η and η' photoproduction

Collaboration:
F. Huang (UGA)
M. Döring (FZJ)

Part of a combined analysis of

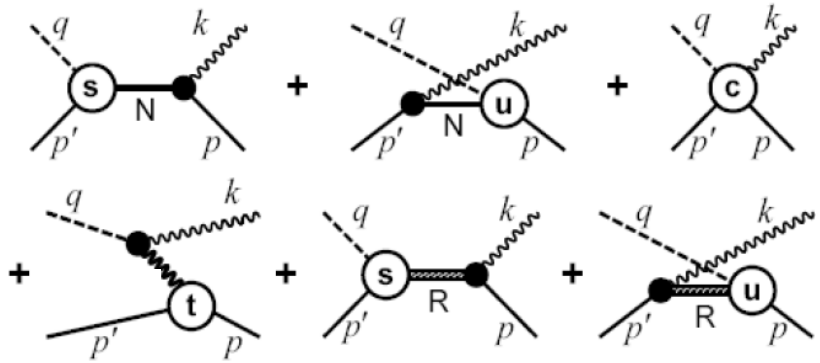
- $\gamma + N \rightarrow M + N$
- $\pi + N \rightarrow M + N$ ($M = \eta, \eta', \omega, \phi, \ldots$)
- $N + N \rightarrow M + N + N$

General motivation

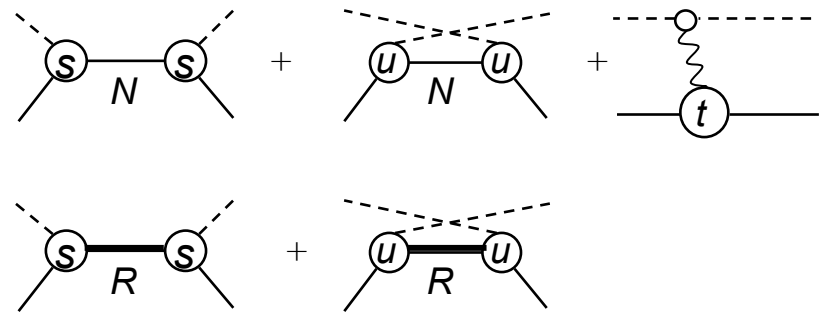
- Extract information on nucleon resonances in the less explored higher N* mass region:
  - high-mass resonances in low partial-wave states.
  - missing resonances.
  - excitation mechanism of these resonances.

Model (for meson production):

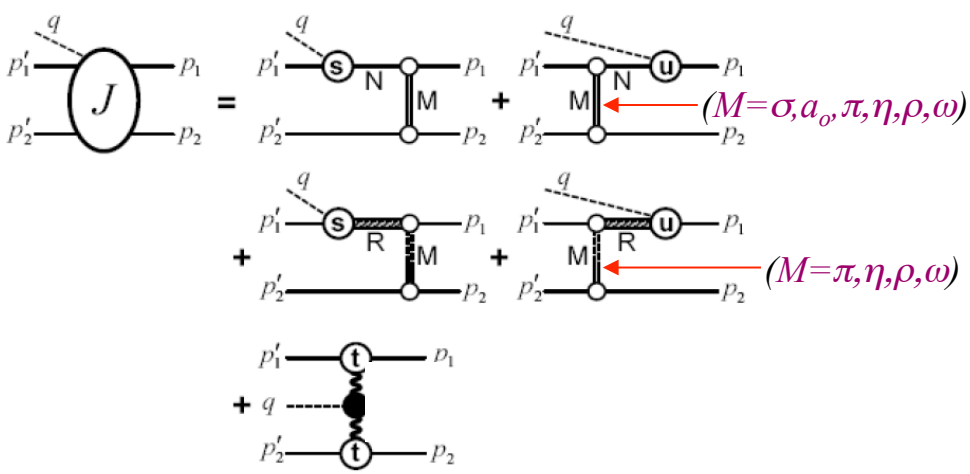
γ + N → M + N:



π + N → M + N:



N + N → M + N + N:



DWBA:

$$A = (1 + \underbrace{T_f G_f}_{\text{FSI}}) J (1 + \underbrace{G_i T_i}_{\text{ISI}})$$

transition current

η' production

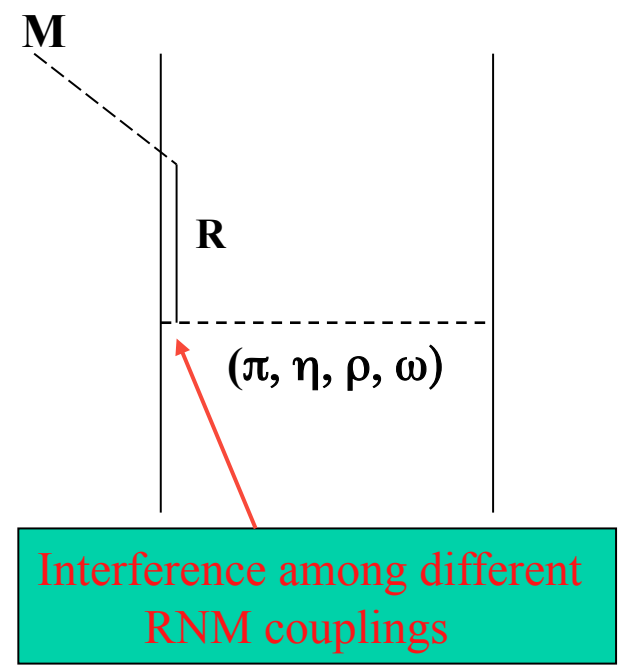
Combined analysis of η' production (in the resonance region):

η' meson production :

- $\gamma + N \rightarrow \eta' + N$
  - σ for free proton [ABBHHM'68, AHHM'76]
  - dσ/dΩ for free proton [SAPHIR'98, CLAS'06, CBELSA/TAPS'09, CLAS'09,LEPS'10]
  - dσ/dΩ for quasi-free proton & neutron [CBELSA/TAPS (R. Beck, plenary talk, Thursday)]
  - beam asymmetry [CLAS efforts]

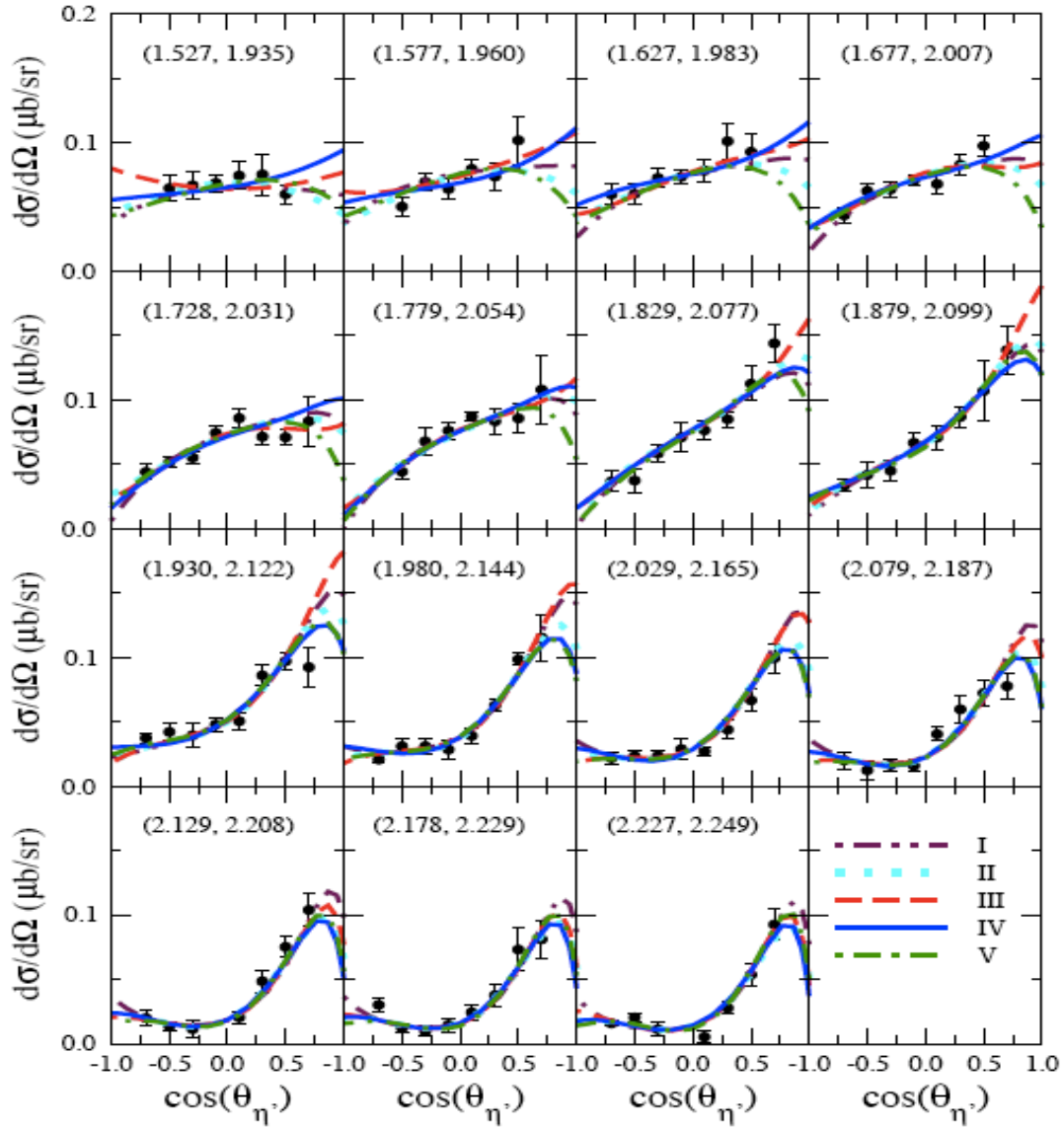
- $N + N \rightarrow \eta' + N + N$
  - cross sections for pp [SPECIII'98, DISTO'00, COSY-11'00]
  - cross sections for pn [COSY-11 (preliminary)]
  - pp and pη' invariant mass distributions [COSY-11'10]

NN → MNN



$\gamma p \rightarrow \eta' p$: cross sections

(K. Nakayama and H. Haberzettl, PRC73,'06)



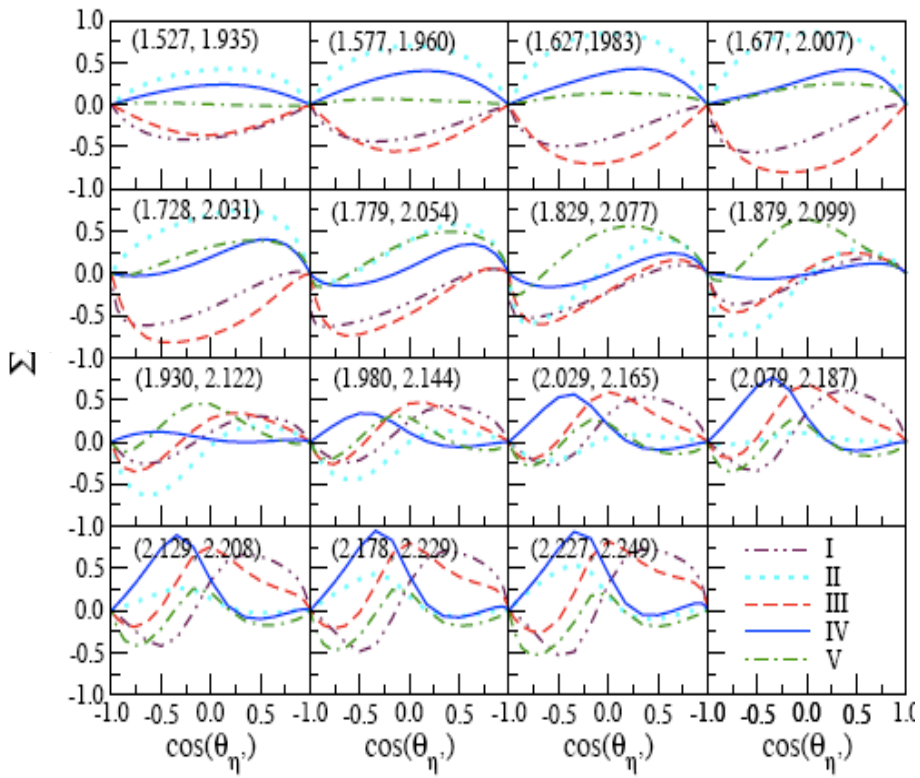
- resonances required: S_{11}, P_{11}, P_{13}, D_{13}
- curves correspond to different set of parameters with comparable fit.
- data at more forward and backward angles would constrain more the model parameters.

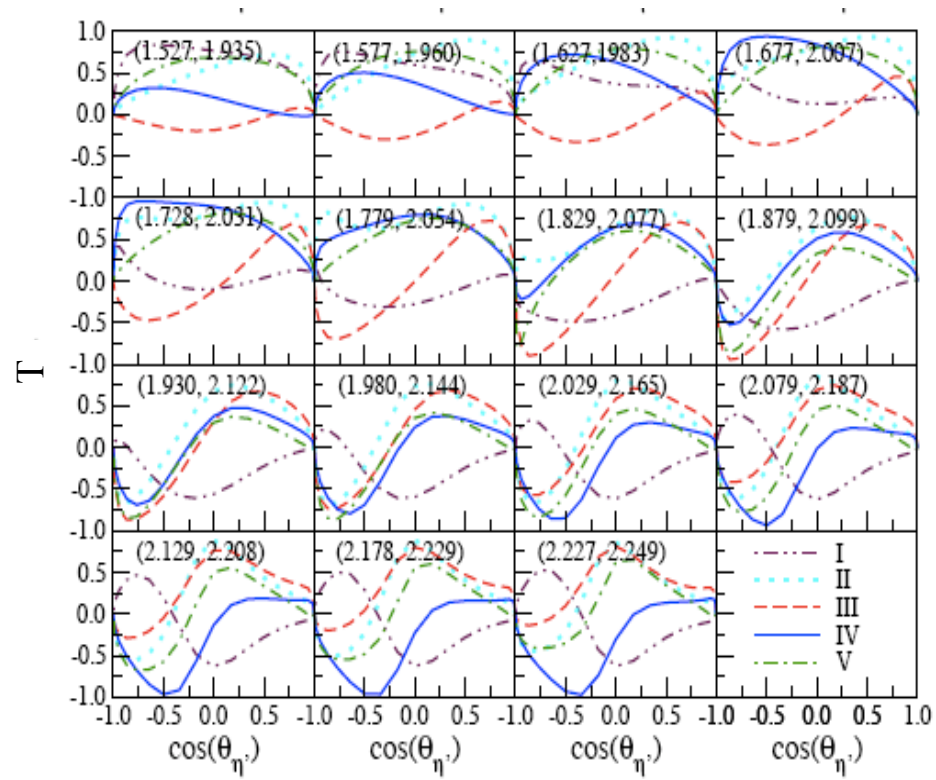
CLAS data:

M. Dugger et al., PRL96, '06

$\gamma p \rightarrow \eta' p$: beam and target asymmetries

(K. Nakayama and H. Haberzettl, PRC73,'06)



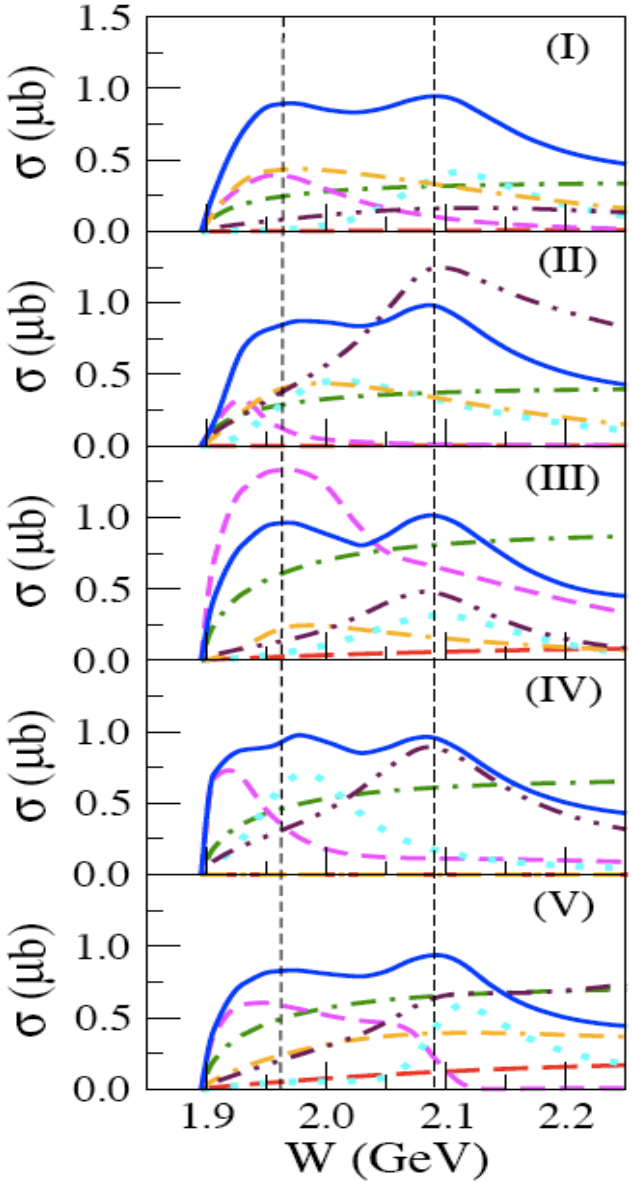


much more sensitive to the model parameters than cross sections

CLAS effort: beam asymmetry (M. Dugger et at.)

$\gamma p \rightarrow \eta' p$: *prediction for the total cross section*

(K. Nakayama and H. Haberzettl, PRC73,'06)



- sharp rise near threshold due to S_{11} resonance.
- bump around W=2.09 GeV due to D_{13} (and possibly P_{11}) resonance.

  [PDG: $D_{13}(2080)$ **, $P_{11}(2100)$ *]

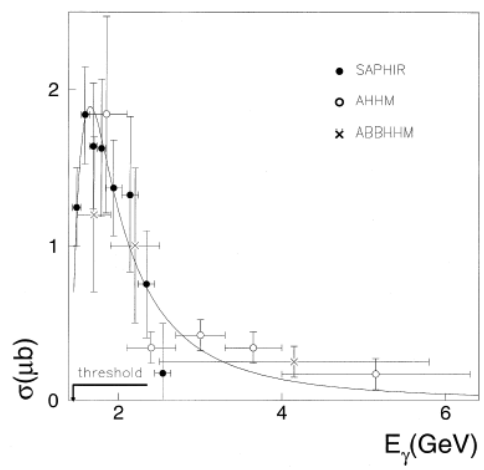
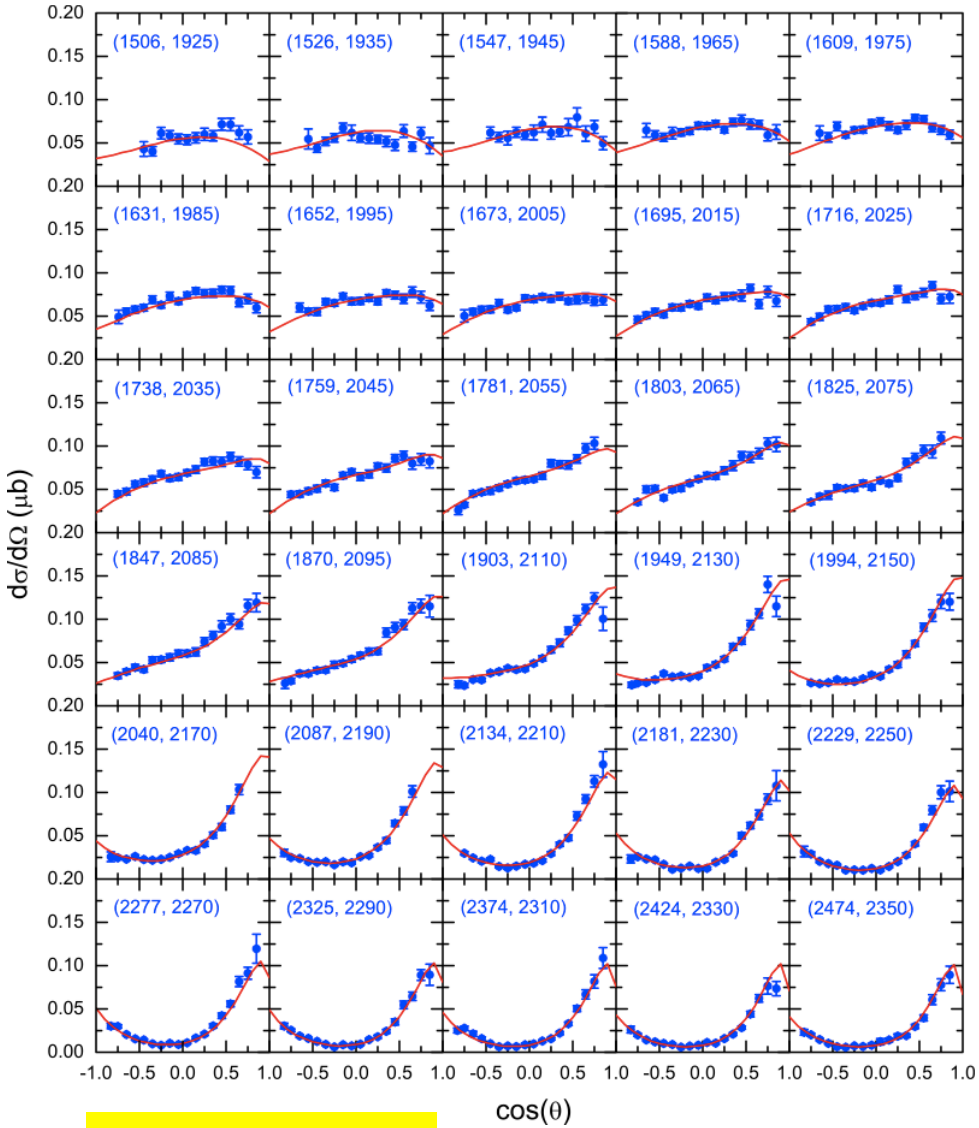


Fig. 4. Measured η'-photoproduction cross section, from this experiment (●), from ABBHHM [1] (×) and from AHHM [2] (○). The solid curve represents the two-resonance fit to the SAPHIR data described below.

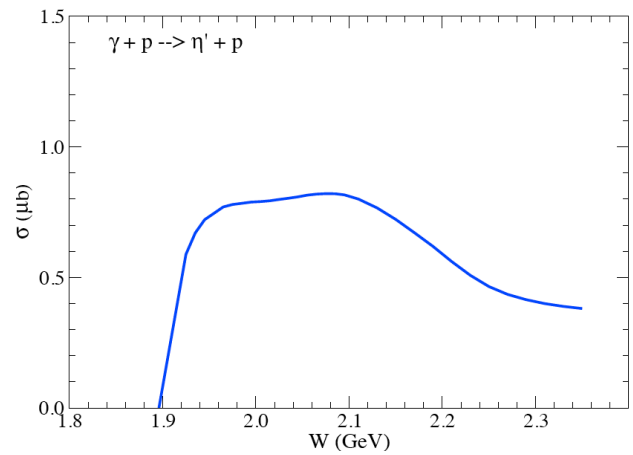
$\gamma p \rightarrow \eta' p$: *high precision CLAS'09 data*

(restrict ourselves to W<2.35 GeV)



S_{11}, P_{11}, P_{13}, D_{13}

data: CLAS '09 (M. Williams et al.)

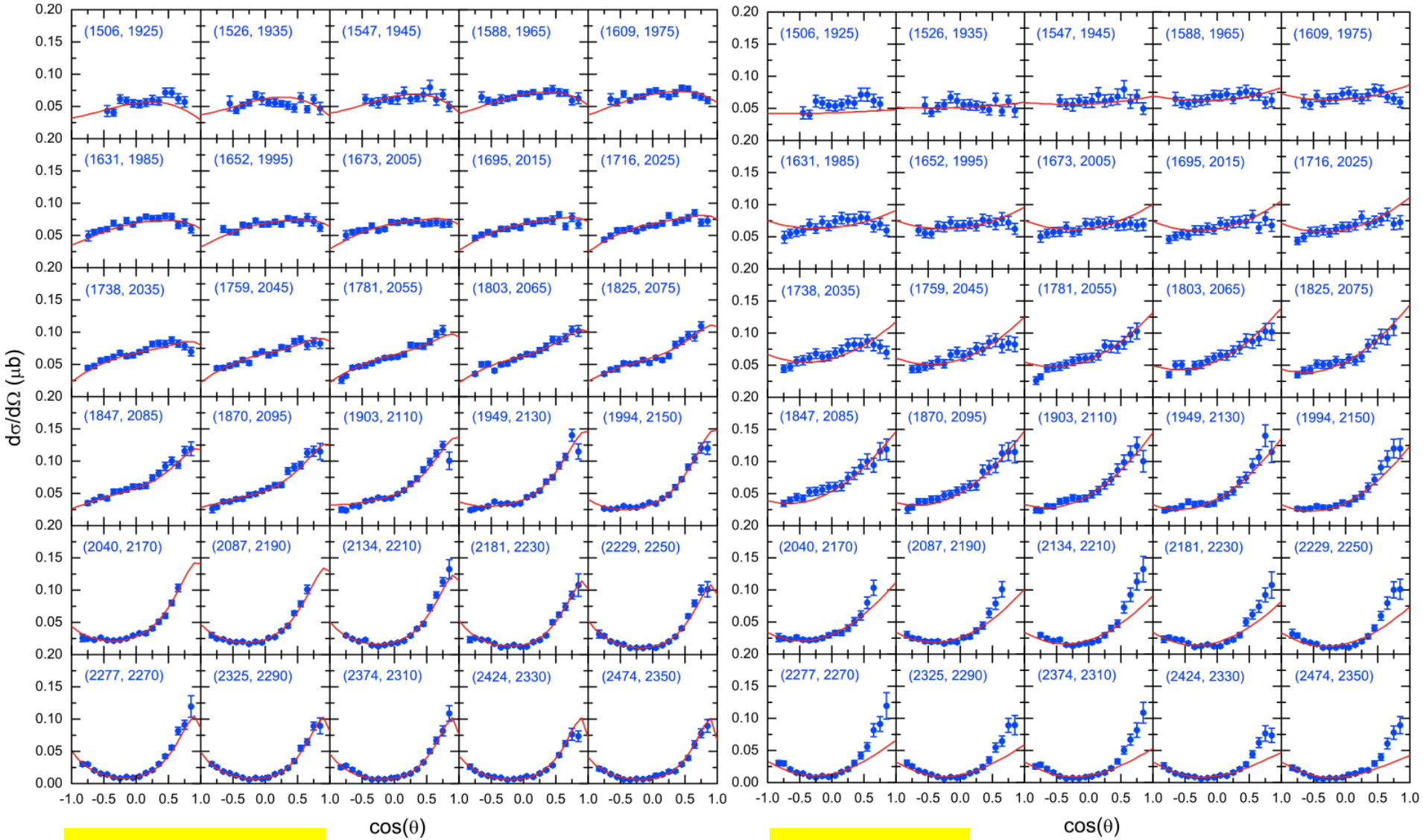


	P13	D13	S11	P11
mass	1876.	1965.	2206.	2097.
width	39.	184.	146.	210.
$\sqrt{\beta_{N\eta'}}$ A_1/2	----	11.9	11.9	-36.1
$\sqrt{\beta_{N\eta'}}$ A_3/2	----	2.33	----	----

$\beta_{N\eta'}$ = branching ratio; $\sqrt{\beta_{N\eta'}}\,A_J$ in 10^{-3} $GeV^{-1/2}$

phase convention: $g_{N*N\eta'} > 0$

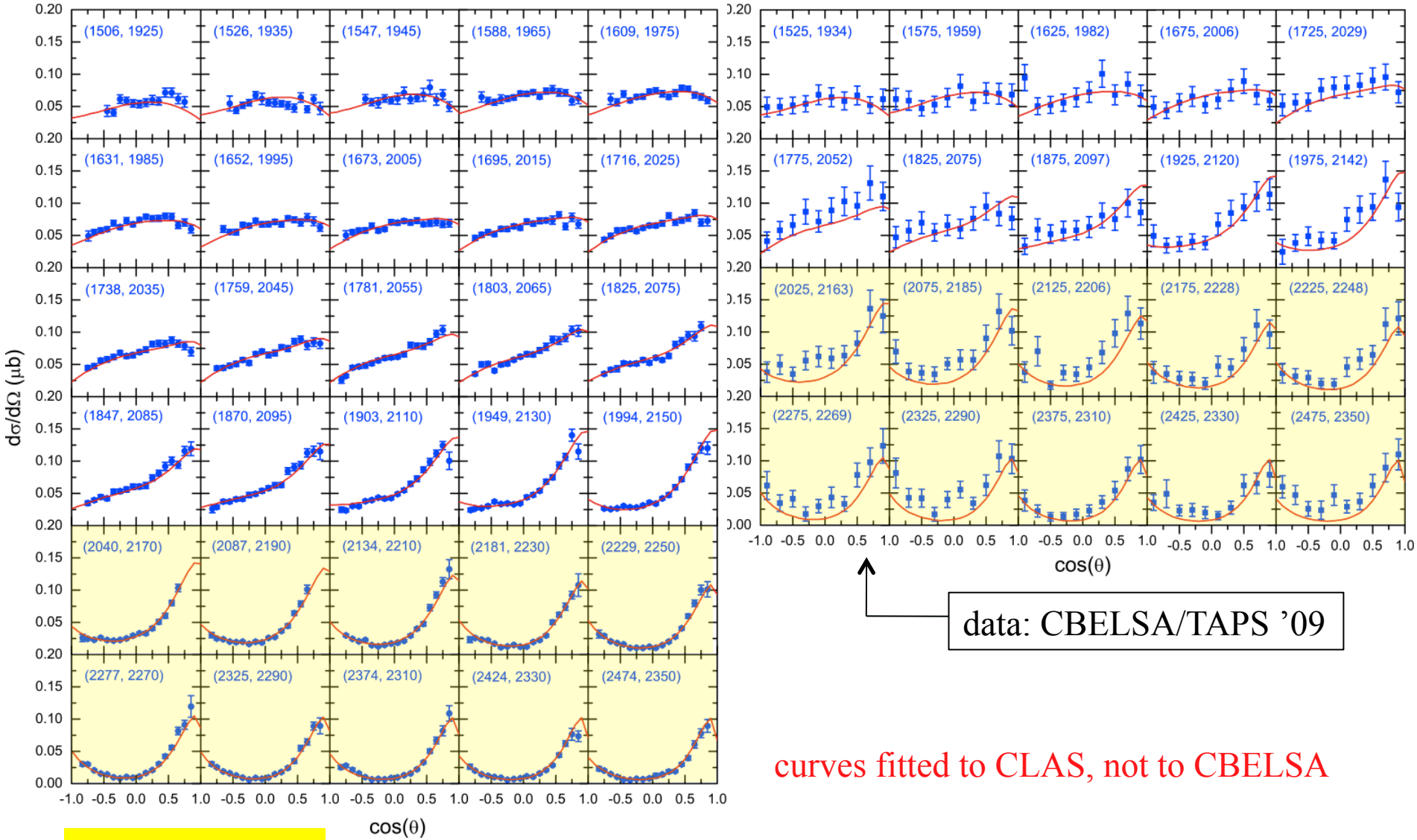
$\gamma p \rightarrow \eta' p$ CLAS'09 data: *more stringent constraints*



S_{11}, P_{11}, P_{13}, D_{13}

S_{11}, P_{13}, D_{13}

$\gamma p \rightarrow \eta' p$: CLAS'09 versus CBELSA/TAPS'09



data: CBELSA/TAPS '09

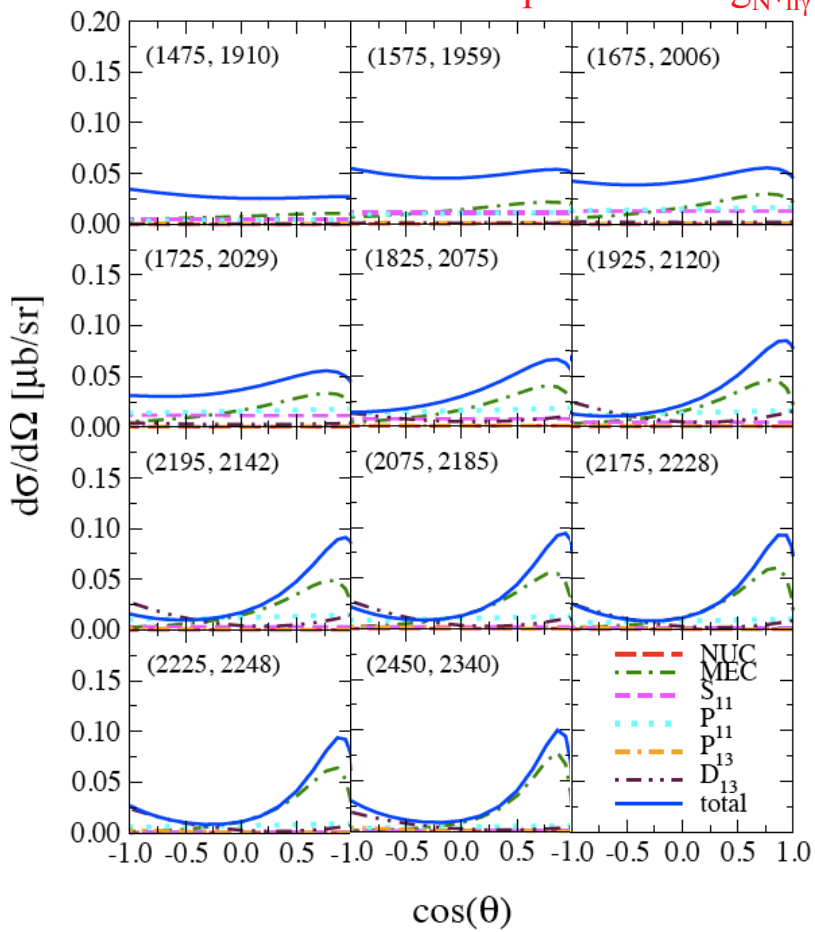
curves fitted to CLAS, not to CBELSA

S_{11}, P_{11}, P_{13}, D_{13}

$\gamma N \rightarrow \eta' N$: *quasi-free neutron & proton*

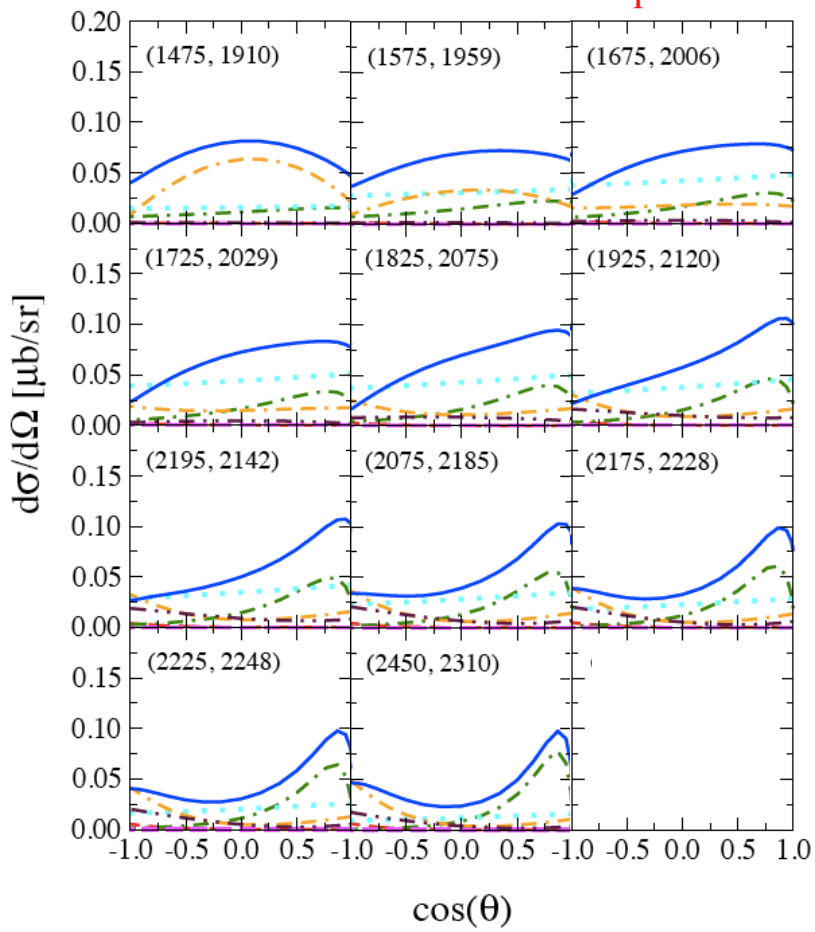
quasi-free neutron

free parameters: $g_{N^*n\gamma}$



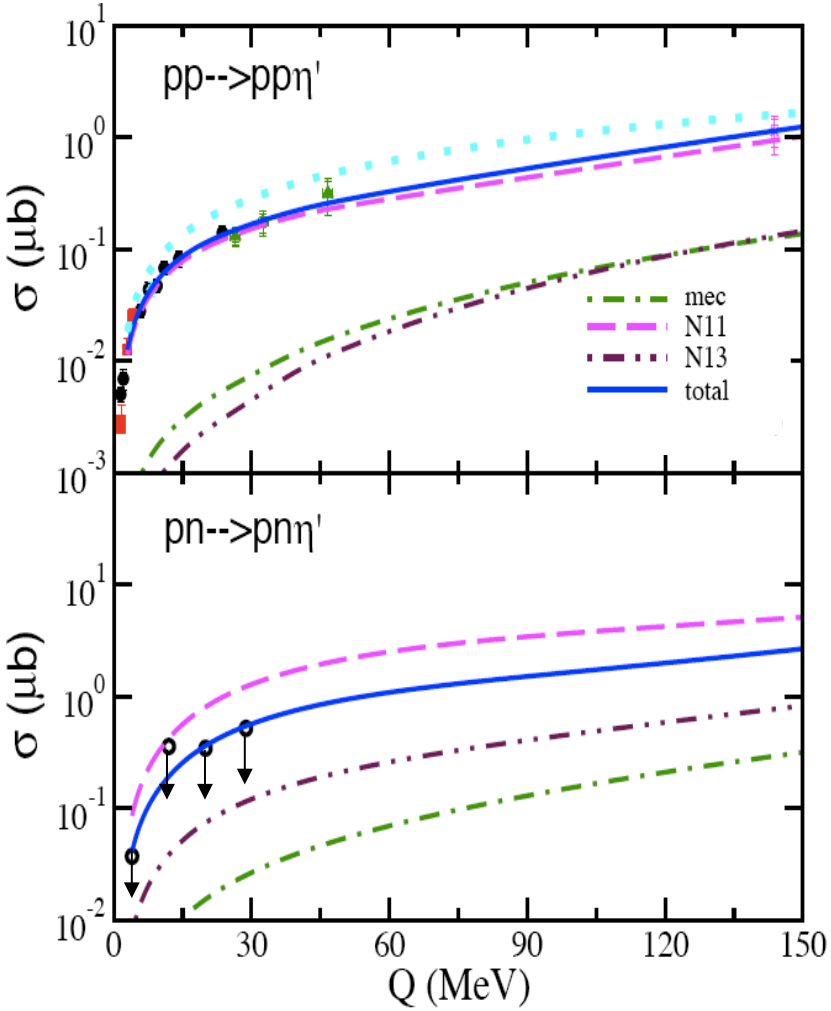
quasi-free proton

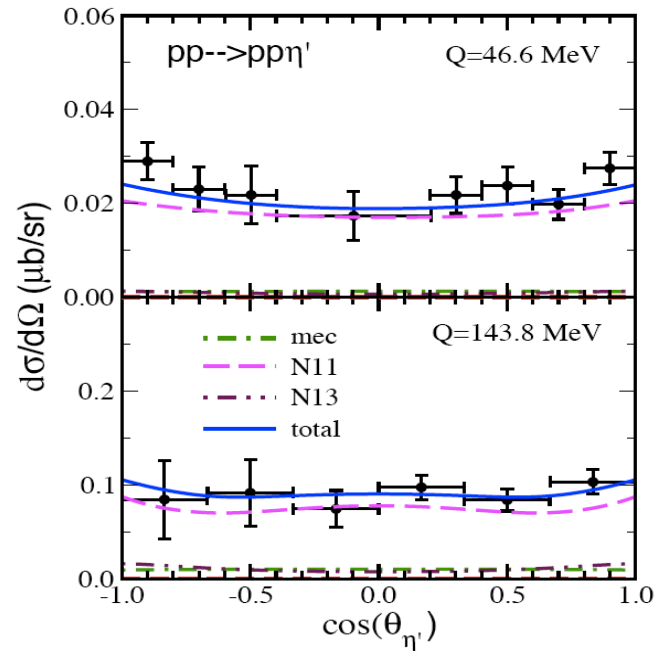
no free parameter

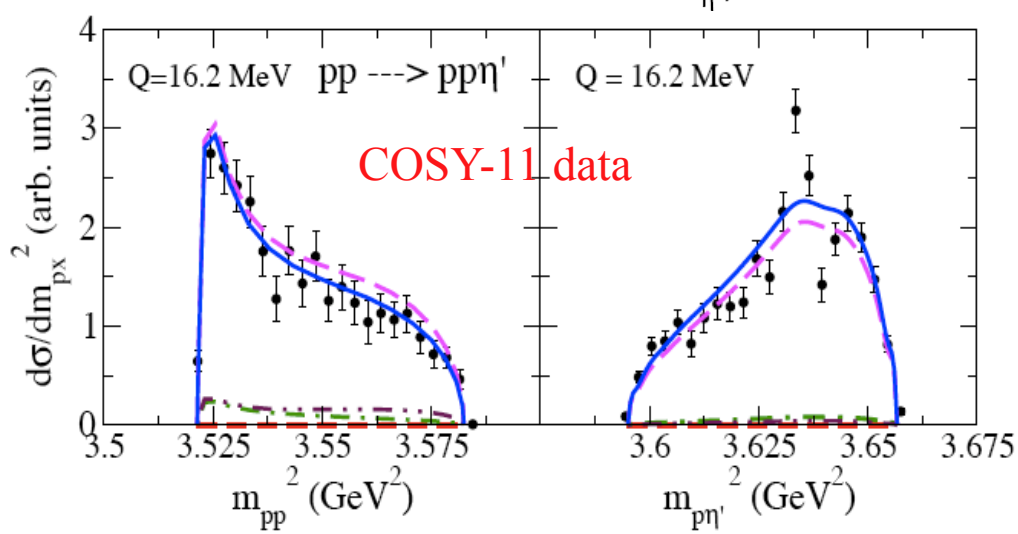


Fermi motion: by folding with the deuteron w.f.

$NN \rightarrow \eta' NN$ *(in combination with photoproduction):*

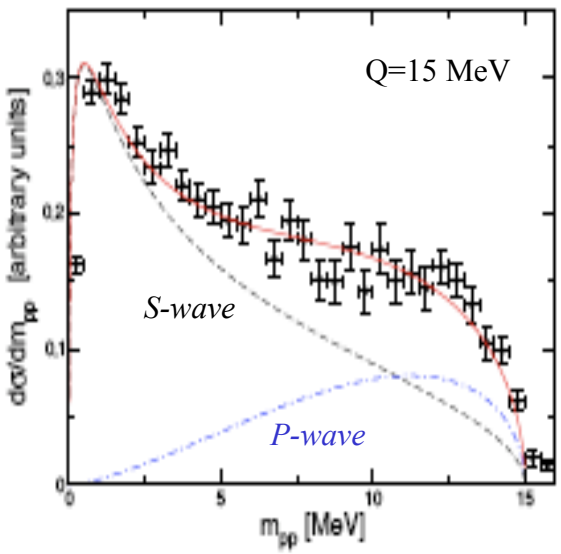






pnη' prelim. COSY data: (J. Klaja et al.)

$NN \rightarrow \eta NN$: *[possible explanation of the pp inv. mass distr.]*



(requires an extra p'^2 dependence in the amplitude)

1) *$p\eta$ FSI & three-body effects (in the S-wave).*
   (Fix & Arenhövel, PRC'04)

2) *energy dependence in the (basic) production amplitude.*
   (Delof, PRC'04)

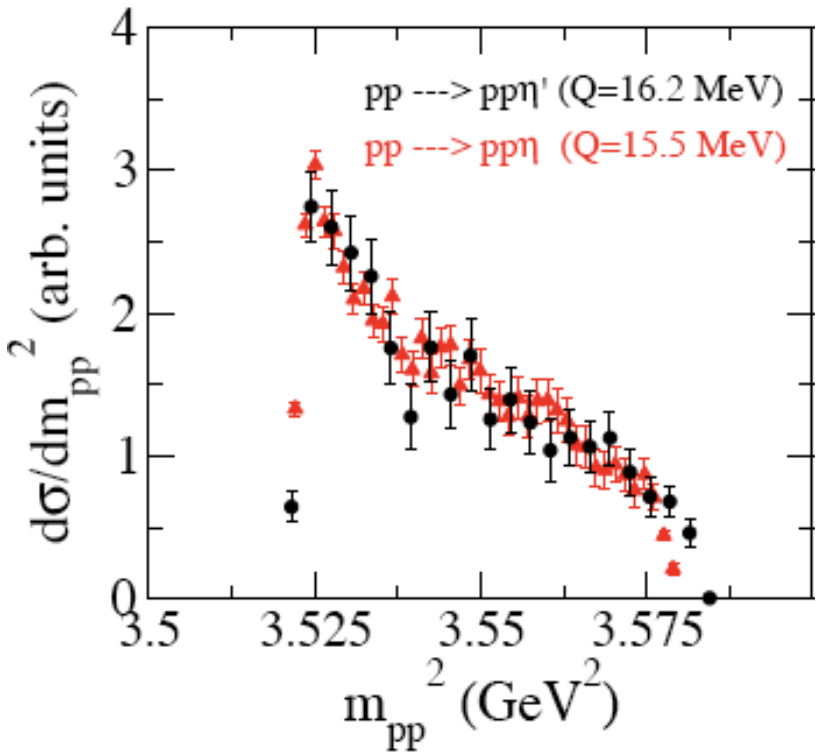
3) *higher partial-waves.*
   (Nakayama et al., PRC'03)

Model independent result (to isolate the S-wave) :

$$\boxed{{}^3\sigma_\Sigma = \frac{1}{4}\sigma_o(2 + A_{xx} + A_{yy}),}$$

(at threshold: $A_{xx}=A_{yy}=1$) *(Nakayama et al., PRC'03)*

$NN \rightarrow \eta' NN$ *(pp invariant mass distribution comparison with $NN \rightarrow \eta NN$)*



pη' FSI is expected to be much weaker than the pη FSI.

<u>COSY-11 collaboration data:</u>

pη : P. Moskal et al., PRC69, '04.

pη' : P. Klaja et al., PLB684, '10.

Some conclusions :

- Resonances are required to describe both the $\gamma + N \rightarrow \eta' + N$ and $N + N \rightarrow \eta' + N + N$ processes.

- (S11, P11, P13, D13) resonances account for the existing data. The high precision CLAS'09 cross section data already impose much more stringent constraint on the model parameters as compared to the previously existing data. In particular, $\gamma + p \rightarrow \eta' + p$ seems to require a P13 resonance close to threshold.

- The same set of resonances describe the CBELSA/TAPS quasi-free neutron and proton data, but the relative coupling strengths differ for neutron and proton.

- Spin observables (in particular Σ and T) are needed to further impose more stringent constraints on the model parameters.

η photoproduction

Combined analysis of η production (in the resonance region):

η meson production :

- $\gamma + N \rightarrow \eta + N$
  - cross sections for free proton [GRAAL, CBELSA/TAPS, CLAS, LNS, LEPS]
  - cross sections for quasi-free proton & neutron [GRAAL, CBELSA/TAPS]
  - beam & target asymmetry for proton [GRAAL, BONN'98]

  beam asymmetry for neutron [GRAAL]

- $\pi^- + p \rightarrow \eta + n$
  - cross sections [mostly from '70, SAID database]

- $N + N \rightarrow \eta + N + N$
  - cross sections for pp & pn [CELSIUS, COSY]
  - pp and pη invariant mass distributions [COSY]
  - analyzing power in pp [COSY]

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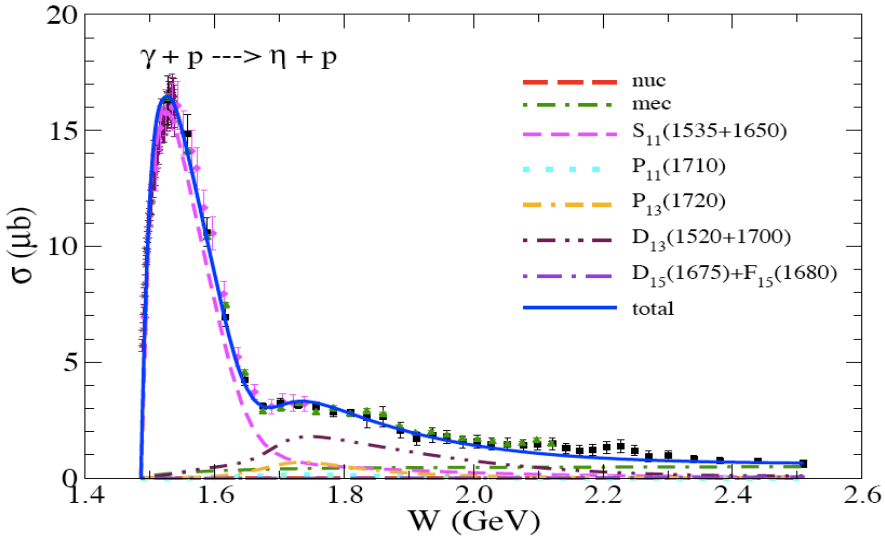
- $N + N \rightarrow \eta + N + N$
  - cross sections for pp & pn [CELSIUS, COSY]
  - pp and pη invariant mass distributions [COSY]
  - analyzing power in pp [COSY]

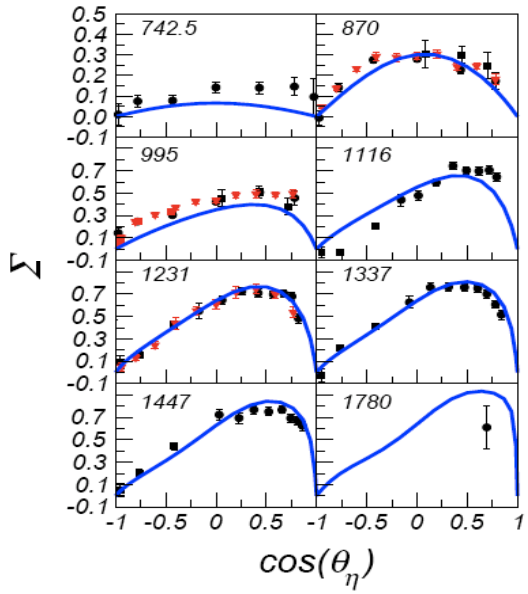
Strong coupling to $S_{11}(1535)$

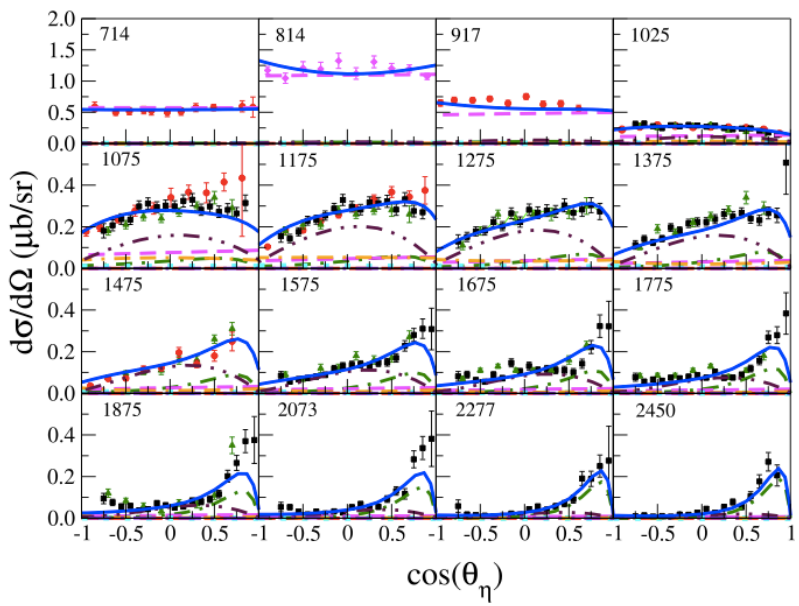
Issue of the bump structure in the ratio σ_n/σ_p :
signal for pentaquark?

$\gamma p \rightarrow \eta p$: *combined analysis with* $\pi p \rightarrow \eta n$ & $NN \rightarrow \eta NN$

(Nakayama, Oh, Haberzettl, '08)



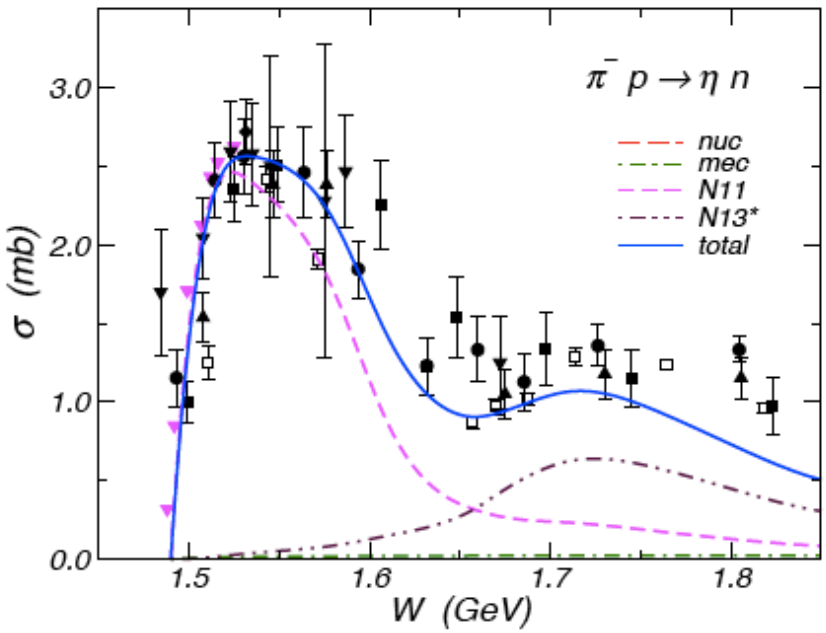


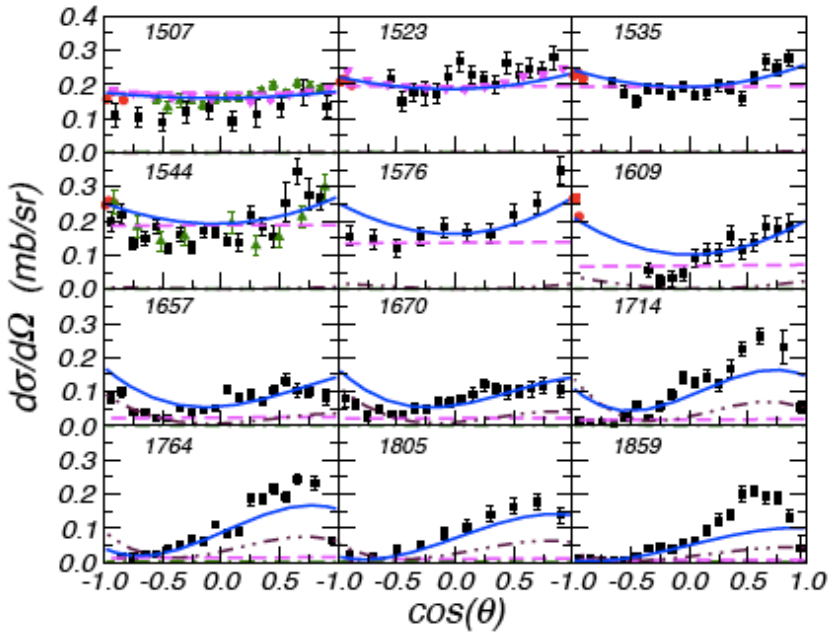


data: GRAAL'02
BONN'95&'05
JLAB'02
LNS'06

$\pi^- p \rightarrow \eta n$: *combined analysis*

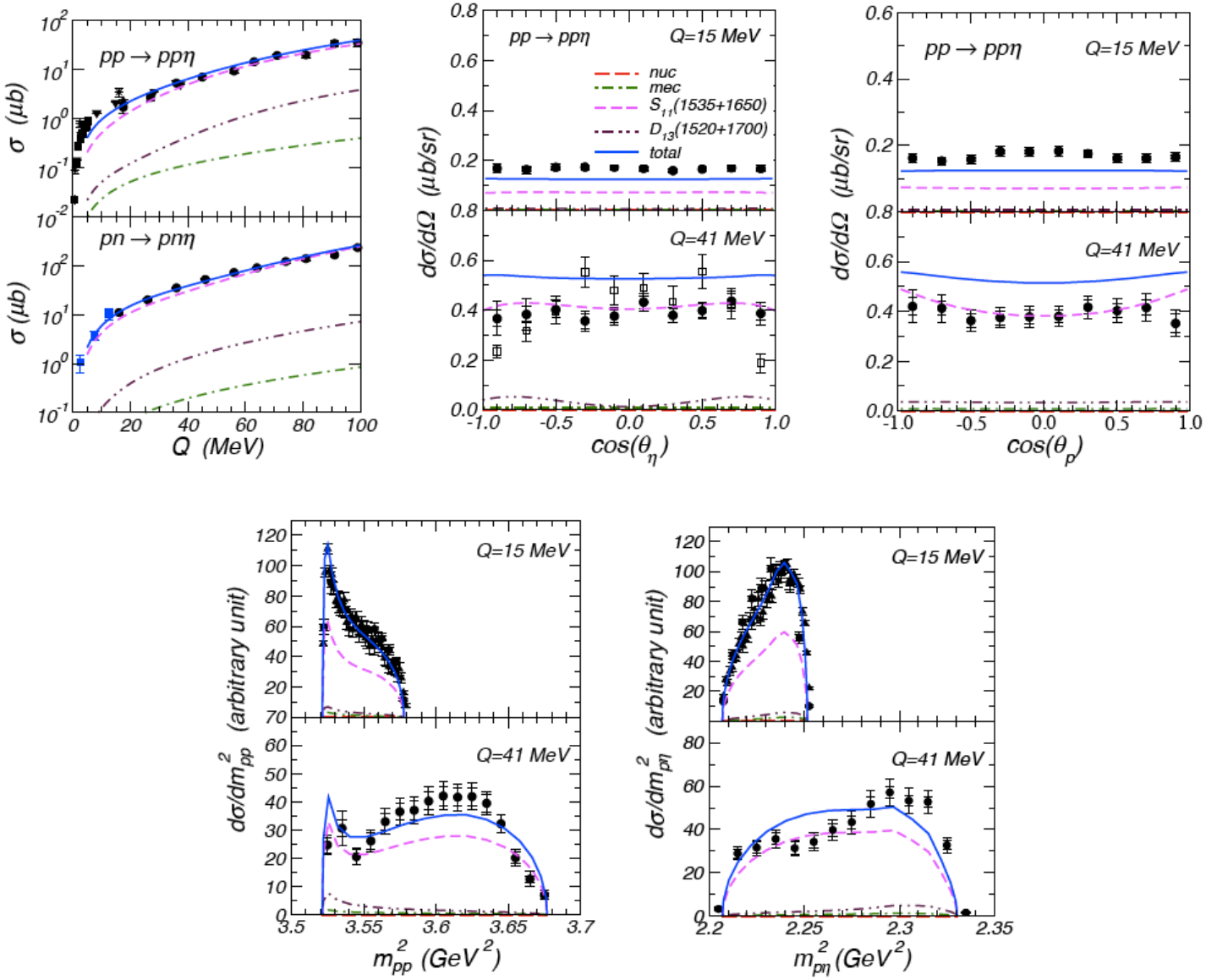
(Nakayama, Oh, Haberzettl, '08)



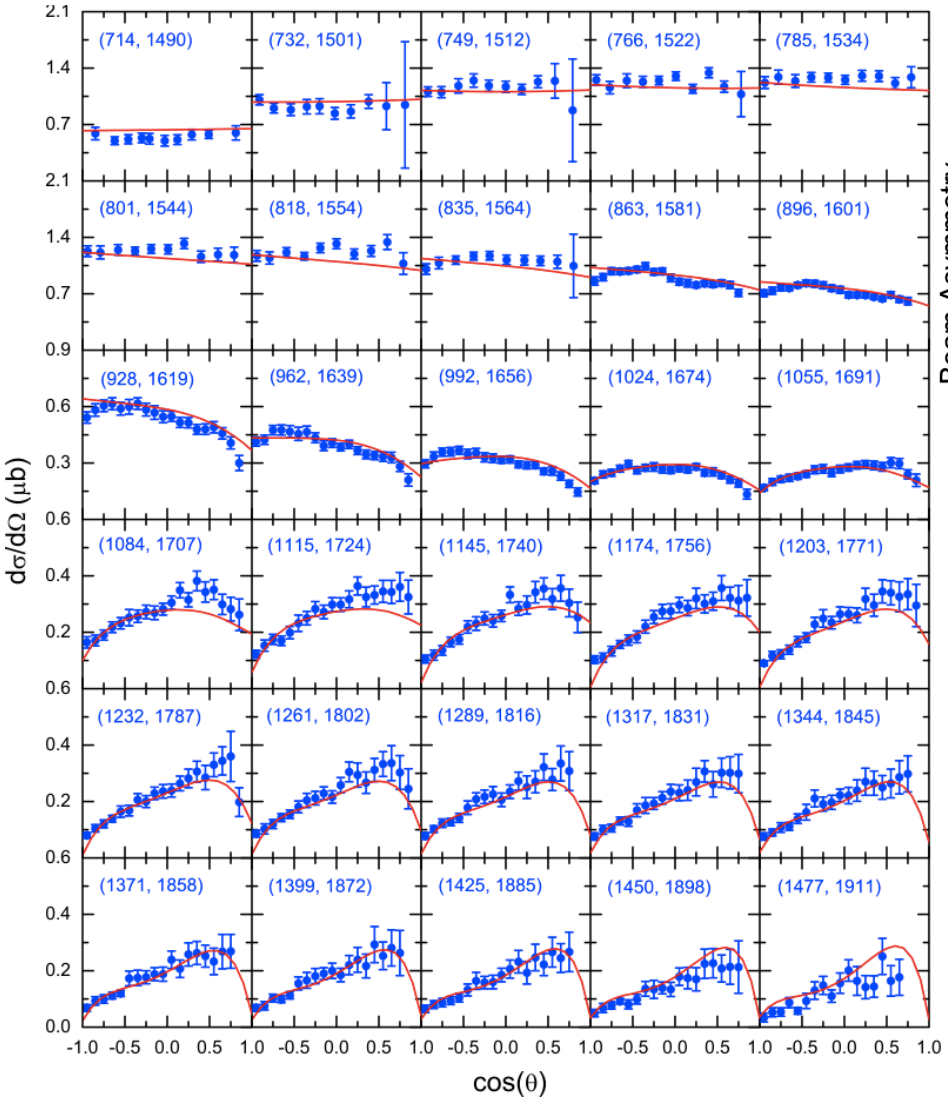


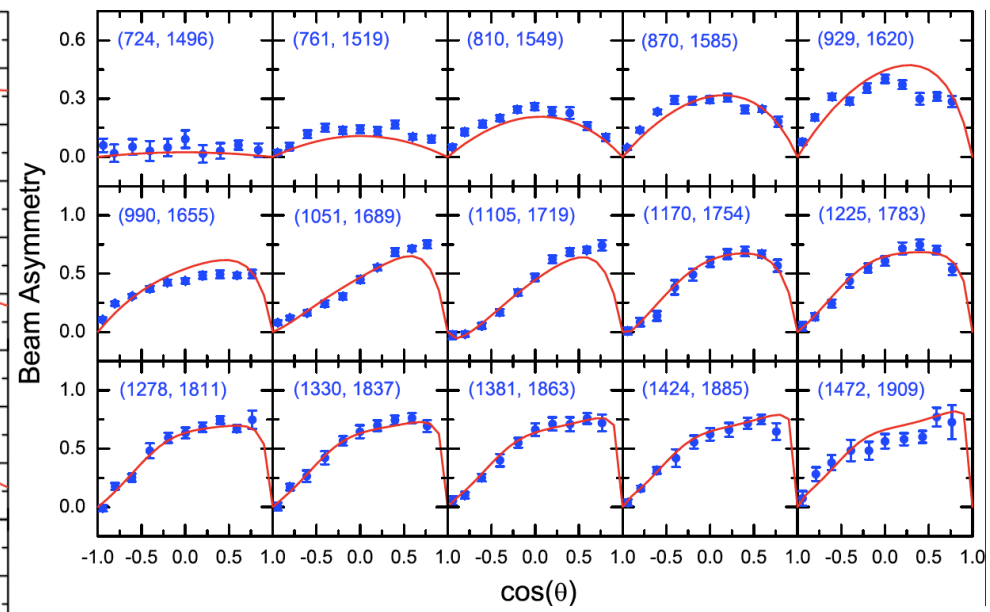
$NN \rightarrow \eta NN$: *combined analysis*

(Nakayama, Oh, Haberzettl, '08)



$\gamma p \rightarrow \eta p$: *fit to the 2007 GRAAL data (W<1.91 GeV)*





	D13	S11	S11	D15	F15	P11	P13
mass	1515.	1525.	1635.	1669.	1700.	1739.	1690.
width	90.	185.	135.	127.	110.	74.	189.
$\sqrt{\beta_{N\eta}}$ A_1/2	0.244	77.588	-22.532	-2.371	1.122	-6.559	-2.471
$\sqrt{\beta_{N\eta}}$ A_3/2	1.988	-----	-----	3.354	1.587	----	4.279

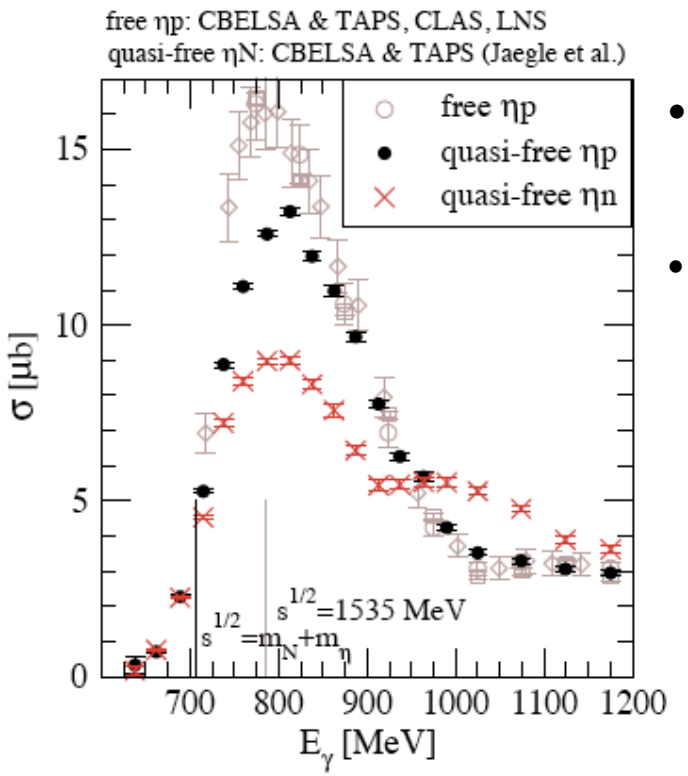
$S_{11}, P_{11}, P_{13}, D_{13}, D_{15}, F_{15}$

$\beta_{N\eta}$ = branching ratio; $\sqrt{\beta_{N\eta}}\, A_J$ in $10^{-3}\ GeV^{-1/2}$

phase convention: $g_{N*N\eta} > 0$

The issue of σ_p & σ_n in η photoproduction:

Excess of η in quasi-free γn → ηn :



- Excess of η on n found by GRAAL [Kuznetsov et al., PLB647,'07]
  confirmed by CBELSA & TAPS [Jaegle et al., PRL100,'09]
  and LNS [Miyahara et al., PTPS168,'07]
- Vivid discussion: workshop on *Narrow Nuclear Resonances*, Edinburgh, June'09, [http://2009physicsevents.org/pages/speakers.hmtl]
  - non-strange pentaquark [Diakonov et al., ZPA359,'97, Polyakov et al., EPJA18, '03,…]
  - $S_{11}(1650)/P_{11}(1710)$ interference [Shklyar et at., PLB650,'09]
  - interference of various partial waves [Choi et al., PLB363'06; Shyan et al., arXiv:0808.0632]
  - $D_{15}(1675)$ [ηMAID, NPA700'02] or P_{11} [Fix et al., EPJA32'07]
  - ≈ 80% of σ_p is S-wave; how about σ_n?
    P-wave? polarization data. [Kuznetsov, Polyakov et al., APPolonB39 …,'08]
    S-wave dominance? [Anisovich et al., EPJA41,'09; Miyahara et al., PTPS168,'07]

The issue of σ_p & σ_n in η photoproduction:

Excess of η in quasi-free γn → ηn :

[Kuznetsov &Polyakov, JETP88,'08]

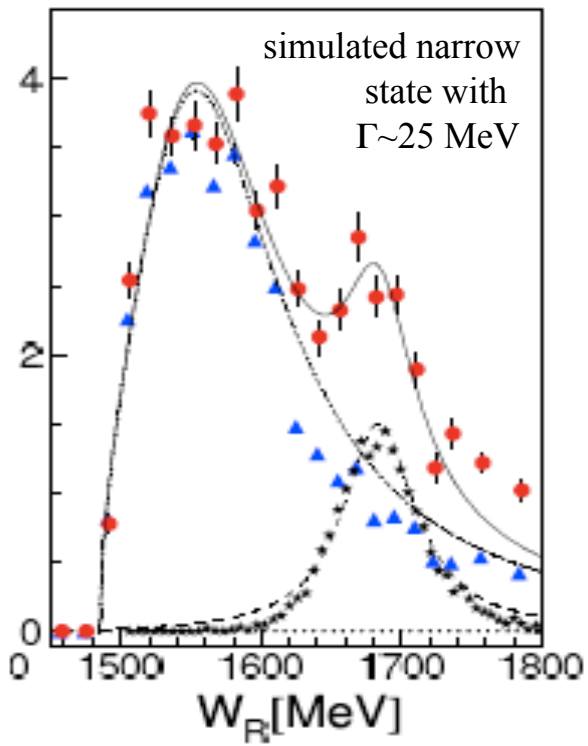


Fig. 2. $M(\eta n)$ spectrum from CBELSA/TAPS [12] (filled circle) in comparison with $M(\eta p)$ spectrum (filled triangles) Stars show the simulated signal of a narrow state.

- Excess of η on n found by GRAAL [Kuznetsov et al., PLB647,'07]
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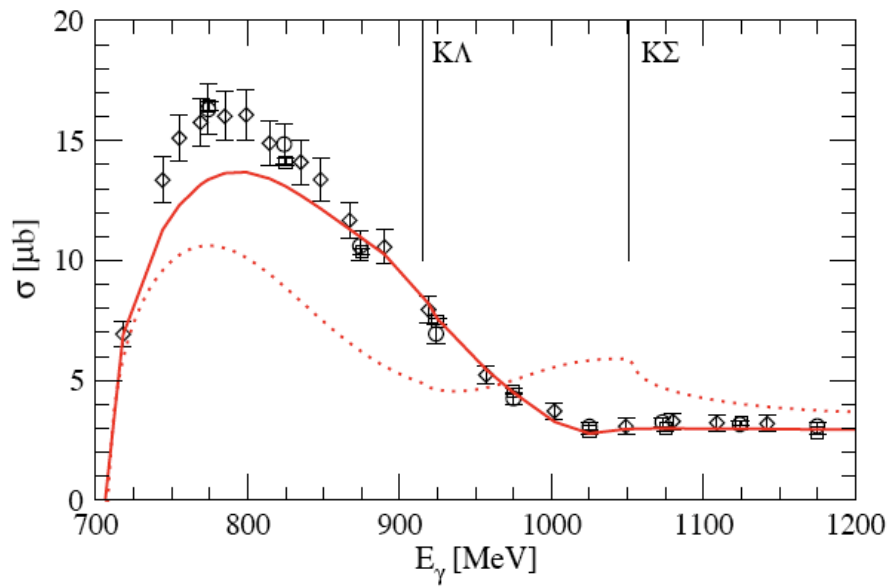
Results of UχPT $(B_8 \otimes M_8)$:

(M. Döring and K.Nakayama, PLB683 '10)

free

solid : $\gamma p \to \eta p$
dotted: $\gamma n \to \eta n$

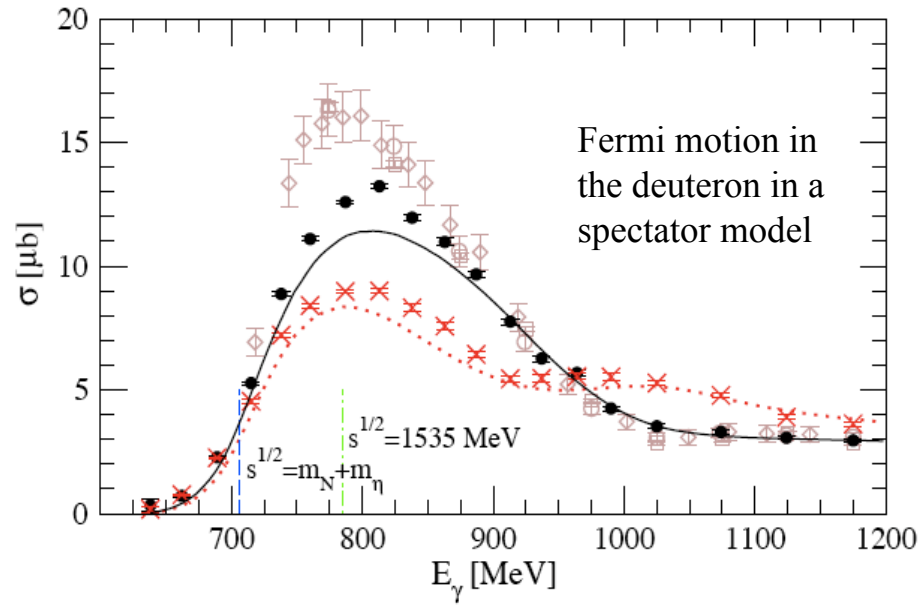
Data: Jlab-Clas, Bonn CB-Elsa, LNS



quasi-free

solid : $\gamma p \to \eta p$
dotted: $\gamma n \to \eta n$

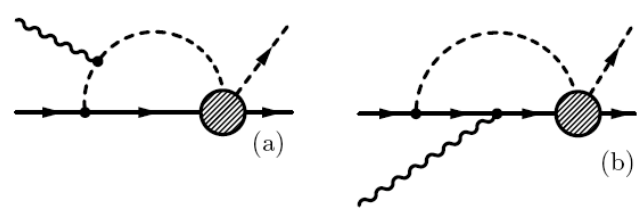
Data: I. Jaegle *et al.*, CBELSA & TAPS



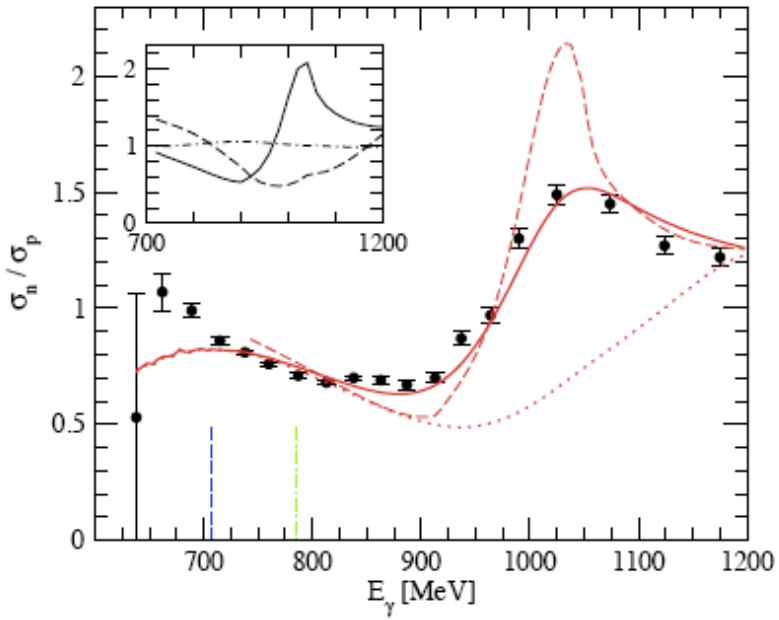
<u>intermediate state in the photon loops:</u>

neutron: $\pi^- p$, $\pi^0 n$, ηn, $K^0\Lambda$, $K^+\Sigma^-$, $K^0\Sigma^0$

proton : $\pi^0 p$, $\pi^+ n$, ηn, $K^+\Lambda$, $K^+\Sigma^0$, $K^0\Sigma^+$



Results : cross section ratio σ_n/σ_p



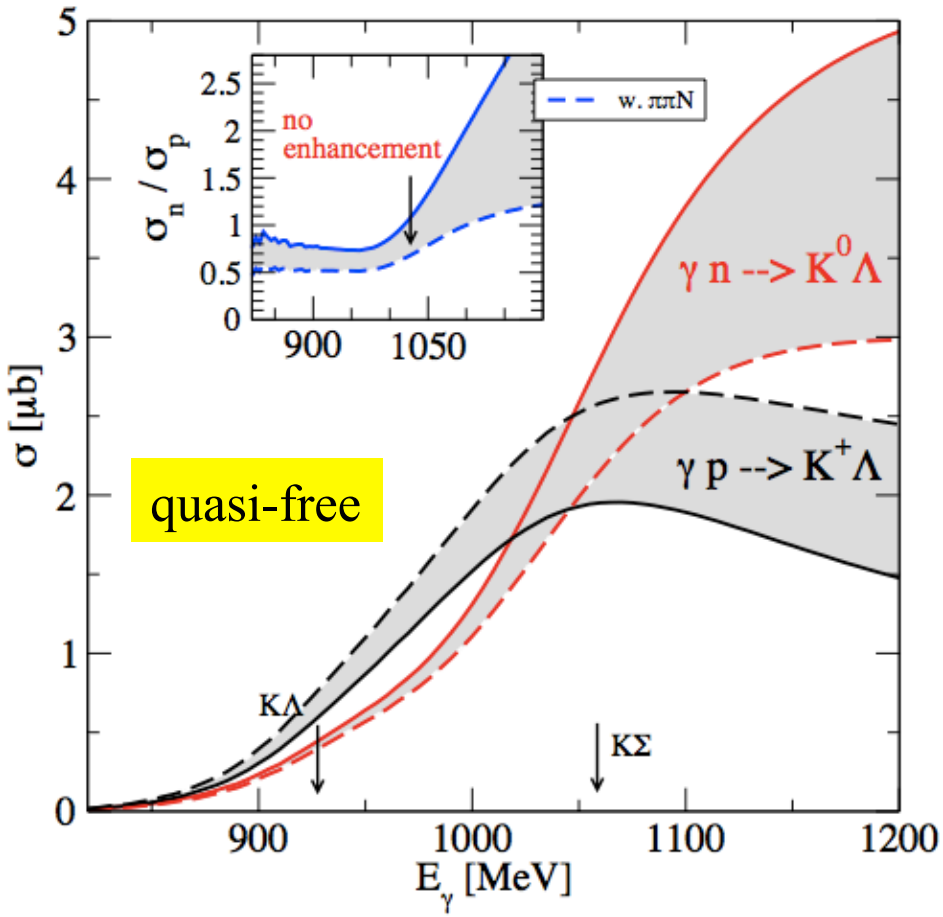
Data: I. Jaegle *et al.*, CBELSA & TAPS

solid : full result (with Fermi motion)
dashed: no Fermi motion
dotted: no $K^+\Lambda$ intermediate state
inset (dash-dotted): only πN intermediate state

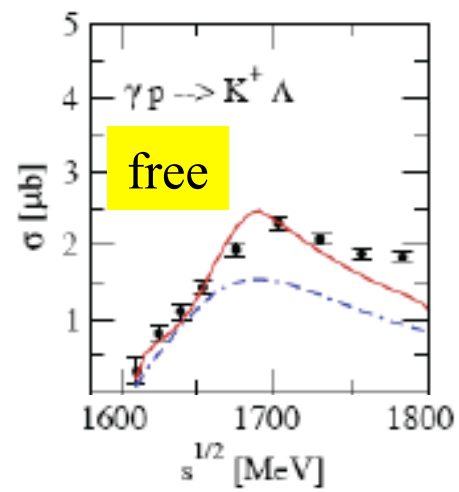
- Peak in σ_n/σ_p :
  direct consequence of the Weinberg-Tomozawa interaction with the strong couplings to $K\Lambda$ and $K\Sigma$ channels given by SU(3) (and $f_K \cong 113$ MeV).
- Simple and quantitative explanation.
- Should study the influence of higher partial wave states (dynamical models?)
- Does not rule out the P_{11} pentaquark explanation.

How one can disentangle the coupled channel versus pentaquark scenarios?

Prediction: σ_n/σ_p *in (quasi-free)* $\gamma N \rightarrow K\Lambda$



$\gamma N \rightarrow K\Lambda$
might be able to test the coupled channel effect
vrs
pentaquark



Model independent results:

Exploiting the general spin structure of the photoproduction amplitude:

$$\hat{M} = F_1 \vec{\sigma} \cdot \vec{\epsilon} + i F_2 \vec{\epsilon} \cdot (\hat{k} \times \hat{q}) + F_3 \vec{\sigma} \cdot \hat{k}\hat{q} \cdot \vec{\epsilon} + F_4 \vec{\sigma} \cdot \hat{q}\hat{q} \cdot \vec{\epsilon}$$

(CGLN,'57 rewritten)

S-wave

$$M_0 = i F_2 \sin(\theta) \ , \qquad M_1 = F_1 + F_4 \sin^2(\theta) \ ,$$

$$M_2 = F_1 \ , \qquad M_3 = [F_3 + F_4 \cos(\theta)] \sin(\theta) \ ,$$

longitudinal spin transfer coefficient

$$\frac{d\sigma}{d\Omega} = |M_0|^2 + |M_2|^2 + |M_1|^2 + |M_3|^2$$

$$\frac{d\sigma}{d\Omega} K_{zz} = |M_0|^2 - |M_1|^2 - |M_2|^2 + |M_3|^2$$

target and recoil nucleon asymmetries with circularly polarized photon

$$\frac{d\sigma^{\pm}}{d\Omega} T_z^{\pm} = \mp Re\,[M_1 M_2^*] \mp Im\,[M_0 M_3^*]$$

$$\frac{d\sigma^{\pm}}{d\Omega} P_z^{\pm} = \pm Re\,[M_1 M_2^*] \mp Im\,[M_0 M_3^*]$$

$$\frac{d\sigma_K}{d\Omega} \equiv \frac{d\sigma}{d\Omega}(1 + K_{zz})$$

no S-wave

$$\frac{d\sigma^{\pm}{}_{TP}}{d\Omega} \equiv \frac{d\sigma^{\pm}}{d\Omega}(T_z^{\pm} + P_z^{\pm})$$

challenge to experimentalists

The End