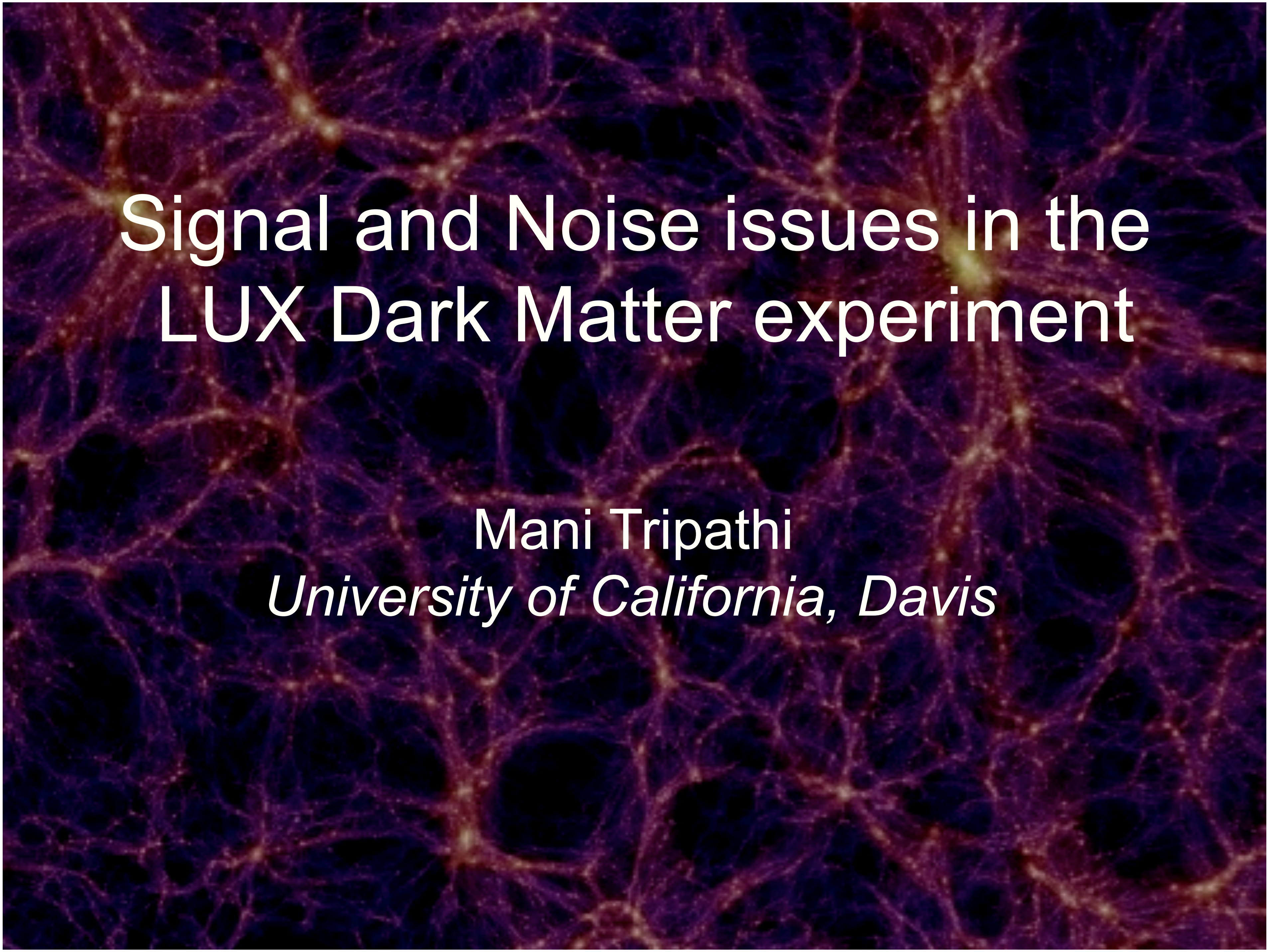
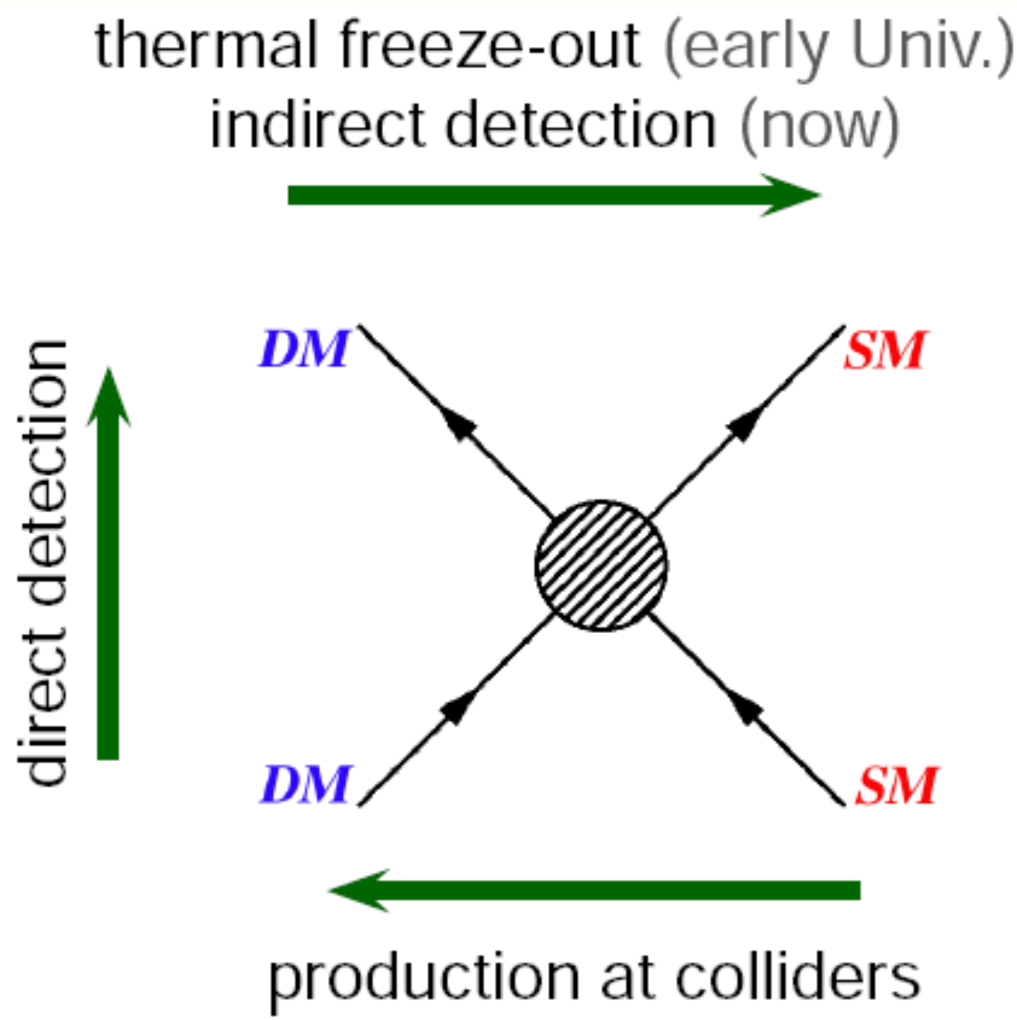


Signal and Noise issues in the LUX Dark Matter experiment

Mani Tripathi
University of California, Davis

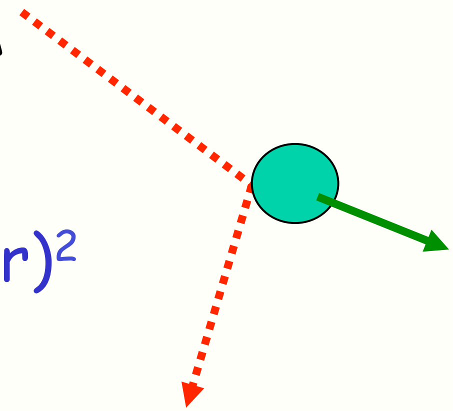
Dark Mater Direct Detection Techniques

- Three major categories of investigations.
- LUX follows the vertical arrow



Direct Detection

Basic goal: search for nuclear recoil from DM elastic scattering.



Simple dynamics. Cross section α (form factor)^2

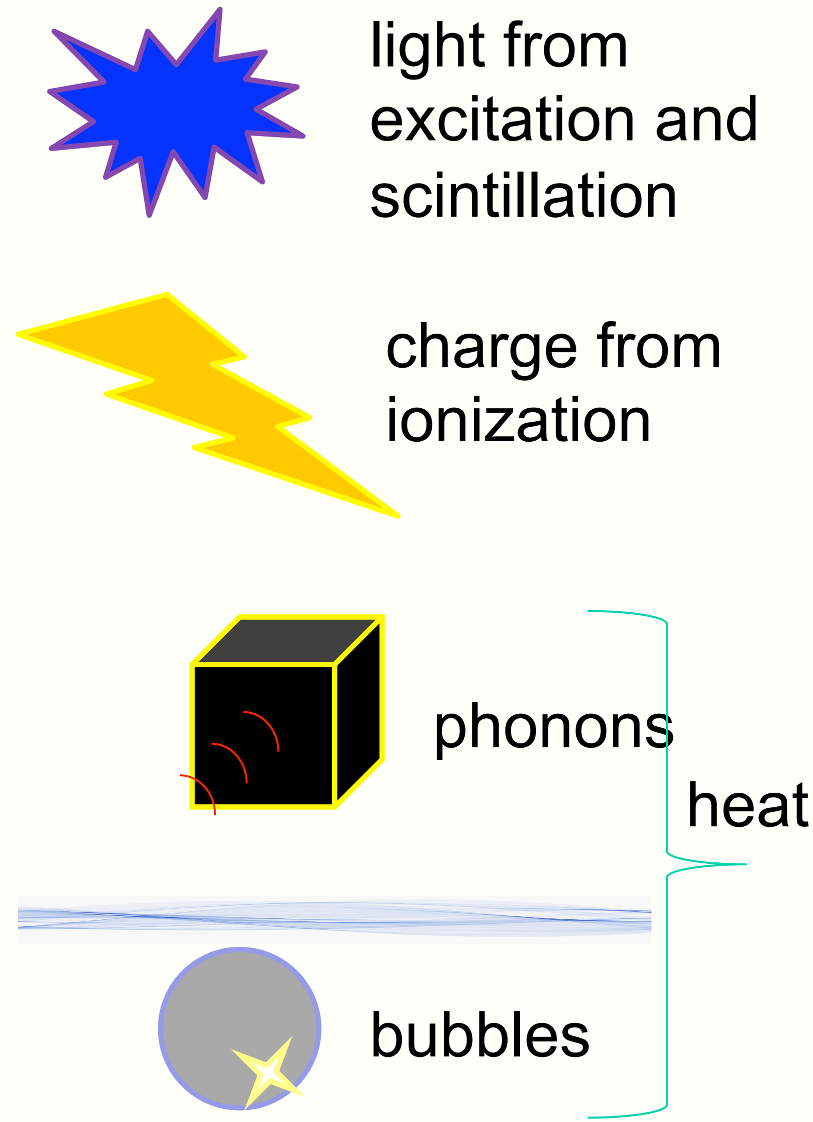
Spin-independent: Nucleon form factor gives rise to A^2 enhancement due to coherence.

The dependence on q^2 is also contained in the form-factors.

Spin-dependent: Form factor depends on nuclear spin. No coherence enhancement.

Different Direct Detection Methods

- Scintillation light
  - Liquid/gas scintillators: Xe, Ar, Ne (noble)
  - Solid scintillators: NaI, CsI, $CaWO_4$, LiF, CaF_2
- Ionized electrons can be collected in an electric field.
  - Xe à la LUX (in combination with light)
  - Ge à la CDMS (in combination with phonons)
- Lattice vibration (phonons).
  - bolometers/calorimeters: Ge, Si, $CaWO_4$
- Recoiling neutrons can boil superheated liquid. Cameras and microphones detect bubbles.
  -- CF_3I, CF_3Br, C_3F_8, C_4F_{10}, C_2ClF_5



Background Suppression

For these experiments the main "noise" is background "signals". A large suppression of backgrounds required.

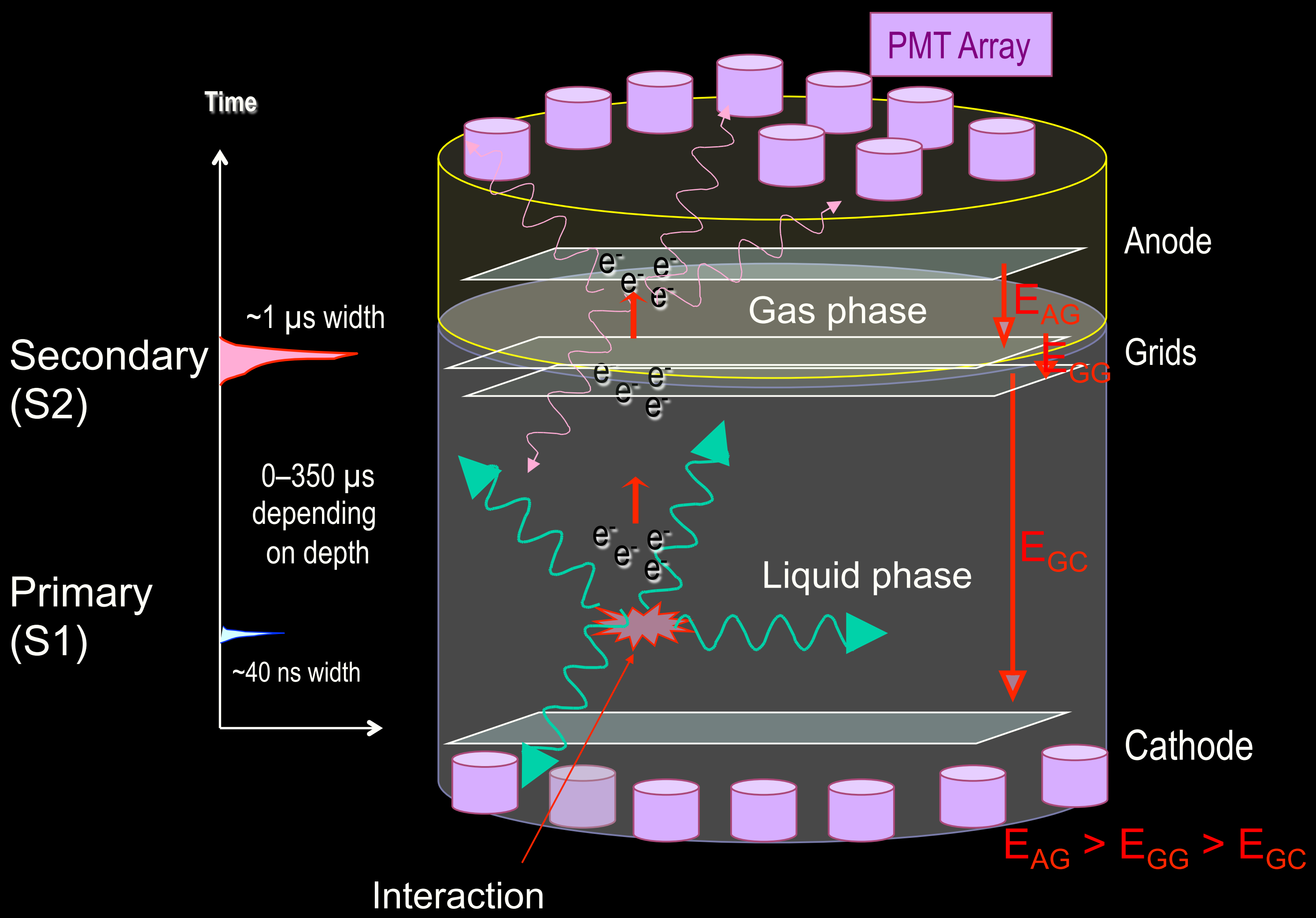
1. Gamma ray induced electron recoils. Discrimination is based on measuring two characteristic signals from the recoil.

	Liquid Xenon	Liquid Argon	Low temp. Ge	Bubble Chamber
Ionization	√	√	√	high density
Scintillation	√	√		
Phonons			√	
Other		Pulse shape	Pulse shape	Acoustic

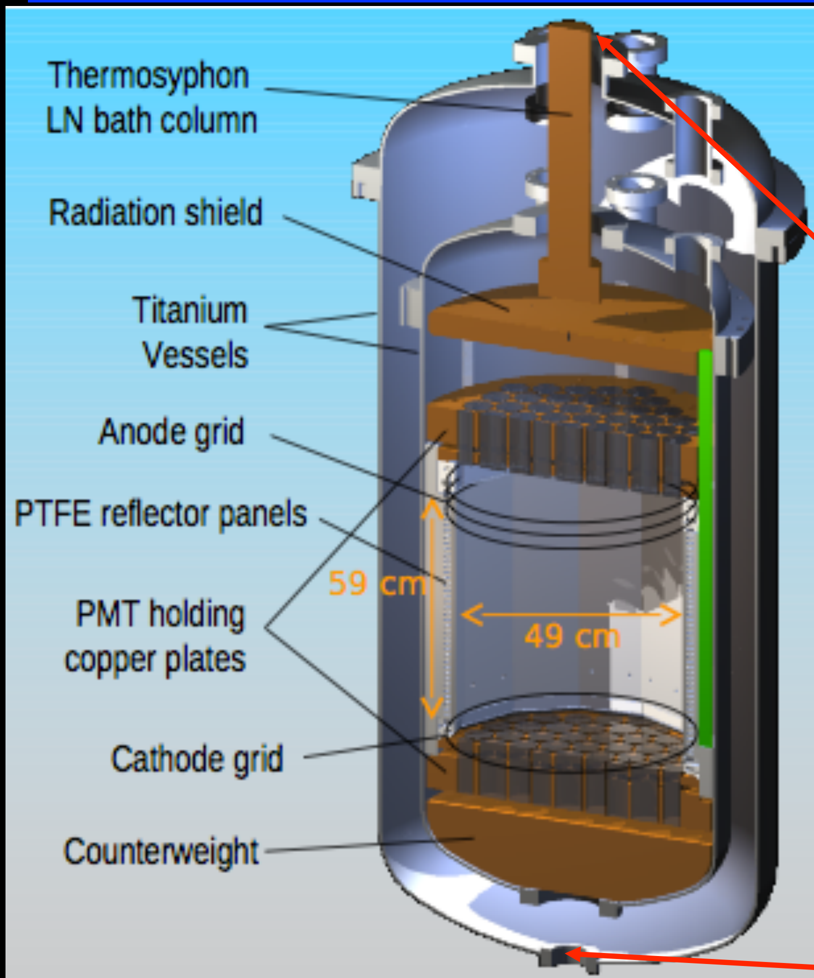
2. Neutron induced nuclear recoils. Neutrons need to be eliminated:

- Deep underground deployment
- Use of ultra-low radioactivity materials and components
- Large external shields (water and/or lead)
- Active veto (e.g., gadolinium doped liquid scintillator)
- Double scatters (DM does not)

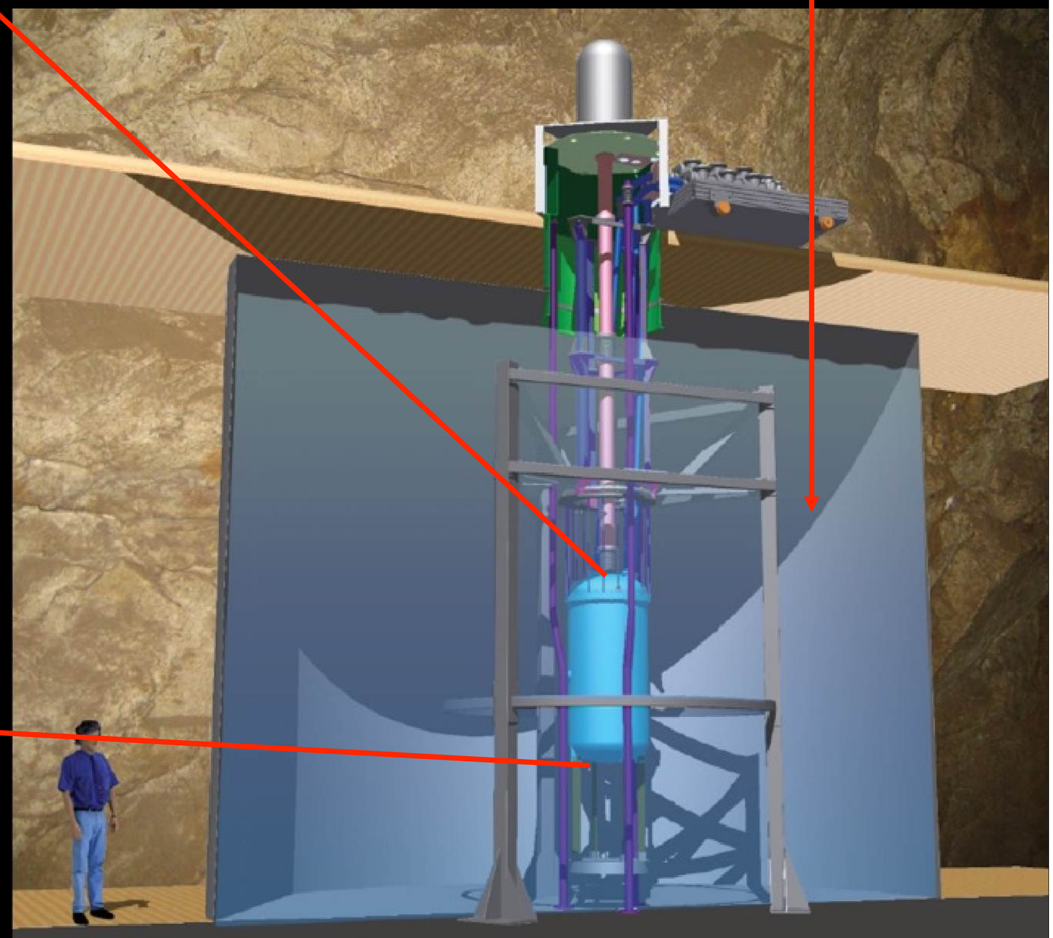
Two Signal Technique



The LUX detector



~ 7m diameter Water Cerenkov Shield.



- 350 kg of Lxe
- 122 photomultiplier tubes (top plus bottom)

Assembly completed on the surface

Detector: By the Numbers

- 370 kg gross/250 active/118 fiducial Xe inside
- 48 cm H (gate to cathode) X 47 cm D active region with 181 V/cm drift field
- Good purity: 87-134 cm e^- m.f.p. over course of run (~500-900 us "lifetime")
- 6.0 kV/cm extraction field (3.1 in LXe) resulting in 65% extraction efficiency
- 200 phe S2 analysis threshold or mean 8 e^-'s (~25 phe/e^-) avoids few-e^- BGs

Why Xenon?

Nobel element => Inert. Can be purified via gettering techniques.

No long-lived radio-isotopes. Metastable istopes useful in calibration.

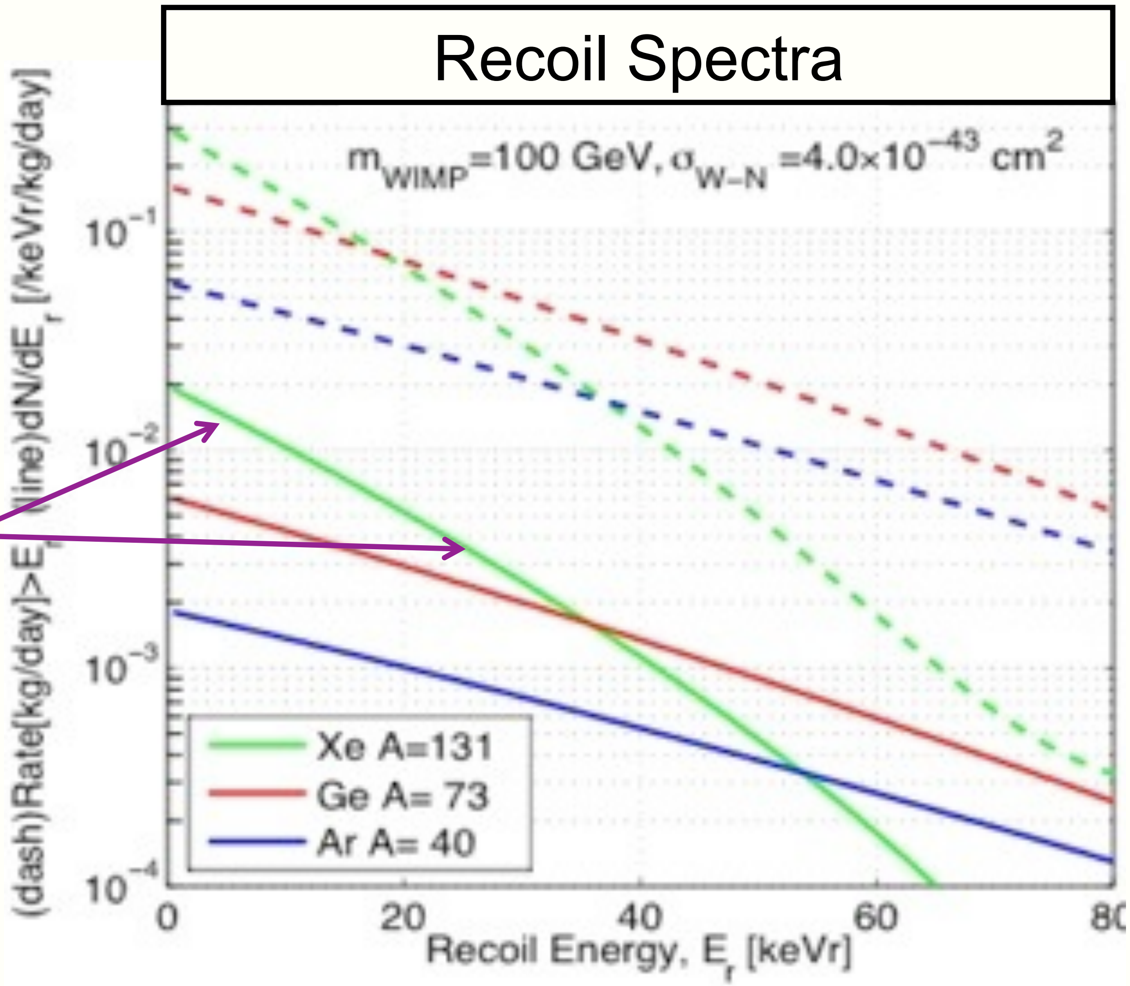
High density (~3g/cm^3)
=> Powerful self-shielding.

High A (131) => Large
elastic σ

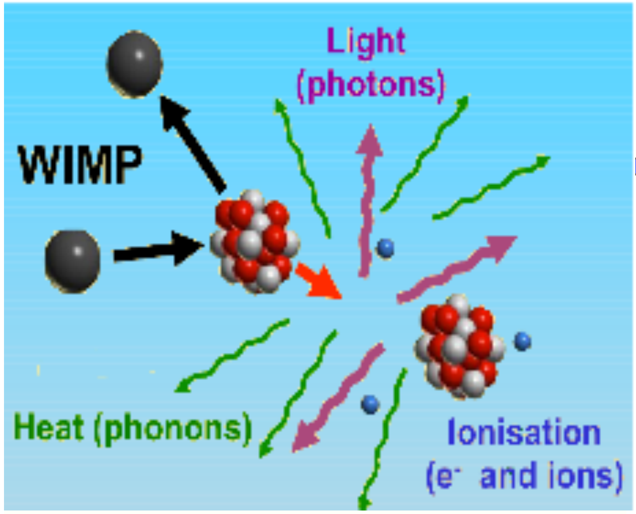
Higher Sensitivity in the
range 5 keV < E < 25 keV.

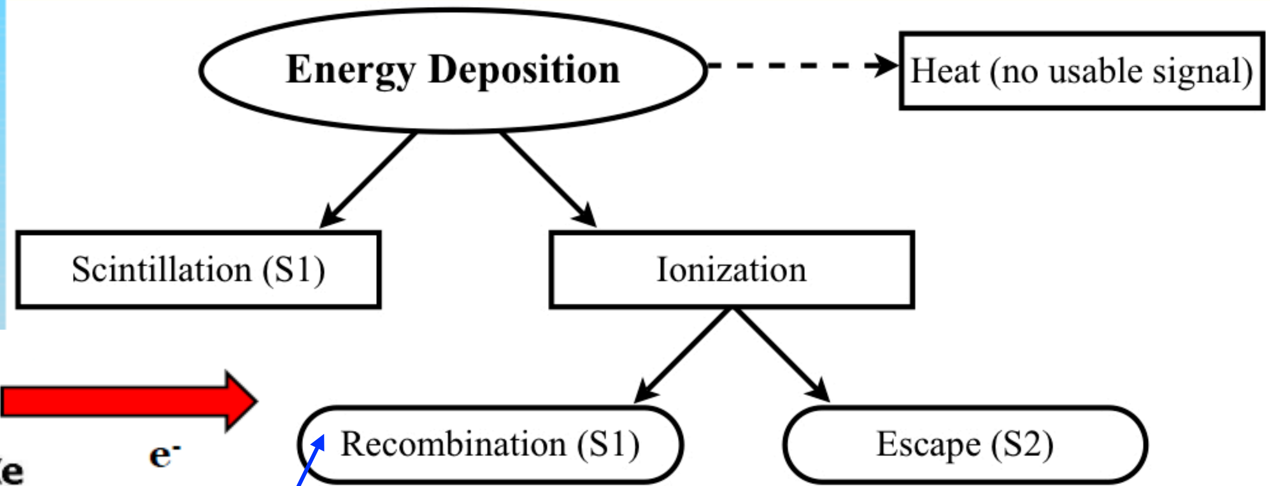
Long electron drift
lengths (few m) => scalable

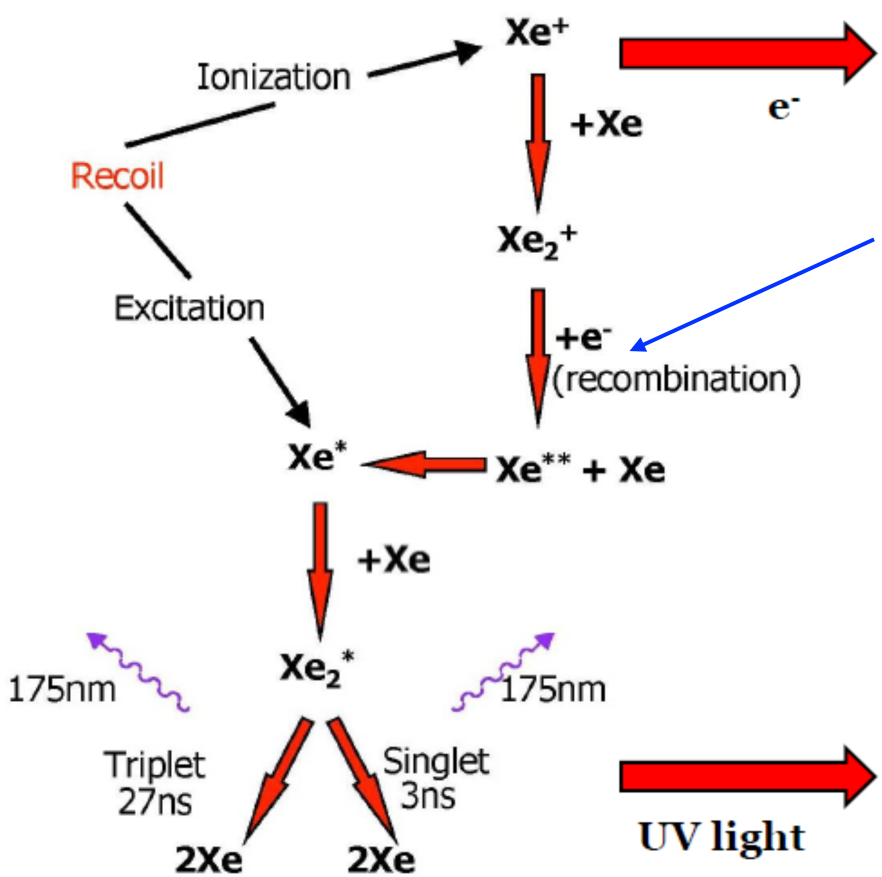
Efficient scintillator



Scintillation process in LXe







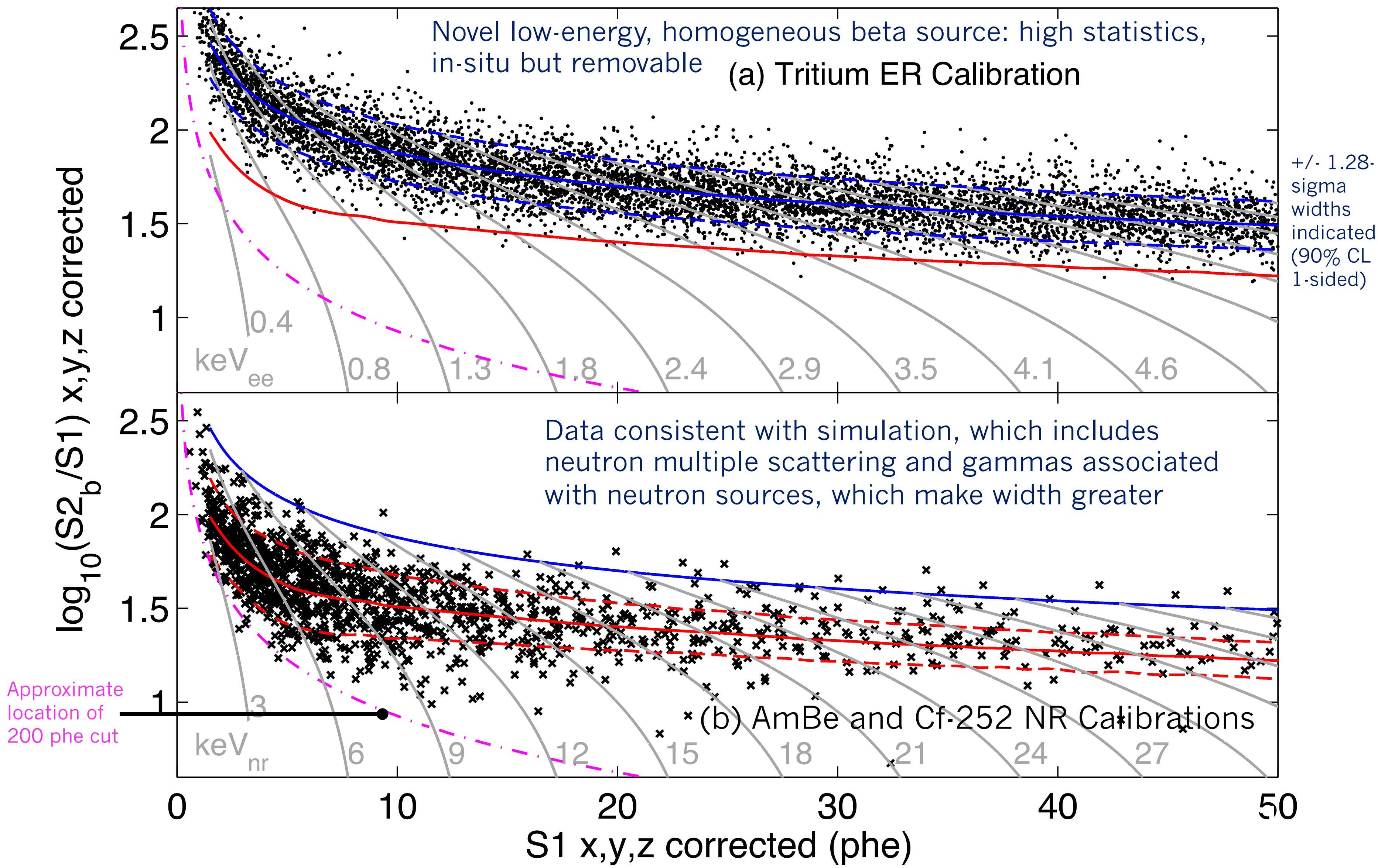
Difference in in recombination efficiency is exploited to discriminate between electron and nuclear recoils.

Xenon is transparent to its own scintillation light !

Figure of merit derived from plots of:

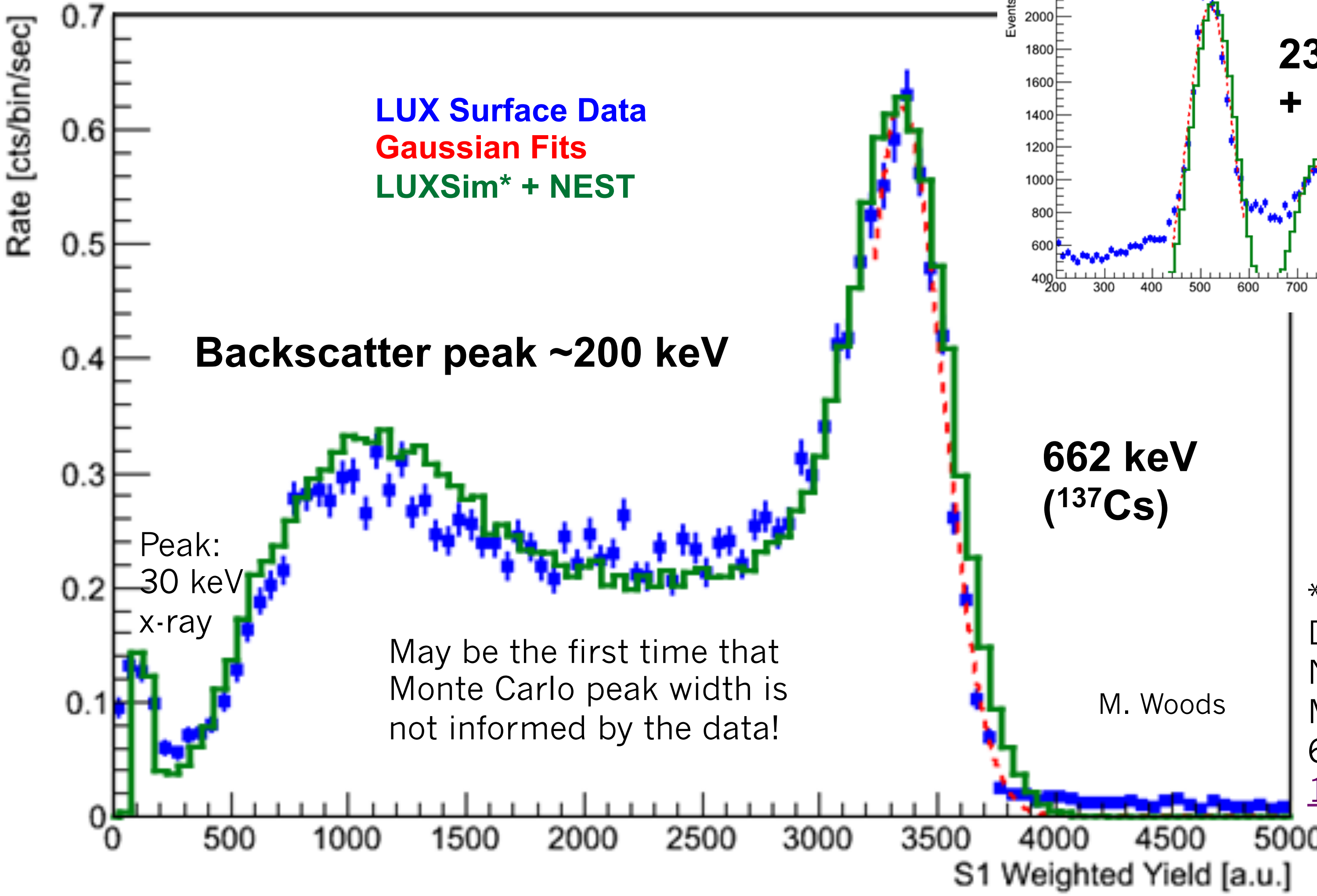
Log (charge escaping recombination/ total primary light produced)

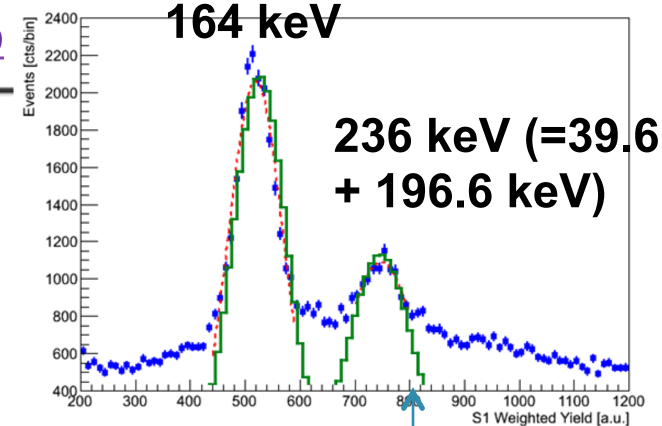
ER and NR Band Calibrations



Energy Resolution

LUX surface engineering run, arXiv:1210.4569

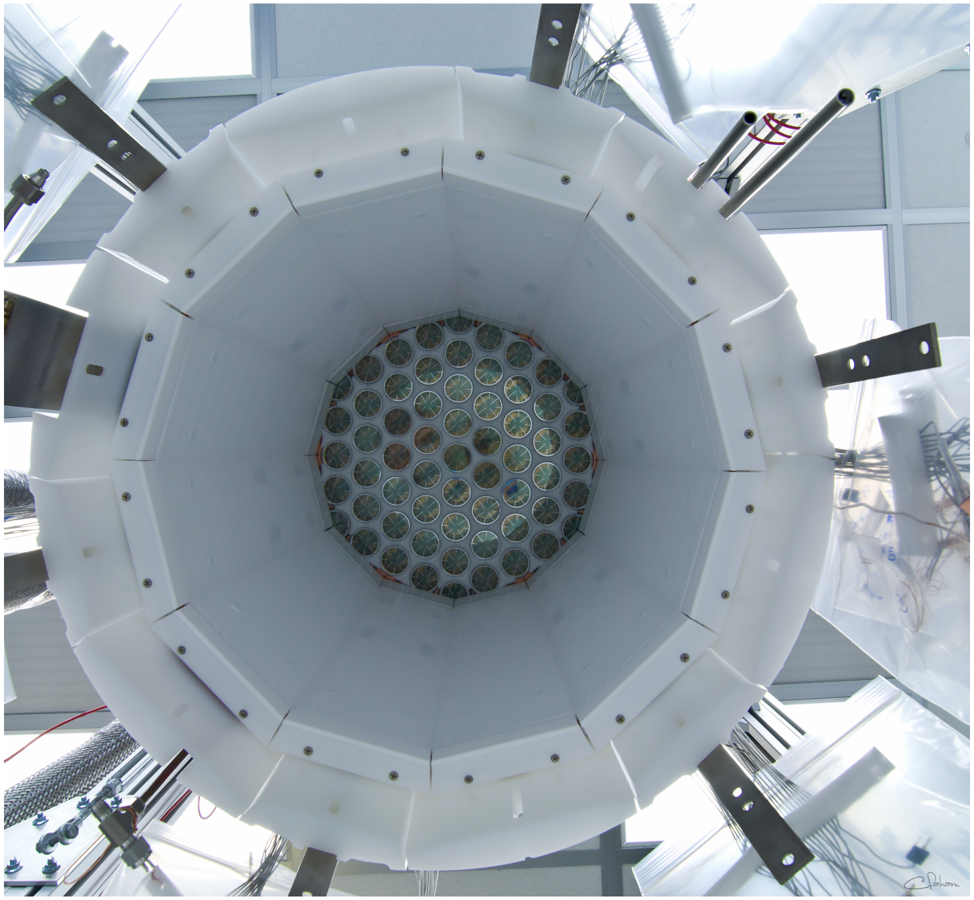




Fit at
same time
with same
model

*LUXSim paper: D.S. Akerib et al., Nucl. Inst. and Methods A675, 63 (2011). arXiv:1111.2074

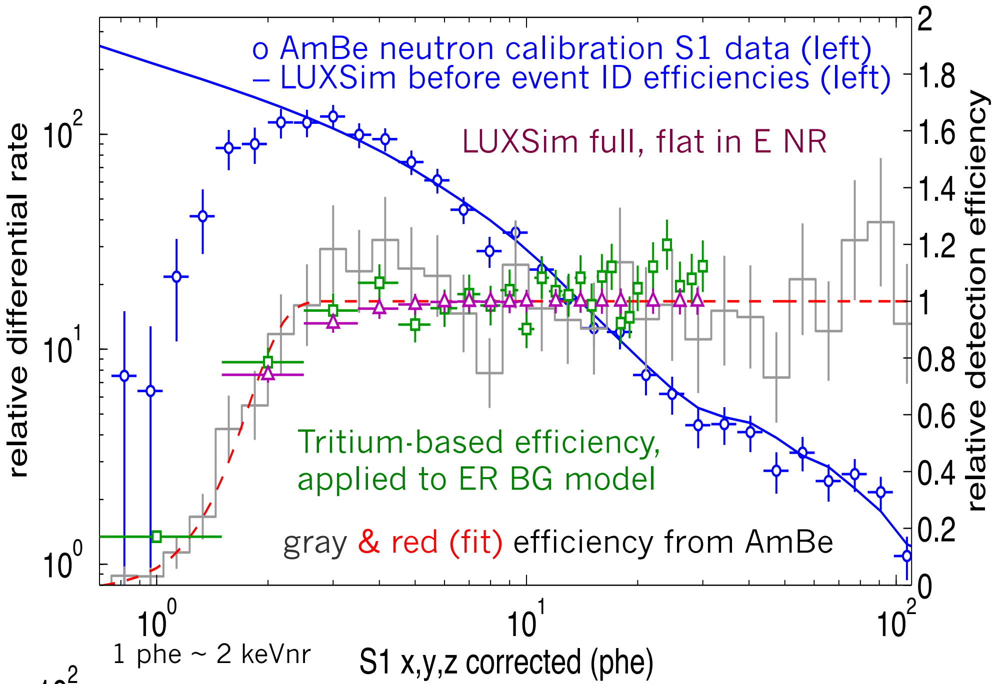
Light Collection

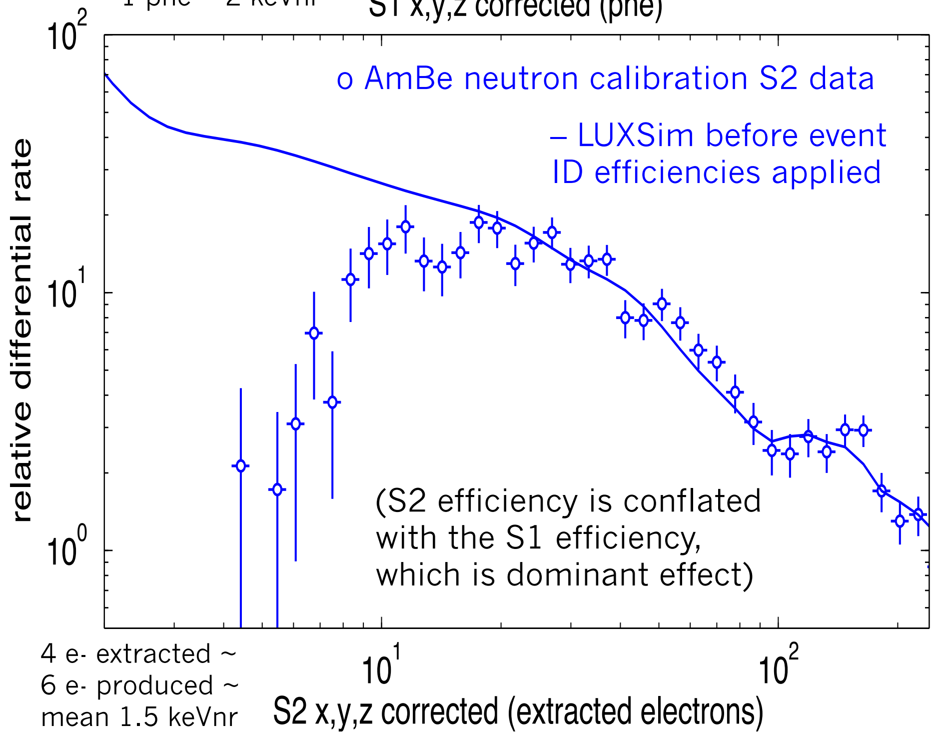


- Estimated zero-field yield at 122 keV of 8.8 phe/keV.
- Compare to XENON100 at 3.9 phe/keV
- LUX is >2x better

- All Non-VUV-reflective metallic surfaces - Field-shaping rings, spaces between PMTs etc - covered with PTFE
- Measurements consistent with >95% reflectivity
- 14% efficiency for the detection of a primary scintillation photon at the PMTs after journey
- Varies between 11 to 17% from top and bottom. Mapped out with Kr83m

Pulse Finding



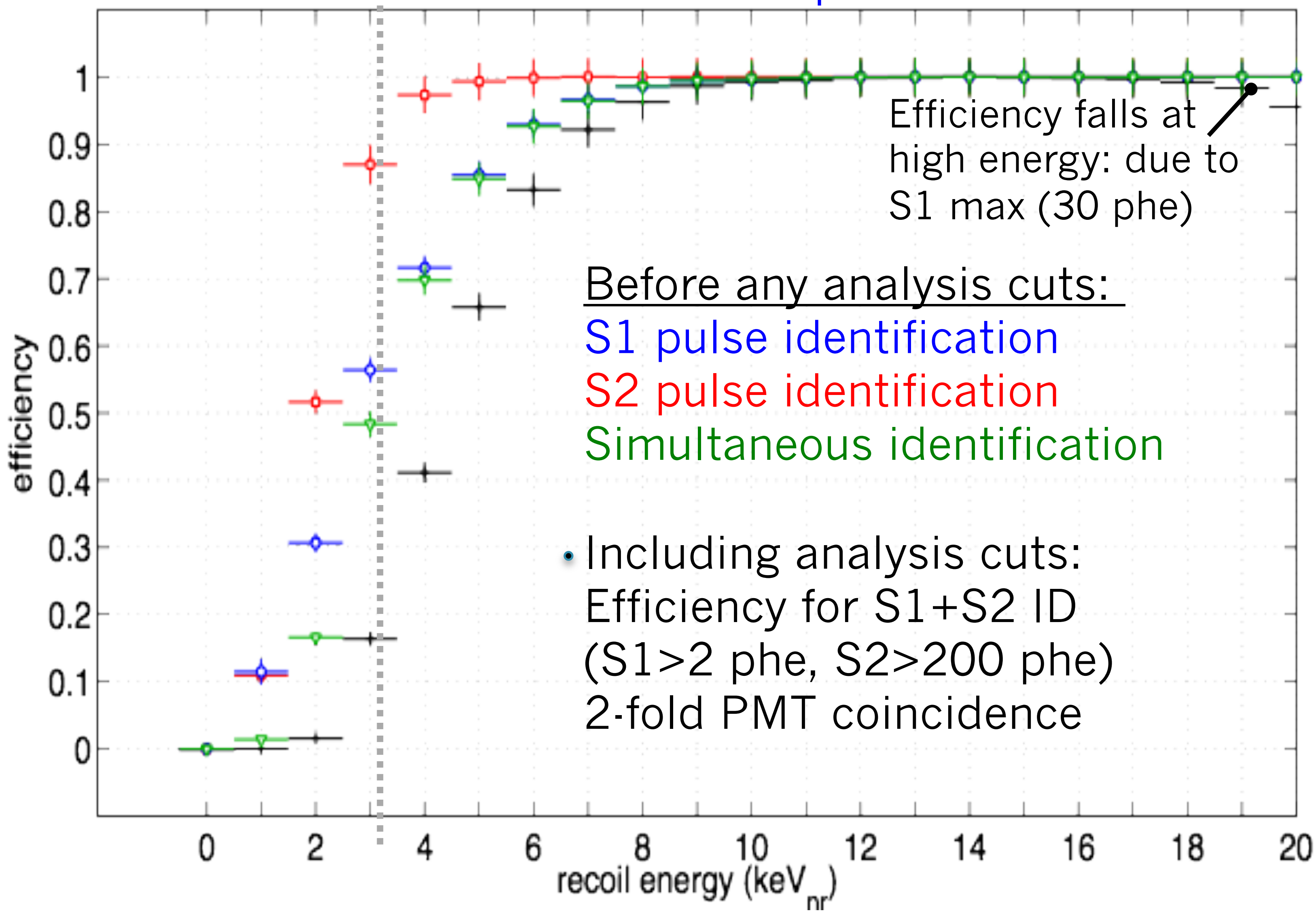


- Calibration data and full MC simulations used:
  - AmBe / Cf-252 (low-E NR)
  - Tritiated methane (ER)
- Excellent agreement used to derive relative efficiency and threshold.
- Hand-scan estimated absolute efficiency 98% cross-checked against expected number of H-3 injection events

All Pulse Finding Efficiencies

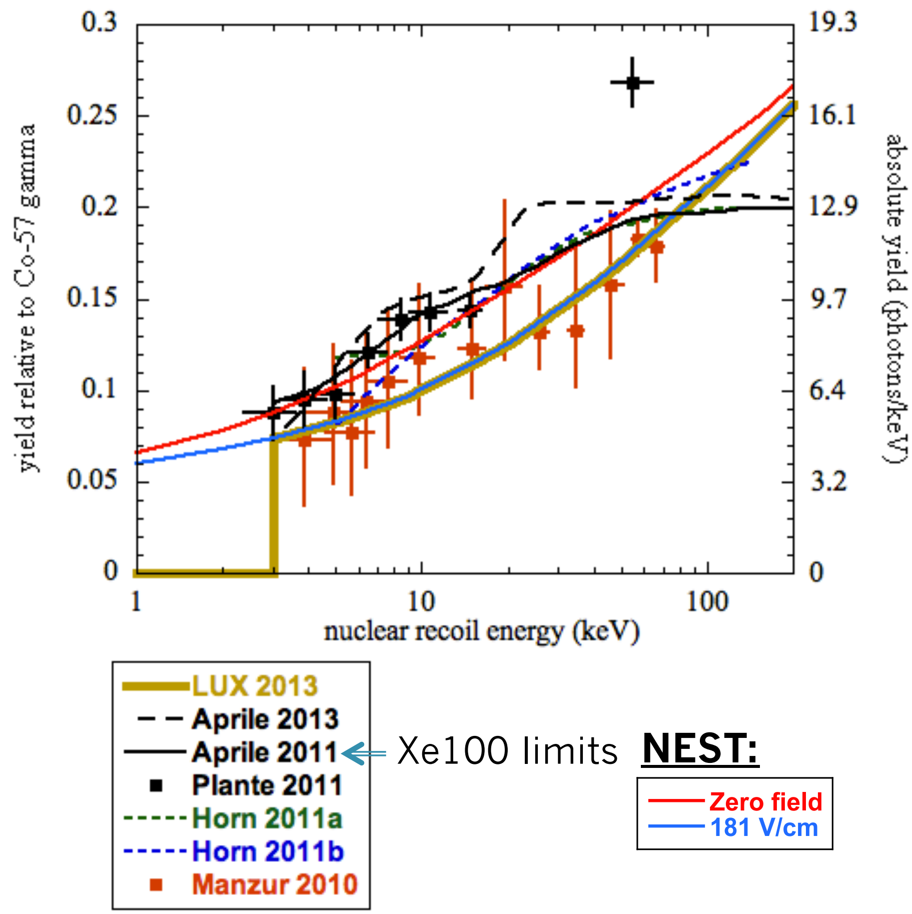
3 keVnr (true, not reconstructed)

S1 area ~ 2.0 phe   S2 area ~ 200 phe



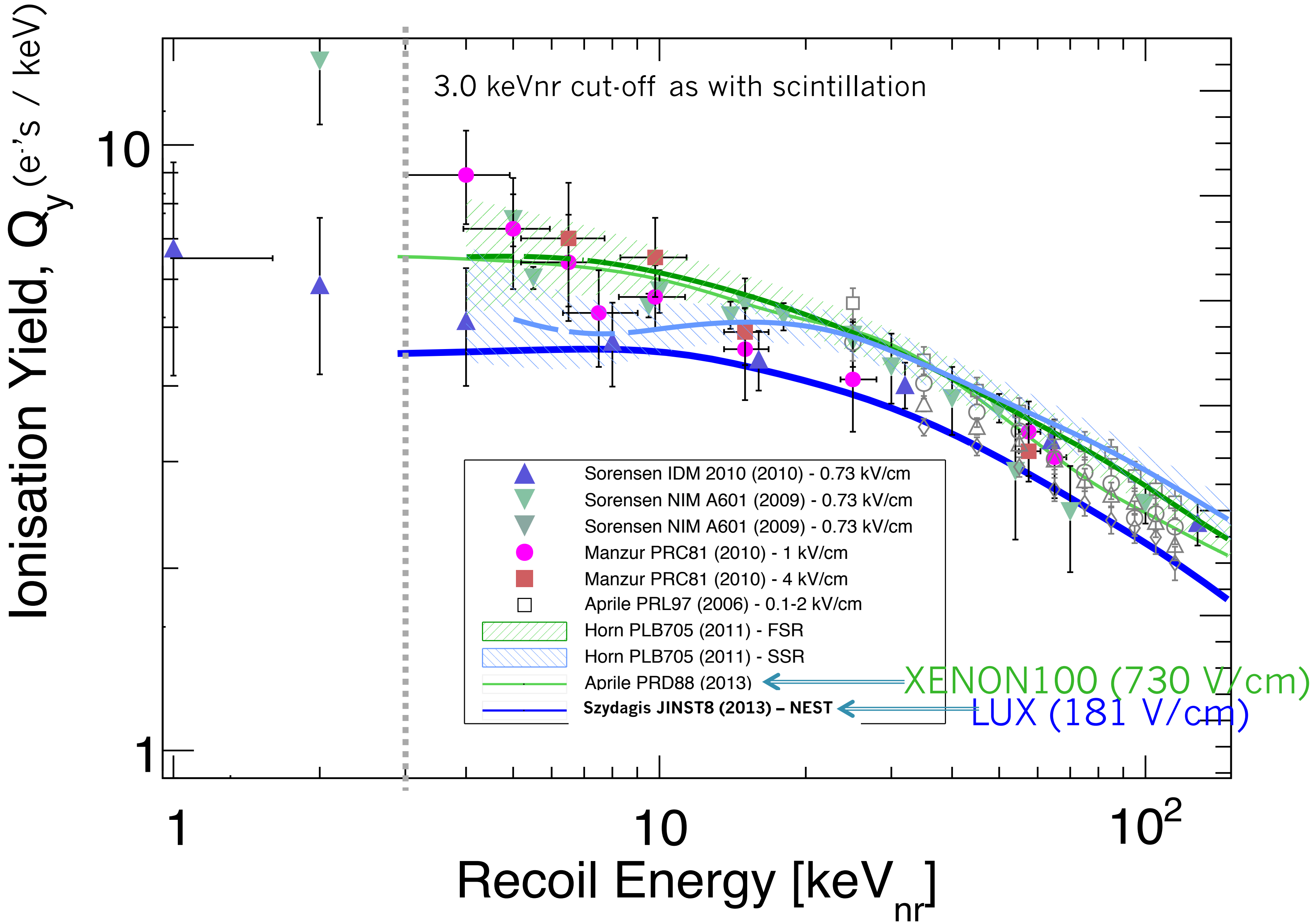
NR Scintillation Yield

- Modeled using NEST and G4 optical model for light collection
  - Extracted energy-dependent light suppression factors (S_{nr}, S_{ee}) for electric field (at expense of charge via recombination probability)
  - Result is a conservative approach (~0.8 of light at 181 V/cm compared to 0 V/cm)
  - Conservative, but also predictive, and matches LUX data!
- No need to use 63 photons/keV Co-57 zero-field (can't penetrate anyway)

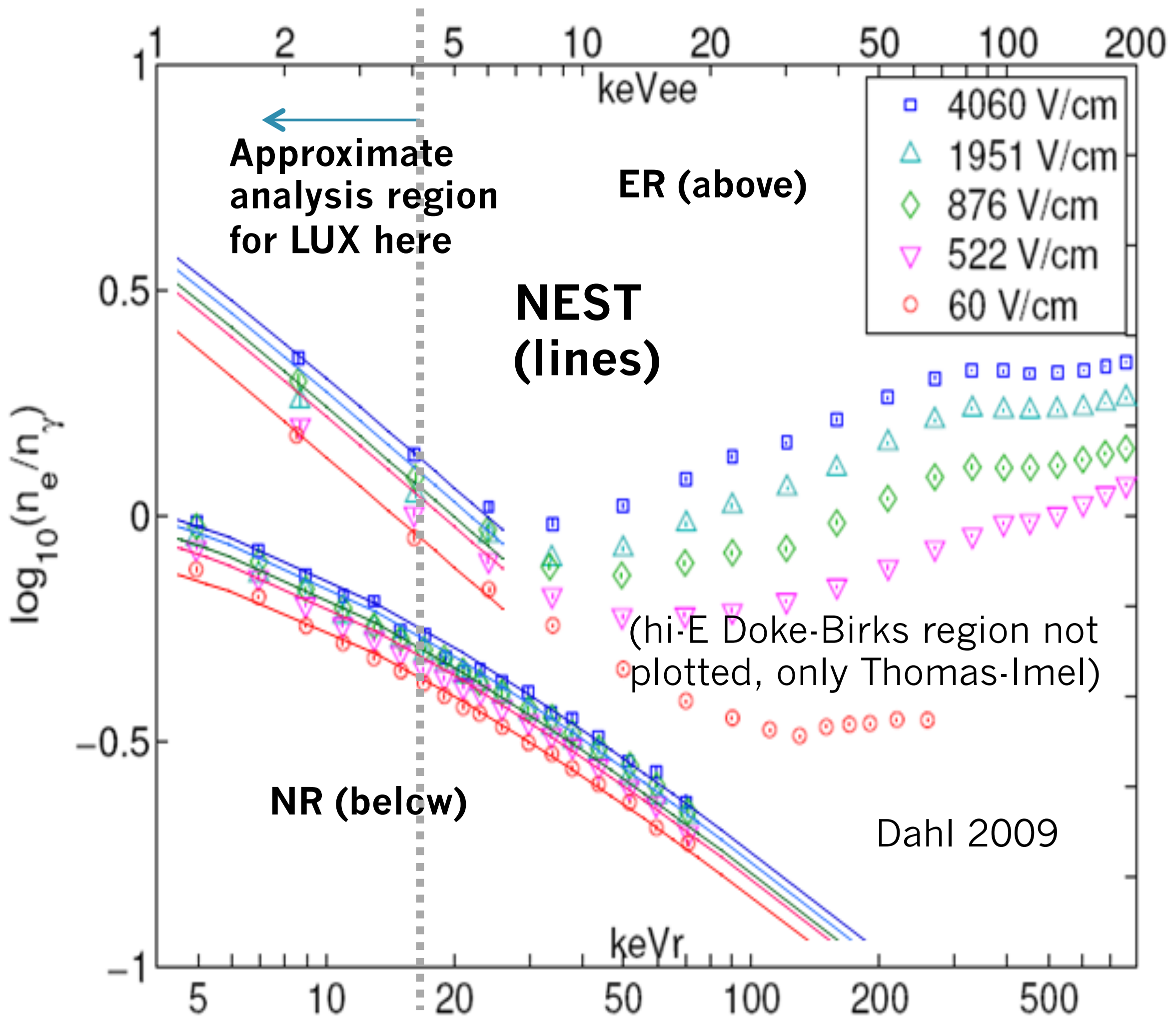


Data taken at non-zero field is translated by those reporting the results, assuming reduction of 0.95 (Aprile 2013, 730 V/cm) or 0.9 (Horn 2011, ~4000 V/cm, from ZEPLIN-III). LUX is 181 V/cm. All other data points actually taken at zero field.

NR Ionization Yield



Electric Field Dependence



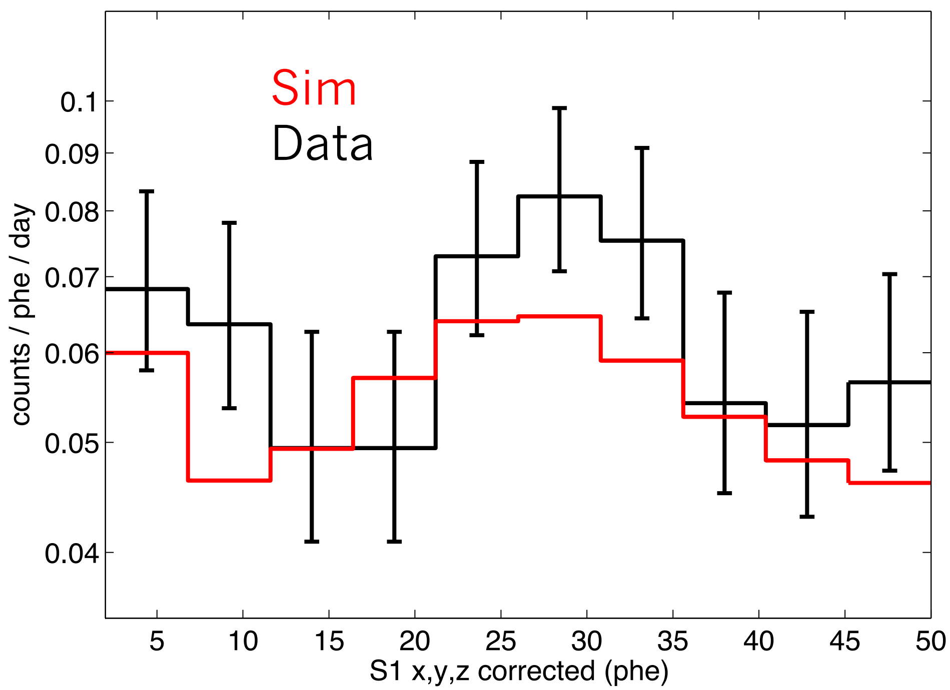
The keVnr energy scale shown here is Dahl's, and assumes an old, flat $\mathcal{L}$ = 0.25: using Hitachi, the 5 keVnr point is actually 8.67 and the 70 keVnr point is 85.5 (and this correction has been accounted for in NEST when fitting the data). The keVee scale is still correct

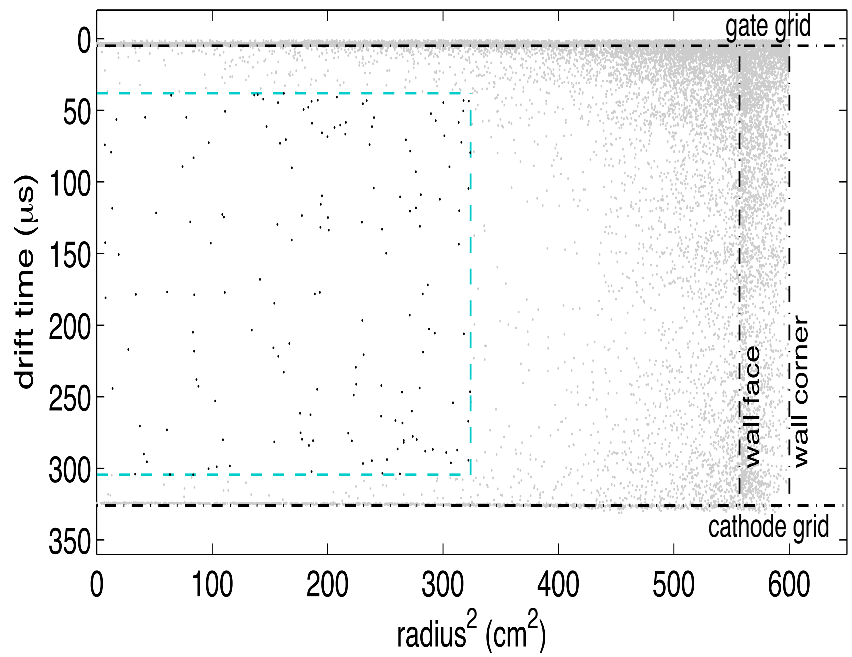
- Data presented in terms of $\log(n_e/n_\gamma)$, converted from log(S2/S1), but keVee scale is (n_e+n_γ)*13.7e-3 keV and so can easily extract n_γ and n_e alone and get their field dependencies
- *AmBe and Cf-252 sources, not an angle-tagged neutron scattering measurement, but important thing is *relative* yield is well-established*

Backgrounds

- 3.1 +/- 0.2 x 10^{-3} counts/(keV-kg-day) in region of interest
- Averaged over April-August WIMP search (85.3 live-days)
- 3.5 ppt Kr (measured)
- Getting better: cosmogenics from surface run decaying away

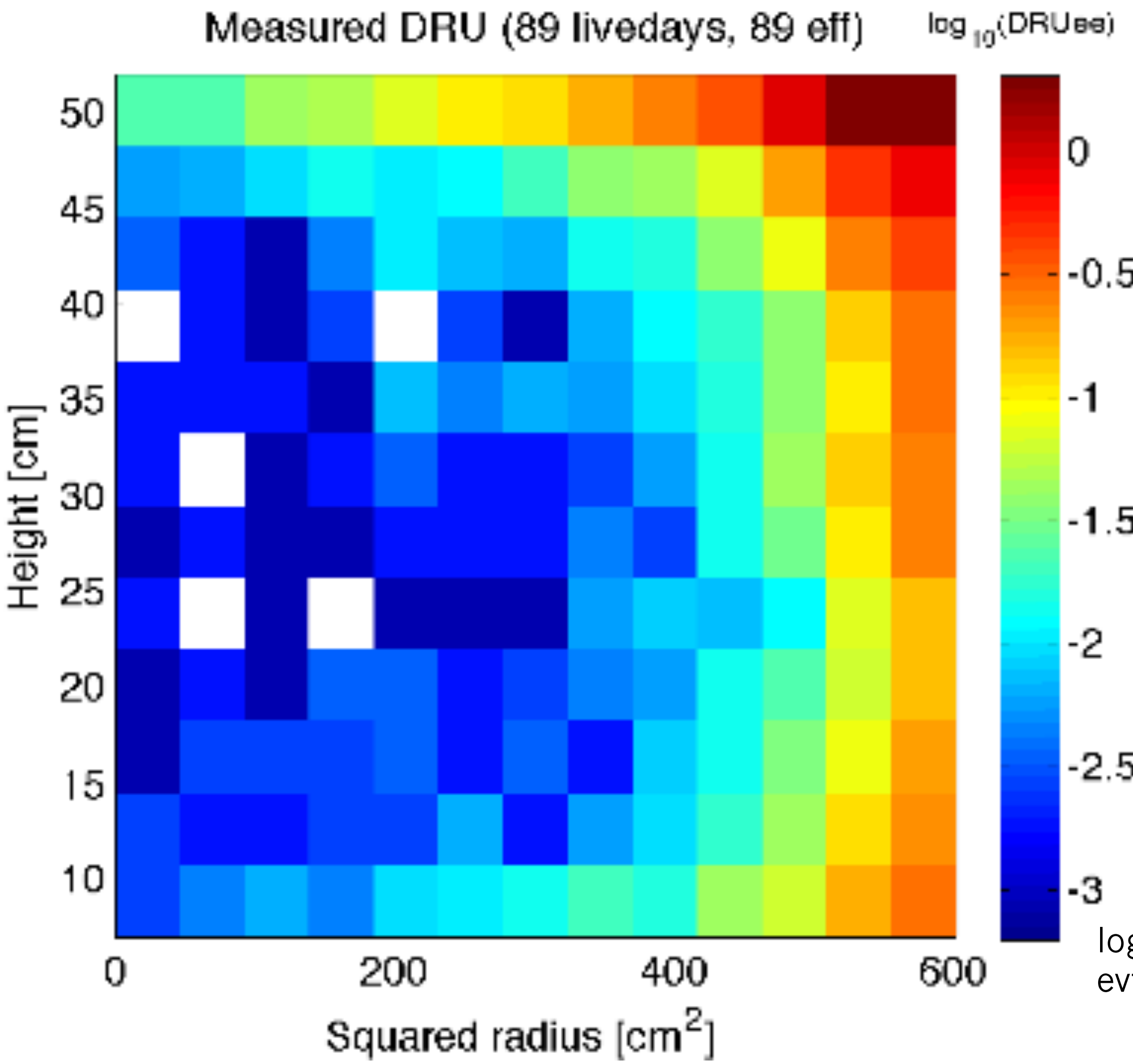
Source	Background rate, $\mathrm{mDRU_{ee}}$
γ-rays	$1.8 \pm 0.2_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}}$
$^{127}\mathrm{Xe}$	$0.5 \pm 0.02_{\mathrm{stat}} \pm 0.1_{\mathrm{sys}}$
$^{214}\mathrm{Pb}$	0.11–0.22 (90% C. L.)
$^{85}\mathrm{Kr}$	$0.13 \pm 0.07_{\mathrm{sys}}$
Total predicted	$2.6 \pm 0.2_{\mathrm{stat}} \pm 0.4_{\mathrm{sys}}$
Total observed	$3.1 \pm 0.2_{\mathrm{stat}}$





BG (<5 keVee)

Quiet detector with <2 events / day in energy and volume regions of interest, and it's getting quieter

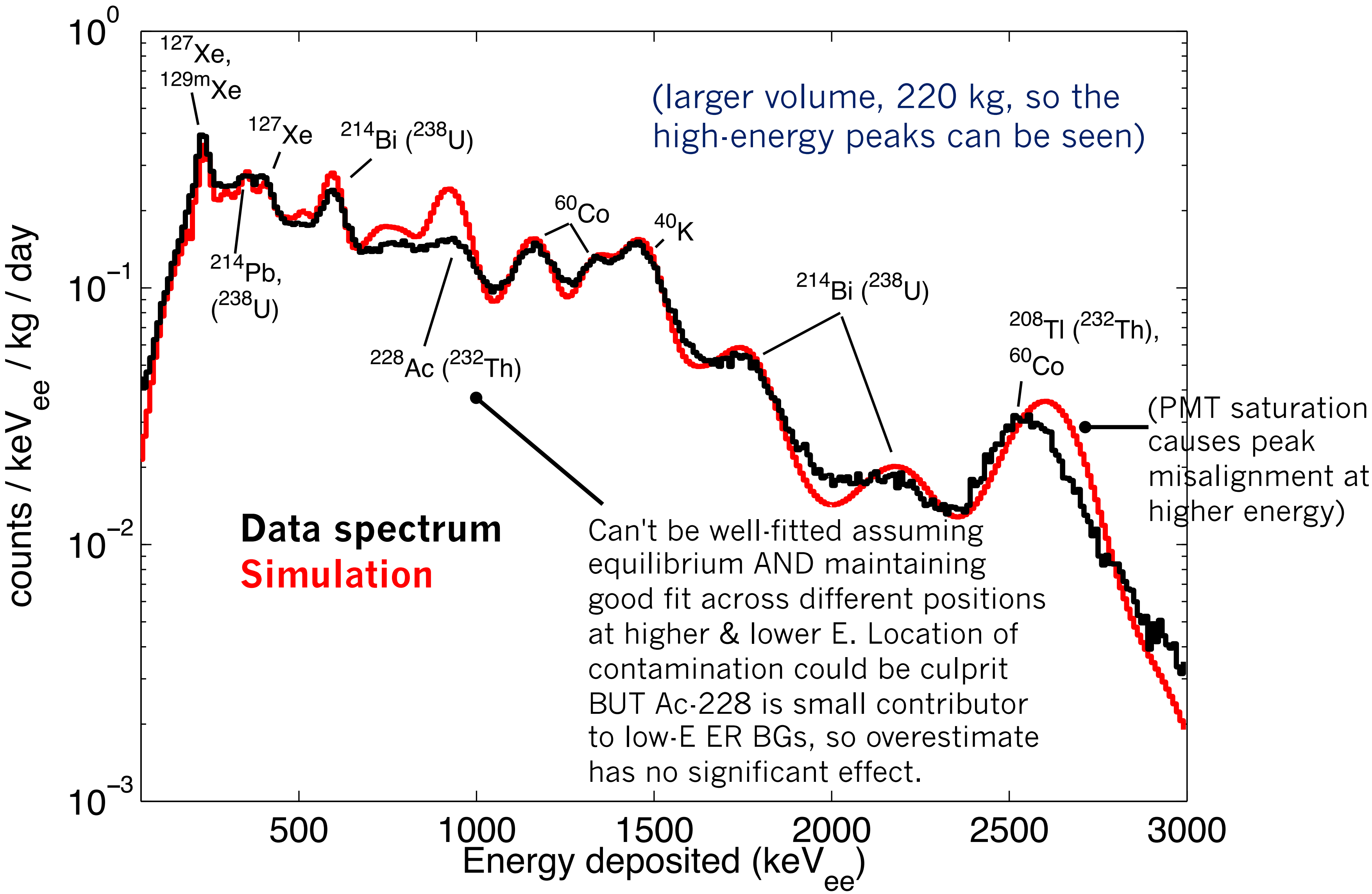


log10
evts/keVee/kg/day

118.3 +/- 6.5 kg
3.1 +/- 0.2 mdru
(0.5 cosmogenic)

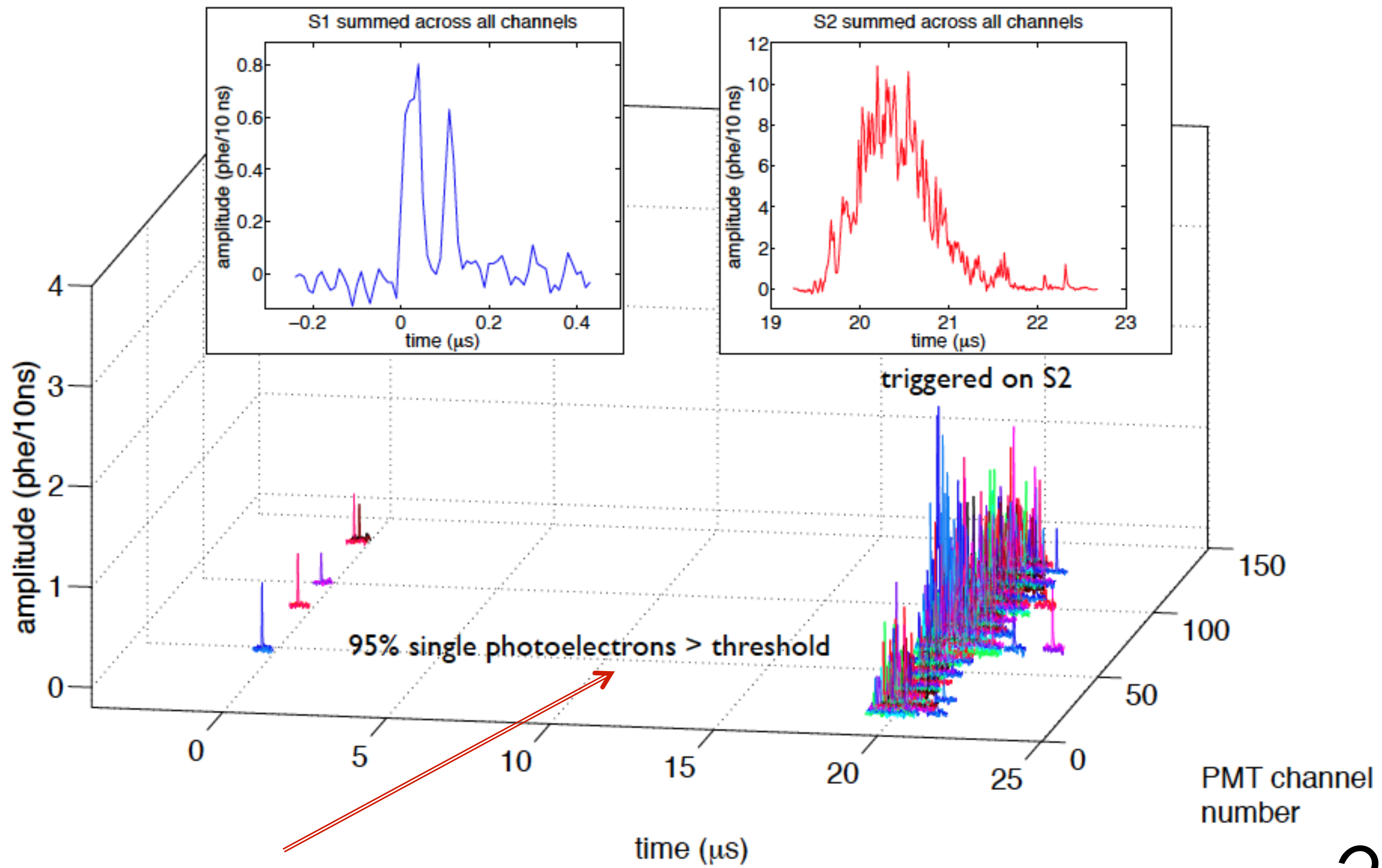
R < 18 cm
Z = 7 - 47 cm

Full Background Model



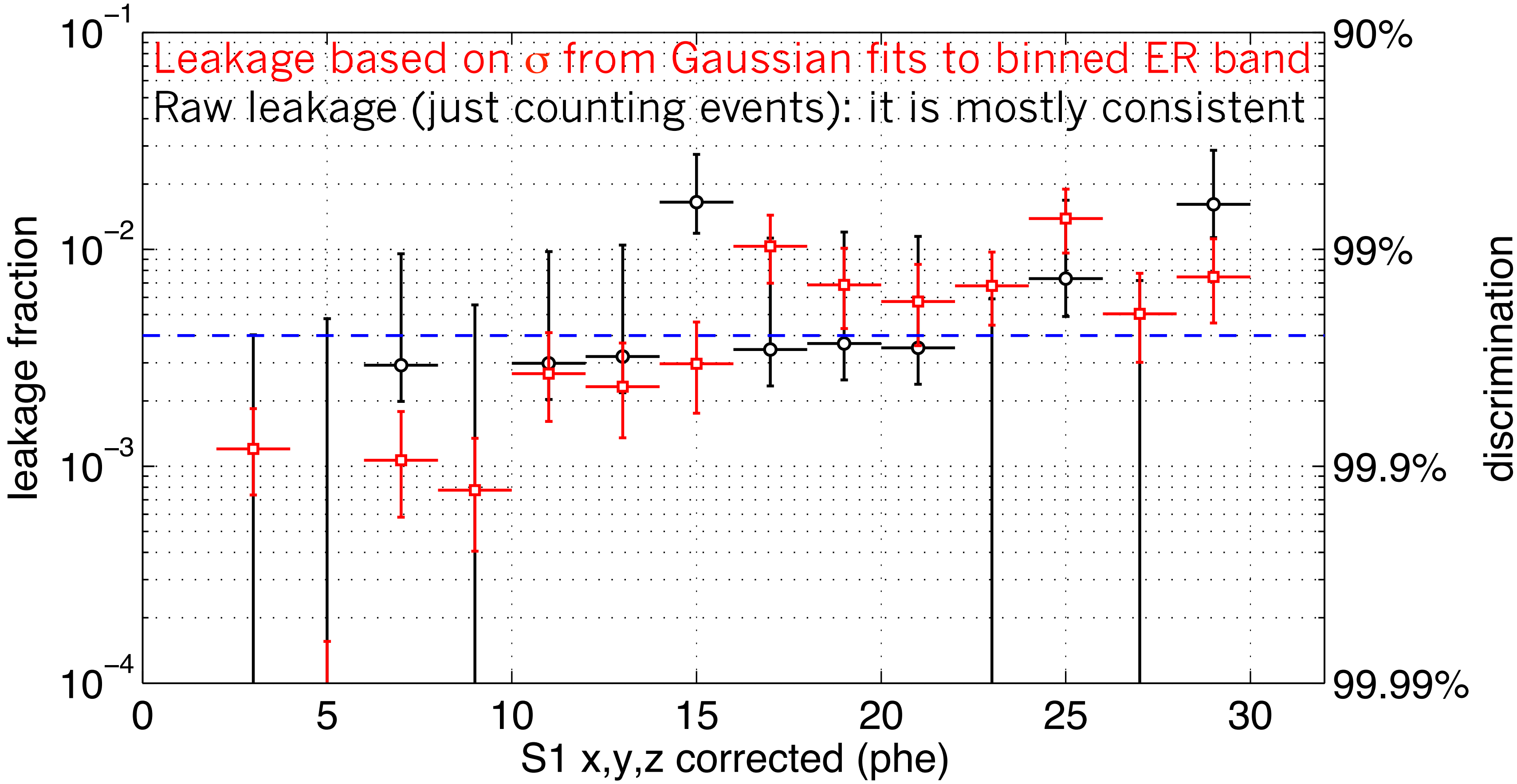
Typical Event

1.5 keVee (combined energy reconstruction) ER event



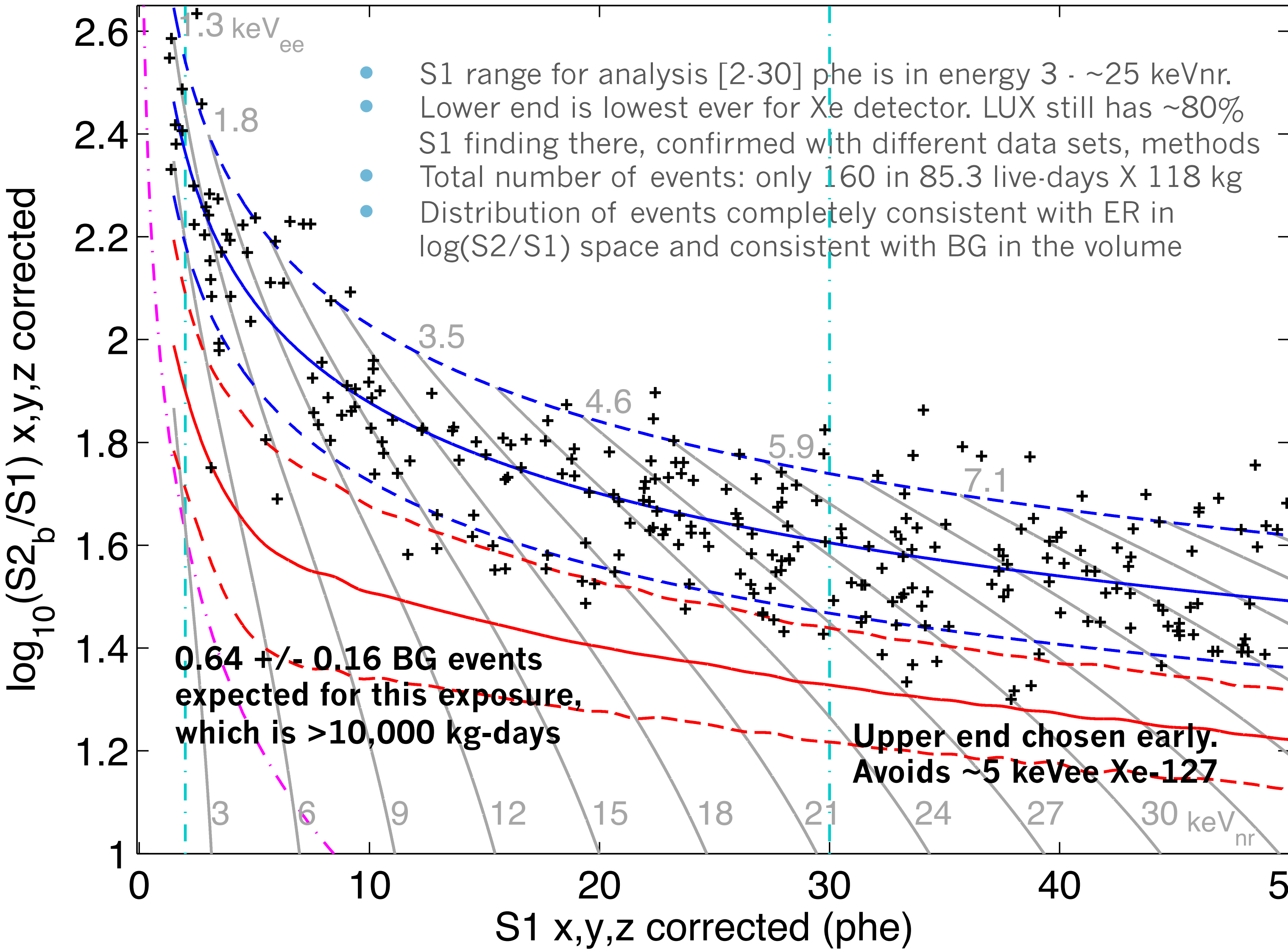
Lack of electronic noise is apparent

ER Leakage below NR Band



- Mean leakage 0.4 +/- 0.1% (2-30 phe S1 region) accepting all NR events below power law fit to the NR Gaussian mean in slices
- Not used directly in our limit calculation, which is a PLR (Profile Likelihood Ratio) not cut-and-count, but illustrates separation

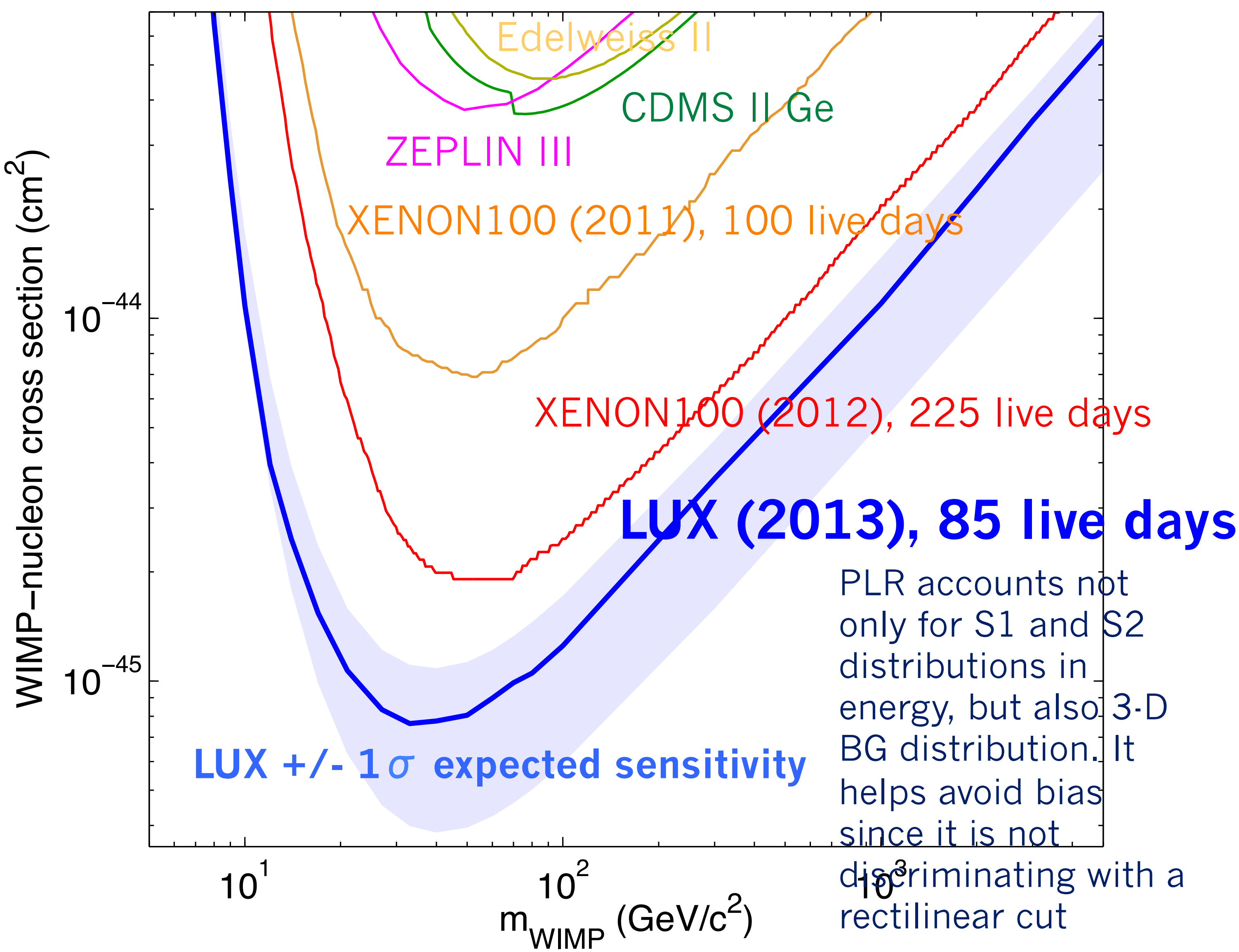
WIMP Search Result



Summary of Events Post-Cuts

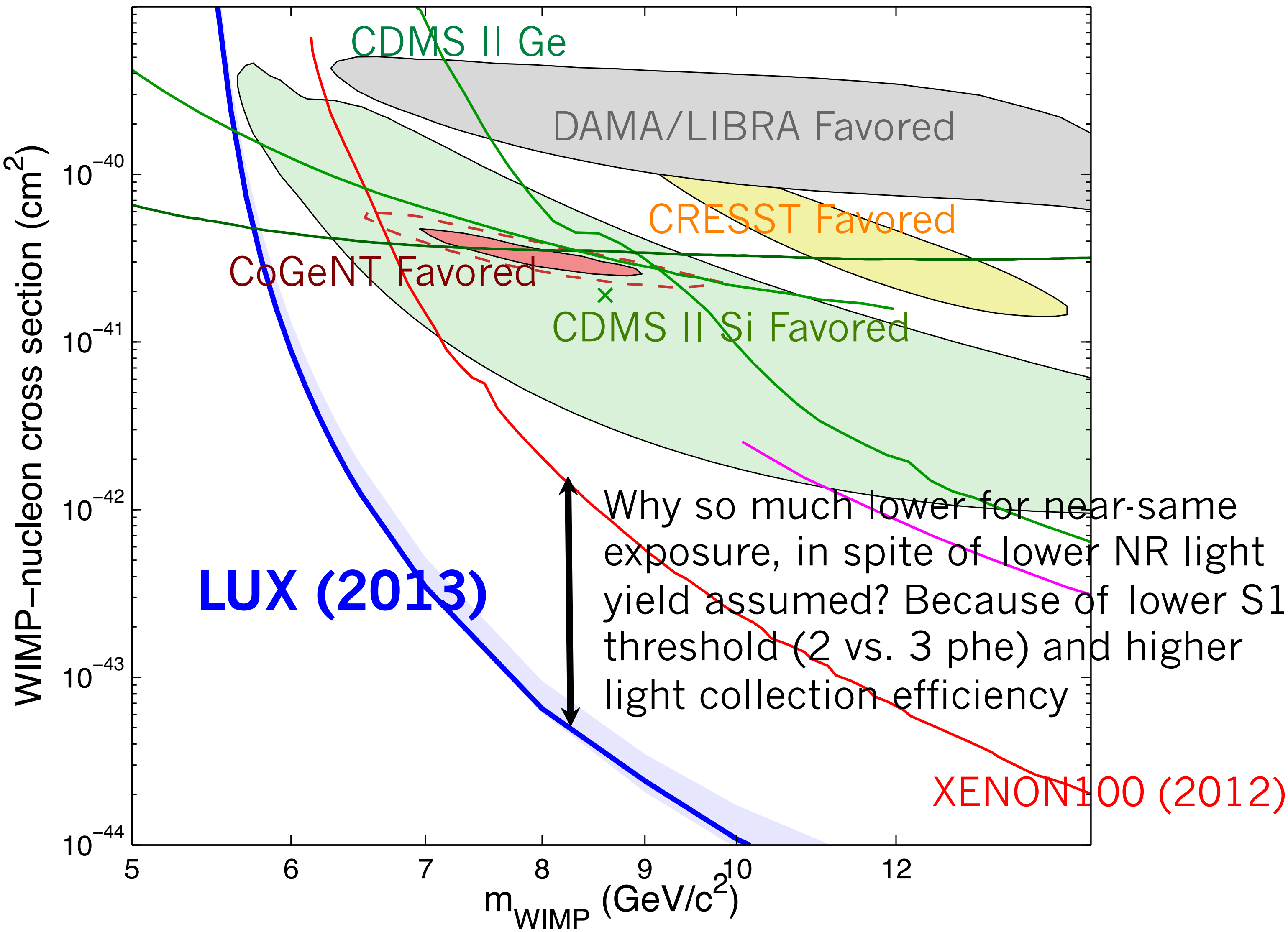
Cut	Explanation	Events Remaining
All Triggers	S2 Trigger >99% for $S2_{raw}$>200 phe	83,673,413
Detector Stability	Cut periods of excursion for Xe Gas Pressure, Xe Liquid Level, Grid Voltages	82,918,901
Single Scatter Events	Identification of S1 and S2. Single Scatter cut.	6,585,686
S1 energy	Accept 2-30 phe (energy ~ 0.9-5.3 keVee, ~3-18 keVnr)	26,824
S2 energy	Accept 200-3300 phe (>8 extracted electrons) Removes single electron / small S2 edge events	20,989
S2 Single Electron Quiet Cut	Cut if >100 phe outside S1+S2 identified +/-0.5 ms around trigger (0.8% drop in livetime)	19,796
Drift Time Cut away from grids	Cutting away from cathode and gate regions, 60 < drift time < 324 us	8731
Fiducial Volume radius and drift cut	Radius < 18 cm, 38 < drift time < 305 us, 118 kg fiducial	160

WIMP Dark Matter Limit



PLR accounts not only for S1 and S2 distributions in energy, but also 3-D BG distribution. It helps avoid bias since it is not discriminating with a rectilinear cut

Low-Mass WIMP Region



Summary

- LUX has the largest kg-days exposure of any xenon TPC, as well as the lowest energy threshold
- Pioneering work with internal calibration sources. Helps identify and suppress backgrounds.
- Low-energy NR data agree with MC, with location of band at LUX field (predicted for the first time)
- Currently have the most stringent limit on the WIMP-nucleon spin-independent interaction cross-section across a wide range of WIMP masses
- Our result is in conflict with low-mass WIMP interpretations of signals seen in CoGeNT, CDMS, and elsewhere