First Measurement of the Beam Normal Single Spin Asymmetry in Δ Resonance Production by Q-weak

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(https://userweb.jlab.org/~nur)

for the Q-weak Collaboration

New Perspectives 2015 *June 8-9 at Fermilab*

in conjunction with the 48th Fermilab Users Meeting

Beam Normal Single Spin Asymmetry

- Beam Normal Single Spin Asymmetries (B_n) are generated when transversely polarized electrons scatter from unpolarized targets

- B_n is parity conserving and is time-reversal invariant

B_n is also known as transverse asymmetry

$$B_n = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow}$$

$\uparrow$ spin UP

$\downarrow$ spin DOWN

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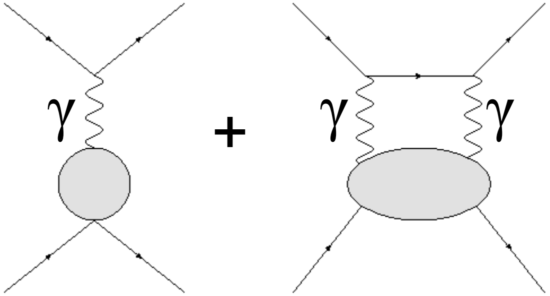

$$B_n = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} = \frac{2T_{1\gamma} \times \mathrm{Im}\, T_{2\gamma}}{|T_{1\gamma}|}$$

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$T_{1\gamma}$ – amplitude for 1-photon exchange
$T_{2\gamma}$ – amplitude for 2-photon exchange

B_n arises from the interference of 2-photon exchange with 1-photon exchange in e-N scattering

- B_n provides direct access to the imaginary part of the two-photon exchange amplitude

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Contains information about the Intermediate states of the nucleon

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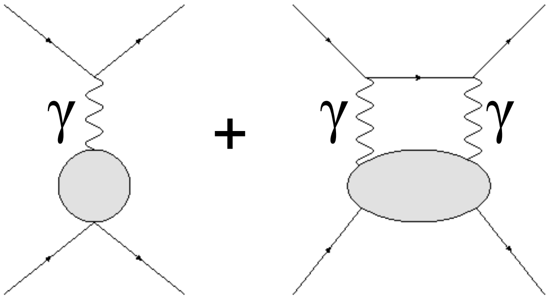

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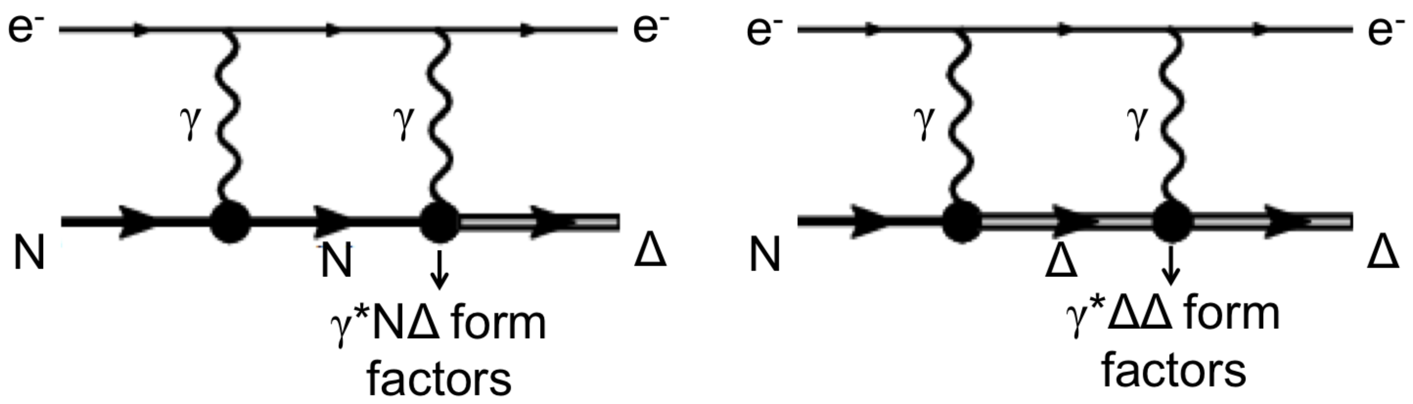
B_n in the Production of the Δ Resonance

Measuring B_n in $e + p \rightarrow e + \Delta$

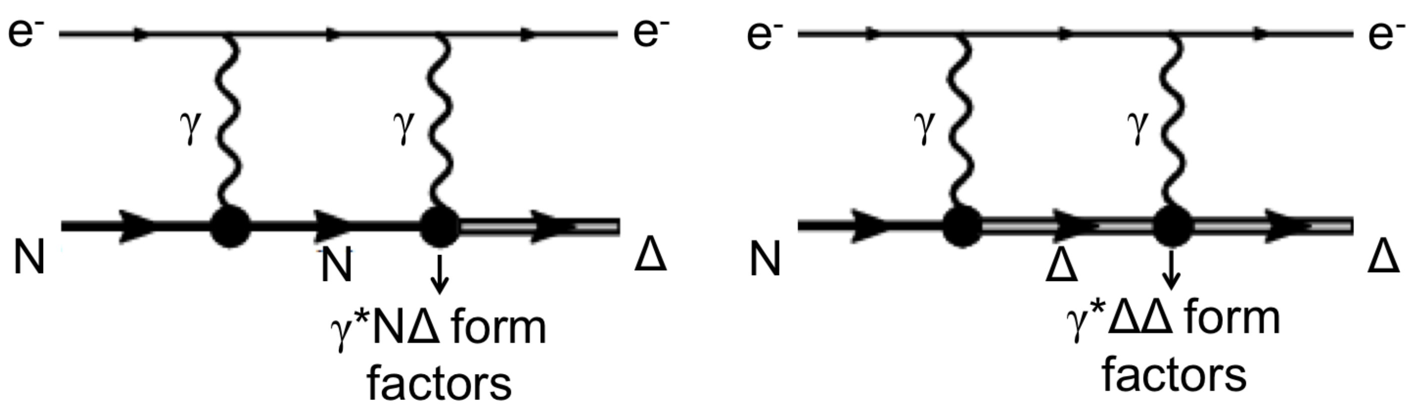


B_n in the Production of the Δ Resonance

Measuring B_n in e + p → e + Δ

Physics Motivation:

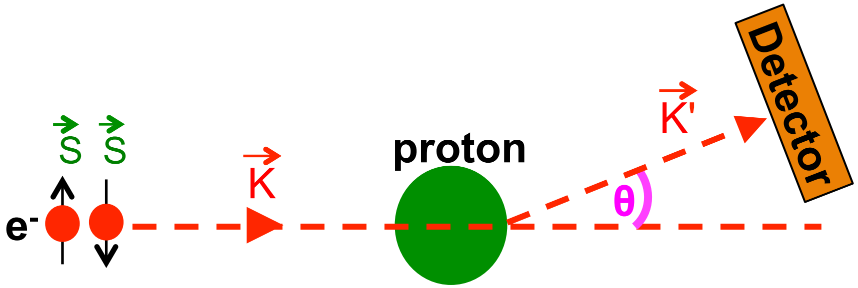
For p and Δ intermediate hadrons, vertices are known
- except for γ*ΔΔ electromagnetic (EM) vertex



- Proton EM FF well known. N→Δ EM transition FF fairly well known
- Unique tool to study γ*ΔΔ form factors
- Potential to constrain charge radius and magnetic moment of Δ!

Asymmetry Measurement

Can be measured with a transversely polarized beam to determine the magnitude



Measured asymmetry

$$\epsilon_M(\phi) = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

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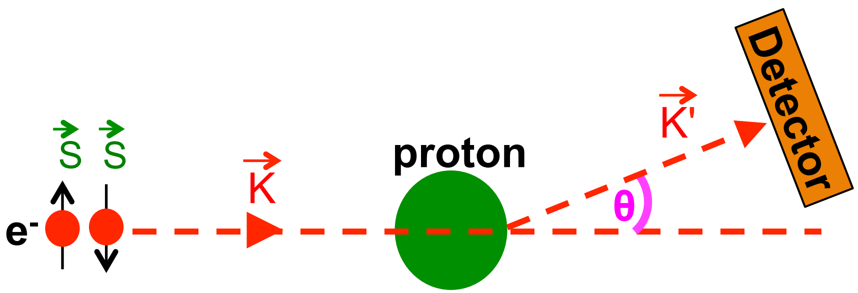
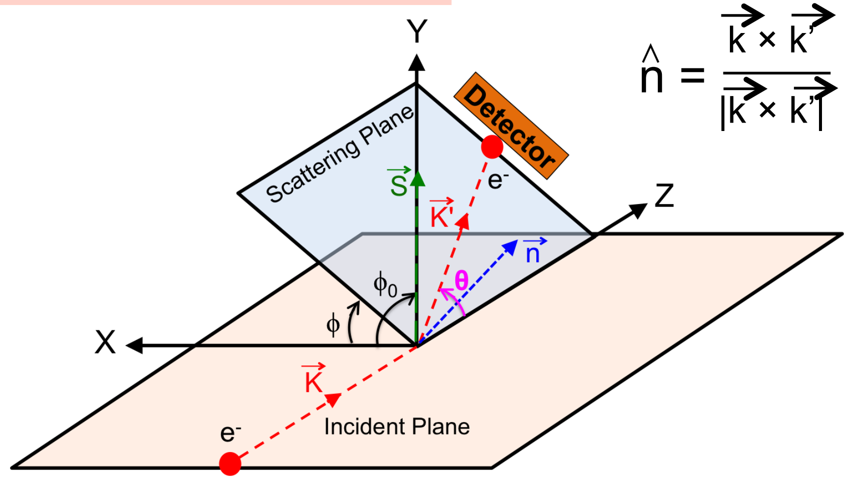


$$\hat{n} = \frac{\vec{k} \times \vec{k}'}{|\vec{k} \times \vec{k}'|}$$



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$$\epsilon_M(\phi) = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow} = -B_n \vec{S}.\hat{n} = B_n S \sin(\phi - \phi_0) = B_n\,[P^V \cos(\phi) - P^H \sin(\phi)]$$

Measured asymmetry has a small azimuthal dependence

- Horizontal : $P^H = S\cos(\phi_0)$
- Vertical : $P^V = S\sin(\phi_0)$

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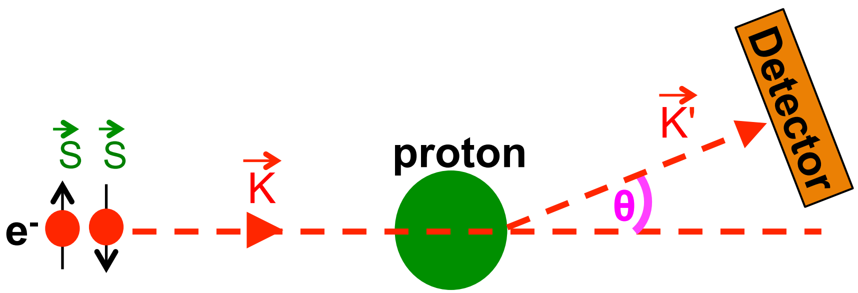

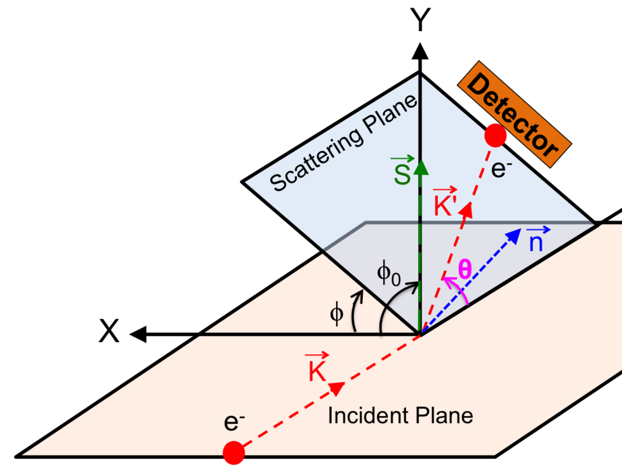

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Data taken on targets

- Hydrogen
- Aluminum
- Carbon

Transverse polarization:

- Horizontal
- Vertical

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Q-weak has data with different beam energy and physics process

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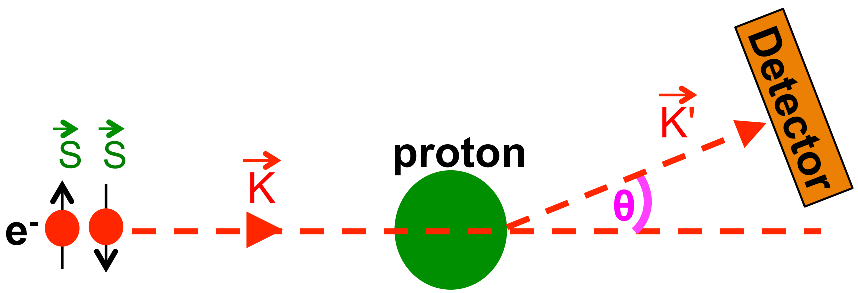

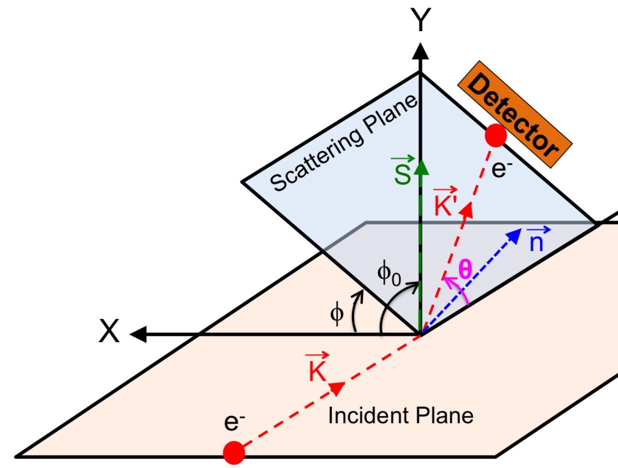

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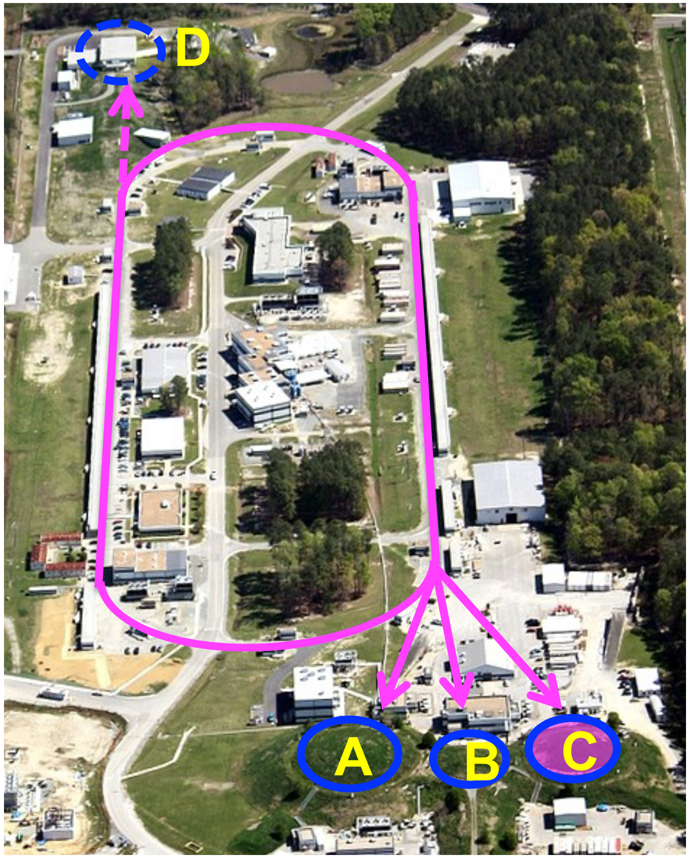
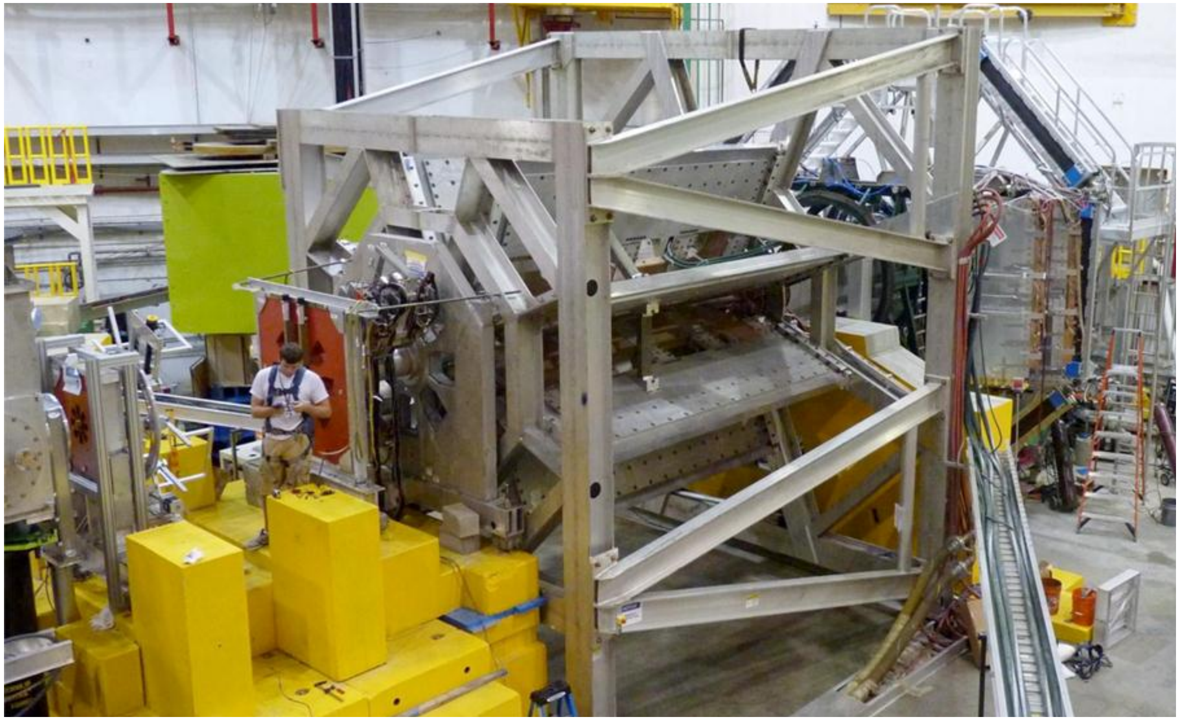
This talk: Inelastic e-p scattering with a Δ(1232) final state at E = 1.16 GeV

Jefferson Lab and Q-weak Setup



Aerial view of Jefferson Lab



Q-weak setup inside Hall-C (during construction)

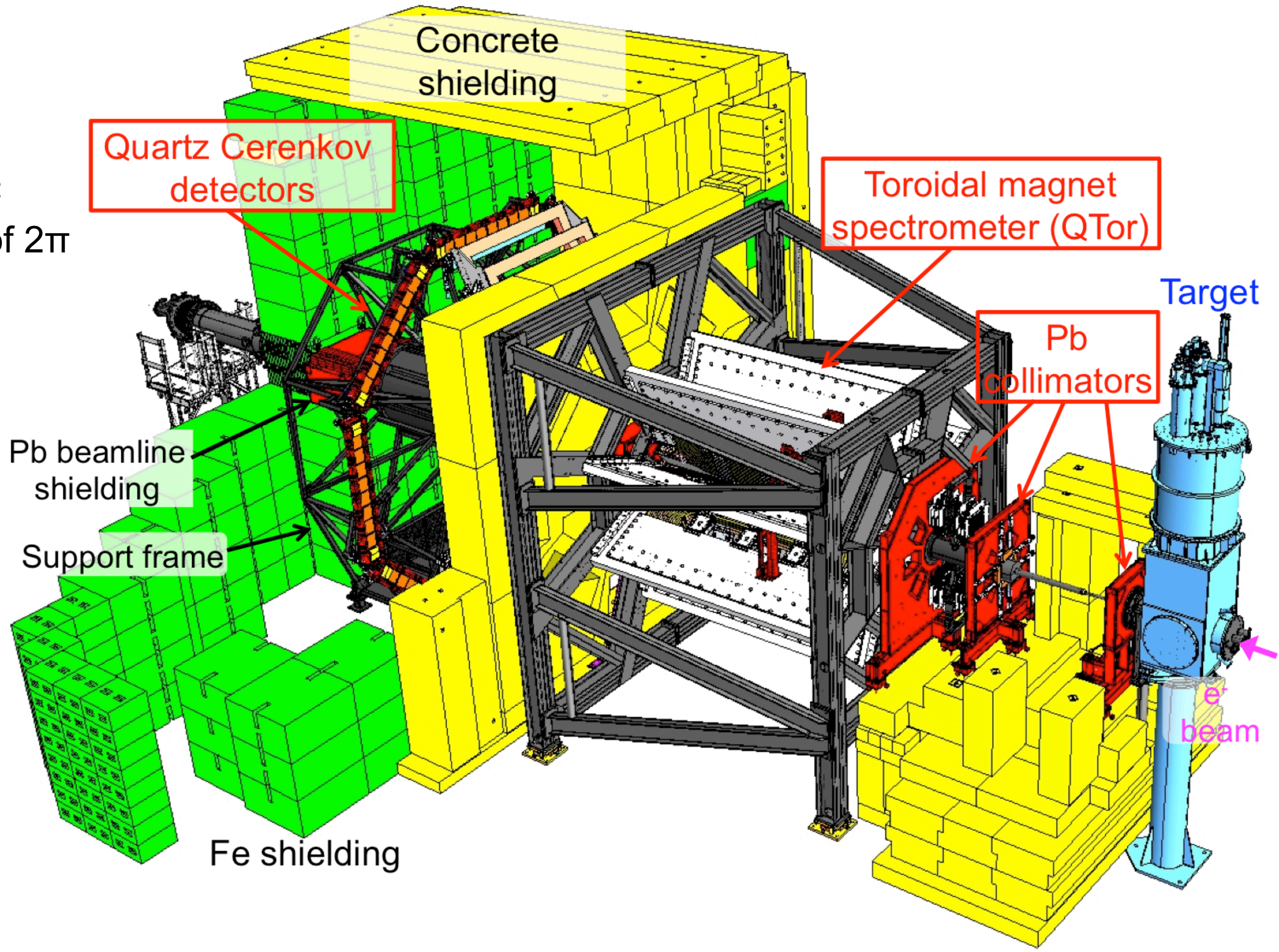
Q-weak experiment ran in Hall-C at the Thomas Jefferson National Laboratory in Newport News, Virginia from Jan 2010 – May 2012

Transverse measurements were taken from 16 - 20 February, 2012

Q-weak Apparatus

Kinematics

- E_{beam} = 1.16 GeV
- <θ> ~ 8.3°
- Q^2 = 0.021 (GeV/c)^2
- ϕ coverage ~ 49% of 2π
- Current = 180 μA
- Polarization = 88%



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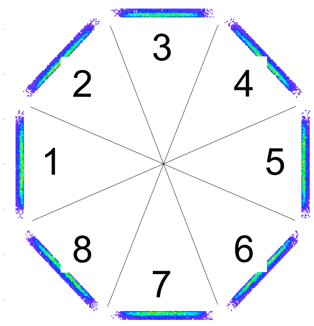
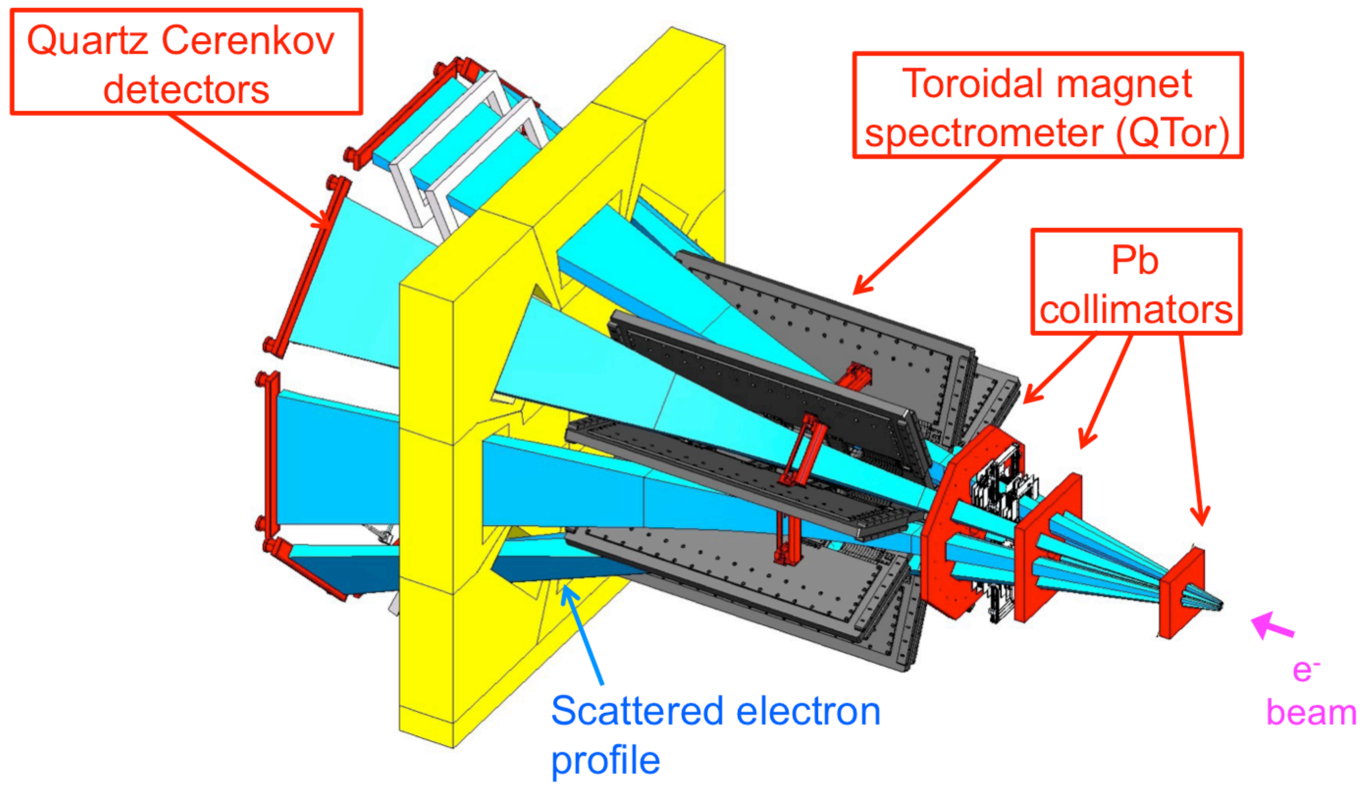


ϕ ➔ (octant # − 1) x 45°



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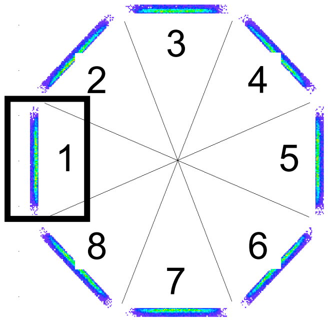

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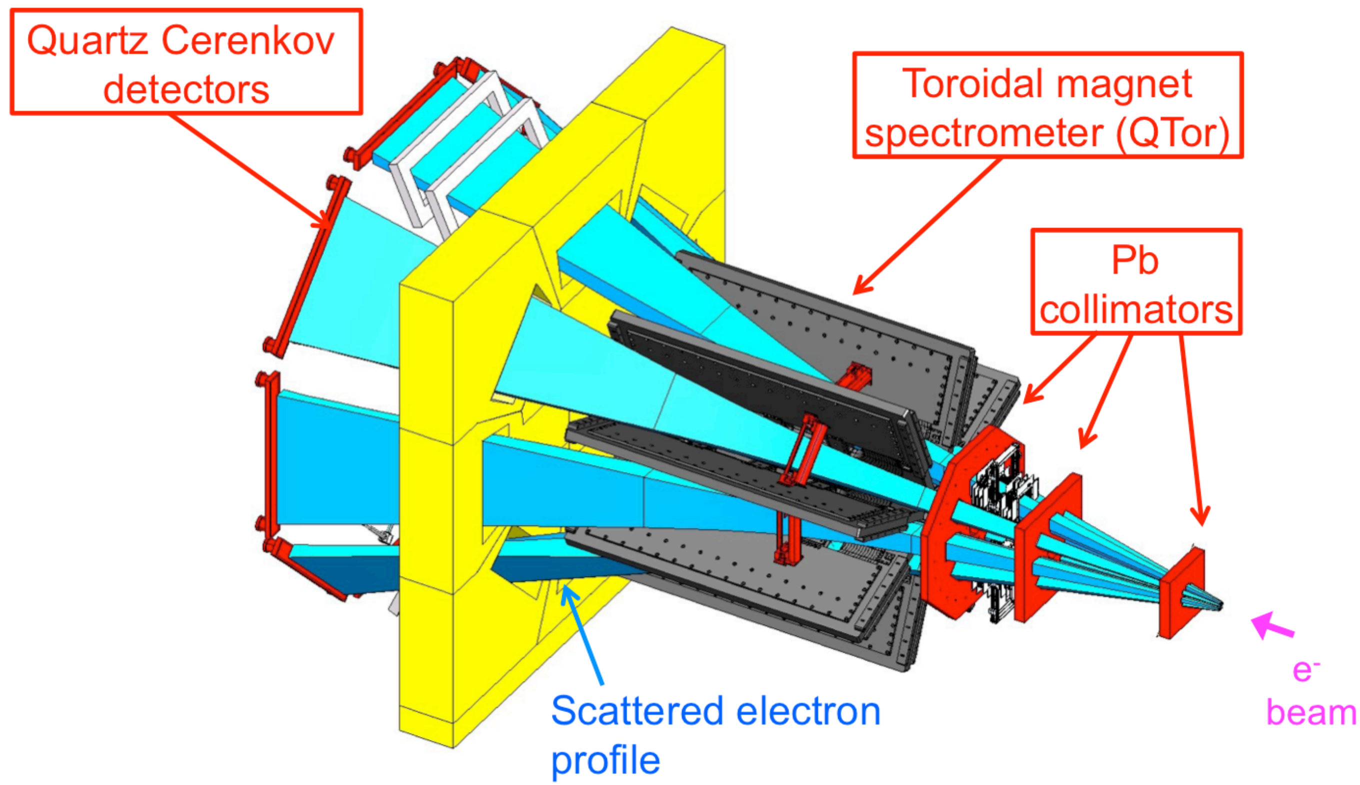
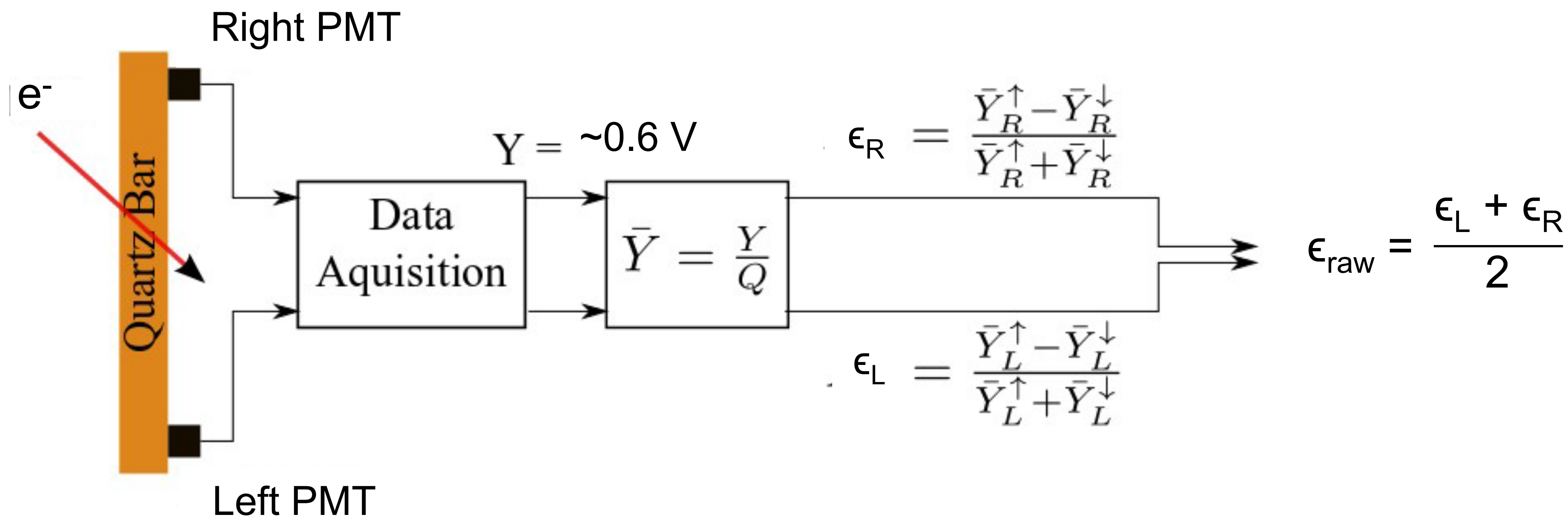


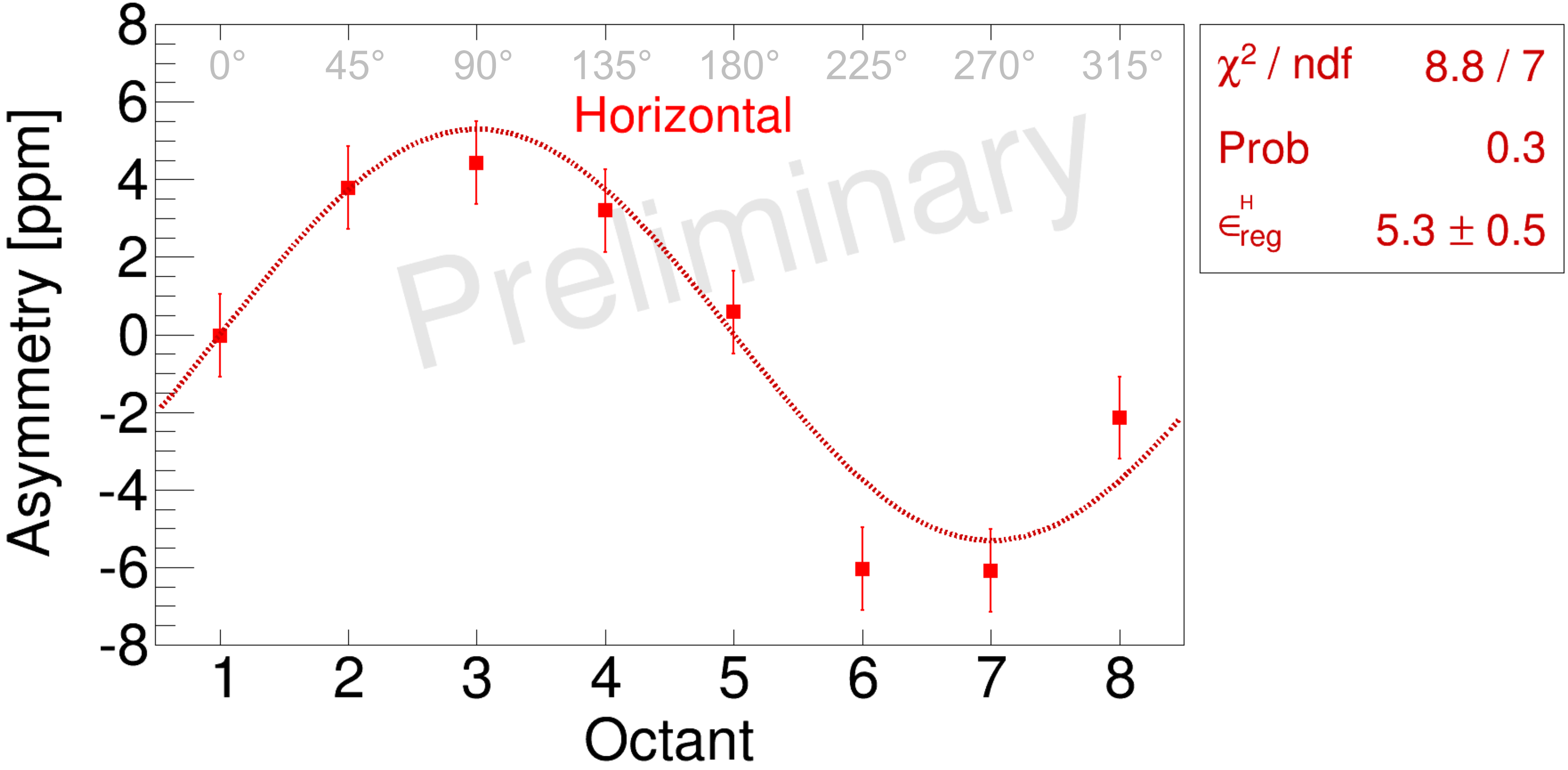
Asymmetries from Cerenkov Detector Signals



Not corrected for

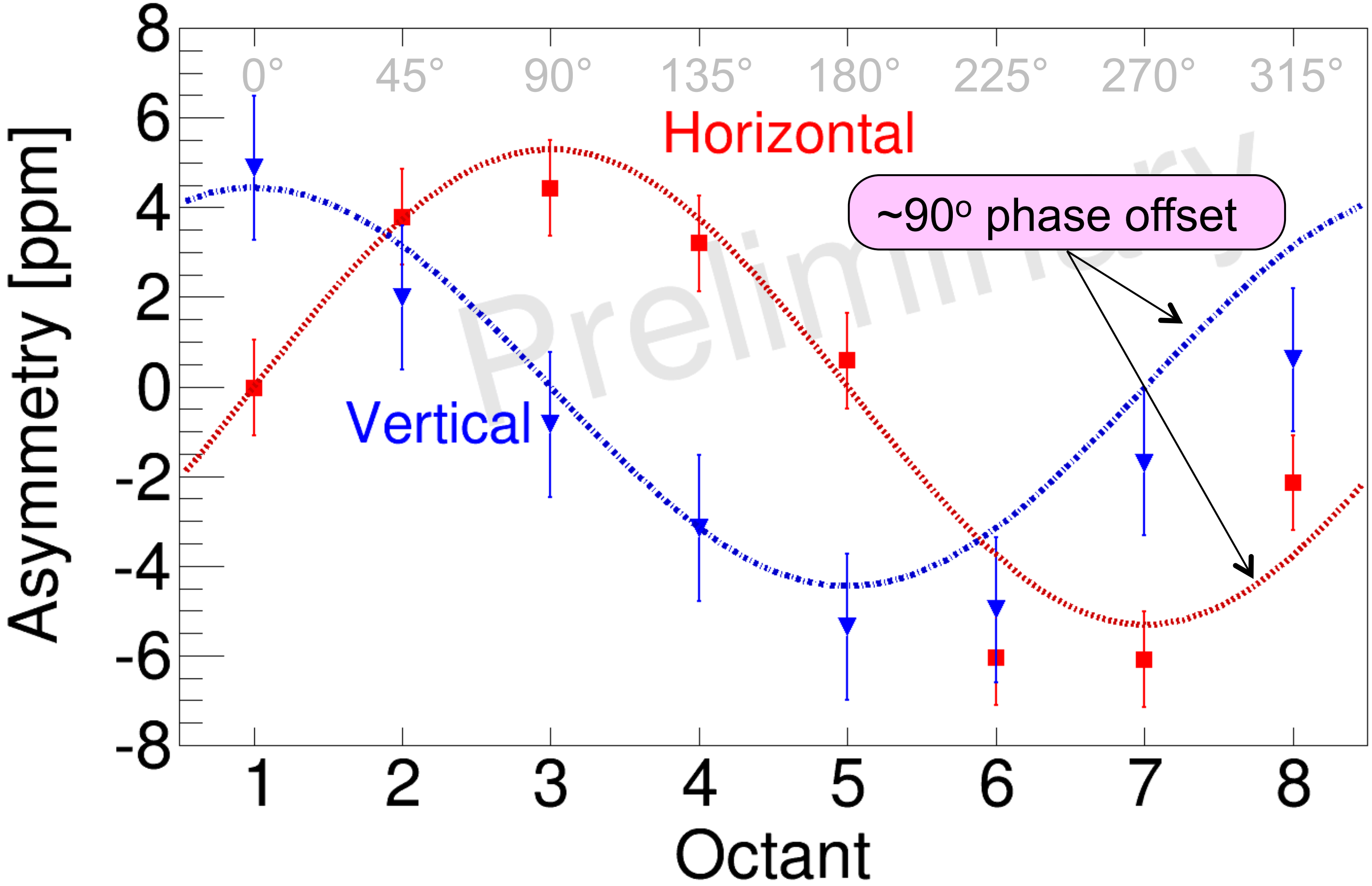
- False beam asymmetries
- Polarization
- Backgrounds

Regressed Transverse Asymmetries



- Regressed asymmetries
- Not corrected for polarization and backgrounds

Regressed Transverse Asymmetries



χ^2 / ndf	8.8 / 7
Prob	0.3
ϵ_{reg}^{H}	5.3 ± 0.5

χ^2 / ndf	6.1 / 7
Prob	0.5
ϵ_{reg}^{V}	4.4 ± 0.8

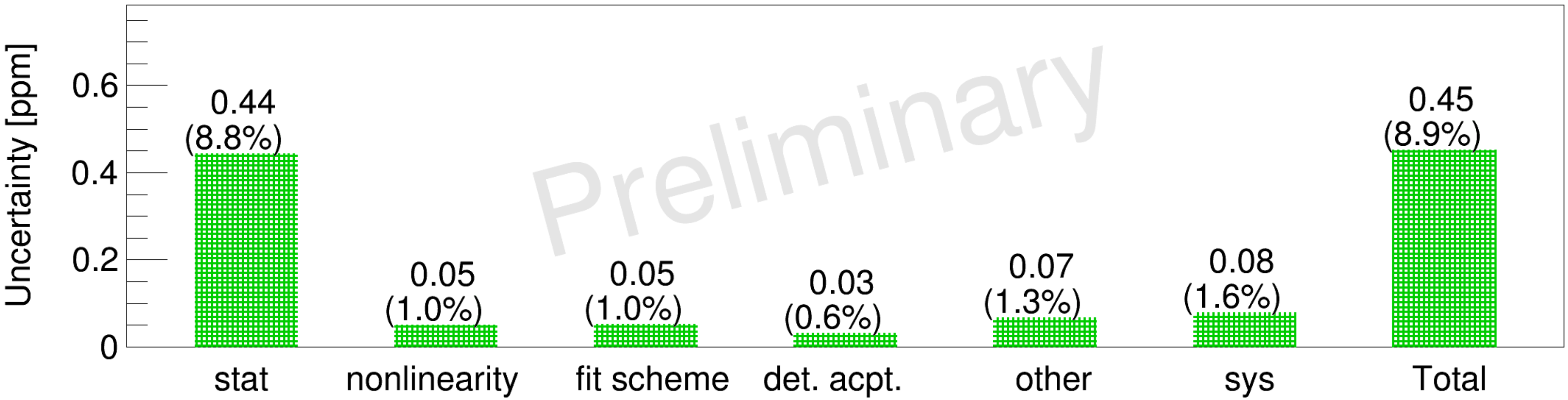
Fit function for
horizontal: $\epsilon_{reg}{}^{H} \sin(\phi)$
vertical: $\epsilon_{reg}{}^{V} \cos(\phi)$

- Regressed asymmetries
- Not corrected for polarization and backgrounds

Summary of Uncertainties on ϵ_{reg}

Measured asymmetry $\epsilon_{reg} = 5.1 \pm 0.4 \text{ (stat)} \pm 0.1 \text{ (sys) ppm}$

- Error weighted (H and V) regressed asym.
- Corrected for detector acceptance
- Not corrected for polarization and backgrounds



dominated by statistics

systematics are under control

Extraction of Physics Asymmetry

Beam Normal Single Spin Asymmetry

$$B_{\rm n} = M_{\rm kin}\left[\frac{\frac{\epsilon_{\rm reg}}{P} - B_{\rm Al}f_{\rm Al} - B_{\rm BB}f_{\rm BB} - B_{\rm QTor}f_{\rm QTor} - B_{\rm el}f_{\rm el}}{1 - f_{\rm Al} - f_{\rm BB} - f_{\rm QTor} - f_{\rm el}}\right]$$

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Extracting B_n from the experimental measured asymmetry by

- removing false asymmetries
- $\epsilon_{reg} = \epsilon_{raw} - \sum_i \frac{\partial \epsilon_{raw}}{\partial T_i} \Delta T_i$, cor. for det. acpt.

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Extracting B_n from the experimental measured asymmetry by

- removing false asymmetries
- correcting for the beam polarization

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Extracting B_n from the experimental measured asymmetry by
- removing false asymmetries
- correcting for the beam polarization
- removing background asymmetries

- $\epsilon_{reg} = \epsilon_{raw} - \sum_i \frac{\partial \epsilon_{raw}}{\partial T_i} \Delta T_i$, cor. for det. acpt.

- B_{bi} = Background asymmetries
  f_{bi} = dilution factors
  - Al : aluminum window backgrounds
  - BB : scattering from the beamline
  - QTor: neutral particles in the magnet acpt.
  - el : elastic radiative tail

Extraction of Physics Asymmetry

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$$B_{\mathrm{n}} = \boxed{M_{\mathrm{kin}}} \left[\frac{\frac{\epsilon_{\mathrm{reg}}}{P} - B_{\mathrm{Al}} f_{\mathrm{Al}} - B_{\mathrm{BB}} f_{\mathrm{BB}} - B_{\mathrm{QTor}} f_{\mathrm{QTor}} - B_{\mathrm{el}} f_{\mathrm{el}}}{1 - f_{\mathrm{Al}} - f_{\mathrm{BB}} - f_{\mathrm{QTor}} - f_{\mathrm{el}}} \right]$$

Extracting B_n from the experimental measured asymmetry by

- removing false asymmetries
- correcting for the beam polarization
- removing background asymmetries
- correcting for radiative tails and other kinematic correction

- $\epsilon_{reg} = \epsilon_{raw} - \sum_i \frac{\partial \epsilon_{raw}}{\partial T_i} \Delta T_i$, cor. for det. acpt.

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  - Al : aluminum window backgrounds
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- M_{kin} = kinematic correction

Summary of Uncertainties

Beam Normal Single Spin Asymmetry

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Preliminary

B_n = 43 ± 16 ppm

at kinematics

- $\langle E \rangle$ = 1.16 GeV
- $\langle W \rangle$ = 1.2 GeV
- $\langle \theta \rangle$ = 8.3°
- $\langle Q^2 \rangle$ = 0.021 GeV^2

~ 38% measurement of beam normal single asymmetry in Δ resonance production

Summary of Uncertainties

Beam Normal Single Spin Asymmetry

$$B_{\rm n} = M_{\rm kin}\left[\frac{\frac{\epsilon_{\rm reg}}{P} - B_{\rm Al}f_{\rm Al} - B_{\rm BB}f_{\rm BB} - B_{\rm QTor}f_{\rm QTor} - B_{\rm el}f_{\rm el}}{1 - f_{\rm Al} - f_{\rm BB} - f_{\rm QTor} - f_{\rm el}}\right]$$

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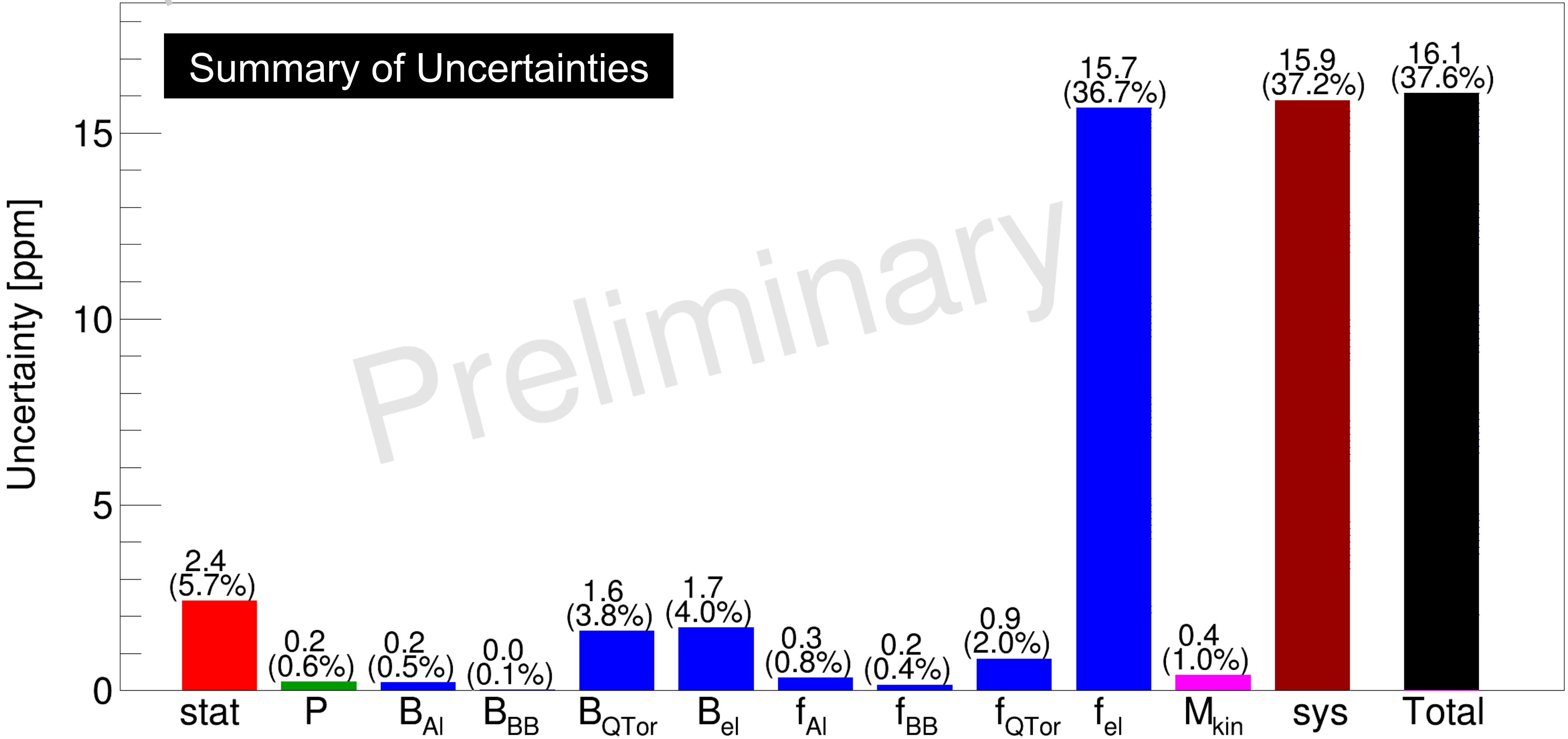

Beam Normal Single Spin Asymmetry

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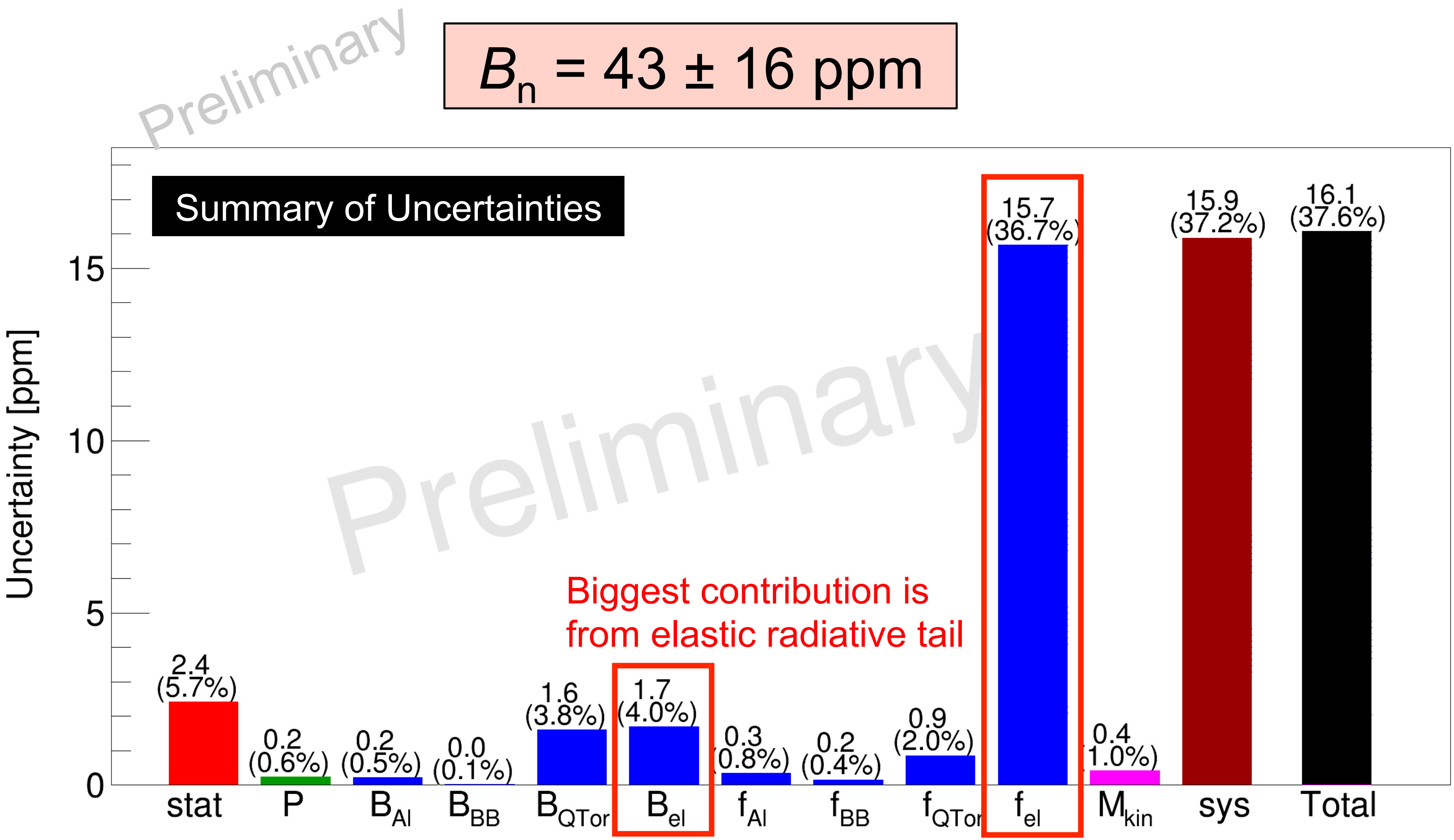

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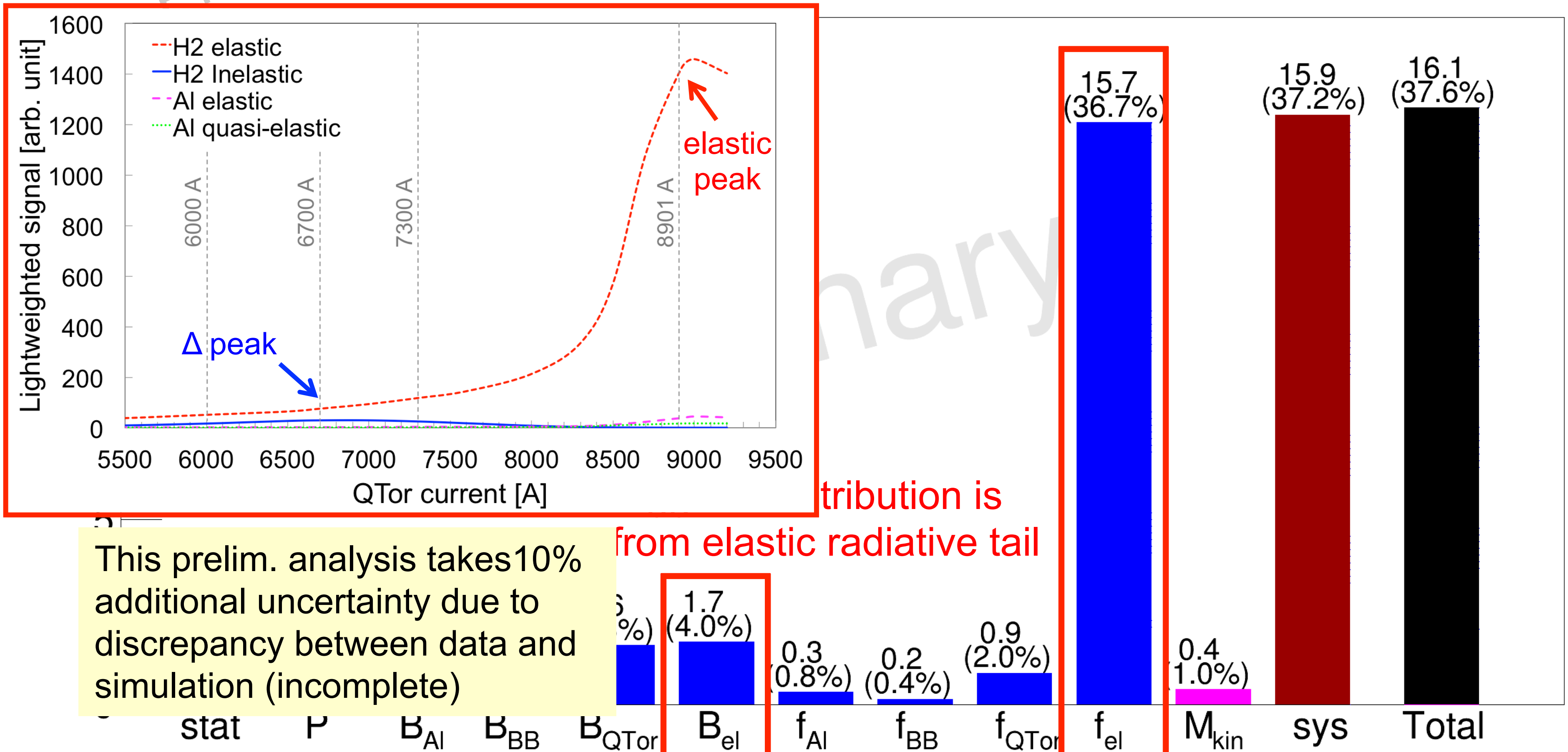
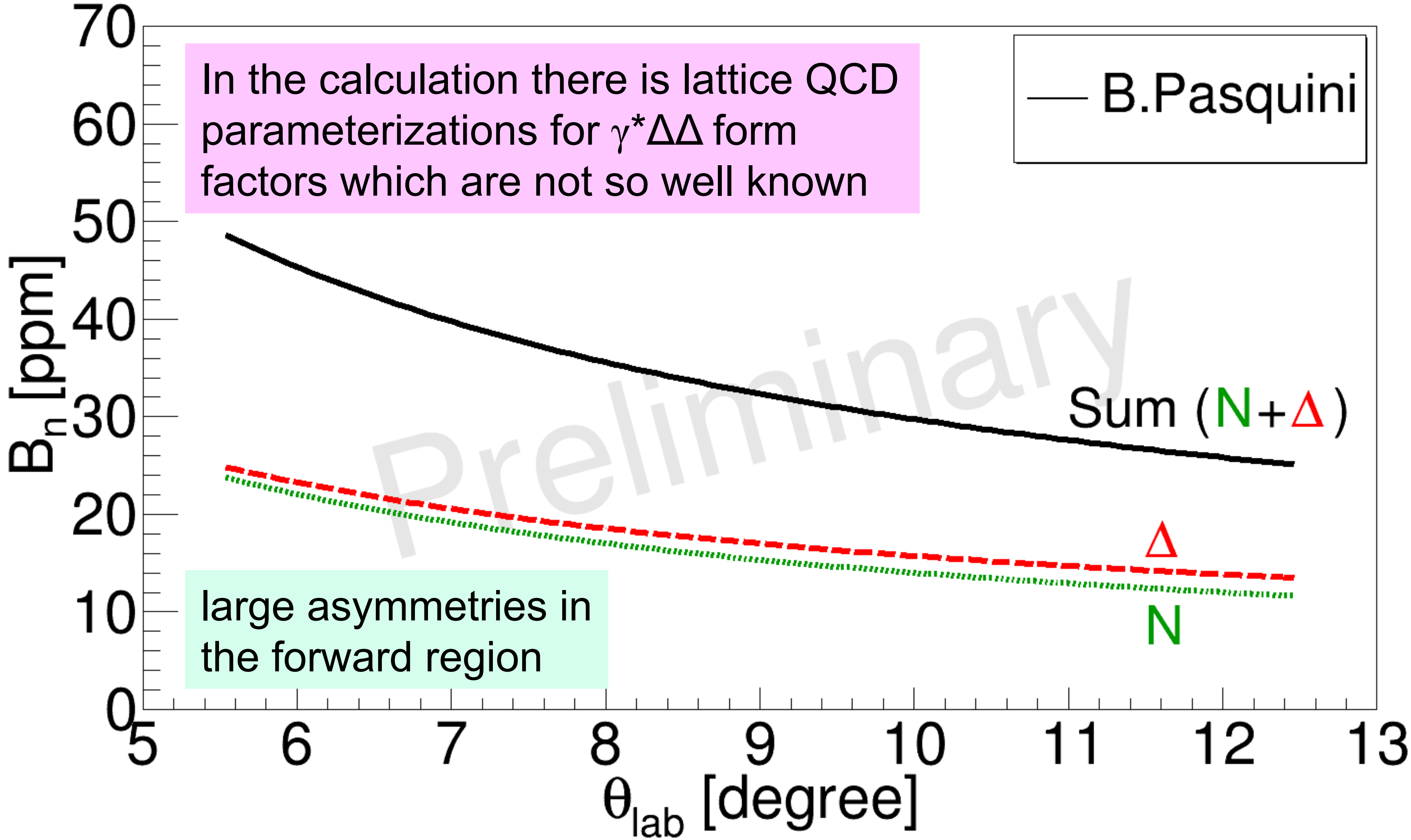


tribution is from elastic radiative tail

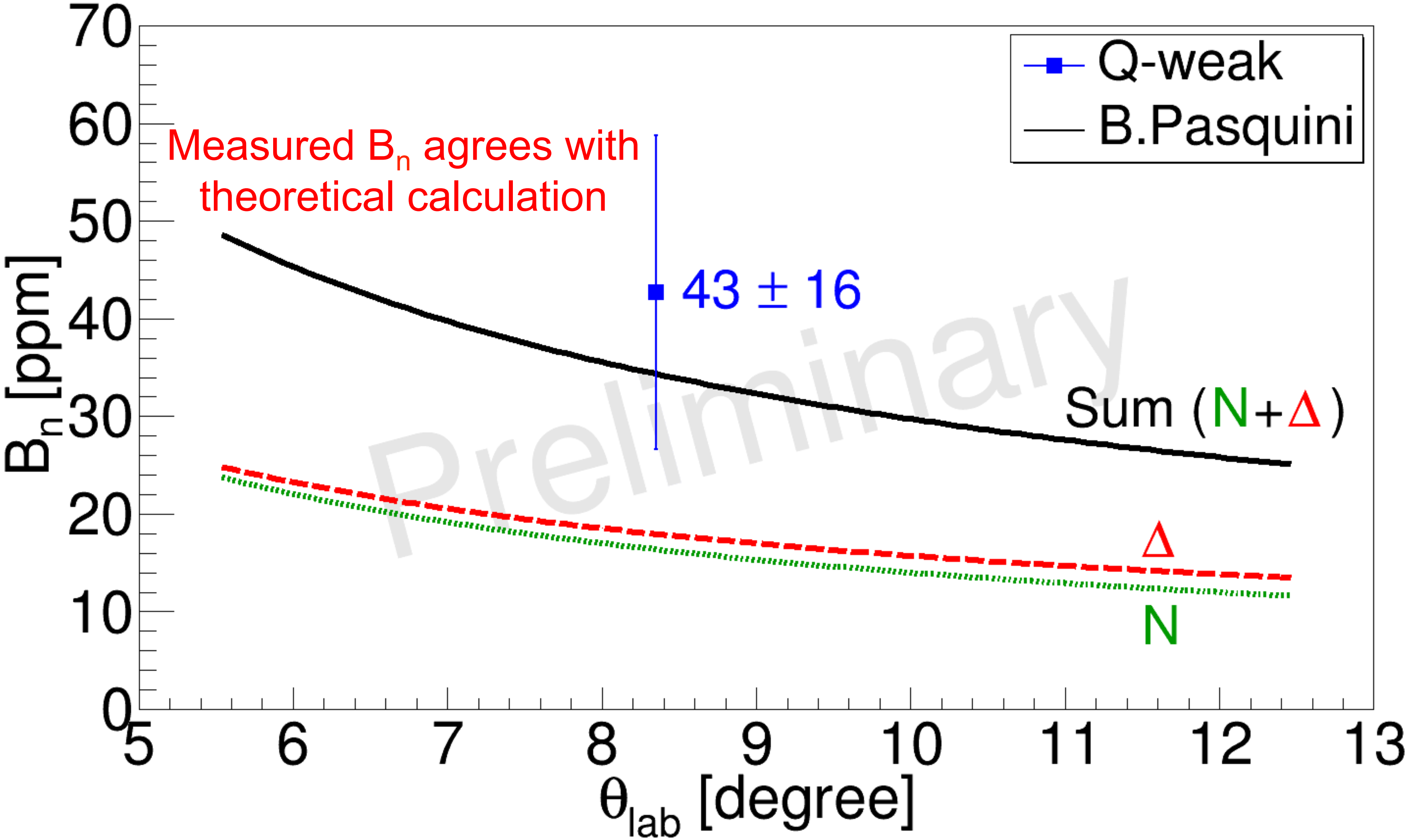
This prelim. analysis takes10% additional uncertainty due to discrepancy between data and simulation (incomplete)

Comparison of B_n to Theory Calculation



- sensitive to $\gamma^*\Delta\Delta$ form factors

Comparison of B_n to Theory Calculation



- sensitive to $\gamma^*\Delta\Delta$ form factors
- Q-weak transverse dataset along with world data has potential to constrain models and study charge radius and magnetic moment of Δ

Summary

Q-weak has measured B_n in the N-to-Δ transition on H_2

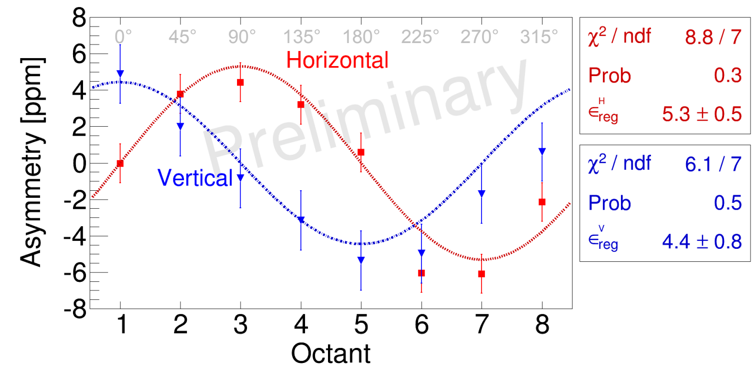
43 ± 16 ppm

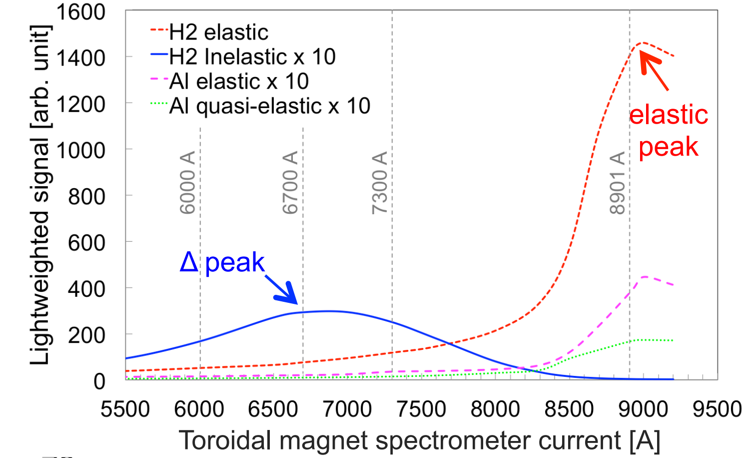
<E> = 1.16 GeV, <W> = 1.2 GeV, <θ> = 8.3°, <Q^2> = 0.021 GeV^2

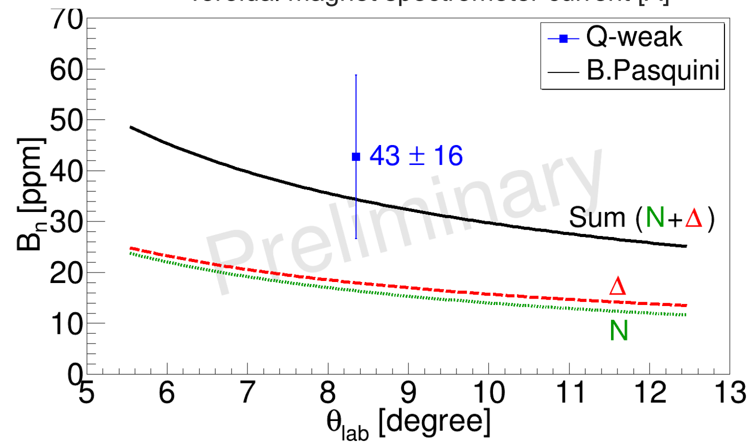
- preliminary result shows agreement with a theoretical calculation
- physics implications of the model needs investigation
- sensitive to $\gamma^*\Delta\Delta$ form factors
- working towards the improvement in systematic uncertainty

Data for B_n at low Q^2 in elastic and inelastic scattering with a Δ(1232) final state from several targets and energy are available.

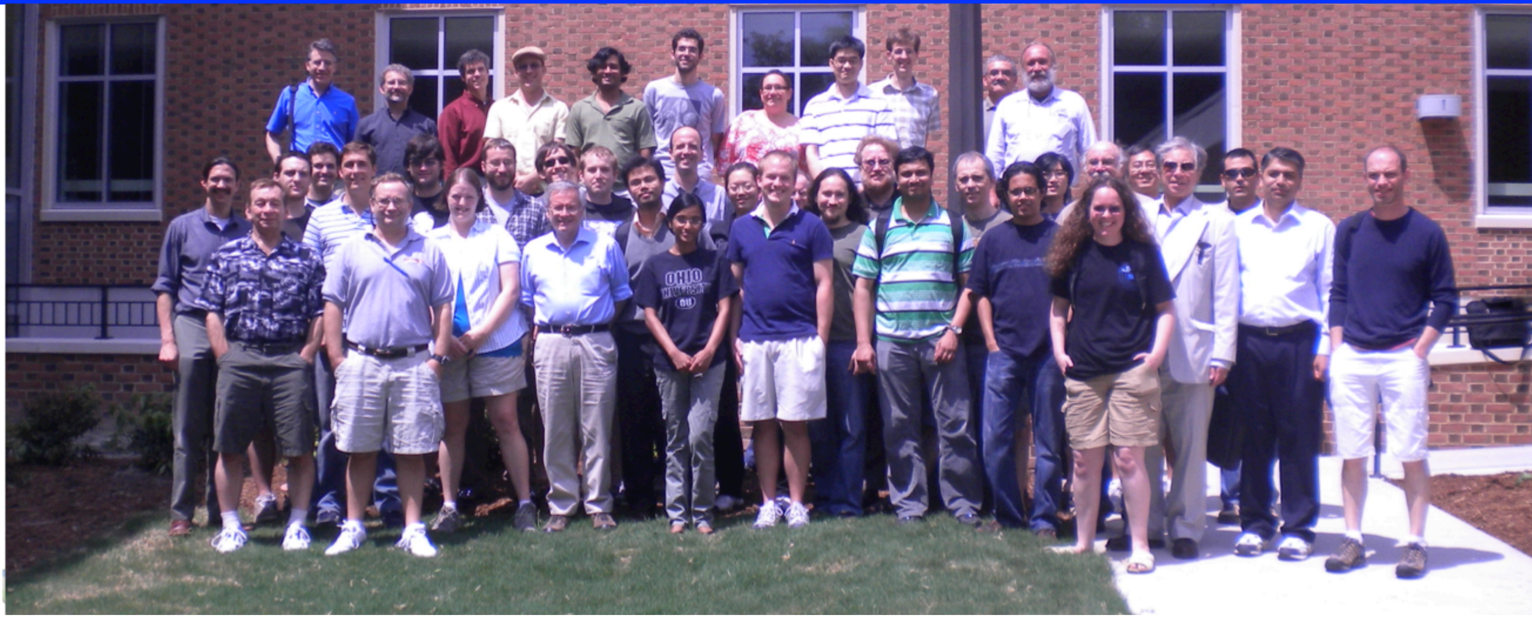
- looking for model predictions !
- Q-weak transverse dataset along with world data has potential to constrain models and study charge radius and magnetic moment of Δ







Q-weak Collaboration



D.S. Armstrong, A. Asaturyan, T. Averett, J. Balewski, J. Beaufait, R.S. Beminiwattha, J. Benesch, F. Benmokhtar, J. Birchall, R.D. Carlini[1], J.C. Cornejo, S. Covrig, M.M. Dalton, C.A. Davis, W. Deconinck, J. Diefenbach, K. Dow, J.F. Dowd, J.A. Dunne, D. Dutta, W.S. Duvall, M. Elaasar, W.R. Falk, J.M. Finn[1], T. Forest, D. Gaskell, M.T.W. Gericke, J. Grames, V.M. Gray, K. Grimm, F. Guo, J.R. Hoskins, K. Johnston, D. Jones, M. Jones, R. Jones, M. Kargiantoulakis, P.M. King, E. Korkmaz, S. Kowalski[1], J. Leacock, J. Leckey, A.R. Lee, J.H. Lee, L. Lee, S. MacEwan, D. Mack, J.A. Magee, R. Mahurin, J. Mammei, J. Martin, M.J. McHugh, J. Mei, R. Michaels, A. Micherdzinska, K.E. Myers, A. Mkrtchyan, H. Mkrtchyan, A. Narayan, L.Z. Ndukum, V. Nelyubin, Nuruzzaman, W.T.H van Oers, A.K. Opper, S.A. Page[1], J. Pan, K. Paschke, S.K. Phillips, M.L. Pitt, M. Poelker, J.F. Rajotte, W.D. Ramsay, J. Roche, B. Sawatzky,T. Seva, M.H. Shabestari, R. Silwal, N. Simicevic, G.R. Smith[2], P. Solvignon, D.T. Spayde, A. Subedi, R. Subedi, R. Suleiman, V. Tadevosyan, W.A. Tobias, V. Tvaskis, B. Waidyawansa, P. Wang, S.P. Wells, S.A. Wood, S. Yang, R.D. Young, S. Zhamkochyan

[1]Spokespersons [2]Project Manager Grad Students

Backup Slides

Transverse Dataset

Data on 3 types of targets

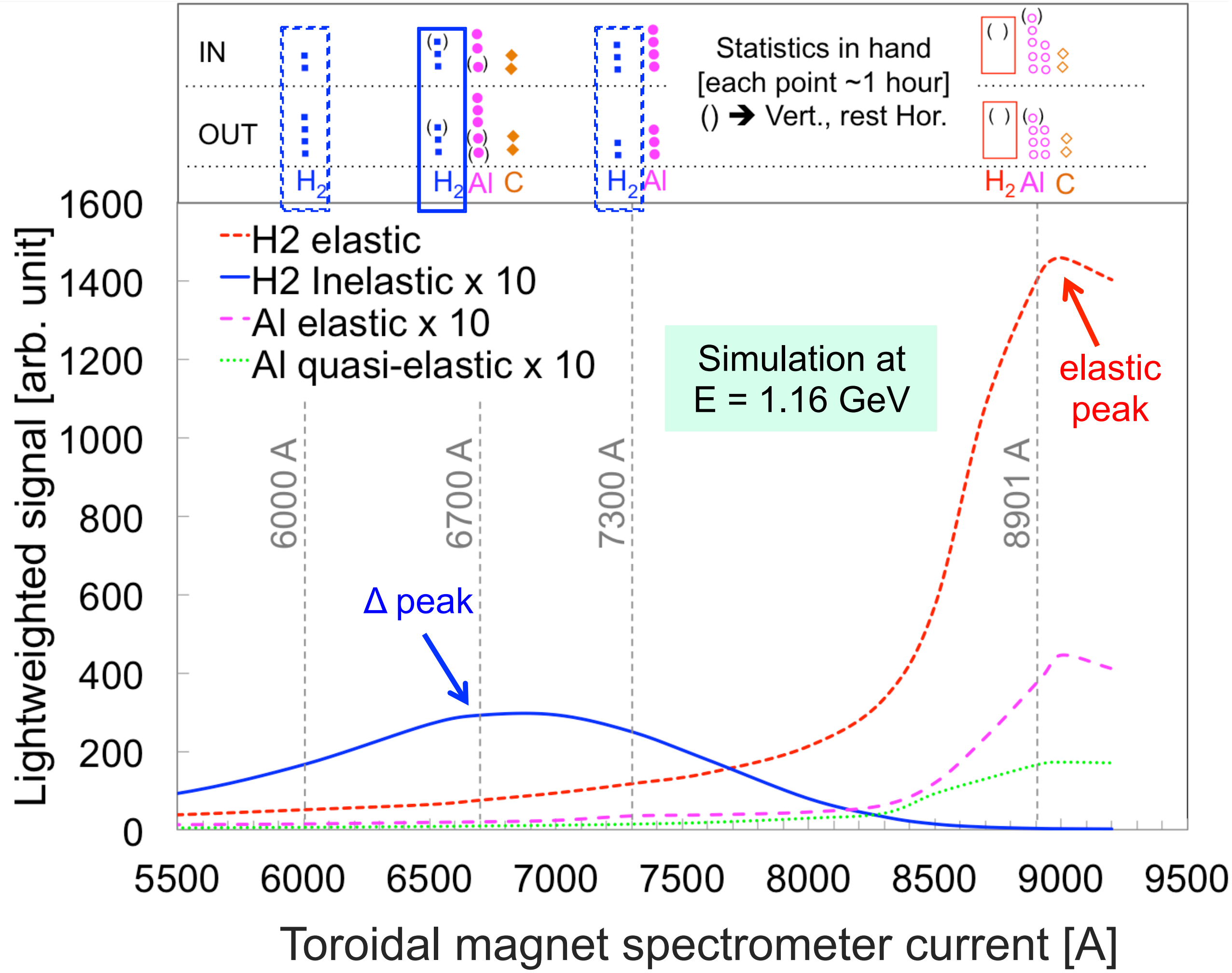
- Hydrogen
- Aluminum
- Carbon

Transverse polarization:

- Horizontal
- Vertical

This talk: Inelastic e-p scattering with a Δ(1232) final state at E = 1.16 GeV

Data on both side of the inelastic peak were taken to study the elastic dilution



Other datasets:

- in the $N\rightarrow\Delta$ region (Al, C)
- in the $N\rightarrow\Delta$ region (H_2, 0.877 GeV)
- elastic scattering (H_2, Al, C)
- elastic Møller scattering (H_2)
- in the DIS region (3.3 GeV)
- in pion photoproduction

Elastic Radiative Tail

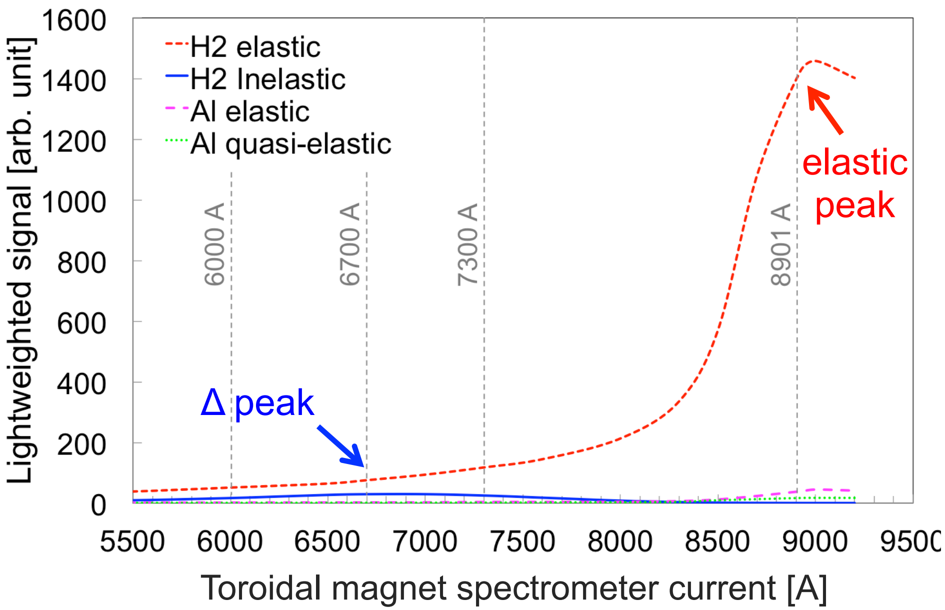
Beam Normal Single Spin Asymmetry

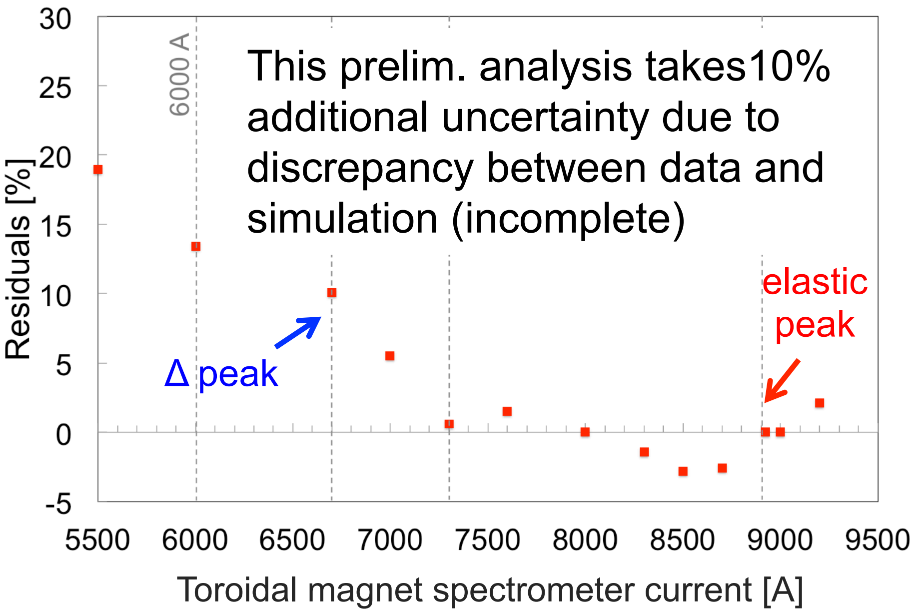
$$B_{\rm n} = M_{\rm kin}\left[\frac{\frac{\epsilon_{\rm reg}}{P} - B_{\rm Al}f_{\rm Al} - B_{\rm BB}f_{\rm BB} - B_{\rm QTor}f_{\rm QTor} - \boxed{B_{\rm el}f_{\rm el}}}{1 - f_{\rm Al} - f_{\rm BB} - f_{\rm QTor} - \boxed{f_{\rm el}}}\right]$$

Background Corrections

Elastic radiative tail

Dilution





$$\text{Residual} = \frac{(\text{data} - \text{sim.})}{\text{data}}$$

B_{el} = -5.1 ± 0.5 ppm

f_{el} = 0.70 ± 0.07

Δ Elastic Form Factors

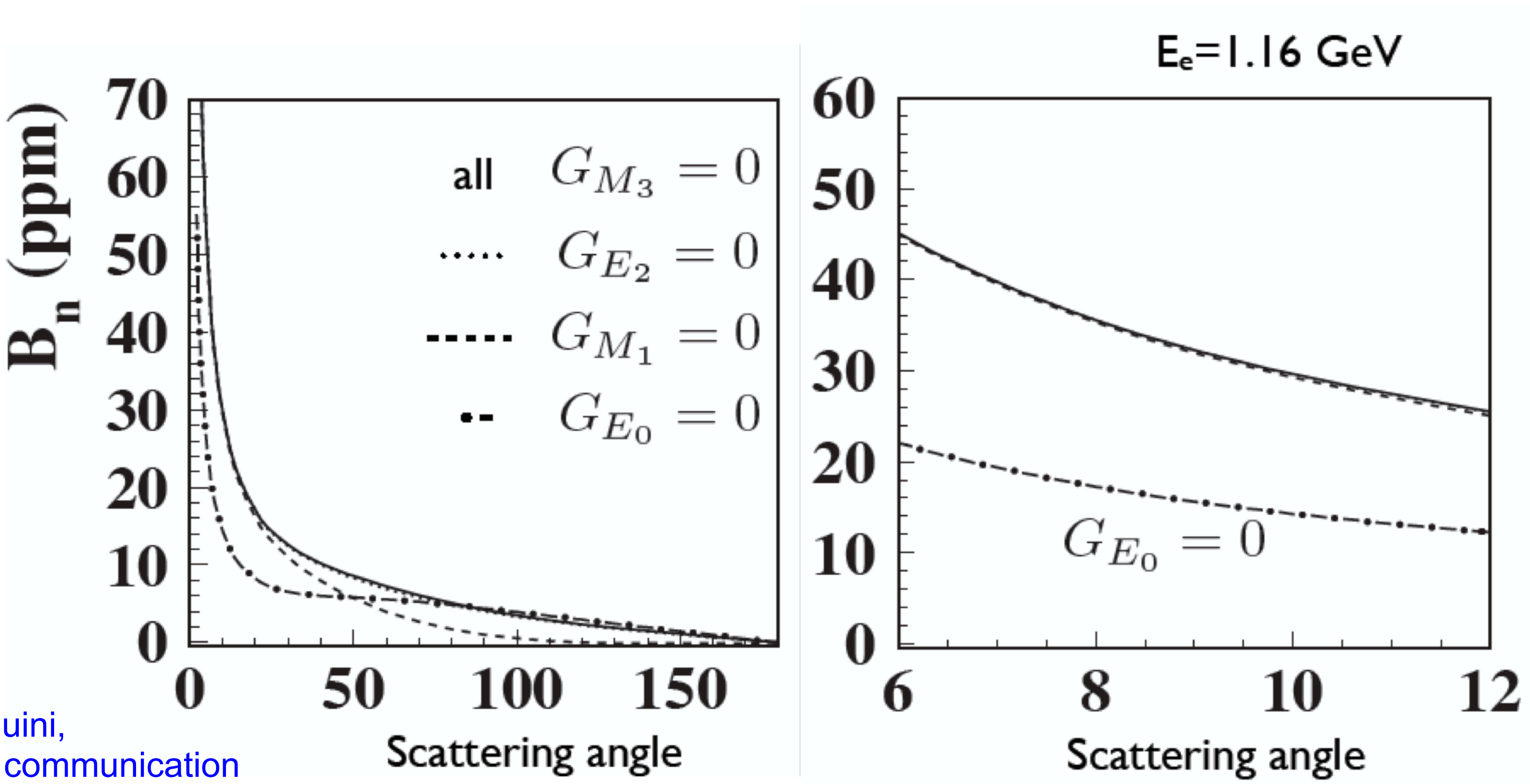
There are 4 elastic form factors (spin 3/2)

$G_{E0}(Q^2)$, $G_{M1}(Q^2)$, $G_{E2}(Q^2)$, $G_{M3}(Q^2)$

J. Segovia et. al. arXiv:1308.5225 (2013)

$Q^2 = 0$ define dimensionless multipole moments

- $G_{E0}(0) = e_\Delta$ charge
- $G_{M1}(0) \propto \mu_\Delta$ magnetic moment
- $G_{E2}(0) \propto D_\Delta$ dipole moment
- $G_{M3}(0) \propto O_\Delta$ octopole moment



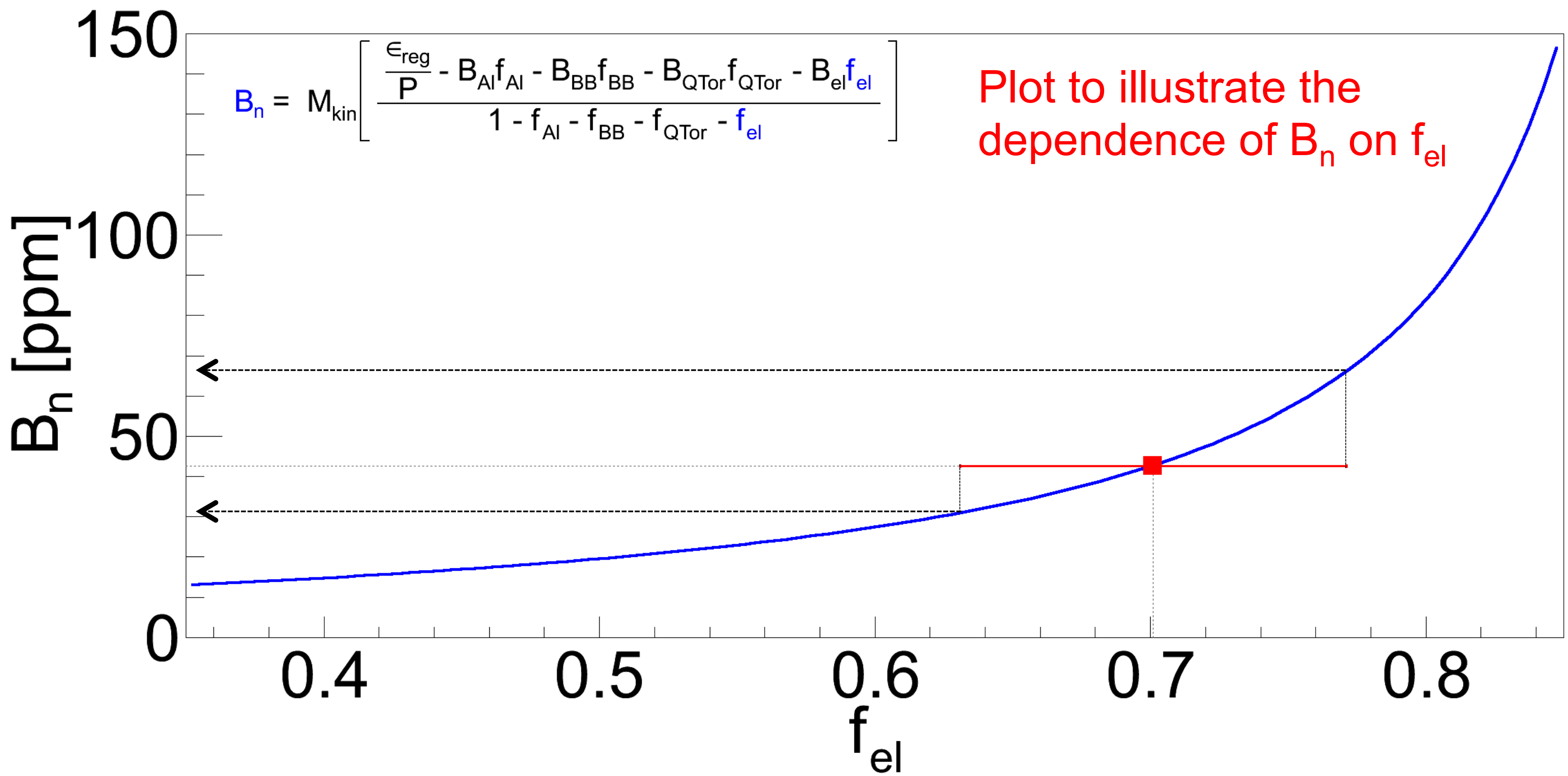
B Pasquini,
private communication

Asymmetry is Diluted by Elastic Radiative Tail

Simplifying* the extraction equation
(* for illustrative purposes)

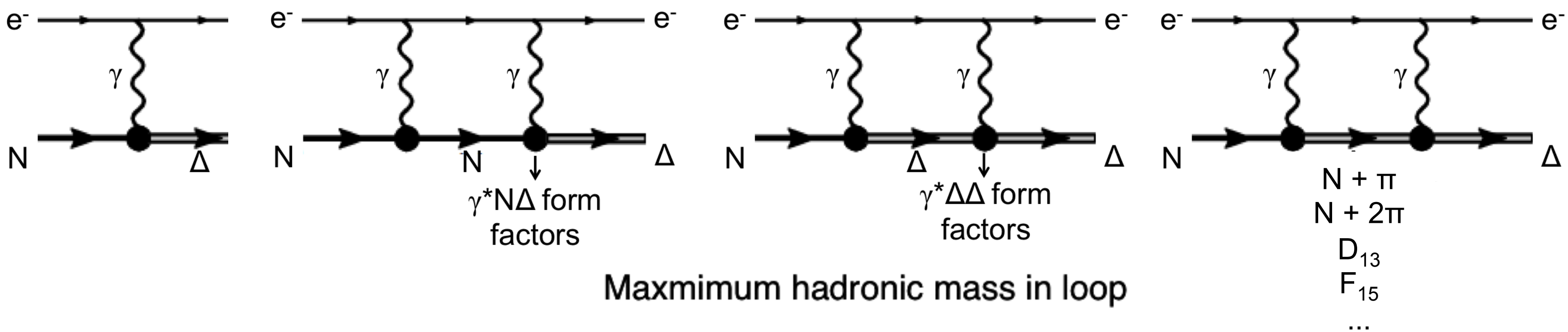
$$\frac{(1-f_{total})}{M_{kin}} B_n = \frac{\epsilon_{reg}}{P} - B_{el} f_{el} - \text{others}$$

0.214×43 ppm = 9.2 ppm ≈ (5.1/0.875) - 0.70×(-5.1) - 0.3 = 5.8 - (-3.6) - 0.3 ppm



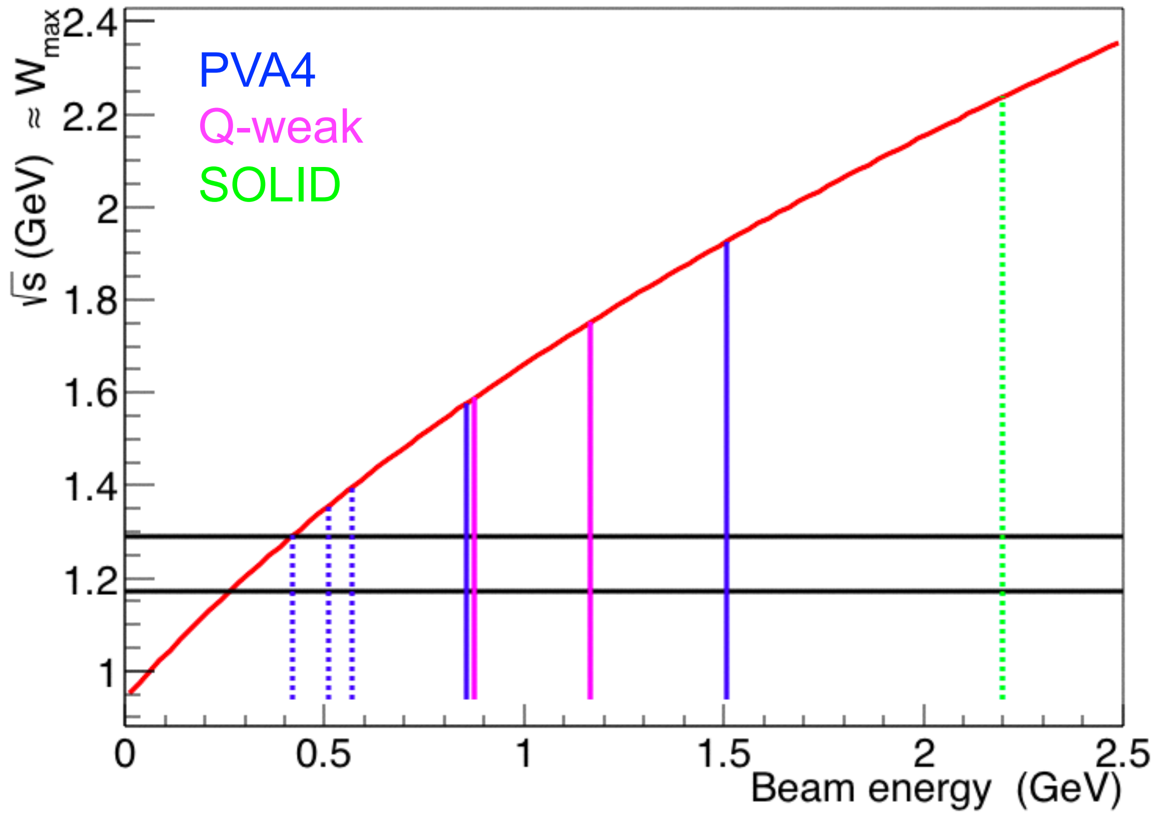
- The extraction of B_n depends strongly on the elastic dilution
- Careful study is ongoing to reduce uncertainty in f_{el}

Summary of Measurements



Maxmimum hadronic mass in loop

Higher beam energies allow more intermediate states



Why B_n=0 at θ=0 ?

$$B_n = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} = \frac{2T_{1\gamma} \times \mathrm{Im}\, T_{2\gamma}}{|T_{1\gamma}|}$$

$$\varepsilon^{-1} = 1 + 2\left[1 + \frac{\nu^2}{Q^2}\right]\tan^2\frac{\theta_e}{2}$$

$$(1-\varepsilon) = \varepsilon(1/\varepsilon - 1)$$

$$= 2\varepsilon\left[1 + \frac{\nu^2}{Q^2}\right]\tan^2\frac{\theta_e}{2}$$

$$\sigma\uparrow - \sigma\downarrow \propto \frac{2m_e}{Q}(1-\varepsilon)\underbrace{\left[\frac{\varepsilon_L}{\varepsilon}\right]^{1/2}}_{\frac{Q}{\nu}} = \frac{2m_e}{Q}(1-\varepsilon)\frac{Q}{\nu} = \frac{2m_e}{\nu}(1-\varepsilon)$$

$$= \frac{4m_e\varepsilon}{\nu}\left[1 + \frac{\nu^2}{Q^2}\right]\tan^2\frac{\theta_e}{2}$$

$$\nu = K \bullet P$$

K is the average incoming four-momenta of the electron
P is the average outgoing four-momenta of the proton

ν_{el} = 0.013
ν_{in} = 0.348
ν_{min} = 300 MeV + K. E.

Private communication with
Carl Carlson