Analysis of the G0 Backward Angle experiment

Fatiha Benmokhtar

Carnegie Mellon University

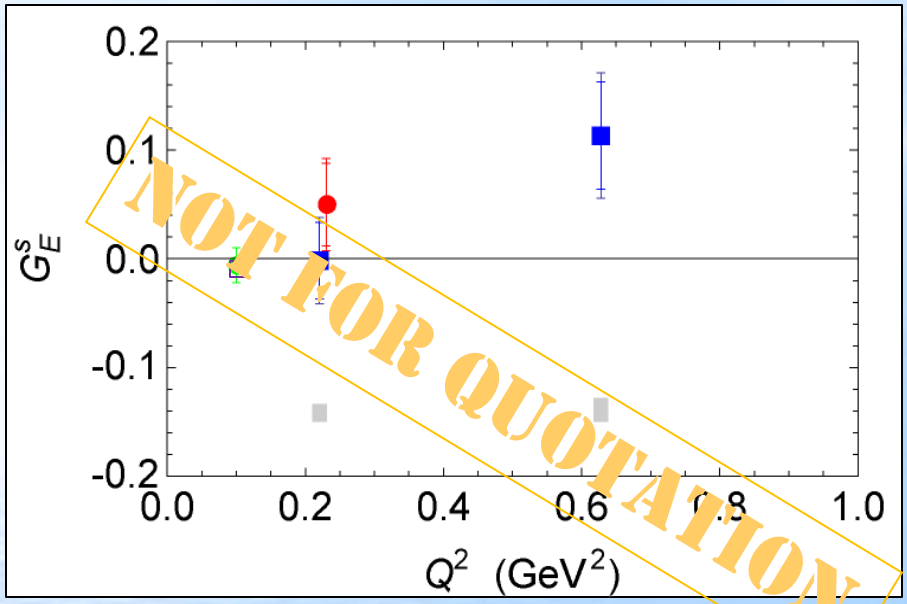
PAVI09, Bar Harbor , Maine

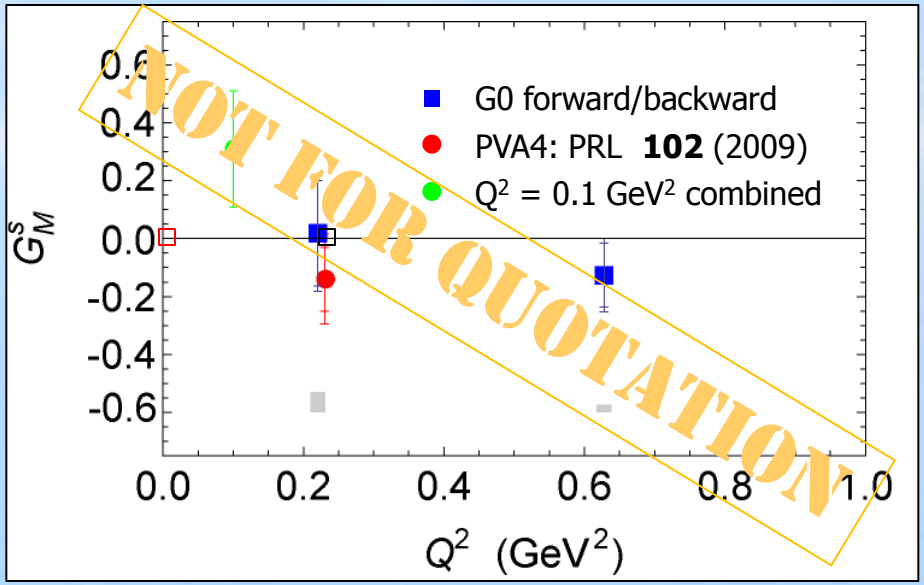
June 22nd-26th

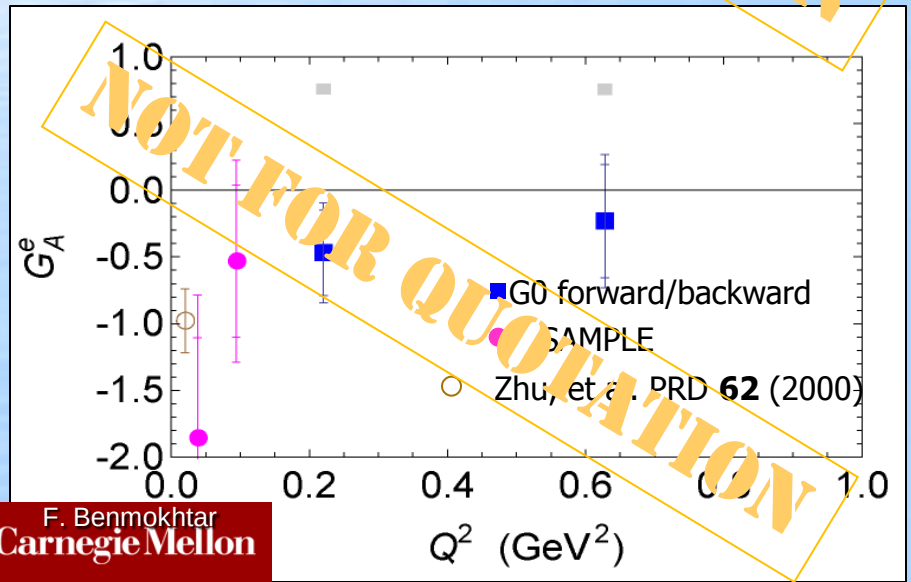
fatiha@ernest.phys.cmu.edu

Reminder: Form Factor Results

- Using interpolation of G0 forward measurements







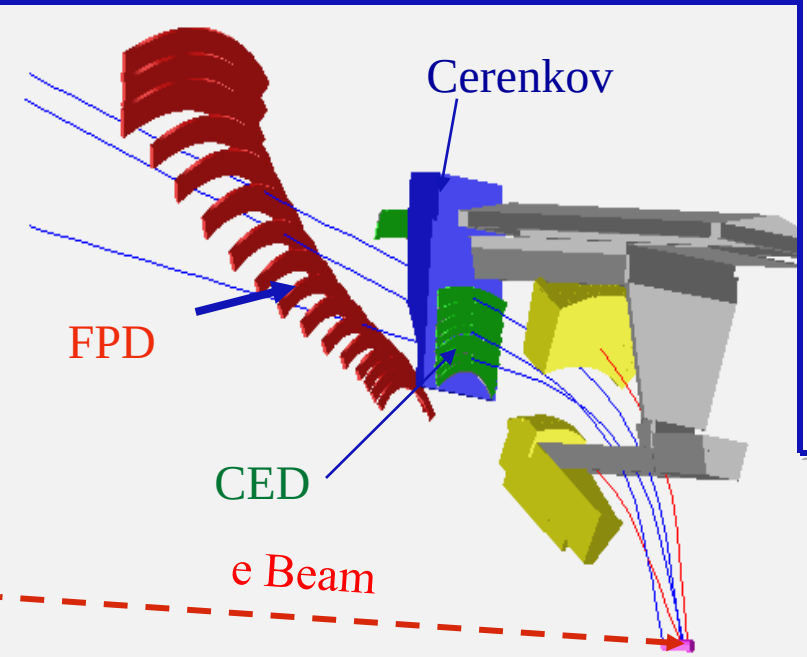
Global uncertainties

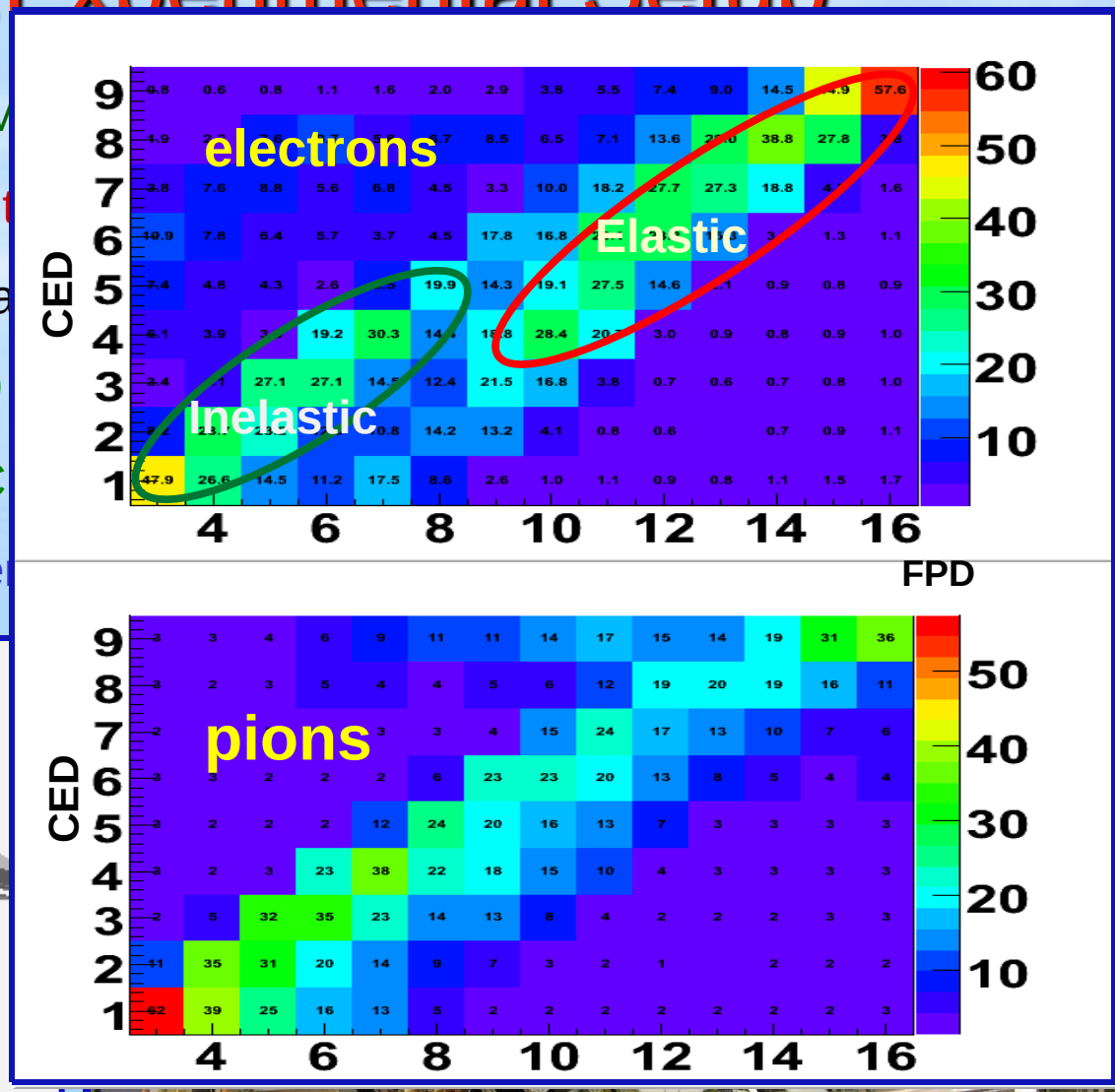
Calculations:

- Leinweber, et al. PRL 97 (2006) 022001
- Leinweber, et al. PRL 94 (2005) 152001
- Wang, et al arXiv:0807.0944 (Q^2 = 0.23 GeV^2)
- Doi, et al, arXiv:0903.3232 (Q2 = 0)

Reminder:Experimental Setup

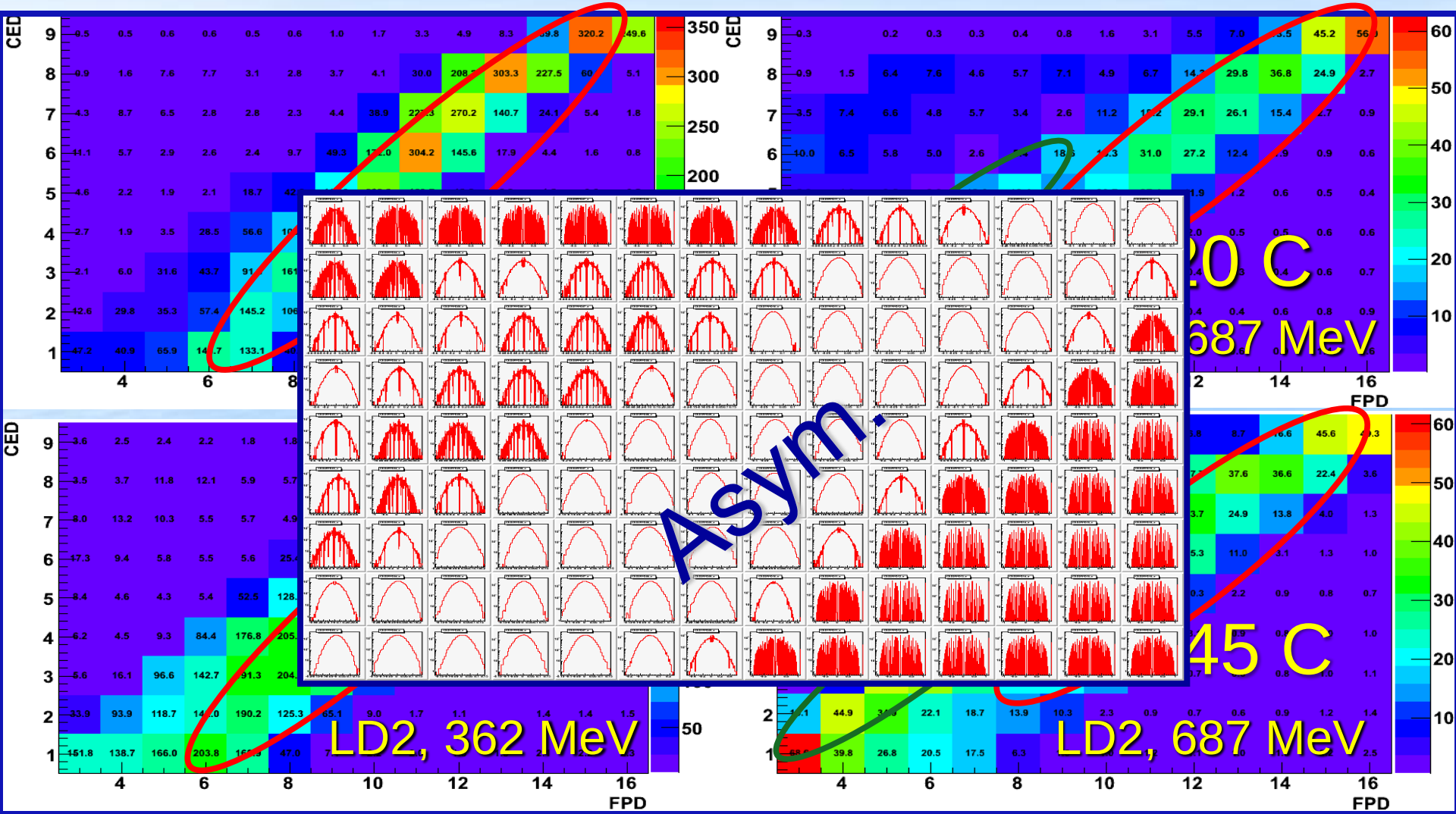
- Electron Beam: 362 and 687 M
- Electron off 20 cm LH_2 or LD_2 t
- Turn-around of the magnet, cha
- Add Cryostat Exit Detectors (9
  and inelastic electrons in the C
- Aerogel Cerenkov detector pe





Recorded data

(Hz/μA/Oct)



Analysis Strategy

Blinding Factors X0.75-1.25

H, D Raw Asymmetries, A_{meas} ~10-50 ppm

Corrections
- Scaler counting correction — < 1% of A_{phys}
- Rate corrections from electronics — 1 to 10%
- Helicity-correlated corrections — < 0.1 ppm
- Background asymmetry
- Beam polarization — P= 0.8578 ± 0.007 ± .014

Unblinding

Electromagnetic radiative corrections — 4% on asymmetry

Q^2 Determination — ± 0.003 GeV^2

ElectroWeak radiative corrections — 0.5 to 1.5% on asymmetry

H, D Physics Asymmetries, A_{phys}

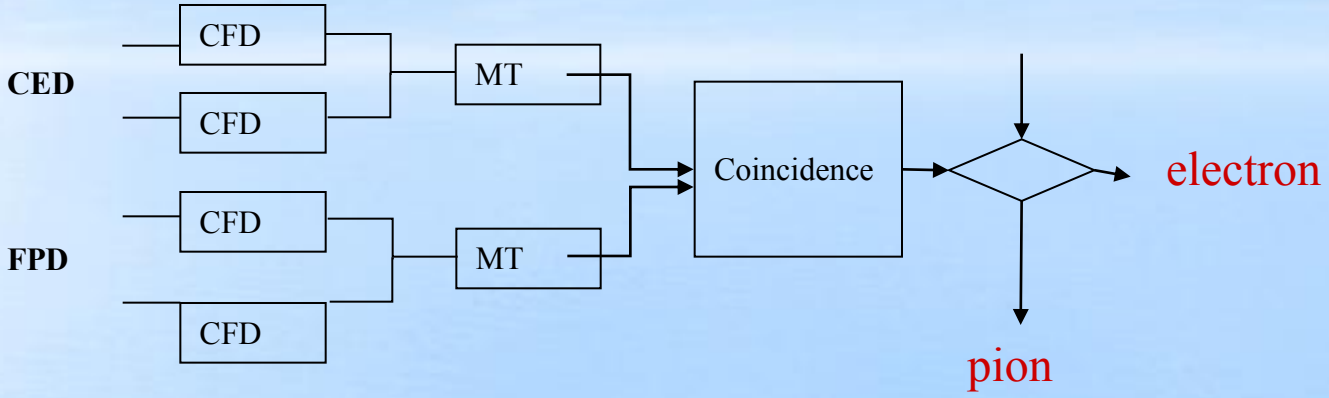
G_E^s, G_M^s, G_A^e

Forward measurements

Nucleon EM form factors

Rate Corrections

- **Rate correction study for counting experiment is complicated!**



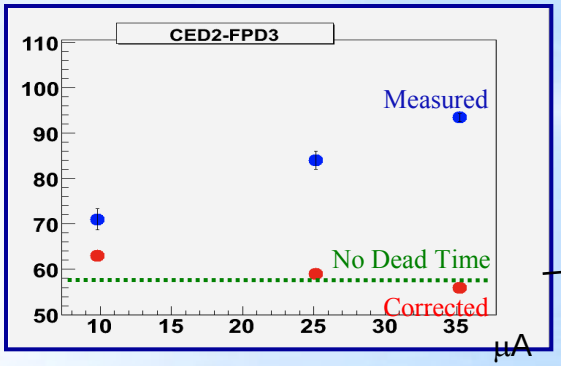
- **DT from Constant Fraction Discriminators**
- **DT from Mean Timers**
- **DT from Trigger module**
- **Multihits.**
- **Random coincidences subtraction**
- **DT and randoms in the cerenkov electronics.**

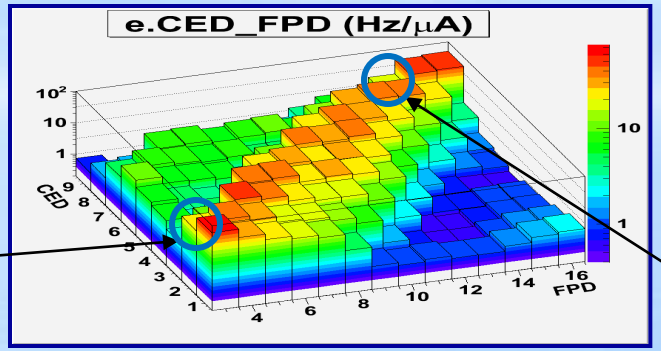
- Simulate the full electronic chain. (inputs from real measurements)
- Study Rate changes with current scans.
- Introduce large charge Asymmetry and see what is the effect in the detector asymmetry. (what we call Well's plot).
- Delay the cerenkov signal to measure random coincidences.

Examples

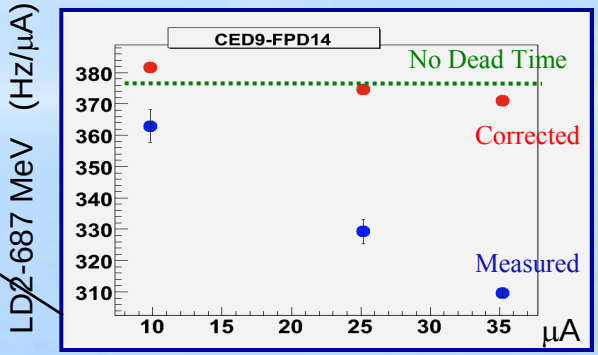
- **Current Scans:**

Electron *Measured-Corrected Yield*

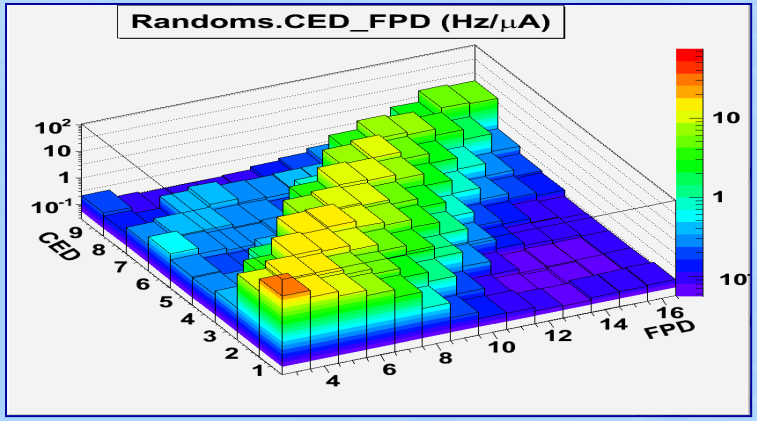




Electron *Measured-Corrected Yield*



- **Random coincidences:**
  - LH2 randoms small
  - LD2 randoms significant
    - higher pion rate
  - Direct (out-of-time) measurement



- **Multihit corrections smaller (yield)**

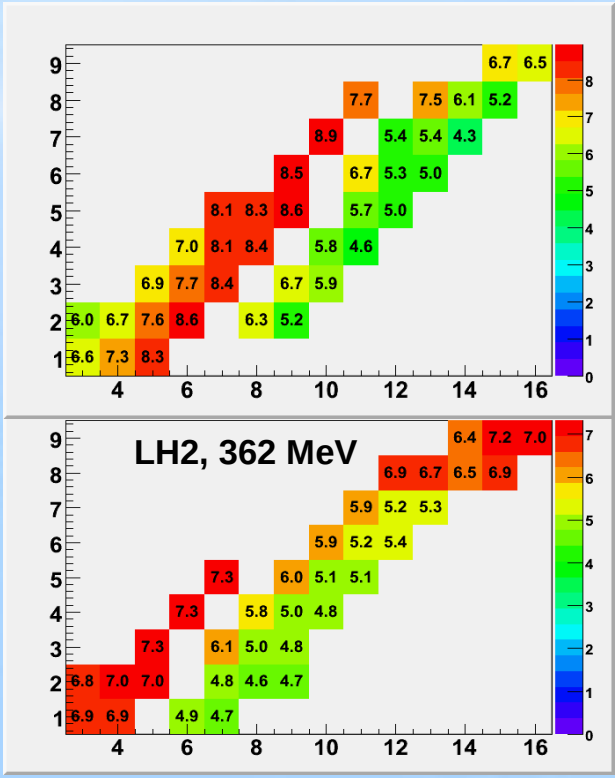
Arise because of trigger:
(any CED) and (any FPD)

Total Rate correction:

$$A_{syst} = A_{single} + A_{Trig} + A_{MH_{12}} + A_{contam}$$

Data set	Correction to Yield (%)	Asymmetry Correction (ppm)	systematic error (ppm)
H 362	6	0.3	0.06
H 687	7	1.4	0.17
D 362	13	0.7	0.2
D 687	9	6	1.8

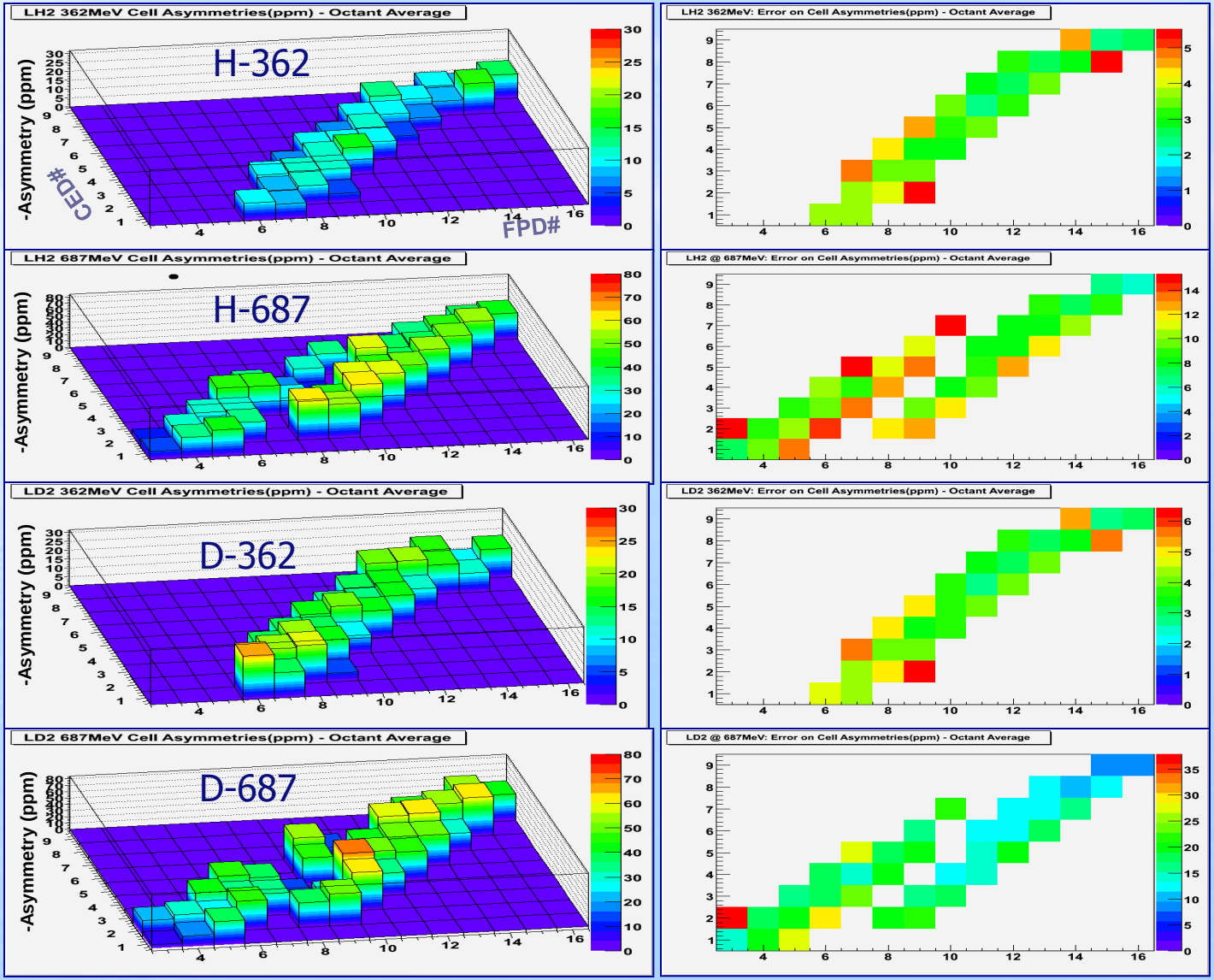
Deadtimes (%) (yield)



- **Linear regression will then take care of any residual corrections.**

Total rate correction is from 0 to ~ 10 % to the asymmetry

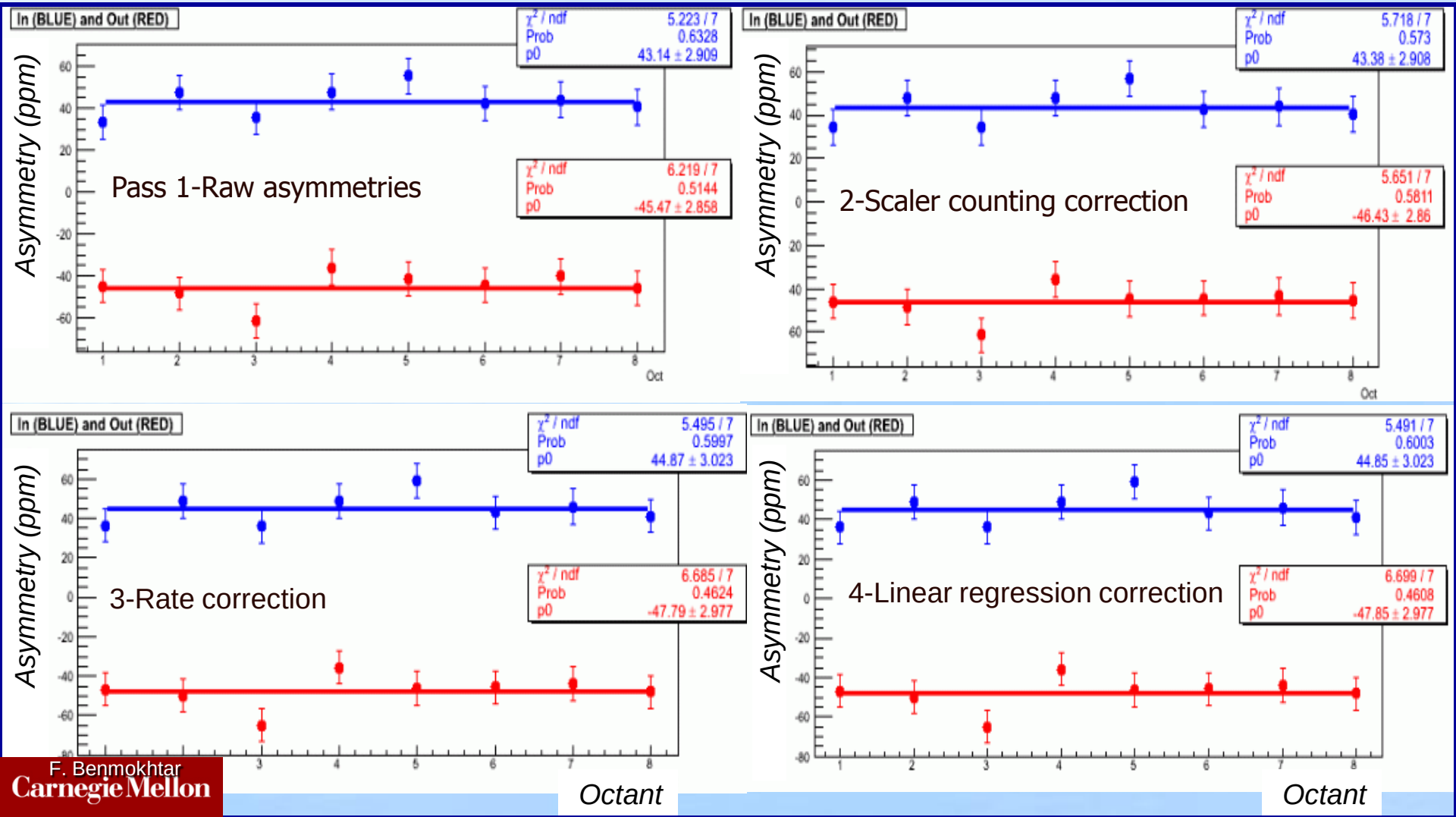
Asymmetry stability along the loci



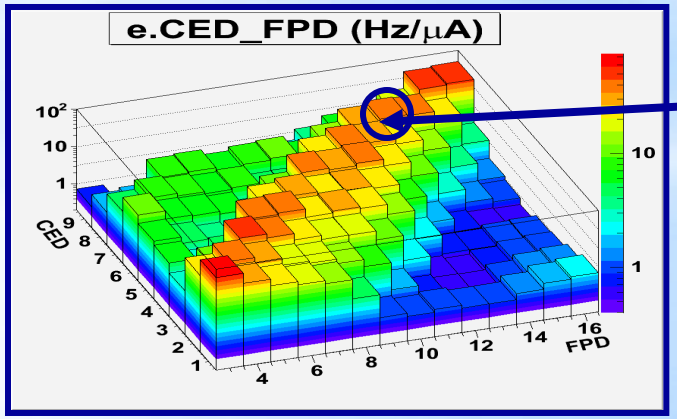
- These asymmetries are beam and rate corrected
- Note the stability along the elastic or the inelastic loci
- Non-locus cells are suppressed.

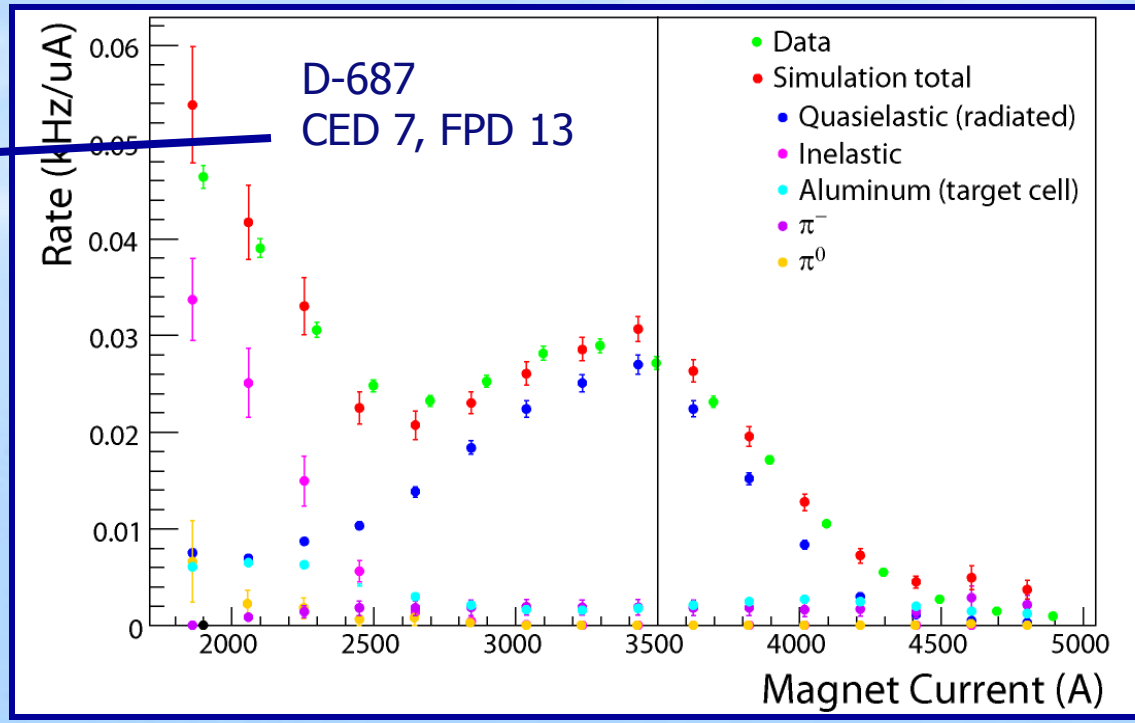
Elastic Asymmetries

- Hydrogen, 687 MeV, BLINDED
- Including rate, helicity-correlated corrections



Reminder: Physics Backgrounds





- **Primary background from Al target windows:**
  - **about 12% of yield for all target/energy combinations**
- **π^- contamination in D, 687 MeV**
  - **-5% contribution (measured), nearly 0 asymmetry (measured)**

Data set	Asymmetry Correction (ppm)	systematic error (ppm)
H 362	0.50	0.37
H 687	0.13	0.78
D 362	0.06	0.02
D 687	2.03	0.37

Physics Asymmetry
(Preliminary Results)

all entries in ppm

Data Set	Asymmetry	Stat	Sys pt	Correlated
H 362	-11.01	0.84	0.26	0.37
D 362	-16.50	0.79	0.39	0.19
H 687	-44.76	2.36	0.80	0.72
D 687	-54.03	3.22	1.91	0.62

H: systematic uncertainties dominated by beam polarization
D: rate corrections also contribute to uncertainty
Note: No electromagnetic or electroweak radiative corrections applied.

From Asymmetry to Strange Form Factors

- Proton

$$A = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \frac{1}{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}} \Big\{ \left(1 - 4\sin^2\theta_W\right)\left(\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}\right)\left(1 + R_V^p\right) - \left(\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n\right)\left(1 + R_V^n\right) - \varepsilon G_E^p \left(G_E^s + \eta G_M^s\right)\left(1 + R_V^{(0)}\right) - \varepsilon'\left(1 - 4\sin^2\theta_W\right) G_M^p G_A^e \Big\}$$

- Deuteron

$$A = -\frac{G_F Q^2}{2\alpha\sqrt{2}} \frac{v_L R_L^V(q,\omega) + v_T R_T^V(q,\omega) - (1 - 4\sin^2\theta_W) v'_T R_T^A(q,\omega)}{v_L R_L^\gamma + v_T R_T^\gamma}$$

R. Schiavilla (priv. communication)

- Proton&Deuteron

$$A = a_0 + a_1 G_E^s + a_2 G_M^s + a_3 G_A^{e(T=1)} + a_4 G_A^s$$

to be extracted

Isoscalar strange ff

Choice of Nucleon Form Factors

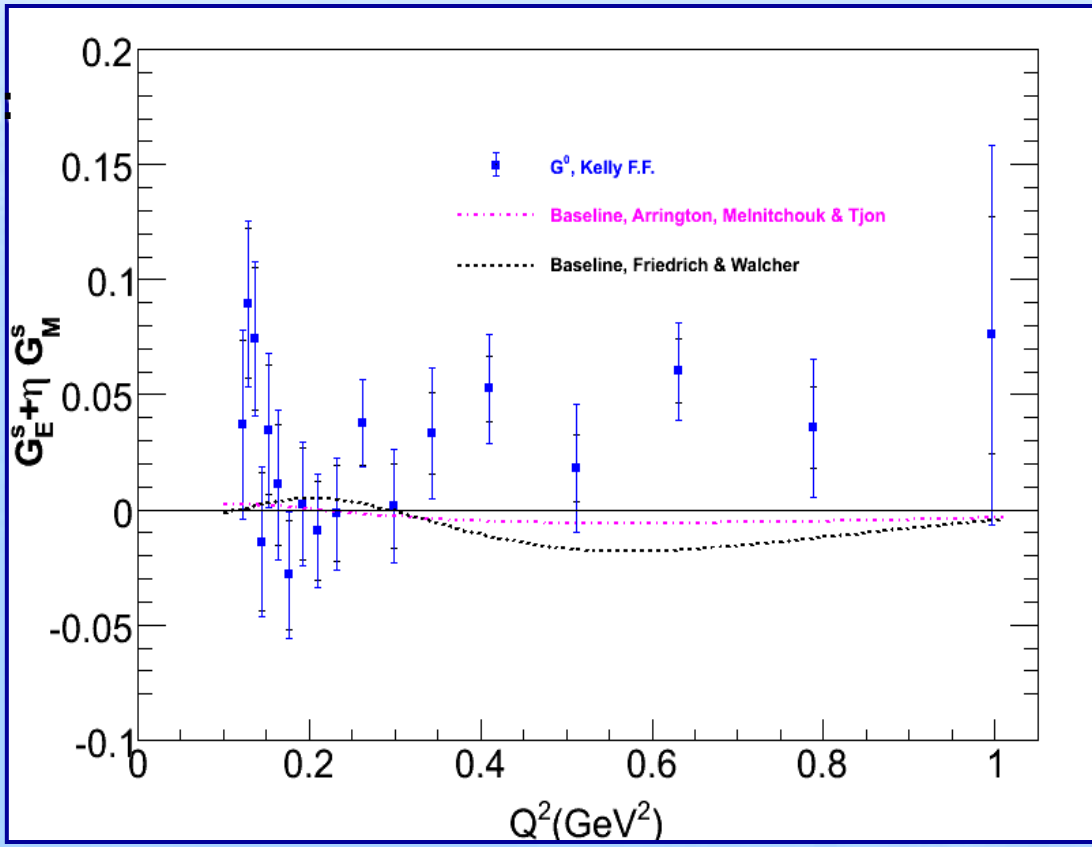
- These results: Kelly form factors from (PRC **70** (2004))
  - used in R. Schiavilla deuterium calculation.

- Including all published low Q^2 data:

- **Arrington , Melnitchouk & Tjon for proton** (Phys. Rev. C 76035205(2007))

- **Arrington & Sick for the neutron** (Phys. Rev. C 76, 035201 (2007))

-> Changes are from 0.5 to 1% to the Asymmetry in our Backward and Forward angle kinematics.



- With the addition of the preliminary Hall A unpublished proton FFs, the asymmetry changes within only 0.5% from AMT.

Electroweak Radiative corrections and two boson exchanges

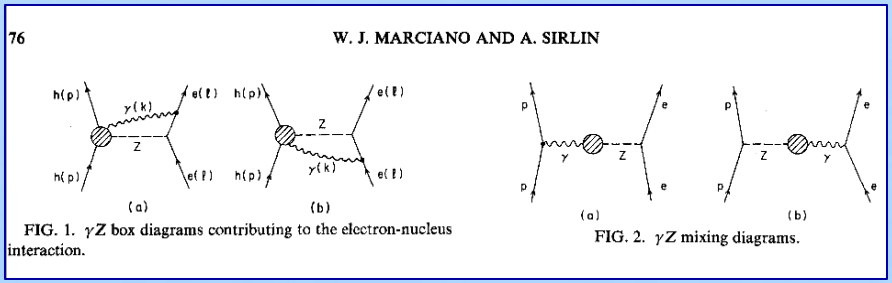
$$A = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \frac{1}{\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}} \Big\{ \left(1 - 4\sin^2\theta_W\right)\left(\varepsilon G_E^{p\,2} + \tau G_M^{p\,2}\right)\left(1 + R_V^p\right) - \left(\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n\right)\left(1 + R_V^n\right) - \varepsilon G_E^p \left(G_E^s + \eta G_M^s\right)\left(1 + R_V^{(0)}\right) - \varepsilon'\left(1 - 4\sin^2\theta_W\right) G_M^p G_A^e \Big\}$$

$$1 + R_V^n = \rho + 2\left(\lambda_{1u} + 2\lambda_{1d}\right),$$

$$1 + R_V^p = \frac{\rho\left(1 - \kappa 4\sin^2\theta_W\right)}{\left(1 - 4\sin^2\theta_W\right)}$$

$$Q_w = 1 - 4\sin^2\theta_W \;\rightarrow\; \rho(1 - 4\kappa\sin^2\theta_W)\ .$$

Marciano et al., Phys. Rev. D 29, 75 - 88 (1984)



-PDG values of (ρ,κ) contain vertex corrections, corrections to the propagators, and γZ exchange corrections at Q2=0. They do not contain γγ corrections or recent evolutions on the γZ box diagrams.

- To avoid double counting, one has to remove the 'hadronic' part of the γZ box diagram from ρ, κ

Addition of two boson corrections

Two groups use hadronic calculation with finite size of the nucleon:

- Blunden, Melnitchouk & Tjon (**Phys. Rev. C 79, 055201 (2009)**)
- Keitaro, Zhou, Kao & Yang (Phys.Rev.C79.062501,2009)

-To avoid double counting, one has to remove the 'hadronic' part of the γZ box diagram from ρ, κ

→ (ρ, κ) = (0.988210, 1.003520),

→ and feed them back the Asymmetry then apply the new corrections as follows:

$$A_{meas} = (1+\delta) A_{Born} = \left(\frac{1+\delta_{Z(\gamma\gamma)} + \delta_{\gamma(\gamma Z)}}{1+\delta_{\gamma(\gamma\gamma)}} \right) A_{Born}$$

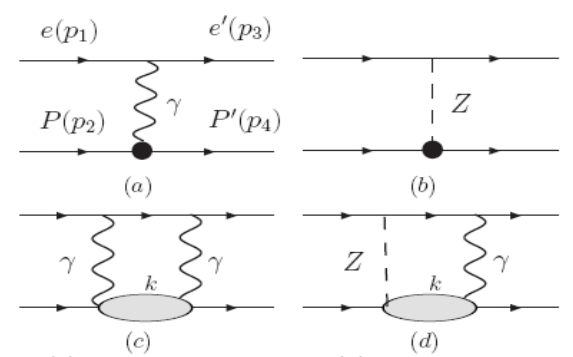


FIG. 1: (a) one-photon-exchange, (b) Z-boson-exchange, (c) TPE, and (d) γZ-exchange diagrams for elastic ep scattering. Corresponding cross-box diagrams are implied.

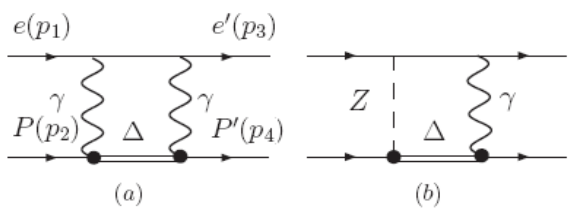
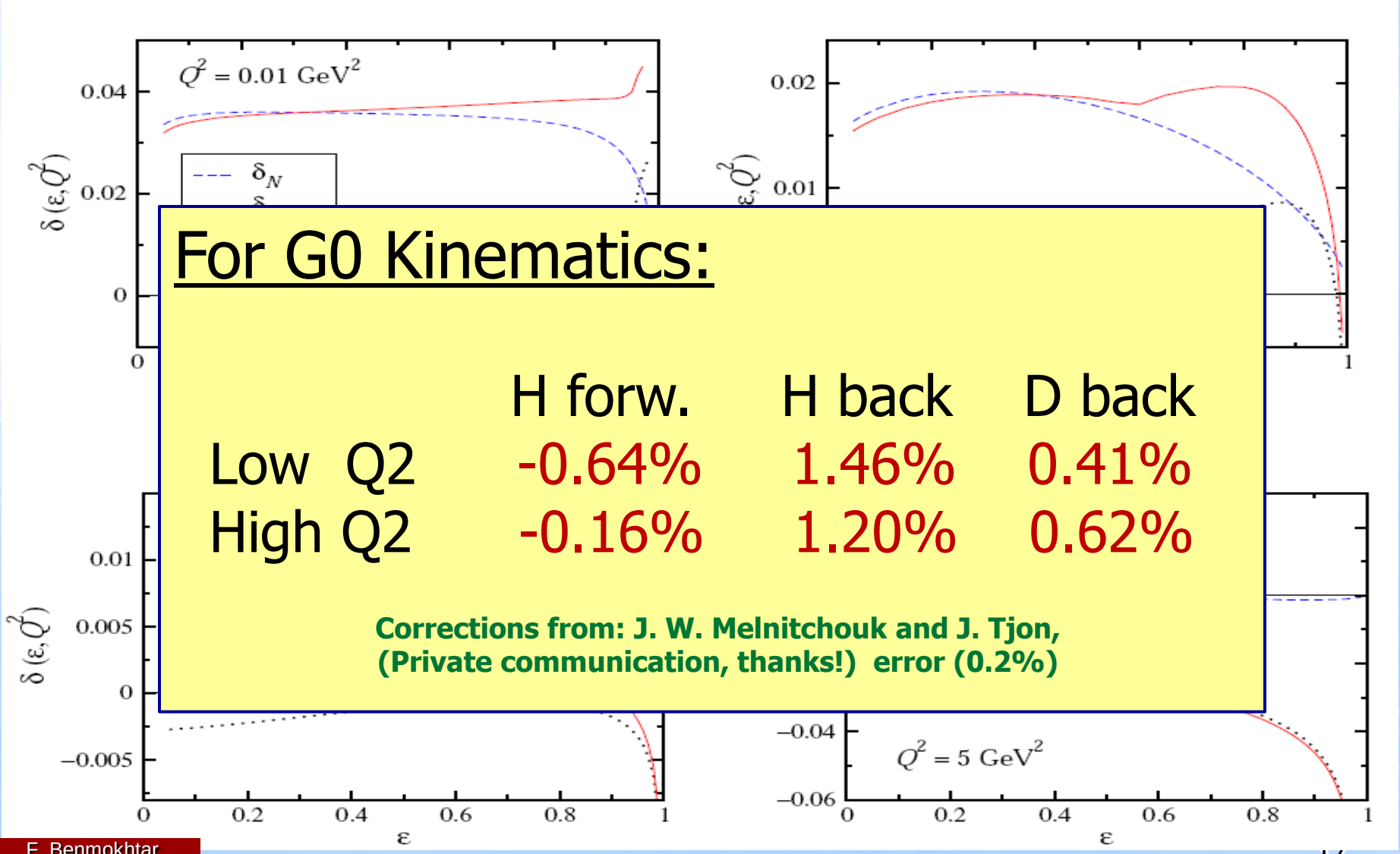


FIG. 2: (a) TPE and (b) γZE box diagrams with Δ intermediate states. Corresponding crossed diagrams are implied.

2Boson exchange contribution to the Nucleon + Δ = Total (Melnitchouk, Blunden and Tjon)



For G0 Kinematics:

	H forw.	H back	D back
Low Q2	-0.64%	1.46%	0.41%
High Q2	-0.16%	1.20%	0.62%

Corrections from: J. W. Melnitchouk and J. Tjon, (Private communication, thanks!) error (0.2%)

The G0 Backward Angle Collaboration

***G⁰ Spokesperson*: Doug Beck (*UIUC*)**

California In University,
College o PN Orsay,
JLab, LPSC lexico State
University of Illinois,
University niversity of
Maryland Yerevan

Analysis Coordinator*: Fatiha Benmokhtar *CMU (Maryland)

***Students*:**

Carissa Capuano (*W&M*), Alexandre Coppens (*Manitoba*), Colleen Ellis (*Maryland*) , Juliette Mammei (*VaTech*), Mathew Muether (*UIUC*), John Schaub (*NMSU*), Maud Versteegen (*LPSC*), Stephanie Bailey (*Ph.D. W&M, Jan '07*)

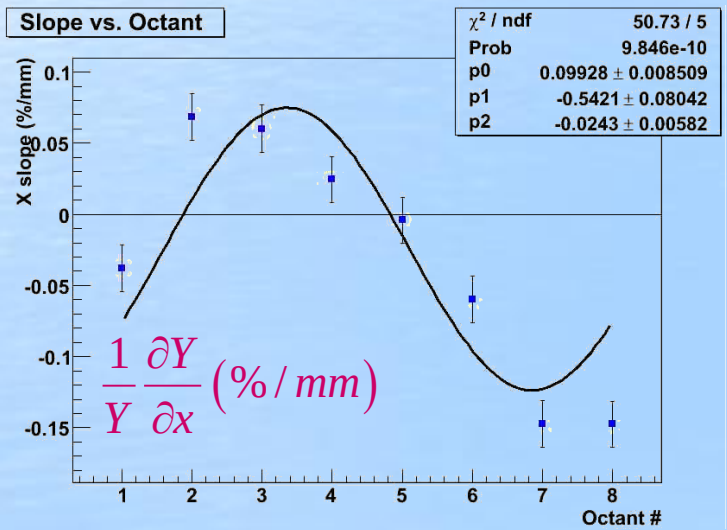
Backup Slides

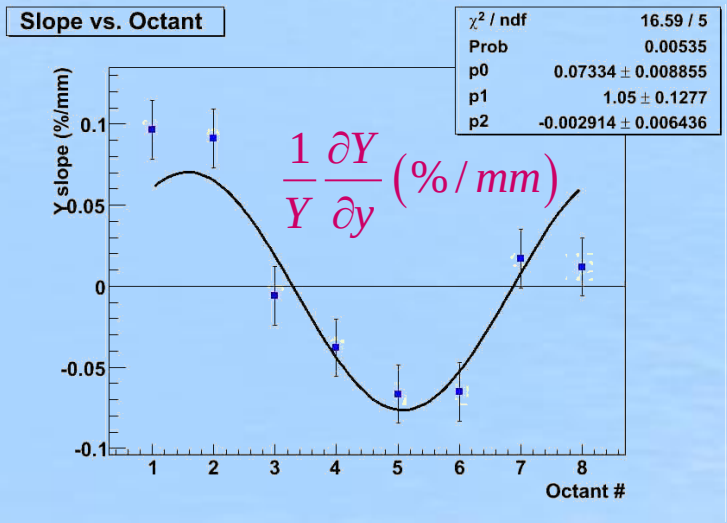
Helicity-correlated Beam Properties: Linear Regression

- Cross check with sensitivities determined from natural beam motion and from deliberate 'coil-pulsing' runs

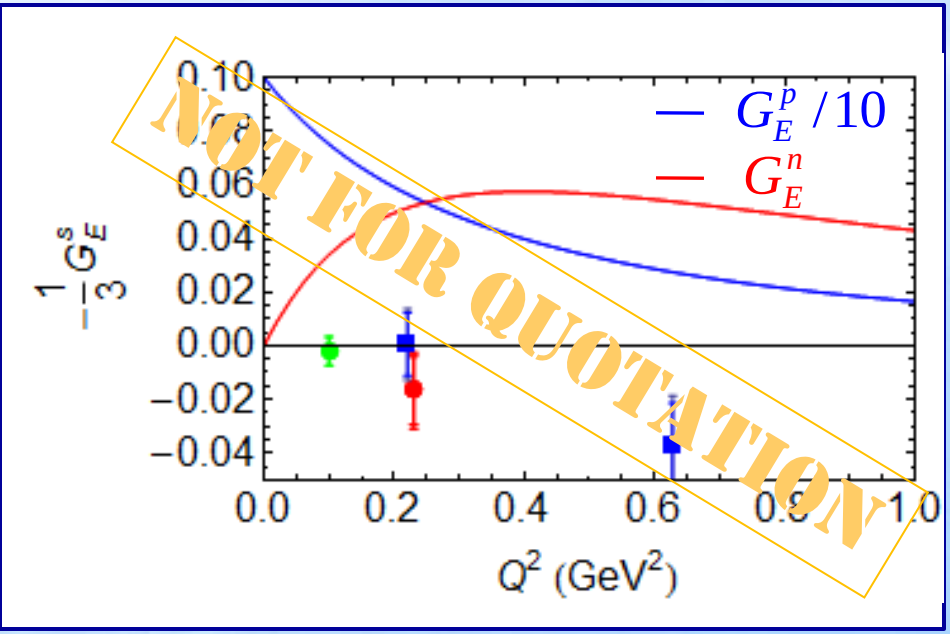
- Sensitivities smaller at backward angles
  - ~ 1/5 of slopes at forward angles
  - Kinematic correlation (momentum/angle) combined with spectrometer acceptance

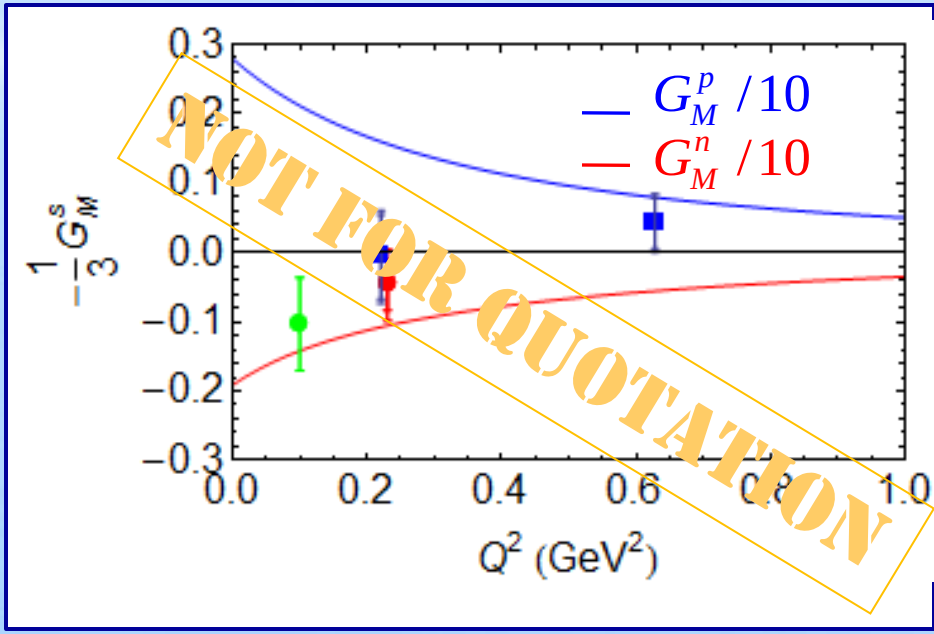
Simulation





Contributions to Overall Form Factors

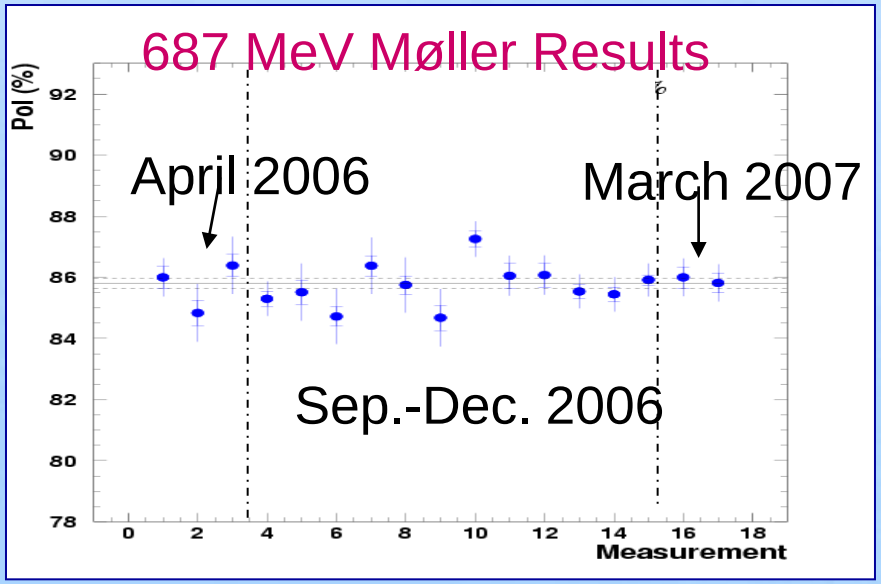




- Error bars dominated by statistics.
- Systematic experimental: backgrounds → Small

Beam Polarization

- Measurements of Møller asymmetry at 687 MeV (explained in E. Shudakov's talk)
- Use Mott (at the injector level) scattering for 362 MeV measurements
  - Mott asymmetry measured at 5 MeV injector
  - New work on effect of background improves agreement with Møller



P_e(687 MeV) = 85.78±0.07±1.38%
P_e(362 MeV) = 85.78±0.07±2.05%

ASYMMETRY UNCERTAINTIES (1)

Hydrogen, 687 MeV

	Value (ppm)	Stat (ppm)	Sys Pt (ppm)	Sys Gl (ppm)	Total (ppm)
Measured Asymmetry	-38.14				
Background Asymmetry	-38.27		0.40		
Dilution Correction			0.47	0.52	
Transverse Correction				0.008	
Rate Correction	-38.39		0.17		
Beam Polarization	-44.76		0.52	0.53	
EM Radiative Correction	-46.14		0.16		
Physics Asymmetry	-46.14	2.43	0.84	0.75	2.68

ASYMMETRY UNCERTAINTIES (2)

Deuterium, 687 MeV

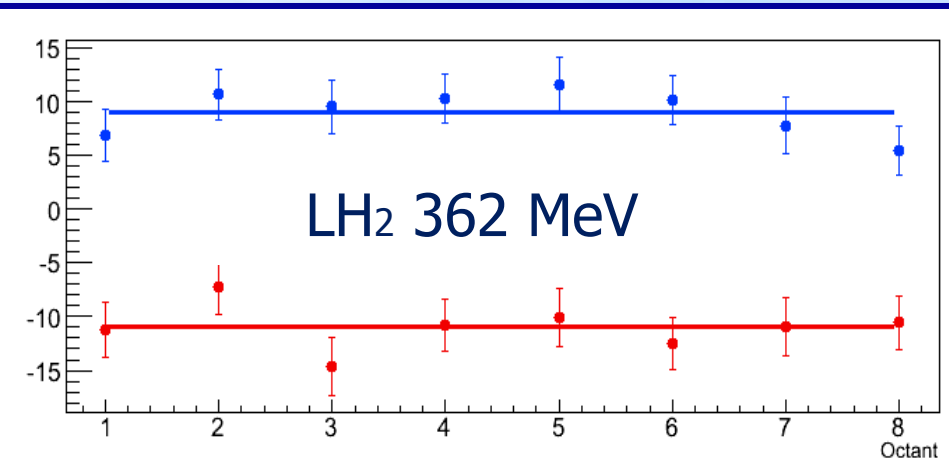
	Value (ppm)	Stat (ppm)	Sys Pt (ppm)	Sys Gl (ppm)	Total (ppm)
Measured Asymmetry	-44.02				
Background Asymmetry	-46.05		0.050		
Dilution Correction			0.38		
Transverse Correction			0.009	0.008	
Rate Correction	-46.35		1.82		
Beam Polarization	-54.03		0.62	0.64	
EM Radiative Correction	-55.87		0.19		
Physics Asymmetry	-55.87	3.34	1.98	0.64	3.92

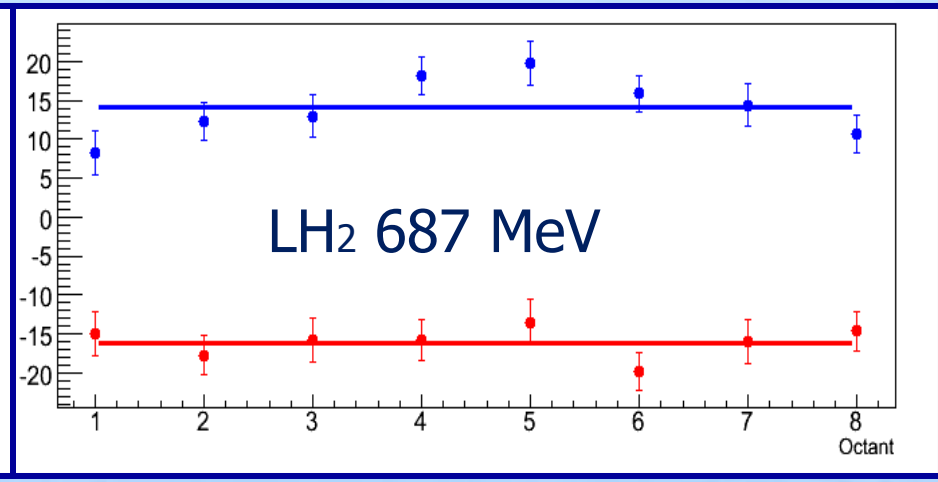
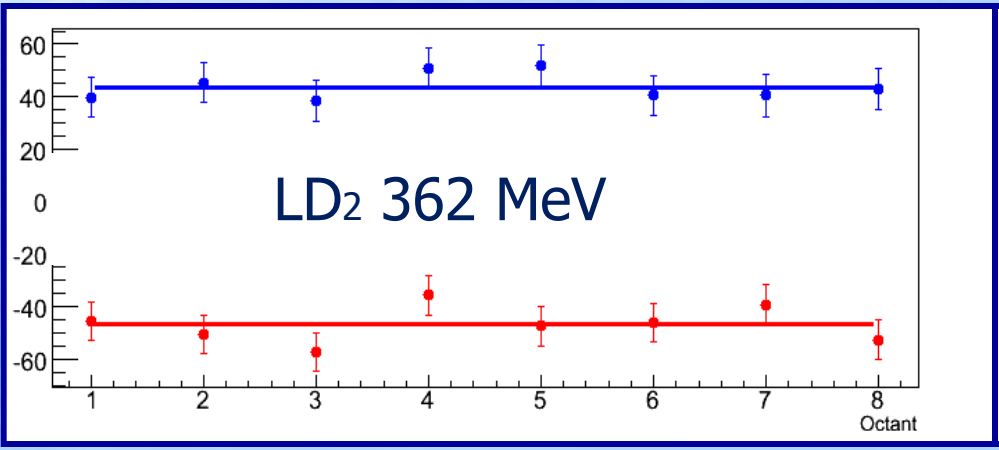
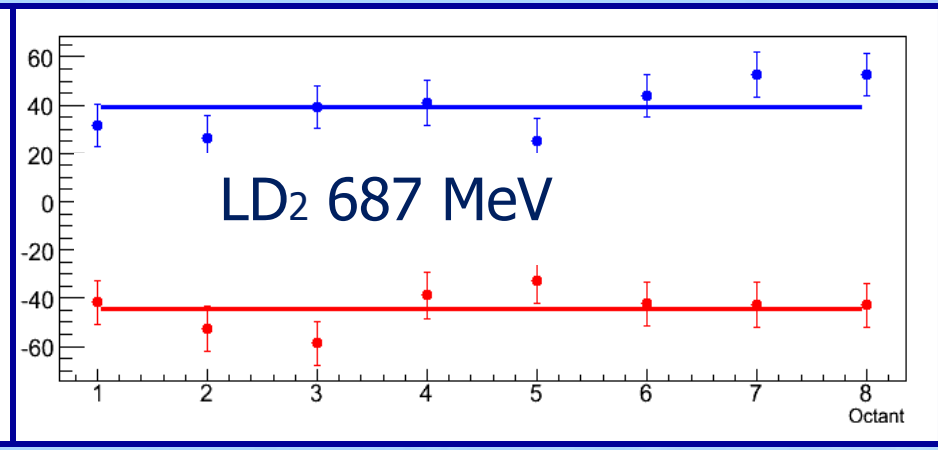
ASYMMETRY UNCERTAINTIES

Hydrogen, 362 MeV

	Value (ppm)	Stat (ppm)	Sys Pt (ppm)	Sys Gl (ppm)	Total (ppm)
Measured Asymmetry	-9.941				
Background Asymmetry	-9.441		0.034		
Dilution Correction			0.109	0.362	
Transverse Correction			0.025	0.008	
Rate Correction	-9.444		0.090		
Beam Polarization	-11.010		0.223	0.132	
EM Radiative Correction	-11.416		0.022	0.000	
Physics Asymmetry	-11.416	0.872	0.268	0.385	0.990

Raw Blinded Asymmetries per Kinematics





octant # (azimuthal distribution) ⟶