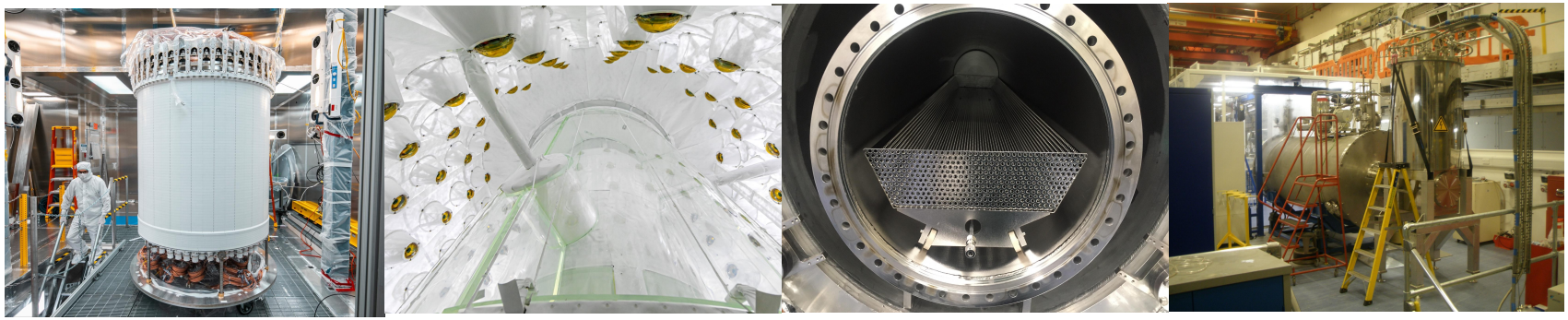
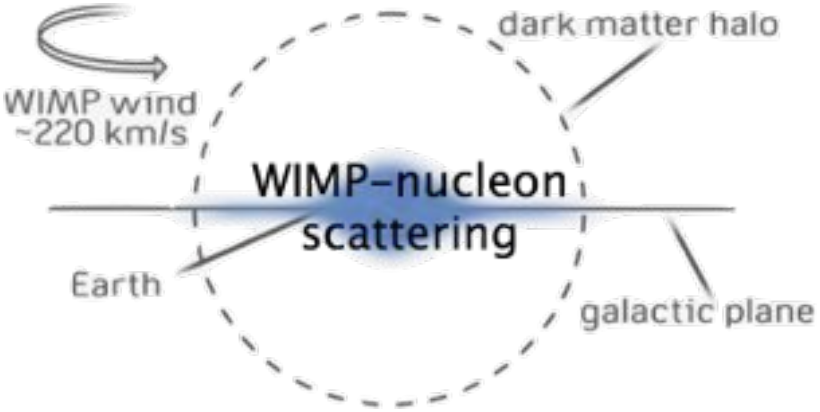
New physics searches with LUX-ZEPLIN & development of next generation dark matter low background technologies at the Cold Radon Emanation Facility

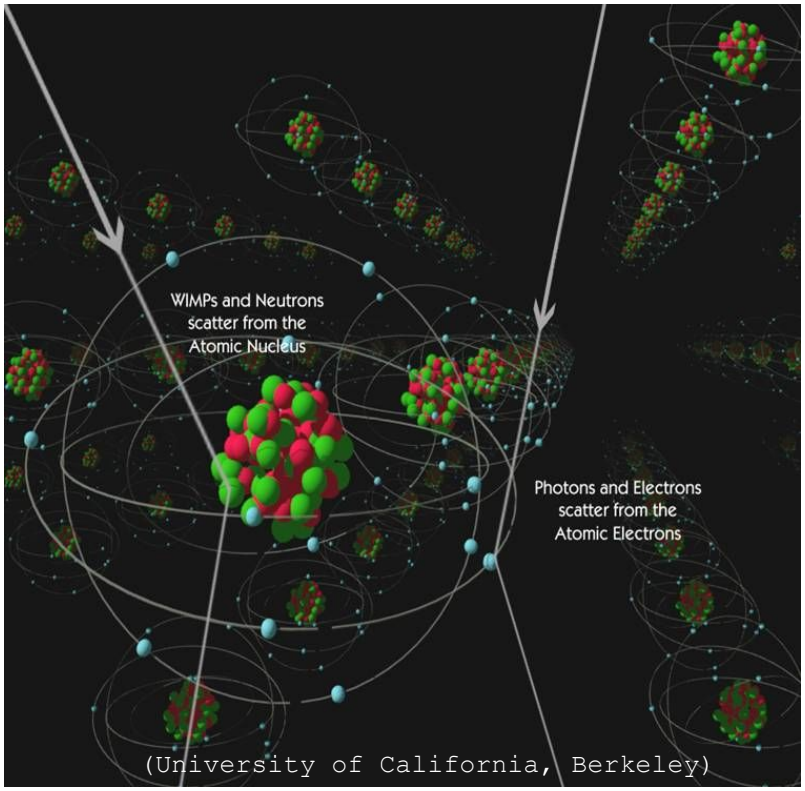


Supervisors:
Dr Jim Dobson (King's College London) & Dr Maurits van der Grinten (RAL/PPD)

jim.dobson@kcl.ac.uk – RAL PhD Open Day - 20/2/24

Direct detection of Dark Matter

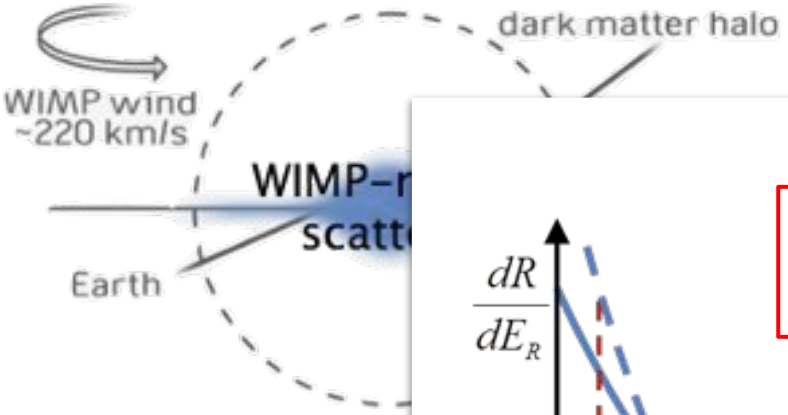




Standard Halo Model

- Isothermal sphere of DM, $\rho \propto r^{-2}$
- Local density ρ_0 ~ 0.3 GeV/cm3
- Maxwellian (truncated) velocity distribution
- Characteristic velocity v_0=220 km/s → non-relativistic!

Direct detection of Dark Matter



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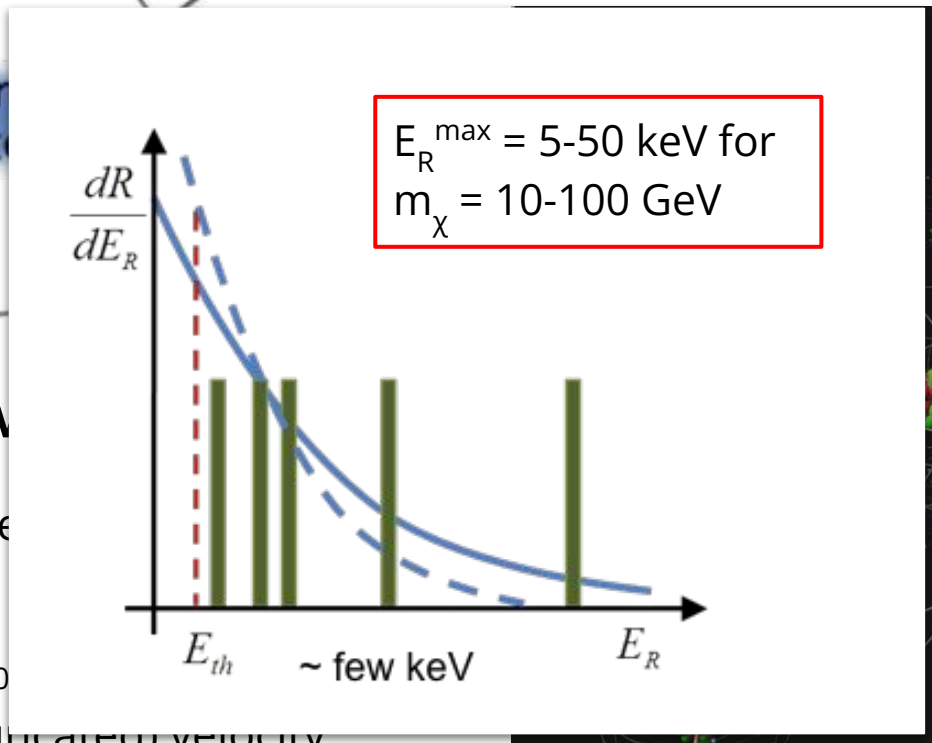
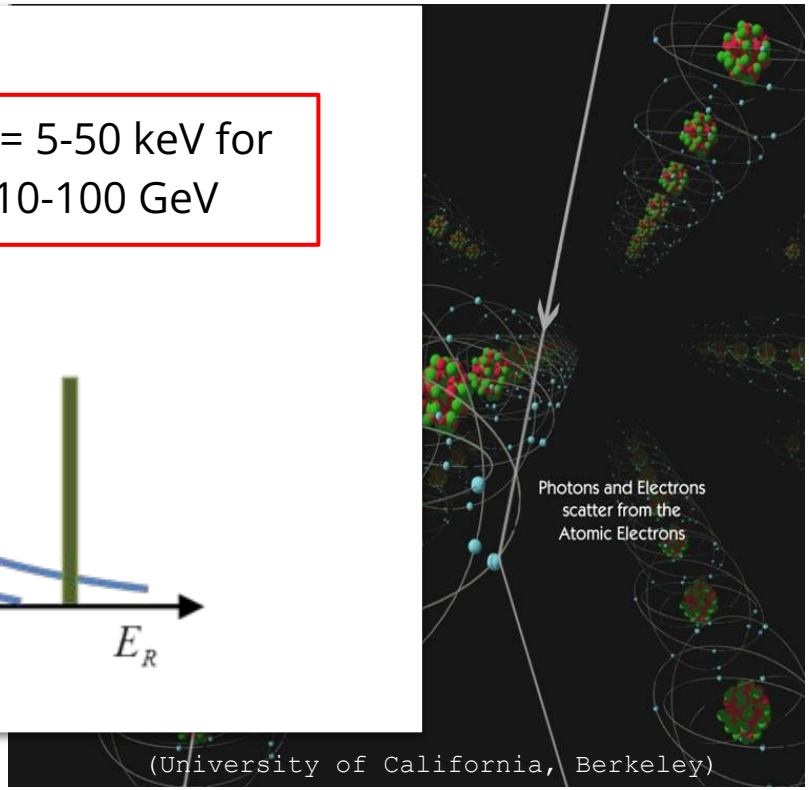
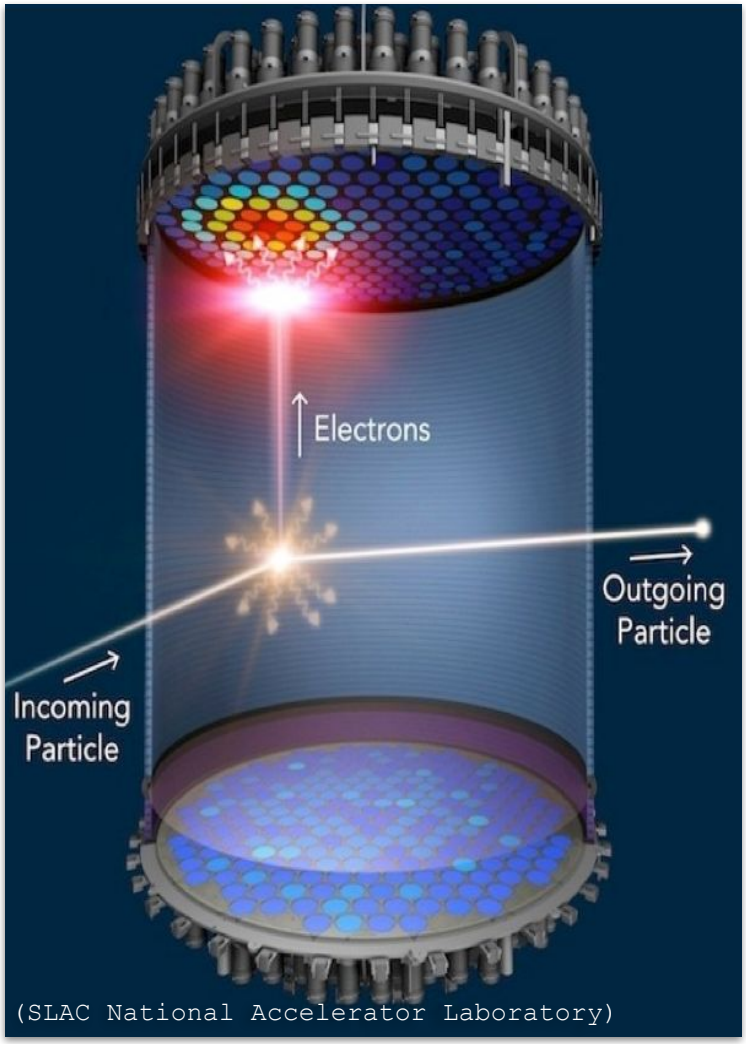
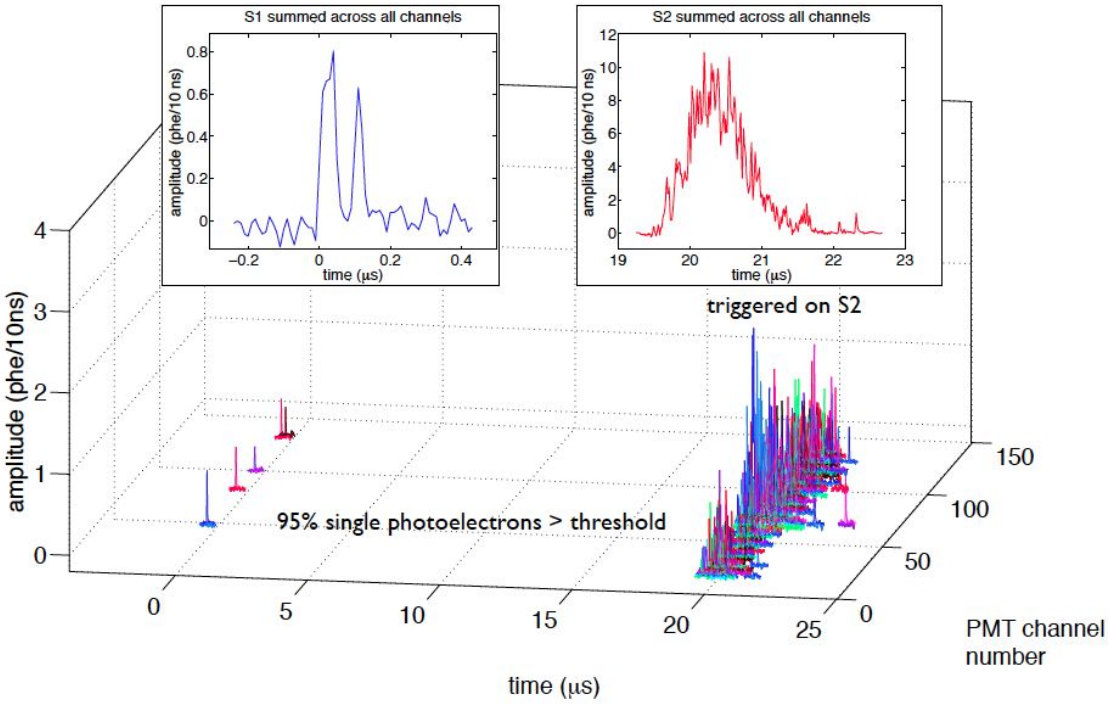


E_R^{max} = 5-50 keV for
m_χ = 10-100 GeV



Liquid Xenon Time Projection Chambers





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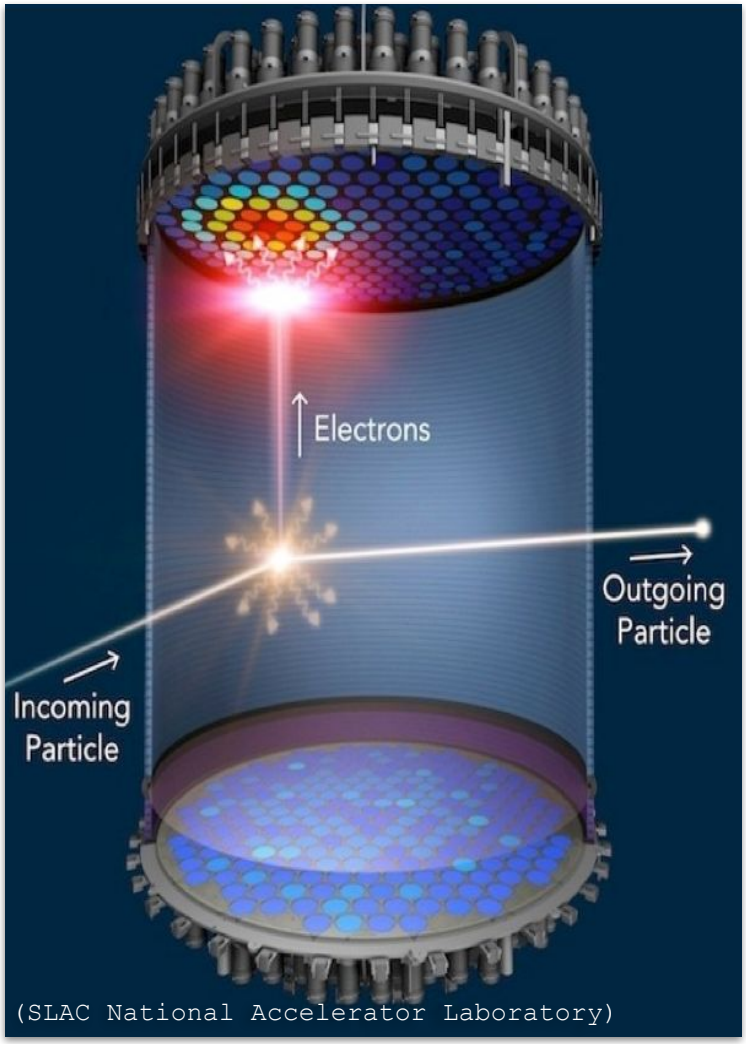
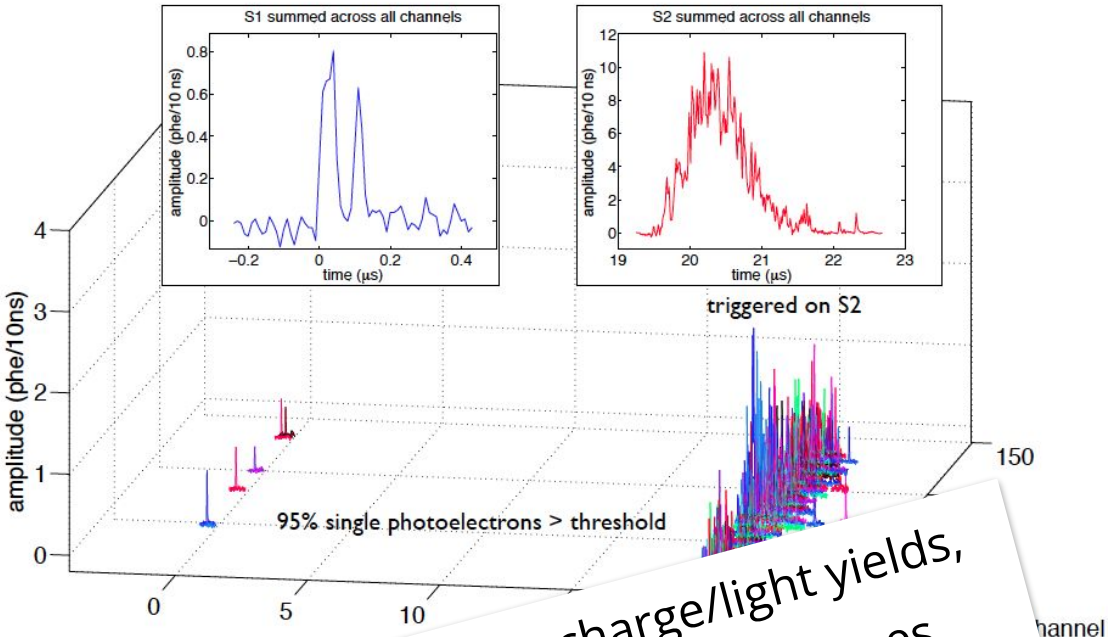




Key features: excellent charge/light yields, $\sigma \propto A^2$, lack of long-lived radioisotopes, fiducialisation →highly scalable.

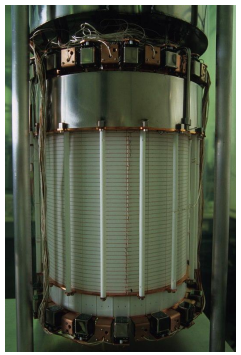
Leading technology above a ~few GeV

ZEPLIN-III

12 kg (7 kg)

2008

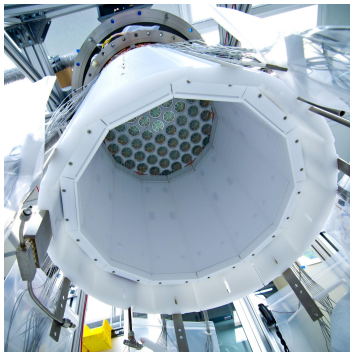
XENON100



62 kg (34 kg)

2013

LUX



250 kg (100 kg)

2016

PANDAX-II

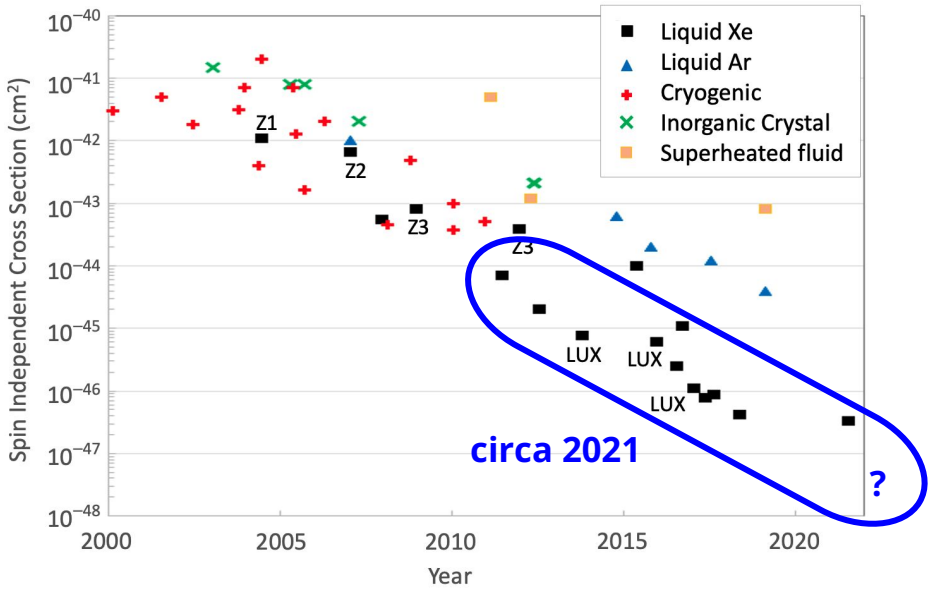
580 kg (362 kg)

2017

XENON1T

2,000 kg (1,042 kg)

2018



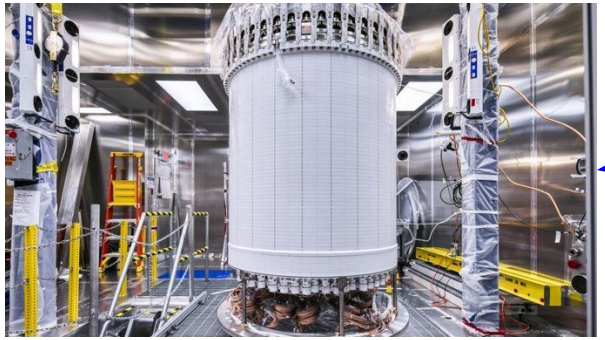
LUX-ZEPLIN

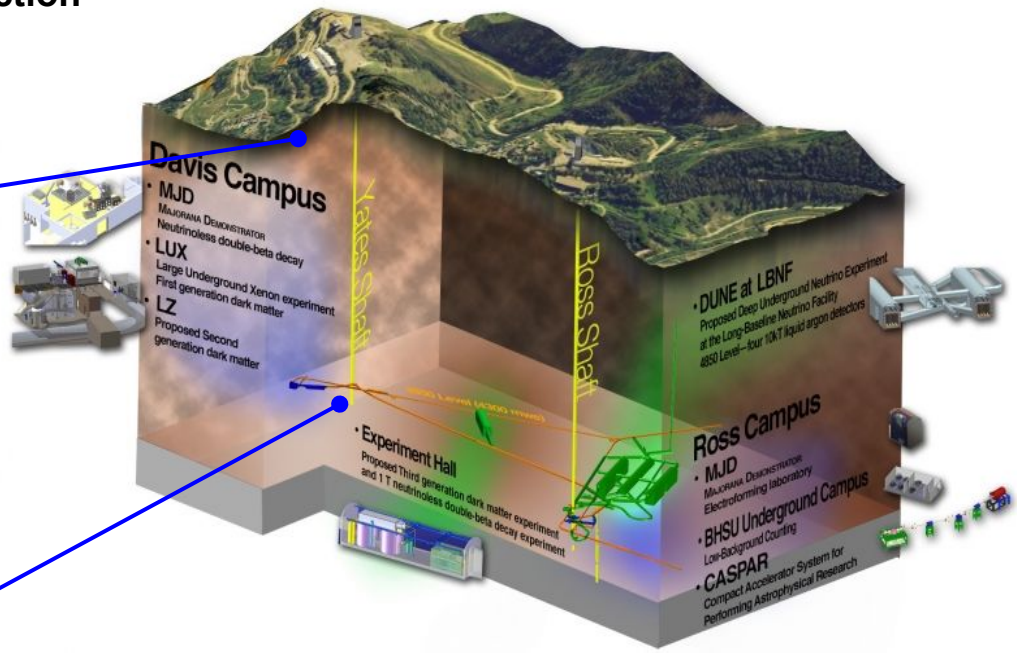
7,000 kg (5,600 kg)

2022-25

Backgrounds, backgrounds, backgrounds

1) Ultra-radio pure materials and construction





2) Take 1 mile underground

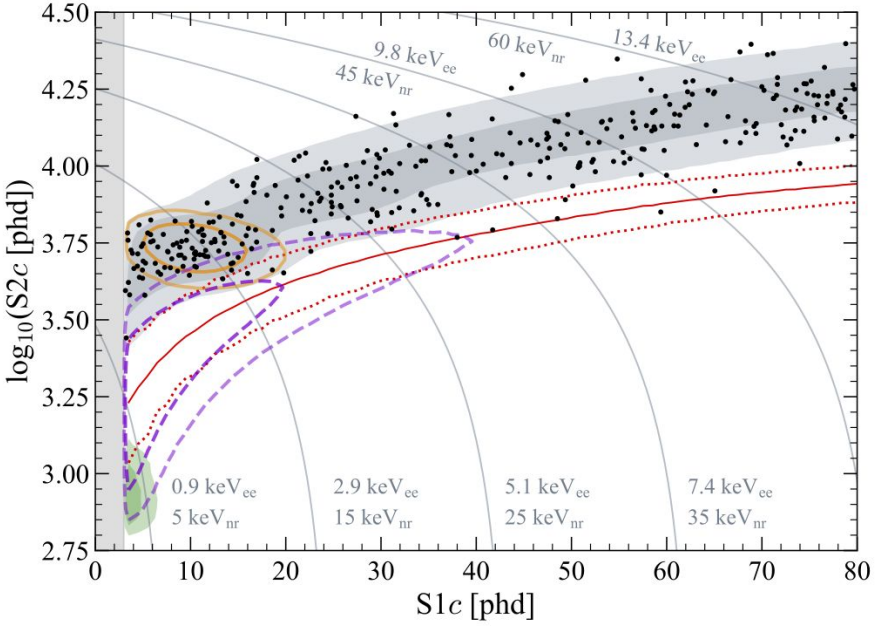
3) Run until background limited

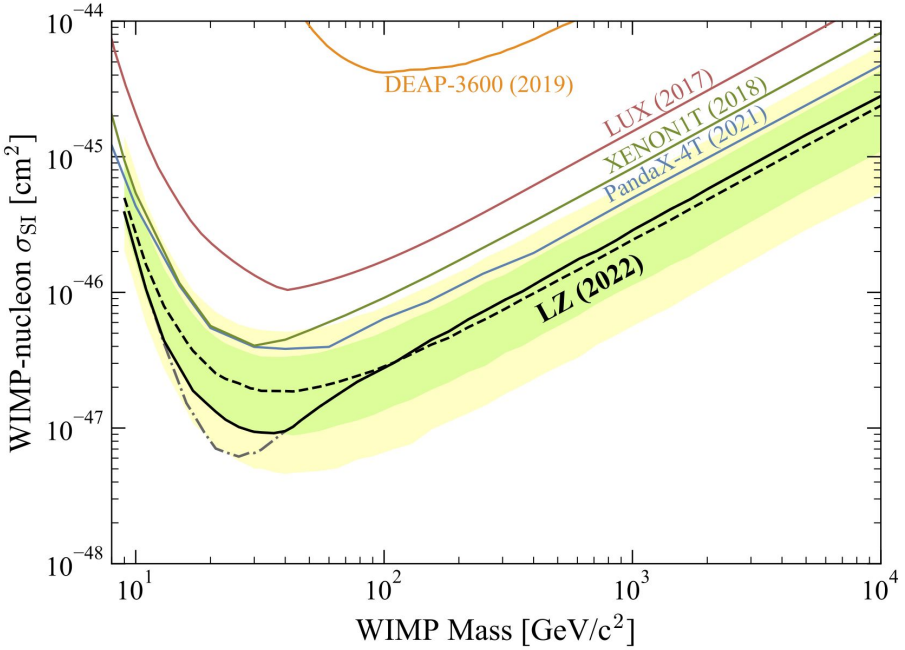
Radiopurity is key:

- ➔ Xe purification with chromatography
- ➔ Extensive radioassay campaign > 1000 assays
- ➔ Strict cleanliness controls

See Eur.Phys.J.C 80 (2020) 11

LZ's first look for WIMP dark matter





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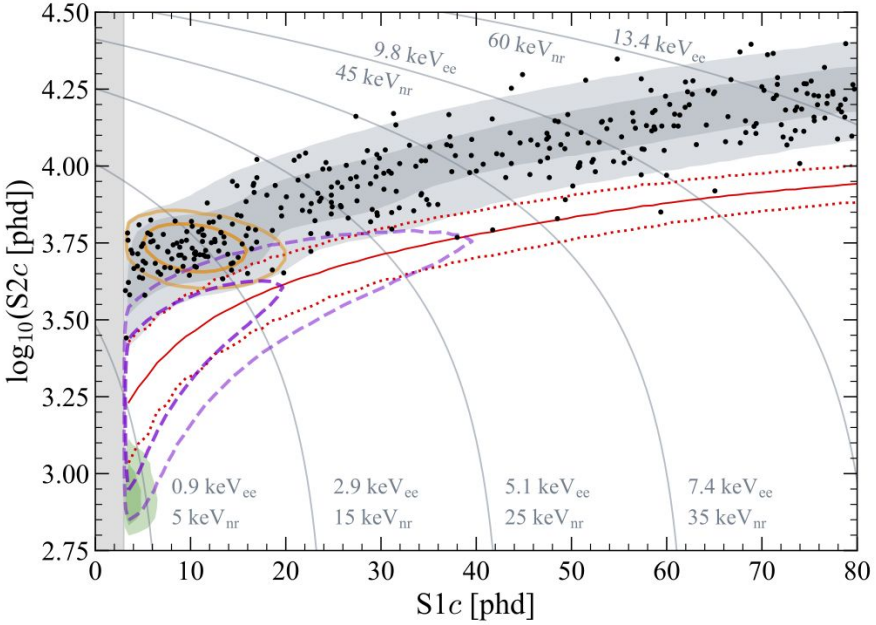
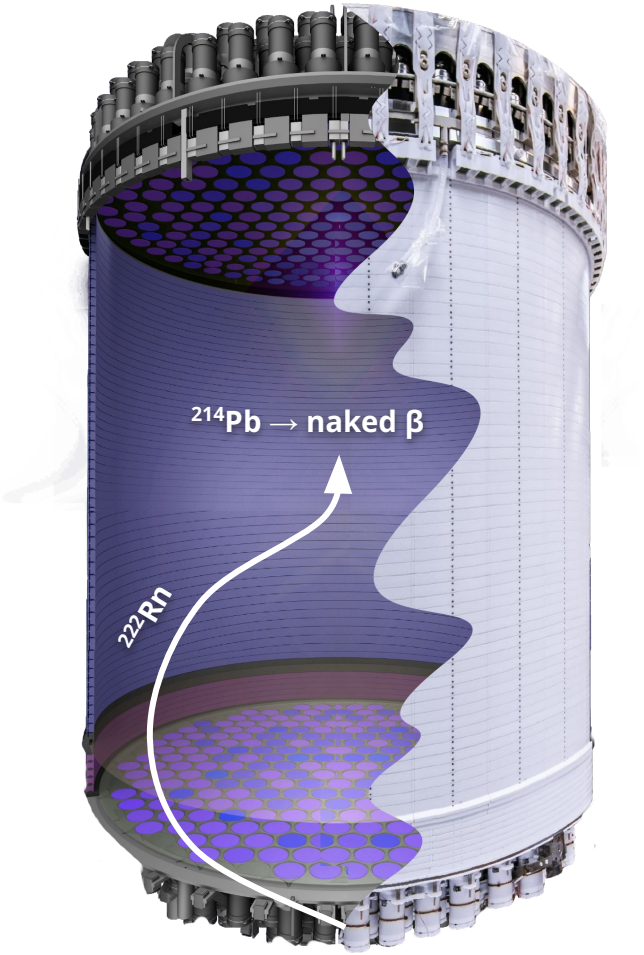
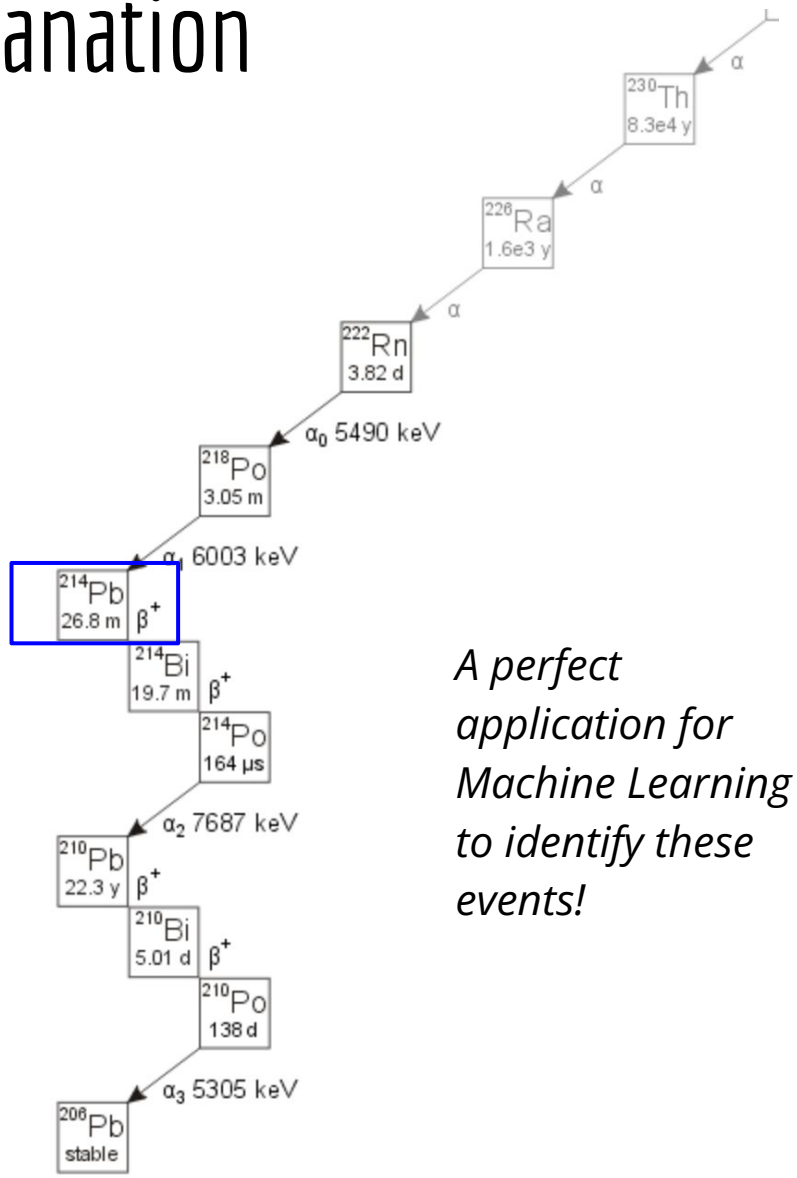


Source	Expected Events	Fit Result
β decays + Det. ER	215 ± 36	222 ± 16
ν ER	27.1 ± 1.6	27.2 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.1 ± 2.4	15.2 ± 2.4
^{8}B CEνNS	0.14 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	273 ± 36	280 ± 16
^{37}Ar	[0, 288]	$52.5^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	–	333 ± 17

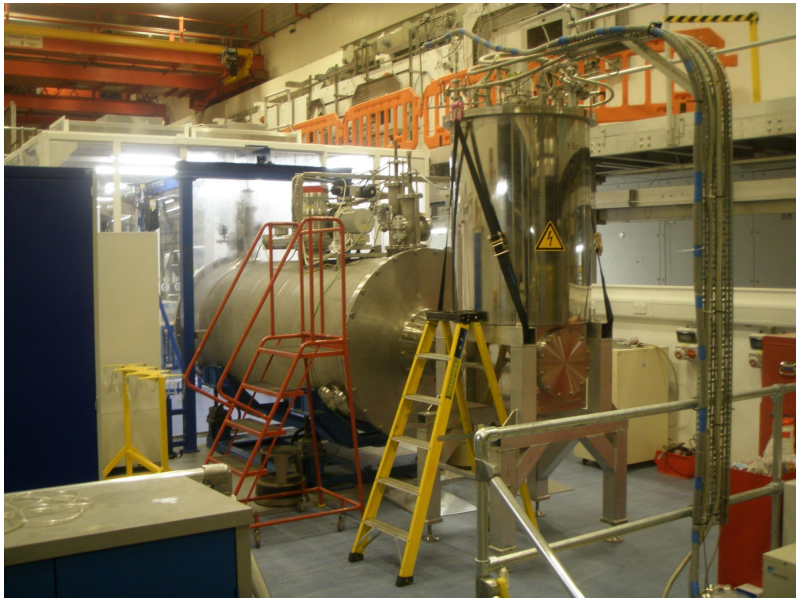
Radon emanation





A perfect application for Machine Learning to identify these events!

Cold Radon Emanation Facility @ RAL



World's first dedicated cryogenic radon emanation system

- 2 emanation chambers that can be cooled down to ~77 K
  - 2.7 L chamber
  - A 200 L chamber → whole detector components
- Study emanation rate as a function of temperature

The next generation detector

Requires:

- ➔ At least factor 10 reduction in radon
- ➔ **need 0.1 uBq/kg total**
- ➔ c.f. LZ which is around 4 uBq/kg

Overview of the PhD

- Detector development at RAL on CREF
  - Improving the system sensitivity for world leading measurements
  - Studies of materials for the next generation of LXe-detector
- Analysis of LZ data
  - Validate ML techniques for tagging and rejecting Radon backgrounds
  - Contribute to long science run dark matter search
- Studies for a next generation detector
  - Combining CREF measurements with LZ rejections techniques
  - Requirements for next-generation detector
- Plus potential for time on site at SURF, South Dakota

Opportunity to combine hands on detector development work & analysis of data from world-leading experiment!

Thanks for listening, do reach out to Maurits or me if you have questions.