Noble Element Simulation Technique

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NEST

NEST Scintillation and Ionization Model

NEST offers a unified, heuristic model of noble element scintillation and ionization. Energy deposition in a noble element leads to excitation and ionization. Ionization electrons can either escape from the interaction site or recombine and add to the primary scintillation light. One task of NEST is to correctly model the recombination probability. This is achieved in one of two ways. The recombination probability for "long," high-energy tracks is modeled with a modified Doke-Birks Law and "short" tracks with a Thomas-Imel Box approach, both of which are shown below.

Long tracks

$$r = \frac{A\frac{dE}{dx}}{1+B\frac{dE}{dx}} + C$$

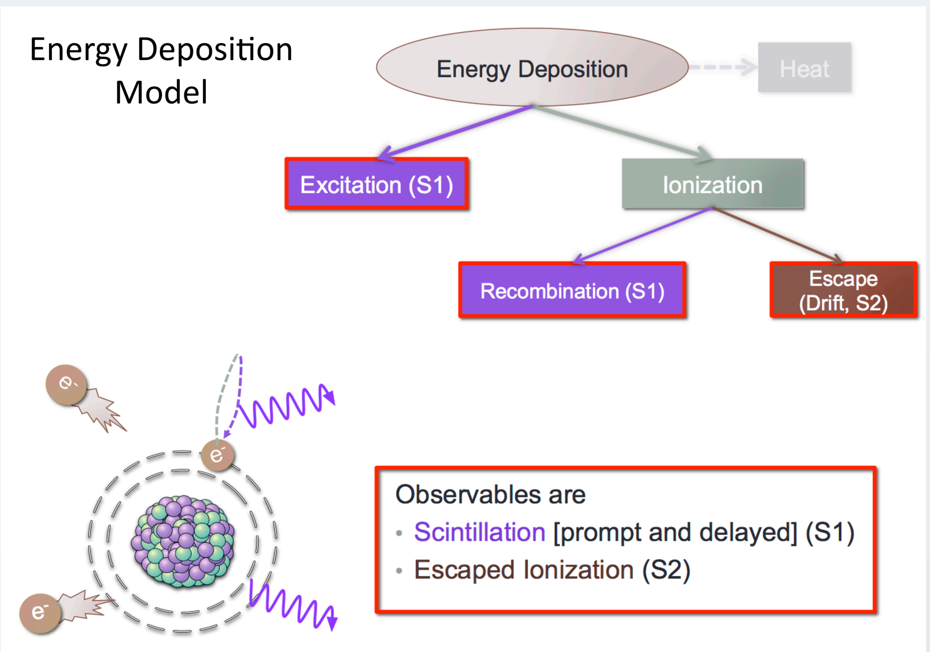
$C = 1 - A/B$

Short Tracks

$$r = 1 - \frac{\ln(1+\xi)}{\xi}$$

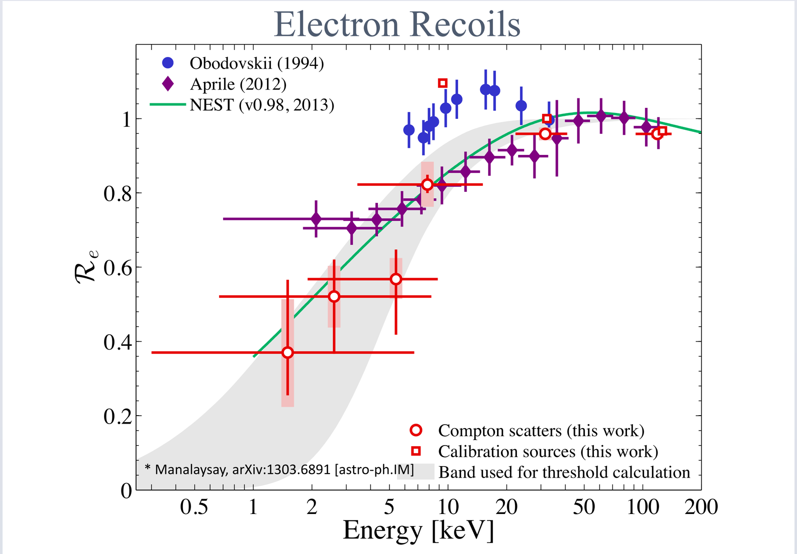
$$\xi = \frac{N_i\alpha'}{4a^2 v}$$

$$N_\gamma = N_{ex} + rN_i$$
$$N_{e^-} = (1-r)N_i$$



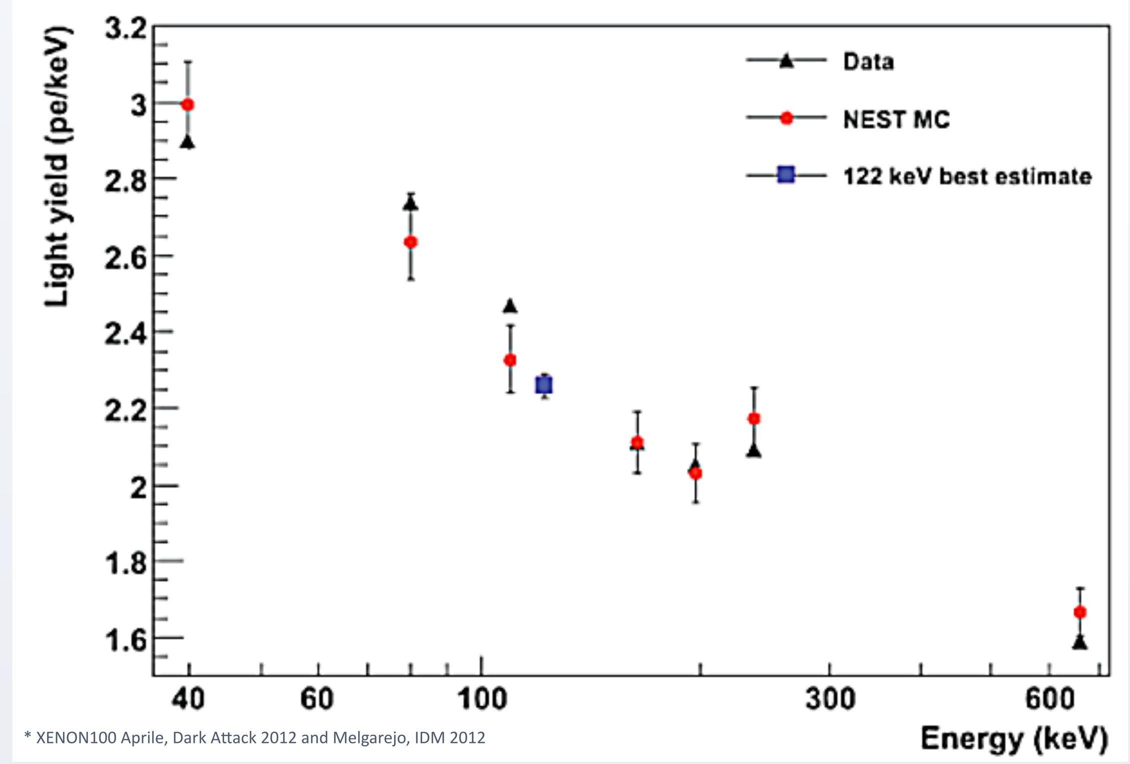
Zero Field Comparison to Data

The NEST model is an empirical one based on past detector data, but does not simply spline the data. Instead, it models the microphysical processes to predict, with excellent agreement to new data, the macroscopic light and charge yields for electron and nuclear recoil events. Comparisons between NEST predictions and actual data are shown below.



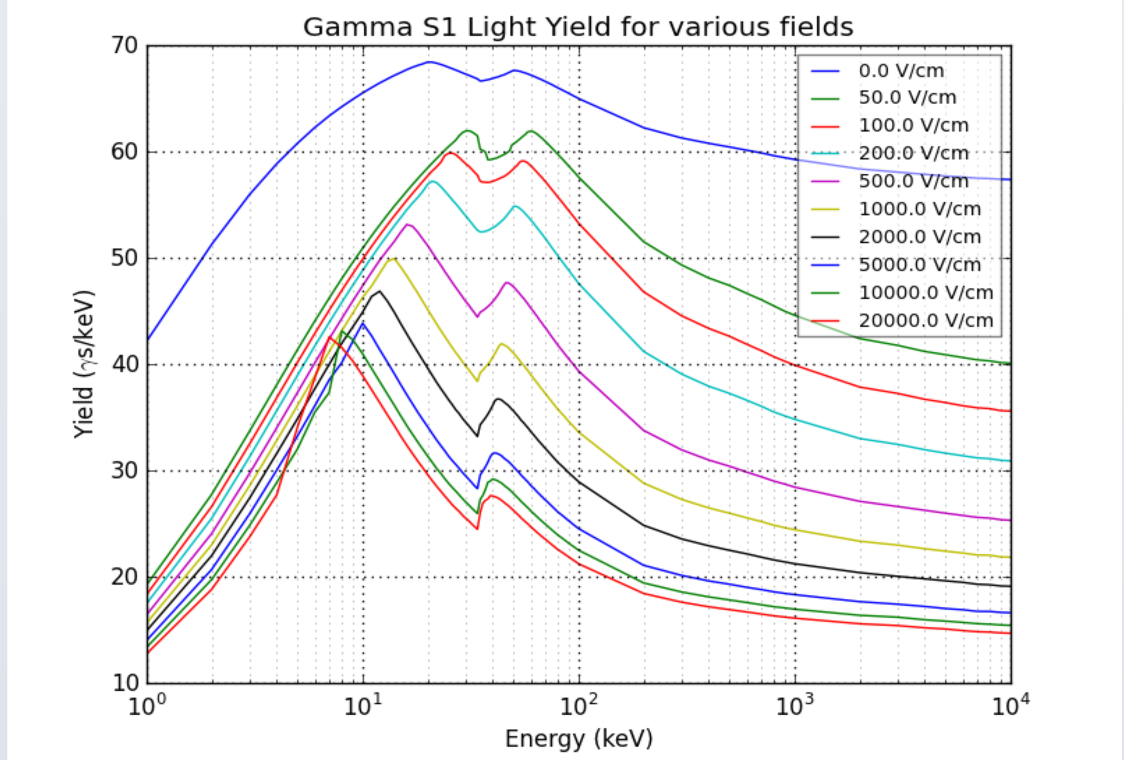
Predictive Power of NEST

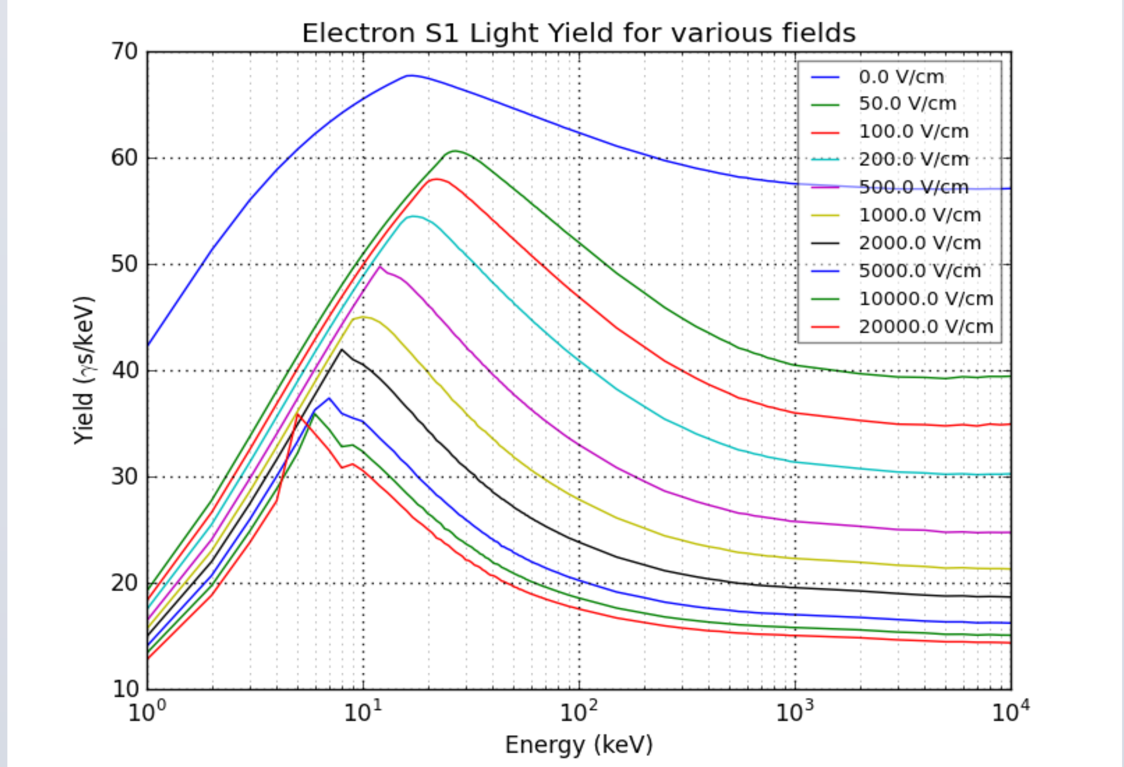
XENON100, a dual phase xenon dark matter detector, used NEST within Geant4 to compare their data with the energy-dependent prediction and observed excellent agreement.



NEST with Applied Electric Field

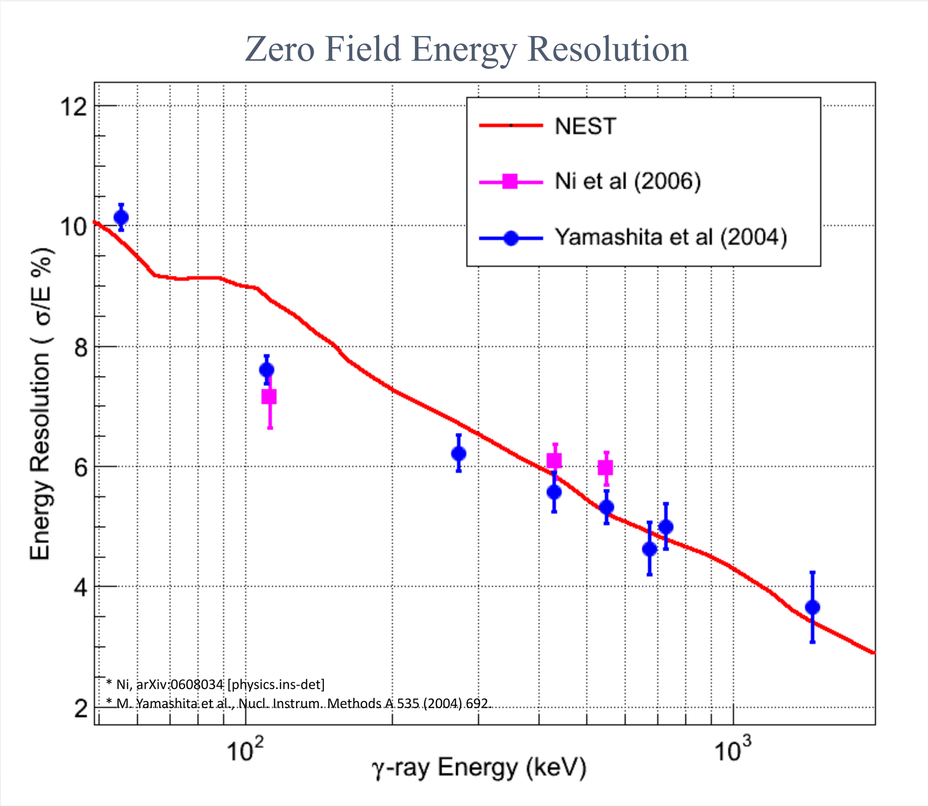
Many rare event searches incorporate an applied electric field to drift the ionization electrons to a charge collector or an acceleration region, to reconstruct position as well as discriminate between nuclear and electron recoil by considering the ratio of charge to light. The recombination decreases as applied field increases. Here we present the light yield as a function of energy at various electric fields.

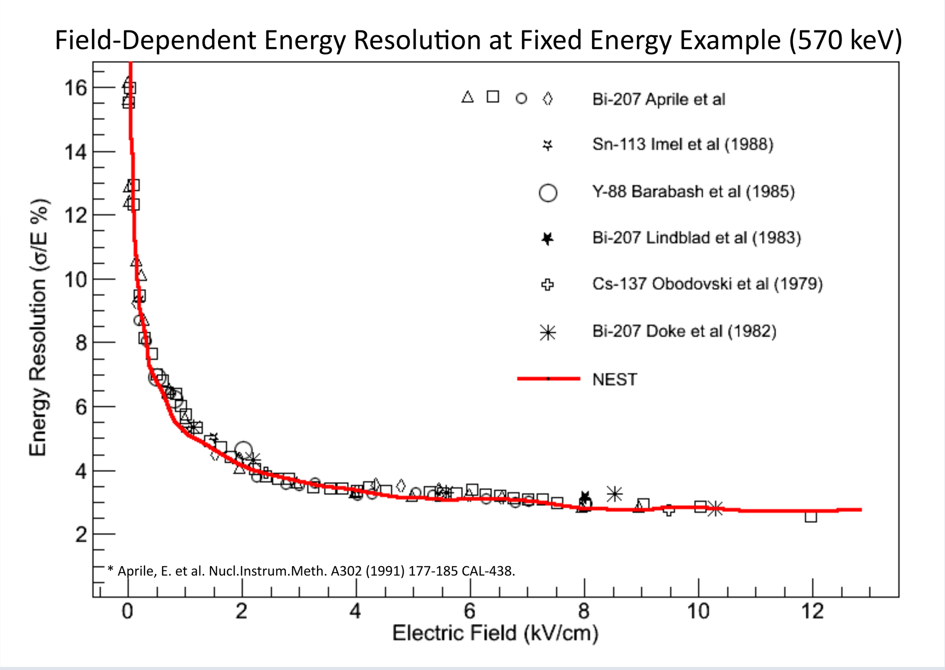




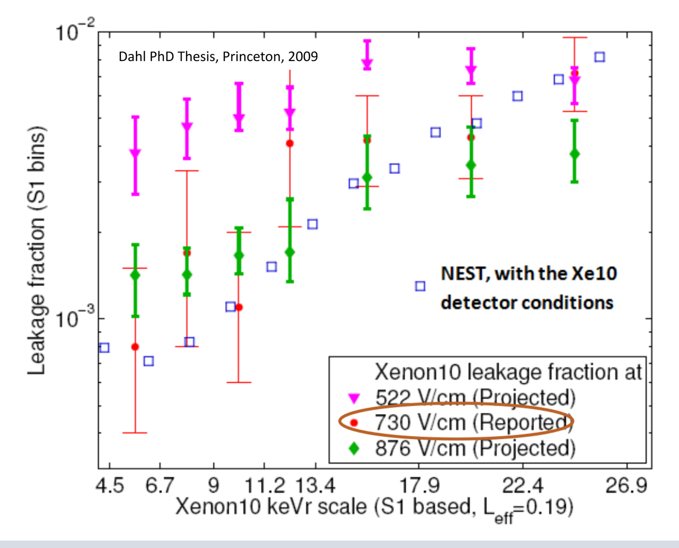
Energy Resolution

Stochastic variation in the mean yields must be added to model real detectors as closely as possible. To complicate matters, the energy resolution of a noble element detector is not smooth vs. energy. NEST incorporates the Fano factor when calculating the sum of light and charge. For recombination, a correction is added to match historical data. It is a "Fano-like" factor that is field-dependent, but independent of energy except at low energies, creating worse-than-Poisson fluctuations. This is the only parameter in NEST in need of better physics motivation. All others can be explained from first principles.





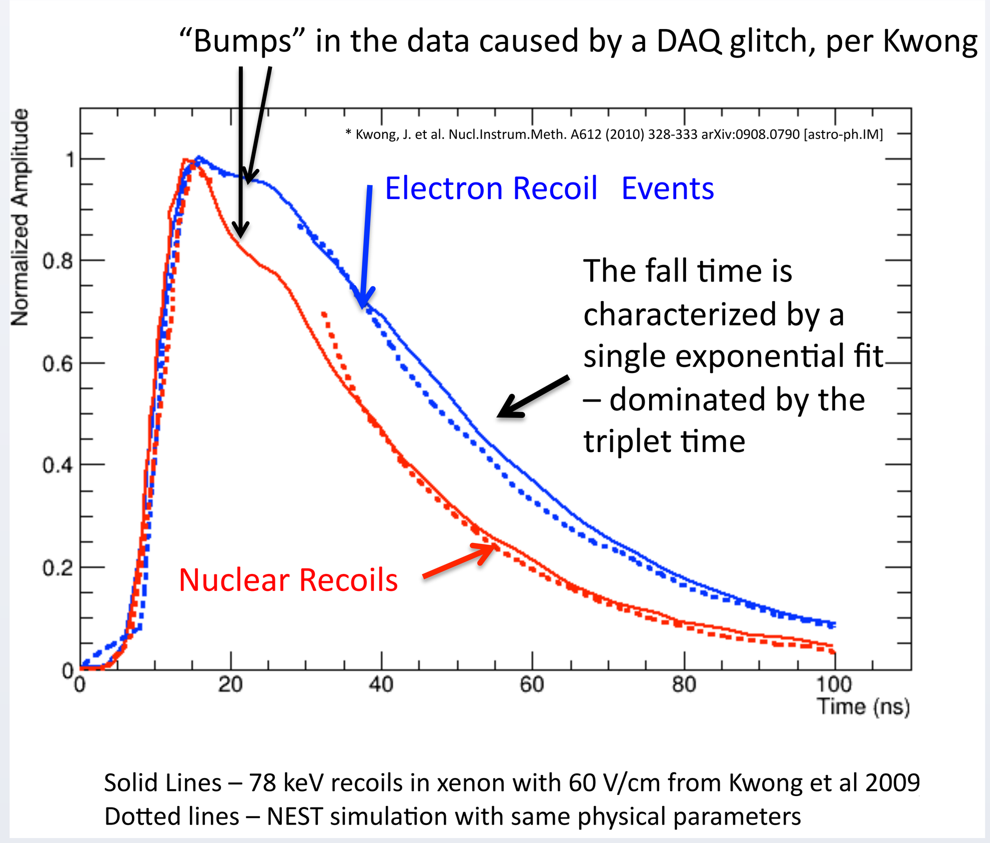
In order to build a model of energy resolution as it relates to field strength, available older data was incorporated, to calculate the dependence of the additional, non-Poissonian recombination fluctuations on field. As is shown at both zero and non-zero electric field, NEST now accurately post-dicts resolution.



For XENON10 the NEST model accurately predicts the leakage fraction, the fraction of electron recoil events (background) misidentified as nuclear recoil events (potentially dark matter), vs. energy, given the reported 730 V/cm field. To give context for the field-dependence, points at other fields are shown from Dahl, upon whose seminal work much of NEST is based.

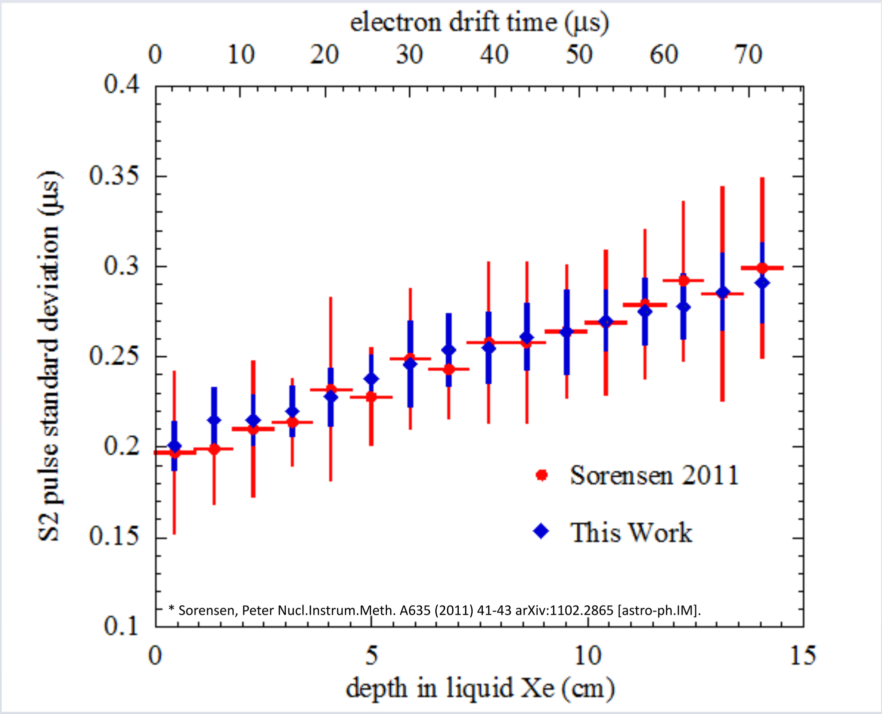
S1 Pulse Shape

The primary scintillation, or S1, is produced either via direct excitation or recombination. Its shape (time profile) is determined by the singlet and triplet decay times of the medium as well as the recombination time. The dominant feature is the exponential triplet time. The recombination time is only relevant for electron recoils, and its time constant is modeled as proportional to the inverse of the recombination probability. As electric field increases, the recombination time vanishes and electron recoils look more like nuclear recoils.



S2 Pulse Shape

The electroluminescence or S2 pulse is created in two-phase detectors. The ionization electrons are drifted from the bulk liquid target and extracted into the gas phase where they are accelerated. This produces a secondary scintillation signal. The features that define the S2 pulse shape are the drift speed which is constant, set by the electric field strength, and the diffusion of drifting electrons. Only longitudinal diffusion in liquid has a noticeable effect, and the electron trapping time. The latter is the effect of becoming trapped at the liquid/gas interface before extraction. All of these effects are in NEST and are plotted below step by step. The plot below demonstrates the power of these effects by plotting the width of the S2 pulse as it varies in depth for simulated data compared to real detector data.



More Information

For more information or to download the software, please visit our website
* nest.physics.ucdavis.edu

Please also see our publication:

* Szydagis, M. et al. JINST 6 (2011) P10002 arXiv:1106.1613 [physics.ins-det]