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Nuclear physics program at MAX-lab*

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Abstract The upgrade of the MAX-lab injector and the construction of MAX Ⅲ, provided the opportunity for upgrading the tagged-photon facility and thus lead to the possibility of more extensive program in nuclear physics research. This upgrade increased the injected electron energy to an eventual maximum of 250 MeV and allows for the extraction of electrons from the MAX Ⅰ ring operated in the stretcher mode. The first stretched beam was delivered in September 2005. The tagged-photon facility was commissioned in parallel with the commissioning of new experimental equipment. The PAC approved experimental program is current in progress, including measurements of pion photoproduction below the Δ(1232). The efforts at the tagged photon-facility are pursued within an international collaboration with around fifty members.

Key words photonuclear reactions, pion production, compton scattering

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1 Introduction

The nuclear physics tagging facility at MAX-lab in Lund was recently upgraded in connection with the upgrade of the MAX-lab injector and the construction of MAX Ⅲ. This upgrade increased the possible injected electron energy to 250 MeV. These electrons are slowly extracted from the MAX Ⅰ Ring operated in the stretcher mode. The nuclear physics experimental area was enlarged to house several large detector systems and provides longer flight paths. Furthermore a new achromatic beam line has been designed and installed together with the tagging spectrometers formerly used at the Saskatchewan Accelerator Laboratory (SAL). The first stretched beam was delivered in September 2005. Since then the tagging facility and the MAX Ⅰ stretcher ring has been commissioned in parallel with the commissioning of new experimental equipment. The experimental program is well underway and frequent run reports are issued on the MAX-lab home page. At present the nuclear physics program have 18 weeks of beam time per year. The currently available electron energy range is 142 to 200 MeV. The electron beam from the injector, operating at 10 Hz, is about 200 ns wide. In MAX Ⅰ this beam is stretched over 100 ms resulting in a duty cycle of about 50%. The intensity of the beam has gradually increased and is at present about 30 nA.

The tagged photon facility at MAX-lab is used for photonuclear experiments with a high degree of precision and a series of experiments are taking data. The efforts at the tagged photon facility are pursued within an international collaboration with around fifty members.

2 The MAX-lab facility

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Lund University. The laboratory is a highly international forum. Nearly half of the scientists working at the laboratory are from foreign countries. The common language at the laboratory is English.

MAX-lab supports three distinct research areas: Accelerator Physics, research based on the use of Synchrotron Radiation, and Nuclear Physics using energetic electrons and tagged photons. Time at MAX-lab is shared between groups working within these three fields.

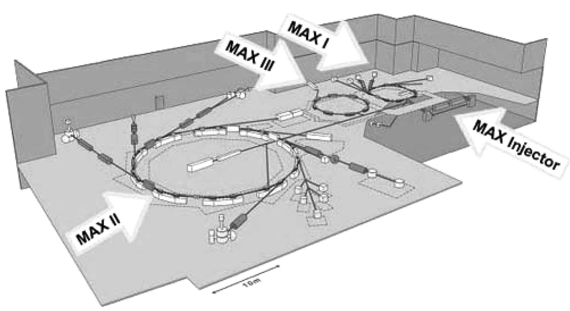

Fig. 1. MAX-lab accelerator and ring layout.

2.1 MAX-lab accelerators

The accelerators at MAX-lab consist of three electron storage rings (MAX Ⅰ, MAX Ⅱ and MAX Ⅲ) and one electron pre-accelerator (MAX injector) (Fig. 1). All three storage rings produce synchrotron light used for experiments and measurements in a wide range of disciplines and technologies. The MAX Ⅰ ring is also used as an electrons source for experiments in nuclear physics.

2.1.1 MAX injector

This accelerator delivers electrons to all three storage rings as well as to the Free Electron Laser (FEL) experiment. The electrons from an RF gun are accelerated in two linear accelerator structures (linacs) and are then recirculated through these linacs by a compact magnet structures of novel type.

Electrons are emitted at the electron gun by the cathode which is either operated in the thermal or photo-electric effect mode. The thermal mode is used for storage ring injection while a short pulse laser is used to generate photo-electrons used for the FEL experiments.

After being pre-accelerated by the RF gun to 2 MeV, the electrons are then further accelerated by two linear accelerators (linacs), each having an energy gain of about 100 MeV. The electron beam can then either be brought upwards to the MAX Ⅰ storage ring or recirculated by two 180 deg bending magnet structures for another acceleration in the linacs up to 400 MeV. These electrons are then injected into the MAX Ⅱ or MAX Ⅲ rings or used for a FEL experiment set up inside the MAX Ⅱ ring.

2.1.2 MAX Ⅰ storage ring

MAX Ⅰ was the first storage ring at MAX-lab, commissioned 1986. The magnet structure is of the Chasman-Greene achromatic type. After commissioning, the MAX Ⅰ ring stimulated synchrotron light science in Sweden. Seven beam-lines were connected to this ring, although more recently the synchrotron light activity is carried out at the MAX Ⅲ ring, which offers a higher performance. In the pulse-stretching mode used for experiments in nuclear physics, the electron beam is injected into MAX Ⅰ via a Lambertson injection septum. The electron pulse, (200 ns long) is wound up in two turns in the ring. These electrons are the extracted gently during the next 100 ms, when a new electron pulse is injected. The electron beam is thus stretched a factor of 500,000.

2.1.3 MAX Ⅱ storage ring

This 3rd generation storage ring was commissioned 1996 and delivers synchrotron light, primarily from insertion devices, in the soft X-ray to hard X-ray spectral region. This ring is equipped with superconducting magnet structures to cover the hard X-ray spectral region. This ring is one of the first of the 3rd generation light sources. The synchrotron light is mainly emitted by insertion devices, wigglers and undulators, placed in long straight sections. The ring design was initially focused on the Vacuum Ultraviolet and soft X-ray region and four undulators are now installed in the ring operating in these regions.

As the need of intense harder X-rays increased, multipole superconducting wigglers with cold bores of a novel type were constructed at MAX-lab. These devices opened up the harder X-ray spectral region.

2.1.4 MAX Ⅲ storage ring

MAX Ⅲ was commissioned 2007. The construction of this ring was motivated by an increasing demand of beam-lines fed by insertion devices which even a fully build out the MAX Ⅱ ring not could match. A cheap, low energy 3rd generation storage ring could then reduce the load on the MAX Ⅱ ring and allow for an expansion of the scientific activity at MAX-lab in all spectral ranges. The same novel magnet technology tried in the MAX injector (see above) was further developed at the MAX Ⅲ storage ring, thereby opening up the possibility to design a new storage ring of unprecedented performance-MAX Ⅳ.

2.1.5 The MAX Ⅳproject

MAX Ⅳ (Fig. 2) is planned to be the next generation Swedish Synchrotron Radiation Facility. It will replace the existing laboratory. The main source at MAX Ⅳ will be a 3-GeV ring with state-of-the-art low emittance for the production of soft and hard X-rays. The linac injector will provide short pulses to a short pulse facility. In addition the MAX Ⅲ ring and an upgraded MAX Ⅱ ring will be reinstalled at the new locations. This solution allows the production of synchrotron radiation with optimal characteristics in a wide energy region, fulfilling the needs of most diverse research areas. The MAX Ⅳ design also includes an option for a Free Electron Laser as a second development stage of the facility. Planning is underway to install a Laser Backscattering Facility for an experimental program in Photonuclear Physics.

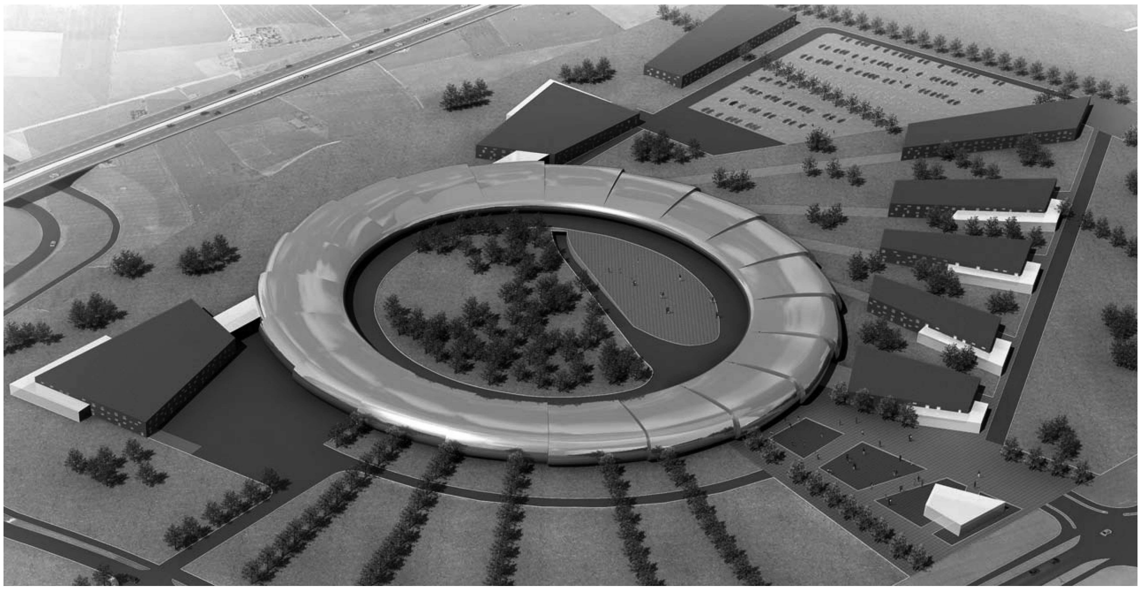

Fig. 2. Design artist conception of the MAX-IV facility.

3 Nuclear physics at MAX-lab

The research program at the upgraded tagging facility was initially discussed at an international workshop in 1997[1] and after that in connection with the Program Advisory (2002, 2004, 2006, and 2008) and Scientific Advisory Committee meetings at MAX-lab. At present the accepted proposals cover the following topics.

3.1 Light nuclei

At the pre-upgrade facility the ^{4}He(γ,n) reaction was investigated in the energy range 25 to 42 MeV[2] and 50 to 71 MeV[3] using two segmented neutron detectors[4] which resulted in seven-point angular distributions. The differential cross sections[5] show a resonant behavior peaking at a photon energy of 28 MeV, in good agreement with newer calculations. Also the photodisintegration of 3He was investigated in the energy range 14 to 32 MeV at 90° with Si-detector telescopes[6]. The 90° differential cross section for the two-body break-up channel was compared to theoretical predictions in order to study the influence of three-nucleon-forces. A prototype He gas scintillator active target was used to study the total absorption cross section in ^{4}He. A new active target has been constructed and new measurements, including detection of neutrons and photons, are in progress at the upgraded tagging facility[7]. These measurements are largely motivated by new ab initio calculations based on the method of Lorentz-Integral-Transforms. This is also the motivation for a new set of measurements of the total photoabsorption cross section for ^{6}Li and ^{7}Li using the attenuation method[8].

3.2 Compton scattering

At the pre-upgrade facility Compton scattering was measured with nominal 10 in × 10 in NaI(Tl) detectors. At that time four such spectrometers were available. Most of the differential cross sections were measured with scattering angles 45°, 60°, 90° and 135°. Studies of ^{4}He, ^{12}C, ^{16}O, ^{40}Ca and ^{208}Pb were mostly done in a parasitic mode downstream other experiments[9]. The last pre-upgrade experiment was Compton scattering on deuterium[10] with the goal to extract the electric and magnetic polarizabilities of the neutron[11]. The cross section was measured in two 10 MeV energy bins (average energies 55 and

66 MeV) at 45°, 125° and 135°, and are in good agreement with previous measurements at University of Illinois.

At the upgraded facility Compton scattering on deuterium has been measured in the energy range 66 to 116 MeV using a LD_2 target. This requires high energy resolution since the break up channel in deuterium is at 2,2 MeV. Three very large NaI(Tl) spectrometers are presently available at MAX-lab; BUNI, CATS and DIANA, all with excellent energy resolutions[12].

3.3 Studies of the (γ,π) reaction

A major consequence of the energy upgrade of the tagging facility is the possibility to investigate the (γ,π) reaction at and close to the pion production threshold. At present the investigations are concentrated on the (γ,π^+) reaction in H, ^{2}H, ^{12}C, and a few heavier nuclei[13]. The existing data set for the proton is limited to measurements close to threshold and above 180 MeV. The goal is to improve this situation to facilitate comparisons with theoretical calculations with e.g. Chiral Perturbation Theory. Three different detector systems are used, a set of dE-E scintillators[14], range telescopes[15], and a Si-strip dE-CsI(Tl) E telescope[16]. The Ge6[17] detector set-up has been tested in combination with Si-strip detectors. These detectors were primarily brought to MAX-lab to study halo nuclei in e.g. the ^{6}Li$(\gamma,\pi^+)^6$He reaction, however, these detectors are available also for other studies.

3.4 Polarized photons

Within the I3HP Hadron Physics Program a coherent bremsstrahlung facility has been designed with the emphasis on the production of polarized photons below 100 MeV. A goniometer system has been built with a diamond radiator and first measurements show clear evidence of the production of polarized photons with about 40% polarization. This program is a collaboration with the groups from Kharkov and Glasgow[18].

3.5 Investigations of knockout reactions

At the pre-upgrade facility a large part of the program was investigations of knockout reactions mainly in the quasi-deuteron region with photon energies above 30—40 MeV. Besides the light nuclei already mentioned the (γ,p) reaction was studied for ^{6}Li, ^{10}B, ^{12}C, ^{14}N, ^{16}O, ^{27}Al, ^{40}Ca, ^{51}V and ^{208}Pb[19]. The emphasis of these experiments and the investigations of the (γ,n) reaction in ^{6}Li, ^{12}C and ^{16}O[19], and the (γ,pn) reaction in ^{6}Li and ^{16}O[19], was the question of the importance of meson exchange currents. The analyses showed that the quasi-deuteron mechanism is the dominating process in the energy range above the Giant Dipole Resonance and below 80 MeV. So far these reactions have not been investigated at the upgraded facility. The ^{208}Pb(γ,p) reaction is studied as possible method to study deeply bound pionic atoms[20].

3.6 Investigations of detector responses to photons

The response of different scintillators to electrons and photons started already at the pre-upgrade facility, however, these investigations have been a more frequent topic at the upgraded facility. Part of the Swedish interest in the FAIR facility is the detector PANDA which will be equipped with a large electromagnetic calorimeter consisting of PWO scintillators. Groups from Uppsala, Stockholm and Lund are studying the response of such detectors using tagged photons from 10 to 120 MeV[21].

4 Pion Photoproduction at MAX-lab

One of the current challenges in nuclear science is to connect the observed properties of the nucleon with the theoretical framework provided by QCD. Since pion photoproduction involves an explicit rearrangement of the quarks in the nucleon, studies of this elementary process are directly probing the strong interaction in terms of the quark description of QCD. At Lund we investigate pion photoproduction in the energy range between threshold and the first-resonance region in order to address this challenge.

Pion photoproduction at energies below the Δ-resonance is one of a few nuclear processes for which exact calculations can be formulated within a QCD-based framework. One of the methods used to perform these calculations is Chiral Perturbation Theory (ChPT). CPT is an effective-field theory which uses the pion and nucleon as the appropriate degrees-of-freedom, and makes use of the known symmetries in order to restrict the form of possible interactions. There are only a few processes for which the multipole analyses can be done well, and for which the results are useful. One such case is pion photoproduction close to threshold, since the inelasticities are well removed, and the multipole decomposition and model-independent predictions from the ChPT calculations converge rapidly and reliably. Accurate measurements of the angular distribution and total cross section for pion photoproduction in the region below the Δ-resonance region therefore play an important role in explicitly testing the predictions from the Chiral Perturbation Theory calculations, and confirming their usefulness.

On a broader note, these new measurements significantly improve the databases used by the SAID and MAID partial-wave analyses. These PWA fits and the resulting parameterizations are used as inputs by various models describing intermediate-energy nuclear processes, as well as model-independent theoretical approaches such as ChPT and dispersion relations. New measurements of pion photoproduction will lead, through these applications, to an improved understanding of other fundamental nuclear processes such as πN scattering, muon-capture reactions, and nuclear Compton scattering.

4.1 Pion photoproduction below the first resonance region

At energies below the two-pion production threshold, there are four reaction channels for pion photoproduction: $\gamma p \rightarrow \pi^+ n$, $\gamma n \rightarrow \pi^- p$, $\gamma p \rightarrow \pi^\circ p$, and $\gamma n \rightarrow \pi^\circ n$. Of these, neutral pion photoproduction from the proton $\gamma p \rightarrow \pi^\circ p$ has been extensively investigated in experiments performed at the SAL and MAMI-B facilities in the early 1990s. These measurements have provided high-quality data on the angular distribution, absolute cross sections and polarization observables for this channel. The two charged channels, $\gamma p \rightarrow \pi^+ n$ and $\gamma n \rightarrow \pi^- p$, have much less available data, with only one modern measurement on each of these channels. The fourth channel $\gamma n \rightarrow \pi^\circ n$ has not been investigated experimentally due to the issues associated with the interpretation of the data coming from "neutron" targets such as ^{2}D or ^{3}He.

4.2 Threshold measurements and the *s*-wave

At energies close to the reaction threshold, the relative angular momentum between the nucleon and pion is predominately s-wave ($l=0$), with some small p-wave ($l=1$) component. The total cross section σ_{total} can be expressed as

$$\sigma_{\text{total}} = 4\pi \left(\frac{q}{k}\right)\left\{|E_{0+}|^2 + |p\text{-wave}|^2\right\},$$

where q is the pion three-momentum and k is the photon three-momentum. Since the p-wave component is proportional to the pion momentum in the center-of-mass frame, this contribution goes to zero at threshold while the s-wave contribution remains finite. Thus, measurements of the pion photoproduction cross section close to threshold allow for a direct measurement of the s-wave amplitudes, and, by extrapolation to threshold, enable the extraction of the fundamental electric dipole E_{0+} amplitude.

4.3 Theoretical considerations

The leading-order terms of the E_{0+} amplitude have been predicted in a model-independent manner using Low-Energy Theorems (LET)[22] based on current algebra and partially-conserved axial current. More recently, Chiral Perturbation Theory has been applied to this process[23]. These ChPT calculations include higher-order terms (through the inclusion of rescattering diagrams) than were possible with the LET calculations. These new calculations have produced predictions for the threshold amplitudes which differ from the older LET predictions, particularly for the neutral pion channels. Charged pion production at threshold is well described by the Kroll-Rudermann term[24] which is non-vanishing in the chiral limit. In the limit of massless pions, the LET calculations predict that the threshold amplitudes for the two charged channels should be equal and opposite, namely $E_{0+}(\pi^+ n) = -E_{0+}(\pi^- p)$. For pions with finite mass, this symmetry is broken and the LET amplitudes decrease in magnitude. The ChPT calculations using the Born, pion, and kaon loops together with ρ-meson exchange, produce results that are very similar to those predicted by the LET calculations. In both cases, the exact value of the amplitudes depends upon the value of the πNN coupling constant used.

In the case of charged-pion photoproduction, the leading Born terms ensure that the contribution of the pion-loop diagrams (and other higher order terms) is small, and that the chiral expansion rapidly converges. This leads to reliable theoretical predictions from ChPT for the threshold value of the E_{0+} amplitudes for the charged channels. Consequently, the experimental investigation of the charged channels very close to threshold can be used to study the convergence of the ChPT calculations. With confidence in these calculations, comparison between theory and experiment can provide new constraints on other inputs to the calculations such as the πN scattering lengths and the πN coupling constant $g_{\pi N}$.

4.4 Experimental measurements

Much of the experimental effort to date has gone into studying neutral pion photoproduction from the proton[25—27] since the predictions for the $E_{0+}(\pi^\circ p)$ and $E_{0+}(\pi^\circ n)$ amplitudes from the ChPT calculations are quite different from the earlier LET predictions. Measurements performed at the SAL and MAMI-B facilities have produced nearly 1200 data points for $\gamma p \to \pi^{\circ} p$ from 10 different data sets, spanning the energy range from threshold to $E_\gamma = 200$ MeV. The agreement between the threshold E_{0+} amplitude determined from this extensive data set and the predictions of the ChPT calculations is good.

In the case of the charged pion channels, most of the existing data is over 20 years old, with only two modern measurements having been performed – one each on the $\pi^+ n$[28] and $\pi^- p$[29] channels. As a result, there are fewer than 50 data points for each of the charged-pion channels at energies below 200 MeV, and these cover only a limited energy and angular range. Clearly, newer, additional high-quality measurements on each of the charged-pion channels would be an important contribution to the study of pion photoproduction near threshold. New data on the $\gamma n \to \pi^- p$ channel closer to threshold than the existing data would go a long way to resolving the issue with respect to the threshold $E_{0+}(\pi^- n)$ amplitude.

4.5 Chiral perturbation theory and the *p*-waves

As the photon energy increases, the *p*-wave contributions begin to become more important, and the cross section description must explicitly include their effect. When the matrix elements describing the pion photoproduction process are written in terms of a multipole expansion truncated at the *p*-wave level, the unpolarized differential cross section can be written as

$$\frac{d\sigma}{d\Omega}\Big|_{l=1} = \left(\frac{q}{k}\right)[A(E_\pi) + B(E_\pi)\cos\theta_{\rm cms} + C(E_\pi)\cos^2\theta_{\rm cms}],$$

where q is the pion three-momentum, k is the photon three-momentum and the parameters A, B, and C are related to the *s*- and *p*-wave multipoles E_{0+}, P_1, P_2 and P_3[1)].

$$A(E_\pi) = |E_{0+}|^2 + \frac{1}{2}|P_2|^2 + \frac{1}{2}|P_3|^2,$$
$$B(E_\pi) = 2\,\mathrm{Re}(E_{0+}P_1^*),$$
$$C(E_\pi) = |P_1|^2 - \frac{1}{2}|P_2|^2 - \frac{1}{2}|P_3|^2.$$

By fitting the three energy-dependent parameters A, B, and C to the differential cross sections it is possible to determine three bi-linear combinations of the four low-energy multipoles, E_{0+}, P_1, P_2 and P_3.

4.5.1 Theoretical Predictions of ChPT

When terms other than E_{0+} are considered (those which contribute to the *p*-waves), it becomes possible to test different aspects of the ChPT calculations. For the $\gamma p \to p\pi^{\circ}$ channel, ChPT calculations of the four *s*- and *p*-wave multipoles have been made to next-to-leading order ($O(p^4)$). On the experimental side, the existence of high-quality data with extensive energy and angular coverage enables the *s* -and *p*-wave contributions to be determined. The ChPT predictions have been compared with the values determined from the experimental results, with good agreement observed between theory and experiment.

Much less is known about the charged pion photoproduction channels from both the theoretical and experimental viewpoints. On the theoretical side, the ChPT calculations are harder to deal with than the neutral pion analogues, and detailed calculations exist only for leading order ($O(p^3)$). This is unfortunate, since the details of the ChPT calculations for the charged channels are different than the calculations for the neutral pion channels, particularly regarding the single-loop contributions and the role of the counter-terms. Consequently, comparison between the ChPT calculations and the results of angular distribution measurements for the charged pion channels will provide an important test of these other terms in the ChPT calculations.

As has been noted earlier, much of the existing data for the charged channels is over 20 years old (with the associated questions regarding the absolute normalizations and the systematic uncertainties), with only a few modern data sets available. Further, these data sets have rather sparse energy and angular coverage. Close to threshold there are only two recent measurements on charged pion production – one each on the π^+[28] and π^-[29] channels, with 45 and 12 data points respectively. Away from threshold, there are three recent measurements of the $\gamma p \to n\pi^+$ reaction (using tagged photons) at energies below 200 MeV[30—32], with a total of 31 data points. No data exists in the energy range from 155—180 MeV.

Some theoretical effort has been undertaken to calculate the *p*-wave multipoles[33]. This work used the existing data on the charged pion channels[28, 29] to make predictions for the *s*- and *p*-wave multipoles at threshold. Overall, these predictions agree reasonably well with existing dispersion relation analyses for these multipoles, however discrepancies as large as 30% exist between the theory and experi-

1) The terms P_{1-3} are related to the traditional *p*-wave multipoles E_{1+}, M_{1+} and M_{1-} via $P_1 = 3E_{1+} + M_{1+} - M_{1-}$, $P_2 = 3E_{1+} - M_{1+} - M_{1-}$ and $P_3 = 2M_{1+} + M_{1-}$.

ment. The predictions for the p-waves, and particularly their energy dependence, have not been directly tested. For this reason, new measurements of the differential cross section for the charged pion photoproduction channels are required in order to better understand the p-wave multipoles, both to extract the threshold values as well as to determine their energy dependence.

New information on the p-wave contribution to charged pion photoproduction will provide a direct handle on the low-energy coupling constants (c_{1-4}) in the ChPT calculations. Currently, these constants are not well constrained, with uncertainties of up to 50%. For example, the determination of the low-energy constants from NN-scattering[34] and πN-scattering[35], have yielded conflicting values for the constants c_2 and c_3. Careful measurements of charged pion photoproduction will enable better constraints to be placed on the low-energy constants.

The values for the low-energy constants are the dominant uncertainty in measurements of πN scattering lengths and scattering volumes. These processes, in particular the P_{33} partial-wave, have been calculated using a ChPT approach in which the N−Δ mass difference is included as an additional parameter (the so-called small scale expansion)[36]. Thus, the results from new measurements of pion photoproduction will serve to improve our understanding of πN-scattering.

In addition to their importance for the ChPT calculations, accurate values for the low-energy coupling constants are an important input in other models; for example, calculations of the two-pion exchange three-nucleon force[34]. Finally, there are theoretical efforts underway to determine the values of these low-energy constants directly using QCD-lattice calculations[38]. It is therefore crucial that the values for the low-energy constants are determined from a range of experiments.

4.6 Partial wave analyses

To interpret pion photo- and electroproduction data with respect to aspects such as their threshold behaviour and baryon resonances, a partial-wave analysis is essential. Such analyses, with constraints provided by the requirement to satisfy unitarity and gauge invariance, as well as input from πN scattering analyses, are produced by the SAID and MAID groups.

The sparse data currently available for iso-vector pion production results in poorly constrained fits produced by these partial-wave analyses. New, high-quality measurements of the charged pion photoproduction channels will significantly improve the databases which are at the core of the MAID and SAID fits. Without new, high-quality measurements of total and differential cross sections for the charged channels which match the extent and quality of the recent data for the neutral pion channel, the comparatively substantial π° data cannot be exploited to separate the isospin channels in a model-independent manner[37]. Such analyses are important now that predictions based upon the iso-vectoral pieces of the ChPT Lagrangian are being made. These predictions are largely unchecked, as theory is well ahead of experiment[39].

At present, the partial-wave solutions from MAID[41] and SAID[42] exhibit rather large differences at energies below the Δ-resonance. As a result, there are large uncertainties in the non-resonance background amplitudes. The properties of the higher lying baryon resonances are determined from PWA fits to the data, and these fits depend strongly on the details of the non-resonance background. Consequently, high-quality measurements on charged pion photoproduction in the energy range below the Δ-resonance are critical to the accuracy of the PWA fits, and thus to the reliability of the resonance parameters extracted from these fits.

The MAID and SAID partial-wave analyses are also important for any dispersion relation analysis of processes involving pions and/or photons, since these relations rely heavily on the accuracy of the data for their analytical continuation. Dispersion relations connect kinematically different processes such as Compton scattering and pion photoproduction by analyticity of the S-matrix, thus they can serve as a method to check the consistency of experiments involving the different processes. This is particularly useful when there are discrepancies between theory and experiment, or if the experiments in one regime are difficult. One example of this is the determination of spin-polarizabilities from Compton scattering. There is an active effort at MAX-lab to investigate Compton scattering from proton, deuteron and nuclear targets[40], and the availability of high-quality pion photoproduction data would complement this effort.

Finally, it must be noted that to be most effective, the partial-wave analyses such as MAID (which makes use of particular models) and SAID (which is, as far a possible, model-independent) require comparable databases for the charged and neutral channels. At present, these databases are not comparable.

Despite the importance of such data, there are only a few modern (tagged photon) measurements of the $\gamma p \rightarrow n\pi^+$ reaction at energies below $E_\gamma = 200$ MeV, and none between threshold and 180 MeV. At low energies, facilities such as LEGS at Brookhaven National Laboratory in the United States, SAL in Canada, MAMI at Mainz, Germany, together with the photon tagging facility now in operation at MAX-lab in Lund, provide the means and opportunity to perform precision measurements of pion photoproduction at energies near threshold. With the closure of the SAL and LEGS photonuclear facilities, and the MAMI energy upgrade to 1.5 GeV, MAX-lab is one of the few facilities where pion photoproduction in the threshold region will be investigated.

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