$K^{+}\Sigma^{-}$ Photoproduction Within an Isobar Model

P. Bydžovský, A. Cieplý, D. Petrellis, **D. Skoupil**, and N. Zachariou

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Motivation

- We aim at understanding the baryon spectrum and production dynamics of particles with strangeness at low energies.
- Constituent Quark Model predicts a lot more N^* states than was observed in pion production experiments $\rightarrow$ "missing" resonance problem.
- Models for the description of elementary hyperon electroproduction are a suitable tool for hypernuclear physics calculations.
- New good-quality photoproduction data from LEPS, GRAAL, MAMI and (particularly) CLAS collaborations allow us to tune free parameters of the models.
- As the α_s increases with decreasing energy, we cannot use perturbative QCD at low energies $\rightarrow$ need for introducing effective theories and models.

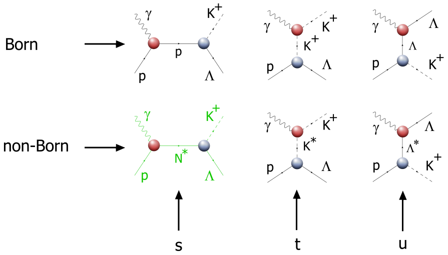
Isobar model

Single-channel approximation

- higher-order contributions (rescattering, FSI) included, to some extent, by means of effective values of the coupling constants

Use of effective hadron Lagrangian

- hadrons either in their ground or excited states
- amplitude constructed as a sum of tree-level Feynman diagrams
  - **background part**: Born terms with an off-shell proton (s channel), kaon (t), and hyperon (u) exchanges; non Born terms with (axial) vector K^* (t) and Y^* (u) exchange
  - **resonance part**: s-channel Feynman diagram with N^* exchanges



Free parameters adjusted to experimental data

Satisfactory agreement with the data in the energy range $W = 1.6 - 2.5\,\mathrm{GeV}$

Isobar model

Novel features of our IM

Exchanges of high-spin resonant states

- non physical lower-spin components removed by appropriate choice of $\mathcal{L}_{int}$

$$V_S^{\mu}\, \mathcal{P}^{(1/2)}_{ij,\mu\nu}\, V^{\nu}_{EM} = 0$$

Energy-dependent decay widths of nucleon resonances $\rightarrow$ restoration of unitarity

$$\Gamma(\vec{q}) = \Gamma_{N^*} \frac{\sqrt{s}}{m_{N^*}} \sum_i x_i \left(\frac{|\vec{q}_i|}{|\vec{q}_i^{N^*}|} \right)^{2l+1} \frac{D(|\vec{q}_i|)}{D(|\vec{q}_i^{N^*}|)},$$

Extension from photoproduction to electroproduction

- Phenomenological form factors in the electromagnetic vertex
- Longitudinal couplings of N^*'s to γ^* (crucial at small Q^2)

$$V^{EM}(N^*_{1/2}p\gamma) = -i\frac{g_3^{EM}}{(m_R+m_p)^2}\Gamma_{\mp}\,\gamma_\beta\,\mathcal{F}^{\beta},$$

$$V^{EM}_{\mu}(N^*_{3/2}p\gamma) = -i\frac{g_3^{EM}}{m_R(m_R+m_p)^2}\gamma_5\Gamma_{\mp}\,(\not{q}\,g_{\mu\beta} - q_\beta\gamma_\mu)\,\mathcal{F}^{\beta},$$

$$V^{EM}_{\mu\nu}(N^*_{5/2}p\gamma) = -i\frac{g_3^{EM}}{(2m_p)^5}\Gamma_{\mp}(q_\alpha q_\beta g_{\mu\nu} + q^2 g_{\alpha\mu}g_{\beta\nu} - q_\alpha q_\nu g_{\beta\mu} - q_\beta q_\nu g_{\alpha\mu})\,p^{\alpha}\mathcal{F}^{\beta}.$$

New fits for $K^+\Sigma^-$ channel

Fitting procedure

- non resonant part: Born terms and exchanges of K^* and K_1 (t channel) and Σ^* (u channel)
- resonant part: exchanges of N^*'s and Δ's in the s channel
- around 600 data utilized to fit $\approx$ 25 parameters
- the main coupling, $g_{K^+\Sigma^-n} = \sqrt{2} g_{K^+\Sigma^0 p} = 1.568$, taken from $K^+\Lambda$ channel
- result with the smallest $\chi^2/\mathrm{ndf} = 2.3 \rightarrow$ **fit M** (25 parameters, 14 resonances)
- **LASSO method** used: $\chi^2/\mathrm{ndf} = 3.4 \rightarrow$ **fit L** (17 parameters, 9 resonances) (see talk of D. Petrellis for details)

Characteristics of models

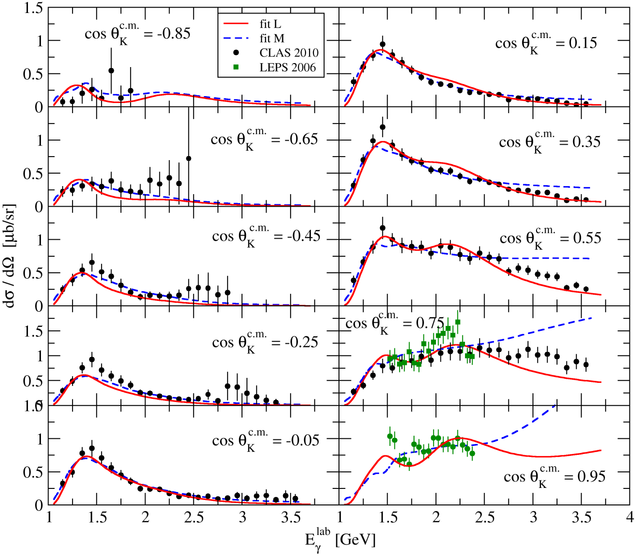
- only one Δ resonance introduced
- no hyperon resonances needed for reliable data description
- results in very good agreement with the cross-section and beam-asymmetry data
- fit L: a very economical fit

New fits for the $K^+\Sigma^-$ channel

Tag	Resonance	Mass (MeV)	Width (MeV)	Branching ratio $K\Lambda$	$K\Sigma$	Fit M g_1	g_2	Fit L g_1	g_2
K*	$K^*(892)$	891.7	50.8			0.366 ± 0.024	1.103 ± 0.198	0.310 ± 0.019	
K1	$K_1(1270)$	1270	90			-1.448 ± 0.189	0.473 ± 0.156		
N3	$N(1535)\ 1/2^-$	1530	150			-0.709 ± 0.071			
N4	$N(1650)\ 1/2^-$	1650	125	0.07	0.00	0.314 ± 0.034		-0.085 ± 0.006	
N8	$N(1675)\ 5/2^-$	1675	145			-0.013 ± 0.001	0.022 ± 0.003	-0.010 ± 0.001	0.003 ± 0.002
N6	$N(1710)\ 1/2^+$	1710	140	0.15	0.01	-0.940 ± 0.093			
N7	$N(1720)\ 3/2^+$	1720	250	0.05	0.00	-0.098 ± 0.017	-0.082 ± 0.002	-0.187 ± 0.004	-0.126 ± 0.002
P4	$N(1875)\ 3/2^-$	1875	200	0.01	0.01	-0.220 ± 0.023	-0.223 ± 0.023	-0.042 ± 0.015	0.025 ± 0.013
P1	$N(1880)\ 1/2^+$	1880	300	0.16	0.14	-0.050 ± 0.064			
Mx	$N(1895)\ 1/2^-$	1895	120	0.18	0.13	-0.063 ± 0.005		0.019 ± 0.002	
P2	$N(1900)\ 3/2^+$	1920	200	0.11	0.05	-0.051 ± 0.005	-0.004 ± 0.001	0.027 ± 0.003	0.010 ± 0.001
M4	$N(2060)\ 5/2^-$	2100	400	0.01	0.03	-0.00001 ± 0.0001	0.003 ± 0.0003	-0.003 ± 0.0001	0.004 ± 0.0002
M1	$N(2120)\ 3/2^-$	2120	300			-0.034 ± 0.014	-0.010 ± 0.013	0.0003 ± 0.001	0.0 ± 0.0001
D1	$\Delta(1900)\ 1/2^-$	1860	250		0.01	0.298 ± 0.028			
D2	$\Delta(1930)\ 5/2^-$	1880	300						
D3	$\Delta(1920)\ 3/2^+$	1900	300						
D4	$\Delta(1940)\ 5/2^-$	1950	400						
S1	$\Sigma(1660)\ 1/2^+$	1660	100						
S2	$\Sigma(1750)\ 1/2^-$	1750	90						
S3	$\Sigma(1670)\ 3/2^-$	1670	60						
S4	$\Sigma(2010)\ 3/2^-$	1940	220						

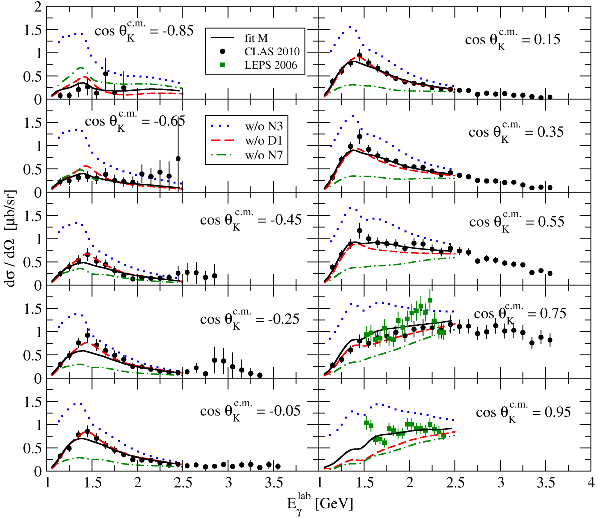
New fits for $K^+\Sigma^-$ channel

Differential cross section in dependence on the photon lab energy



New fits for $K^+\Sigma^-$ channel

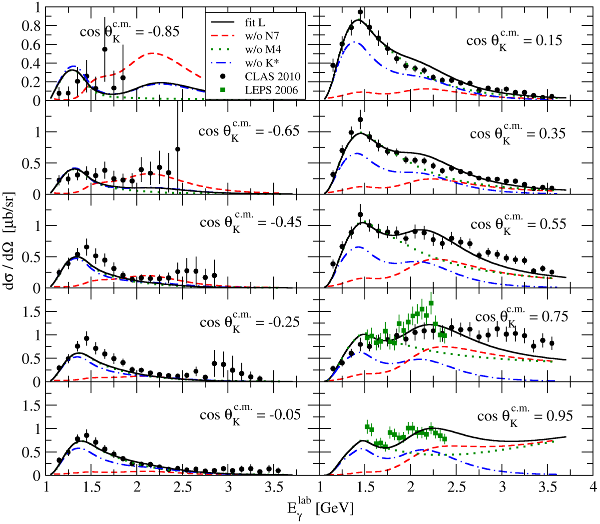
Differential cross section in dependence on the photon lab energy - fit M w/o individual resonances



N3: N(1535)$1/2^-$, D1: Δ(1900)$1/2^-$, N7: N(1720)$3/2^+$

New fits for $K^+\Sigma^-$ channel

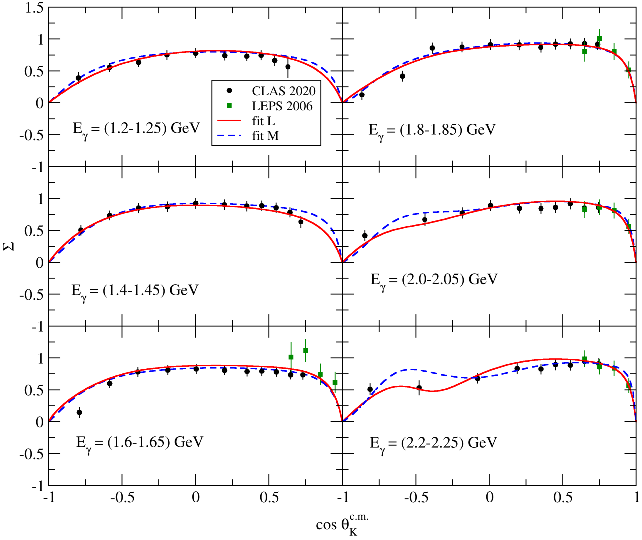
Differential cross section in dependence on the photon lab energy - fit L w/o individual resonances



N7: N(1720)$3/2^+$, M4: N(2060)$5/2^-$

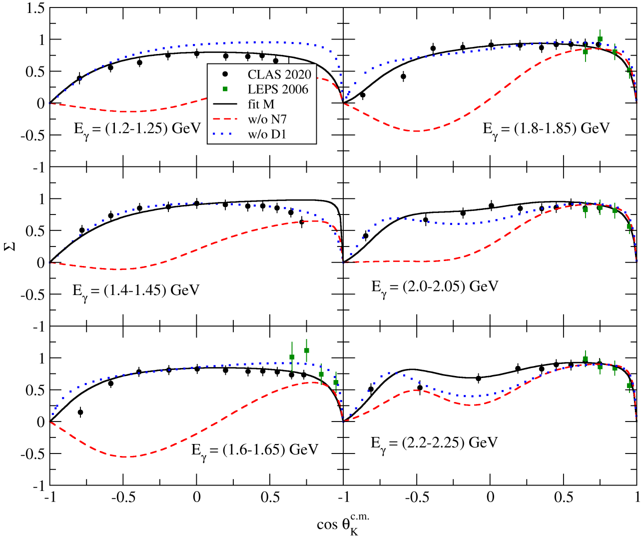
New fits for $K^+\Sigma^-$ channel

Beam asymmetry in dependence on the kaon center-of-mass angle



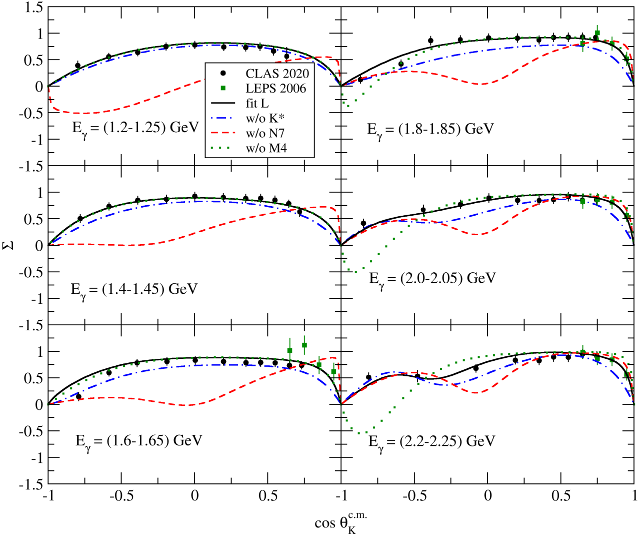
New fits for $K^+\Sigma^-$ channel

Beam asymmetry in dependence on the kaon center-of-mass angle - fit M w/o individual resonances



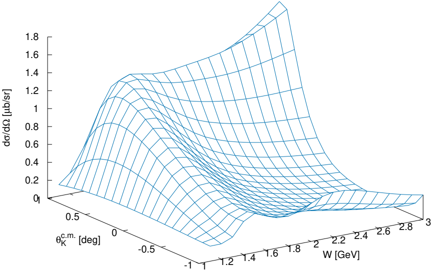
New fits for $K^+\Sigma^-$ channel

Beam asymmetry in dependence on the kaon center-of-mass angle - fit L w/o individual resonances

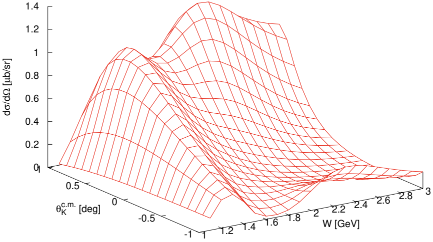


New fits for $K^+\Sigma^-$ channel

Differential cross sections in dependence on energy and kaon angle



Fit M



Fit L

Outlook: Analysis of Σ production channels

Three-step process

- derive scalar amplitudes $\mathcal{A}_j$ for all channels involved
- use SU(2) isospin symmetry in the strong vertex to relate the couplings
    - isospin symmetry of various meson and baryon multiplets is assumed to be exact
- use known helicity amplitudes for relating electromagnetic couplings
    - the helicity amplitudes for N^*'s are used to determine neutral-to-charge ratio of the electromagnetic coupling constants

$$g^{EM}_{N^*\gamma n}/g^{EM}_{N^*\gamma p}$$

Fit to the data

- $K^+\Sigma^0$ dominates in number of data:
  $\sim$ 92% of Σ photoproduction data concentrated in this channel
- use of Minuit + regularization methods

Summary

Description extended from the $K^+\Lambda$ channel to the $K^+\Sigma^-$ channel

- only one Δ resonance found to play any role; no Y^*'s needed
- fitting method upgraded by adding regularisation techniques (LASSO) $\rightarrow$ economical fit

Thank you for your attention!