A Review of NEST Models and Their Application to Particle Identification

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on behalf of the NEST collaboration

What is NEST?

- The Noble Element Simulation Technique (NEST) is an open source software that simulates the scintillation, ionization, and electroluminescence processes in LXe, GXe, SXe, and LAr
- “Inter-collaboration” collaboration
  - Members from LUX/LZ, XENON, DUNE, nEXO, RED, COHERENT
- C++ package with Python equivalent (nestpy)
- Optional GEANT4, ROOT and Garfield++ integration
- Github: https://github.com/NESTCollaboration
- Collaboration Website: http://nest.physics.ucdavis.edu/

University at Albany
State University of New York

University of California San Diego

The University of California Davis

Rice

MEPhI
National Research Nuclear University

Colorado State University

UC Riverside

University of Michigan

Universität Zürich[UZH]

Berkeley
University of California

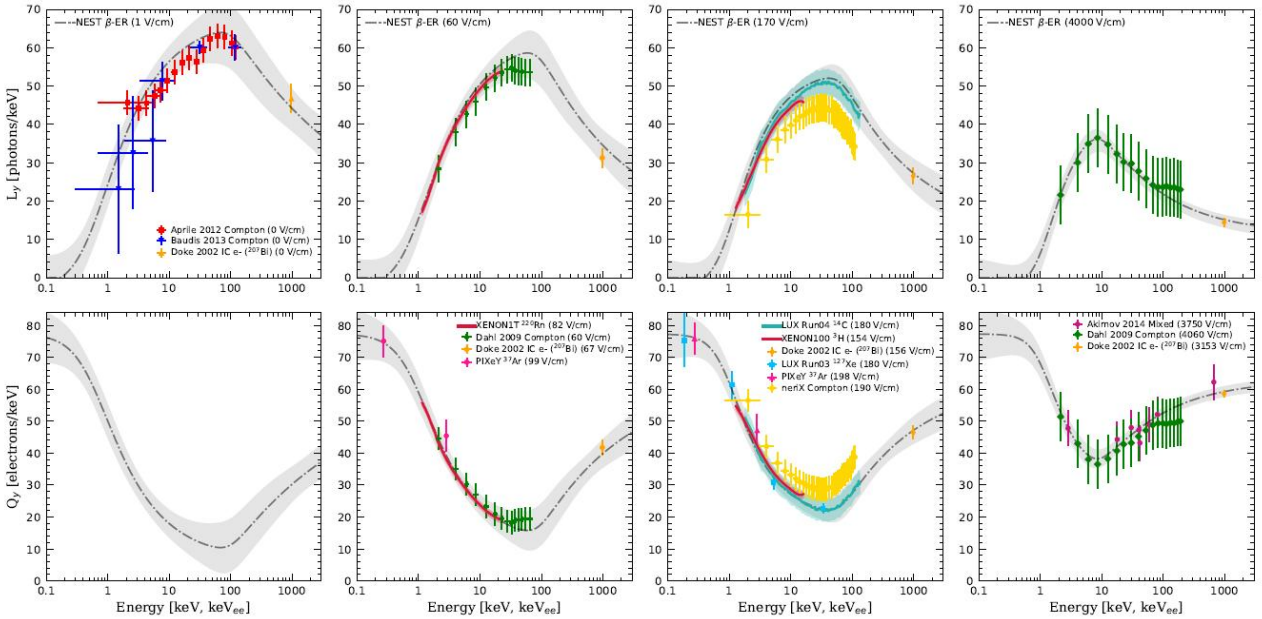
Lawrence Livermore National Laboratory

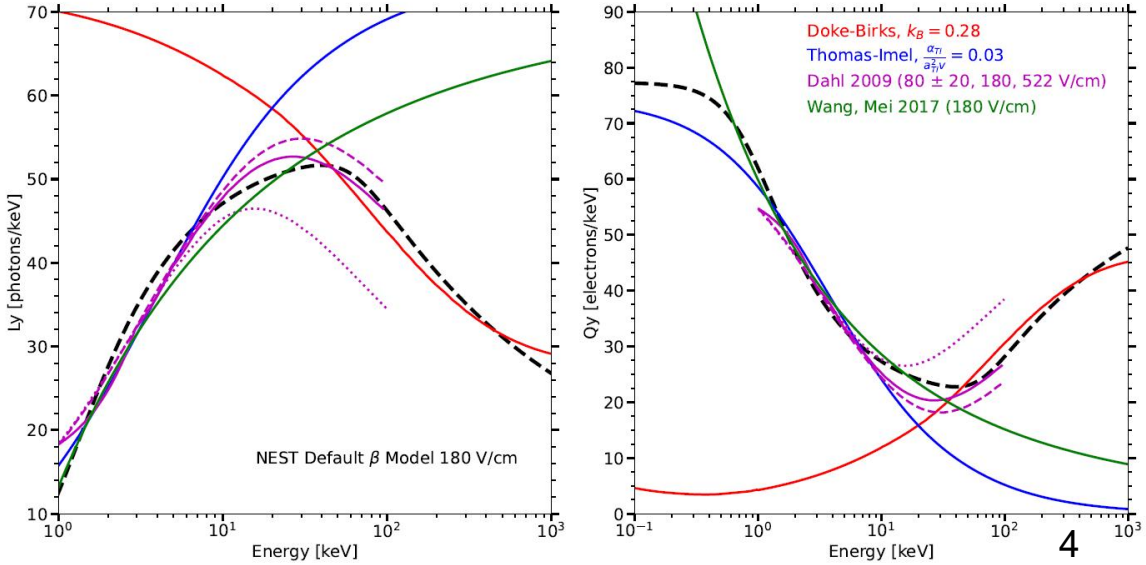
What does NEST do?

- Reproduces charge and light yields from different particles
  - including fluctuations
- Simulates actual energy deposits in a detector
  - taking into account detector parameters
  - calculates detector-dependent parameters (drift velocity, etc.)
- Special features:
  - background discrimination
  - pulse shaping
  - and much more!

ER models (β)

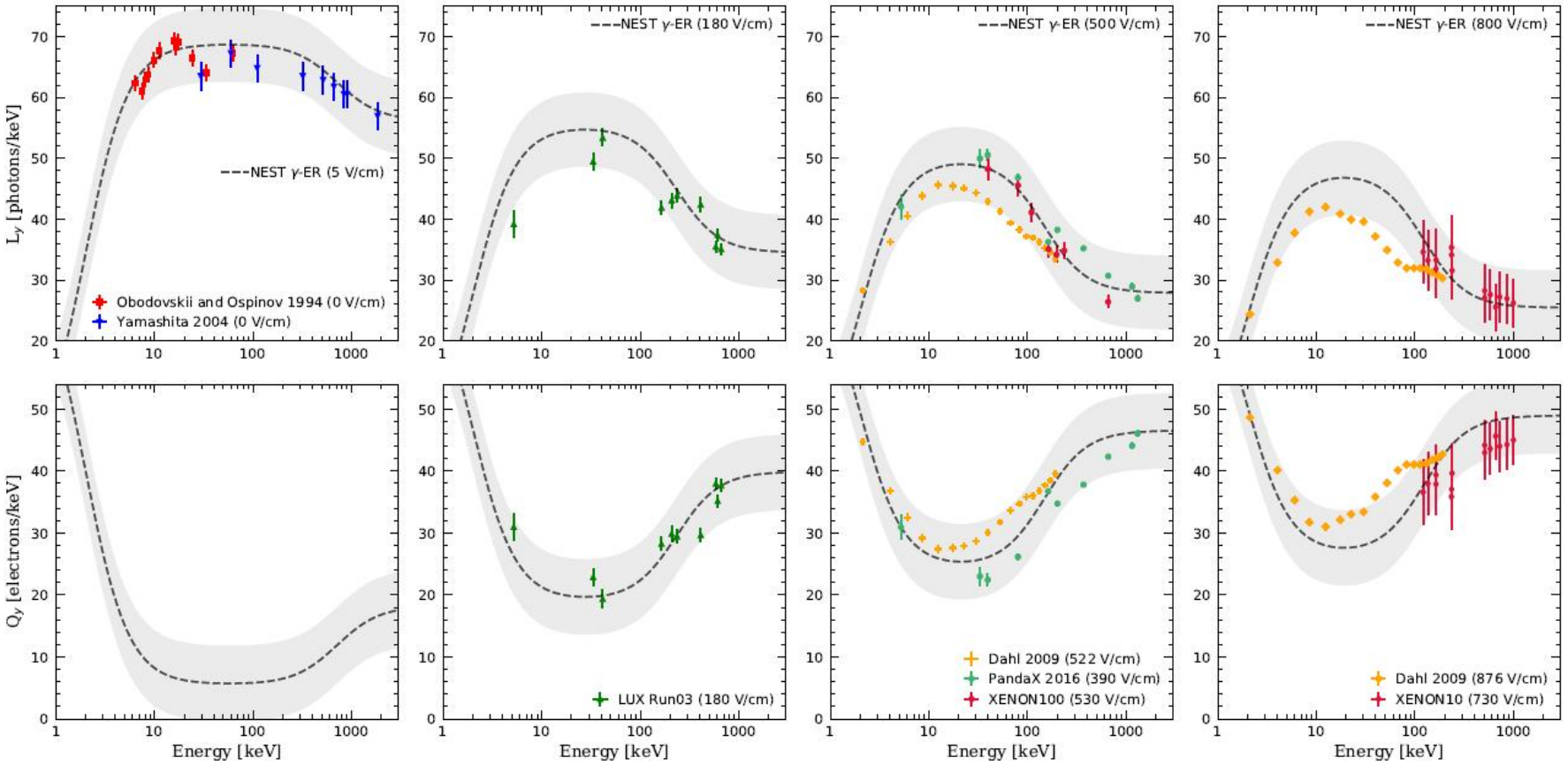
- ER Models are a sum of two sigmoids
- Sum of light and charge is constant
- In agreement with theoretical predictions for all energy regions
  - Solving the issue of applicability!





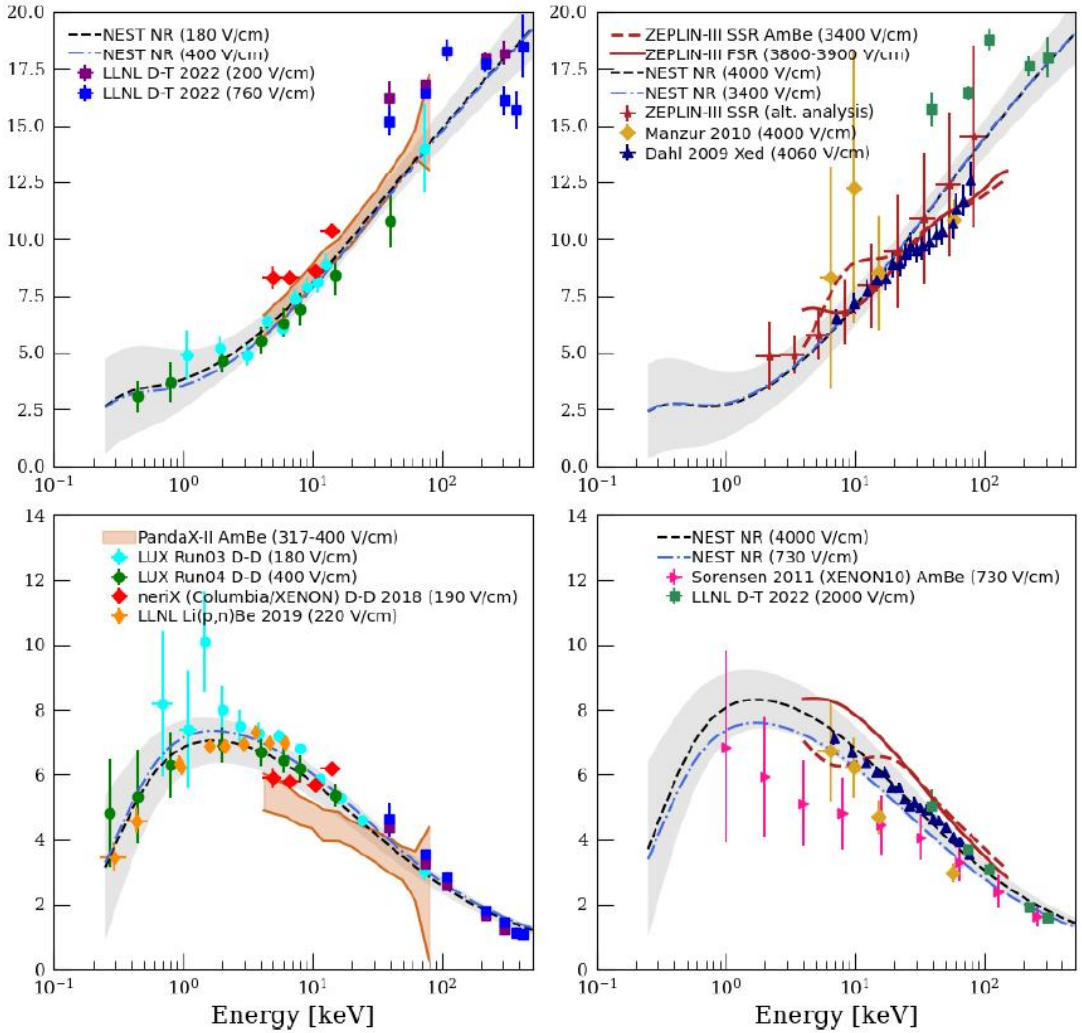
ER models (γ)

- A bit different coefficients than ER-β, but same logic



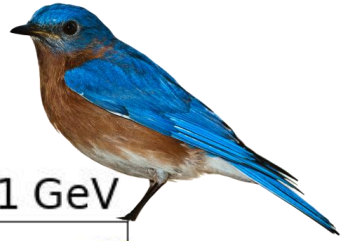
NR model

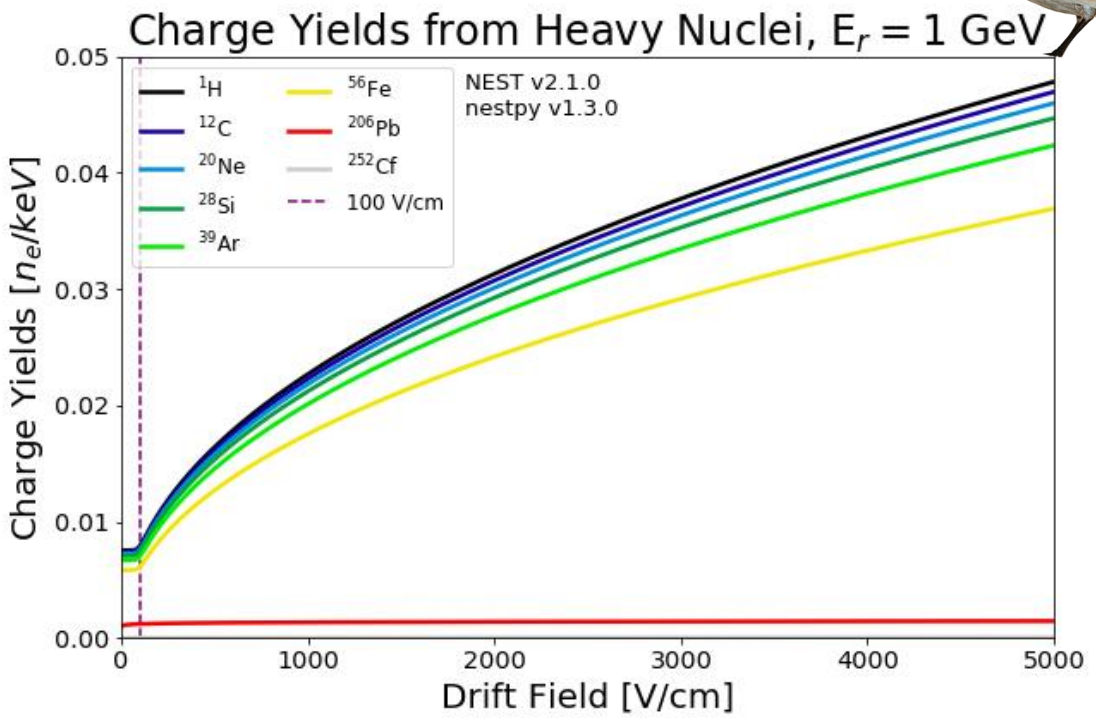
- Covers all experimental data (including LLNL and LUX)
- Works from 0.2 keVnr
  - Suitable even for rare low energy processes like CEvNS

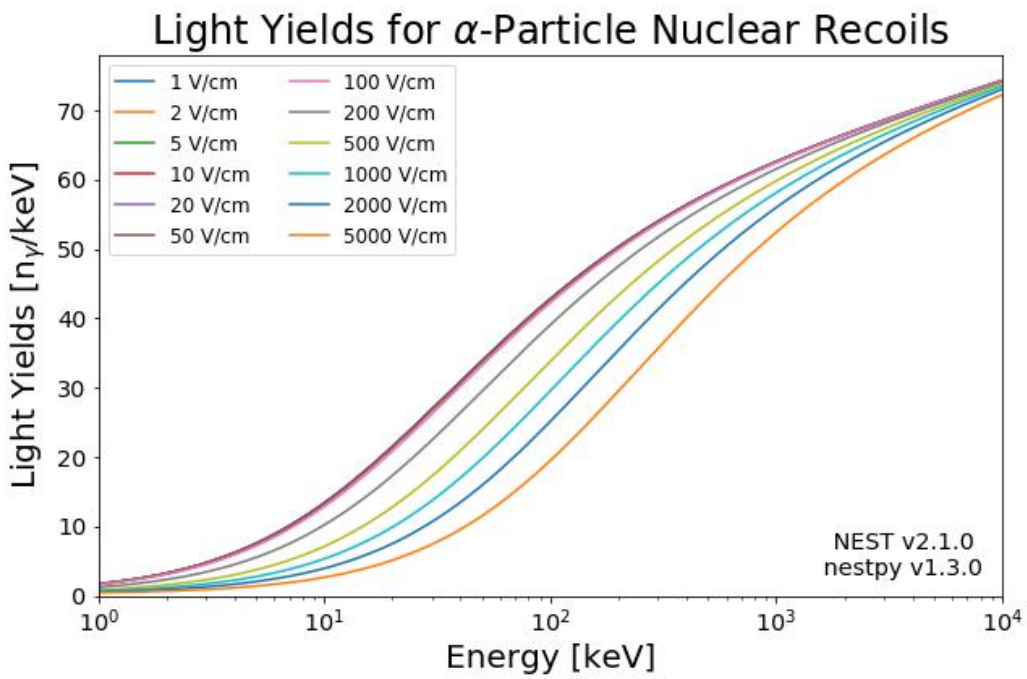


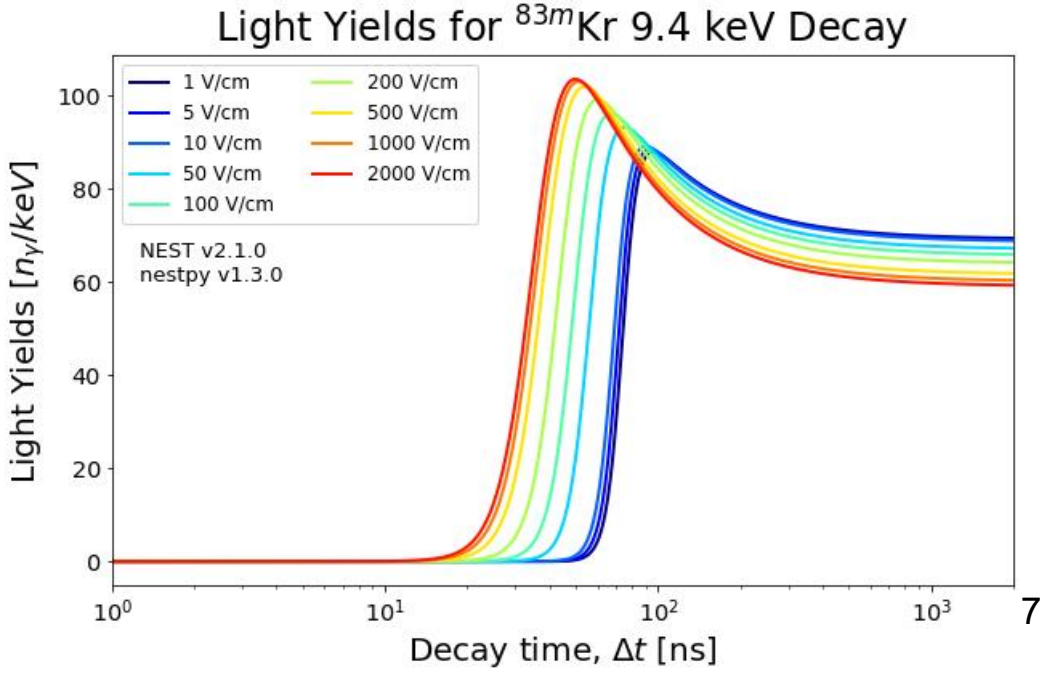
Other models

- ^{83m}Kr, alphas, heavy ions







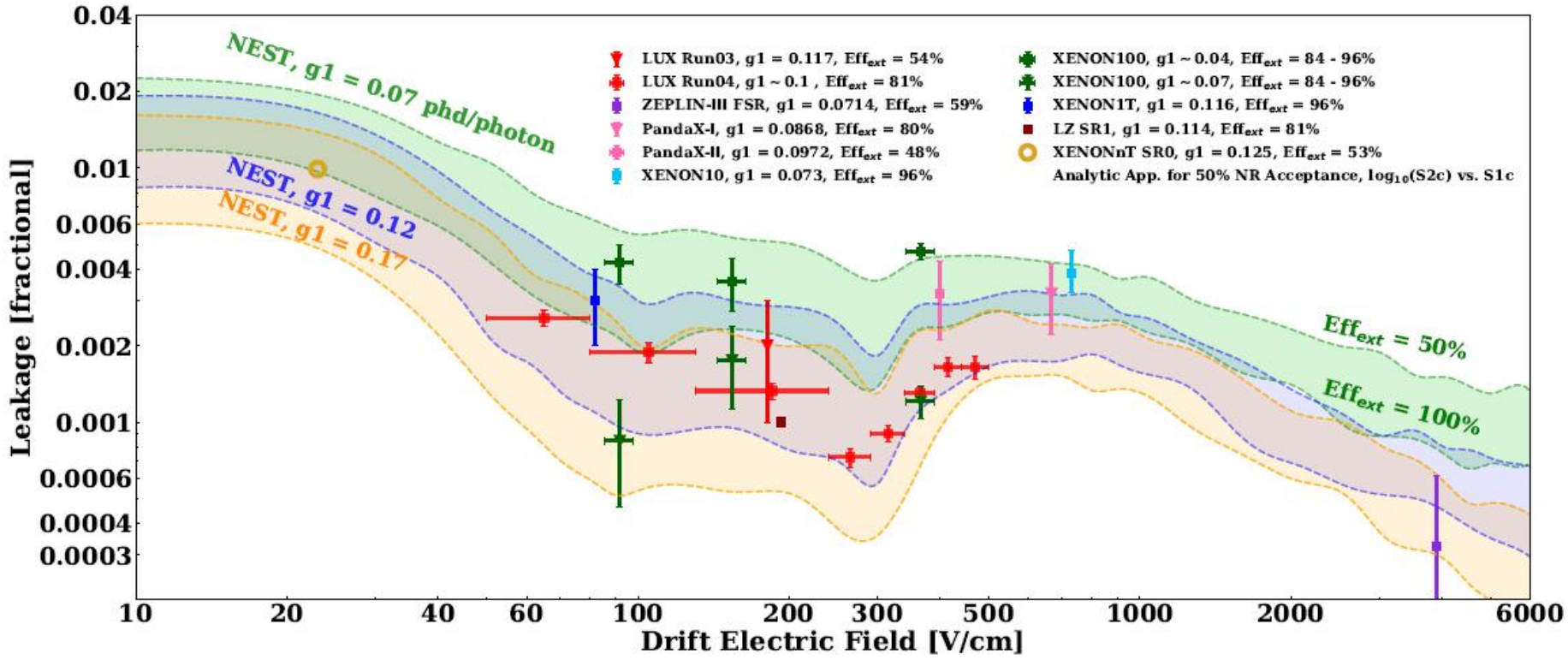


Fluctuations

- **Quantum Fluctuations**
  - First estimates of fluctuations in energy resolution and fluctuations in quanta produced were by Ugo Fano in the 1940's
  - Fluctuations modeled using an empirical "Fano-like" factor proportional to $\sqrt{N_q F_q}$
    - Different for excitation and ionisation channels for NR
- **Recombination Fluctuations**
  - Binomial recombination has never matched data well
  - Additional non-binomial part is used
    - Energy and field dependent

Leakage simulation

- Cruicial for WIMP searches
- Able to accurately predict discrimination power for new detectors/backgrounds with NEST

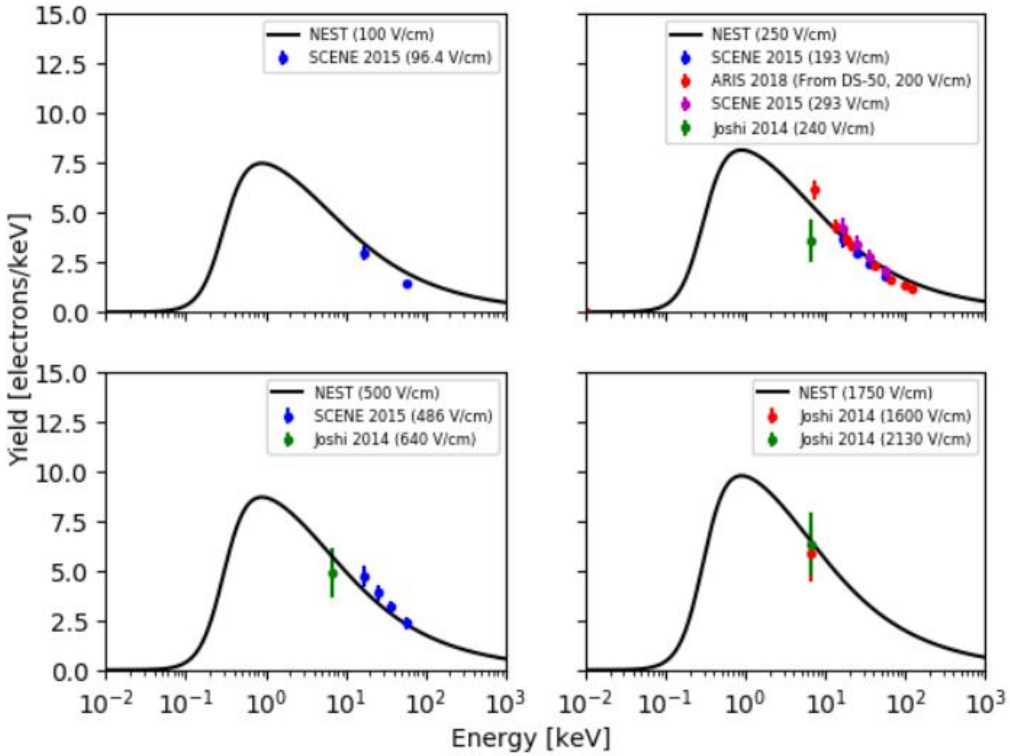


Liquid argon

- Liquid argon is based on LXe model
- In alpha version right now
- Already has NR, ER and alpha mean yield models
- Current work is on PSD and fluctuations model
  - PSD is more important for LAr experiments than for LXe

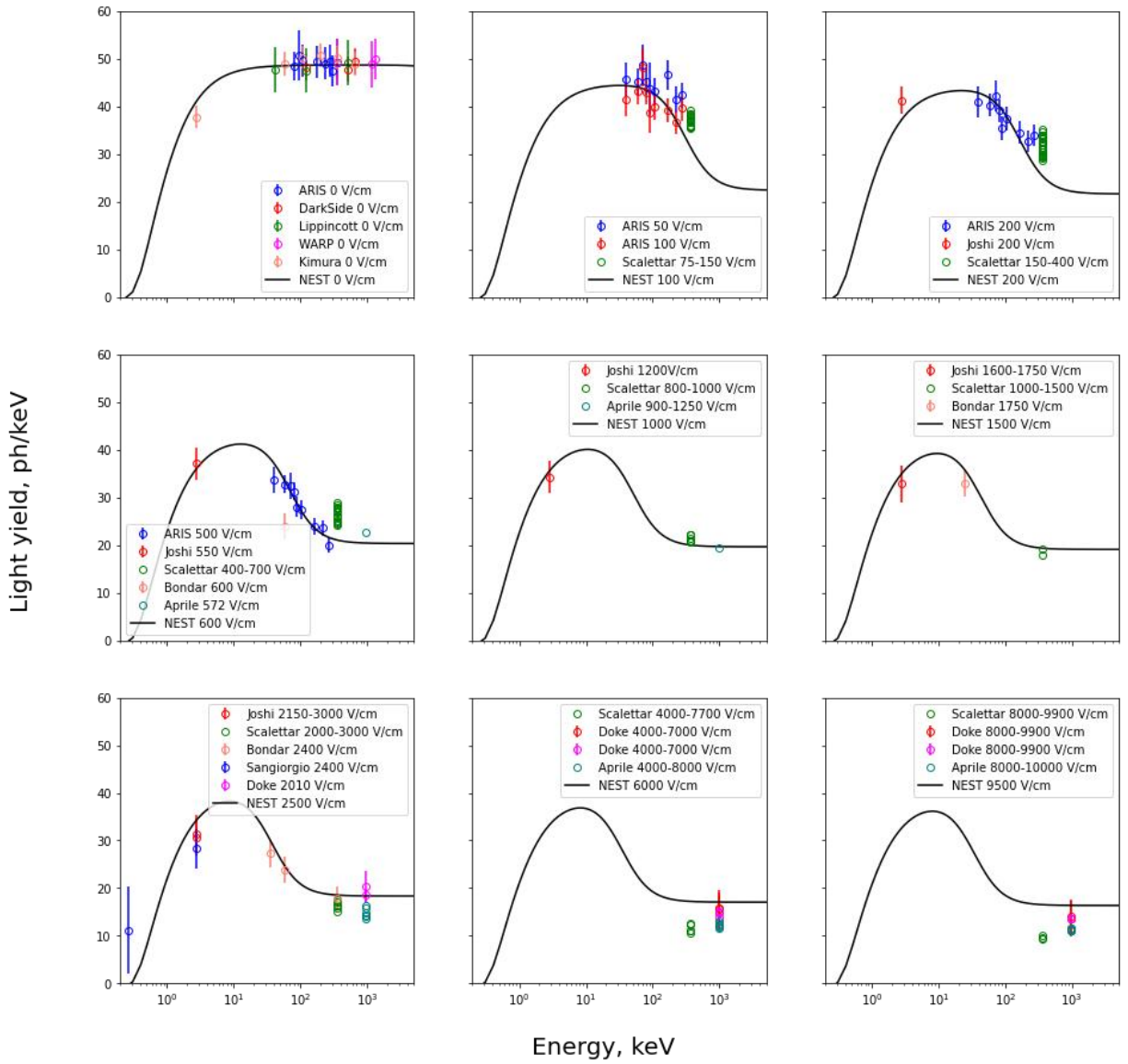
NR model

- Based on same principles as LXe model
- Also has “anti-anticorrelation”, but in a bit different manner
- In agreement with the most of data



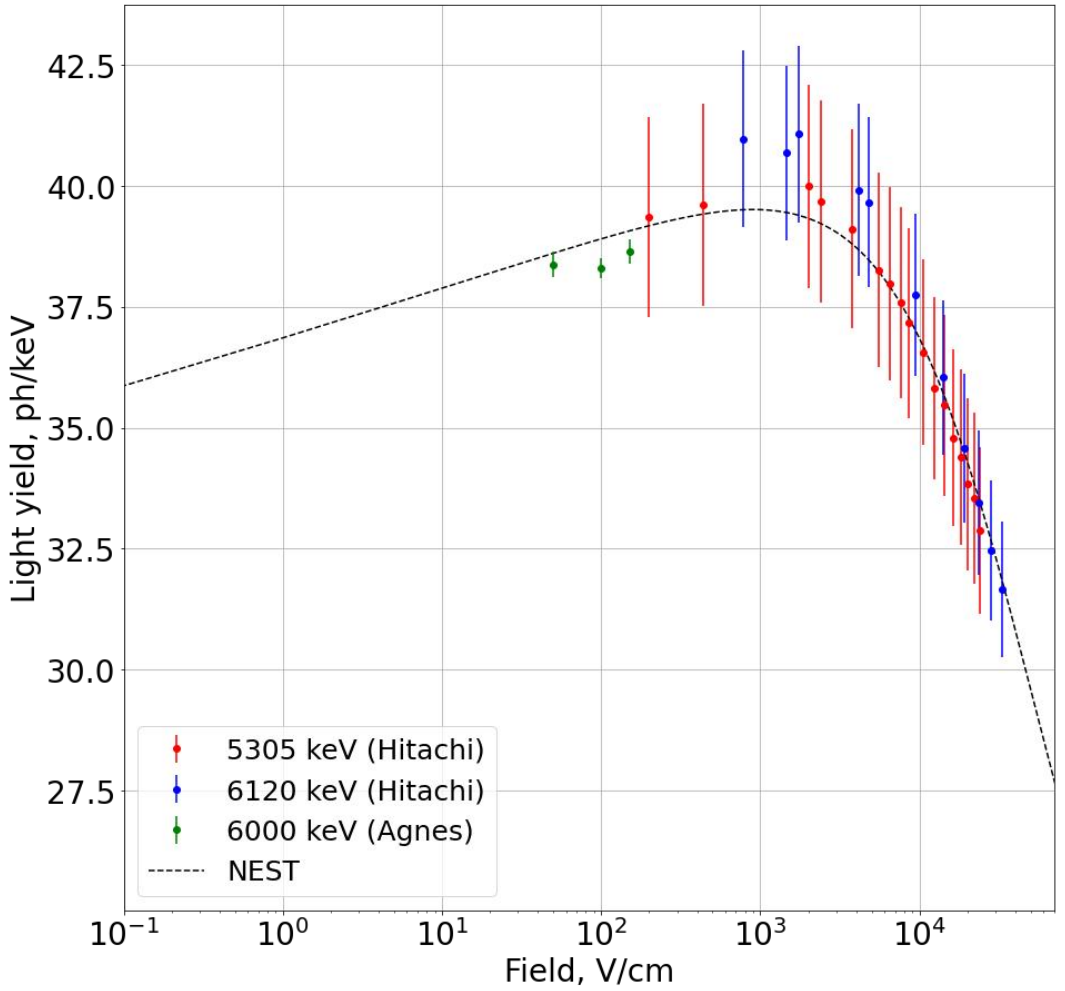
ER model

- Currently the same for beta and gamma
- Based on LXe beta model
- Applicable for very high fields (>9000 V/cm)



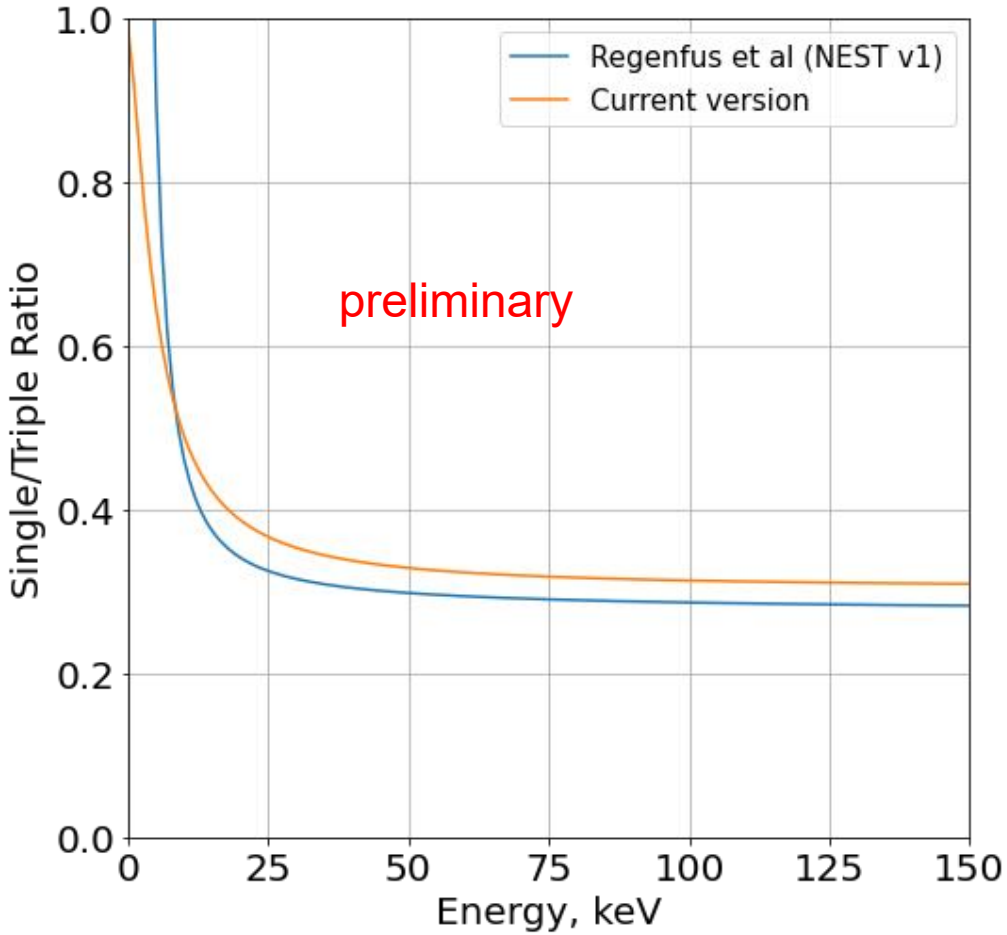
Alpha model

- Based on LXe ion model
- Currenlty only field-dependent
- Covers the phenomena reported independently by Hitachi and Agnes



Pulse shape discrimitation

- Currently being updated with data from various experiments
  - better behavior at low energies
- Possible feature: dependence of emission times from particle type (arXiv:1511.07721)
  - Current model also takes into account “intermediate” time, but on the next step



Conclusion

- NEST is a powerful simulation framework, accurately describing the signal yields
- Simulates many different interactions in LXe and GXe
  - argon models are in alpha version already
- User-friendly code
  - allows to use alternate models
- More about NEST:
  - arXiv:2211.10726
  - https://doi.org/10.3390/instruments5010013

Thank you for your attention!