# Search for Dark Matter with the LUX/LZ detectors

Mani Tripathi
*University of California, Davis*

AAPCOS
SINP, Kolkata
10/16/15

# Search for Dark Matter with the LUX/LZ detectors

Mani Tripathi
*University of California, Davis*

AAPCOS
SINP, Kolkata
10/16/15

# Search for Dark Matter with the LUX/LZ detectors

Mani Tripathi
*University of California, Davis*

AAPCOS
SINP, Kolkata
10/16/15

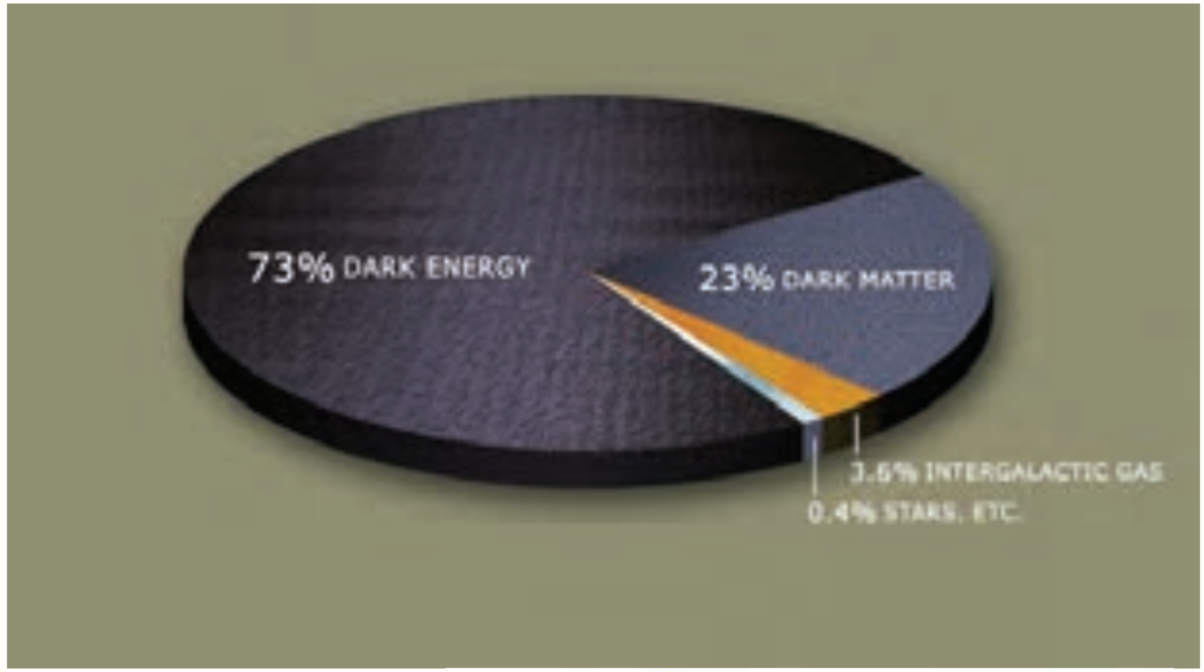
# Outline

1. The Dark Matter problem
2. Direct detection of DM in a laboratory
3. Two-phase Xenon Time Projection Chambers
4. Updated calibrations of the LUX detector
5. The future: LZ program

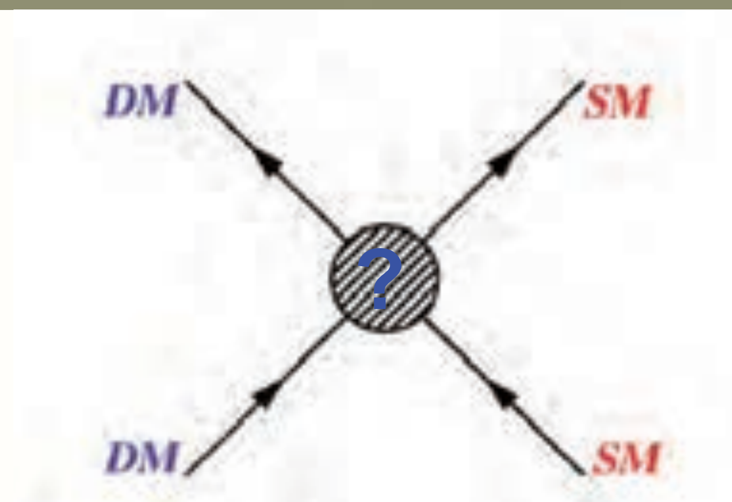
# The Dark Matter Problem

A good problem to have. There is a known effect looking for an answer … as opposed to a known solution looking for an experimental effect.

A real challenge for experimentalists to study this known energy density.




- Postulate 1: DM is a particle.
- Postulate 2: DM and SM particles interact with some force that is very weak but <u>much</u> stronger than gravity.



# WIMP Miracle

1. Flat region. Constant density. Equal production and annihilation.
$n_{eq} \sim T^3$

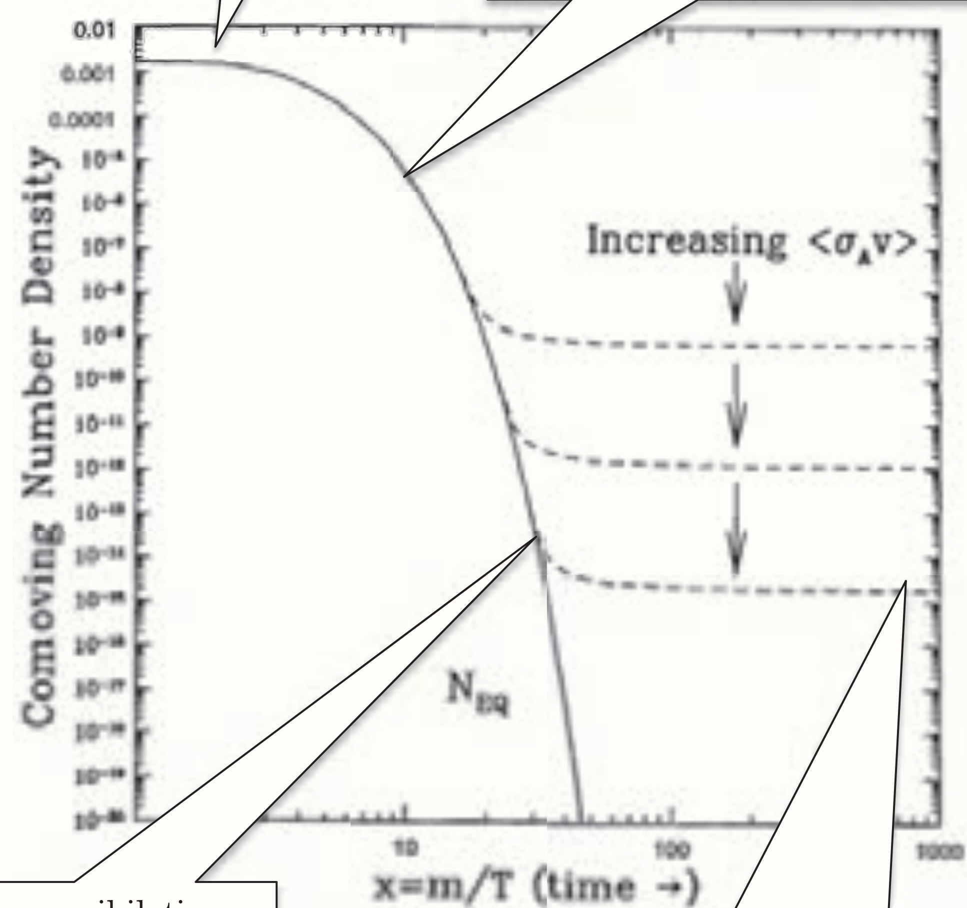
2. Exponential suppression as temperature falls below mass of dark matter particle.

$n_{eq} \sim (m/T)^{3/2} e^{-m/T}$

A happy coincidence implied that new physics at the TeV scale with appropriately weak cross section leads to a dark matter relic (with a new quantum number preventing decay).

$$\Omega_x h^2 = \frac{3 \cdot 10^{-27} cm^3 / s}{\langle \sigma_A v \rangle} \approx 0.12$$

$$\Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$



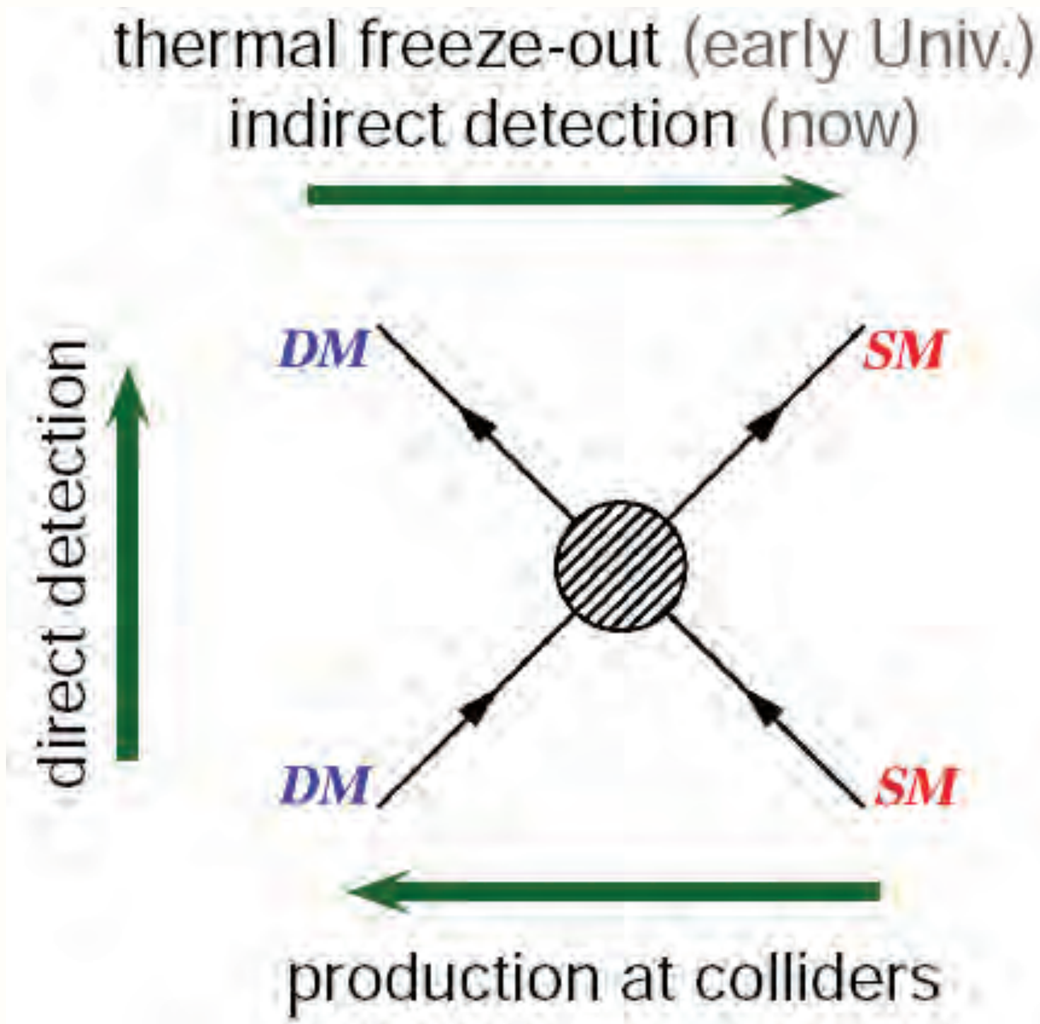

3. Turn over as annihilation rate decreases, becoming smaller than the expansion rate.

4. Relic abundance remains. Larger cross-sections keep annihilations occurring for longer.

# Detection Techniques

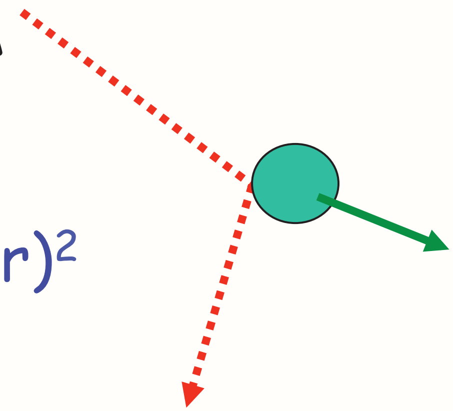
- Three major categories of investigations.

- Important to maintain the theoretical connection between these approaches.



# Direct Detection

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



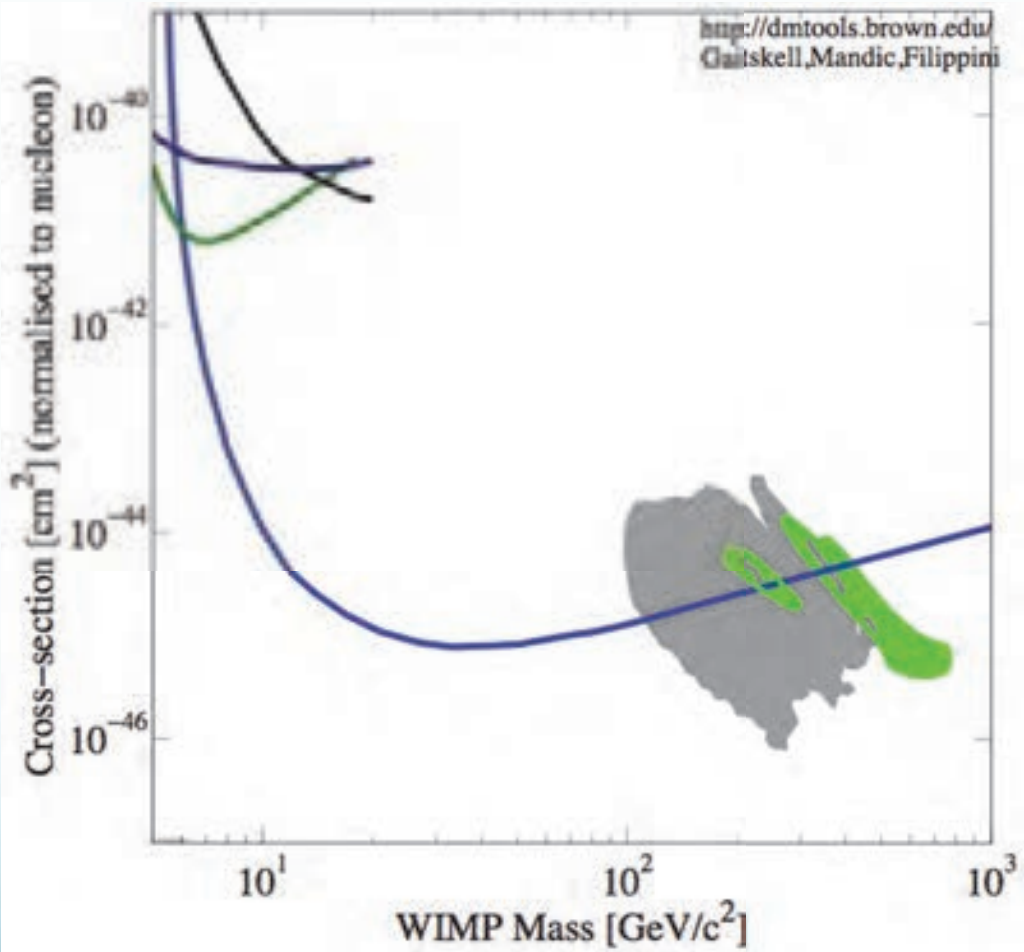
Simple dynamics. Cross section $\alpha$ (form factor)$^2$

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

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

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

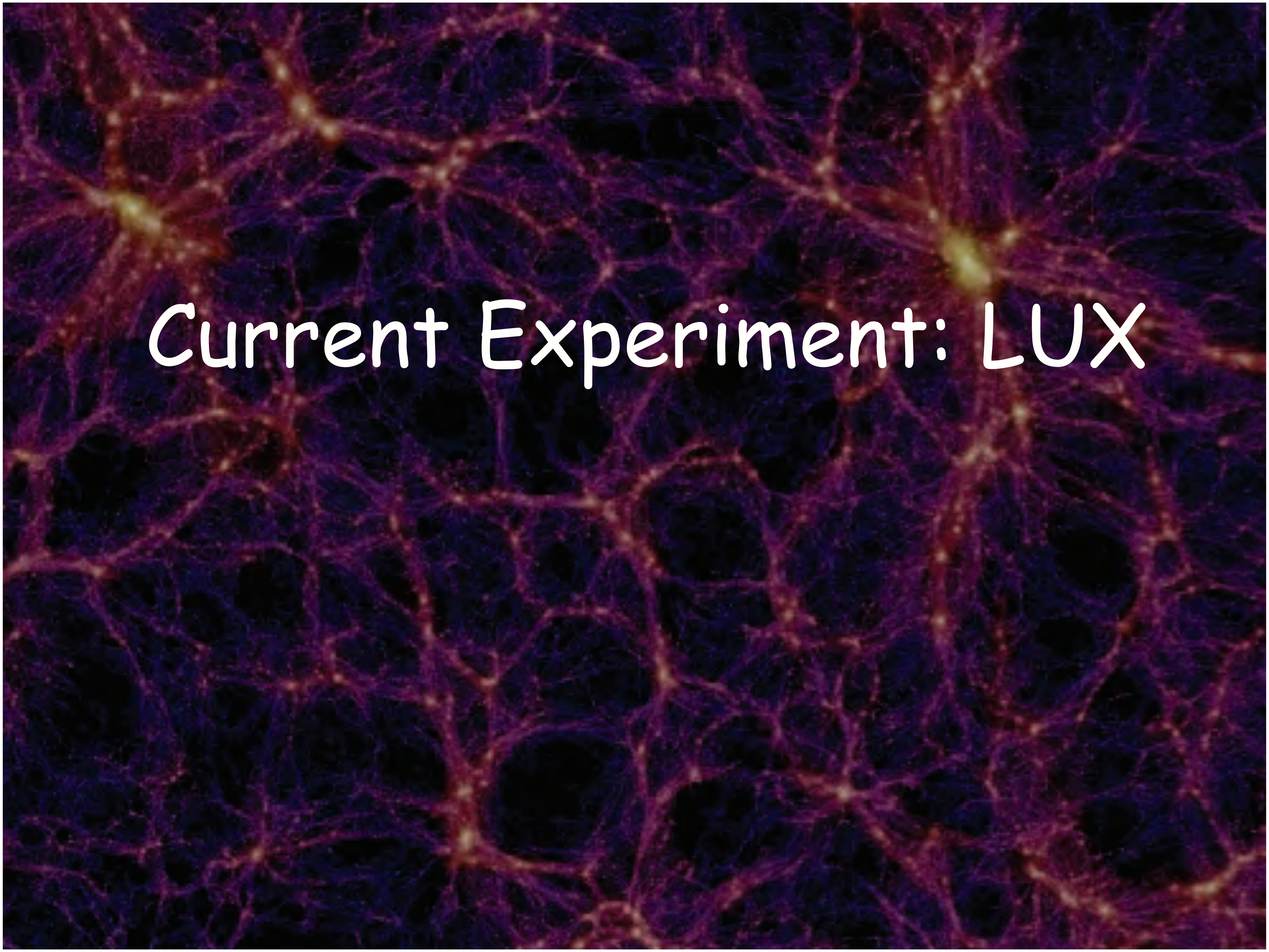
# Time Progression of Sensitivity




Years 2000-2013

Animation courtesy of Aaron Manalaysay, UC Davis

# Current Experiment: LUX



# The LUX Collaboration

### Brown

| | |
|---|---|
| **Richard Gaitskell** | PI, Professor |
| **Simon Fiorucci** | Research Associate |
| **Samuel Chung Chan** | Graduate Student |
| **Dongqing Huang** | Graduate Student |
| **Casey Rhyne** | Graduate Student |
| **Will Taylor** | Graduate Student |
| **James Verbus** | Graduate Student |

### Imperial College London

| | |
|---|---|
| **Henrique Araujo** | PI, Reader |
| **Tim Sumner** | Professor |
| **Alastair Currie** | Postdoc |
| **Adam Bailey** | Graduate Student |
| **Khadeeja Yazdani** | Graduate Student |

### Lawrence Berkeley + UC Berkeley

| | |
|---|---|
| **Bob Jacobsen** | PI, Professor |
| **Murdock Gilchriese** | Senior Scientist |
| **Kevin Lesko** | Senior Scientist |
| **Peter Sorensen** | Scientist |
| **Victor Gehman** | Scientist |
| **Attila Dobi** | Postdoc |
| **Daniel Hogan** | Graduate Student |
| **Mia Ihm** | Graduate Student |
| **Kate Kamdin** | Graduate Student |
| **Kelsey Oliver-Mallory** | Graduate Student |

### Lawrence Livermore

| | |
|---|---|
| **Adam Bernstein** | PI, Leader of Adv. Detectors Grp. |
| **Kareem Kazkaz** | Staff Physicist |
| **[illegible]enardo** | Graduate Student |

### LIP Coimbra

| | |
|---|---|
| **Isabel Lopes** | PI, Professor |
| **Jose Pinto da Cunha** | Assistant Professor |
| **Vladimir Solovov** | Senior Researcher |
| **Francisco Neves** | Auxiliary Researcher |
| **Alexander Lindote** | Postdoc |
| **Claudio Silva** | Postdoc |

### SLAC Nation Accelerator Laboratory

| | |
|---|---|
| **Dan Akerib** | PI, Professor |
| **Thomas Shutt** | PI, Professor |
| **Kim Palladino** | Project Scientist |
| **Tomasz Biesiadzinski** | Research Associate |
| **Christina Ignarra** | Research Associate |
| **Wing To** | Research Associate |
| **Rosie Bramante** | Graduate Student |
| **Wei Ji** | Graduate Student |
| **T.J. Whitis** | Graduate Student |

### SD School of Mines

| | |
|---|---|
| **Xinhua Bai** | PI, Professor |
| **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 |
| **Paul Terman** | Graduate Student |

### University at Albany, SUNY

| | |
|---|---|
| **Matthew Szydagis** | PI, Professor |
| **Jeremy Mock** | Postdoc |
| **Steven Young** | Graduate Student |

### UC Davis

| | |
|---|---|
| **Mani Tripathi** | PI, Professor |
| **Britt Hollbrook** | Senior Engineer |
| **John Thmpson** | Development Engineer |
| **Dave Herner** | Senior Machinist |
| **Ray Gerhard** | Electronics Engineer |
| **Aaron Manalaysay** | Postdoc |
| **Scott Stephenson** | Postdoc |
| **Jacob Cutter** | Graduate Student |
| **James Morad** | Graduate Student |
| **Sergey Uvarov** | Graduate Student |

### UC Santa Barbara

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

### University College London

| | |
|---|---|
| **Chamkaur Ghag** | PI, Lecturer |
| **Sally Shaw** | Graduate Student |


### University of Edinburgh

| | |
|---|---|
| **Alex Murphy** | PI, Reader |
| **Paolo Beltrame** | Research Fellow |
| **James Dobson** | Postdoc |
| **Tom Davison** | Graduate Student |
| **Maria Francesca Marzioni** | Graduate Student |

### University of Maryland

| | |
|---|---|
| **Carter Hall** | PI, Professor |
| **Jon Balajthy** | Graduate Student |
| **Richard Knoche** | Graduate Student |

### University of Rochester

| | |
|---|---|
| **Frank Wolfs** | PI, Professor |
| **Wojtek Skutski** | Senior Scientist |
| **Eryk Druszkiewicz** | Graduate Student |
| **Dev Ashish Khaitan** | Graduate Student |
| **Mongkol Moongweluwan** | Graduate Student |

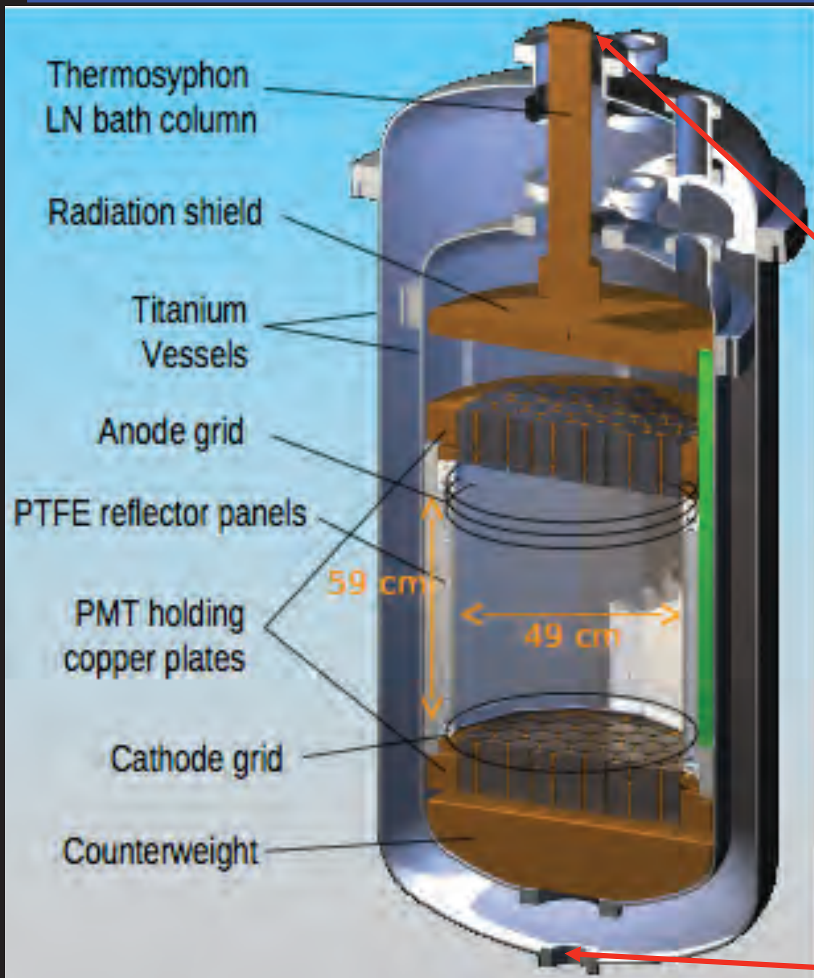
### University of South Dakota

| | |
|---|---|
| **Dongming Mei** | PI, Professor |
| **Chao Zhang** | Postdoc |
| **Angela Chiller** | Graduate Student |
| **Chris Chiller** | Graduate Student |

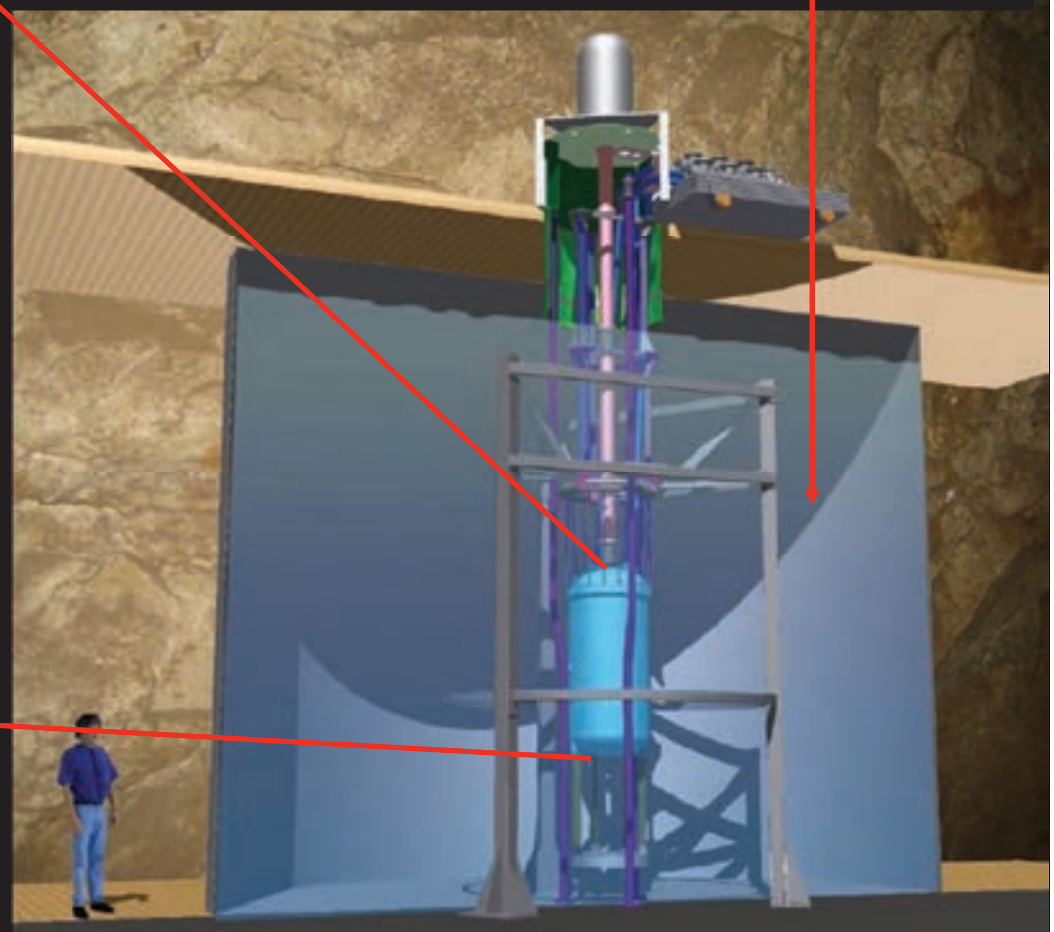
### Yale

| | |
|---|---|
| **Daniel McKinsey** | PI, Professor |
| **Ethan Bernard** | Research Scientist |
| **Markus Horn** | Research Scientist |
| **Blair Edwards** | Postdoc |
| **Scott Hertel** | Postdoc |
| **Kevin O'Sullivan** | Postdoc |
| **Elizabeth Boulton** | Graduate Student |
| **Nicole Larsen** | Graduate Student |
| **Evan Pease** | Graduate Student |
| **Brian Tennyson** | Graduate Student |
| **Lucie Tvrznikova** | Graduate Student |

# The LUX detector

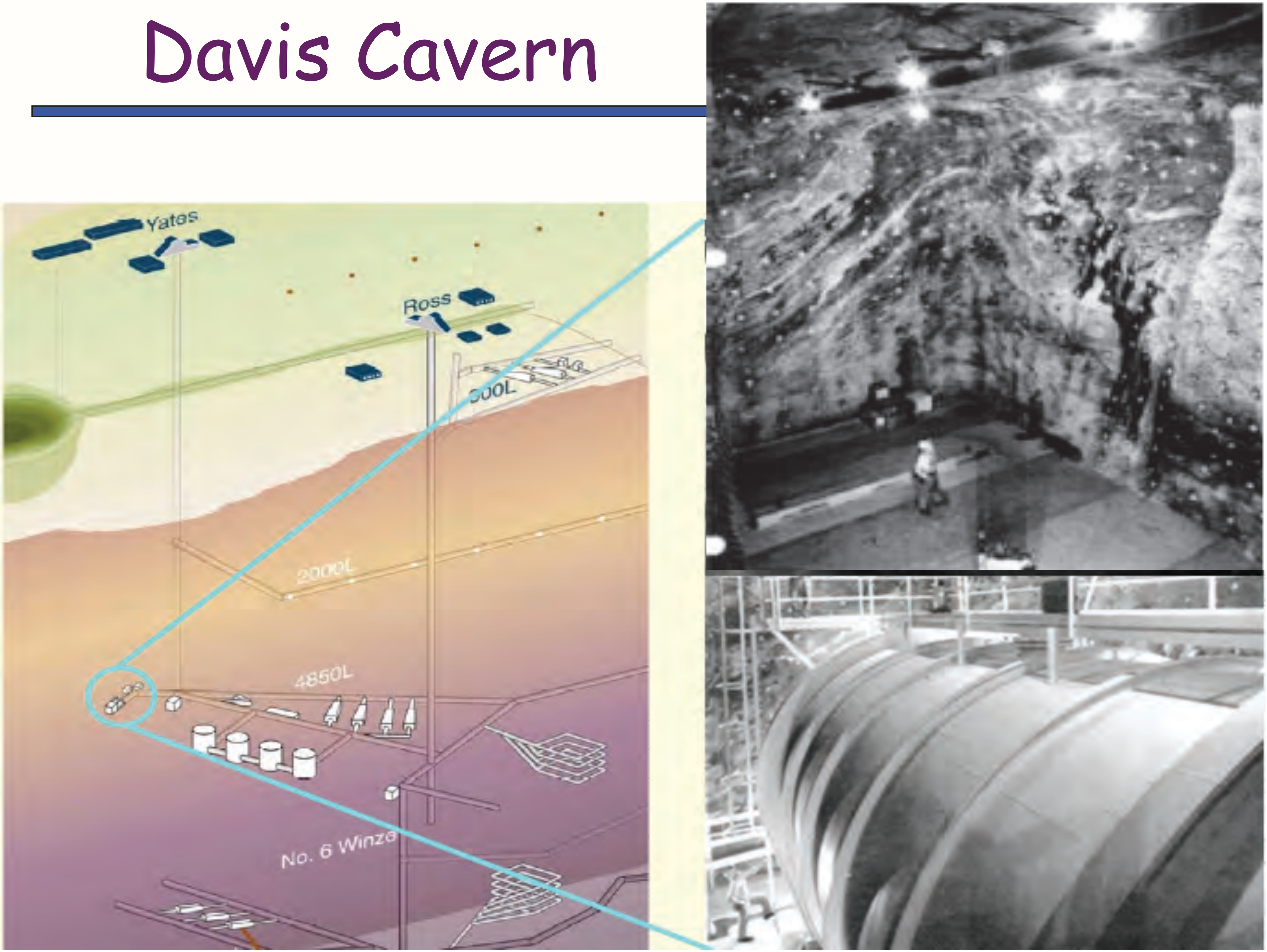



- ~ 7m diameter Water Cerenkov Shield.
- 48 cm H (gate to cathode) X 47 cm D active region with 181 V/cm drift field



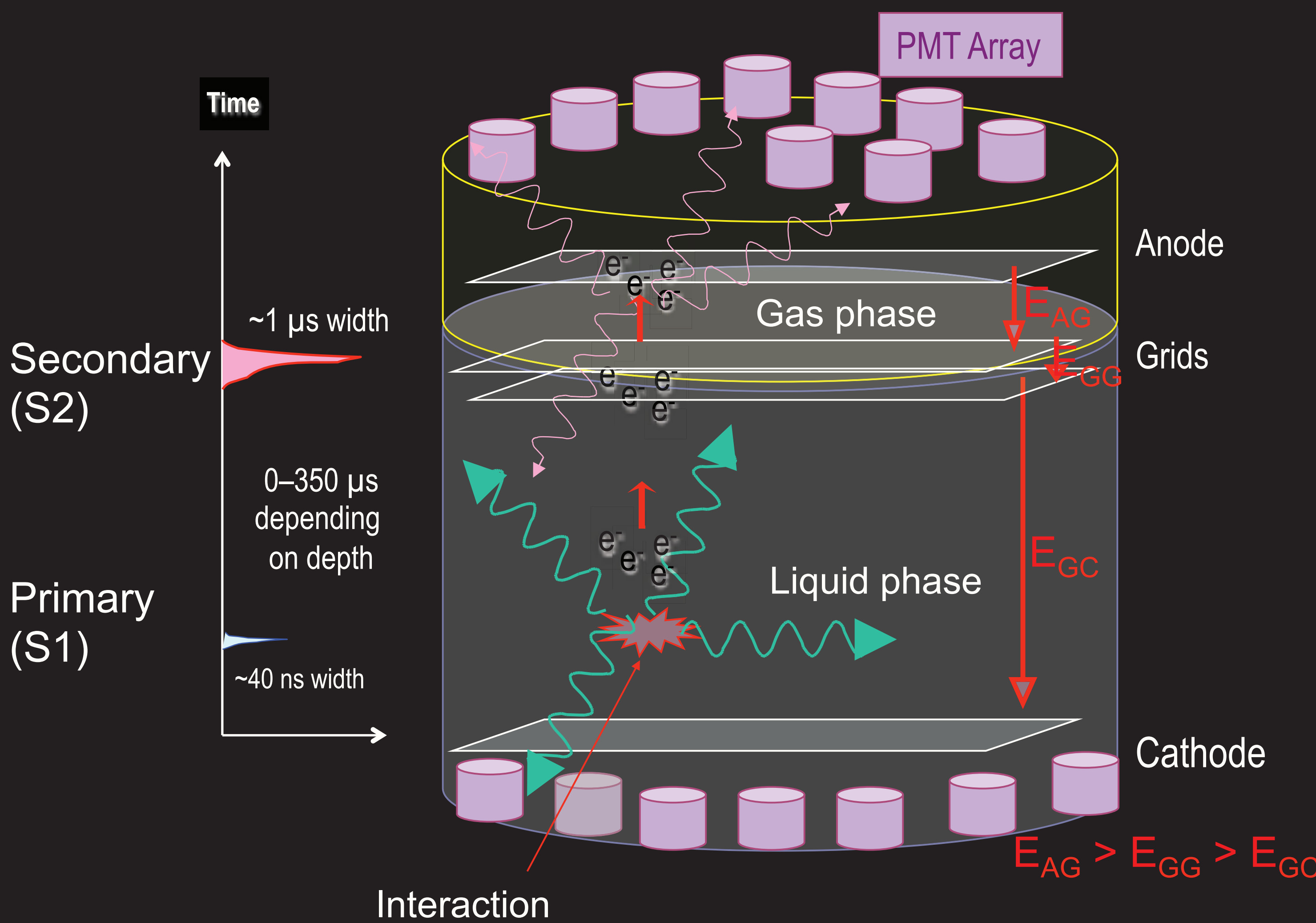
•250 kg (active), 118 kg (fiducial) of Lxe
•122 photomultiplier tubes (top plus bottom)

# Davis Cavern




Commissioned in 2012
First results in 2013

# Two Signal Technique



# Why Xenon?

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

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

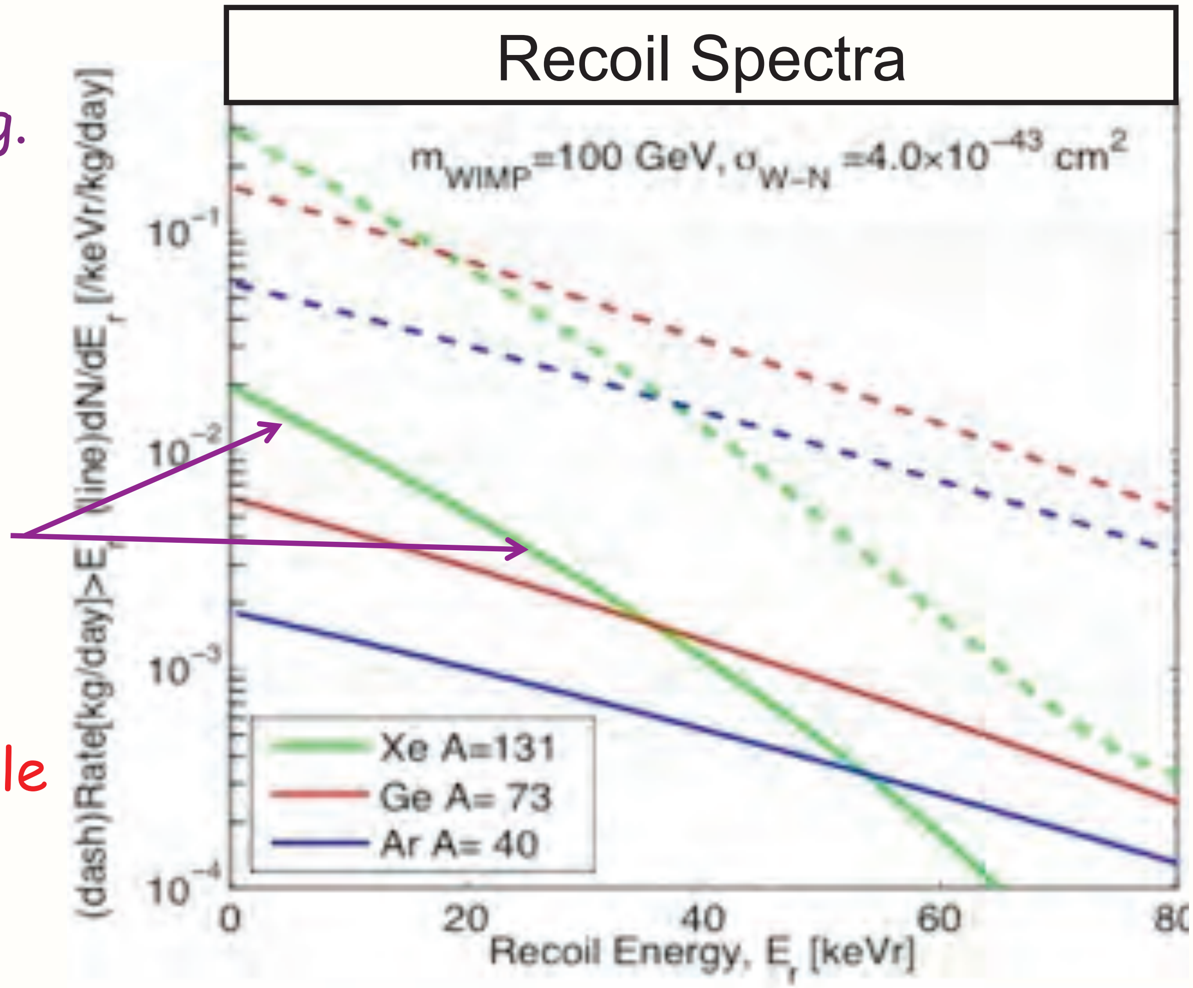
High density (~3g/$cm^3$)
=> Powerful self-shielding.

High A (131) => Large elastic $\sigma$

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

Long electron drift lengths (few m) => scalable

Efficient scintillator



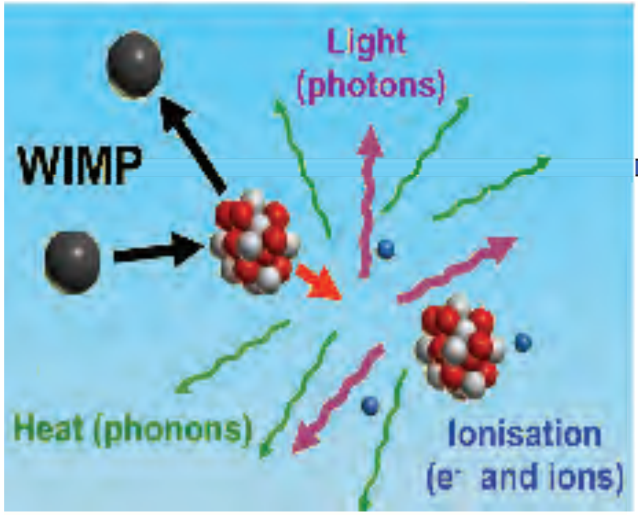
# Background Suppression

A large suppression of backgrounds required:

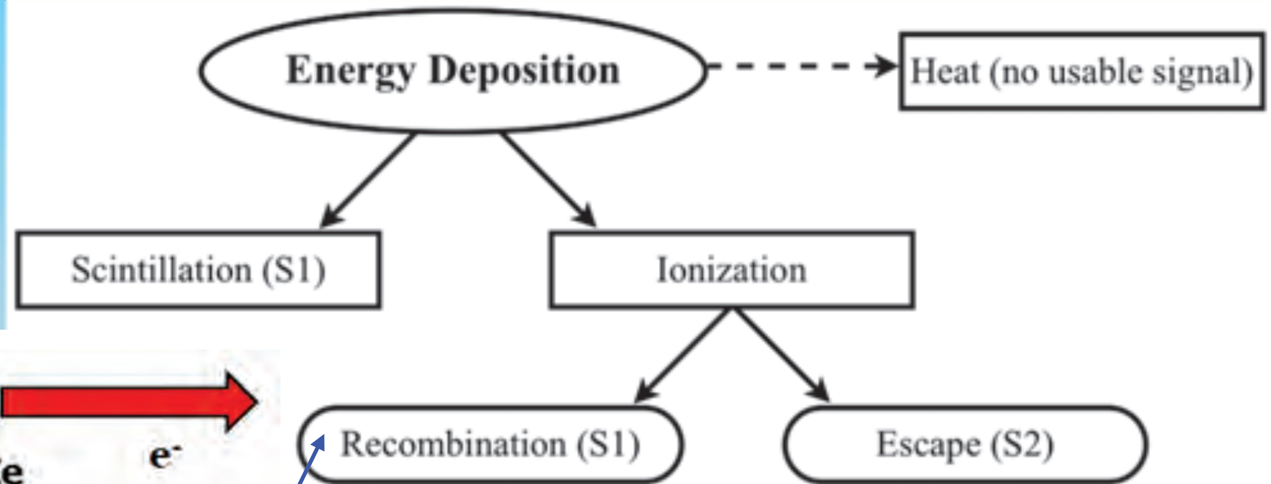
1. Gamma induced electron recoils. Discrimination is based on measuring two characteristic signals from the recoil. The discriminant employed is log (S2/S1) as a function of S1

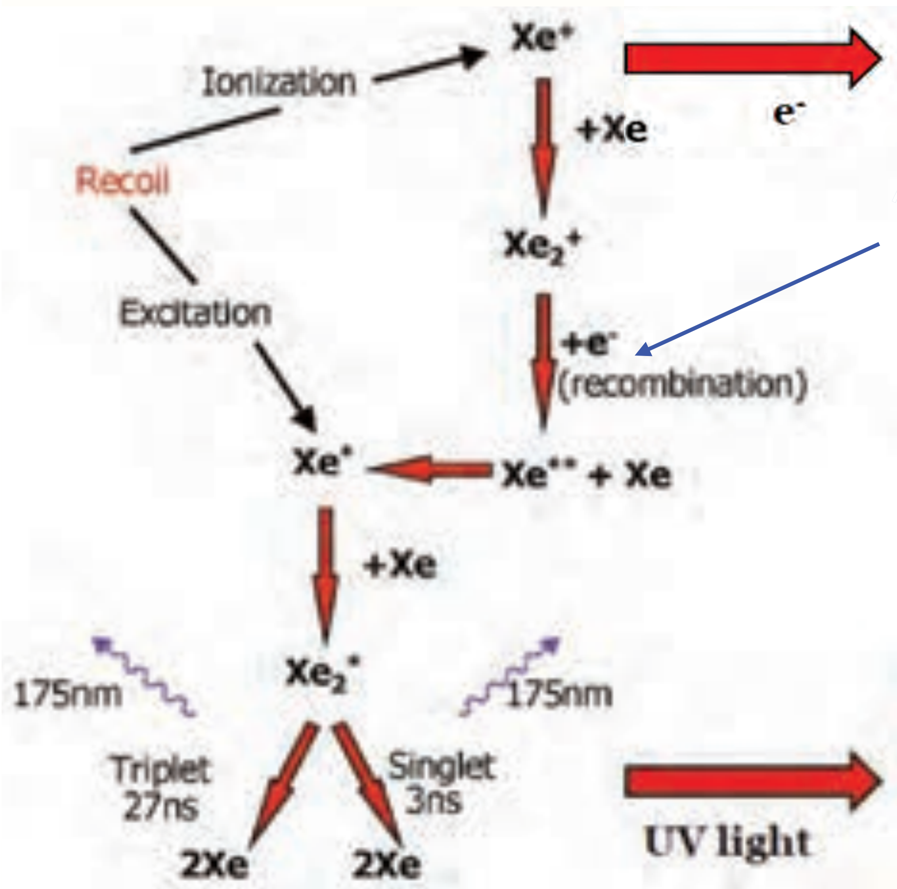
2. Neutron induced nuclear recoils. Neutrons need to be eliminated:

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




# Scintillation process in LXe




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

Xenon is transparent to its own scintillation light !

Figure of merit derived from plots of:

Log (charge escaping recombination/ total primary light produced)

# Physics Handled by NEST

- **N**oble **E**lement **S**imulation **T**echnique is a a data-driven model explaining the scintillation and ionization yields of noble elements as a function of particle type, electric field, and *dE/dx* or energy
- Provides a full-fledged Monte Carlo (in Geant4) with
  - Mean yields: light and charge, and photons/electron
  - Energy resolution: key in discriminating background
  - Pulse shapes: S1 and S2, including single electrons
- The wealth of data on noble elements was combed and all of the physics learned combined


M. Szydagis et al., JINST 8 (2013) C10003. arxiv:1307.6601
M. Szydagis et al., JINST 6 (2011) P10002. arxiv:1106.1613
J. Mock et al., Submitted to JINST (2013). arxiv:1310.1117

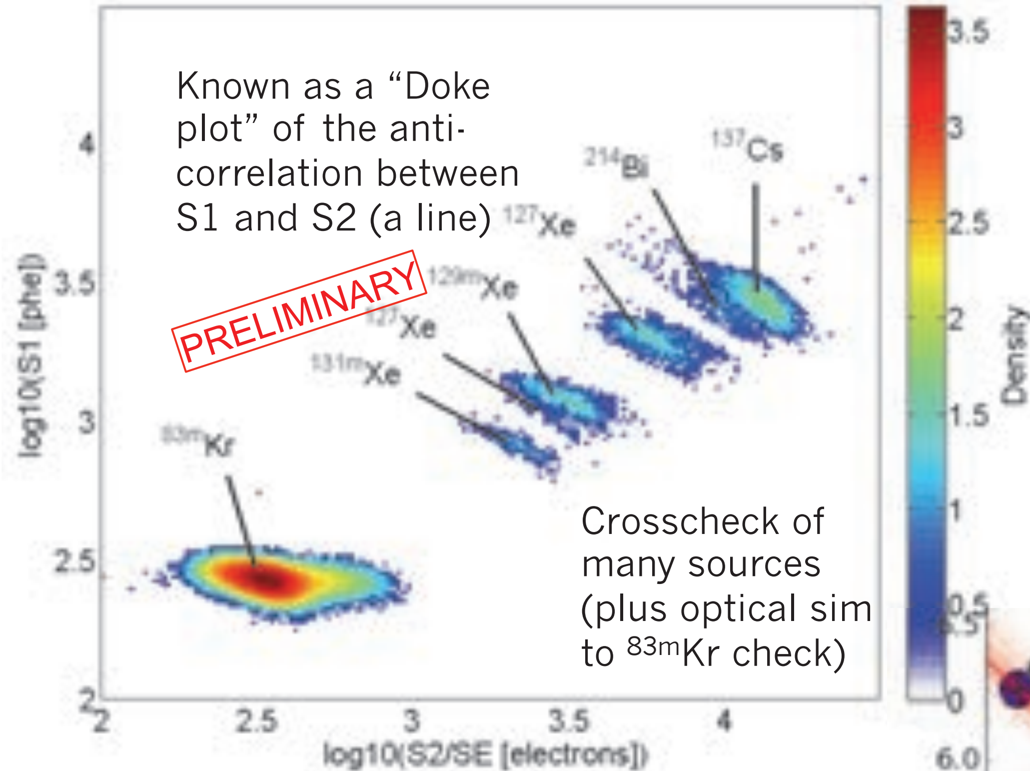
# Event Energy Reconstruction

$$\text{Energy} = [\, N_{ph} + N_{e-} \,] * W$$
$$= [\, ( S1 / g_1 ) + ( S2 / g_2 ) \,] * 13.7\text{e-}3 \text{ keV(ee)}$$

- $g_1$ is an overall efficiency, mapped out with Kr83m
- $g_2$ accounts for electron extraction efficiency and number of photons detected per extracted electron

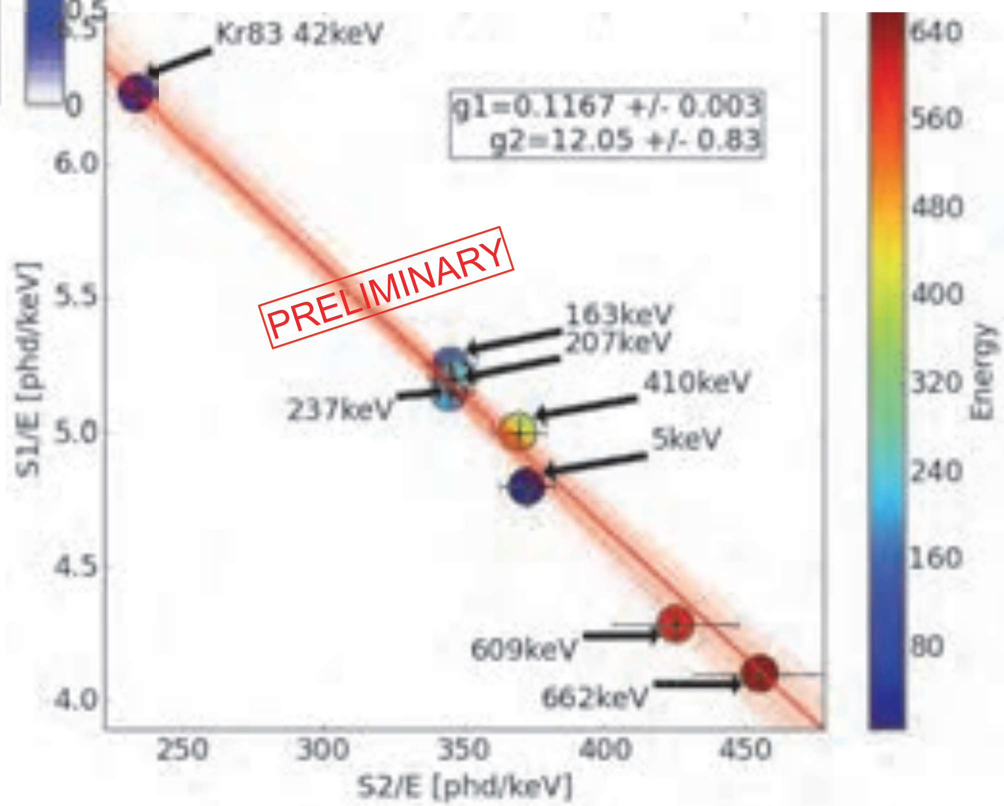
- NR has factor $\mathcal{L} < 1$ accounting for fewer overall quanta (not just S1 photons) being generated due to NR being more effective making more NR (i.e. heat)

# New Calculation of the g-Factors




12% efficiency for the detection of a primary scintillation photon

Previously 14% quoted




49% extraction, coupled with 24.66 detected photons per single electron to make "$g_2$"

Previously 65%, but it is product of absolute yield with is what matters

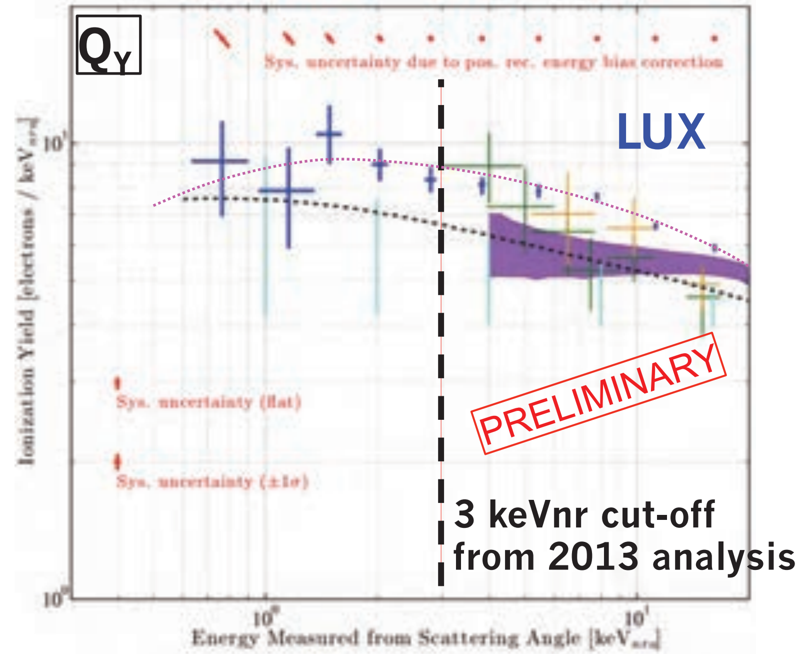
# NR Charge and Light Yields

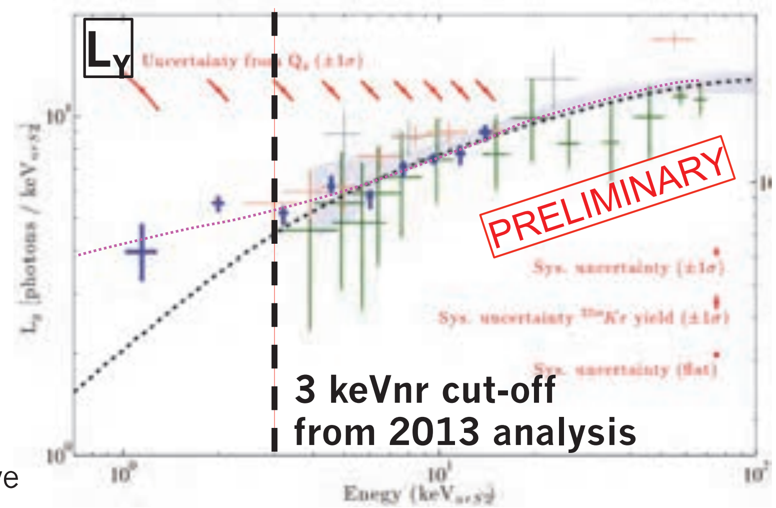
- *in situ* measurements

- No longer relying on LUX AmBe, $^{252}Cf$, or modeling from old data, or extrapolating from results of small test chambers.
- *Charge yield* Measured down to ~0.8 keVnr. (Previous low 4 keV)

- Data from Deuterium-Deuterium neutron gun. Use S2 to identify double scatters. Determine energy deposition from scattering angle. For S1, S2-derived energy scale.
- *Light yield* measured down to ~1.2 keVnr. (Previous low 3 keV)

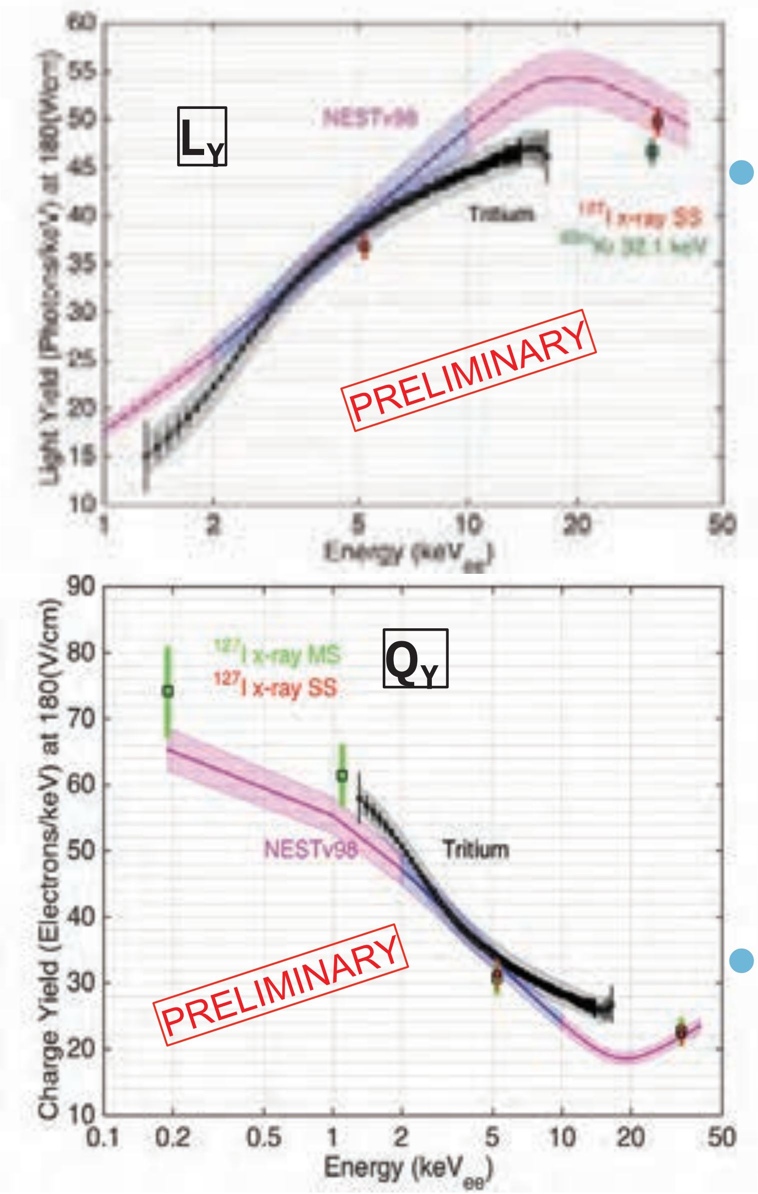
- New modeling




------ NEST 1.0 still too conservative
------ Modified NEST for re-analysis

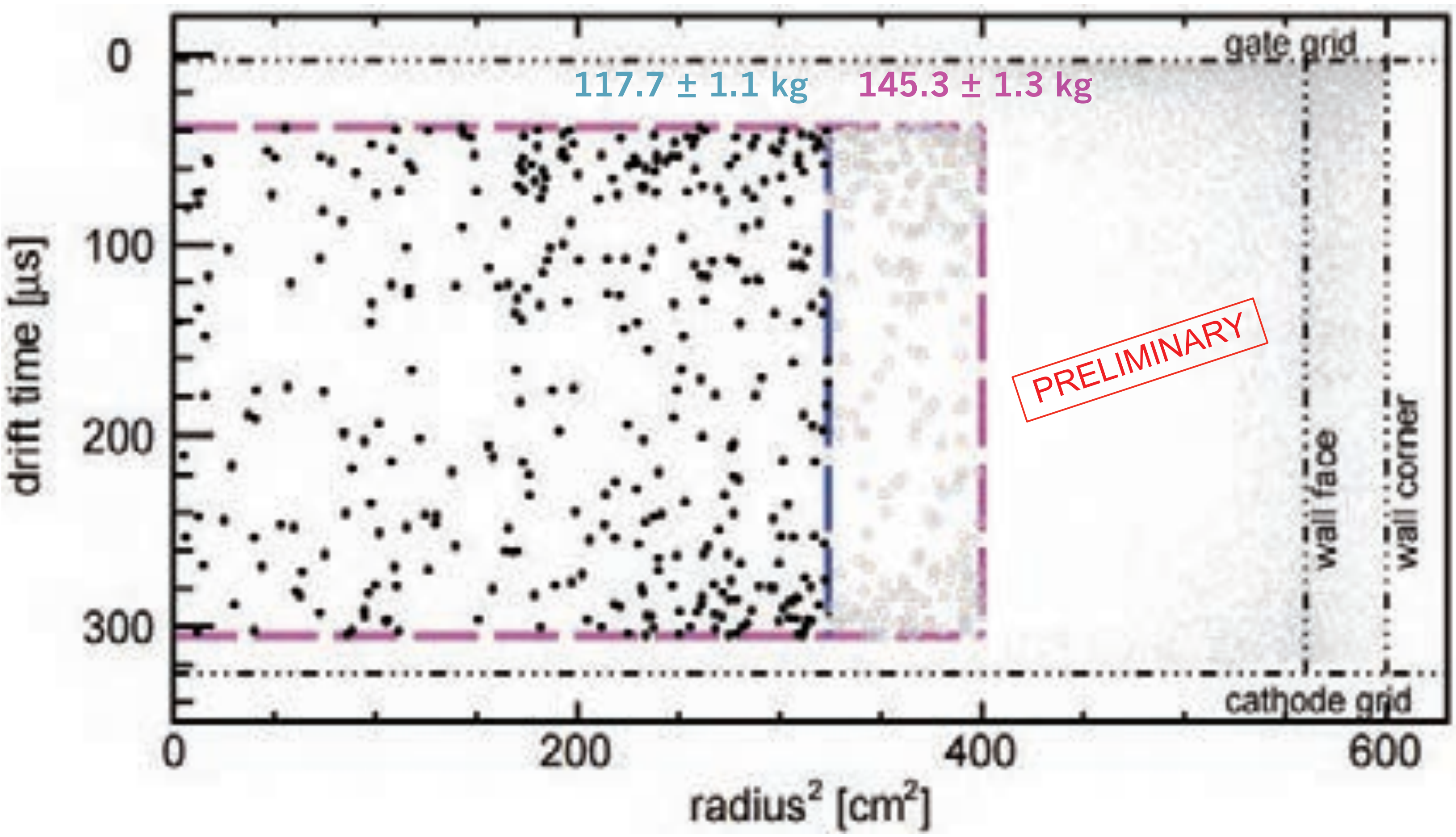
# Same scrutiny for ER




- Internally-deployed tritium source provides ER from 0 to 18 keVee
  - LUX measurably efficient at 1 keV!
- Improved stats over calibration in first LUX result, running longer
  - High statistics provide very precise determination of probability for an ER event to "leak" down into NR S2/S1 region, as a function of S1
  - This ER provides us with both light and its charge yield too
- Because uniformly distributed, used with $^{83m}$Kr for good, accurate measure of the fiducial volume

# Distribution of Backgrounds

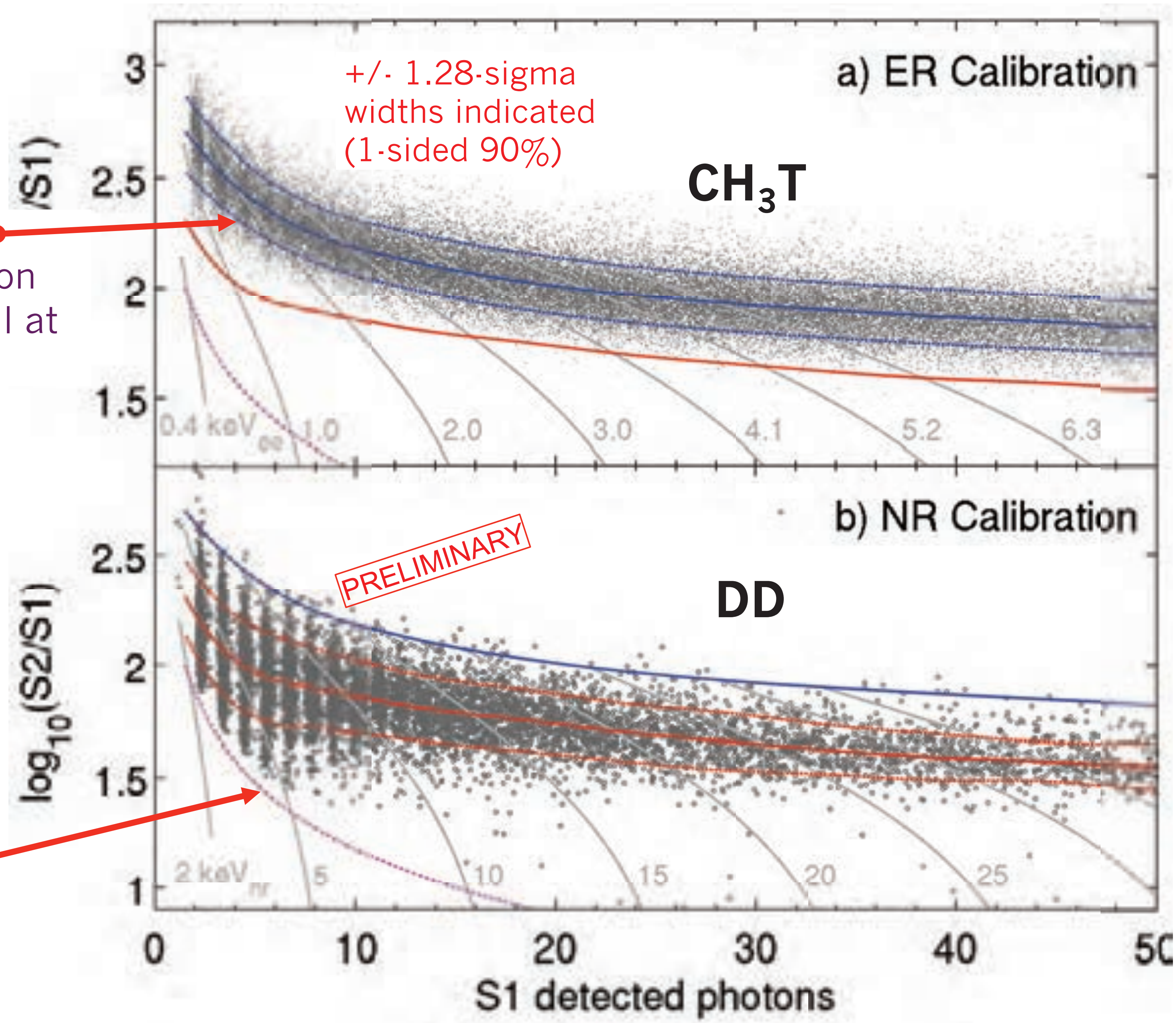
- 3.6 +/- 0.3 x $10^{-3}$ single scatters/(keV-kg-day) in low-energy regime
  - Measured 3.5 ppt Kr with RGA. PMT gamma-rays = biggest background
  - Cosmogenics from surface run have decayed away (Xe131m, Xe129m)
  - Potential fiducial mass increase (was 118 kg in 2013)



# The "Bands"

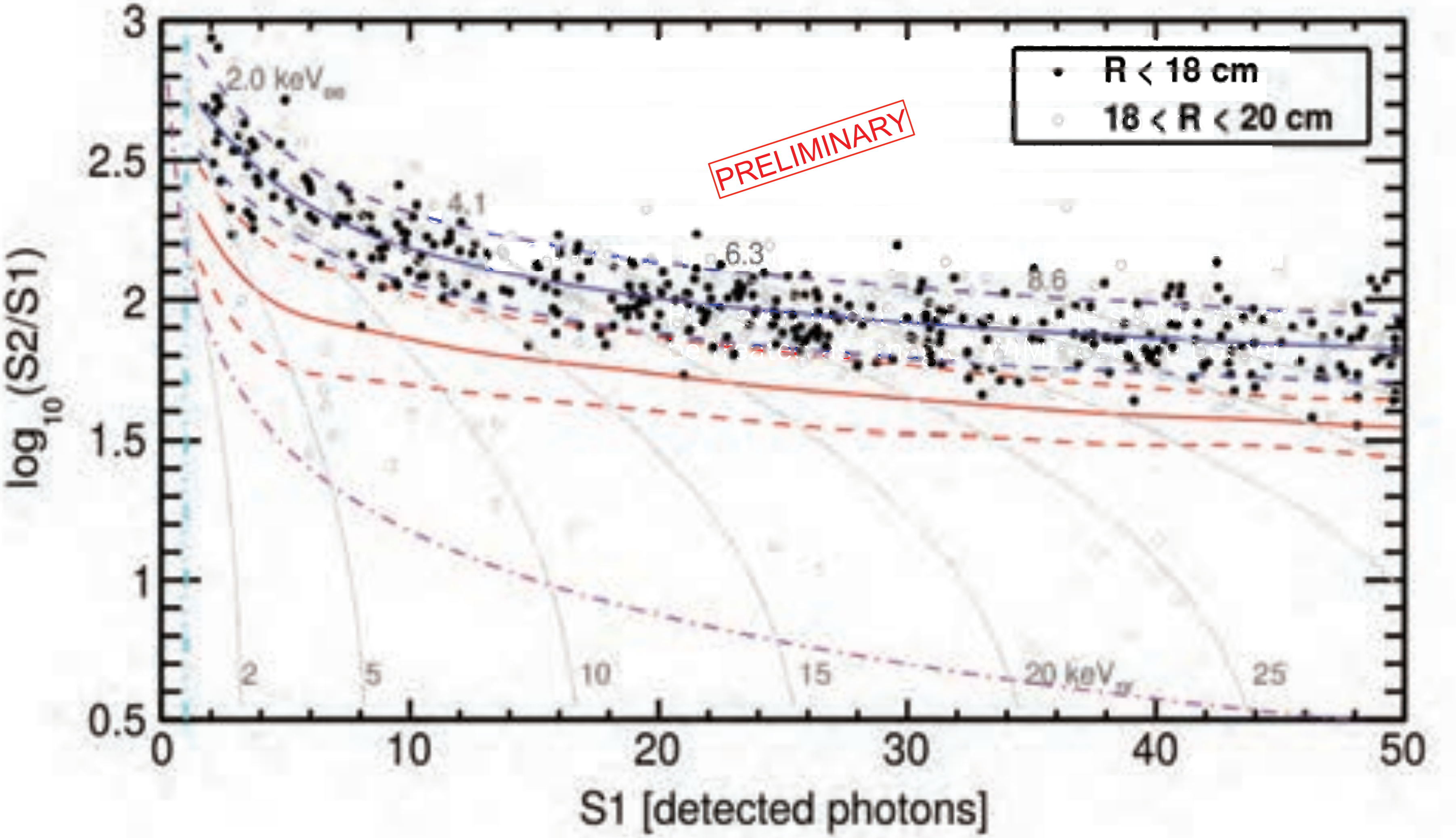
New: DIGITAL individual photon counting, useful at low energies

Approximate location of 165 phd cut, lowered from 200 previous (8 => 6 e⁻'s)



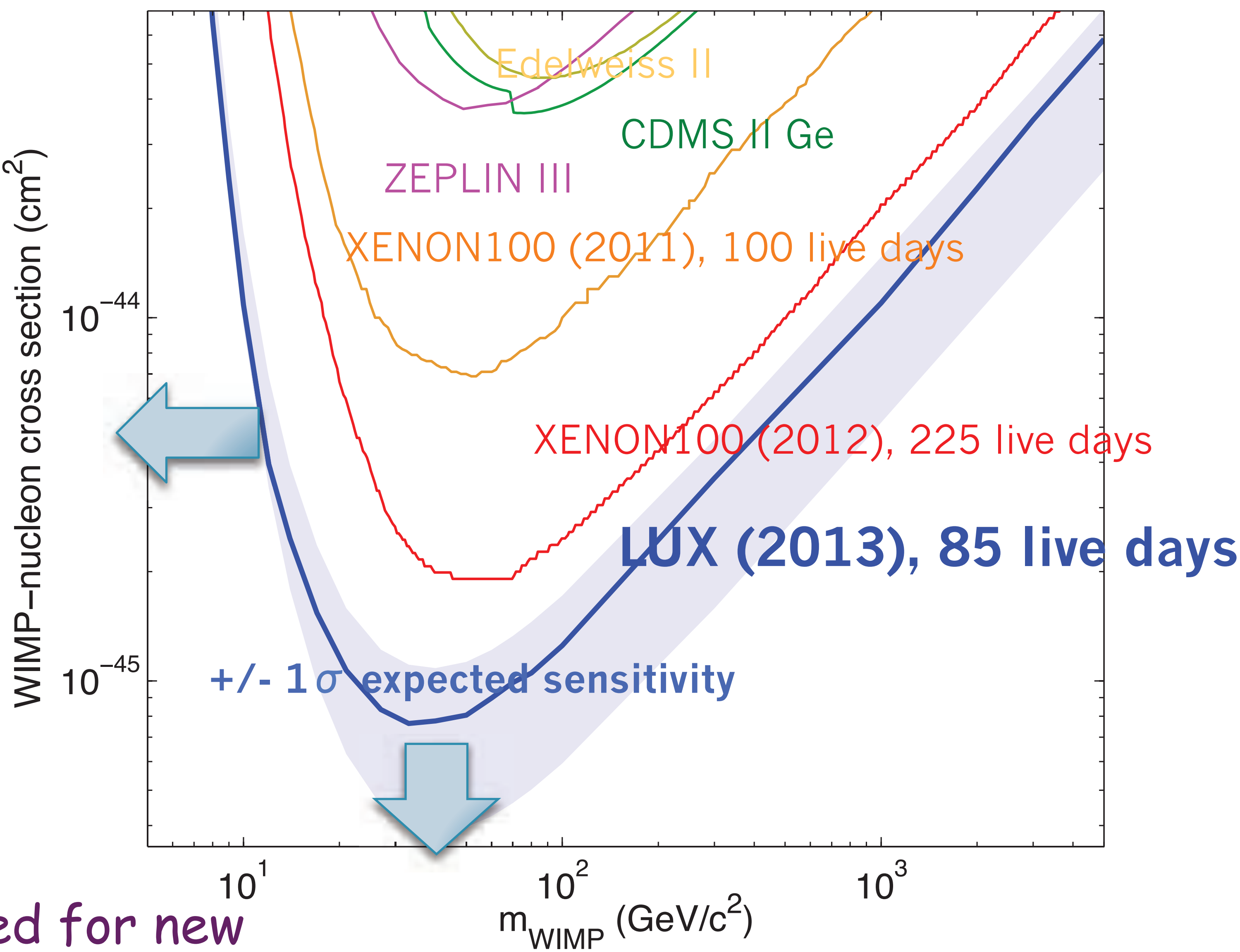

S1 and S2 are both position-corrected using Kr

# Updated WIMP Search Data



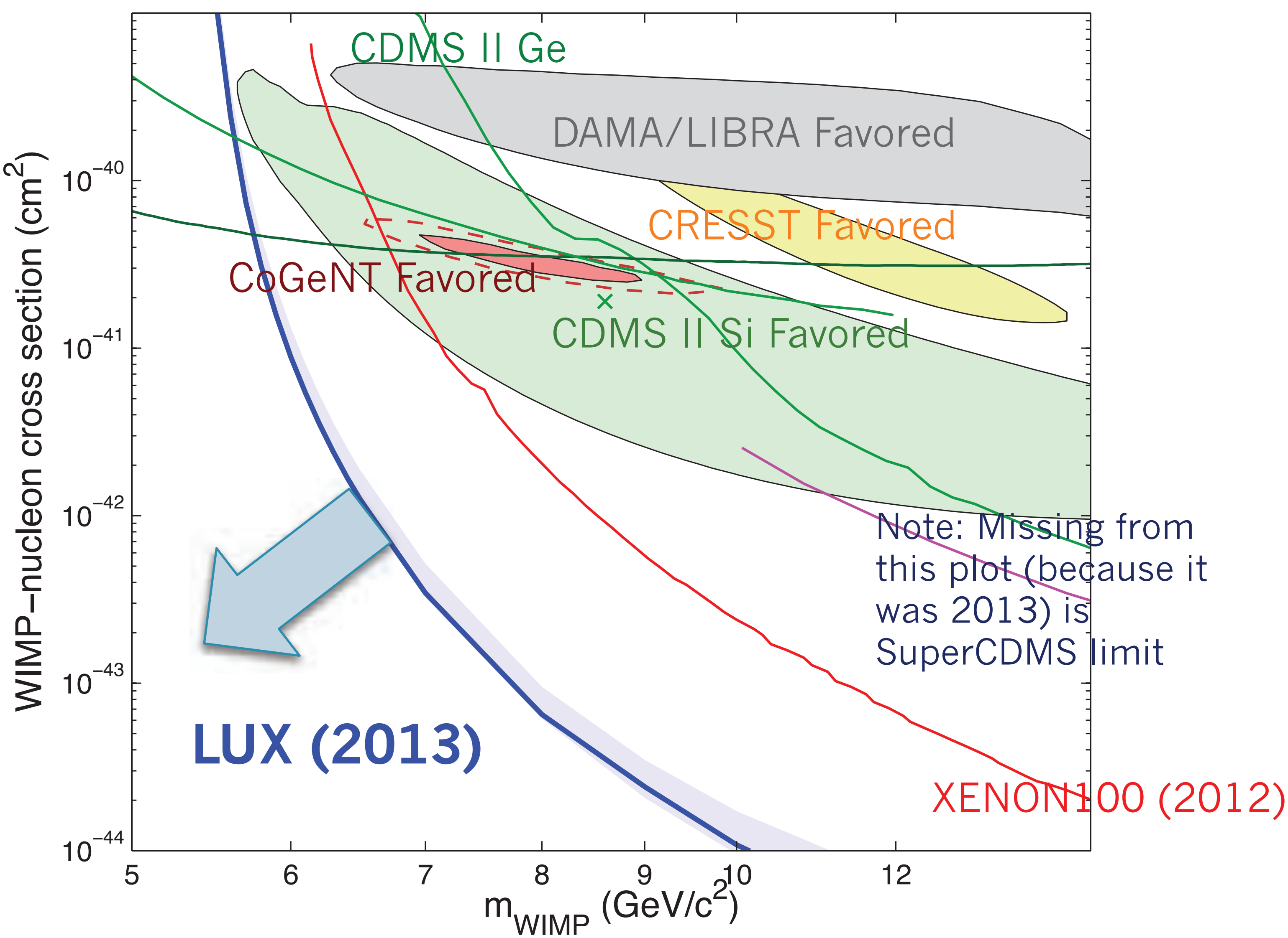

A Profile Likelihood Ratio (not cut-and-count) method uses all events.

# WIMP Dark Matter Limit

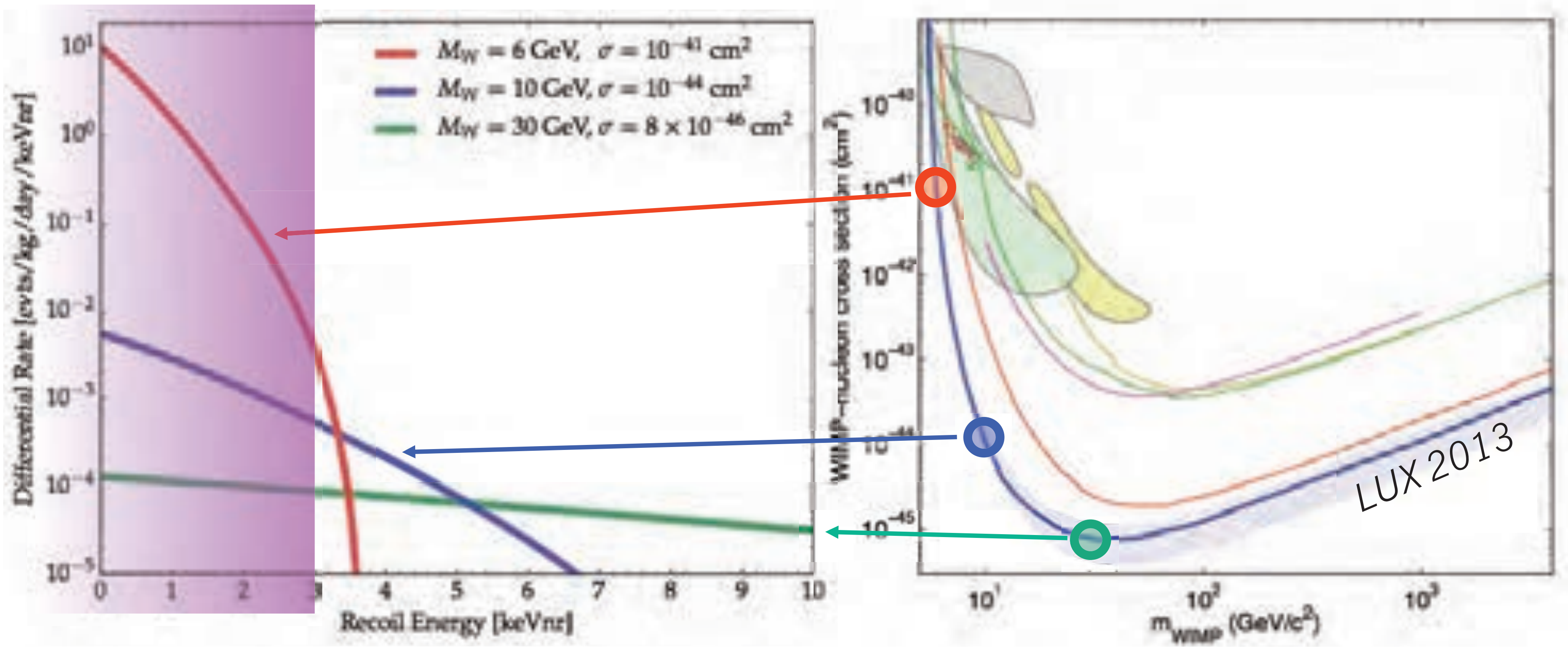



Stay tuned for new results later this year.

# LUX Low-Mass Sensitivity



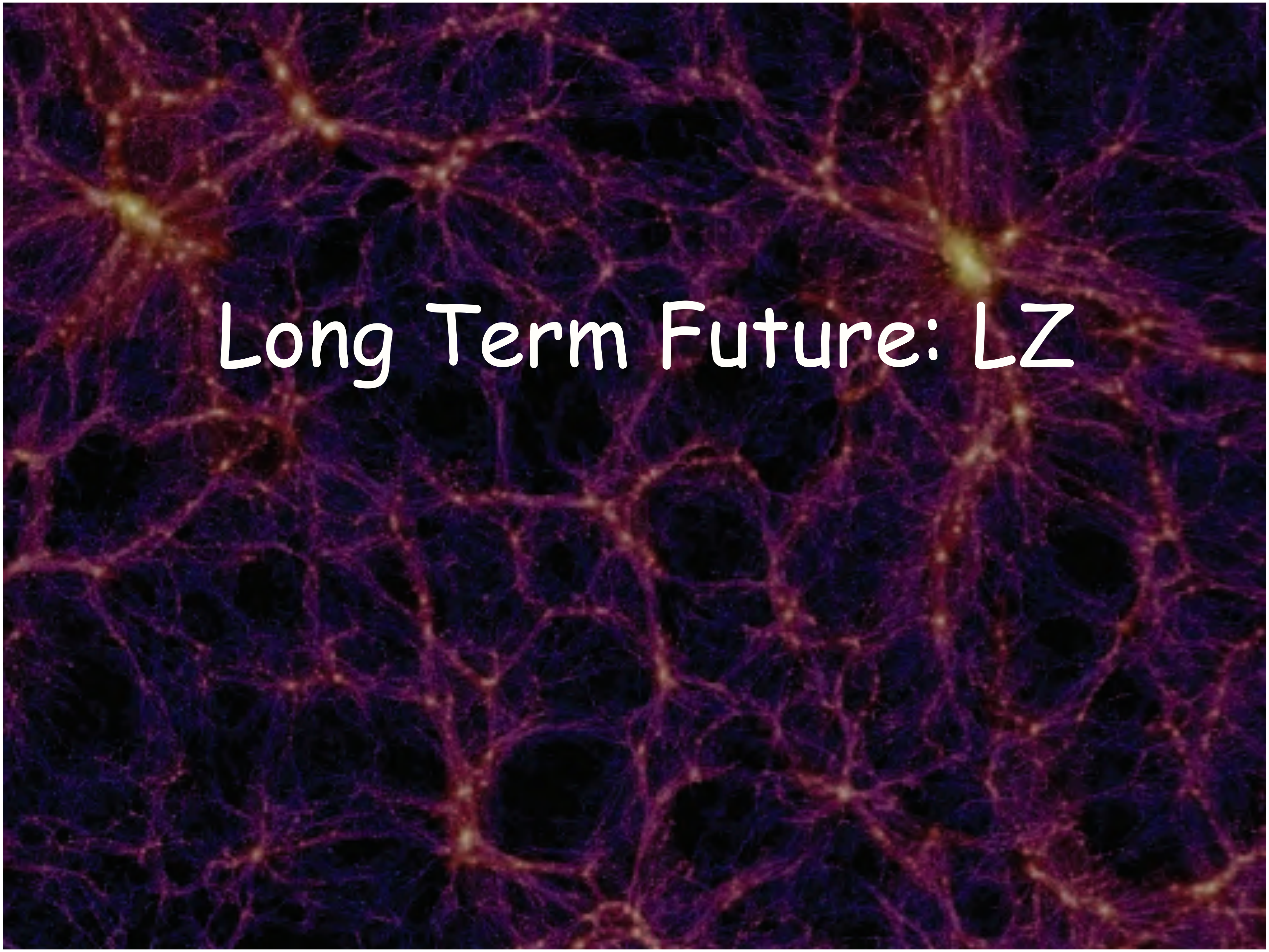
# Another Look at Light WIMPs



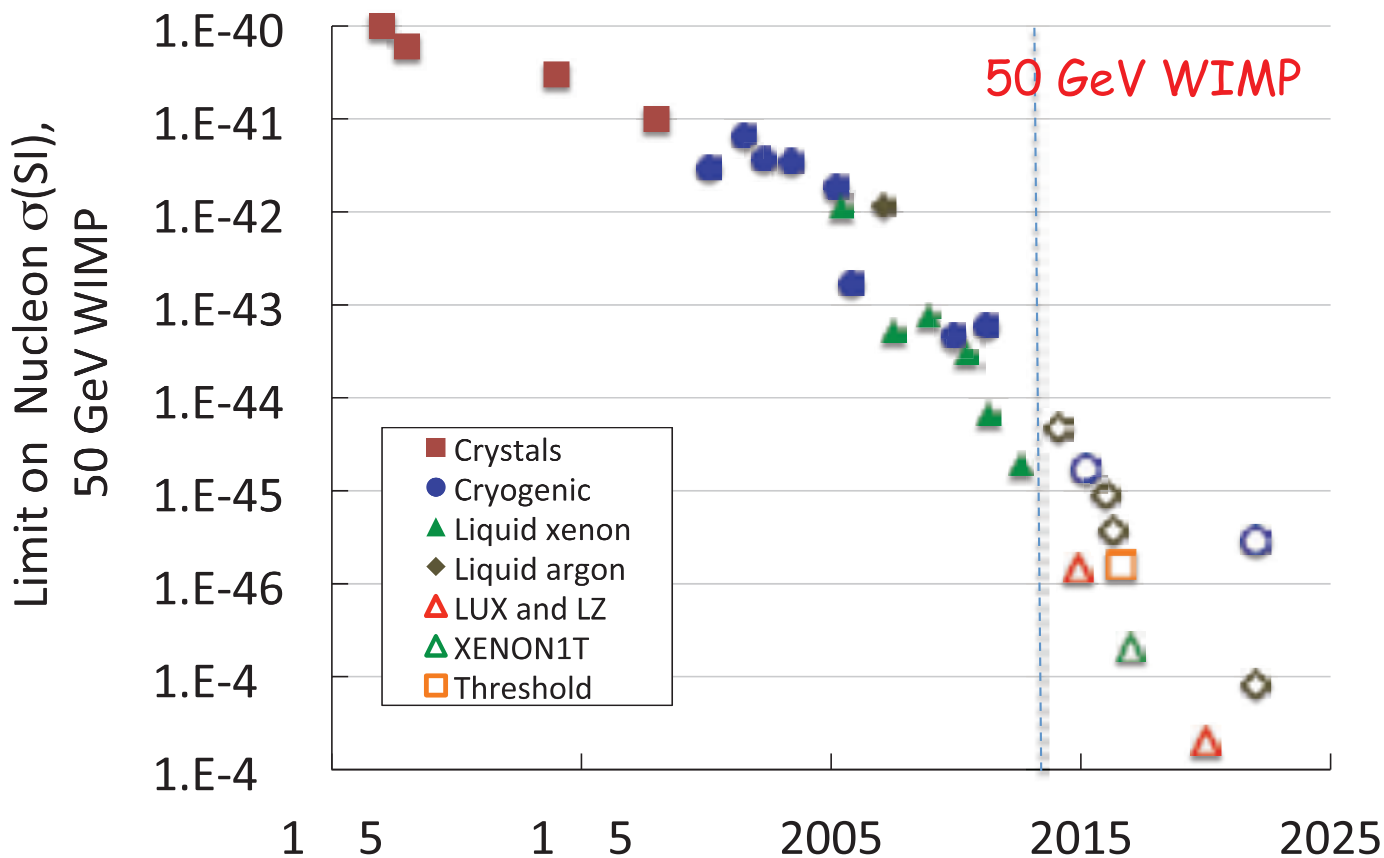

LUX 2013 upper limits assumed NO SENSITIVITY to recoils below 3 keVnr. This was not an *analysis* threshold, but an artificial one, a hard cut-off

For example, decreasing this response cutoff from 3 keV to 1 keV provides access to a factor of 1000* more signal at $M$ = 6 GeV/c$^2$.

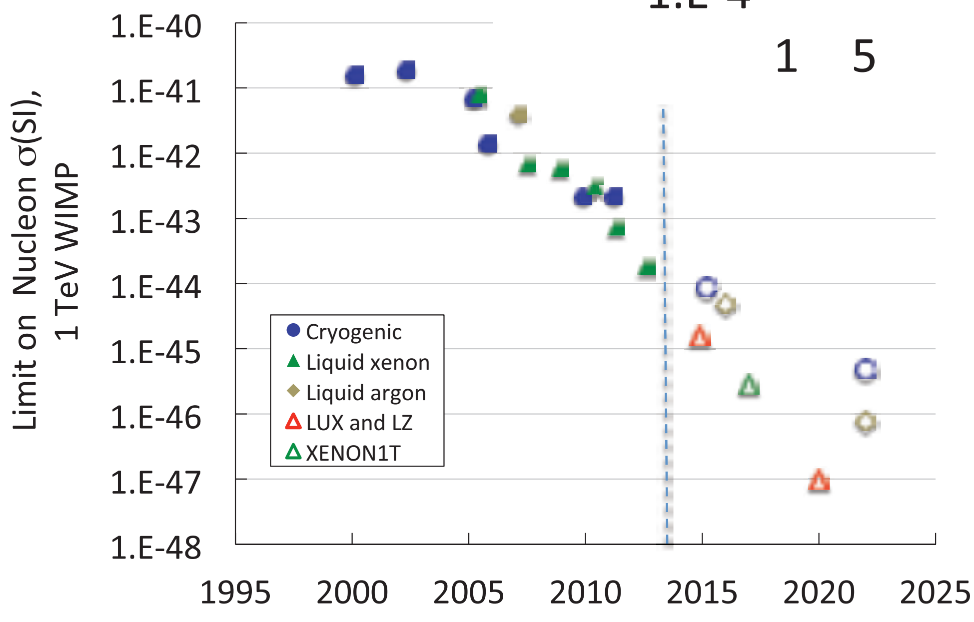
# Long Term Future: LZ



# A compact history of WIMP Searches



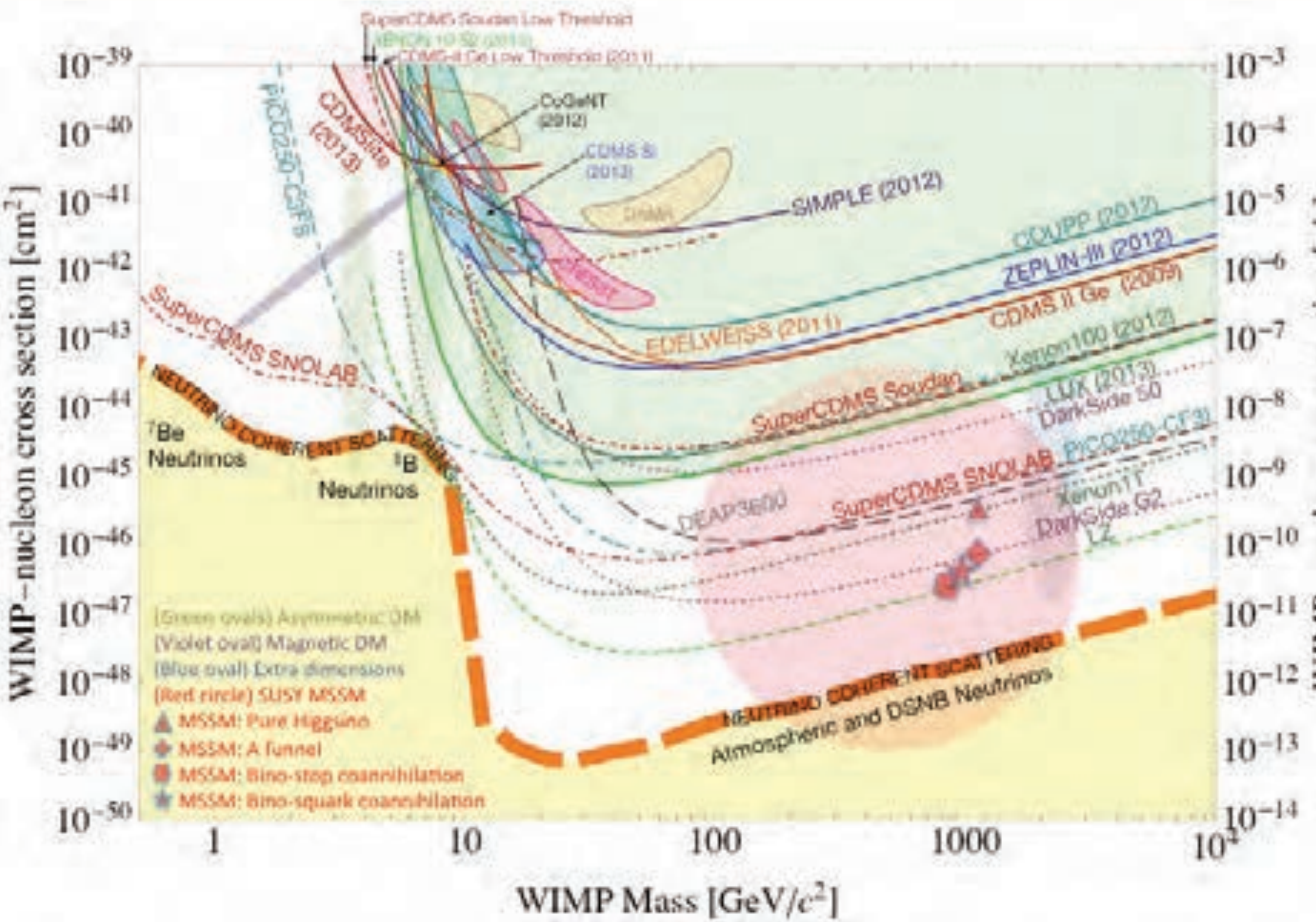

1 TeV WIMP




LZ is poised to possibly provide an end-point to this saga … hopefully by discovering WIMPs or, by ruling out most of the theoretical <u>and</u> experimentally accessible landscape.

Plots compiled by Mike Witherell, UCSB

# Snowmass Projections



# LZ = LUX + ZEPLIN

32 institutions currently
About 190 people

LIP Coimbra (Portugal)
MEPhI (Russia)
Edinburgh University (UK)
University of Liverpool (UK)
Imperial College London (UK)
University College London (UK)
University of Oxford (UK)
STFC Rutherford Appleton Laboratories (UK)
Shanghai Jiao Tong University (China)
University of Sheffield (UK)

University of Alabama
University at Albany SUNY
Berkeley Lab (LBNL)
University of California, Berkeley
Brookhaven National Laboratory
Brown University
University of California, Davis
Fermi National Accelerator Laboratory
Kavli Institute for Particle Astrophysics & Cosmology
Lawrence Livermore National Laboratory
University of Maryland
University of Michigan
Northwestern University
University of Rochester
University of California, Santa Barbara
University of South Dakota
South Dakota School of Mines & Technology
South Dakota Science and Technology Authority
SLAC National Accelerator Laboratory
Texas A&M
Washington University
University of Wisconsin
Yale University

# LZ Meeting at U. of Alabama

# LZ: Evolution of LUX and ZEPLIN

Building on experiences gained in both programs, the proposed new experiment will utilize the LUX infrastructure at the Sanford Underground Research Facility to mount a state-of-the-art detector. Highlighted features include:

- LUX water shield and an added liquid scintillator active veto.
- Instrumented "skin" region of peripheral xenon as another veto system.
- Unprecedented levels of Kr removal from Xe.
- Radon suppression during construction, assembly and operations.
- Photomultipliers with ultra-low natural radioactivity.
- Cryogenics and Xe purification systems made external to the main detector in a unique design.
- Fully digital deadtime-less data acquisition and trigger system.

# LZ Timeline

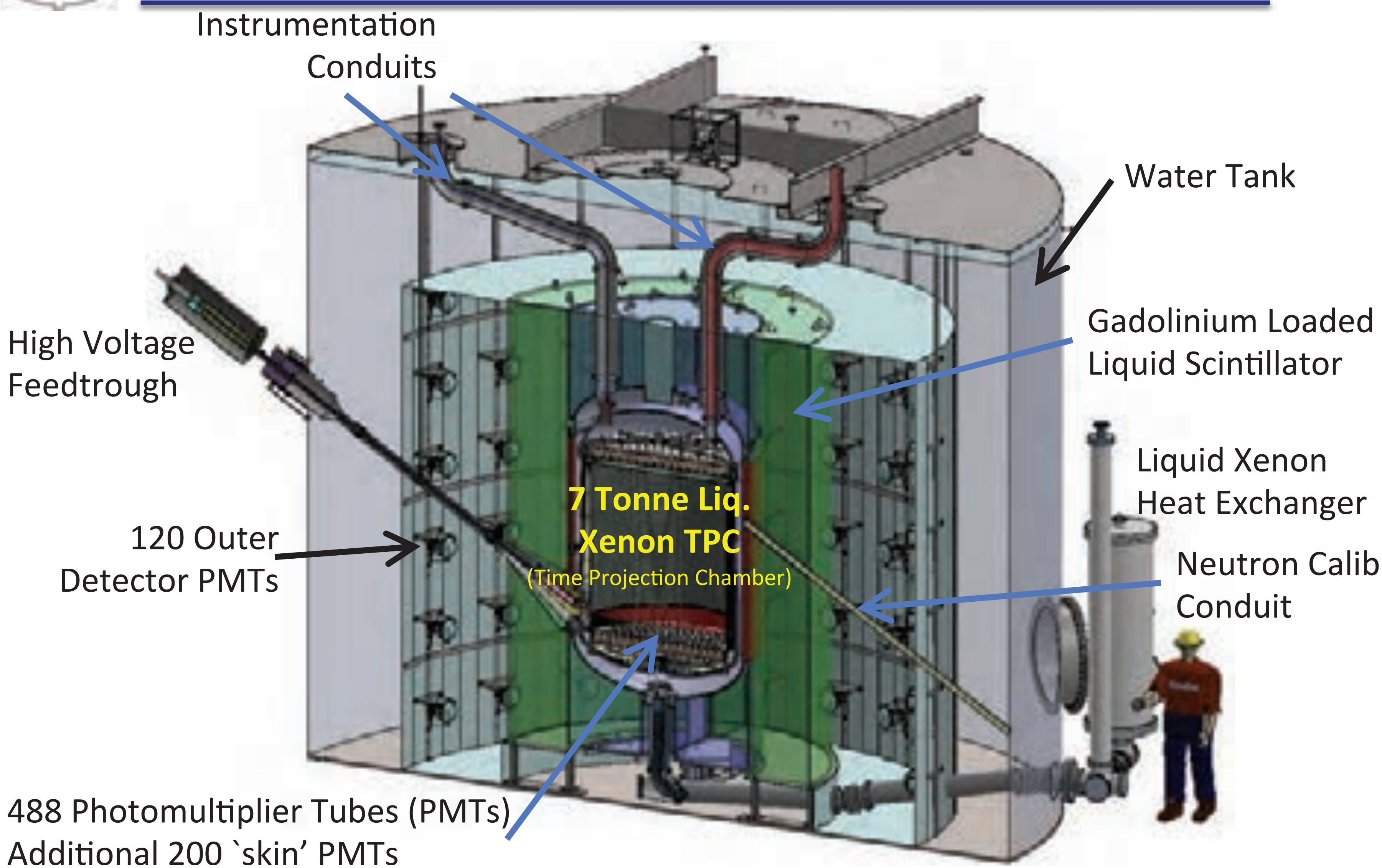
| Year | Month | Activity |
|---|---|---|
| 2012 | March | LZ (LUX-ZEPLIN) collaboration formed |
| | May | First Collaboration Meeting |
| | September | DOE CD-0 for G2 dark matter experiments |
| 2013 | November | LZ R&D report submitted |
| 2014 | July | LZ Project selected in US and UK |
| 2015 | April | DOE CD-1/3a approval, similar in UK<br>Begin long-lead procurements(Xe, PMT, cryostat) |
| 2016 | April | DOE CD-2/3b approval, baseline, all fab starts |
| 2017 | June | Begin preparations for surface assembly @ SURF |
| 2018 | July | Begin underground installation |
| 2019 | Feb | Begin commissioning |

# Scale Up ≈50 in Fiducial Mass

**LZ**

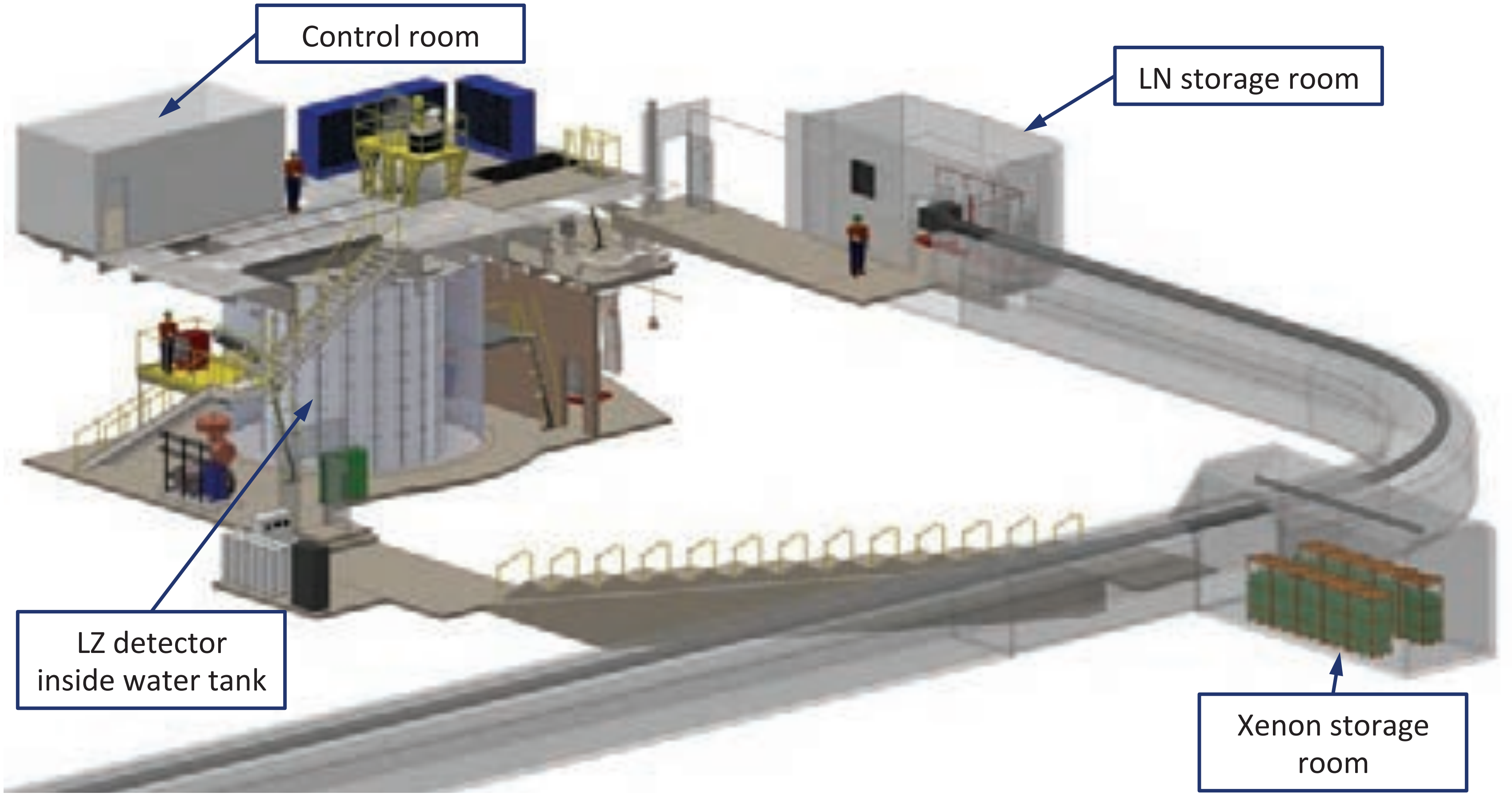
Total mass – 10 T
Active Mass – 7 T
Fiducial Mass – 5.6 T

# LZ Overview


Instrumentation
Conduits
Water Tank
High Voltage
Feedtrough
Gadolinium Loaded
Liquid Scintillator
Liquid Xenon
Heat Exchanger
7 Tonne Liq.
Xenon TPC
(Time Projection Chamber)
120 Outer
Detector PMTs
Neutron Calib.
Conduit
488 Photomultiplier Tubes (PMTs)
Additional 200 `skin' PMTs

# LZ Underground at SURF

Years of experience at SURF from LUX



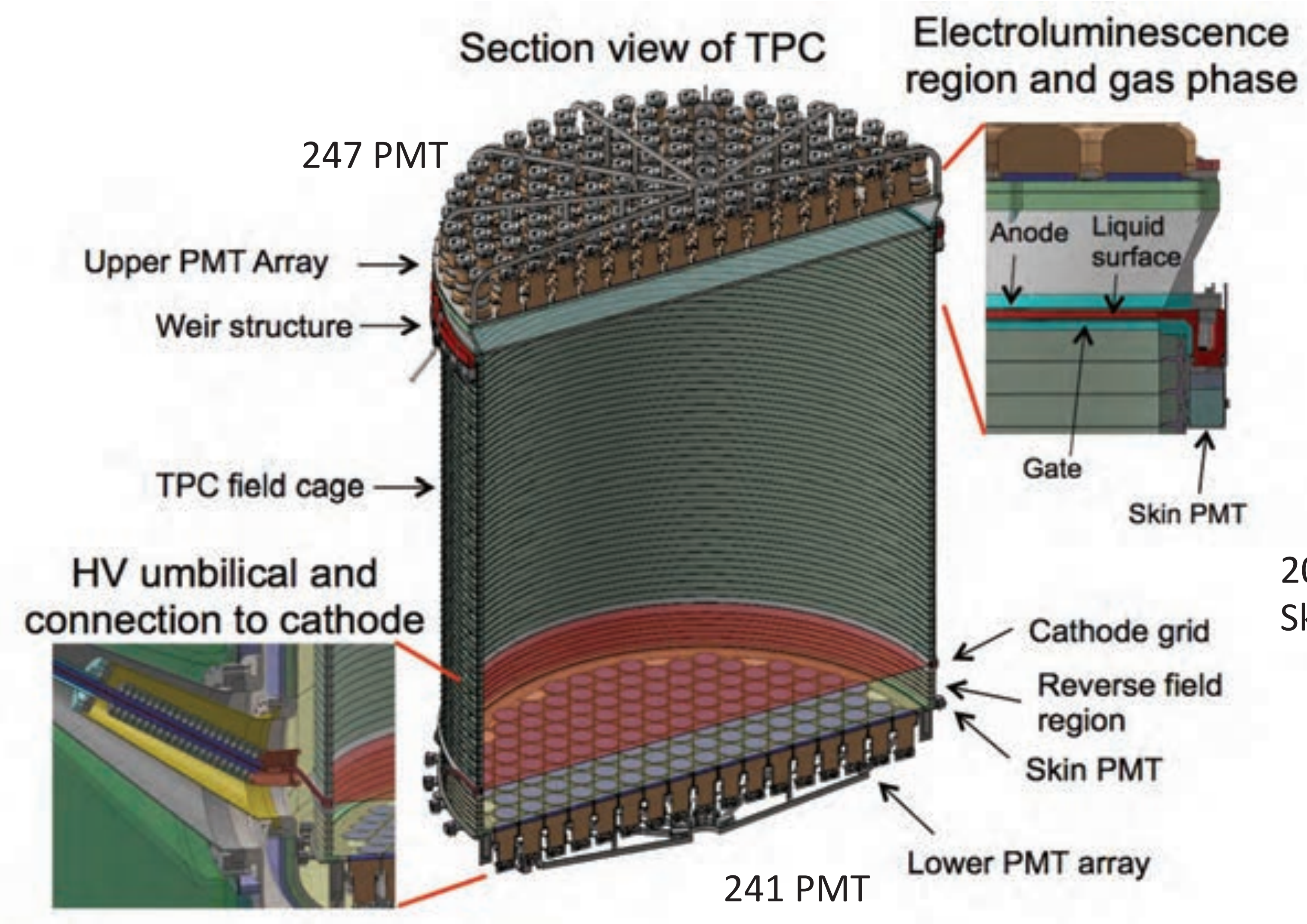
# Key Design Points

- ✓ 7 active tonnes of LXe can yield 2 x $10^{-48}$ $cm^2$ sensitivity in about three years of running
- ✓ 5.6 tonne fiducial volume, 1000 days
- ✓ Requires all detector systems working together
  - ◆ Xe detector with good light collection, reasonable background rejection (ER discrimination) and good signal detection efficiency
  - ◆ Sophisticated veto system: skin (outside active Xe region) + scintillator/water allows maximum fiducial volume to be obtained, maximizes use of Xe and substantially increases reliability of background measurements
  - ◆ Control backgrounds, both internal (within the Xe) and external from detector components/environment

# Design Status Summary

- Conceptual, and in some cases more advanced design, completed for all aspects of detector
- Conceptual Design Report about to appear on arXiv
- Acquisition of Xenon started
- Procurement of PMTs and cryostat started
- Collaboration - wide prototype program underway to guide and validate design
- Backgrounds modeling and validation well underway

# Xe TPC Detector




200 total Skin PMT

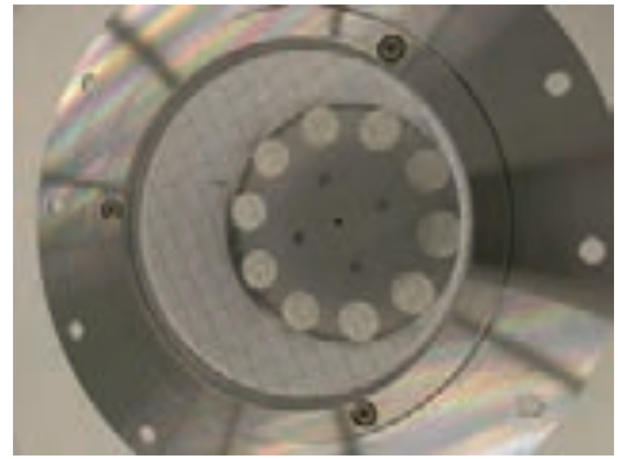
# Xe Detector PMTs

- R11410-22 3” PMTs for TPC region
  - Extensive development program, 50 tubes in hand, benefit from similar development for XENON, PANDA-X and RED
  - Materials ordered and radioassays started prior to fabrication.
  - First production tubes early 2016.
  - Joint US and UK effort
- R8520-406 1” for skin region
  - Considering using 2” or 3” for bottom dome region, recycle tubes from older detectors

# Xe Detector Prototyping

- Extensive program of prototype development underway
- Three general approaches
  - Testing in liquid argon, primarily of HV elements, at Yale and soon at LBNL
  - Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, Yale-> UC Berkeley, LBNL, U Michigan, UC Davis, Imperial College, MEPhI
  - System test platform at SLAC, Phase I about 100 kg of LXe, TPC prototype testing to begin in few months

# High Voltage Studies



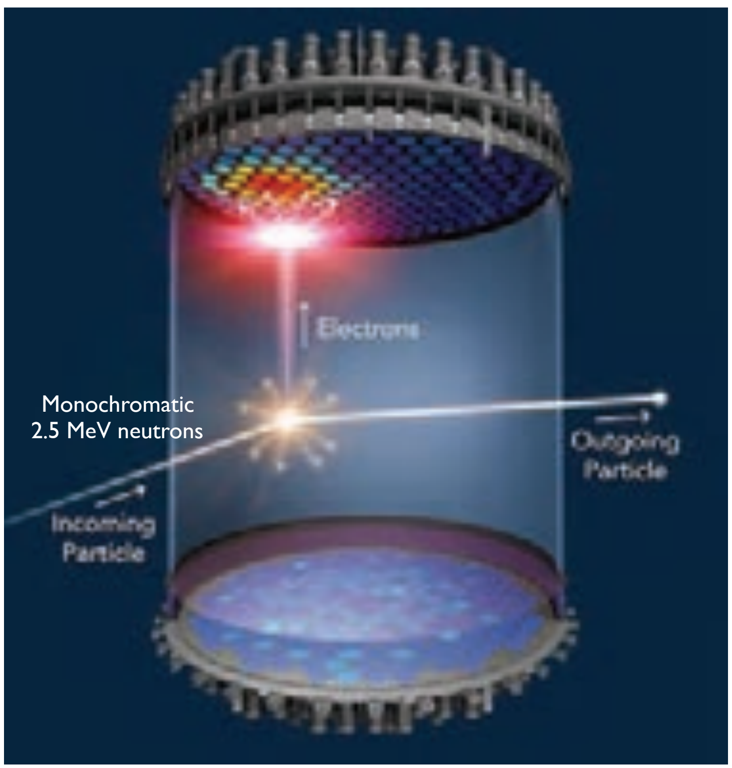
Prototype of highest E-field region tested in LAr

Wire grid tests ongoing

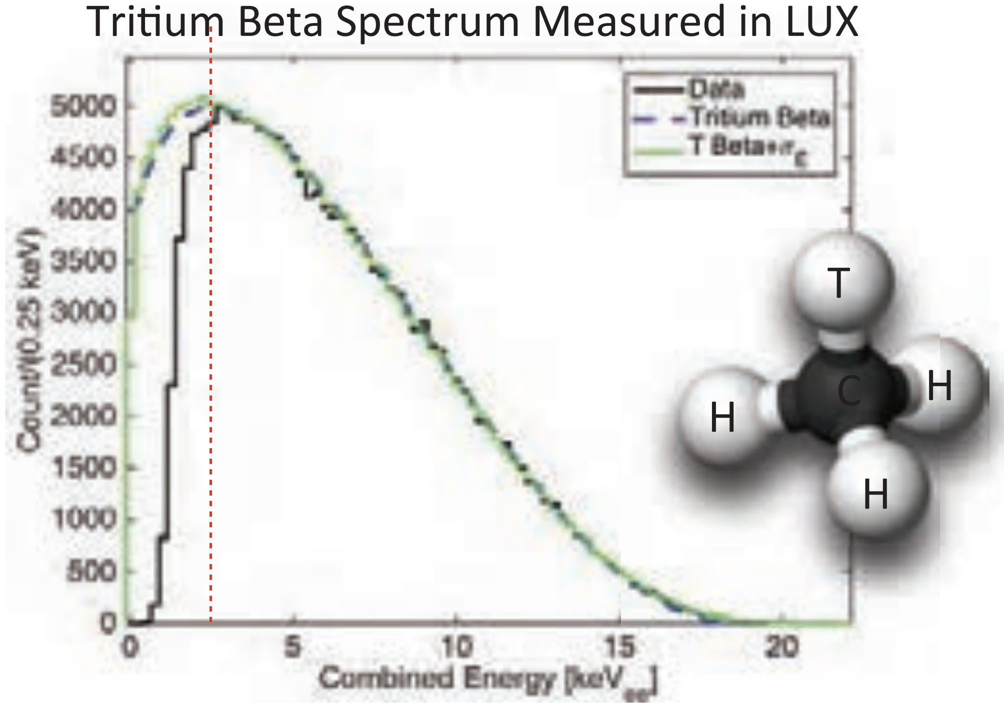

- ✦ Cathode voltage design goal: 200 kV (provides margin)
- ✦ LZ nominal operating goal: 100 kV (~700 V/cm)
- ✦ Feedthrough prototype tested to 200 kV
- ✦ Prototype TPC for 100 kg LXe system fabrication starting
- ✦ HV prototyping expanding at Berkeley

# LZ Calibrations

- ✦Demonstrated in LUX. Calibrate The Signal and Background Model *in situ.*
- ✦DD Neutron Generator (Nuclear Recoils)
- ✦Tritiated Methane (Electron Recoils)
- ✦Additional Sources e.g. YBe Source for low energy (Nuclear Recoils)




Tritium Beta Spectrum Measured in LUX



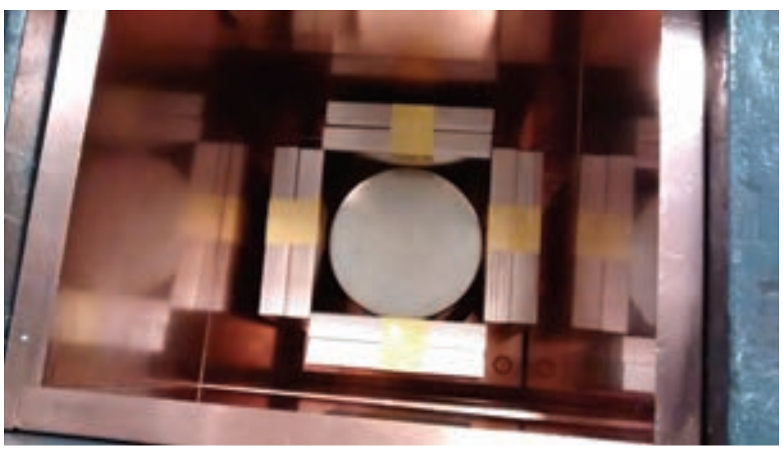
# Extensive Calibration

- LUX has led the way to detailed calibrations. LZ will build on this and do more.

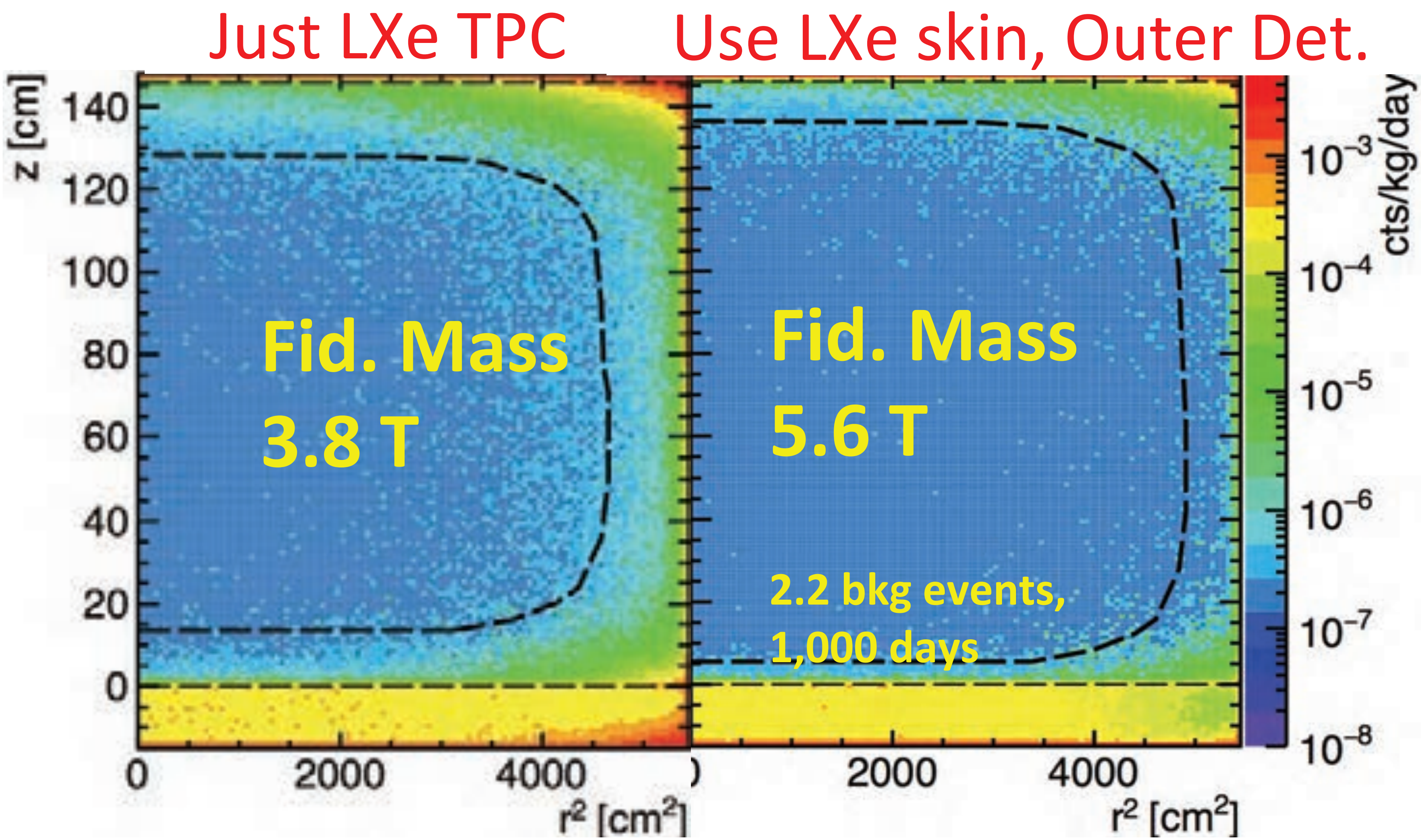
| Done in LUX and will be done in LZ | Not done in LUX, but will do in LZ |
|---|---|
| $^{83m}$Kr (routine, roughly weekly) | Activated Xe ($^{129m}$Xe and $^{131m}$Xe) |
| Tritiated methane (every few months) | $^{220}$Rn |
| External radioisotope neutron sources | AmLi |
| External radioisotope gamma sources | YBe |
| DD neutron generator(upgraded early next year to shorten pulse) | |

# Cryostat Vessels

- UK responsibility
- Low background titanium chosen direction
  SS alternative advanced as backup
- Ti slab for all vessels(and other parts) received and assayed
- Contributes < 0.05 NR+ER counts in fiducial volume in 1,000 days after cuts

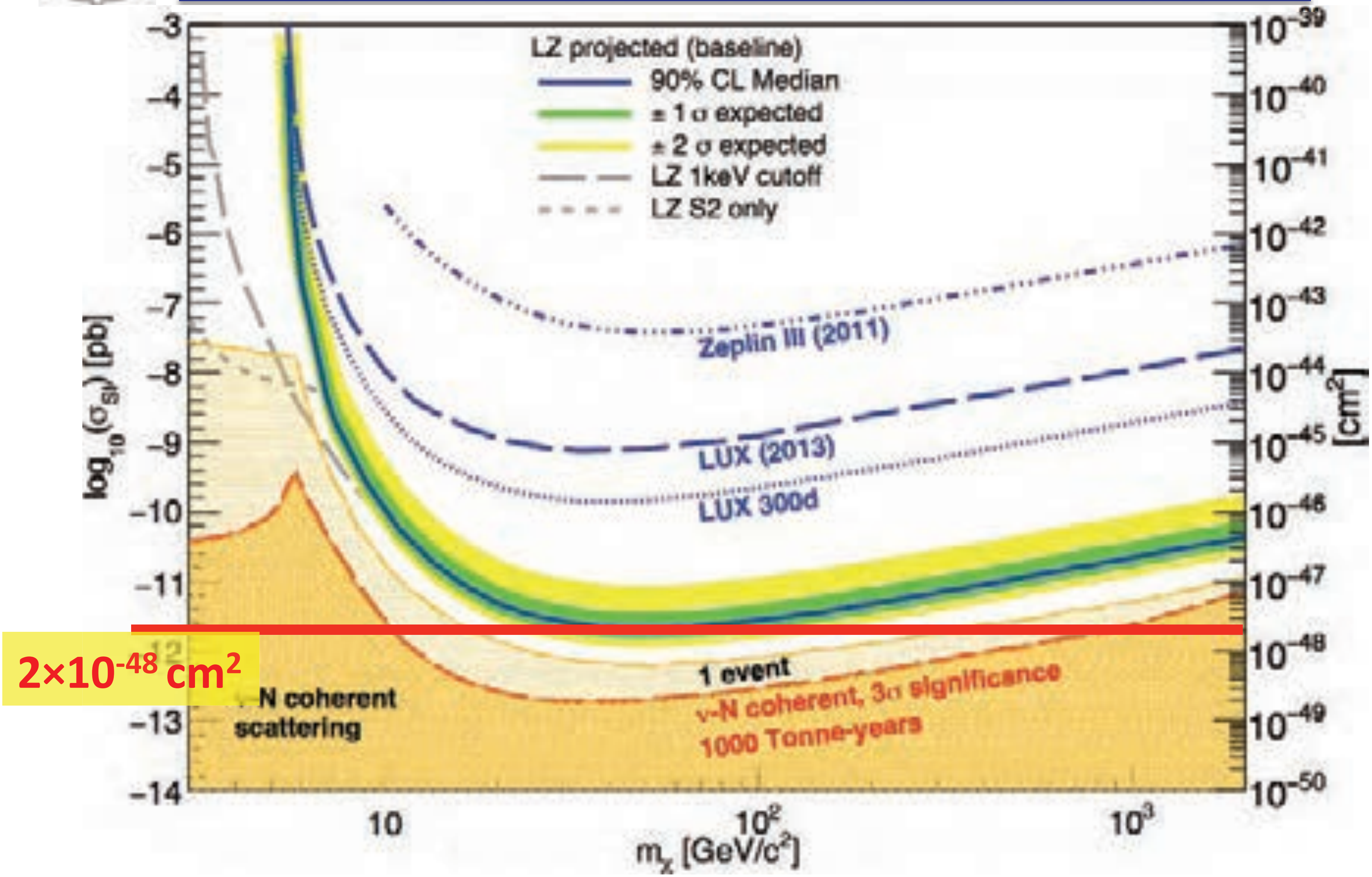


# Background Modeled

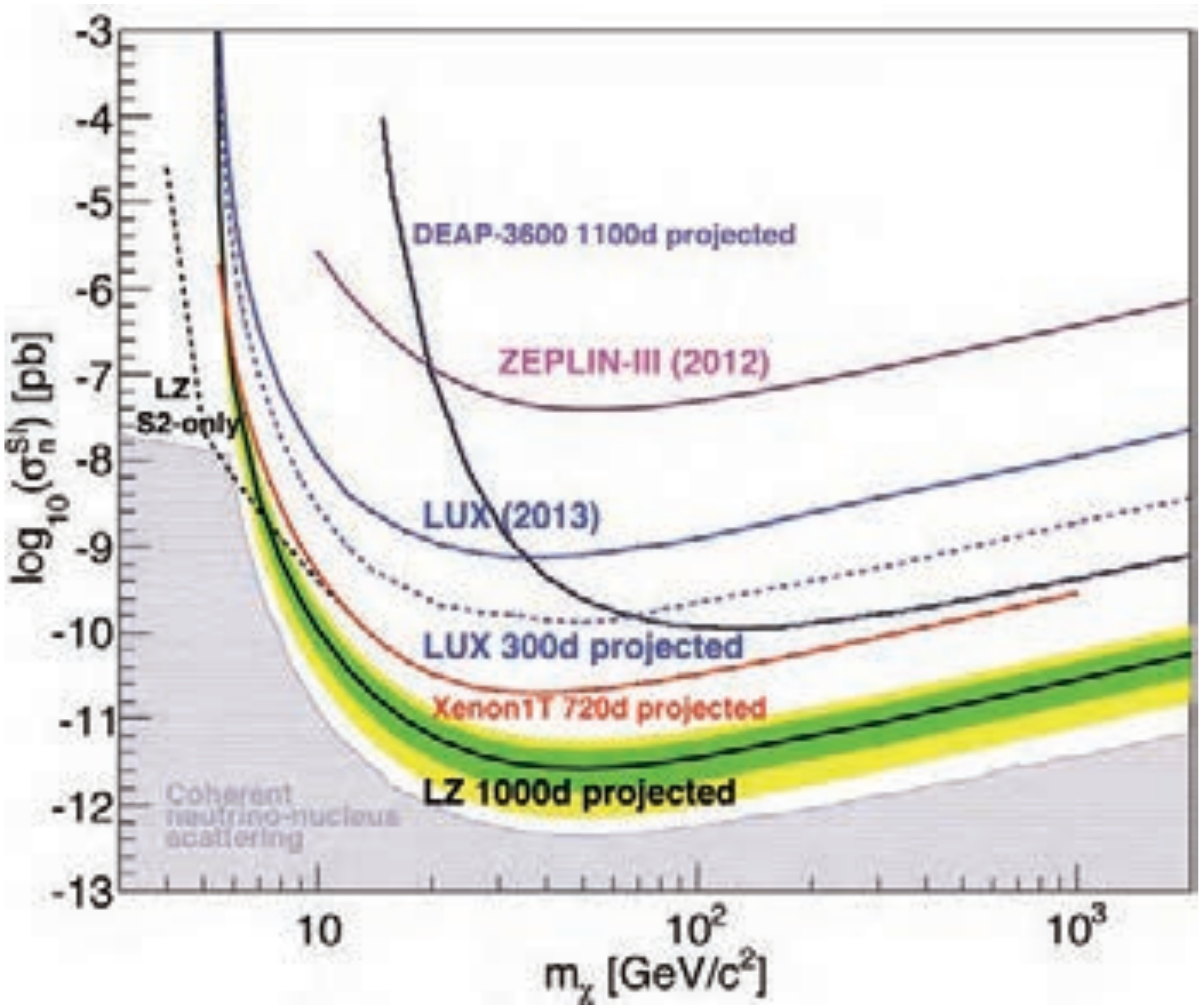


# Projected Sensitivity – Spin Independent

(LZ 5.6 Tonnes, 1000 live days)



# Sensitivity with Competition



# Summary

- LUX has the largest kg-days exposure of any xenon TPC, as well as the lowest energy threshold
- Pioneering work with internal calibration sources. Low-energy NR data agree with MC.
- LUX has provided the most stringent limit on the WIMP-nucleon spin-independent interaction cross-section.
- LUX result is in conflict with low-mass WIMP interpretations of signals seen in CoGeNT, CDMS, and elsewhere
- LZ holds the promise to be the ultimate WIMP search experiment. Limited by neutrino-induced `background'
- LZ Project well underway. Procurement of Xe, PMTs and cryostat vessels started. Extensive prototype program.
- LZ benefits from the excellent LUX calibration techniques and understanding of background

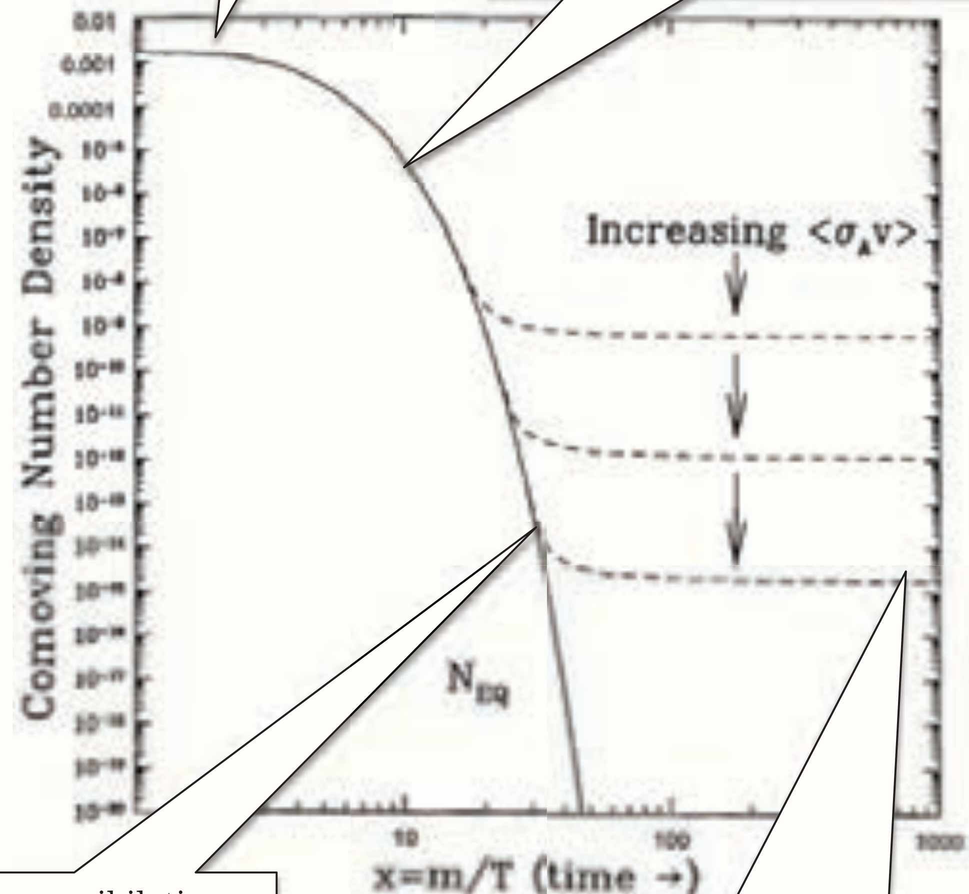
# Waiting for the Jackpot

# WIMP Miracle

A happy coincidence implied that new physics at the TeV scale with appropriately weak cross section leads to a dark matter relic (with a new quantum number preventing decay).

$$\Omega_x h^2 = \frac{3 \cdot 10^{-27}\, cm^3 / s}{\langle \sigma_A v \rangle} \approx 0.12$$

$$\Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$




1. Flat region. Constant density. Equal production and annihilation. $n_{eq} \sim T^3$

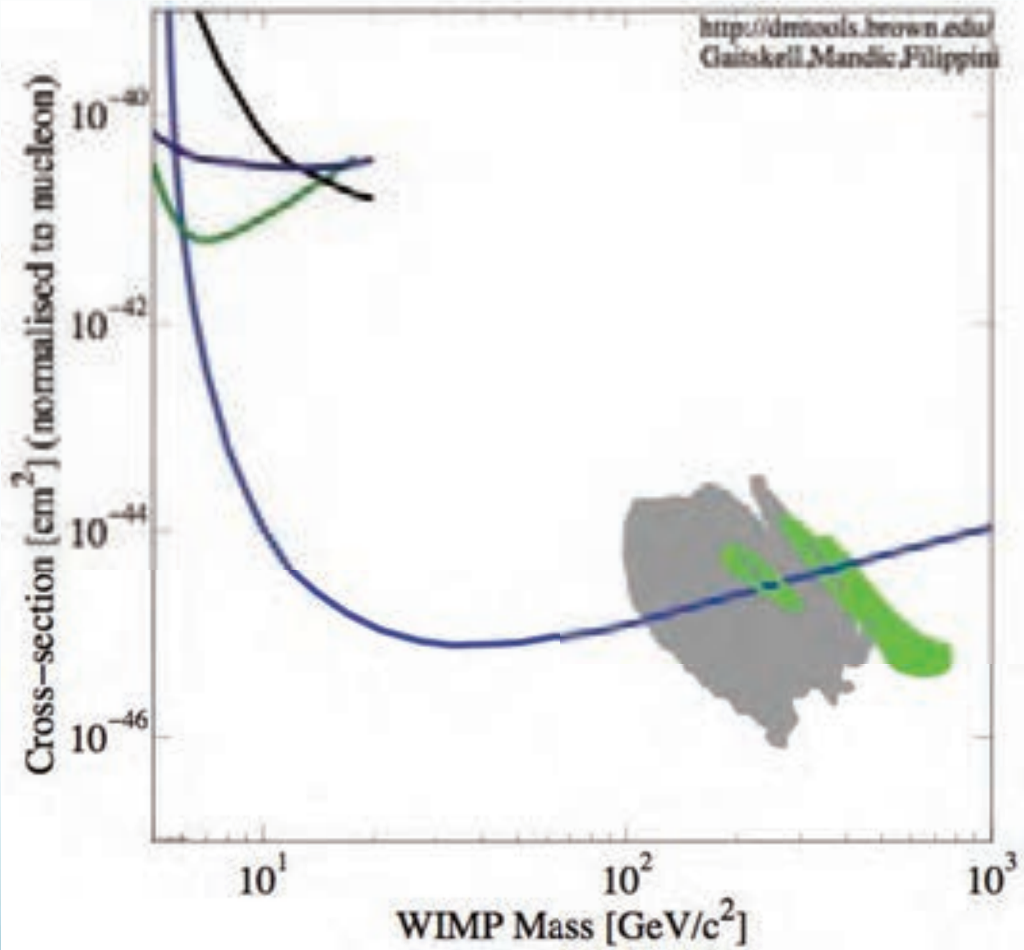
2. Exponential suppression as temperature falls below mass of dark matter particle.

$n_{eq} \sim (m/T)^{3/2}\, e^{-m/T}$

3. Turn over as annihilation rate decreases, becoming smaller than the expansion rate.

4. Relic abundance remains. Larger cross-sections keep annihilations occurring for longer.

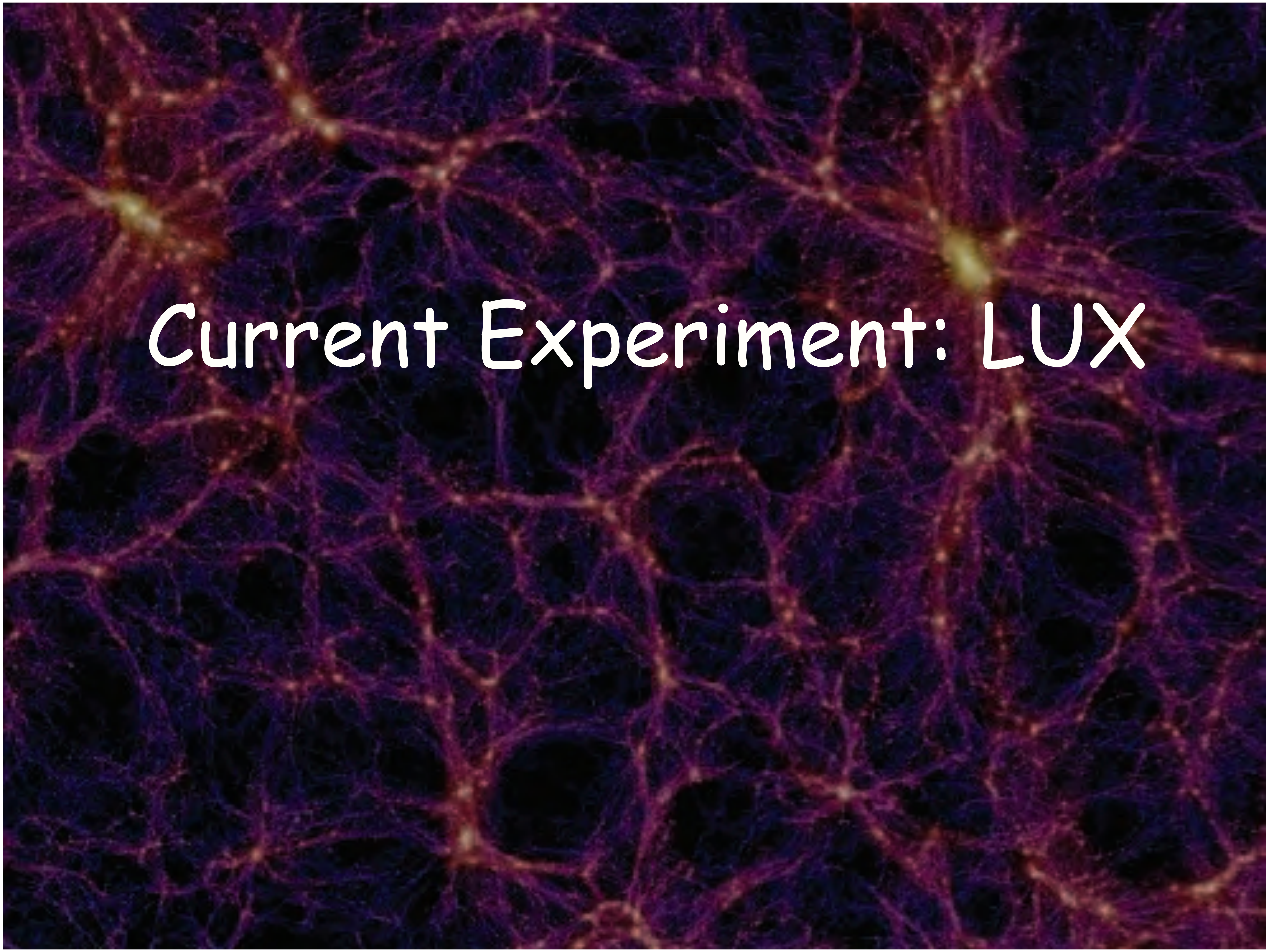
# Time Progression of Sensitivity




Years 2000-2013

Animation courtesy of Aaron Manalaysay, UC Davis

# Current Experiment: LUX



# The LUX Collaboration

### Brown

| | |
|---|---|
| **Richard Gaitskell** | PI, Professor |
| **Simon Fiorucci** | Research Associate |
| **Samuel Chung Chan** | Graduate Student |
| **Dongqing Huang** | Graduate Student |
| **Casey Rhyne** | Graduate Student |
| **Will Taylor** | Graduate Student |
| **James Verbus** | Graduate Student |

### Imperial College London

| | |
|---|---|
| **Henrique Araujo** | PI, Reader |
| **Tim Sumner** | Professor |
| **Alastair Currie** | Postdoc |
| **Adam Bailey** | Graduate Student |
| **Khadeeja Yazdani** | Graduate Student |

### Lawrence Berkeley + UC Berkeley

| | |
|---|---|
| **Bob Jacobsen** | PI, Professor |
| **Murdock Gilchriese** | Senior Scientist |
| **Kevin Lesko** | Senior Scientist |
| **Peter Sorensen** | Scientist |
| **Victor Gehman** | Scientist |
| **Attila Dobi** | Postdoc |
| **Daniel Hogan** | Graduate Student |
| **Mia Ihm** | Graduate Student |
| **Kate Kamdin** | Graduate Student |
| **Kelsey Oliver-Mallory** | Graduate Student |

### Lawrence Livermore

| | |
|---|---|
| **Adam Bernstein** | PI, Leader of Adv. Detectors Grp. |
| **Kareem Kazkaz** | Staff Physicist |
| **Brian Lenardo** | Graduate Student |

### LIP Coimbra

| | |
|---|---|
| **Isabel Lopes** | PI, Professor |
| **Jose Pinto da Cunha** | Assistant Professor |
| **Vladimir Solovov** | Senior Researcher |
| **Francisco Neves** | Auxiliary Researcher |
| **Alexander Lindote** | Postdoc |
| **Claudio Silva** | Postdoc |

### SLAC Nation Accelerator Laboratory

| | |
|---|---|
| **Dan Akerib** | PI, Professor |
| **Thomas Shutt** | PI, Professor |
| **Kim Palladino** | Project Scientist |
| **Tomasz Biesiadzinski** | Research Associate |
| **Christina Ignarra** | Research Associate |
| **Wing To** | Research Associate |
| **Rosie Bramante** | Graduate Student |
| **Wei Ji** | Graduate Student |
| **T.J. Whitis** | Graduate Student |

### SD School of Mines

| | |
|---|---|
| **Xinhua Bai** | PI, Professor |
| **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 |
| **Paul Terman** | Graduate Student |

### University at Albany, SUNY

| | |
|---|---|
| **Matthew Szydagis** | PI, Professor |
| **Jeremy Mock** | Postdoc |
| **Steven Young** | Graduate Student |

### UC Davis

| | |
|---|---|
| **Mani Tripathi** | PI, Professor |
| **Britt Hollbrook** | Senior Engineer |
| **John Thmpson** | Development Engineer |
| **Dave Herner** | Senior Machinist |
| **Ray Gerhard** | Electronics Engineer |
| **Aaron Manalaysay** | Postdoc |
| **Scott Stephenson** | Postdoc |
| **Jacob Cutter** | Graduate Student |
| **James Morad** | Graduate Student |
| **Sergey Uvarov** | Graduate Student |

### UC Santa Barbara

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

### University College London

| | |
|---|---|
| **Chamkaur Ghag** | PI, Lecturer |
| **Sally Shaw** | Graduate Student |


Collaboration Meeting, Lead, June 2015

### University of Edinburgh

| | |
|---|---|
| **Alex Murphy** | PI, Reader |
| **Paolo Beltrame** | Research Fellow |
| **James Dobson** | Postdoc |
| **Tom Davison** | Graduate Student |
| **Maria Francesca Marzioni** | Graduate Student |

### University of Maryland

| | |
|---|---|
| **Carter Hall** | PI, Professor |
| **Jon Balajthy** | Graduate Student |
| **Richard Knoche** | Graduate Student |

### University of Rochester

| | |
|---|---|
| **Frank Wolfs** | PI, Professor |
| **Wojtek Skutski** | Senior Scientist |
| **Eryk Druszkiewicz** | Graduate Student |
| **Dev Ashish Khaitan** | Graduate Student |
| **Mongkol Moongweluwan** | Graduate Student |

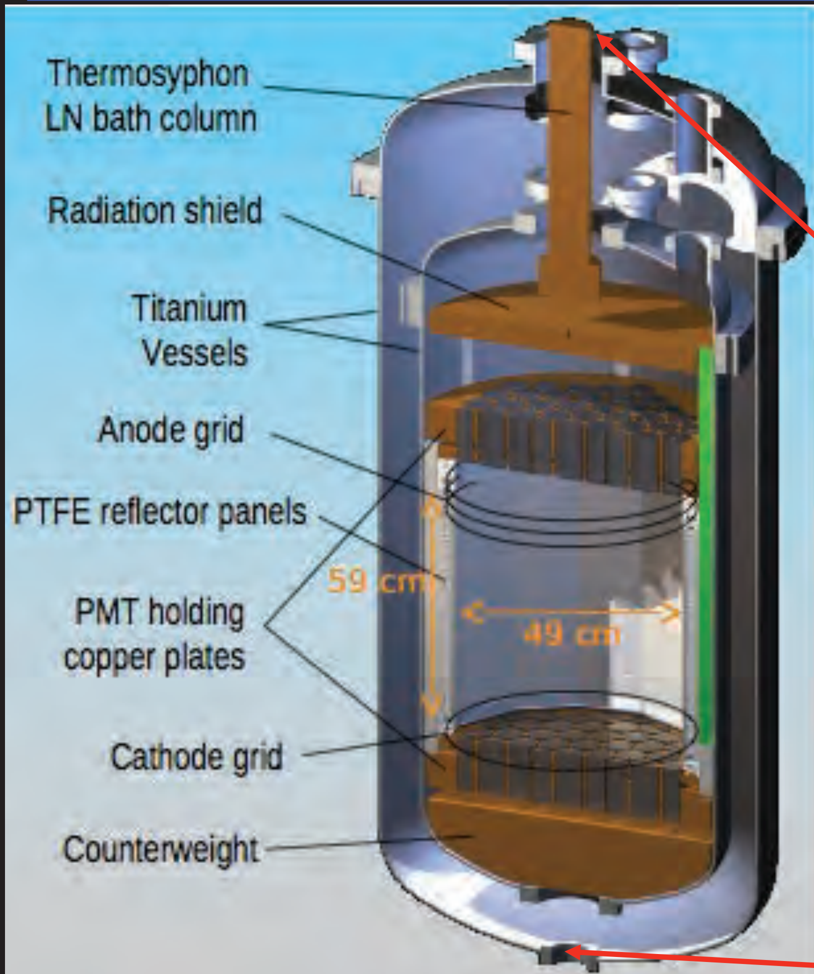
### University of South Dakota

| | |
|---|---|
| **Dongming Mei** | PI, Professor |
| **Chao Zhang** | Postdoc |
| **Angela Chiller** | Graduate Student |
| **Chris Chiller** | Graduate Student |

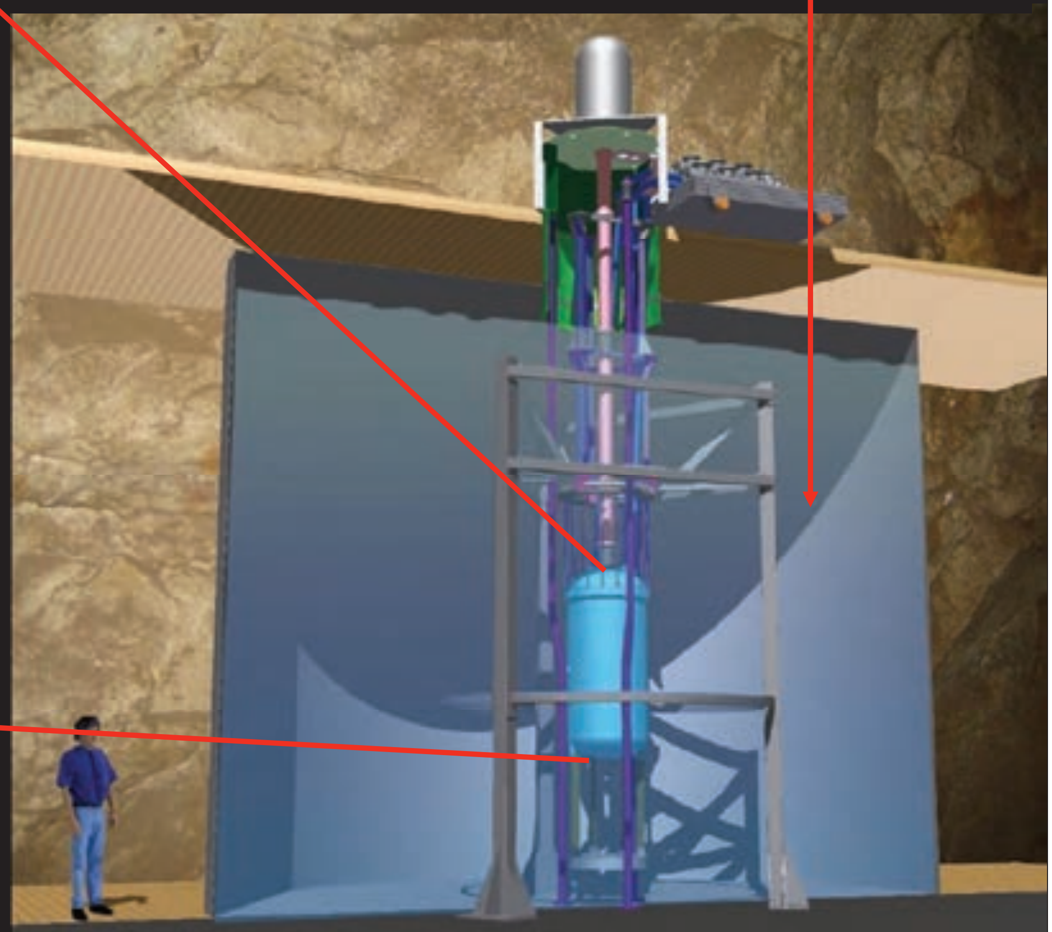
### Yale

| | |
|---|---|
| **Daniel McKinsey** | PI, Professor |
| **Ethan Bernard** | Research Scientist |
| **Markus Horn** | Research Scientist |
| **Blair Edwards** | Postdoc |
| **Scott Hertel** | Postdoc |
| **Kevin O'Sullivan** | Postdoc |
| **Elizabeth Boulton** | Graduate Student |
| **Nicole Larsen** | Graduate Student |
| **Evan Pease** | Graduate Student |
| **Brian Tennyson** | Graduate Student |
| **Lucie Tvrznikova** | Graduate Student |

# The LUX detector

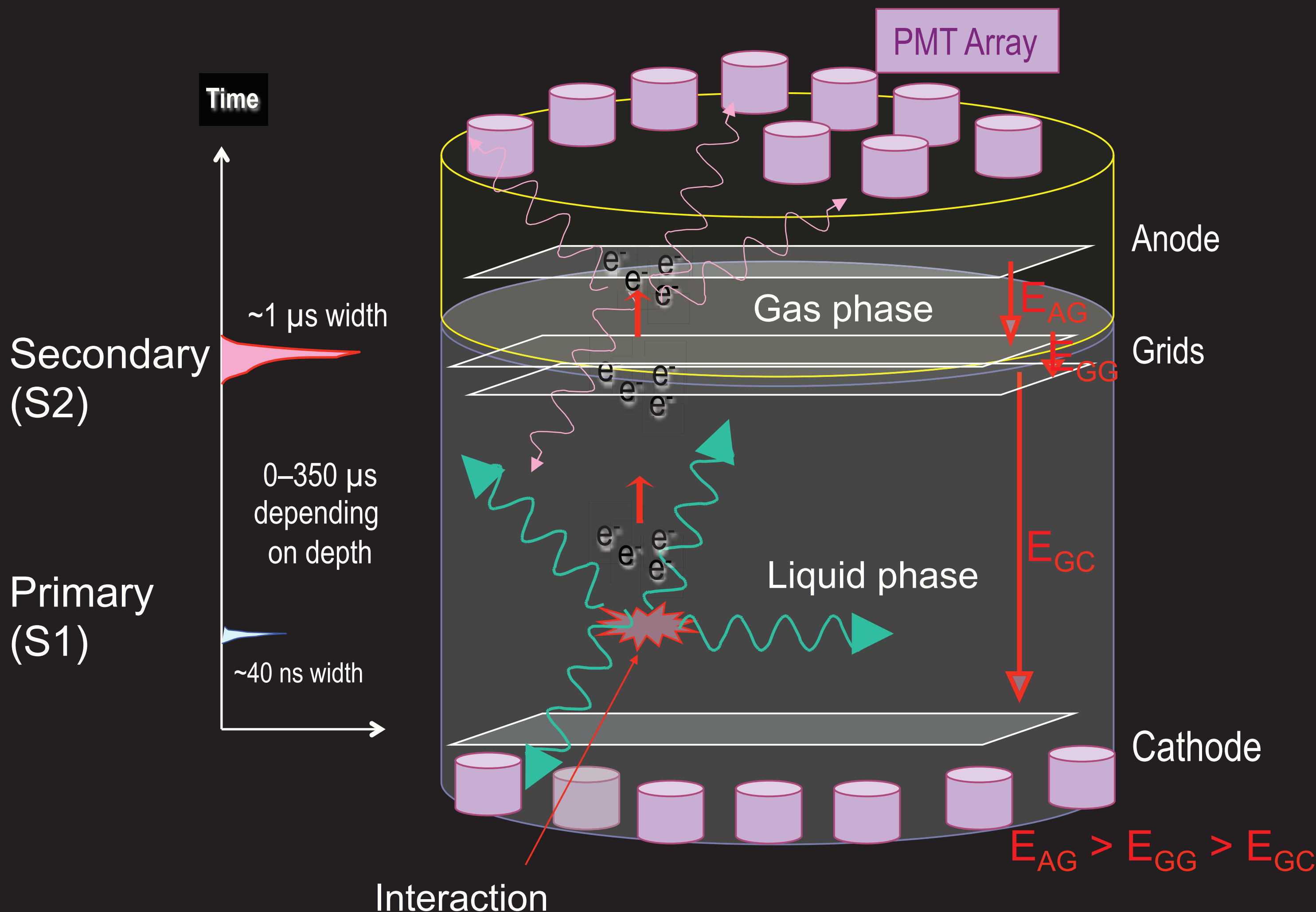



- ~ 7m diameter Water Cerenkov Shield.
- 48 cm H (gate to cathode) X 47 cm D active region with 181 V/cm drift field

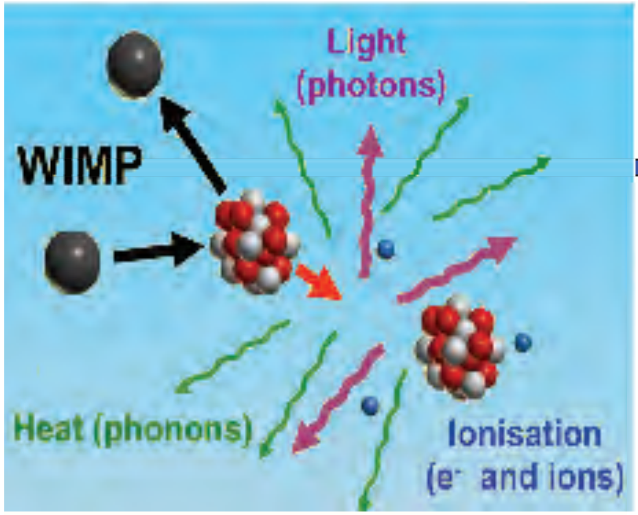


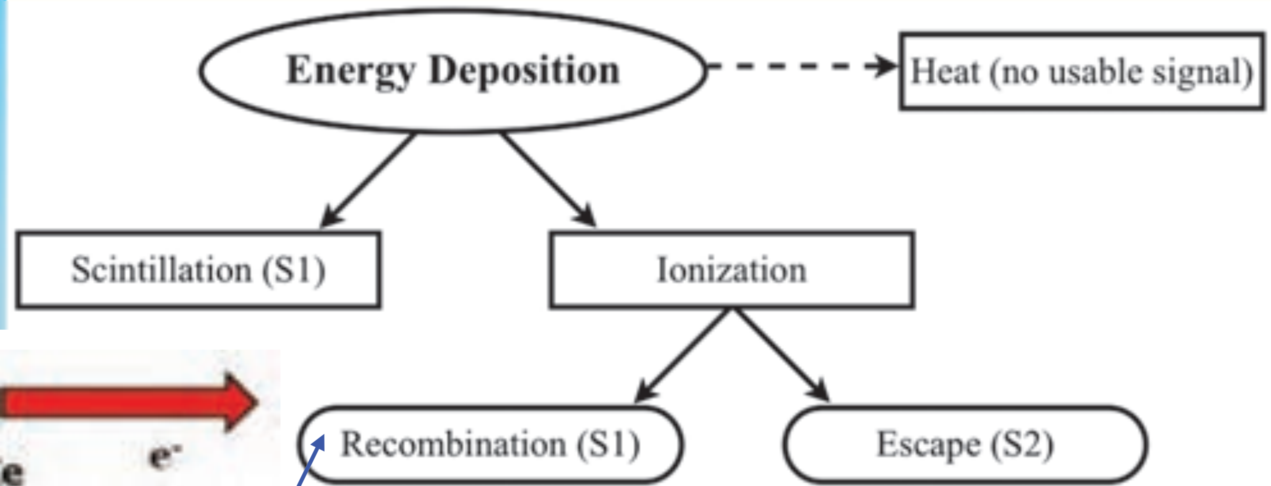
•250 kg (active), 118 kg (fiducial) of Lxe
•122 photomultiplier tubes (top plus bottom)

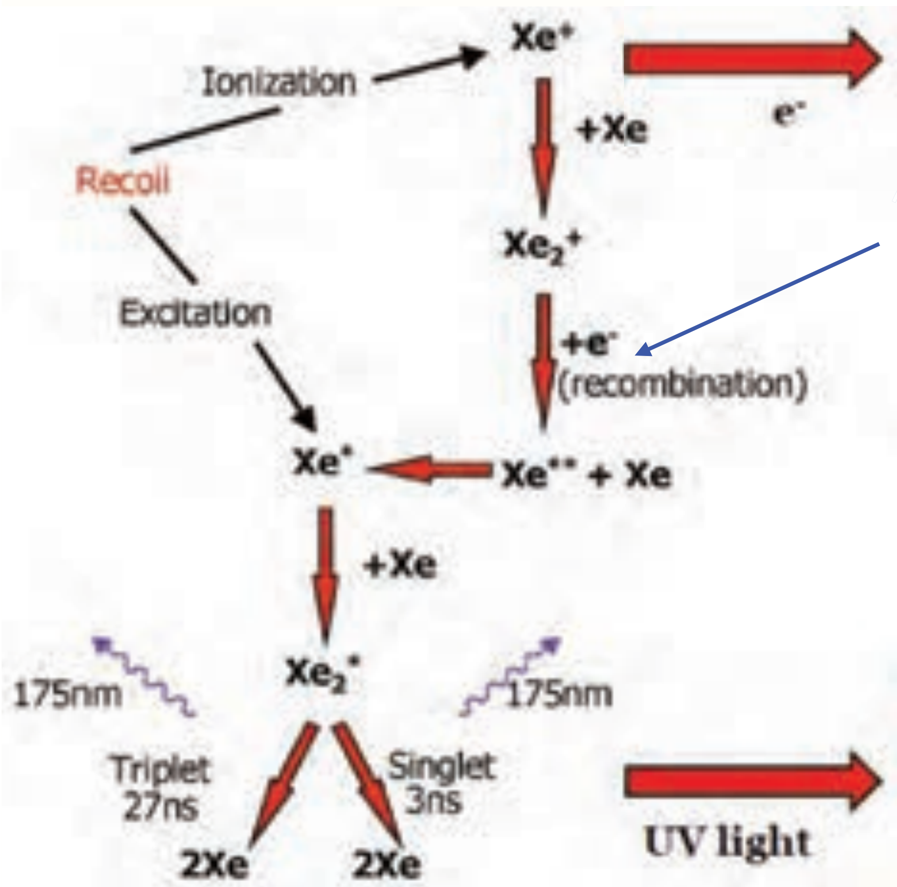
# Two Signal Technique



# Scintillation process in LXe



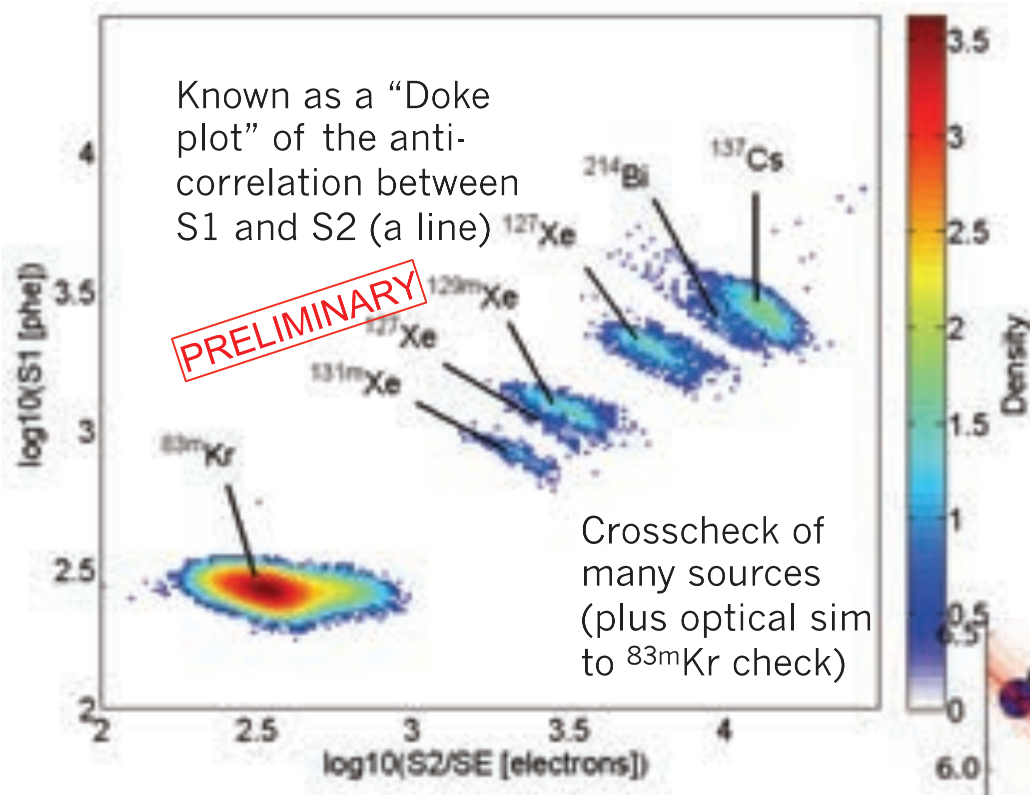

Difference in in recombination efficiency is exploited to discriminate between electron and nuclear recoils.

Xenon is transparent to its own scintillation light !

Figure of merit derived from plots of:

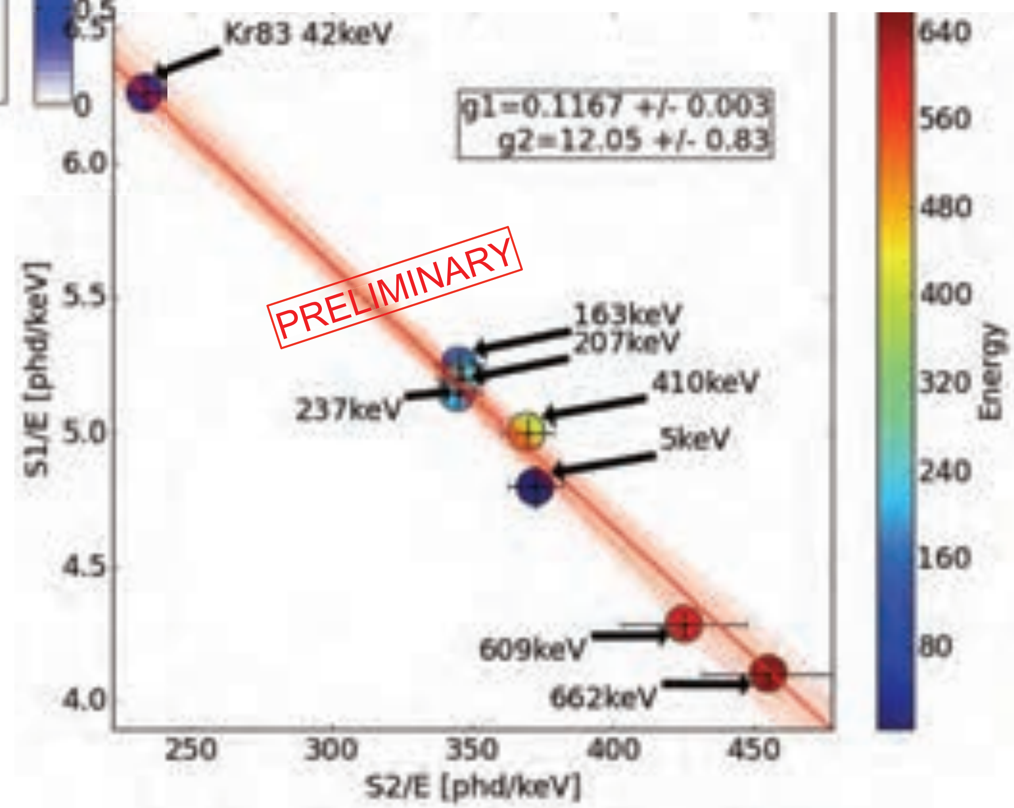
Log (charge escaping recombination/ total primary light produced)

# New Calculation of the g-Factors




12% efficiency for the detection of a primary scintillation photon

Previously 14% quoted

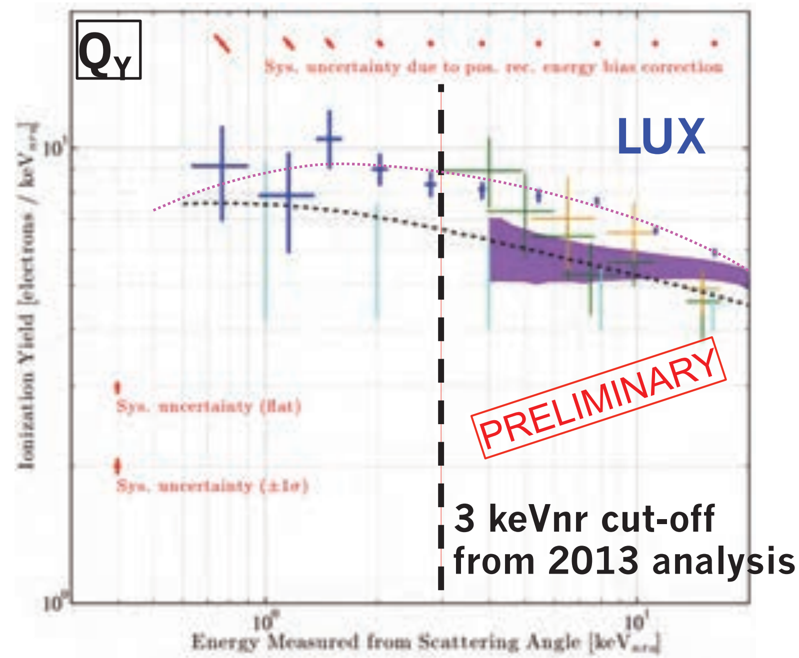


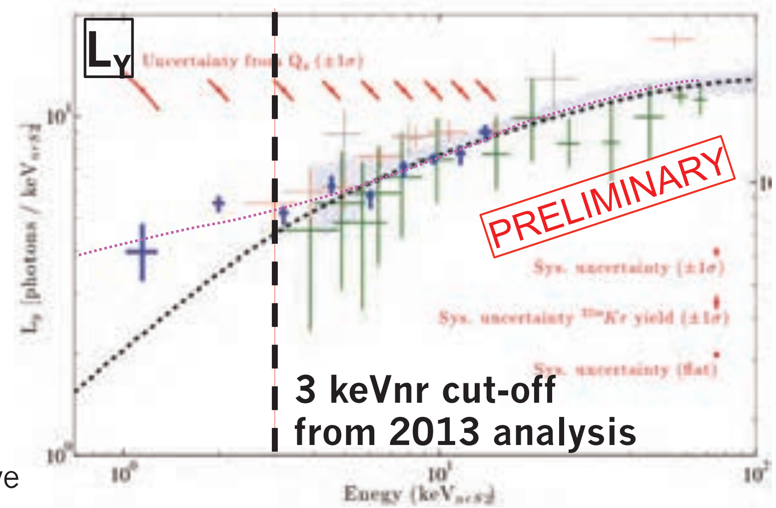

49% extraction, coupled with 24.66 detected photons per single electron to make "$g_2$"

Previously 65%, but it is product of absolute yield with is what matters

# NR Charge and Light Yields

- *in situ* measurements
- No longer relying on LUX AmBe, $^{252}Cf$, or modeling from old data, or extrapolating from results of small test chambers.
- *Charge yield* Measured down to ~0.8 keVnr. (Previous low 4 keV)
- Data from Deuterium-Deuterium neutron gun. Use S2 to identify double scatters. Determine energy deposition from scattering angle. For S1, S2-derived energy scale.
- *Light yield* measured down to ~1.2 keVnr. (Previous low 3 keV)
- New modeling



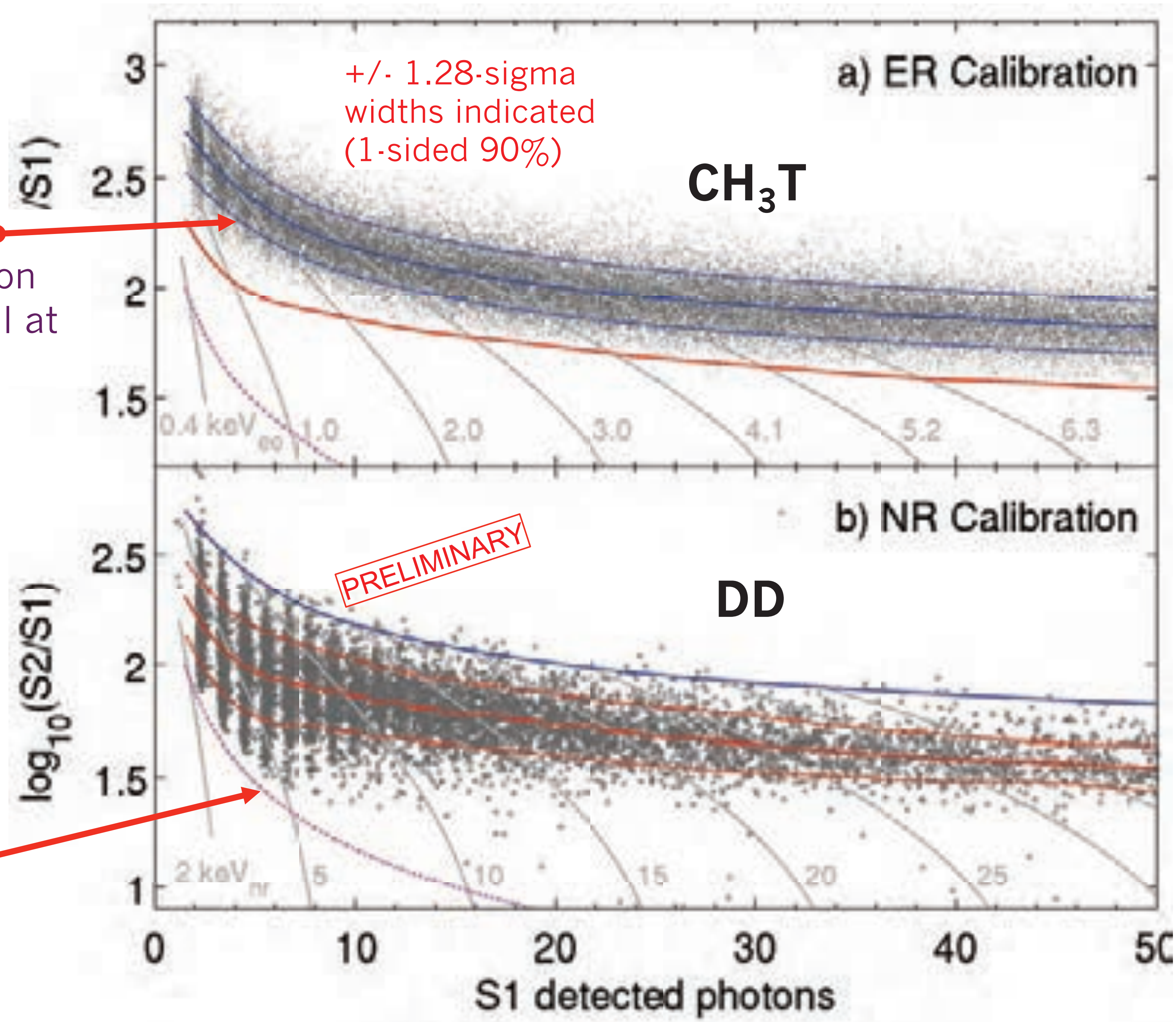




------ NEST 1.0 still too conservative
------ Modified NEST for re-analysis

# The "Bands"

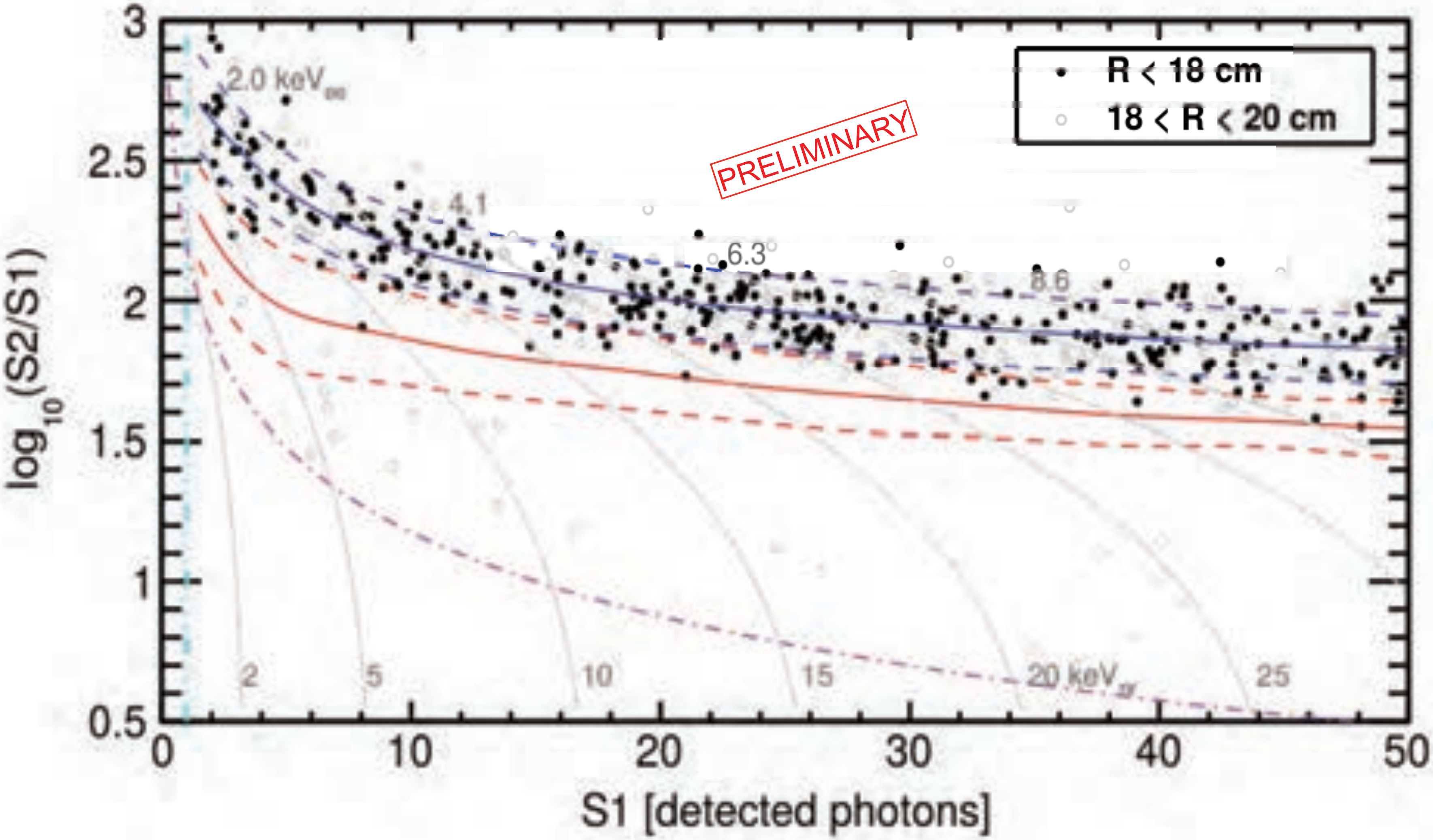
New: DIGITAL individual photon counting, useful at low energies

Approximate location of 165 phd cut, lowered from 200 previous (8 => 6 e⁻'s)



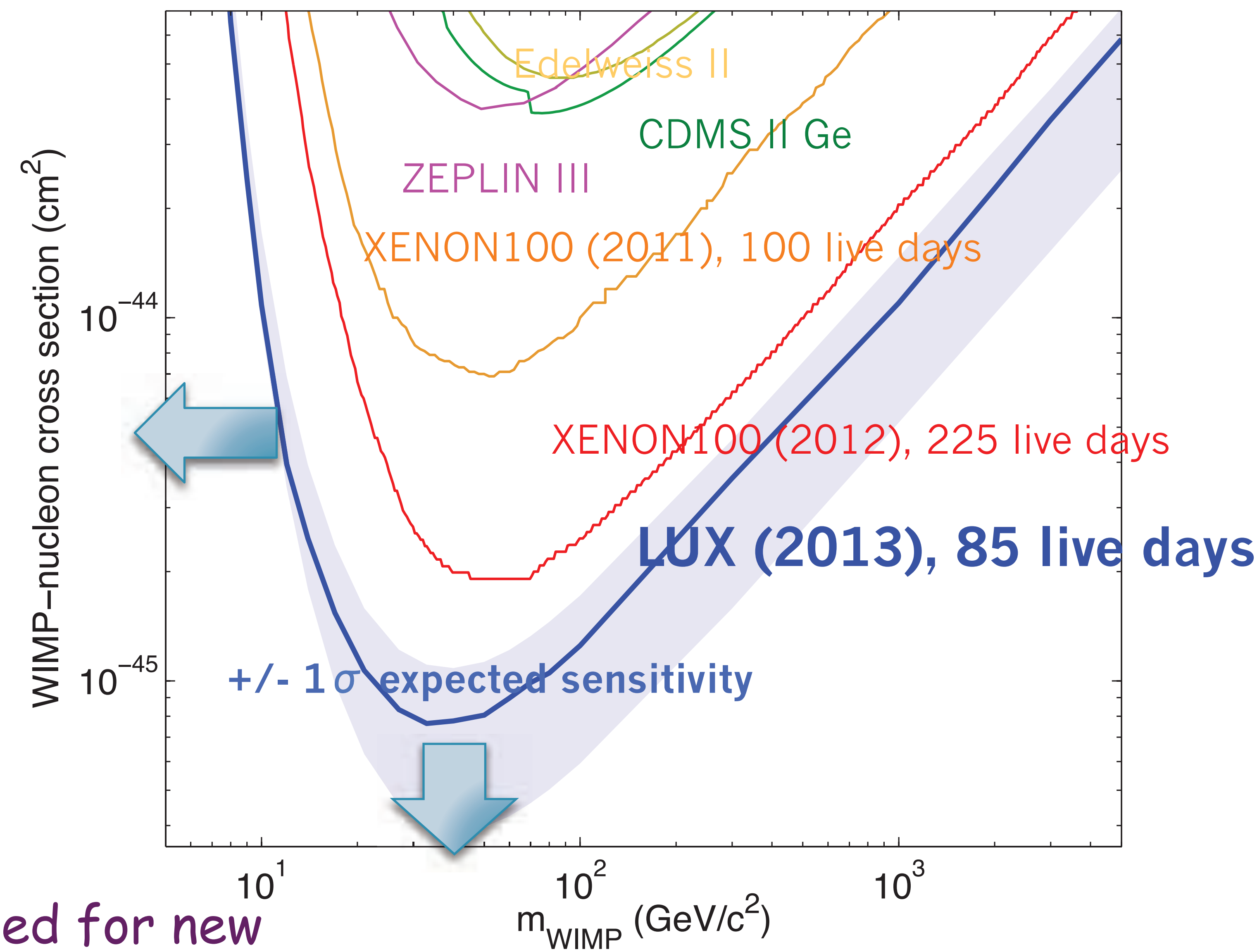

S1 and S2 are both position-corrected using Kr

# Updated WIMP Search Data



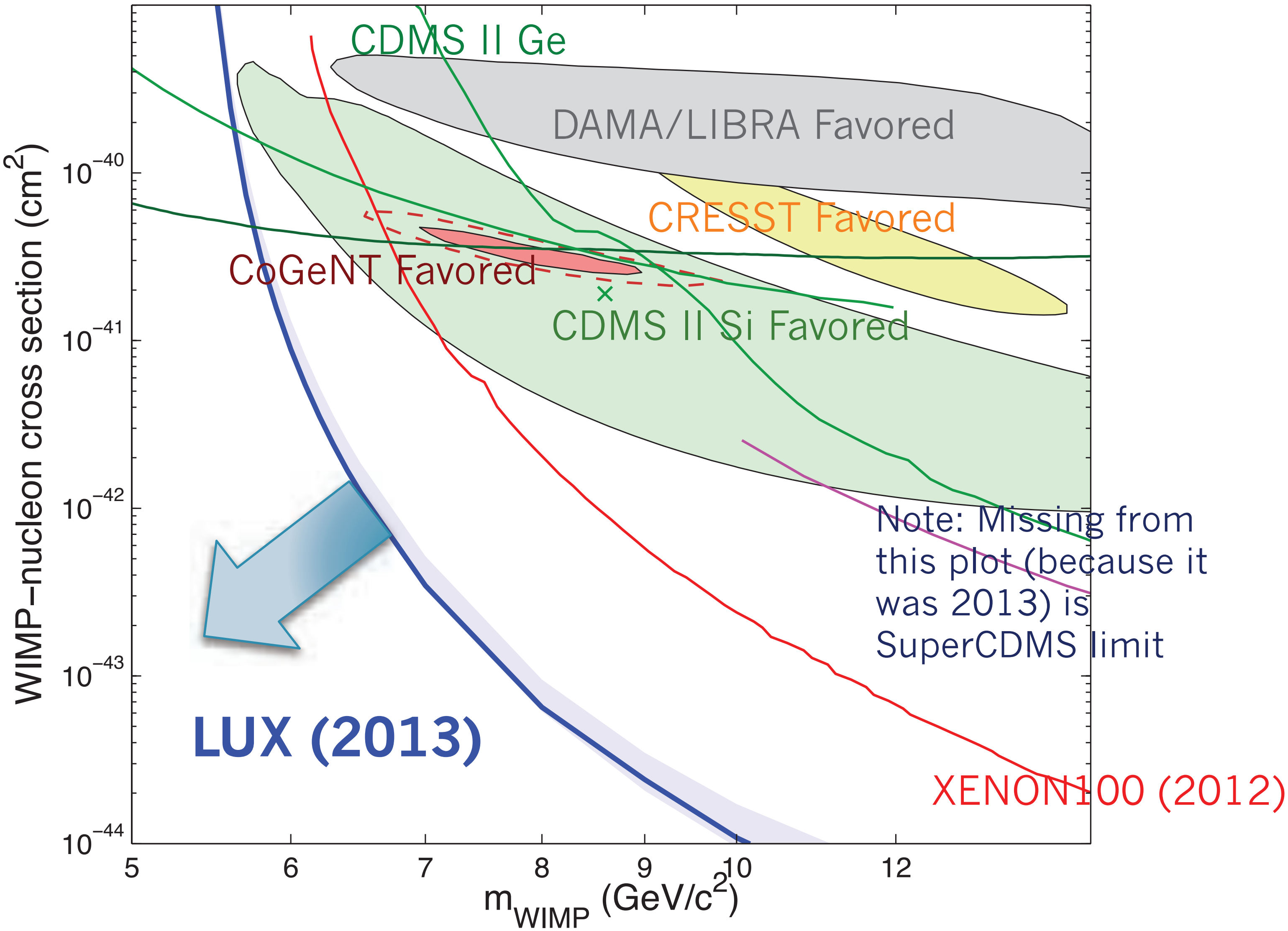

A Profile Likelihood Ratio (not cut-and-count) method uses all events.

# WIMP Dark Matter Limit

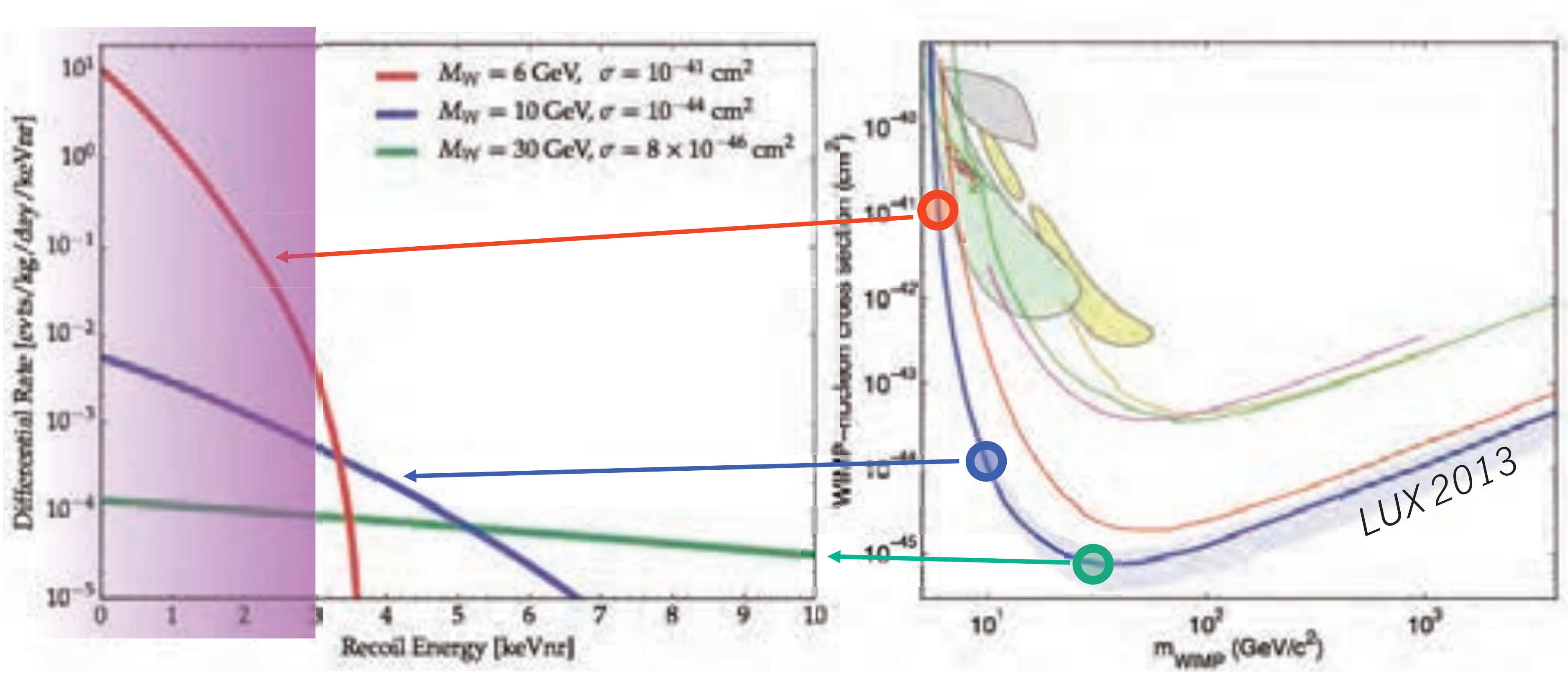



Stay tuned for new results later this year.

# LUX Low-Mass Sensitivity



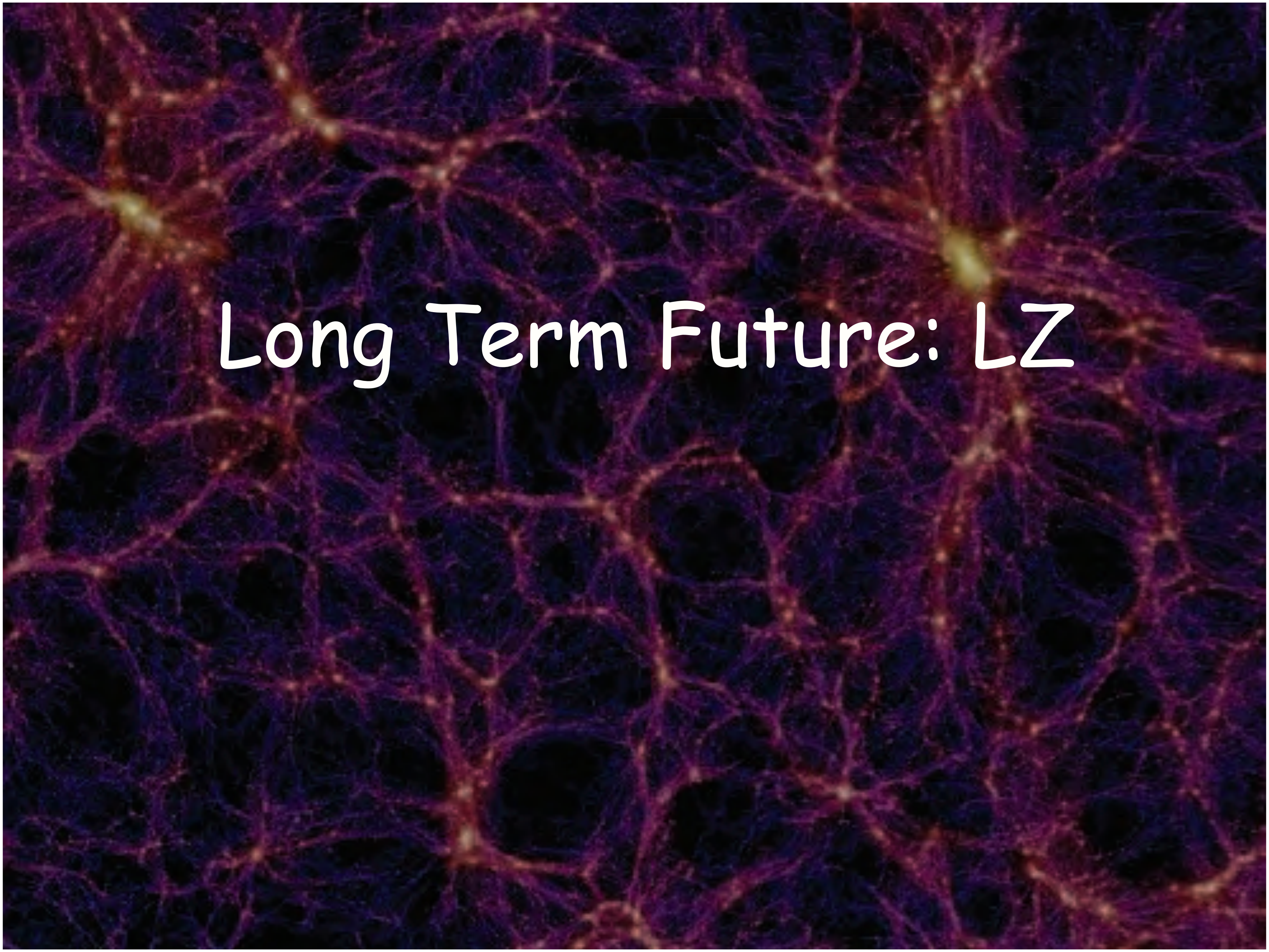
# Another Look at Light WIMPs



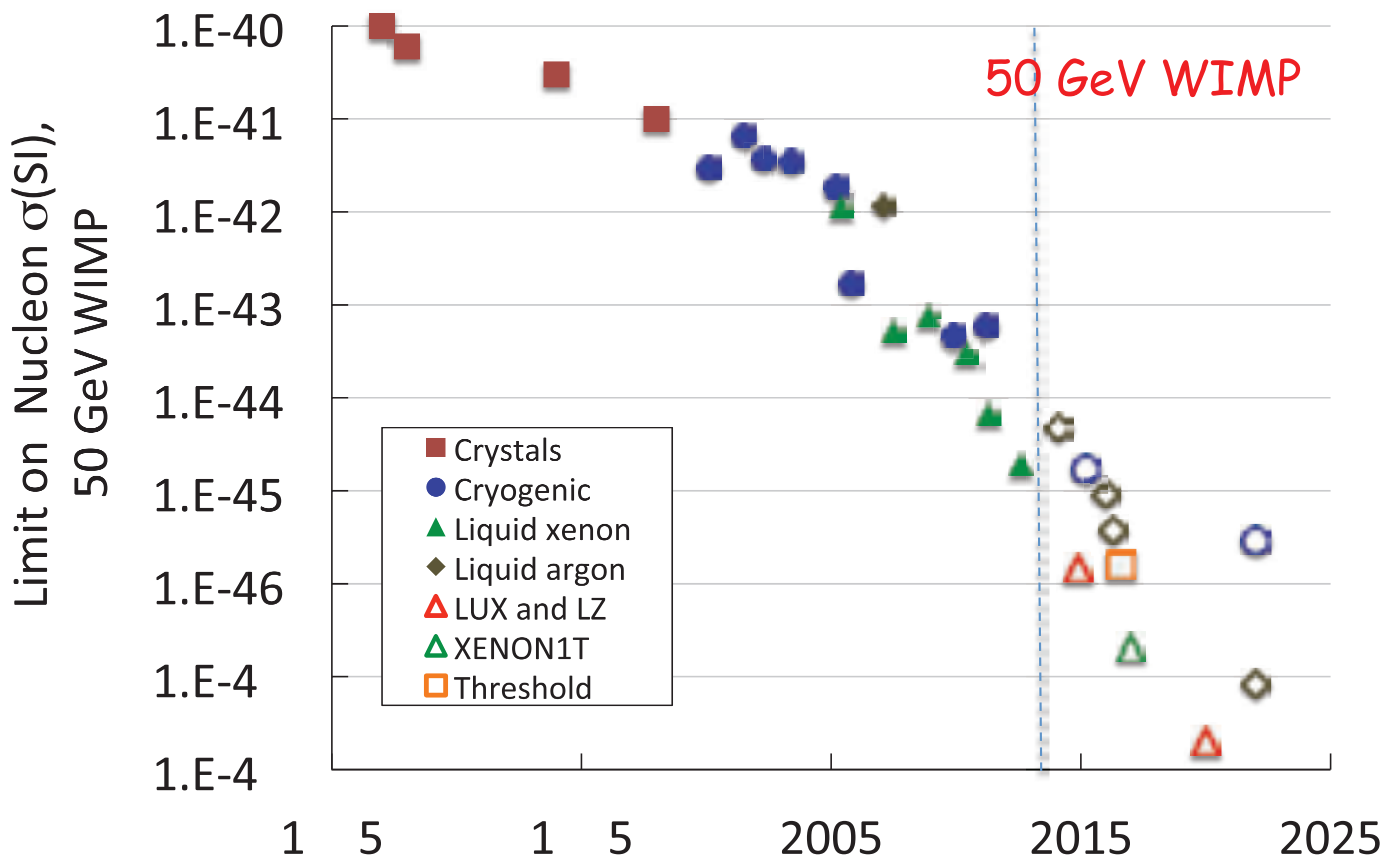

LUX 2013 upper limits assumed NO SENSITIVITY to recoils below 3 keVnr. This was not an *analysis* threshold, but an artificial one, a hard cut-off

For example, decreasing this response cutoff from 3 keV to 1 keV provides access to a factor of 1000* more signal at $M$ = 6 GeV/c$^2$.

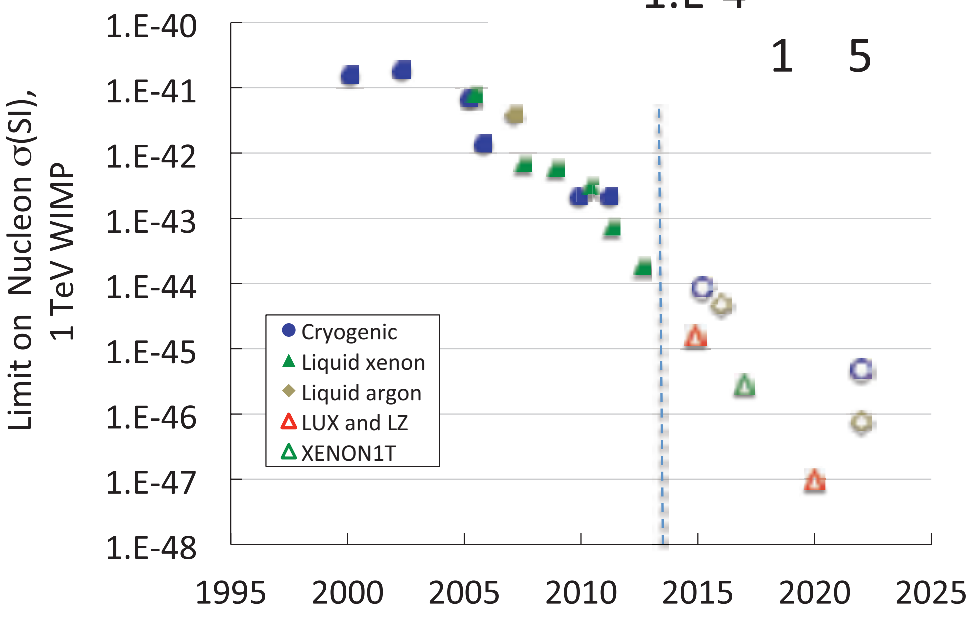
# Long Term Future: LZ



# A compact history of WIMP Searches



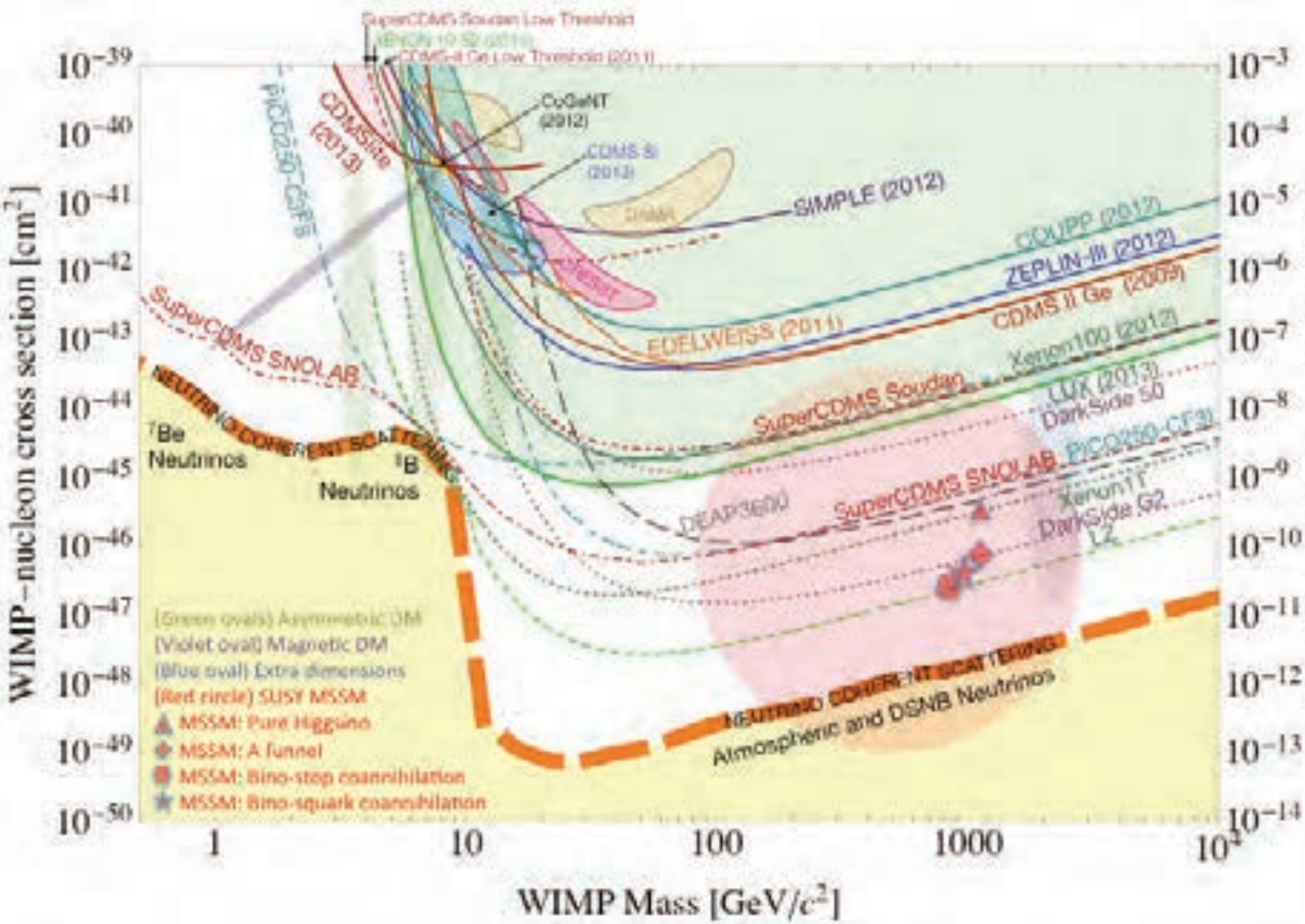

1 TeV WIMP




LZ is poised to possibly provide an end-point to this saga … hopefully by discovering WIMPs or, by ruling out most of the theoretical <u>and</u> experimentally accessible landscape.

Plots compiled b
Mike Witherell UCSB

# Snowmass Projections



# LZ LUX ZEPLIN

ins t ons c rrentl
Abo t people

LIP Coimbra Port gal
MEPhI R ssia
Edinb rgh Uni ersit UK
Uni ersit of Li erpool UK
Imperial College London UK
Uni ersit College London UK
Uni ersit of O ford UK
STFC R therford Appleton Laboratories UK
Shanghai Jiao Tong Uni ersit China
Uni ersit of Sheffield UK

Uni ersit of Alabama
Uni ersit at Alban SUNY
Berkele Lab LBNL
Uni ersit of California Berkele
Brookha en Na onal Laborator
Bro n Uni ersit
Uni ersit of California Da is
Fermi Na onal Accelerator Laborator
Ka li Ins t te for Par cle Astroph sics Cosmolog
La rence Li ermore Na onal Laborator
Uni ersit of Mar land
Uni ersit of Michigan
North estern Uni ersit
Uni ersit of Rochester
Uni ersit of California Santa Barbara
Uni ersit of So th Dakota
So th Dakota School of Mines Technolog
So th Dakota Science and Technolog A thorit
SLAC Na onal Accelerator Laborator
Te as A M
Washington Uni ersit
Uni ersit of Wisconsin
Yale Uni ersit

# LZ Meeting at U. of Alabama

# LZ Timeline

| Year | Month | Activity |
| --- | --- | --- |
| | March | LZ LUX ZEPLIN collabora on formed |
| | Ma | First Collabora on Mee ng |
| | September | DOE CD for G dark ma er e periments |
| | No ember | LZ R D report s bmi ed |
| | J l | LZ Project selected in US and UK |
| | April | DOE CD a appro al similar in UK<br>Begin long lead proc rements Xe PMT cr ostat |
| | April | DOE CD b appro al baseline all fab starts |
| | J ne | Begin prepara ons for s rface assembl SURF |
| | J l | Begin ndergro nd installa on |
| | Feb | Begin commissioning |

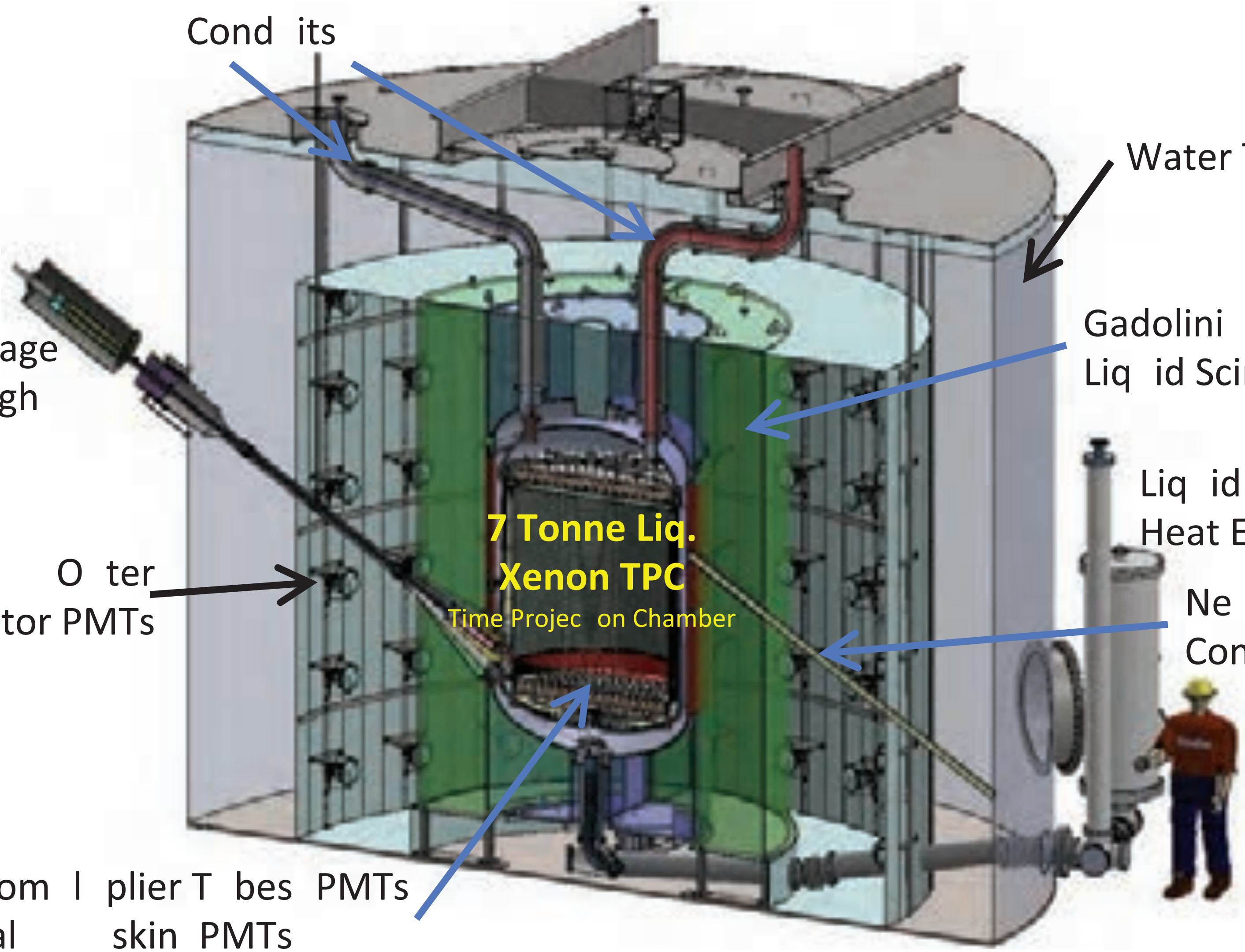
# Scale Up in Fid cial Mass

LUX

**LZ**

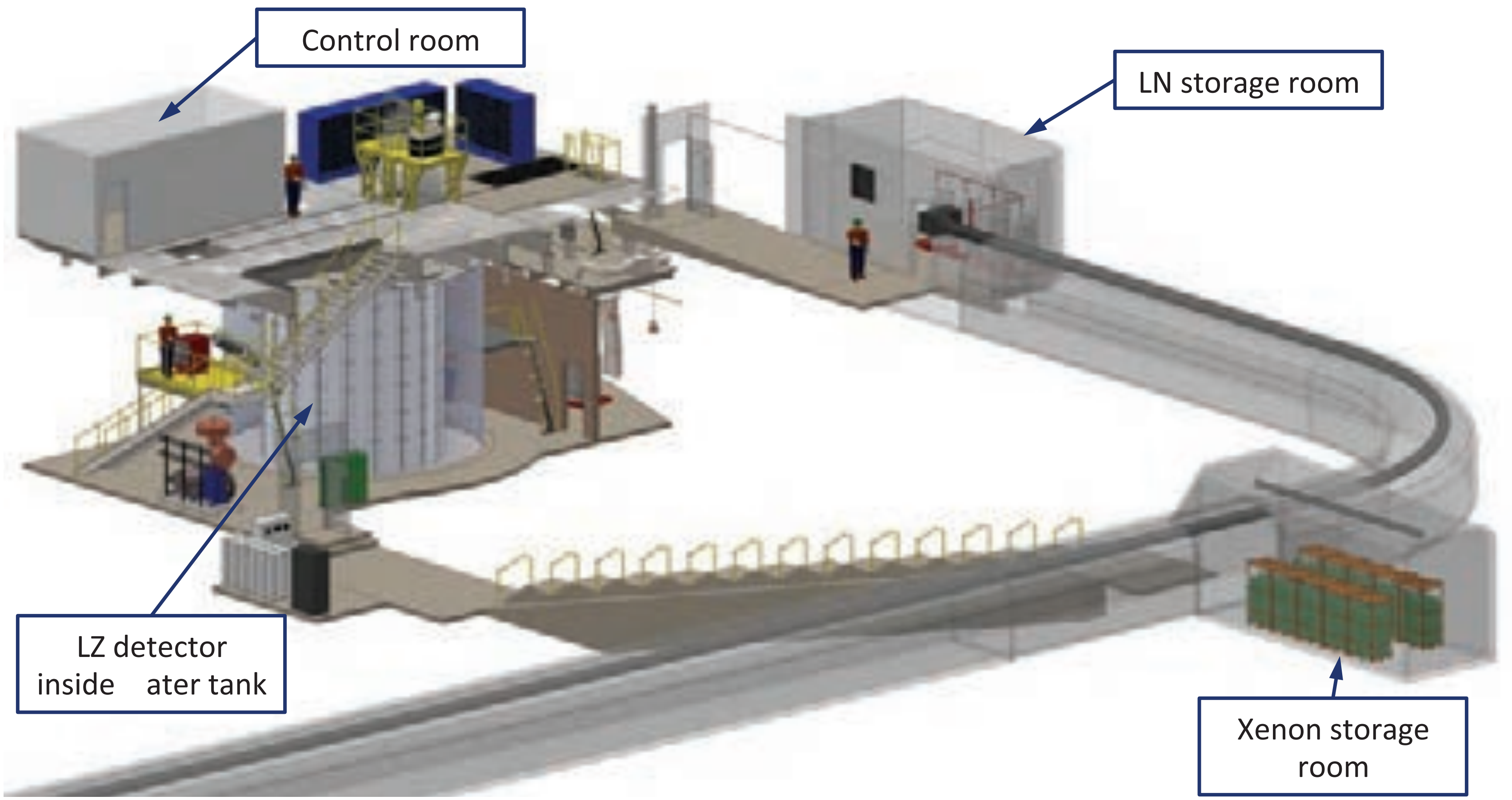
Total mass - 10 T
Active Mass - 7 T
Fiducial Mass - 5.6 T

# LZ O er ie


Instr menta on
Cond its
Water Tank
High Voltage
Feedtro gh
Gadolini m Loaded
Liq id Scin llator
Liq id Xenon
Heat E changer
7 Tonne Liq.
Xenon TPC
Time Projec on Chamber
O ter
Detector PMTs
Ne tron Calib
Cond it
Photom l plier T bes PMTs
Addi onal skin PMTs

# LZ Undergro nd at SURF

Years of e perience at SURF from LUX



# Key Design Points

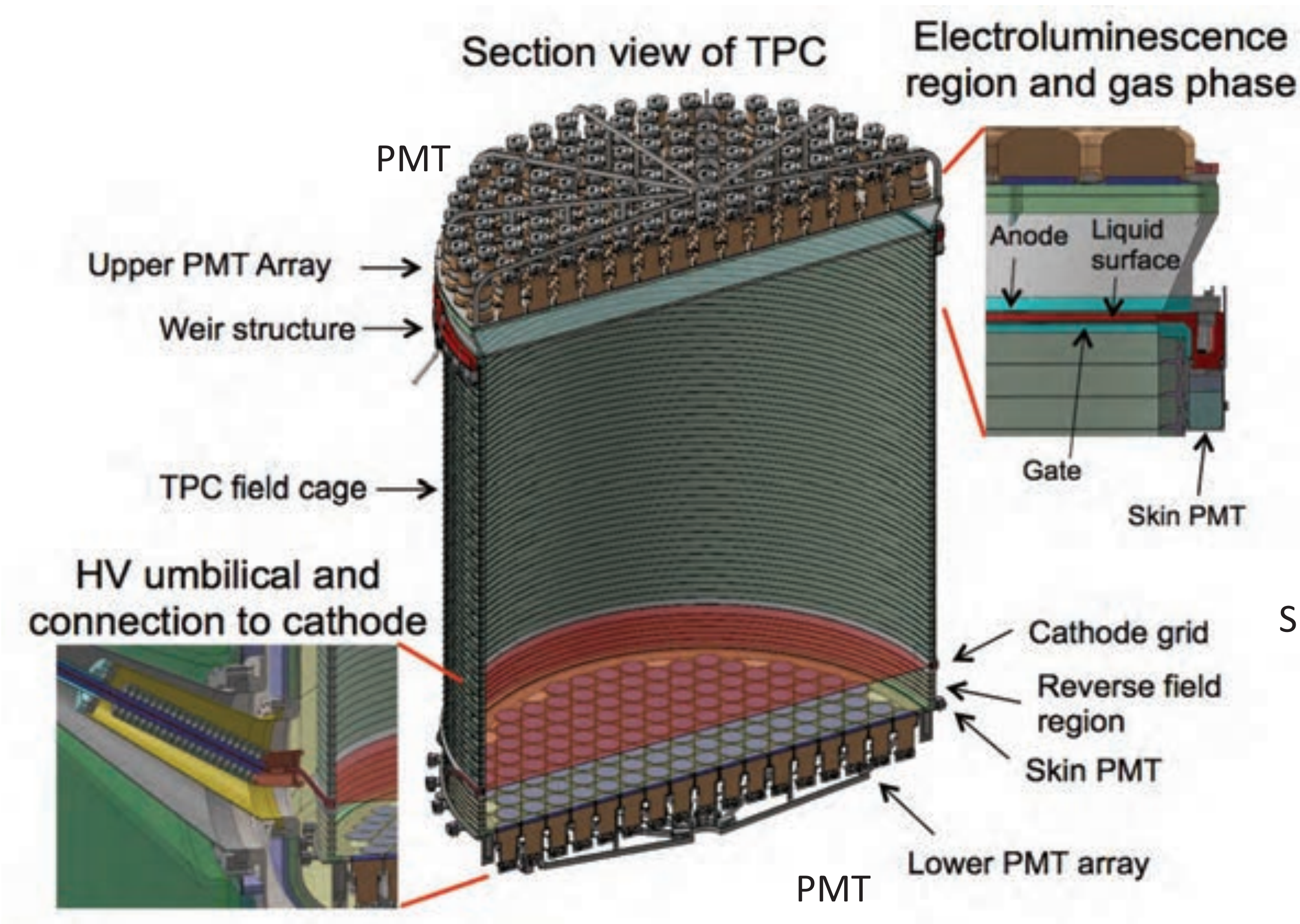
- ✓ 7 active tonnes of LXe can yield 2 x $10^{-48}$ $cm^2$ sensitivity in about three years of running
- ✓ 5.6 tonne fiducial volume, 1000 days
- ✓ Requires all detector systems working together

  - ◆ Xe detector with good light collection, reasonable background rejection (ER discrimination) and good signal detection efficiency
  - ◆ Sophisticated veto system: skin (outside active Xe region) + scintillator/water allows maximum fiducial volume to be obtained, maximizes use of Xe and substantially increases reliability of background measurements
  - ◆ Control backgrounds, both internal (within the Xe) and external from detector components/environment

# Design Status Summary

- Conceptual, and in some cases more advanced design, completed for all aspects of detector
- Conceptual Design Report about to appear on arXiv
- Acquisition of Xenon started
- Procurement of PMTs and cryostat started
- Collaboration – wide prototype program underway to guide and validate design
- Backgrounds modeling and validation well underway

# Xe TPC Detector




PMT

PMT

total
Skin PMT

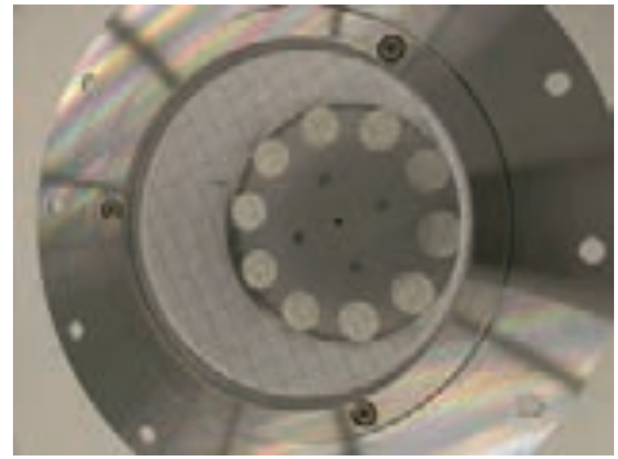
# Xe Detector PMTs

- R PMTs for TPC region
  - E tensi e de elopment program t bes in hand benefit from similar de elopment for XENON PANDA X and RED
  - Materials ordered and radioassa s started prior to fabrica on
  - First prod c on t bes earl
  - Joint US and UK effort
- R for skin region
  - Considering sing or for bo om dome region rec cle t bes from older detectors

# Xe Detector Protot ping

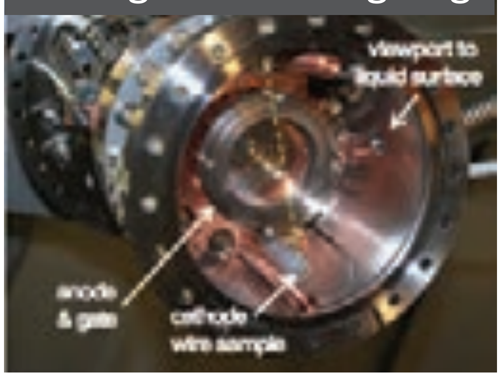
- Extensive program of prototype development underway
- Three general approaches
  - Testing in liquid argon, primarily of HV elements, at Yale and soon at LBNL
  - Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, Yale-> UC Berkeley, LBNL, U Michigan, UC Davis, Imperial College, MEPhI
  - System test platform at SLAC, Phase I about 100 kg of LXe, TPC prototype testing to begin in few months

# High Voltage St dies



Protot pe of highest E field region tested in LAr

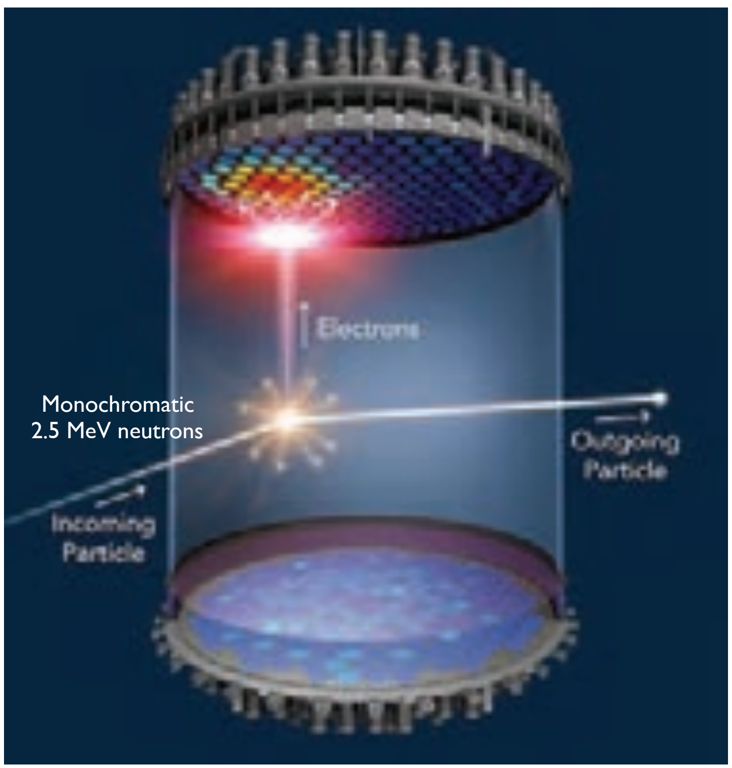
Wire grid tests ongoing



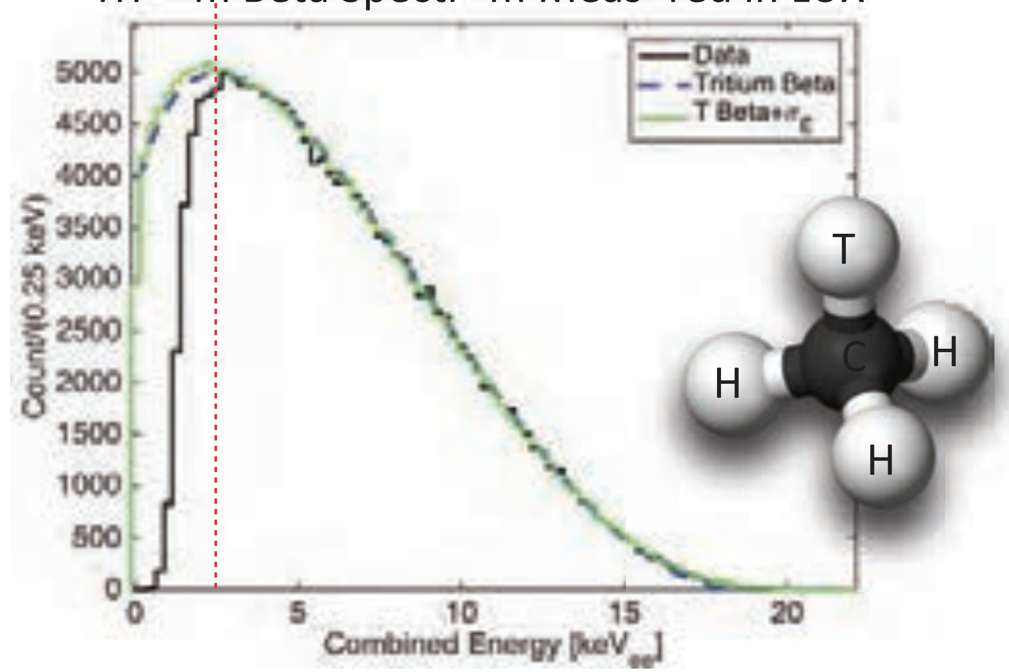

- ✦Cathode oltage design goal kV pro ides margin
- ✦LZ nominal opera ng goal kV V cm
- ✦Feedthro gh protot pe tested to kV
- ✦Protot pe TPC for kg LXe s stem fabrica on star ng
- ✦HV protot ping e panding at Berkele

# LZ Calibrations

- Demonstrated in LUX  Calibrate The Signal and Backgro  nd Model *in situ.*
- DD Ne  tron Generator  N  clear Recoils
- Tri  ated Methane  Electron Recoils
- Addi  onal So  rces e g  YBe So  rce for lo    energ    N  clear Recoils




Tri     m Beta Spectr  m Meas  red in LUX



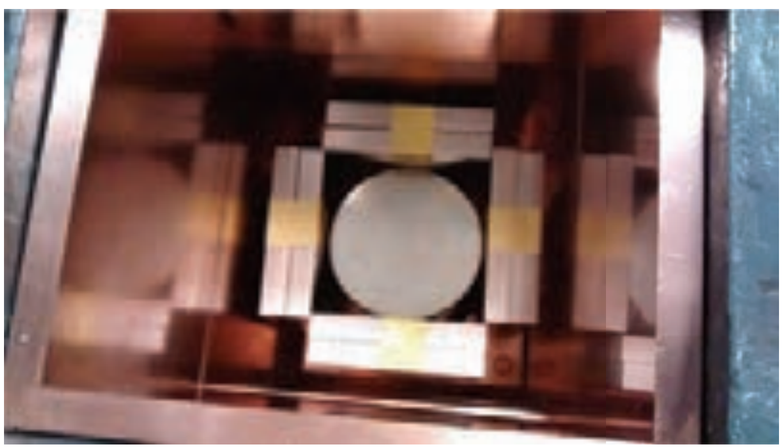
# E tensi e Calibra on

- LUX has led the a to detailed calibra ons LZ ill b ild on this and do more

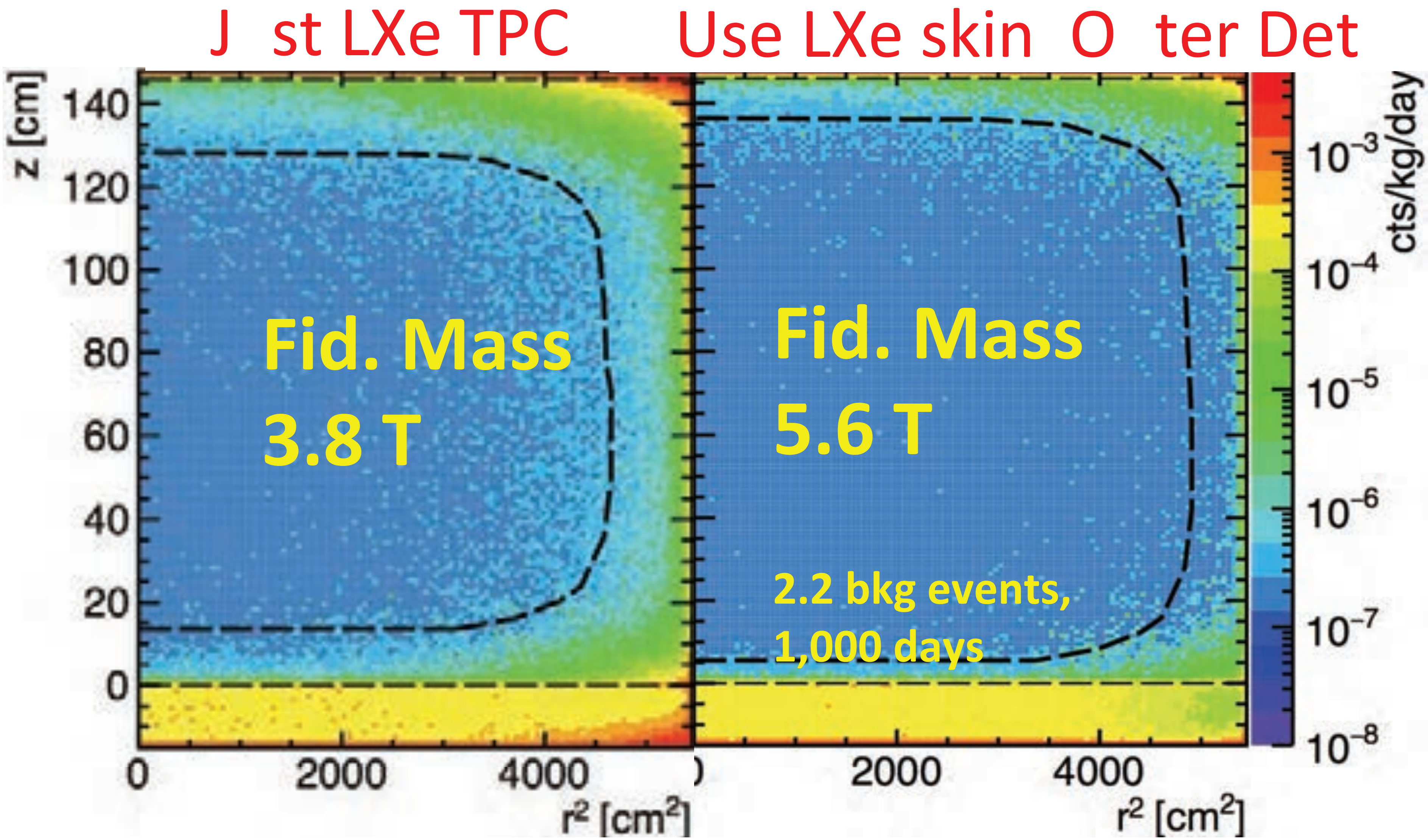
| Done in LUX and will be done in LZ | Not done in LUX, but will do in LZ |
|---|---|
| $^{m}$Kr ro ne ro ghl eekl | Ac ated Xe $^{m}$Xe and $^{m}$Xe |
| Tri ated methane e er fe months | Rn |
| E ternal radioisotope ne tron so rces | AmLi |
| E ternal radioisotope gamma so rces | YBe |
| DD ne tron generator pgraded earl ne t ear to shorten p lse | |

# Cr ostat Vessels

- UK responsibilit
- Lo backgro nd tani m chosen direc on
  SS alterna e ad anced as back p
- Ti slab for all essels and other parts recei ed and assa ed
- Contrib tes NR ER co nts in fid cial
  ol me in da s after c ts

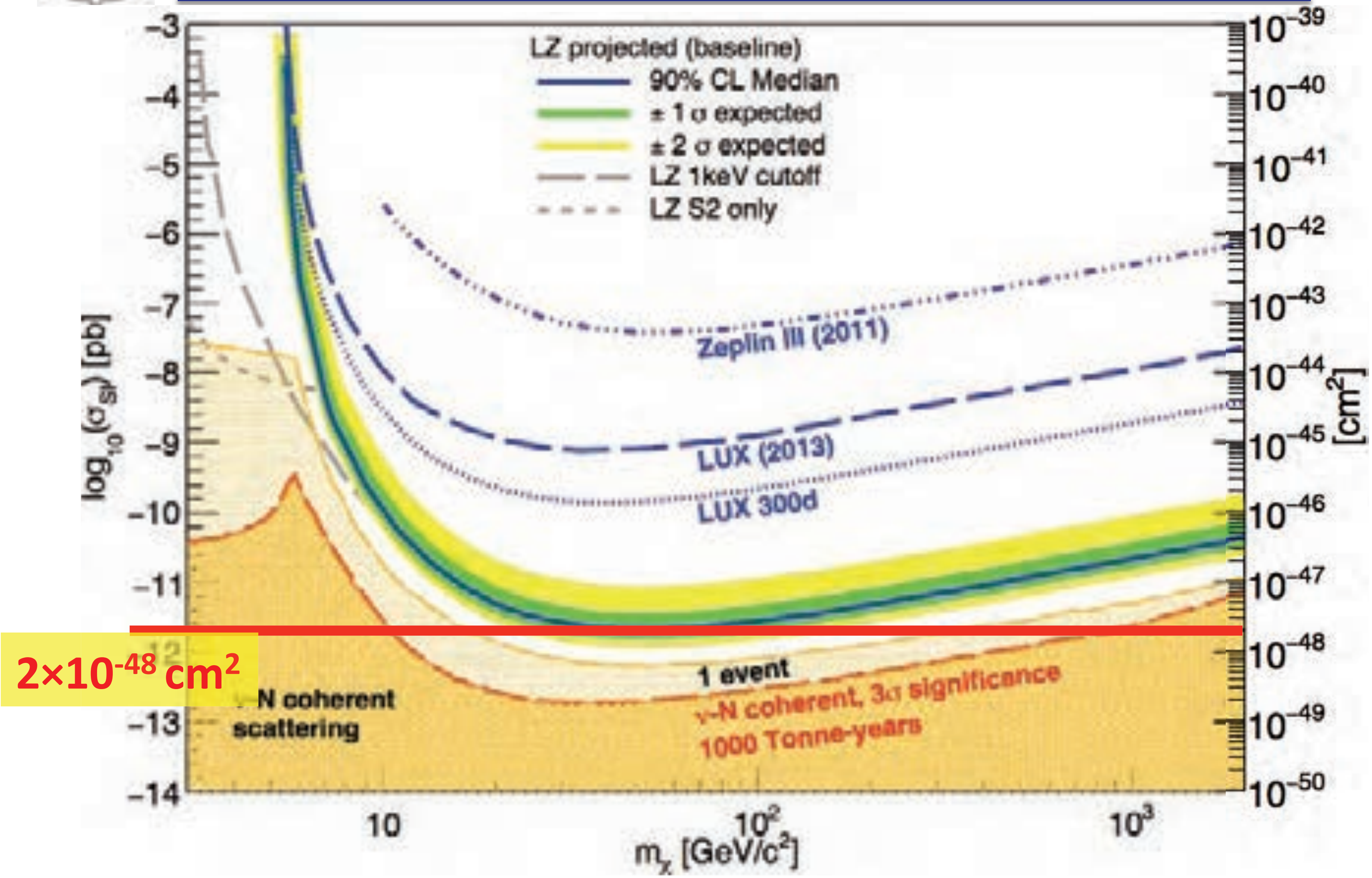


# Backgro  nd Modeled

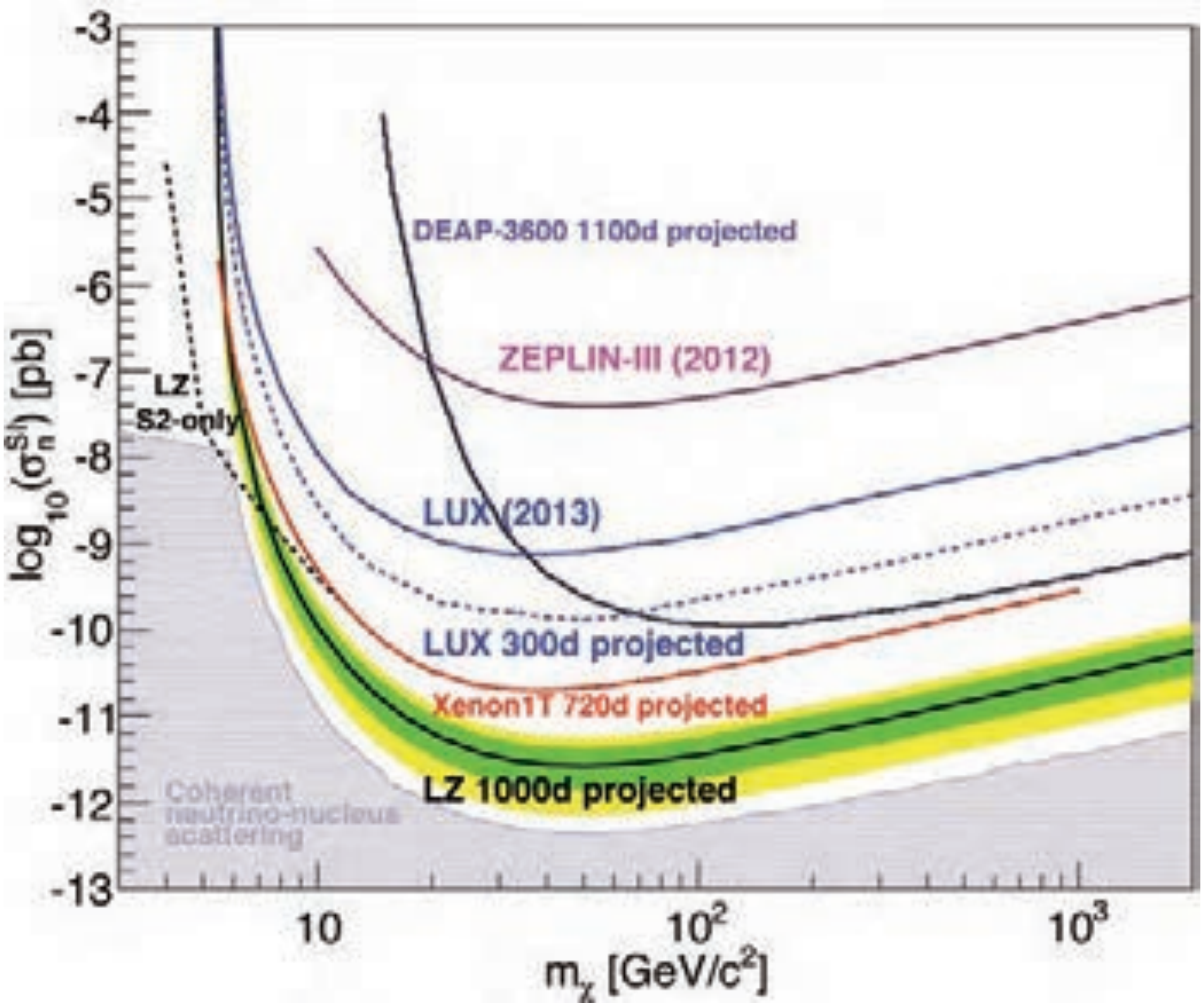


# Projected Sensi it Spin Independent

LZ Tonnes li e da s



# Sensi it ith Compe on



# Waiting for the Jackpot

# WIMP Miracle

A happy coincidence implied that new physics at the TeV scale with appropriately weak cross section leads to a dark matter relic (with a new quantum number preventing decay).

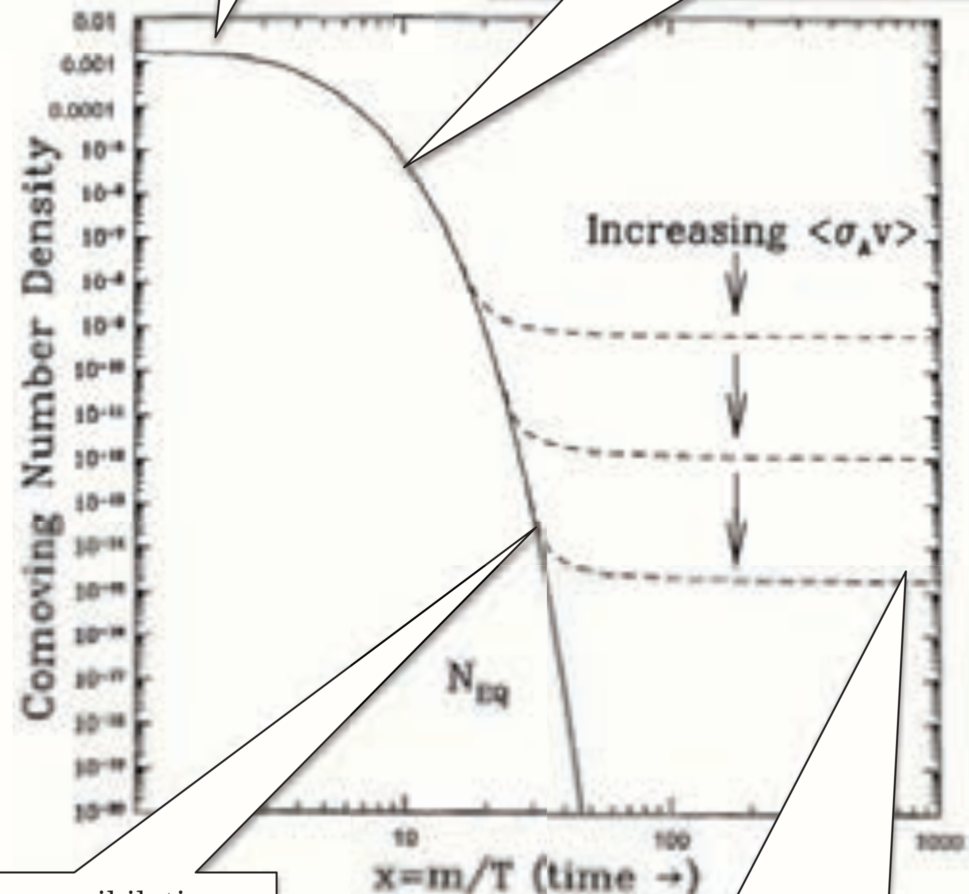
$$\Omega_x h^2 = \frac{3\cdot 10^{-27}\,cm^3/s}{\langle \sigma_A v \rangle} \approx 0.12$$

$$\Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

1. Flat region. Constant density. Equal production and annihilation. $n_{eq} \sim T^3$

2. Exponential suppression as temperature falls below mass of dark matter particle.

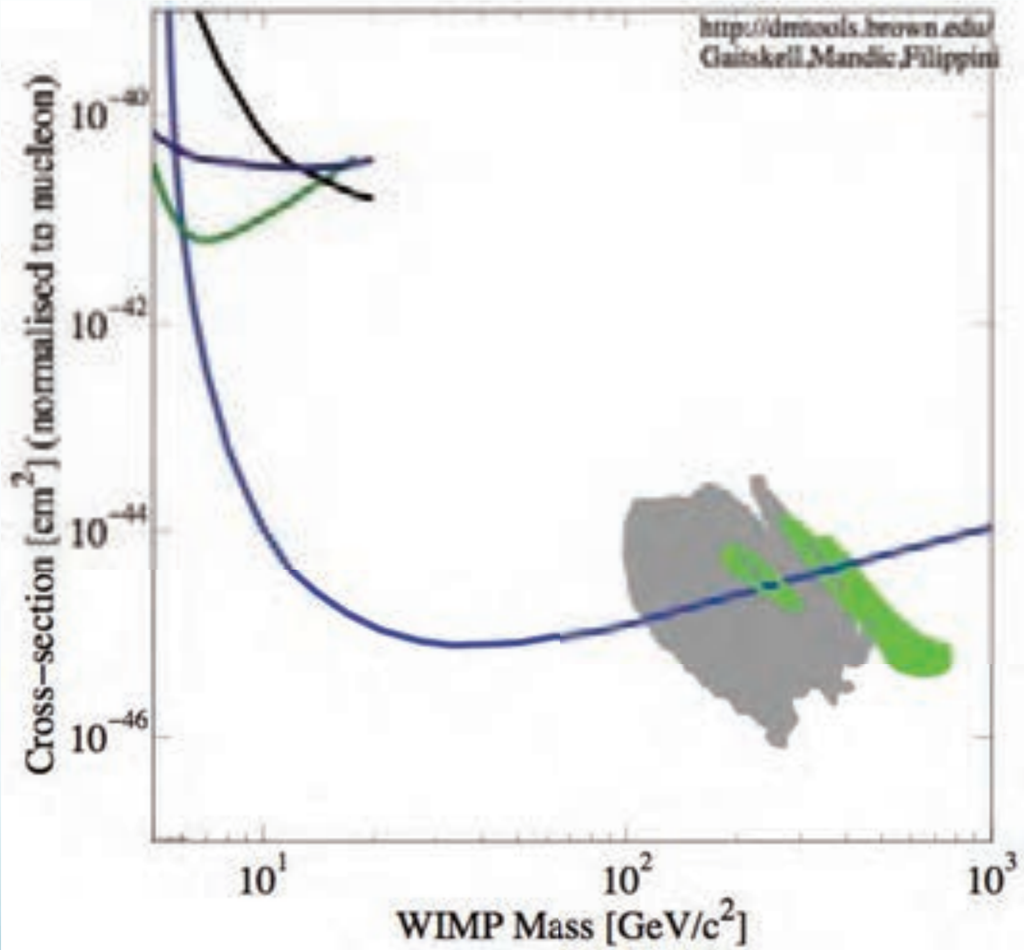
$$n_{eq} \sim (m/T)^{3/2}\, e^{-m/T}$$




3. Turn over as annihilation rate decreases, becoming smaller than the expansion rate.

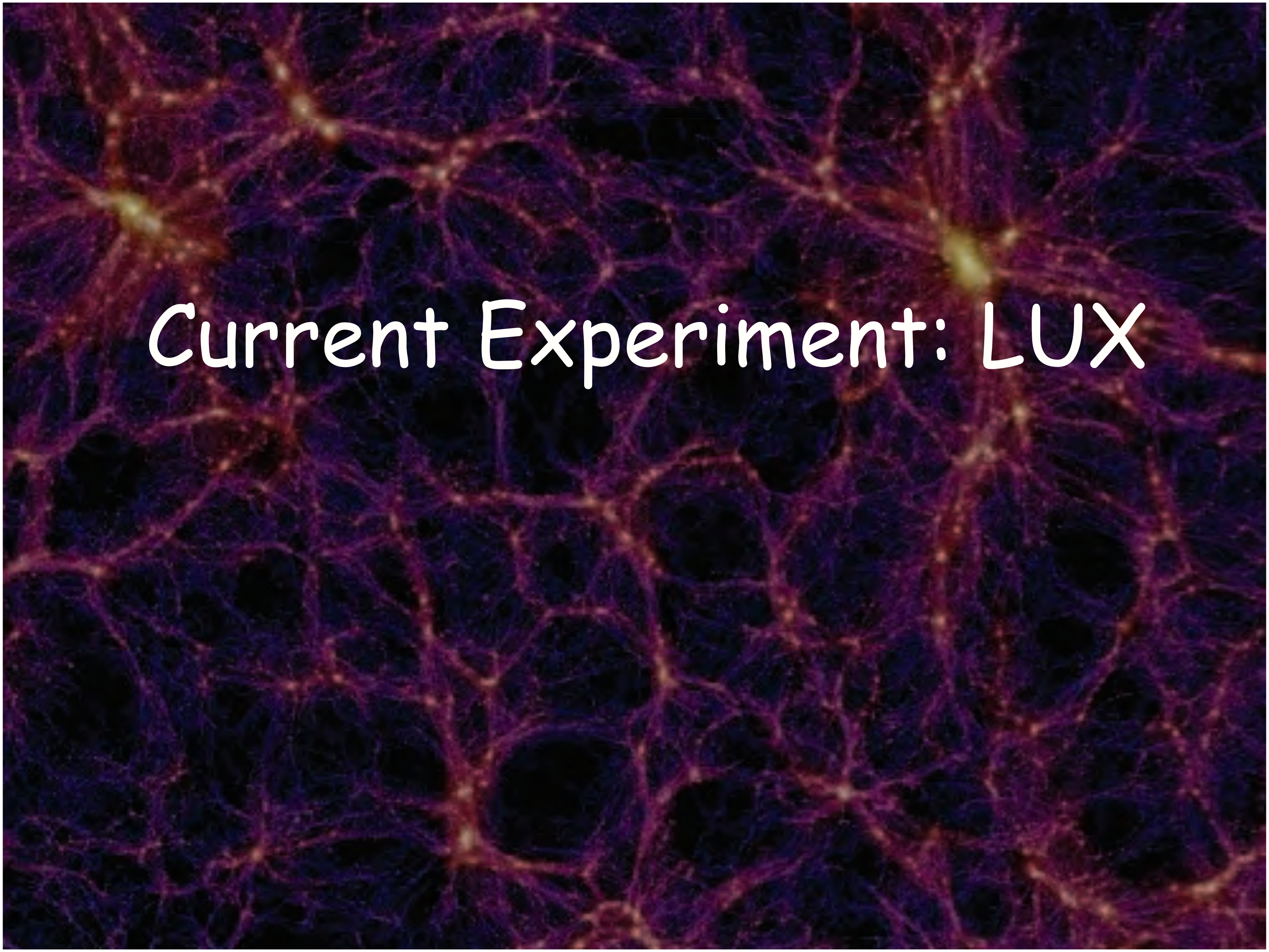
4. Relic abundance remains. Larger cross-sections keep annihilations occurring for longer.

# Time Progression of Sensitivity




Years 2000-2013

Animation courtesy of Aaron Manalaysay, UC Davis


Current Experiment: LUX

# The LUX Collaboration

## Brown

| | |
|---|---|
| **Richard Gaitskell** | PI, Professor |
| **Simon Fiorucci** | Research Associate |
| **Samuel Chung Chan** | Graduate Student |
| **Dongqing Huang** | Graduate Student |
| **Casey Rhyne** | Graduate Student |
| **Will Taylor** | Graduate Student |
| **James Verbus** | Graduate Student |

## Imperial College London

| | |
|---|---|
| **Henrique Araujo** | PI, Reader |
| **Tim Sumner** | Professor |
| **Alastair Currie** | Postdoc |
| **Adam Bailey** | Graduate Student |
| **Khadeeja Yazdani** | Graduate Student |

## Lawrence Berkeley + UC Berkeley

| | |
|---|---|
| **Bob Jacobsen** | PI, Professor |
| **Murdock Gilchriese** | Senior Scientist |
| **Kevin Lesko** | Senior Scientist |
| **Peter Sorensen** | Scientist |
| **Victor Gehman** | Scientist |
| **Attila Dobi** | Postdoc |
| **Daniel Hogan** | Graduate Student |
| **Mia Ihm** | Graduate Student |
| **Kate Kamdin** | Graduate Student |
| **Kelsey Oliver-Mallory** | Graduate Student |

## Lawrence Livermore

| | |
|---|---|
| **Adam Bernstein** | PI, Leader of Adv. Detectors Grp. |
| **Kareem Kazkaz** | Staff Physicist |
| **[illegible] Lenardo** | Graduate Student |

## LIP Coimbra

| | |
|---|---|
| **Isabel Lopes** | PI, Professor |
| **Jose Pinto da Cunha** | Assistant Professor |
| **Vladimir Solovov** | Senior Researcher |
| **Francisco Neves** | Auxiliary Researcher |
| **Alexander Lindote** | Postdoc |
| **Claudio Silva** | Postdoc |

## SLAC Nation Accelerator Laboratory

| | |
|---|---|
| **Dan Akerib** | PI, Professor |
| **Thomas Shutt** | PI, Professor |
| **Kim Palladino** | Project Scientist |
| **Tomasz Biesiadzinski** | Research Associate |
| **Christina Ignarra** | Research Associate |
| **Wing To** | Research Associate |
| **Rosie Bramante** | Graduate Student |
| **Wei Ji** | Graduate Student |
| **T.J. Whitis** | Graduate Student |

## SD School of Mines

| | |
|---|---|
| **Xinhua Bai** | PI, Professor |
| **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 |
| **Paul Terman** | Graduate Student |

## University at Albany, SUNY

| | |
|---|---|
| **Matthew Szydagis** | PI, Professor |
| **Jeremy Mock** | Postdoc |
| **Steven Young** | Graduate Student |

## UC Davis

| | |
|---|---|
| **Mani Tripathi** | PI, Professor |
| **Britt Hollbrook** | Senior Engineer |
| **John Thmpson** | Development Engineer |
| **Dave Herner** | Senior Machinist |
| **Ray Gerhard** | Electronics Engineer |
| **Aaron Manalaysay** | Postdoc |
| **Scott Stephenson** | Postdoc |
| **Jacob Cutter** | Graduate Student |
| **James Morad** | Graduate Student |
| **Sergey Uvarov** | Graduate Student |

## UC Santa Barbara

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

## University College London

| | |
|---|---|
| **Chamkaur Ghag** | PI, Lecturer |
| **Sally Shaw** | Graduate Student |


## University of Edinburgh

| | |
|---|---|
| **Alex Murphy** | PI, Reader |
| **Paolo Beltrame** | Research Fellow |
| **James Dobson** | Postdoc |
| **Tom Davison** | Graduate Student |
| **Maria Francesca Marzioni** | Graduate Student |

## University of Maryland

| | |
|---|---|
| **Carter Hall** | PI, Professor |
| **Jon Balajthy** | Graduate Student |
| **Richard Knoche** | Graduate Student |

## University of Rochester

| | |
|---|---|
| **Frank Wolfs** | PI, Professor |
| **Wojtek Skutski** | Senior Scientist |
| **Eryk Druszkiewicz** | Graduate Student |
| **Dev Ashish Khaitan** | Graduate Student |
| **Mongkol Moongweluwan** | Graduate Student |

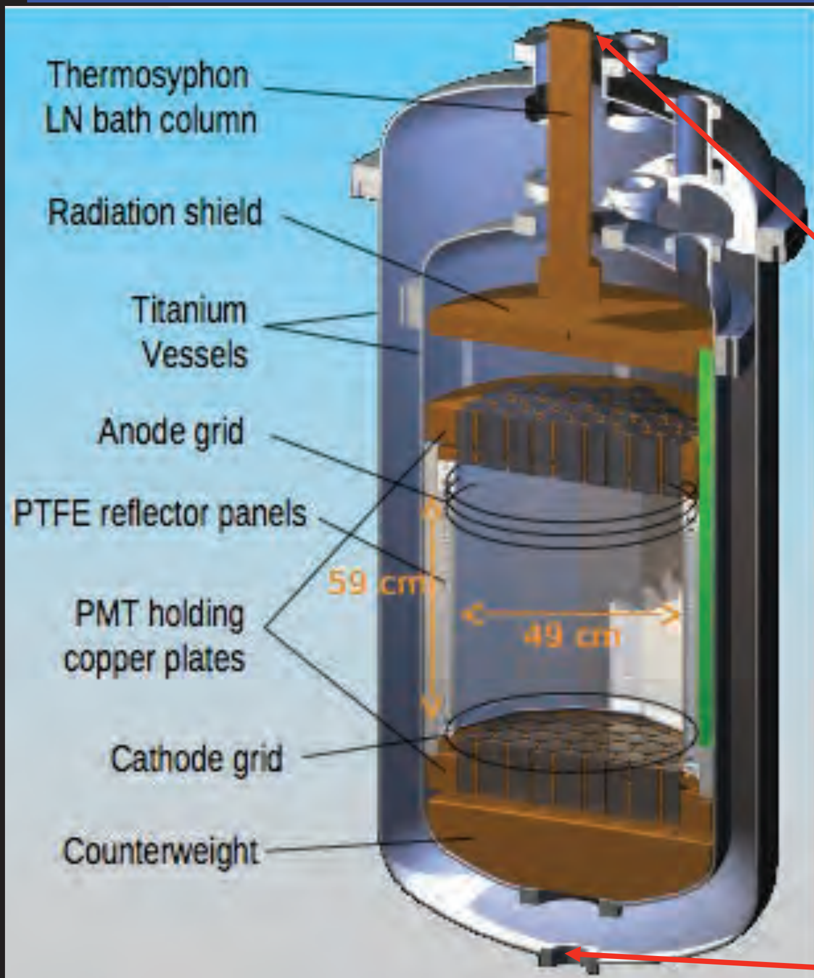
## University of South Dakota

| | |
|---|---|
| **Dongming Mei** | PI, Professor |
| **Chao Zhang** | Postdoc |
| **Angela Chiller** | Graduate Student |
| **Chris Chiller** | Graduate Student |

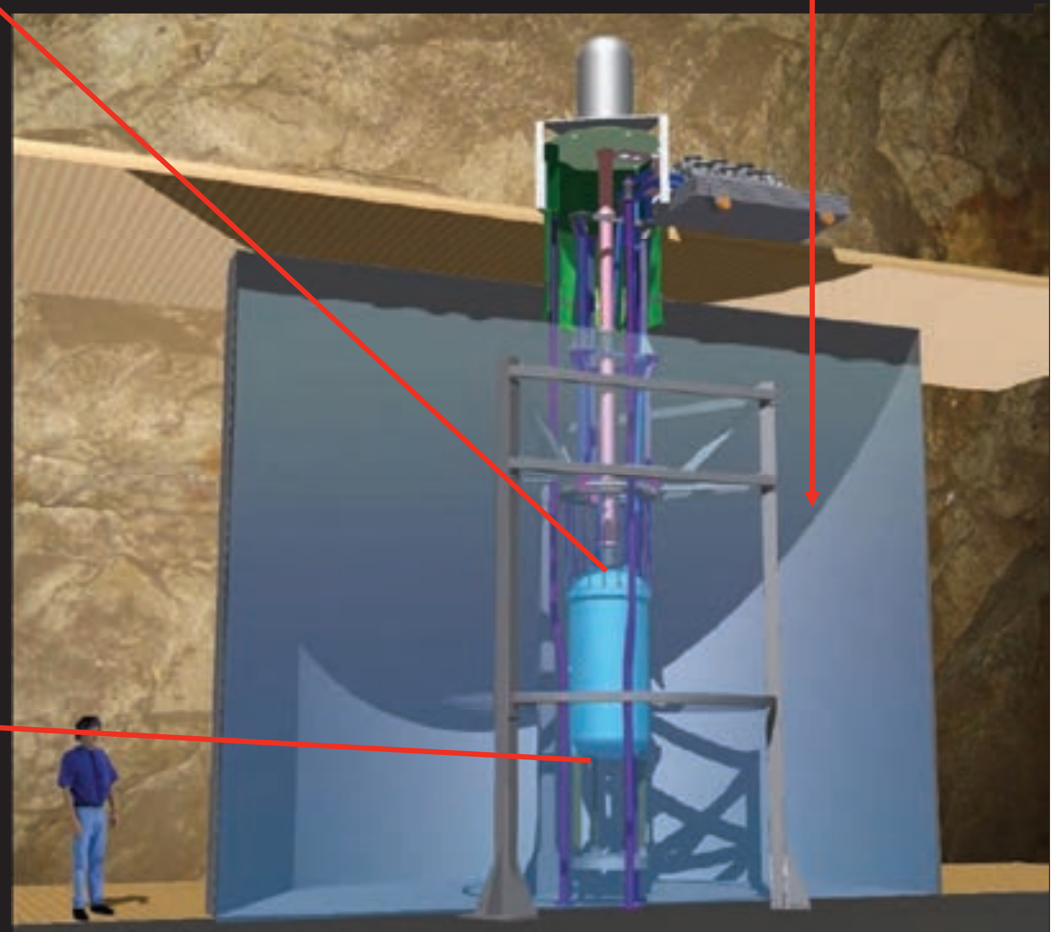
## Yale

| | |
|---|---|
| **Daniel McKinsey** | PI, Professor |
| **Ethan Bernard** | Research Scientist |
| **Markus Horn** | Research Scientist |
| **Blair Edwards** | Postdoc |
| **Scott Hertel** | Postdoc |
| **Kevin O'Sullivan** | Postdoc |
| **Elizabeth Boulton** | Graduate Student |
| **Nicole Larsen** | Graduate Student |
| **Evan Pease** | Graduate Student |
| **Brian Tennyson** | Graduate Student |
| **Lucie Tvrznikova** | Graduate Student |

# The LUX detector



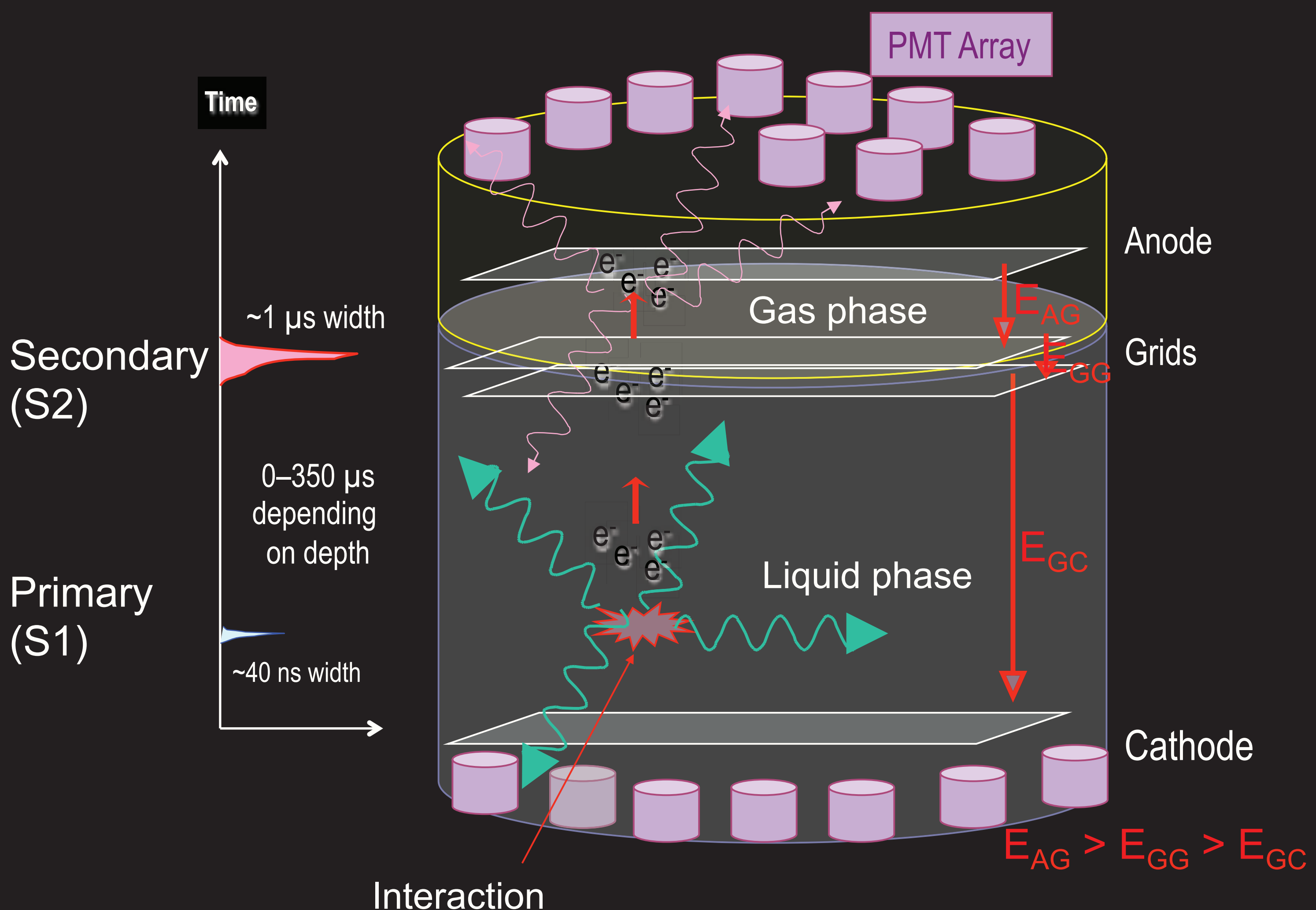

- ~ 7m diameter Water Cerenkov Shield.
- 48 cm H (gate to cathode) X 47 cm D active region with 181 V/cm drift field



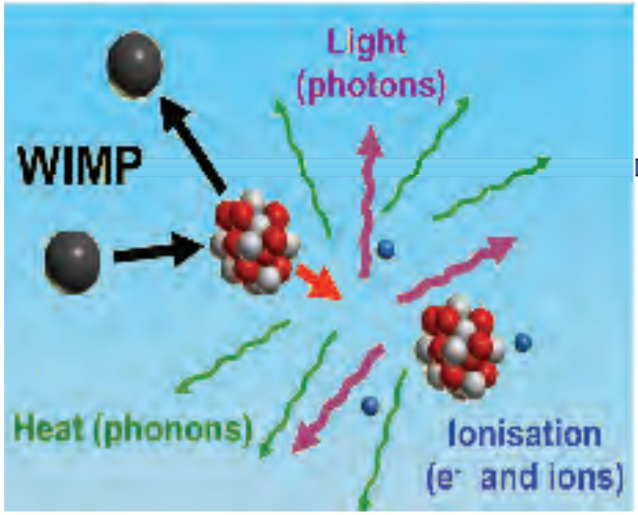
•250 kg (active), 118 kg (fiducial) of Lxe

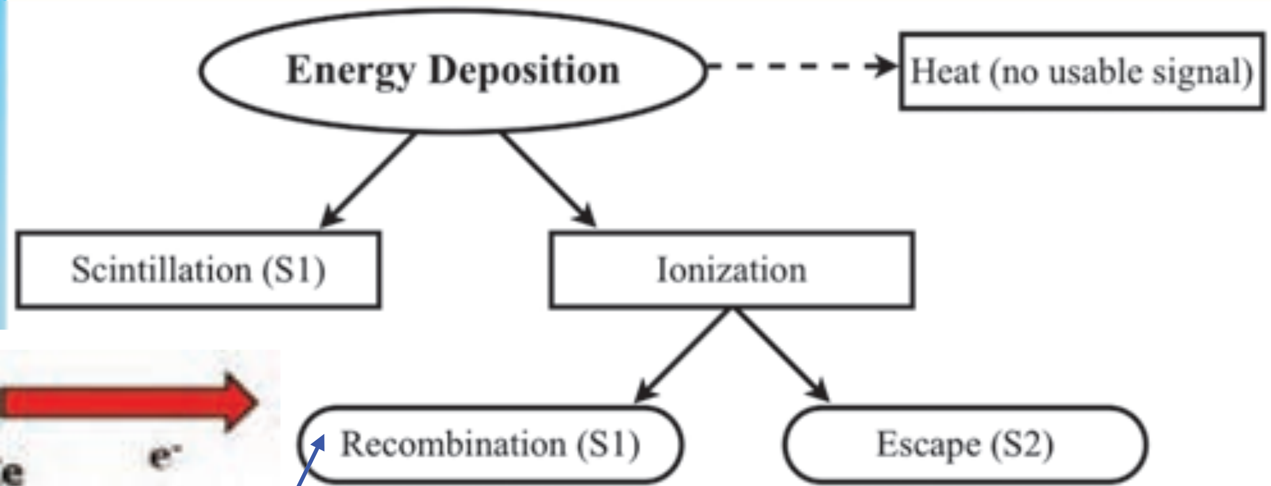
•122 photomultiplier tubes (top plus bottom)

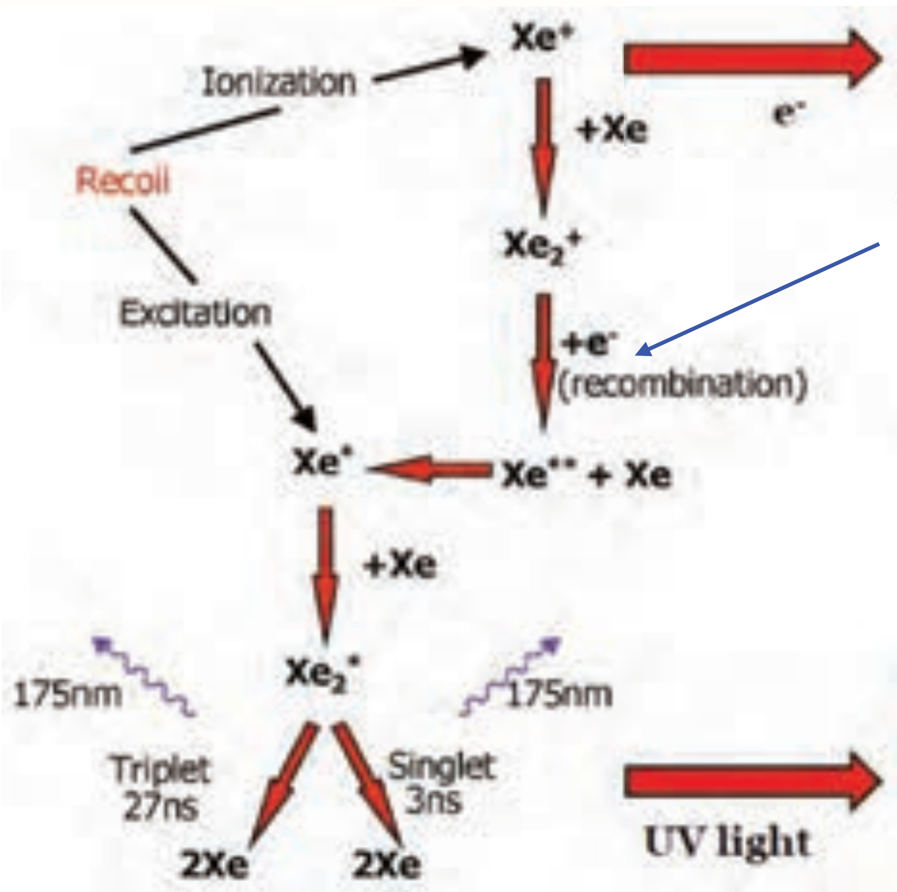
# Two Signal Technique



# Scintillation process in LXe



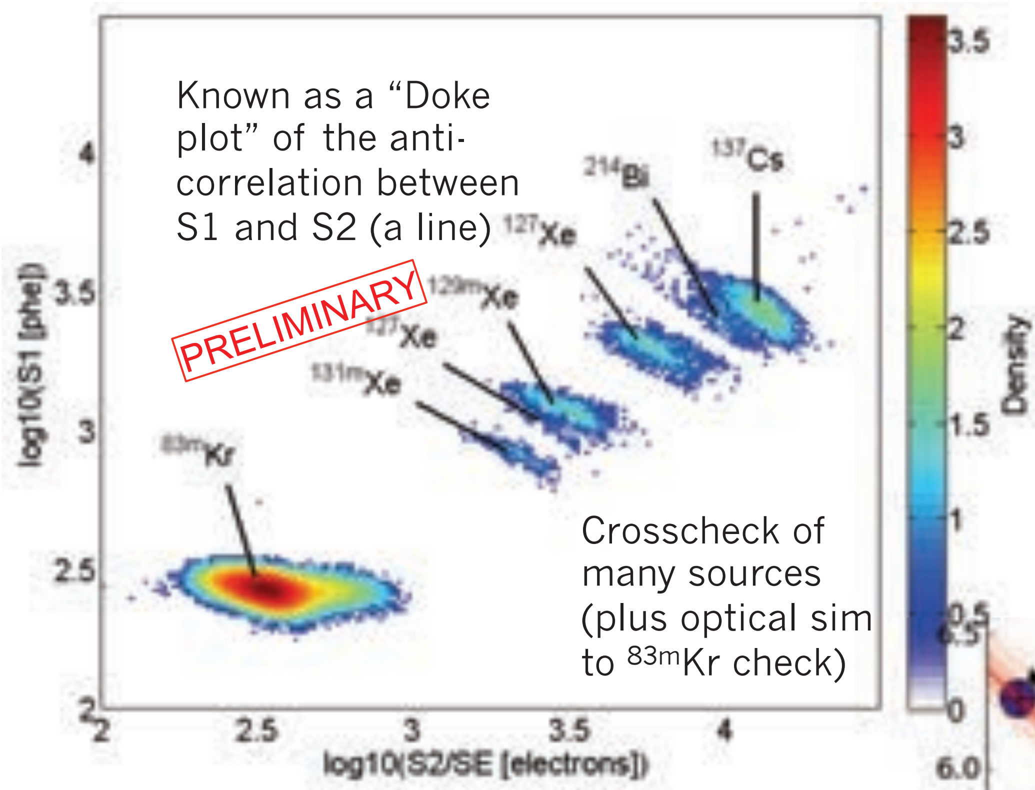

Difference in in recombination efficiency is exploited to discriminate between electron and nuclear recoils.

Xenon is transparent to its own scintillation light !

Figure of merit derived from plots of:

Log (charge escaping recombination/ total primary light produced)

# New Calculation of the g-Factors

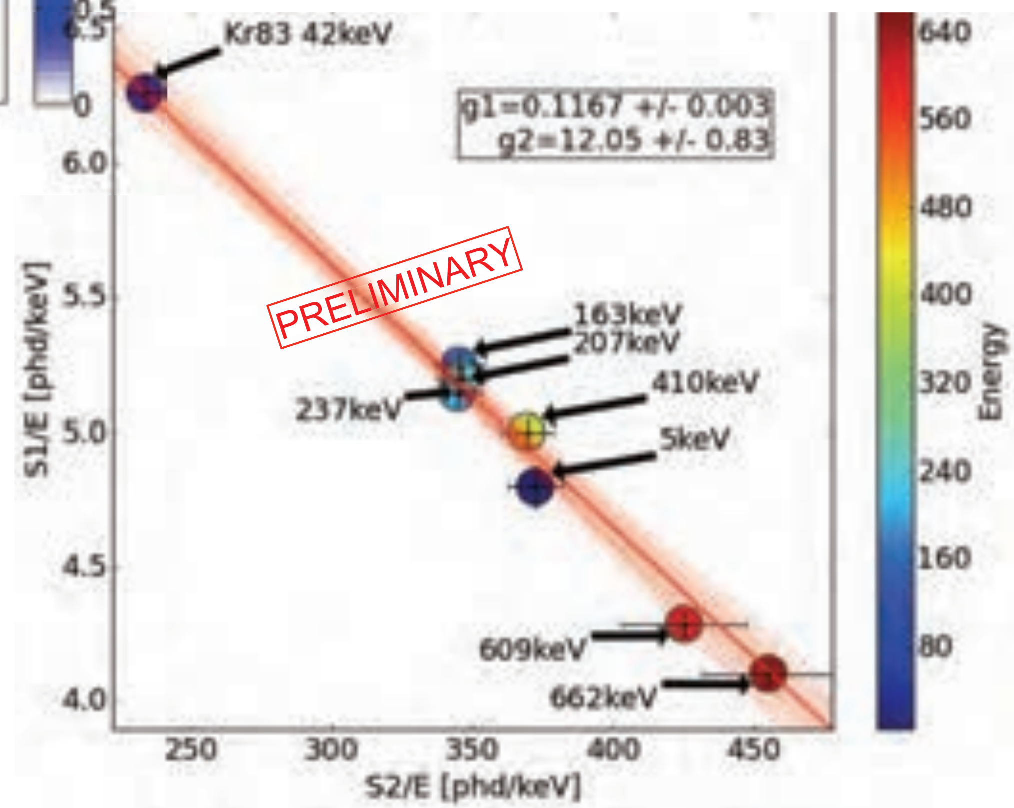



12% efficiency for the detection of a primary scintillation photon

Previously 14% quoted

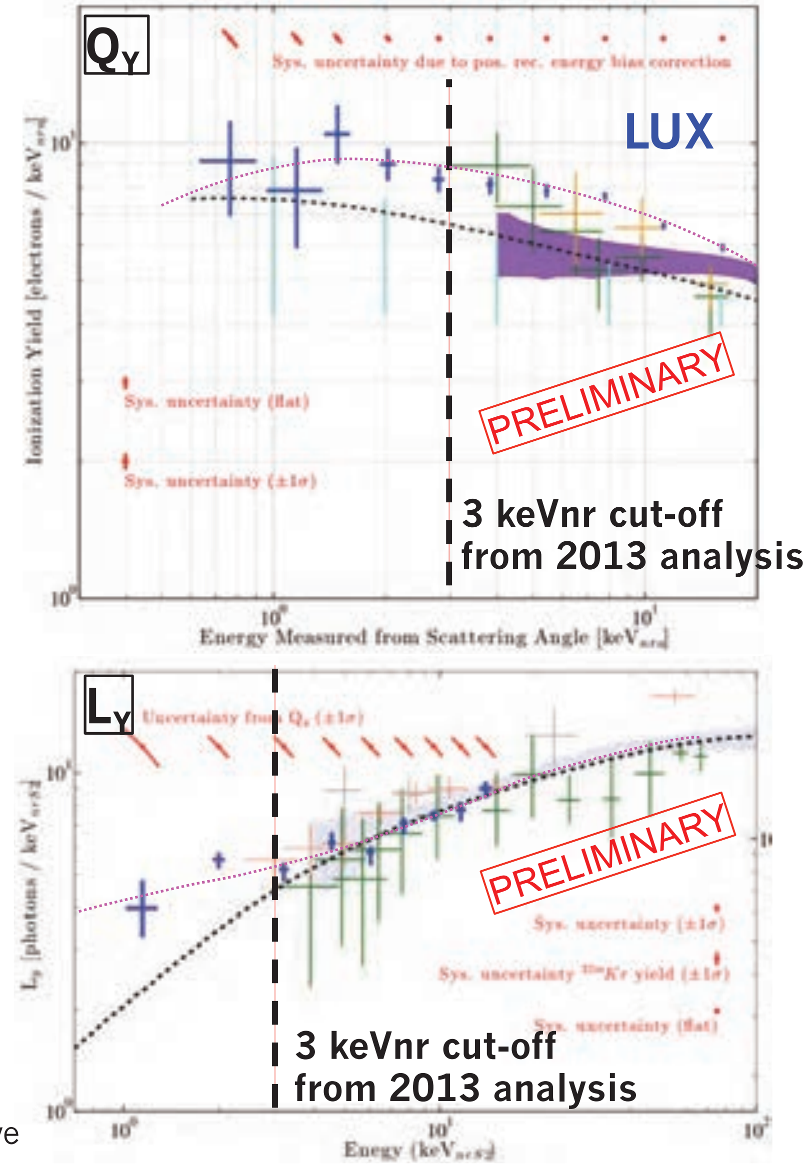
49% extraction, coupled with 24.66 detected photons per single electron to make "$g_2$"

Previously 65%, but it is product of absolute yield with is what matters



# NR Charge and Light Yields

- *in situ* measurements
- No longer relying on LUX AmBe, $^{252}Cf$, or modeling from old data, or extrapolating from results of small test chambers.
- *Charge yield* Measured down to ~0.8 keVnr. (Previous low 4 keV)
- Data from Deuterium-Deuterium neutron gun. Use S2 to identify double scatters. Determine energy deposition from scattering angle. For S1, S2-derived energy scale.
- *Light yield* measured down to ~1.2 keVnr. (Previous low 3 keV)
- New modeling

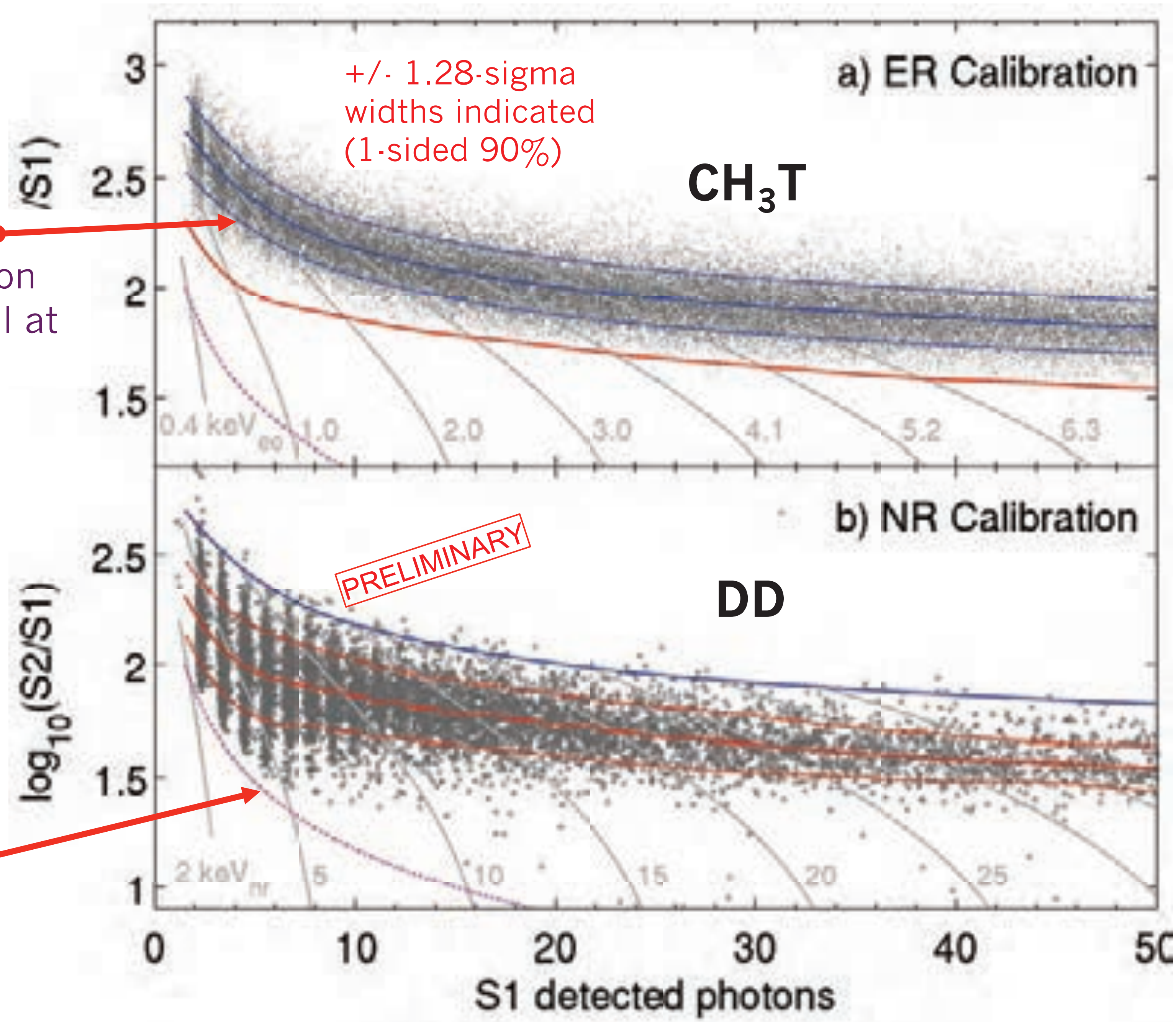



------ NEST 1.0 still too conservative
------ Modified NEST for re-analysis

# The "Bands"

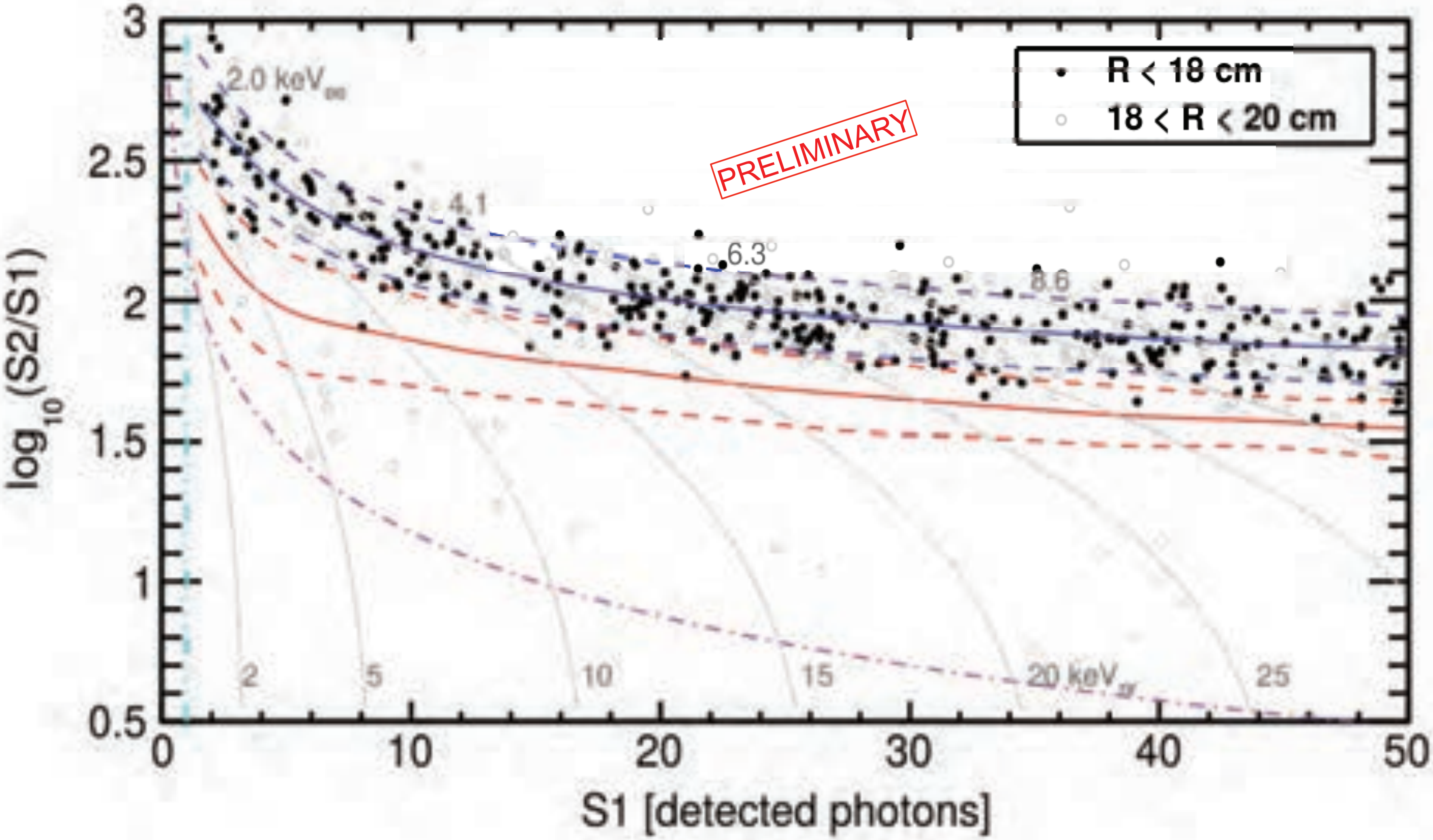
New: DIGITAL individual photon counting, useful at low energies

Approximate location of 165 phd cut, lowered from 200 previous (8 => 6 e⁻'s)



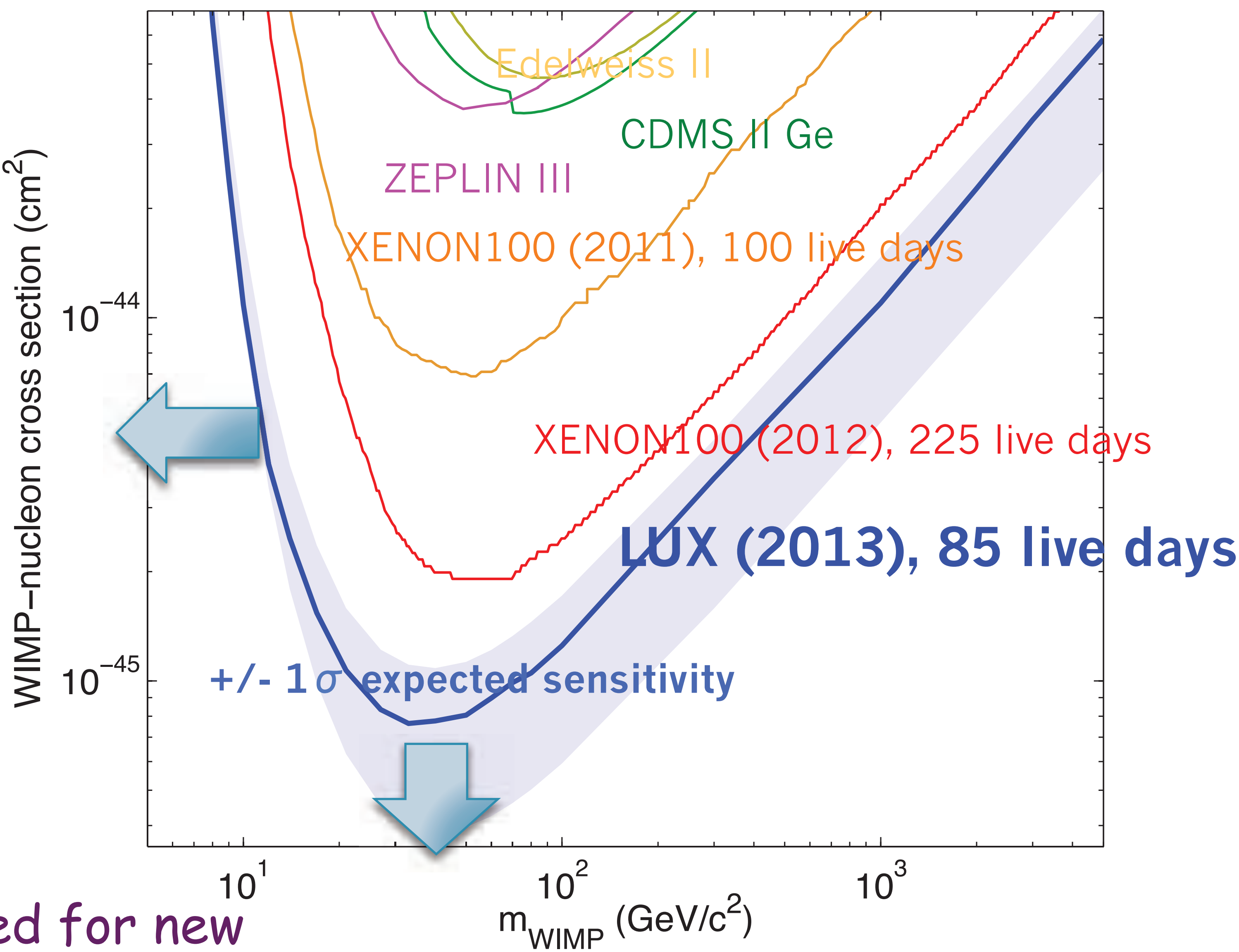

S1 and S2 are both position-corrected using Kr

# Updated WIMP Search Data



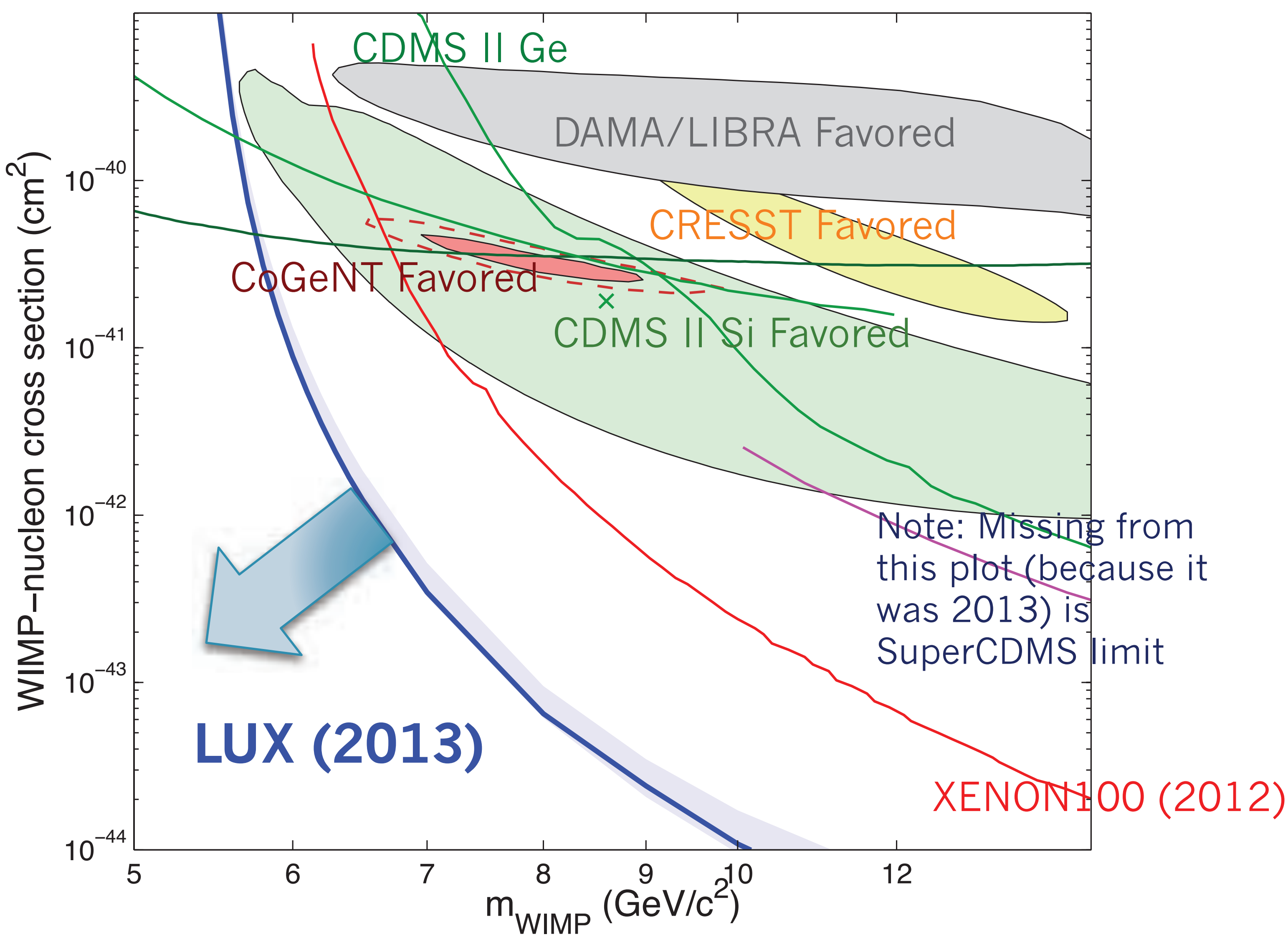

A Profile Likelihood Ratio (not cut-and-count) method uses all events.

# WIMP Dark Matter Limit

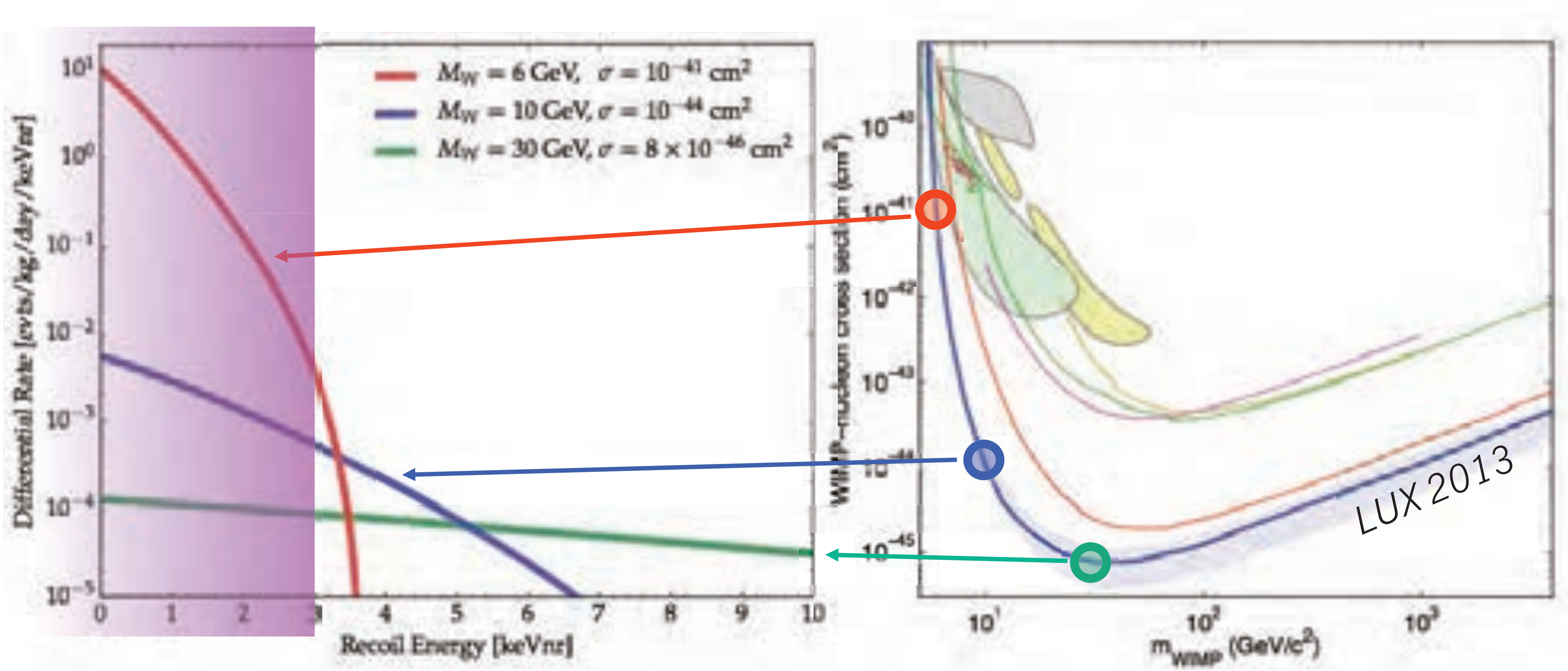



Stay tuned for new results later this year.

# LUX Low-Mass Sensitivity



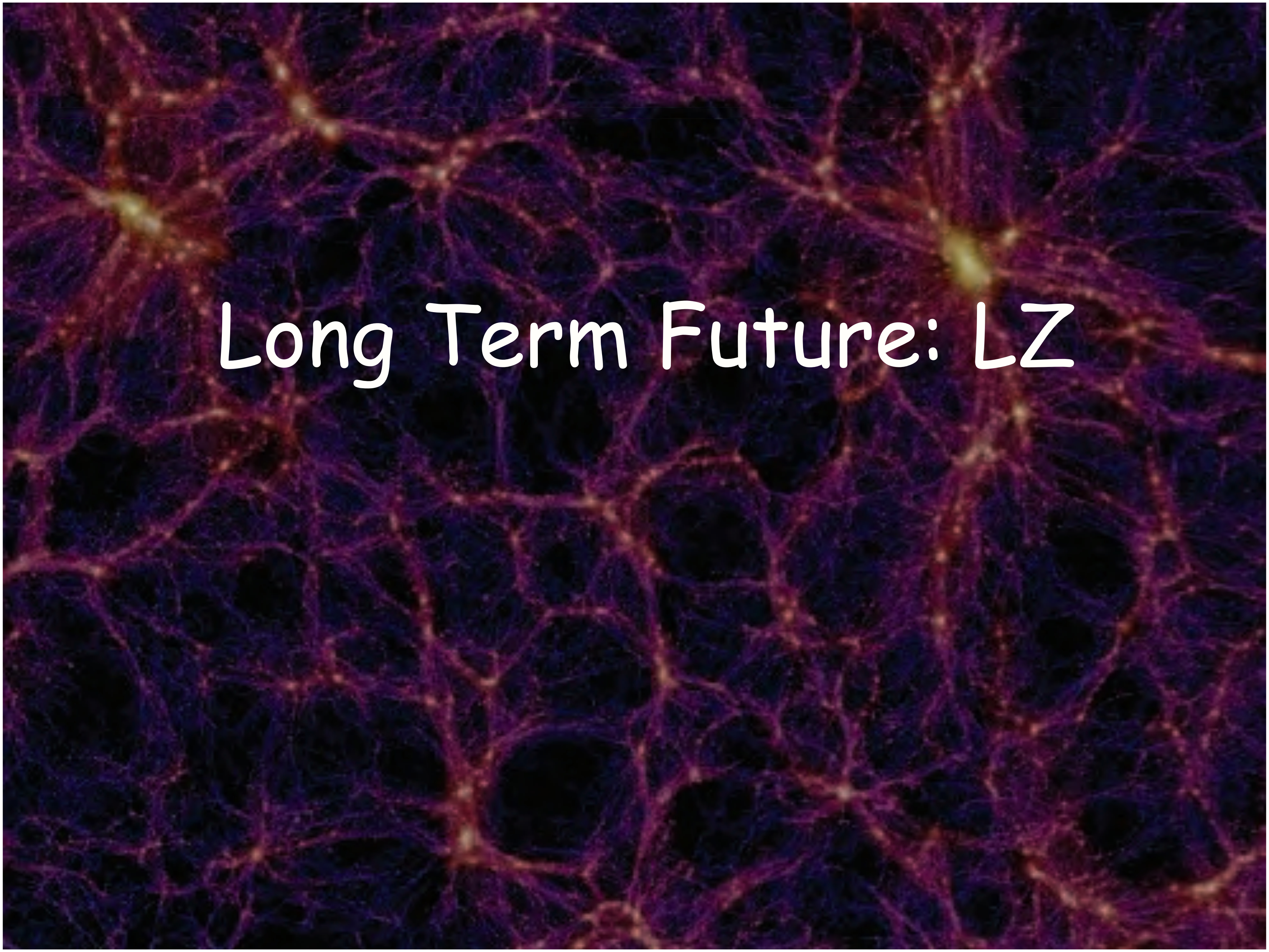
# Another Look at Light WIMPs



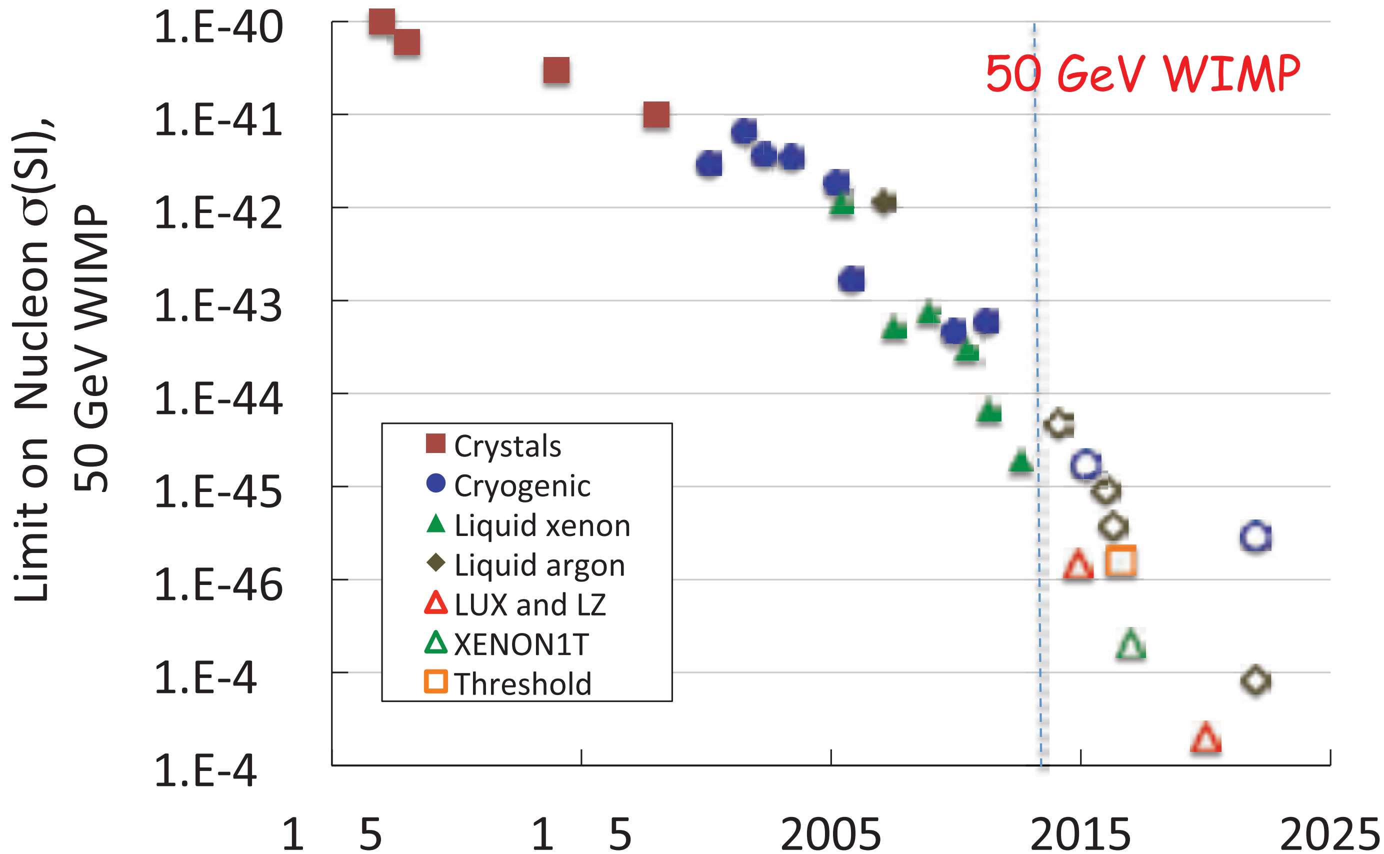

LUX 2013 upper limits assumed NO SENSITIVITY to recoils below 3 keVnr. This was not an *analysis* threshold, but an artificial one, a hard cut-off

For example, decreasing this response cutoff from 3 keV to 1 keV provides access to a factor of 1000* more signal at $M$ = 6 GeV/c$^2$.

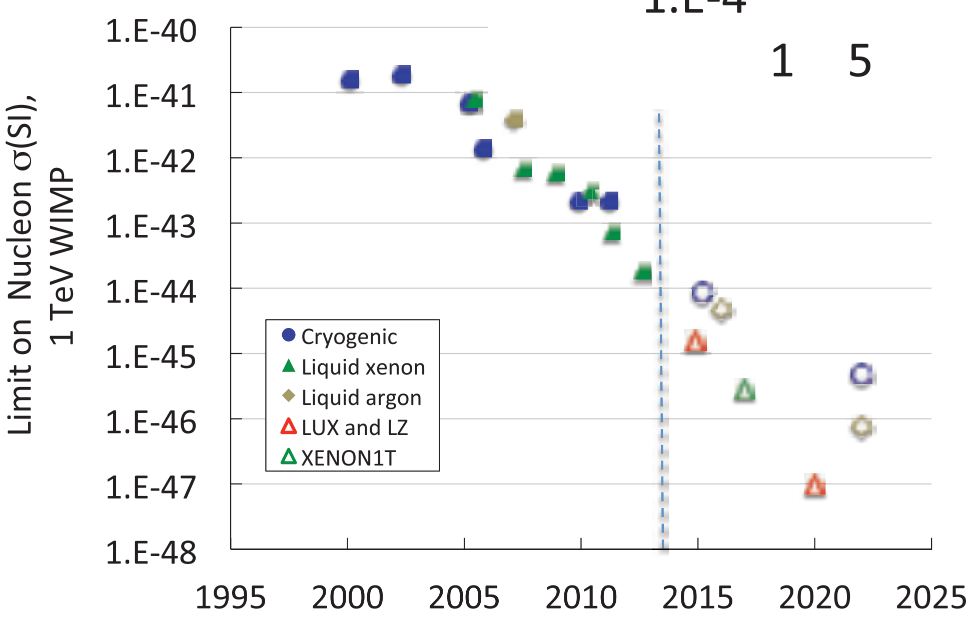
# Long Term Future: LZ



# A compact history of WIMP Searches



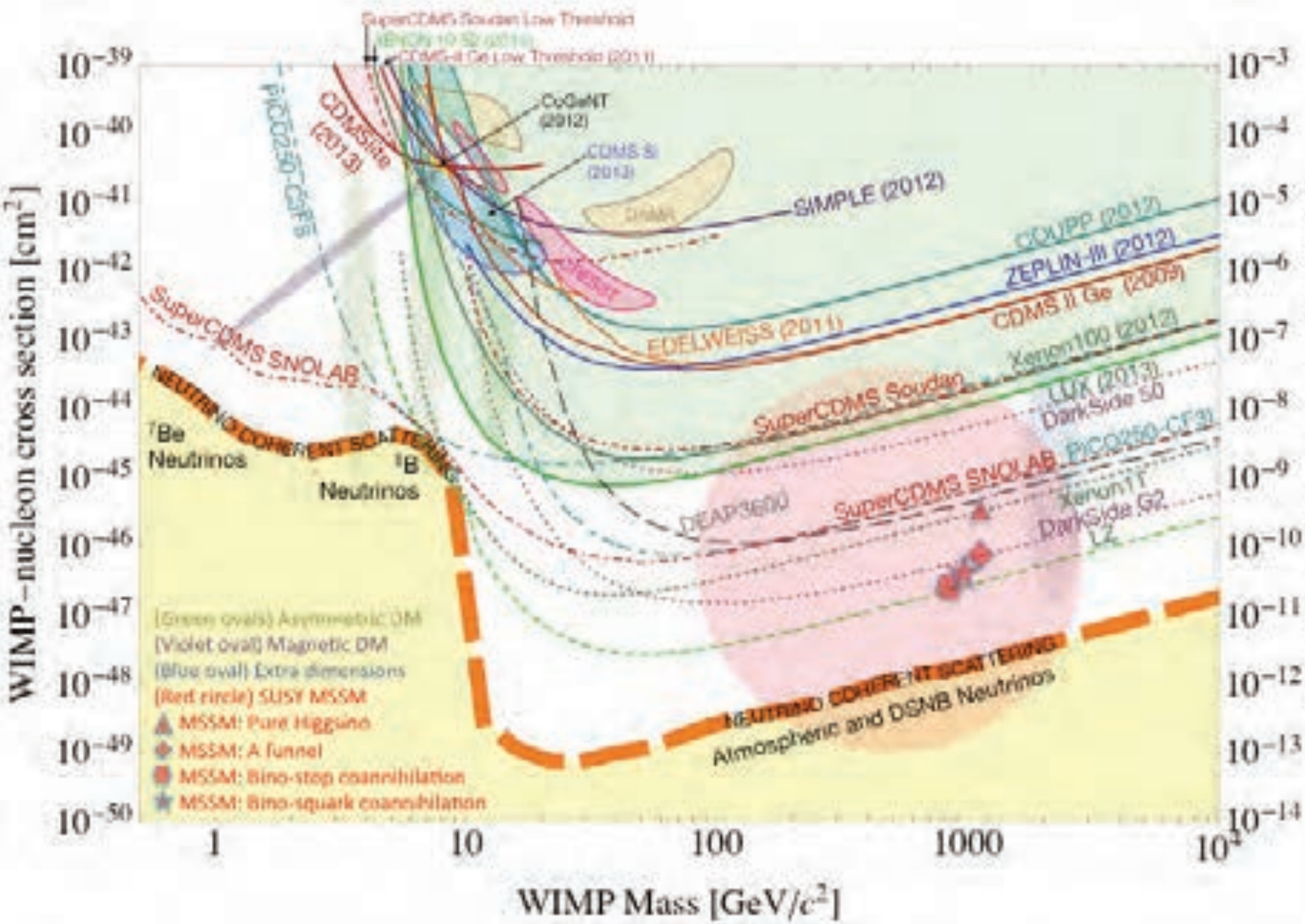

1 TeV WIMP




LZ is poised to possibly provide an end-point to this saga … hopefully by discovering WIMPs or, by ruling out most of the theoretical <u>and</u> experimentally accessible landscape.

Plots compiled b
Mike Witherell UCSB

# Snowmass Projections



# LZ LUX ZEPLIN

ins t ons c rrentl
Abo t people

LIP Coimbra Port gal
MEPhI R ssia
Edinb rgh Uni ersit UK
Uni ersit of Li erpool UK
Imperial College London UK
Uni ersit College London UK
Uni ersit of O ford UK
STFC R therford Appleton Laboratories UK
Shanghai Jiao Tong Uni ersit China
Uni ersit of Sheffield UK

Uni ersit of Alabama
Uni ersit at Alban SUNY
Berkele Lab LBNL
Uni ersit of California Berkele
Brookha en Na onal Laborator
Bro n Uni ersit
Uni ersit of California Da is
Fermi Na onal Accelerator Laborator
Ka li Ins t te for Par cle Astroph sics Cosmolog
La rence Li ermore Na onal Laborator
Uni ersit of Mar land
Uni ersit of Michigan
North estern Uni ersit
Uni ersit of Rochester
Uni ersit of California Santa Barbara
Uni ersit of So th Dakota
So th Dakota School of Mines Technolog
So th Dakota Science and Technolog A thorit
SLAC Na onal Accelerator Laborator
Te as A M
Washington Uni ersit
Uni ersit of Wisconsin
Yale Uni ersit

# LZ Meeting at U. of Alabama

# LZ Timeline

| Year | Month | Activity |
|---|---|---|
| | March | LZ LUX ZEPLIN collabora on formed |
| | Ma | First Collabora on Mee ng |
| | September | DOE CD for G dark ma er e periments |
| | No ember | LZ R D report s bmi ed |
| | J l | LZ Project selected in US and UK |
| | April | DOE CD a appro al similar in UK<br>Begin long lead proc rements Xe PMT cr ostat |
| | April | DOE CD b appro al baseline all fab starts |
| | J ne | Begin prepara ons for s rface assembl SURF |
| | J l | Begin ndergro nd installa on |
| | Feb | Begin commissioning |

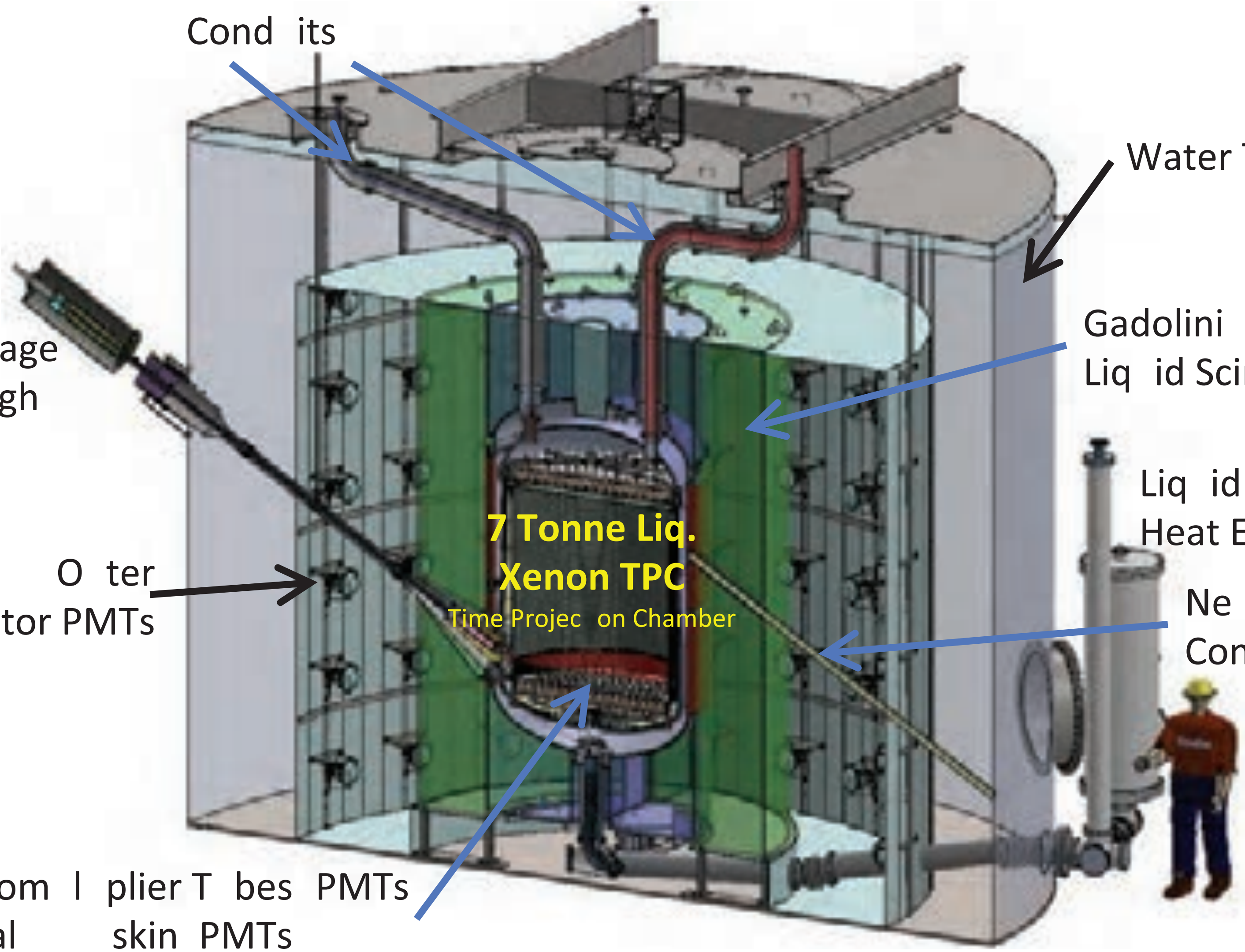
# Scale Up in Fid cial Mass

LUX

## LZ

Total mass – 10 T
Active Mass – 7 T
Fiducial Mass – 5.6 T

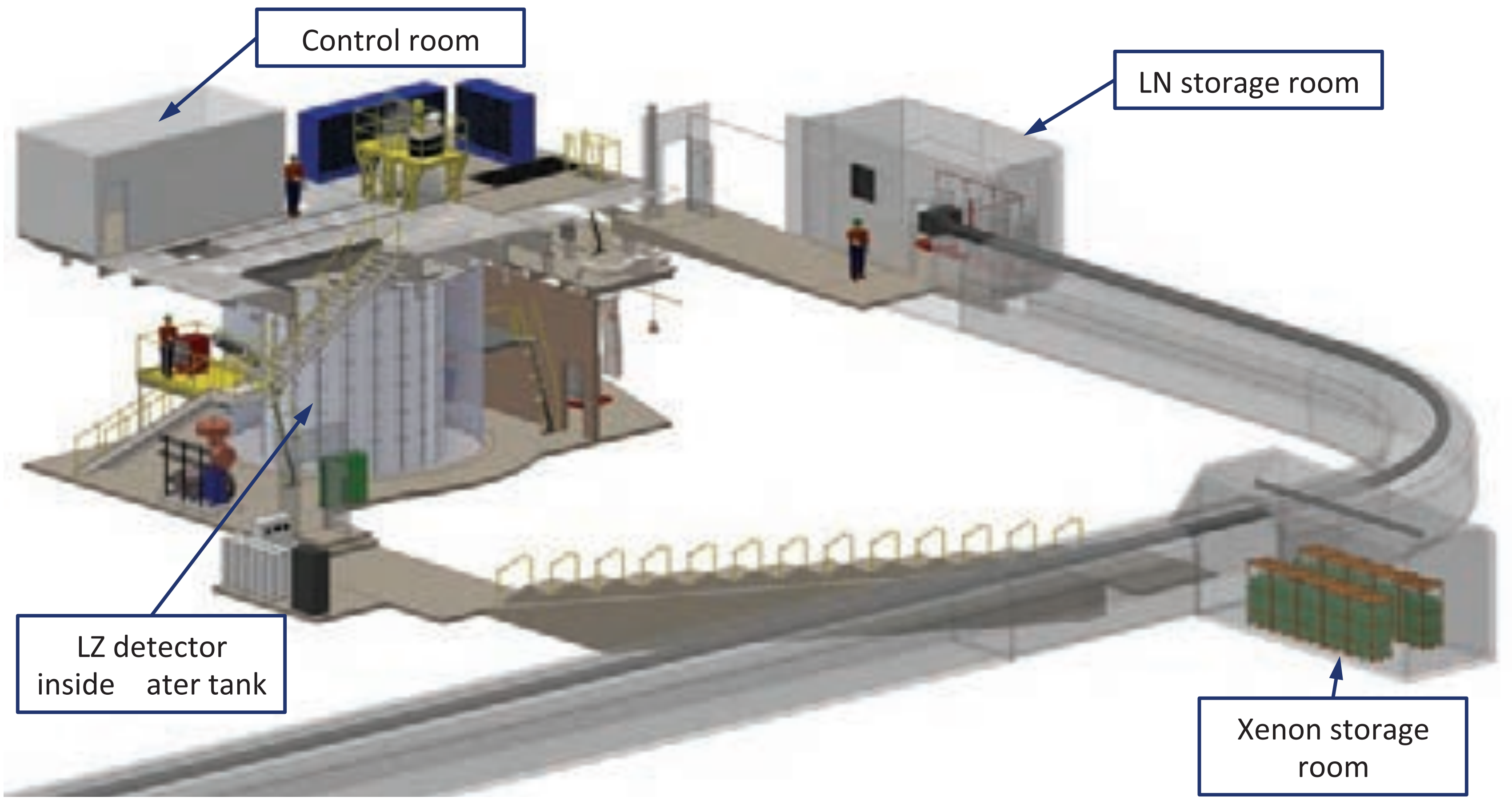
# LZ O er ie



Instr menta on
Cond its
Water Tank
High Voltage
Feedtro gh
Gadolini m Loaded
Liq id Scin llator
7 Tonne Liq.
Xenon TPC
Time Projec on Chamber
Liq id Xenon
Heat E changer
O ter
Detector PMTs
Ne tron Calib
Cond it
Photom l plier T bes PMTs
Addi onal skin PMTs

# LZ Undergro nd at SURF

Years of e perience at SURF from LUX



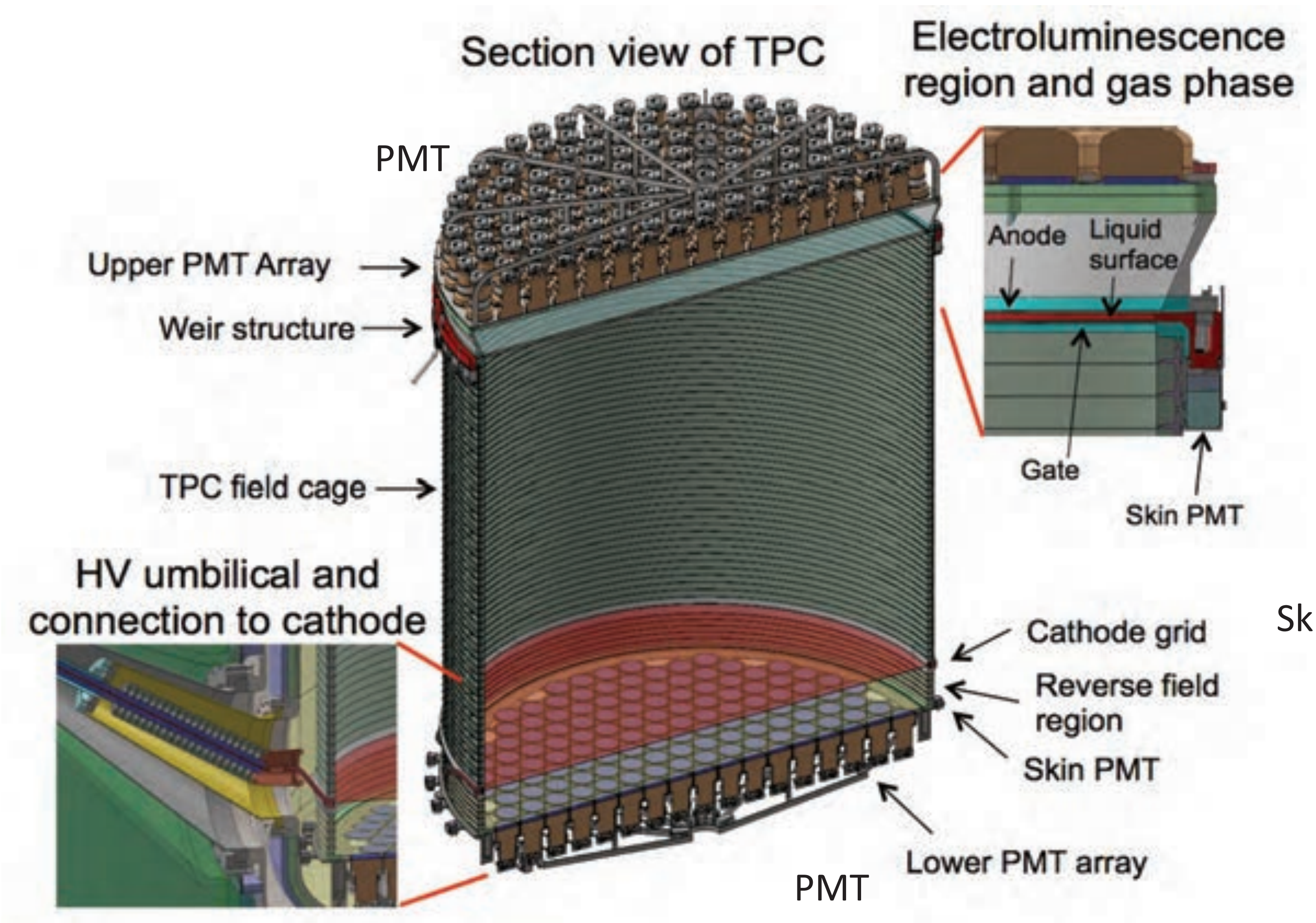
# Key Design Points

- ✓ 7 active tonnes of LXe can yield 2 x $10^{-48}$ $cm^2$ sensitivity in about three years of running
- ✓ 5.6 tonne fiducial volume, 1000 days
- ✓ Requires all detector systems working together
  - ◆ Xe detector with good light collection, reasonable background rejection (ER discrimination) and good signal detection efficiency
  - ◆ Sophisticated veto system: skin (outside active Xe region) + scintillator/water allows maximum fiducial volume to be obtained, maximizes use of Xe and substantially increases reliability of background measurements
  - ◆ Control backgrounds, both internal (within the Xe) and external from detector components/environment

# Design Status Summary

- Conceptual, and in some cases more advanced design, completed for all aspects of detector
- Conceptual Design Report about to appear on arXiv
- Acquisition of Xenon started
- Procurement of PMTs and cryostat started
- Collaboration – wide prototype program underway to guide and validate design
- Backgrounds modeling and validation well underway

# Xe TPC Detector




total
Skin PMT

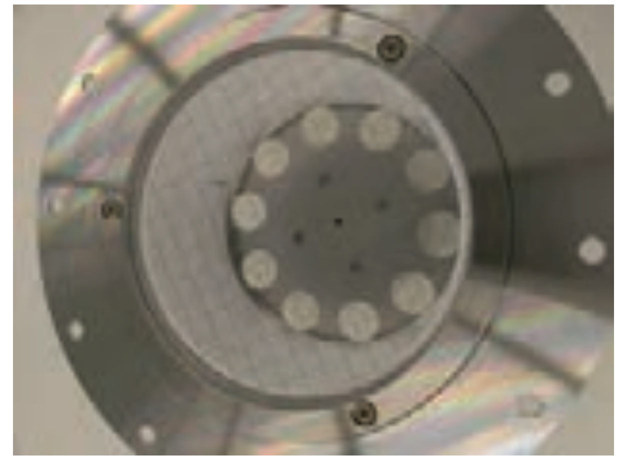
# Xe Detector PMTs

- R PMTs for TPC region
  - □ E tensi e de elopment program t bes in hand benefit from similar de elopment for XENON PANDA X and RED
  - □ Materials ordered and radioassa s started prior to fabrica on
  - □ First prod c on t bes earl
  - □ Joint US and UK effort
- R for skin region
  - □ Considering sing or for bo om dome region rec cle t bes from older detectors

# Xe Detector Protot ping

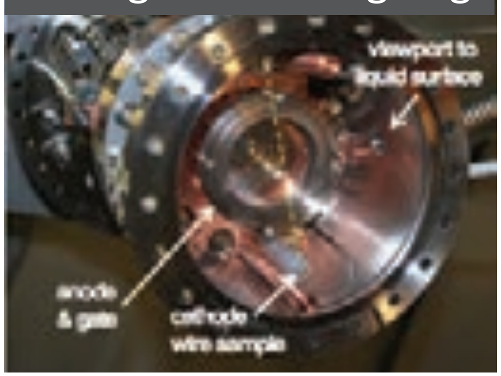
- Extensive program of prototype development underway
- Three general approaches
  - Testing in liquid argon, primarily of HV elements, at Yale and soon at LBNL
  - Design choice and validation in small (few kg) LXe test chambers in many locations: LLNL, Yale-> UC Berkeley, LBNL, U Michigan, UC Davis, Imperial College, MEPhI
  - System test platform at SLAC, Phase I about 100 kg of LXe, TPC prototype testing to begin in few months

# High Voltage St dies



Protot pe of highest E field region tested in LAr

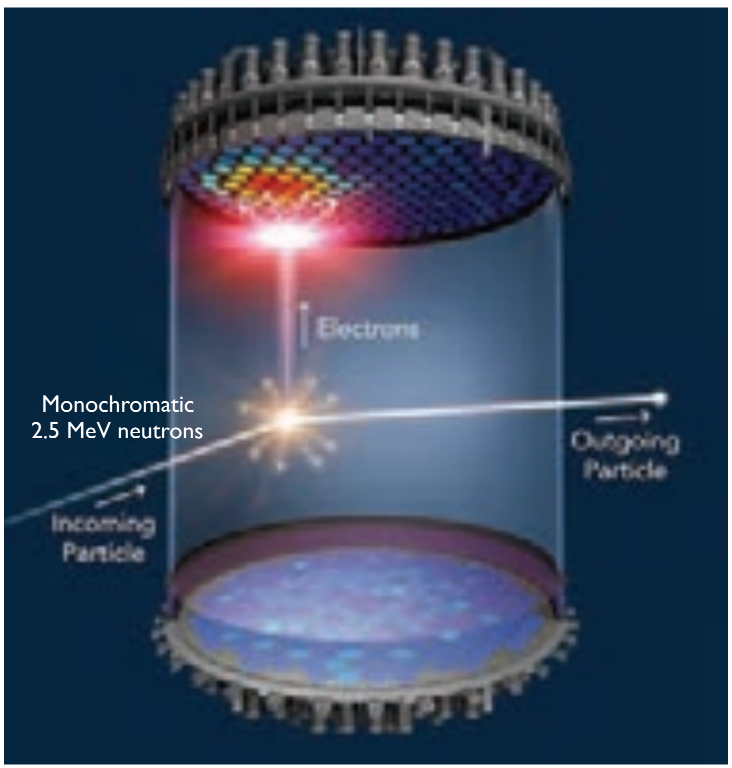
Wire grid tests ongoing



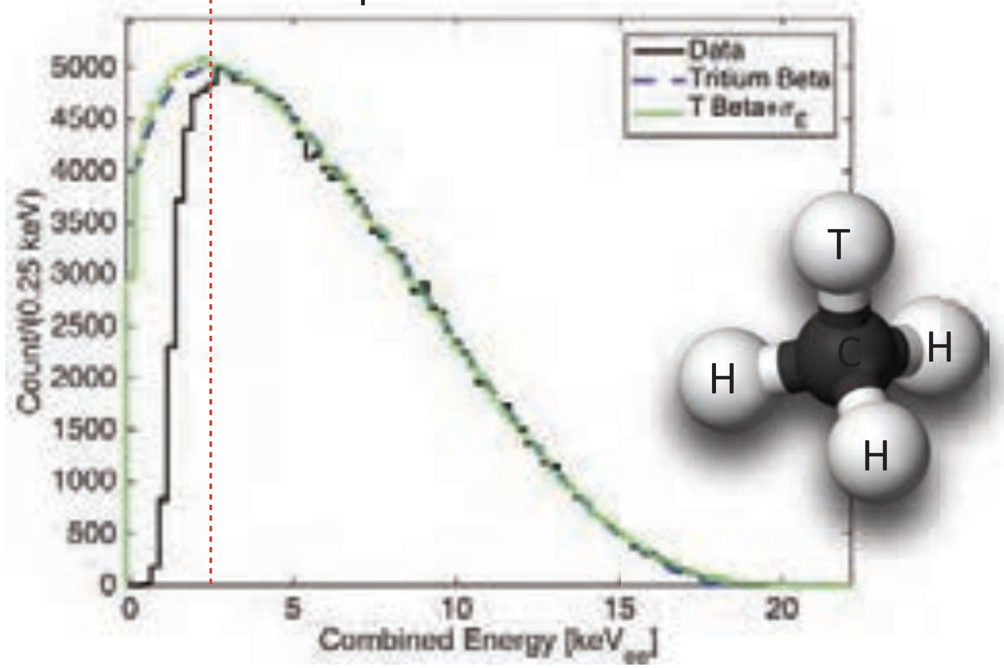

- Cathode oltage design goal kV pro ides margin
- LZ nominal opera ng goal kV V cm
- Feedthro gh protot pe tested to kV
- Protot pe TPC for kg LXe s stem fabrica on star ng
- HV protot ping e panding at Berkele

# LZ Calibrations

- ✦Demonstrated in LUX  Calibrate The Signal and Backgro  nd Model *in situ.*
- ✦DD Ne  tron Generator  N  clear Recoils
- ✦Tri  ated Methane  Electron Recoils
- ✦Addi  onal So  rces e g  YBe So  rce for lo    energ    N  clear Recoils




Tri    m Beta Spectr  m Meas  red in LUX



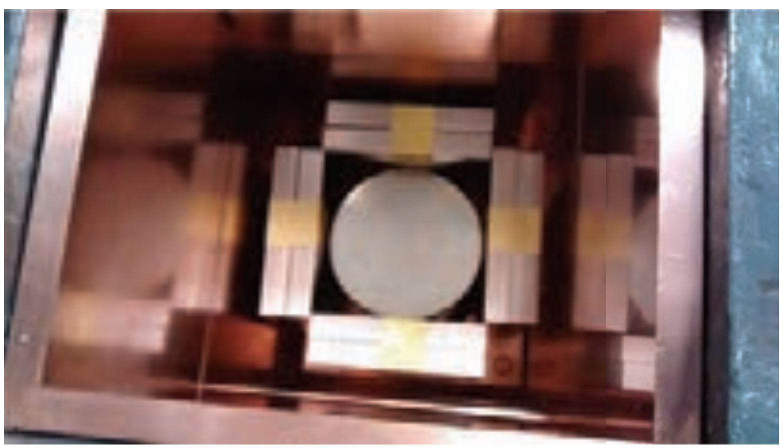
# E tensi e Calibra on

- LUX has led the a to detailed calibra ons
  LZ ill b ild on this and do more

| Done in LUX and will be done in LZ | Not done in LUX, but will do in LZ |
|---|---|
| $^{m}$Kr ro ne ro ghl eekl | Ac ated Xe $^{m}$Xe and $^{m}$Xe |
| Tri ated methane e er fe months | Rn |
| E ternal radioisotope ne tron so rces | AmLi |
| E ternal radioisotope gamma so rces | YBe |
| DD ne tron generator pgraded earl ne t ear to shorten p lse | |

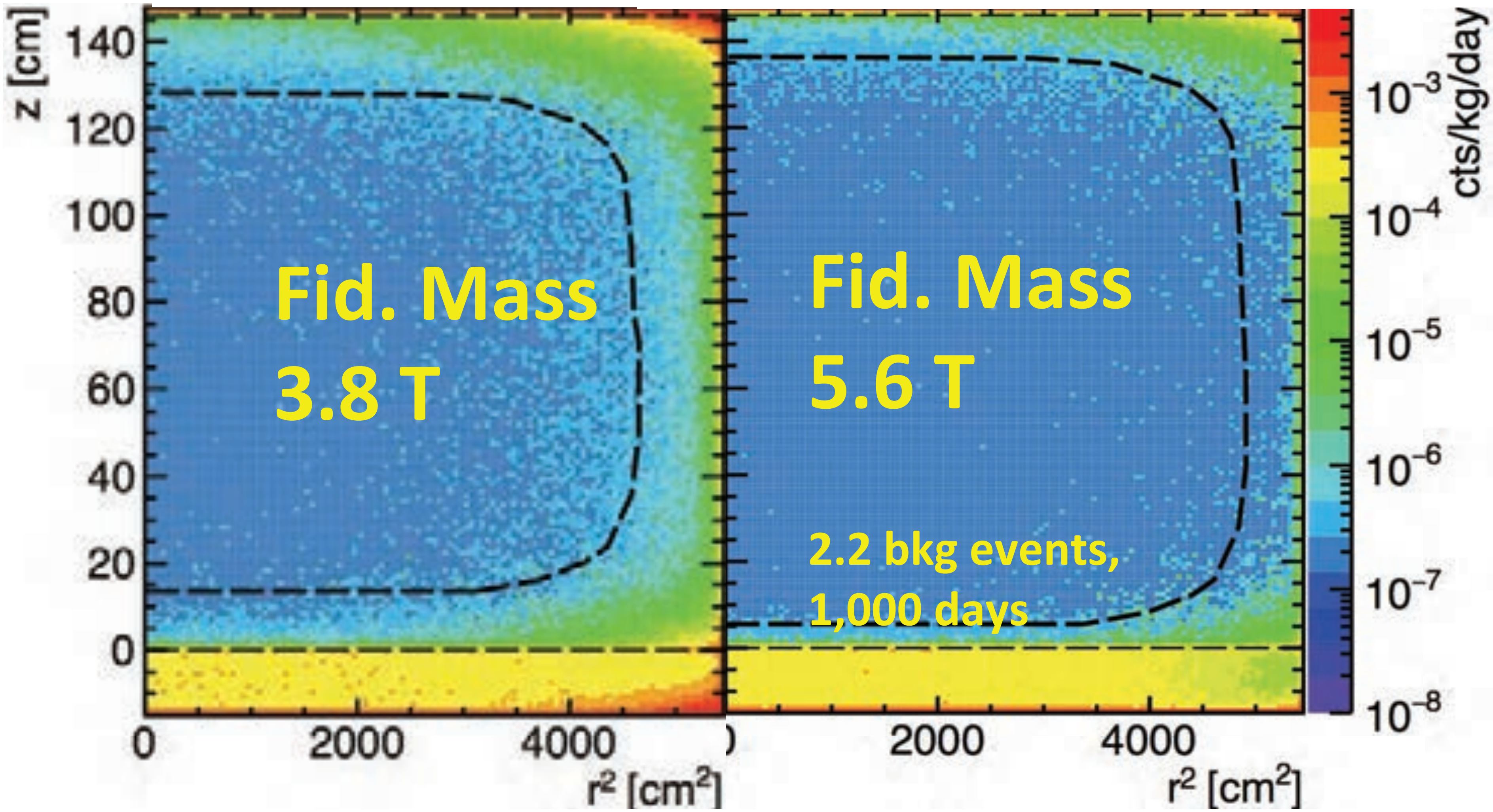
# Cr  ostat Vessels

- UK responsibilit
- Lo    backgro  nd   tani  m chosen direc  on SS alterna    e ad  anced as back  p
- Ti slab for all   essels and other parts  recei  ed and assa  ed
- Contrib  tes          NR  ER co  nts in fid  cial   ol  me in          da  s after c  ts



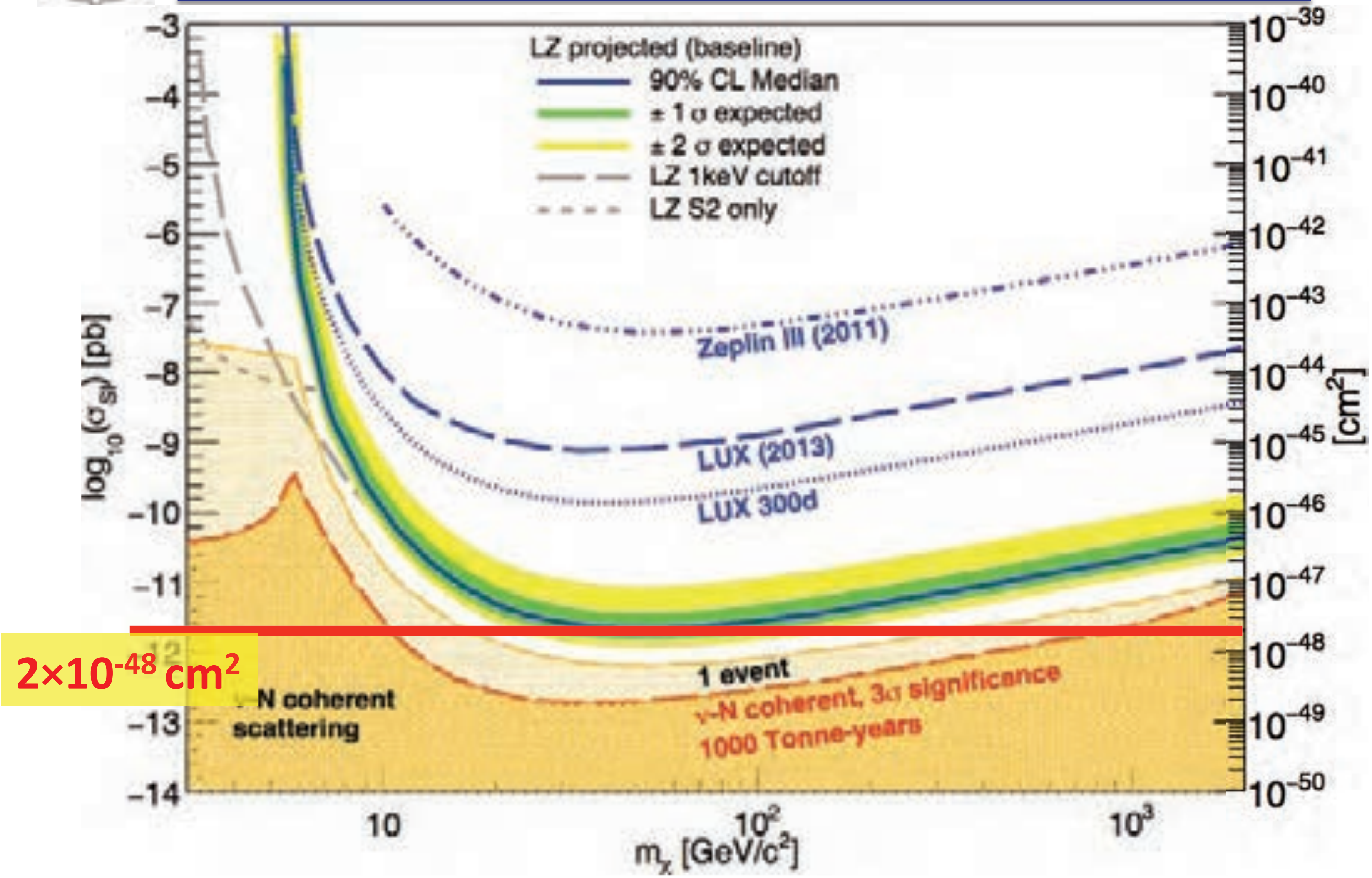
# Backgro nd Modeled

J st LXe TPC Use LXe skin O ter Det

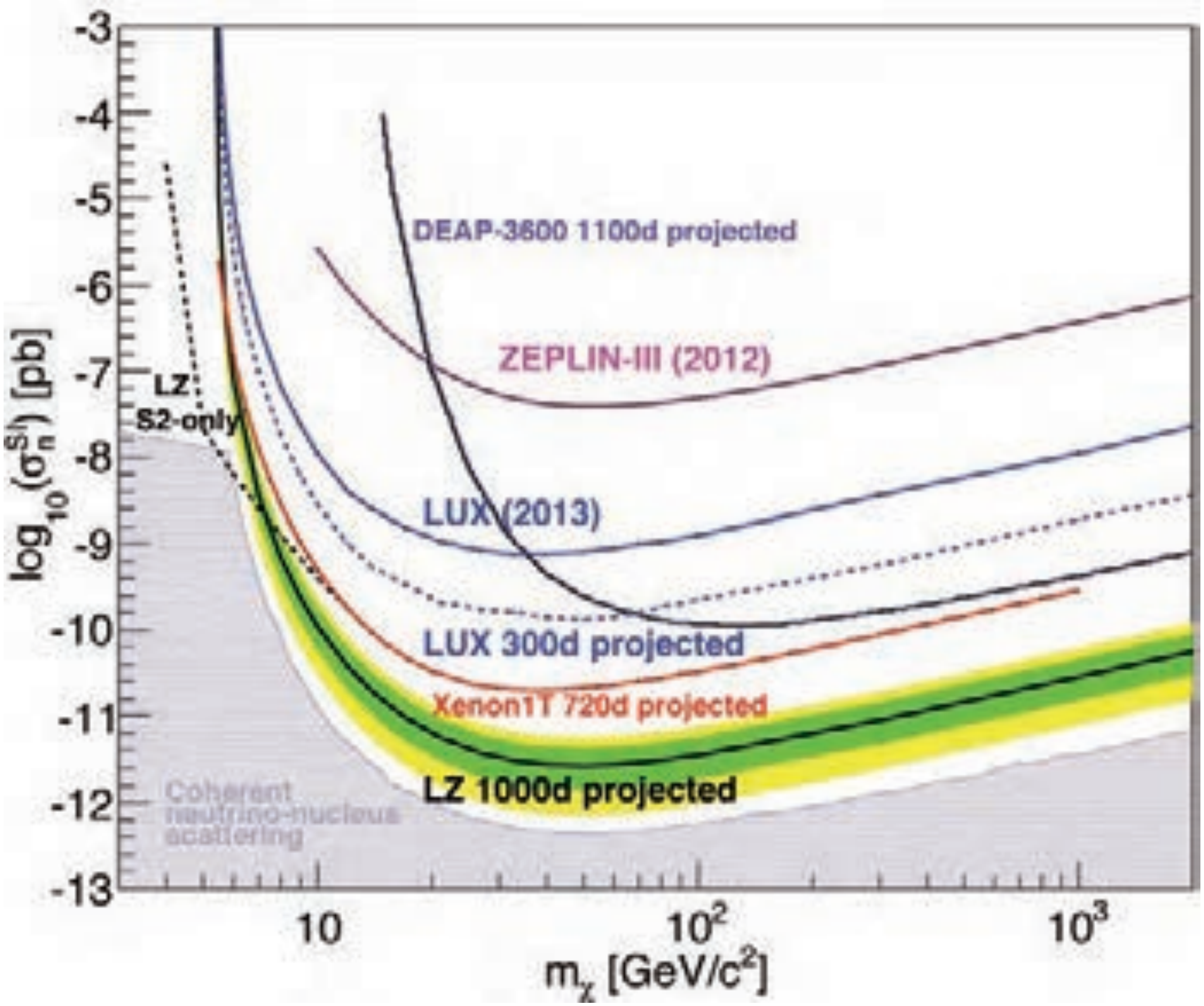


# Projected Sensi    it      Spin Independent

LZ      Tonnes        li  e da  s



# Sensi it ith Compe on



# Waiting for the Jackpot