Photoproduction of eta-mesons in the presence of a narrow $P_{11}(1675)$ resonance

- introduction
- the isobar model EtaMaid
- t-channel exchanges: poles vs. Regge trajectories
- $D_{15}(1675)$ resonance vs. narrow $P_{11}(1675)$
- summary

η - MAID

- **EtaMaid 2001**
  W.-T Chiang
  C. Bennhold
  D. Drechsel
  L.T.

Born terms in s- and u-channel
ρ,ω pole terms in t-channel
N* resonances:
D13(1520), S11(1535), S11(1650), D15(1675)
F15(1680), D13(1700), P11(1710), P13(1720)

- **ReggeMaid 2003**
  W.-T. Chiang
  M. Vanderhaeghen
  L.T.

Born terms
ρ,ω Regge trajectories
N* resonances:
D13(1520), S11(1535), S11(1650), D15(1675)

- **EtaMaid 2006**
  A. Fix
  M. Polyakov
  L.T.

Regge isobar model as ReggeMaid2003
with additional narrow P11(1675) resonance

MAID

the Mainz-Dubna Unitary Isobar Model

$$t^{\alpha}_{\gamma,\pi} = v^{\alpha}_{\gamma,\pi}(Born + \omega, \rho)\,(1 + i\,t^{\alpha}_{\pi,\pi})$$

K-matrix unitarization

$$+\; t^{\alpha}_{\gamma,\pi}(Resonances)\; e^{i\Phi(W)}$$

unitarization phase
determined by the Watson theorem, below 2π threshold
relaxed above 2π threshold

ETA-MAID

uses a simpler approach without unitarization

$$t_{\gamma,\eta} = v_{\gamma,\eta}(Born + \omega, \rho) + t_{\gamma,\eta}(Resonances)$$

what is missing:

influence of other coupled channels

possibly: $K\Lambda$, $K\Sigma$, ...

Born terms do not play an important role in eta production

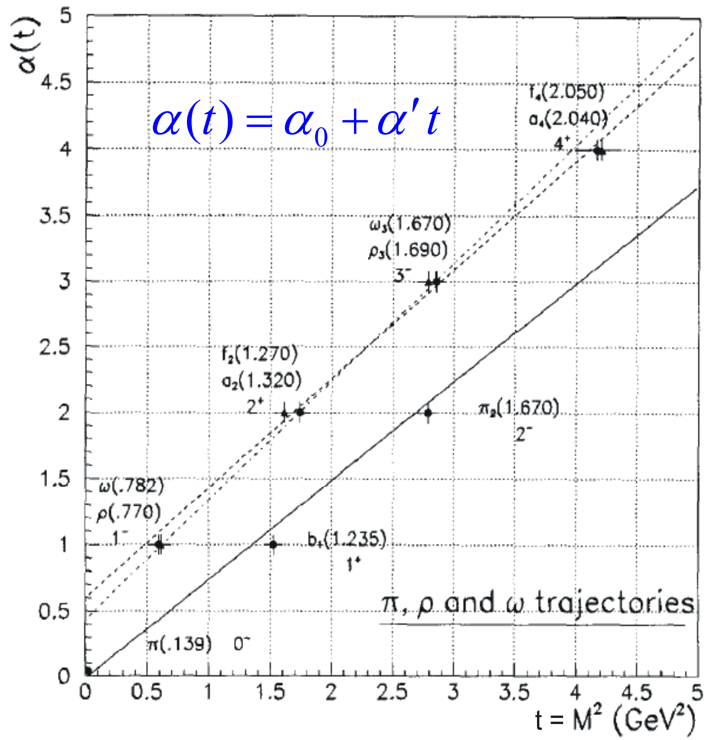
$$g^2/4\pi \sim 0.1$$

Vector meson exchanges of ω,ρ in the t-channel can be treated in 2 different ways:

1. as t-channel poles (with additional form factors)
2. as Regge trajectories (giving rise to questions about duality and double counting)

Regge Trajectory Exchanges

At high *s* and low *t*, it is known that meson photoproduction can be well described by Regge trajectories in the *t*-channel.



Replace pole-like propagator

$$P^V_{\text{pole}} = \frac{1}{t - m_V^2}$$

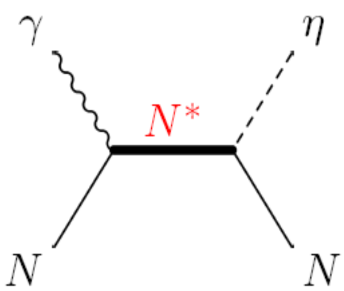
With Regge propagator

$$P^V_{\text{Regge}} = \left(\frac{s}{s_0}\right)^{\alpha_V(t)-1} \frac{\pi \alpha'_V}{\sin(\alpha_V(t))} \frac{S_V + e^{-i\pi\alpha_V(t)}}{2} \frac{1}{\Gamma(\alpha_V(t))}$$

The idea is to economically take into account the exchanges of high-spin particles in the *t*-channel which cannot be neglected at higher energies

Resonances

Breit-Wigner form



$$\begin{pmatrix} E_{\ell\pm} \\ M_{\ell\pm} \end{pmatrix} = \begin{pmatrix} \tilde{E}_{\ell\pm} \\ \tilde{M}_{\ell\pm} \end{pmatrix} f_{\gamma N}(W) \frac{\Gamma_{tot} W_R}{W_R^2 - W^2 - iW_R \Gamma_{tot}} f_{\eta N}(W)\, C_{\eta N}\, \zeta_{\eta N}$$

isospin factor $C_{\eta N} = -1$

$$f_{\eta N}(W) = \left[\frac{1}{(2j+1)\pi} \frac{k}{|\boldsymbol{q}|} \frac{m_N}{W_R} \frac{\Gamma_{\eta N}}{\Gamma_{tot}^2} \right]^{1/2}$$

$$\Gamma_{\eta N} = \beta_{\eta N} \Gamma_R \left(\frac{|\boldsymbol{q}|}{|\boldsymbol{q_R}|} \right)^{2\ell+1} \left(\frac{X^2 + \boldsymbol{q_R}^2}{X^2 + \boldsymbol{q}^2} \right)^{\ell} \frac{W_R}{W}$$

$$\Gamma_{tot} = \Gamma_{\eta N} + \Gamma_{\pi N} + \Gamma_{\pi\pi N}$$

$$f_{\gamma N}(W) = 1$$

$\zeta_{\eta N} = \pm 1$: hadronic phase

8 resonances are included in η-MAID :

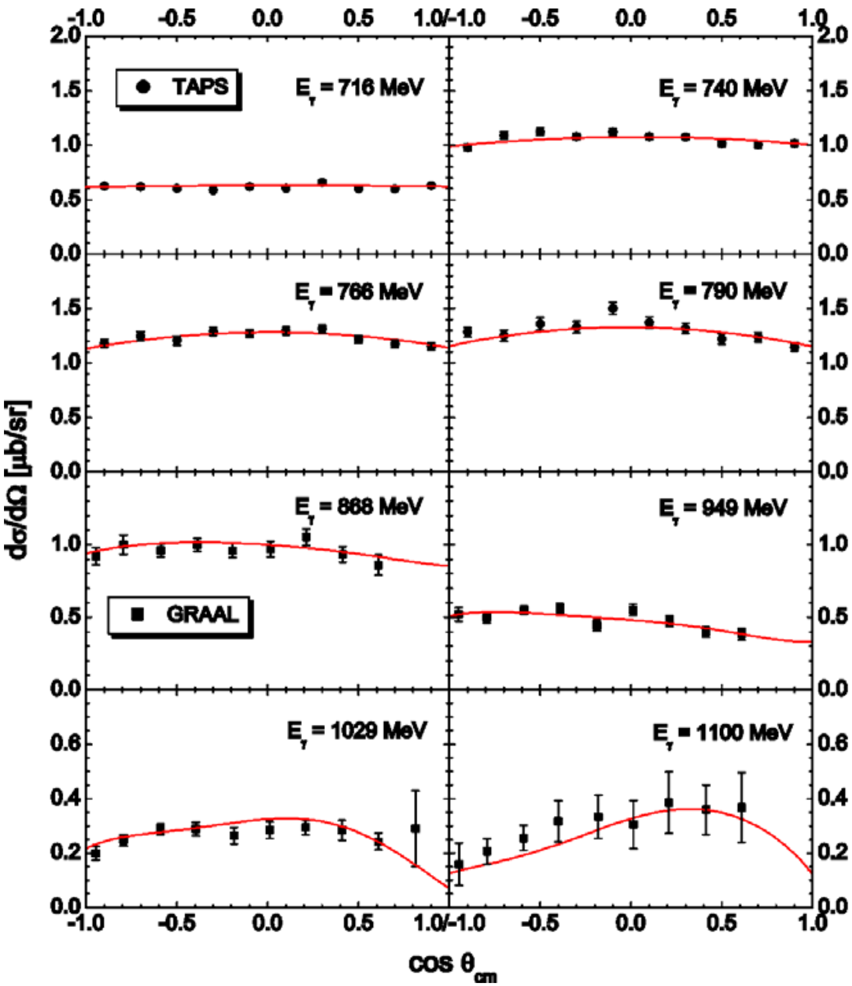
- $D_{13}(1520)$ very important
- $S_{11}(1535)$ most important
- $S_{11}(1650)$ very important
- $D_{15}(1675)$ very important
- $F_{15}(1680)$ less important
- $D_{13}(1700)$ unimportant
- $P_{11}(1710)$ important
- $P_{13}(1720)$ unimportant

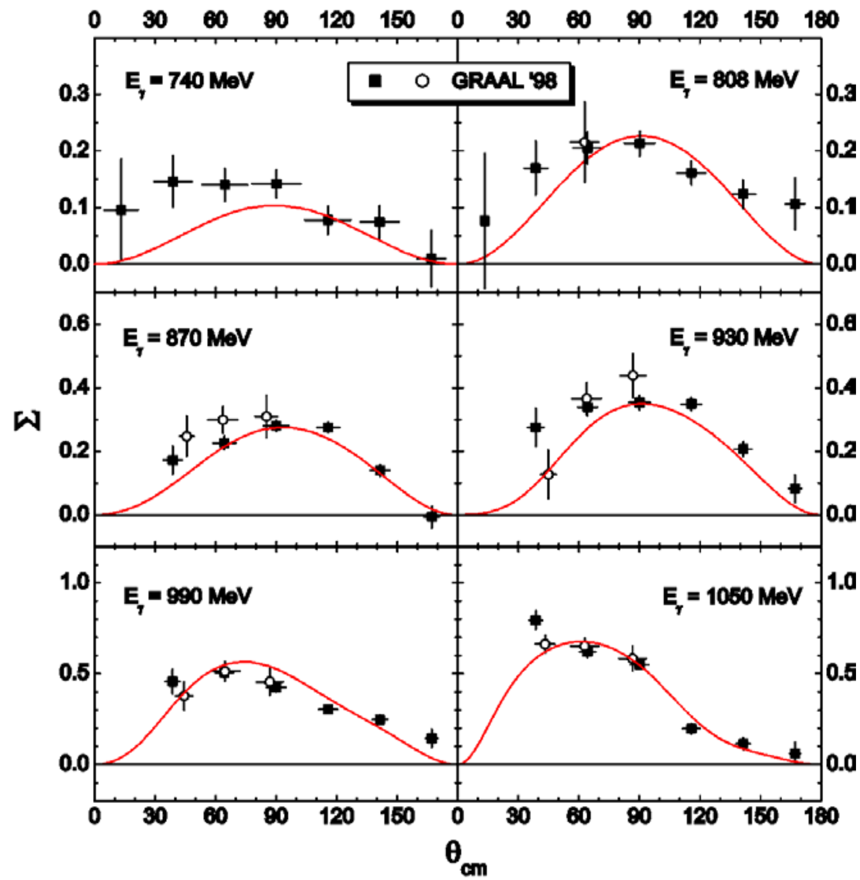
Resonance Parameters from η-MAID 2001

N^*	mass	width	$\beta_{\eta N}$	$\zeta_{\eta N}$	proton $A^p_{1/2}$	proton $A^p_{3/2}$	neutron (PDG/SQTM $A^n_{1/2}$	neutron (PDG/SQTM $A^n_{3/2}$
$D_{13}(1520)$	1520	120	0.06%	1	-52	166	-41	-135
$S_{11}(1535)$	1541	191	50.%	1	118	-	-97	-
$S_{11}(1650)$	1638	114	8.%	-1	68	-	-56	-
$D_{15}(1675)$	1665	150	17.%	-1	18	24	-43	-58
$F_{15}(1680)$	1682	130	0.06%	1	-21	124	52	-41
$D_{13}(1700)$	1700	100	0.3%	-1	-18	-2	0	-3
$P_{11}(1710)$	1720	100	26.%	1	23	-	-2	-
$P_{13}(1720)$	1720	150	3.%	-1	18	-19	1	-29

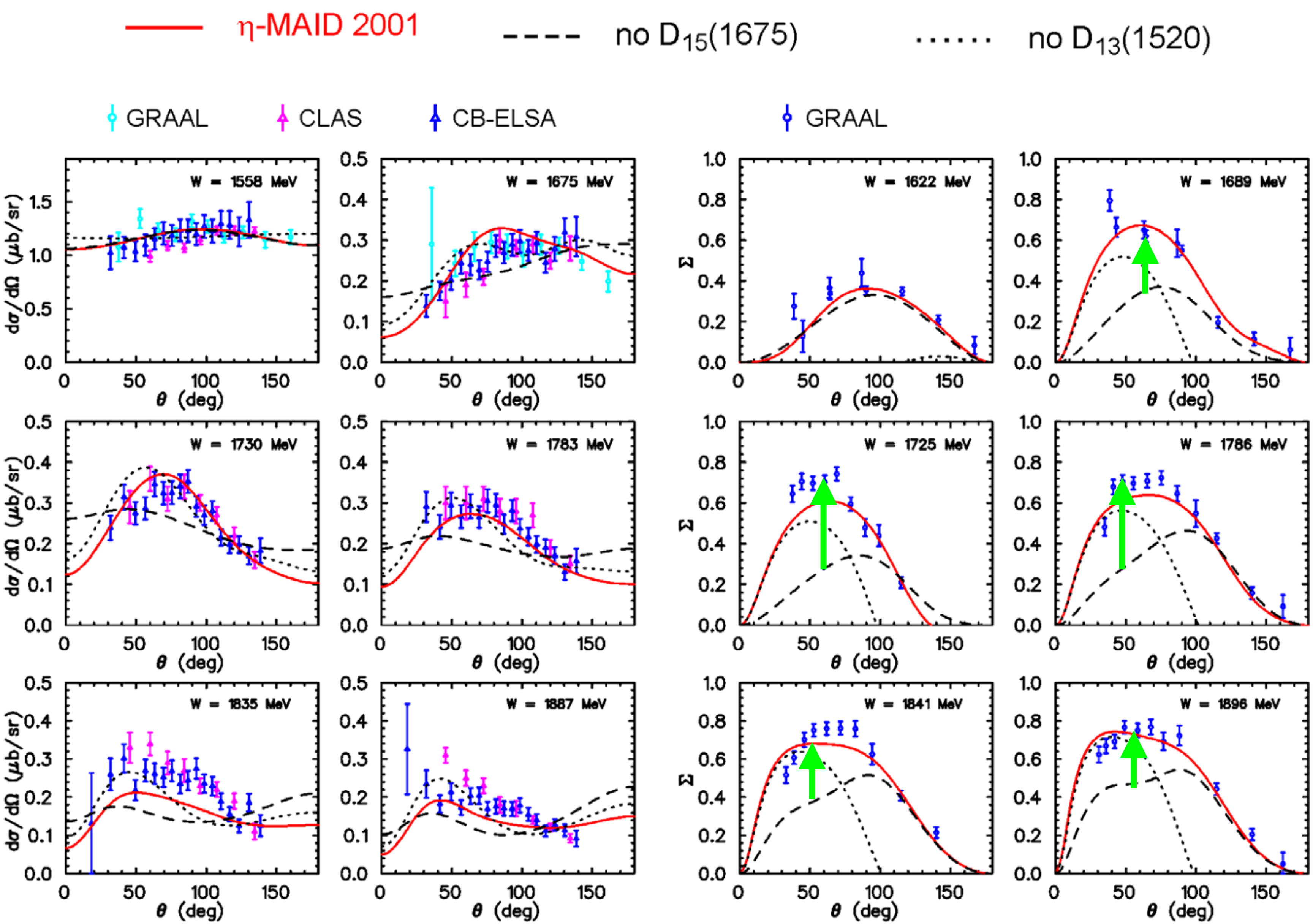
Numbers in red are fitted parameters:
photo couplings are fitted in reasonable ranges
strong ηN coupling is more freely varied

Eta-Maid 2001 compared to data from TAPS@Mainz and GRAAL



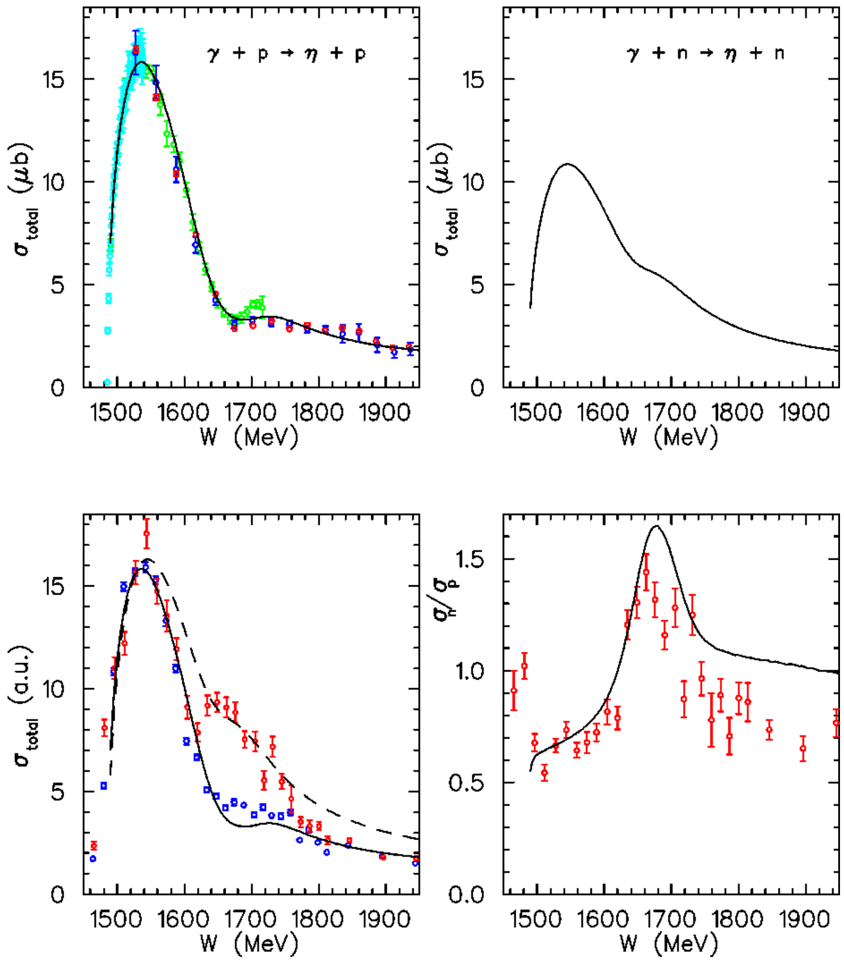


The role of the $D_{15}(1675)$ resonance



η-MAID 2001
no D15(1675)
no D13(1520)
GRAAL
CLAS
CB-ELSA
GRAAL
W = 1558 MeV
W = 1675 MeV
W = 1622 MeV
W = 1689 MeV
W = 1730 MeV
W = 1783 MeV
W = 1725 MeV
W = 1786 MeV
W = 1835 MeV
W = 1887 MeV
W = 1841 MeV
W = 1896 MeV
dσ/dΩ (μb/sr)
Σ
θ (deg)

isobar model Eta-Maid2001



(preliminary data from CB-ELSA, I. Jaegle, priv. comm. 2006)

problems with the $D_{15}(1675)$ resonance:

1) in the std EtaMaid model it fits the neutron data very well
   but needs a large branching ratio of $\beta_{\eta N}$ = 17 %
   fits with $SU(3)_{fl}$ for baryon octett
   gives a prediction of $\beta_{\eta N}$= 2.5 %.
   (Guzey and Polyakov, hep-ph/0512355)

2) in the Regge model the $D_{15}(1675)$ would not play any
   important role.

comparison of our models:

proton PDG/Fit — neutron PDG

EtaMaid 2001

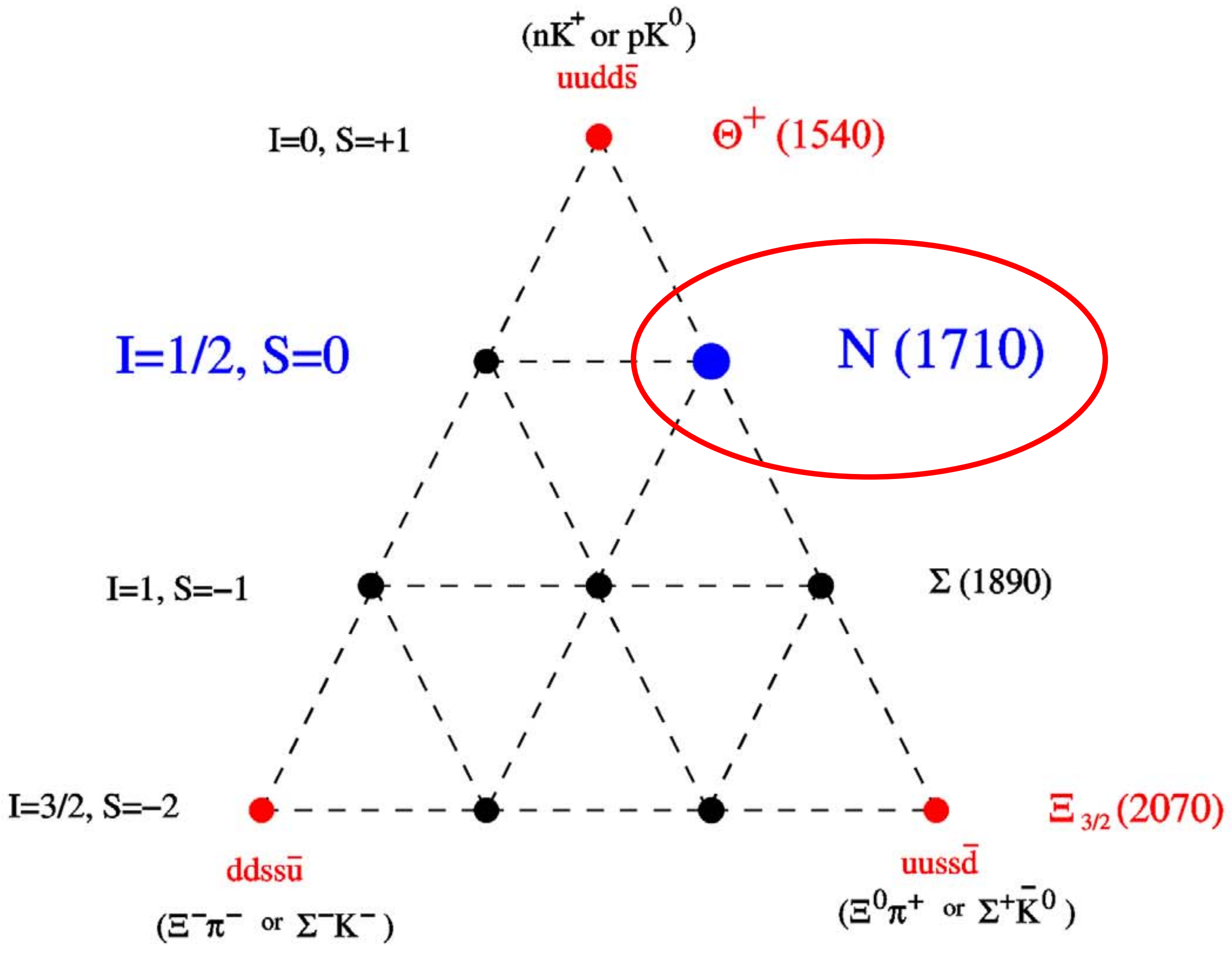
N^*	mass	width	$\beta_{\eta N}$	$\zeta_{\eta N}$	$A^p_{1/2}$	$A^p_{3/2}$	$A^n_{1/2}$	$A^n_{3/2}$
$D_{13}(1520)$	1520	120	0.06%	1	-52	166	-41	-135
$S_{11}(1535)$	1541	191	50.%	1	118	-	-97	-
$S_{11}(1650)$	1638	114	8.%	-1	68	-	-56	-
$D_{15}(1675)$	1665	150	17.%	-1	18	24	-43	-58
$F_{15}(1680)$	1682	130	0.06%	1	-21	124	52	-41
$D_{13}(1700)$	1700	100	0.3%	-1	-18	-2	0	-3
$P_{11}(1710)$	1720	100	26.%	1	23	-	-2	-
$P_{13}(1720)$	1720	150	3.%	-1	18	-19	1	-29

ReggeMaid 2003

N^*	mass	width	$\beta_{\eta N}$	$\zeta_{\eta N}$	$A^p_{1/2}$	$A^p_{3/2}$	$A^n_{1/2}$	$A^n_{3/2}$
$D_{13}(1520)$	1520	120	0.04%	1	-24	166	-59	-139
$S_{11}(1535)$	1545	118	50.%	1	80	-	-65	-
$S_{11}(1650)$	1635	120	16.3%	-1	46	-	-38	-
$D_{15}(1675)$	1665	150	0.69%	1	19	15	-43	-58
$F_{15}(1680)$	1670	130	0.003%	1	-15	133	29	-33
$D_{13}(1700)$	1700	100	0.025%	-1	-18	-2	0	-3
$P_{11}(1710)$	1700	100	26.%	-1	9	-	-2	-
$P_{13}(1720)$	1720	150	4.1%	1	18	-19	1	-29

Pentaquark States

anti-decuplet in the chiral soliton model by Diakonov, Petrov and Polyakov (1997)



Estimate of Resonance Parameters for Non-Strange Partner of Θ^+

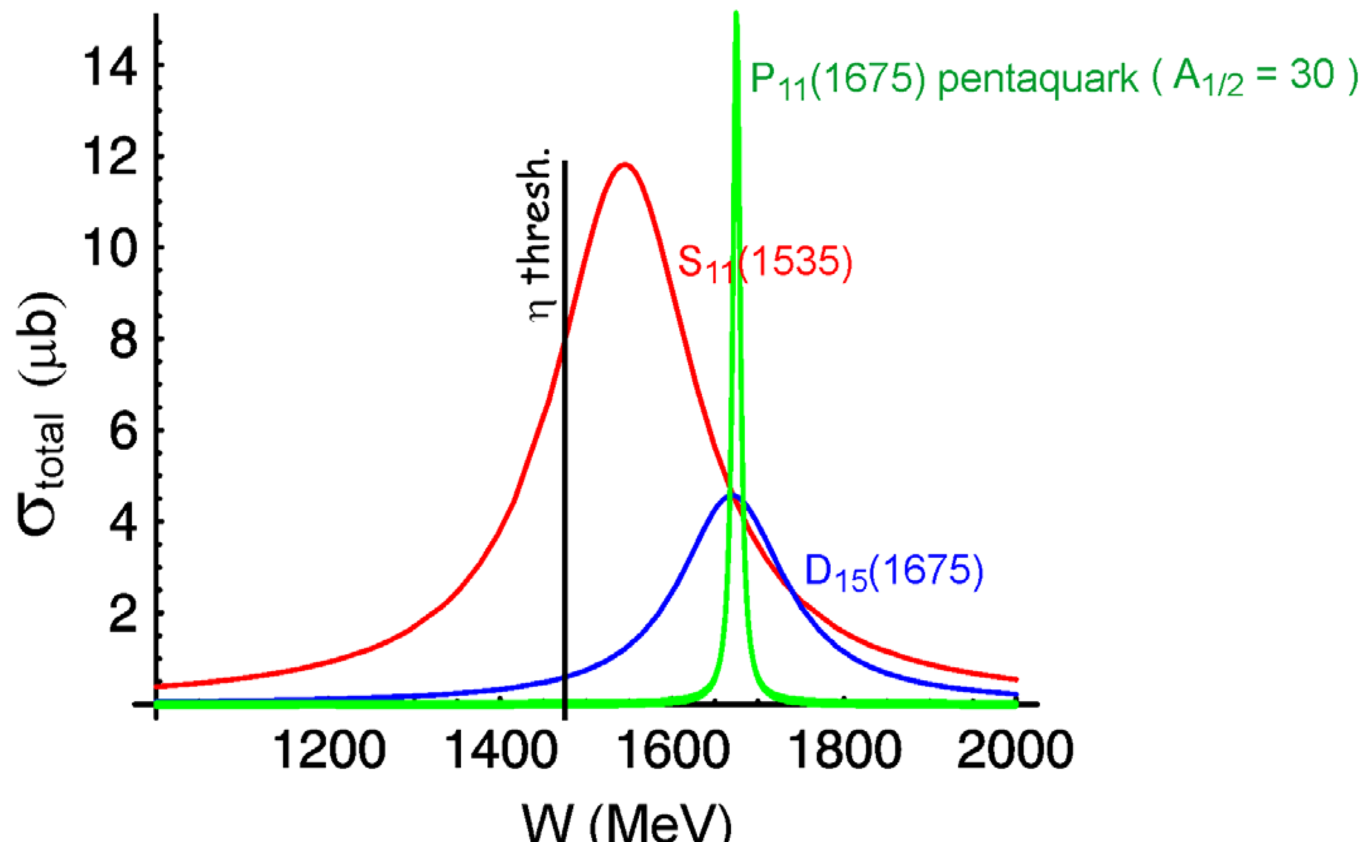
Ya. Azimov, V. Kuznetsov, M.V. Polyakov and I. Strakovsky
Eur. Phys. J. A 25 (2005) 325

triggered by the observation of an irregular behaviour of the cross section for $\gamma n \to \eta n$ near $W_{c.m.} = 1675$ MeV

quantum numbers	J^π	:	$1/2^+ \Rightarrow P_{11}$
mass	M^*	=	$1675\,\mathrm{MeV}$
total width	Γ_{tot}	=	$10\,\mathrm{MeV}$
branching into ηN channel	$\Gamma_{\eta N}/\Gamma_{tot}$	=	40%
neutron magnetic transition moment	$\lvert\mu(n^* \to n)\rvert$	=	$(0.13 - 0.37)\,\mu_N$
neutron photon coupling	$A_{1/2}(n)$	=	$(20 - 60)\,10^{-3}/\sqrt{GeV}$
proton photon coupling	$A_{1/2}(p)/A_{1/2}(n)$	<	$1/3$

in the following we use $A_{1/2}(p)=8$ and $A_{1/2}(n)=25$

η photoproduction on the neutron



quasifree eta photoproduction on the deuteron

in collaboration with Alexander Fix

(e.g. A. Fix and H. Arenhövel, Z. Phys. A 359 (1997) 427)

in impulse approximation:

ηNN fsi is negligible

NN fsi is larger but only important near threshold

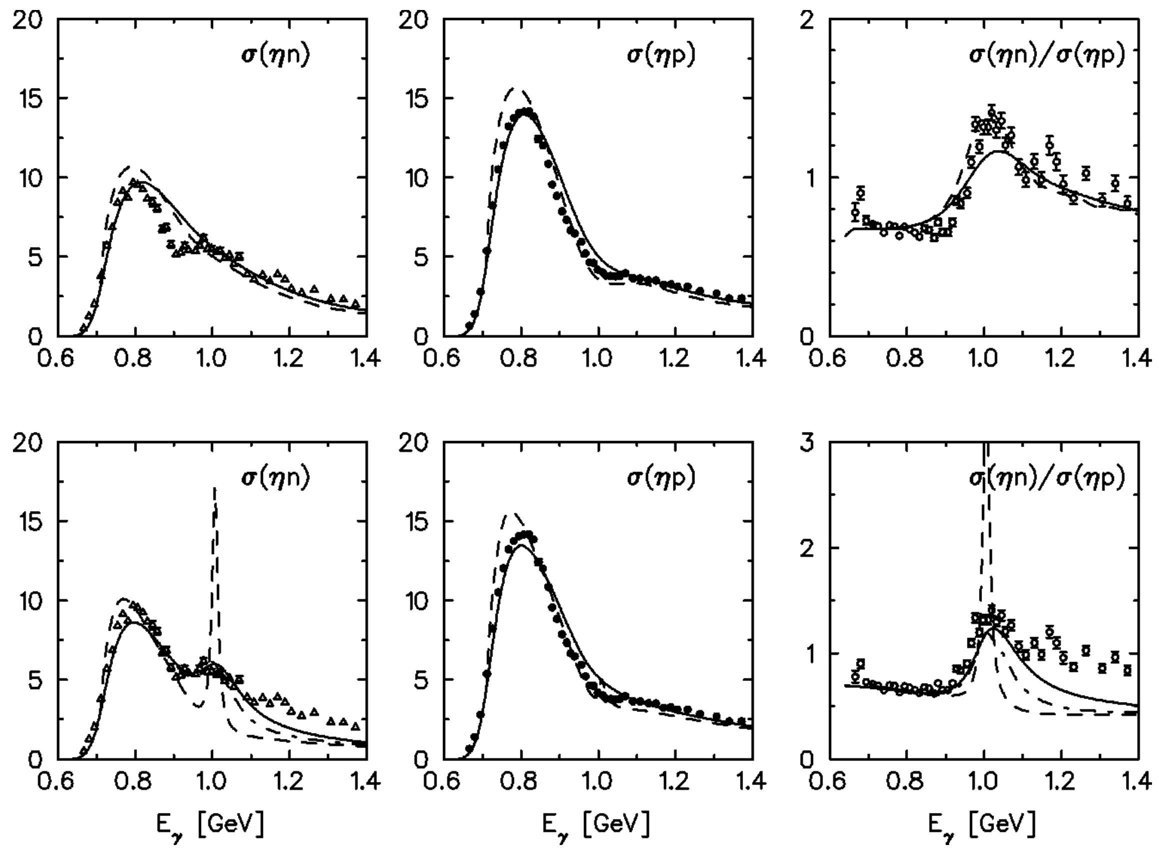
input: EtaMaid with additional pentaquark state $P_{11}(1675)$

Photoproduction of η mesons on the deuteron in the presence of a narrow $P_{11}(1670)$ resonance

A. Fix, L.T., and M.V. Polyakov, EPJ A32 (2007) 311

resonance parameters for the pentaquark in our calculations:

Mass $[MeV]$	Width $[MeV]$	$\beta_{\eta N}$ $[\%]$	$\beta_{\pi\Delta}$ $[\%]$	$\beta_{K\Lambda}$ $[\%]$	${}_pA_{1/2}$ $[10^{-3}/\sqrt{GeV}]$	${}_nA_{1/2}$ $[10^{-3}/\sqrt{GeV}]$
1670	10	40	30	30	8	30



comparison of GRAAL proton data with narrow resonance solutions

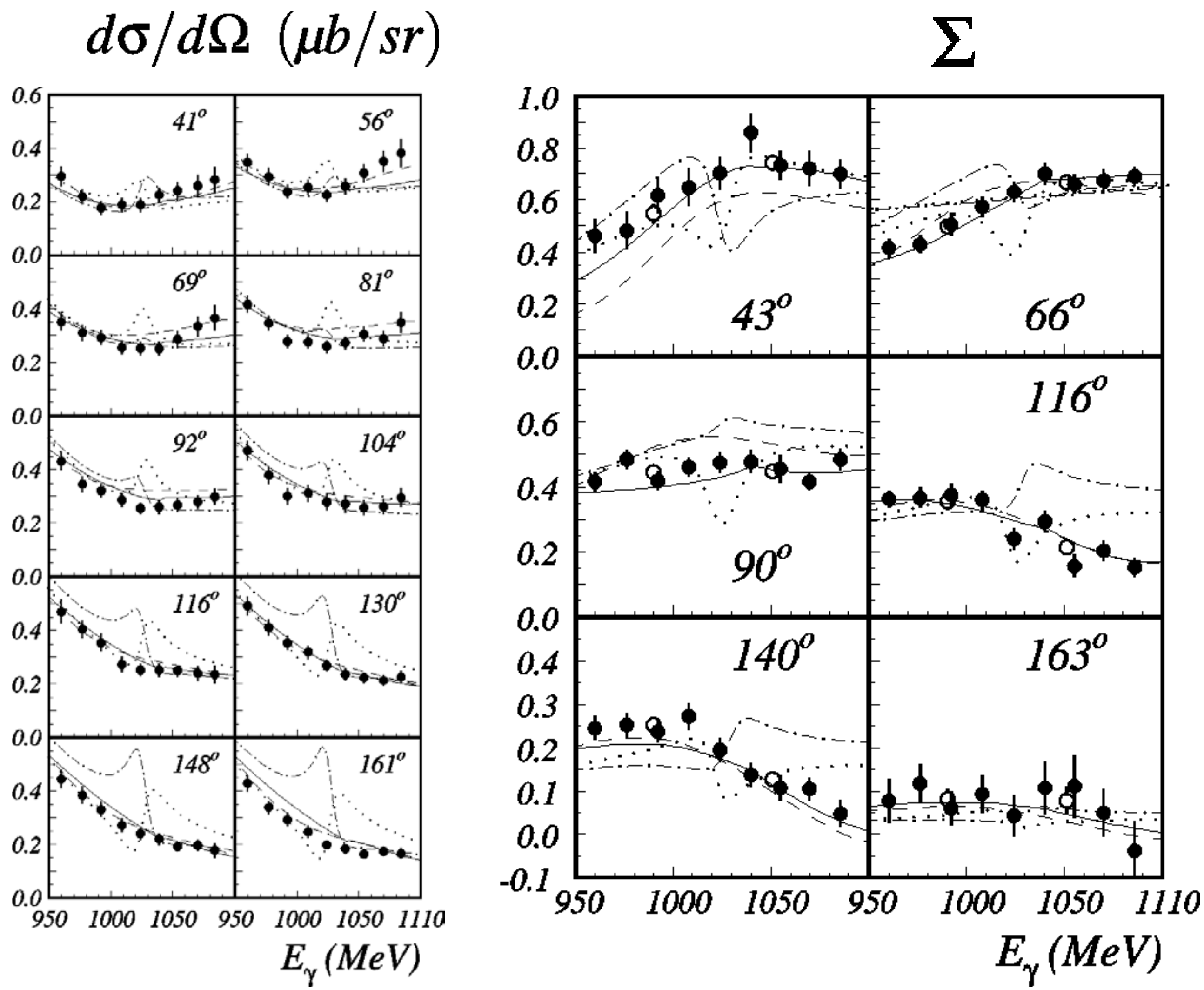
data: Bartalini et al. (GRAAL), EPJ A33 (2007) 169

- - - EtaMaid

——— Bonn pw analysis Sarantsev et al.

- · - · ReggeMaid + P11(1670)

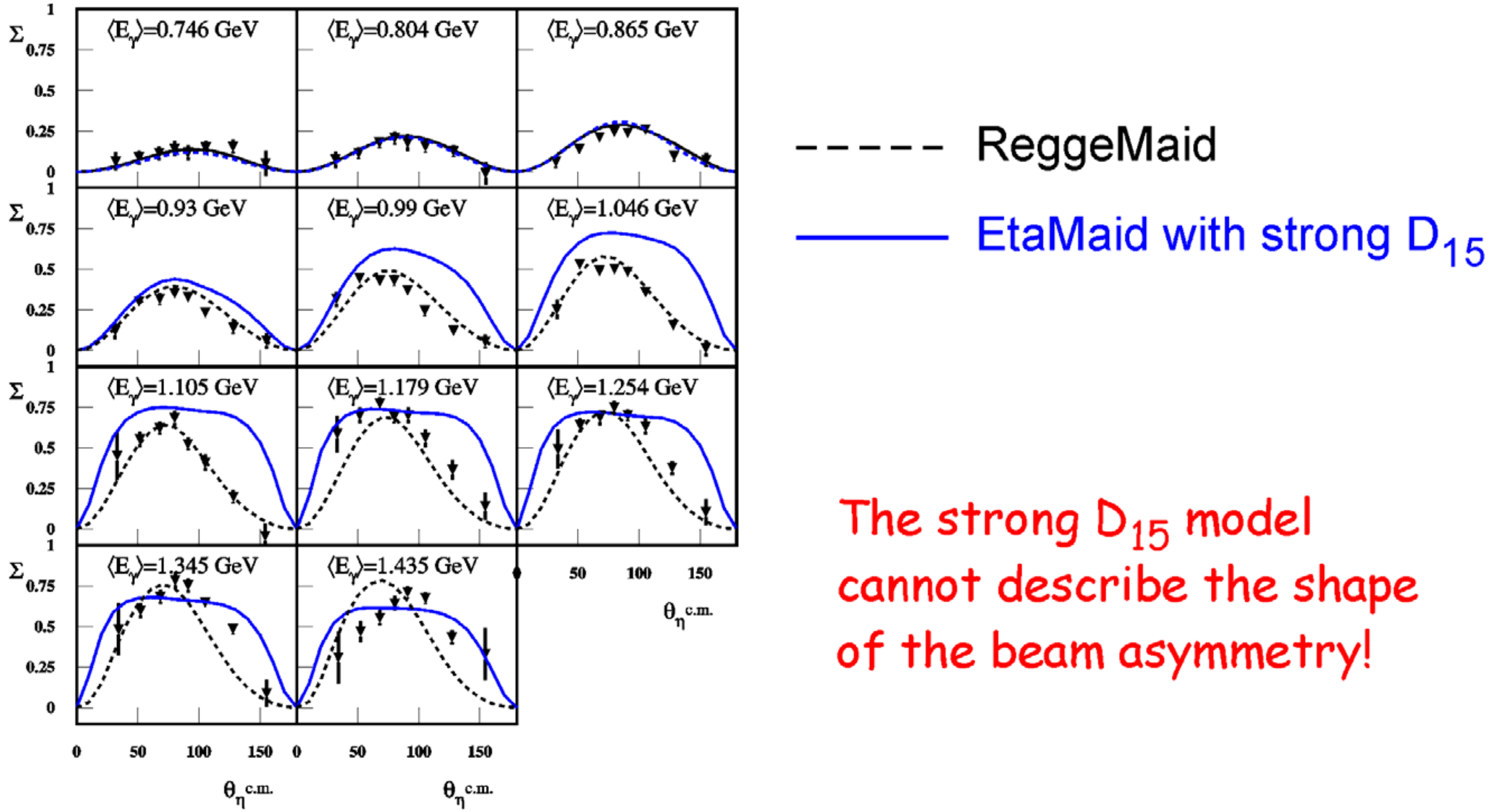
·········· ReggeMaid - P11(1670)



the proton data of Bartalini et al. does not show any pentaquark arrow structure !!

Beam Asymmetry Σ in η photoproduction on quasi-free neutrons

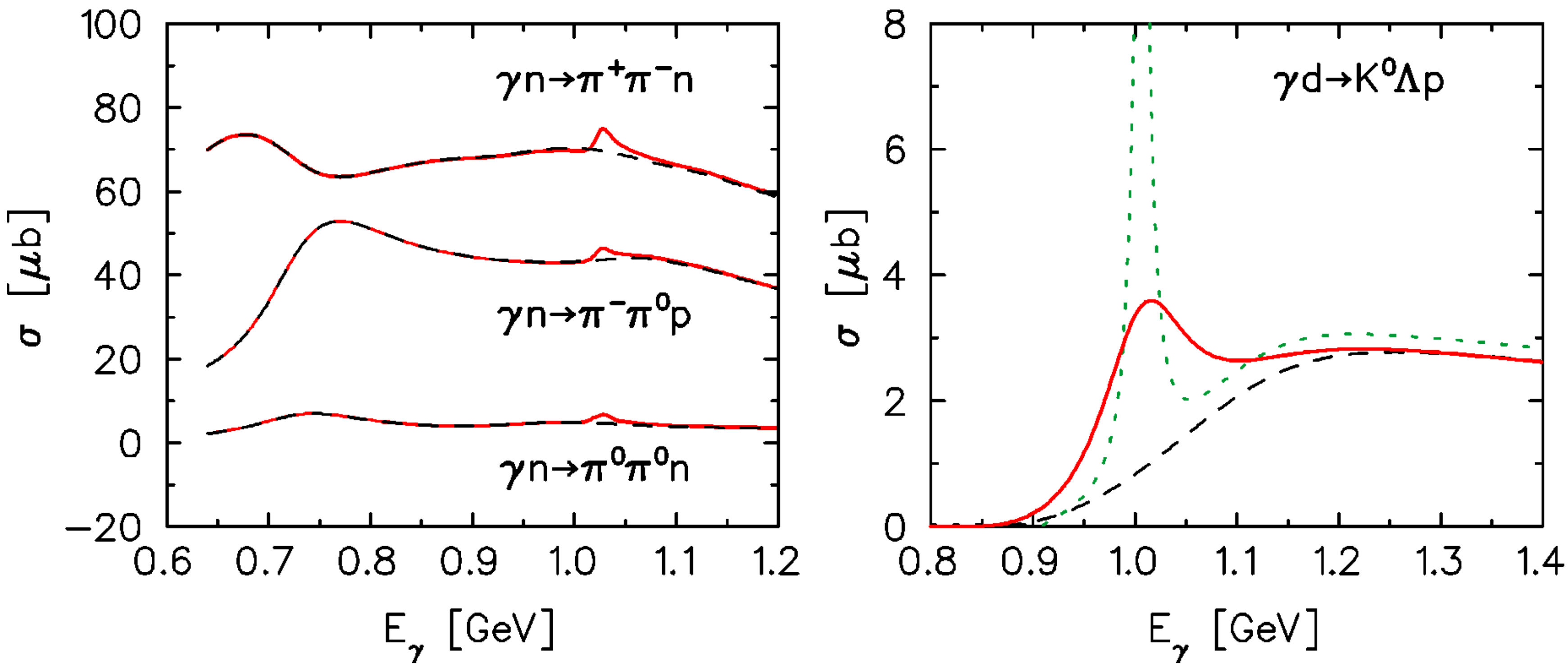
A. Fantini et al. (GRAAL), Phys. Rev. C78, 015203, 2008



The strong D_{15} model cannot describe the shape of the beam asymmetry!

The effect of a narrow P11(1670) in the 2π and $K\Lambda$ channels

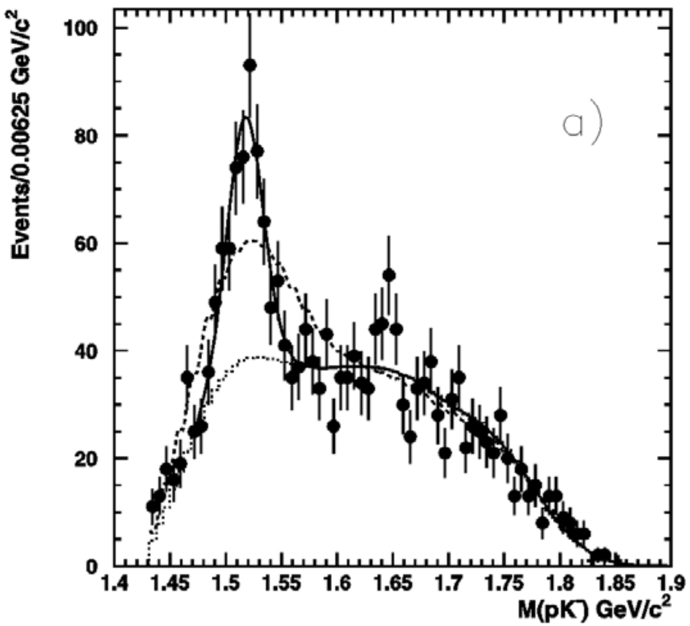
A. Fix, L.T., and M.V. Polyakov, EPJ A32 (2007) 311



recent developments on the pentaquark

Evidence of the Θ^+ in the $\gamma d \to K^+K^-pn$ reaction

T. Nakano et al., arXiv:0812.1035

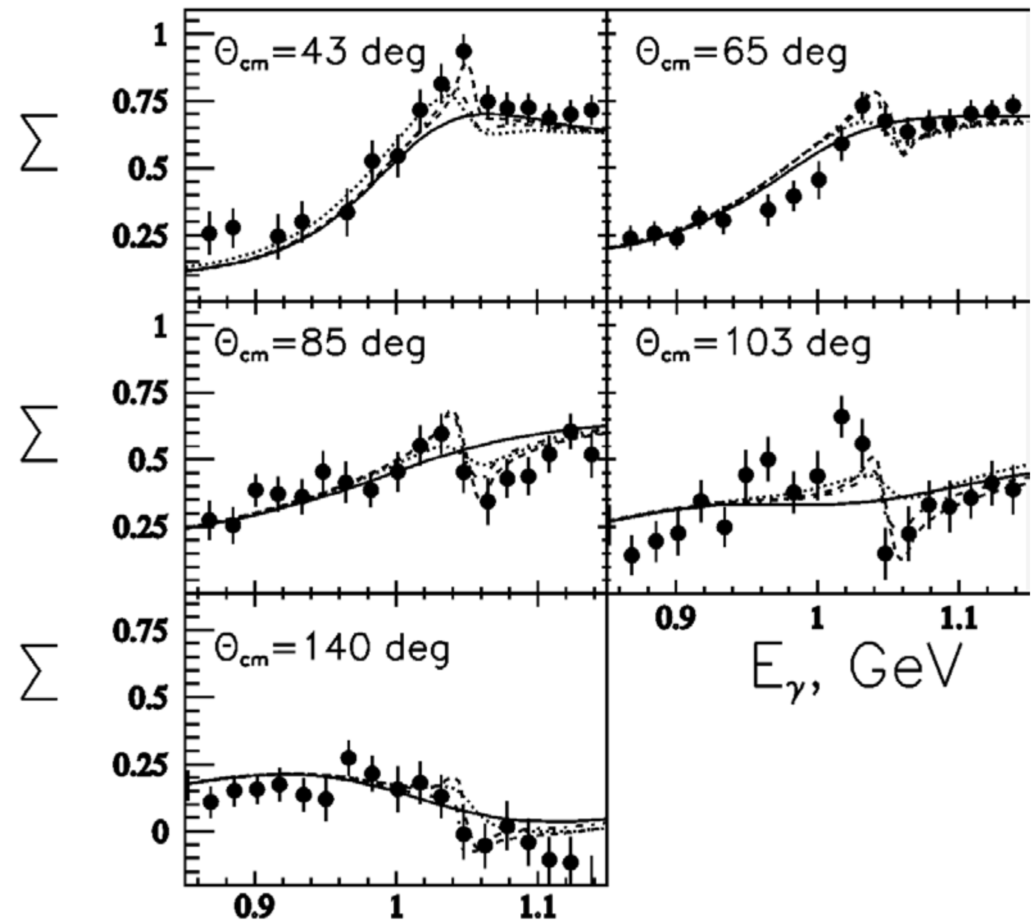


$M(pK^-)$ distribution

with a fit to the RMM background spectrum

Narrow Nucleon N*(1685) in the γp –> ηp

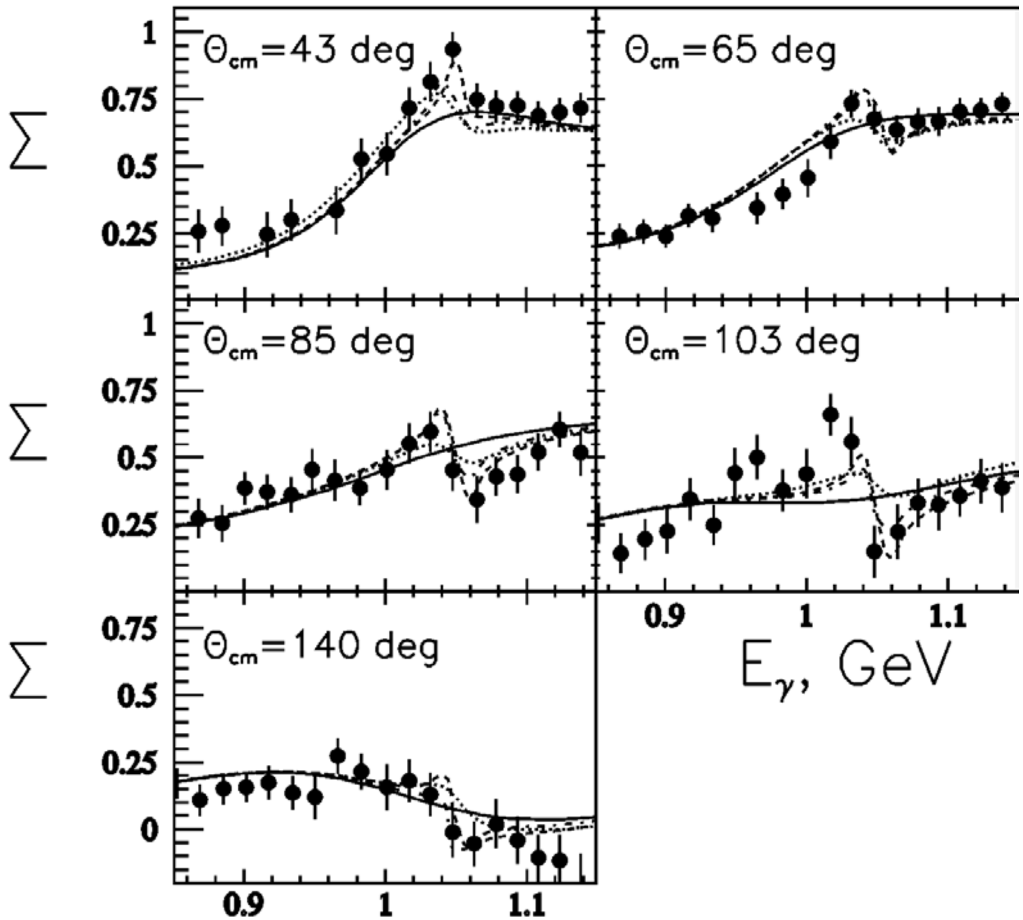
V. Kuznetsov and M.V. Polyakov,
JETP Lett. 88 (2008) 347 [arXiv:0807.3217]



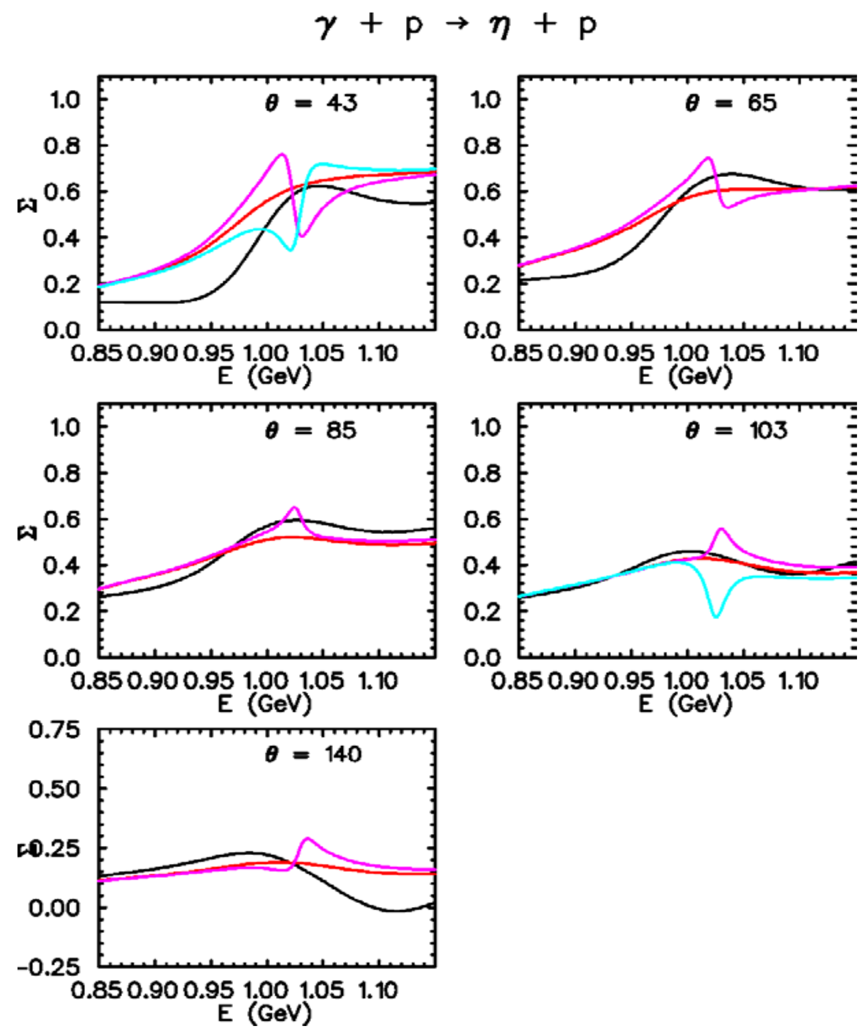
$\Sigma(\eta p)$ with narrow P_{11} or P_{13}

Narrow Nucleon N*(1685) in the $\gamma p \to \eta p$

V. Kuznetsov and M.V. Polyakov,
JETP Lett. 88 (2008) 347 [arXiv:0807.3217]



our calculations



$\Sigma(\eta p)$ with narrow P_{11} or P_{13}

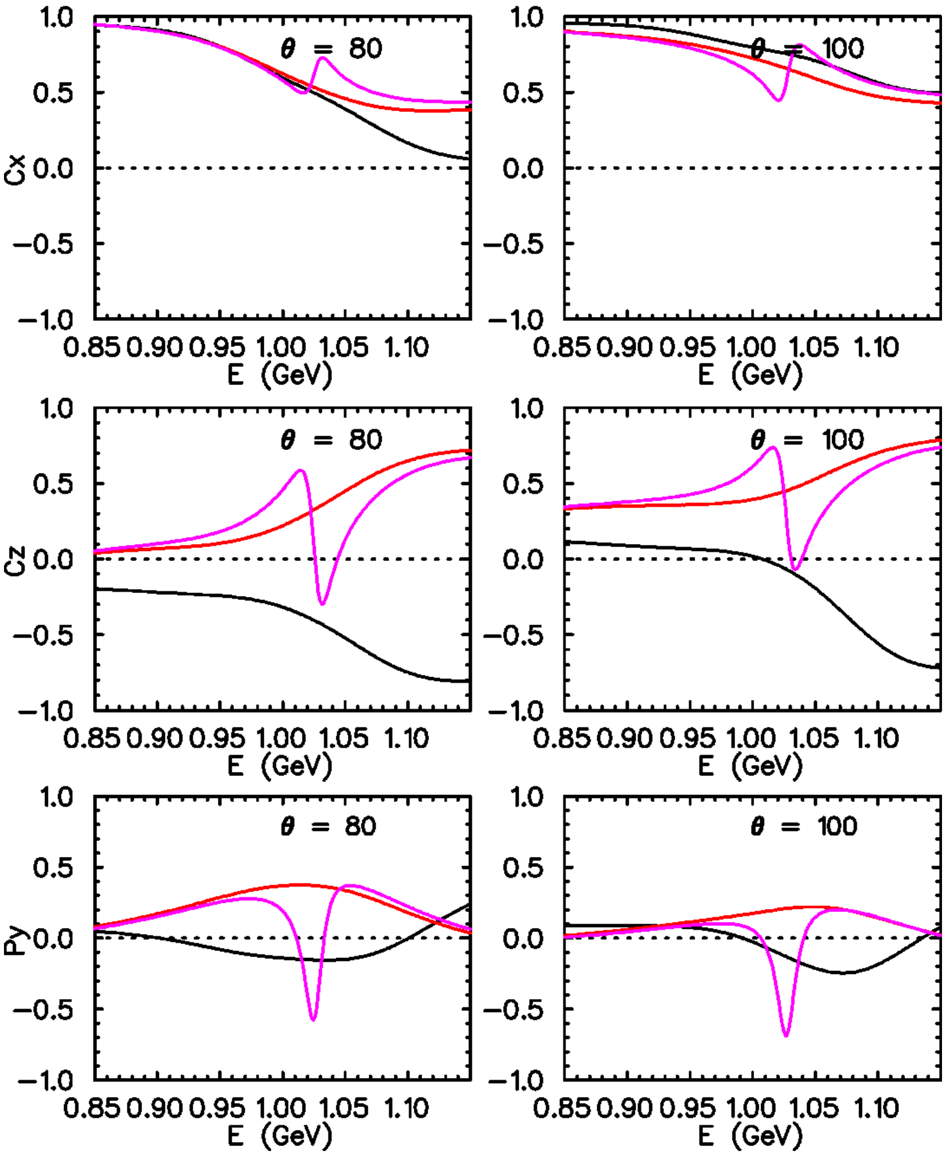
narrow resonance signals in recoil polarization

$\gamma + p \rightarrow \eta + p$

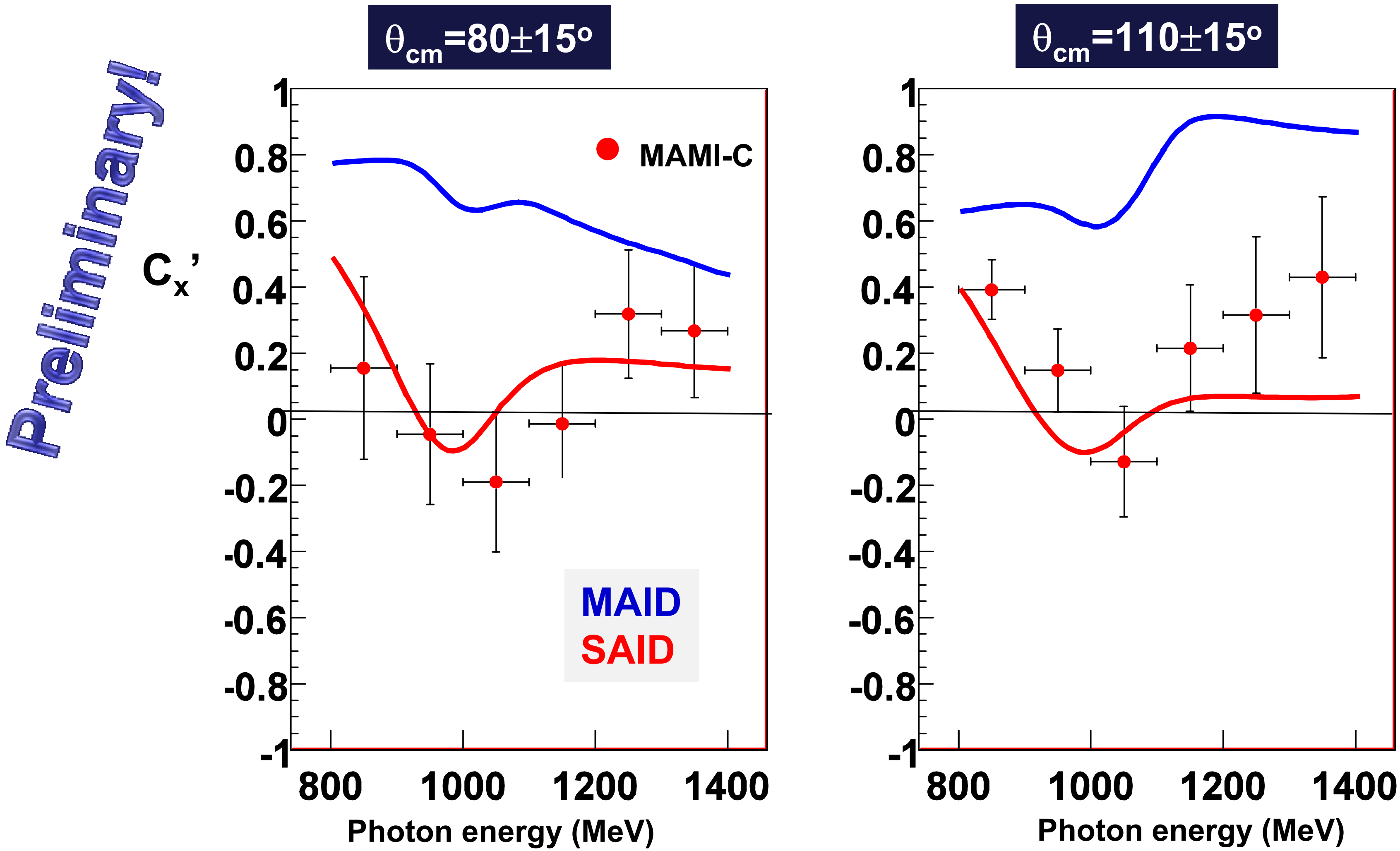
Cx‘

Cz‘

P



p(γ,η)p C_x'



• Next steps O_x, T, P also p(γ,2π) and p(γ,πη) channels

D. Watts, CB@MAMI

Summary on η production

- The old EtaMaid 2001 describes new data > 2002 very well
- D_{15} resonance needs a very large ηN branching ratio,
  to describe the photon asymmetry on the proton
  this leads to the peak in σ(n)/σ(p)
  ds/dW is described very well, but it fails for S
- a non-strange narrow pentaquark state P_{11}(1675)
  Fermi averaged in the deuteron would also produce such a peak
  with 1670 MeV < M* < 1685 MeV
- other observables which could show strong signals
  from narrow P11 resonances are: T, P, F, H, Cz