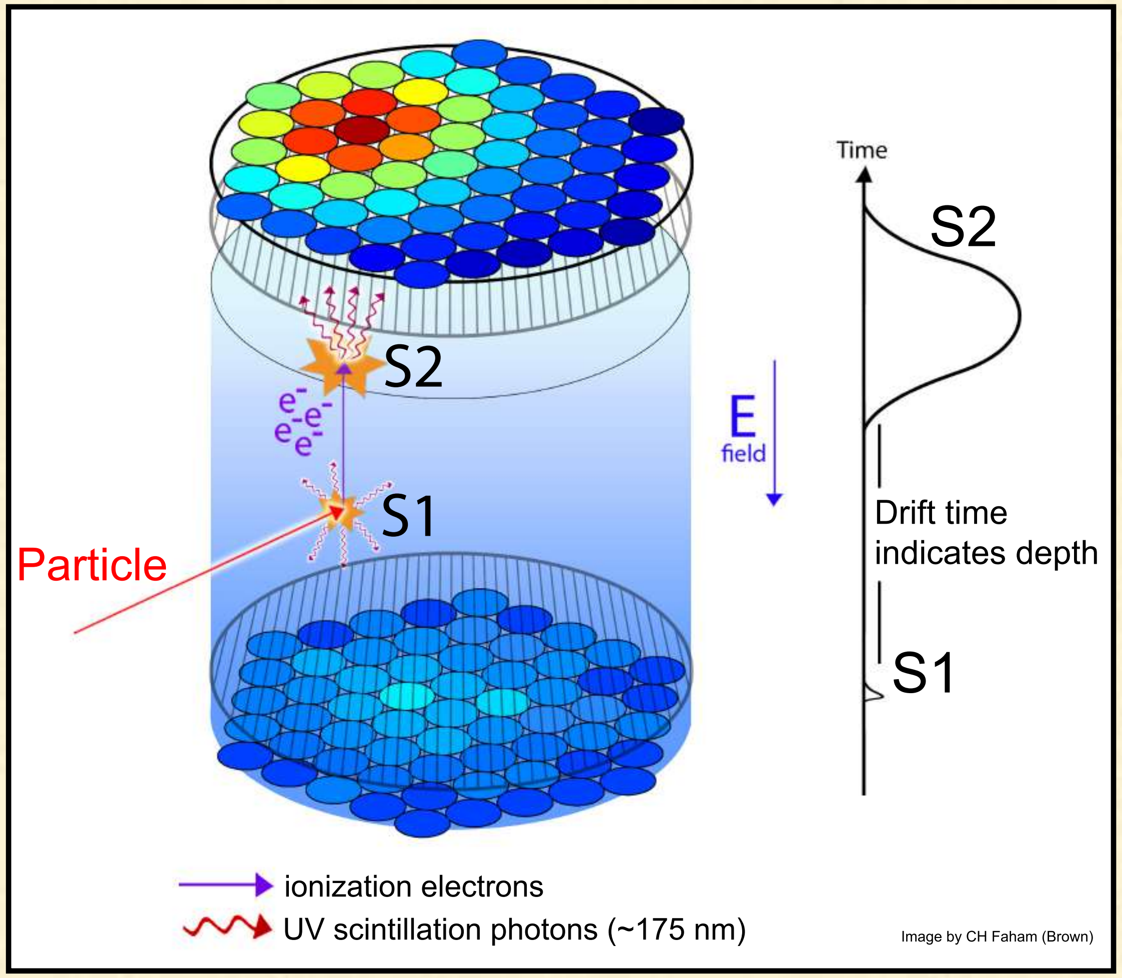
The Noble Element Simulation Technique v2

Jacob Cutter, University of California, Davis
For the NEST Collaboration

CPAD, October 13, 2017

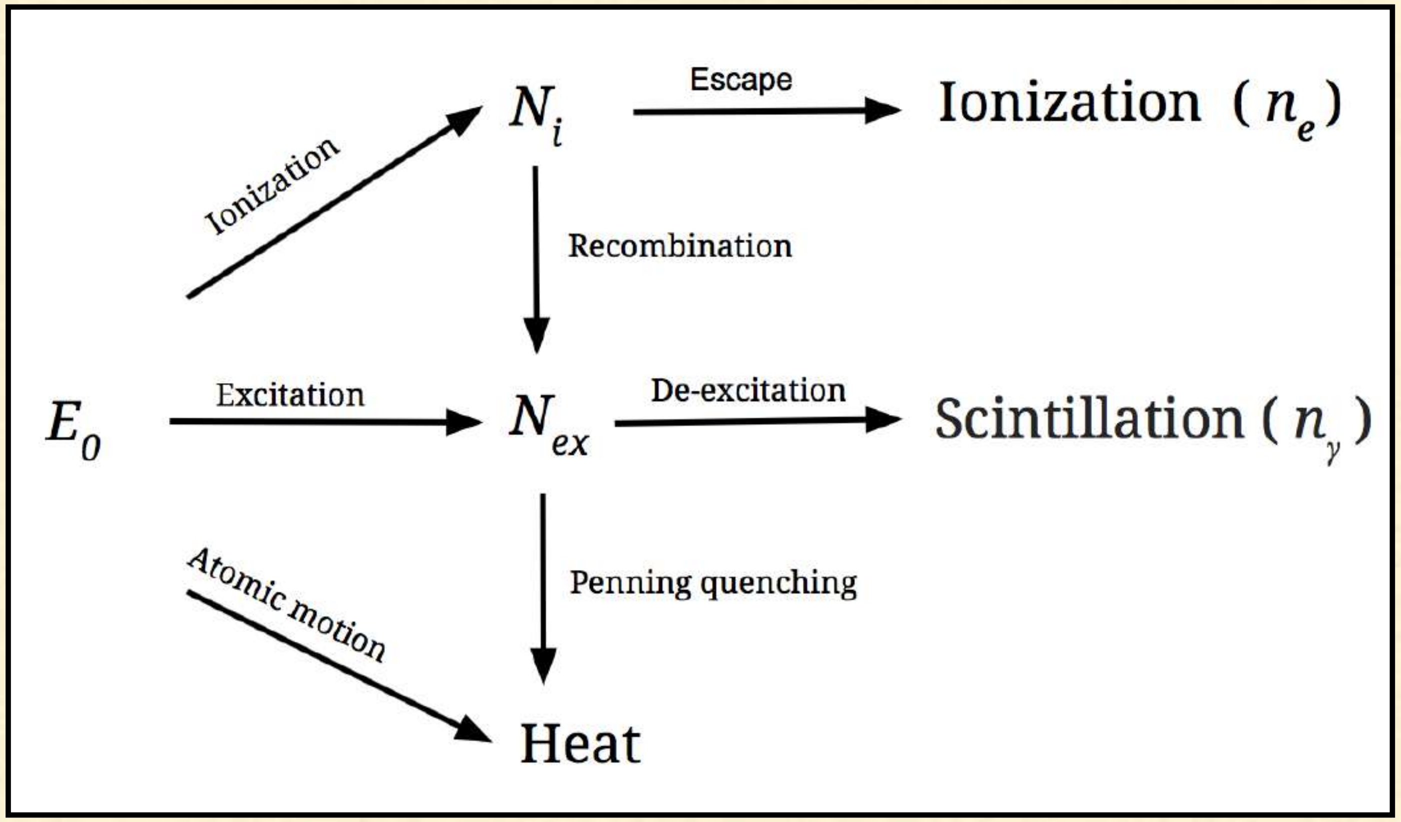
Noble Element Detectors



- Noble elements serve as high quality detection media, and yield measurable quanta even for low-energy interactions.
- Dual-phase time projection chambers (TPCs) are a common example, where energy reconstruction is done using both scintillation and ionization channels.
- It is important to model light and charge yields for a variety of interaction types.

Light and Charge Production in Xenon

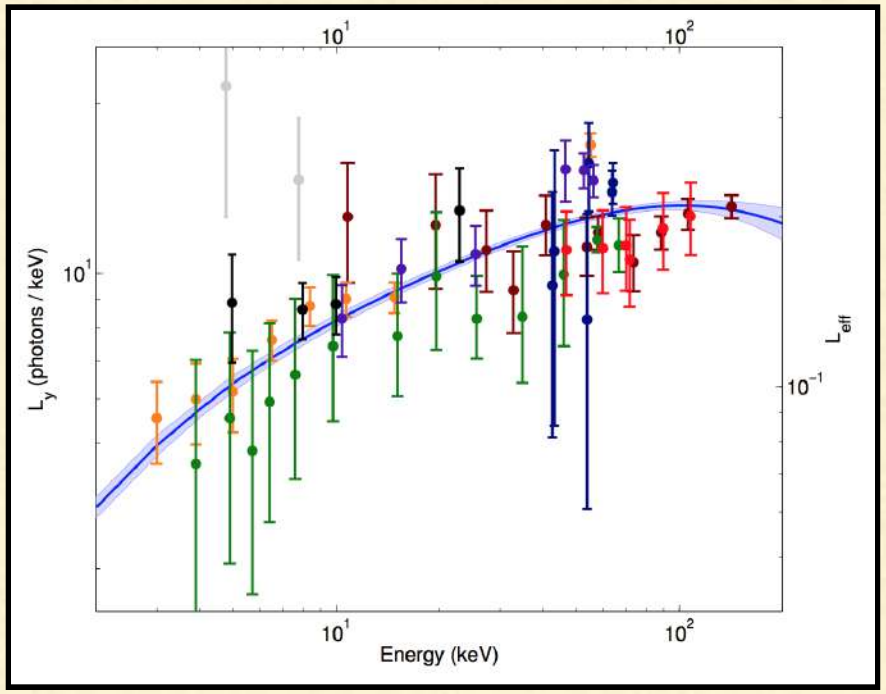
Lenardo et al.

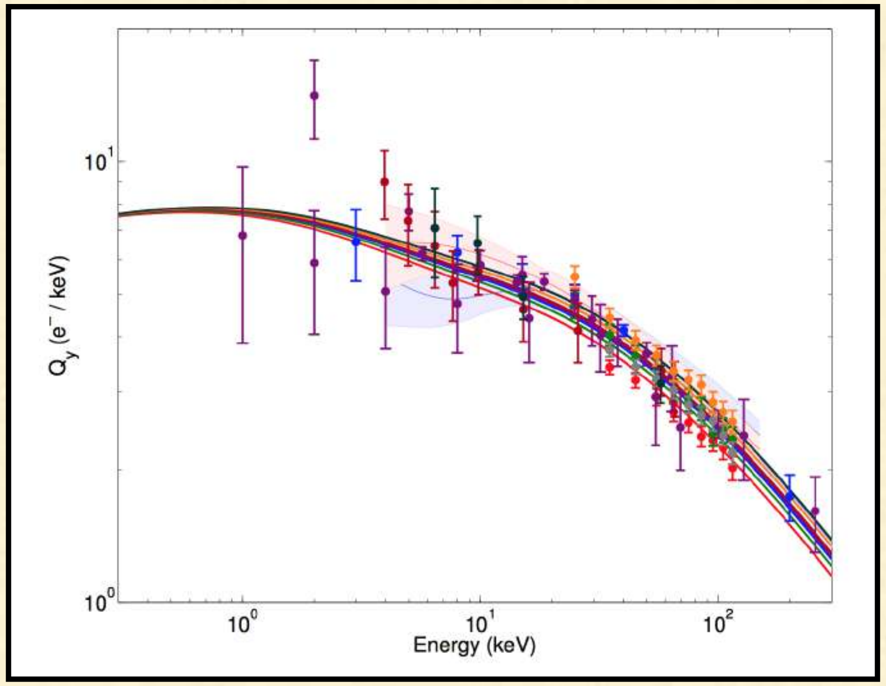


- The actual microphysics of scintillation and ionization pathways is complicated, and for xenon we cannot completely track the recoil cascades from first principles.
- NEST (**N**oble **E**lement **S**imulation **T**echnique) began as a semi-empirical model that uses first-principles physics to follow these pathways, but does global fitting of experimental data to calculate yields.

The Original NEST

- NEST v1.0 combined various experimental results for scintillation and ionization yields of liquid nobles into a single model.
- The software was implemented as C++ classes to be used within GEANT4-based simulations, allowing inclusion of detector response parameters.
- Has been successfully used to predict yields for a variety of experiments at different fields.





Lenardo et al.

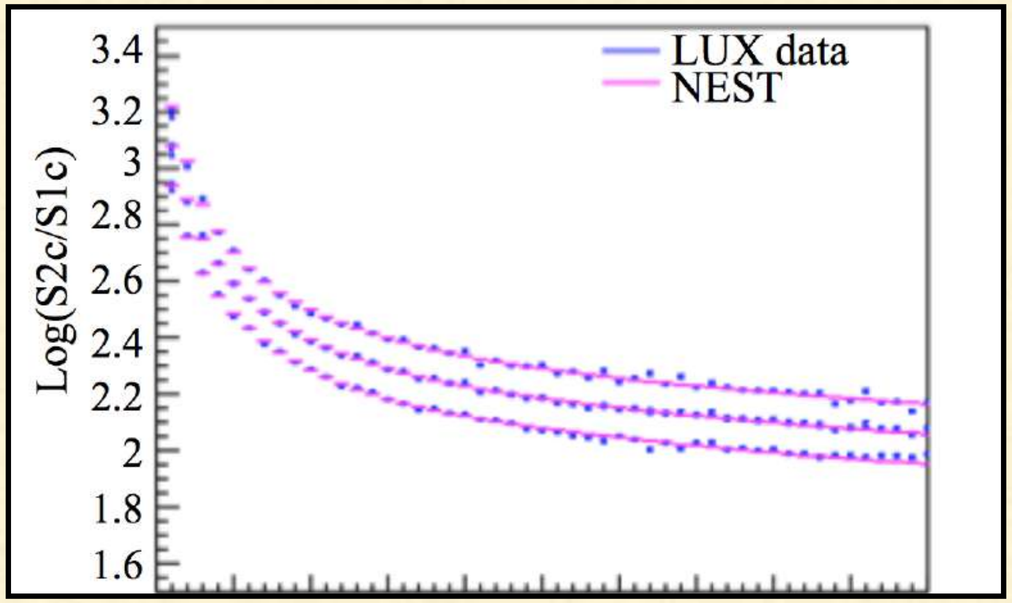
Applications of NEST

- Having simulations of yields as a function of electric field is crucial for optimizing detector designs and operational parameters (electric grid voltages, optical properties of detector materials, etc.).
- Not only can NEST guide the process of detector planning, but it also informs the data analysis during runs and provides crucial cross-checks.
- Having well-understood background and signal models is crucial for low background experiments and rare event searches.

Some Examples

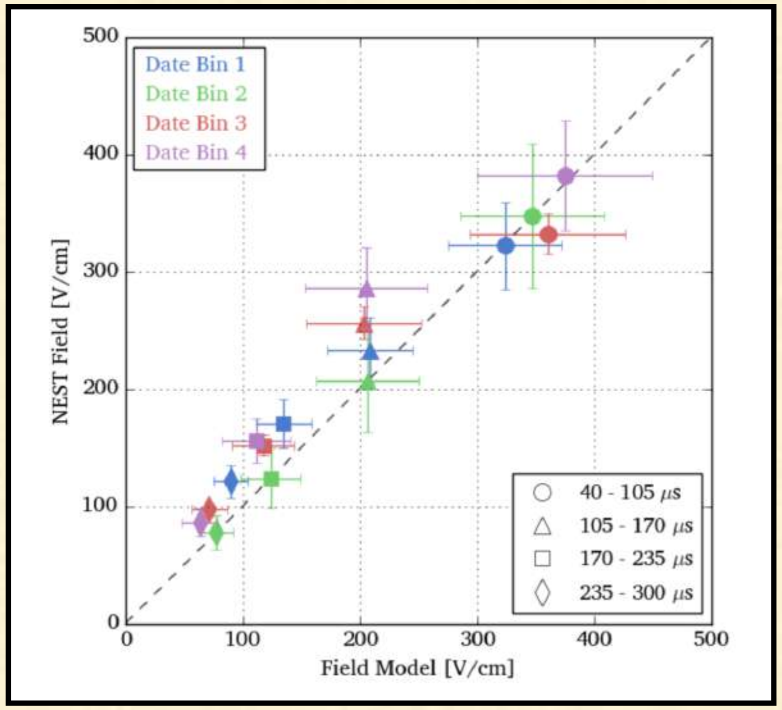
- For the LUX dark matter experiment, NEST aided in the verification of electric field modeling.

- NEST is used to generate ER bands with field as a floating parameter. By matching with LUX tritium data at various drift times, the electric field can be obtained at those depths.



LUX (Akerib et al.)

LUX (Akerib et al.)

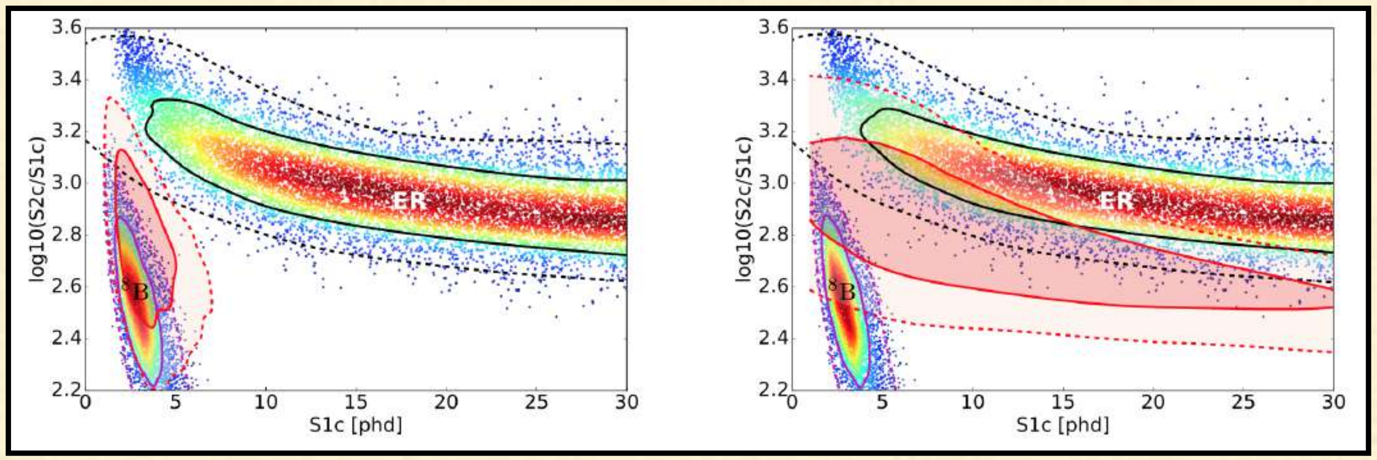


- The electric field is obtained *independently* by developing a model for the charged PTFE detector walls and producing field maps from COMSOL.

- These results cross-check nicely at various dates throughout the dark matter search.

Some Examples

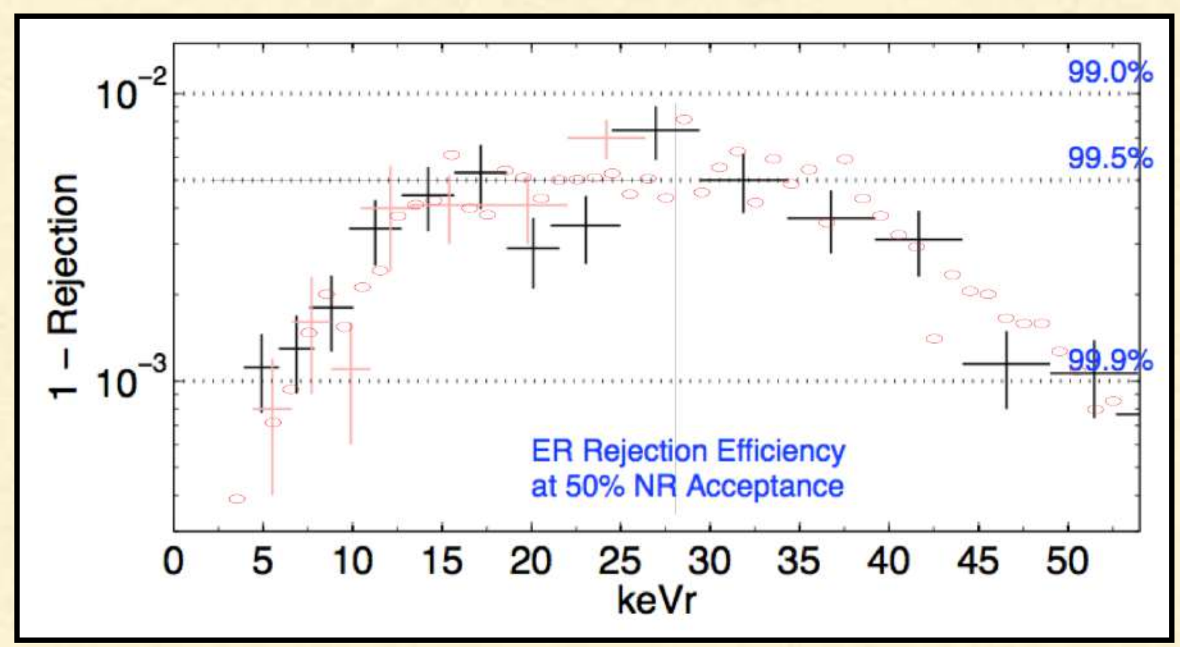
10 GeV/c^2 WIMP   1000 GeV/c^2 WIMP



LZ TDR (Mount et al.)

- LZ has used NEST (with detector response) to generate signal and background PDFs and predict the leakage of projected background populations into WIMP regions.

XENON10



- Similarly, for XENON10, NEST yields can be used to generate ER bands for assessing discrimination power.
- NEST (red circles) correctly predicts ER rejection efficiency as a function of energy.

Reasons to Update

- The NEST package should be a standalone library that does not require coupling with GEANT4. Detector specifics should be dealt with separately to broaden its application.
- The code should be clear and succinct, allowing easier collaboration and user adjustments.
- It should be optimized for speed and ease of data processing.
- Underlying physics models themselves are being improved and expanded as new measurements emerge.

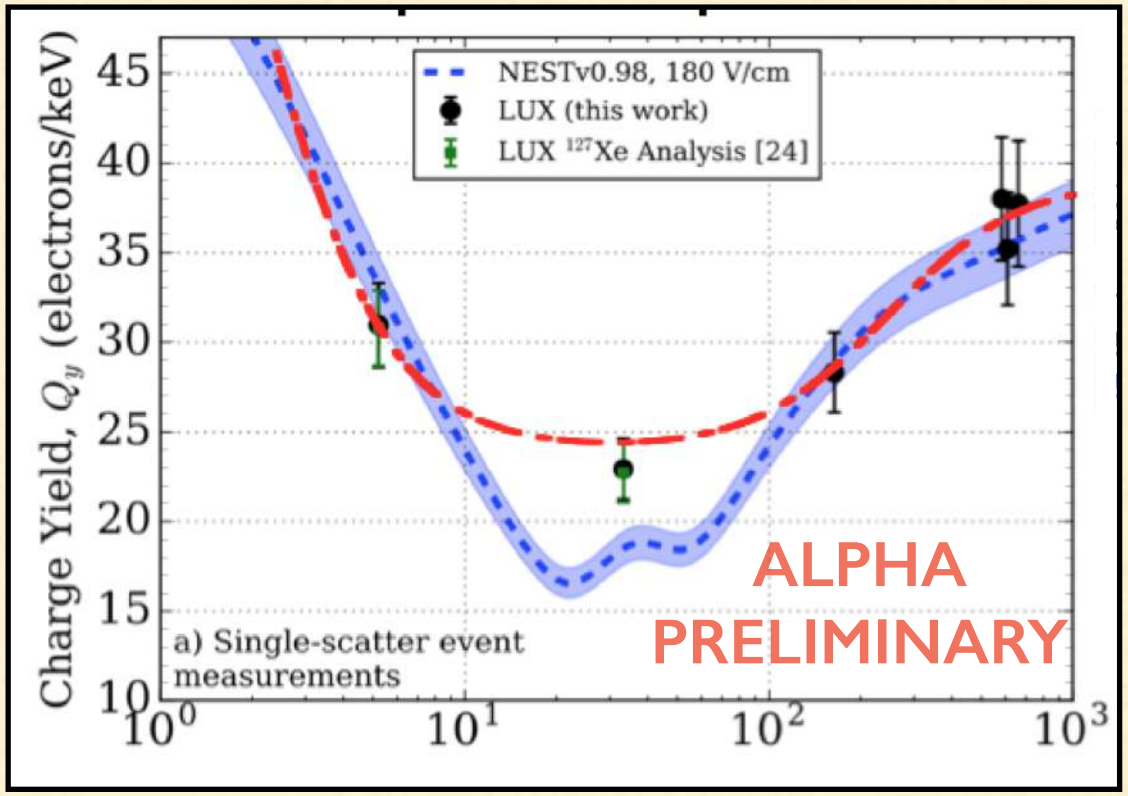
Enter NEST v2.0

- The NEST v2.0 (beta version) package incorporates all of the aforementioned improvements.
- This version is not limited to use in user-developed software, but also includes command line functions for quick calculations.
- NEST v2 compiles without dependencies on GEANT4 or ROOT, making it a faster and more accessible tool that works right out of the box.
- Each interaction type/recoil species is clearly indicated in the code, each with a readable formula in $\leq$12 lines of code.

Model Improvements

- The abundance of precision experiments is too constraining for the semi-empirical model, so a sum of sigmoidal functions is now used to fit experimental data.
- This new empirical model applies to many categories and interaction types:
  - Compton scatters and beta decays
  - Photo-absorption
  - ^{83m}Kr
  - Xe nuclear recoils
  - Other heavy nuclear recoils (e.g. ^{206}Pb)
  - Alphas

Blue: NEST v0.98
Red: NEST v2
Black: LUX Data

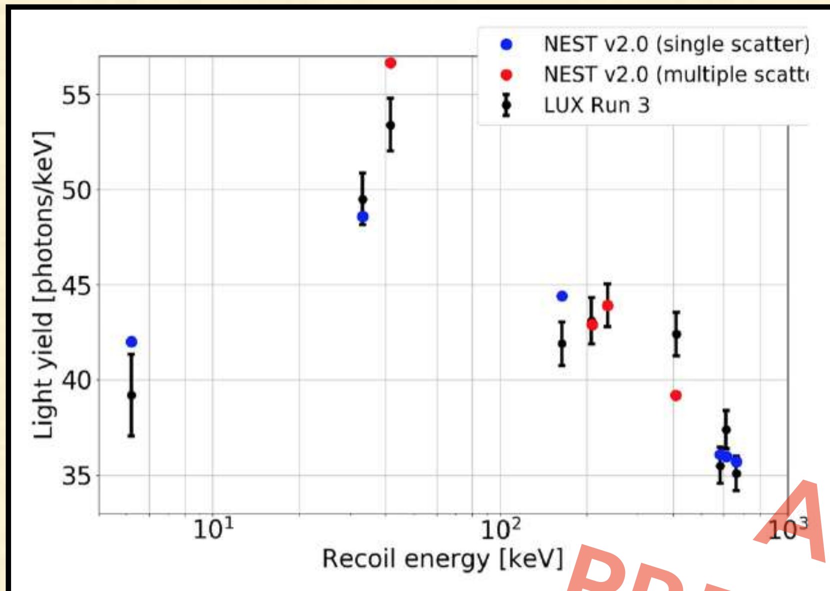


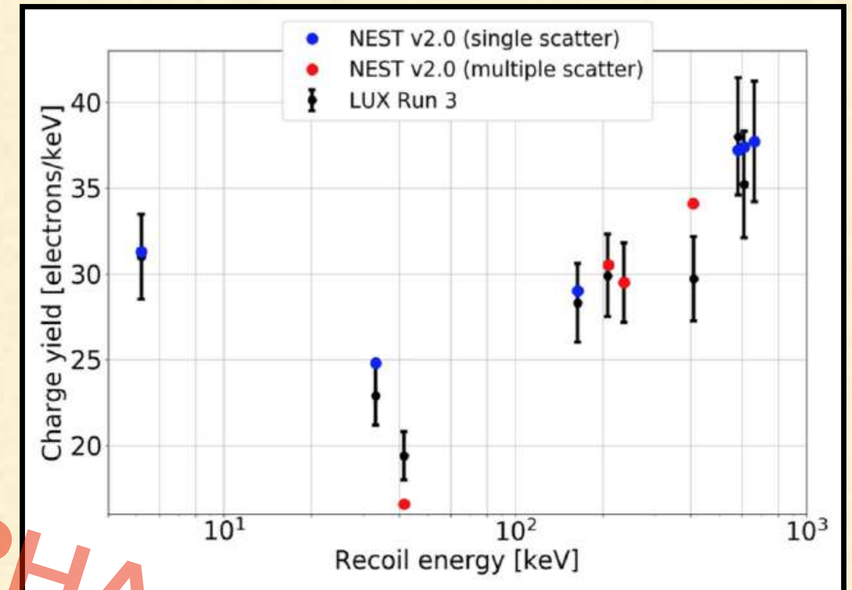
LUX ER (180 V/cm Drift)

Validation Campaign (Photo-absorption)

Light | Charge

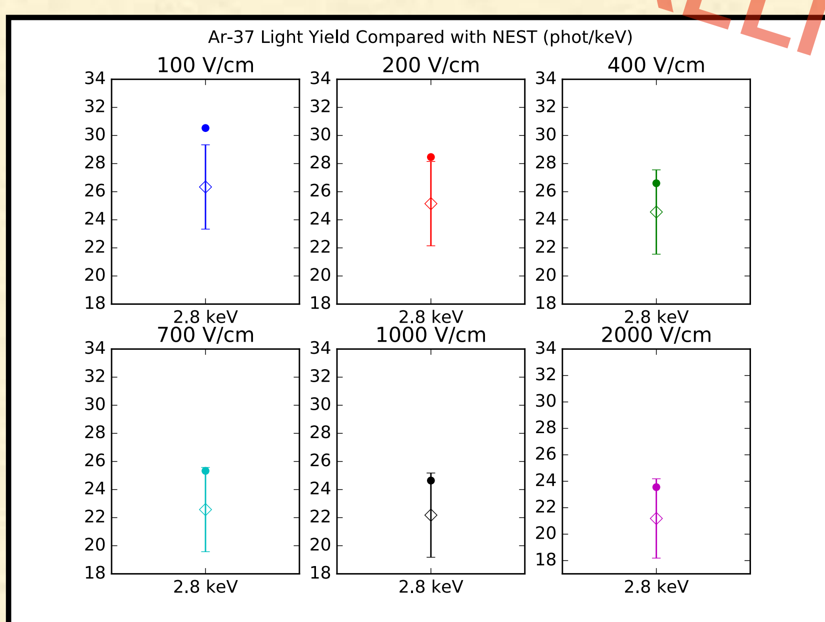
LUX

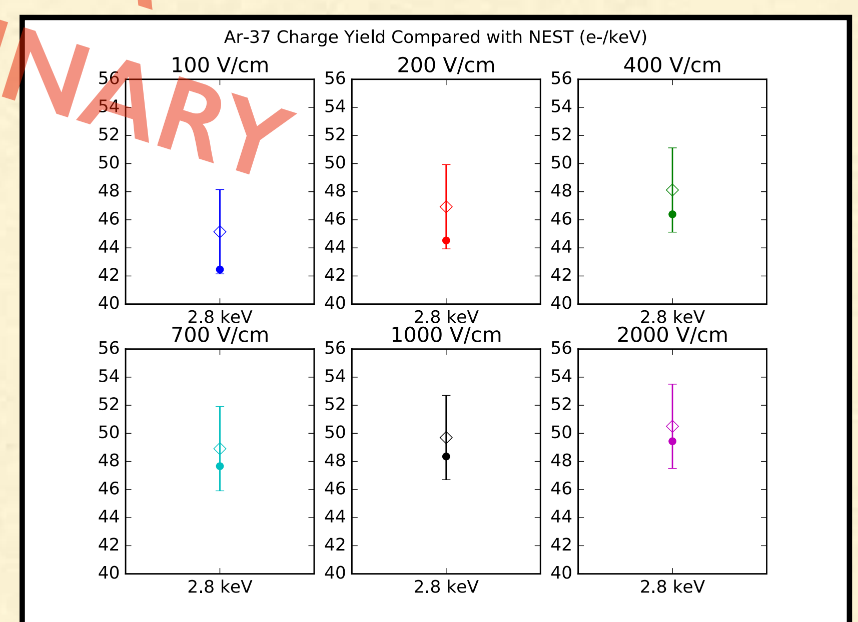




ALPHA PRELIMINARY

PIXeY



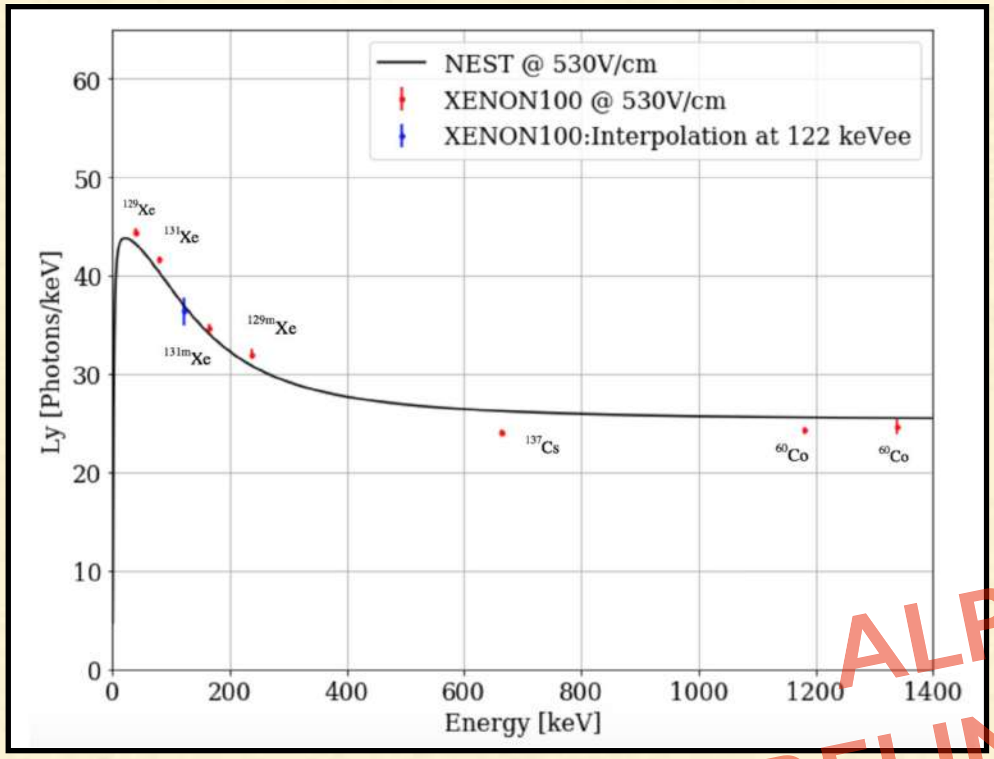


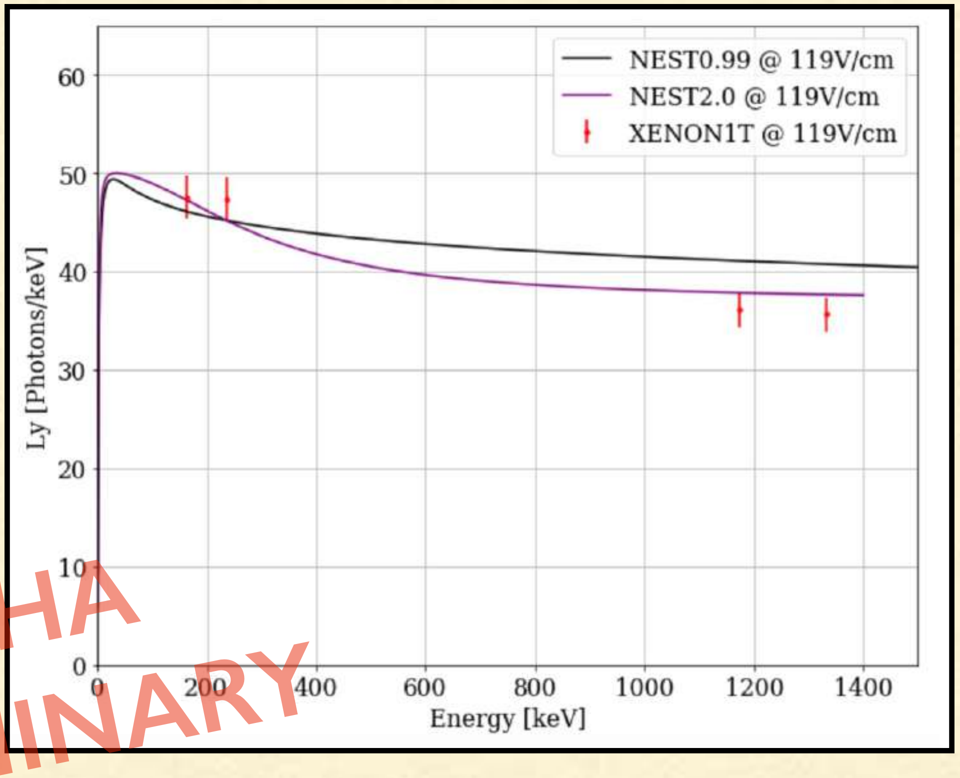
Validation Campaign (Photo-absorption)

XENON100

XENON1T

Light Yield

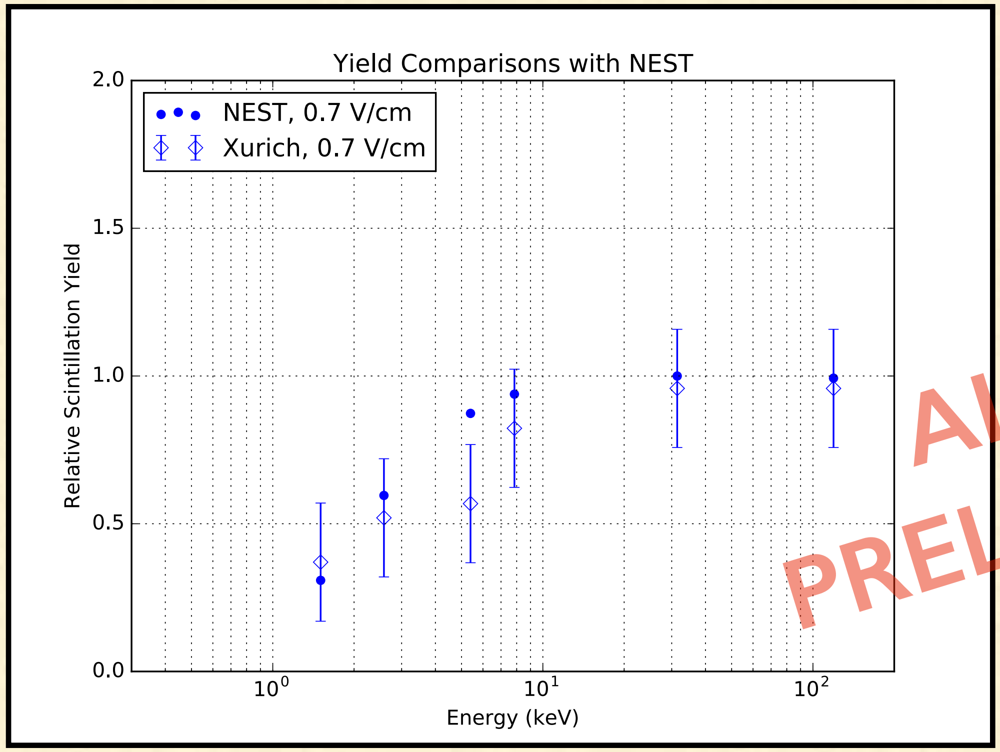




ALPHA PRELIMINARY

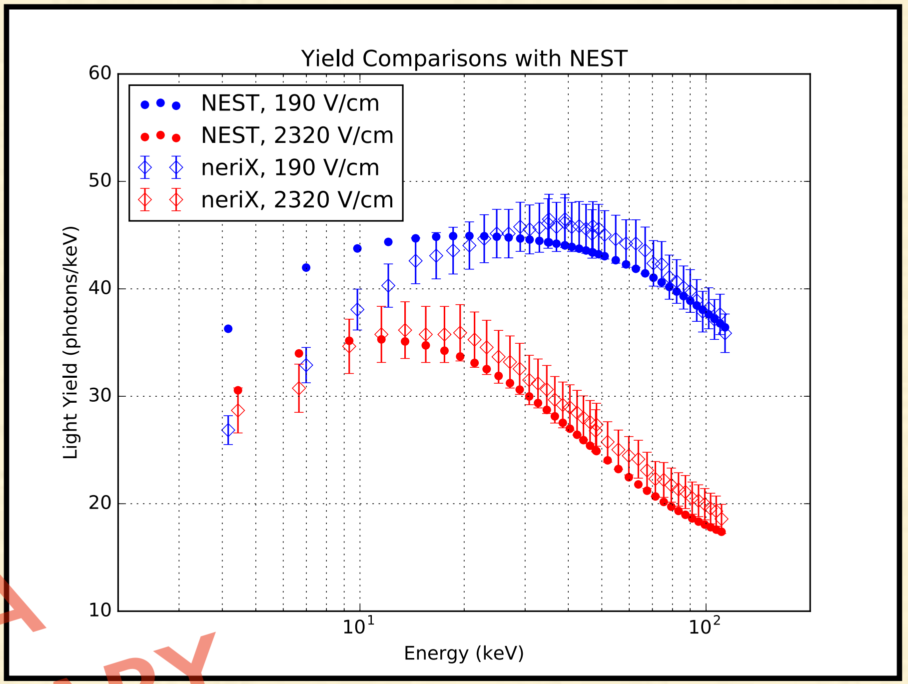
Validation Campaign (Beta/Compton)

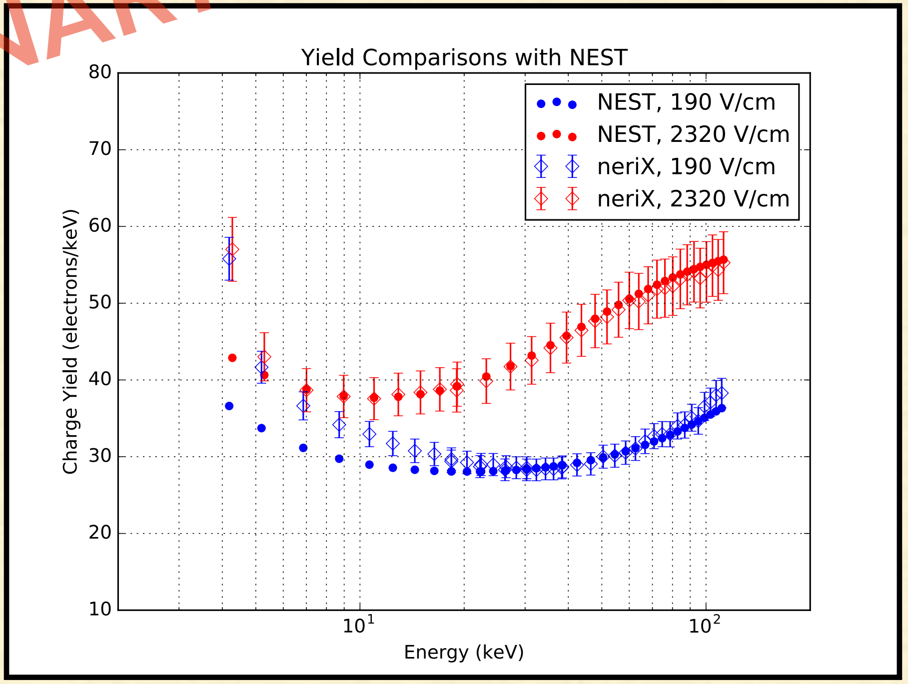
Xurich (Light Yield)



ALPHA PRELIMINARY

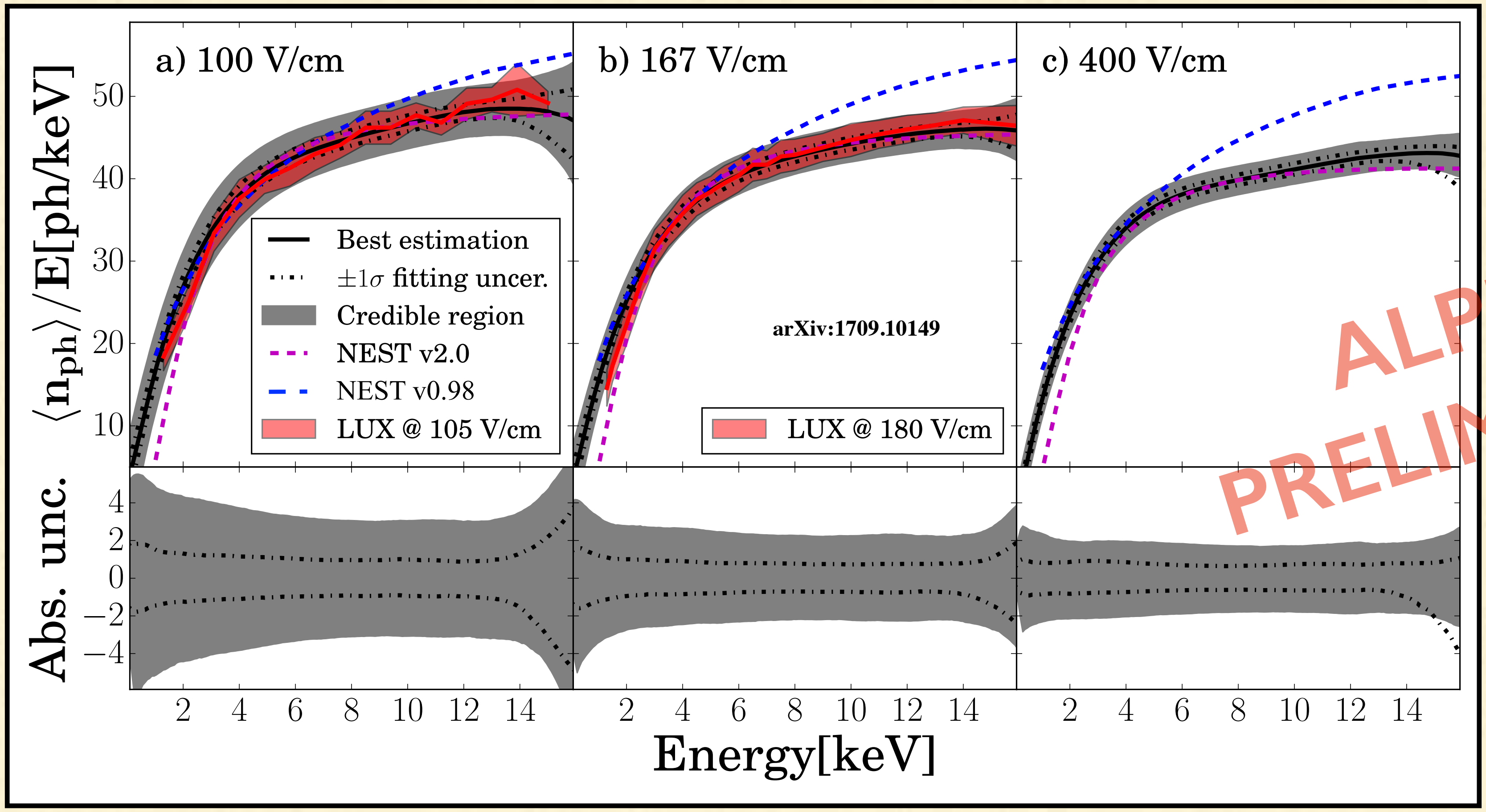
neriX





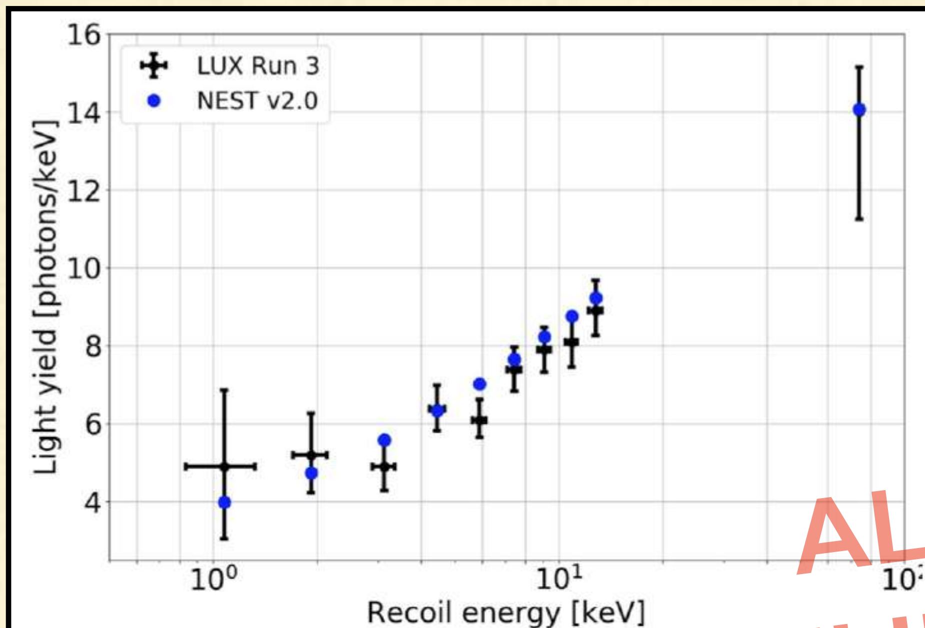
Validation Campaign (Beta/Compton)

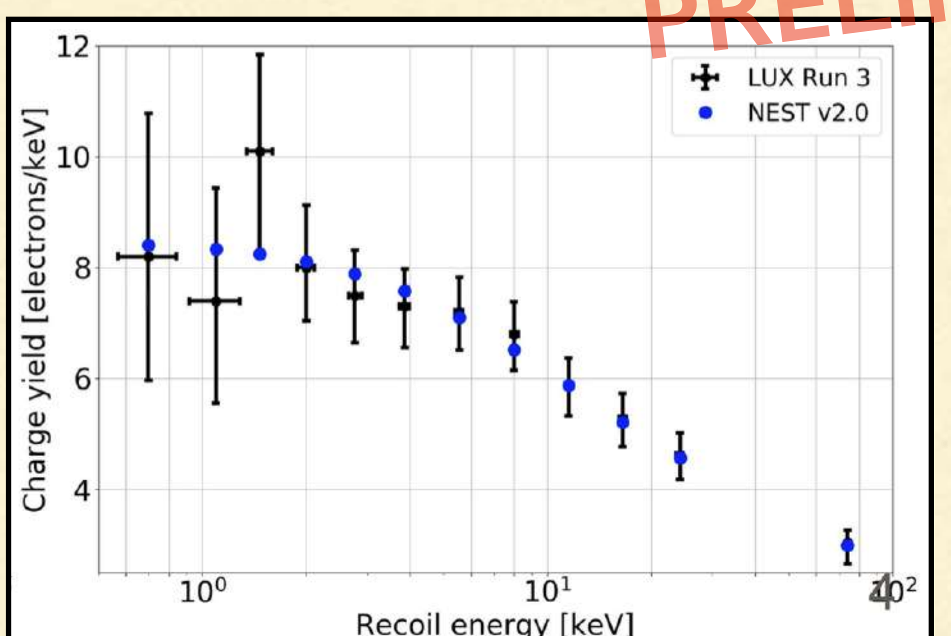
XENON100 (Tritium)



Validation Campaign (Nuclear Recoils)

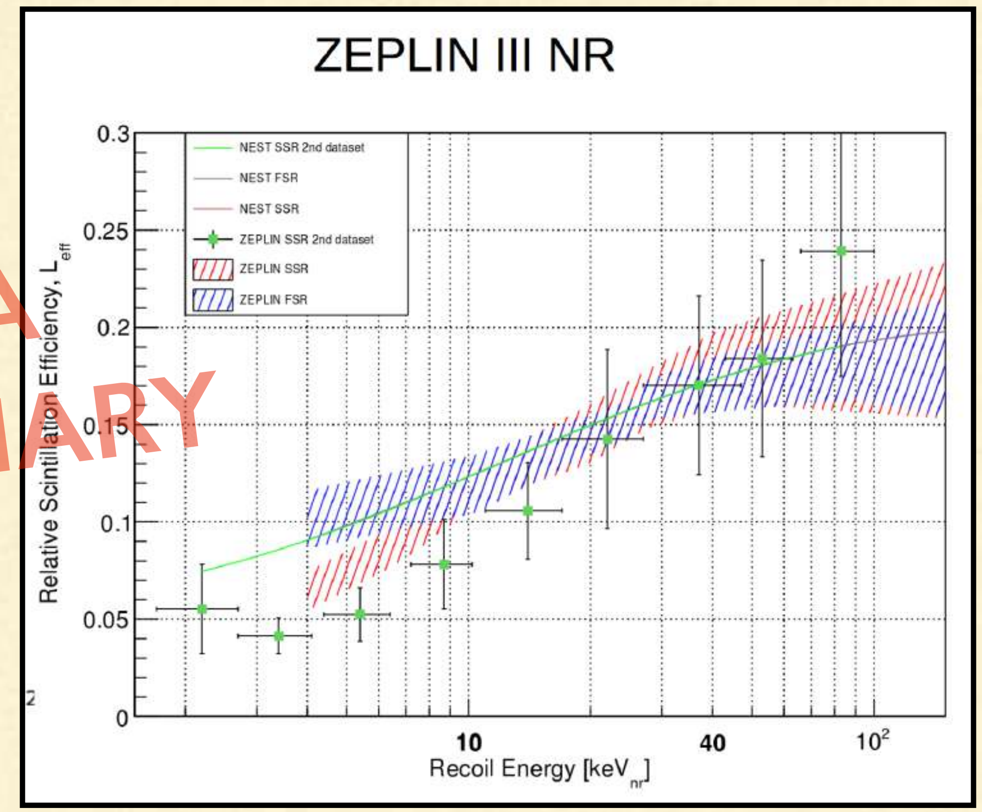
LUX DD Results





ALPHA PRELIMINARY

ZEPLIN III (Light Yield)



Conclusions

- NEST v2, with improved physics models and greater usability, will be available as a public beta version by the end of this year.
- Future goals include the addition of non-binomial recombination fluctuations to the physics models, an optional GEANT4 integration for full detector simulations, and a web tool for quick calculations.
- We plan to use the new empirical models as a point of comparison for an eventual first-principles atomic physics model, NEST v3.

NEST Collaboration

UC DAVIS
UNIVERSITY OF CALIFORNIA

Mani Tripathi
Aaron Manalaysay
Jacob Cutter

UNIVERSITY AT ALBANY
State University of New York

Matthew Szydagis
Jack Genovesi
Madison Wyman
Emily Magnus

UNIVERSITY OF MARYLAND 1856

Jon Balajthy
Carter Hall

UC San Diego

Kaixuan Ni
Junying Huang

MEPhI

Ekaterina Kozlova

Lawrence Livermore National Laboratory

Jason Brodsky
Kareem Kazkaz
Brian Lenardo

Berkeley
UNIVERSITY OF CALIFORNIA

Dan McKinsey
Vetri Velan

Thank you!

Questions?