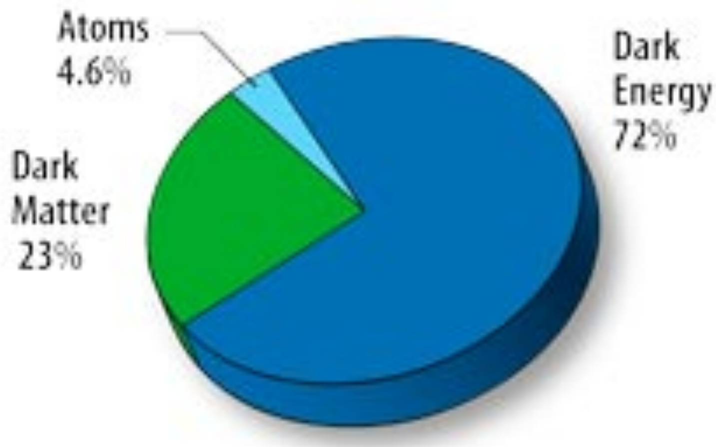
Searching for Dark Matter with the LUX and LZ Detectors

Bob Webb, Texas A&M University
(for the LUX and LZ Collaborations)

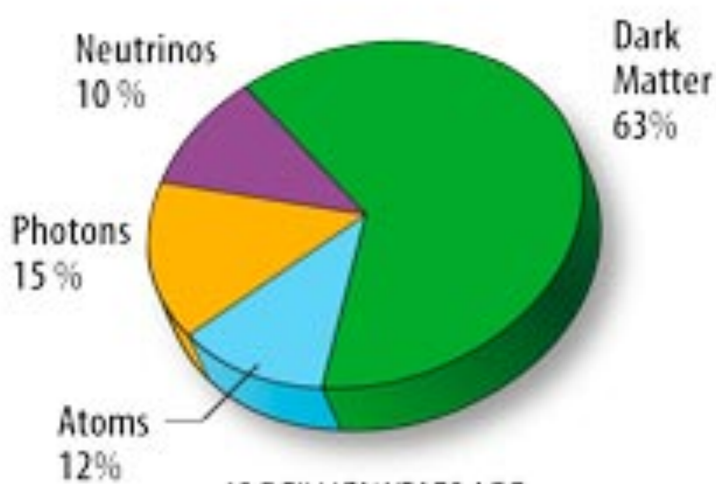
Workshop on Collider Physics and Dark Matter
Mitchell Institute, TAMU
May 21, 2015

Outline

- Direct searches for Dark Matter (WIMPs)
- The LUX detector
- Overview of two phase TPC detectors
- Current LUX results
- Future prospects with the next generation DM detector, LZ



TODAY



13.7 BILLION YEARS AGO
(Universe 380,000 years old)

Direct Detection of Big Bang WIMPs

Goals:

- ✖ Directly Detect WIMPs as Earth plows through the DM Halo
- ✖ Measure Mass and Scattering cross-section

Challenges:

- ✖ Very low flux & rate
- ✖ Must maintain ultra low background < few events/year/kg

The
Large Underground Xenon Experiment

The LUX Collaboration

TEXAS A&M UNIVERSITY

Brown

Richard Gaitskell	PI, Professor
Simon Fiorucci	Research Associate
Monica Pangilinan	Postdoc
Jeremy Chapman	Graduate Student
David Malling	Graduate Student
James Verbus	Graduate Student
Samuel Chung Chan	Graduate Student
Dongqing Huang	Graduate Student

Case Western

Thomas Shutt	PI, Professor
Dan Akerib	PI, Professor
Karen Gibson	Postdoc
Tomasz Biesiadzinski	Postdoc
Wing H To	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student
Kati Pech	Graduate Student

Imperial College London

Henrique Araujo	PI, Reader
Tim Sumner	Professor
Alastair Currie	Postdoc
Adam Bailey	Graduate Student

Lawrence Berkeley + UC Berkeley

Bob Jacobsen	PI, Professor
Murdock Gilchriese	Senior Scientist
Kevin Lesko	Senior Scientist
Carlos Hernandez Faham	Postdoc
Victor Gehman	Scientist
Mia Ihm	Graduate Student

Lawrence Livermore

Adam Bernstein	PI, Leader of Adv. Detectors Group
Dennis Carr	Mechanical Technician
Kareem Kazkaz	Staff Physicist
Peter Sorensen	Staff Physicist
John Bower	Engineer

LIP Coimbra

Isabel Lopes	PI, Professor
Jose Pinto da Cunha	Assistant Professor
Vladimir Solovov	Senior Researcher
Luiz de Viveiros	Postdoc
Alexander Lindote	Postdoc
Francisco Neves	Postdoc
Claudio Silva	Postdoc

SD School of Mines

Xinhua Bai	PI, Professor
Tyler Liebsch	Graduate Student
Doug Tiedt	Graduate Student

SDSTA

David Taylor	Project Engineer
Mark Hanhardt	Support Scientist

Texas A&M

James White †	PI, Professor
Robert Webb	PI, Professor
Rachel [illegible]	Graduate Student

UC Davis

Mani Tripathi	PI, Professor
Bob Svoboda	Professor
Richard Lander	Professor
Britt Holbrook	Senior Engineer
John Thomson	Senior Machinist
Ray Gerhard	Electronics Engineer
Aaron Manalaysay	Postdoc
Matthew Szydagis	Postdoc
Richard Ott	Postdoc
Jeremy Mock	Graduate Student
James Morad	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student
Sergey Uvarov	Graduate Student
Brian Lenardo	Graduate Student

UC Santa Barbara

Harry Nelson	PI, Professor
Mike Witherell	Professor
Dean White	Engineer
Susanne Kyre	Engineer
Carmen Carmona	Postdoc
Curt Nehrkorn	Graduate Student
Scott Haselschwardt	Graduate Student

University College London

Chamkaur Ghag	PI, Lecturer
Lea Reichhart	Postdoc

University of Edinburgh

Alex Murphy	PI, Reader
Paolo Beltrame	Research Fellow
James Dobson	Postdoc

University of Maryland

Carter Hall	PI, Professor
Attila Dobi	Graduate Student
Richard Knoche	Graduate Student
Jon Balajthy	Graduate Student

University of Rochester

Frank Wolfs	PI, Professor
Wojtek Skutski	Senior Scientist
Eryk Druszkiewicz	Graduate Student
Mongkol Moongweluwan	Graduate Student

University of South Dakota

Dongming Mei	PI, Professor
Chao Zhang	Postdoc
Angela Chiller	Graduate Student
Chris Chiller	Graduate Student
Dana Byram	*Now at SDSTA

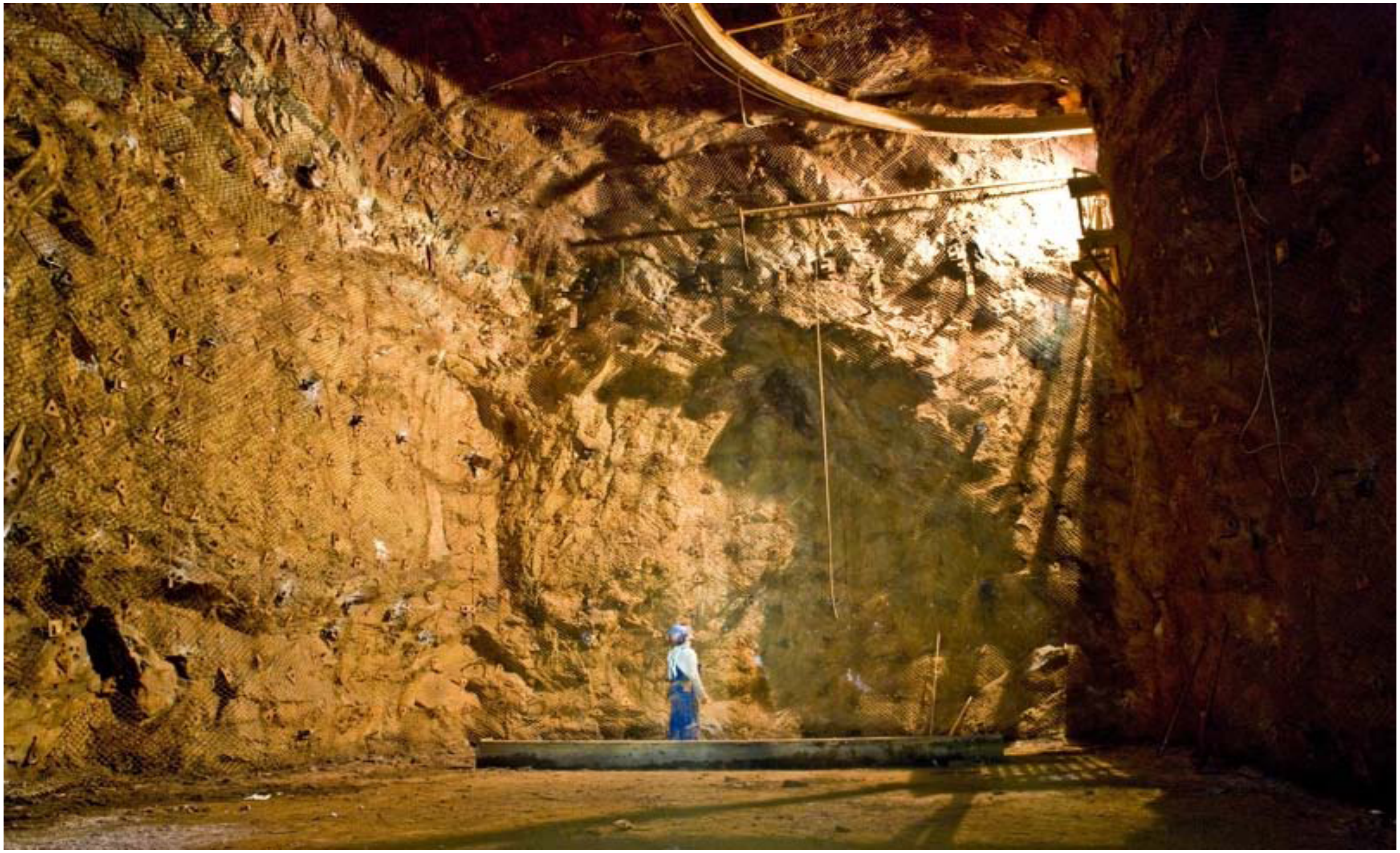
Yale

Daniel McKinsey	PI, Professor
Peter Parker	Professor
Sidney Cahn	Lecturer/Research Scientist
Ethan Bernard	Postdoc
Markus Horn	Postdoc
Blair Edwards	Postdoc
Scott Hertel	Postdoc
Kevin O'Sullivan	Postdoc
Nicole Larsen	Graduate Student
Evan Pease	Graduate Student
Brian Tennyson	Graduate Student
Ariana Hackenburg	Graduate Student
Elizabeth Boulton	Graduate Student

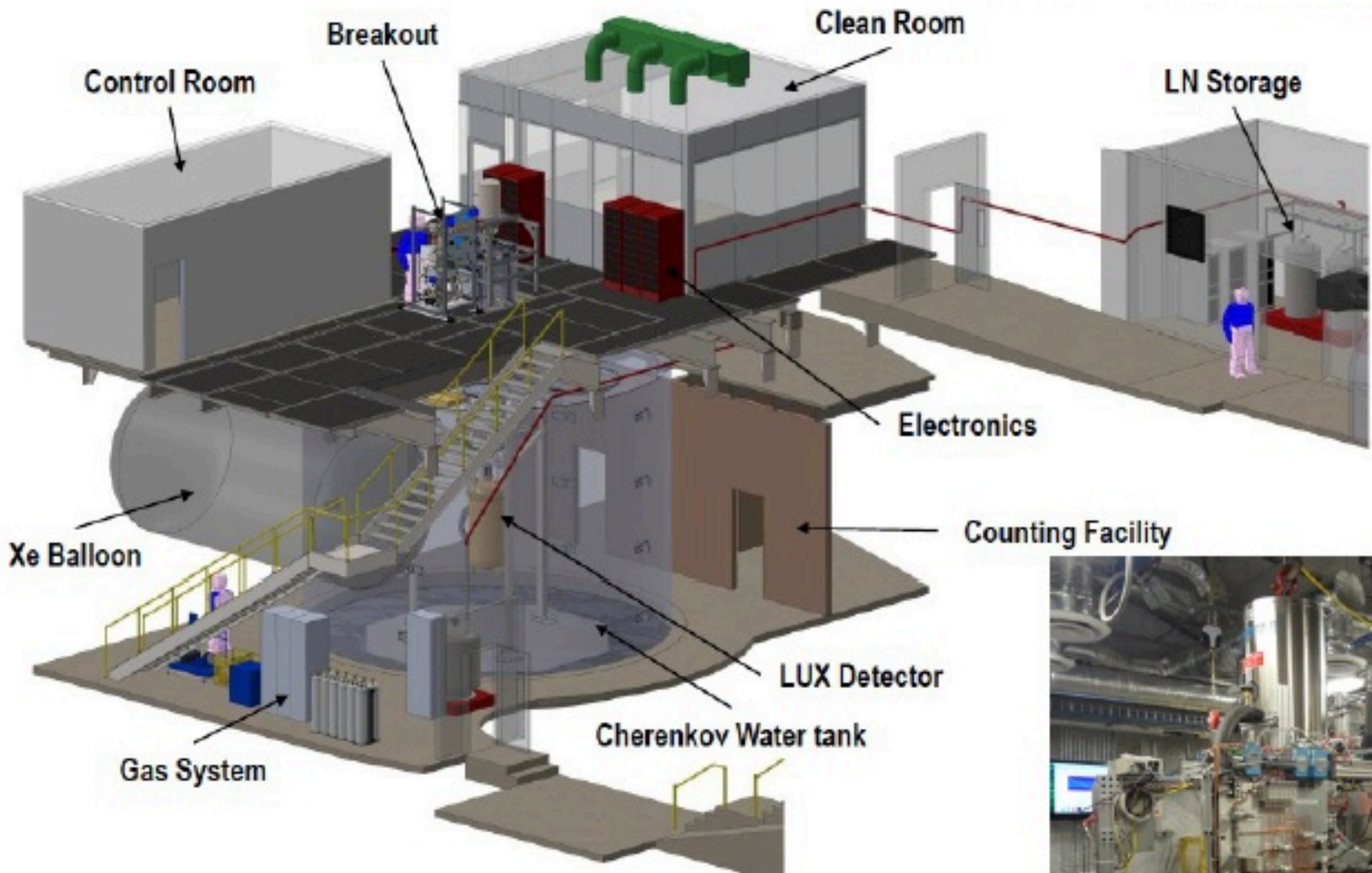
SURF above ground

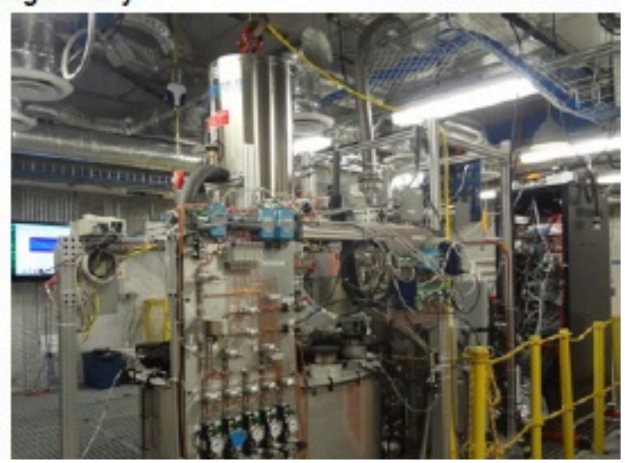
The Davis Underground Campus

Davis cavern after tank removed



The Davis Campus



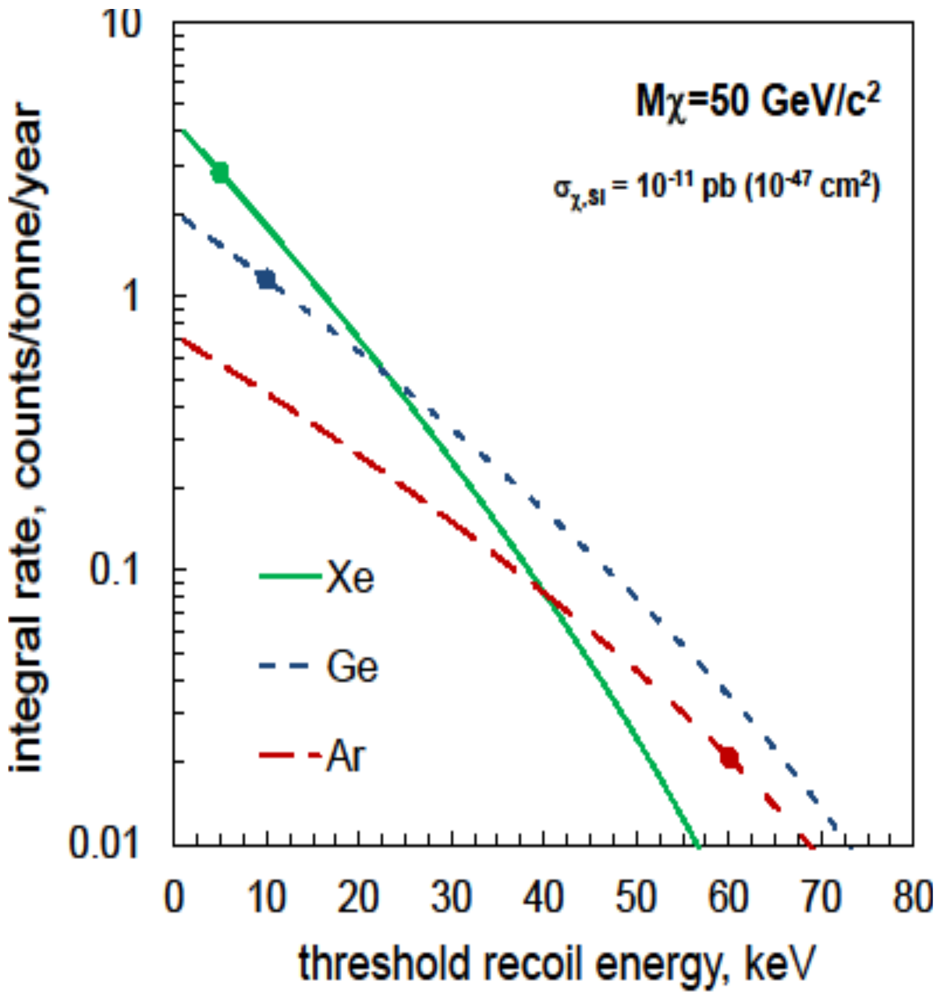


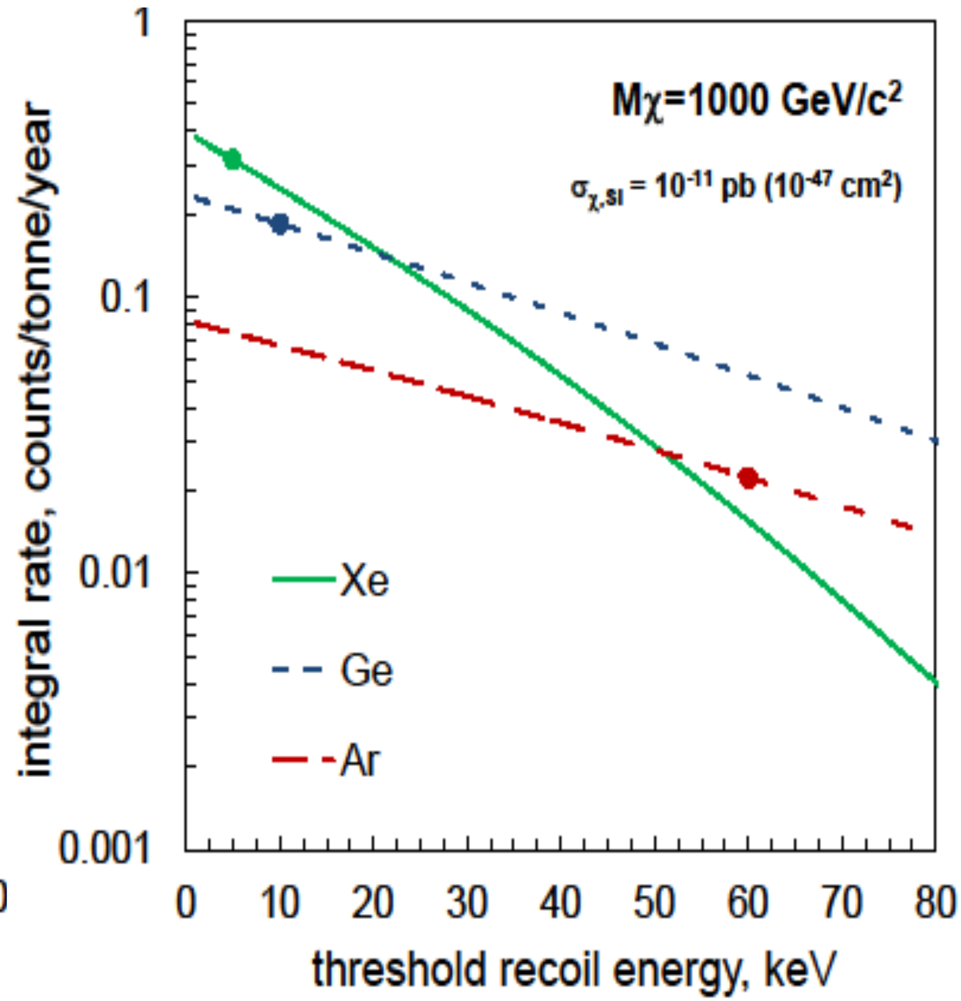
Why Xenon?

- Scintillates, comparison with ionization allows `discrimination' of signal and background
- Plenty of signal ≈1 keV
- Liquid ρ≈3 gm/cm^3, purity
- No long-lived radioisotopes
- 9 stable isotopes
- 2 with odd neutron

^AZ	$\tau_{1/2}$ or f	J^p
^{122}Xe	20 h	0^+
^{123}Xe	2.1 h	$(1/2)^+$
^{124}Xe	0.10 %	0^+
^{125}Xe	17 h	$(1/2)^+$
^{126}Xe	0.09 %	0^+
^{127}Xe	**36 d**	**$(1/2)^+$**
^{128}Xe	1.91 %	0^+
^{129}Xe	**26.4 %**	**$(1/2)^+$**
^{130}Xe	4.1 %	0^+
^{131}Xe	**21.2 %**	**$(3/2)^+$**
^{132}Xe	26.9 %	0^+
^{133}Xe	5.2 d	$(3/2)^+$
^{134}Xe	10.4 %	0^+
^{135}Xe	9.1 h	$(3/2)^+$
^{136}Xe	8.9 %	0^+

Per tonne, Xenon Most Sensitive (SI)



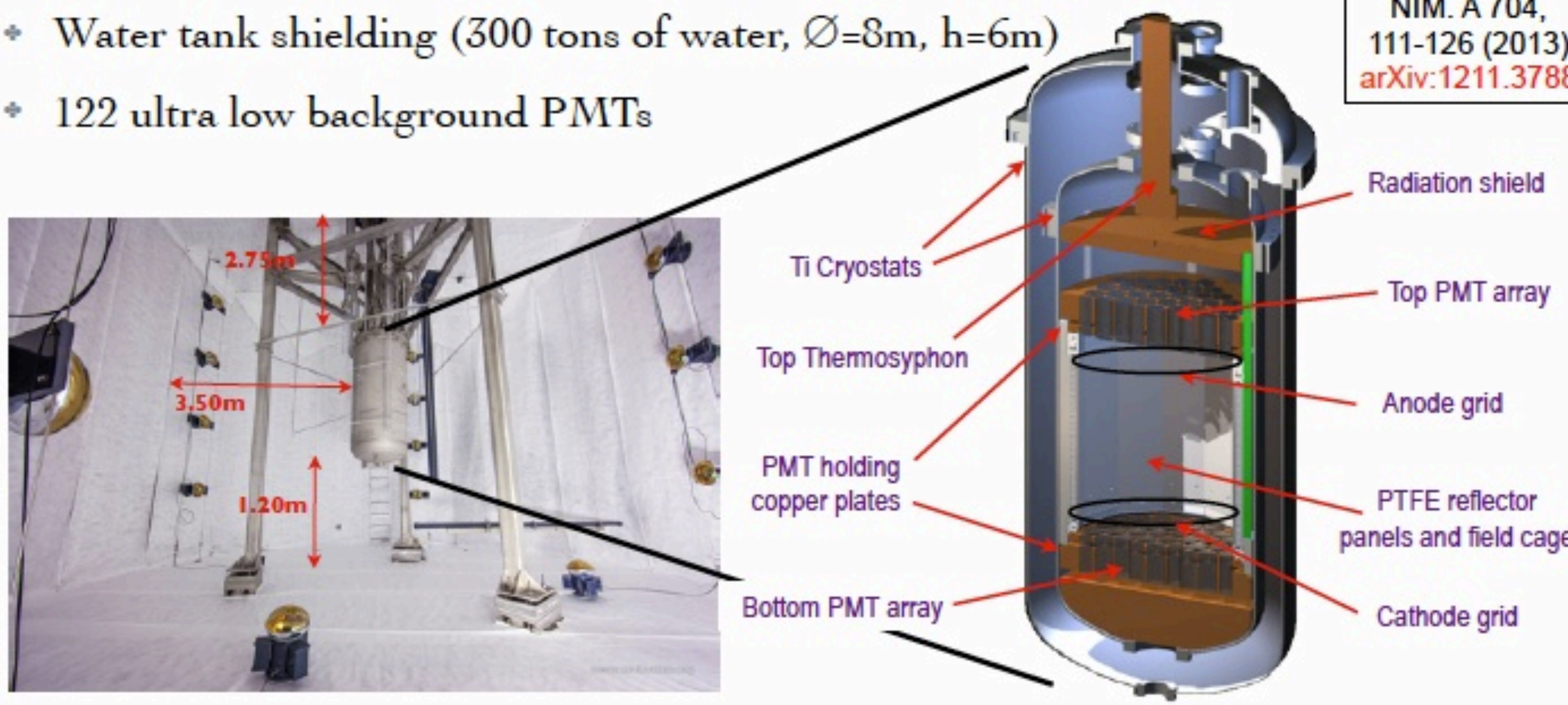


The LUX Detector

- 370 kg Xe TPC (active volume: 49 cm height, 47 cm diameter)
- Cooling system based on thermosyphons
- Heat exchanger system and high flow plumbing for rapid circulation through external purifier (229kg/day)
- Water tank shielding (300 tons of water, Ø=8m, h=6m)
- 122 ultra low background PMTs

Surface test:
Astr.Phys. 45, 34-43 (2013)
arXiv:1210.4569

LUX Detector:
NIM. A 704, 111-126 (2013)
arXiv:1211.3788



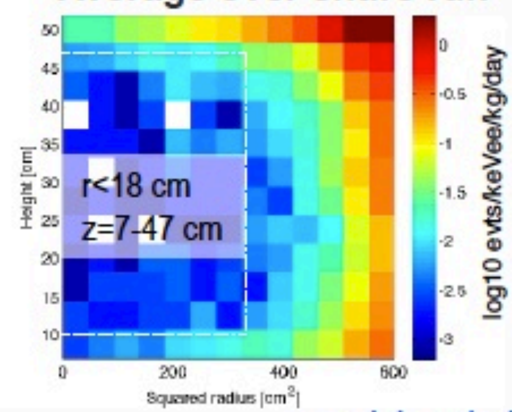
LUX Backgrounds

Dedicated publication: arXiv:1403.1299

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	$0.17 \pm 0.10_{sys}$
Predicted	Total	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Observed	Total	$3.6 \pm 0.3_{stat}$

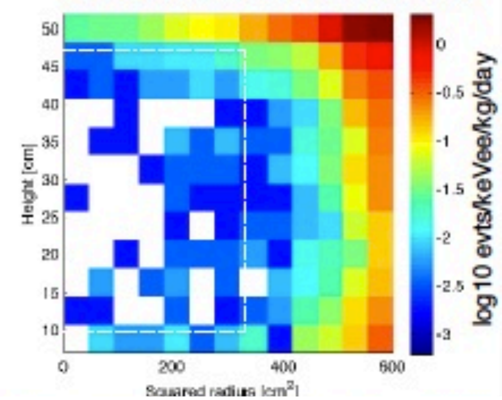
Event Rate for E < 5 keVee in 118 kg fiducial volume

Average over entire run



… and dropping!

Second half of the run

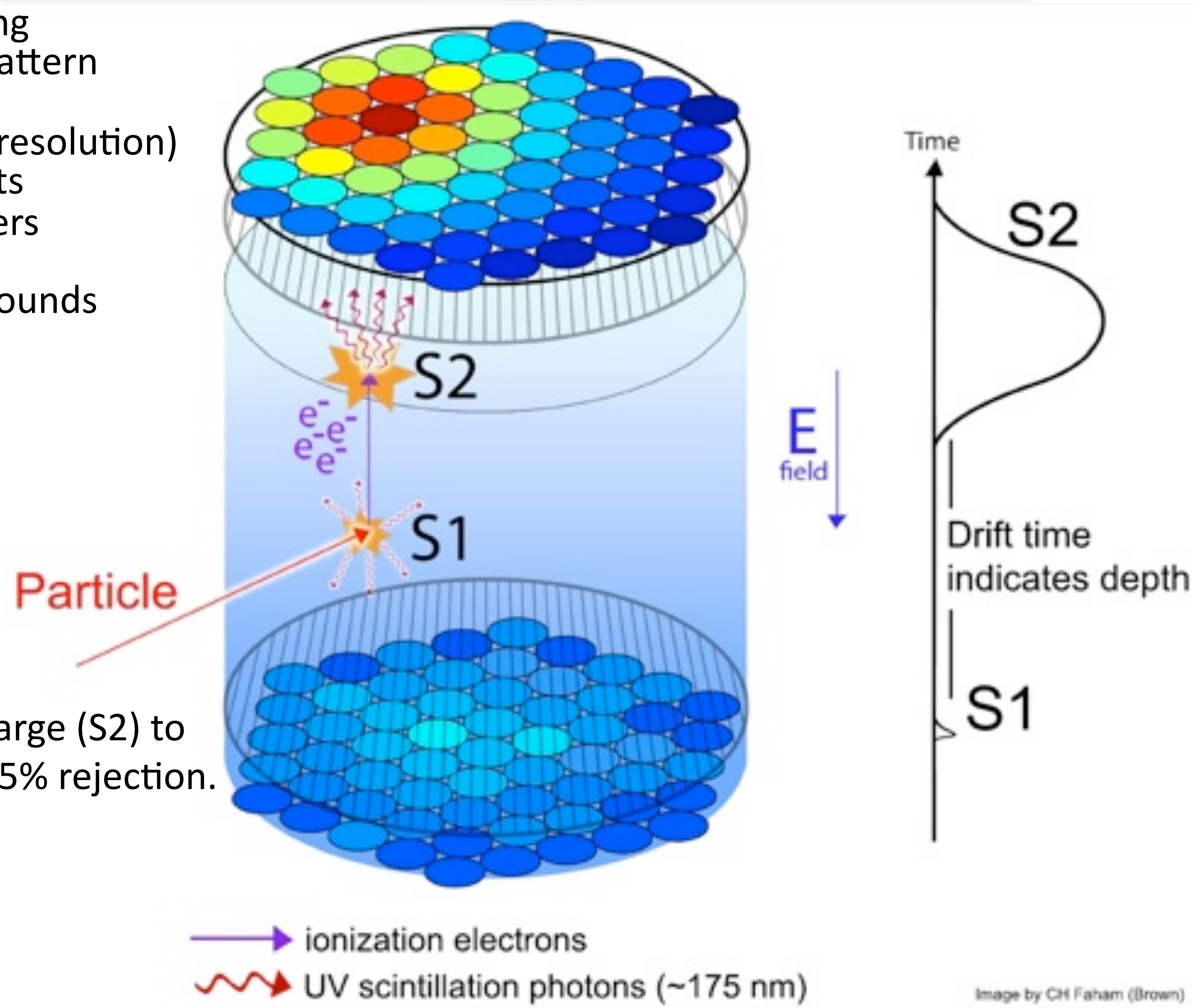


Two-phase Xenon WIMP Detectors

Z position from S1 – S2 timing
X-Y positions from S2 light pattern

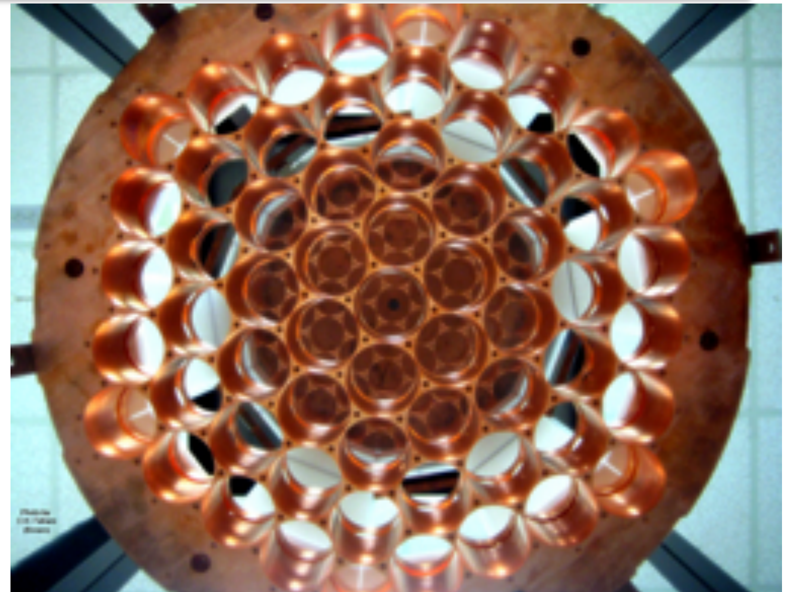
Excellent 3D imaging (~mm resolution)
- eliminates edge events
- rejects multiple scatters

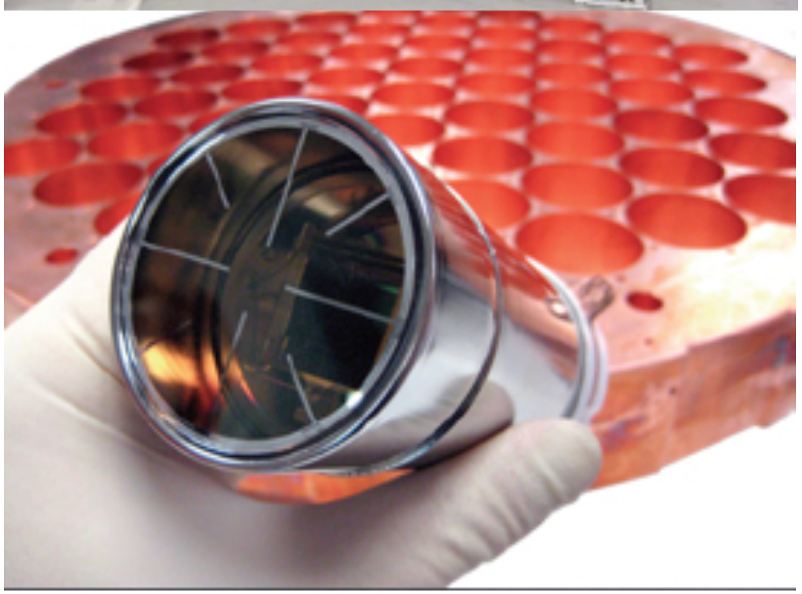
Gamma ray, neutron backgrounds reduced by self-shielding

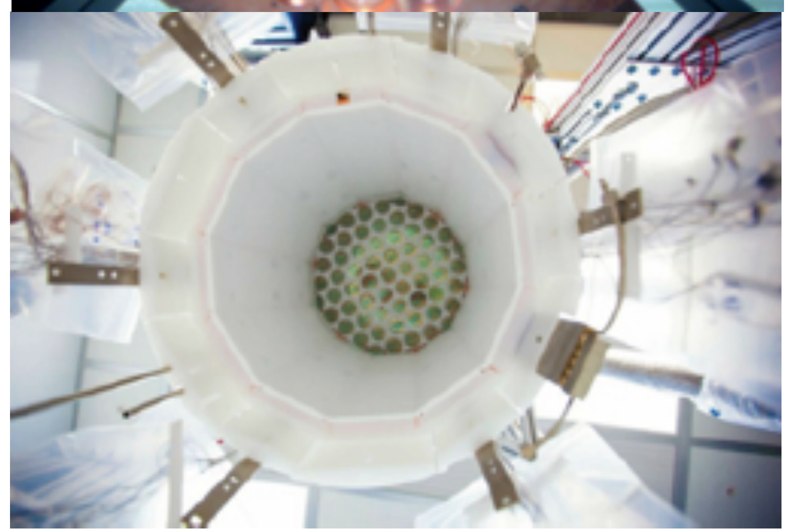


Reject gammas, betas by charge (S2) to light (S1) ratio. Expect > 99.5% rejection.

LUX – the Instrument

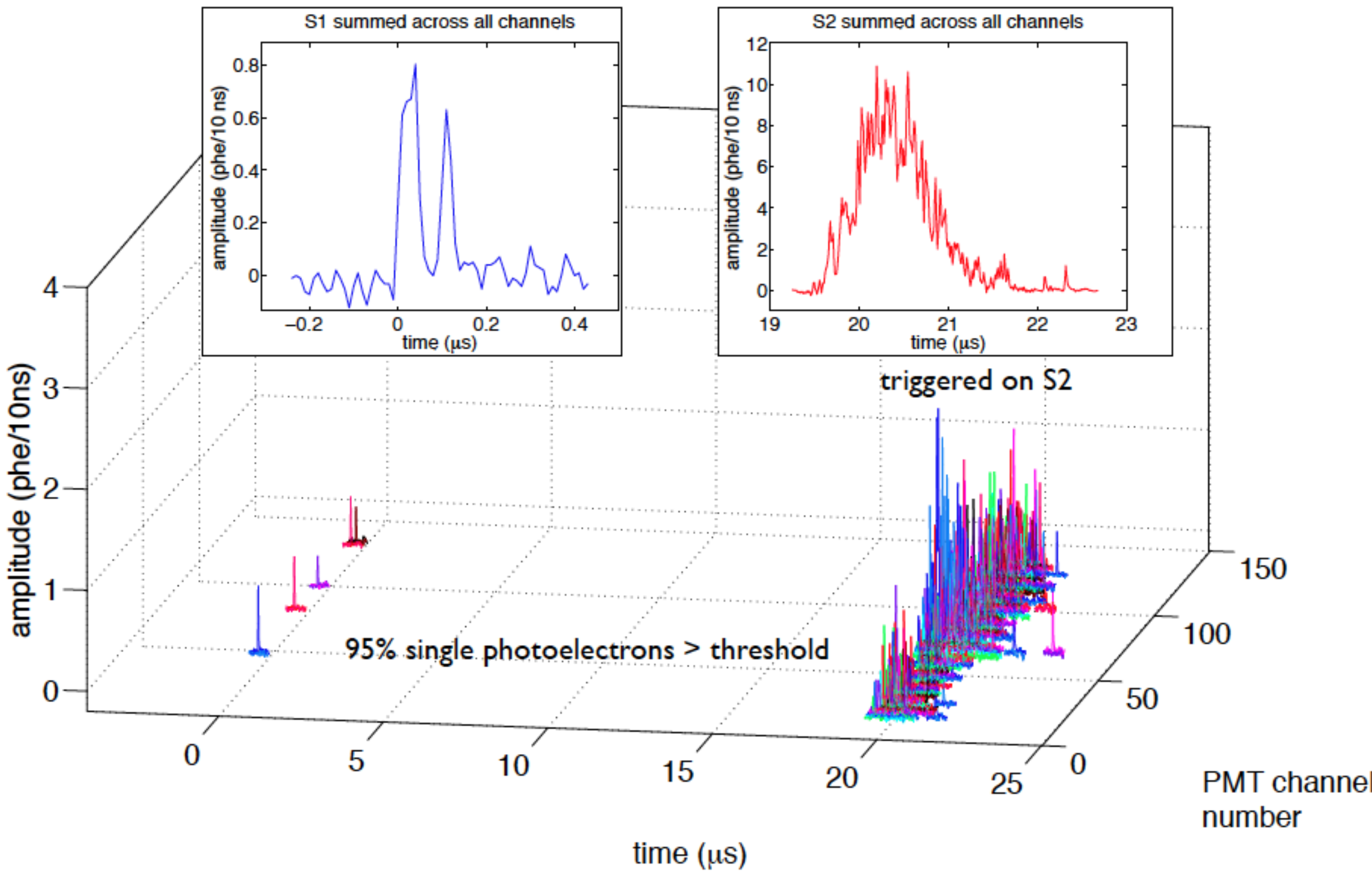






Typical Event in LUX

1.5 keV gamma ray scattering event



LUX Has Demonstrated Exceptional Technical Performance

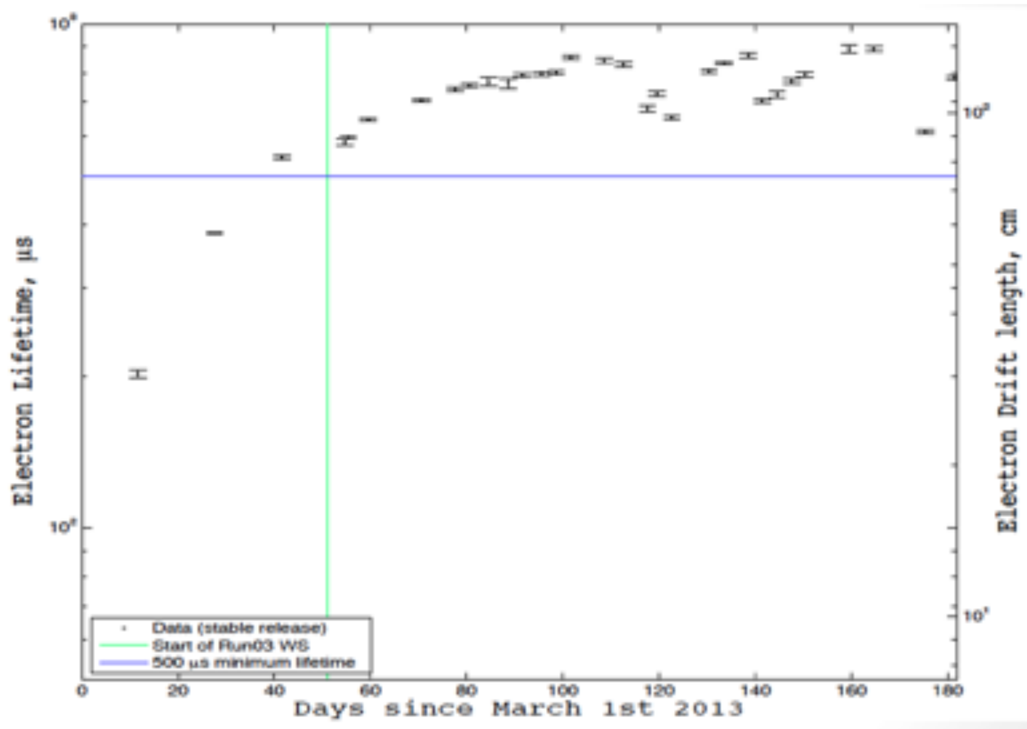
Low-energy electron recoil rate of 3e-3 events/keV/kg/day.

Kr/Xe ratio of 3.5 ppt.

Electron drift length longer than 130 cm.

Light detection efficiency of 14%.

Electron recoil discrimination of 99.6%, with drift field of 181 V/cm.



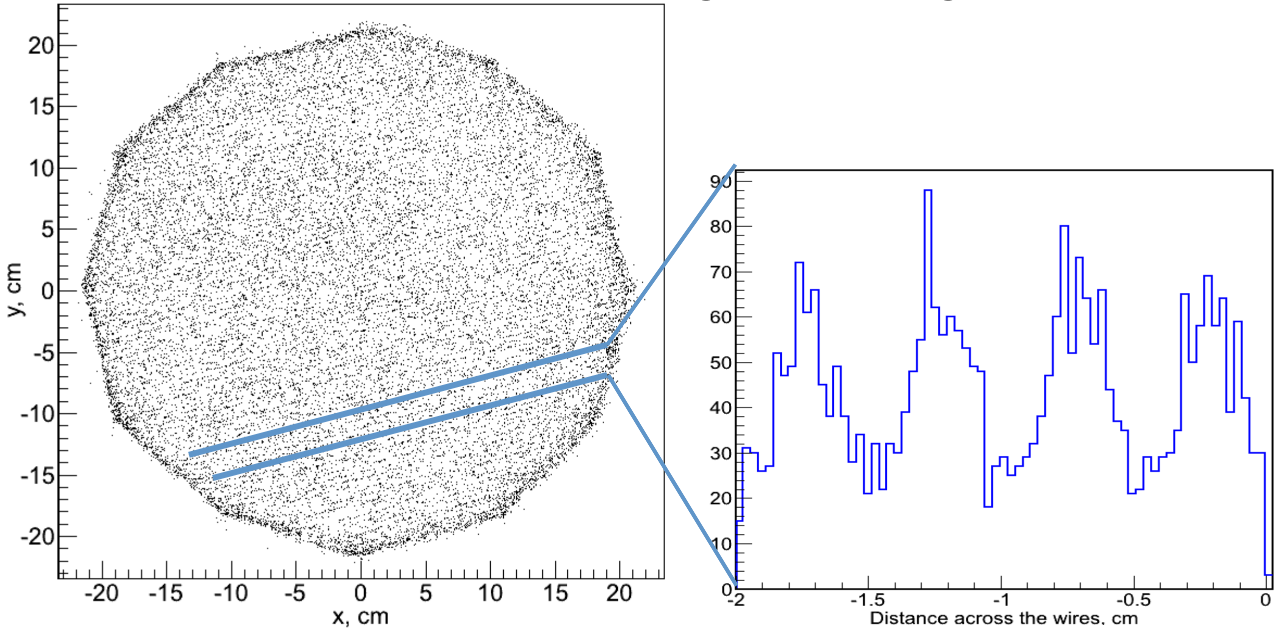
XYZ Position Reconstruction

Z coordinate is determined by the time between S1 and S2 (electron drift speed of 1.51 mm/microsecond)

Light Response Functions (LRFs) are found by iteratively fitting the distribution of S2 signal for each PMT.

XY position is determined by fitting the S2 hit pattern relative to the LRFs.

Reconstruction of XY from events near the anode grid resolves grid wires with 5 mm pitch.

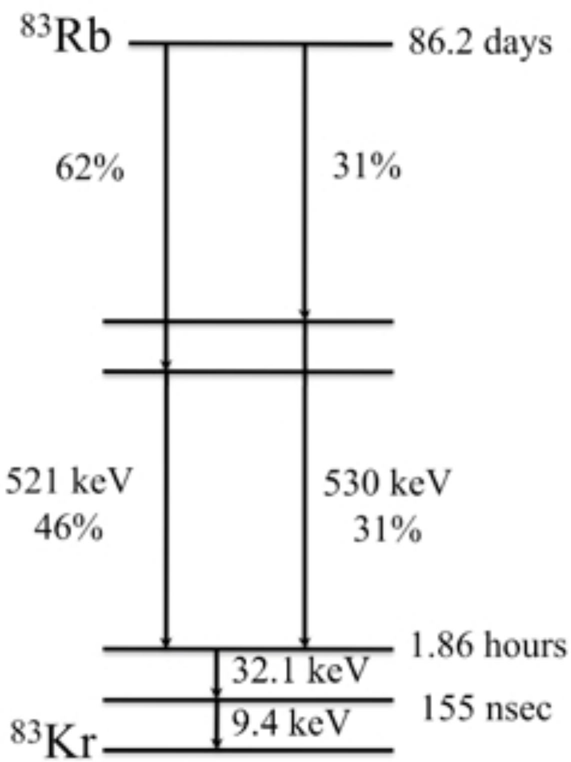


Various Calibrations

- Kr 83
- Tritiated Methane
- Sources- Cs, AmBe, Cf-252
- Most recently using neutrons from a DD generator

Energy Reconstruction - Kr-83m Calibration

- Rb-83 produces Kr-83m when it decays; this krypton gas can then be flushed into the LUX gas system to calibrate the detector as a function of position.
- Provides reliable, efficient, homogeneous calibration of both S1 and S2 signals, which then decays away in a few hours, restoring low-background operation..

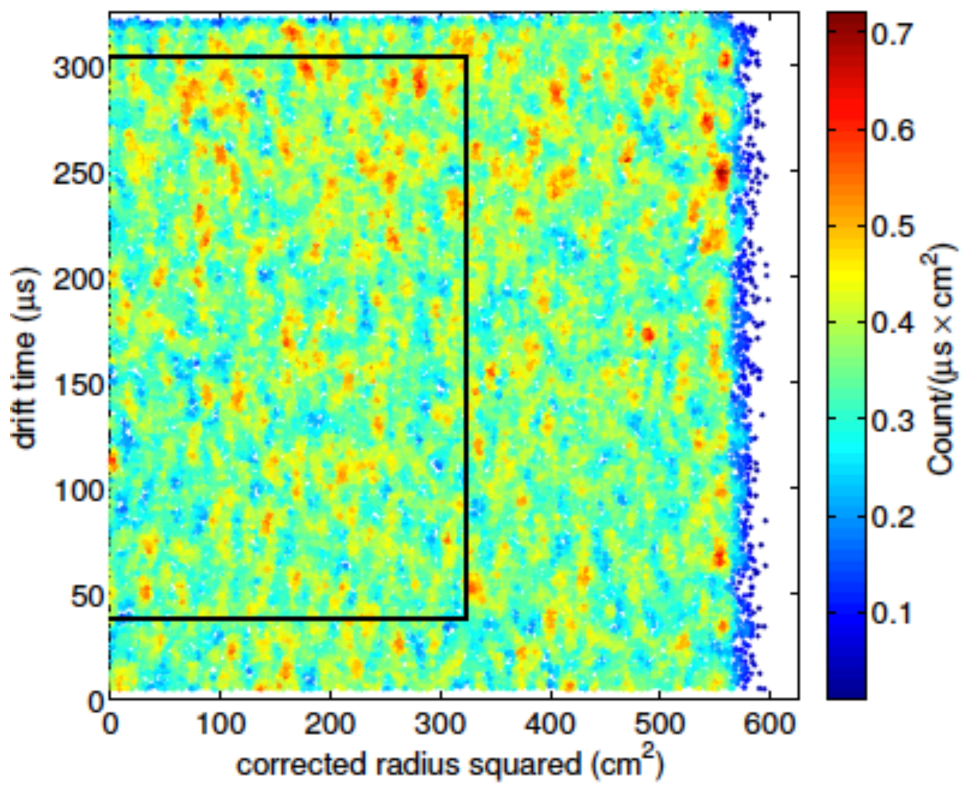


Kr-83m source (Rb-83 coated on charcoal, within xenon gas plumbing)

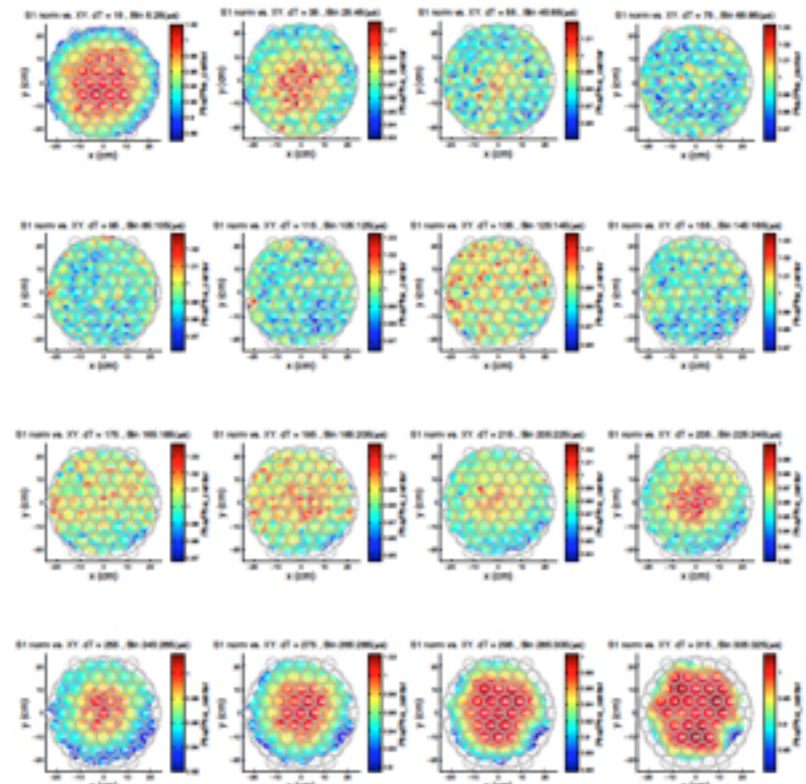
Kr-83m Calibration

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

Fiducial volume determination

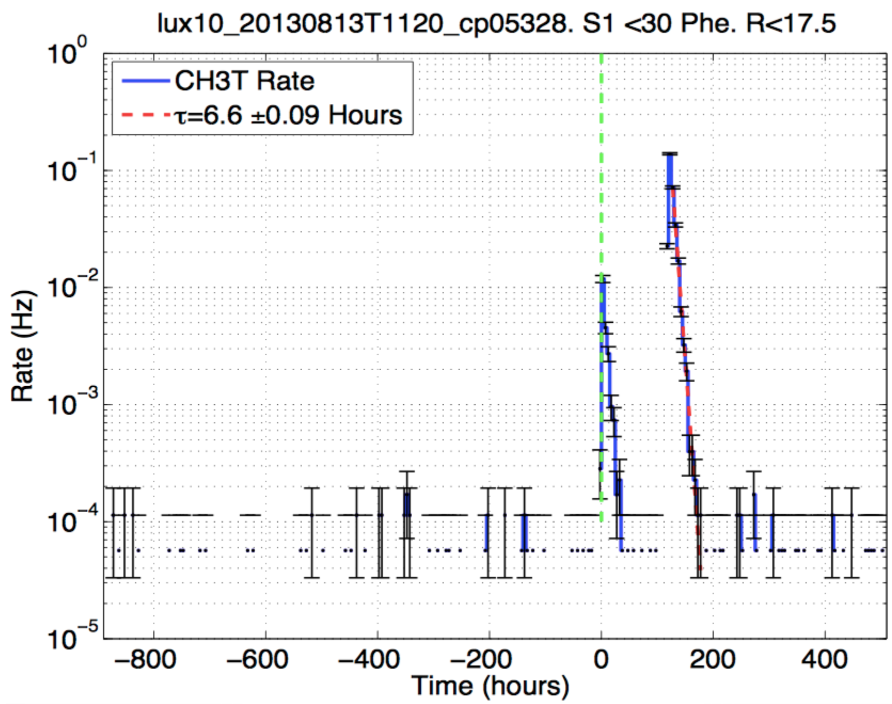


Position-based S1 corrections

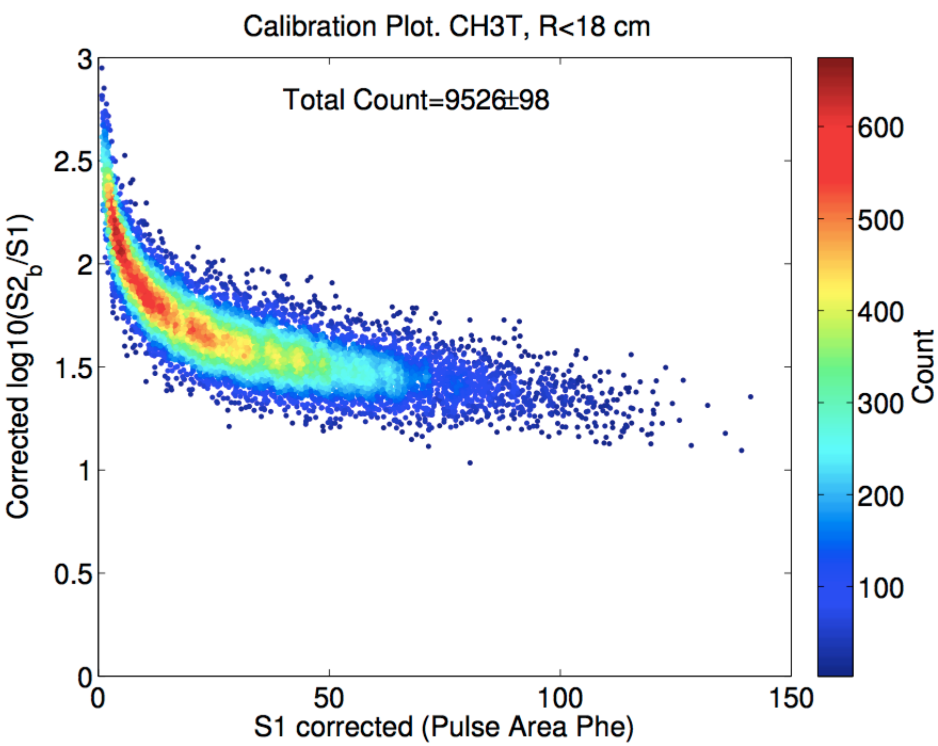


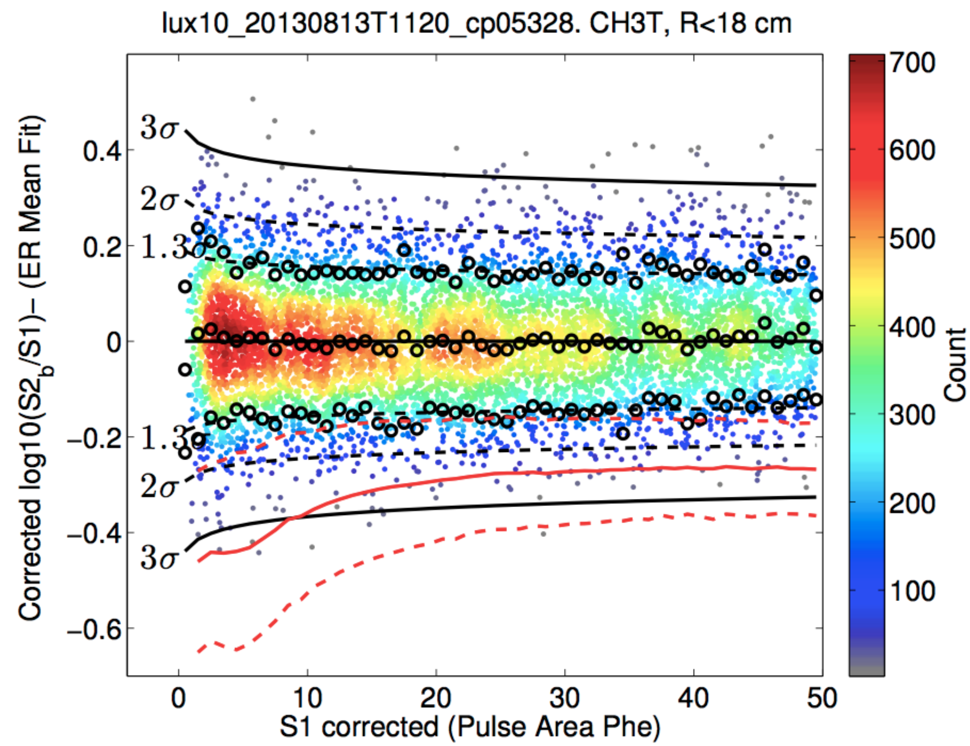
Tritiated Methane Calibration

- LUX uses tritiated methane, doped into the detector, to accurately calibrate the efficiency of background rejection.
- This beta source (endpoint energy 18 keV) allows electron recoil S2/S1 band calibration with unprecedented accuracy.
- The tritiated methane is then fully removed by circulating the xenon through the getter.
- Parametrization of the electron recoil band from the high-statistics tritiated methane data is then used to characterize the background model.



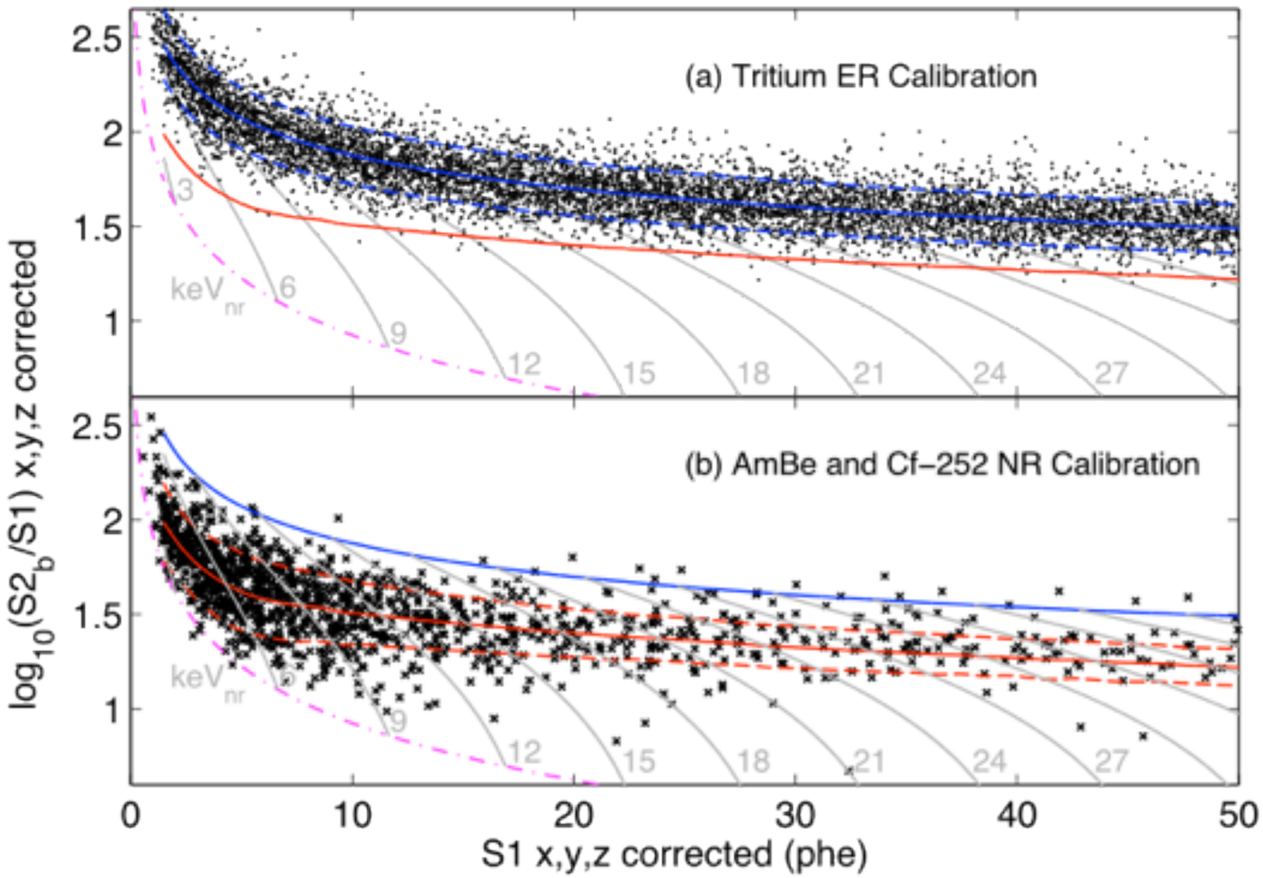
Tritiated Methane Data





Electron Recoil and Nuclear Recoil Bands

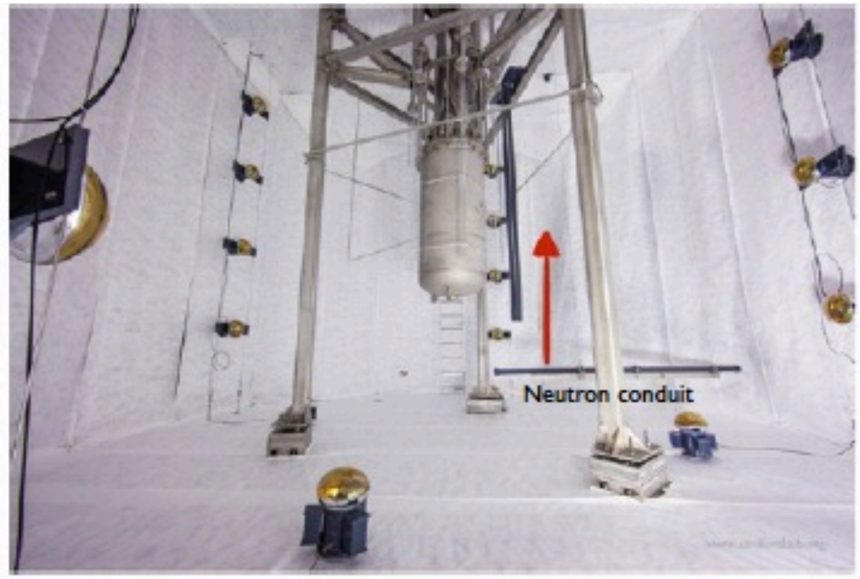
Tritium provides very high statistics electron recoil calibration (200 events/phe)
Neutron calibration is consistent with NEST + simulations

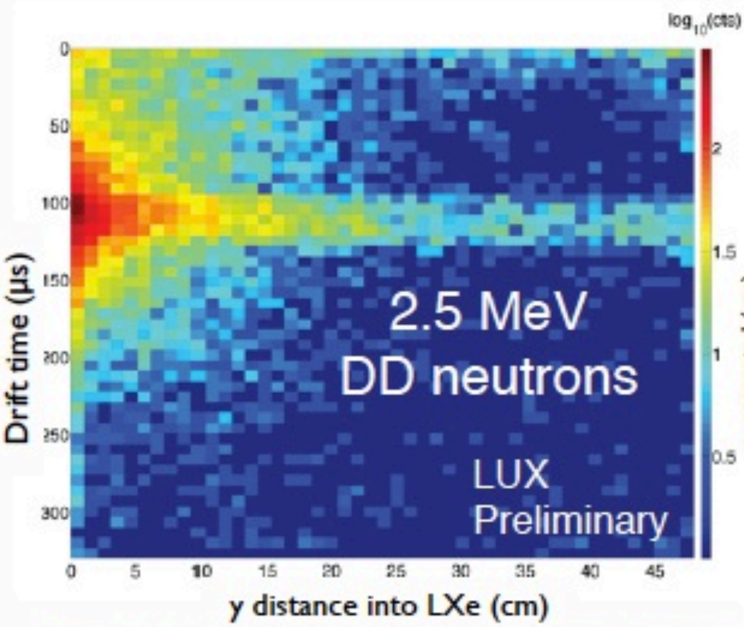


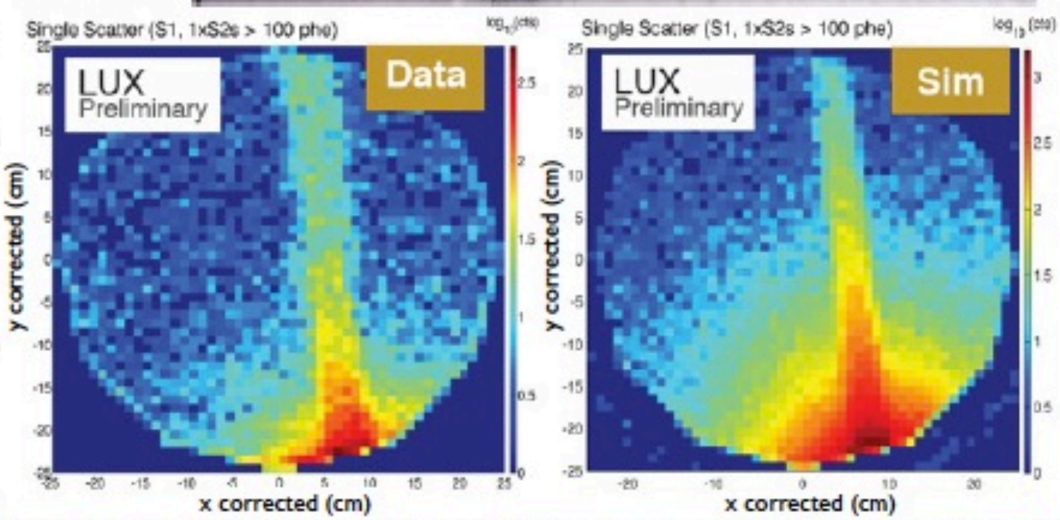
Gray contours indicate constant energies using a S1-S2 combined energy scale

Neutron Generator Calibration

- Neutron generator beam pipe aligned 15.5 cm below top of active region
- Beam leveled to ~1 degree
- 105.5 hours of data acquired
- Complete GEANT4 LUXSim + NEST simulation of DD neutron calibration

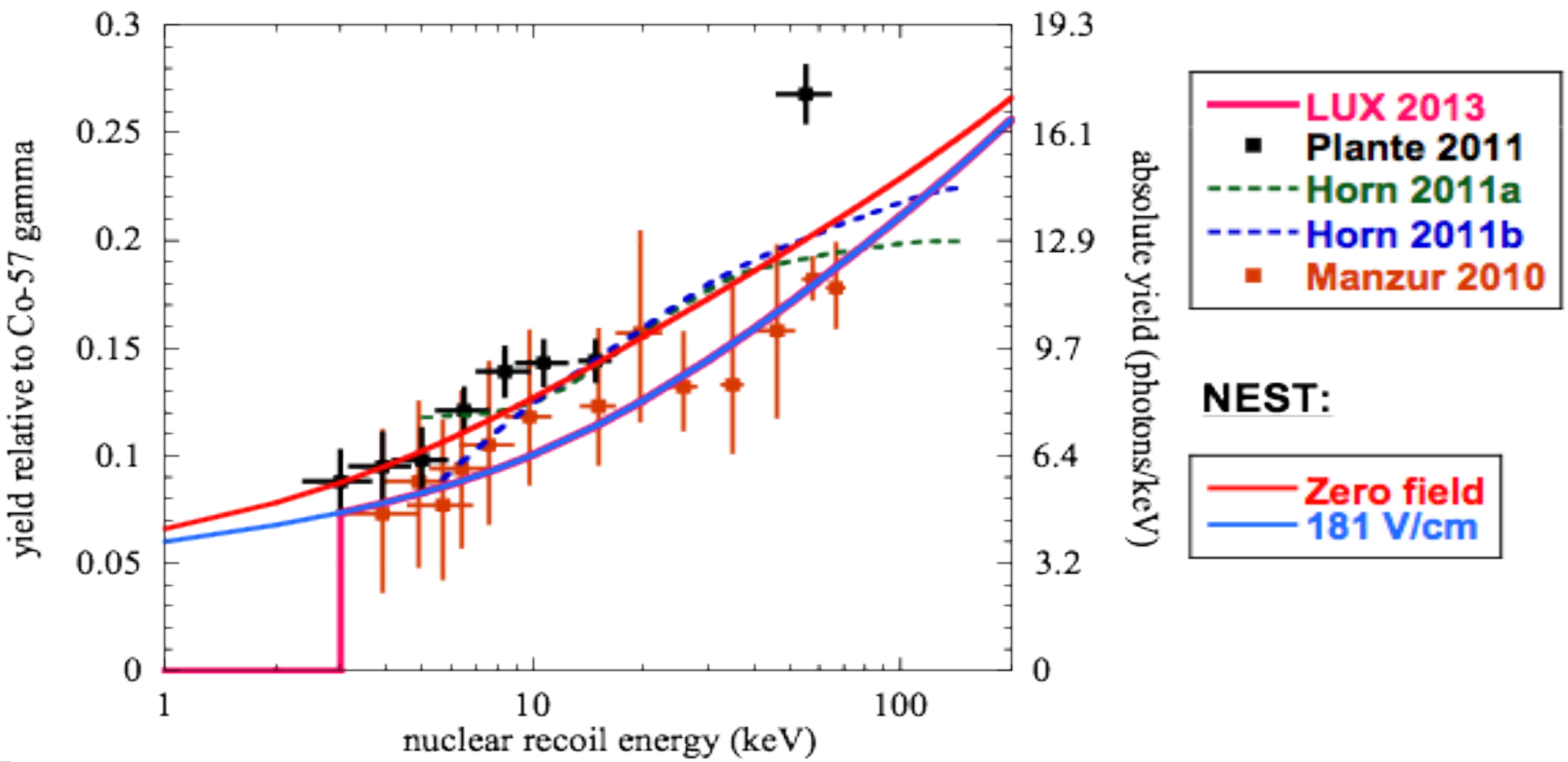






Light and Charge Yields in LUX

- Modeled Using Noble Element Simulation Technique (NEST).
- NEST based on canon of existing experimental data.
- Artificial cutoff in light and charge yields assumed below 3 keVnr, to be conservative.
- Includes predicted electric field quenching of light signal, to 77-82% of the zero field light yield



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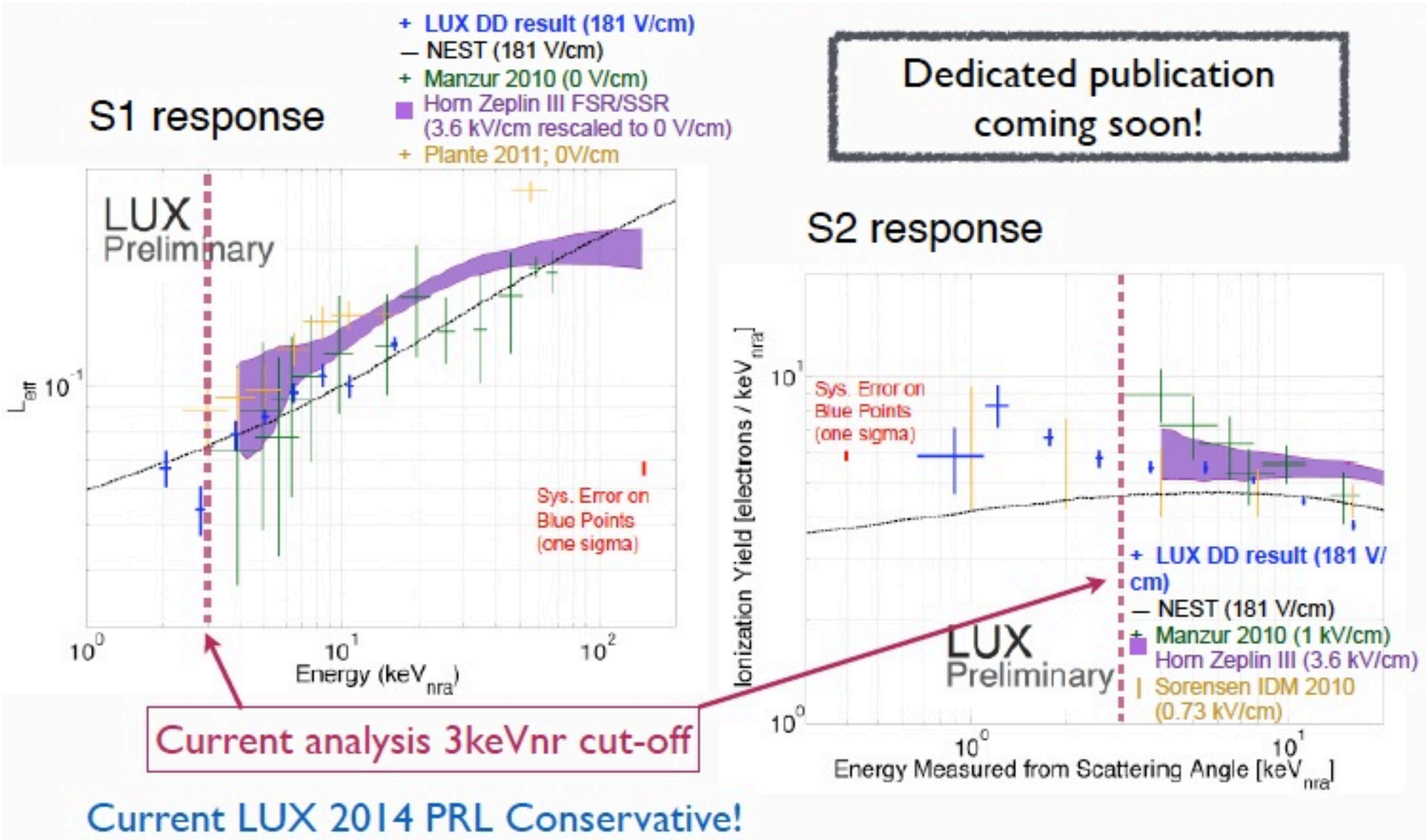
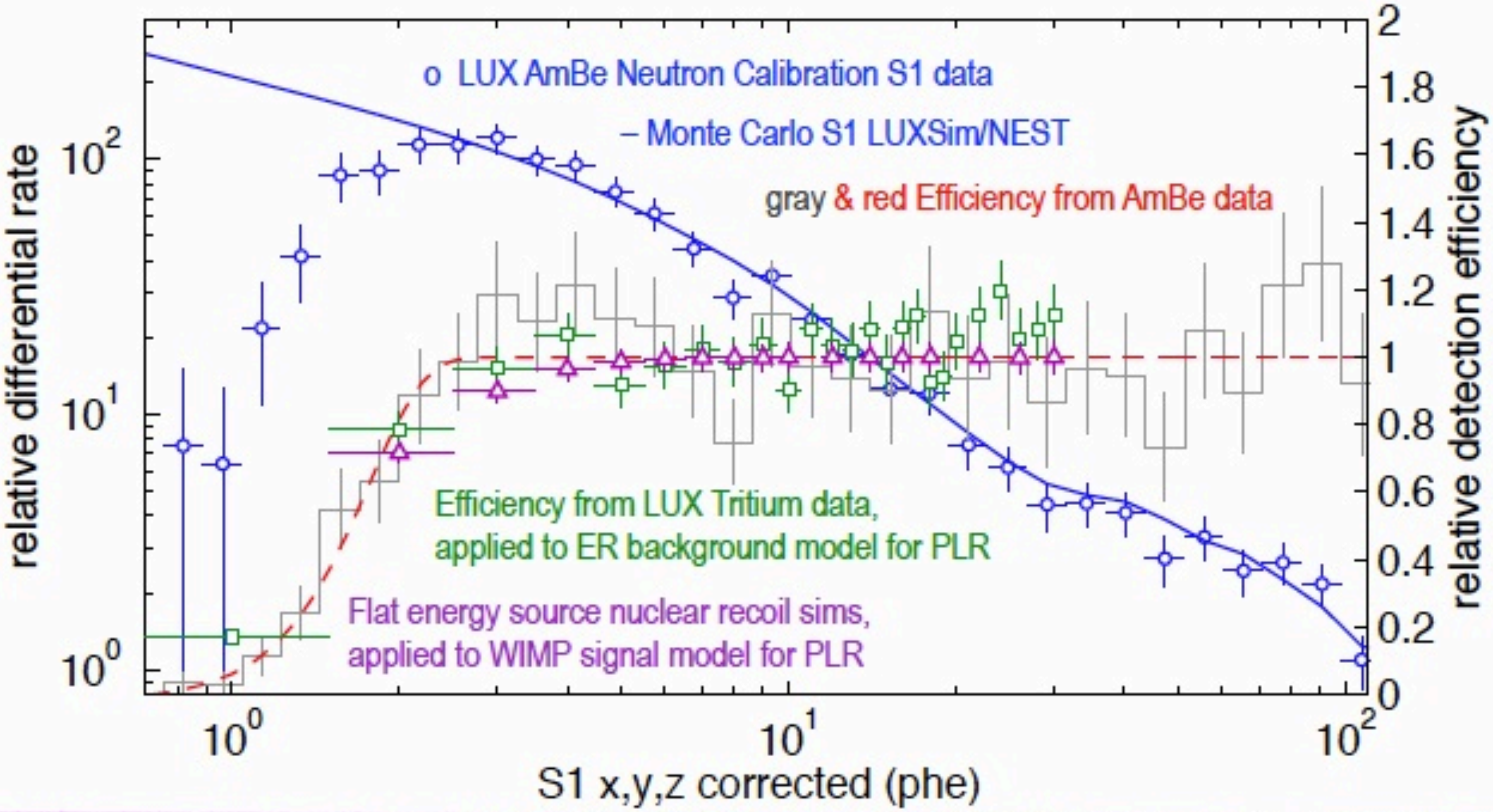
Nuclear Recoil Calibration Using the DD Neutron Source

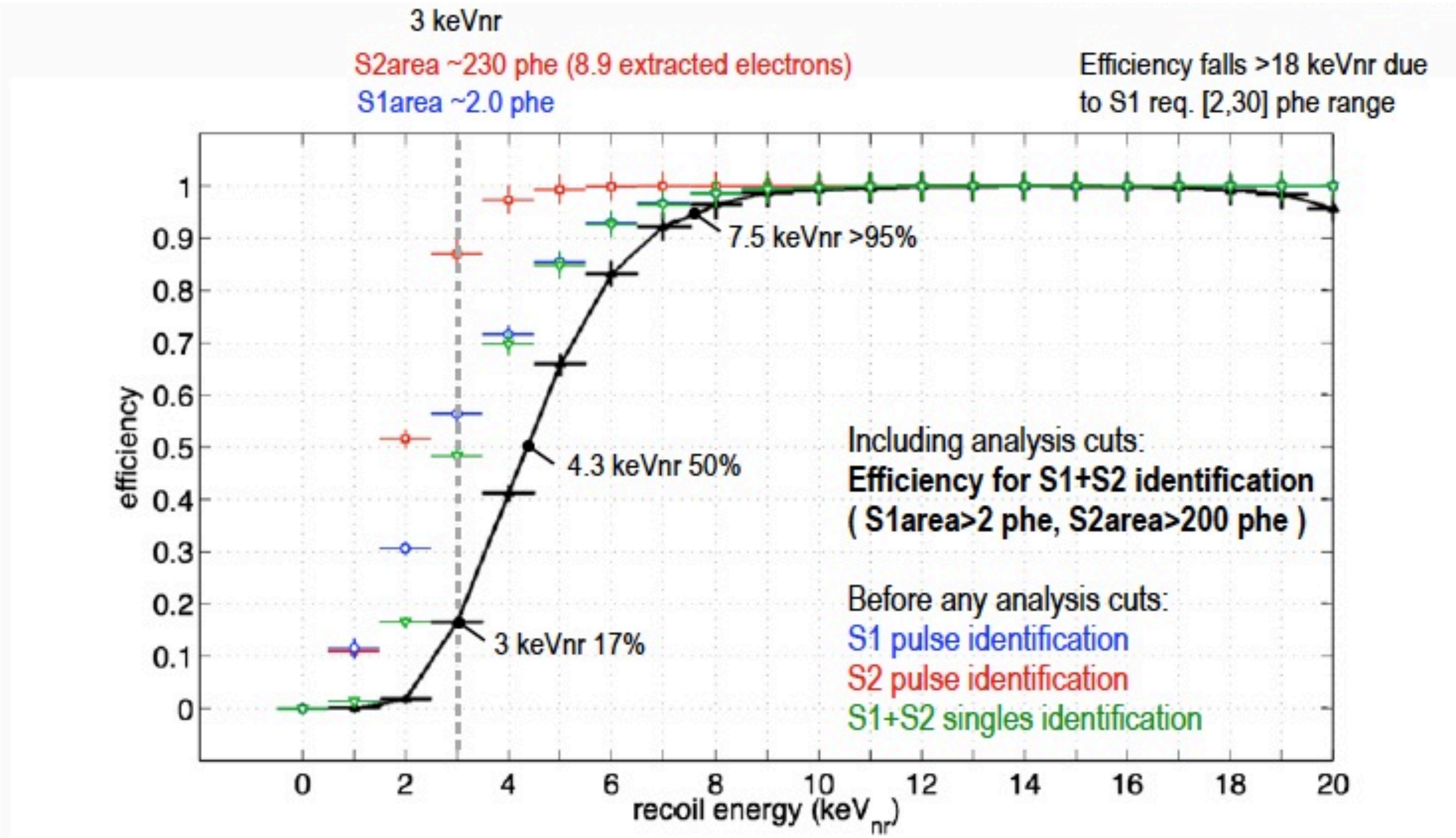


S1 Efficiency

- Universal S1 efficiency
  - AmBe NR calibration
  - Tritiated-Methane calibration
  - Full Monte Carlo of NR events (S1+S2 processed by same analysis chain)
  - Mono-energetic d-d neutron source



WIMP Detection Efficiency



True Recoil Energy equivalence based on LUX 2013 Neutron Calibration/NEST Model

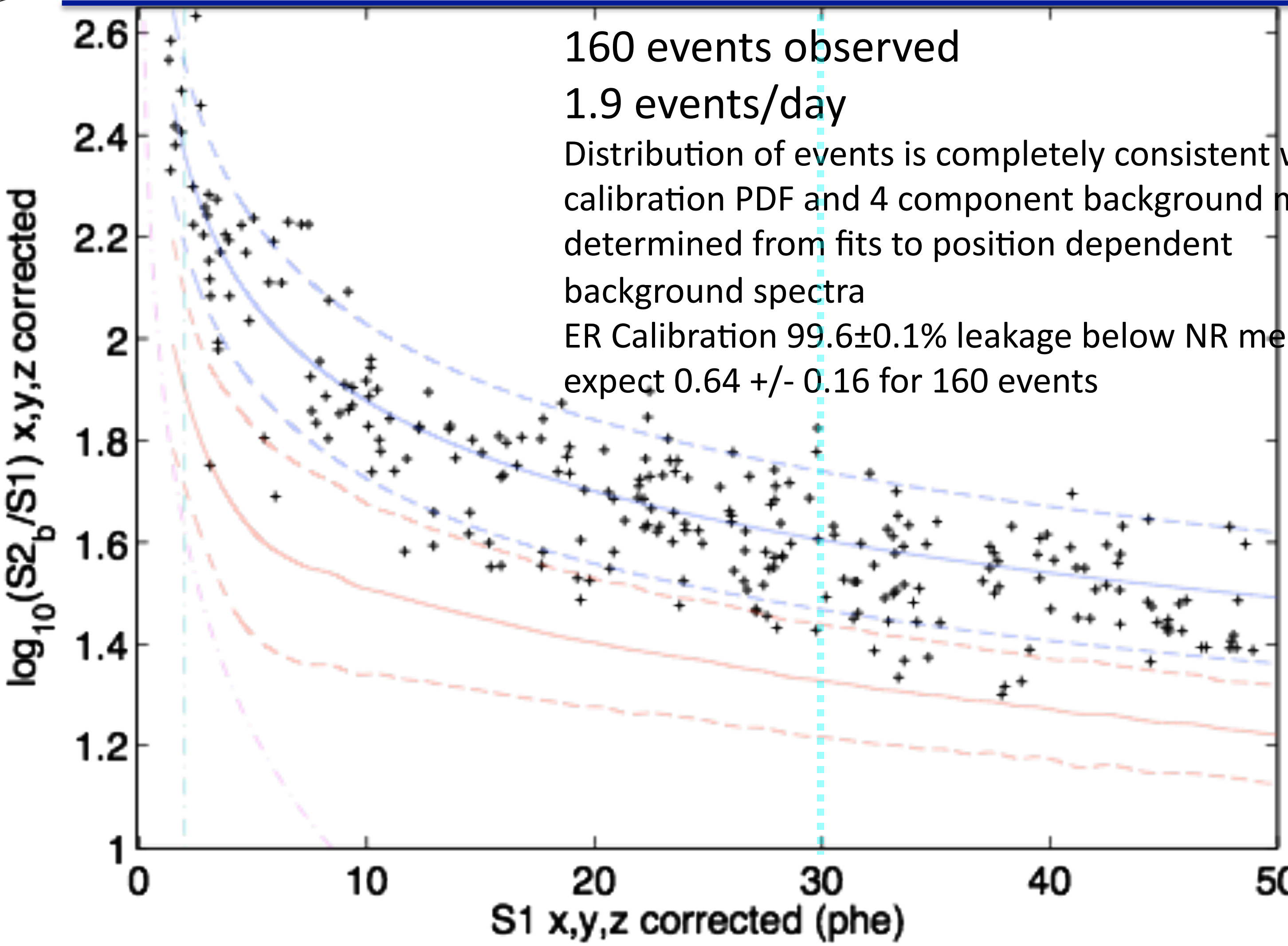
LUX WIMP Search, 85 live-days, 118 kg

160 events observed

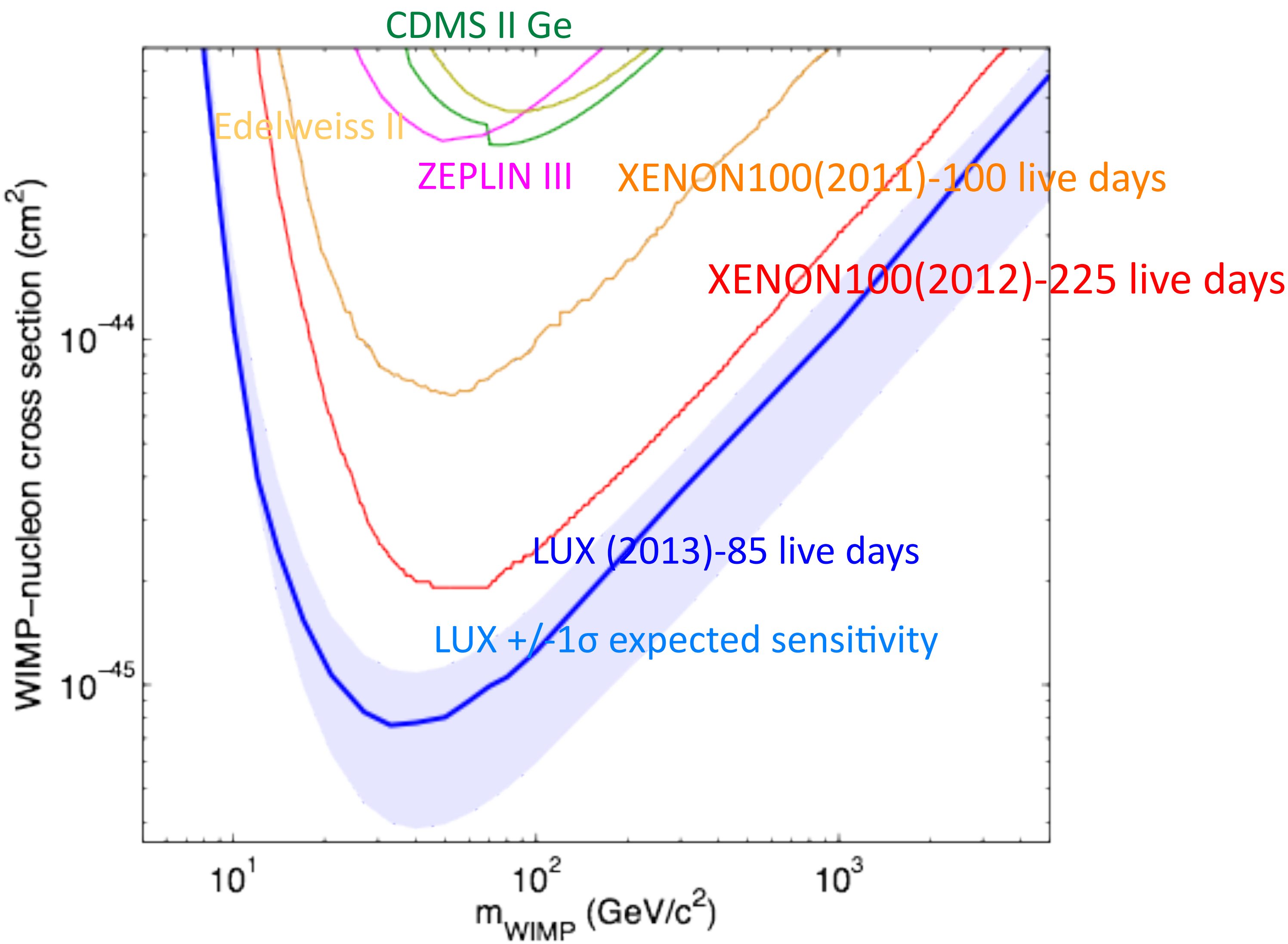
1.9 events/day

Distribution of events is completely consistent with ER calibration PDF and 4 component background model determined from fits to position dependent background spectra

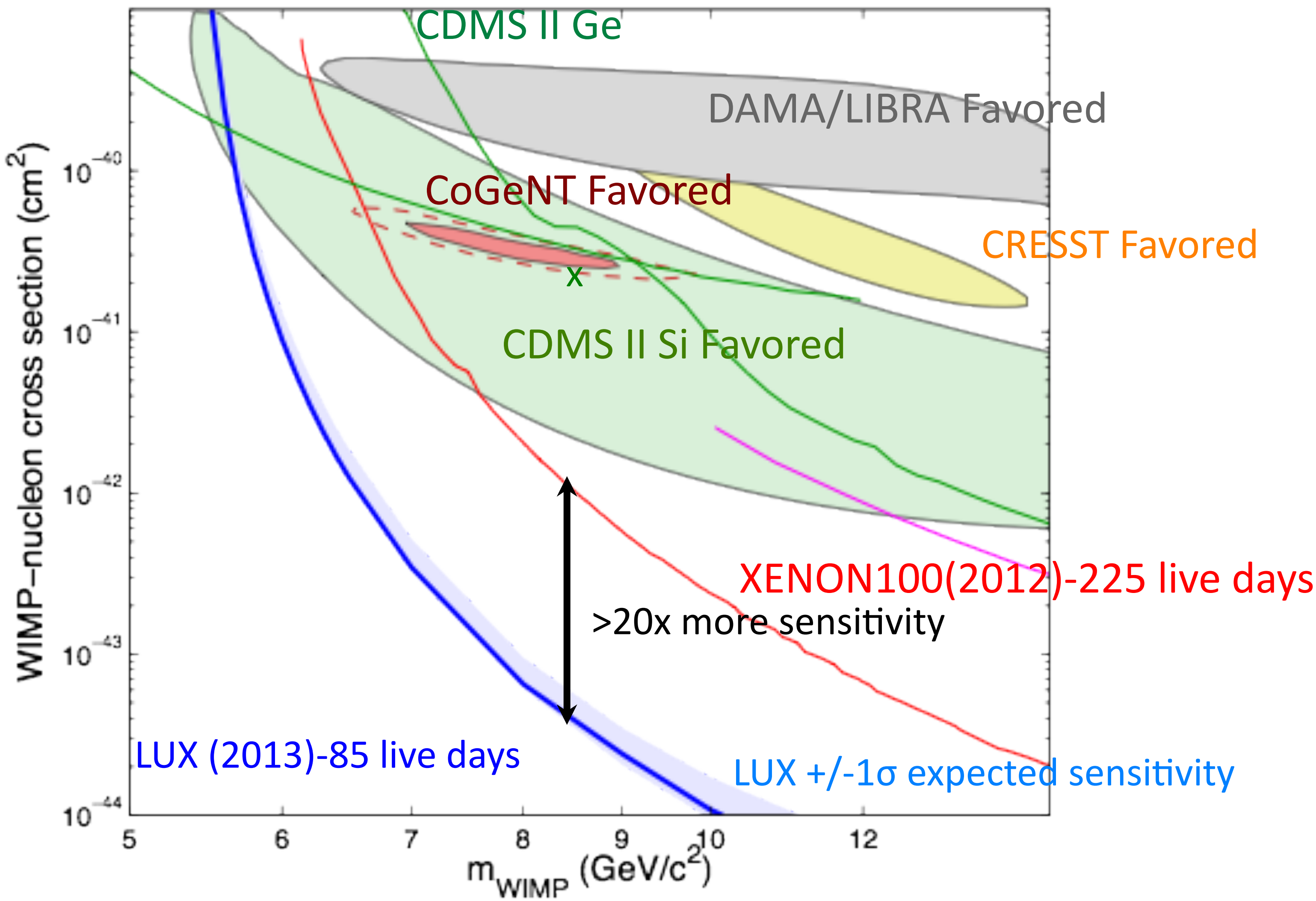
ER Calibration 99.6±0.1% leakage below NR mean, so expect 0.64 +/- 0.16 for 160 events



Spin Independent Sensitivity Plots

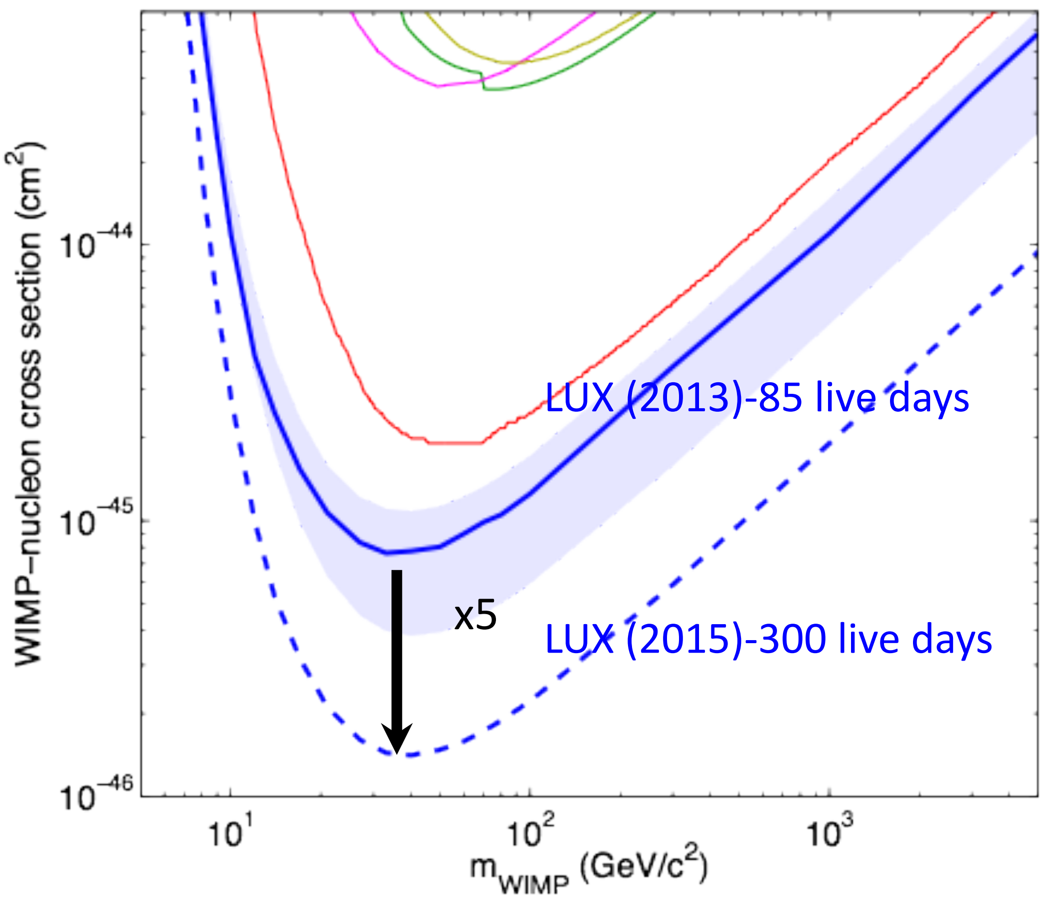


Low Mass WIMPs - Fully excluded by LUX



Projected LUX 300 day WIMP Search Run

- We intend to run LUX for a new run of 300 days in 2015-16
  - Extending sensitivity by another factor 5
  - Even though LUX sees no WIMP-like events in the current run, it is still quite possible to discover a signal when extending the reach
  - LUX does not exclude LUX
- WIMPs remain our favored quarry
- LZ 20x increase in target mass
  - If approved plans to be deployed in Davis Lab in >2017



The Future

- LUX – 300 day, salted data run, 4X sensitivity in 1 year
- Upgrade... LZ (LUX-ZEPLIN) to 10 tons (total)
  - Factor of 20 in mass
  - Factor of 100 in sensitivity... 10^{-48} cm^2
  - Background from atmospheric, solar neutrinos starts to creep in.
  - ~2017 commissioning if all goes well.

The LZ Collaboration

University of Alabama
UC Berkeley
LIP Coimbra (Portugal)
STFC Daresbury Laboratory (UK)
University of Liverpool (UK)
University of Maryland
University of California, Santa Barbara
South Dakota Science and Technology Authority

SUNY at Albany
Brown University
UC Davis
Edinburgh University (UK)
Imperial College London (UK)
MEPhI (Russia)
University of South Dakota
SLAC National Accelerator Laboratory

Berkeley Lab (LBNL)
Case Western Reserve
Brookhaven National Lab
Lawrence Livermore National Laboratory
University College London (UK)
University of Rochester
South Dakota School of Mines & Technology
Texas A&M University

LZ Overview

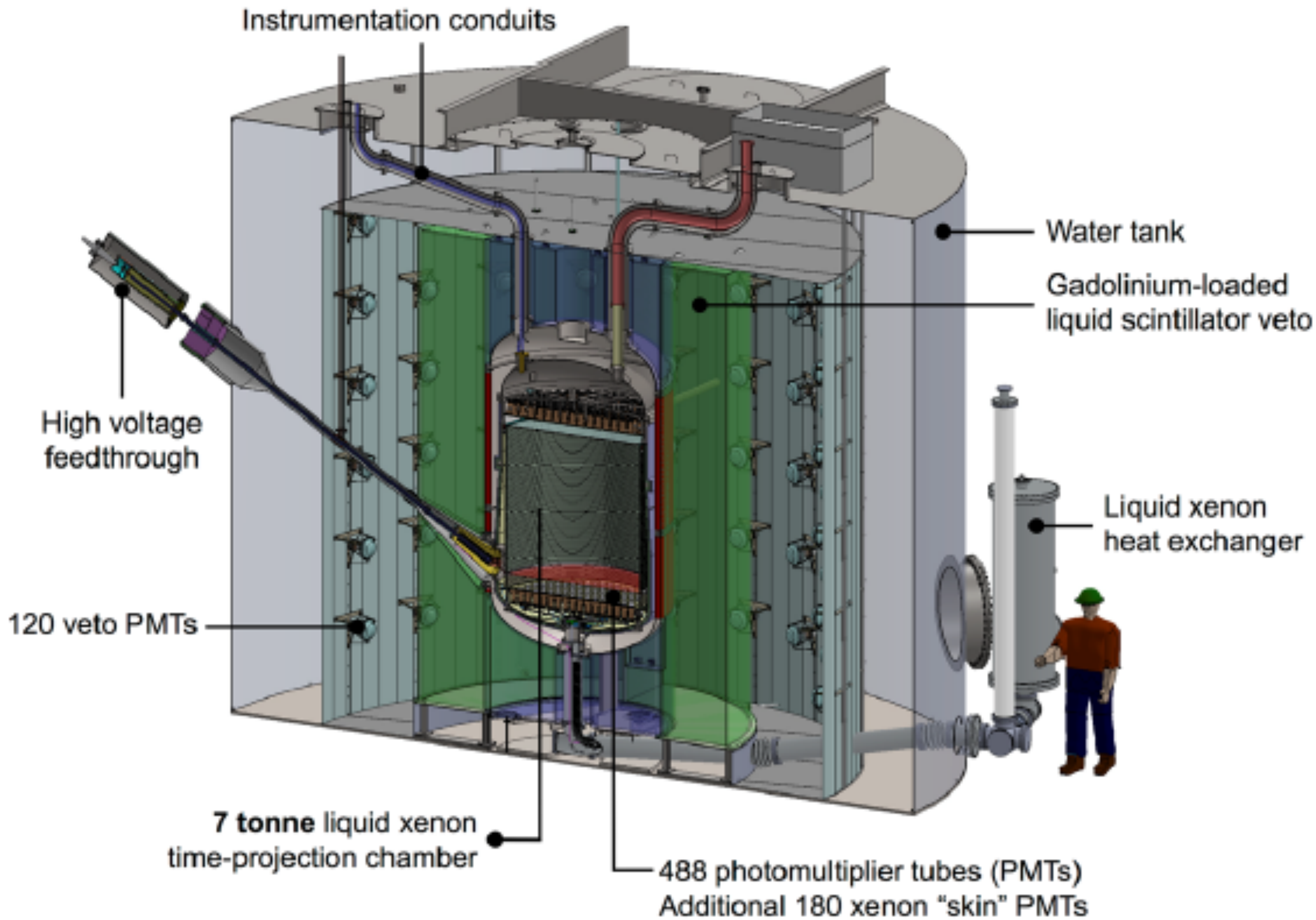
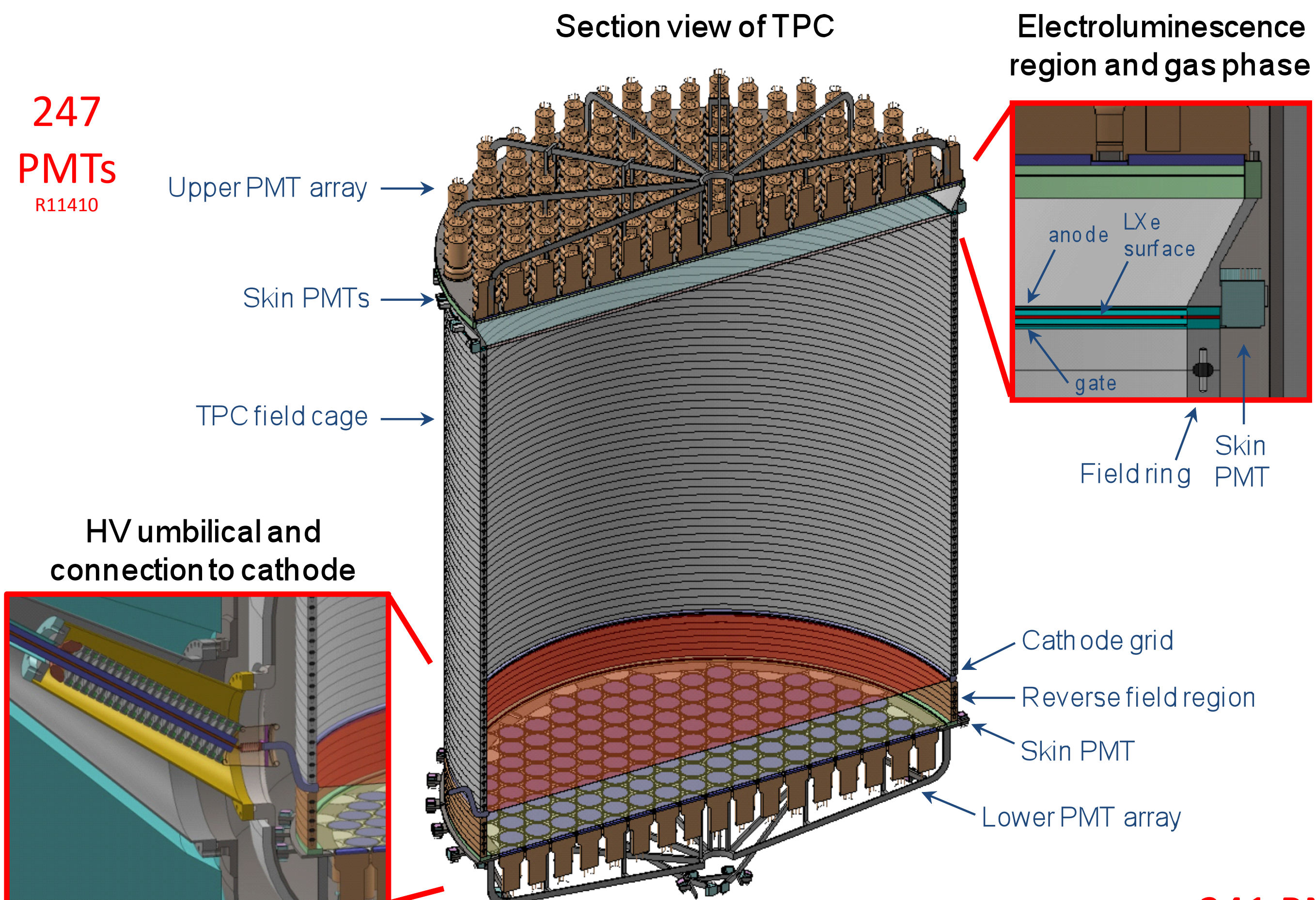


Figure 2.1. LZ detector concept.

LZ Central TPC Region

247 PMTs
R11410

100-200 kV



241 PMTs

LZ Background Targets

Item	^{238}U	^{232}Th	^{40}K	ER Counts	NR Counts
Ti Cryostat	0.62 mBq/kg	0.61 mBq/kg	2.48 mBq/kg	(2.1) 2.1 (10.5)	(0.03) 0.04 (0.22)
PTFE panels	0.01 mBq/kg	0.002 mBq/kg	0.06 mBq/kg	(0.002) 0.002 (0.01)	(0.0006) 0.0009 (0.004)
3" PMT	3 mBq/PMT	3 mBq/PMT	30 mBq/PMT	(5.3) 7.9 (26)	(0.003) 0.02 (0.07)
Other	Various	Various	Various	3.5	(0.04) 0.04 (0.06)
Extra-TPC Subtotal				(11) 14 (40)	(0.05) 0.10 (0.35)
Kr + Rn				46	
Neutrinos				234	0.61
Totals	Raw			(291) 294 (312)	(0.66) 0.71 (0.96)
	99.5% ER rejection, 50% NR acceptance			(1.46) 1.47 (1.56)	(0.33) 0.36 (0.48)
	Combined			**(1.79) 1.83 (2.04)**	

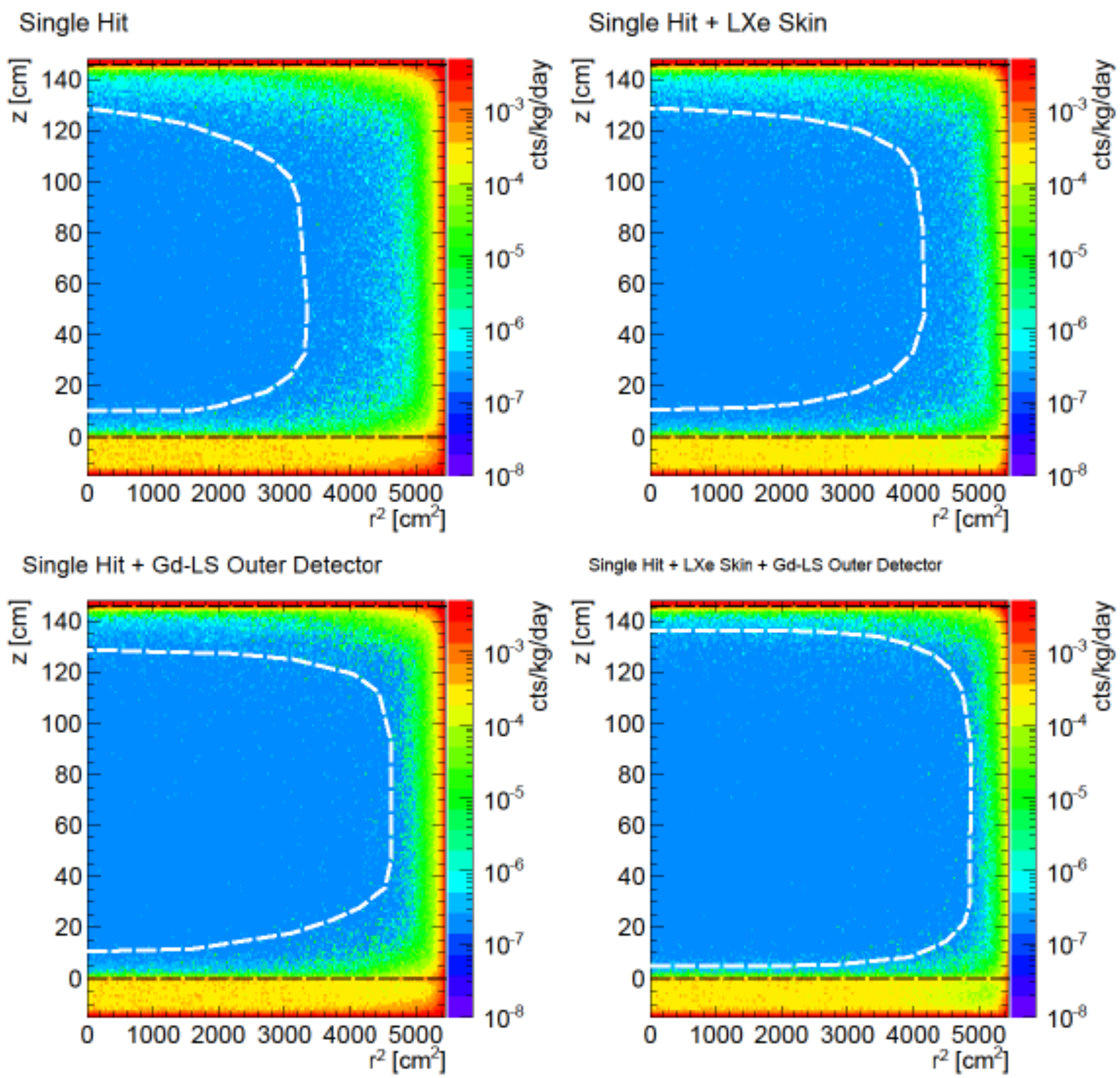
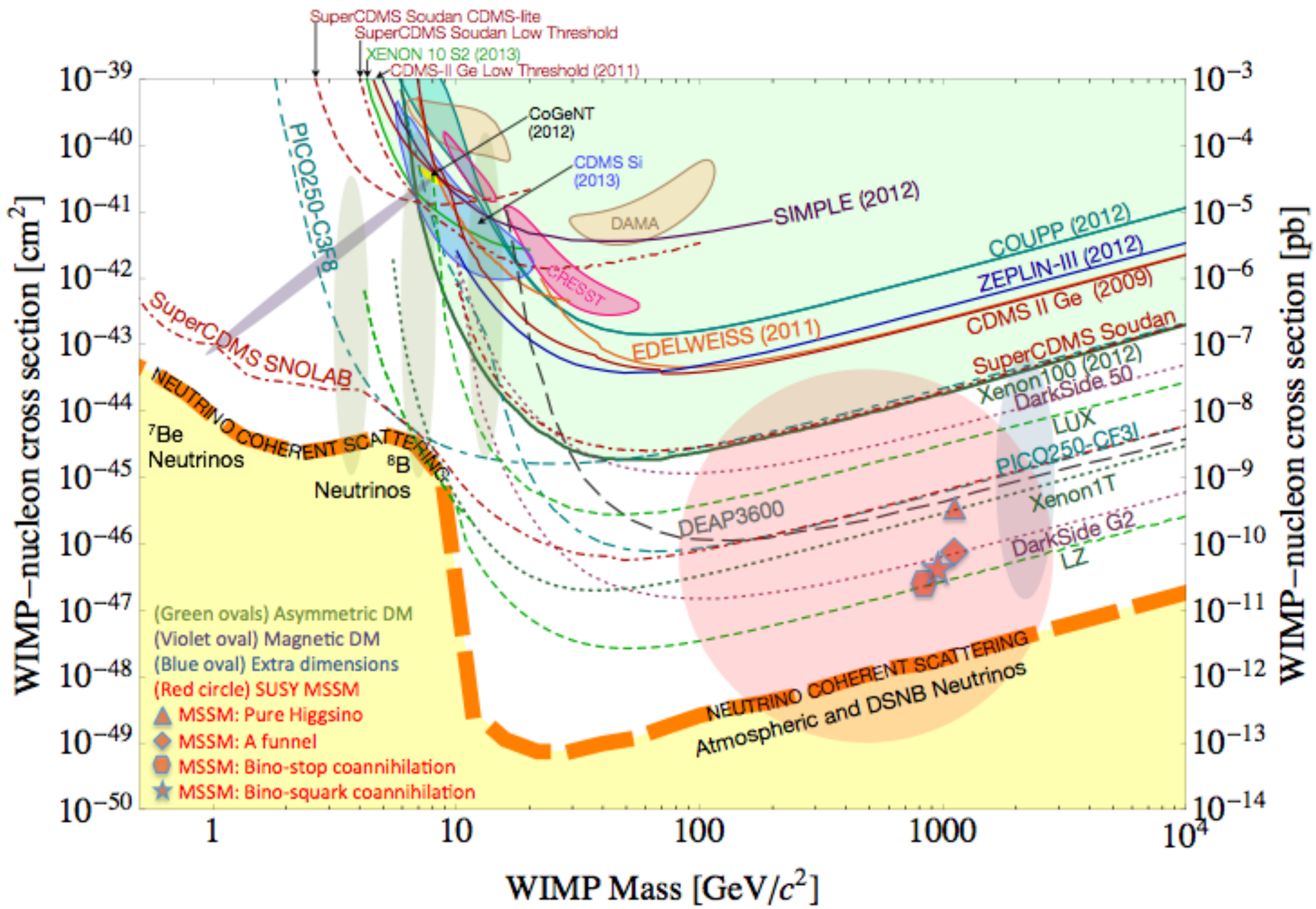


Figure 3.8.5.1. Total NR background plus ER leakage from sources external to the liquid xenon in the TPC, counted over a 6–30 keV acceptance region; a discrimination efficiency of 99.5% is applied to electron recoils from gamma-rays and solar pp neutrinos. Top Left: Single scatters only, no vetoing by the anti-coincidence systems. Top Right: Adding LXe skin only. Bottom Left: Adding Gd-LS outer detector only. Bottom Right: Adding the combination of both vetos. In each panel approximate fiducial contours are shown in white and weigh 3.3, 4.0, 4.5 and 5.6 tonnes, respectively.

Shielding and Veto Tagging Capability

Current WIMP Cross-section Limits



41

DM limits as a function of time

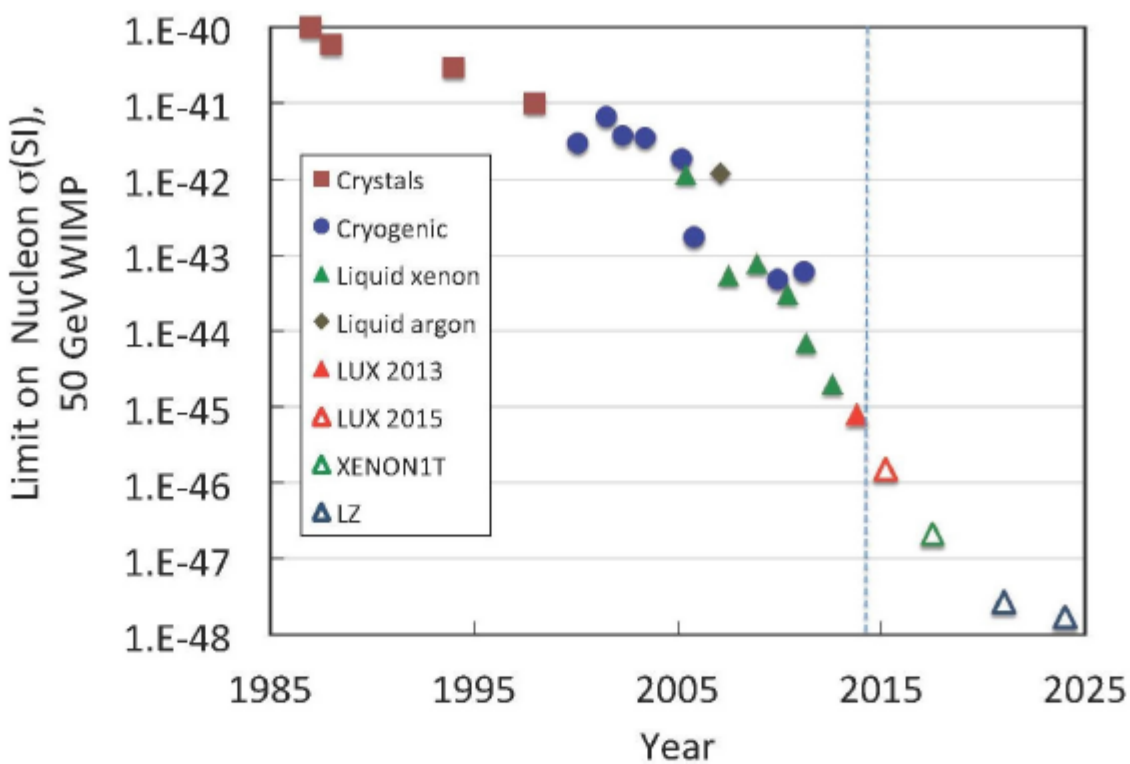


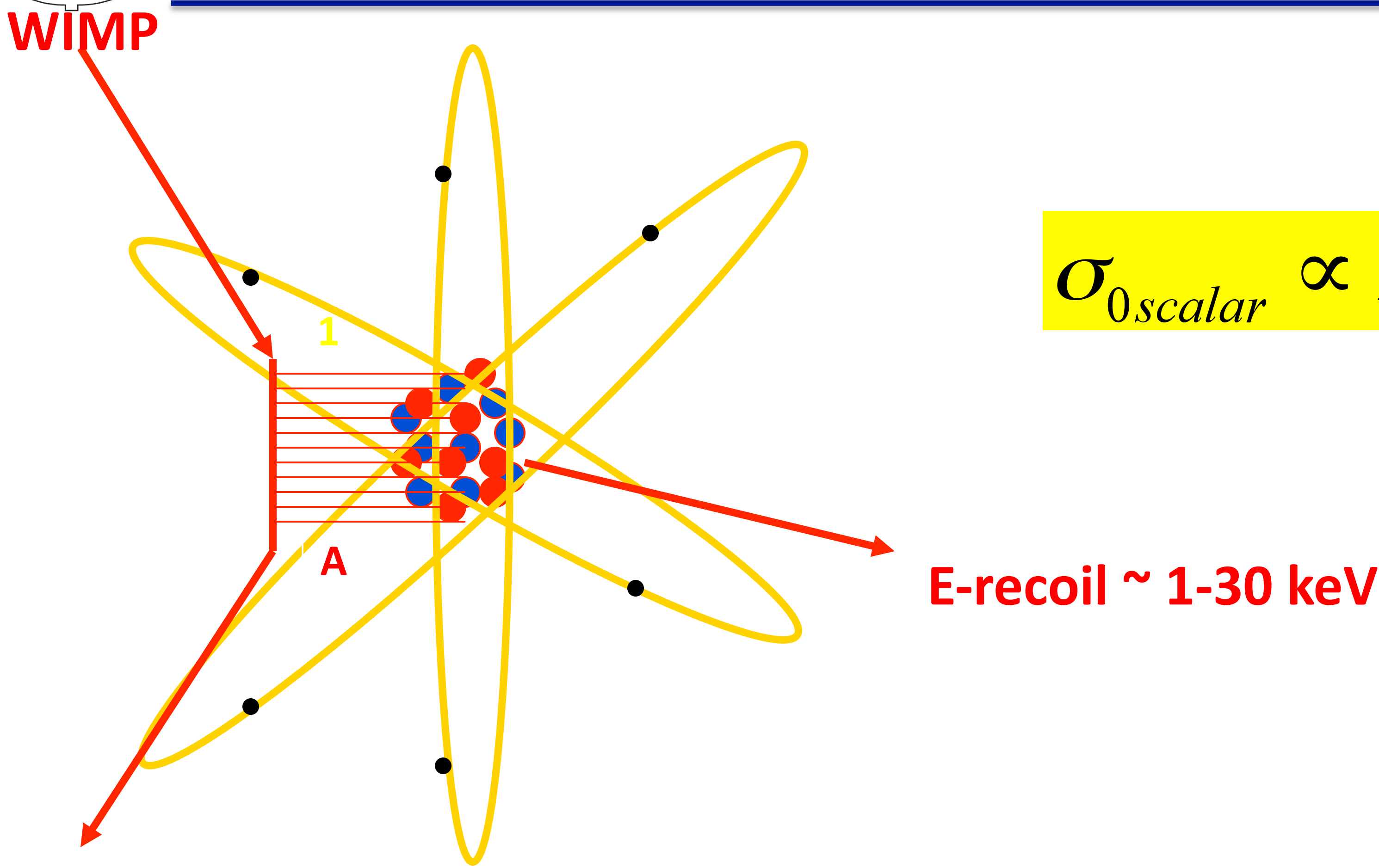
Figure 1.2.2. The evolution of cross-section limit for 50 GeV WIMPs as a function of time. Past points are published results. Future points are from the Snowmass meetings [26].

Conclusions

- The search for Dark Matter is one of the most compelling science question facing the current generation of researchers.
- LUX has made a WIMP Search run of 86 live-days and released the analysis + PRL.
  - Backgrounds as expected, inner fiducial ER rate <2 events/day in region of interest
  - Major advances in calibration techniques including ^{83m}Kr and Tritiated-CH_4 injected directly into Xe target
  - Very low energy threshold achieved 3 keVnr with no ambiguous/leakage events
  - ER rejection shown to be 99.6+/-0.1% in energy range of interest
- Intermediate and High Mass WIMPs
  - Extended sensitivity over existing experiments by x3 at 35 GeV and x2 at 1000 GeV
- Low Mass WIMP Favored Hypotheses ruled out
  - LUX WIMP Sensitivity 20x better
  - LUX does not observe 6-10 GeV WIMPs favored by earlier experiments
- A new round of next generation DM detectors, LZ, is being planned for commissioning in >~2017 time frame.

- Backup slides

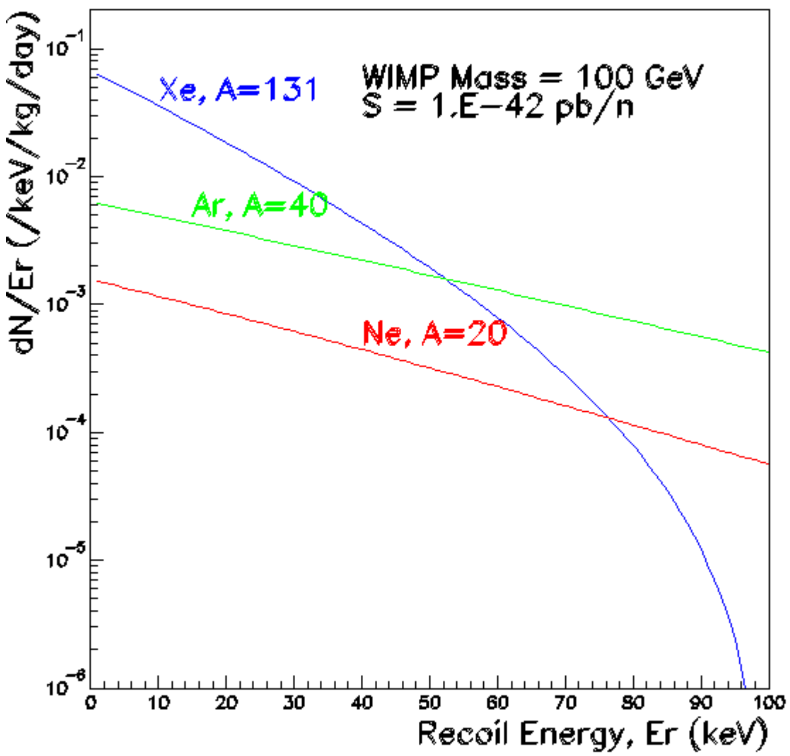
Coherent Scattering



$$\sigma_{0scalar} \propto A^2$$

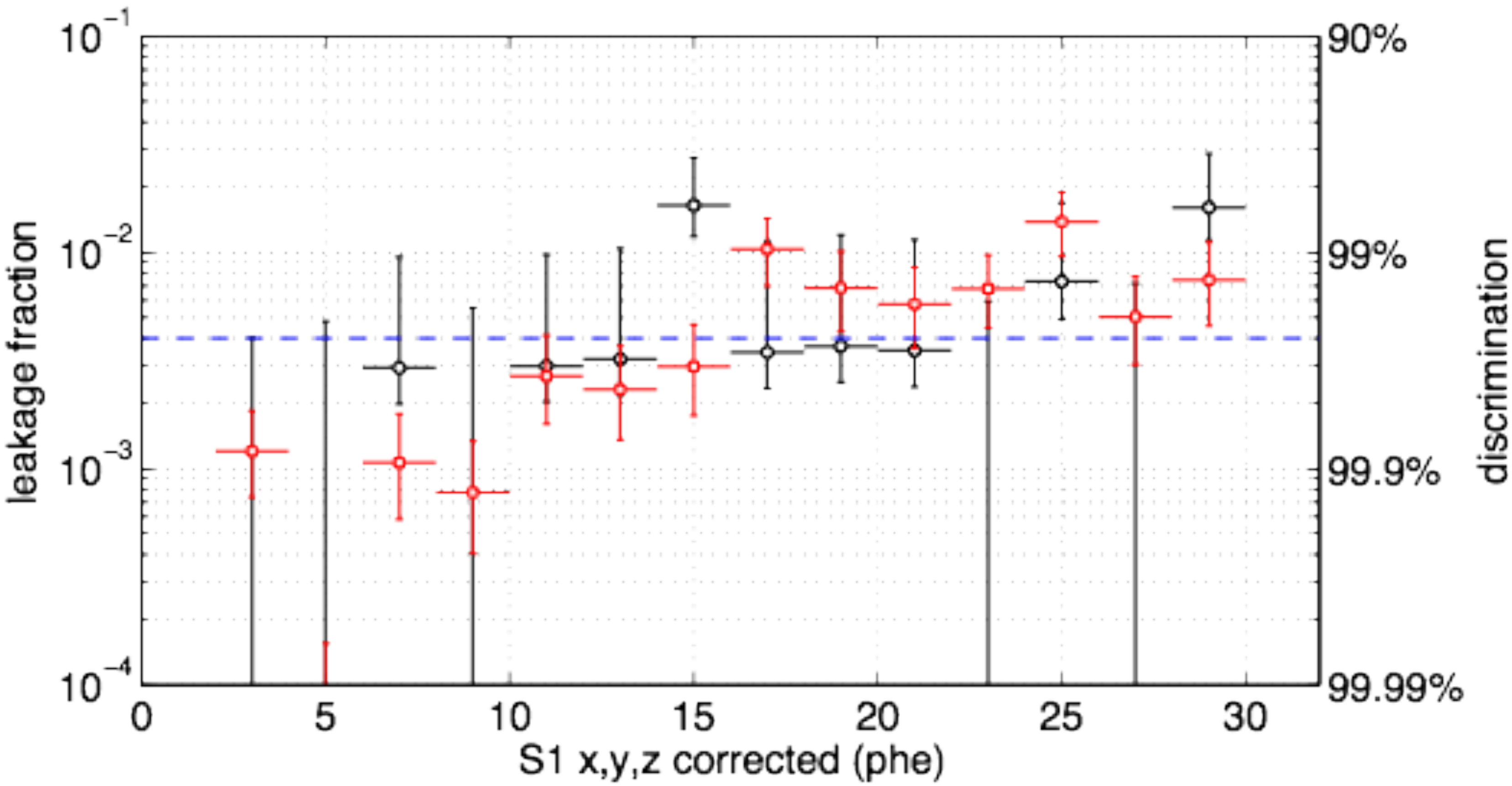
A^2 Dependence of Recoil Spectra

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{4 v_e m_x m_r^2} F^2(E_R) \left[erf\left(\frac{v_{\min} + v_e}{v_0} \right) - erf\left(\frac{v_{\min} - v_e}{v_0} \right) \right]$$



Electron Recoil Discrimination

Average discrimination from 2-30 S1 photoelectrons measured to be 99.6% (with 50% nuclear recoil acceptance)

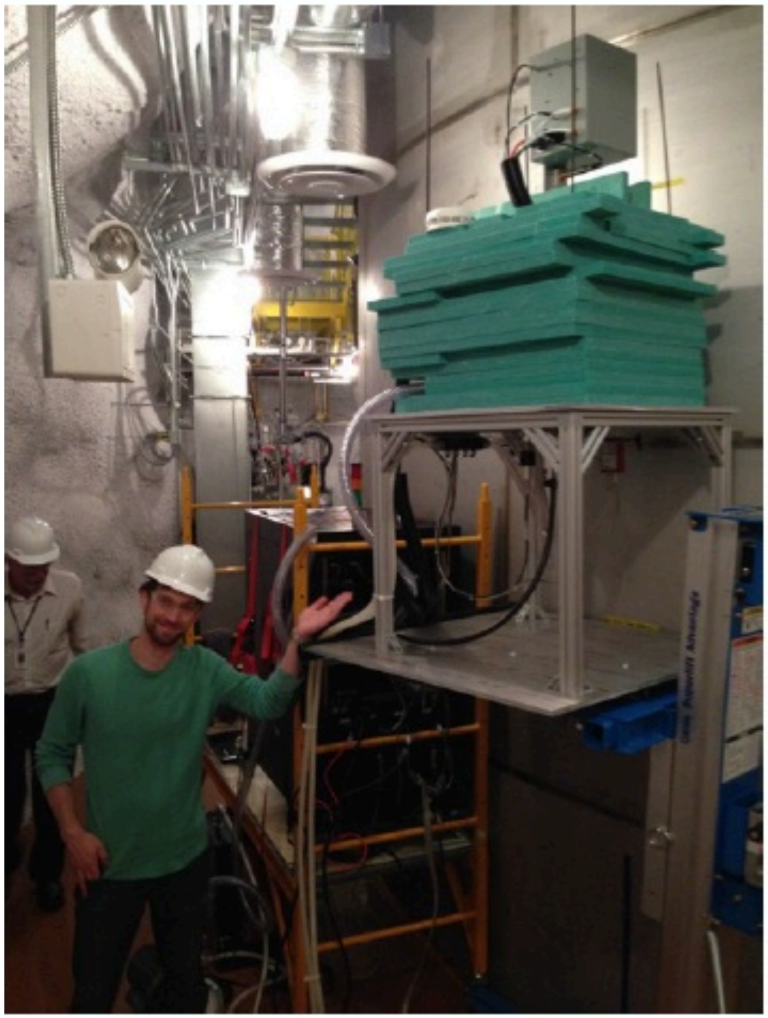


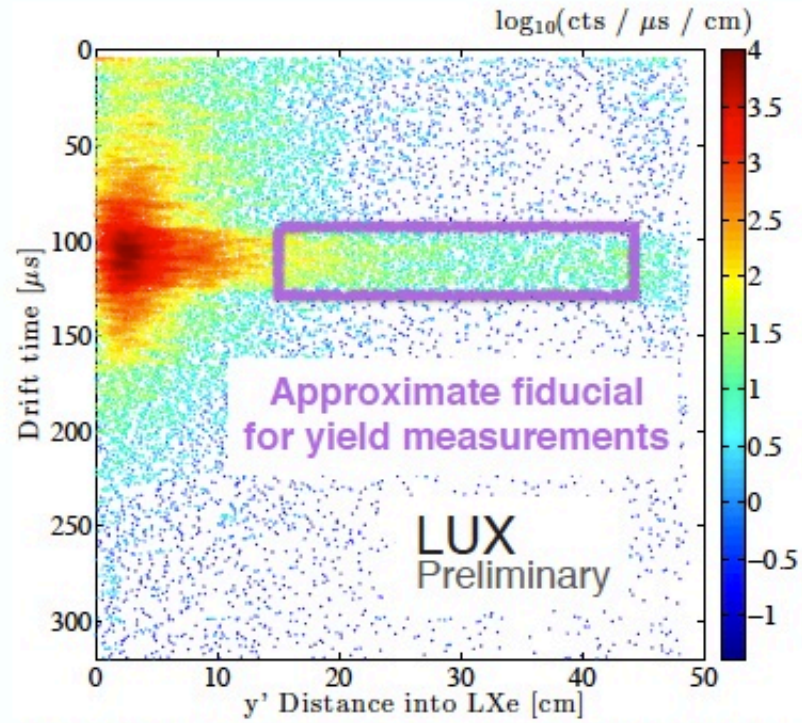
Black circles show leakage from counting events from the dataset

Red circles show projections of Gaussian fits below the nuclear recoil band mean

Neutron Generator outside the LUX Water Tank

Adelphi DD108 Neutron Generator Installed Outside LUX Water Tank





- This cut eliminates shine from passive materials and ensures 95% of neutrons in beam sample have energy within 4% of 2.45 MeV
- The mean energy of neutrons produced at 90° by the DD108 was measured to be 2.45 ± 0.05 MeV at Brown University

Ionization Signal Measured below 1 keV_{nra}

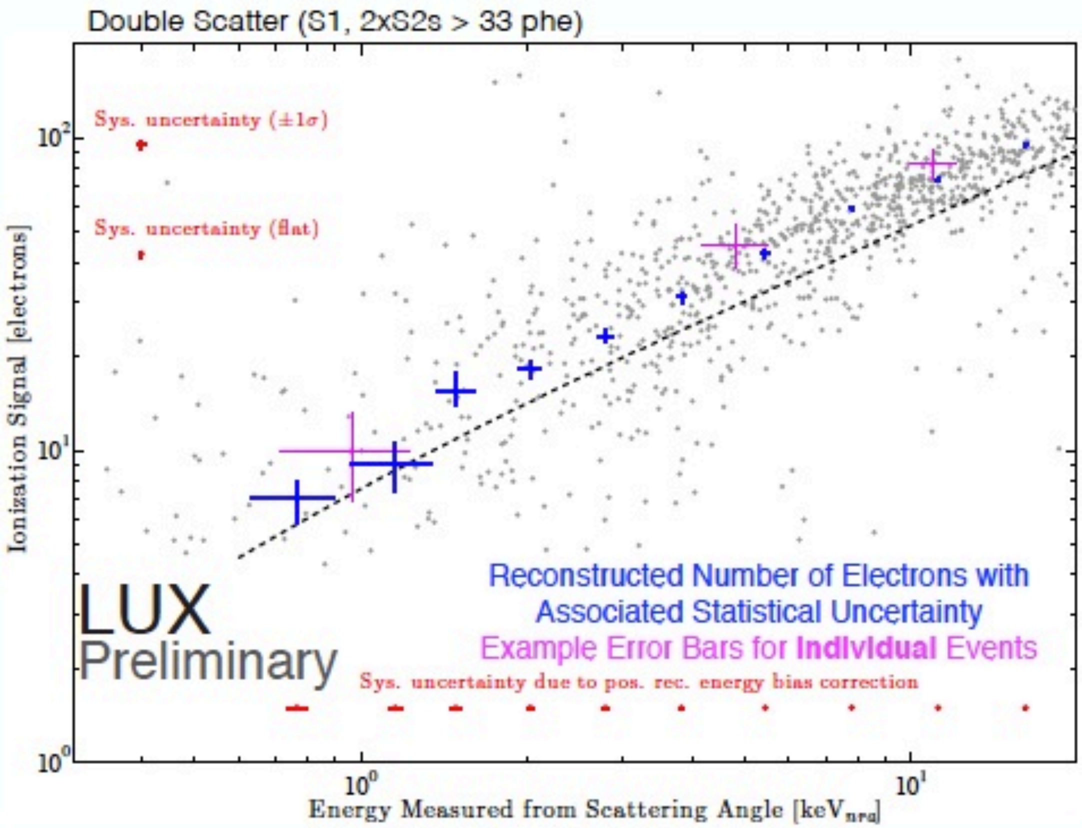
- Reconstruct number of electrons at interaction site by matching ionization signal model with observed event distribution using extended maximum-likelihood
- Red systematic error bar shows common scaling factor uncertainty. Dominated by uncertainty in electron extraction efficiency.
- Lowest event energy included for analysis is 0.3 keV_{nra}.

Grey Points - Individual double scatter events

Magenta Crosses - Error bars for individual event from best 10% from each bin

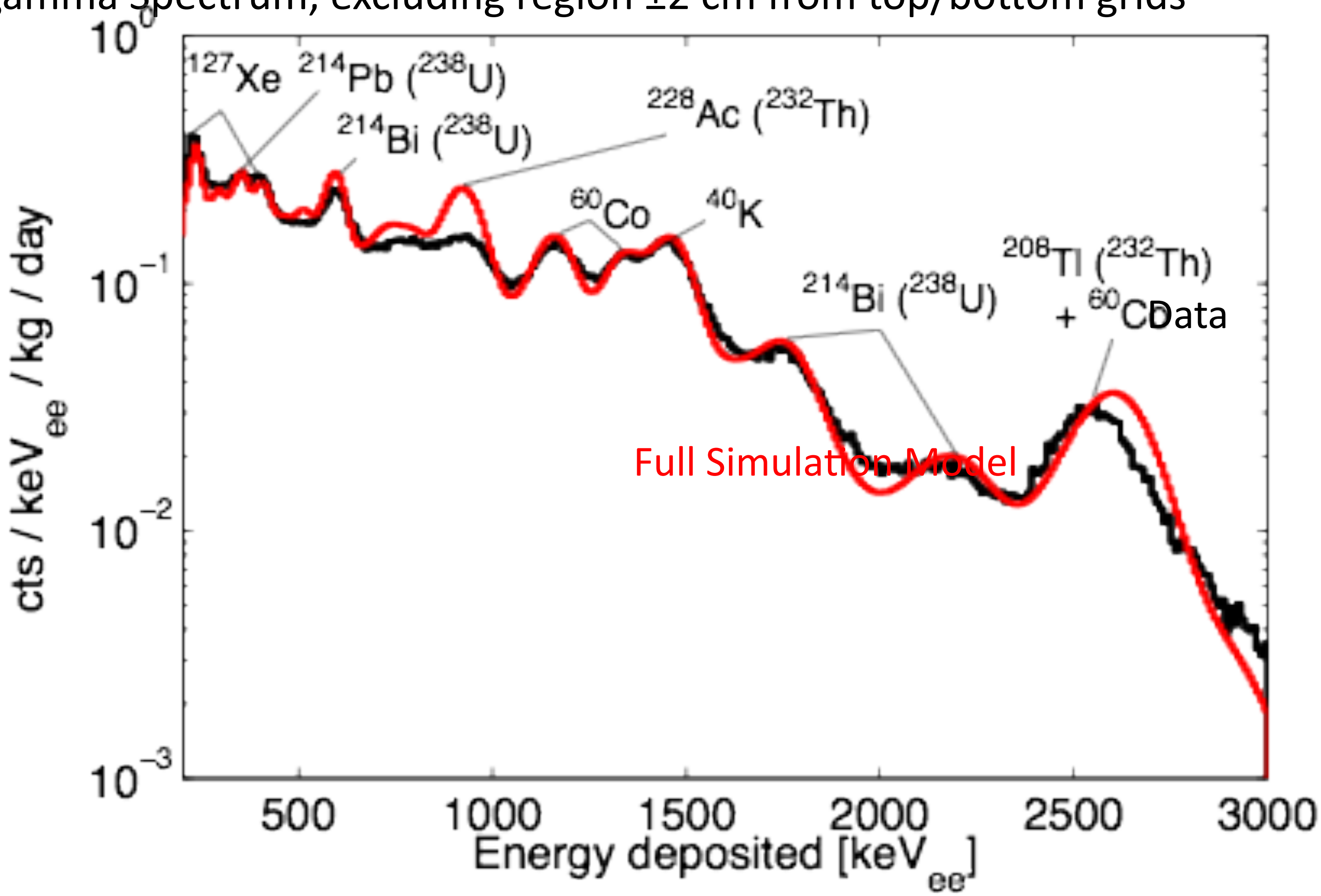
Blue Crosses - Reconstructed number of electrons at interaction site accounting for threshold effects in signal analysis

Black Dashed Line - Szydagis et al. (NEST v1.0) Predicted Ionization Signal at 180 V/cm



LUX High Energy Gamma Background in 220 kg

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



LUX WIMP Search Summary

- April 21 - August 8, 2013 - 110 calendar days
  - 85.3 live days of WIMP Search
  - 118.3+/-6.5 kg fiducial mass

- Calibrations
  - Frequent injected ^{83m}Kr calibration to correct for any S1 or S2 gain shifts
  - AmBe & Cf calibrations & Sims to define NR band
  - Injected Tritiated Methane defines full ER band at all relevant energies

- Efficiency
  - Efficiency for WIMP event detection was studied using data from calibration sets using multiple techniques and all were all shown to be consistent with one another

Event & Cuts Summary: 85 live days

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

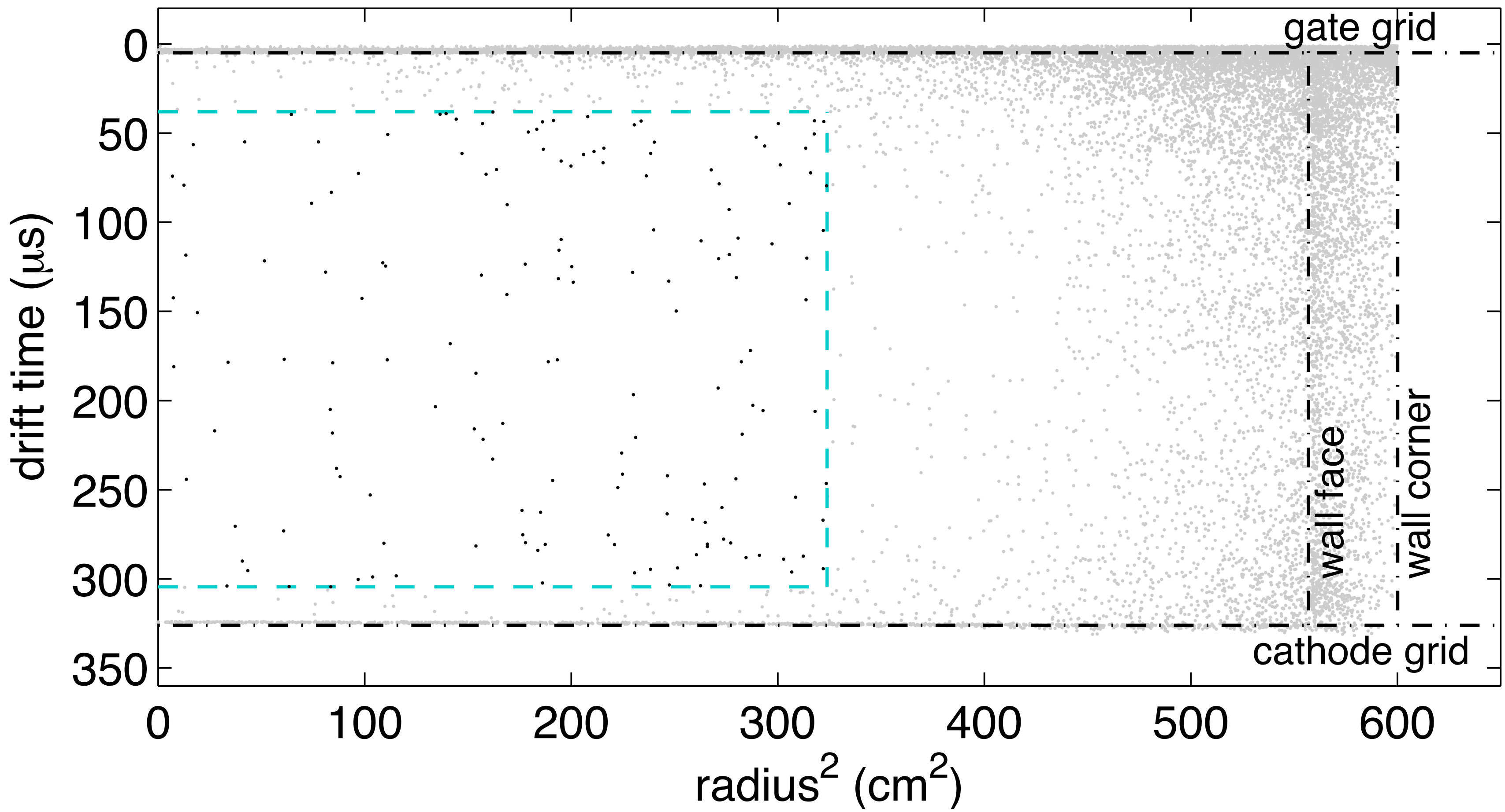
~11.5 Hz of S2-like triggers

>99% efficiency for events S2area>200 phe

keVnr = keV nuclear recoil

keVee = keV electron equivalent

The Events in our Detector



Background Summary for 118 kg Fiducial

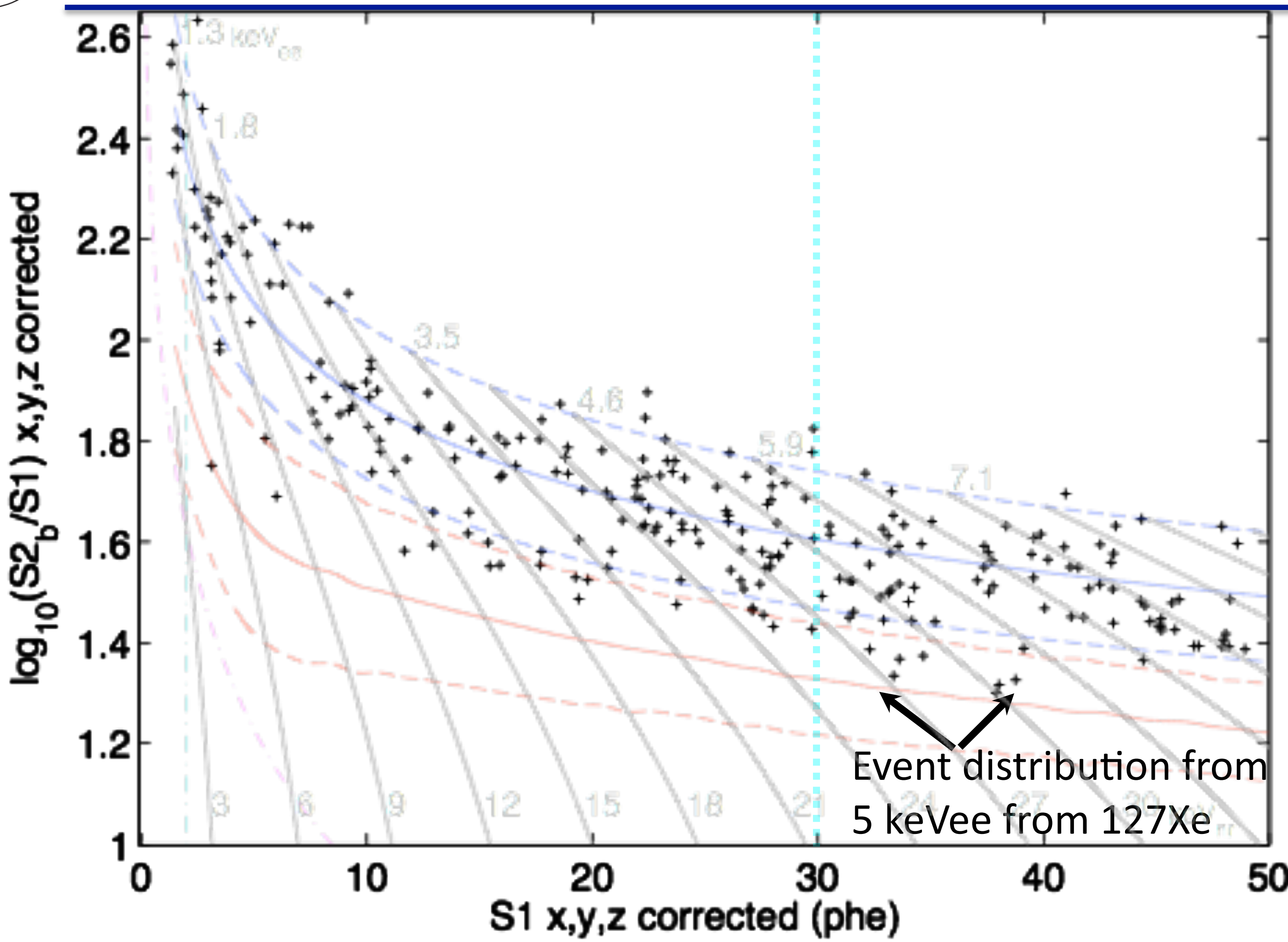
Average levels over period April-August WIMP Search Run

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	222Rn	$0.11\text{-}0.22_{(90\%\ CL)}$
^{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	$3.1 \pm 0.2_{stat}$

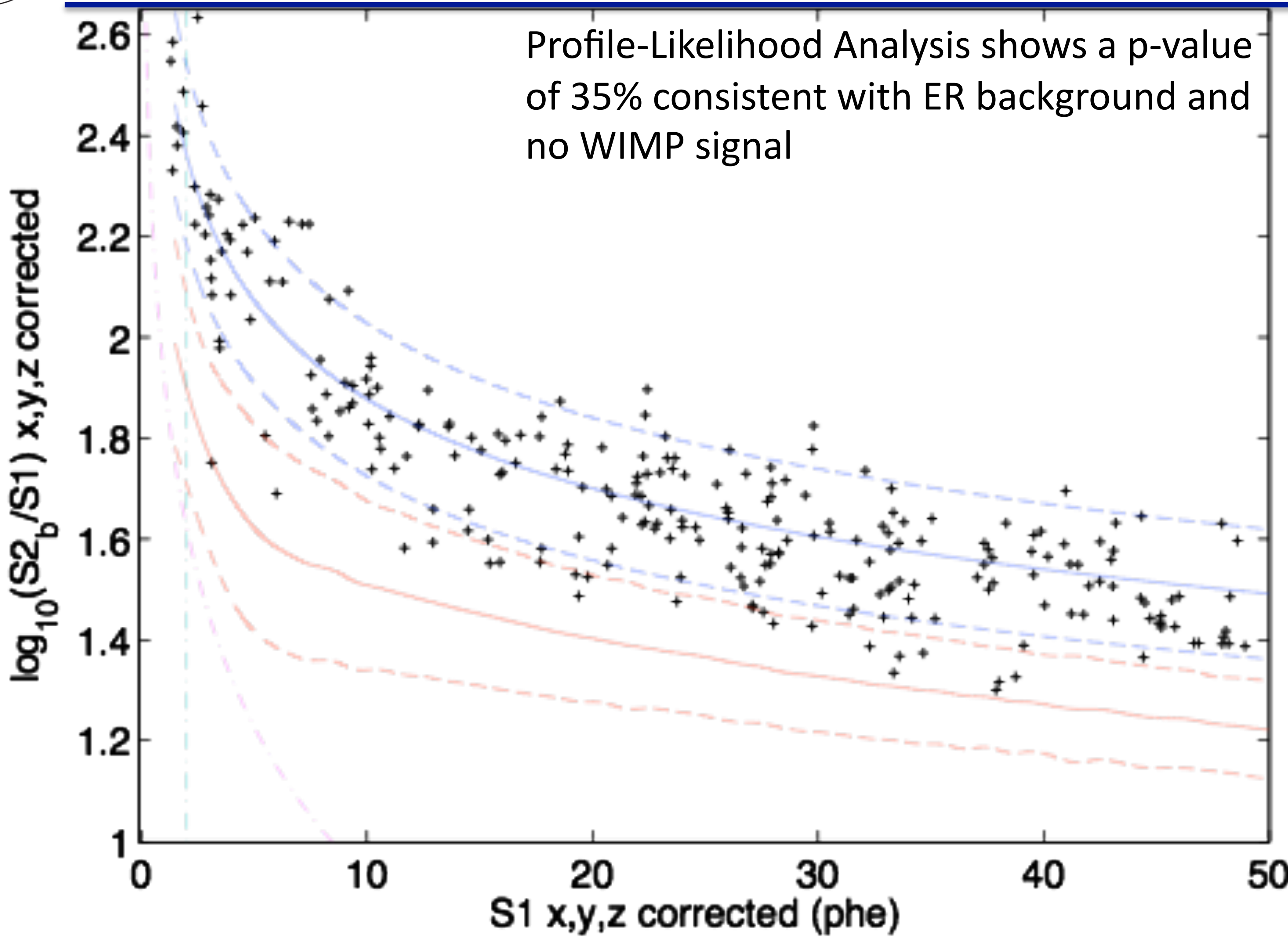
LUX WIMP Analysis Summary

1) The Xe Target inner fiducial volume is very simple, it sits inside a larger volume of Xe with only a "virtual" surface dividing them
   - Modeling of extrinsic and intrinsic background signals in large monolithic Xe volume has low systematics
2) No blinding was imposed for the first WIMP data analysis
   - We aimed to apply minimum set of cuts in order to reduce any tuning of event cuts/acceptance.
   - The cuts list is very short ...
3) Fiducial Volume was selected based on requirement to keep low energy events from grid and teflon surface out of WS data. Primarily alpha-decay events.
   - Low energy alpha-parent nuclear recoil events generate small S2 + S1 events. Studies position reconstruction resolution. Tested using data outside WIMP search S1 energy range. This ensured that position reconstruction for sets were similar, and definition of fiducial was not biased.
4) Use of Profile Likelihood Ratio (PLR) analysis means we don't have to draw acceptance boxes
   - This avoids potential bias in data analysis from selecting regions in S1,S2 signal-space
5) Inputs for Profile Likelihood Ratio analysis were developed using high statistics in situ calibrations, with some simulations to cross check

LUX WIMP Search, 85 live-days, 118 kg

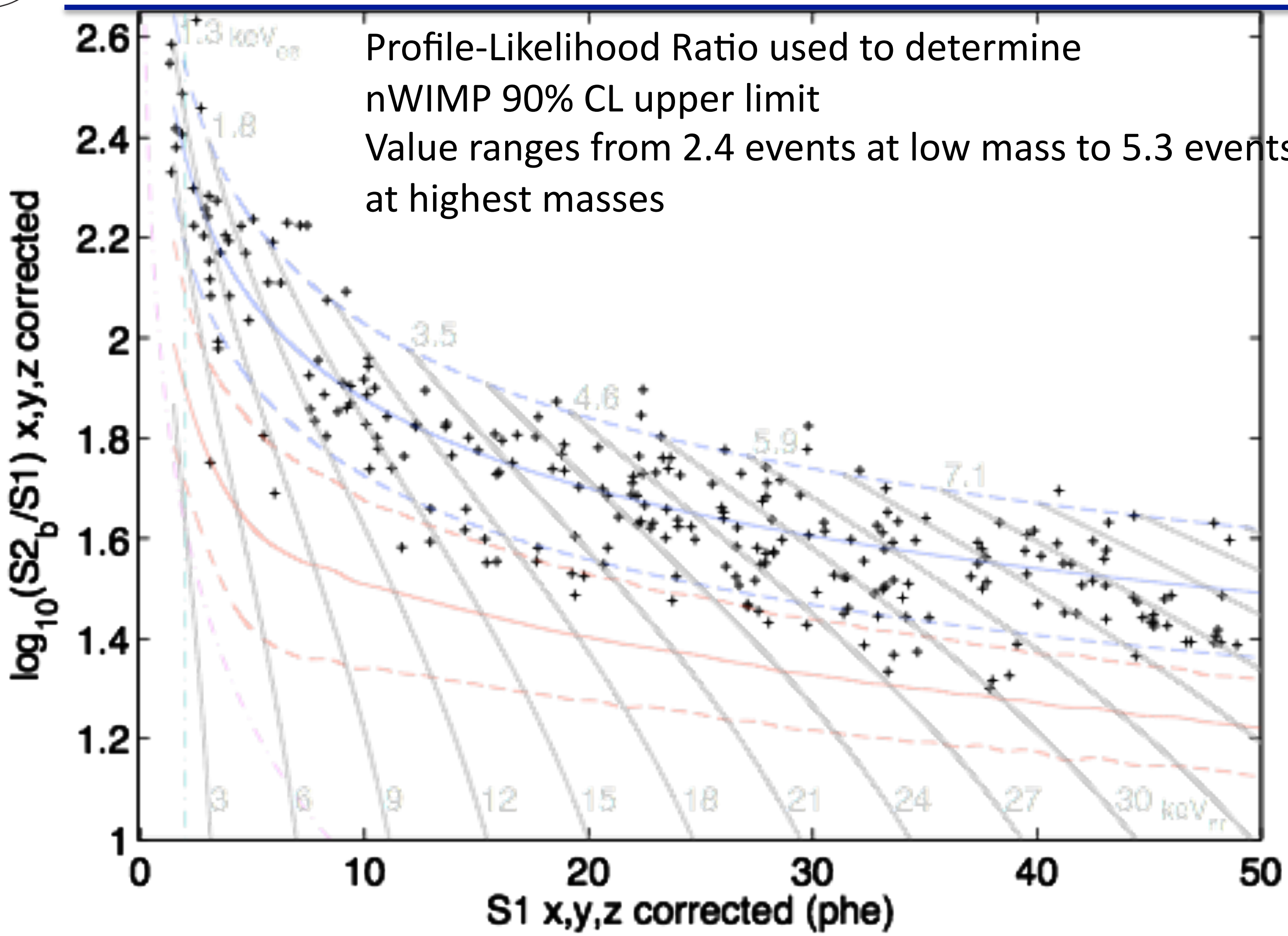


LUX WIMP Search, 85 live-days, 118 kg

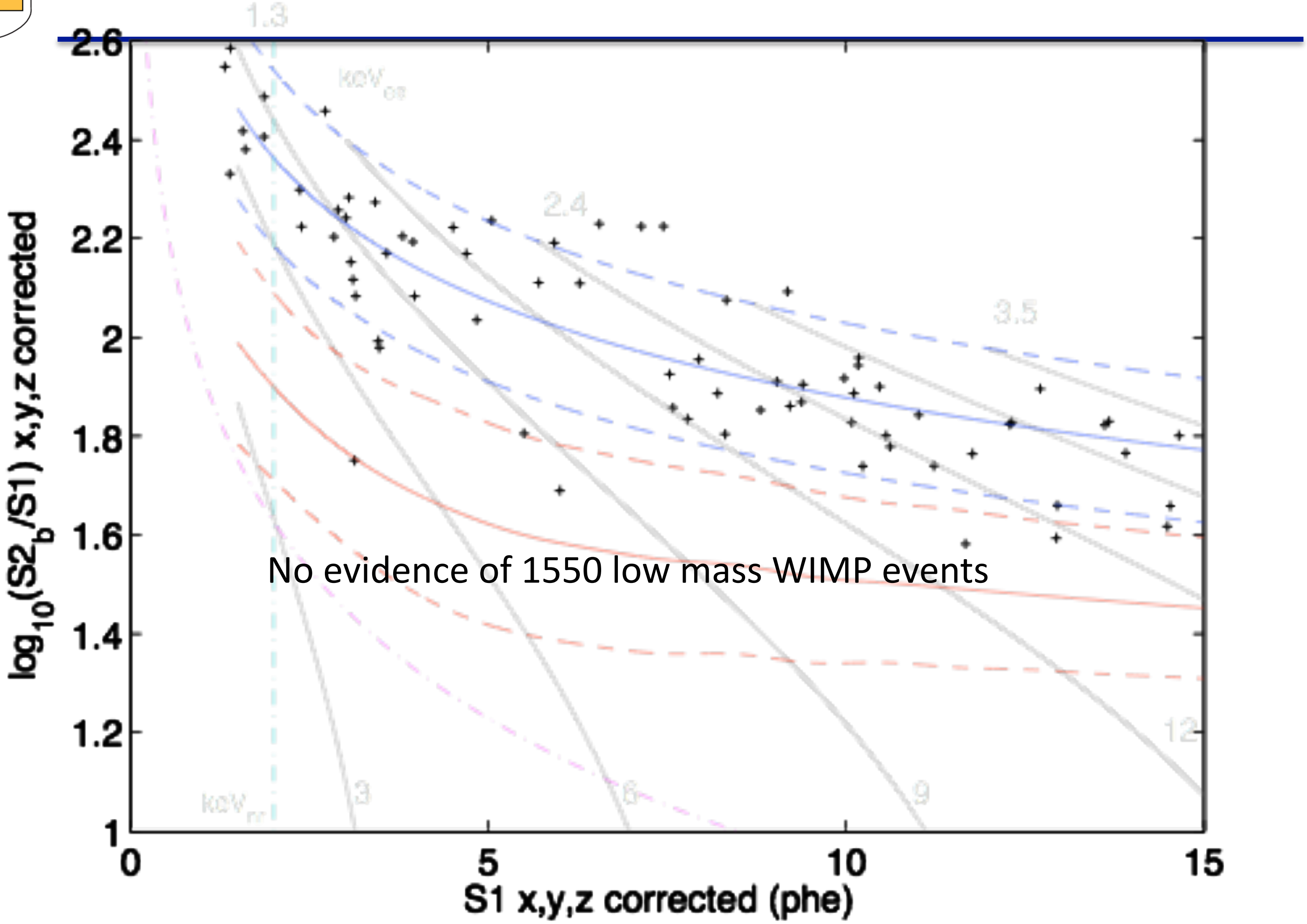


LUX WIMP Search, 85 live-days, 118 kg

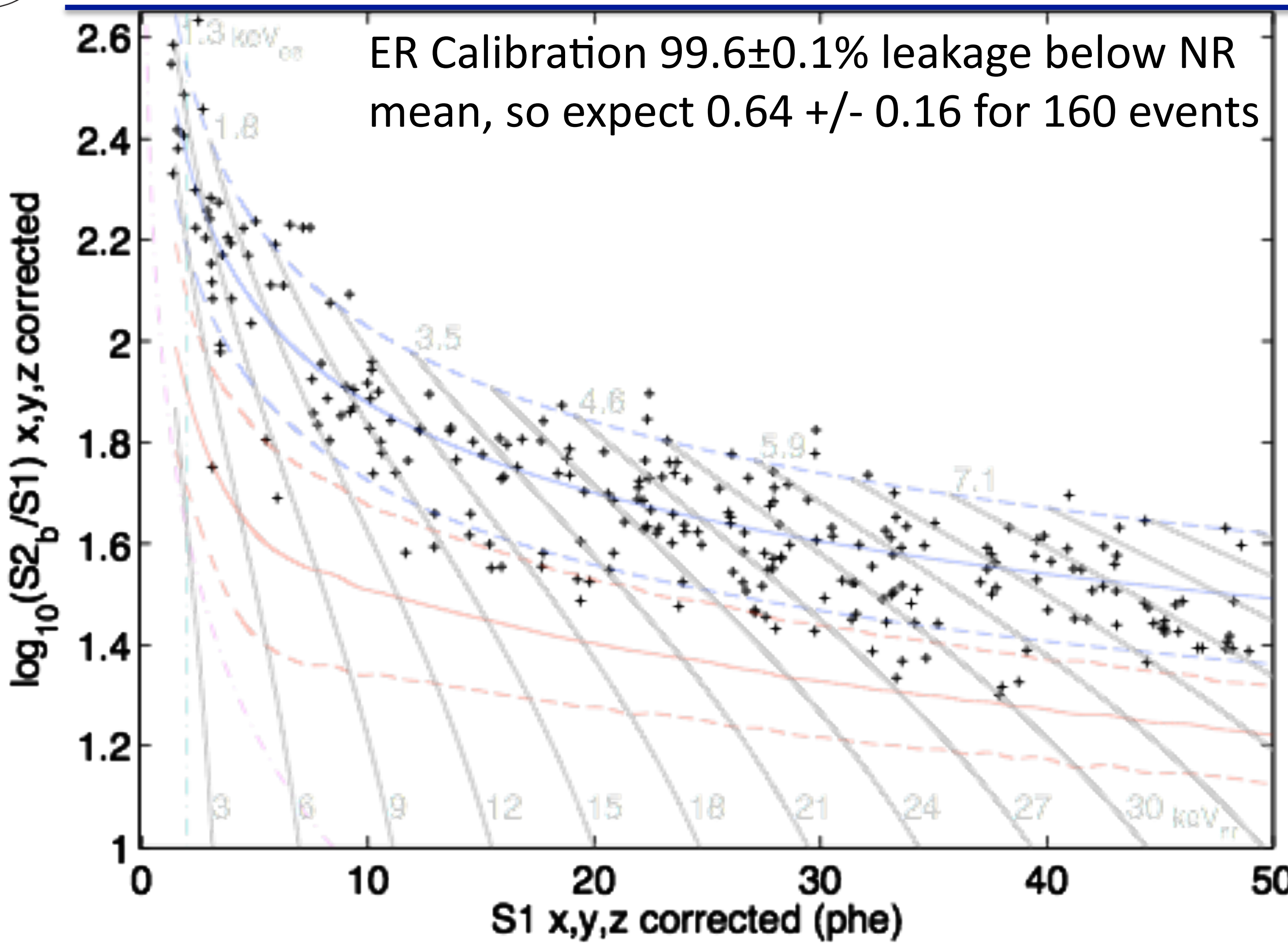
Profile-Likelihood Ratio used to determine nWIMP 90% CL upper limit
Value ranges from 2.4 events at low mass to 5.3 events at highest masses



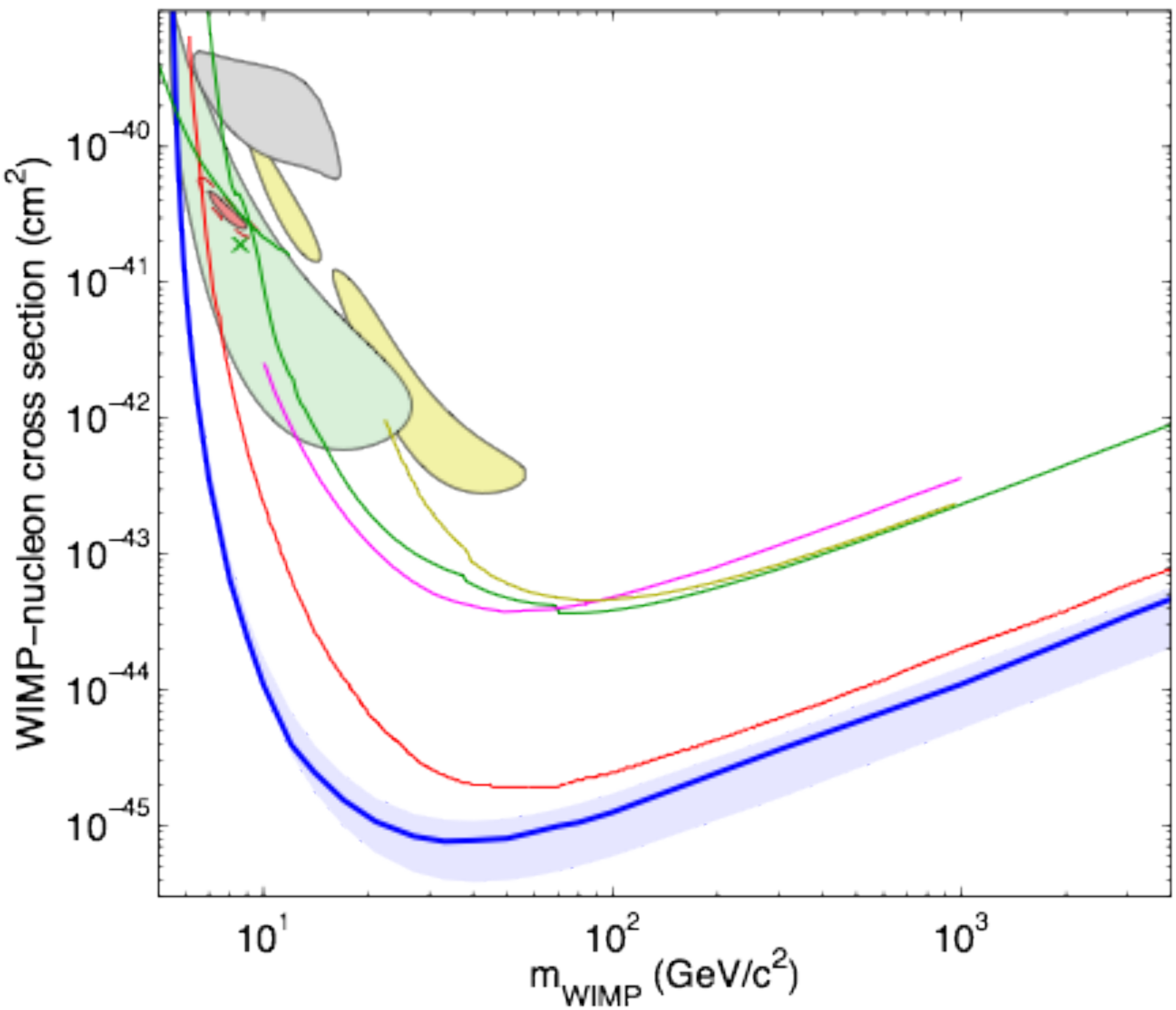
LUX WIMP Search, 85 live-days, 118 kg



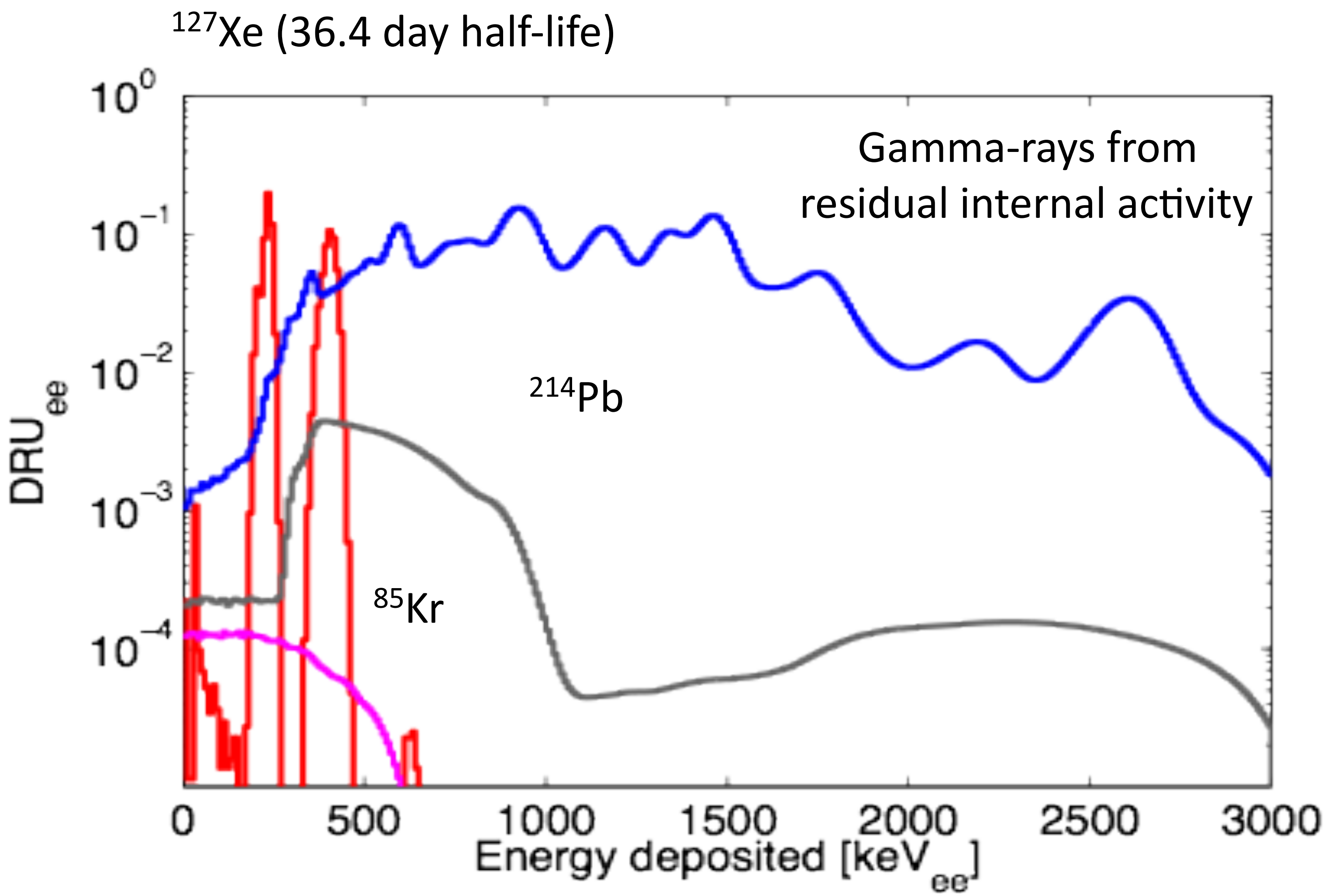
LUX WIMP Search, 85 live-days, 118 kg



Spin Independent Sensitivity Plots

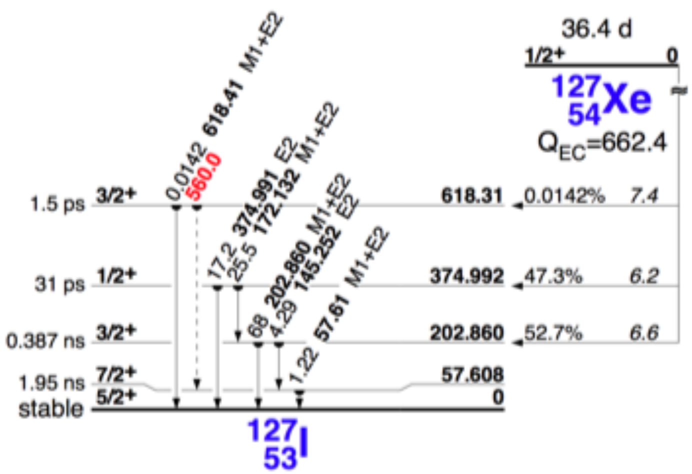


Full Background Model Fits ER Data Over Entire Range

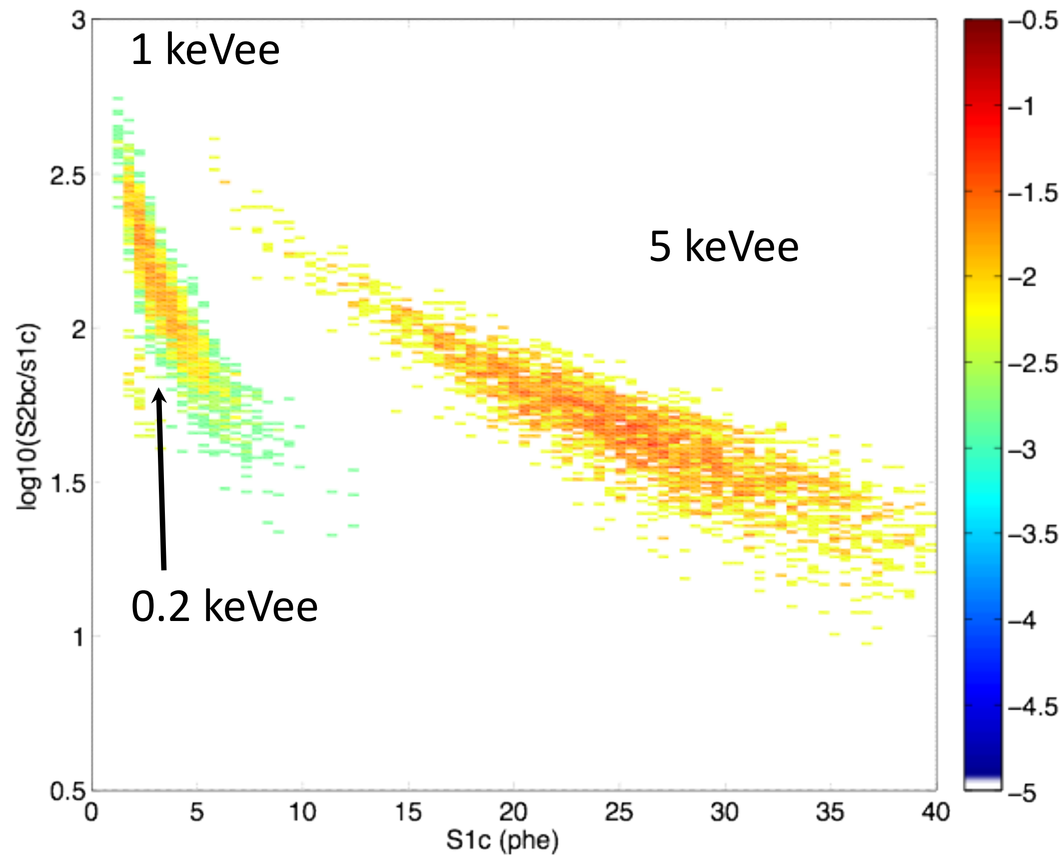


127Xe Electron Capture - Simulation

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



Probability Density Function



Xenon Properties

- Scintillates, comparison with ionization allows `discrimination' of signal and background
- Plenty of signal ≈1 keV
- Liquid ρ≈3 gm/cm^3, purity
- No long-lived radioisotopes
- 9 stable isotopes
- 2 with odd neutron

^{A}Z	$\tau_{1/2}$ or f	J^{p}
^{122}Xe	20 h	0^+
^{123}Xe	2.1 h	$(1/2)^+$
^{124}Xe	0.10 %	0^+
^{125}Xe	17 h	$(1/2)^+$
^{126}Xe	0.09 %	0^+
^{127}Xe	**36 d**	**$(1/2)^+$**
^{128}Xe	1.91 %	0^+
^{129}Xe	**26.4 %**	**$(1/2)^+$**
^{130}Xe	4.1 %	0^+
^{131}Xe	**21.2 %**	**$(3/2)^+$**
^{132}Xe	26.9 %	0^+
^{133}Xe	5.2 d	$(3/2)^+$
^{134}Xe	10.4 %	0^+
^{135}Xe	9.1 h	$(3/2)^+$
^{136}Xe	8.9 %	0^+

Central Xenon – 5600 kg Fiducial

241 PMTs

R11410

(110 skin PMTs)

R8520

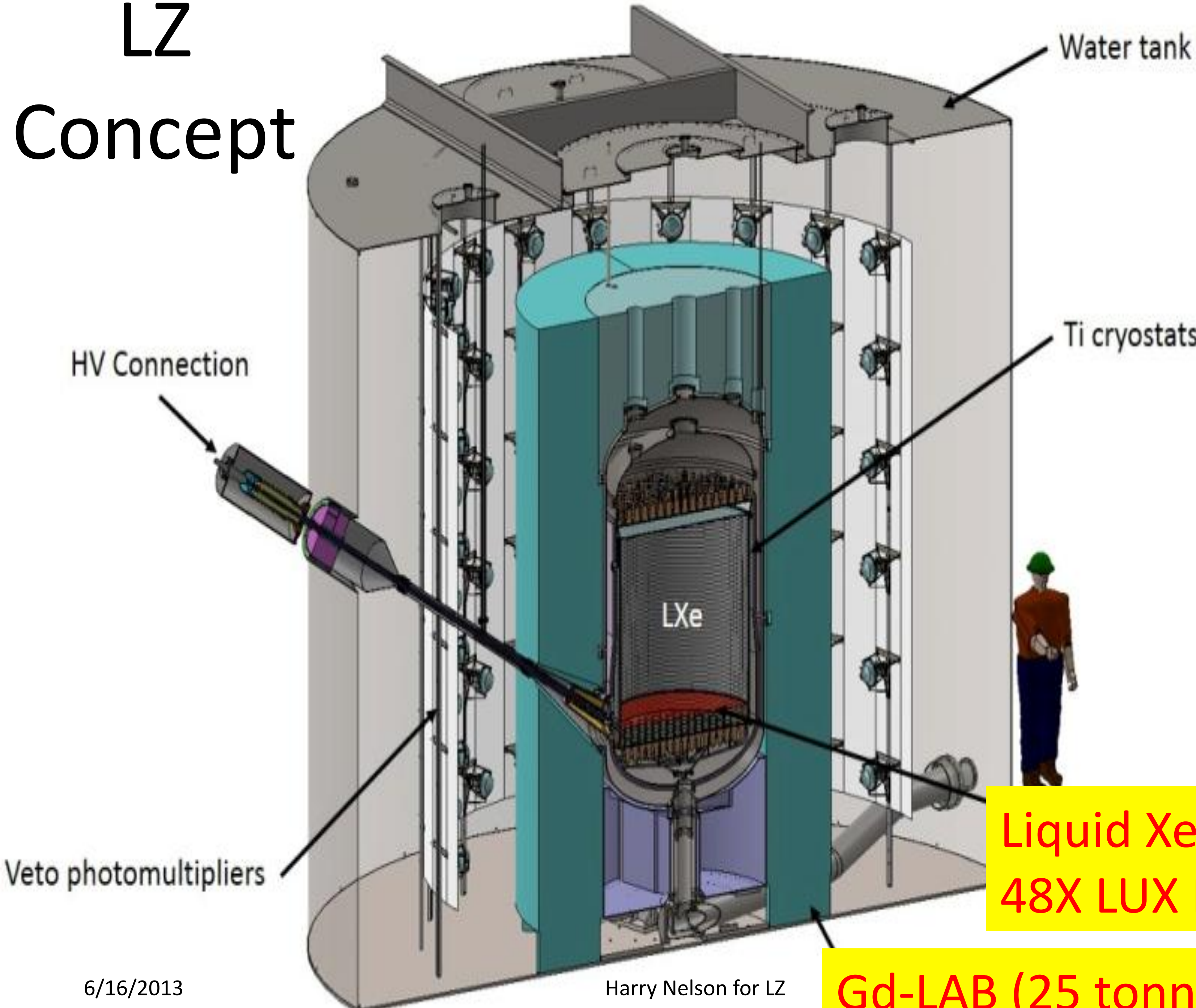
100-200 kV

146 cm D x H

670 μs drift

241 PMTs

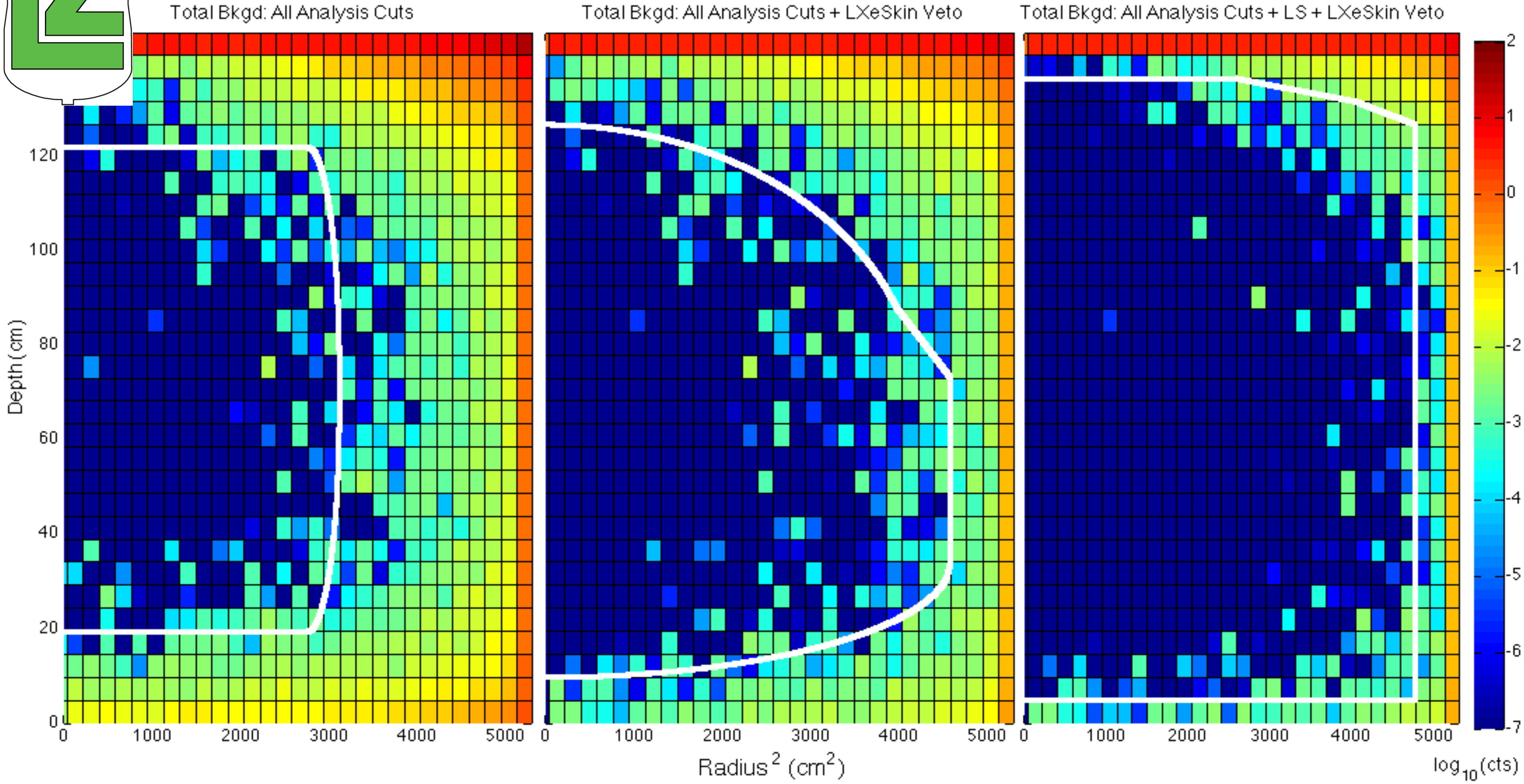
LZ Concept



Liquid Xenon: 7T
48X LUX Fiducial

Gd-LAB (25 tonne)

Self Shielding, Veto… Calibrate?



2.8 Tonne

Skin Veto
4.1 Tonne

+ Gd-LAB
5.6 Tonne

Estimated Background

ER NR

5.6 tonnes fiducial

1000 days

(best) baseline (pessimistic) – bkg of ϒ, n

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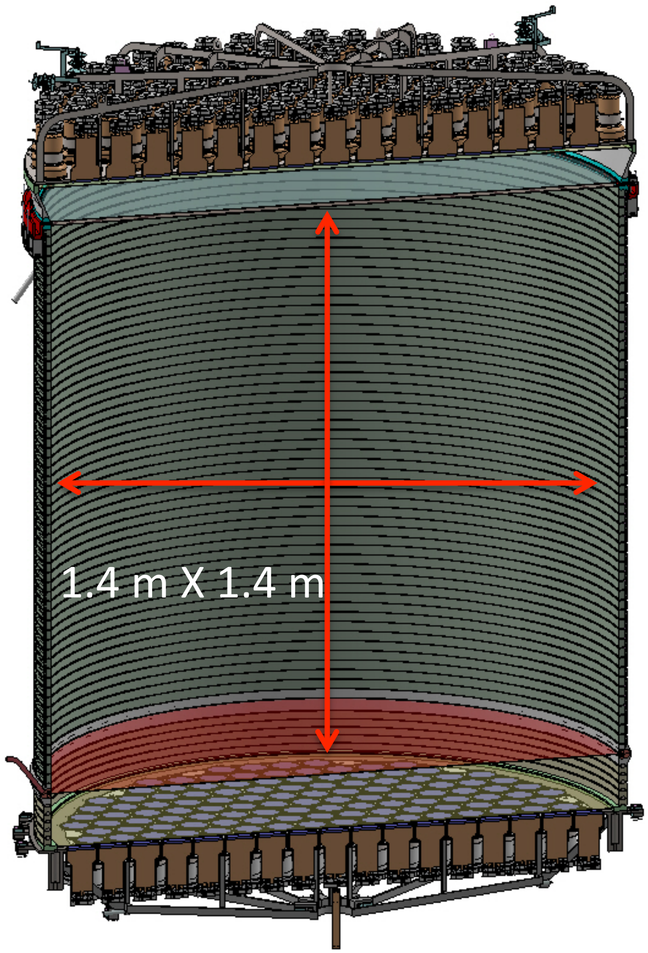

Table 2.1 Work Breakdown Structure (WBS) and principal parameters of the LZ detector.

WBS	Description	Quantity
1.1	Xenon Procurement	
	Approximate total mass	10 tonnes
	Mass inside TPC active region	7 tonnes
	Approximate fiducial mass	5.6 tonnes
1.2	Cryostat	
	Inner cryostat — inside diameter (tapered), height, wall thickness	1.58-1.66 m, 2.52 m, 6 mm
	Outer cryostat — inside diameter, height, wall thickness	1.83 m, 3.09 m, 8 mm
	Approximate cryostat weights — inner, outer	670 kg, 1,060 kg
1.3	Cryogenic System	
	Cooling power	1 kW @ 80 K
	Input electrical power	11 kW
1.4	Xenon Purification	
	Krypton content	<0.015 ppt (g/g)
	^{222}Rn content in active Xe	<0.67 mBq
	Recirculation rate	≥ 500 SLPM
	Electron lifetime	>0.75 ms
	Charge attenuation length	>1.5 m
1.5	Xenon Detector	
	Top (Bottom) TPC 3-inch PMT array	247 (241), 488 total tubes
	"Side skin readout" and "bottom" 1-inch PMT	60 top skin, 60 bottom skin, 60 bottom
	Nominal (Design) cathode operating voltage	100 (200) kV
	Reverse field region (cathode to bottom tube shield)	0.146 m
	TPC height (cathode to gate grid)	1.46 m
	TPC effective diameter	1.46 m
1.6	Outer Detector System	
	Weight of Gd-loaded LAB scintillator	27 tonnes
	Number of acrylic vessels, total acrylic mass	9 vessels, 3.8 tonnes
	Number of 8-inch PMTs	120
	Average thickness of scintillator	0.70 m
	Diameter of water tank	7.62 m
	Height of water tank	5.92 m
	Approximate weight of water	228 tonnes
1.7	Calibration System	
	Number of source (γ, n) calibration tubes	3
	Other calibration tools	^{83m}Kr, n-generator, tritiated CH_4, ^{37}Ar
1.8	Electronics, DAQ, Controls, and Computing	
	Trigger rate (all energies, 0-40 keV)	40 Hz, 0.4 Hz
	Average event size (noncalibration, uncompressed)	0.2–1.0 MB
	Data volume per year	350–850 TB
1.9	Integration and Installation	