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Intrinsic energy resolution of the liquid argon scintillation signal

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Liquid argon (LAr) detectors are widely used in modern astroparticle and neutrino physics, with experiments such as DarkSide-20k, DEAP-3600, and DUNE relying on their scintillation response. A precise characterisation of the energy resolution is essential for optimising the sensitivity of these experiments to rare events, improving neutrino energy reconstruction, and lowering detection thresholds.

In organic and inorganic scintillators, a contribution to the energy resolution is observed that cannot be described by photoelectron statistics, PMT response, or light collection non-uniformities, and is referred to as the intrinsic resolution of the scintillation medium. In this work, we test whether a similar contribution is present in the energy resolution of the liquid argon scintillation signal. Using a phenomenological model that separates independent fluctuation sources, we extract an effective parameter that characterises the intrinsic resolution at 1 MeV from three independent datasets. Afterpulses falling within the PMT signal window are not accounted for in the statistical term extracted from PMT calibrations performed in a short window, and must therefore be added explicitly. Together with the fluctuations due to photon re-emission at the TPB wavelength shifter, these contributions fully account for the extracted parameter: after their subtraction, effective parameter is compatible with zero, and no additional intrinsic component is needed.

This result holds consistently across all three datasets. It indicates that the measured energy resolution of LAr scintillation detectors can be described by these contributions alone, without invoking an intrinsic resolution of the scintillation medium itself, in contrast to what is observed in organic and inorganic scintillators. The fluctuations due to photon re-emission at the TPB wavelength shifter may, in turn, provide a key to understanding the line-broadening mechanism observed in organic scintillators. These findings have direct implications for the interpretation of the energy resolution in large-scale LAr detectors with light yields of several thousand p.e./MeV.

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