Precision Measurement of Electroproduction of π^0 Near Threshold

Khem Chirapatpimol
University of Virginia

Co-spokespersons: J. Annand, D. Higinbotham, B. Moffit,
R. Lindgren, V. Nelyubin, and B. Norum

Ph. D. students K. Chirapatpimol, M. Shabestari, J. Ge

and

Hall A collaboration

Background

Because the coupling between quarks in QCD increases at low energies, normal perturbation theory does not work at low energy.

There is a effective theory known as chiral perturbation theory(ChPT) that is expected to work well at low Q^2, low energy and momentum

ChPT

Start with a Lagrangian embodying the underlying symmetries of QCD expressed in terms of the relevant degrees of freedom: the pion and nucleon.
Scattering or production processes can be described in terms of small quantities Q/M, and m_π /M.

The detail of interaction are absorbed into parameters called Low Energy Constants(LEC's), which obtained by measurement. Once LEC's are determined, one can predict the evolution of cross section with Q^2 and W(center of mass energy of the π-N system).

Differential cross section

The differential cross section for pion electro-production using an unpolarized electron beam can be written as

$$\frac{d\sigma}{d\Omega_e d\Omega_\pi^{cm} dE'} = \Gamma \left\{ \frac{d\sigma_T}{d\Omega_\pi^{cm}} + \epsilon_L \frac{d\sigma_L}{d\Omega_\pi^{cm}} + \left[2\epsilon_L(1+\epsilon)\right]^{1/2} \frac{d\sigma_{LT}}{d\Omega_\pi^{cm}} \cos\phi + \epsilon \frac{d\sigma_{TT}}{d\Omega_\pi^{cm}} \cos 2\phi \right\}$$

The transverse and longitudinal photon polarization parameters, ϵ and ϵ_L, and the virtual flux factor, Γ are defined as,

$$\epsilon = \frac{1}{1 + 2\vec{q}^2/Q^2 \tan^2 \frac{\theta_e}{2}},$$

$$\epsilon_L = \frac{Q^2}{\nu_{cm}^2}\epsilon,$$

$$\Gamma = \frac{\alpha E' k_\gamma}{2\pi^2 E Q^2 (1-\epsilon)},$$

$$k_\gamma = \frac{W^2 - m^2}{2m},$$

$$\nu_{cm} = \frac{W^2 - m^2 - Q^2}{2W}.$$

S and P Waves Give 7 Pion Multipoles

- $\frac{d\sigma_T}{d\Omega_\pi^{cm}} = |E_{0+}|^2 + \frac{1}{2}\left(|P_2|^2 + |P_3|^2\right) + 2\,\mathrm{Re}\left(E_{0+}P_1^*\right)\cos\theta_\pi^* + \left(|P_1|^2 - \frac{1}{2}\left(|P_2|^2 + |P_3|^2\right)\right)\cos^2\theta_\pi^*$

- $\frac{d\sigma_L}{d\Omega_\pi^{cm}} = \left(|L_{0+}|^2 + |P_5|^2\right) + 2\,\mathrm{Re}\left(L_{0+}P_4^*\right)\cos\theta_\pi^* + \left(|P_4|^2 - |P_5|^2\right)\cos^2\theta_\pi^*$

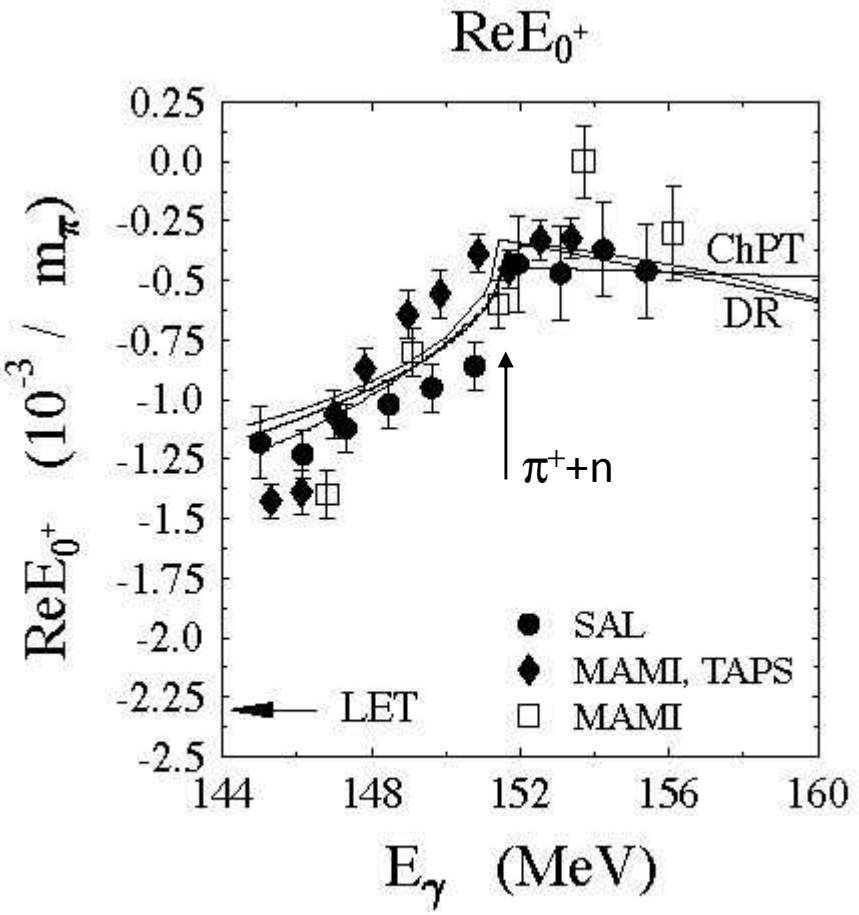
- $\frac{d\sigma_{TT}}{d\Omega_\pi^{cm}} = \frac{1}{2}\left(|P_2|^2 - |P_3|^2\right)\sin^2\theta_\pi^*$

- $\frac{d\sigma_{LT}}{d\Omega_\pi^{cm}} = -\mathrm{Re}\left(L_{0+}P_2^* + E_{0+}P_5^*\right)\sin\theta_\pi^* - \mathrm{Re}\left(P_1P_5^* + P_4P_2^*\right)\sin\theta_\pi^*\cos\theta_\pi^*$

S Waves	P waves
E_{0+} and L_{0+}	$P_1, P_2, P_3, P_4,$ and P_5

Previous experiments

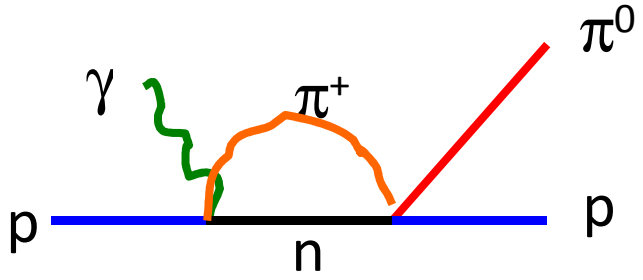
π^0-photo production on the proton $Q^2=0$



(Unitary Cusp)

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

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



Explained by one loop corrections.
Was a real triumph of ChPT.
LEC = 14.84 MeV^{-3} [O $(p)^3$],

Classic LET result is -2.3 x $10^{-3}/m_\pi$. (Born terms)
Measured value is -1.3 x $10^{-3}/m_\pi$

π^0-electro production on the proton

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

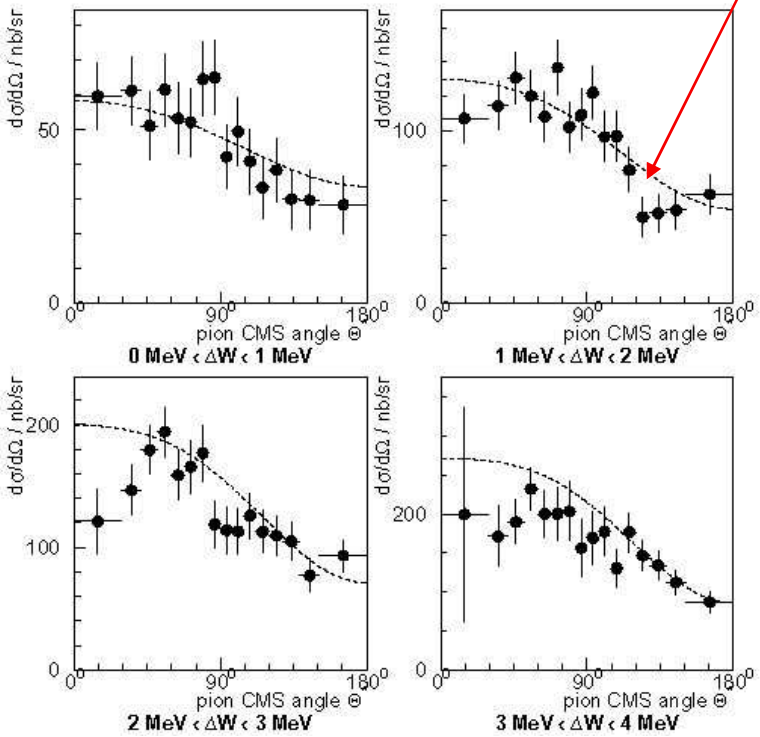
ChPT

ChPT --------

MAID -·-·-·-·-

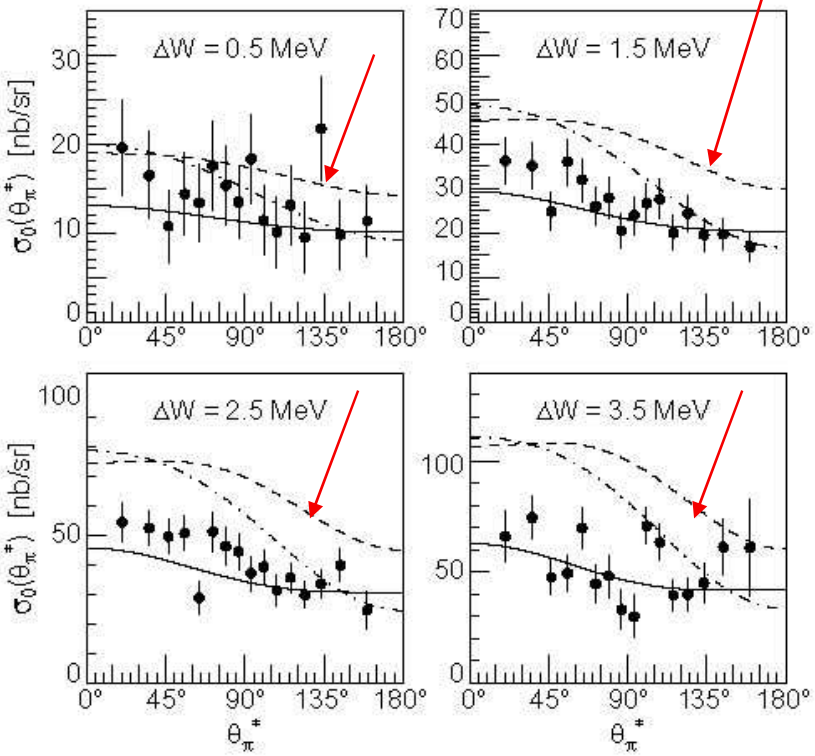
Fit s+p ——

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



Distler et al. PRL 80, 2294 (1998)

Q^2=0.05 (GeV/c)^2



Merkel et al. PRL 88, 12301 (2002)

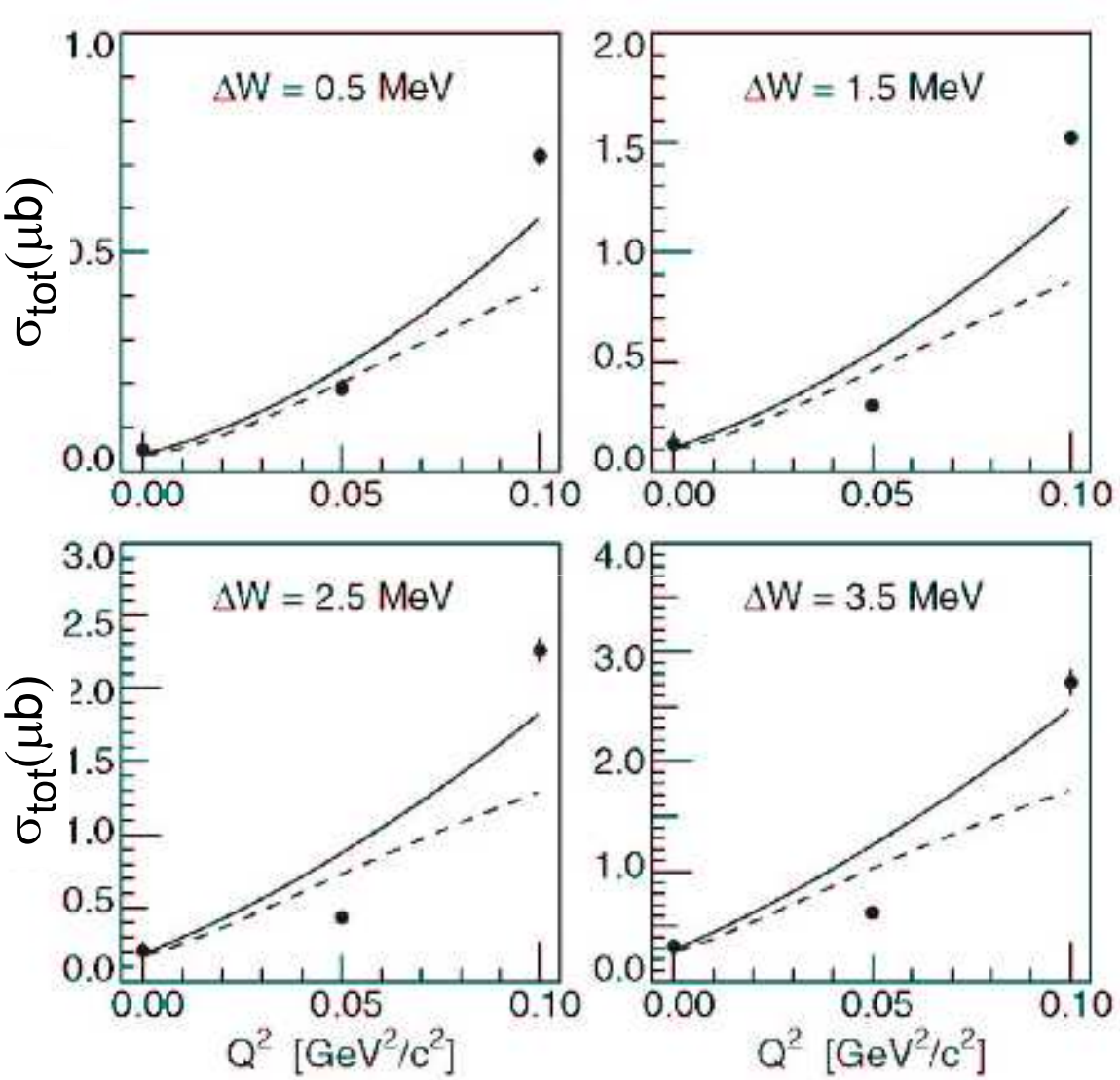
Fixes LEC's

a_3 = - 0.92 and a_4 = - 0.99

Shows the quality of the fit to the data that determines LECs. ChPT prediction gets progressively worse away from threshold.

ChPT Bernard et al. NP A607, 379(1996)

π^0-electro production on the proton



Q^2=0.10 (GeV/c)^2
Distler PRL 80, 2294 (1998)

LEC's
a_3 = - 0.92 and a_4 = - 0.99

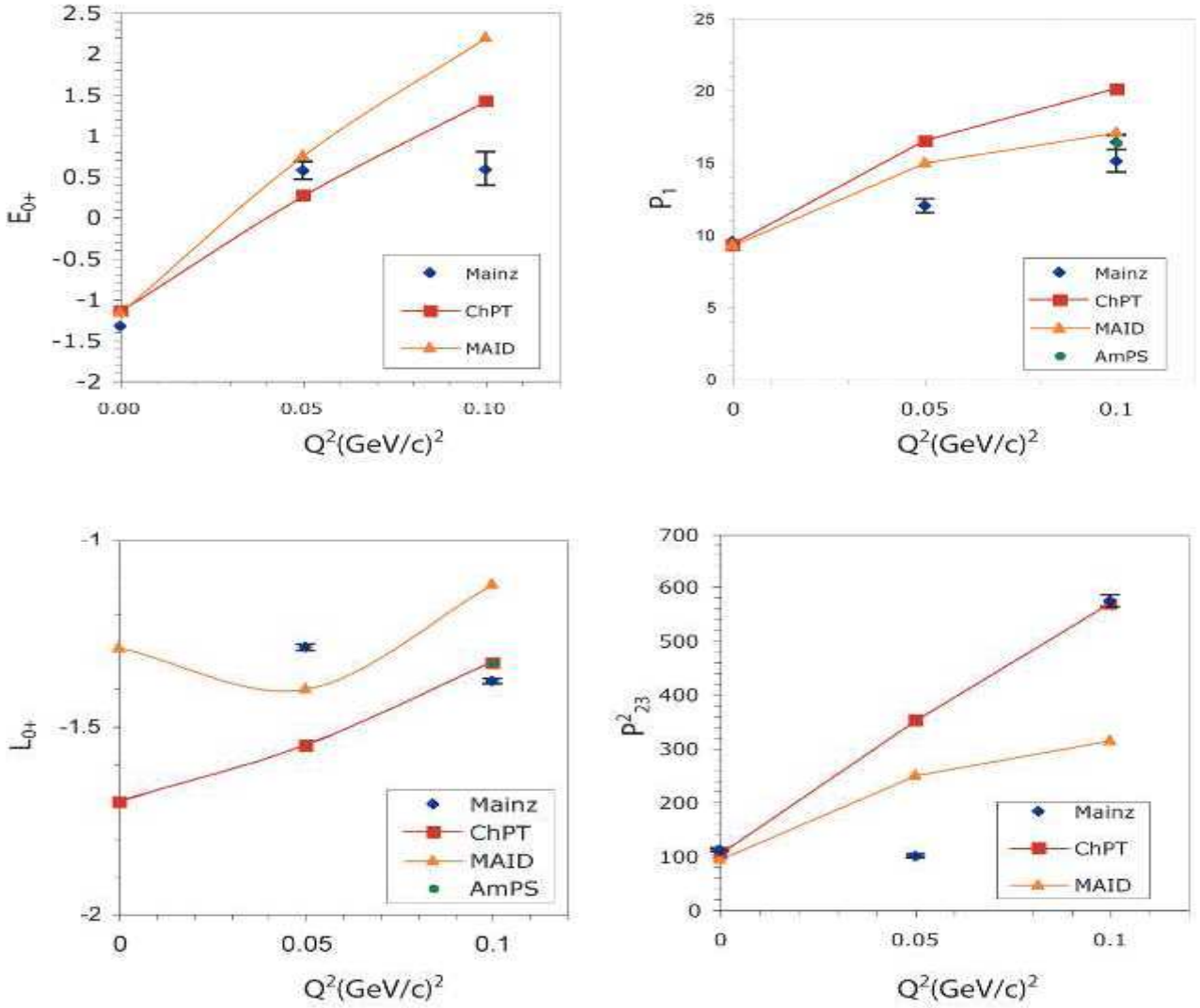
Q^2=0.05 (GeV/c)^2
Merkel et al. PRL 88, 1230 (2002)

ChPT ——
Bernard, et al. NP A607, 379(1996)

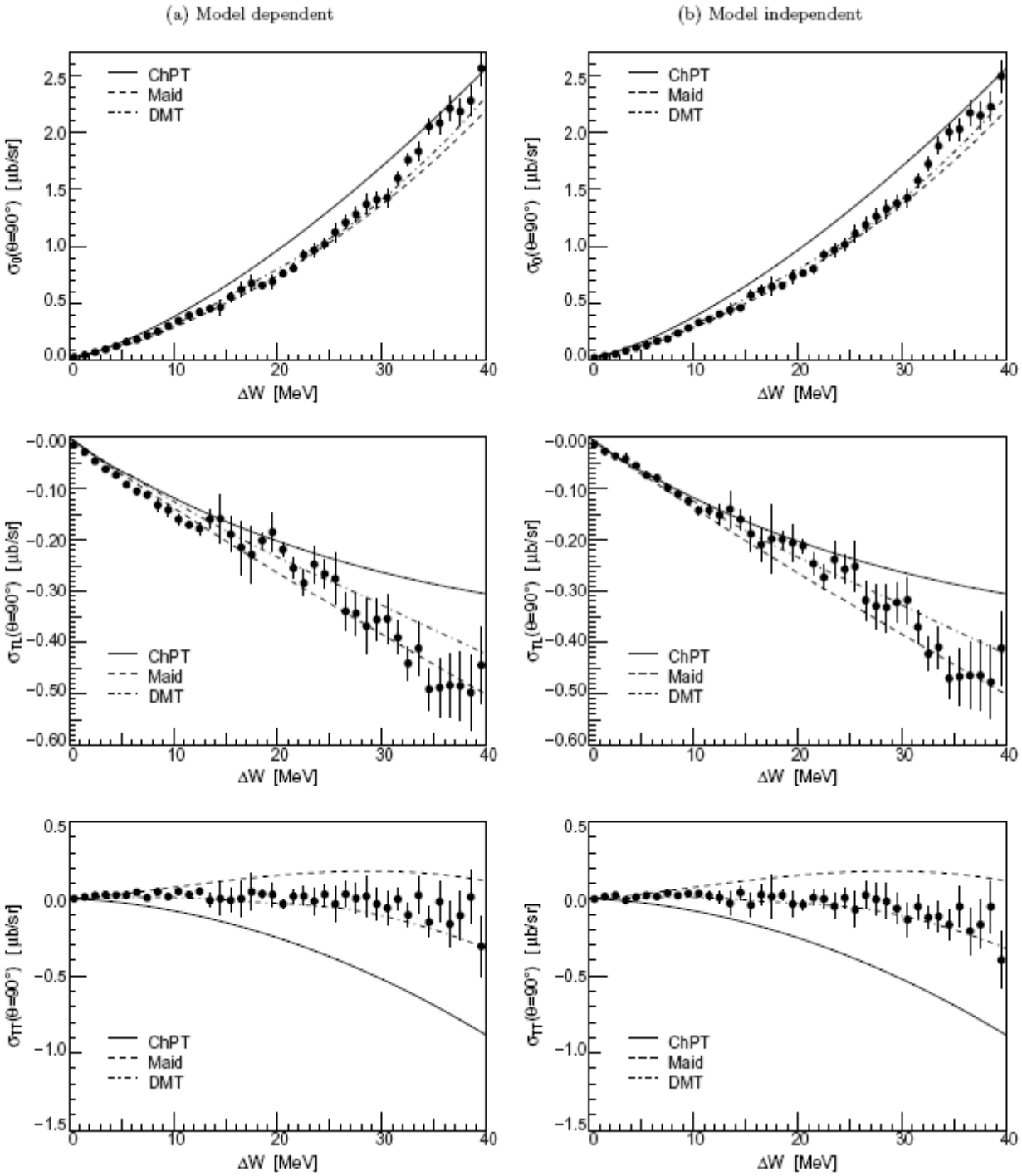
MAID -----

- Large deviations between ChPT and data
- Need data in a finer grid in Q^2

π^0-electro production on the proton



Mainz data are from Distler PRL80 (1998) 2294 and Merkel PRL. 88 (2002)12301
AmPS NIKHEF data are from Welch PRL 69 (1992) 2761



π^0-electro production on the proton Q^2=0.05

From MAMI recent experiment

Weis, Eur. Phys. J. A 38, 27-33(2008)

By the cut in θ a large fraction of events was lost. In addition, the acceptance in θ was different for each kinematical setting. To overcome these two problems, a second, model-dependent method was used to separate the cross-sections. In this method, the phenomenological model MAID was used as parameterization of the cross-section. For each event, the differential cross-section was projected to the nominal kinematics at $\theta = 90°$ by

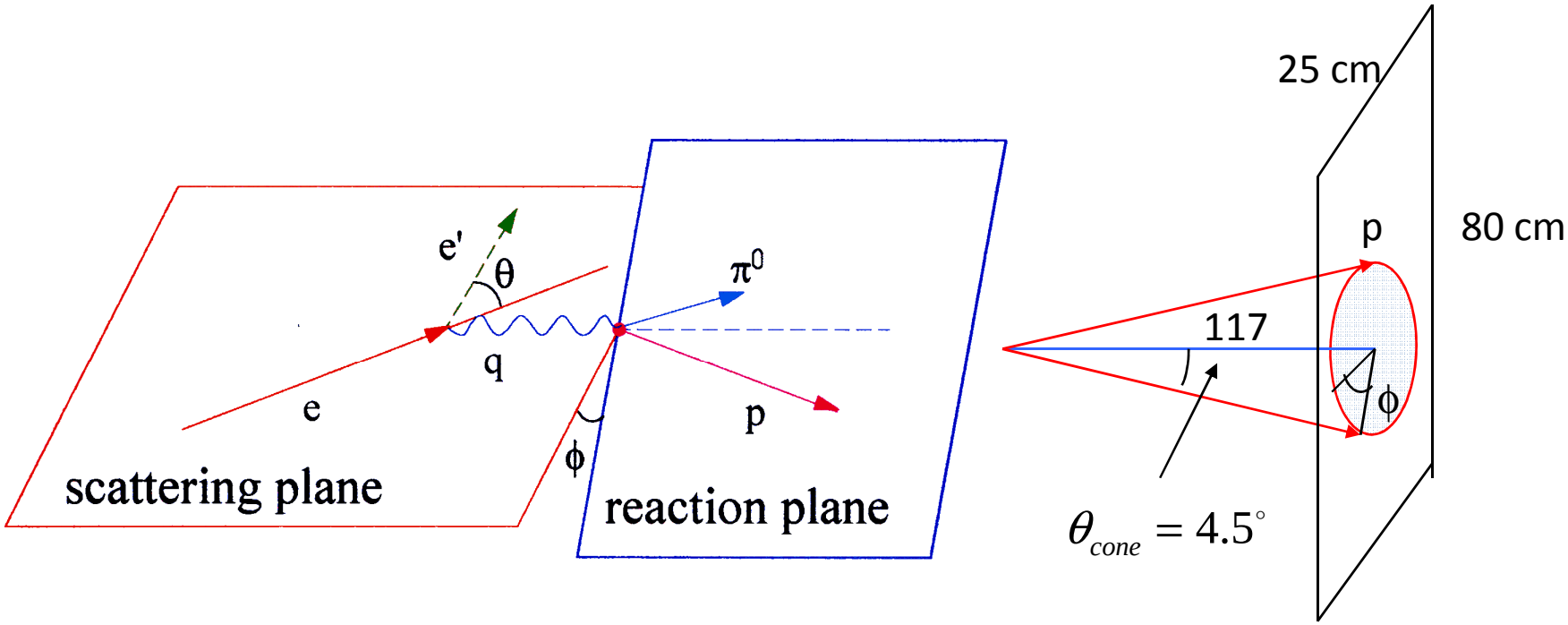
$$\sigma(90°, \phi) = \sigma(\theta, \phi) \frac{\mathrm{MAID}(90°, \phi)}{\mathrm{MAID}(\theta, \phi)} .$$

By this method, the statistical error could be reduced for the price of an additional model error.

The experiment

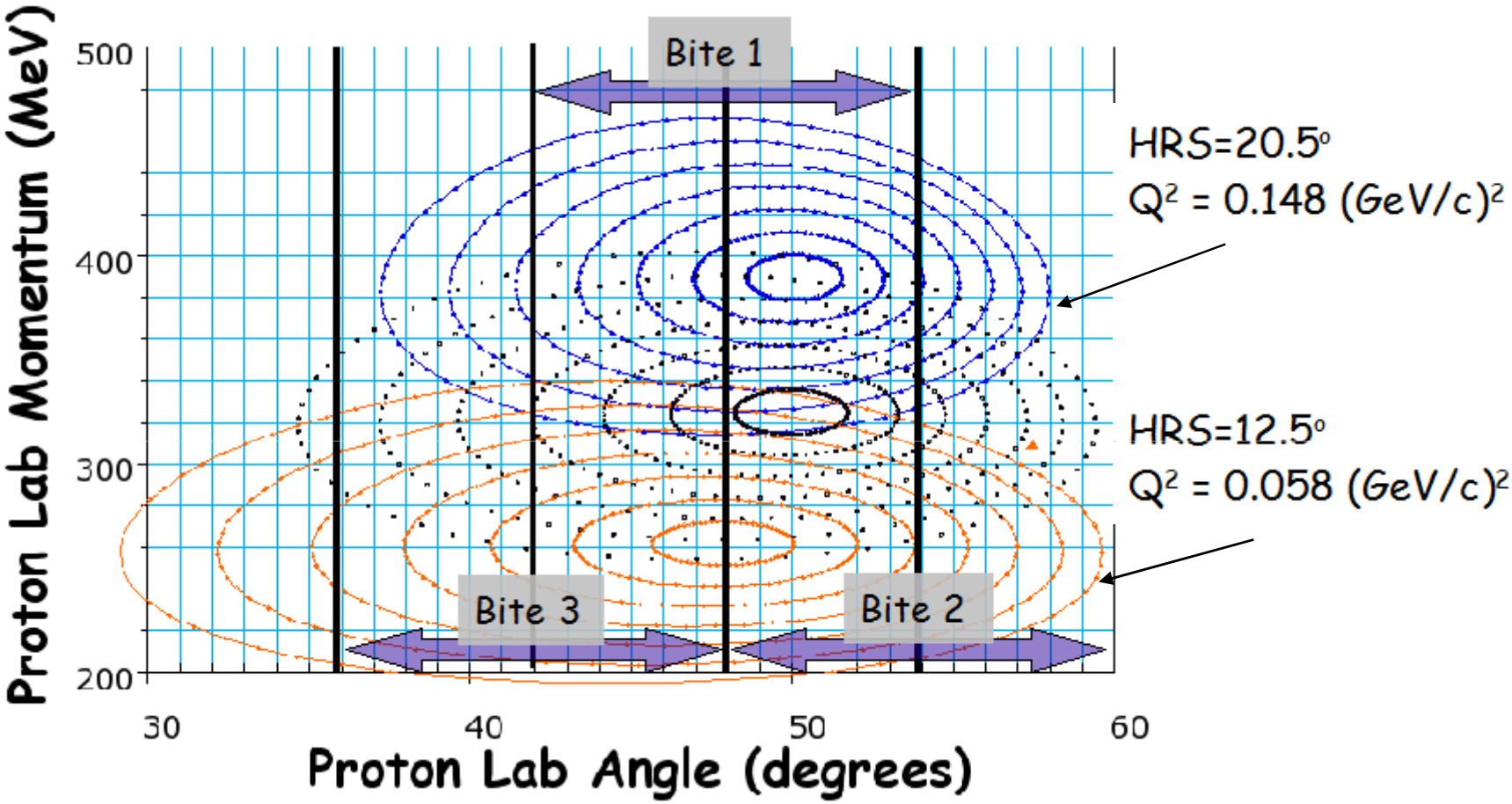
Extract structure functions $\sigma_T+\epsilon_L\sigma_L$, σ_{TL} and σ_{TT} and the asymmetry A_{TL} from $p(e,e'p)\pi^0$ in a fine grid of Q^2 and W from Q^2 = 0.05 - 0.15 in steps of 0.01 $(GeV/c)^2$ and from above threshold$(M+m_\pi)$
ΔW = 0 - 20 MeV in steps of 1 - 2 MeV.
This results will provide a test of chiral dynamics.

W (MeV)	Above Threshold	Q2 (GeV/c)	θ_{cone} (Deg.)
1075	1.7	- 0.05	4.5
1076	2.7	- 0.10	4.5
1095	22	- 0.10	9



BigBite Solid Angle ~100msr Vertical +/- 18 deg
Horizontal +/_ 5 deg

Coverage of bigbite at 1.2 GeV

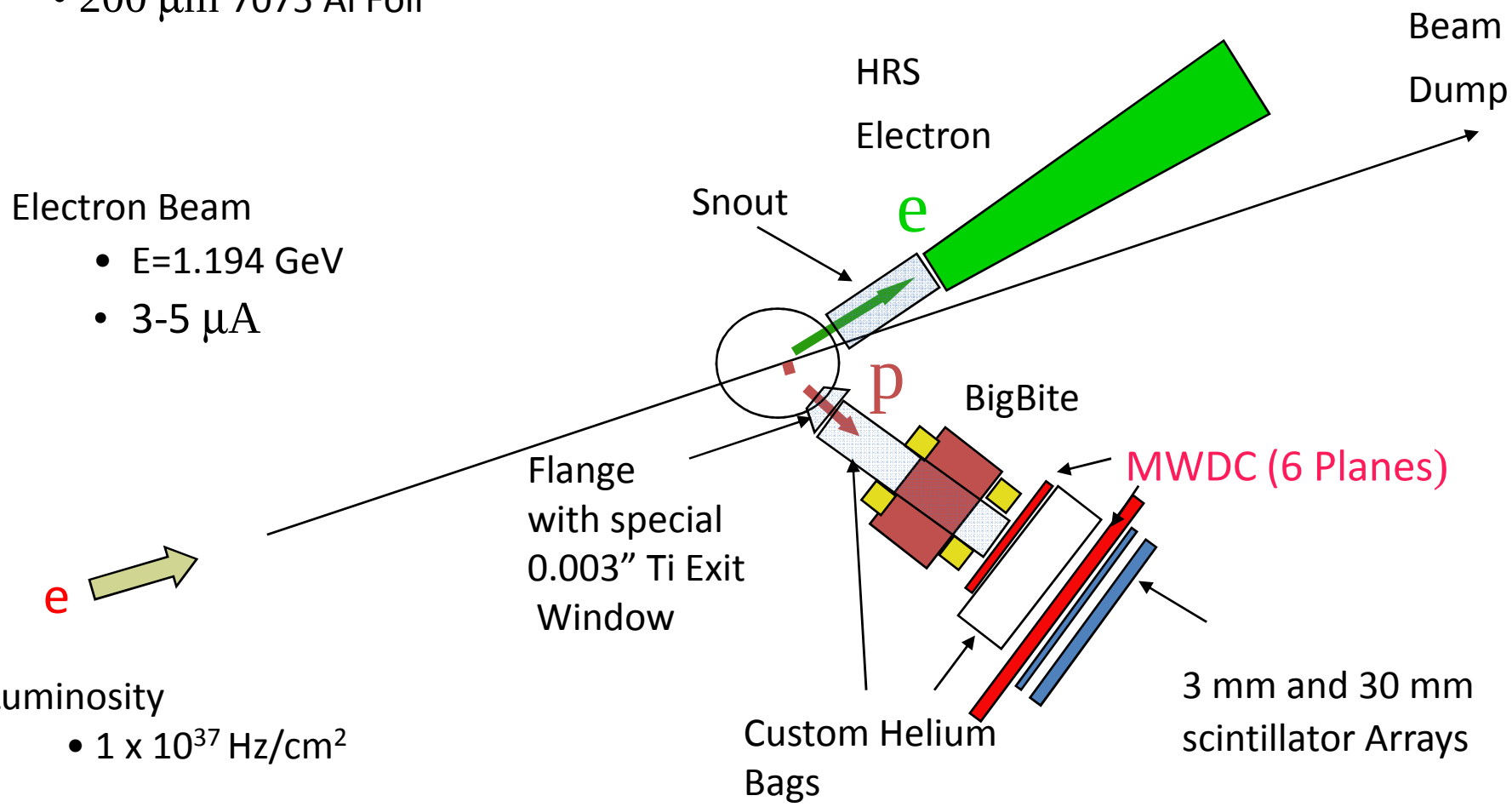


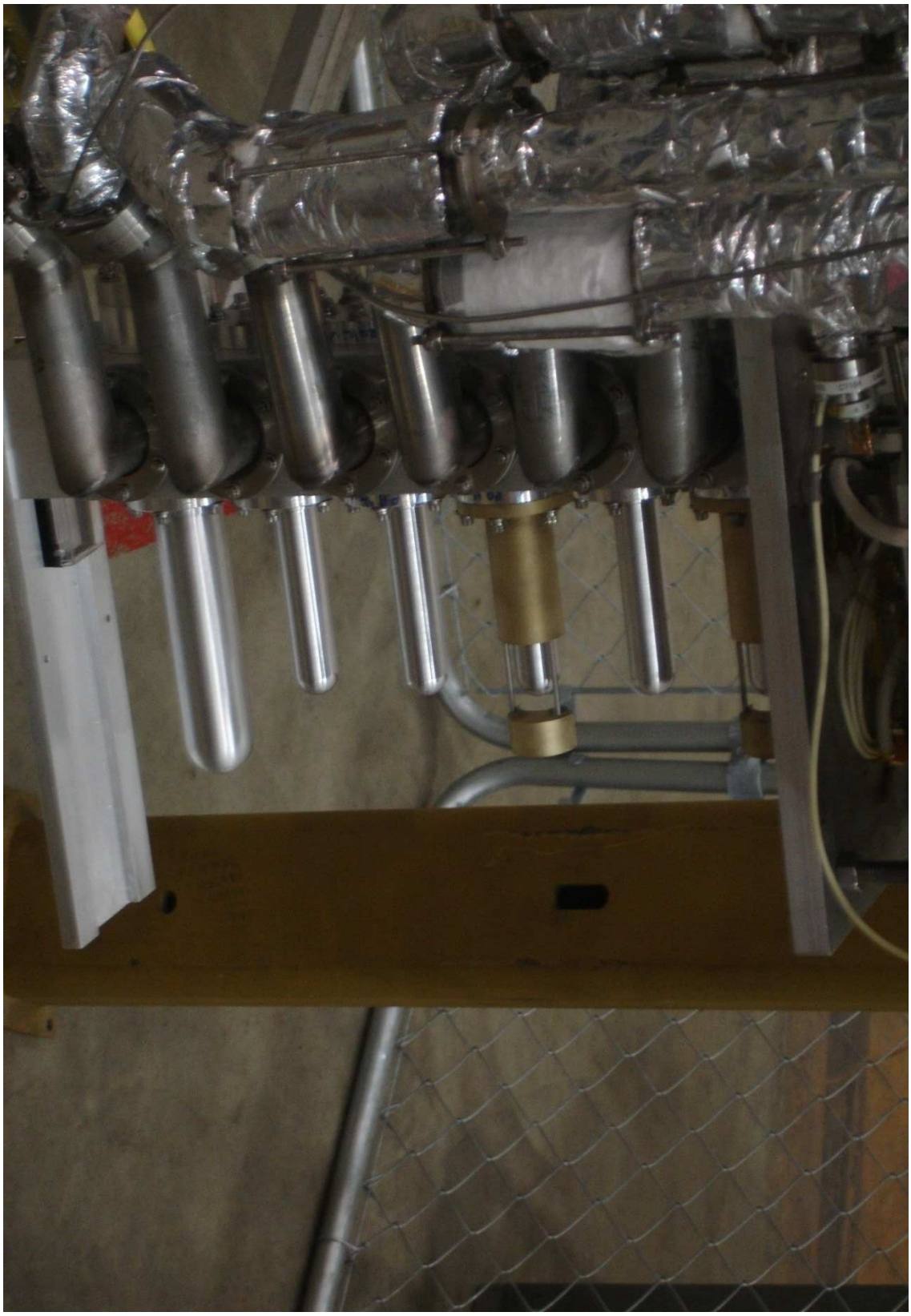
Ellipses of constant ΔW (W relative to π threshold)

E04-007: Threshold H(e,e'p)π° Layout

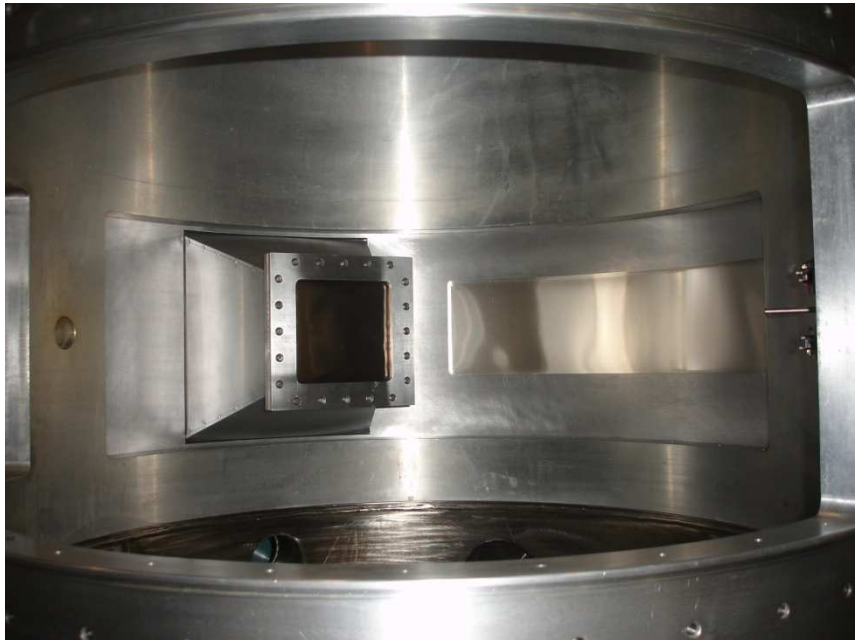
Target

- New 6 cm long, 1” diameter LH2 cell
- 200 μm 7075 Al Foil

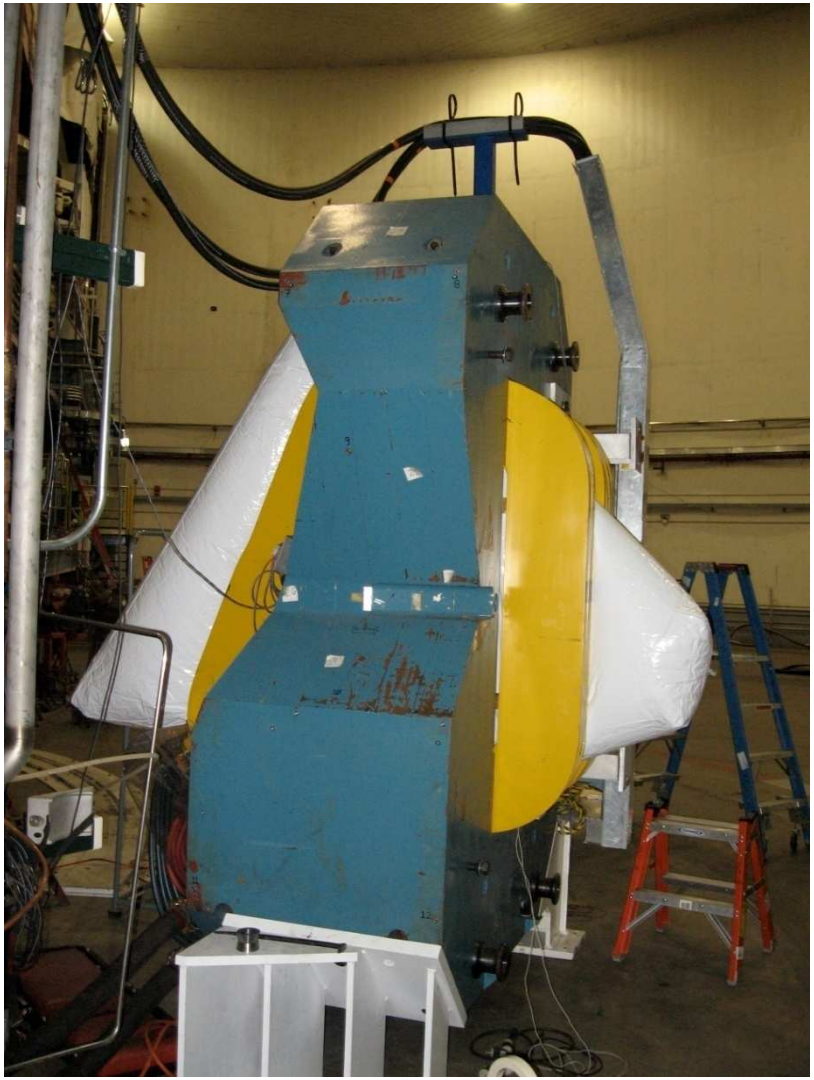




Special Flange with 0.003” Ti Window



E04-007: Custom 0.0035" thick polyurethane helium filled balloon



BigBite Arm

• BigBite Dipole Magnet

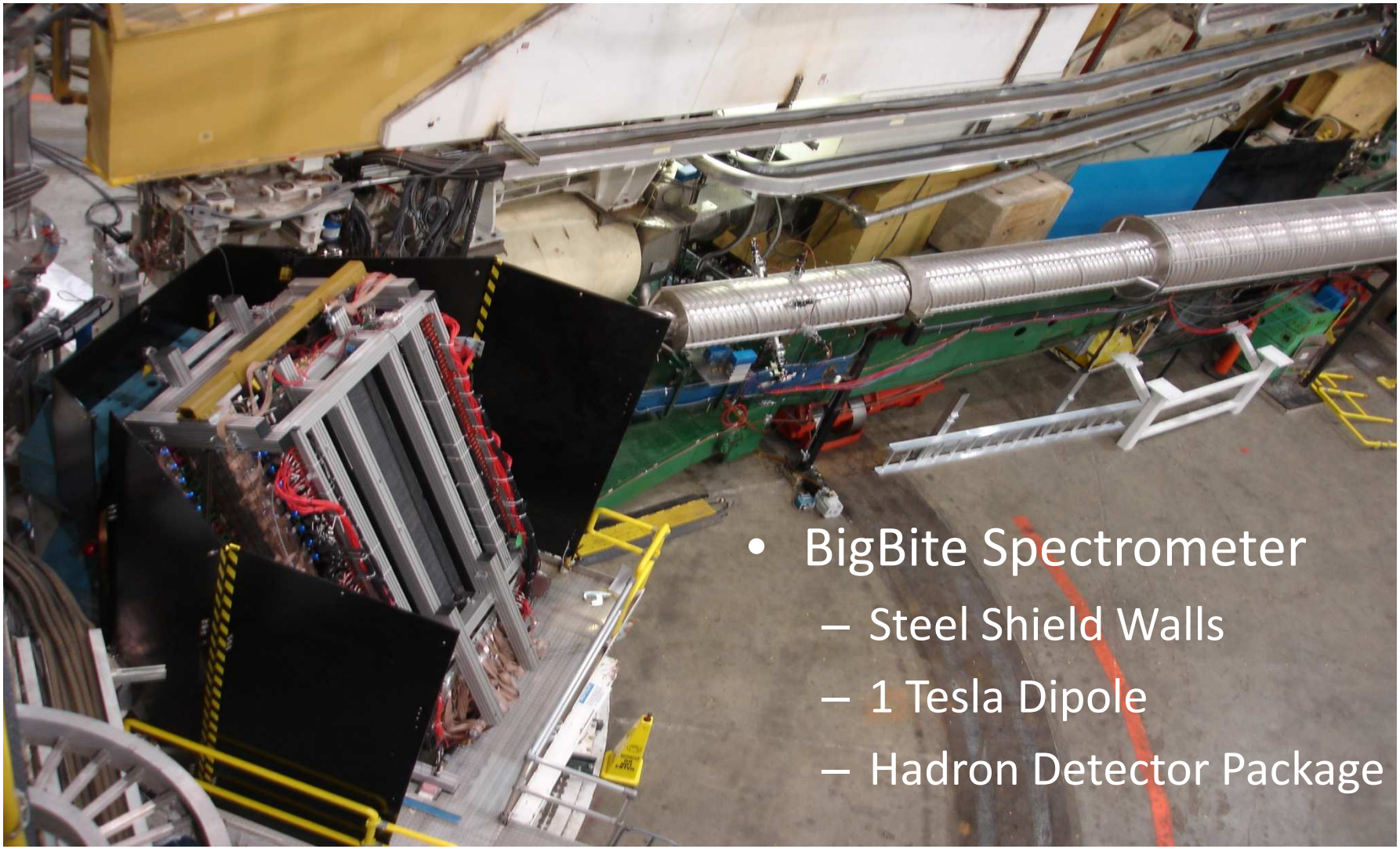
•Front and back MWDC chambers

• BigBite acceptance matches HRS
Resolution $\Delta p/p = 1\%$

• Two large arrays of Scintillators. One 3 mm thick and the other 30 mm thick as trigger planes form coincident with LHRS and for PID.

•helium bag in magnet gap and between MWDC chambers

E04-007: Installed In Hall A

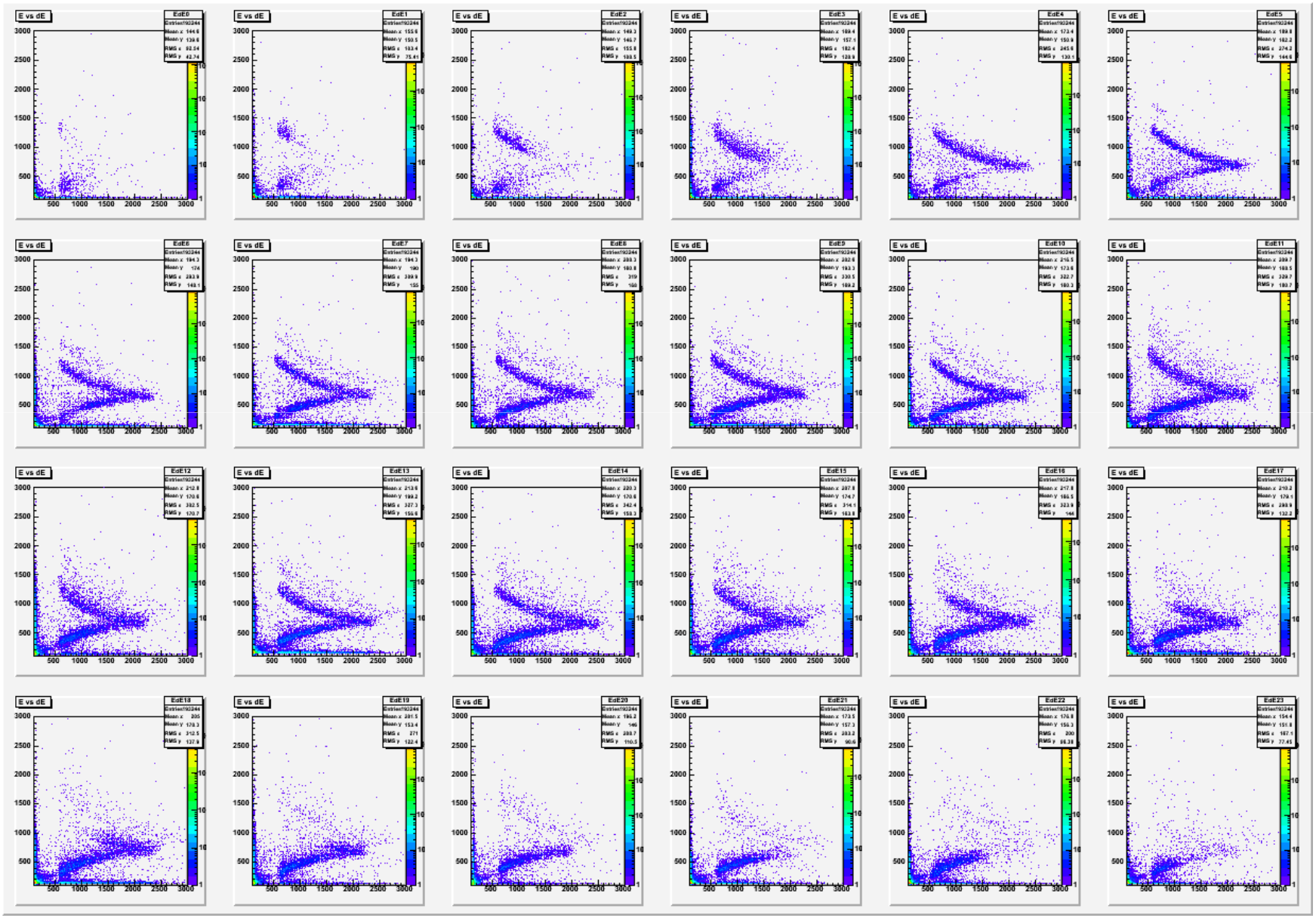


E04-007: Calibration Data

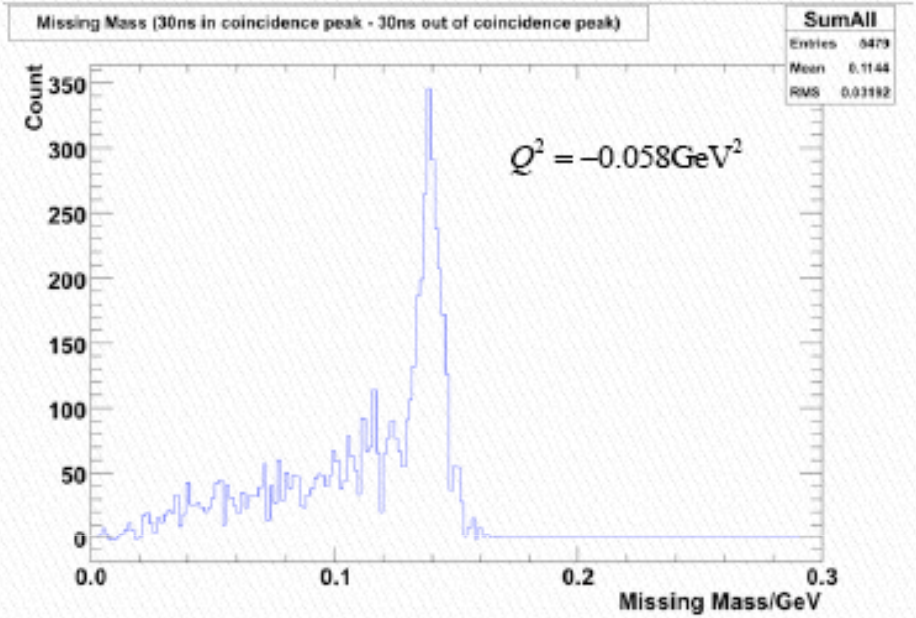
For each production kinematics we took:

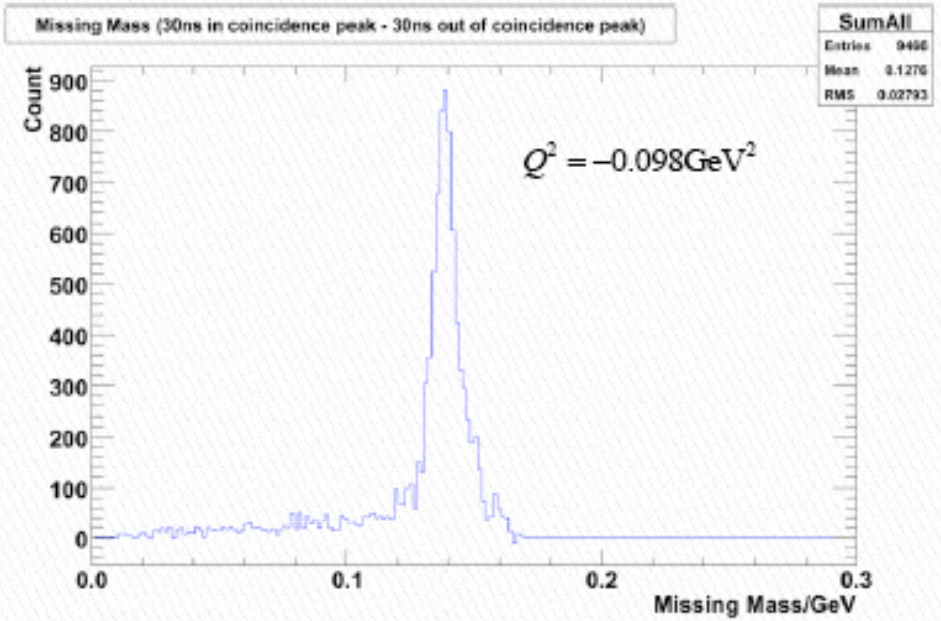
- Tantalum elastic - absolute beam energy- electron in HRS
- Proton elastic - electron in HRS, check cross section, proton in BigBite optics
- Carbon elastic and inelastic - check beam energy and cross section
- HRS Sieve slit data with hydrogen elastic
- BigBite Sieve Slit data with Quasi elastic from deuterium for optics
- Hydrogen data with collimated target cell
- Elastic recoil proton data with different currents in BigBite
- Production data with different beam currents (1- 6 ua)
- Data with different wire chamber high voltage and threshold. First time used for protons.
- Electronic 1 KHz pulser in data stream to measure computer dead time correction
- Production data with widely varied prescale factors.

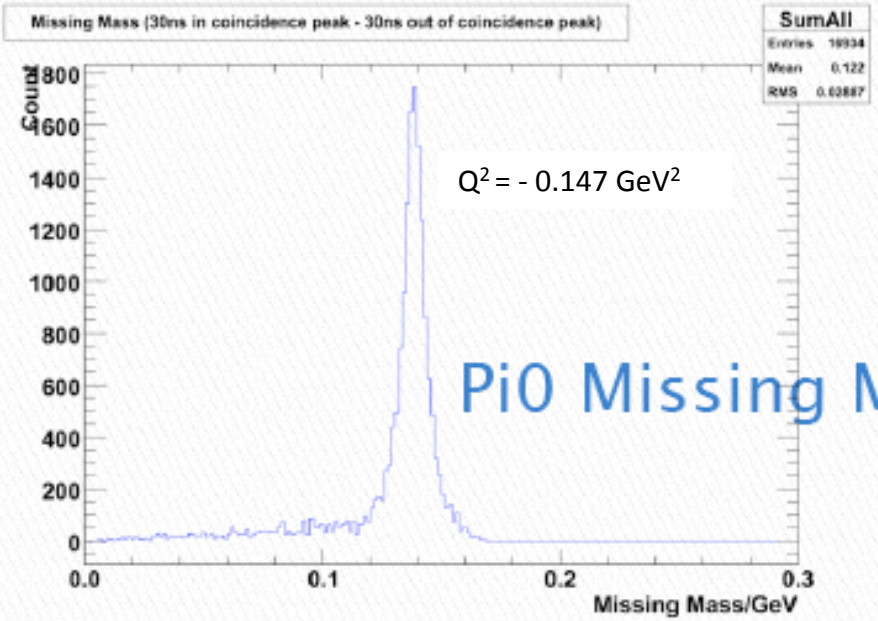
E04-007: E-ΔE from 30 mm and 3 mm paddles



E04-007: BigBite "Online" Optics Jin Huang





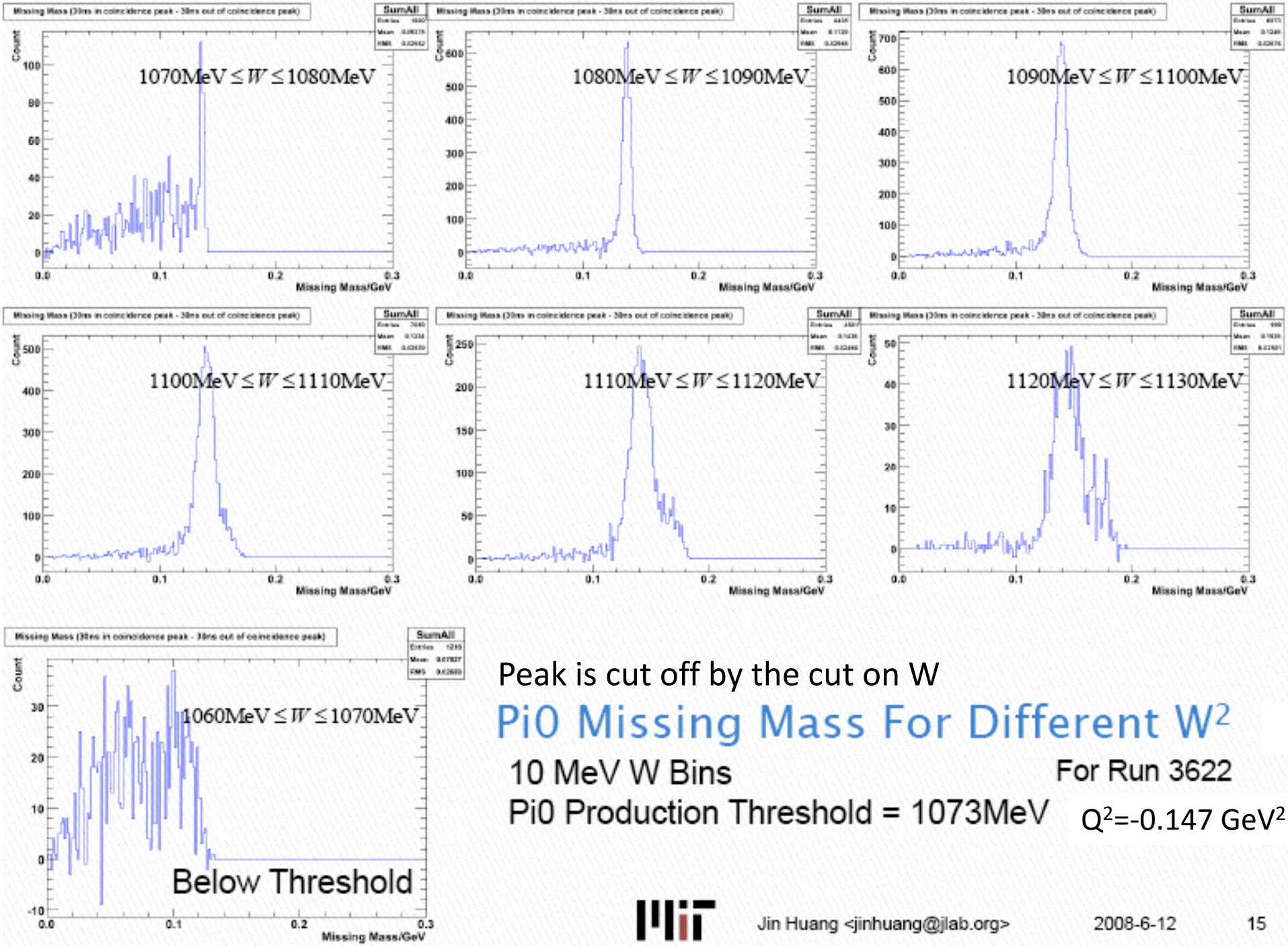


E plane scintillator Trigger

Cut on 30 ns peak - 30 ns background

Cut on W above Threshold

Pi0 Missing Mass For Different Q^2 Run



Peak is cut off by the cut on W

Pi0 Missing Mass For Different W^2

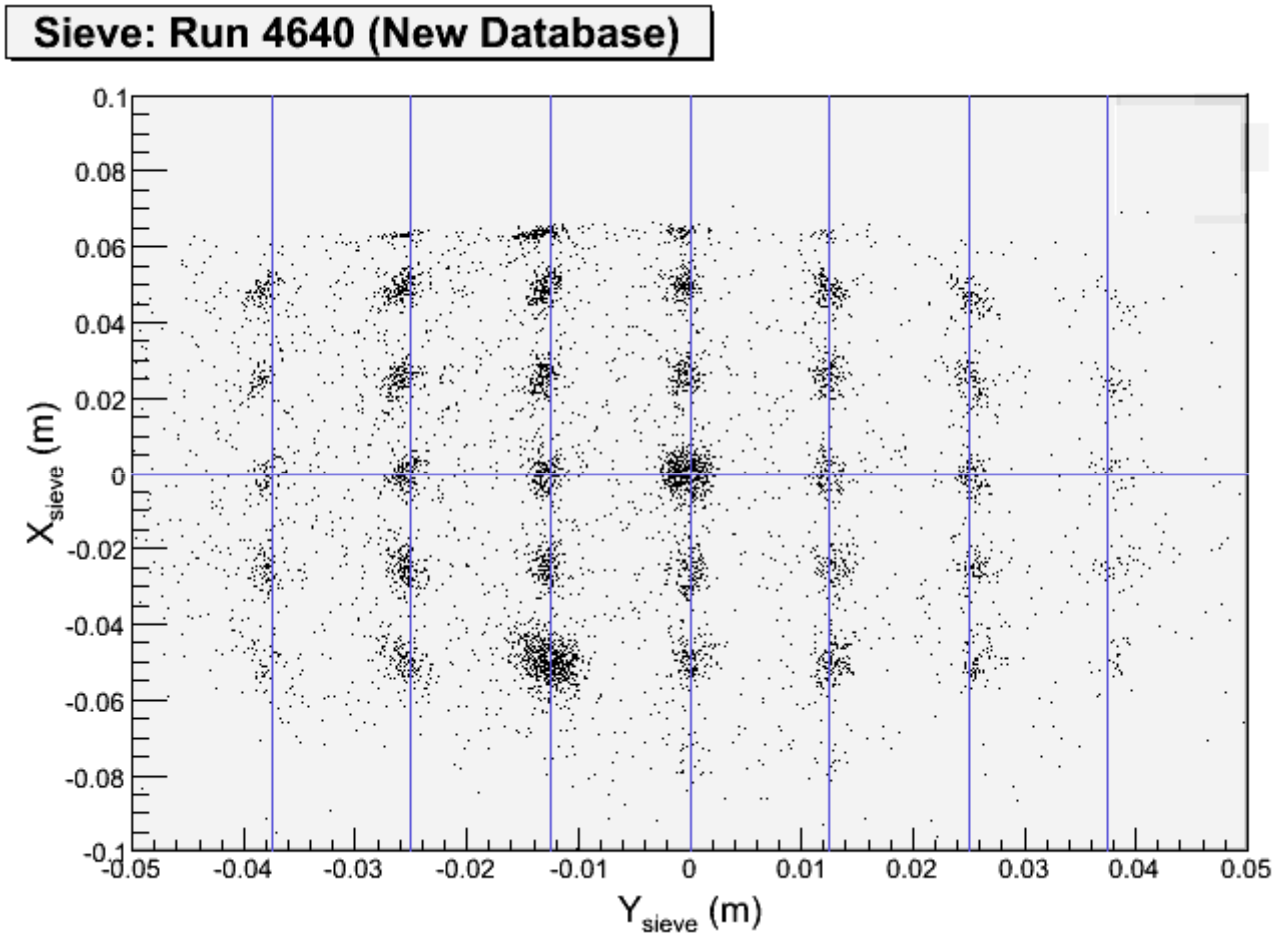
10 MeV W Bins

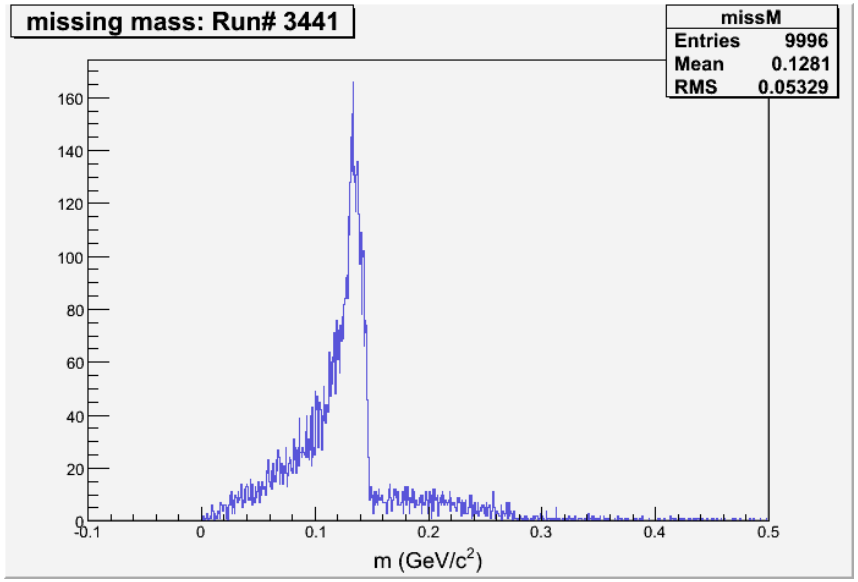
For Run 3622

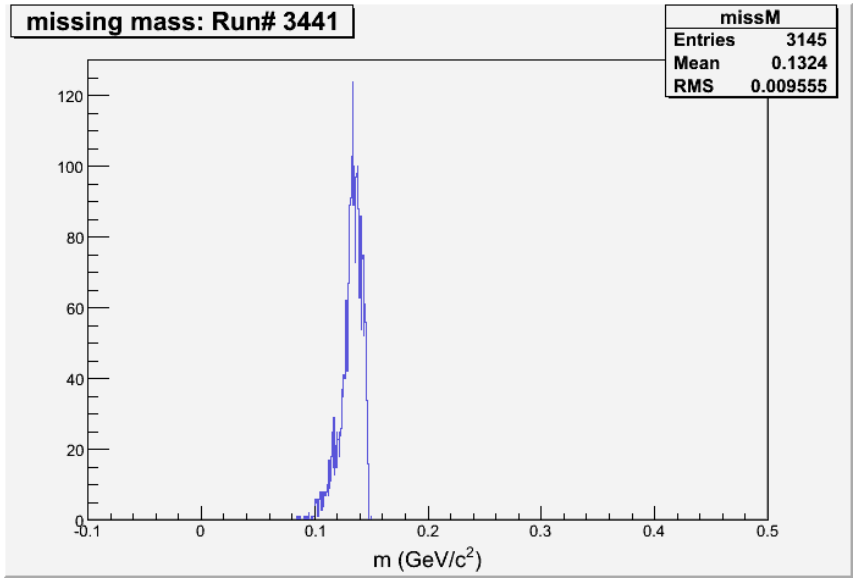
Pi0 Production Threshold = 1073MeV

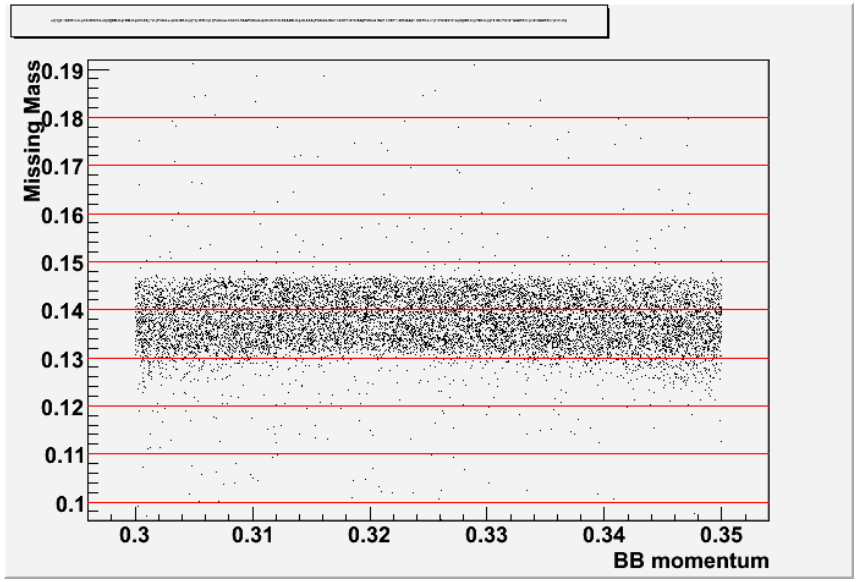
Q^2=-0.147 GeV^2

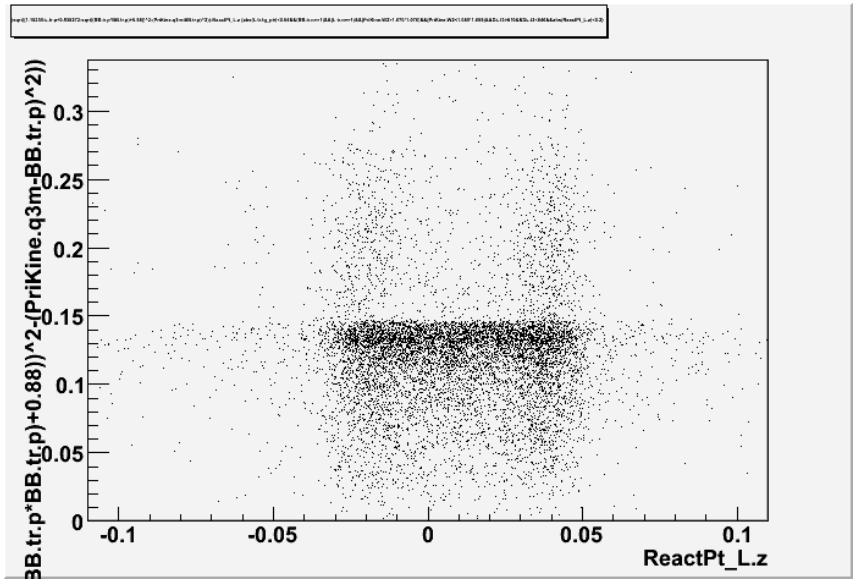
HRS Optics


Sieve: Run 4640 (New Database)
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
X_sieve (m)
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
Y_sieve (m)

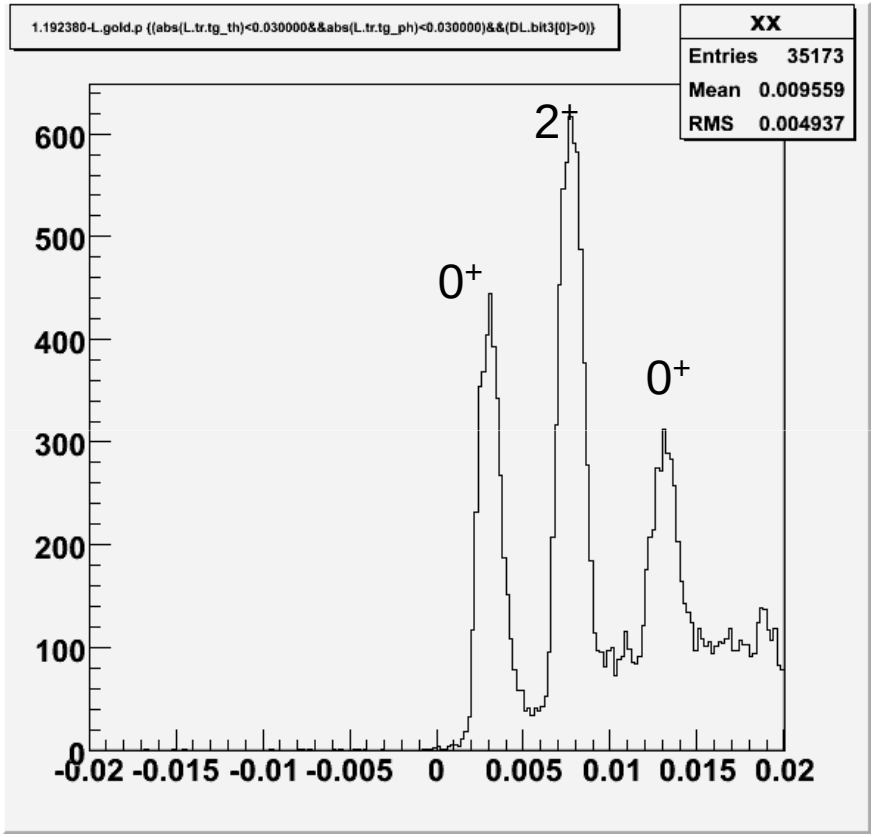

missing mass: Run# 3441
missM
Entries 9996
Mean 0.1281
RMS 0.05329
m (GeV/c^2)


missing mass: Run# 3441
missM
Entries 3145
Mean 0.1324
RMS 0.009555
m (GeV/c^2)

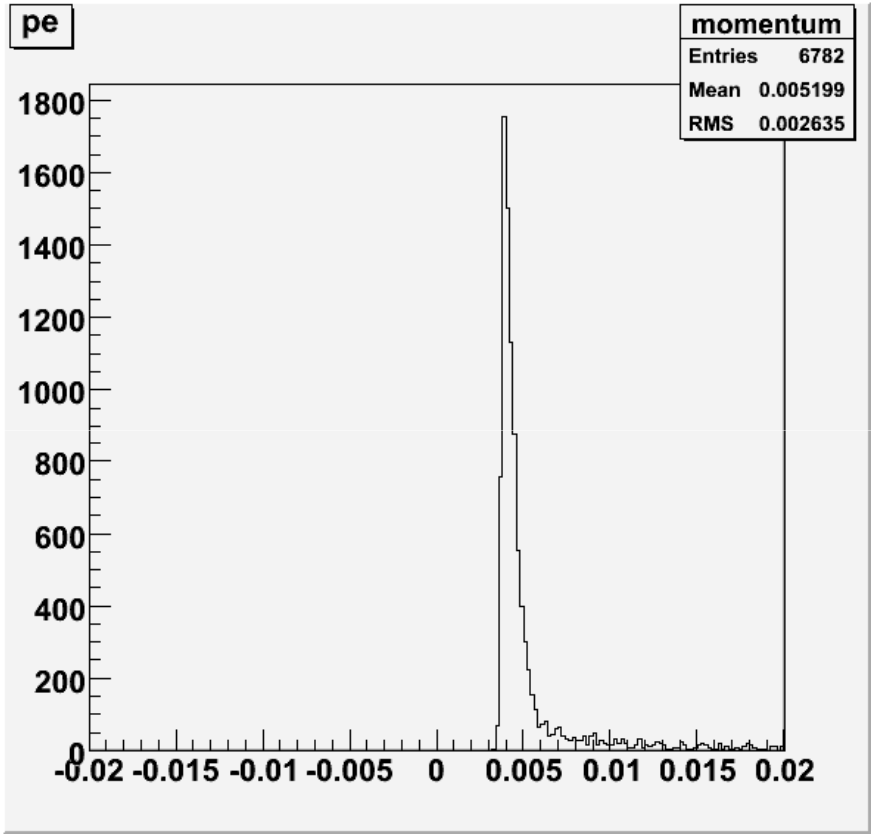

Missing Mass
BB momentum


BB.tr.p*BB.tr.p)+0.88))^2-(PriKine.q3m-BB.tr.p)^2))
ReactPt_L.z

C12 data

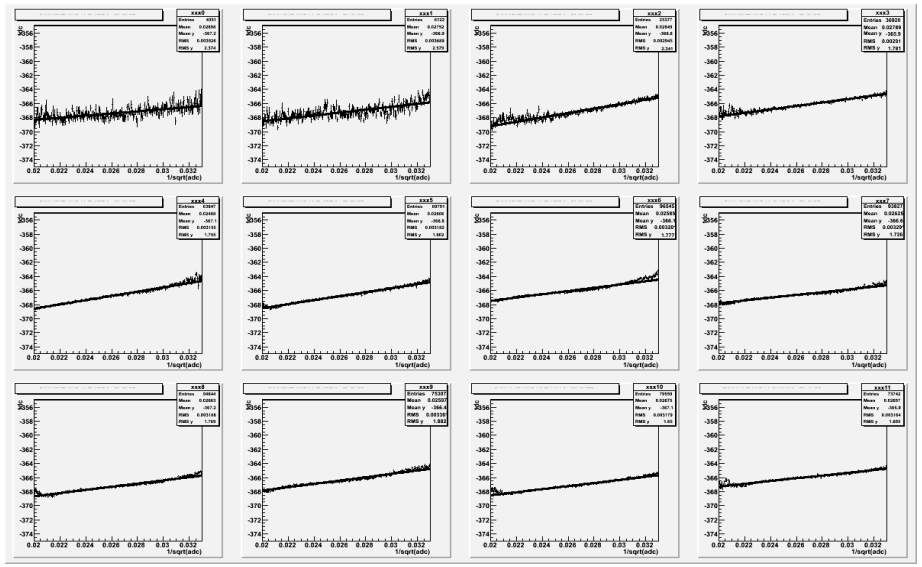


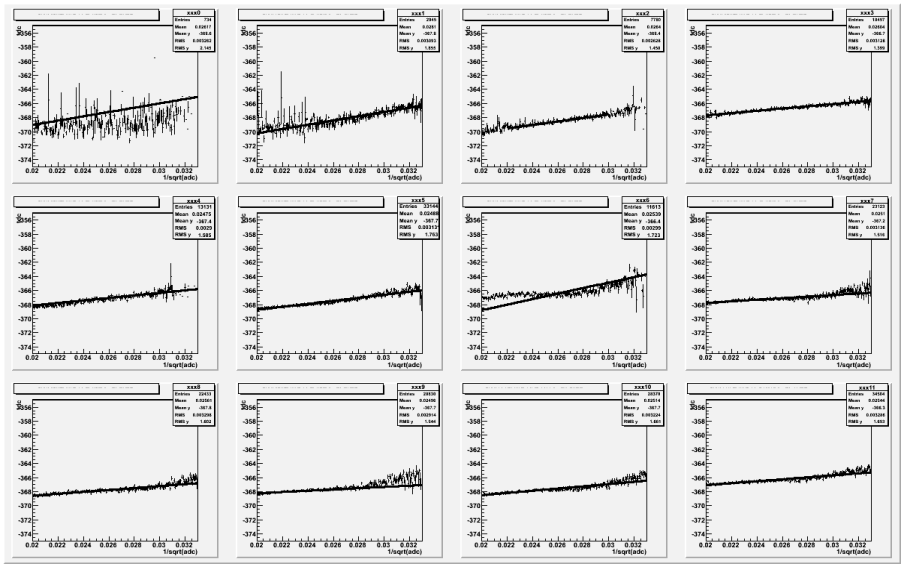
C12 elastic simulation
(from mceep)

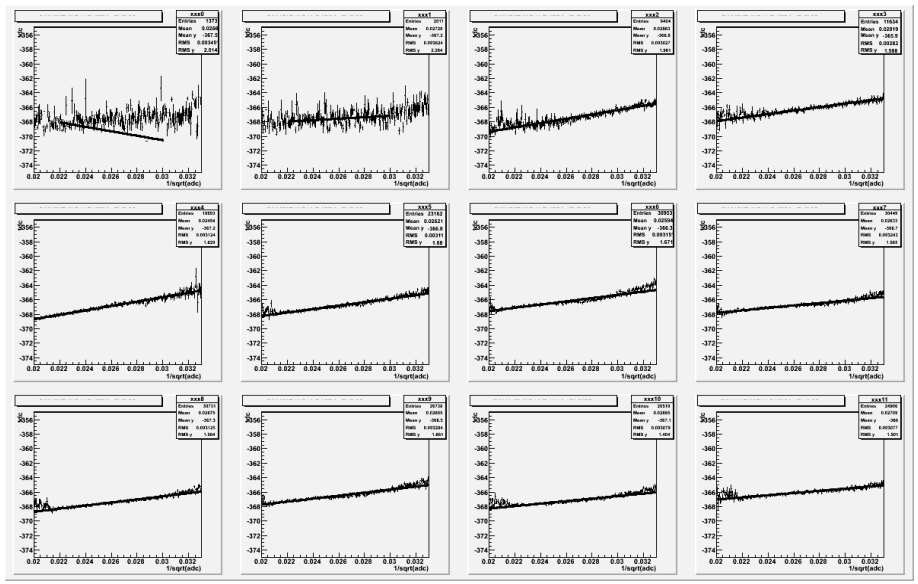


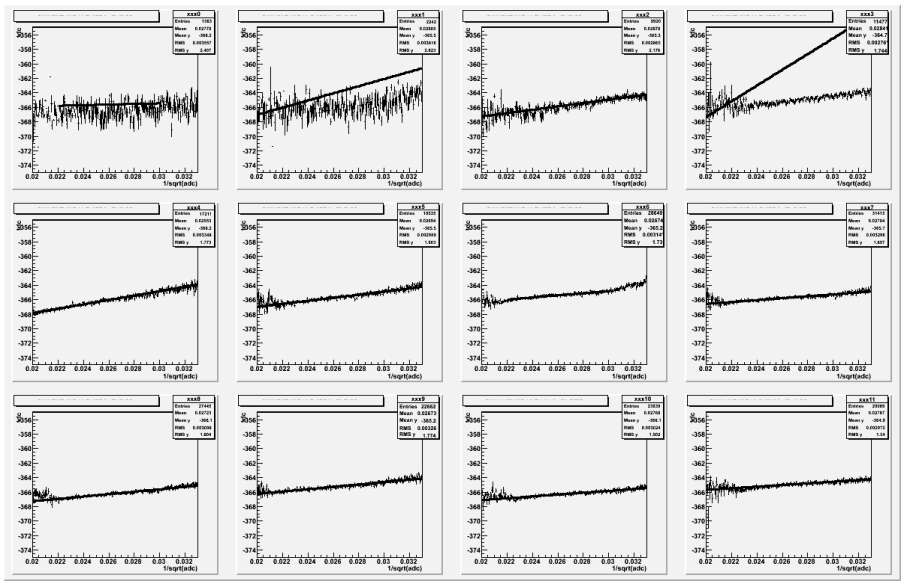
Run 4390

Time walk correction(1/sqrt(adc) vs tdc)

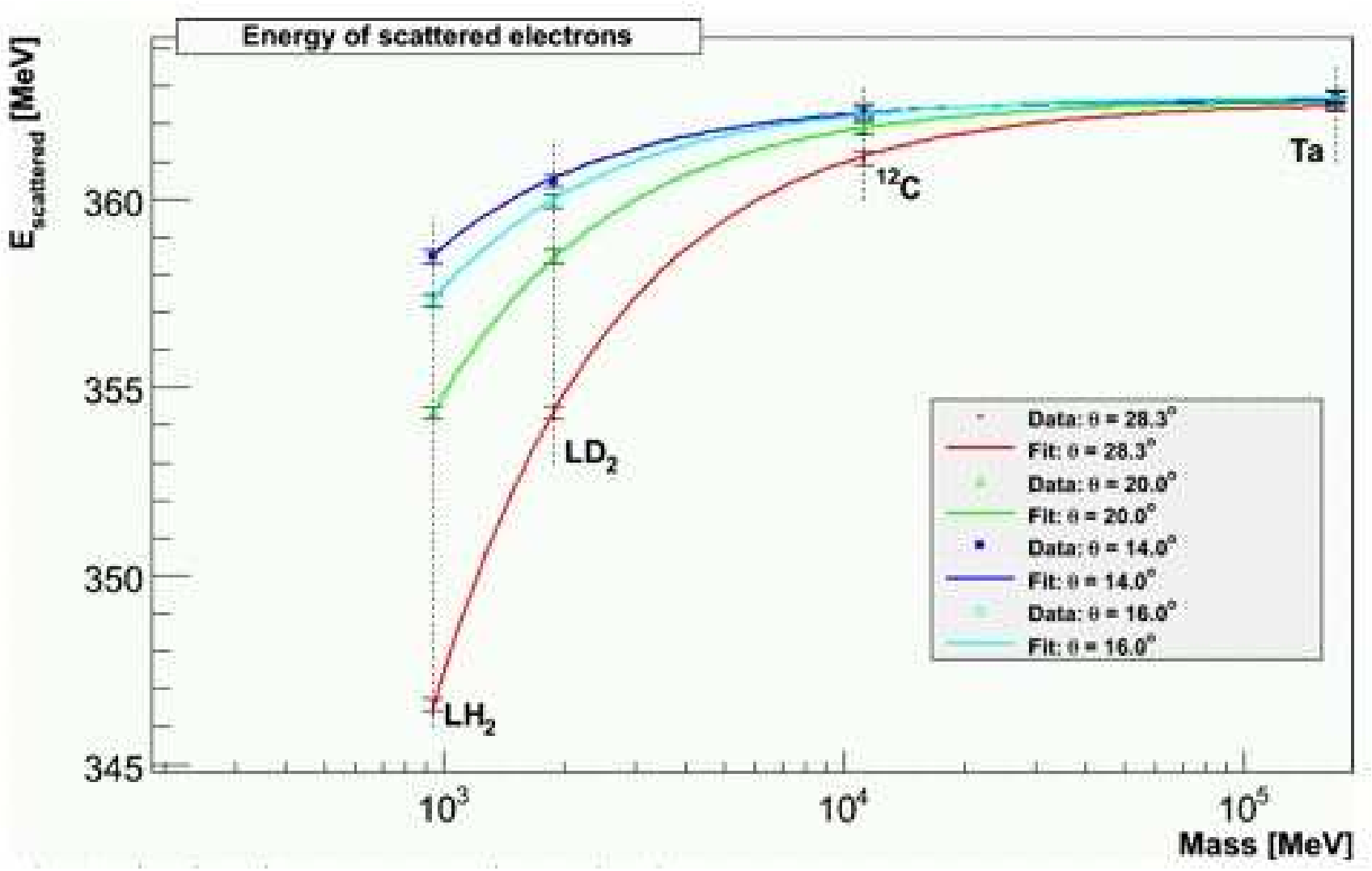








Beam energy determination



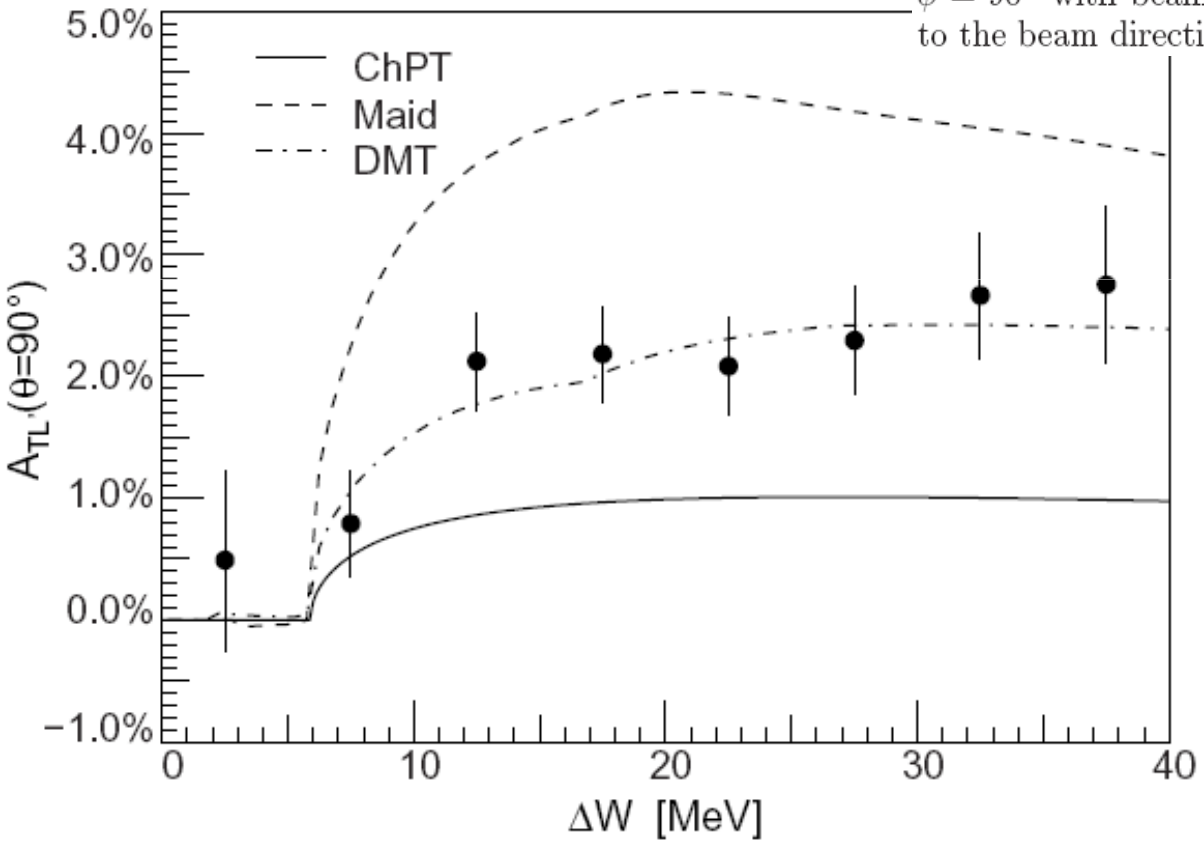
Analysis tool developed using previous data(G0 in Hall C) preliminary error < 0.1%

Miha Mihovilovic
(University of Ljubljana)

Asymmetry

$$A_{LT'}(\theta) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\sqrt{2\epsilon(1-\epsilon)}\,\sigma_{LT'}(\theta)}{\sigma_T(\theta) + \epsilon\,\sigma_L(\theta) - \epsilon\,\sigma_{TT}(\theta)}$$

where σ^+ and σ^- are the differential cross-sections for $\phi = 90°$ with beam polarization parallel and antiparallel to the beam direction, respectively.

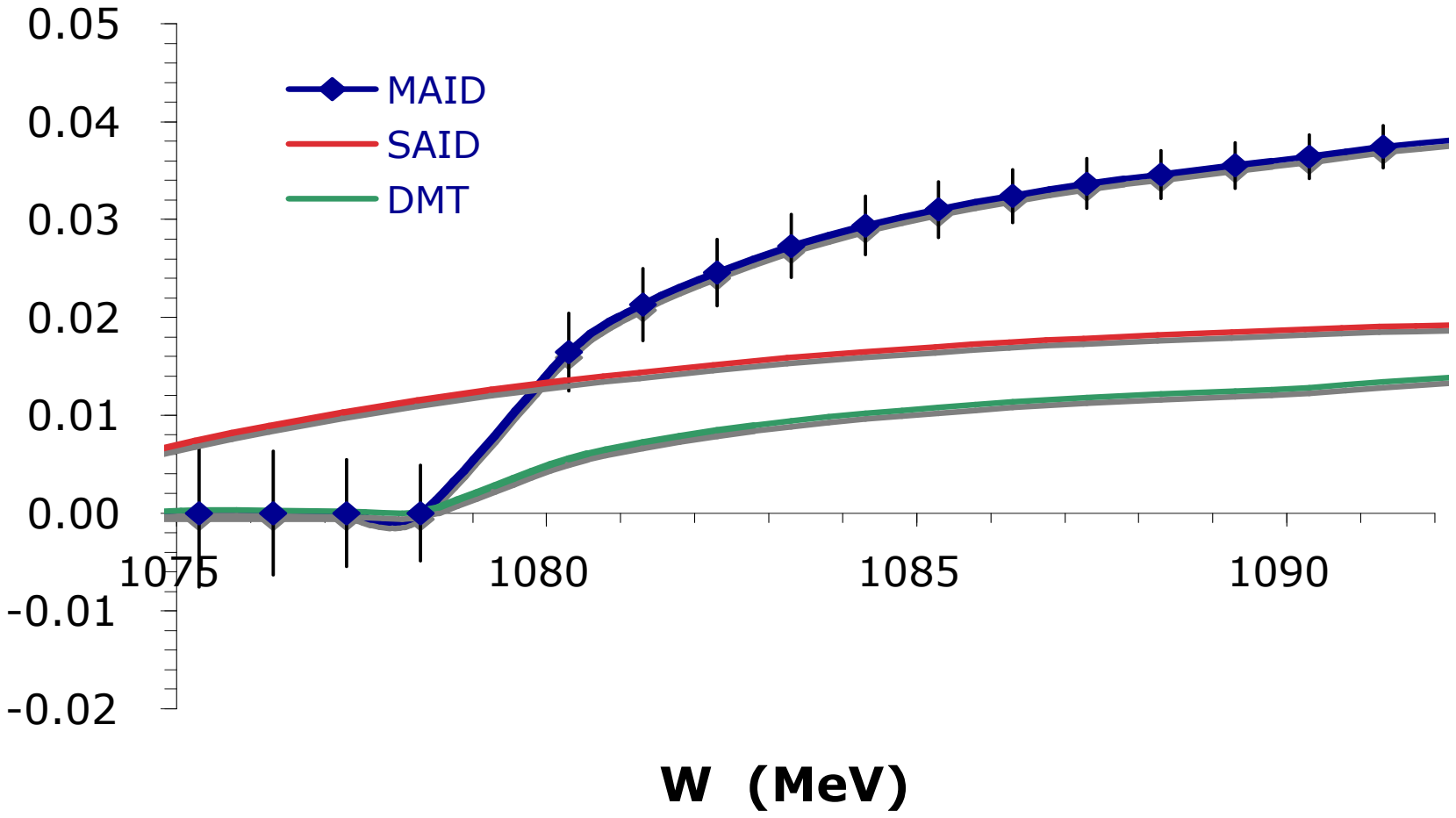


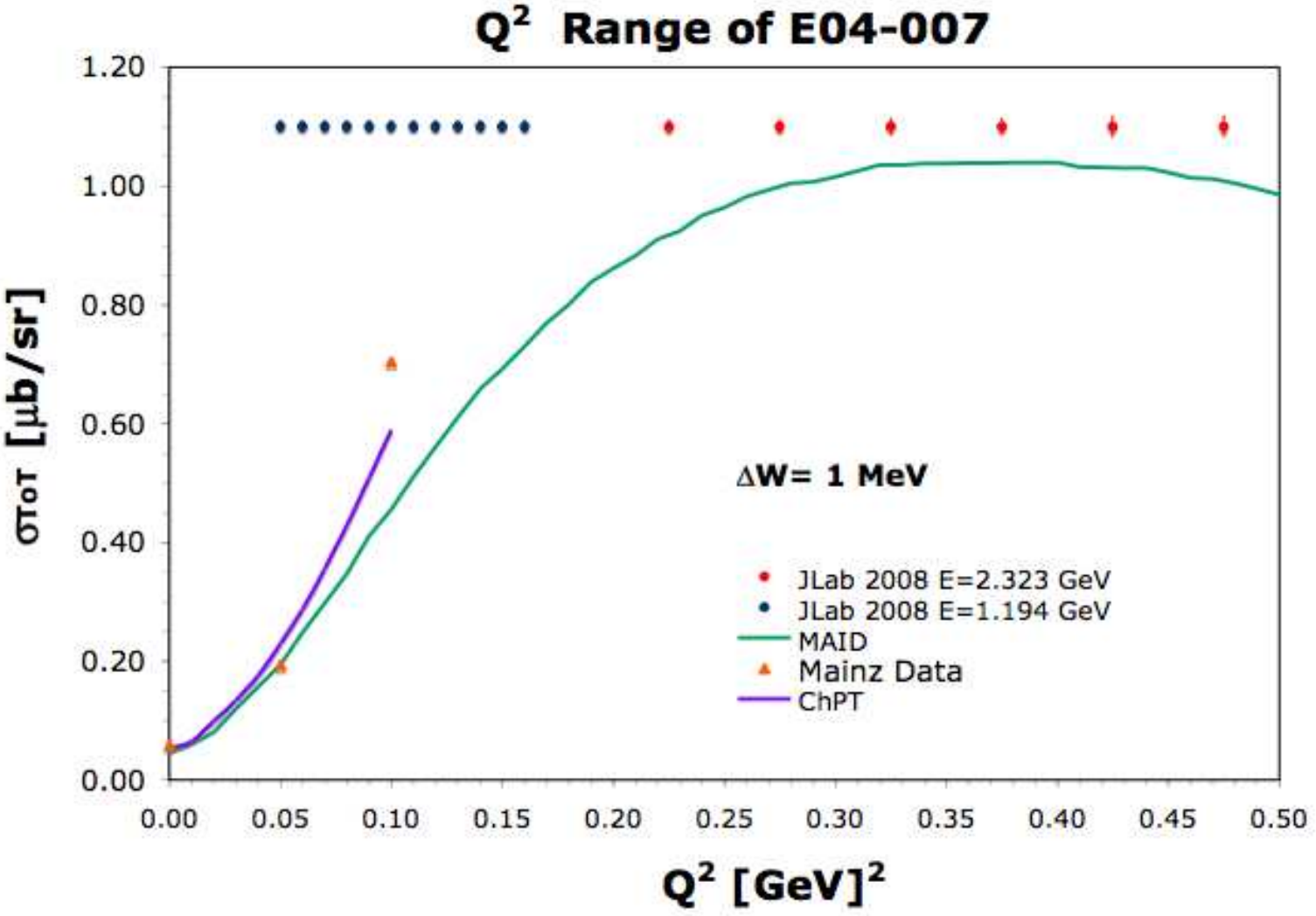
Weis Eur. Phys. J. A 38, 27-33(2008)

From MAMI recent experiment

Our accumulated charge will give us
- stat. error from 20% to 5 %
0.67 polarization, ave phi ~0.5

Q^2=0.058 GeV ^{2}
E=1.194 GeV




Q² Range of E04-007
1.20
1.00
0.80
0.60
0.40
0.20
0.00
σTOT [μb/sr]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Q² [GeV]²
ΔW= 1 MeV
JLab 2008 E=2.323 GeV
JLab 2008 E=1.194 GeV
MAID
Mainz Data
ChPT

Summary

The experiment is done
Data look good

Expect to finish analysis in 1 ½ year