η and kaon production on the proton : results and prospectives

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Motivations

Early motivations and new one

- Search for missing / new baryon resonances
  Methodology : Develop formalisms allowing to handle *all* "'known"' resonances *and* avoid too many free parameters.

- Formalisms : Effective Lagrangian Approach (ELA) and constituent quark model (CQM)
- Study reaction mechanisms $\gamma p \to K^+\Lambda$ and $\gamma p \to \eta p$
- **Natural evolution :** Go beyond direct reactions and investigate **coupled-channels :** processes $\to$ EBAC : study baryons properties.

PLAN :

- Recent results for $\pi^- p \to MB \to \eta n$ and $\gamma p \to MB \to \eta p$, $W \lesssim 2$ GeV and above.
- EBAC + Chiral constituent quark model ($\gamma p \to \eta p$).
- Pre-EBAC results for $\pi N \to MB \to K^+\Lambda$ and $\gamma p \to MB \to K^+\Lambda$.
- Findings, near future plans and questions.

Investigating $\gamma p \to MB \to \eta p$

$$T_{\gamma N \to \eta N} = (v^{NR}_{\gamma N \to \eta N} + v^{R}_{\gamma N \to \eta N})(1 + G_{\eta N} t^{NR}_{\eta N \to MB \to \eta N}) + v^{NR}_{\gamma N \to \pi N} G_{\pi N} t^{NR}_{\pi N \to MB \to \eta N}$$

- Direct channel : $\gamma p \to \eta p$
  CQM : He, Saghai, Li, PR C78, 035204 (2008)
- Coupled-channels $\pi N \to MB \to \eta n$, $MB \equiv \pi N, \eta N, \pi\Delta, \sigma N, \rho N$
  Durand, Julia-Diaz, Lee, Saghai, Sato, PR C78, 025204 (2008)
  EBAC : $\pi N \to MB \to \pi N$: Julia-Diaz, Lee, Matsuyama, Sato, PR C76, 065201 (2007)
  $\to$ **JLMS Model**
- $\gamma N \to \pi N$
  Sato and Lee, PR C54, 2660 (1996).
- Coupled-channels $\gamma p \to MB \to \eta p$

Direct channel : Chiral constituent quark model

$$\mathcal{L} = \bar{\psi}[\gamma_\mu(i\partial^\mu + V^\mu + \gamma_5 A^\mu) - m]\psi + \cdots$$

$$\frac{d\sigma^{c.m.}}{d\Omega} = \alpha_e g_{\eta NN} \frac{(E_N + M_N)(E_f + M_f)}{4s(M_f + M_N)^2} \frac{|\mathbf{q}|}{|\mathbf{k}|} |\mathcal{M}_{fi}|^2$$

$$\mathcal{M}_{fi} = \langle N_f|H_{m,e}|N_i\rangle + \sum_j \left\{ \frac{\langle N_f|H_m|N_j\rangle\langle N_j|H_e|N_i\rangle}{E_i + \omega - E_j} + \frac{\langle N_f|H_e|N_j\rangle\langle N_j|H_m|N_i\rangle}{E_i - \omega_m - E_j} \right\} + \mathcal{M}_T$$

$$H_m = \sum_j \frac{1}{f_m} \bar{\psi}_j \gamma_\mu^j \gamma_5^j \psi_j \partial^\mu \phi_m \; ; \; H_e = -\sum_j e_j \gamma_\mu^j A^\mu(\mathbf{k}, \mathbf{r})$$

$$\mathcal{M}_{N^*} = \frac{2M_{N^*}}{s - M_{N^*}^2 - iM_{N^*}\Gamma(\mathbf{q})} e^{-\frac{\mathbf{k}^2+\mathbf{q}^2}{6\alpha^2}} \mathcal{O}_{N^*}$$

transition amplitude for the n^{th} harmonic-oscillator shell

$$\mathcal{O}_n = \mathcal{O}_n^2 + \mathcal{O}_n^3$$

First (second) term : incoming photon and outgoing meson absorbed and emitted by the same (different) quark.

$$\mathcal{O}_{N^*} = if_{1l\pm}\sigma \cdot \epsilon + f_{2l\pm}\sigma \cdot \hat{\mathbf{q}}\sigma \cdot (\hat{\mathbf{k}} \times \epsilon) + if_{3l\pm}\sigma \cdot \hat{\mathbf{k}}\hat{\mathbf{q}} \cdot \epsilon + if_{4l\pm}\sigma \cdot \hat{\mathbf{q}}\epsilon \cdot \hat{\mathbf{q}}$$

$f_{kl\pm}$ (k=1,...,4) : partial wave amplitude of resonance $l_{2I,\ 2l\pm1}$

$SU(6) \otimes O(3)$ symmetry

- Underlying $SU(6) \otimes O(3)$ structure of the baryon spectrum established in 70's.
- Configuration mixing among the three-constituent quraks is a consequence of the $SU(6) \otimes O(3)$ breakdown.
- Either $\mathcal{O}_n \to \mathcal{C}^*_N \mathcal{O}_n$:

Wave function within the $SU(6) \otimes O(3)$ symmetry for $n \leq 2$ shells as $X^{2S+1} L_\pi J^P$ and configuration mixings, with J^P :

$$|S_{11}(1535)\rangle = \cos\theta_S |N^2 P_M \tfrac{1}{2}^-\rangle - \sin\theta_S |N^4 P_M \tfrac{1}{2}^-\rangle$$
$$|S_{11}(1650)\rangle = \sin\theta_S |N^2 P_M \tfrac{1}{2}^-\rangle + \cos\theta_S |N^4 P_M \tfrac{1}{2}^-\rangle$$

Also similar relations for D_{13}s., with θ_D

Saghai and Li, Few-Body Syst. 47, 105 (2010).

- Or One-Gluon-Exchange mechanism generating the configuration mixing of the wave-function ; e.g.,

$$|Nucleon\rangle = c_1|N^2 S_S \tfrac{1}{2}^+\rangle + c_2|N^2 S'_S \tfrac{1}{2}^+\rangle + c_3|N^4 D_M \tfrac{1}{2}^+\rangle + c_4|N^2 S_M \tfrac{1}{2}^+\rangle + c_5|N^2 P_A \tfrac{1}{2}^+\rangle$$

Also similar relations for N^*s.

CQM : He, Saghai, Li, PR C78, 035204 (2008)

Coupled-channels (EBAC)

cf. Talks by Hiroyuki Kamano, Satoshi Nakamura, Toru Sato, & Bruno Julia-Diaz

Schematically, in each partial wave, the MSL model solves

$$t_{MB,M'B'}(E;k,k') = v_{MB,M'B'}(k,k') + \sum_{\alpha} \int_0^{\infty} dk'' v_{MB,\alpha}(k,k'') G_{\alpha}(E,k'') t_{\alpha,M'B'}(E;k'',k')$$

where $\alpha,\ \beta,\ \gamma \equiv \gamma N,\ \pi N,\ \eta N$ and $\pi\pi N$, which has $\pi\Delta,\ \rho N,\ \sigma N$ resonant components.

$$t^R_{MB,M'B'}(E) = \sum_{N^*_i, N^*_j} \bar{\Gamma}_{MB \to N^*_i}(E) \frac{1}{(E - M^0_{N^*_i})\delta_{i,j} - \bar{\Sigma}_{ij}(E)} \bar{\Gamma}_{N^*_j \to M'B'}(E)$$

Self-energies :

$$\bar{\Sigma}_{ij}(E) = \sum_{MB} \Gamma_{N^*_i \to MB} G_{MB}(E) \bar{\Gamma}_{MB \to N^*_j}$$

Dressed vertex interactions :

$$\bar{\Gamma}_{MB \to N^*}(E) = \Gamma_{MB \to N^*} + \sum_{M'B'} t_{MB,M'B'}(E) G_{M'B'}(E) \Gamma_{M'B' \to N^*}$$

Models

- Ingredients (N*s)
- Adjustable parameters
- Model / data comparisons
- Reaction mechanism

Model for $\pi^- p \to MB \to \eta n$; $W \leq 1.8$ GeV

- $MB \equiv \pi N,\ \eta N,\ \pi\Delta,\ \sigma N,\ \rho N$
- 9 N^* : $S_{11}(1535),\ S_{11}(1650),\ P_{11}(1440),\ P_{11}(1710),\ P_{13}(1720),$

  $D_{13}(1520),\ D_{13}(1700),\ D_{15}(1675),\ F_{15}(1680)$

Adjustable Parameters :

- Background terms : 2 parameters

  $g_{\eta NN}$
  $V_{\eta NN} \in [600; 1200]$ MeV

- N^*s : 3 parameters per resonance

  $M_{N^*} \in [M - 20MeV; M + 20MeV]$
  $g_{\eta NN^*}$
  Λ

Total of 29 parameters.

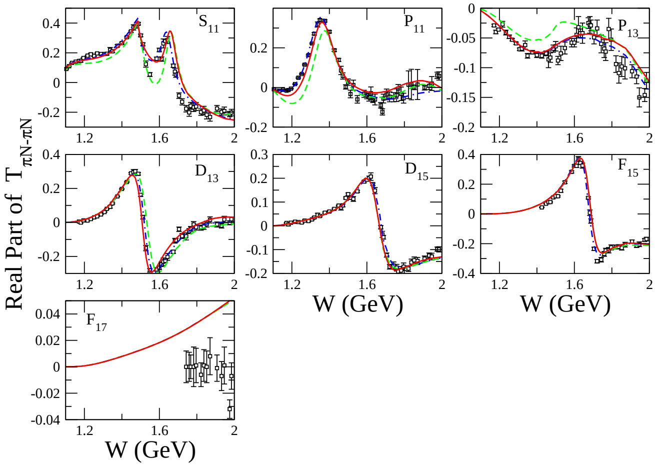
Parameters for other intermediate states ($MB \equiv \pi N,\ ,\ \pi\Delta,\ \sigma N,\ \rho N$) fixed to their values determined by JLMS fitting $\pi N \to \pi N$)

Data base : 255 $d\sigma/d\Omega$

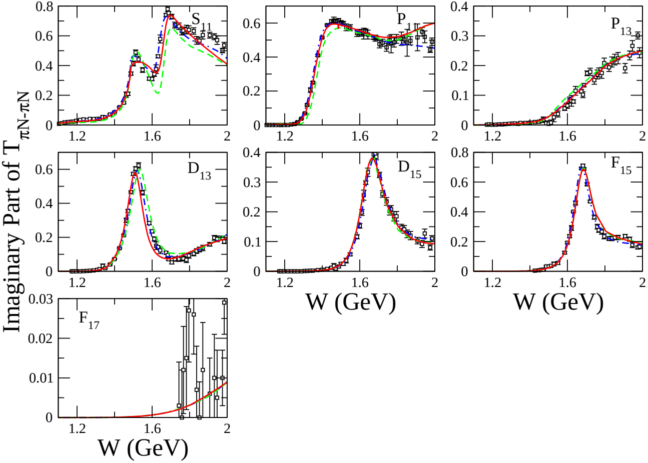
$\chi^2_{pdp} = 2.32$; JLMS : $\chi^2_{pdp} = 6.94$

Category	Parameter	$JLMS$	Model B	$EBAC - Saclay$
Non-resonant :	$f_{\eta NN}$	3.8892	4.9999	0.4481
	$\Lambda_{\eta NN}$	623.56	591.91	1183.98
Bare mass $M_0^{N^*}$	$S_{11}(1535)$	1800	1808	1820
	$S_{11}(1650)$	1880	1861	1851
	$P_{13}(1720)$	1711	1691	1731
	$F_{15}(1680)$	2187	2207	2207
$C_{N^* \to MB(LS)}$:	$C_{\eta N S_{11}(1535)}$	9.1000	7.8344	7.8344
	$C_{\eta N S_{11}(1650)}$	0.6000	-0.4221	-0.3000
	$C_{\rho N S_{11}(1535)}$	2.028	-0.4935	0.5000
	$C_{\rho N S_{11}(1650)}$	-9.5179	2.0000	-2.0000
$\Lambda_{N^* \to MB(LS)}$:	$\Lambda_{\eta N S_{11}(1535)}$	598.97	799.90	587.99
	$\Lambda_{\rho N S_{11}(1535)}$	1999.8	670.89	2000.0
		1893.8	955.8	500.0
	$\Lambda_{\eta N S_{11}(1650)}$	500.02	1999.70	1400.0
	$\Lambda_{\rho N S_{11}(1650)}$	796.83	2000.00	2000.0

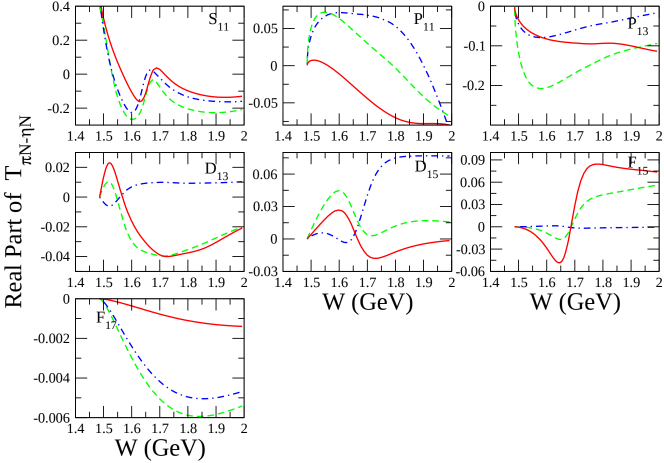
Real parts of the $\pi N \to \pi N$ T-matrices for isospin 1/2 partial waves



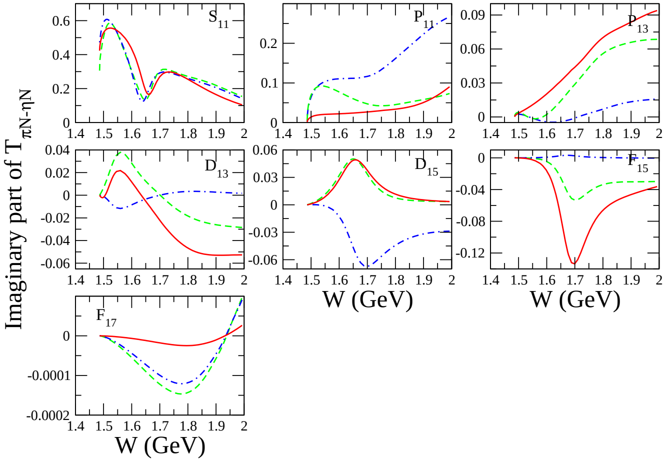
Imaginary parts of the $\pi N \to \pi N$ T-matrices for isospin 1/2 partial waves



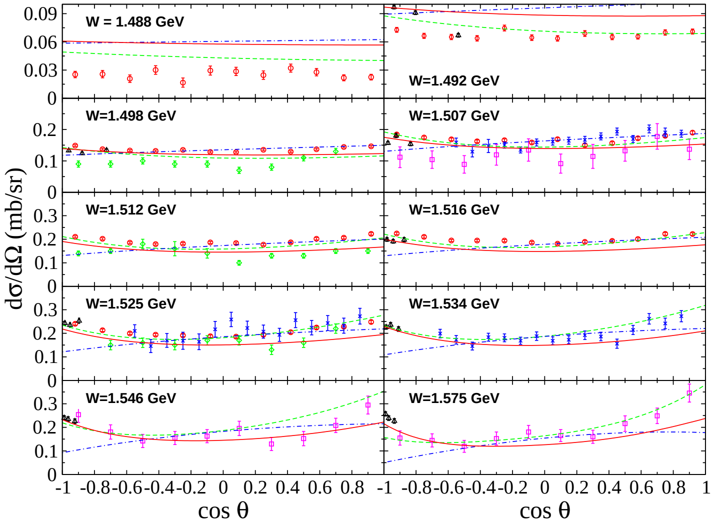
Real parts of the $\pi N \to \eta N$ T-matrices for isospin 1/2 partial waves



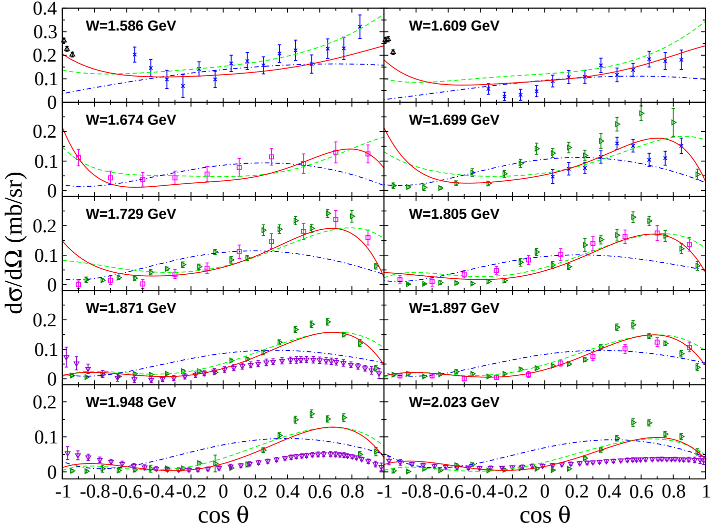
Imaginary parts of the $\pi N \to \eta N$ T-matrices for isospin 1/2 partial waves



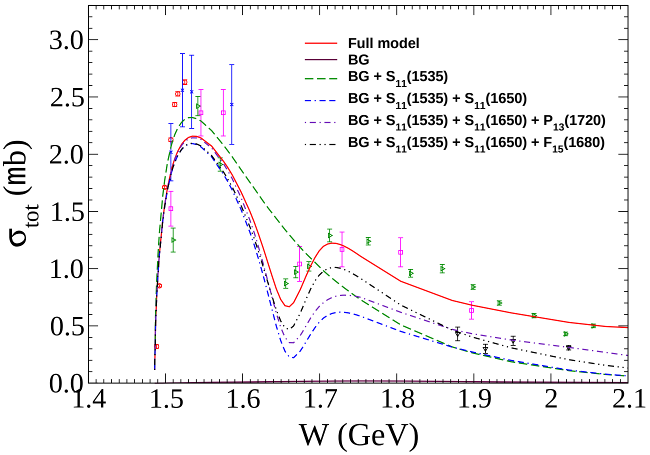
$d\sigma/d\Omega$ for $\pi^- p \to \eta n$



$d\sigma/d\Omega$ for $\pi^- p \to \eta n$



"Postdiction" : σ_{tot} for $\pi^- p \to \eta n$



Model for $\gamma p \to MB \to \eta p$; $W \leq 2.1$ GeV

- $MB \equiv \pi N$, ηN, $\pi\Delta$, σN, ρN
- 12 N^* : $S_{11}(1535)$, $S_{11}(1650)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $P_{13}(1900)$,
  $D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$, $F_{15}(1680)$, $F_{15}(2000)$, $F_{17}(1990)$
- Higher mass $N^* > 2$ GeV : HM N^*
- 2 new N^* :

  S_{11} : $M = 1707$ MeV, $\Gamma = 222$ MeV (in line with Saghai-Li NPA 11 (2001)
  D_{13} : M=1950 MeV, $\Gamma = 139$ MeV

- No evidence for missing N^*s

Adjustable Parameters :

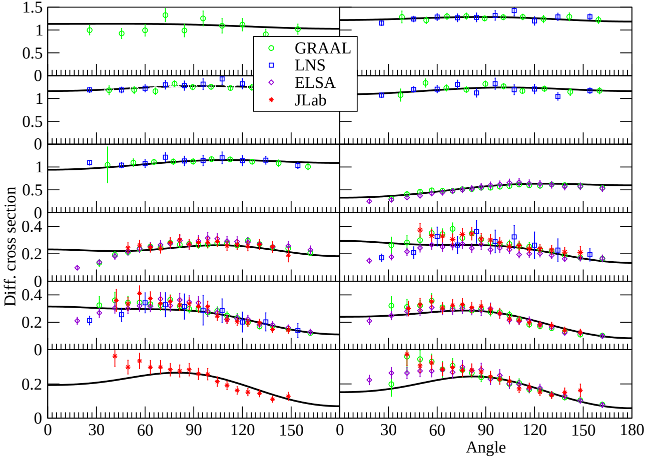
- $g_{\eta NN}$
- m_q : non-strange quarks average mass
- α : harmonic-oscillator strength
- α_s : QCD coupling constant
- Ω, Δ : confinement constants
- $C_{P_{13}}$: Strength of the P_{13}
- Higher mass N^* : 3 parameters (M, Γ, and C_{N^*})
- New N^*s : 3 parameters per new resonance (M, Γ, and C_{N^*})

Total of 10+9=19 parameters.

Data base : 818 $d\sigma/d\Omega$, 119 Σ

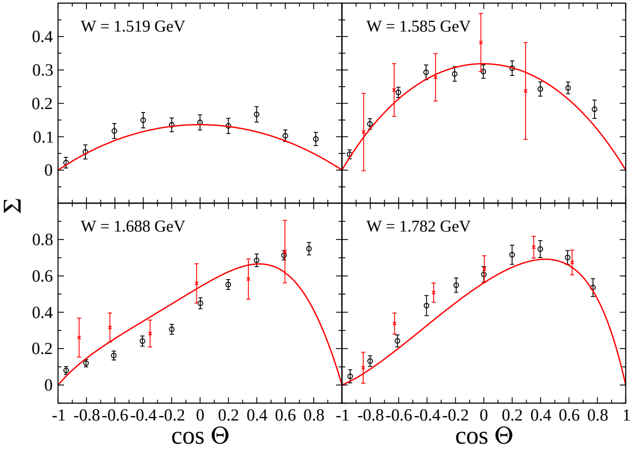
$\chi^2_{pdp} = 1.34$ $d\sigma/d\Omega$, 2.48 Σ

$d\sigma/d\Omega$ for $\gamma p \to \eta p$ $1.5 \le W \le 1.8$ GeV



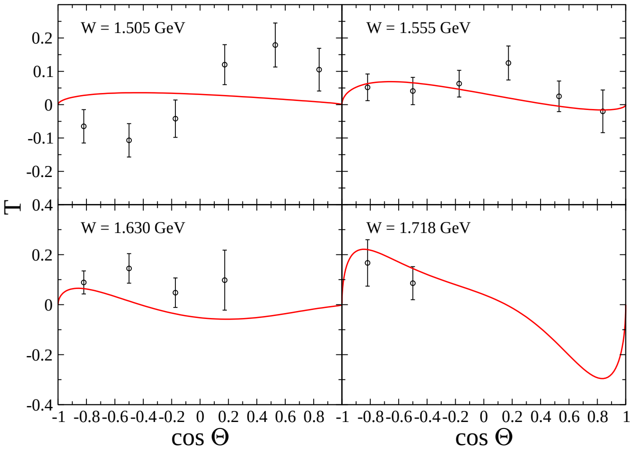
Data : GRAAL 07 , LNS 06 , JLab 09, ELSA 09

Σ for $\vec{\gamma} p \to \eta p$

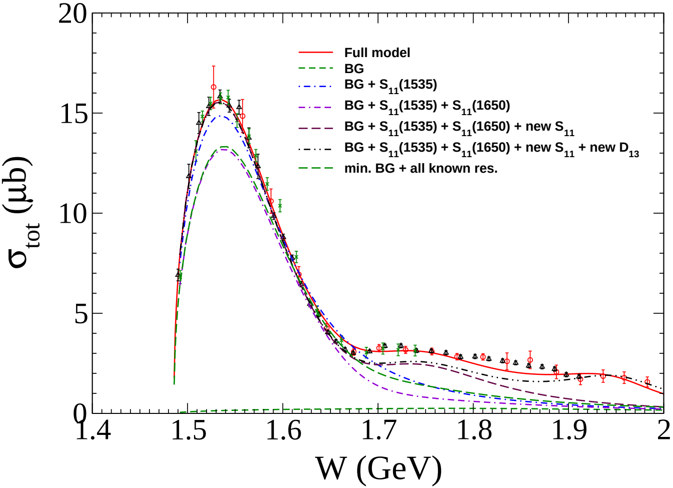


Data : GRAAL , ELSA

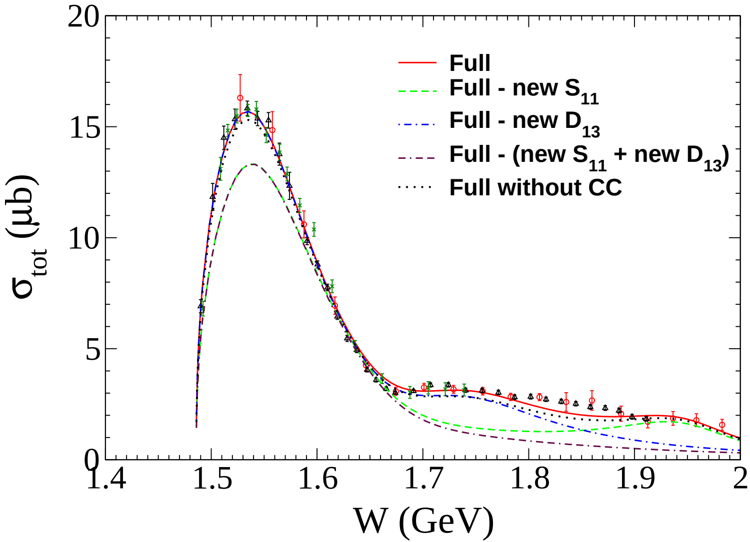
"Postdiction" : T for $\gamma\vec{p} \to \eta p$



"Postdiction" : σ_{tot} for $\gamma p \to \eta p$



$\gamma p \rightarrow \eta p,$



Coupled-channels effects turn out to be small !

- Already the case for $\pi N \to \pi N$, except around the Δ-resonance.
- Nevertheless, important draw backs :

  $g_{\eta NN}$ decreased by about one order of magnitude.

  High sensitivity to the parameters of S_{11}-resonances.

  Sensitivity to the parameters of P_{13}- and F_{15}-resonances, also to $g_{\rho NS_{11}}$

  $\to$ Contributes to improve the whole EBAC approach.

  $\to \to$ Coupled-channels studies to all meson production final states are **mandatory** !
- Main conclusions of the direct channel confirmed.
- Direct channel can hence be extended to **higher energies** :

  Either extend the CQM to $n > 2$

  Or introduce t-channel contributions.

η production off the proton in a Regge-plus-chiral quark approach

Jun He and B. Saghai, arXiv : 1005.2797 [nucl-th]

In the Reggeized model the main change is substituting the meson exchange poles by the Regge propagator :

$$\frac{1}{t-m_V^2} \to \mathcal{P}_{Regge}^V = \left(\frac{s}{s_0}\right)^{\alpha_V(t)-1} \frac{\pi\alpha'_V}{\sin\left[\pi\alpha_V(t)\right]} \frac{\mathcal{S}_V + e^{-i\pi\alpha_V(t)}}{2} \frac{1}{\Gamma\left(\alpha_V(t)\right)},$$

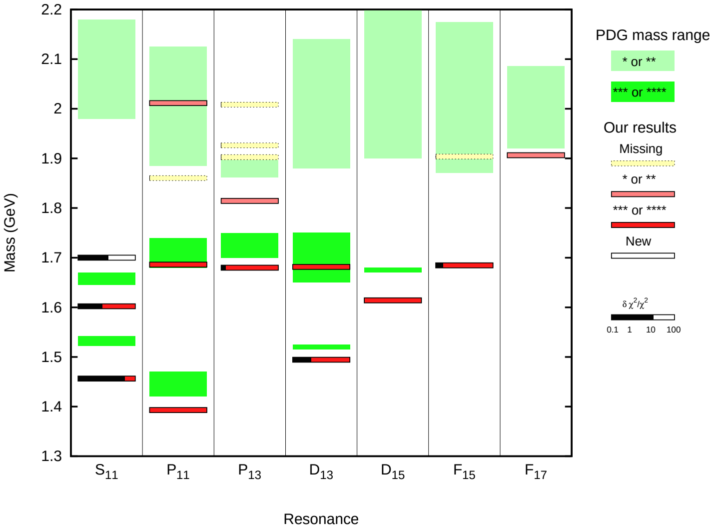
vector-meson Regge trajectory is taken in the following linear form :

$$\alpha_V(t) = \alpha_V^\circ + \alpha'_V t,$$

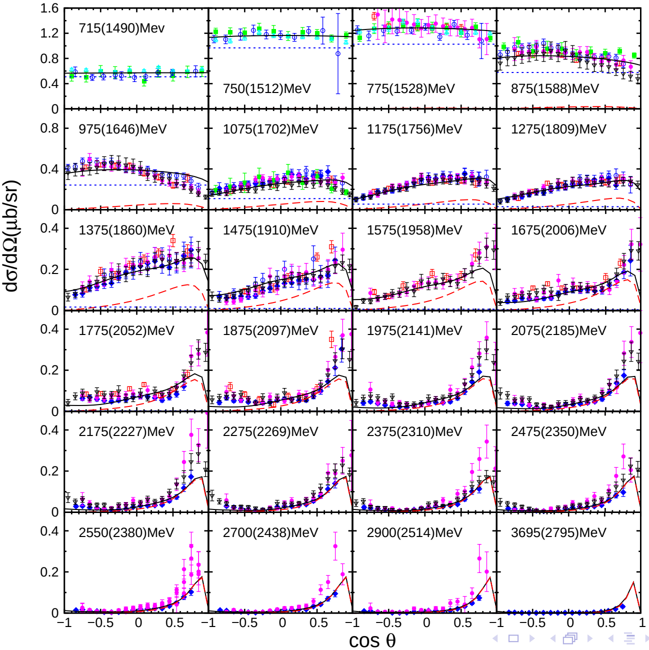
with t the Mandelstam variable, and read for ρ and ω, respectively, as

$$\begin{aligned} \alpha_\rho(t) &= 0.55 + 0.8t, \\ \alpha_\omega(t) &= 0.44 + 0.9t. \end{aligned}$$

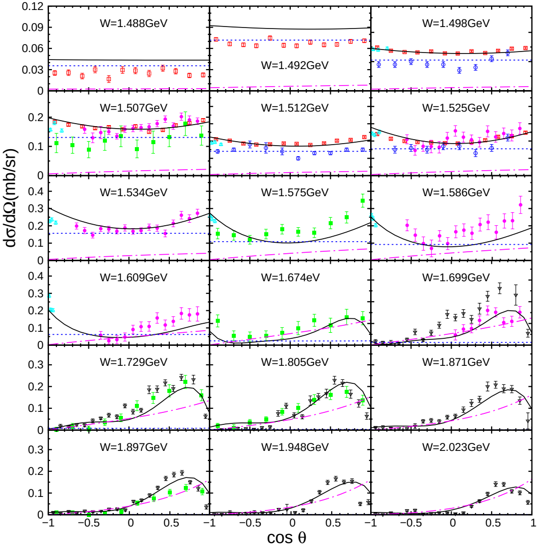
Spectrum of baryon resonances



$\gamma p \to \eta p$, full model (full curves), S_{11} (dotted), t-channel (dashed)



$\pi^- p \to \eta n$, full model (full curves), S_{11} (dotted), u-channel (dash-dotted)



Backward angles improved with respect to the CQM, without t-channel contriutions, Jun He and B. Saghai, Phys. Rev. C 80, 015207 (2009).

Investigating $\gamma p \rightarrow MB \rightarrow K^+\Lambda$

- Direct channel : $\gamma p \rightarrow K^+\Lambda$

  CQM (few parameters, but lmited to photoproduction) or ELA (too many parameters, but handles electroproduction))

- Coupled-channels $\pi N \rightarrow MB \rightarrow K^+\Lambda$, $MB \equiv \pi N, K^+\Lambda, K^+\Sigma^\circ, K^\circ\Sigma^+$

  Chiang, Saghai, Tabakin, Lee, PR C69, 065208 (2004)

- $\gamma N \rightarrow \pi N$

  SAID

- Coupled-channels $\gamma p \rightarrow MB \rightarrow K^+\Lambda$

  CQM + CC : Julia-Diaz, Saghai, Lee, Tabakin, PR C73, 055204 (2006)

  ELA + CC : Chiang, Tabakin, Lee, Saghai, PL B517, 101 (2001)

Project collaborations :

CQM : He

ELA : Bydzovsky

CC : An, Julia-Diaz, Lee...

Concluding remarks

- EBAC's Dynamical coupled-channels apprach complemented with a CQM
- Reasonable agreement with data for both strong and electromagnetic initial states for $W \lesssim 2$ GeV
- Reaction mechanisms dominated by : $S_{11}(1535)$, $S_{11}(1650)$, $P_{13}(1720)$, $D_{13}(1520)$, $F_{15}(1680)$
- S_{11} : $M = 1707$ MeV, $\Gamma = 222$ MeV ; D_{13} : M=1950 MeV, $\Gamma = 139$ MeV

Forthcoming improvements :

- Extend of the CQM to $n > 2$-shell
  in progress
- Embody the EBAC approach for $\pi\pi N$ channel in the $\pi N \to MB \to \pi N$ code
  Kamano, Julia-Diaz, Lee, Matsuyama, Sato, PR C79, 025206 (2009)
- Go back to $\gamma p \to MB \to \eta p$
- investigate $\gamma p \to MB \to KY$

Data :

- Badly missing $\pi N \to \eta N$, KY !
- Data from double polarization measurements at JLab and ELSA are awaited for.

Thank you for your attention !