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Mesonproduction and experimental studies of the excitation spectrum of the nucleon

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Abstract. Key issues of the structure of the nucleon can be addressed by experimental studies of Mesonproduction. Depending on the selected channels and kinematics, different aspects can be investigated. The measurements of charged channels at low t constitute a large part of the cross section and exhibit a special sensitivity of the meson cloud. These contributions can be strongly suppressed by using a polarized beam and target. Instead, the excitation of resonances are emphasized in this case. The choice of neutral channels in the final state shows also dominant sensitivities for resonance excitation. The sequential decay of resonances can be studied systematically for the first time.

1 Introduction

Several key questions in low energy QCD can be addressed by studying the complete spectrum of excited states of the nucleon . This includes the determination of the quantum numbers and decay branching ratios of these states as well as the extraction of the photocouplings of the states. The identification of the relevant degrees of freedom is one of the most important issues to settle. From the knowledge of the low energy part of the excitation spectrum it can be inferred that the nucleon is built from the degrees of freedom of spin -1/2 fermions confined to a valence qqq system. Further questions wait for answers: Are there, in addition, excitations of the gluonic and sea quark degrees of freedom? Can as many states be found as results from calculations based on symmetric quark models suggest or are degrees of freedom frozen out? The quarks considered in the qqq system are quasiparticles with masses of a third of the nucleon mass. Do the properties of these quasiparticles change when excited to the highest energies? Does the relatively large energy splitting of the parity doublets change to get degenerate at higher excitation energies? An answer to these questions leads to an understanding how in the framework of QCD baryons are formed and provides the basis for a description of the origin of the forces between nucleons. This motivation and the recent progress concerning advanced equipment revives programs of studies of the excitation spectrum of the nucleon in several laboratories. With the study of reactions like $\gamma + N \Longrightarrow N + n \cdot mesons$ a comprehensive experimental program can be carried out. Using polarized beams and targets as well as large acceptance detectors, the relevant observables can be extracted. Illustrated by data taken recently at ELSA , a general picture of photo - meson production will be presented.

2 Total photon cross sections

2.1 The total photon absorption cross section

The total photon absorption cross [1] section on the proton (see Fig. 1) shows two remarkable features: The pronounced resonance structure at low photon energies ($E_\gamma \leq 1.5GeV$) and the seemingly structureless shape of the cross section at higher energies ($E_\gamma \geq 1.5GeV$). The magnetic and electric dipole excitations of the nucleon are seen in the first and second peak, respectively. The structureless part is well described by an extrapolation of a Regge fit for photon energies with $6GeV \leq E_\gamma \leq 200GeV$ [2]. The successful extrapolation into the resonance region suggests that the same absorption mechanism as in the high energy regime is responsible for this “background” contributions, as this part of the cross section is called in the resonance region. The detailed study of this “background” contribution is interesting by itself, because it constitutes a mayor part of the total absorption cross section which determines via dispersion theory such static properties of the nucleon like the electric and magnetic polarizabilities. These again, are test cases for the validity of extended calculations based on the Chiral Perturbation Theory, the low energy realization of QCD.

2.2 Total meson production cross sections

Figure 2 shows, together with the total photon absorption cross section, the total cross sections of the reactions $\gamma + p \Longrightarrow p + \pi^+ + \pi^-$, $\gamma + p \Longrightarrow p + \pi^+ + \pi^- + \pi^0$, $\gamma + p \Longrightarrow p + \rho^0$, $\gamma + p \Longrightarrow p + \omega$ and $\gamma + p \Longrightarrow p + K^+ + K^-$ as measured with the SAPHIR detector at ELSA [3,4].

These cross sections represent a large portion of the total absorption cross section for $E_\gamma \geq 1GeV$. A first step to

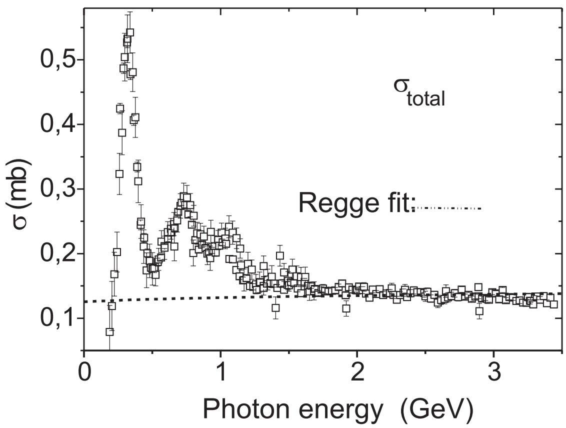

Fig. 1. The total absorption cross section of the proton

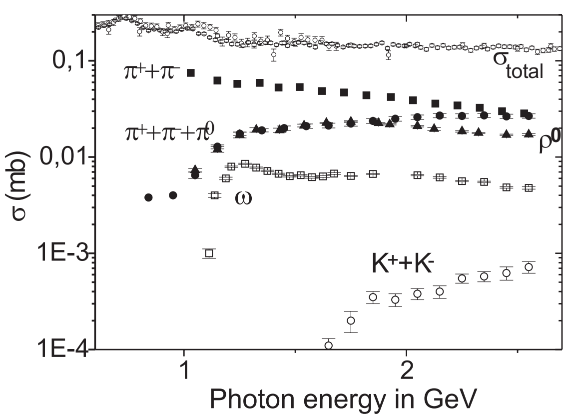

Fig. 2. Total meson production cross sections

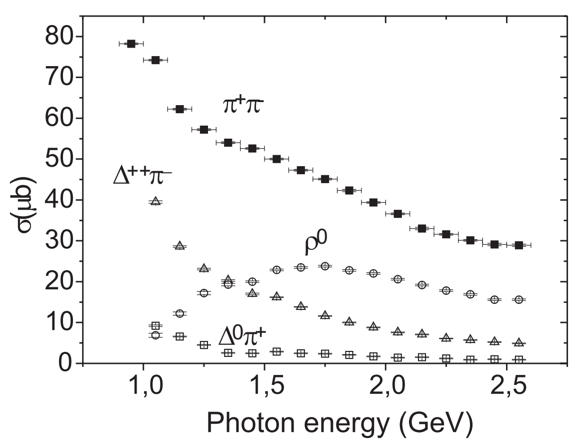

Fig. 3. Decomposition of the two pion cross section

get insight into the reaction mechanism provides the decomposition of the $\gamma + p \Longrightarrow p + \pi^+ + \pi^-$ cross section into the different reaction channels $\gamma + p \Longrightarrow p + \rho^0$, $\gamma + p \Longrightarrow \Delta^{++} + \pi^-$ and $\gamma + p \Longrightarrow \Delta^0 + \pi^+$ which is shown in Fig. 3. The dominance of the reactions $\gamma + p \Longrightarrow \Delta^{++} + \pi^-$ and $\gamma + p \Longrightarrow p + \rho^0$ indicates diffractive processes. Is there a general way to "switch off" the dominance of the diffractive processes? The results of recent measurements point into the direction of using polarized beams and targets.

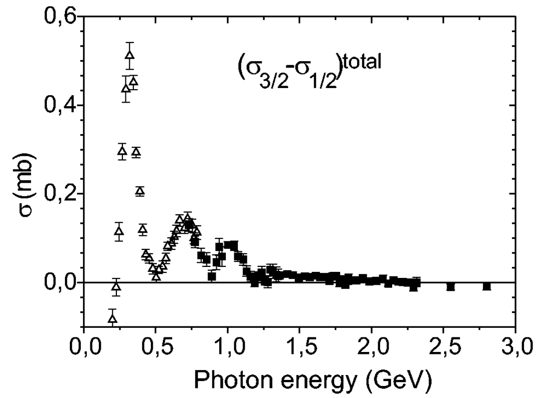

Fig. 4. Total cross section difference

2.3 Total photon absorption cross sections for a polarized beam and target

With the development and implementation of polarized targets and beams for $\gamma-$ induced reactions new classes of experiments become possible. The spin structure in the resonance region can be investigated in a more direct way by using longitudinally polarized $\gamma-$ beams in combination with longitudinal polarized targets. A mayor experimental achievement has been the development of polarized targets [5] which are suitable to be used in the whole angular acceptance range of 4π- detectors. Linearly polarized $\gamma-$beams, prepared by using coherent bremsstrahlung, are suitable to investigate transitions due to convection currents and allow to separate parity even and parity odd transitions. For the first time the total absorption cross section for circular polarized photons has been determined by performing double polarization experiments. By measuring the difference of the spin projected cross sections $\sigma_{3/2}- \ \sigma_{1/2}$ the spin response of the nucleon excitation spectrum up to $E_\gamma = 3GeV$ has been extracted. Figure 4 shows the total photon absorption cross section difference $\sigma_{3/2}- \ \sigma_{1/2}$ in the photon energy range $.2GeV \leq E_\gamma \leq 3GeV$ as has been measured in a double polarization experiment at MAMI ($0.2GeV \leq E_\gamma \leq 0.8GeV$) [6] and ELSA ($0.75GeV \leq E_\gamma \leq 3GeV$) [7,8].

At a first glance by looking at the cross section the very pronounced peaks in the resonance region become apparent. The missing of the above mentioned "background" terms constitutes the second remarkable feature. This signifies the suppression, especially of the diffractive or peripheral contributions to the cross section, by performing double polarization experiments. With these data the GDH - sum rule has been checked, a fundamental relation between the total absorption cross section for circular polarized photons on longitudinal polarized protons and the anomalous magnetic moment of the proton. Extensive experimental programs are on the horizon to use double polarization experiments to disentangle and identify via partial wave analyses the different production amplitudes. More detailed information concerning the reaction mechanism yields the t- dependence of the different reaction channels. A few typical examples in selected γ- energy ranges will be presented.

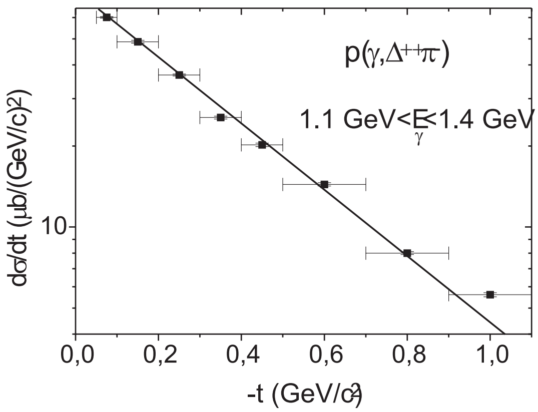

Fig. 5. t-dependence:$\gamma + p \Longrightarrow \Delta^{++} + \pi^-$.

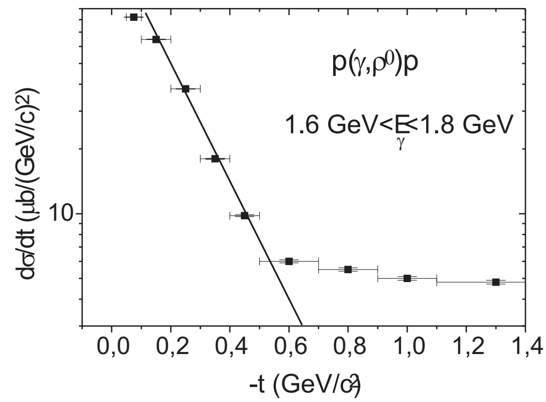

Fig. 7. t-dependence:$\gamma + p \Longrightarrow p + \rho^0$

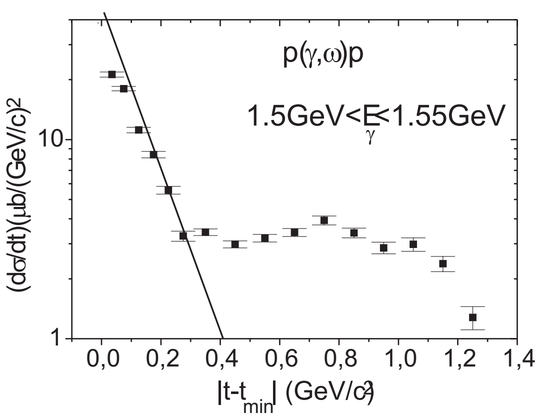

Fig. 6. t-dependence:$\gamma + p \Longrightarrow p + \omega$

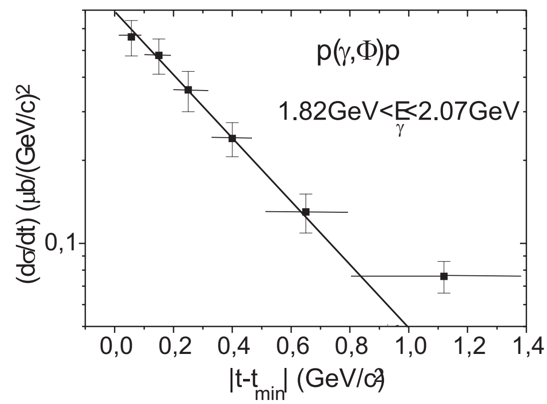

Fig. 8. t-dependence:$\gamma + p \rightarrow p + \Phi$

3 Differential cross sections

Figure 5 shows the t- dependence of the cross section for the reaction $\gamma + p \Longrightarrow \Delta^{++} + \pi^-$.

The large cross section at small t and its linear decrease over the whole range as a function of t on a logarithmic scale signifies the dominance of a diffractive process. For the reaction $\gamma + p \Longrightarrow p + \omega$, shown in Fig. 5, a different behavior of the cross section can be seen: In the low t- range again the diffractive process dominates but in addition, at larger t, the cross section flattens out. This behavior of the differential cross section indicates contributions of certain partial waves due to resonances.

A similar picture as with the $\gamma + p \Longrightarrow p + \omega$ reaction can be seen in the $\gamma + p \Longrightarrow p + \rho^0$ reaction, Fig. 7.

Both reactions hold, therefore, the promise to be very useful channels to find so far unidentified resonances. Remains to be considered (Fig. 8) the last vector meson with the quantum numbers of the photon, the $\Phi-$meson. The Φ- meson production is dominated by the diffractive process as expected due to the composition of the $\Phi-$meson by strange quarks. Two directions become visible to use these reactions for investigations of the excitation spectrum of the nucleon. The first one, to perform a partial wave analysis with the identification of the quantum numbers of resonance contributions, is under way. The second one, will be the observation of excited states of the nucleon by using the inelasticity of the diffractive process. As an example [9] the reactions $\gamma + p \Longrightarrow Roper + \rho^0 \Longrightarrow n + \pi^+ + \pi^+ + \pi^-$ and $\gamma + p \Longrightarrow Roper + \omega \Longrightarrow n + \pi^+ + \pi^+ + \pi^- + \pi^0$ are considered. Especially interesting will be a systematic study of scalar excitations as proposed in [9] and a careful examination of the isospin sector due to the "availability" of virtual isovector -and isoscalar vector mesons in the photon beam. Photon beams with photon energies $E_\gamma \geq 3.2GeV$ are mandatory in order to cover the whole excitation spectrum of the nucleon via these unique inelastic vector meson scattering reactions.

4 The observation of multi photon states in the final state

A decomposition of the total $\gamma-$absorption cross section into its final states exhibits a strong dominance of charged mesonic states as can be seen e.g. in Fig. 2. Because of large "background" contributions no obvious resonance structures are seen in the total cross sections. However, by choosing reactions like $\gamma + p \Longrightarrow p + \eta$, $\gamma + p \Longrightarrow p + \eta'$, $\gamma + p \Longrightarrow p + \pi^0 + \pi^0$, $\gamma + p \Longrightarrow p + \eta + \pi^0$ resonances are expected to stand out of the background very clearly as the example of experimental studies on the $S_{11}(1535)$ have demonstrated,e.g. [10]. At ELSA an experimental program has been started to investigate, in a first round of

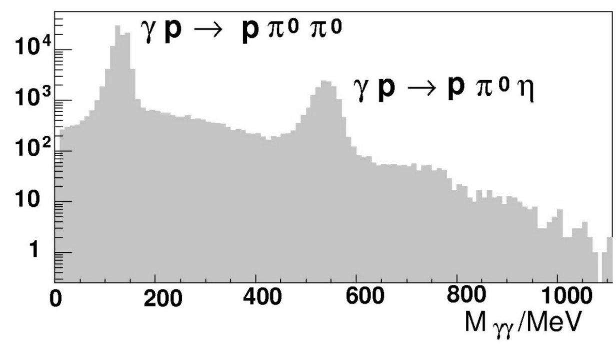

Fig. 9. Sum spectrum of the barrel: 4 photons

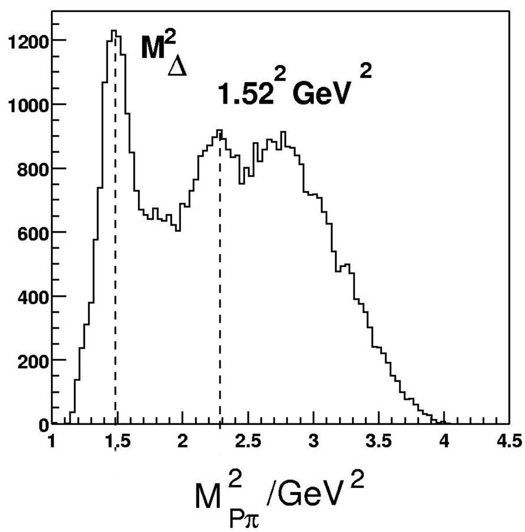

Fig. 10. The reconstructed mass spectrum of the reaction: $\gamma + p \Longrightarrow p + \pi^0 + \pi^0$,

experiments, the multi photon decay channels. The high segmented (1380 CsJ- crystals) CRYSTAL BARREL [11] detector serves as the main instrument in an experimental set-up with a photon tagger, a forward time of flight wall and fiber detectors inside the barrel. Figure 9 shows a spectrum of 4 photons in the final state.

By identifying the hit pattern and adding up the collected energy, the expected mesonic final states stand up very clearly. These many photon final states can be measured almost background free. Besides transitions from excited states leading to the ground state, cascade transitions can be observed for the first time in a systematic way. Figure 10 shows a cascade decay, as indicated in Fig. 11, for the two pion channel, photo excited up to $\sqrt{s} = 2100 MeV$. The excited state decays via intermediate states to the ground state. Clearly visible are in this example the $\Delta_{33}(1232)$ and the $D_{13}(1520)$ as intermediate states.

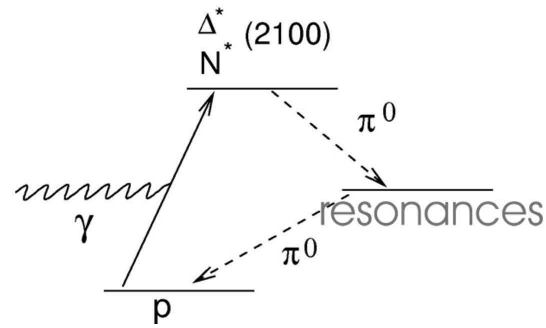

Fig. 11. Decay scheme for two π^0

The high energy part of the excitation spectrum, which can be investigated in an optimal way via these sequential decays, are of great interest for studies of chiral symmetry restoration [12].

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