Measurement of the $\gamma p \rightarrow \eta p$ Reaction with the Crystal Ball Detector at the Mainz Microtron (MAMI-C)

Igor Strakovsky (GW), S. Prakhov (UCLA), R.A. Arndt (GW), Ya. Azimov (PNPI),
W.J. Briscoe (GW), B. Krusche (Basel U), B.M.K. Nefkens (UCLA),
M. Ostrick (Mainz U), M.W. Paris (GW), and R.L. Workman (GW)

[For the Crystal Ball Collaboration @ MAMI]

- Motivation
- Crystal Ball and TAPS at MAMI-C
- Photoproduction of η-mesons on protons
- PWA and multipoles
- Summary and Prospects

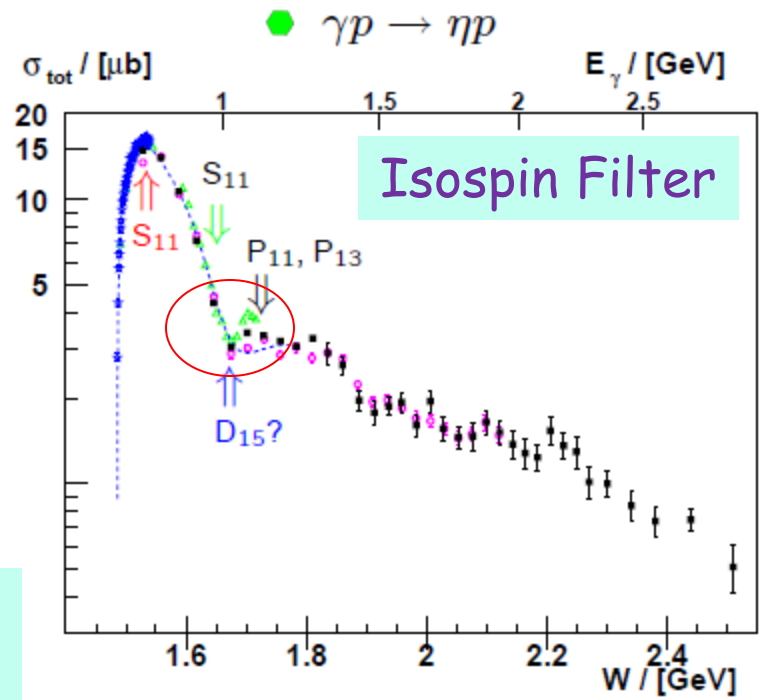
MENU2010, Williamsburg, June 2010

Resonance Couplings to η Photoproduction

[what was known]

branching ratios and elm. couplings (PDG):

state	b_η [%]	$A^p_{1/2}$	$A^p_{3/2}$	$A^n_{1/2}$	$A^n_{3/2}$
• $D_{13}(1520)$:	0.23±0.04	-24	166	59	139
• $S_{11}(1535)$:	30 - 55	90		-46	
• $S_{11}(1650)$:	3 - 10	53		-15	
• $D_{15}(1675)$:	0 ± 1	19	15	-43	-58
• $F_{15}(1680)$:	0 ± 1	-15	133	29	-33
• $D_{13}(1700)$:	0 ± 1				
• $P_{11}(1710)$:	6.2±1.0				
• $P_{13}(1720)$:	4±1				



- **N(1675)D_{15}** has stronger electromagnetic couplings to the neutron than to the proton but parameters are very uncertain:
  $A^p_{1/2}$= 6-34, $A^p_{3/2}$= 3-30
  $A^n_{1/2}$ =–(21-57), $A^n_{3/2}$ =–(30-77)
  b_η=0-1% (PDG) bη=17% (ηMAID)
- interference structure in S_{11}-sector?

Data:

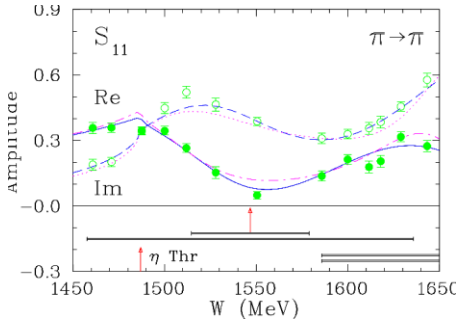
- TAPS: B. Krusche et al., PRL74 (1995) 3736
- GRAAL: F. Renard et al., PLB528 (2002) 215
- CLAS: M. Dugger et al., PRL89 (2002) 222002
- Crystal Barrel: V. Crede et al., PRL94 (2005) 012004

[Courtesy of Bernd Krusche, NNR 2009]

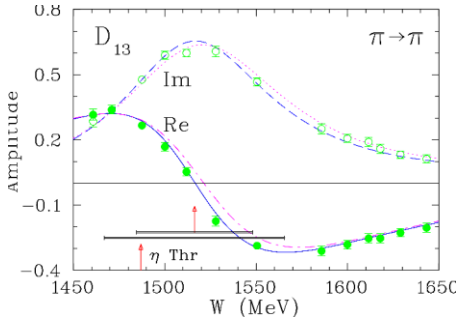
- There is really no room for large BR of **N(1675)D_{15}**
- It visibly exceeds the boundaries given by the **SU(3)**

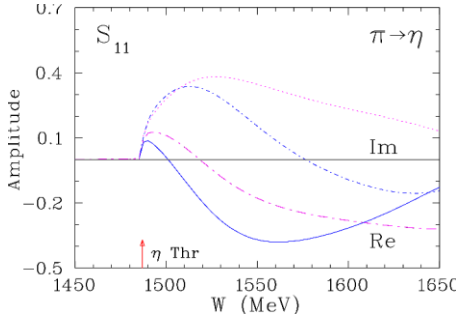
Multi-Channel Fit for S_{11} & D_{13}: ηn BRs

[R. Arndt, W. Briscoe, IS, R. Workman, A. Gridnev, Phys Rev C **72**, 045202 (2005)]

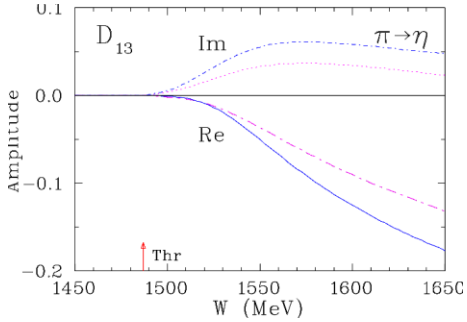


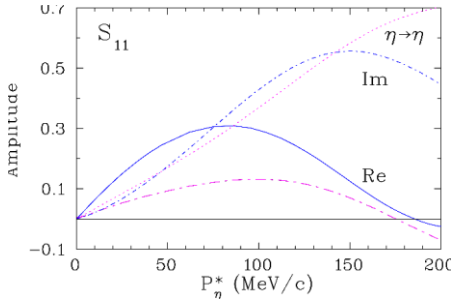
- N(1535)S_{11}: $\Gamma_\eta > \Gamma_\pi$
- N(1520)D_{13}: Γ_η/Γ = **0.0008 – 0.0016**





- D_{13} [Mainz (γ, η)]: Γ_η/Γ = 0.0008±0.0001
  D_{13} [Giessen, multi-ch]: Γ_η/Γ = 0.0023±0.0004





- 28 σ^t and 37 P data above 800 MeV
- Limited energy range restricts possibilities to determine resonance parameters

	T (MeV)	E (MeV)	W (MeV)
Thr	559	707	1487
πN limit	800	947	1632

$\pi^- p \to \eta n$ $\gamma p \to \eta p$

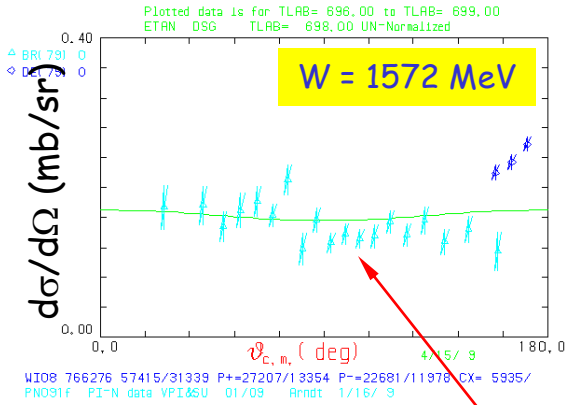
No E913/914 BNL thr data
E913/914 CB BNL thr data included

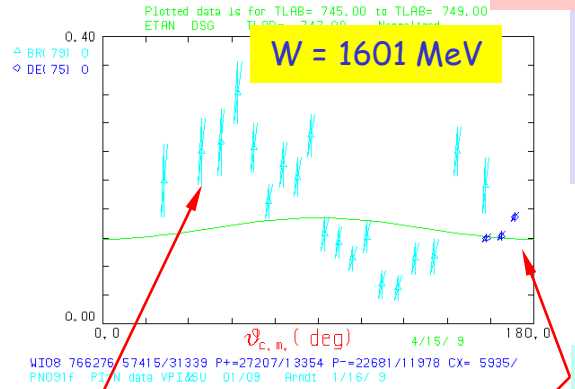
$\pi^- p \to \eta n$ Puzzle

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

- Several groups evaluated data before 1992

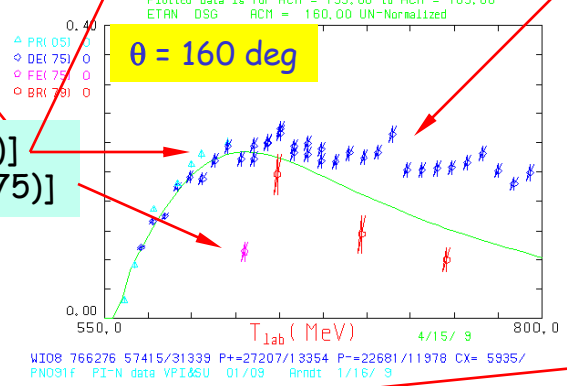
Clajus & Nefkens, πN News Lett **7**, 76 (1992)
Cutkosky *et al* Phys Rev D **20**, 2804 (1979)
Koch & Pietarinen, Nucl Phys **A336**, 331 (1980)
Wighman *et al* Phys Rev D **38**, 3365 (1988)





[Debenham *et al*, Phys Rev D **12**, 2545 (1975)]

[Brown *et al*, Nucl Phys **B153**, 89 (1979)]
[Feltesse *et al*, Nucl Phys **B93**, 242 (1975)]



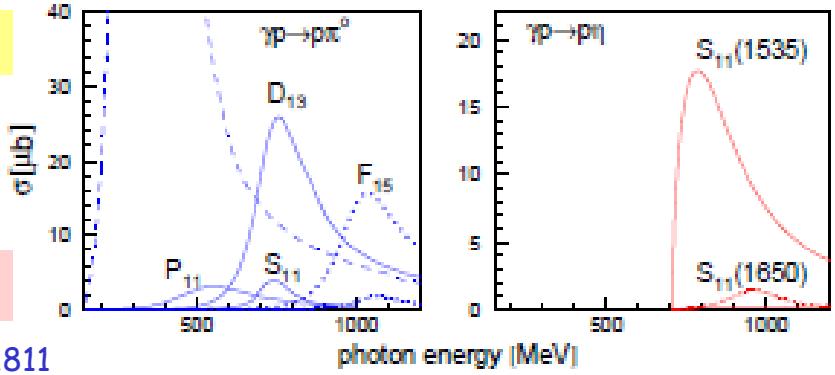
Nimrod was a 7 GeV proton synchrotron operating in the Rutherford Appleton Laboratory in UK between 1964 and 1978

- Most of **Nimrod** data do not satisfy requirements
  [systematics (10% or more), momentum err (up to 50 MeV/c), and so on]
- For that reason, we are not able to use them in $\pi^- p \to \pi^- p$, $\pi^0 n$, and ηn PWAs

GW PWA for γp→ηp

[R. Arndt, W. Briscoe, M. Paris, IS, R. Workman, in progress]

- Res contribution from scalar meson photoproduction



- There is no discrimination against any measurements

E429: (E=700-2900 MeV) χ^2/dp=2818/1811
ηMAID : (E=700-1900 MeV) χ^2/dp=4153/1329

Obs		Nexp	Ndata	χ^2(1)	χ^2(2)
dσ/dΩ	Norm	91	542	667	662
	UnNorm			1221	1168
Pol	Norm	33	106	198	389
	UnNorm			204	442

χ^2/dp(UnNorn) = **2.1** **2.5**
χ^2/dp(Norn) = **1.3** **2.2**

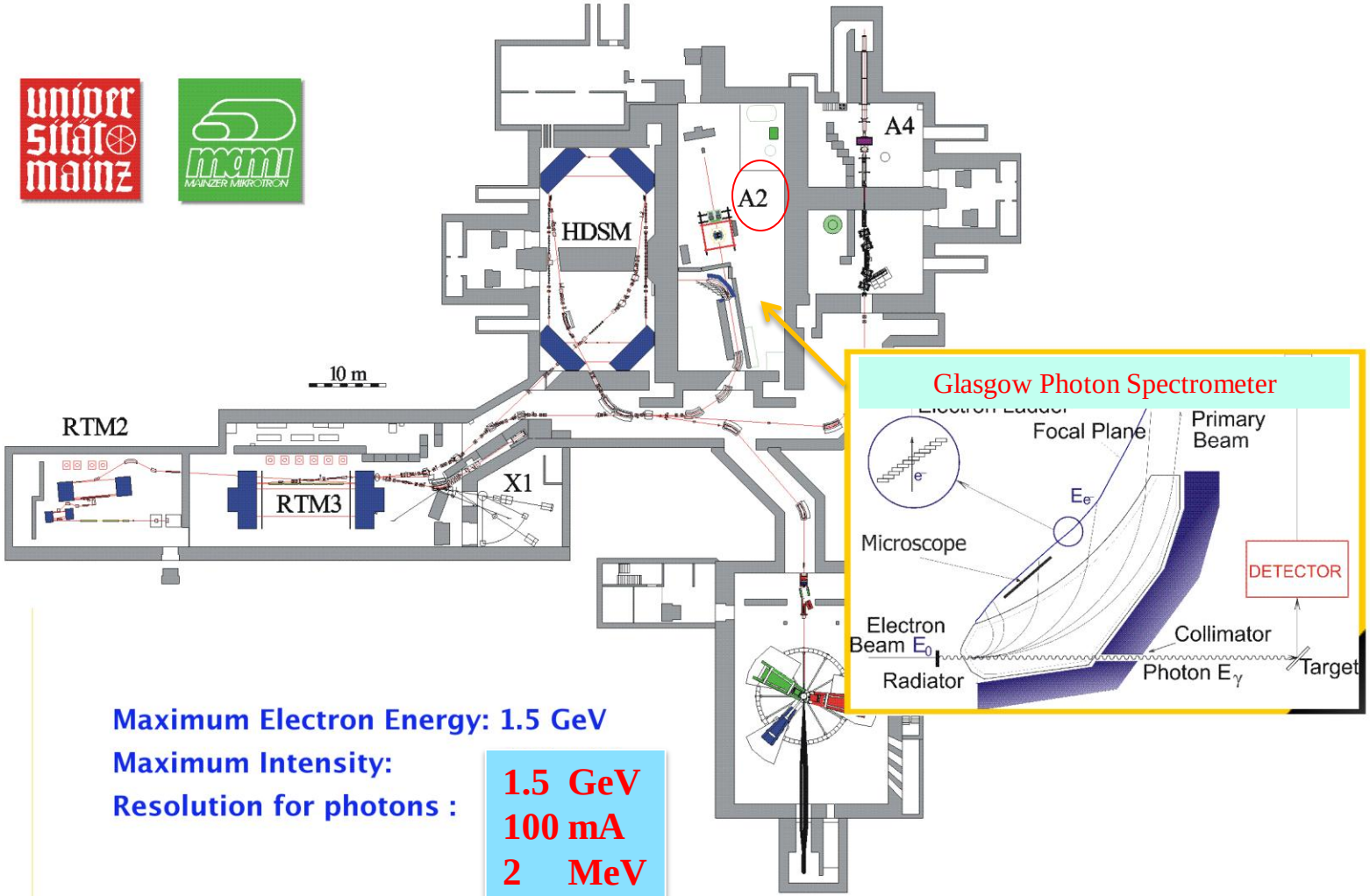
- For **ηMAID**, the normalization constants were searched to minimize χ^2 (no adjustment of the partial waves was possible)

- Renormalization freedom provides a significant improvement for the best fit results

$$\chi^2 = \sum_i \left(\frac{X\theta_i - \theta_i^{\exp}}{\epsilon_i}\right)^2 + \left(\frac{X-1}{\epsilon_X}\right)^2$$

ηMAID : W.-T. Chiang *et al* Nucl Phys **A700**, 429 (2002)

MAMI-C Facility



Maximum Electron Energy: 1.5 GeV

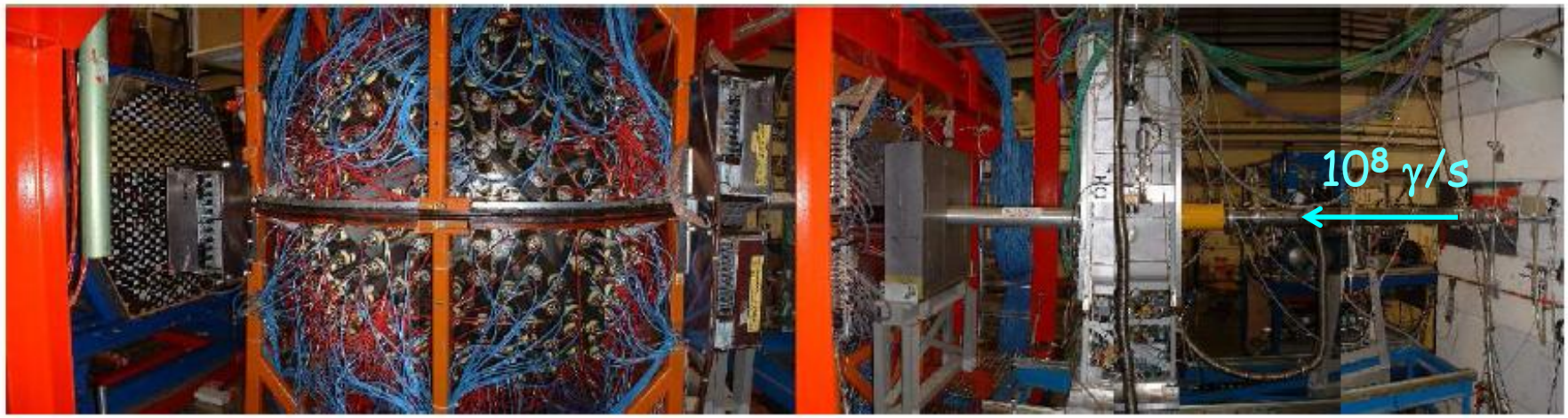
Maximum Intensity: **1.5 GeV**

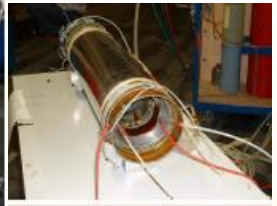
Resolution for photons : **100 mA**

2 MeV

More details about **MAMI-C** and Recent results are in **Juergen Arends's** talk

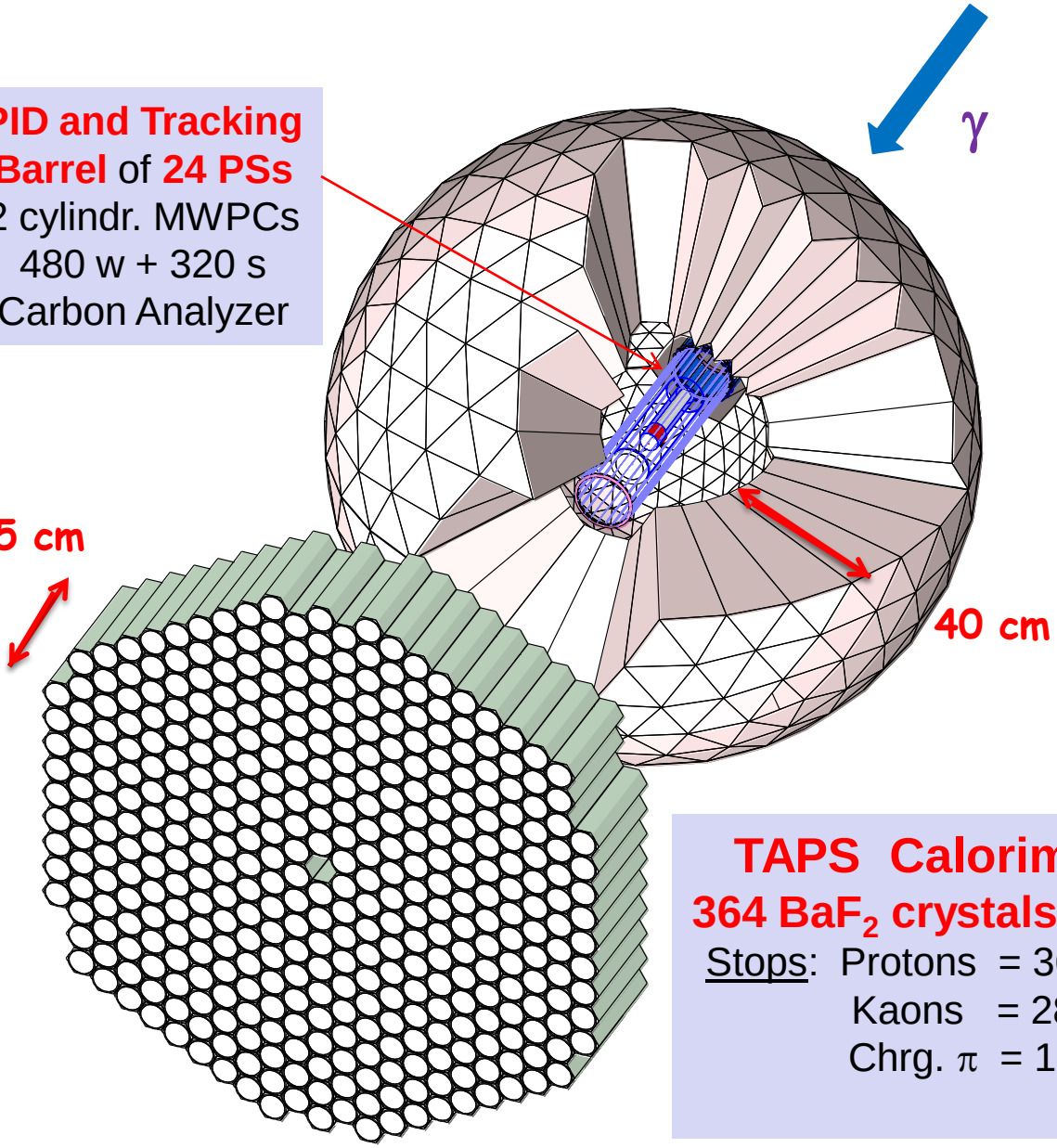
Crystal Ball and TAPS @ MAMI-C





Crystal Ball, TAPS, and Tracking

PID and Tracking Barrel of **24 PSs**
2 cylindr. MWPCs
480 w + 320 s
Carbon Analyzer

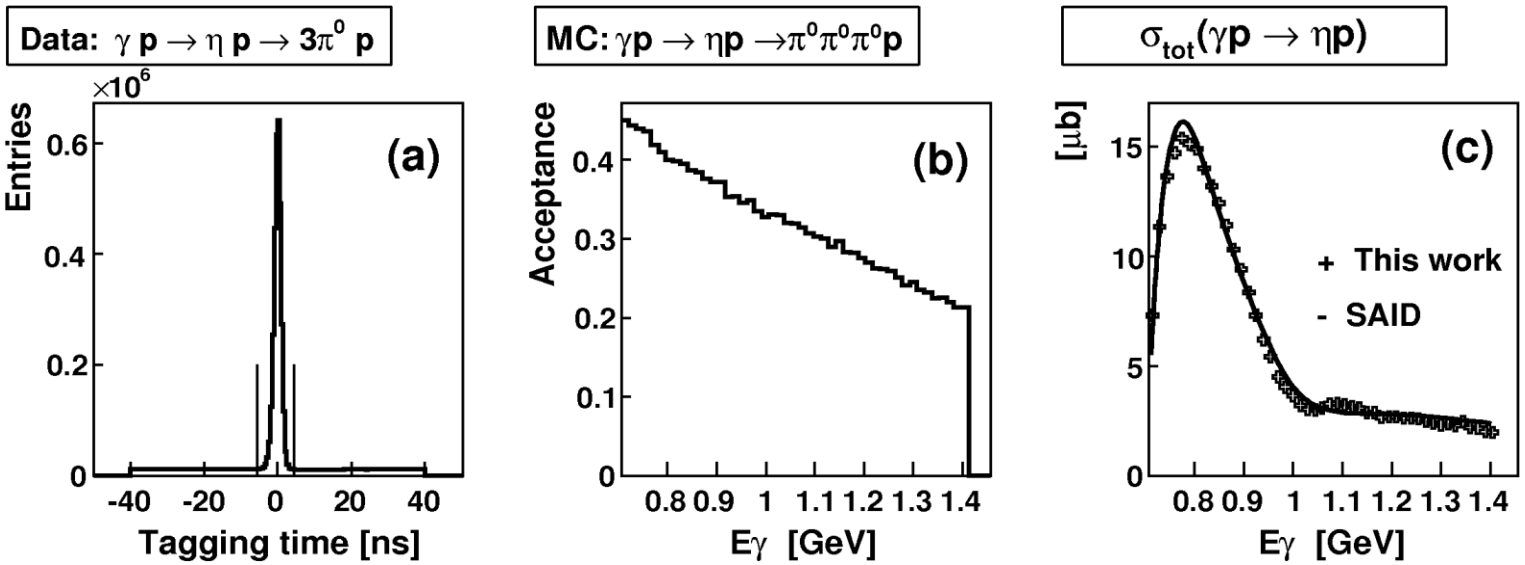


Crystal Ball
672 NaI crystals [20-160º]
Stops: Protons = 420 MeV
Kaons = 340 MeV
Chrg. π = 240 MeV
Chrg. μ = 230 MeV

σ(E) = 2 MeV
σ(θ) = 2.5º
σ(ϕ) = 2º/sinθ

TAPS Calorimeter
364 BaF_2 crystals [0-20º]
Stops: Protons = 360 MeV
Kaons = 280 MeV
Chrg. π = 180 MeV

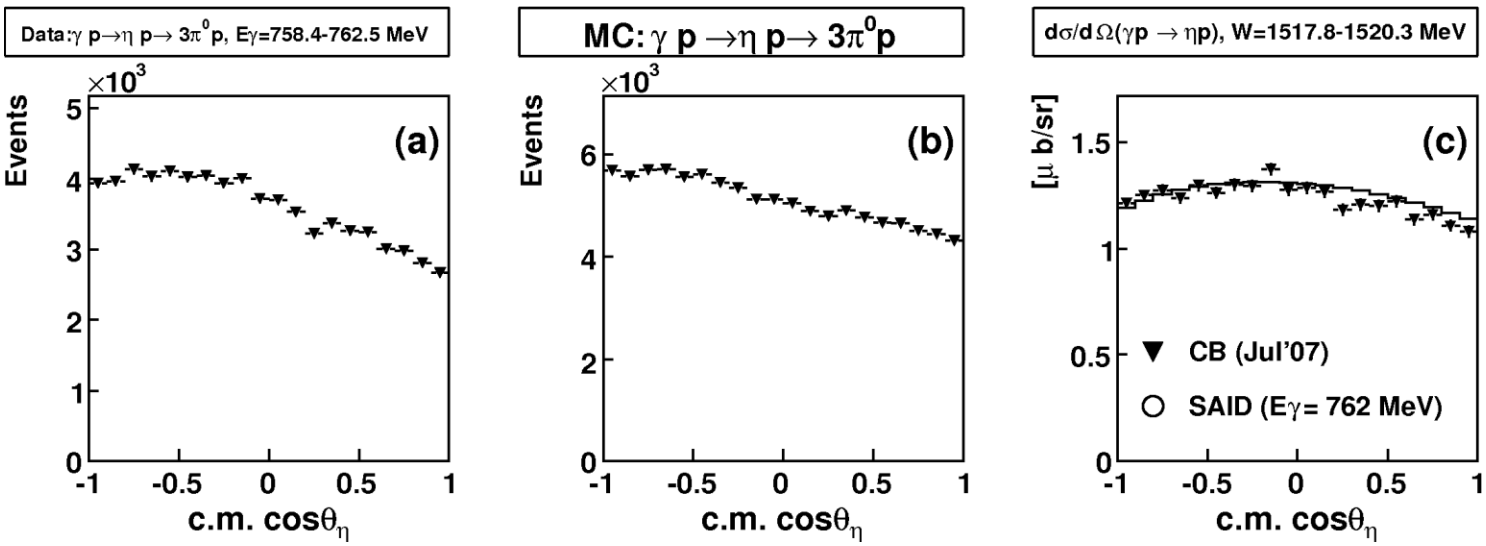
Production of $\eta \to 3\pi^0$ Events @ MAMI-C



- Reaction $\gamma p \to \eta p \to 3\pi^0 p$ at **MAMI-C**: E_γ = 707 – 1402 MeV is tagged
- CB + TAPS →30% average acceptance, 80% of the protons are detected
- Kinematic fit of $\gamma p \to \eta p \to 3\pi^0 p \to 6\gamma p$ at the 2% **CL** is used to identify $\eta \to 3\pi^0$ events
- Remaining Background contributions: Random coincidences in the tagger ~8%,

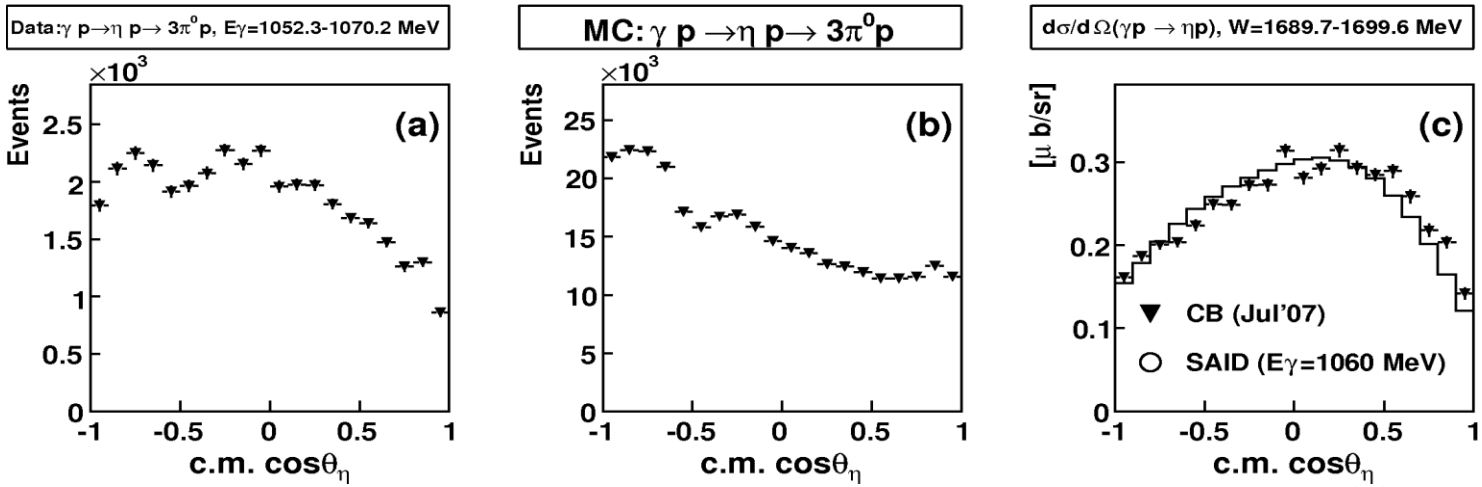
  $\gamma p \to 3\pi^0 p$ from 0.4% to 4%, Empty target from 1% to 4%

Production Angular Distributions for $\gamma p \to \eta p$



3.8×10^6 $\gamma p \to \eta p \to 3\pi^0 p \to 6\gamma p$ events allow to get 2400 $d\sigma/d\Omega$s

E_γ = 707 - 1402 MeV; W = 1487 - 1875 MeV; θ = 0 - 180 deg; Stat = 2%; Syst = 4%



$\gamma p \rightarrow \eta p$: Angular Distributions

[Data: Courtesy of Sergey Prakhov for the CB Collab @ MAMI]

1489 MeV

- **120 Energy bins:**

Energy binning ~ 3 MeV

E_γ = 707 - 1402 MeV

W = 1487 - 1875 MeV

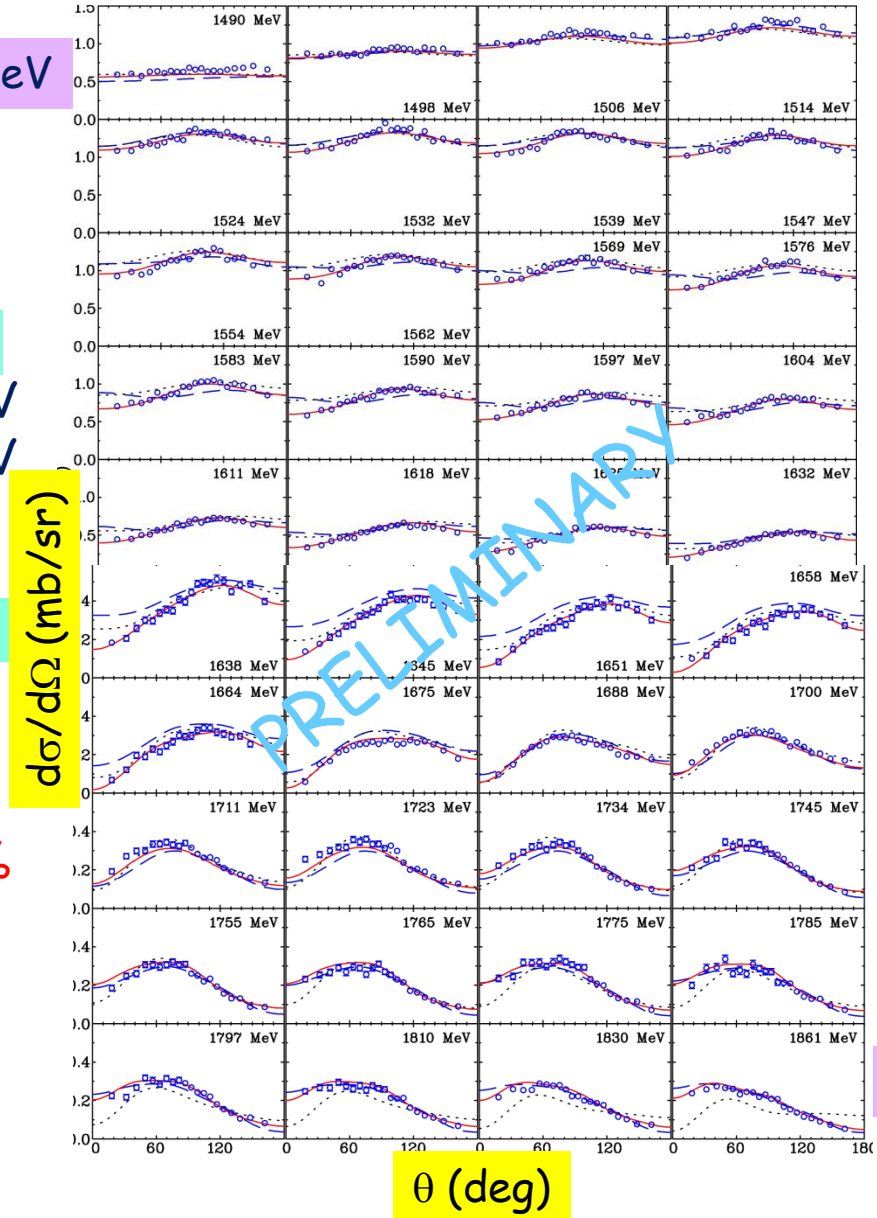
- **20 Angular bins:**

Angular binning ~ 9 deg

θ = 0 - 180 deg

- **Uncertainties:**

Stat = 2% Syst = 4%



- - - E429

····· ηMAID

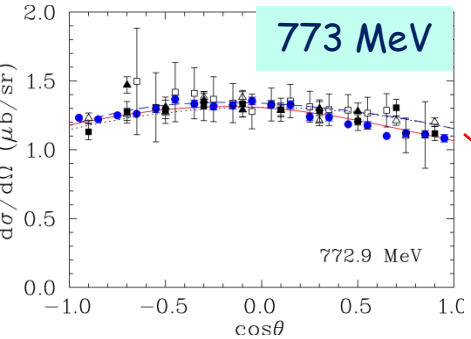
—— GE09

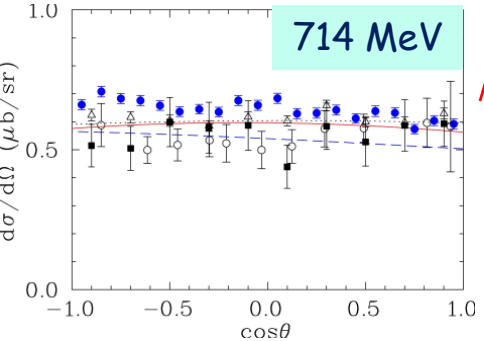
o CB+TAPS@MAMI-C *included*

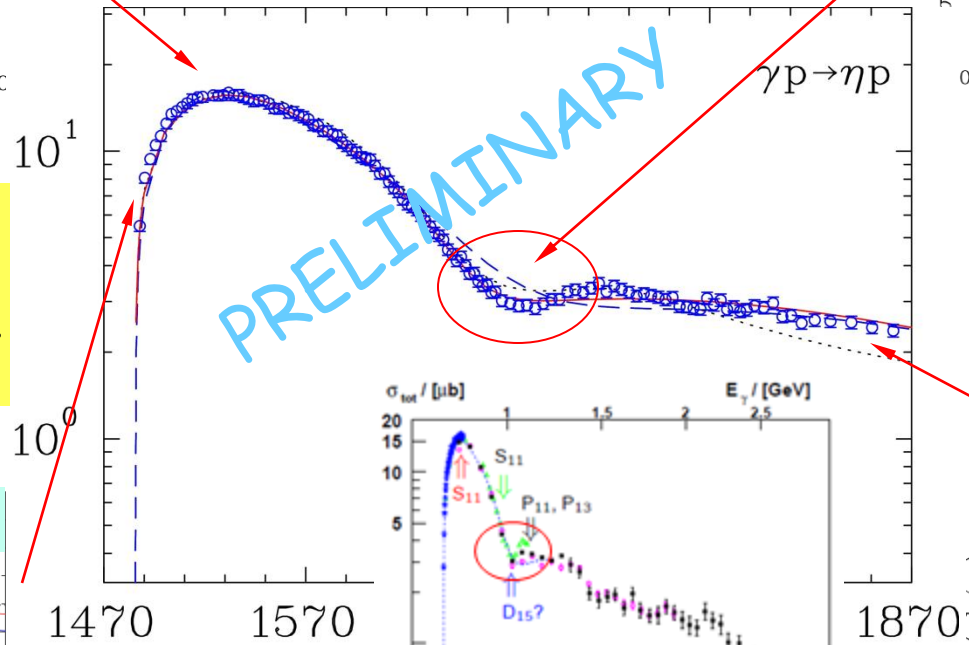
1872 MeV

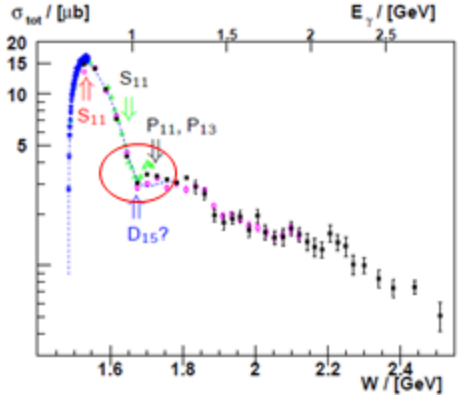
γp→ηp: Total Cross Sections

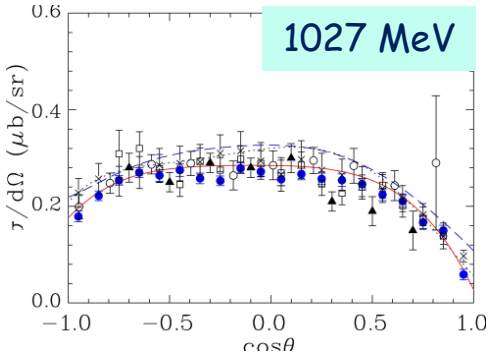
[Data: Courtesy of Sergey Prakhov for the CB Collab @ MAMI]

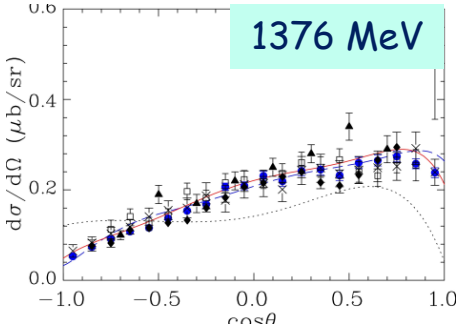












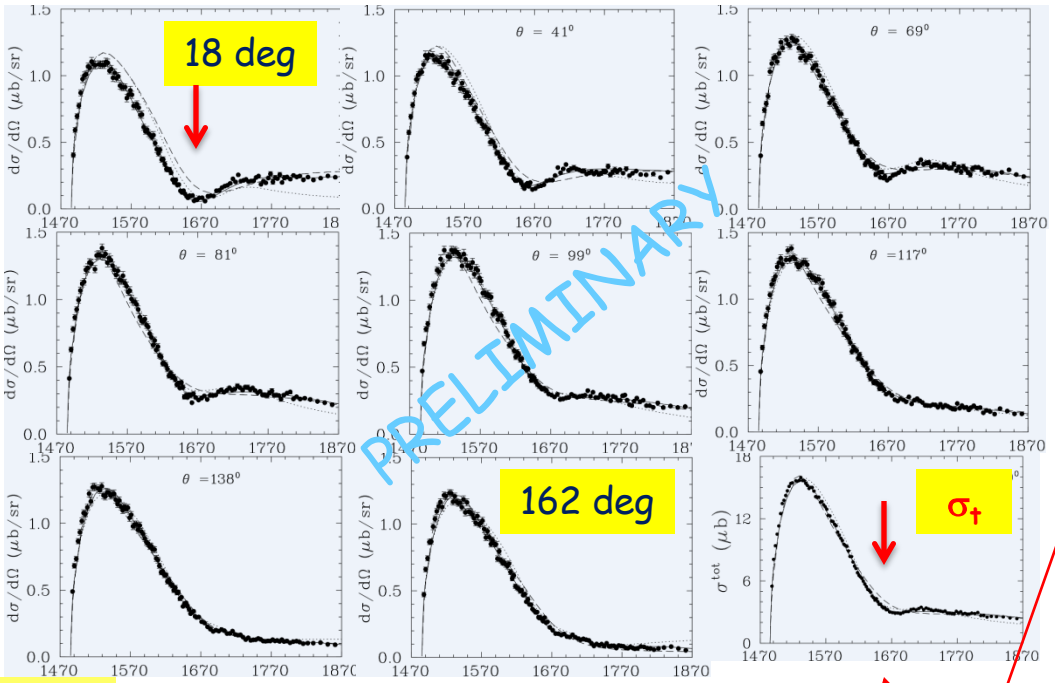
- - - E429

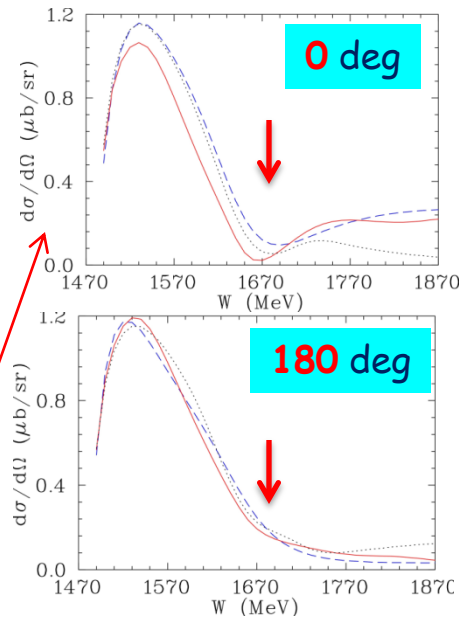
……..ηMAID

—— GE09

γp→ηp: Excitation Functions

[Data: Courtesy of Sergey Prakhov for the CB Collab @ MAMI]





- - - E429

.... ηMAID

—— GE09

o CB+TAPS@MAMI-C *included*

- Our data show a dip near W = **1670** MeV in σ_t and its association with a significant dip in the forward dσ/dΩ
- This feature was missed or questionable in the analysis of previous data

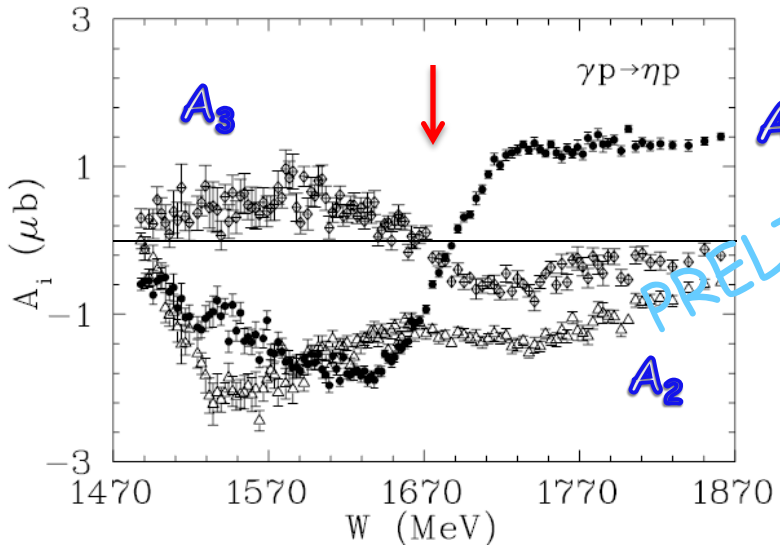
$\gamma p \rightarrow \eta p$: Puzzle for CB @ MAMI-C Data

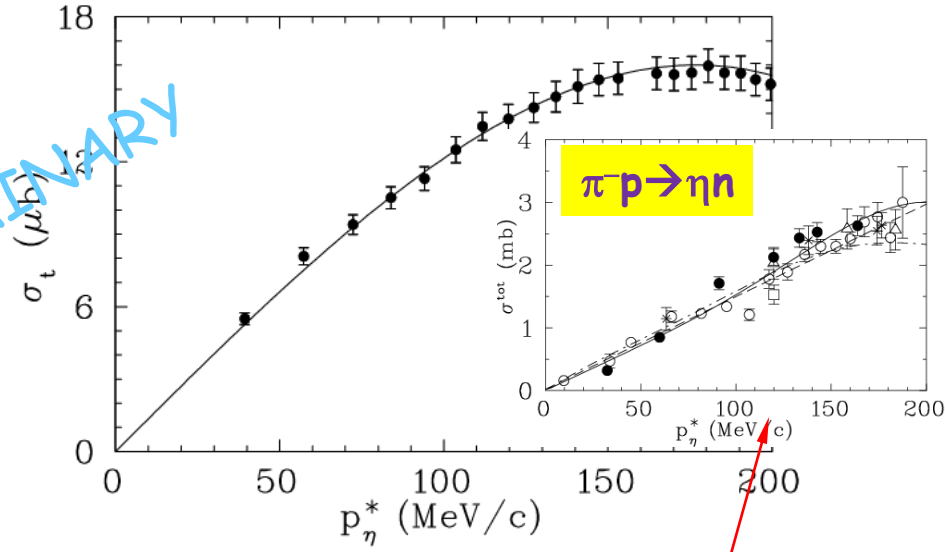
$d\sigma/d\Omega = A_0 + A_1P_1 + A_2P_2 + A_3P_3 + A_4P_4 + A_5P_5$

P_i are Legendre polynomial terms of order i

$\sigma_t = B_0P_\eta + B_1P_\eta^3$

P_η is the η-momentum in CM





- The full angular coverage of our $d\sigma/d\Omega$ in connection with small statistical uncertainties allows reliable determination of coefficients A_i of the Legendre series
- This was hard to do with the previous data

- Threshold behavior

E913/914 CB @ BNL

PWA for Recent dσ/dΩ of γp→ηp

Thr: E=706.9 MeV W=1487 MeV

E429 : (E=700-2900 MeV) χ^2/dp=2818/1811
GE09 : (E=700-2900 MeV) χ^2/dp=6295/4211
ηMAID : (E=700-1900 MeV) χ^2/dp=4153/1329

New CB-MAMI-C data included; No CR09

Valid up to W = 2.11 GeV
Does not include 2009 data

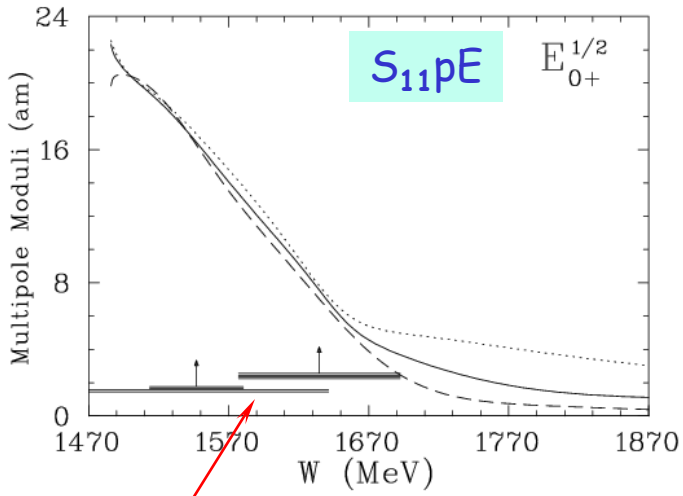
30% of World Statistics

Lab	E_γ (MeV)		W (MeV)		θ (deg)		#	Stat (%)	Syst (%)	χ^2/dp E429	GE09	ηMAID	Ref
CB-MAMI-C	707	1402	1487	1875	0	180	**2400**	2	4	5.5	1.4	6.8	PR10
GRAAL	714	1100	1491	1718	17	162	**244**	10	3	1.2	0.9	0.7	RE02
MAMI-B	716	790	1493	1539	26	154	**100**	4	4	1.4	1.4	1.2	KR95
LNS	718	1142	1494	1740	26	154	**180**	2	6	0.9	1.5	0.9	NA06
CB-ELSA	774	2887	1530	2511	18	139	**631**	2	15	1.3	1.3	3.1	CR05
CLAS-g1c	775	1925	1530	2121	46	134	**190**	3	5	2.3	2.3	5.6	DU02
CB-ELSA/TAPS	875	2525	1590	2372	18	162	**680**	4	10	2.6	2.6	11.2	CR09
CLAS-g11a	1044	2861	1690	2502	33	148	**979**	7	11	4.3	5.7	12.0	WI09
LEPS	1650	2350	2000	2300	130	162	**32**	5-10		coming	soon		SU09

!

- For **ηMAID**:
  the normalization constants were searched to minimize χ^2
  (no adjustment of the partial waves was possible)

γp→ηp: Proton Amplitudes



BW from πN PWA

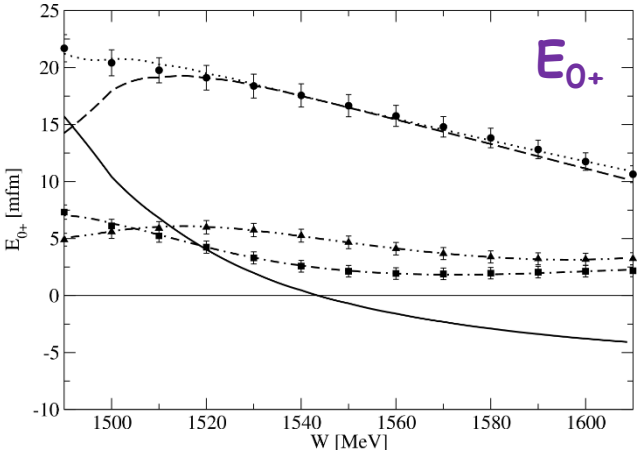
$A = A^* E_{0+} \times Mag(E_{0+})$

----- E429

..... ηMAID

_____ GE09

More details are in **Mark Paris's** talk



- The predicted values for the Re (solid curve) and Im (dashed curve) for ηE_{0+}
- The modulus $\eta|E_{0+}|$ (dotted curve), the Re (dot-dashed curve), and the Im (double dot-dashed curve) parts of the πE_{0+} were fit to amplitude generated from the **ηMAID**

[M. Paris and R. Workman, arXiv:1001.3626 [hep-ex]

Summary and Prospects

Experimental Results:

2400 $d\sigma/d\Omega$s have been measured using CB+TAPS @ MAMI for
W = 1487 - 1875 MeV & θ = 0 - 180 deg; Stat = 2%; Syst = 4%

Phenomenological Results:

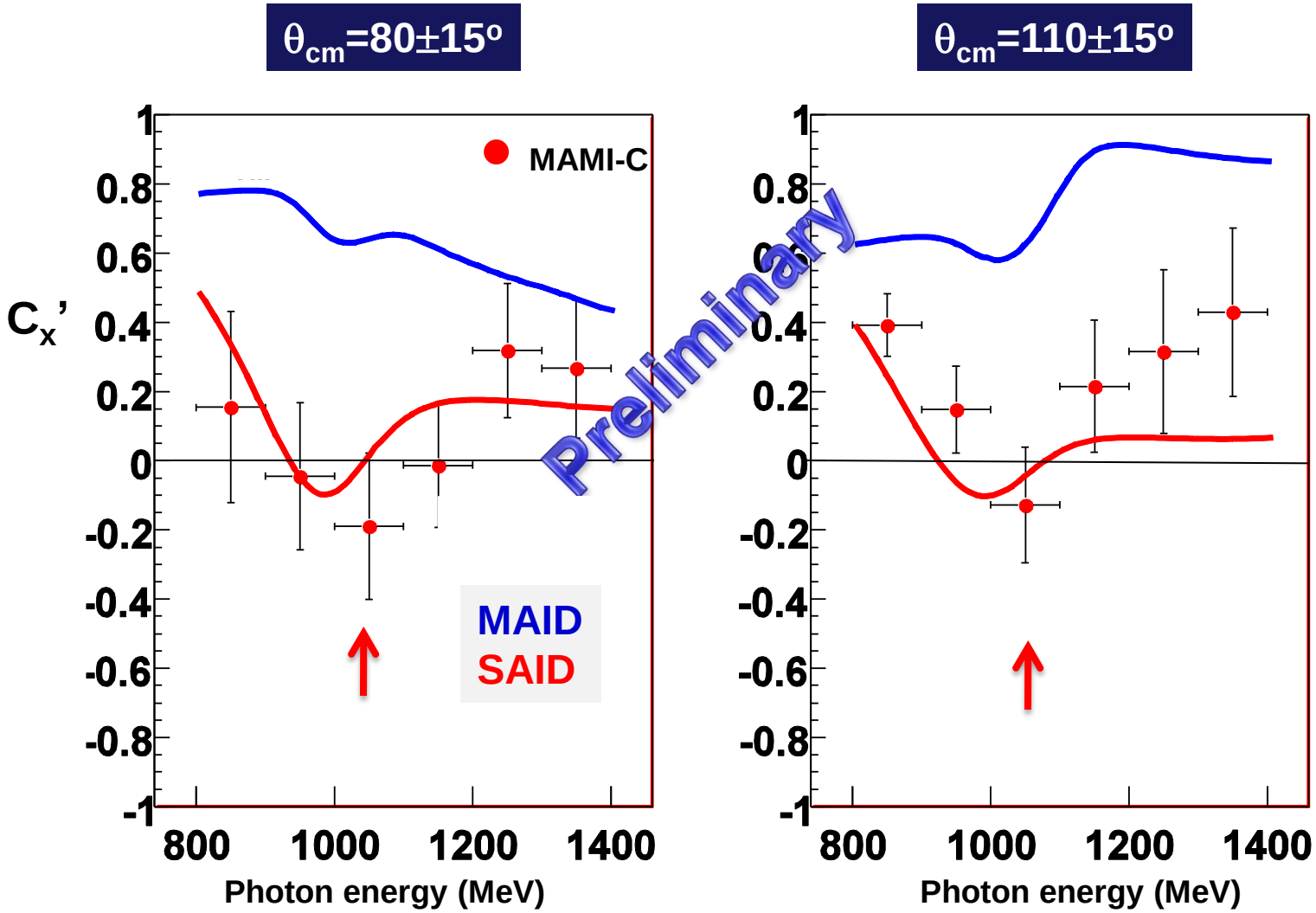
The inclusion of new CB+TAPS @ MAMI data in the SAID database improves the fit significantly

The new data have been used to evaluate the ηp multipoles in the vicinity of several low-lying $I = \frac{1}{2}$ baryon resonances

Advantage:

New quality data allow to search for narrow states such as the possible N(1680)

$p(\gamma,\eta)p \Rightarrow C_{x'}$ from MAMI

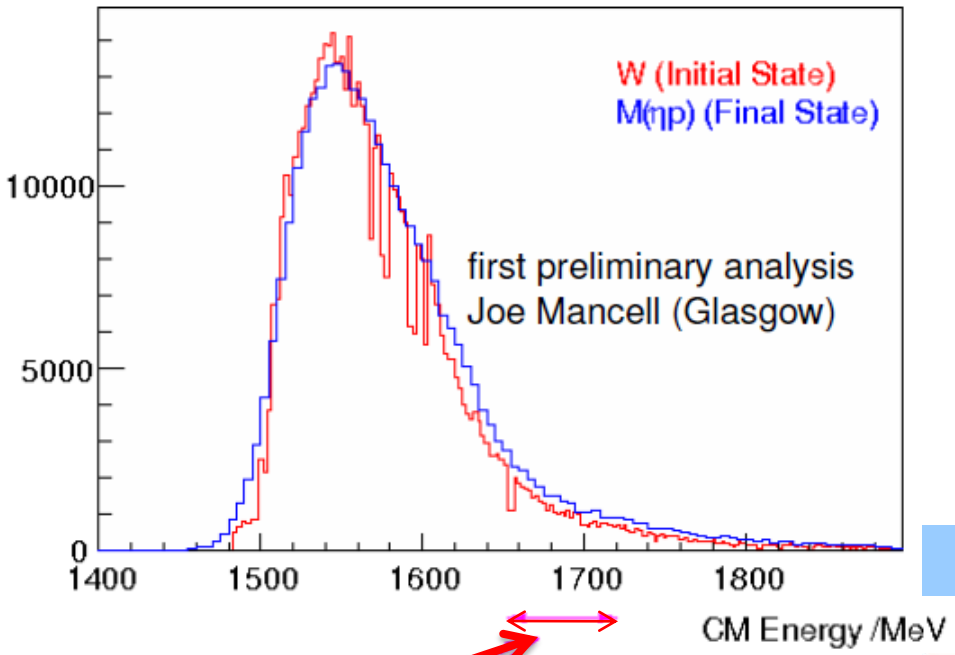


- Next steps: O_x, T, and P also $p(\gamma, 2\pi)$ and $p(\gamma, \pi\eta)$

[Courtesy of Dan Watts, N*2009]

Next Step is to Look for the Narrow N(1680)

- New MAMI-C data from April 2009



- Covered by high resolution microscope ΔE ~ 1 MeV

More details about N(1680) at

Narrow Nucleon Resonances:
Predictions, Evidences, Perspectives
June 8 - 10

http://2009physicsevents.org/index.htm

[Courtesy of Michael Ostrick, NNR 2009]