Dark Matter Experiments

Hans Kraus, Oxford

UK Focus:

LZ (LUX-ZEPLIN)	Edinburgh, Imperial, Liverpool, Oxford, STFC-RAL, Sheffield, STFC-Daresbury, UCL

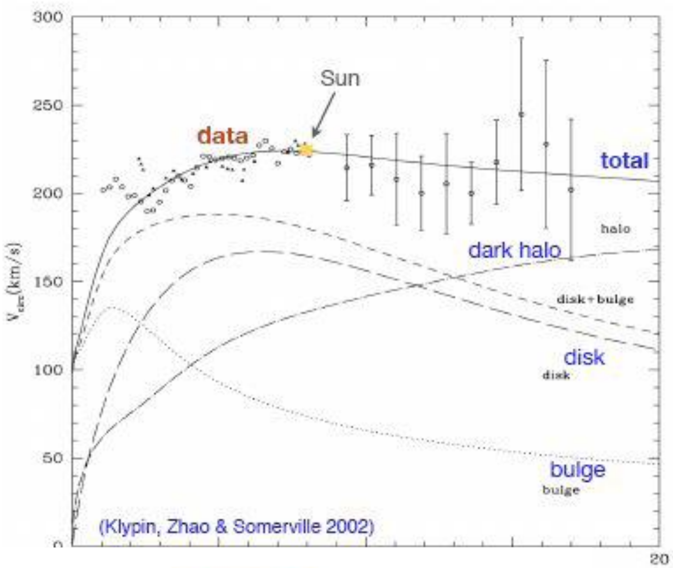
And:

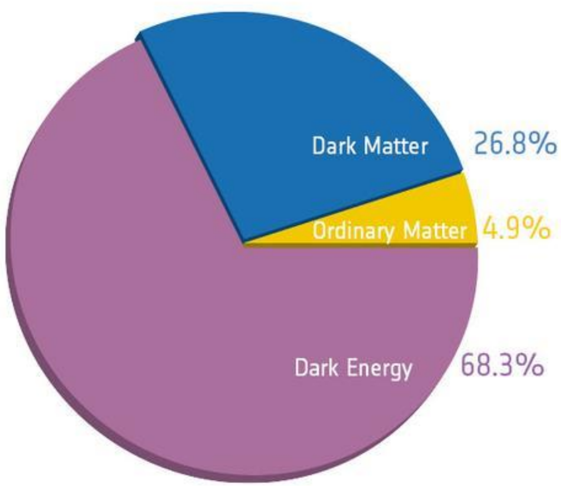
DEAP-3600	RHUL, STFC-RAL, Sussex
DRIFT	Edinburgh, Sheffield, STFC-Boulby

The Key Science Question

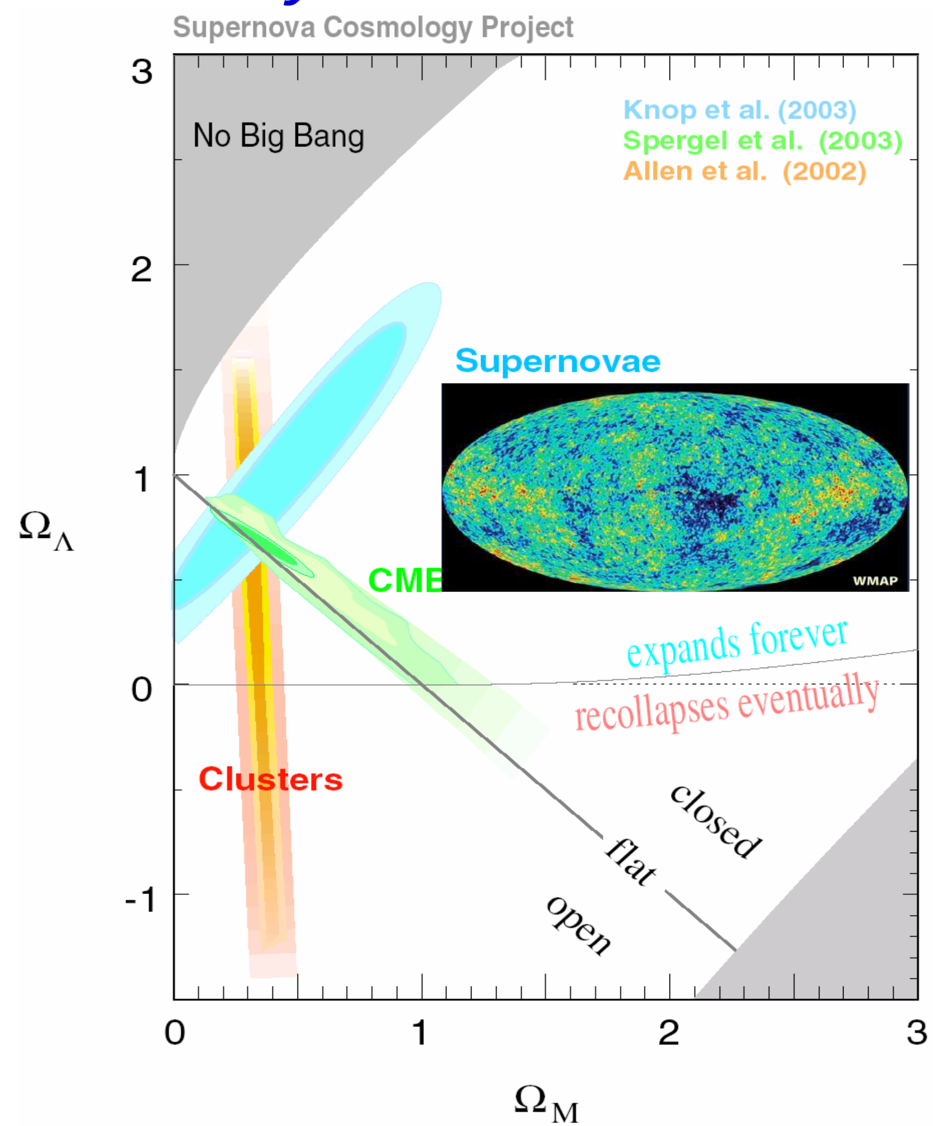
Strong evidence for the existence of Dark Matter

Obvious Link to LHC Physics





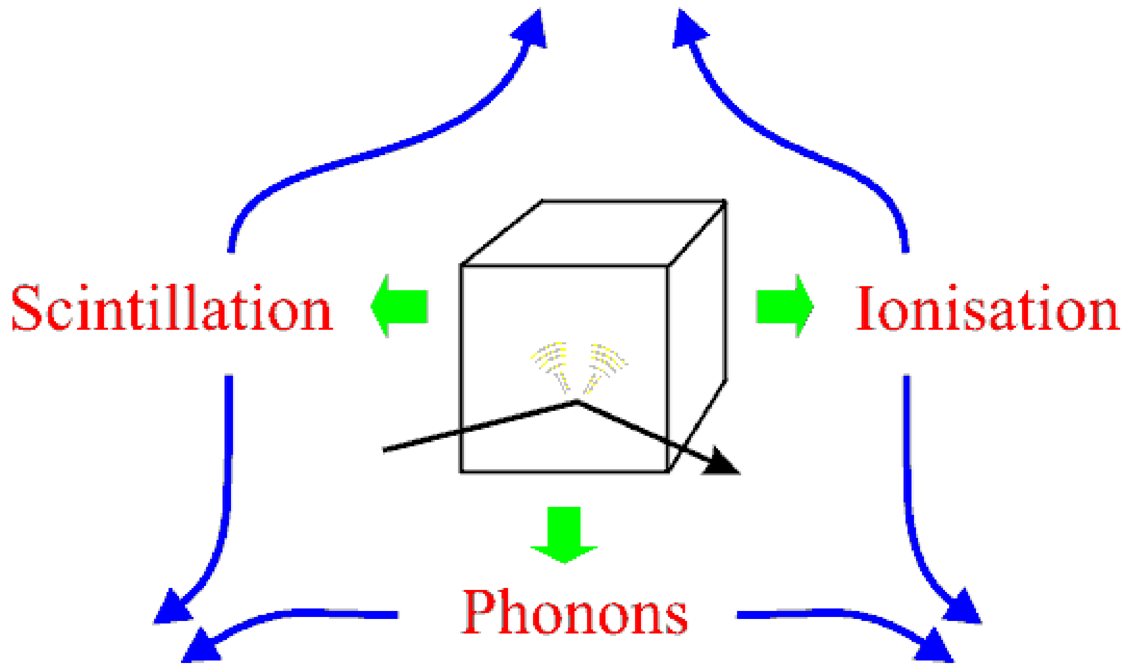
Cosmic "makeup". Credit: ESA/Planck



Focus on Direct Detection Techniques

Ar, Xe
ArDM, Darkside, LUX, LZ, Panda-X, XENON, ZEPLIN

NaI, Ar, Xe
DAMA/LIBRA
ANAIS
NAIAD
KIMS
XMASS
DEAP/CLEAN
ZEPLIN-I



Ge
CoGENT
GERDA
MAJORANA
IGEX

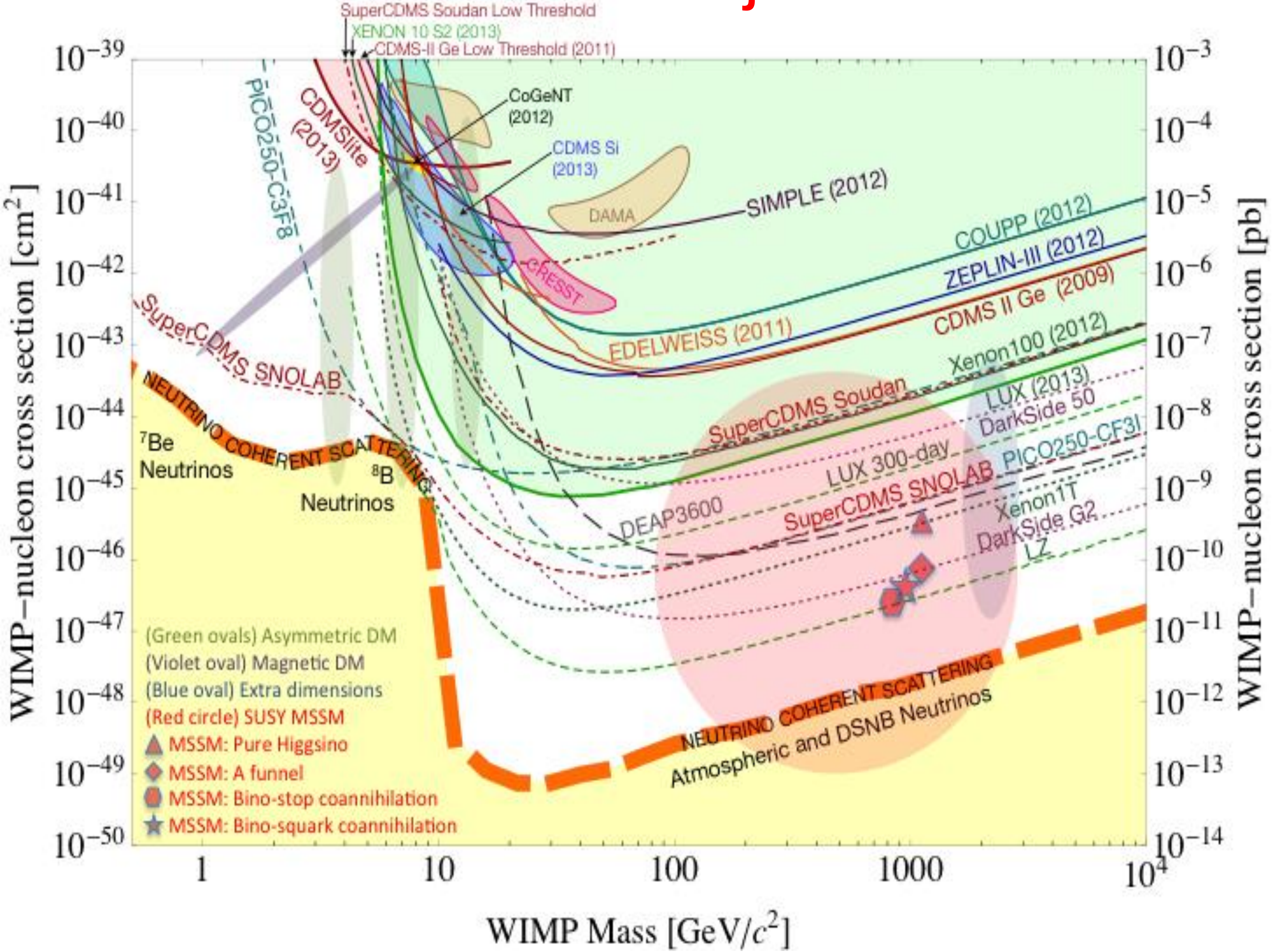
$CaWO_4$, $ZnWO_4$
CRESST II
ROSEBUD
EURECA

Al_2O_3 and others
CRESST I
CUOPP
PICASSO

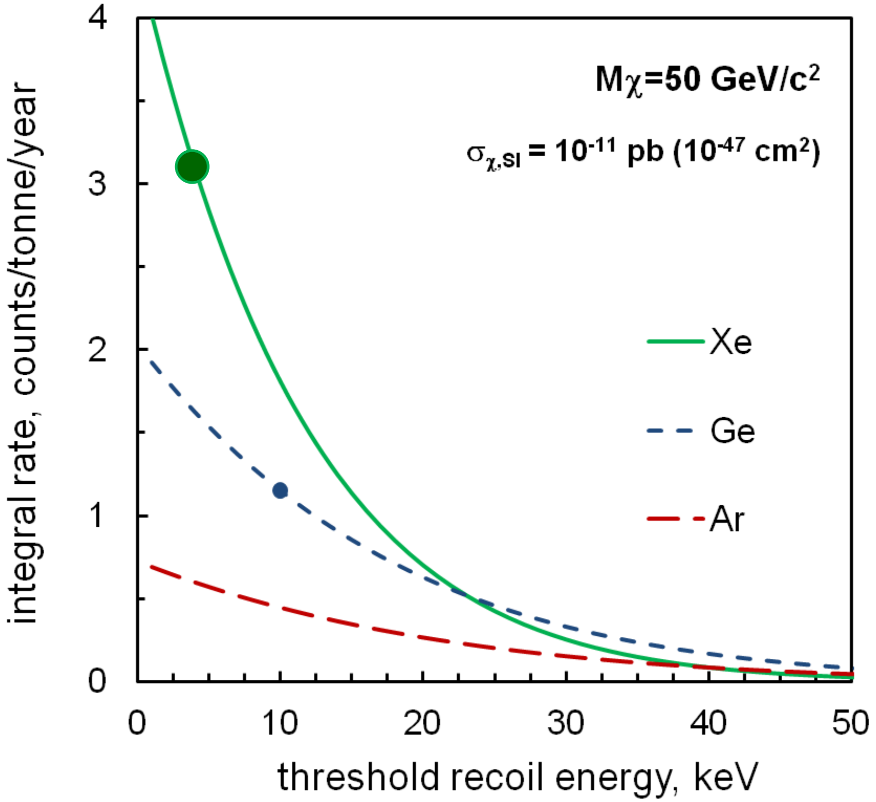
Si, Ge
CDMS
EDELWEISS
EURECA

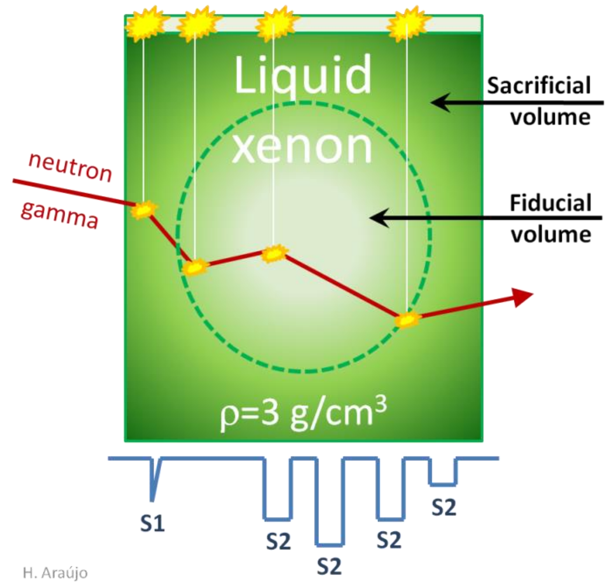
Displacement / tracking: DRIFT, Newage, MIMAC, DM-TPC

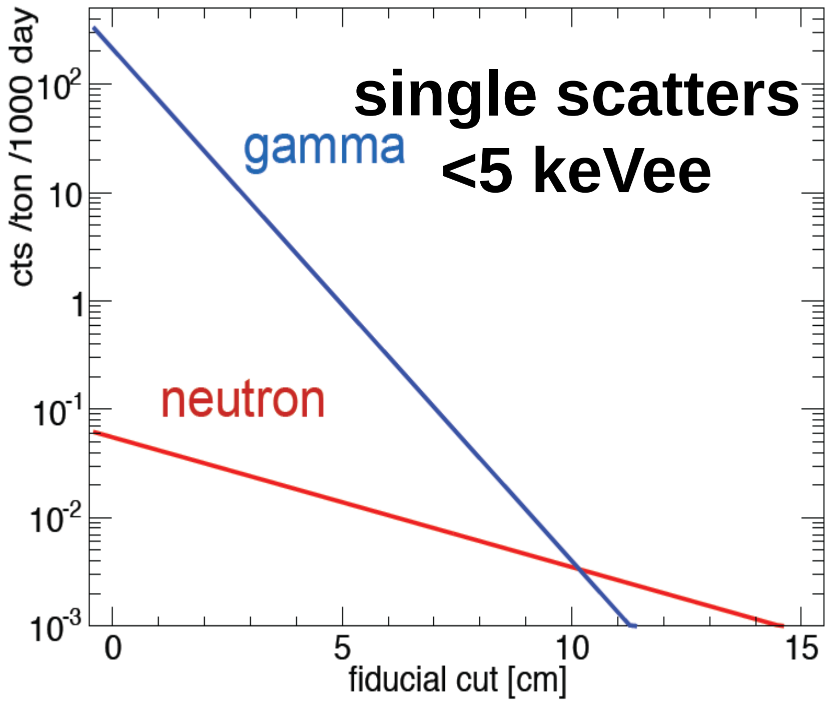
Limits and Projections



The Noble Liquid Xenon

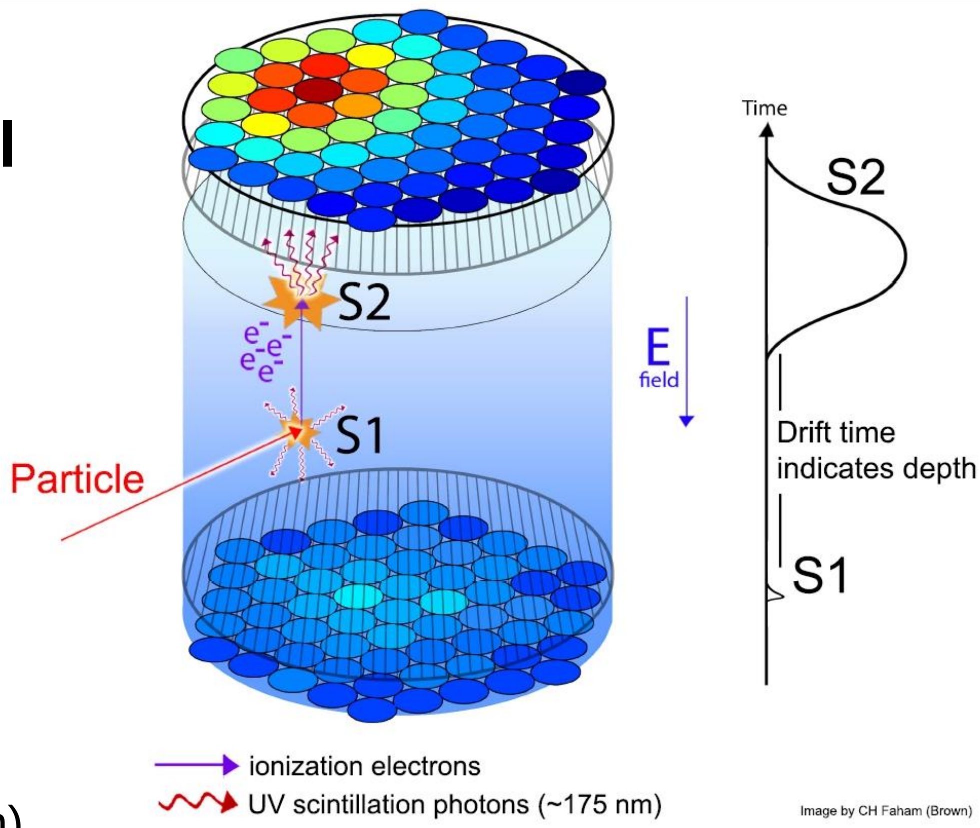






Searches for RARE *and* LOW ENERGY events: a challenging combination

Two-phase Xenon TPC Principle



S1: prompt scintillation signal

- Light yield: ~60 ph/keV (ER, 0 field)
- Scintillation light: 178 nm (VUV)
- Nuclear recoil threshold ~5 keV

S2: delayed ionisation signal

- Electroluminescence in vapour phase
- Sensitive to single ionisation electrons
- Nuclear recoil threshold ~1 keV

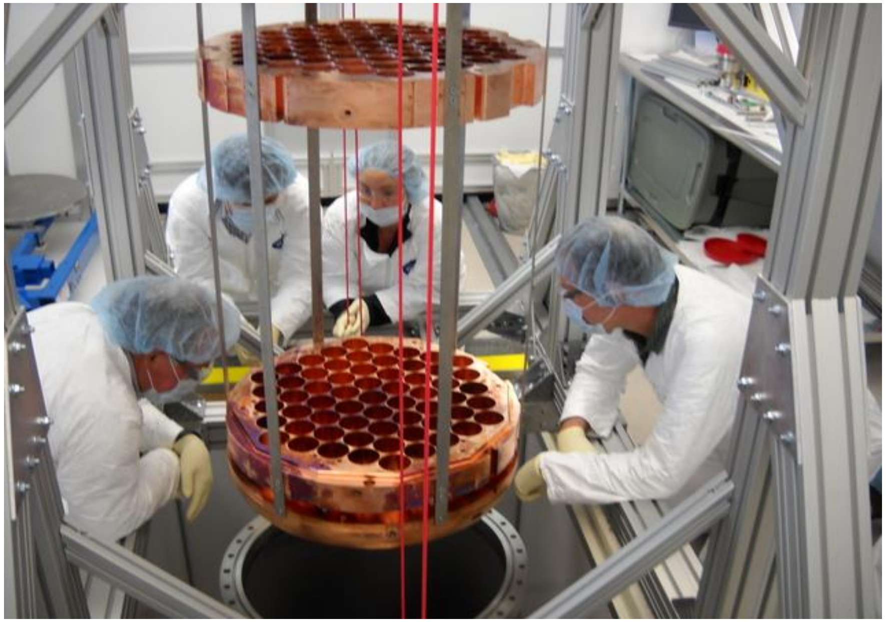
S1+S2 event by event

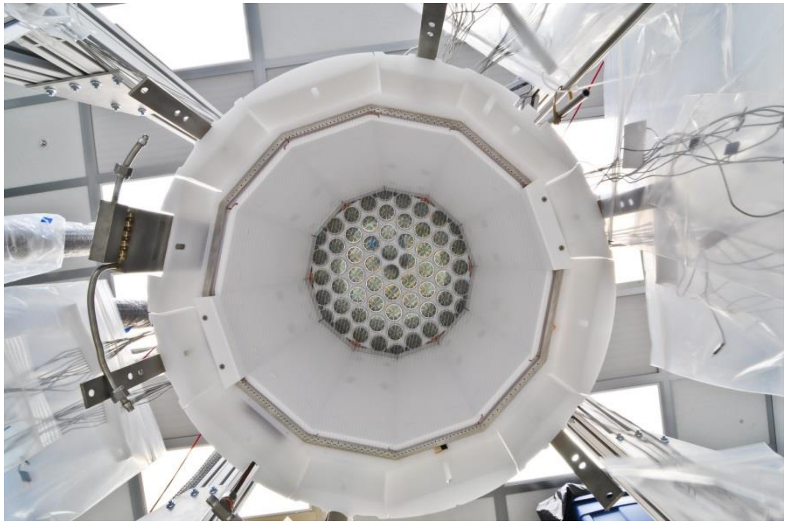
- ER/NR discrimination (>99.5% rejection)
- mm vertex resolution + high density: self-shielding of radioactive backgrounds

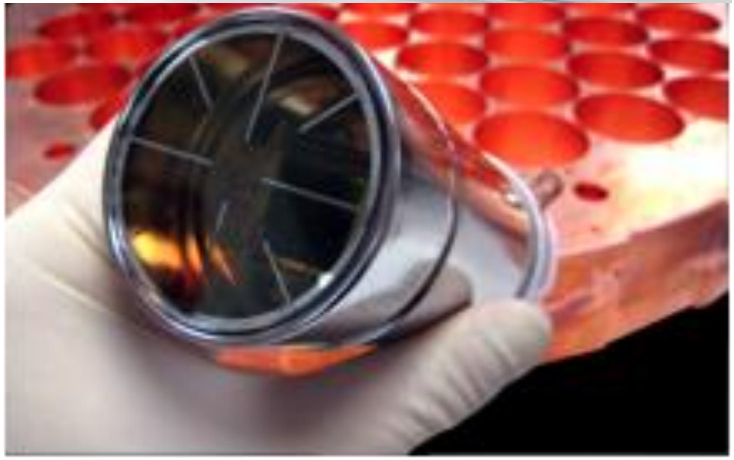
LXe is the leading WIMP target:

- Scalar WIMP-nucleon scattering rate dR/dE ~A^2, broad mass coverage (> 5 GeV)
- Odd-neutron isotopes (^{129}Xe, ^{131}Xe) enable SD sensitivity; target exchange possible
- No damaging intrinsic nasties (^{127}Xe short-lived, ^{85}Kr removable, ^{136}Xe $2\nu\beta\beta$ ok)

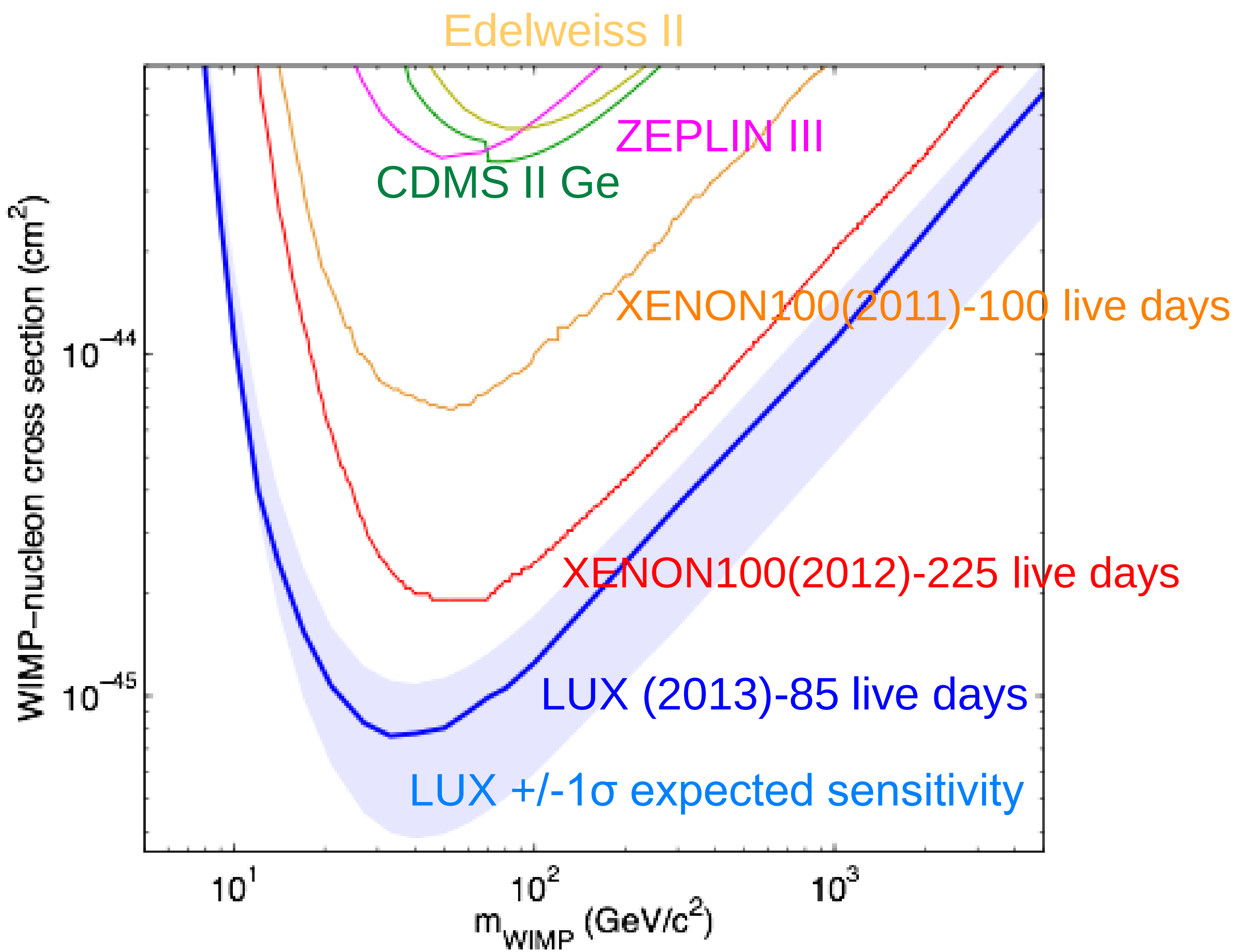
LUX being built



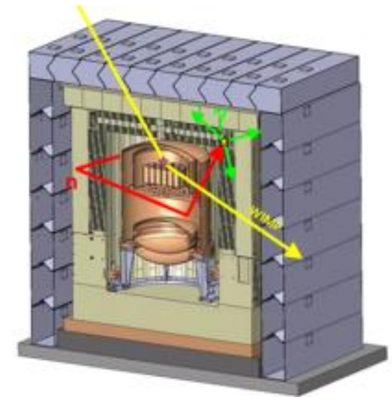




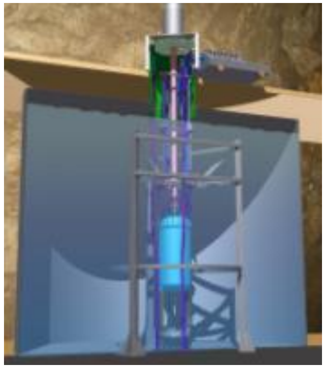
The LUX Result (and sensitivity progress)



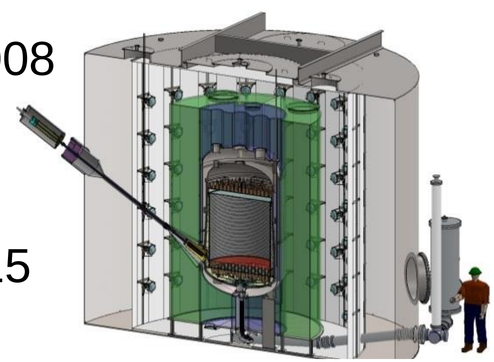
ZEPLIN → LUX → LUX-ZEPLIN



- **UK-led ZEPLIN programme at Boulby (2001-2011)**
  - Pioneered two-phase xenon technology
  - World class results from 3 xenon experiments
  - Fiducial mass ~6 kg

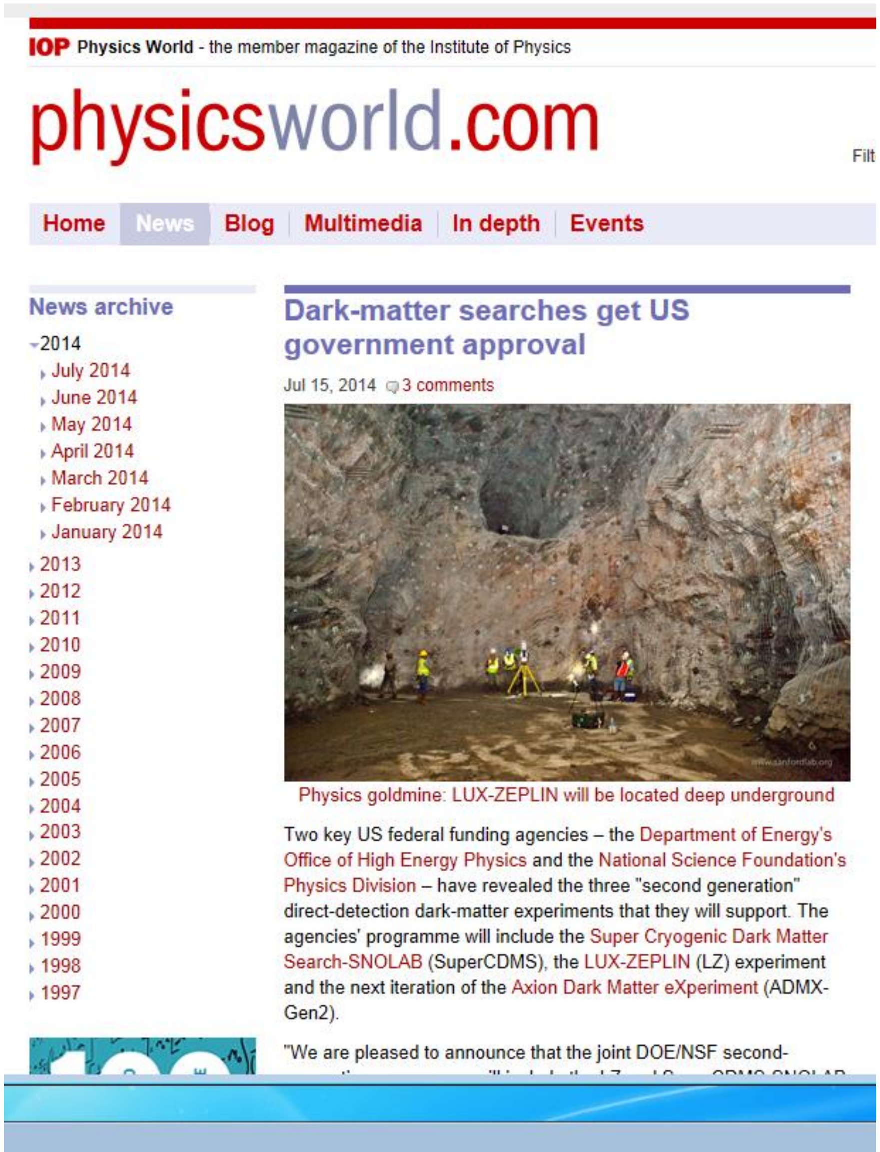


- **LUX operating at Sanford Underground Laboratory**
  - Imperial, Edinburgh and UCL joined after ZEPLIN-III
  - Present world-leading experiment
  - Fiducial mass ~100 kg



- **LZ: next-generation experiment**
  - LZ formed with MOU between LUX and ZEPLIN-III in 2008
  - Selected by DMUK for construction proposal to STFC
  - Fiducial mass ~6,000kg (~10^{-48} cm^2 sensitivity)
  - Conceptual design nearly completed, construction f. 2015

The Timeline and UK Focus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Dark-matter searches get US government approval

Jul 15, 2014 3 comments

Physics goldmine: LUX-ZEPLIN will be located deep underground

Two key US federal funding agencies – the Department of Energy's Office of High Energy Physics and the National Science Foundation's Physics Division – have revealed the three "second generation" direct-detection dark-matter experiments that they will support. The agencies' programme will include the Super Cryogenic Dark Matter Search-SNOLAB (SuperCDMS), the LUX-ZEPLIN (LZ) experiment and the next iteration of the Axion Dark Matter eXperiment (ADMX-Gen2).

"We are pleased to announce that the joint DOE/NSF second-

April 2013: DMUK chose LZ for construction proposal to STFC.

Oct 2013: LUX – world-leading result

July 2014: LZ selected in the US as G2 project*

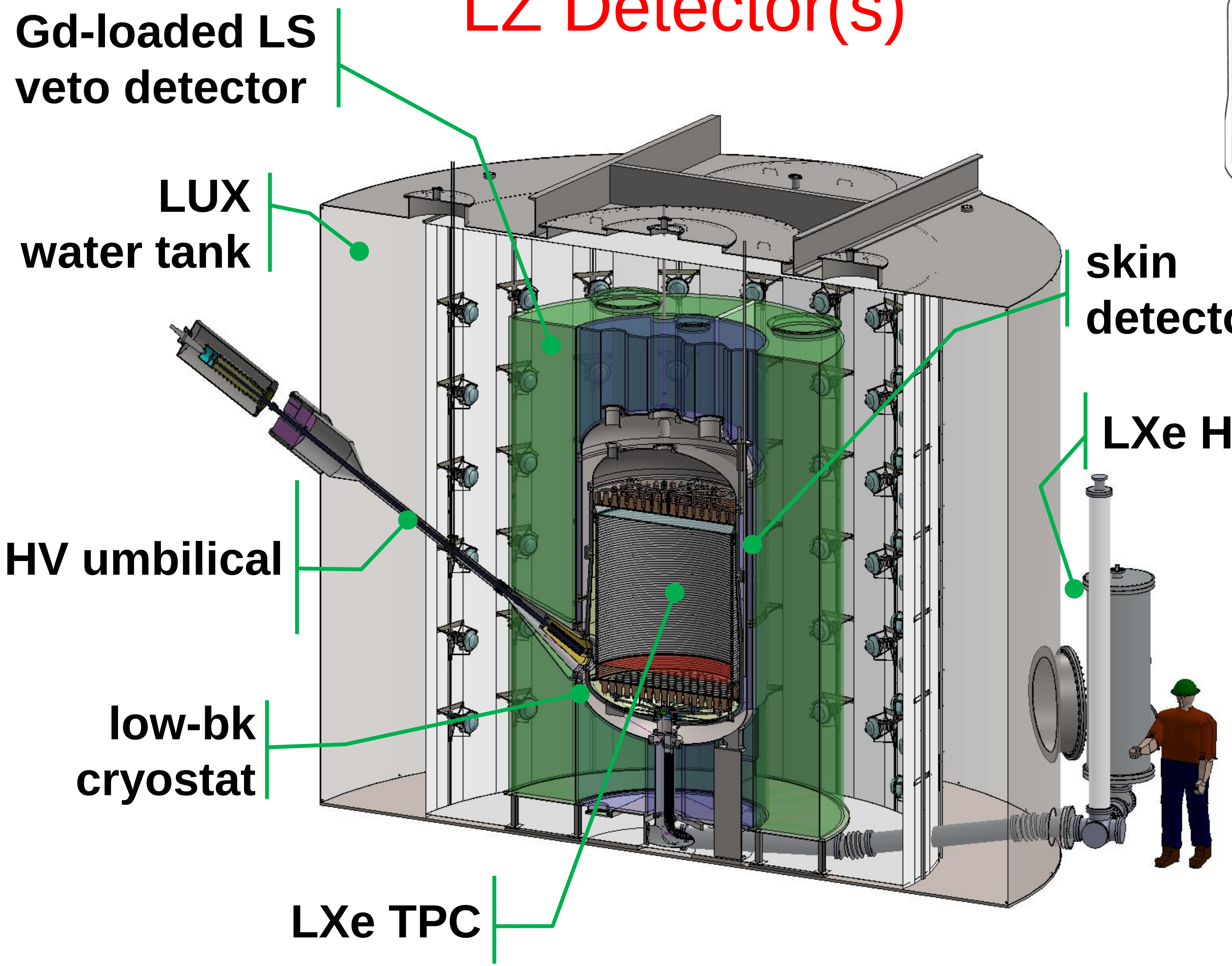
>150 members in 28 groups
US (18), UK (8), Pt(1), Ru(1)
www.lzdarkmatter.org

* Together with:
SuperCDMS at SNOLab and ADMX-Gen2

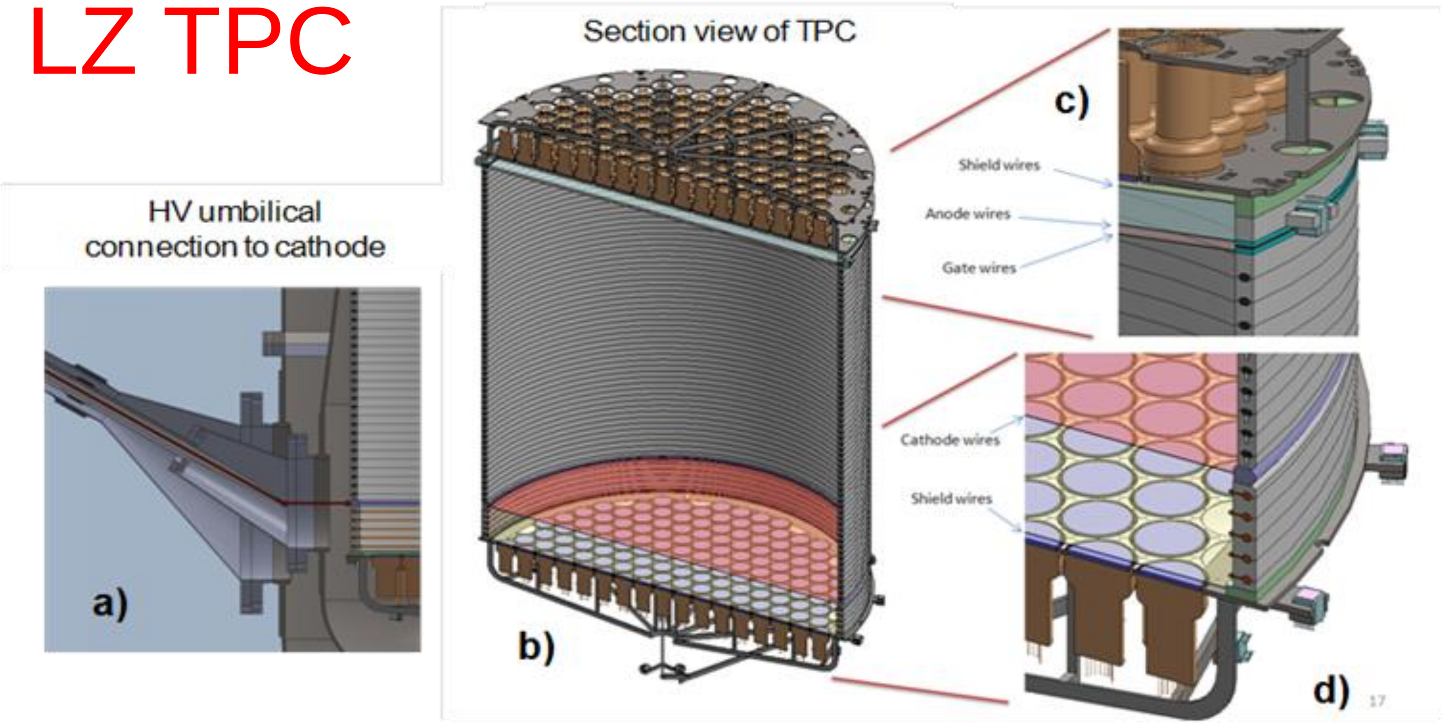
Sanford Underground Research Facility

LUX Water Tank in Davis Cavern: 4850 ft underground

LZ Detector(s)



The LZ TPC



- **TPC PARAMETERS**
  - **1.5 m diameter/length (3x LUX)**
  - **7 tonne active LXe mass (28x LUX)**
  - **2x 241 3-inch PMTs (4x LUX)**
  - **Highly reflective PTFE field cage**
  - **100 kV cathode HV (10x LUX)**
  - **Electron lifetime 3 ms (3x LUX)**

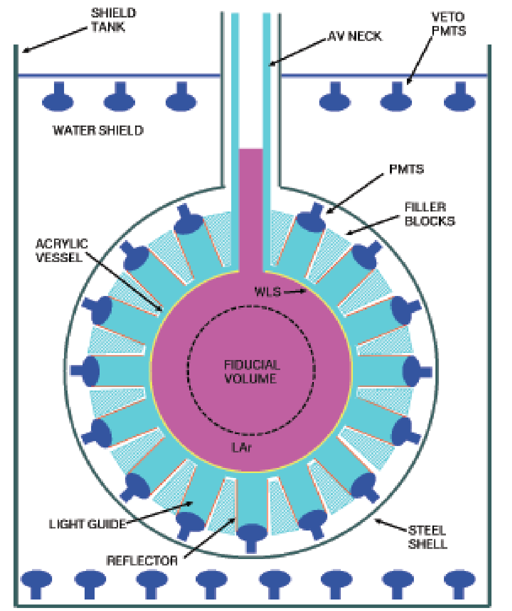
PHYSICS PARAMETERS

- **5.8 keVr S1 threshold (4.5 keVr LUX)**
- **0.7 kV/cm drift field, 99.5% ER/NR disc. (already surpassed in LUX at 0.2 kV/cm)**

TPC CALIBRATION

- **ER: Dispersed sources: Kr-83m, CH3T**
- **NR: AmBe, YBe, D-D generator**

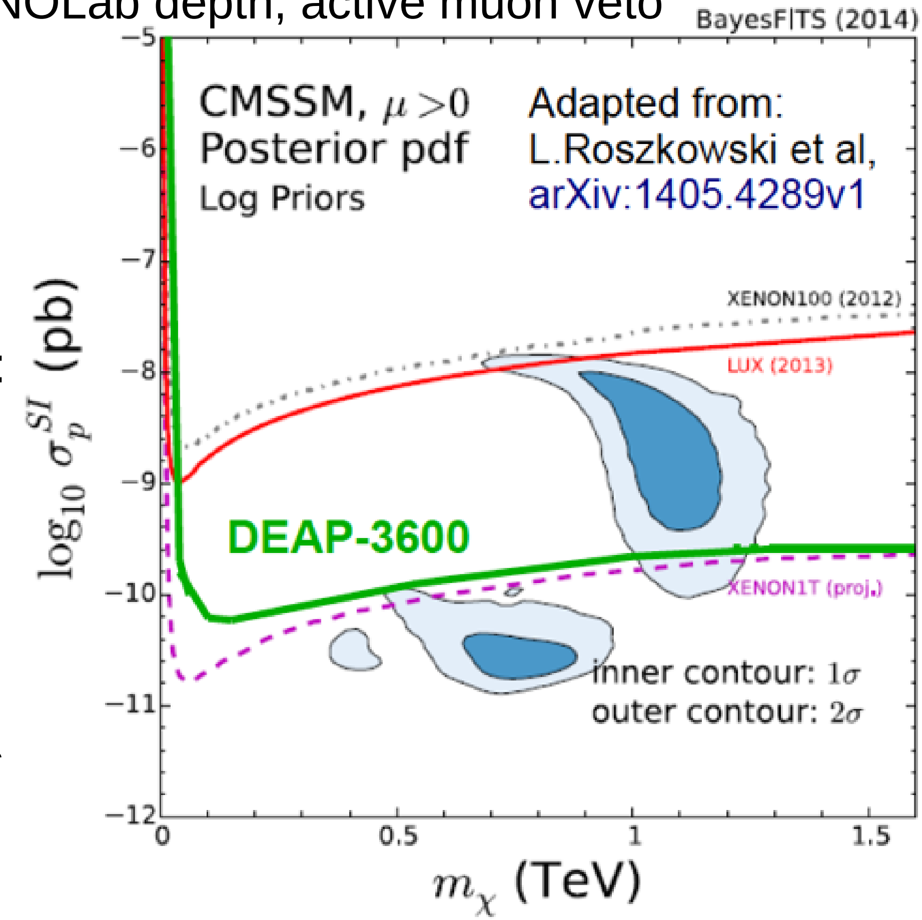
DEAP/CLEAN Single Phase Detectors



McKinsey and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2

Open volume of cryogen, surrounded by PMTs in 4**π**, no electric field, to maximize detected PE per keV

Background strategy: pulse shape discrimination using fast/slow scintillation to ID recoils and reject ^{39}Ar, self-shielding of LAr target to mitigate alphas, gammas, neutrons, + SNOLab depth, active muon veto



Staged detector development programme:

MiniCLEAN: measure PSD, prototype LAr/LNe target exchange to test A^2 scaling

DEAP3600: dark matter discovery reach of 10^{-46} cm^2 in 3 tonne-yrs exposure, at conservative 60 keVr threshold

UK: Calibration, Refrigeration, Veto systems

DEAP3600 Calibration System

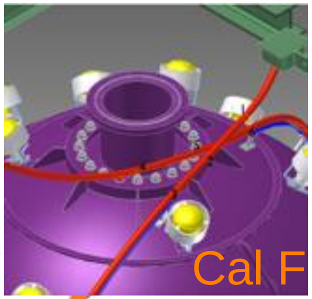
1. Sources and Ports:

- tagged Na-22 source Cal A,B,E pipes, Cal F around detector, neck (RAL)
- tagged AmBe source in Cal A,B,E (RHUL)
- optical calibration sources in neck (laser- and LED-flasks), PMT lightguide reflectors (fixed), and neck laser (Sussex)

2. Deployment systems:

- source deployment systems for Cal F and Cal A,B,E
- neutron source deployment / HV delivery system for Cal A,B,E
- LED flask deployment through neck
- Acrylic reflector array + fibers + LED drivers

Calibration commissioning on-site now underway!



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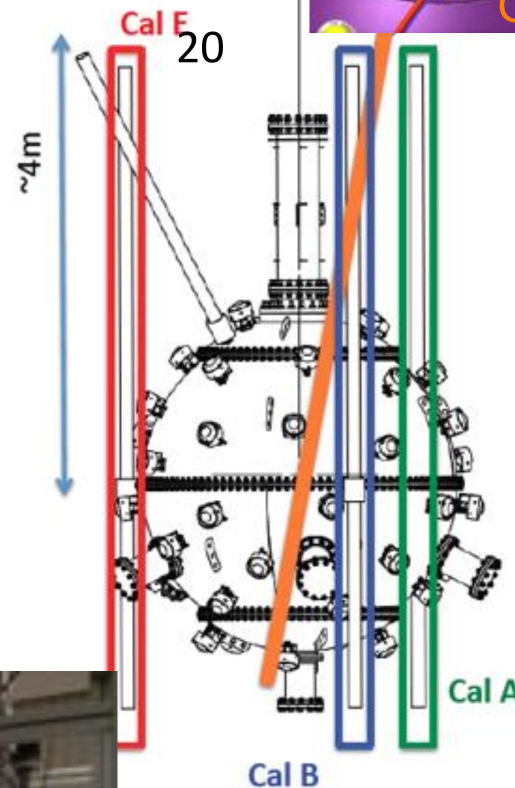
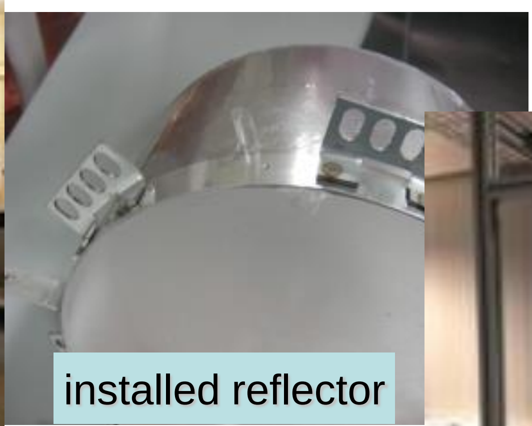
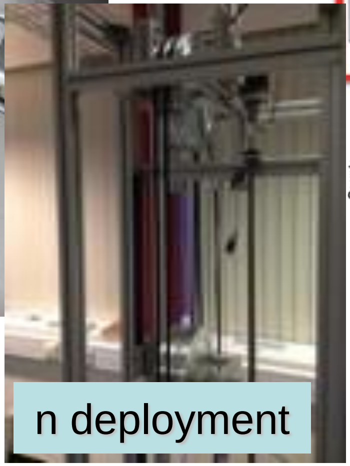
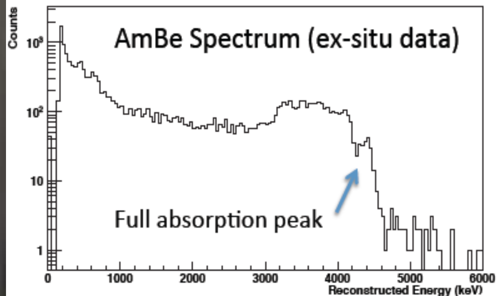



gamma system deployment test

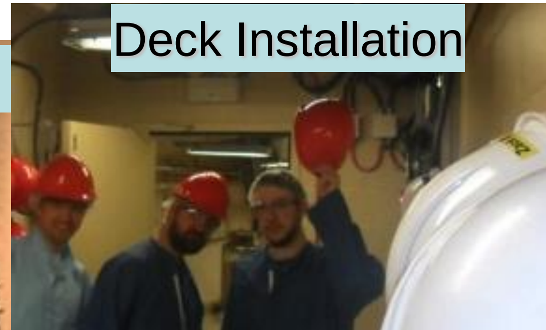

installed reflector

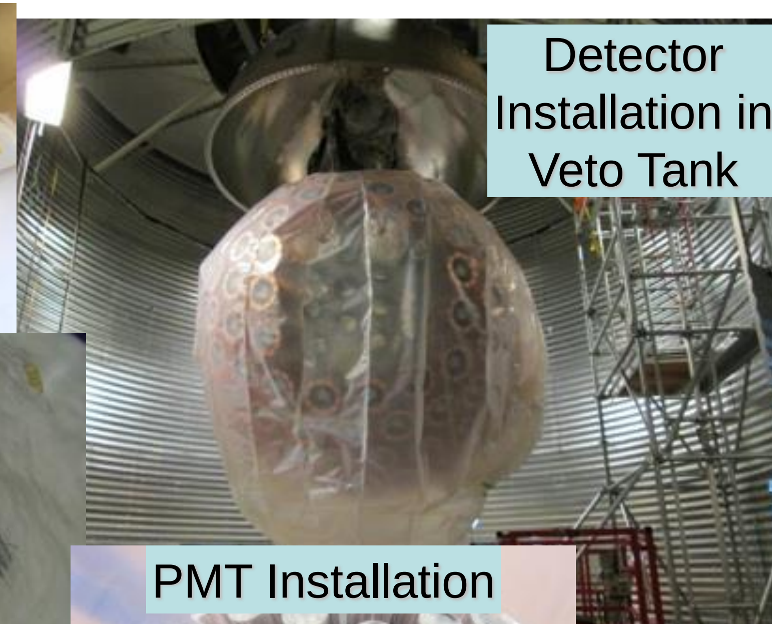

n deployment

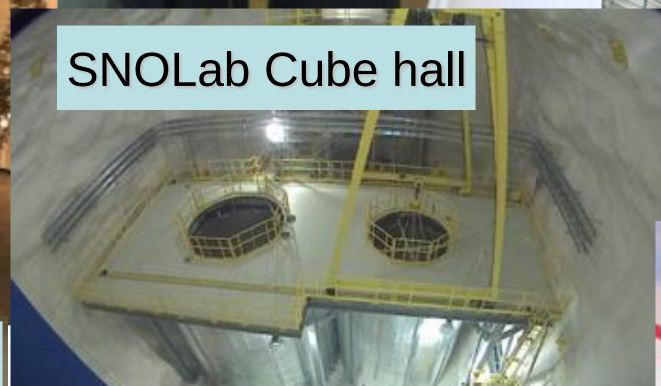


Construction Progress

Nearly complete! Internal resurfacing now, LAr fill Sept. 2014, physics data 2015.







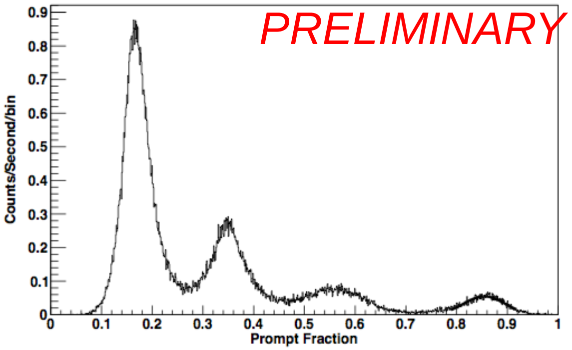
UK students & PDRAs took >10 months of shifts!

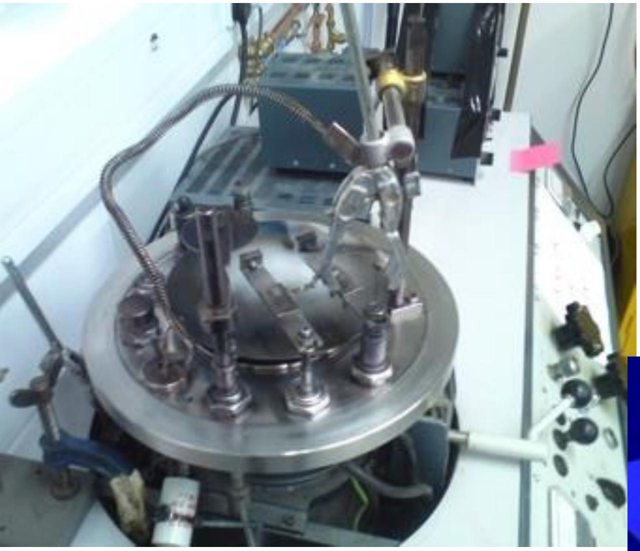
Calibration R&D (STFC PRD)

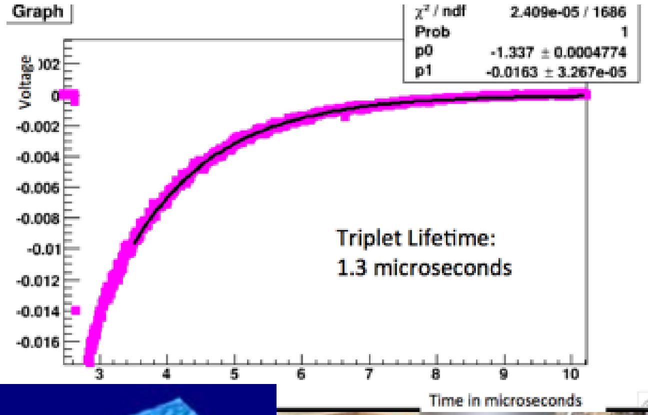
What if we see 5 events? How will we know if this is a signal?

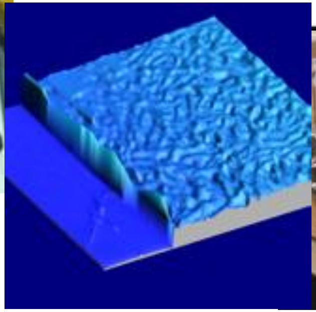
Objectives: ex-situ measurement input to calibration analysis,
(i) reduce systematics on energy, radius reconstruction,
(ii) break correlations between parameters for MC tuning

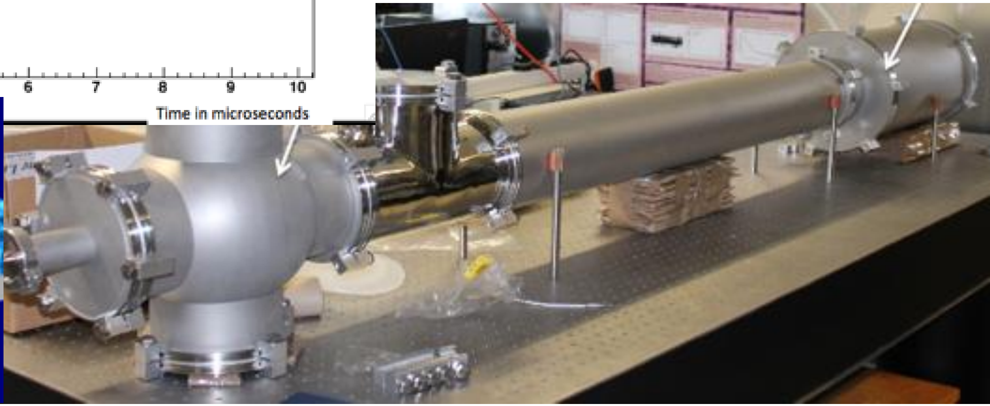
- source R&D: study modeling of source calibration (RAL)
- scintillation R&D: measure the scattering length and temp. dependence in noble liquids, explore laser calibration (RHUL)
- optical response R&D: measure the optical properties of TPB wavelength shifter (University of Sussex)









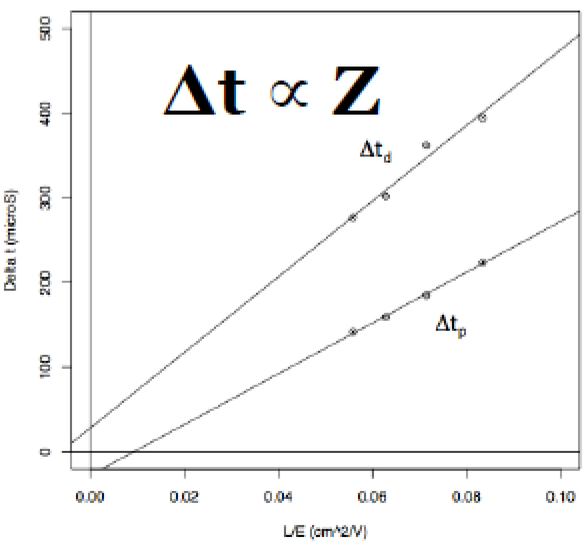


DRIFT – Directional Detection

- Directional Detector (PRD, **61** (2000) 1, NIMA, **600** (2009) 417, AstroPle, **31** (2009) 261)
- DRIFT has been operating in Boulby since 2001
- DRIFT-I -> DRIFT-II (a-e)
- DRIFT-IId volume = 0.8 m^3, 40 Torr gas
- MWPC readouts (NIMA, **555** (2005) 173)
- Negative CS2 anion drift to limit diffusion (PRD, **61** (2000) 1)
- Phenomenal Compton background rejection (AstroPle, **28** (2007) 409)
- Many gas mixtures possible
- DRIFT-IId used a 30-10 Torr of CS2-CF4 to optimize for spin-dependent limits, 139 g target mass. (AstroPle, **35**(2007) 397)
- Relatively cheap, clean, stable and scalable technology.

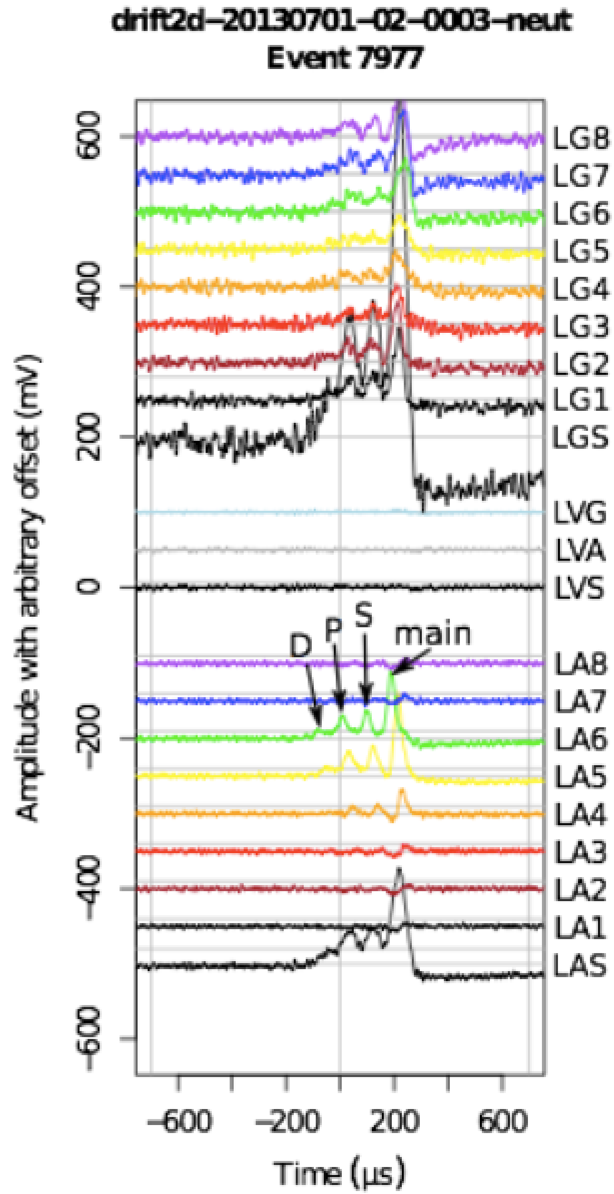
DRIFT – z-fiducialisation

- **1% oxygen** added to normal 30:10 Torr CS_2: CF_4 mixture
- Appearance of "minority carrier" peaks **earlier** than the "majority" peak, carrying ~1/2 of the total charge (see Snowden-Ifft Rev. Sci. Instr. 85 (2014))
- Timing between main peak and minority peaks gives **absolute Z information** on events
- This allows rejection of RPR events that originate near the cathode at z = 50 cm or MWPC planes at z = 0 cm



$$z = (t_m - t_p)\frac{v^m_{drift} v^p_{drift}}{v^m_{drift} - v^p_{drift}}$$

Example event display from minority carrier data. The main peak and the earlier 'S', 'P' and 'D' minority peaks can be seen on LA 3, 4, 5 and 6.



Summary

UK groups are focussing of LUX-ZEPLIN.

Complementary detectors being provided on a global level.

LZ seeking construction funds now.