# First Dark Matter Search Results from the LUX Detector


## Cláudio Silva, LIP/UC Coimbra

### on behalf of the LUX collaboration


## seminar at LNGS, 12 December 2013

# INTRODUCTION

- What is LUX?
  - Dark Matter direct search experiment
  - Dual-phase (gas/liquid) TPC
  - 370 kg of xenon
- LUX first WIMP search results
  - Presented last October 30$^{th}$
  - 85 live-days (21 April - 8 August)

# LUX Collaboration

### 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 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 |


Collaboration Meeting, Sanford Lab, April 2013

### 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

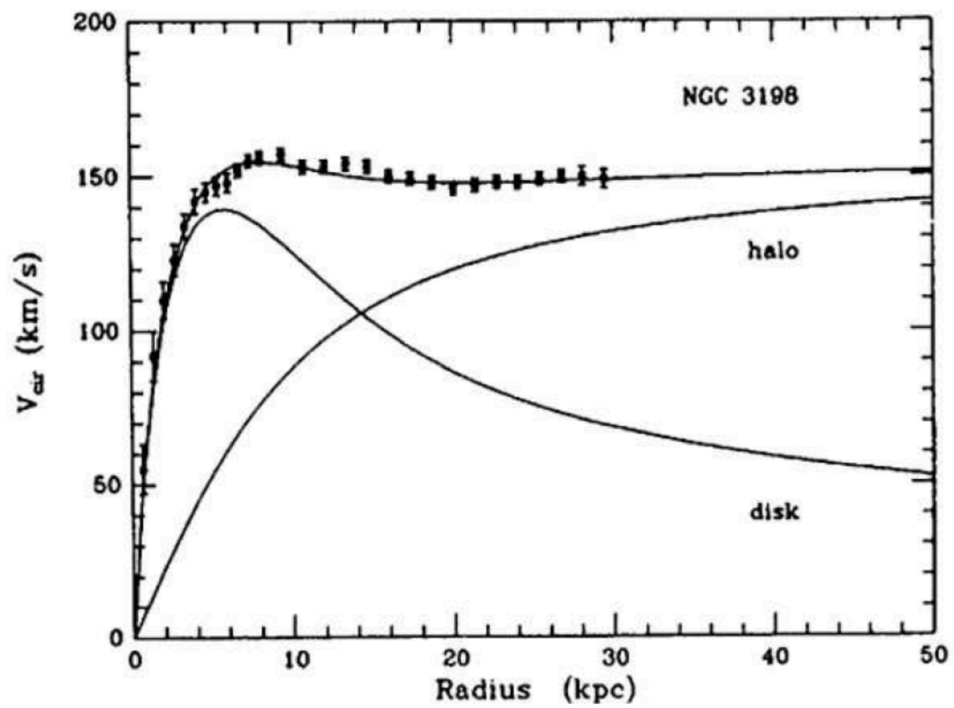
| | |
|---|---|
| Dongming Mei | PI, Professor |
| Chao Zhang | Postdoc |
| Angela Chiller | Graduate Student |
| Chris Chiller | Graduate Student |
| Dana Byram | *Now at SDSTA |

### 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 |

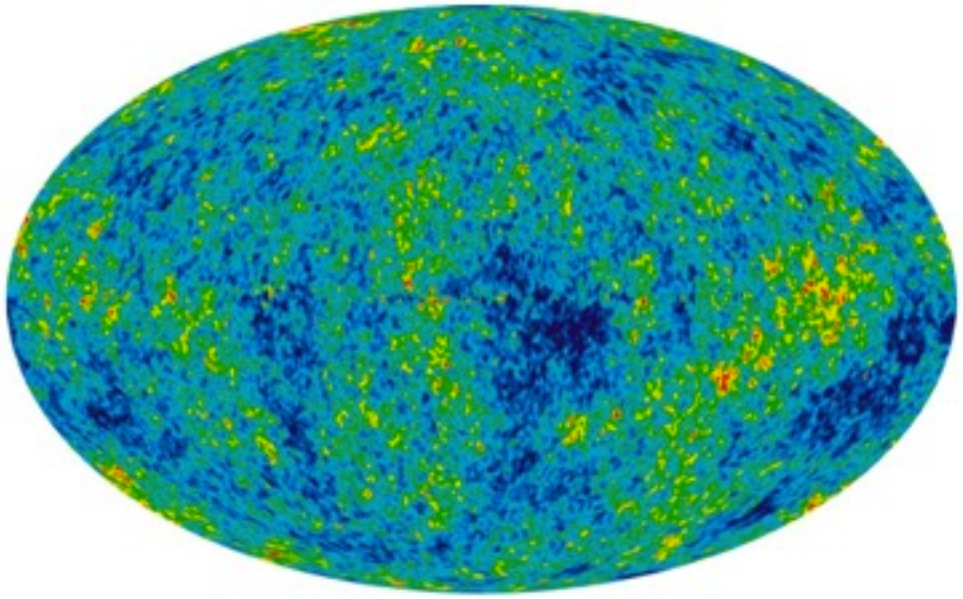
# Dark Matter Evidences

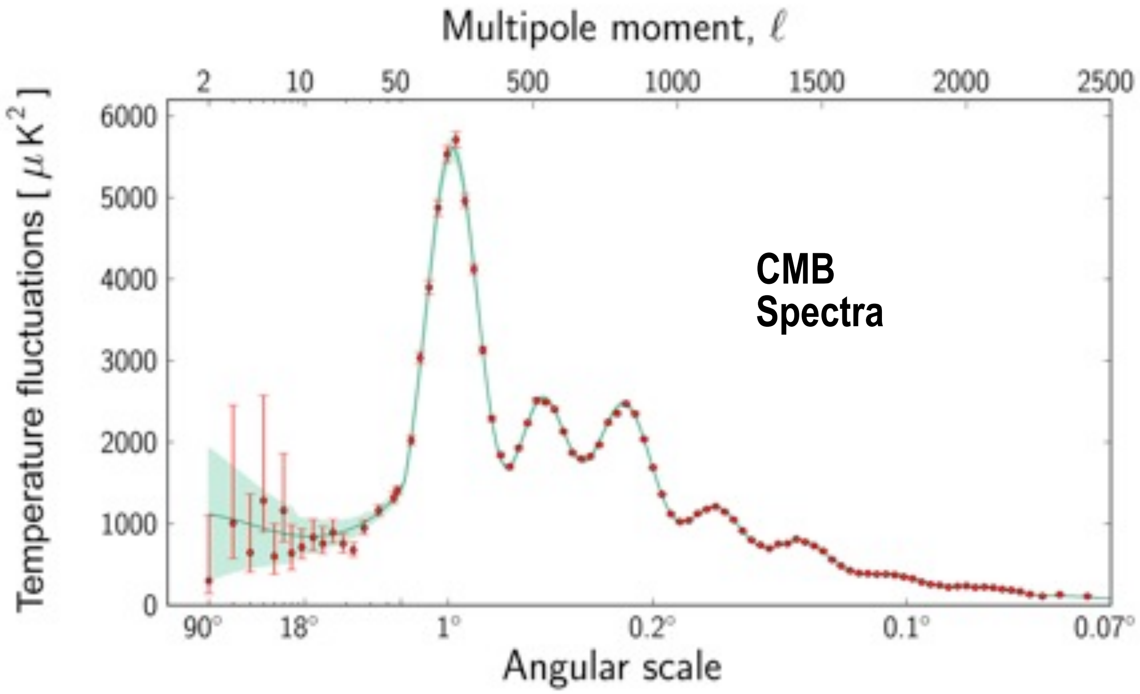
**Rotation curve NGC-3198**



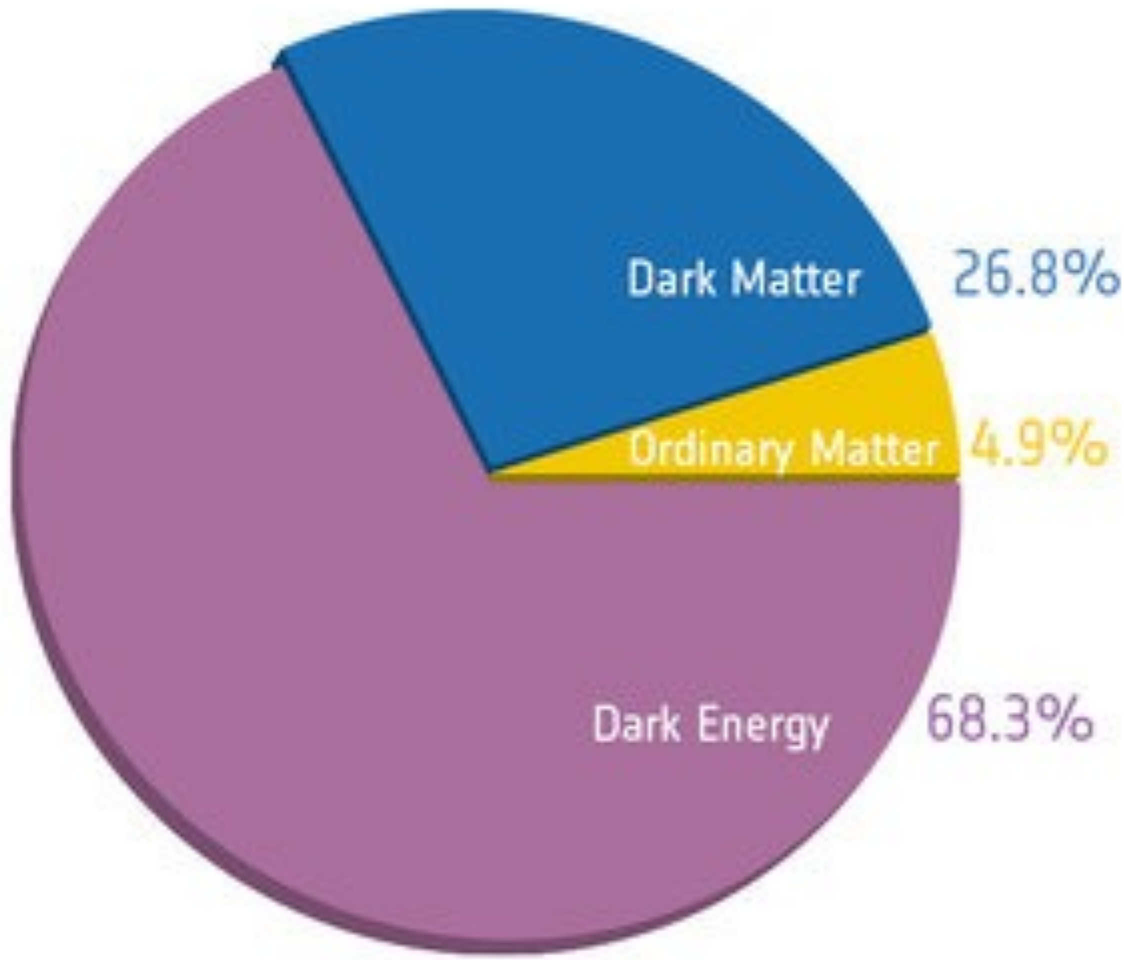

**Bullet-cluster: DM not MOND**


**CMB + BAO: precision tests of ΛCDM**





# Dark Matter Fraction



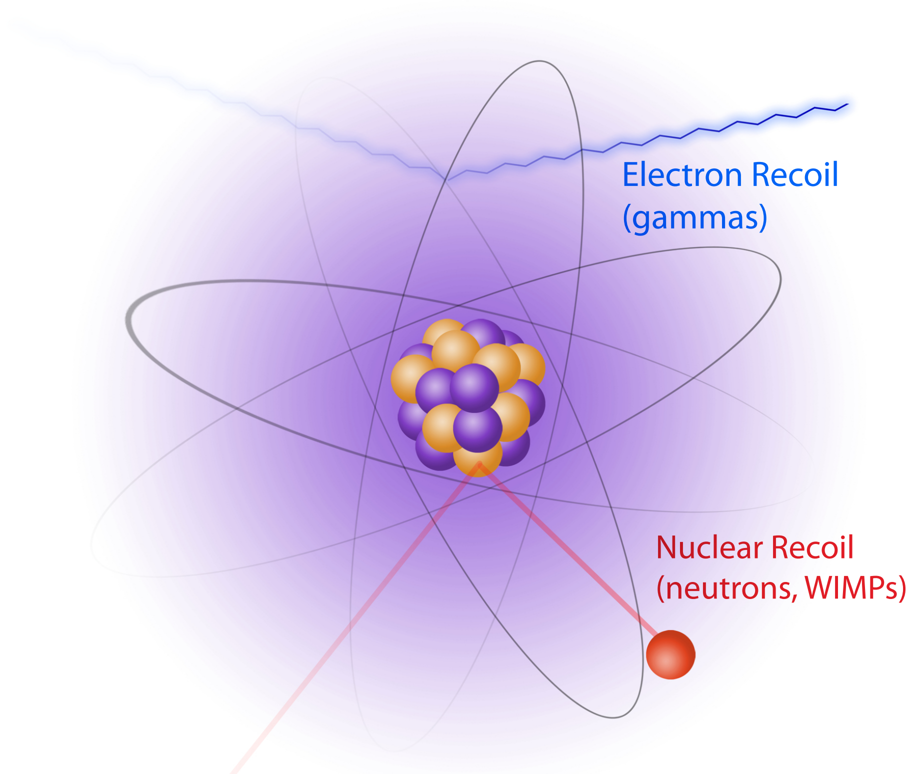

$$\frac{\text{Dark Matter}}{\text{Ordinary Matter}} \approx 5.44 \pm 0.14$$

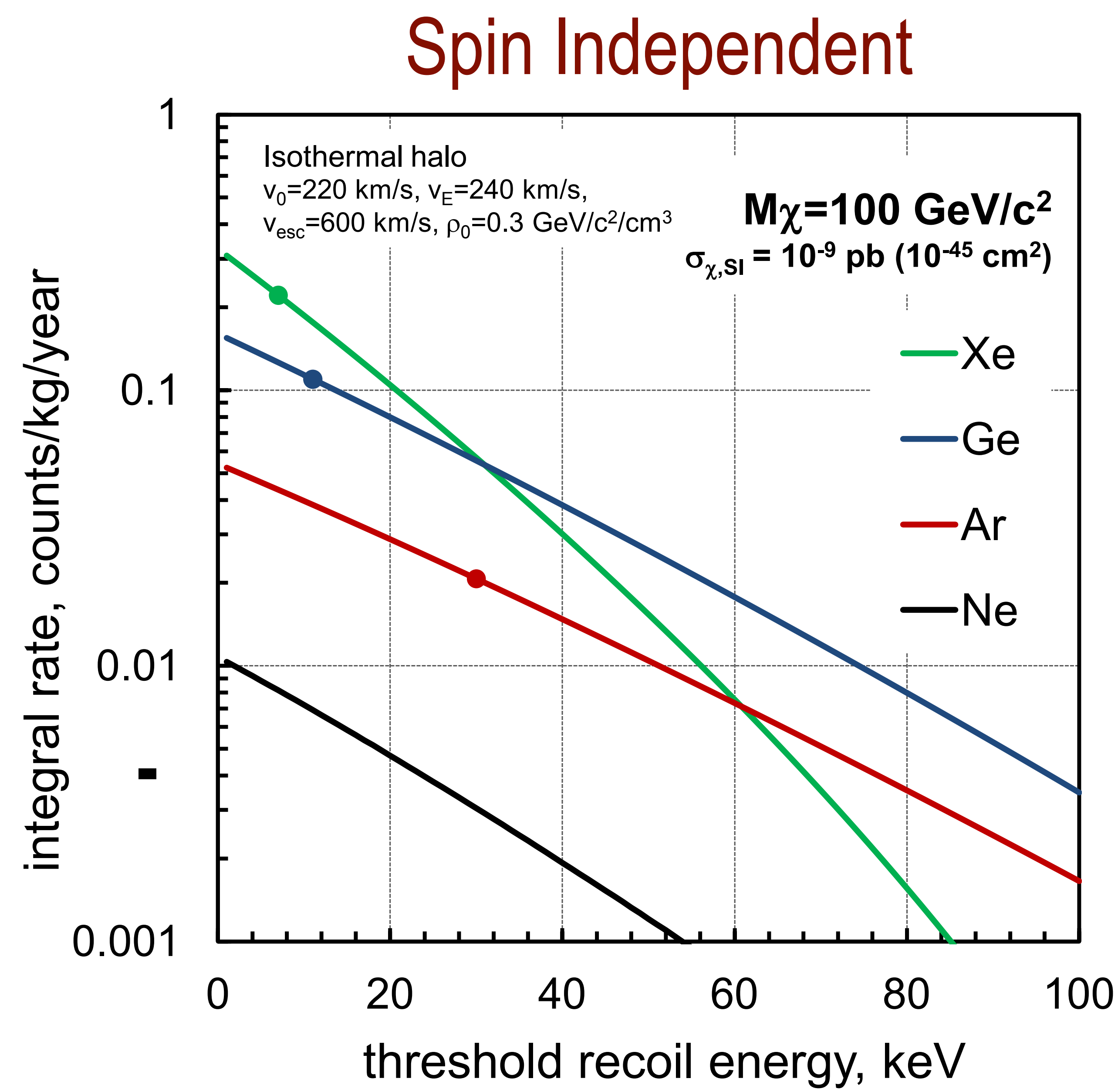
# Weakly Interacting Massive Particles (WIMPs)

- Favoured candidates for cold dark matter
- Neutral in most scenarios
- Non-relativistic freeze-out resulting in relic density today of ~1000/$m^3$
- Requires physics beyond the standard model:
  - Super-symmetry: LSP neutralino, $10^{-40}$ to $10^{-50}$ $cm^2$, mass range from $M_{proton} \longrightarrow 1000 \times M_{proton}$
    - If $m_{WIMP}$ = 100 GeV $\Rightarrow$ 3 WIMPs/liter

# DIRECT DETECTION

- Elastic scattering of galactic WIMPs with the nucleus of the target material.




- Isothermal model: WIMP speed ~220 km/s expect recoil <10 keV require detectors with low threshold
- Weak interaction
  - Spin dependent
  - Spin independent $\sigma \propto A^2$

# Direct Detection

## Problem

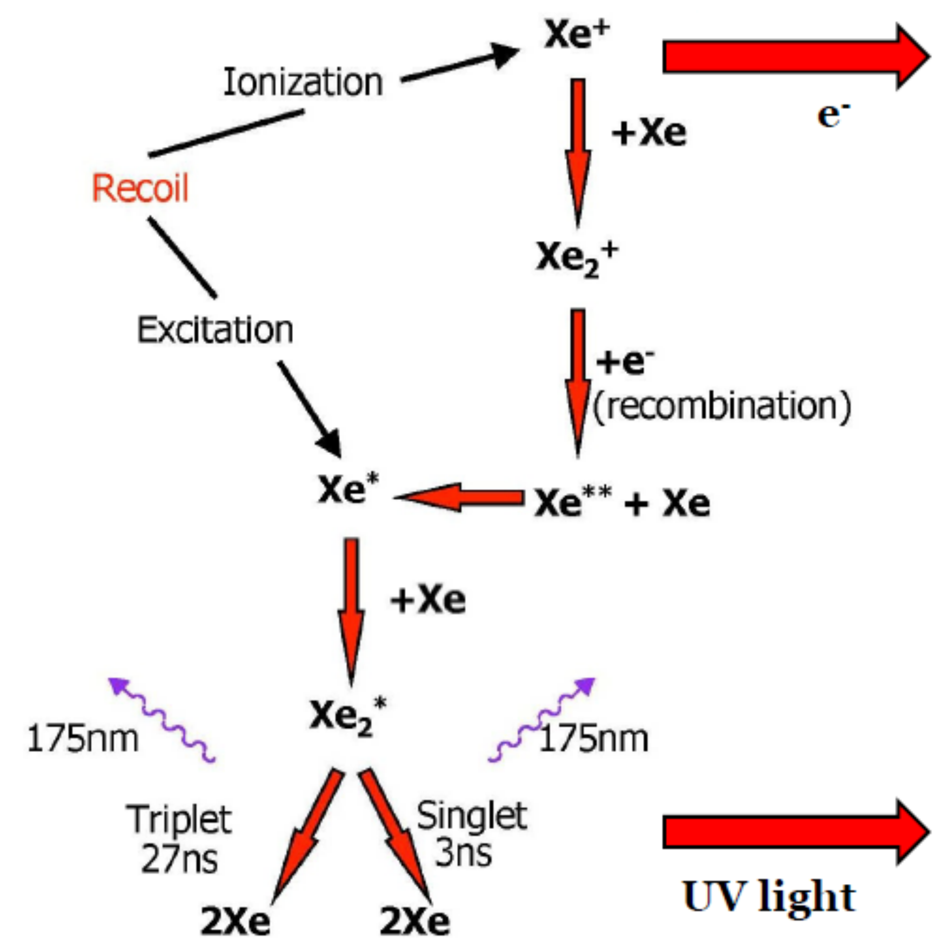
- Very low event rate (< 1 event/kg/year) versus high background from μ, γ and neutrons (~kHz).

## Solutions

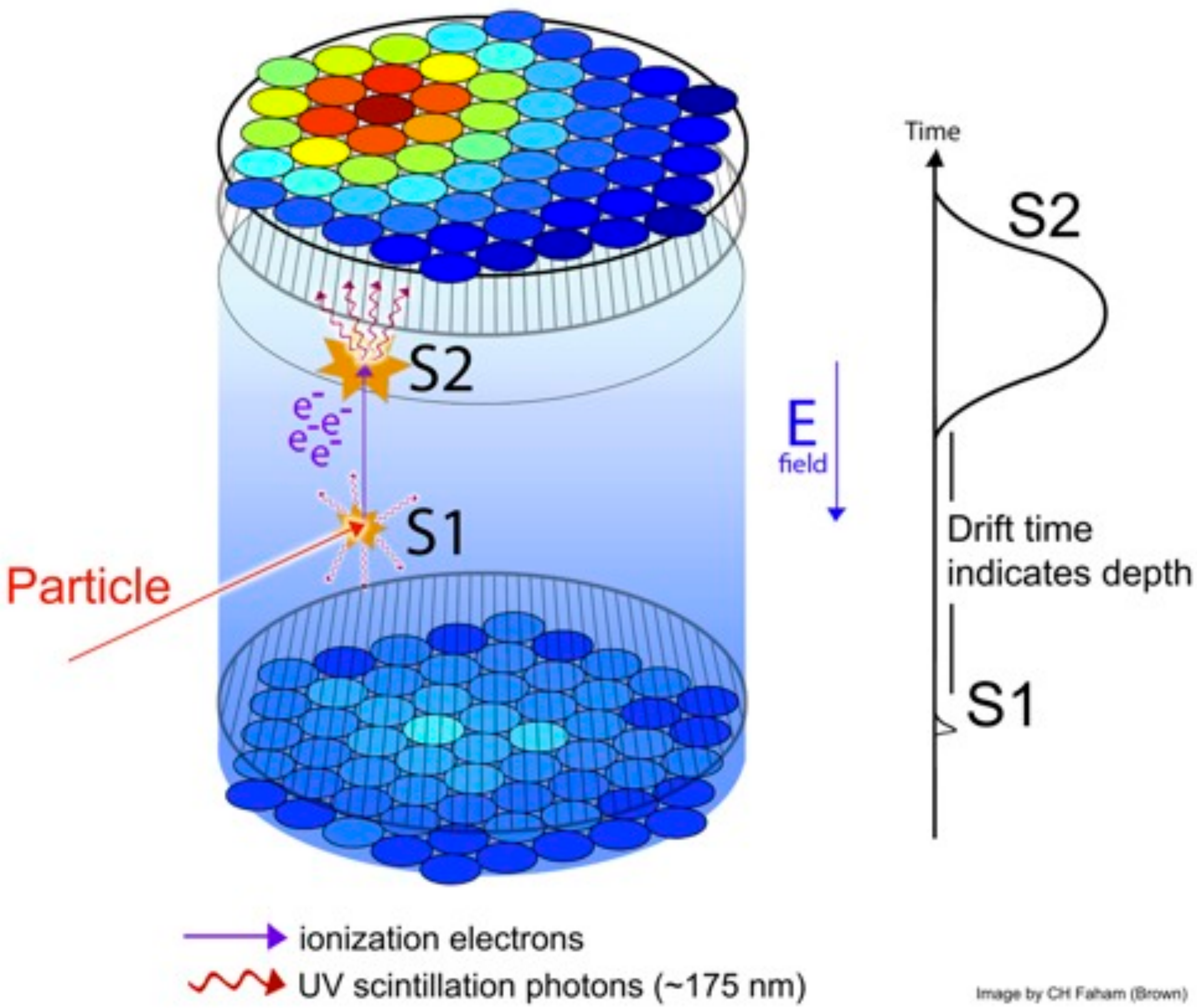
- Reduce Background
  - Low background Materials
  - Passive shielding
  - Active shielding
  - Scalability
  - Go Deep Underground
- Reject Background
  - Discriminate between electron and nuclear recoils

# Xenon as a Detector Medium

- **Why xenon?**
  - High atomic mass (A=131 g/mol)
  - Relatively high density (2.9 g/cm3)
  - Spin-dependent sensitive isotopes
  - Large light output and fast response
  - Long electron drift lengths (~1 m)
  - No intrinsic backgrounds
  - Self-shielding (using position recons.)
  - Scalable to multi-ton size
- **Recoil energy deposited in two channels:**
  - Light (photons)
  - Charge (electrons)



# DOUBLE-PHASE TPC



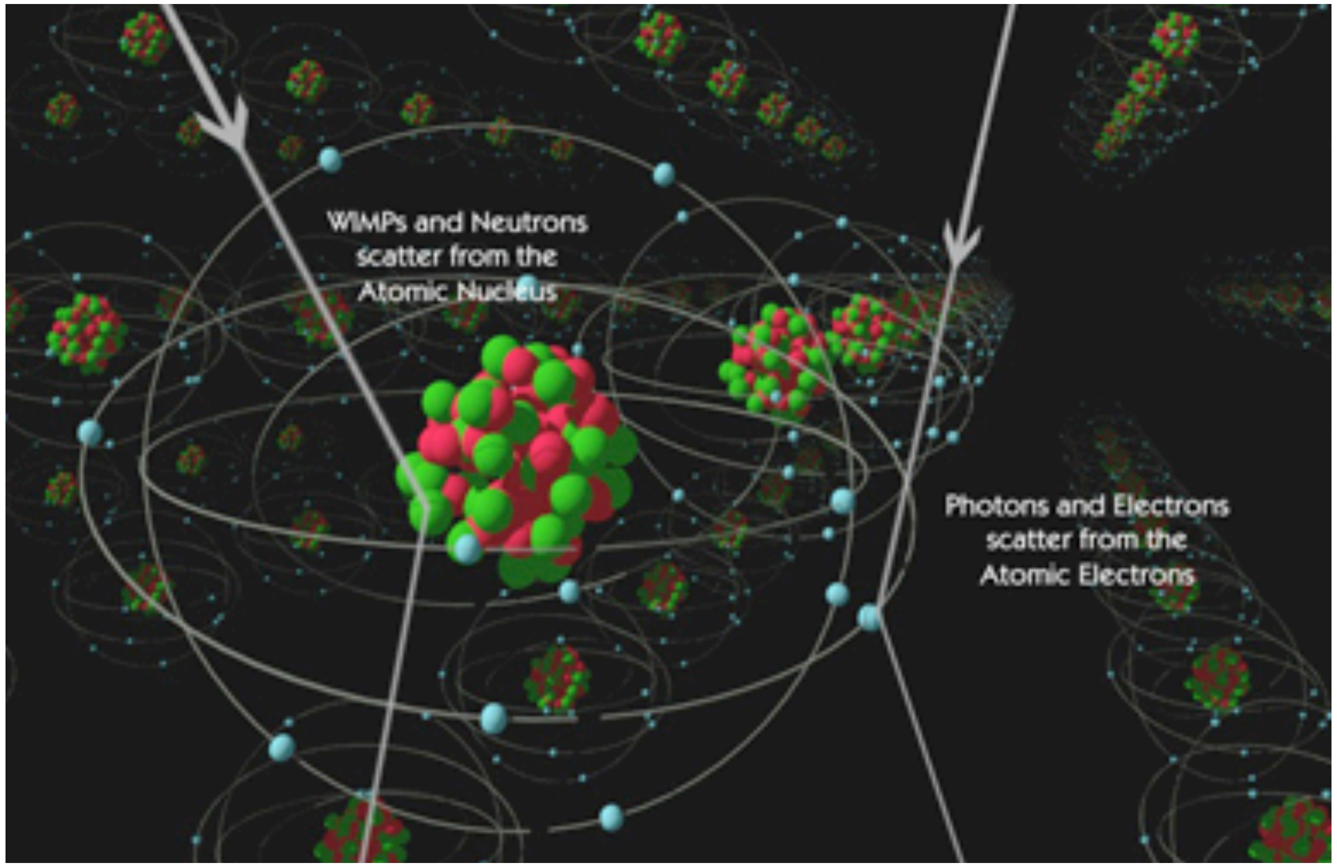

- Primary scintillation (**S1**)
- Secondary scintillation signal from electroluminescence after drift (**S2**)
- Position reconstruction
  - Z from time difference between S1 and S2 (1.51 mm/μs in LUX for a electric field of 181 V/cm)
  - XY reconstructed from light pattern observed in the top array.
    - Typical resolution of some mm.

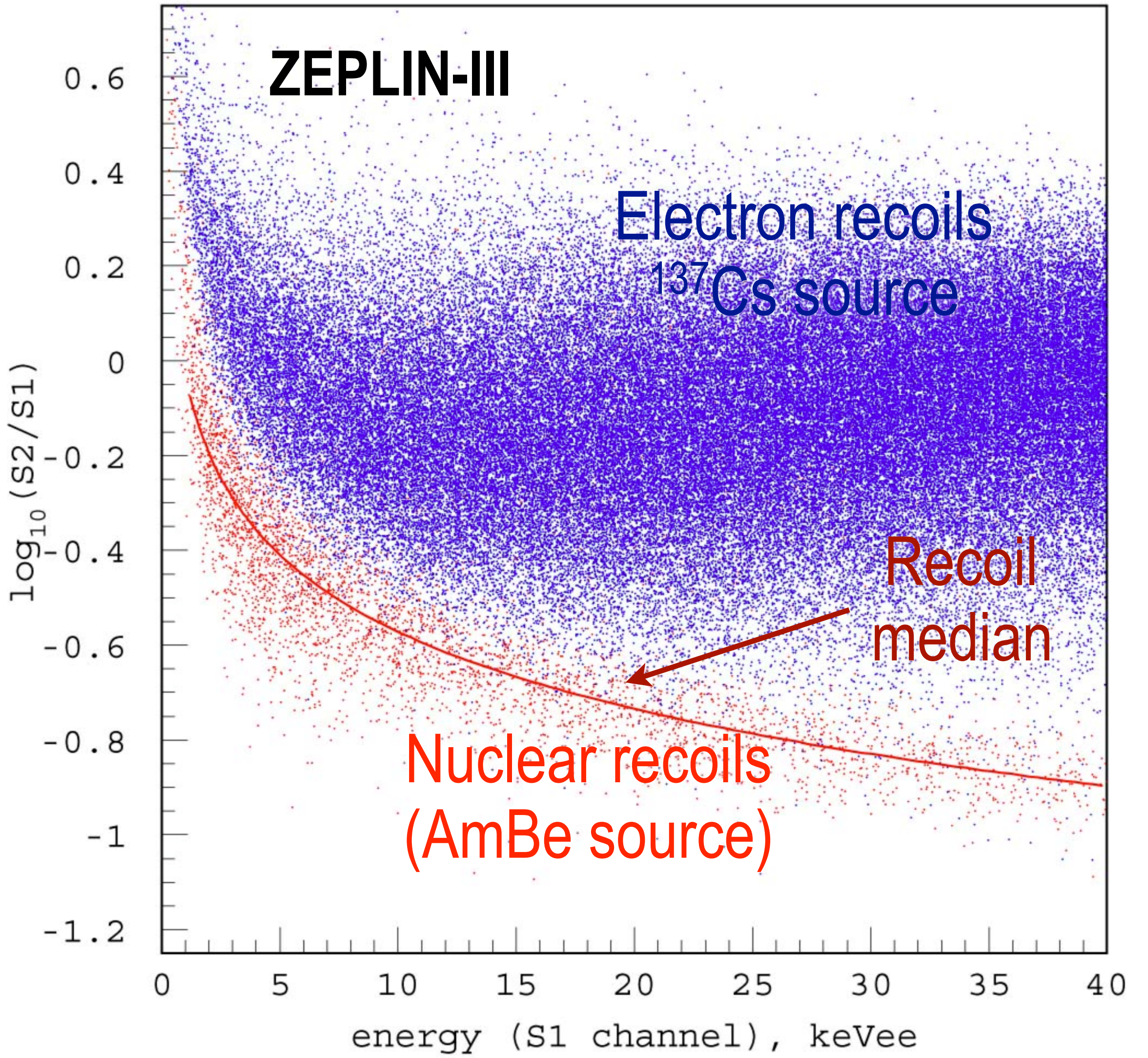
**Efficient way to reject events near the walls (self shielding) and multiple scatterers**

# Descrimination between nuclear and electronic recoils

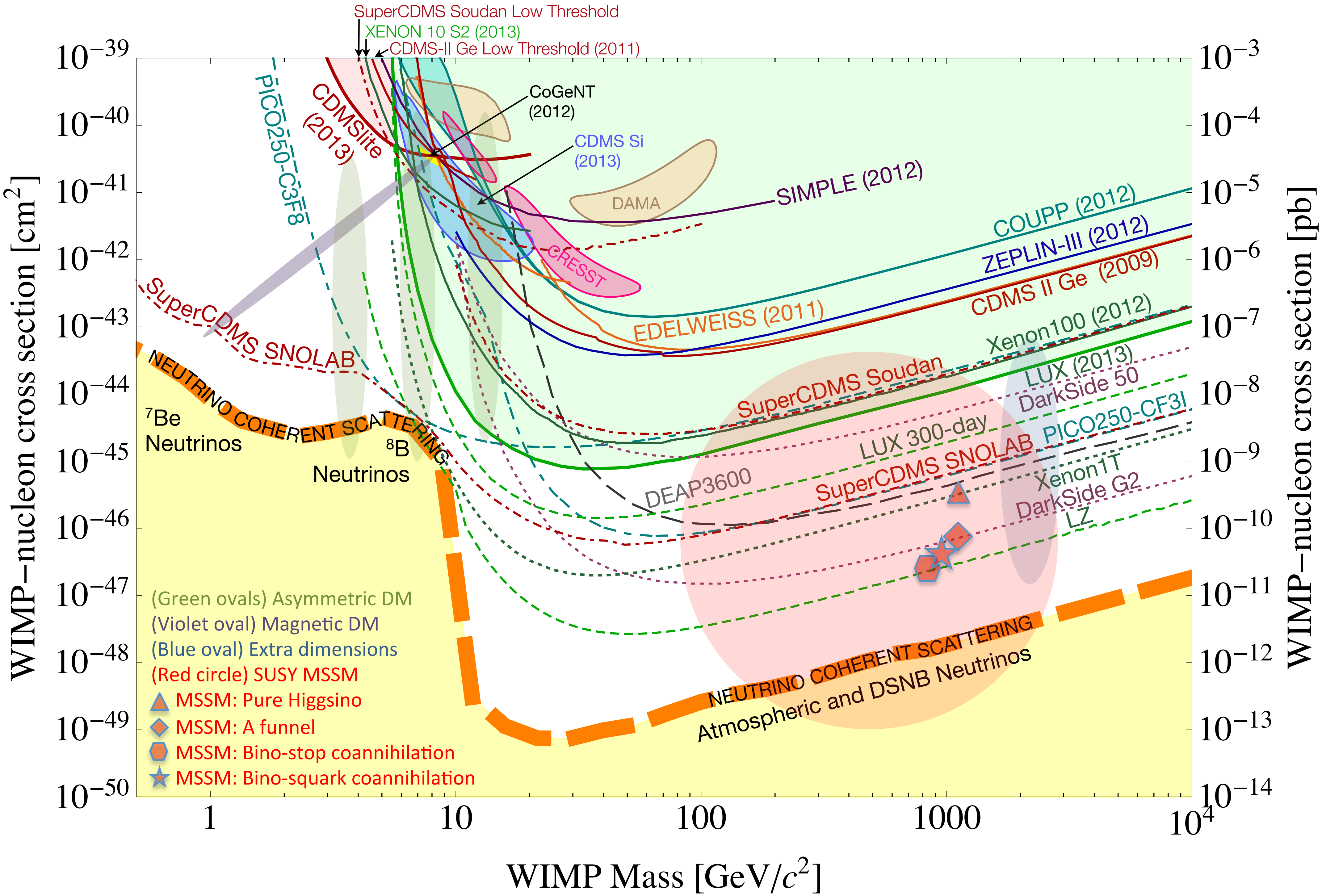


- WIMPs and neutrons interact with the nucleus ⇒ **short, dense tracks**
- $\gamma$s and $e^-$ interact with the atomic electrons ⇒ **long, less-dense tracks**
- S2/S1 used for discrimination $(S2/S1)_{\gamma e} > (S2/S1)_{WIMP}$

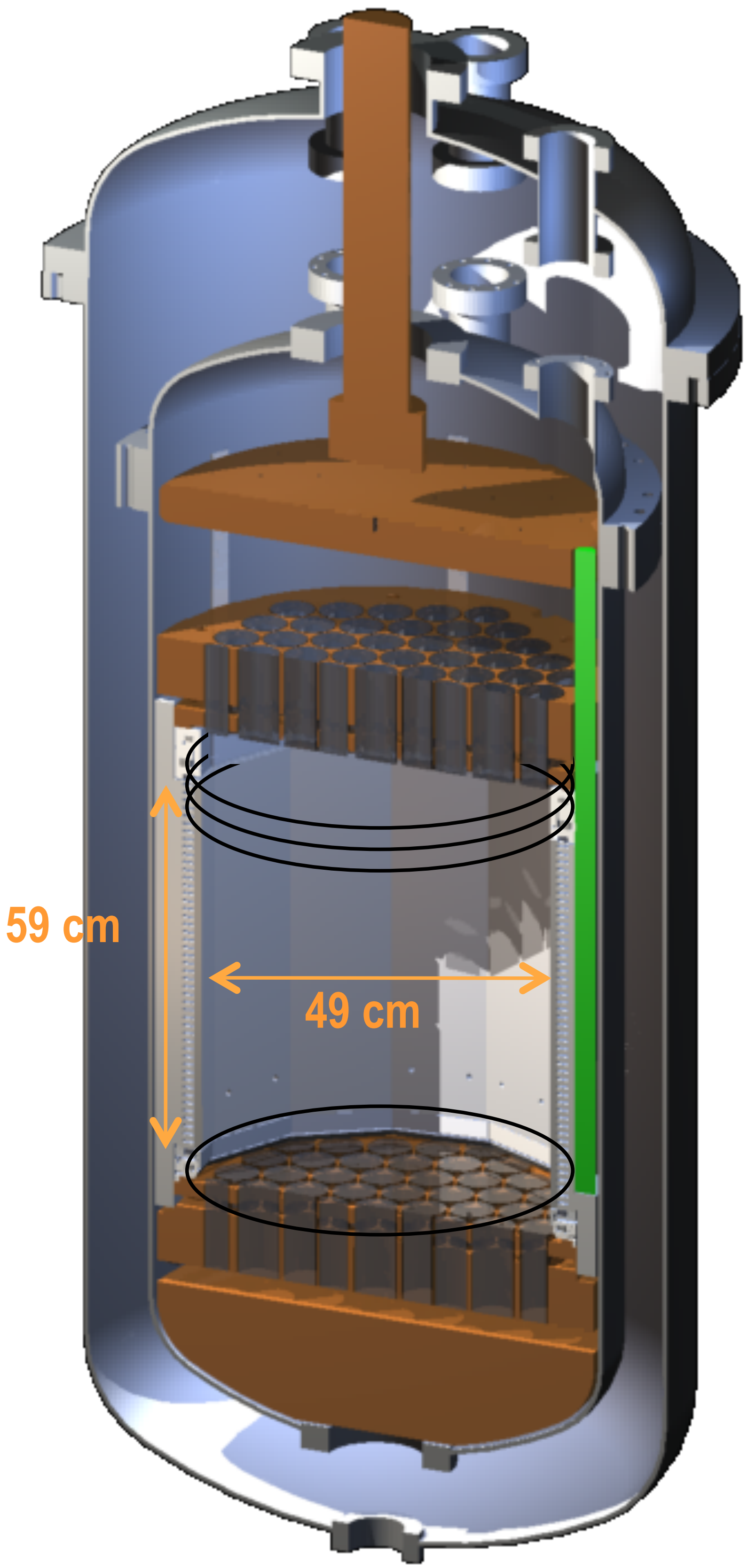


# Current WIMP Cross-Section Limits



# The LUX Detector - Self Shielding



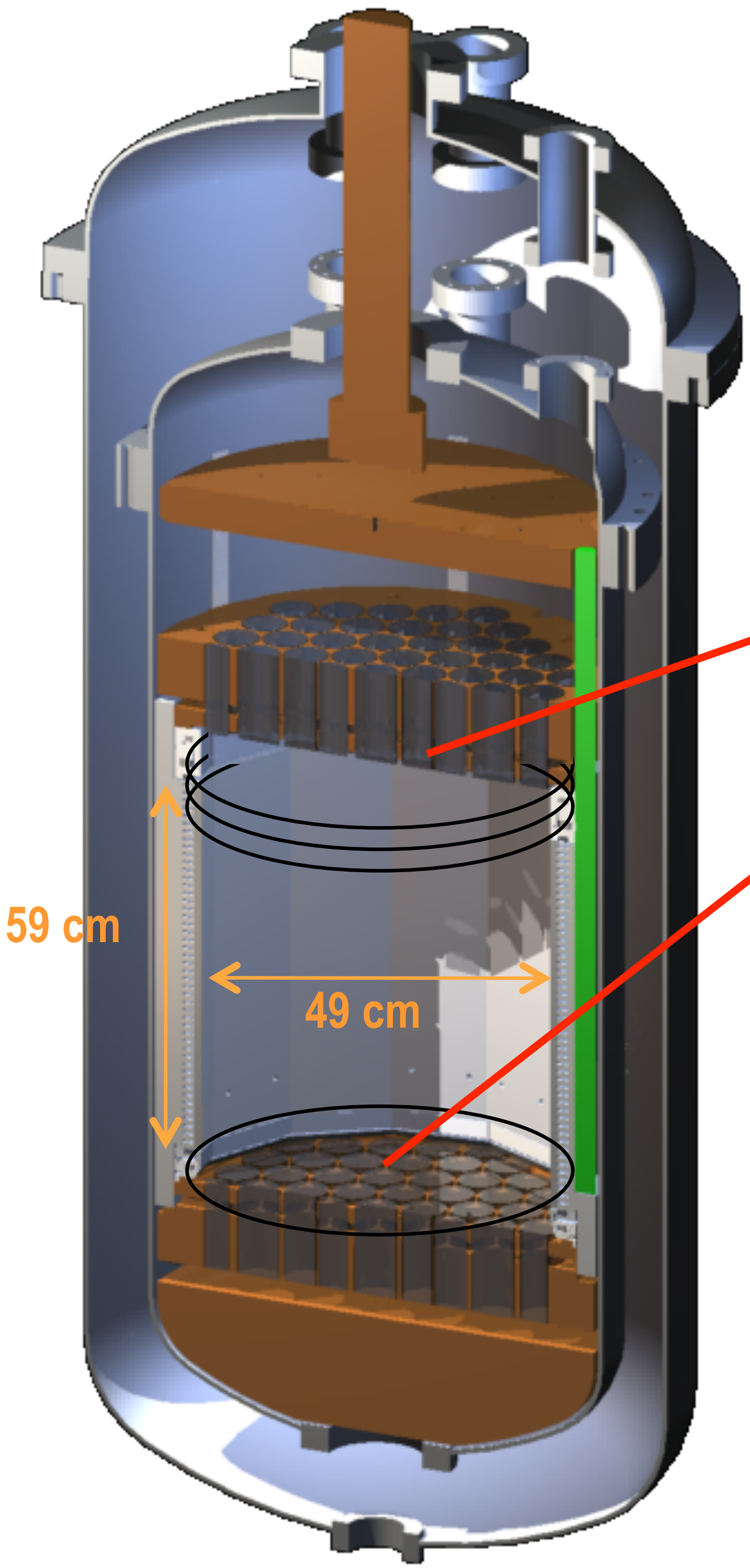

- 370 kg Liquid Xenon Detector (59 cm height, 49 cm diameter) in Gas/liquid fases.
  - 250 kg in the active volume
  - 118 kg in the fiducial volume
- Construction materials chosen for low radioactivity: Ti, Cu, PTFE
- Screened for radioactivity at SOLO counting facilities and at LBNL

| | Unit | Screening Result | | | | |
|---|---|---|---|---|---|---|
| | | U238 | Th232 | Co60 | K40 | Sc46 |
| PMTs | mBq/PMT | 9.5±0.6 | 2.7±0.3 | 2.6±0.1 | 66±2 | |
| Ti | mBq/kg | <0.18 | <0.25 | | | 4.4±0.3* |
| Cu | mBq/kg | | | 2.1±0.19* | | |
| PTFE | mBq/kg | <3 | <1 | | | |
| HDPE | mBq/kg | <0.5 | <0.35 | | | |
| Stainless steel** | mBq/kg | | | 19±1 | | |

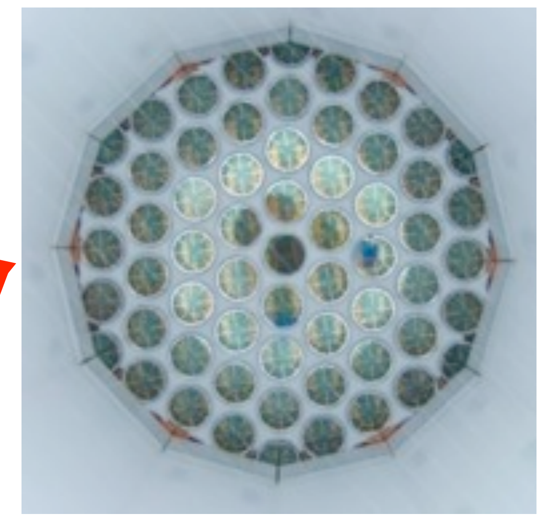
**Type 304 stainless steel used in electric field grids

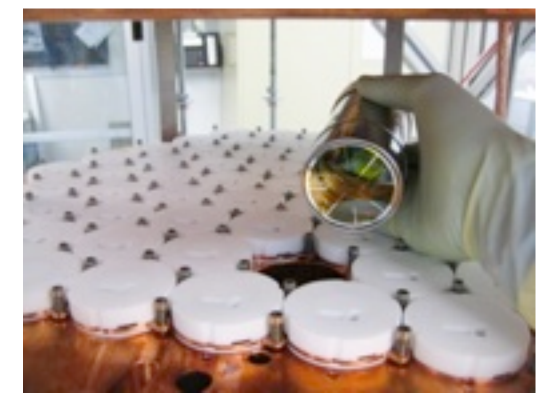
*Cosmogenic equilibrium at 1 mile above SL; decays below ground

# THE LUX DETECTOR - PMTS



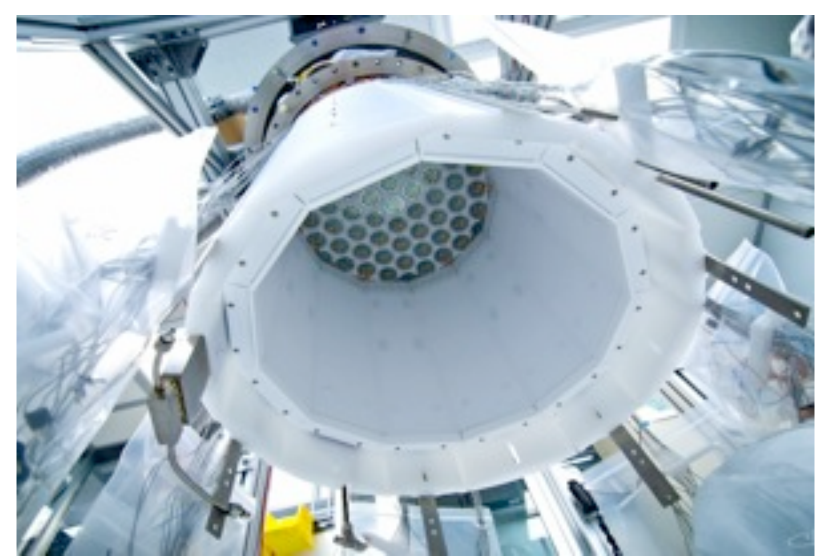

- 122 ultra low-background PMTs (61 on top, 61 on bottom).





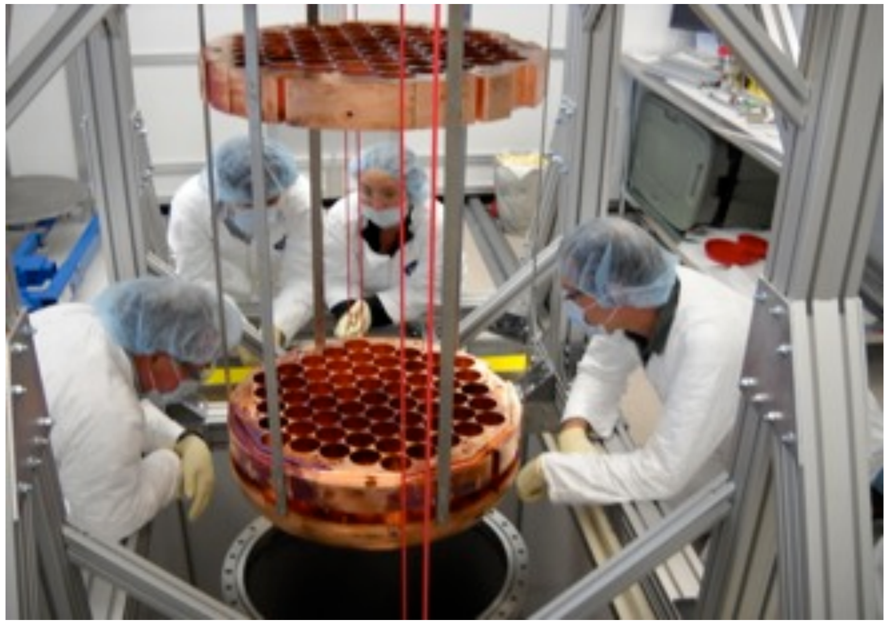
2 x 61 PMT arrays

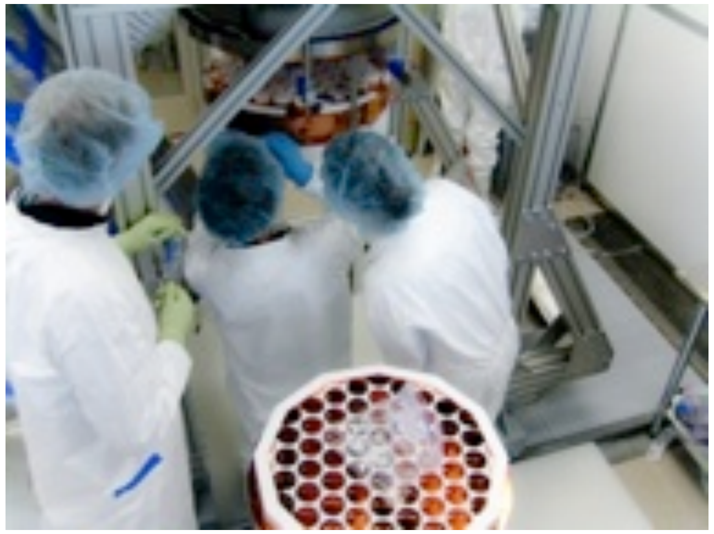
- Active region defined by PTFE (high reflectivity for the VUV light - high light collection)



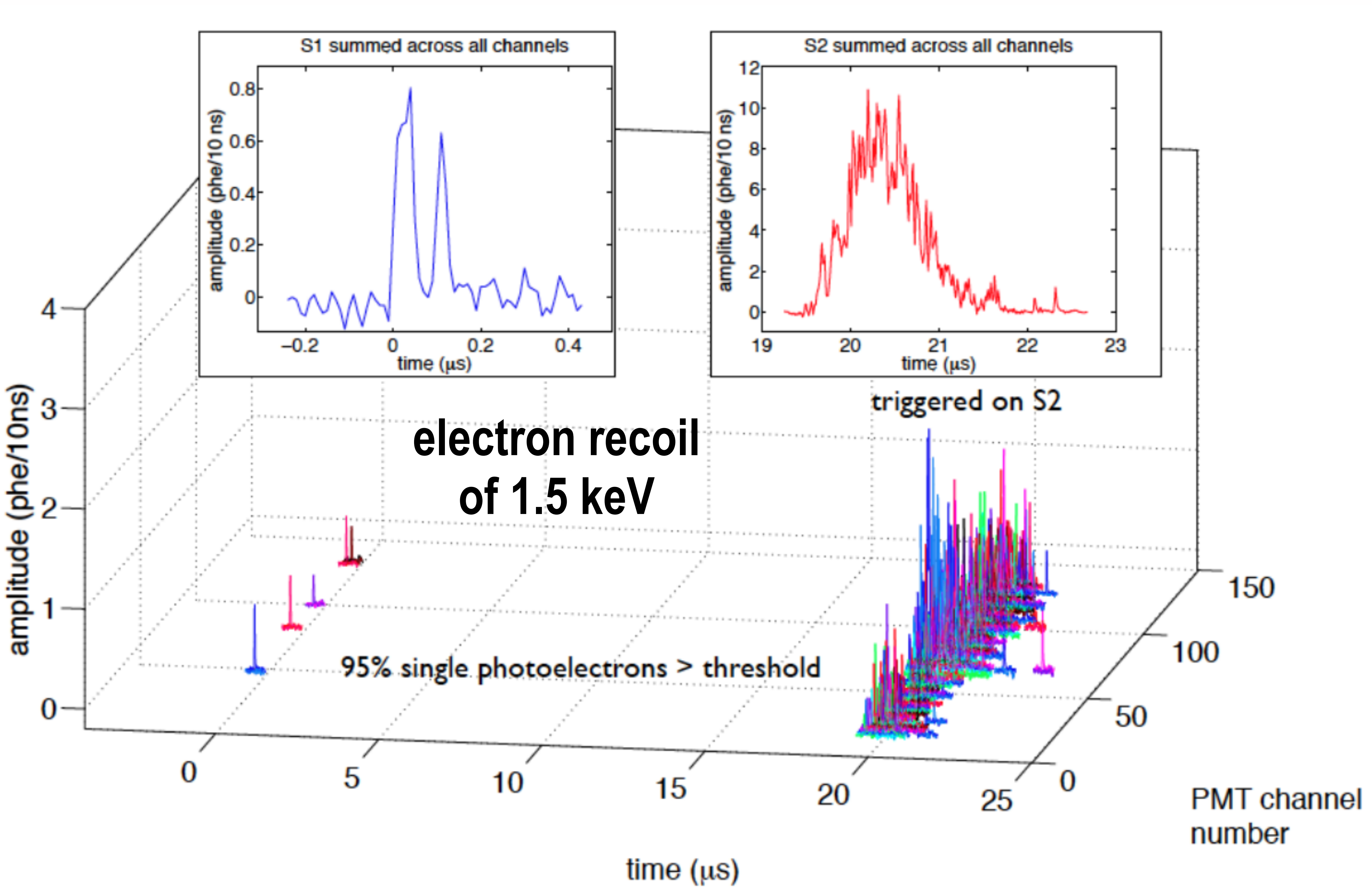
# ASSEMBLING THE DETECTOR

- The detector was assembled during the year of 2011.



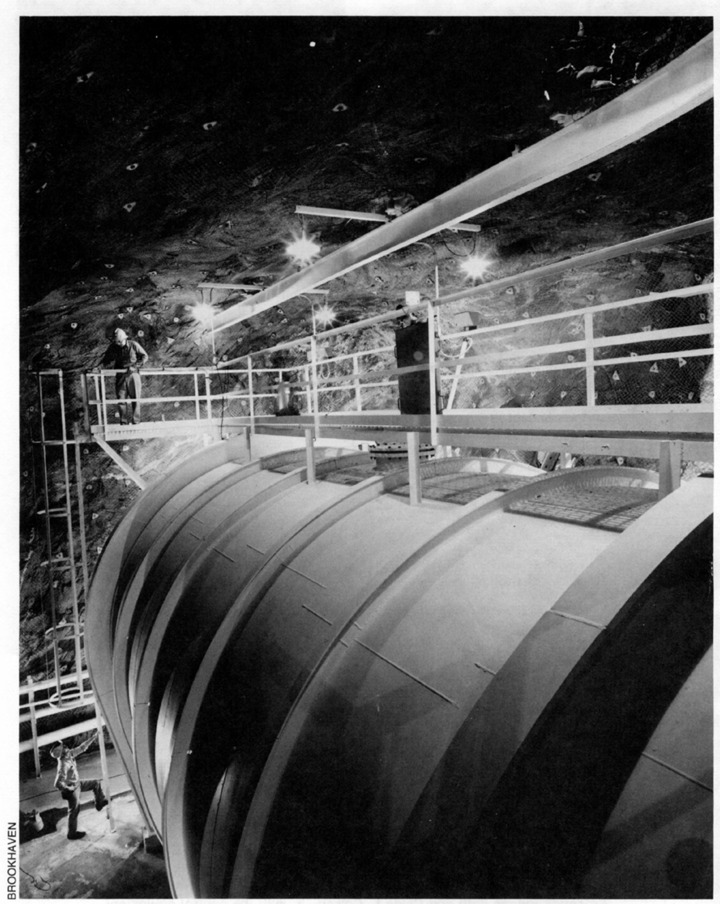


# Typical S1+S2 Event

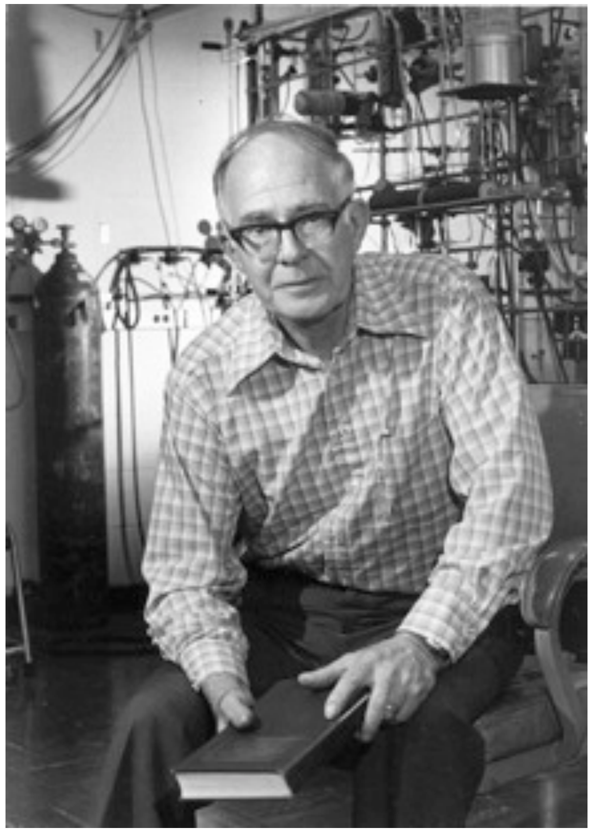


# LUX AT SURF


- Sanford Underground Research Facility Lead, South Dakota, USA.
- Former Home of the Homestake Solar Neutrino Experiment 1970-1994

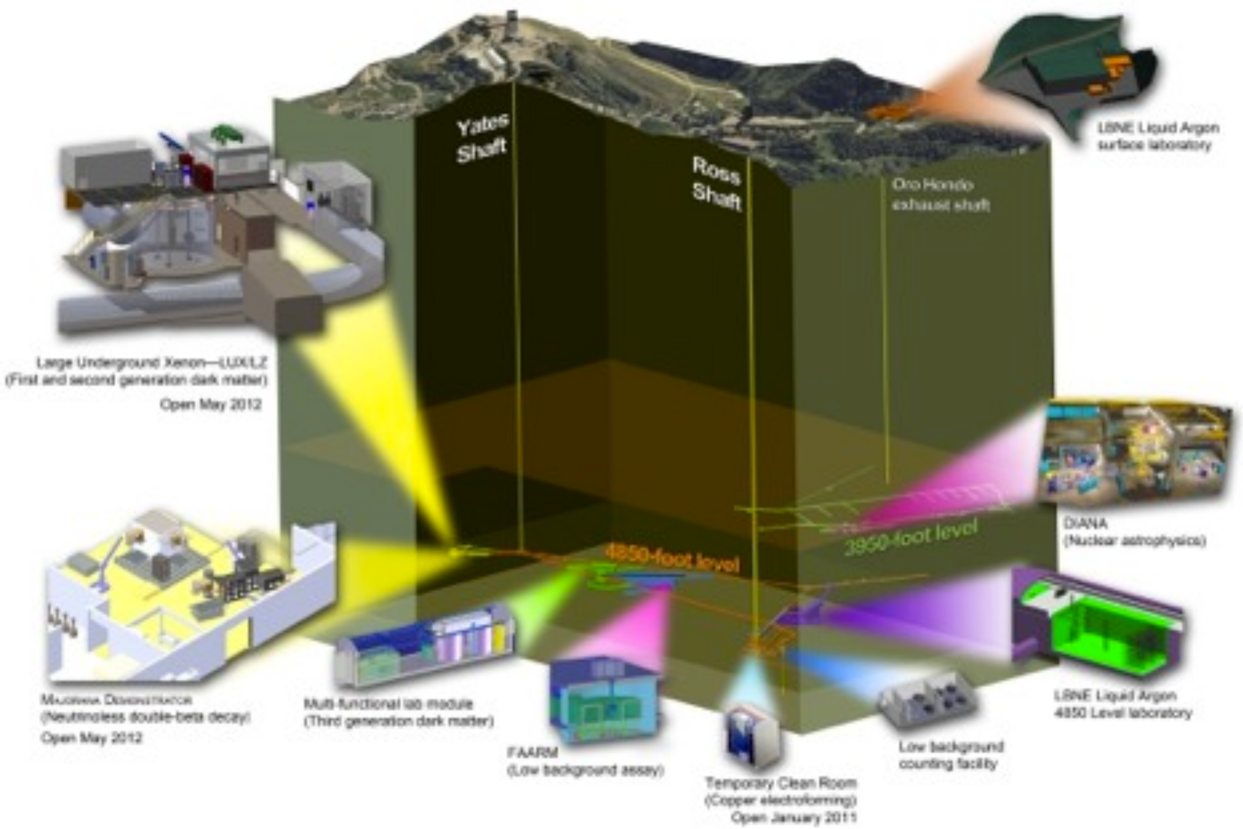


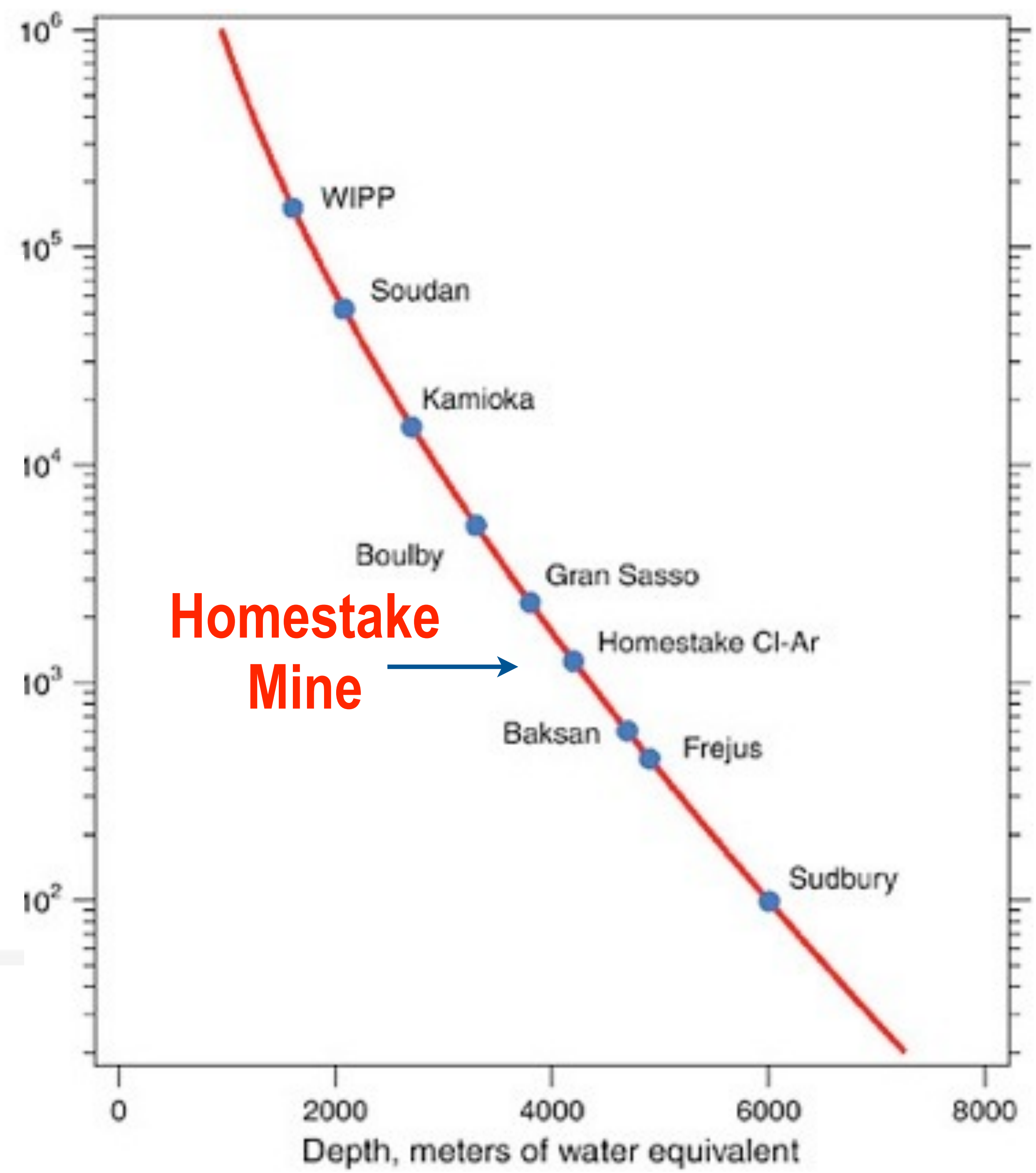

Davis' neutrino detection apparatus one kilometer underground in the Homestake Gold Mine, Lead, South Dakota. The tank contains 400,000 liters of perchloroethylene.



**Raymond Davis (Nobelpriset i fysik 2002)**

# LUX AT SURF



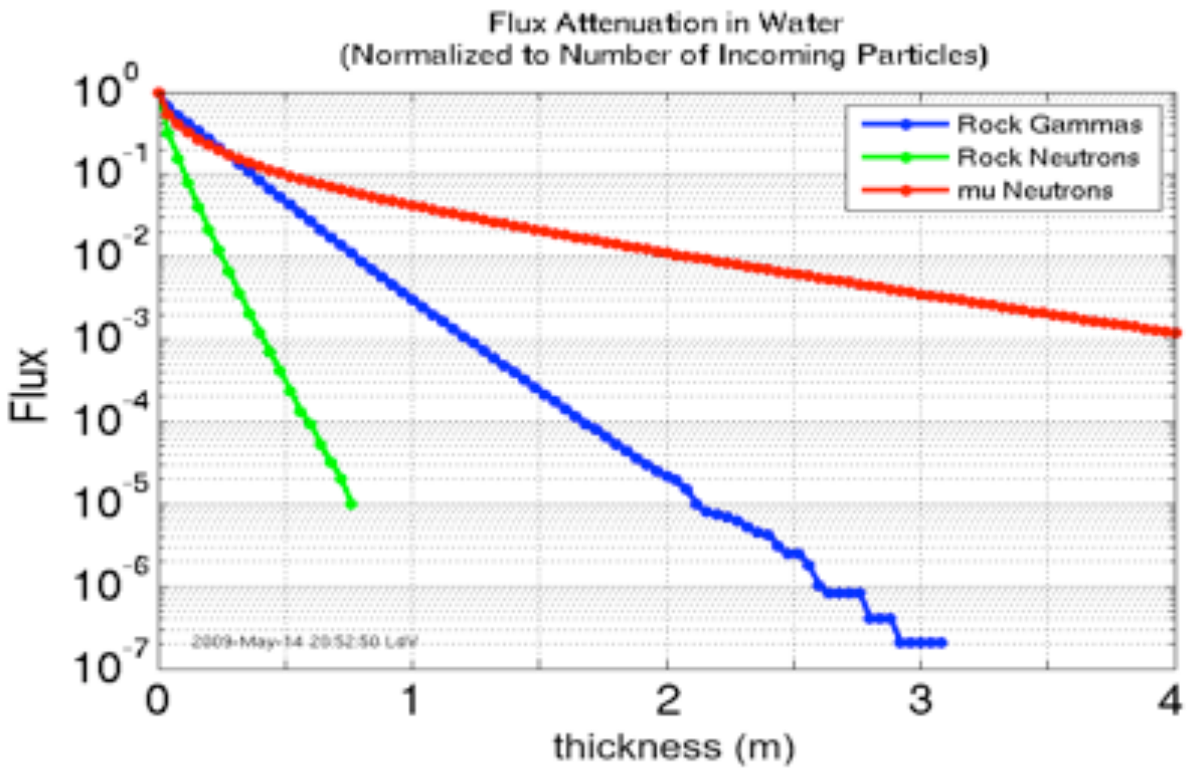



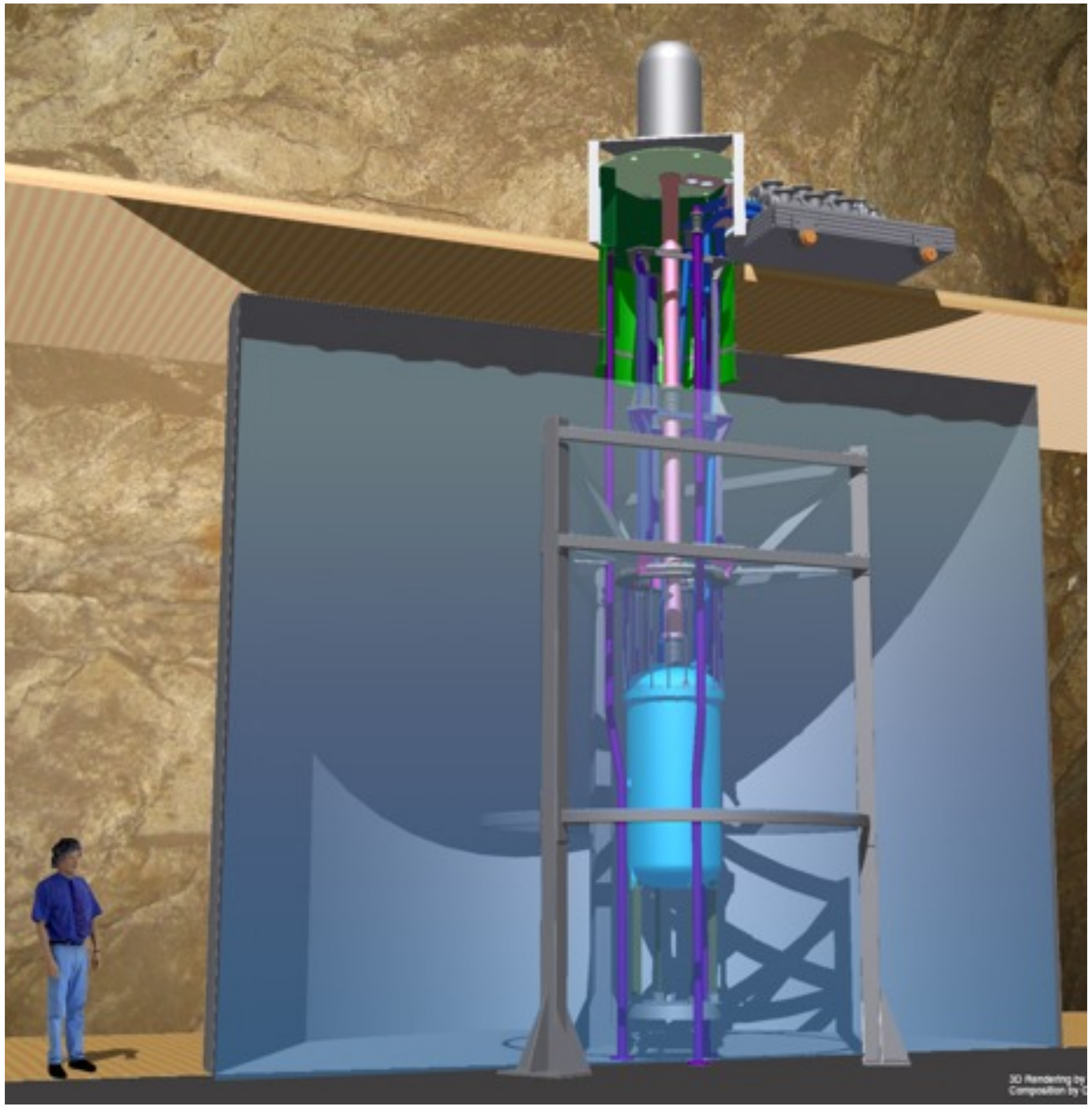

**1478 m deep**

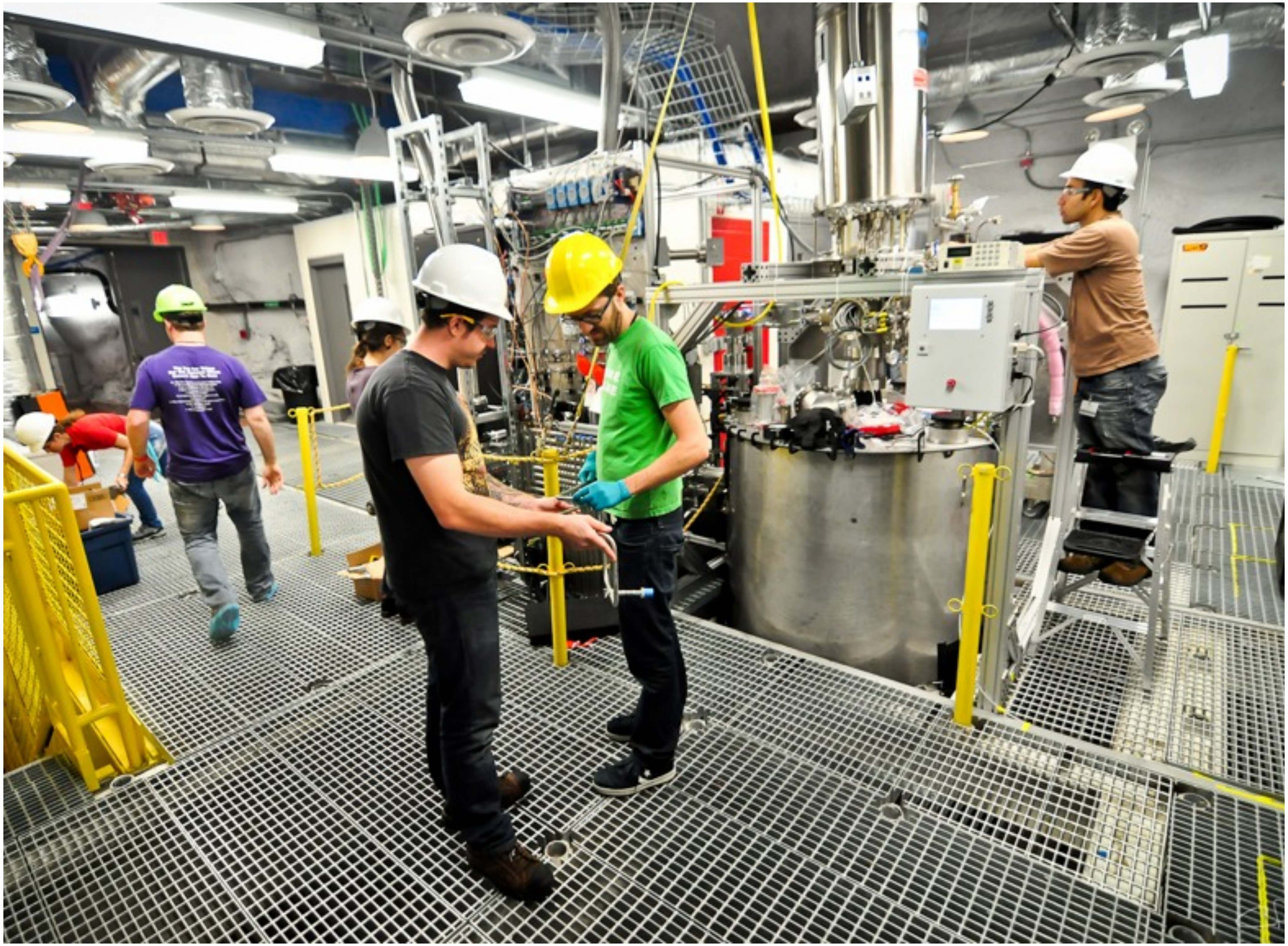
**μ flux reduced by x$10^{-7}$ (compared to sea level)**

# THE WATER SHIELD

- **Water Tank**
  - Dimensions: ø = 8 m, h = 6 m (300 tonnes).
  - Passive shielding
  - Muon active veto: 20 PMTs Ø10”.
- **Ultra-low Background**
  - γ suppression: x$10^{-9}$
  - Neutron sup. ($E_n$ >10 MeV ~$10^{-3}$ and $E_n$ <10 MeV >$10^{-9}$).



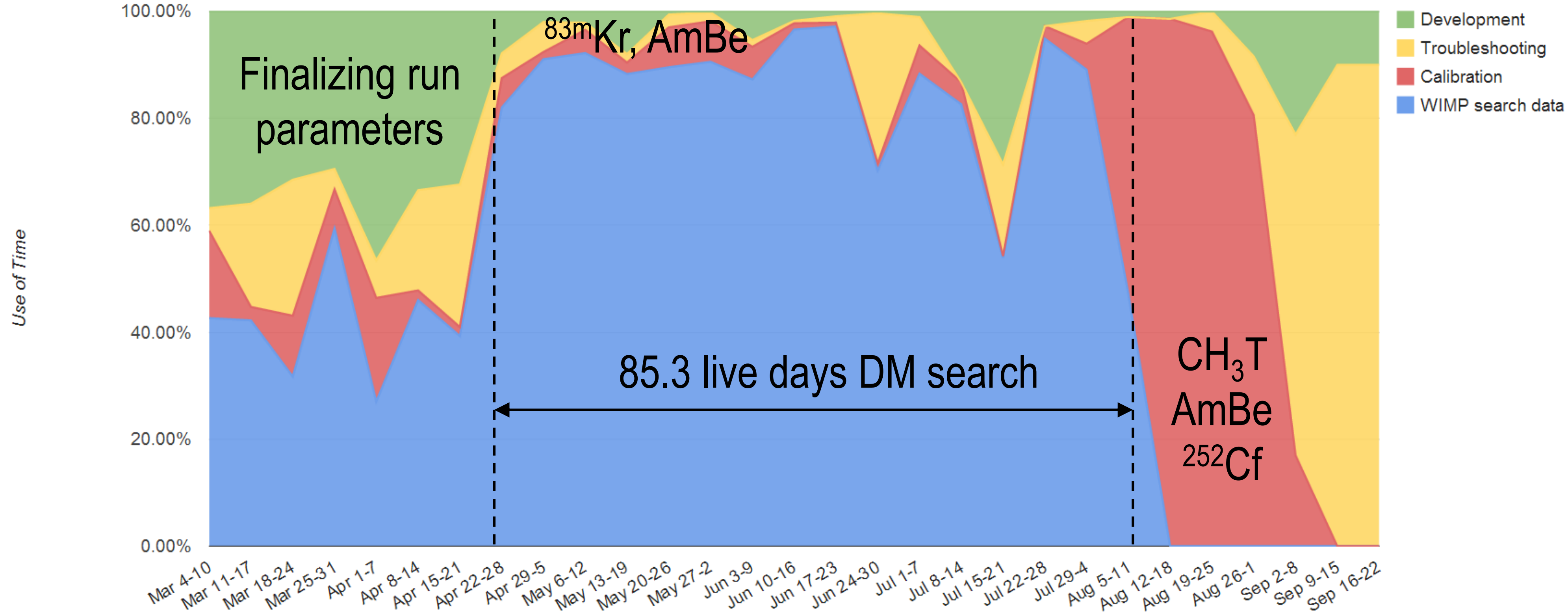


Davis Cavern SURF - Upper Floor, September 2012

LUX in the water tank, September 2012

**LUX in the water tank, September 2012**

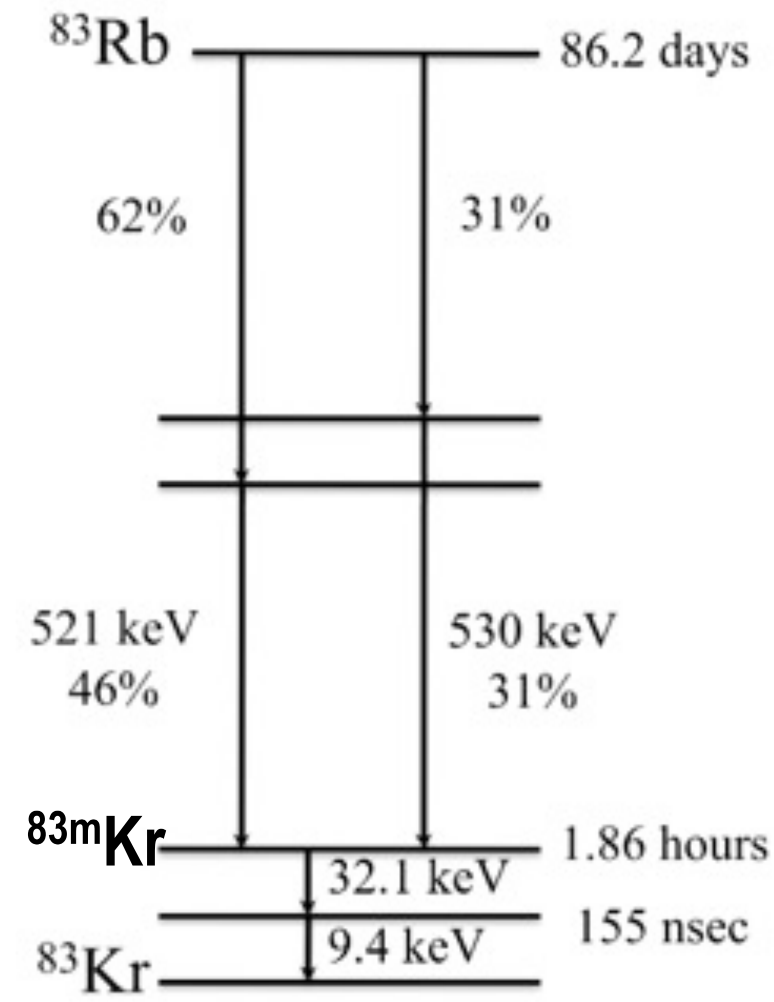
# Run 3 Data-Taking

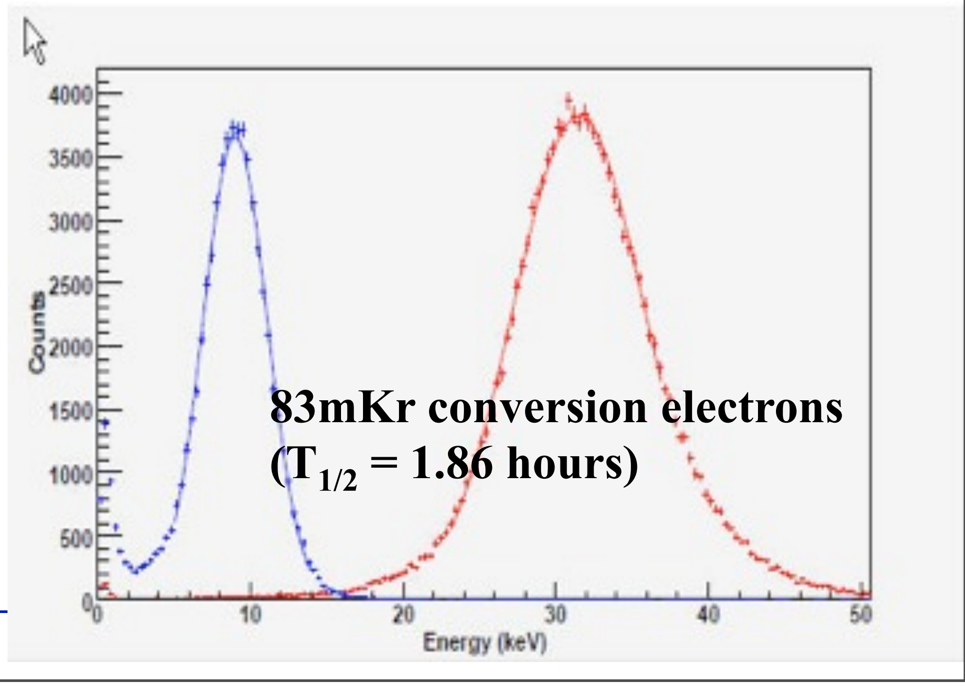



- **Detector cool-down January 2013, Xe condensed mid-February 2013**
- **Data-taking April 21 - August 8, 2013, 85 live days**
- **> 95% data taking efficiency over WIMP search region**
- **Drift field of 181 V/cm and extraction field of 6.0 kV/cm in the gas**
- **Very stable conditions during the run: thermal stability of $\Delta T<0.2$ K, pressure stability $\Delta P/P<1\%$ and liquid level variation of <0.2 mm**
- **$^{83m}$Kr and AmBe calibrations throughout, $CH_3T$ after WIMP search**
- **Non-blind analysis**

# Krypton Calibration

- $^{83}$Rb produces $^{83m}$Kr 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.
- Krypton calibrations is used to measure
  - Correct S1 and S2 with position
  - Electron drift length measurement
  - Light detection efficiency

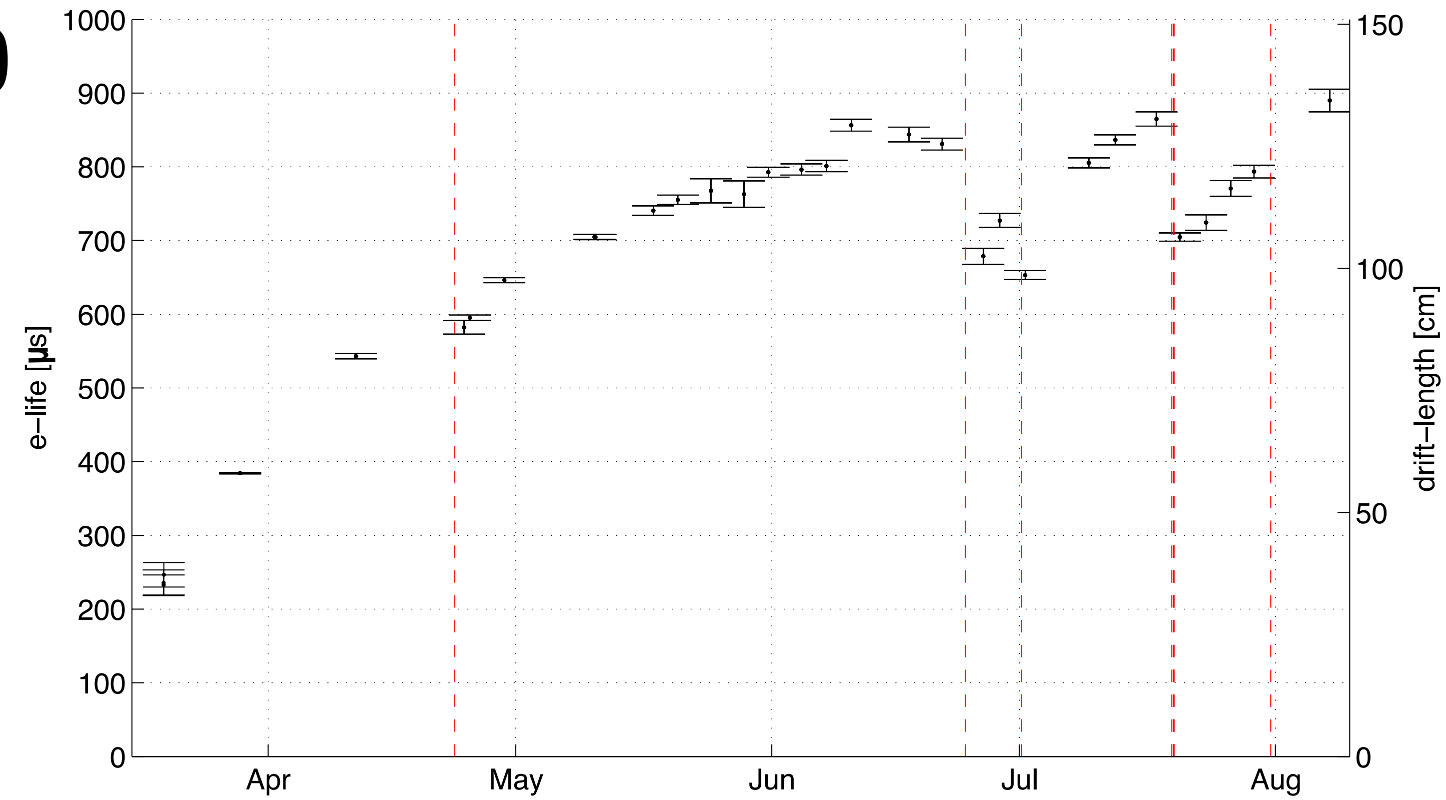


# DETECTOR PERFORMANCE

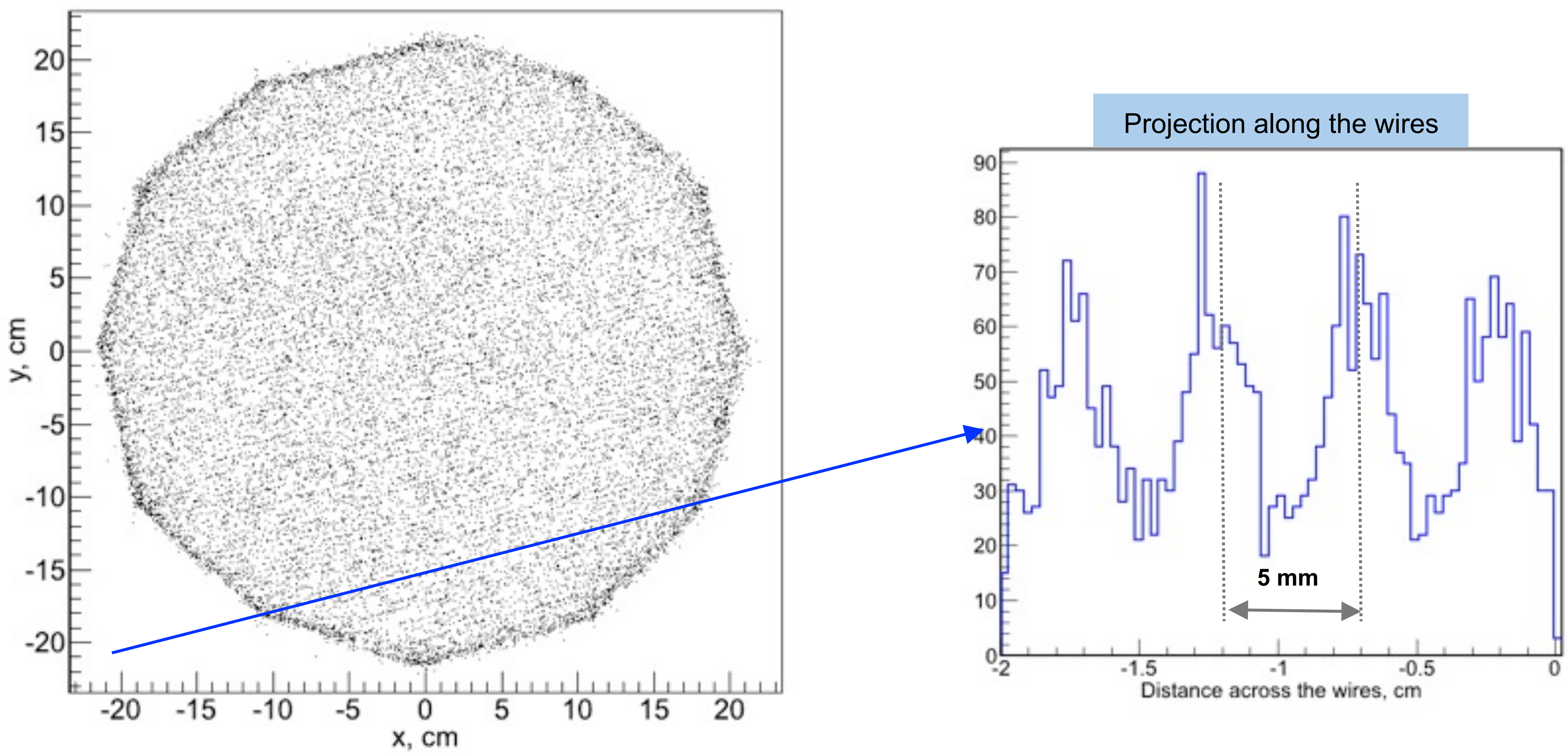


- **Electron drift length between 90 and 130 cm during.**
- **Light detection efficiency of 14%.**
- **65% extraction efficiency**



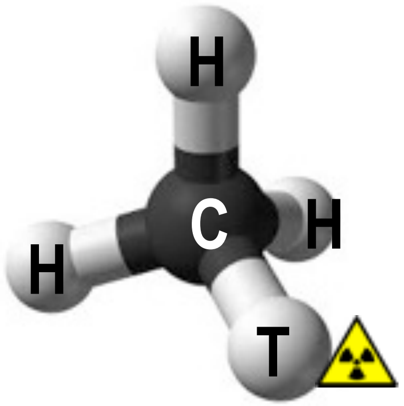
# Position Reconstruction

- 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.

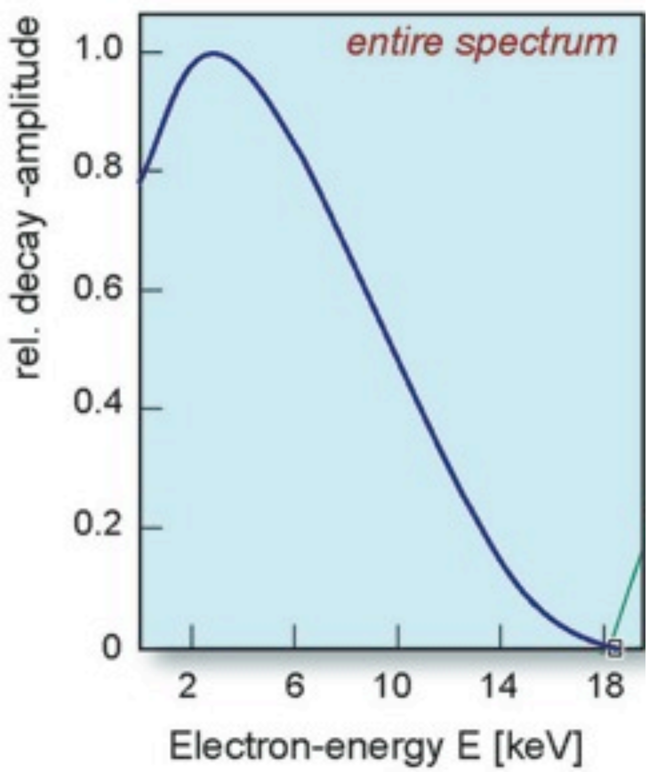


# TRITIUM CALIBRATION

- Tritium is an ideal source for determination of the detector's electron recoil band and low energy threshold
  - E(max) - 18.6 keV
  - <E> - 5.9 keV
  - β decay with $T_{(1/2)}$ = 12.6 a - Long Lifetime

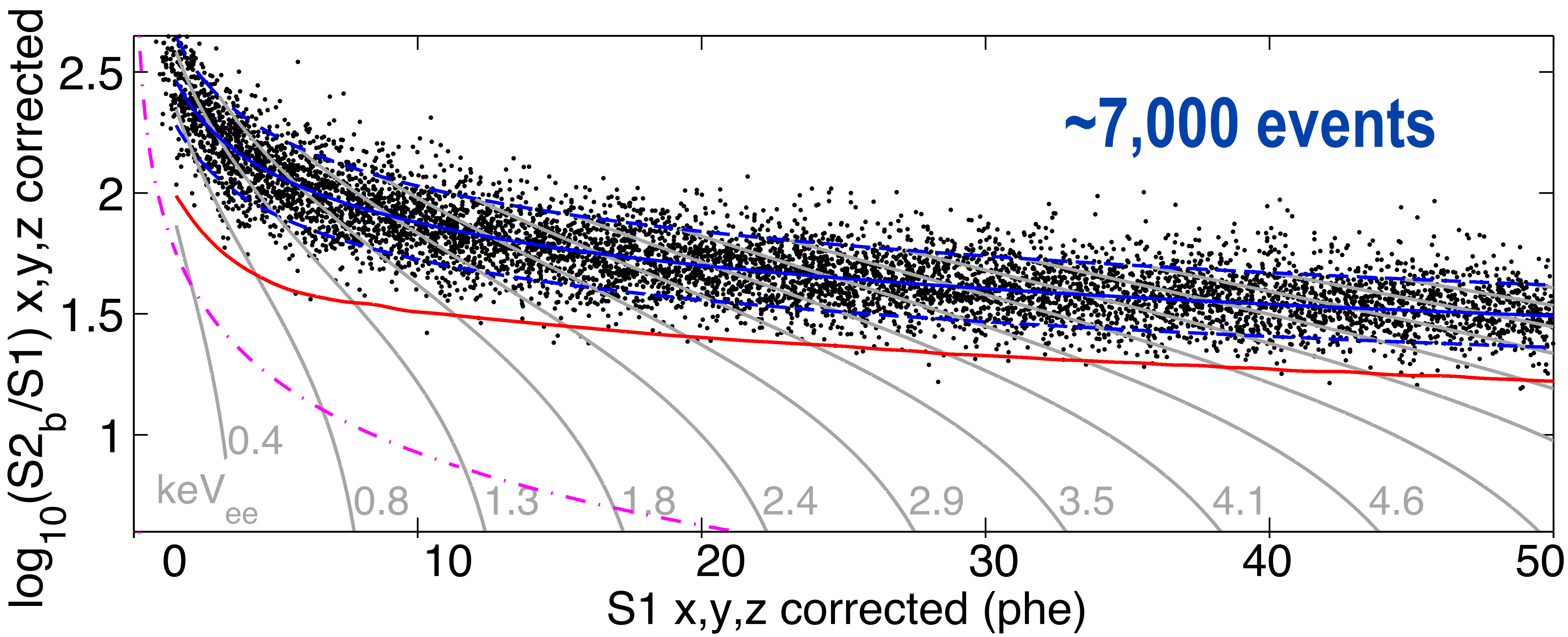



- Tritiated methane was injected in the gas system and removed by the getter.



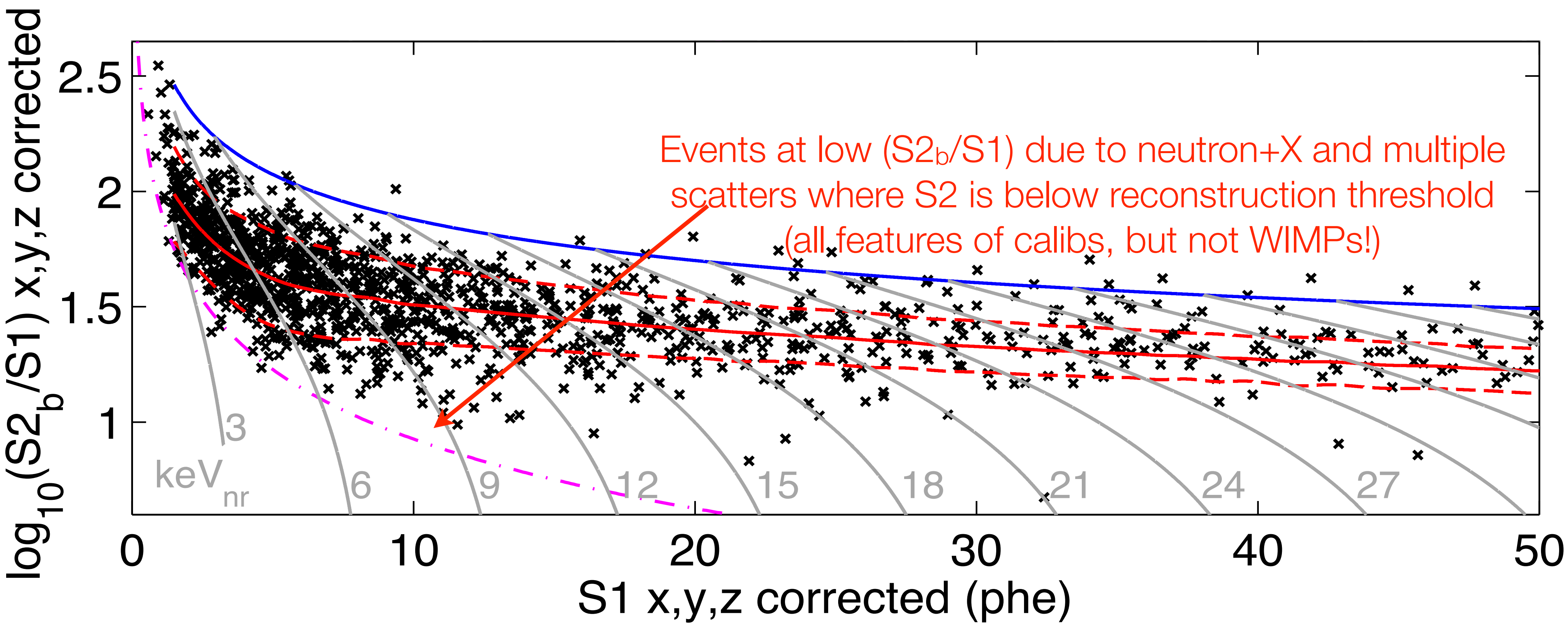

system of tritium injection

# ER Band - Tritium Calibration

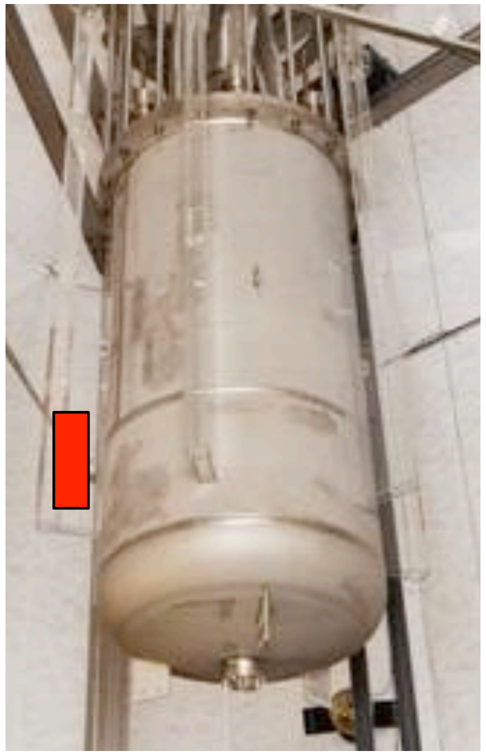


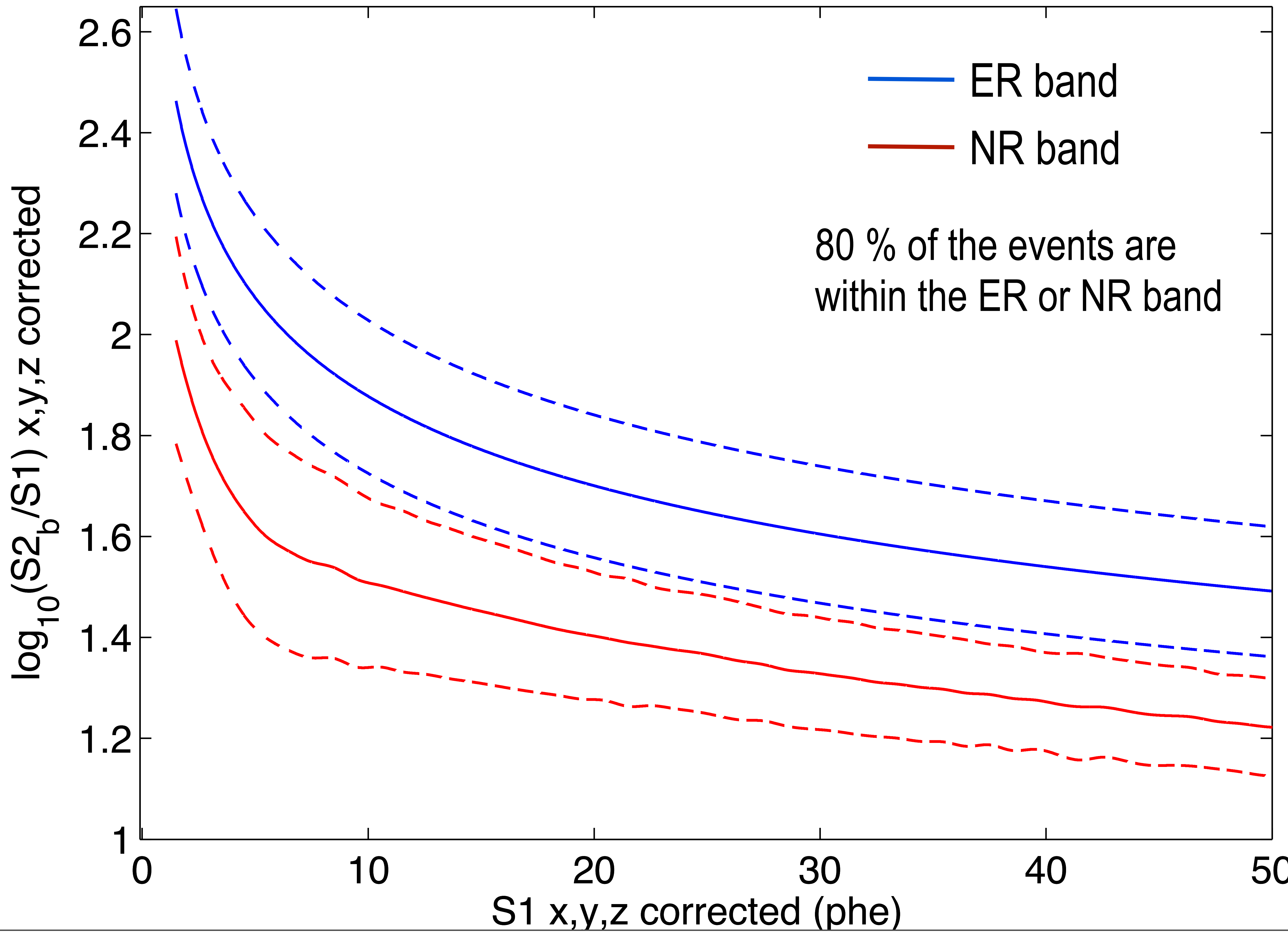

- **Parameterize as Gaussian, with power laws for mean and sigma in 1 phe S1 slices**

# Neutron Calibrations



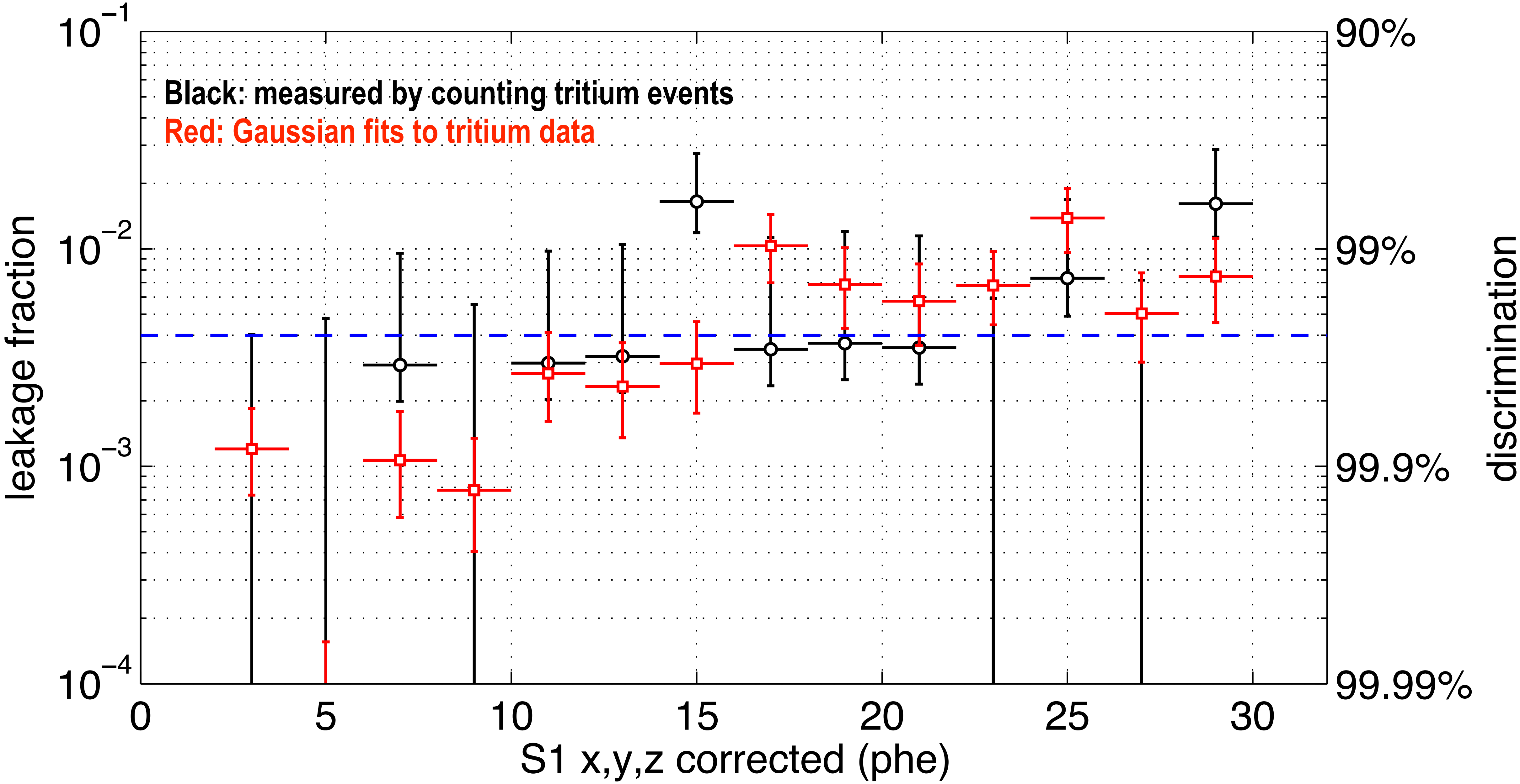

- Obtained with $^{241}$AmBe and $^{252}$Cf.
- The results are consistent with NEST (Noble Element Simulation Technique) which is based on the canon of existing experimental data
  - (see http://nest.physics.ucdavis.edu).
- GEANT4 + NEST MC was carried out that includes Neutron+X, to allow direct comparison




ER band
NR band
80 % of the events are within the ER or NR band
$\log_{10}(S2_b/S1)$ x,y,z corrected
S1 x,y,z corrected (phe)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50

# Electron Recoil Discrimination

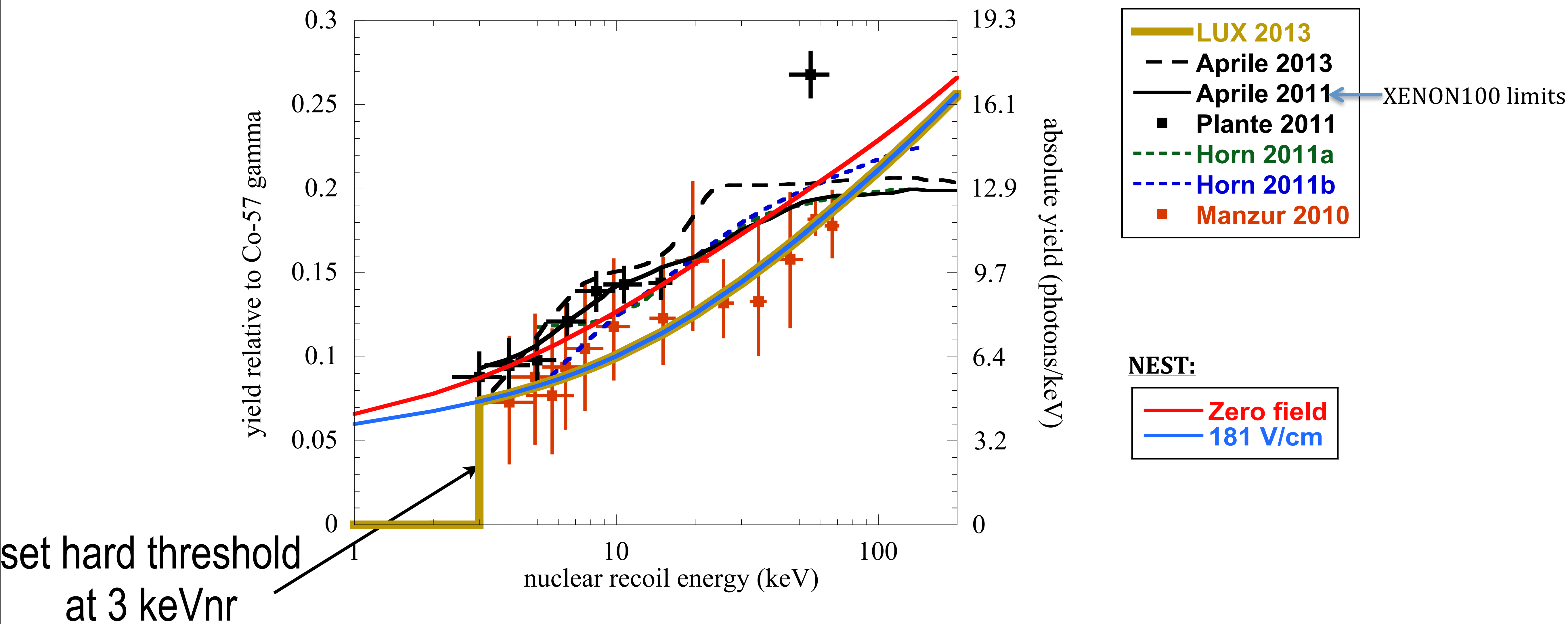
- Average discrimination from 2-30 S1 photoelectrons measured to be **99.6%** (with 50% nuclear recoil acceptance)




**Leakage Fraction**: fraction of the events in the ER band that spill over the lower half of the NR band

# LIGHT YIELD

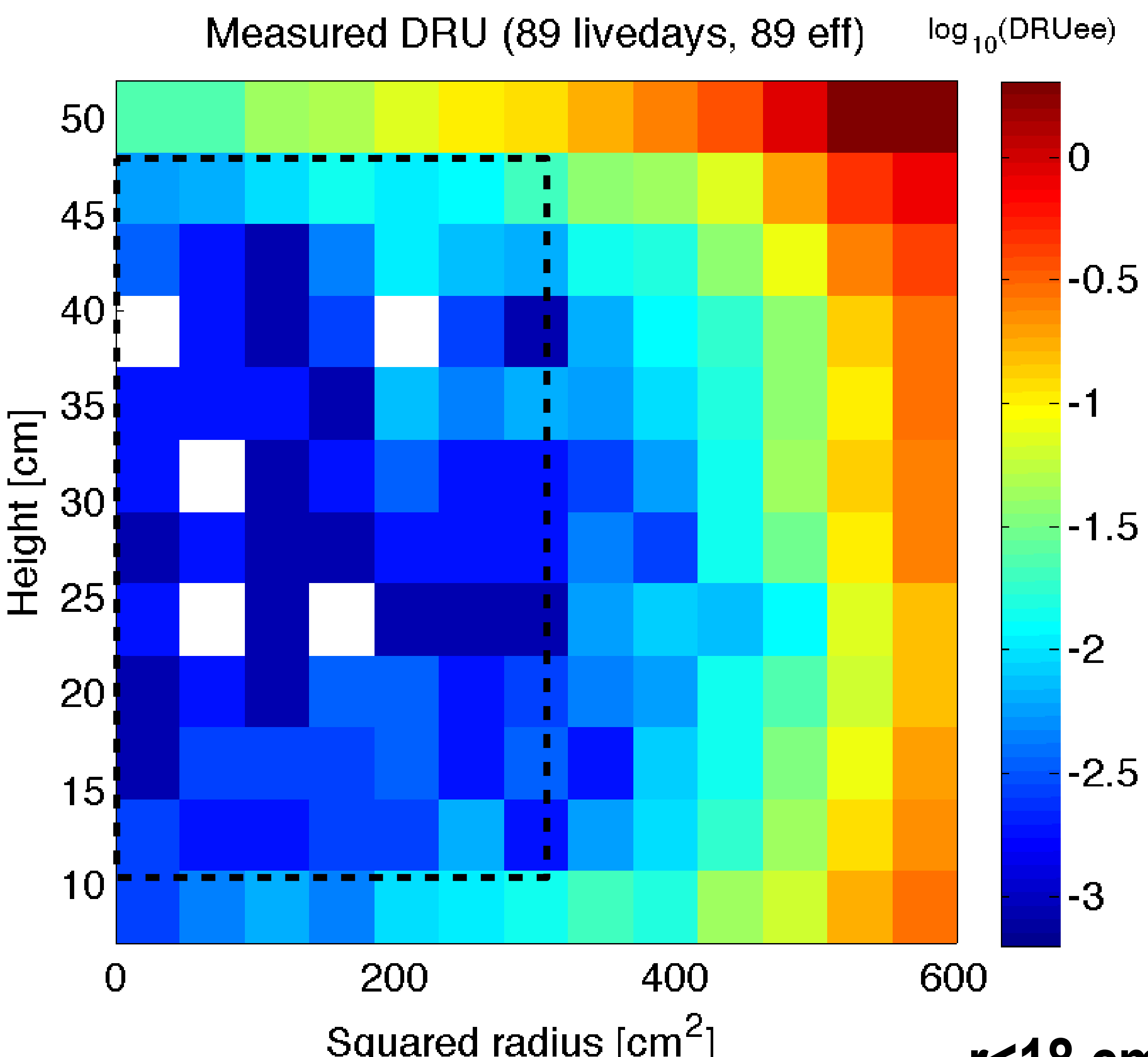
- •Modeled using the NEST.
- •Artificial cutoff in light and charge yields assumed below 3 $keV_{nr}$ . This is to be conservative and it does not represent actual physics.
- •Includes E field quenching of light signal (77-82% compared to zero field)



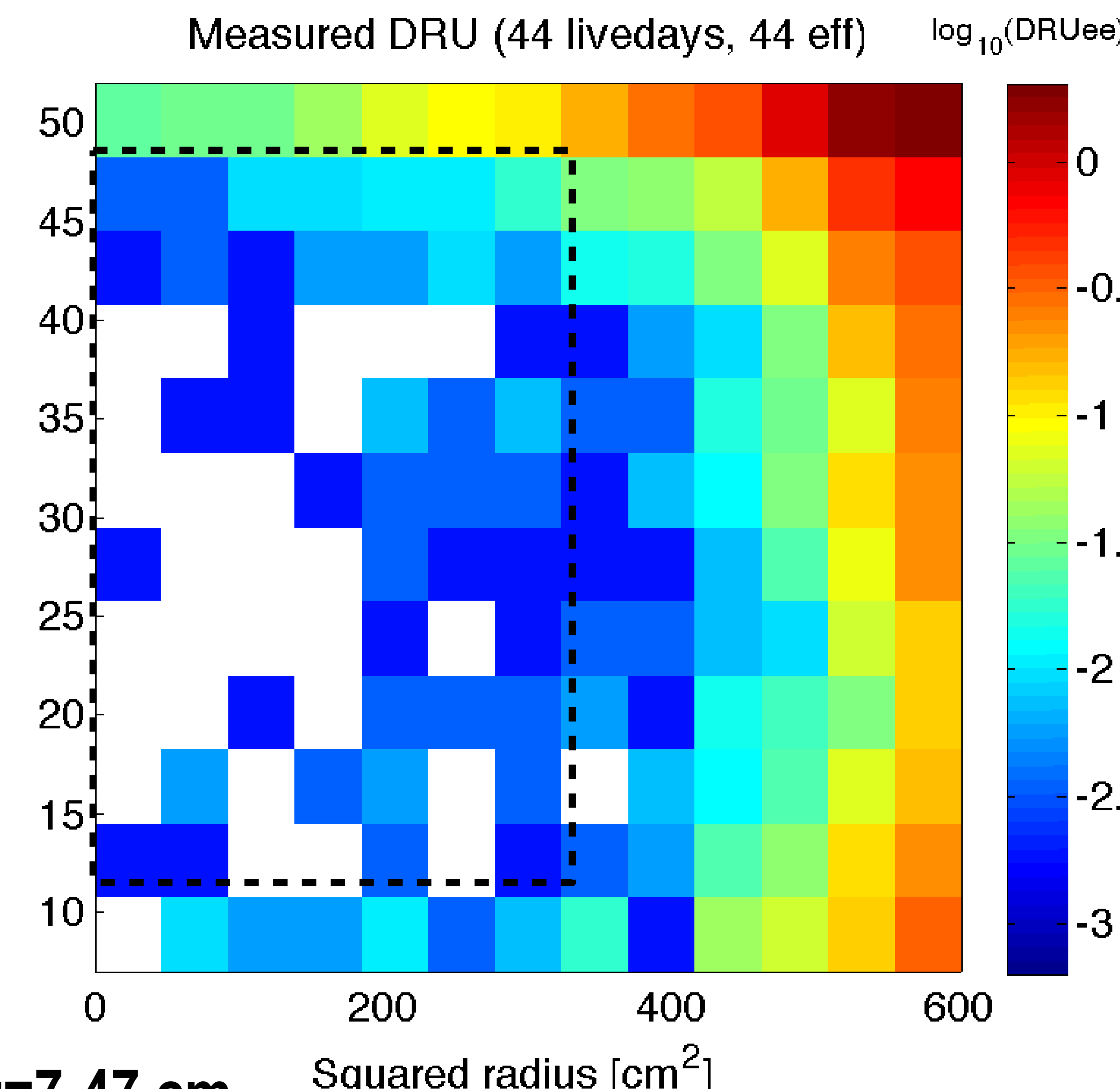
# Observed Backgrounds

- 118 kg average Apr. - Aug. is $3.1\times10^{-3}$ events/keVee/kg/day ($0.5\times10^{-3}$ are cosmogenic)

## All the run

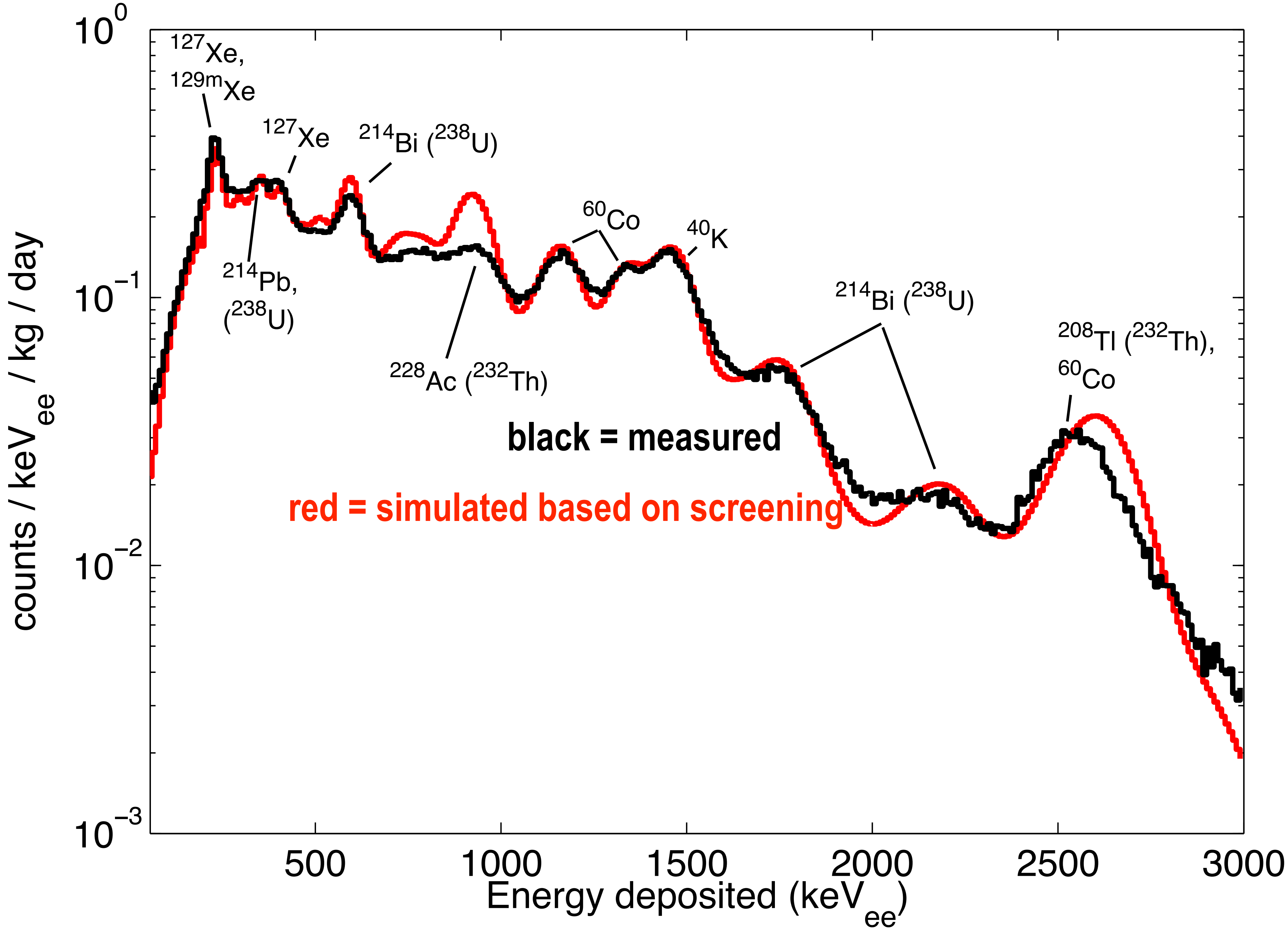



## Last 44 days




**r<18 cm z=7-47 cm**

# Backgrounds in LUX

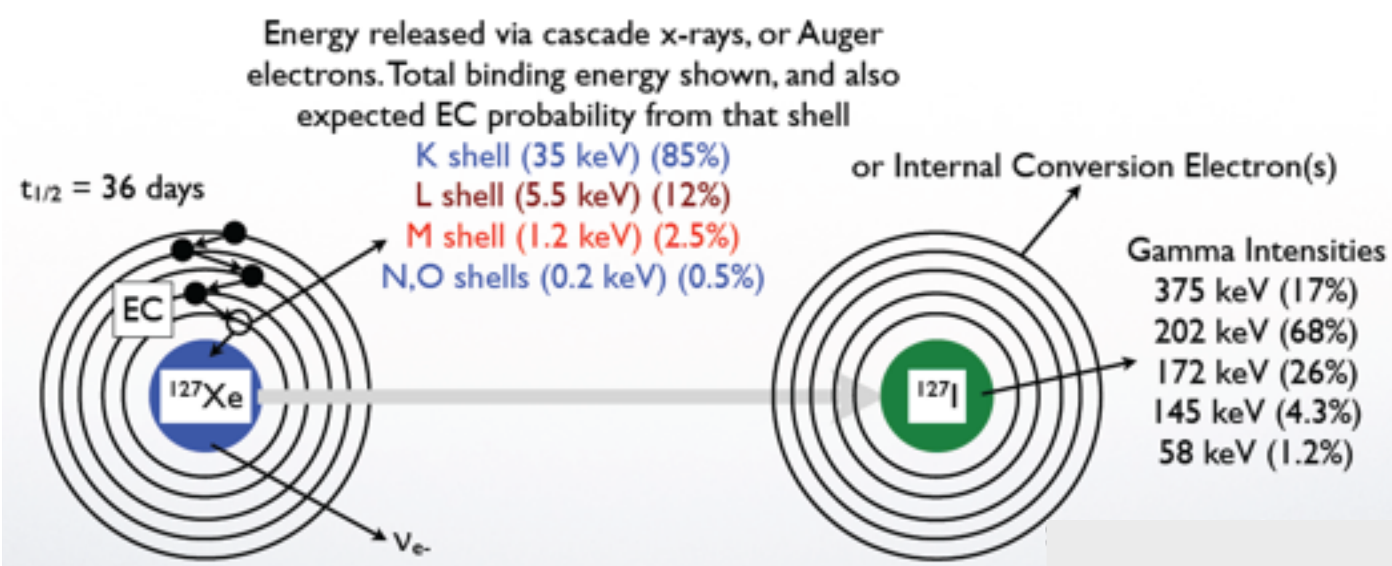


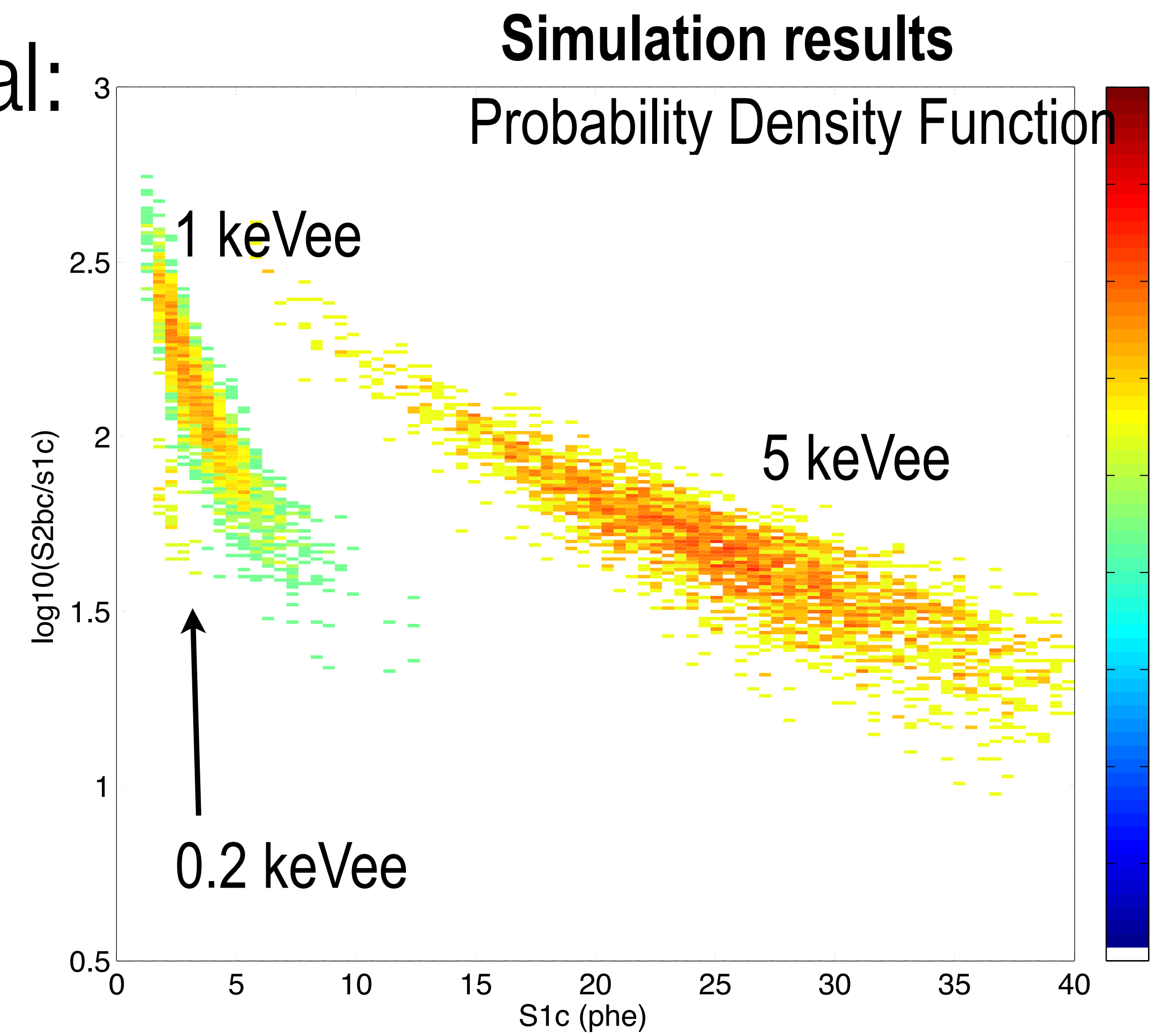

- Full gamma Spectrum, excluding region ±2 cm from top/bottom grids

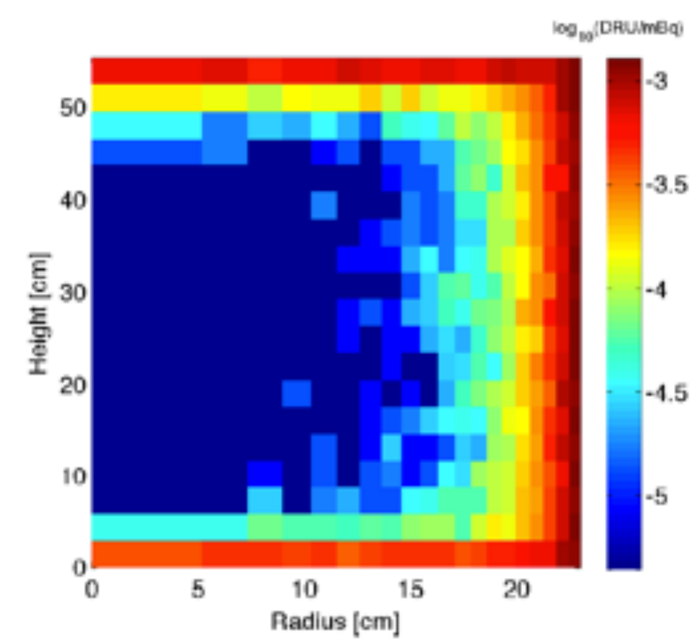
# BACKGROUND FROM XE-127

- Electron capture from S-wave orbital:

$$p + e^- \rightarrow n + \nu_e$$



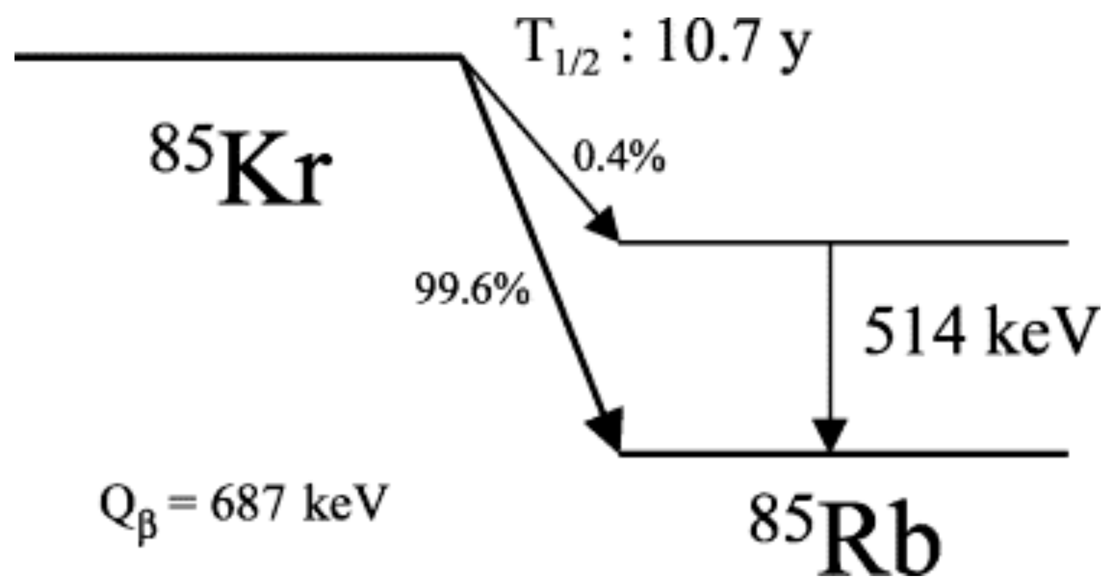




Predict 15 events in WIMP search data

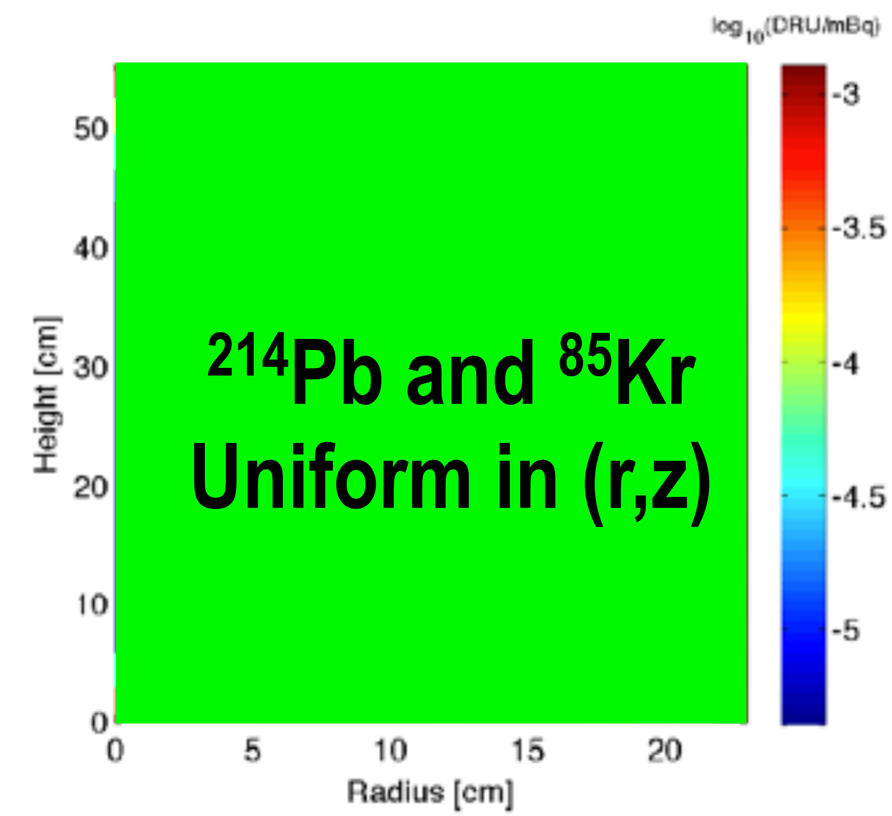
# Background from Pb-214/Kr-85

- $^{85}$Kr - beta decay – intrinsic background in liquid X
- Kr concentration reduced from 130 ppb to 3.5 ppt (factor of 30000) using a chromotographic system developped by the LUX collaboration

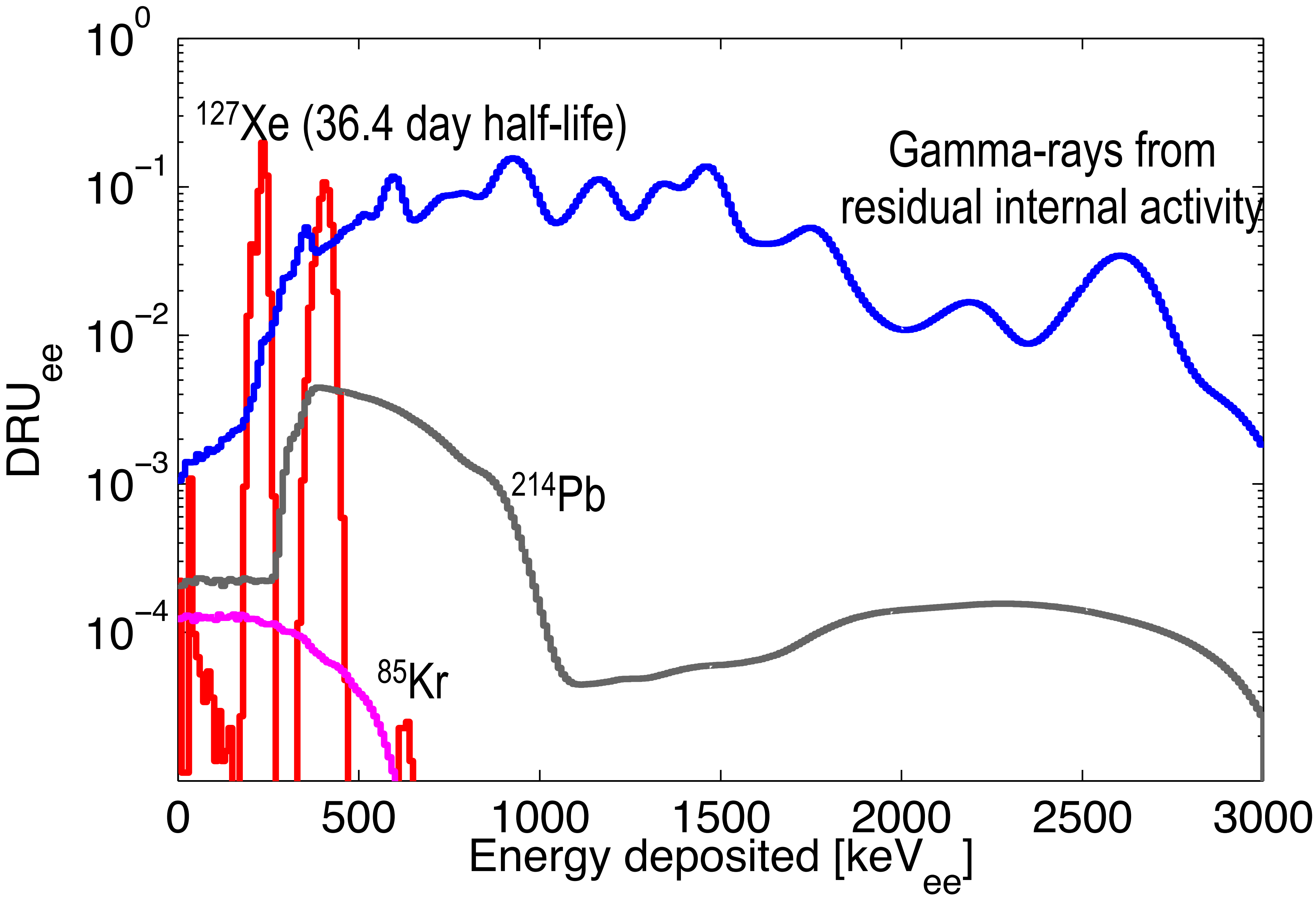



$^{214}$Pb (from $^{238}$U chain) has a half-life of 27 minutes and undergoes a beta decay. This generates a low-energy ER background in the WIMP search region.

**Predict 10 events in WIMP search data**



# Full Background Model




**Full Background Model Fits ER Data Over Entire Range**

# Low Energy Backgrounds

- Monte Carlo predictions of low-energy ER background rates from all significant sources, 118 kg fiducial and 0–8 keVee energy

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

# Run 3 Event Selection and Cuts

| Cut | Events Remaining |
|---|---|
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

- We aimed to apply minimum set of cuts in order to reduce any tuning of event cuts/acceptance.
- The cut list is very short.
- Hardware trigger: at least two trig. channels > 8 phe within 2 μs window (16 PMTs per trig. channel)
  - > 99% efficient for raw S2 > 200 phe (~8 $e^-$).

| Cut | Events Remaining |
| --- | --- |
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

- **Remove periods of live-time when liquid level, gas pressure or grid voltages were out of nominal ranges:**
  - **Less than 1.0 % live-time loss!**

| Cut | Events Remaining |
|---|---|
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

- **Exactly 1 S2 and 1 S1 as identified by the pulse finding and classification code:**
  - **Separate S1s from S2s using pulse shape and PMT hit distributions.**
  - **S1s identification includes a two fold PMT coincidence requirement.**

| Cut | Events Remaining |
|---|---|
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

- **Accept events with S1 between 2-30 phe (0.9-5.3 $keV_{ee}$, ~3-25 $keV_{nr}$):**
  - **We impose that at least 2 PMTs are above threshold.**
  - **2 phe analysis threshold allows sensitivity down to low WIMP masses. Expected S1 for a 3 keVnr event is 1.94 phe.**
  - **Upper limit avoids $^{127}Xe$ 5 $keV_{ee}$ activation.**

| Cut | Events Remaining |
|---|---|
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

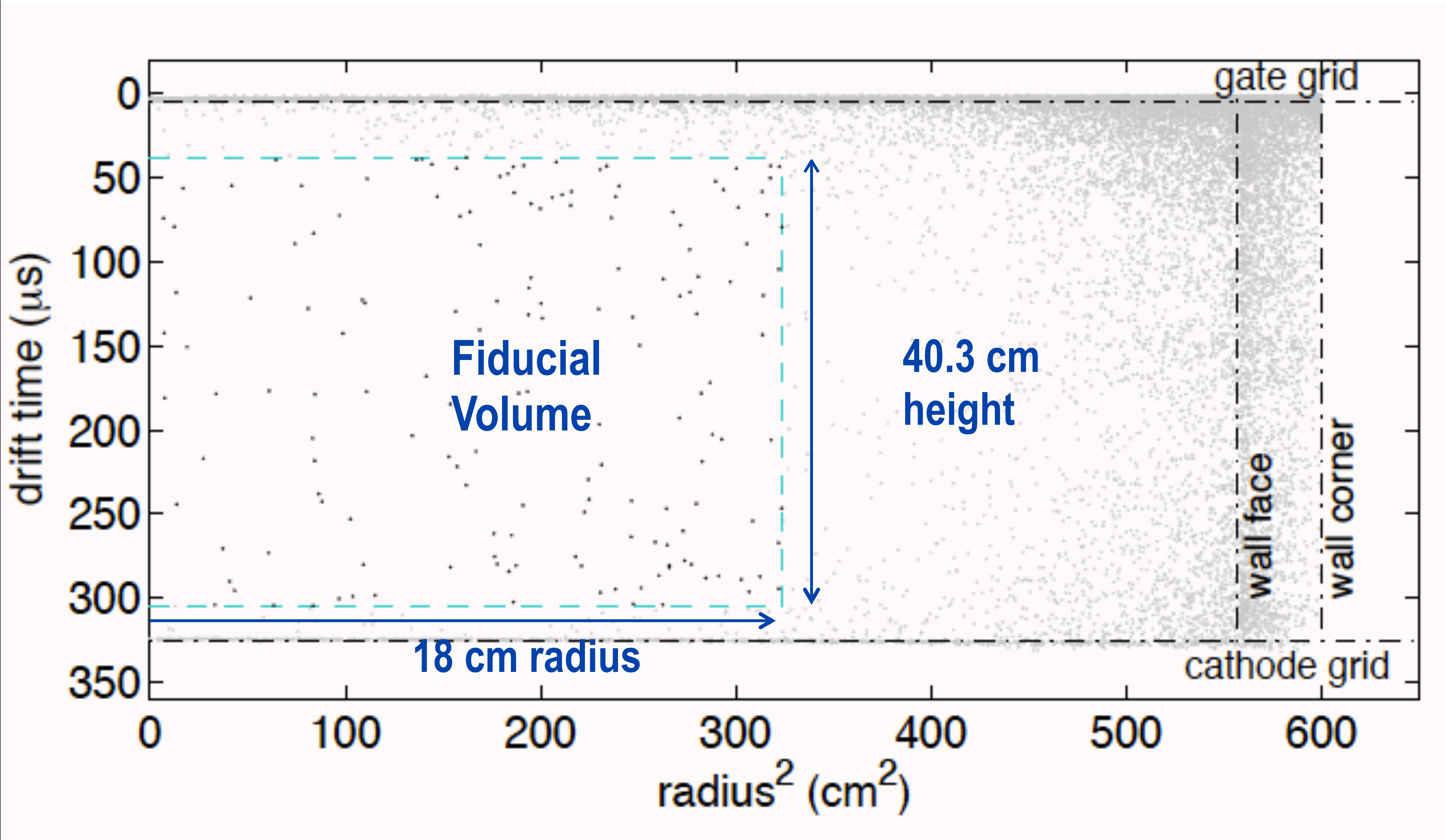
- **S2 threshold cuts subdominant to S1:**
  - 200 phe ~ 8 single electrons
  - Removes small S2 edge events and single electron events

| Cut | Events Remaining |
|---|---|
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

- Require less than 100 phe (< 4 extracted electrons) of additional signal in 1 ms period around S1 and S2 signals:
  - Simple cut to removes additional single electron events in 0.1-1 ms following large S2 signals
  - Only 0.8% hit on live-time

| Cut | Events Remaining |
|---|---|
| All Triggers | 83,673,413 |
| Detector Stability | 82,918,904 |
| Single Scatterer (1 S1 + 1 S2) | 6,585,686 |
| S1 Yield 2-30 phe | 26,824 |
| S2 Yield 200-3300 phe | 20,989 |
| Single Electron Background | 19,796 |
| Fiducial Volume | 160 |

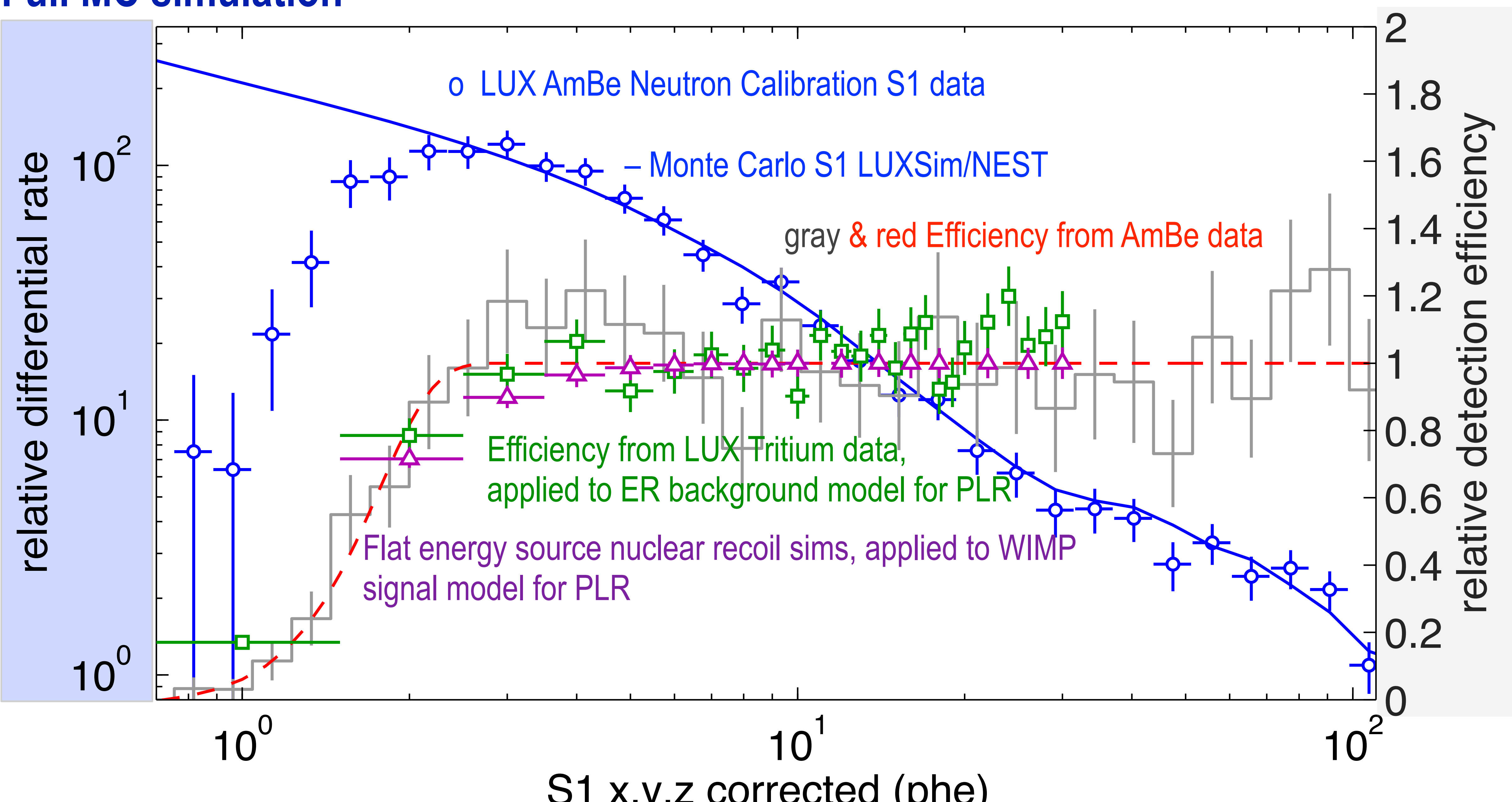
- Fiducial Cut: radius < 18 cm, 38<drift time<305 μs, 118.3+-6.5 kg fiducial
    - Low energy alpha-parent nuclear recoil events generate small S2+S1 events. The radius and drift time cuts were set using population of events which had S1's outside of the WIMP signal search range, but with S2's of a comparable size to lower S1 events in same population. This ensured that position reconstruction for sets were similar, and definition of fiducial was not biased.
    - Cuts also remove corner regions where ER event rates are proportionally very high.



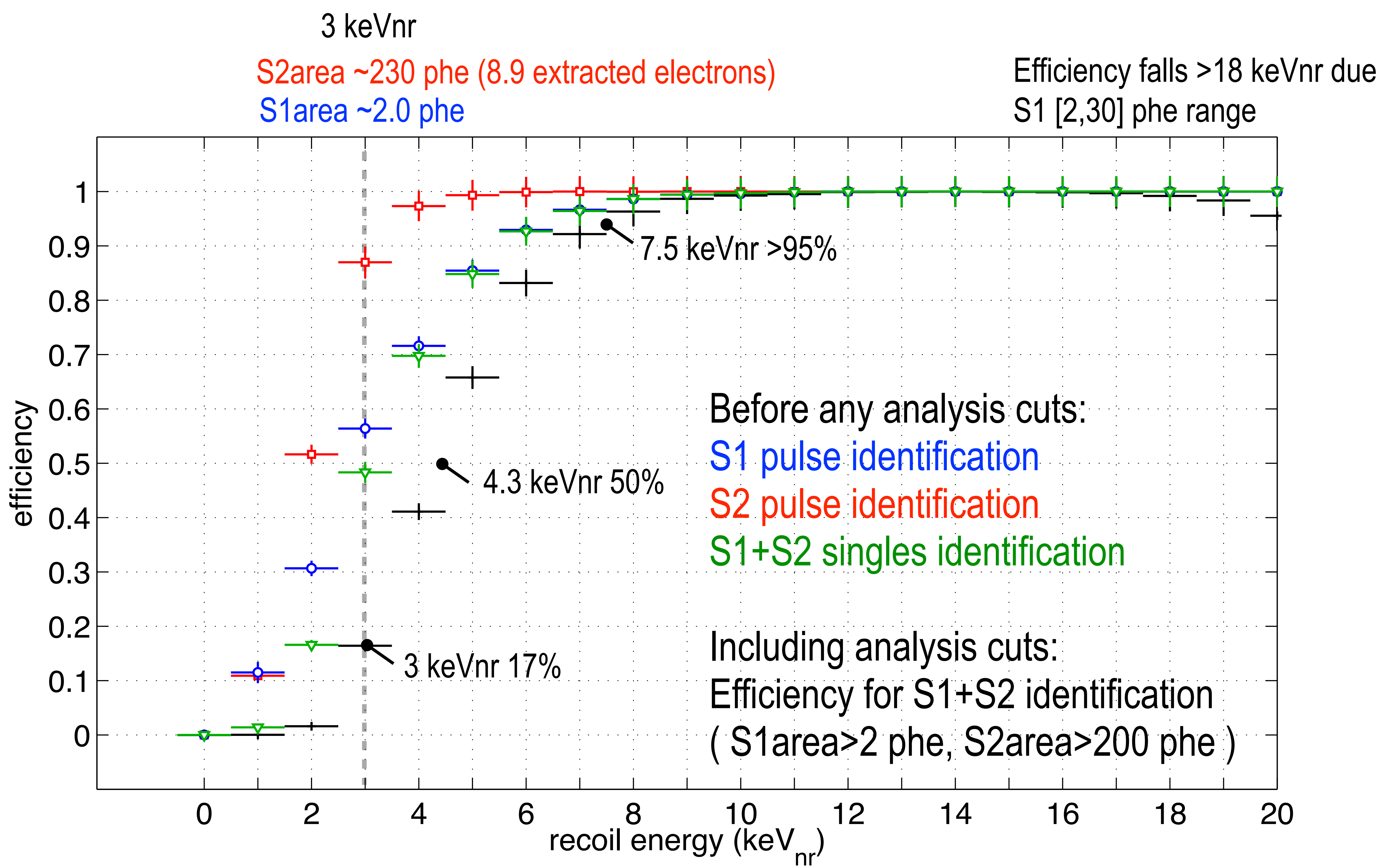

**Total mass in the fiducial volume 118 kg**

# Single Scatterer Efficiency for WIMP Detection

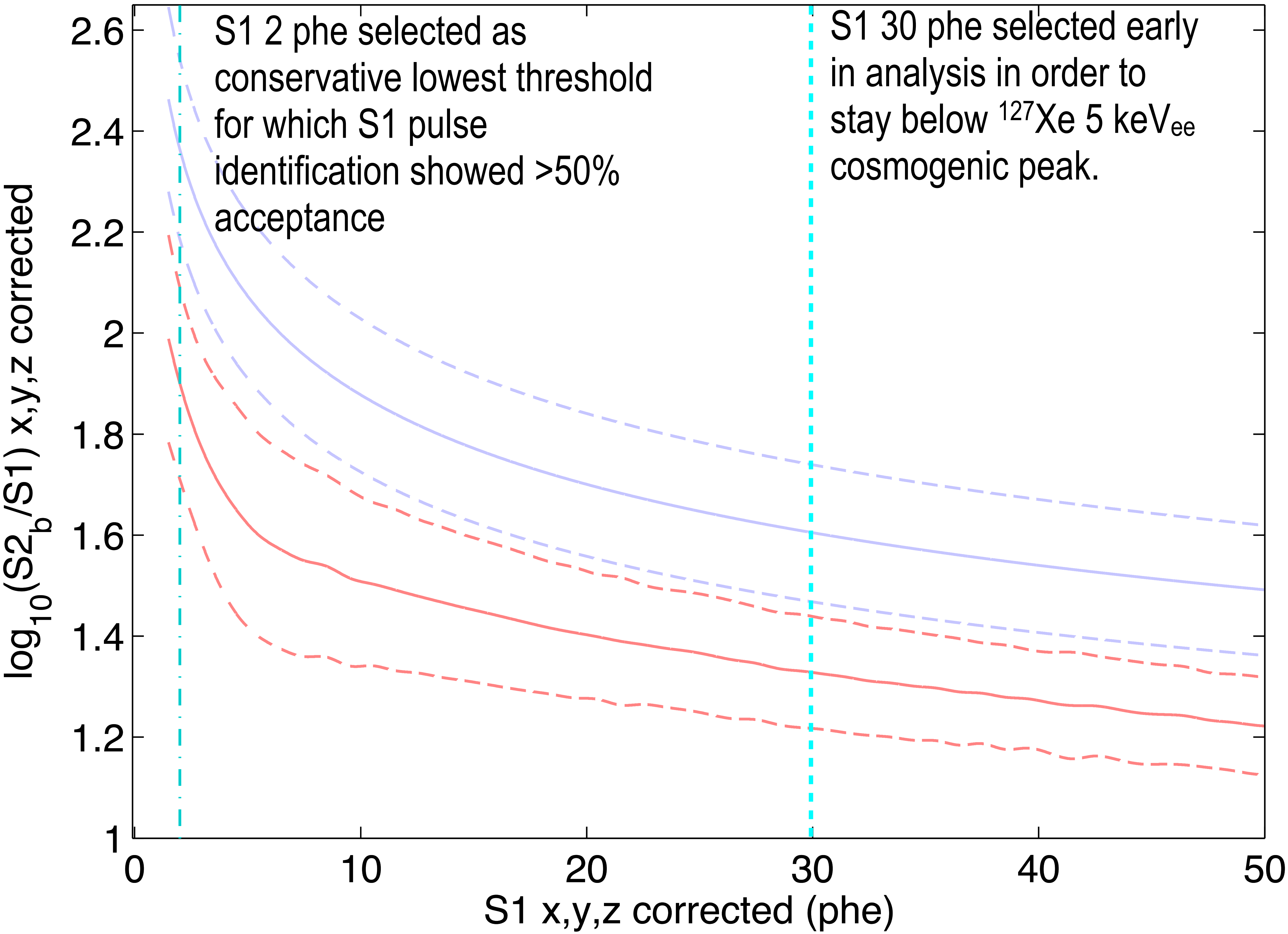
- **S1 efficiency studied using**
  - **Calibration with neutrons ($^{241}$AmBe e $^{252}$Cf)**
  - **Tritium calibration**
  - **Full MC simulation**



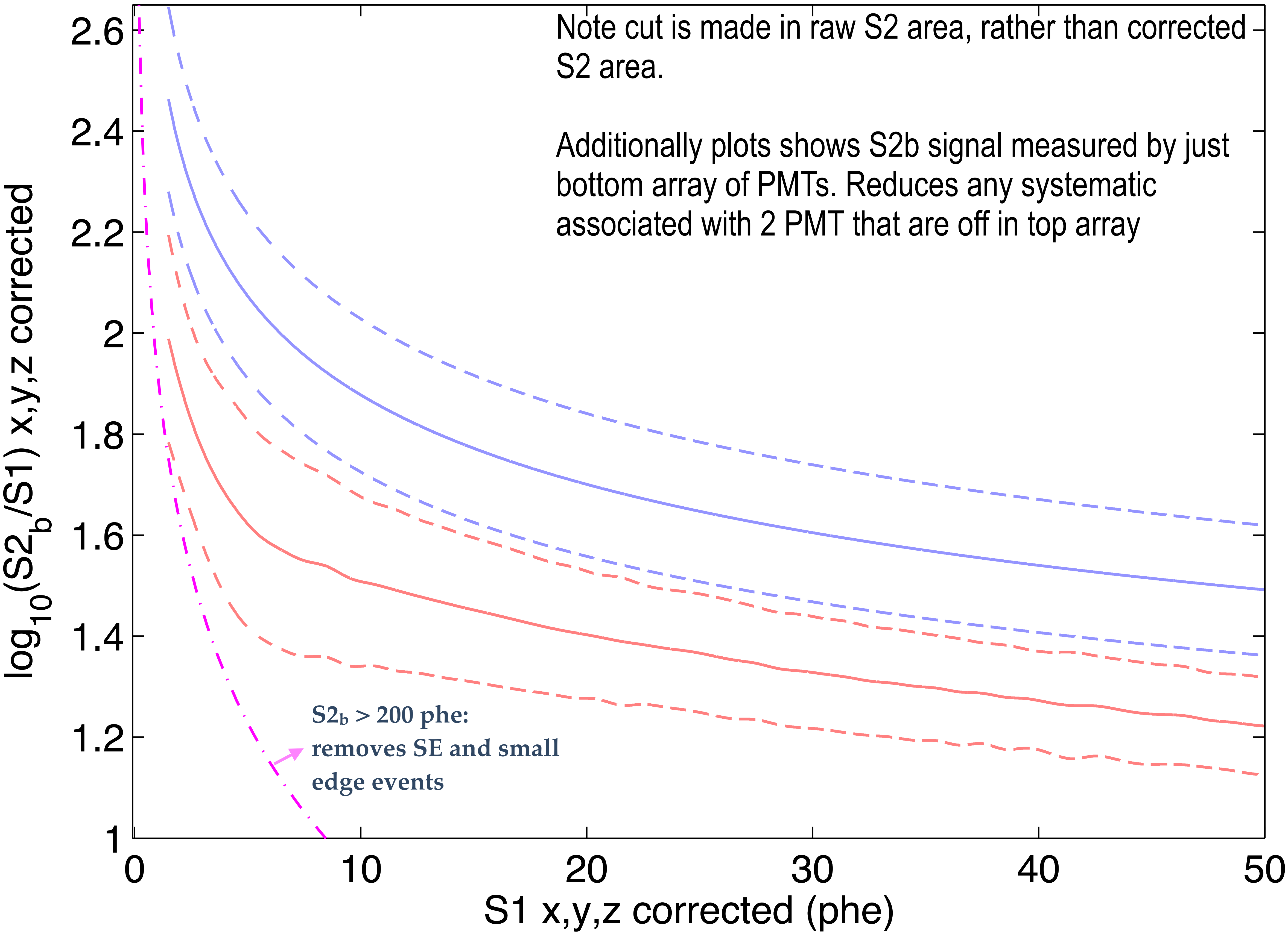
# WIMP Detection Efficiency - True Recoil Energy

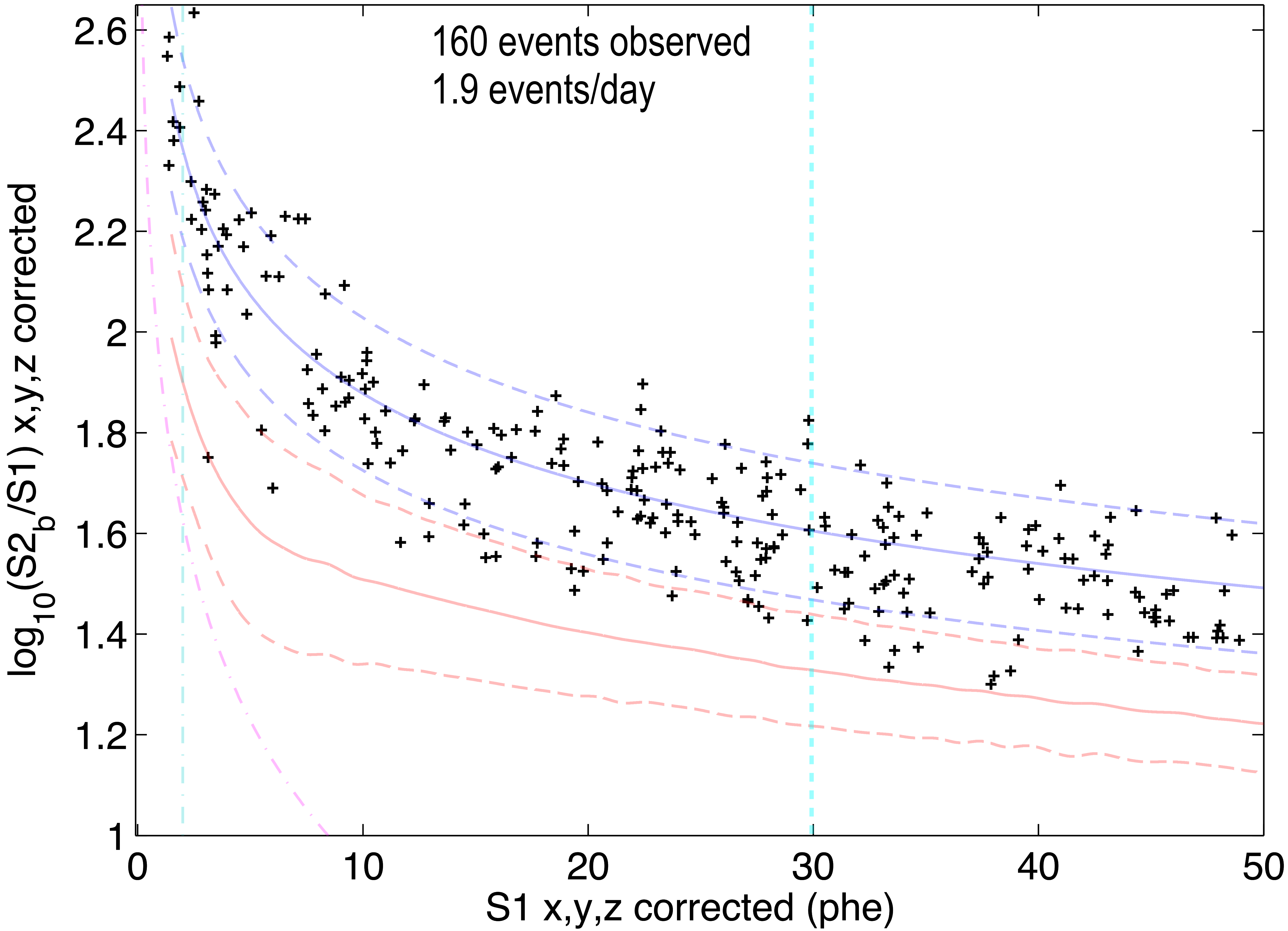


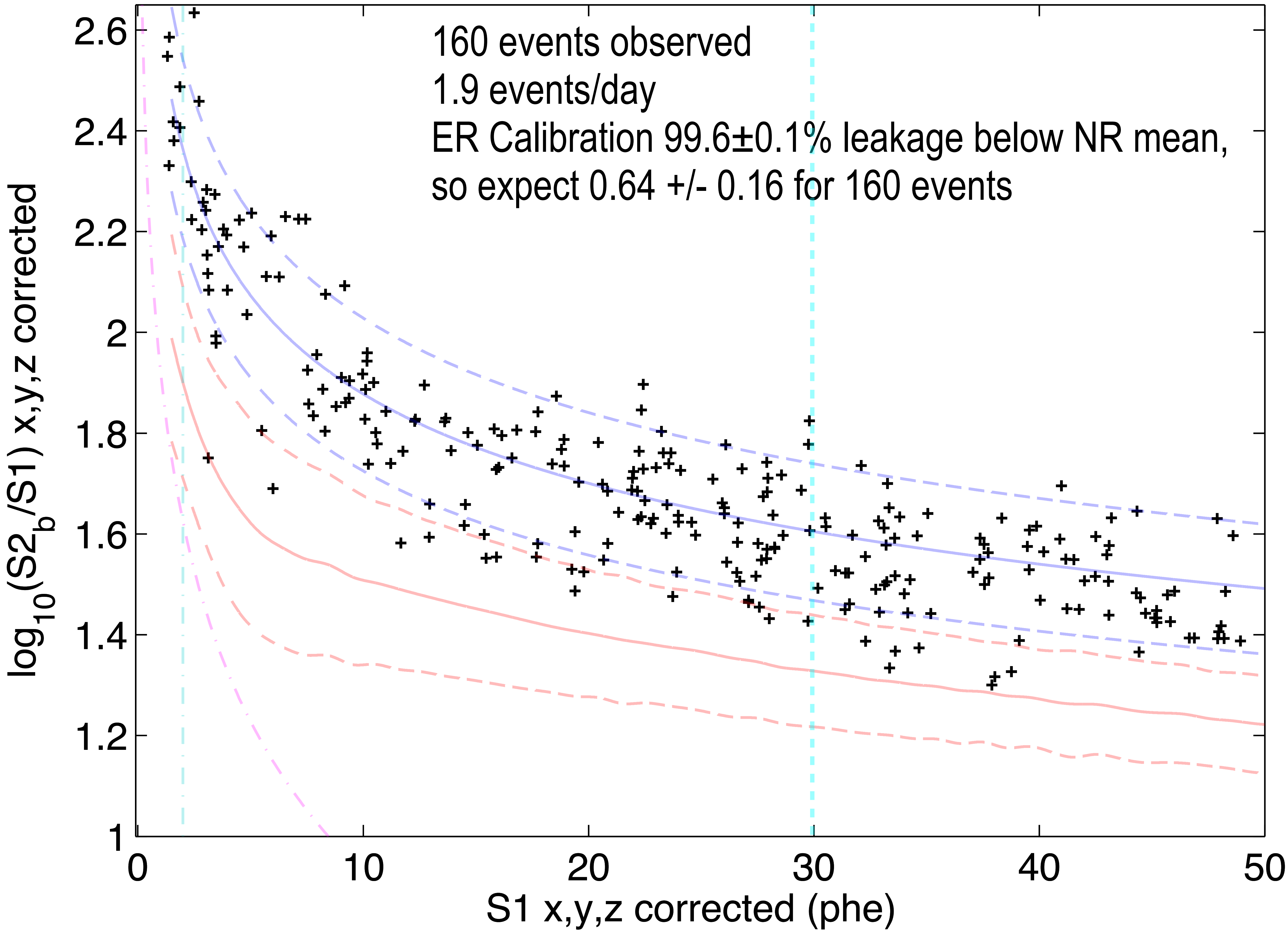

True Recoil Energy equivalence based on LUX 2013 Neutron Calibration/NEST Model



S1 2 phe selected as conservative lowest threshold for which S1 pulse identification showed >50% acceptance
S1 30 phe selected early in analysis in order to stay below $^{127}Xe$ 5 $keV_{ee}$ cosmogenic peak.
$\log_{10}(S2_b/S1)$ x,y,z corrected
S1 x,y,z corrected (phe)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50

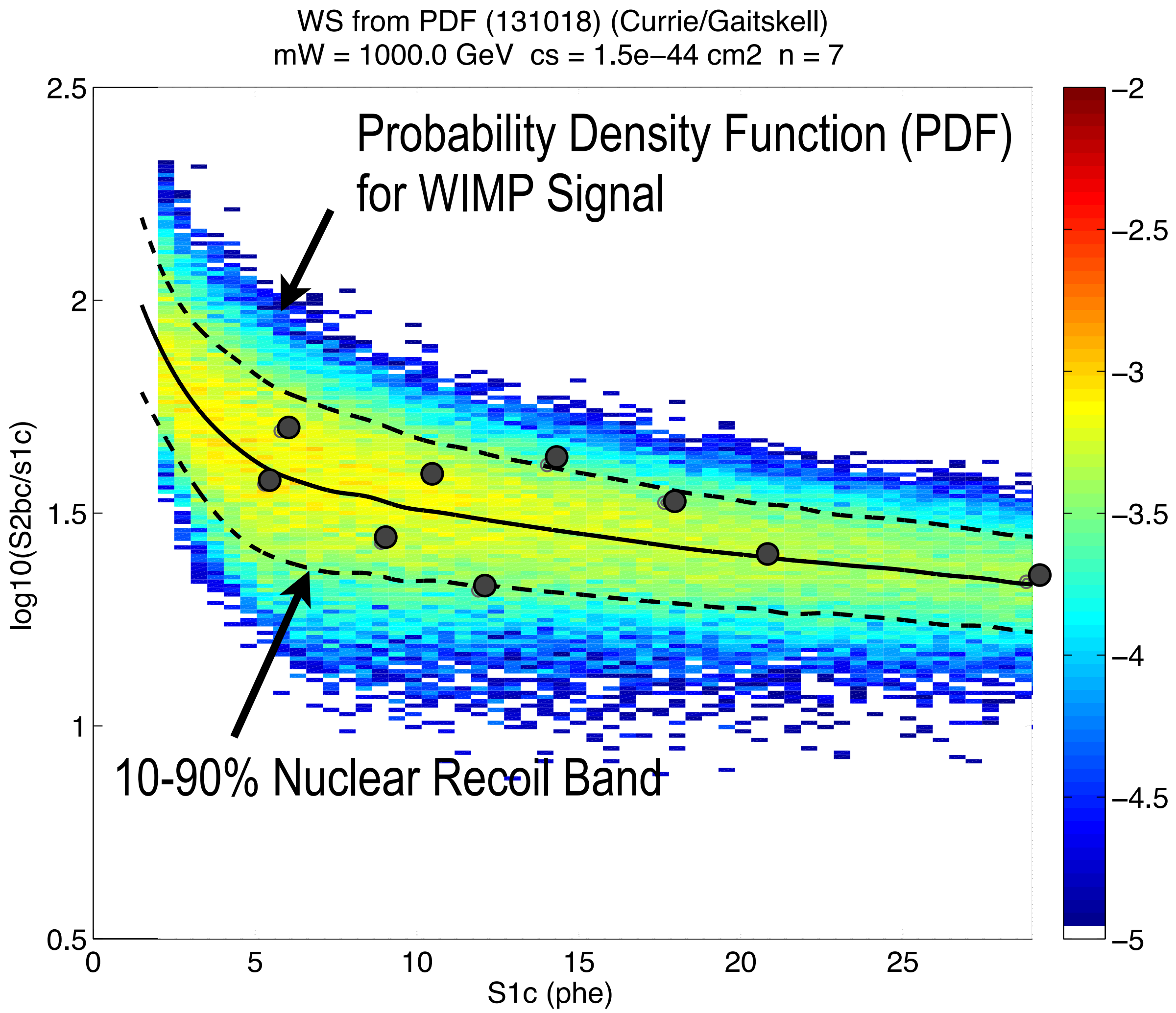

Note cut is made in raw S2 area, rather than corrected S2 area.
Additionally plots shows S2b signal measured by just bottom array of PMTs. Reduces any systematic associated with 2 PMT that are off in top array
S2b > 200 phe:
removes SE and small edge events
log10(S2b/S1) x,y,z corrected
S1 x,y,z corrected (phe)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50

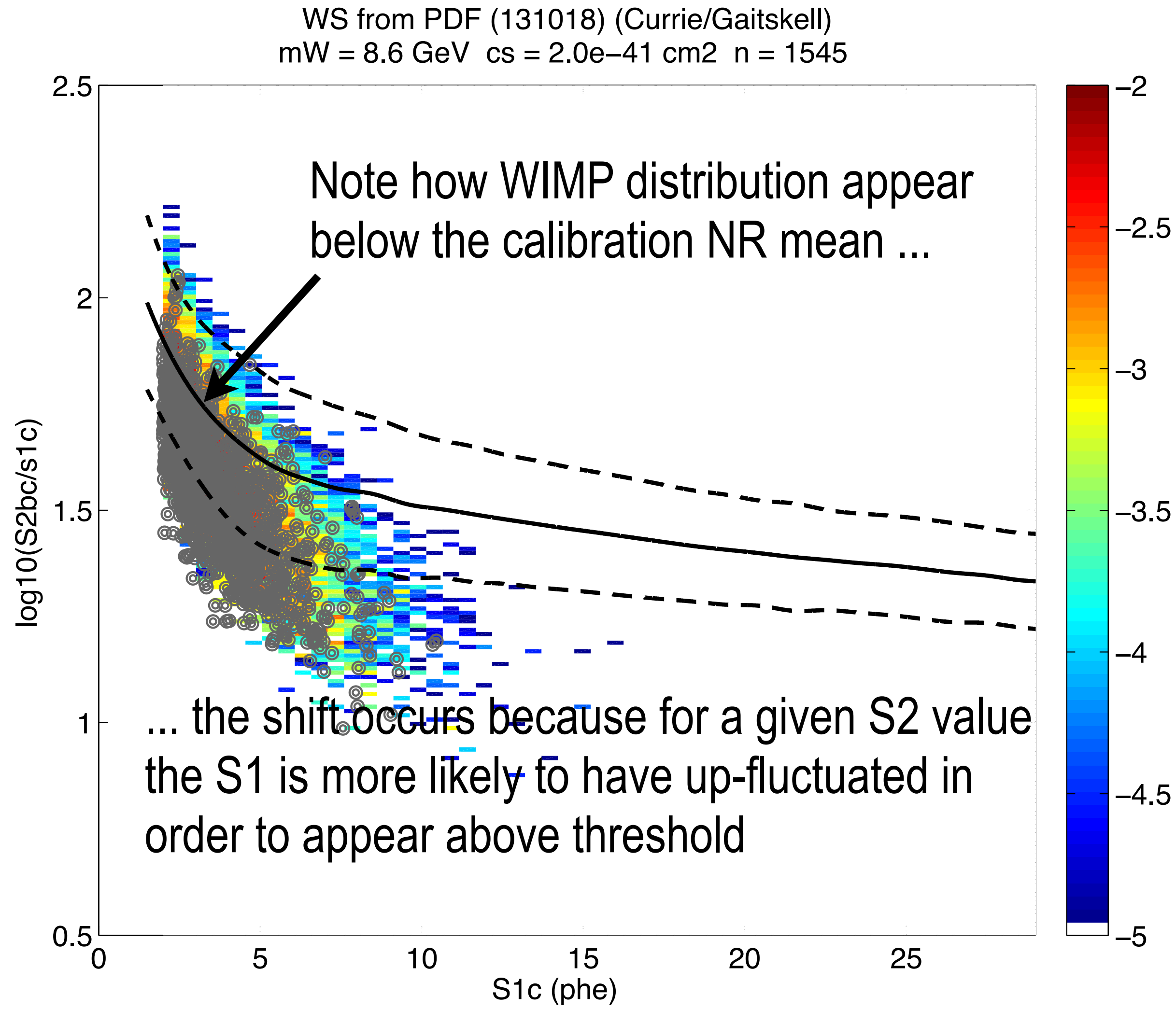

160 events observed
1.9 events/day
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50
log10(S2b/S1) x,y,z corrected
S1 x,y,z corrected (phe)


160 events observed
1.9 events/day
ER Calibration 99.6±0.1% leakage below NR mean,
so expect 0.64 +/- 0.16 for 160 events
log10(S2b/S1) x,y,z corrected
S1 x,y,z corrected (phe)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50

# Simulated Response for Hypothetical WIMP Signals

- For a 1000 GeV WIMP and cross section at the existing XENON100 90% CL Sensitivity $1.9 \times 10^{-44}$ cm$^2$
  - expect 9 WIMPs in LUX search
- For 8.6 GeV WIMP at $2.0 \times 10^{-41}$ cm$^2$, CDMS II Si (2012) 90% CL:
  - expect 1550 WIMPs in LUX search




**PDF assumes Standard Milky Way Halo parameters as described in Savage, Freese, Gondolo (2006) $v_0$=220 km/s, $v_{escape}$ = 544 km/s, $\rho_0$ = 0.3 GeV/c$^2$, $v_{earth}$ = 245 km/s.**

# Setting the Limit

- **Use of Profile Likelihood Ratio (PLR)**
  - **we don't have to draw acceptance boxes avoiding potential bias in data analysis from selecting regions in S1,S2 signal-space.**

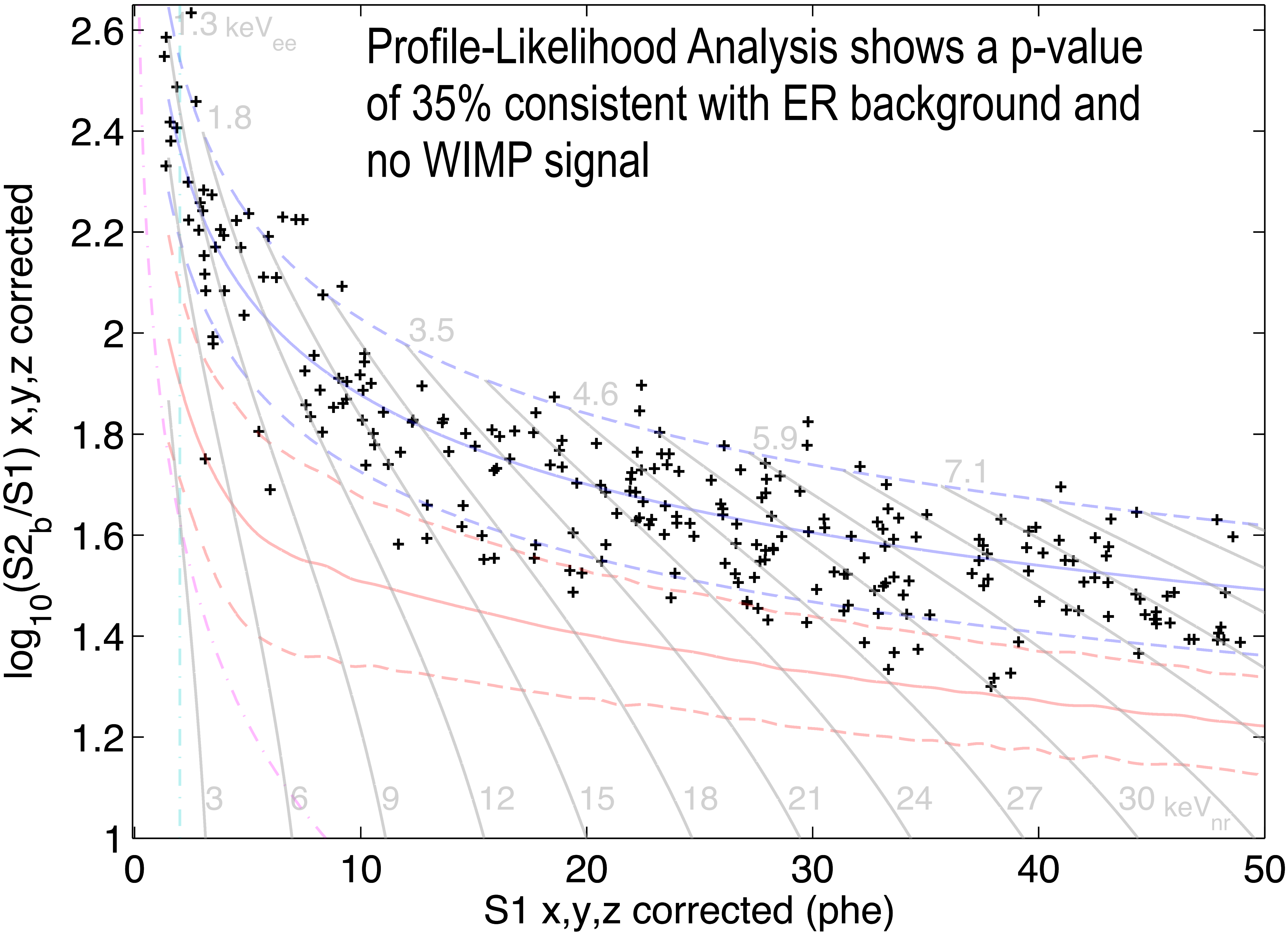
Fixed point to test

Nuisance parameters, not fixed

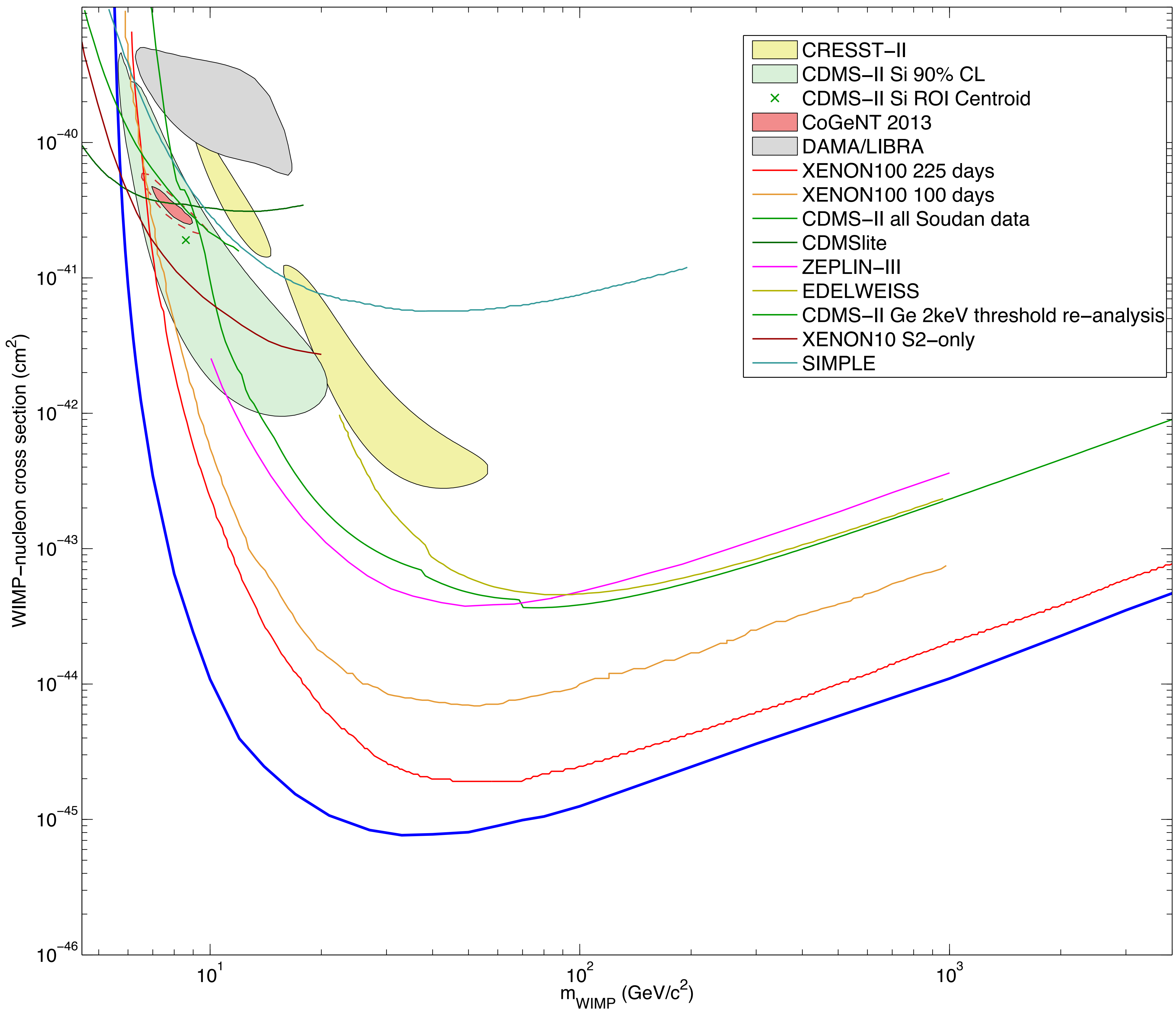
$$q_\sigma \equiv -2\log\left[\frac{\mathcal{L}\left(\sigma_{\rm test},\hat{\hat{\boldsymbol{\theta}}}\right)}{\mathcal{L}\left(\hat{\sigma},\hat{\boldsymbol{\theta}}\right)}\right]$$

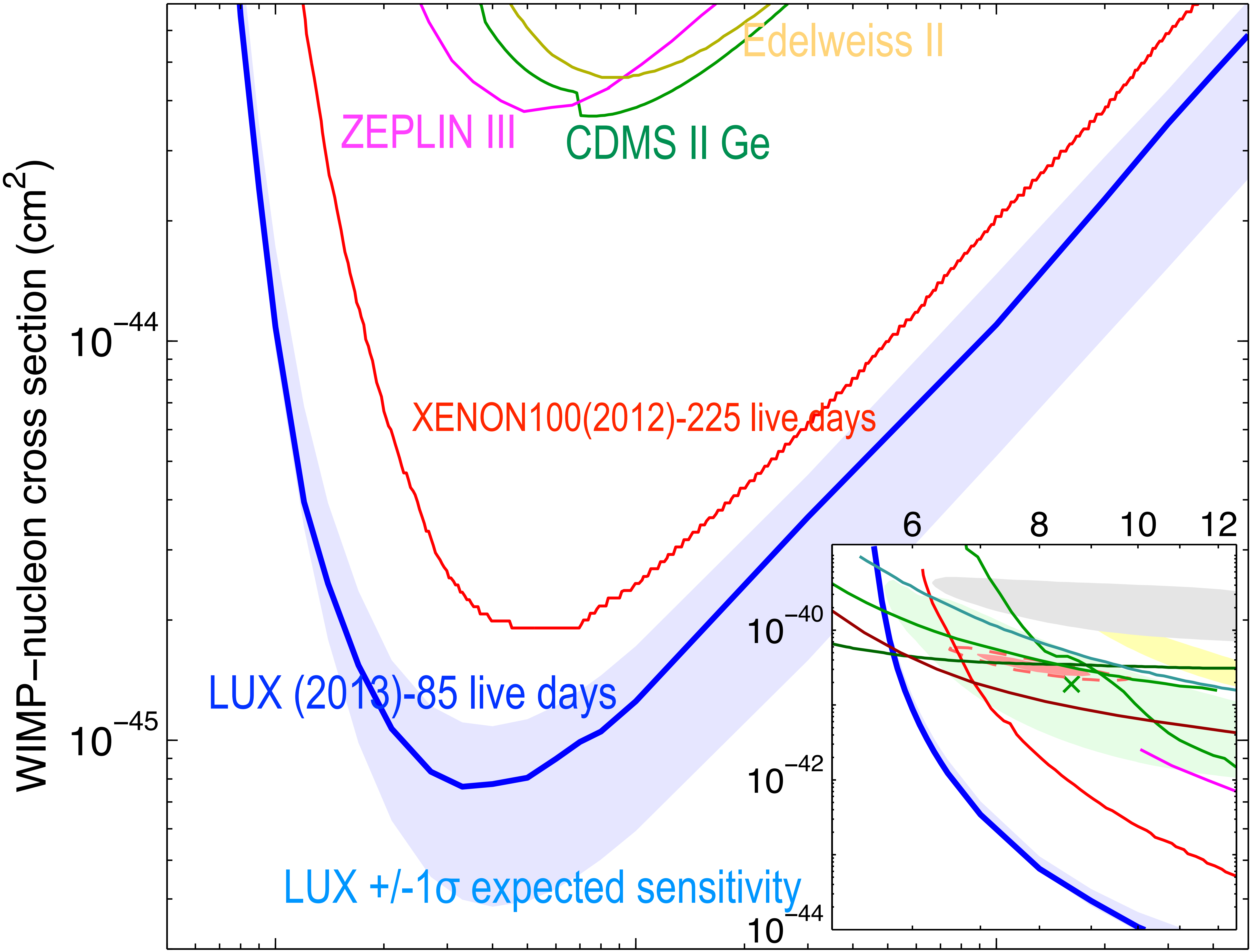
Value of maximum likelihood

- **Generate pseudo-experiments for $\sigma_{test}$, compare the value of test statistic in data with the value of $q_{\sigma,i}$ from each pseudo-experiment and from that get the p-value.**

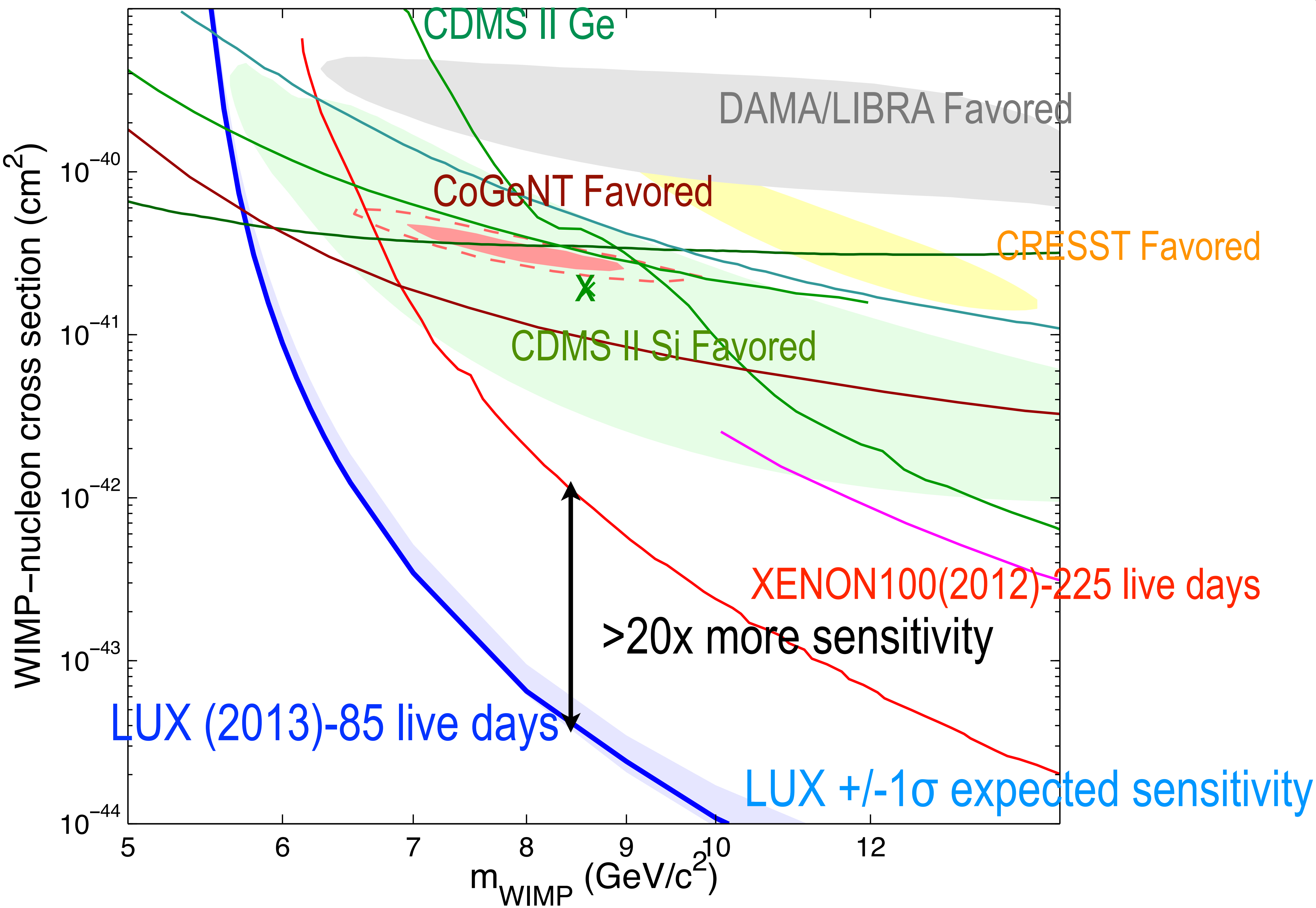

1.3 keVee
1.8
3.5
4.6
5.9
7.1
3
6
9
12
15
18
21
24
27
30 keVnr
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50
log10(S2b/S1) x,y,z corrected
S1 x,y,z corrected (phe)
Profile-Likelihood Analysis shows a p-value of 35% consistent with ER background and no WIMP signal

# Spin-Independent Sensitivity Plots



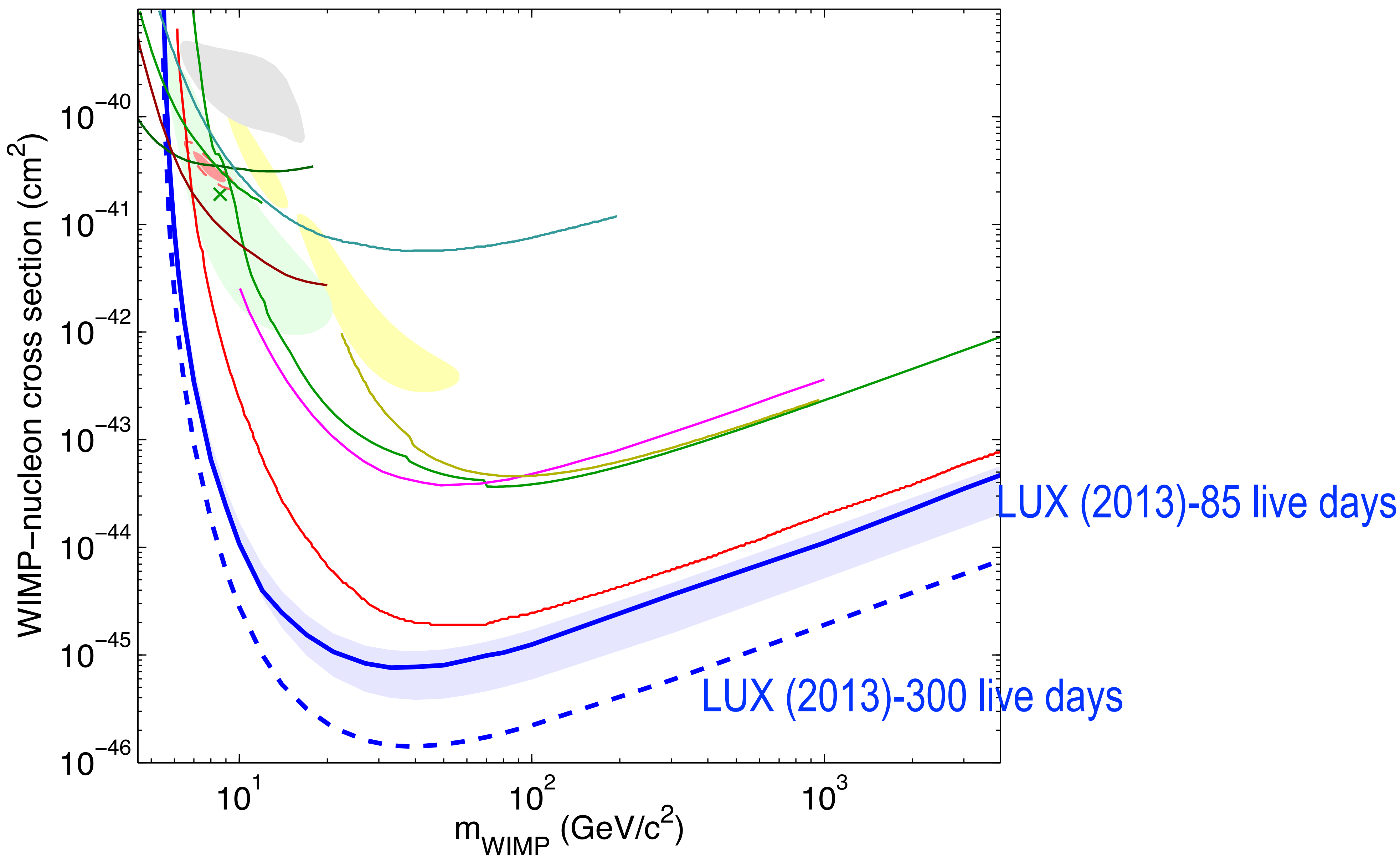


WIMP–nucleon cross section (cm$^2$)
$10^{-44}$
$10^{-45}$
Edelweiss II
ZEPLIN III
CDMS II Ge
XENON100(2012)-225 live days
LUX (2013)-85 live days
LUX +/-1σ expected sensitivity
6
8
10
12
$10^{-40}$
$10^{-42}$
$10^{-44}$




**Low-mass WIMPs fully excluded**

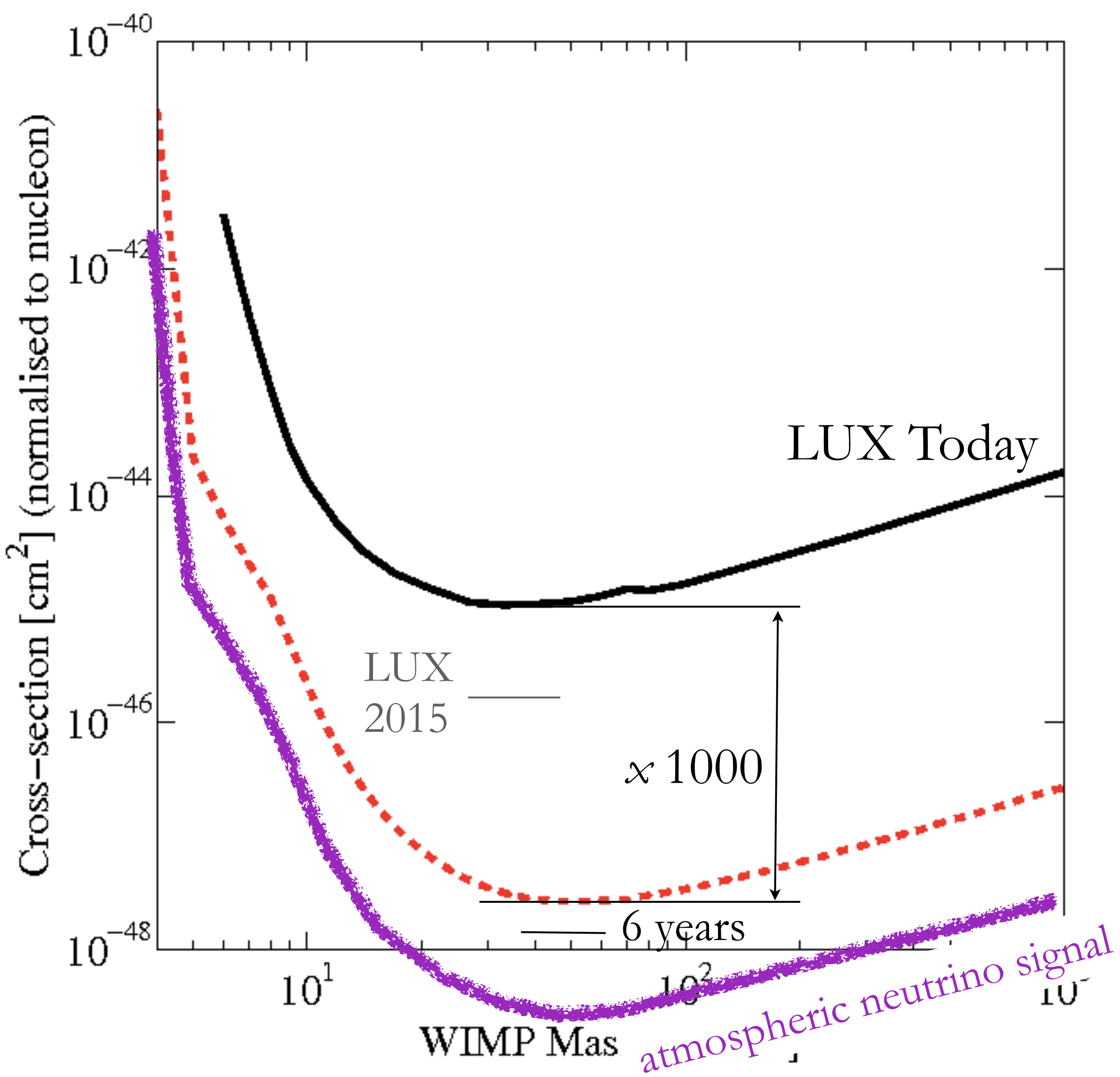
# LUX 300 DAY RUN



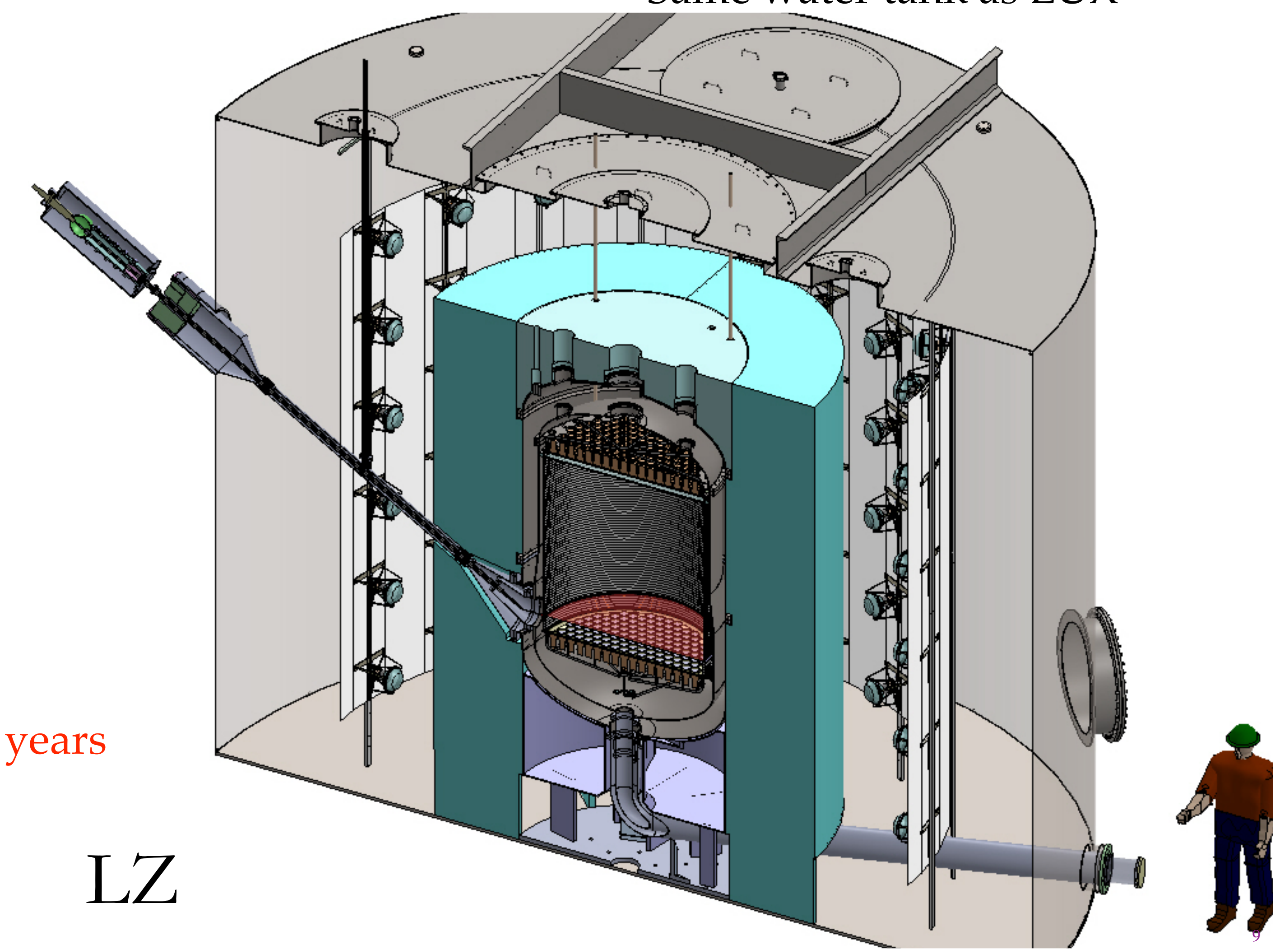

- 300 day run planned for 2014/2015
  - Still not background limited and expect factor of ~5 improvement in sensitivity → discovery possible
  - Potential for improvements to E fields/calibrations /reconstruction

# Longer Term: LUX-ZEPLIN (LZ)

- 20 times LUX Xenon mass, active scintillator veto, Xe purity at sub ppt level
- Ultimate direct detection experiment - approaches coherent neutrino scattering backgrounds
- Proposal for US down-select process end of Nov., decision expected Jan 2014
- If approved will be deployed Davis lab 2016+



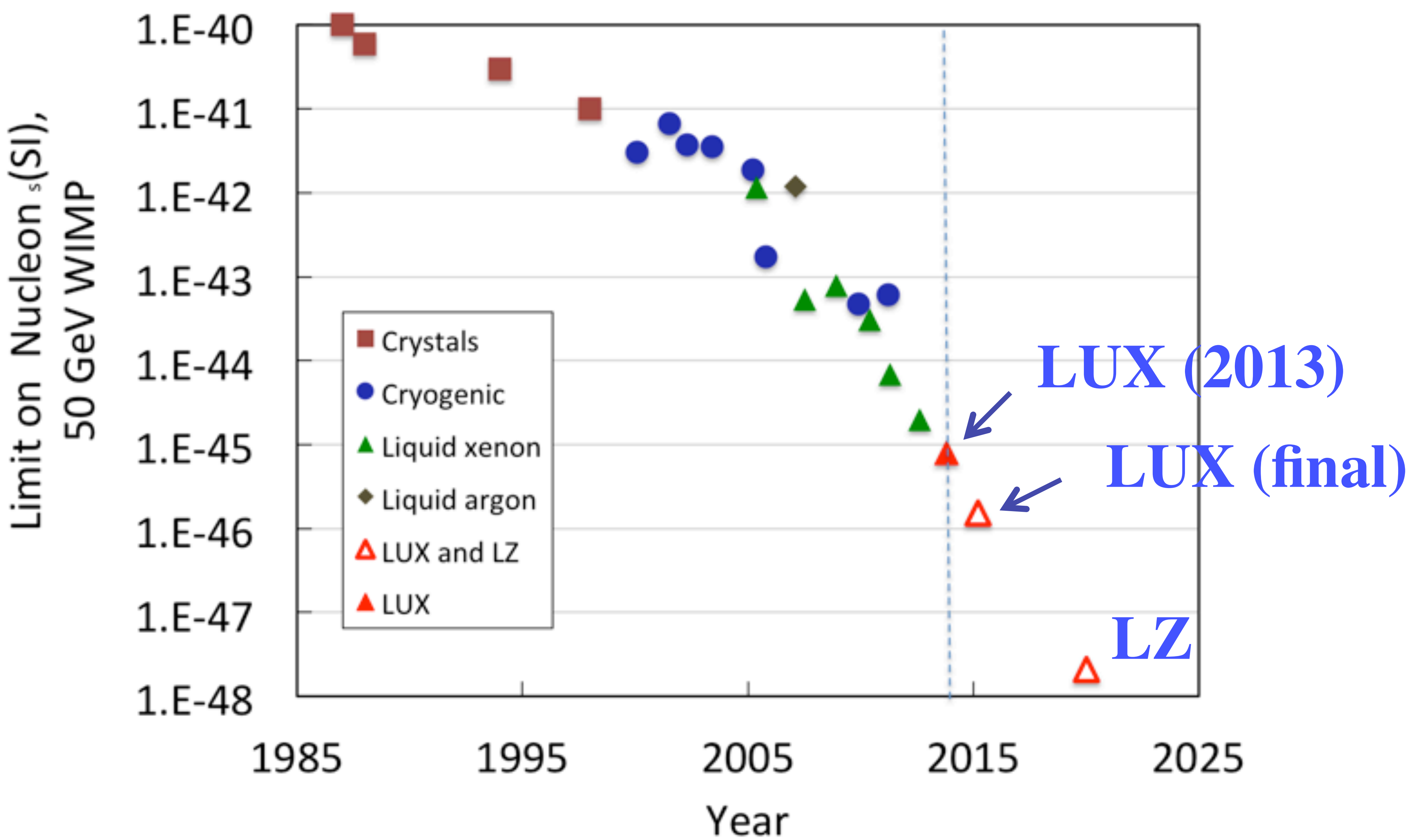

Same water tank as LUX



LZ

# Historical Progress in the Limits





# CONCLUSION

- LUX has made a WIMP Search run of 86 live-days and released the analysis within 9 months of first cooling in Davis Lab
  - 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 $keV_{nr}$ 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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Grazie!