Analysis Update of the G^0 Forward Angle Run

JLab E-00-006, D.H. Beck, spokesperon

Jianglai Liu
Univ. of Maryland

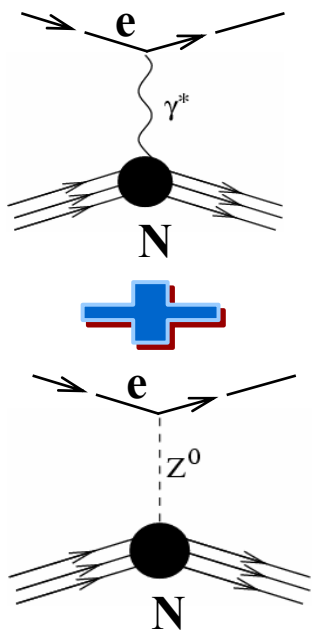
For the G^0 Collaboration :

Caltech, Carnegie-Mellon, William&Mary, Grinnell College, Hampton, IPN-Orsay, LPSN-Grenoble, JLab, Kentucky, LaTech, NMSU, TRIUMF, U Conn, UIUC, U Manitoba, U Maryland, U Mass, UNBC, U Winnipeg, VPI, Yerevan

Jefferson Lab Hall C meeting 01/06/2005

Flavor Decomposition of the Nucleon Form Factors

Elastic e-N scattering



Proton and Neutron Electromagnetic Form Factors

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

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

Strange quark E/M form factors

Proton Weak Form Factors :

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

Assume charge symmetry

$$G_{E,M}^{u,p} = G_{E,M}^{d,n} \equiv G_{E,M}^{u} \ \ldots$$

3 equations, 3 unknowns

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

Extraction of the strange quarks contribution :

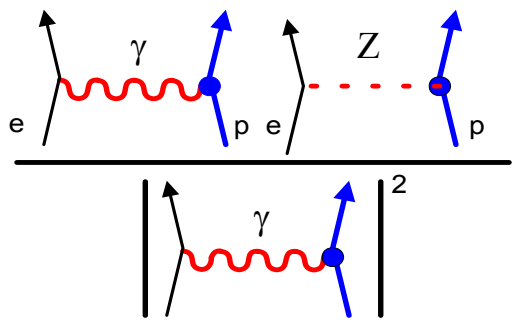
$$G_{E,M}^{s} = \left(1 - 4\sin^2\theta_W\right)G_{E,M}^{\gamma,p} - G_{E,M}^{\gamma,n} - G_{E,M}^{Z,p}$$

But how do we measure the G^Z . . .

Parity Violating Electron Scattering – Probe of Neutral Weak Form Factors

polarized electrons, unpolarized target

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



$$A_E = \varepsilon(\theta)\, G_E^Z(Q^2) G_E^\gamma(Q^2) \rightarrow G_E^s$$

$$A_M = \tau(Q^2)\, G_M^Z(Q^2) G_M^\gamma(Q^2) \rightarrow G_M^s$$

$$A_A = -(1 - 4\sin^2\theta_W)\varepsilon' G_A^e(Q^2) G_M^\gamma(Q^2) \rightarrow G_A^e$$

kinematic factors

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

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

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

3 unknowns. So need 3 independent measurements at a given Q^2. Can tune the experiment to have different sensitivity on G_E^s, G_M^s, G_A^e ("Rosenbluth" technique)

- **Forward angle $\vec{e} + p$ (elastic) → (G_E^s, G_M^s)**
- **Backward angle $\vec{e} + p$ (elastic) → (G_M^s, G_A^e)**
- **Backward angle $\vec{e} + d$ (quasi-elastic) → (G_M^s, G_A^e)**

G^0 Physics Program

Plan : Full separation of G_E^s, G_M^s and G_A^e for Q^2 = 0.3, 0.5 and 0.8 $(GeV/c)^2$

- **Forward Angle mode:**

LH_2 measurement for $0.1 < Q^2 < 1$ $(GeV/c)^2$

- **Backward Angle mode:**

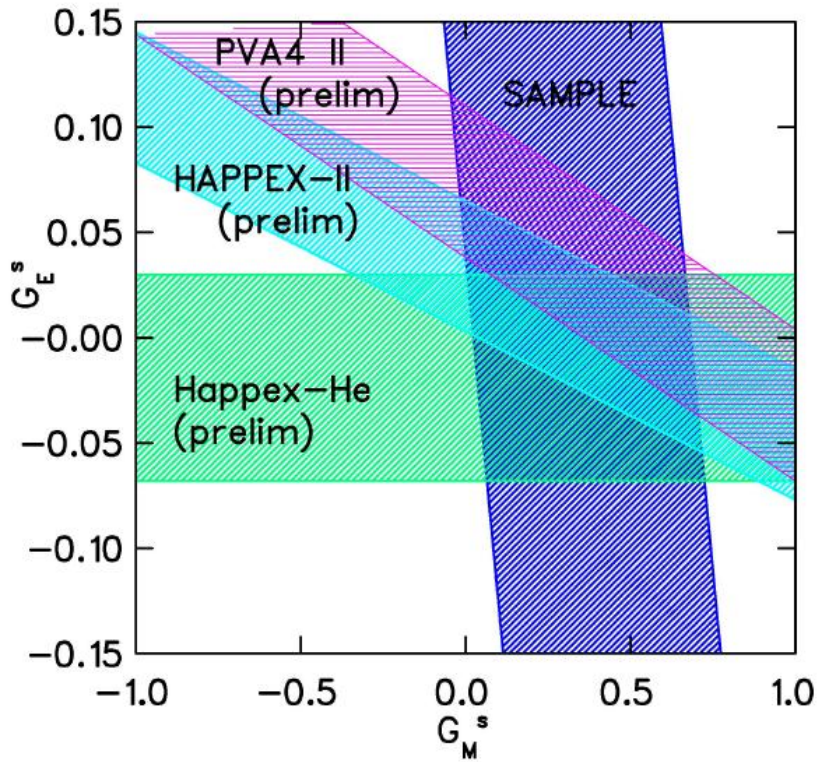
LH_2 (elastic) and LD_2 (quasi-elastic)

measurements for Q2 = 0.3, 0.5 and 0.8 $(GeV/c)^2$

Measurements of A_{PV} ~-3 to -70 ppm

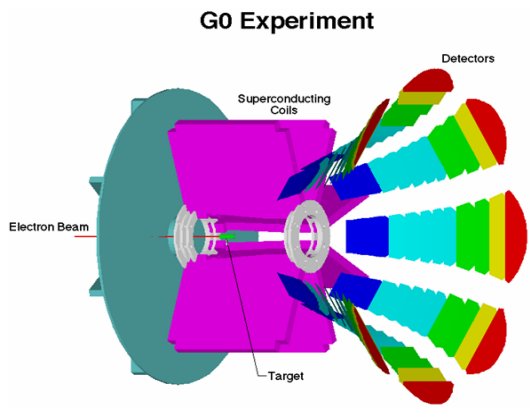
with a precision of $\delta A_{PV}/A_{PV}$ ~ 5%

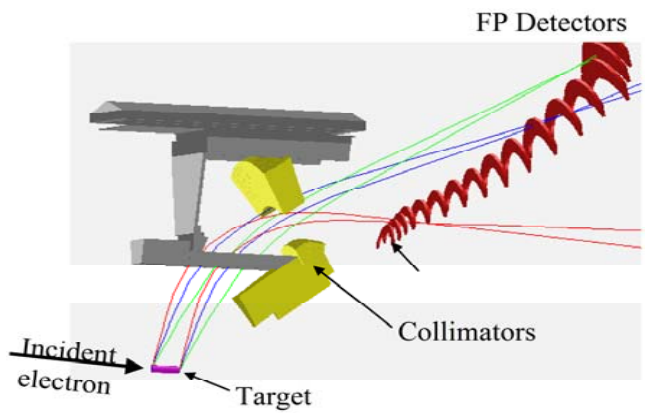
Exciting results @ Q2 = 0.1$(GeV/c)^2$

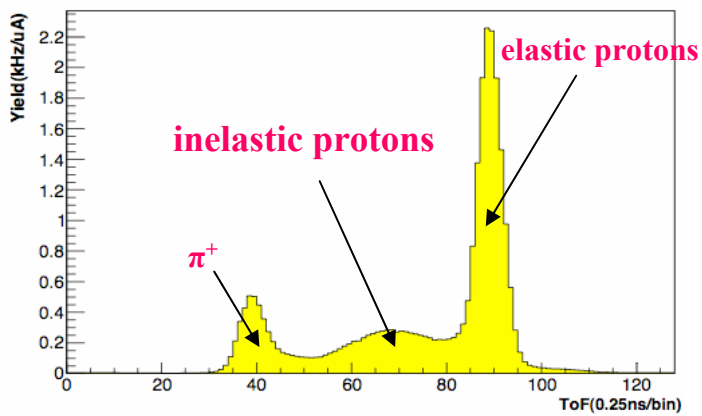


G^0 Forward Angle Mode

- Installed in Hall C at Jefferson Lab
- Detect recoil **protons**
- One energy setting for all Q^2
  - Q^2 = 0.1-1.0 $(GeV/c)^2$
  - E = 3.0 GeV
  - Liquid hydrogen target
- Details
  - Beam bunches separated by 32 ns
  - Spectrometer sorts protons by Q^2 in focal plane detectors (16 rings in total)
  - Time-of-flight separates protons from pions
  - High counting rates (~>1MHz per detector)
- Status
  - Run completed in May 2004 (began in November 2003)
  - 744 hours of parity quality beam (103 Coulombs)







Road to Physics Asymmetry

Raw ToF yields

Correct for dead time

$$Y_{corr} = \frac{Y_{meas}}{1-f_{dead}}, f_{dead} = 10-20\%$$

$$A_{meas} = \frac{Y^+ - Y^-}{Y^+ + Y^-} \times \alpha_{blind}$$

$$\alpha_{blind} \in [0.75, 1.25]$$ secret

Correct for 499MHz leakage

$$\Delta A \approx 0.4 \pm 0.1 \text{ ppm}$$

$$A_{corr} = A_{meas} - \alpha A_{leak}$$

Correct for false asymmetries from helicity-correlated beam properties

$$\Delta A \approx 0.01 \pm 0.01 \text{ ppm}$$

$$A_{corr} = A_{meas} - \sum \frac{1}{2Y} \frac{\partial Y}{\partial P_i} (P_i^+ - P_i^-)$$

low Q^2 high Q^2

Correct for background and its asymmetry

$$\Delta A \approx 0.3 \sim 7.0 \text{ ppm}$$

$$A_{elas} = \frac{A_{corr} - A_{bkg} f_{bkg}}{1 - f_{bkg}}$$

Correct for beam polarization & radiative correction

$$P_{beam} \approx 0.74 \pm 0.015$$

Unblind results

$$A_{PV}(G_M^s, G_E^s, G_A^e) = \frac{R_c}{P_B \alpha_{blind}} A_{elas}$$

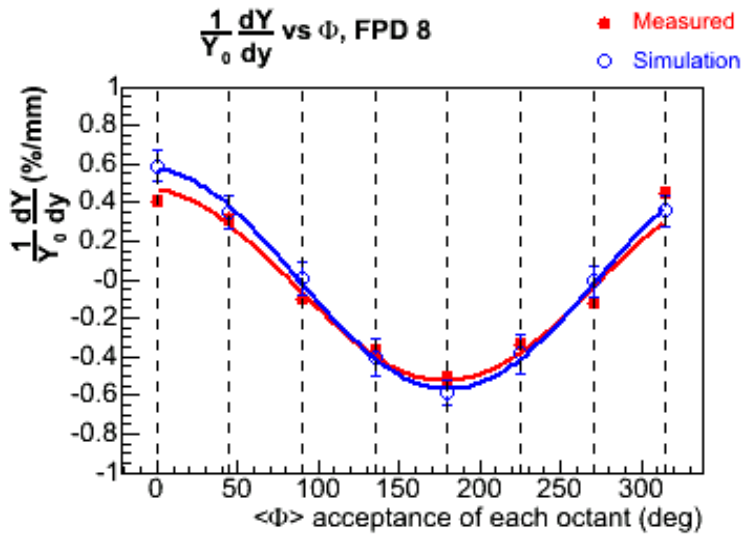
Helicity Correlated Beam Properties and Their Corrections

$$A_{\text{false}} = \sum_i \frac{1}{2\langle Y\rangle}\left(\frac{\partial Y}{\partial P_i}\right)\Delta P_i$$

So require
- Small ΔP_i
- Small sensitivity to P_i

Beam Parameters	Achieved	"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, thanks to the beam feedback systems!



Azimuthal symmetry → Large reduction of sensitivity

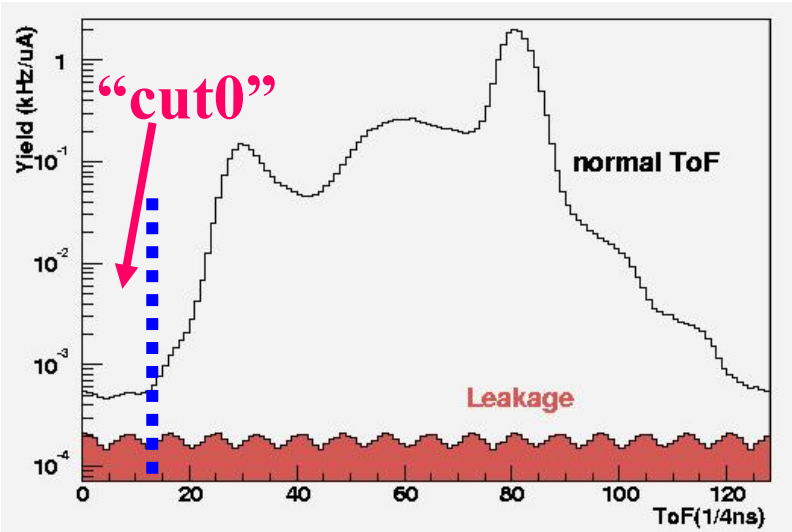
Results :

- **All parity quality Specs achieved**

Thanks to EGG and CASA!

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

499 MHz Leakage and Its Correction



- Small amount of current (I_L ~ 50 nA) from Halls A & B leaks into Hall C beam (Ic ~ 40 uA)
- Leakage has a different time structure from the main beam
  - 32 MHz for Hall C (beam pulse every 32 ns)
  - 499 MHz for Halls A & B (beam pulse every 2 ns)
- Leakage current has large, varying asymmetry (A_{IL} ~ 340 ppm), which is NOT measured by 30Hz BCMs
- Time-of-flight and current dependent false asymmetry induced!

Asymmetries corrected by:

- measuring leakage asymmetry in signal-free region ("cut0") of TOF,
- performing systematic studies with individual lasers, and
- cross-checking against low current runs

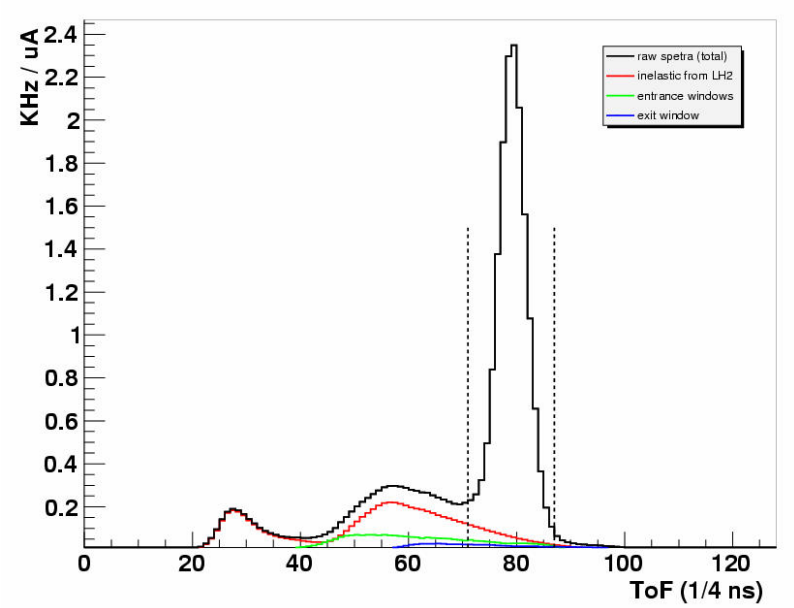
In elastic region:

$$A_{\text{false}} \approx \frac{I_L}{I_C} A_{IL} \approx 0.4\,\text{ppm}$$

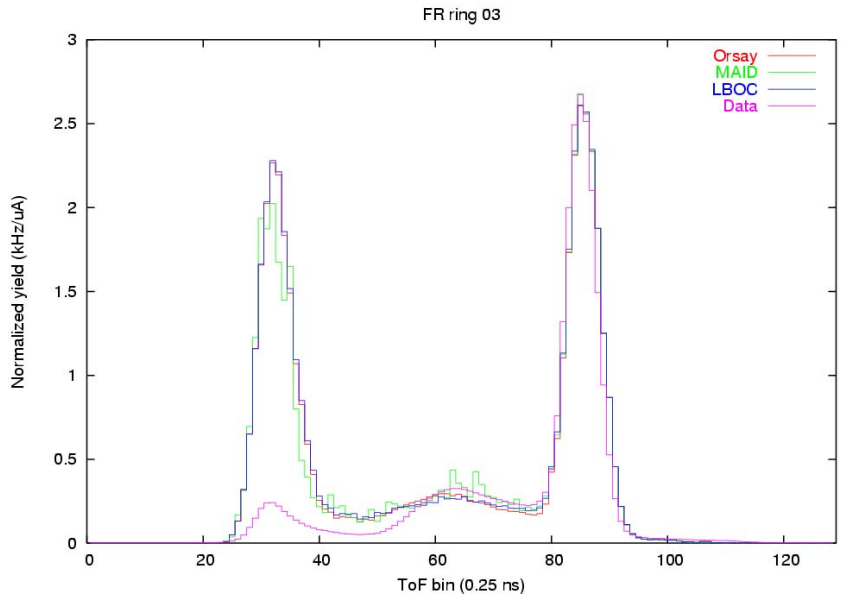
Correction of order 0.4 ppm.
Systematic error of 0.1 ppm.

Background Corrections (Yield)

Empirical studies with various target configurations enable us to unfold backgrounds from target windows and pure LH2 processes



Improved background simulation with three independent inelastics generators reproduce the data reasonable well

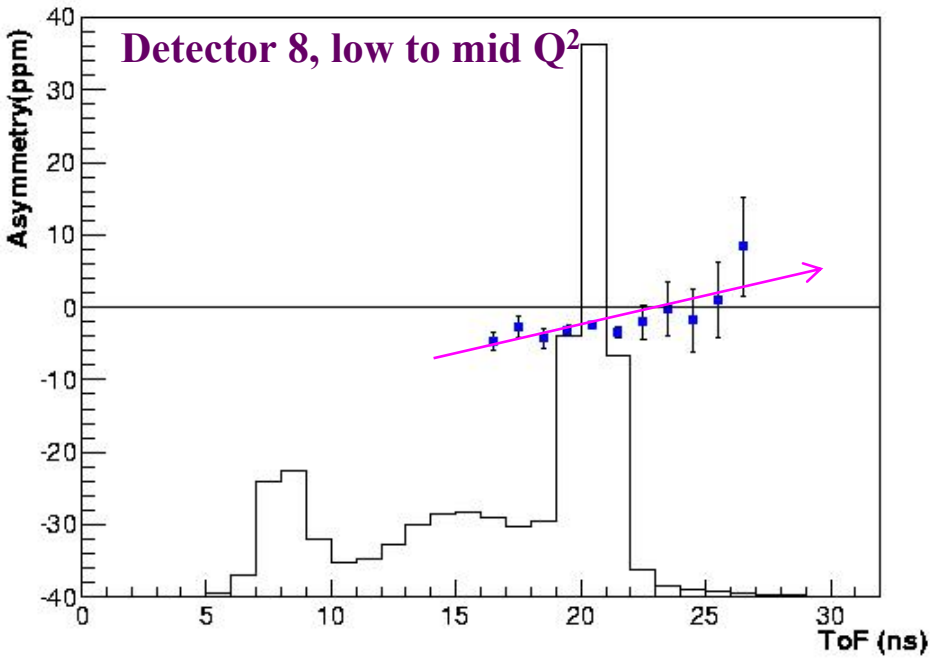


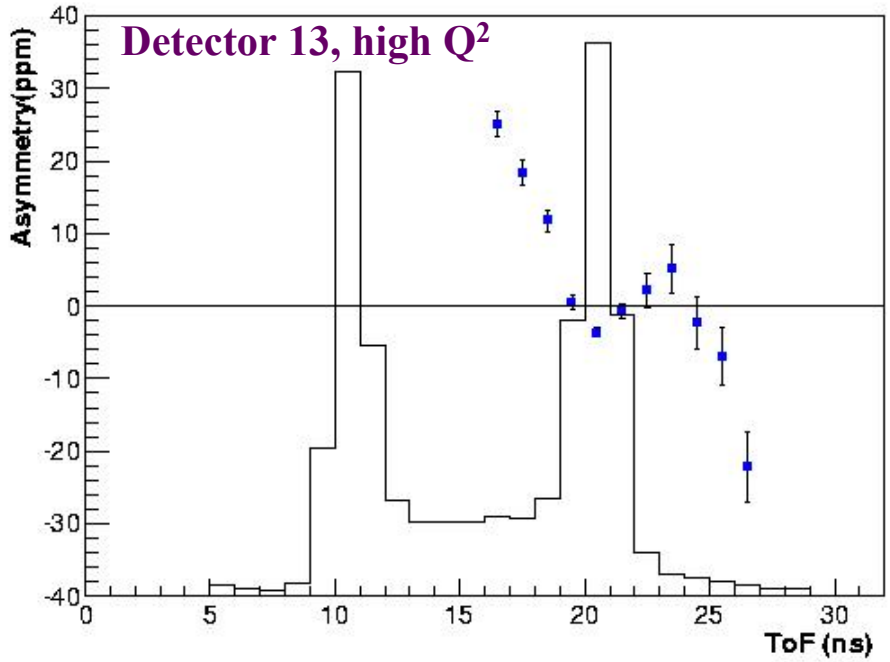
Combining the two studies, we establish that a smooth fitting function (gaus + polynomial) will enable us to determine f_{bkg} up to 10% OF ITS VALUE

Background Corrections (Asymmetry)

$$A_{elas} = \frac{A_{raw} - A_{bkg} f_{bkg}}{1 - f_{bkg}}$$

How do we determine A_{bkg}?





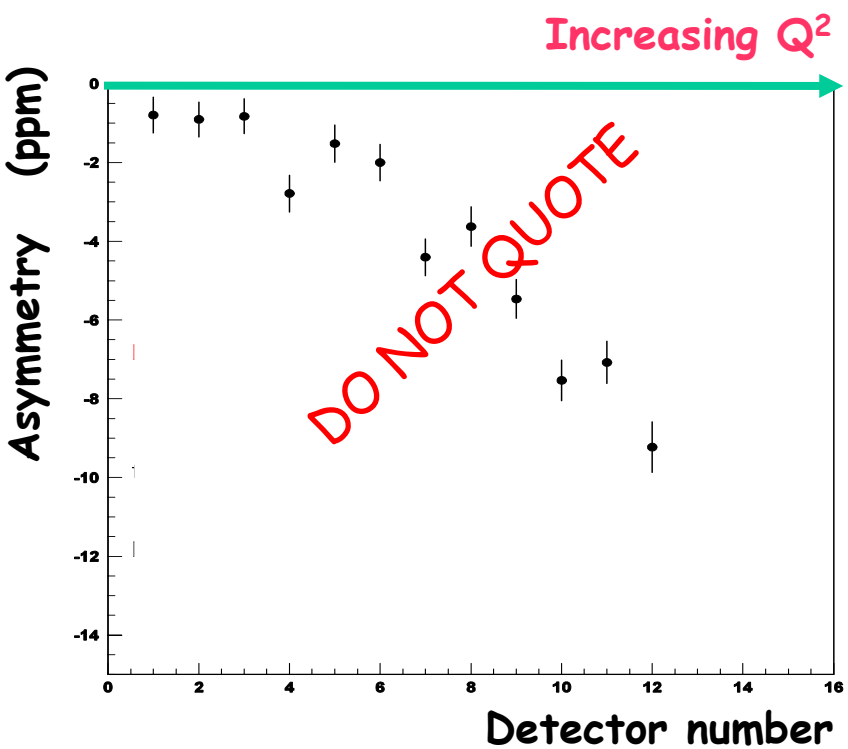
- Asymmetries vary smoothly across elastic peak
  ➔ **linear interpolation**
- Small increase in systematic error on elastic asymmetry

- Large variation in asymmetry across elastic peak
- Positive background asymmetry
- Correction likely to dominate systematic error on elastic asymmetry

Preliminary Results

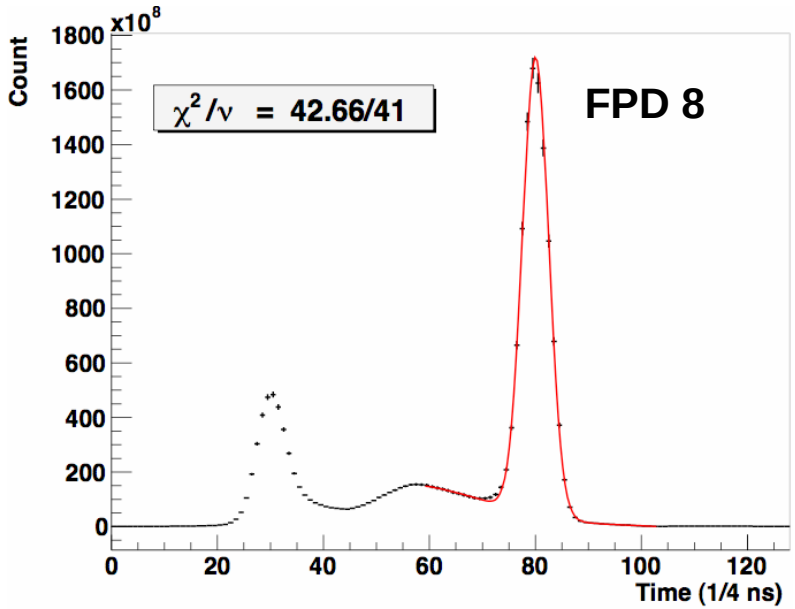
Forward angle asymmetries

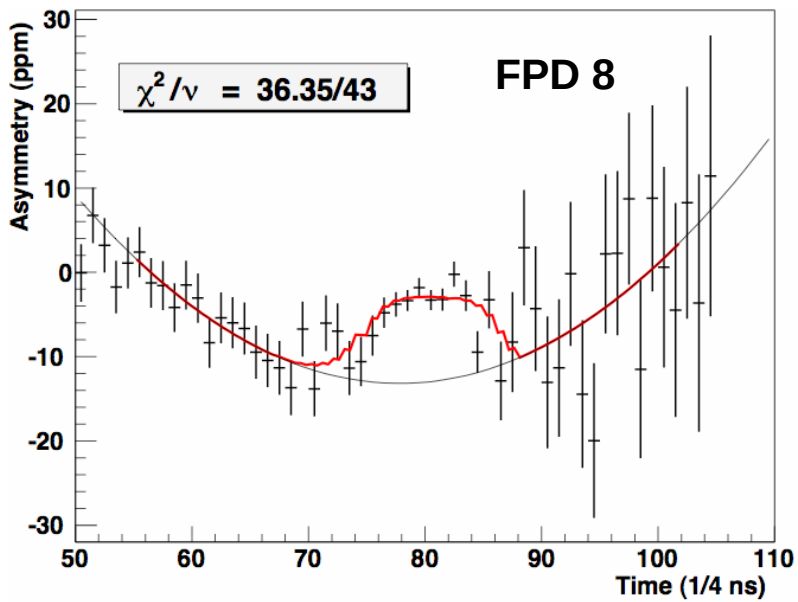
- **Blinding factor ∈ (0.75,1.25) applied**
- **Full statistics**
- **Primitive background correction (linear interpolation of A_{bkg})**
- **Detectors 13-15 not shown**



Systematic Effect	Error
Deadtime Correction	<2%
Beam Parameter Correction	0.01 ppm
Leakage Correction	0.10 ppm
Beam Polarization	2%
Q^2 Determination	1%
Background Correction	Under Study
Radiative Corrections	Still to do, small
EM Form Factors	Still to do

Improved Background Correction – the "Combined Fits"





- Extract **bin-by-bin** dilution factor $f_{bkg}(t)$ by fitting time-of-flight spectra (gaussian signal + 2nd order polynomial background)
- Use results to perform asymmetry fit

$$A_{raw}(t) = (1 - f_{bkg}(t))A_{elas} + f_{bkg}(t)A_{bkg}(t)$$

Constant

Quadratic

$$f_{bkg}(t) = \frac{Y_{bkg}(t)}{Y_{elas}(t) + Y_{bkg}(t)}$$

- Recently, consistent results also obtained by minimizing yield & asymmetry fits **simultaneously**

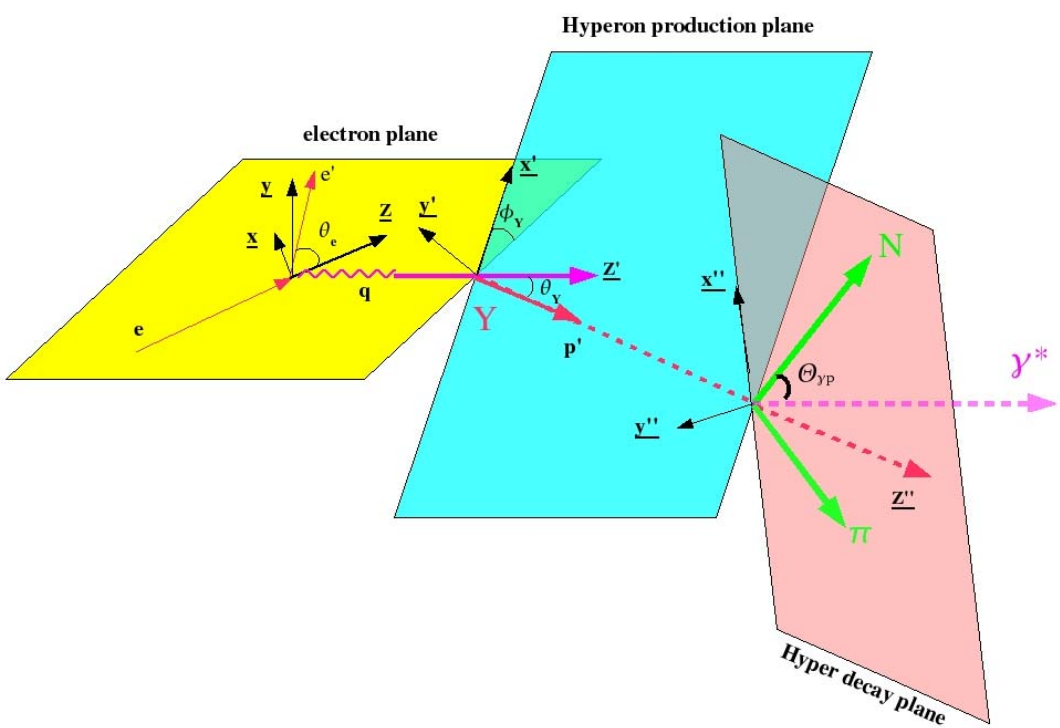
Physics Origin of the Positive Background Asymmetry

Ruled Out:

- Aluminum in target vessel
- Multiple scattering in target
- Deuterium contamination in target
- Pion electroproduction

Possible:

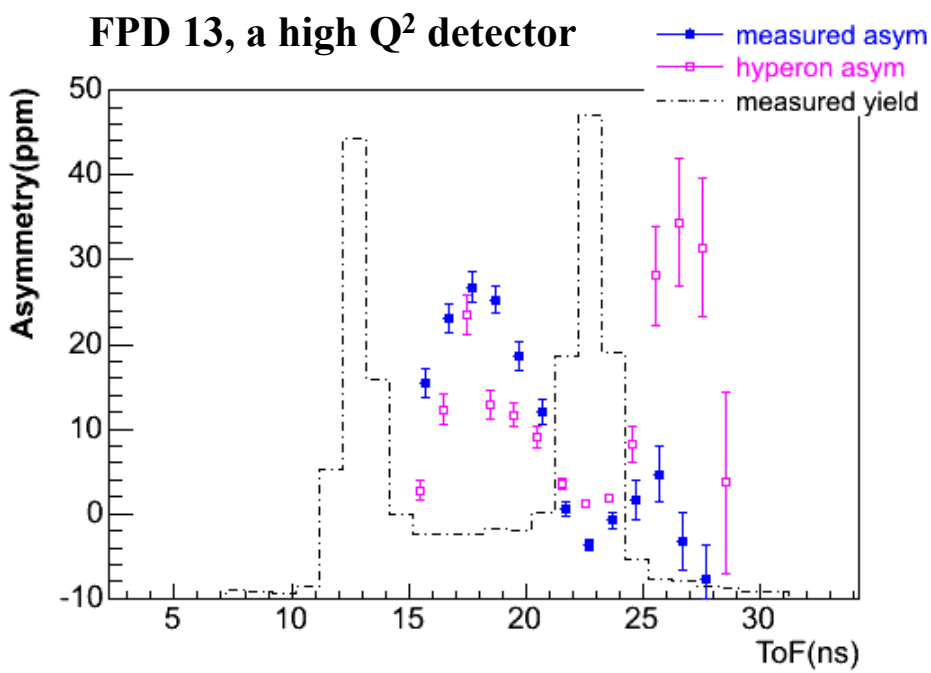
- Pion photoproduction (electroweak radiative effects, subject to study in the back-angle run) (less likely)
- Hyperon ($\Lambda,\Sigma^+,\Sigma^0$) production and weak decays (very likely)

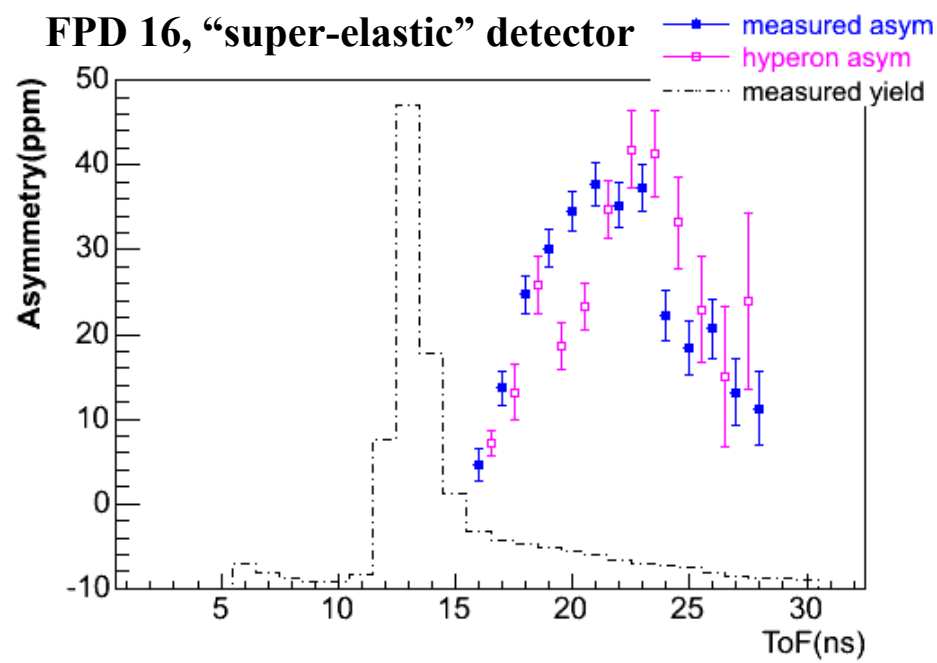


- CLAS results: Λ maximally (~80%) polarized along q
- $Y \rightarrow N+\pi$ is self-analyzing with very large asymmetry (~1)
- So the decay products and their secondaries will carry large PV asymmetries
- Yet Y decay protons are not favored by G^0 acceptance. Would they make it ???

Hyperon Simulation

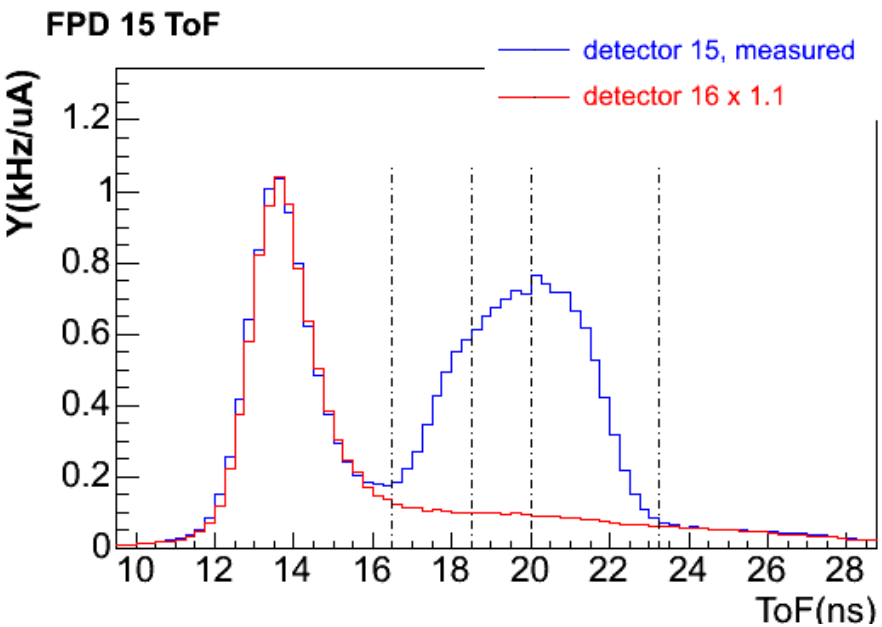
- Generator: tuned KaonMAID against existing cross-section data
- Considered $\Lambda, \Sigma^+, \Sigma^0$ electro/photo production
- Assumed Σ^+, Σ^0 transferred polarization behavior similarly as Λ





- Simulation reproduces the measured background asymmetry qualitatively
- Characteristics: low rate (~a few hundred Hz per detector); large asymmetry (~ 0.1)
- Combining detector 16 measurement & the hyperon MC → a better-controlled background correction for high Q^2 detectors

Detector 15 (3 high Q^2 bins)



$$A_{raw}(t) = (1 - f_{bkg}(t))A_{elas} + f_{bkg}(t)A_{bkg}(t)$$

$f_{bkg}(t)$ determined by

- **fits (quadratic, etc ...)**
- **(scaled) detector 16 yield**
- **simulation**
- **interpolation across more detectors**

Asymmetry fits:

- **A_{elas} by**
  - **constant in each Q^2 bin**
  - **other parametrizations**
- **$A_{bkg}(t)$ by**
  - **Quadratic in ToF**
  - **(scaled & shifted) detector 16 asymmetry (based on hyperon MC)**

So far, comparing $Y_{elas}(t)$ with simulation →
the uncertainty in Q^2 ~ a few %

To do: radiative corrections

Status of the background corrections

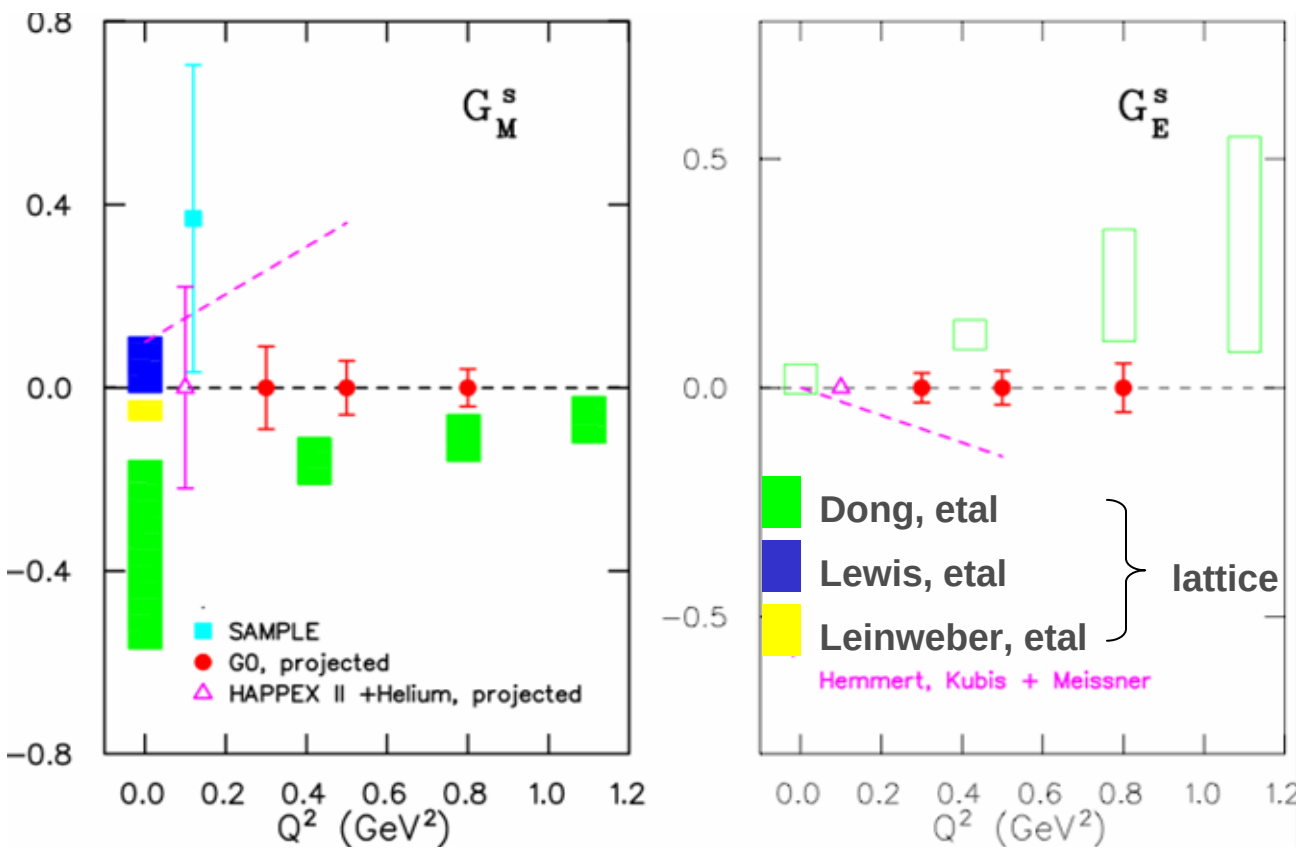
We are at the last stage — evaluating the systematic uncertainties of the correction

- Low to mid Q^2 detectors (1-12): Smooth background. Comparison of different $A_{bkg}(t)$ function forms (linear, quadratic …)
- High Q^2 detectors (13-15): Large varying background. Comparison of
  - "Combined fit"
  - "Detector 16 + hyperon MC"
  - "Hybrid" detectors (NA FPD 14 &15 with French electronics)

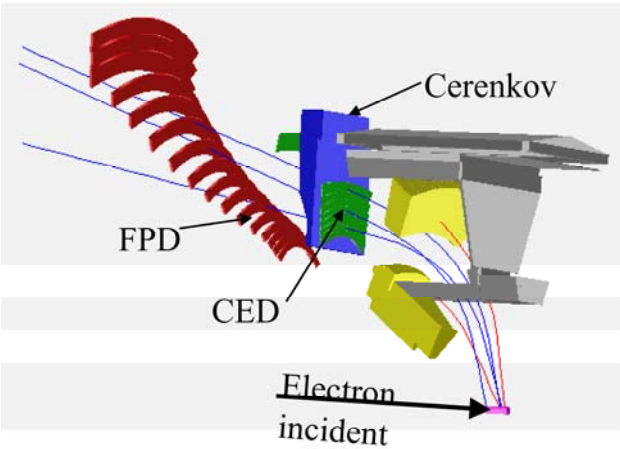
Collaboration meeting comes in two weeks on which we will discuss finalizing this stage of the analysis.

Summary & Outlook

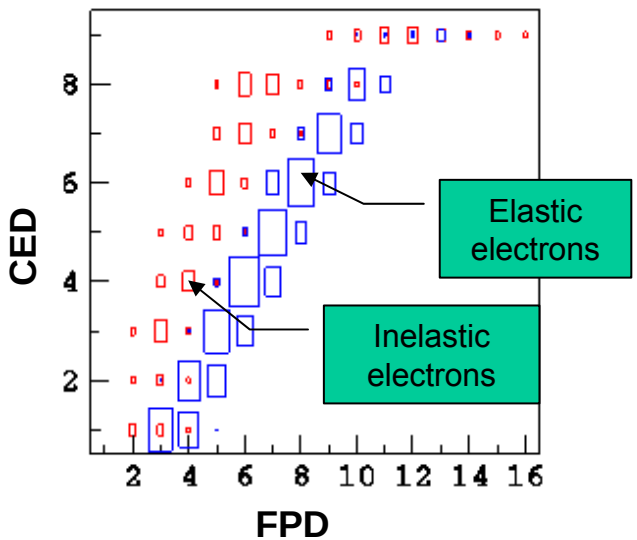
- We have made very good progress in understanding and correcting the background asymmetry
- Forward angle data analysis is close to be finalized
- We are looking forward to the back angle runs to complete a wide Q^2 map of the electric and magnetic strange form factors



G^0 Backward Angle Mode



CED-FPD Coincidences at Q^2 = 0.3 (GeV/c)^2



- Detect scattered electrons at 110°
- One energy/magnet setting per Q^2
  - **Q^2 = 0.3, 0.5, 0.8 (GeV/c)^2**
  - **E = 424, 576, 779 MeV**
  - **Liquid hydrogen and deuterium targets**
  - **80 uA of normal CEBAF 2 ns beam**
  - **700 hours of beam per run**
  - **Modification of beam polarimetry @ low E**
- Additional Detectors
  - **Cryostat Exit Detectors (CEDs): separate elastic and inelastic electrons by trajectory**
  - **Cerenkov Detectors: pion detectors**
  - **Counting electronics only (no ToF separation)**

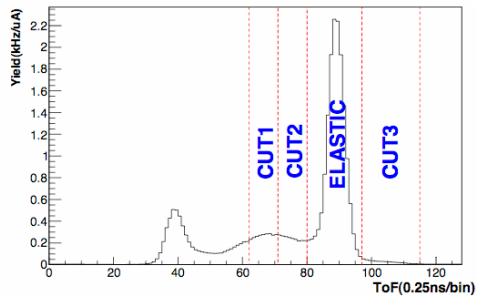
As already implied by the excitement at low Q^2, G^0 back angle will provide fascinating physics! See D. McKee's talk.

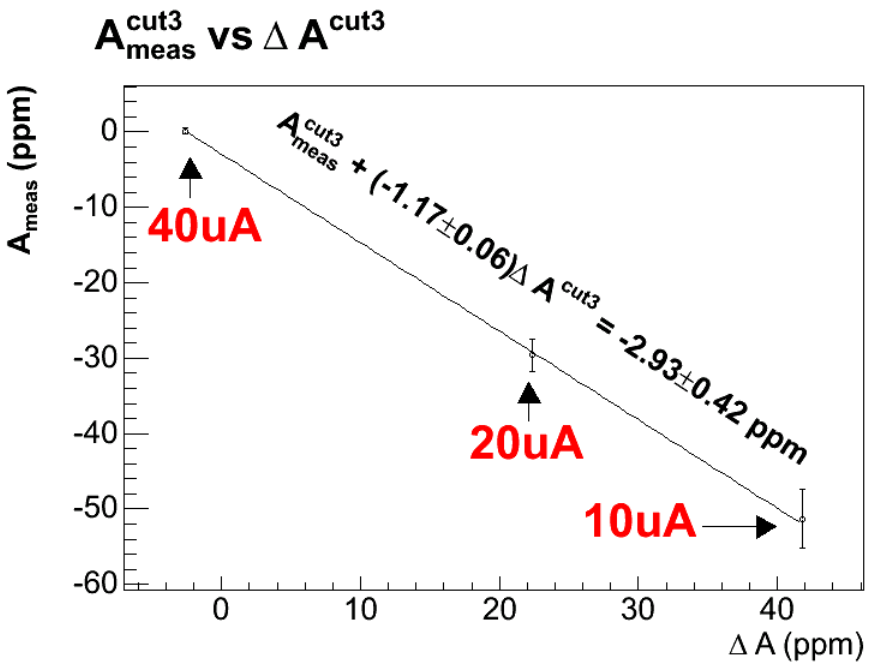
Systematics of leakage correction

We made several independent assessments. Below is one of them …

Principle: $A_{phys} = A_{meas} + \Delta A = \text{constant}$

- So for individual measurements (@ 10, 20 and 40 uA), A_{meas} vs ΔA slope should be -1.
- The systematics of the correction is manifested as a slope differ from -1.
- To increase the sensitive, we chose to use "cut3" (a low rate region in ToF spectrum).





- Therefore, $\frac{\delta\Delta A}{\Delta A} \sim 17\%$
- $\Delta A \propto A_{leak}$, so this is how well we determine A_{leak}
- So this evaluation holds for the whole spectrum