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Research and Development

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Understanding Detector Response and Energy Resolution of Noble Elements

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Introduction

- Project title: **NEST, the Noble Element Simulation Technique**

- Noble-element particle detectors could potentially be very useful in reactor monitoring and port monitoring.

- NEST is a simulation package for modeling and understanding the scintillation and ionization response of noble element particle detectors considering a wide range of properties, including energy deposition, applied field, particle type.

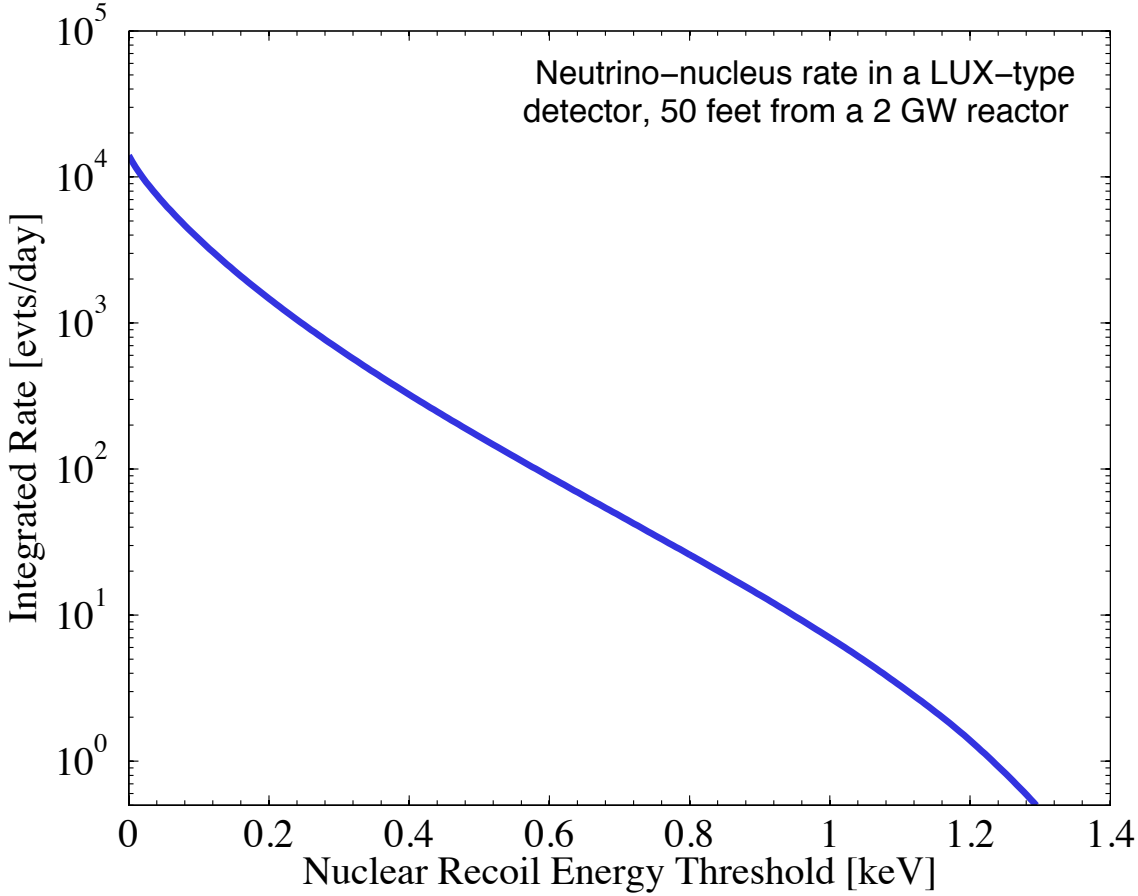
- NEST code is free and publicly available: http://nest.physics.ucdavis.edu

- It is a supplement to the standard GEANT4 particle-transport Monte Carlo simulation package, developed heavily at CERN. As such GEANT4+NEST facilitates construction of an entire virtual experiment to aid in forming expected signals and behaviors.

Example application of noble-element detectors

- Coherent neutrino-nucleus scattering could provide a robust, relatively high-rate method for passive reactor monitoring.

- LUX liquid-xenon detector used as an example (250 kg) [D.S. Akerib *et al.*, *Phys. Rev. Lett.* **112**, 091303 (2014)]
- An energy threshold of fractions of a keV could yield upwards of thousands of neutrino events per day from a reactor.
- This work in collaboration with LLNL

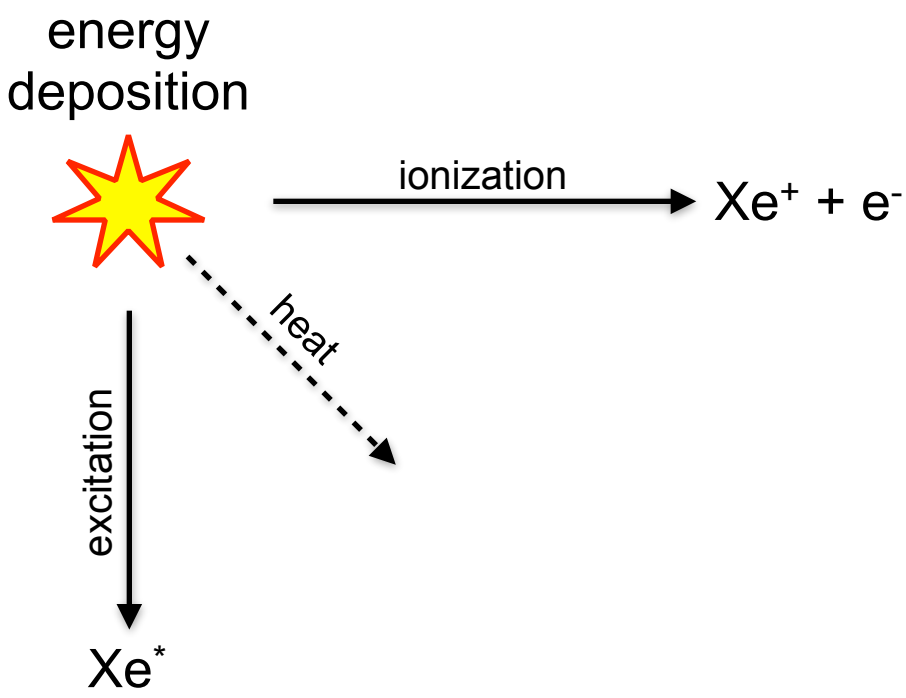


Reactor anti-neutrino spectrum taken from F.T. Avignone, *Phys. Rev.* D2, 2609 (1970)

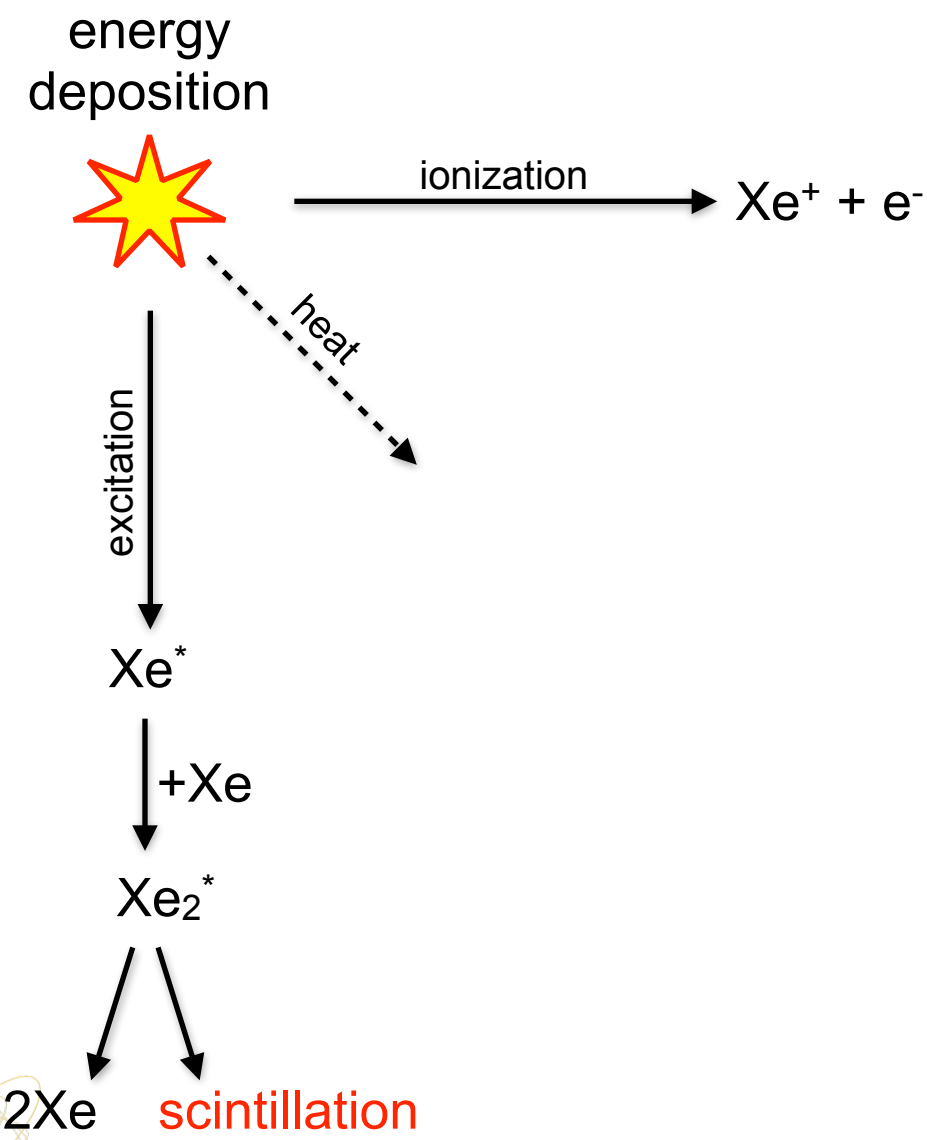
Technical Challenges and Progress

- NEST is already consistent with a wealth of experimental results using liquid xenon, for both electronic recoils and nuclear recoils.
- Until recently, particle interactions in gaseous xenon were not modeled by NEST. Progress has been made here, particularly relating to the effect of electrons drifting through gas in a dual-phase detector. (J. Mock *et al*., 2014 JINST 9 T04002).
- Gaseous and liquid argon are also commonly used media for particle detection, and work is ongoing on this front.
- A technical challenge related to NEST is obtaining low-energy nuclear recoil response data (e.g. in liquid xenon), which goes into constraining the physical model implemented in NEST. Recently, the LUX collaboration has released a preliminary result on nuclear recoils in liquid xenon in the sub-keV regime.

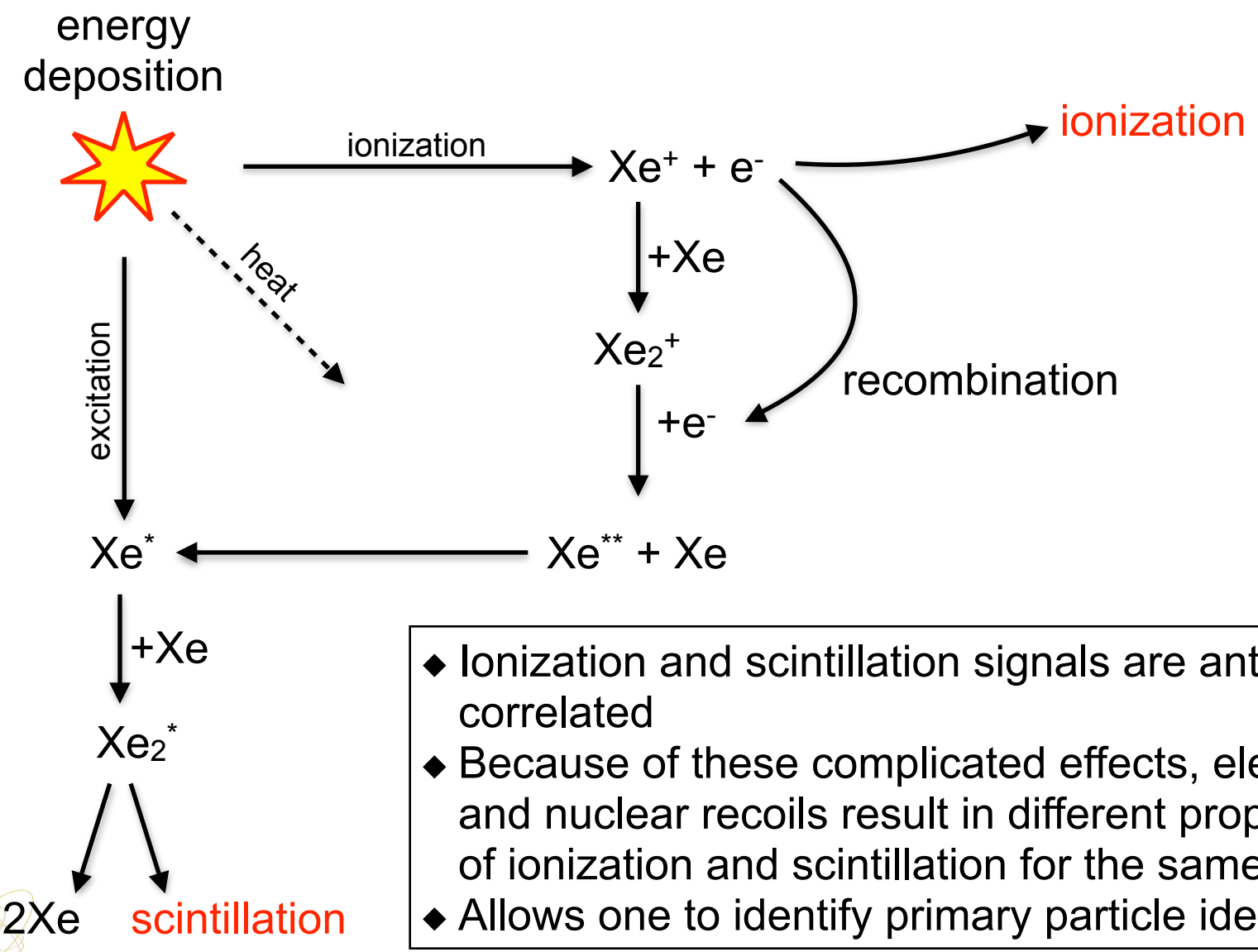
Basic Physics Model



Basic Physics Model



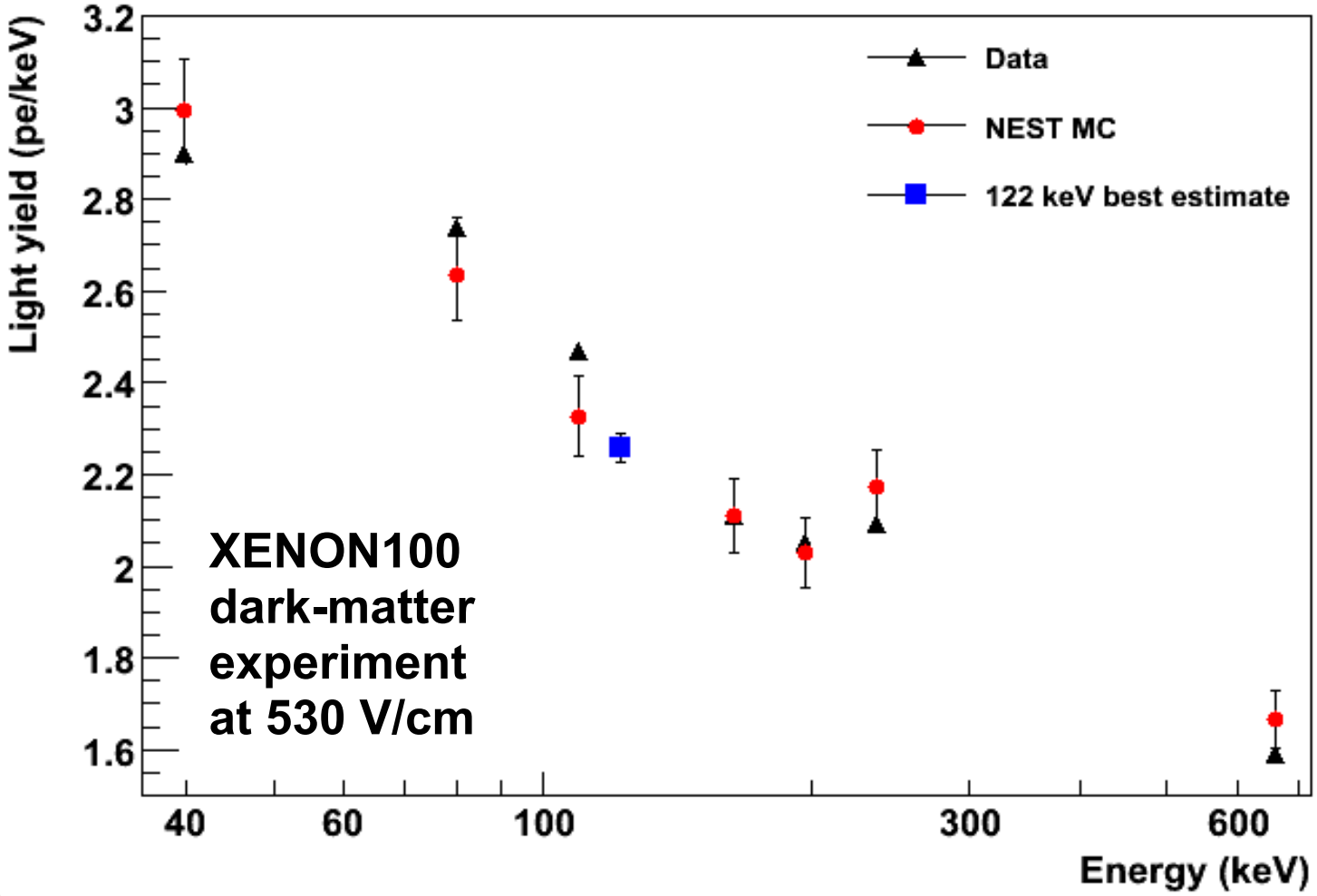
Basic Physics Model



- Ionization and scintillation signals are anti-correlated
- Because of these complicated effects, electronic and nuclear recoils result in different proportions of ionization and scintillation for the same energy
- Allows one to identify primary particle identity

Comparison to data

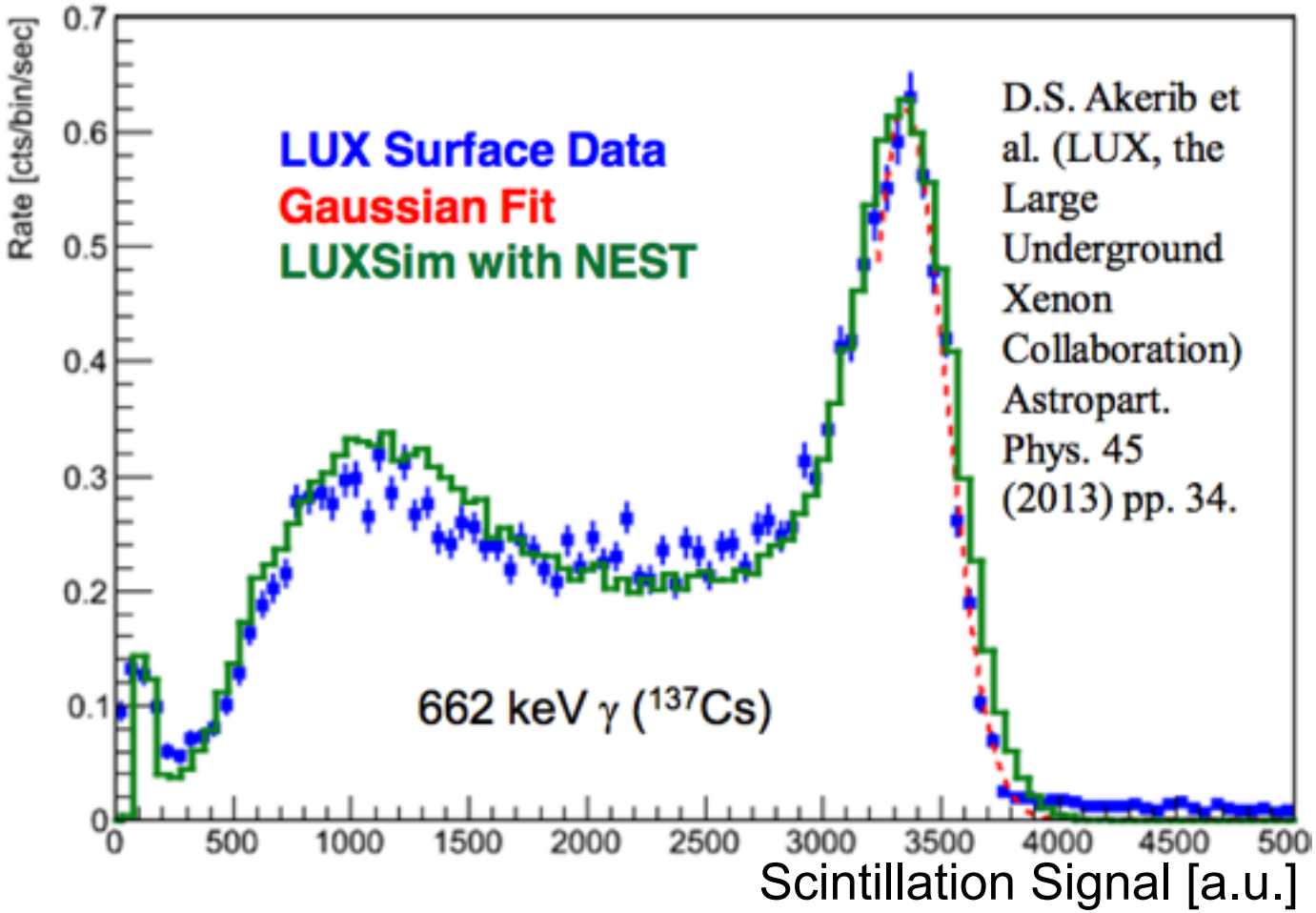
- Scintillation yields over a wide range of energies are accurately predicted



Plot from Antonio Melgarejo IDM 2012

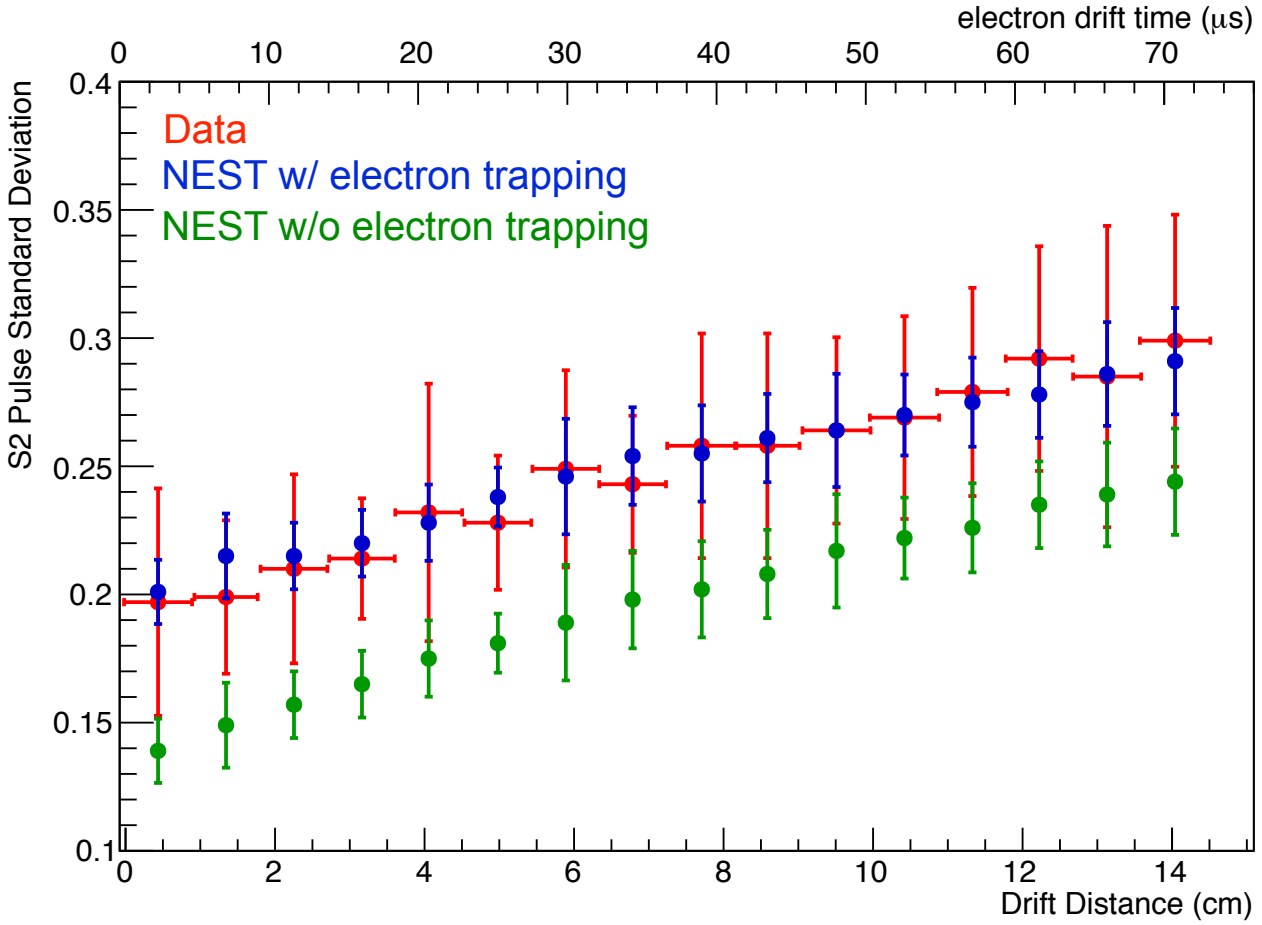
Comparison to data

- Statistical fluctuations, which determine the energy resolution, are naturally produced by the simulation, with no tuning.
- First instance in noble element detectors of a simulation naturally and correctly predicting the detector resolution.



Recent work

- Recently published, the inclusion of the time structure of both scintillation and ionization signals in liquid xenon has been included in NEST (error bars include both statistical and systematic uncertainties).

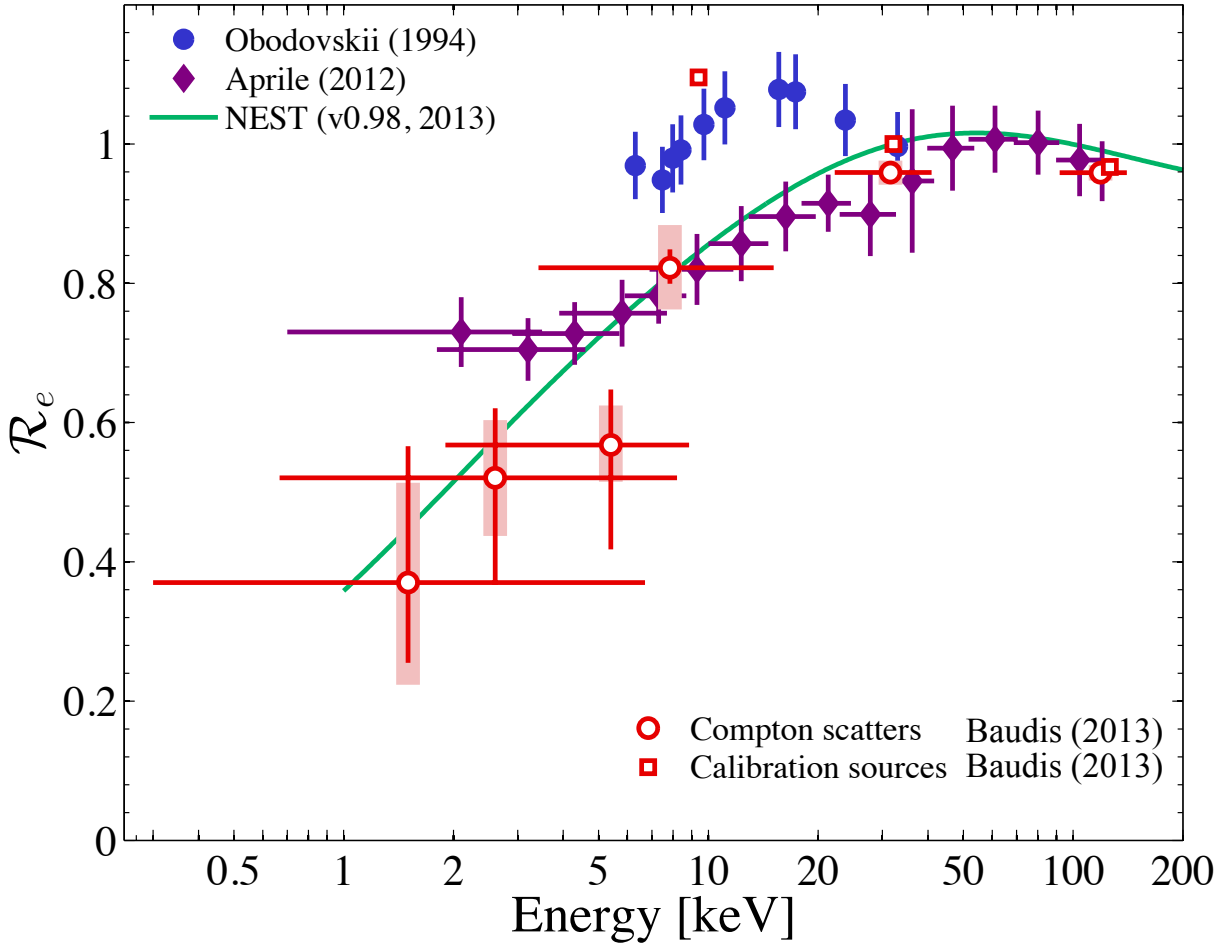


- Many effects contribute to the width of the ionization signal, including even the lateral diffusion of the charge cloud as it drifts through the detector.

J. Mock *et al.*, (2014) JINST 9 T04002

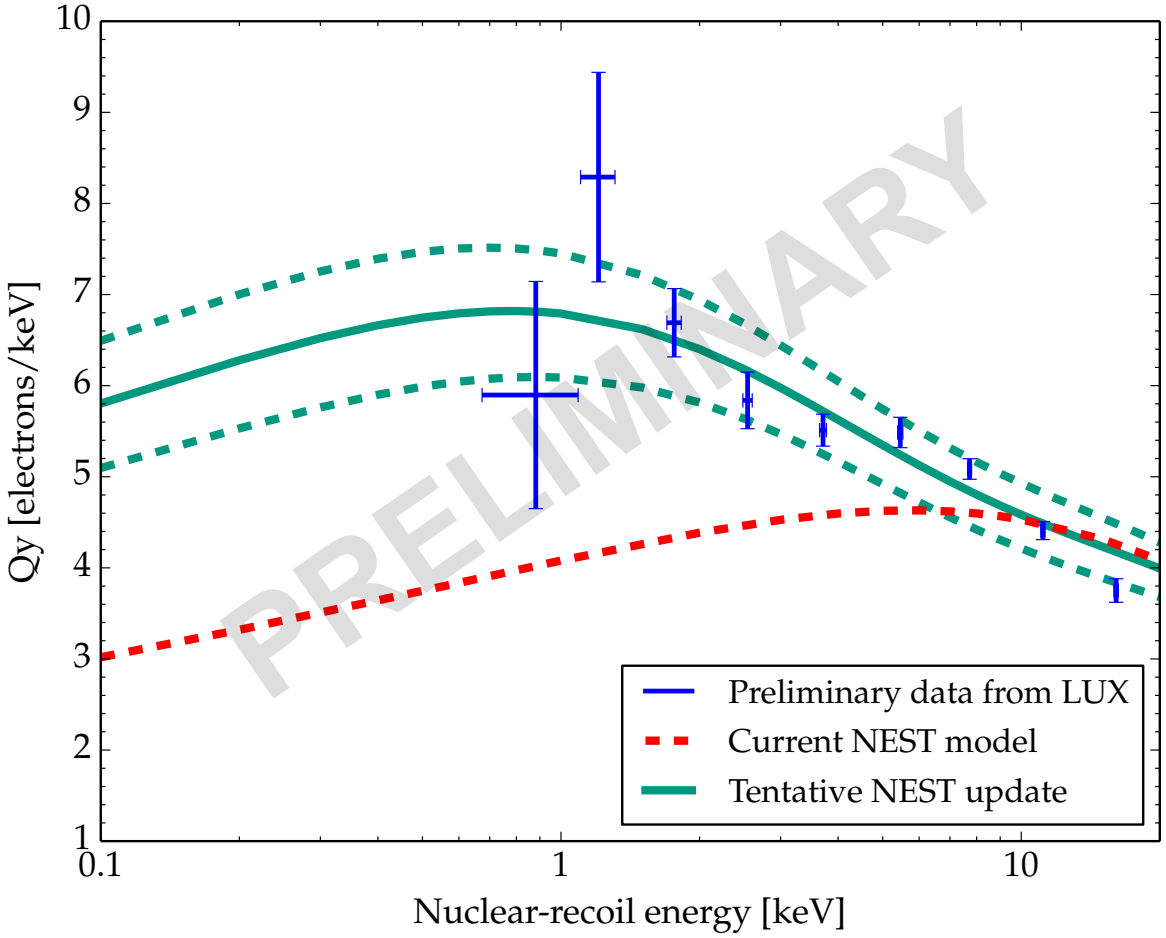
Recent confirmation

- Recent experimental work by another group studying electronic recoils in liquid xenon showed results consistent with the behavior predicted by NEST.



L. Baudis *et al.*, Phys. Rev. **D87** (2013) 115015

LUX enters sub-keV regime



- The ionization channel is generally much more sensitive than the scintillation channel.
- Recall that an energy threshold of fractions of a keV could serve as a high-rate anti-neutrino monitor of reactors.
- Preliminary data recently released from the LUX collaboration produced the first probe of nuclear recoils in the sub-keV range. NEST is currently in the process of being updated with these new data as constraints.

Preliminary LUX Qy results from: http://www.pa.ucla.edu/sites/default/files/webform/20140228_jverbus_ucla2014.pdf

Conclusions

- NEST predicts and reproduces the response of a generic noble liquid detector to ionizing radiation.
- The code is publicly available for download and is to be used as a supplement to the (also publicly available) GEANT4 simulation framework.
- Ongoing work on low-energy nuclear recoils in liquid xenon.
- NEST is cross-disciplinary, applicable to many fields of physics research, including dark matter direct detection, neutrino physics, passive reactor monitoring, and medical physics.