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Proton & Neutron Polarizabilities with Compton Scattering from Low-Mass Nuclear Targets at the High Intensity Gamma-ray Source (HIGS)

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The Compton@HIGS collaboration is embarking on a program of absolute differential cross-section measurements of elastic Compton scattering from 1H [1], 2H , 3He , and 4He [2,3] nuclei over a wide range of scattering angles at energies below the pion production threshold. Using a Chiral Effective Field Theory (EFT) framework [4], we can extract the electric and magnetic polarizabilities of protons and neutrons. These quantities characterize the response of a nucleon's internal degrees of freedom to external electromagnetic fields and offer insight into its internal dynamics. They provide stringent tests of Quantum Chromodynamics (QCD) at low energies in the non-perturbative regime, serving as a bridge between EFTs and lattice QCD calculations, which can now be performed at the physical pion mass [5]. Proton polarizabilities are also an important input in determining the proton charge radius. Despite their significance, these quantities remain relatively poorly constrained; for example, the neutron's electric and magnetic polarizabilities (α_n and β_n) are known to approximately $\pm 10\%$ and $\pm 30\%$, respectively. While the proton's electric and magnetic polarizabilities (α_p and β_p) are better known, there is an approximate 2σ tension between our recent proton electric polarizability result and that from MAMI [6].

To measure these nanobarn-scale cross-sections at the few-percent level, our collaboration uses ~ 60 – 110 MeV monoenergetic, linearly or circularly polarized photon beams from the free-electron-laser-based High Intensity Gamma-ray Source (HIGS) at the Triangle Universities Nuclear Laboratory (TUNL). This is combined with an array of large NaI detectors—featuring single-crystal cores up to ~ 90 L in size—and a cryogenic liquid target system capable of reaching temperatures down to ~ 1.5 K. The target includes optical access and thin-walled, low-background windows to a 0.3-liter-sized liquid cell. In the summer of 2024, we completed our first runs with liquid 3He at nominal energies of 60 MeV and 100 MeV, safely handling 350 STP-bar-L of 3He inventory, and achieved our operational temperature and stability goals. These results should improve our uncertainties in α_n and β_n by approximately a factor of two. In parallel, we have initiated R&D efforts for a scintillating polarized proton target, which is essential for our future intent to measure proton spin polarizabilities.

[1] Li et al. (Compton@HIGS), Phys. Rev. Lett. 128, 132502 (2022)

[2] Sikora et al. (Compton@HIGS), Phys. Rev. C 96, 055209 (2017)

[3] Li et al. (Compton@HIGS), Phys. Rev. C 101, 034618 (2020)

[4] Griesshammer et al., Prog. Part. Nucl. Phys. 67, 841 (2012)

[5] Wang et al., Phys. Rev. Lett. 133, 141901 (2024).

[6] Mornacchi et al., Phys. Rev. Lett. 128, 132503 (2022)

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