Sanford Underground Research Facility

First Result from the LUX experiment

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Imperial College London

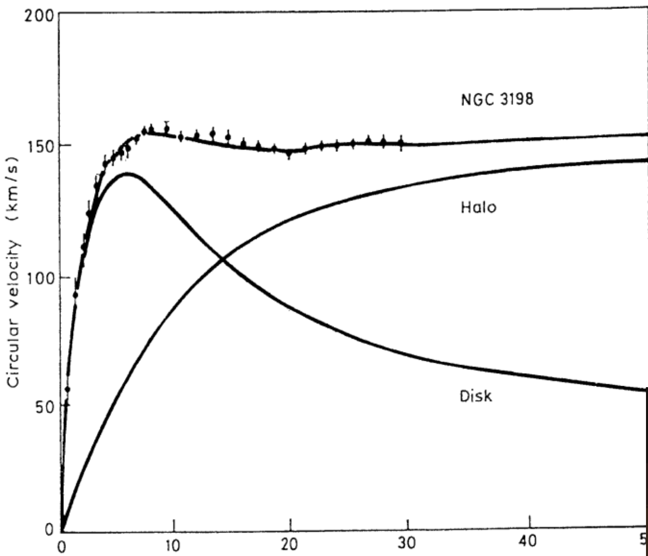
on behalf of the LUX collaboration

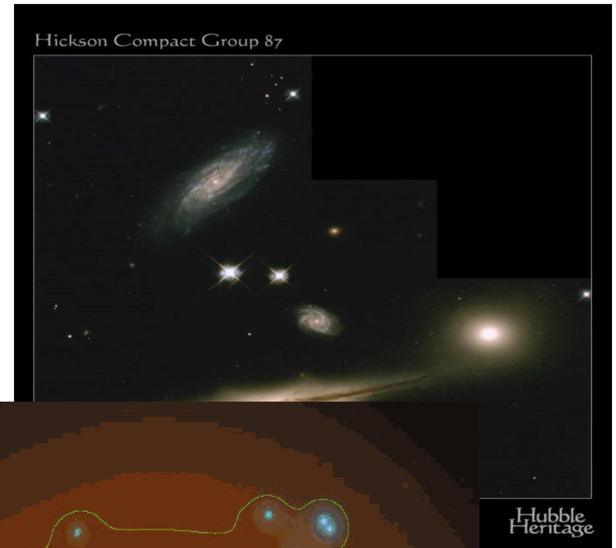
Imperial College London

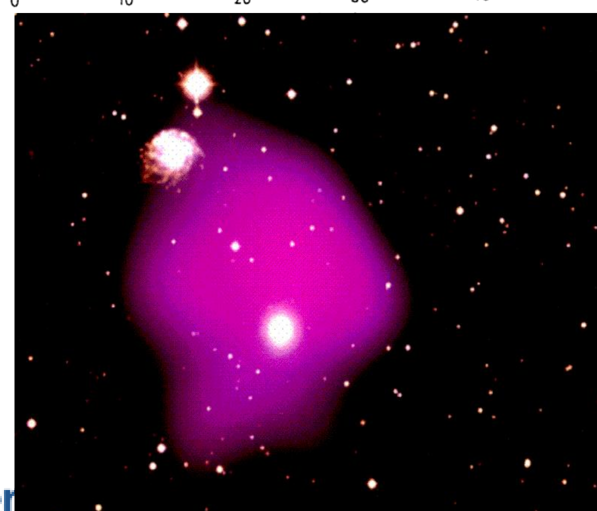
- Motivation
- Detection
- LUX Description
- LUX Commissioning Performance
- LUX WIMP Search
- Future plans

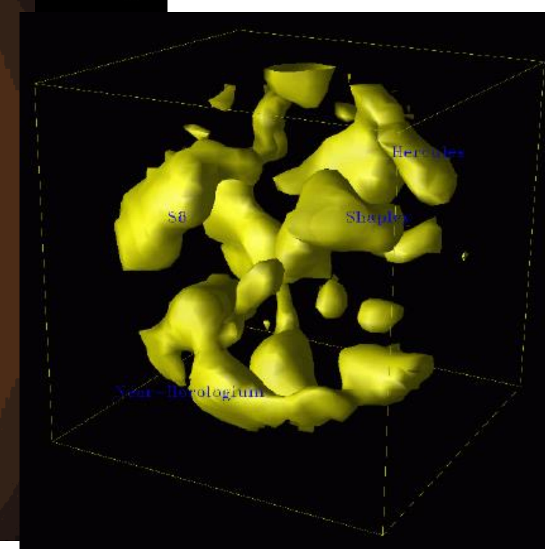
Evidence for Dark Matter

a)Probing gravitational potentials



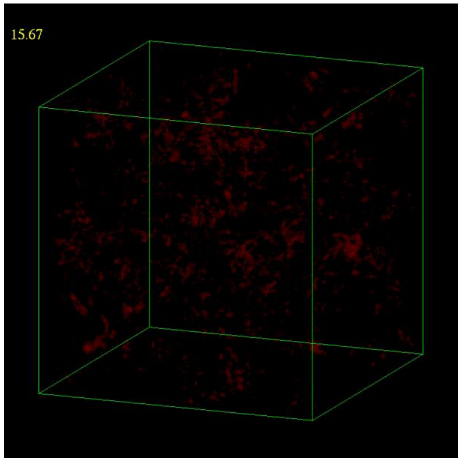


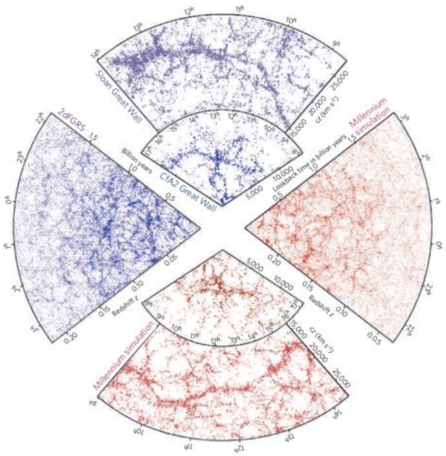


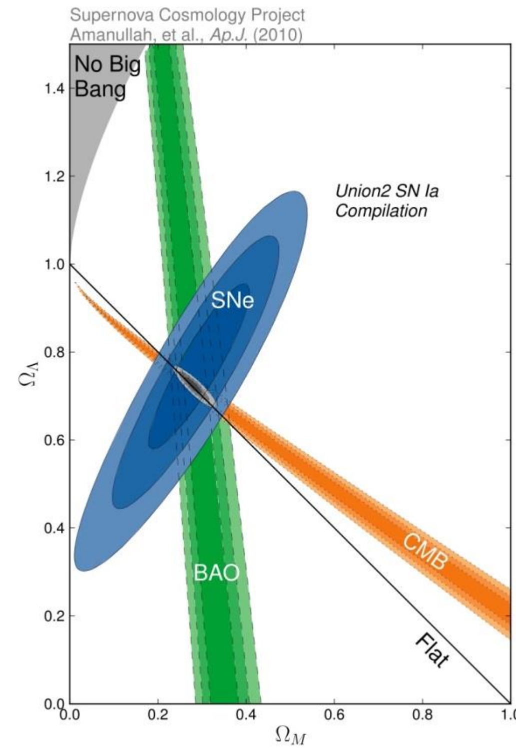


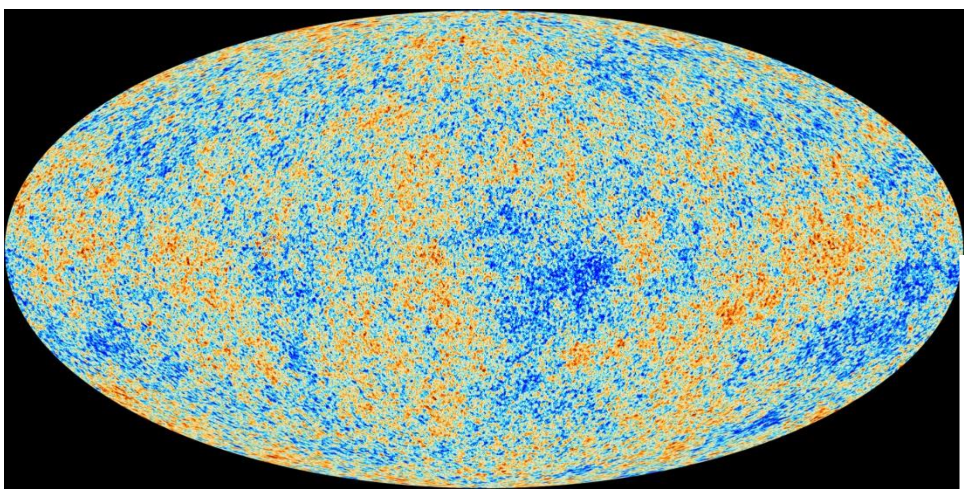
Evidence for Dark Matter

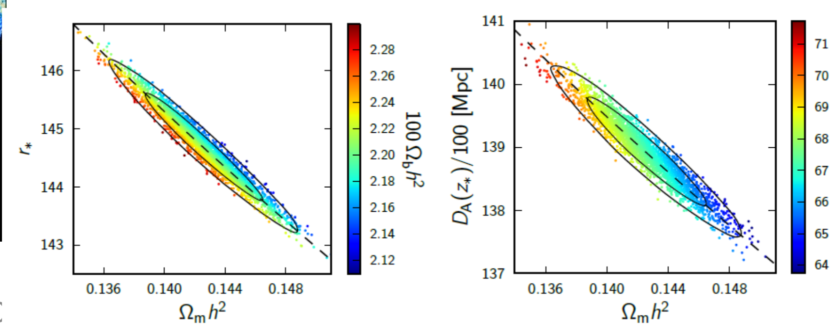
b)Structure and evolution of the Universe











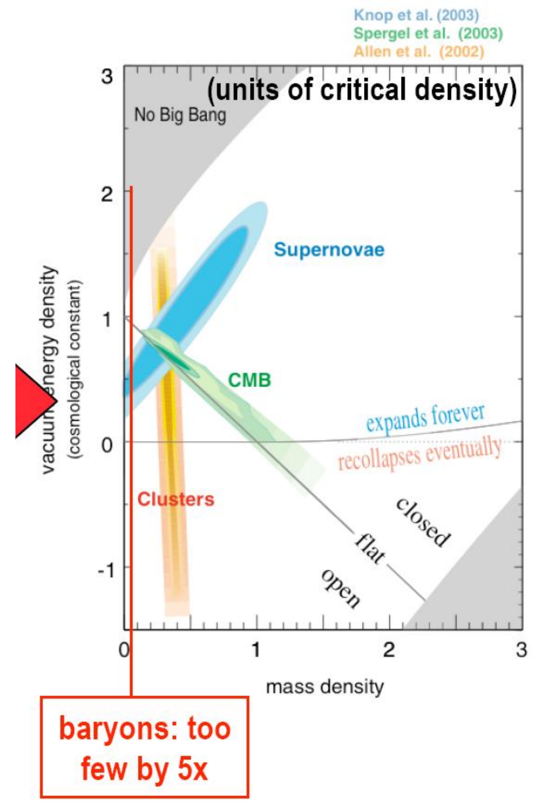
Scientific Motivation

Dark matter detection goals are driven by three questions

- **Cosmology – is the dark matter that makes up ~26% of the Universe in the form of massive particles?**

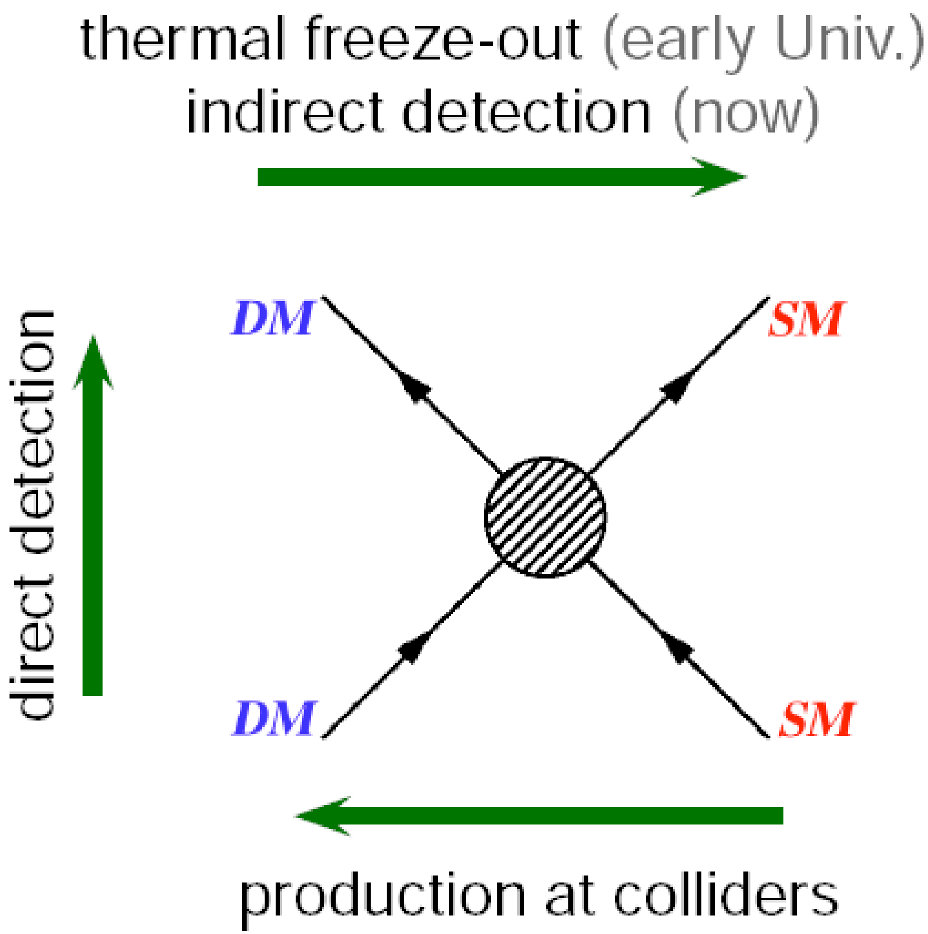
- **Unification – are these the particles predicted by frameworks *such as* supersymmetry?**

- **Galaxy formation and dynamics – how do these particles behave within galaxies?**



How to Detect WIMPs

This talk



WIMP DIRECT SEARCH TECHNOLOGY ZOO

WIMP elastic nuclear recoils deposit < 50keV of energy at a rate < 1 event/day/tonne

Ionisation Detectors

Targets: Ge, Si, CS_2, CdTe

CoGeNT, DRIFT, DM-TPC

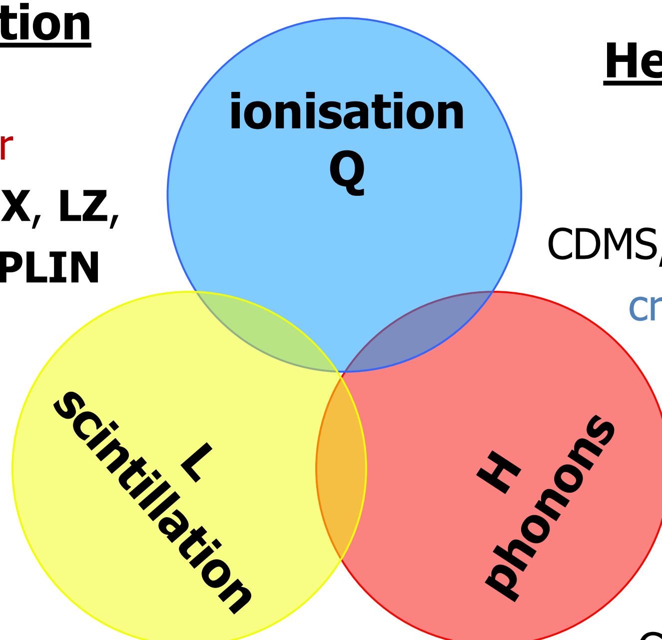
GENIUS, HDMS, IGEX, NEWAGE

Light & Ionisation Detectors

Targets: Xe, Ar

ArDM, Darkside, **LUX**, **LZ**, WARP, XENON, **ZEPLIN**

cold (LN_2)



Heat & Ionisation Bolometers

Targets: Ge,Si

CDMS, EDELWEISS, EURECA

cryogenic (<50 mK)

Scintillators

Targets: NaI, Xe, Ar

ANAIS, CLEAN, DAMA, DEAP, KIMS, LIBRA, NAIAD, XMASS, **ZEPLIN-I**

Bolometers

Targets: Ge, Si, Al_2O_3, TeO_2

CRESST-I, CUORE, CUORICINO

Light & Heat Bolometers

Targets: $CaWO_4$, BGO, Al_2O_3

CRESST, ROSEBUD

cryogenic (<50 mK)

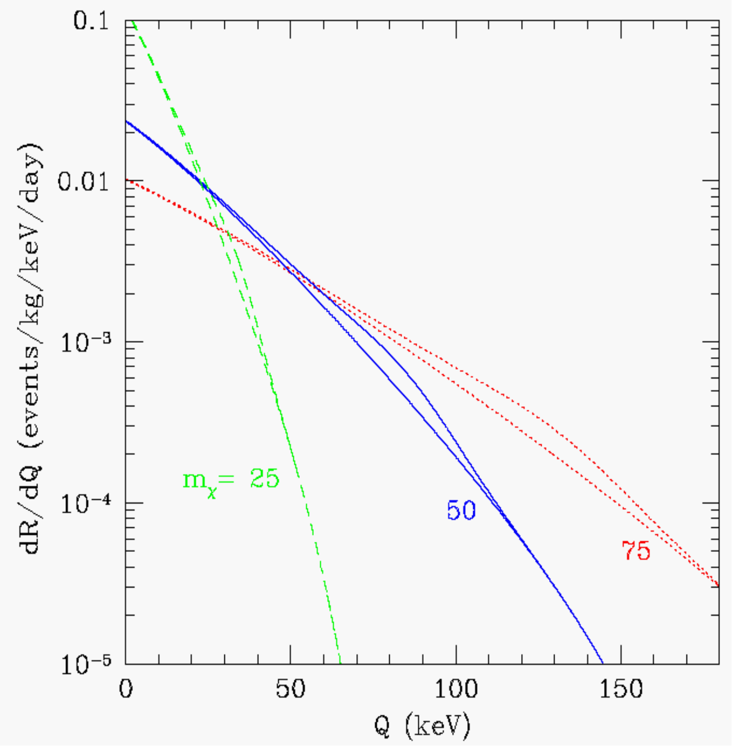
Bubbles & Droplets

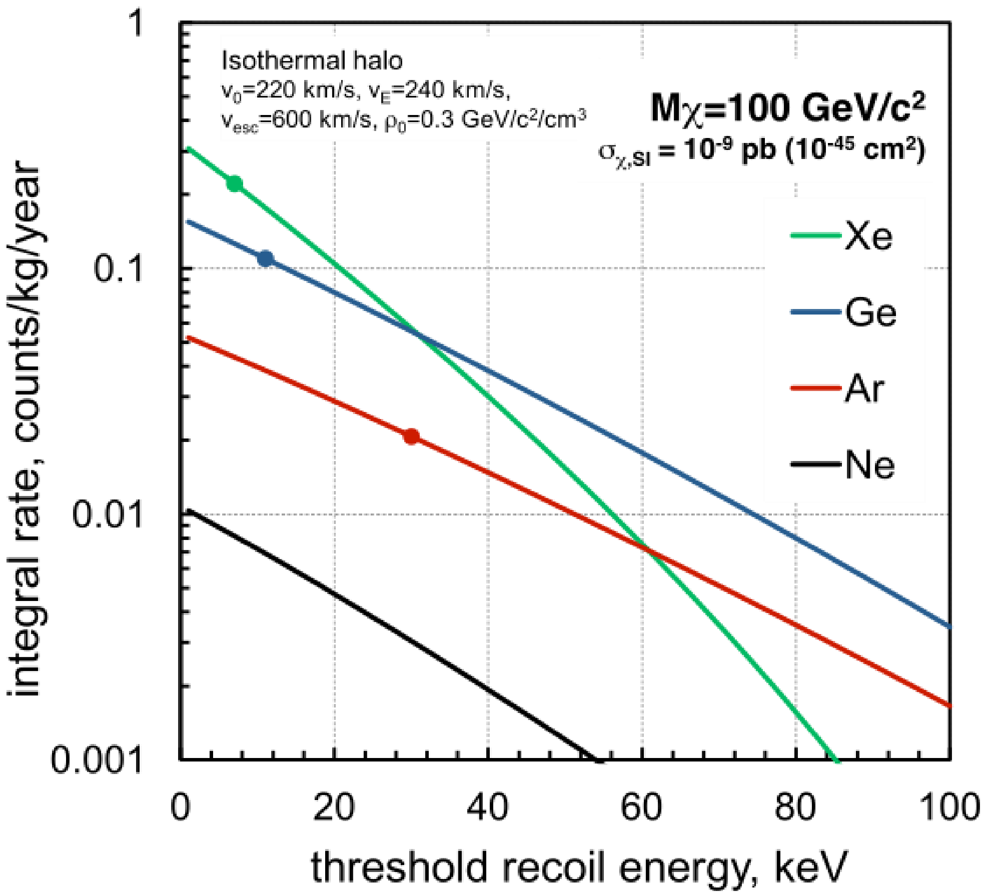
CF_3Br, CF_3I, C_3F_8, C_4F_{10}

COUPP, PICASSO, SIMPLE

The Challenge

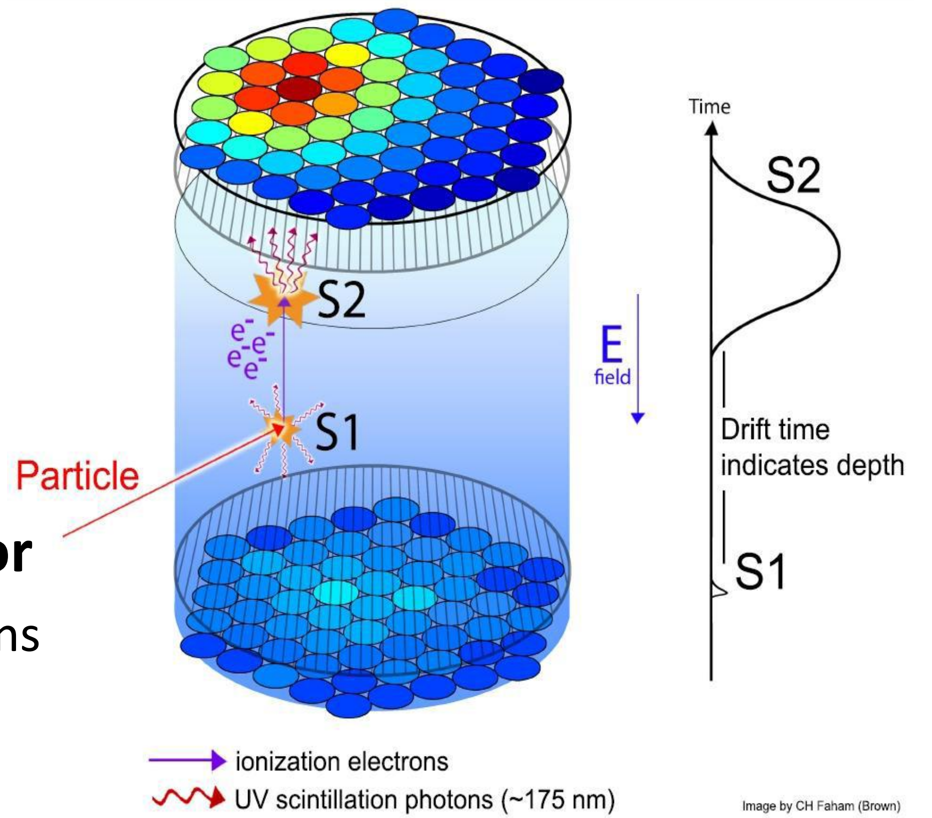
WIMP elastic nuclear recoils deposit < 50keV of energy at a rate < 1 event/day/tonne





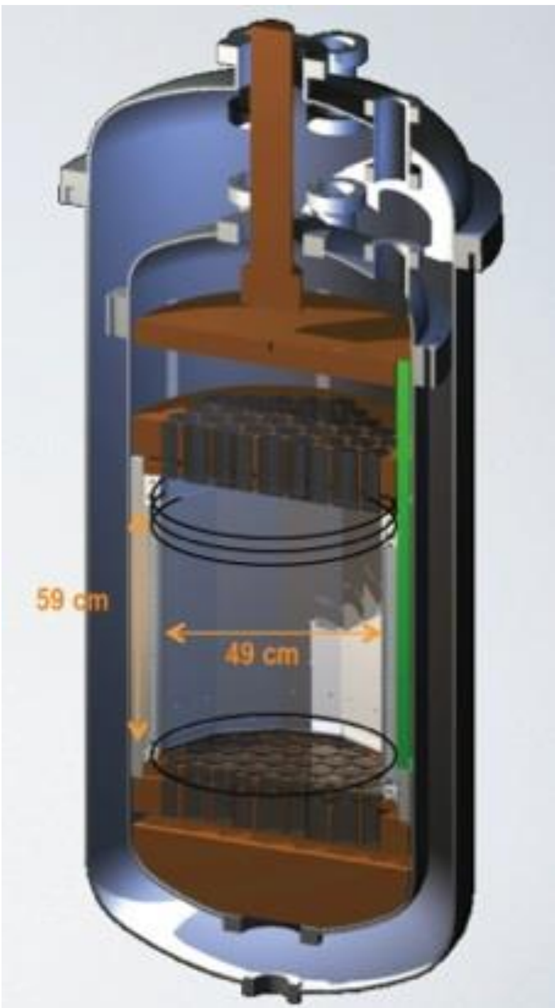
TWO-PHASE XENON DETECTORS

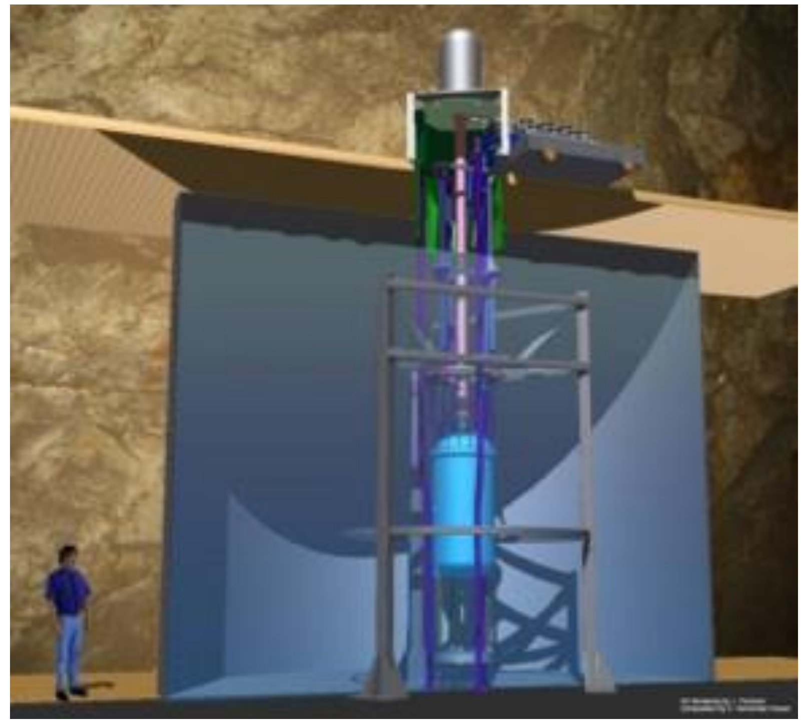
- **S1: LXe is an excellent scintillator**
  - Density: 3 g/cm^3
  - Light yield: ~70 ph/keV (0 field)
  - Scintillation light: 178 nm (VUV)
  - **Nuclear recoil threshold ~5-10 keV**
- **S2: Even better ionisation detector**
  - Sensitive to single ionisation electrons
  - **Nuclear recoil threshold ~1 keV**



- **And a great WIMP target too**
  - Scalar WIMP-nucleon scattering rate $dR/dE \sim A^2$
  - Odd-neutron isotopes (^{129}Xe, ^{131}Xe) enable spin-dependent sensitivity
  - Excellent ionisation threshold: 'light WIMP' searches using S2 only
  - No intrinsic backgrounds (^{85}Kr can be removed effectively)

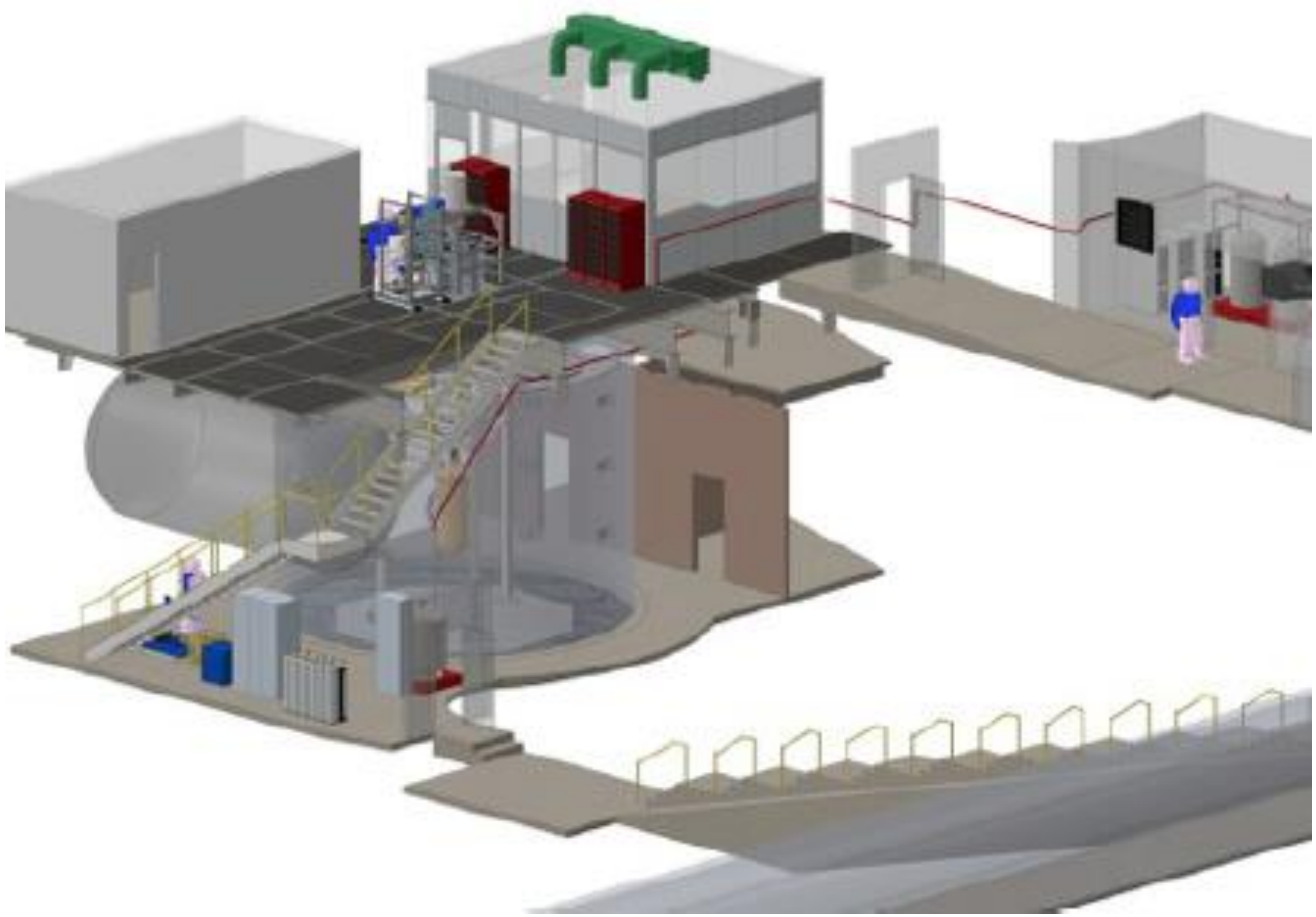
The Large Underground Xenon (LUX) Experiment



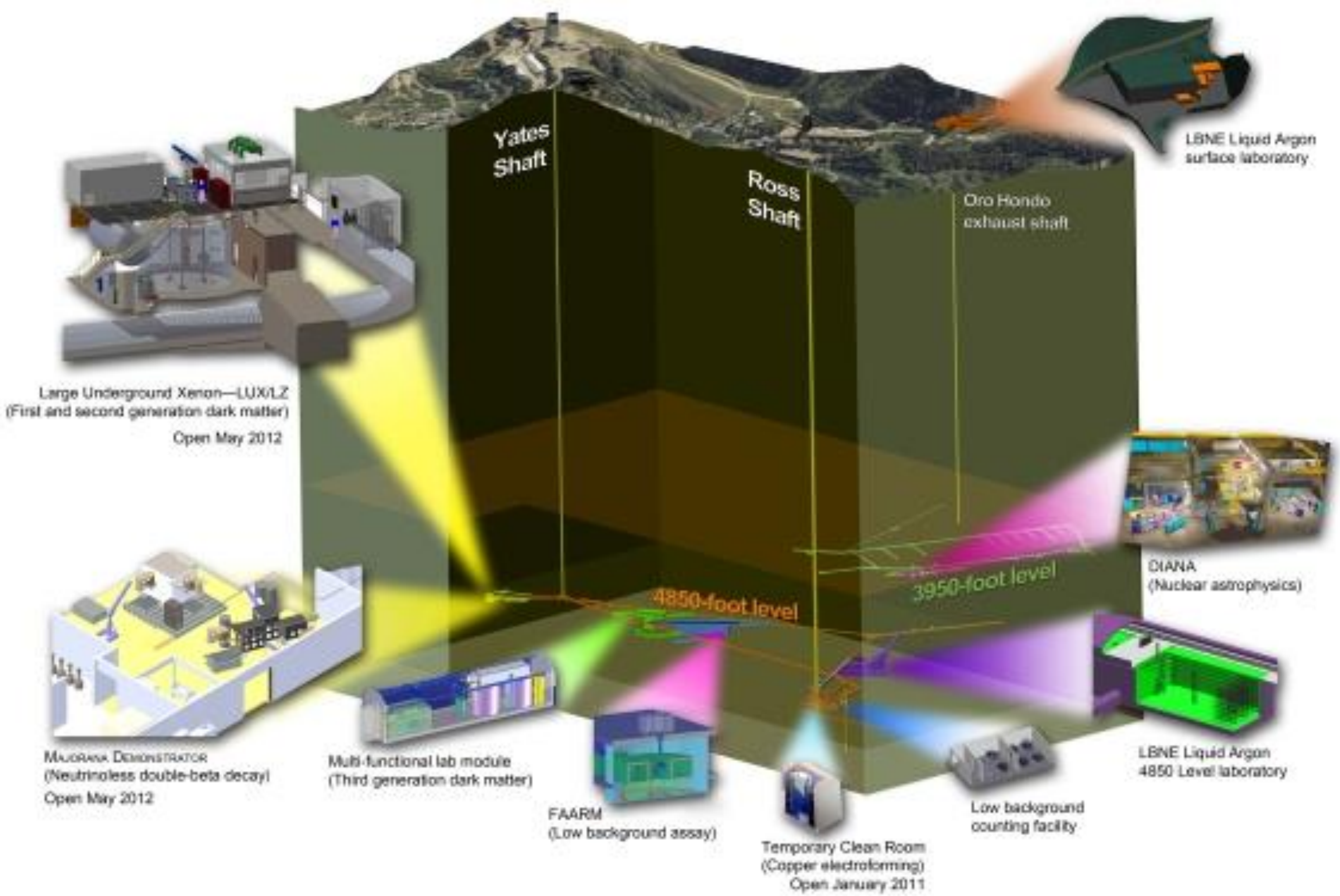


370 kg total xenon mass
250 kg active liquid xenon
118 kg fiducial mass

LUX in the Davis Cavern



LUX in the SURF at Homestake



LUX collaboration (at Homestake)

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	Postdoc
Victor Gehman	Scientist
Mia Ihm	Graduate Student

Lawrence Livermore

Adam Bernstein	PI, Leader of Adv.
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 Mannino	Graduate Student
Clement Sofka	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	Graduate Student

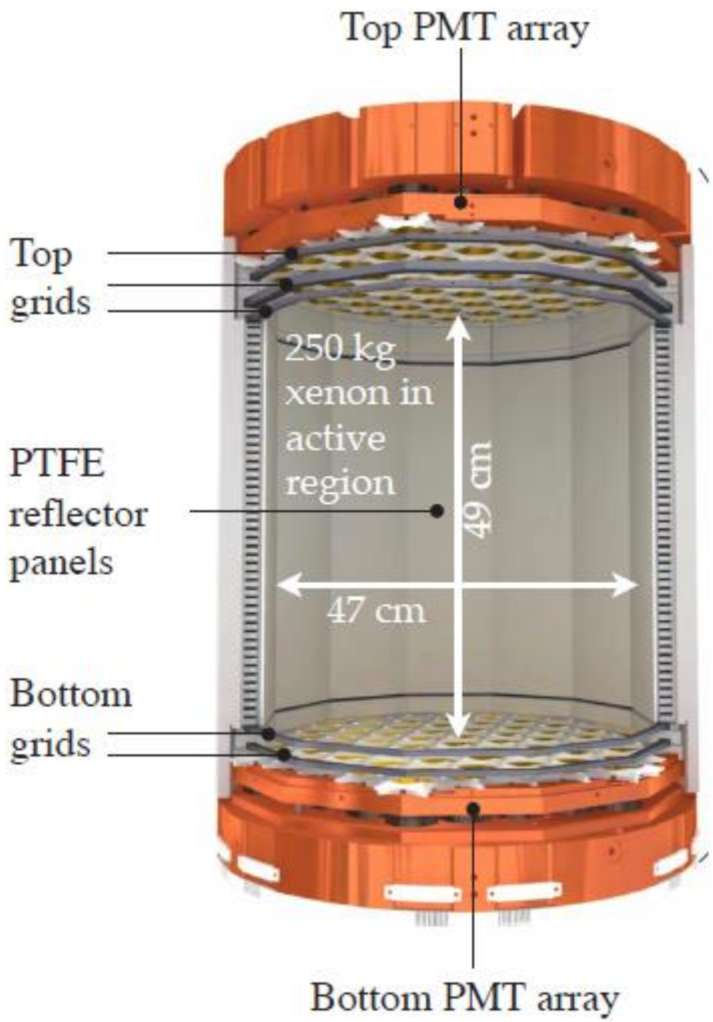
University of South Dakota

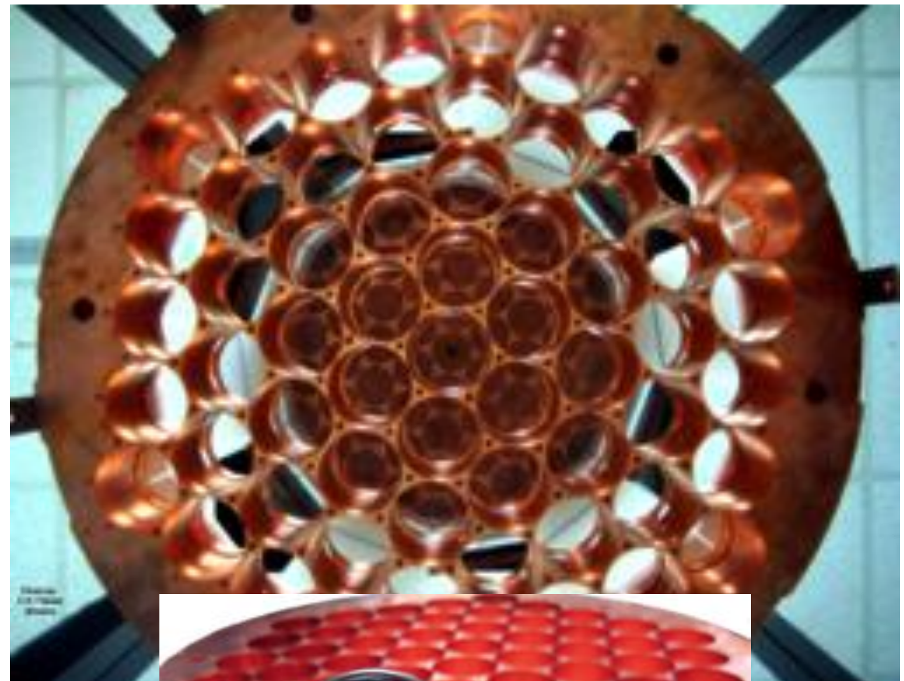
Dongming Mei	PI, Professor
Chao Zhang	Postdoc
Angela Chiller	Graduate Student
Chris Chiller	Graduate Student
Dana Byram	*Now at SDSTA

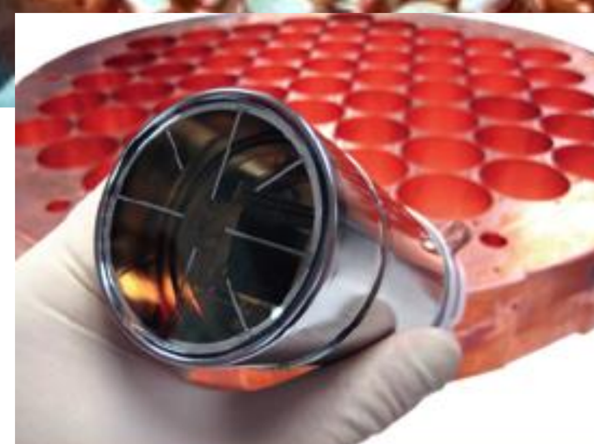
Yale

Daniel McKinsey	PI, Professor
Peter Parker	Professor
Sidney Cahn	Lecturer/Research
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

The LUX Detector







LUX Detector Installation

LUX Detector Commissioning

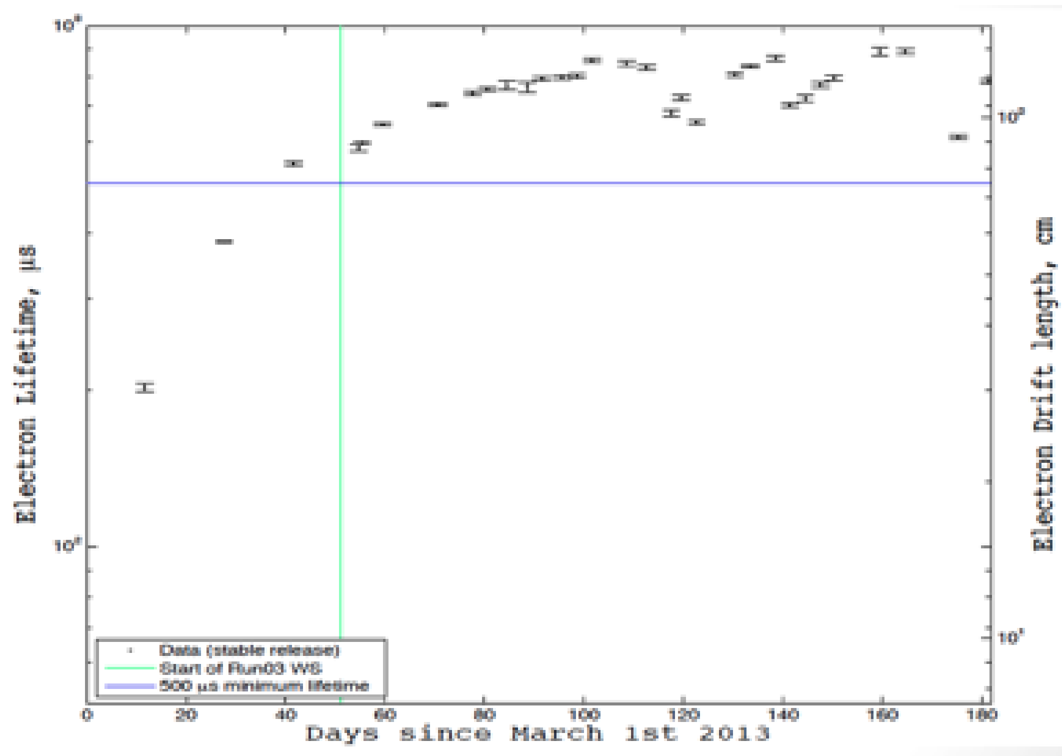
Low-energy electron recoil background of 3e-3 e/keV/kg/day.

Kr/Xe ratio of 3.5 ppt.

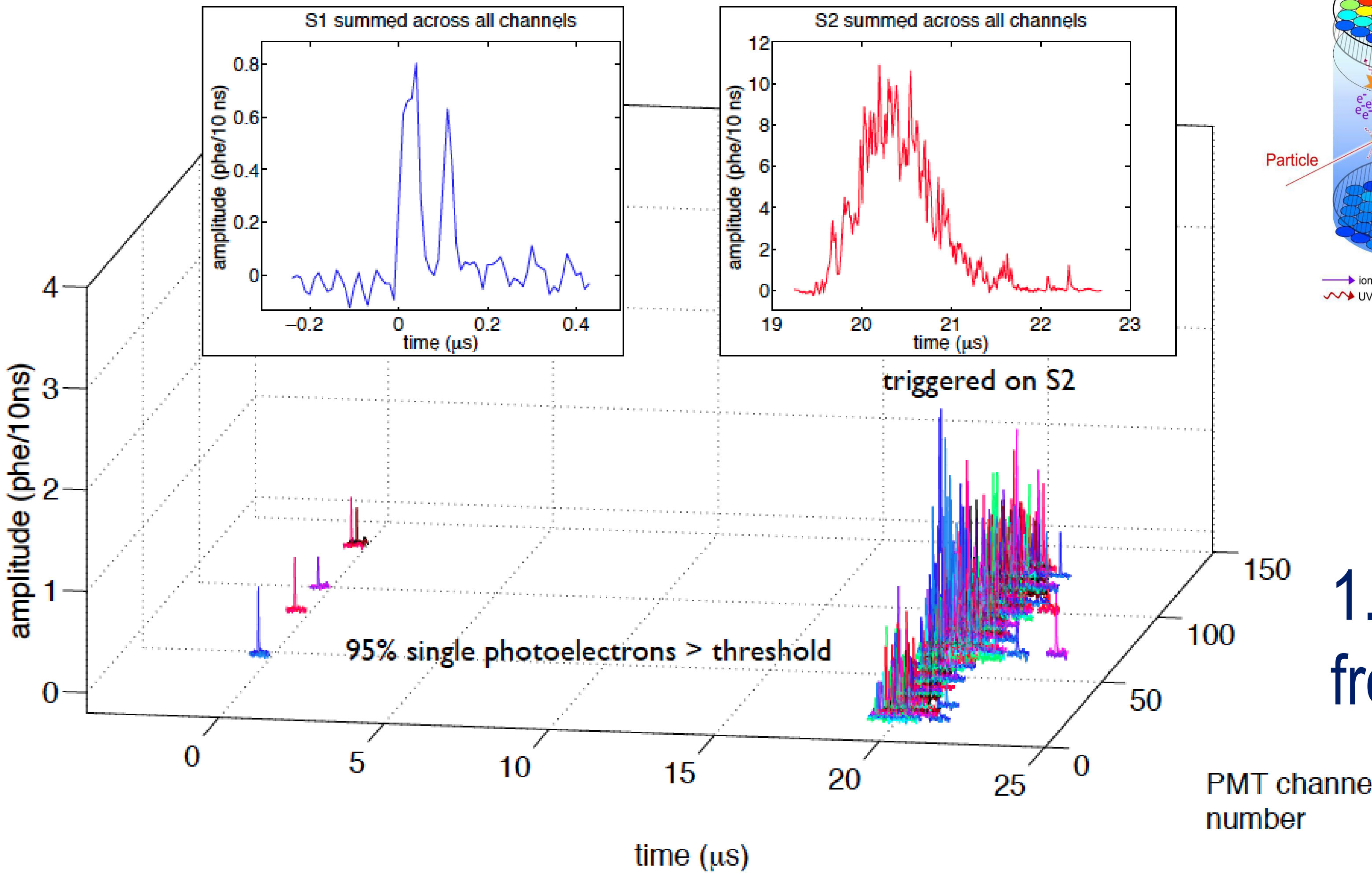
Electron drift length >130 cm.

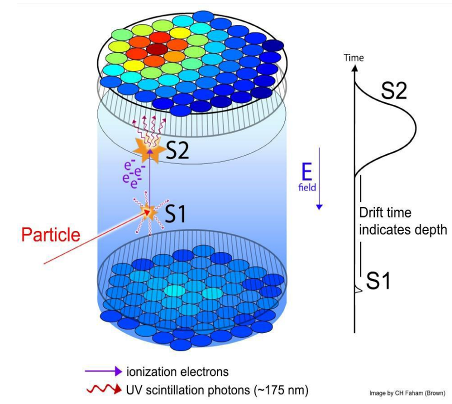
Light detection efficiency of 14%.

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



LUX Detector Commissioning



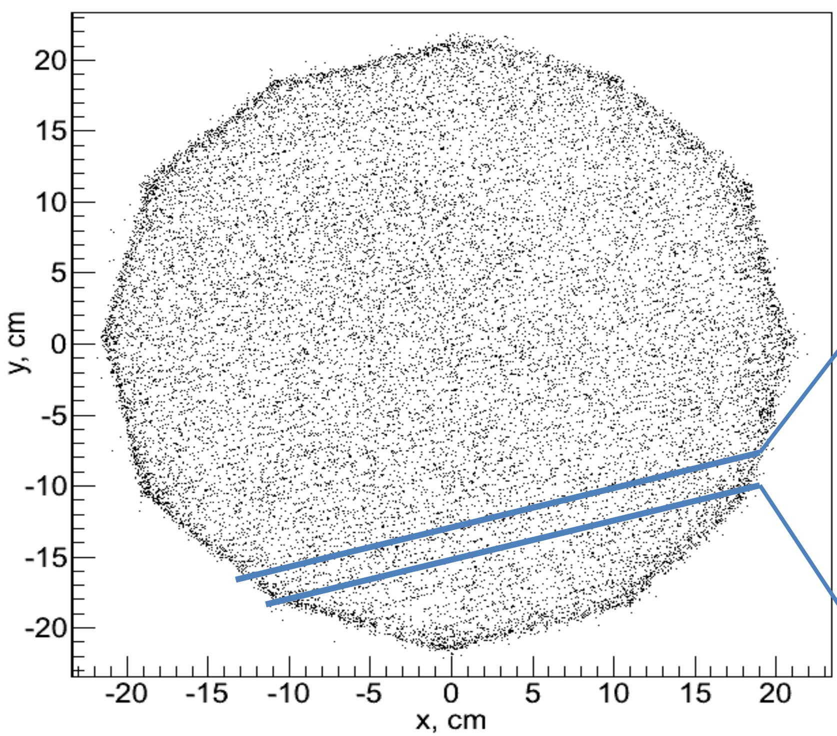


1.5 keV from γ-ray

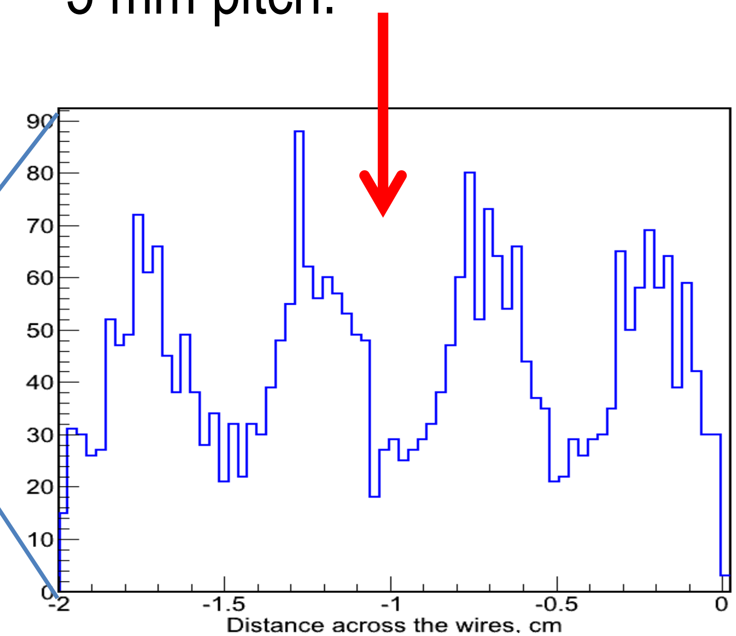
Detector Calibration

Position Reconstruction

- *Z* from S1-S2 time delay (1.51 mm/microsecond)
- *X,Y* from fitting the S2 hit pattern



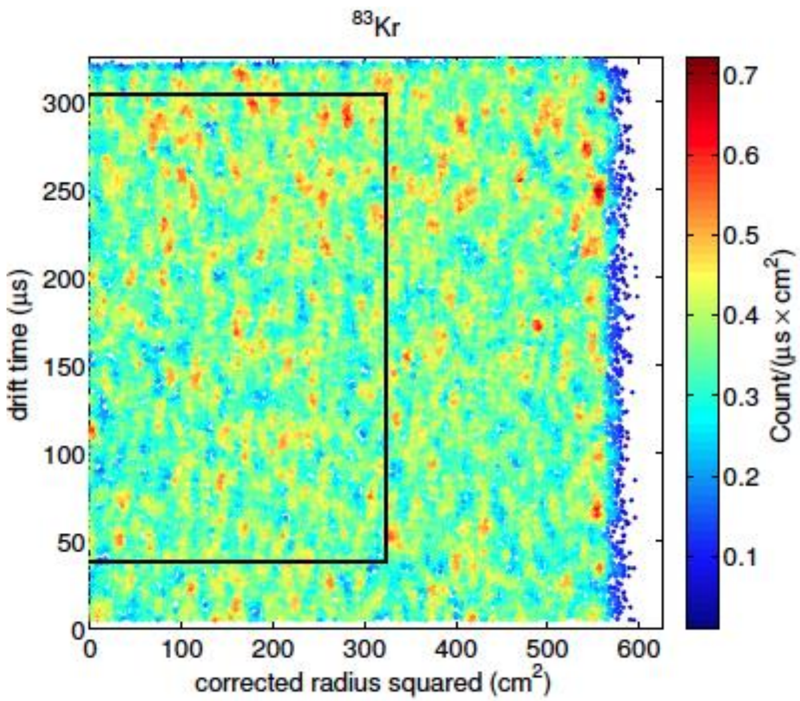
X,Y reconstruction of events near anode grid resolves grid wires with 5 mm pitch.

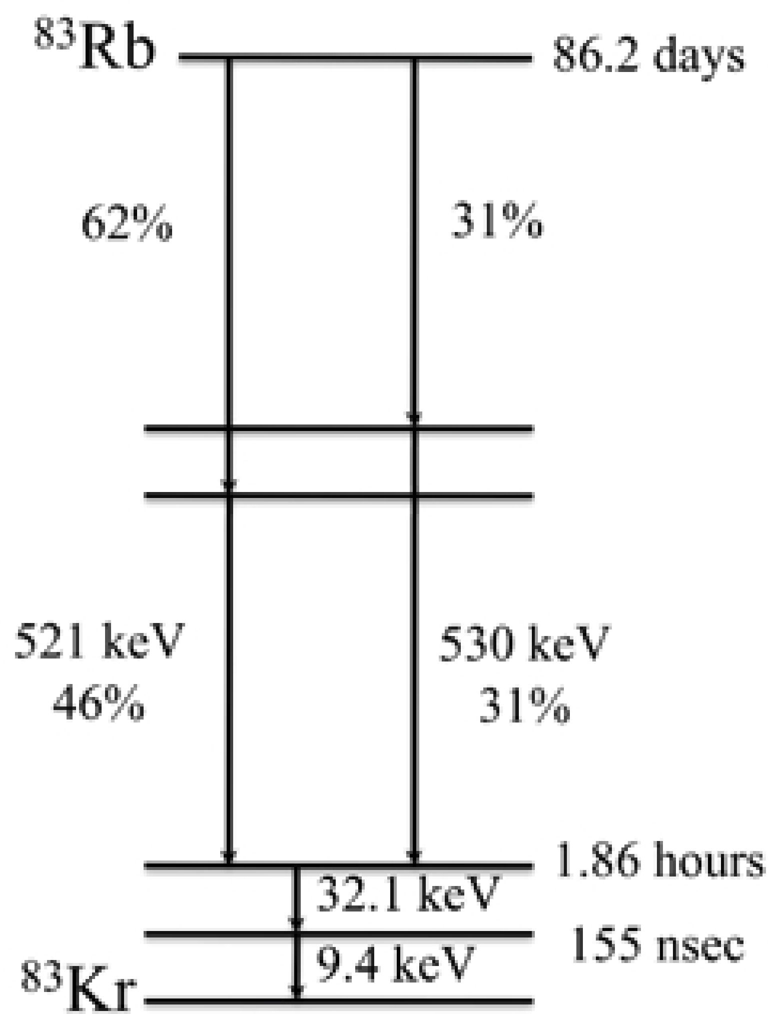


LUX Detector Calibration

Light Collection

- Dispersed Kr-83m calibration gives uniform volume sampling of S1 and S2
- Naturally decays away in few hours
- Over 10^6 events per calibration



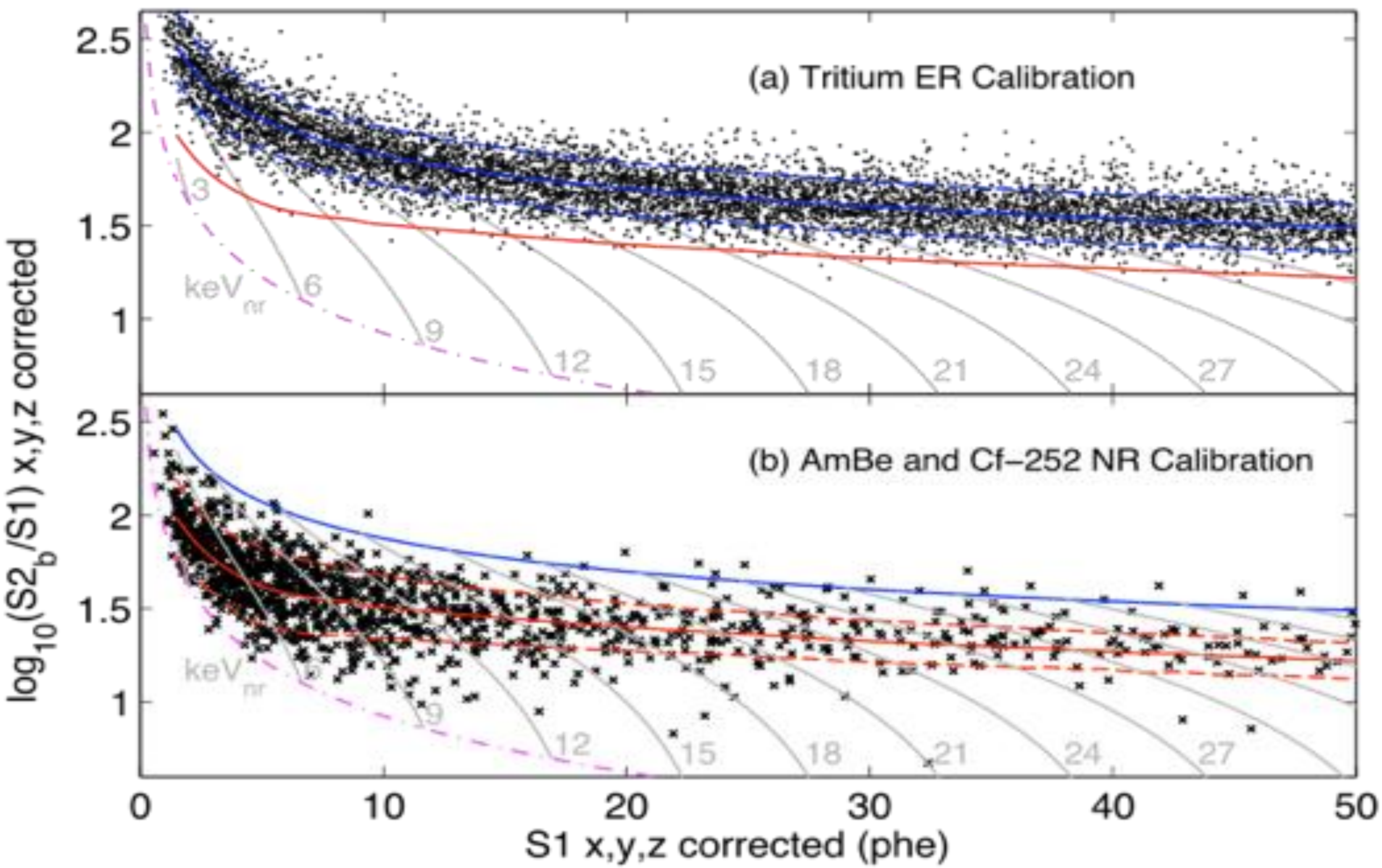


LUX Detector Commissioning

Recoil Band Calibration

- Dispersed tritiated methane calibration gives uniform sampling of the electron recoil band shape and width
- Low-energy β source (18 keV endpoint) populates relevant low-energy region of the S2/S1 plot with unprecedented accuracy
- Fully removed by recirculation system through the getter
- Nuclear recoil band is cross-referenced by using an external neutron source together with detector response function modelling using NEST and simulations
- [Between 2-30 S1 photoelectrons discr. is 99.6% relative to 50% nuclear recoil acceptance]

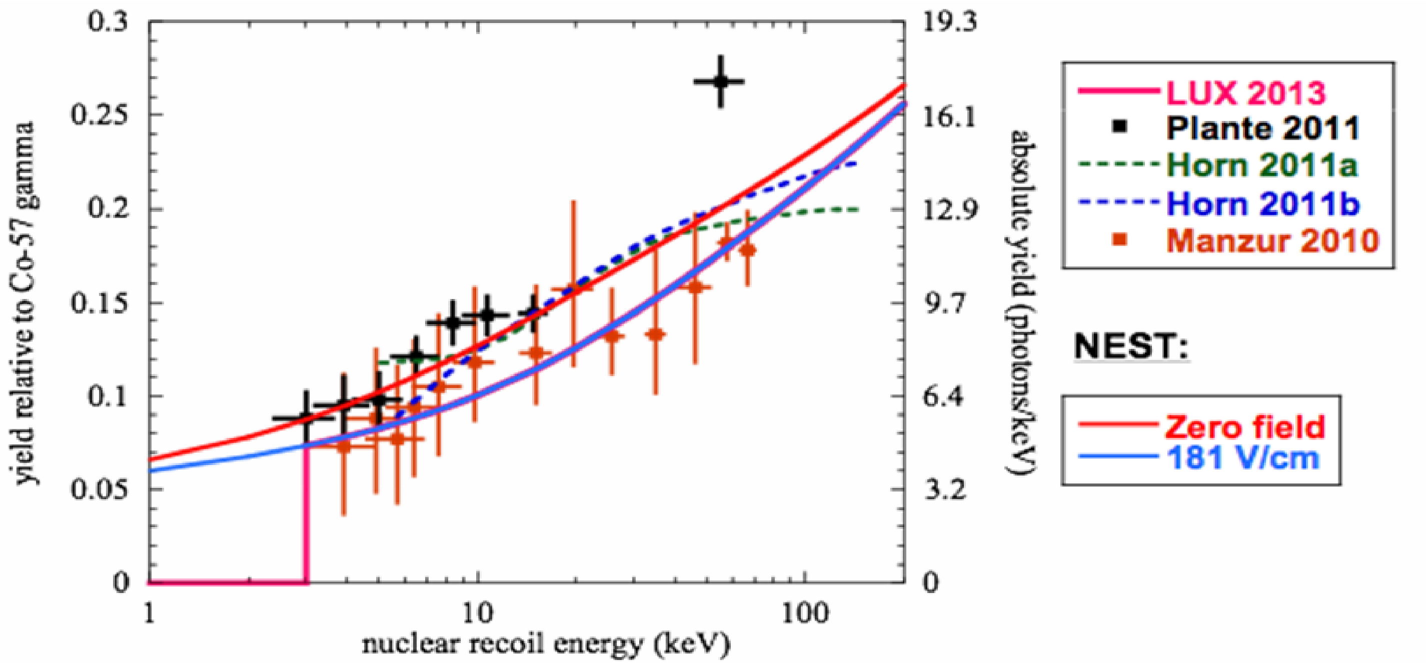
LUX Detector Calibration



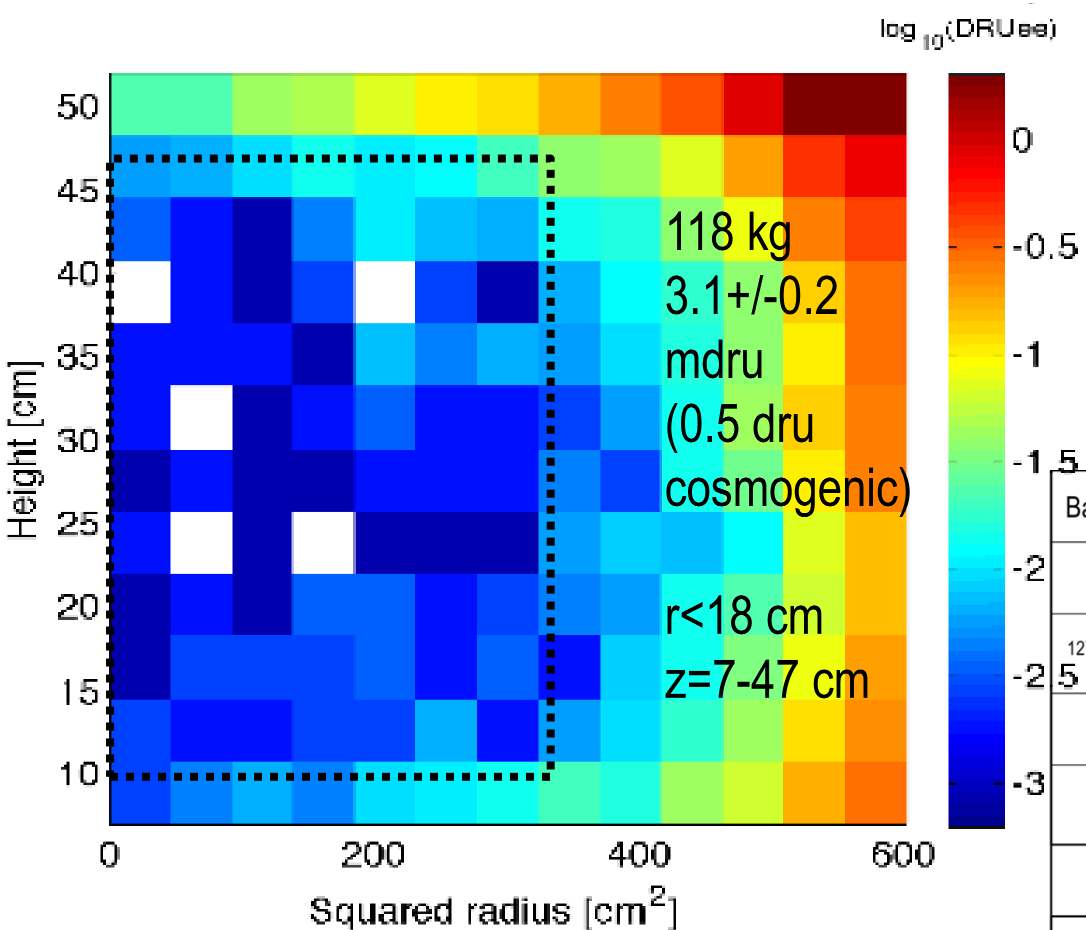
LUX Detector Calibration

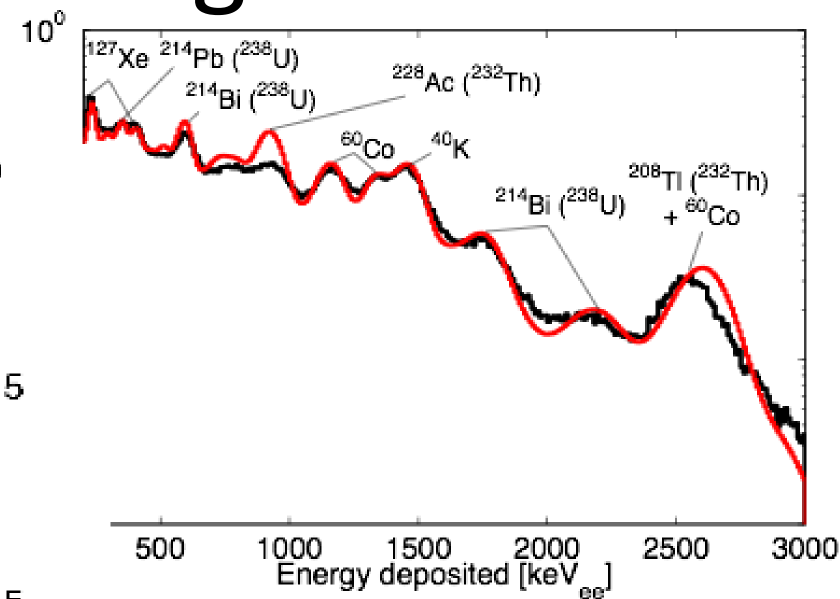
Nuclear Recoil Band Calibration Notes

- NEST (Noble Element Simulation Technique) is based on extensive existing experimental data
- Artificial cut-off in light and charge yields assumed <3 keVnr
- Includes predicted electric field quenching



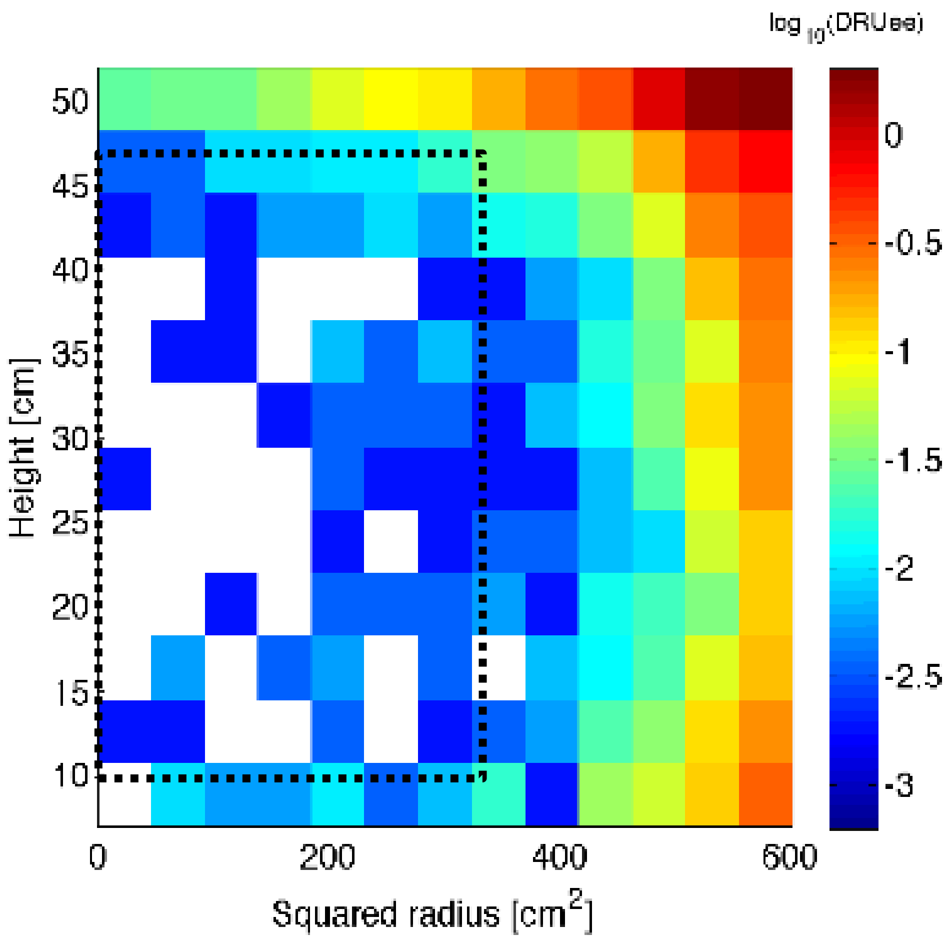
LUX Detector Background

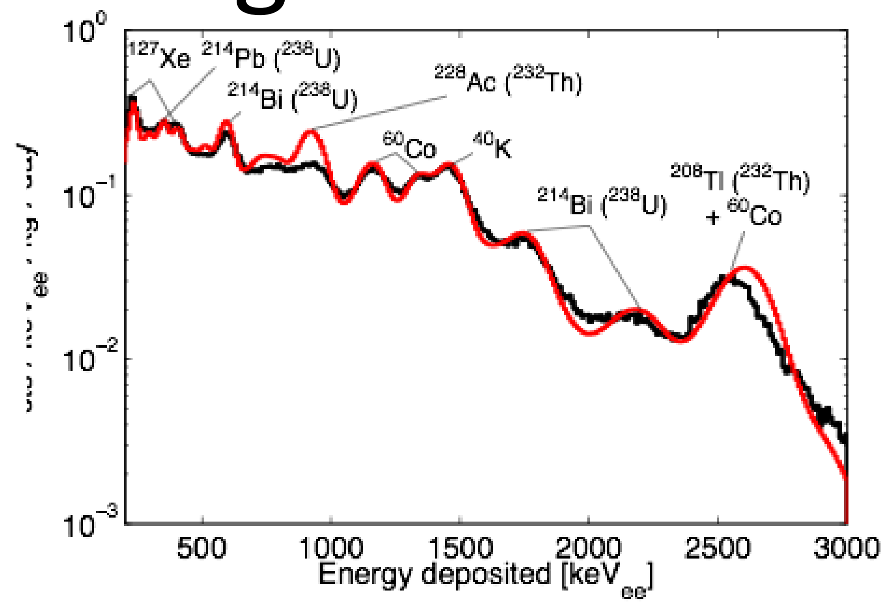




Background Component	Source	10^{-3} x evts/keVee/kg/day
Gamma-rays	Internal Components including PMTS (80%), Cryostat, Teflon	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe (36.4 day half-life)	Cosmogenic 0.87 -> 0.28 during run	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	222Rn	$0.11\text{-}0.22_{(90\%\ CL)}$
^{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	$3.1 \pm 0.2_{stat}$

Detector Background





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LUX WIMP Search

- April 21 - August 8, 2013 - 110 calendar days
  - 85.3 live days of WIMP Search
  - 118.3+/-6.5 kg fiducial mass
- Calibrations
  - Frequent ^{83m}Kr calibration of any S1 or S2 gain shifts
  - AmBe&Cf calibrations + Sims to define NR band
  - Injected Tritiated Methane for relevant ER band
- Efficiency
  - WIMP efficiency from calibration sets using multiple techniques

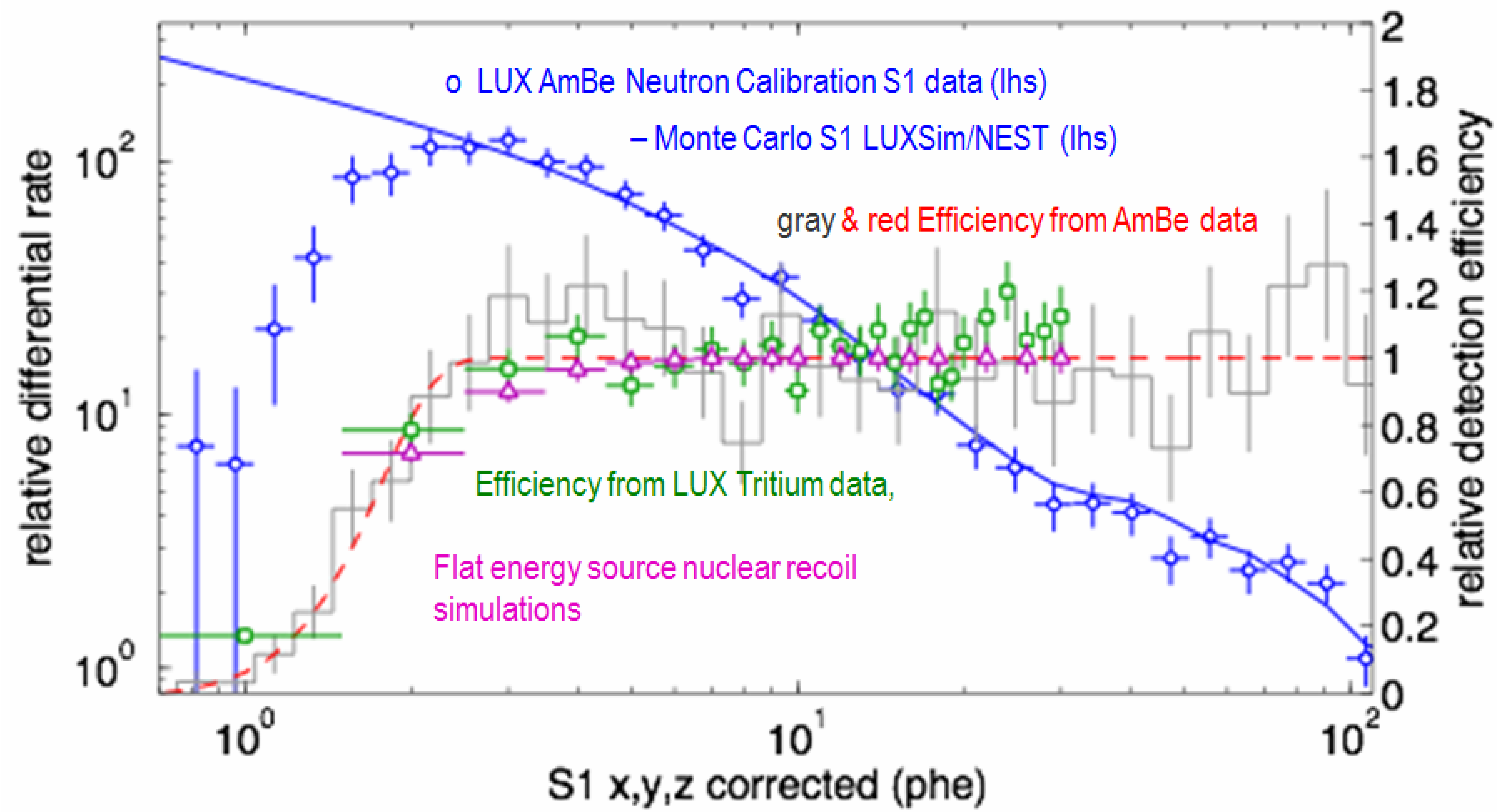
LUX WIMP Search

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 radius and drift cut	Radius < 18 cm, 38 < drift time < 305 us, 118 kg fiducial	160

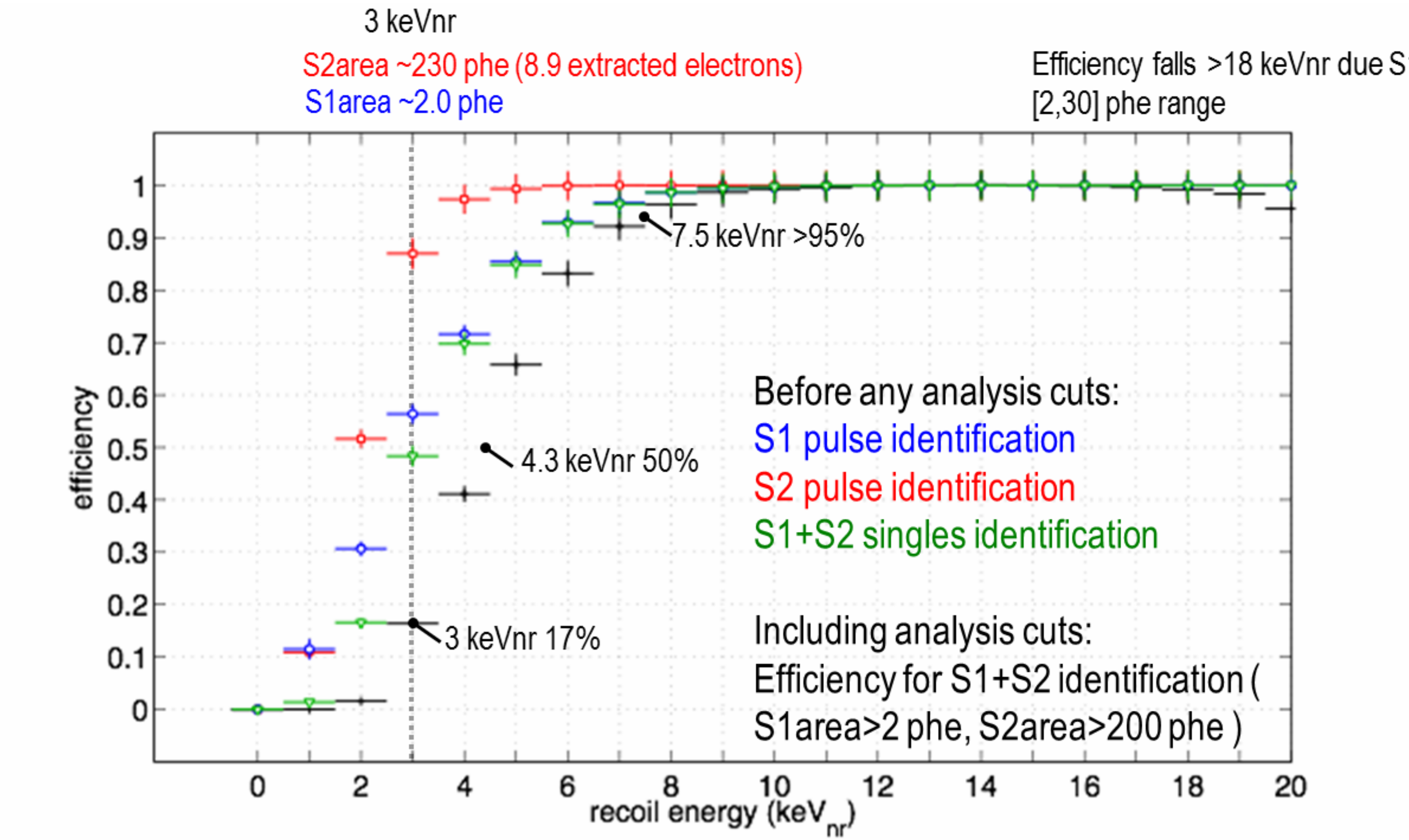
LUX WIMP Search

Efficiency in S1 phe



LUX WIMP Search

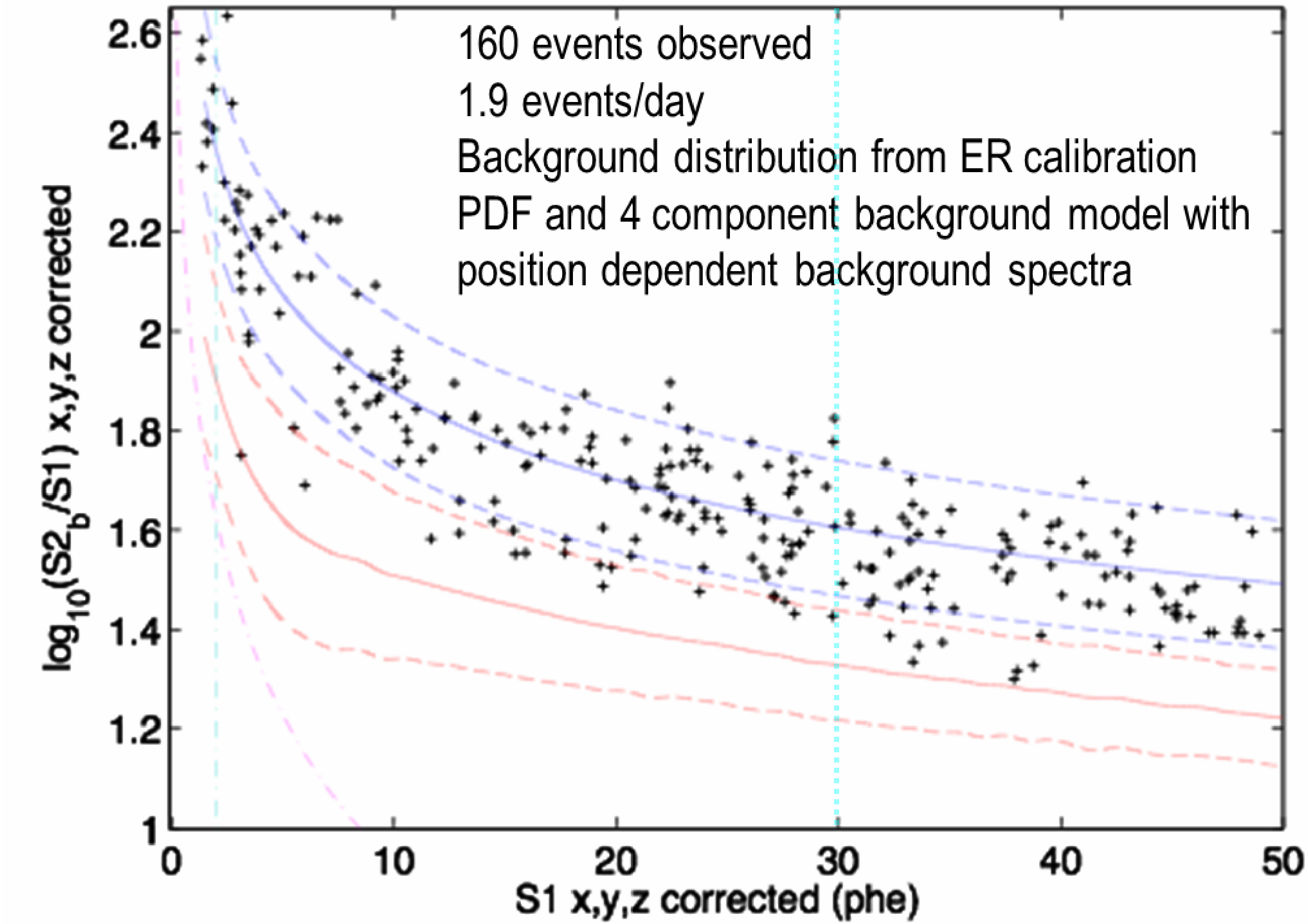
Efficiency in keVnr



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

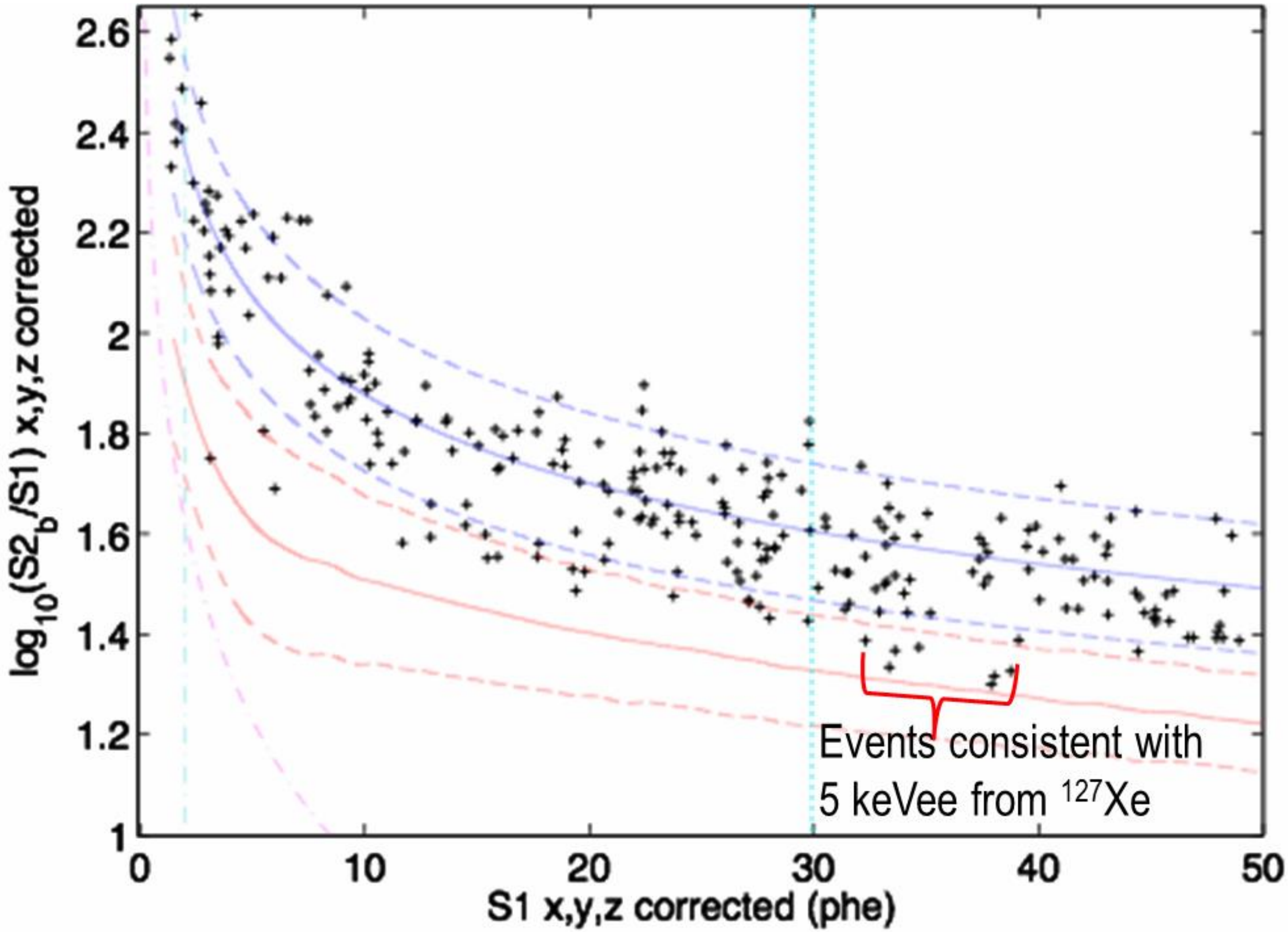
LUX WIMP Search

S2/S1 plot



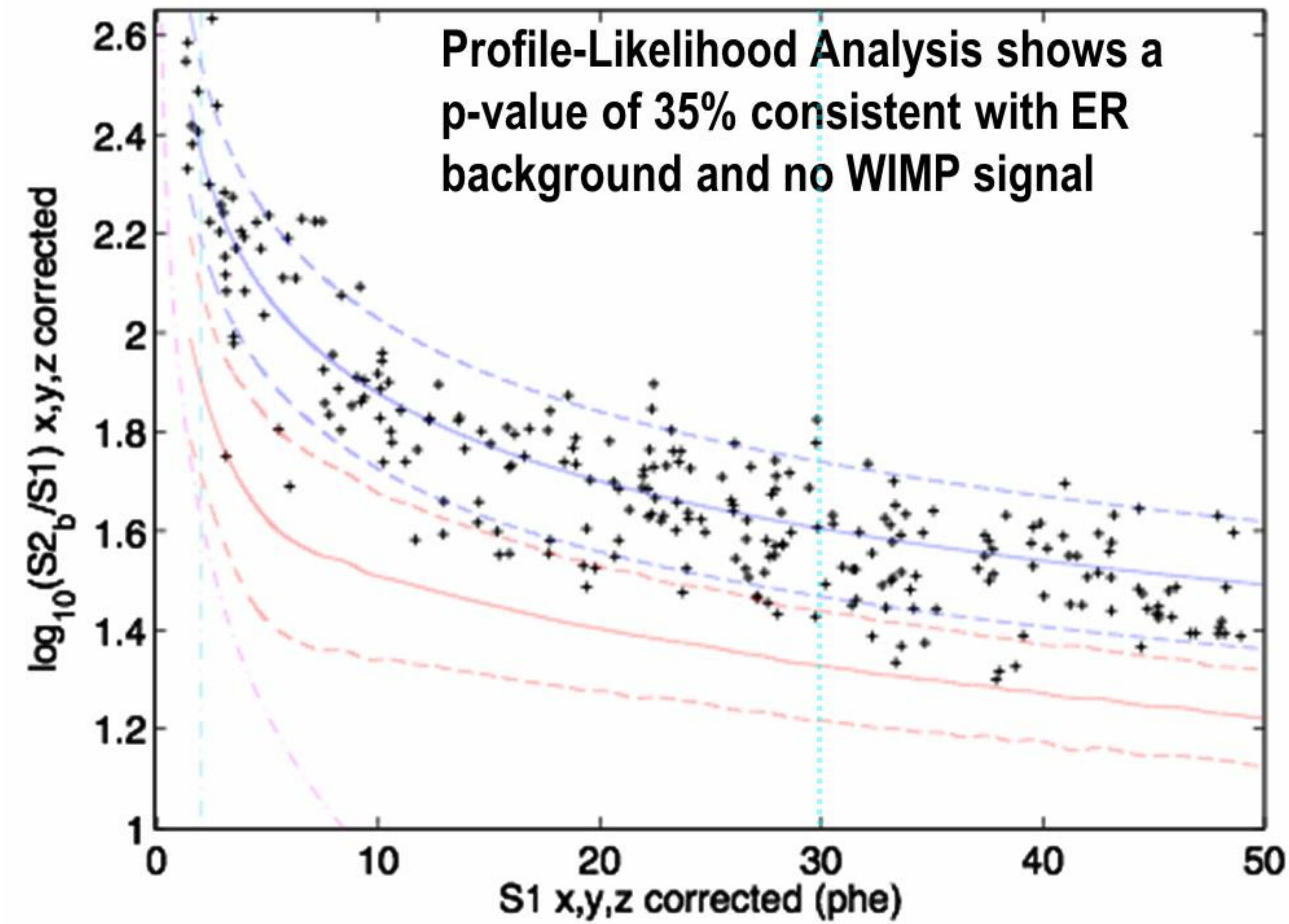
LUX WIMP Search

S2/S1 plot



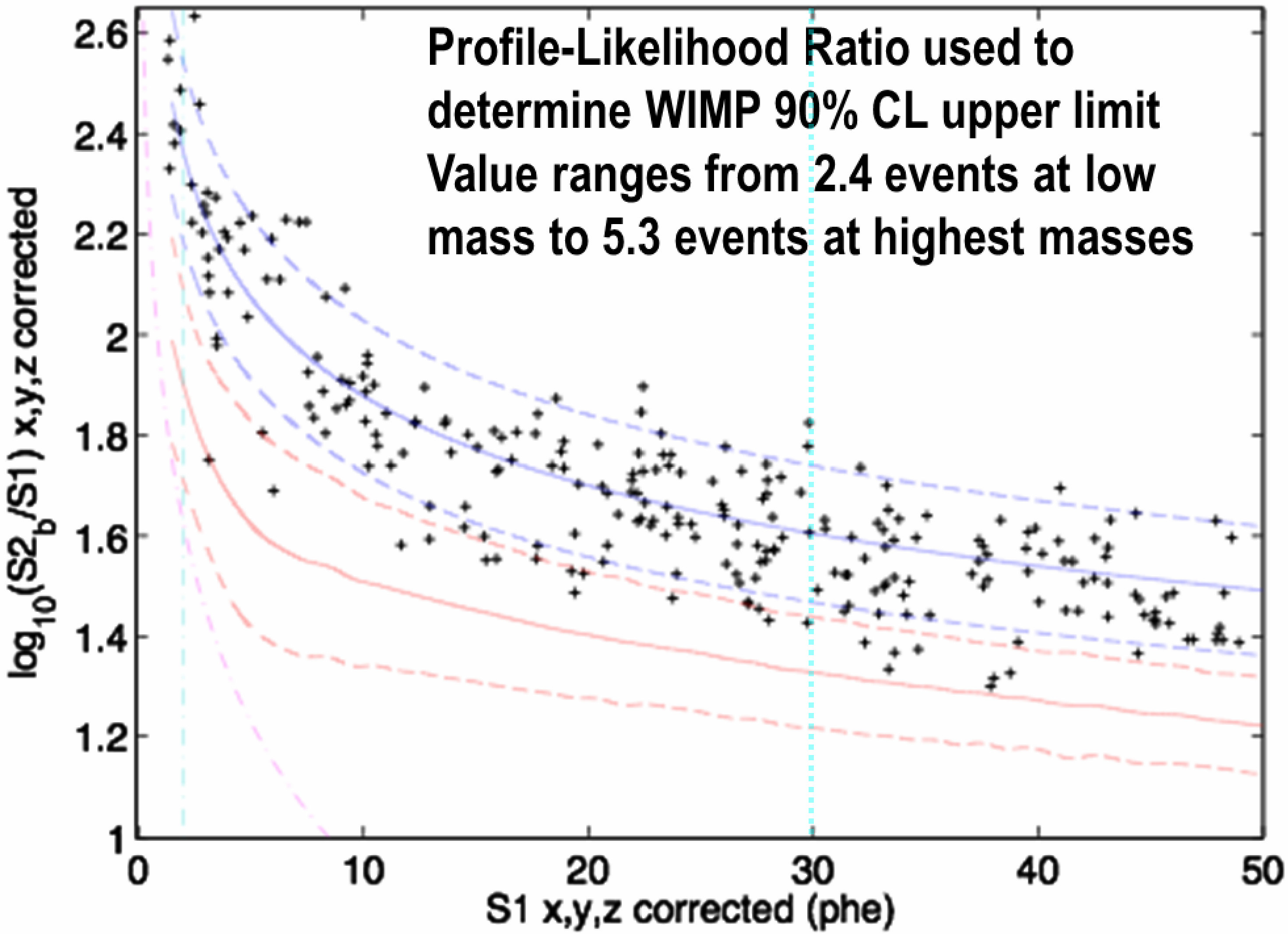
LUX WIMP Search

S2/S1 plot



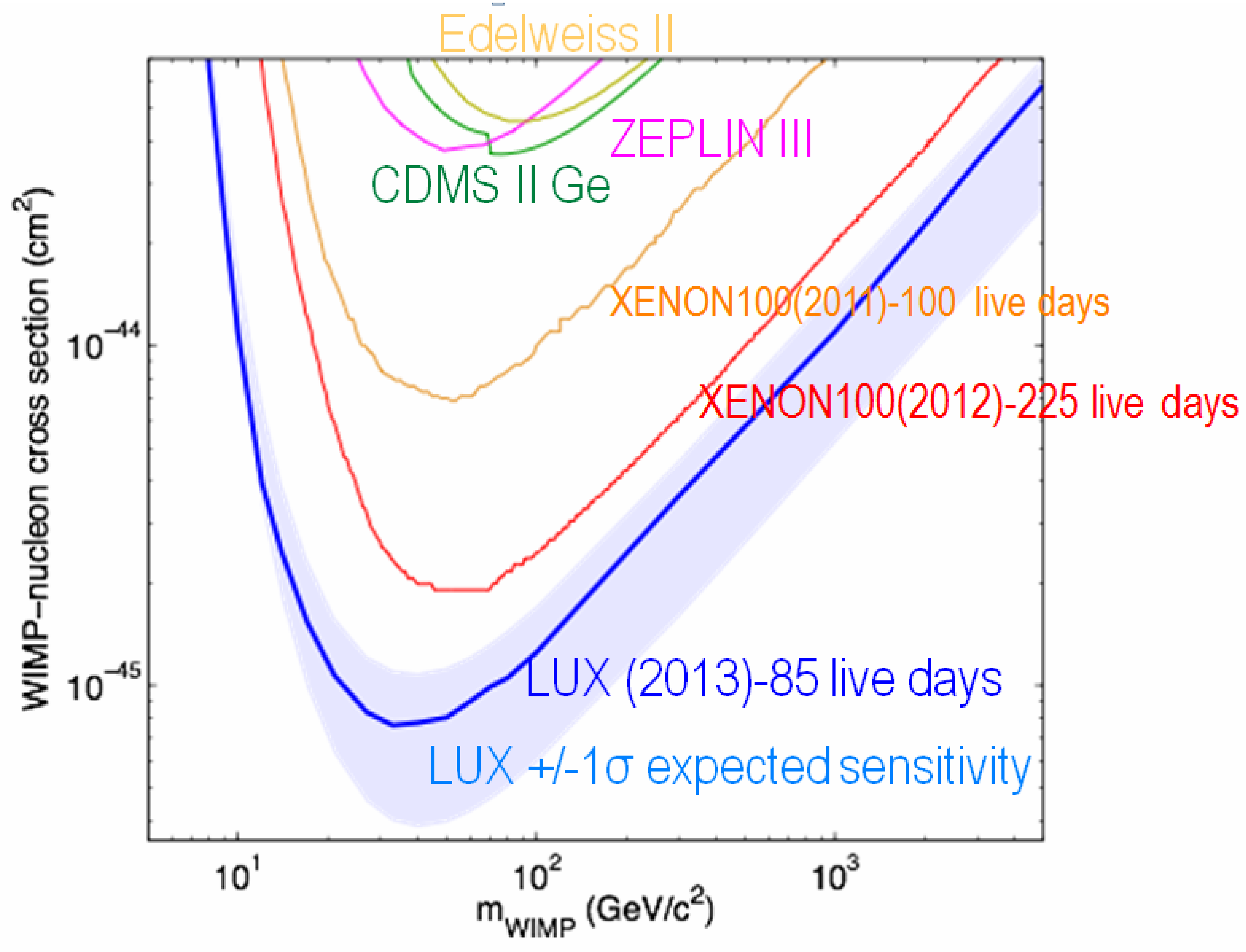
LUX WIMP Search

S2/S1 plot



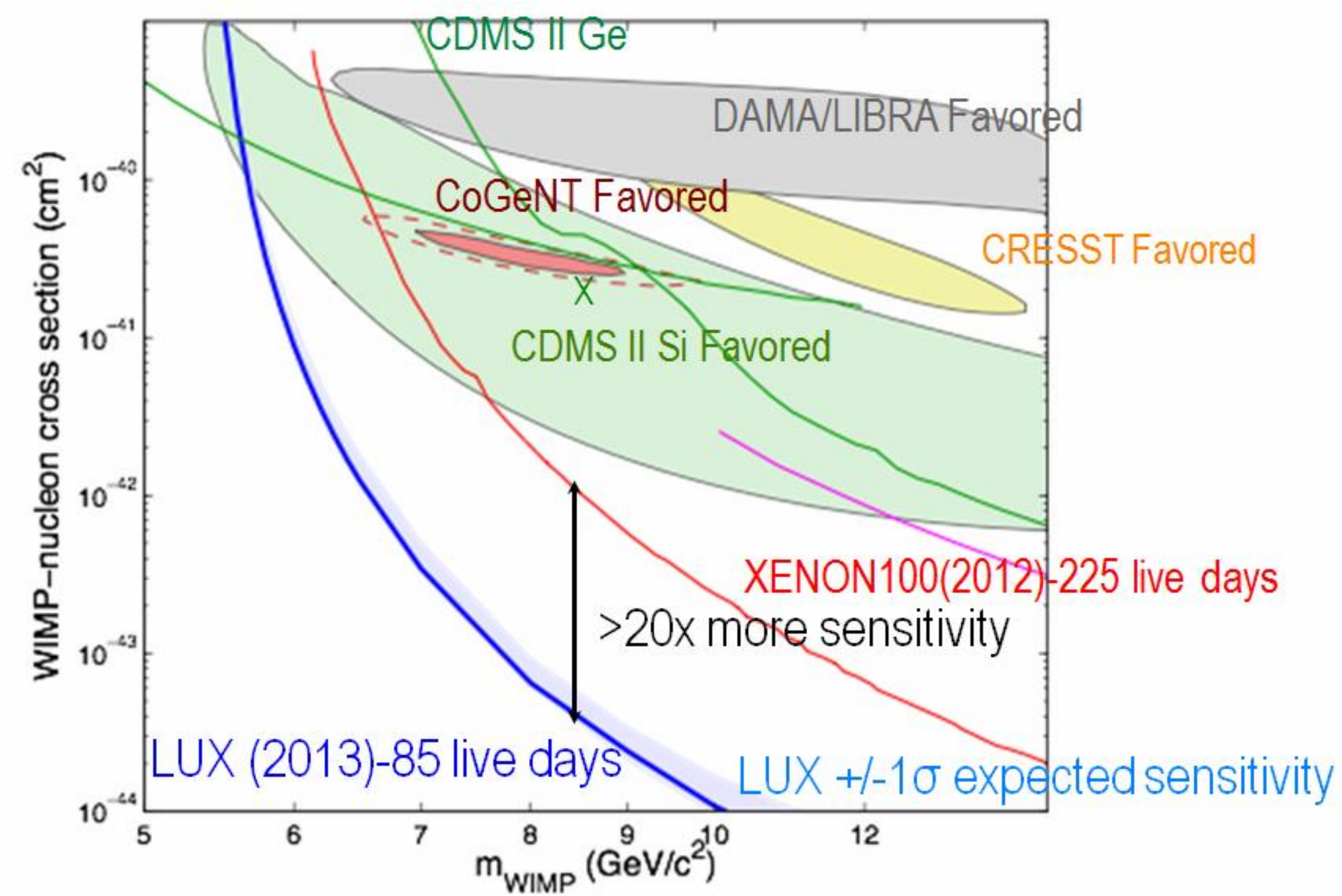
LUX WIMP Search

Upper limit



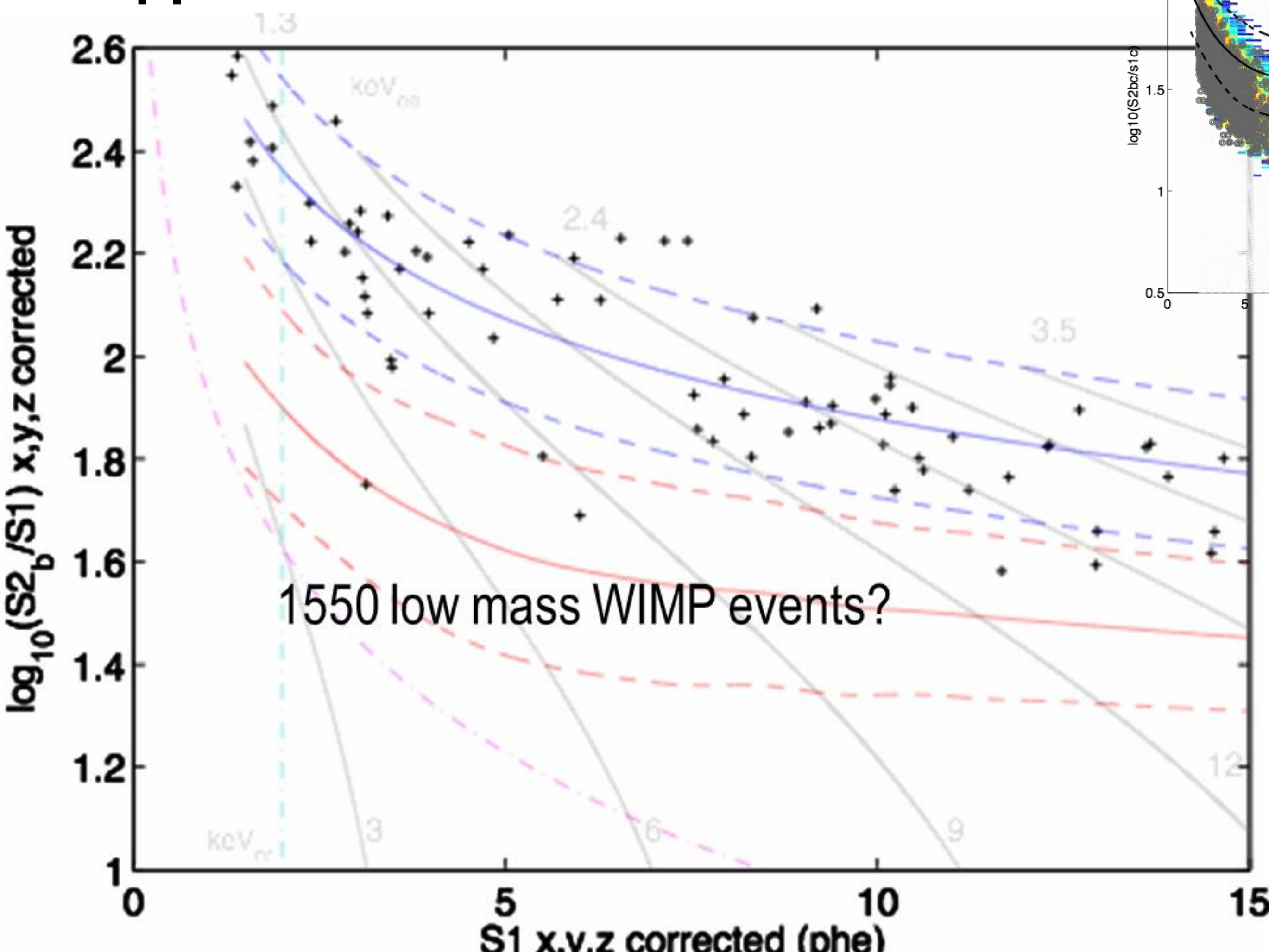
LUX WIMP Search

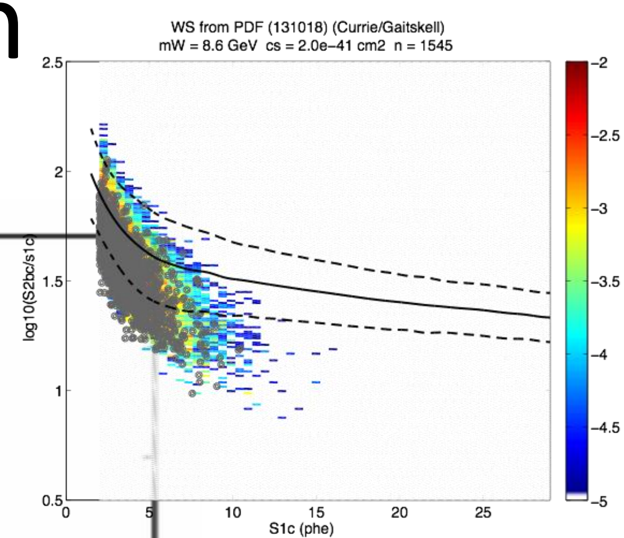
Upper limit



LUX WIMP Search

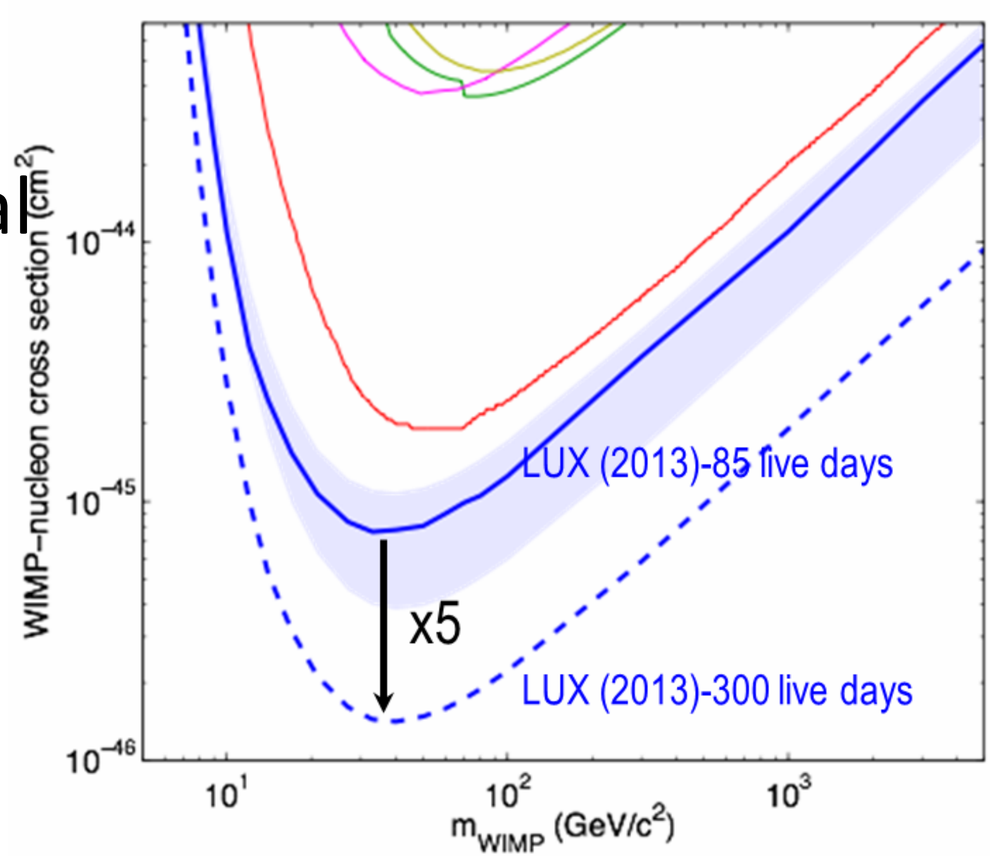
Upper limit at low masses





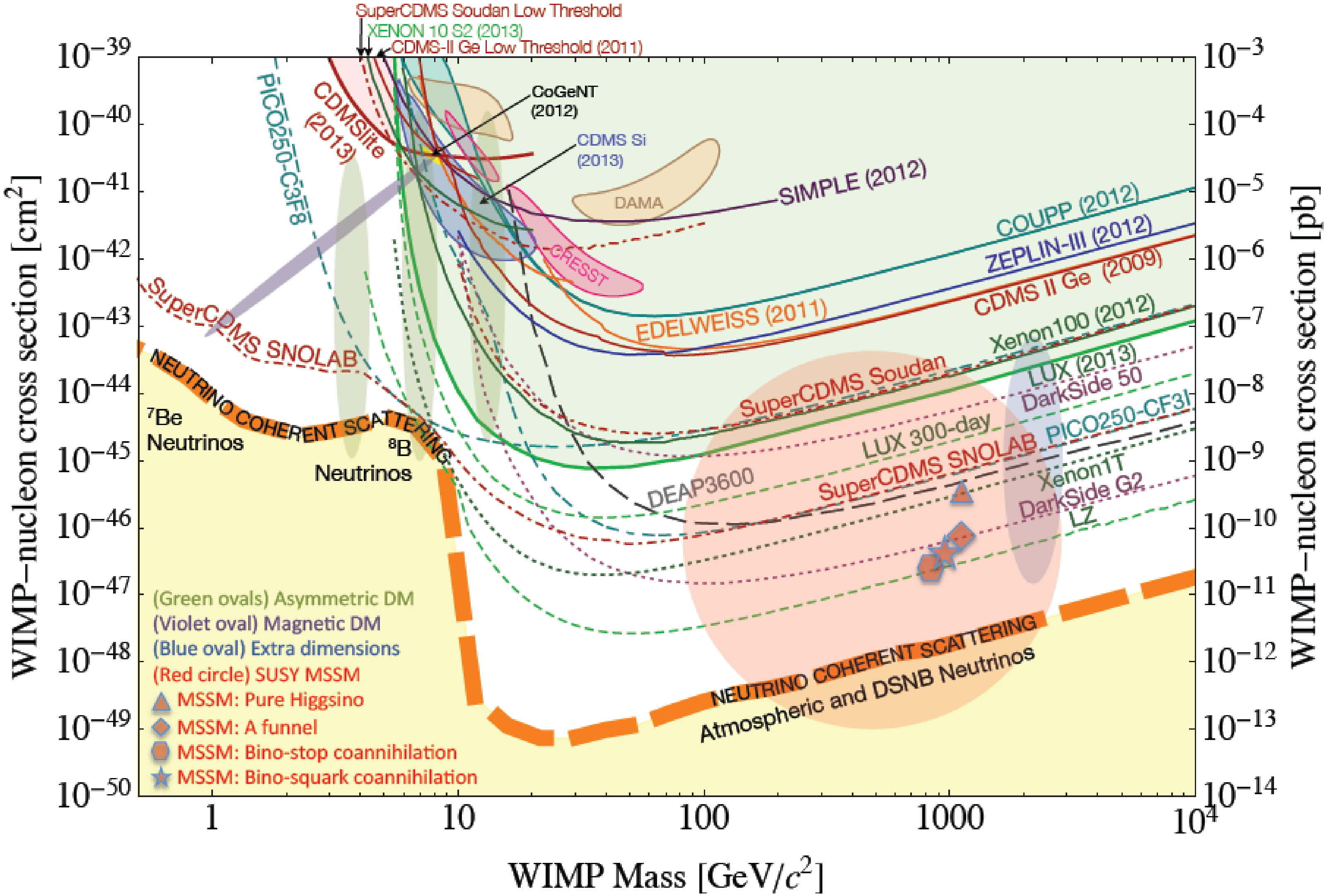
LUX Next WIMP Search

- New run of 300 days in 2014/15
- x5 in sensitivity
- Still discovery potential
- WIMPs remain our favoured quarry



- LZ 20x increase in target mass
  - If approved plans to be deployed in Davis Lab in 2016+

next generation



LUX Summary

- LUX WIMP Search run of 86 live-days
  - 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 range of interest
- Intermediate and High Mass WIMPs
  - Extended sensitivity 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 favoured by earlier experiments