Direct Search for Dark Matter with Two-phase Xenon Detectors: Current Status of LUX and Plans for LZ

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Vulcano Workshop 2014:

Frontier Objects in Astrophysics and Particle Physics

Vulcano Island, Italy

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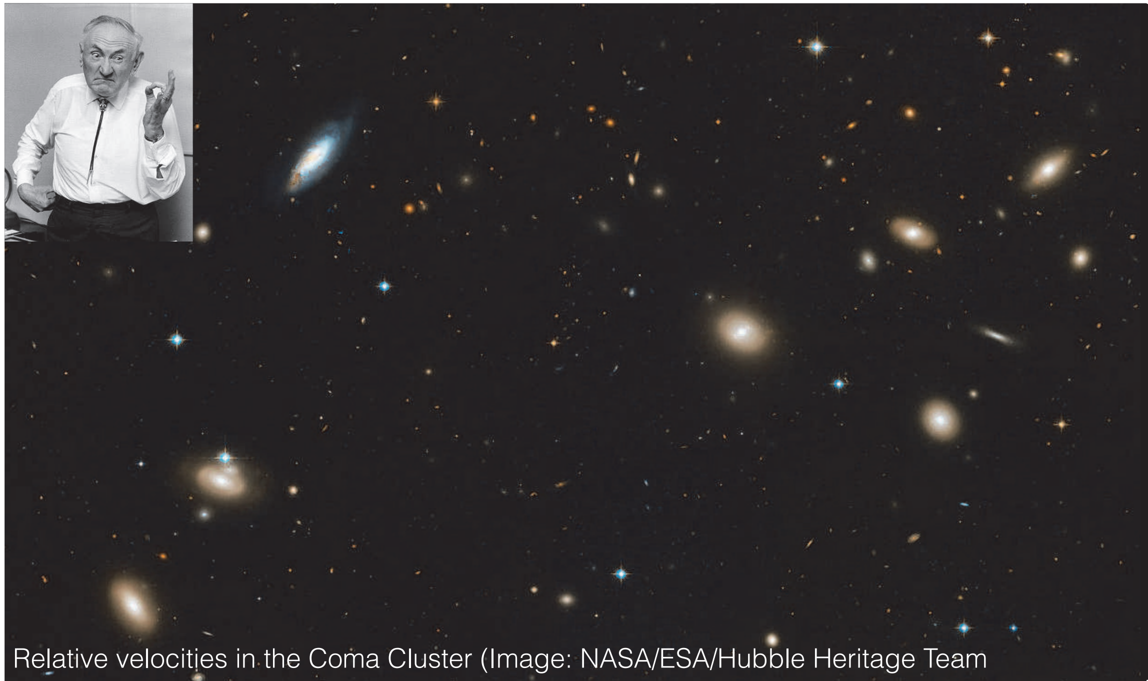
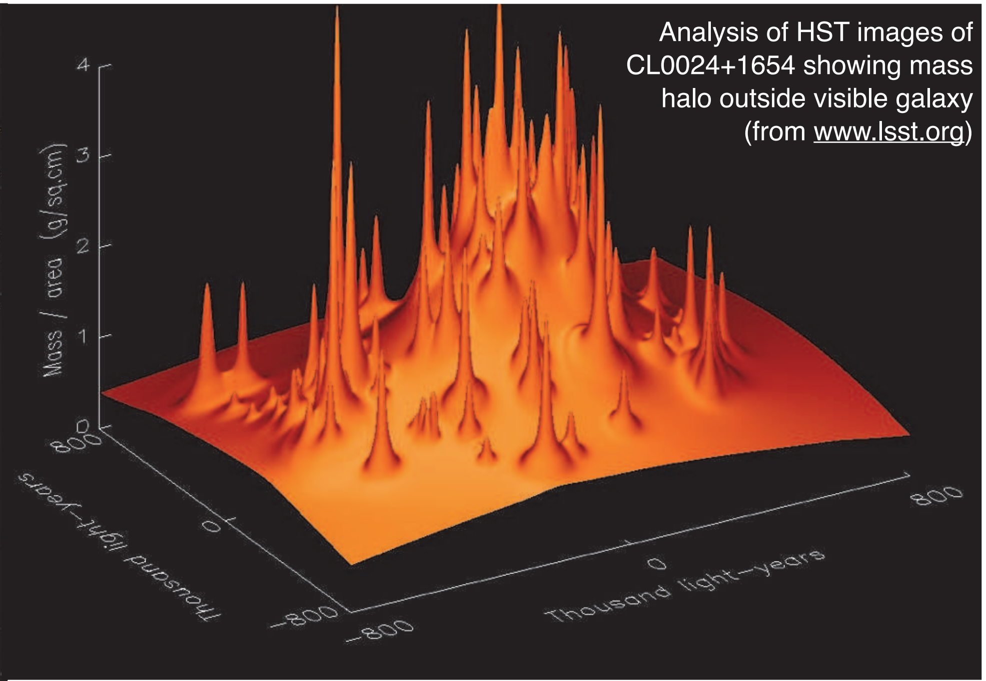
Outline:

- **WIMP Dark Matter:** the most conservative idea that still fits all the data
- **Our Detector:** two-phase, noble gas TPC
- **The Past:** LUX surface runs, installation, commissioning and early science
- **The Present:** status of the LUX experiment
- **The Future:** LUX + ZEPLIN = LZ
- **Conclusions:** a few words to wrap things up

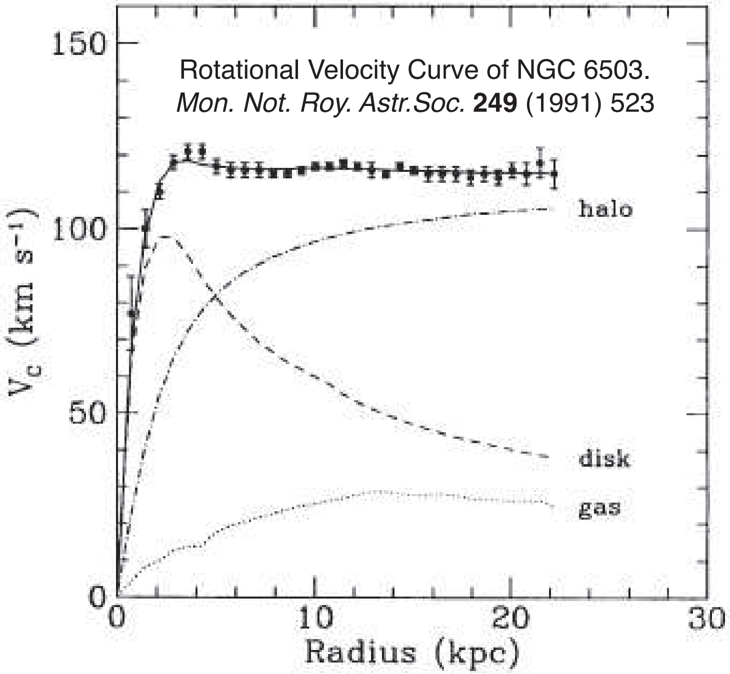
The Evidence: Galaxies, Clusters



Relative velocities in the Coma Cluster (Image: NASA/ESA/Hubble Heritage Team

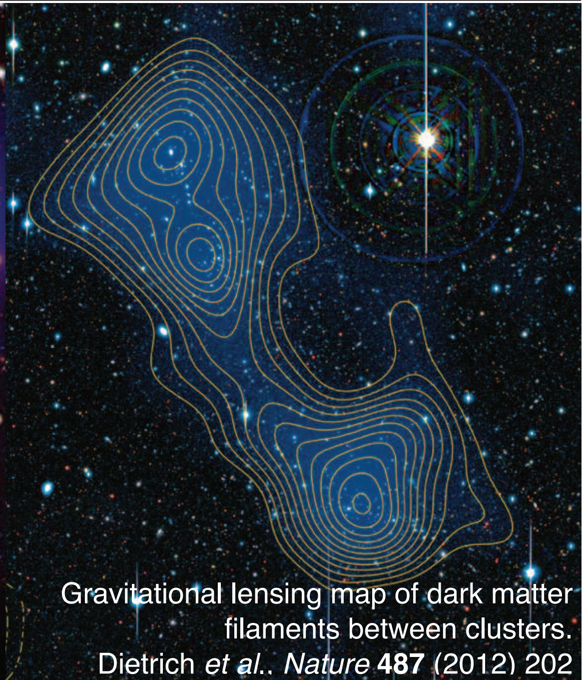


Analysis of HST images of CL0024+1654 showing mass halo outside visible galaxy (from www.lsst.org)



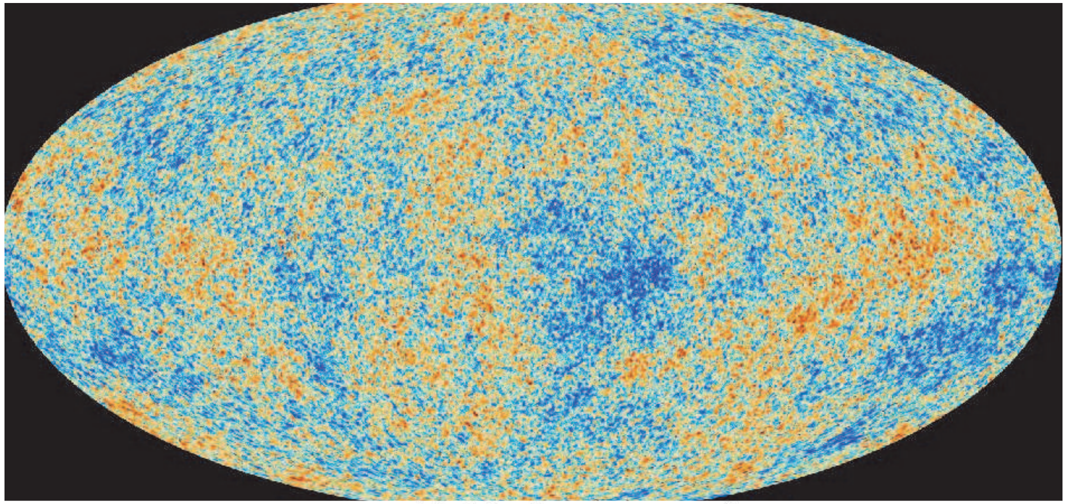
Rotational Velocity Curve of NGC 6503.
Mon. Not. Roy. Astr.Soc. **249** (1991) 523

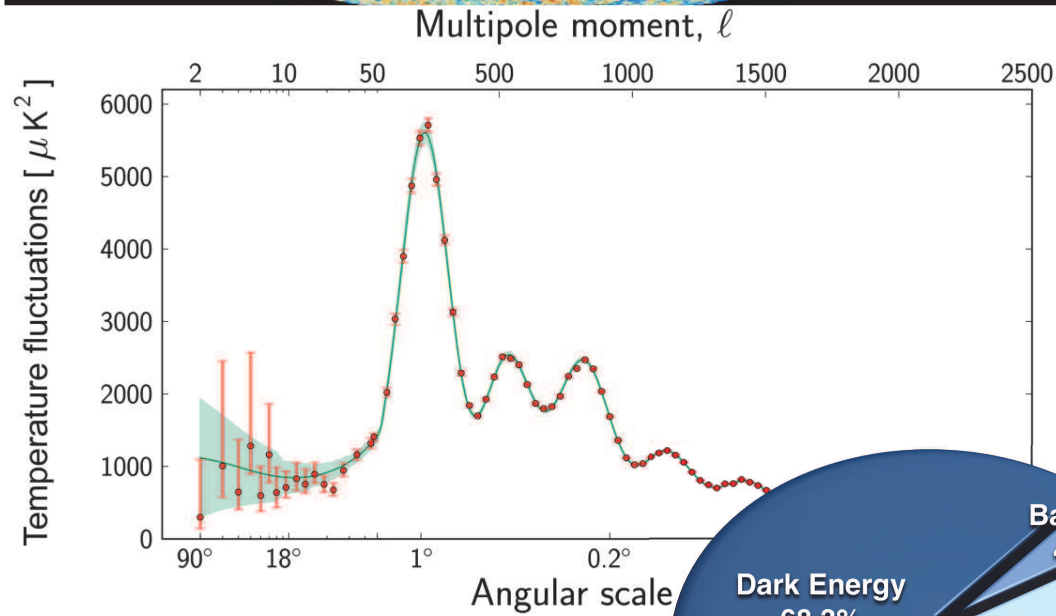
Composite image of the "Bullet Cluster," showing separation of cluster mass (seen with gravitational lensing, blue) from atoms (seen with Chandra x ray data, red).
Nature, 21 April 2006



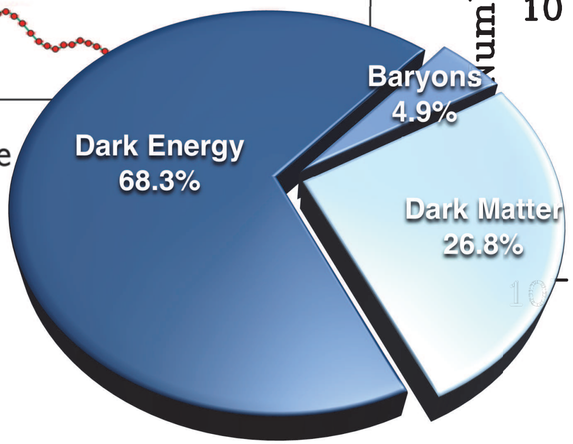
Gravitational lensing map of dark matter filaments between clusters.
Dietrich *et al.*, *Nature* **487** (2012) 202

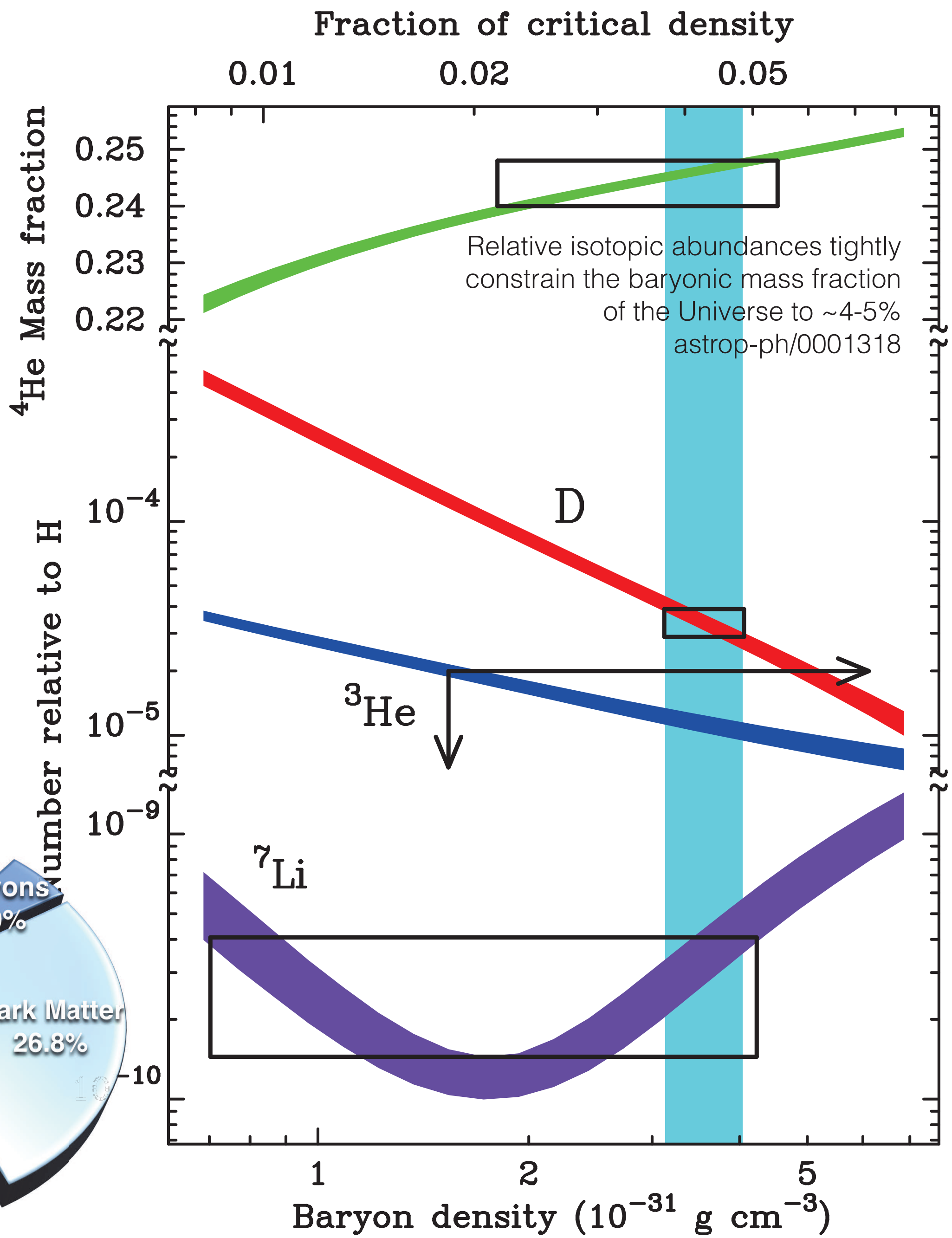
The Evidence: CMB, Isotopic Abundance





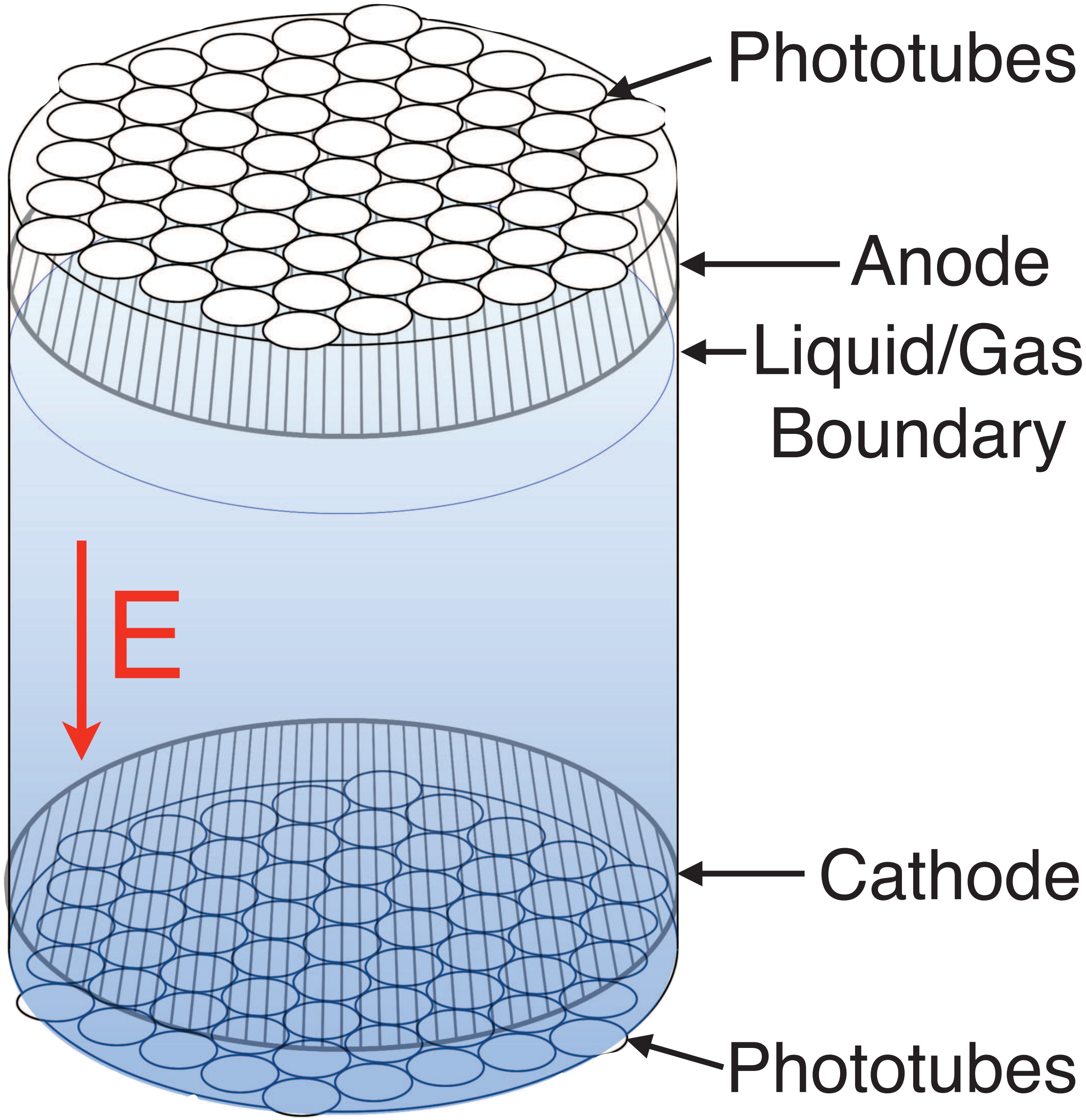
Planck, 2013 Results





Two-Phase TPC Detector

- Collect scintillation and ionization signals for simple position/energy reconstruction, and high target mass in a small footprint
- Xe is a good target:
  - no long-lived radioactive isotopes
  - boiling temperature is fairly high (165 K)
  - high density (~3 g/cm^3)
  - A^2 scaling boosts sensitivity for coherent WIMP scattering on nuclei
  - Good dielectric properties for high bias field



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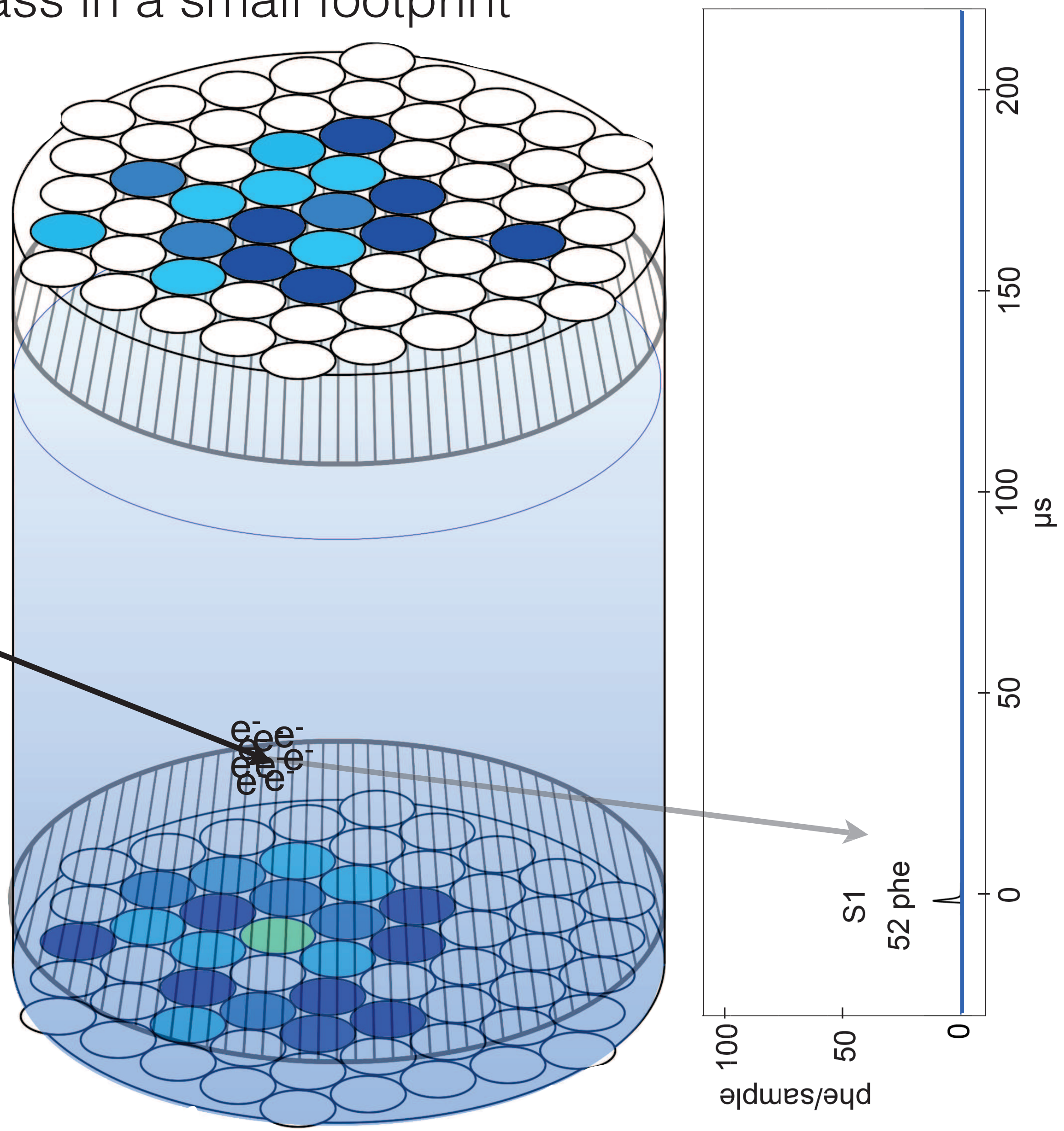

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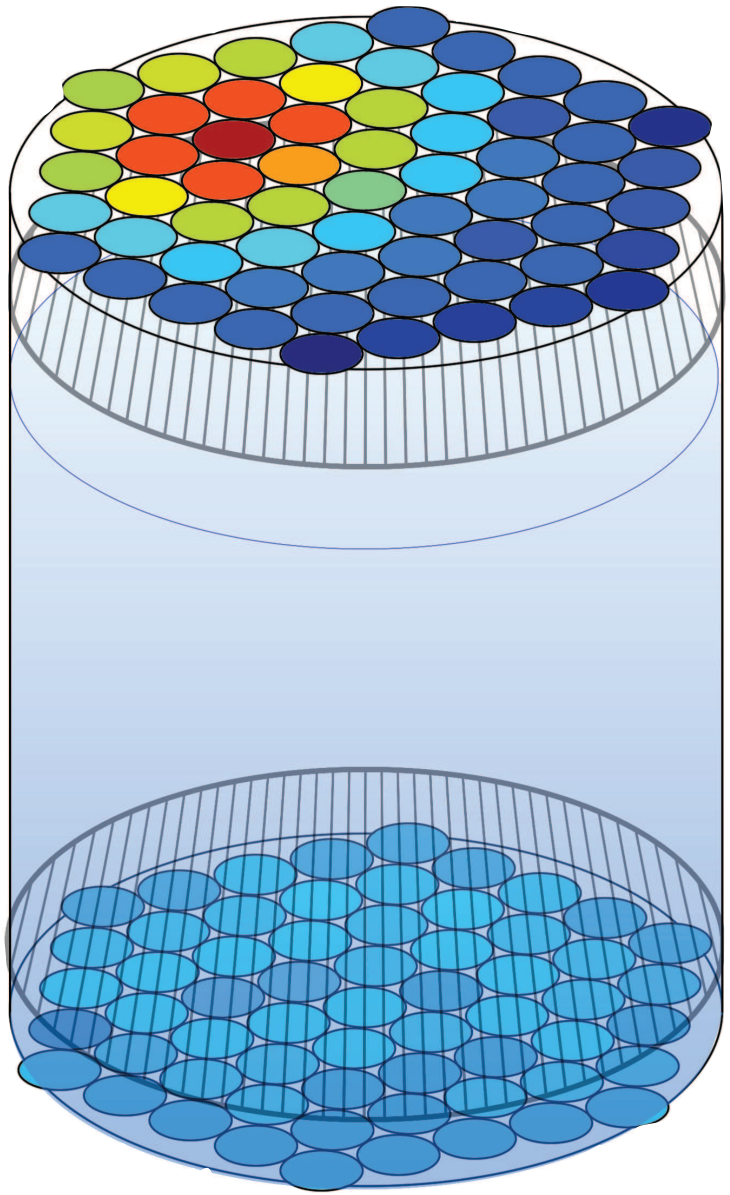

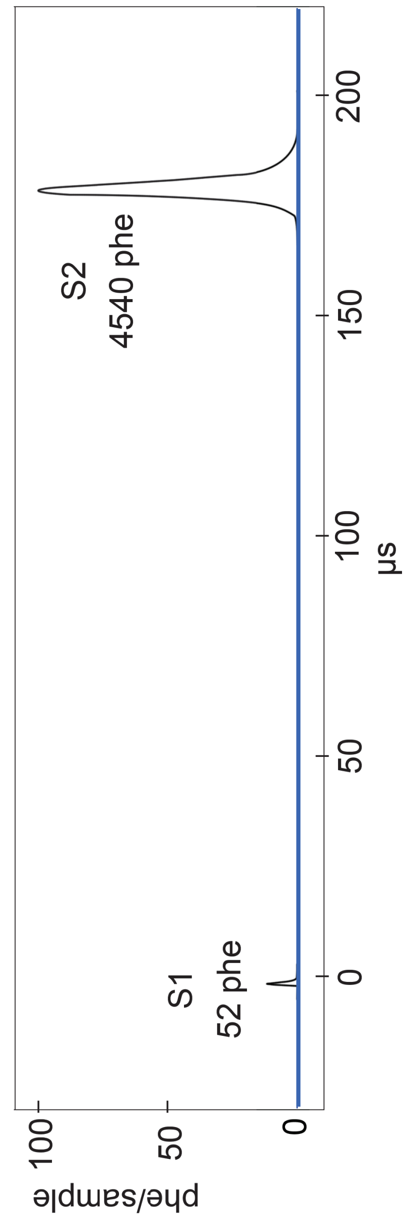

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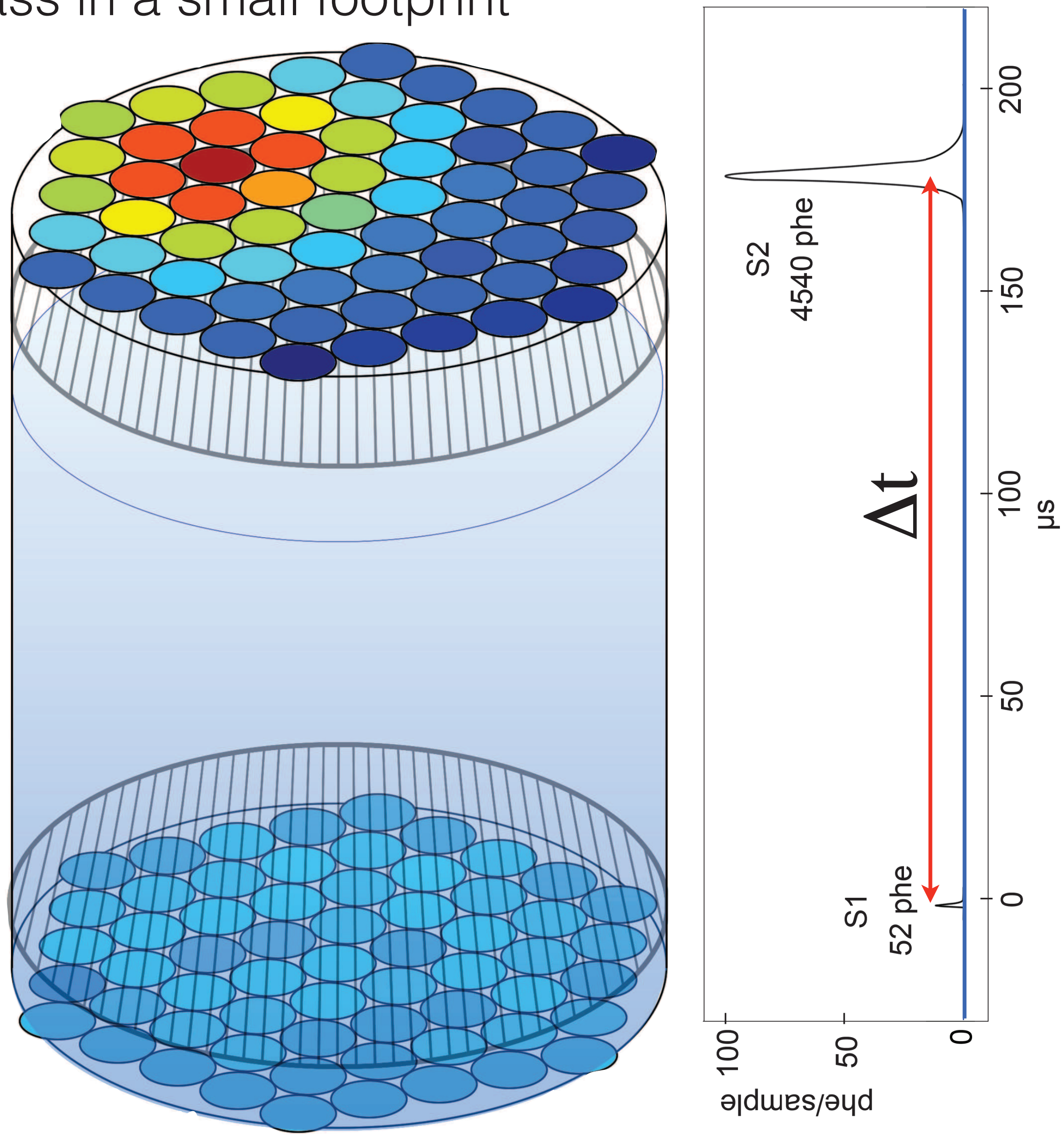
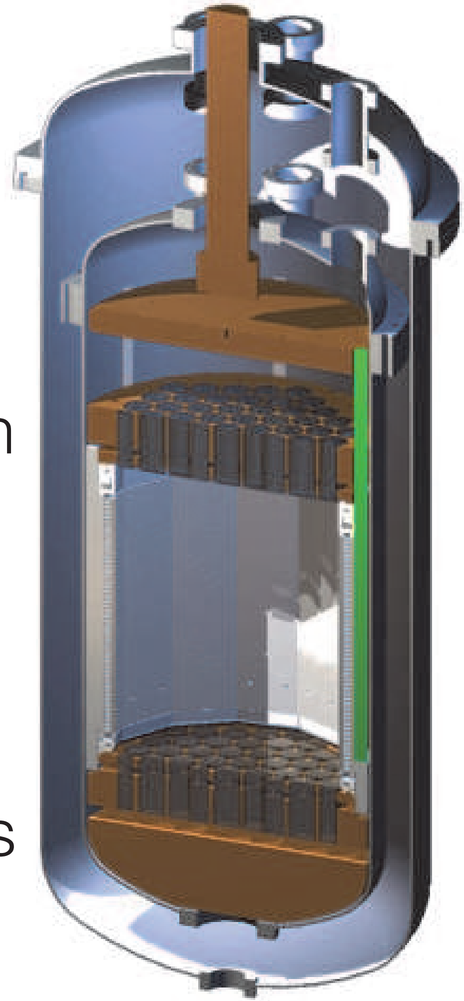


The LUX Experiment

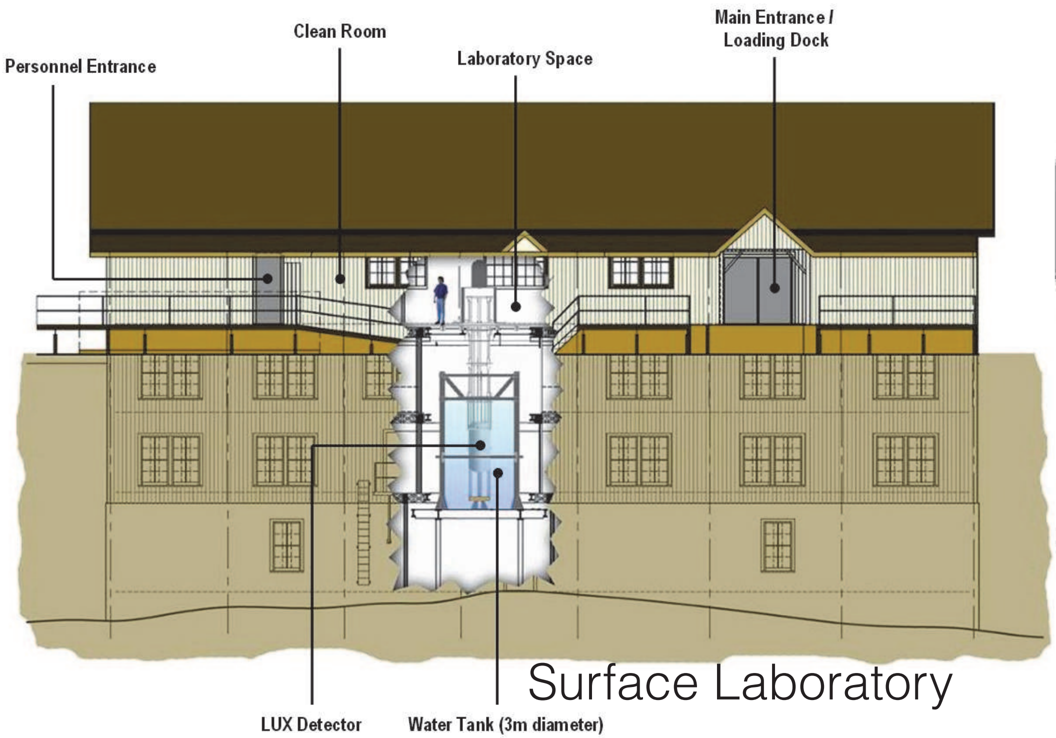


- Dual-phase xenon TPC, 370 kg (~100 kg fiducial)
- Located at Sanford Underground Research Facility in Lead, SD (4850 feet, 4300 m.w.e. overburden)
- First science run: April to August 2013
- First results in October 2013
- Currently paused for maintenance and improvements
- Projected sensitivity (300 days live time) ~10^{-46} cm^2

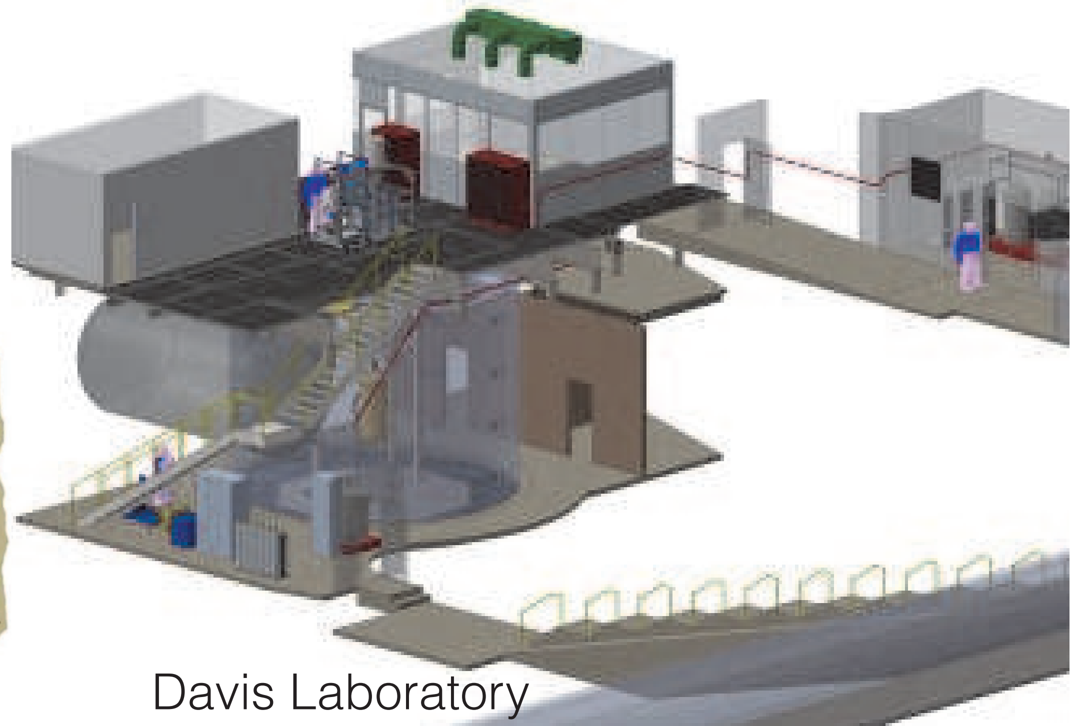
LUX Collaboration Meeting, March 2014 in Lead. The Yeti is photoshopped, but the horizontal snow is not!

LUX Experimental Program

- Run01: Fall 2011, DAQ test (gas Xe surface)
- Run02: Winter 2011 to spring 2012, detector tests (liquid Xe surface)
- Run03: Installation summer 2012, commissioning spring 2013, physics data summer 2013, first results fall 2013 (liquid Xe underground)
- Run04: Upgrades winter/spring 2014, recommissioning spring 2014, then run for a full year (liquid Xe underground, final sensitivity)



Surface Laboratory


Davis Laboratory

LUX Surface Run

Collage from Lyashenko talk, CIPANP12

Moving LUX Underground

- Surface lab to the Yates head frame building on July 11, 2012
- Head frame to Davis Lab on July 12, 2012

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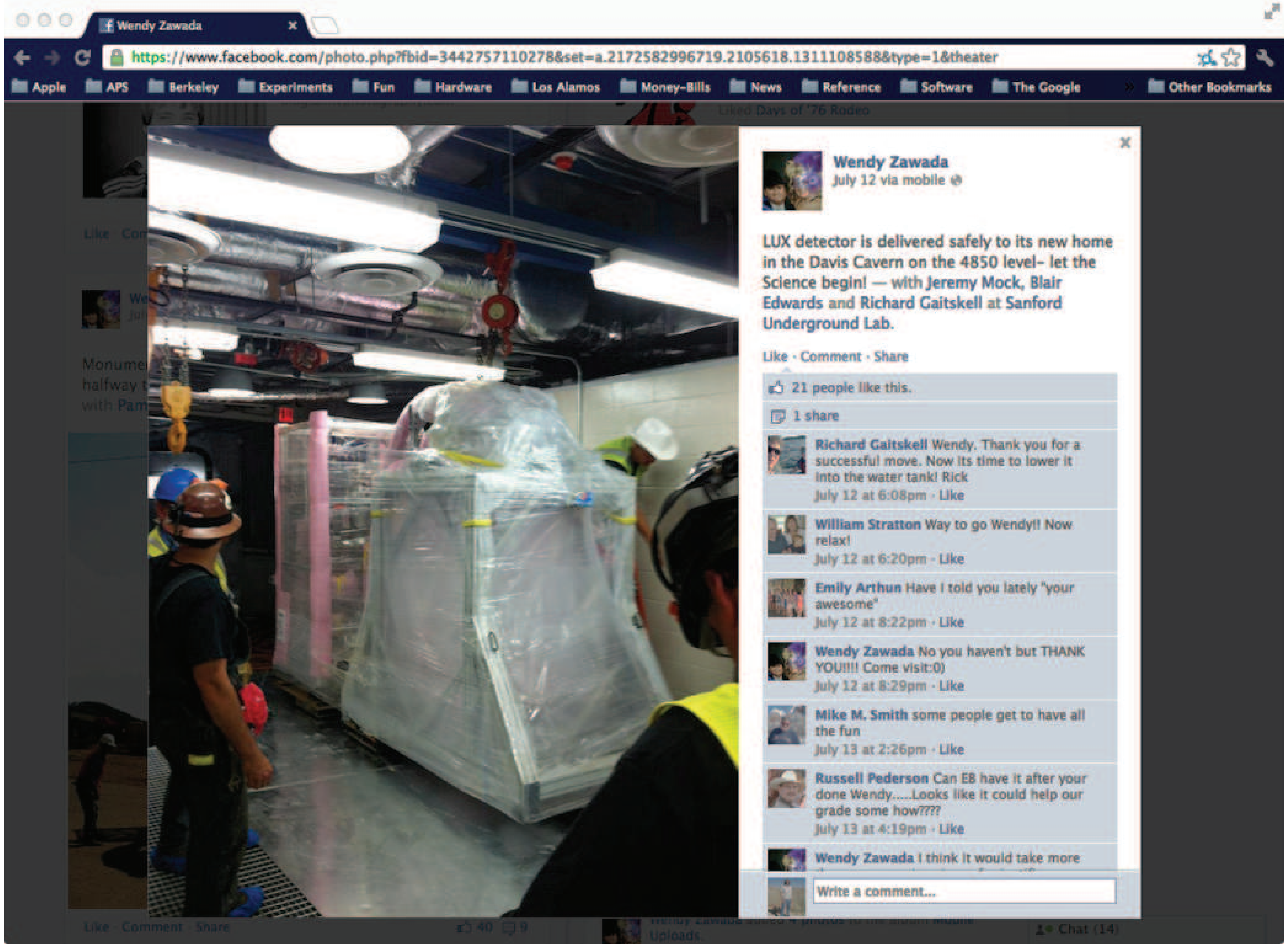
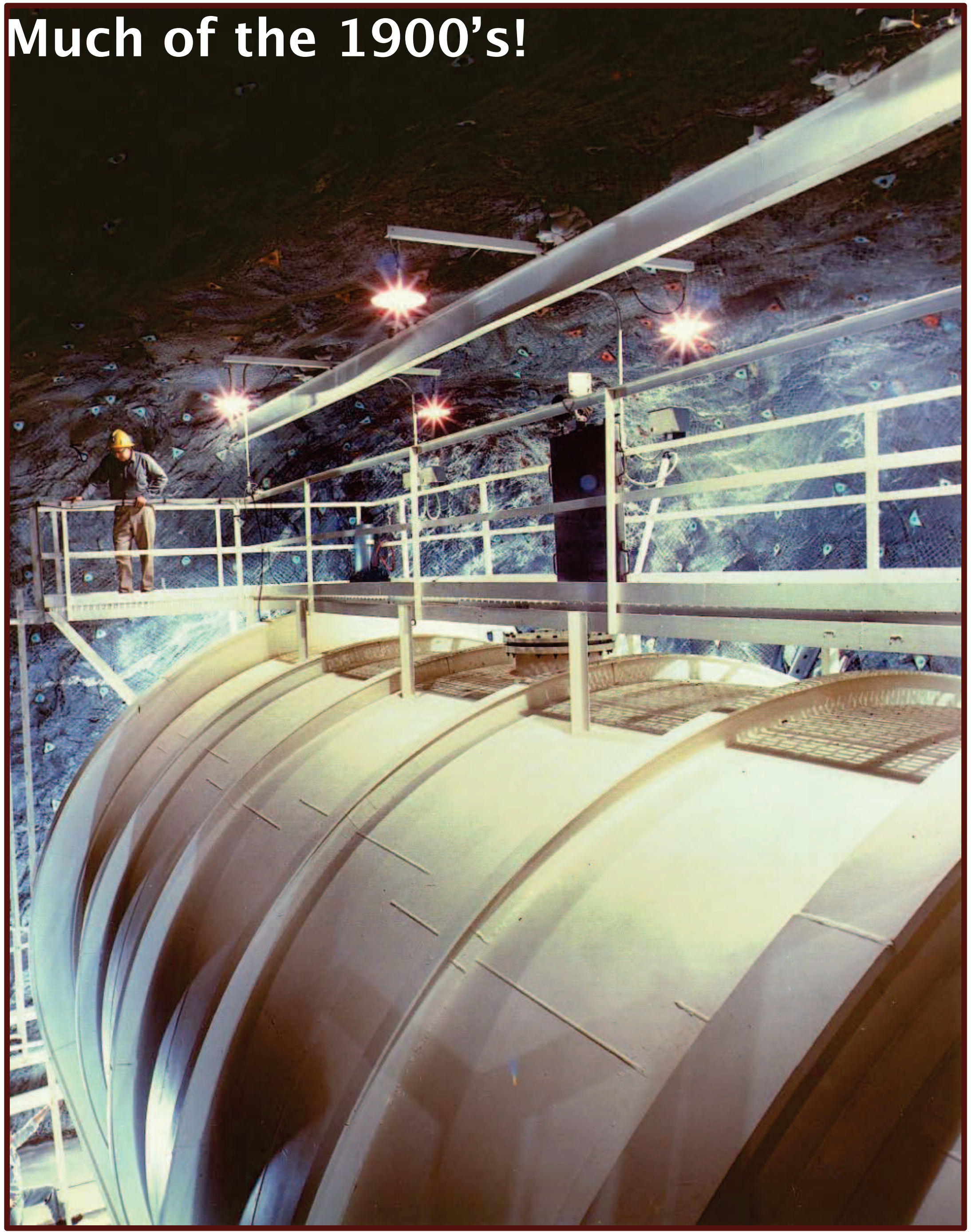
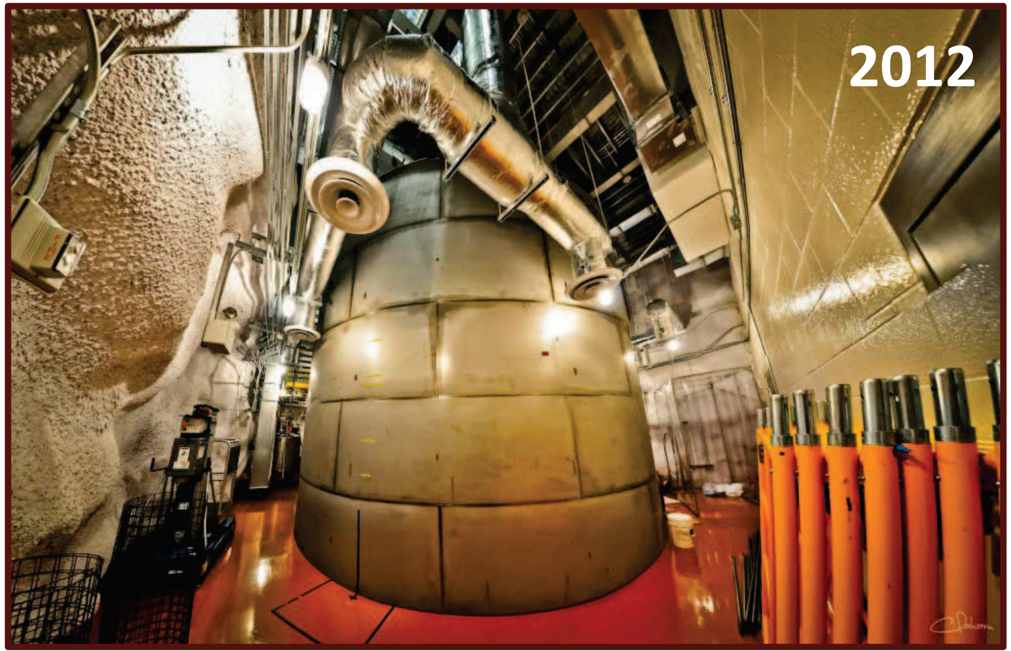


LUX @ Home





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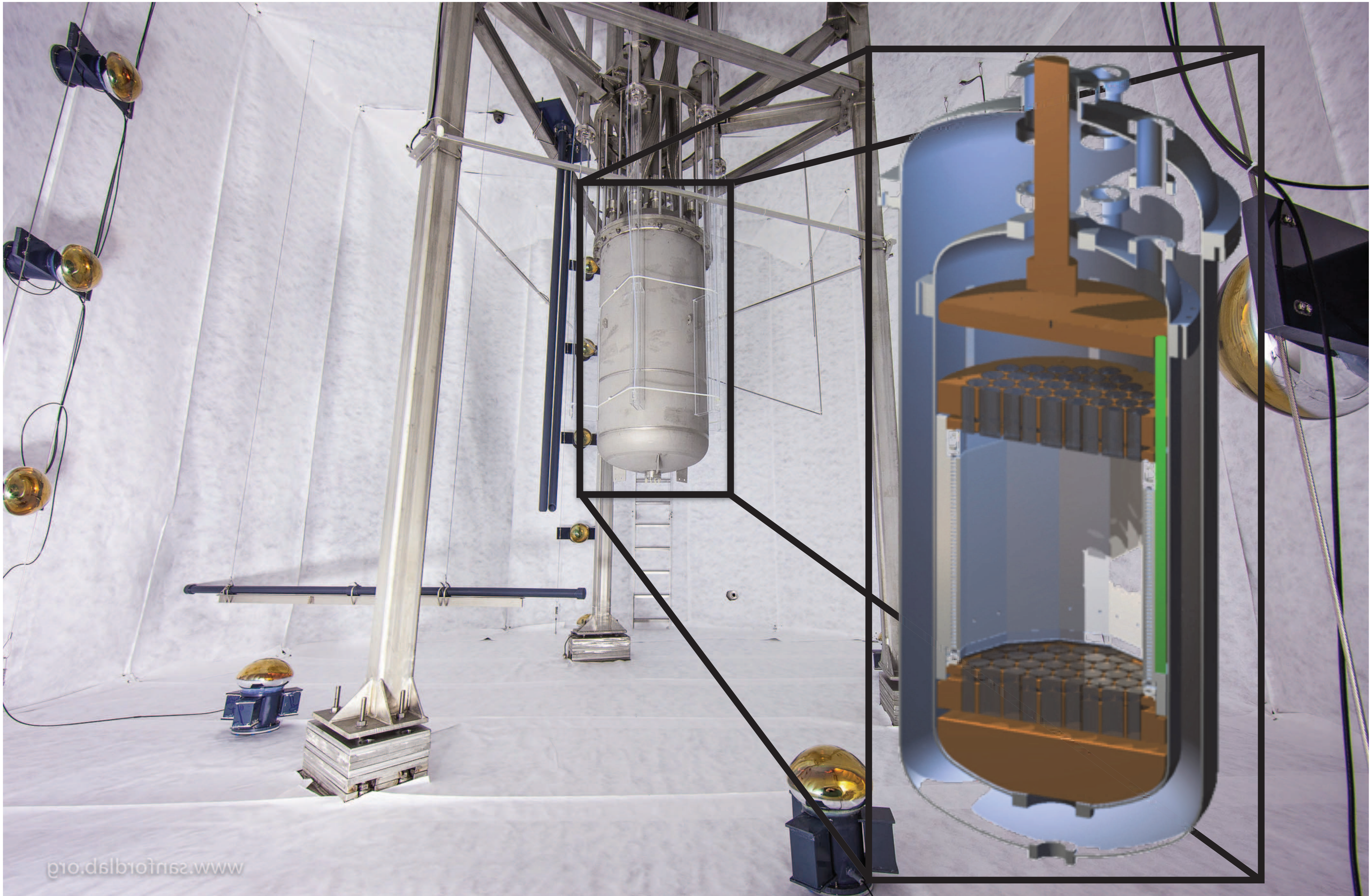

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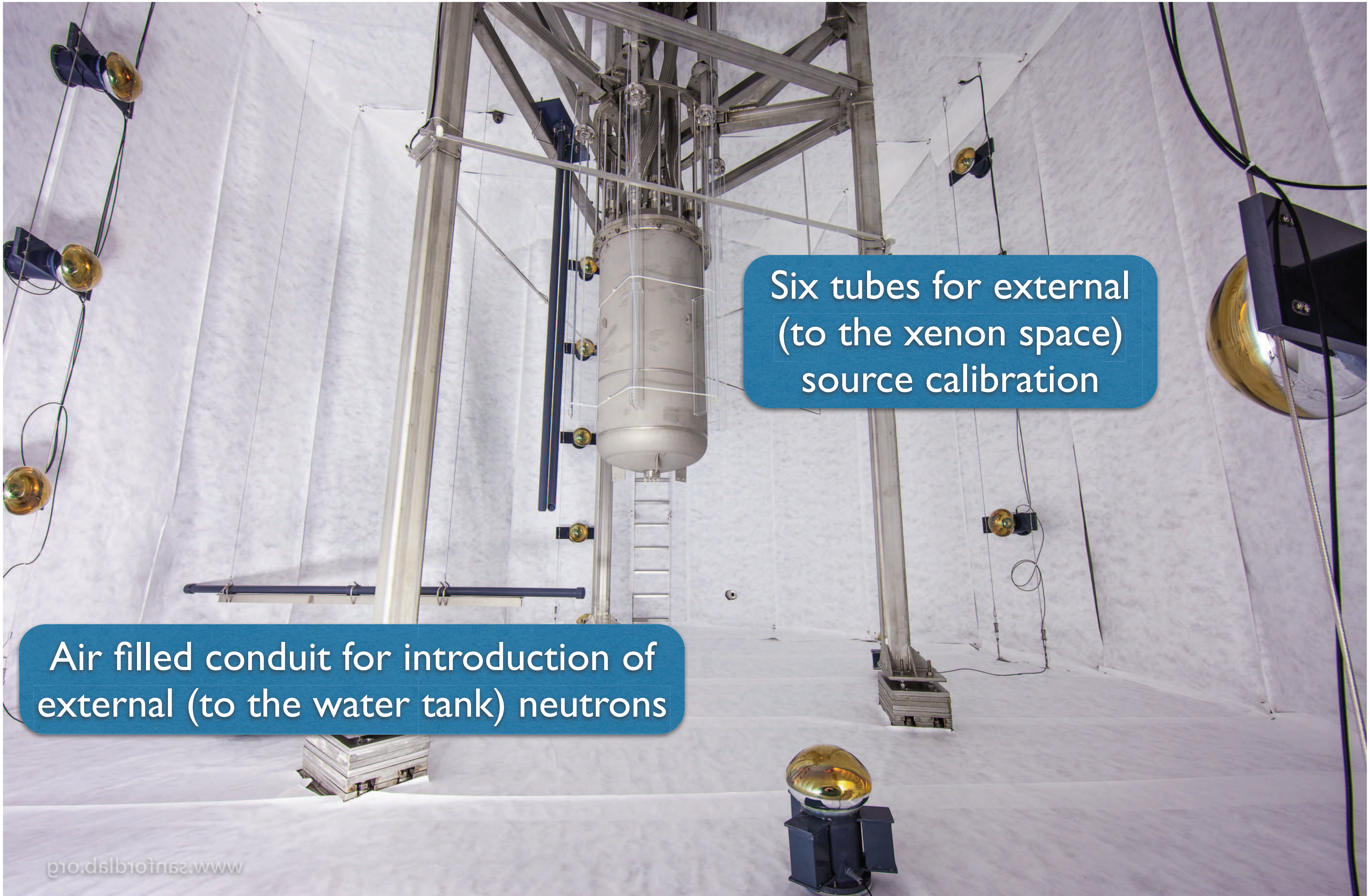
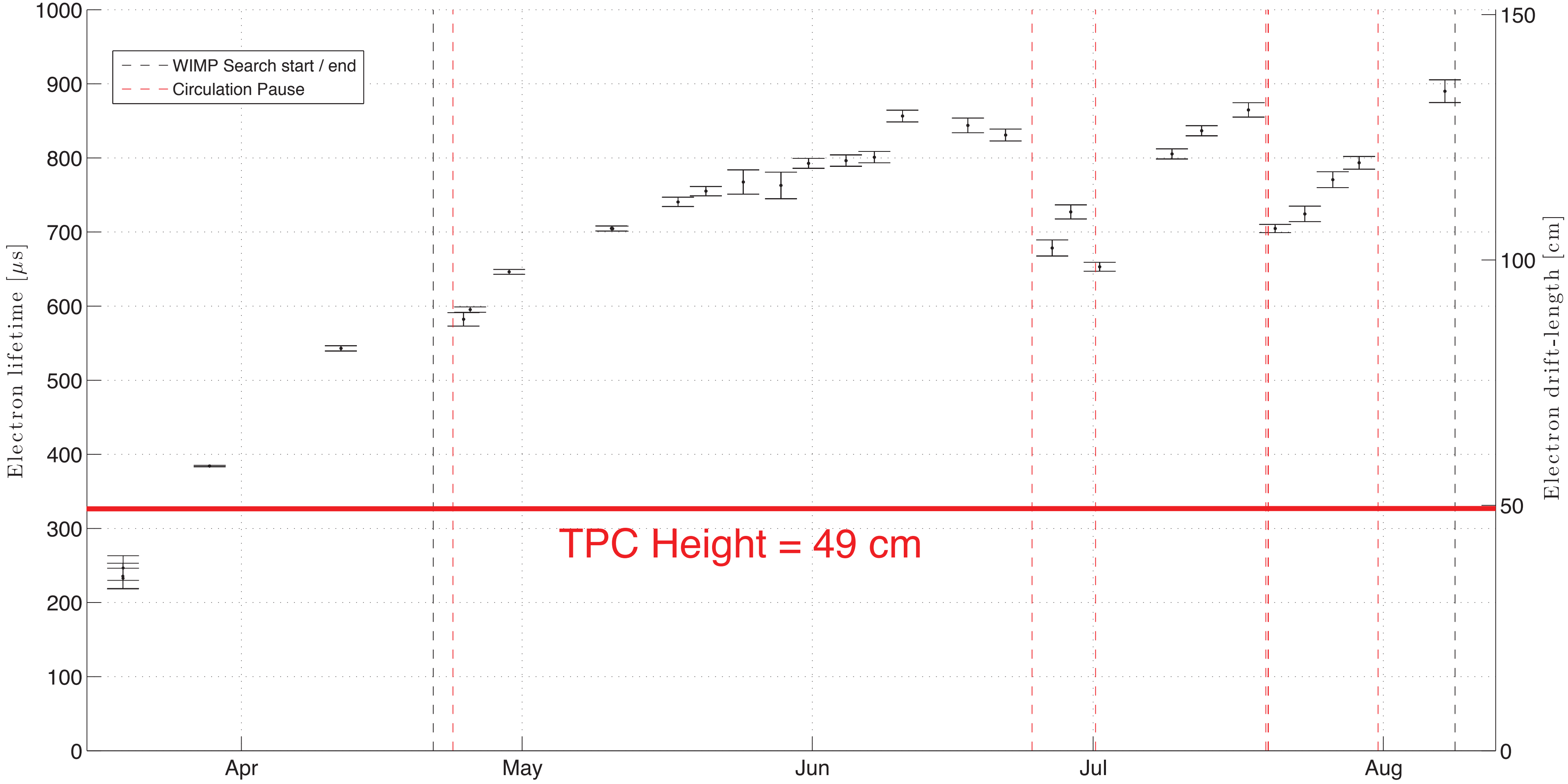

Six tubes for external (to the xenon space) source calibration
Air filled conduit for introduction of external (to the water tank) neutrons

Purity

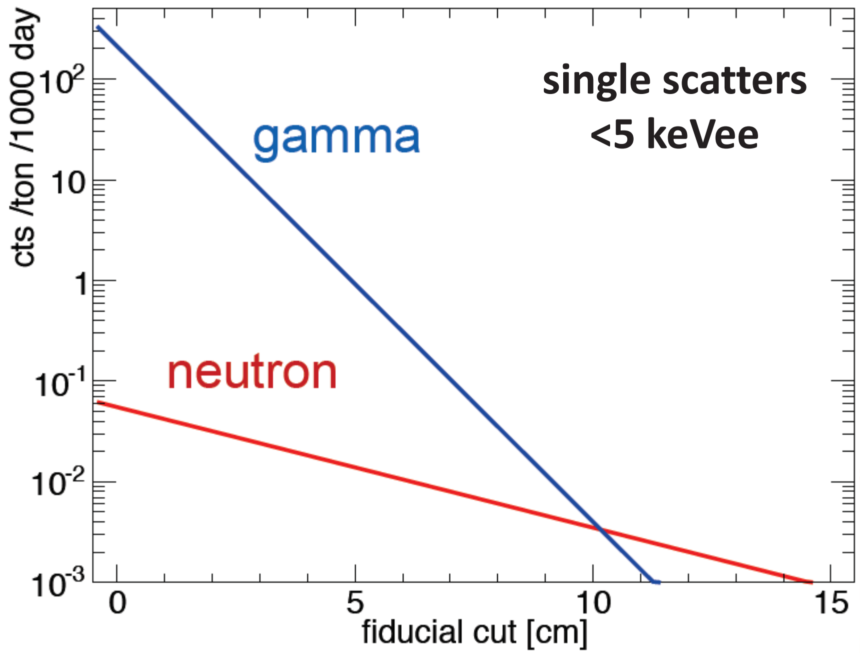
- Removal of radioactive ^{85}Kr successful at CWRU (4 ppt)
- Cool down completed Feb 7 (~2 weeks), xenon condensed by Feb 10
- Circulation and external purification worked really well!

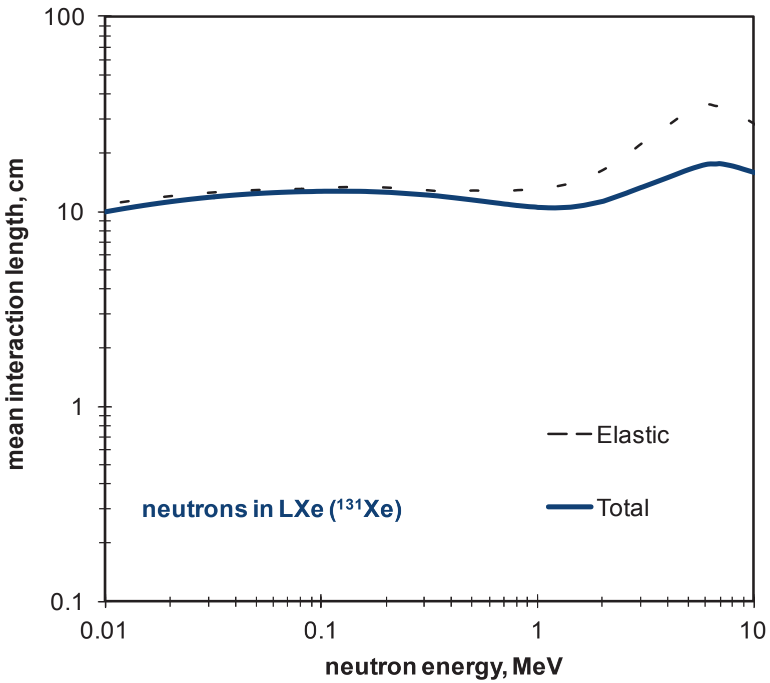


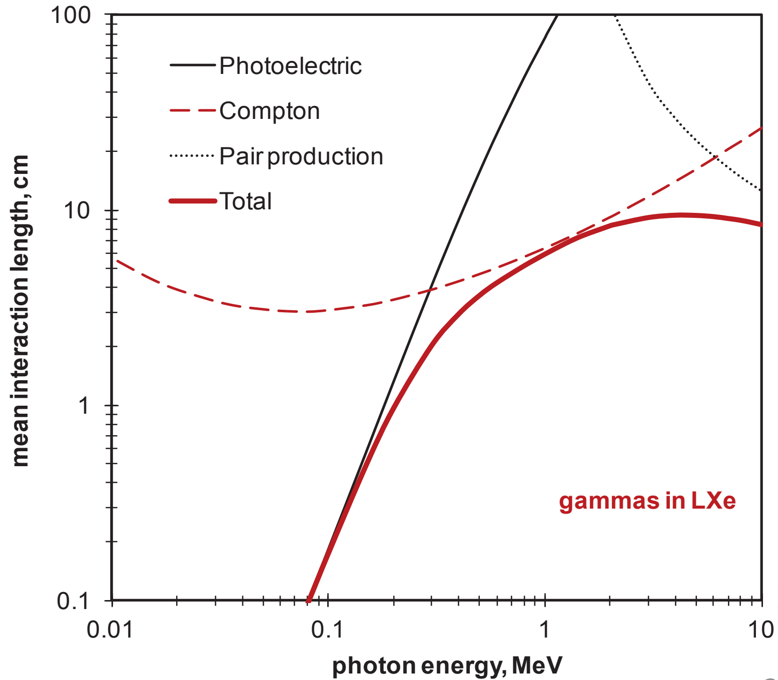
Calibration

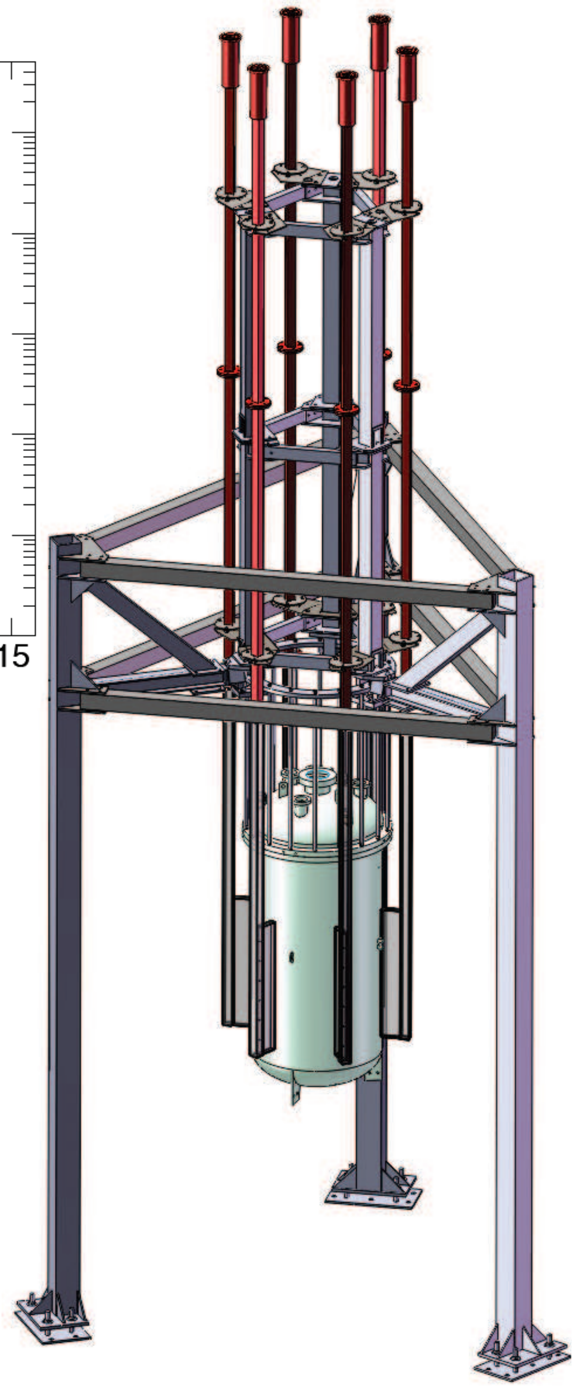
- External Sources
- ^{83m}Kr
- Tritiated methane
- DD neutrons

Victim of self shielding!









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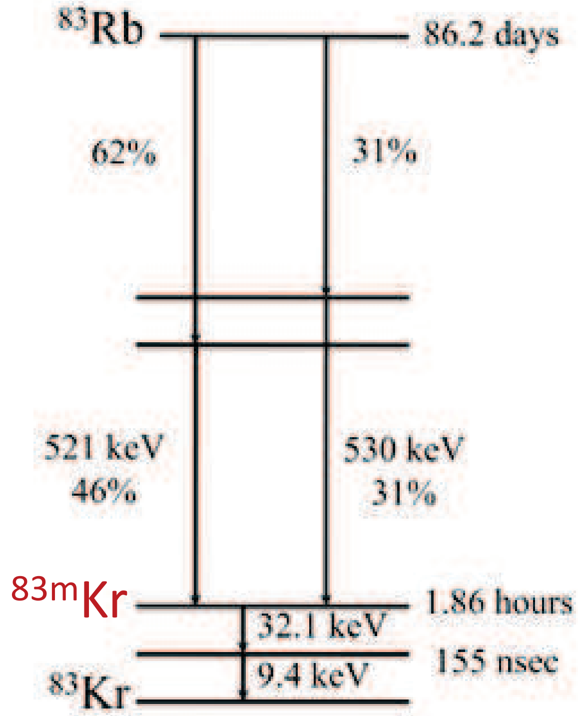

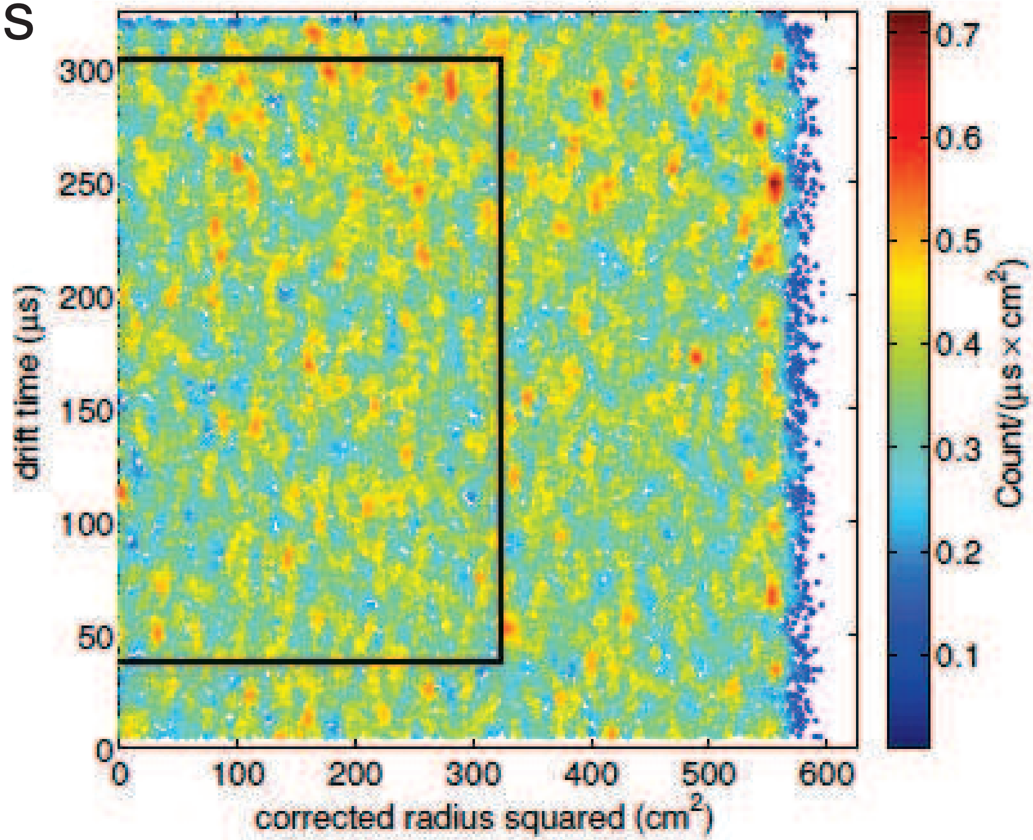

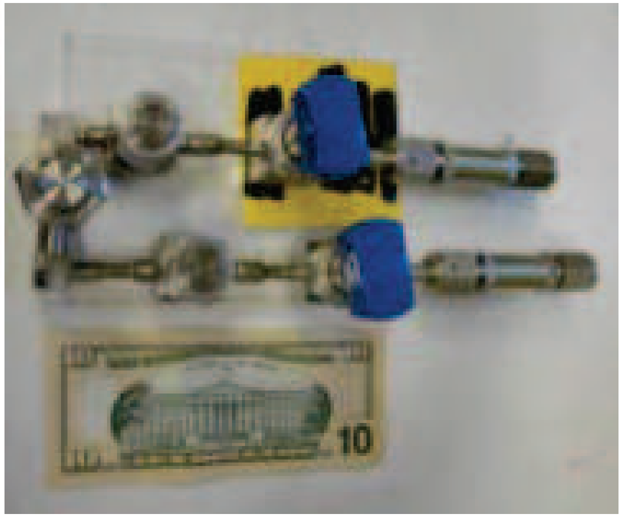

Inject ^{83m}Kr into the xenon circulation system:
^{83}Rb infused in zeolite, where Xe can be circulated through it.

Calibration

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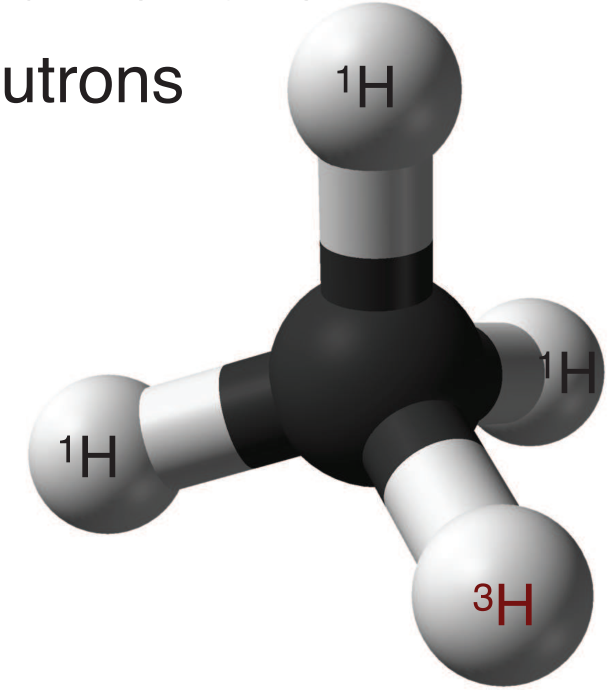
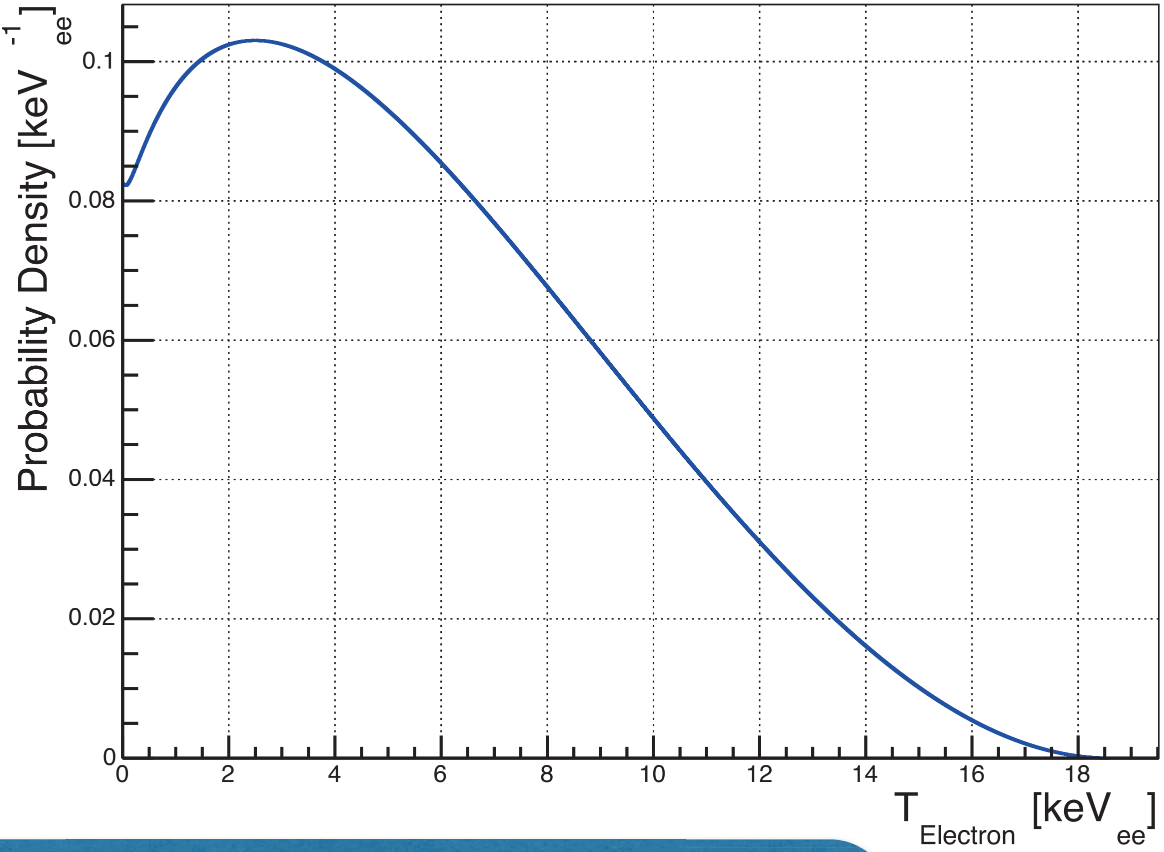
- DD neutrons

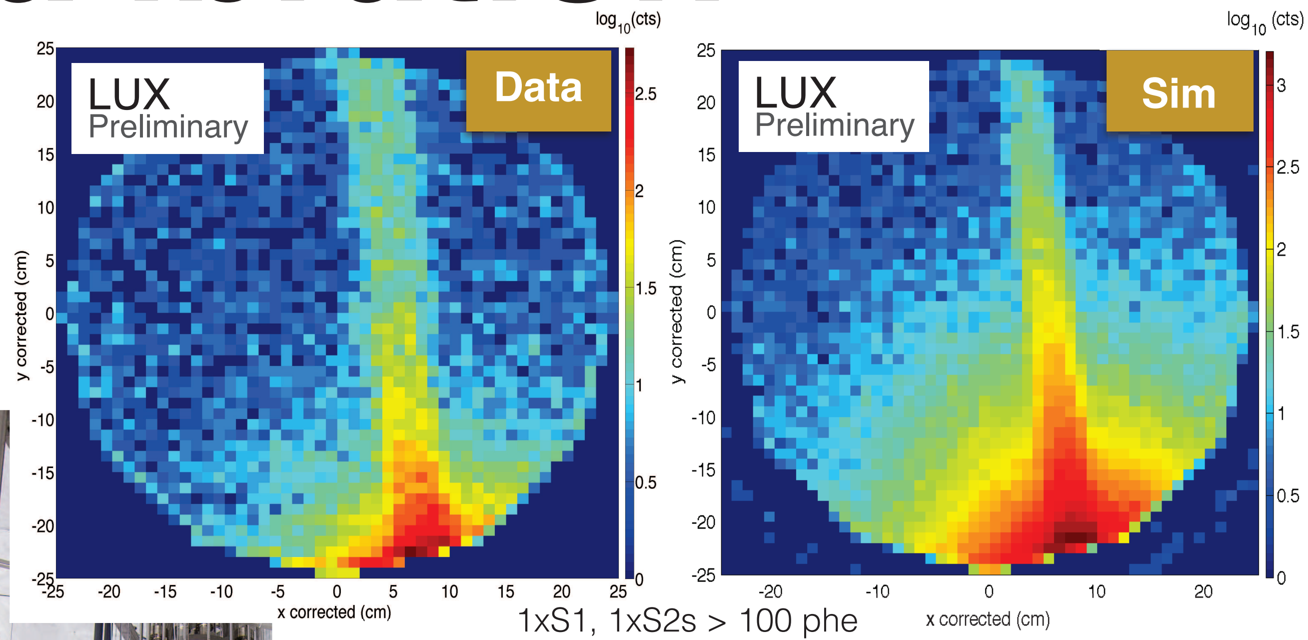




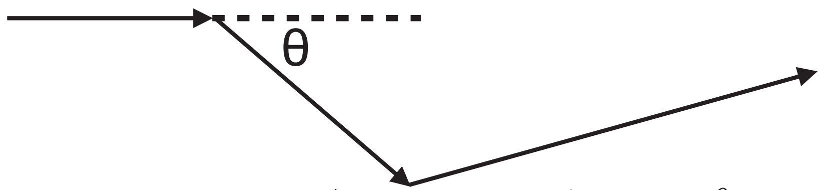
- Continuous spectrum from 0 to 18.6 keV$_{ee}$ (mean ~ 6 keV$_{ee}$, mode ~2.5 keV$_{ee}$)
- Uncomfortably long lifetime ($T_{½}$ = 12.6 years!)
- Don't just wait for it to decay. Use tritiated methane instead of pure tritium, then the getter will take it out!

LUX Calibration

- External Sources
- ^{83m}Kr
- Tritiated methane
- DD neutrons



1xS1, 1xS2s > 100 phe

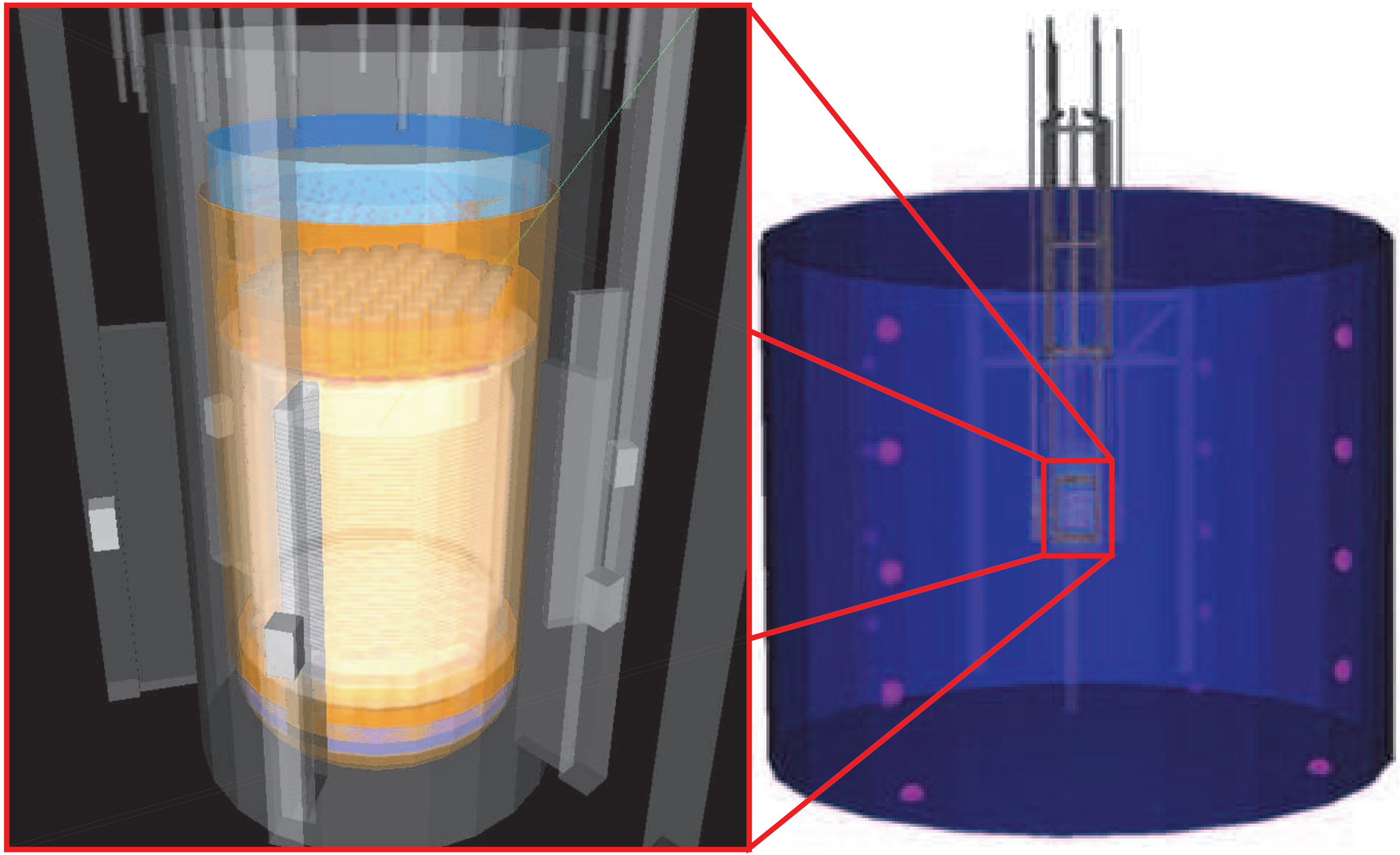


$$E_r = E_n \frac{4 m_n m_{Xe}}{(m_n + m_{Xe})^2} \frac{1 - \cos\theta}{2}$$

Mono-energetic (2.5 MeV) neutrons plus kinematic reconstruction of double scatter events allows for precise determination of nuclear recoil energy!

LUX Simulations

- LUXSim is a nice high-fidelity Geant4 Monte Carlo (*NIM-A* **675** 63)
- Incorporates “NEST” to get scintillation and ionization yields correct (*J. Inst.* **6** P10002)
- Reproduces calibration data, and can extract optical parameters



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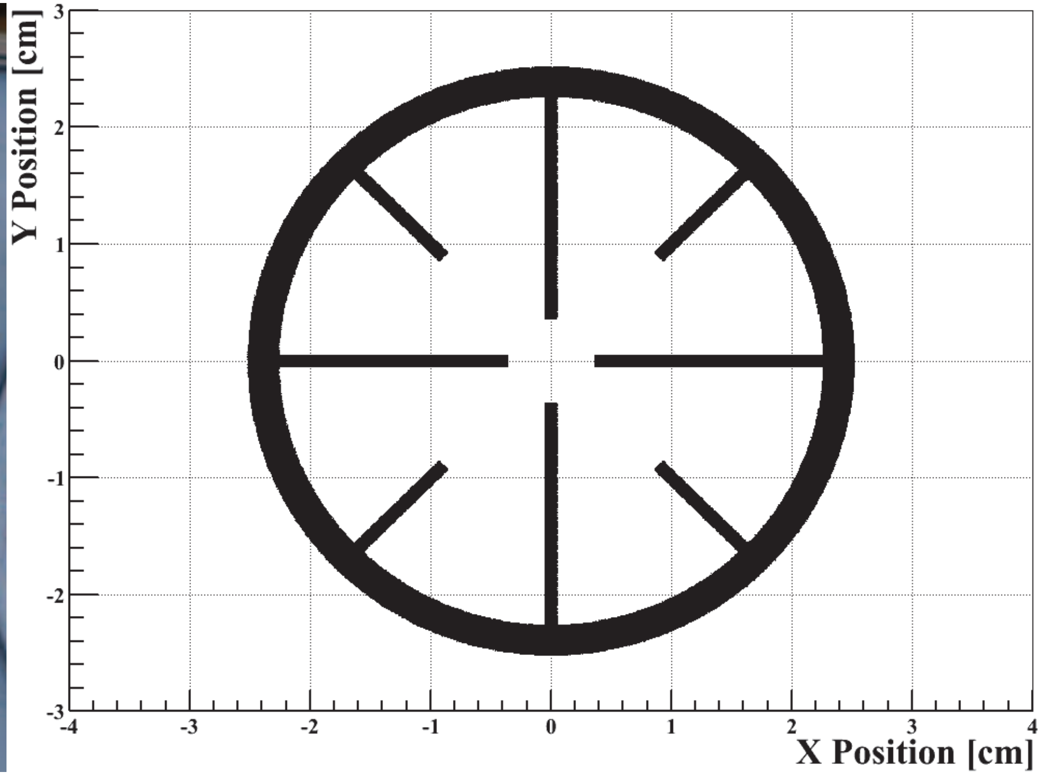

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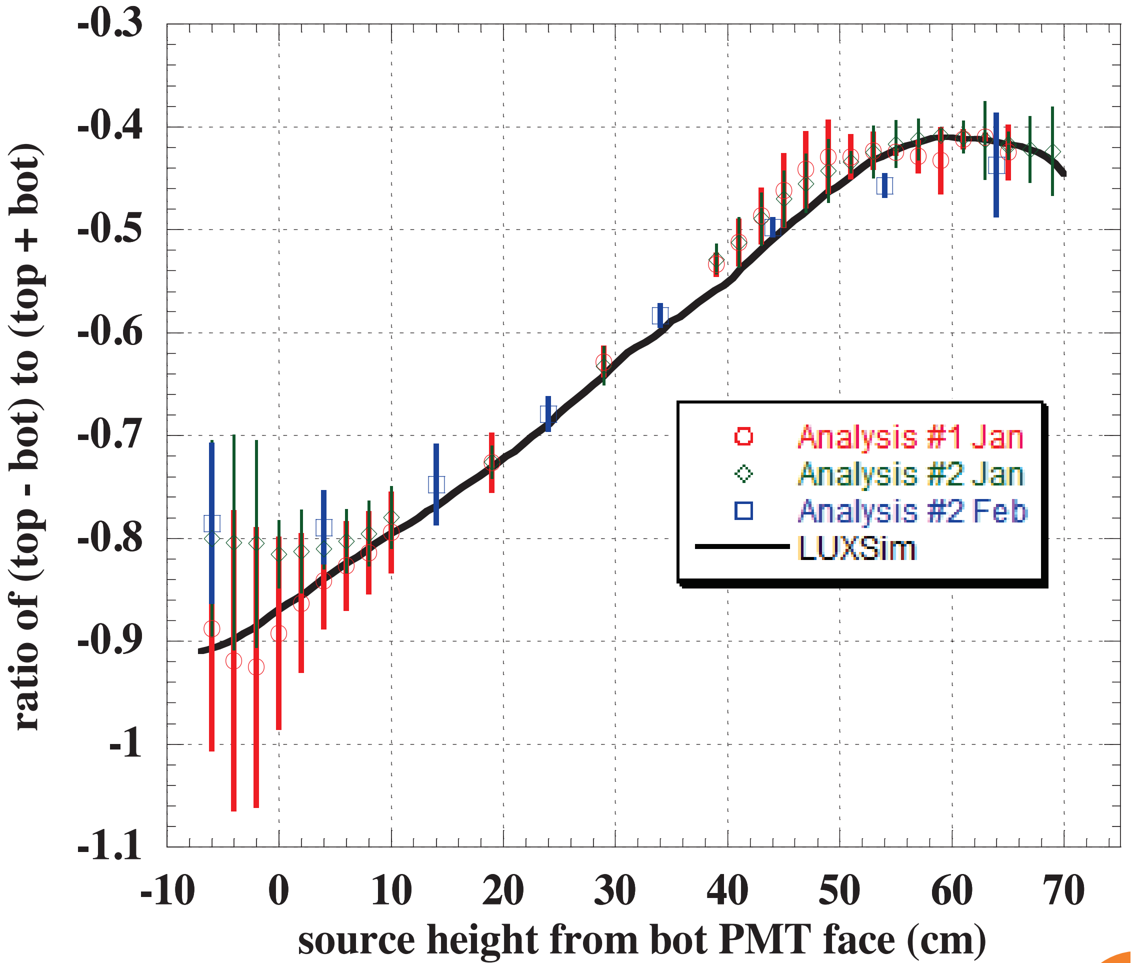
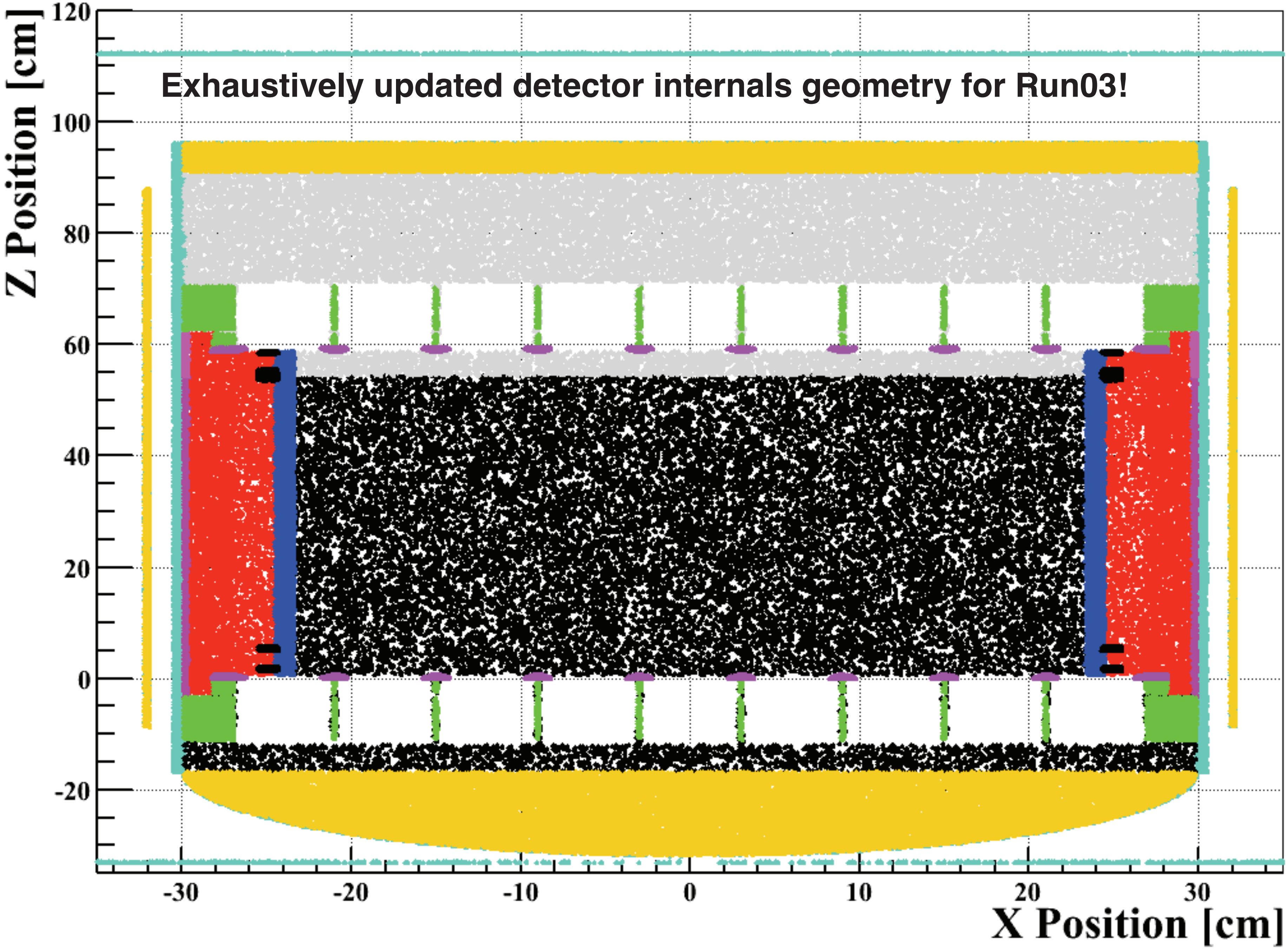
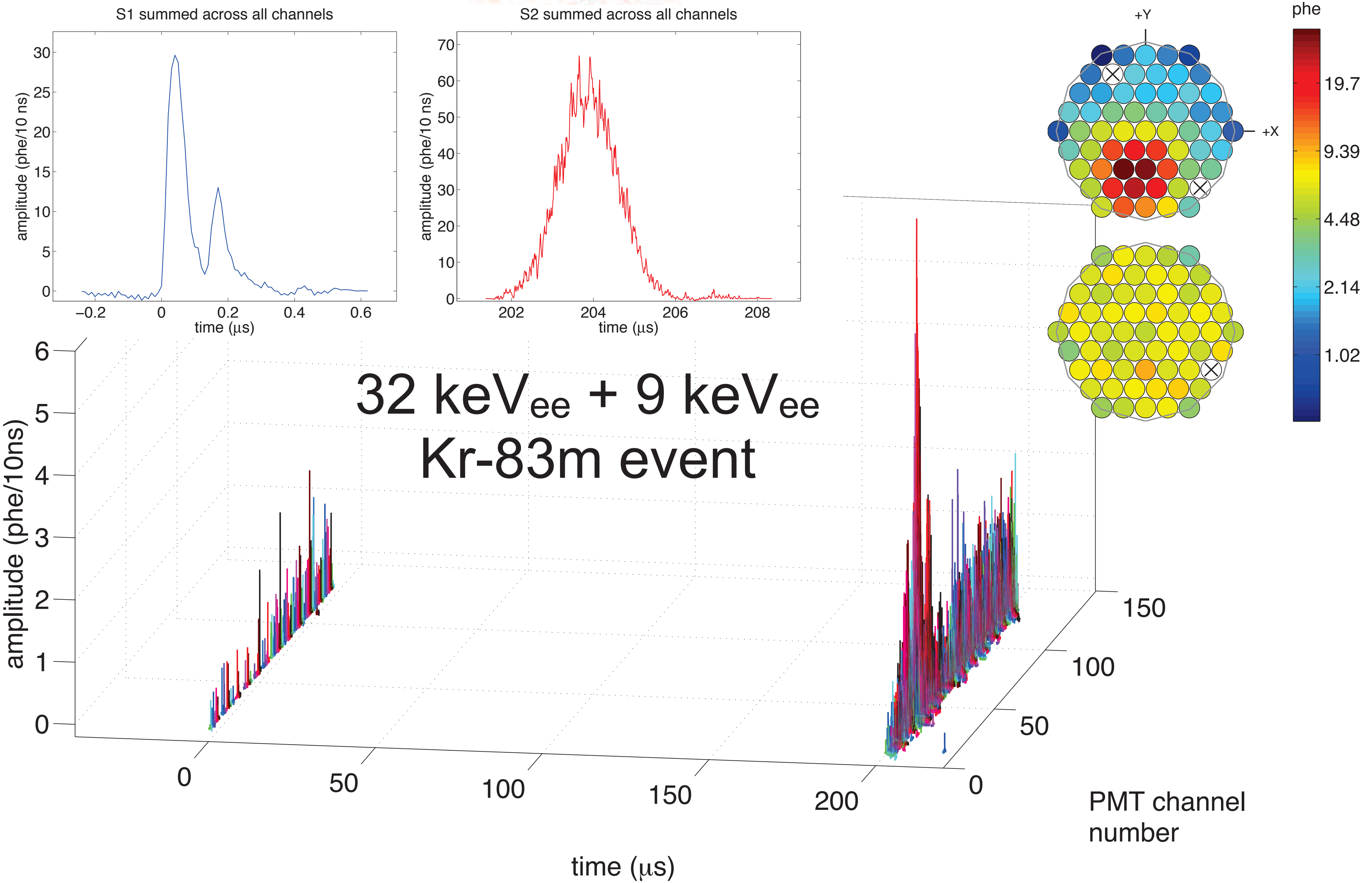


- $R_{PTFE}^{LXe} = 100\%$
- $R_{PTFE}^{GXe} = 65\%$
- $R_{grid}^{LXe} = 50\%$
- $R_{grid}^{GXe} = 10\%$
- $R_{Al}^{quartz} = 90\%$
- $\lambda_{abs}^{LXe} = 11$ m
- $\lambda_{abs}^{GXe} = 110$ m
- $\lambda_{rayl}^{LXe} = 29$ cm

Simulations

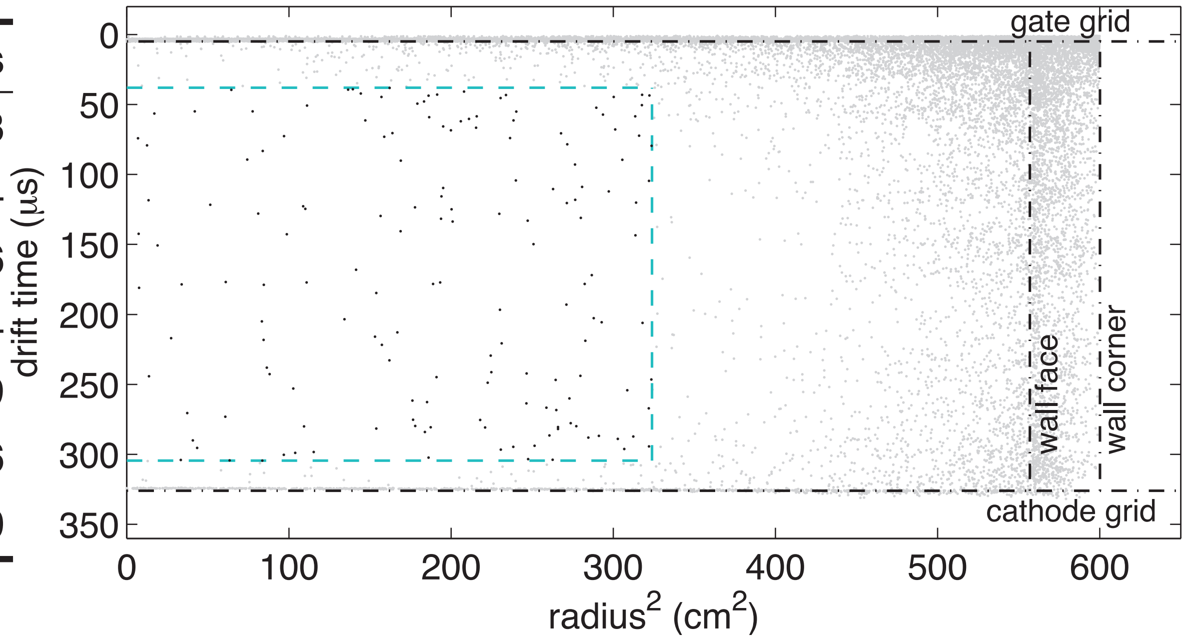


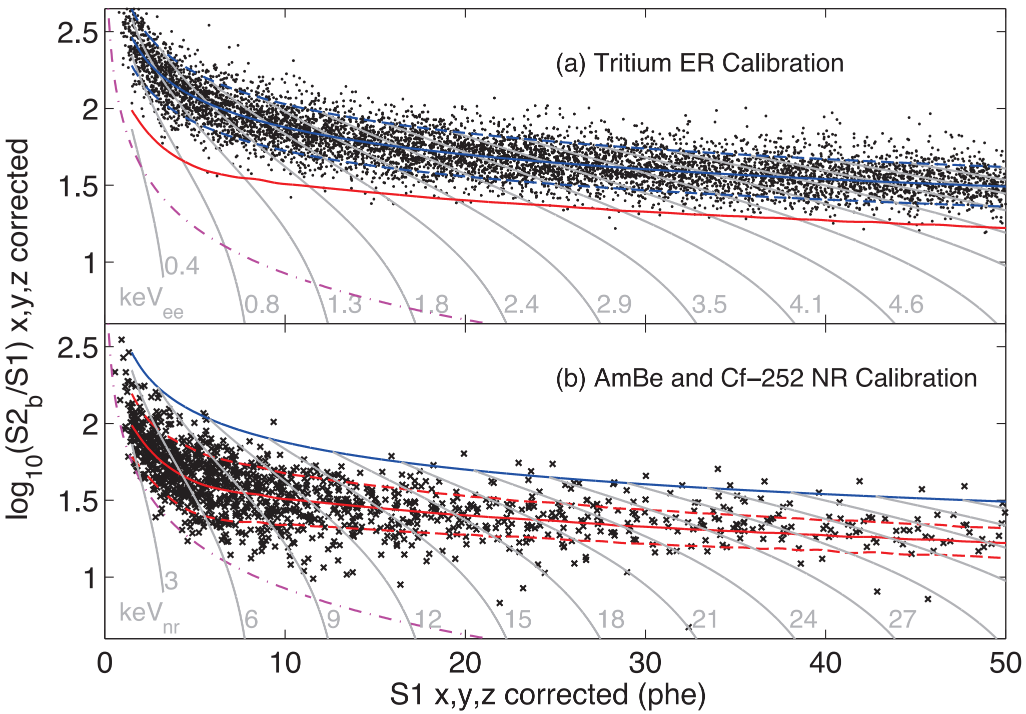
Actual LUX Waveforms

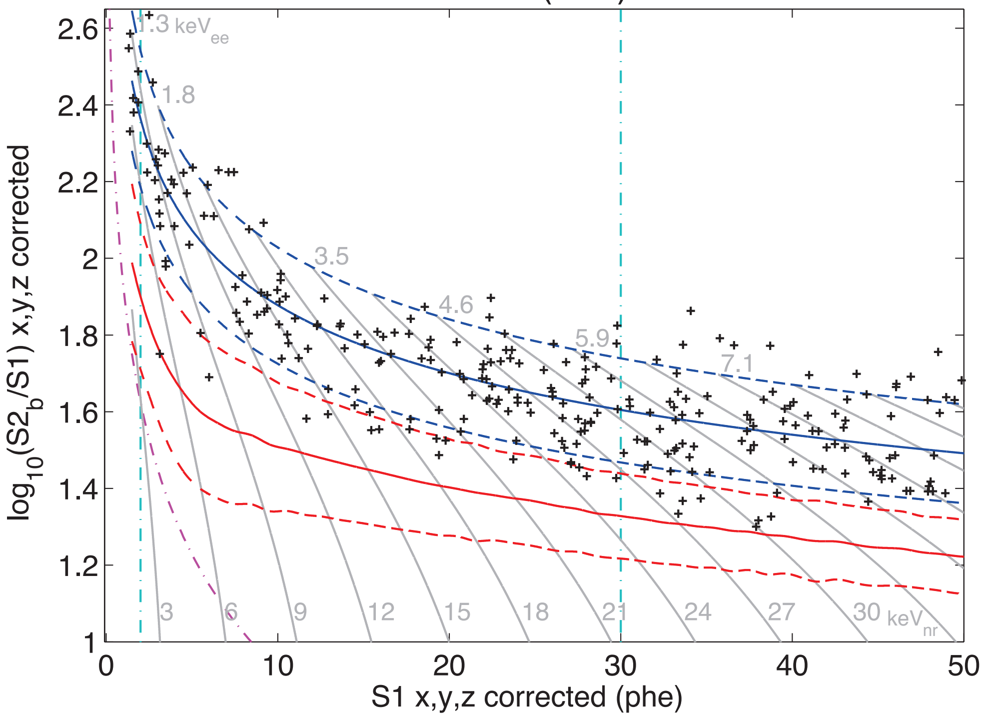


Run 03 Data

Cut	Remaining Events
All Triggers	83,673,413
Detector Stability	82,918,904
Single Scatters (1 S1 + 1 S2)	6,585,686
2 phe < S1 Area < 30 phe	26,824
200 < S2 Area < 3300 phe	20,989
Single Electons	19,796
Fiducial Volume	160







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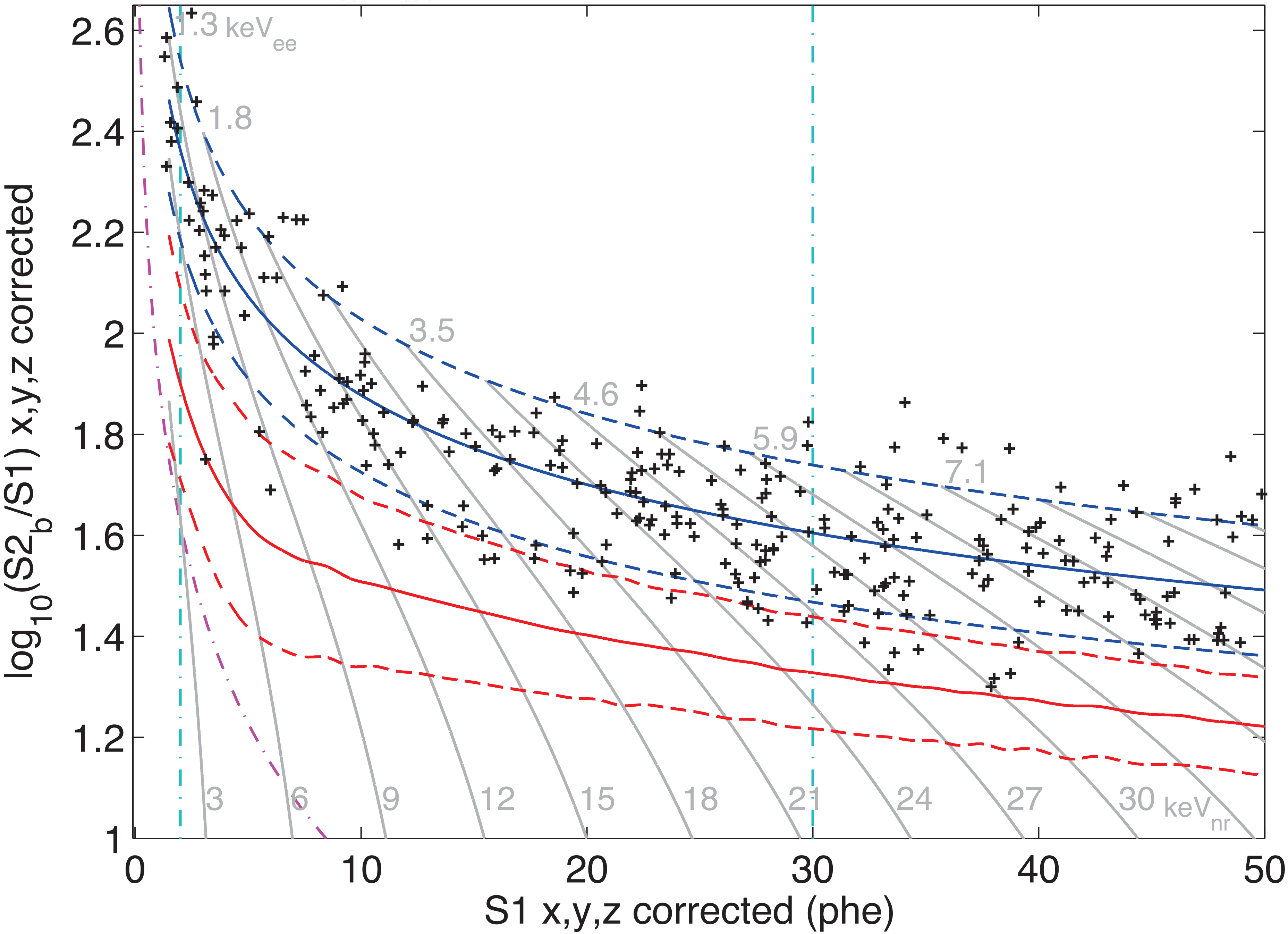
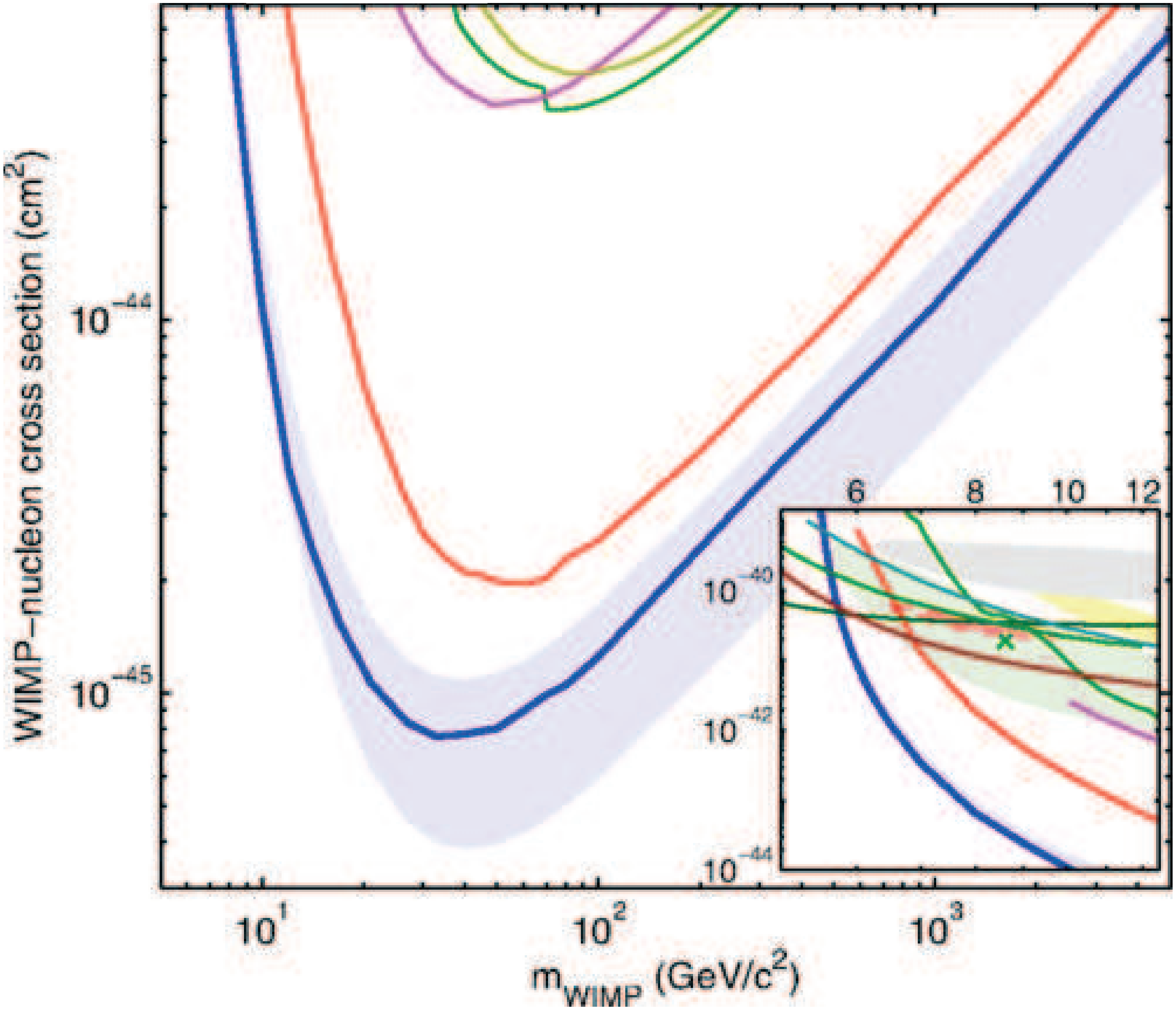


1.3 keV$_{ee}$
1.8
3.5
4.6
5.9
7.1
3
6
9
12
15
18
21
24
27
30 keV$_{nr}$
$\log_{10}(S2_b/S1)$ x,y,z corrected
S1 x,y,z corrected (phe)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
10
20
30
40
50

Run 03 Limits



LUX
EDELWEISS II
CDMS II
ZEPLIN III
CDMSlite
XENON10 (S2)
SIMPLE
XENON100
CDMS II (low thr.)

CoGeNT
CDMS II-Si
CREST II
DAMA/LIBRA

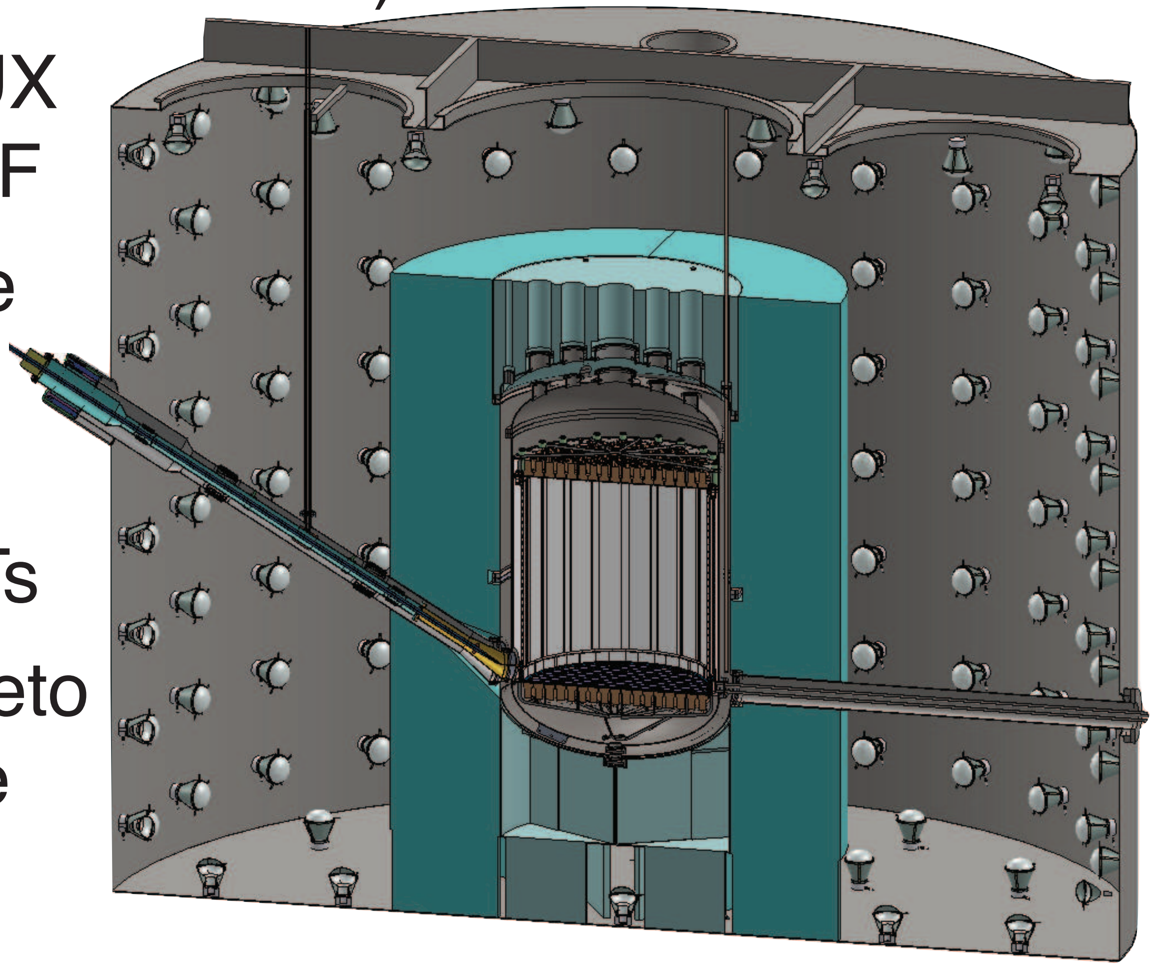
Phys. Rev. Lett. **112**, 091303

Current LUX Status

- Grid conditioning:
  - LUX ran at 181 V/cm in Run03. This was good enough, but we would like to go higher in Run04.
  - Conditioning campaign is wrapping up now.
- Revised Run03 limit with DD calibration: lower threshold means greatly enhanced sensitivity at low WIMP mass.
- Veto upgrades: PMT bias supplies now more reliable and more spare units on hand.
- Lots of papers coming soon!

LZ: Go Big!

- The LUX and ZEPLIN collaborations are joining forces for a multi-ton two-phase xenon search (“LUX” + “ZEPLIN” = “LZ” Get it?)
- 5-6 tons fiducial mass (8-9 tons total)
- Will fit into the current LUX water shield tank at SURF
- More sophisticated active veto system
    - Xe outside field cage instrumented with PMTs
    - Add liquid scintillator veto (outside cryostat inside shield)



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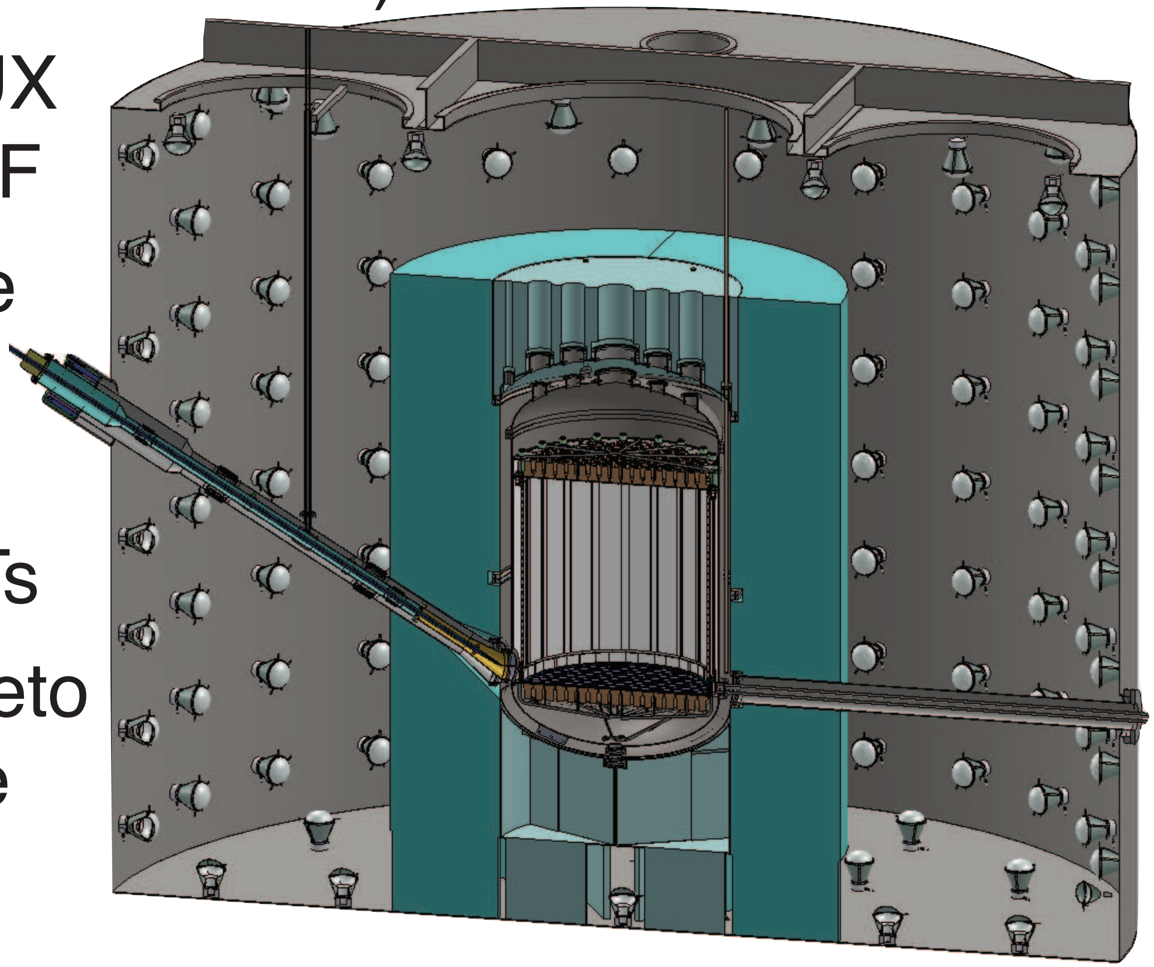
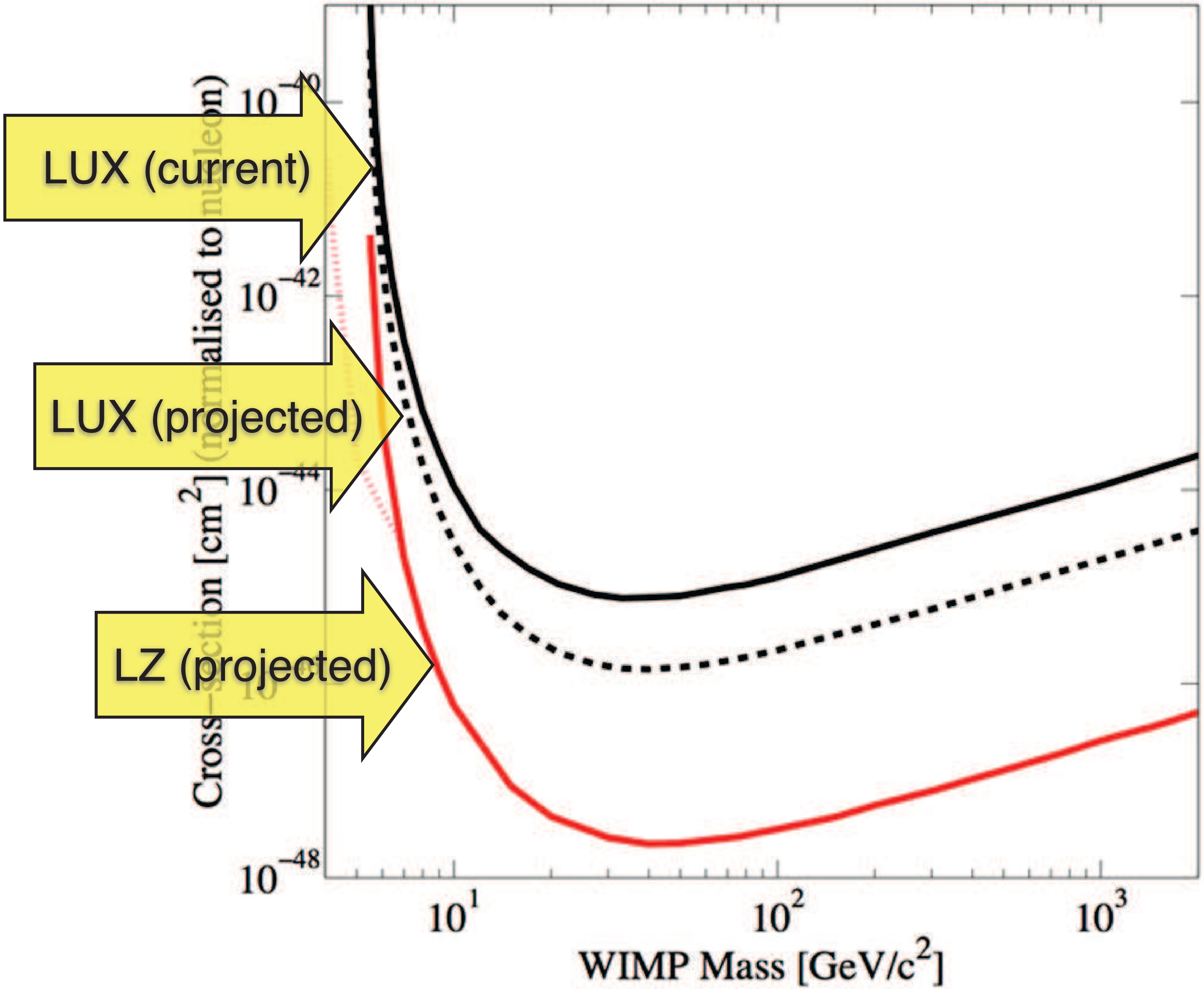
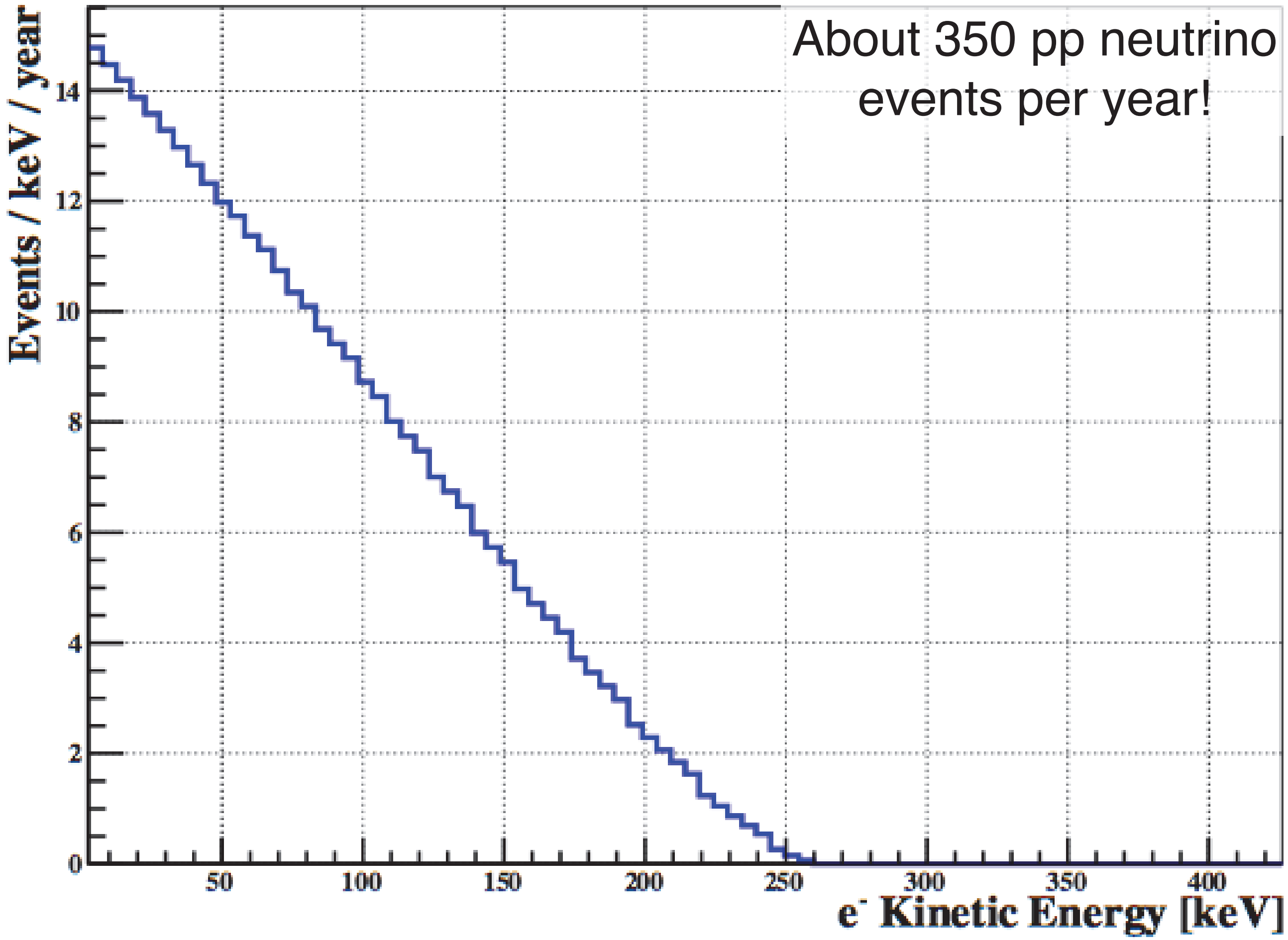


Some Sensitivity Plots!



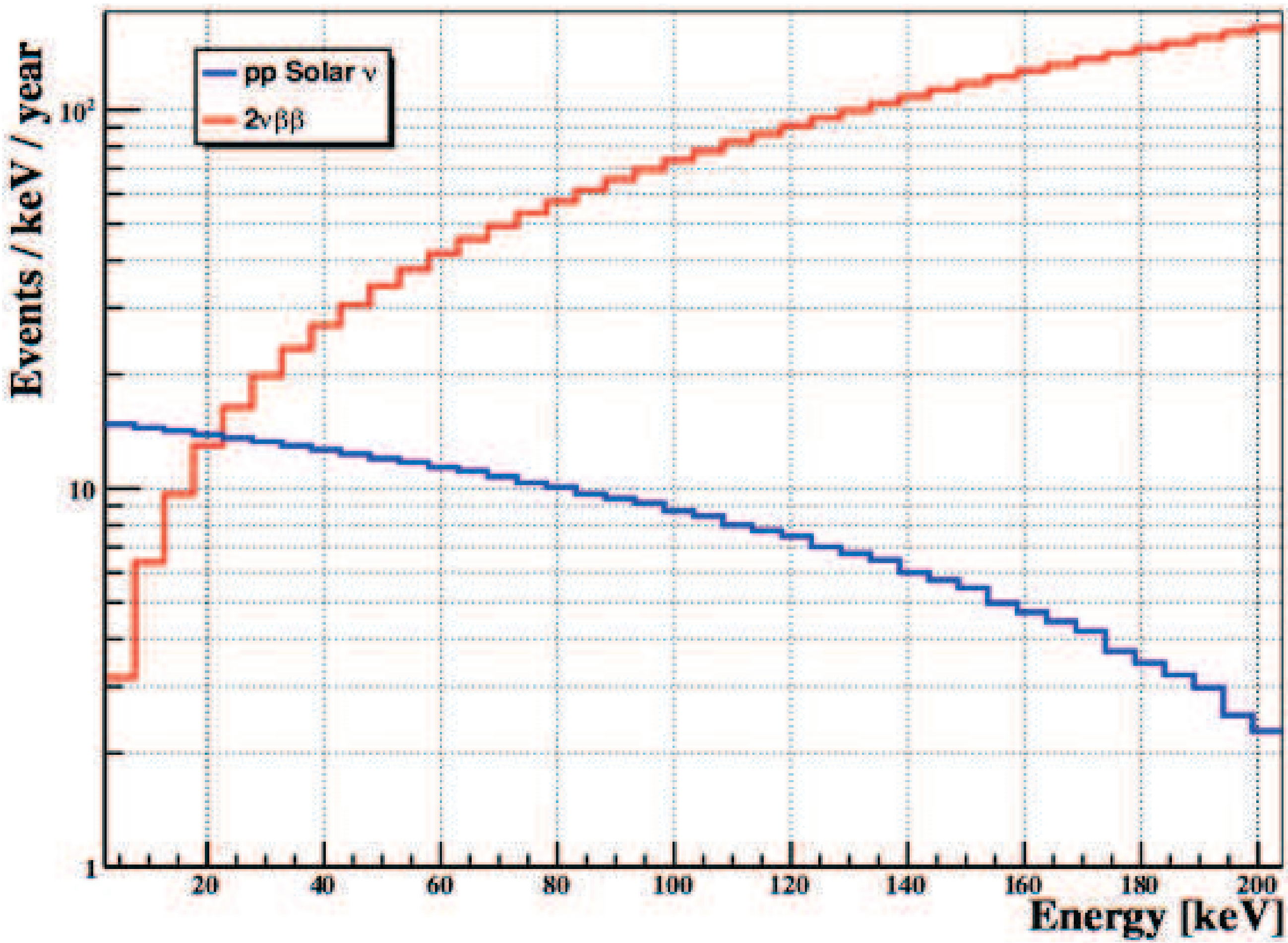
Other Physics with LZ

- Low-energy solar neutrinos?
- $2\nu\beta\beta$ is actually a background... How many $2\nu\beta\beta$ events will slip through the NR/ER rejection in to the dark matter signal box?
- Can we get some physics out of the $2\nu\beta\beta$ shape?



Other Physics with LZ

- Low-energy solar neutrinos?
- 2νββ is actually a background... How many 2νββ events will slip through the NR/ER rejection in to the dark matter signal box?
- Can we get some physics out of the 2νββ shape?



Other Physics with LZ

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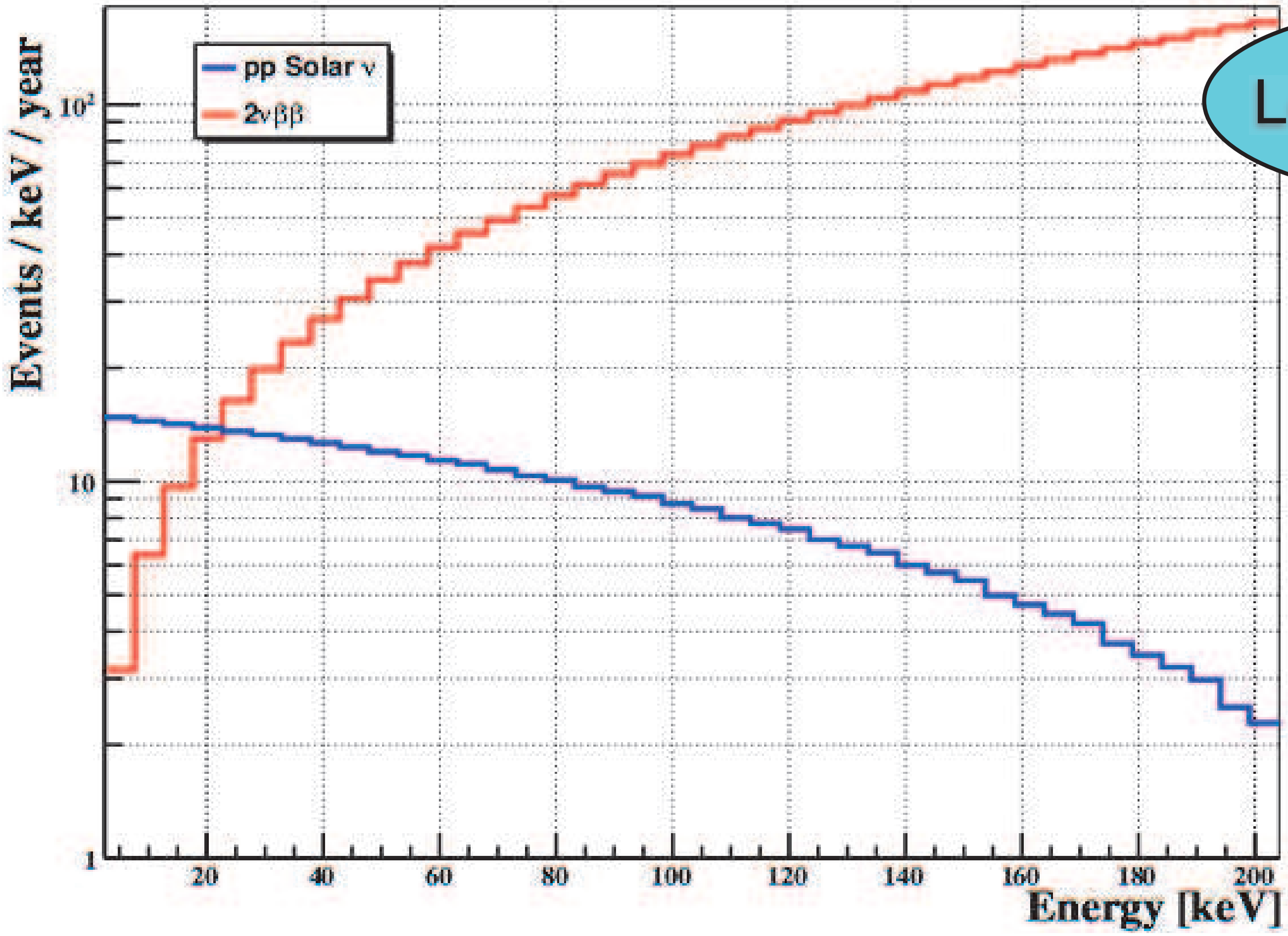

Less than 0.1

Conclusions

- The LUX experiment has been a huge success so far!
  - Current sensitivity is better than 10^{-45} cm^2
  - Roughly an order of magnitude is coming soon
- Lots of new papers are in the pipeline:
  - Spin/momentum-dependent limits,
  - Axions,
  - Halo/astrophysics-independent limits
  - S2-only
  - Revised Run03 limit with absolute nuclear recoil calibration (from DD data)
- LUX is helping to explore the frontier of dark matter detection, and these are really exciting times!


Thank you for your attention!
Any questions?