The Latest on LUX

New Dark Matter Results and Prospects

www.luxdarkmatter.org

S. Fiorucci – LBNL

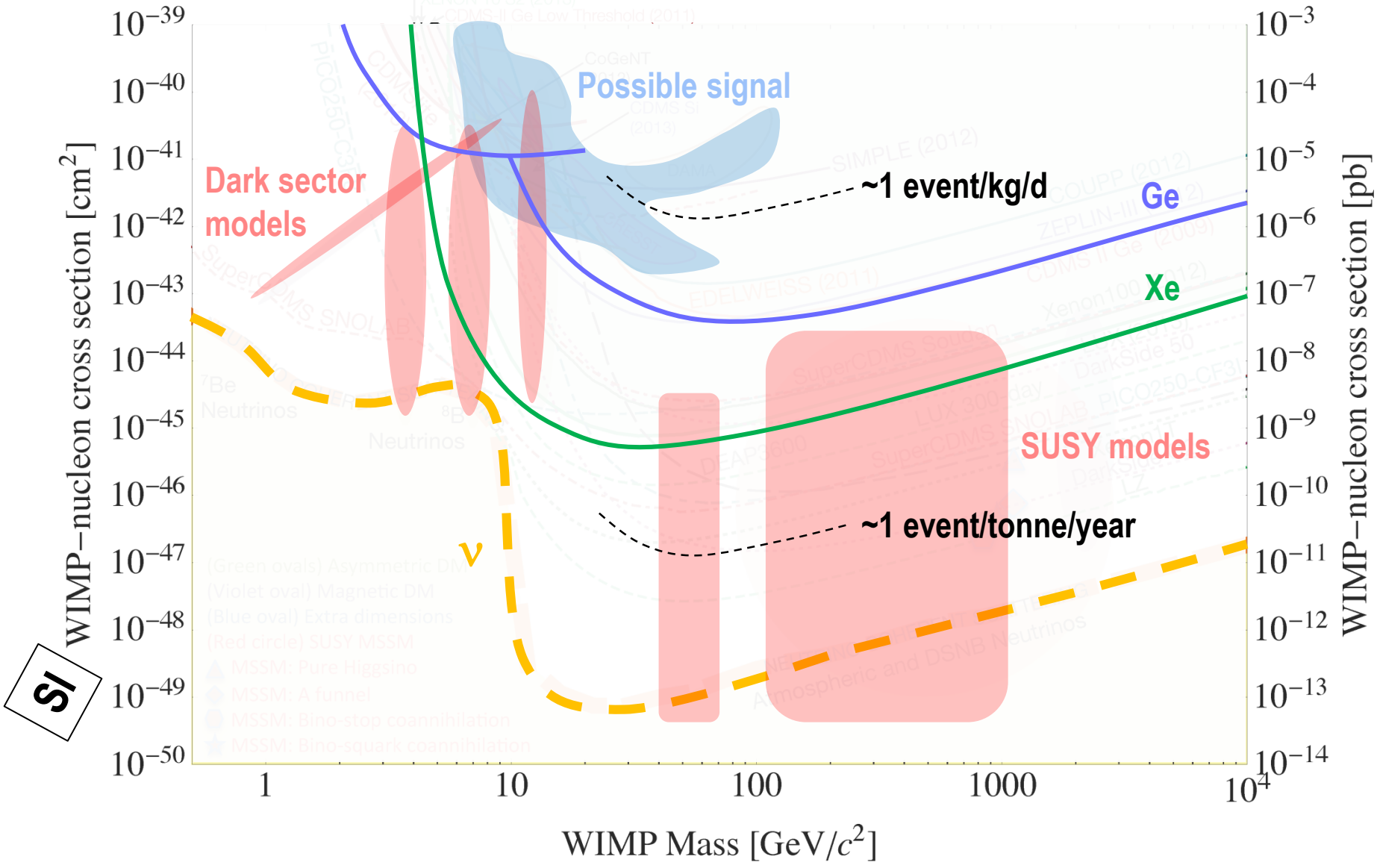
Outline

1. Quick overview of LUX goals and means
2. Results from 2013 physics “Run 3”
3. Completion of physics “Run 4”
4. LUX end-game

Quick refresher on the basics

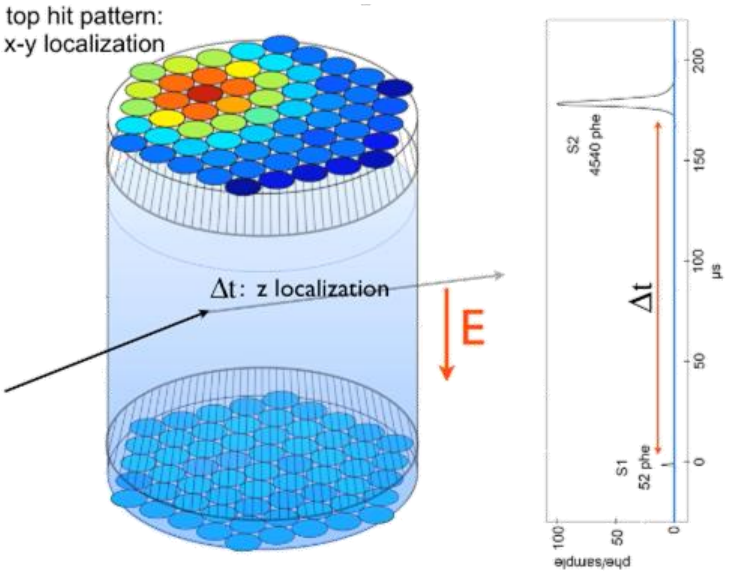
1. LUX and DM Direct Search 101

Eyes on Target



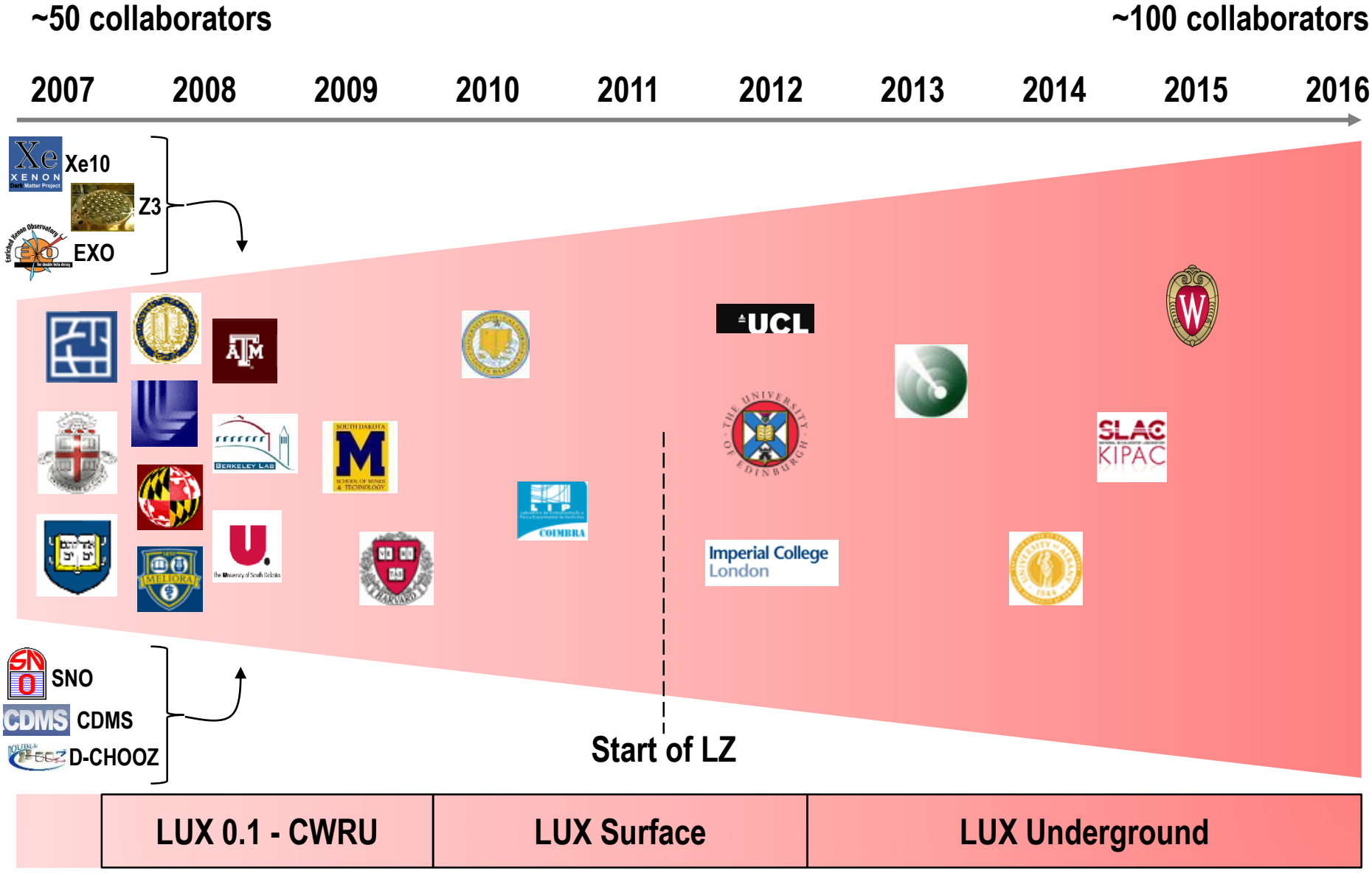
Xenon TPCs as Dark Matter Detectors

- Virtues of a dark matter detector:
  - Quiet
  - Low-threshold
  - Massive
  - Discriminatory
- Xenon is Quiet because it's Massive
  - No damaging long-lived isotopes
  - Can be constantly purified
  - High density 3 g/cm^3
  - Self-shielding
  - Scalable to multi-ton scale
- Xenon is Low-threshold
  - 178 nm UV scintillator with S1 light yield > 60 ph / keV (ZF)
  - S2 ionization sensitive to single extracted electrons
  - LUX demonstrated sensitivity:
    - ER ~ 0.2 keVee
    - NR ~ 1 keVnr

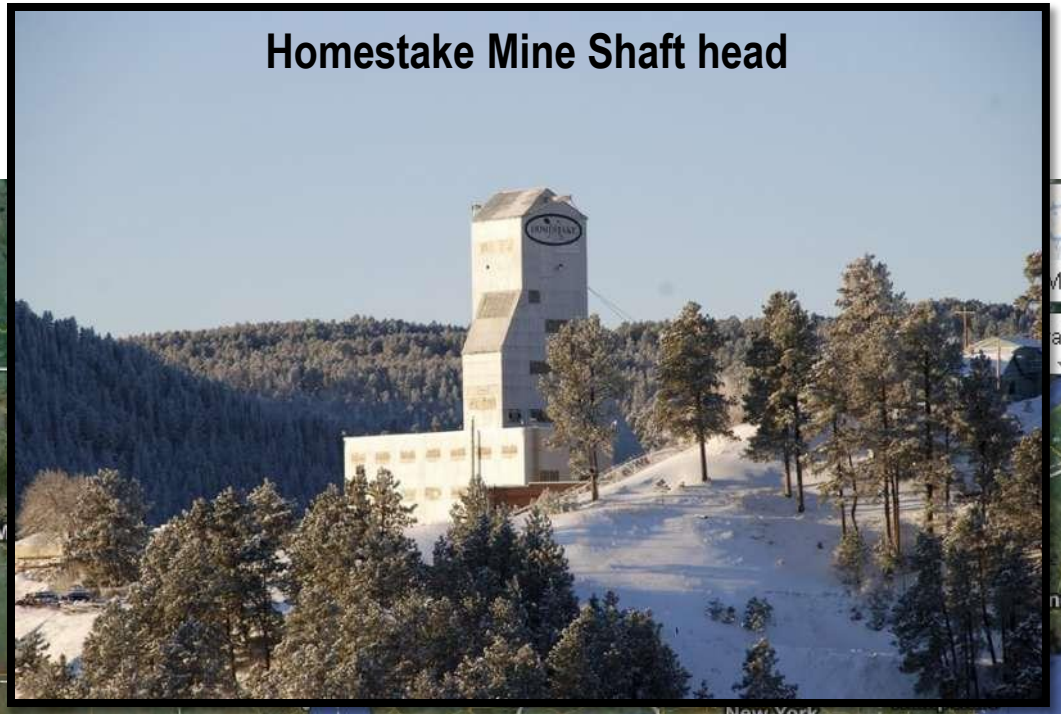


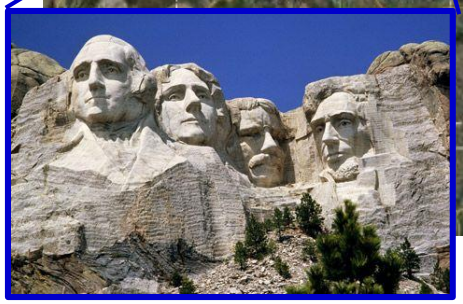
- Xenon has powerful Event Discrimination
  - S1+S2 allows mm vertex reconstruction
    - → Fiducialization, take advantage of self-shielding
    - → Rejection of multiple scatters
  - Ratio S2/S1
    - → Differentiate Electron Recoils / Nuclear Recoils
- Additional Perks:
  - Scalar WIMP-nucleon rate dR/dE ~ A^2
  - Contains odd-neutron isotopes for SD coupling

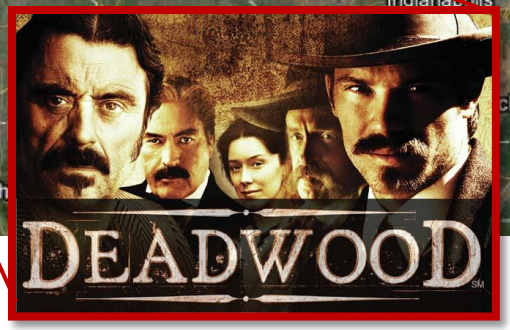
LUX Collaboration – 2007 to Now



The Sanford Laboratory at Homestake





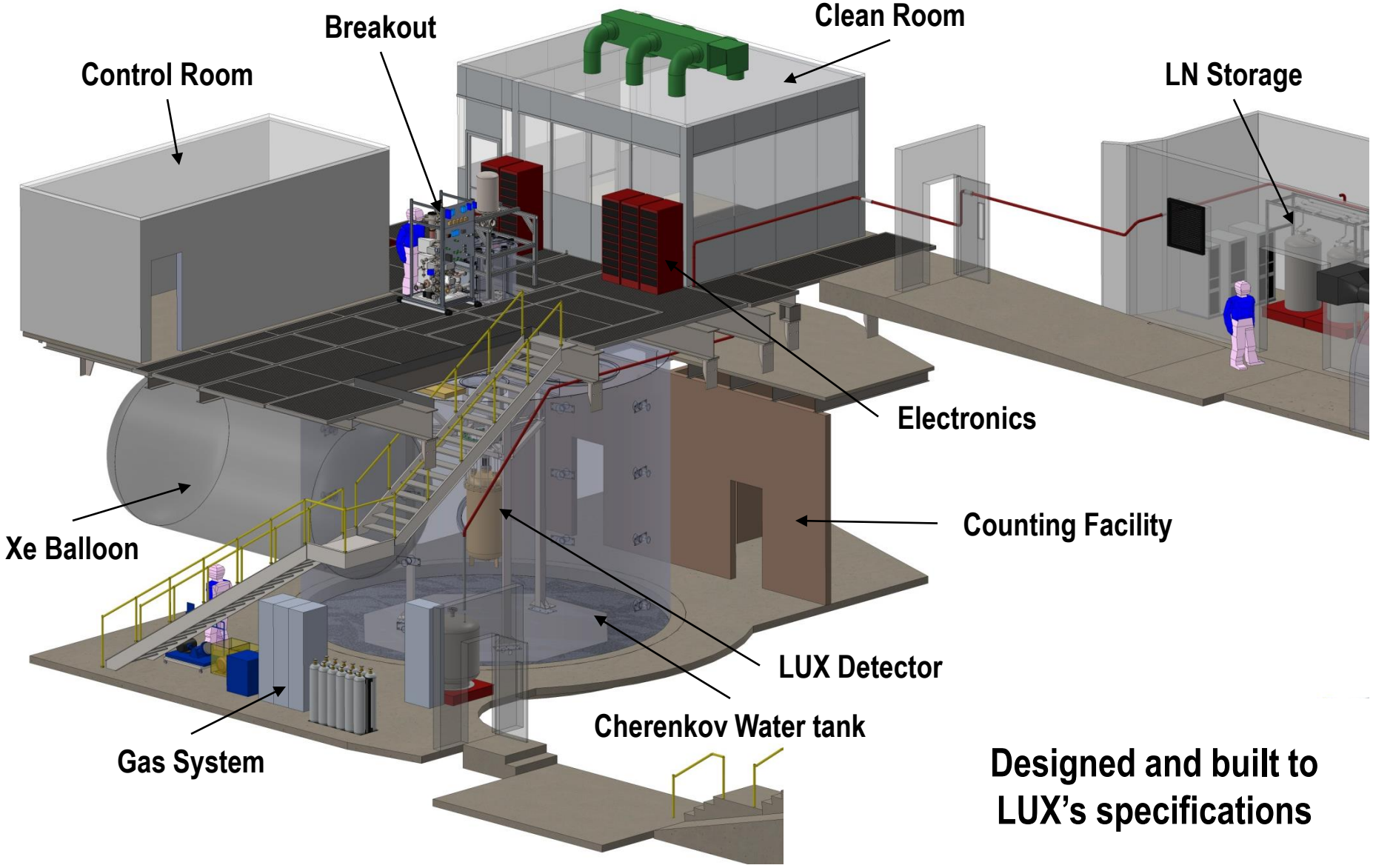


SD / South Korea:
2 x area
1/50 x population

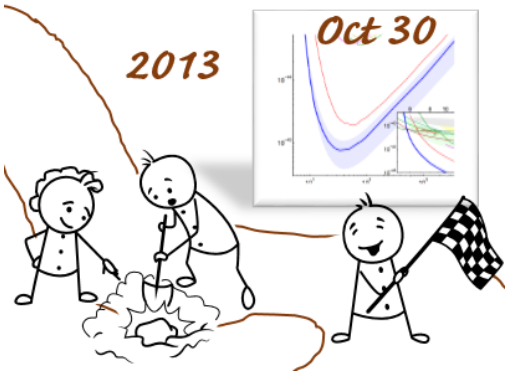
Thanks Google

www.sanfordlab.org

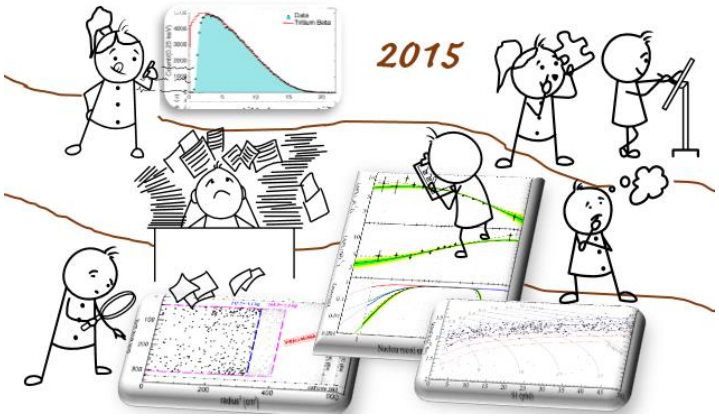
Sanford Lab – LUX in the Davis Laboratory



Designed and built to LUX's specifications



...

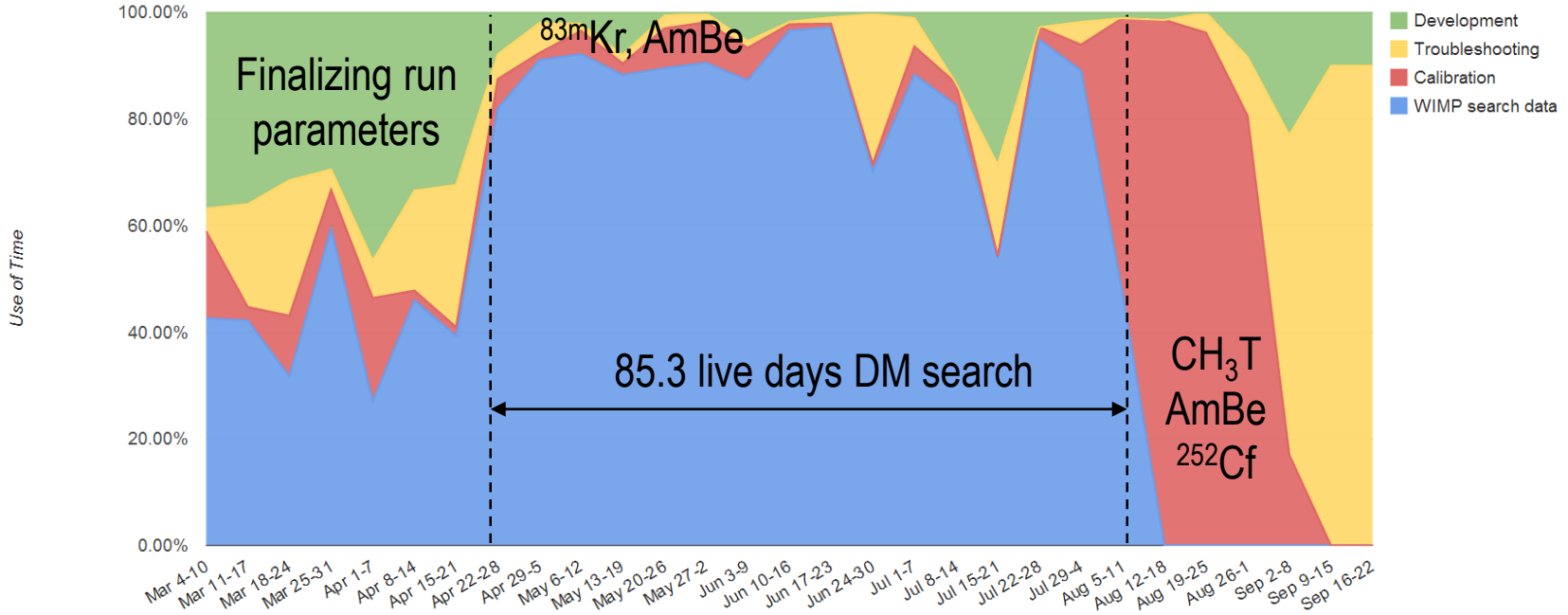


The State of the Art

2. LUX “Run 3” Result(s)

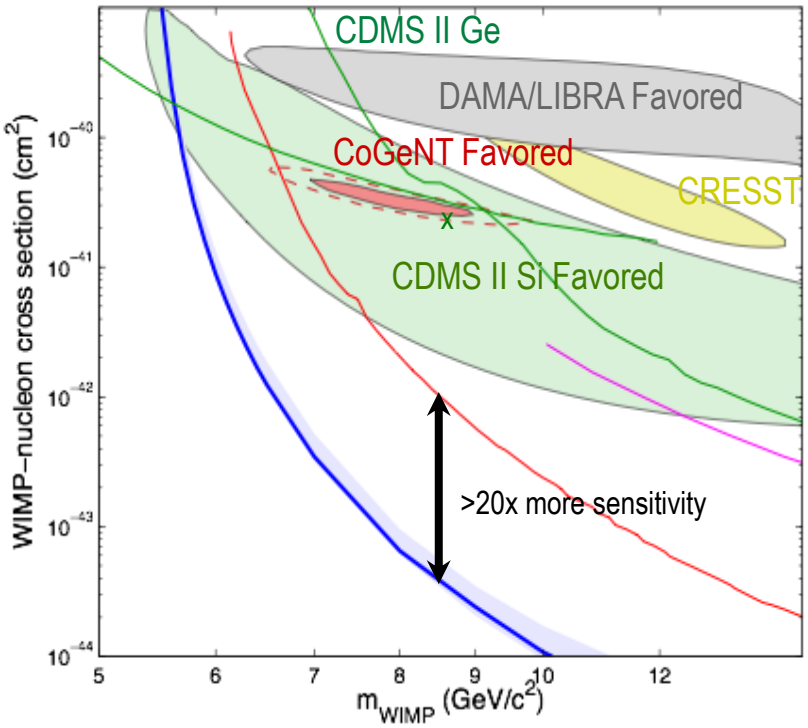
First Underground Science (Run 3 – 2013)

- **WIMP Search dataset** — **April – August 2013**
- **First result announcement** — **September 30, 2013**

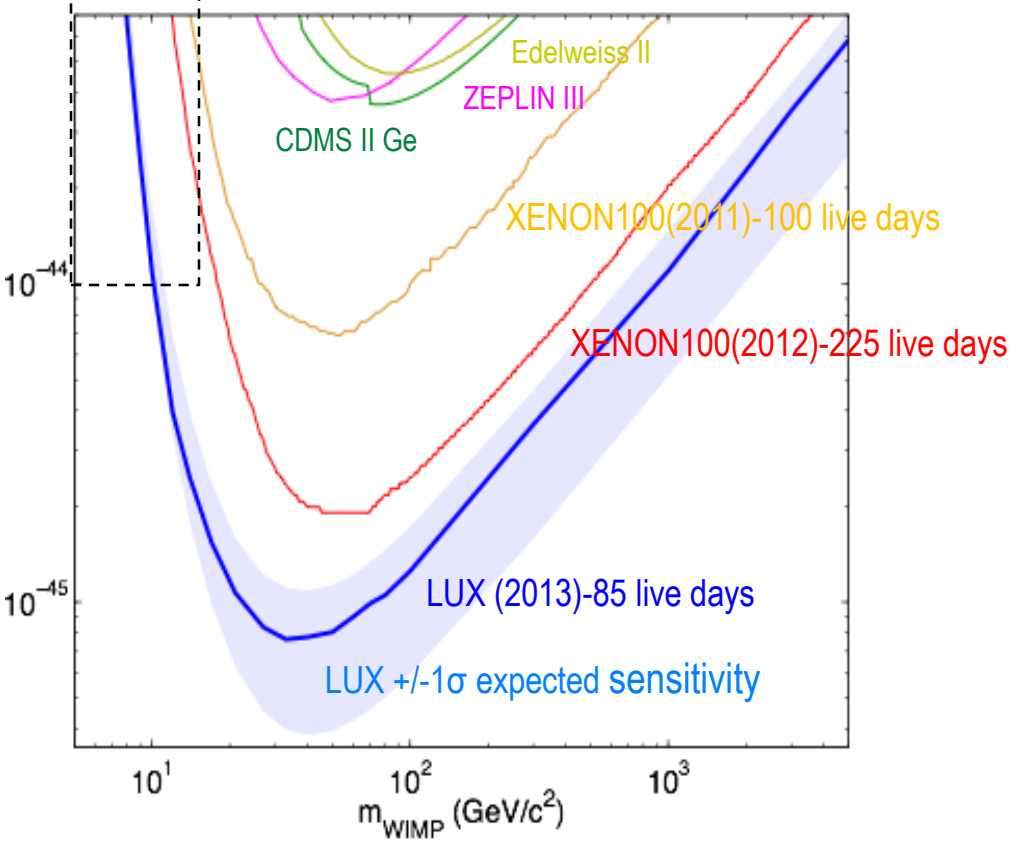


- **Important lessons**
  - **Real-time data quality control is mandatory** - **spent 1 month with non-optimal trigger**
  - **Data taking efficiency tracking is very effective**
  - **Offsite support "remote shifts" helps a lot with collaboration involvement, fast turn-around**
  - **Plan for both summer and winter storms in South Dakota…**

LUX 2013 World-leading Result



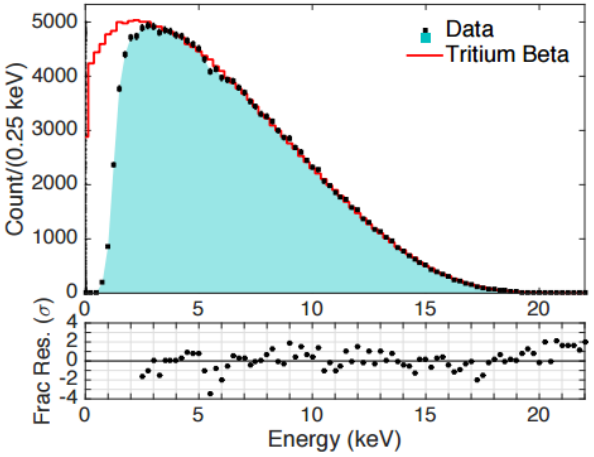
- **World-leading sensitivity**, with optimum at 33 GeV/c^2
  - Improvement factor x2-3
- >1000 result citations on Inspire-HEP by Jan 2016

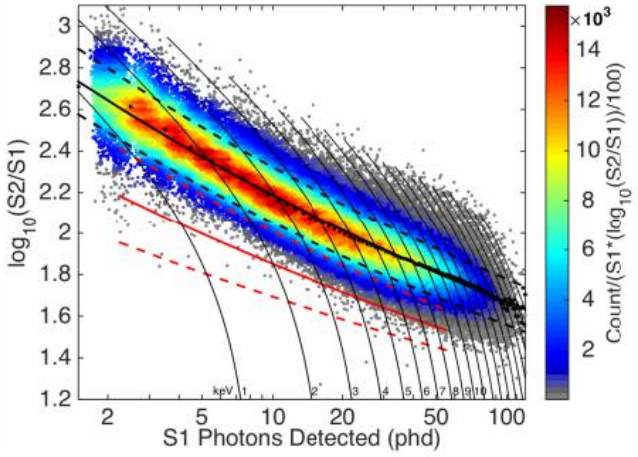


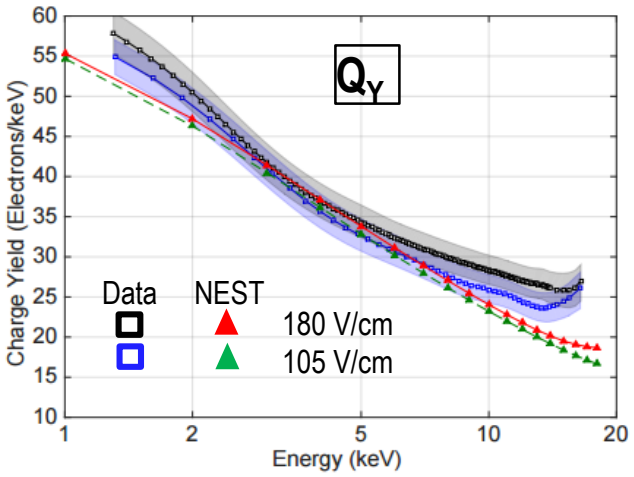
- Low-mass regime: **several "hints" of WIMP signal strongly disfavored**
- Dramatic relative improvement in sensitivity due to excellent light collection
- Precision calibrations yet to come

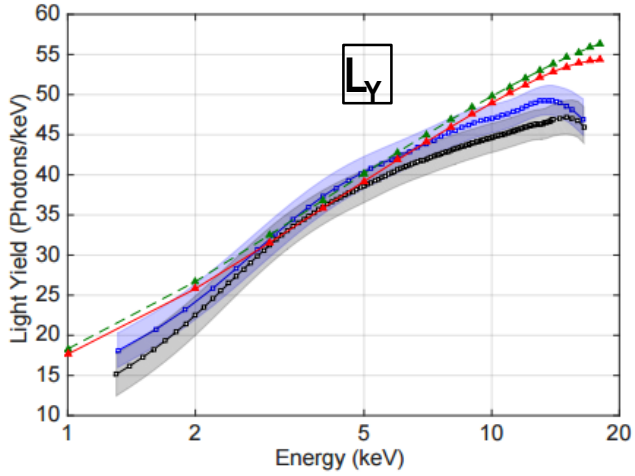
Electron Recoil Response – CH_3T

- Recent improvements to analysis thanks to CH_3T data:
  - ER light and charge yields vs Energy down to ~ 1 keVee
  - Detection efficiency vs Energy
  - Parametrization of the 90% C.L "ER Band" (170k events)
  - Discrimination factor vs Energy in [0.2 – 5] keVee
  - Recombination vs Energy and drift electric field value
- Detailed paper published this year
  - Phys. Rev. D 93, 072009 or arXiv:12512:03133





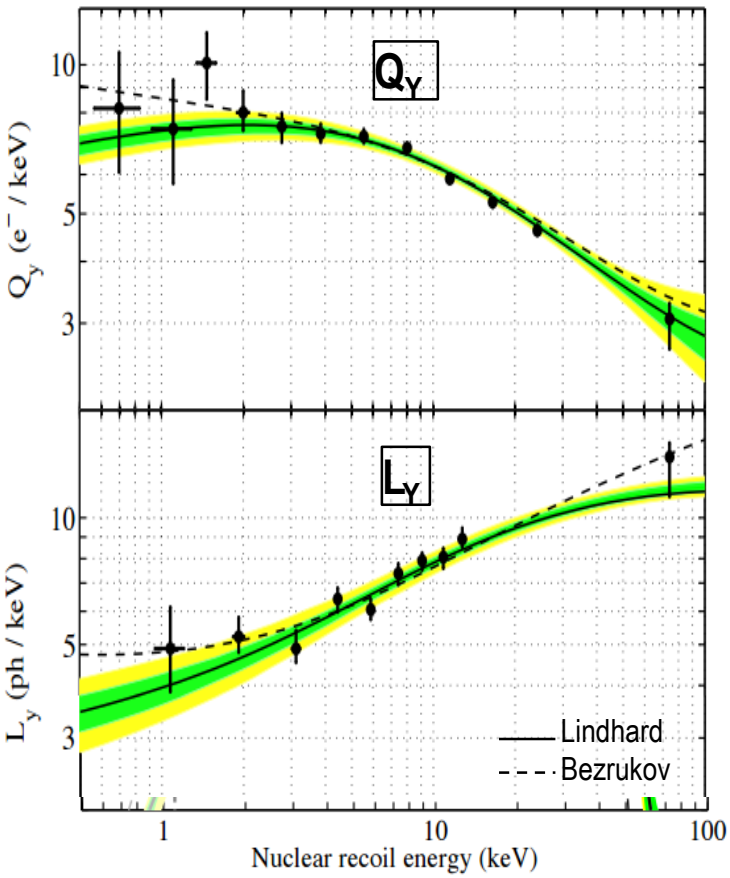




- 2013 result used NEST model above
- 2015 result used fit to calibration data, which then was used to update NEST

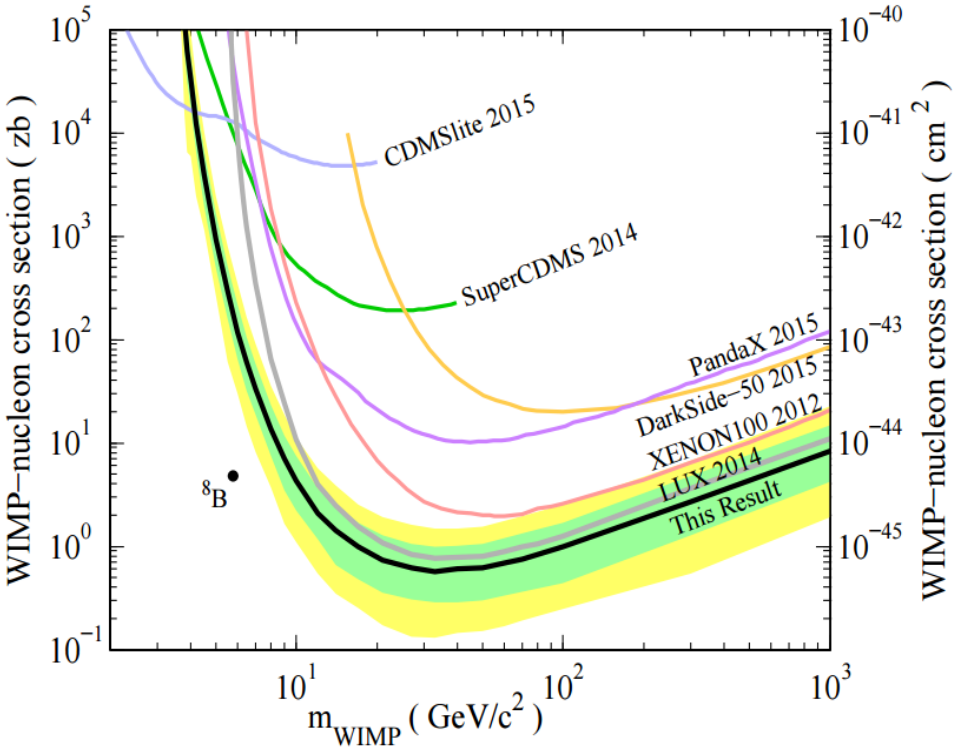
Nuclear Recoil Response

- Data first shown in Feb 2014 with very preliminary analysis. Showed potential to reach ~1 keVr
- Significant effort to refine analysis since then
  - Study of all systematics
  - Optimization of events selection
  - Improved models of ionization and scintillation
- Great progress!
  - Q_Y measured down to 0.7 keVr (double scatters)
  - L_Y measured down to 1.1 keVr (single scatters)
  - Used Lindhard model fit to describe the data in most recent analysis
- Can now kinematically reach WIMP masses as low as 3.3 GeV/c^2 !
- Detailed paper in final stages of preparation



Re-analysis of 2013 Data

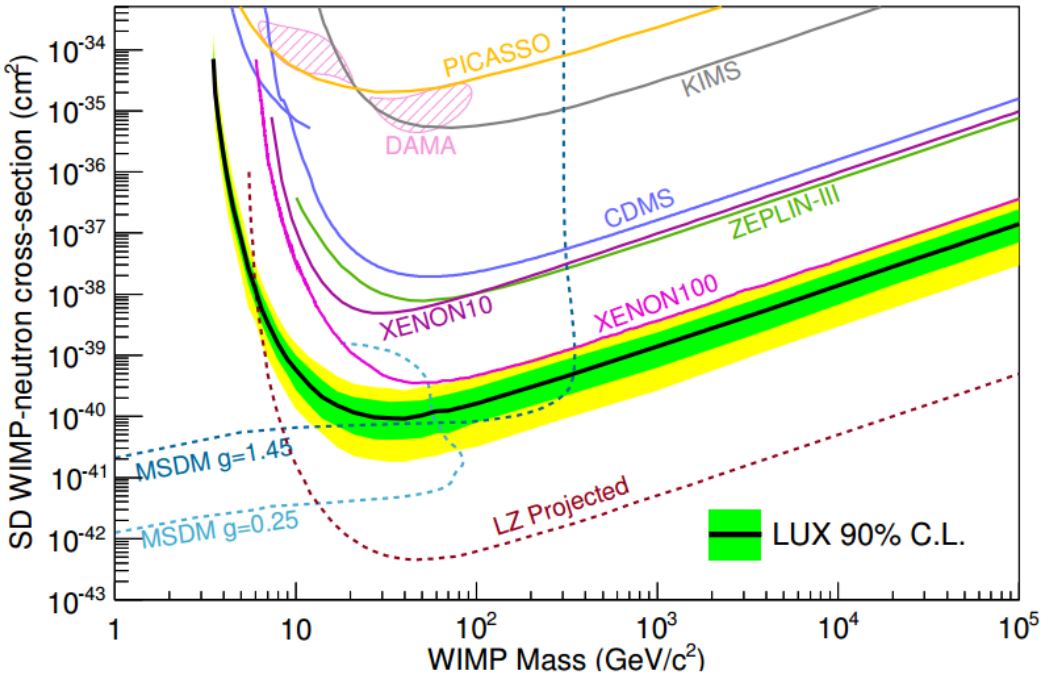
- Several key improvements over 2013 analysis:
  - Increased net exposure 85 d → 95 d (reclaimed with tighter quality cuts)
  - Increased fiducial volume 118 kg → 145 kg (from better background modeling, position rec.)
  - Extended signal range 2-30 phe → 1-50 phd (pulse counting/finding, background model)
  - Lowered S2 raw threshold 200 phe → 165 phd (now using both arrays instead of just bottom)
  - Lowered signal cut-off 3.0 keV → 1.1 keV (from precision NR calibrations)
- Result released at end of 2015
  - Phys. Rev. Lett. 116, 161301 arXiv:1512.03506
  - Mild improvement at all WIMP masses
  - Competitive down to ~4 GeV/c^2
- Also released SD result paper
  - Phys. Rev. Lett. 116, 161302 arXiv:1602.03489
  - Competitive for WIMP-neutron coupling



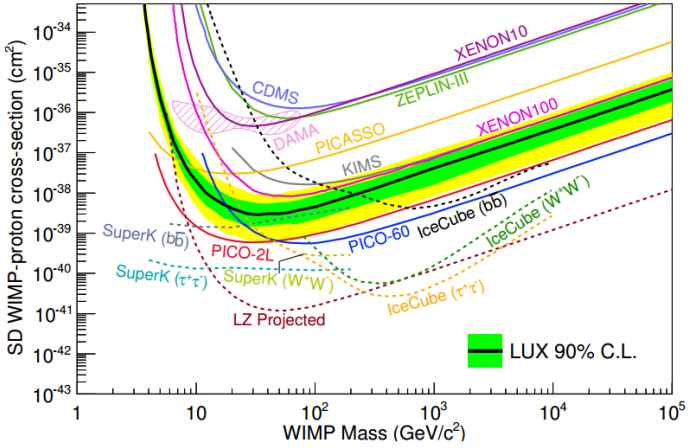
LUX Run 3 Spin-Dependent Result

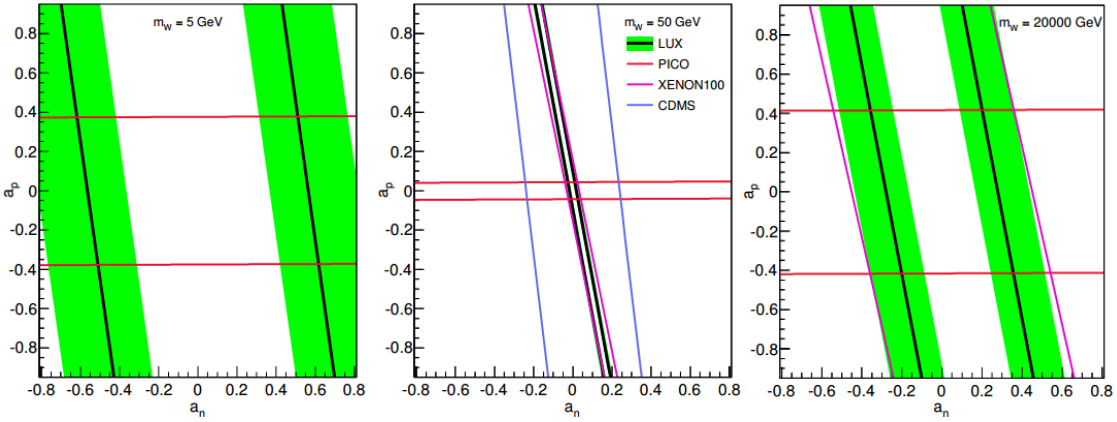
- **Phys. Rev. Lett. 116, 161302 – arXiv:1602.03489**

WIMP-neutron



WIMP-proton





More LUX Results Coming in 2016

- Already published:
  - ^{85}Kr removal paper, submitted to Astropart.Phys. – arXiv:1605.03844
  - CH_3T calibration, Phys. Rev. D 93, 072009 – arXiv:1512.03133

DD neutron calibration paper	before fall 2016
Extensive Run 3 re-analysis detailed paper, in PRD	before end of 2016
^{127}Xe sub-keV ER calibration paper	before end of 2016
ER yields and recombination paper	before end of 2016
Axion-like interaction result paper	before end of 2016

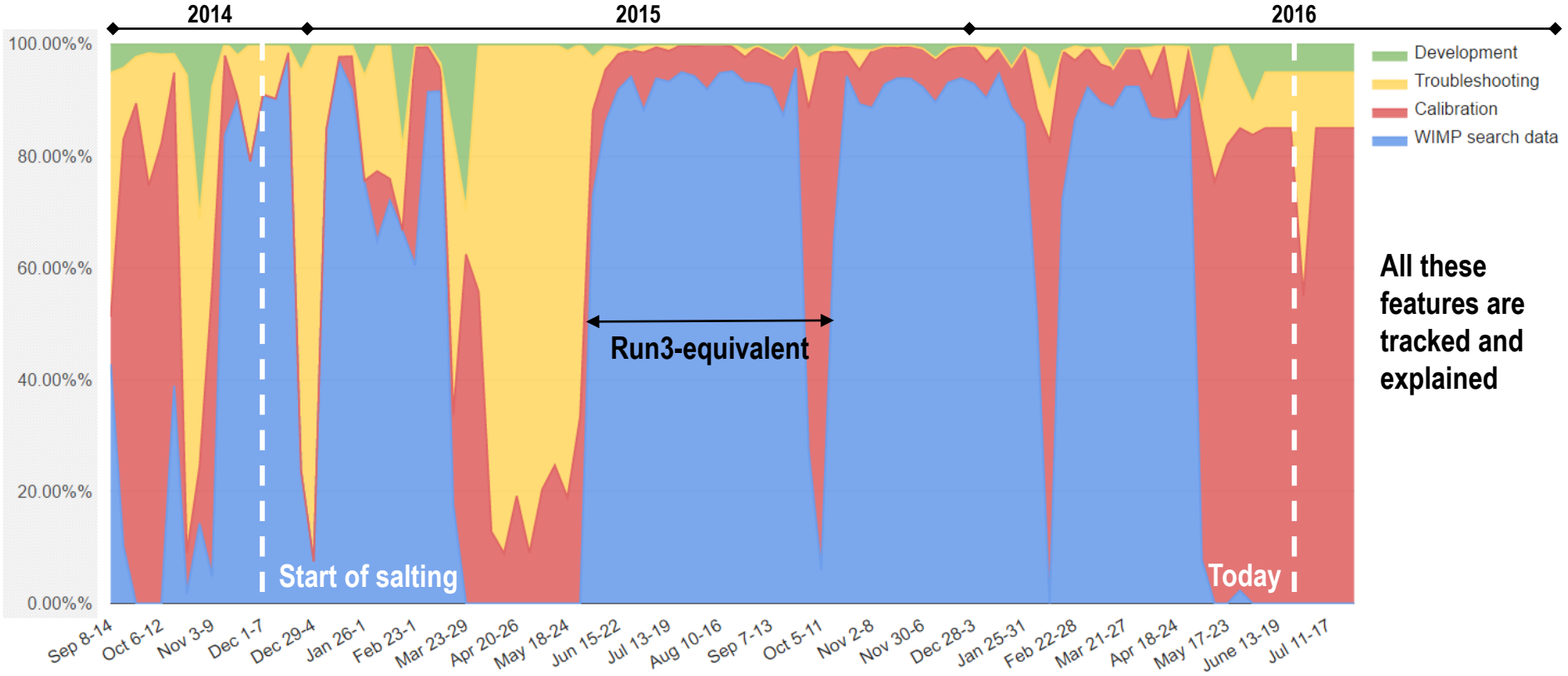
- … Run 4 SI WIMP result (and final LUX combined result) before end of 2016!
  - See next slides

LUX final stretch

3. Next Results and Endgame

LUX Run 4 : Status Update

- Run 4 started September 2014, completed May 2016
  - Implemented new "salting" strategy in December 2014 – preferred way to blind data
  - Have accumulated ~300 live days WS stats , plus ~30 live days data unsalted or outside QC
    - That's more than 3x Run 3 !
  - Weekly ^{83m}Kr, ^{137}Cs. 2-week CH_3T + DD calibrations every quarter



All these features are tracked and explained

LUX Run 4: Analysis

- Currently ongoing
- Expect published result before end of 2016
- …Cannot give out details just yet! Sorry
  - Expectation of sensitivity scaling with exposure is not unreasonable

- LUX will combine Run 4 salted data and all other LUX WIMP search data for final WIMP sensitivity result

LUX - End of the Run and Decommissioning

- [LUX in the Davis Lab] is a unique instrument that can provide invaluable data past the end of the WIMP search campaign. Being planned:
  - Upgrades to DD neutron generator
    - Short pulse mode → lower reachable S2 threshold < 0.5 keVnr, reduce analysis systematics
      - This is currently ongoing
    - D2 backscatter mode → neutron energy 272 keV, kinematic reach in Xe down to 150 eV
      - Hardware already tested. Will accumulate statistics in July
  - Increase statistics by order(s) of magnitude for CH_3T, ^{127}Xe data
  - Test several new potential injection sources
    - Particularly relevant for LZ
    - In August

Some good reference slides presented at APS 2016 on these topics, for anyone interested.

- Taking LUX apart and making room for LZ
  - September 2016 – Beginning 2017
  - Planning well underway
    - We have done it once before!

In summary:

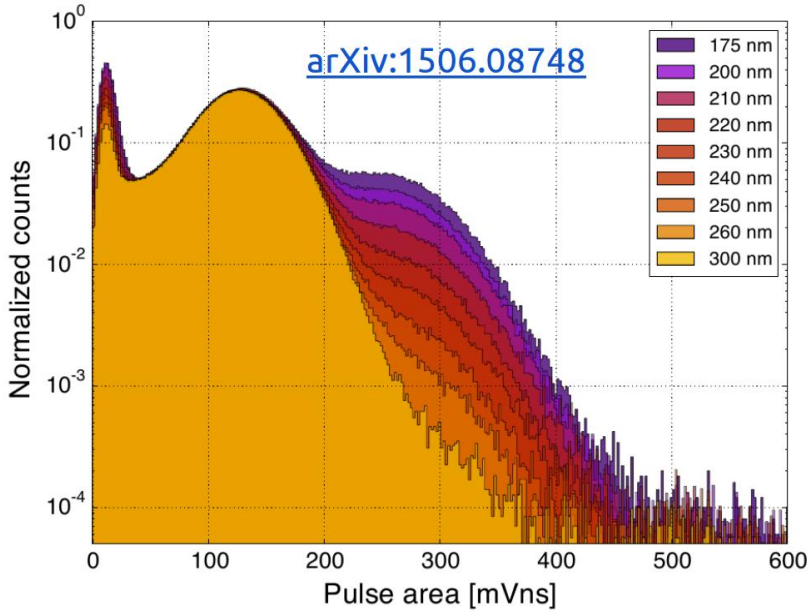
- Updated Run 3 LUX results published Jan 2016.
- Completed WIMP search data taking in May 2016. Results before end of year.
- Exciting new calibration techniques will be tested this summer.
- All of that is directly helping LZ to eventually hit the ground running.
  - See talk by Isabel Lopes later today!

Thank you

Additional Slides

Introducing Photon Counting

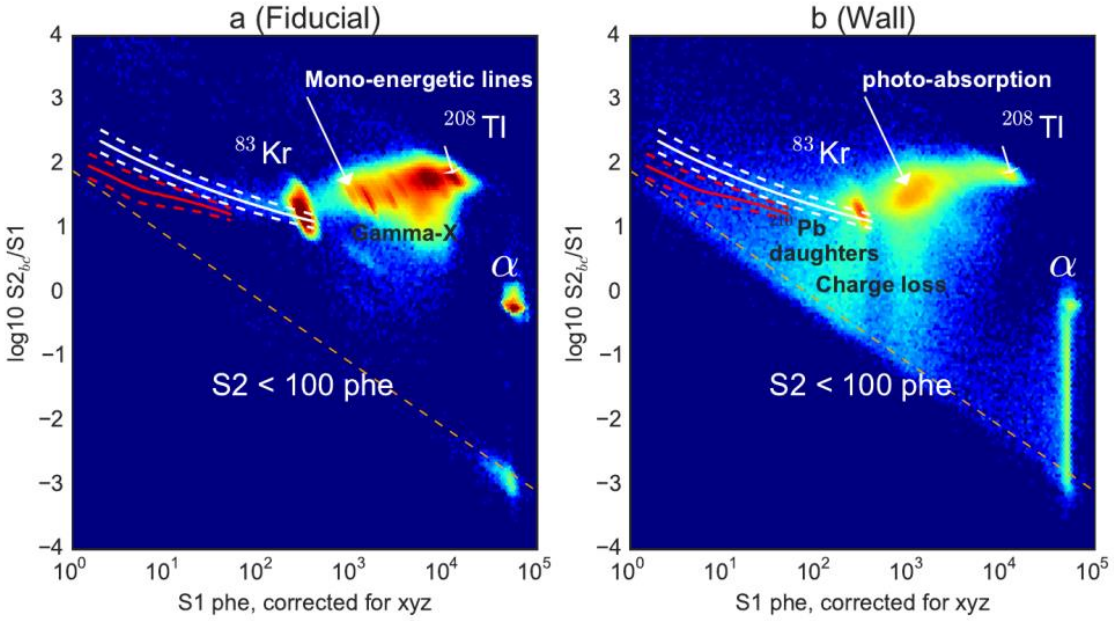
- S1 previously obtained from integrating area in "pulse window"
  - But close to threshold we are counting (few) individual photons!
  - Now we identify photon "spikes" in PMT waveforms for a better estimate, then transition smoothly to area at higher energy
- Additional twist: VUV photons
  - General PMT idea:
    - 1 photon → photocathode → 1 photo-electron
  - Except…
    - Xe scintillation light is more energetic than typical calibration LED light
    - 175 nm (7.1 eV) vs 470 nm (2.6 eV)
  - About 20% of the time 1 photon → 2 electrons
  - We now correct for this effect and use unit "detected photons" (phd) instead of "photo-electrons" (phe)

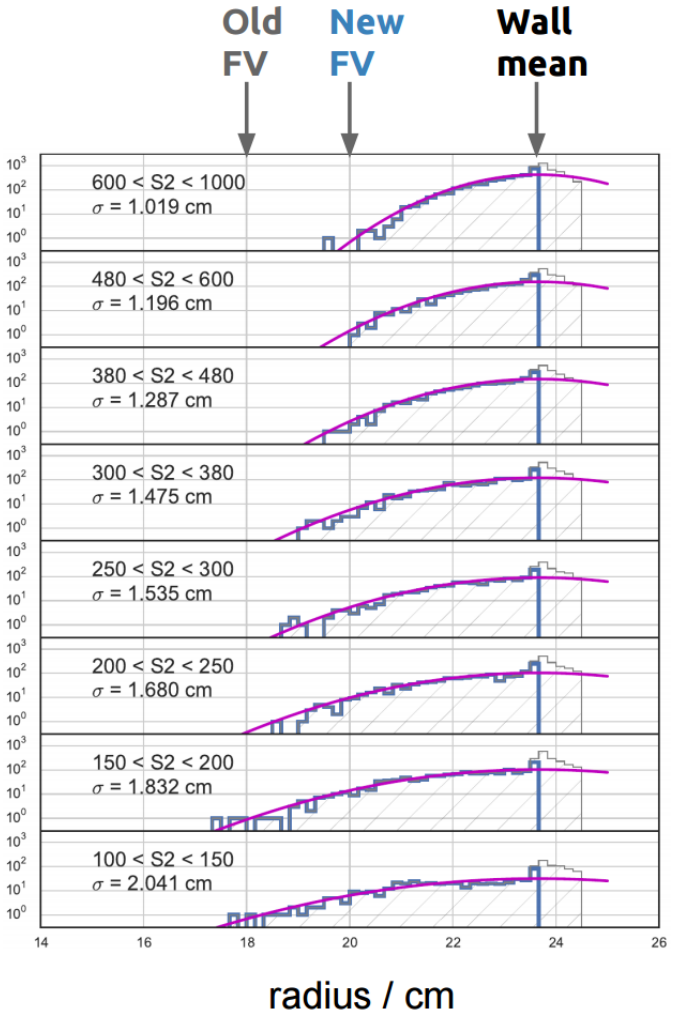


- All S1s with 2 identified photons are now accepted regardless of area
  → lower effective detection threshold

Improvements to the Background Model

- Identified population of alphas from the PTFE walls, leaking in to central region via charge loss leading to position mis-reconstruction
  - Gets worse at bottom of detector
  - Developed empirical model of charge loss that fits the data well. Using it as input to PLR.
    - See C. Lee Ph.D Thesis, CWRU, 2015
- Result: Can expand fiducial volume used for signal region by 20% ! (R< 18 cm → 20 cm)



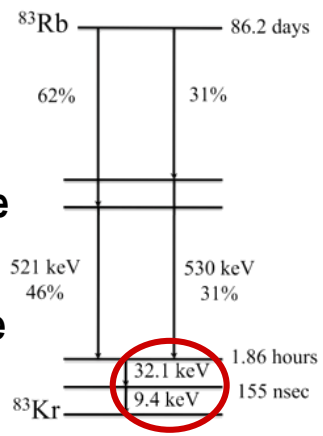


LUX Calibration Innovations

Internal gamma sources

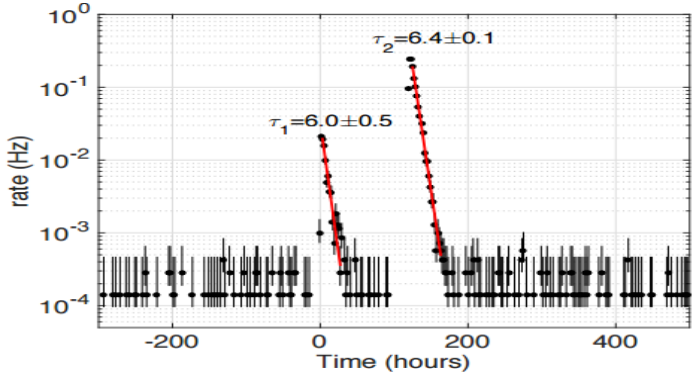
^{83m}Kr

- Homogeneous
- Reliable
- Just outside WIMP range
- Decays away in hours
- Used for S1,S2 response vs XYZ



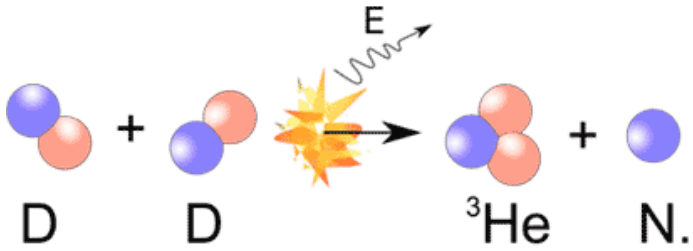
CH_3T

- Beta with endpoint 18 keV
- Demonstrated full removal in ~days
- Used for ER response, high stats



Mono-energetic neutron source

D-D



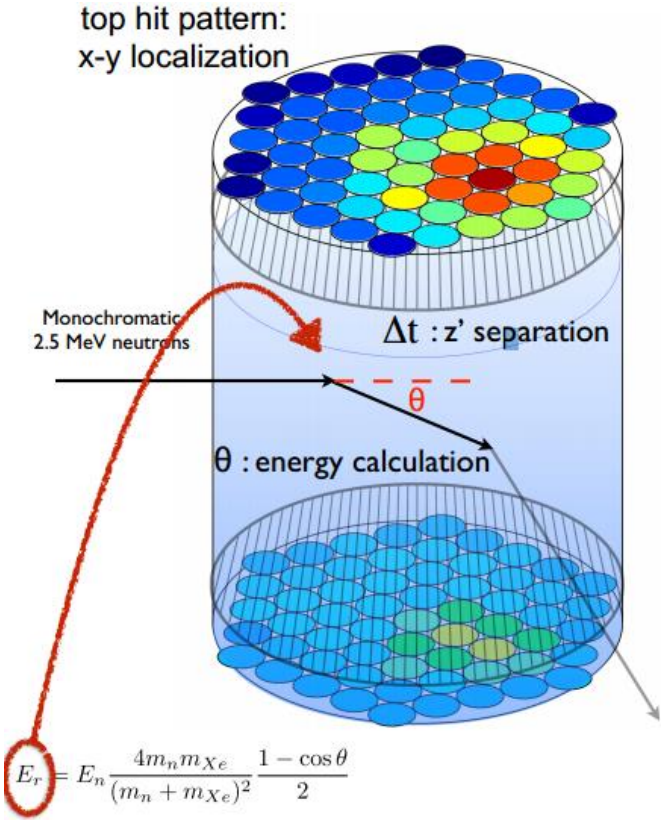
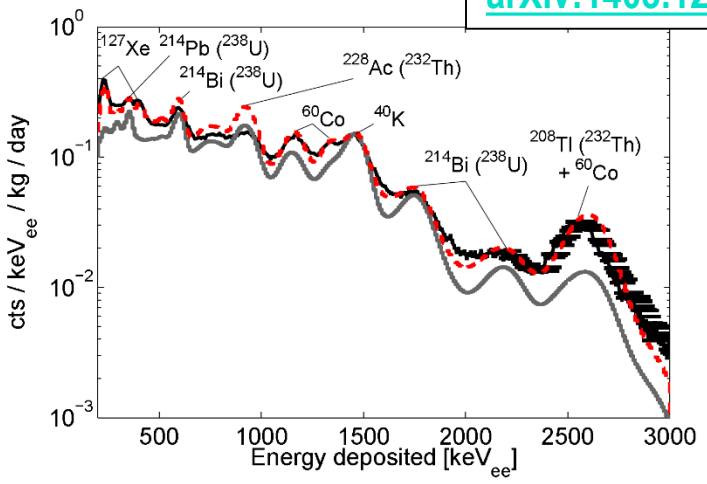


Illustration of LUX Performance: Backgrounds

AP.Phys.62 33-46 (2015), arXiv:1403.1299

- First test of model: gamma spectrum
  - Outstanding agreement data / model
  - Multiple scatter reconstruction needed > 200 keV_{ee}
  - But region of interest for WS is < 5 keV_{ee} !

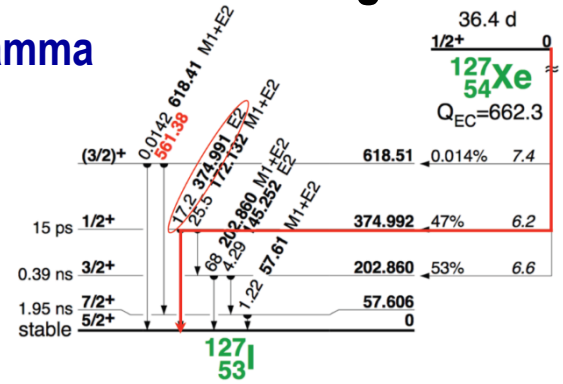


- Closer: lines from cosmogenic activation of xenon
  - Predicted lines observed, in correct ratio

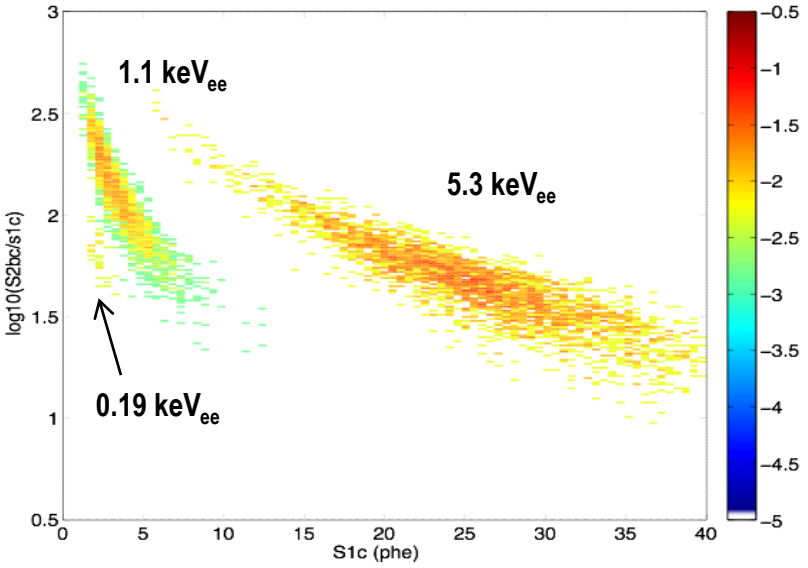
Isotope	Half-life [Days]	Decay Rate [μBq kg^{-1}] Predicted	Observed
^{127}Xe	36	420	490 ± 95
^{129m}Xe	8.9	4.1	3.2 ± 0.6
^{131m}Xe	12	25	22 ± 5
^{133}Xe	5.3	0.014	0.025 ± 0.005

Predicted rates all multiplied by x8

- One of them really matters for WS range: ^{127}Xe
  - EC decay, x-ray + gamma 33, 5, 1, 0.2 keV_{ee}
  - Depth-dependent
  - One of PLR PDFs
  - Sub-keV calibration!



Probability Density Function



What Happened Between Run 3 and Run 4?

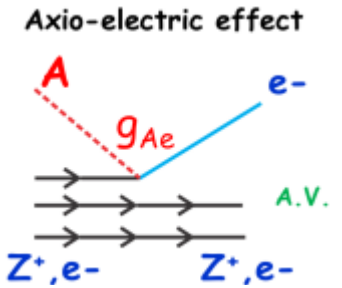
- Precisions Run3 ER and NR calibrations — Oct – Dec 2013
- "Grids Conditioning" — Jan – Mar 2014
  - LUX 2013 ran at 180 V/cm drift field and ~50% extraction efficiency.
    - Higher voltages cause light emission in TPC, "glow"
  - Can we gain in discrimination power, S2 gain?
  - Continuously apply high voltage, watch current on grids, glow patterns, electron emission…
    - Required emptying and warming up the TPC to room temperature
  - Results: mixed
    - Gained 20% on S2 extraction field
    - No significant change on nominal drift field value
    - Limitation likely due to construction (e.g. wires polishing → LZ)
  - In parallel: redundancy/stability work on several subsystems

- Restart
  - Cool down, condense, purify the xenon again — Apr – May 2014
  - Initial calibrations CH_3T + DD neutron with new HV parameters — Jun – Aug 2014
    - We now know that we are able to resume WS data right afterwards

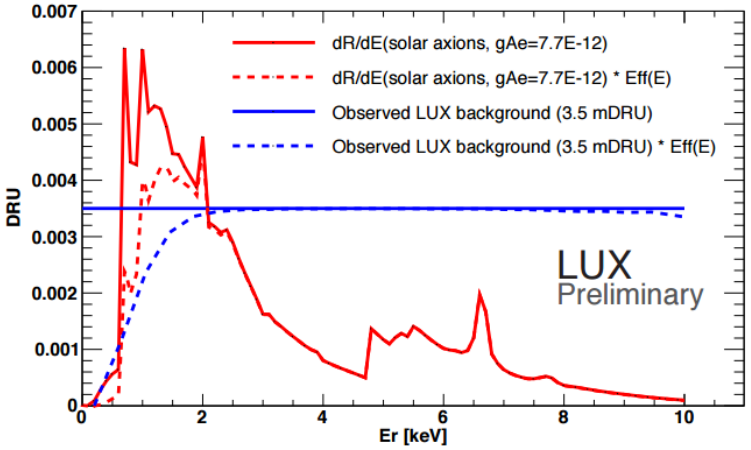
Axion Search with LUX

Ongoing!

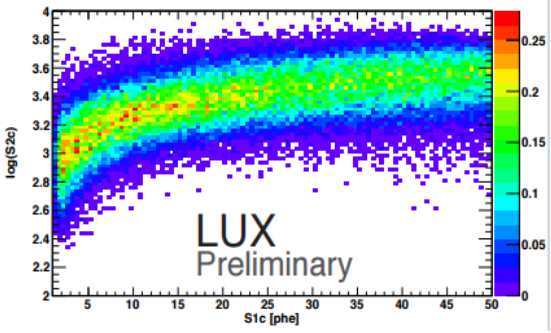
- **The theory:**
  - Axions and ALPs can couple to electrons (g_{Ae} – axio-electric effect)
  - Coming from the Sun, or diffuse within galaxy
  - Mass range anywhere from μeV to TeV



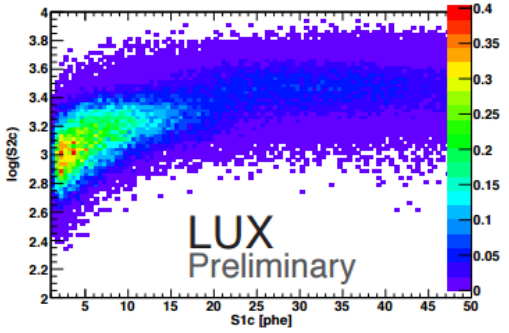
- **LUX analysis**
  - Signal = very small ER events
  - Can be simulated with LUXSim + NEST
  - Use Profile Likelihood method to extract signal from background, for a known background
  - Challenge = precise background model very near threshold



Background



Solar axion g_{Ae}=7.7E-12, null mass



Galactic axion g_{Ae}=1.5E-13, mA=2 keV/c^2