THE NOBLE ELEMENT SIMULATION TECHNIQUE (NEST)

A Model of Scintillation and Electroluminescence in Noble Elements

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NEST

Collaborators

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Breakdown of N.E.S.T.

Noble Element

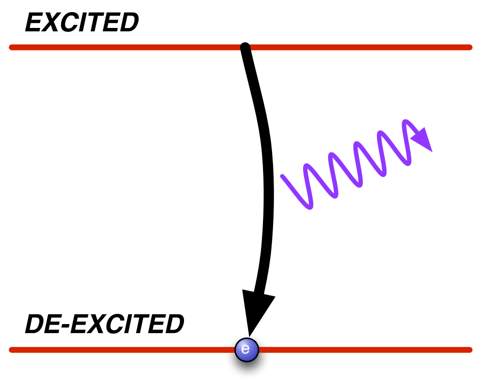
- Thinking of He, Ne, Ar, Kr, Xe, Rn
- Non-reactive.
- Filled electron shells.

GEANT4

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

Scintillation

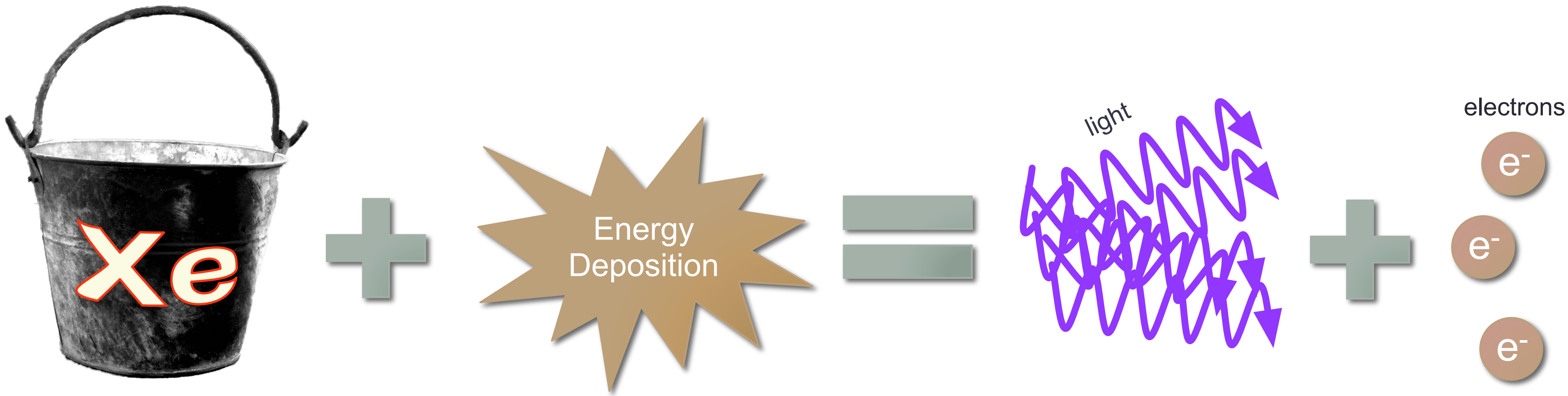
- Response of a material to the passage of particles to create light.
- Incoming particle causes molecular excitation.



Why simulate scintillation noble elements well?

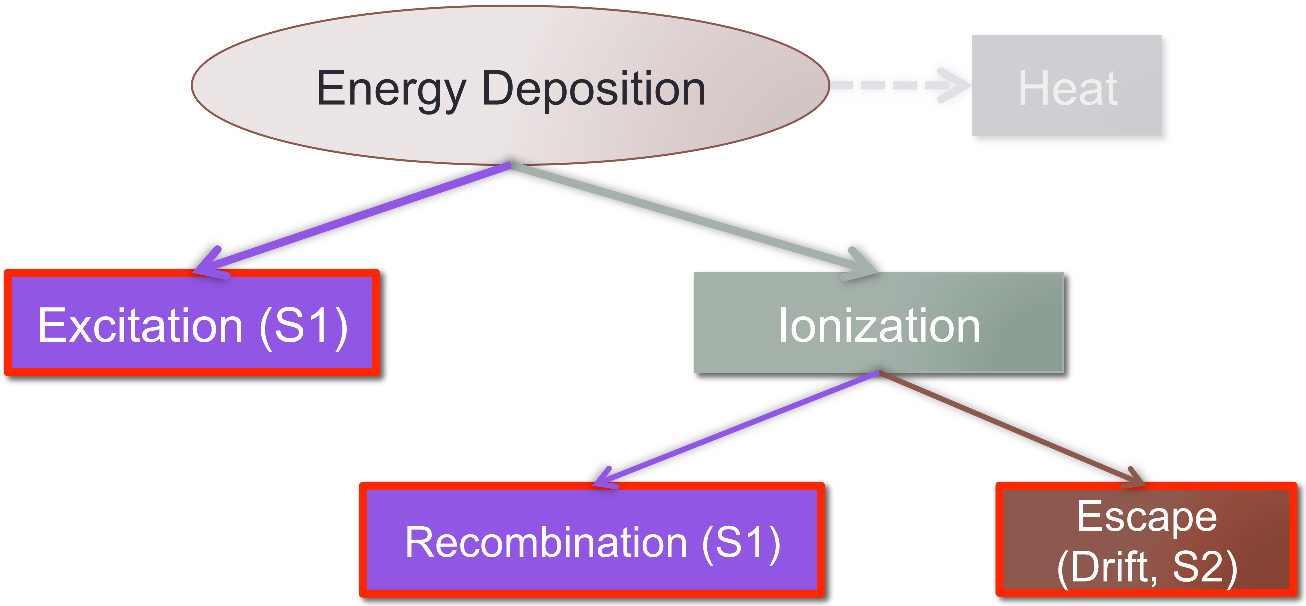
- Direct dark matter detection experiments
  - Calibration for LUX, XENON, ZEPLIN, LZ, WArP, DarkSide, ArDM, XMASS, DARWIN, MAX, Xürich, Xed, XeCube, PANDA-X, PIXeY, DEAP, CLEAN, ... 1- and 2-phase
- Double beta decay (0vßß, 2vßß)
  - NEXT, EXO
- Positron Emission Tomography (PET) scans for medical applications: detect 511 keV γ's
  - Other particle detection applications, e.g. collider experiments (MEG, Olive, et al.)

Purpose of NEST

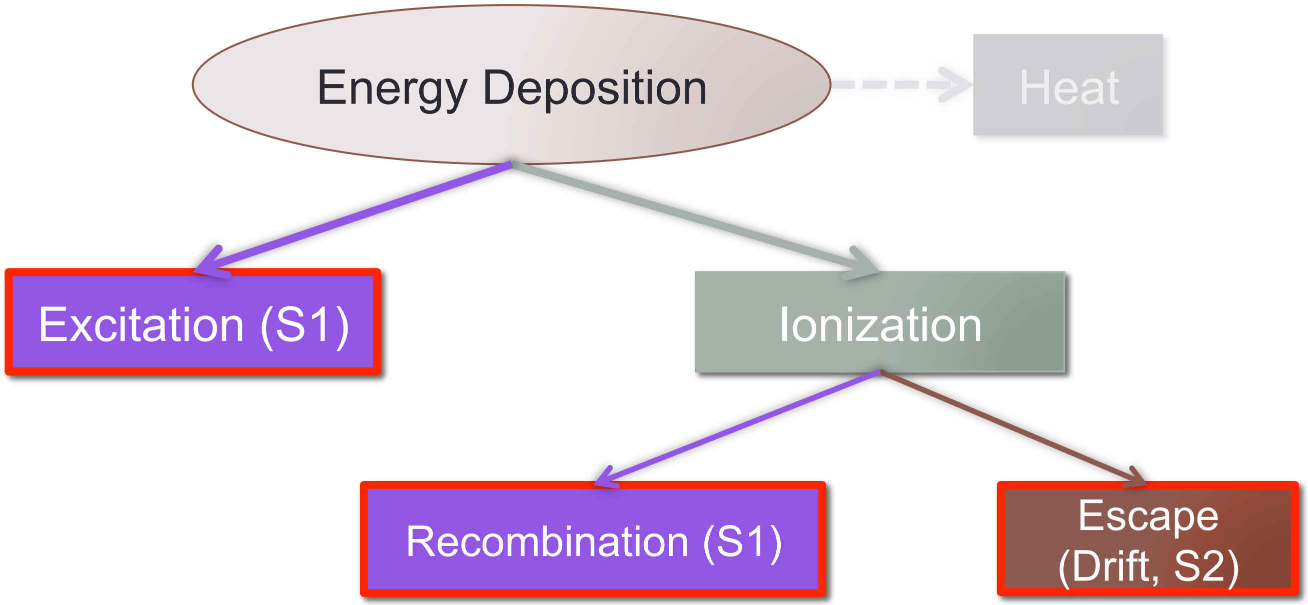


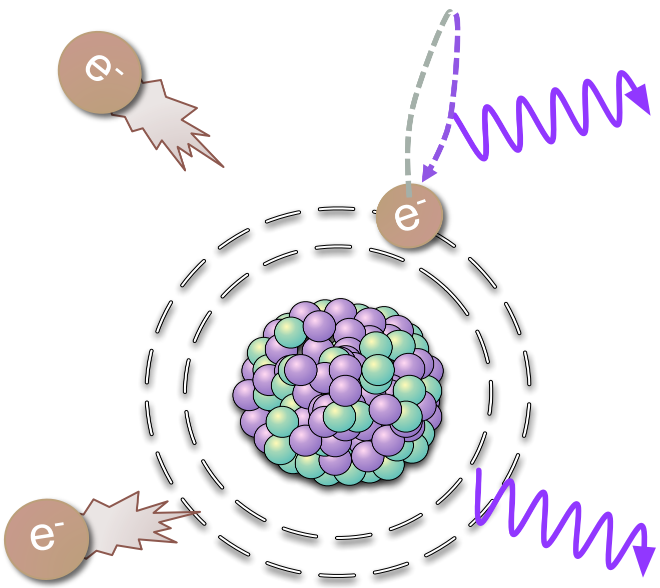
- Create full-fledged simulation based on a physical, albeit heuristic/quasi-empirical approach.
- Unify simulation response across the many dark matter, double beta decay, and other experiments.
    - For both electron recoil (BG) and nuclear recoil (BG and signal)
- Started with LXe (for sake of LUX)

Scintillation Path



Scintillation Path





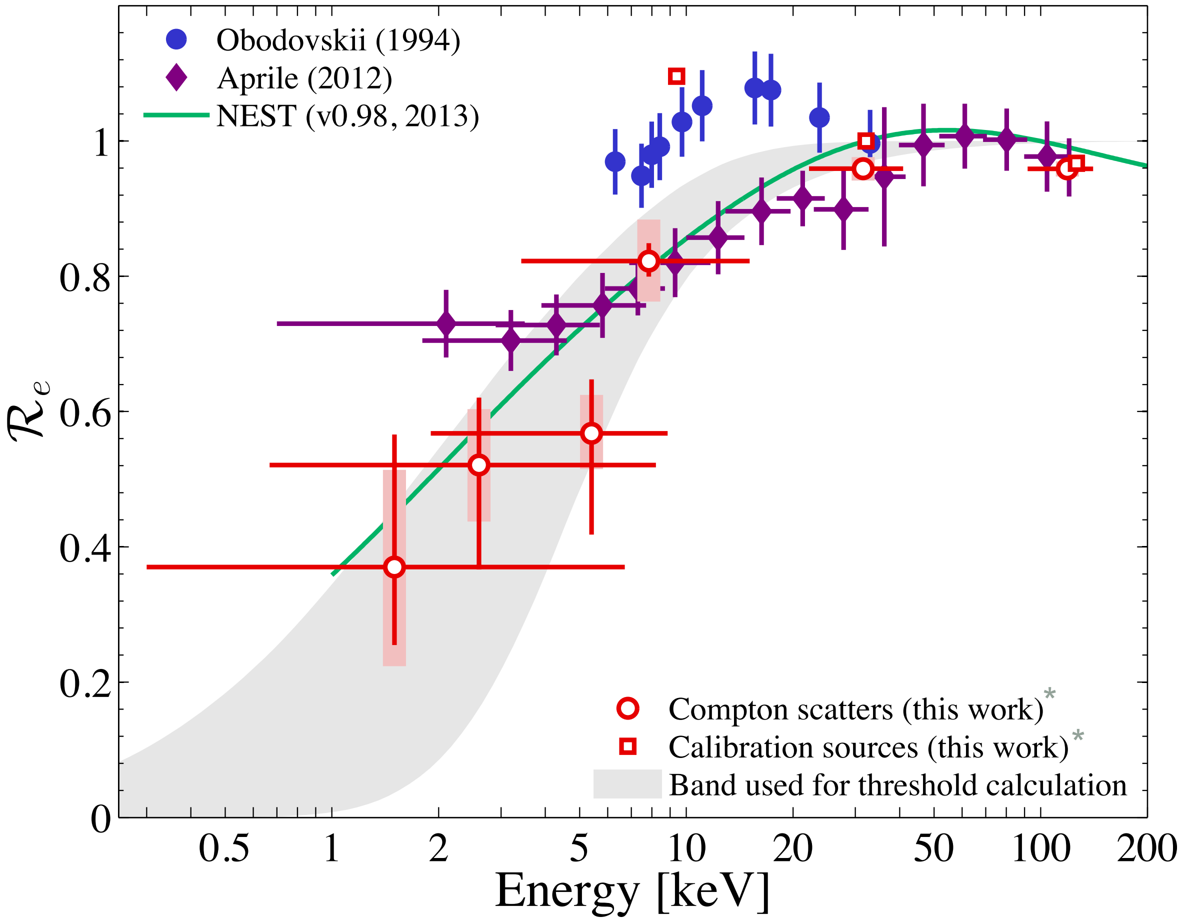
Observables are

- Scintillation [prompt and delayed] (S1)
- Escaped Ionization (S2)

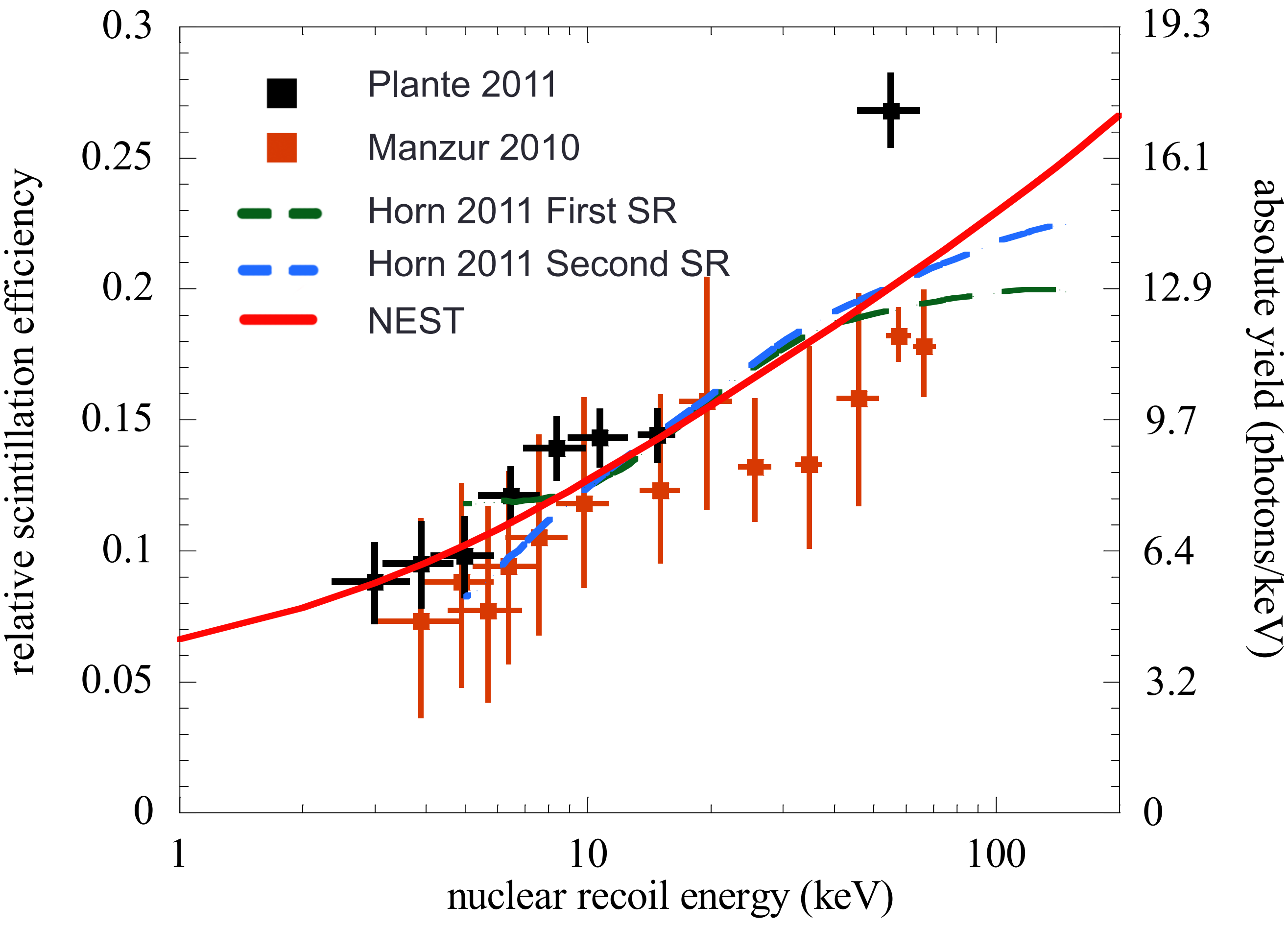
Excellent Yield Agreement

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

* Manalaysay, arXiv:1303.6891 [astro-ph.IM]



Nuclear Recoil



Quanta Manipulation

- Cornerstone: the work function for either **q**uantum (γ or **e**lectron) is the same.

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

- But how much N_γ 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

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

Micron scale

Long tracks

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

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

$$C = 1 - A/B$$

Short Tracks

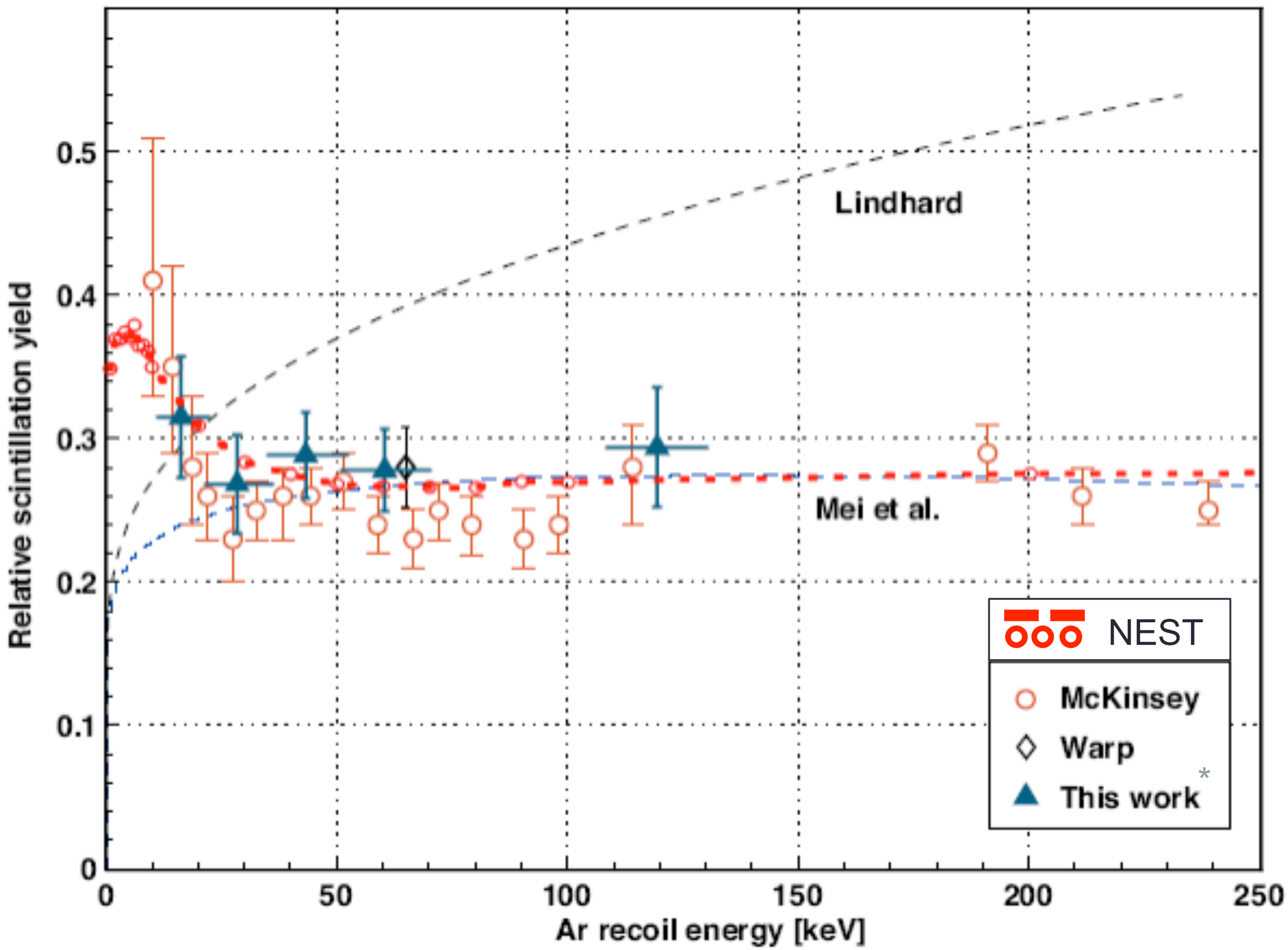
- Thomas-Imel box model
- Model recombination with electron/hole mobilities, dielectric constant, temperature.

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

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

Argon

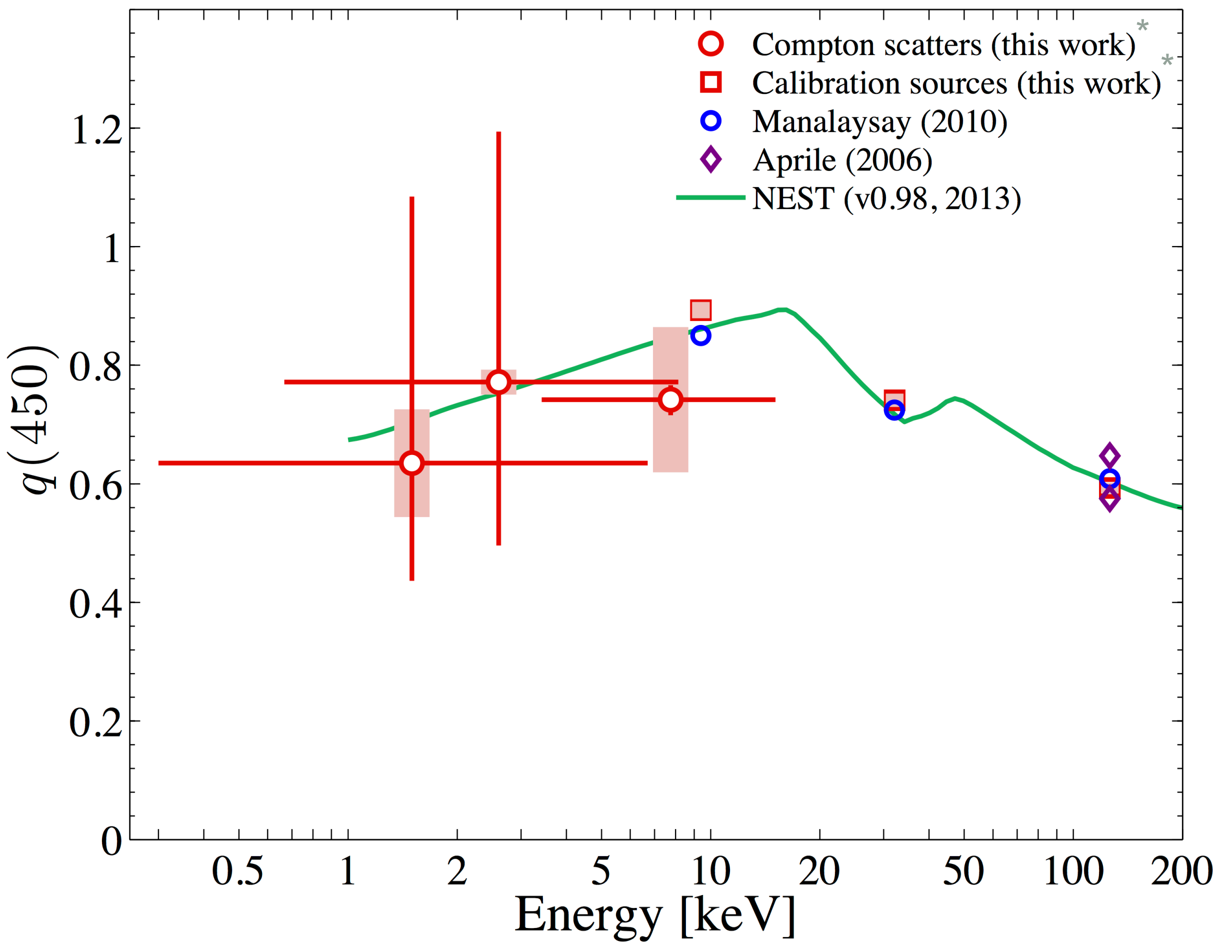
* Regenfus, arXiv:1203.0849v1 [astro-ph.IM] 5 Mar 2012



Agreement with applied electric fields

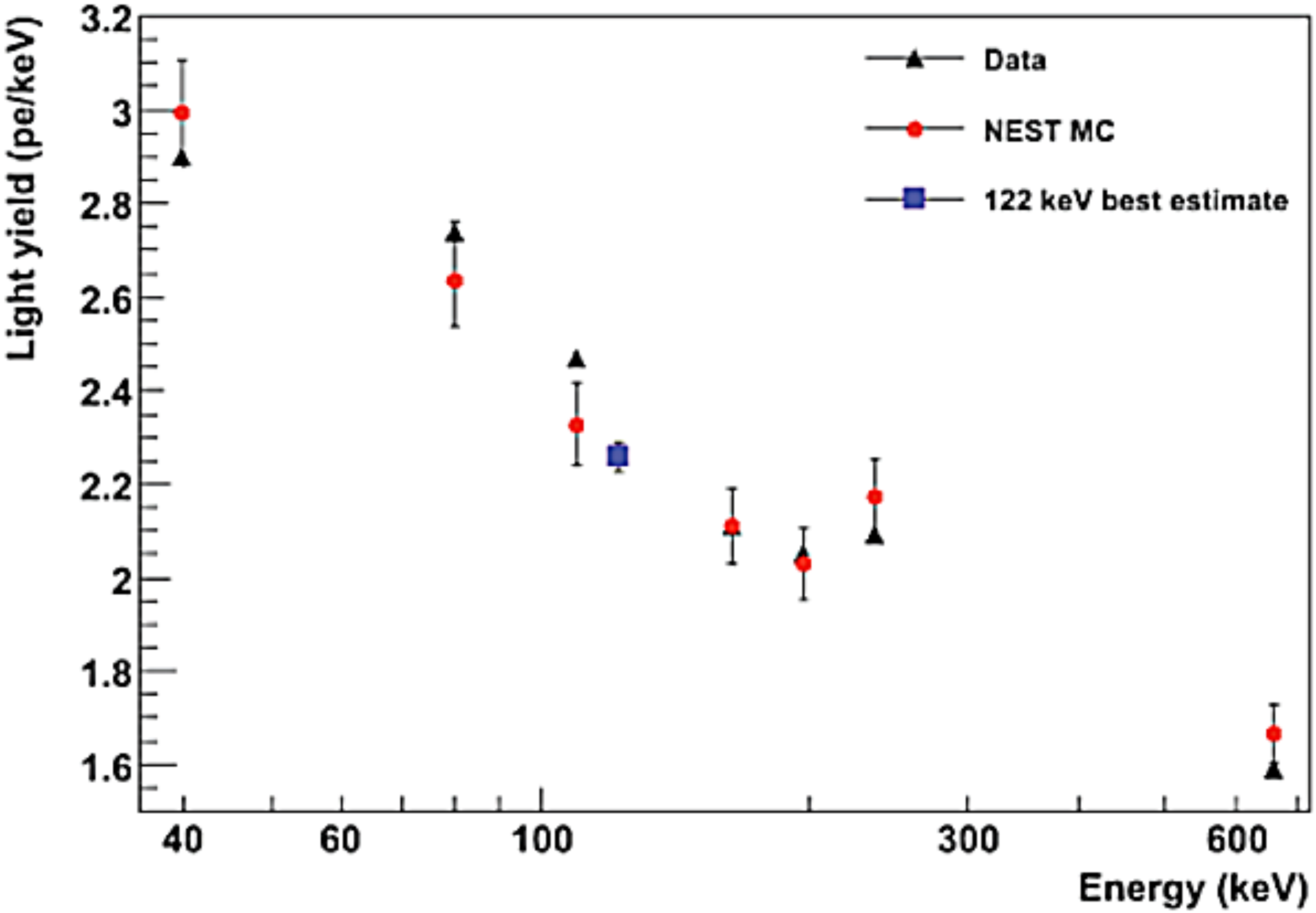
- Back to Xe
- 450 V/cm field
- Quenching factor
  - The proportionality of scintillation yield at field to zero field.

* Manalaysay, arXiv:1303.6891 [astro-ph.IM]



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