BLED WORKSHOPS
IN PHYSICS
VOL. 13, NO. 1
p. 36

Proceedings of the Mini-Workshop
Hadronic Resonances
Bled, Slovenia, July 1 - 8, 2012

Pion- and photon-induced hadronic reactions in a combined coupled-channel analysis

Deborah Rönchen

Institut für Kernphysik and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany

1 Introduction and Formalism

To gain insight into the non-perturbative sector of Quantum Chromodynamics the knowledge of the excited hadron spectrum is essential, providing the connection between experiment and QCD. Most resonances have been identified through elastic πN scattering in the past to present day. On the other hand, combining different reactions for resonance extraction allows to determine those states which couple only weakly to πN. The simultaneous analysis of different final states of pion- and photon-induced reactions is especially interesting regarding the new experimental window that has opened through the recent high-precision photon beam facilities, e.g., at ELSA, JLab and MAMI. Among other approaches, dynamical coupled-channel (DCC) models provide a sophisticated tool to analyze those data on excited baryons as they obey a maximum of theoretical requirements of the S-matrix such as analyticity to allow for a reliable extraction of resonances.

The DCC model developed and employed in this study (*Jülich model*) is based on an approach pursued over the years [1–9]. The scattering amplitude is obtained as the solution of a Lippmann-Schwinger equation (Eq. (1)) which guarantees two-body unitarity and approximates three-body unitarity,

$$\langle L'S'k'|T^{IJ}_{\mu\nu}|LSk\rangle = \langle L'S'k'|V^{IJ}_{\mu\nu}|LSk\rangle + \sum_{\gamma\, L''\, S''} \int_0^\infty k''^2\, dk'' \langle L'S'k'|V^{IJ}_{\mu\gamma}|L''S''k''\rangle \frac{1}{z - E_\gamma(k'') + i\epsilon} \langle L''S''k''|T^{IJ}_{\gamma\nu}|LSk\rangle \quad (1)$$

In Eq. 1 z is the scattering energy, $J\,(L)$ is the total angular (orbital angular) momentum, $S\,(I)$ is the total spin (isospin), $k(k',\, k'')$ are the incoming (outgoing, intermediate) momenta, and μ, ν, γ are channel indices. E_γ is the on-mass shell energy in channel γ [4]. The pseudo-potential V iterated in Eq. (1) is constructed from an effective interaction based on the Lagrangians of Wess and Zumino, supplemented by additional terms [2, 3] for including the Δ isobar, the ω, η, a_0 meson, and the σ. The channel space is given by $N\pi, N\eta, N\sigma, \Delta\pi, N\rho$, ΛK and ΣK. The non-resonant interactions are constructed of t- and u-channel exchanges of known mesons and baryons, while bare resonances can be considered as s-channel processes. The explicit treatment of the background in terms of t- and u-channel diagrams introduces strong correlations between the different partial waves and generates a non-trivial energy and angular dependence of the observables. Analyticity is respected in the sense that dispersive, real parts of intermediate states are included, as well as the correct structure of branch points, some of them being in the complex plane, and the correct off-shell behavior as dictated by the interaction Lagrangians. Thus, a reliable determination of resonance properties given in terms of pole positions and residues is possible. In the *Jülich model* SU(3) flavor symmetry is exploited to link the different reaction channels, while it is broken e.g. by physical masses and different cut-offs in the form factors of the vertices.

The extension of the model to photoproduction within a fully gauge-invariant approach has been accomplished recently [9].

In the following, the results of a simultaneous analysis of elastic πN-scattering and pion-induced K and η production within the framework of the *Jülich model* will be presented. In the present study, we perform a resonance analysis of the isospin $I = 1/2$ and $I = 3/2$ sector, considering the world data on the set of reactions $\pi^- p \to \eta n$, $K^0\Lambda$, $K^0\Sigma^0$, $K^+\Sigma^-$, and $\pi^+ p \to K^+\Sigma^+$, together with $\pi N \to \pi N$ scattering. Within the framework of DCC approaches, this is the first analysis of this type realized. The approach also includes the three effective $\pi\pi N$ channels $\pi\Delta$, σN and ρN. The considered energy range has been extended beyond 2 GeV and resonances up to $J = 9/2$ are included in this study.

The present study is the first step towards a global analysis of pion- and photon-induced production of πN, ηN, $K\Lambda$ and $K\Sigma$.

2 Results

While for the reaction $\pi N \to \pi N$ the partial waves from the GWU/SAID analysis [10] are used, for the inelastic channels, $\pi N \to \eta N$ and $\pi N \to KY$, we fit directly to total and differential cross sections as well as to polarization observables. The bulk of the existing data for the inelastic channels was obtained in the 1960's and 70's. Though many experiments have been carried out at different facilities, unfortunately, there are still energy ranges where the data situation is not ideal. All in all we include about 6000 data points in our analysis. The present solution was obtained in a fit procedure using MINUIT on the JUROPA supercomputer at the *Forschungszentrum Jülich*.

In the previous analysis [5], the reaction $\pi^+ p \to K^+\Sigma^+$ and πN scattering were considered and only resonance parameters, i.e. bare masses and couplings of the resonances to the different channels, were fitted. In this study, in addition the important T^{NP} parameters are varied. Those are the cut-offs of the form factors in t- and u-channel exchange diagrams.

Resonances with a total spin up to $J = 9/2$ are included, with the corresponding new parameters. One bare s-channel state is included in each of the $I = 1/2$ partial waves D13, D15, F15, P13, F17, H19 and G19, while we have two in S11 and P11. In the $I = 3/2$ sector, one bare s-channel state is included in the S31, D33, F35, P31, D35, F37, G37 and G39 partial waves and two are included in P33. These states couple to all channels πN, ρN, ηN, $\pi\Delta$, $K\Lambda$ and $K\Sigma$ if allowed by isospin. In total, we have 196 free parameters, of which 128 are resonance parameters and 68 belong to the T^{NP} part (t- and u-channel exchanges). The values of the parameters will be quoted elsewhere.

In Figs. 1, 2 and 3 we show a selection of our present results at typical energies.

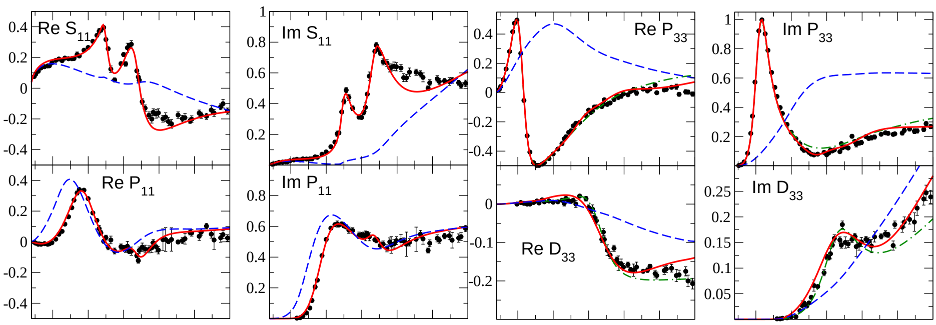

Fig. 1. Reaction $\pi N \to \pi N$, real and imaginary part of the S11, P11, P33 and D33 partial waves. (Red) solid lines: present solution. (Blue) dashed lines: only T^{NP}. (Green) dash-dotted lines: Jülich model, solution 2011 from Ref. [5]. Data points: GWU/SAID partial wave analysis (single energy solution) from Ref. [10]. (Preliminary)

In summary, a first combined analysis of the reactions $\pi N \to \pi N$, ηN, $K\Lambda$, and the three measured $K\Sigma$ final states $K^+\Sigma^+$, $K^0\Sigma^0$, and $K^+\Sigma^-$ within a dynamical coupled-channel framework has been performed. In the Lagrangian-based calculation, the full off-shell solution of the Lippman-Schwinger equation provides the correct analytic structure allowing for a reliable extrapolation into the complex plane to extract resonance pole positions and residues up to $J^P = 9/2^{\pm}$. The amplitude features also effective $\pi\pi N$ channels with branch points in the complex plane and a dispersive treatment of σ and ρ t-channel exchanges.

A publication of the full results together with a resonance analysis in terms of poles and residues is in progress.

The present results, in combination with the recent extension to pion photoproduction [9], will be used as input into a global study of pion- and photon-induced production of πN, ηN, $K\Lambda$ and $K\Sigma$. This means a major step towards the analysis of high-precision photoproduction data of ηN, $K\Lambda$, and $K\Sigma$ data produced, e.g., at ELSA, JLab, and MAMI.

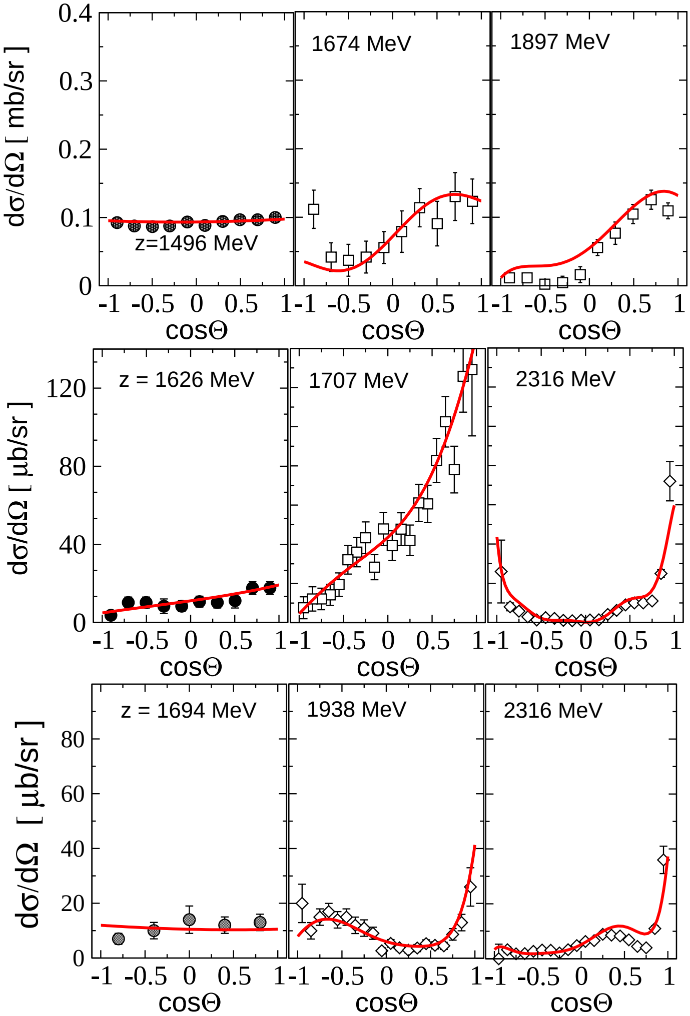

Fig. 2. Differential cross section for the reactions $\pi^- p \to \eta n$ (upper row), $\pi^- p \to K^0 \Lambda$ (middle) and $\pi^- p \to K^0 \Sigma^0$ (lower). (Red) solid lines: present solution. Selected results (Preliminary).

Acknowledgment

This work has been carried out in collaboration with M. Döring, F. Huang, H. Haberzettl, J. Haidenbauer, C. Hanhart, S. Krewald, U.-G. Meißner and K. Nakayama. I am also grateful to the German Academic Exchange Service (DAAD) for financial support within a “DAAD-Doktorandenstipendium”.

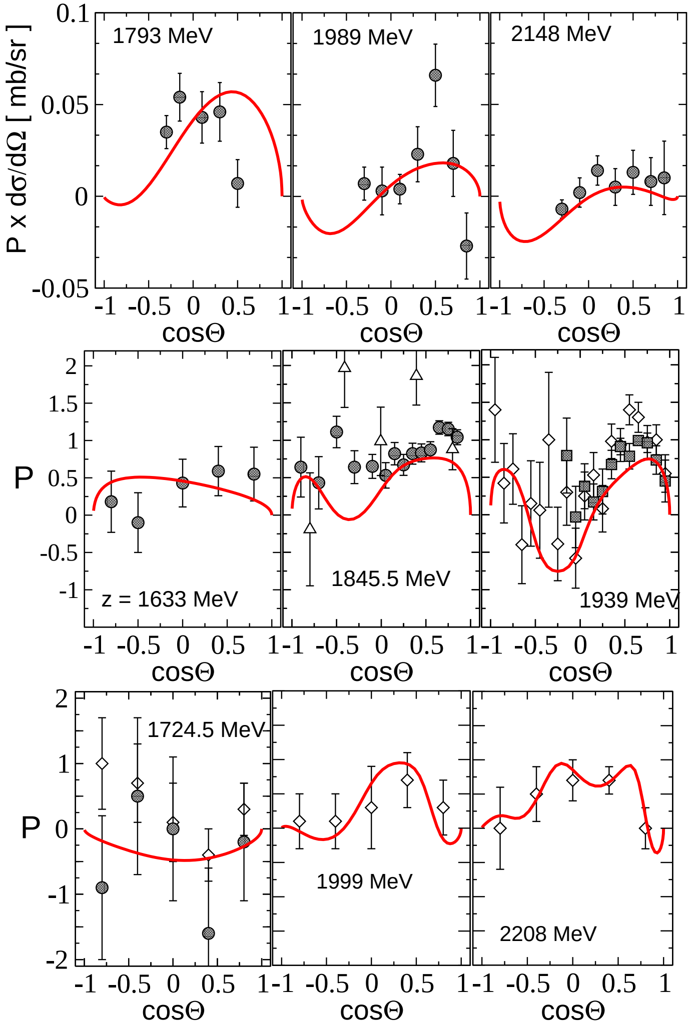

Fig. 3. Polarization for the reactions $\pi^-p \to \eta n$ (upper row), $\pi^-p \to K^0\Lambda$ (middle) and $\pi^-p \to K^0\Sigma^0$ (lower). (Red) solid lines: present solution. Selected results (Preliminary).

References

1. Schütz C, Haidenbauer J, Speth J and Durso J W 1998, Phys. Rev. C **57** 1464 (1998).
2. O. Krehl, C. Hanhart, S. Krewald and J. Speth, Phys. Rev. C **62**, 025207 (2000).
3. A. M. Gasparyan, J. Haidenbauer, C. Hanhart and J. Speth, Phys. Rev. C **68**, 045207 (2003).
4. M. Döring, C. Hanhart, F. Huang, S. Krewald and U.-G. Meißner, Nucl. Phys. A **829**, 170 (2009).
5. M. Döring, C. Hanhart, F. Huang, S. Krewald, U.-G. Meißner and D. Rönchen, Nucl. Phys. A **851**, 58 (2011).
6. H. Haberzettl, Phys. Rev. C **56** (1997) 2041.
7. H. Haberzettl, K. Nakayama, S. Krewald, Phys. Rev. **C74** (2006) 045202.

8. H. Haberzettl, F. Huang and K. Nakayama, Phys. Rev. C **83** (2011) 065502.
9. F. Huang, M. Döring, H. Haberzettl, J. Haidenbauer, C. Hanhart, S. Krewald, U.-G. Meißner and K. Nakayama, Phys. Rev. C **85**, 054003 (2012).
10. R. A. Arndt, W. J. Briscoe, I. I. Strakovsky and R. L. Workman, Phys. Rev. C **74**, 045205 (2006).