Response of Xe to low energy electron recoils from tritium with the LUX detector

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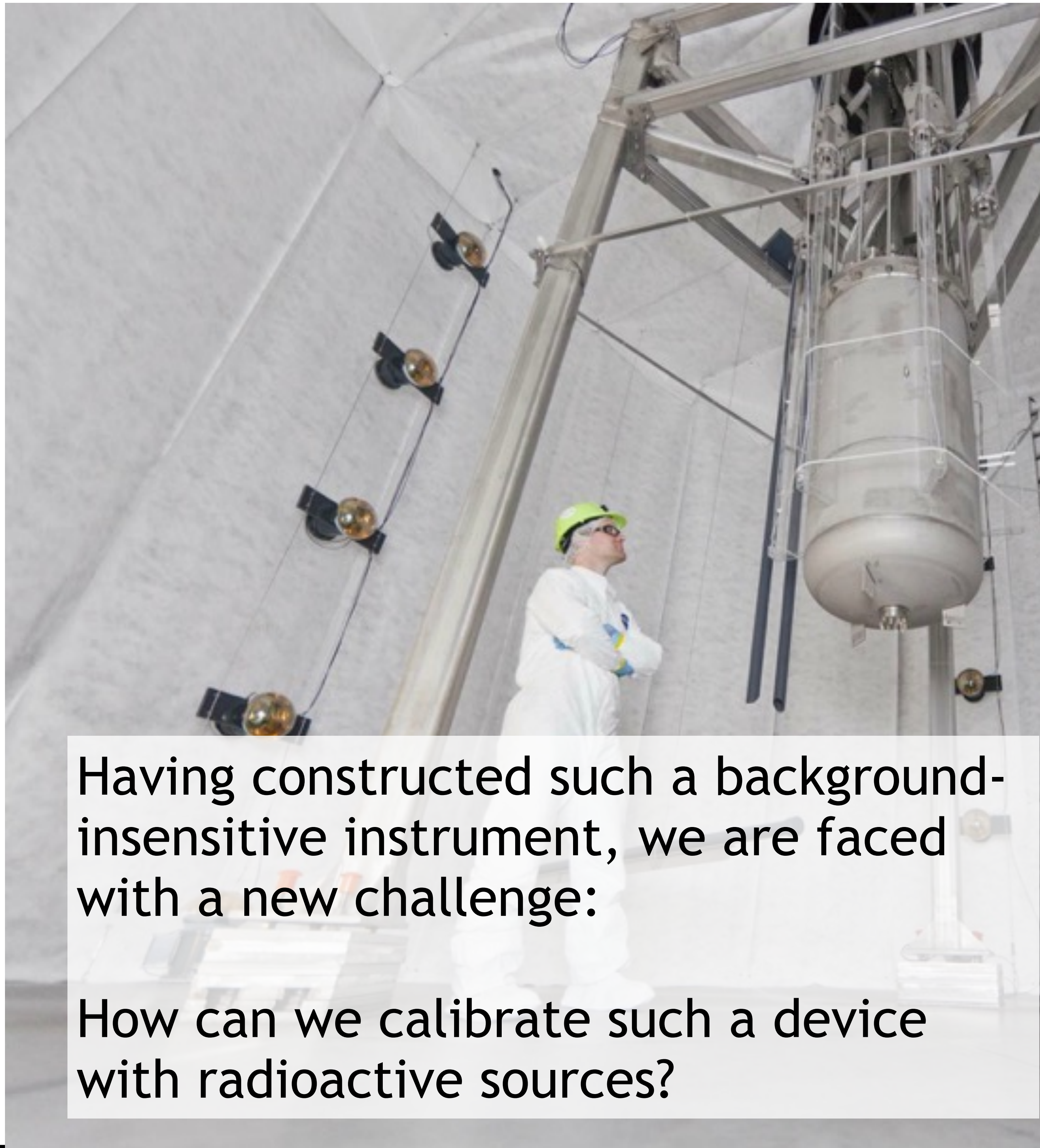
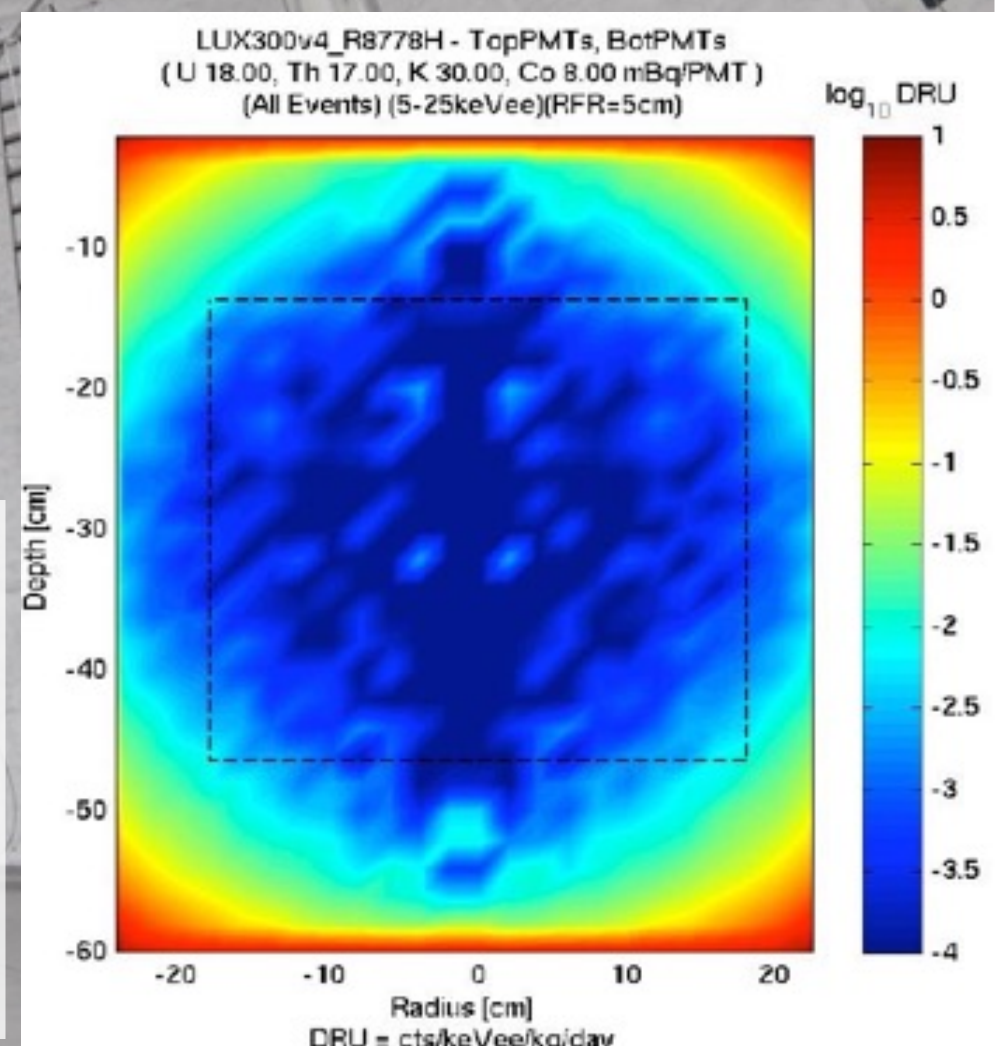
LBL

The Electron Recoil (Background) Calibration



Self-shielding makes external gamma sources impractical

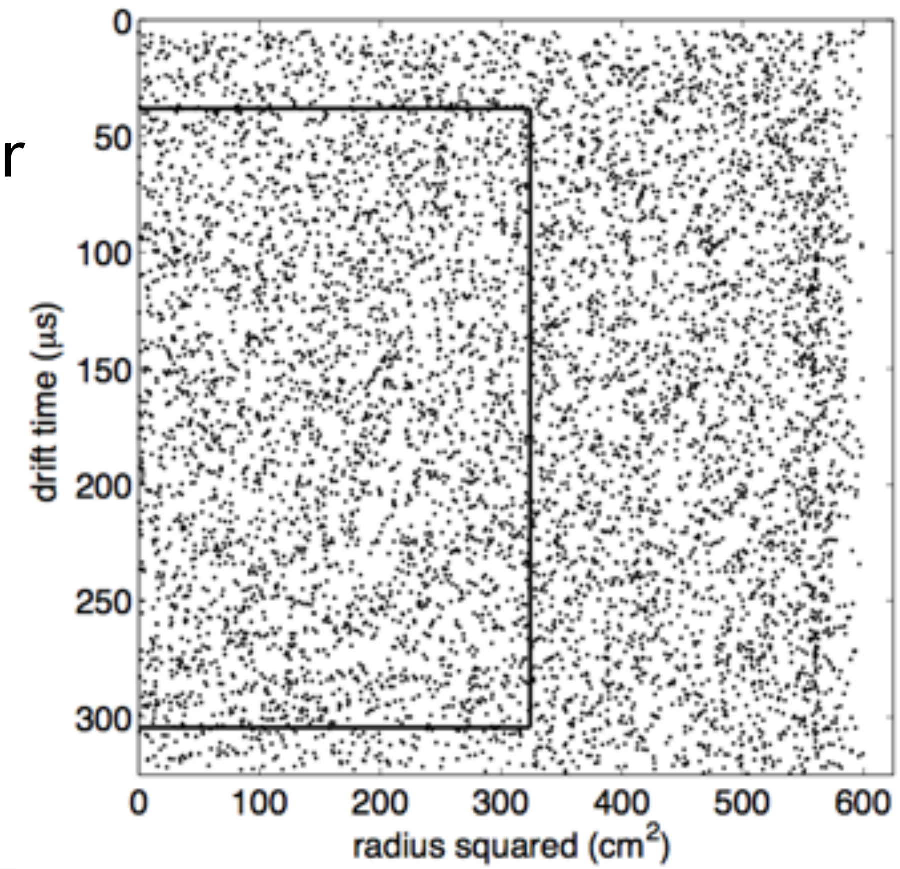


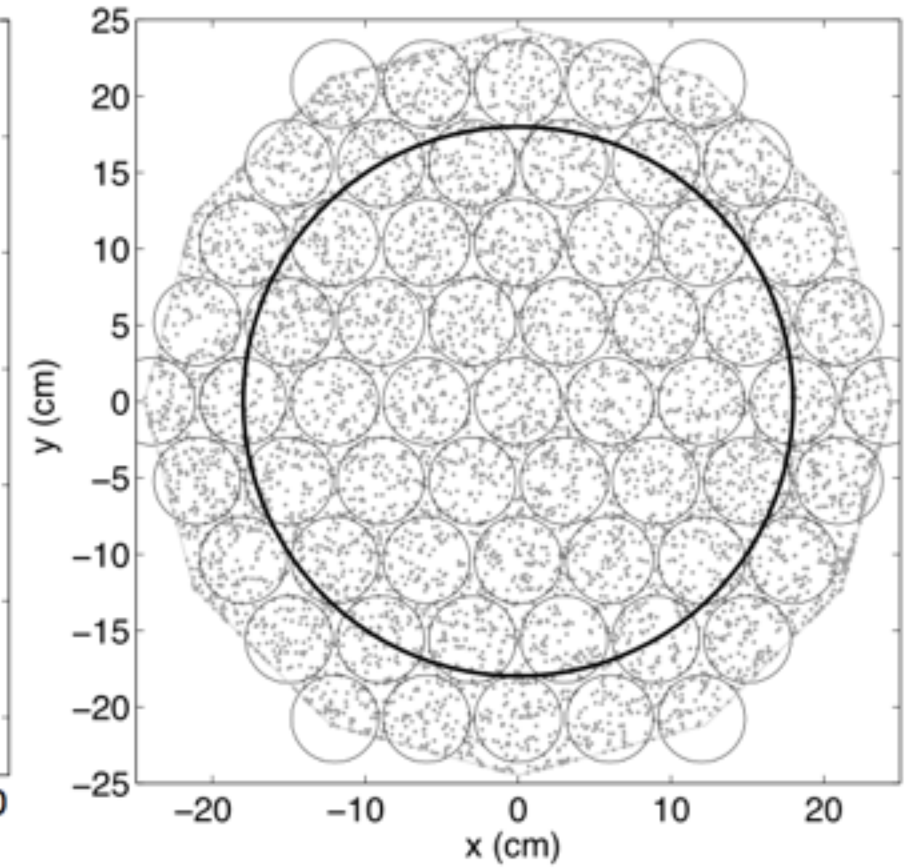
Having constructed such a background-insensitive instrument, we are faced with a new challenge:

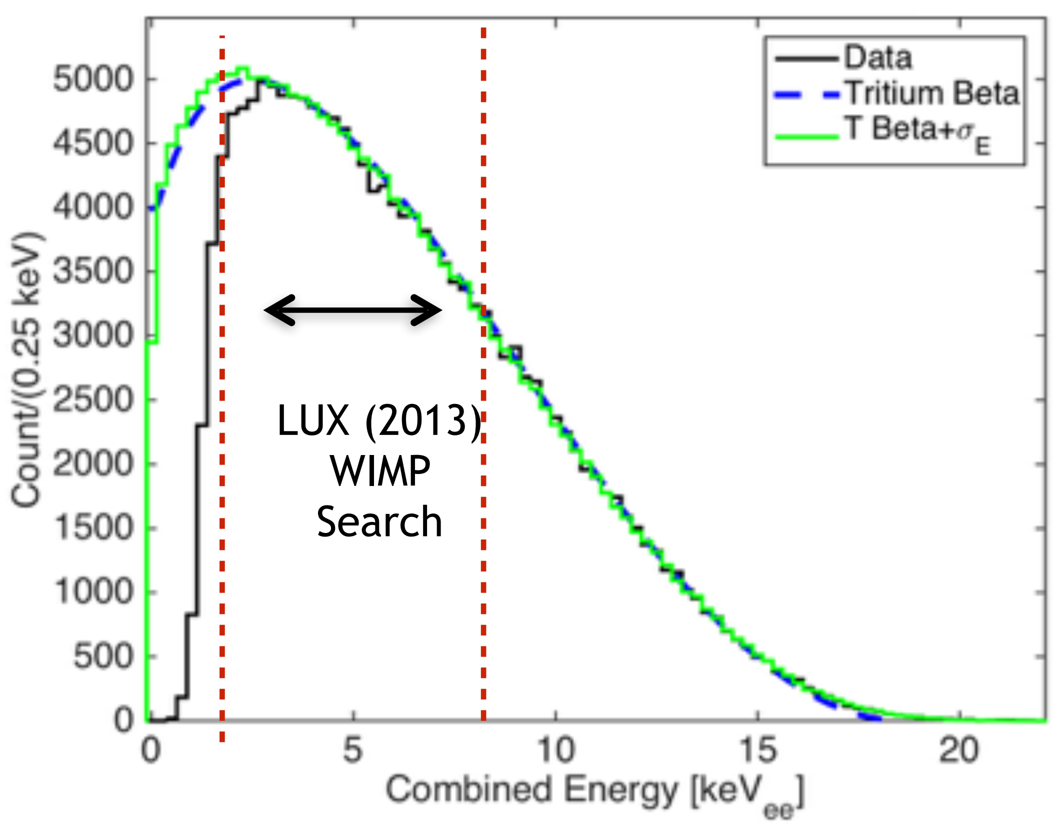
How can we calibrate such a device with radioactive sources?

Tritiated-Methane, The Ideal ER Calibration Source

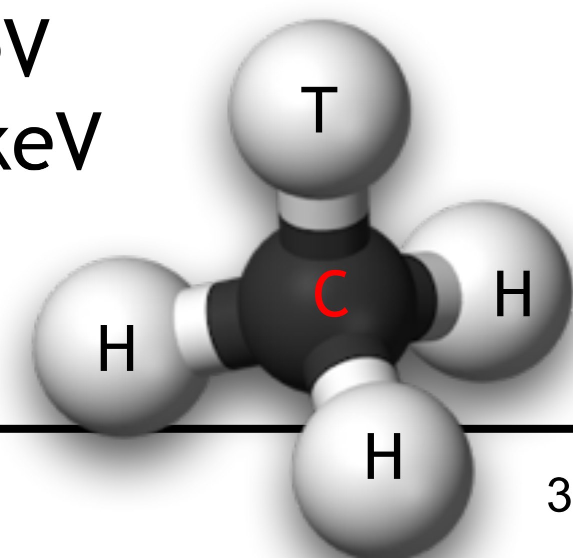
- Methane diffuses much slower than bare tritium.
- Dissolved uniformly in the xenon.
- Removed with standard purification technology.
- Used to calibrate the fiducial volume.



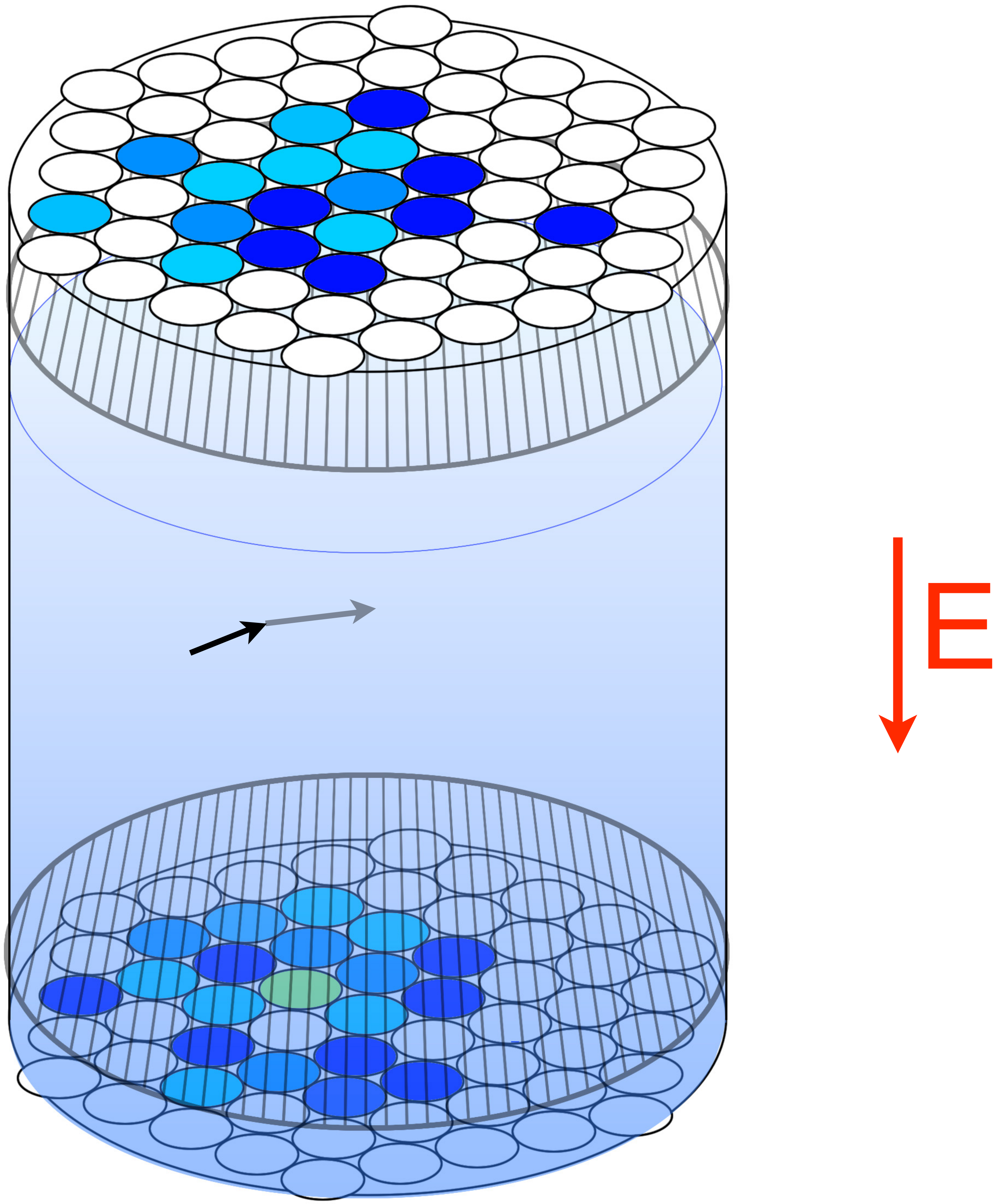


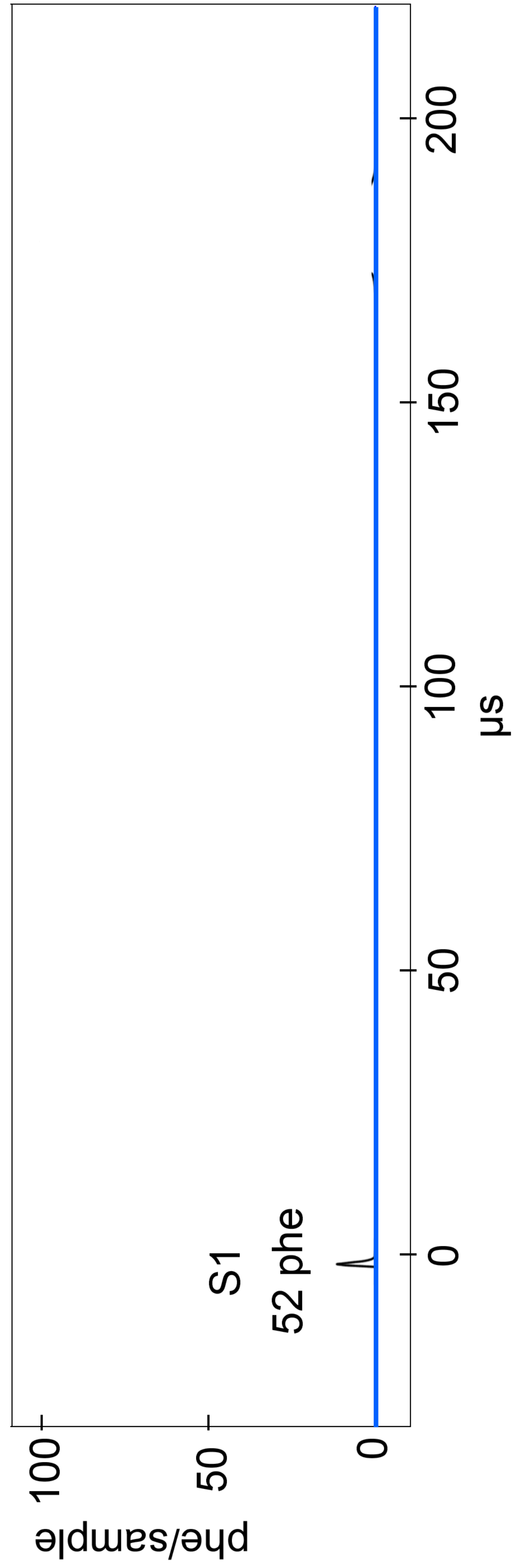


- Single Scatter ER events in energy region of interest: 0.1 keV to 18 keV
- Mean energy: 5 keV
- Peak energy: 2.5 keV



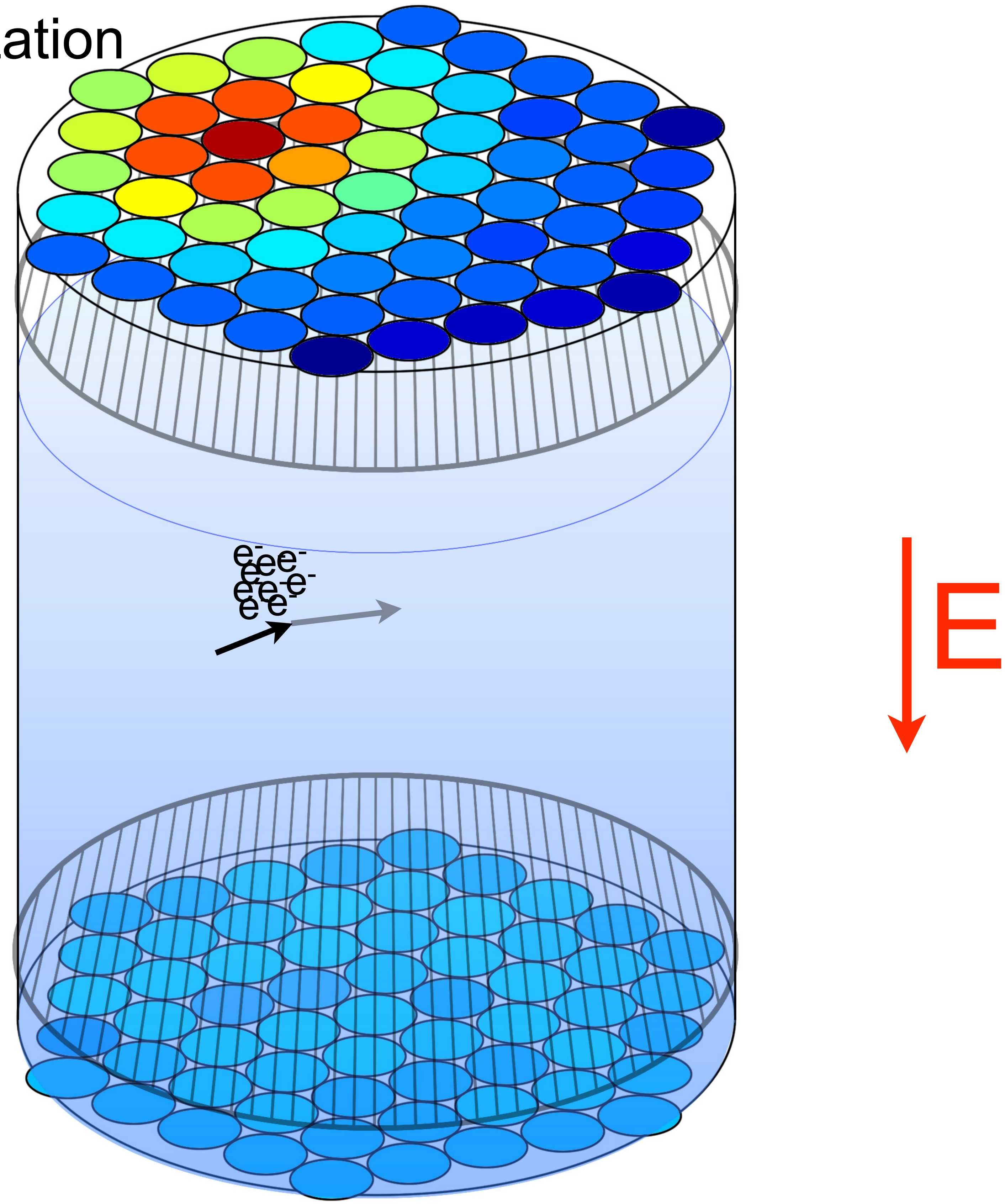
The S1 signal ~ Photons

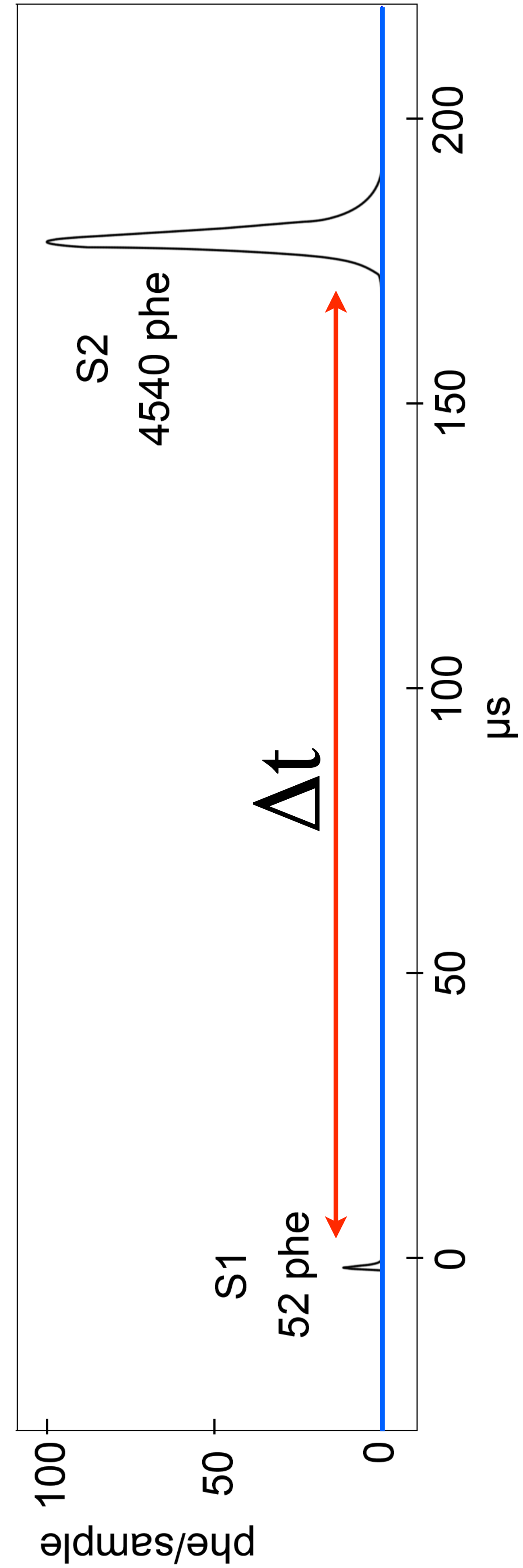




The S2 signal ~ Electrons

top hit pattern:
x-y localization





Energy Reconstruction

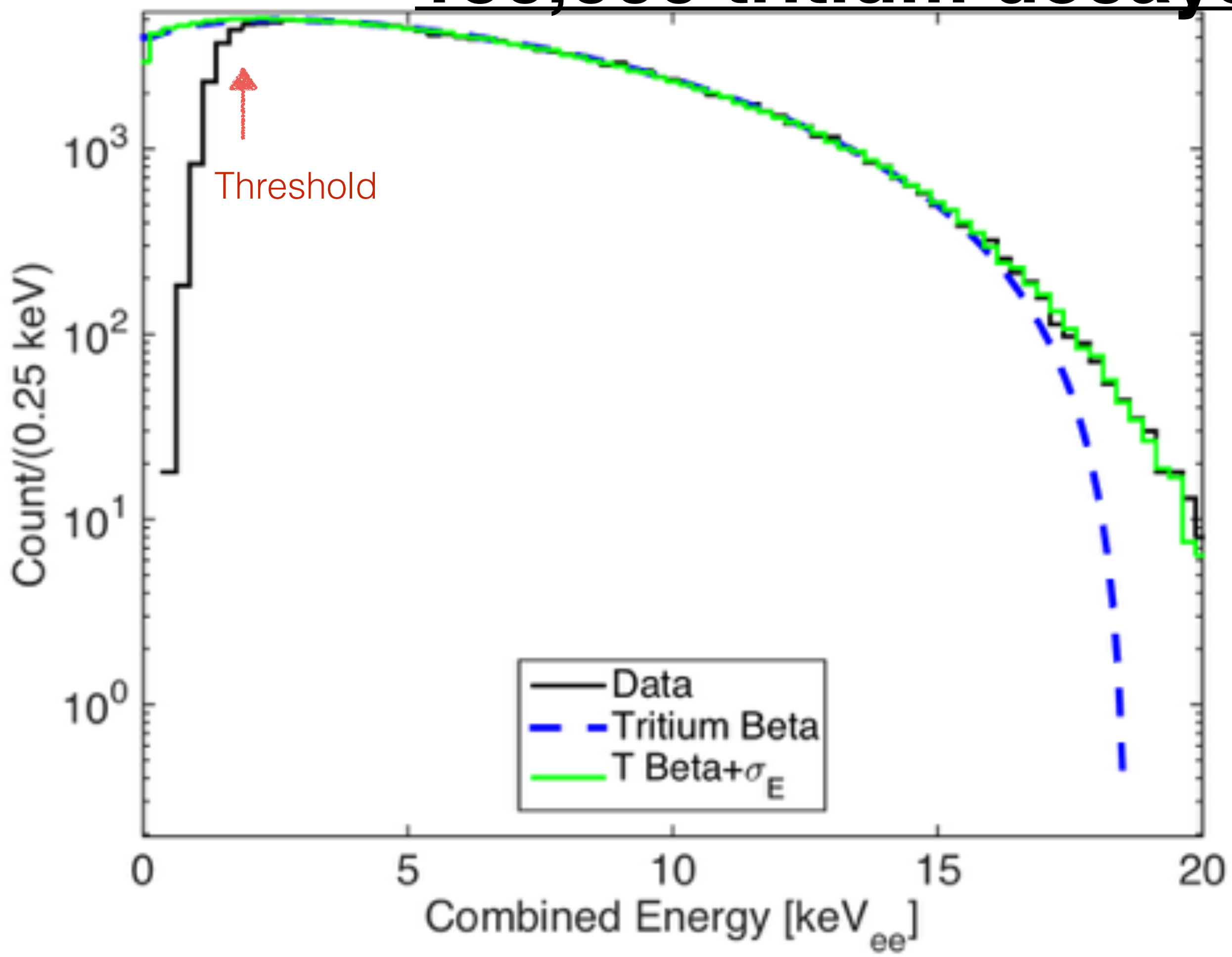
Platzmann Model

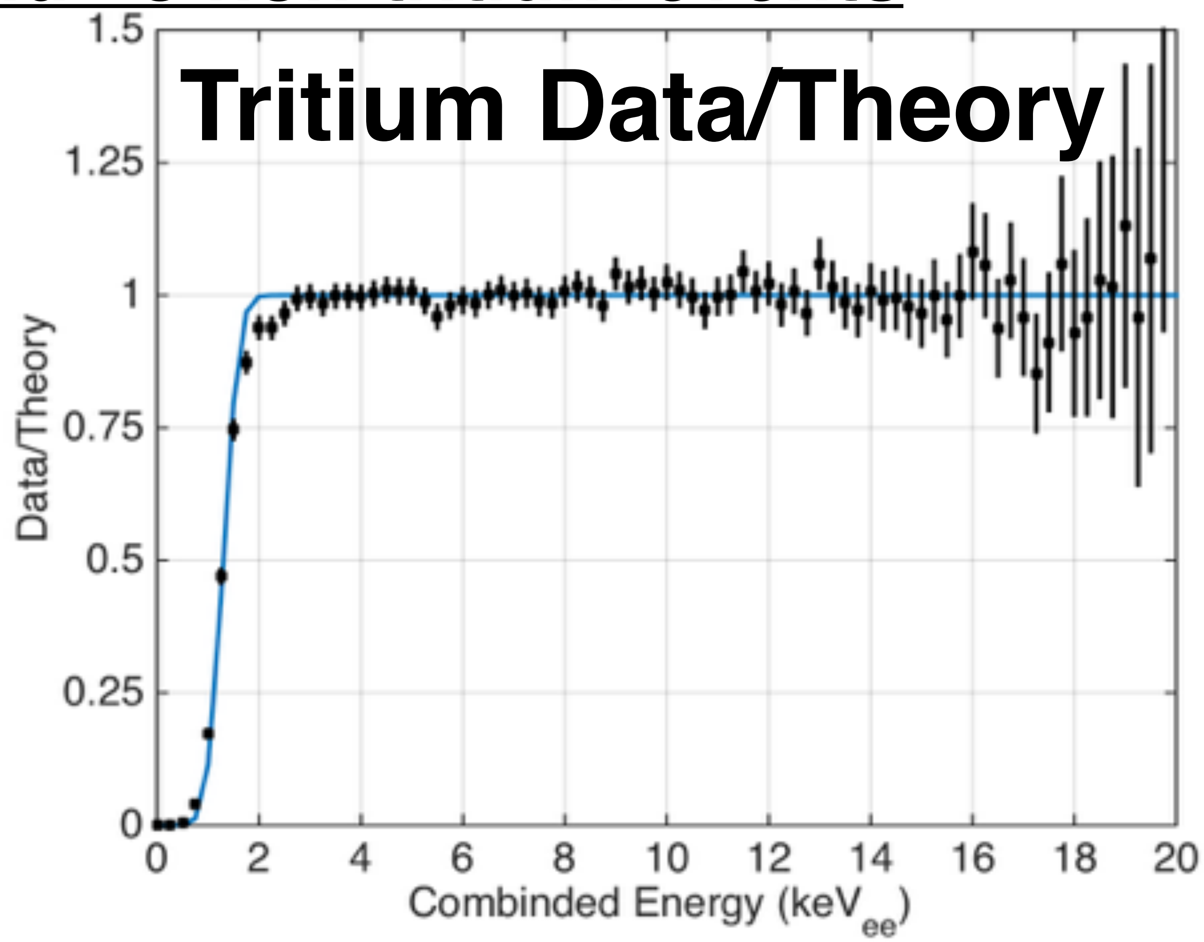
$$\frac{E}{W} = n_\gamma + n_e = \frac{S1}{g_1} + \frac{S2}{g_2}$$

$$\langle n_\gamma \rangle = \frac{\langle S1 \rangle}{g_1}$$
$$\langle n_e \rangle = \frac{\langle S2 \rangle}{g_2}$$

- For electronic recoils in xenon W = 13.7 eV
- Measure S1 and S2 then convert to photons and electrons with gains g1 and g2

Tritium Energy Spectrum as Measured in the LUX Fiducial Volume 150,000 tritium decays and ~3 non-tritium events

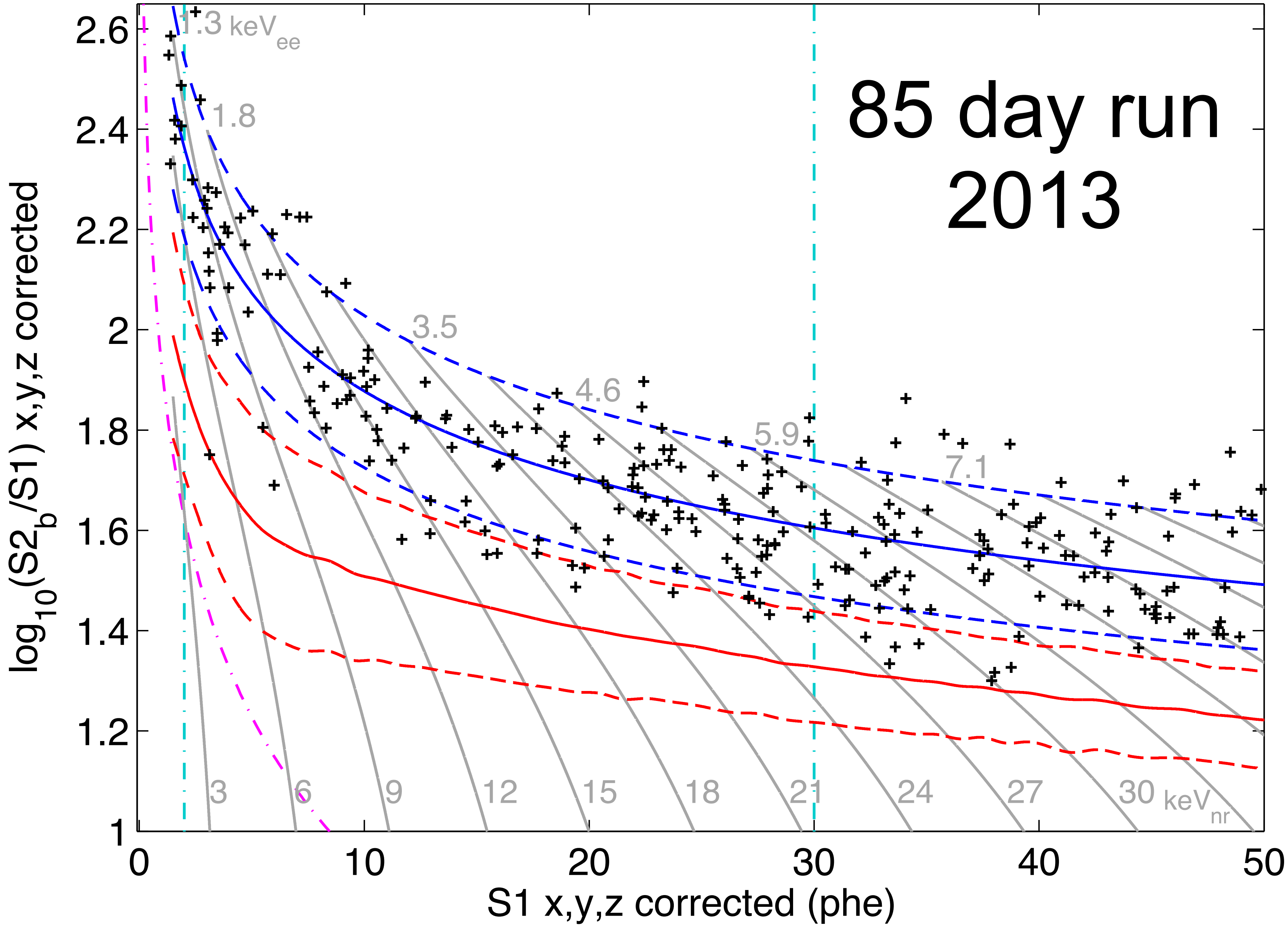




Signal-Background Discrimination

LUX WIMP search data

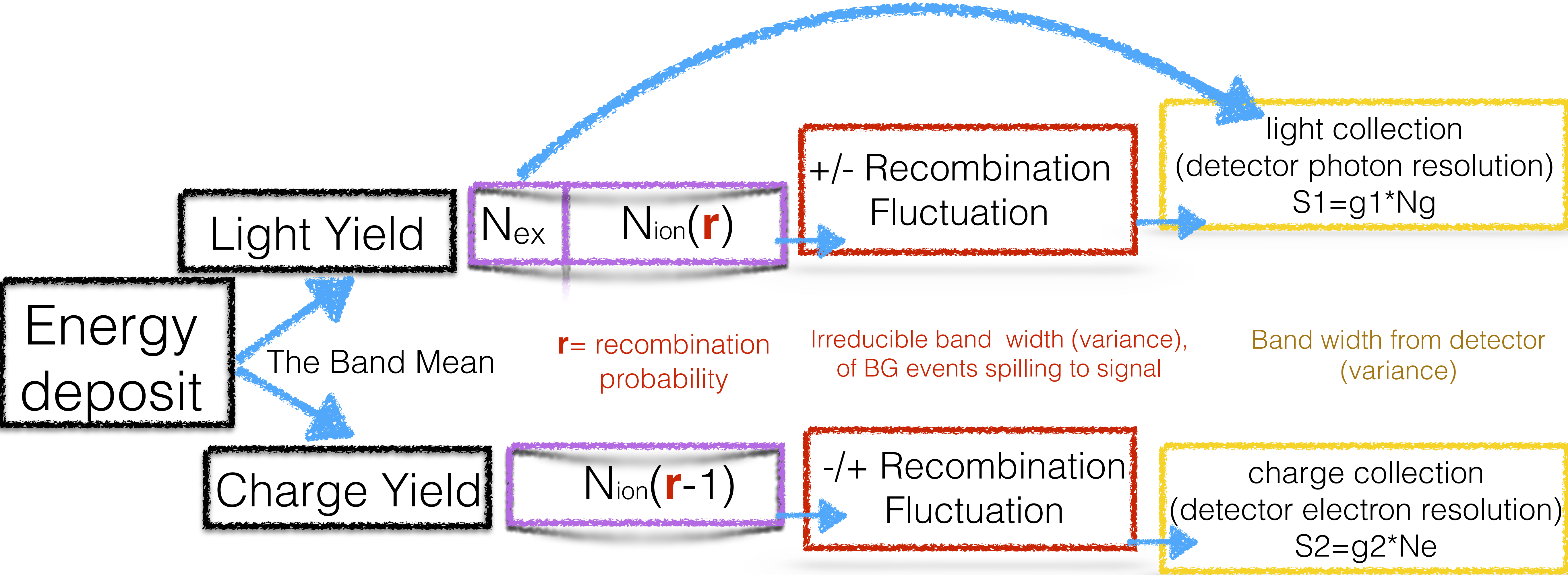
Charge/Light



Light ~ Energy

In our 2013 analysis we used a low stats tritium injection to define the ER band location. Since then we have have increase the stats by 20x to produce a more detailed understanding of LY, QY in order to model backgrounds.

Understanding the WIMP and Background Signals



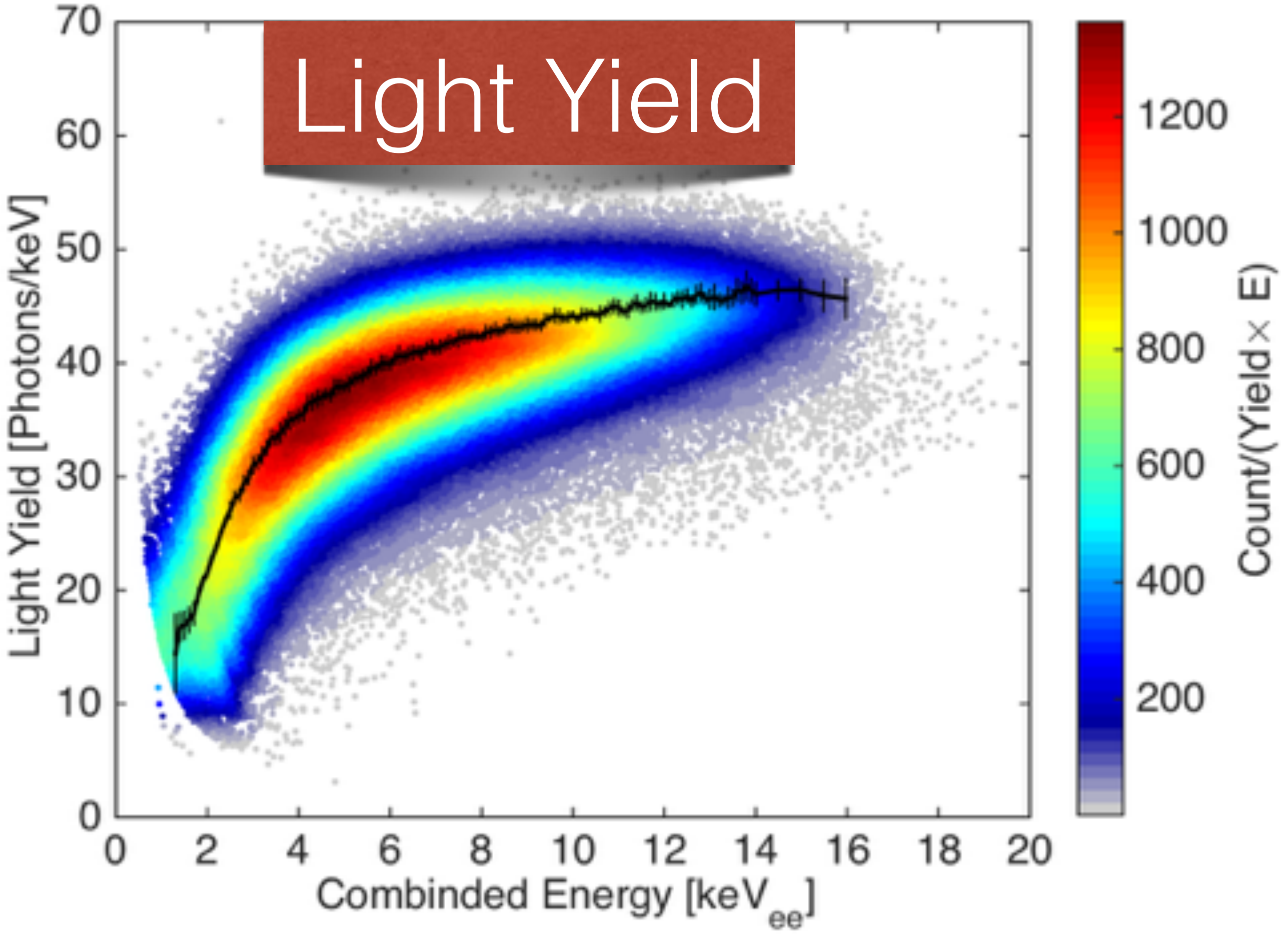
Electron Recoil Band Mean: $\log_{10}(S2/S1)=\log_{10}(QY/LY)+\log_{10}(g1/g2)$

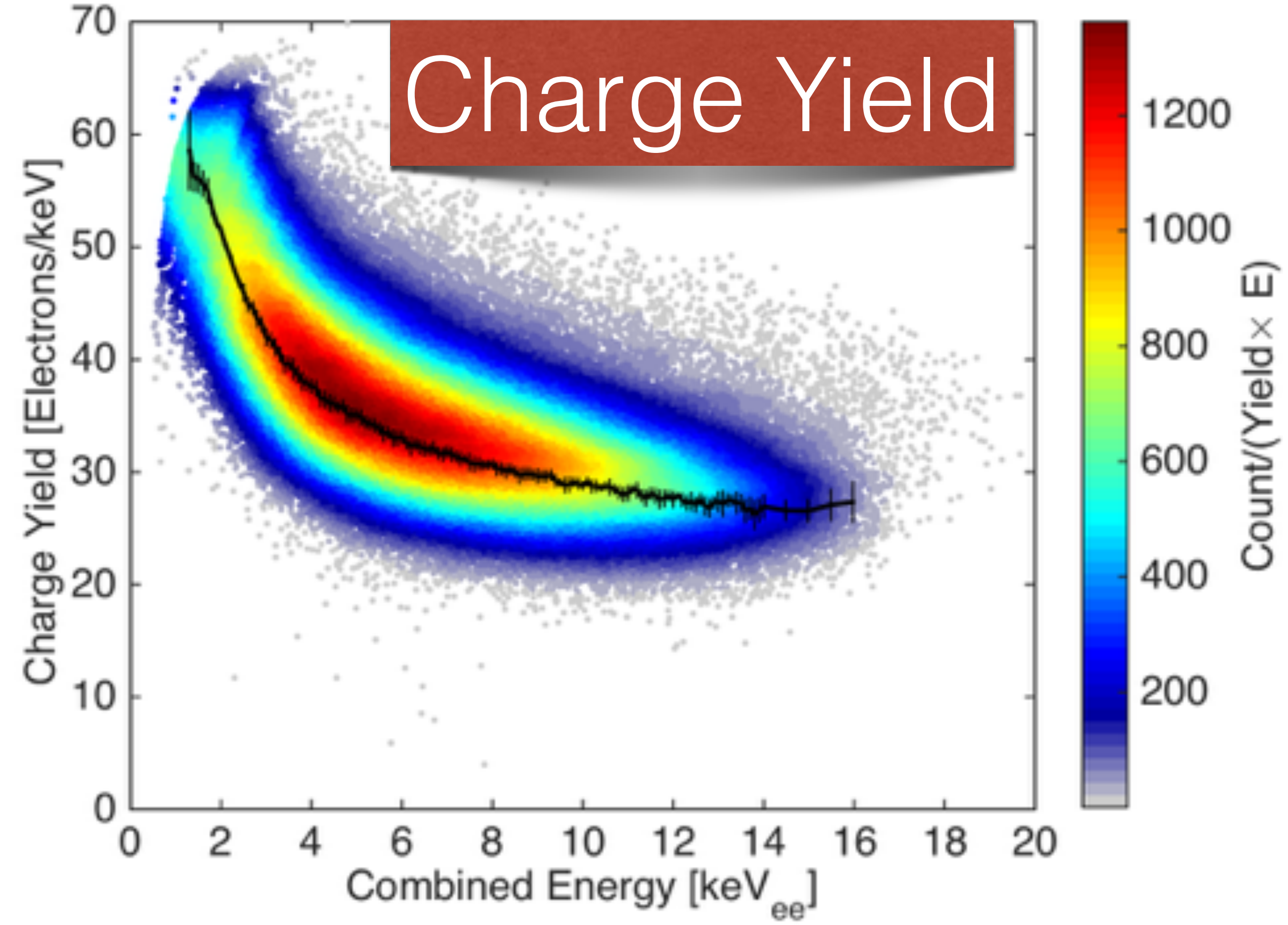
Electron Recoil Band Variance: (from recombination)

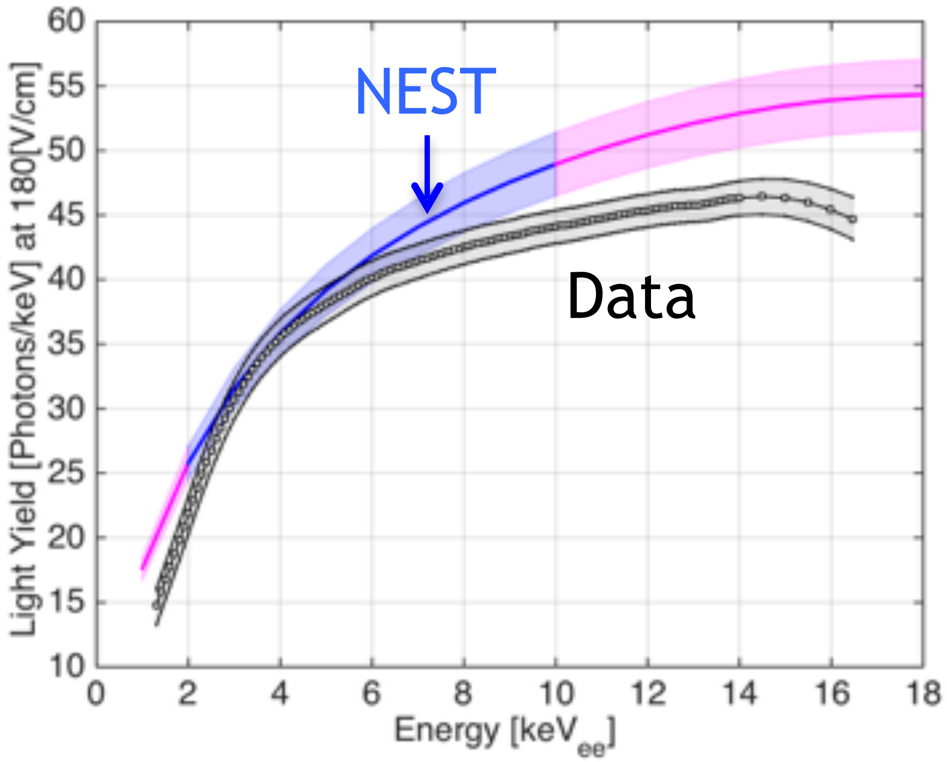
$$\mathrm{Var}_{\log_{10}(S2/S1)} = \frac{1}{(\log(10))^2} \times \sigma_R^2 \left(\frac{-(\alpha+1)}{(1-r)(r+\alpha)N_i} \right)^2$$

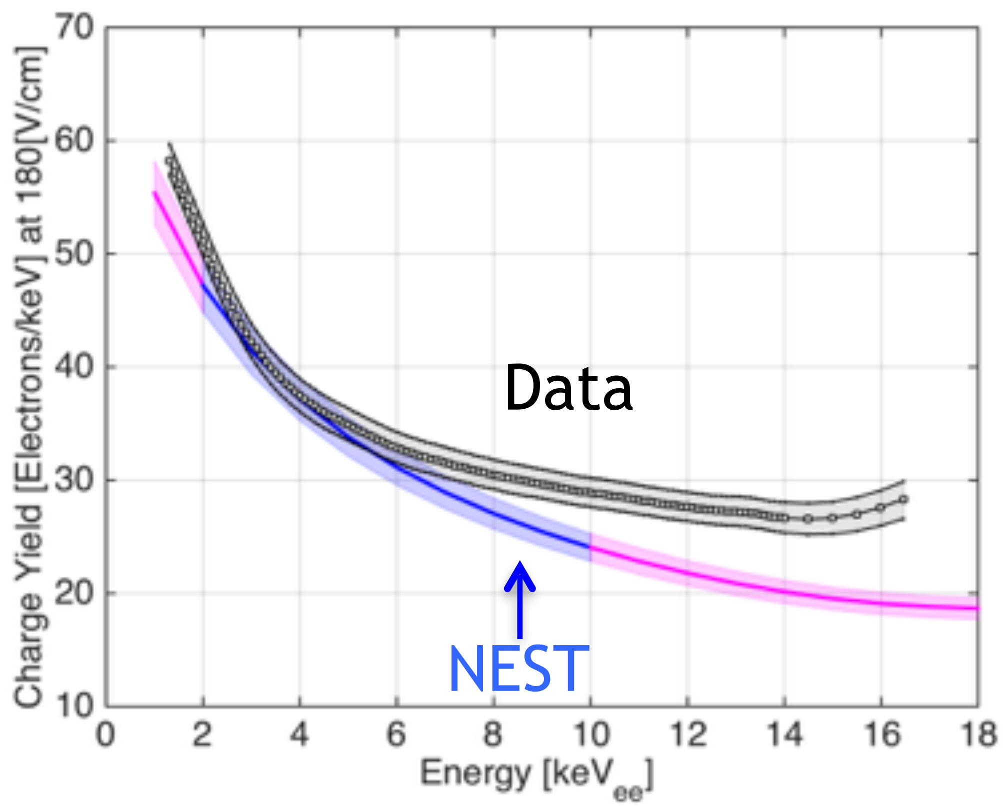
Relying on modeling introduces systematics as α (exciton-to-ion ratio) and σ_R are dependent on field, Energy deposit, detector conditions. Ideally want to calibrate in-situ

Yields Measured in LUX Fiducial Volume



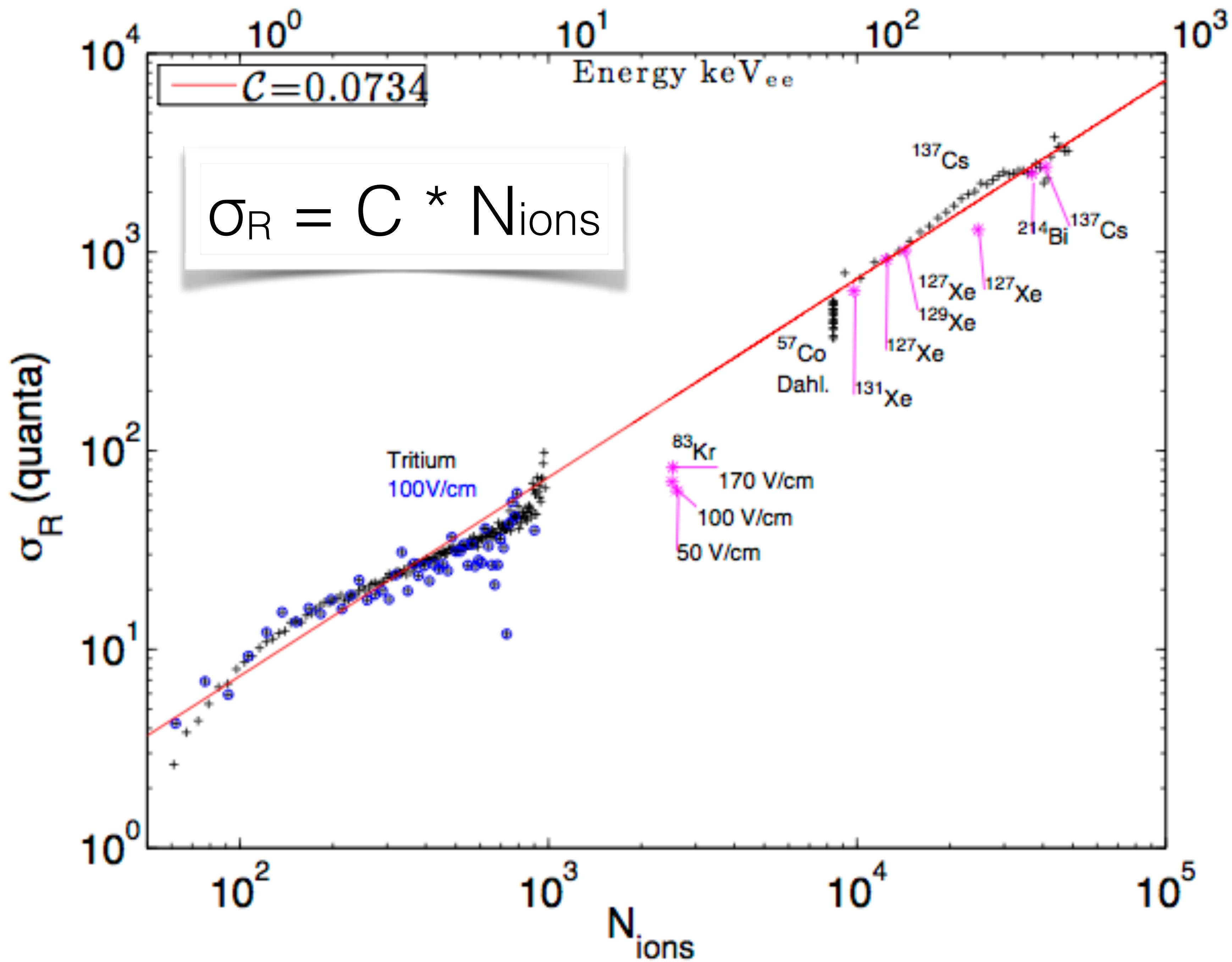






Recombination Fluctuations

We still do not have a physical model to predict recombination variance… but we can measure it with tritium



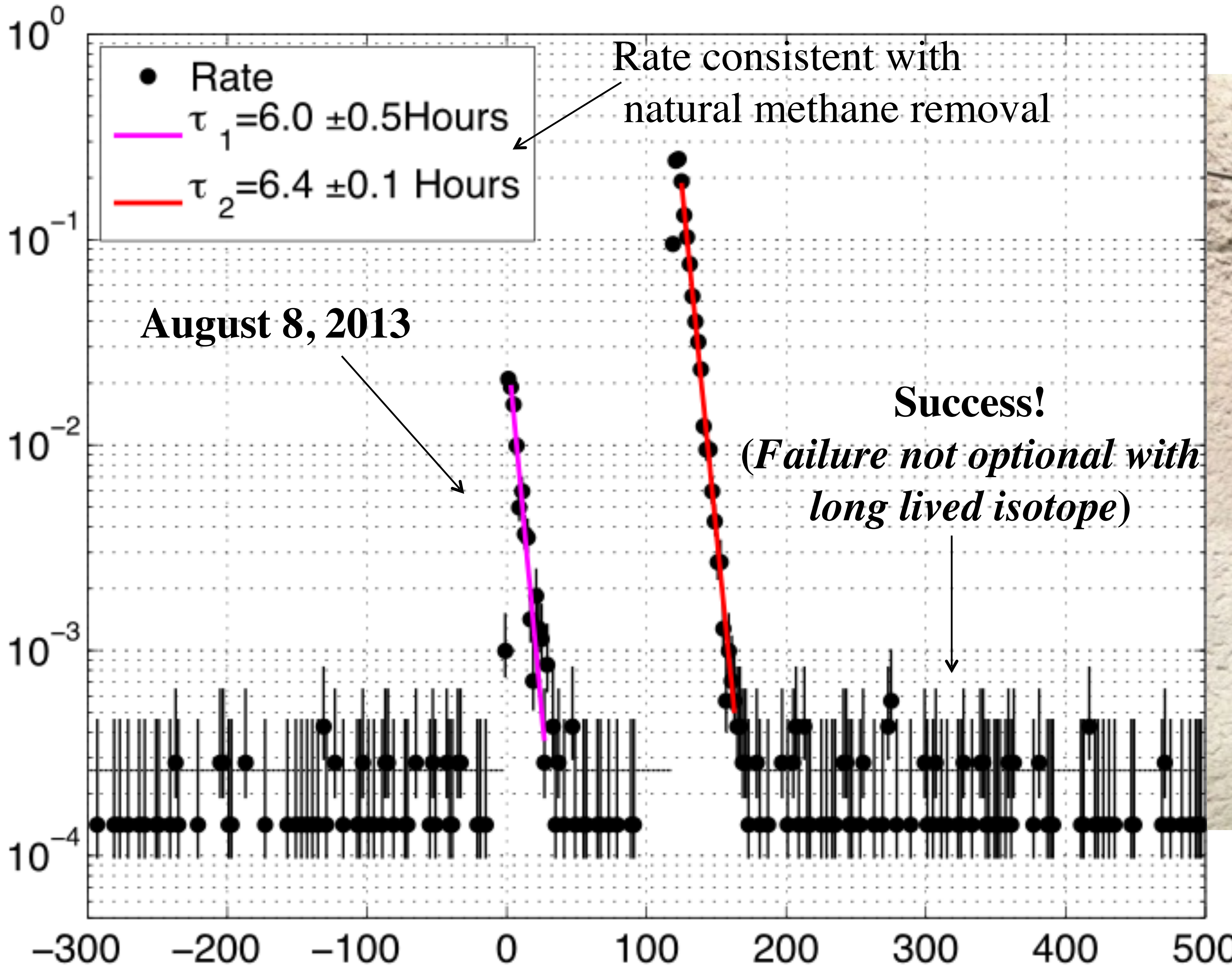
- With the tritium calibration source we can extract yields and model WIMP search backgrounds accurately in-situ
  - Systematics from interpolations and using measurements from other detectors removed.
- Since 2013 LUX results, we have high stats tritium injections and new DD data. We are working on updating the WIMP search analysis.
  - Will be applied to 2014-2015 data
- LY, QY, R are fundamental properties of liquid xenon. Depend on energy, electric field and LXe density.
  - Feed latest tritium data into NEST model to improve predictive power.

1. For DD neutron generator talk from James Verbus.
2. QY Measurement at 0.2 and 1.1 keV from Dongqing Huang
3. Tritium Source, Richard Knoche

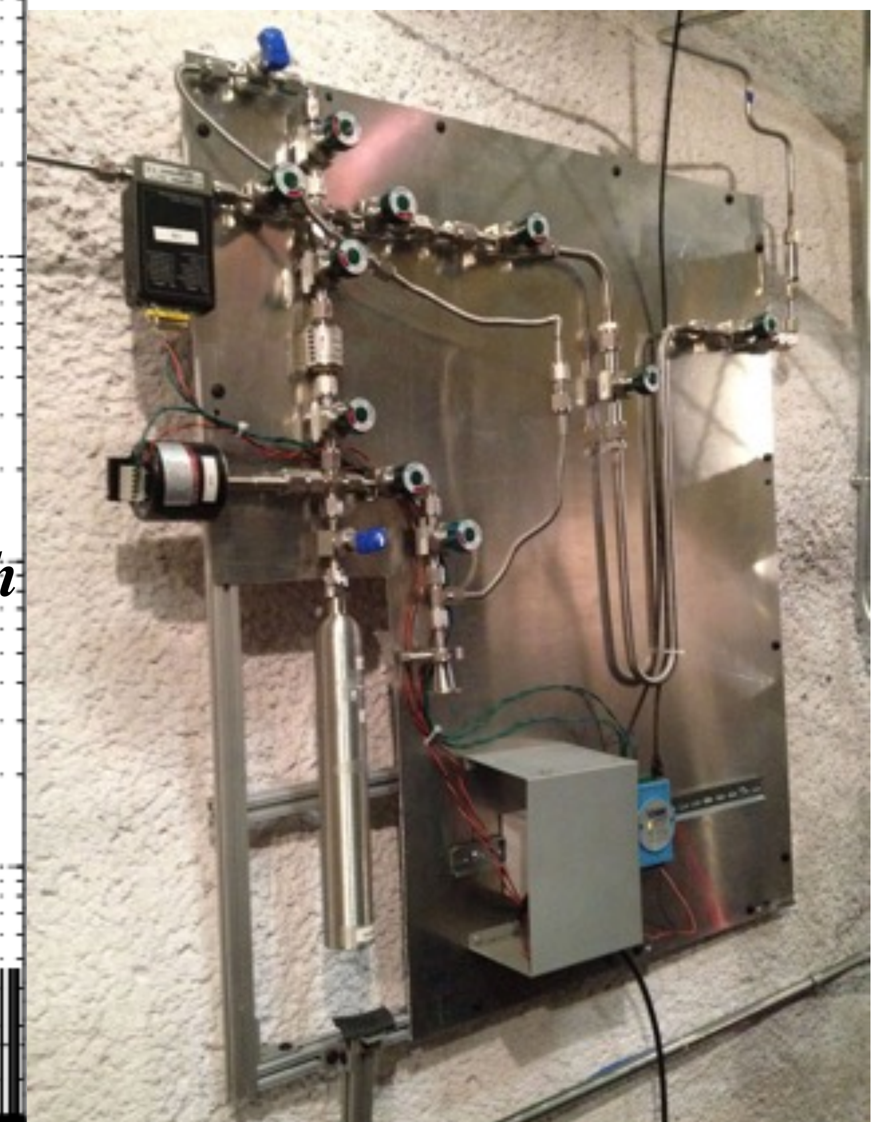

Thank you

Backup

Injection and removal of tritiated methane from LUX, August 2013



UMD/LUX tritium injection system



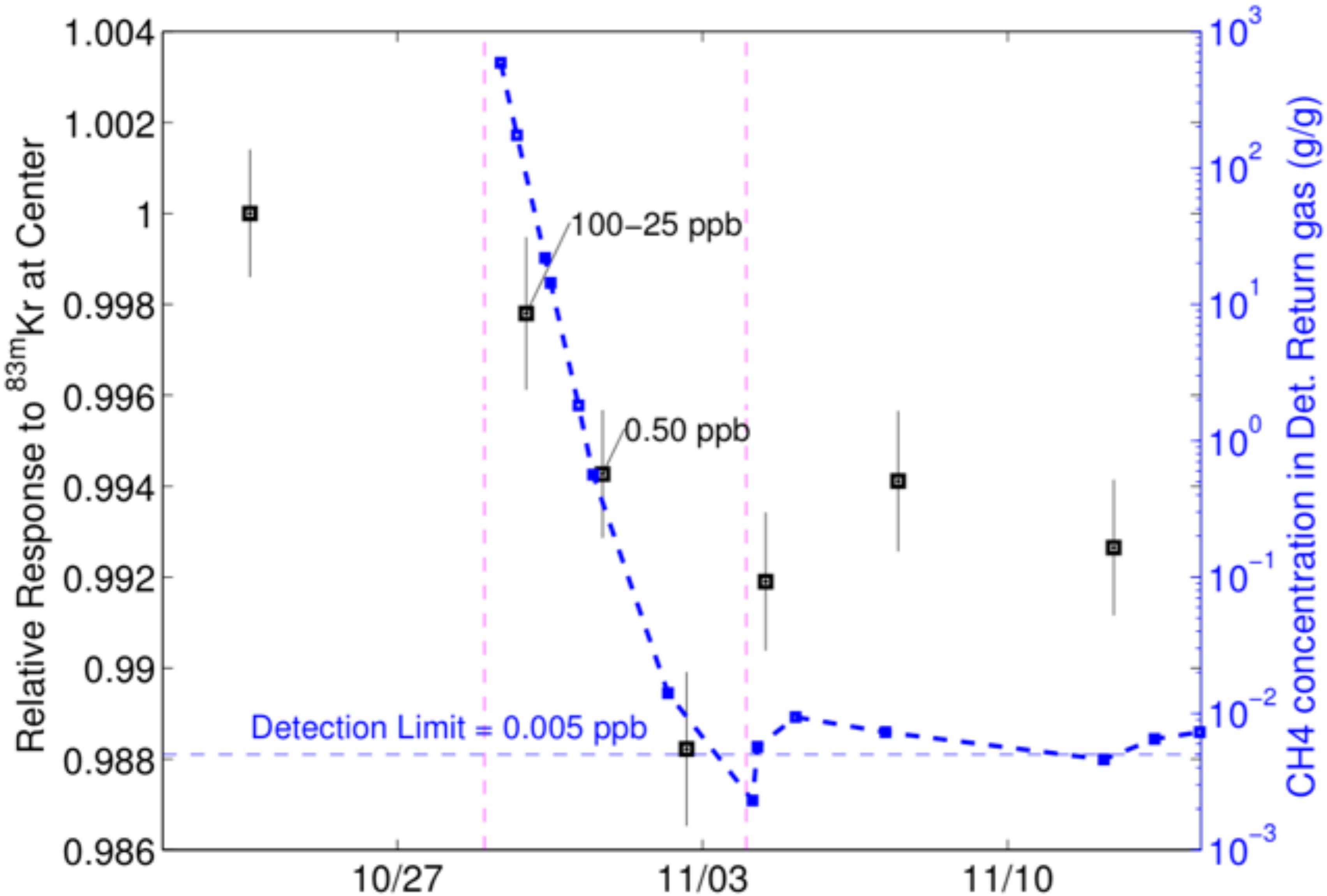
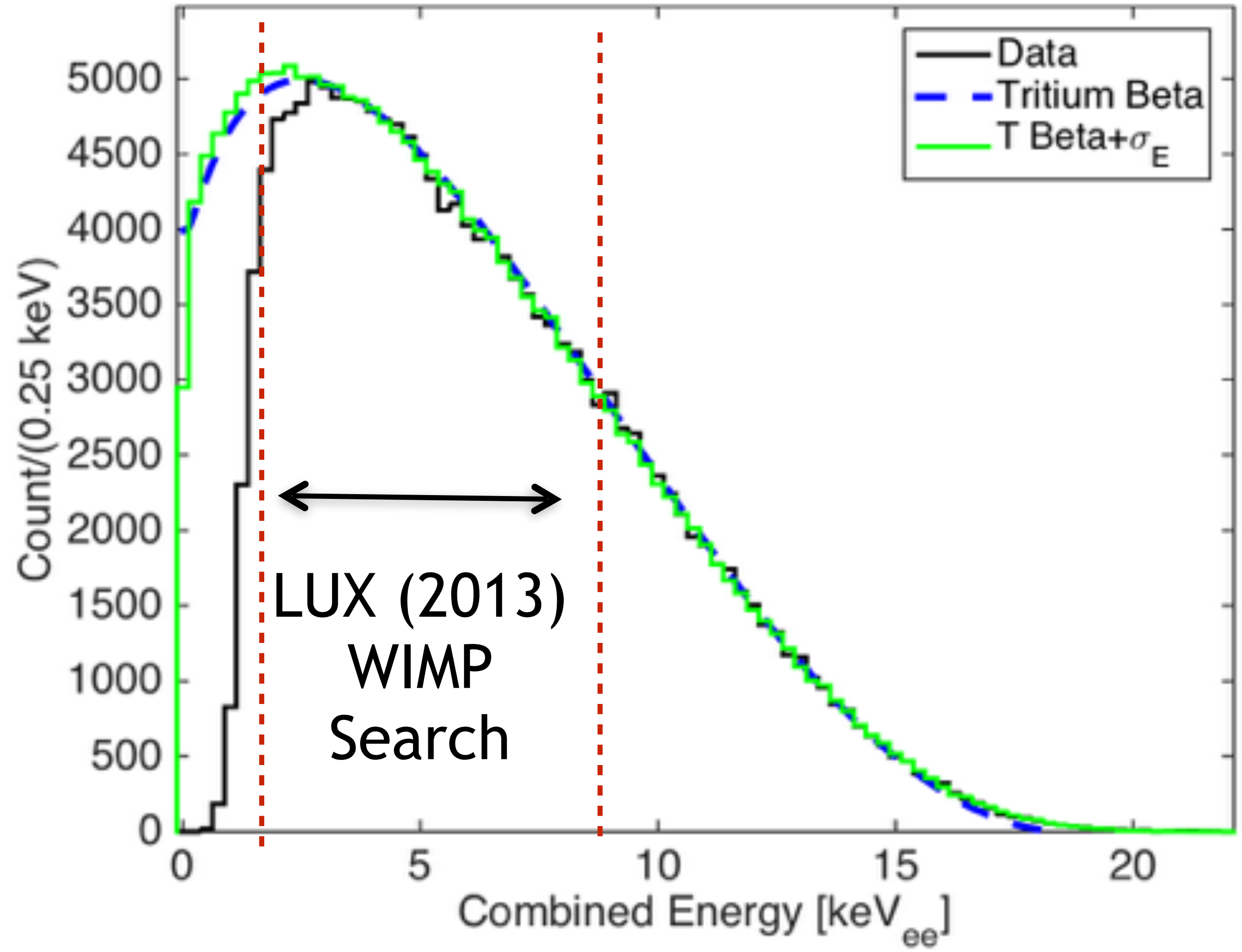


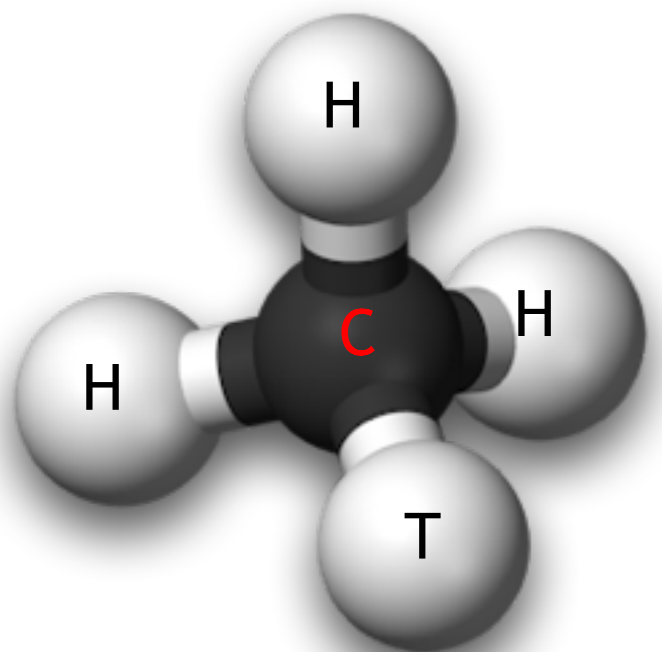
Figure 7.3: In black, the response to scintillation from ^{83m}Kr at the center of the detector normalized to the first data point before the natural methane (CH_4) injection. The dashed magenta lines represent the time window from the beginning of the natural methane injection to the time the background of 5 ppt is reached. The blue points represent that methane concentration in the gas returning from the bulk liquid of the detector. The concentration in the liquid xenon is roughly 1/6 of the concentration measured in the gas phase due to solubility.

Tritiated-Methane, The Ideal ER Calibration Source

- Single Scatter events in energy region of interest:
- Q = 18.6 keV
- Mean energy: 5 keV
- Peak energy: 2.5 keV

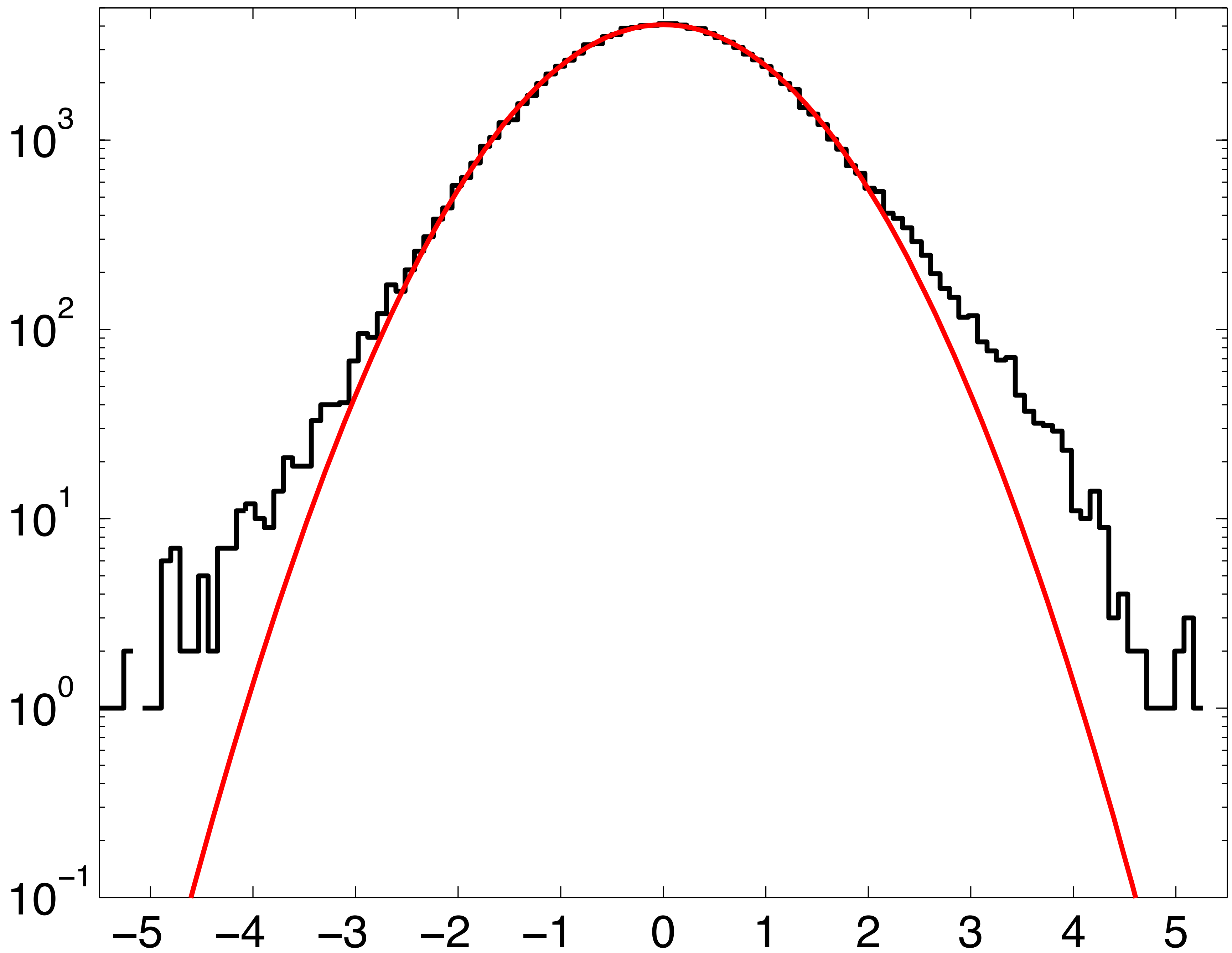


- Bare tritium diffuses quickly into detector components.
- Must be removed after calibration.
- Can't afford to simply wait for activity to decay away.
- 12.3 year half-life!

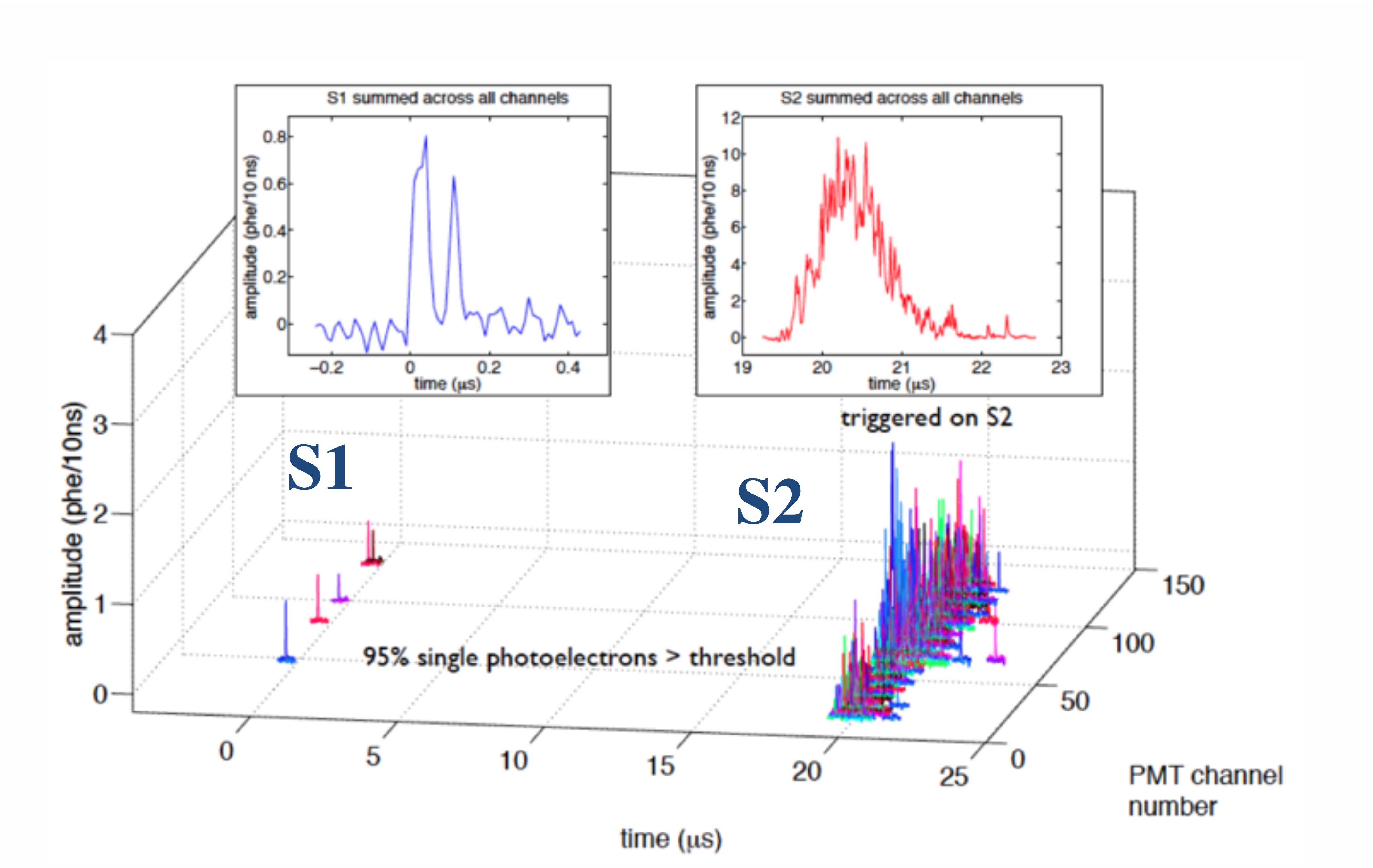


- Methane is non-polar, and has saturated covalent C-H bonds, which makes it chemically very inert.
- Well-known that methane will dissolve in liquid xenon.
- As a larger molecule, tritiated methane has a smaller diffusion constant than bare tritium.
- Methane diffusion and permeability in Teflon is 11x less than tritium.
  - H. Miyake, et. Al. J.Vac. Sci. Technol. A 1:1447 (1983).
- We have characterized the SAES getter for methane and the chemically identical tritiated methane
  - DOI: 10.1016/j.nima.2010.04.152
  - DOI: 10.1016/j.nima.2010.03.151,
  - DOI:10.13016/M24P5P.
  - See Richard Knoche and Jon Balajthy's talk

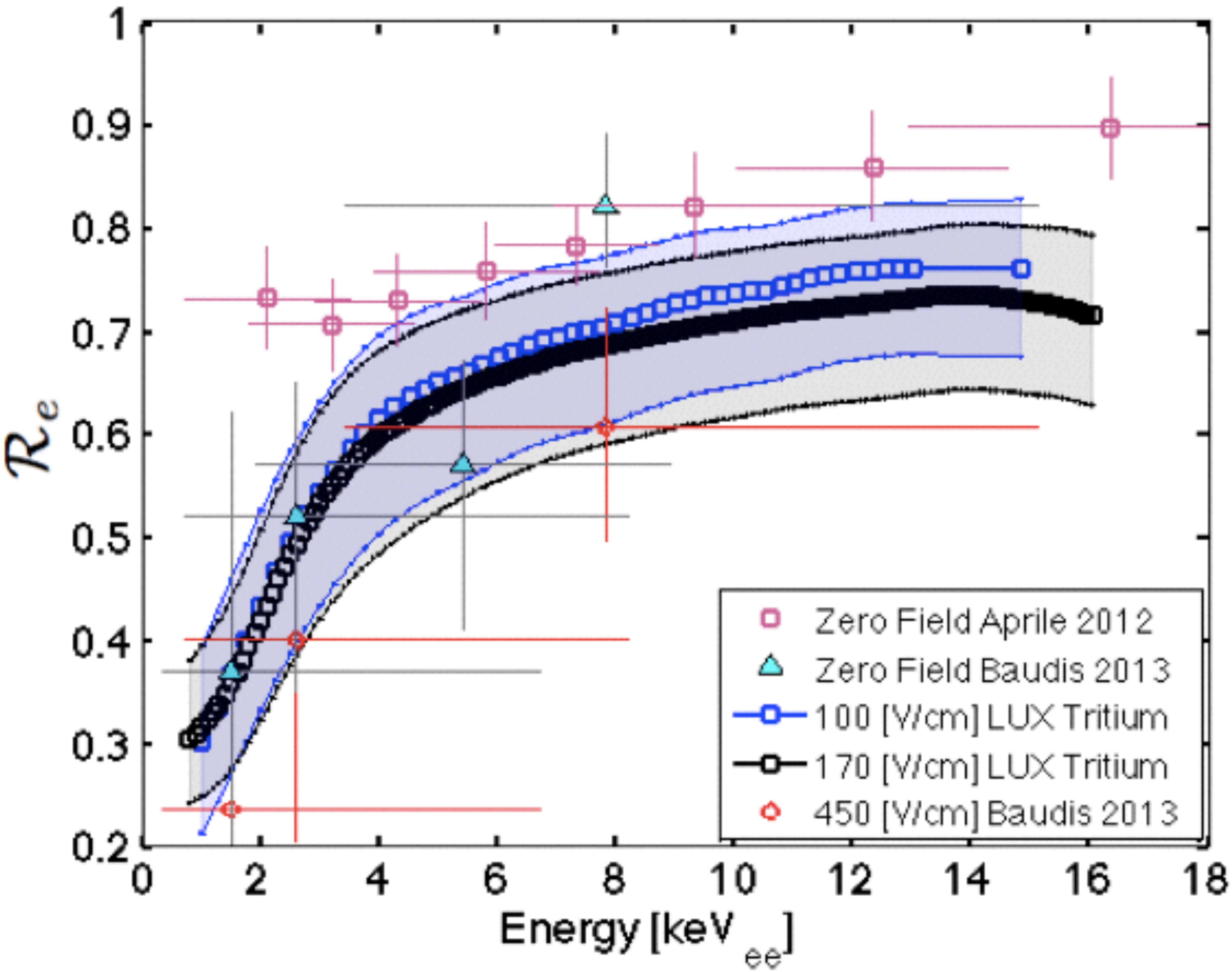
ER band Gaussianity, Tritium Calibration



Typical Event in LUX



LY QY, Compton Scatter

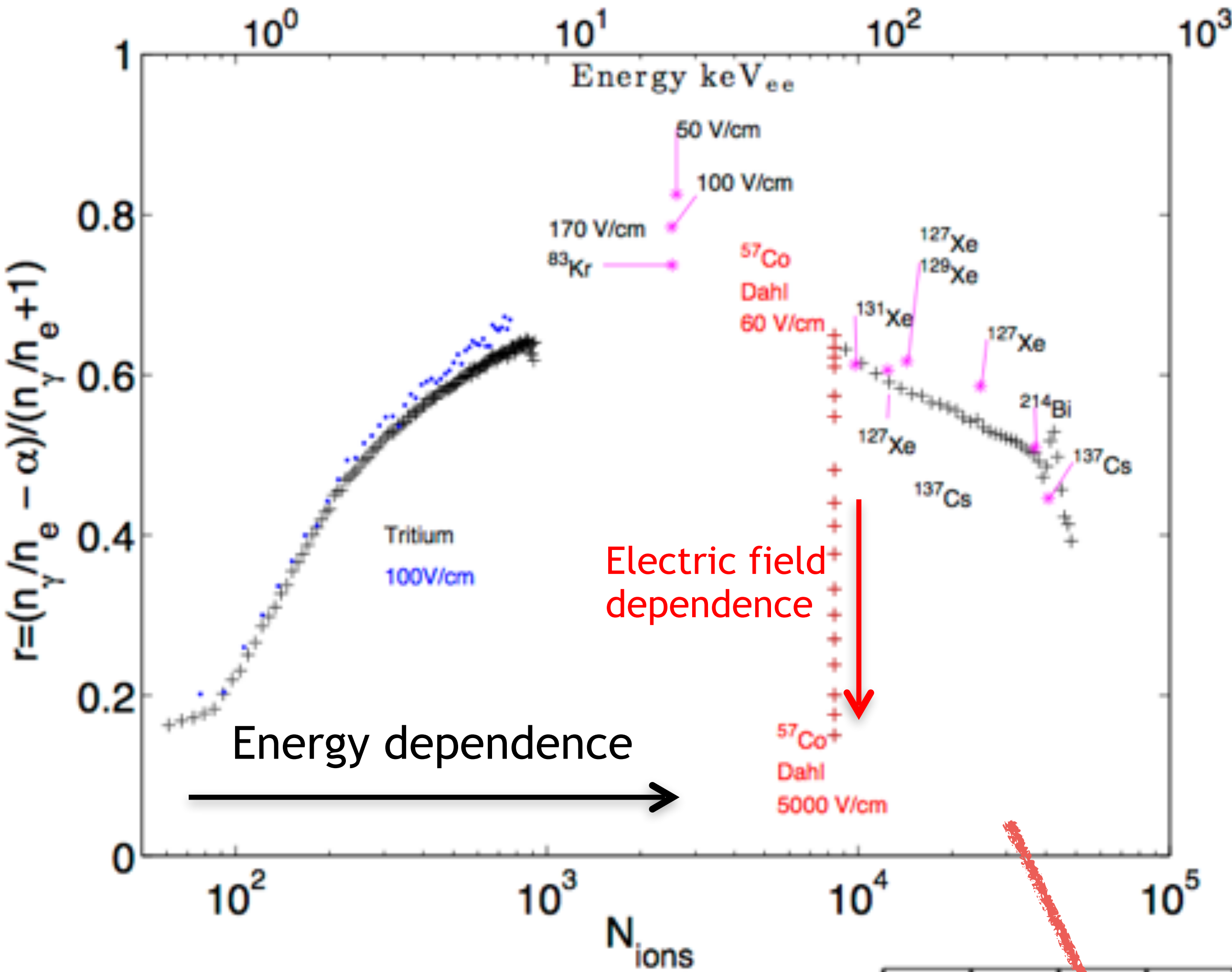


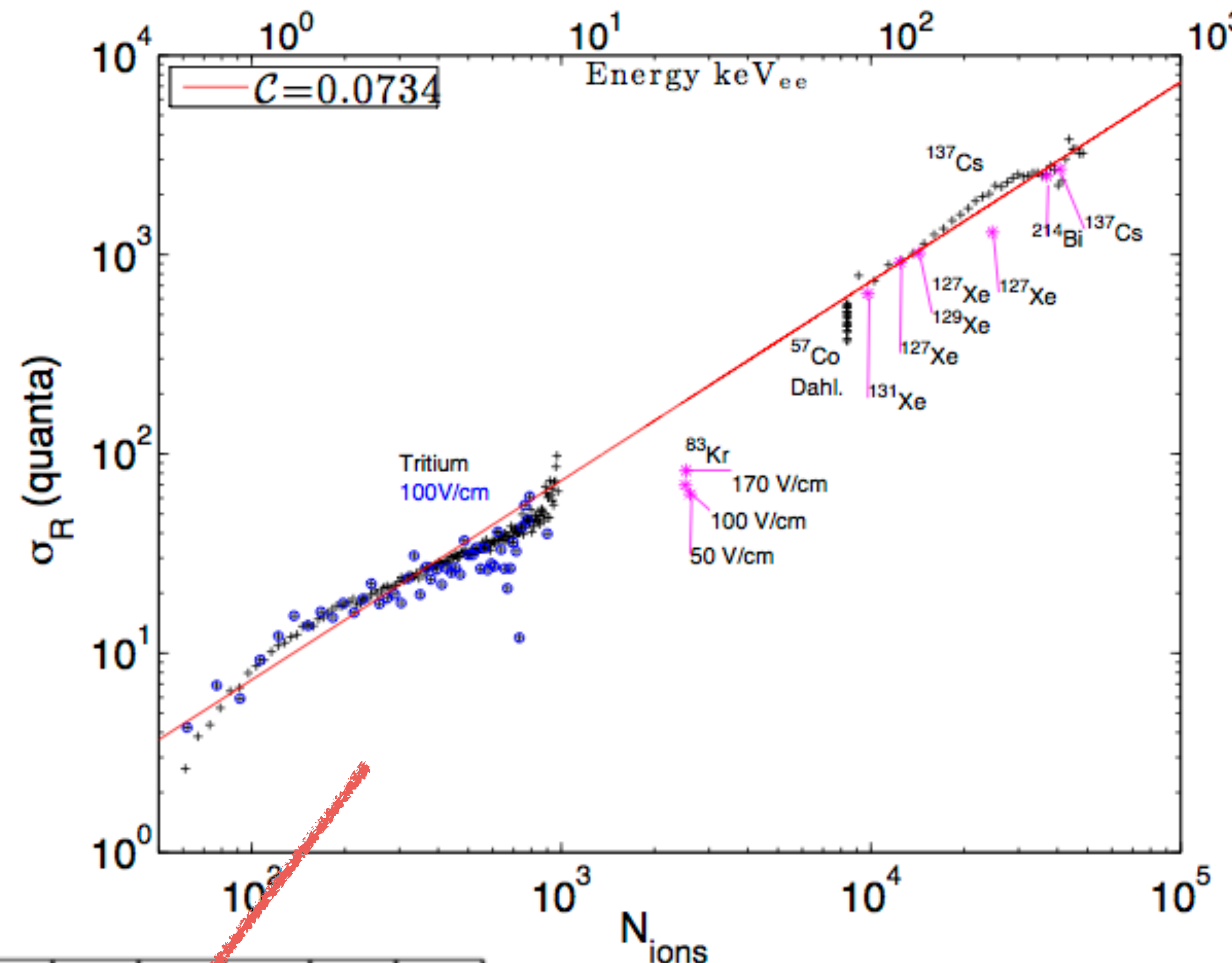
R_e== Light Yield normalized to Yield of 32.1 keV of ^{83}Kr.

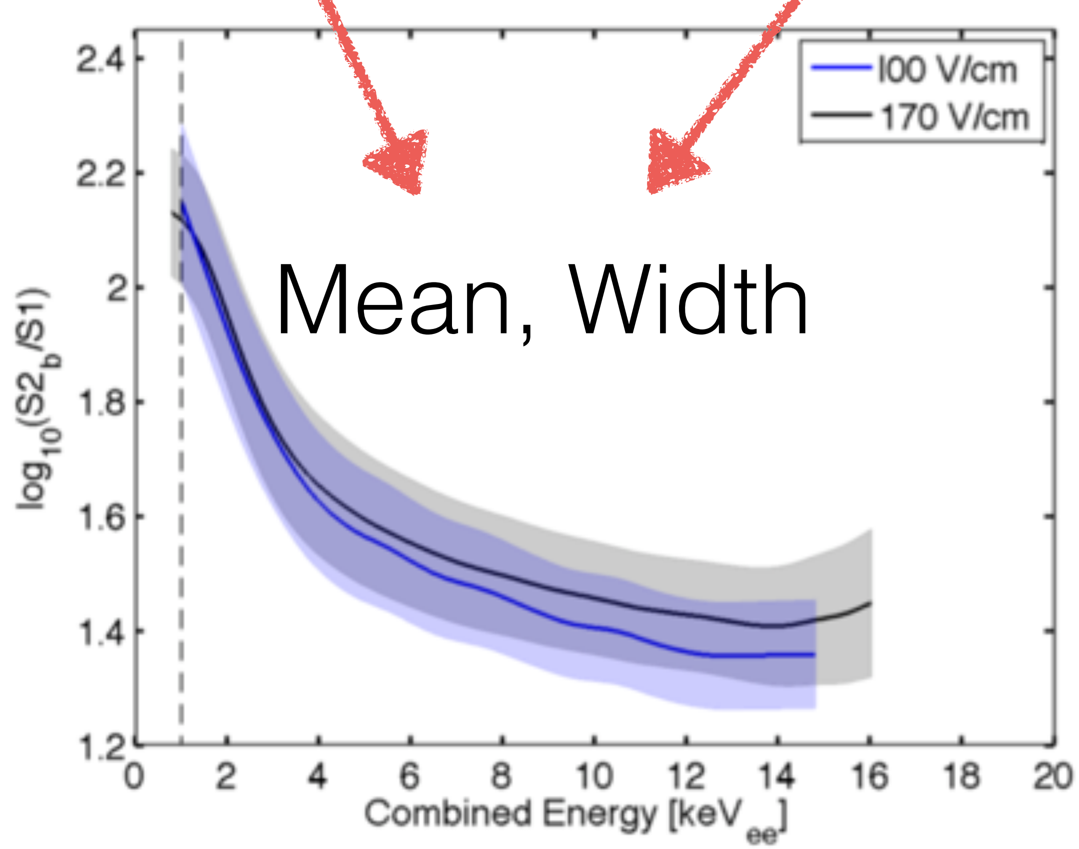
The tritium Beta calibration applies to our ER backgrounds (mainly gamma).

Sub ppt Methane in xenon does not quench light yield

Recombination Results





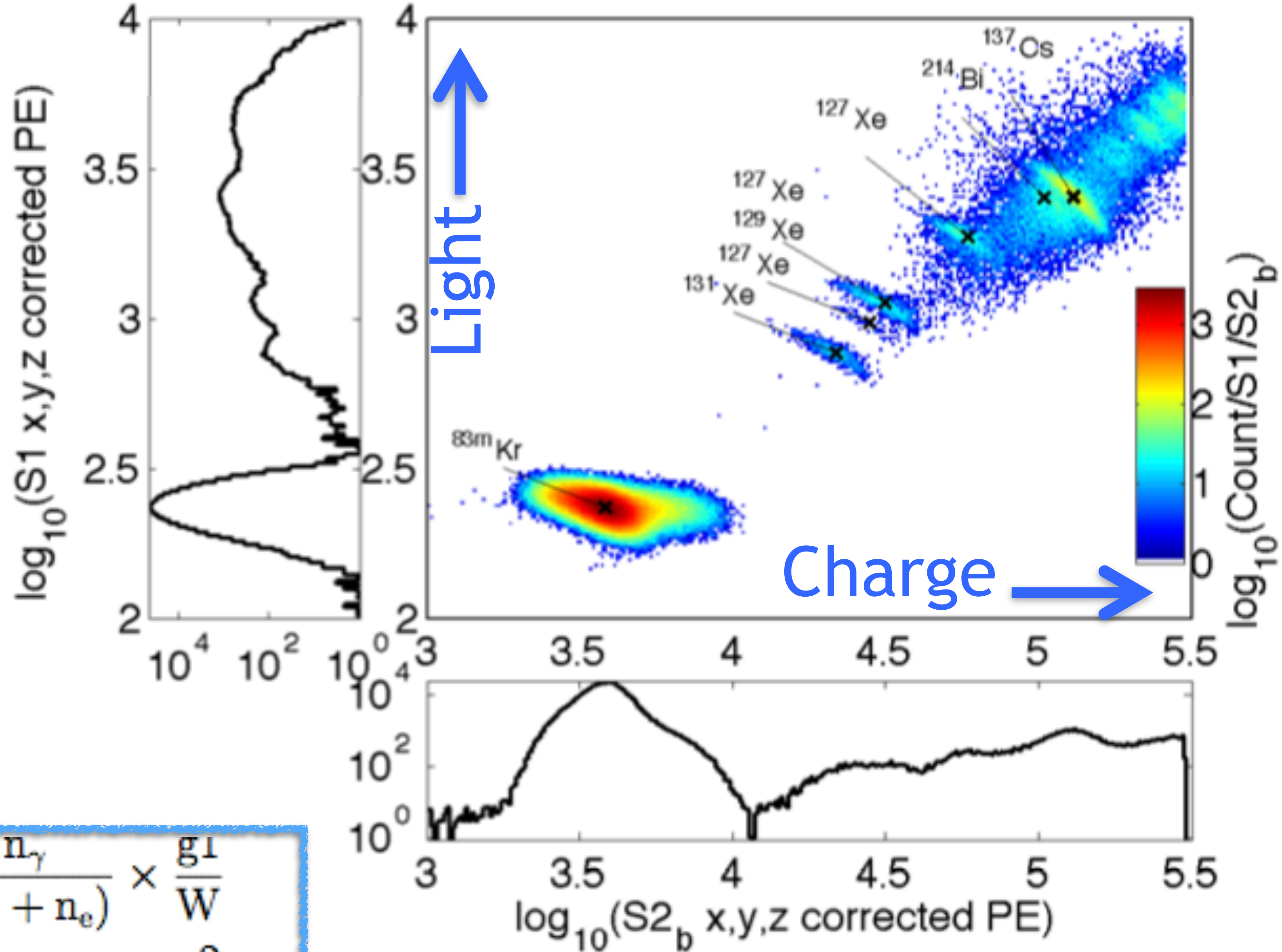


Mean, Width

Energy Scale Calibration using line sources

Source	Energy [keV]	Decay Type
Xe K shell	*29.7, 34*	*X-ray*
^{83m}Kr	*41.55*	*Internal Conversion*
^{131}Xe	*163.9*	*Internal Conversion*
^{127}Xe	*203 or 375*	*γ -emission*
^{127}Xe	*33.8*	*Kb shell X-ray*
^{127}Xe	*5.3*	*L shell X-ray*
^{129m}Xe	*236.1*	*Internal Conversion*
^{214}Bi	*609*	*γ -emission*
^{137}Cs	*661.6*	*γ -emission*

Doke Plot

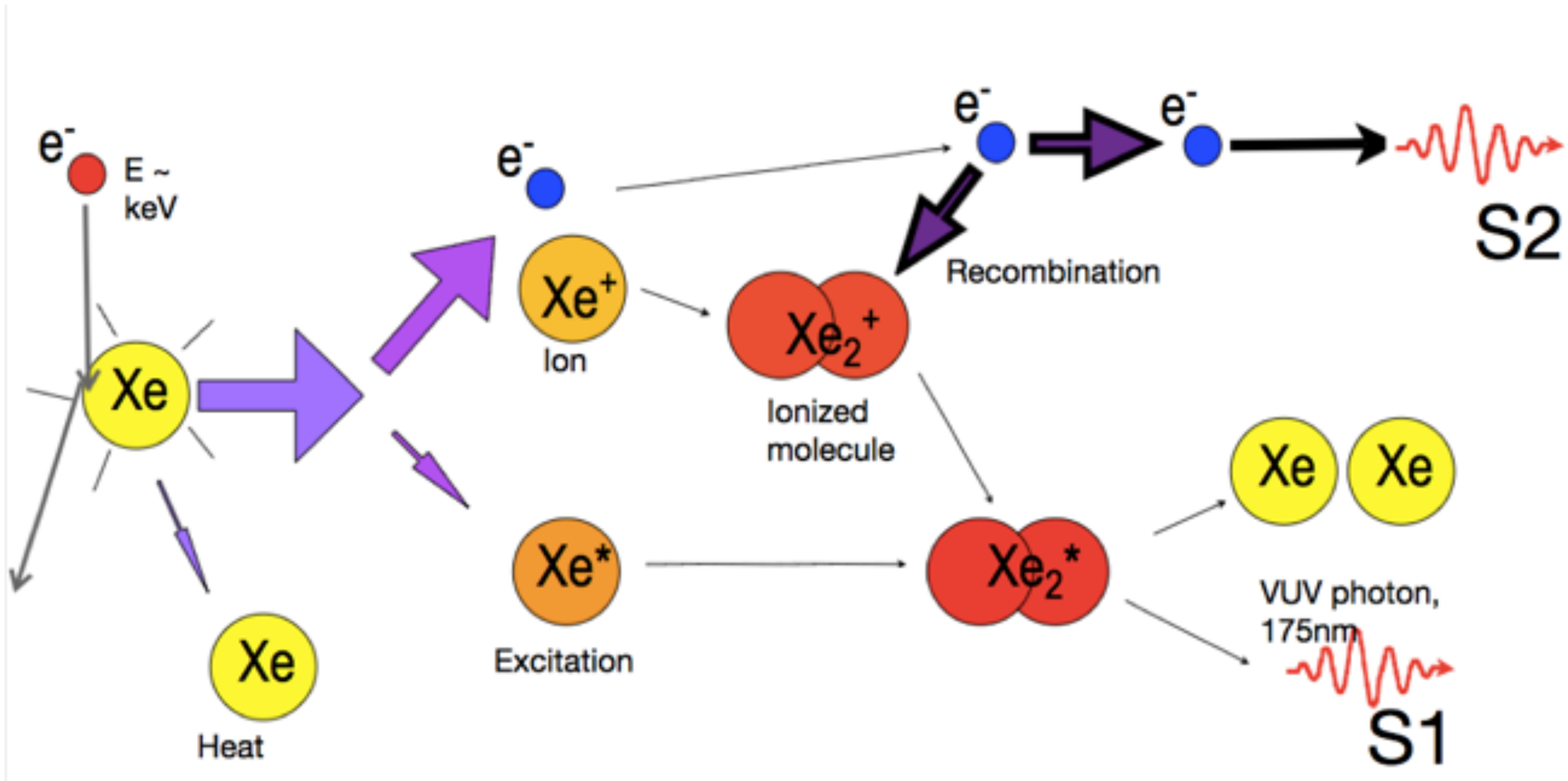


$$\langle n_\gamma \rangle = \frac{\langle S1 \rangle}{g_1} \qquad S1/E = \frac{n_\gamma}{(n_\gamma + n_e)} \times \frac{g1}{W}$$

$$\langle n_e \rangle = \frac{\langle S2 \rangle}{g_2} \qquad S2/E = \frac{n_e}{(n_\gamma + n_e)} \times \frac{g2}{W}$$

Platzmann Model

ER diagram



Energy deposit

Quanta created
$E/W = n_{ex} + n_i$

Light Yield

+/- Recombination Fluctuation

light collection
(detector photon resolution)
S1=g1*Ng

$$n_\gamma = n_{ex} + n_i r = n_i(r + \alpha)$$

?
vs field & energy

$$n_e = n_i(1 - r)$$

Charge Yield

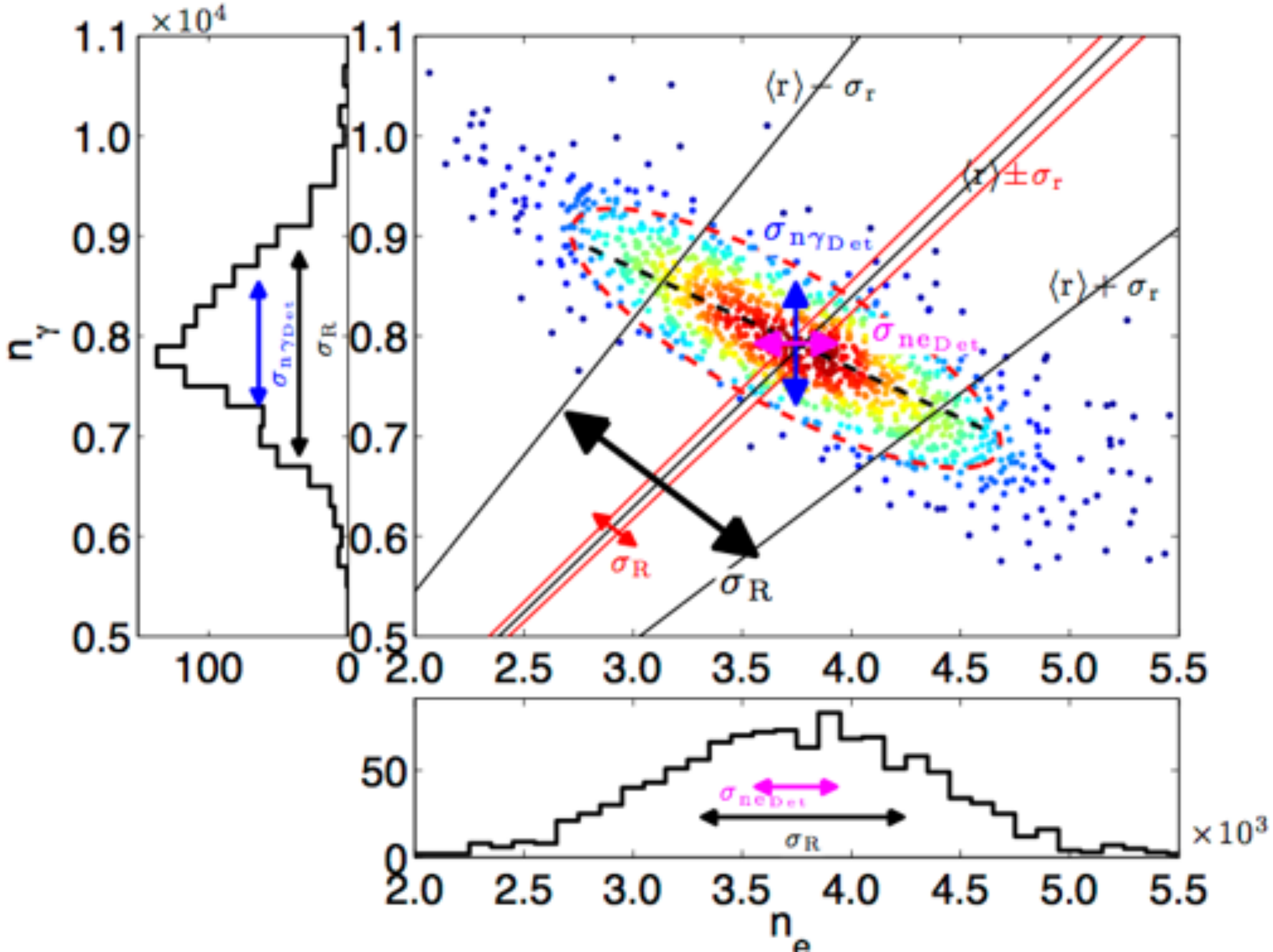
-/+ Recombination Fluctuation

charge collection
(detector electron resolution)
S2=g2*Ne

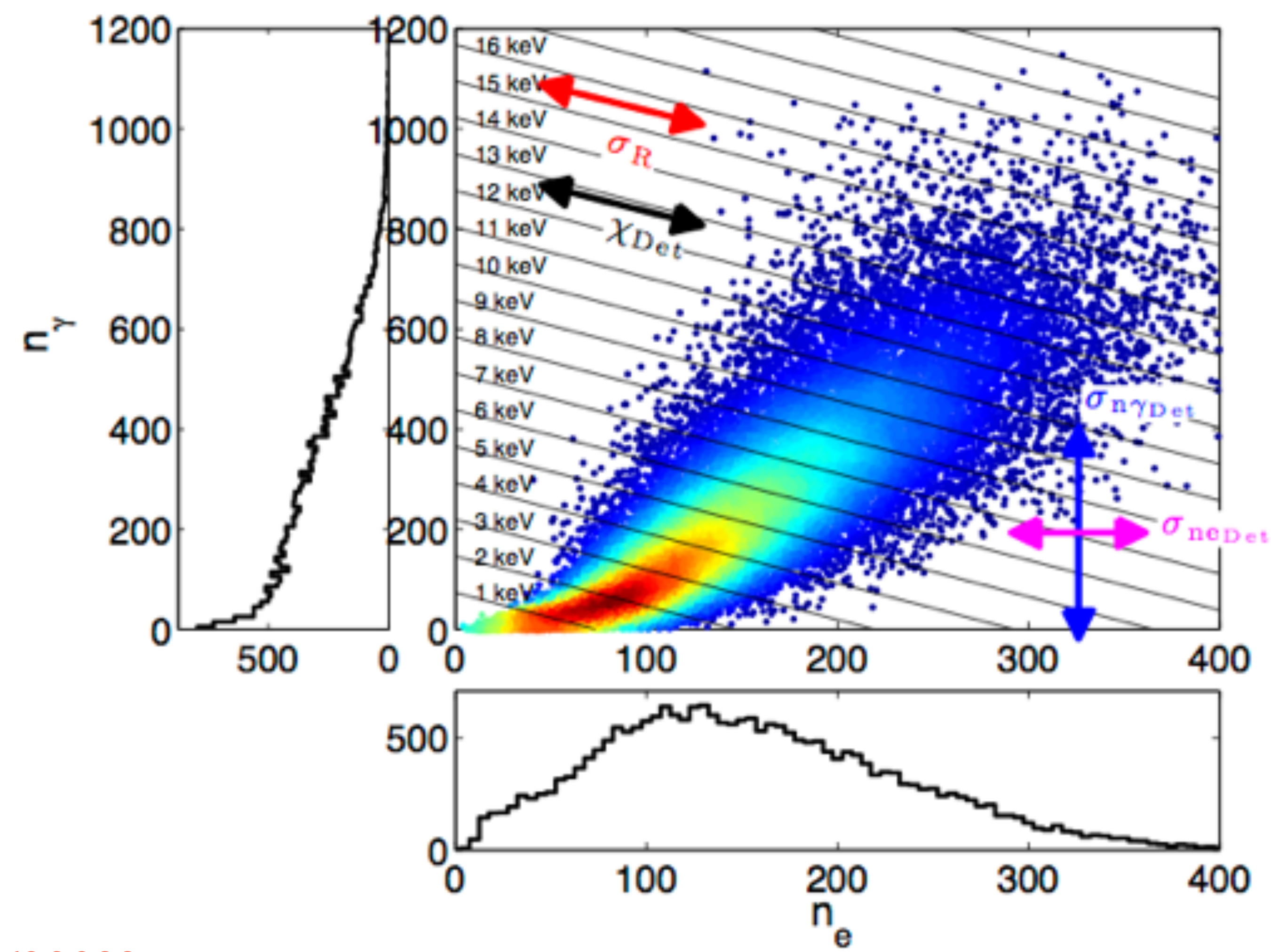
$\alpha = n_{ex}/n_i$

ER Band Width (Fluctuations)

131Xe: 164 keV



Tritium: 1-18 keV



red: recombination fluctuation expected from binomial process

… will add sqrt(Ni) to the plot. (similar to binomial)

black: Observed recombination fluctuation.

Much worse than Normal, Poisson or Binomial

- LY, QY yield the mean photons and electrons produced.
- Recombination fluctuations and detector resolution give rise to the width of the ER band in discrimination space (S2/S1) vs. S1
- Given infinite resolution, the fundamental limitation of ER and NR discrimination is set by recombination fluctuations.