G^0 Backward Angle: Analysis Update

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for the G^0 Collaboration

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Introduction:

- **What is *G^0*?**
  - Measure parity-violating (PV) asymmetry of electrons scattering from the nucleon
  - Primary Physics Topic:
    - Studying the strange quark contribution to the proton
  - Secondary Physics Topics:
    - Measurements of inelastic electron, pion and transverse asymmetries are also made

- **Data Taking: *Complete***
  - Four target/energy combinations:
    - Hydrogen and deuterium targets, each at 687MeV and 362MeV
  - Ran in Hall C from March '06 to March '07

- **Data Analysis: *Nearing Completion***
  - Will present a status report in this talk

The *G^0* Collaboration:

CalTech, Carnegie-Mellon, William & Mary, Hendrix, IPN-Orsay, LPSC-Grenoble, JLab, LaTech, NMSU, Ohio University, TRIUMF, U Conn, UIUC, U Manitoba, U Maryland, U Mass, UNBC, U Winnipeg, VPI, Yerevan, Zagreb

Graduate Students:

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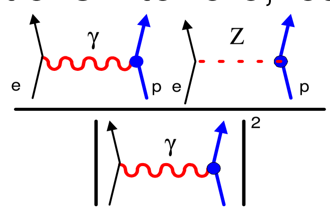
G^0: Overview

- **Strange Quarks and the proton**
  - Strange form factors G^S_E, G^S_M tell us how the presence of strange quarks in the quark sea contribute to the proton's form factors

- **Electron-Nucleon Scattering:**
  - EM and weak interactions interfere, leading to PV asymmetry

$$A \propto \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \propto \frac{M^\gamma M^Z}{|M^\gamma|^2} \propto$$



$$\Rightarrow A_{PV} = \left[\frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\right] \frac{A_E + A_M + A_A}{\sigma_{total}}$$

- **Relationship between PV asymmetry and form factors:**

G^0 Forward

$$A_E = \varepsilon(\theta) G_E^Z G_E^\gamma \Rightarrow G_E^s$$

$$A_M = \tau G_M^Z G_M^\gamma \Rightarrow G_M^s$$

G^0 Backward

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

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

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

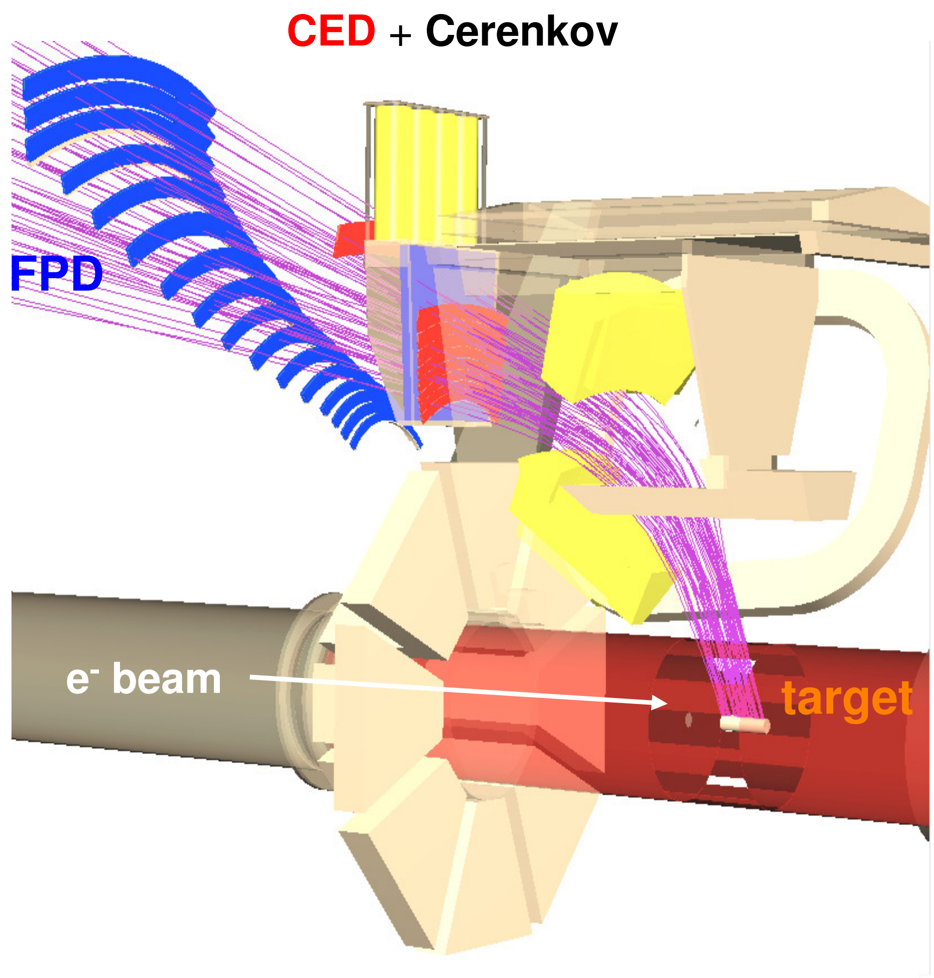
$$\varepsilon' = \sqrt{(1-\varepsilon^2)\tau(1+\tau)}$$

3 terms → 3 measurements needed

- ***G^0* Measurements:**
  - Measuring forward angle scattering from H and backward angle scattering from H and D gives us all the information we need to separate out the terms
    - Forward angle H: Measure asymmetry of recoiling protons ✓ **Complete**
      - *D.S. Armstrong, et al., PRL 95, 092001 (2005)*
    - Backward angle H: Measure asymmetry of scattered electrons
    - Backward angle D: Measure asymmetry of scattered electrons

Experimental Setup:

- **Cryotarget:**
  - LH_2 or LD_2
- **Beam:**
  - Longitudinally polarized beam with ~85% polarization throughout the run.
- **Detector System:**
  - Scintillators:
    - Two sets allow for kinematic separation of elastic and inelastic regions
      - **Cryostat Exit Detectors (CED)**
      - **Focal Plane Detectors (FPD)**
  - Cerenkov Detectors (CER):
    - Allow us to distinguish between pions and electrons
  - Measured events: Coincidences
    - CER + CED + FPD fire → electron
    - CED + FPD fire (CER doesn't fire) → pion

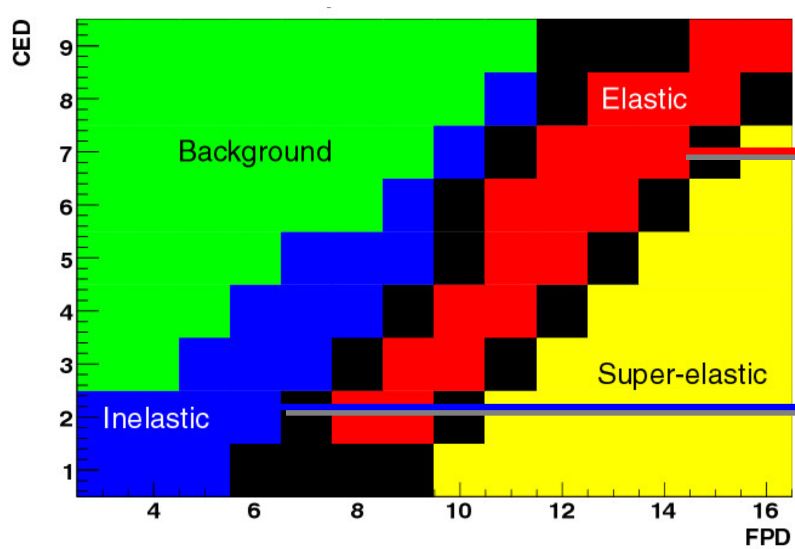


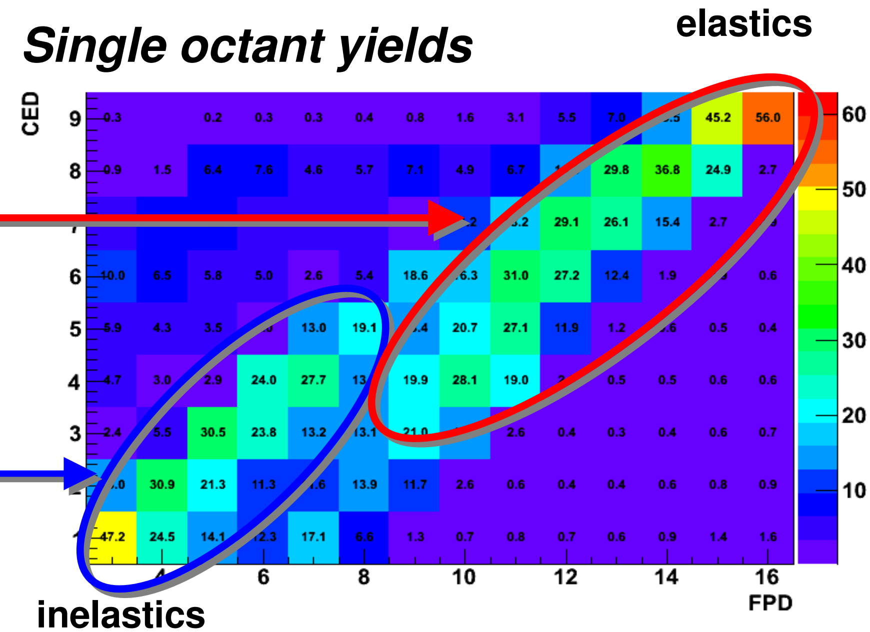
Cutaway view of a single octant

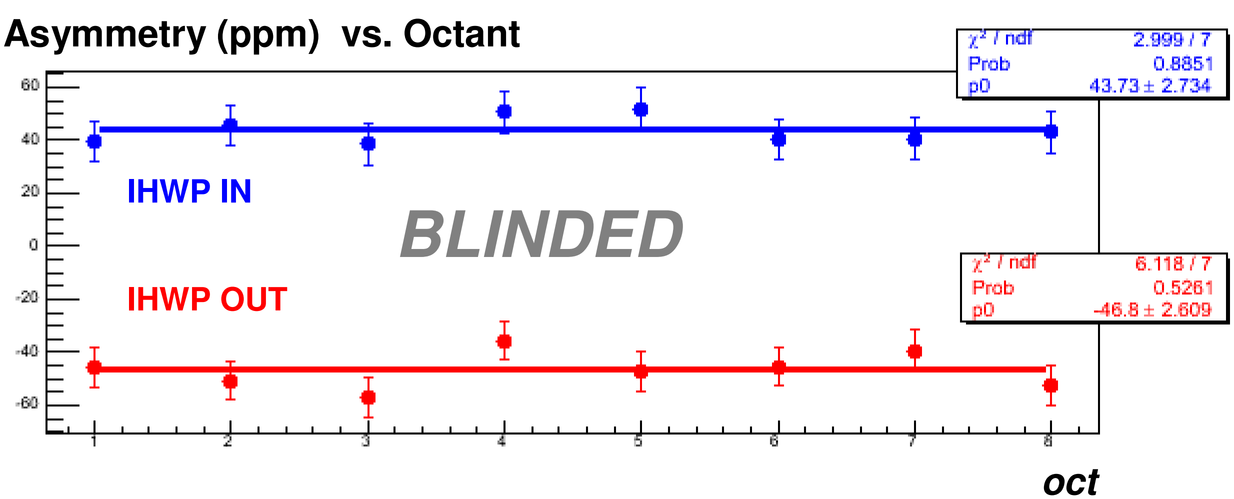
Eight detector arrays like the one above are arranged symmetrically around the target

Data: Electron Yield and Asymmetry

- Hydrogen @ 687MeV



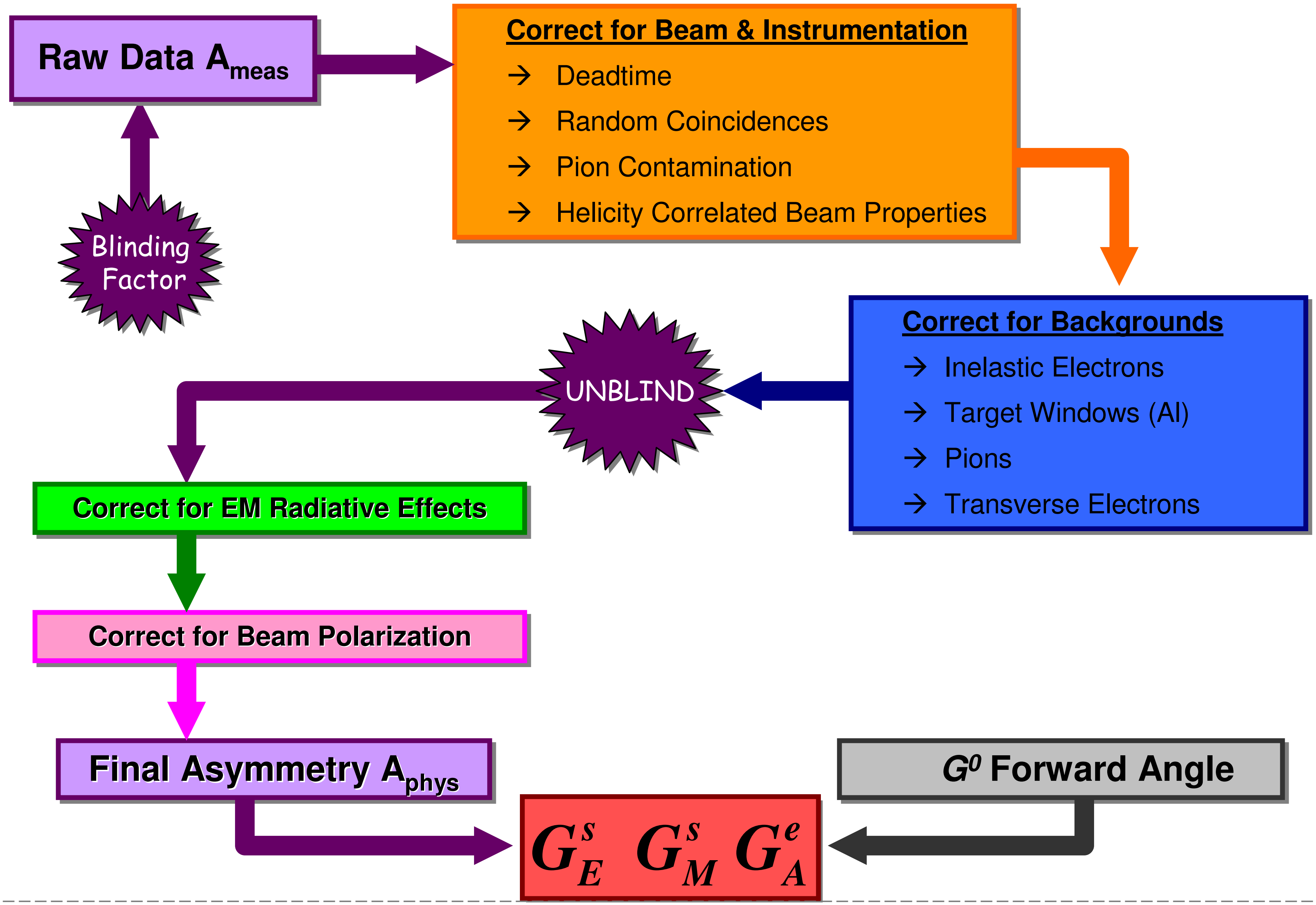




<u>Octant asymmetries:</u>

- ✓ No octant dependence
- ✓ Consistent between half wave plate states

Analysis Strategy:



Analysis: Preliminary Asymmetries

- **Replay:**
  - Use multi-stage analysis to apply corrections related to beam and instrumentation
  - Replay completed Late Summer '08

Preliminary Blinded Asymmetries

Corrections Applied	H Asymmetries (ppm)		D Asymmetries (ppm)	
	362 MeV	**687 MeV**	**362 MeV**	**687 MeV**
Raw	-9.93 ± 0.62	-45.34 ± 1.89	−15.13 ± 0.65	–41.56 ± 2.27
Rate Corrected	-10.23 ± 0.63	-46.70 ± 1.97	−15.89 ± 0.75	–48.43 ± 2.87
Helicity Correlated Beam Parameter Corrected	-10.13 ± 0.64	-46.76 ± 1.97	−15.92 ± 0.75	–48.39 ± 2.87

Note: Errors are statistics only

Analysis: Summary of Corrections

- **Rate Corrections:**
  - Three corrections applied:
    - Correct for detector and electronics deadtime
    - Correct for random coincidences
    - Correct for misidentified pions
  - Each piece contributes separately to the measured asymmetry
  - Overall size of corrections (A_{false})
    - Hydrogen:
      - 362MeV: $A_{false} < 1$ ppm (*< 5%*)
      - 687MeV: $A_{false} \sim 1.5$ ppm (*< 5%*)
    - Deuterium:
      - 362MeV: $A_{false} < 1$ ppm (*< 5%*)
      - 687MeV: $A_{false} \sim 5$ ppm (*< 15%*)
        - » Correction larger here due to increased presence of pions

- **Linear Regression:**
  - Corrects for helicity correlated beam properties
  - Correction < 0.1 ppm for all target/energy combinations

Analysis: Summary of Corrections

- **Transverse Asymmetry:**
  - Longitudinally polarized beam has a small transverse component
    - Measured θ_{spin} ~ 2 degrees
  - Measure the effect by taking dedicated transverse polarization runs
    - Contributes < 1ppm to overall asymmetry for each target/energy combination

- **Radiative Effects:**
  - Use simulation to determine the effect of radiation on the cell by cell yield distribution
    - Reduced Q^2 for the scattered electron changes it's location in space when it hits the detectors.
      → Correct for events pushed out of our acceptance
  - Represents a ~4-5% correction to the asymmetry for all target/energies

- **Background Correction:**
  - Correct for various backgrounds contributing to the measured asymmetry
    - i.e. inelastic electrons, pions, scattering from target windows
  - Use this information to correct the measured asymmetry
    → Want to know the true elastic asymmetry

Background Correction:

- **Method: Field Scan**
  - Take data over a range of magnet current settings
  - Total yield at each current contains contributions from several processes

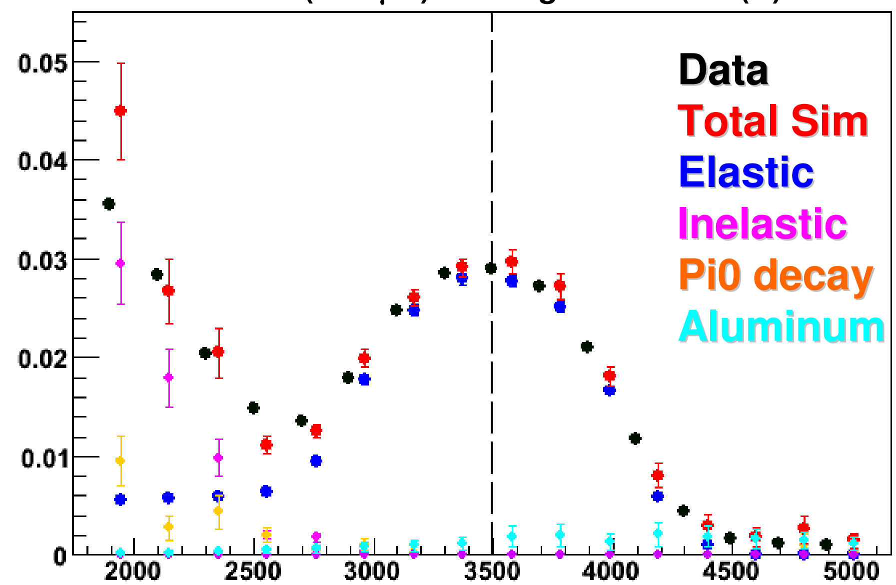
→ *Want to know the size of each contribution*

- **Use Simulation:**
  - Run GEANT simulations for contributing processes over the same range of fields
    - Electrons scattered elastically from H (D) and Al
    - Electrons scattered inelastically from H (D) and Al
    - Pi0 decay

- **How big is the correction?**
  - Hydrogen: Preliminary Results
    - Average dilution ~10% across elastic locus for both energies
    - Asymmetry correction is small due to similarities in measured and background asymmetry values
  - Deuterium:
    - → Results still to come…

H @ 687MeV:

Cell Yield (kHz/μA) vs. Magnet Current (A)

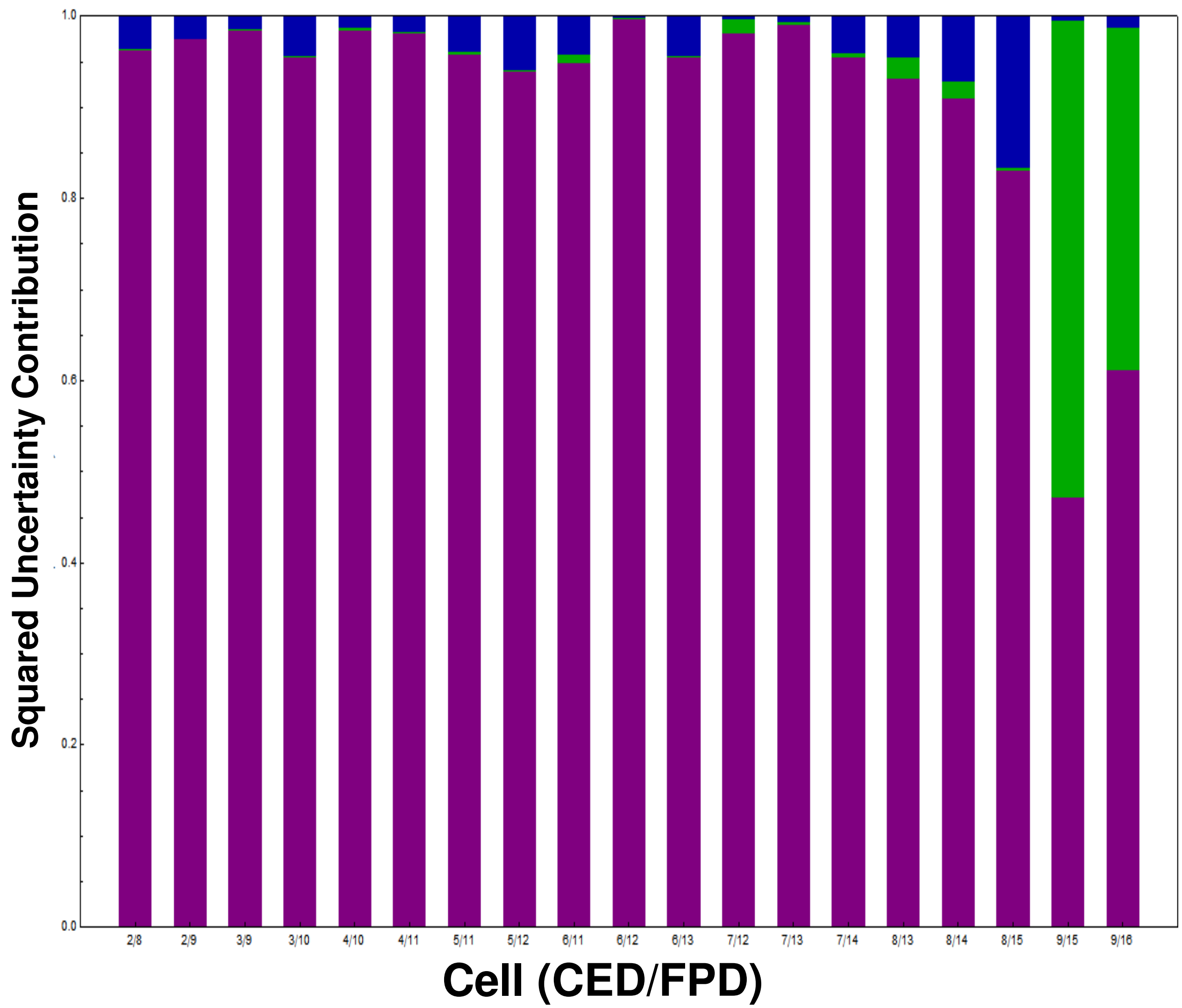


Plot: Data and simulation yields for a typical elastic cell

(Vertical line represents nominal current setting during run)

Uncertainties…

- Preliminary error budget for 687 MeV H dilutions:



[o] Statistics

[o] Background Asym, A_{bck}

[o] Dilution Factor, f

$$A_{phys} = \frac{A_{meas} - A_{bck} f}{(1 - f)}$$

Avg Error (ppm²)
Preliminary

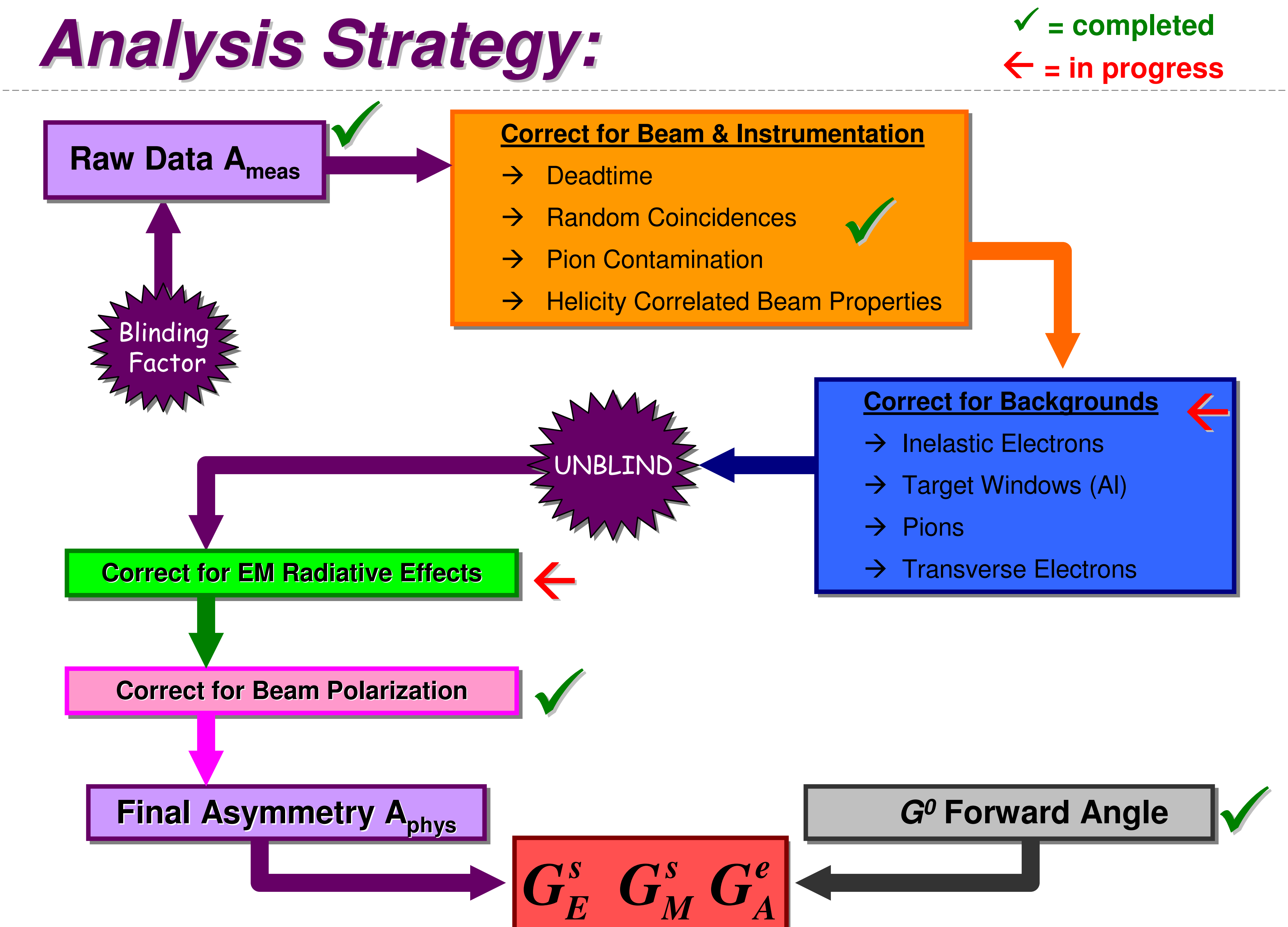
σA_{meas}^2	4.76
σA_{back}^2	0.32
$\sigma A_{dilution}^2$	0.21
σA_{total}^2	**5.29**

Other Physics Topics:

- **PV Asymmetry in the *N*-Δ transition:**
  - Inelastic electron asymmetry from 687MeV H is being used to extract the **axial transition form factor $G^A_{N\Delta}$**
  - Represents the first measurement of $G^A_{N\Delta}$ in the neutral current sector
- **Pion Photoproduction:**
  - Pion data from 362MeV D is being used to determine the scale of the **low energy constant** characterizing the **PV $\gamma N\Delta$ coupling**
  - Represents the first time this constant has been studied experimentally
- **Transverse Measurements:**
  - Transverse beam polarization data is being used to study the **2γ exchange**
  - Represents one of the first measurements with neutron

Much of the analysis on these topics runs concurrently with the analysis already described. In addition, analysis tasks specific to each of these topics are currently ongoing…

Analysis Strategy:



Summary:

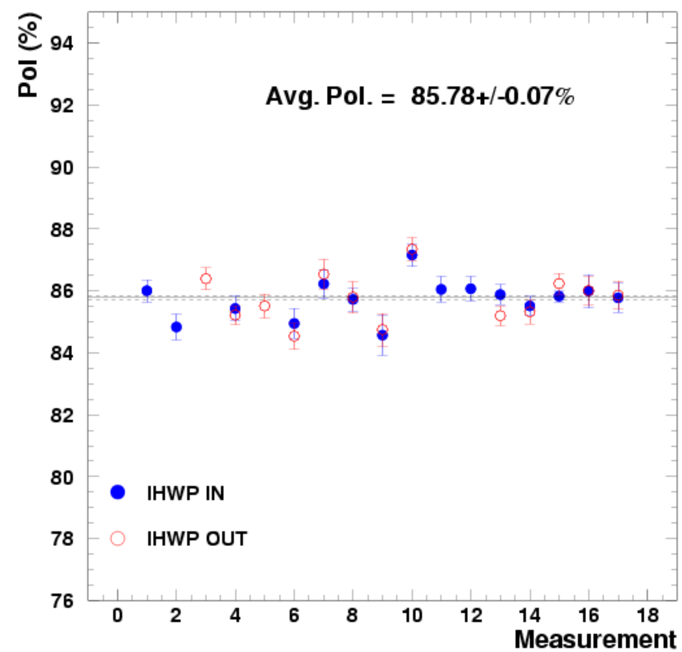
- **Data taken on 4 energy/target combos**
  - Completed 2007
- **Much progress made in data analysis**
  - Final asymmetry corrections for H near completion
  - Final corrections for D should follow soon after H
- **Uncertainty**
  - Error will be dominated by statistics
- **Asymmetries to Form Factors:**
  - Will use most up to date EM form factors in extracting strange form factors
    - Uncertainty due to form factors << experimental errors
- **Unblinding**
  - **Expect to unblind soon**
    - Mainly waiting to finalize D simulation for dilution
      - Want to make sure we have the best model for our kinematics
  - Aim for publishing soon after unblinding

THE END ☺

Backup Slides Follow:

G^0 Backward Angle : Beam Specifications

Beam Parameter	Achieved (IN-OUT)/2	"Specs"
Charge asymmetry	0.09 +/- 0.08	2 ppm
x position difference	-19 +/- 3	40 nm
y position difference	-17 +/- 2	40 nm
x angle difference	-0.8 +/- 0.2	4 nrad
y angle difference	0.0 +/- 0.1	4 nrad
Energy difference	2.5 +/- 0.5	34 eV
Beam halo (out 6 mm)	< 0.3 x 10^{-6}	10^{-6}



- Beam parameters specifications were set to assure: $A_{P_i}^{false} \leq 5\% \Delta A_{stat}^{meas}$
- Helicity correlated beam properties

⇨ false asymmetry

Correction : linear regression

$$A_{cor} = A_{meas} - \sum_i \frac{1}{2Y} \frac{\partial Y}{\partial P_i} \Delta P_i$$

Polarization from Møller measurements @ 687MeV:

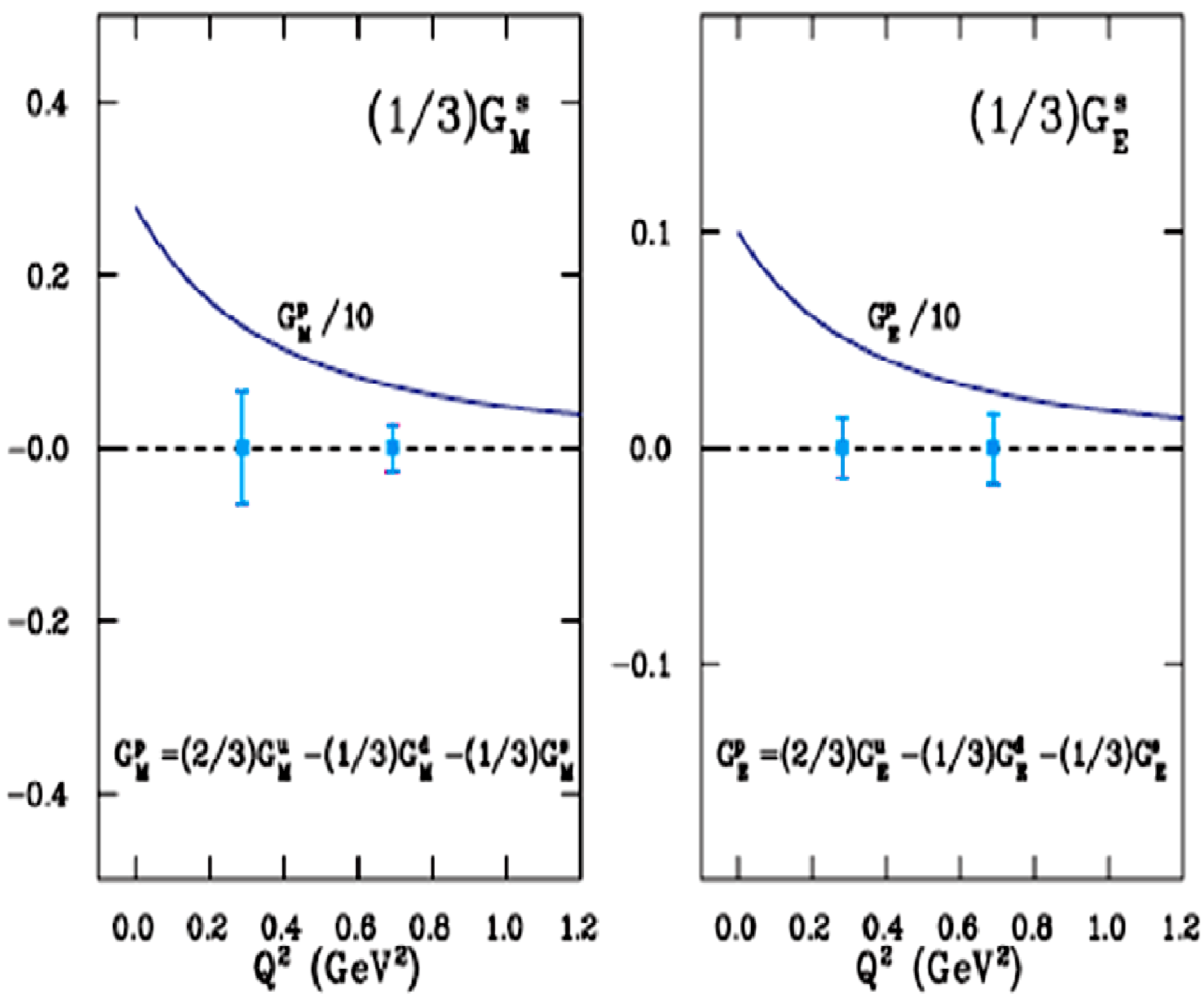
P_{687}=85.78 +/- 0.07 (stat) +/-1.38 (sys) %

P_{362}=85.78 +/- 0.20 (stat) +/- 2.55 (sys) %

→ *Larger error here due to use of Mott*

Expected G^0 Results:

- Error bars dominated by statistics (shown below)



Background Correction:

- **Determine the Dilutions**
  - Simulated yields at the nominal current give the contribution of each process to Y_{meas}
  - Compute dilution factor, f

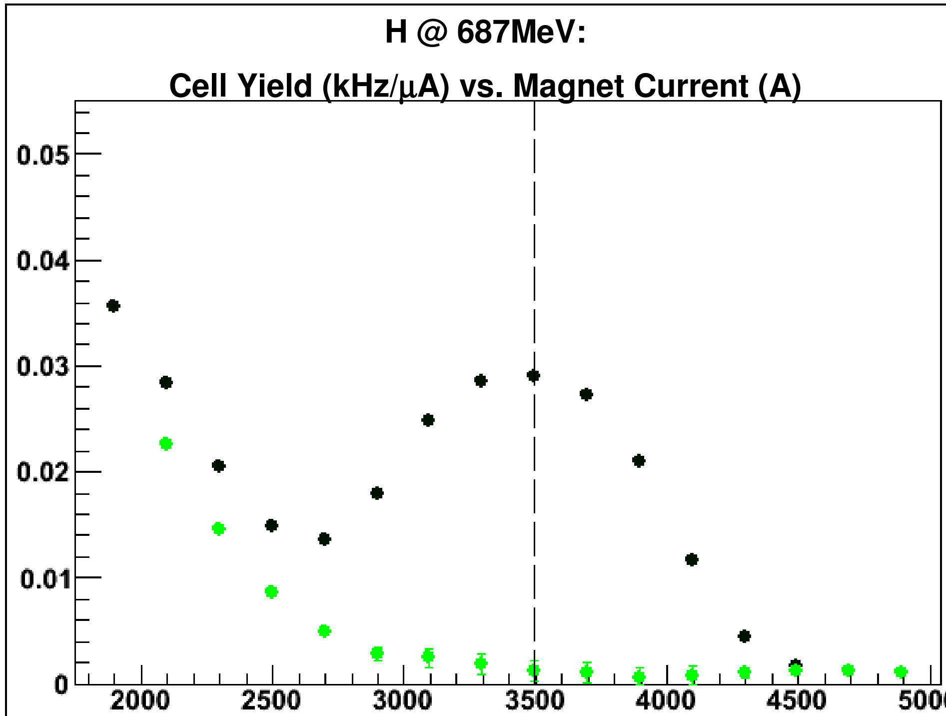
$$Y_{meas} = Y_{elast} + \sum_i Y_{bck,i}$$

$$\Rightarrow Y_{elast} = 1 - \sum_i \frac{Y_{bck,i}}{Y_{meas}} = 1 - \sum_i f_i$$

- **Apply the Correction:**
  - Determine the elastic asymmetry (A_{phys}) by subtracting off dilutions due to other processes

$$A_{meas} = A_{phys}(1-f) + A_{bck} f$$

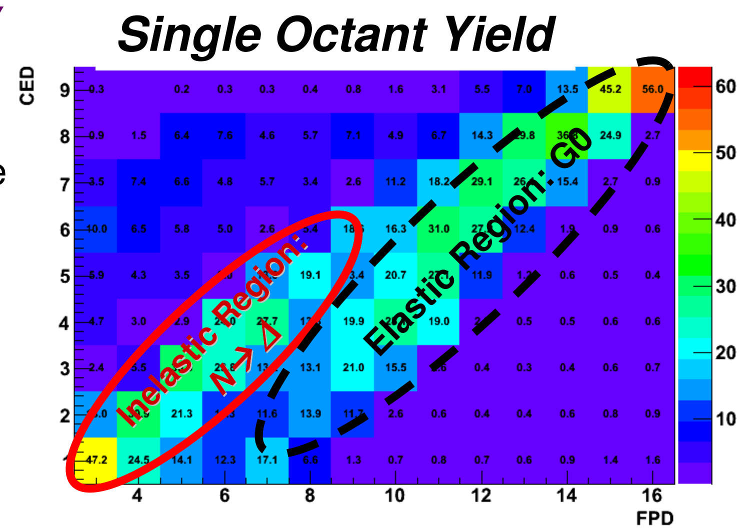
$$\Rightarrow A_{phys} = \frac{A_{meas} - A_{bck} f}{(1-f)}$$



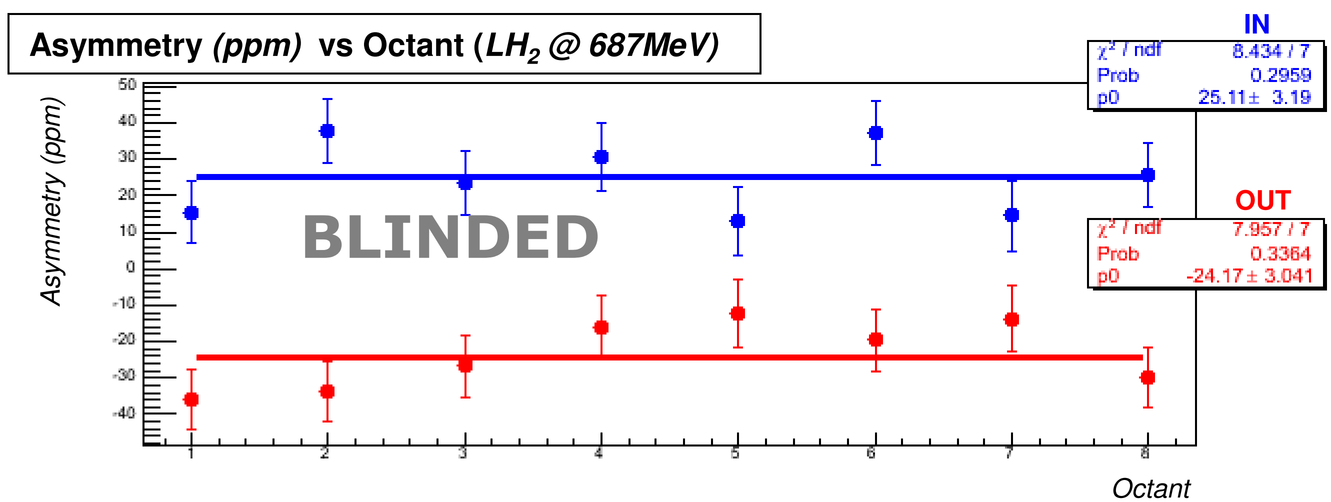
Plot shows data (black) and residual Y_{bck} (green) after subtracting simulated elastic yield

G^0 Inelastics: $N \rightarrow \Delta$

- Measurement: *Parity-violating asymmetry of electrons scattered inelastically*
  - $A_{N\Delta}$ gives direct access to $G^A_{N\Delta}$
    - Directly measure the axial (intrinsic spin) response during $N \rightarrow \Delta^+$ transition
  - Will find $G^A_{N\Delta}$ over a range of Q^2
    - *$0.25\ GeV/c^2 < Q^2 < 0.5\ GeV/c^2$.*
  - First measurement in neutral current process



- Data: *Inelastic electrons measured by G^0*
  - Scattered from both LH2 and LD2 @ 687MeV



Raw Asymmetry *(averaged over inelastic region)*

Transverse Polarization Data:

$$A_\perp^m = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = A_n \vec{p}_e \cdot \hat{n} = |A_n| \sin(\phi + \phi_0)$$

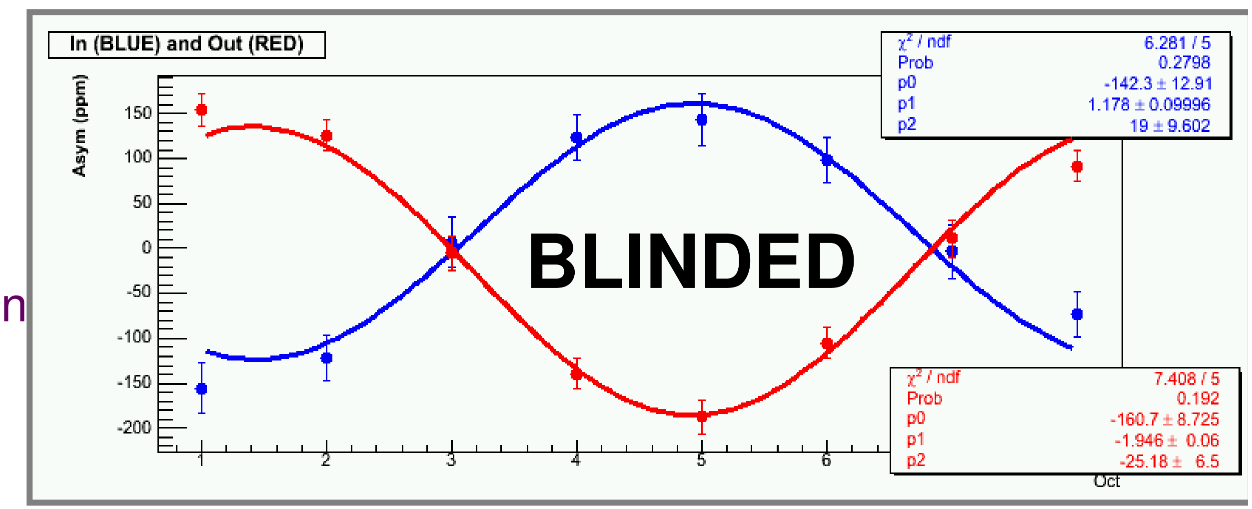
magnitude of transverse asymmetry

depends on direction of transverse beam polarization

$$A_n = \eta \times \{ -\tau G_M \,\mathrm{Im}(\tilde{F}_3 + \beta \tilde{F}_5) - \mathrm{Im}(\tilde{F}_4 + \beta \tilde{F}_5) \} + \vartheta(\alpha^2)$$

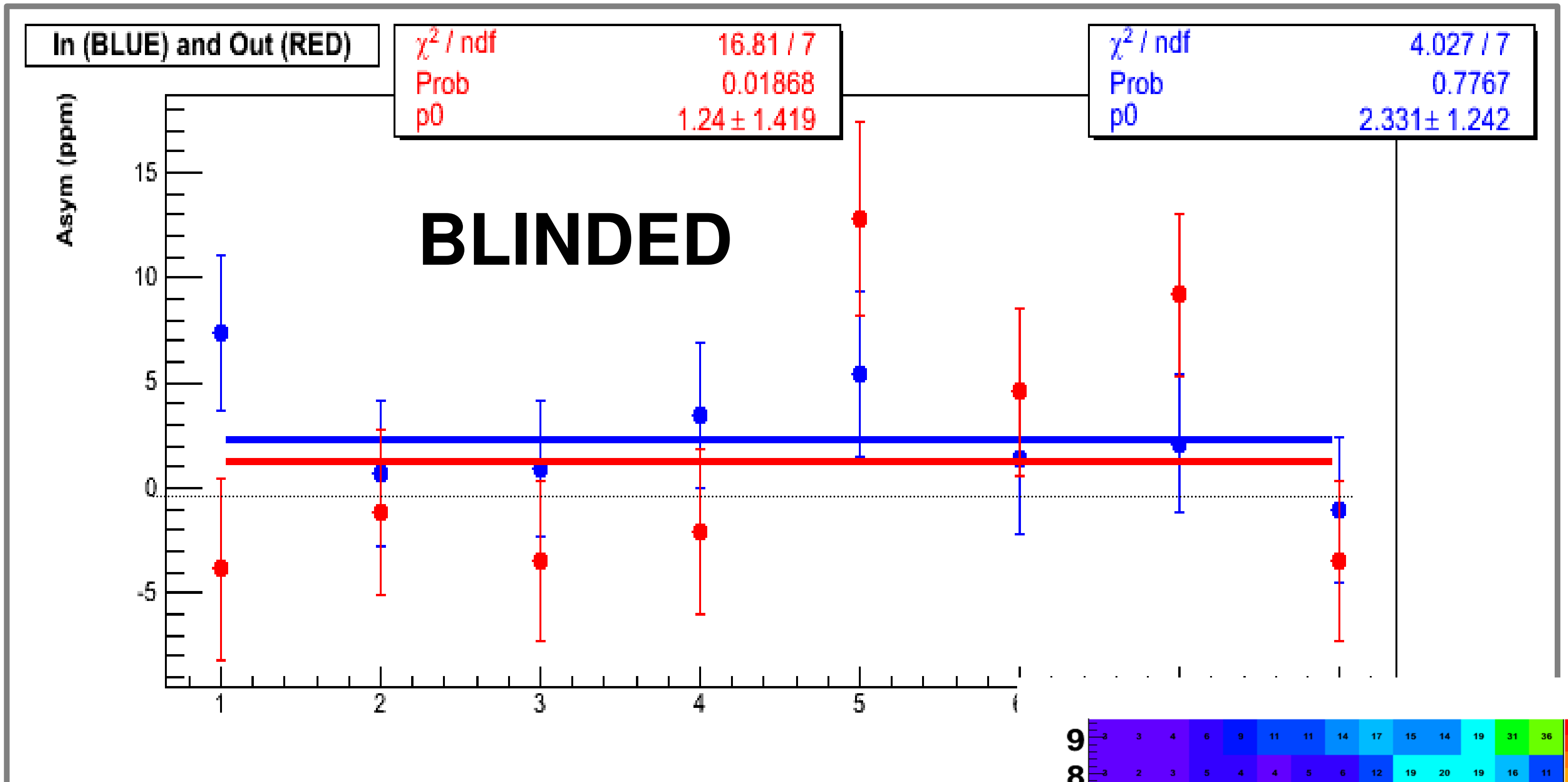
$$\eta = \frac{2m_e}{Q^2} \frac{\sqrt{2\varepsilon(1-\varepsilon)}\sqrt{1+\tau^{-1}}}{(G_M^2 + \frac{\varepsilon}{\tau} G_E^2)}$$

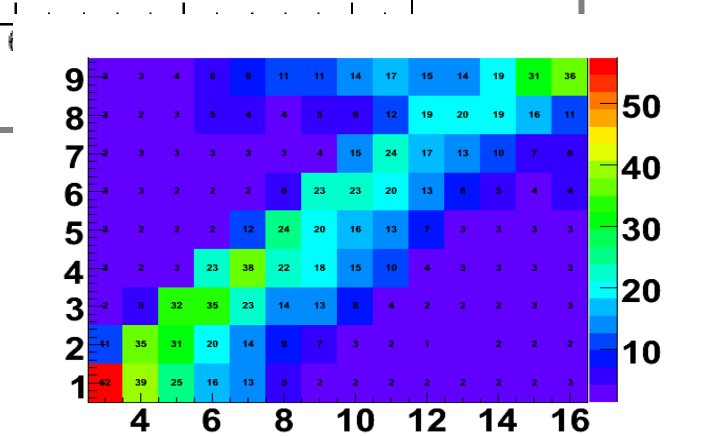
$\tilde{F}_i$ - contains intermediate hadronic state information



Pion Asymmetries: LH_2 687MeV

Longitudinal – corrected for transverse :



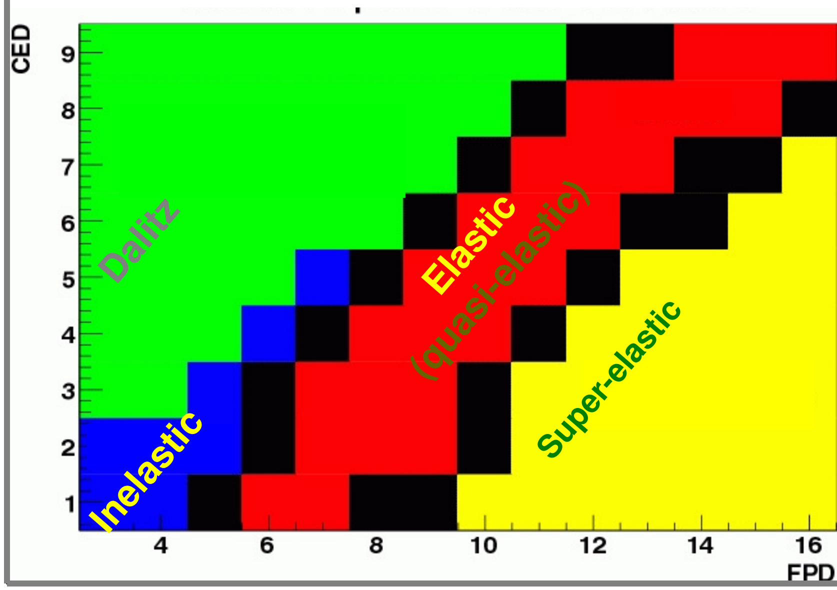


Blue data points : Half Wave plate "in"

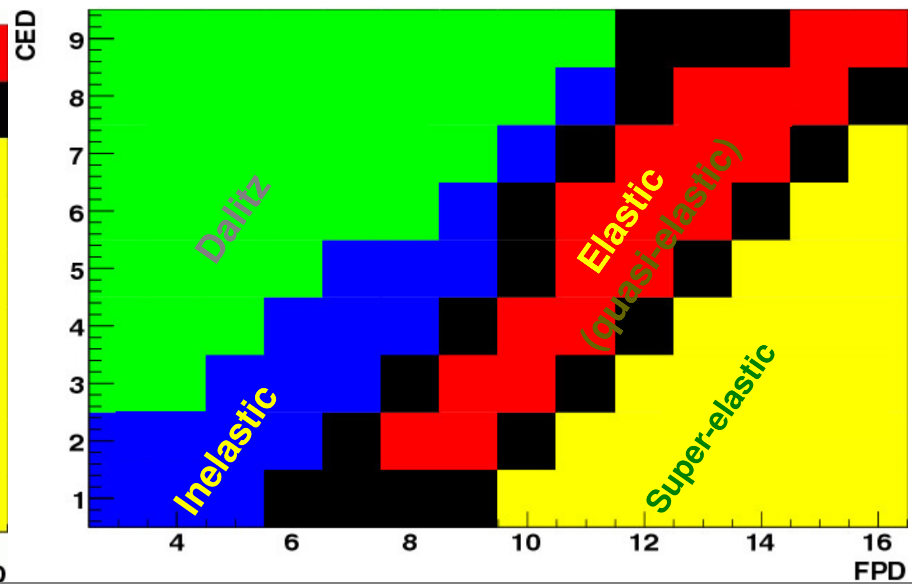
Red data points : Half Wave plate "out"

CED-FPD Electron Matrix:

LH2, LD2 362 MeV: Q2 = 0.23 (GeV/c)2



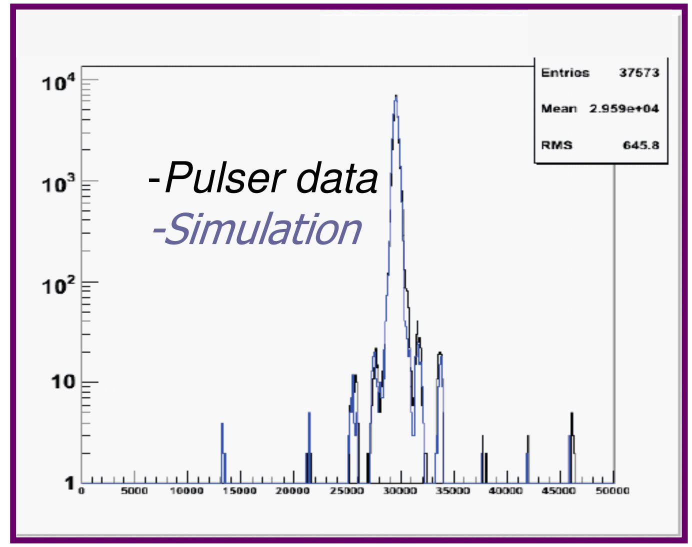
LH2, LD2 687 MeV: Q^2 = 0.62 $(GeV/c)^2$



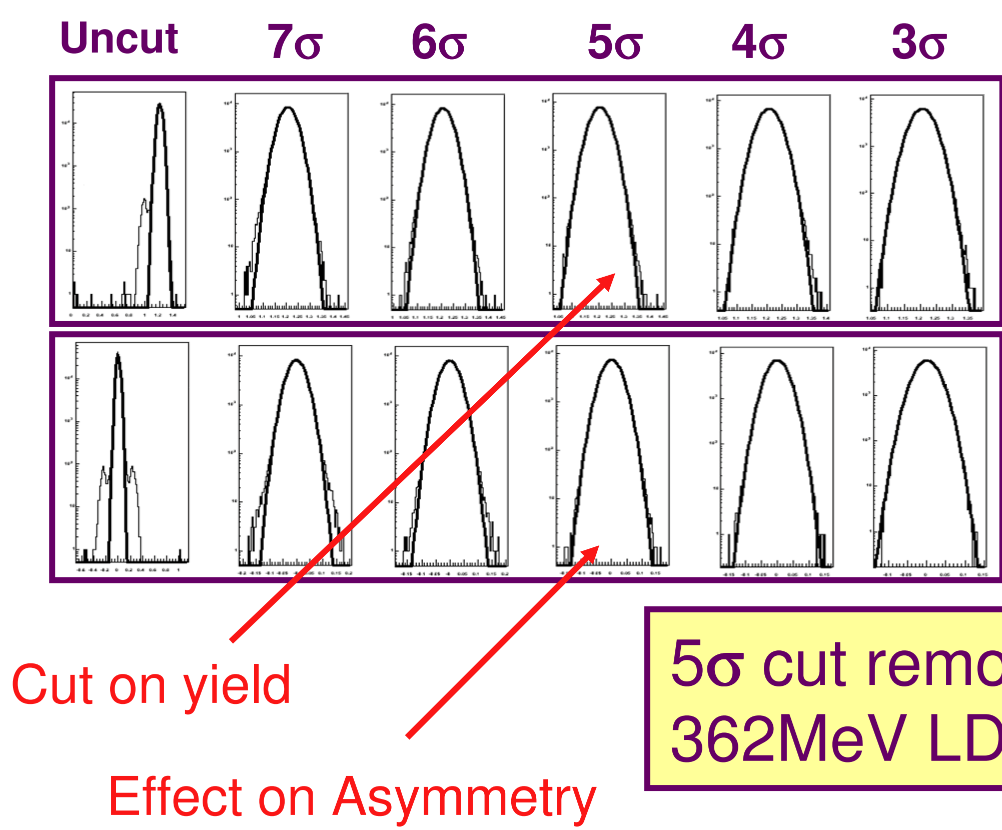
- Elastic band: ep->ep
- Inelastic band: N-Δ
- Dalitz: $e+p \rightarrow \pi^o + p \rightarrow 2\gamma \rightarrow e^+e^-$
- Super-elastic: no reaction mechanism is possible
- Locus determination: Field scans, dilution factors

NA Scalar Counting Problem:

- **An occasional bit drop in a North American scaler was traced down to trigger electronics. Was noticed at high rates: LD2 target at 362 MeV.**
  - **→ This was fixed during the run (Jan07)**
- **Problem blind to helicity.**



- Test by cutting data; compare with French octants.
- Confirmed by unchanged asymmetry after fix



5σ cut removes ~1% of our data for 362MeV LD2,which is the worst case! ☺

From Asymmetries to Strange Form Factors

- Proton

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

- Deuteron

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

Ref:Diaconescu, Schiavilla & van Kolck, PRC **63** (2001) 044007
(Addition of the 2body currents corrections)

From Asymmetries to Strange Form Factors

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

to be extracted

Isoscalar sff
(Estimated 0.02 ppm)

- **We will use the best and up to date inputs for the quantities going into the a_i *coefficients.*** **Nucleon ffs, Elecroweak Radiative Corrections, etc…**

Solve the system for the G0 Forward (proton target) and G0 Backward kinematics (proton and deuteron targets)

Nucleon Form Factors and electroweak Radiative Corrections

- Use Arrington, Melnitchouk and Tjon's model with the 2photon exchange correctrions to the proton ffs.

-Electroweak radiative corrections: We do have two group of theorists

doing the calculations for us:

-Y-Z box diagram contribution. Melnitchouk/Blunden are working on the contribution of the excitation of the Delta(1232) in the intermediate states to the elastic e-p scattering. Zhou et al. estimated this effect to be opposite to the 2PE+YZ box diagrams combined contributions, most probably no much effect will be seen for the G0 kinematics. Private communication with Shin-Nan.

-References:

- Arrington, Melnitchouk & Tjon: Phys. Rev. C 76035205(2007)
- Zhou, Kao & Yang, PRL 99 (2007) 262001
-Tjon & Melnitchouk PRL 100 (2008) 082003
- Keitaro Nagata, Hai Qing Zhou, Chung Wen Kao, Shin Nan Yang nucl-th > arXiv:0811.3539

THE END AGAIN