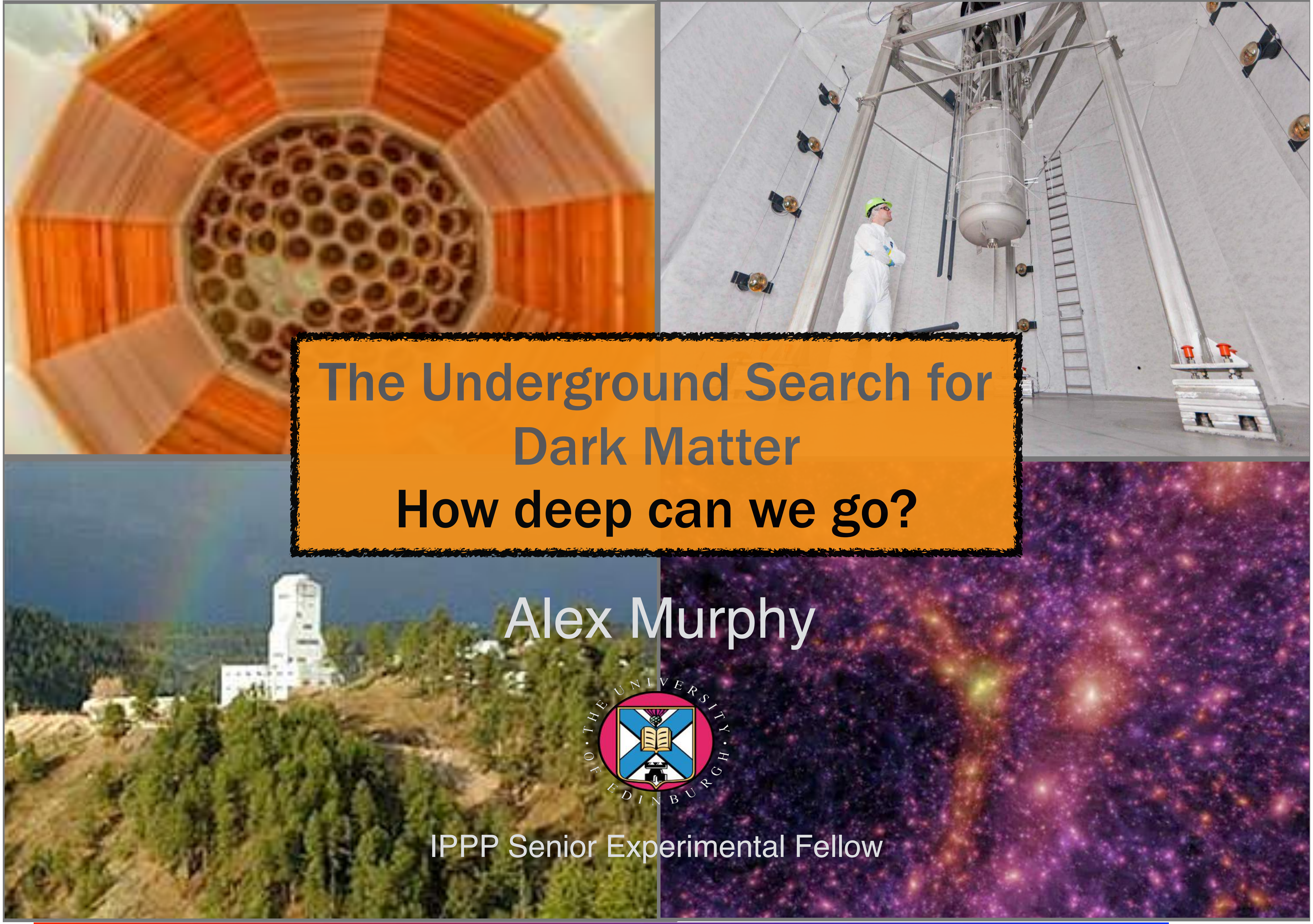


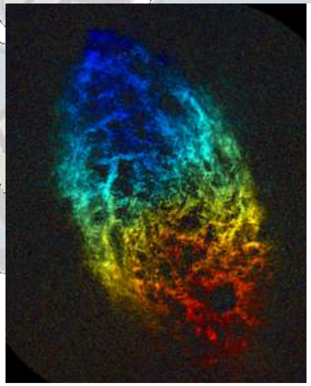
The Underground Search for Dark Matter

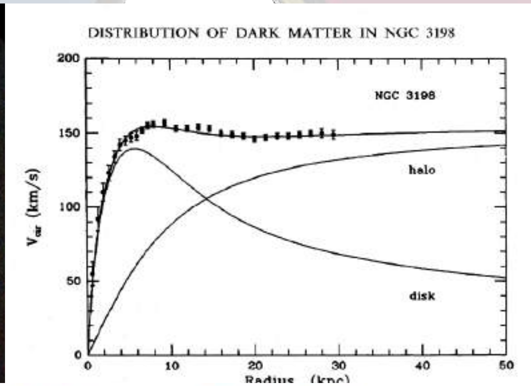
How deep can we go?

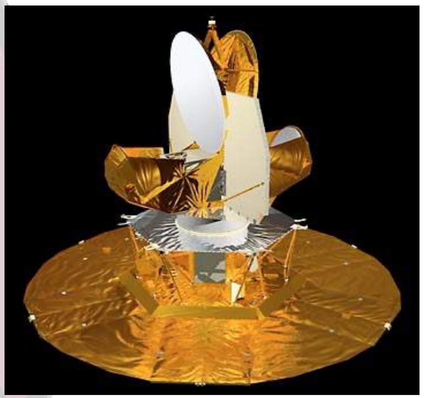
Alex Murphy

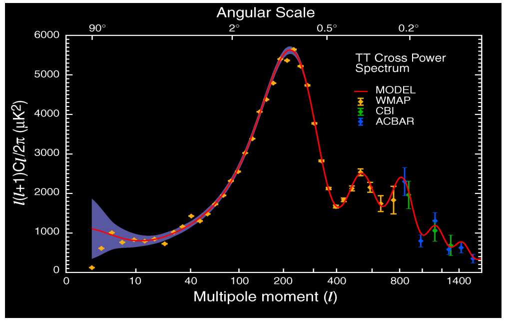
THE UNIVERSITY OF EDINBURGH

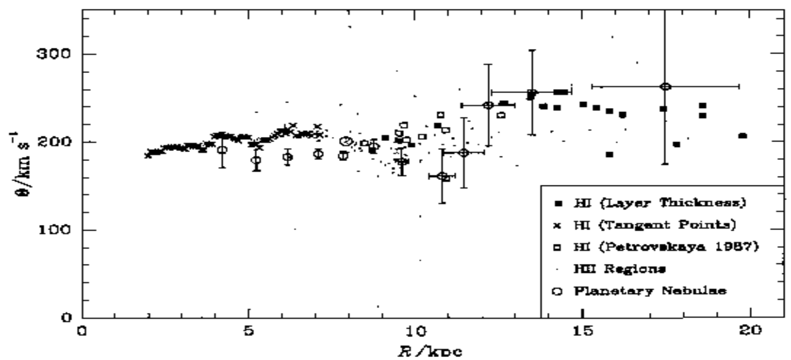
IPPP Senior Experimental Fellow



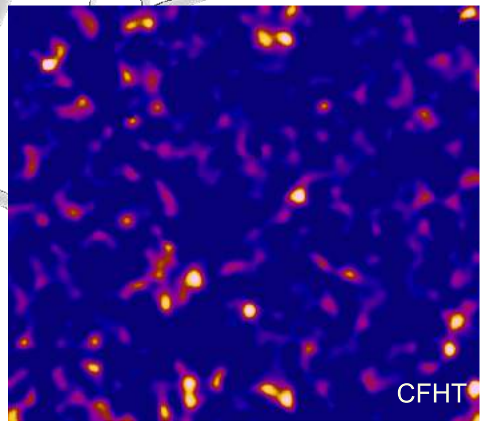


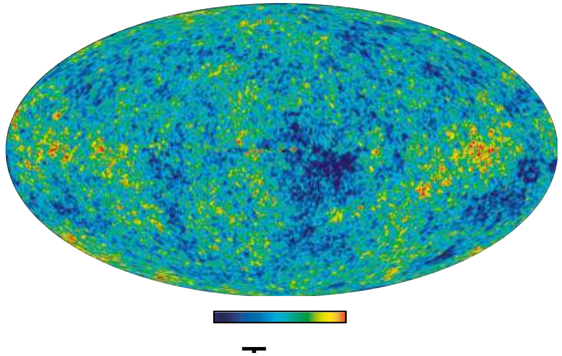


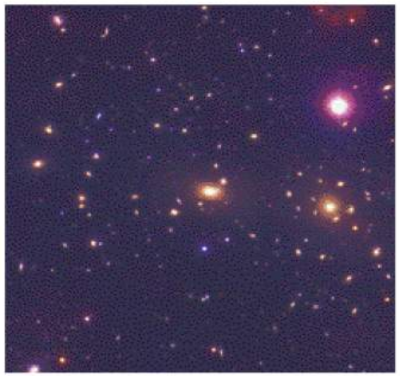




Comparison of the rotation curves calculated by all the methods discussed (assuming $R_0 = 7.9$ kpc and $\Theta_0 = 200$ km s^{-1}).

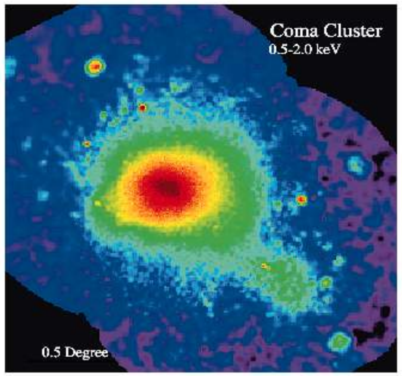




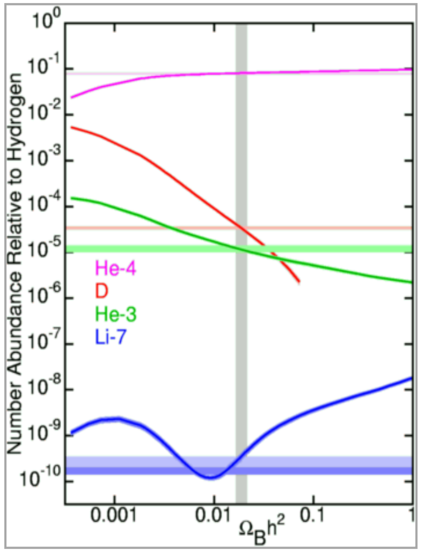


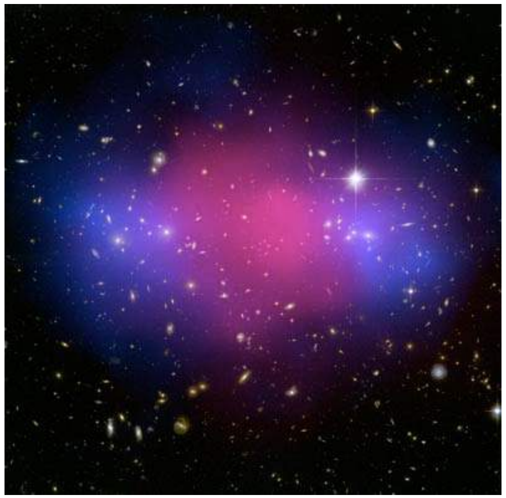
(a)

Copyright © Addison Wesley.

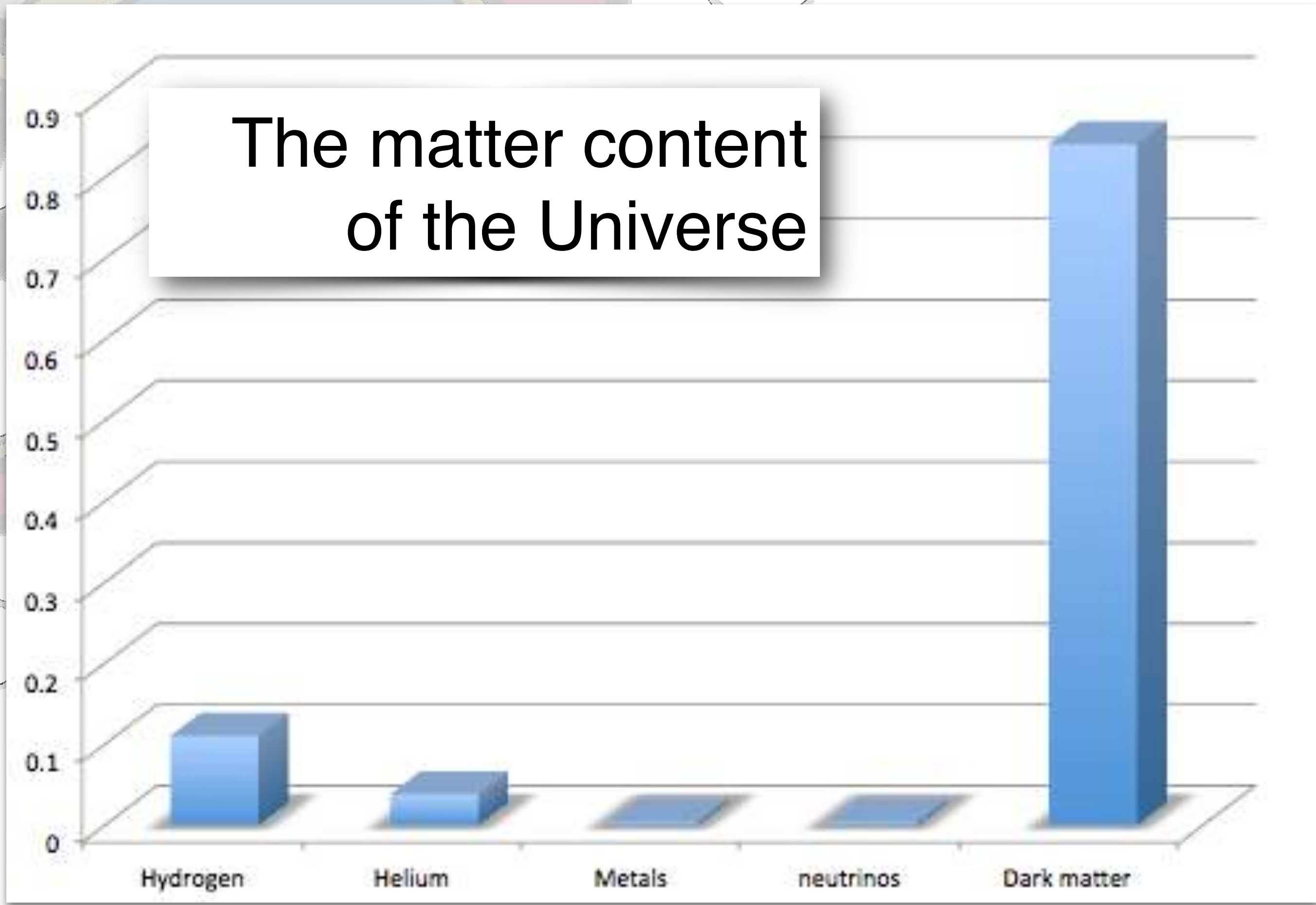


(b)





The *consistent* conclusion

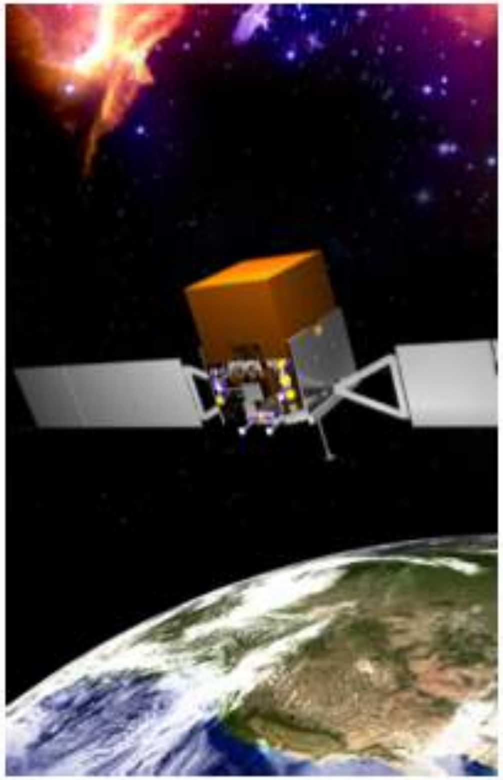


How to search for dark matter?

Collider

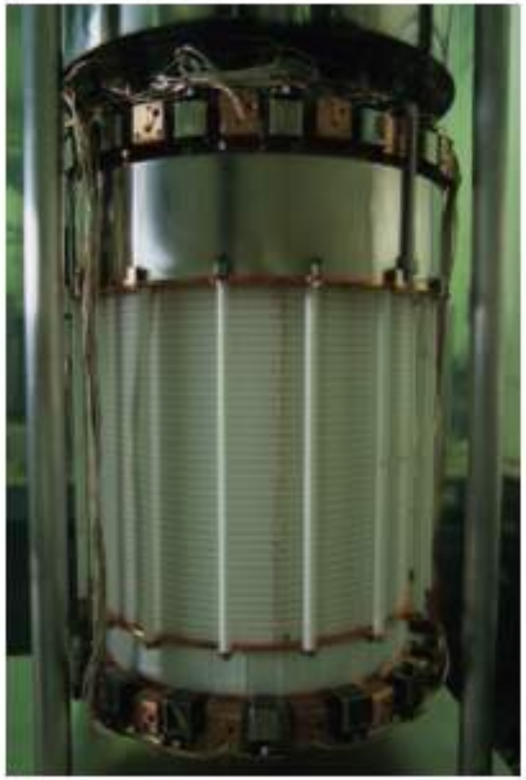
Production

Indirectly



Annihilation

Directly



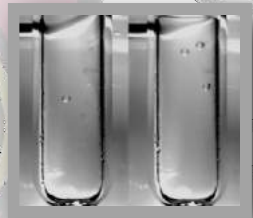
Scattering

Detection techniques

- Active targets - target is also detector
- Rare signal
- ....Radiologically pure material
- ...in a highly shielded environment
- DM particle weakly scatters ➜ one of the target atoms recoils, depositing energy
- Deposited energy generates photons, phonons and charge

Detection techniques

CDMS
EDELWEISS



CUOPP
PICASSO
PICO

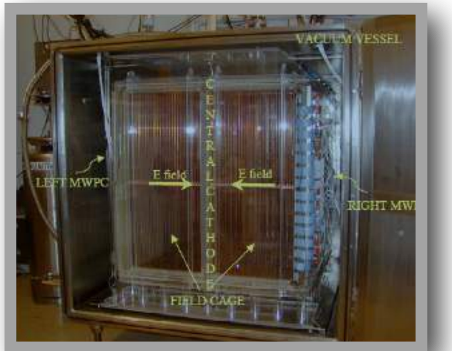
CRESST
ROSEBUD

Phonons

dE/dx

Charge

Light



HDMS
DRIFT
GERDA
MAJORANA
NEWS

ArDM
DARKSIDE
LUX
LZ
XENON
ZEPLIN

DAMA
LIBRA
XMASS
CLEAN
ANAIS
KIMS
DEAP/CLEAN

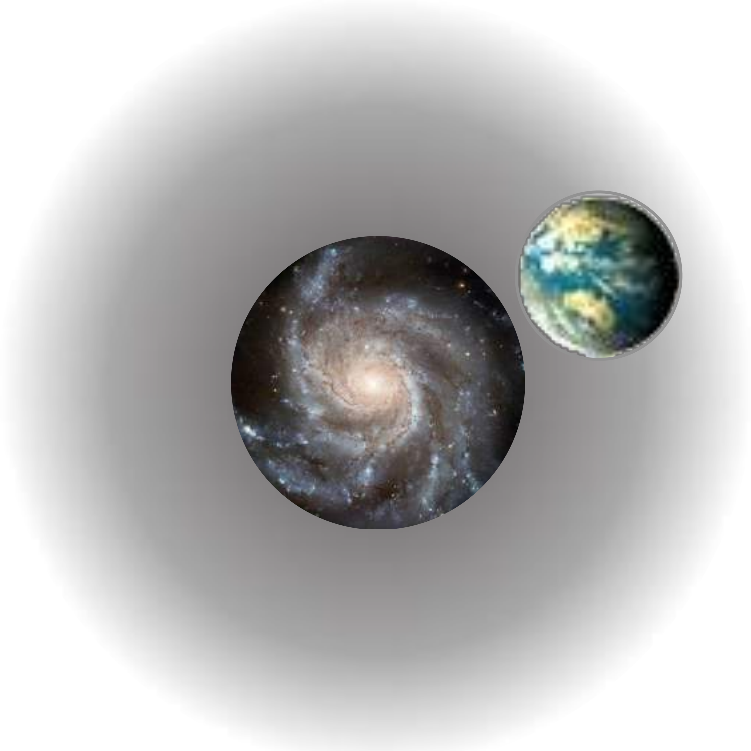
Implications for technology

- Going **underground** removes most CR muons
- **Radiopure** materials reduce backgrounds
- **Shielding** reduces backgrounds
- **Fiducialisation** (self-shielding) reduces backgrounds
- **Discrimination** separates remaining electron recoil background from signal

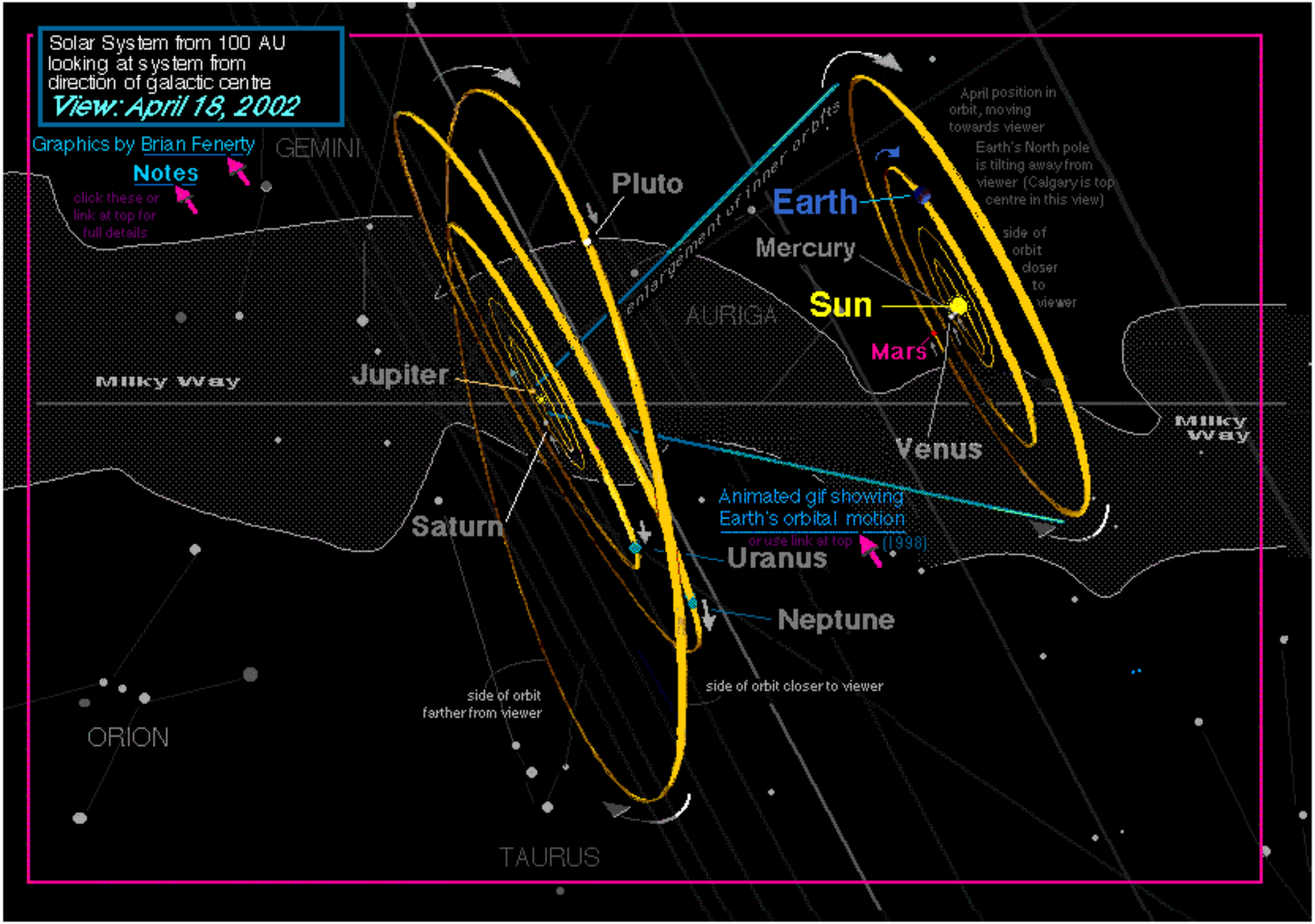
The 'direct' detection premise...

Interaction of galactic WIMPs (*our* Dark Matter) in ultra-low background terrestrial detectors

- Earth should be passing through a halo of weakly interacting massive particles



- We search for the ***rare*** collisions of DM particles with normal matter here on Earth.



Solar System from 100 AU
looking at system from
direction of galactic centre
View: April 18, 2002
Graphics by Brian Fenerty
Notes
click these or
link at top for
full details
GEMINI
Pluto
enlargement of inner orbits
Earth
Mercury
Sun
Mars
Venus
AURIGA
April position in
orbit, moving
towards viewer
Earth's North pole
is tilting away from
viewer (Calgary is top
centre in this view)
side of
orbit
closer
to
viewer
Milky Way
Jupiter
Saturn
Uranus
Neptune
Animated gif showing
Earth's orbital motion
or use link at top
(1998)
side of orbit closer to viewer
side of orbit
farther from viewer
ORION
TAURUS
Milky Way

^ top

This session

	Lumley Castle		12:30 - 14:00
14:00	**The underground search for dark matter: how deep can we go?**	*Alexander MURPHY*	
	Lumley Castle		14:00 - 14:30
	SuperCDMS	*Wolfgang RAU*	
	Lumley Castle		14:30 - 14:50
	Status of KIMS	*Moo Hyun LEE*	
15:00	*Lumley Castle*		14:50 - 15:10
	Testing DAMA/LIBRA signal with ANAIS112	*Maria MARTINEZ*	
	Lumley Castle		15:10 - 15:30
	PICO: dark matter detection with bubble chamber detectors	*Miquel ARDID*	
	Lumley Castle		15:30 - 16:00

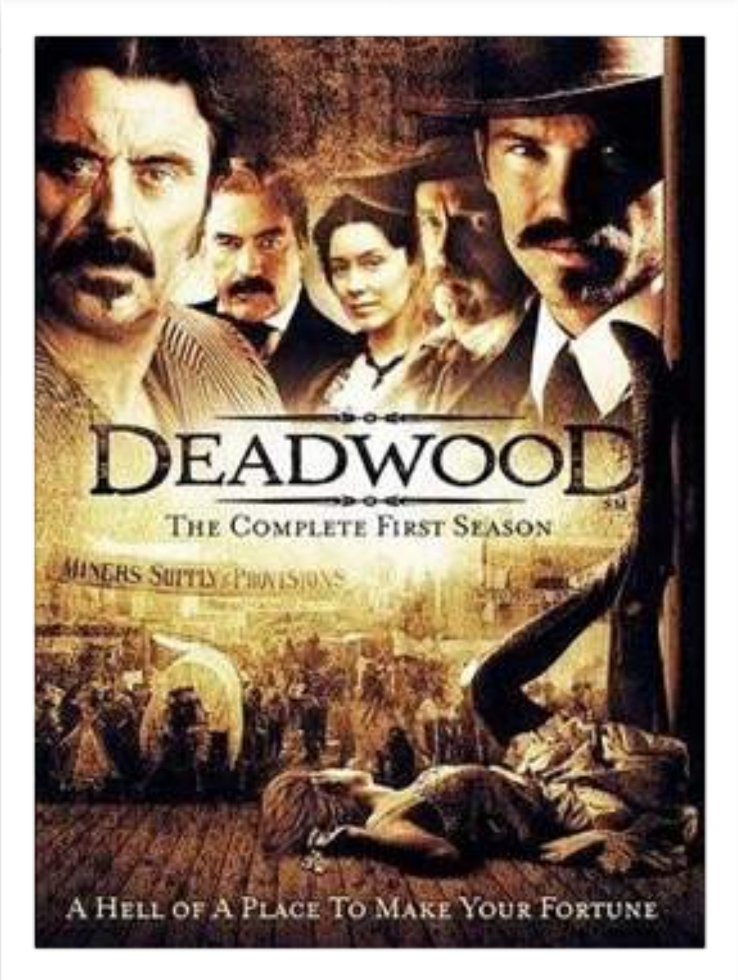
So here I'll discuss:

- Two phase xenon TPCs
  LUX (PandaX, XENON1T, XENONnT, LUX-ZEPLIN)
- Single phase argon: DEAP
- Something different: NEWS

LUX

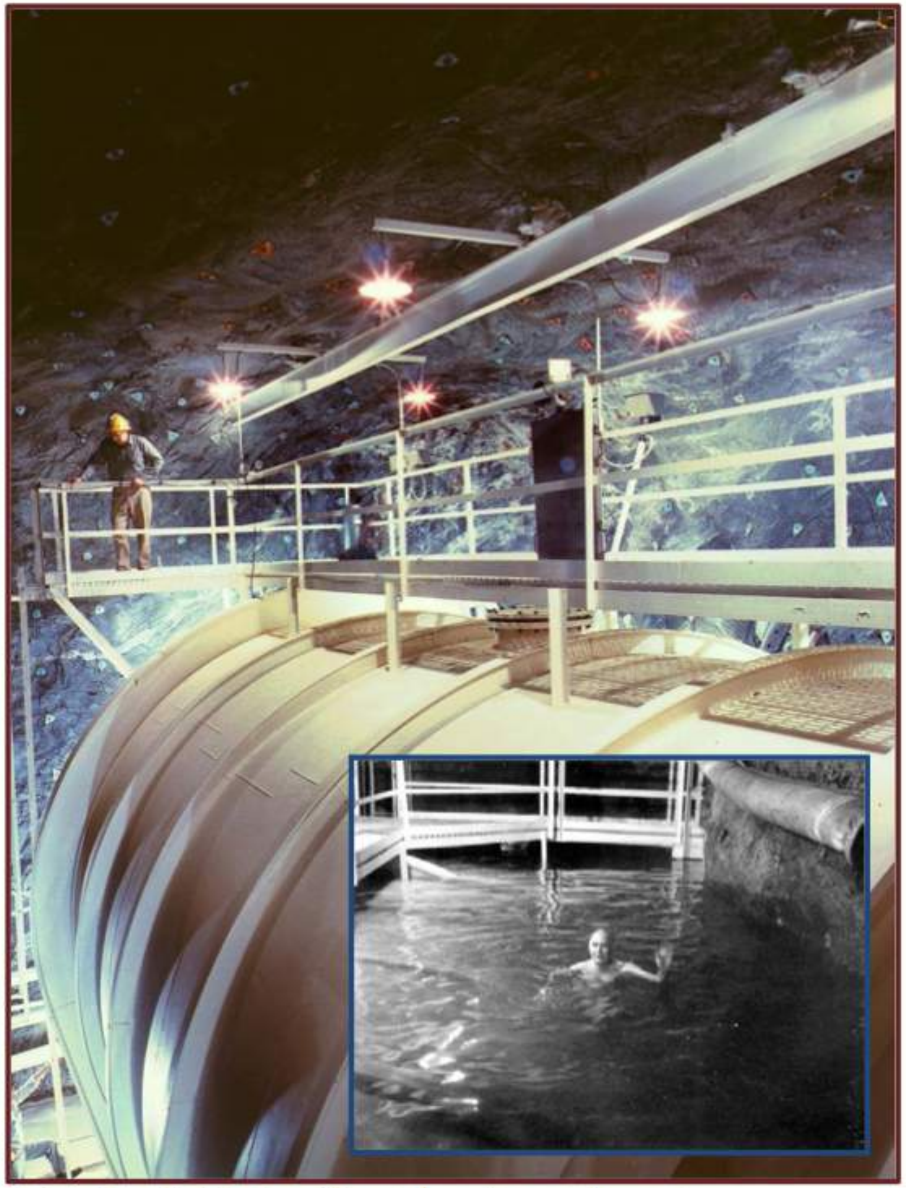
(and two-phase LXe TPCs in General)


SOUTH
DAKOTA
Denver, CO
Dallas, TX


DEADWOOD
THE COMPLETE FIRST SEASON
MINERS SUPPLY & PROVISIONS
A HELL OF A PLACE TO MAKE YOUR FORTUNE


Sanford Underground Research Laboratory

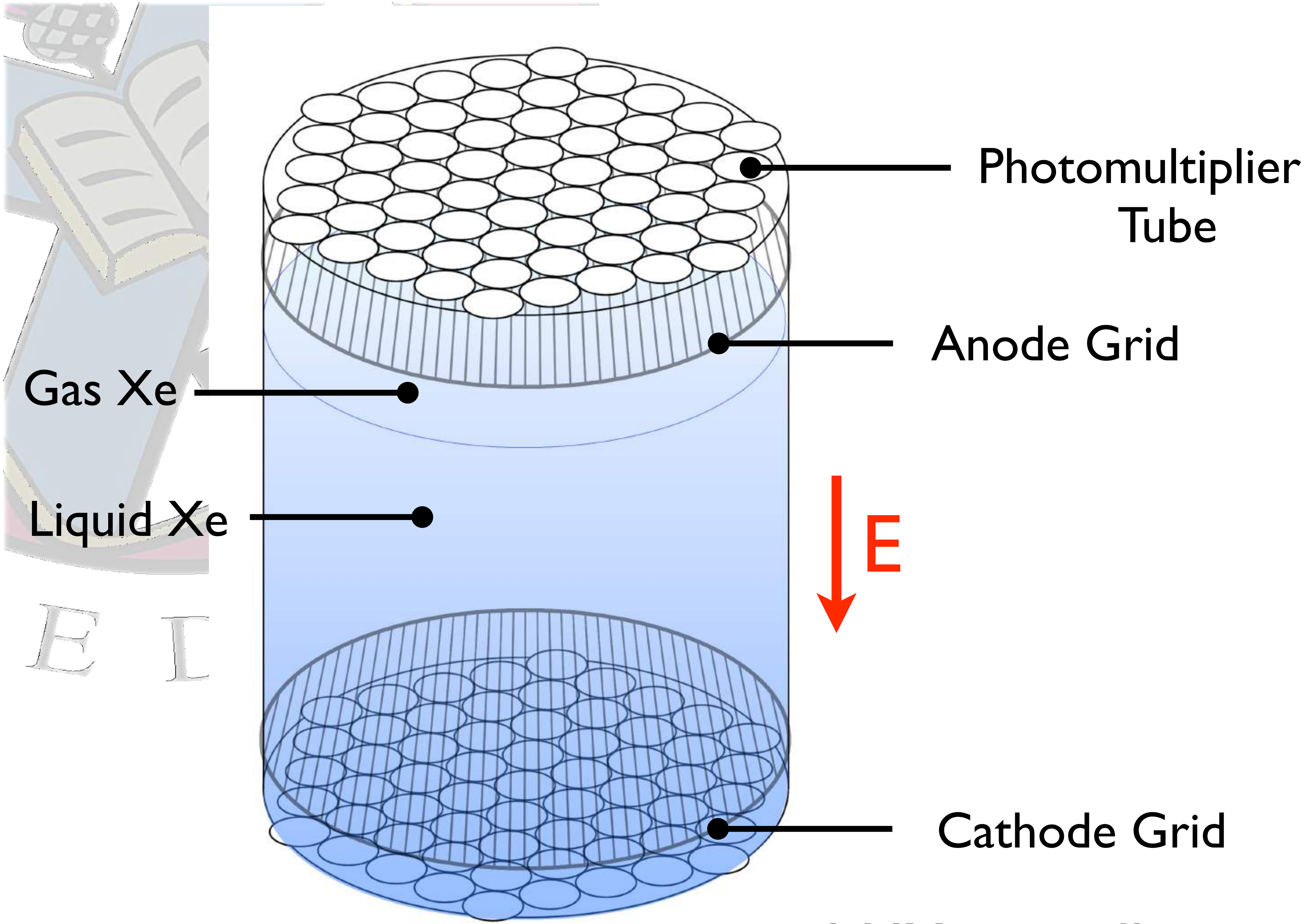
SURF – DAVIS CAVERN, 4850-FT U/G LEVEL



Ray Davis' Solar Neutrino Experiment

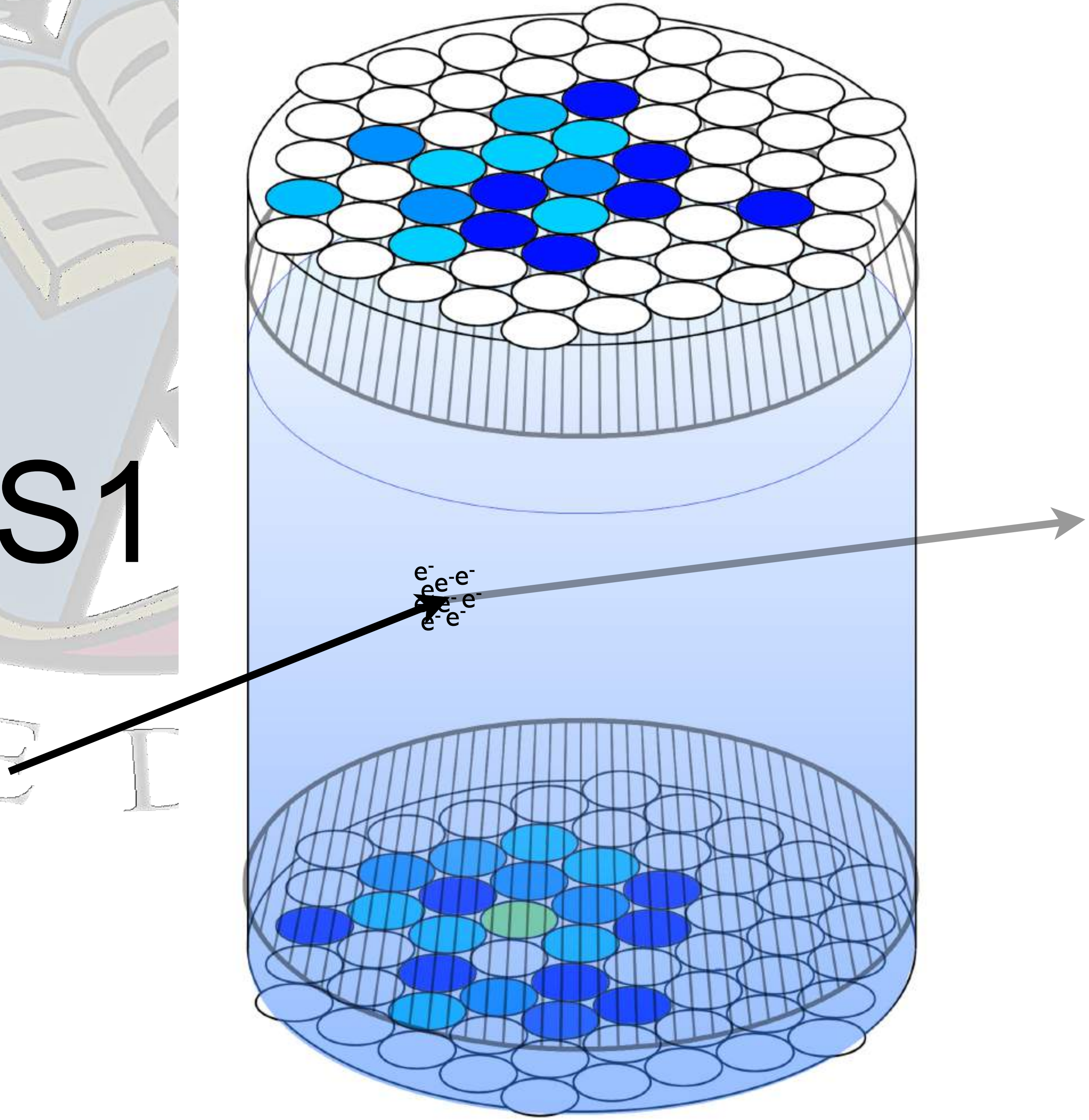
LUX Water Tank in Davis Campus

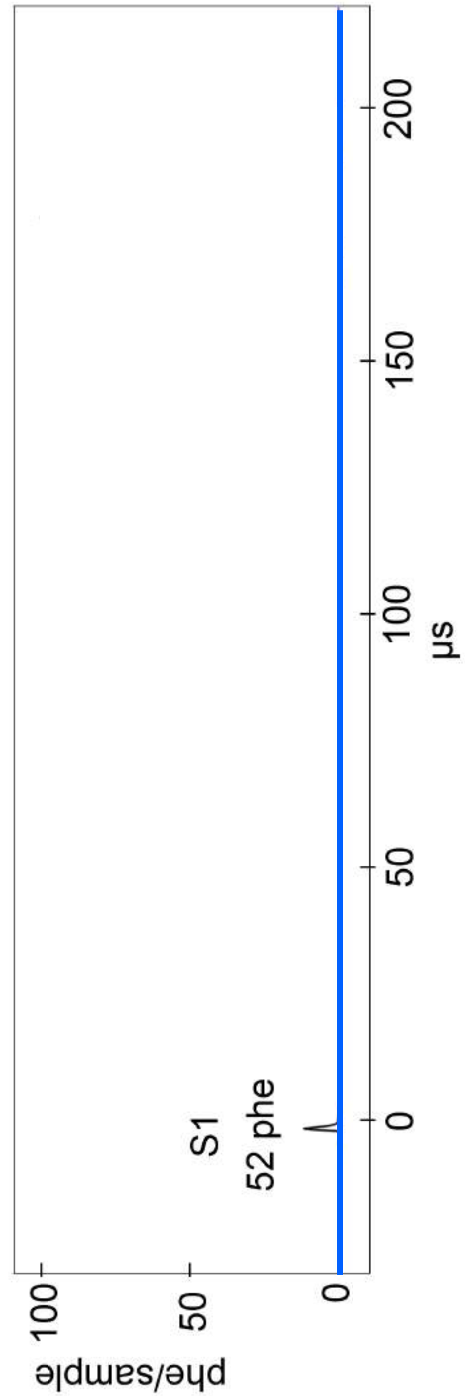
9

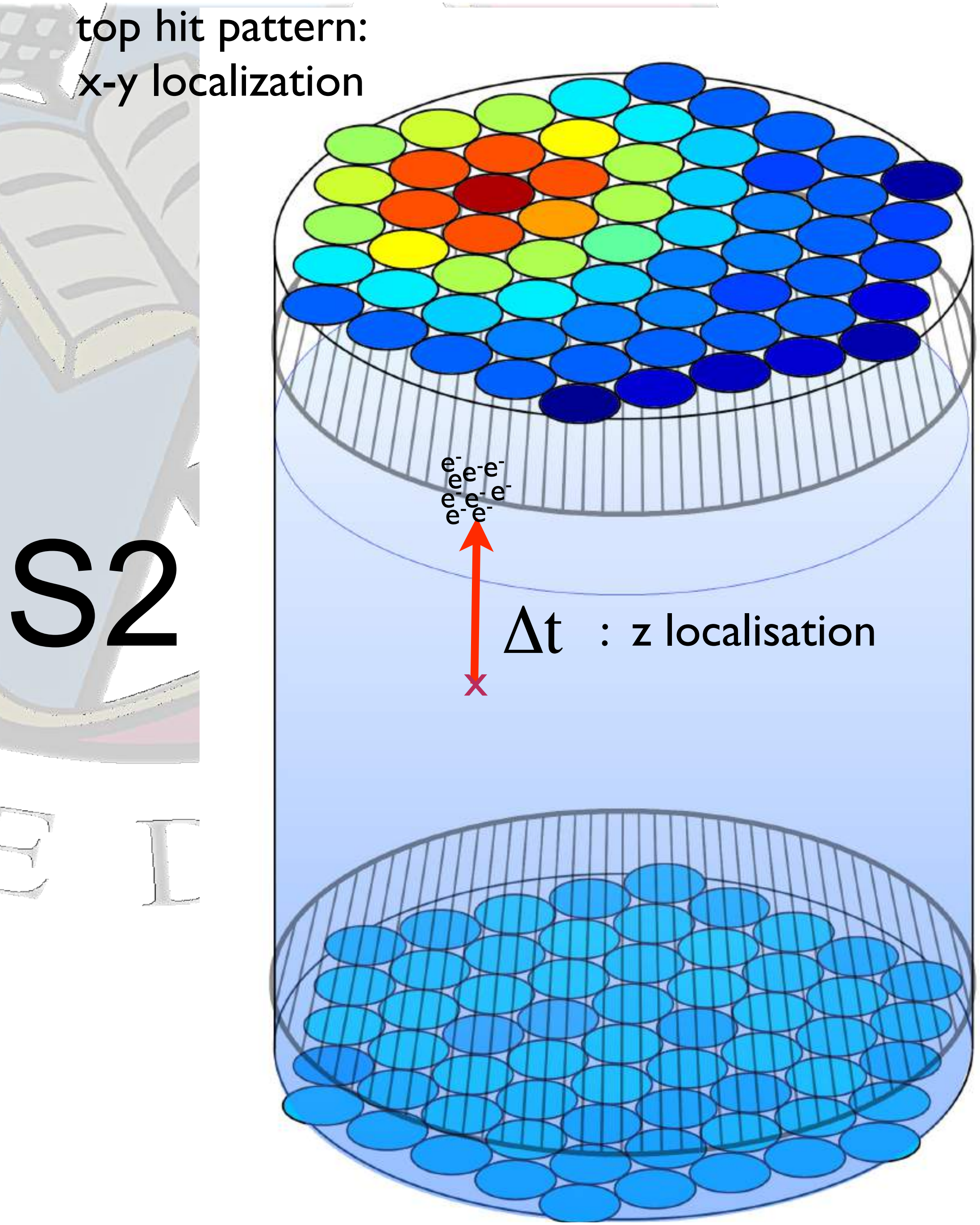


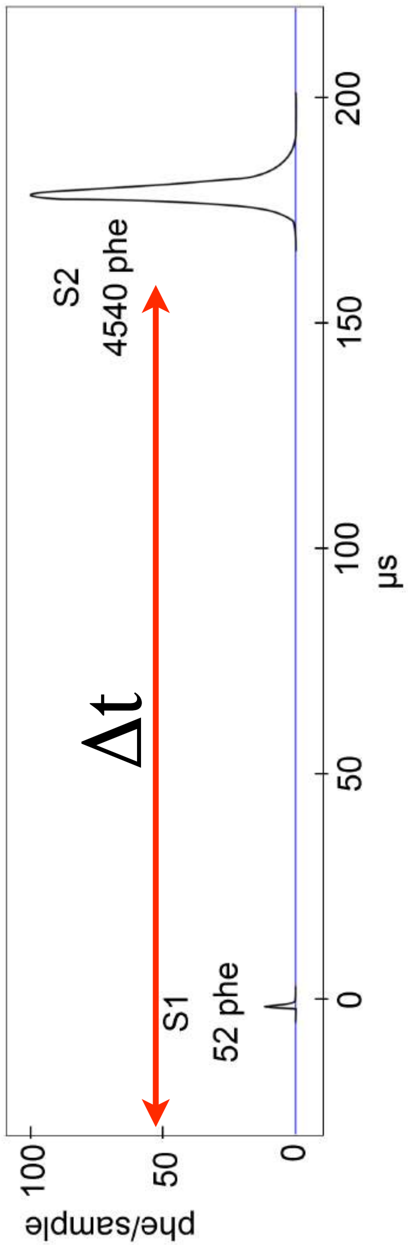
LUX ~250 litres

S1

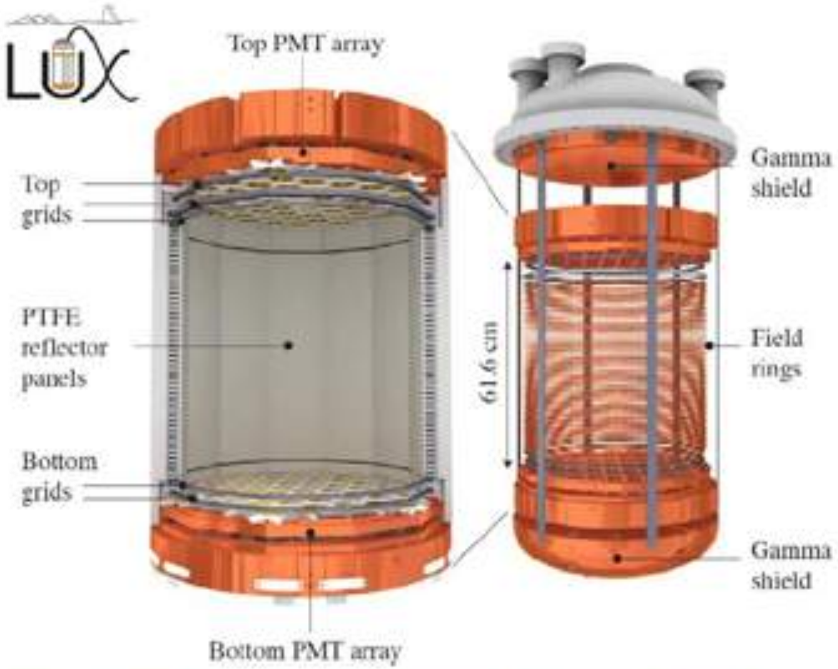


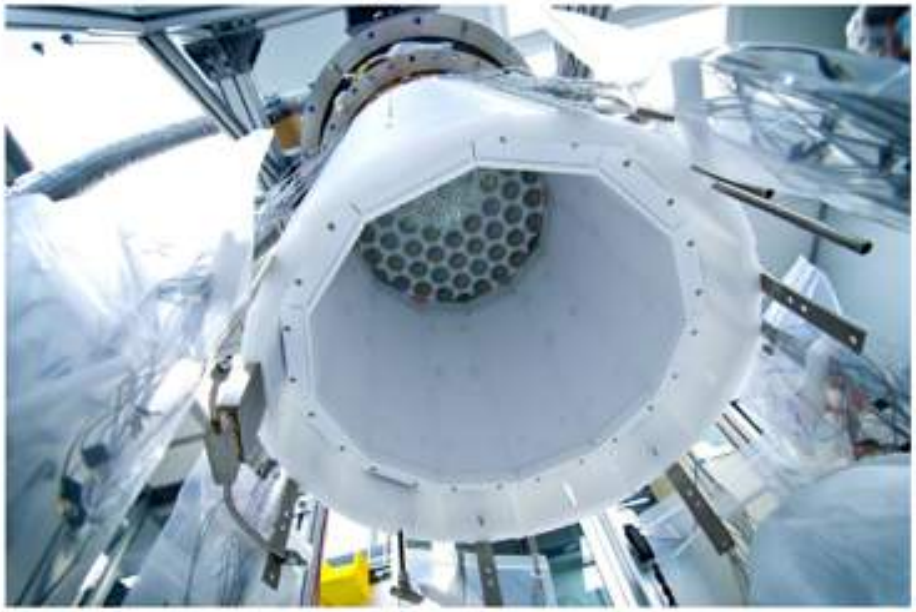


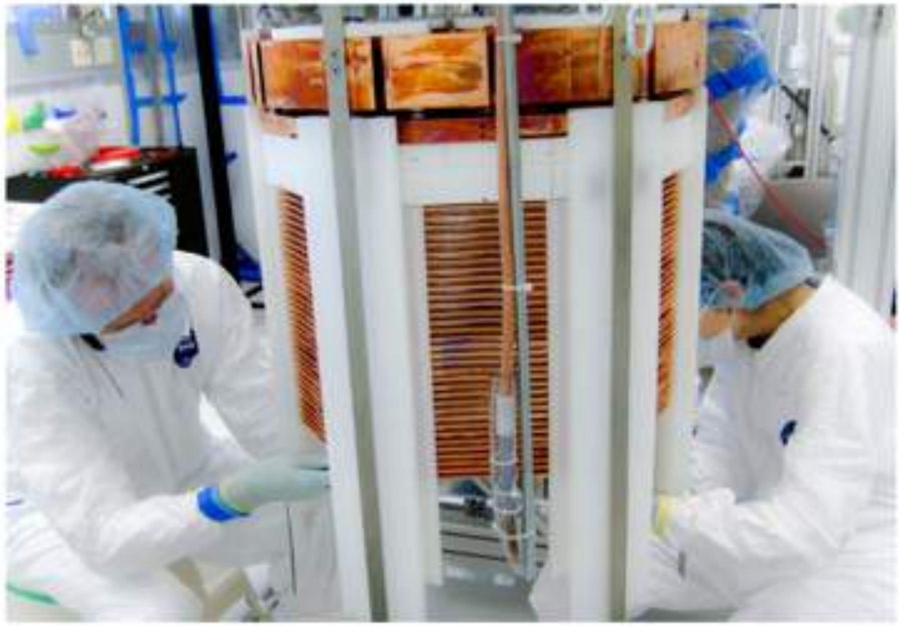


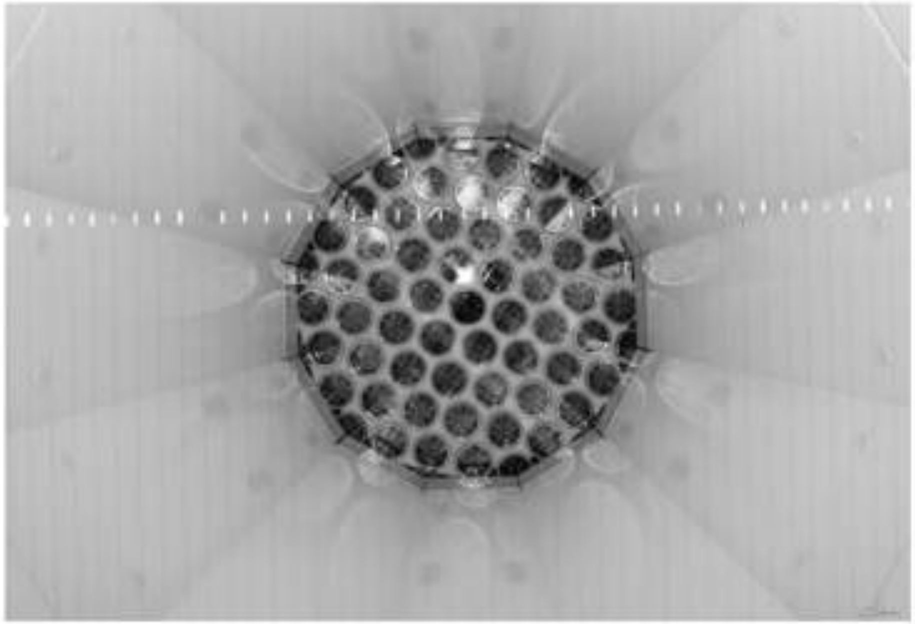


Ratio of S2 to S1 depends on the type of incident particle - allows us to reject >99.5% of background events


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








LUX within the
empty water
tank before
filling (Dec 2012)

PRL 112, 091303 (2014) PHYSICAL REVIEW LETTERS week ending 7 MARCH 2014

First Results from the LUX Dark Matter Experiment at the Sanford Underground Research Facility

D. S. Akerib,[2] H. M. Araújo,[4] X. Bai,[8] A. J. Bailey,[4] J. Balajthy,[16] S. Bedikian,[19] E. Bernard,[19] A. Bernstein,[6] A. Bolozdynya,[2] A. Bradley,[2] D. Byram,[18] S. B. Cahn,[19] M. C. Carmona-Benitez,[2,14] C. Chan,[1] J. J. Chapman,[1] A. A. Chiller,[18] C. Chiller,[18] K. Clark,[2] T. Coffey,[2] A. Currie,[4] A. Curioni,[19] S. Dazeley,[6] L. de Viveiros,[7] A. Dobi,[16] J. Dobson,[15] E. M. Dragowsky,[2] E. Druszkiewicz,[17] B. Edwards,[19,†] C. H. Faham,[1,5] S. Fiorucci,[1] C. Flores,[13] R. J. Gaitskell,[1] V. M. Gehman,[5] C. Ghag,[11] K. R. Gibson,[2] M. G. D. Gilchriese,[5] C. Hall,[16] M. Hanhardt,[8,9] S. A. Hertel,[19] M. Horn,[19] D. Q. Huang,[1] M. Ihm,[12] R. G. Jacobsen,[12] L. Kastens,[19] K. Kazkaz,[6] R. Knoche,[16] S. Kyre,[14] R. Lander,[13] N. A. Larsen,[19] C. Lee,[2] D. S. Leonard,[16] K. T. Lesko,[5] A. Lindote,[7] M. I. Lopes,[7] A. Lyashenko,[19] D. C. Malling,[1] R. Mannino,[10] D. N. McKinsey,[19] D.-M. Mei,[18] J. Mock,[13] M. Moongweluwan,[17] J. Morad,[13] M. Morii,[3] A. St. J. Murphy,[15] C. Nehrkorn,[14] H. Nelson,[14] F. Neves,[7] J. A. Nikkel,[19] R. A. Ott,[13] M. Pangilinan,[1] P. D. Parker,[19] E. K. Pease,[19] K. Pech,[2] P. Phelps,[2] L. Reichhart,[11] T. Shutt,[2] C. Silva,[7] W. Skulski,[17] C. J. Sofka,[10] V. N. Solovov,[7] P. Sorensen,[6] T. Stiegler,[10] K. O'Sullivan,[19] T. J. Sumner,[4] R. Svoboda,[13] M. Sweany,[13] M. Szydagis,[13] D. Taylor,[9] B. Tennyson,[19] D. R. Tiedt,[8] M. Tripathi,[13] S. Uvarov,[13] J. R. Verbus,[1] N. Walsh,[13] R. Webb,[10] J. T. White,[10,*] D. White,[14] M. S. Witherell,[14] M. Wlasenko,[3] F. L. H. Wolfs,[17] M. Woods,[13] and C. Zhang[18]

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(Received 30 October 2013; revised manuscript received 21 January 2014; published 4 March 2014)

The Large Underground Xenon (LUX) experiment is a dual-phase xenon time-projection chamber operating at the Sanford Underground Research Facility (Lead, South Dakota). The LUX cryostat was filled for the first time in the underground laboratory in February 2013. We report results of the first WIMP search data set, taken during the period from April to August 2013, presenting the analysis of 85.3 live days of data with a fiducial volume of 118 kg. A profile-likelihood analysis technique shows our data to be consistent with the background-only hypothesis, allowing 90% confidence limits to be set on spin-independent WIMP-nucleon elastic scattering with a minimum upper limit on the cross section of 7.6×10^{-46} cm^2 at a WIMP mass of 33 GeV/c^2. We find that the LUX data are in disagreement with low-mass WIMP signal interpretations of the results from several recent direct detection experiments.

DOI: 10.1103/PhysRevLett.112.091303 PACS numbers: 95.35.+d, 29.40.Gx, 95.55.Vj

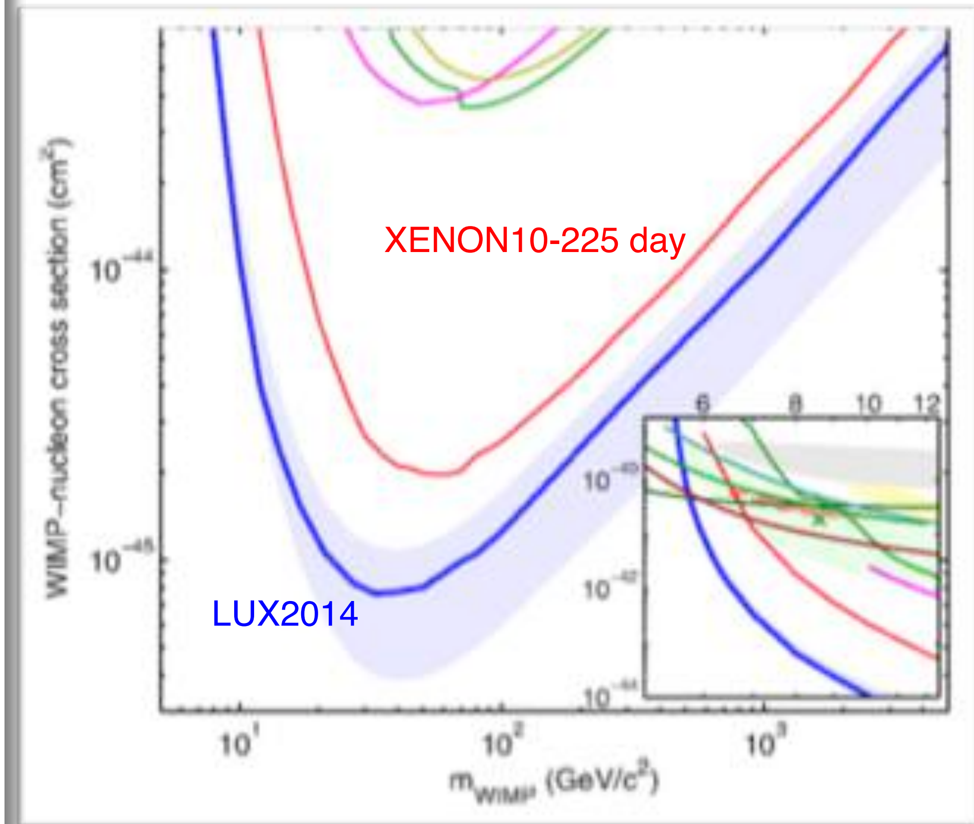
Convincing evidence for the existence of particle dark matter is derived from observations of the Universe on scales ranging from the galactic to the cosmological [1–3]. Increasingly detailed studies of the cosmic microwave background anisotropies have implied the abundance of dark matter with remarkable precision [4,5]. One favored

0031-9007/14/112(9)/091303(7) 091303-1

Physical Review Letters 112 (2014), 091303

Initial run Spin Independent results

118 kg
85.3 live days
AmBe and fixed source gamma ray calibrations
Enforced threshold at 3 keV$_{NR}$



Physical Review D 93 (2016), 072009

Dispersed tritium calibration

In situ measurement of ER response to low energies
Tritiated methane

PHYSICAL REVIEW D **93,** 072009 (2016)

Tritium calibration of the LUX dark matter experiment

D. S. Akerib,[1,2,3] H. M. Araújo,[4] X. Bai,[5] A. J. Bailey,[4] J. Balajthy,[6] P. Beltrame,[7] E. P. Bernard,[8] A. Bernstein,[9] T. P. Biesiadzinski,[1,2,3] E. M. Boulton,[8] A. Bradley,[1] R. Bramante,[1,2,3] S. B. Cahn,[8] M. C. Carmona-Benitez,[10] C. Chan,[11] J. J. Chapman,[11] A. A. Chiller,[12] C. Chiller,[12] A. Currie,[4] J. E. Cutter,[13] T. J. R. Davison,[7] L. de Viveiros,[14] A. Dobi,[15] J. E. Y. Dobson,[16] E. Druszkiewicz,[17] B. N. Edwards,[8] C. H. Faham,[15] S. Fiorucci,[11] R. J. Gaitskell,[11] V. M. Gehman,[15] C. Ghag,[16] K. R. Gibson,[1] M. G. D. Gilchriese,[15] C. R. Hall,[6] M. Hanhardt,[5,18] S. J. Haselschwardt,[10] S. A. Hertel,[19,8] D. P. Hogan,[19] M. Horn,[19,8] D. Q. Huang,[11] C. M. Ignarra,[2,3] M. Ihm,[19] R. G. Jacobsen,[19] W. Ji,[1,2,3] K. Kazkaz,[9] D. Khaitan,[17] R. Knoche,[6] N. A. Larsen,[8] C. Lee,[1,2,3] B. G. Lenardo,[13,9] K. T. Lesko,[15] A. Lindote,[14] M. I. Lopes,[14] D. C. Malling,[11] A. G. Manalaysay,[13] R. L. Mannino,[20] M. F. Marzioni,[7] D. N. McKinsey,[19,8] D.-M. Mei,[12] J. Mock,[21] M. Moongweluwan,[17] J. A. Morad,[13] A. St. J. Murphy,[7] C. Nehrkorn,[10] H. N. Nelson,[10] F. Neves,[14] K. O'Sullivan,[19,15,8] K. C. Oliver-Mallory,[19] R. A. Ott,[13] K. J. Palladino,[2,3] M. Pangilinan,[11] E. K. Pease,[8] P. Phelps,[1] L. Reichhart,[16] C. Rhyne,[11] S. Shaw,[16] T. A. Shutt,[1,2,3] C. Silva,[14] V. N. Solovov,[14] P. Sorensen,[15] S. Stephenson,[13] T. J. Sumner,[4] M. Szydagis,[21] D. J. Taylor,[18] W. Taylor,[11] B. P. Tennyson,[8] P. A. Terman,[20] D. R. Tiedt,[5] W. H. To,[1,2,3] M. Tripathi,[13] L. Tvrznikova,[8] S. Uvarov,[13] J. R. Verbus,[11] R. C. Webb,[20] J. T. White,[20] T. J. Whitis,[1,2,3] M. S. Witherell,[10] F. L. H. Wolfs,[17] S. K. Young,[21] and C. Zhang[12]

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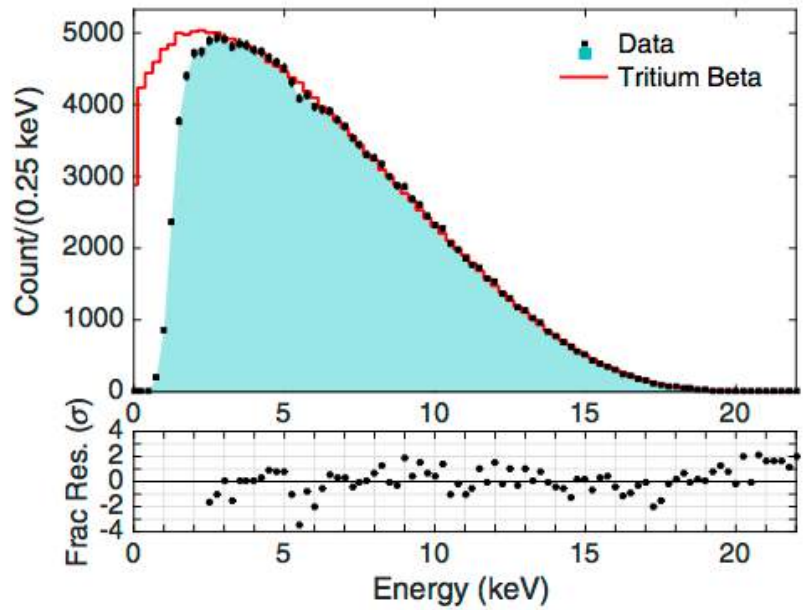
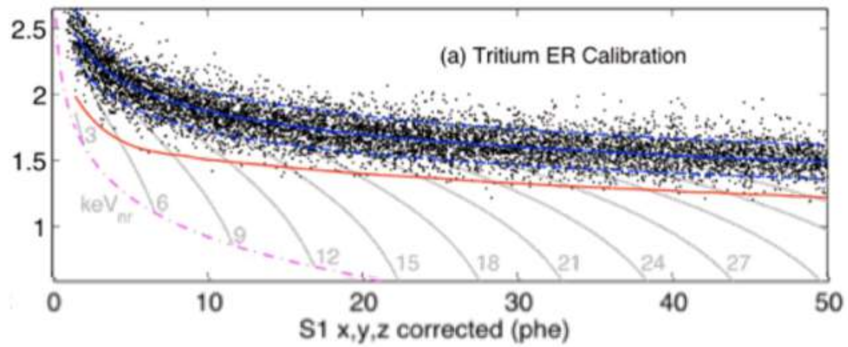
(Received 9 December 2015; published 20 April 2016)

We present measurements of the electron-recoil (ER) response of the LUX dark matter detector based upon 170 000 highly pure and spatially uniform tritium decays. We reconstruct the tritium energy spectrum using the combined energy model and find good agreement with expectations. We report the average charge and light yields of ER events in liquid xenon at 180 and 105 V/cm and compare the results to the NEST model. We also measure the mean charge recombination fraction and its fluctuations, and we investigate the location and width of the LUX ER band. These results provide input to a reanalysis of the LUX run 3 weakly interacting massive particle search.

DOI: 10.1103/PhysRevD.93.072009

2470-0010/2016/93(7)/072009(12) 072009-1





Submitted Phys. Rev. C, arXiv: 1608.05381

DD neutron generator calibration
Low energy NR response

Low-energy (0.7–74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics

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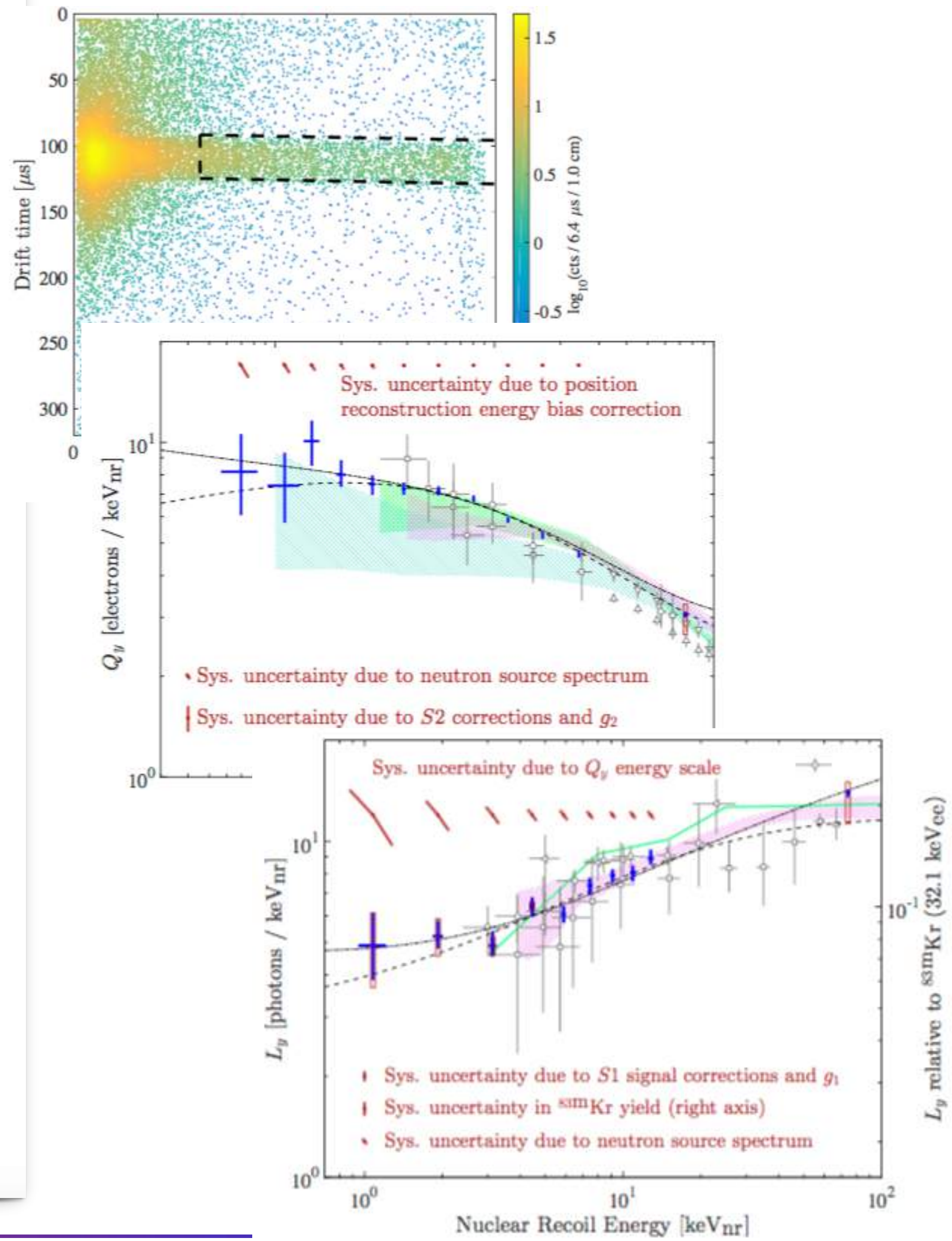
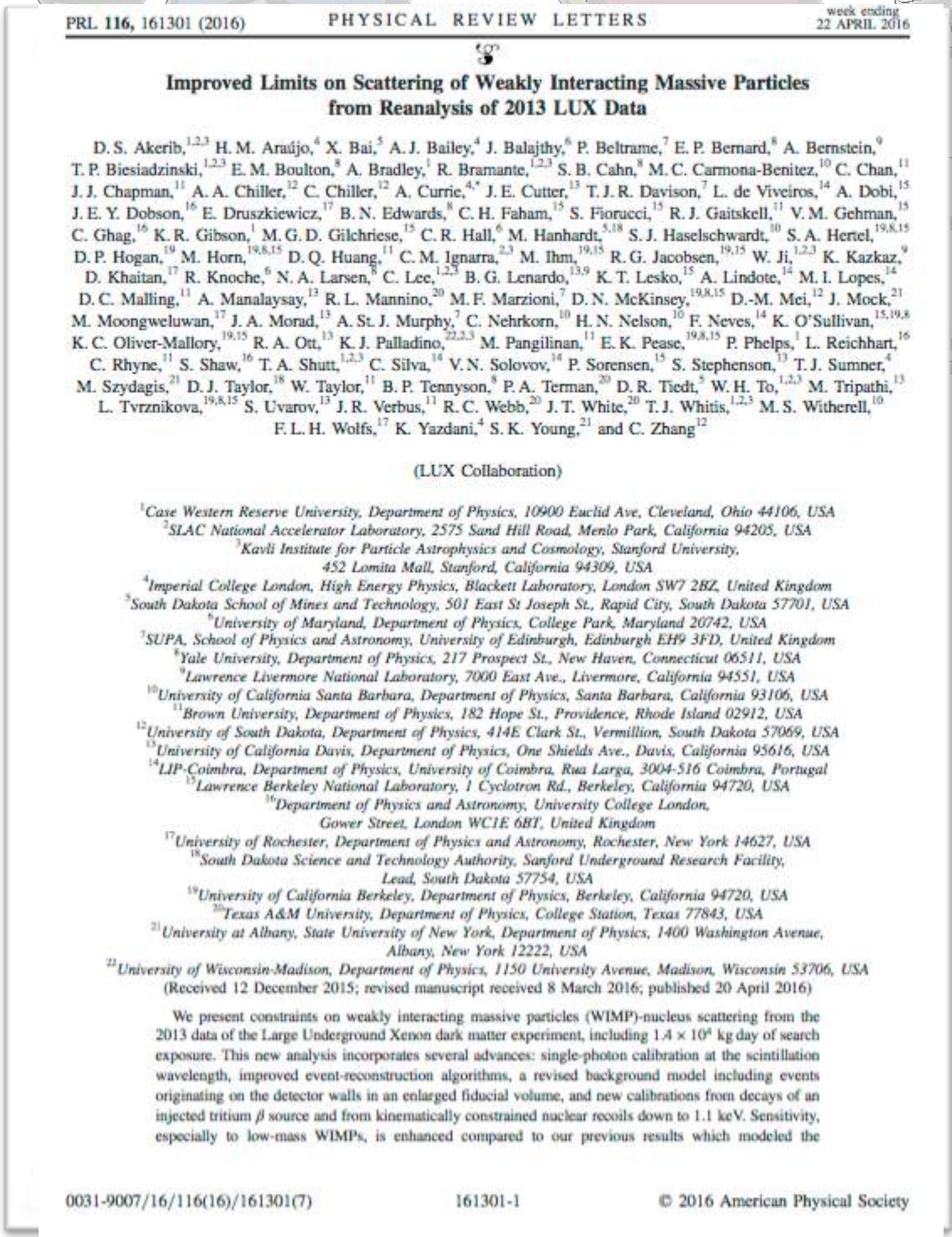
(Dated: October 27, 2016)

The Large Underground Xenon (LUX) experiment is a dual-phase liquid xenon time projection chamber (TPC) operating at the Sanford Underground Research Facility in Lead, South Dakota. A calibration of nuclear recoils in liquid xenon was performed *in situ* in the LUX detector using a collimated beam of mono-energetic 2.45 MeV neutrons produced by a deuterium-deuterium (D-D) fusion source. The nuclear recoil energy from the first neutron scatter in the TPC was reconstructed using the measured scattering angle defined by double-scatter neutron events within the active xenon volume. We measured the absolute charge (Q_y) and light (L_y) yields at an average electric field of 180 V/cm for nuclear recoil energies spanning 0.7 to 74 keV and 1.1 to 74 keV, respectively. This calibration of the nuclear recoil signal yields will permit the further refinement of liquid xenon nuclear recoil signal models and, importantly for dark matter searches, clearly demonstrates measured ionization and scintillation signals in this medium at recoil energies down to $\mathcal{O}$(1 keV).





PRL 116, 161301 (2016) PHYSICAL REVIEW LETTERS week ending 22 APRIL 2016

Improved Limits on Scattering of Weakly Interacting Massive Particles from Reanalysis of 2013 LUX Data

D. S. Akerib,[1,2,3] H. M. Araújo,[4] X. Bai,[5] A. J. Bailey,[4] J. Balajthy,[6] P. Beltrame,[7] E. P. Bernard,[8] A. Bernstein,[9] T. P. Biesiadzinski,[1,2,3] E. M. Boulton,[8] A. Bradley,[1] R. Bramante,[1,2,3] S. B. Cahn,[8] M. C. Carmona-Benitez,[10] C. Chan,[11] J. J. Chapman,[11] A. A. Chiller,[12] C. Chiller,[12] A. Currie,[4,*] J. E. Cutter,[13] T. J. R. Davison,[7] L. de Viveiros,[14] A. Dobi,[15] J. E. Y. Dobson,[16] E. Druszkiewicz,[17] B. N. Edwards,[8] C. H. Faham,[15] S. Fiorucci,[15] R. J. Gaitskell,[11] V. M. Gehman,[15] C. Ghag,[16] K. R. Gibson,[1] M. G. D. Gilchriese,[15] C. R. Hall,[6] M. Hanhardt,[5,18] S. J. Haselschwardt,[10] S. A. Hertel,[19,8,15] D. P. Hogan,[19] M. Horn,[19,8,15] D. Q. Huang,[11] C. M. Ignarra,[2,3] M. Ihm,[19,15] R. G. Jacobsen,[19,15] W. Ji,[1,2,3] K. Kazkaz,[9] D. Khaitan,[17] R. Knoche,[6] N. A. Larsen,[8] C. Lee,[1,2,3] B. G. Lenardo,[13,9] K. T. Lesko,[15] A. Lindote,[14] M. I. Lopes,[14] D. C. Malling,[11] A. Manalaysay,[13] R. L. Mannino,[20] M. F. Marzioni,[7] D. N. McKinsey,[19,8,15] D.-M. Mei,[12] J. Mock,[21] M. Moongweluwan,[17] J. A. Morad,[13] A. St. J. Murphy,[7] C. Nehrkorn,[10] H. N. Nelson,[10] F. Neves,[14] K. O'Sullivan,[15,19,8] K. C. Oliver-Mallory,[19,15] R. A. Ott,[13] K. J. Palladino,[22,2,3] M. Pangilinan,[11] E. K. Pease,[19,8,15] P. Phelps,[1] L. Reichhart,[16] C. Rhyne,[11] S. Shaw,[16] T. A. Shutt,[1,2,3] C. Silva,[14] V. N. Solovov,[14] P. Sorensen,[15] S. Stephenson,[13] T. J. Sumner,[4] M. Szydagis,[21] D. J. Taylor,[18] W. Taylor,[11] B. P. Tennyson,[8] P. A. Terman,[20] D. R. Tiedt,[5] W. H. To,[1,2,3] M. Tripathi,[13] L. Tvrznikova,[19,8,15] S. Uvarov,[13] J. R. Verbus,[11] R. C. Webb,[20] J. T. White,[20] T. J. Whitis,[1,2,3] M. S. Witherell,[10] F. L. H. Wolfs,[17] K. Yazdani,[4] S. K. Young,[21] and C. Zhang[12]

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We present constraints on weakly interacting massive particles (WIMP)-nucleus scattering from the 2013 data of the Large Underground Xenon dark matter experiment, including 1.4×10^4 kg day of search exposure. This new analysis incorporates several advances: single-photon calibration at the scintillation wavelength, improved event-reconstruction algorithms, a revised background model including events originating on the detector walls in an enlarged fiducial volume, and new calibrations from decays of an injected tritium β source and from kinematically constrained nuclear recoils down to 1.1 keV. Sensitivity, especially to low-mass WIMPs, is enhanced compared to our previous results which modeled the

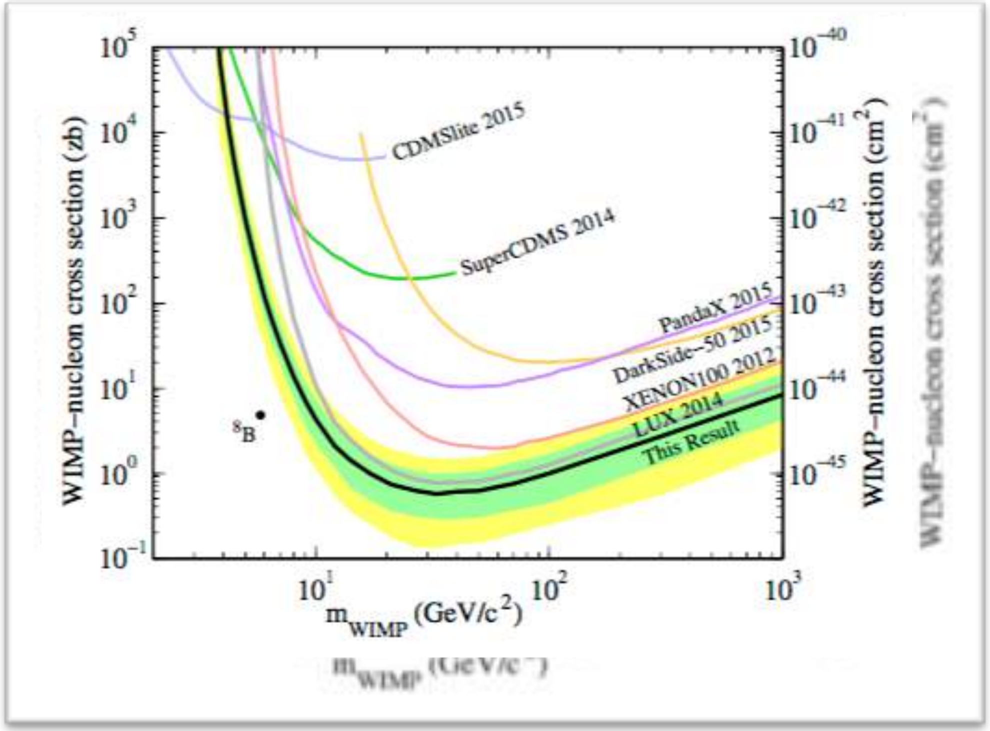
0031-9007/16/116(16)/161301(7) 161301-1

Physical Review Letters 116 (2016), 161301

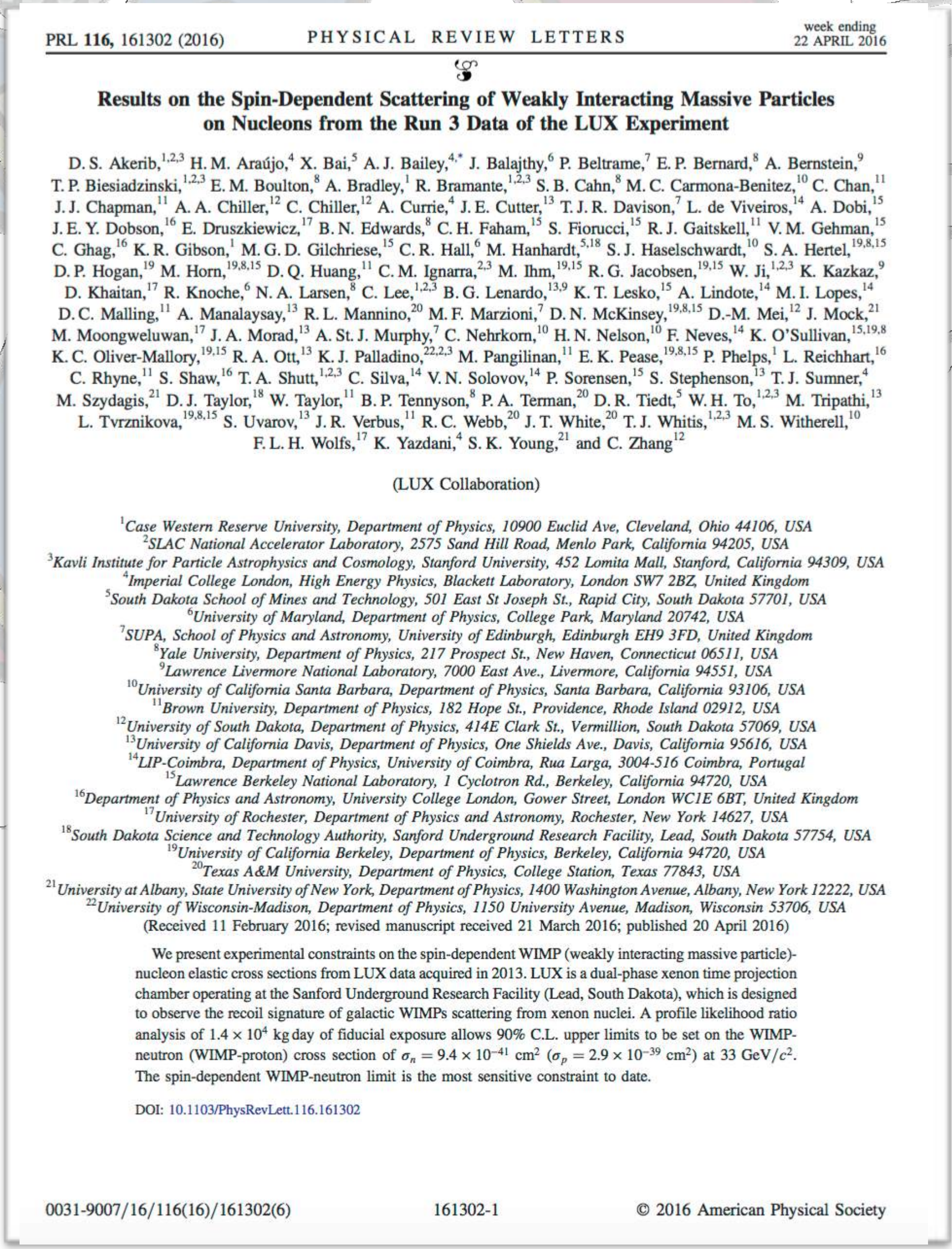
Improved Spin Independent results

Additional DD and tritium calibrations used
Improved peak finding, analysis
145.4 kg
95 days
Threshold reduced to 1.1 keV_{NR}

Significant improvement for low masses



Physical Review Letters 116 (2016), 161302



PRL 116, 161302 (2016) PHYSICAL REVIEW LETTERS week ending 22 APRIL 2016

Results on the Spin-Dependent Scattering of Weakly Interacting Massive Particles on Nucleons from the Run 3 Data of the LUX Experiment

D. S. Akerib,[1,2,3] H. M. Araújo,[4] X. Bai,[5] A. J. Bailey,[4,*] J. Balajthy,[6] P. Beltrame,[7] E. P. Bernard,[8] A. Bernstein,[9] T. P. Biesiadzinski,[1,2,3] E. M. Boulton,[8] A. Bradley,[1] R. Bramante,[1,2,3] S. B. Cahn,[8] M. C. Carmona-Benitez,[10] C. Chan,[11] J. J. Chapman,[11] A. A. Chiller,[12] C. Chiller,[12] A. Currie,[4] J. E. Cutter,[13] T. J. R. Davison,[7] L. de Viveiros,[14] A. Dobi,[15] J. E. Y. Dobson,[16] E. Druszkiewicz,[17] B. N. Edwards,[8] C. H. Faham,[15] S. Fiorucci,[15] R. J. Gaitskell,[11] V. M. Gehman,[15] C. Ghag,[16] K. R. Gibson,[1] M. G. D. Gilchriese,[15] C. R. Hall,[6] M. Hanhardt,[5,18] S. J. Haselschwardt,[10] S. A. Hertel,[19,8,15] D. P. Hogan,[19] M. Horn,[19,8,15] D. Q. Huang,[11] C. M. Ignarra,[2,3] M. Ihm,[19,15] R. G. Jacobsen,[19,15] W. Ji,[1,2,3] K. Kazkaz,[9] D. Khaitan,[17] R. Knoche,[6] N. A. Larsen,[8] C. Lee,[1,2,3] B. G. Lenardo,[13,9] K. T. Lesko,[15] A. Lindote,[14] M. I. Lopes,[14] D. C. Malling,[11] A. Manalaysay,[13] R. L. Mannino,[20] M. F. Marzioni,[7] D. N. McKinsey,[19,8,15] D.-M. Mei,[12] J. Mock,[21] M. Moongweluwan,[17] J. A. Morad,[13] A. St. J. Murphy,[7] C. Nehrkorn,[10] H. N. Nelson,[10] F. Neves,[14] K. O'Sullivan,[15,19,8] K. C. Oliver-Mallory,[19,15] R. A. Ott,[13] K. J. Palladino,[22,2,3] M. Pangilinan,[11] E. K. Pease,[19,8,15] P. Phelps,[1] L. Reichhart,[16] C. Rhyne,[11] S. Shaw,[16] T. A. Shutt,[1,2,3] C. Silva,[14] V. N. Solovov,[14] P. Sorensen,[15] S. Stephenson,[13] T. J. Sumner,[4] M. Szydagis,[21] D. J. Taylor,[18] W. Taylor,[11] B. P. Tennyson,[8] P. A. Terman,[20] D. R. Tiedt,[5] W. H. To,[1,2,3] M. Tripathi,[13] L. Tvrznikova,[19,8,15] S. Uvarov,[13] J. R. Verbus,[11] R. C. Webb,[20] J. T. White,[20] T. J. Whitis,[1,2,3] M. S. Witherell,[10] F. L. H. Wolfs,[17] K. Yazdani,[4] S. K. Young,[21] and C. Zhang[12]

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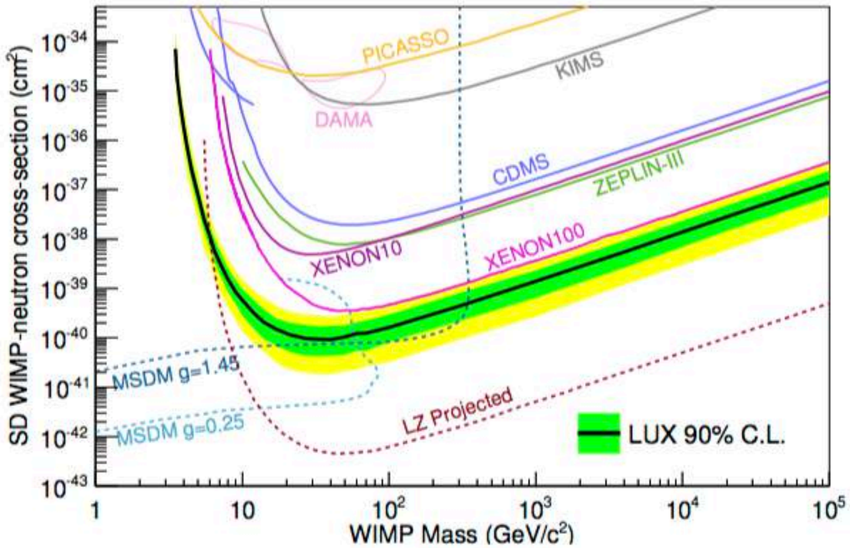
(Received 11 February 2016; revised manuscript received 21 March 2016; published 20 April 2016)

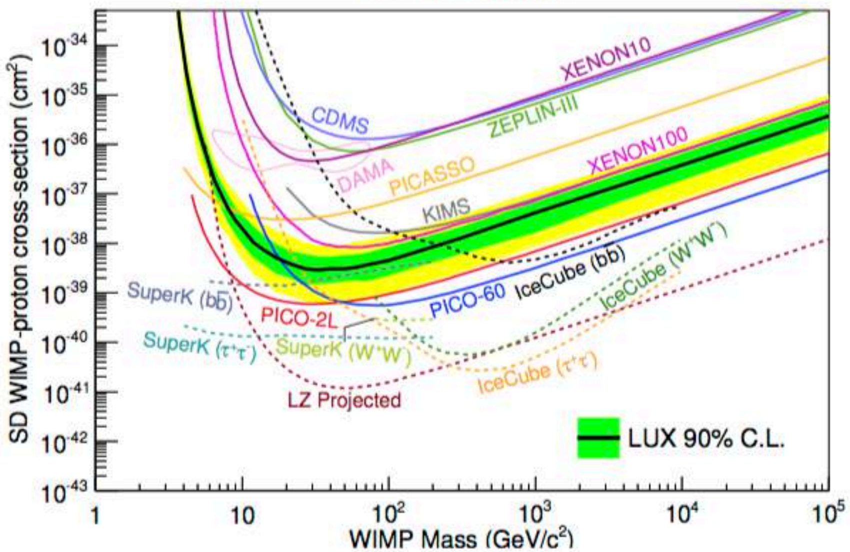
We present experimental constraints on the spin-dependent WIMP (weakly interacting massive particle)-nucleon elastic cross sections from LUX data acquired in 2013. LUX is a dual-phase xenon time projection chamber operating at the Sanford Underground Research Facility (Lead, South Dakota), which is designed to observe the recoil signature of galactic WIMPs scattering from xenon nuclei. A profile likelihood ratio analysis of 1.4×10^4 kg day of fiducial exposure allows 90% C.L. upper limits to be set on the WIMP-neutron (WIMP-proton) cross section of $\sigma_n = 9.4 \times 10^{-41}$ cm^2 ($\sigma_p = 2.9 \times 10^{-39}$ cm^2) at 33 GeV/c^2. The spin-dependent WIMP-neutron limit is the most sensitive constraint to date.

DOI: 10.1103/PhysRevLett.116.161302

0031-9007/16/116(16)/161302(6) 161302-1

Spin Dependent results
from the 'Improved' 2013 data set



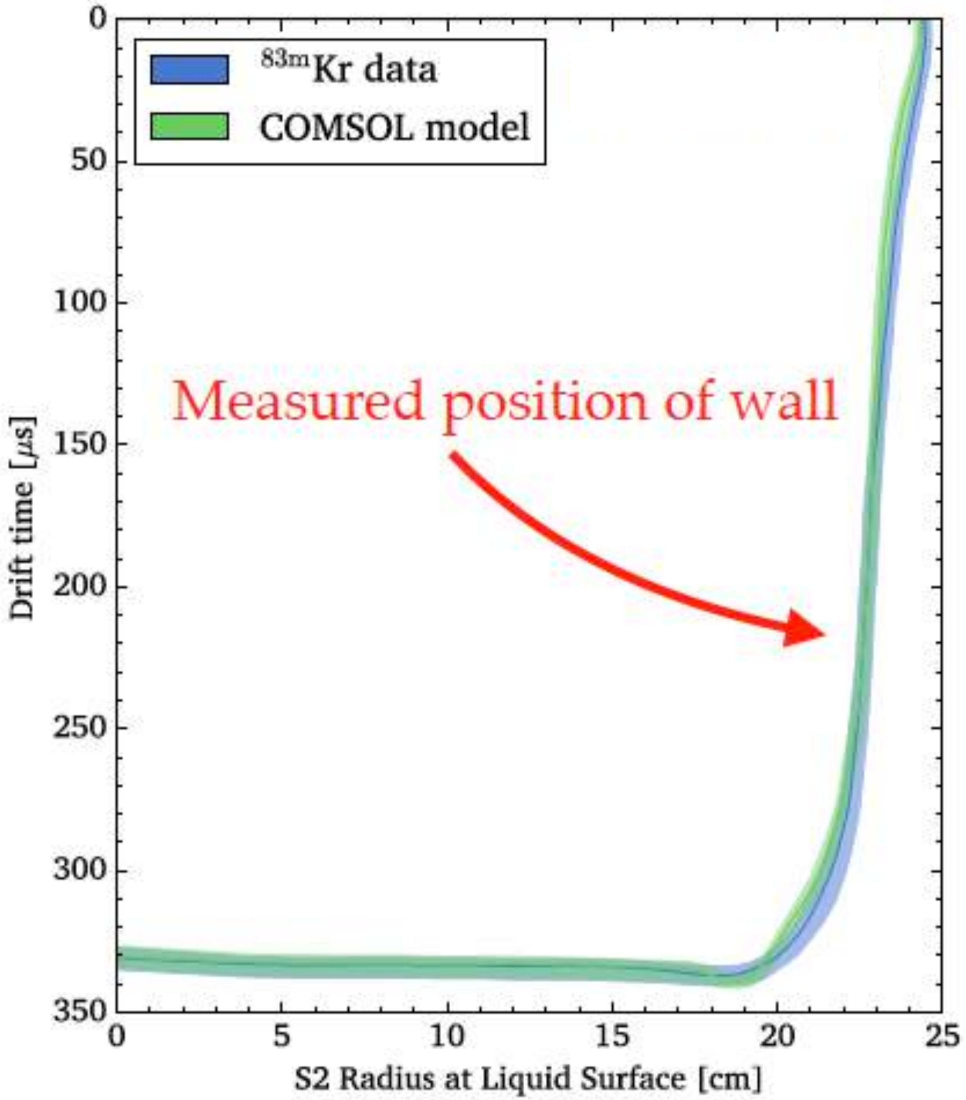


Maximal exploitation
“300 live days of data”

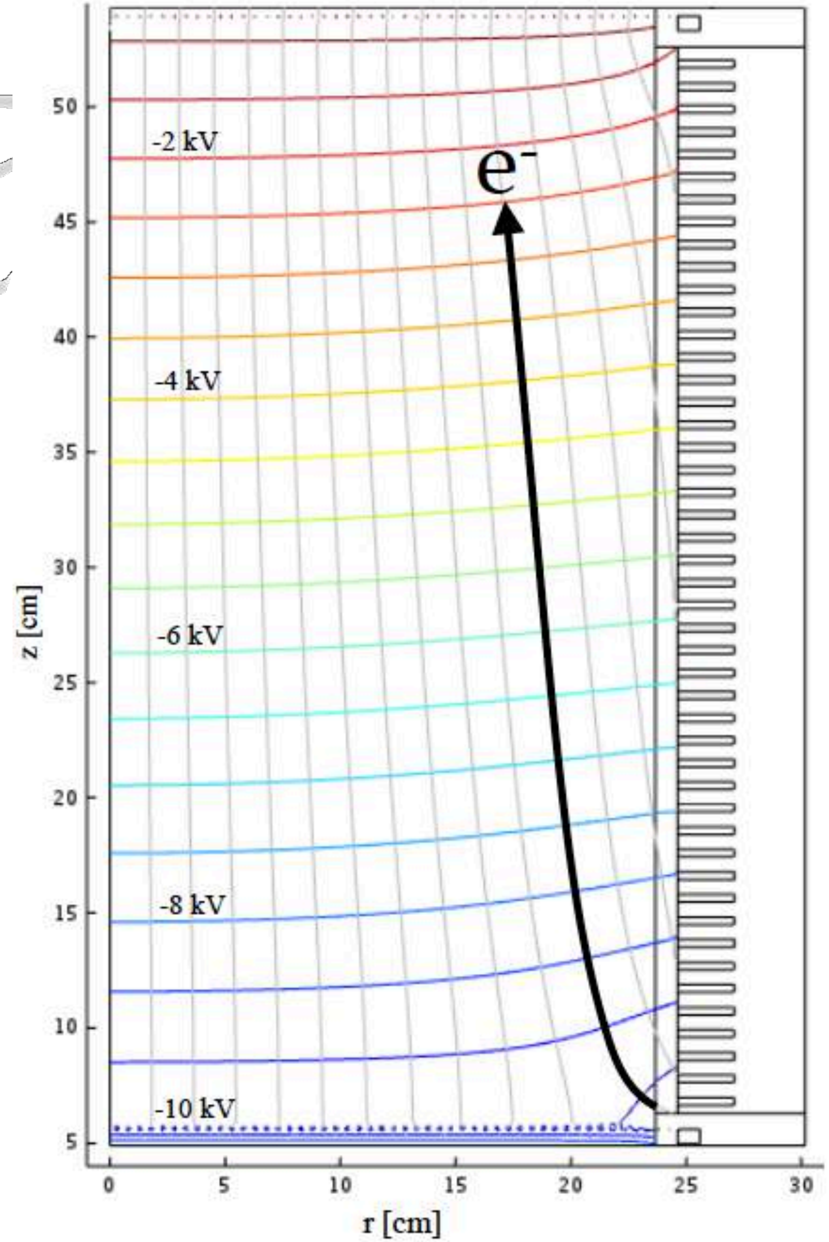
Improve electron extraction

- Was ~50% in initial data
- Conditioning campaign…
- Voltage on electrodes raised, until significant current was drawn, for extended period
- Successfully raised electron extraction efficiency to ~75%
- Commenced run (11 September 2014)
- But…

LUX Run 3

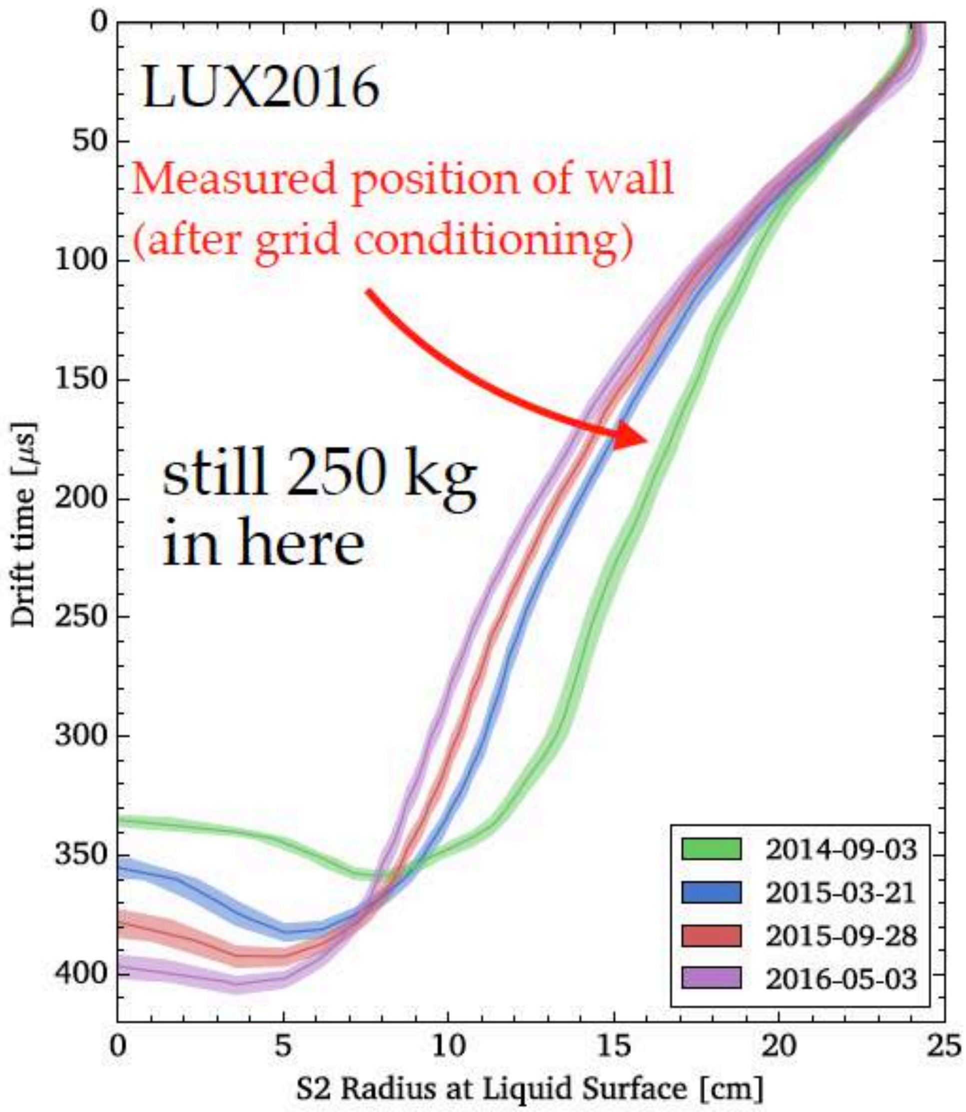


83mKr data
COMSOL model
Measured position of wall
Drift time [μs]
S2 Radius at Liquid Surface [cm]
0
50
100
150
200
250
300
350
0
5
10
15
20
25

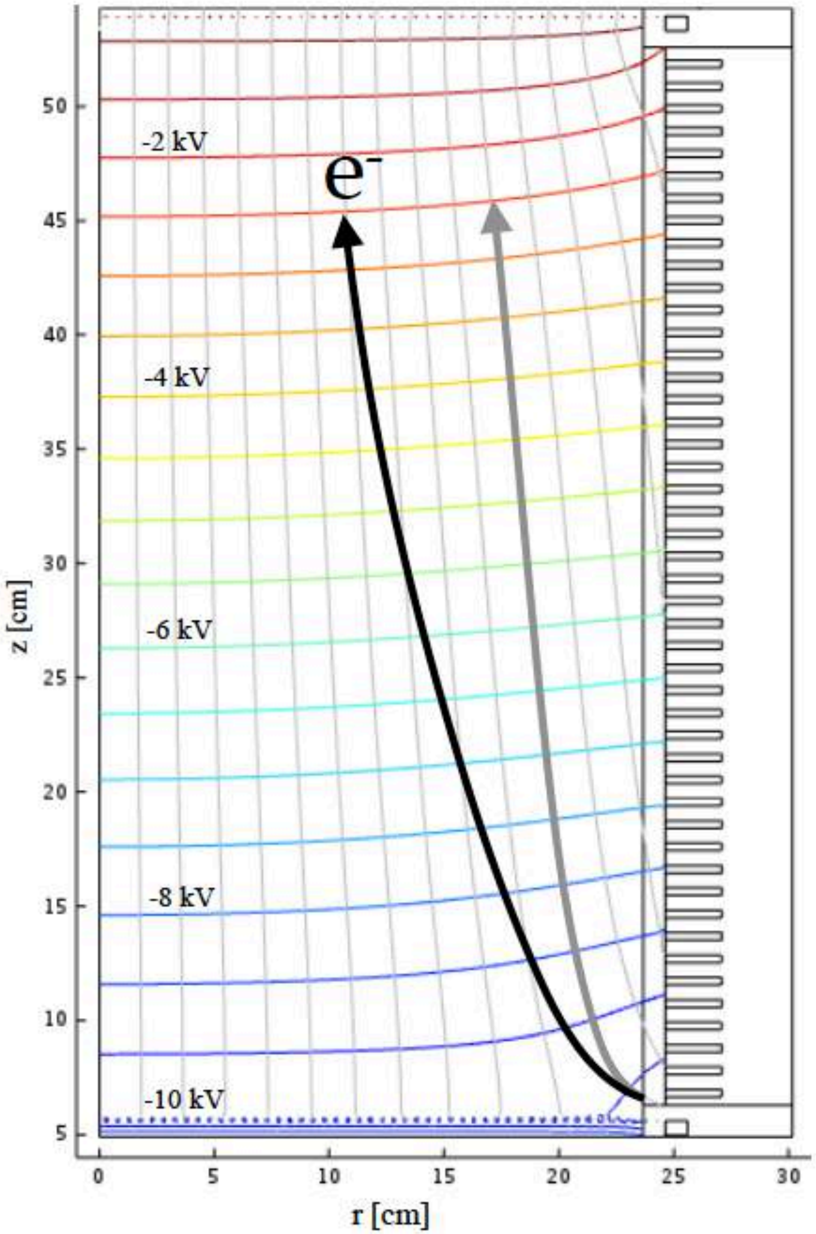


-2 kV
-4 kV
-6 kV
-8 kV
-10 kV
e-
z [cm]
r [cm]

LUX Run 4



LUX2016
Measured position of wall
(after grid conditioning)
still 250 kg
in here
Drift time [μs]
S2 Radius at Liquid Surface [cm]
2014-09-03
2015-03-21
2015-09-28
2016-05-03



-2 kV
e-
-4 kV
-6 kV
-8 kV
-10 kV
z [cm]
r [cm]

Charge build up on PTFE

- Understood in terms of build up of negative charge on internal PTFE walls
- Detailed COMSOL™ model developed
- Magnitude of effect continued to evolve during run
- Roughly rotational symmetry, but strong depth dependence

300 live days of blinded data completed 03 May 2016

Photo 28 April 2016

Data Analysis

- Considered data set as 4 time bins and 4 volumes.
- Each segment then has its own model for ER and NR response
- Likelihood analysis performed on S1 and S2 observables
- S1 and S2 modelled with the Noble Element Simulation Technique (NEST, http://www.albany.edu/physics/NEST.shtml)
- NEST is “tuned” to each of the 16 detectors by varying the applied field until we see a match between model and calibration data.
- Periodic CH_3T, Kr, DD calibrations throughout run
- Background estimates... (^{127}Xe has now decayed away)
- Cuts… Efficiencies…

Background expectations

Background source	Expected number below NR median
External Gamma rays	1.5 +/- 0.2
Internal beta particles	1.2 +/- 0.06
Radon plate out (wall background)	8.7 +/- 3.5
Accidental S1-S2 coincidences	0.34 +/- 0.10
^{8}B solar neutrinos (CNNS)	0.16 +/- 0.03

Indicative only: we use PLR

In the bulk, but n/γ discrimination

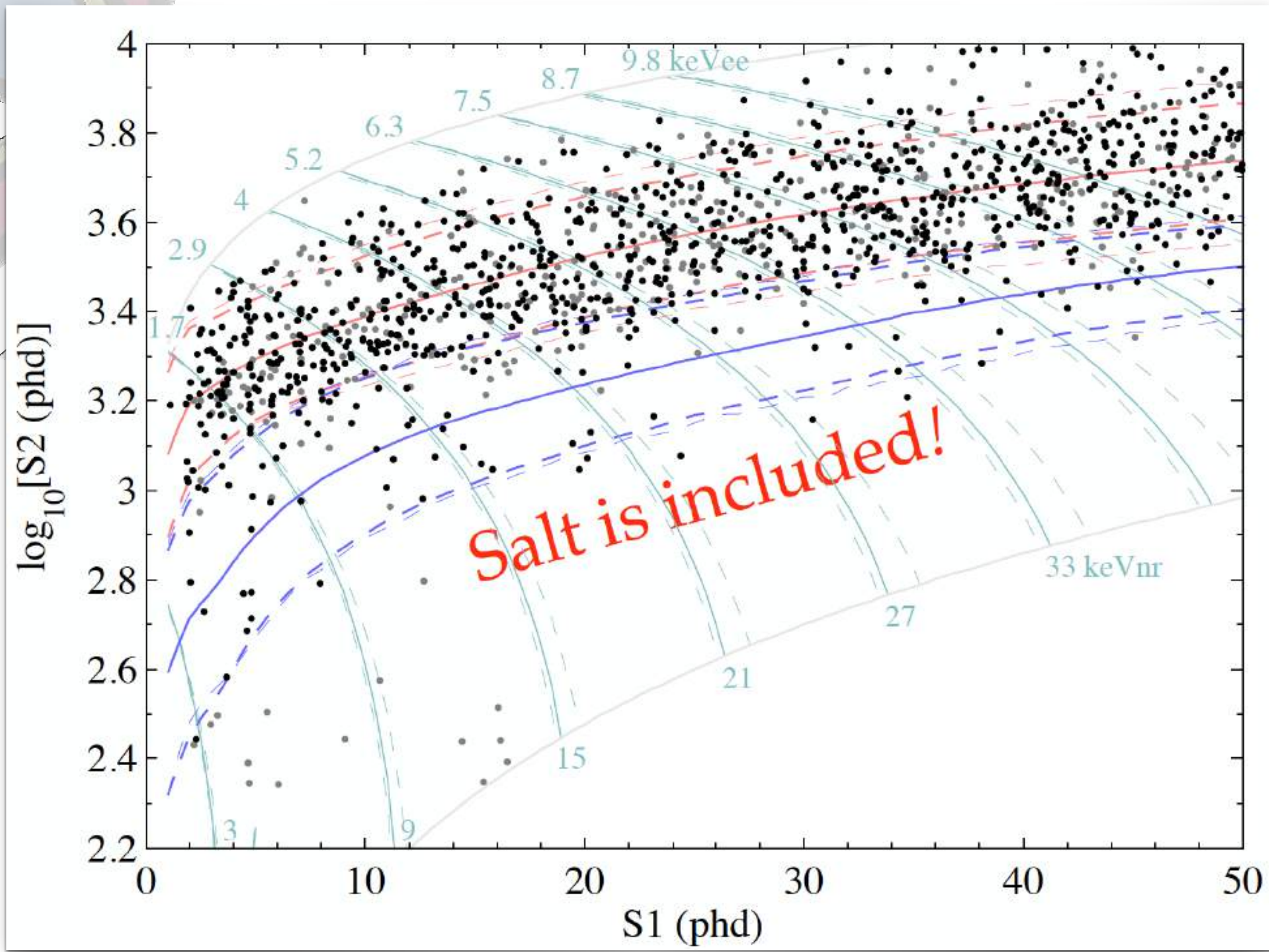
Low energy wall events, but PLR gives these low $\mathcal{L}(\text{signal})$

In the bulk, low energy, NR band

+ ~ **0.3** single scatter neutrons, e.g. from (α, n), not included in PLR

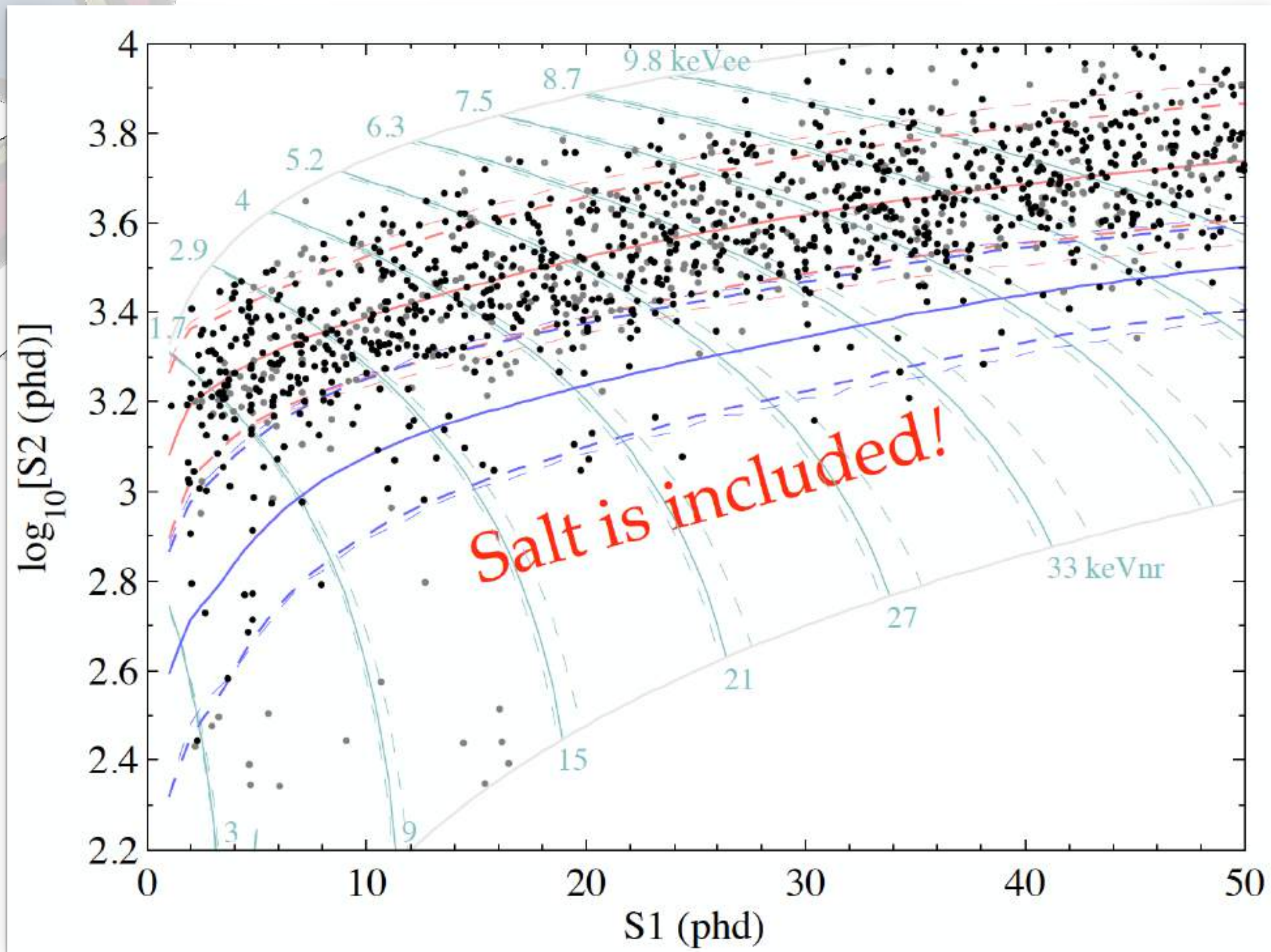
Salting of data

- ‘Fake’ events, built from calibration data (not simulation), are injected at the level of raw waveforms *before analysis*
- Mitigates bias while allowing scrutiny of individual events.
- Previously used by neutrino experiments and searches for fractional charge.



Salting of data

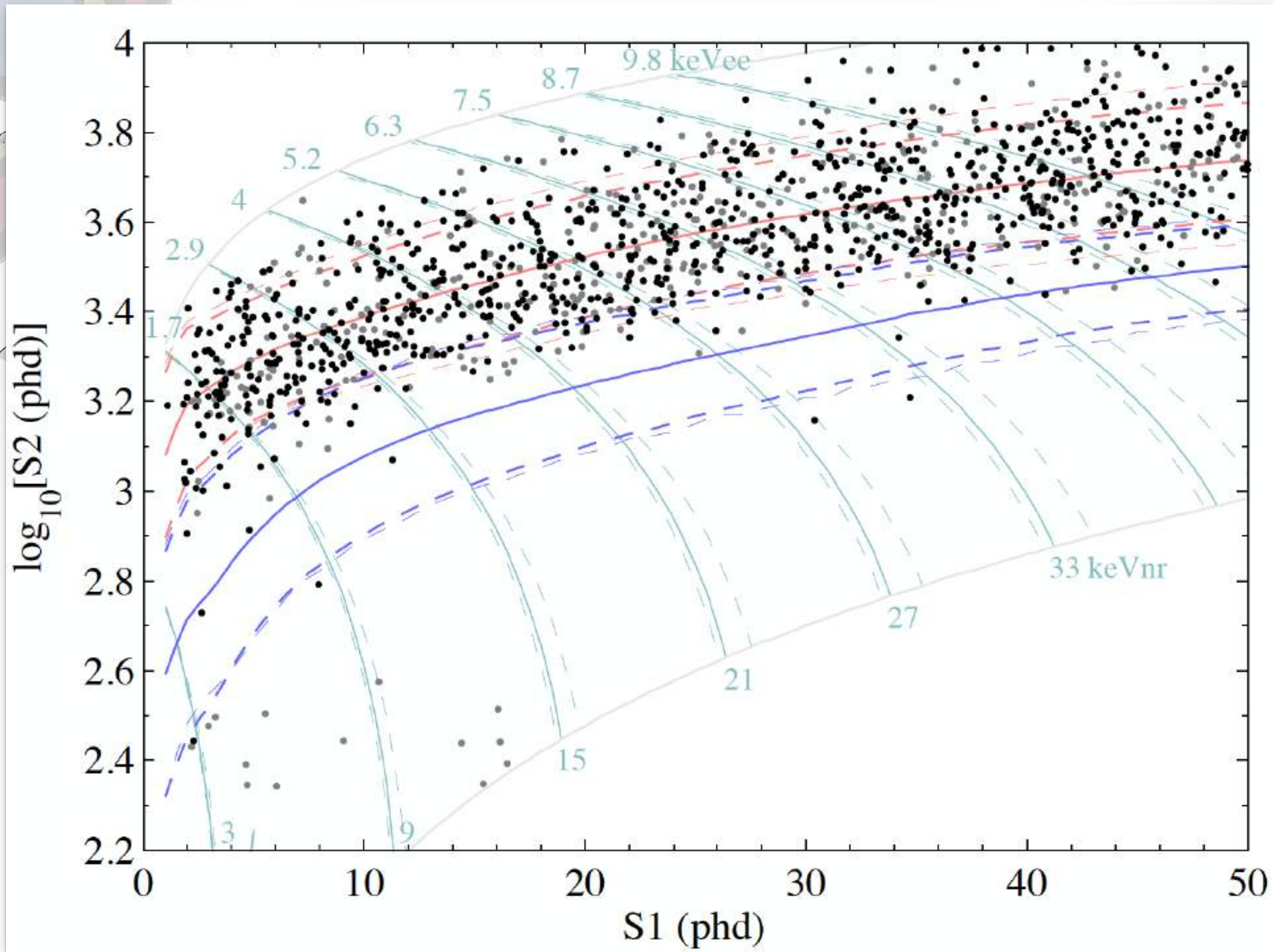
- The plot shows the data from all 16 “detectors”
- Dots are events:
  - Gray: within 1cm of our fiducial boundary
  - Black: bulk events
  - Red and blue curves are the ER and NR bands



Salting of data

- The plot shows the data from all 16 "detectors"
- Dots are events:
  - Gray: within 1cm of our fiducial boundary
  - Black: bulk events
  - Red and blue curves are the ER and NR bands

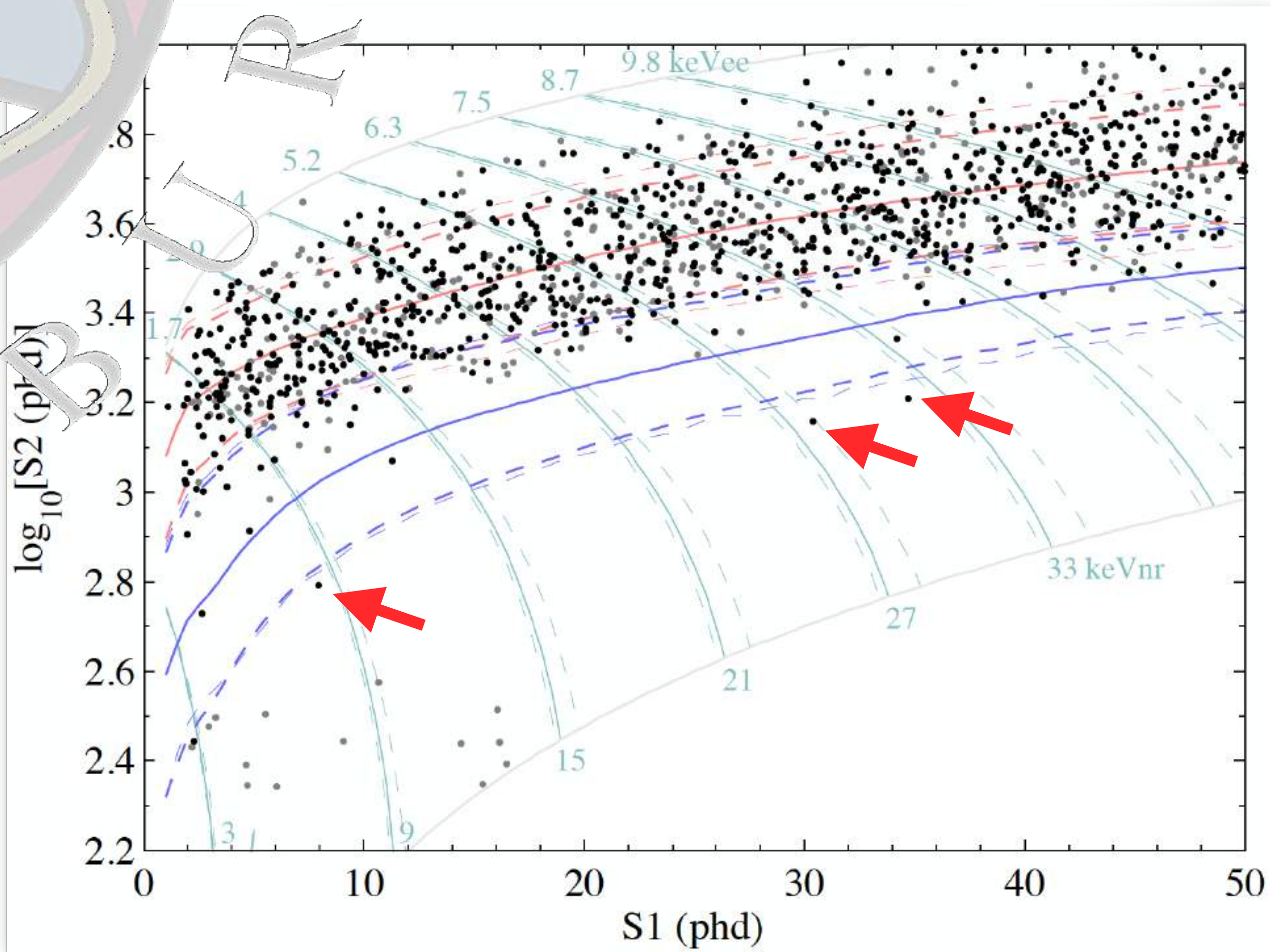
Salt Removed



Post Unsalting

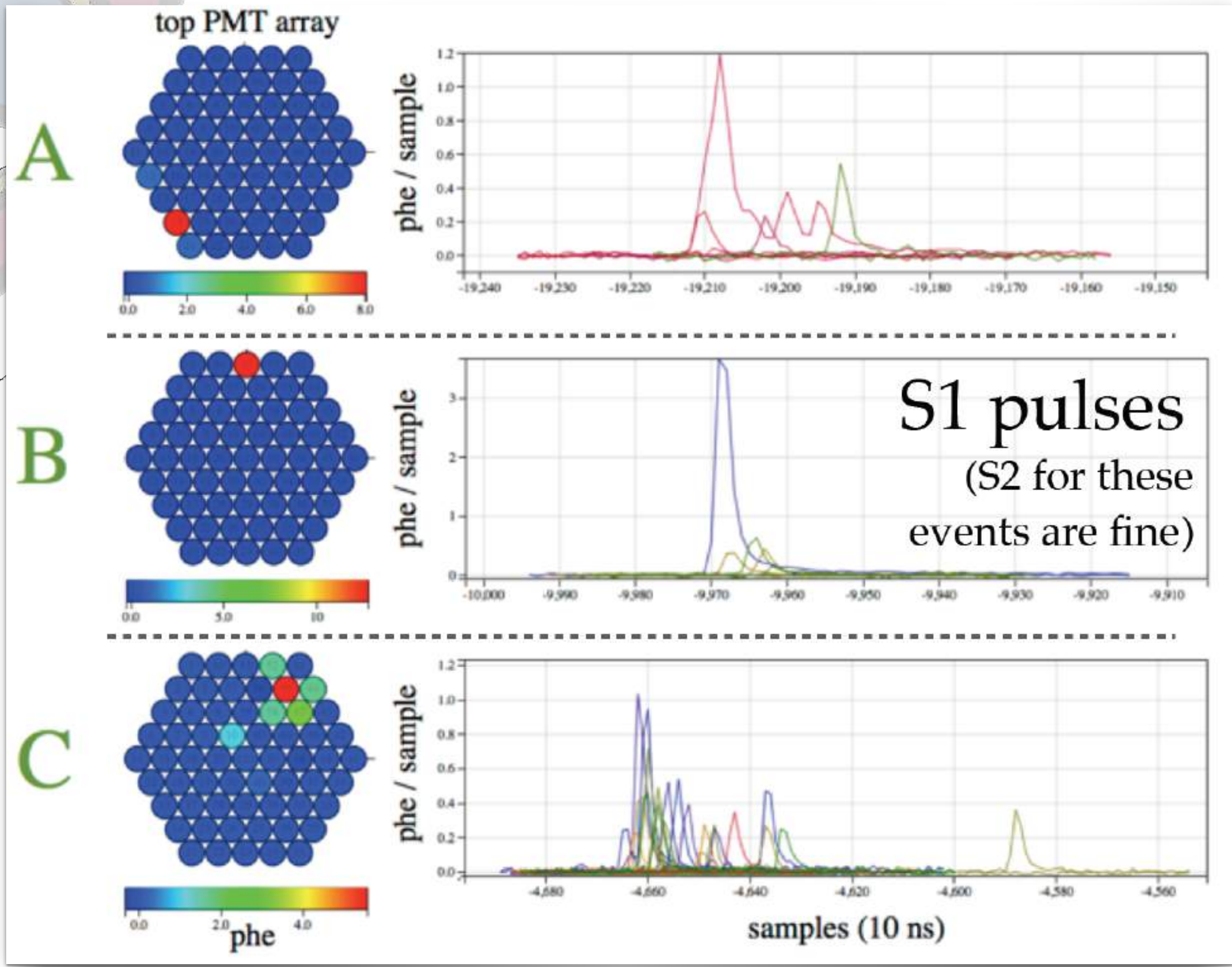
- The plot shows the data from all 16 "detectors"
- Dots are events:
  - Gray: within 1cm of our fiducial boundary
  - Black: bulk events
  - Red and blue curves are the ER and NR bands

Salt Removed



Post Unsalting

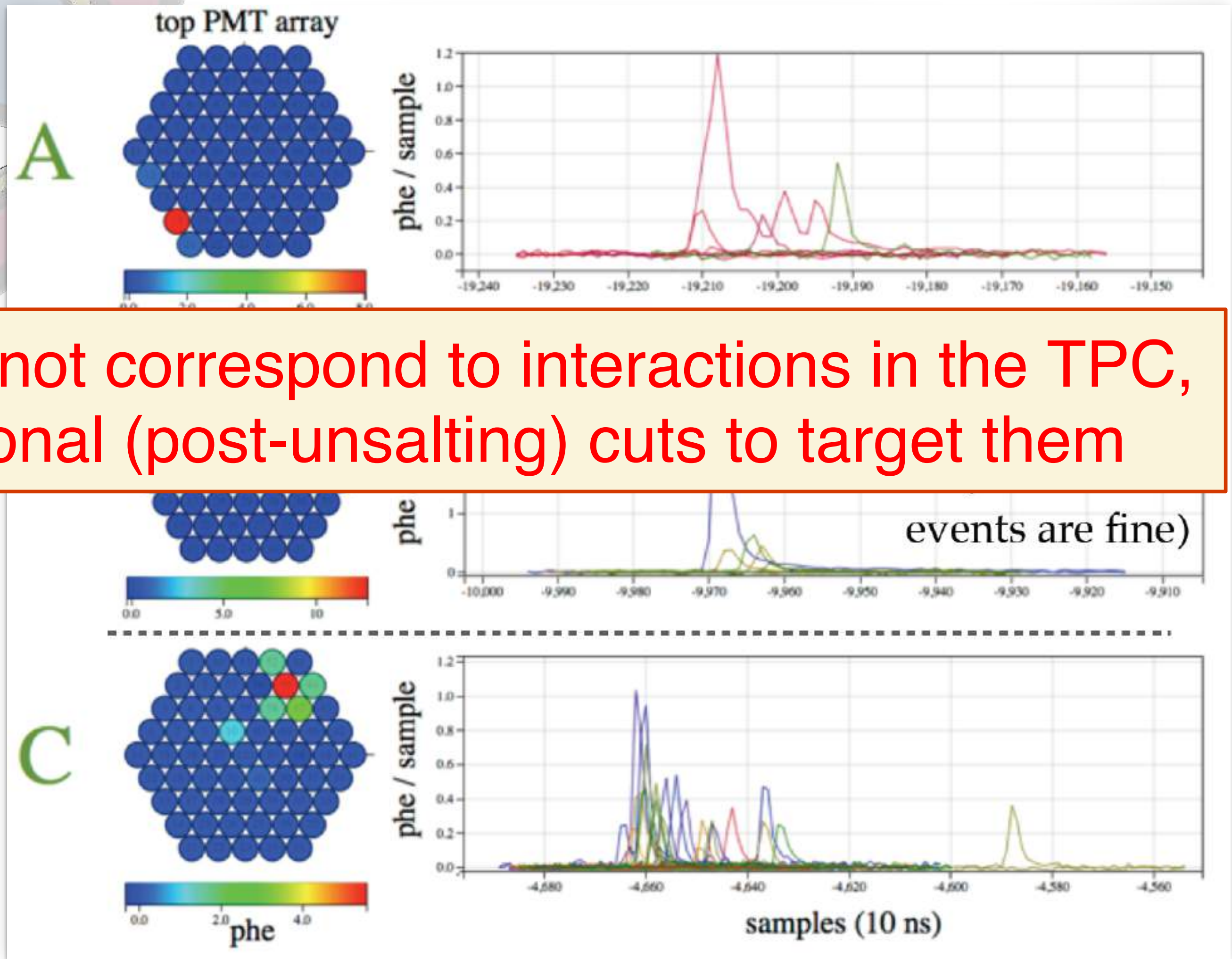
- Two events have ~80% of the light in a single top edge PMT. Consistent with energy deposited outside the TPC, and light leaking through a gap near the edge of the PMT array.
- One event has light concentrated under a few top PMTs and has time structure consistent with gas scintillation emission. Also, this event came after high rate in the preceding 1 second.



Post Unsalting

- Two events have ~80% of the light in a single top edge PMT. Consistent with energy deposited outside the TPC, and light leaking

concentrated under a few top PMTs and has time structure consistent with gas scintillation emission. Also, this event came after high rate in the preceding 1 second.

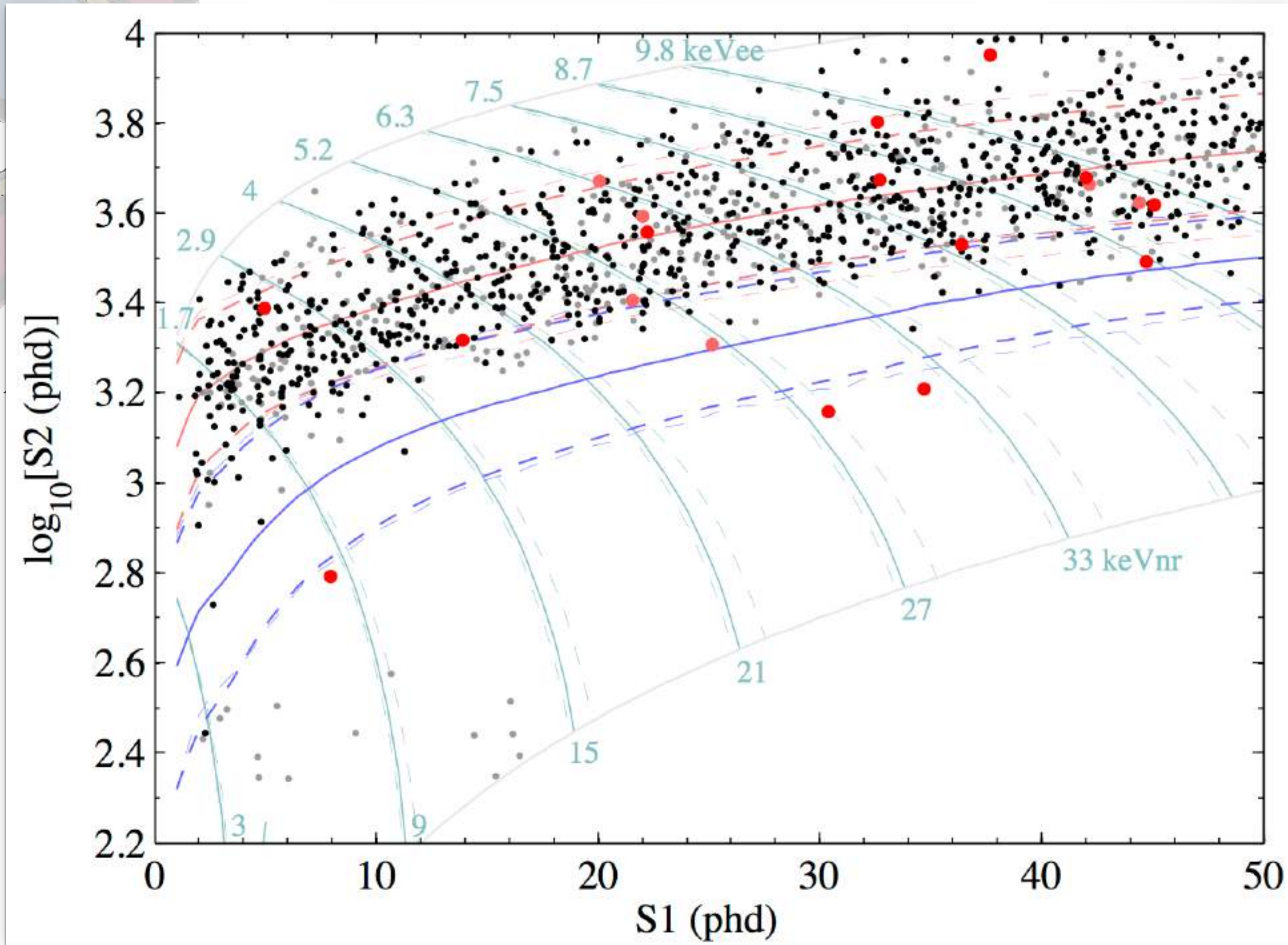


Since these events do not correspond to interactions in the TPC, we developed additional (post-unsalting) cuts to target them

Additional cuts

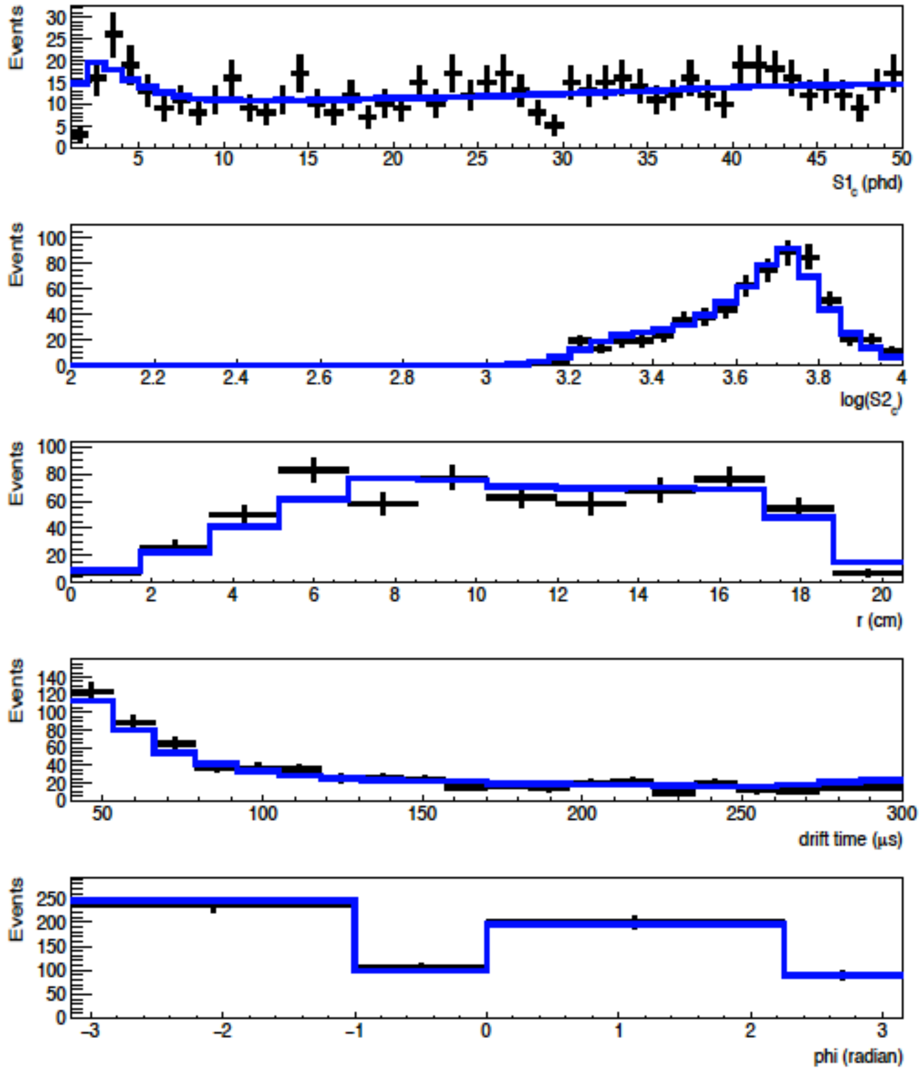
- Post unsalting cuts applied
- Red dots show additional cuts do not unduly target WS candidate events

- ~Flat efficiency of 98.5%



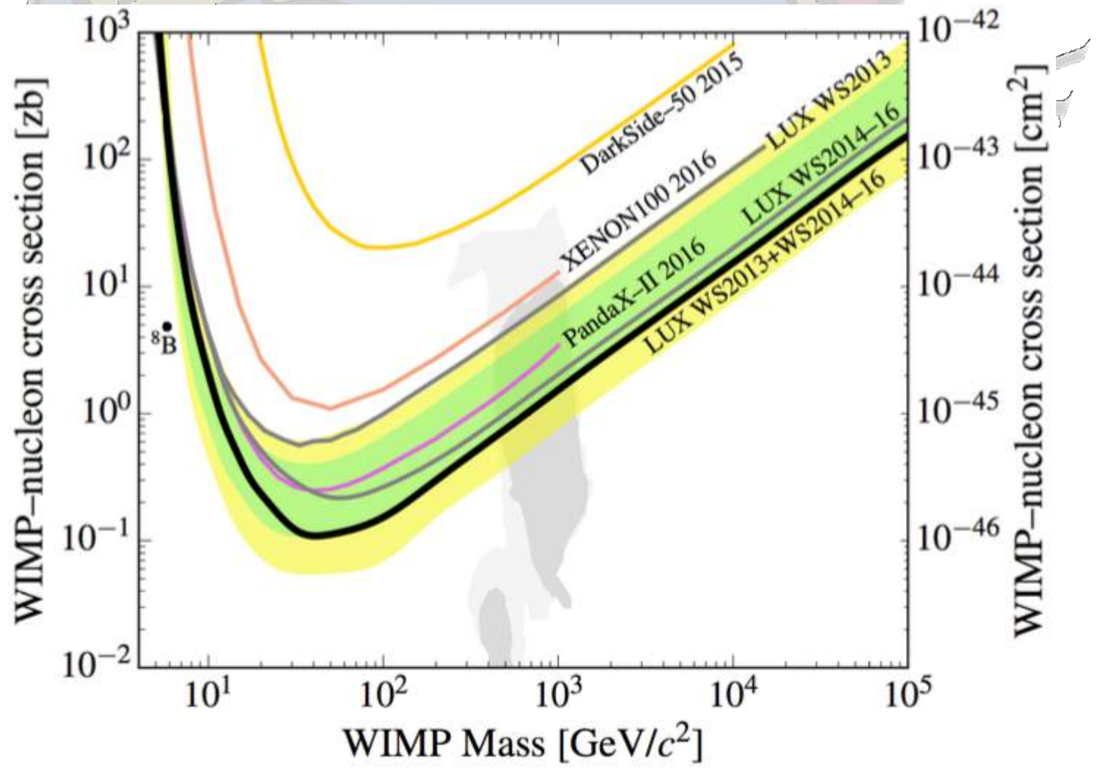
PLR Analysis

- Two-sided PLR
- 5 un-binned PLR dimensions: r, ϕ, drift-time, S1, log10(S2)
- 1 binned PLR dimension: Event date
- Good agreement with background-only model, p-value >0.6 for each projection



332 Live days result

https://arxiv.org/pdf/1608.07648.pdf



Combined Run 3 + Run 4

Minimum at **$1.1\mathrm{x}10^{-46}$ cm^2 at 50 GeV/c^2** (90%c.l.)

arXiv:1608.07648v2 [astro-ph.CO] 13 Oct 2016

Results from a search for dark matter in the complete LUX exposure

D.S. Akerib,[1,2,3] S. Alsum,[4] H.M. Araújo,[5] X. Bai,[6] A.J. Bailey,[5] J. Balajthy,[7] P. Beltrame,[8] E.P. Bernard,[9,10] A. Bernstein,[11] T.P. Biesiadzinski,[1,2,3] E.M. Boulton,[9,10] R. Bramante,[1,2,3] P. Brás,[12] D. Byram,[13,14] S.B. Cahn,[10] M.C. Carmona-Benitez,[15] C. Chan,[16] A.A. Chiller,[13] C. Chiller,[13] A. Currie,[5] J.E. Cutter,[17] T.J.R. Davison,[8] A. Dobi,[18] J.E.Y. Dobson,[19] E. Druszkiewicz,[20] B.N. Edwards,[10] C.H. Faham,[18] S. Fiorucci,[16,18] R.J. Gaitskell,[16] V.M. Gehman,[18] C. Ghag,[19] K.R. Gibson,[1] M.G.D. Gilchriese,[18] C.R. Hall,[7] M. Hanhardt,[6,14] S.J. Haselschwardt,[15] S.A. Hertel,[9,10,*] D.P. Hogan,[9] M. Horn,[14,9,10] D.Q. Huang,[16] C.M. Ignarra,[2,3] M. Ihm,[9] R.G. Jacobsen,[9] W. Ji,[1,2,3] K. Kamdin,[9] K. Kazkaz,[11] D. Khaitan,[20] R. Knoche,[7] N.A. Larsen,[10] C. Lee,[1,2,3] B.G. Lenardo,[17,11] K.T. Lesko,[18] A. Lindote,[12] M.I. Lopes,[12] A. Manalaysay,[17,†] R.L. Mannino,[21] M.F. Marzioni,[8] D.N. McKinsey,[9,18,10] D.-M. Mei,[13] J. Mock,[22] M. Moongweluwan,[20] J.A. Morad,[17] A.St.J. Murphy,[8] C. Nehrkorn,[15] H.N. Nelson,[15] F. Neves,[12] K. O'Sullivan,[9,18,10] K.C. Oliver-Mallory,[9] K.J. Palladino,[4,2,3] E.K. Pease,[9,18,10] P. Phelps,[1] L. Reichhart,[19] C. Rhyne,[16] S. Shaw,[19] T.A. Shutt,[1,2,3] C. Silva,[12] M. Solmaz,[15] V.N. Solovov,[12] P. Sorensen,[18] S. Stephenson,[17] T.J. Sumner,[5] M. Szydagis,[22] D.J. Taylor,[14] W.C. Taylor,[16] B.P. Tennyson,[10] P.A. Terman,[21] D.R. Tiedt,[6] W.H. To,[1,2,3] M. Tripathi,[17] L. Tvrznikova,[9,10] S. Uvarov,[17] J.R. Verbus,[16] R.C. Webb,[21] J.T. White,[21] T.J. Whitis,[1,2,3] M.S. Witherell,[18] F.L.H. Wolfs,[20] J. Xu,[11] K. Yazdani,[5] S.K. Young,[22] and C. Zhang[13]

(LUX Collaboration)

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(Dated: October 14, 2016)

We report constraints on spin-independent weakly interacting massive particle (WIMP)-nucleon scattering using a 3.35×10^4 kg-day exposure of the Large Underground Xenon (LUX) experiment. A dual-phase xenon time projection chamber with 250 kg of active mass is operated at the Sanford Underground Research Facility under Lead, South Dakota (USA). With roughly four-fold improvement in sensitivity for high WIMP masses relative to our previous results, this search yields no evidence of WIMP nuclear recoils. At a WIMP mass of 50 GeV c^{-2}, WIMP-nucleon spin-independent cross sections above 2.2×10^{-46} cm^2 are excluded at the 90% confidence level. When combined with the previously reported LUX exposure, this exclusion strengthens to 1.1×10^{-46} cm^2 at 50 GeV c^{-2}.

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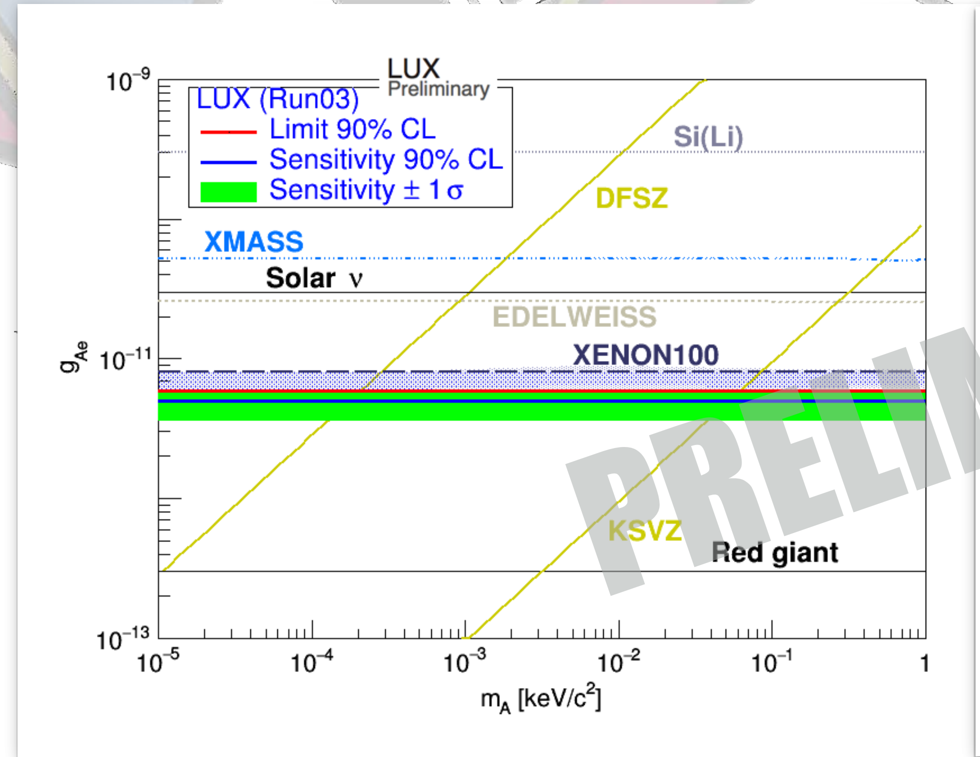
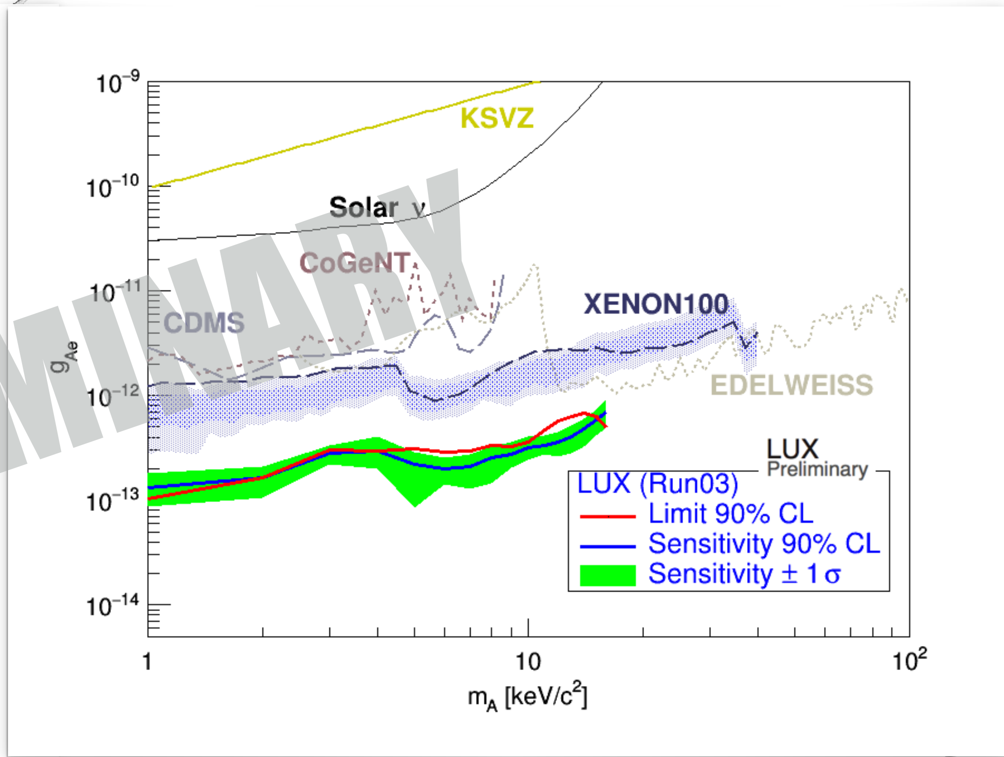
† aaronm@ucdavis.edu

Axions

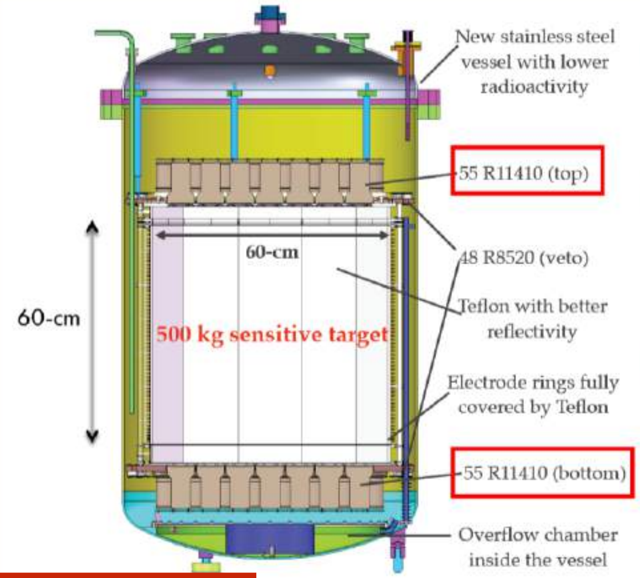
- Searches for axioelectric coupling, g_{Ae}
- Extends science beyond standard WIMP searches
- ER-band search
- …Extending background model





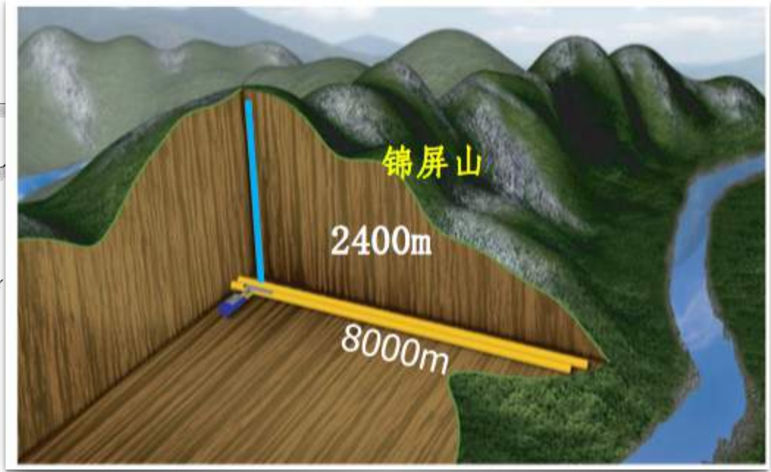
The other LXe TPCs…

PandaX-II

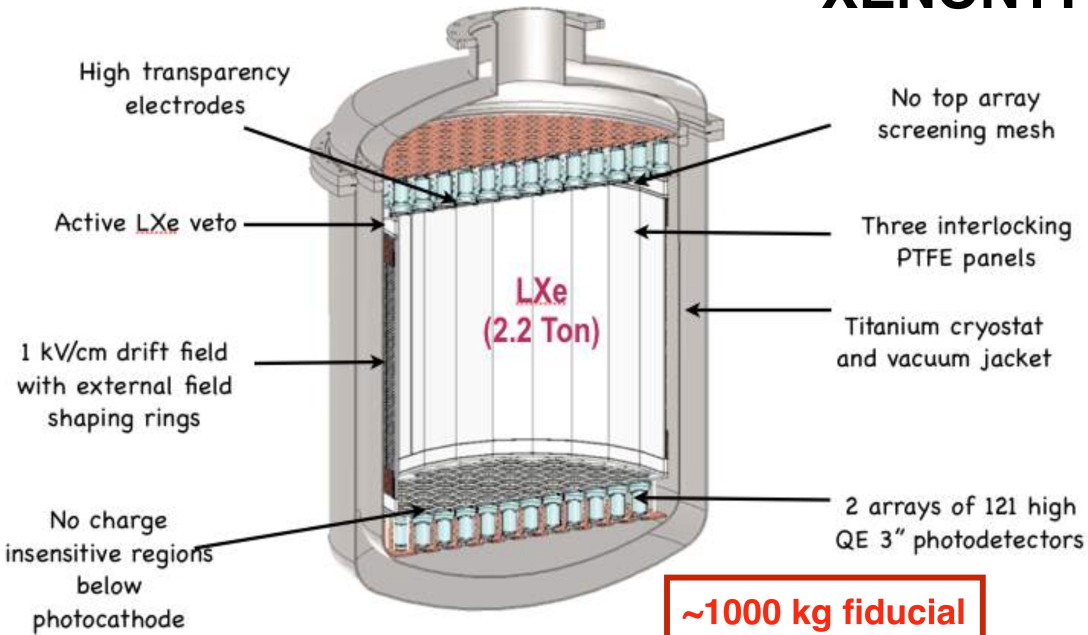


- New inner vessel with clean SS
- New and taller TPC with brand-new electrodes
- More 3” PMTs and improved base design
- New separate skin veto region

~300 kg fiducial

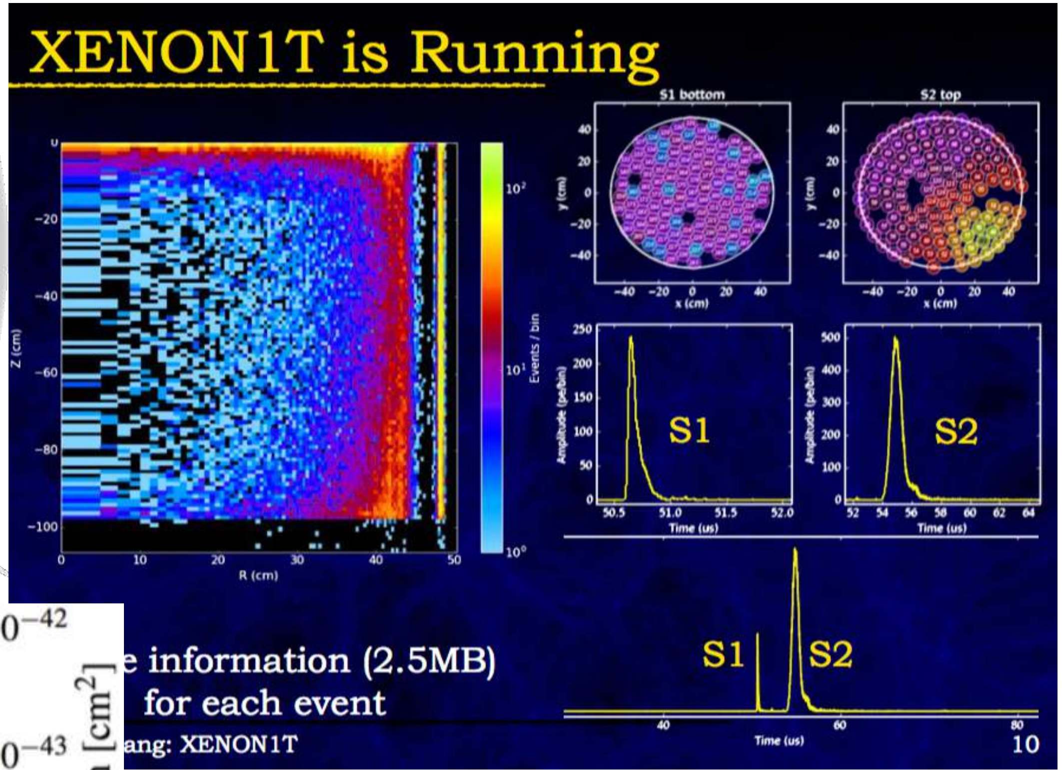


XENON1T

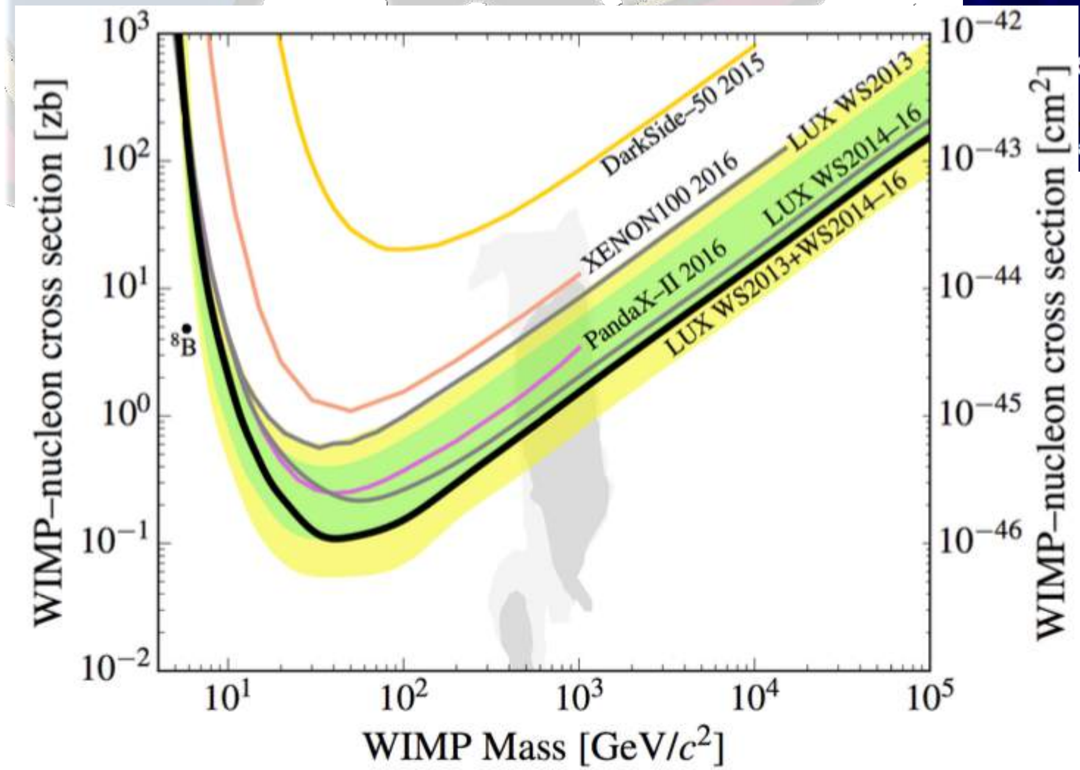


~1000 kg fiducial

PandaX and XENON-1T are running. Expect new results soon.



September 2016 https://indico.cern.ch/event/563885/contributions/2278677/attachments/1342561/2022471/rafael_xenon1t.pdf



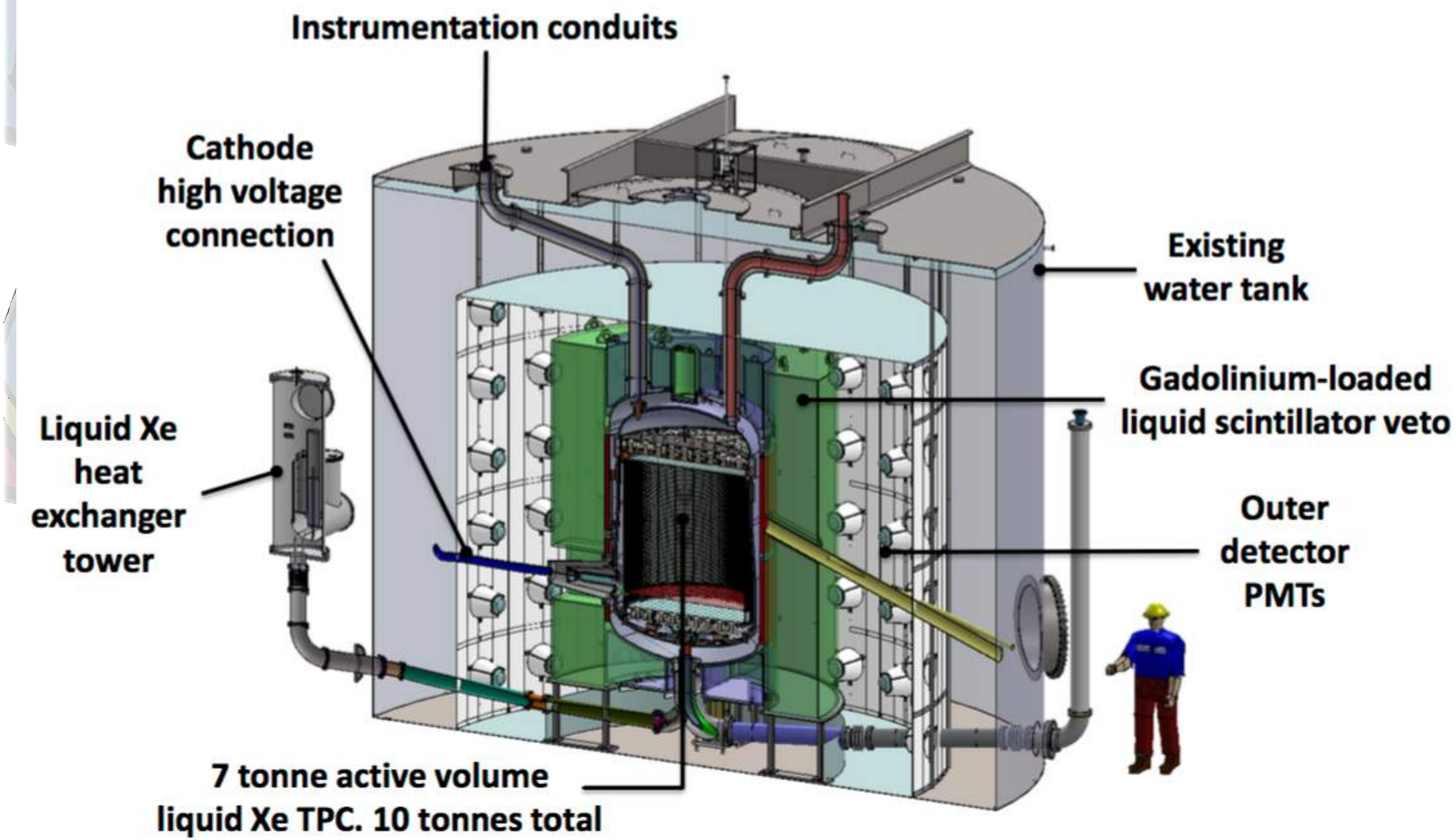
LUX-ZEPLIN

~XENON nT

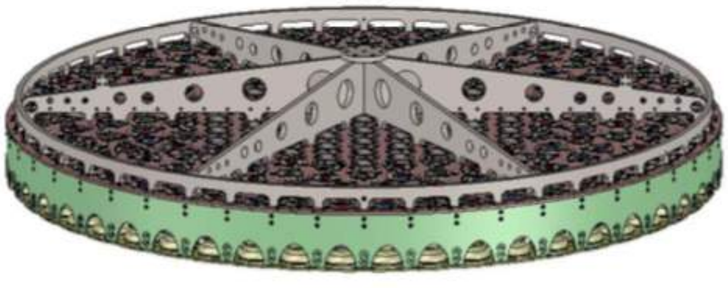
Scale Up ≈50 in Fiducial Mass

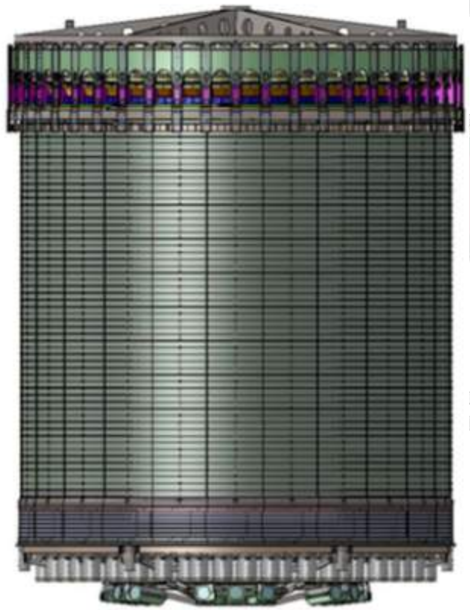
LZ

Total mass – 10 T
WIMP Active Mass – 7 T
WIMP Fiducial Mass – 5.6 T

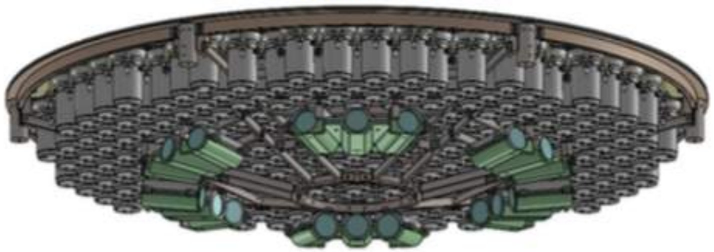

Instrumentation conduits
Cathode
high voltage
connection
Existing
water tank
Gadolinium-loaded
liquid scintillator veto
Liquid Xe
heat
exchanger
tower
Outer
detector
PMTs
7 tonne active volume
liquid Xe TPC. 10 tonnes total

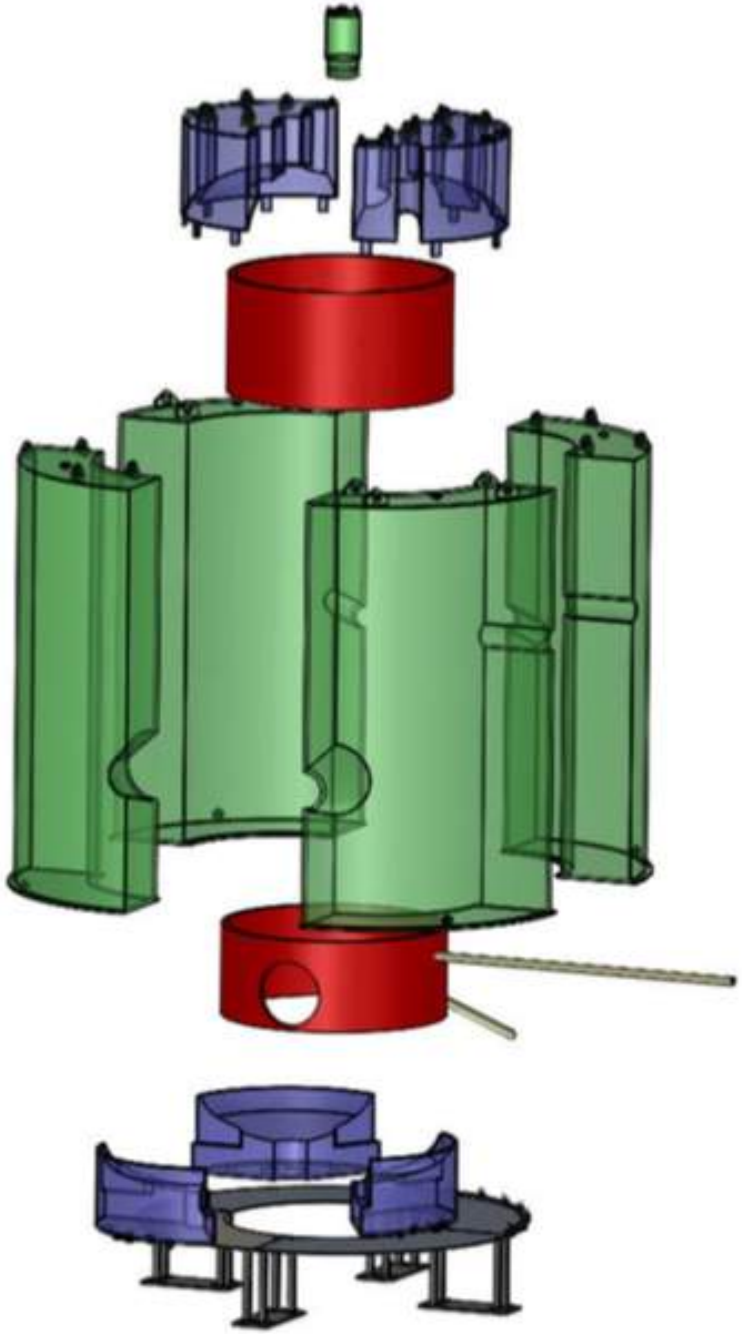
TOP





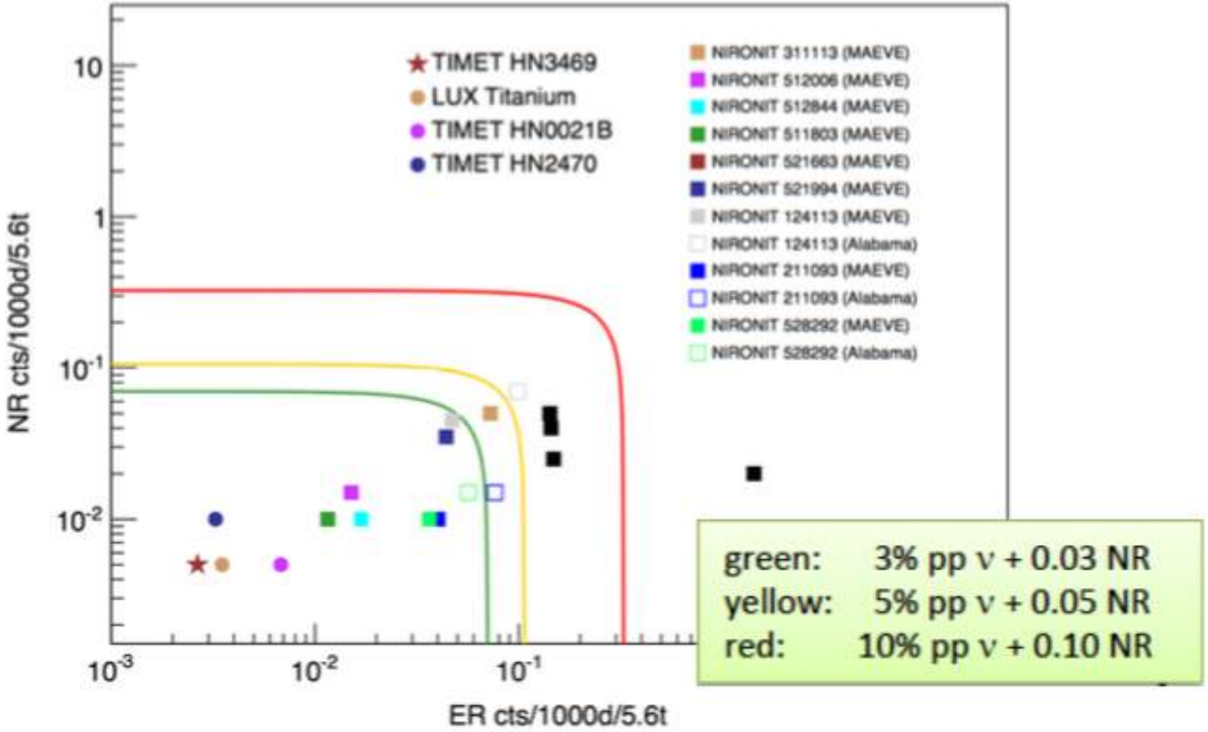
BOTTOM





Key parameters

- Same location as LUX (Davis cavern)
- Active skin, Gd loaded veto
- ~10 Tonnes xenon, **5.6 T fiducial**
- Radon reduced air
- Major screening programme, ultra low radioactivity titanium procured and now being machined
- Major cleanliness programme
- Cryogenics, Xe recirculation, calibration, outer detectors, electronics, DAQ, controls, installation, integration, software,..
- Planning 5 years+ of operations,



Main Experimental Hall (7x4x60m)

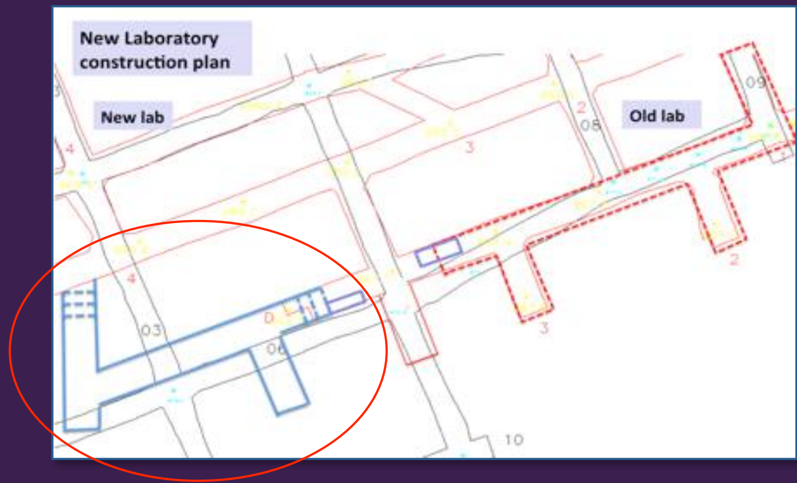
'BUGS' ULB Germanium Facility

Boulby New Lab Construction **March 2016**

Large Experimental Cavern (LEC) (7x7x35m)

Air conditioning, HEPA filtration, internet / comms, 5 & 10 Tonne lifting capacity.

> 4000m^3 of well supported **class 1,000** and **class 10,000** clean room experimental space

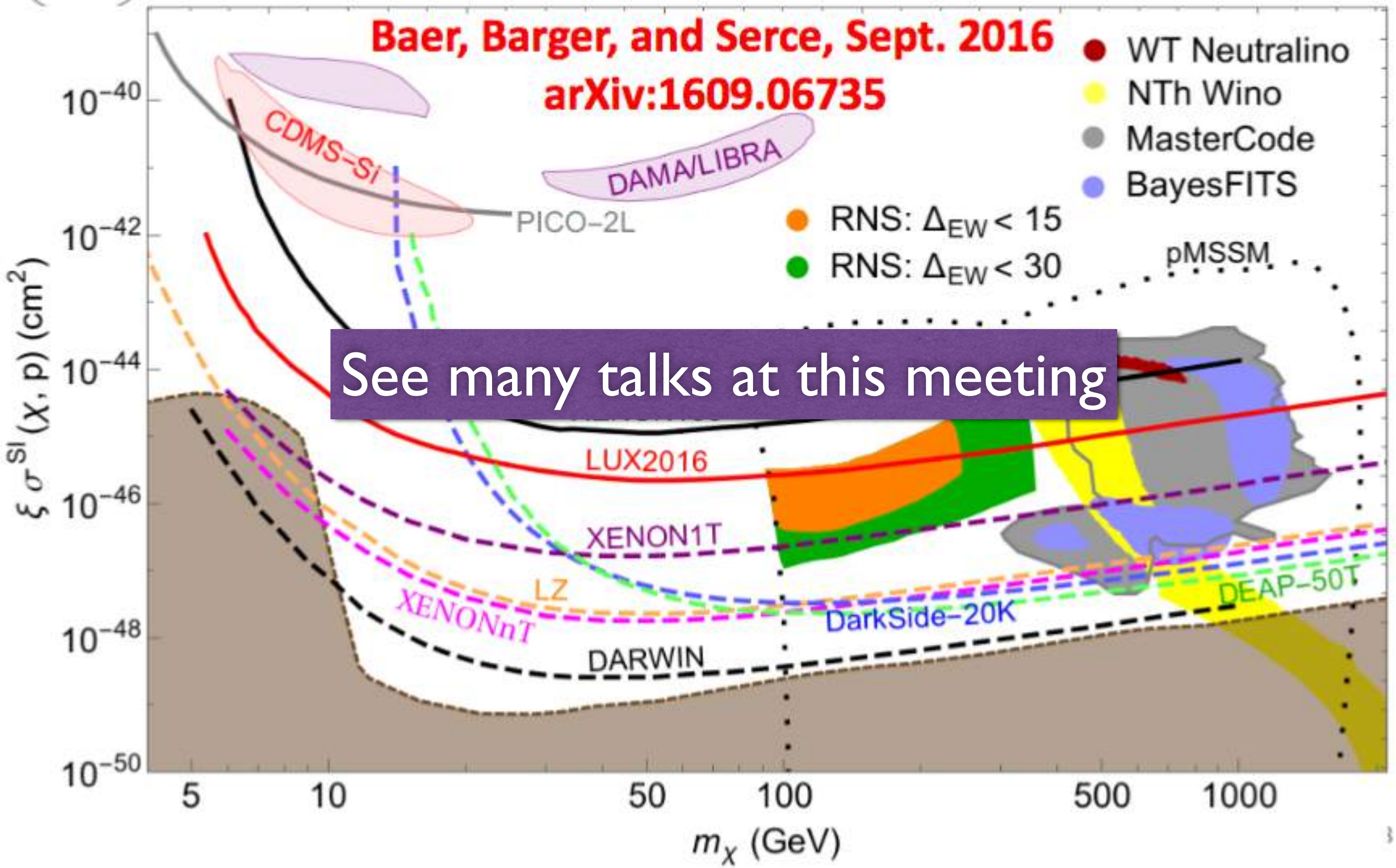


Now moving experiments in from old lab.

Major LZ Screening campaign underway at Boulby

> See talk by Emma Meehan at 5.30 today

Post-LHC Run 2 SUSY... theorists care

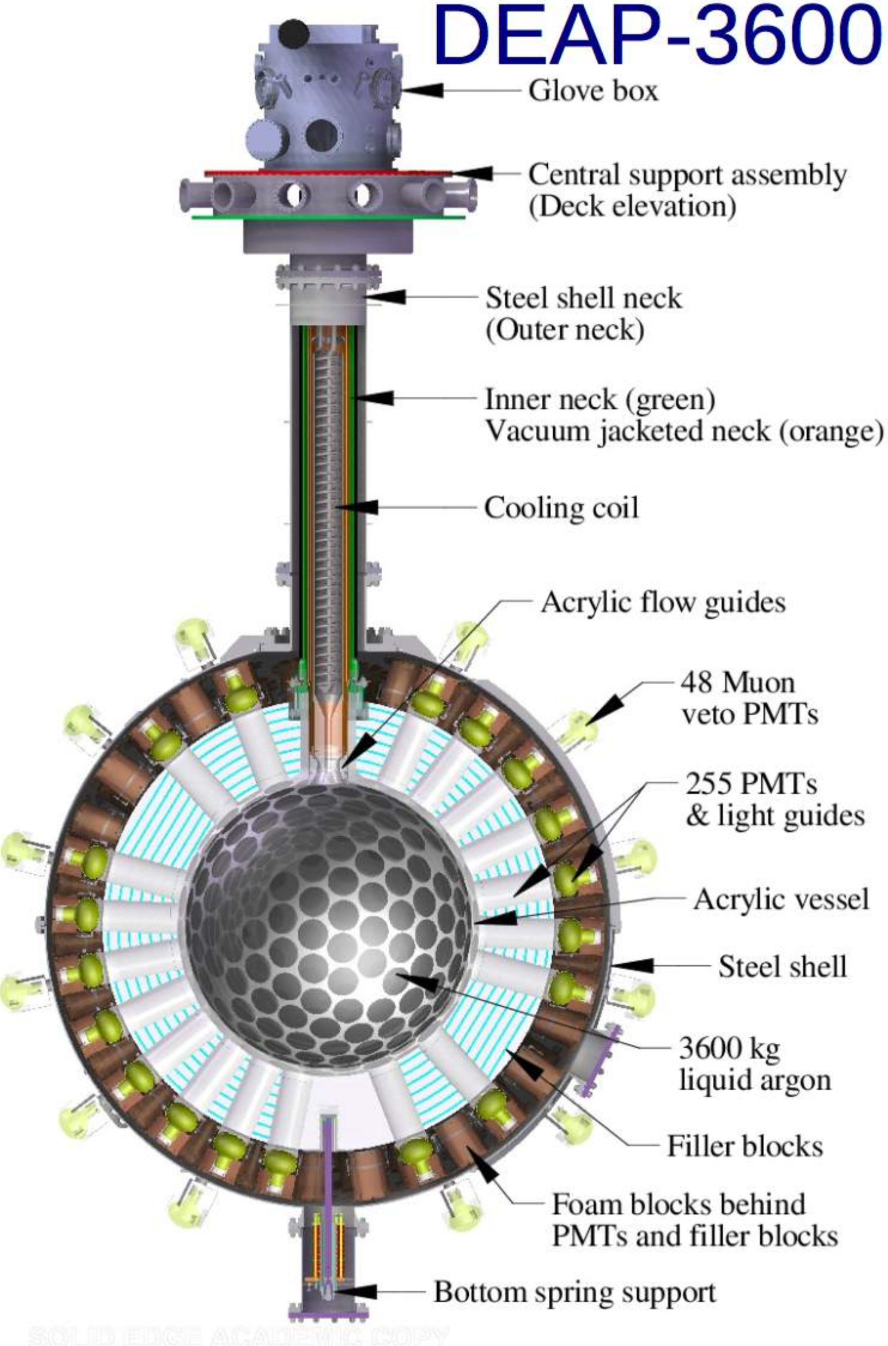


See many talks at this meeting

DEAP

Marcin Kuźniak

DEAP-3600 Dark Matter Search

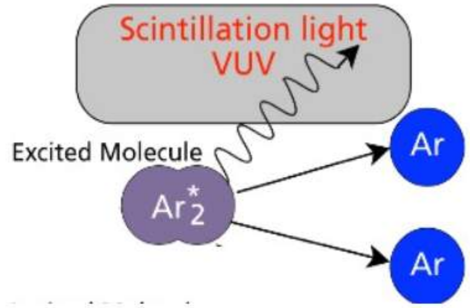


- **Single phase liquid argon** approach: simple, scalable, inexpensive
- 3600 kg target (1000 kg fiducial) in sealed ultraclean Acrylic Vessel
- In-situ vacuum evaporated TPB wavelength shifter (~10 m^2)
- Bonded 50 cm long light guides + PE shielding provide neutron moderation
- 255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)
- Vessel is "resurfaced" in-situ to remove deposited Rn daughters after construction
- Detector immersed in 8 m water shield, instrumented with PMTs to veto muons
- Located 2 km underground at SNOLAB

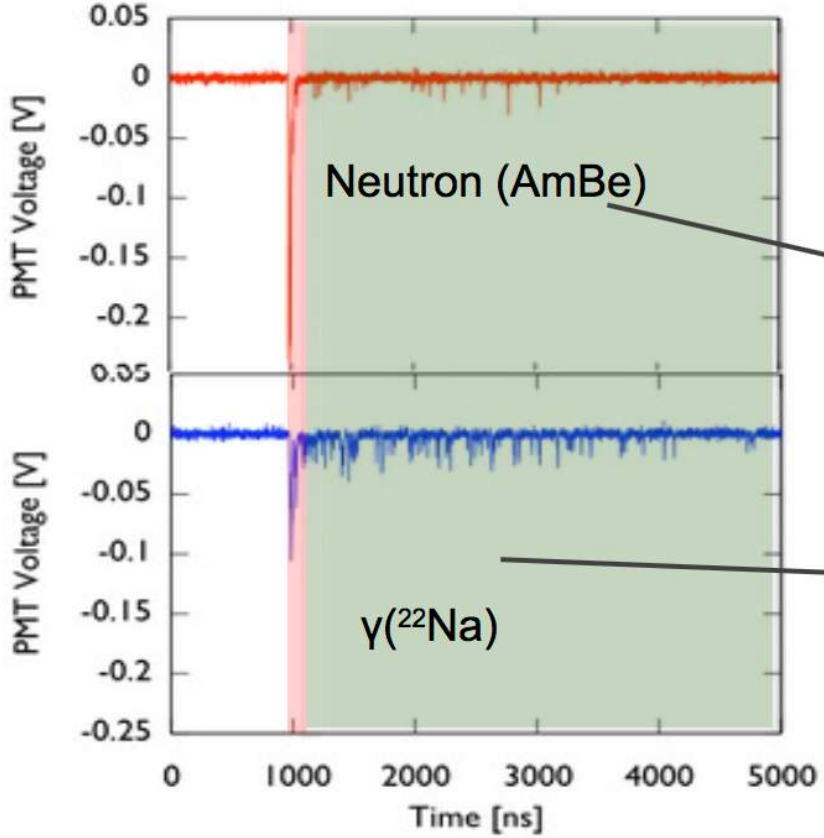
Pulse shape discrimination (PSD)

Marcin Kuźniak

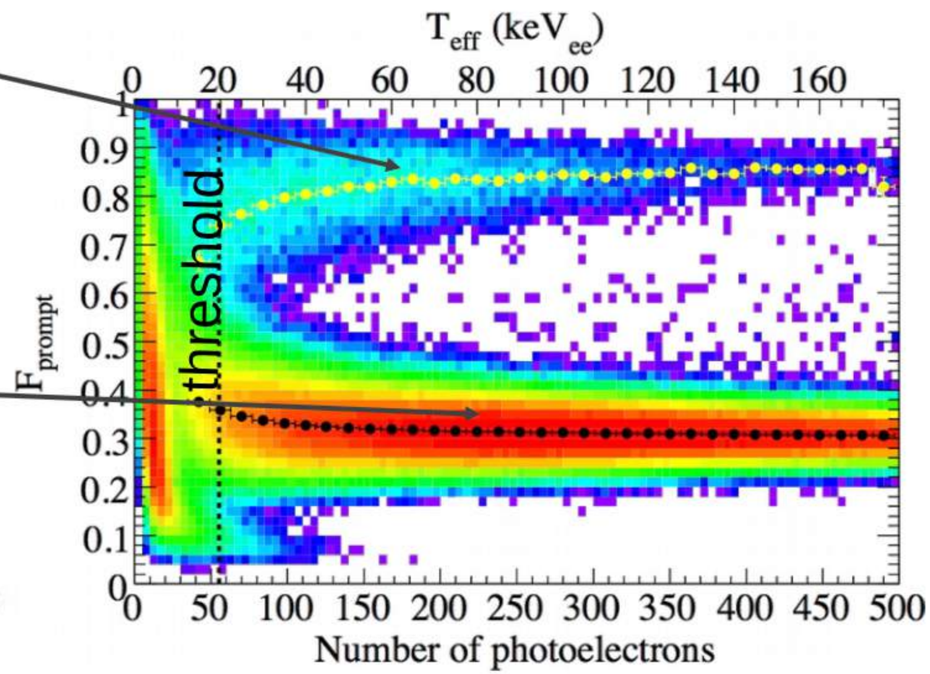
Ar singlet and triplet excited states have well separated lifetimes (7ns vs. ~1.5us)



PMT signal:

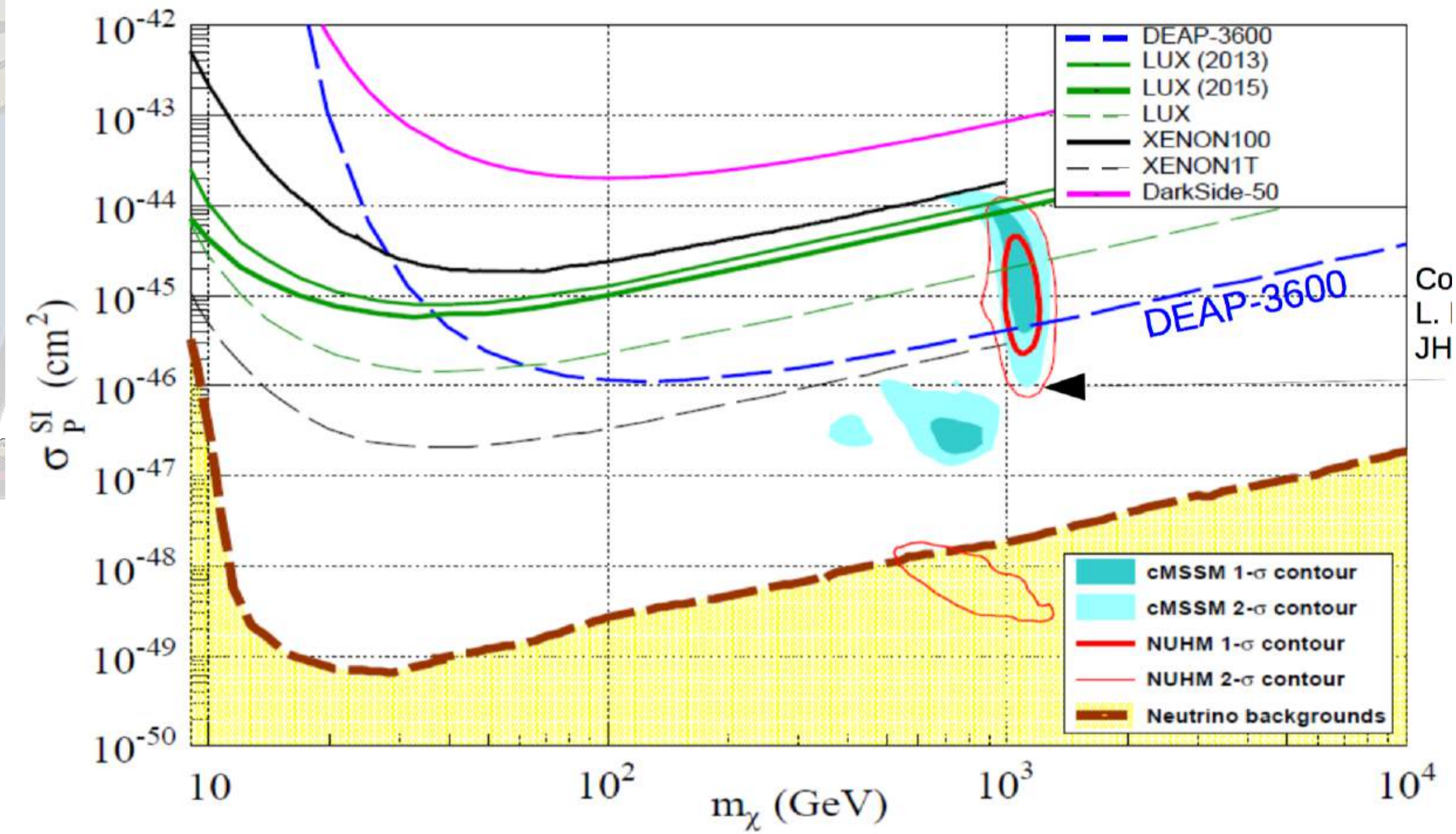


$$\mathrm{FPrompt} = \frac{N_{prompt}}{N_{prompt} + N_{Late}}$$



Prompt : 0-150ns
Late: 150ns-10μs

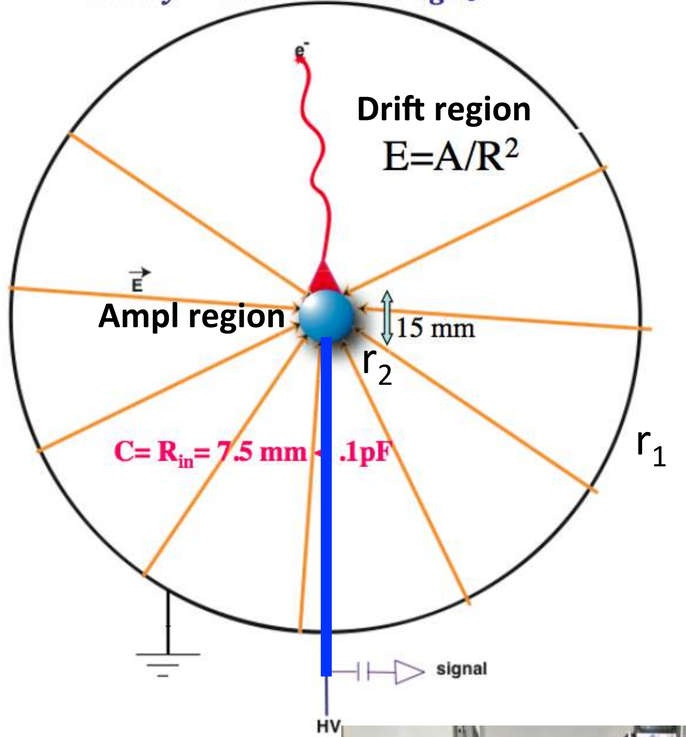
Single phase LAr:
scintillation channel is sufficient, no ionization channel


DEAP-3600
LUX (2013)
LUX (2015)
LUX
XENON100
XENON1T
DarkSide-50
DEAP-3600
cMSSM 1-σ contour
cMSSM 2-σ contour
NUHM 1-σ contour
NUHM 2-σ contour
Neutrino backgrounds
σ_P^{SI} (cm^2)
m_χ (GeV)
Co
L. I
JH

NEWS

Gille Gerbier

Spherical gas detectors
New Experiments With Spheres @ SNOLAB



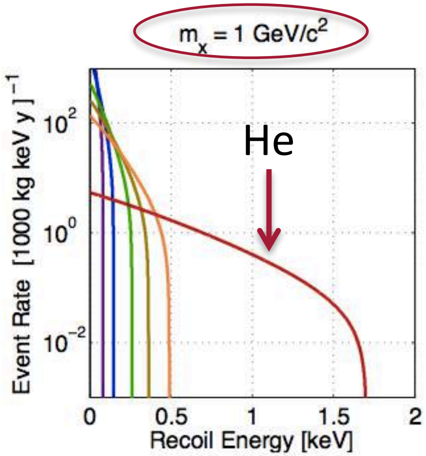
- Sphere cavity + spherical sensor @ HV
- **=> Low threshold (low C), single electron sensitivity**
- **Fiducial volume selection by pulse risetime**
- Flexible (P, gaz)
- Large mass / large volume (30 kg) with single channel
- Simple, sealed mode
- Few materials involved, mostly copper, low activity
- **Adapted for low mass WIMP investigation with Ne/He/H thanks to kinematical match of WIMP-target masses**
- => 60 cm prototype at Laboratoire Souterrain de Modane

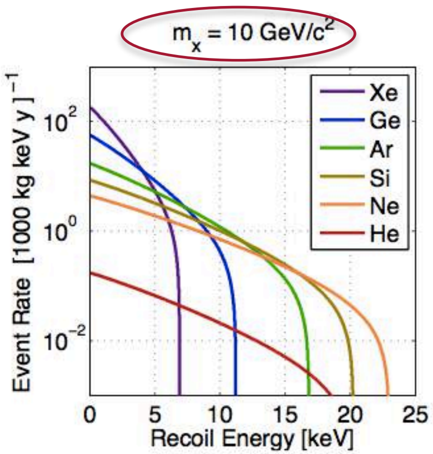
$$C = 4\pi\epsilon\rho$$

$$1/\rho = 1/r_2 - 1/r_1$$

$\rho \approx r_2$ => C does not depend on shell radius

$$E(r) = \frac{V_0}{r^2}\rho$$



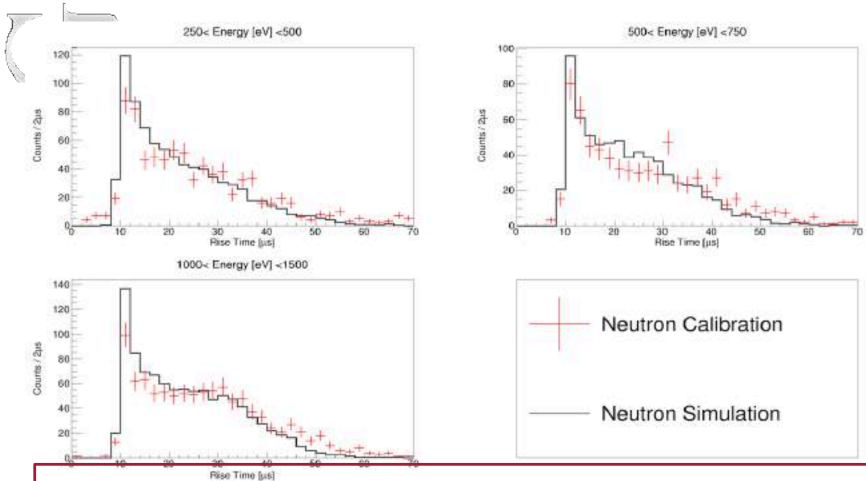


Nov 21st 2016 – G Gerbier 1

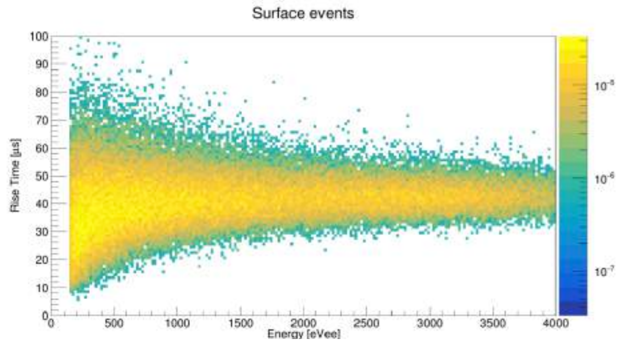
Gille Gerbier

Light dark matter search at LSM
Low activity 60 cm Ø prototype @ LSM : SeDiNe

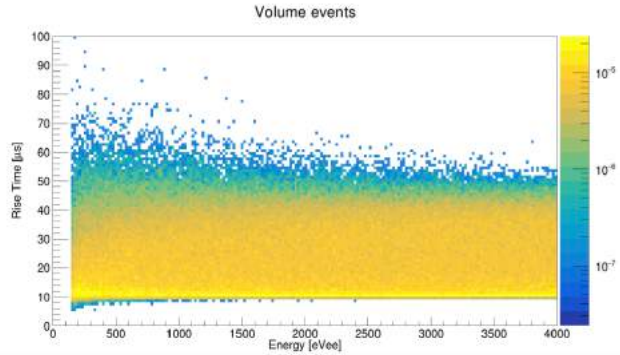
- Copper vessel equipped with 6 mm Ø sensor
- Run with **Neon**+0.7%CH_4 @ 3.1 bars
- => 310 g sensitive mass
- Analysis threshold 150 eVee
- 42 days run for WIMP search
- **Results to be reported at TPC 2016 Paris conference and Berkeley low**



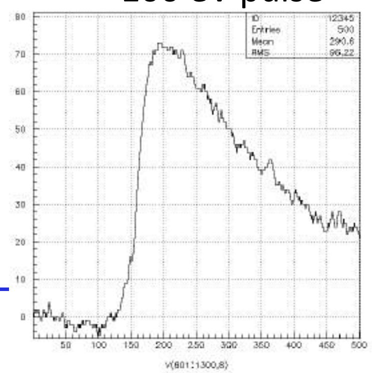
Rise time (diffusion) distributions of neutron induced recoils and simulation => good agreement



Expected behaviours of risetime vs energy distributions for volume and surface (Rn deposits) events => Discrimination



100 eV pulse



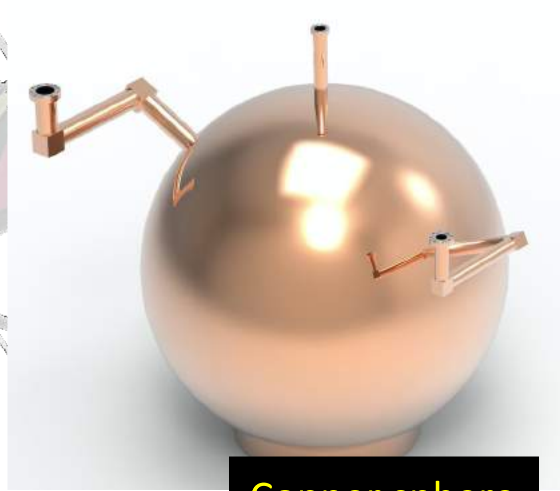
60 cm NOSV copper vessel

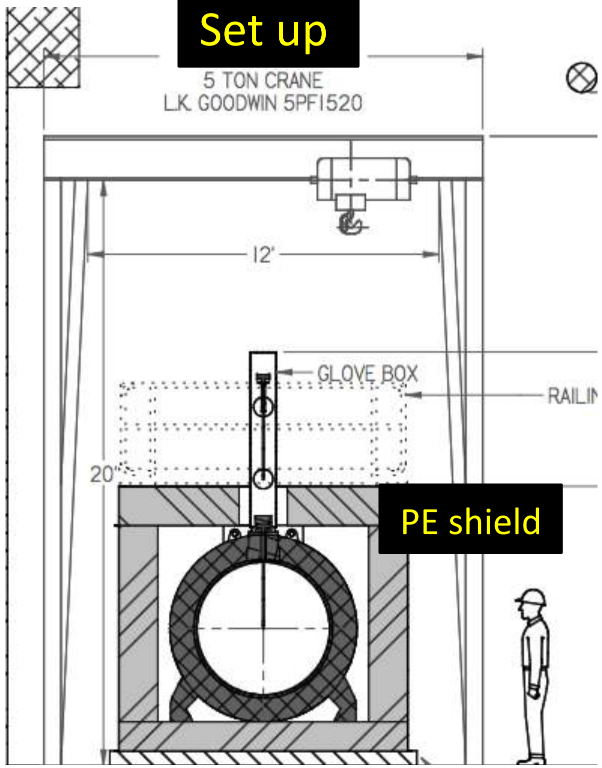
6.3 mm sensor

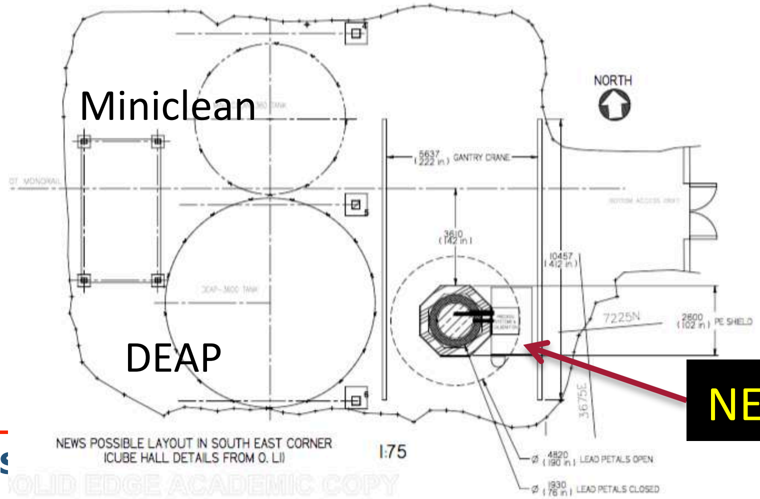
Gille Gerbier

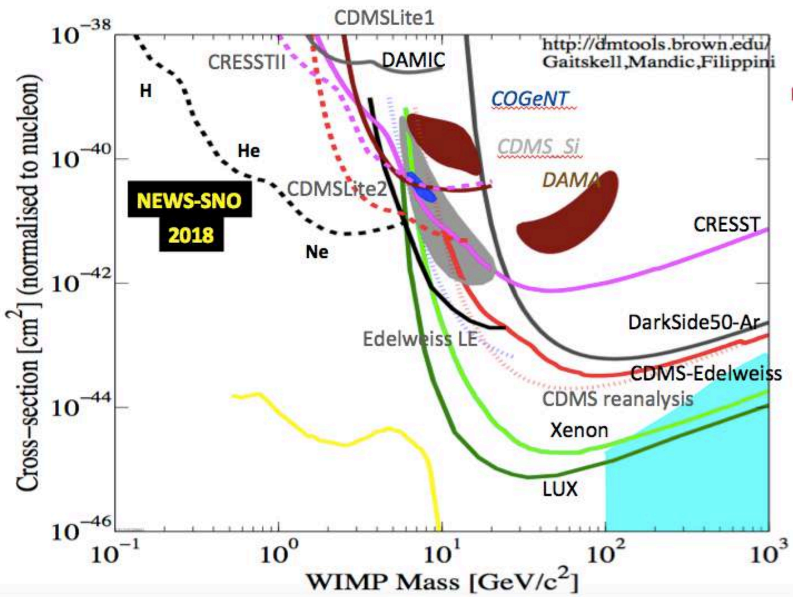
NEWS-SNO : 1.4 m Ø copper detector @ SNOLAB

- 140 cm Ø detector, 10 bars, Ne, He, CH_4
- Copper ≈ few μBq/kg U/Th contamination
- Lead -ancient + low activity- & PE shield
- => Gain of factor >100 wrt LSM prototype backg
- Project at TDR phase



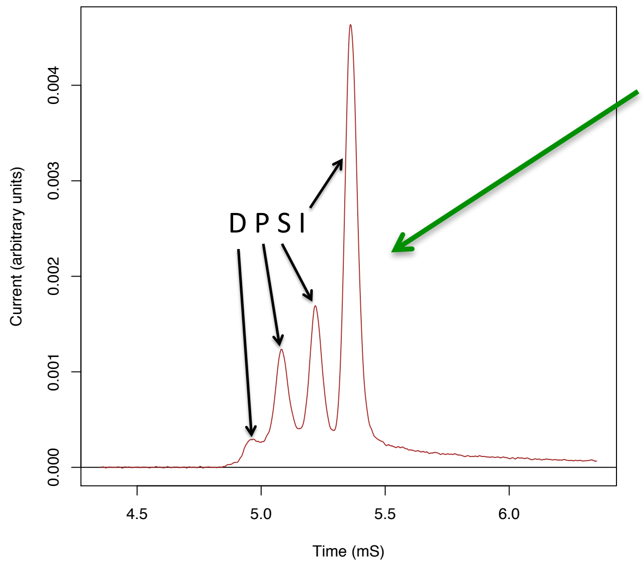




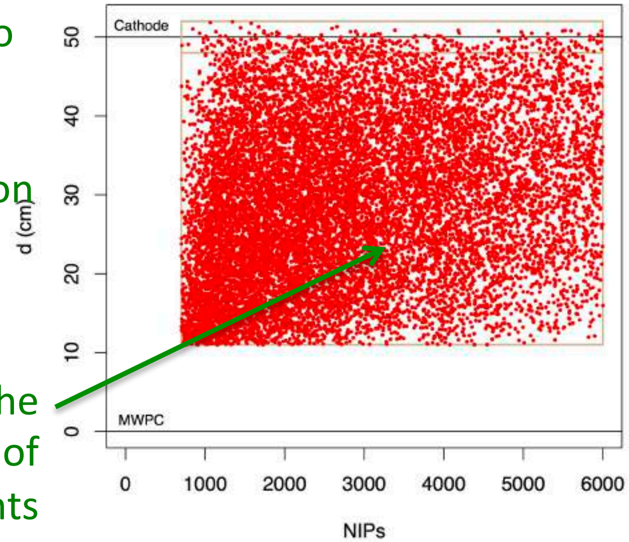


DRIFT

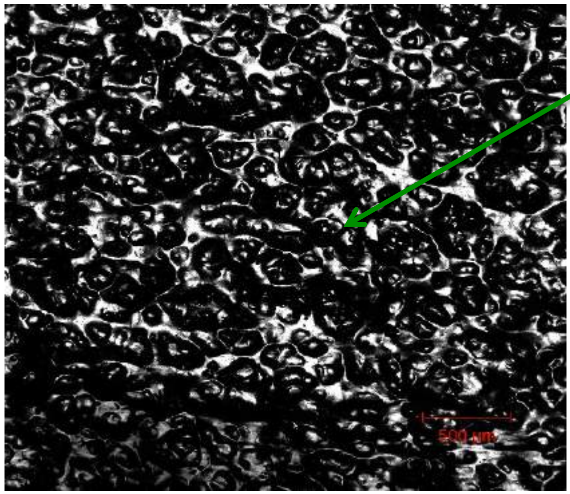
Background-Free DRIFT-IId



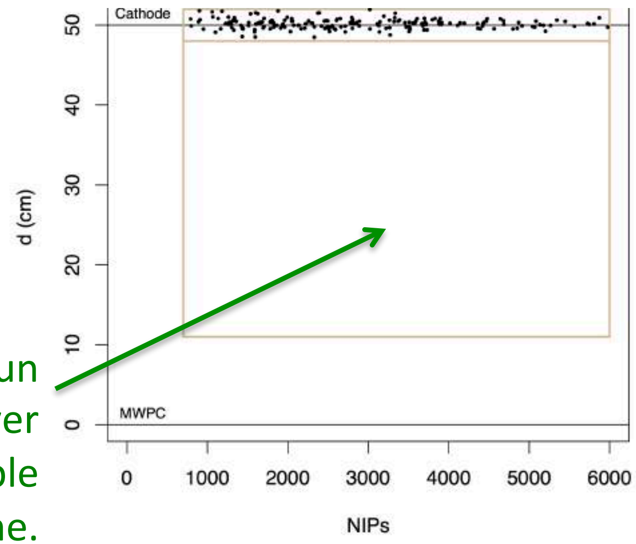
The addition of O_2 to a CS_2-CF_4 mixture produces minority peaks with separation proportional to distance.



This allows for the measurement of *d* of events



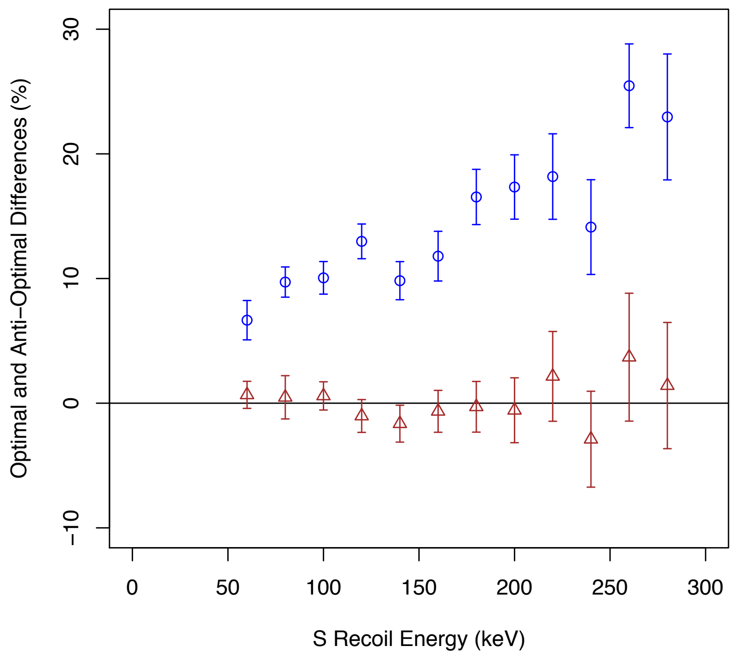
That coupled with a new texturized cathode…



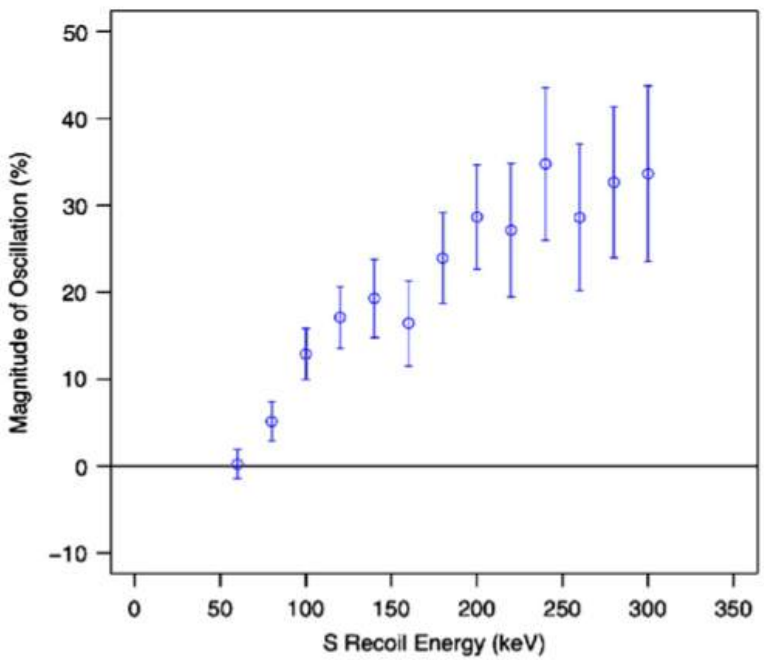
…allows us to run background free over ~75% of our available volume.

Directionality

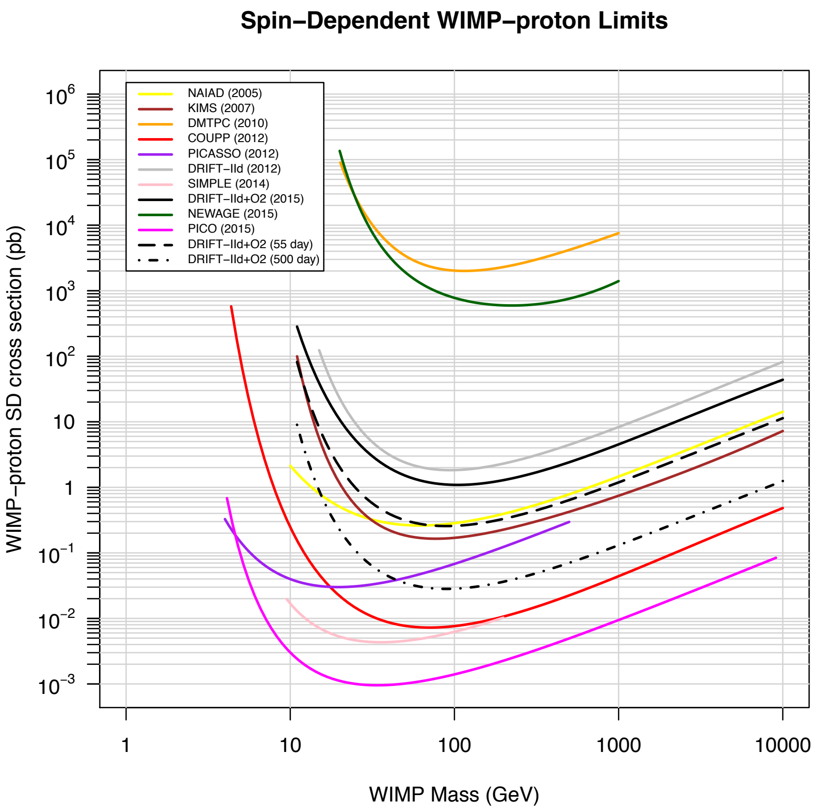
DRIFT Head-Tail Results

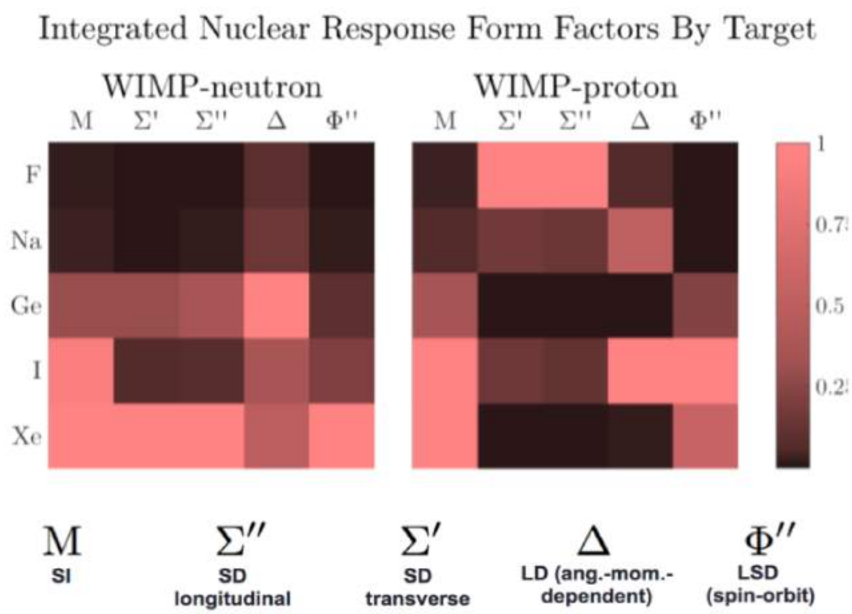


DRIFT Range Results



Future Plans for DRIFT





N. Larsen, http://conference.ippp.dur.ac.uk/event/544/session/0/contribution/7/material/slides/0.pdf

SUMMARY

- Huge progress in recent (SI: 3 orders of magnitude in 5 years!)
- LXe TPCs presently the most competitive technology: LUX
  - Genuinely providing significant constraint to theory
- Further advances very soon: PandaX (500 kg), Xenon1T are both running. Another order of magnitude in ~ 1-2 years (?)
- ~5.5 T LXe devices online in 2019/2020; ***yet another*** order of magnitude by ~2022(?)
- Single phase LAr also now running - very competitive at high masses
- Other techniques being developed for low masses, e.g. NEWS
- Directionality is progressing, e.g. DRIFT (&CYGNUS)
- **Digging deeper in the data; digging deeper in the phase space…**

DMUK Meeting - UCL

https://indico.fnal.gov/conferenceDisplay.py?confId=13260

January 18, 2017 *University College London*
Europe/London timezone

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Support

This is a 1-day meeting for the UK's Dark Matter community to meet up, present research, and discuss the latest progress in the field.

Dates: January 18, 2017 (09:00-16:00)

Timezone: Europe/London

Location: *University College London*
Wilkins Building
Gower Street
London
WC1E 6BT
Room: Haldane Room

Chairs: Dr. Ghag, Chamkaur
Dr. Dobson, James

Additional info: Support for this event is gratefully received from the Astroparticle Physics Group of the IOP.

DMUK

18 January 2017
University College London