Underground measurements of the $^{14}N(p,\gamma)^{15}O$ reaction at LUNA*

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An accurate understanding of the slowest reaction in the CNO cycle, $^{14}N(p,\gamma)^{15}O$, is essential for determining the lifetimes of massive stars and globular clusters, as well as for accurately predicting the solar CNO neutrino flux. Despite extensive experimental efforts over the past two decades, including pioneering underground campaigns by the Laboratory for Underground Nuclear Astrophysics (LUNA) collaboration, this reaction remains a significant source of uncertainty in astrophysical models, largely due to the challenges in directly measuring its extremely low cross section at solar energies.

To address this, two complementary experimental programs have been undertaken by the LUNA collaboration. The *SOCIAL project* (SOlar Composition Investigated At Luna), performed at the LUNA-400kV accelerator in the Laboratori Nazionali del Gran Sasso (LNGS), focuses on reducing the uncertainty in the extrapolated $^{14}N(p,\gamma)^{15}O$ cross section through new low-energy measurements of total and partial cross sections. The experiment utilizes solid nitrogen targets bombarded by high-current proton beams and detects emitted gamma rays with a segmented 4π BGO detector array. Event-by-event digital acquisition combined with gamma-gamma coincidence analysis and detailed Geant4 simulations allows for an improved determination of the cross sections at energies approaching the solar Gamow window.

In parallel, as a pilot study for the new deep-underground *Bellotti Ion Beam Facility* at LNGS, an independent measurement has been performed focusing on the angular distribution of the emitted gamma rays in the energy range 0.3 to 1.5 MeV. This experiment employed Tantalum Nitride solid targets and HPGe detectors achieving excellent sensitivity in synergy with the high-current 3.5 MV accelerator. New differential cross-section data were obtained, including several weaker transitions not observed in previous studies, providing a comprehensive picture of the reaction dynamics in the explored energy range.

Together, these two complementary measurements - one targeting precise total and partial cross-section data at low energies and the other providing new angular distribution results at higher energies - represent a significant step forward in constraining the $^{14}N(p,\gamma)^{15}O$ reaction rate and refining predictions for the solar CNO neutrino flux and stellar evolution models.

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*On the behalf of the LUNA collaboration