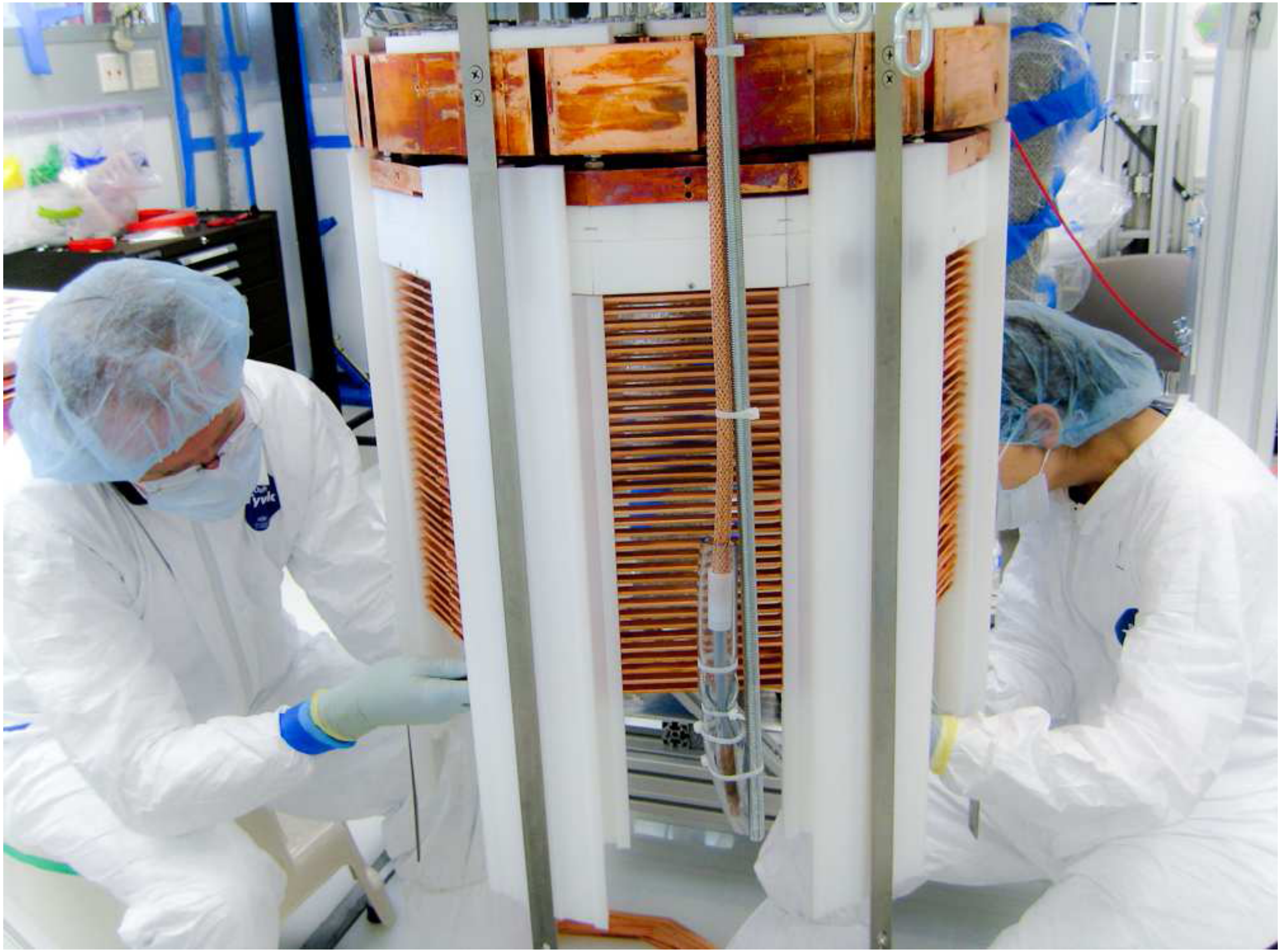
First dark matter search results from LUX

Carter Hall, Univ. of Maryland

Mitchell Workshop on Collider and Dark Matter Physics

Texas A&M Univ., May 12-15, 2014

Texas A&M – the home of the LUX TPC

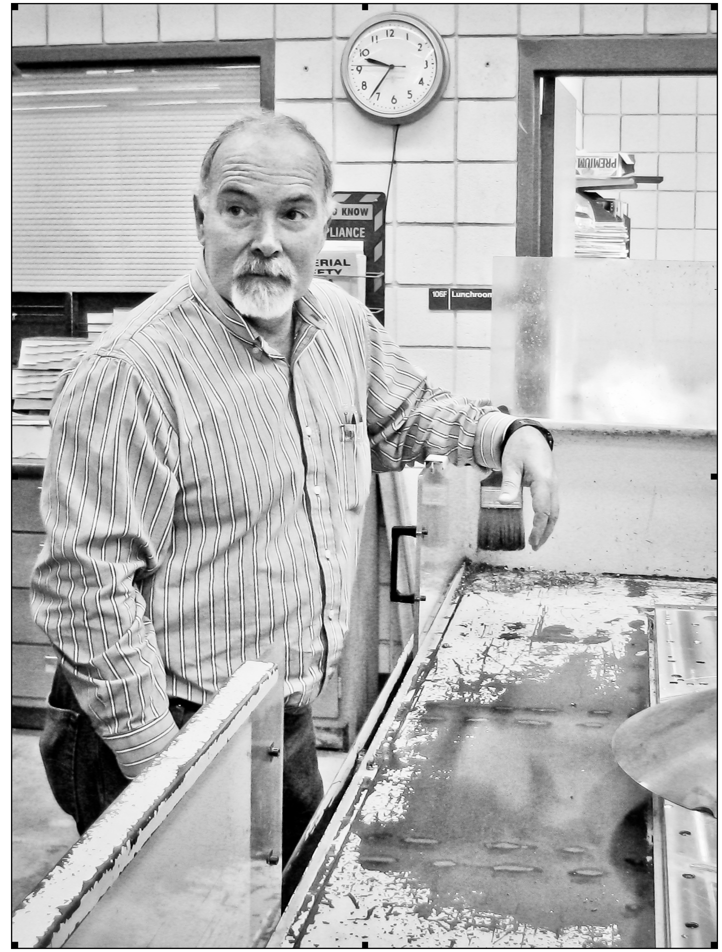


Designed and built at TAMU

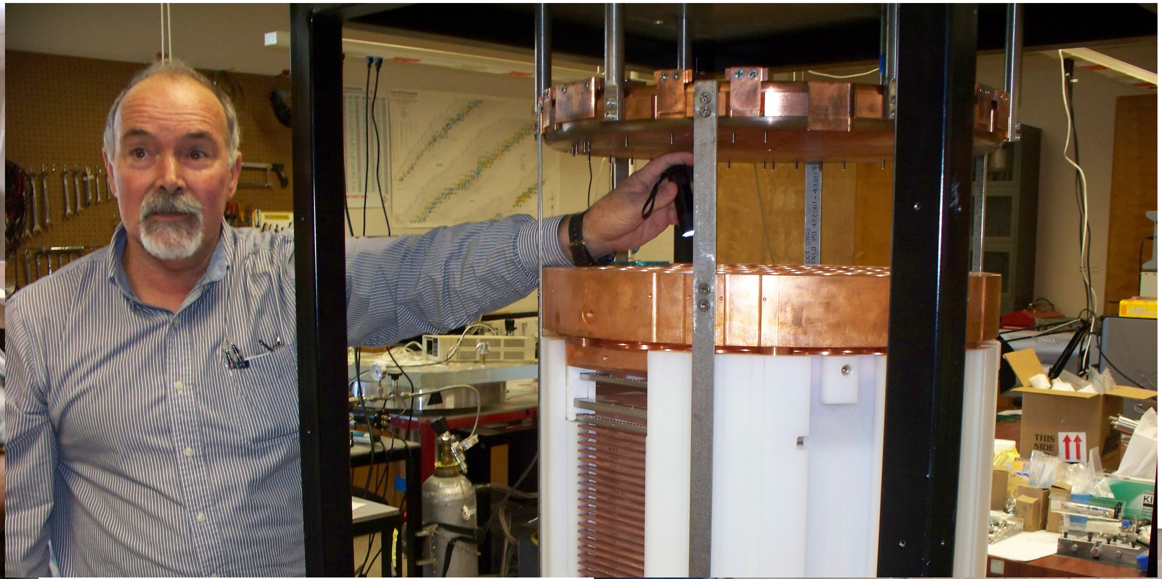
Texas A&M – the home of the LUX TPC

Texas A&M

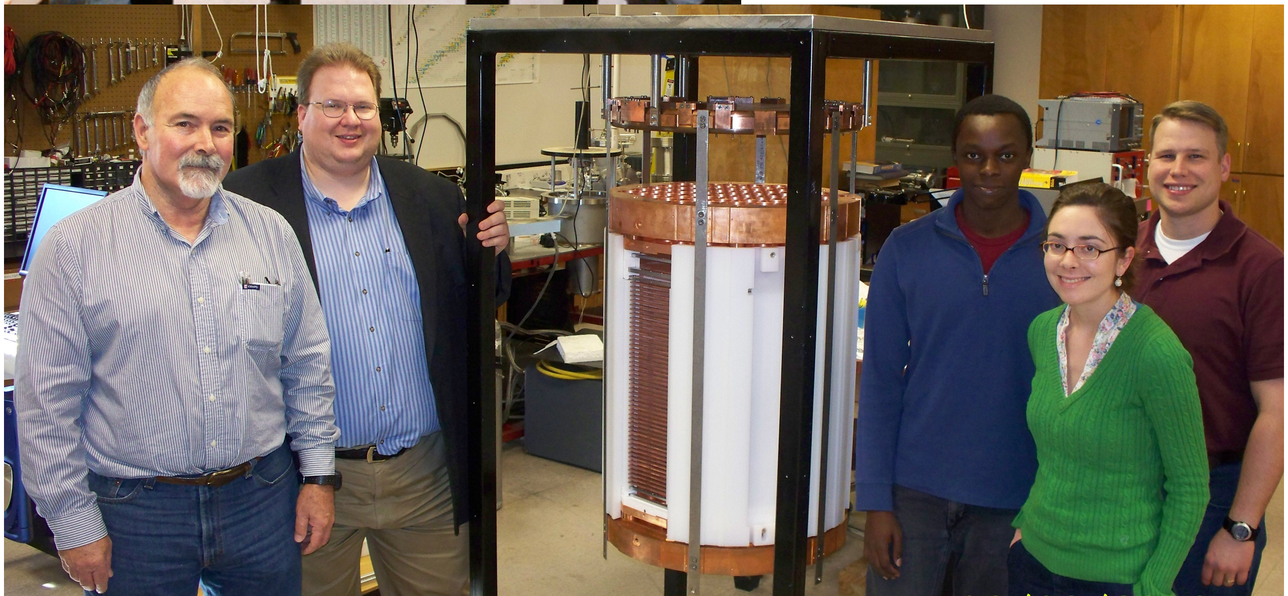
Photo	Name	Title
	Robert Webb	Professor
	James White	PI, Professor
	Rachel Mannino	Graduate Student
	Clement Sofka	Graduate Student
	Paul Terman	Graduate Student

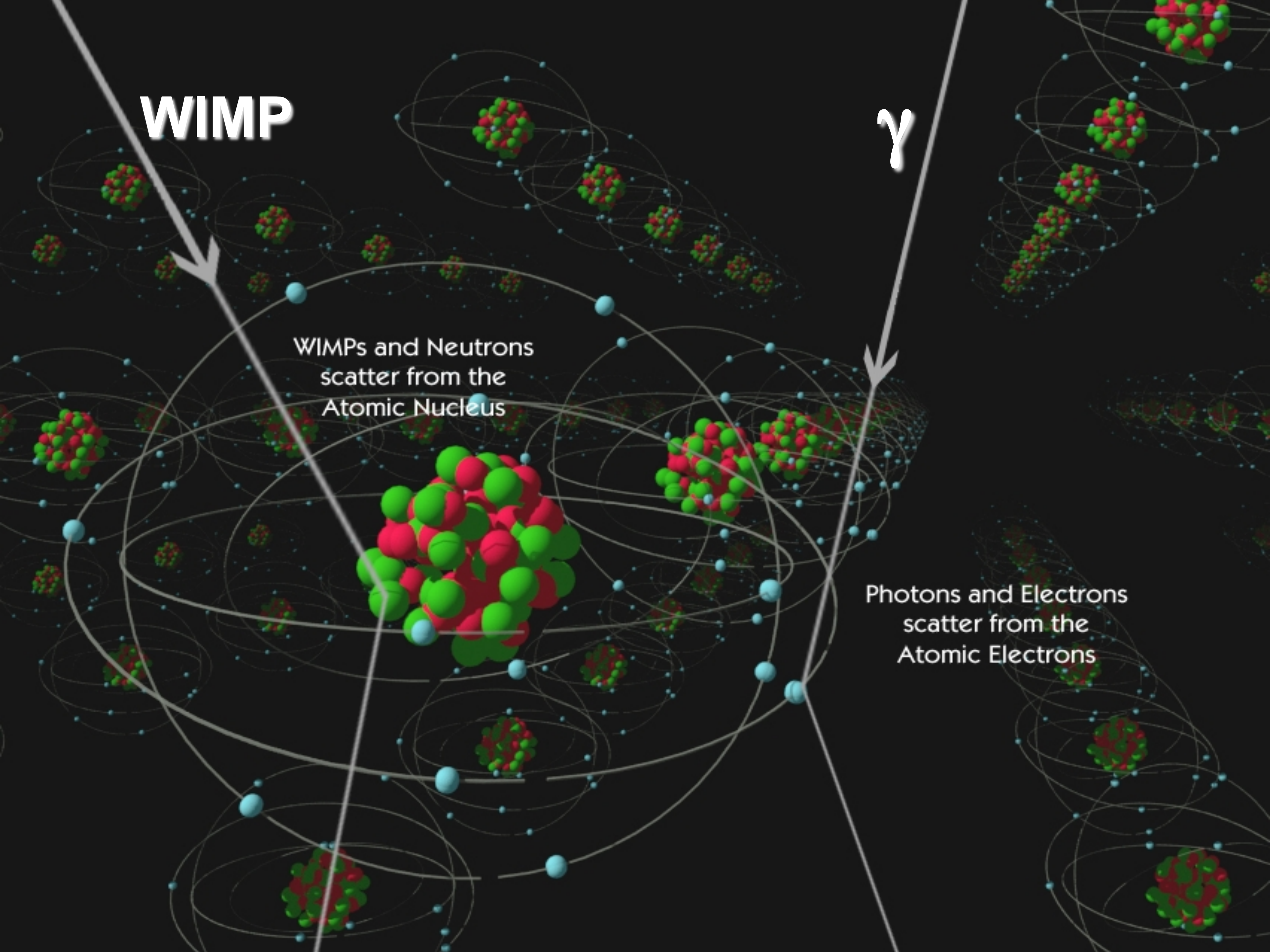


James White, 1953-2013

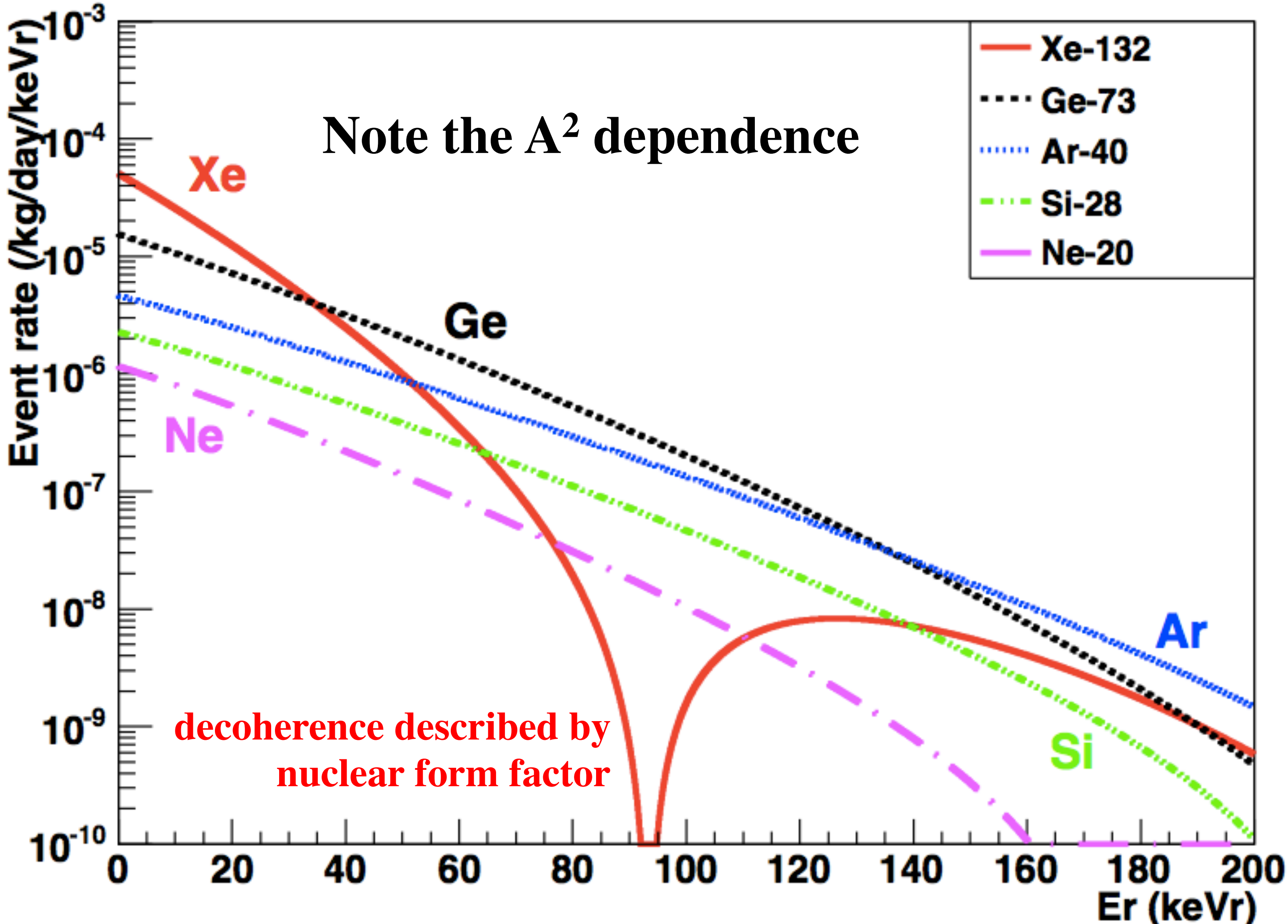


James with the LUX TPC



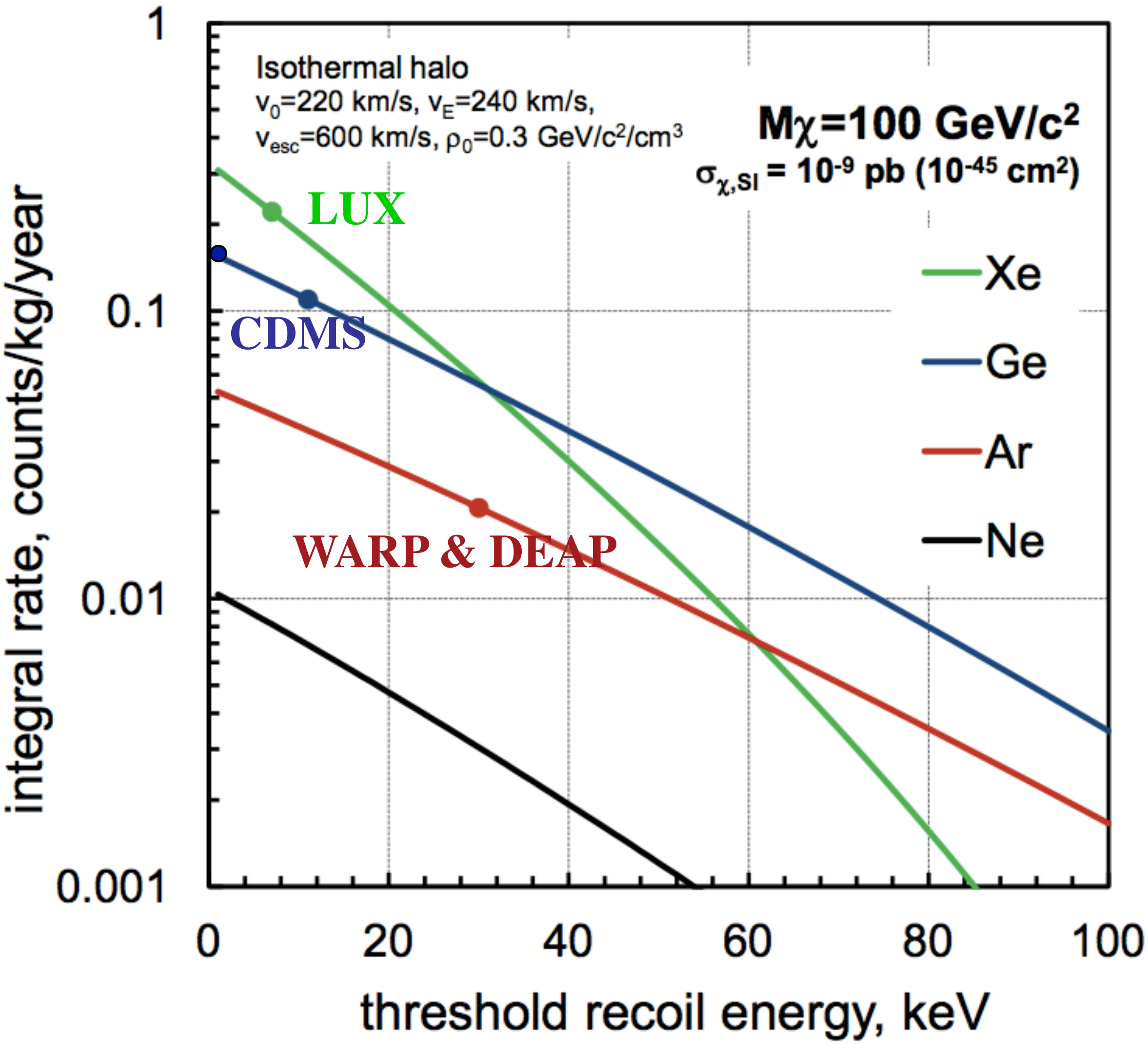

WIMP
γ
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons

Nuclear recoil spectra for various targets



From: arXiv:1107.1295

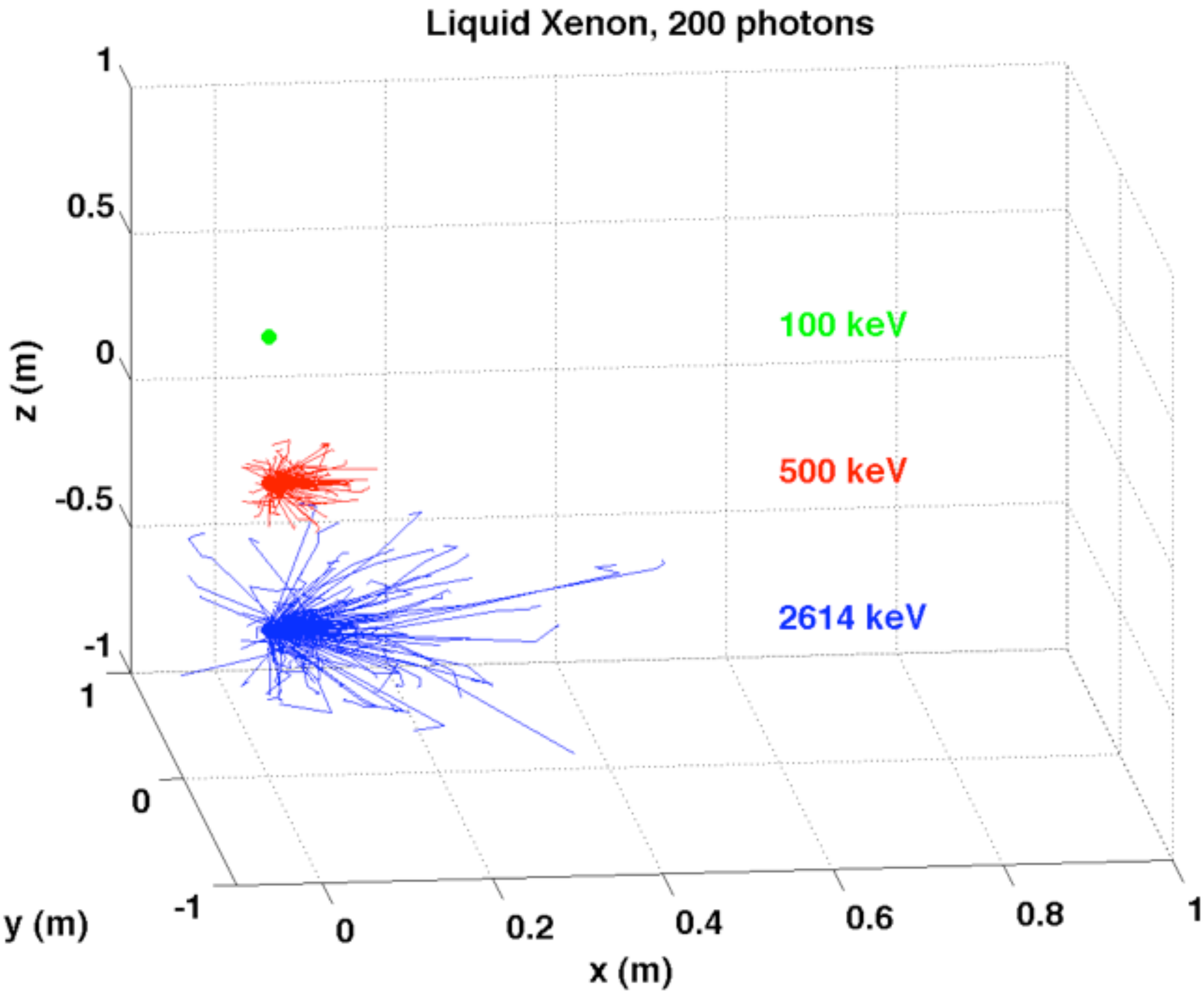
Count rate vs detector threshold



Colored dots indicate thresholds achieved by working experiments with recoil discrimination.

From: "Snowmass CF1 Summary: WIMP Dark Matter Direct Detection", arXiv:1310:8327 (October 2013)

Simulation of self-shielding in liquid xenon

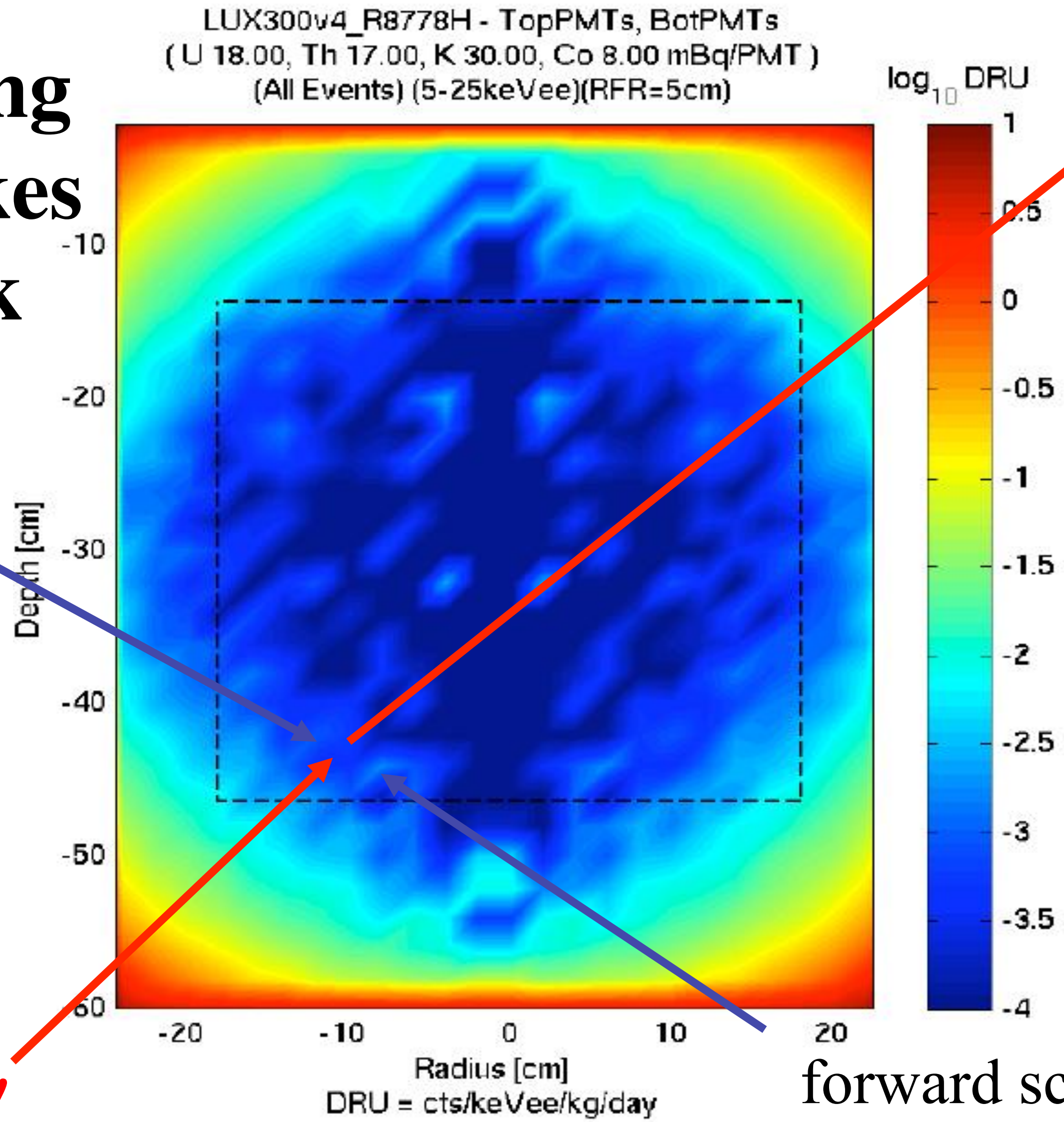


Low energy gammas can't travel far –
Fiducial volume cut rejects most backgrounds

Kinematics alone provides strong rejection

Self-shielding is what makes LUX work

~ keV deposition

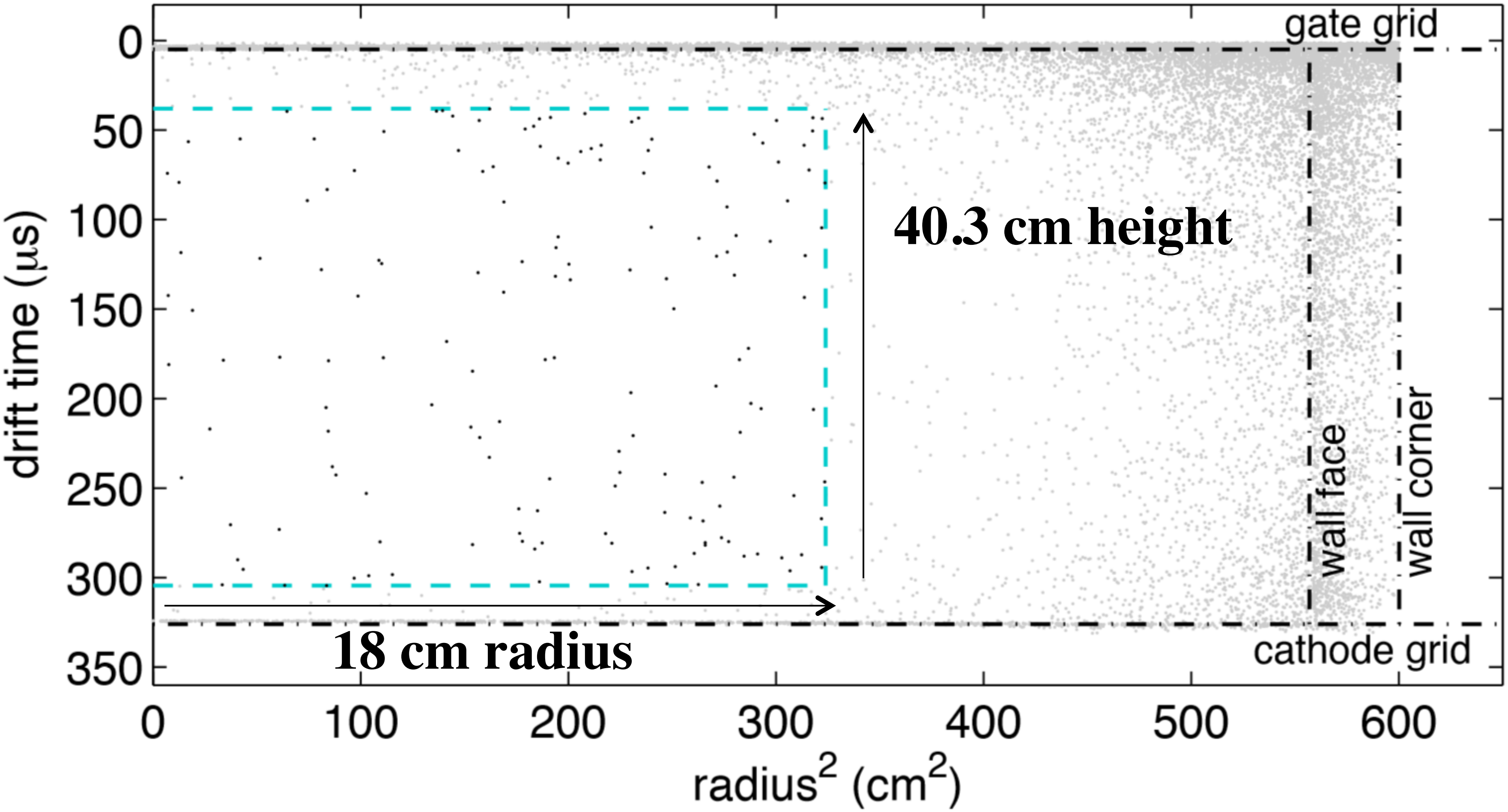


must cross full volume without interacting again

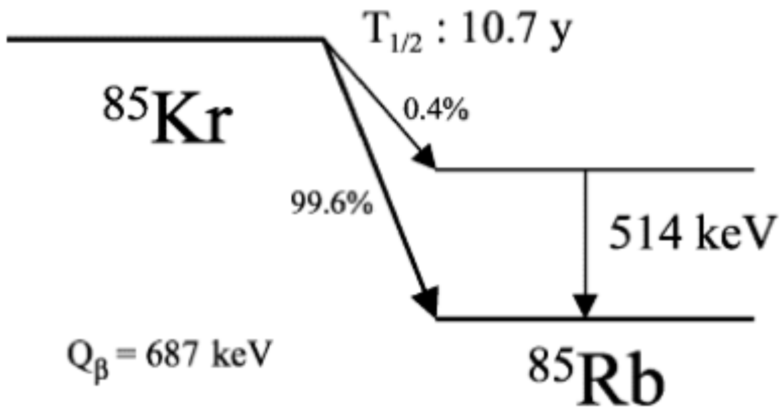
~ MeV γ

forward scattering

LUX fiducial volume cut – 118 kg

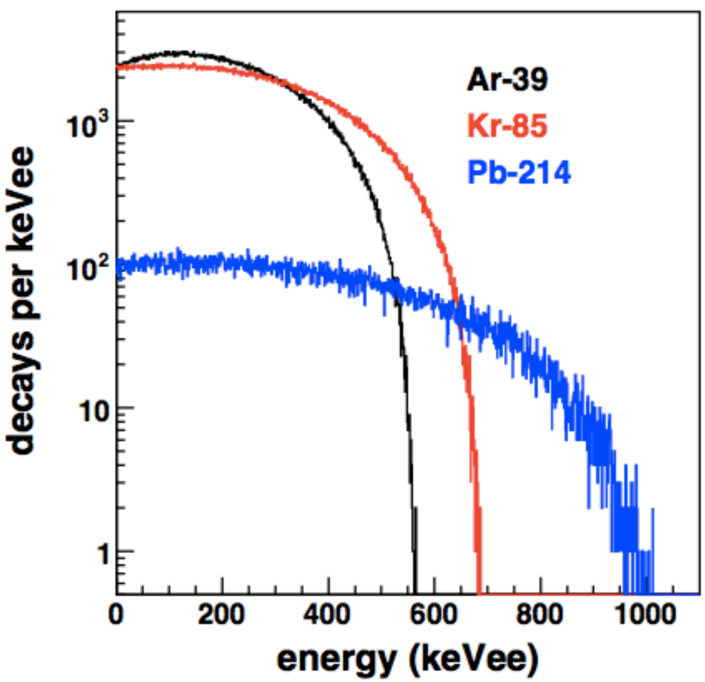


HOWEVER, radioactive isotopes dissolved in the liquid xenon would defeat self-shielding

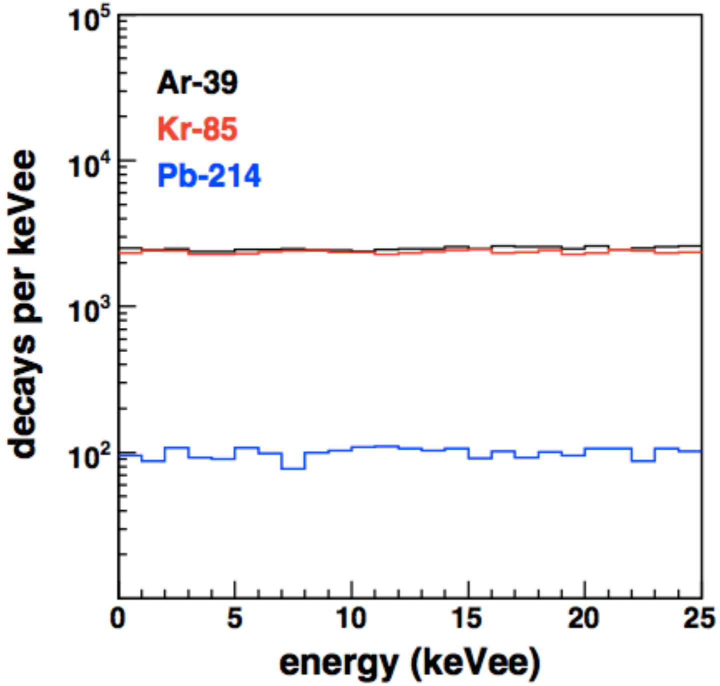


- Krypton-85 is the most important source of internal radioactivity
- Vendor-supplied xenon contains residual krypton at a relative concentration of ~10^{-7}
- LUX goal: reduce Krypton concentration to ~5 x 10^{-12}

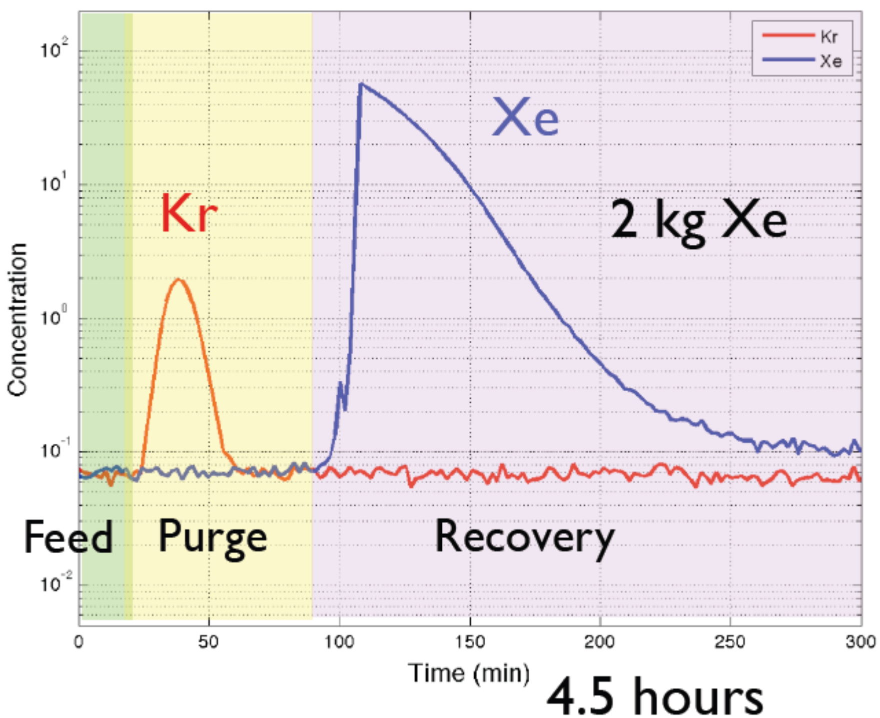
complete spectra

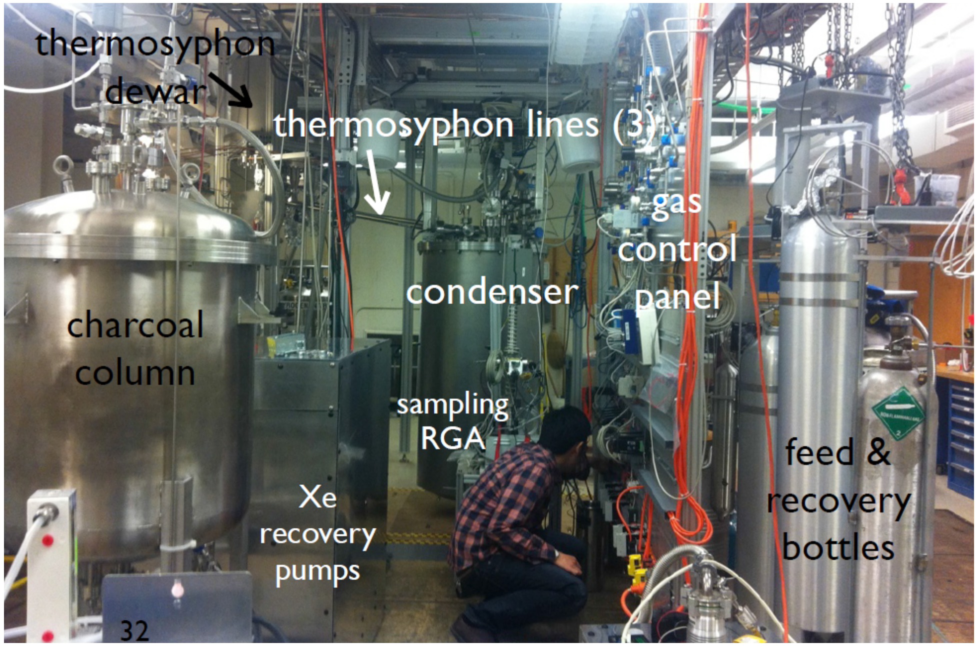


low energy zoom

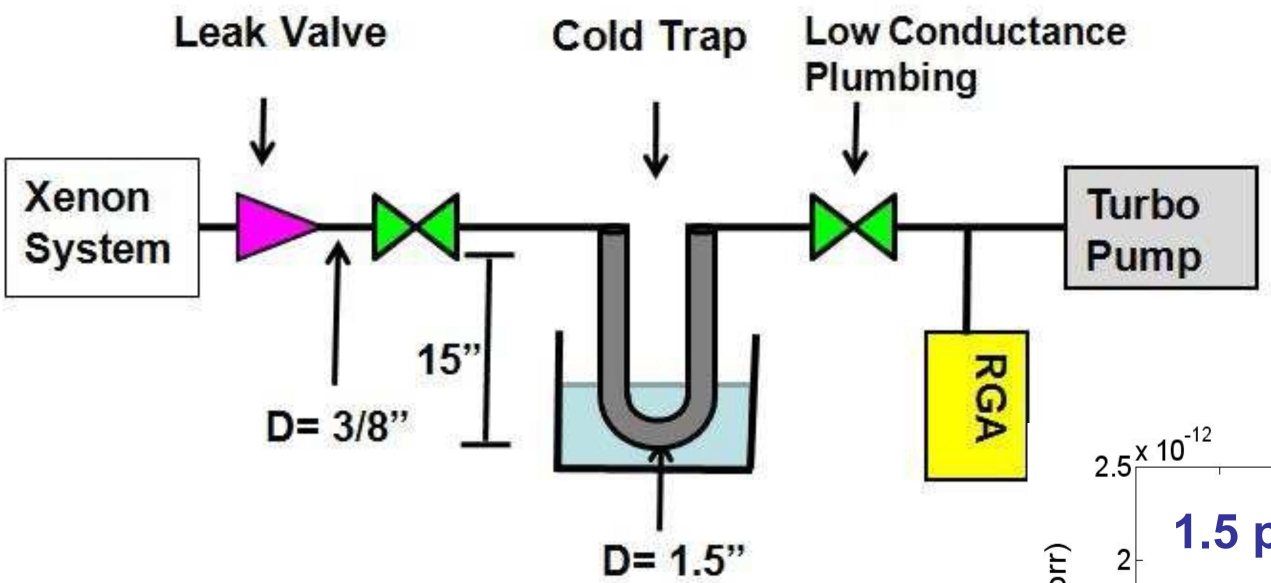


Chromatographic Krypton Removal System @ Case Western (Aug. – Dec. 2012)

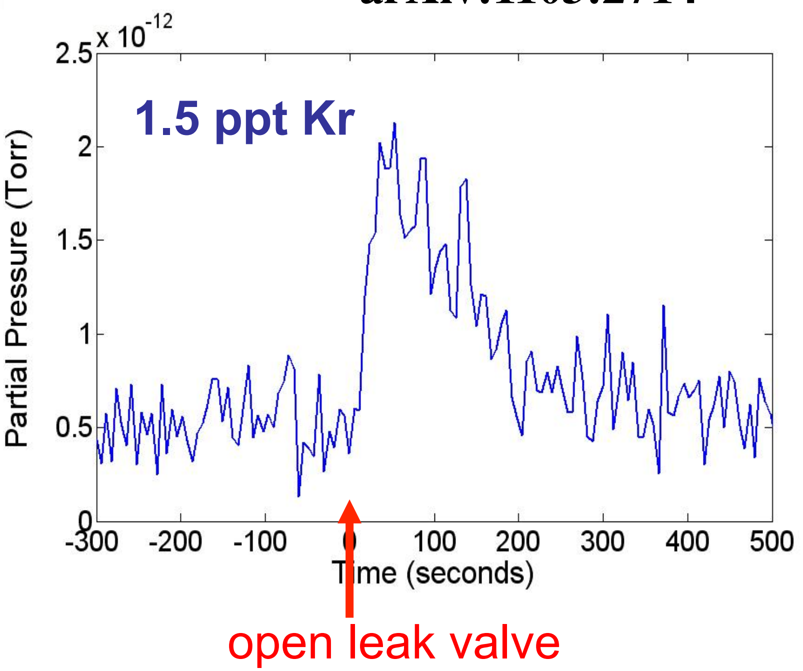




Detection of krypton at the part-per-trillion level

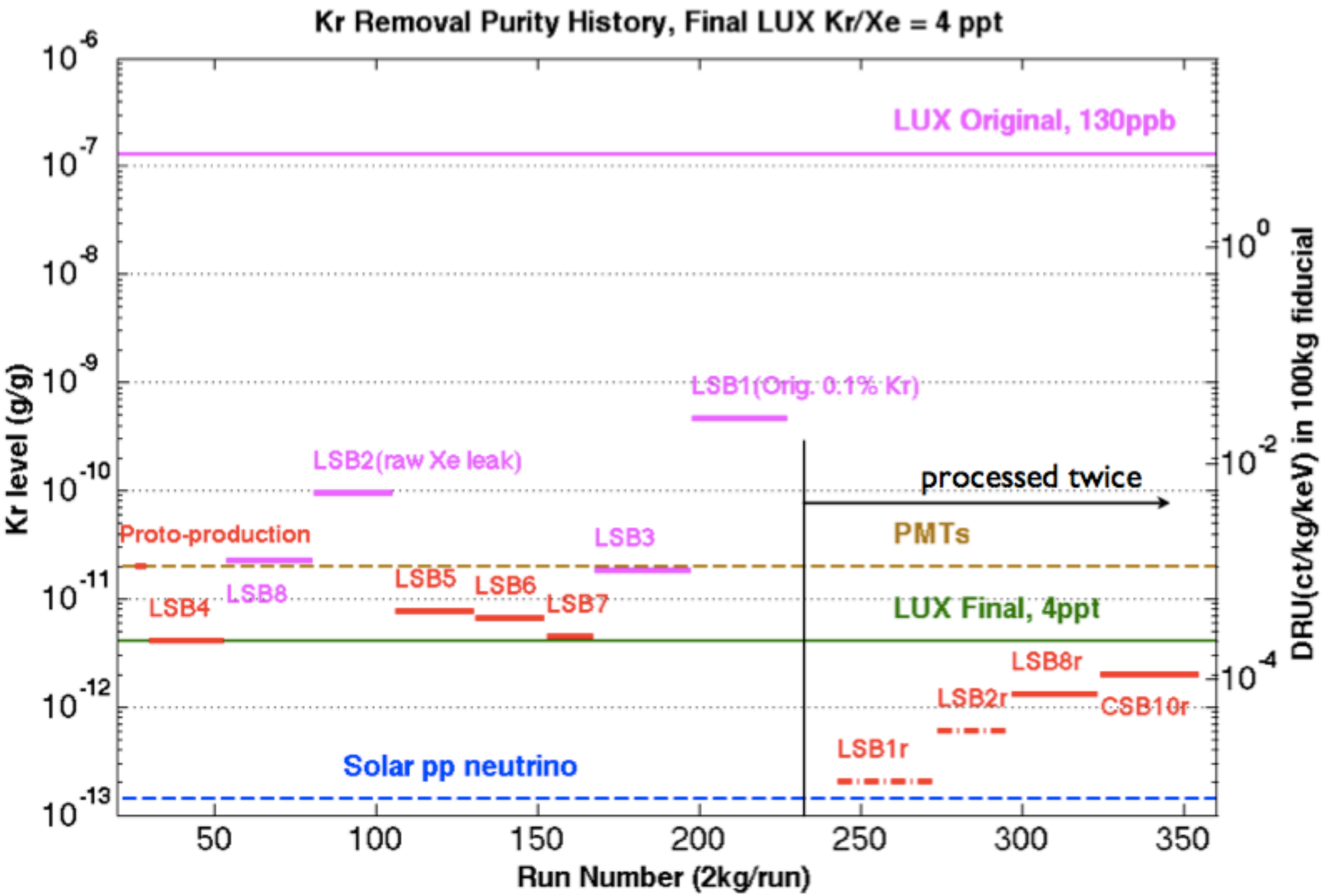


arXiv:1103:2714



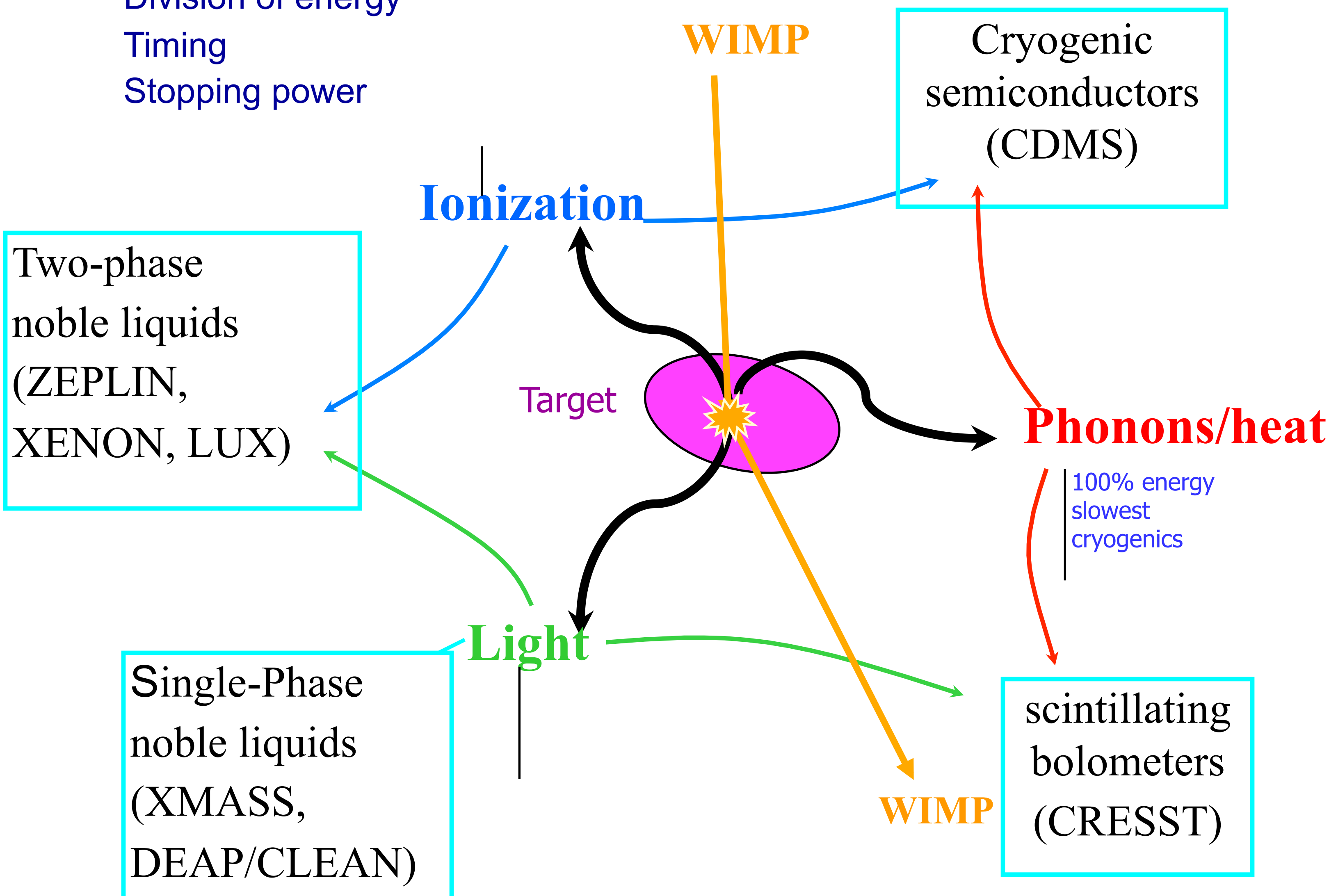
Cold trap technique boosts the krypton sensitivity of the mass spectrometer by a factor of $\sim 10^6$.

LUX Krypton removal – Fall 2012

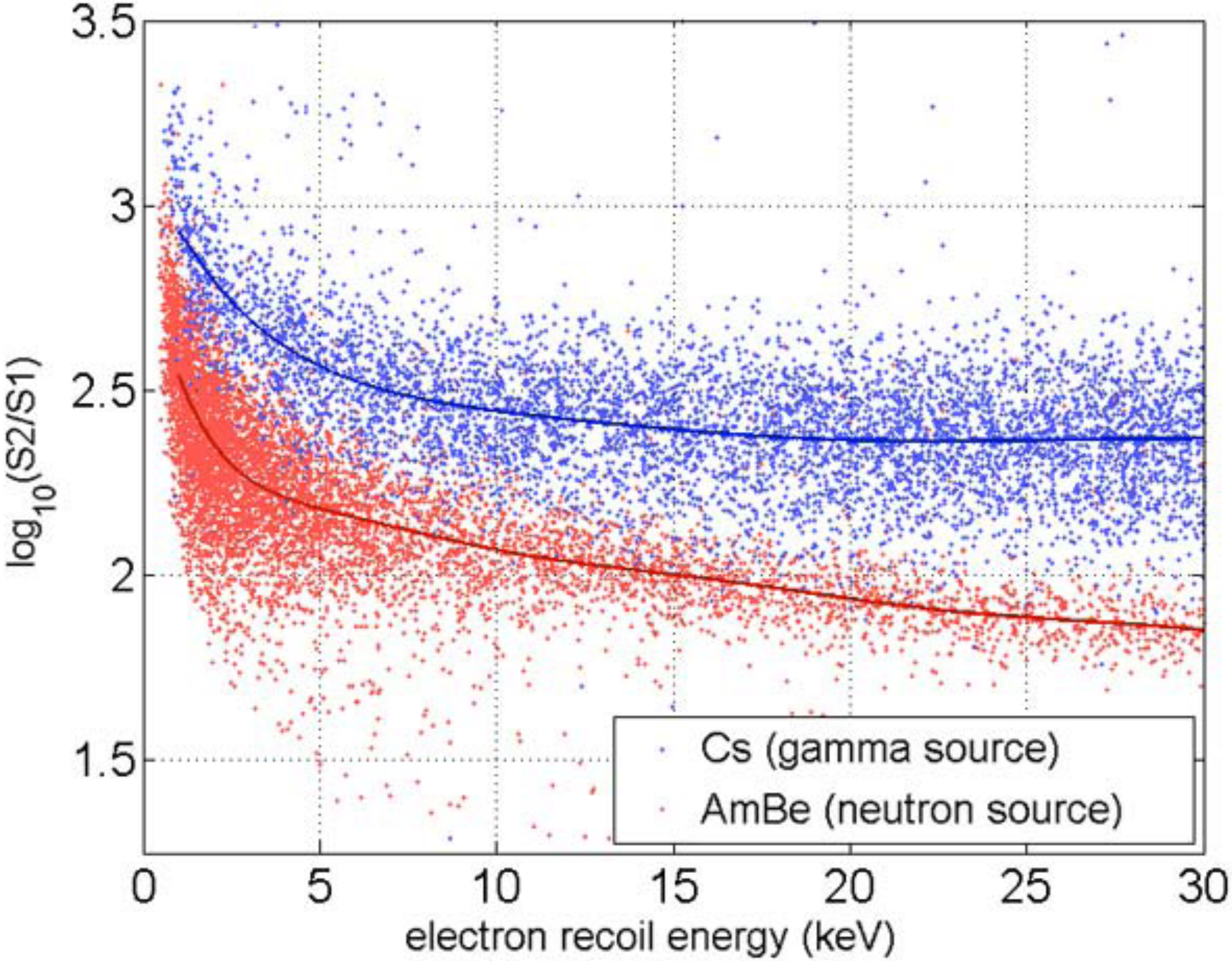


Background rejection through nuclear recoil discrimination

- Nuclear recoils vs. electron recoils
  - Division of energy
  - Timing
  - Stopping power

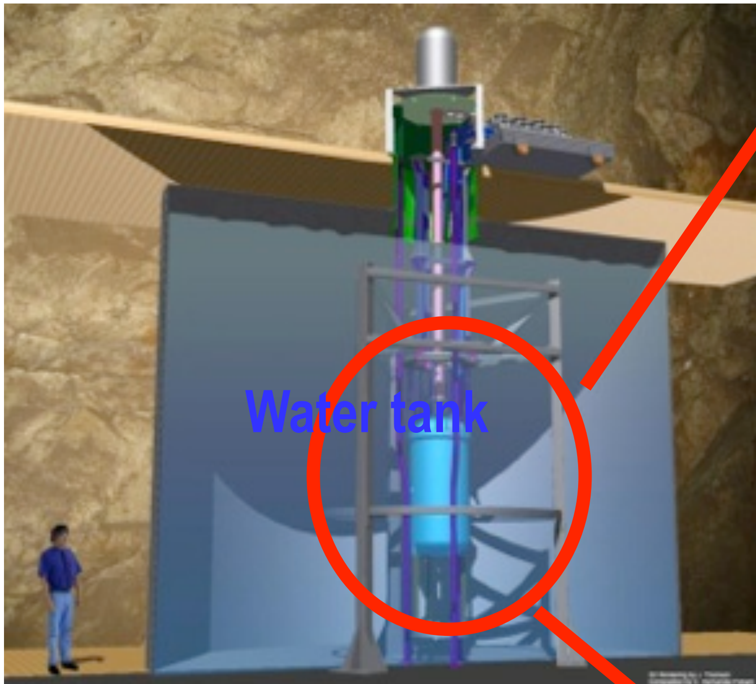


Charge/Light (S2/S1) recoil discrimination in Liquid Xenon

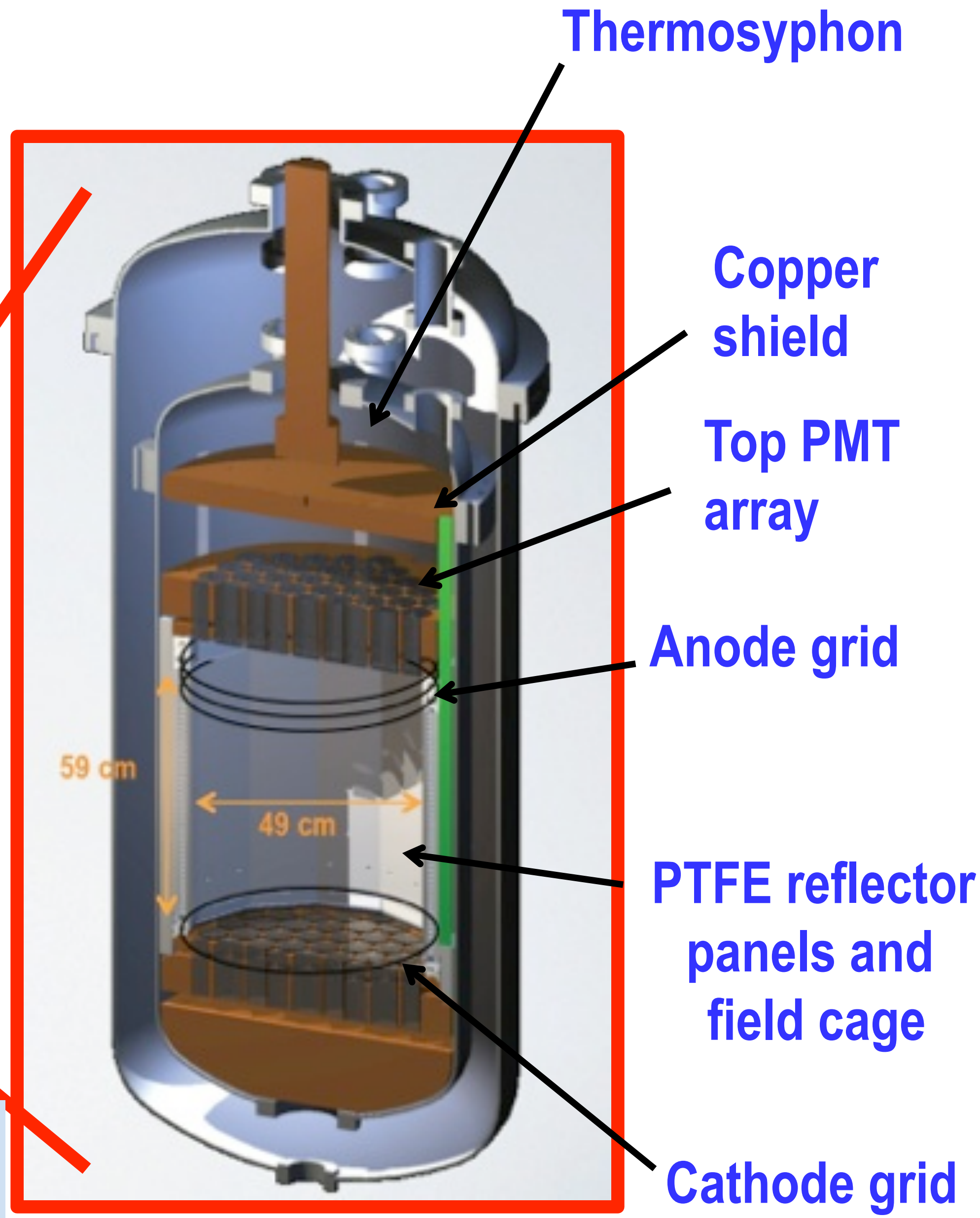


Data from bench-top demonstration experiment at Case Western.

The LUX Detector



Low-radioactivity
Titanium Cryostat



370 kg total xenon mass
250 kg active liquid xenon
118 kg fiducial mass

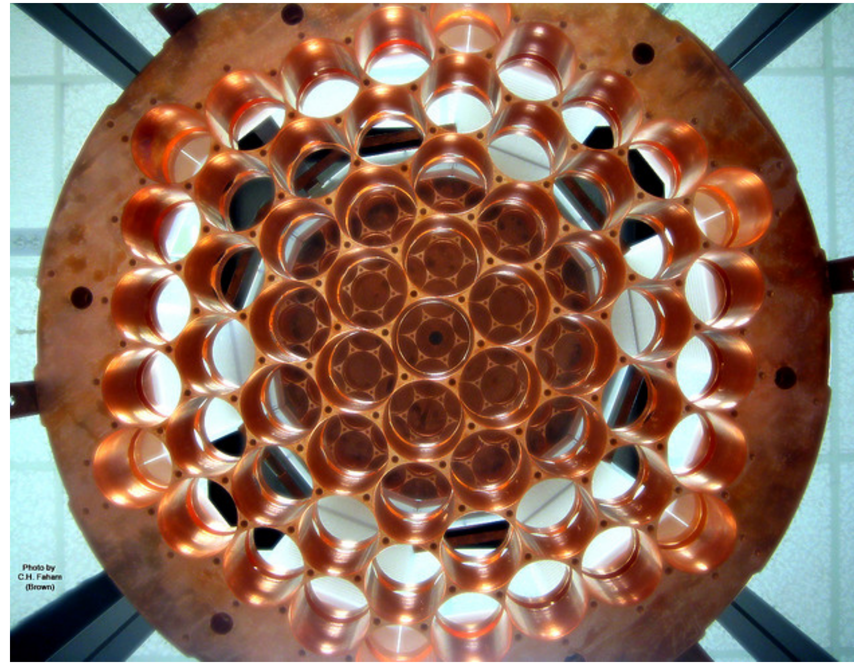
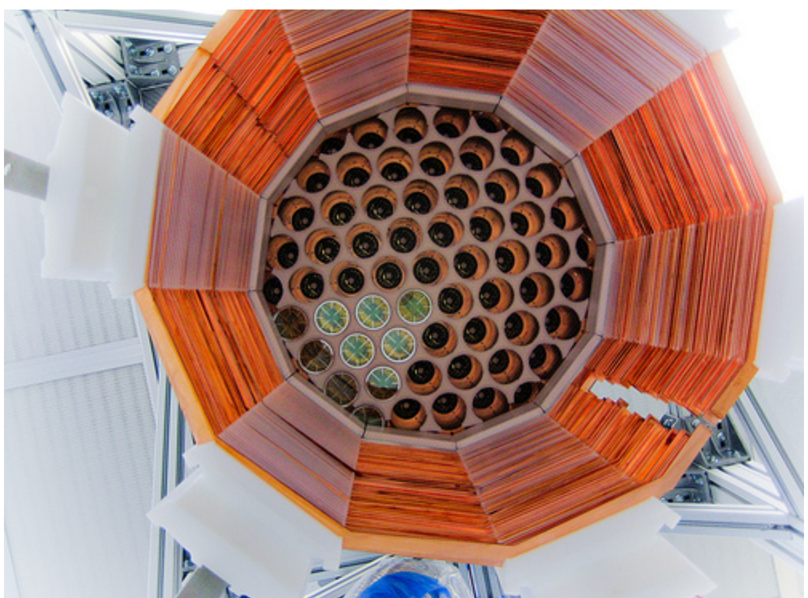
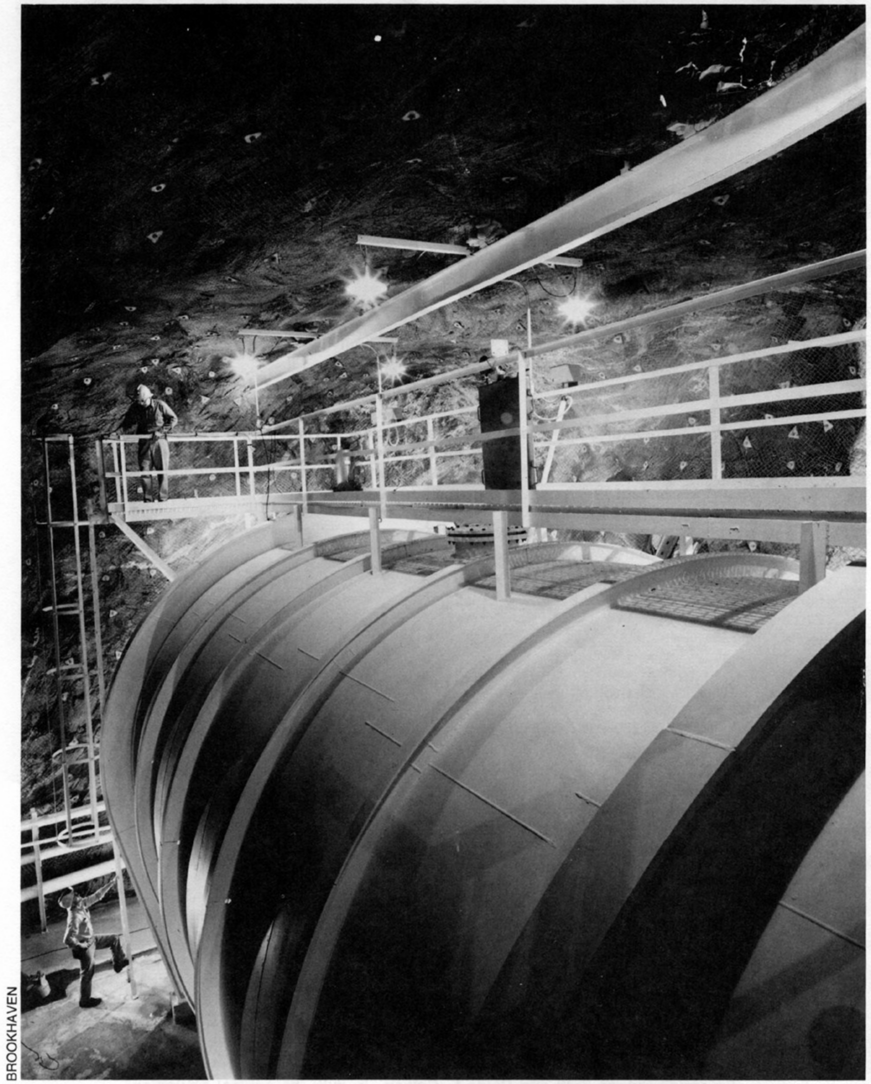


Photo by
C.H. Faham
(Brown)



Sanford Underground Research Facility, Lead, South Dakota

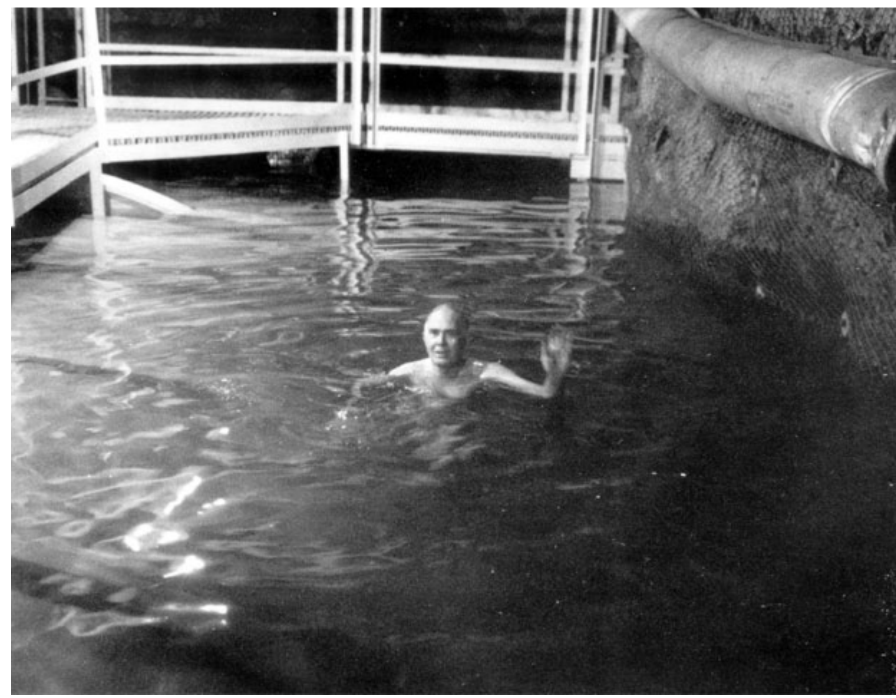
Ray Davis – Homestake Solar Neutrino Experiment



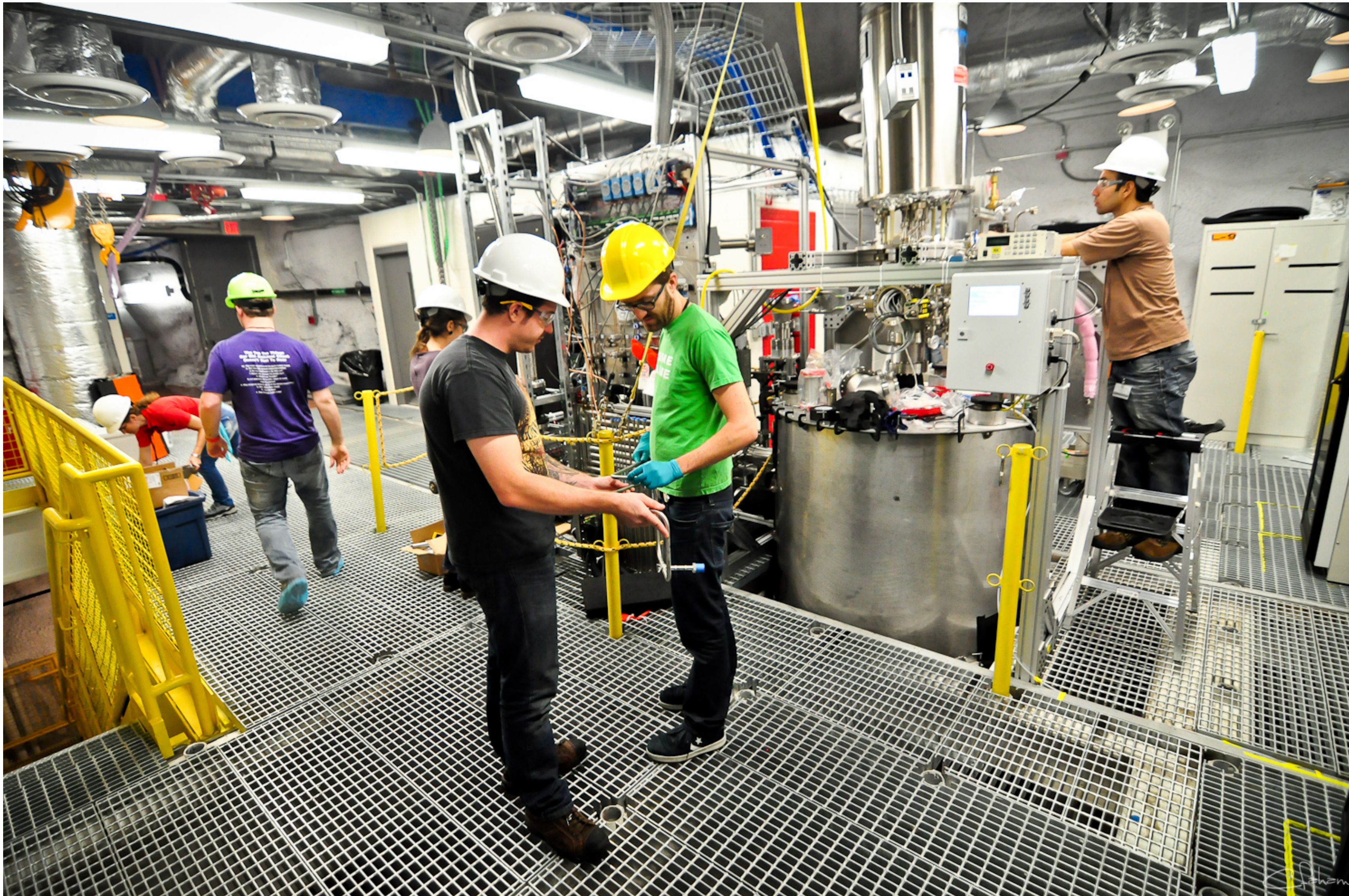
Davis' neutrino detection apparatus one kilometer underground in the Homestake Gold Mine, Lead, South Dakota. The tank contains 400,000 liters of perchloroethylene.

Raymond Davis

2002

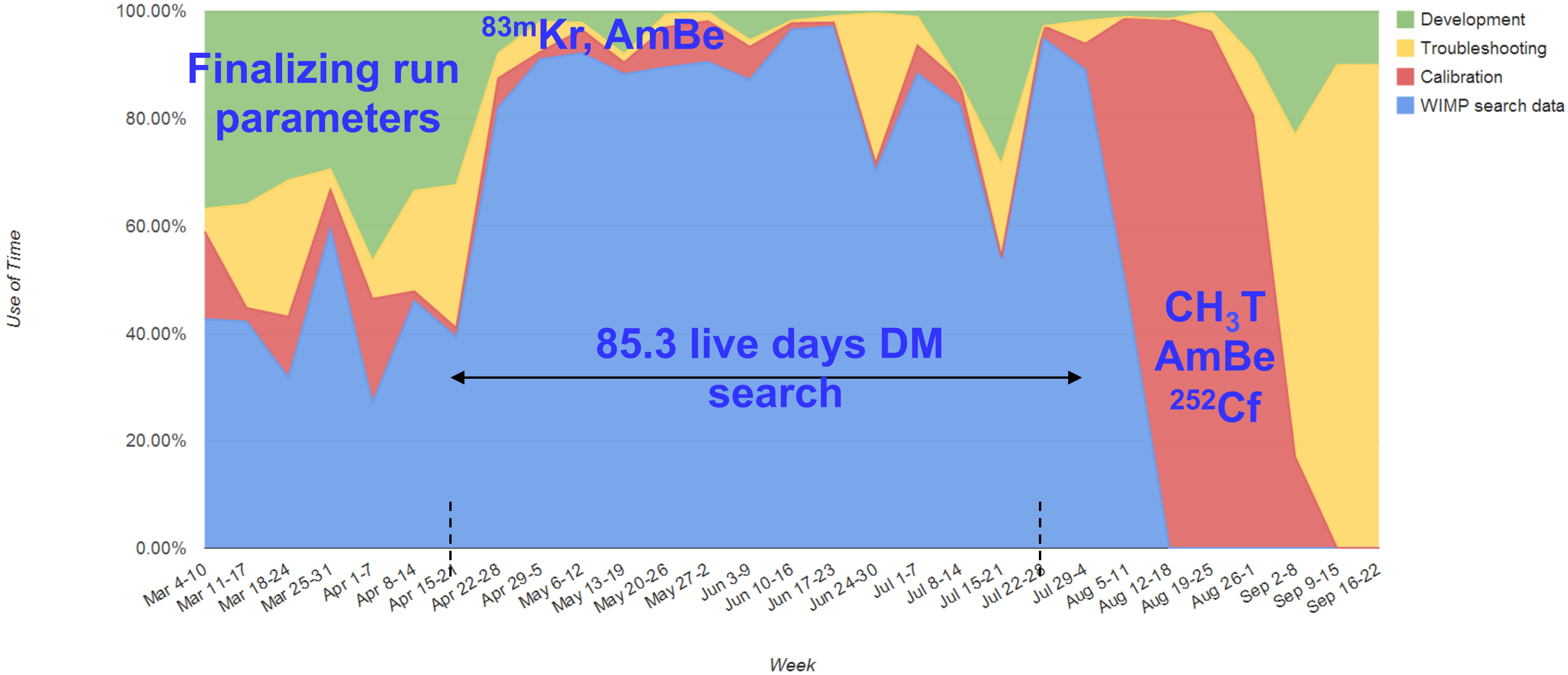


On top of the water shield, Sept. 2012



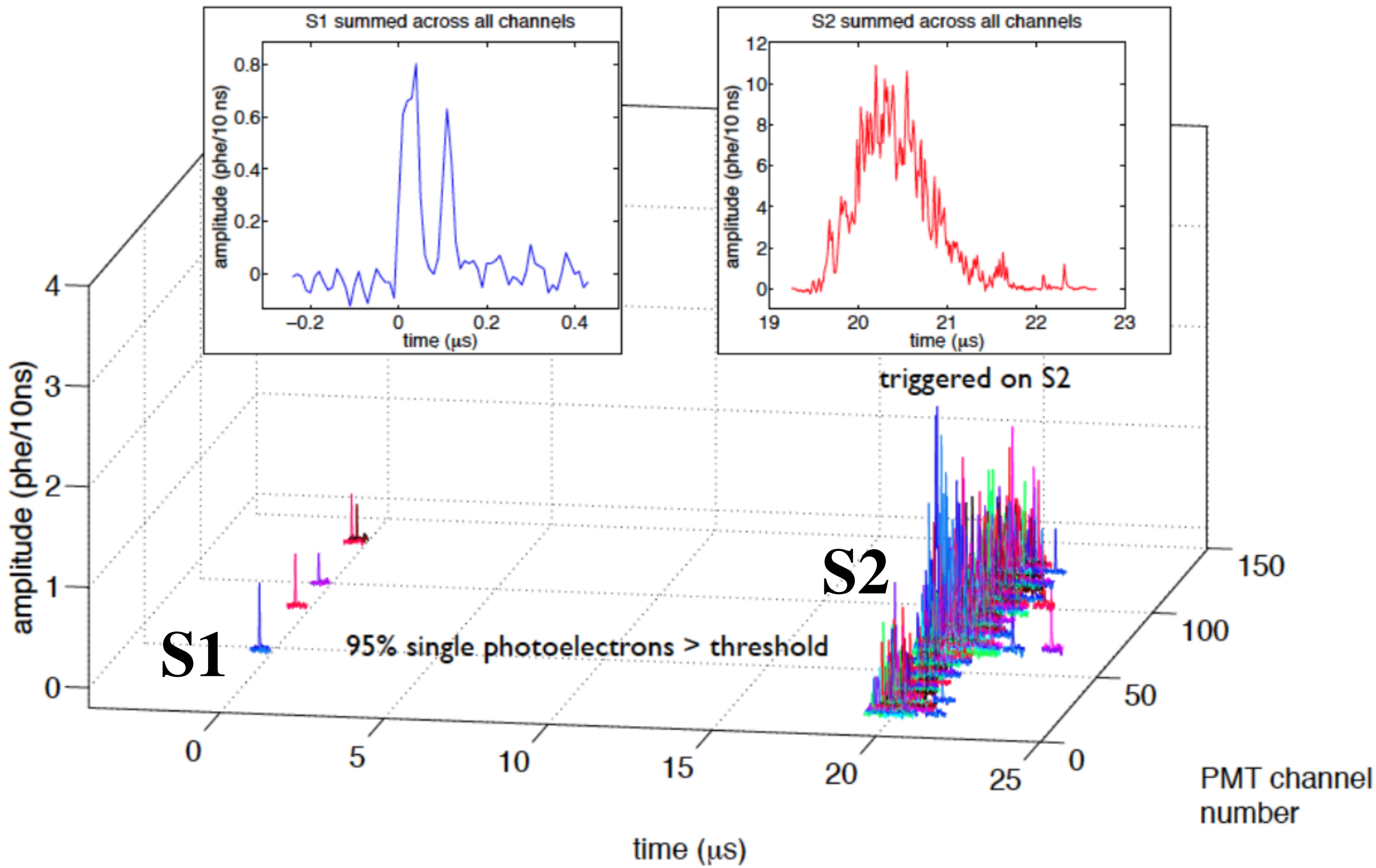
LUX installed in the water tank, Sept. 2012

LUX Run 3 Operations

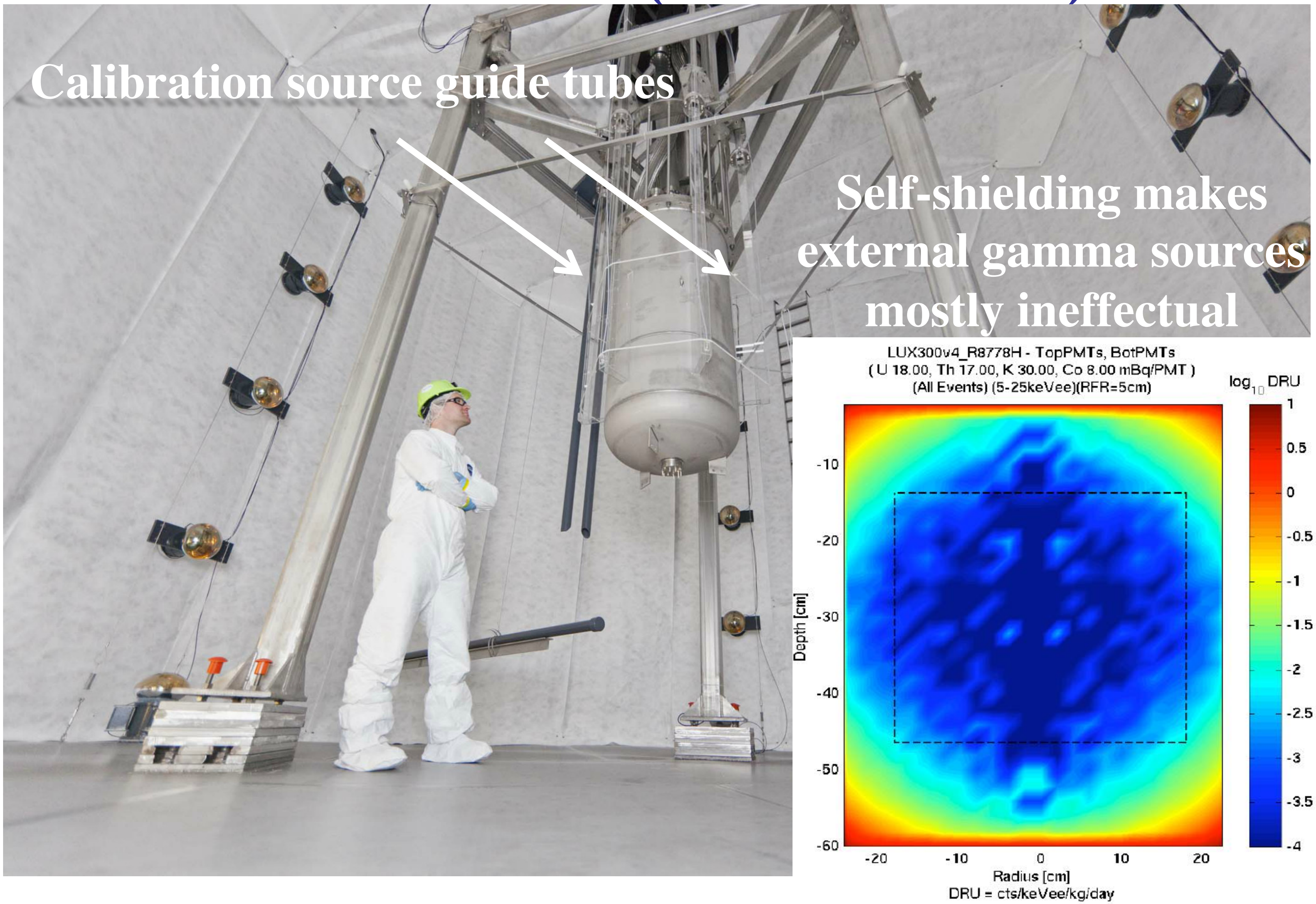


- Detector cool-down Jan. 2013, Xe condensed mid-Feb. 2013
- 95% Data taking efficiency during WIMP search period (minus storms)
- Waited until after WIMP search data was in-hand before performing the precision tritium calibration

Typical Event in LUX

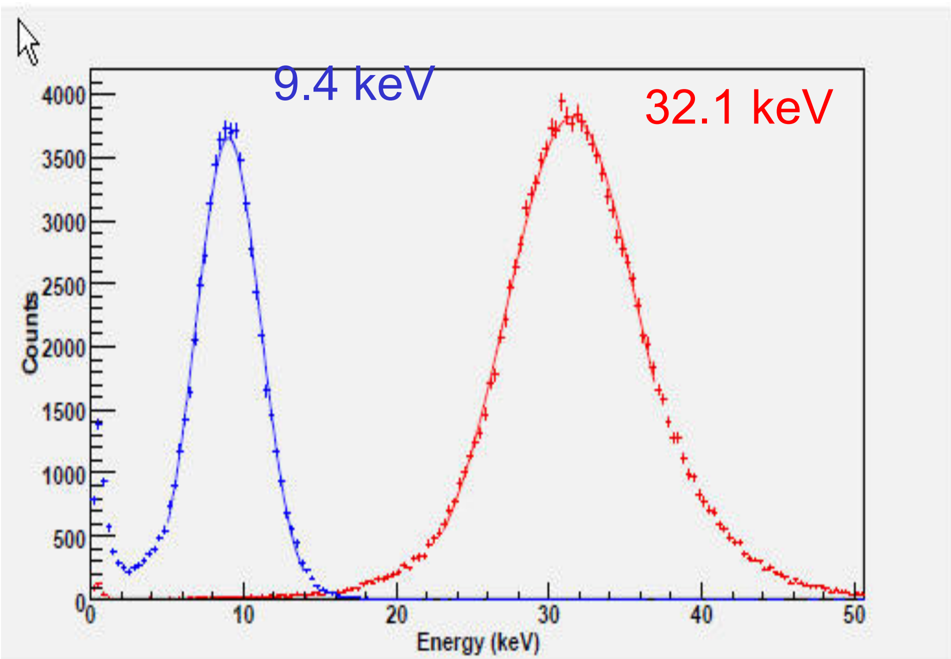


External calibration sources: ^{137}Cs & neutrons (AmBe & ^{252}Cf)



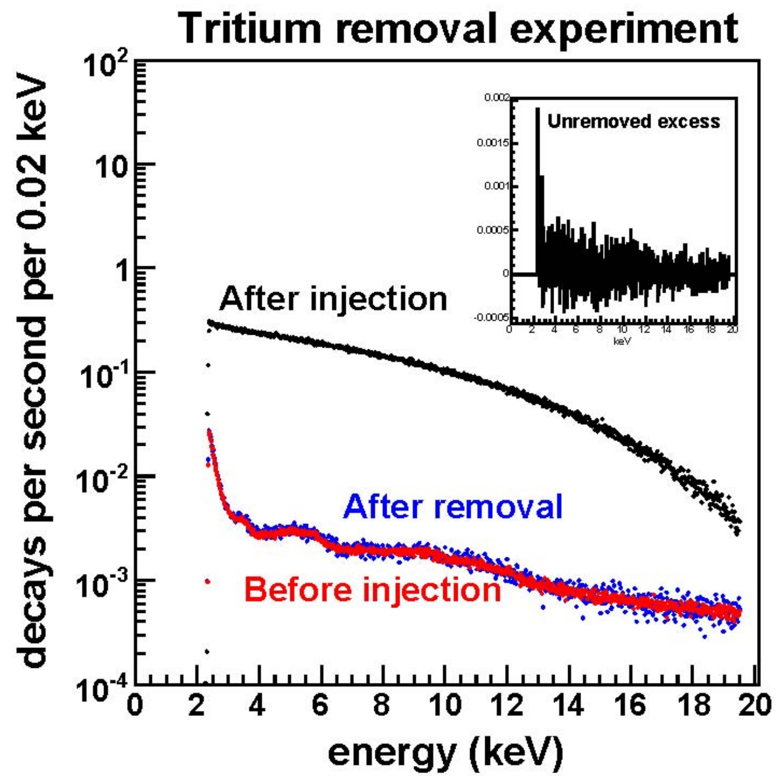
Internal calibration sources: ^{83m}Kr and Tritium - Dissolve them directly in the liquid xenon

83mKr conversion electrons ($T_{1/2}$ = 1.86 hours)



L. Kastens et al., Phys. Rev. C80: 045809,2009,
A. Manalaysay et al., Rev. Sci. Instr. **81**, 073303 (2010)

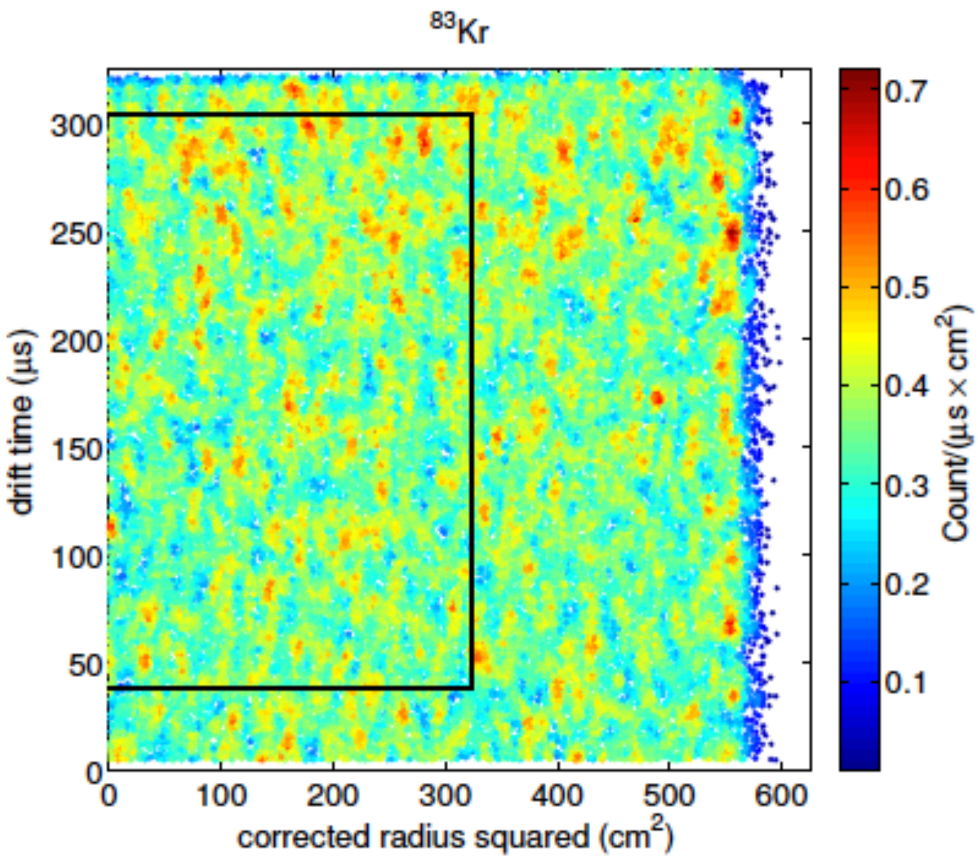
Tritium beta decay ($T_{1/2}$ = 12.6 yrs)

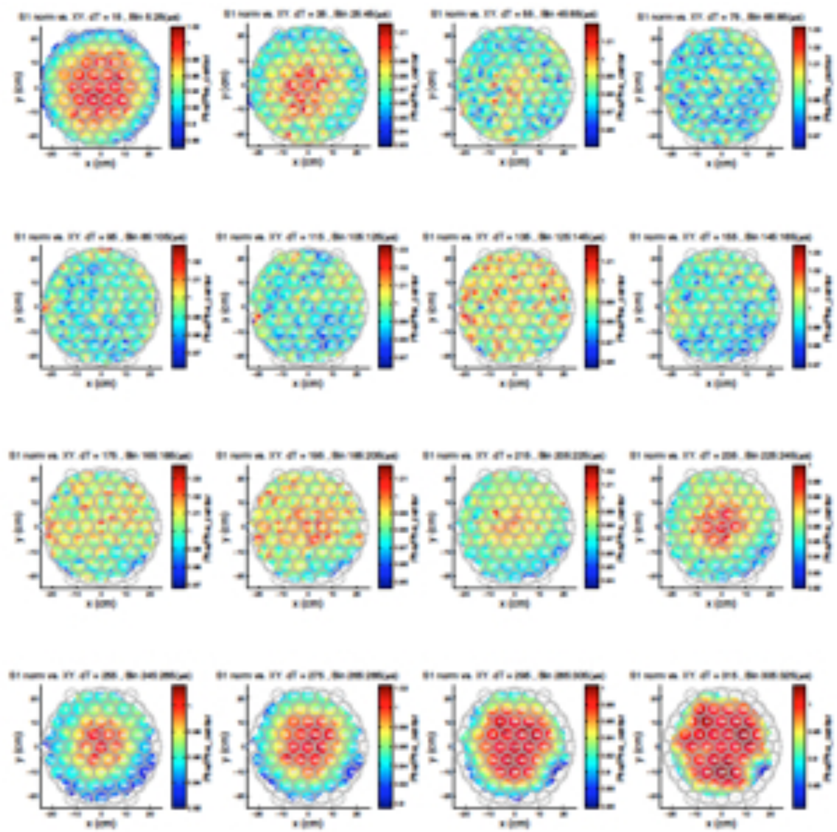


- Chemical form is CH_3T
- Remove with zirconium getter
- Dozens of tritium injection & removal experiments performed
- One-pass removal efficiency > 99%

Kr-83m Calibration

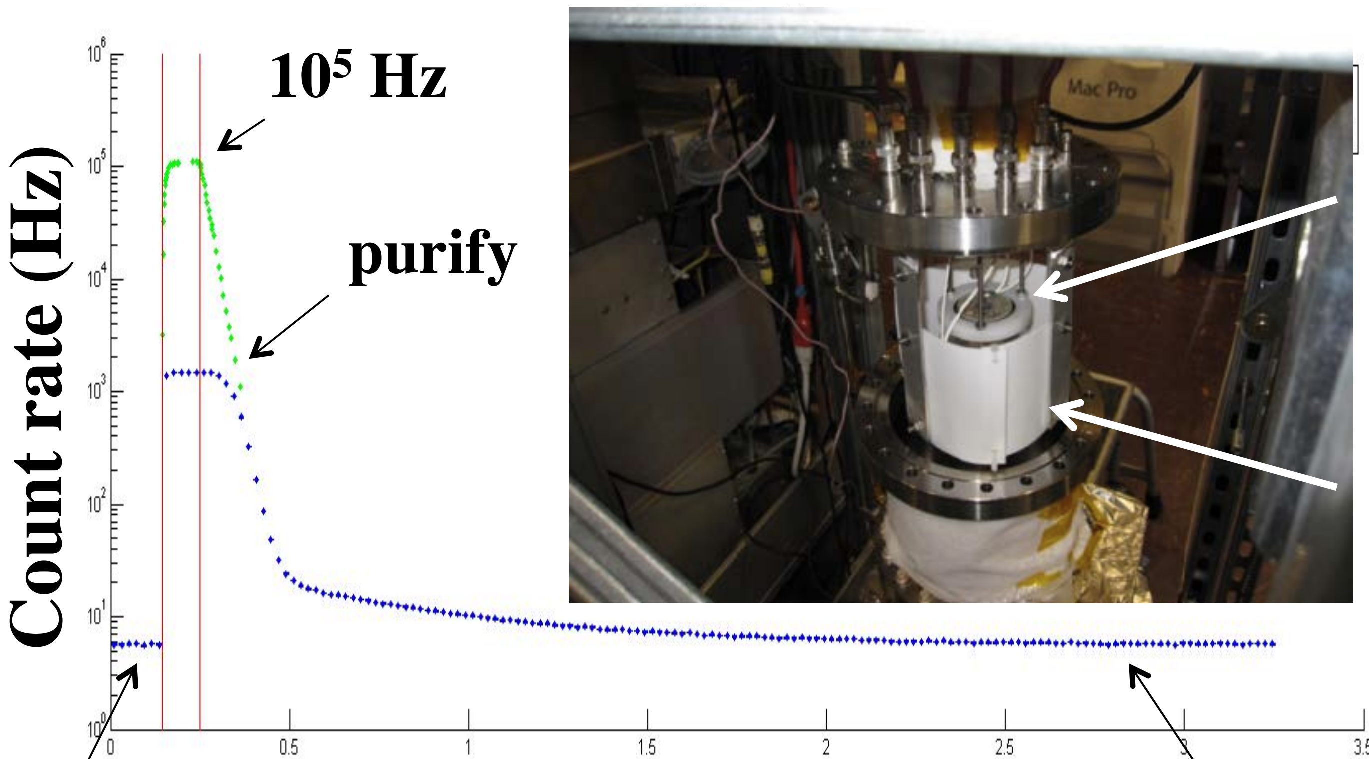
Over 1 million Kr-83m events, spread uniformly through the detector.



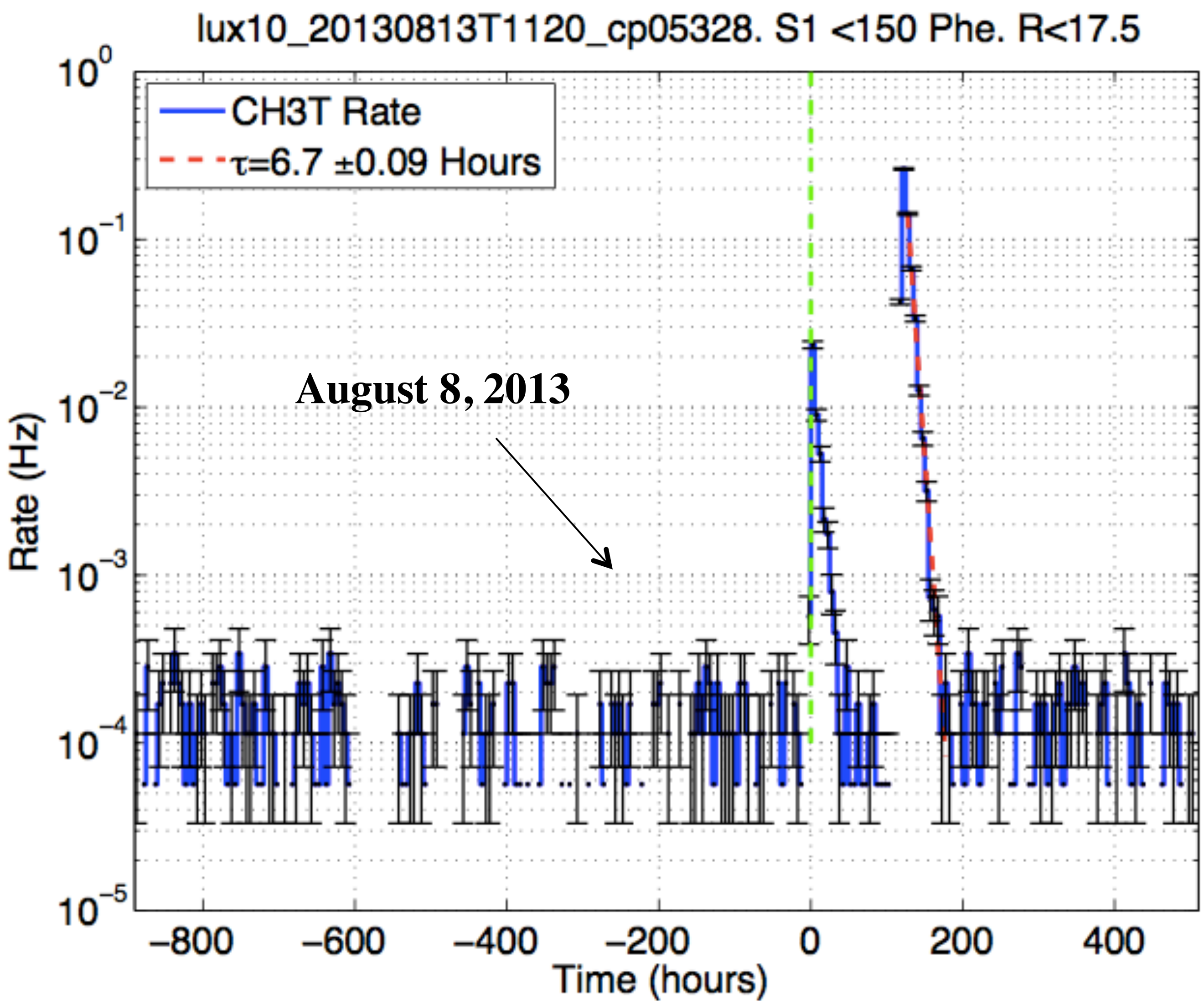


Measurement of the detector response to charge.

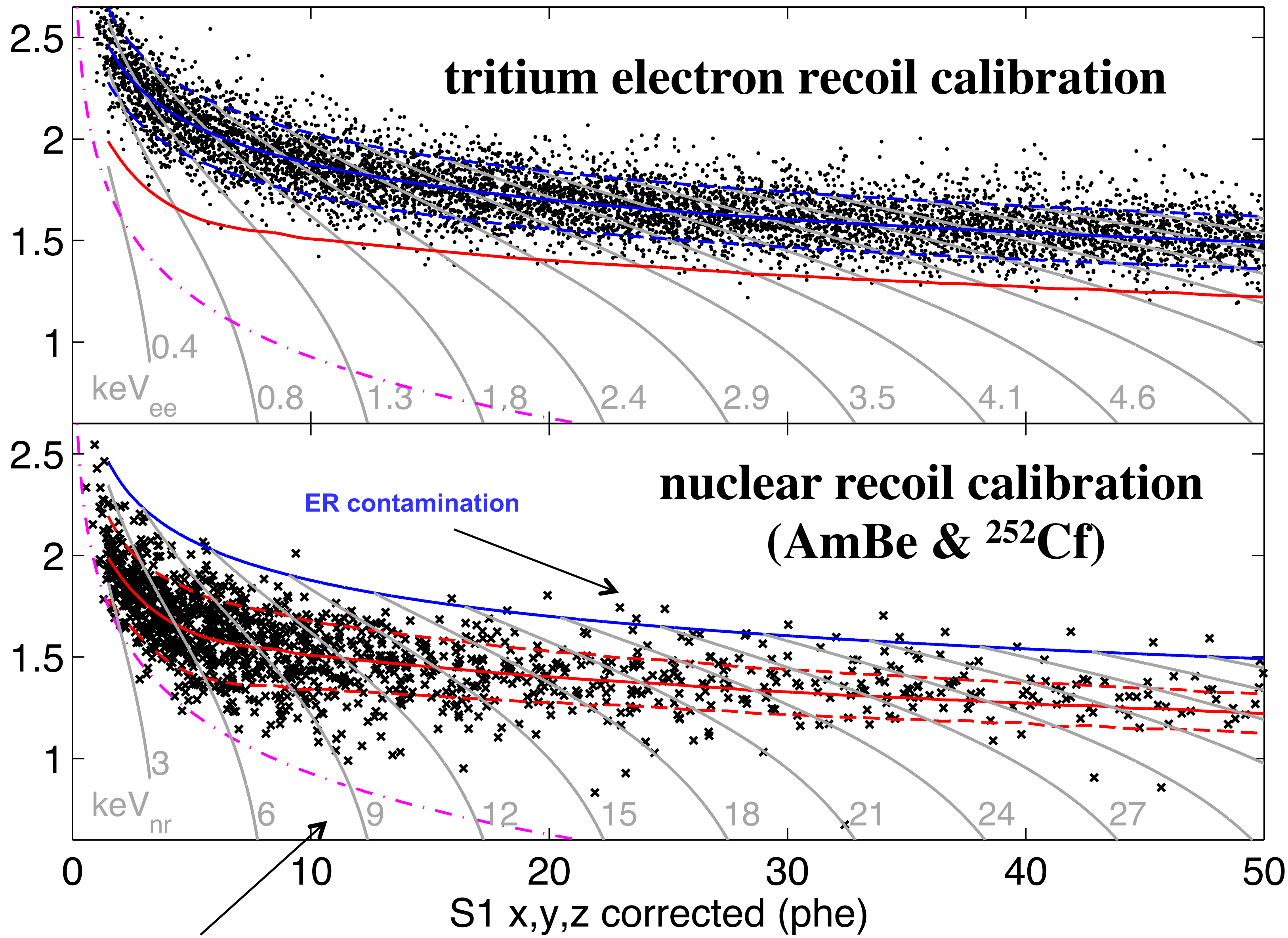
Removal of tritiated methane from liquid xenon – bench-top experiments (2012 – 2013)



Injection and removal of tritiated methane from LUX, August 2013

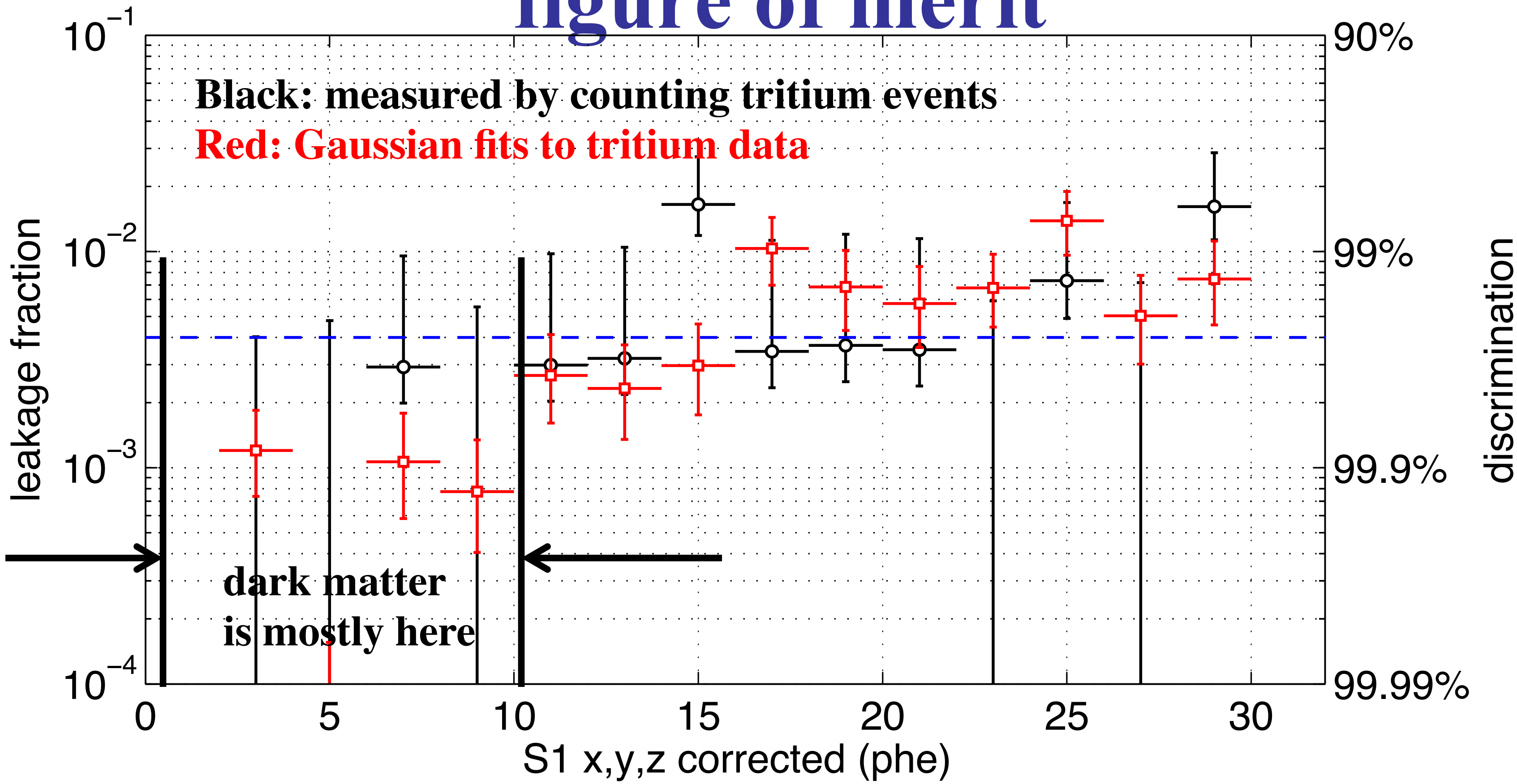


Electron-recoil and nuclear-recoil calibration data



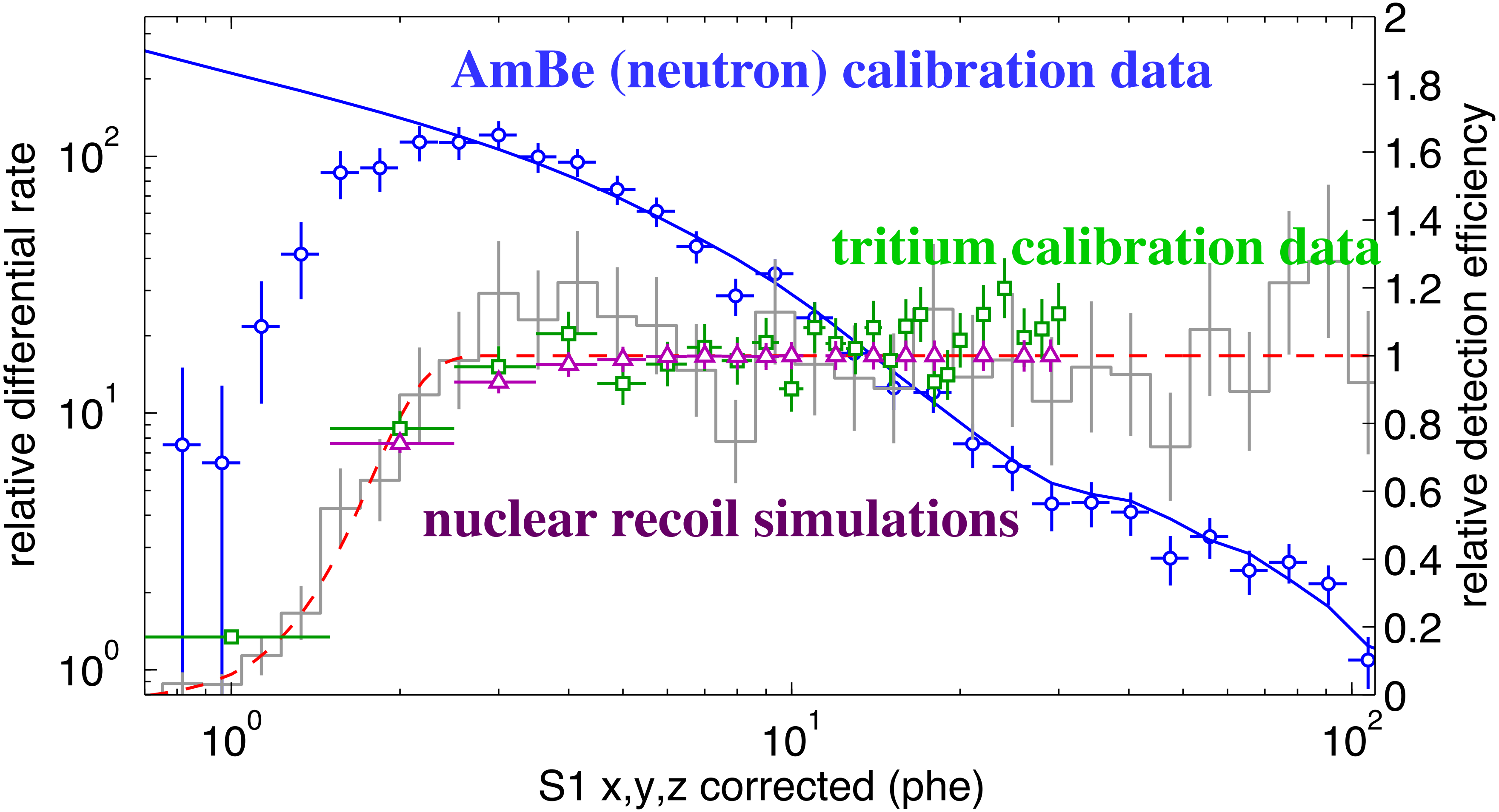
Neutron-X events and multiple scatters with low S2s

Electron-recoil discrimination figure of merit

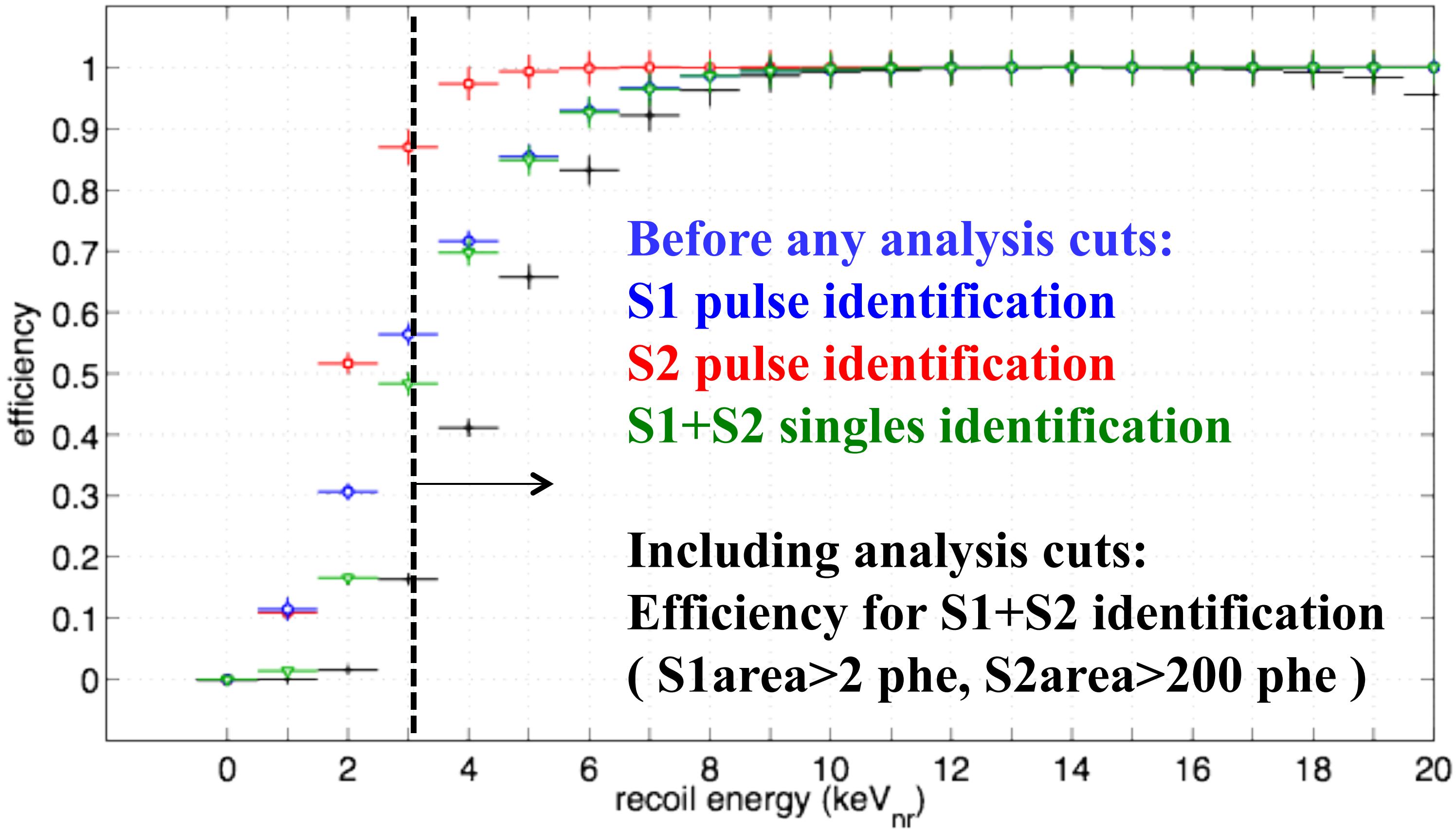


Average discrimination between 2 and 30 S1 photo-electrons measured with tritium to be 99.6% (LUX goal was 99.4%) with 50% nuclear recoil acceptance.

LUX detector threshold vs S1

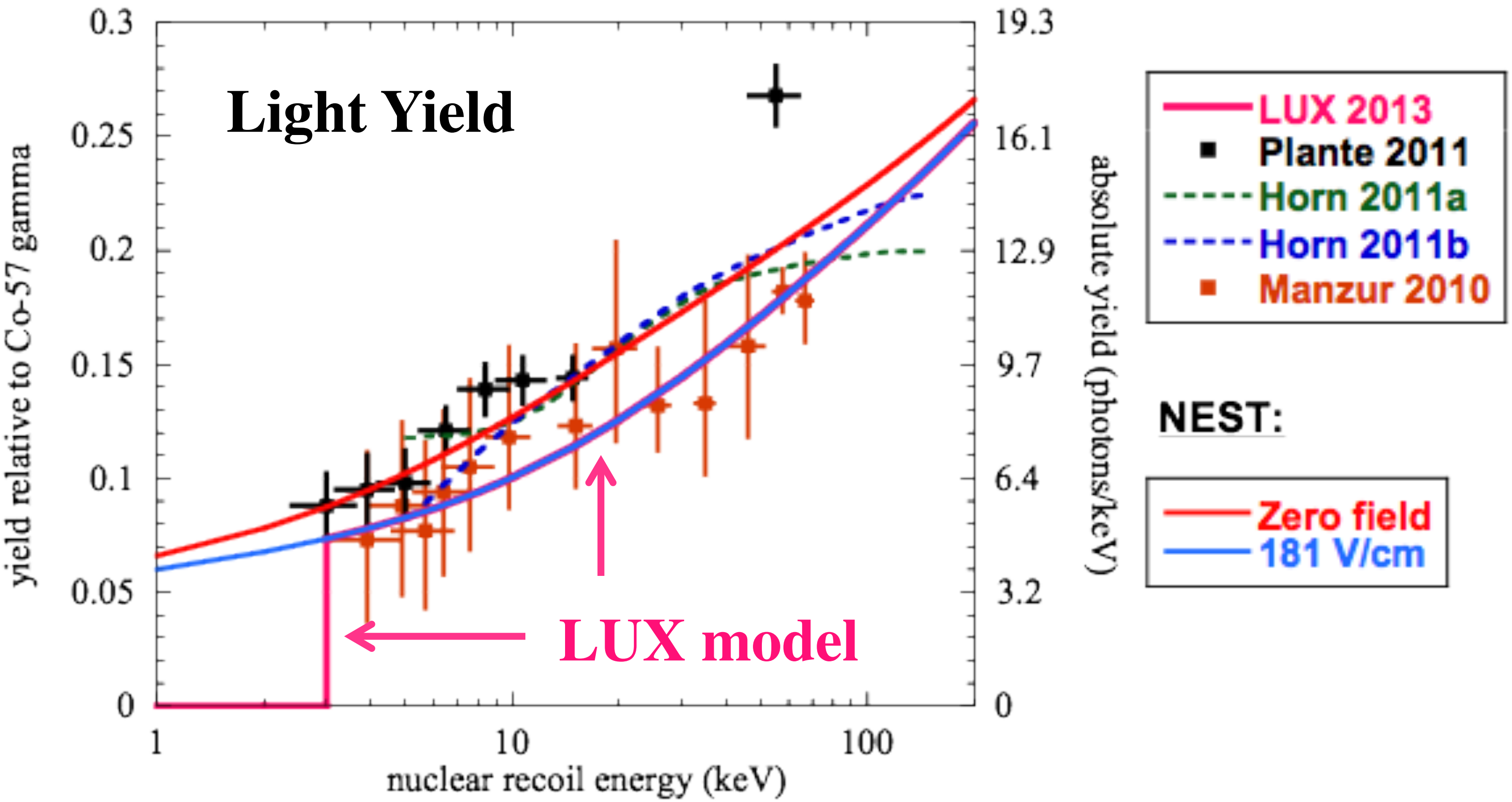


LUX detector threshold translated to recoil energy



Light Yield

- Modeled using the Noble Element Simulation Technique (NEST), based on the canon of existing experimental data.
- **Artificial cutoff in light and charge yields assumed below 3 keVnr, to be conservative.**
- **Includes** E field quenching of light signal (77-82% compared to zero field)
- Charge yield: 26 phe/e-

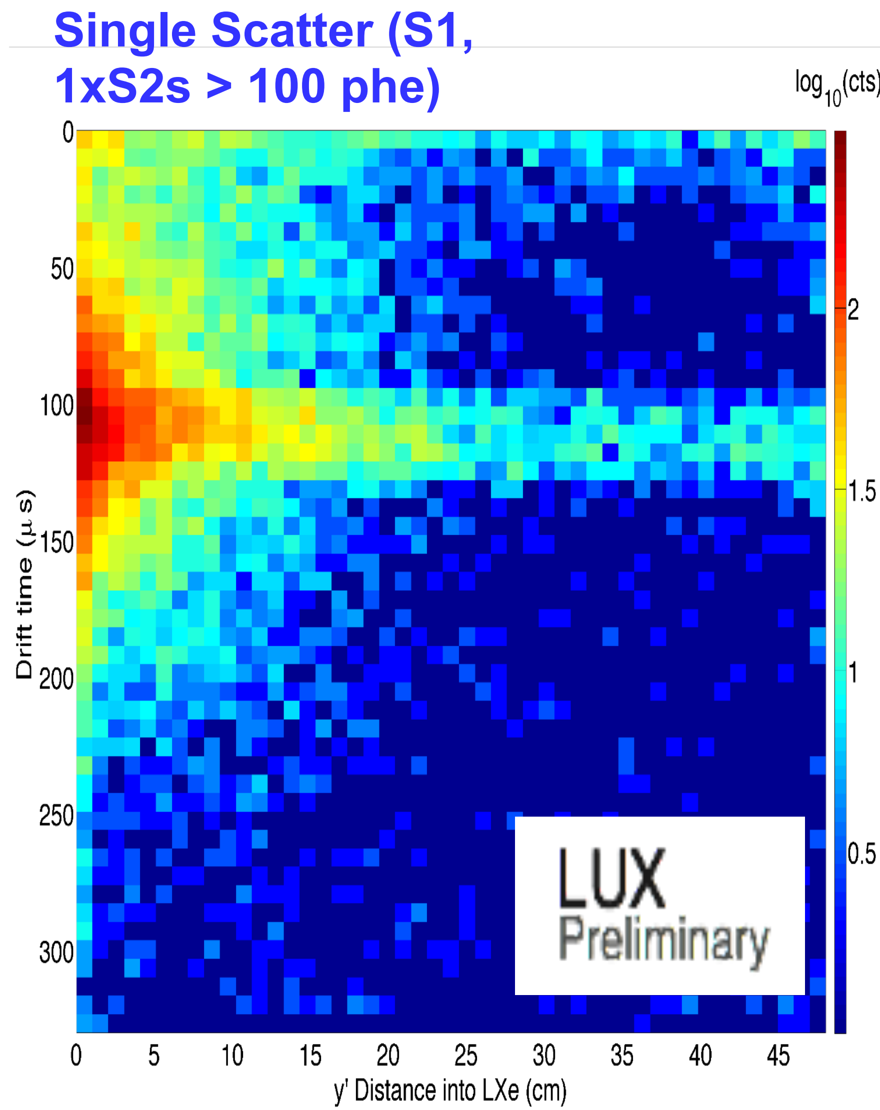


DD Neutron Generator Installed Outside LUX Water Tank - Fall 2013

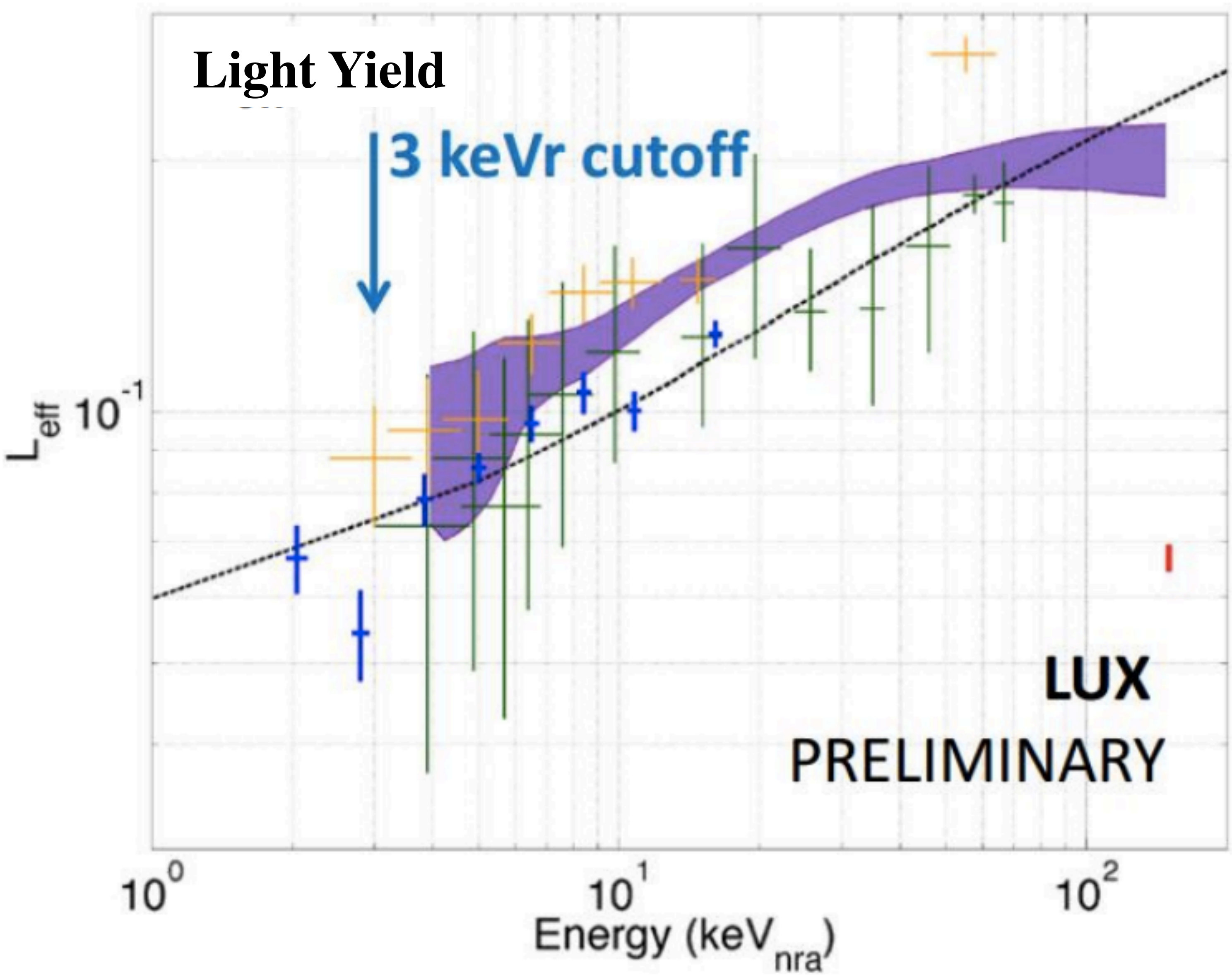
Neutron Tube –

raise into position for DD neutron calibration

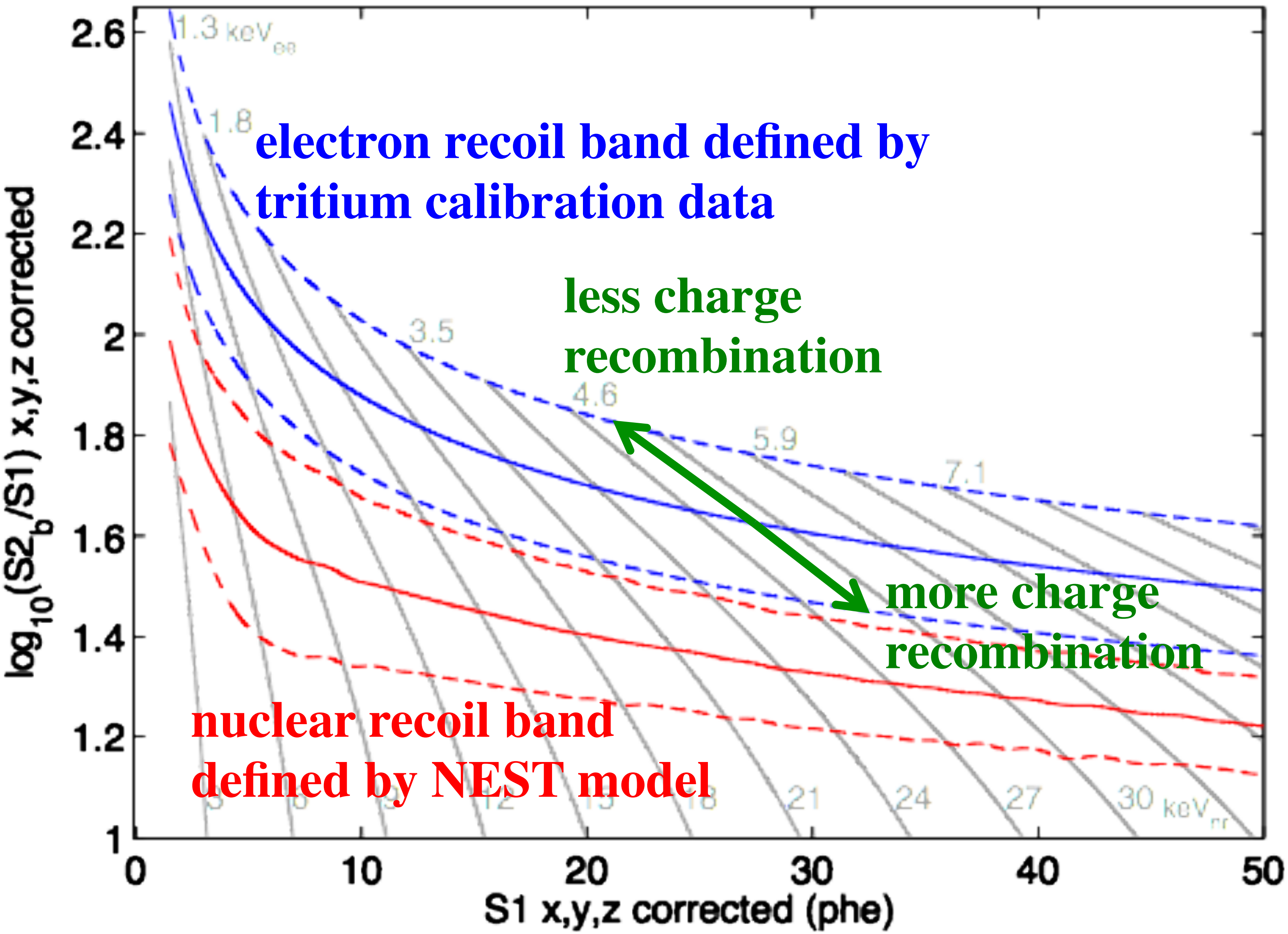
DD Neutron Generator Installed Outside LUX Water Tank - Fall 2013



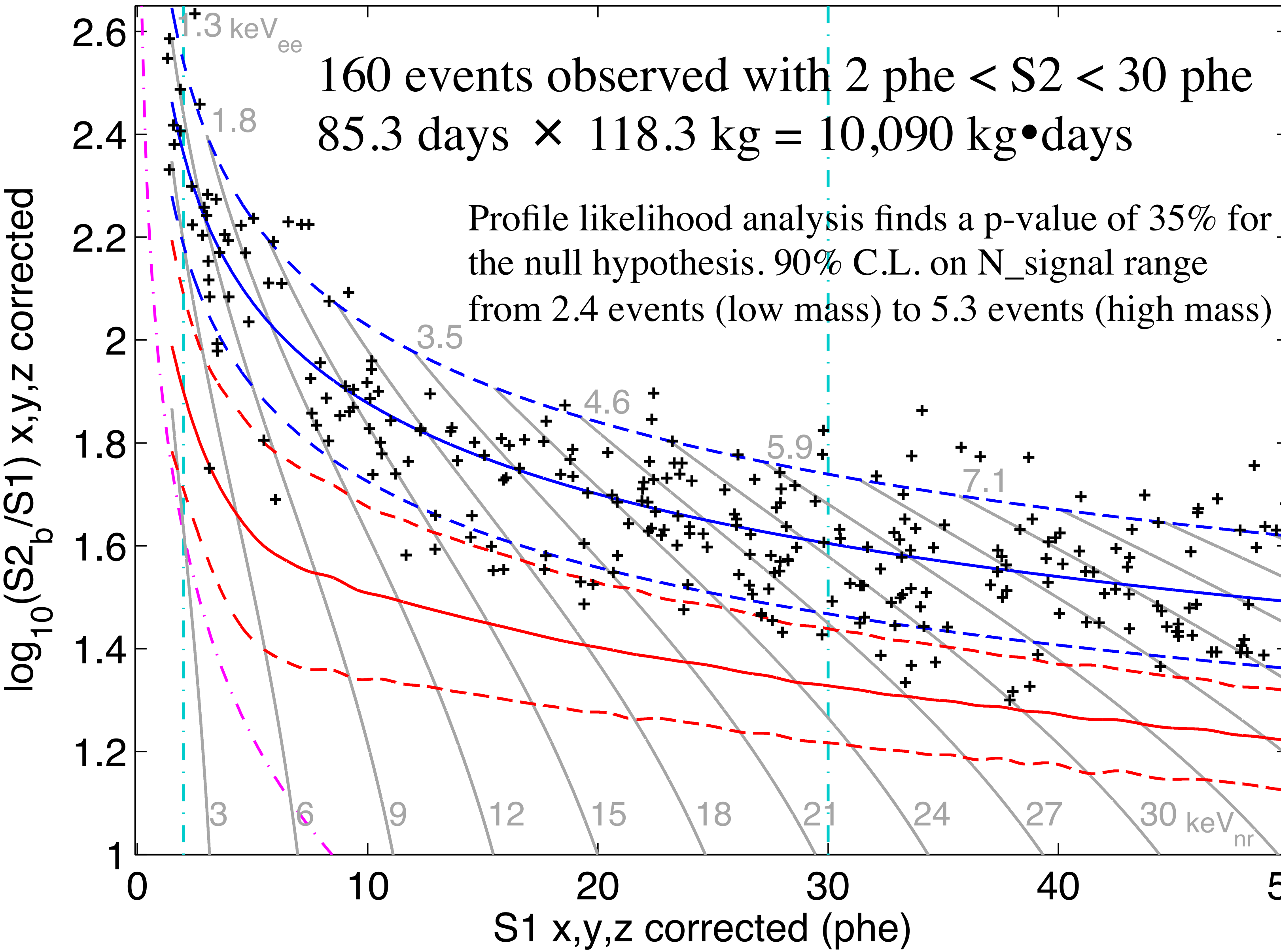
DD Neutron Generator Installed Outside LUX Water Tank - Fall 2013



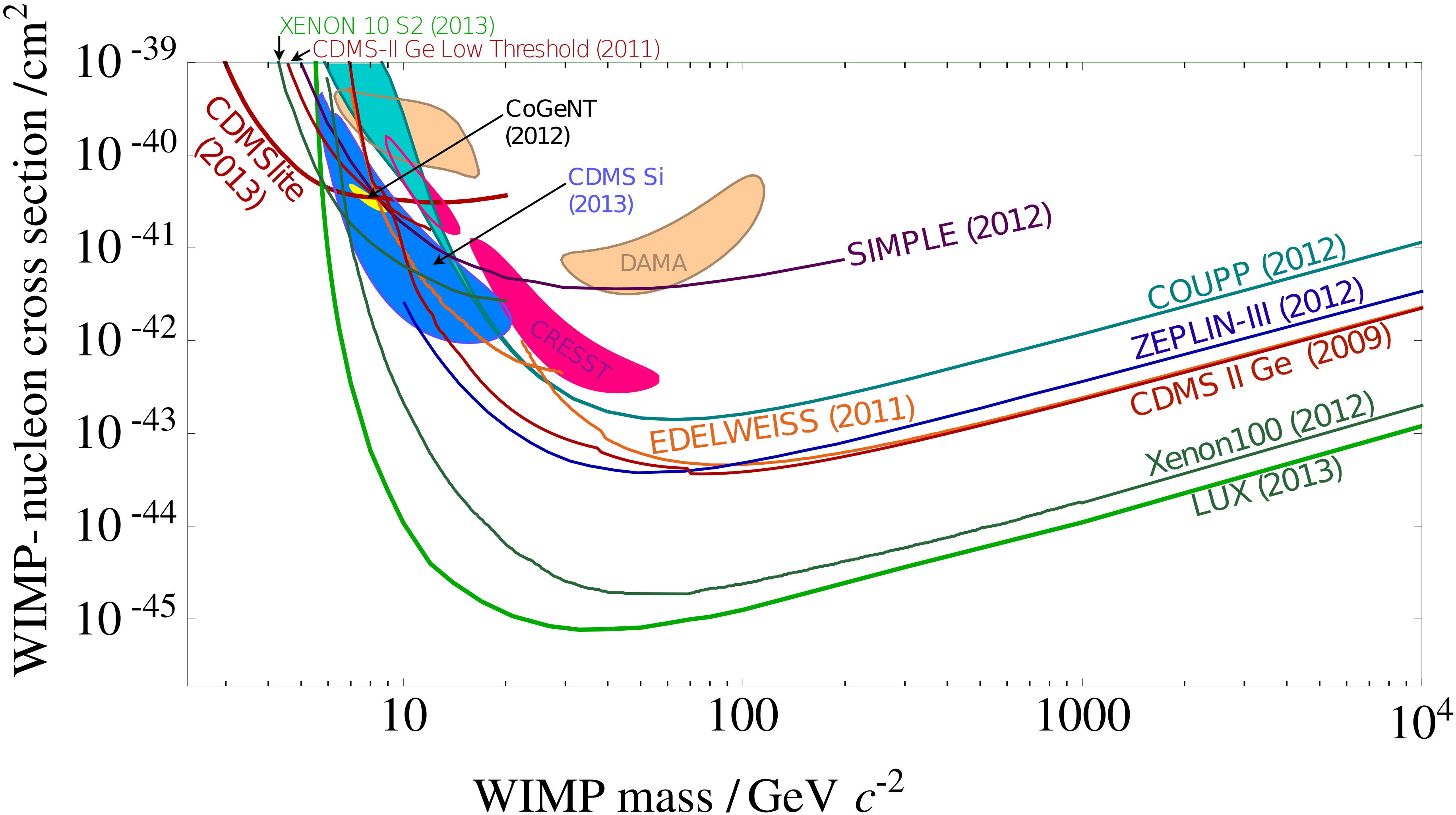
LUX keV$_{ee}$ and keV$_{nr}$ energy scales



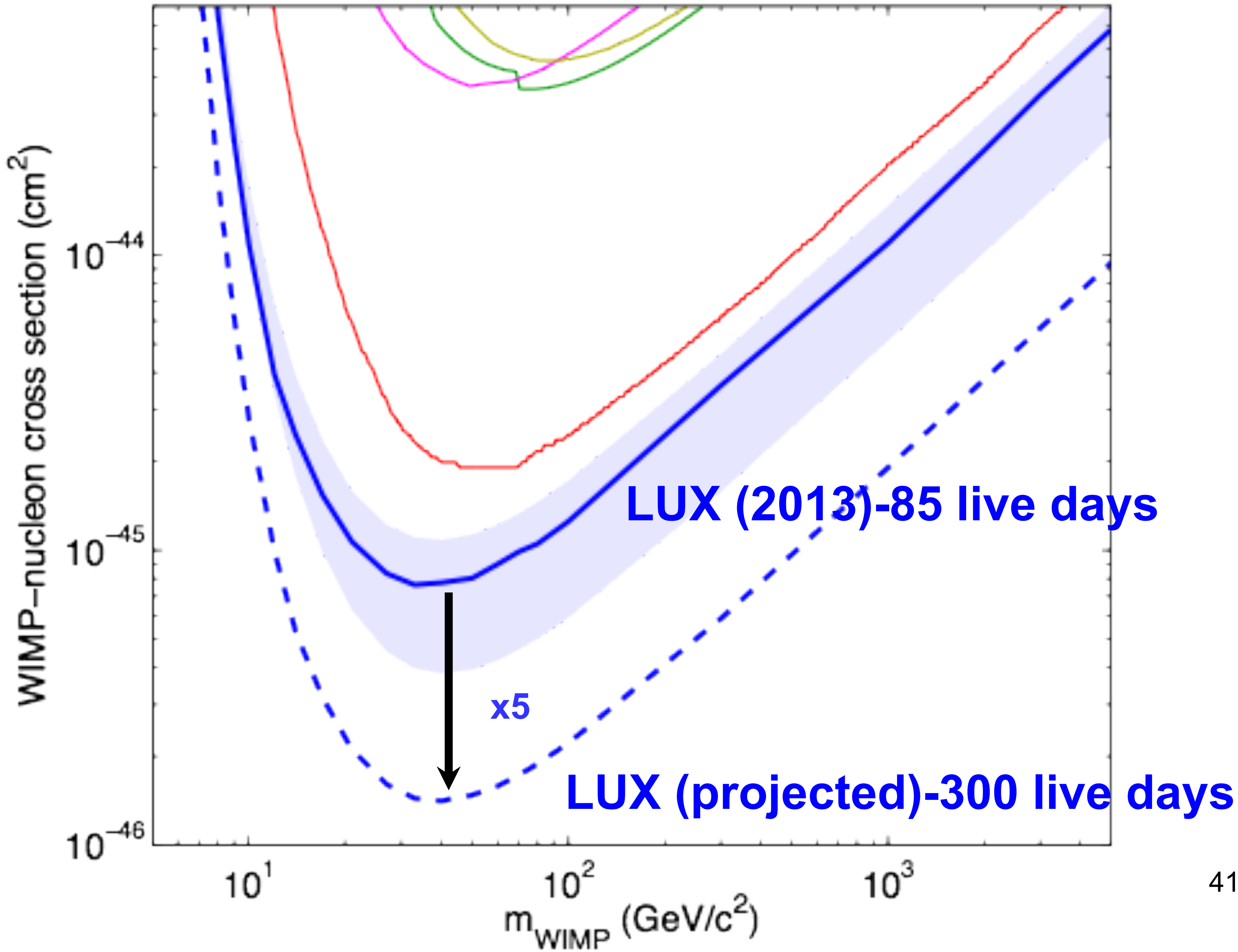
LUX WIMP search data



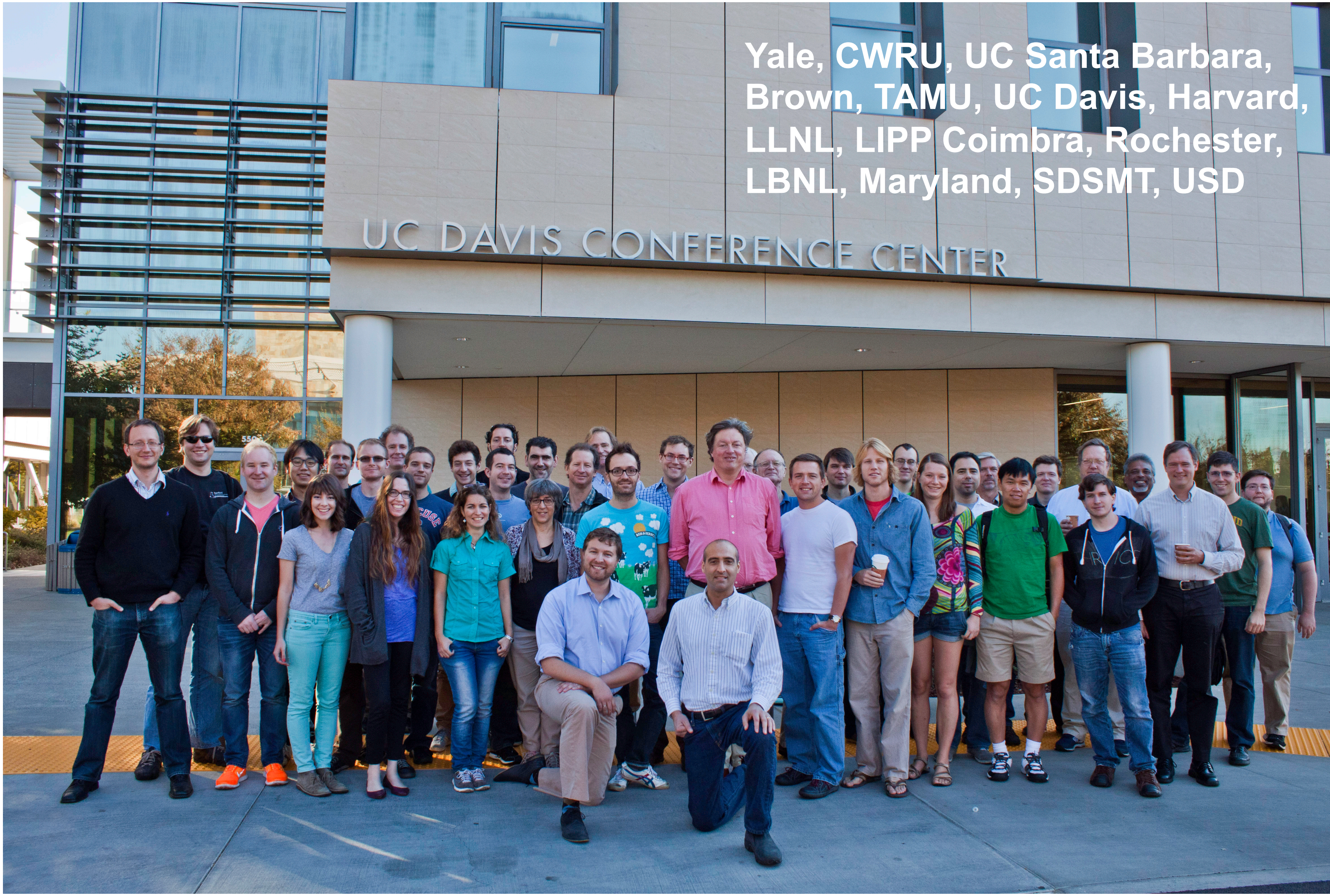
LUX 90% C.L. exclusion limits



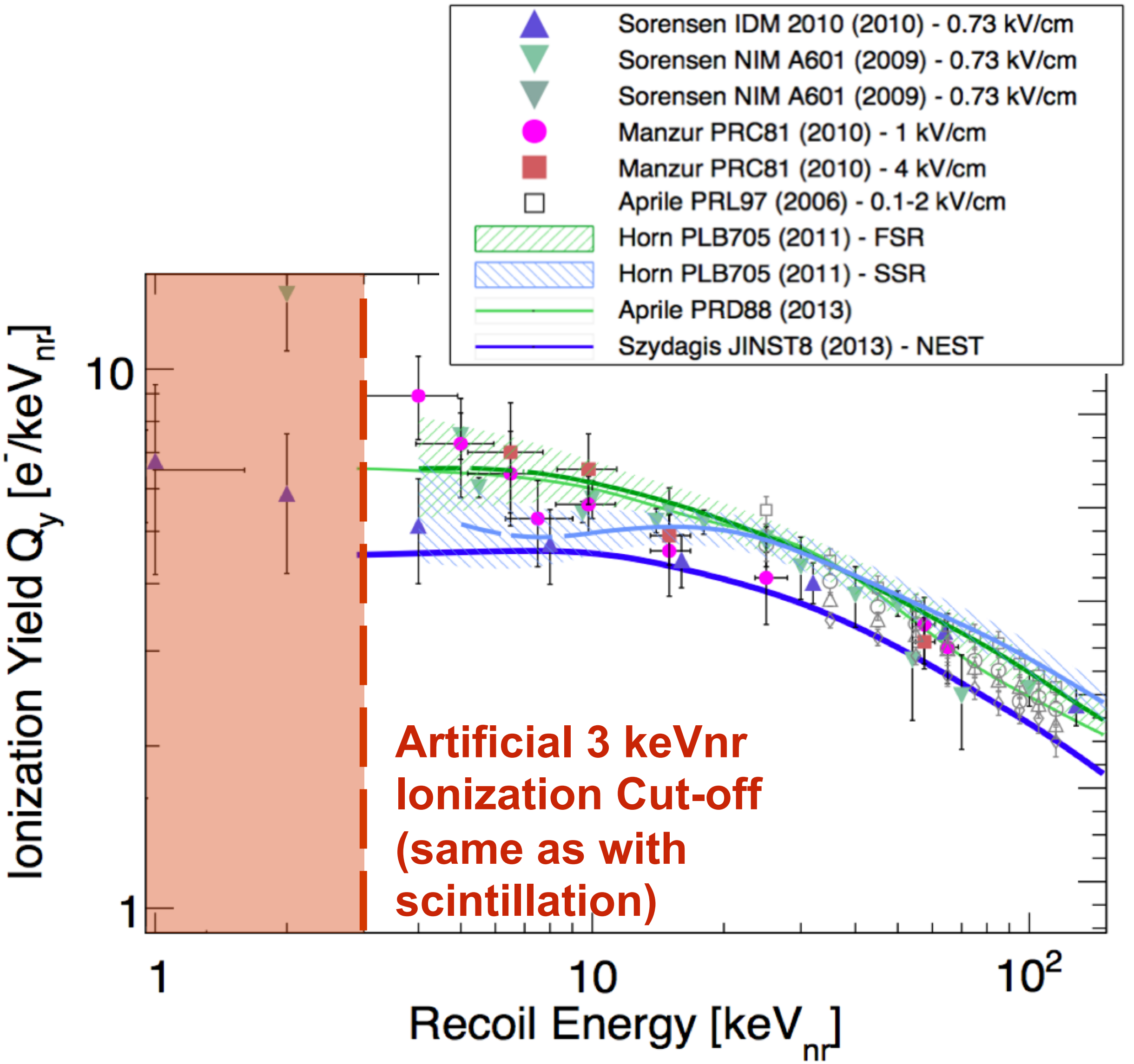
Projected LUX 300 day WIMP search



LUX Collaboration

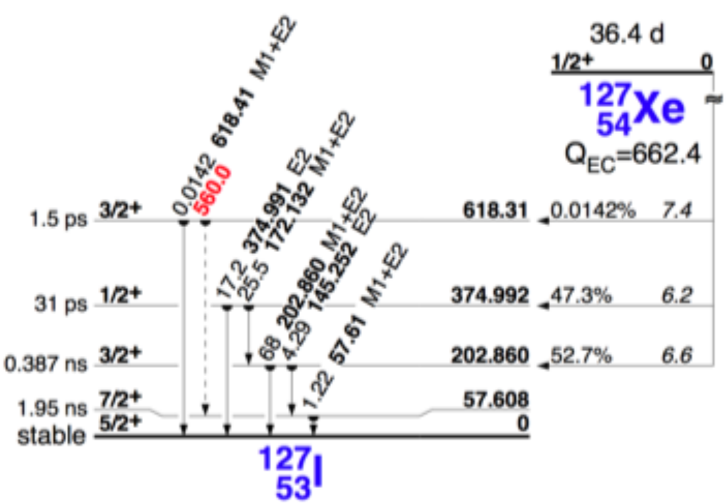


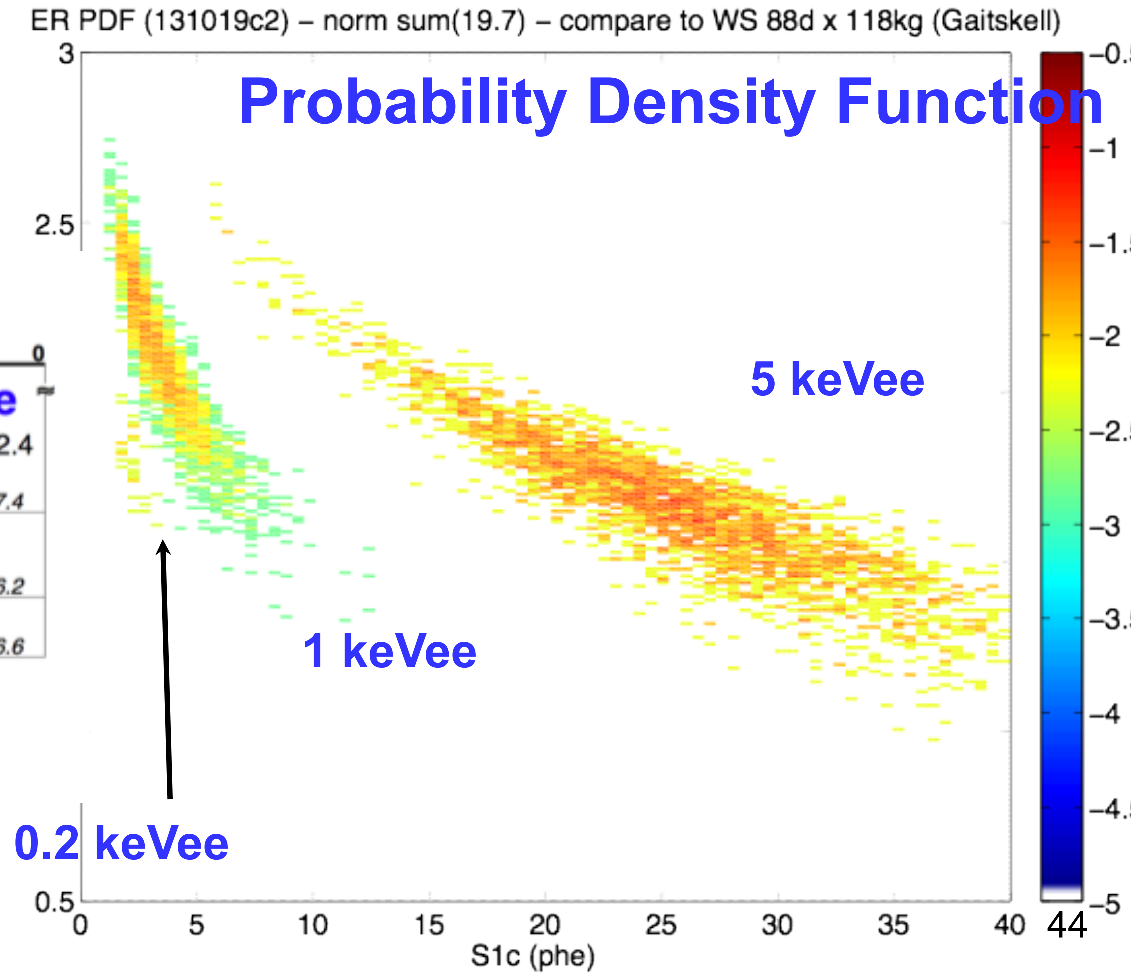
Charge Yield



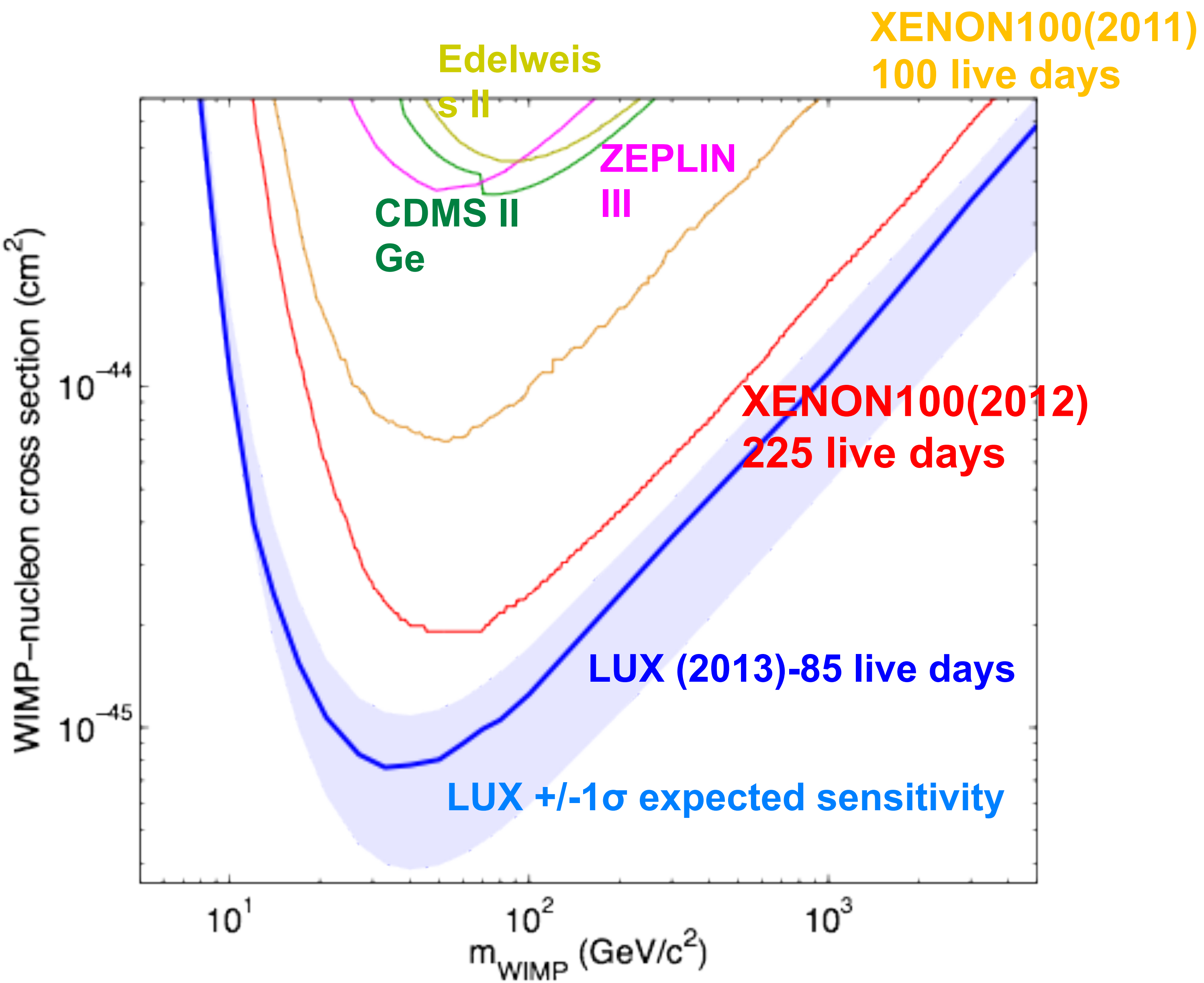
^{127}Xe Electron Capture - Simulation

- **x-ray line emission in center of detector following full escape of gamma associated with nuclear excited state**

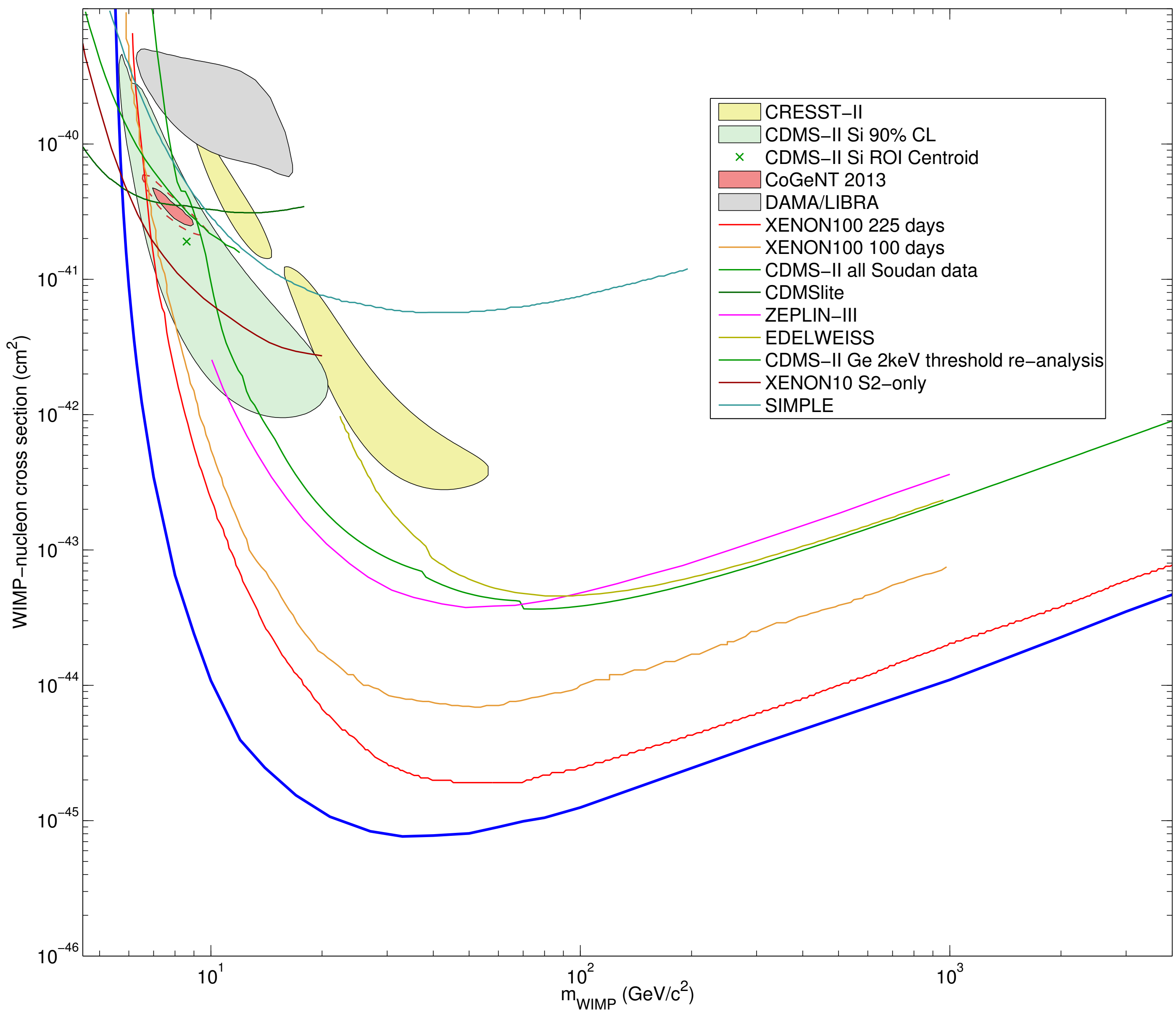




LUX 90% C.L. exclusion limits – high mass

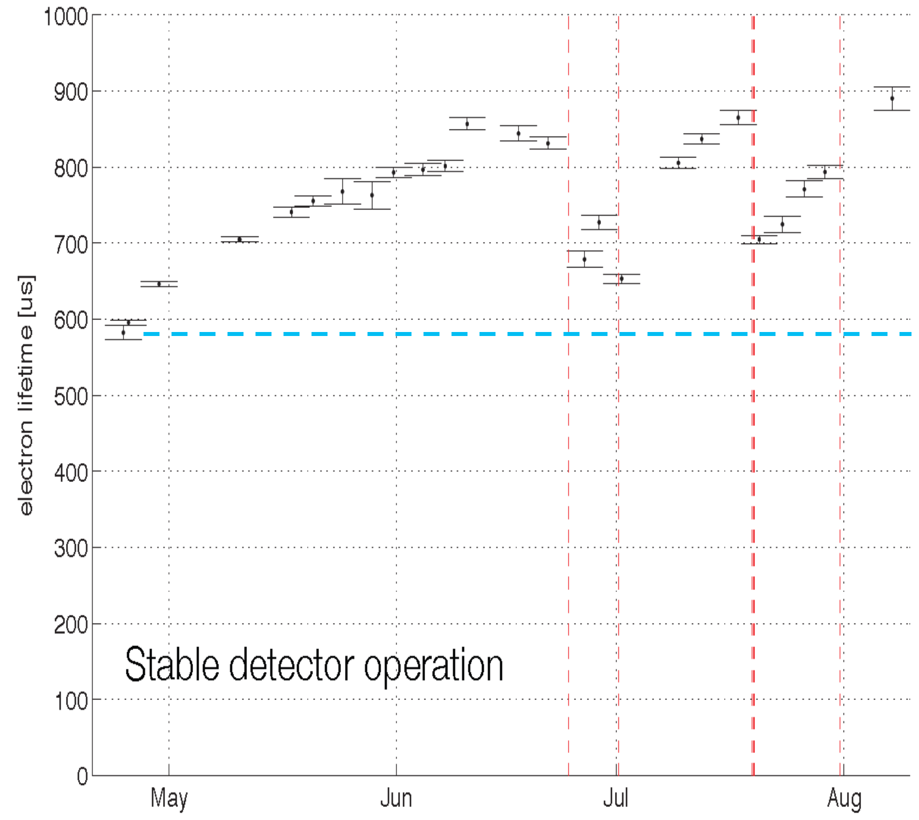


LUX 90% C.L. exclusion limits



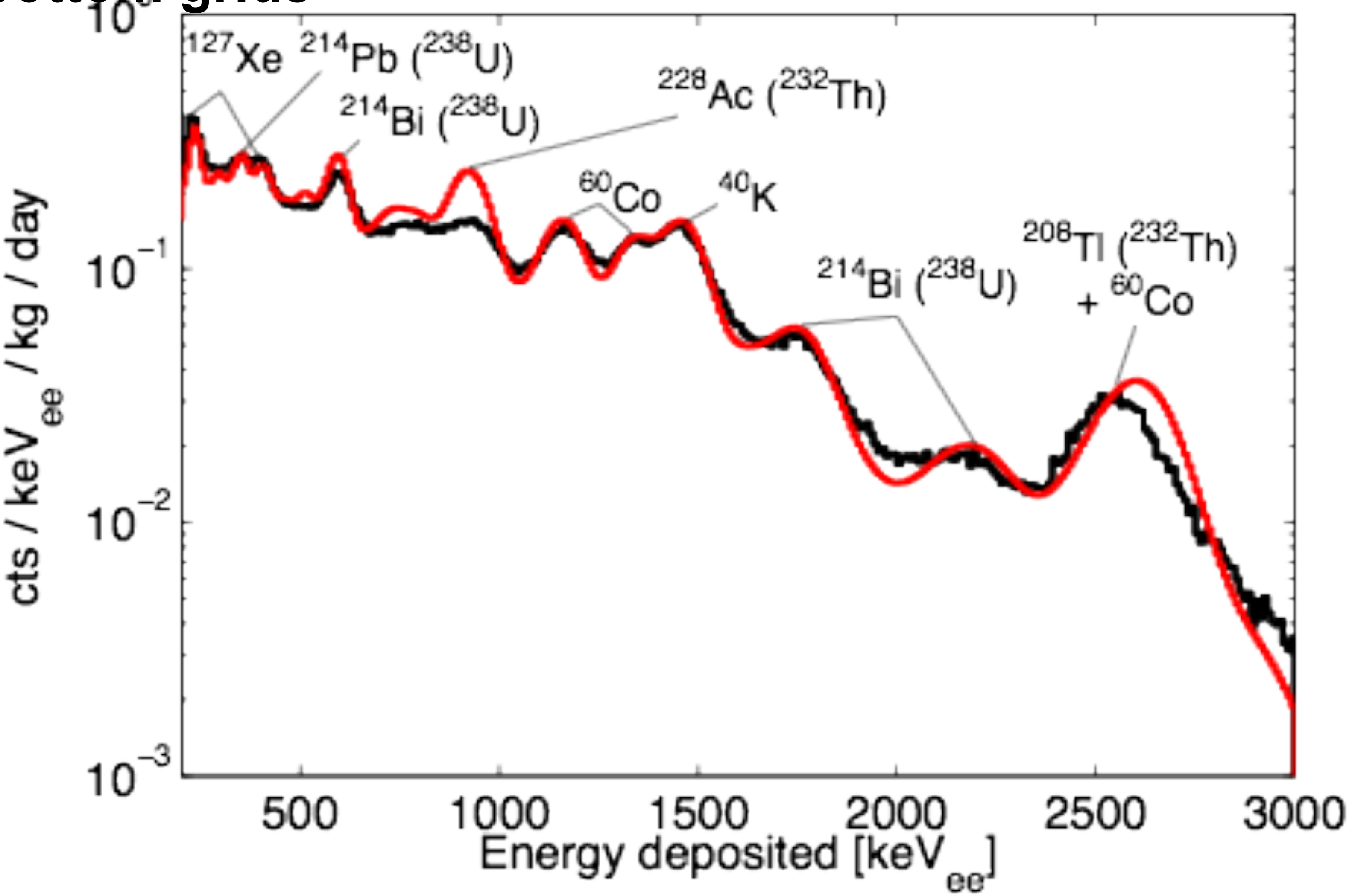
LUX - Run Parameters Overview

- Xenon Purity: electron drift length 87 – 135 cm during Run 3
  - Circulation at 250 kg / day
  - Monitored weekly using ^{83m}Kr data
- Light collection efficiency: 14%
  - Incl. geometry and PMT QE
  - ^{83m}Kr data provides 3D corrections
- Drift field: 181 V/cm
  - Drift speed 1.51 ± 0.01 mm / ms
  - ER discrimination 99.6%
- Electron extraction efficiency: 64%
- Fiducial mass: 118.3 ± 6.5 kg
  - Defined by edges a background
  - Measured with homogeneous ER calibration data… ^{83m}Kr, again!



LUX Run 3 – Background Levels

- Full gamma spectrum, excluding region ±2 cm from top/ bottom grids

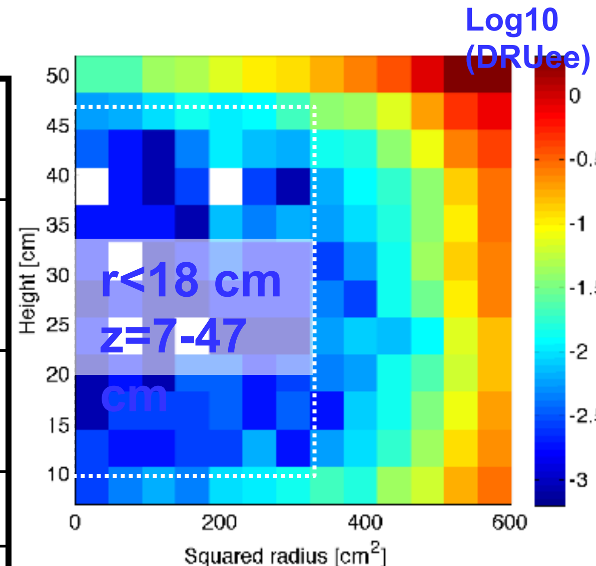


LUX Run 3 – Background Levels

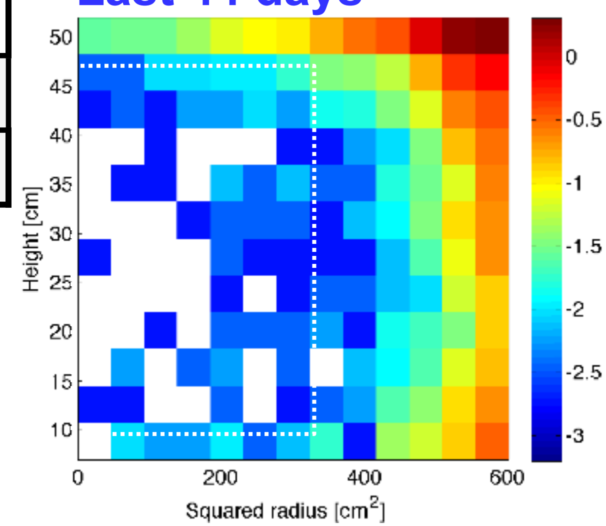
Background Component	Source	10^{-3} x evts/keVee/kg/day
Gamma-rays	Internal Components including PMTS (80%), Cryostat, Teflon	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe (36.4 day half-life)	Cosmogenic 0.87 -> 0.28 during run	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	^{222}Rn	0.11-0.22(90% CL)
^{85}Kr	Reduced from 130 ppb to 3.5 ± 1 ppt	$0.13 \pm 0.07_{sys}$
Predicted	Total	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Observed	Total	$3.1 \pm 0.2_{stat}$

- Dedicated publication is coming

ER < 5 keVee in 118 kg



Last 44 days



LUX Run 3 – Data Selection

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 (R,Z)t cut	Radius < 18 cm, 38 < drift time < 305 us, 118 kg fiducial	160

LUX 90% C.L. exclusion limits