$\pi\,\eta$ photoproduction on the nucleon

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Outline

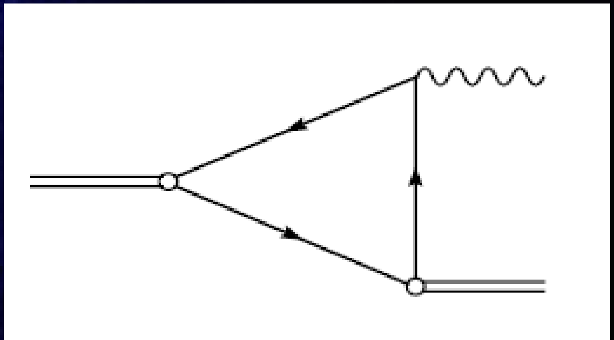
- Why to study the $\pi\eta$ photoproduction ?
- Why we hope thy final state interaction mechanism describes $\pi\eta$ photoproduction ?
- Some model predictions for the $\pi\eta$ (and $\pi\pi$) photoproduction

- Meson interpretation in terms of the $q\bar{q}$ gives a good qualitative description of the light-quark pseudoscalar 0^{-+} ,vector 1^{--} and tensor 2^{++} nonets

- On the other hand the molecular picture is usually referred to in case of light-quark $f_0(500)$, $f_0(980)$, $a_0(980)$ (and $K_0^*(800)$?) scalar mesons.

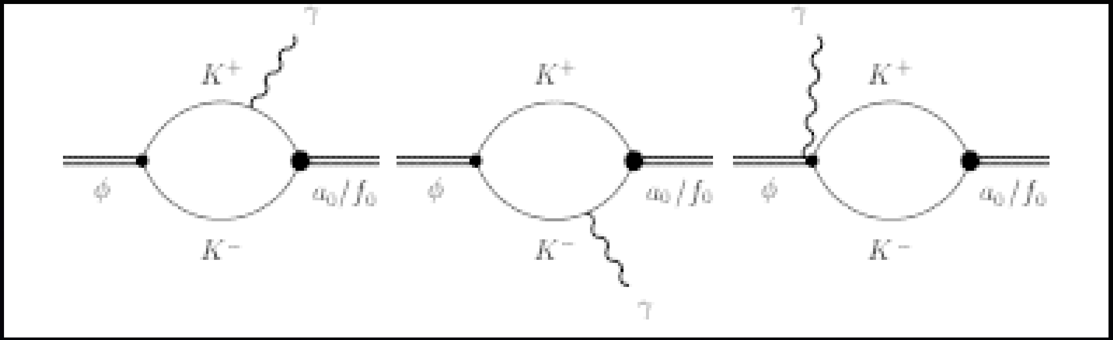
- In many cases, however, the quark-molecular puzzle is difficult to resolve

- In the quark model the electromagnetic decays are mediated by the quark loops



- What we assume is more general, namely that the interaction region is compact or even “point-like” (whatever the microscopic nature of the vertex)

- In the molecular picture the radiative decays are mediated by the kaon loops



The interaction region is diffuse

Resonances in the πη channel

Low partial waves bear interesting features

- S – wave

$a_0(980)$

- near $K\bar{K}$ threshold effects
- inner structure still controversial ($\bar{q}q$, $\overline{qq}$ qq, molecule ?)

$a_0(1450)$

- given the $a_0(980)$ as a molecule should $a_0(1450)$ belong to the $\bar{q}q$ nonet ?
- branching fractions unknown
- (photo-)production mechanism unknown
- unobserved in some experiments (GAMS $\pi^- p \rightarrow \pi^0 \eta n$)

- S – wave (cont'd)
- There are no excessive states in an isovector part of the ground state $q\bar{q}$ nonet (quite remarkably)

- P wave

$\pi_1(1400)$

- has exotic $J^{PC}=1^{-+}$ quantum numbers but its decay products suggest it is not hybrid
- absent (or at least unobserved so far) in certain reactions/channels:

$\pi^- p \rightarrow \eta\pi^0 n$ (E852 Brookhaven)

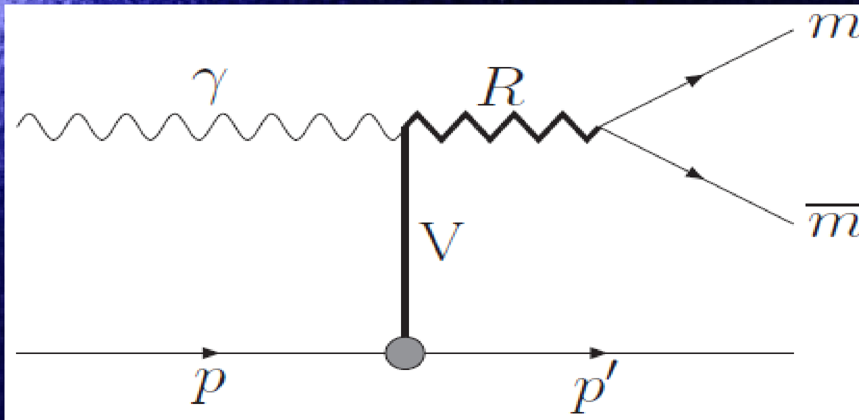
$\gamma p \rightarrow \eta\pi^0 p$ (CLAS JLab)

- interpretation as a resonance – problematic ()

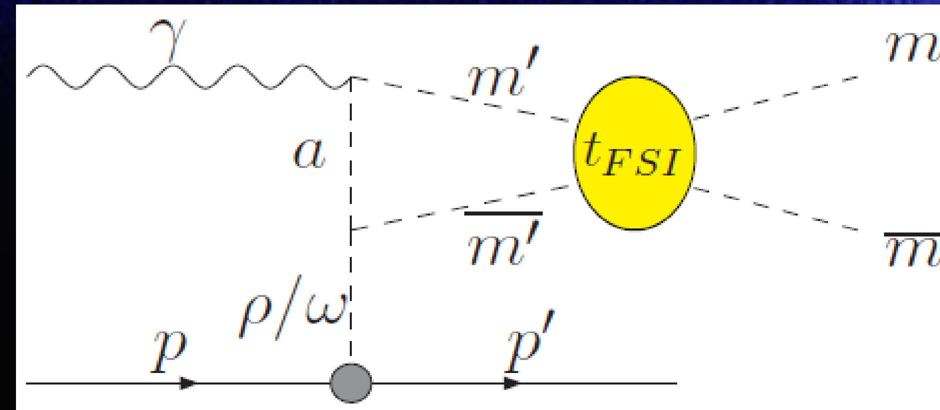
- D wave

$a_2(1320)$

  - seems to be firmly situated in the $q\bar{q}$ tensor nonet
  - but recent papers: ŁB, R. Kamiński PRD 87, 114010 (2013), J-J Xie, E. Oset arXiv:1412.3234, suggest that tensor mesons can be photoproduced dynamically in the final state



Direct resonance photoproduction



Final state (FSI) resonance photoproduction

- FSI amplitude structure (C-R. Ji, et al 1997)

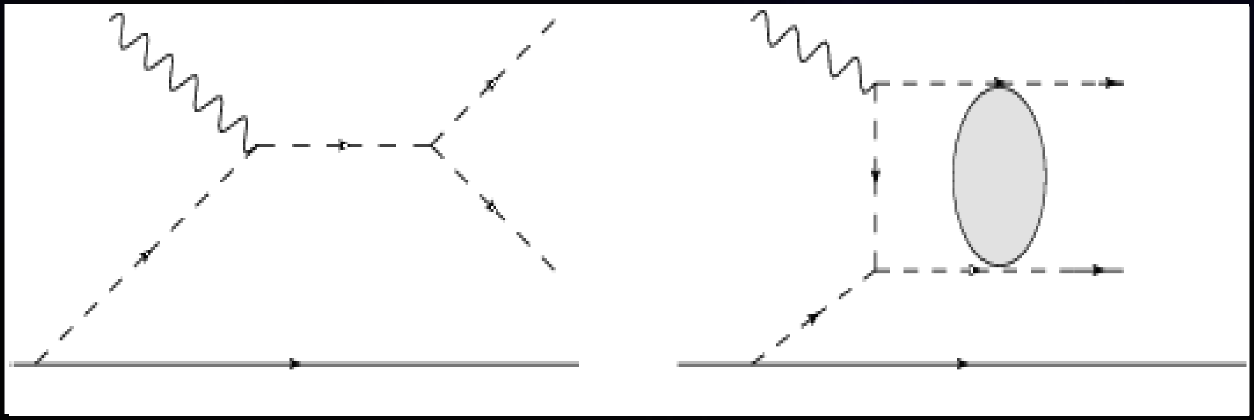
Partial wave projected Born amplitude

$$T_{\pi^+\pi^-} = \left[1 + i r_\pi \left(\frac{2}{3} t^{I=0}_{\pi\pi} + \frac{1}{3} t^{I=2}_{\pi\pi}\right) + \frac{2}{3}\hat{P}^{I=0}_{\pi\pi} + \frac{1}{3}\hat{P}^{I=2}_{\pi\pi}\right] V_{\pi^+\pi^-}$$
$$+\frac{1}{3}[i r_\pi(-t^{I=0}_{\pi\pi} + t^{I=2}) - \hat{P}^{I=0}_{\pi\pi} + \hat{P}^{I=2}_{\pi\pi}] V_{\pi^0\pi^0} + \frac{1}{\sqrt{6}}(i r_K t^{I=0}_{\pi K} + \hat{P}^{I=0}_{\pi K})(V_{K^+K^-} - V_{K^0\overline{K^0}}).$$

Final state scattering amplitude

- This form of the amplitude holds for all partial waves (very economical approach) !

Technical remark



s-channel t-channel

- At the tree diagram level the s- and t- channel amplitudes are complementary
- When FSI is taken into account in the t-channel amplitude the meson loop and FSI amplitude taken together can be treated as the pole approximation of the radiative vertex in the s-channel
- Thus addition of these amplitudes must be considered as “the double counting”

S - wave

- The FSI model to was applied to $\gamma p \to f_0(980) p \to \pi^+ \pi^- p$ reaction *(L.Leśniak, ŁB, 2012)*

- FSI model also successfully applied to $\gamma p \to f_0(980)/a_0(980) p \to K \bar{K} p$ reaction (L.Leśniak, AS, ŁB, 2004)

- For direct photoproduction discussion of this reaction see eg. *Donnachie, Kalashnikova , 2008*

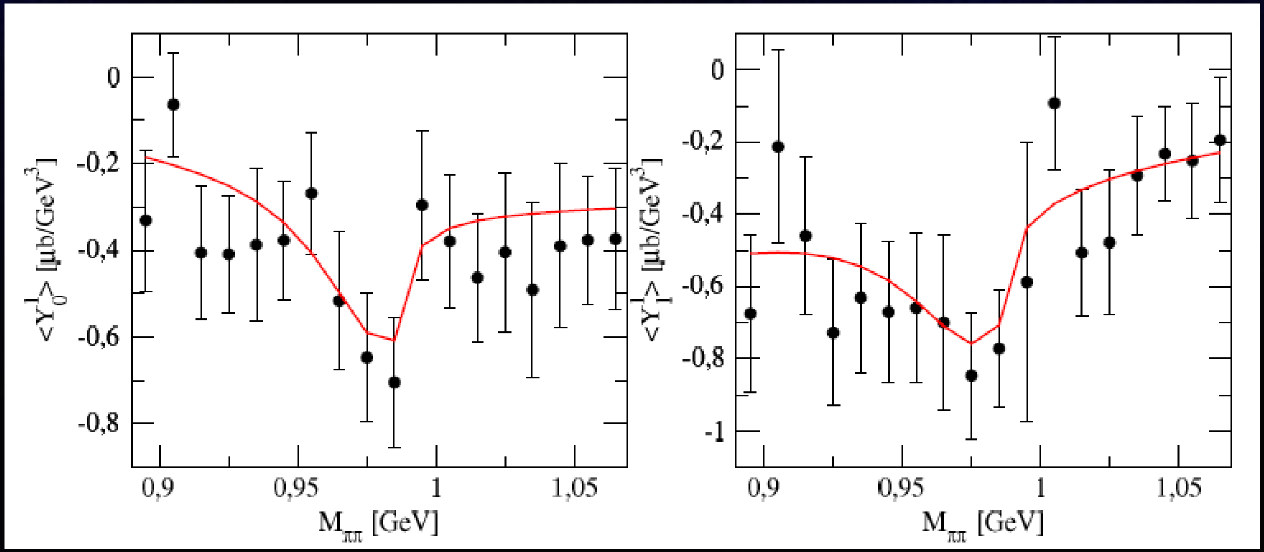
Selected results

- Comprehensive analysis of the $\gamma p \to f_0(980) p \to \pi^+ \pi^- p$ reaction
- The simultaneous fit of the mass distribution and moments of angular distribution measured by CLAS (2009) was made in the mass range of ρ(770)-f_0(980) interference

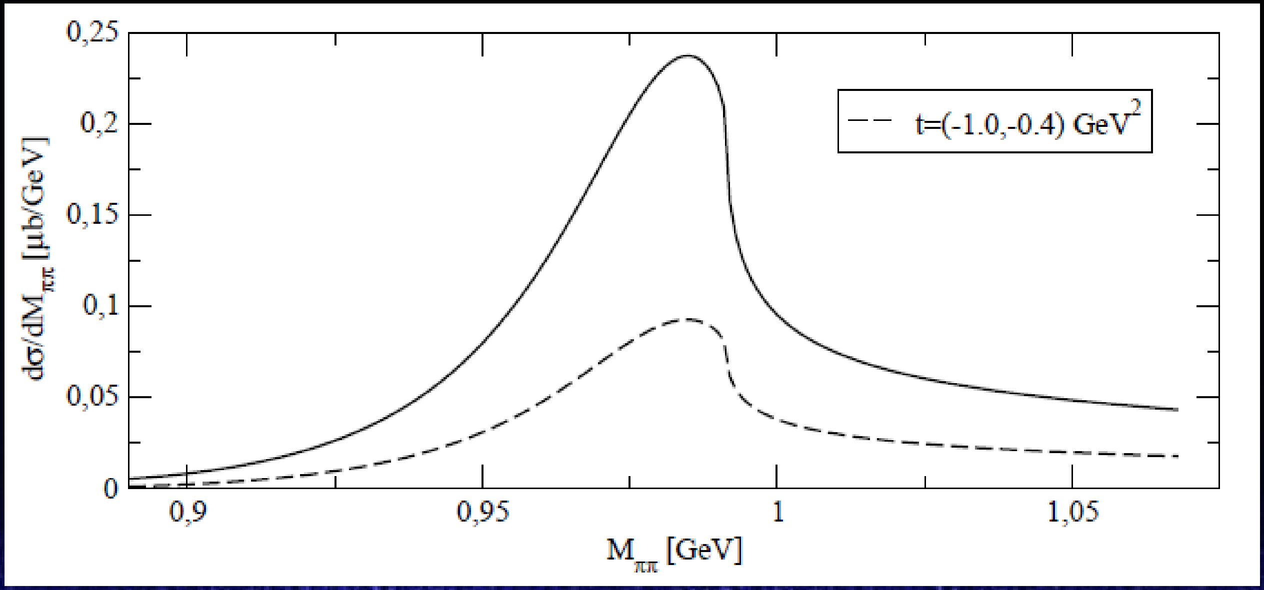
$$\langle Y_M^L(t, M_{\pi\pi})\rangle = \int d\Omega\, Y_M^L(\Omega)\, |A^P + A^\pi + A^\sigma + A^{f_2} + A^D + A^{f_0}|^2$$

- Apart from the f_0(980) photoproduction we included ρ(770) photoproduction with π, σ, f_2(1270) and pomeron exchange as well as Drell background in the fit

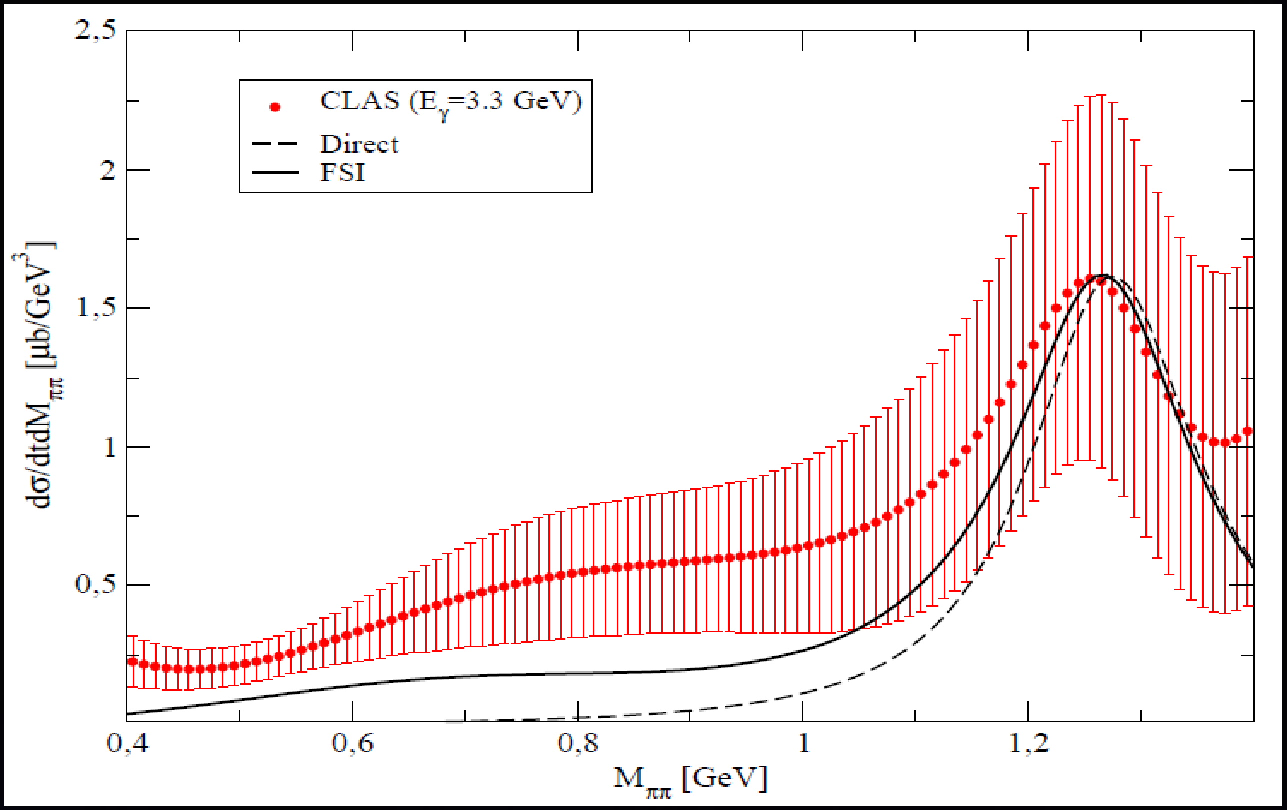
- Moments (E_γ=3.3 GeV, t=-0.5 GeV2)



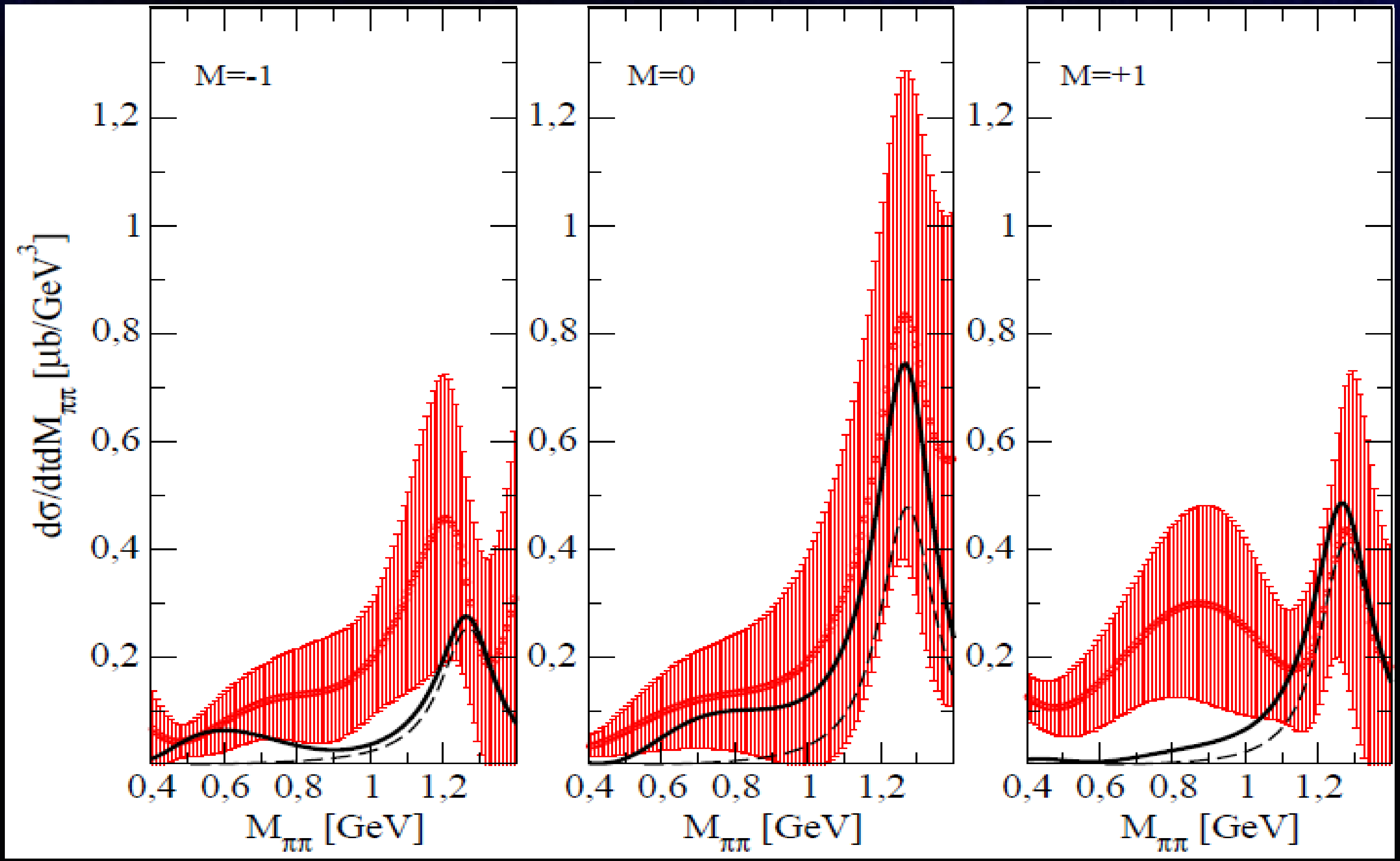
- Having constrained the resonant S-wave we calculated the mass distribution (lower by a factor of ~4 than in direct photoproduction calculations)



- We calculated the (overall) mass distributions and mass distributions for selected helicities +1, 0, -1 and compared them with CLAS data at E_γ=3.3 GeV



- It's not a prediction. It's a fit.
- Both models predict larger D-wave cross sections than measured in CLAS if standard (eg. from Bonn model and f_2 radiative decays) parameters are employed.



E_γ=3.3 GeV, t=-0.55 GeV

Solid line – FSI production model

Dashed line – direct production model

- With the present mass distribution mesurement precision one is not able to refute any of the two models

Do exist any differences in predictions of the FSI and direct production models for the f_2(1270) photoproduction ?

- Look at the spin structure of the direct f_2 photoproduction amplitude:

No spin correlation between the tensor meson and nucleons

$$A_{\sigma'\sigma} \sim a\,\vec{\epsilon}\cdot\vec{\Gamma}_{\sigma'\sigma}\left[(\vec{q}\cdot\vec{k})^2-\frac{1}{3}k^2q^2\right]+b\,q\cdot\Gamma_{\sigma'\sigma}\,\vec{\epsilon}\cdot\vec{k}\,\vec{q}\cdot\vec{k}$$
$$+c\left[\vec{\epsilon}\cdot\vec{k}\,\vec{\Gamma}_{\sigma'\sigma}\cdot\vec{k}-\frac{1}{3}k^2\,\vec{\epsilon}\cdot\vec{\Gamma}_{\sigma'\sigma}\right]$$

Strong spin correlation

where:

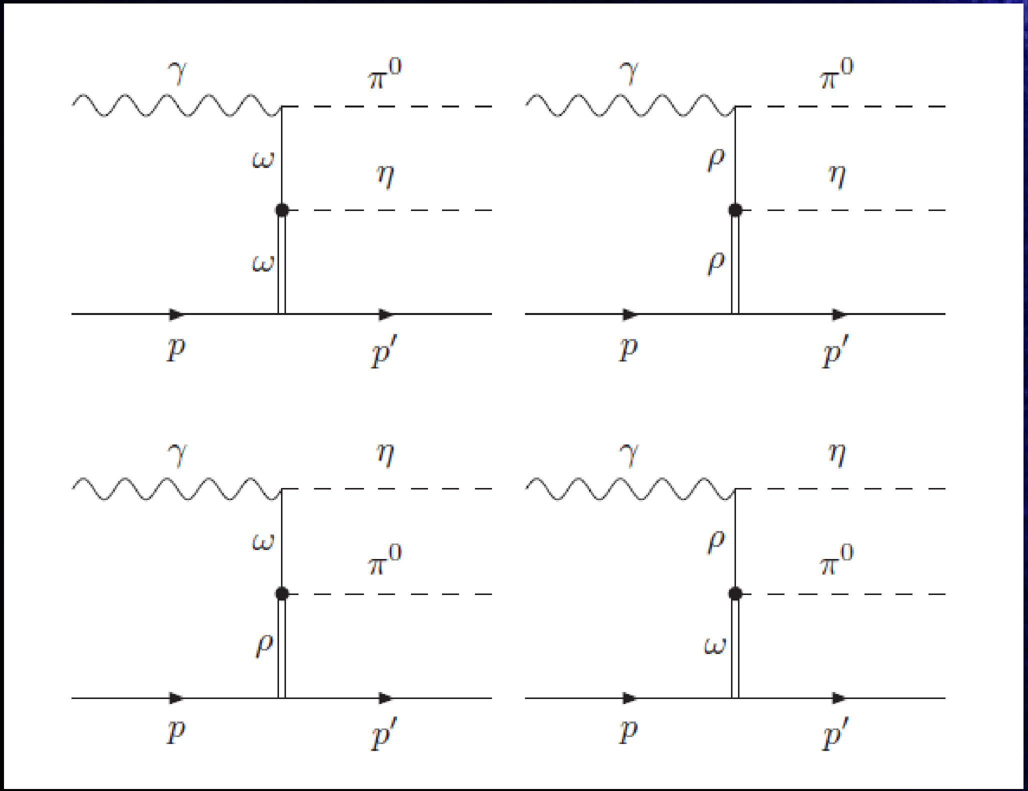
σ', σ – spin indices of the initial and final nucleon

q (k) – photon (π^+) momentum

- There are no terms of the second kind in the FSI amplitudes ! We can expect stronger spin correlations in the direct photoproruction mechanism
- Polarisation data needed to confirm this

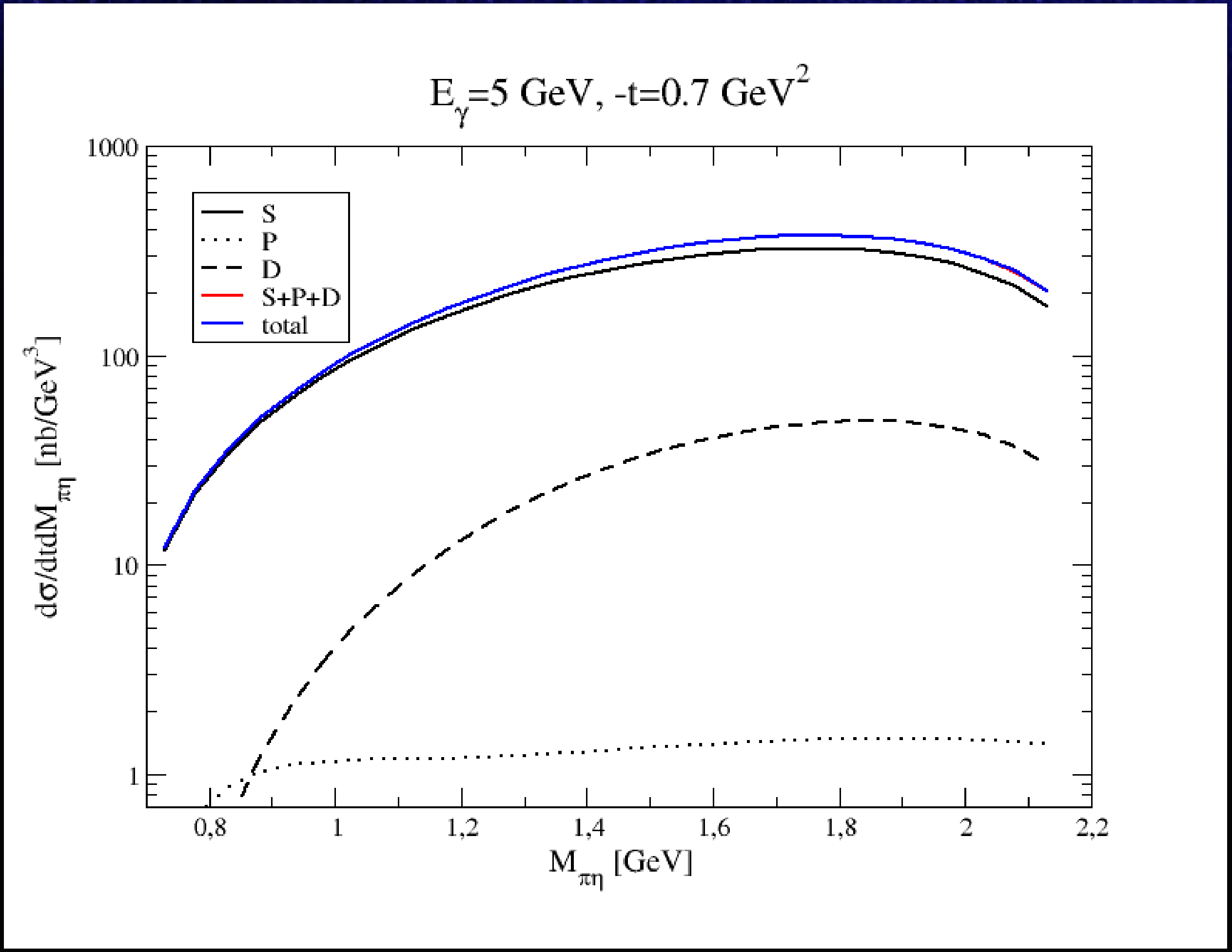
Return to the πη channel

- Diagrams for the Born amplitudes of the πη photoproduction
- In principle pseudoscalar exchanges could be included but they are negligible for energies ~10 GeV

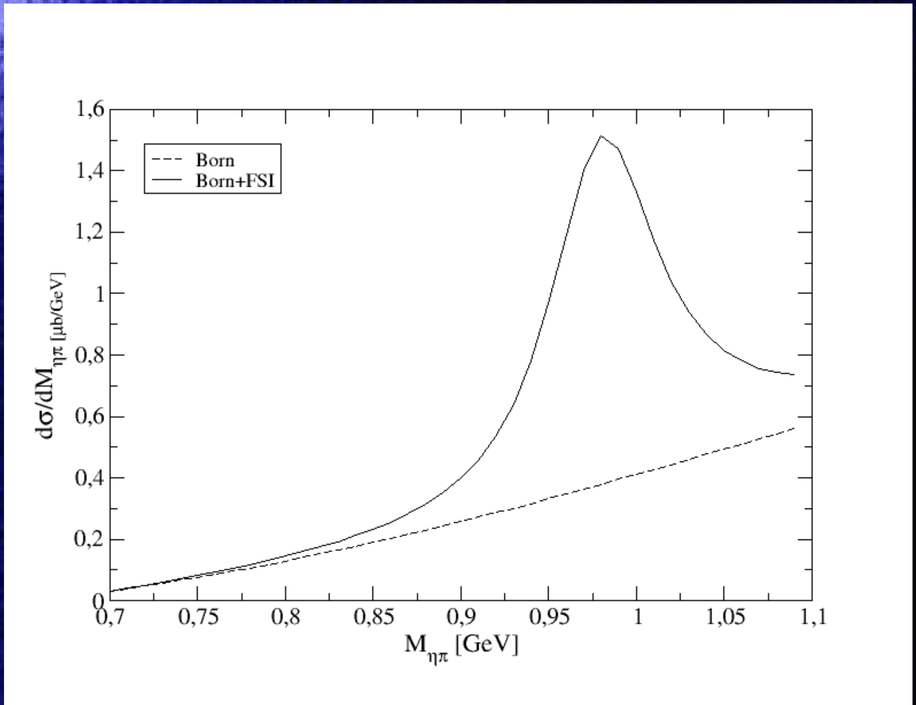


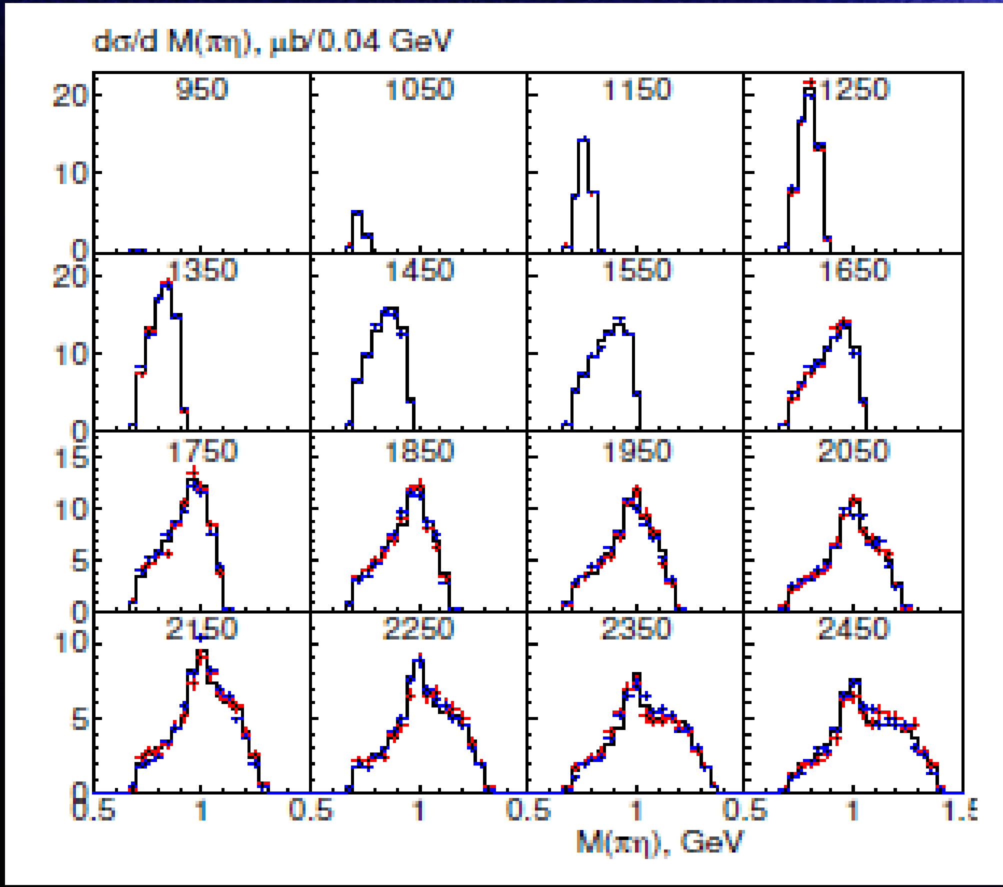
$$T_{\pi\eta} = \left[1 + i r_{\pi\eta}\left(\hat{t}_{\pi\eta} + \hat{P}_{\pi\eta}\right)\right] V_{\pi\eta}$$

- In the first approximation we neglect the $K\bar{K} \rightarrow \pi\eta$ transition
- Justified by the small inter-channel coupling (Furman, Leśniak Phys.Lett.B538:266-274,2002)

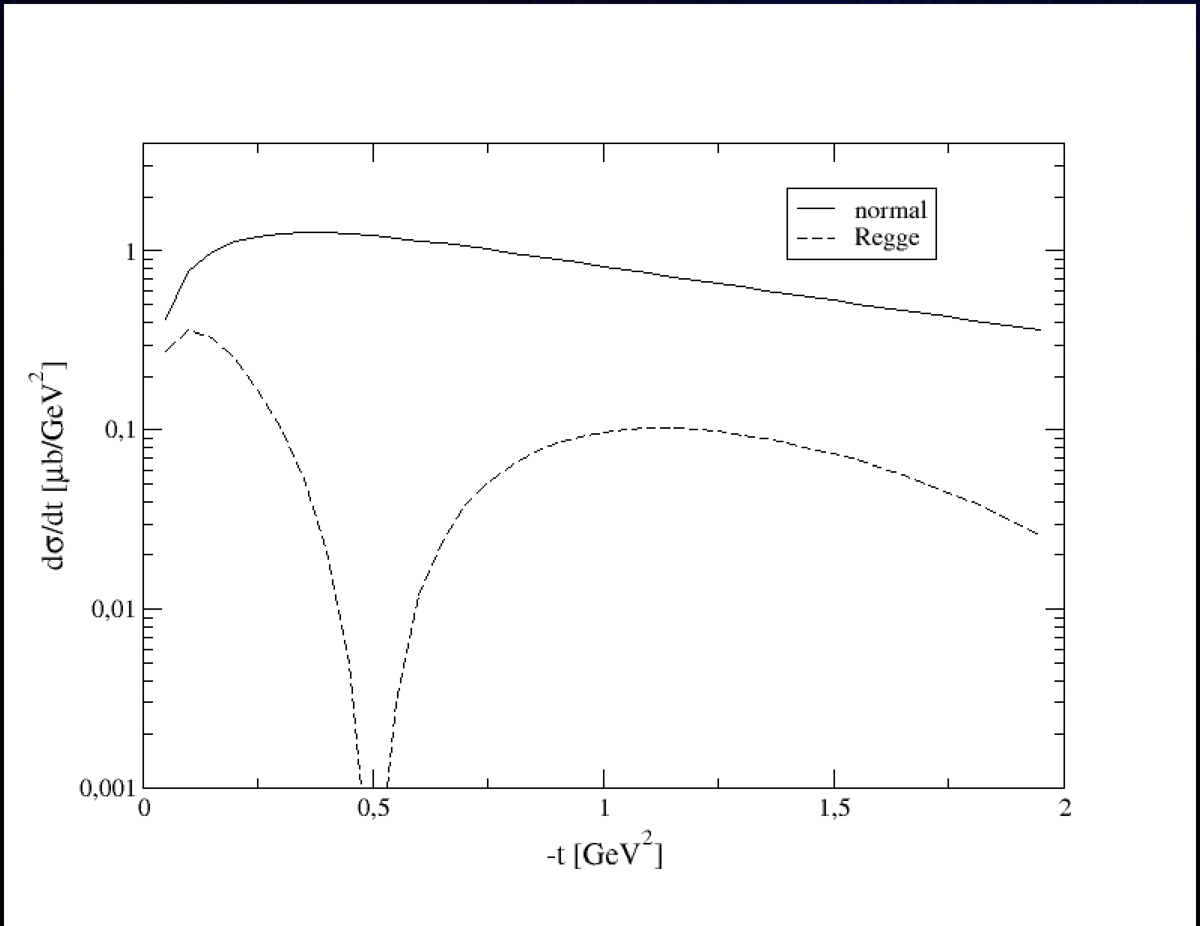


- Born amplitudes dominated by the S-wave amplitude
- P-wave smaller than the S-wave by two orders of magnitude – is this the reason why CLAS didn't see the $\pi_1(1400)$?





- Large Born background for $M_{\pi\eta}$>0.9 GeV
- This is what ELSA experiment (Gutz et al. Eur.Phys.J. A50 (2014) 74) sees for high photon energy bins



- For energies the reggeised version of the model is supposed to apply
- Remedy needed for "filling" of the minimum at $t \approx -0.5$ GeV^2 – Regge cuts ?

Conclusions

- Description of the resonance photoprouction through the FSI amplitudes is a very economical approach – identical amplitude structure for all partial waves
- Isovector P-wave is strongly suppressed at the Born level of the πη photoproduction– which may explain the fail of CLAS to see the $\pi_1(1400)$
- For higher partial waves the spin correlation between the resonance and the nucleon:
  - present in the direct photoproduction model
  - absent in the FSI photoproduction model