LZ Overview

Jornadas LIP 2018

G. Pereira, 17 February 2018

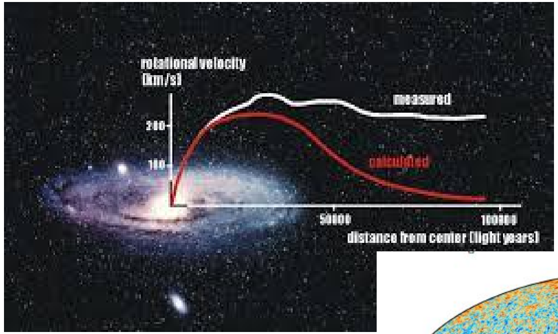
LZ collaboration

1) Center for Underground Physics (South Korea)
2) LIP Coimbra (Portugal)
3) MEPhI (Russia)
4) Imperial College London (UK)
5) STFC Rutherford Appleton Lab (UK)
6) University College London (UK)
7) University of Bristol (UK)
8) University of Edinburgh (UK)
9) University of Liverpool (UK)
10) University of Oxford (UK)
11) University of Sheffield (UK)
12) Black Hill State University (US)
13) Brookhaven National Lab (US)
14) Brown University (US)
15) Fermi National Accelerator Lab (US)
16) Lawrence Berkeley National Lab (US)
17) Lawrence Livermore National Lab (US)
18) Northwestern University (US)
19) Pennsylvania State University (US)
20) SLAC National Accelerator Lab (US)
21) South Dakota School of Mines and Technology (US)
22) South Dakota Science and Technology Authority (US)
23) Texas A&M University (US)
24) University at Albany (US)
25) University of Alabama (US)
26) University of California, Berkeley (US)
27) University of California, Davis (US)
28) University of California, Santa Barbara (US)
29) University of Maryland (US)
30) University of Massachusetts (US)
31) University of Michigan (US)
32) University of Rochester (US)
33) University of South Dakota (US)
34) University of Wisconsin – Madison (US)
35) Washington University in St. Louis (US)
36) Yale University (US)

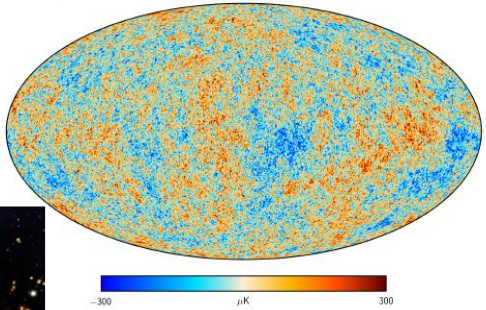




Dark Matter evidences



- Galaxies rotational speed does not match a ~1/r proportion predicted by Newton Mechanics.



- Anisotropies in CMB and cosmological constraints set by Planck agrees with the existence of dark matter with a ~25% component.

- Bullet cluster collision:
  mass measured by
  Gravitational lensing (blue) and
  mass measured by X-rays (pink)
  don’t match in position

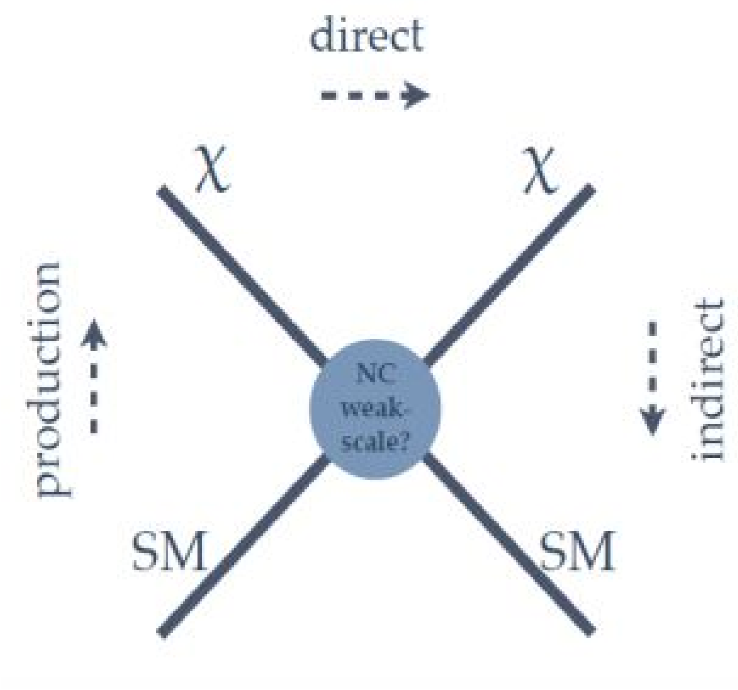
Dark matter detection methods

Most stronger candidates for dark matter are **WIMPs** (Weakly Interacting Massive Particles)

- Indirect detection (annihilation of WIMPs)
  High-energy cosmic-rays, γ-rays, neutrinos

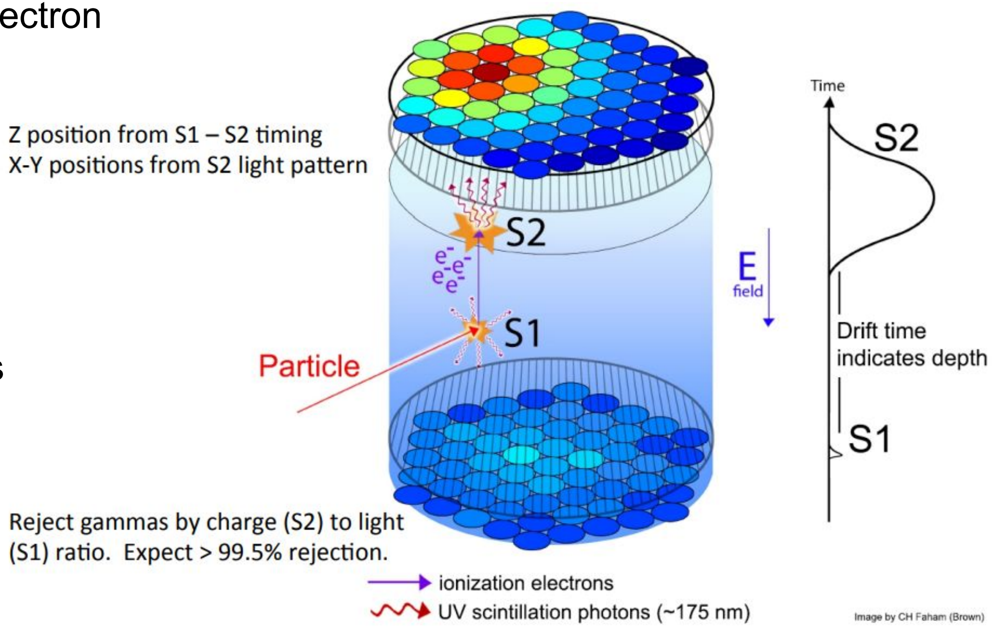
- Production of WIMPs
  Missing energy measurement.

- Direct detection (scattering WIMPs)
  Nuclear (atomic) recoils from elastic scattering



Dual-phase Xenon TPC - Working principle

- **S1 signal**:
  - Light yield:~20-60 photons/keV (electron recoil(ER))
  - Scintillation light: 178 nm (VUV)
  - Nuclear recoil (NR) threshold ~2 keV
- **S2 signal**:
  - Electroluminescence in vapor phase
  - Sensitive to single ionization electrons
  - NR (Nuclear Recoil) threshold ~1keV



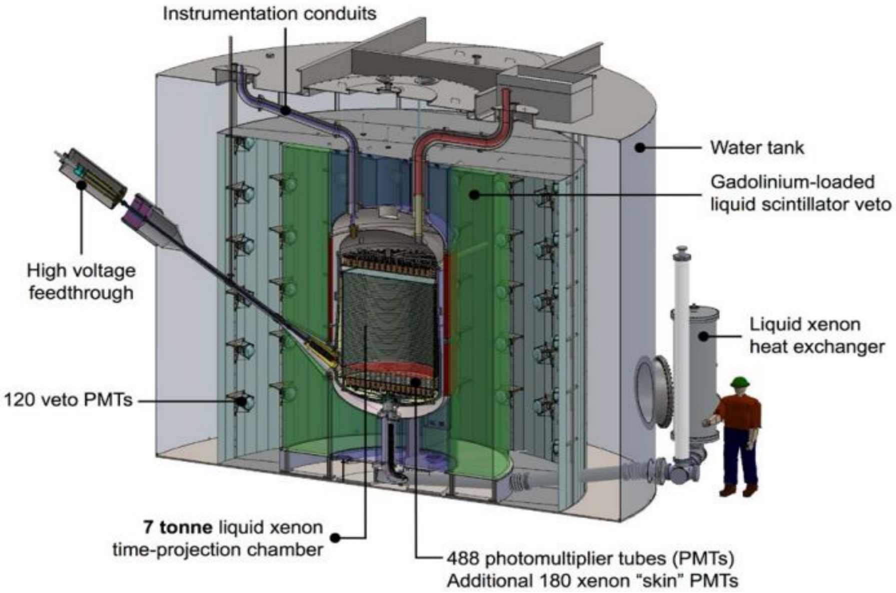
LZ Detector

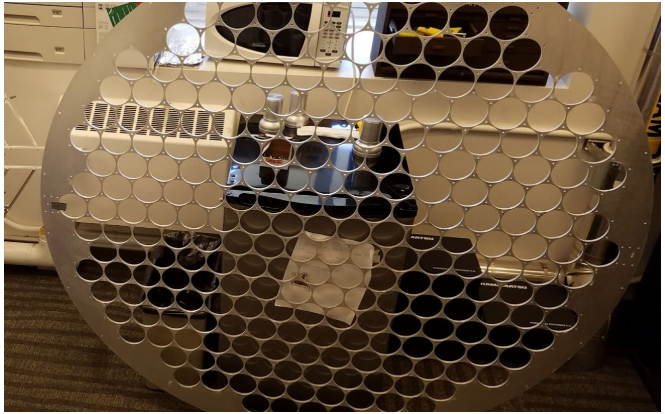
- Double-phase (liquid/gas) Time Projection Chamber:
    - 7 ton Liquid Xenon (10 ton total)

- Three veto detectors:
    - “skin” of the Xe
    - gadolinium-loaded liquid scintillator
    - surrounding water

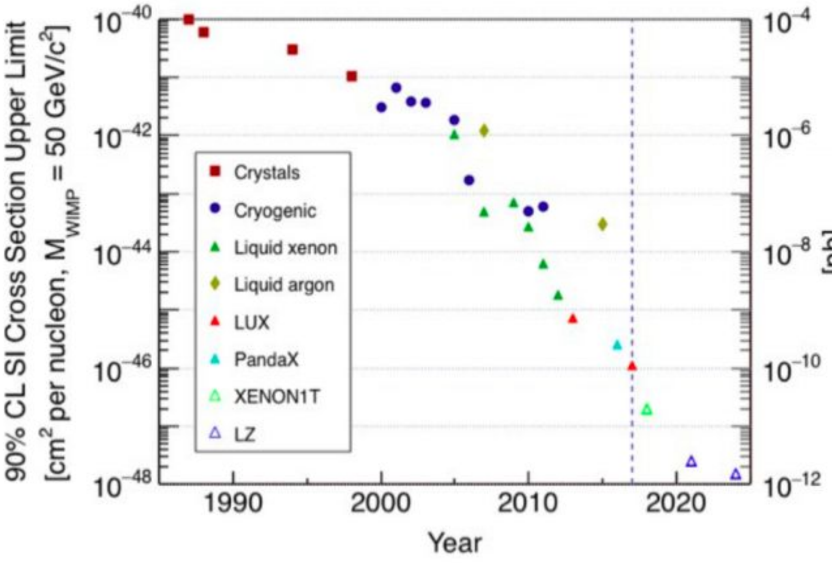
- Excellent background suppression by fiducialisation and active veto systems.

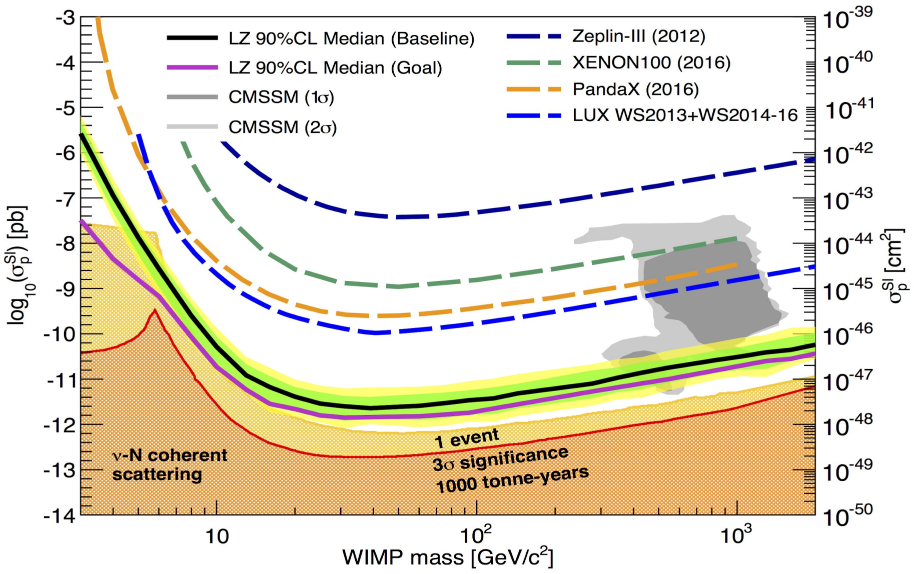
- Total of 745 detectors





LZ goal





2.3×10^-48 cm^2 for a 40 GeV/c^2 (1000 live days)

LIP in LZ - Background model

5.6 tonnes fiducial, 1,000 live-days

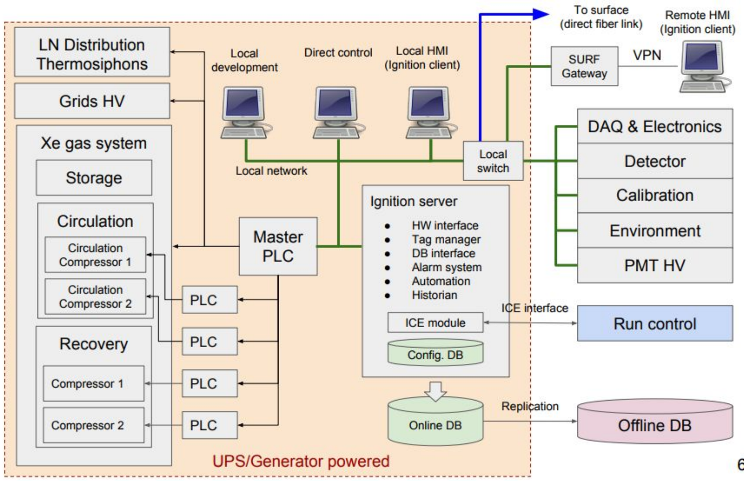
~1.5-6.5 keV, single scatters, no coincident veto

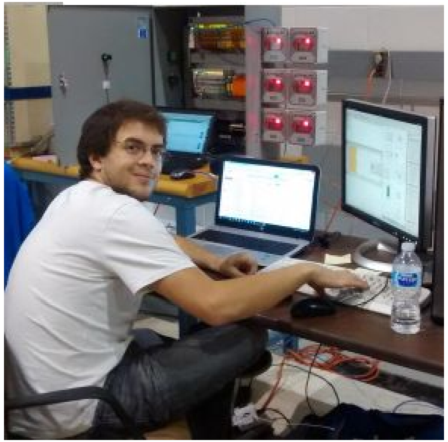
Background Source	ERs	NRs
Detector Components	9	0.07
Dispersed Radionuclides — Rn, Kr, Ar	816	—
Laboratory and Cosmogenics	5	0.06
Surface Contamination and Dust	40	0.39
Physics Backgrounds — 2β decay, neutrinos*	322	0.51
Total **(after 99.5% discrimination and 50% NR efficiency)**	**6.48**	

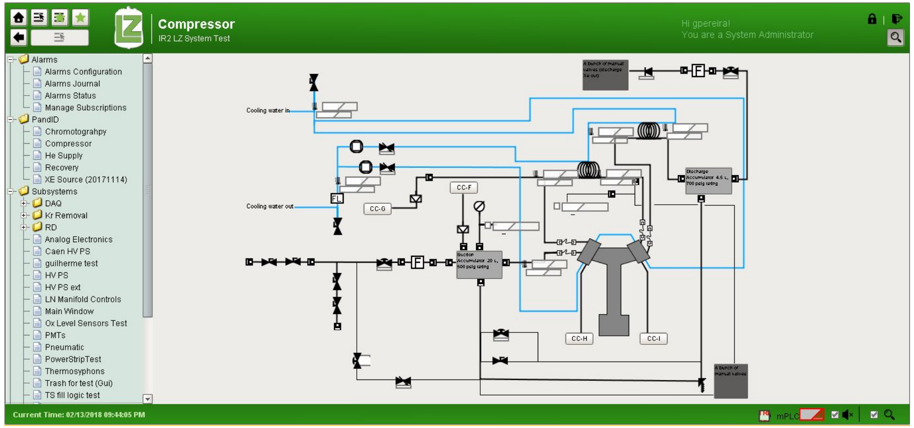
* not including CNNS from ^{8}B and hep neutrinos

LIP in LZ - Control System

- **Control System**
  - Experiment parameter monitoring and logging
  - Control over experiment subsystems
  - Safety
  - User Interface (GUI, plots, access control and action log)

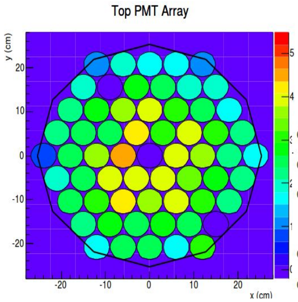


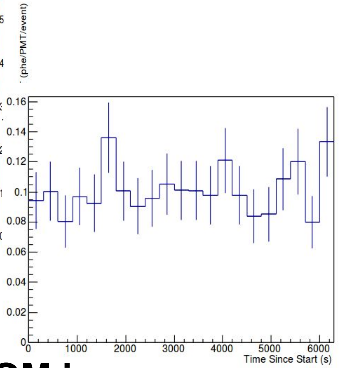


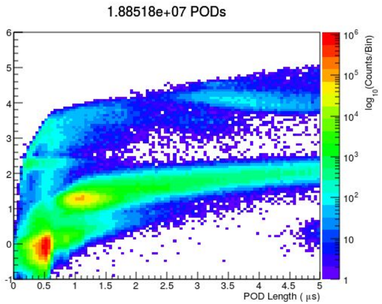


LIP in LZ - DQM

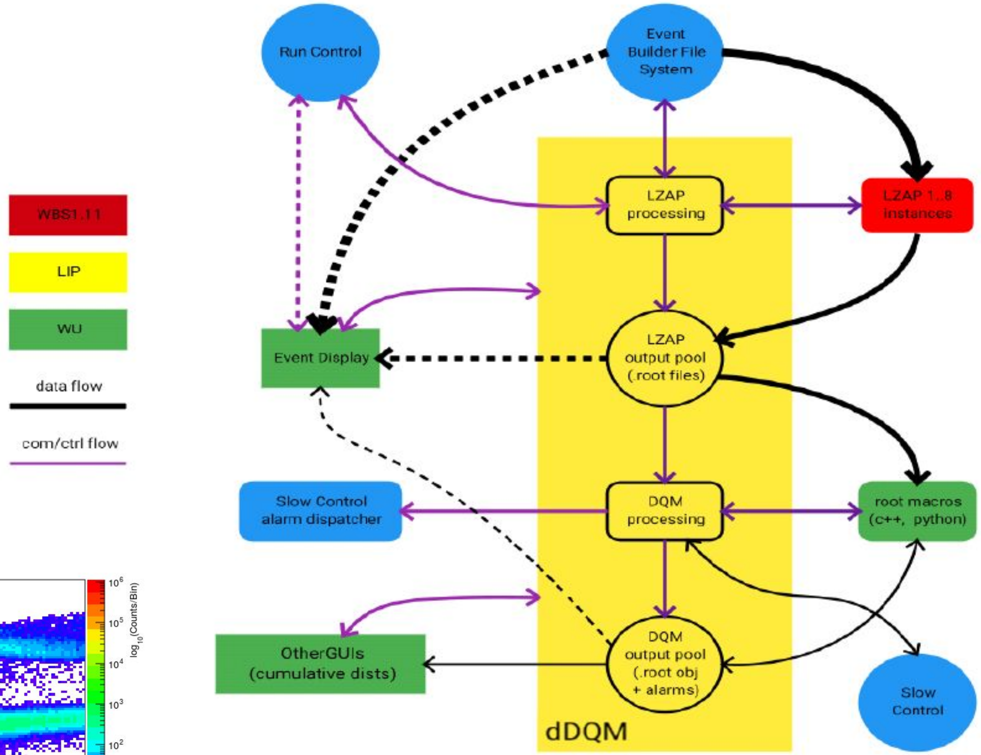
- **DQM** - Data Quality Monitor
- Main objective - rapid identification of irregularities with the system through data analysis (early warning system)
- In LUX - insured high quality of the data through the science runs
- LIP committed to developing the core functionality of the LZ DQM







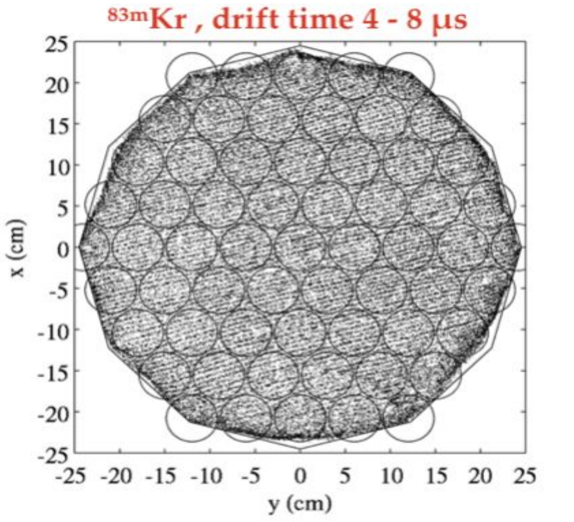
Typical LUX DQM images



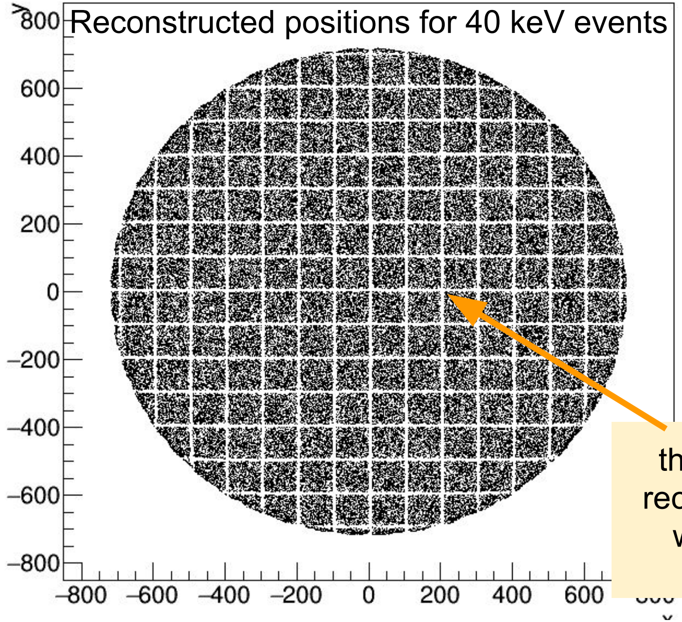
LIP in LZ - Event reconstruction

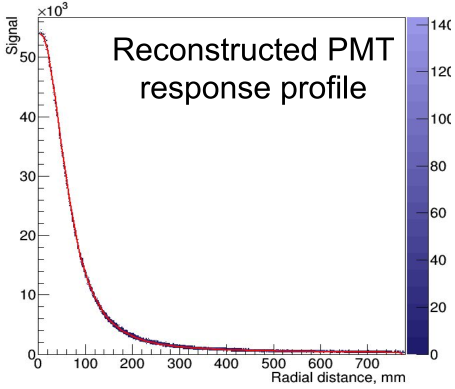
- **Mercury** adaptive reconstruction algorithm, originally developed by LIP team for ZEPLIN III experiment, was adapted for data analysis of LUX
- Also used (with some modifications) by other dual phase DM detectors (DarkSide and PANDA-X)
- We have integrated it into data processing chain of LZ with successful test on mock data (MDC1)
- We are currently responsible for maintenance of the event reconstruction LZap module

LUX experimental data
5mm pitch wires resolved



LZ Mock Data Challenge (MDC1)

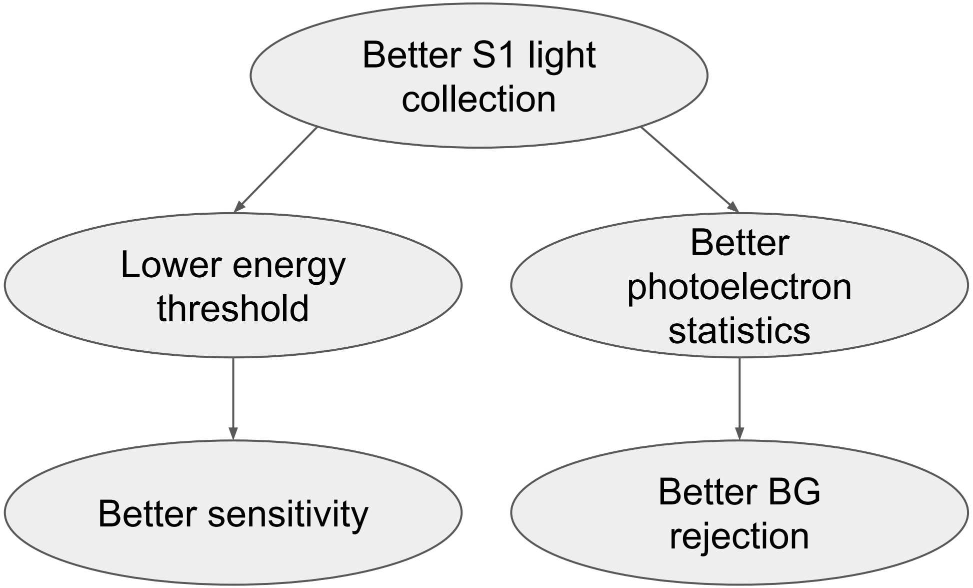




the events with true positions on rectangular grid with 100 mm pitch were excluded to demonstrate linearity

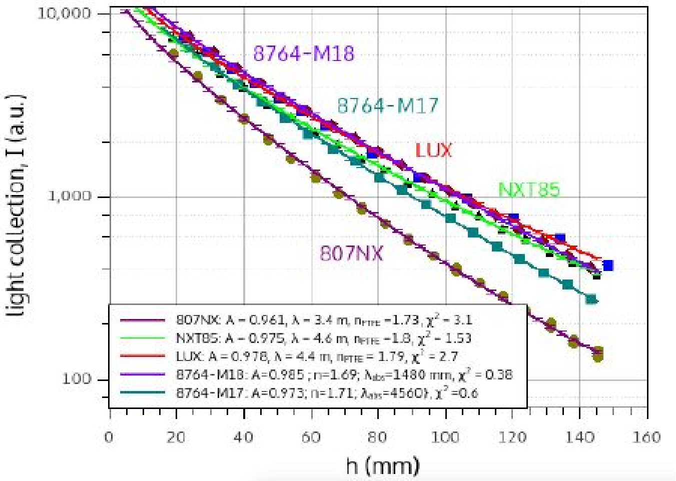
LIP in LZ - PTFE reflectivity

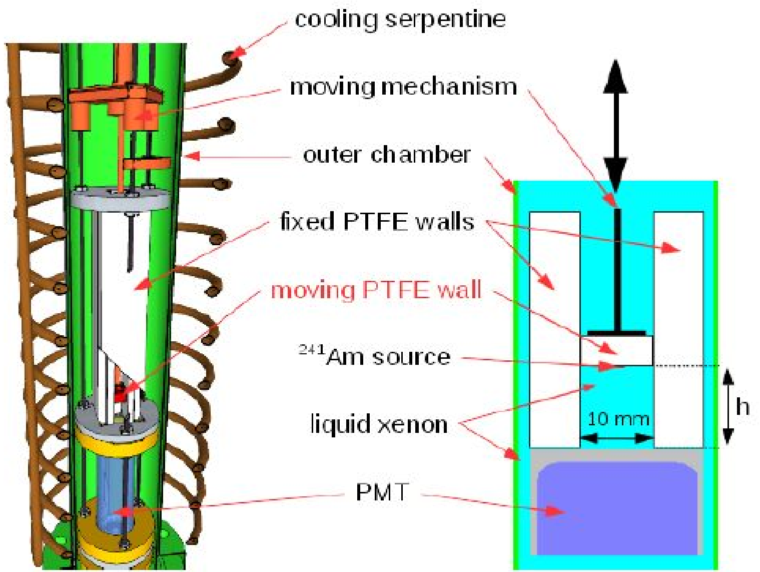
- LZ walls are lined with PTFE to improve light collection for S1 signal
- PTFE reflectivity is between 95% and 100%
- A small variation in reflectivity leads to large change in light collection as most photons are reflected many times before reaching a PMT
- The direct measurement wasn't sufficiently precise - the new method using multiple reflections was developed



LIP in LZ - PTFE reflectivity

- **Measured 5 PTFE samples**
  - 807NX, NXT85
  - LUX
  - 8764 (Daiken M-18)
  - 8764 (Daiken M-17)





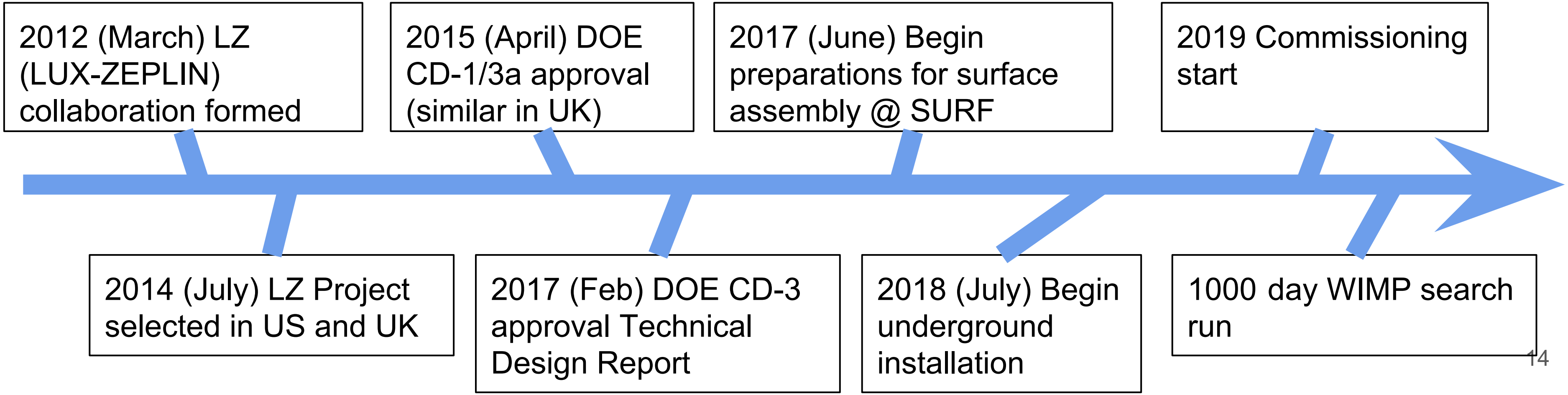
LZ sensitivity estimate

Original: 2.3×10^{-48} cm^2 for R=95%
Updated: 1.7×10^{-48} cm^2 for R=97.7%

(Equivalent to additional 2.5 tons of Xe)

Summary

- LZ dark matter experiment proceeds on schedule.
- LZ benefits from LUX calibration techniques and understanding of backgrounds.
- WIMP sensitivity 2.3×10^{-48} cm^2 for a 40 GeV/c^2 WIMP mass with 1,000 live days and 5.6 tonnes fiducial mass.
- LIP has a major role in LZ in several subgroups.



Physics and analysis studies in LZ

Jornadas LIP 2018

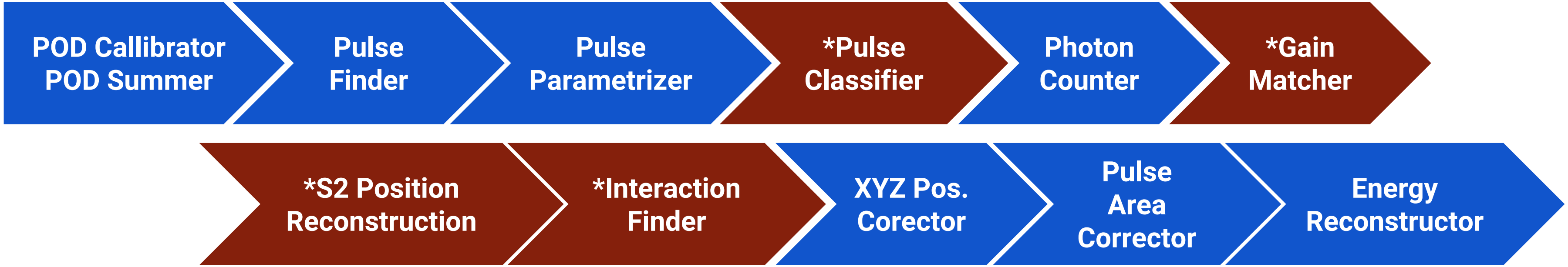
P. Brás, 17 February 2018

The analysis program of LZ (LZap)

Set of packages that handle low level (raw) detector data and process it into high level quantities that can be used for physics analysis.

Input: digitized waveforms (DAQ) - pulse only digitization (POD)

Output: high-level reduced quantities (RQs)

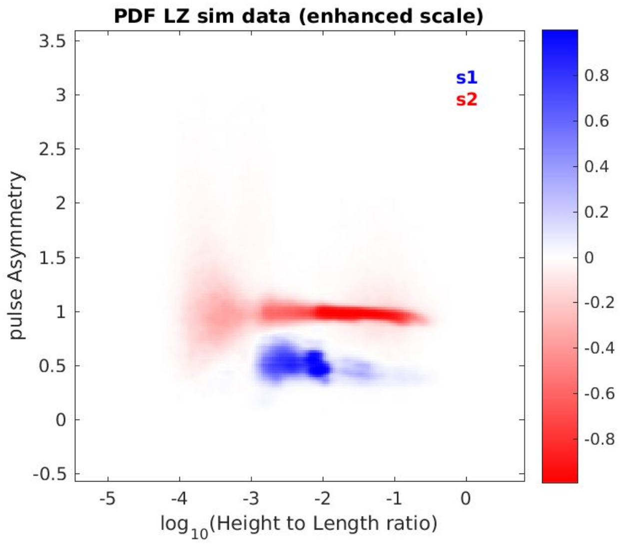


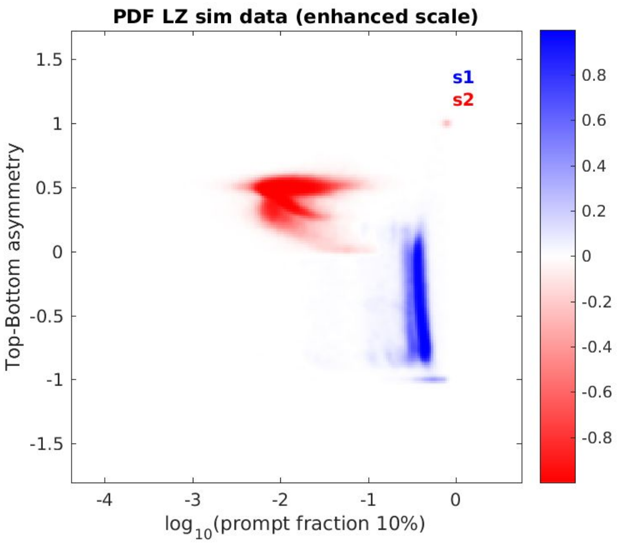
*modules developed and currently maintained by the LIP group

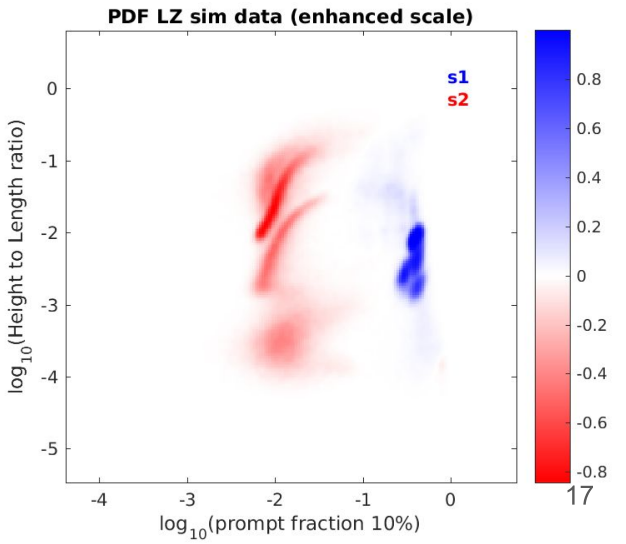
The analysis program of LZ (LZap)

Pulse Classifier - identifying the process that originated a given pulse.

Currently using bivariant PDFs constructed from 4 pulse parameters, extracted from simulated data by upstream LZap modules (pulse parametrizer).







The analysis program of LZ (LZap)

Pulse Classifier - identifying the process that originated a given pulse

1. Probabilistic approach
2. Unbiased method - automatically accounts for data features (generalizable)
3. Flexible to new pulse categories and useful for behavioral analysis
4. Move away from ad-hoc solutions (threshold cuts made to fit a data trend)

Benchmarking:

LUX simulated data (87k pulses)

s1 efficiency	**99.987 %**
s2 efficiency	**99.967 %**

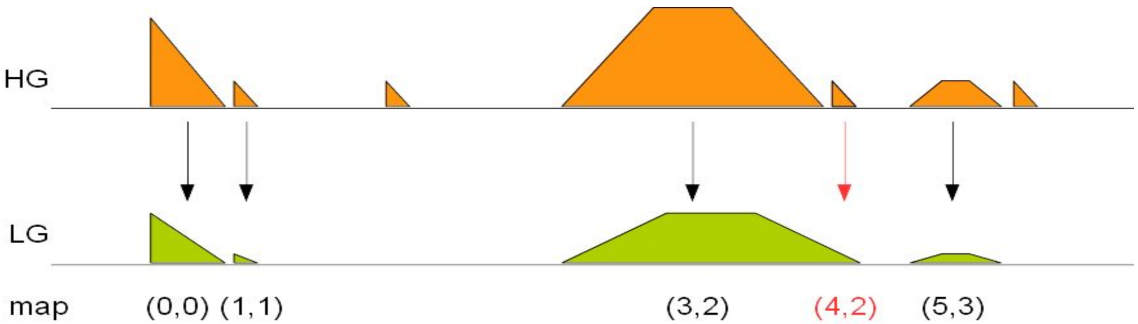
LZ sim data (1k pulses - some saturated)

s1 efficiency	**$100^{-0.08}$ %**
s2 efficiency	**$99.60^{\pm 0.07}$ %**

The analysis program of LZ (LZap)

Gain Matcher - Generates a correspondence map of pulse between the high gain and low gain channels (high sensitivity and low sensitivity)

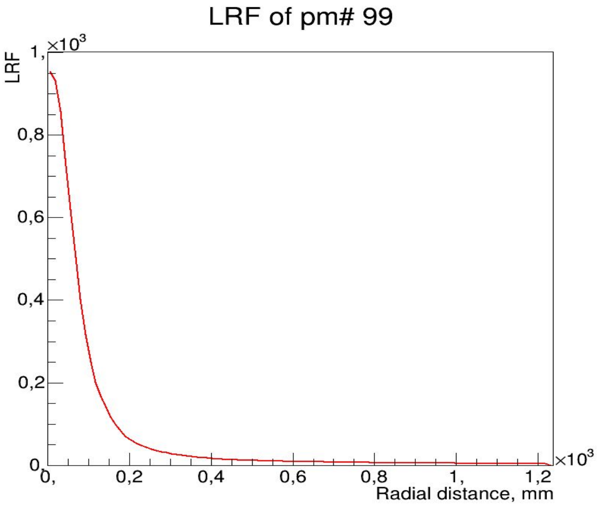
- Transparent interchange between HG and LG in analysis
- Selection of LG data when HG contains saturated pulses
- Relevant for energy calibration

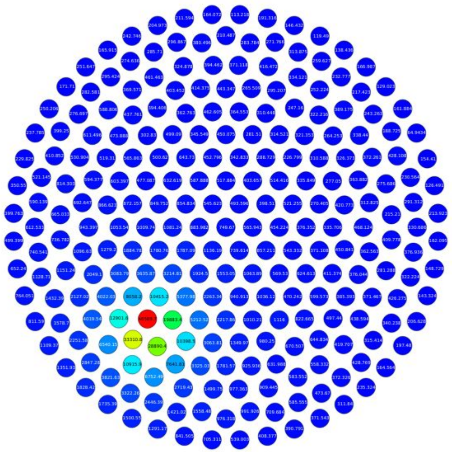


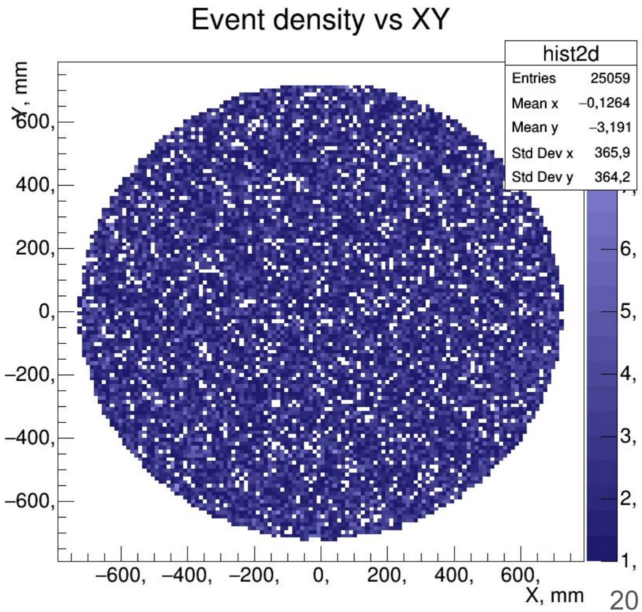
The analysis program of LZ (LZap)

S2 Position Reconstructor - Calculates the XY position of the s2 pulse using the top PMT hit map and the PMTs light response functions (LRFs)

Developed/maintained by LIP group since ZEPLIN-III



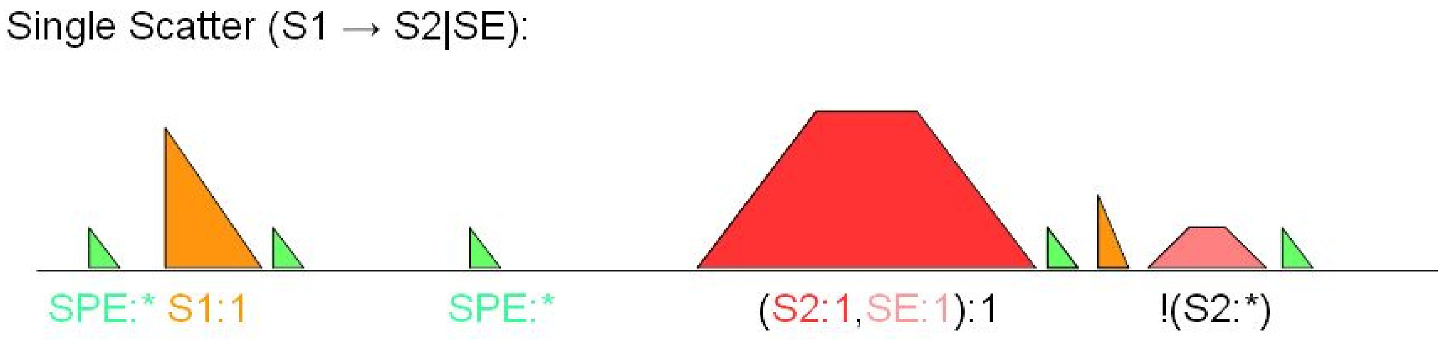




The analysis program of LZ (LZap)

Interaction Finder - Identifying the type of interaction based on the event topology

1. Matching of s1 and s2 signals from a single event
2. Selection of candidate events for dark matter search
3. Recognition of fast decay transitions in transient decay chains
4. Relevant for some detector calibration sources



Searches for rare decays in LZ

LZ sensitivity to **neutrinoless double beta decay ($0\nu\beta\beta$) of ^{136}Xe**
With more than **600 kg of ^{136}Xe** in the active region, LZ could be competitive

$$M_{Xe136}^{(EXO\text{-}200)} = 160\ \mathrm{kg} \qquad M_{Xe136}^{(KamLAND\text{-}ZEN)} = 129\ \mathrm{kg}$$

A sensitivity of $T_{1/2}^{(0\nu)} > 10^{25}$ years is achievable. background reduction on detector materials could increase the sensitivity up to 10^{26} years - KamLAND-Zen best result up to date is $T_{1/2}^{(0\nu)} > 1.01\times10^{26}$ years

- Currently maintaining the background model for this search
- Identification of the most relevant sources of BG for this decay
- Developing analysis strategies to identify these decay signatures in LZ
- Integration of these techniques in the analysis framework of LZ

Searches for rare decays in LZ

LZ sensitivity to **double beta decay ($2\nu\beta\beta$) of ^{134}Xe**

- Challenging due to lower energy - Q value of 825.8 keV
- Background dominated by the $2\nu\beta\beta$ decay of ^{136}Xe and radon

With more than **730 kg of ^{134}Xe** in the active region, LZ could reach a sensitivity of 10^{21} - 10^{22} years, being competitive with current leading experiments:

Latest EXO-200 UL at $T_{1/2}^{(2\nu)} > 8.7\times10^{20}$ years

Currently estimating the relevant backgrounds for this decay and sensitivity projections for LZ.

MPPC chamber for ^{136}Xe $0\nu\beta\beta$ decay

Currently assessing the viability of a LXe TPC with MPPC readout for $0\nu\beta\beta$ decay searches, along with Imperial College London

1. Characterize the event topology and energy signatures of $0\nu\beta\beta$ decay
2. Testing the limits of position resolution for this decay in LXe
3. Development of high-level analysis to identify $0\nu\beta\beta$ decay signatures

Research on detector architecture and simulated signal for viability studies.

Currently 2 masters students working on this

Summary / Future work

LIP is involved in several crucial tasks within the LZ collaboration.

Our main contributions include:

- Analysis algorithms for LZap
- Control System & DQM
- Reflectivity measurements
- Background model
- New physics ($0\nu\beta\beta$ decay, $2\nu\beta\beta$ decay) and analysis strategies

Future plans include:

- Implementing ML methods for data analysis in LZap and for $0\nu\beta\beta$ decay searches
- Continuous maintenance of background model and LZ sensitivity projections for $0\nu\beta\beta$
- MPPC chamber viability studies

Expect 2 papers and 2 masters thesis on these subjects this year

Recent results from LUX

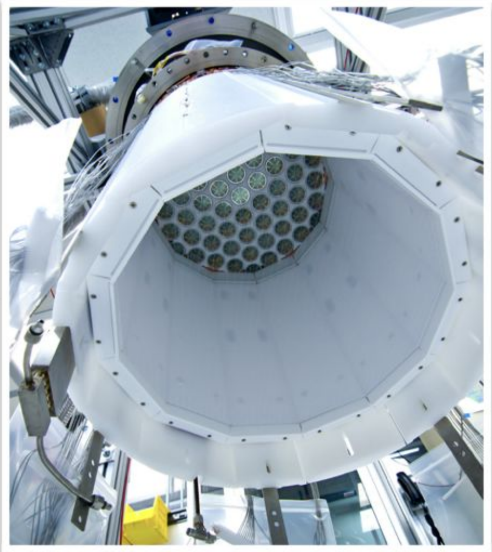
Jornadas LIP 2018

A. Lindote, 17 February 2018

The LUX Detector

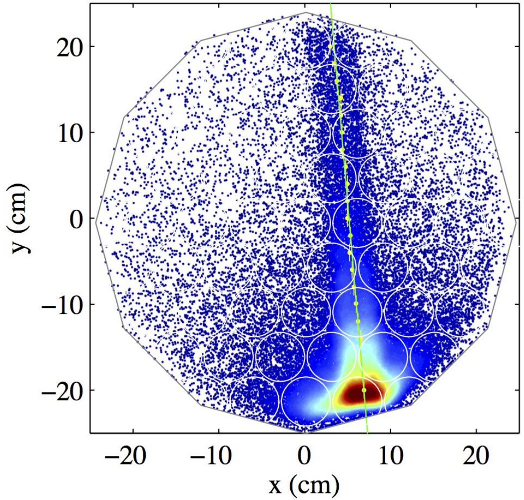
- **World-leader in WIMP sensitivity (2013 - 2017)**
- 250 kg active Xe target
    - ~30× less than LZ
- Technology pioneer:
    - Titanium cryostat (ultra-low background)
    - Use of thermosyphons for cooldown
    - Chromatographic separation of Kr content down to ~4 ppt
    - Precise low-energy calibrations for Xe ER and NR response
        - Sources mixed in Xe (^{83m}Kr, CH_3T, ^{14}C)
        - Neutrons from DD generator

LUX internals: PTFE reflectors and top PMT array



LIP responsibilities

- Hardware
  - LN System (F. Neves)
    - Fully automated system, hardware and software developed at LIP
  - Control System (V. Solovov)
    - ~500 channels (sensors, valves, HV, etc.), interface via mySQL (~2k accesses /s)
- Software and Analysis
  - Position reconstruction algorithm (C. Silva, V. Solovov)
    - Mercury, developed at LIP for ZEPLIN-III (JINST 13 P02001 2018)
  - Data processing (A. Lindote)
    - Development of the DP framework, processing of all the experiment data (>1 PB)
  - Many analysis contributions (WS analysis, wall model, etc.)
- Coordination Positions
  - Detector operations, on-site science operations, data processing
  - Analysis workgroup coordination (C. Silva is the current coordinator)



Reconstructed positions of neutron interactions from the DD generator

LUX Timeline

2006: LUX collab. formed

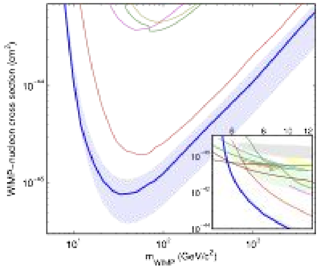
2008: LUX funded (DOE+NSF)

2012 (Jul): UG lab complete, LUX moves UG

2013 (Apr): First science run starts

100 live days

2013 (Nov): First results (3 months) reported

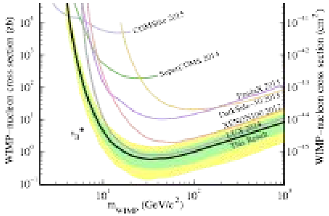


PRL, 112, 091303, 2014
(1575 citations)

2014 (Sep): 332-day run started!

332 live days

2015 (Dec.) 3-month run reanalysis posted



PRL, 116, 161301, 2016
(371 citations)

2016 (May): Run finished

2016 (July): 332 day results announced

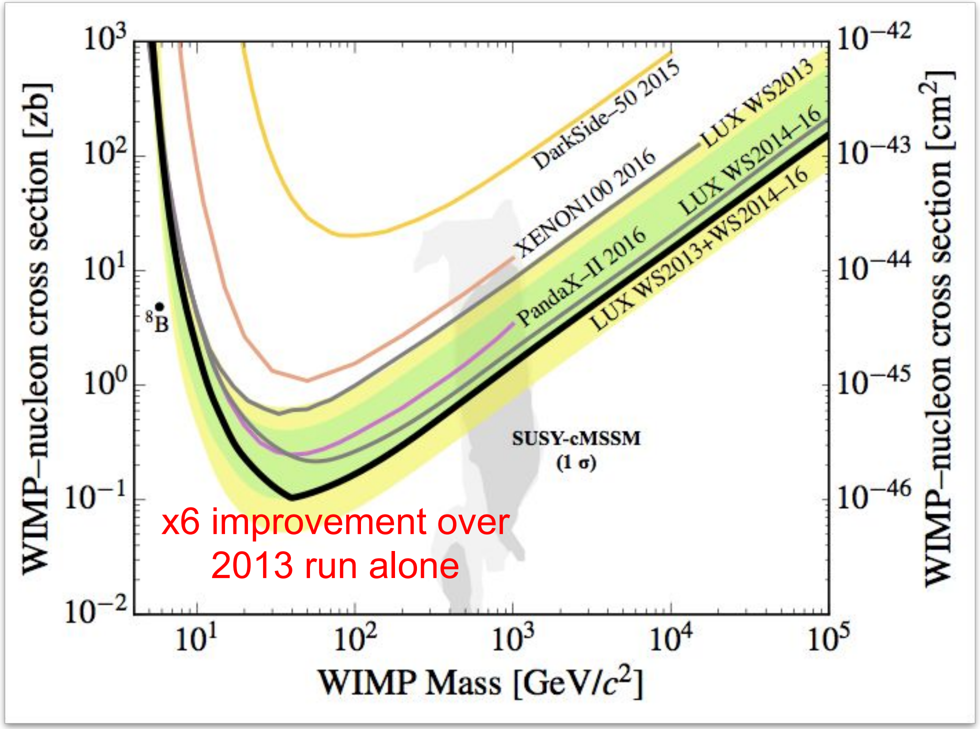
2016 (Sep): Decommis. starts

WIMP SI Sensitivity

In January 2017 LUX published the combined sensitivity of the two runs

PRL 118, 021303 2017
(535 citations)

Most cited particle physics paper of 2017!!!



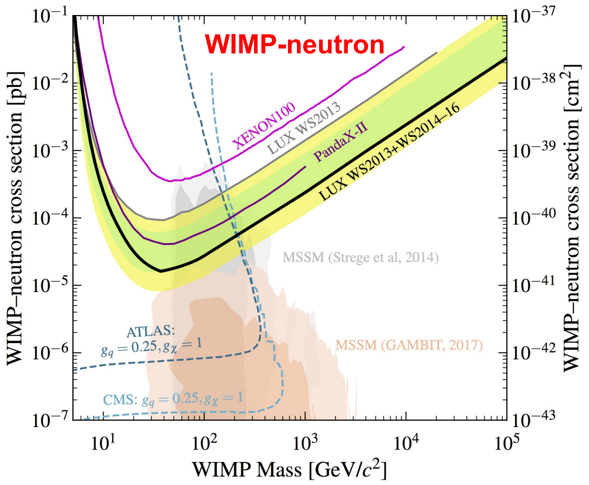
Still world-leading for low mass WIMPs (4 - 10 GeV)

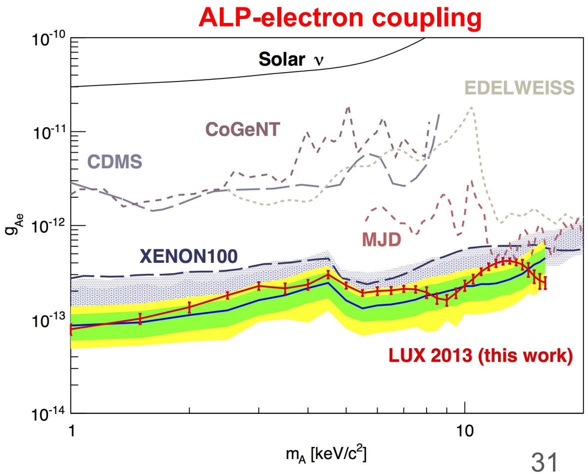
LUX was the most sensitive WIMP detector for 4 years (Oct. 2013 - Oct. 2017)

Other Physics Studies

LUX has a large amount of data which can be used for other analyses:

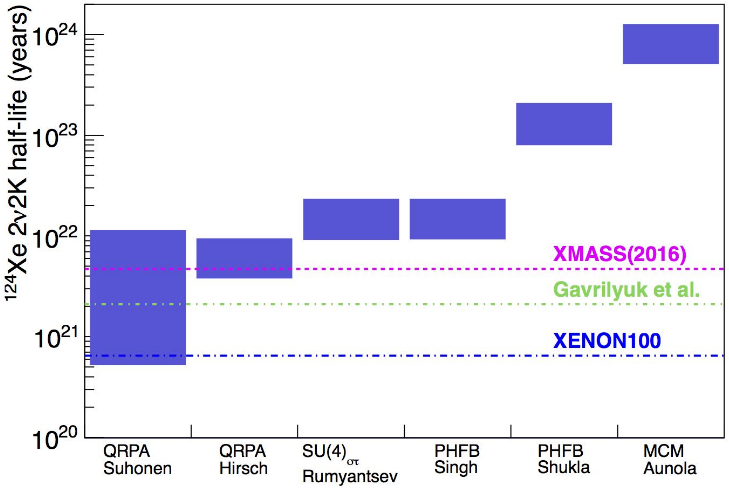
- Spin-dependent WIMP interactions (PRL 118, 251302 2017)
- Xenon physics
  - Low energy ER and NR calibrations (PRD 93, 072009 2016, arXiv:1608.0538
  - Recombination and energy resolution (PRD 95, 012008 2017)
- Other Dark Matter candidates
  - Axions and ALPs (PRL 118, 261301 2017)
  - Mirror DM, light WIMPs, LIPs
- Neutrino studies (e.g magnetic moment)
- Rare decays in xenon isotopes
  - Neutrinoless double beta decay in ^{136}Xe and ^{134}Xe
  - Double beta decay in ^{134}Xe
  - Double electron capture in ^{124}Xe





Double electron capture in ^{124}Xe

- $^{124}Xe + 2e^- \rightarrow {}^{124}Te + 2\nu_e$ (allowed in the SM)
- Neutrinoless mode: lepton number violation, Majorana nature of the neutrino
- Studying the normal decay:
  - Tests nuclear models
  - Improves estimate of 0ν half-life
- In ^{124}Xe: 76.7% of the times the 2 captured electrons are from the K-shell
  - De-excitation X-rays and Auger e^-s: ~64 keV
- Half-life estimate:
  - 10^{20}–10^{24} yr (from different nuclear models)
- In LUX:
  - 10^{21}–10^{22} yr sensitivity achievable



Summary

- LUX had 4 extremely productive years, and is still producing new physics results
  - World leading WIMP search experiment until late 2017
  - Made significant improvements in the calibration of xenon detectors
- Various additional analyses are on-going, to explore the full physics potential of the data
  - WIMP annual modulation, inelastic DM, EFT, etc.
- Accumulated expertise used in the design of LZ
- The LIP team was deeply involved in all areas of the experiment
  - Made crucial contributions in hardware, software, data analysis and team coordination

LUX on display at the SURF visitors center

The LUX Collaboration

20 institutions in the US, Portugal and the UK

~100 scientists