Jlab Experiment E04-007 Status Report

Precision Measurement of the Electroproduction of π^0 Near Threshold: A Test of Chiral QCD Dynamics

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for
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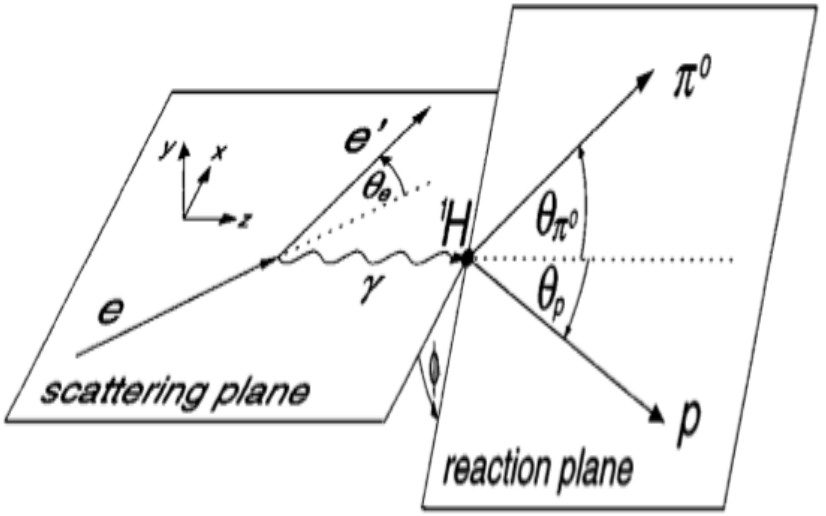
Hall A and BigBite Collaborations

Hall A Meeting Dec 14-16 2011

$$\frac{d^5\sigma}{d\Omega_{e'}dE_{e'}d\Omega_{\pi}^*} = \Gamma_v(\sigma_T(\theta_\pi^*)+\varepsilon_L\sigma_L(\theta_\pi^*)+\sqrt{2\varepsilon_L(1+\varepsilon)}\sigma_{LT}(\theta_\pi^*)\cos\phi_\pi^*+\varepsilon\sigma_{TT}(\theta_\pi^*)\cos 2\phi_\pi^*)+$$

$$h\sqrt{2\varepsilon_L(1-\varepsilon)}\sigma_{LT'}(\theta_\pi^*)\sin\phi_\pi^*)$$



Goal: Extract $\sigma_T(\theta_\pi^*)+\varepsilon_L\sigma_L(\theta_\pi^*)$

$\sigma_{LT}(\theta_\pi^*)$

$\sigma_{TT}(\theta_\pi^*)$

$\sigma_{LT'}(\theta_\pi^*)$

S and P Waves Give 7 Pion Multipoles

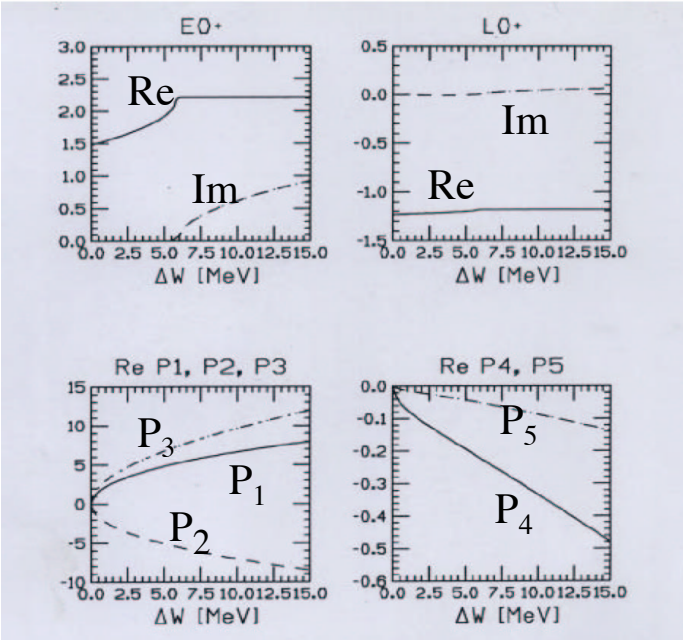
- $\sigma_T = |E_{0+}|^2 + \frac{1}{2}\left(|P_2|^2 + |P_3|^2\right) + 2\,\mathrm{Re}\left(E_{0+}P_1^*\right)\cos\theta_\pi^* + \left(|P_1|^2 - \frac{1}{2}\left(|P_2|^2 + |P_3|^2\right)\right)\cos^2\theta_\pi^*$
- $\sigma_L = \left(|L_{0+}|^2 + |P_5|^2\right) + 2\,\mathrm{Re}\left(L_{0+}P_4^*\right)\cos\theta_\pi^* + \left(|P_4|^2 - |P_5|^2\right)\cos^2\theta_\pi^*$
- $\sigma_{TT} = \frac{1}{2}\left(|P_2|^2 - |P_3|^2\right)\sin^2\theta_\pi^*$
- $\sigma_{LT} = -\mathrm{Re}\left(L_{0+}P_2^* + E_{0+}P_5^*\right)\sin\theta_\pi^* - \mathrm{Re}\left(P_1P_5^* + P_4P_2^*\right)\sin\theta_\pi^*\cos\theta_\pi^*$
- $\sigma_{LT'} = -\mathrm{Im}\left(L_{0+}P_2^* + E_{0+}P_5^*\right)\sin\theta_\pi^* + \mathrm{Im}\left(P_1P_5^* + P_4P_2^*\right)\sin\theta_\pi^*\cos\theta_\pi^*$

S Waves

E_{0+} and L_{0+}

P waves

$P_1, P_2, P_3, P_4,$ and P_5



Units of the y-axes are $10^{-3}/m_\pi$

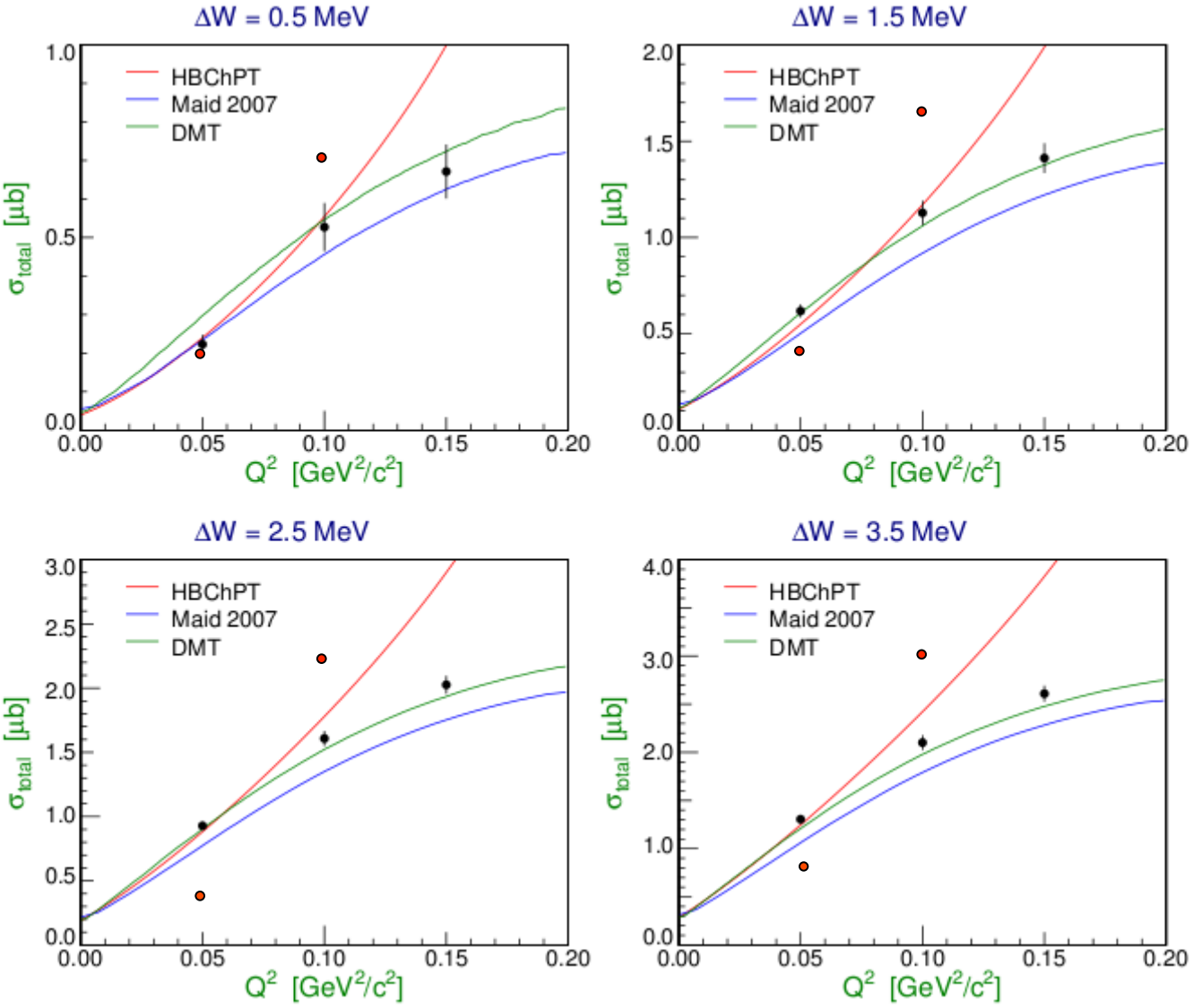
Transverse

$$P_1 = 3E_{1+} + M_{1+} - M_{1-}$$
$$P_2 = 3E_{1+} - M_{1+} + M_{1-}$$
$$P_3 = 2M_{1+} + M_{1-}$$

Longitudinal

$$P_4 = 4L_{1+} + L_{1-}$$
$$P_5 = L_{1-} - 2L_{1+}$$

Mainz Data



- Q^2=0.1 (GeV/c)^2
  Distler PRL 80, 2294 (1998)
- Q^2=0.05 (GeV/c)^2
  Merkel et al.
  PRL 88, 1230 (2002)
- Harald Merkel
  6th International Workshop on Chiral Dynamics
  July 6-10 2009
  Bern, Switzerland

HBChPT was fitted to old data set up to Q^2=0.1 (GeV/c)^2

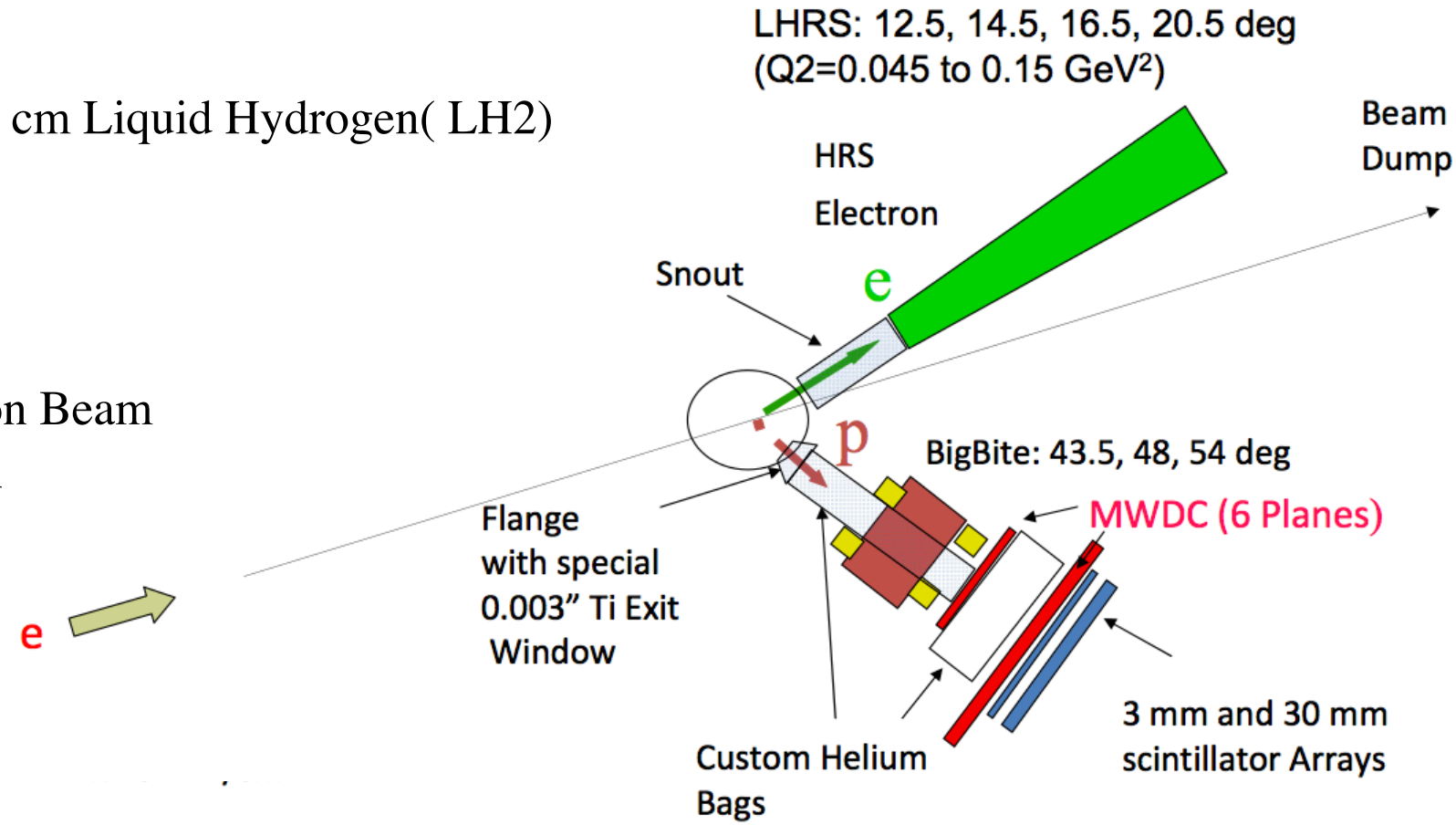
Experimental Setup and Kinematics

We took data in a fine grid of Q^2 and W from $Q^2 = 0.045 - 0.15$ in steps of 0.01 and from $W = 0 - 30$ MeV above threshold in steps of 1 MeV at E=1.193 GeV.

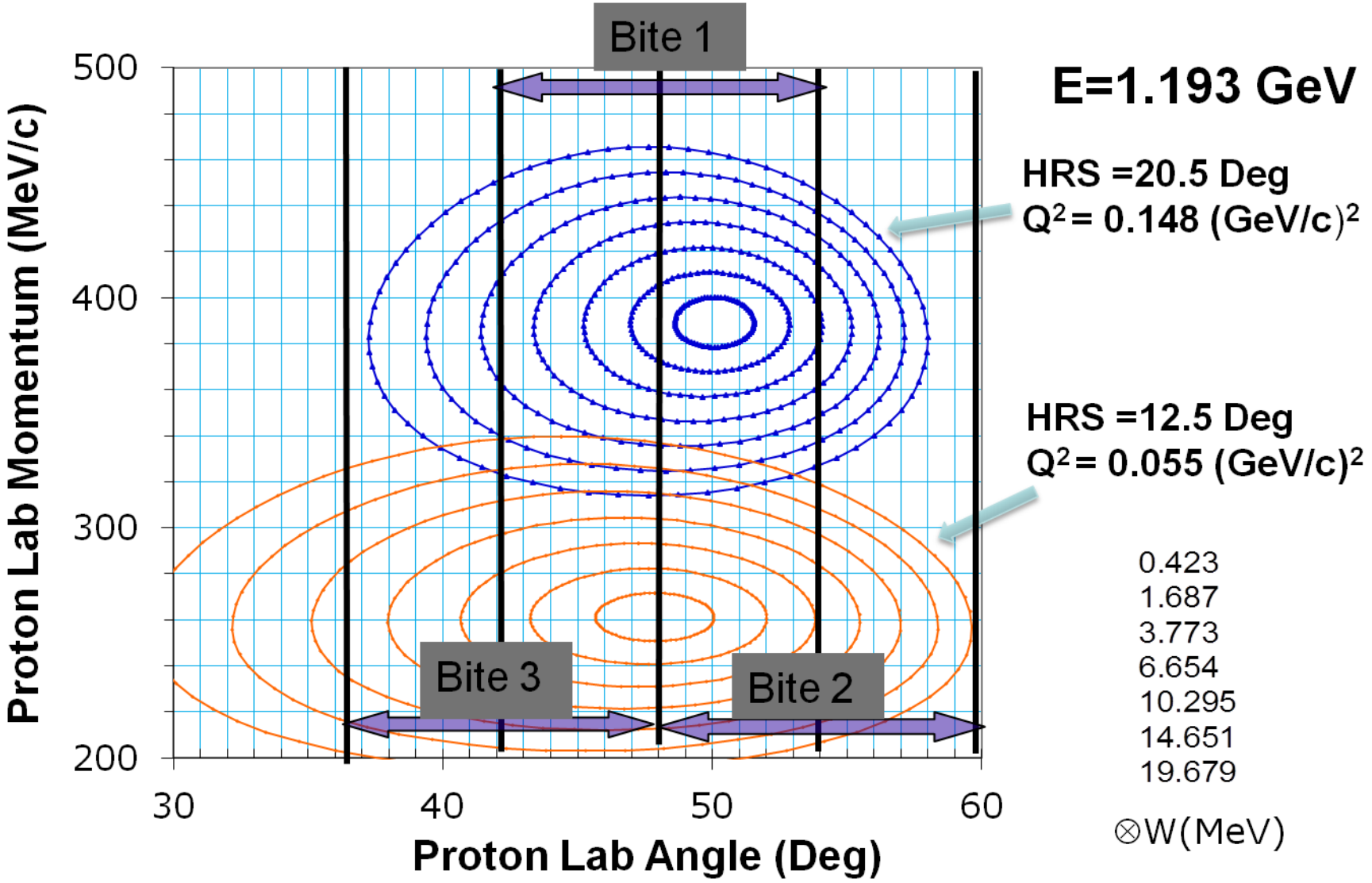
Target

- 6 cm Liquid Hydrogen(LH2)

Electron Beam
1-5 μA



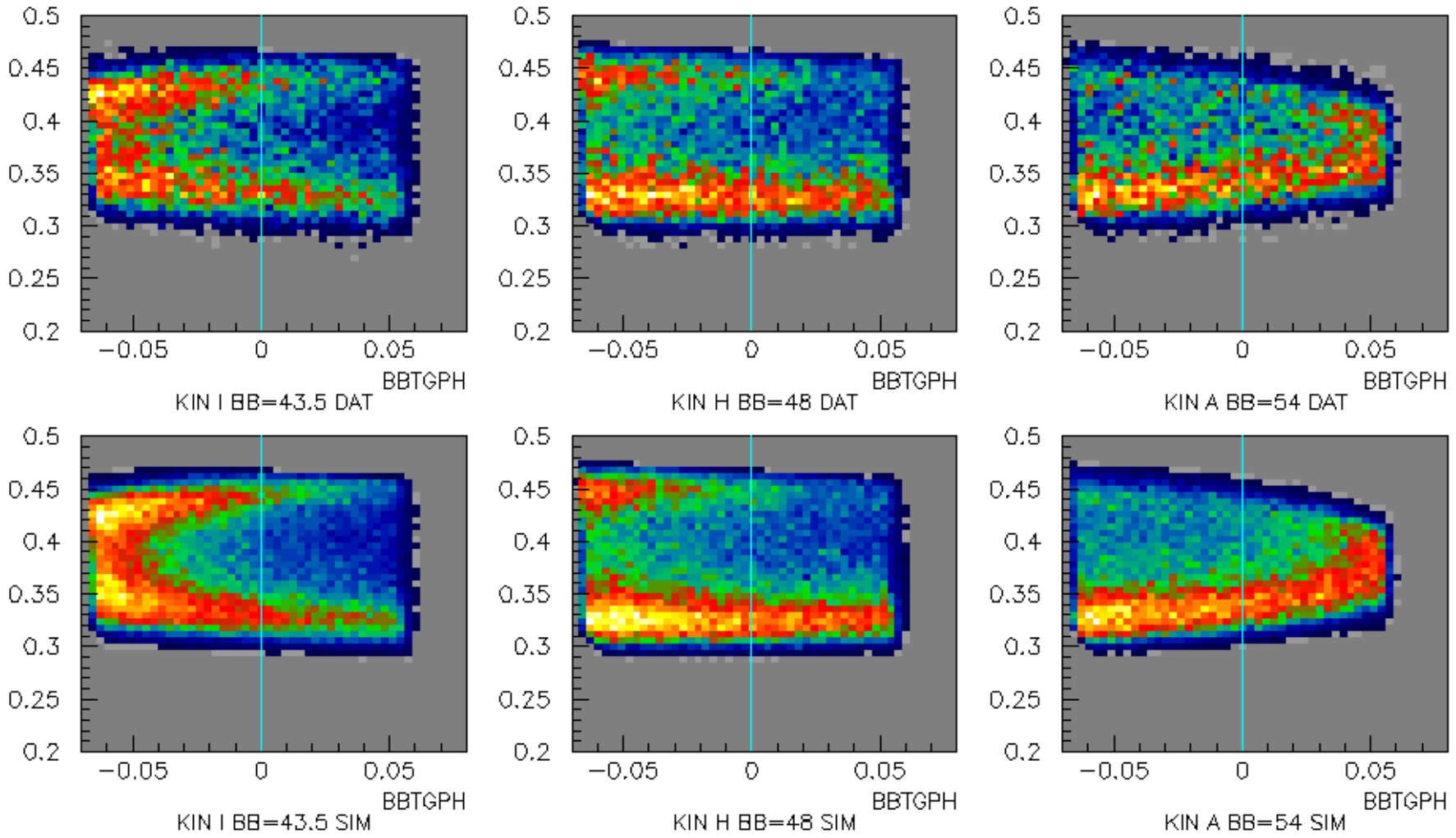
E04-007: Coincidence Kinematics



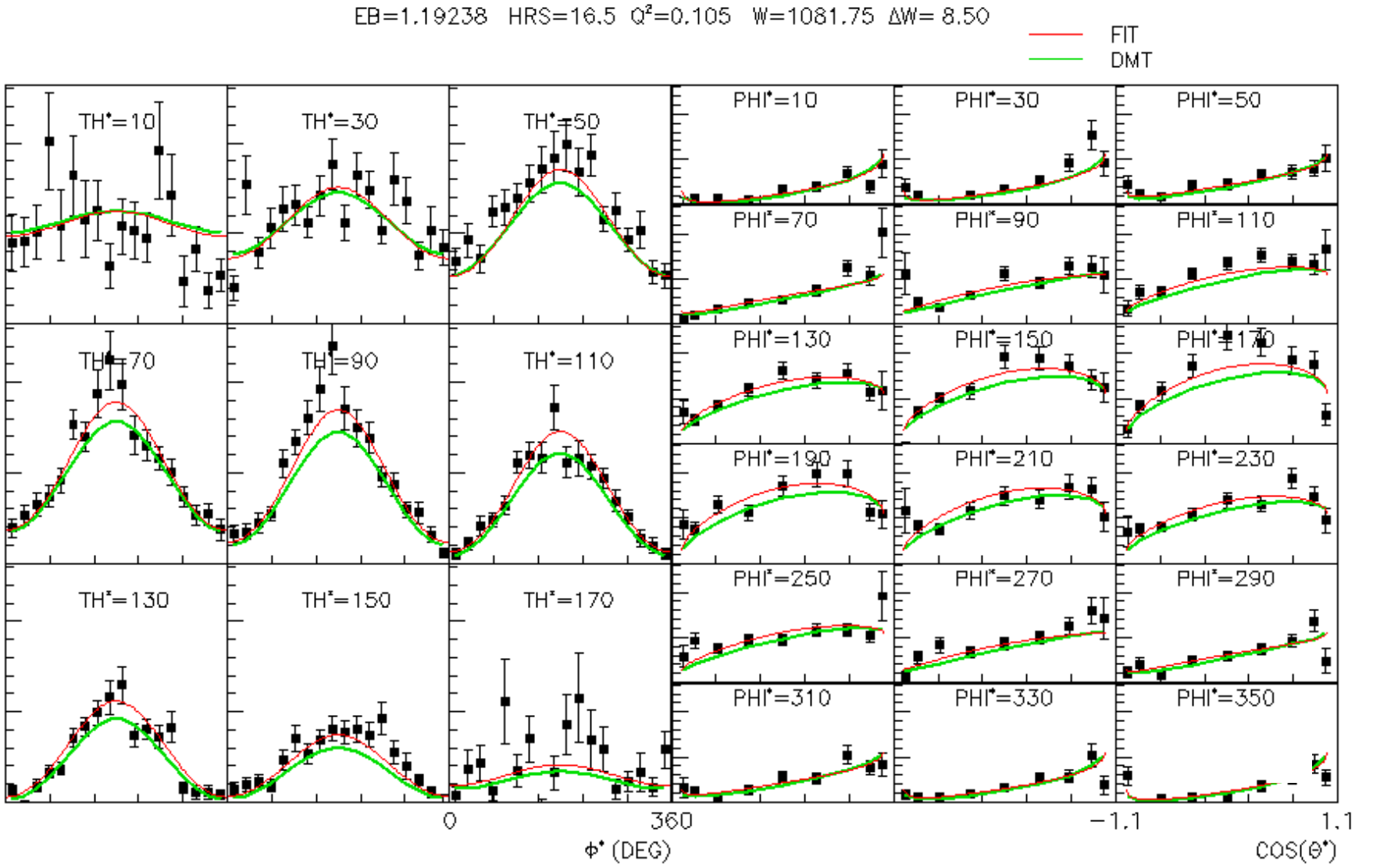
Ellipses of constant ΔW (W relative to π threshold)

Constant ΔW ellipses in Data (top) and Simulation (bottom)

$$\Delta W = 19 - 20 \ MeV$$

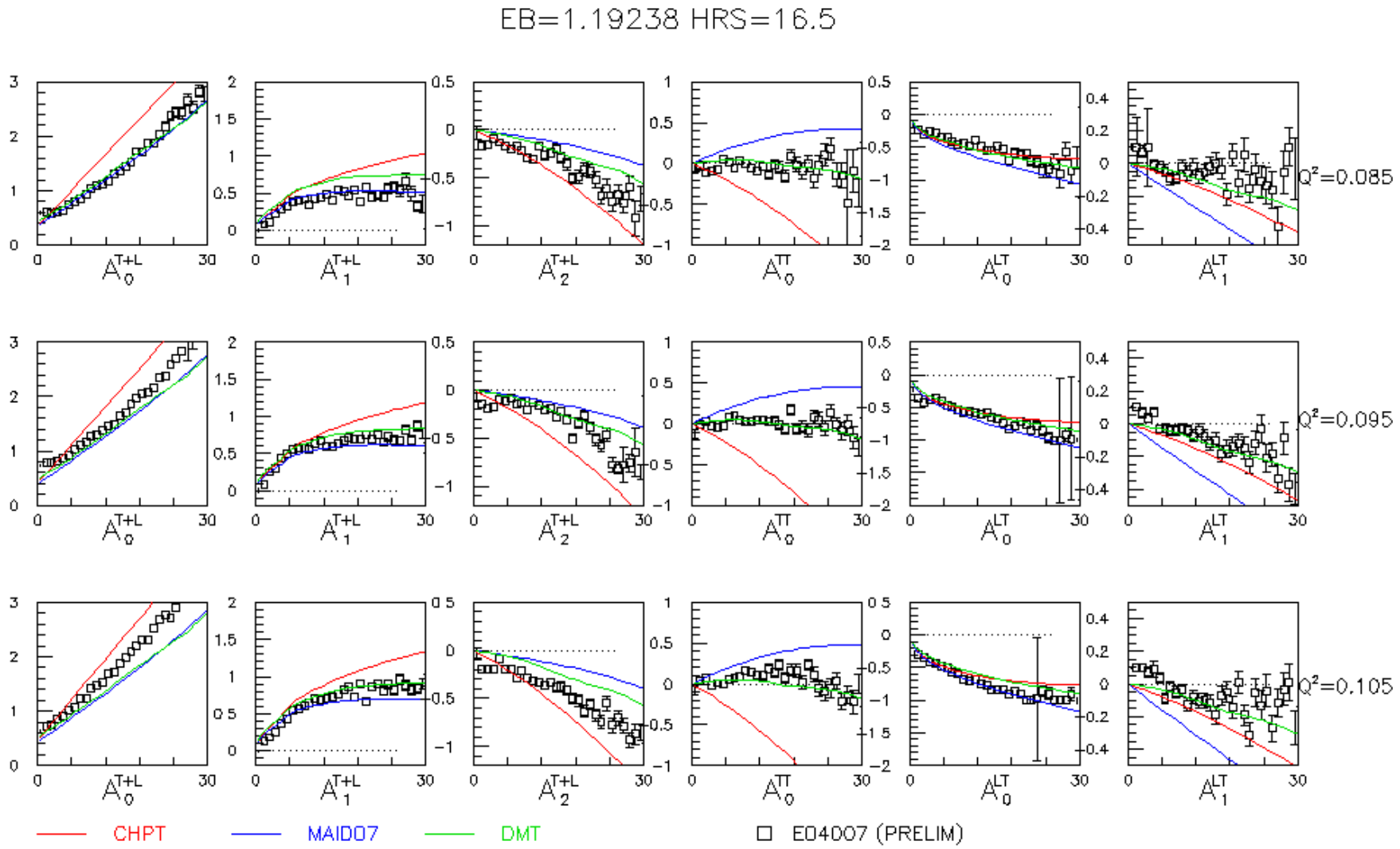


Current Results – Fits to Angular Distributions



$$\frac{d\sigma}{d\Omega_\pi^*} = \frac{p_\pi^*}{k_\gamma^*}(A_0^{T+L} + A_1^{T+L}P_1(cos\theta^*) + A_2^{T+L}P_2(cos\theta^*) + \epsilon A_0^{TT} sin^2\theta^* cos2\phi^* + \sqrt{2\epsilon_L(1+\epsilon)}(A_0^{LT} + A_1^{LT}P_1(cos\theta^*))sin\theta^* cos\phi^*)$$

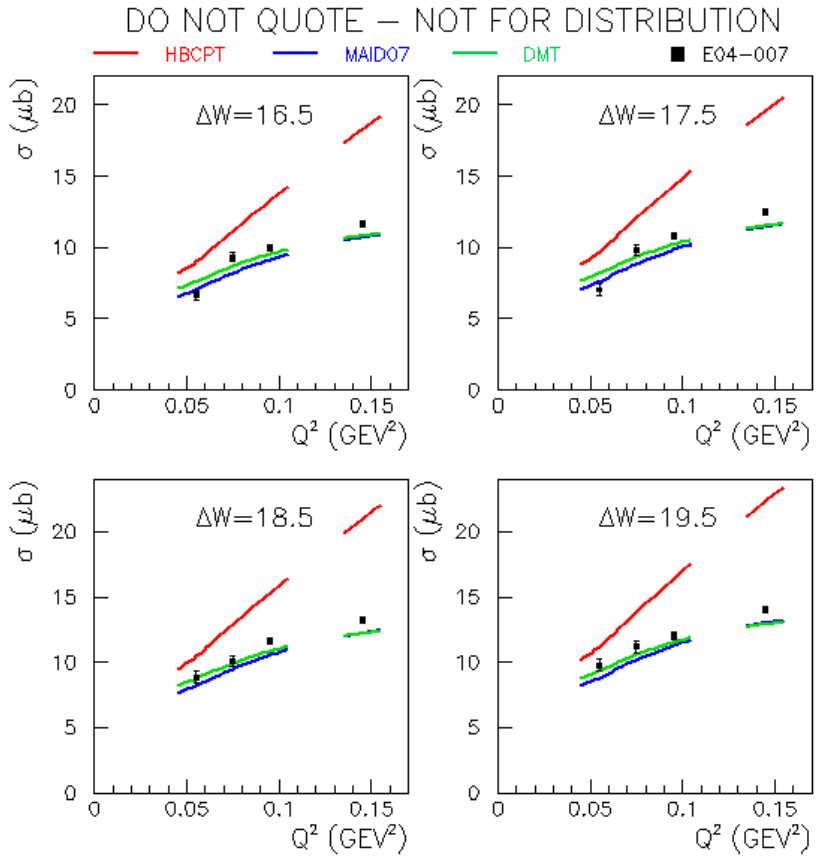
Current Results – ΔW Dependence of Partial Wave Fit

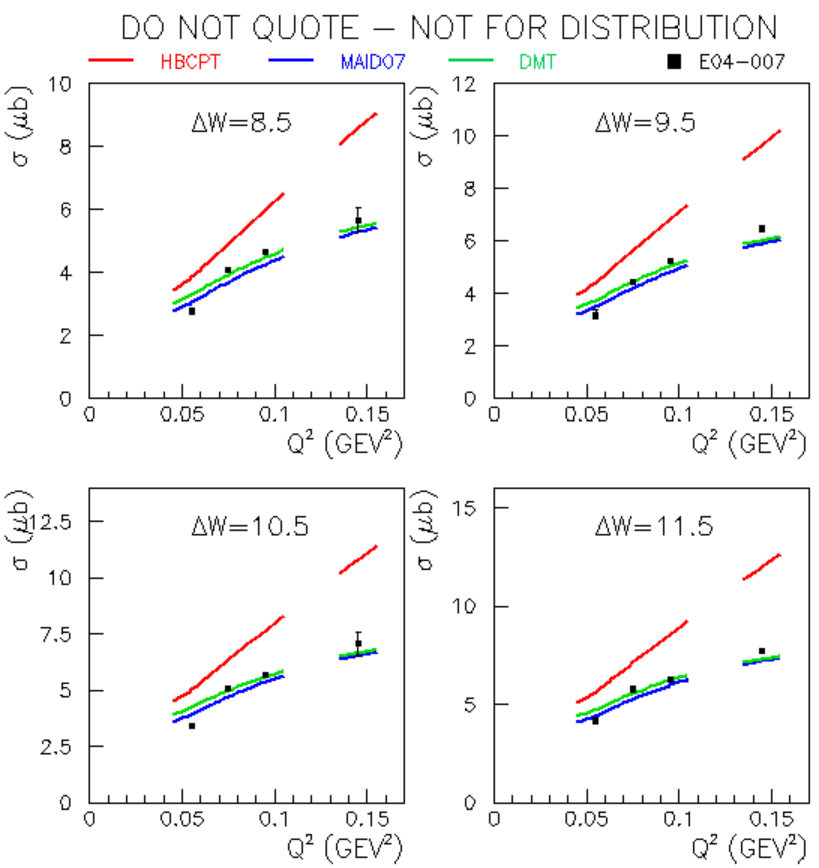


$$\sigma_{TOT} = 4\pi \frac{p_\pi^*}{k_\gamma^*} A_0^{T+L}$$

Current Results – Total Cross Sections

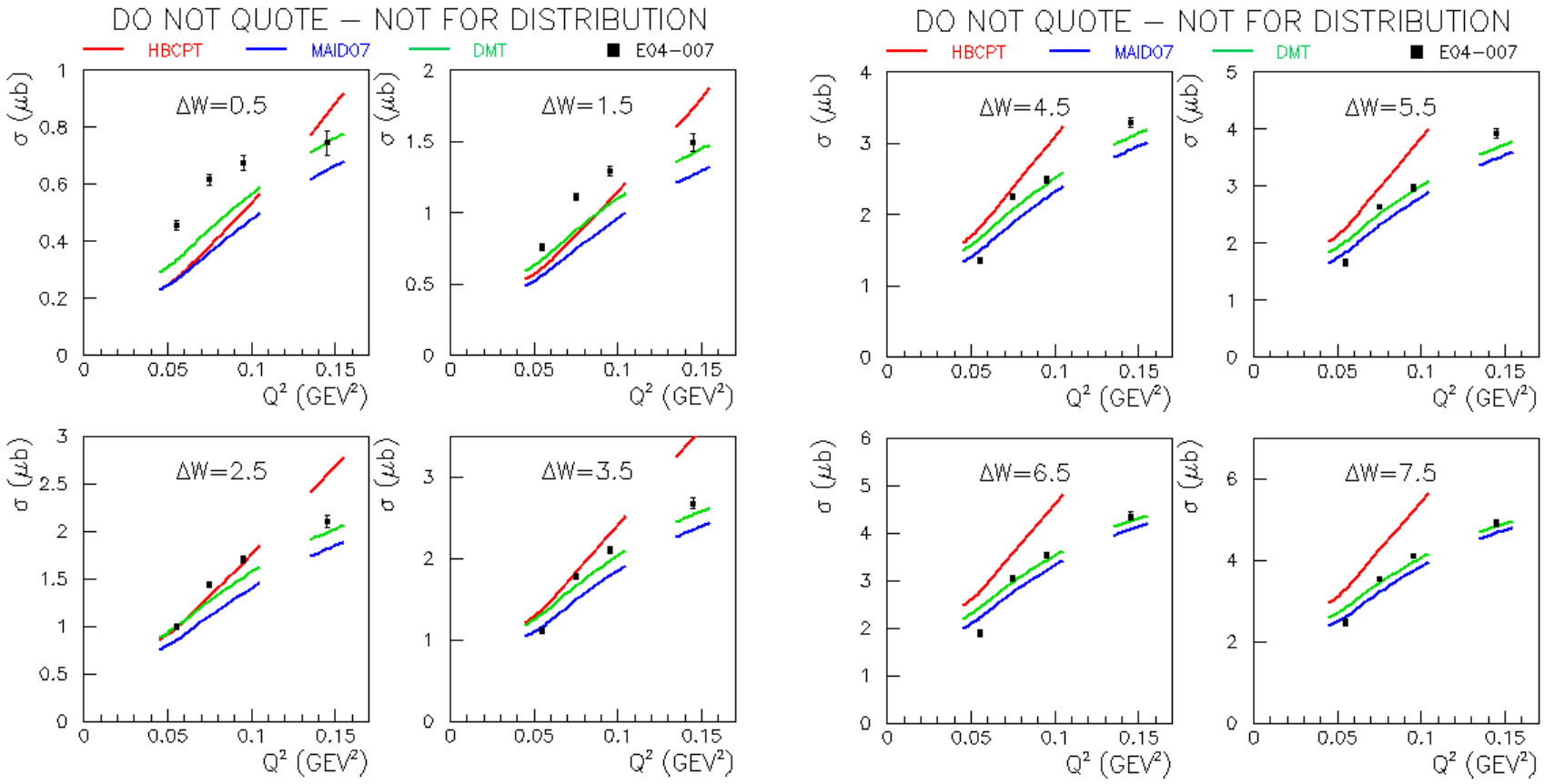
$$\sigma_{TOT} = 4\pi \frac{p_\pi^*}{k_\gamma^*} A_0^{T+L}$$



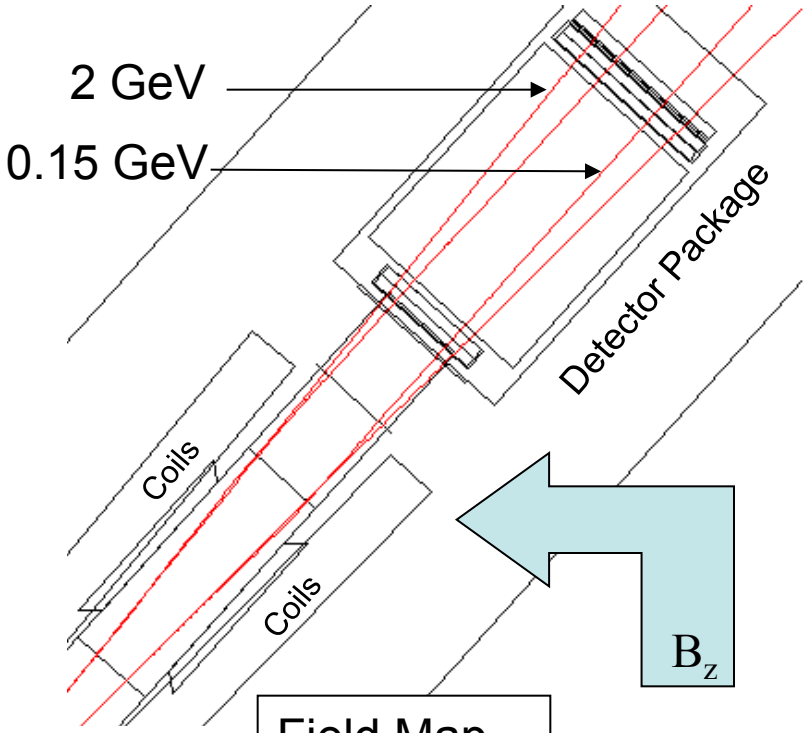


Current Results – Total Cross Sections

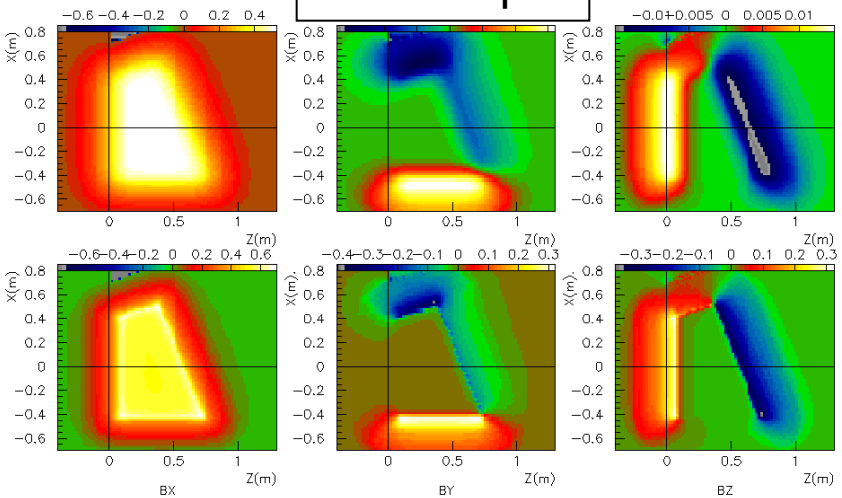
$$\sigma_{TOT} = 4\pi \frac{p_\pi^*}{k_\gamma^*} A_0^{T+L}$$



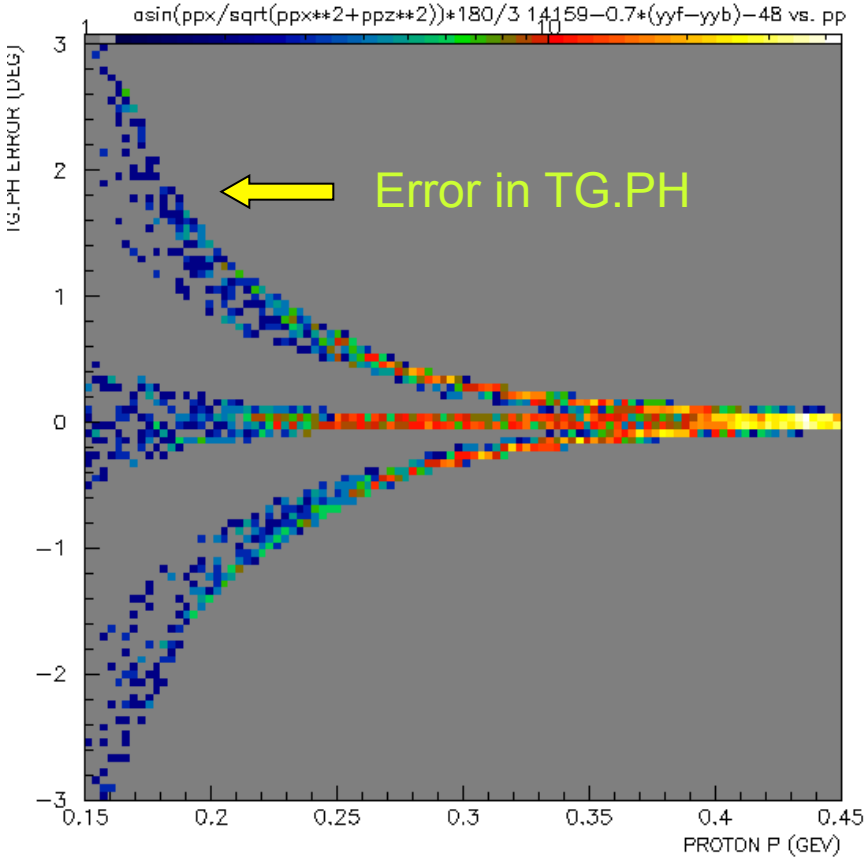
BBSIM: Transverse Focusing in BB Magnet



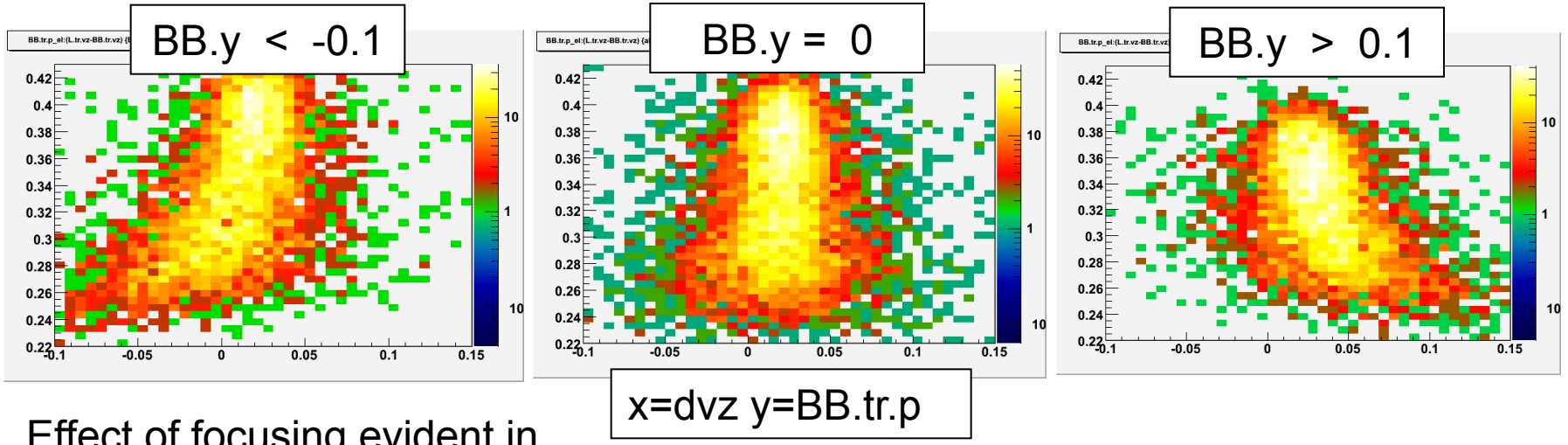
Field Map



- MAFIA field map by V. Nelyubin (2 cm mesh)
- Bz fringe fields → transverse focusing
- Leads to error in tg.ph for low momentum protons (p < 400 MeV/c).

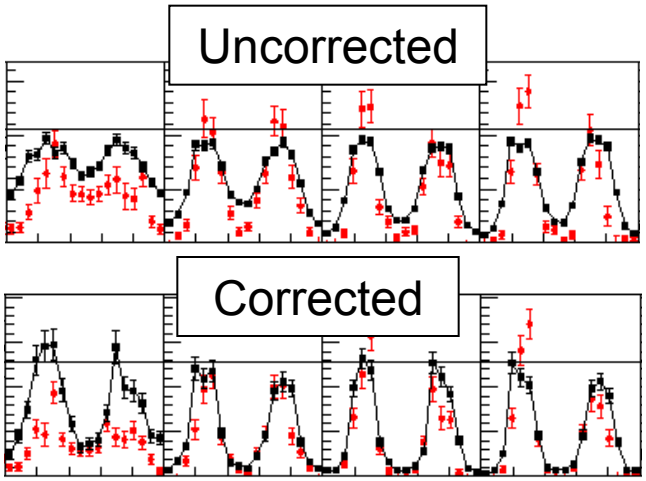


DATA: Transverse Focusing in BB magnet

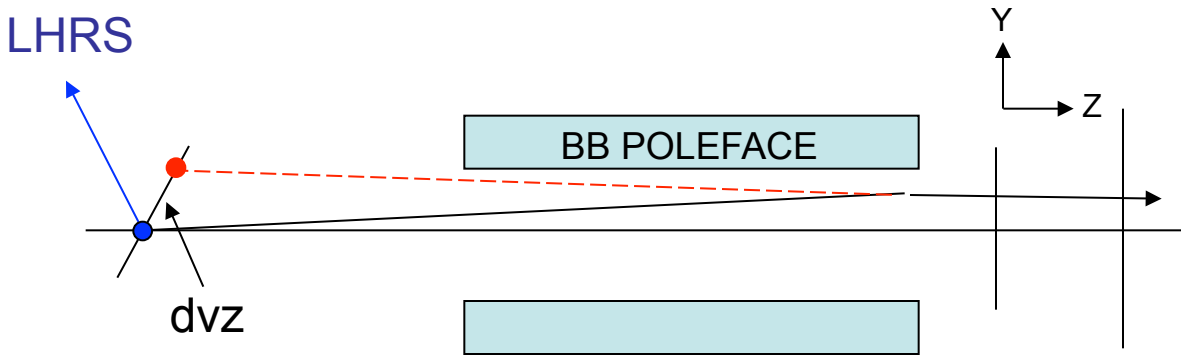


Effect of focusing evident in momentum dependence of target vertex error dvz = L.tr.vz - BB.tr.vz.

Khem developed geometrical correction using dvz to calculate transverse bend angle. Correction applied to both data and simulation.



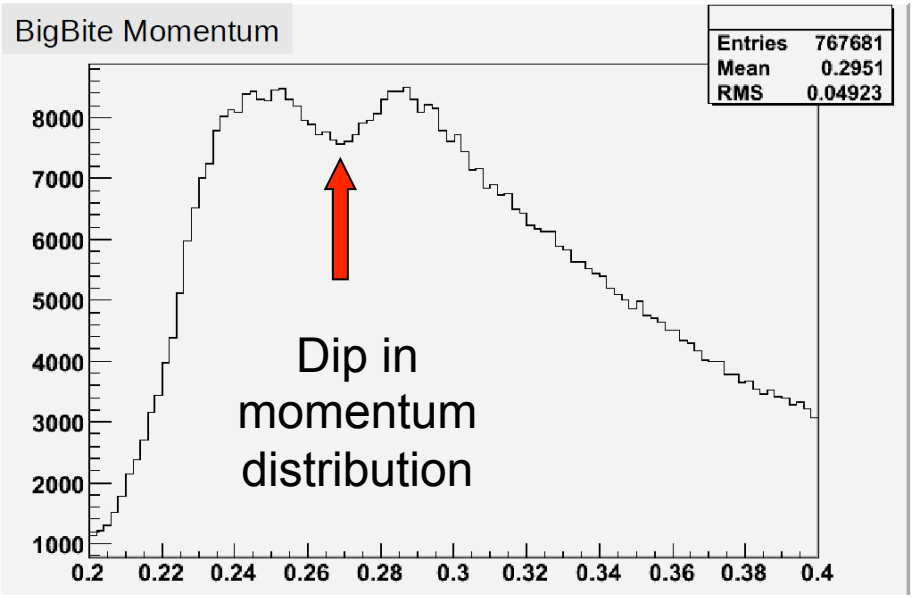
Data Φ* Acceptance



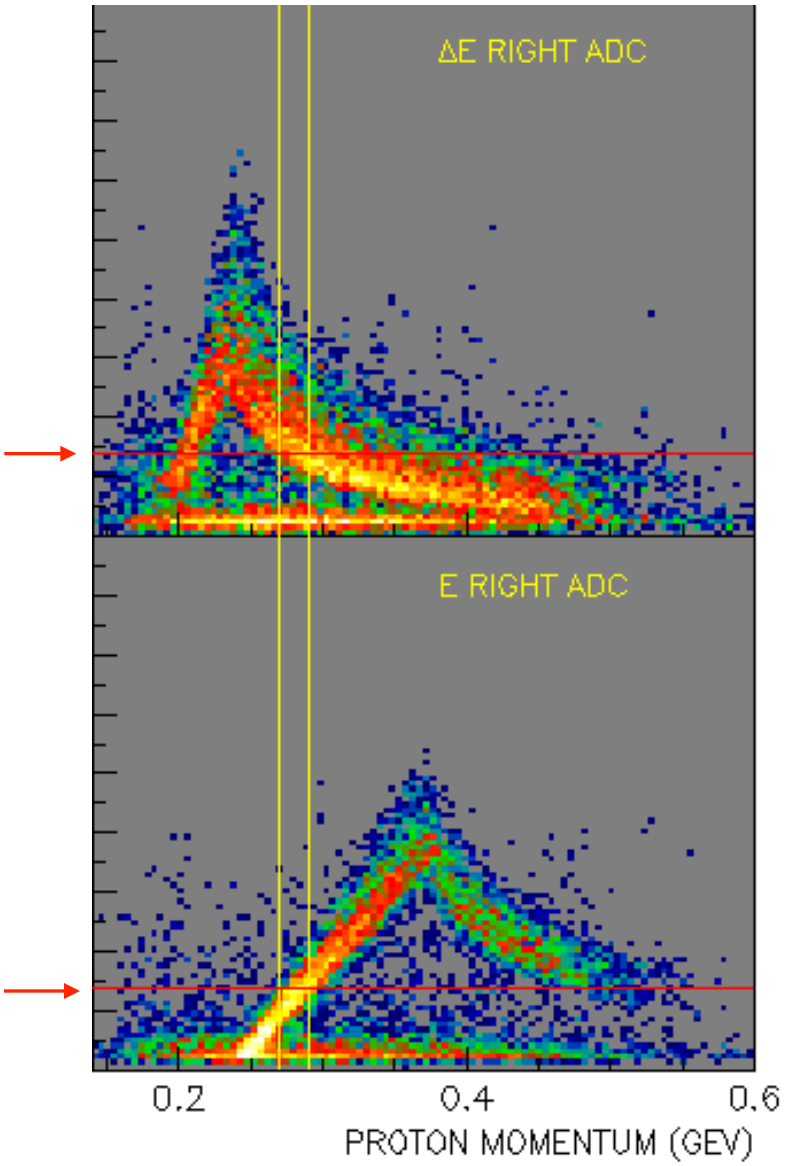
BigBite: E-ΔE Inefficiency 1

Problem

- trigger inefficiency

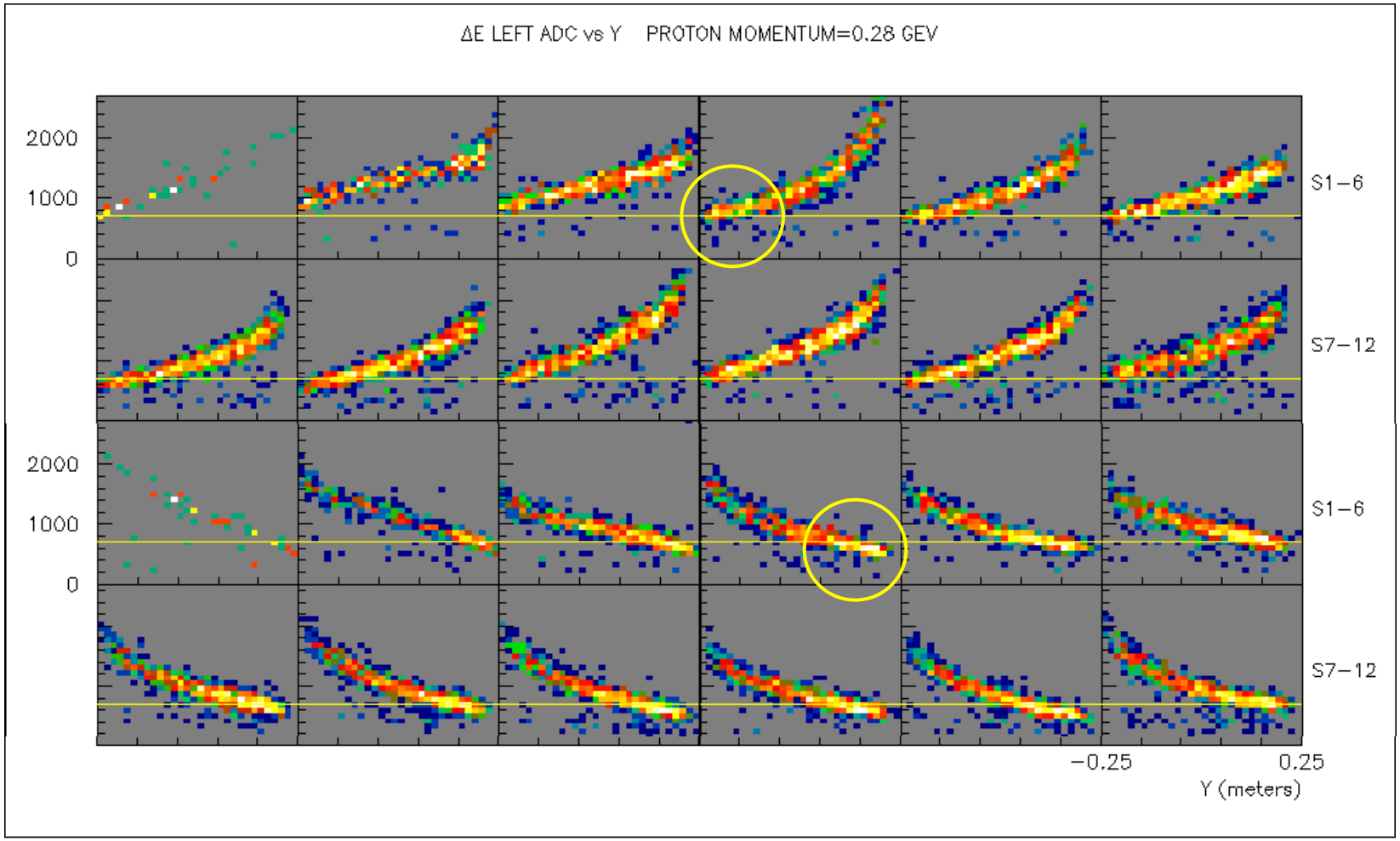


From Khem's June 2011 talk



Explanation: TDC threshold (red line) coincides with overlap in E and ΔE coverage around p=0.27 GeV/c.

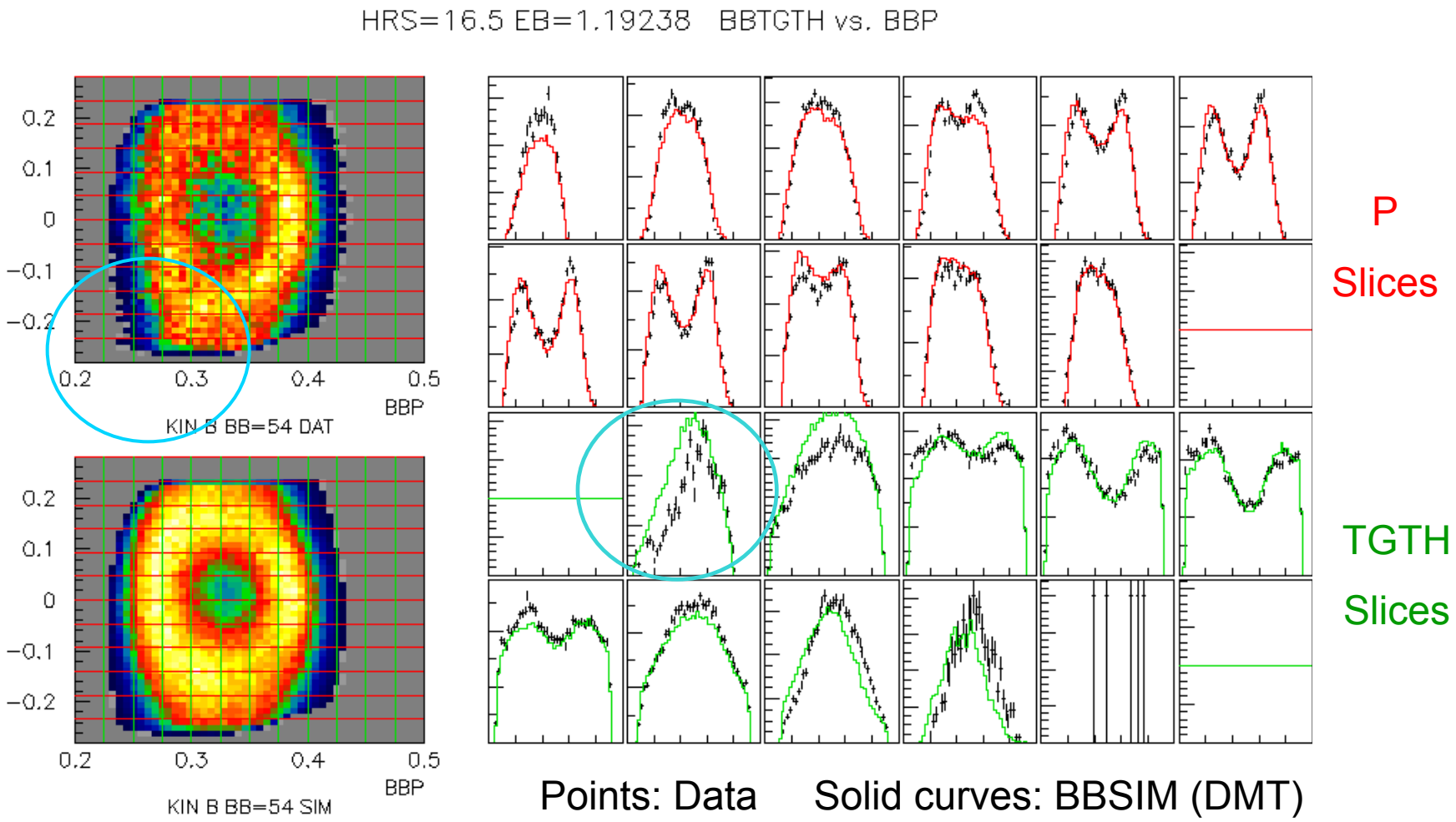
BigBite: E-ΔE Inefficiency 2



Problem is worse at ends of paddles where light attenuation prevents signal from exceeding both L and R TDC thresholds

Solution: Loosen requirement of L•R in software and take either L or R. Requires another method to calculate mean time (use DL.t3 timing, BB.y correction, etc.)

BigBite Acceptance



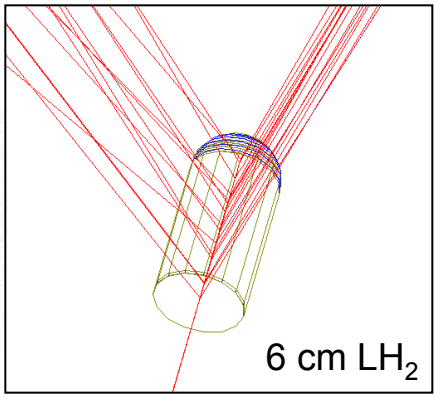
Data and SIM generally in agreement with exceptions near edges at low p.

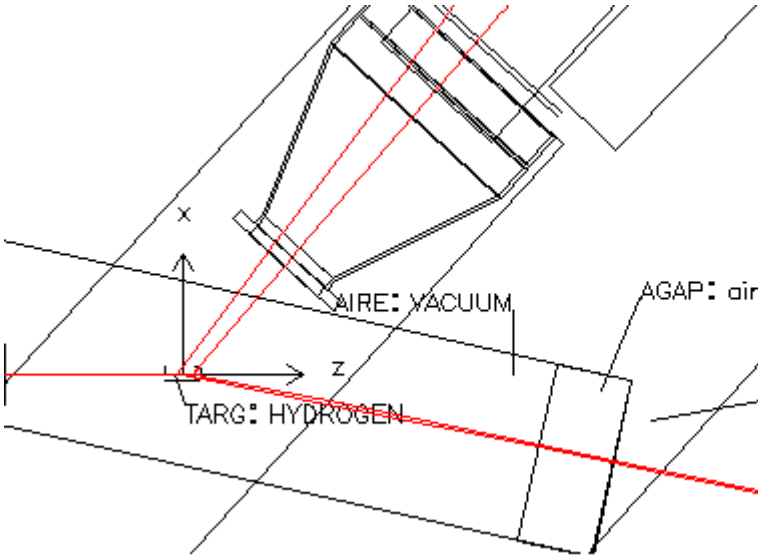
Need to check whether trigger scintillator location in BBSIM is correct.

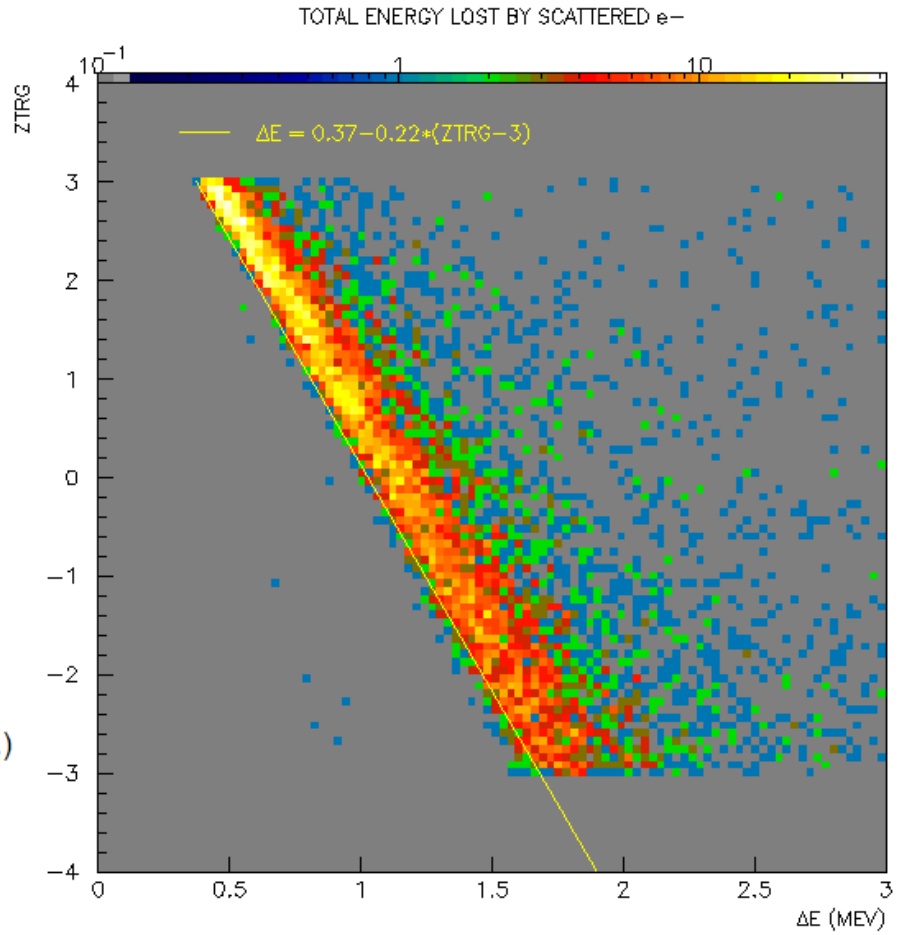
BBSIM: Target

$$\sigma_{exp}(E, E', \Theta) = \frac{d\sigma_{exp}}{d\Omega dE'} = \int_0^T \frac{dT}{T} \int_{E_{min}}^{E} dE_1 \int_{E'}^{E'_{max}} dE'_1$$

$$I_e(E, E_1, t)\ \sigma_{rad}(E_1, E'_1, \Theta)\ I'_e(E'_1, E', T - t)$$



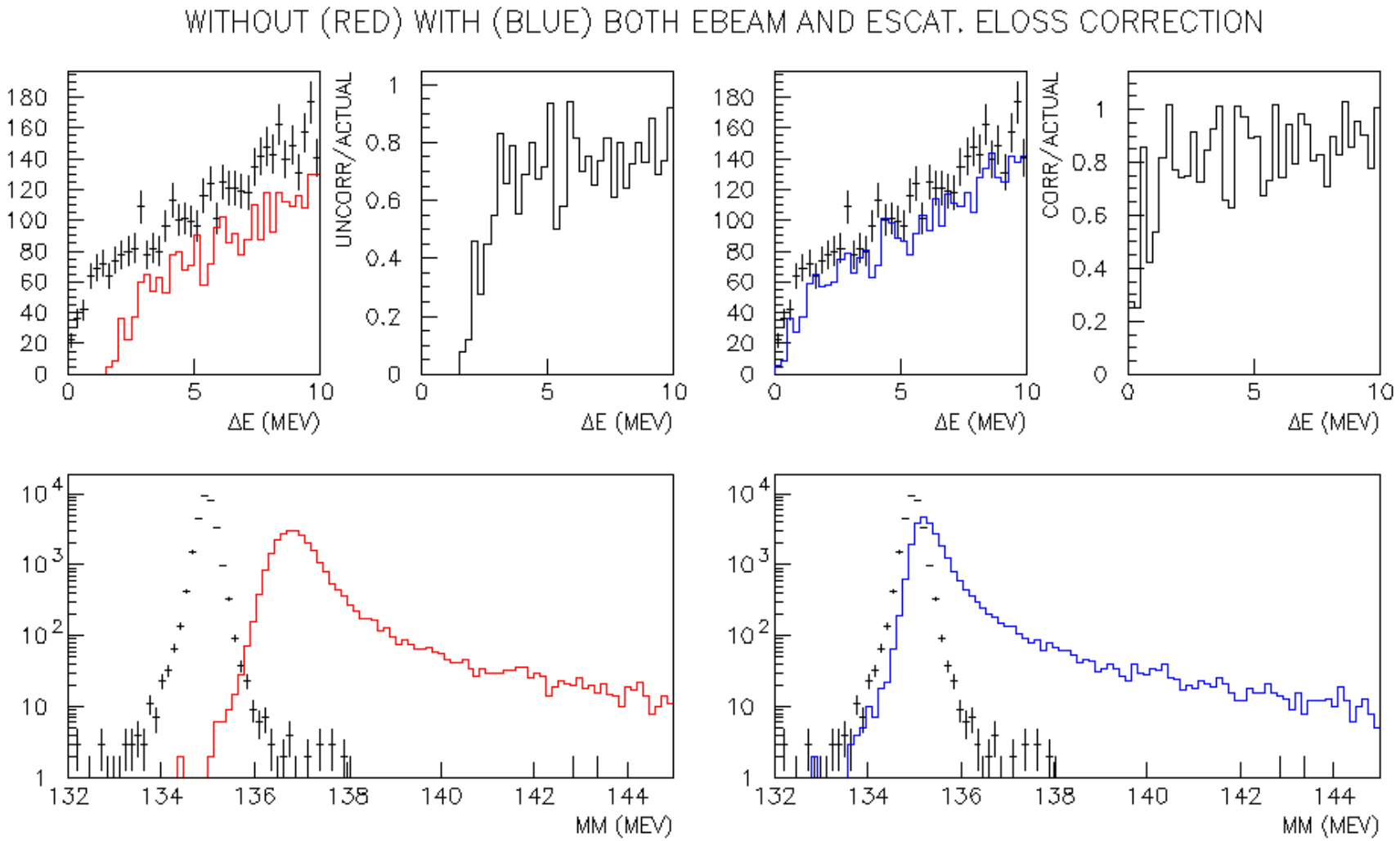




Currently in BBSIM:

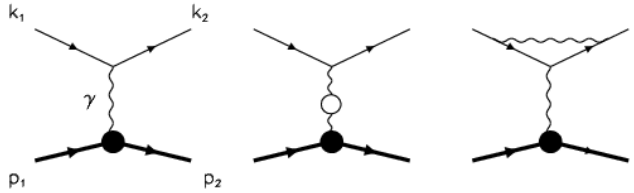
- Target cell walls are 0.0142 cm of AL 7075 (for loop 1 bottom.)
- Target chamber windows are 380 μ AL 7075
- Air gap is 12.7 cm
- HRS entrance window is 175 μ Kapton

Straggling corrections at threshold

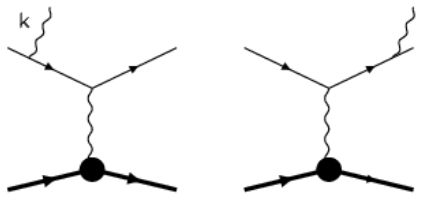


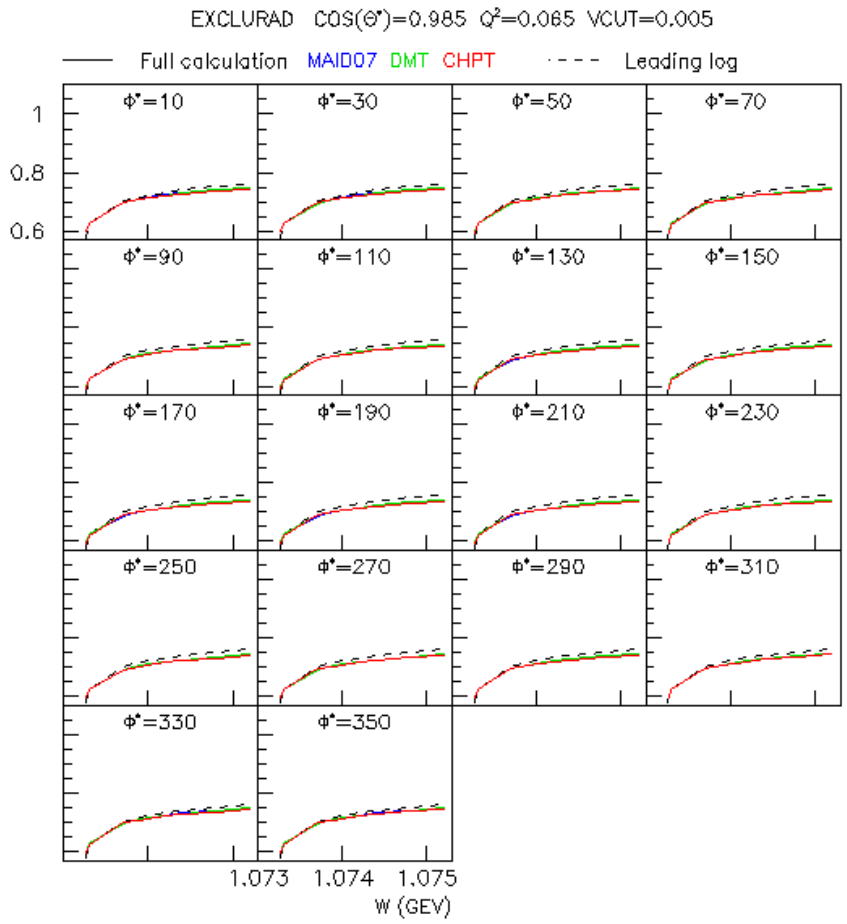
Radiative Corrections

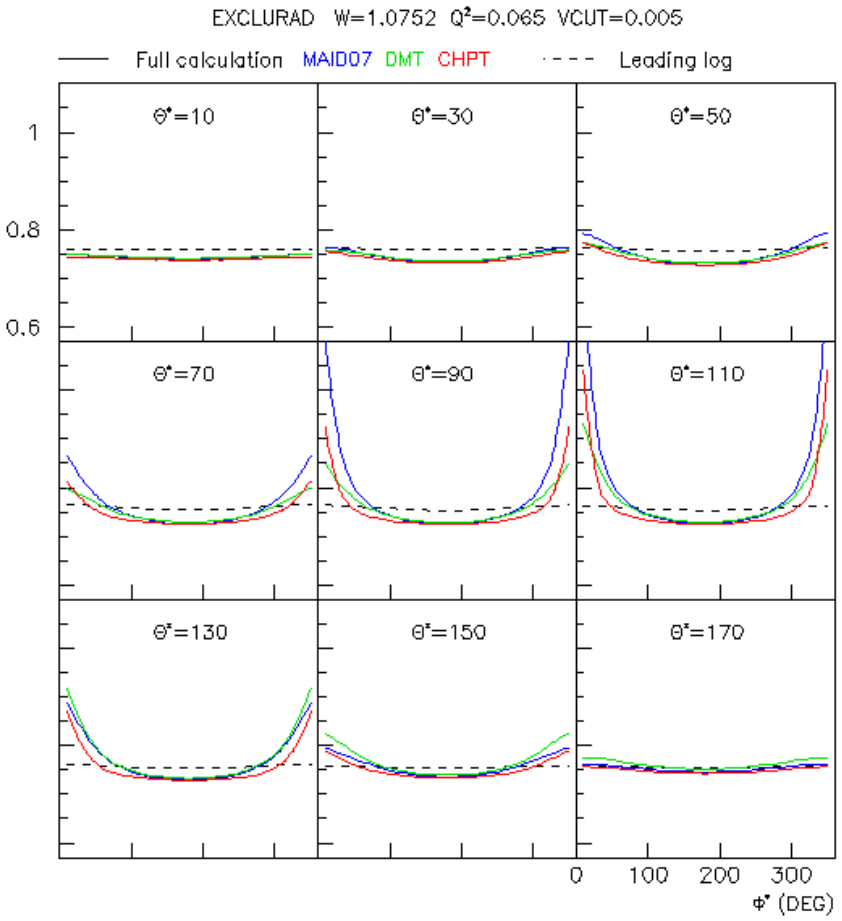
Non-radiated part of cross section



Radiated part of cross section





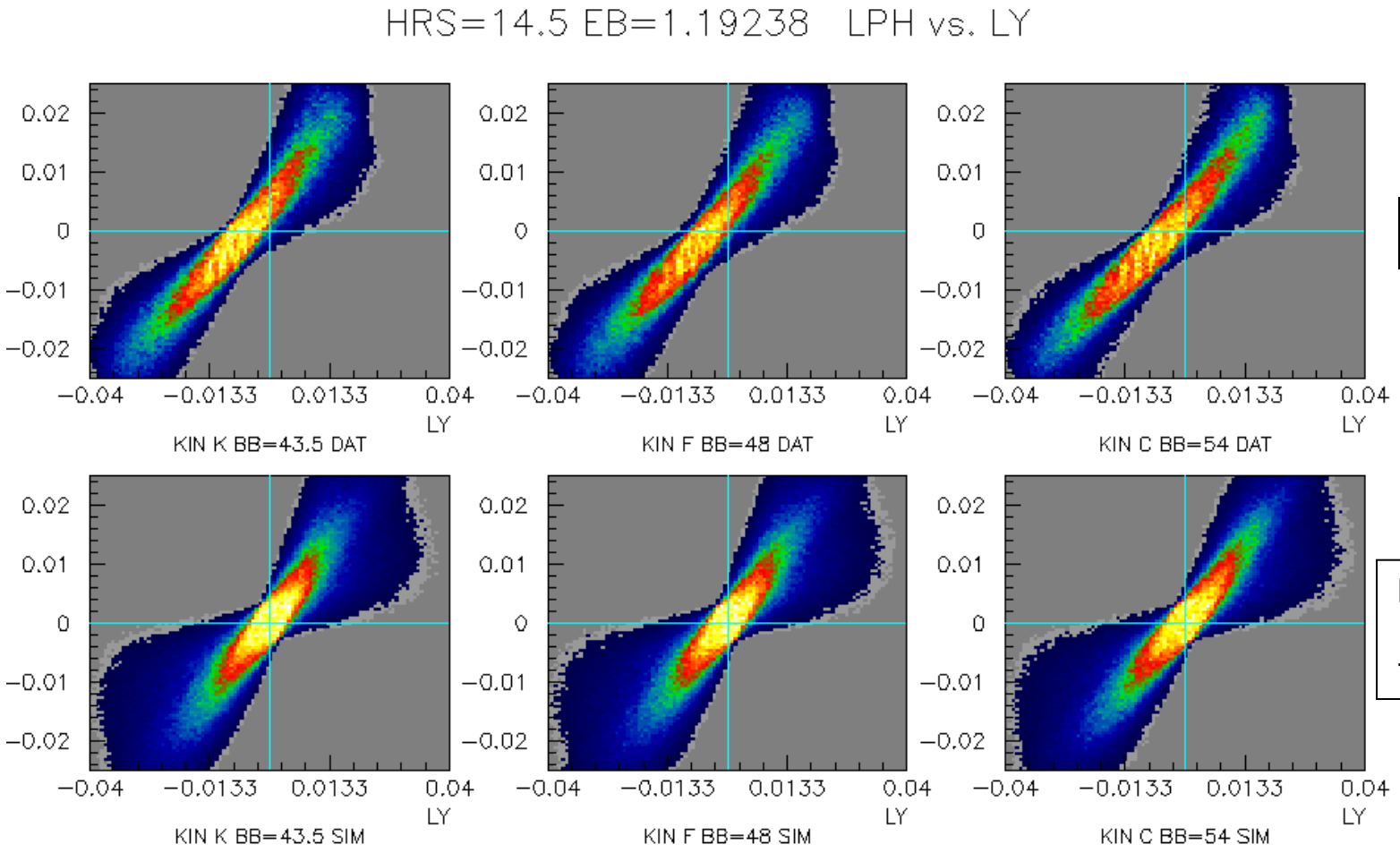


LHRS: Transverse focal plane

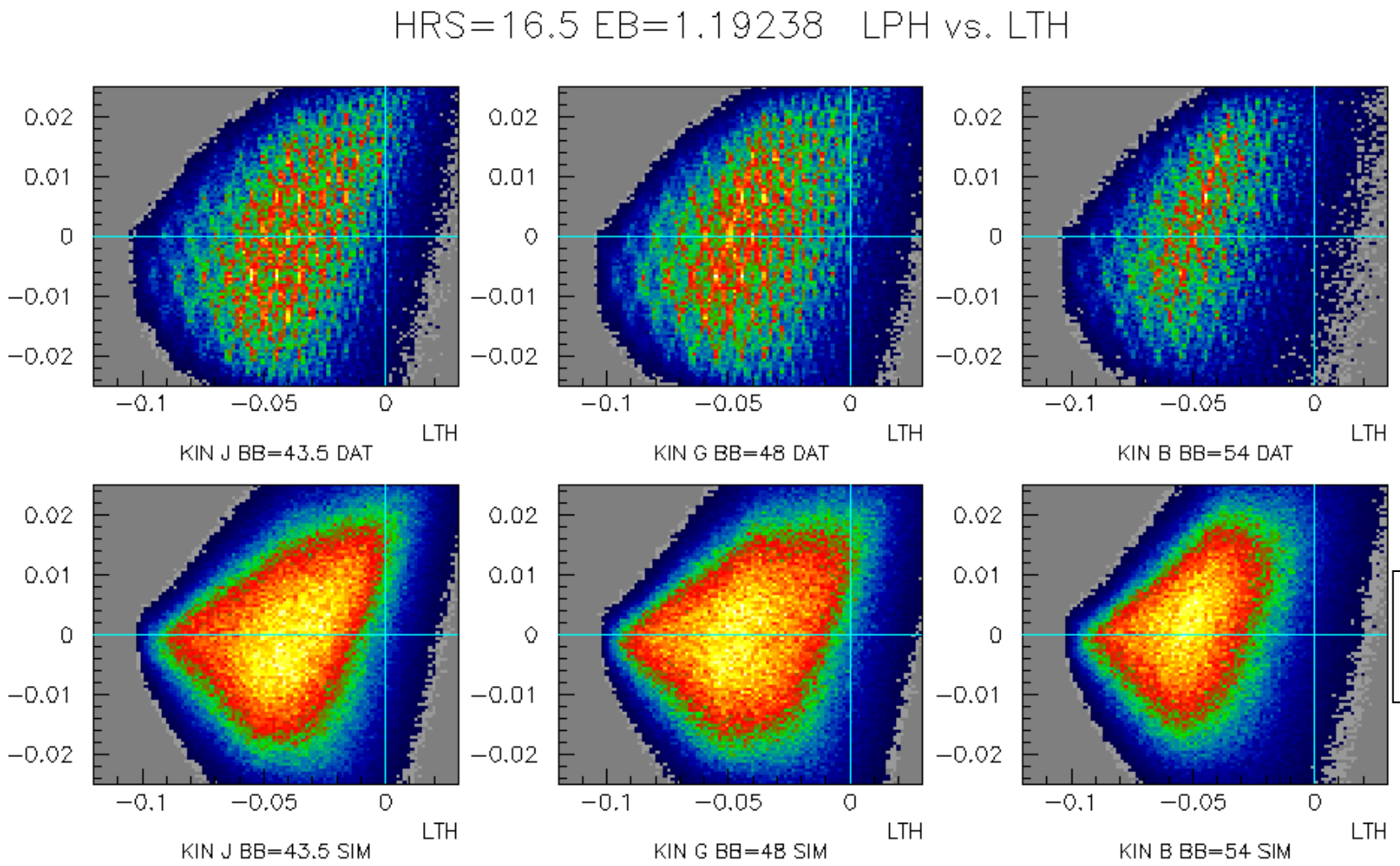
Offsets in LPH and especially LY (~2 wire spacings) larger than nominal.

```
[ L.global ]
0.3327 1 0.0 270.2 0.0 -1.6e-03          VDC Angle, Plane Spacing, G
matrix elements
t 0 0 0  -1.001135e+00 -3.313373e-01 -4.290819e-02  4.470852e-03
y 0 0 0  -8.060915e-03  1.071977e-03  9.019102e-04 -3.239615e-04
p 0 0 0  -2.861912e-03 -2.469069e-03  8.427172e-03  2.274635e-03

D 0 0 0   1.5390638e-04  8.370861e-02  1.186891e-02  1.857411e-03
D 1 0 0  -1.737617e-02  2.506738e-01  3.922391e-02  1.188306e-01
```



LHRS: Miscalibration of VDC T0?



Data

BBSIM + LeRose transport

Summary and still to do

- Three main issues affecting analysis at threshold:
  - Radiation straggling and bin migration due to W resolution.
  - Loss of protons at low momenta (< p = 250 MeV/c) in Big Bite.
  - Quasi-free π^0 production from target windows leaking into cuts.

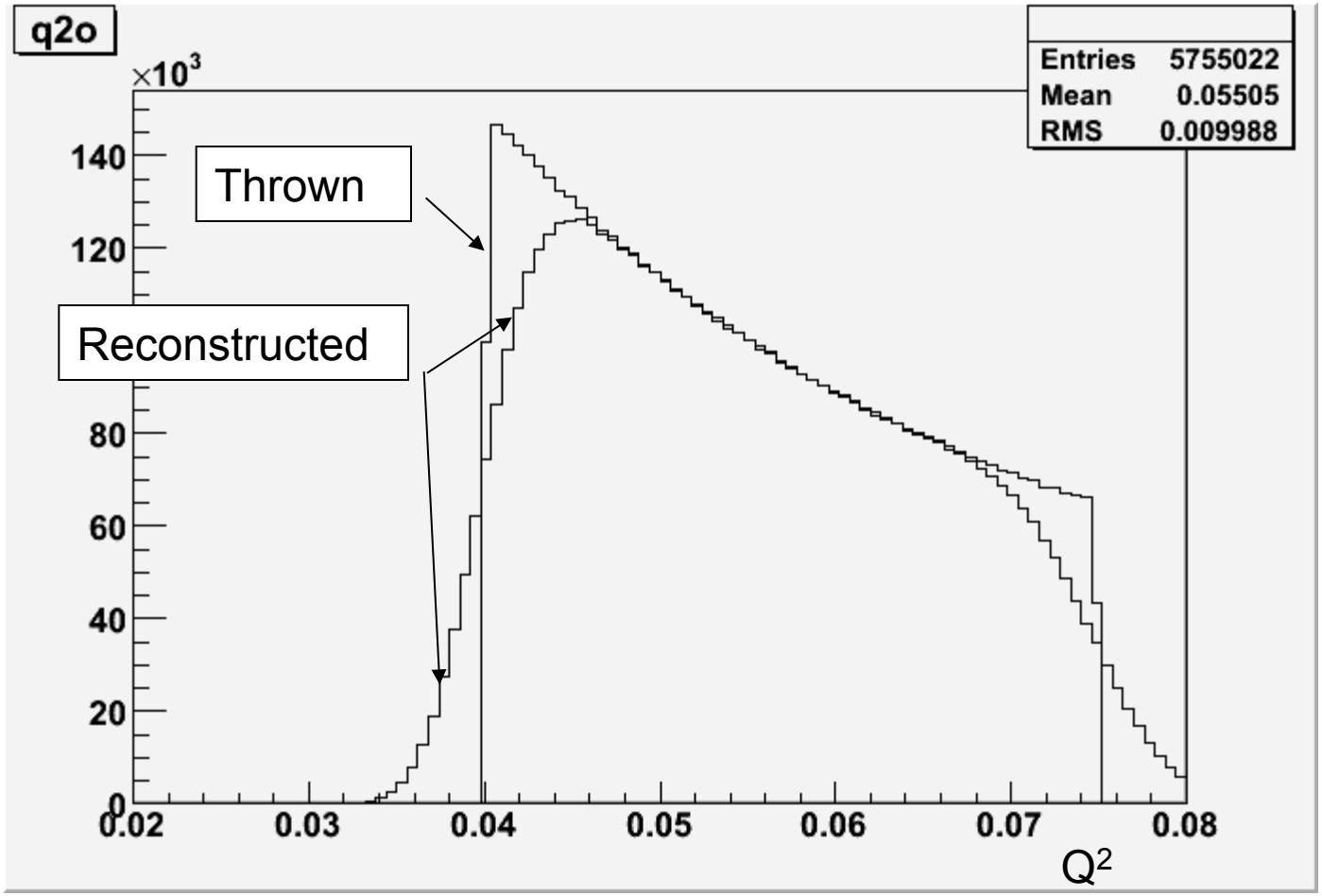
- Need to improve agreement SIM vs. DATA on position and shape of missing mass peak.
  - Tighter cuts on π^0 peak will reduce backgrounds.
  - Also will reduce radiative tail corrections.

- Full bin-by-bin radiative corrections still to be applied.
  - Exclurad or Borie-Drecshel?
  - Probably need to incorporate radiated model into event generator.

- Systematic shifts in cross section (acceptance?) for Q^2 bins at edge of LHRS acceptance.
  - May be related to database or T0 calibration issues.
  - Treatment of resolution smearing at edge of acceptance is always problematic - will probably require MCEEP or SIMC.

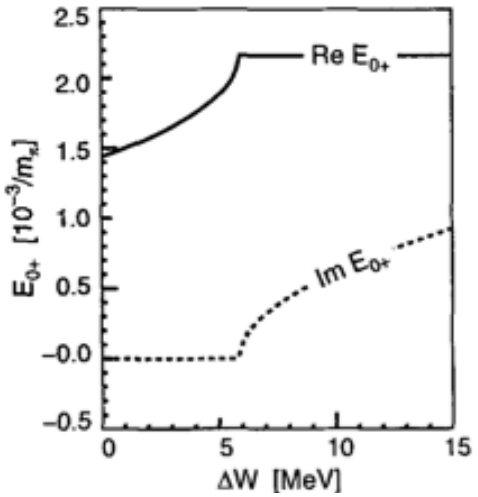
Backup

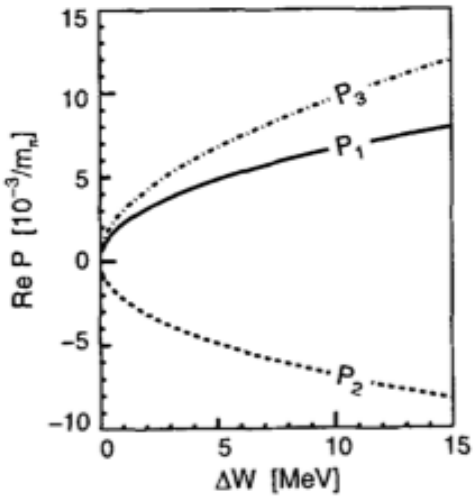
LHRS: Resolution and bin migration



Extraction of s-,p-wave multipoles

$$\sigma_T(\theta) = \frac{p_\pi^*}{k_\gamma^*}(A + B\cdot\cos\theta + C\cdot\cos^2\theta)$$
$$\sigma_L(\theta) = \frac{p_\pi^*}{k_\gamma^*}(A' + B'\cdot\cos\theta + C'\cdot\cos^2\theta)$$
$$\sigma_{TL}(\theta) = \frac{p_\pi^*}{k_\gamma^*}(D\cdot\sin\theta + E\cdot\sin\theta\cos\theta)$$
$$\sigma_{TT}(\theta) = \frac{p_\pi^*}{k_\gamma^*}(F\cdot\sin^2\theta)$$





$$A = |E_{0+}|^2 + \frac{1}{2}(|P_2|^2 + |P_3|^2)$$
$$B = 2\cdot\Re E_{0+}^*\cdot P_1$$
$$C = |P_1|^2 - \frac{1}{2}(|P_2|^2 + |P_3|^2)$$
$$D = -\Re(E_{0+}\cdot P_5^* + L_{0+}\cdot P_2^*)$$
$$E = \Re(P_1\cdot P_5^* + P_4\cdot P_2^*)$$
$$F = \frac{1}{2}(|P_2|^2 - |P_3|^2)$$

$$P_1 = 3E_{1+} + M_{1+} - M_{1-}$$
$$P_2 = 3E_{1+} - M_{1+} + M_{1-}$$
$$P_3 = 2M_{1+} + M_{1-}$$
$$P_4 = 4L_{1+} + L_{1-}$$
$$P_5 = L_{1-} - 2L_{1+}$$

Electroproduction Measurements as of 2002

Q^2=0.05

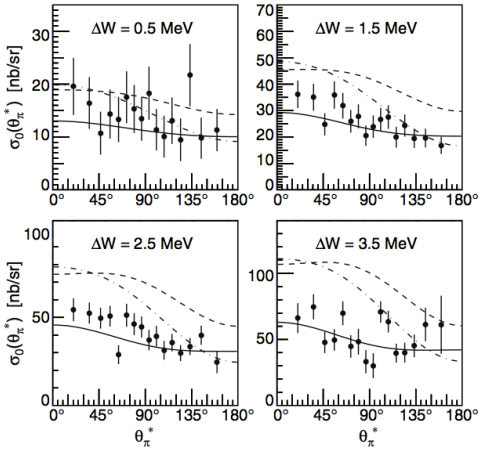


FIG. 1. Differential cross sections for the first 4 MeV above threshold for the virtual photon polarization $\epsilon = 0.72$. The solid line represents a fit with the assumption of only s and p waves contributing, the dashed and dash-dotted lines represent the predictions of HBChPT [12] and MAID [17].

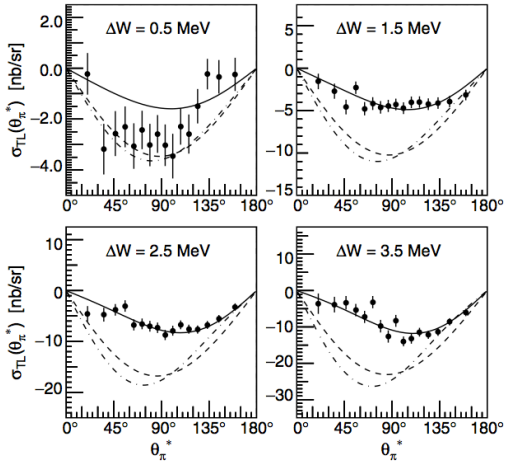


FIG. 2. The transverse-longitudinal interference structure function, determined as weighted average of all three settings for ϵ. Assignment of lines as in Fig. 1.

Q^2=0.10

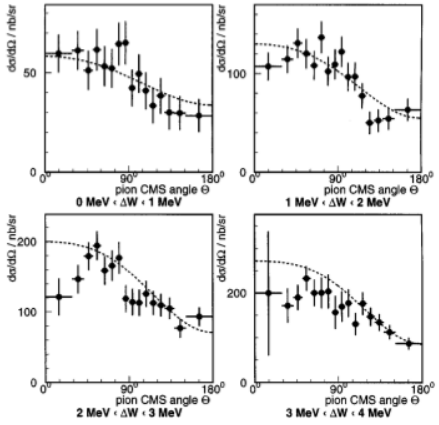


FIG. 2. The differential cross section $(d\sigma/d\Omega_\pi^*)$ as a function of the polar angle θ_π^* of the pion in the cm system at a beam energy of 555 MeV ($\epsilon = 0.713$) for four different regions in the invariant mass above production threshold. The dashed line shows the new fit of HBChPTh.

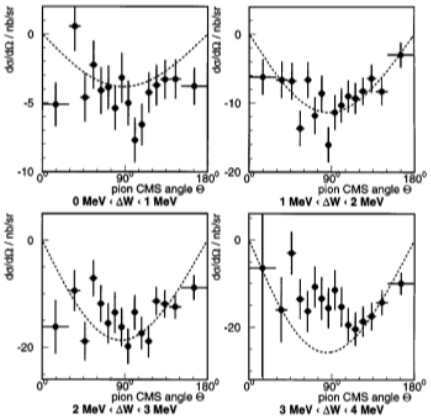


FIG. 3. The same as Fig. 2 for $d\sigma_{LT}/d\Omega_\pi^*$.

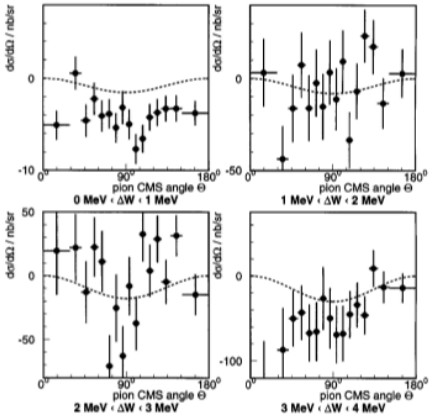


FIG. 4. The same as Fig. 2 for $d\sigma_{TT}/d\Omega_\pi^*$.

Status of Multipole Results - 2002