THE NOBLE ELEMENT SIMULATION TECHNIQUE (NEST)

A Model of Scintillation and Electroluminescence in Noble Elements

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Breakdown of N.E.S.T.

Noble Element

- Thinking of He, Ne, Ar, Kr, Xe, Rn
- Non-reactive.
- Filled electron shells.

GEANT4

- Standard simulation toolkit.
- NEST adds accuracy to scintillation physics.

Scintillation

- Response of a material to the passage of particles to create light.
- Incoming particle causes molecular excitation.
Why simulate scintillation noble elements well?

• Direct dark matter detection experiments
  • Calibration for LUX, XENON, ZEPLIN, LZ, WArP, DarkSide, ArDM, XMASS, DARWIN, MAX, Xürich, Xed, XeCube, PANDA-X, PIXeY, DEAP, CLEAN, ... 1- and 2-phase

• Double beta decay ($0\nu\beta\beta$, $2\nu\beta\beta$)
  • NEXT, EXO

• Positron Emission Tomography (PET) scans for medical applications: detect 511 keV γ’s
  • Other particle detection applications, e.g. collider experiments (MEG, Olive, et al.)
Purpose of NEST

- Create full-fledged simulation based on a physical, albeit heuristic/quasi-empirical approach.
- Unify simulation response across the many dark matter, double beta decay, and other experiments.
  - For both electron recoil (BG) and nuclear recoil (BG and signal)
- Started with LXe (for sake of LUX)
Scintillation Path

- Energy Deposition
- Excitation (S1)
- Ionization
- Recombination (S1)
- Escape (Drift, S2)
Scintillation Path

Observables are
- **Scintillation** [prompt and delayed] (S1)
- Escaped Ionization (S2)
Excellent Yield Agreement

- Photon yield
- Relative to the 32 keV $^{83m}$Kr line
  - 150 PE

Nuclear Recoil

![Graph showing the relationship between nuclear recoil energy (keV) and relative scintillation efficiency, with data points and trend lines for Plante 2011, Manzur 2010, Horn 2011 First SR, Horn 2011 Second SR, and NEST.](image-url)
Quanta Manipulation

- Cornerstone: the work function for either quantum (γ or electron) is the same.

\[ N_q = (N_{e^-} + N_\gamma) = \frac{E_{dep}}{W} \]

- But how much \( N_\gamma \) vs \( N_{e^-} \)?
  - This partitioning is key.

- The recombination of ions to form the total number of photons and escaped electrons is what NEST gets right.

\[ N_\gamma = N_{ex} + rN_i \]

\[ N_{e^-} = (1 - r)N_i \]
Modeling Recombination

Long tracks

- Doke-Birks model.
- Model recombination with bulk ions along a track.

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

\[ C = 1 - \frac{A}{B} \]

Micron scale

Short Tracks

- Thomas-Imel box model
- Model recombination with electron/hole mobilities, dielectric constant, temperature.

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

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

\[ N_\gamma = N_{ex} + r N_i \]

\[ N_{e^-} = (1 - r) N_i \]
Argon

Agreement with applied electric fields

- Back to Xe
- 450 V/cm field
- Quenching factor
  - The proportionality of scintillation yield at field to zero field.

![Graph showing q(450) vs Energy [keV] with various data points and labels such as Compton scatters, Calibration sources, Manalaysay (2010), Aprile (2006), NEST (v0.98, 2013).]
Predictive power

XENON100 Aprile, Dark Attack 2012 and Melgarejo, IDM 2012
Runtime Performance Impact

• Core physics and quanta calculation before propagation.

• All the accuracy, negligible performance degradation.
  • Some fraction of events faster than default Geant4 physics.

• Sub-dominant to photon propagation.
Summary

- Noble element simulation with GEAN4.
- Very fast computationally.
- A breakthrough in accuracy thanks to microphysics modeling.
- ER, NR, field dependence, and more.

Paper

- For all of the references used in this talk, please consult the full bibliography of
  - M. Szydagis et al., NEST: A Comprehensive Model For Scintillation Yield in Liquid Xenon 2011 JINST 6 P10002. arxiv:1106.1613
  - http://nest.physics.ucdavis.edu