*The Microphysics of Noble Liquids

Brian Lenardo, Kareem Kazkaz, Aaron Manalaysay, **Matthew Szydagis**, and Mani Tripathi

Workshop on Low Energy Particle Physics with Liquid Xenon Detectors,
National Research Nuclear University MEPhI, *Thursday 10/23/2014*

* The working model of the physics of the ionization and scintillation processes
* Recent improvements in our understanding
* Examples of both postdictive and predictive power of approach presented today

* Focusing exclusively on liquid xenon here
  * Gas xenon, argon, and other noble elements and phases should work within same framework
* Work is incorporated into NEST (Noble Element Simulation Technique) which is a MC tool

*The Rundown

N_{ph} → biexcitonic quenching (NR: worst at high energy)

E_{dep} → N_{ex} → N_{ph} → S1 (geometric light collection **times** quartz VUV transmission **times** PE conversion probability,…)

E_{dep} → N_i → N_{e-} → Drift, diffuse, die → Extraction → Gas photons → S2

N_i → N_{ex}

E_{dep} → Heat (NR: worst at low energy)

Free parameters used at every step have physical meaning

*Energy Partitioning

* Models Within Model

* Approximation of the Platzman approach
  * Compute average W to generate exciton or ion
* Electron recombination varies with electric field, energy, type of scattering, and density/phase
  * Thomas-Imel model of recombination
* Lindhard theory of electronic stopping power
  * Permit variations within default prescription
  * Quenches the *total* yield, not just scintillation
* Biexcitonic quenching of light yield
  * Birks' Law, a function of the total dE/dx
* Dobi/Mozumder recombination fluctuations

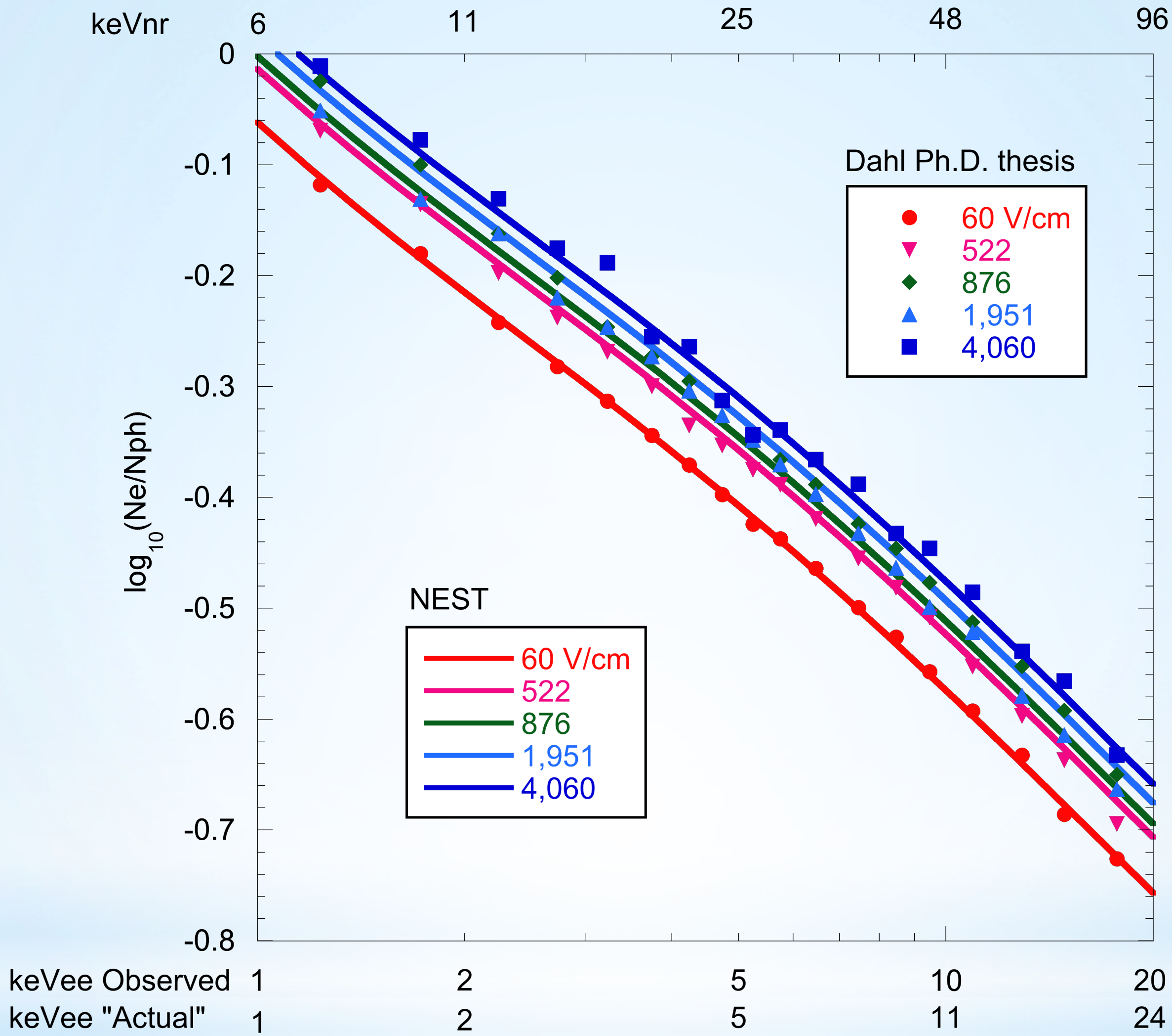
Mozumder, Chem. Phys. Lett. 245 (1995) 359

* W = 13.7 +/- 0.2 eV (higher than excitation or ionization potentials because of heat loss)
* If N_{ex}/N_i = 0.15 for ER (best-fit NEW model) then
* W_i = (traditional definition)
* $E / N_i = (N_{ex}+N_i) * W / N_i = (N_{ex}/N_i + 1) * W = 1.15 * 13.7 \sim 15.8$ eV
  * Compare to Takahashi 1975 result of 15.6 +/- 0.3
  * This is <u>not</u> forced: pieces fit together naturally

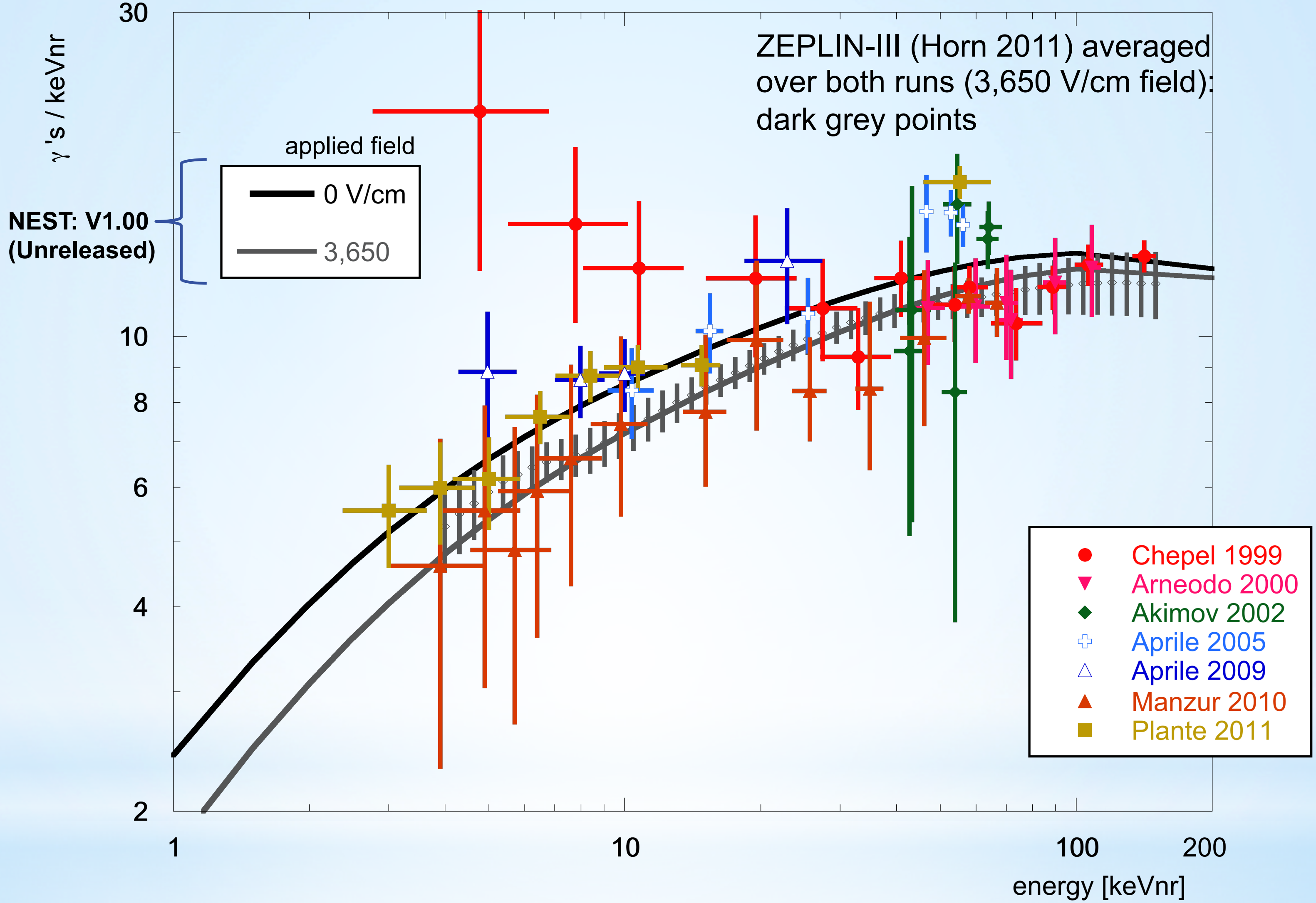
Example Math

* Continuity of zero and non-zero field models
* Reduction in free parameters
  * Less splining and more physical motivation
* Over-conservativeness (low yields) removed
* Global fit over as much data as possible
  * Moving far beyond C.E. Dahl thesis data
* Combined fit of light & charge simultaneously
* For ER, fit to electron data only and gammas/x-rays must follow: much simpler approach

What's New?

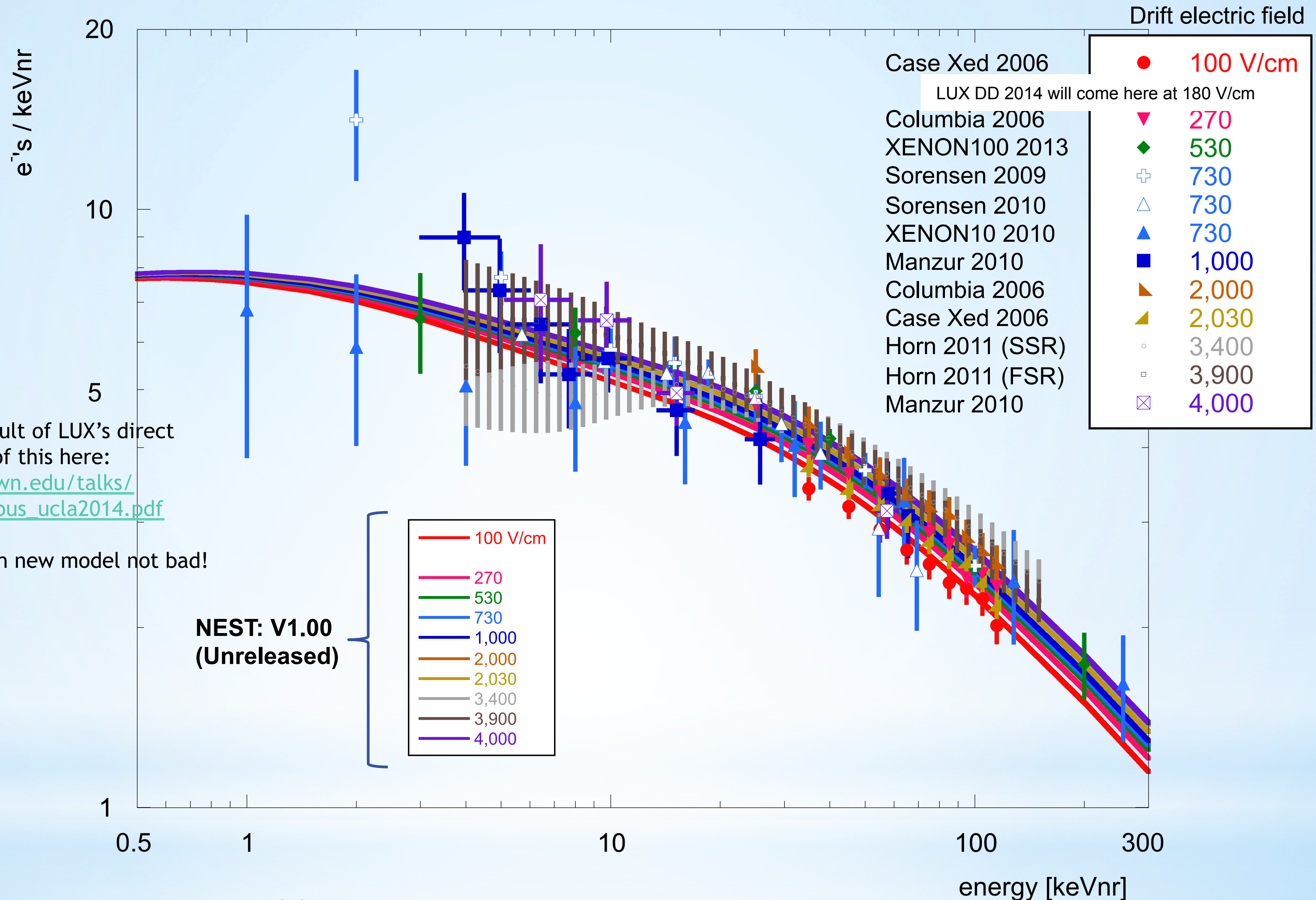


*NR Charge/Light Ratio



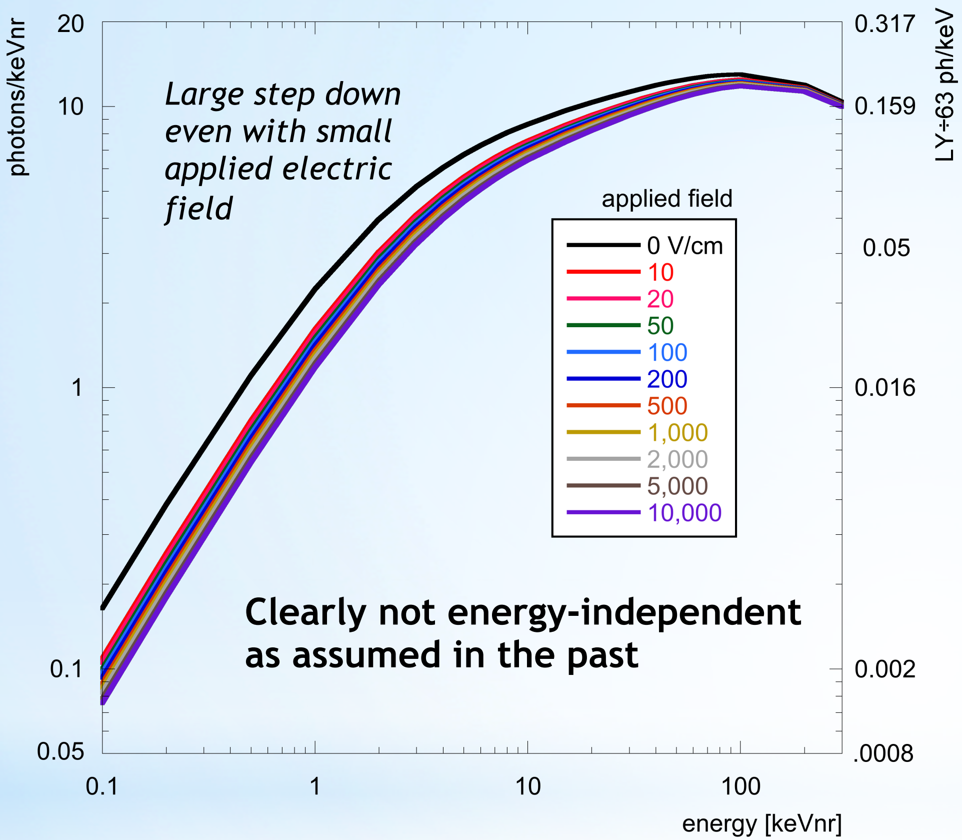
*NR Scintillation Yield

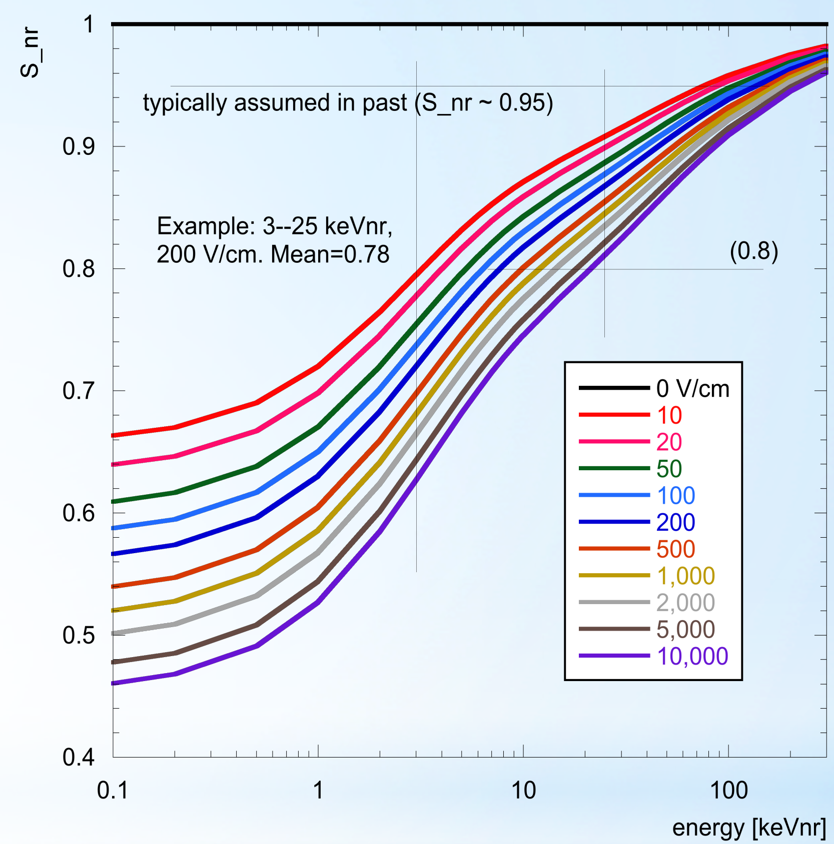
NR Ionization Yield



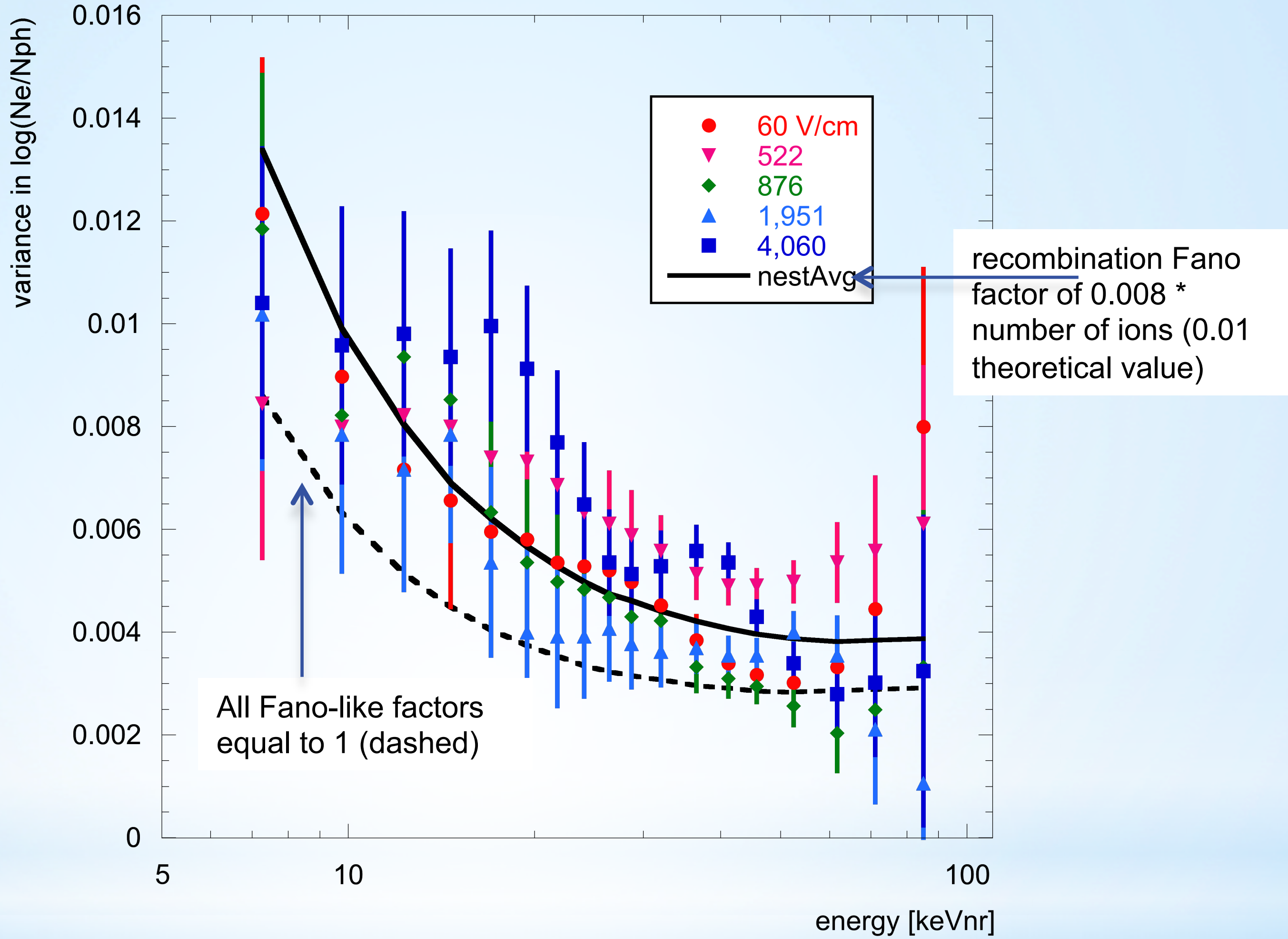
Preliminary result of LUX's direct measurement of this here: http://lux.brown.edu/talks/20140228_jverbus_ucla2014.pdf

Agreement with new model not bad!





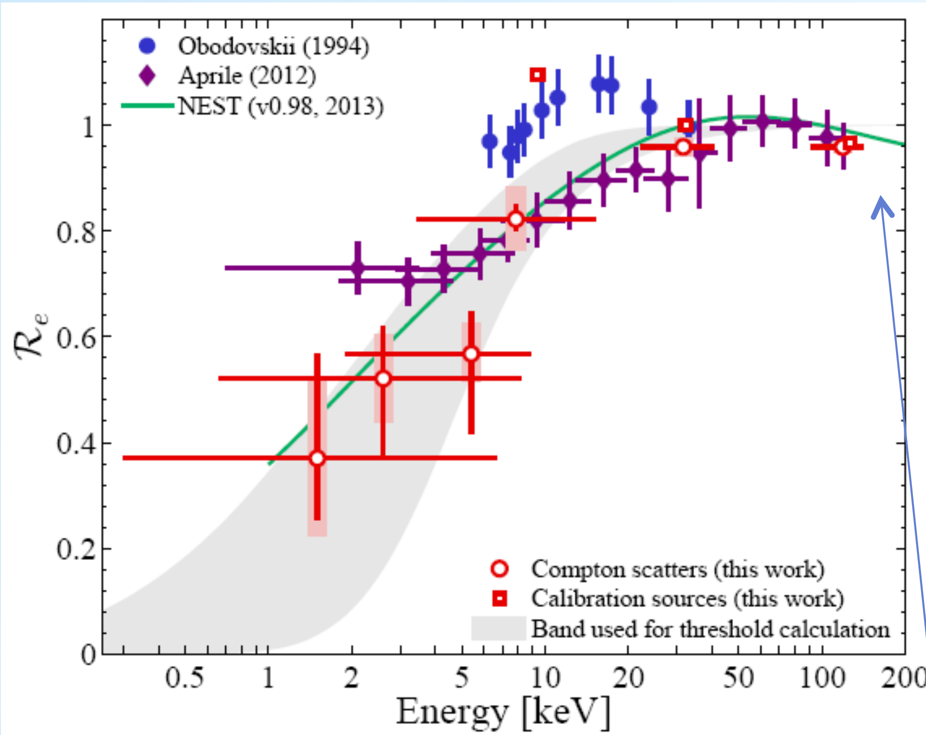
*Relative Yield v. Field



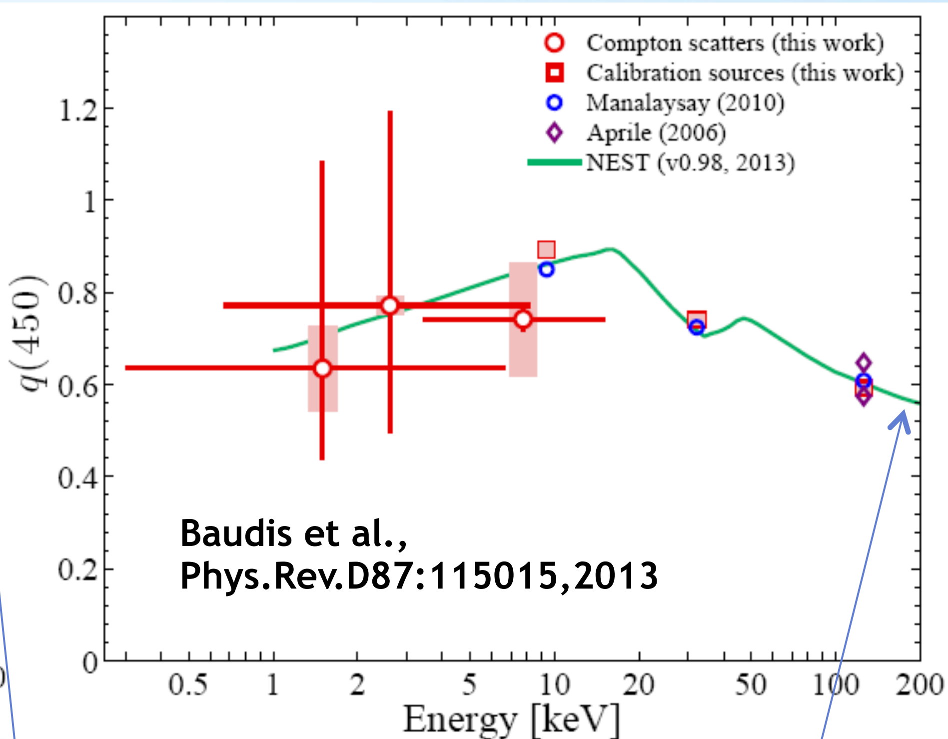
*NR Band Width

ER Scintillation Yield

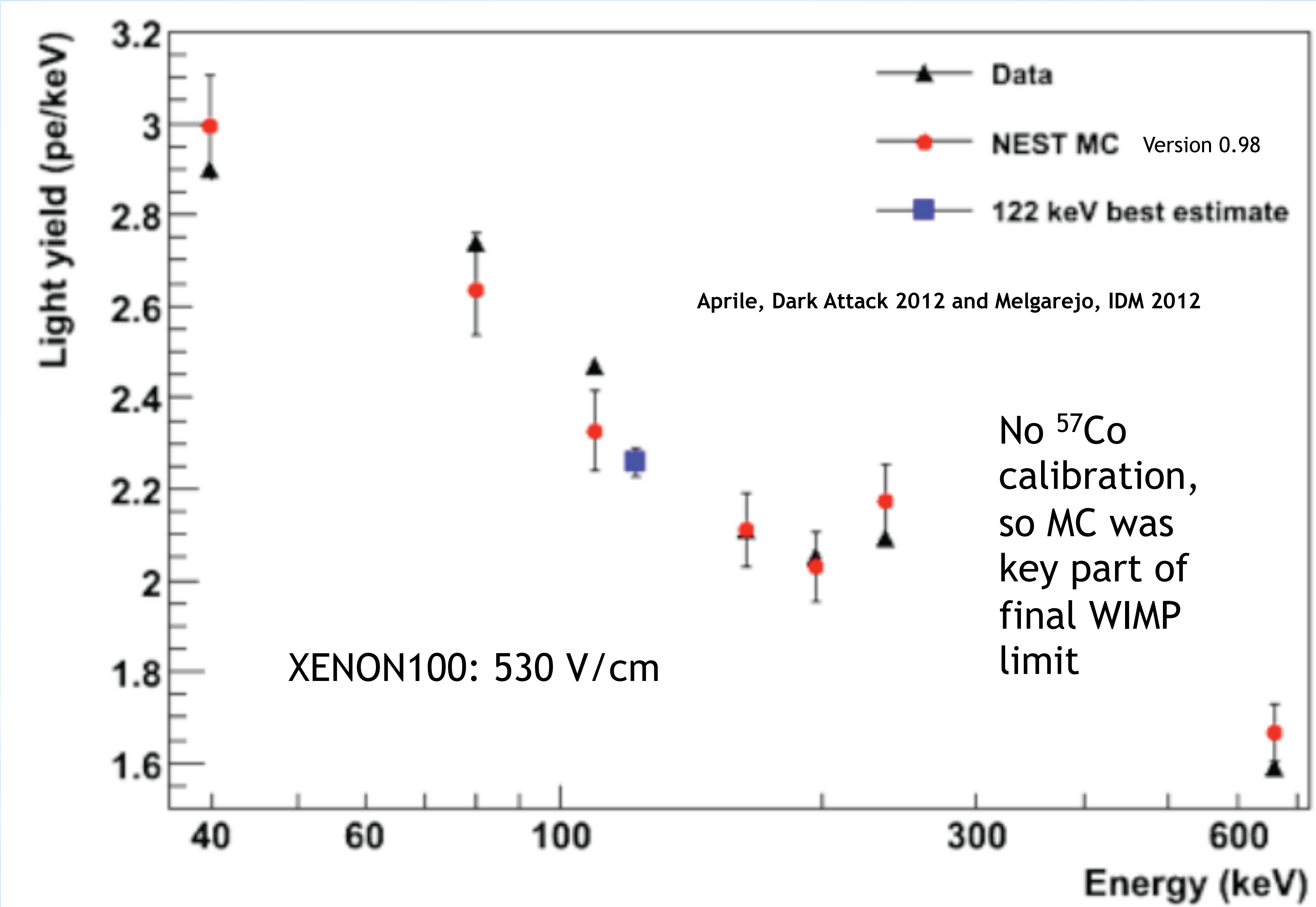
Zero Field



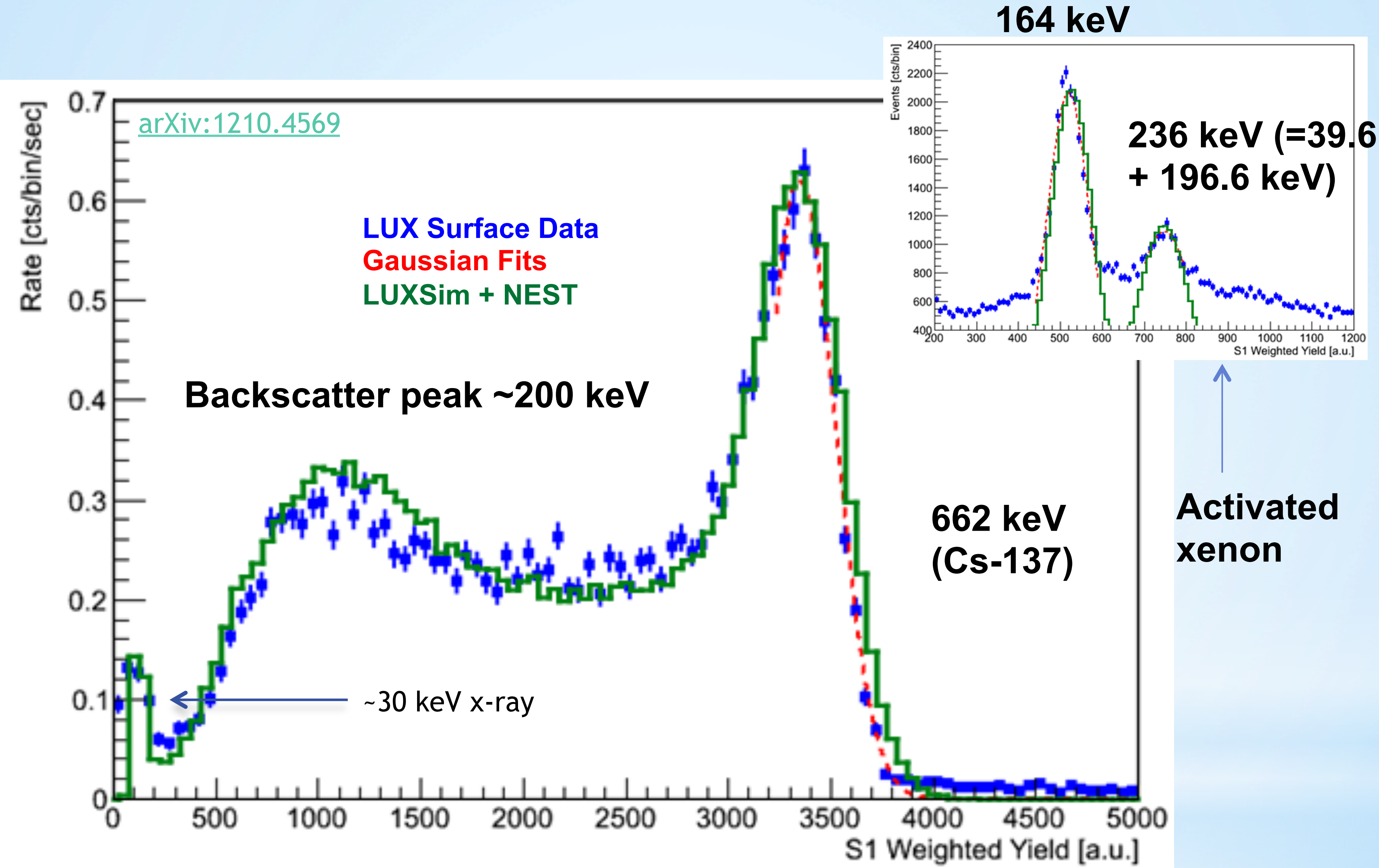
Non-zero Field (450 V/cm)



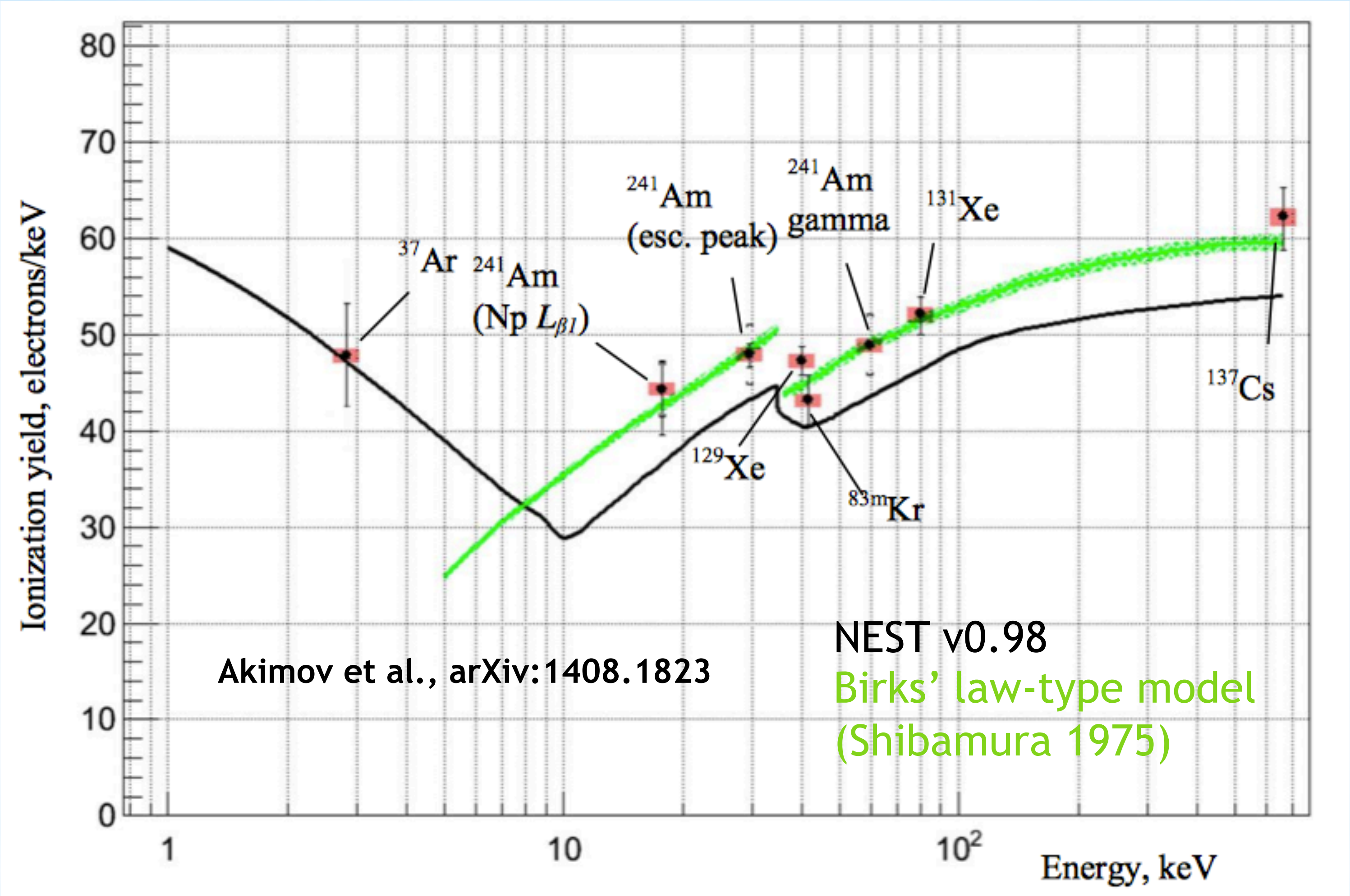
As we approach minimally-ionizing, the curve asymptotes



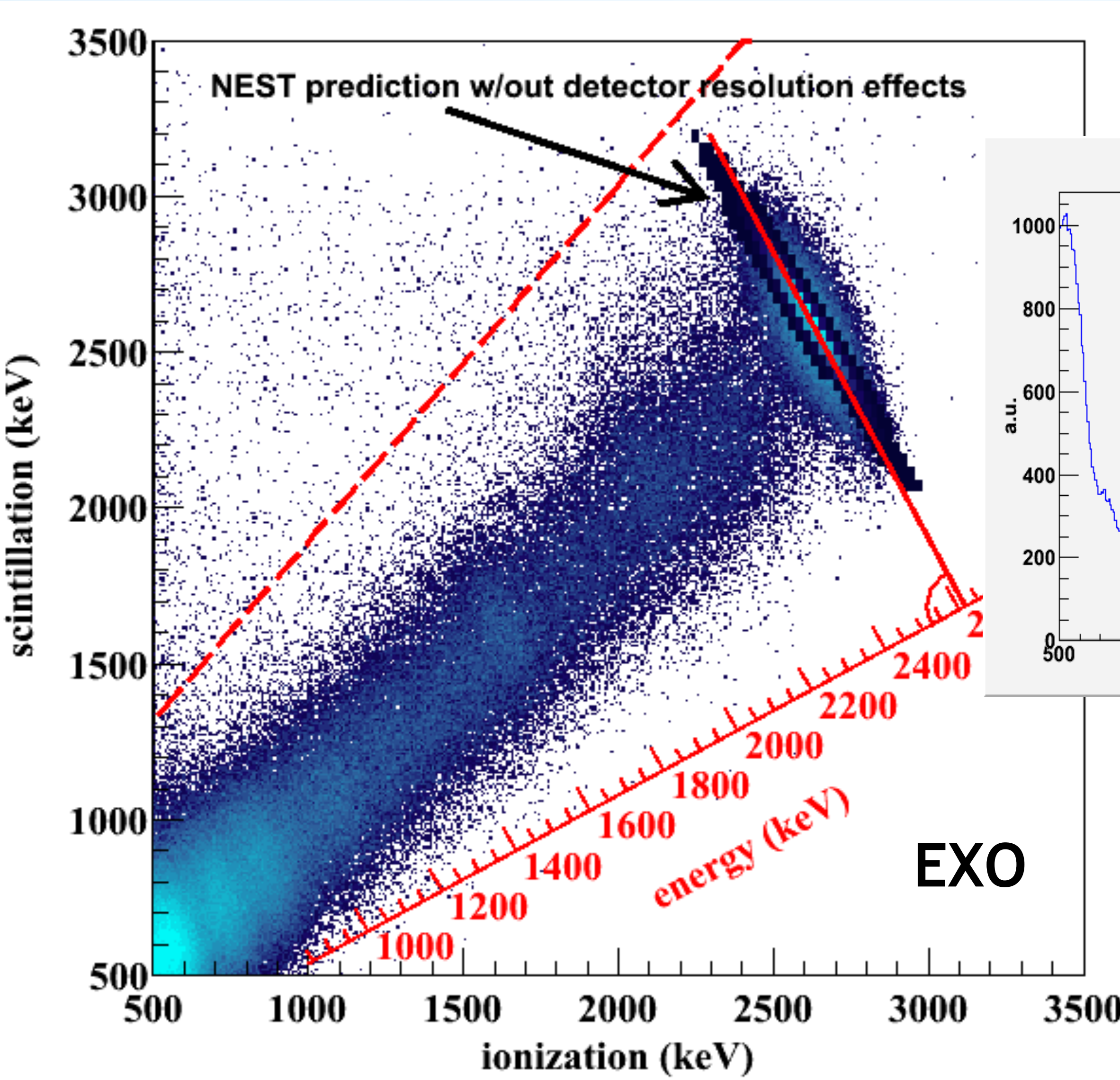
* A True Prediction for ER

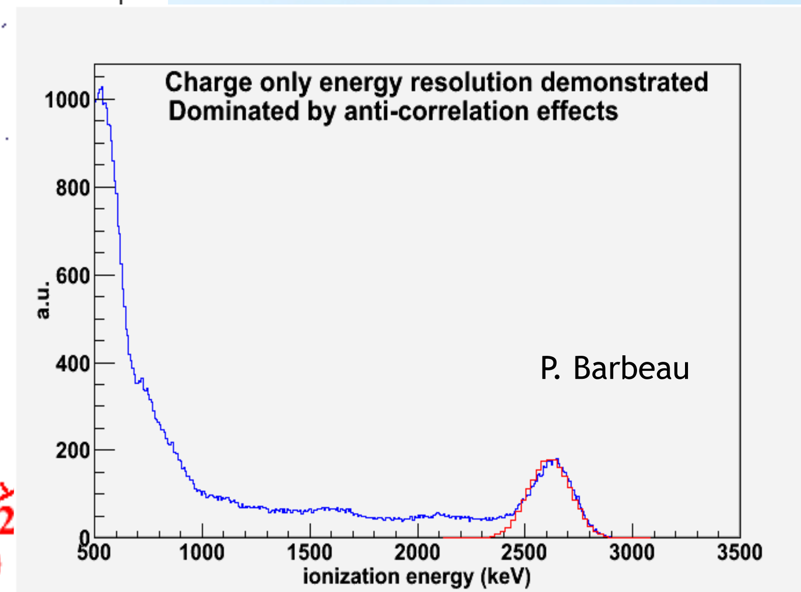


* ER With Detector Effects

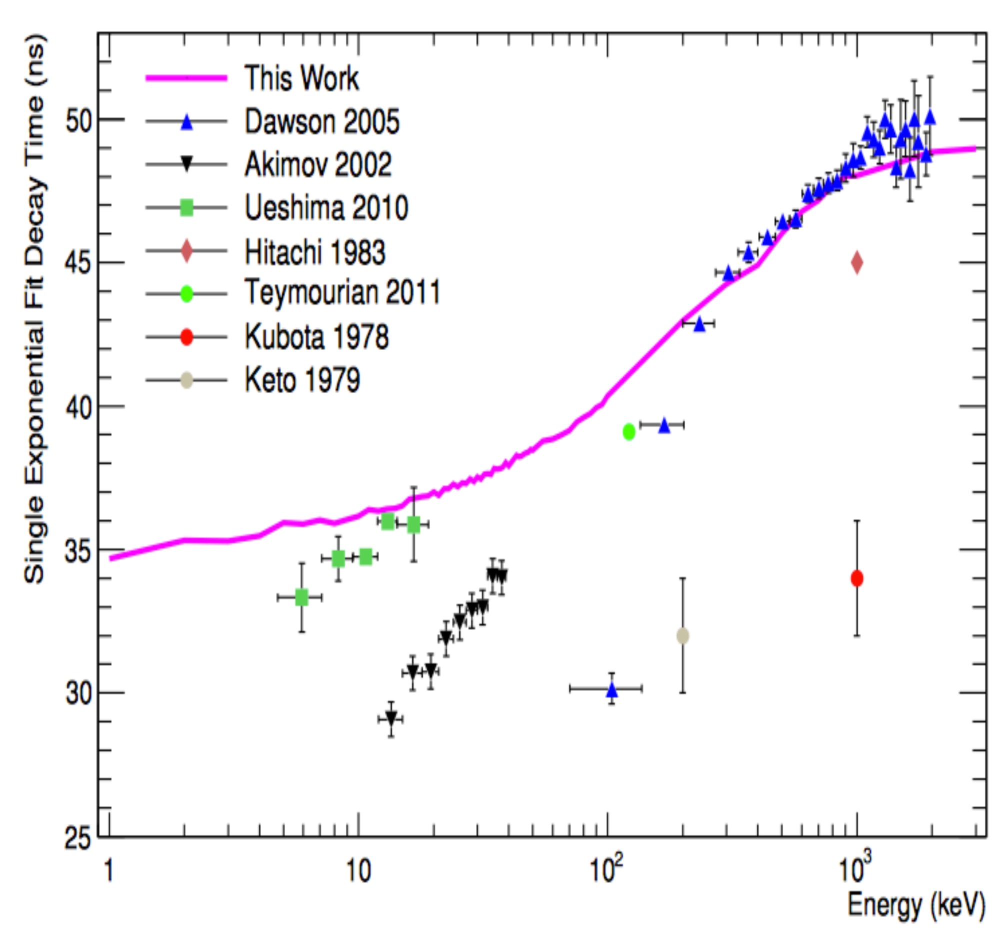


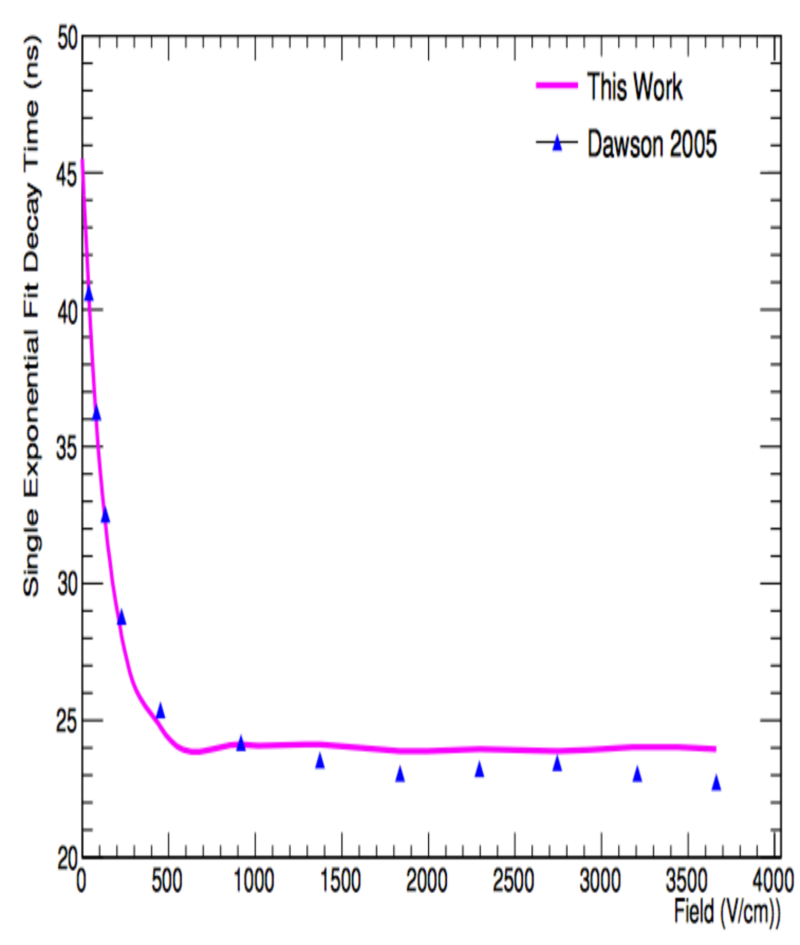
*ER Ionization Yield





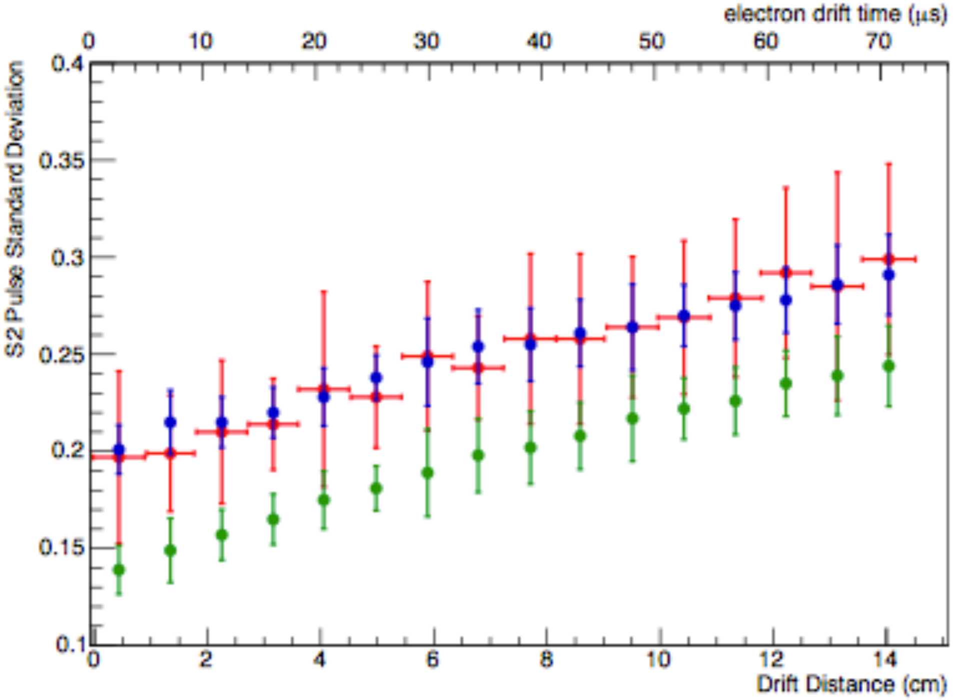
*ER Energy Resolution

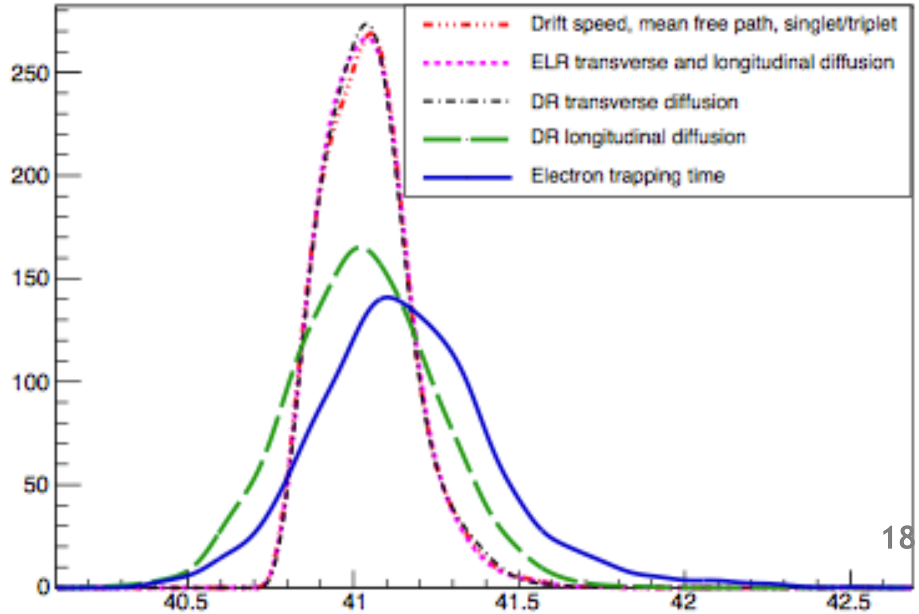




Singlet lifetime	3.1 ± 0.7 ns
Triplet lifetime	24 ± 1 ns
Singlet/Triplet - ER from direct excitation (γ induced)	0.17 ± 0.05
Singlet/Triplet - ER from recombination (γ induced)	0.8 ± 0.2
Singlet/Triplet - ER from both processes (α induced)	2.3 ± 0.51
Singlet/Triplet - NR (neutron induced)	7.8 ± 1.5

*S1 Pulse Shape





XENON10 Data (Sorensen 2008)

Model:
Without extraction delay
With extraction delay

*S2 Pulse Shape

*Publications

This physics is described in

B. Lenardo et al., In preparation, to be submitted to the IEEE Transactions on Nuclear Science

J. Mock et al., JINST 9 (2014) T04002. arXiv:1310.1117

M. Szydagis et al., JINST 8 (2013) C10003. arXiv:1307.6601

M. Szydagis et al., JINST 6 (2011) P10002. arXiv:1106.1613

NEST nest.physics.ucdavis.edu, albany.edu/physics/NEST.shtml

*Questions?