Modeling the Energy Resolution of Xenon with NEST

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Introduction

Noble Element Detectors

➔ Dark Matter Detectors (LUX, Xenon100, DarkSide, etc...)
➔ Neutrino-less double-beta decay (EXO, NEXT, etc...)

Light yield is non-monotonic at low energies

➔ Incident particle type
➔ dE/dx
➔ Electric field

Discrimination

➔ Stochastic variations
Adding Stochastic Variation

Fano Factor

Ionization

Excitation

Recombination

Fano-like Factor

Low Energy Correction

Scintillation

Escaped Electrons
At Zero Electric Field

- Non-monotonic behavior
- Rich features emerge
- Matches zero electric field data
Electric Field Dependence

- Regular Fano factor left alone
- Recombination fluctuations have been modeled as a bounded Gaussian, with a sigma of $\sqrt{F_e \times N_e}$, per interaction site
- Field-dependent but energy-independent
Non-Zero Electric Field

Good simulated resolution will allow us to predict the discrimination power of any detector as a function of field and energy.

Energy Resolution ($\sigma/E\%$) vs Electric Field (kV/cm)

- Bi-207 Aprile et al
- Sn-113 Imel et al (1988)
- Bi-207 Lindblad et al (1983)
- Cs-137 Obodovski et al (1979)
- Bi-207 Doke et al (1982)
- NEST 570
Low Energy Corrections

At low energies, the recombination probability depends on the energy, via the number of ions, and not on dE/dx

- Required a switch from Doke-Birks to Thomas-Imel model

- Introduce an empirically derived multiplicative factor, \( \sqrt{a \cdot F_e^* N_e^*} \)

- Used 876 V/cm data to ground the NEST model

- The anomalously high \( (F_e \sim 10-100) \) recombination fluctuations at high energies are smoothly extrapolated down to 0
The undulations are an “emergent property” of NEST, caused by the “battle” between the increasing energy and the increasing variance.

ER vs NR Discrimination

After the improvements to the recombination model:

- NEST exhibits the correct behavior for low-E discrimination!
- Can make general predictions for present and future detectors of differing light collection efficiencies and electric fields.
Summary

➔ Model behavior from 0 to high electric fields
➔ The emergent properties match real data
➔ Stochastic variations properly models discrimination power
➔ Reproduces correct energy dependence at low and high energies
Back Up Slides
Gaseous Xenon

We can generalize our field-dependent model to be density-dependent, and use it to fit gas data effectively.

The plot at bottom left from Bolotnikov 1997 and Nygren 2009 was considered a bit mysterious: we now have a model to explain it (though it still needs more physical motivation quantitatively).

NEST has ever-broader applications (double beta decay in this case).