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PHYSICS AT ELSA, ACHIEVEMENTS AND FUTURE

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At ELSA interesting results on baryon resonances have been obtained by the CB-ELSA, the CBELSA/TAPS and the SAPHIR collaborations. New resonances were found, in particular a new $D_{15}(2070)$ decaying into $p\eta$, was recently observed by the CB-ELSA experiment. The availability of a polarized beam and a polarized target did allow to measure the GDH sum rule up to 2.9 GeV. In the future double polarization experiments will be performed using the Crystal Barrel detector together with new forward detector components. These polarization observables will provide important additional information for the partial wave analyses performed to extract the contributing resonances and their parameters from the data.

Keywords: Baryon spectroscopy, missing resonances, GDH sum rule

1. Experiments at ELSA

The electron stretcher ring ELSA in Bonn accelerates electrons up to a maximum energy of 3.5 GeV. These have been used for photoproduction experiments with either unpolarized or linearly polarized photons, the latter being produced via coherent bremsstrahlung. For the GDH-experiment polarized electrons with an energy up to 3 GeV were used together with a polarized target to measure the helicity dependent total photoabsorption cross section. The GDH-detector is optimized for inclusive measurements. Its overall acceptance for hadronic processes is better than 99% . The electromagnetic background is suppressed by about five orders of magnitude by means of a threshold Cherenkov detector[?]. The CB-ELSA and the CBELSA/TAPS collaborations both used the Crystal Barrel calorimeter as central detector. In the CB-ELSA setup it did consists of 1380 CsI(Tl) crystals covering 98% of the 4π solid angle. In the CBELSA/TAPS setup the Crystal Barrel calorimeter was opened up in forward direction to $\pm 30°$. This forward angular range was covered with the TAPS detector consisting out of 528 BaF_2 crystals with plastic scintillators in front. Both setups are very well suited to measure photons and reach an almost 4π angular coverage. In contrast to this the SAPHIR detector is well suited to detect charged particles. The CB-ELSA, the CBELSA/TAPS and the SAPHIR detector setups have been used to measure exclusive hadronic channels. In the following some of the results obtained by the different experimental setups will be discussed.

2. Measurement of the GDH sum rule

The Gerasimov-Drell-Hearn (GDH) sum rule,

$$\int_0^\infty \frac{d\nu}{\nu}(\sigma_{3/2}(\nu) - \sigma_{1/2}(\nu)) = \frac{2\pi^2\alpha}{m^2}\kappa^2\,, \tag{1}$$

which connects the anomalous magnetic moment of the nucleon - a static property - with the spectrum of its excited states, has been measured at ELSA and MAMI. κ and m are the anomalous magnetic moment and the mass of the nucleon, respectively. The GDH-integral measured at ELSA and MAMI is extrapolated to lower

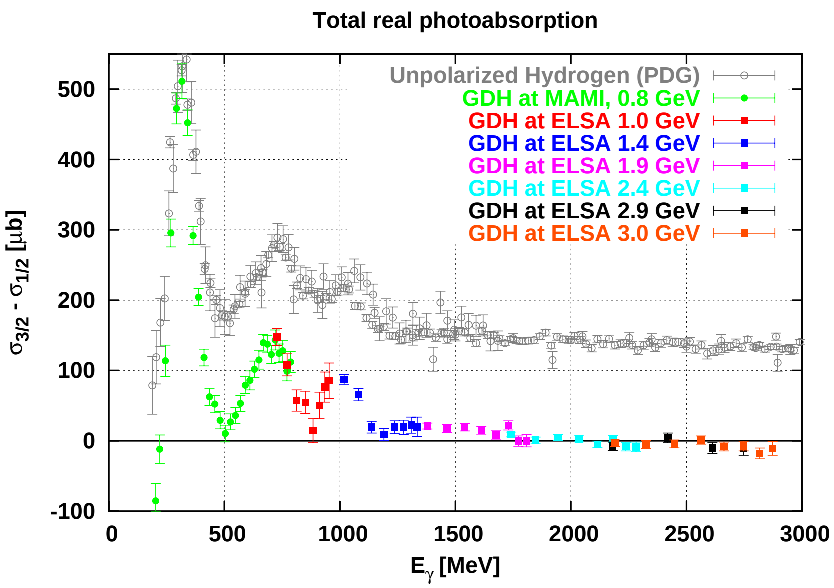

Fig. 1. Difference of the polarized total photoabsorption of the proton as measured at at ELSA and MAMI[?] in comparison to the unpolarized cross section[?]. The picture is taken from[?]

energies by MAID and to higher energies using either a Regge-parametrisation or a fit to the GDH-data[?]. The value for the GDH integral obtained is within the errors consistent with the expected value. Some first data on the neutron has also been taken[?].

3. Baryon spectroscopy

At medium energies, our present understanding of QCD is still very limited. Here, in the energy regime of meson and baryon resonances perturbative methods can no longer be applied. One of the key issues is therefore to identify the relevant degrees-of-freedom and the effective forces between them. A necessary step towards this aim is undoubtedly a precise knowledge of the experimental spectrum of baryon resonances and of their properties. To search for new, or "missing" resonances is one of the aims of experiments performed at ELSA. Experiments with electromagnetic

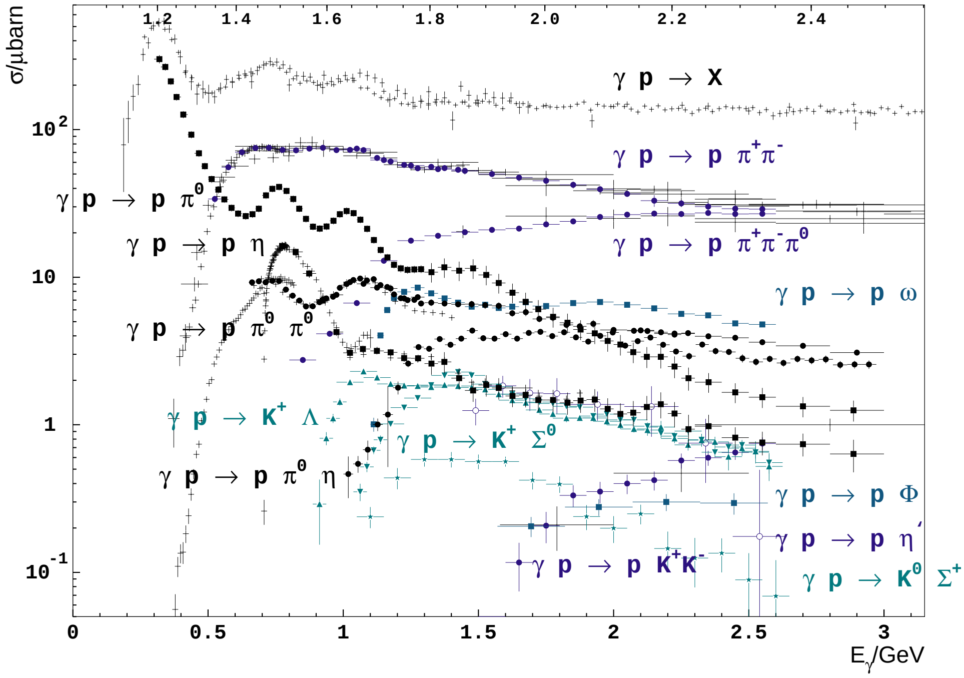

Fig. 2. Total cross sections for various final states measured at ELSA (filled and empty symbols) in comparison with the results from other experiments[?,?,?,?,?,?,?,?] (crosses). Data taken at ELSA: The $\gamma p \to p\pi^0$, $\gamma p \to p\eta$, $\gamma p \to p\pi^0\pi^0$ and the $\gamma p \to p\pi^0\eta$ cross sections shown have been measured by CB-ELSA[?,?,?,?], the other single and multi-meson cross sections by SAPHIR[?,?,?].

probes are of course not only interesting to search for unknown states but also to determine the properties of resonances in general. The properties of a resonance are also of big importance for an interpretation of its nature. One immediate debate in the light of the possible observation of a pentaquark is e.g. whether the $P_{11}(1710)$ and the $P_{11}(1440)$ might be pentaquarks rather than 3-quark states. A good understanding of their production and decay properties may help to elucidate their nature. At ELSA the photoproduction of different final states has been investigated. To provide an overview, total cross sections measured by the SAPHIR and CB-ELSA experiment are summarized in Fig. **??**.

SAPHIR

An interesting example for the results obtained by SAPHIR, apart from the possible observation of a pentaquark state[?], is the $\gamma p \to K^+\Lambda$-channel. The total cross section shows two bumps at W=1700 MeV, and W=1900 MeV[?]. The enhancement around 1900 MeV, which was observed by SAPHIR for the first time, was interpreted by Mart and Bennhold as being due to a new resonance[?]. It was then identified with a $D_{13}(1895)$, a state which would be in nice agreement with quarkmodel predictions. But its existence is still controversially discussed; in different models the observed

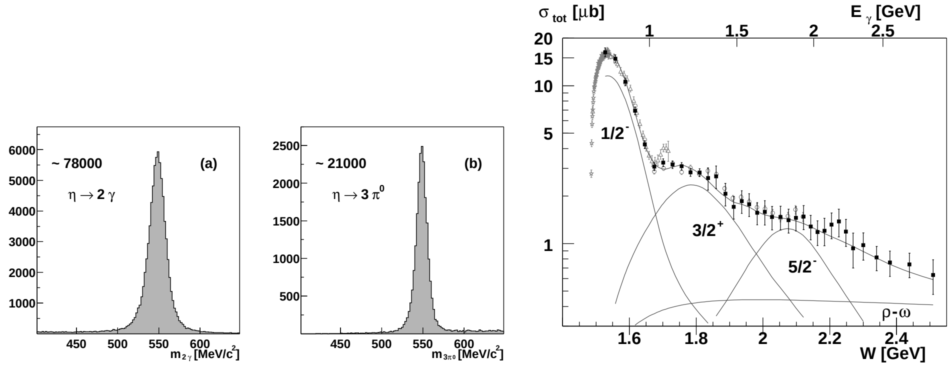

Fig. 3. Left two plots: Invariant $\gamma\gamma$ and $3\pi^0$ invariant mass. Right: Total cross section (logarithmic scale) for the reaction $\gamma\,\mathrm{p} \to \mathrm{p}\,\eta$; CB-ELSA(black squares)[?], TAPS[?],GRAAL[?] and CLAS[?] data (in light gray). The solid line represents the result of our fit.. For further details see [?].

structure is explained by different processes[?]. Recently new high statistics data on this final state became available. SAPHIR[?] and also CLAS[?] did provide new data on cross sections and on the Λ recoil polarization and LEPS[?] on the beam-asymmetry. The new data shows again an enhancement around 1900 MeV. First prelimary results on an interpretation of the higher statistics data have been shown by Mart and Bennhold[?]. Fitting the new SAPHIR data together with the beam asymmetry data from LEPS they find that more than one resonance is needed to describe the mass region around 1900 MeV. This work is still in progress, so no conclusions on the existence of new resonances in the data can be drawn yet.

CB-ELSA

The $\gamma p \to p\eta$-channel

Recently new data on η-photoproduction has been taken by the CB-ELSA experiment, which extends the covered angular and energy range significantly compared to previous measurements[?]. The η was observed either in its $\gamma\gamma$- or $3\pi^0$- decay. The invariant masses show a clear η signal over an almost negligible background (Fig. **??**). The total cross section is also shown in Fig. **??** in comparison to the TAPS[?], GRAAL[?], and CLAS[?] data. It was obtained by integrating the differential cross sections using the result of the partial wave analysis (PWA) discussed below, as an extrapolation to forward and backward angles. The PWA is necessary to extract the contributing resonances from the data. Its result is shown as solid line in Fig. **??**. In the fit the following data sets were included in addition to the CB-ELSA data on $\gamma\mathrm{p} \to \mathrm{p}\eta$: The CB-ELSA data on $\gamma\mathrm{p} \to \mathrm{p}\pi^0$ [?], the TAPS data on $\gamma\mathrm{p} \to \mathrm{p}\eta$ [?], the beam asymmetries $\Sigma(\gamma\mathrm{p} \to \mathrm{p}\pi^0)$ and $\Sigma(\gamma\mathrm{p} \to \mathrm{p}\eta)$ from GRAAL [?], and $\Sigma(\gamma\mathrm{p} \to \mathrm{p}\pi^0)$ and $\gamma\mathrm{p} \to \mathrm{n}\pi^+$ from SAID. Apart from known resonances a new state was found, a $\mathrm{D}_{15}(2070)$ with a mass of $(2068 \pm 22)\,\mathrm{MeV}$ and a width of $(295 \pm 40)\,\mathrm{MeV}$. Its rather strong contribution to the data set is also shown in

Fig.**??**. In addition an indication for a possible new $P_{13}(2200)$ was found. No evidence was found for a third S_{11} for which claims have been reported at masses of 1780 MeV[?] and 1846 MeV[?].

The $\gamma p \to p\pi^0\pi^0$-channel

The $\gamma p \to p\pi^0\pi^0$ cross section was measured by TAPS[?] in the low energy range and by GRAAL[?] up to an incoming photon energy of about 1500 MeV; two peak-like structures are observed. The data has been interpreted within the Laget-[?] and Valencia model[?], resulting in very different interpretations. In the Valencia-model, which is limited to the low energy region, the $D_{13}(1520)$ decaying into $\Delta(1232)\pi$ dominates the lower energy peak, while in the Laget-model the $P_{11}(1440)$ decaying into σp is clearly the dominant contribution.
Recently data on γp $\to$ p$\pi^0\pi^0$ has also been taken by the CB-ELSA experiment extending the covered energy range up the E_γ=3.0 GeV[?]. A PWA has been done to extract the contributing resonances and their properties from the data. The formalism used is summarized in[?]. The fit uses Breit-Wigner resonances and includes s- and t-channel amplitudes. An unbinned maximum-likelihood fit was performed which takes all the correlations between the five independent variables correctly into account. The fits include the preliminary TAPS data[?] in the low energy region in addition to the CB-ELSA data. Resonances with different quantum numbers were introduced in various combinations allowing, so far, for the following decay modes: $\Delta(1232)\pi$, $N(\pi\pi)_s$, $P_{11}(1440)\pi$, $D_{13}(1520)\pi$ and $X(1660)\pi$. For a good description of the data resonances like e.g. the $P_{11}(1440)$, the $D_{13}(1520)$, the $D_{13}/D_{33}(1700)$, the $P_{13}(1720)$, the $F_{15}(1680)$ as well as several additional states are needed. One preliminary result of the PWA is a dominant contribution of the $D_{13}(1520) \to \Delta\pi$ amplitude in the energy range, where the first peak in the cross section occurs. Fig. **??** shows the total cross section obtained by fitting the CB-ELSA and the TAPS data and by integrating the result of the combined fit over phase space. In the CB-ELSA data baryon resonances not only decaying into $\Delta\pi$ but also via $D_{13}(1520)\pi$ and $X(1660)\pi$ are observed for the first time. The enhancements at the corresponding $p\pi$ invariant masses are clearly visible in Fig. **??**. The observation of baryon cascades is also interesting with respect to the search for states which might not couple to πN and γp; they still could be produced in such baryon cascades.

CB-ELSA/TAPS

For the data taking period from 9/2002 until 12/2003, 90CsI crystals have been removed in forward direction to open up a forward region $\pm 30^\circ$ which was then covered by the TAPS detector consisting out of 528 BaF_2 crystals. With this setup, data with unpolarized and linearly polarized photons has been taken using a liquid hydrogen target. The analysis of the data is in progress.
In addition also data with solid targets has been taken to investigate possible medium modifications of mesons in the nuclear medium. The question of interest is

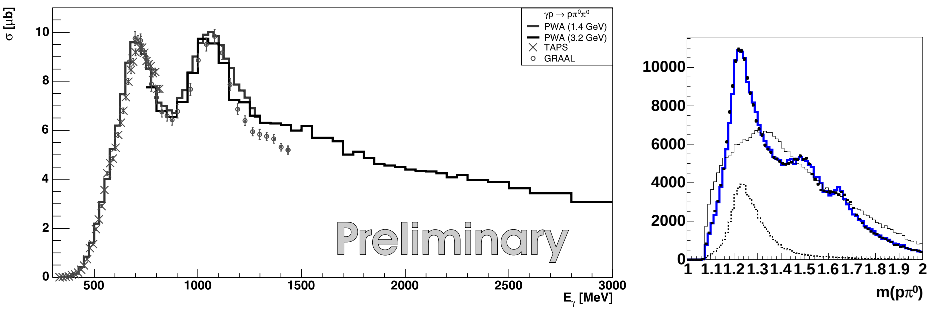

Fig. 4. Left: Total cross section as obtained by integrating the result of the PWA over phase space (solid line), in comparison to preliminary TAPS[?] and GRAAL[?] data. Right: $p\pi^0$ invariant mass for E_γ=0.8-3.0 GeV in comparison to the result of the PWA. The plots shows the experimental data (points with error bars), the result of the PWA (solid gray curve), the contribution of the $D_{13}(1520)$ (dashed black curve) and the phase space distribution (thin black line), preliminary.

here the origin of mass. Hadrons acquire mass because of chiral symmetry breaking. Due to the symmetry breaking the vacuum gains a complex structure ($< q\bar{q} > \neq 0$) and the hadrons gain mass by interacting with this vacuum. The expectation value of the quark-condensate is now expected to decrease with increasing density and/or temperature. Therefore one would expect a partial restoration of chiral symmetry in the nuclear medium resulting also in a change of the meson masses. First preliminary results on $\gamma Nb \to \omega X, \omega \to \pi^0\gamma$ indeed indicate an enhancement at lower ω-masses[?]. The found shape of the signal is in good agreement with calculations[?] assuming an in-medium modification of the ω.

4. Future

After the TAPS detector has left Bonn it is of course necessary to close the forward angular range of $\pm 30°$ again. This will be achieved by a forward detector plug consisting out of the 90 CsI-crystals used in the original detector setup. Differently than the rest of the crystals, which are read out by photodiodes the forward plug crystals will be read out by photomultipliers. This new readout will allow to include the forward plug in the first level trigger. In front of the crystals scintillator plates will be placed to detect charged particles. In addition a Mini-TAPS array will cover the forward angular range further down to 1.5°. Also here plastic scintillators are placed in front of the crystals to allow the discrimination between charged particles and photons. With this detector setup single and double polarization experiments will be performed in 2005. These will help to discriminate between ambiguous solutions in the PWA and will also provide a higher sensitivity to smaller contributions. For the further future it is planned to extent the trigger capabilities of the crystal barrel further to backward angles. This will allow to trigger with high efficiency on rare channels and on channels without any charged particles in the final state measured. In addition it is also planned to install a forward tracking system to be able to detect charged particles such as kaons in forward direction.

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