A Symphony of Scintillation

Noble **E**lement **S**imulation **T**echnique

for Geant4.9.3 and 4.9.4 (4.9.5 testing underway)

http://nest.physics.ucdavis.edu

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AARM Collaboration Meeting, Minneapolis, MN, Friday 06/22/2012

The People of the NEST Team

UC Davis and LLNL, in California

A small but passionate group of individuals who love their work

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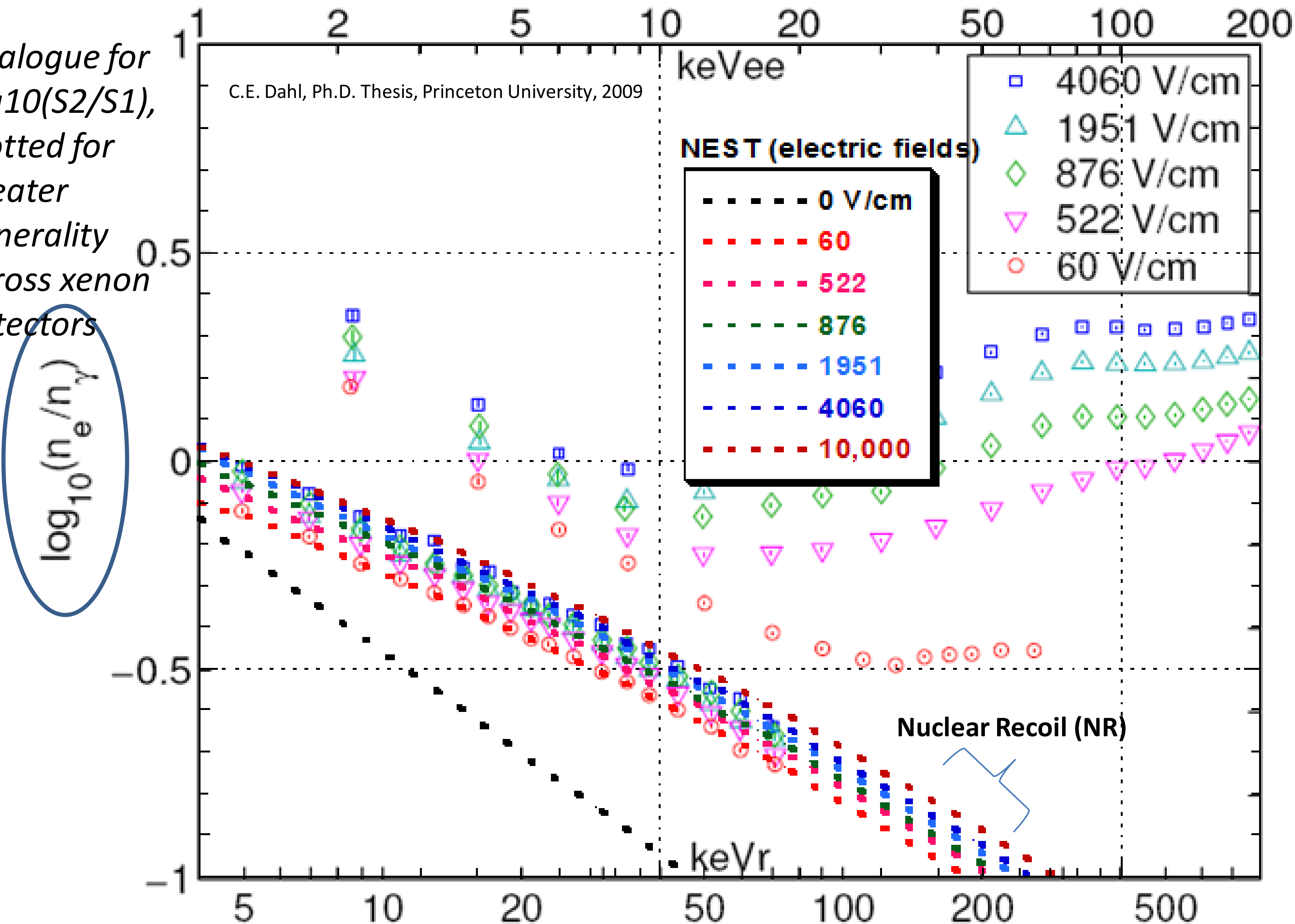
Let’s Review

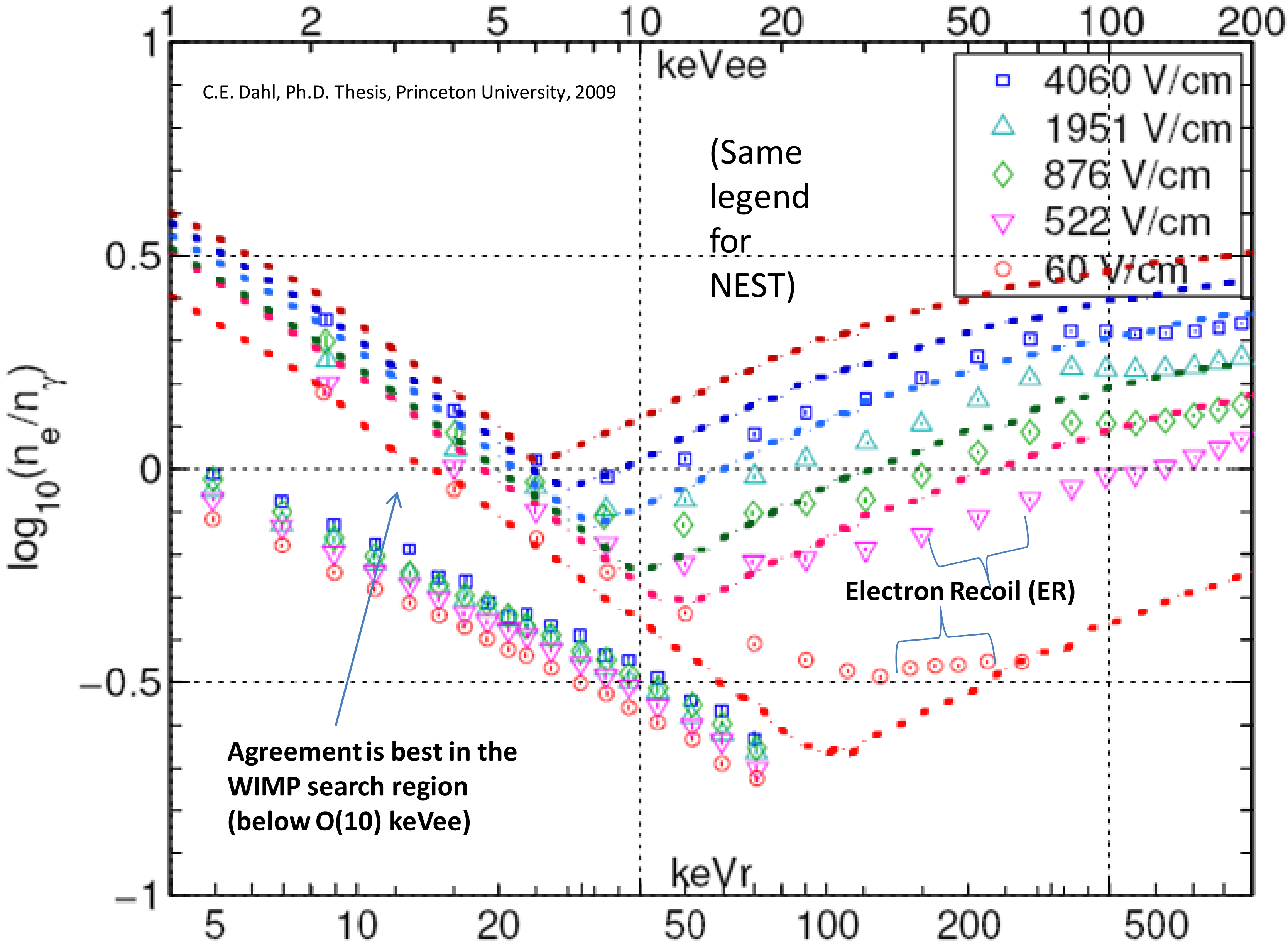
- Covered in past meetings: mean light and charge yields (Gaussian) matched to decades of data
  - Versus energy (data from 3+ keVnr and 2+ keVee)
  - Versus electric field (0 to ~20 kV/cm)
  - Versus particle type (gamma/electron/muon, alpha, ion, neutron/WIMP)
  - Default nuclear recoil model: Hitachi (best match to Manzur et al. and ZEPLIN-III FSR and SSR, and only ~1-sigma below XENON100’s latest measurement)
- Discussing today: significant progress in matching the variation in the light and charge yields
- Data gold mine (60-4,060 V/cm and 2-200 keVee) in Dahl Ph.D. thesis, but it’s not the sole source
- NEST makes it so you don’t have to look up the papers, for Birks’ Law parameters, etc.

Mean Ionization/Scintillation Ratio: NR

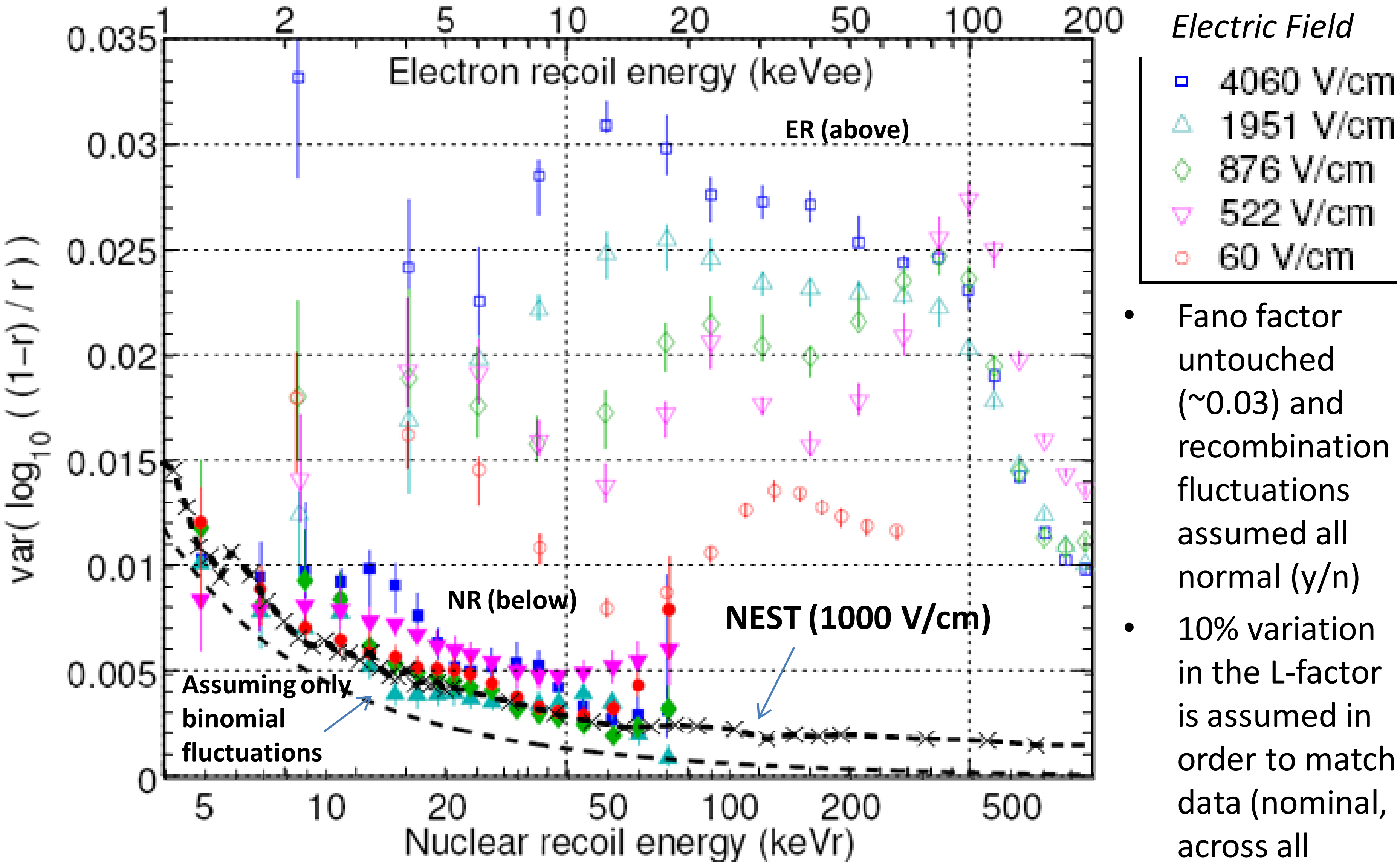
Analogue for log10(S2/S1), plotted for greater generality across xenon detectors



Mean Ionization/Scintillation Ratio: ER



Recombination Fluctuations: NR

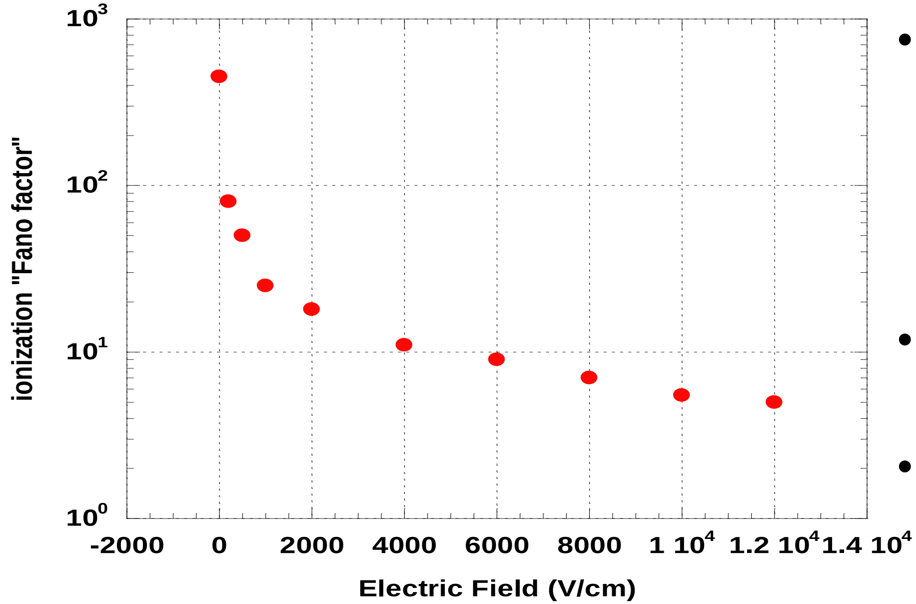


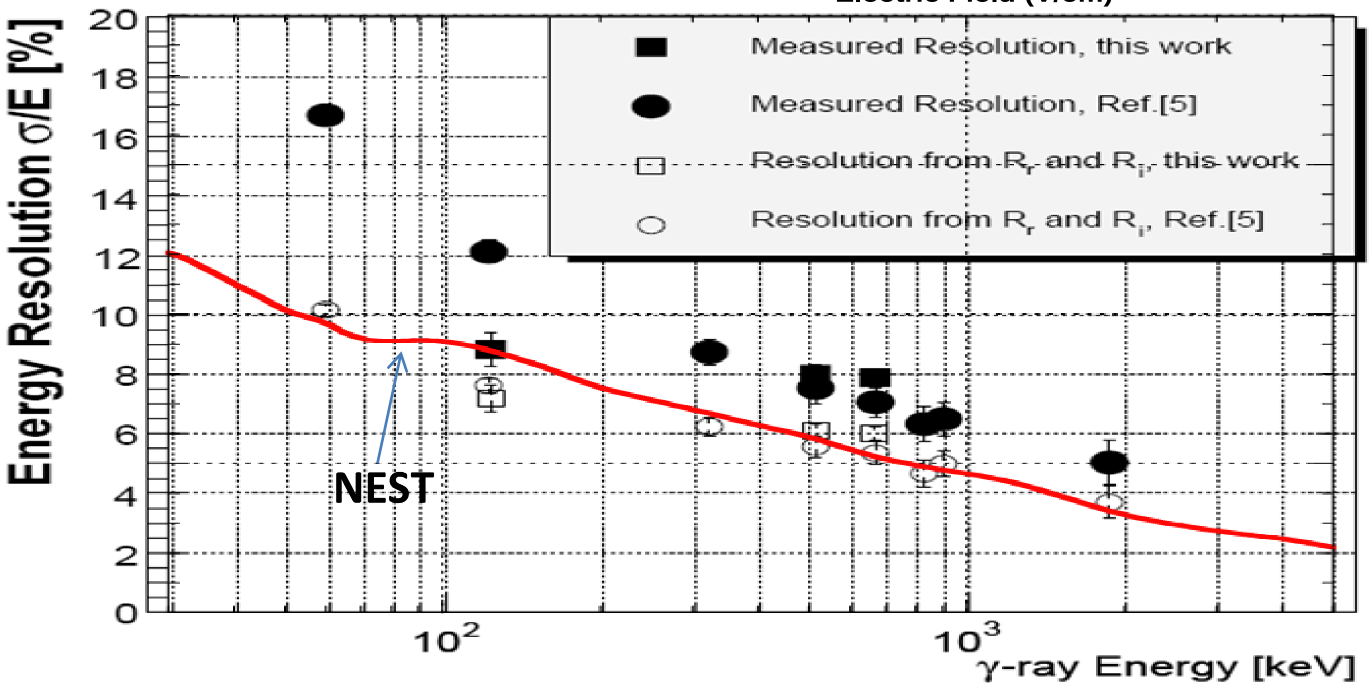
keVr energy scale assumes old L = 0.25: using Hitachi, 5 keVr point is actually 8.67 and 70 keVr point is 85.5

- Fano factor untouched (~0.03) and recombination fluctuations assumed all normal (y/n)
- 10% variation in the L-factor is assumed in order to match data (nominal, across all electric fields)

Recombination Fluctuations: ER

*Regular Fano factor left alone again, but now the recombination fluctuations have been modeled as worse than binomial, with a 1-sigma of sqrt(F_e*N_e), per interaction site, an ionization Fano factor*

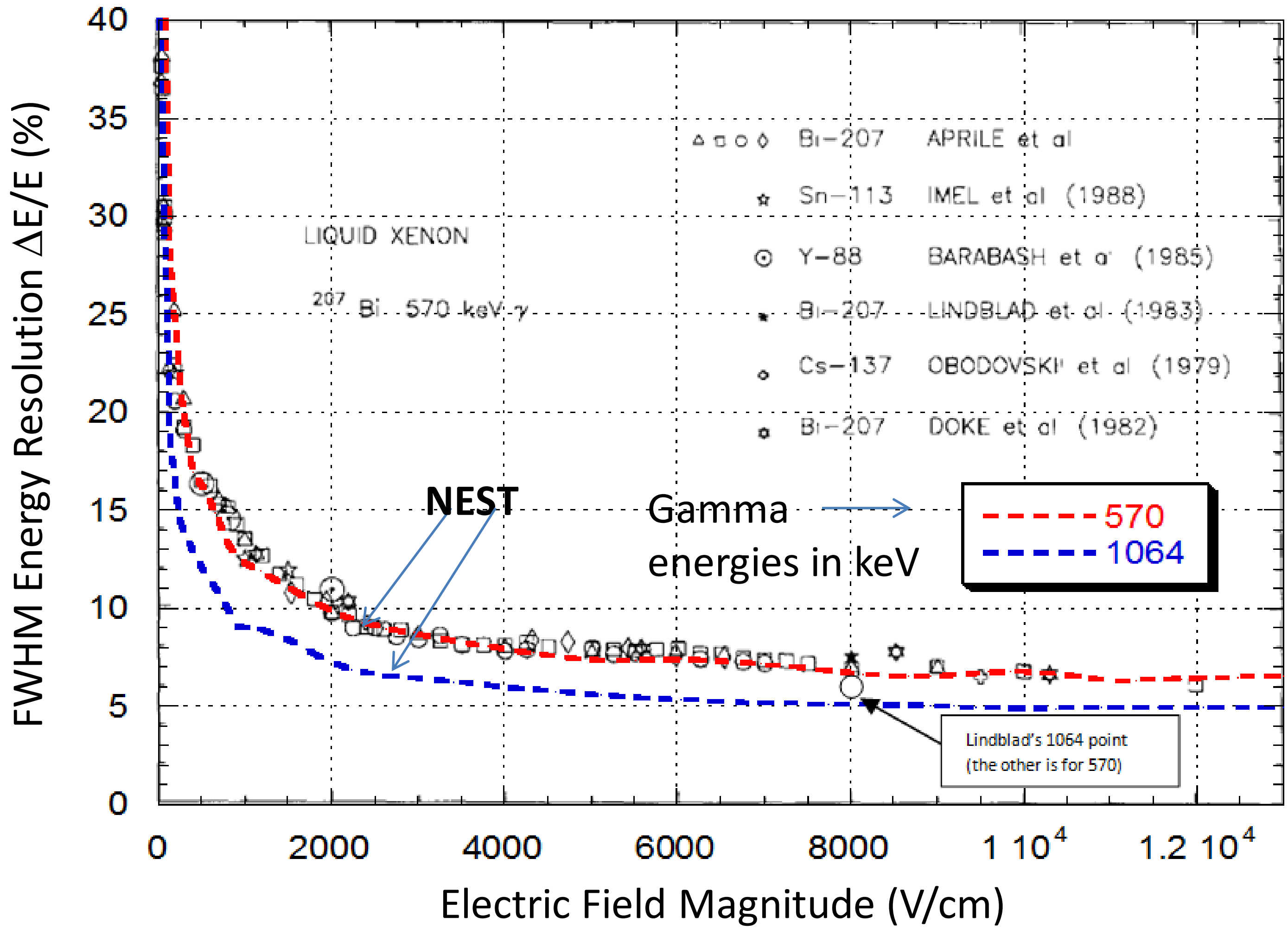




- Gamma rays at zero field (red curve is NEST) vs. incident energy, at lower left
- Data is from Ni et al. 2006 (JINST)
- Long list of effects now included in the NEST LXe sim
  - Fano factor
  - Excitation vs. ionization (binomial)
  - G4 dE/dx variation
  - Particle track history (G4)
  - QE and light collection

Recombination Fluctuations: ER

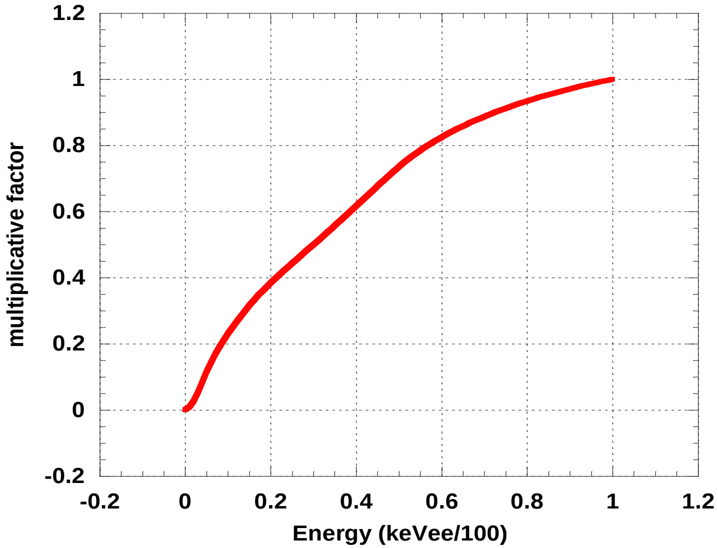
Gamma rays at fixed energies vs. field (red and blue curves are NEST), compared with data compiled in Aprile et al. 1991 (NIM A), though unfortunately all the data is high-energy



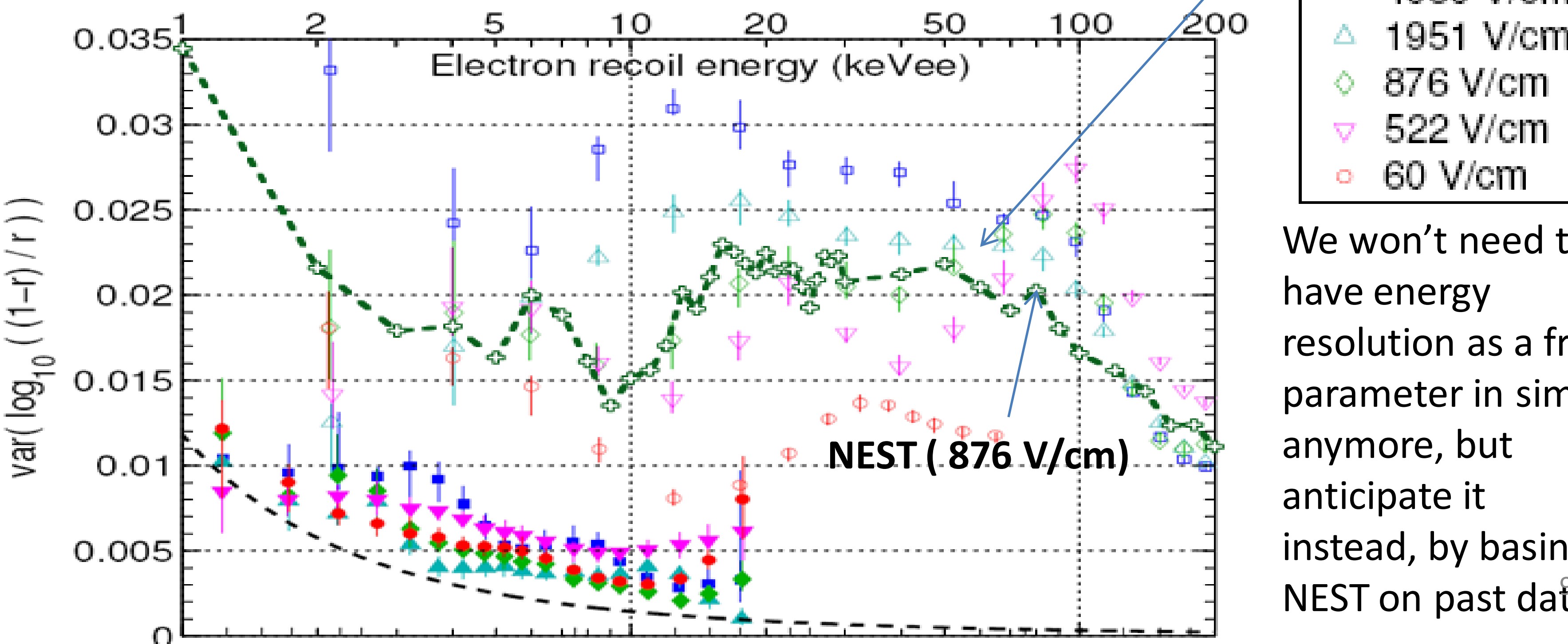
- The used NEST-employed "extra" recombination fluctuation is electric-field-dependent, but energy-independent (working ansatz)
- Showing only ionization channel here
- Good simulated resolution will allow us to predict the discrimination power of any detector as a function of field and energy

Recombination Fluctuations: ER

The anomalously high (F_e ~ 10-100) recombination fluctuations at high energies are smoothly extrapolated down to 0 additional fluctuation (i.e., binomial only) at 0 energy (using 876 V/cm data to ground the NEST model)

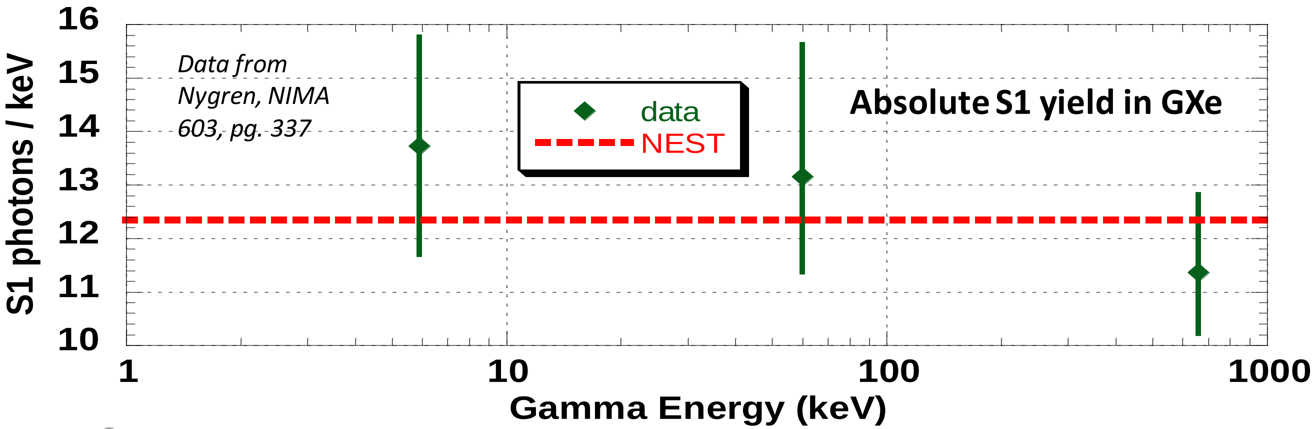


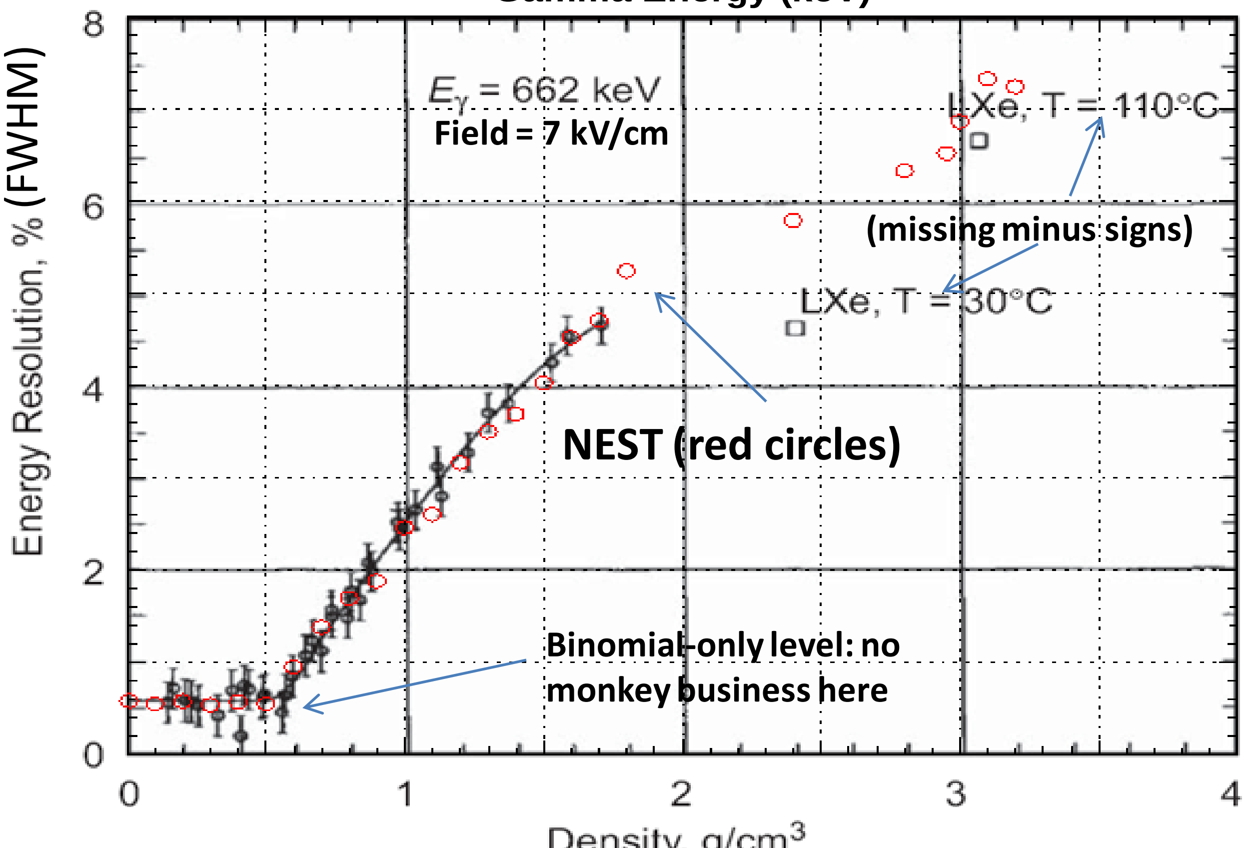
The undulations are at least partially an "emergent property" of NEST, caused by the "battle" between the increasing energy and the increasing variance



We won't need to have energy resolution as a free parameter in sims anymore, but anticipate it instead, by basing NEST on past data

Recombination Fluctuations: ER

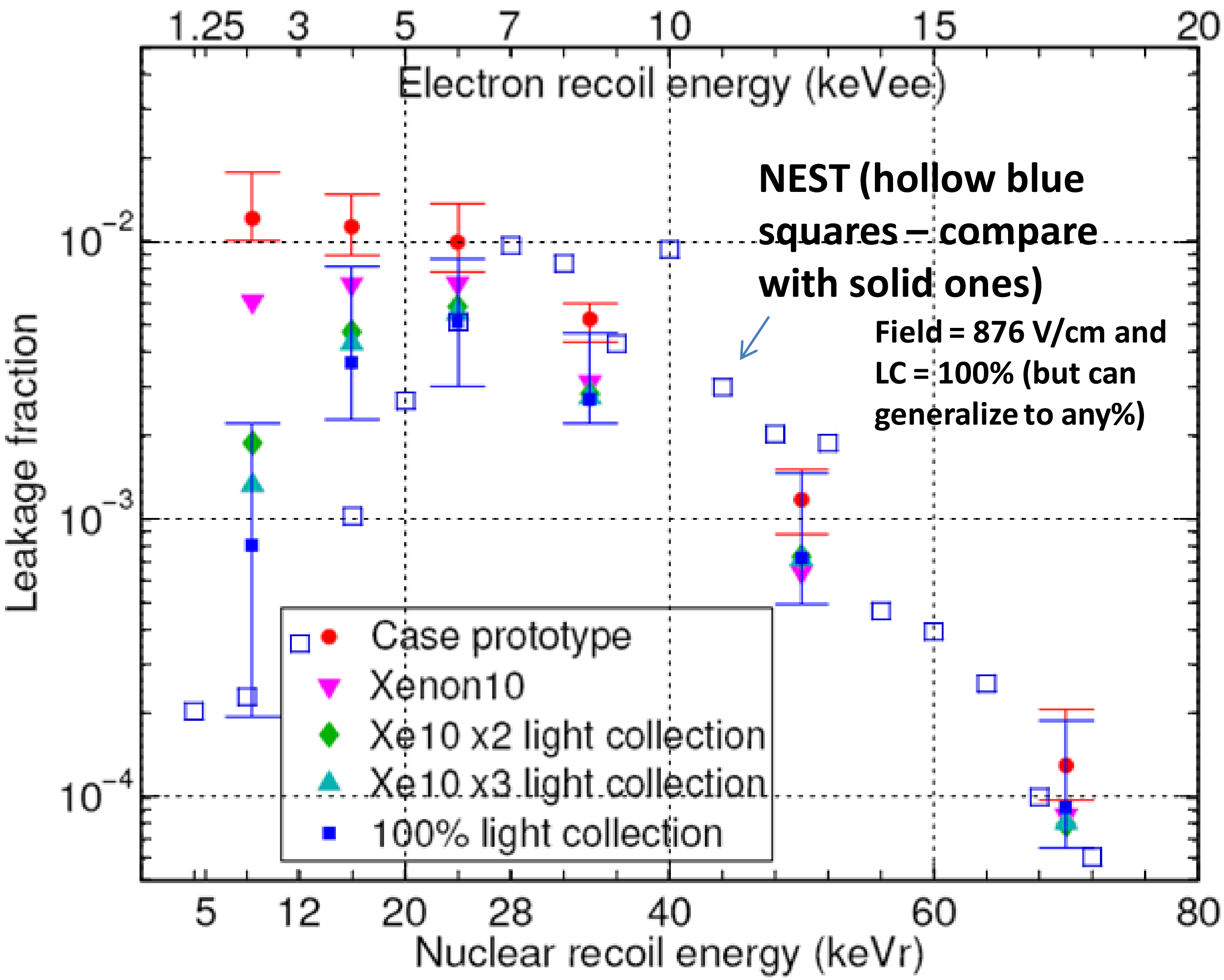




- We can generalize our field-dependent model to be density-dependent, and use it to fit gas data effectively
- The plot at left from Bolotnikov 1997 (and Nygren 2009) was considered mysterious: we now have a model to explain it (though it still needs more physical motivation quantitatively)
- NEST has ever-broader applications (double beta decay in this case)

Discrimination Power vs. Energy

- After the improvements to the recombination model made to reflect real-life energy resolution driven by non-Poissonian fluctuations, NEST exhibits the correct behavior for low-E discrimination!
- It should now be possible to use NEST in order to make general predictions for present and future detectors of differing light collection efficiencies (100% efficiency shown in plot as example)



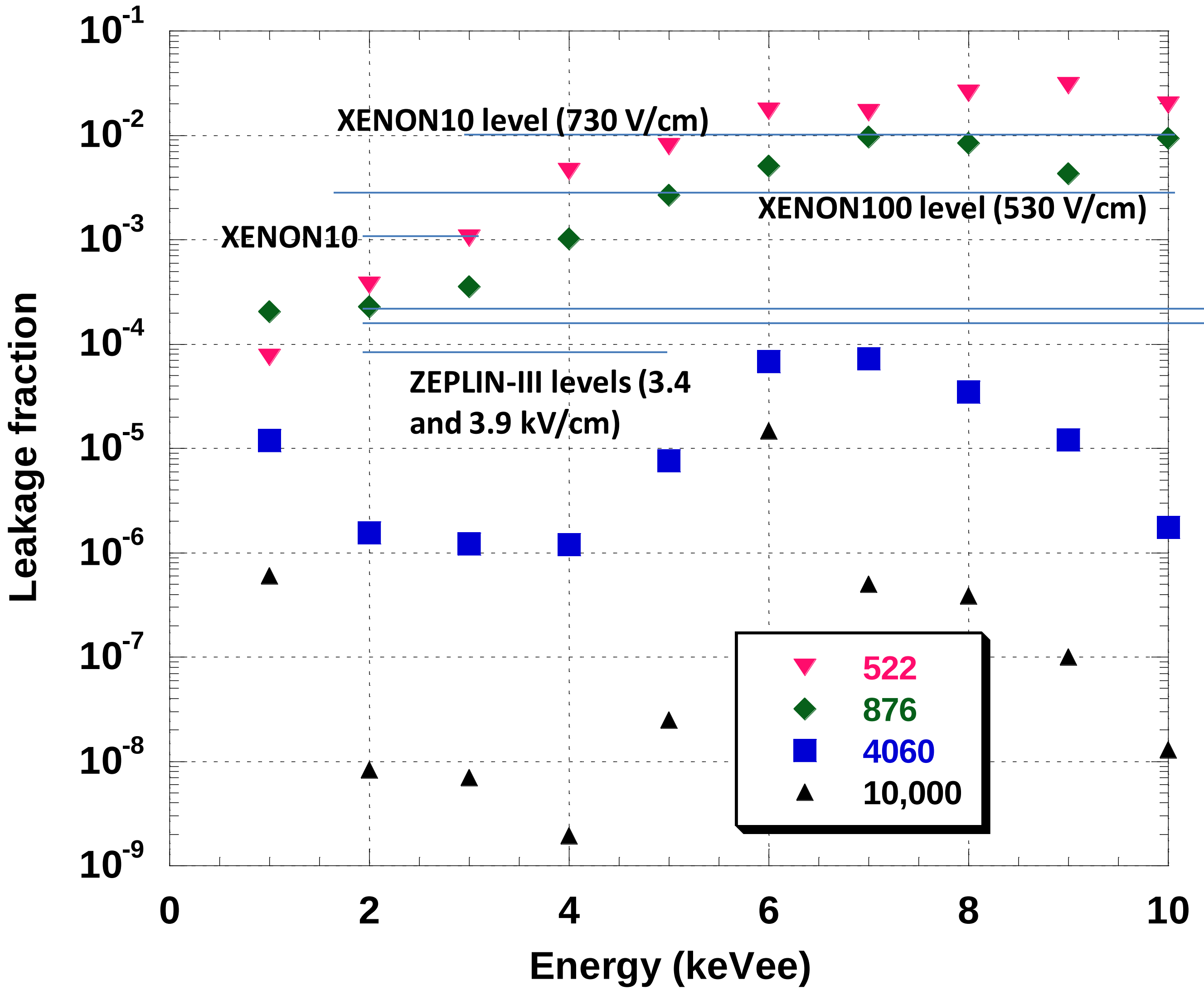
NEST (hollow blue squares – compare with solid ones)

Field = 876 V/cm and LC = 100% (but can generalize to any%)

This plot is the culmination of all other efforts on NEST, since in order to get it right mean light and charge yields for both NR and ER have to be correct, and the width of the ER band, too. This is the first time that publicly available code can do all this!

Discrimination Power vs. Field

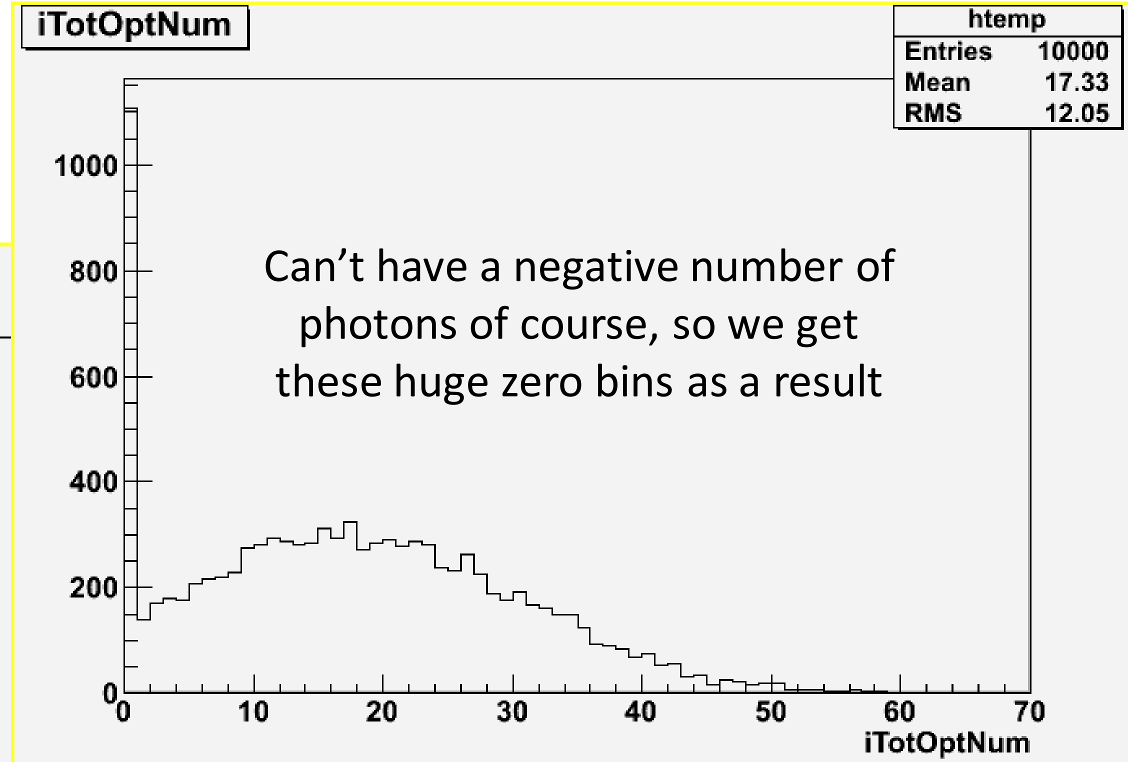
- The log10(S2/S1) ER and NR bands are getting thinner with field AND pulling away from each other, even in the Thomas-Imel regime (low energies) where they are essentially parallel curves
- As field increases, the number of electrons pulled out increases, but it increases MORE for ER than for NR, which changes slowly
- NEST just has one success after another, sometimes making real predictions, not just postdictions

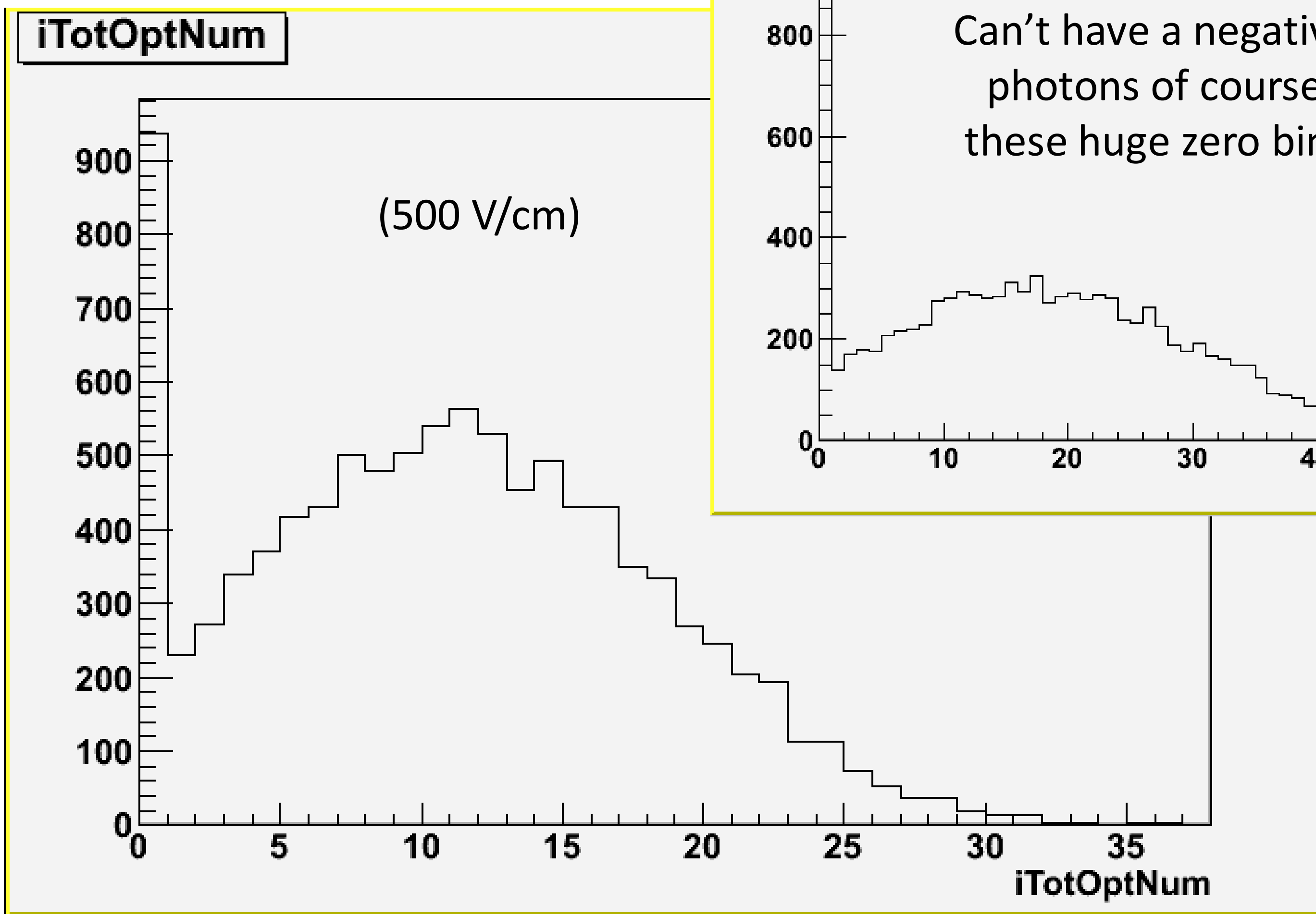


Correct orders of magnitude have been achieved by NEST, but final comparisons must wait for the corrections from the product of LC and QE, and from the fact that a real detector does not know the real energy of an interaction perfectly, so the bins get fuzzy

Non-Gaussianities (Make Tails?)

Absolute numbers of optical photons at low energies: 3 keVnr (below) and 1 keVee (right)



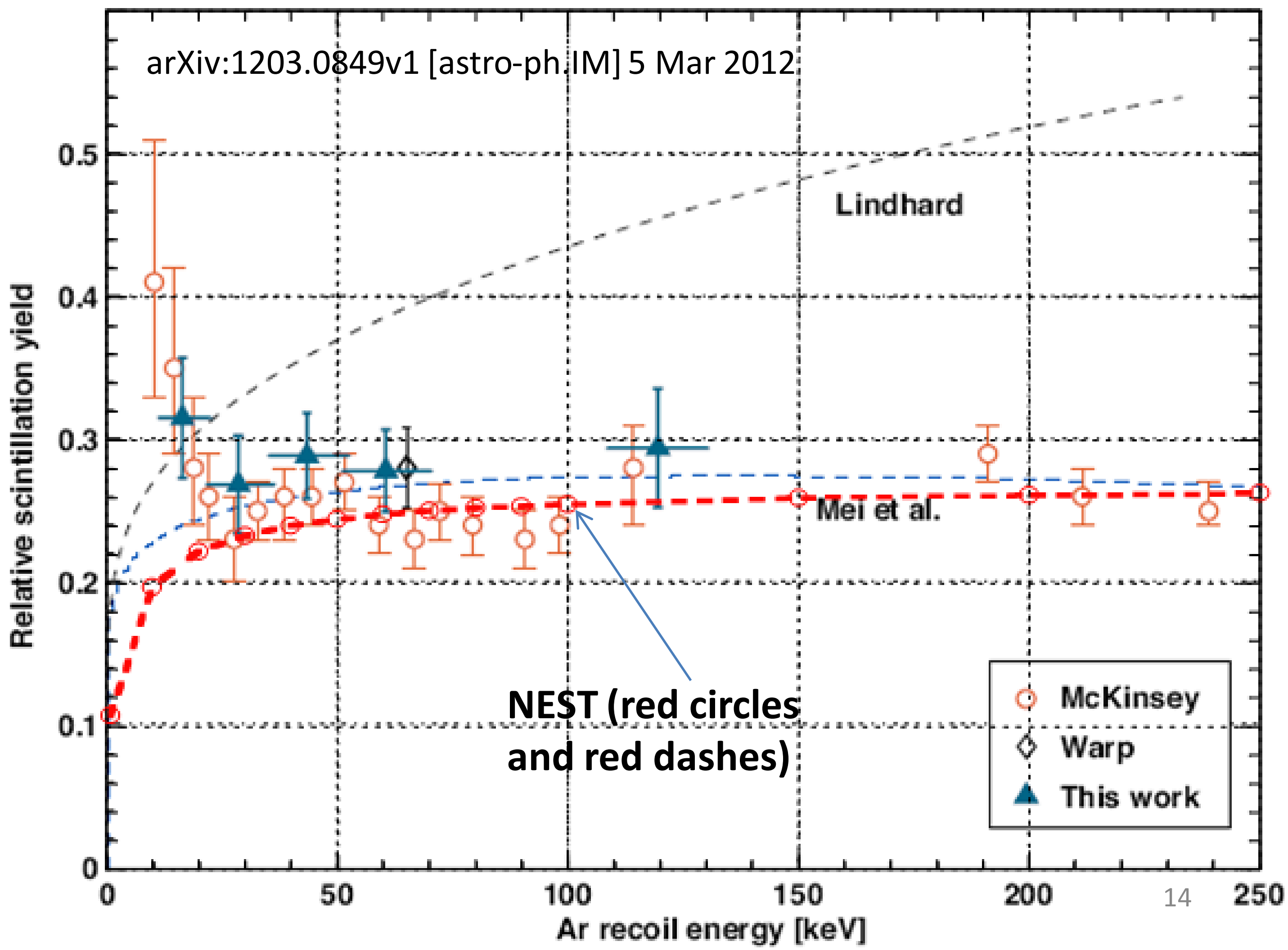


These examples are near the LUX detector threshold (multiply by ~20-30% to get phe, with full, good purity)

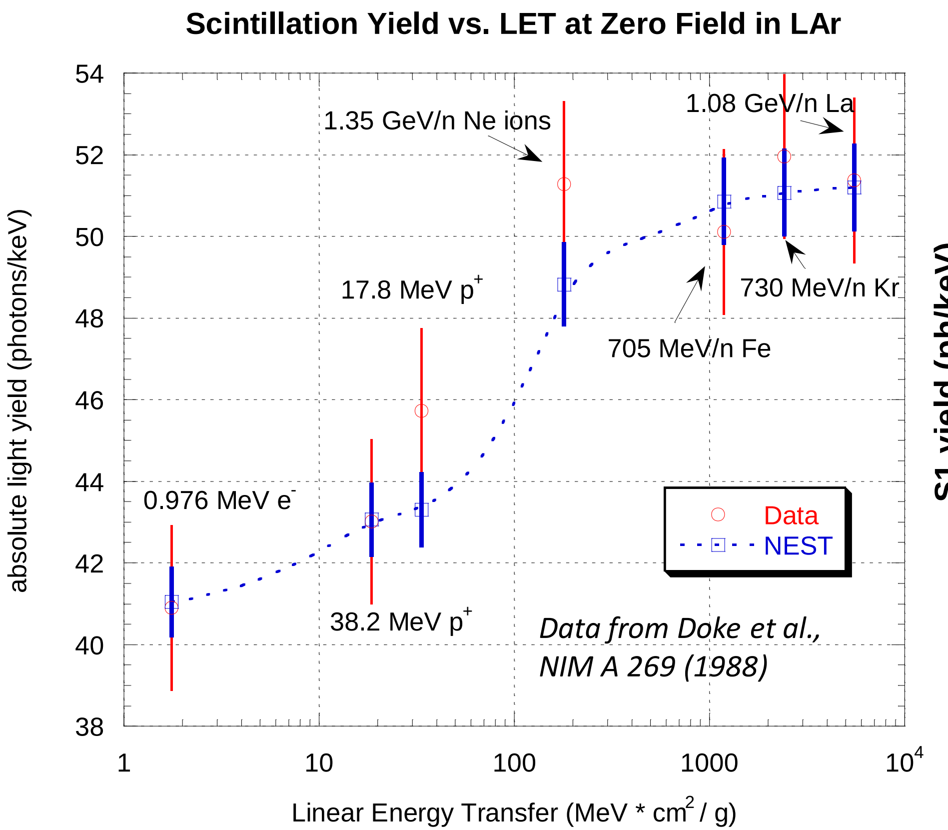
Generalizing This Work to Argon

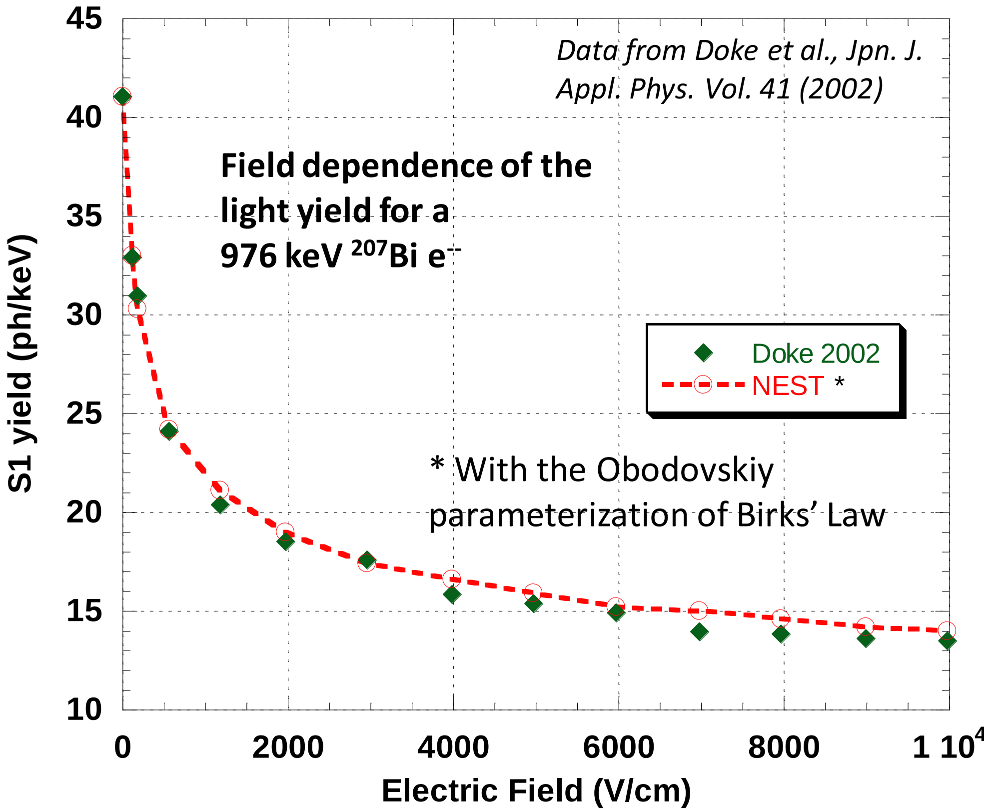
- Rel. yield higher than in xenon, because the lighter argon nucleus is more efficient at transferring energy into ionization or excitation, and the initial ratio of excitons to ions is higher in argon
- Should be able to revise the model to in order to explain the apparent higher yield at lower energies, by appealing to a higher exciton-ion ratio for NR, or to Zeigler dE/dx

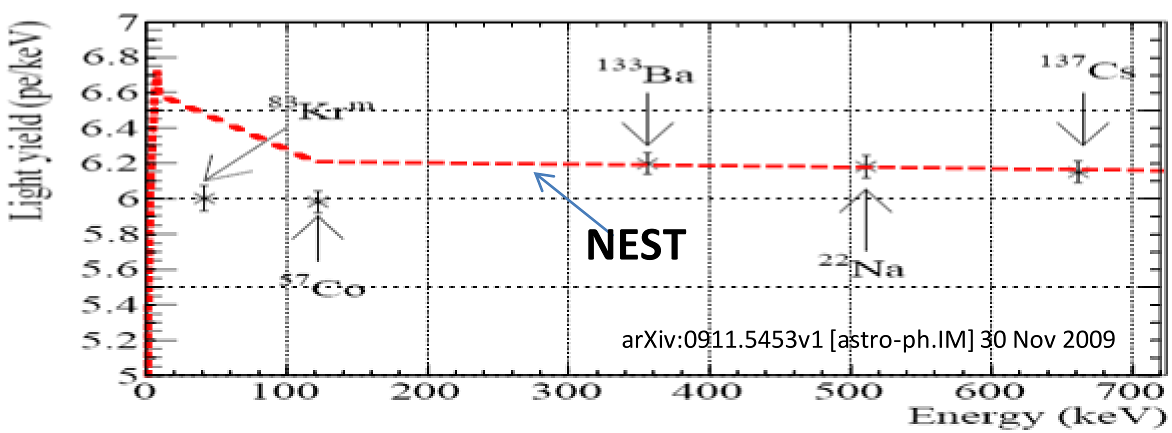
The NEST curve is generated assuming a flat L-factor. The downward curve at low energy is caused by the recombination probability falling of necessity in the Thomas-Imel recombination model



Generalizing This Work to Argon







- NEST even works out to the multi-MeV to GeV regime (applicable to LBNE), and out to O(10) kV/cm (PANDA-X)
- With xenon fully simulated, we're just now scratching the surface of liquid argon

Summary

- The widths of the log10(S2/S1) bands are now more properly modeled than before, with supra-Poissonian fluctuations
- Work on Xe in NEST (for both liquid and gas) is rapidly nearing FULL completion, culminating in being able to model the ER vs. NR discrimination ability in liquid, and the changing energy resolution between liquid and gas: NEST has matured a lot!
- You can now input your background model and get your expected “misidentification-as-WIMP” rate for your detector more accurately than with past simulations
- Maybe first appearance of simulated non-Gaussian tails in LXe
- Work on Ar and other elements is starting to ramp up, and NEST is already starting to tackle the LAr field-dependent yield for electron recoils, and the ever-tricky L-factor for NR, but long way to go before looking at discrimination in argon