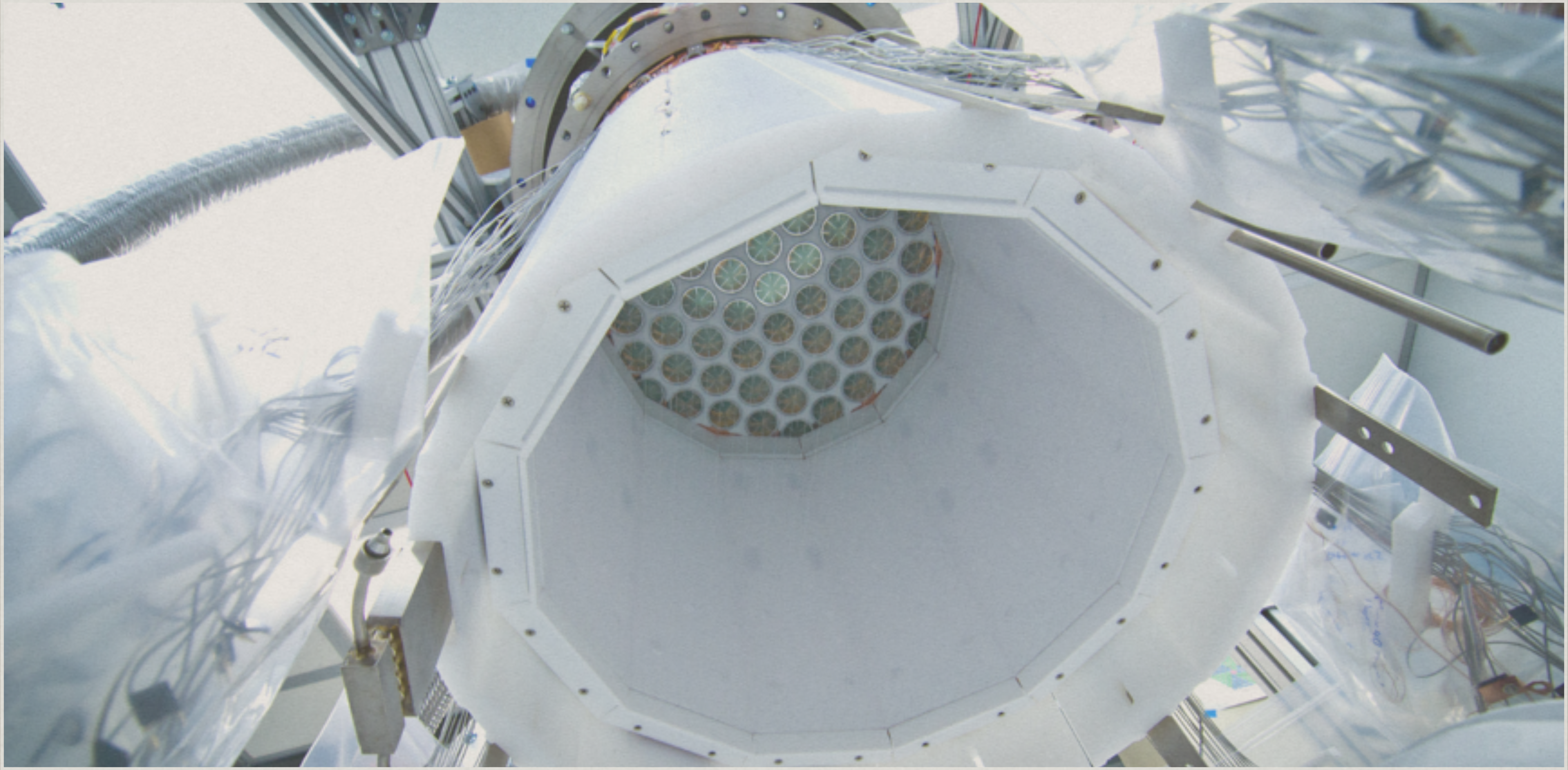

THE LUX DARK MATTER SEARCH

AARON MANALAYSAY

for the LUX collaboration

UC DAVIS
UNIVERSITY OF CALIFORNIA

SUSY2014: The 22nd International Conference on Supersymmetry and Unification of Fundamental Interactions

25 July, 2014, Manchester, United Kingdom

LUX

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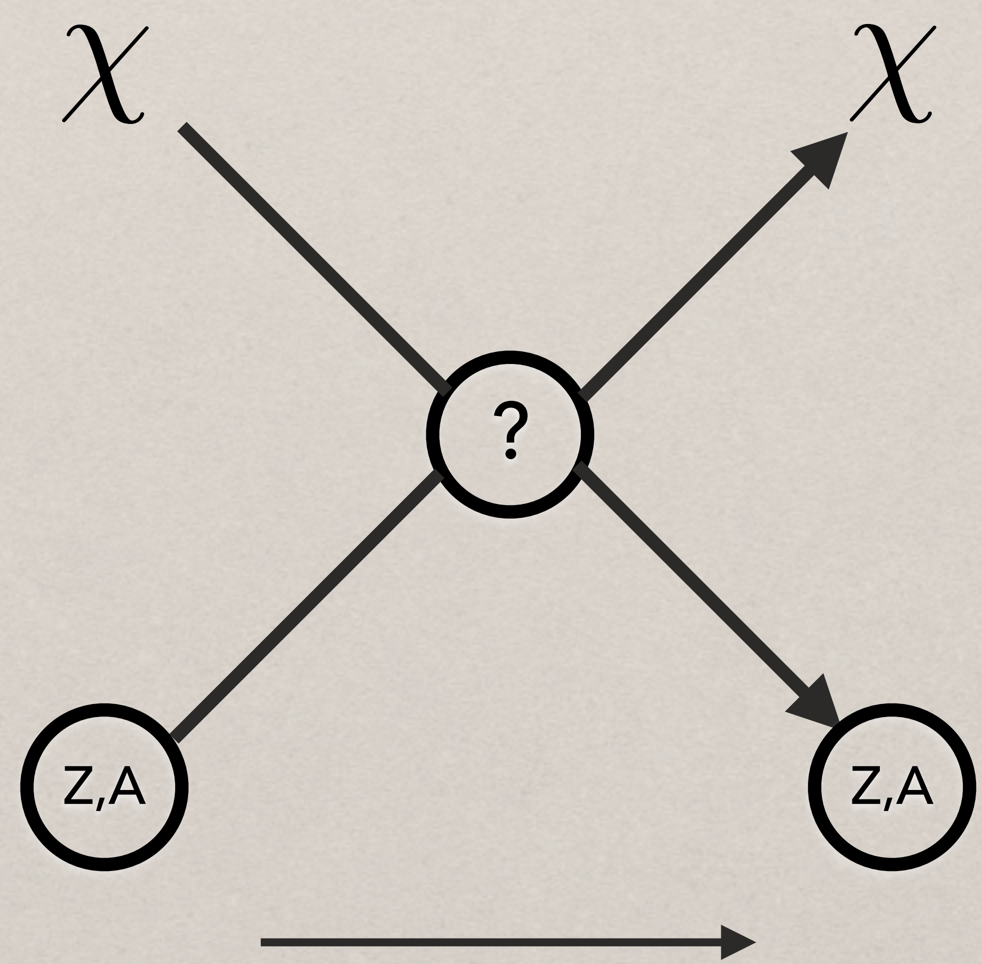
Evan Pease	Graduate Student
Brian Tennyson	Graduate Student
Ariana Hackenburg	Graduate Student
Elizabeth Boulton	Graduate Student

L U X

Large Underground Xenon detector

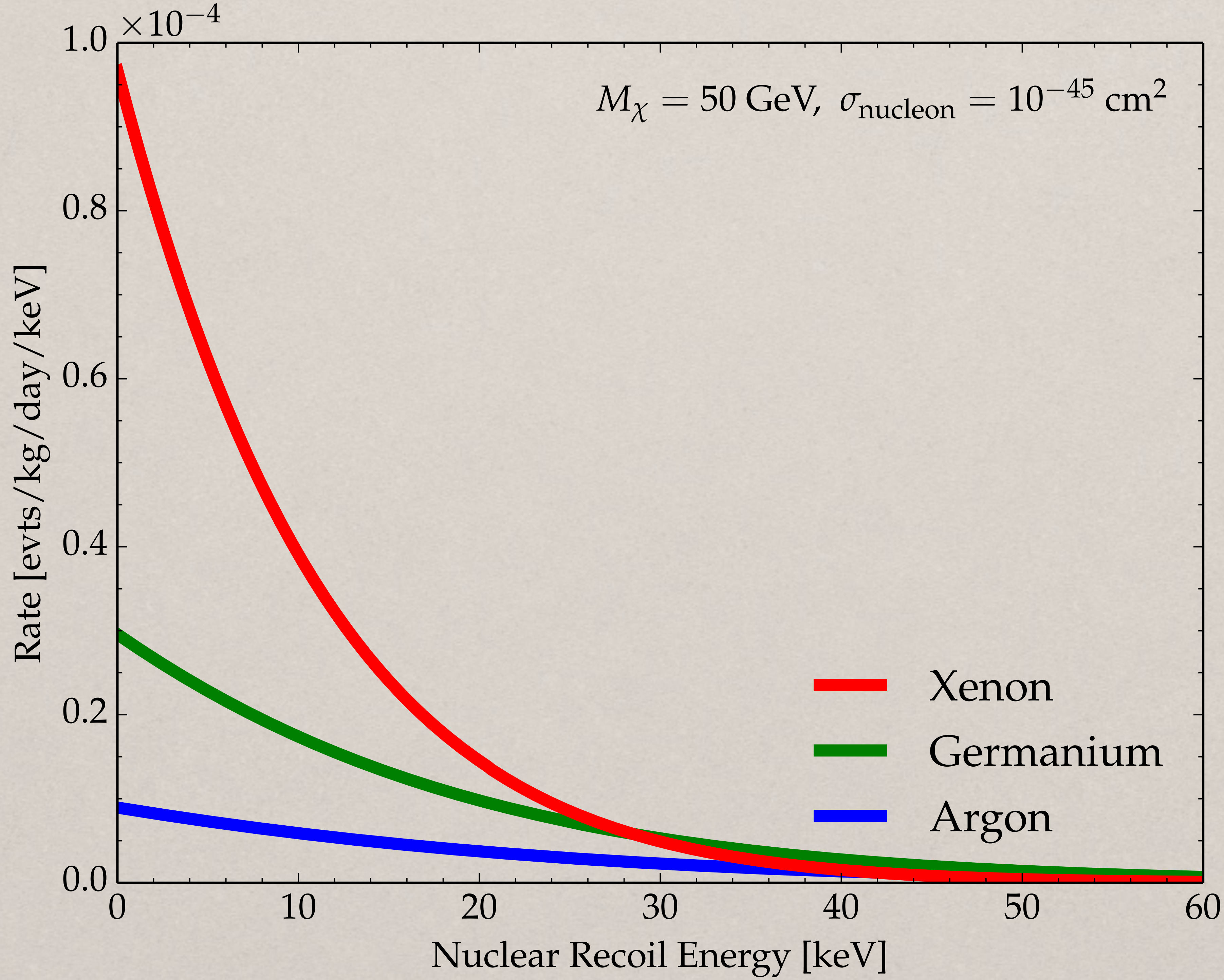
(a direct-detection search, looking primarily for WIMP dark matter)



WHY USE LIQUID XENON TO LOOK FOR WIMPS?

WHY USE LIQUID XENON?

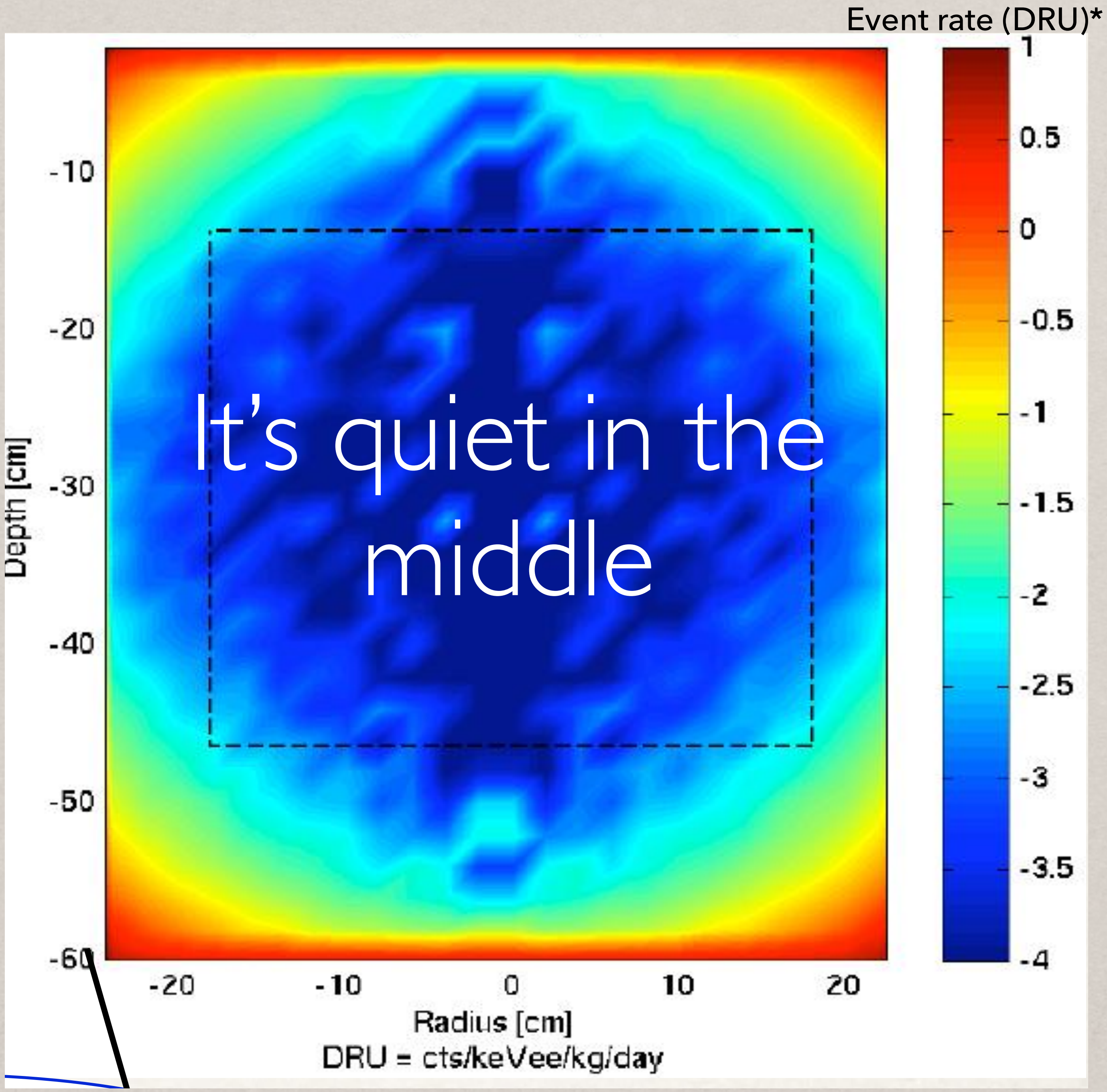
Large signal



- Scalar WIMP-nucleus interactions lead to an A^2 enhancement in the differential rate relative to other commonly used detection media.
- Natural xenon contains ~50% odd isotopes, giving high sensitivity to spin-dependent interactions.

WHY USE LIQUID XENON?

Low background

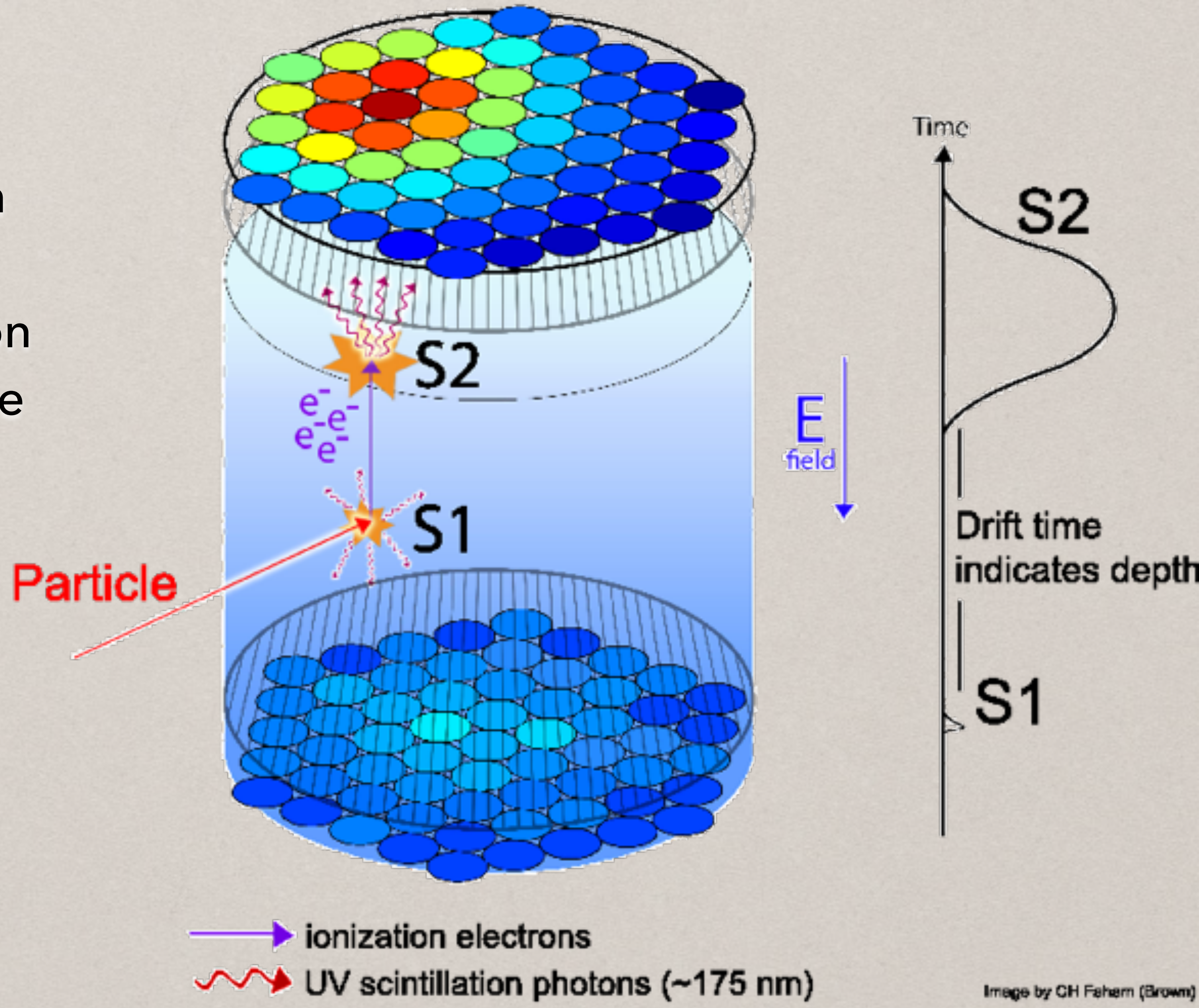


* "DRU" = evt/kg/day/keV

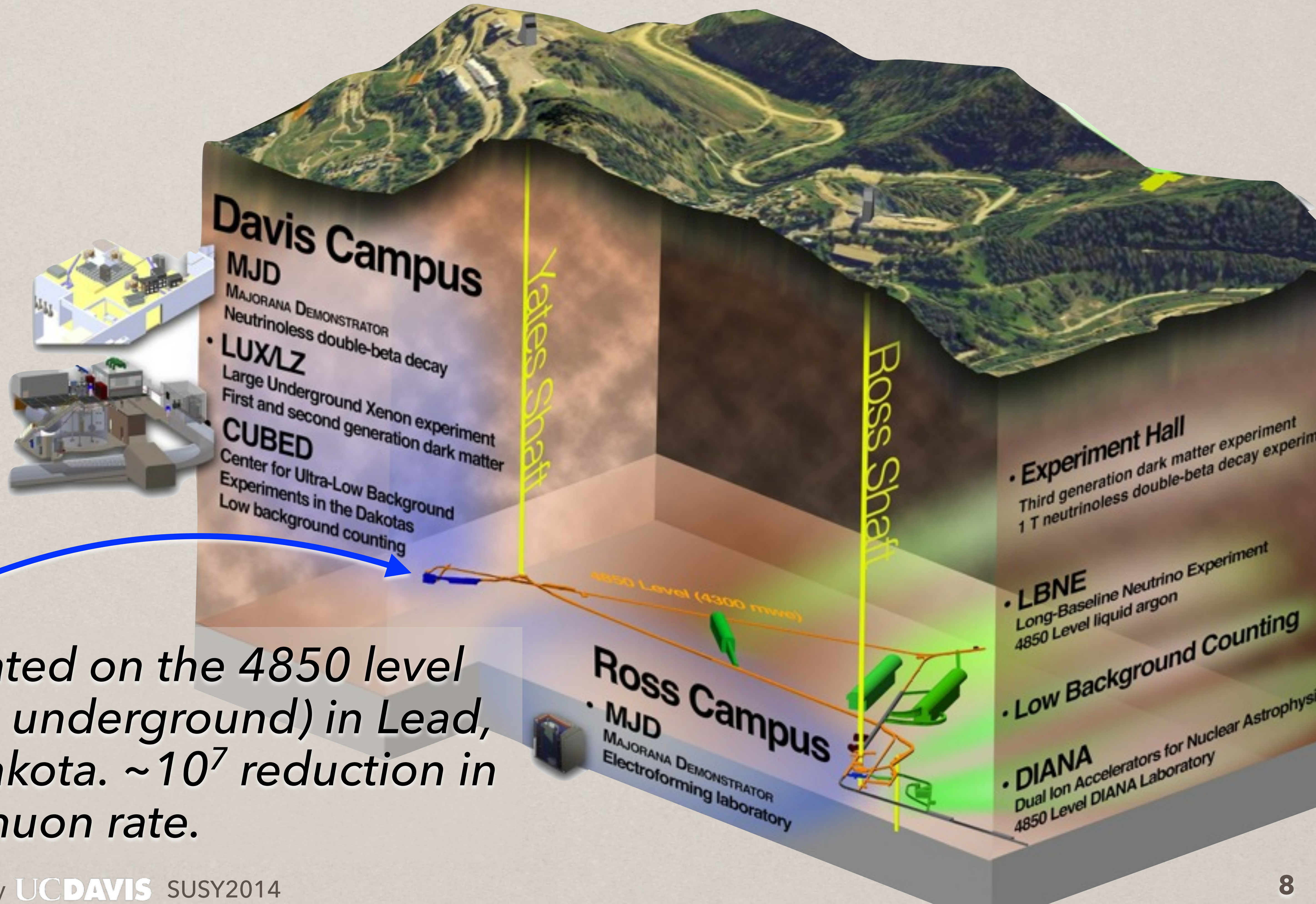
- Liquid detectors are easy to scale up to large size.
- Dual-phase time projection chambers feature 3-D localization of events.
- The combination of these two features permits an ultra-low-background inner region to be defined. In the quietest [central] regions of the detector, one kg of Xe will see on average **one BG event in ~200 days** in our signal region.

DETECTION TECHNIQUE

- LUX is a dual-phase time projection chamber (like most other liquid-noble DM experiments); essentially a cylinder of LXe.
- Primary scintillation light ("S1") is emitted from the interaction vertex, and recorded by an array of PMTs on top and bottom.
- Electrons emitted from the interaction are drifted by and applied field to the surface and into the gas, where they emit proportional scintillation light ("S2"), also recorded by the PMTs.
- This design permits:
  - Identification of multiple scatters (via S2 count).
  - 3-D localization of each vertex.
  - ER/NR discrimination (via S2/S1)
  - Sensitivity to single electrons.

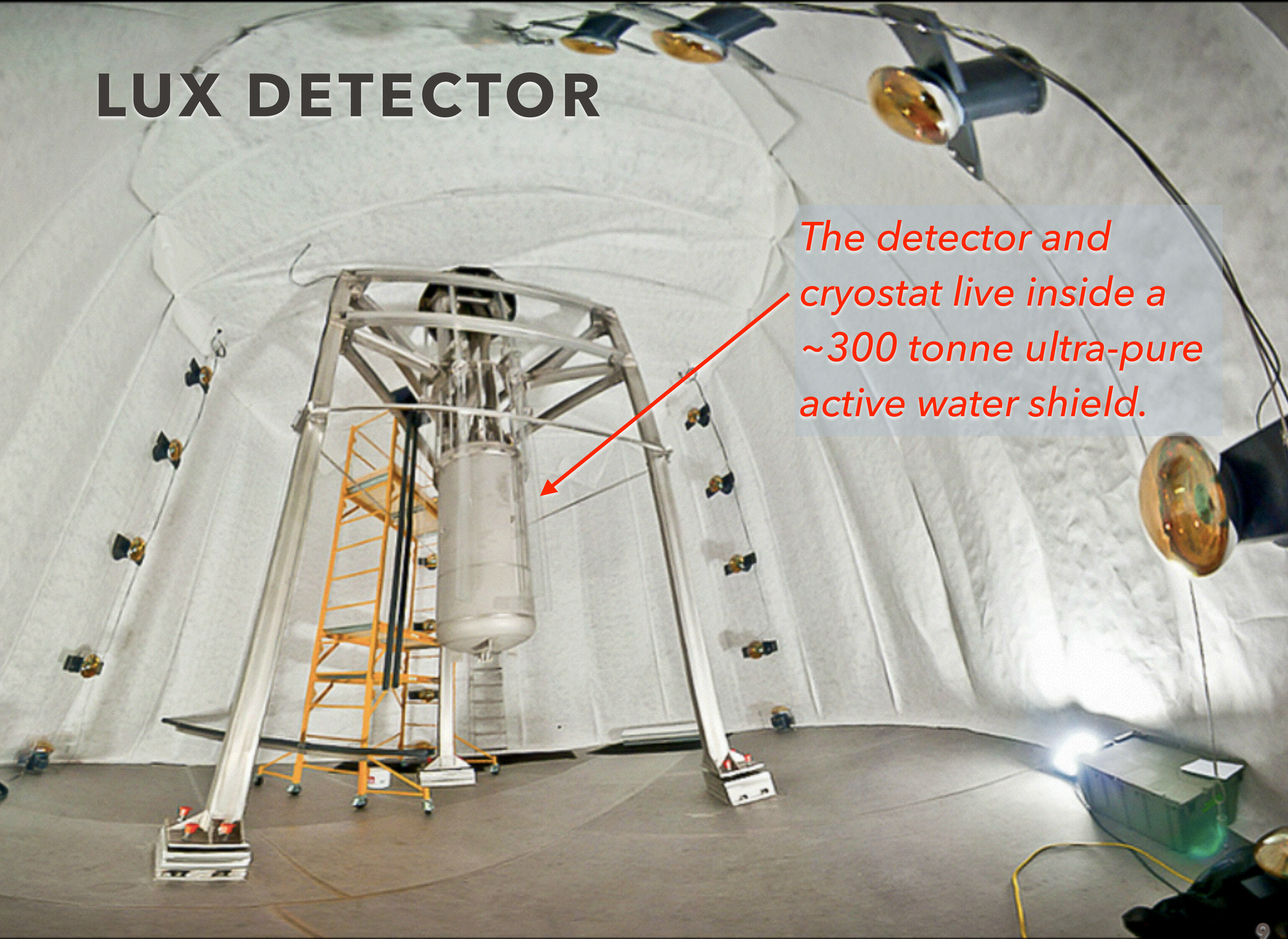


SANFORD UNDERGROUND RESEARCH FACILITY



LUX, located on the 4850 level (~1.5 km underground) in Lead, South Dakota. ~10^7 reduction in cosmic muon rate.

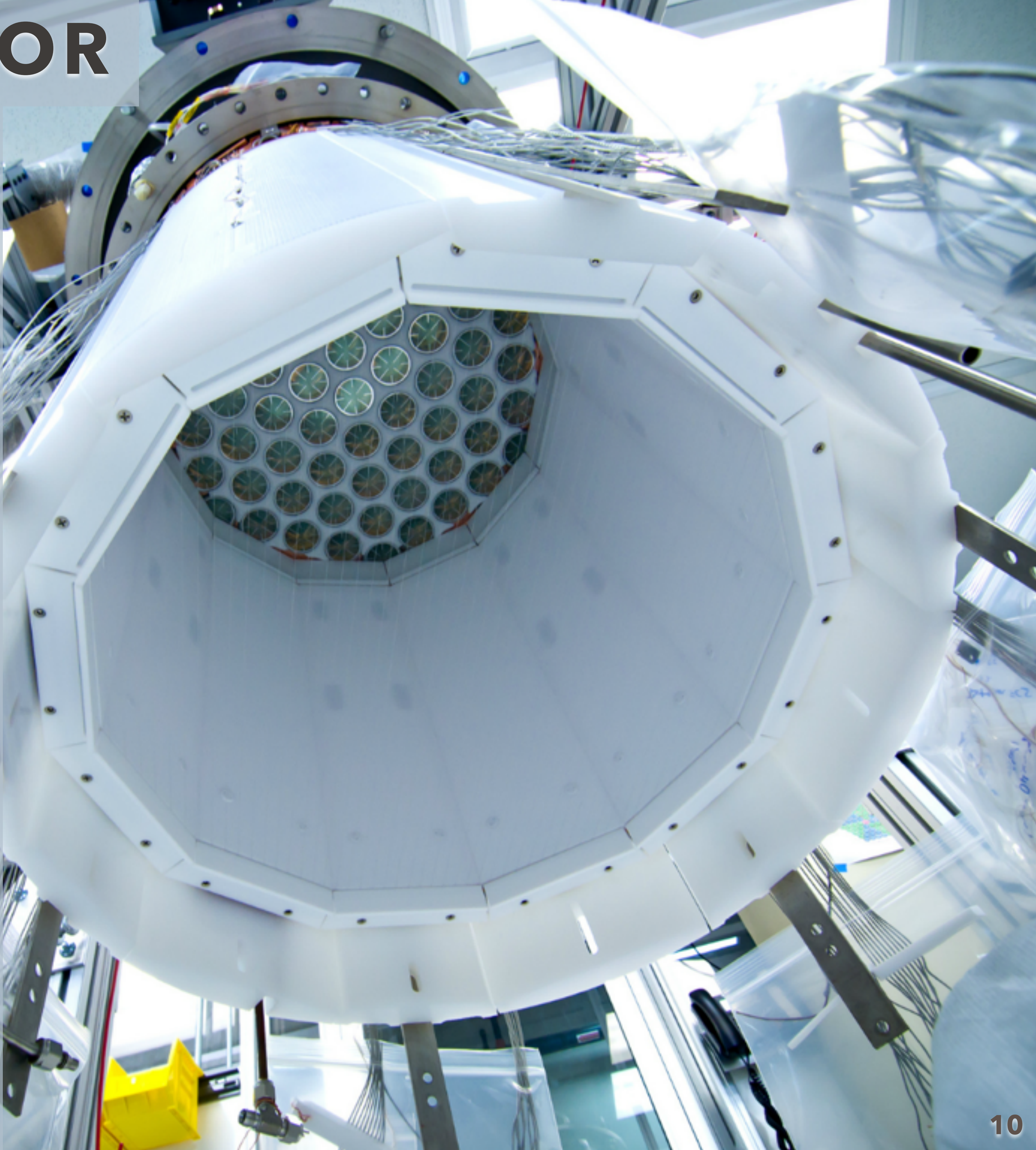
LUX DETECTOR



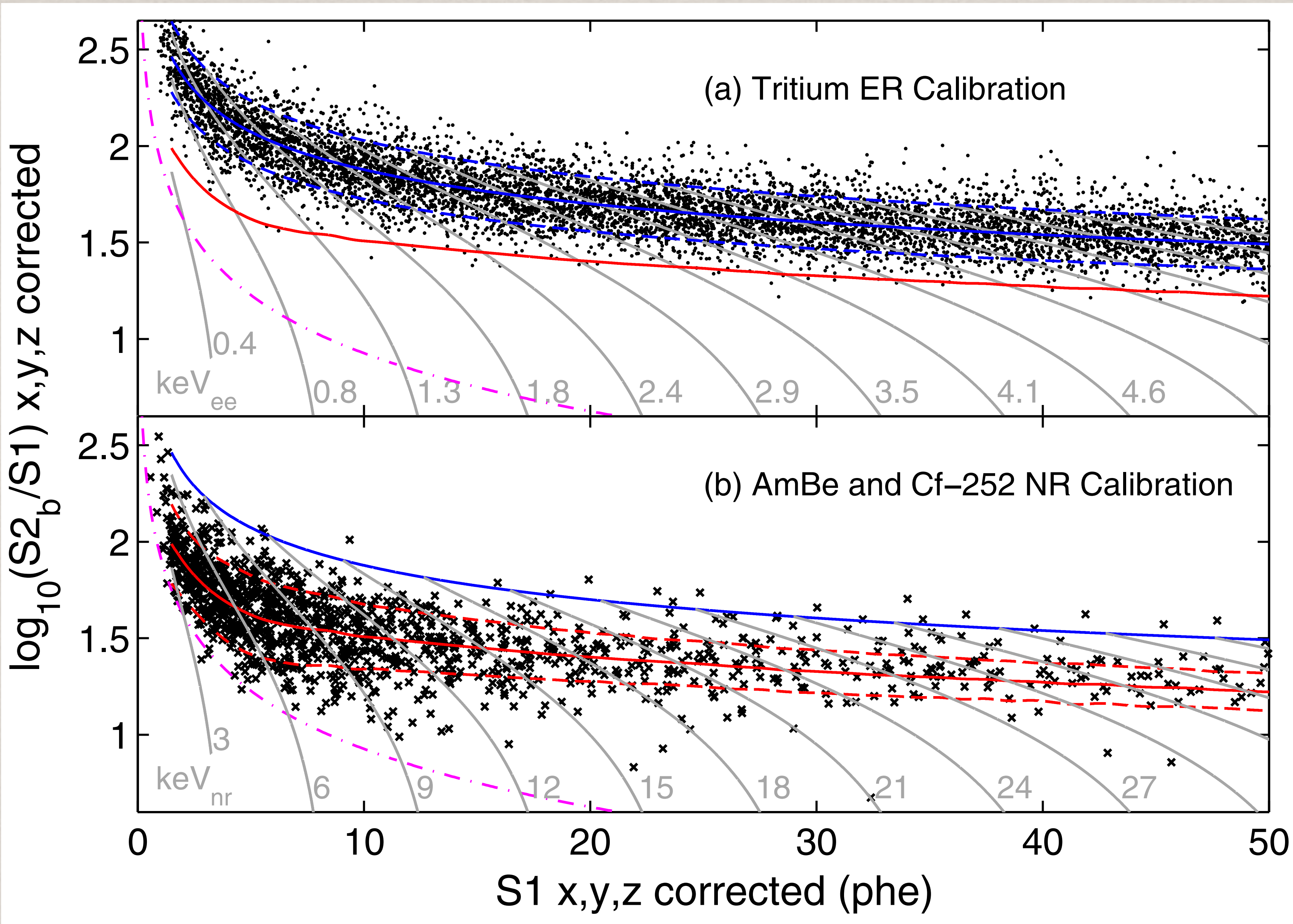
The detector and cryostat live inside a ~300 tonne ultra-pure active water shield.

LUX DETECTOR

- 47cm diameter by 48 cm height dodecagonal "cylinder".
- 370 kg LXe total, 250 kg active region
- 61 PMTs on top, 61 on bottom, specially produced for low radiogenic BGs and VUV sensitivity.
- Xenon was pre-purified via chromatographic separation, reducing residual krypton levels to 3.5±1 ppt (g/g).
- Liquid is continuously recirculated (¼ tonne per day) to maintain chemical purity.
- Ultra-low BG titanium cryostat.



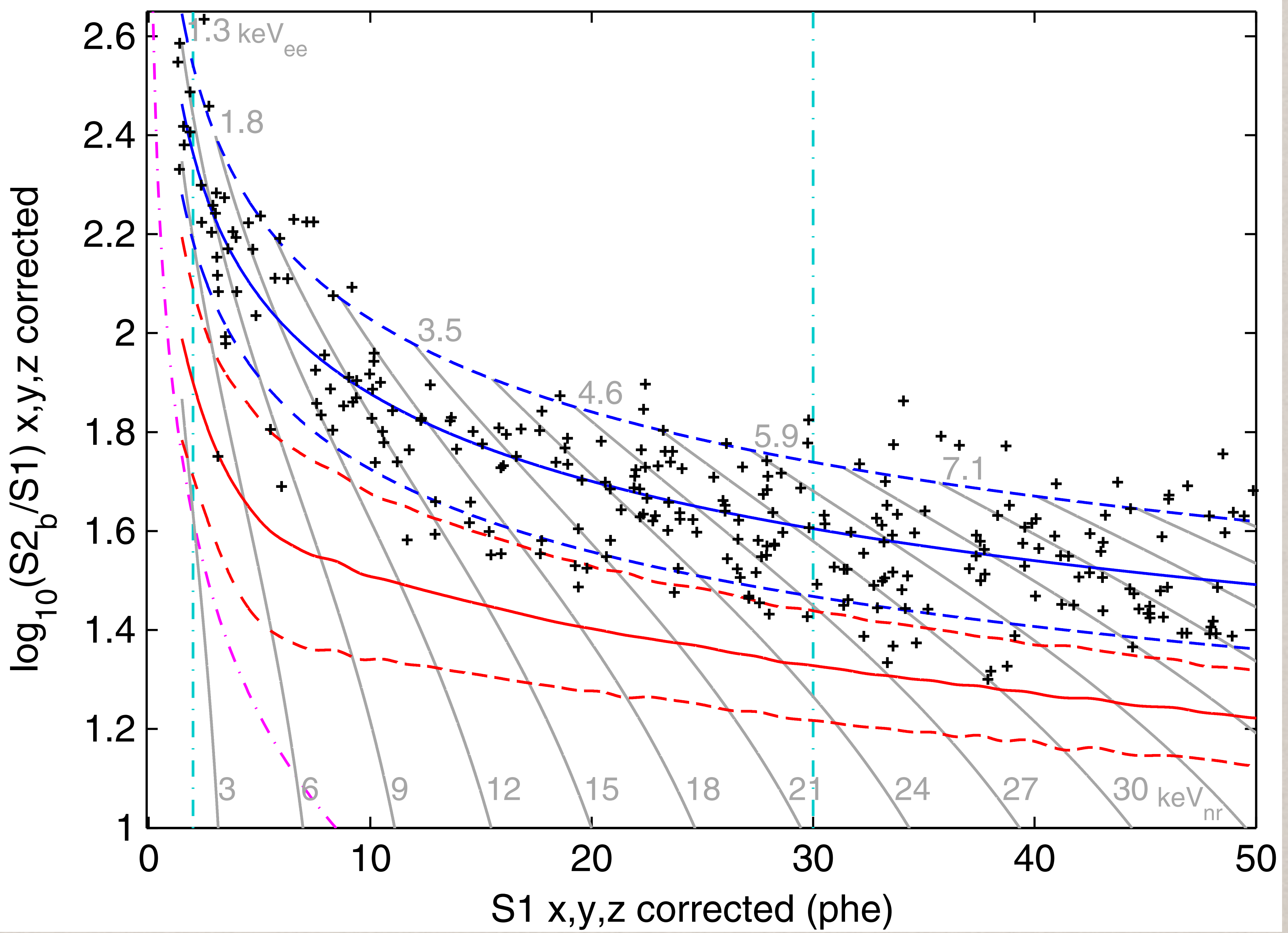
SIGNAL RESPONSE



- The LUX collaboration has pioneered the use of internal, diffuse calibration sources: CH_3T (tritiated methane, for the electronic-recoil (ER) band) and ^{83m}Kr (for position corrections, energy calibration).
- The nuclear-recoil (NR) band is calibrated with external neutron sources (AmBe, ^{252}Cf).
- ≳99.5% rejection of ER events at 50% NR acceptance

THE WIMP SEARCH

- 181 V/cm drift field
- 85.3 live days
- 118 kg fiducial mass
- 160 observed background events.
- Data are analyzed with a 4-parameter profile likelihood test.
- p-value of 35% consistent with ER backgrounds.
- PRL **112**, 091303 (2014), arXiv:1310.8214



THE WIMP SEARCH

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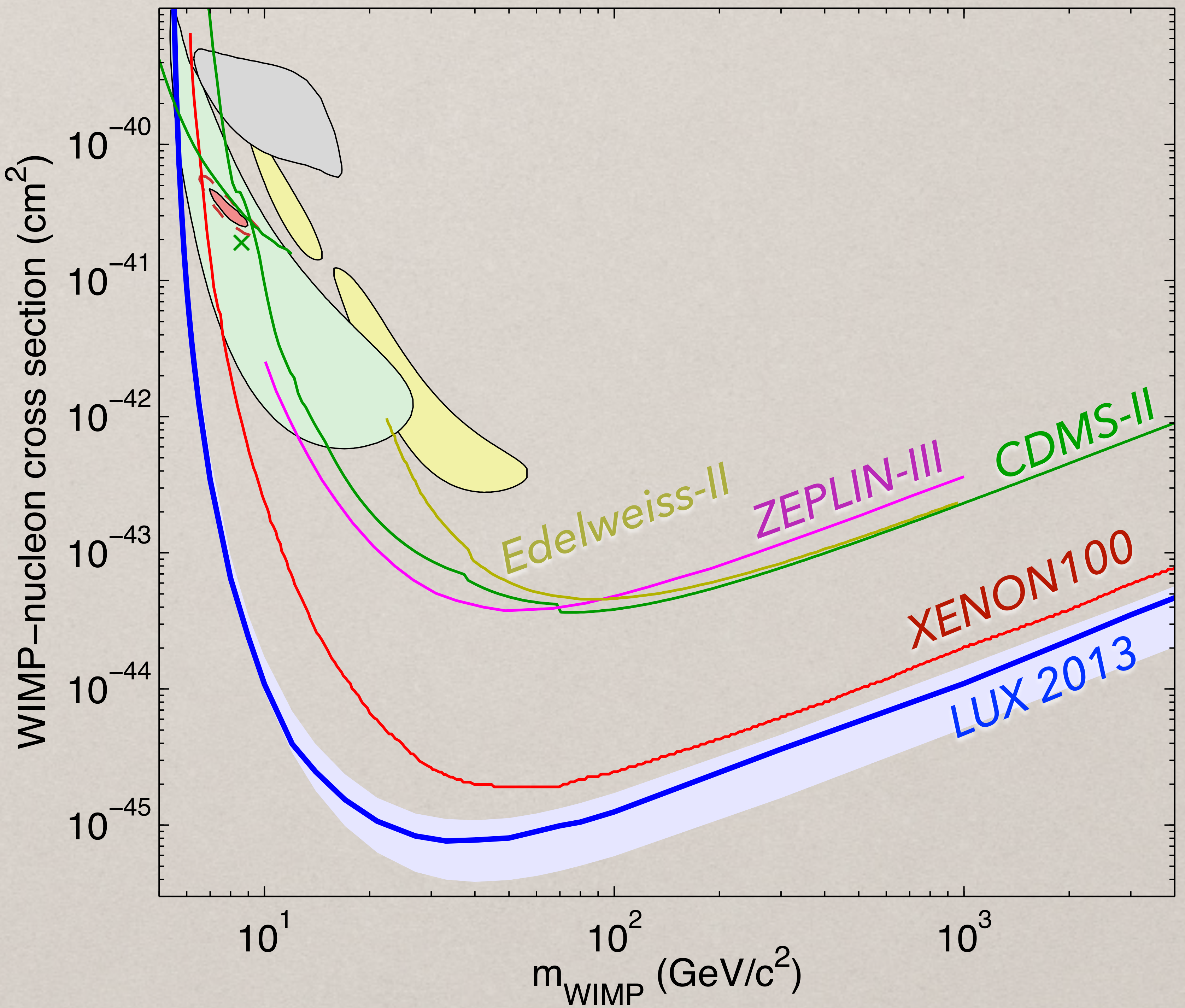
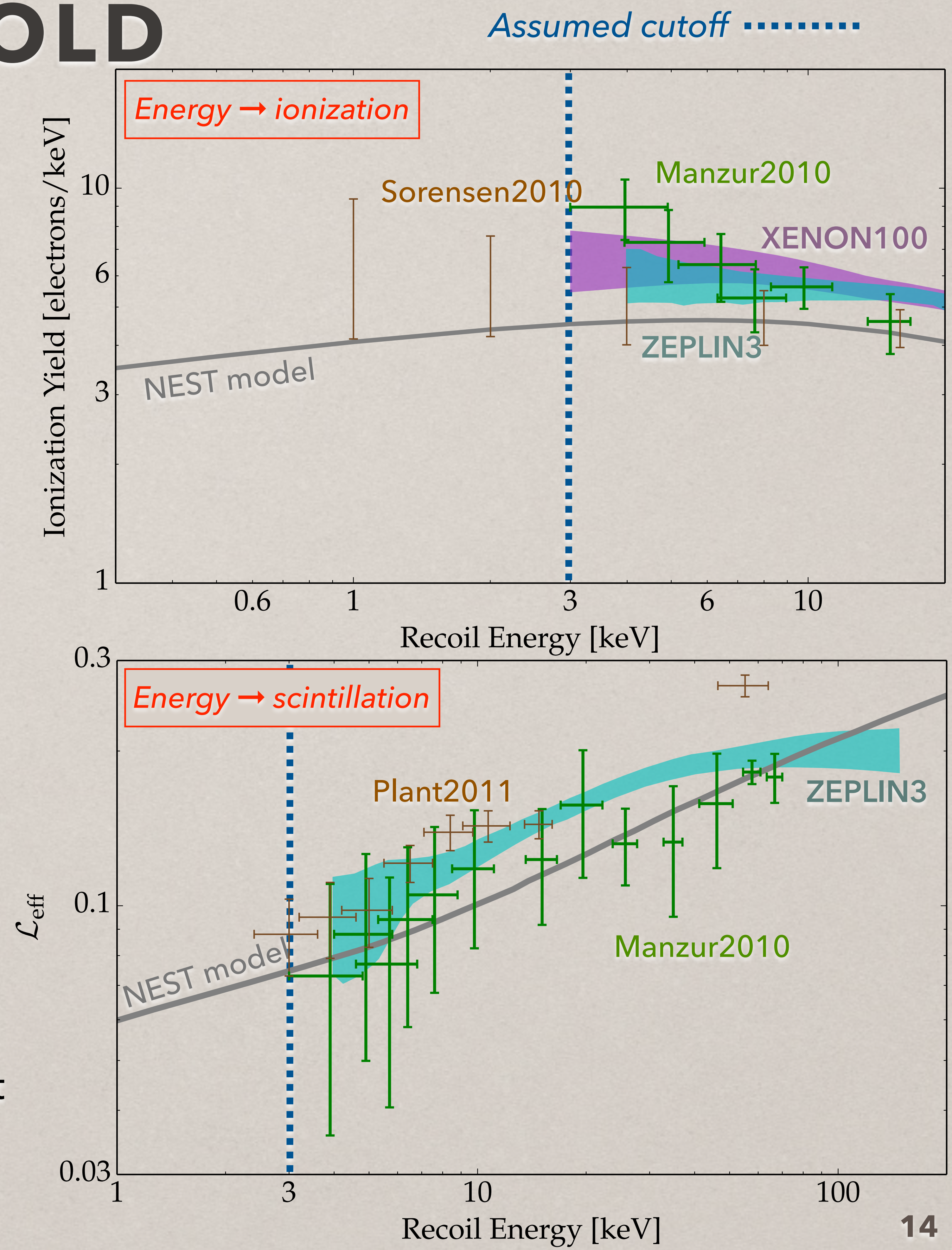
- Data are analyzed with a 4-parameter profile likelihood analysis.
- p-value of 35% consistent with ER backgrounds.
- PRL **112**, 091303 (2014), arXiv:1310.8214
- 7.6×10^{-46} cm^2 at 33 GeV/c^2
- That's sub-**zepto**barn*!*



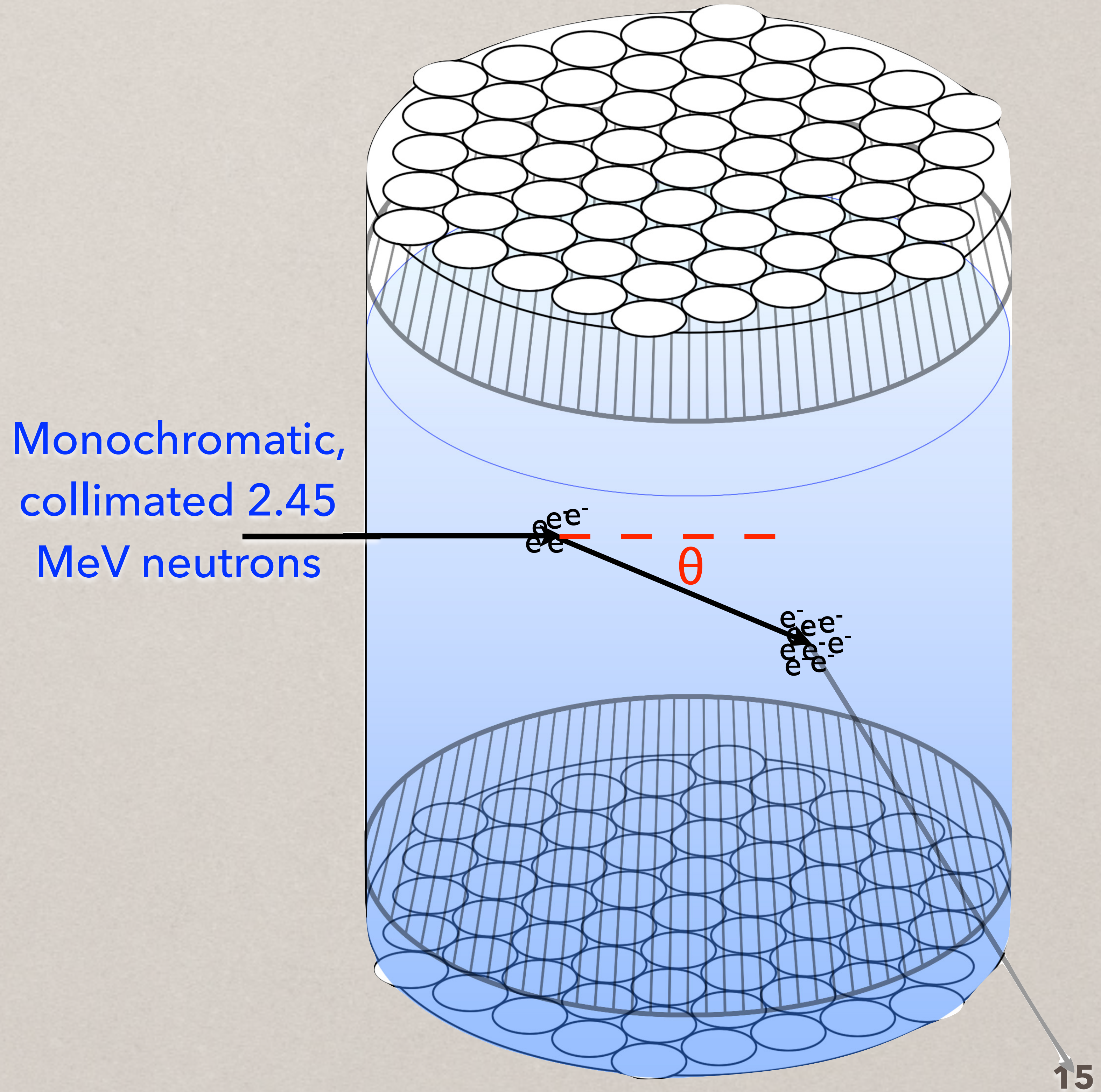
ENERGY-THRESHOLD ASSUMPTIONS

- $\mathcal{L}_{\rm eff}$ quantifies the linearity between deposited energy and scintillation signal.
- $\mathcal{Q}_y$ ("ionization yield") quantifies the linearity between deposited energy and ionization signal.
- Lowest-energy published direct measurement of $\mathcal{L}_{\rm eff}$ is at 3 keV, and of $\mathcal{Q}_y$ is at 4 keV.
- LUX first results used the un-physically conservative assumption that $\mathcal{L}_{\rm eff}$ and $\mathcal{Q}_y$ drop to zero below 3 keV.
- Gray curve in these plots is the NEST model prediction (pre-3keV cutoff)
- Is there any development on this front since the LUX results?



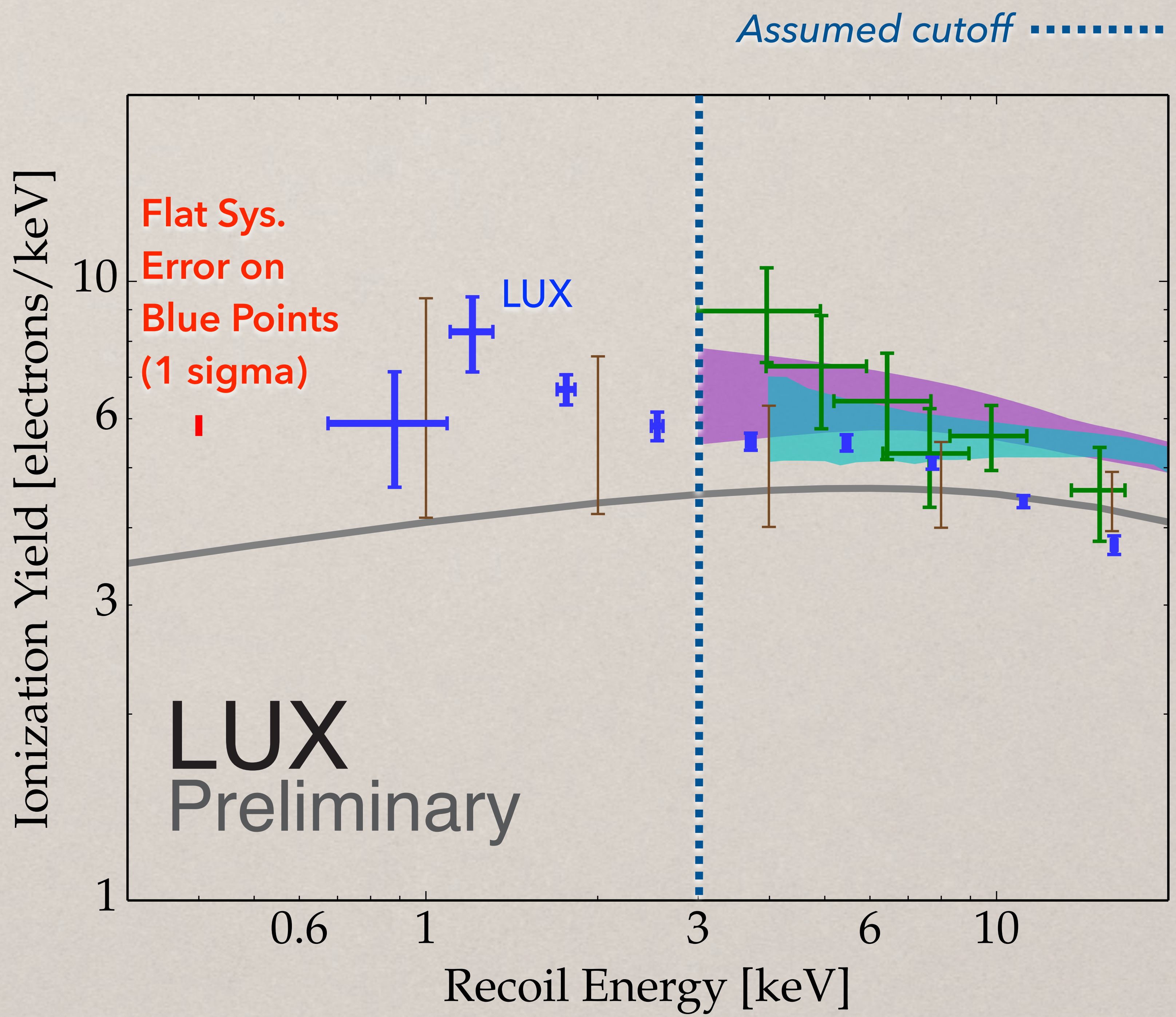
DIRECT MEASUREMENT OF NR ENERGY SCALE IN LUX

- Measurement made in LUX with a collimated and monochromatic D-D neutron generator.
- Double-scatter events are selected, from which the scattering angle of the first vertex can be determined.
- Kinematics provides the energy deposited at the first scattering vertex, independent of ionization response.



DIRECT MEASUREMENT OF NR ENERGY SCALE IN LUX

- Direct, *in situ* measurement of $\mathcal{Q}_y$ indicates continued excellent sensitivity to NR events below 3 keV (these preliminary results extend below 1 keV!).

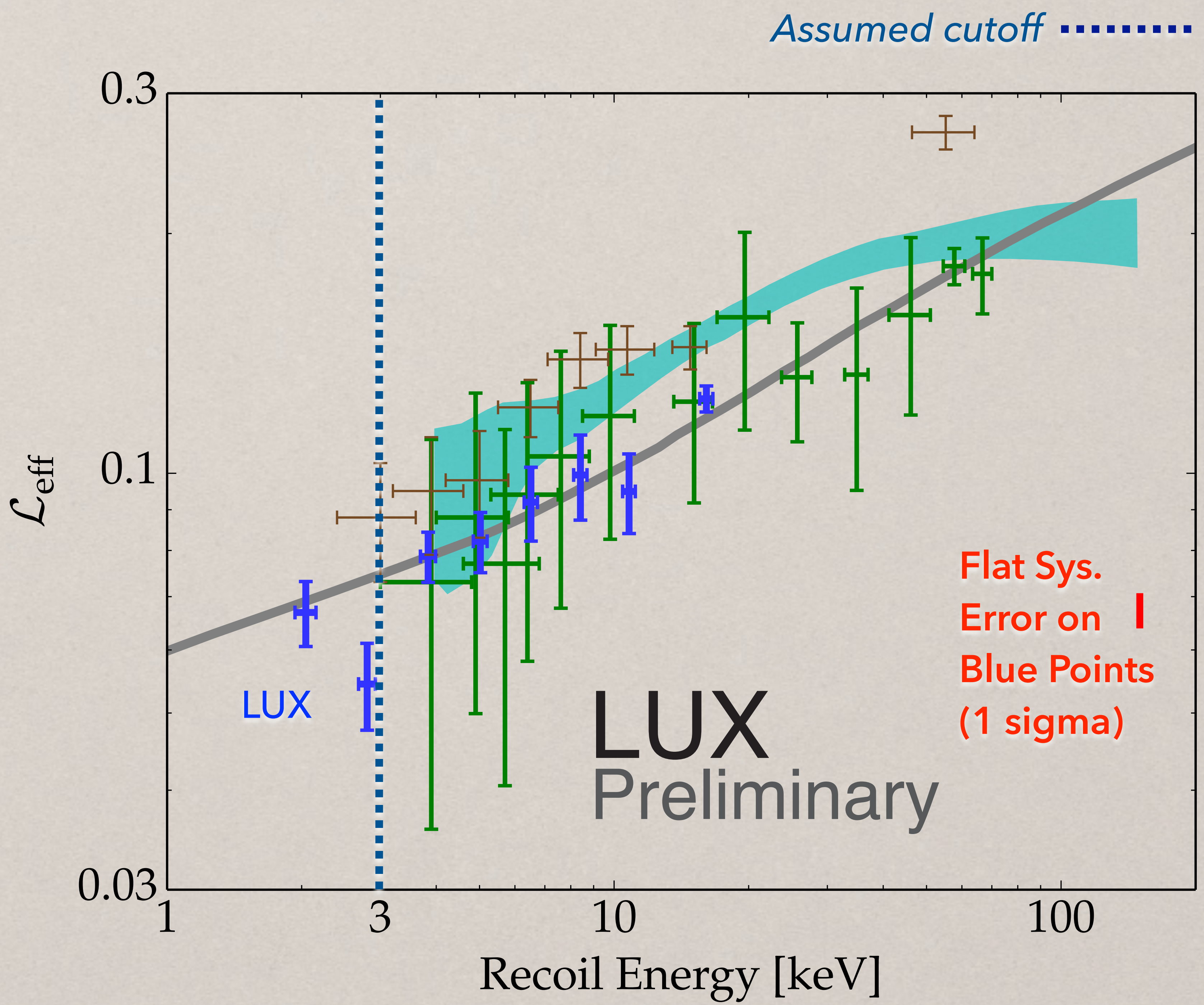


http://www.pa.ucla.edu/sites/default/files/webform/20140228_jverbus_ucla2014.pdf

J. Verbus, for the LUX collaboration (paper in preparation)

DIRECT MEASUREMENT OF NR ENERGY SCALE IN LUX

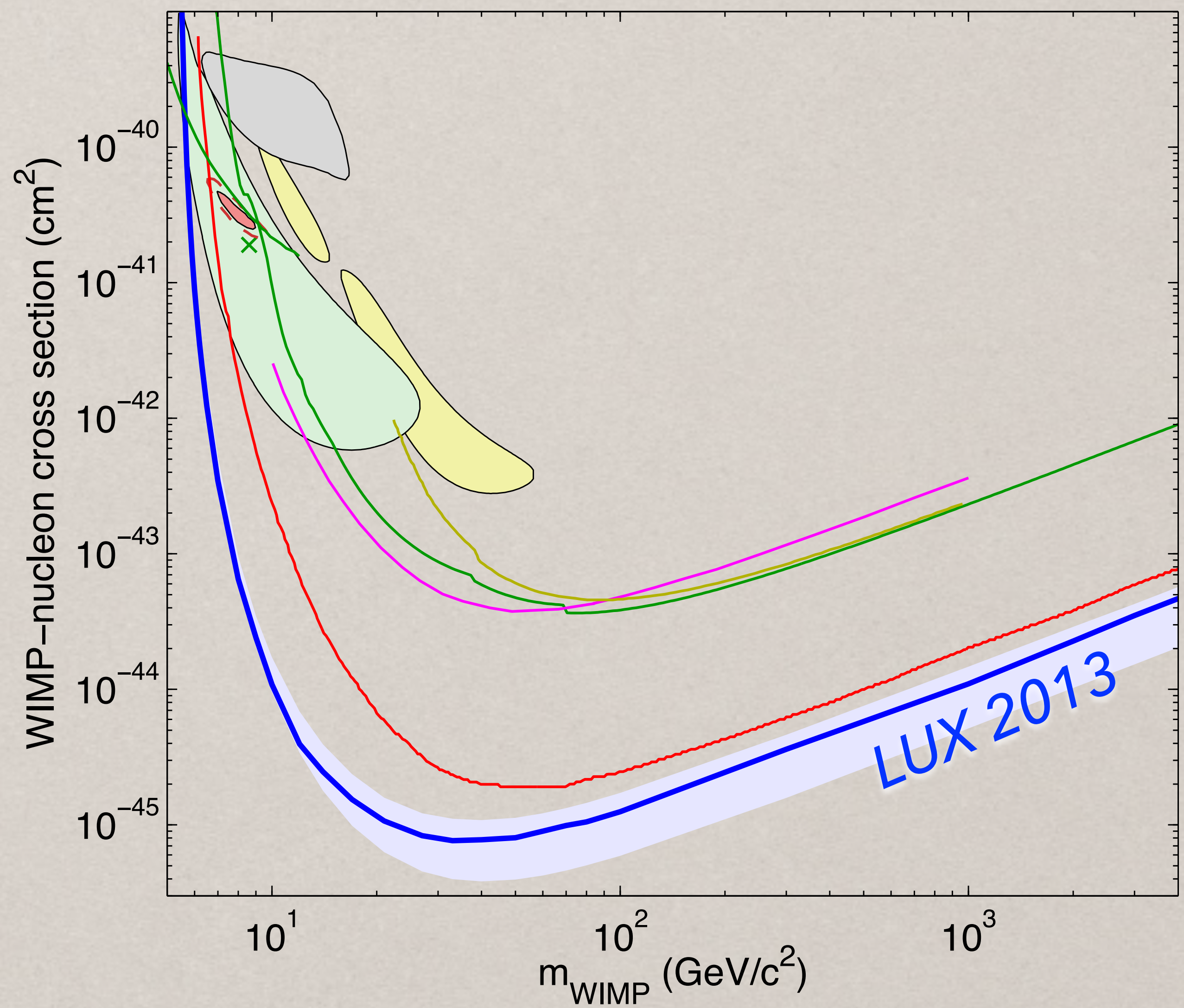
- Using the determined $\mathcal{Q}_y$ and the measured relationship between ionization and scintillation, the scintillation energy scale can be determined from the same data.
- These data extend the measured scintillation response down to 2 keV.



http://www.pa.ucla.edu/sites/default/files/webform/20140228_jverbus_ucla2014.pdf

J. Verbus, for the LUX collaboration (paper in preparation)

HOW SIGNIFICANT ARE THE NEW ENERGY-SCALE RESULTS?



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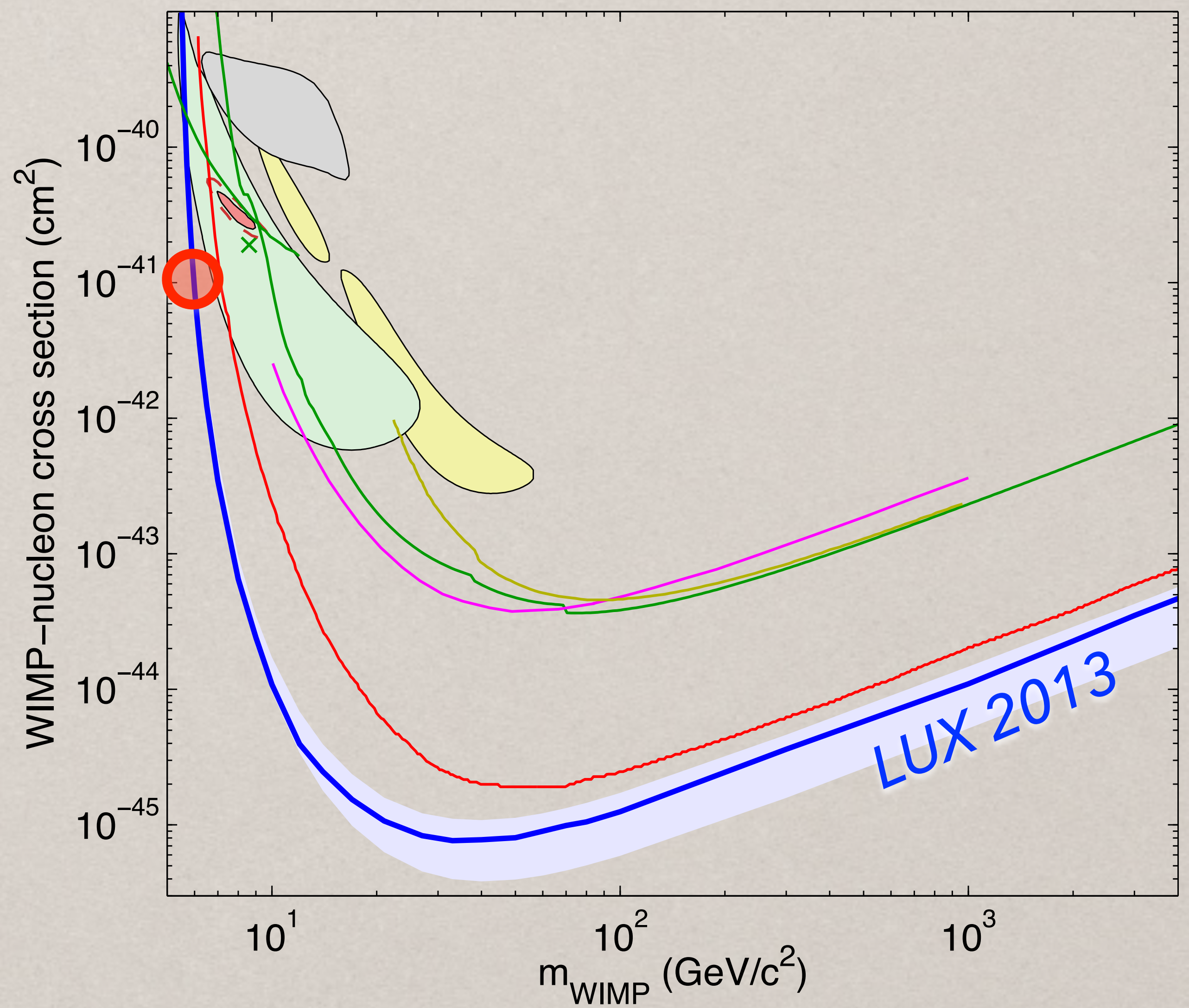

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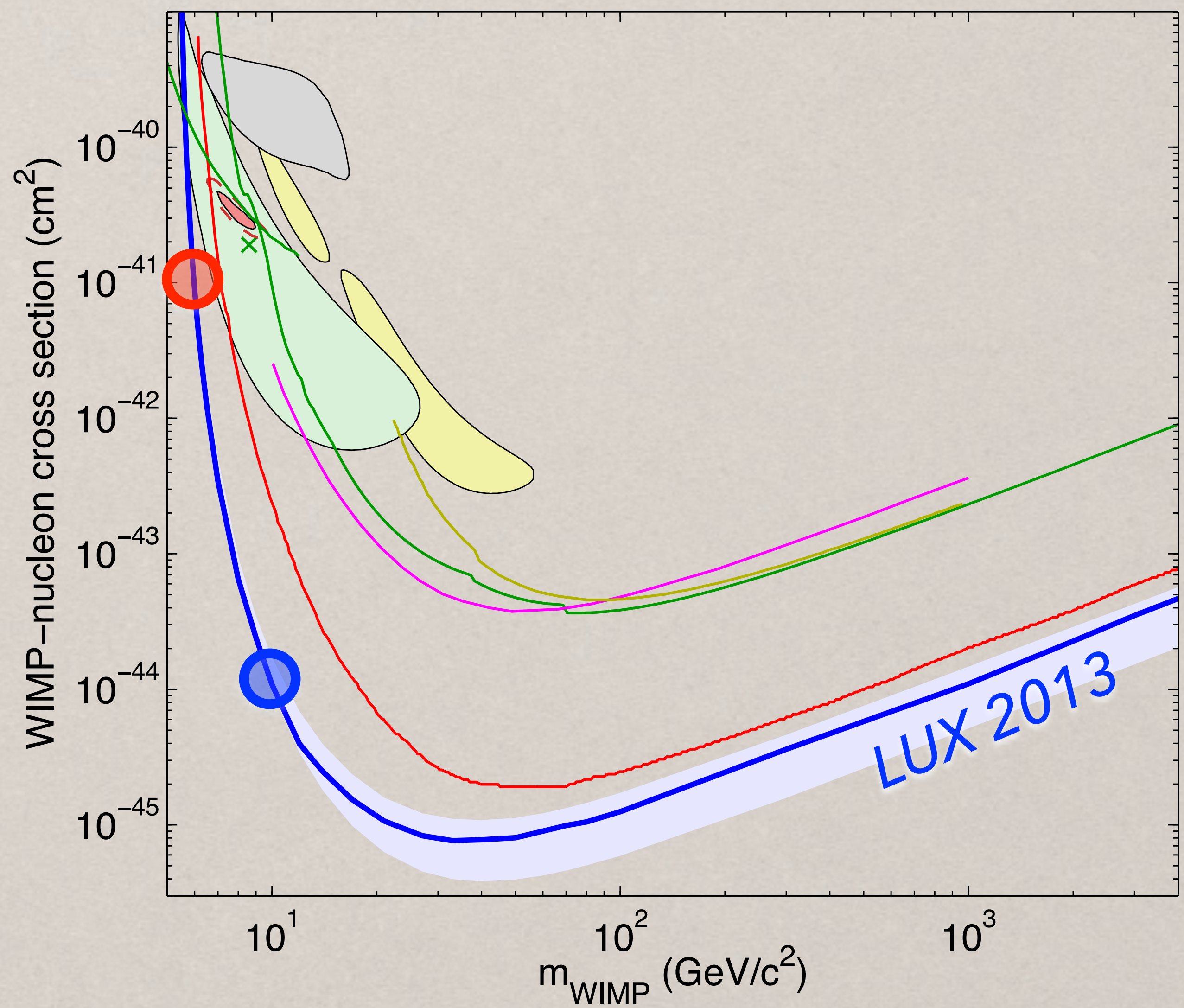

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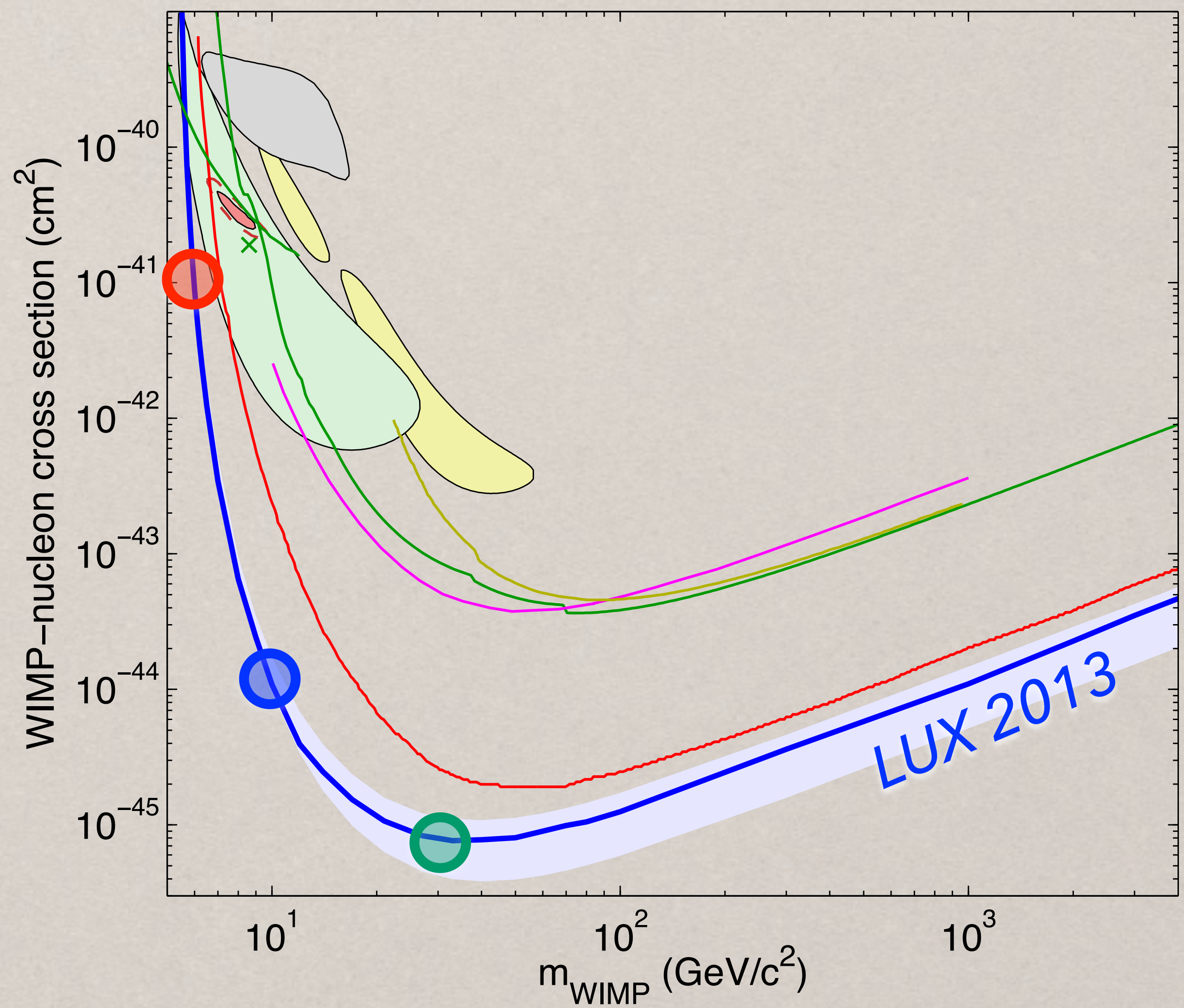

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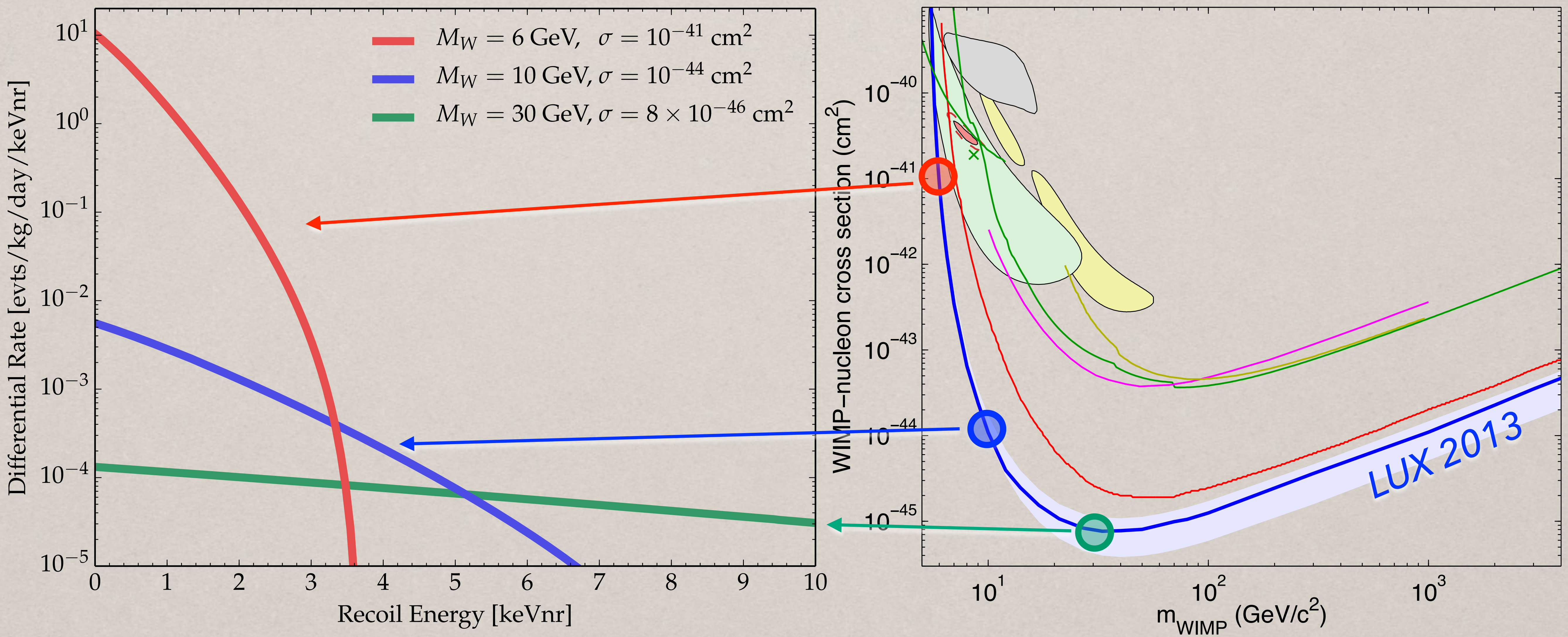

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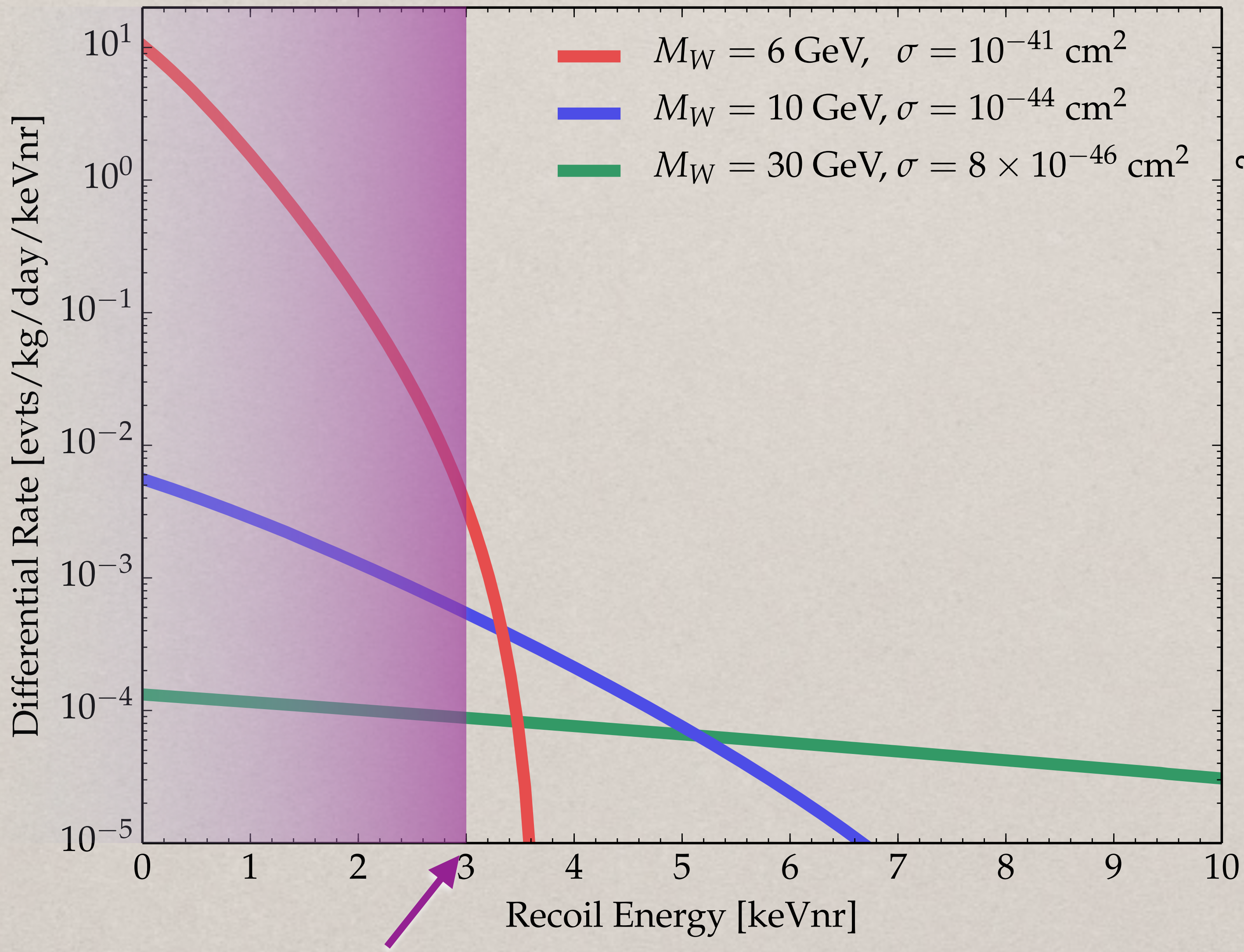
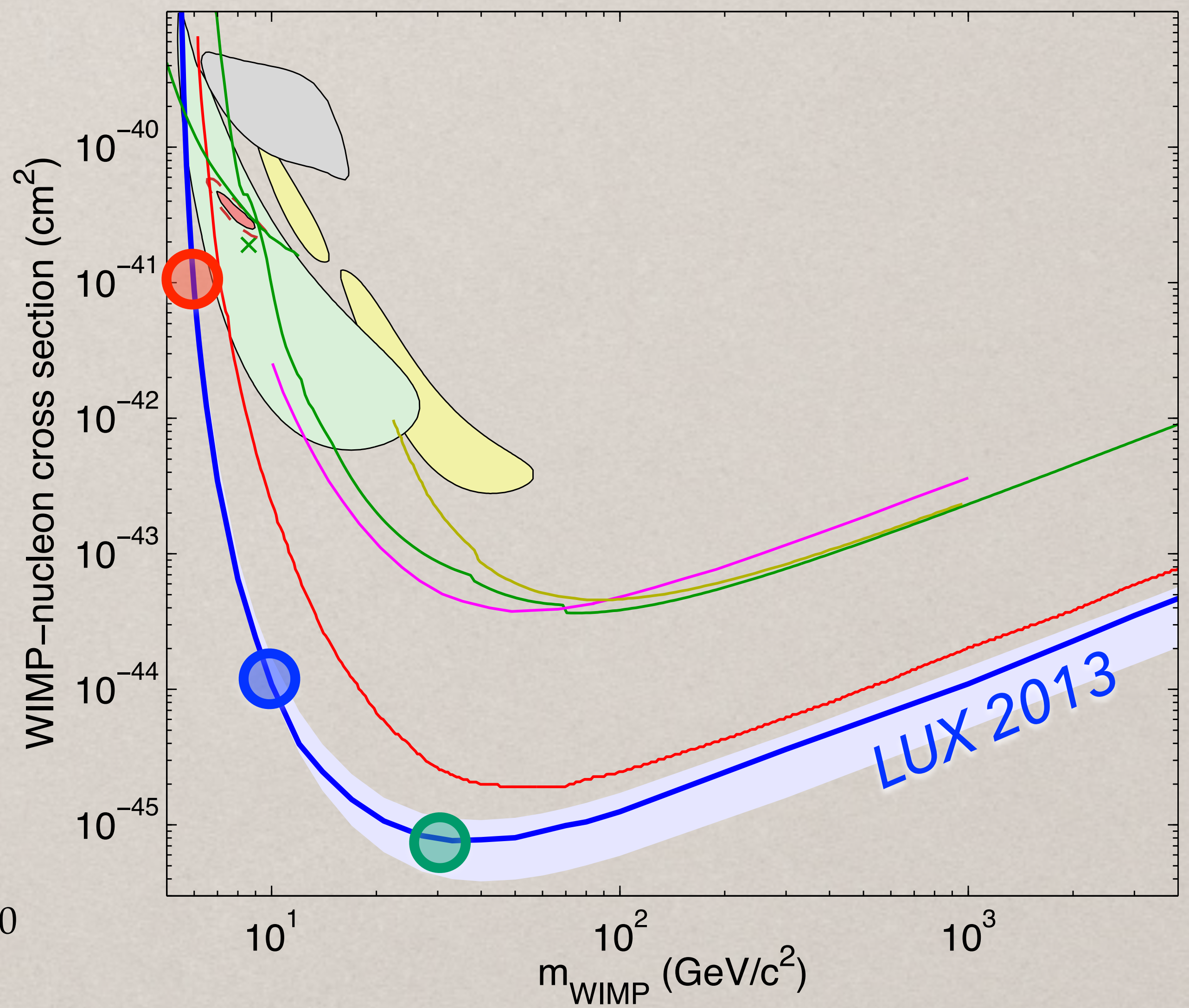
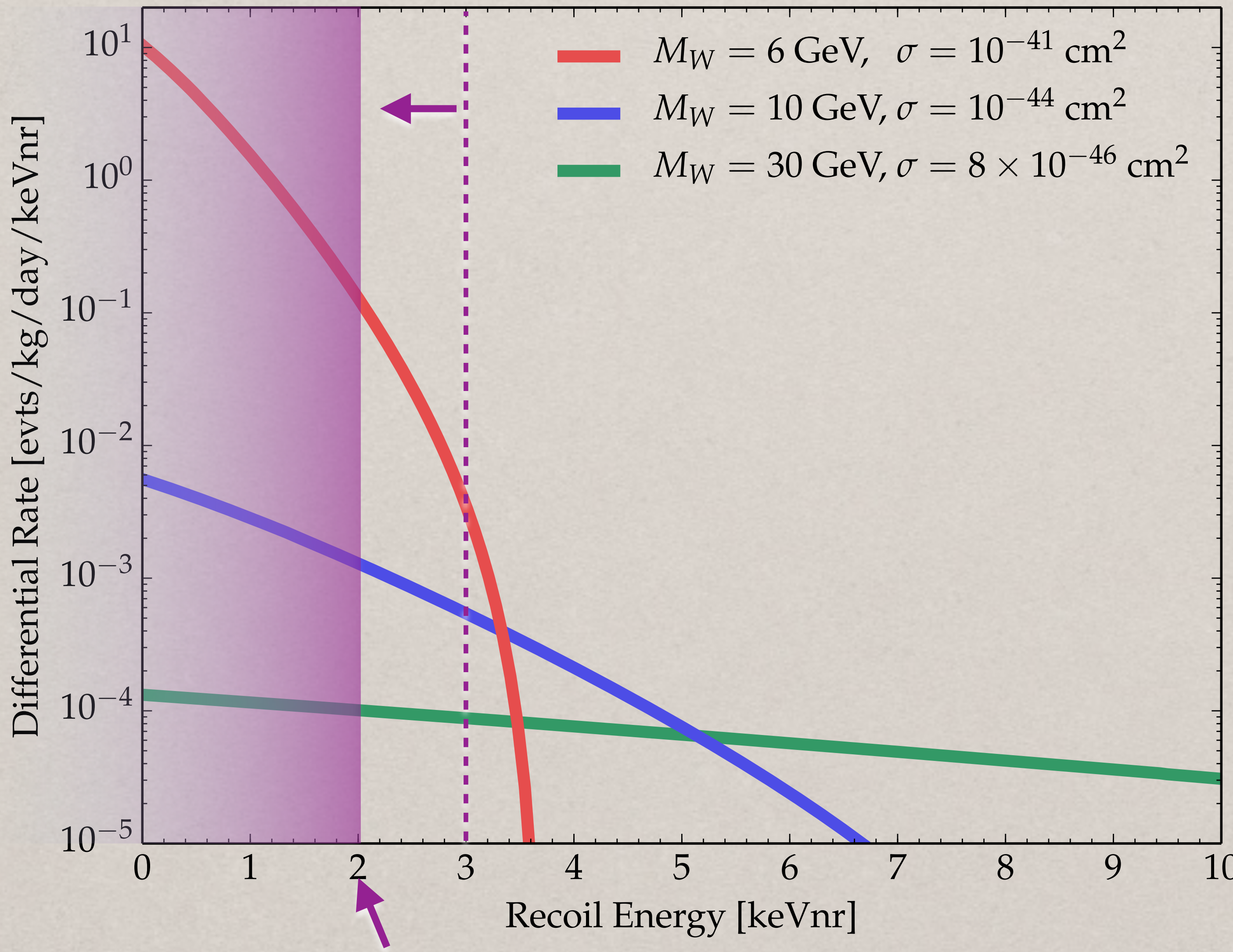
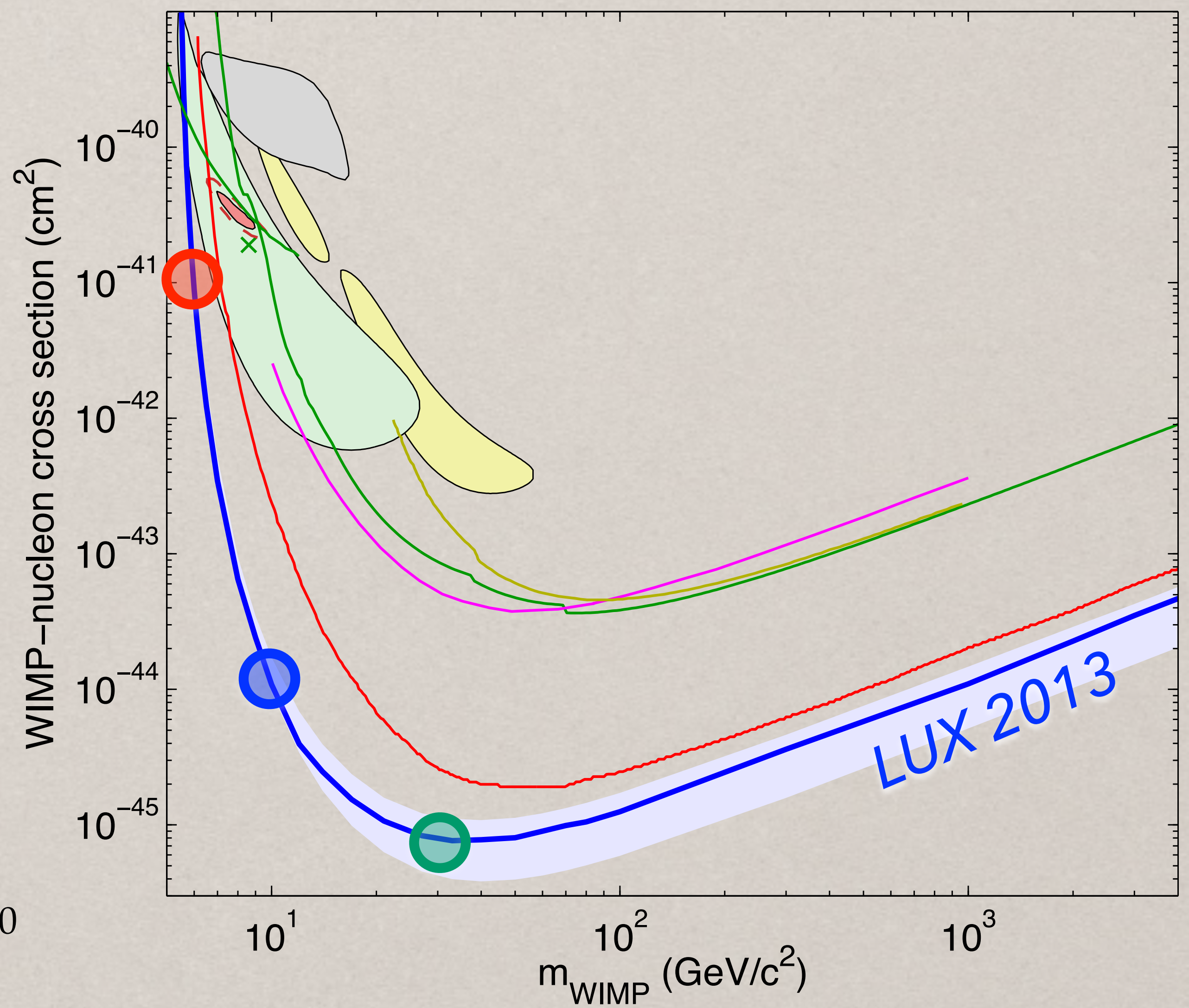




LUX 2013 upper limits assumed NO SENSITIVITY to recoils below 3 keV

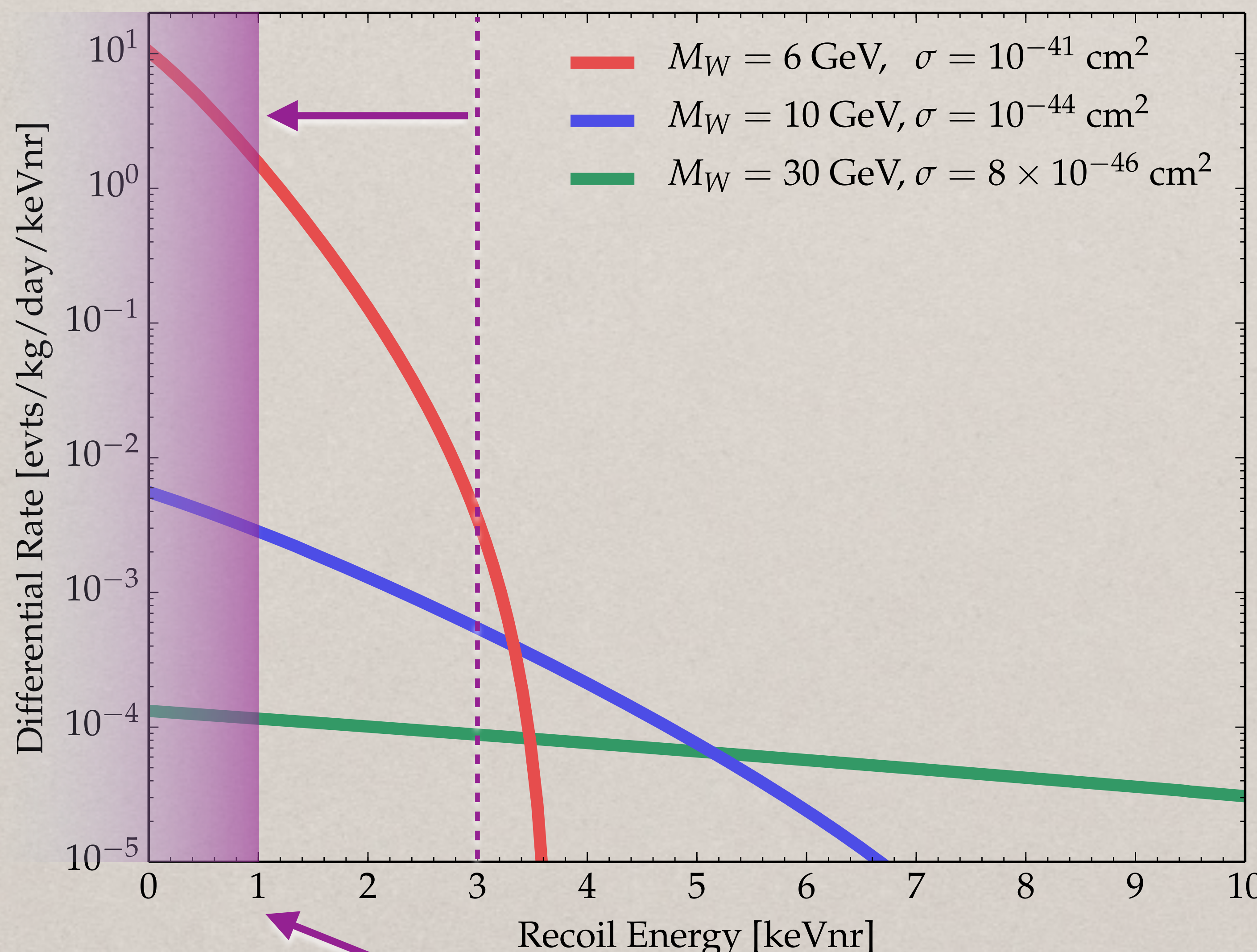
HOW SIGNIFICANT ARE THE NEW ENERGY-SCALE RESULTS?

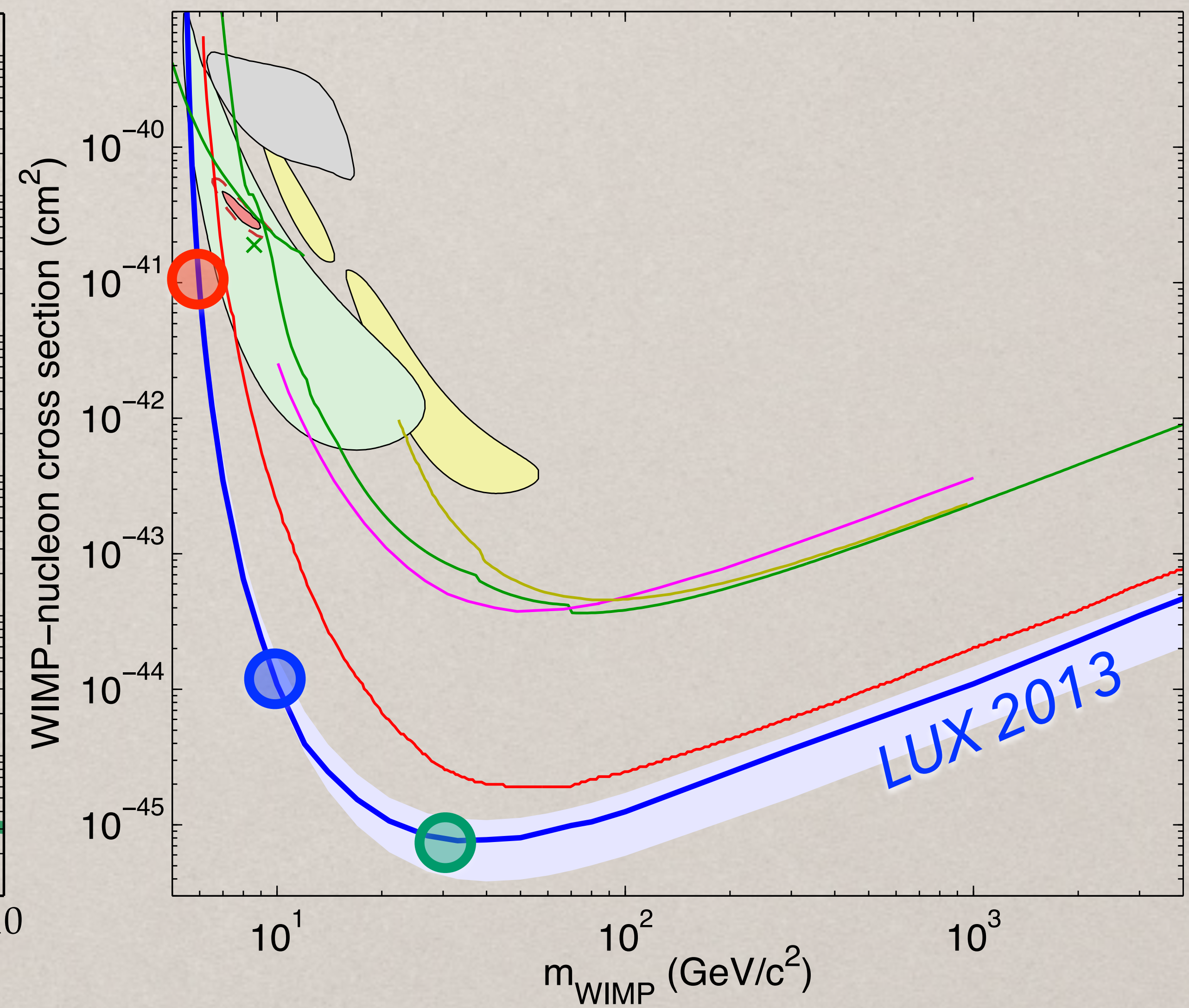




Decreasing this response cutoff from 3keV to 2keV provides access to a factor of **70* more signal** at M = 6 GeV

HOW SIGNIFICANT ARE THE NEW ENERGY-SCALE RESULTS?

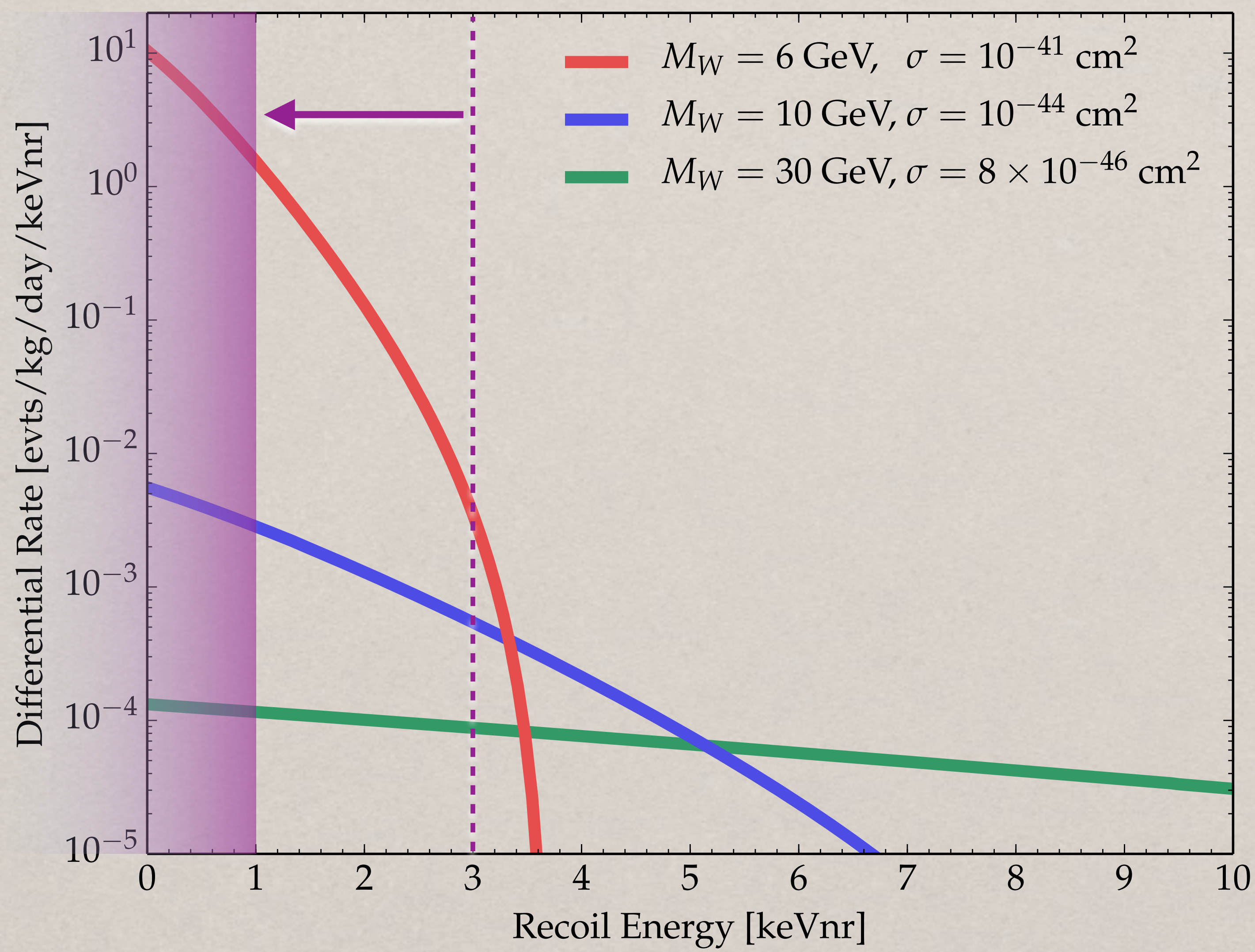




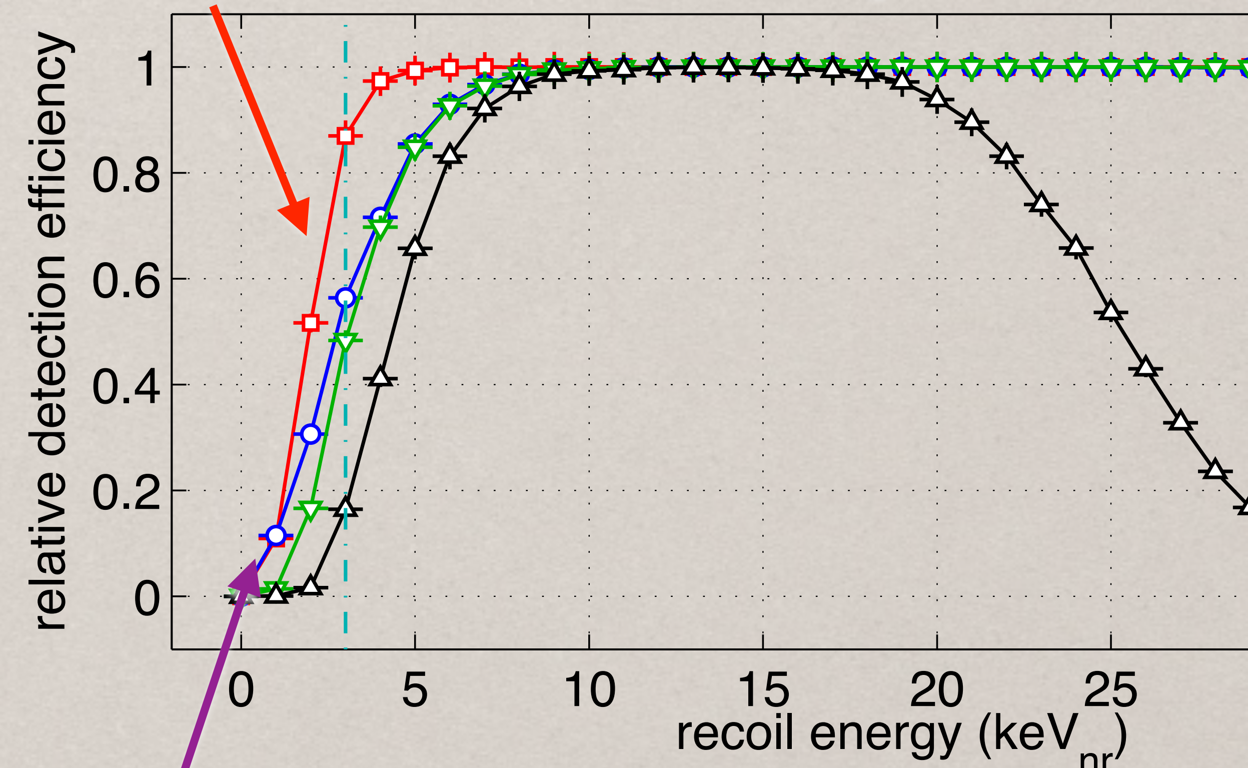
Decreasing this response cutoff from 3keV to 1keV provides access to a factor of <u>**1000***</u> **more signal** at *M* = 6 GeV

*Before folding in detection efficiencies

HOW SIGNIFICANT ARE THE NEW ENERGY-SCALE RESULTS?



Ionization efficiency, assuming ~4-electron threshold *(we can go lower)*



***We do have sensitivity to 1keV nuclear recoils!**

Decreasing this response cutoff from 3keV to 1keV provides access to a factor **<u>1000*</u> more signal** at M = 6 GeV

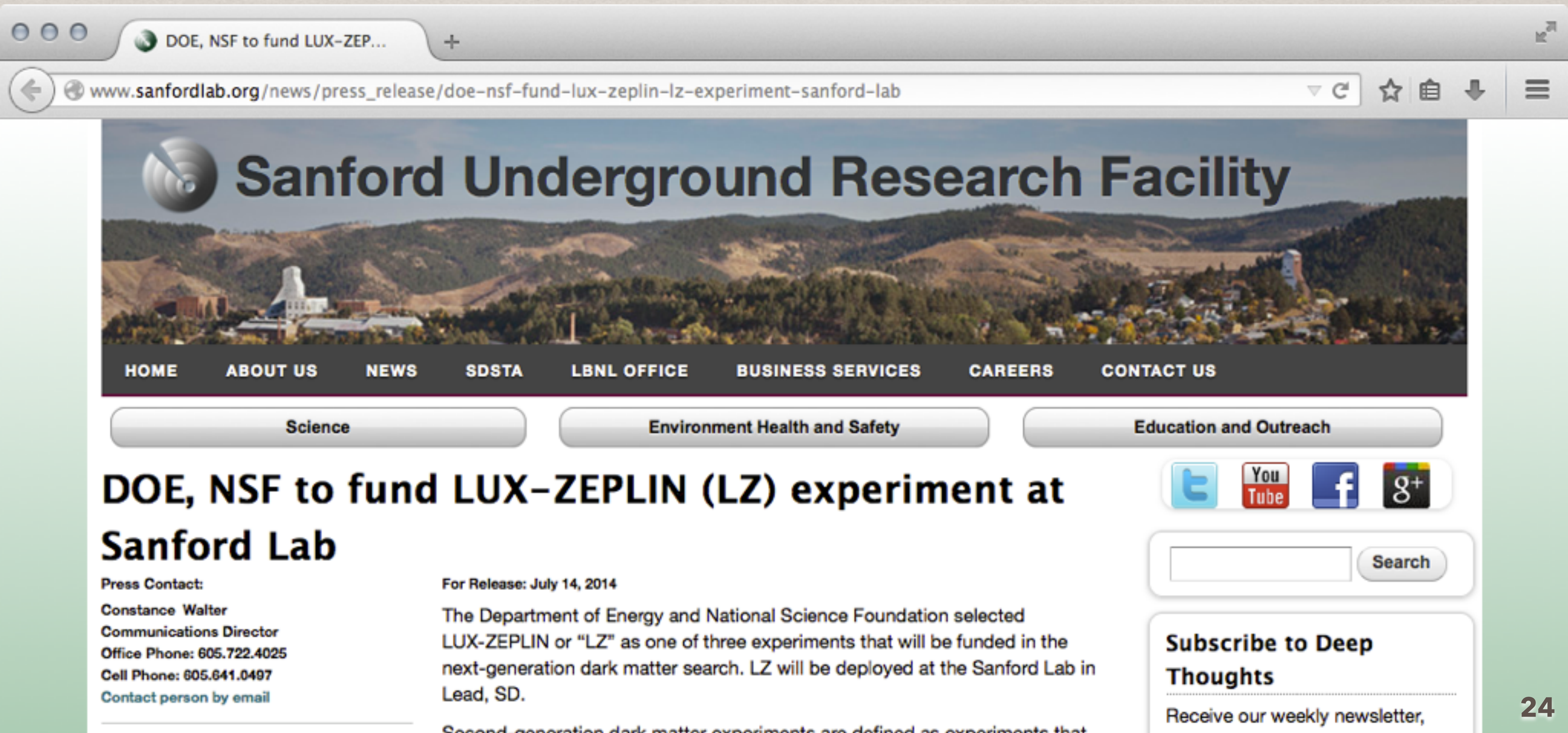
*Before folding in detection efficiencies

THE FUTURE AND LZ

- LUX's first results (85.3 days) were cautious: we chose *very* conservative assumptions of the detector response.
- Re-analysis in the works, exploiting our improved understanding of LXe's response to low-energy nuclear recoils. This will also feature reduced analysis thresholds.
- LUX is a very versatile detector, capable of much more than just setting limits on "vanilla" WIMP spin-independent interactions:
  - *Spin/momentum-dependent searches*
  - *Inelastic DM*
  - *Low-mass WIMP searches*
  - *Solar axions/ALPs*
  - *Astrophysics-independent limits*
  - *Hidden-sector searches*
- We are currently gearing up for a 300-day search, projecting a factor of x5 increase in sensitivity.

THE FUTURE AND LZ

Next generation, the LUX-ZEPLIN (LZ) experiment, very recently selected as one of three "G2" DM projects! Projected for 2017-2018, 1000-fold sensitivity improvement over LUX.



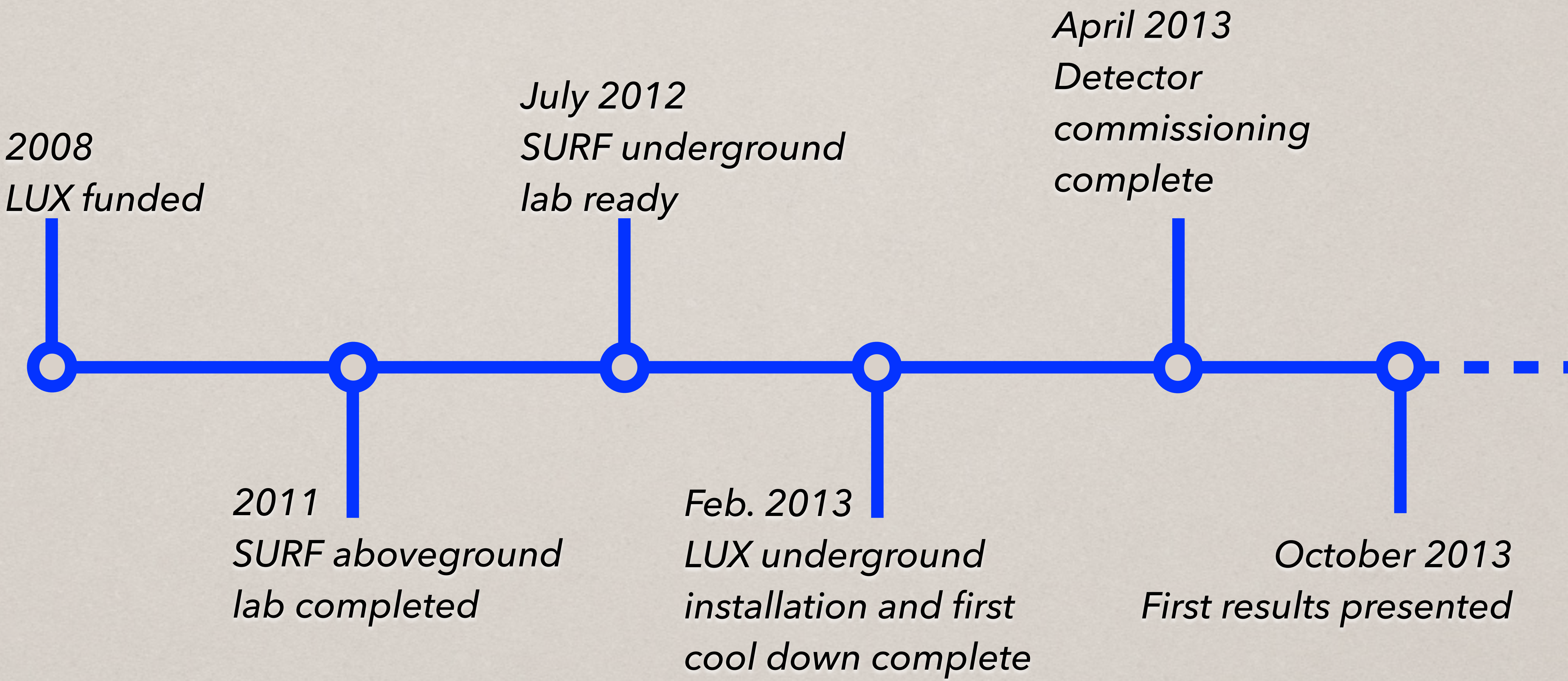
CONCLUSIONS

- LUX's first results, after only 3 months of running, has immediately set a world record in WIMP sensitivity.
- WIMP-nucleon scalar interactions: minimum exclusion limit of <u>σ < 760 yoctobarns</u> at M_χ=33 GeV/c^2.
- Expect a new re-analysis of the 3-month search, updated with input from our new NR energy-scale measurements.
- Currently gearing up for a 300-day run, expect ~x5 increase in sensitivity.
- LUX's future looks bright, with the good news of LZ's selection as one of three G2 projects.

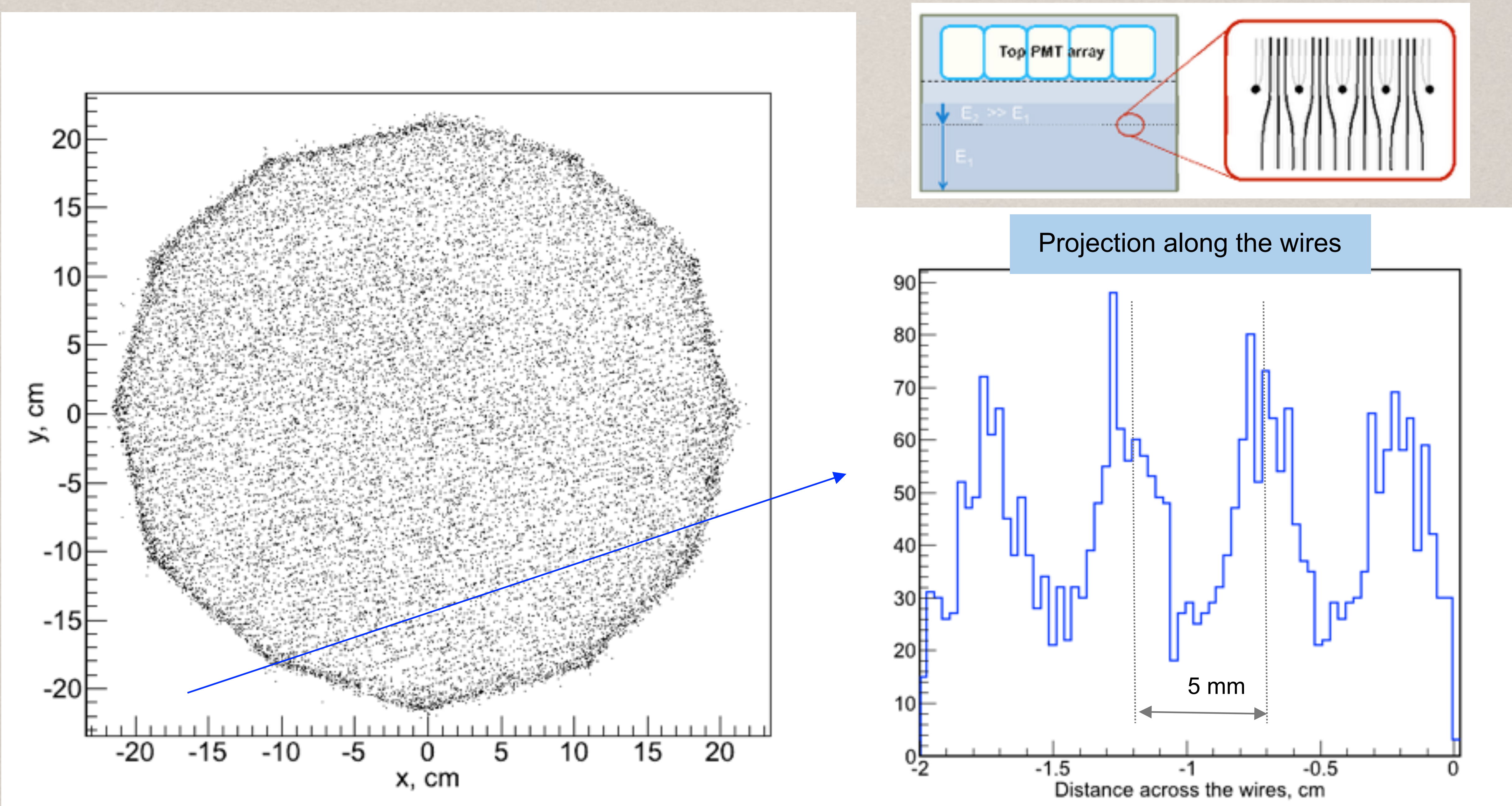
Thanks for your attention!

BACKUP SLIDES

LUX TIMELINE



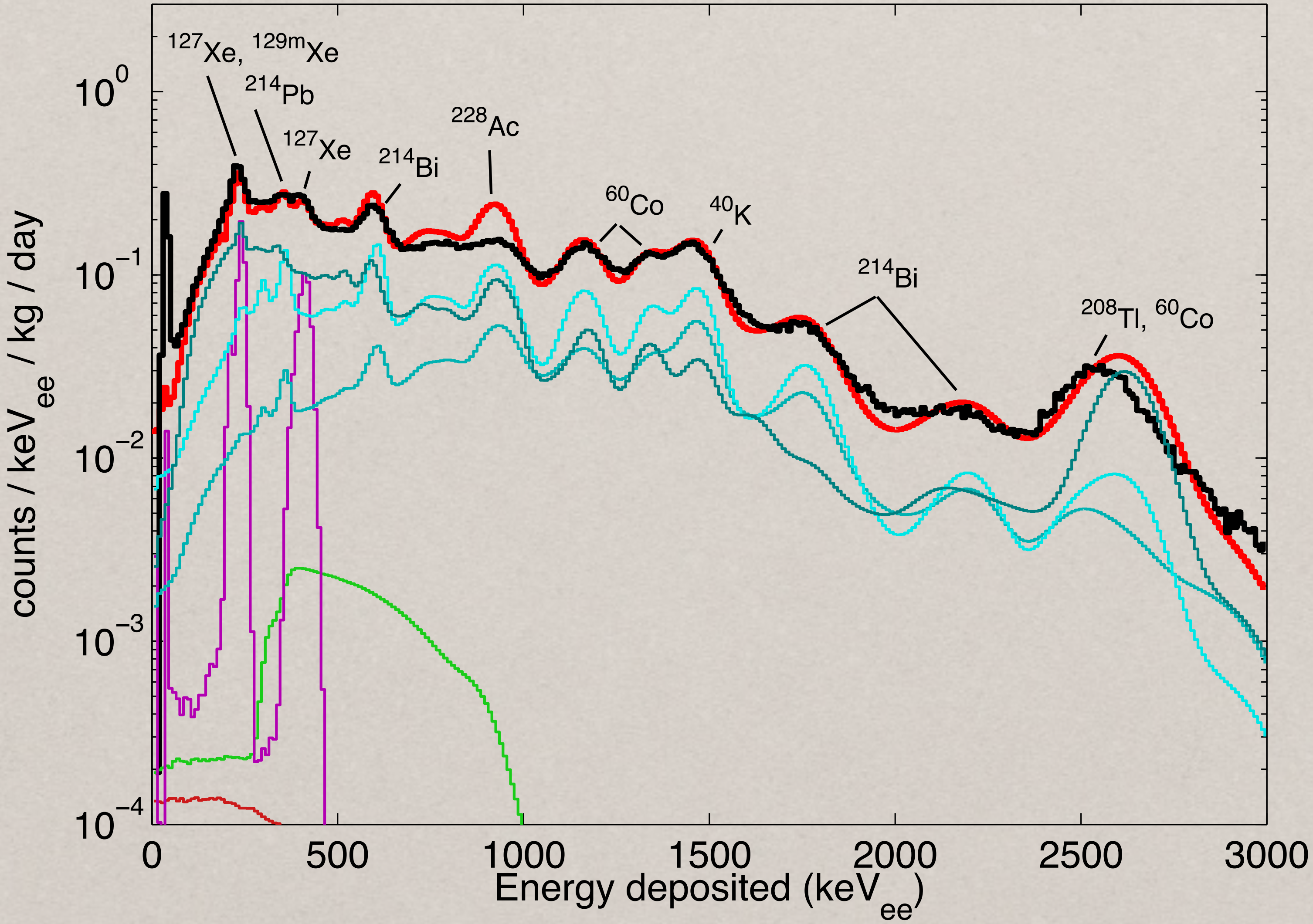
POSITION RECONSTRUCTION



- 4-6 mm resolution for S2 signals in WIMP-search region
- Improves to ~3 mm at higher energies

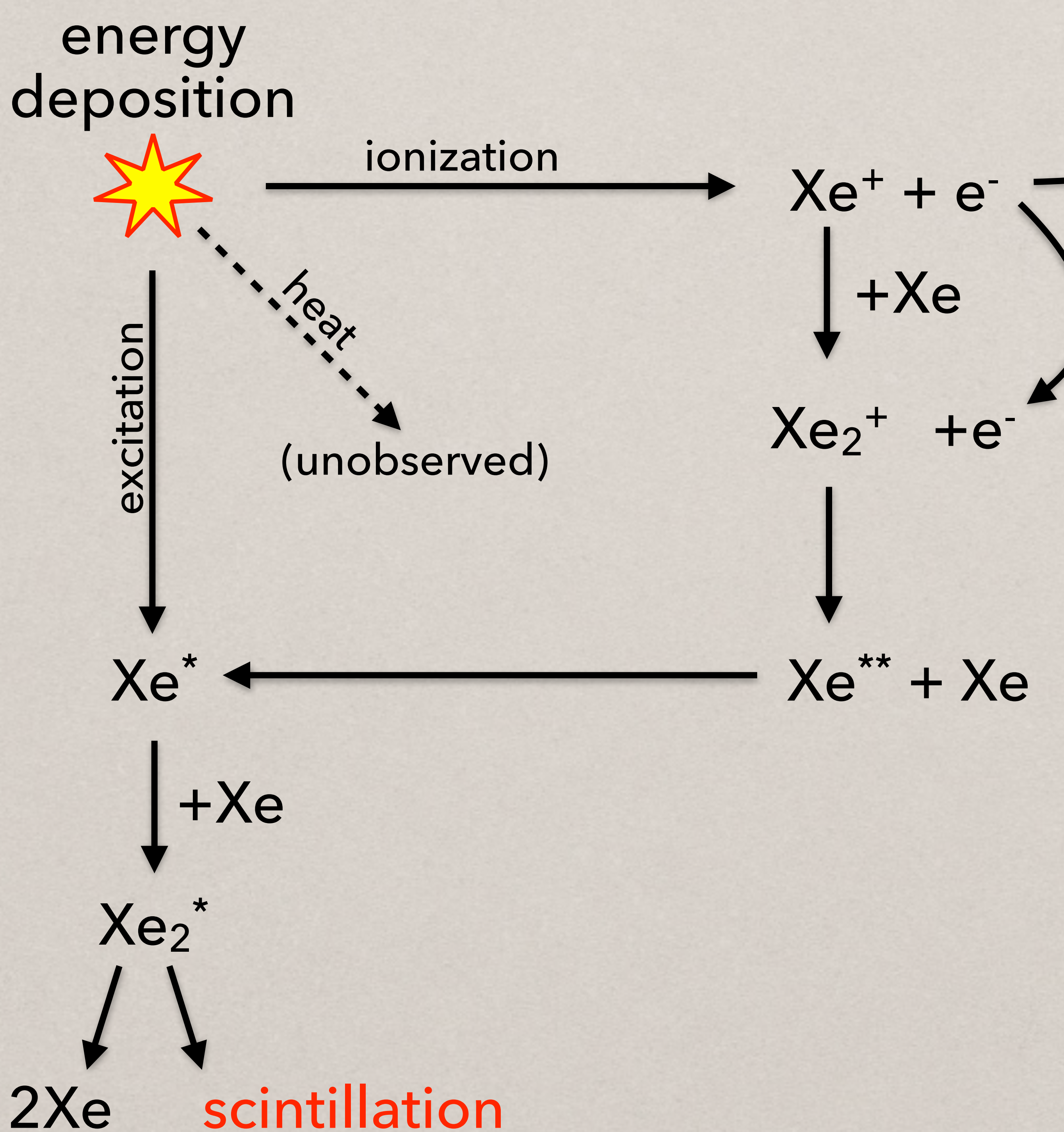
BACKGROUNDS

Source	Background Rate [mDRU$_{ee}$]
γ rays	$1.8 \pm 0.2_{\text{stat}} \pm 0.3_{\text{sys}}$
^{127}Xe	$0.5 \pm 0.02_{\text{stat}} \pm 0.1_{\text{sys}}$
^{214}Pb	$0.11 - 0.22$ (0.20 expected)
^{85}Kr	$0.17 \pm 0.10_{\text{sys}}$
Total predicted	$2.6 \pm 0.2_{\text{stat}} \pm 0.4_{\text{sys}}$
Total observed	$3.6 \pm 0.3_{\text{stat}}$



- "DRU" = "differential rate unit", or evts/kg/day/keV
- Backgrounds in LUX are very well constrained by high-energy gamma ray lines.
- Events in the fiducial region are dominated by external gamma rays.
- Internal sources (^{85}Kr, ^{214}Pb, ^{127}Xe) also contribute.
- Full BG study available at arXiv:1403.1299

SCINTILLATION AND IONIZATION SIGNALS



- Ionization and scintillation signals are anti-correlated
- Because of these complicated effects, electronic and nuclear recoils result in different proportions of ionization and scintillation for the same energy
- Allows one to identify primary particle identity

THE FUTURE AND LZ