Imperial College London

WIMP SEARCHES WITH LIQUID XENON: LUX AND LZ

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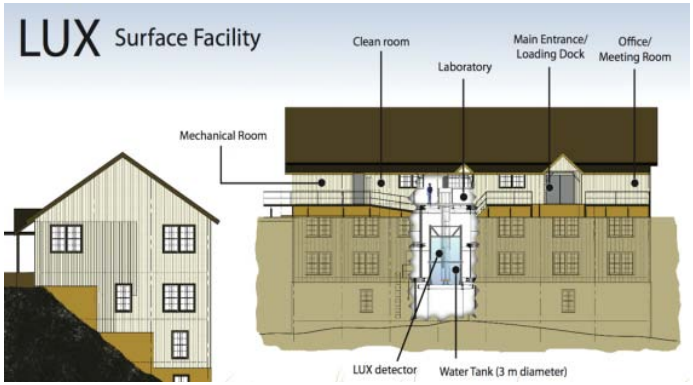
IOP HEPP/APP MEETING, LIVERPOOL, APRIL 2013

ZEPLIN → LUX → LUX-ZEPLIN (LZ)

- UK-led **ZEPLIN** programme at Boulby completed (2001-2011)
  - **Pioneering xenon technology, world class results from 3 experiments**
- MOU between ZEPLIN-III and LUX groups signed in 2008
- **LUX** tested on the surface at Sanford Lab (Homestake), now including UK
- Underground commissioning under way, first physics in 2013



- **LZ** project following 'G2 down-selection' process in the US (and similar in UK)
  - One of 4 WIMP experiments selected by DOE to progress to R&D/Design
  - Coordinated proposals to DOE/NSF – and hopefully STFC – in late 2013
  - Construction planned to start late 2014, commissioning from 2016/7

COLLABORATING INSTITUTES (US-UK-PT)

ZEPLIN-III

Edinburgh University ⌑ Imperial College London ⌑ LIP-Coimbra ⌑ Rutherford Appleton Laboratory ⌑ ITEP-Moscow

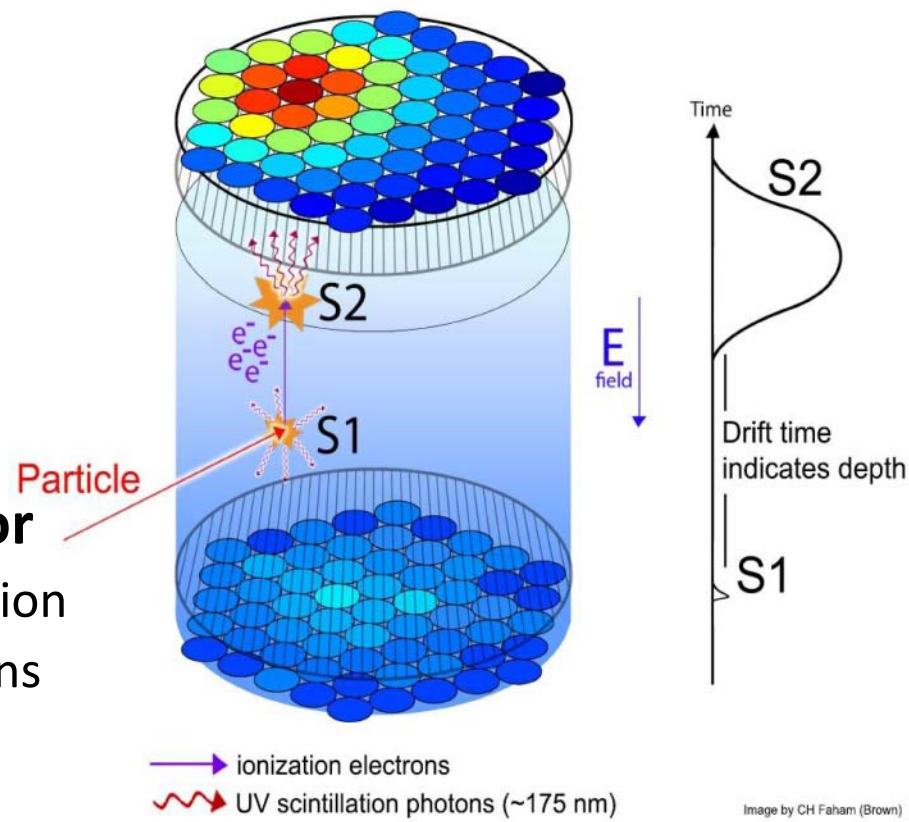
Brown University ⌑ University of California, Berkeley ⌑ University of California, Davis ⌑ University of California, Santa Barbara ⌑ Case Western Reserve University ⌑ Edinburgh University ⌑ Imperial College London ⌑ Lawrence Berkeley National Laboratory ⌑ Lawrence Livermore National Laboratory ⌑ LIP-Coimbra, Portugal ⌑ University of Maryland ⌑ University of Rochester ⌑ South Dakota School of Mines & Technology ⌑ University of South Dakota ⌑ Texas A&M University ⌑ University College London ⌑ Yale University

LZ

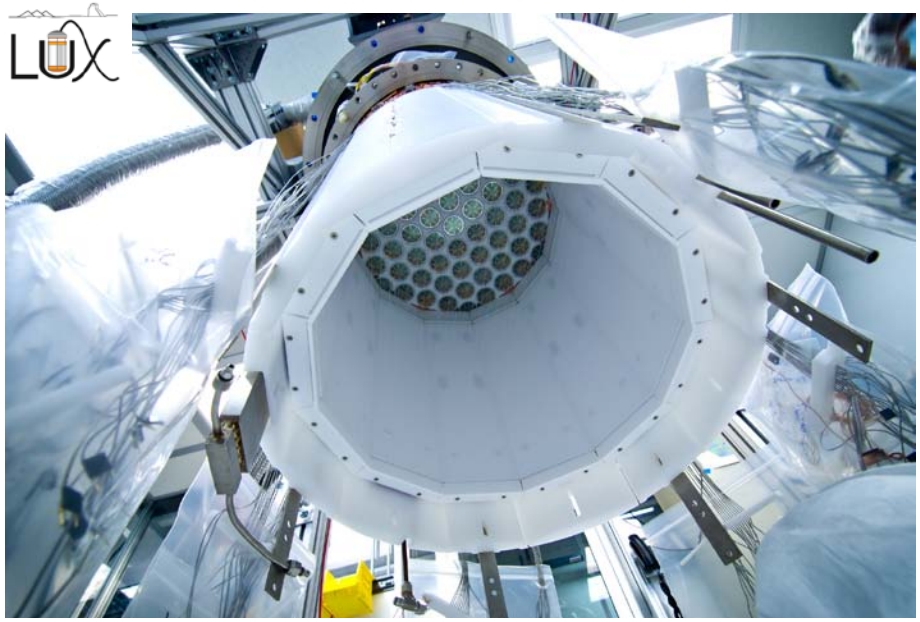
= LUX + University of Alabama ⌑ Daresbury Laboratory ⌑ Rutherford Appleton Laboratory ⌑ SLAC National Accelerator Laboratory ⌑ University of Wisconsin

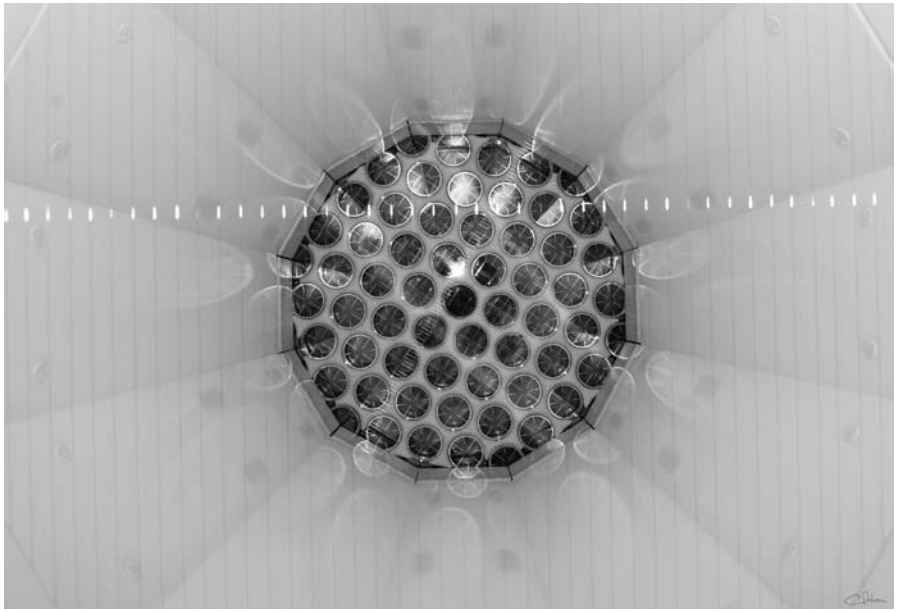
TWO-PHASE XENON DETECTORS

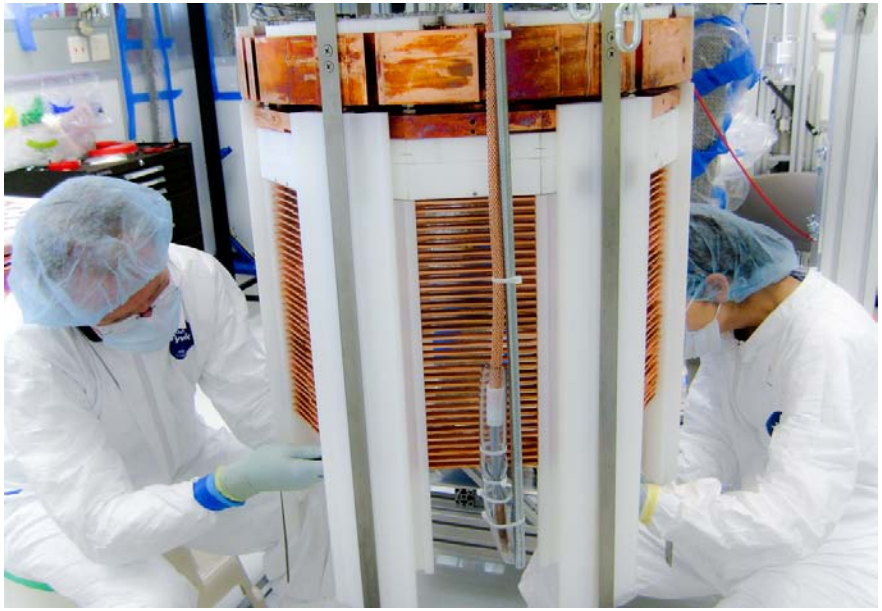
- **S1: LXe is an excellent scintillator**
  - Density: 3 g/cm^3
  - Light yield: >60 ph/keV (0 field)
  - Scintillation light: 178 nm (VUV)
  - **Nuclear recoil threshold ~5-10 keV**
- **S2: Even better ionisation detector**
  - S1+S2 allows mm vertex reconstruction
  - Sensitive to single ionisation electrons
  - **Nuclear recoil threshold ~1 keV**

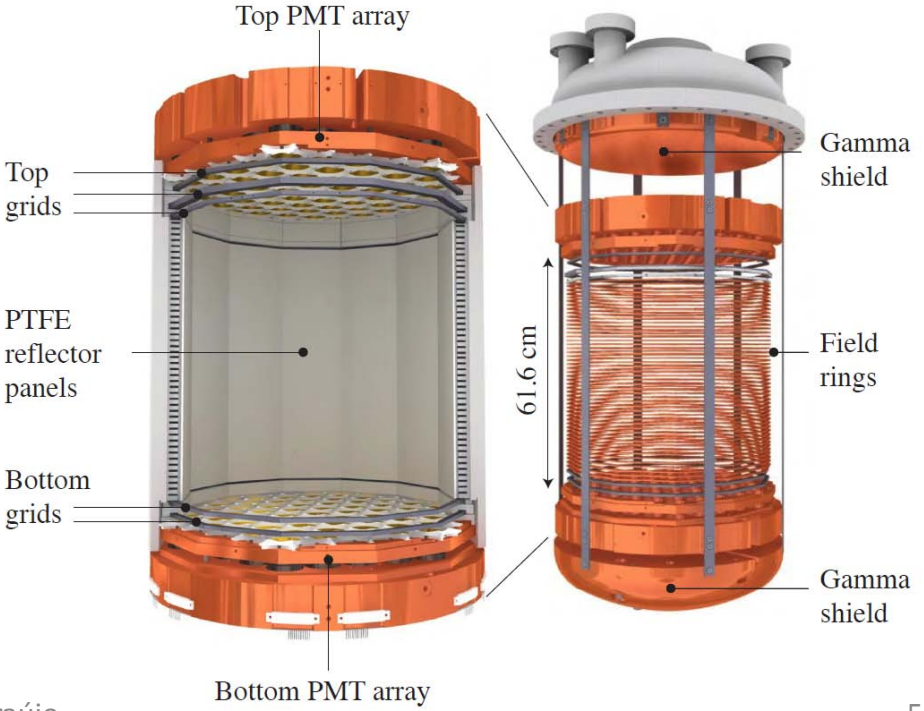


- **And a great WIMP target too**
  - Scalar WIMP-nucleon scattering rate dR/dE~A^2
  - Odd-neutron isotopes (^{129}Xe, ^{131}Xe) enable spin-dependent sensitivity
  - Excellent ionisation threshold: 'light WIMP' searches using S2 only
  - No intrinsic backgrounds (^{85}Kr can be removed, low rate from ^{136}Xe $2\nu\beta\beta$)

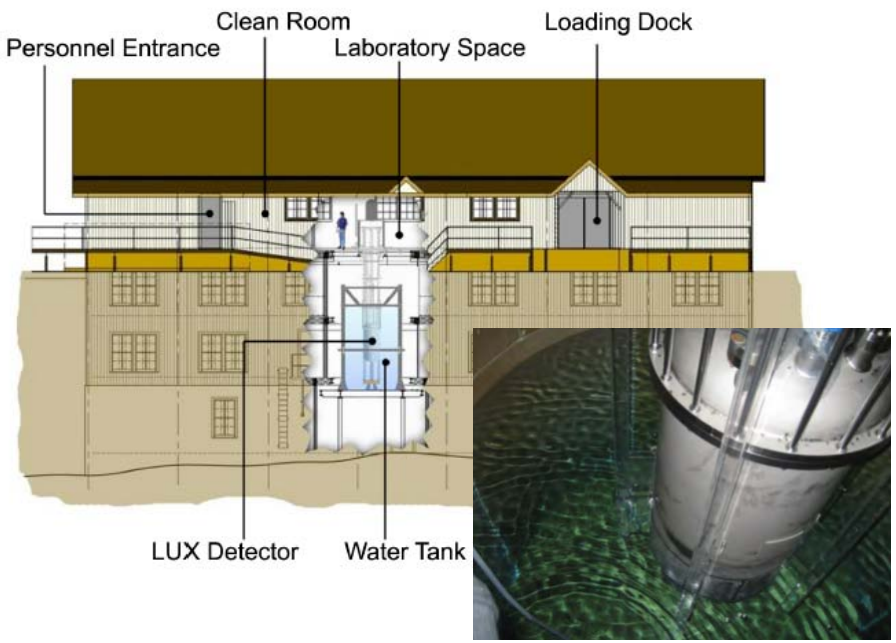


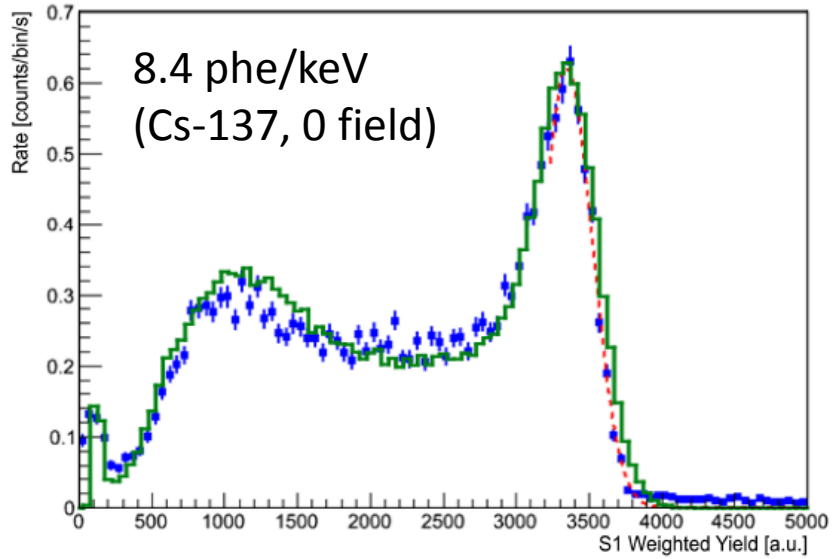


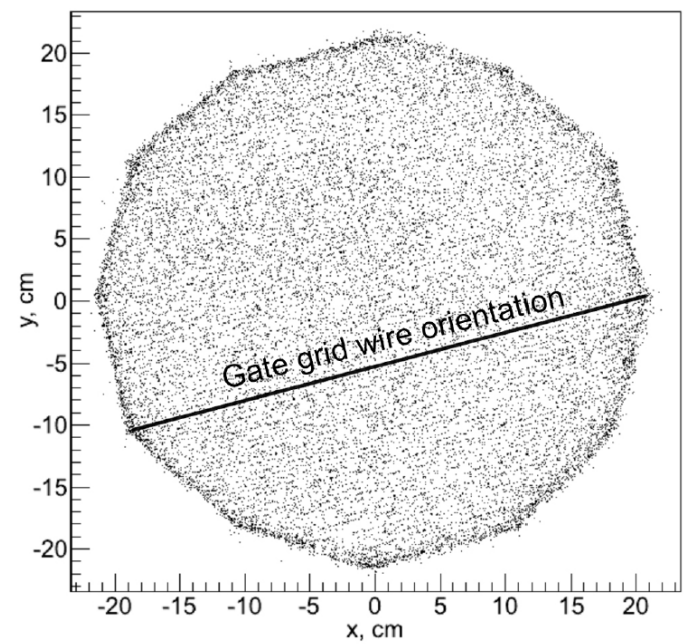



Top PMT array
Top grids
PTFE reflector panels
Bottom grids
Bottom PMT array
61.6 cm
Gamma shield
Field rings
Gamma shield

ENGINEERING RUN IN SURFACE LAB





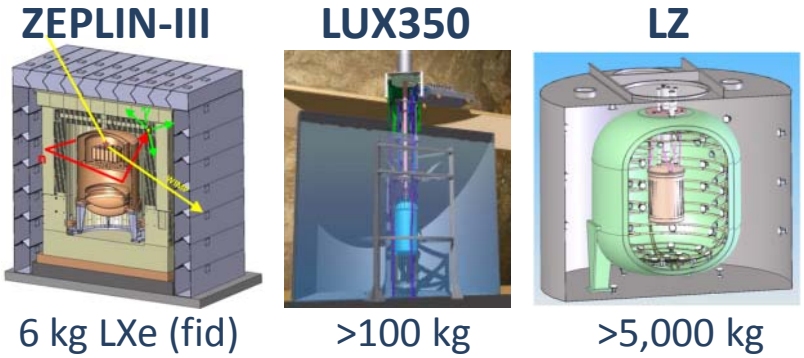


- Operation in purpose-build water tank
- Demonstrated performance of most sub-systems
- Excellent light yield: 2.5x that of XENON100
- 3D position reconstruction: mm resolution (x,y)

Akerib *et al*, NIM A 704: 111 (2013)
Akerib *et al*, arXiv: 1210.4569 (2013)

LUX detector in shielding water tank, 1.5 km underground at Sanford Lab (Homestake)

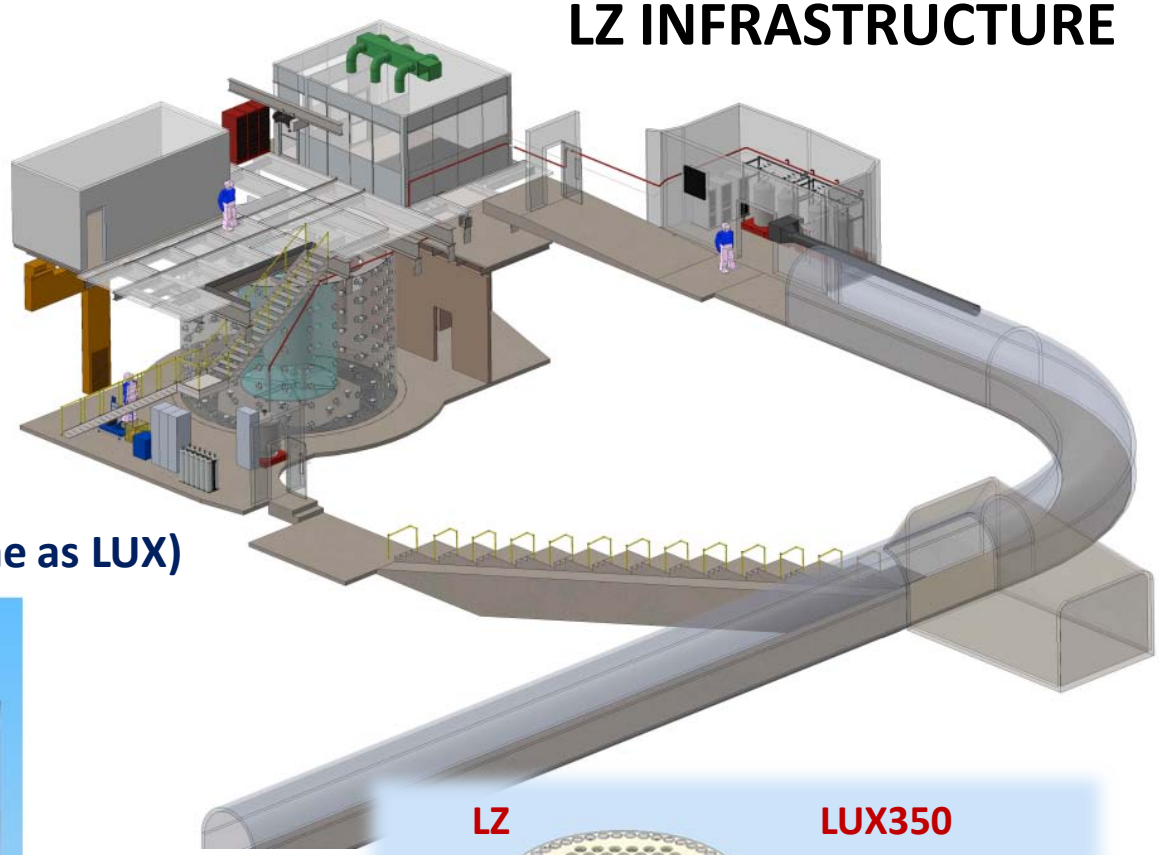
LUX-ZEPLIN (LZ)



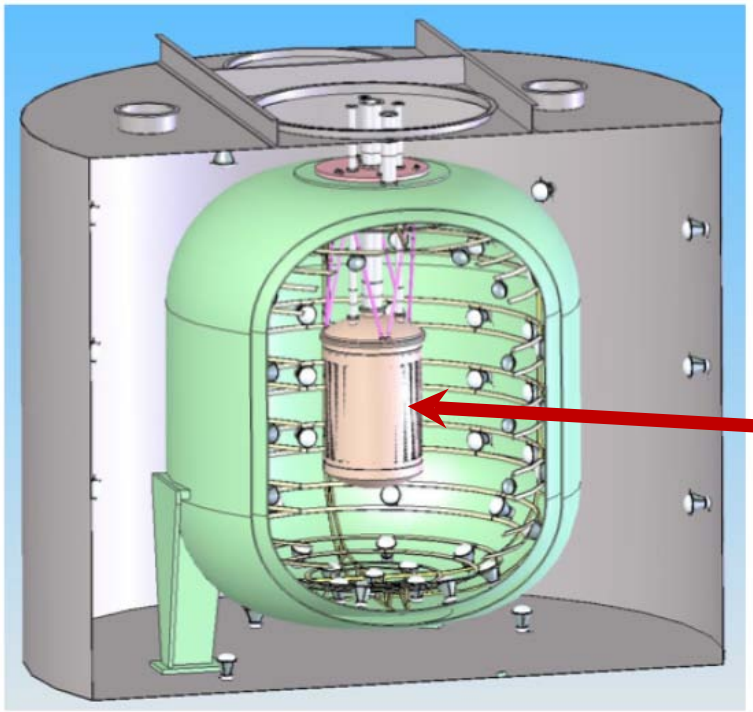
Next-generation LXe experiment building on LUX and ZEPLIN programmes

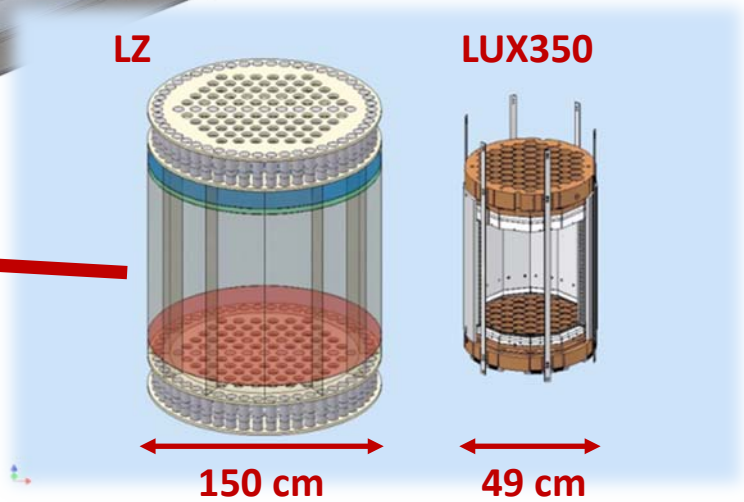
- **Route to detection & study: a <u>progressive</u> programme**
  - UK-led **ZEPLIN** programme pioneered liquid xenon for WIMP searches
  - **LUX** (now with UK) about to turn on – expect leading sensitivity in 2013
  - **LZ** could discover at 10^{-11} pb or exclude at 10^{-12} pb with 3 year run
- **Experimental approach: a <u>low risk</u> and <u>aggressive</u> programme**
  - Internal bk-free strategy (self-shielding, modest discrimination assumed)
  - Two-phase Xe technology: high readiness level (ZEPLIN, XENON, LUX)
  - Team with huge track record in DM searches
  - Much infrastructure inherited from LUX350
- **LXe provides exciting physics for light & heavy WIMPs (GeV-TeV)**
  - Since we do not yet know what BSM physics looks like!

SANFORD LAB, DAVIS COMPLEX (4850-ft)
LZ INFRASTRUCTURE

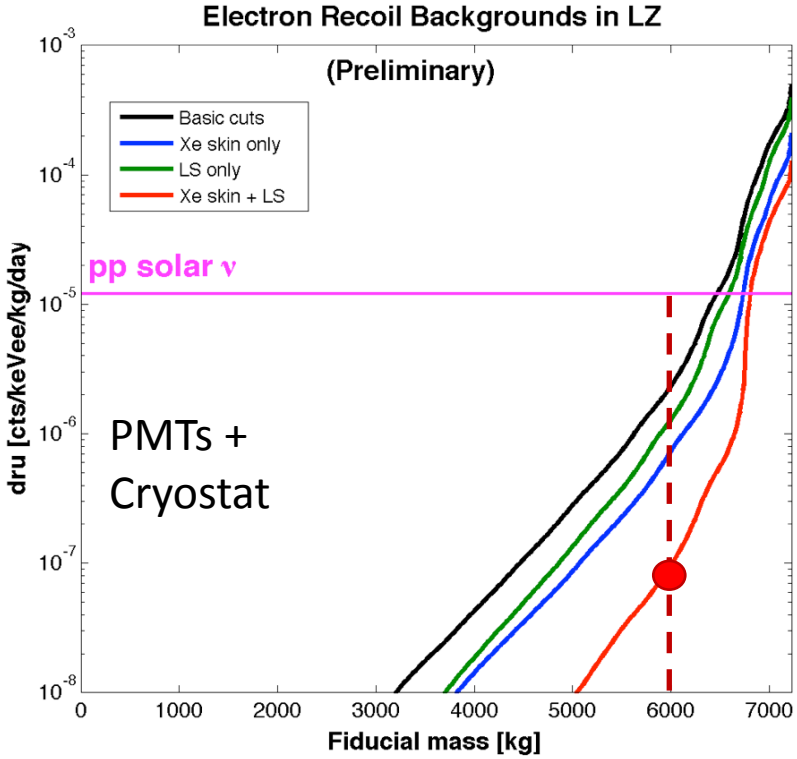


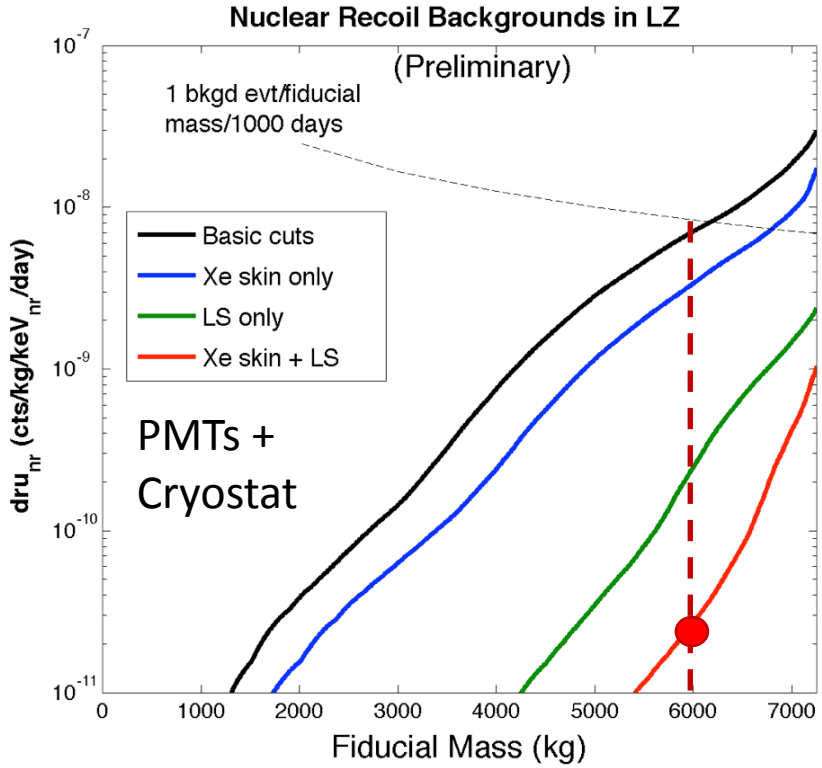
- 7 tonne LXe TPC (~9t total LXe)
- Only 20-fold scale-up from LUX
- But >100x increase in sensitivity
- Layered veto strategy
  - Instrumented LXe Skin detector
  - Liquid scintillator Veto detector
  - Instrumented water shield (same as LUX)





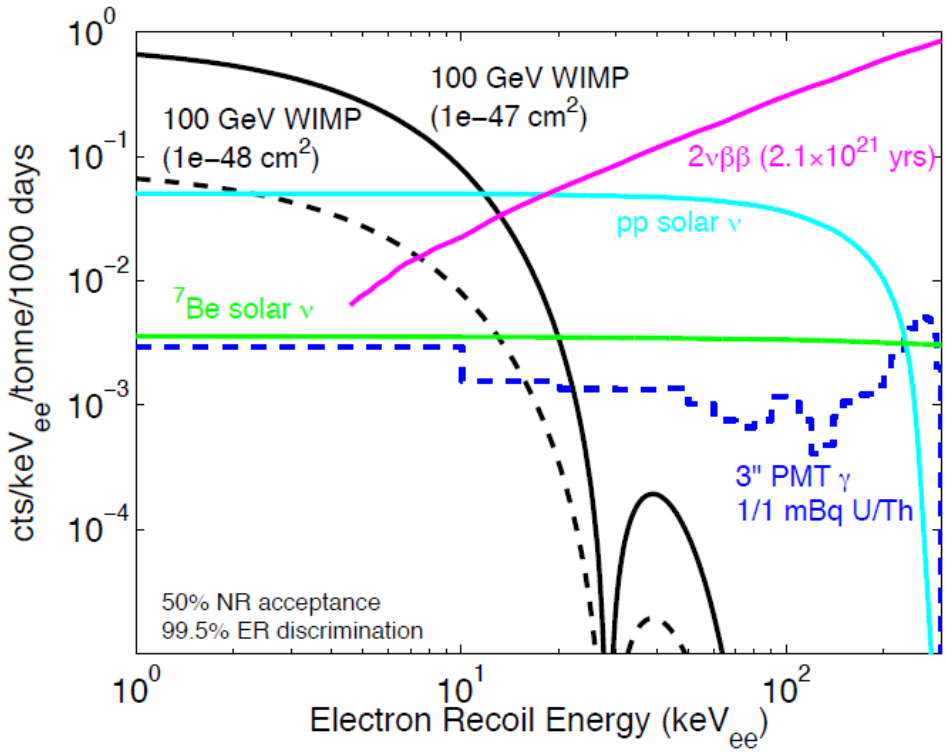
IMPORTANT LZ BACKGROUNDS

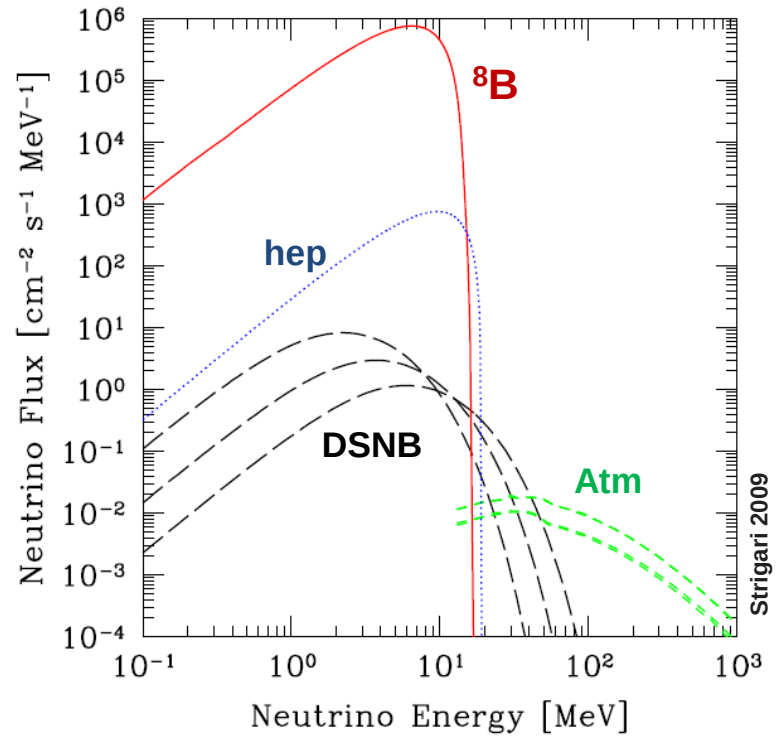




- **Internal radioactivity neutrons, gamma-rays:** sub-dominant in >6-tonne fiducial
  - Self-shielding and accurate 3D position reconstruction are extremely effective
- **Intrinsic electron backgrounds:** controlled with modest discrimination (99.5%)
  - **^{85}Kr:** require ~0.02 ppt Kr, but could live with ~0.2 ppt (best LUX production batch)
  - **Radon**: require 0.6 mBq (^{214}Pb) in full active volume (cf. ~μBq in Borexino, SNO)
  - **2νββ decay from ^{136}Xe** dominates only above ~20 keVee (signal acceptance <10 keVee)

DOMINANT LZ BACKGROUNDS

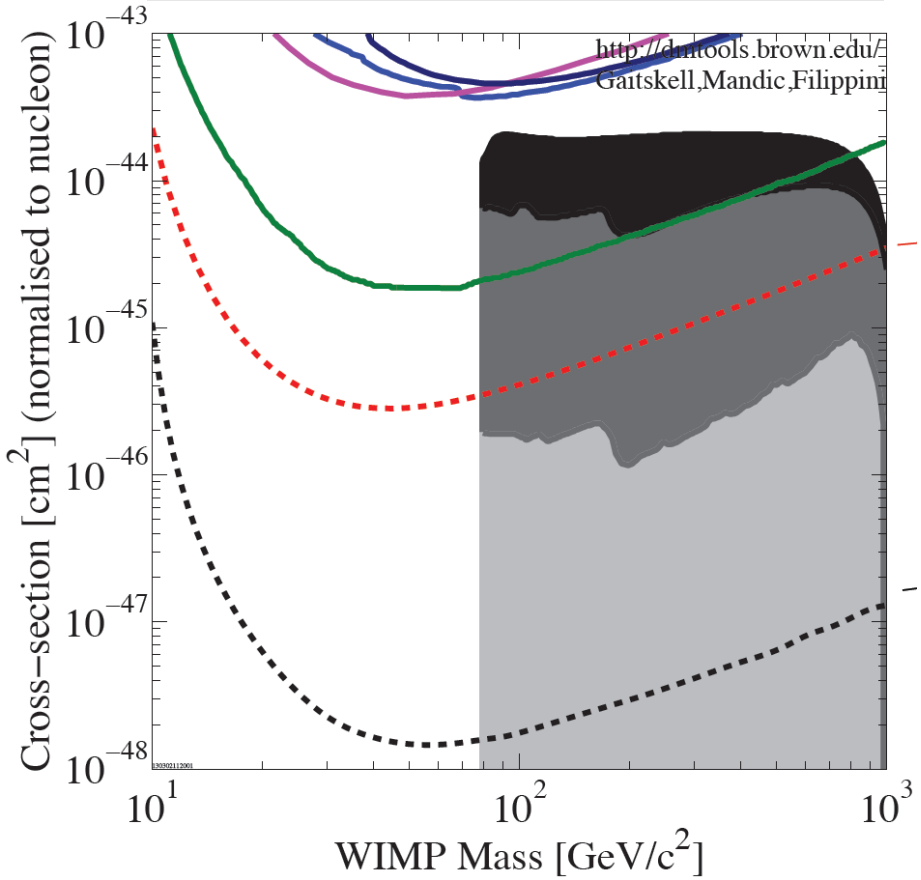




- **Solar pp ν-e elastic scattering is dominant electron recoil background**
  - Requires 99.5% discrimination (achieved in XENON10; ZEPLIN-III reached 99.99% at high field)
- **Coherent neutrino-nucleus scattering is dominant nuclear recoil background**
  - From ^{8}B solar neutrinos: significant number of events, but ~0 above 5 keVr
  - Small background from Atmospheric and Diffuse Supernova neutrinos (<0.5 evts in ROI)
- LZ will push WIMP sensitivity down to the astrophysical neutrino window

CONCLUSION

Here lie many other experiments (and theories) going back 25 years!



- **ZEPLIN-III, CDMS-II, EDELWEISS-II**
  Technology development
  Competitive experiments at 10 kg scale
- **XENON100 – present world's best**
  62 kg active two-phase xenon
- **LUX**
  300 kg fully active LXe, 370 kg total
  Operations underway, through to 2015
- **LZ**
  7 tonnes fully active, 9 tonnes total
  Start 2017
  To boldly go where nobody's been…
  (and faster!)