E04-007: π^o Threshold Electroproduction Status Report

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Hall A Collaboration Meeting

December 10 2012

Since last collaboration meeting

- Khem Chirapatimol received PhD and returned to Thailand.
- Richard Lindgren presented first public results at JLAB Chiral Dynamics Workshop August 2012.
- U. Meisner agreed to extend HBChPT electroproduction calculation after seeing our data.
- A. Bernstein and Nikos Sparveris want to use E04-007 data to investigate VCS.
- Continue to work with Khem on systematic error analysis in preparation for publication.

Motivation

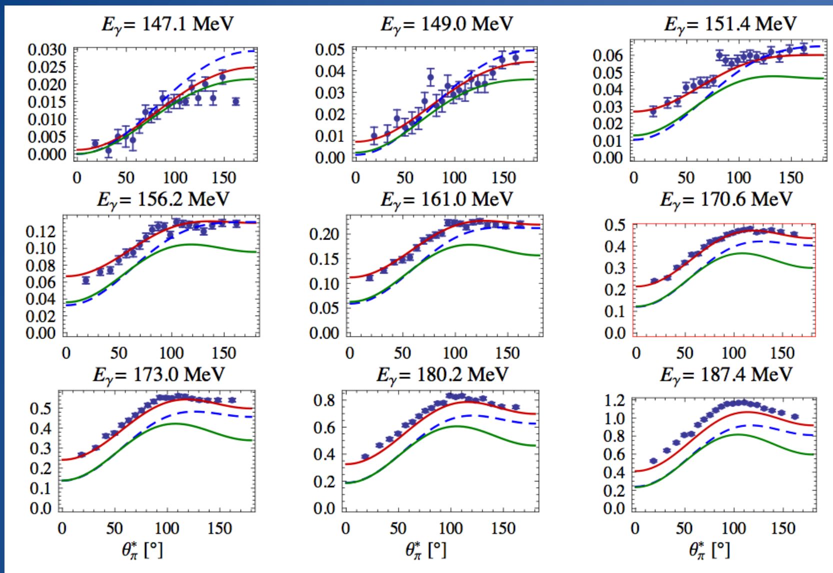
- Chiral Perturbation Theory (ChPT): Low energy effective theory based on spontaneous breaking of chiral symmetry in QCD.
- Long range degrees of freedom: Goldstone boson (mesons) and baryons and their mutual interactions (tree + loops).
- Short distance physics: Low Energy Constants (LEC) whose number can be constrained by suitable choice of kinematics. Crucial question: At what energy (W) and distance (Q^2) scale does chiral dynamics fail (need baryon/vector meson resonance physics)?
- Precision measurement of (Q^2,W) evolution of p(e,e'p)π^o reaction near threshold can test validity of low energy expansion *once LECs are fixed*.
- Total cross section, polarization observables, EM multipoles.

Theory: Current Status

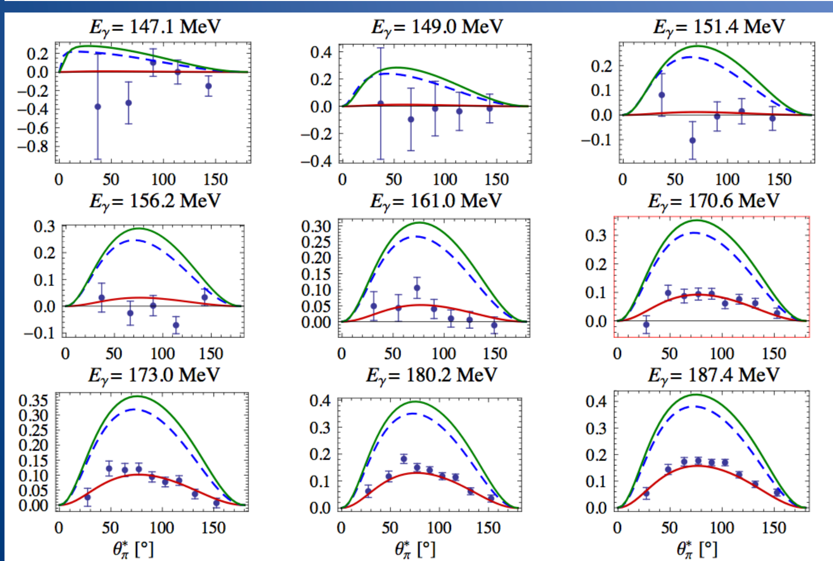
- V. Bernard et al.: Heavy Baryon HBChPT
  - Q^2=0: $O(p^4)$ *s*-wave (2 LECs) $O(p^4)$ *p*-wave (3 LECs)
  - Q^2>0: $O(p^5)$ *s*-wave (5 LECs) $O(p^3)$ *p*-wave (1 LEC)
- M. Hilt: Relativistic BChPT
  - All Q^2: $O(p^4)$ with five LECs, but better convergence.
- Gasparyan and Lutz: Unitary chiral EFT beyond threshold
  - Chiral Lagrangian truncated at $O(p^3)$.
  - Resonances enter thru infinite summation of counter terms.
- A. Bernstein: Unitary fit
  - No LECs. Fits s-wave cusp using unitarity *ansatz*.
- Phenomenological Fits to Global Data: DMT, MAID, SAID
  - Used to constrain ChPT fits.

Photoproduction Data: CB-TAPS@MAMI-C

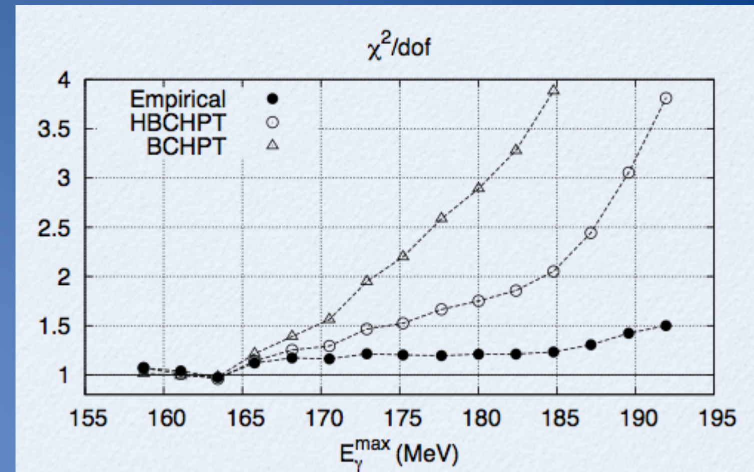
$\gamma + p \rightarrow \pi^0 + p$



$d\sigma/d\Omega$



Σ



Fourth order theory required to describe most recent MAMI photoproduction data.

Surprising result: relativistic BChPT departs from data at lower photon energies compared to HBChPT (see above plot).

Data: D. Hornidge *et al.* arXiv:1211.5495v1
Theory: Marius Hilt, Bosen 2011

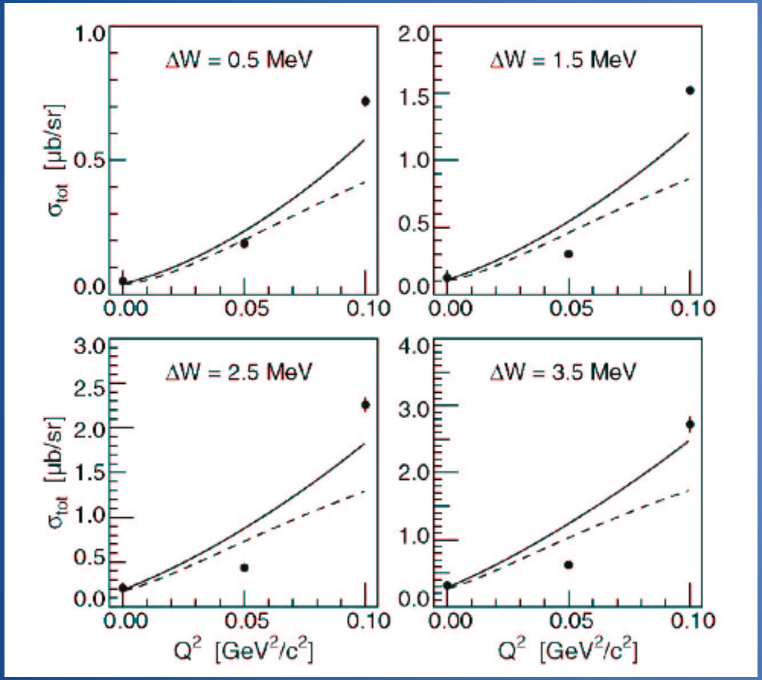
$\mathcal{O}(q^3)$, $\mathcal{O}(q^3)$+VM, $\mathcal{O}(q^4)$

Electroproduction Data: MAMI

2002

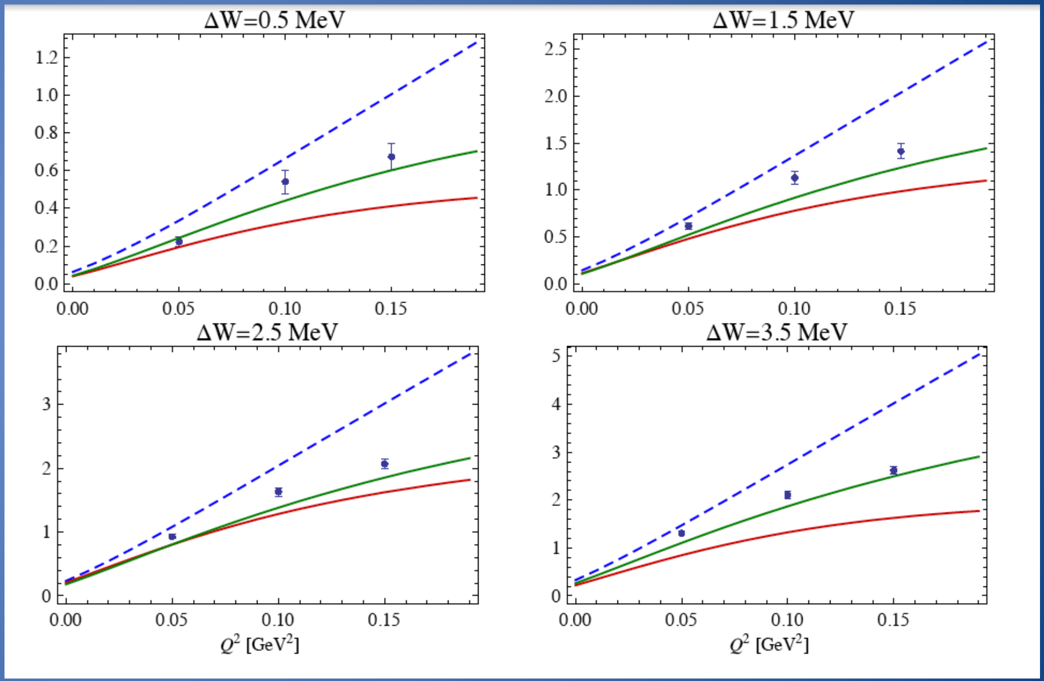
$Q^2 = 0.10$: Distler et al. PRL 80, 2294 (1998)

$Q^2 = 0.05$: Merkel et al. PRL 88, 1230 (2002)



2009

$Q^2 = 0.05 - 0.15$: Merkel et al. arXiv:1109.5075



—— HBChPT (1996)

- - - - MAID

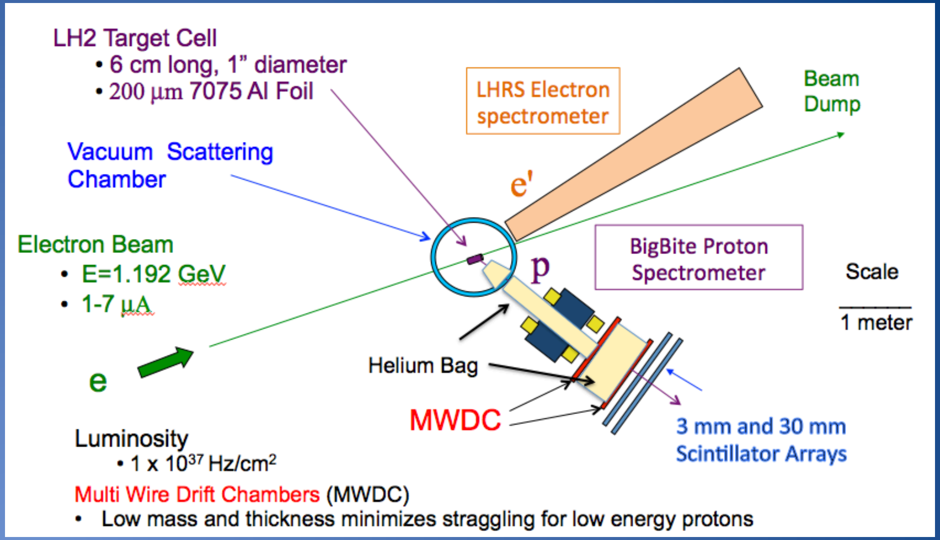
Theory: BChPT, Marius Hilt, Bosen 2011

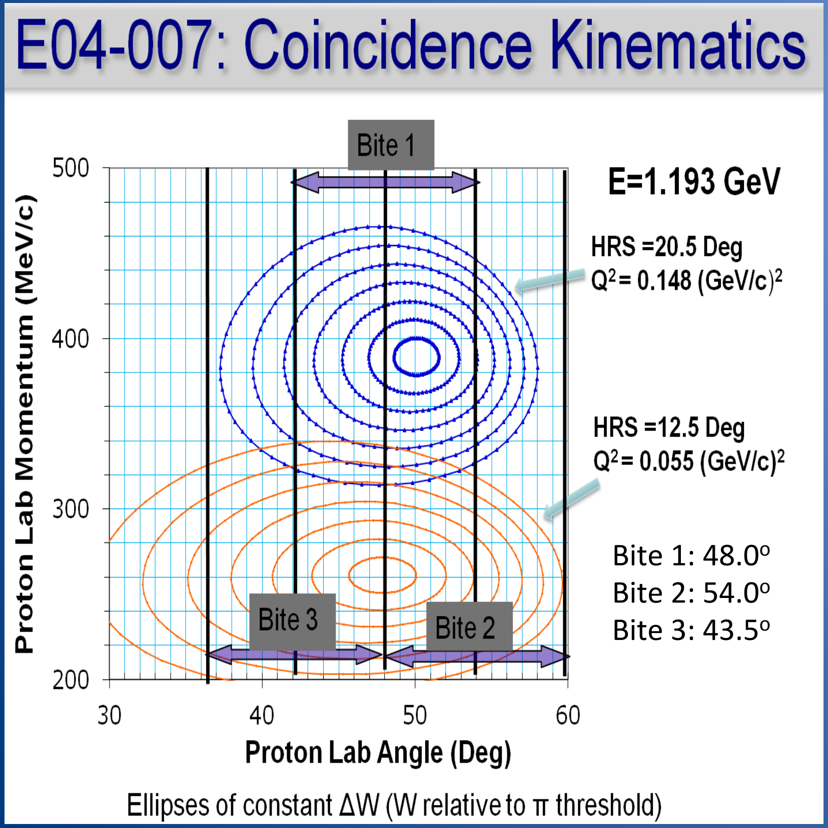
$\mathcal{O}(q^3)$, $\mathcal{O}(q^3)$+VM, $\mathcal{O}(q^4)$

Conflicting measurements require more extensive data set

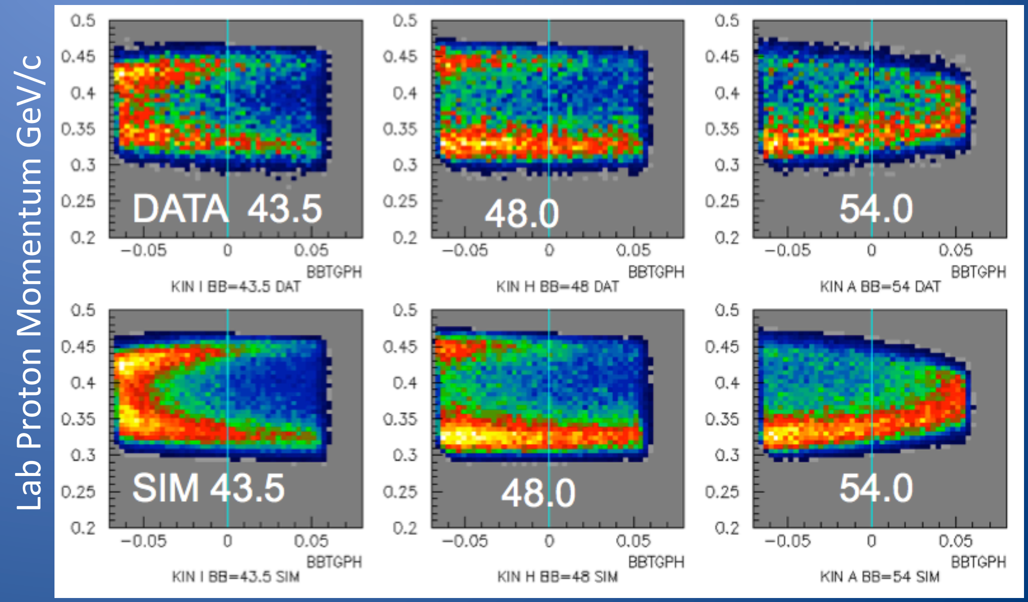
JLAB Experiment E04-007: Hall A

Experiment was designed to provide finer Q^2 granularity and extend the W range up to 20 MeV above π^o threshold.

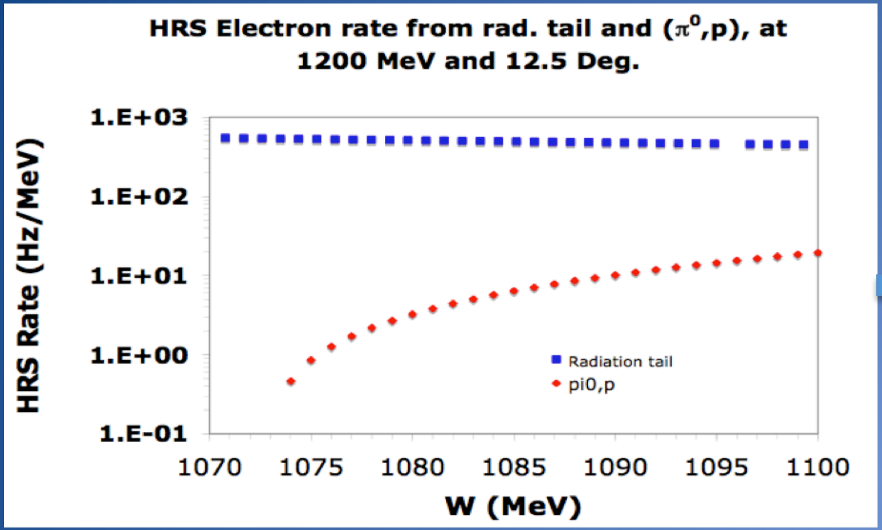


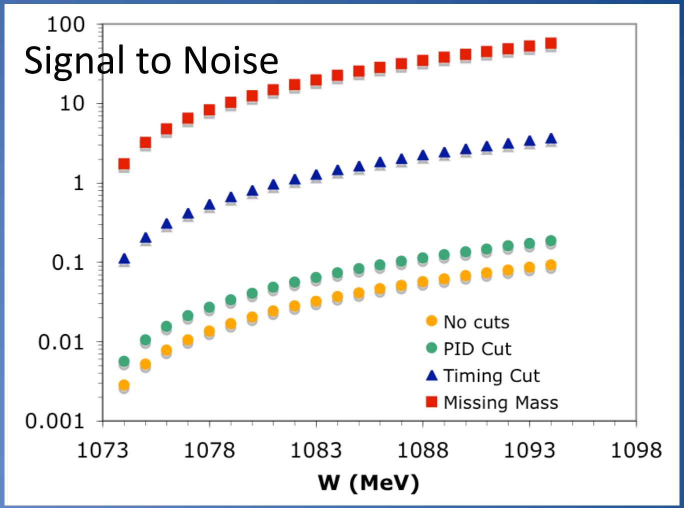


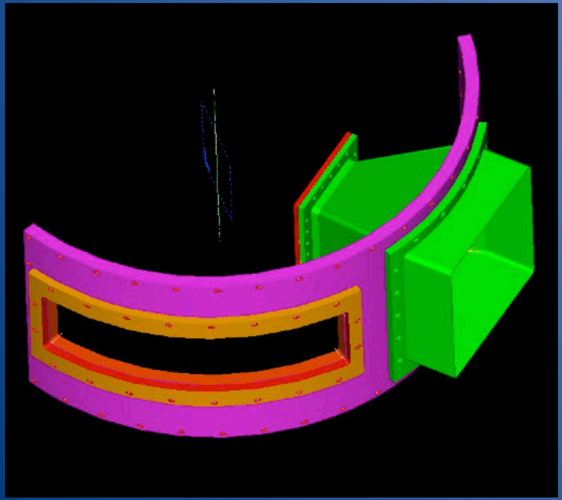
Data and Simulation ΔW=19-21 MeV

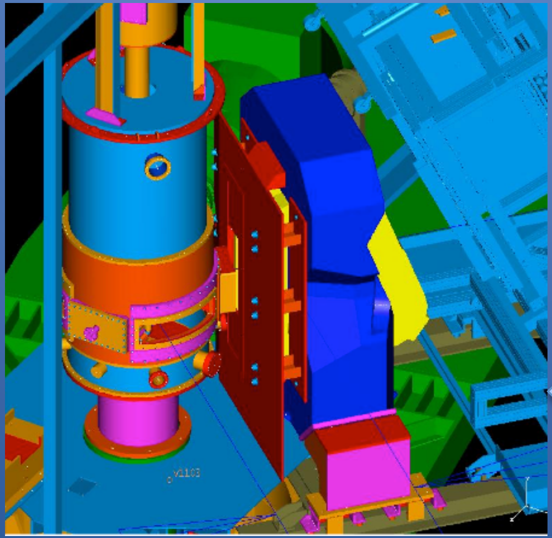


Experimental Challenges





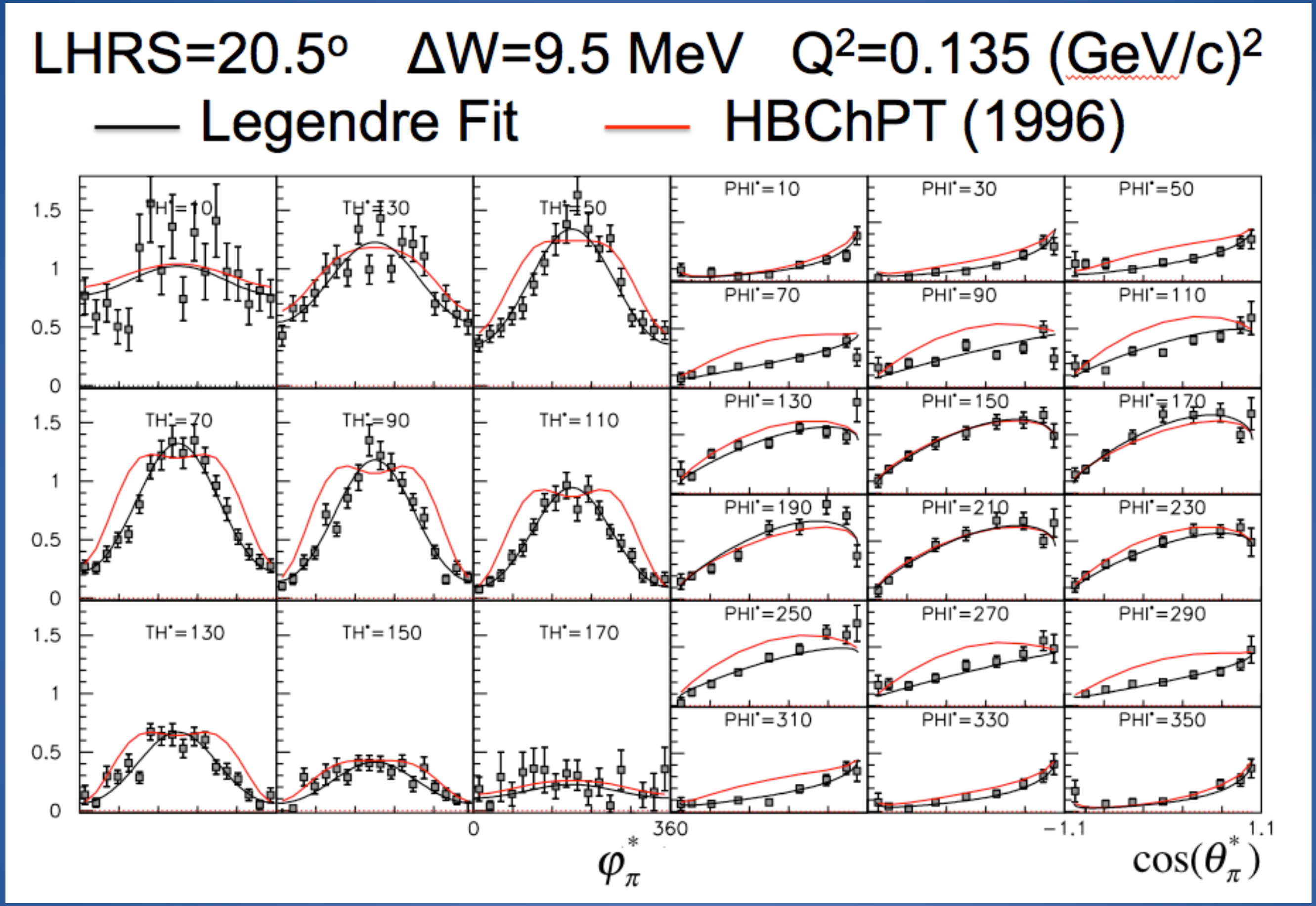




LHRS: Large singles rate from radiative tail. Limits beam current to < 5 μA.

BigBite: Very low momentum protons. Helium bags and special inset flange to permit thin Ti window w/o sacrificing vertical acceptance.

Quality of Data Above Threshold Region



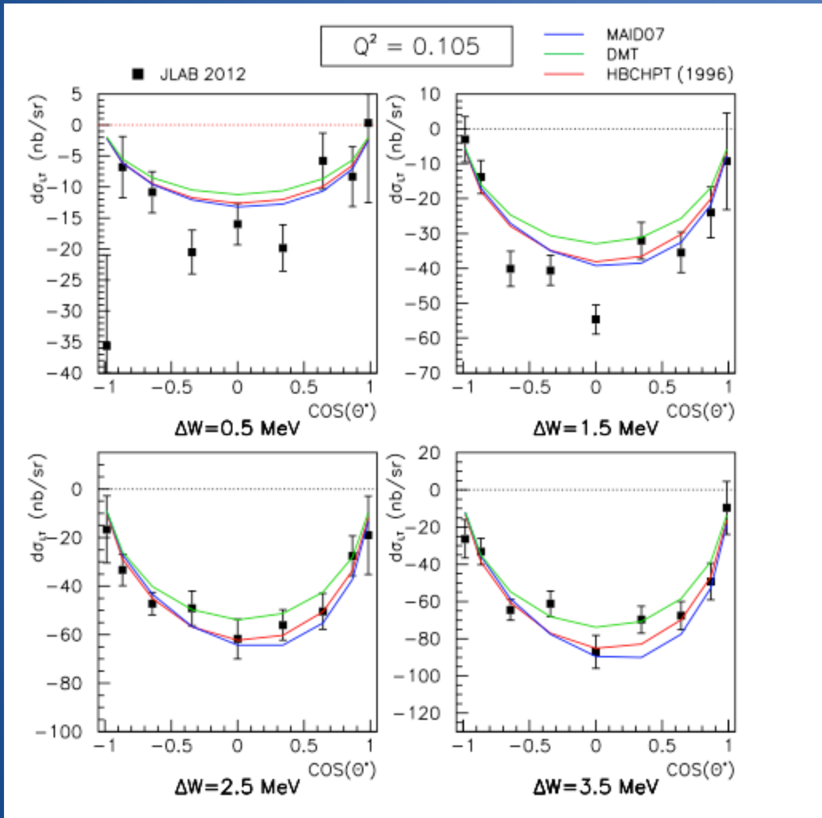
$$\frac{d\sigma}{d\Omega_\pi^*} = \frac{p_\pi^*}{k_\gamma^*}\left(A_0^{T+L} + A_1^{T+L} P_1(x) + A_2^{T+L} P_2(x)\right) \quad \text{T+L}$$

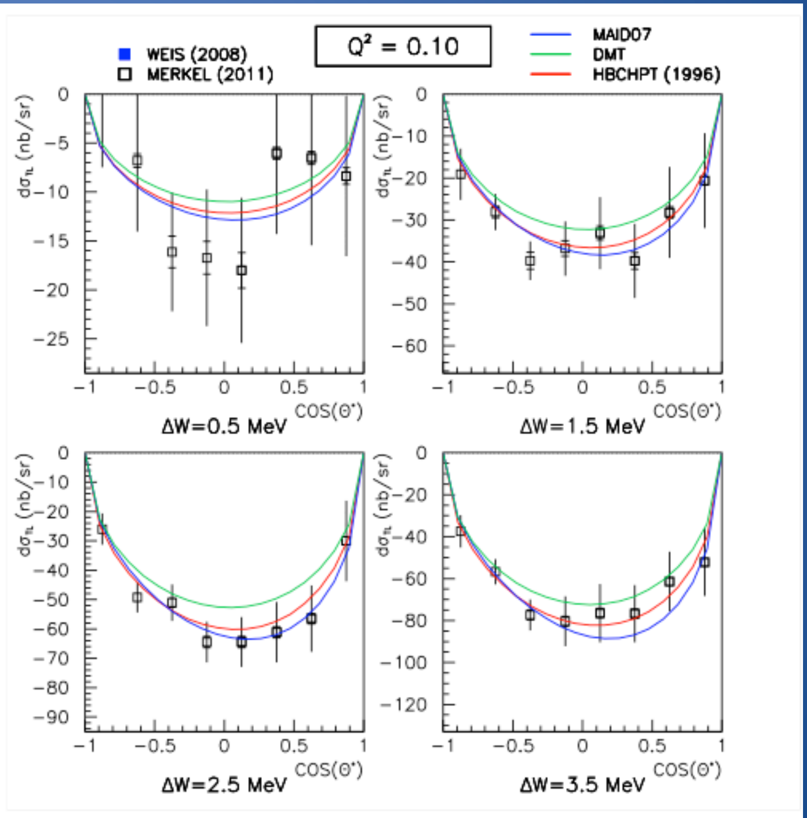
$$+ \frac{p_\pi^*}{k_\gamma^*}\sqrt{2\varepsilon_L(1+\varepsilon)}\left(A_0^{LT} + A_1^{LT} P_1(x)\right)(1-x^2)^{1/2}\cos\phi_\pi^* \quad \text{LT}$$

$$+ \frac{p_\pi^*}{k_\gamma^*}\varepsilon A_0^{TT}(1-x^2)\cos 2\phi_\pi^* \quad \text{TT}$$

Quality of Data at Threshold

$$A_0^{LT}$$



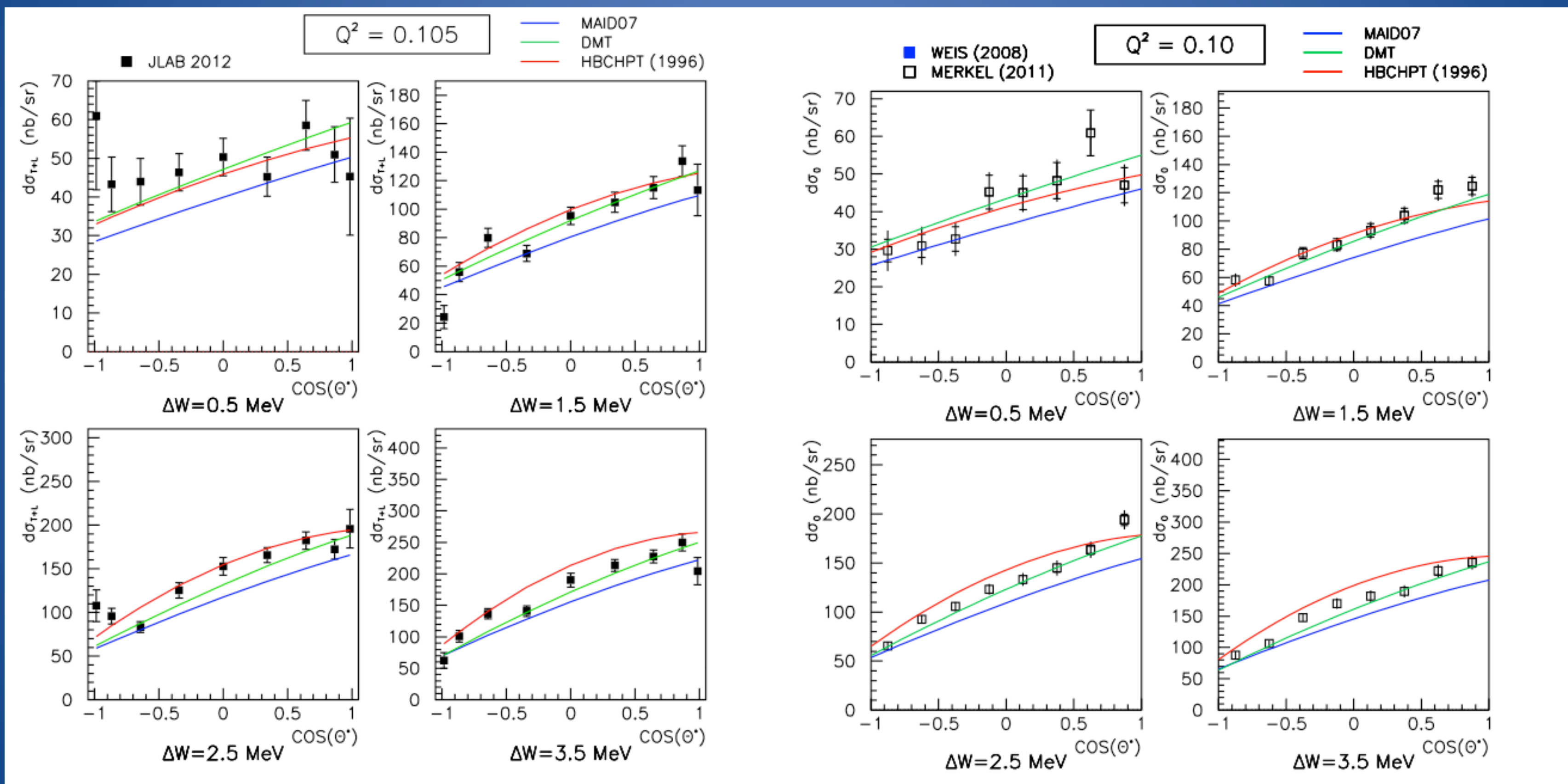


JLAB 2012
E=1.192 GeV

MAMI 2011
E=0.880 GeV

Quality of Data at Threshold

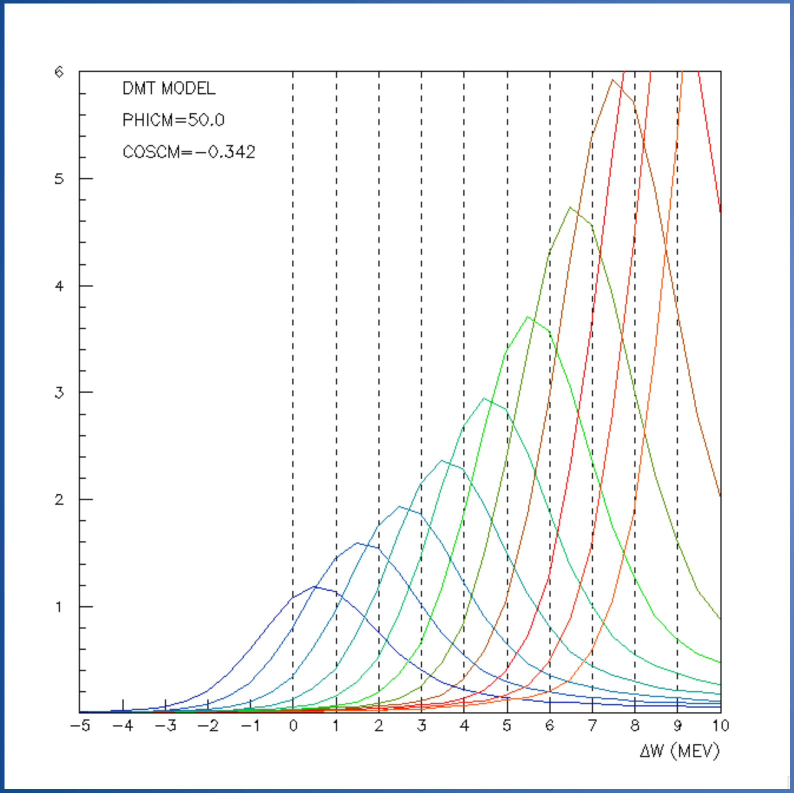
$$A_0^{T+L}$$



JLAB 2012	MAMI 2011
E=1.192 GeV	E=0.880 GeV
ε=0.943	ε=0.882

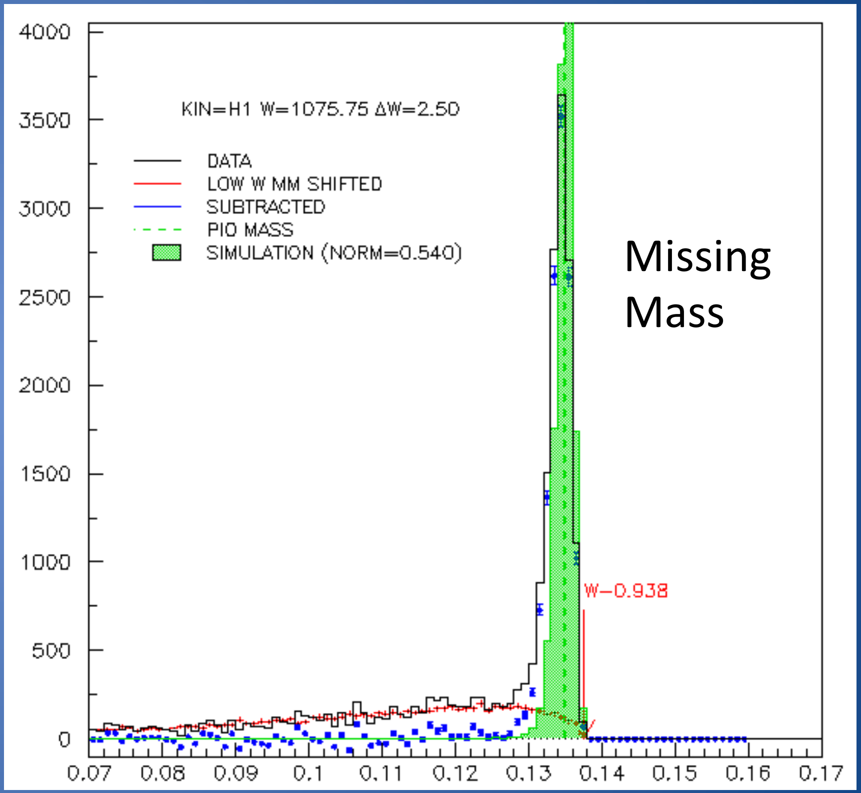
Dominant Systematic Errors

W Calibration and Resolution



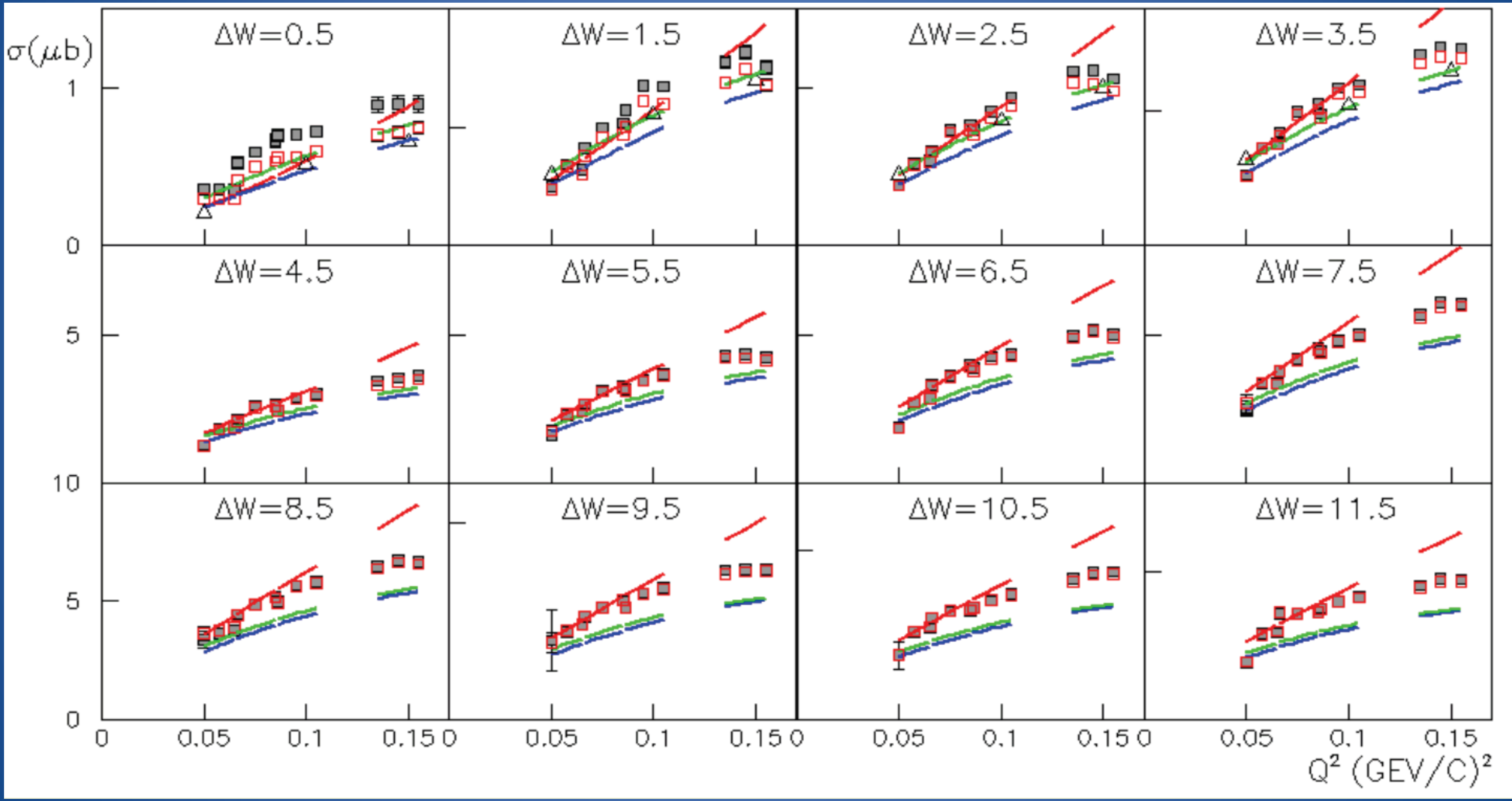
Knowledge of absolute W calibration and simulation of W resolution crucial to obtaining correct cross sections at threshold.

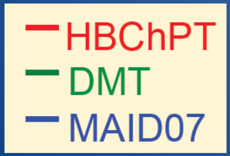
Target Window Backgound Subtraction

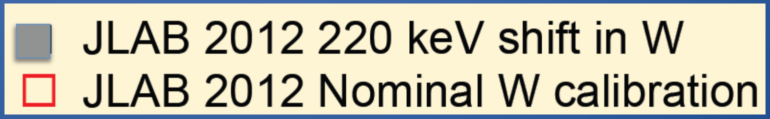


Full target yield used (no VZ cuts).
Data with W < π^o threshold used to estimate contribution from windows.

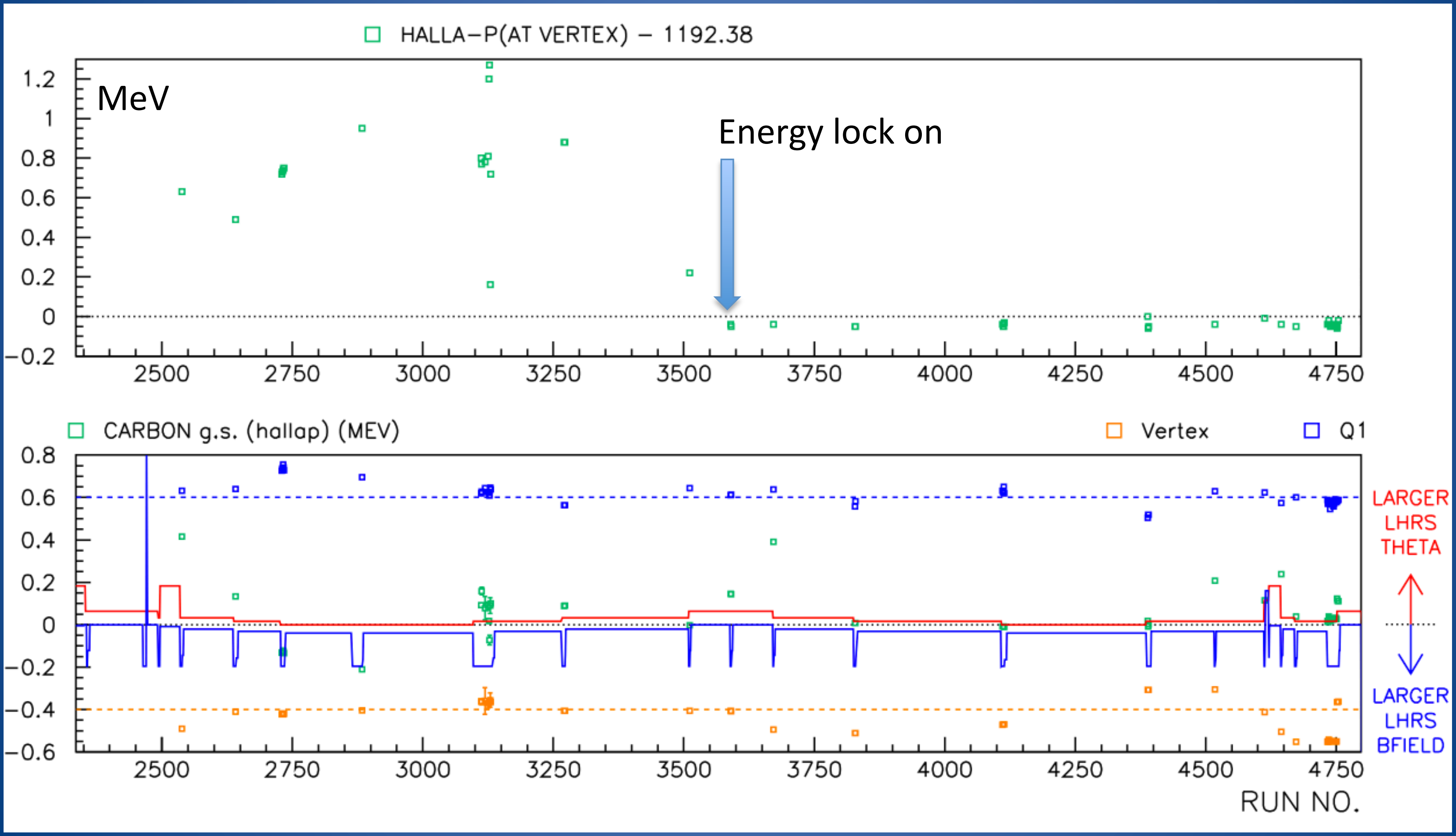
Effect on Total Cross Section of Shift in Energy Calibration



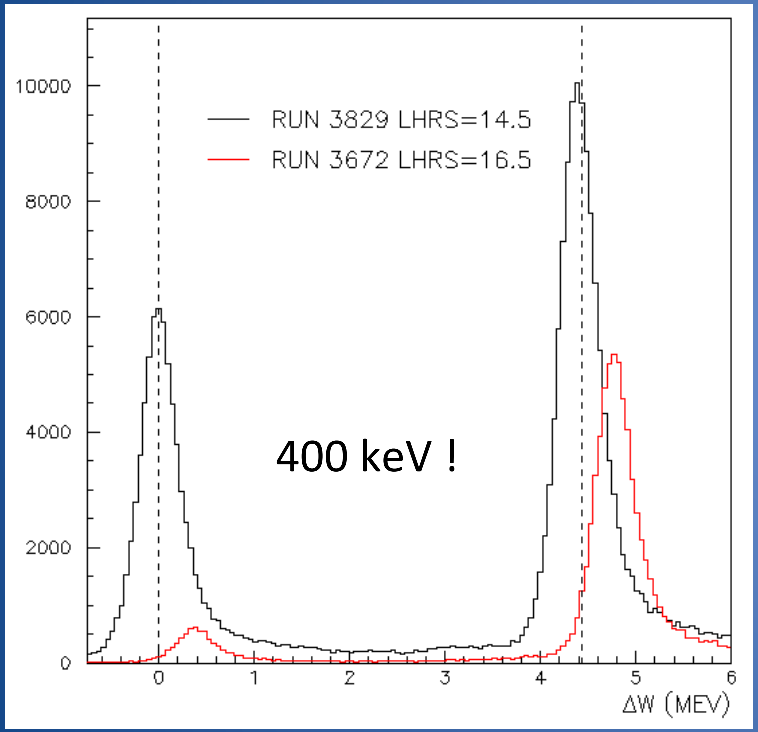


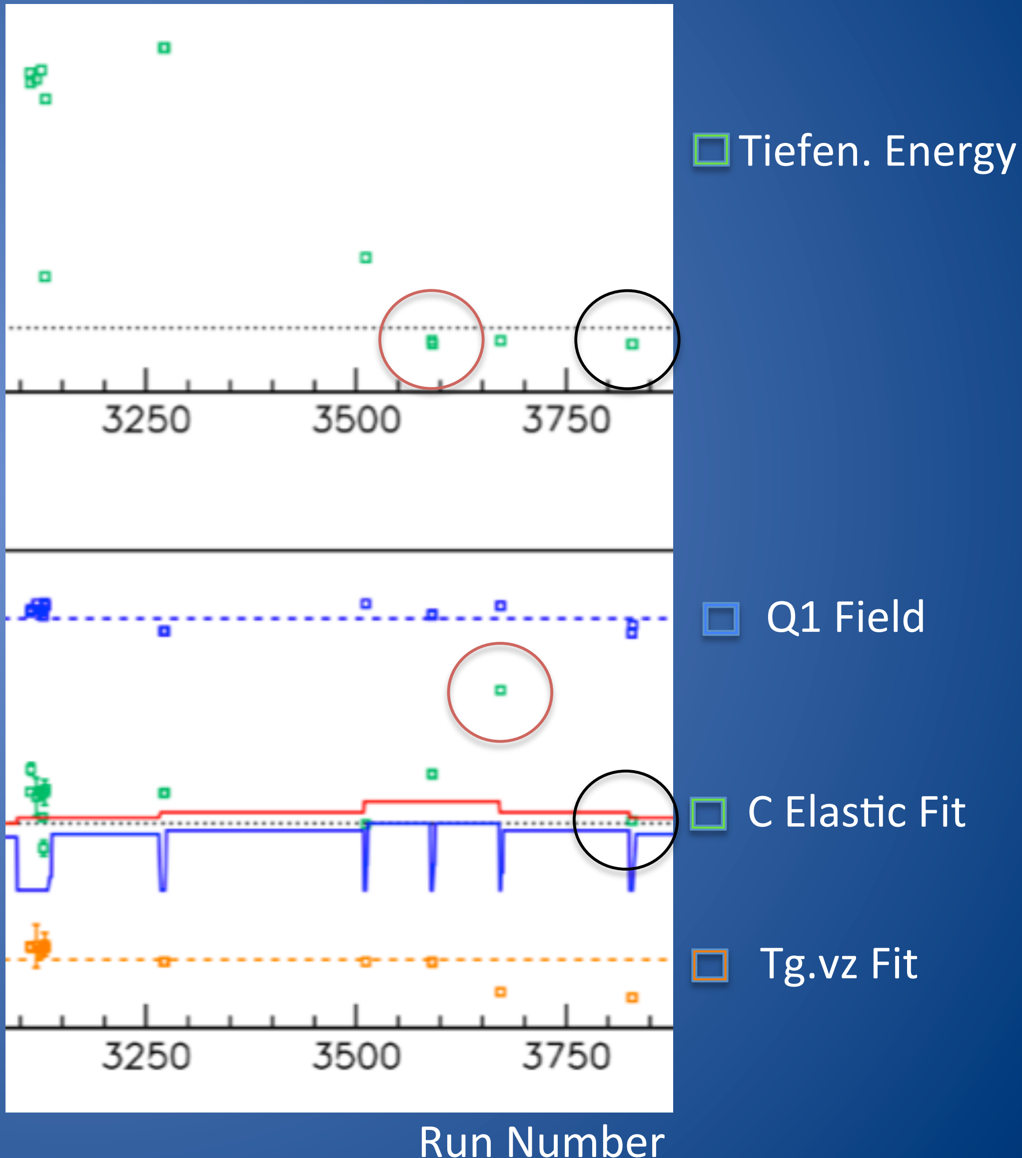


Carbon Elastic Peak vs. Run No.



Example of Shift in LHRS W Calibration





Possible Sources of C Elastic Peak Shifts

- LHRS mis-pointing (shift in recoil factor R)
  - $dR/d\theta = 4\text{-}6 \times 10^{-4}$/deg 0.1^o error = 40-60 keV
  - Exp't variation in L.tr.vz +/- 4 mm or +/- 0.03^o
- LHRS magnetic field
  - Dipole stable. Q1 Hall probe stability ~ 200 ppm.
- Beam energy shifts
  - Kinematics uses Tiefenbach energy.
- Beam Y-position shifts
  - Fluctuations of 2-3 mm common in early runs.
- Software (Hall A Analyzer misconfigured).

Sensitivity to Y-Position

The standard HRS transport matrix is listed at hallaweb.jlab.org/news/minutes/fo_matrix.html:

$$\begin{pmatrix} x \\ \theta \end{pmatrix}_{fp} = \begin{pmatrix} -2.18 & -0.198 & 11.9 \\ -0.10 & -0.469 & 1.967 \end{pmatrix} \begin{pmatrix} x_0 \\ \theta_0 \\ d \end{pmatrix}$$ where distances are in meters, angles in radians.

In my notation, the solution for the ray's vertical angle and momentum at the target is

$$\begin{pmatrix} \theta_0 \\ d \end{pmatrix} = \begin{pmatrix} -0.198 & 11.9 \\ -0.469 & 1.967 \end{pmatrix}^{-1} \begin{pmatrix} x \\ \theta \end{pmatrix}_{fp} - \begin{pmatrix} -0.198 & 11.9 \\ -0.469 & 1.967 \end{pmatrix}^{-1} \begin{pmatrix} -2.18 \\ -0.10 \end{pmatrix} x_0$$

or

$$\begin{pmatrix} \theta_0 \\ d \end{pmatrix} = \begin{pmatrix} 0.379 & -2.229 \\ 0.090 & -0.038 \end{pmatrix} \begin{pmatrix} x \\ \theta \end{pmatrix}_{fp} - \begin{pmatrix} -1.055 \\ -0.201 \end{pmatrix} x_0$$

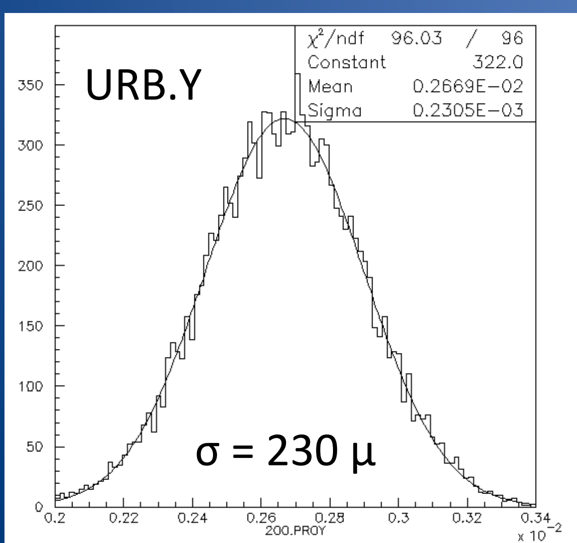
To first order, the momentum is thus

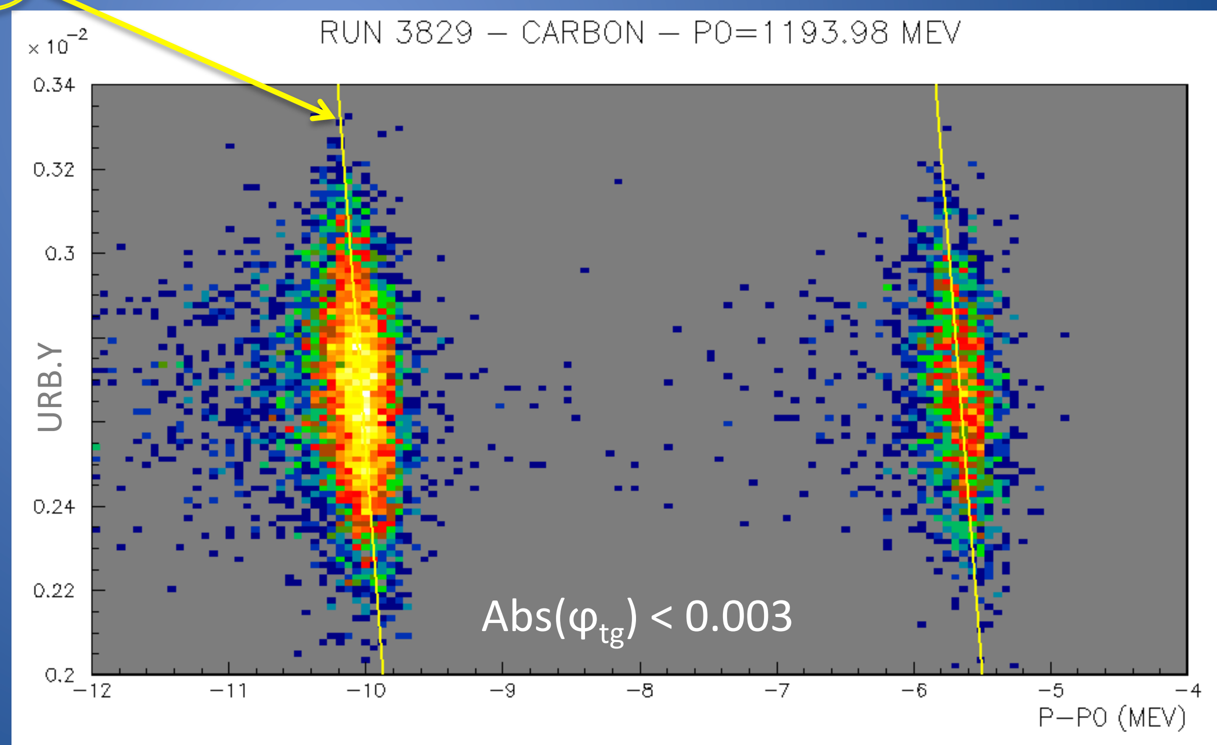
$$P\text{-}P_{central} = P_{central}\, d = P_{central}\{0.090\ x - 0.038\ \theta - 0.201\ x_0\}$$

(G. Franklin, Aug. 18, 2010)

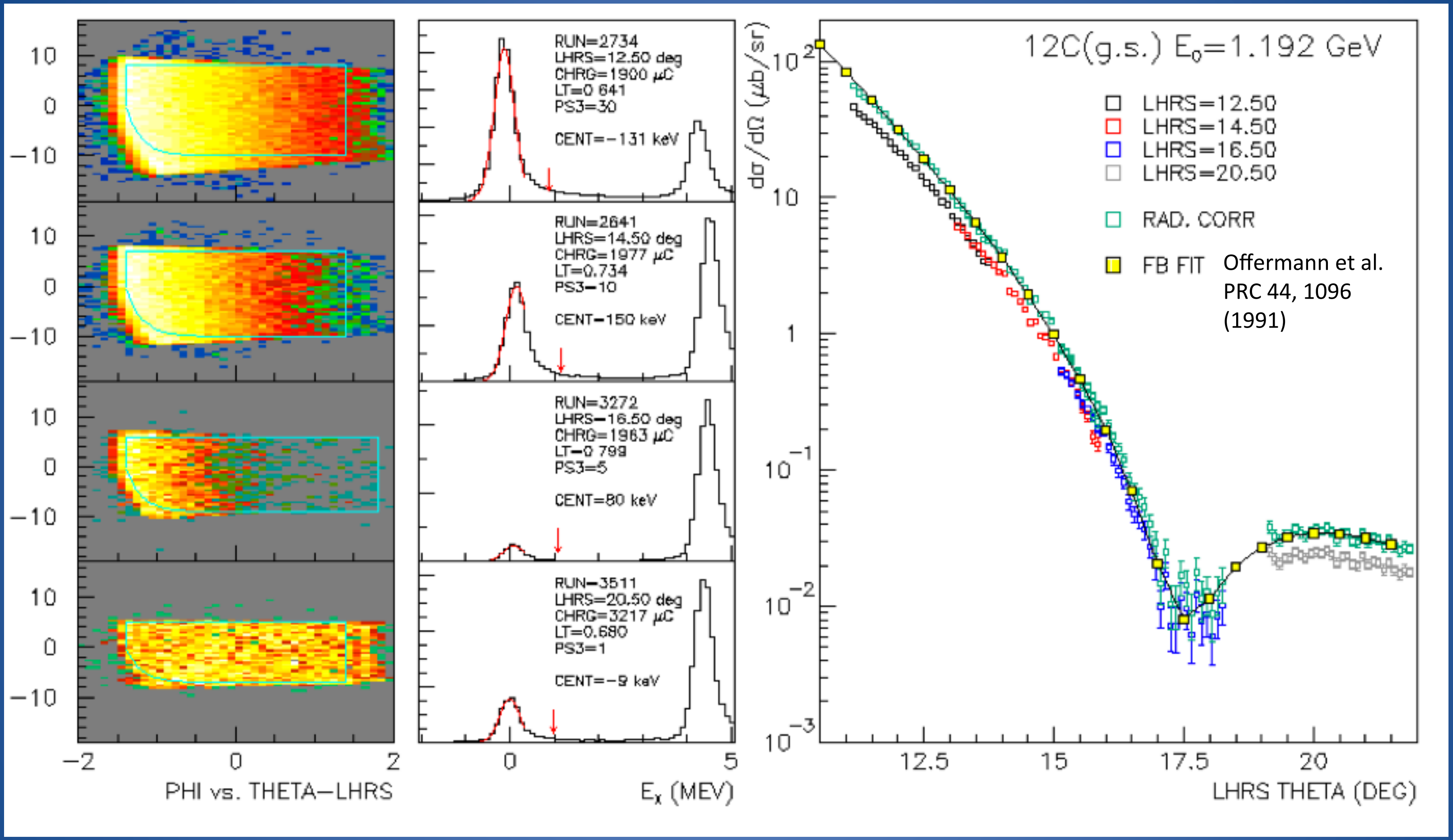
Since raster was not used raster-y corrections were turned off.

This means our W calibration was vulnerable to shifts in vertical beam position > 0.5 mm.





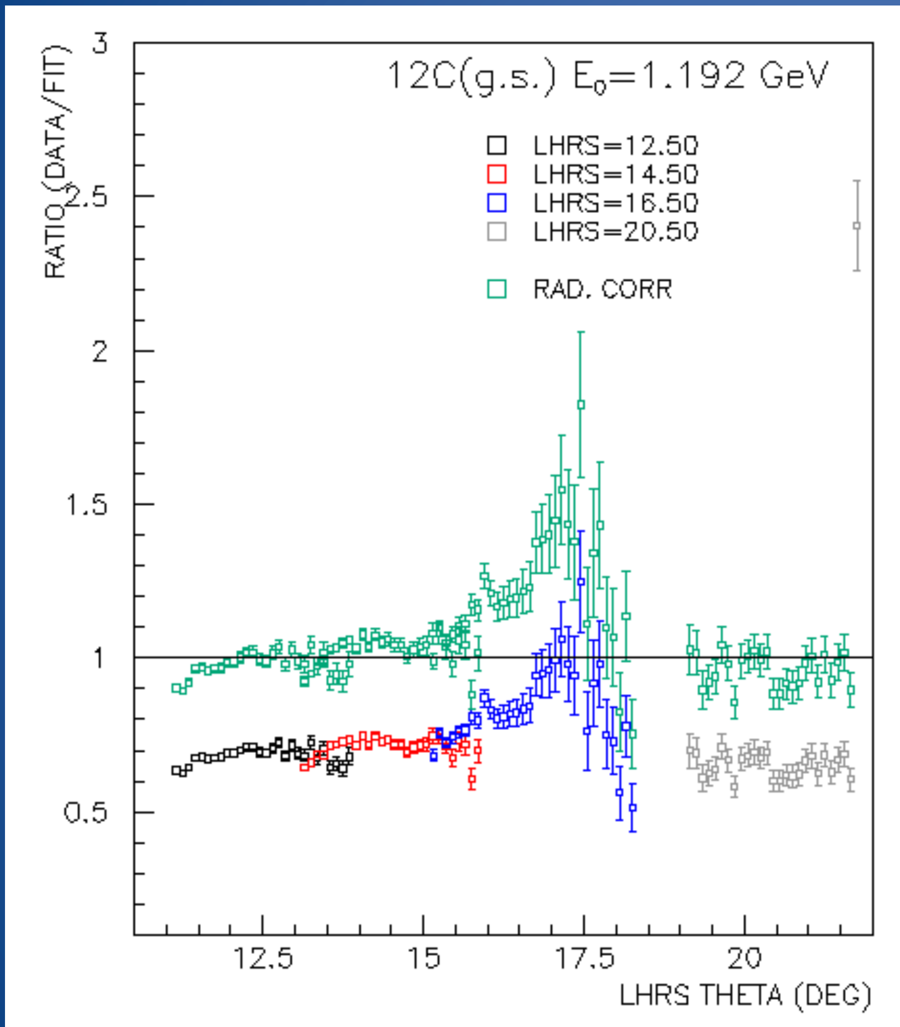
Carbon Elastic Cross Sections

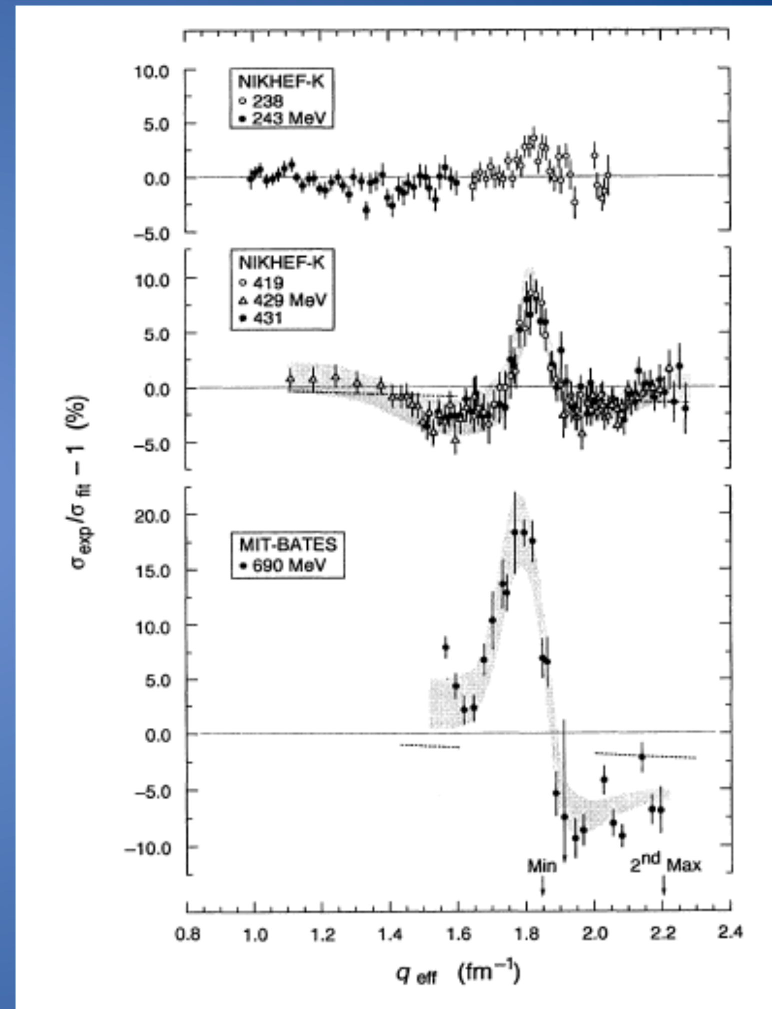


Cross section is sensitive to pointing errors, but not so much to energy calibration.

Fourier-Bessel fit to NIKHEF-K data taken from Offermann et al. and recalculated for E=1.192 GeV using DWBA phase-shift code from J. Heisenberg (R. Lindgren).

Carbon Elastic – Ratio with FB Fit





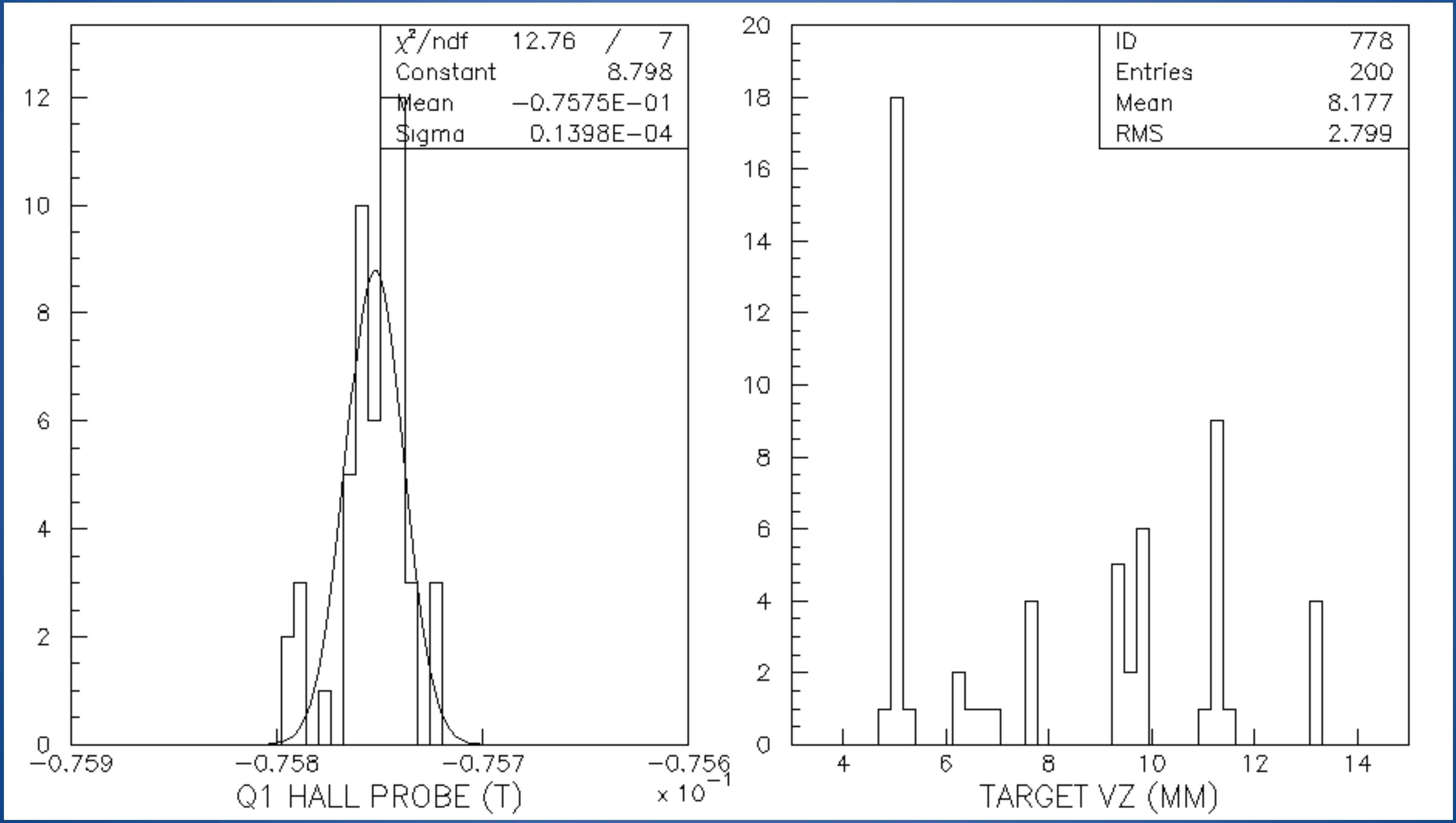
From Offermann et al.

Significant discrepancies only for 16.5^{o} data near diffraction minimum.
Similar to enhancements seen in previous measurements at lower beam energies.

Summary and Still to Do

- Large data set with unprecedented W, Q^2 , C.M. coverage and many available chiral theories to test.
- Estimates of systematic errors due to W calibration and target background subtraction.
- Compare pi0 yields for similar kinematics having large C elastic peak shifts to estimate systematics.
- Start writing paper in early 2013. Chiral Dynamics Workshop writeup due in Jan 2013.

Carbon Runs: Q1 and VZ stability



ΔW Dependence of A^{TT}_0

$$A_0^{TT} = \frac{1}{2}(|P_2|^2 - |P_3|^2)$$

— HBChPT
— DMT
— MAID07

■ JLAB 2012
■ MAMI 2011

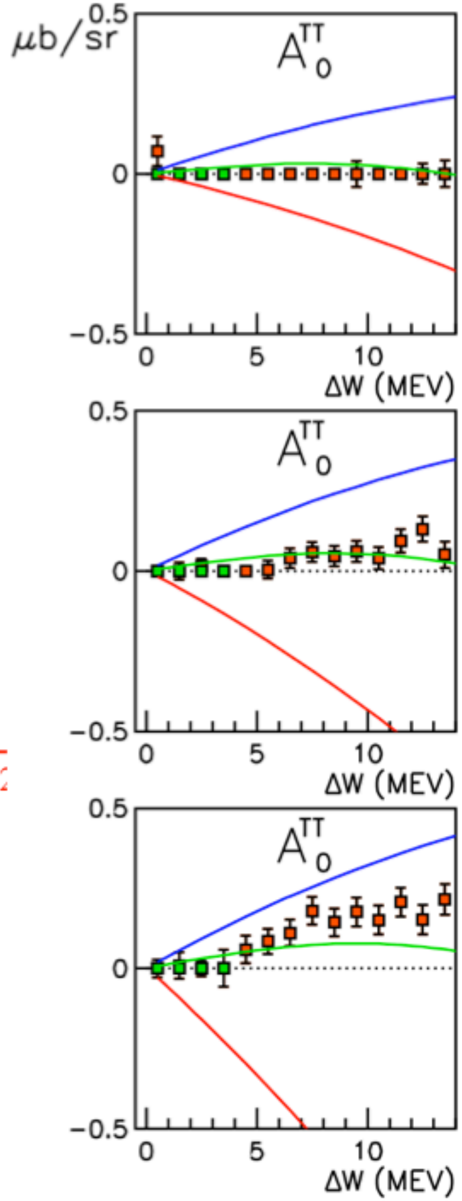
H. Merkel et al.,
arXiv:1109.5075v1 [nucl-ex].

$$P_3^{Born+ct} = eq(\frac{g_{\pi n}}{16\pi m^3} + b_p)\sqrt{\omega^2 - k^2}$$

$$b_p = 13.0 \text{ x } 10^{-9} \text{ MeV}^{-3}$$

HBCHPT : $|P_3|^2 > |P_2|^2$

Data : $|P_3|^2 \approx |P_2|^2$



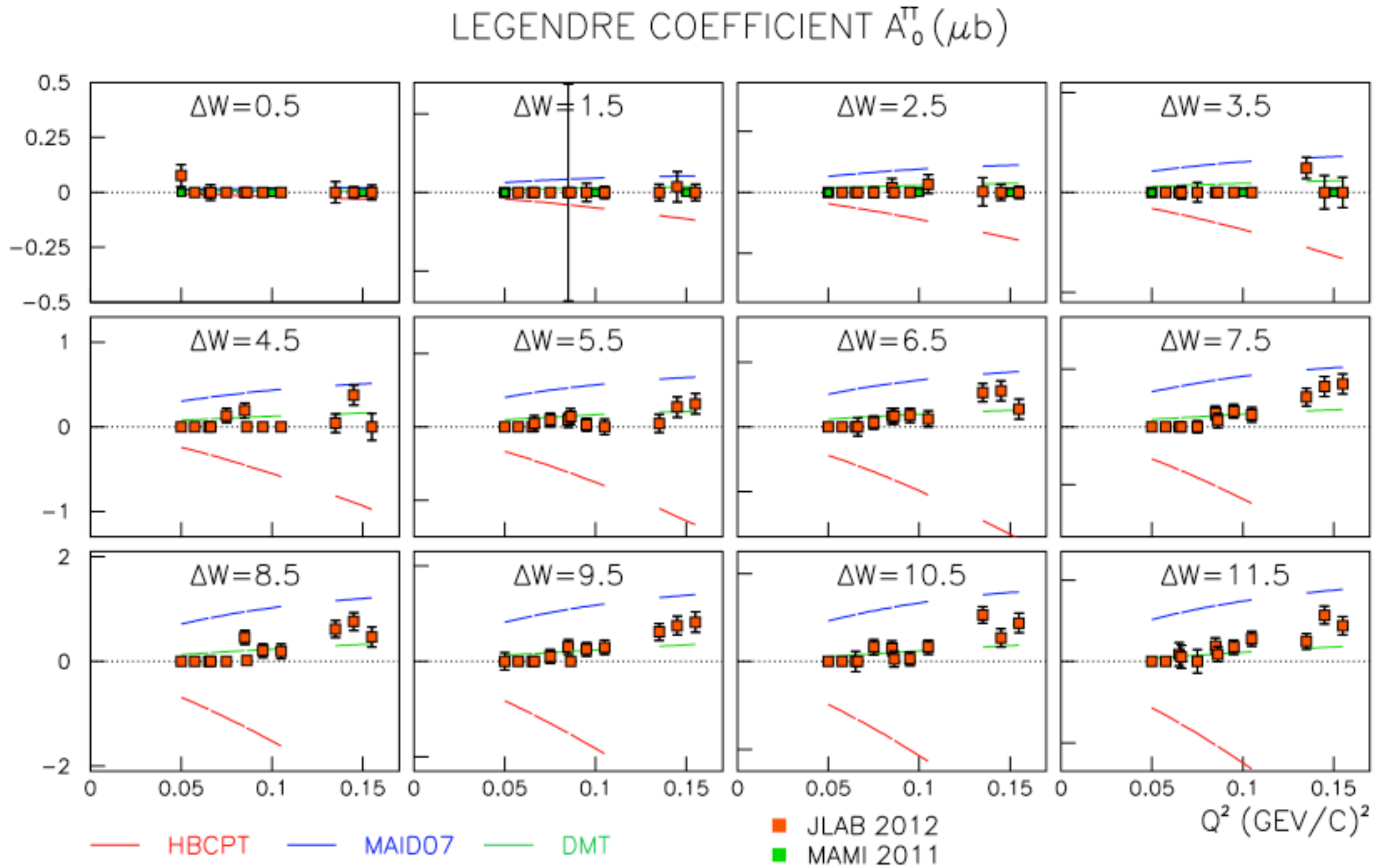
Q^2=0.05 (GeV/c)^2
(Consistent with zero)

Q^2=0.10 (GeV/c)^2

Q^2=0.15 (GeV/c)^2

Jefferson Lab

Q^2 Dependence of A_0^{TT}



A0TT

Both Q^2 and W dependence of σ_{TT} in strong disagreement with $O(q^3)$ ChPT. Changing b_p LEC to compensate may destroy agreement with other p-wave observables.

Jefferson Lab