Spin observables with the Crystal Ball at MAMI

Michael Ostrick

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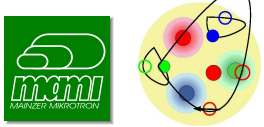

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

- The Crystal Ball at MAMI
- Threshold Pion Photoproduction
- Spin Observables and Partial Wave Analyses above the $\Delta(1232)$ resonance

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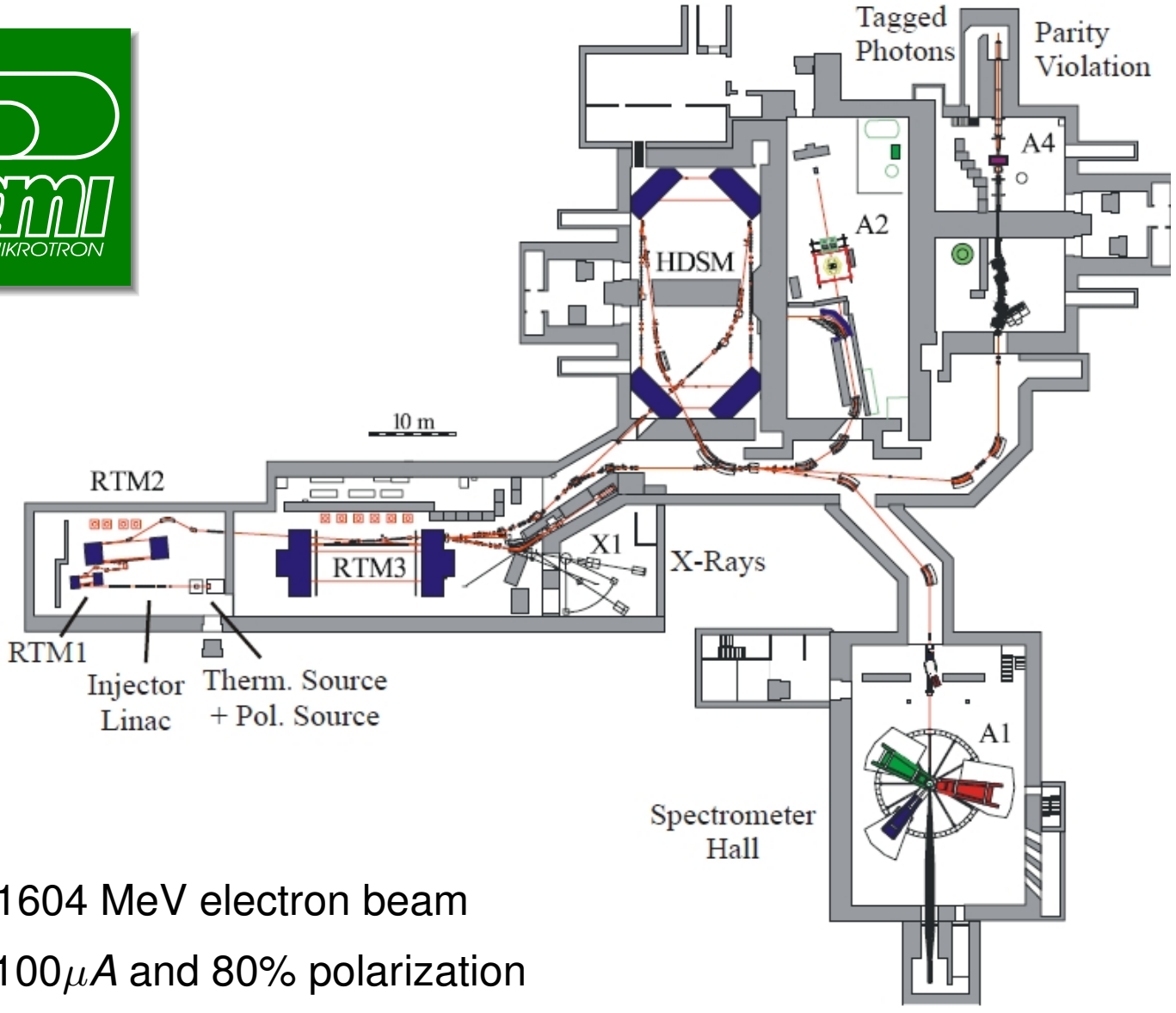
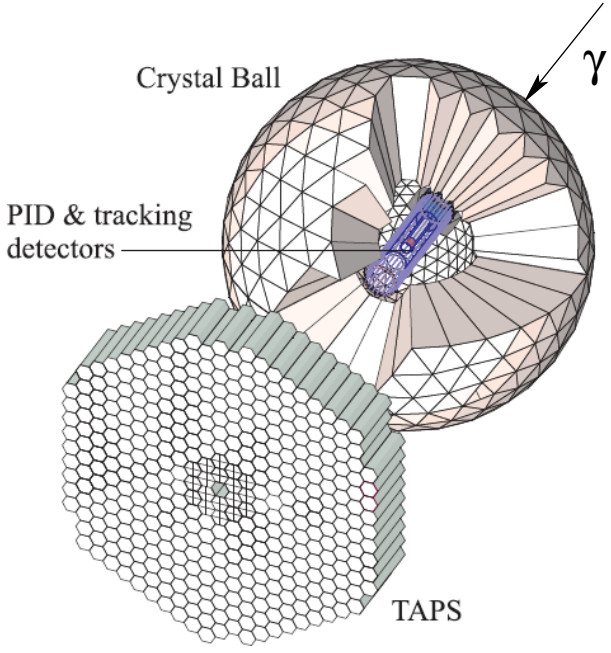
in collaboration with:
Amherst, Basel, Bochum, Bonn, Edinburgh, Giessen, GWU, MIT, JINR Dubna, PNPI, Glasgow, Halifax, KSU, Mainz, Moscow, Pavia, Regia, Sackville, UCLA, Zagreb

The Mainz Microtron MAMI



- 180 - 1604 MeV electron beam
- up to 100μA and 80% polarization
- δE $\sim$ 100 KeV

The Crystal Ball at MAMI



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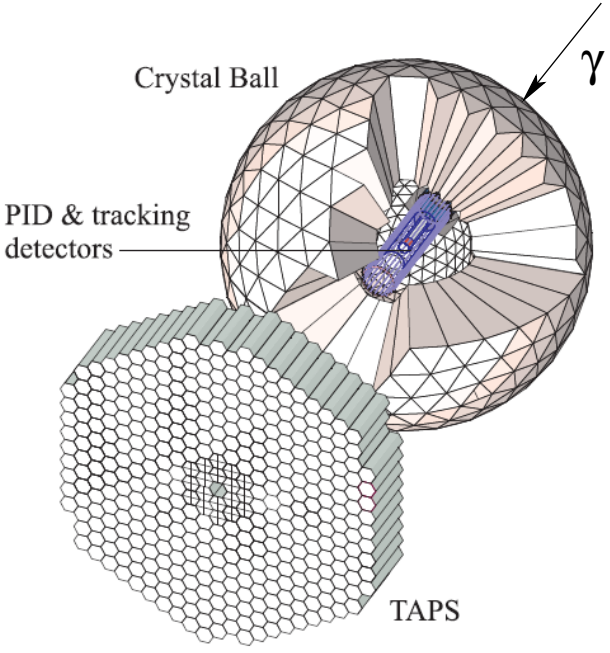
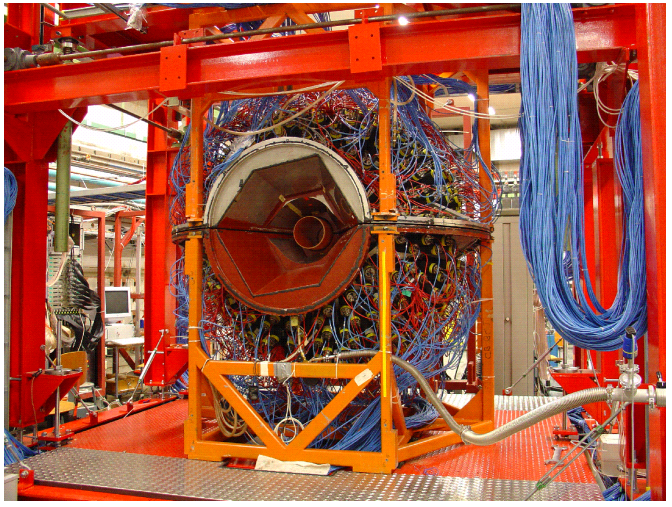
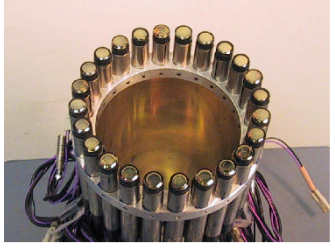
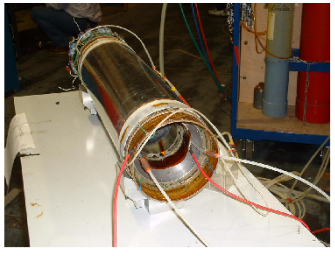




Crystal Ball: 672 NaI crystals

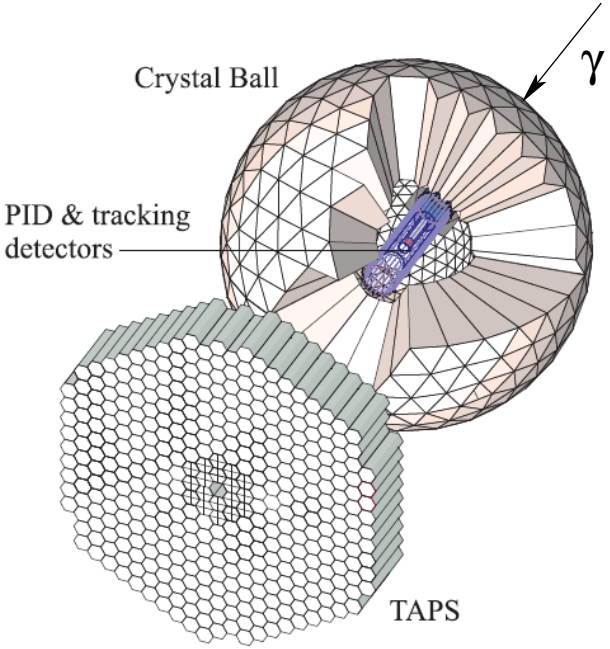


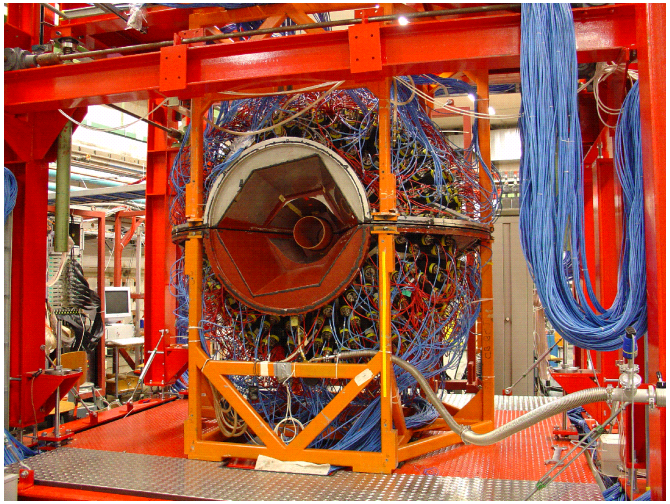


PID and tracking:

24 plastic scintillators + MWPCs

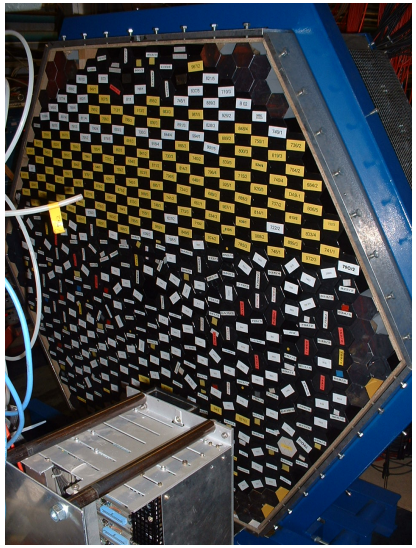
The Crystal Ball at MAMI

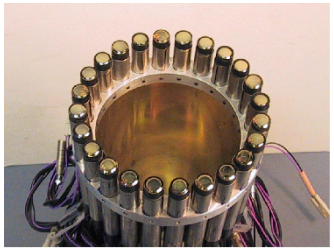


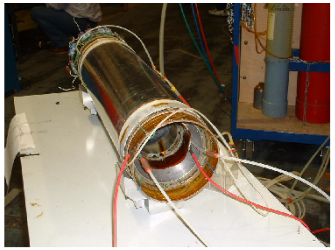


Crystal Ball: 672 NaI crystals

TAPS:
384 BaF_2,
72 $PbWO_4$







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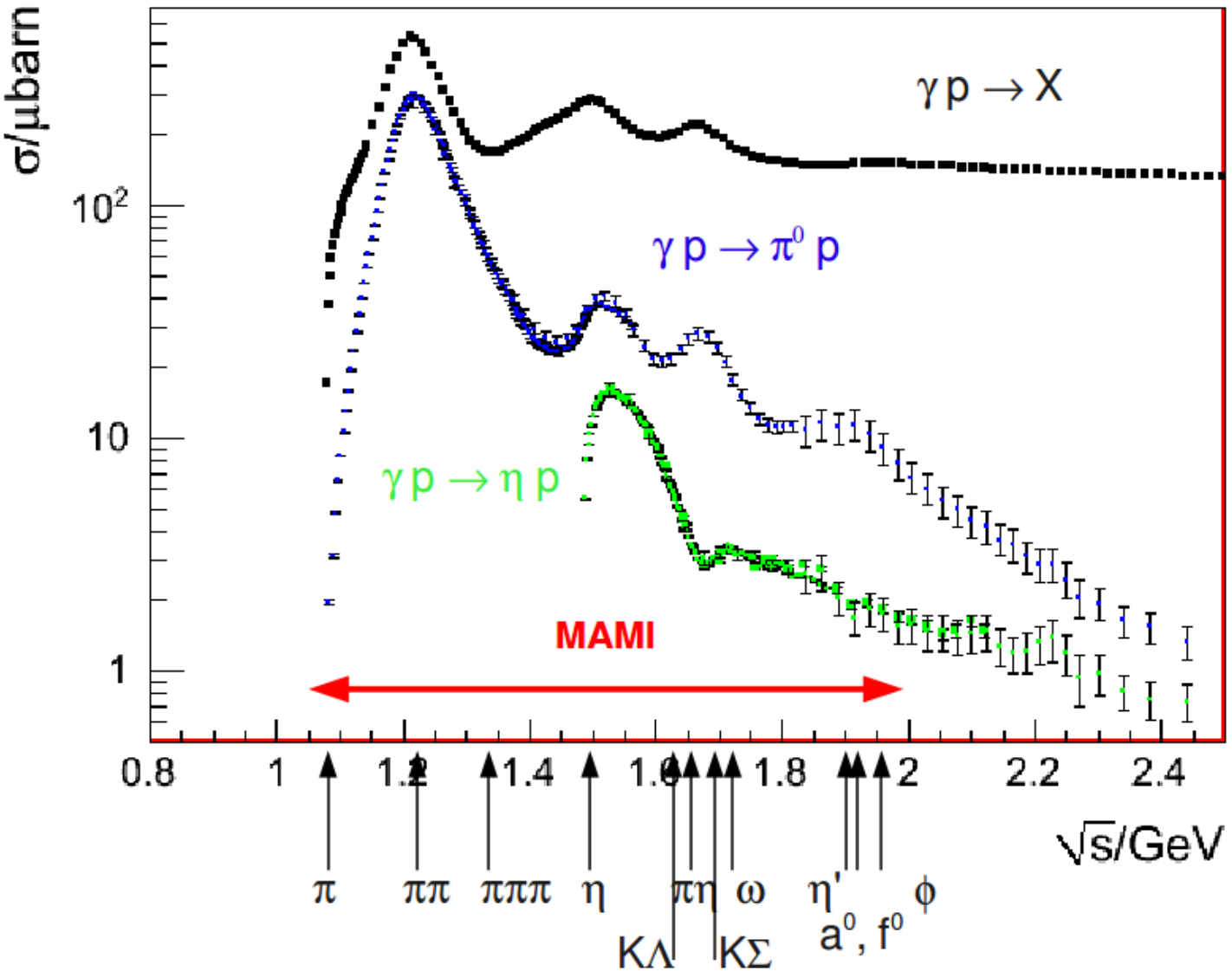

Threshold Pion Photoproduction

T-matrix for $\gamma(k) + p(p) \to \pi^0(q) + p(p')$ close to threshold:

$$T \sim i\sigma \cdot \epsilon(E_{0+} + k \cdot q P_1) + i\sigma \cdot k\epsilon \cdot q P_2 + i\sigma(q \times k) P_3 + (d - waves)$$

- s- and p-waves:

$$E_{0+}, P_1, P_2, P_3 \Leftrightarrow E_{0+}, E_{1+}, M_{1+}, M_{1-}$$

- d-wave amplitudes fixed by Born terms

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- neglect tiny phase of p-waves below $\sim$200MeV

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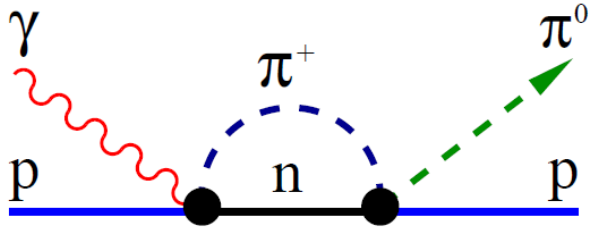
- d-wave amplitudes fixed by Born terms
- multipoles are real below the $\pi^+ n$ threshold
- neglect tiny phase of p-waves below $\sim$200MeV
- $Im(E_{0+})$ determined by unitarity:

$$Im(E_{0+}) = q \cdot \quad E_{0+}(\gamma p \to \pi^+ n) \cdot a(\pi^+ n \to \pi^0 p)$$



Threshold Pion Photoproduction

- differential cross section

$$\frac{d\sigma}{d\Omega_{cm}} = \frac{q}{k} \quad (A + B\cos\Theta + C\cos^2\Theta)$$

- linearly polarized photon asymmetry

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- Observables: A, B, C and D

$$\Rightarrow Re(E_{0+}), \quad E_{1+}, \quad M_{1+} \text{ and } M_{1-}$$

Threshold Pion Photoproduction

New measurement with the Crystal Ball at MAMI in Dec. 2008:

$$\vec{\gamma}p \;\rightarrow\; \pi^0 p \;\rightarrow\; \gamma\gamma\,(p)_{miss}$$

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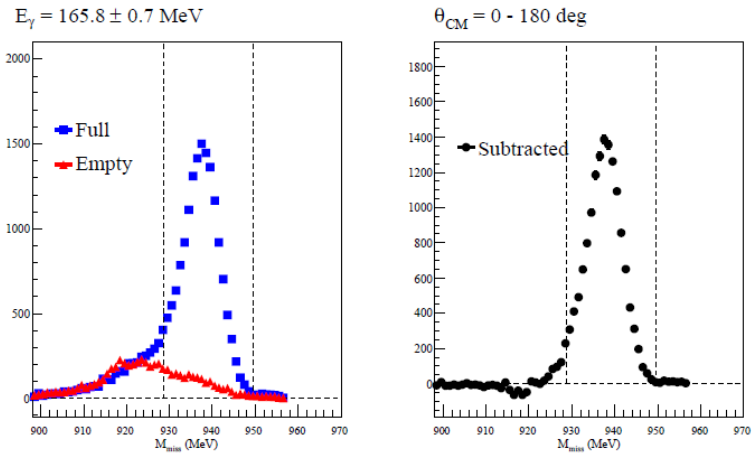

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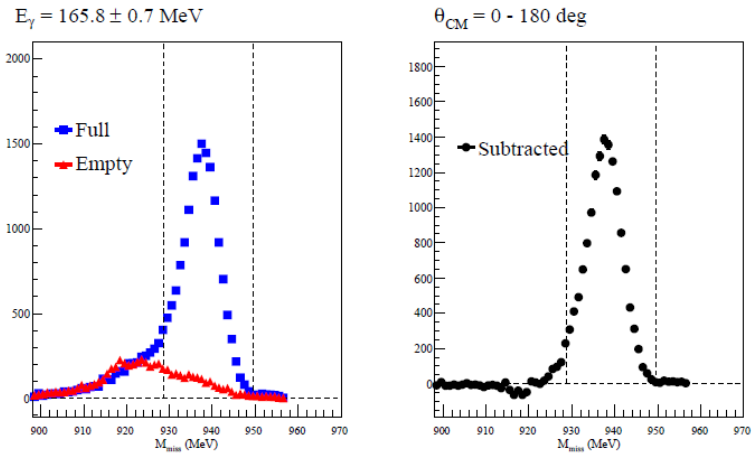

background has $\Sigma = 1$!

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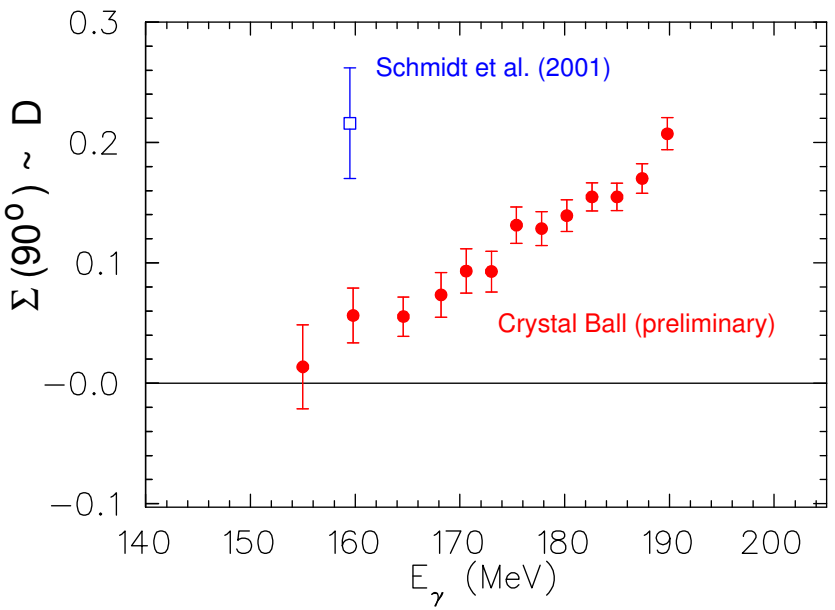

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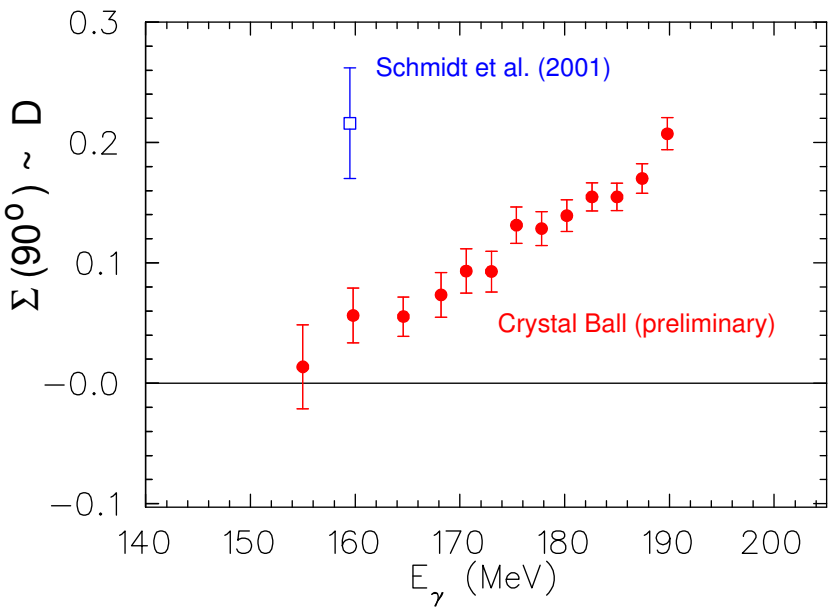
detection, trigger and reconstruction efficiencies



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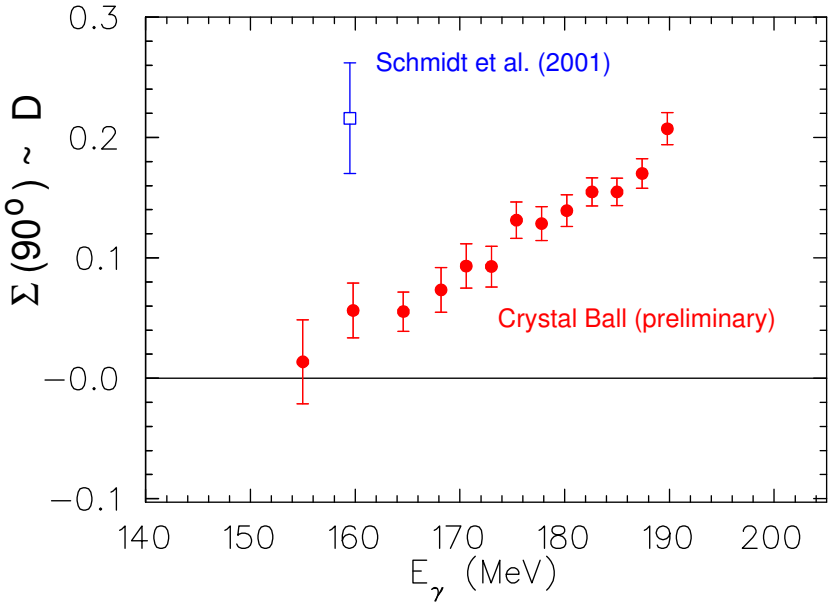

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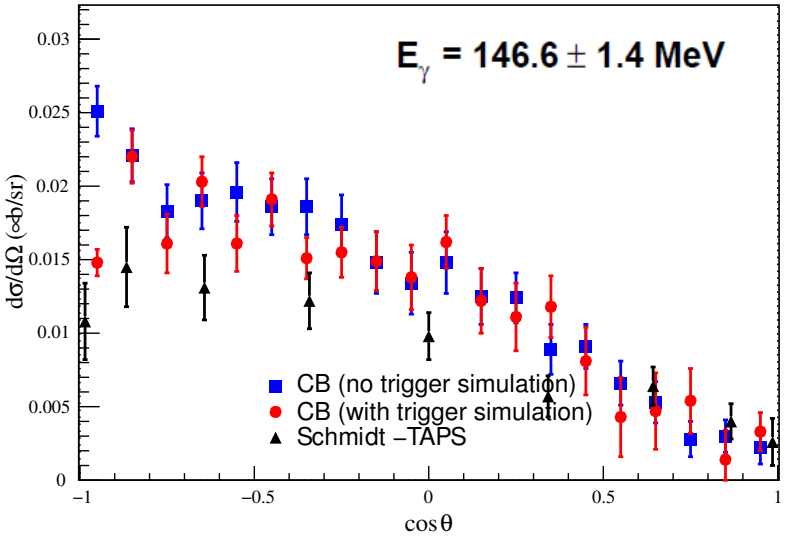

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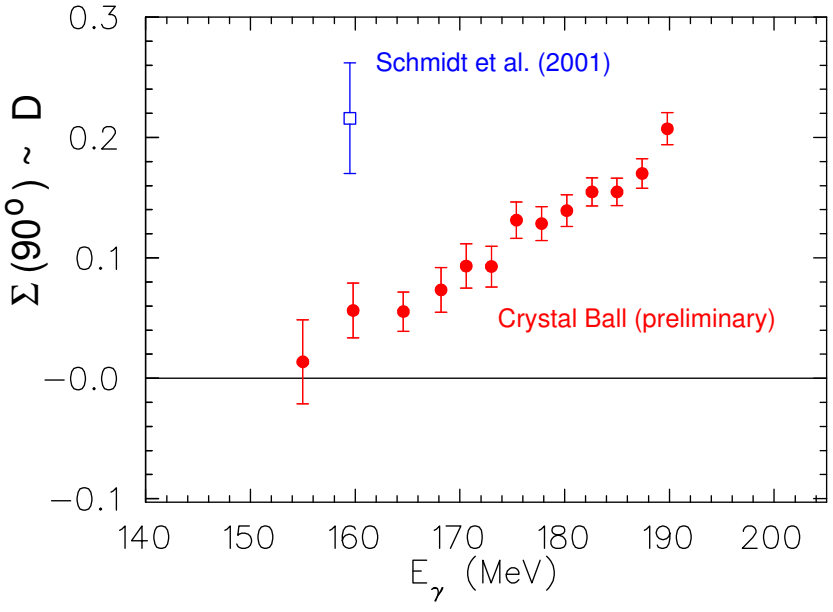

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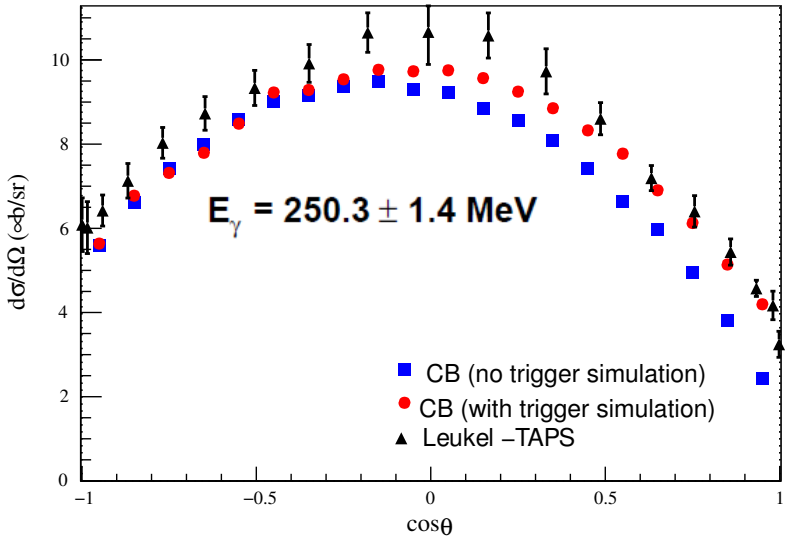

Threshold Pion Photoproduction

single energy fits (L.Tiator, preliminary)

A,B,C and D $\Rightarrow$ $Re(E_{0+})$, E_{1+}, M_{1+} and M_{1-}

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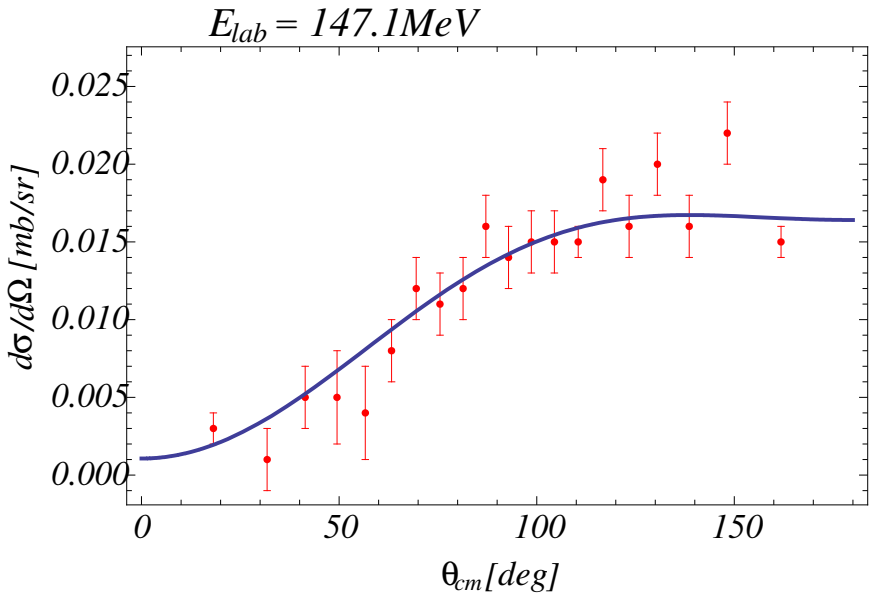

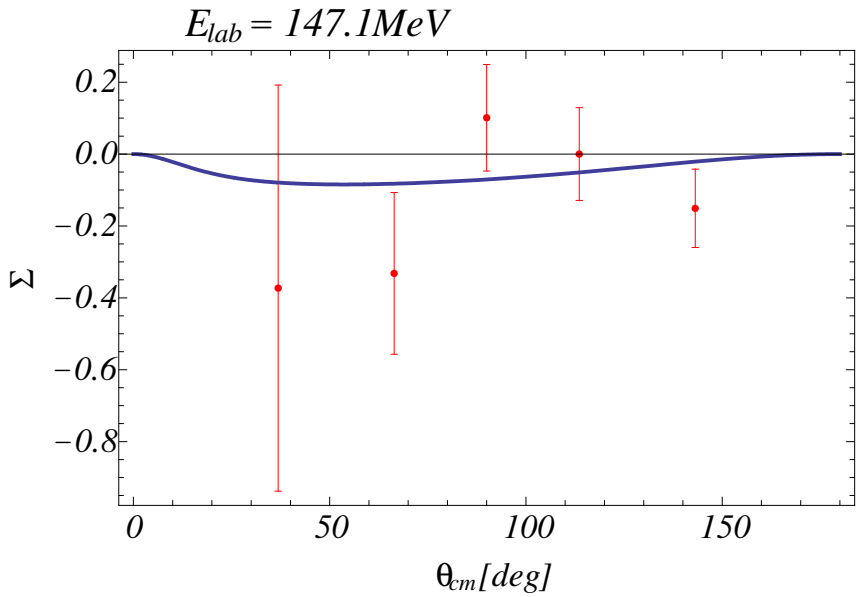

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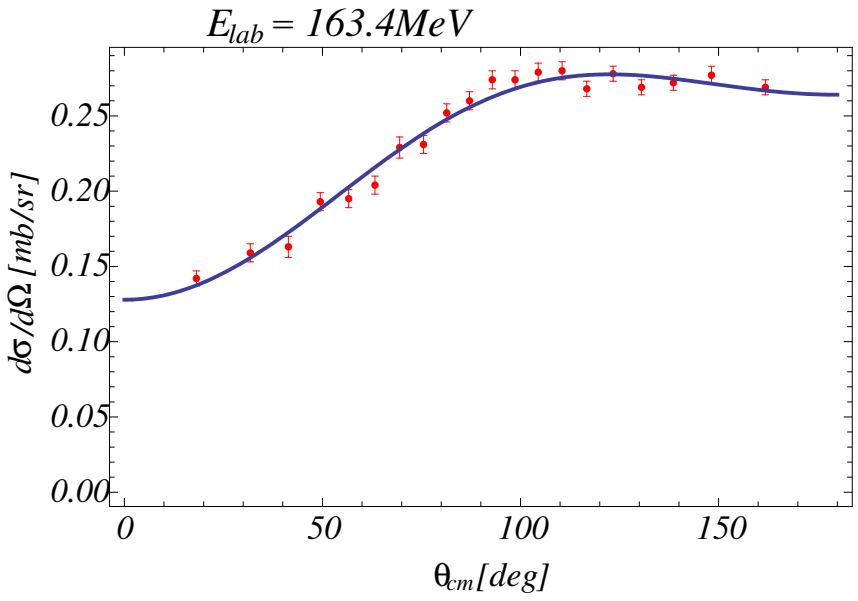

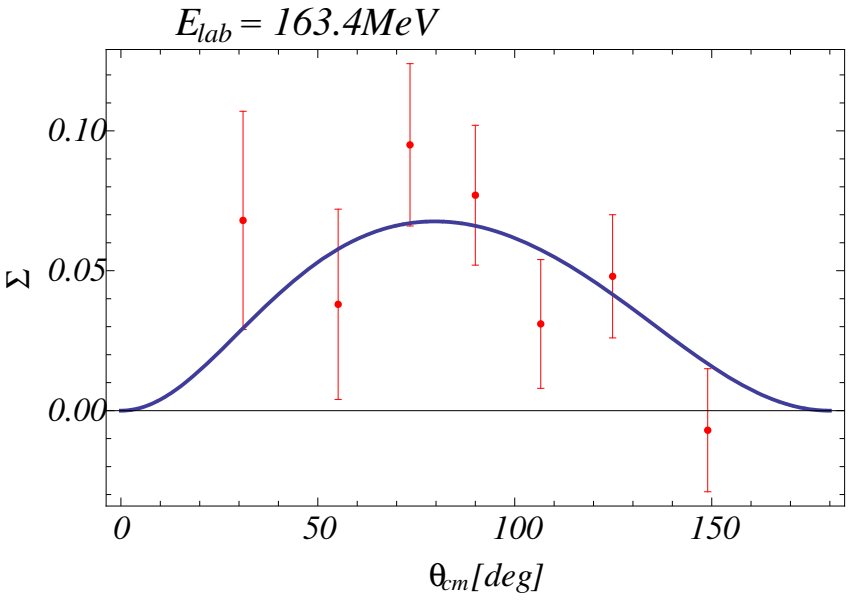

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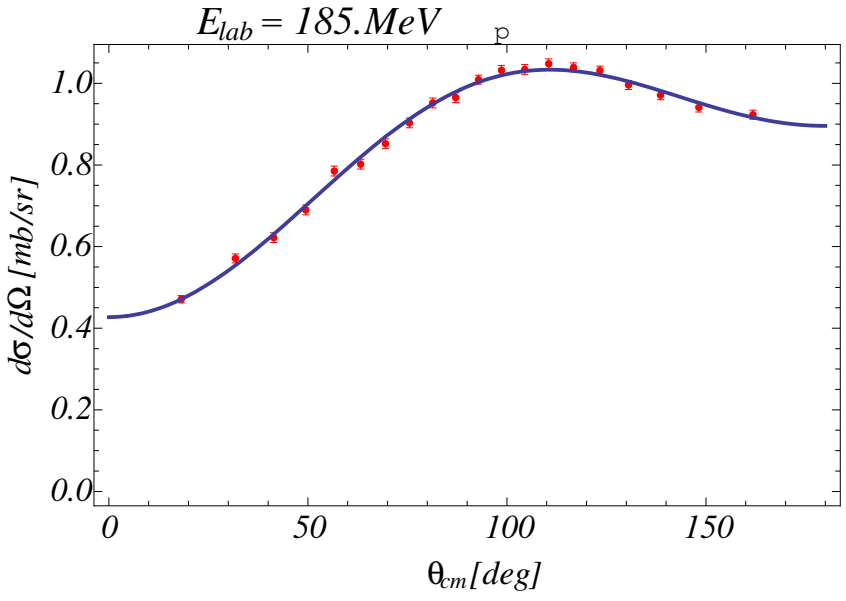
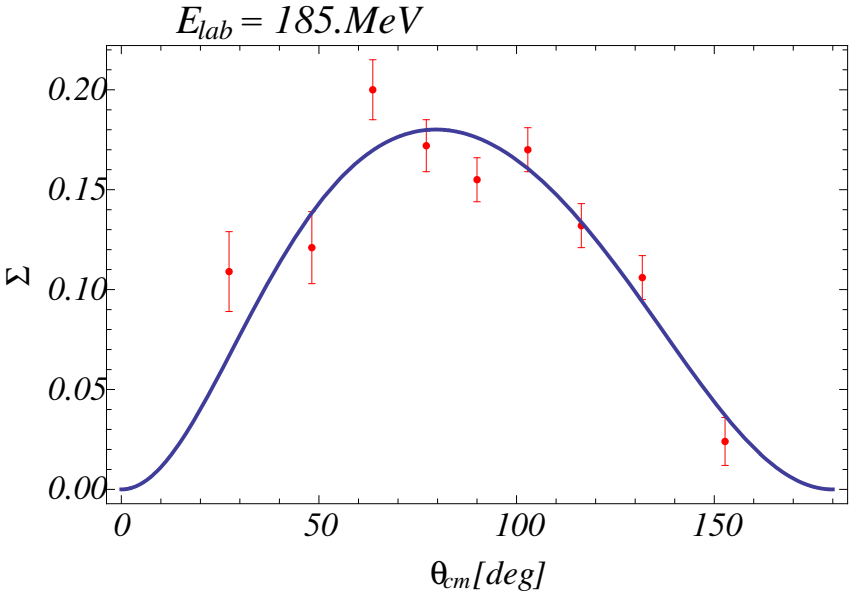
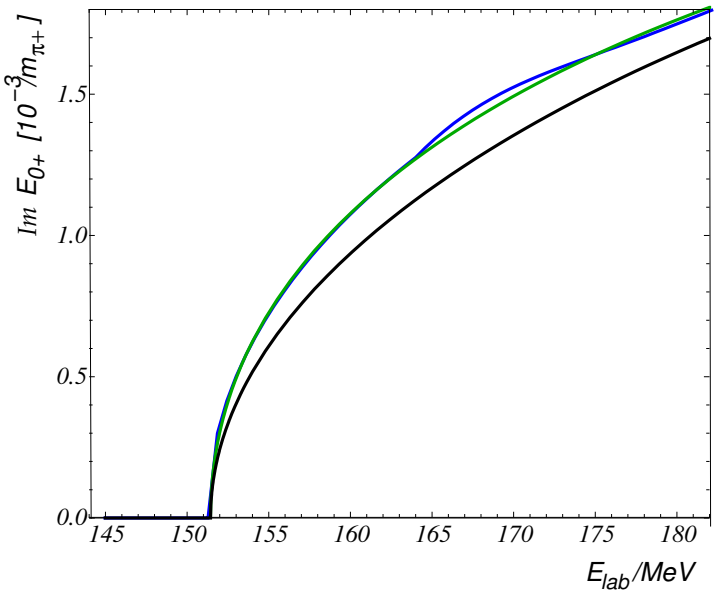
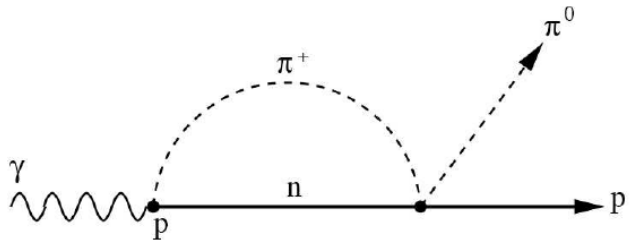




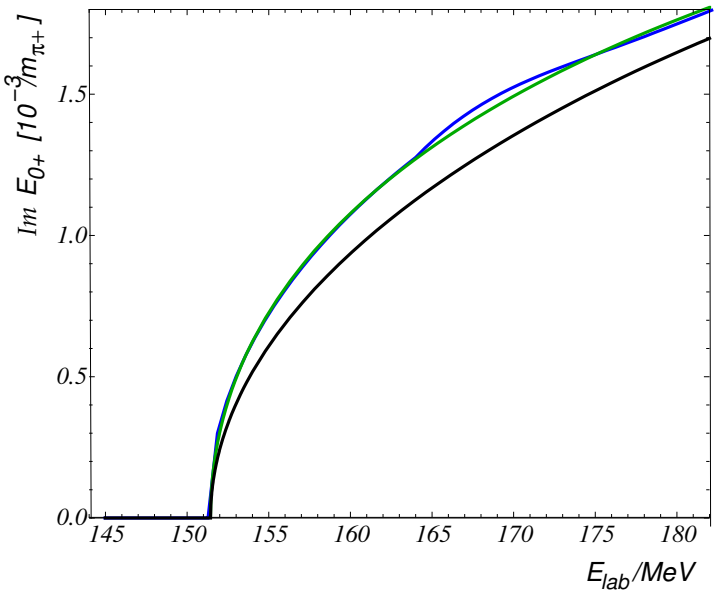
Threshold Pion Photoproduction: $Im(E_{0+})$

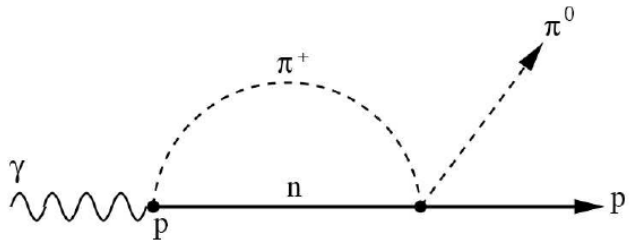




$$\beta = E_{0+}(\gamma p \to \pi^+ n) \cdot a(\pi^+ n \to \pi^0 p)$$

Threshold Pion Photoproduction: $Im(E_{0+})$





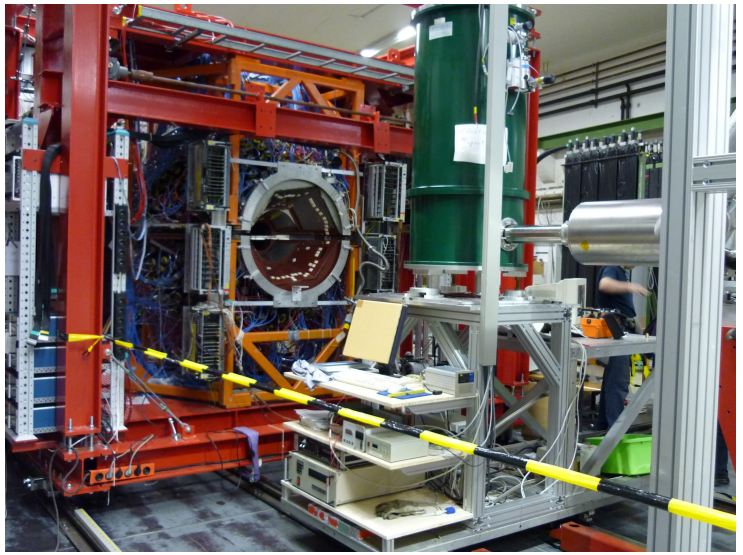
$$\beta = E_{0+}(\gamma p \to \pi^+ n) \cdot a(\pi^+ n \to \pi^0 p)$$

directly related to transverse target asymmetry:

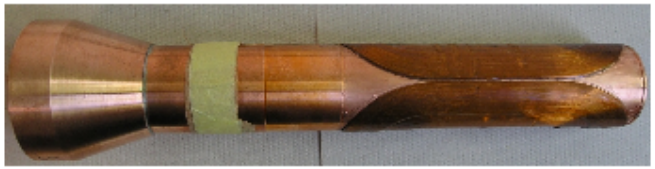
$$T = \frac{d\sigma^y - d\sigma^{-y}}{d\sigma^y + d\sigma^{-y}}$$

$$\sim Im\left[(E_{0+}^* + P_1^* \cos\Theta)(P_2 - P_3)\right] \sin\Theta$$

Frozen Spin Target for Crystal Ball at MAMI



- $^3He - ^4He$ dilution refrigerator (Mainz/Dubna)
- Material: buthanol (>80%), D-buthanol(>70%)
- 1500h relaxation time
- holding coils for transverse and longitudinal spin orientation



Threshold Pion Photoproduction: $Im(E_{0+})$

Feb./March 2011 - measurement with Crystal Ball at MAMI

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_0 \cdot \left\{ P_T \sin\phi_T \cdot T + P_T \cos\phi_T \cdot P_\gamma^{circ} \cdot F \right\}$$

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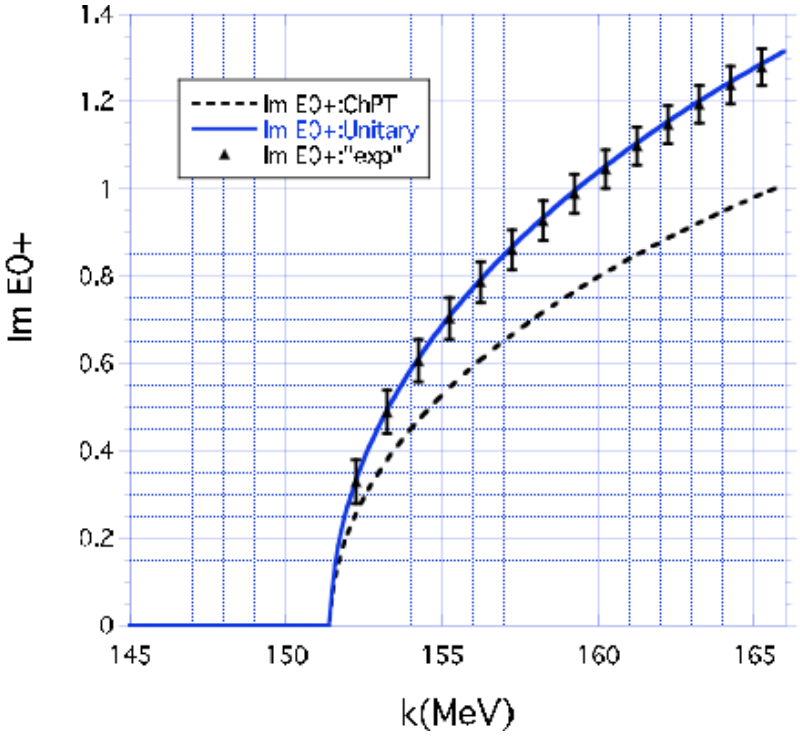
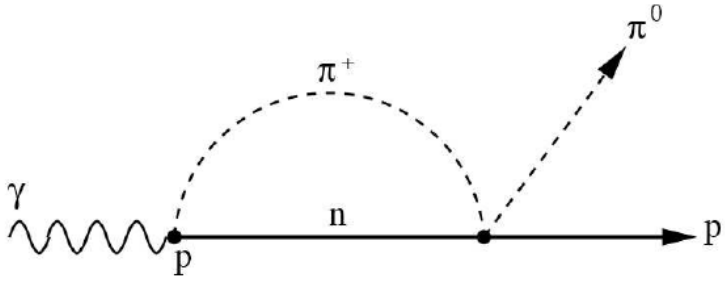
expected uncertainties:





$$\beta = E_{0+}(\gamma p \to \pi^+ n) \cdot a(\pi^+ n \to \pi^0 p)$$

Transverse Asymmetries T and F

Feb./March 2011 - measurement with Crystal Ball at MAMI

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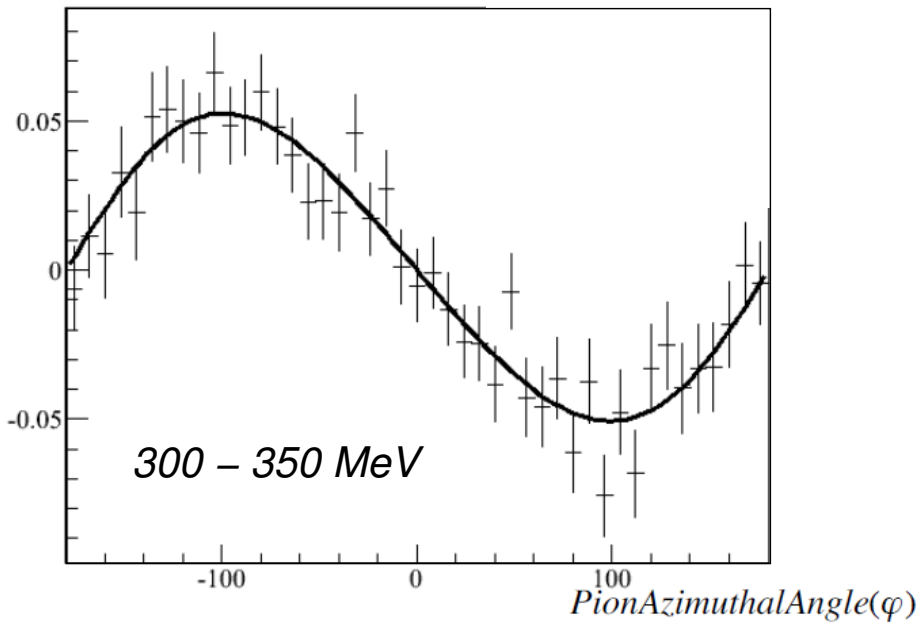
helicity asymmetry:

$$\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{P_T P_\gamma \cos\phi_T \cdot F}{1 + P_T \sin\phi_T \cdot T}$$



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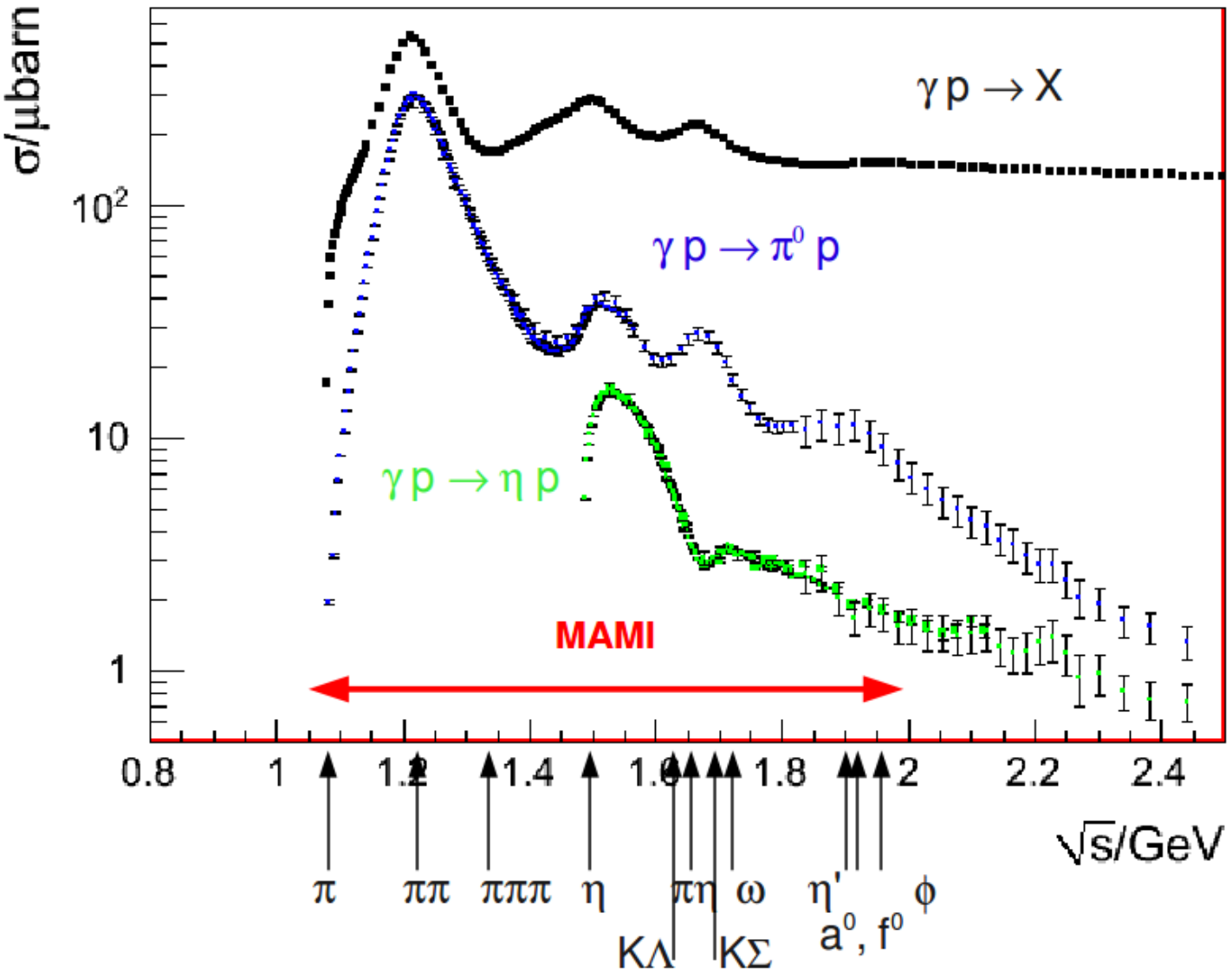

Partial Wave Analyses above the $\Delta(1232)$ resonance

- $\Delta(1232)$ energy region
  - Phases constrained by Watson theorem
  - Model independent PWA with $d\sigma/d\Omega$ and Σ from MAMI (R.Beck et al. 1997)
  - Will be repeated with the new data
  - T und F could provide further constraints

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  - Model independent PWA with $d\sigma/d\Omega$ and Σ from MAMI (R.Beck et al. 1997)
  - Will be repeated with the new data
  - T und F could provide further constraints
- Goal: single energy PWA in 2nd resonance region

$$\begin{aligned} \gamma p &\rightarrow \pi^+ n \\ \gamma p &\rightarrow \pi^0 p \\ \gamma p &\rightarrow \eta p \end{aligned}$$

Spin observables (target, beam-target, beam-recoil)

Transverse target asymmetries

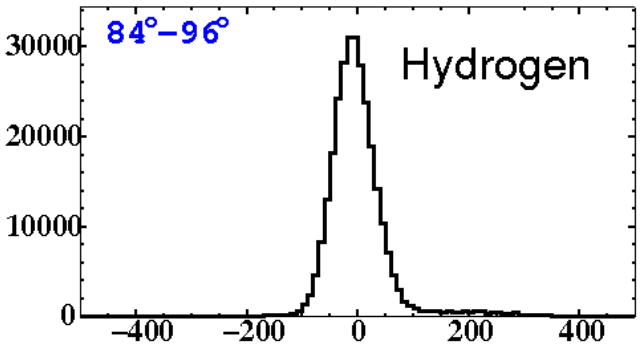
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0} \cdot \left\{1 + P_T \sin\phi_T \cdot T + P_T \cos\phi_T \cdot P_\gamma^{circ} \cdot F\right\}$$

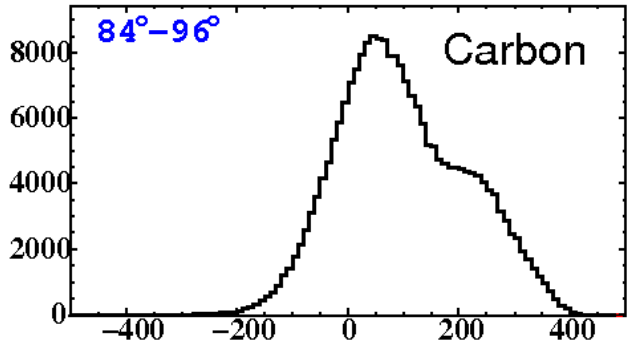
- circularly polarized γ-beam: $E_\gamma = 400 - 1400$MeV
- transversely polarized target
- May/June 2010 $\sim$500 hours / Feb. 2011 $\sim$200 hours

Transverse target asymmetries

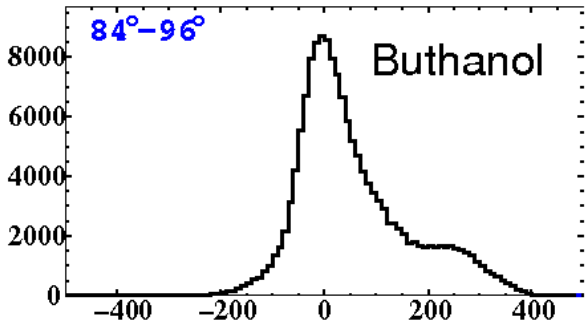
background subtraction

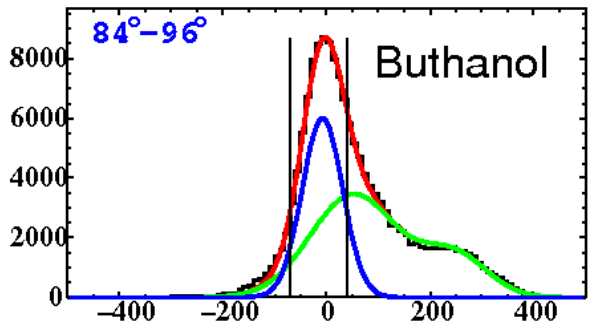
E_γ = 650 – 750 MeV





$MM(\gamma p,\pi^o) - m_p\,(MeV)$



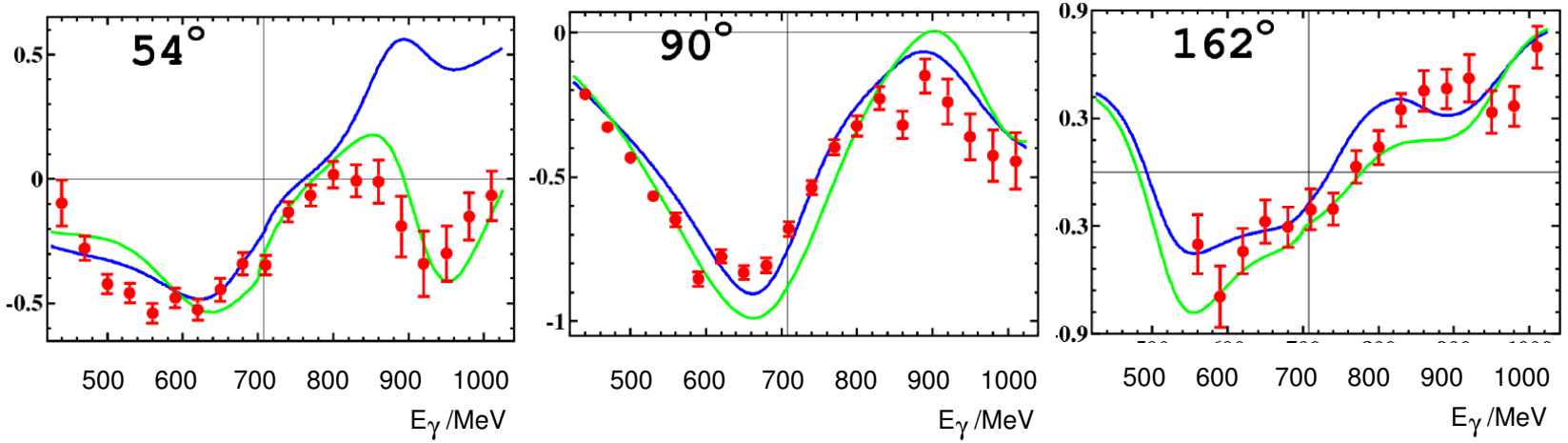


$MM(\gamma p,\pi^o) - m_p\,(MeV)$

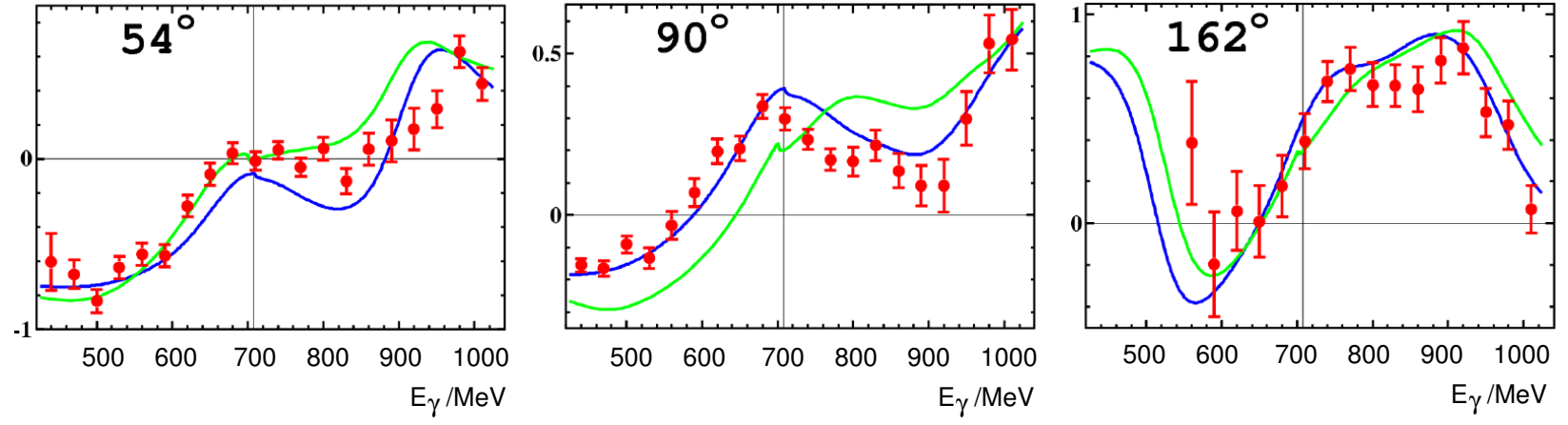
$\gamma\vec{p} \to \pi^0 p$: transverse target asymmetries T and F

preliminary results ($\Delta\theta = 15^o$, $\Delta E_\gamma = 30 MeV$):

T



F



MAID–2007 SAID

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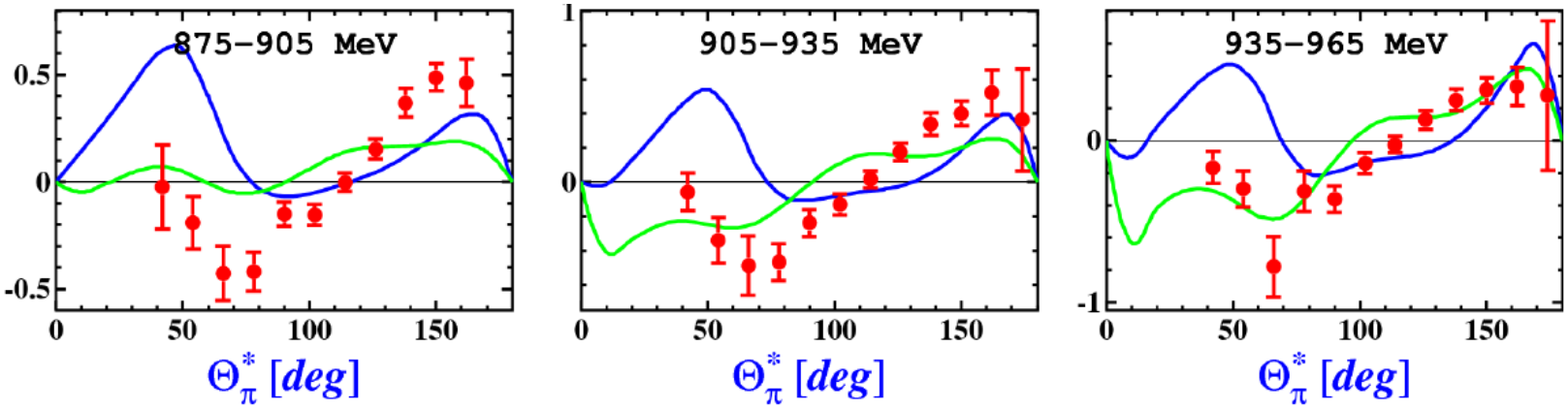
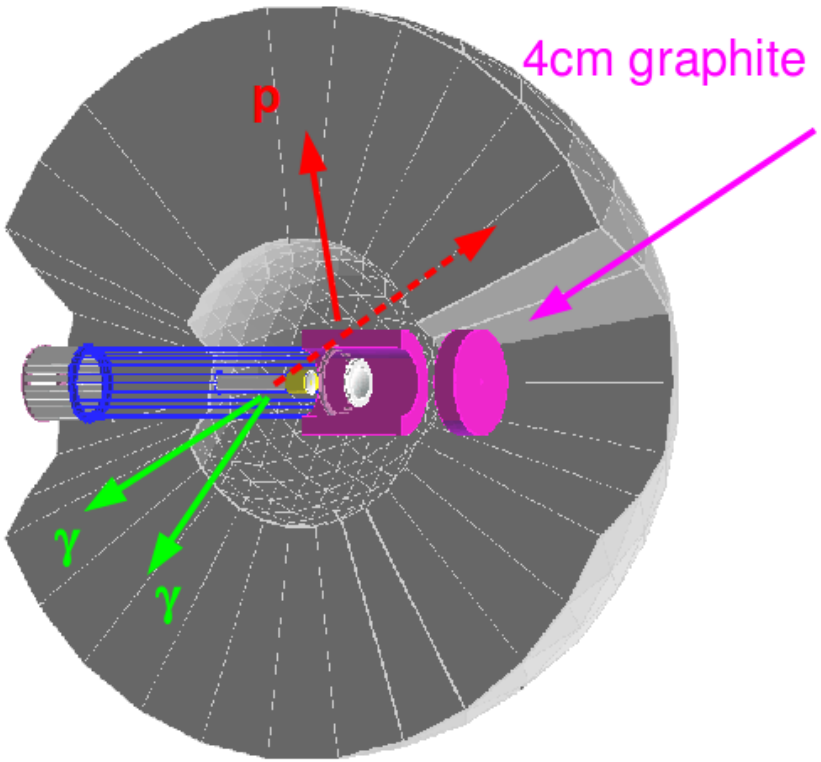
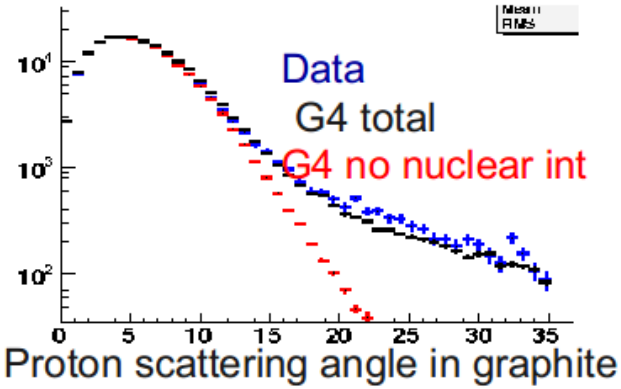


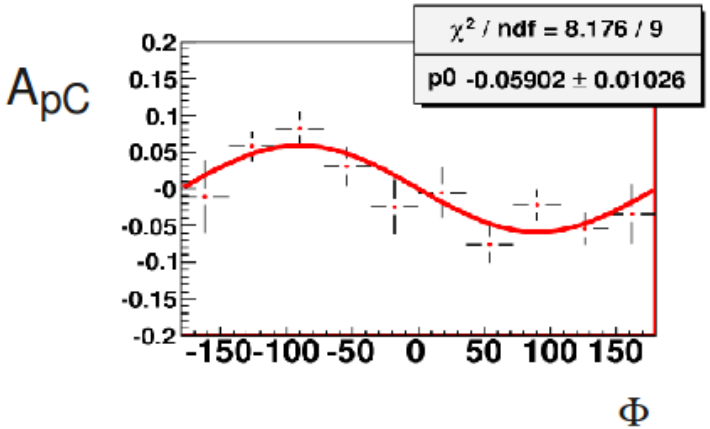
Recoil Polarimetry at Crystal-Ball/TAPS

analysing power A_{pC} in C($\vec{p}$, p') scattering

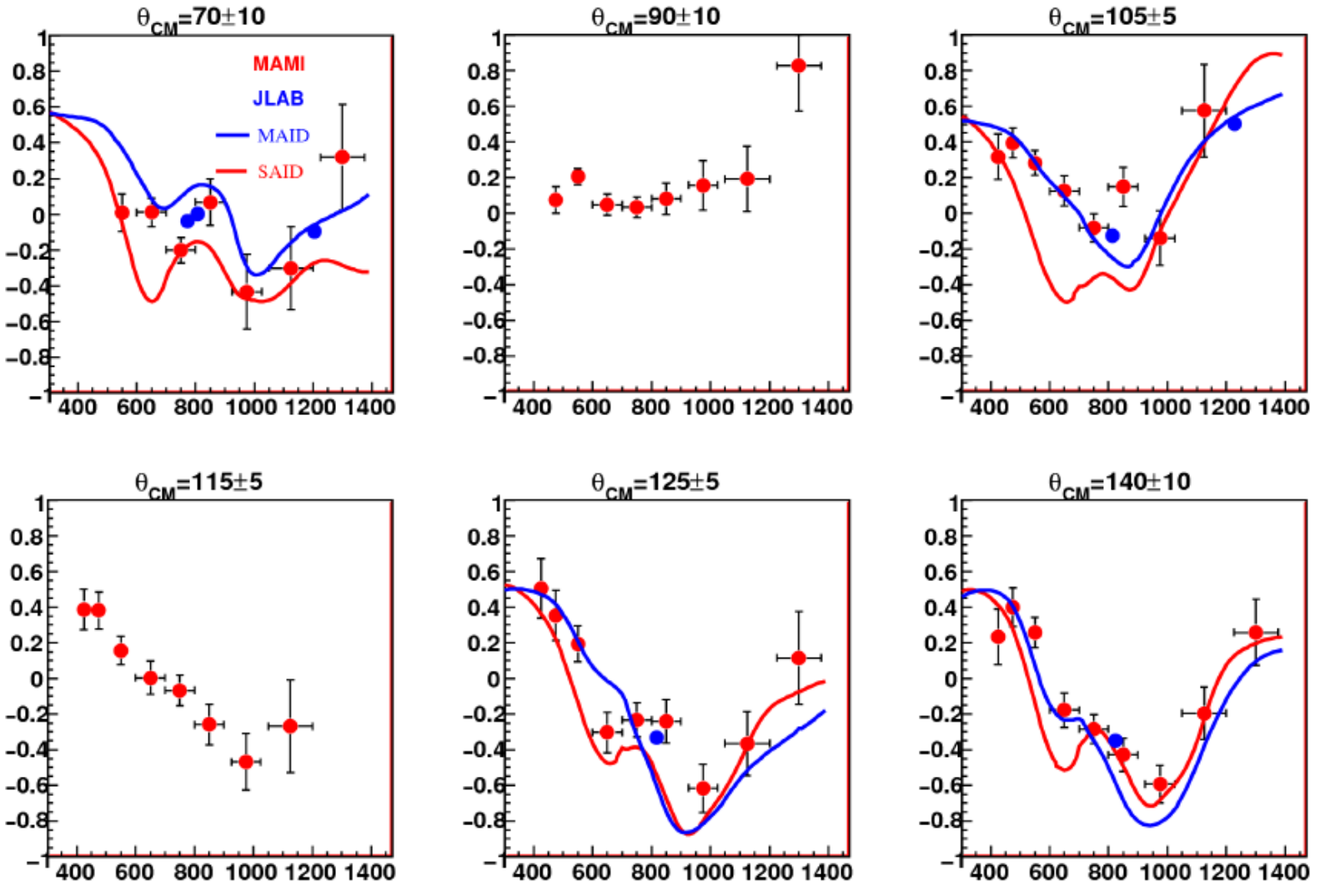
$$n(\theta,\phi) = n_o(\theta)\{1 + A_{pC}(E,\theta)[P_y\cos(\phi) - P_x\sin(\phi)]\}$$







C_x in $\vec{\gamma}p \rightarrow \pi^0\vec{p}$



Summary

- Goal:
  PWA with minimum model constraints in π and η
  photoproduction on protons,
  open strangeness, γn reactions
- Crystal Ball at MAMI:
  hermetic photon spectrometer
  beam–, target– and recoil polarization up to $\sqrt{(s)} \approx 2$ GeV

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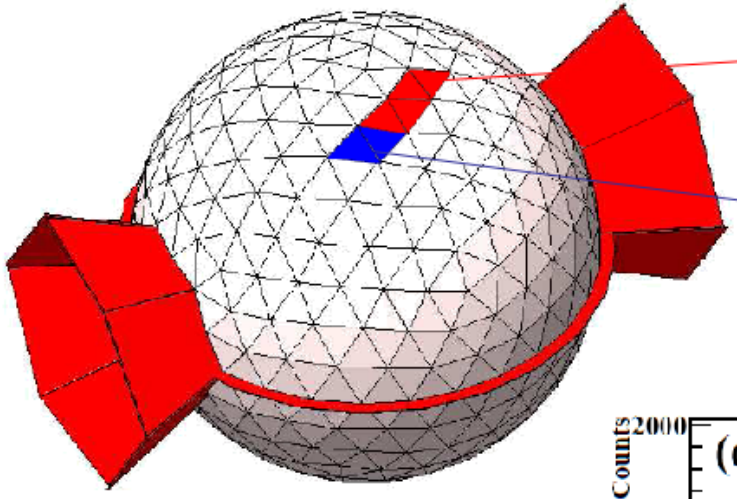
- π^0 threshold:
  - energy dependence of all s- and p-wave multipoles extracted from experimental data.
  - convergence of χPth and chiral unitary models
- Transverse target (T) and beam-target (F) and beam-recoil (C_x) asymmetries
  - Preliminary results from threshold up to $W = 1.6$ GeV

Kaon identification with the Crystal Ball

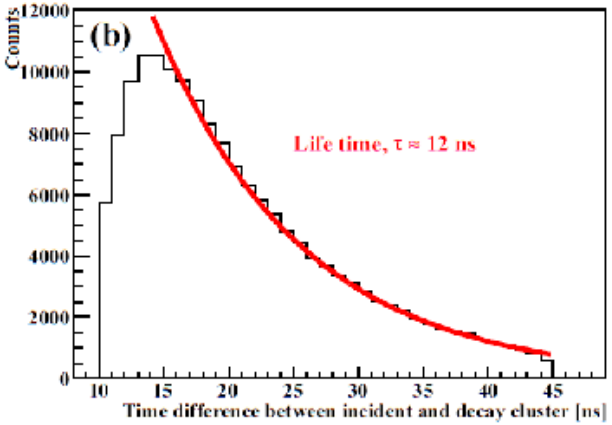
$K^+ \rightarrow \mu^+ + \nu_\mu$ (~ 63%) Mean lifetime of K^+ ~ 12 ns

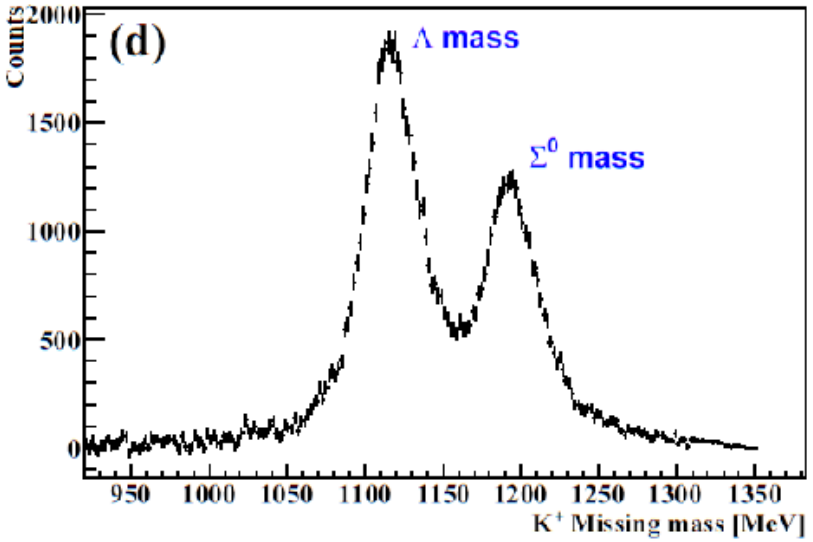
$\pi^+ + \pi^0$ (~ 21%)



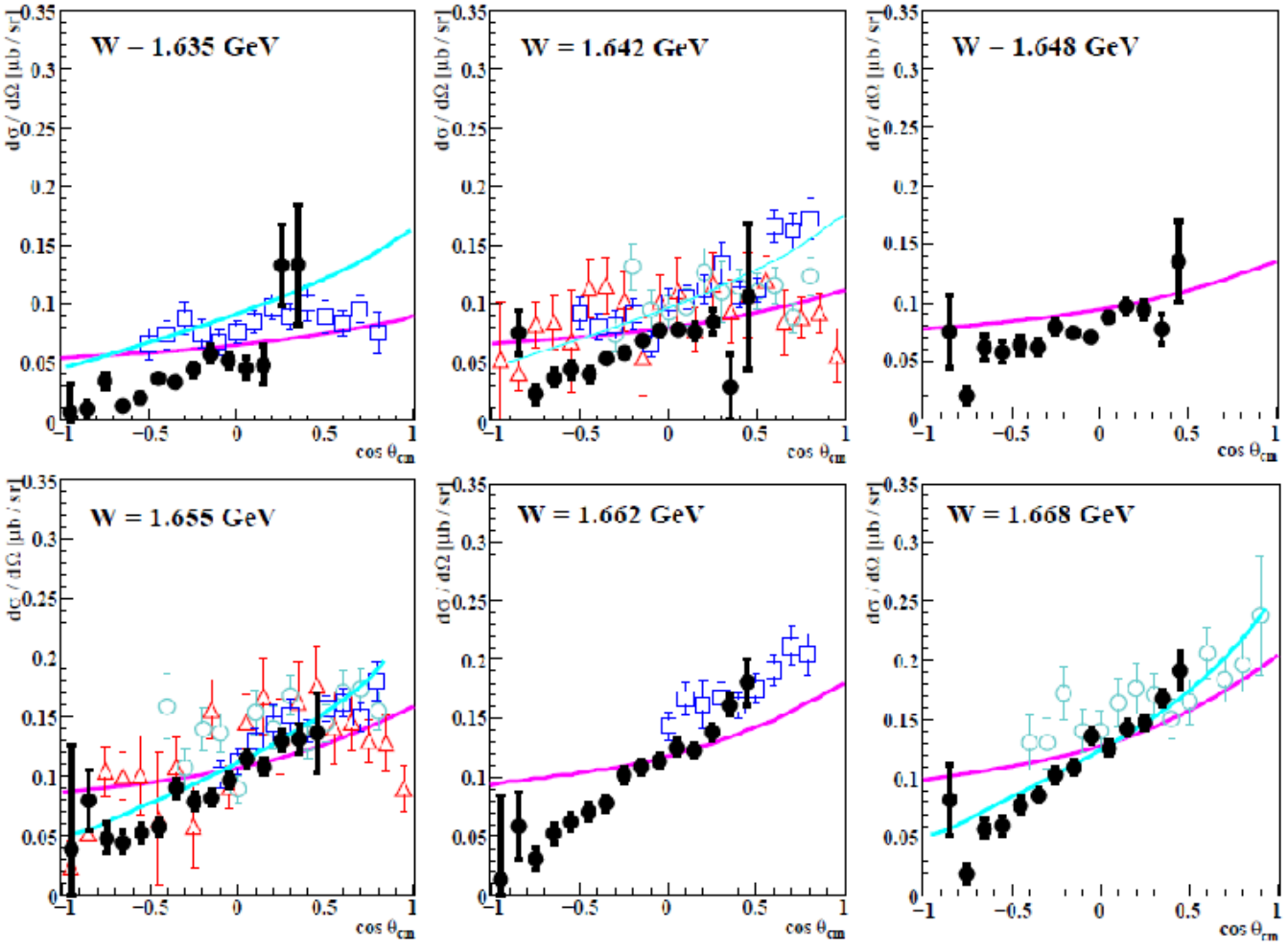
Incident sub-cluster from K^+ ~ 3ns

Decay sub-cluster from $K^+ \rightarrow \mu^+ + \nu_\mu$ decay ~ 20ns



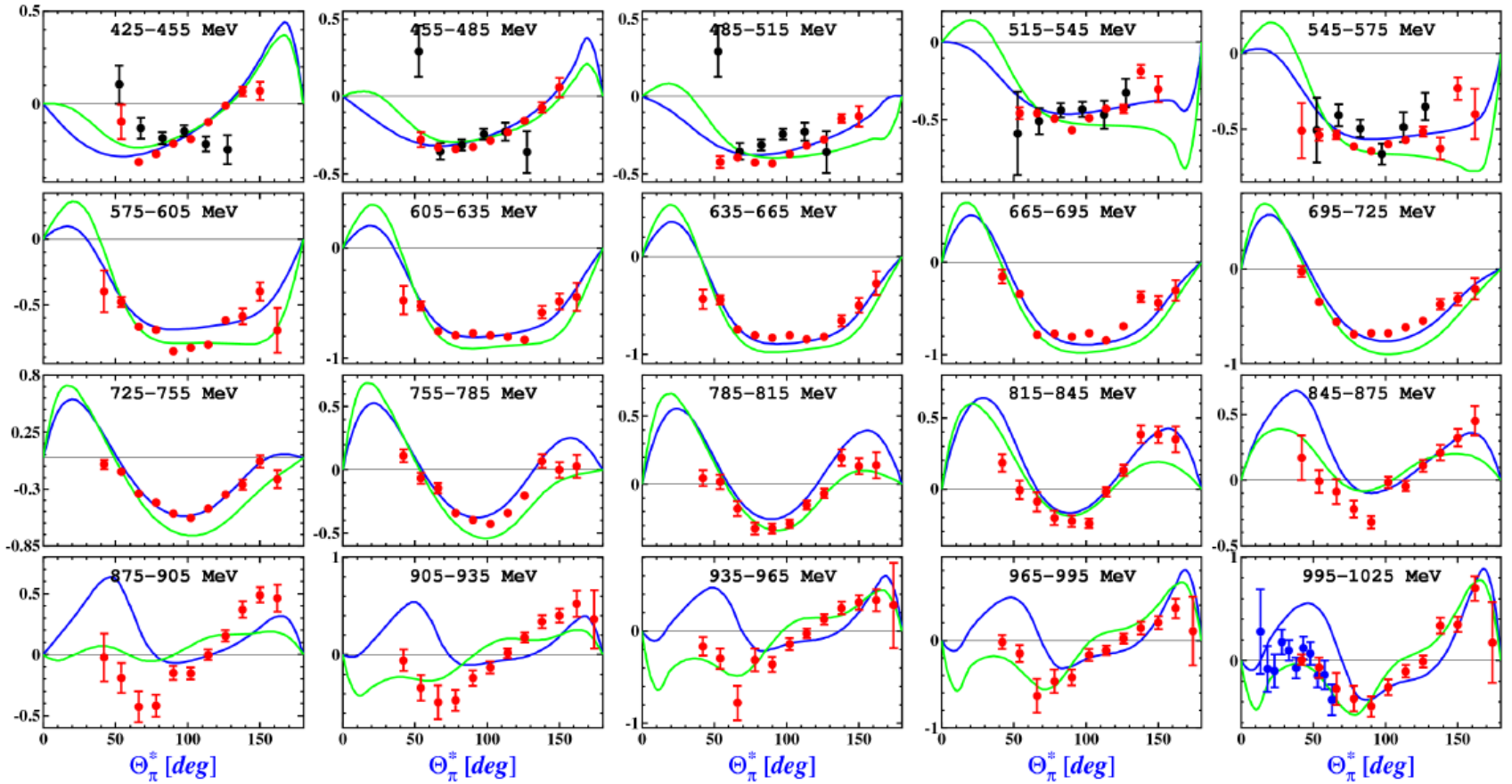


$K^+\Lambda$ threshold production

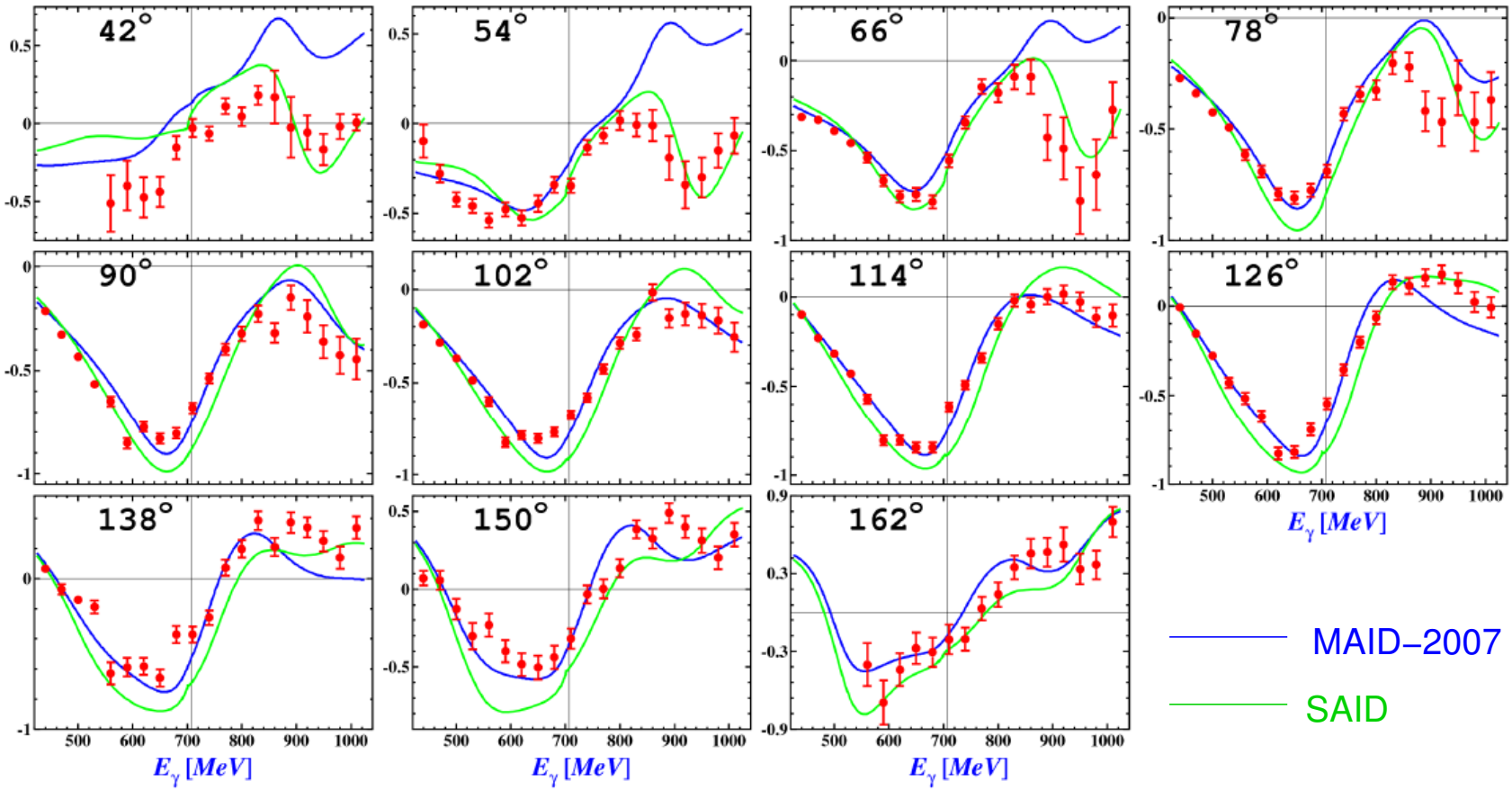


SAPHIR: Eur Phys. J. A **19**, 251 (2004)
CLAS: PRC **73**, 035202 (2006)
PRC **81**, 025201 (2010)

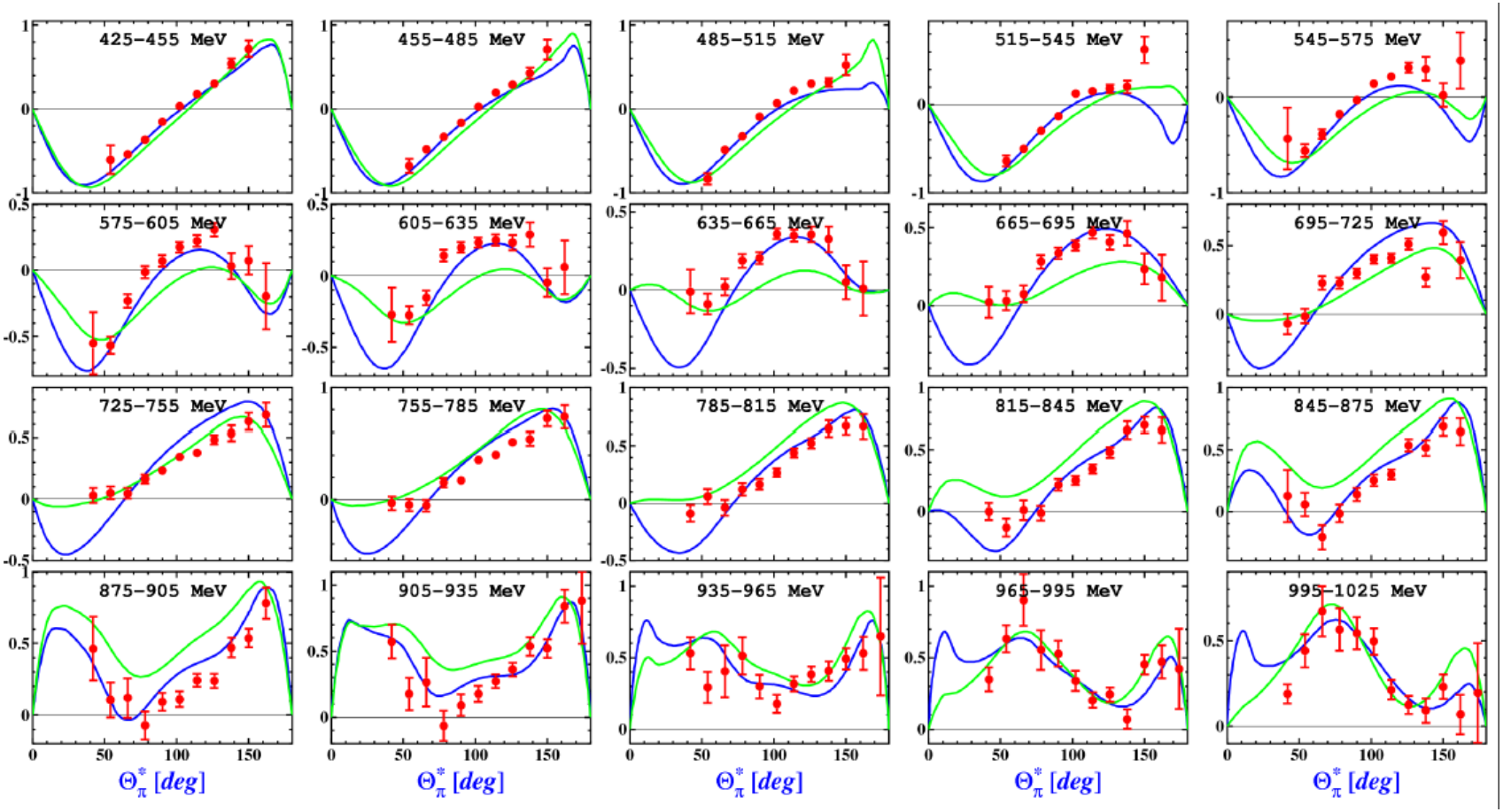
$\gamma\vec{p} \to \pi^0 p$: transverse target asymmetry T



$\gamma\vec{p} \to \pi^0 p$: transverse target asymmetry T



$\vec{\gamma}\vec{p} \to \pi^0 p$: transverse beam-target asymmetry F



$\vec{\gamma}\vec{p} \to \pi^0 p$: transverse beam-target asymmetry F