Concerning: Theory Viewpoint on Extracting Nucleon Polarisabilities in Low-Energy Compton Scattering

During the workshop Compton Scattering off Protons and Light Nuclei: Pinning Down the Nucleon Polarisabilities at the ECT* (Trento, Italy), we have been asked by our experimental colleagues to summarise the present common theoretical understanding on the feasibility of extracting the static dipole scalar and spin polarisabilities from low-energy Compton scattering off the proton and light nuclei. These quantities parametrise the deformation of the nucleon in external electric and magnetic fields, and lattice QCD results for them are emerging. Besides being fundamental properties of the nucleon, they play an important role in the Lamb shift of muonic Hydrogen as well as in radiative corrections to the proton charge radius, and provide the biggest source of uncertainty in theoretical determinations of the proton-neutron mass shift. Spin polarisabilities parametrise the optical activity of the nucleon and test its spin degrees of freedom. Scattering on light nuclei allows one to differentiate between proton and neutron values, and thus to study chiral symmetry breaking.

As highlighted in the Long-Range Plans in the USA (NSAC 2007, NAS 2012) and Europe (NuPECC 2010), this vibrant and renewed theoretical interest prompted a new generation of high-accuracy facilities with unpolarised and polarised photon beams and targets to focus on Compton scattering. Interpreting such data needs commensurate theoretical support for interpretations with minimal theoretical bias.

Our credentials are publications in a range of theoretical approaches to the problem, namely several variants of both Dispersion Relations and Effective Field Theories [1–18]. We agree on the following statements.

Compton scattering up to the first resonance region can roughly be divided into three regimes of different theoretical interest. The transition from one regime to another is of course gradual rather than sudden.

In the first regime, comfortably below the single pion production threshold, our theoretical approaches contain very similar physics. Therefore, an extraction of static polarisabilities by running cross sections and other observables down to zero energy suffers only from minimal discrepancies between the different theoretical approaches. At these scales, this running is dominated by the physics of the pion cloud, which is for these energies adequately captured by each approach. We therefore anticipate that when the same data is used by different approaches, their values for the static polarisabilities will agree very well. Scalar polarisabilities should be extractable with high theoretical accuracy and minimal theory error. The same holds for the spin-polarisabilities – if the necessary experimental accuracy can be reached. At present, single and double polarised data is sorely missed.

In the second regime, around and above the pion production threshold, the sensitivity to the spin polarisabilities is increased. The different theoretical approaches still largely agree, but different physics at this scale leads to some discrepancies. Data in this regime
will help to understand and resolve these issues and provide first values for the spin polarisabilities, triggering even more theoretical efforts.

In the third regime, around and above the $\Delta(1232)$ resonance, all theoretical approaches gradually become less reliable for different reasons. In Dispersion Relations, an accurate inclusion of the two-pion production process in present formulations becomes crucial and is subject to further investigation. In Effective Field Theories, the dimensionless expansion parameter starts to approach unity, indicating increasingly worse convergence. At present, all theoretical approaches must thus resort to well-motivated but not fully controlled approximations. Concurrently, sensitivity to the static polarisabilities decreases substantially. Taken together, this makes their extraction from data at these energies less reliable. Instead, one gains access to details of $\Delta(1232)$ resonance properties, as well as potential information on the degrees of freedom exchanged between photons and the nucleon in the t-channel. Data in this regime will help improve our theoretical understanding of the lowest nucleonic resonance, of excitations with the same quantum numbers as the QCD vacuum, and of the interplay between the two.

In summary, we strongly support our experimental colleagues in their goal to provide data of great relevance and high accuracy with reliable systematic uncertainties. Only a concerted effort of both experiment and theory will improve our understanding of the two-photon response of the nucleon. We thus look forward to study with them the sensitivities of both unpolarised and polarised cross sections and asymmetries of protons and light nuclei on scalar and spin polarisabilities. This will lead to strong experimental proposals which address these fundamental questions. In the longer term, we welcome a complete set of experiments up to the pion production threshold to disentangle detailed information from the energy dependence of the Compton multipoles.

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