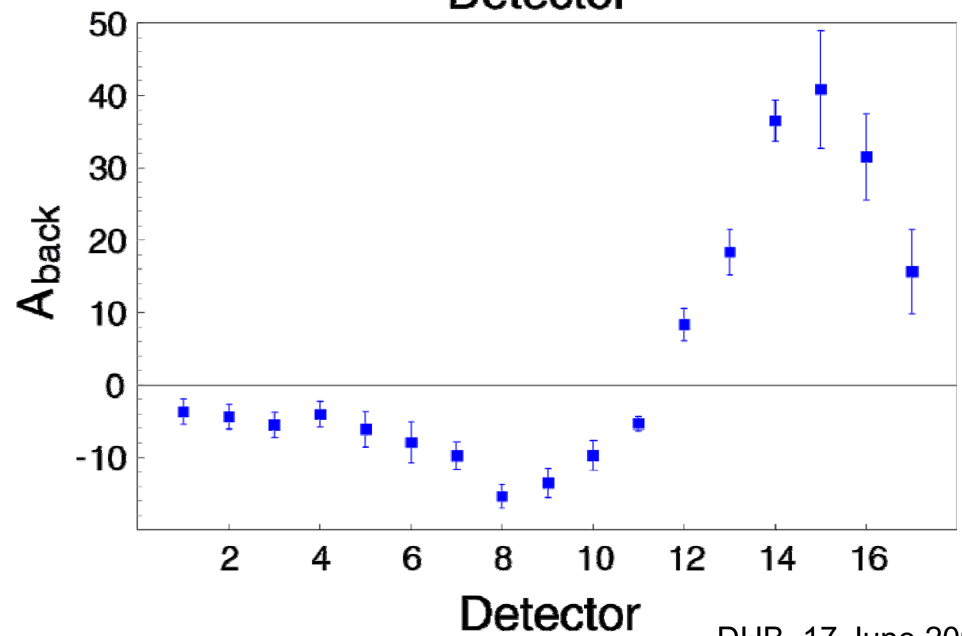
$$\Delta^2 A_{el,pt-pt} = \frac{1}{2}\Delta^2 A_{el,sys}$$

$$\Delta^2 A_{el,glob} = \frac{1}{2}\Delta^2 A_{el,sys}$$

Dilution factor and Background Asymmetry

- Smooth, systematic progression
  - dilution factor
  - background asymmetry
  - both averaged over t.o.f. for demonstration

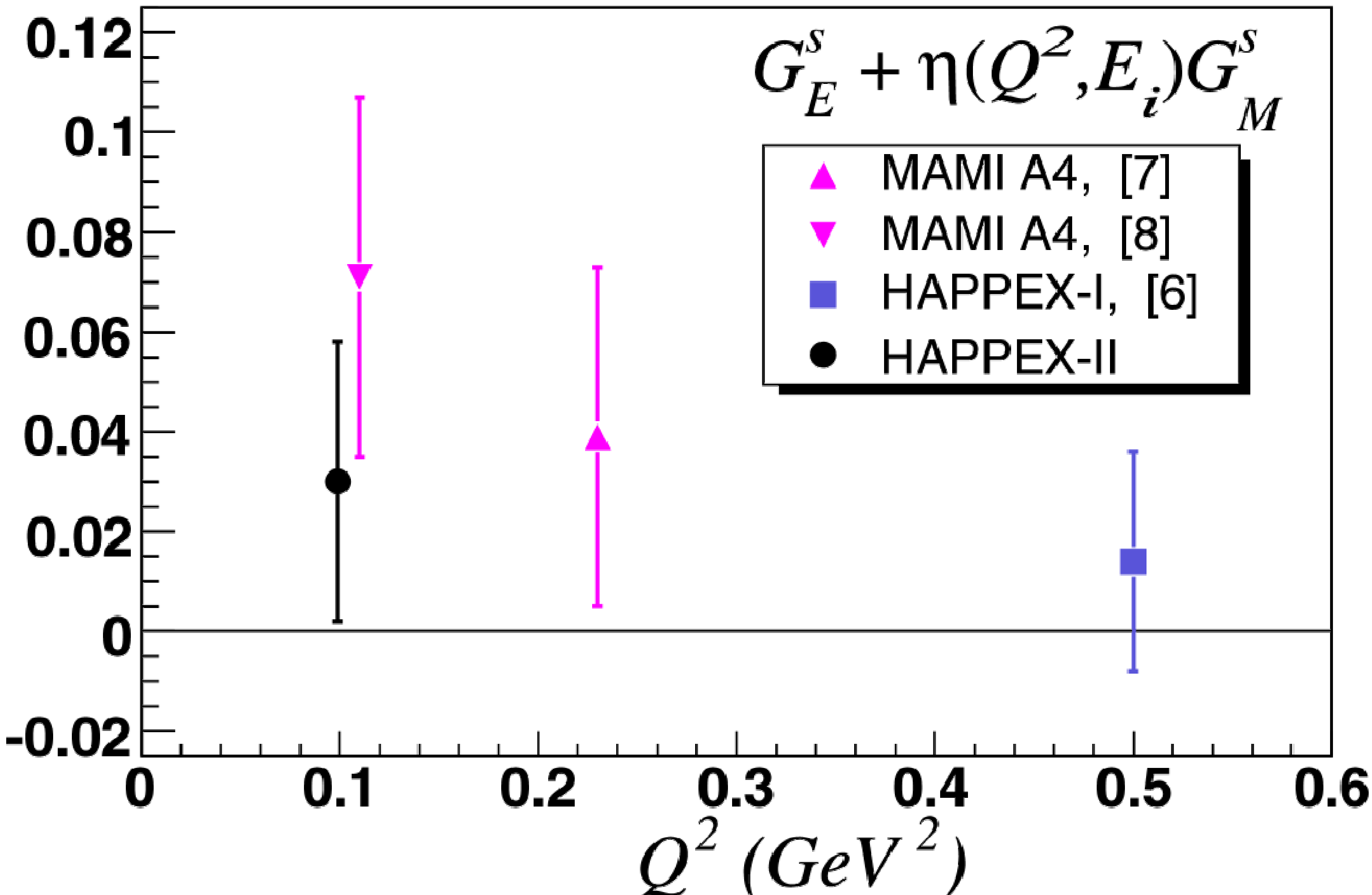




G0 results

Where Were We?

- From HAPPEX H preprint nucl-ex/0506011



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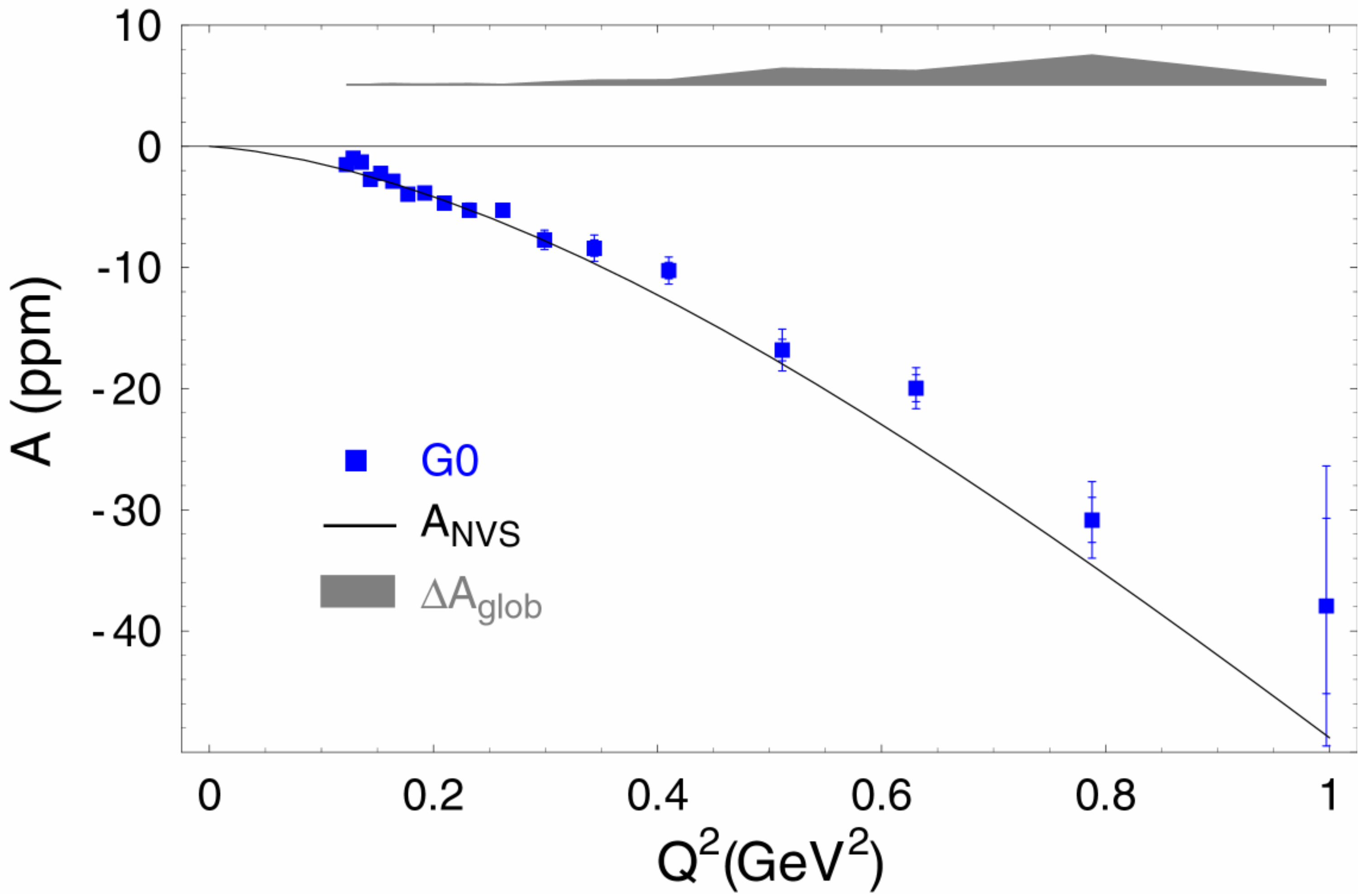
Experimental Results

- A_{phys} corrected for all beam, electronics, background factors

Det	Q^2 (GeV^2)	A_{phys} (ppm)	ΔA_{stat} (ppm)	$\Delta A_{sys,pt}$ (ppm)	$\Delta A_{sys,glob}$ (ppm)	f (ppm)	ΔA_{meas}
1	0.122	−1.513	0.436	0.224	0.176	0.061	−1.380
2	0.128	−0.972	0.409	0.198	0.173	0.084	−1.070
3	0.136	−1.298	0.424	0.174	0.170	0.085	−1.340
4	0.144	−2.707	0.433	0.183	0.176	0.077	−2.670
5	0.153	−2.223	0.431	0.284	0.214	0.096	−2.460
6	0.164	−2.880	0.434	0.324	0.234	0.100	−3.130
7	0.177	−3.949	0.426	0.251	0.205	0.110	−4.470
8	0.192	−3.850	0.485	0.218	0.192	0.110	−5.010
9	0.210	−4.683	0.475	0.258	0.212	0.116	−5.730
10	0.232	−5.267	0.505	0.301	0.232	0.136	−6.080
11	0.262	−5.260	0.520	0.108	0.166	0.154	−5.550
12	0.299	−7.715	0.602	0.531	0.349	0.174	−5.400
13	0.344	−8.400	0.676	0.850	0.521	0.182	−3.650
14 a	0.410	−10.25	0.674	0.895	0.551	0.180	−1.700
15 a	0.511	−16.81	0.889	1.478	1.498	0.190	−5.800
15 b	0.631	−19.96	1.112	1.277	1.306	0.200	−9.740
15 c	0.788	−30.83	1.857	2.556	2.589	0.400	−12.660
14 b	0.997	−37.93	7.237	9.000	0.519	0.780	4.210

Experimental Asymmetries

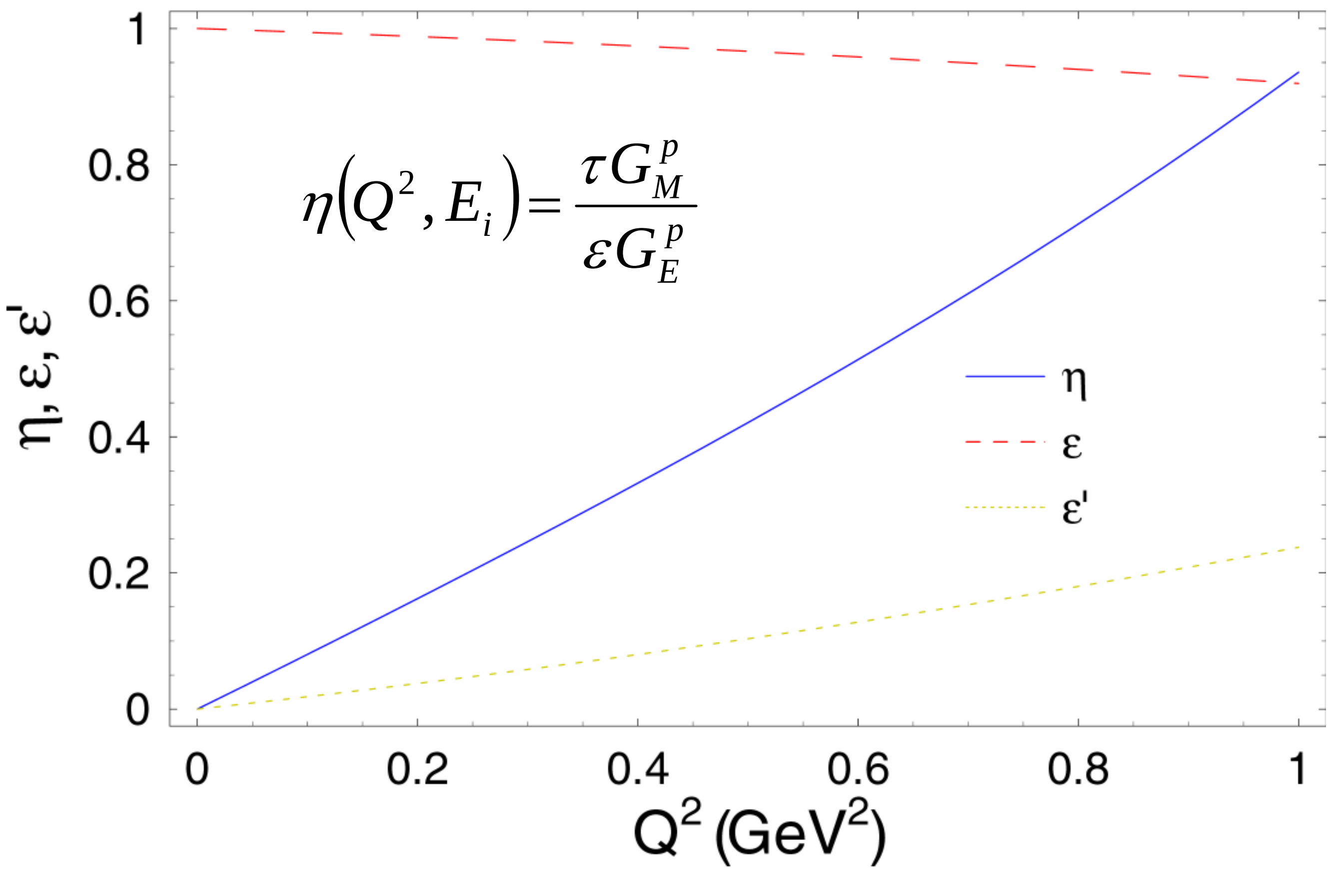
- em form factors: Kelly PRC **70** (2004) 068202
- "no vector strange" asymmetry, A_{NVS}, is $A(G_E^s, G_M^s = 0)$
- inside error bars: stat, outside: stat & pt-pt



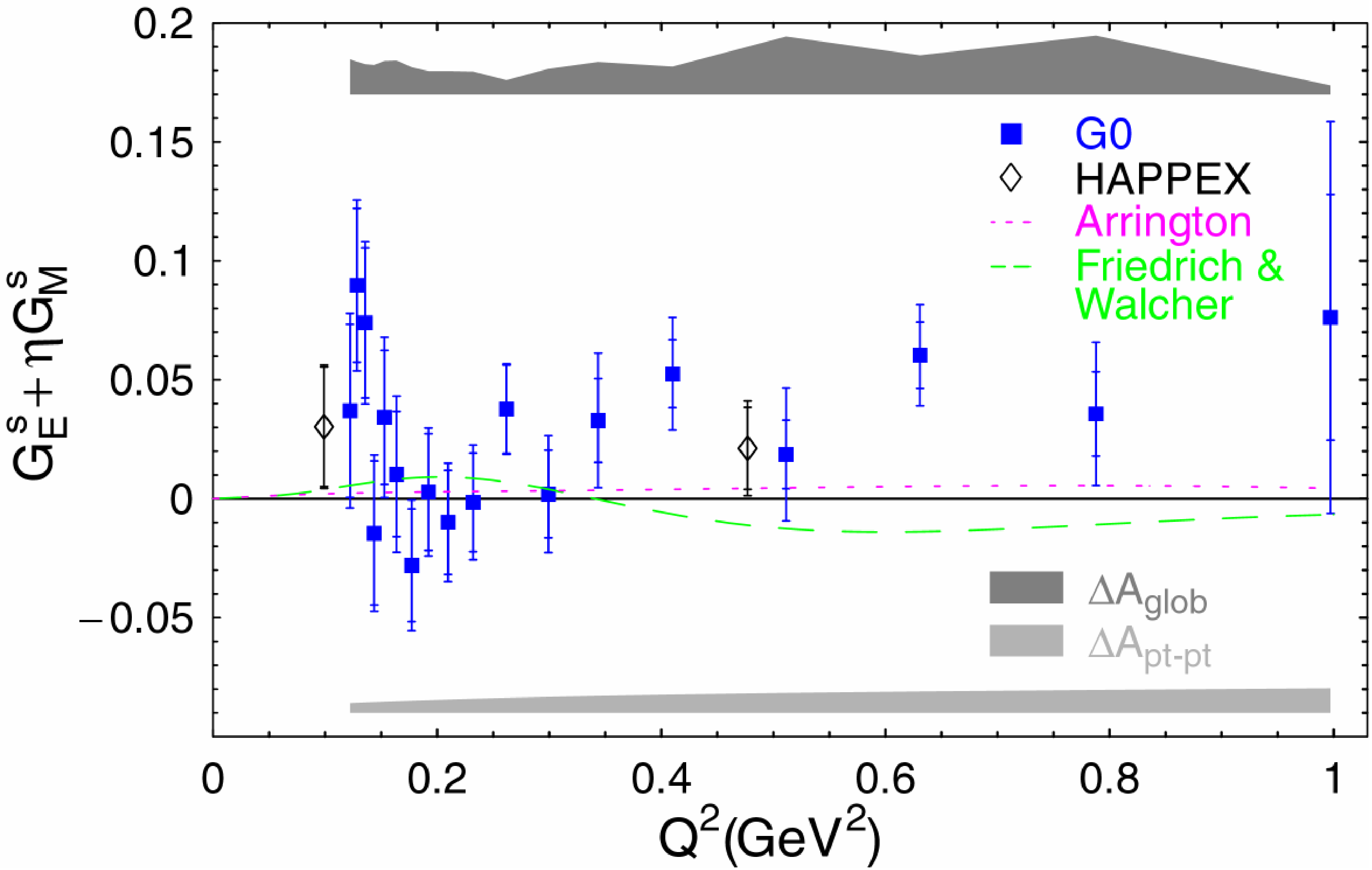
Strange Quark Contribution

- Strange quark contribution to asymmetry

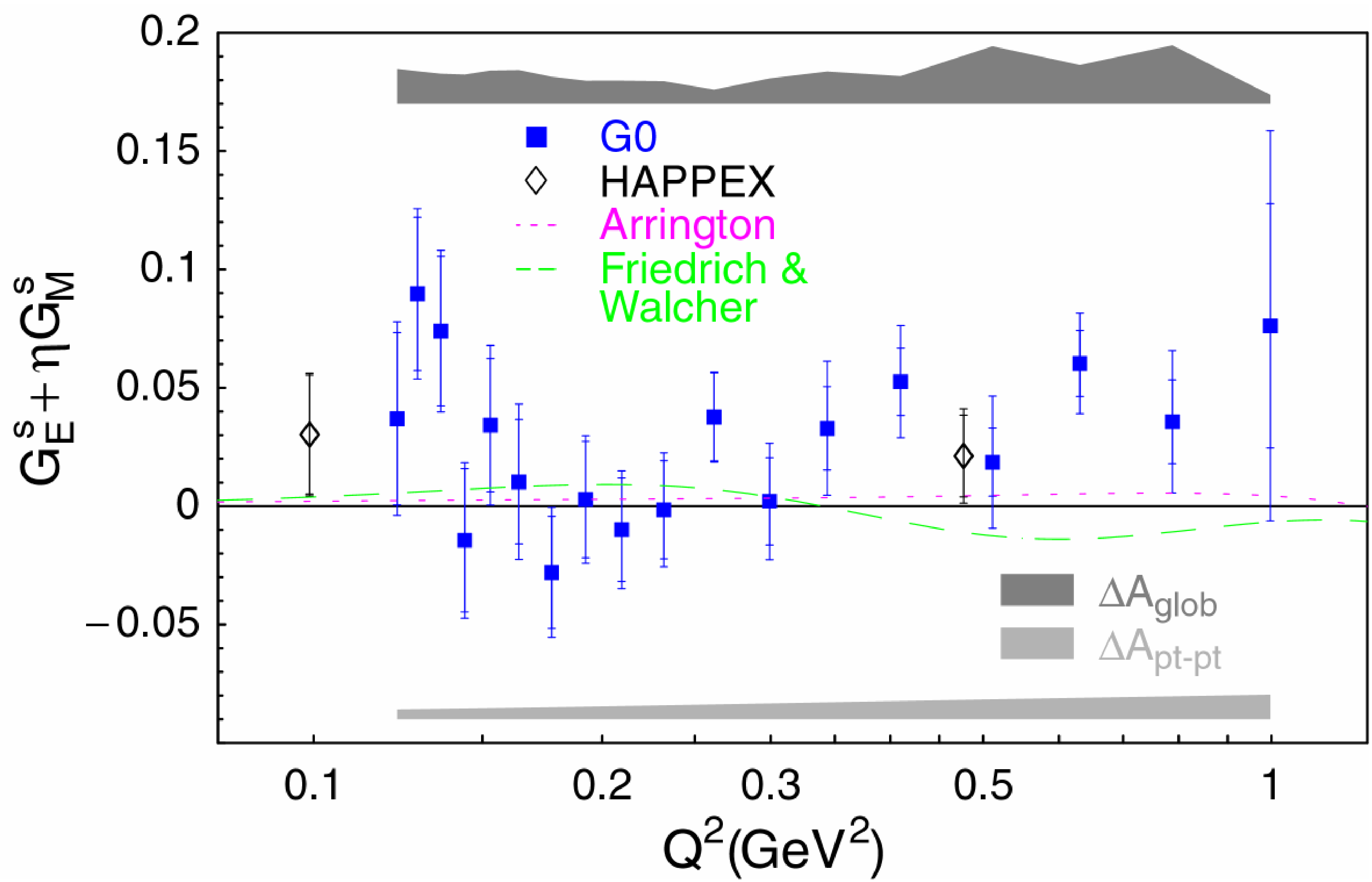
$$G_E^s + \eta G_M^s = \frac{4\pi\alpha\sqrt{2}}{G_F Q^2} \frac{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}}{\varepsilon G_E^p \left(1 + R_V^{(0)}\right)} \left(A_{phys} - A_{NVS}\right)$$



Strange Quark Contribution to Proton



Strange Quark Contribution to Proton



http://www.npl.uiuc.edu/exp/G0/Forward

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Are the G0 Data Consistent with Zero?

- Test hypothesis $G_E^s + \eta G_M^s = 0$
- Simple χ^2 incorrect because of correlated uncertainties

- Instead, generate many copies of data set
  - each data value:
    - value from normal distribution with width = random uncertainty

    PLUS
    - value from normal distribution with width = correlated uncertainty
  - use new choices for each data point for random uncertainty
  - for each data set, use single random number for correlated uncertainty, scale according to our global uncertainty

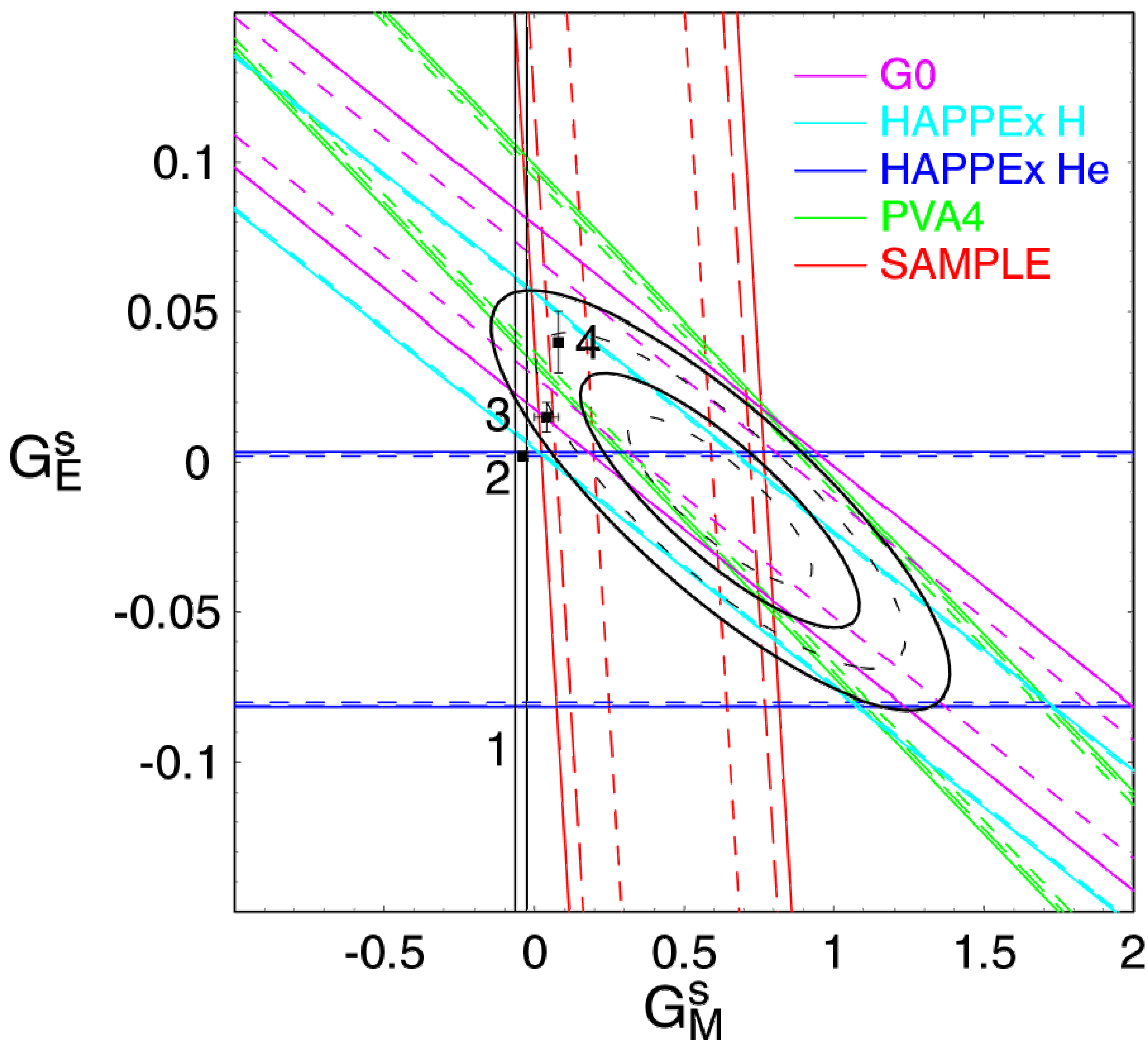
- Result
  - 11% of resulting χ^2 values for test data sets are larger than that for our data
    - ~ independent of uncertainties used to calculate χ^2

Combination of G0 with SAMPLE, HAPPEX, PVA4

G0 With Other Experiments

- Show all uncertainties
  - short dash: statistical
  - long dash: statistical & overall systematic
  - solid: statistical & overall systematic & model
- Kelly form factors
- $Q^2 = 0.1$ GeV^2
  - extrapolate G0 using simple average of A_i/Q^2_i for first 3 Q^2 points
    - $Q^2 = \{0.122, 0.128, 0.136\}$
    - uncertainties are those of average
  - contours
    - simple prescription (PDG §32.1.2, Eqn. 32.11) using likelihood function
    - 1σ, 2σ shown
- $Q^2 = 0.23$ (PVA4-I), 0.477 (HAPPEX-I) GeV^2
  - average $(A - A_{NVS})/Q^2$ for three nearest G0 points
    - essentially averaging $G_E^s + \eta\, G_M^s$
    - $Q^2 = \{0.210, 0.232, 0.262\}$
    - $Q^2 = \{0.410, 0.511, 0.631\}$

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

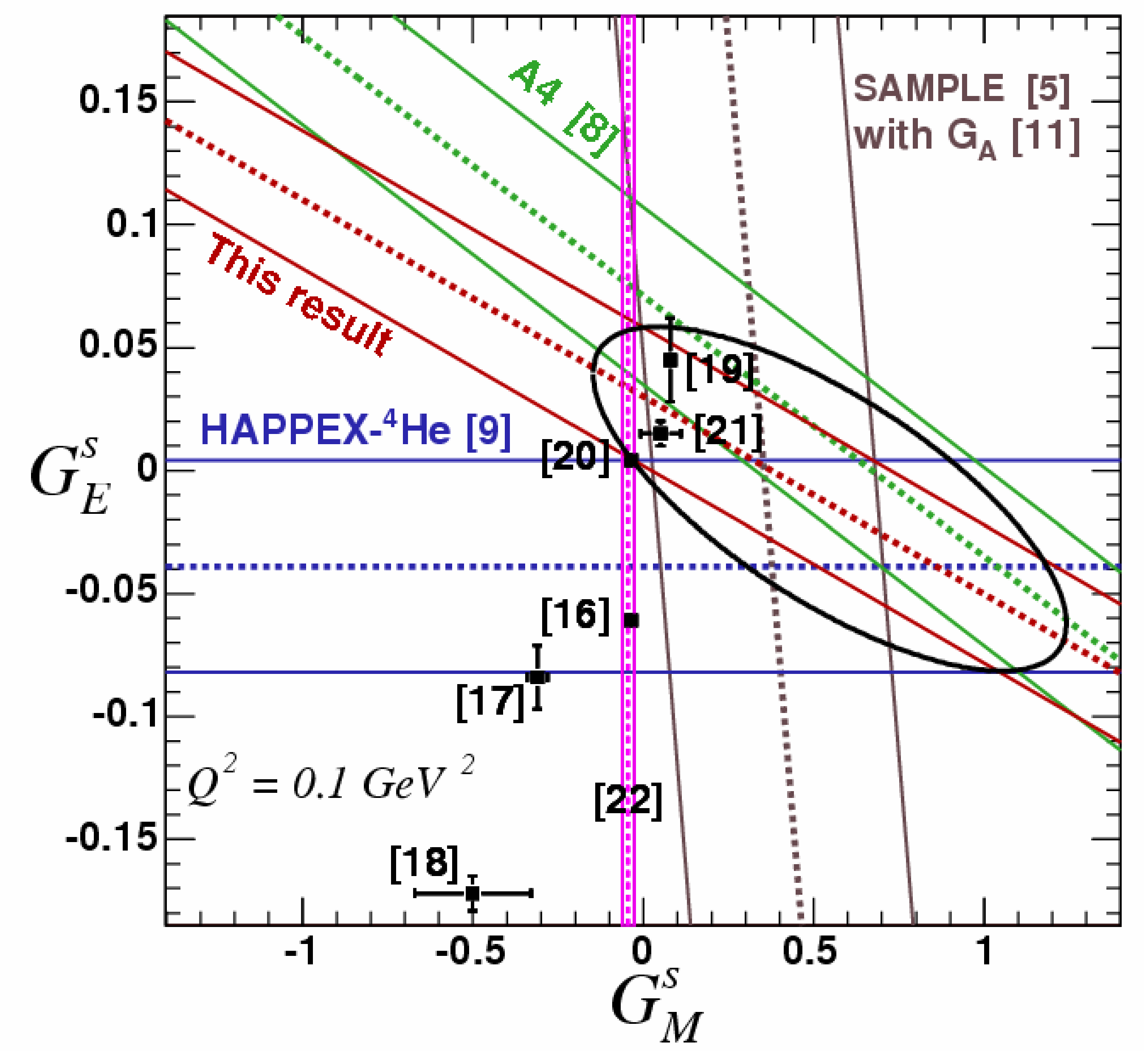
- - - - - 1σ, 2σ

——— 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

HAPPEX H Fig. 3

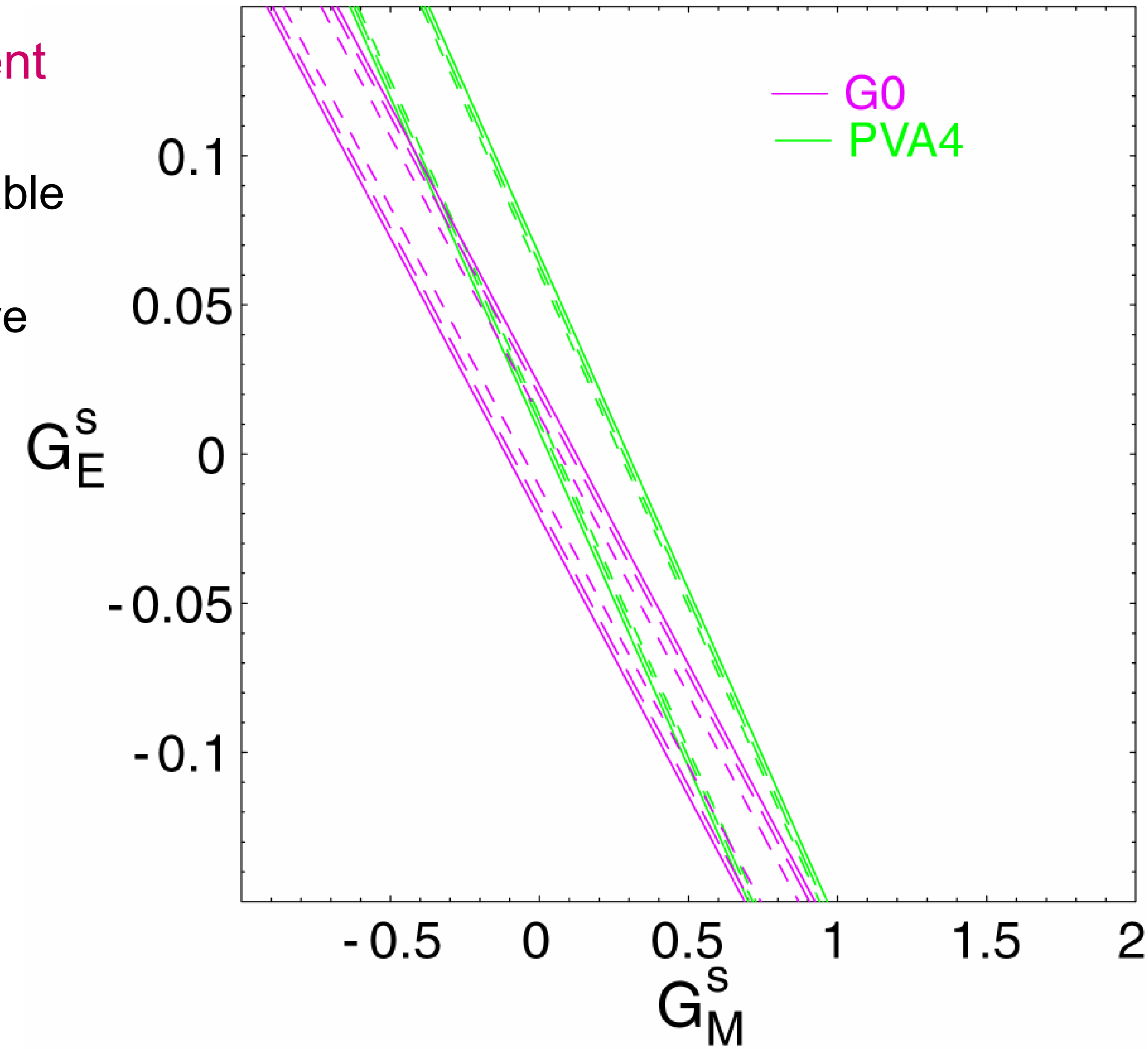


$G_E^s = -0.01 \pm 0.03$

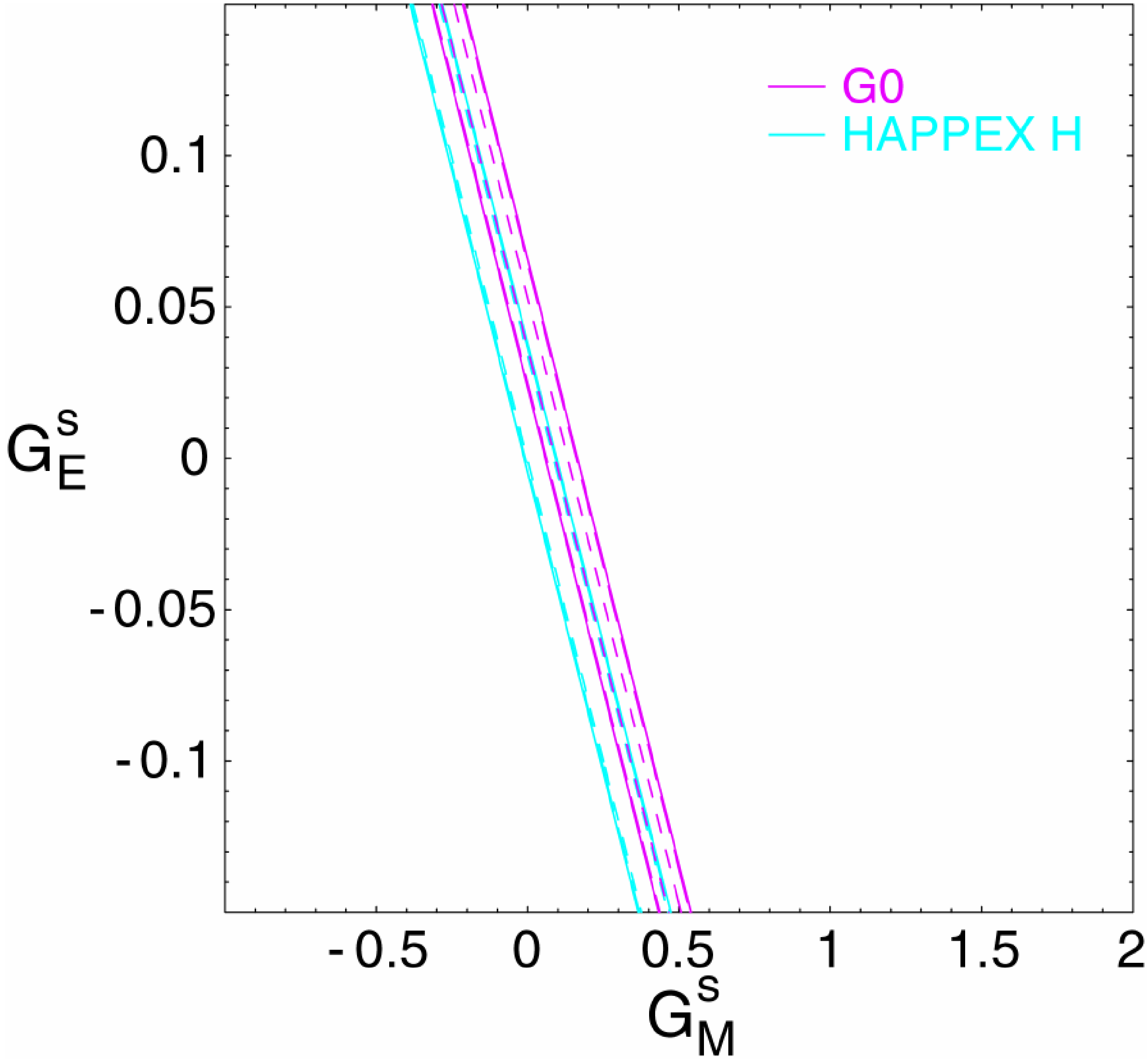
$G_M^s = +0.55 \pm 0.28$

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

- PVA4 measurement at $Q^2 = 0.23\ GeV^2$
  - consistent probable value for G_M^s
  - supports negative G_E^s



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



http://www.npl.uiuc.edu/exp/G0/Forward

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Speculation

Simple Fits to World Hydrogen Data

- Fit

$$G_E^s(Q^2)+\eta(Q^2,E_i)G_M^s(Q^2)=$$

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

with simple forms for G_E^s , G_M^s

$$G_E^s(Q^2)=\frac{c_2 Q^4}{1+d_1Q^2+d_2Q^4+d_3Q^6}$$

à la Kelly

$$G_M^s(Q^2)=\frac{G_M^s(Q^2=0)}{\left(1+Q^2/\Lambda_M^{s\,2}\right)^2}$$

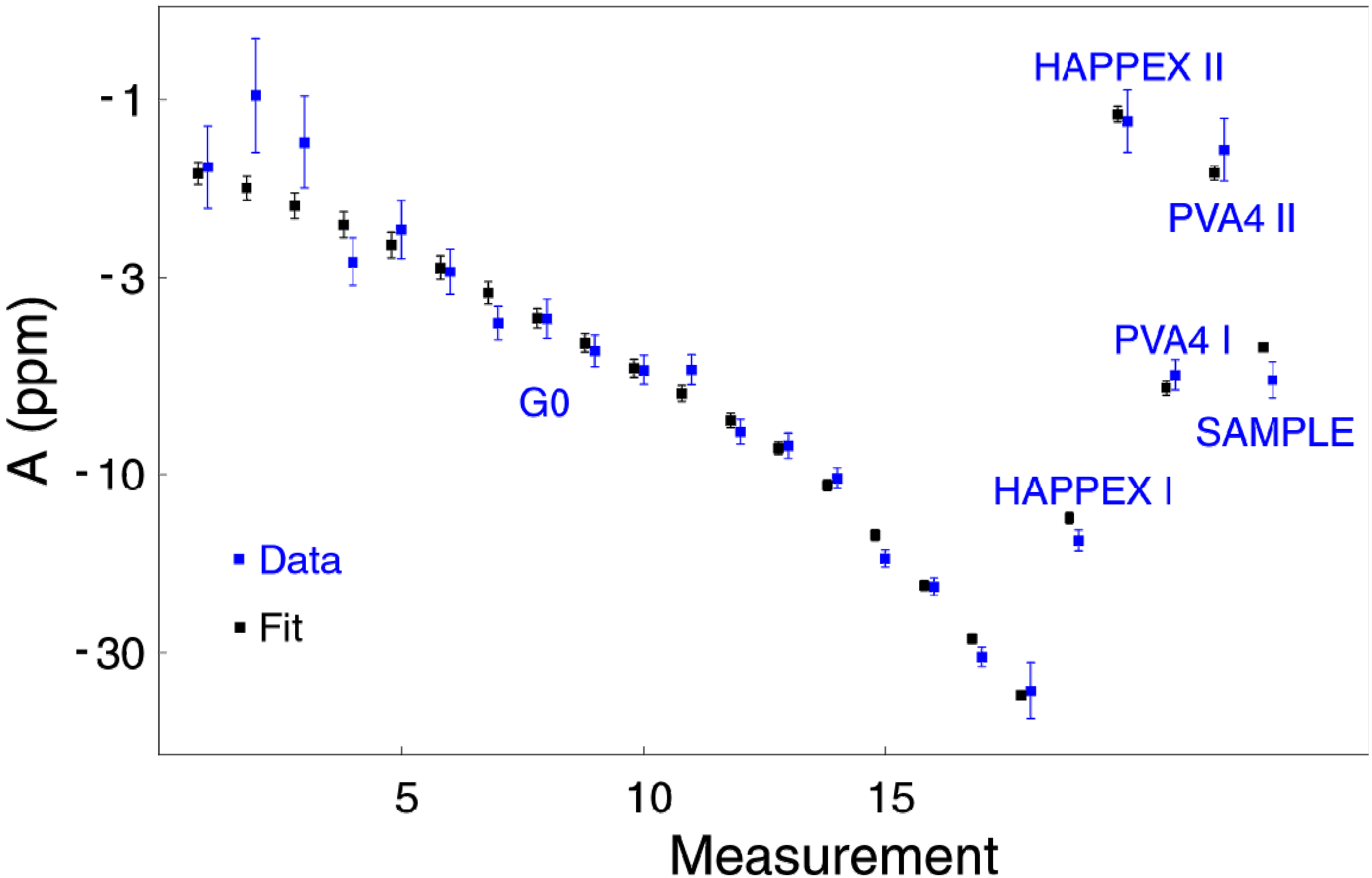
with

$$G_M^s(Q^2=0)=0.81$$

from Q^2 = 0.1 GeV^2 plot, dipole ff

"Fit" to World Hydrogen Data

- $\chi^2 = 31/20$



“Fit” to World Hydrogen Data

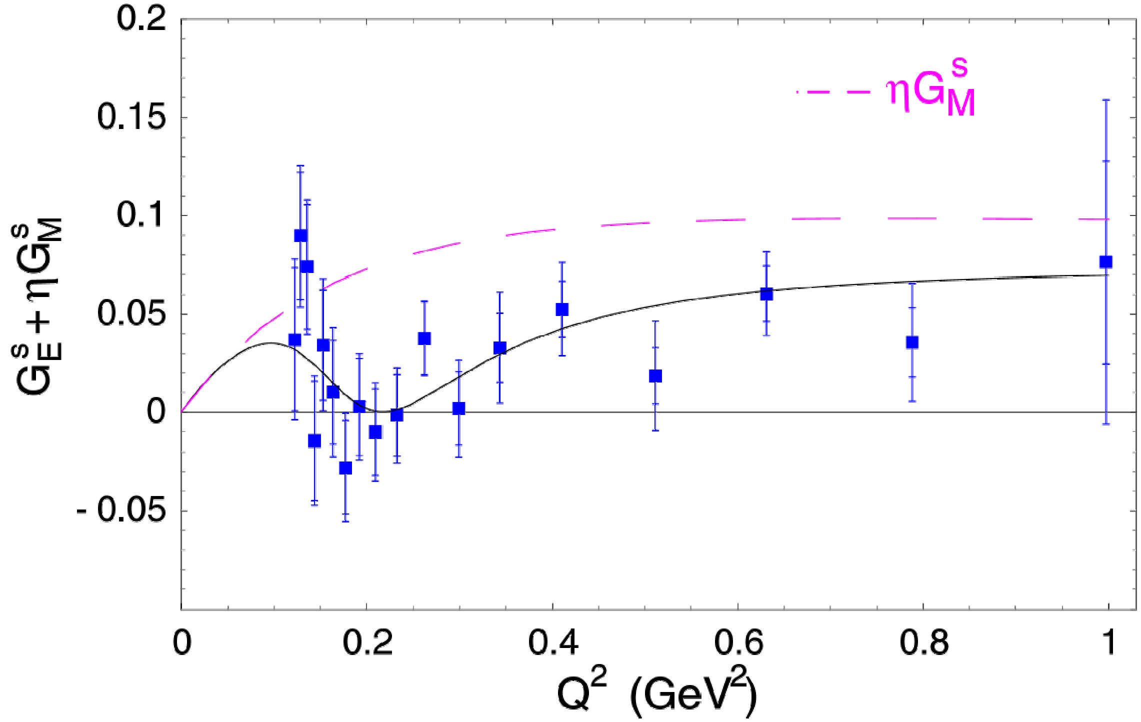
$c_2 = -0.51 \pm 0.25$

$d_1 = -8.5 \pm 0.9$

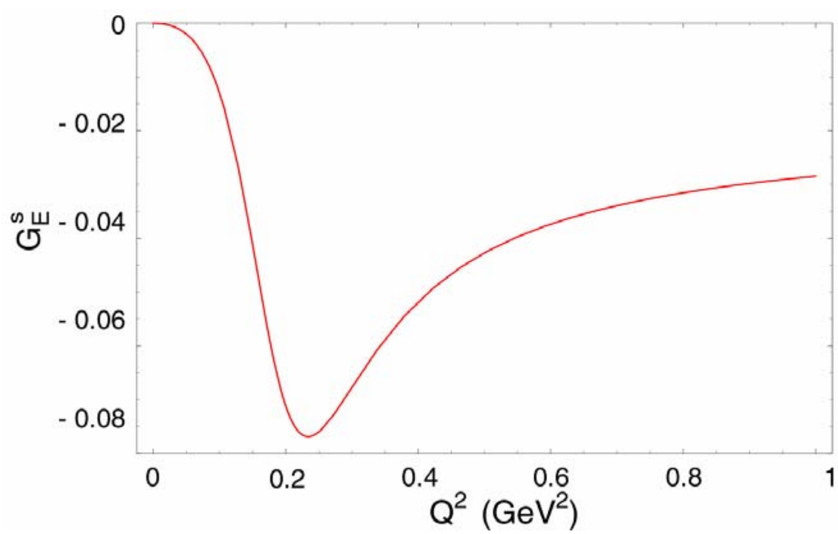
$d_2 = 24 \pm 6$

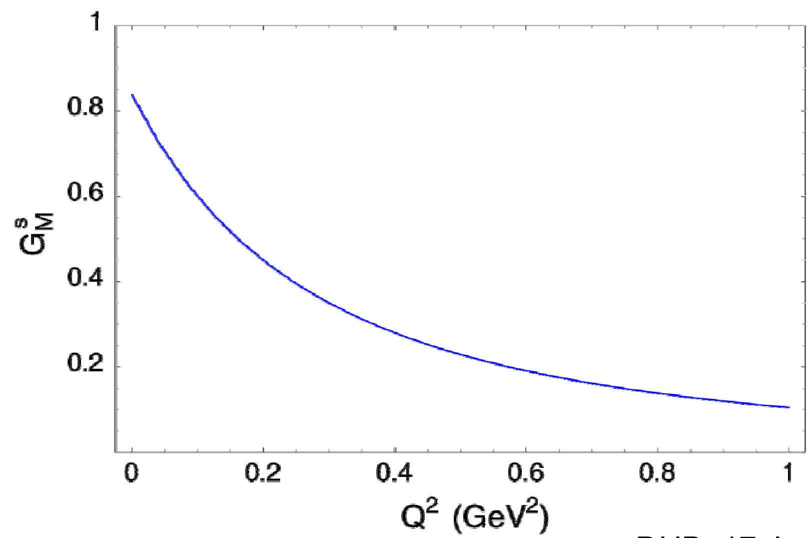
$d_3 = 1$

$\Lambda_M^{s\,2} = \Lambda^2 / 1.3$



Remember the factor of -1/3





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G0 Backward Angle Measurements

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
		D_2	2.80	-25
0.5	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

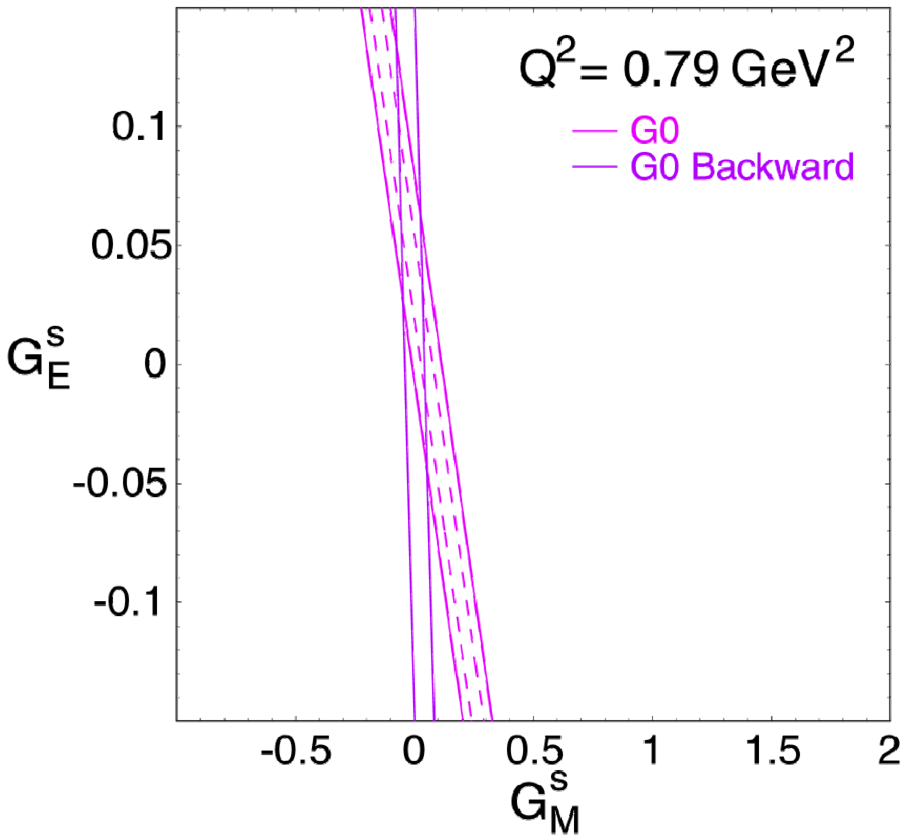
Scheduled:
Dec 05 – May 06

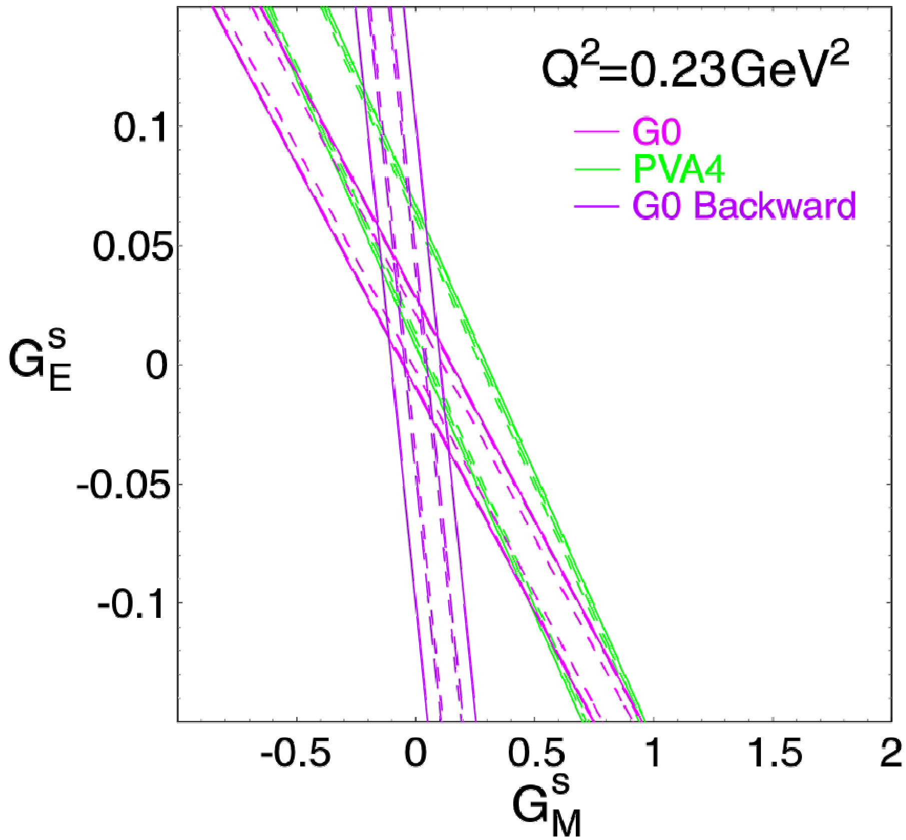
- New detectors (scintillator array, Cherenkov): commissioning
- New electronics assembly (tested previously)
- Trigger change to run with standard beam (499 MHz)

} collaboration

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

- Run in Dec '05 at $Q^2 = 0.79\ GeV^2$ (H and D targets)
- Possible run at $Q^2 = 0.23\ GeV^2$ next (H alone?)





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G0 Summary

- First measurement of parity-violating asymmetries over broad Q^2 range
- Excellent performance of accelerator, experimental equipment
- Conservative estimates of uncertainties
  - careful assessment of backgrounds

- Results consistent with previous measurements
- Emerging picture
  - $G_M^s > 0$ at low Q^2
  - $G_E^s < 0$ at medium Q^2 a possibility
  - $G_E^s + \eta\, G_M^s$ positive at higher Q^2

Acknowledgements

- We gratefully acknowledge the support of our funding agencies
  - DOE (US), NSF (US), IN2P3-CNRS (Fr) and NSERC (CA)

- We would also like to extend sincere thanks to the very strong technical support from many groups
  - Caltech, Illinois, LPSC-Grenoble, IPN-Orsay, TRIUMF
  - especially: JLab Accelerator
JLab Hall C