Chiral dynamical aspects of recently measured (low energy) reactions at MAMI, ELSA, GRAAL, and other labs

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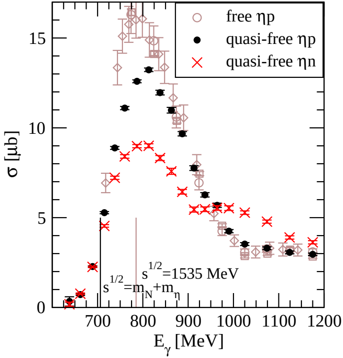
Excess of ηn production

The reactions $\gamma p \to \eta p$ and $\gamma n \to \eta n$ on free and quasi-free nucleons in the deuteron

free ηp: CBELSA & TAPS, CLAS, LNS
quasi-free ηN: CBELSA & TAPS (Jaegle et al.)



- η excess on n found at Graal [Kuznetsov *et al.*, PLB 647 (2007)].
- Confirmed by CBELSA & TAPS [Jaegle *et al.*, PRL 100 (2008)]; LNS [Miyahara *et al.*,PTPS 168 (2007)].

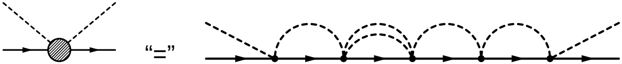
- Some concepts: [Talks of the "Narrow Nuclear Resonances" conference, Edinburgh 06/2009]
  - Non-strange pentaquark, χQSM prediction [Diakonov *et al.* ZPhysA 359 (1997), Polyakov *et al.*,EPJA 18 (2003),...].
  - Prediction of narrow P11 resonance in πN Arndt et al., PRC 69
  - $S_{11}(1650)/P_{11}(1710)$ interference effect [Shklyar, Lenske, Mosel, PLB 650 (2007)].
  - Interference of various partial waves [Shyam *et al.*, arXiv:0808.0632, Choi *et al.*, PLB 363 (2006)].
  - $D_{15}(1675)$ [ηMAID, NPA 700 (2002)] or P_{11} [Fix *et al.*, EPJA 32 (2007)]?
- Around 80 % of σ_p is S-wave; and σ_n? P-wave? Polarization data [Kuznetsov, Polyakov *et al.*, APPolonB 39,...(2008)] S-wave dominance (?) [Anisovich *et al.*, EPJA 41 (2009), Miyahara *et al.*,PTPS 168 (2007)].

Coupled channels and unitarity

N. Kaiser et al., PLB **362** (1995) 23, NPA **612** (1997) 297,
T. Inoue *et al.*, PRC **65** (2002) 035204
Nieves, Ruiz Arriola, PRD **64** (2001)
García Recio, Lutz, Nieves, PLB **582** (2004)

- $(0^-)_M \otimes (1/2^+)_B$ in $SU(3)$: Coupled channels in $S = Q = 0$ are πN, ηN, $K\Sigma$, $K\Lambda$.
- Interaction V from the LO chiral Lagrangian: (Isovector) Weinberg-Tomozawa interaction.
- Unitarization through the Bethe-Salpeter equation Loop G

$$T = (1 - VG)^{-1}\, V.$$

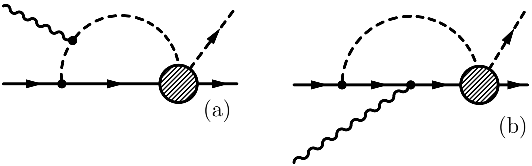


- Strong channel coupling.
- Attraktion + Unitarization $\rightarrow$ Pole in the scattering amplitude. Dynamically generated $N^*(1535)$ (not the main issue here).

Photon coupling to the coupled channels

Formalism along the lines of [Haberzettl, Nakayama, Krewald, PRC 56 (1997), PRC 74 (2006)]

- Electromagnetic properties provide independent tests, because the couplings of the photon to the mesons & baryons are well known. Predictions of, e.g., helicity amplitudes [D. Jido, M. D., E. Oset, PRC77 (2008)].

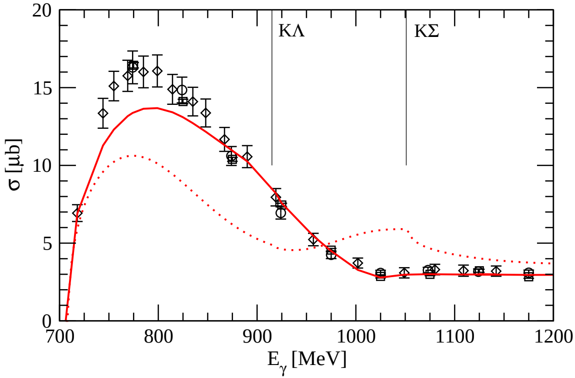


1. γp, γn initial state.
2. Excitation of intermediate meson-baryon states MB (πN, ηN, $K\Lambda$, $K\Sigma$).
3. Superposition of initial $(MB)_{\text{initial}} \to MB_{\text{final}}$.
4. $MB_{\text{final}} = \pi N,\ \eta N,\ K\Lambda,\ K\Sigma$. Details/other results

- Global fit to 18 reactions (Multipoles & partial waves): $\gamma N,\ \pi N \to \eta N,\ \pi N,\ K\Lambda$
- Gauge invariance ensured.

η photoproduction on free p and n

M. D., K. Nakayama, PLB 683 (2010)

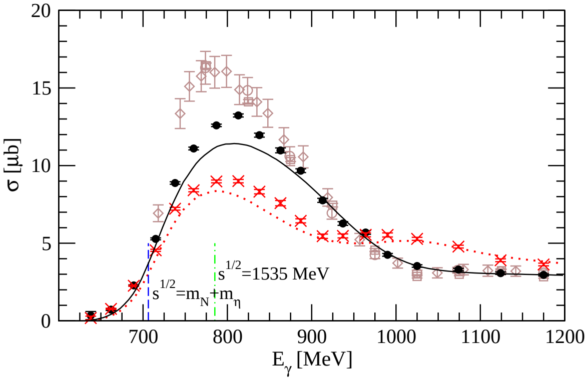


Data: Jlab-Clas, Bonn CB-Elsa, LNS [Recent high precision MAMI data not yet included (PRC 82, 2010)].

Solid: $\gamma p \to \eta p$
Dotted: $\gamma n \to \eta n$

η photoproduction on quasi-free p and n

Inclusion of Fermi motion in the deuteron in a spectator model.

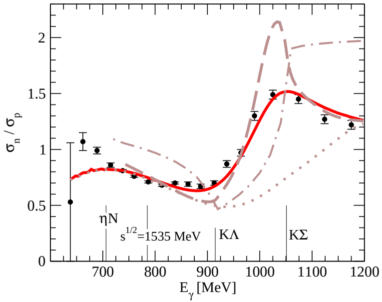


Data: I. Jaegle *et al.*, CBELSA & TAPS

Solid/Black: $\gamma p \to \eta p$

Dotted/Red: $\gamma n \to \eta n$

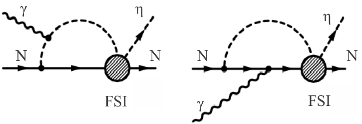
The ratio $\sigma_n/\sigma_p = \dfrac{\sigma(\gamma n \to \eta n)}{\sigma(\gamma p \to \eta p)}$



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

- Solid line: Present result (incl. Fermi)
- Dotted: No $\gamma K^+\Lambda$
- Dash-dotted: from NLO chiral (x20)
- Dashed: no Fermi motion

- Intermediate states in photon loops, $Q = 0,\ 1$:
- $\pi^- p,\ \pi^0 n,\ \eta n,\ K^0\Lambda,\ K^+\Sigma^-,\ K^0\Sigma^0$
- $\pi^0 p,\ \pi^+ n,\ \eta p,\ K^+\Lambda,\ K^+\Sigma^0,\ K^0\Sigma^+$



- Photon excitation of intermediate, SU(3) allowed states (photon loops) renders σ_n and σ_p differently.
  $K\Sigma$ threshold enhancement in σ_n.
- Peak in σ_n/σ_p: Direkt consequence of Weinberg-Tomozawa driving term from LO χ Lagrangian.
- Further tests of the model

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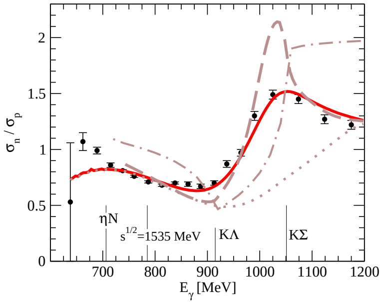

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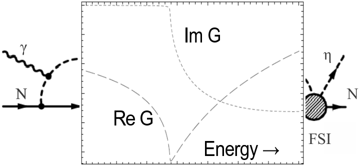

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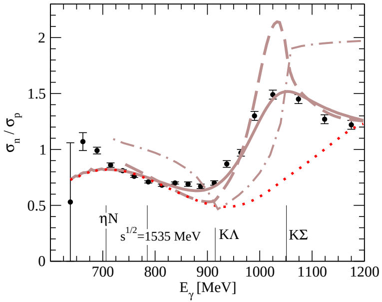

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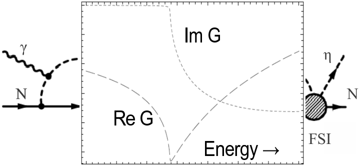

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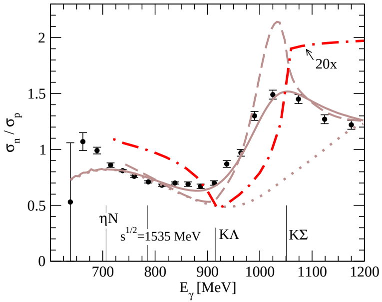

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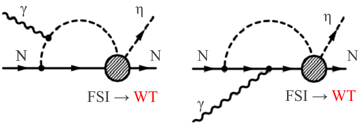

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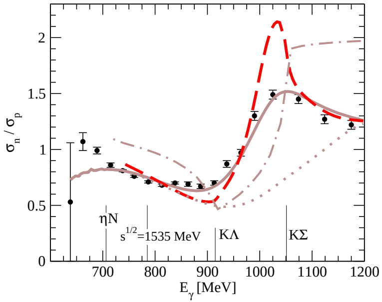

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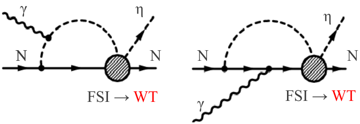

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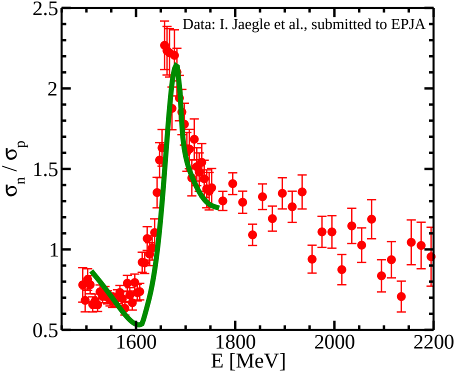
Prediction σ_n/σ_p (N reconstructed)

M. D., K. Nakayama, PLB 683 (2010)

Combining curve from PLB 683 with recent data.

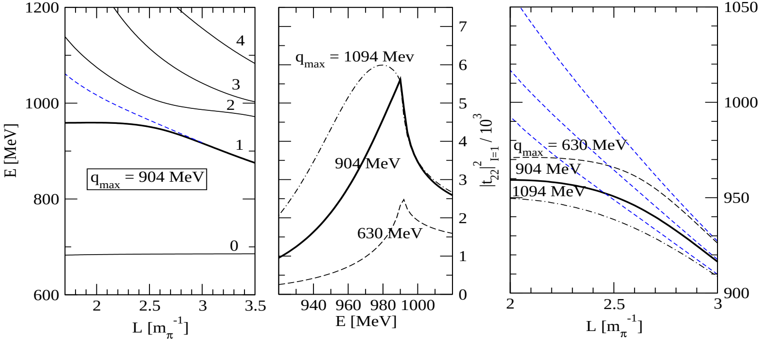


- Neutron in final state reconstructed $\rightarrow$ Elimination of Fermi motion
- Prediction (at least) as narrow as new CBELSA/TAPS data.
- Overall different scale in individual σ_n, σ_p data compared to previous measurement $\rightarrow$ Compare ratio.
- Nuclear effects neglected (supported by experiment).
- Analogy: Cusp in $\gamma p \rightarrow \pi^0 p$

Distinguishing cusps from resonances on the lattice [ex.: $a_0(980)$]

M. D., U.-G. Meißner, E. Oset, A. Rusetsky, in preparation

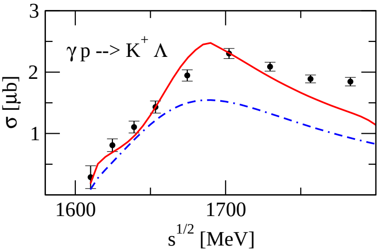
Hadronic model: Oller/Oset, NPA (1997)



- Cusp vs. resonance: Different signals in lattice levels E(L) [Lüscher formalism in coupled channels].
- Twisted boundary conditions shift thresholds but not resonances $\rightarrow$ may be suited to distinguish resonances from cusps [enhanced signal (dashed lines)].

Prediction for the reaction $\gamma n \to K^0\Lambda$

Free $K^+\Lambda$ production on p:

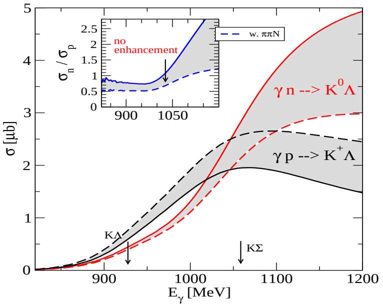


Dash-dotted line: KAON-Maid, S-wave only

Data: Saphir

- Much larger uncertainties from $\pi\pi N$ channel than in case of η.

Quasifree $K\Lambda$ production on p and n:



- Pentaquark coupling to γn and $K\Lambda$ $\to$ Peak in σ_n/σ_p expected like for η.
- No peak (rather dip) predicted in present approach.
- Can serve to distinguish between both explanations.

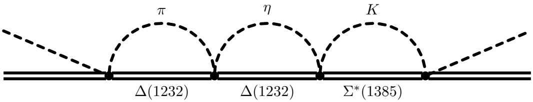
Conclusions

- Global fit (18 parms.) of 11 photoproduction and 8 hadronic, independent reaction data sets, spanning 700 MeV in energy and involving πN, ηN, $K\Lambda, K\Sigma$ final states.
- $\gamma n \to \eta n$: Intermediate $K\Lambda$, $K\Sigma$ loops + photon coupling leads to $K\Sigma$ threshold enhancement (peak in σ_n/σ_p).
- Consequence of underlying hadron dynamics: Weinberg-Tomozawa term from chiral Lagrangian induces strong channel coupling through its SU(3) structure.
- New data (not yet considered) from CBELSA/TAPS, GRAAL, $\cdots$:
  - Polarization in $\gamma p \to \eta p$ [Kuznetsov/Polyakov, JETP Lett. (2008)],
  - Compton scattering [Kuznetsov/Polyakov et al., arXiv 1003.4585 (2008)],
  - Fermi-defolded, angular binned data [A2/MAMI, PRC82 (2010)].
  - $\gamma n \to K^0\Lambda, \cdots$ [Jaegle et al., under analysis], planned with higher statistics at MAMI-C.

The $\Delta^*(1700)$ and its $\pi\Delta$, $\eta\Delta$, $K\Sigma^*$ decays

M.D., E. Oset, D. Strottman, PRC 73 (2006), PLB 639 (2006)

- 0^- meson octet $\otimes$ $3/2^+$ baryon decuplet $\longrightarrow$ $3/2^-$ resonances
  M.F.M Lutz *et al.*, PLB 585 (2004)
  S. Sarkar *et al.*, NPA 750 (2005)
- Unitarized coupled channel interaction



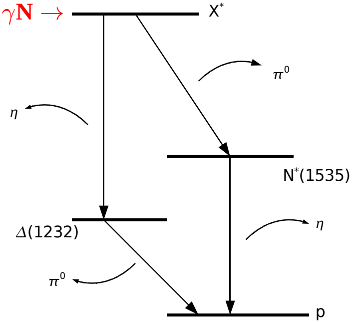
Couplings	$\Delta\pi$	$\Delta\eta$	$\Sigma^* K$
$\lvert g_{\rm generated}\rvert^2$(**)	1	4.8	11.56
$g^2_{SU(3)}$ (*,**)	1	$1/5$	$2/5$
Ratio	1	24	29

(*) assuming $\Delta^*(1700)$ belongs to a decuplet (see PDB)

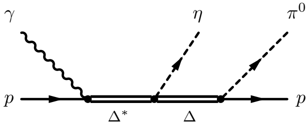
(**) rescaled to $\Delta\pi$ coupling

The $\pi^0\eta p$ final state

- De-excitation modes into $\pi^0\eta p$ final state: $\gamma\mathbf{N} \rightarrow$



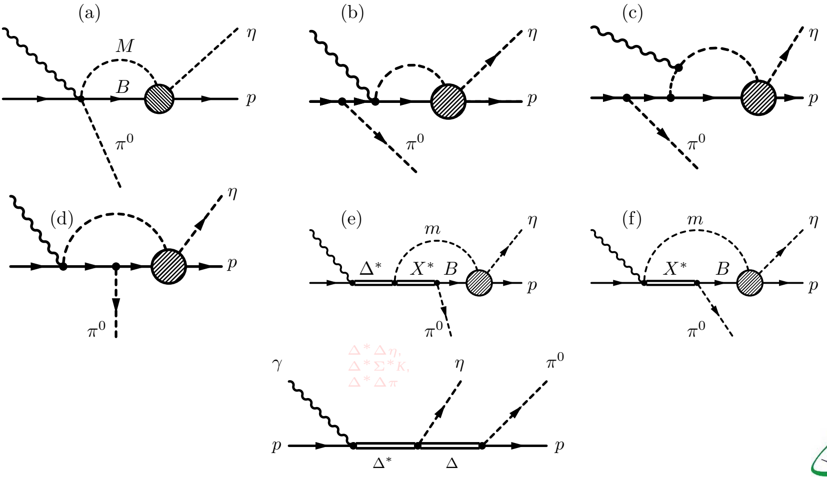
- $\Delta^*(1700)\Delta(1232)\eta$
  coupling provided by model
  for dynamically generated $\Delta^*(1700)$.
- "Tree level" contribution:



- $\gamma p \rightarrow \pi^0\eta p$ and $\gamma p \rightarrow K^0\pi^0\Sigma^+$ measured at many experimental facilities (ELSA, GRAAL, MAMI, LNS).

Diagrammatic expansion of $\gamma p \to \pi^0 \eta p$

Adding a π^0 to the $\gamma N \to \eta N$ amplitude is not enough...



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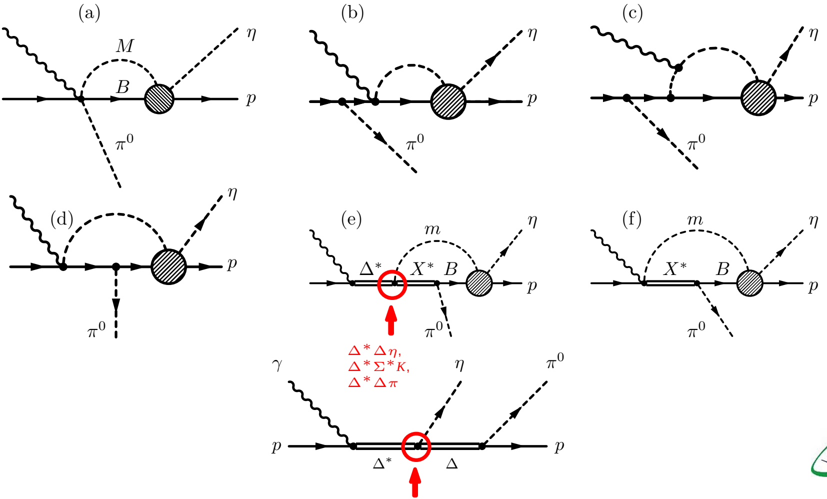
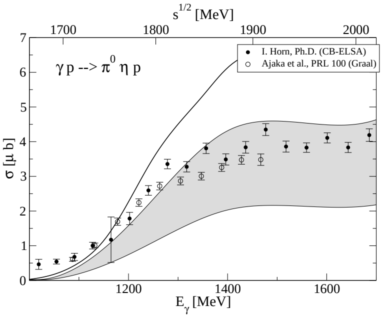


Cross section



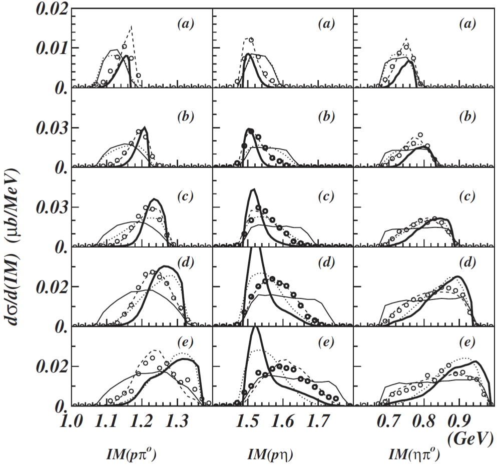
Solid line: Full model for the $N^*(1535)$ from M.D., E. Oset, D. Strottman, PRC 73 (2006).

Gray Band: Update from M.D., E. Oset, D. Strottman, PLB 639 (2006).

(realistic $\Delta^*(1700)$ width, exp. error from $A_{1/2}\,A_{3/2}$ for $\gamma p \Delta^*(1700)$ coupling).

Invariant mass distributions

from Ajaka et al., PRL100 (2008) [GRAAL]

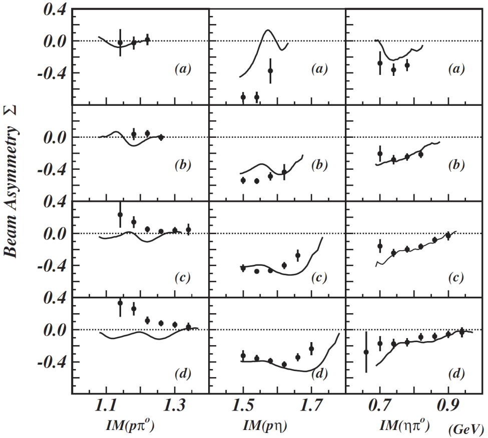


(a) → E_γ=1.1 (b) → 1.2 (c) → 1.3 (d) → 1.4 (e) → 1.5 (GeV)

- open circles: Data from PRL 100 (2008).
- thick solid lines: Present model
- thin solid line: phase space
- dashed line: pure $\eta\,\Delta$ final state
- dotted lines: pure $\pi^0\,S_{11}$ final state

Beam asymmetry

from Ajaka et al., PRL100 (2008)

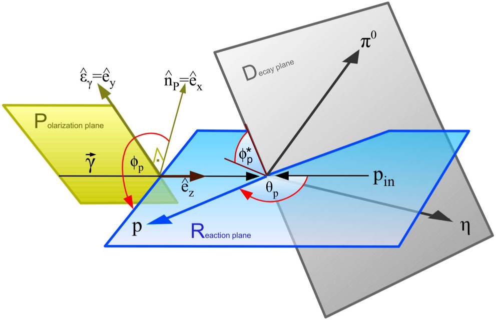


(a) → E_γ=1.1-1.2 (b) → E_γ=1.2-1.3 (c) → E_γ=1.3-1.4 (d) → E_γ=1.4-1.5 (GeV)

- solid circles: Data from PRL 100 (2008).
- Solid lines; Present model.
- Test: Remove $\Delta^*(1700)\Delta\eta$ coupling $\rightarrow$ even sign changes!

The polarization observables I^S and I^C

M. D., E. Oset, Ulf-G. Meißner, EPJA 46 (2010).



First measurement of I^S, I^C (fixed ϕ^*)

$$\frac{d\sigma}{d\phi} = \sigma_0[1 + I^S \sin(2\phi) + I^C \cos(2\phi)]$$

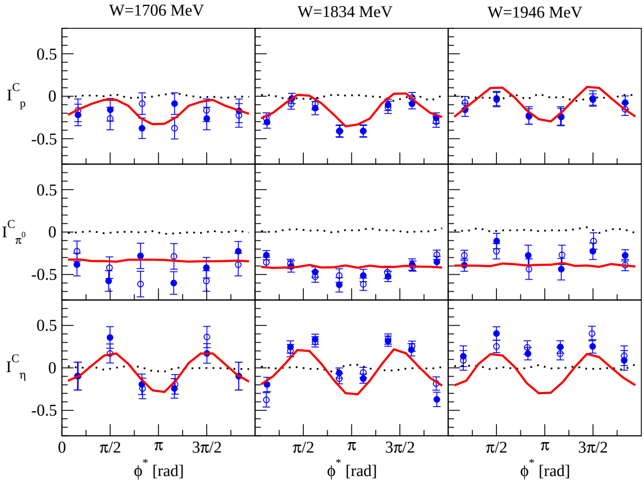
by CBELSA/TAPS E. Gutz *et al.*, Phys.Lett.B **687**,11,2010

- Monte-Carlo evaluation of the binned double differential cross section

$$\frac{d^2\sigma(\phi,\phi^*)}{d\phi\, d\phi^*} \simeq \frac{\Delta^2\sigma(\phi_i,\phi^*_k)}{\Delta\phi\, \Delta\phi^*}$$

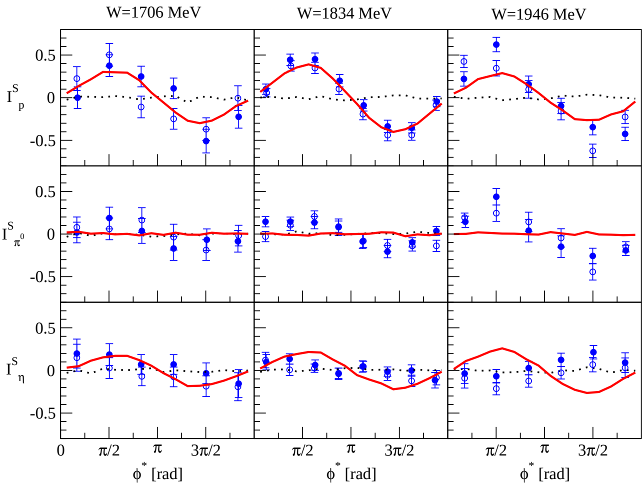
- Prediction of I^S, I^C (and other observables) using the 2006 model [M.D., E. Oset, D. Strottman, PLB 639 (2006)]

Predictions for I^C DATA: CBELSA/TAPS, E. Gutz *et al.*, Phys.Lett.B **687**,11,2010



Red solid lines: Predicted results. Black dotted lines: Without the $\Delta(1700)\eta\Delta$ and $\Delta(1700)K\Sigma(1385)$ couplings predicted from the chiral unitary model.

Predictions for I^S DATA: CBELSA/TAPS, E. Gutz *et al.*, Phys.Lett.B **687**,11,2010



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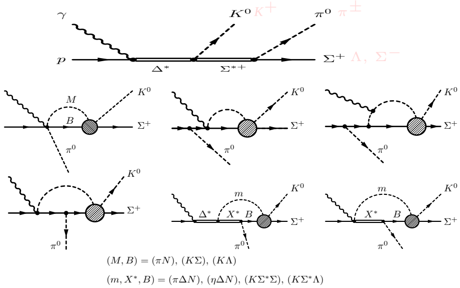
γ induced strangeness production

M.D., E. Oset, D. Strottman, PLB **639**



- Data: Saphir

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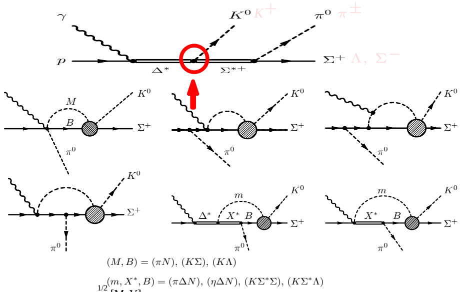
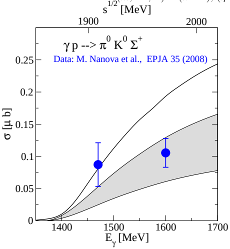
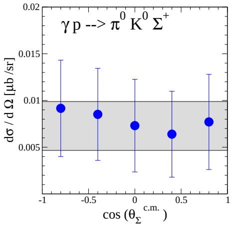
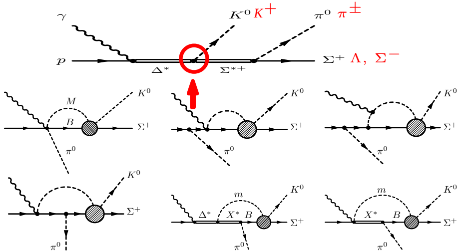






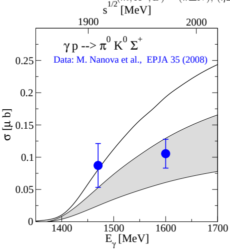
γ induced strangeness production

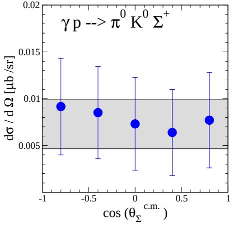
M.D., E. Oset, D. Strottman, PLB **639**



$(M, B) = (\pi N), (K\Sigma), (K\Lambda)$

$(m, X^*, B) = (\pi\Delta N), (\eta\Delta N), (K\Sigma^*\Sigma), (K\Sigma^*\Lambda)$





- Data: Saphir

Rad. decay...

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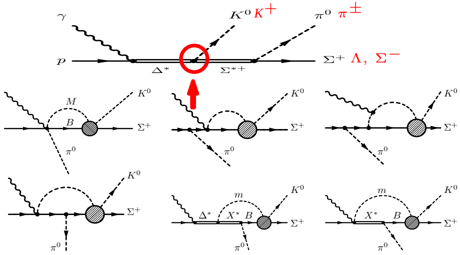

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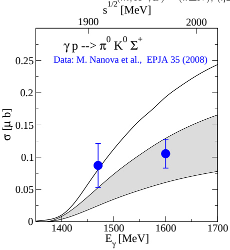
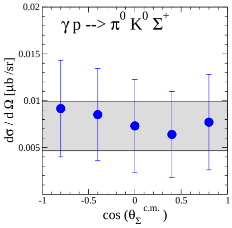
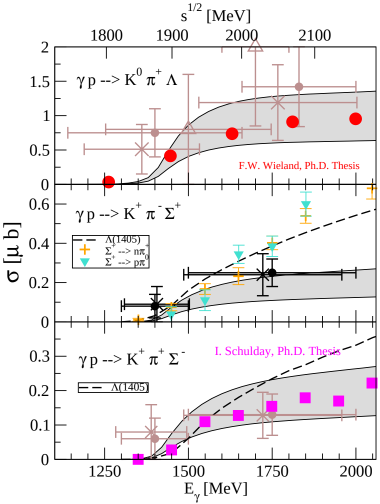






Large error bars: Aachen Coll., PR188, N. Cim. 49A
Cambridge Bubble Chamber Group, PR156

- Data: Saphir

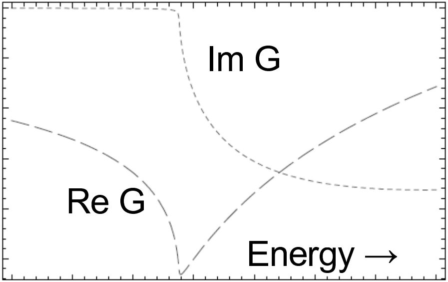
Rad. decay,...

Conclusions ($\pi^0\eta$ photoproduction)

- χ unitary predictions for $\Delta^*(1700) \to \Delta\eta, \Sigma^* K, \gamma N, \cdots$ can be tested in recent experiments at ELSA/MAMI/GRAAL.
- I^S and I^C (and other observables) have been predicted; experimental support for strong $\eta\Delta$ channel in S-wave.
- New data (not yet considered): circular beam asymmetry (MAMI, [PLB693, 2010]), $\cdots$.

The loop function G

back



- Imaginary part opens at threshold.
- Real, dispersive part shows pronounced structure at threshold.

Resonance content of the photoproduction amplitude

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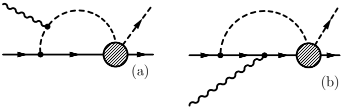
Analytic continuation of Feynman parameterized loops

- Analytic continuation of hadronic part $MB \to \eta N$ trivial.
- Photon loop $\tilde{d}_j$:

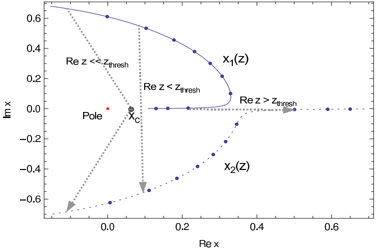


$$\tilde{d}_j = \int_0^1 dx \int_0^{1-x} dy$$
$$\times \frac{x(y-1)}{x[(x-1)z^2 + y(z^2 - M_N^2) + M_j^2] + (1-x)m_j^2 - i\epsilon}$$

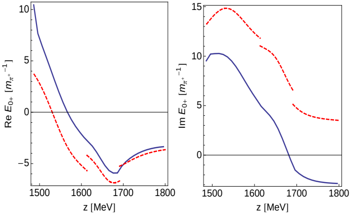
$$i\,\mathrm{Im}\,\tilde{d}_j = i\pi \int_{x_-}^{x_+} dx \, \frac{a+1}{M_N^2 - z^2}, \qquad x_\pm = \frac{E_m \pm q_{cm}}{z}$$

- $\tilde{d}_j^{(2)} = \tilde{d}_j + 2\delta\tilde{d}_j$

Feynman integral $\to$ contour integral



Pole approximation $\gamma n \to \eta n$



$\to$ not saturated by resonances.

Additional degrees of freedom

back

M. D., K. Nakayama, EPJA 43 (2010)

- The $N^*(1650)$: Closeby resonance with the $N^*(1535)$'s quantum numbers $\to$ interfering resonances
- Could the $N^*(1535)$ be genuine? $\to$ put it as a resonance!
- $\to$ Include two genuine pole terms $\delta V_{ij} \sim \frac{g_i\, g_j}{(\sqrt{s}-M)}$ in the potential; supply $\gamma N \to N^*$ bare couplings.
  $\to$ Check dependence of the results on these ingredients
- Almost no freedom to tune photoproduction on neutron and proton independently.
- Difference to SAID, MAID η photoproduction analyses, ...: only S-wave; but: includes KY coupled channels and dispersive parts of loop integral (not K-matrix; not an isobar analysis).
- Fit appropriate "data" (partial waves, multipoles) on pion- and photon-induced reactions (Global fit).

Photoproduction

$\gamma N \to \pi N$, $\gamma N \to K\Lambda$, $\gamma N \to K\Sigma$

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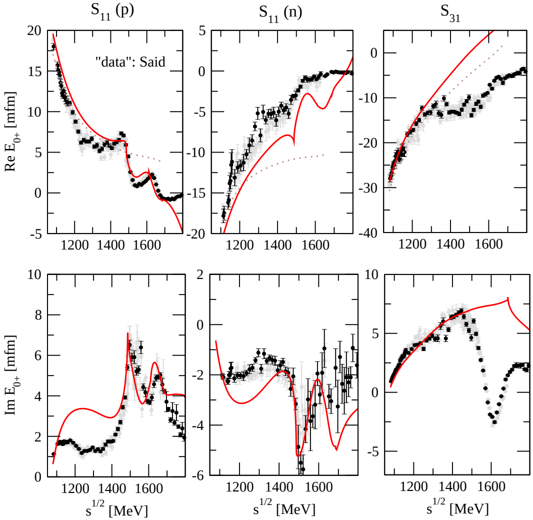
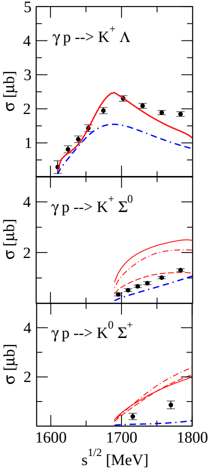


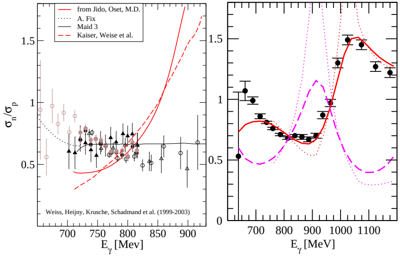


Tests of η photoproduction

Add/Remove ingredients (no refit)

back

Previous calculations/ $U\chi PT$ framework:

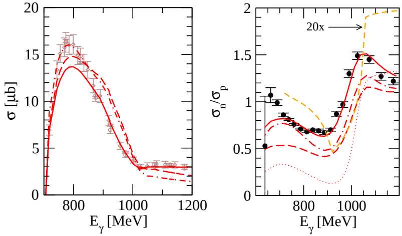


Left: Low energy region;
left shoulder of σ_n/σ_p peak.

Right: [Jido, Oset, M.D., PRC 77 (2008)]
with Fermi motion (dashed).

$\rightarrow$ (Shoulder of the) peak in σ_n/σ_p is present in previous calculations in $U\chi PT$ coupled channel framework; there: no $N^*(1650)$, no ηN data in the fit.

Baryon pole term and $\pi\pi N$ channel:



- Solid: Present result.
- Dashed: incl. higher order baryon terms.
- Dashed dotted: incl. $\pi\pi N$.
- Dotted: No genuine resonance states [$N^*(1650)$+BG].
- Orange dashed: only WT term (scaled by x20; no Fermi)

Analytic structure

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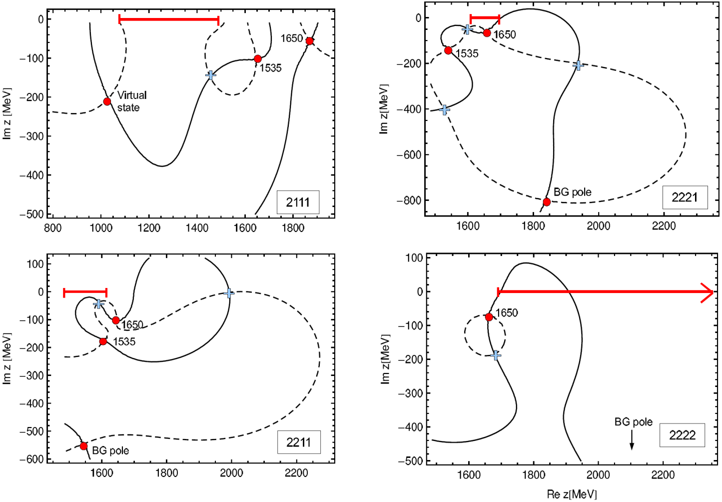
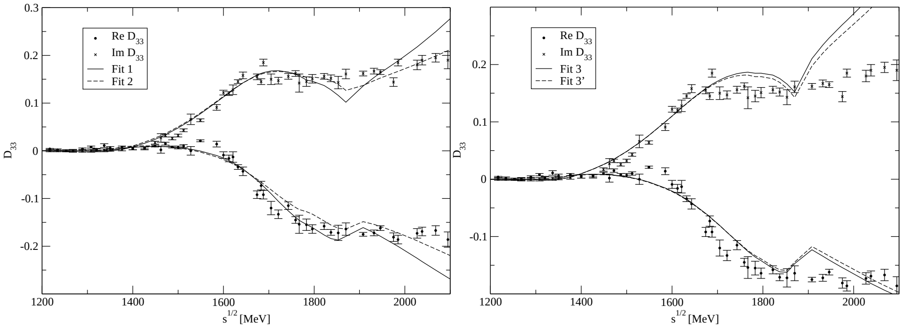


The $\Delta^*(1700)$ in πN scattering

back

M.D., NPA 786 (2007)

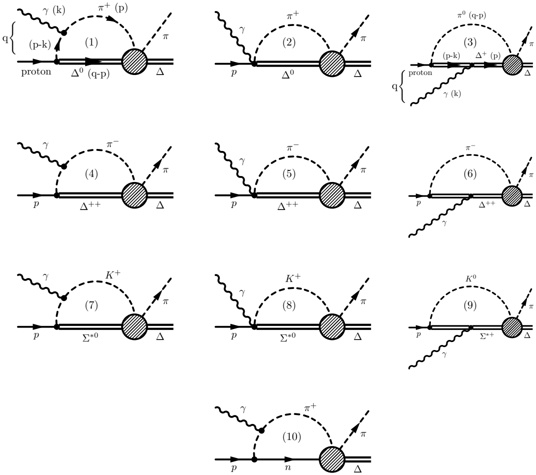


Coupled channels $\Delta(1232)\pi$, $\Delta(1232)\eta$, $\Sigma^*(1385)\pi$

Novelty: Inclusion of $(N\pi)_d$

Prediction for the radiative decay

M.D., NPA 786 (2007)



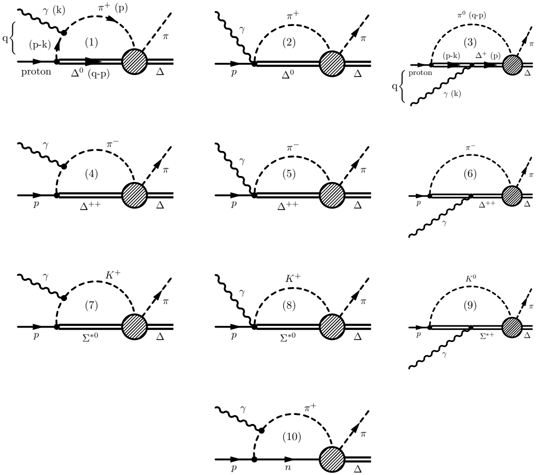
Mechanisms for the $\Delta^*(1700)$ decay in s- and d-wave loops. The shaded circles represent the $\Delta^*(1700)$.

$\Gamma_\gamma = 602 \pm 140$ keV
vs.
$\Gamma_\gamma = 570 \pm 254$ keV
from experiment

Prediction for the radiative decay

back

M.D., NPA 786 (2007)



Mechanisms for the $\Delta^*(1700)$ decay in s- and d-wave loops. The shaded circles represent the $\Delta^*(1700)$.

$\Gamma_\gamma = 602 \pm 140$ keV
vs.
$\Gamma_\gamma = 570 \pm 254$ keV
from experiment

Analogy: Cusp in $\gamma p \to \pi^0 p$

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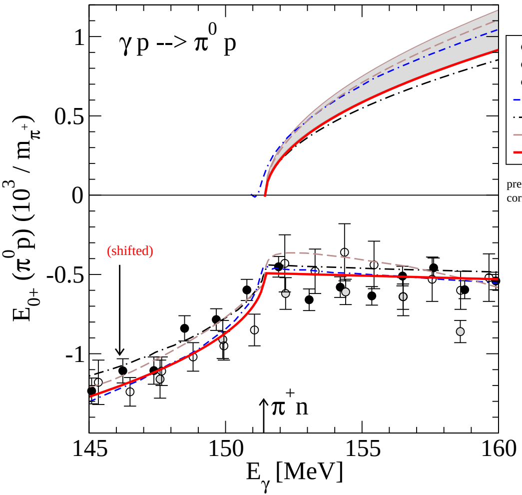
M.D., K. Nakayama, EPJA 43 (2010)



present model: Re E_{0+} shitfted by -0.59
corresponds to 10 % change in Re phototransi. loop