Direct detection of Dark Matter at LUX-ZEPLIN

Mariana Letra
Paulo Pires
Pedro Tovar

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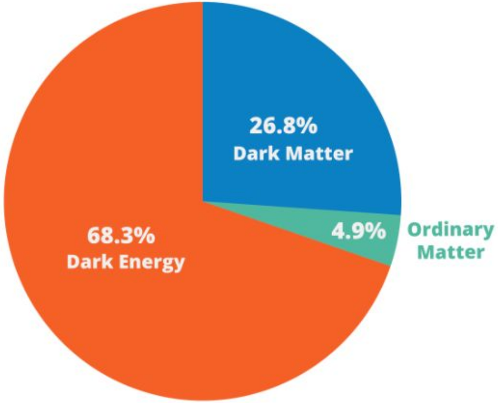
Universidade de Coimbra

Internship Program

Coimbra Lisboa Minho

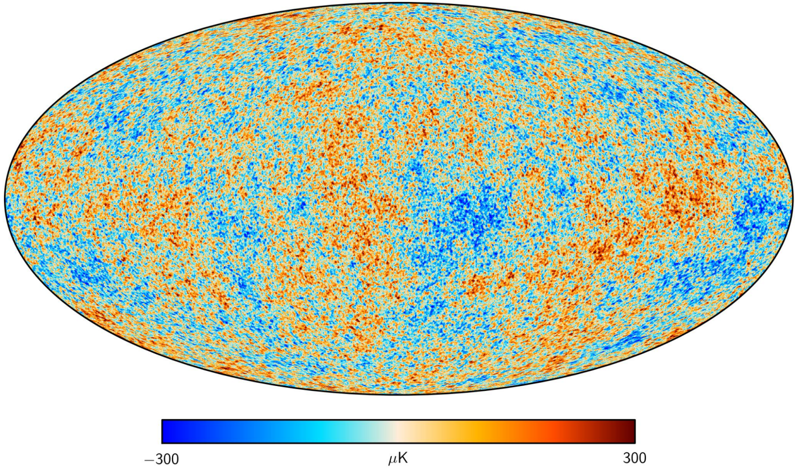
Dark Matter



About 26.8% of the universe (85% of all matter) is **dark matter**.

Some evidences:
- Cosmic microwave background radiation;
- Gravitational lenses;
- Galaxies orbital speed.

There are some candidates such as the **Weakly Interacting Massive Particles** (WIMPs).



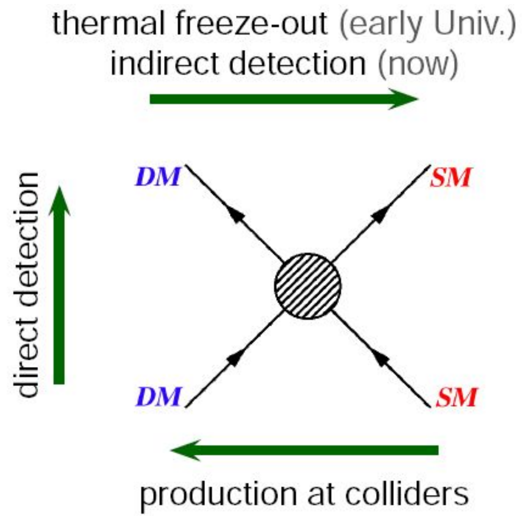
The existence of DM in the universe might imply physics beyond the **Standard Model**.

Planck Collaboration: Planck results (2018)

Dark Matter detection

Possible ways to detect DM:

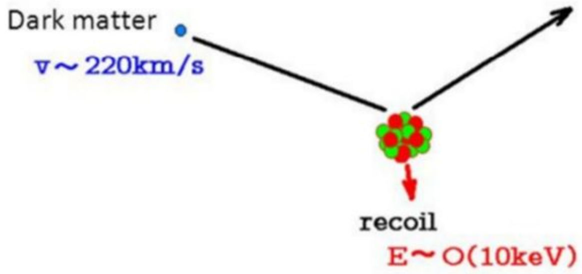
- Direct detection;
- Indirect detection;
- Production.



Direct detection consists on detecting DM interactions with a target of ordinary matter.

Detection of rare events such as DM require:

- Extremely low background;
- High amount of the target mass;
- Low energy detection threshold.



LUX-ZEPLIN Experiment

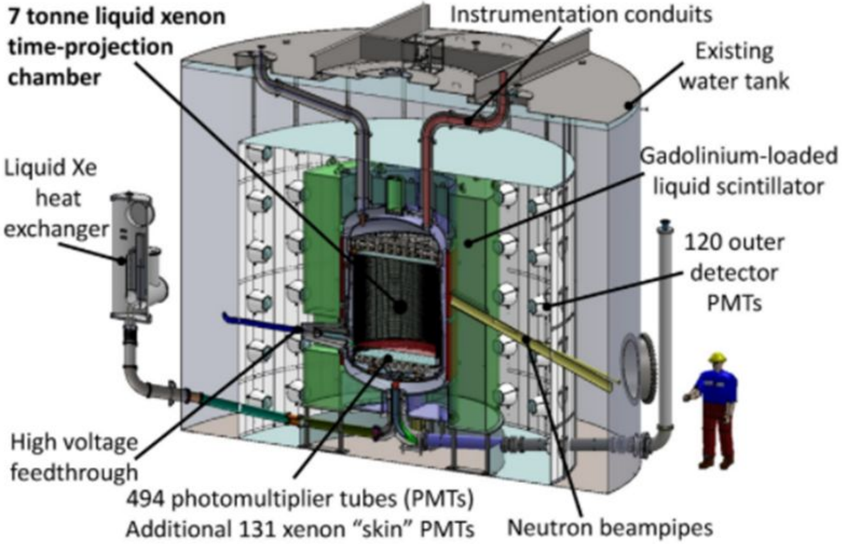
It is a Dual-phase noble element TPC's located in Davis cavern, at Sanford Underground Research Facility, US.

Recent data showed that LZ is the most sensitive experiment for direct detection of DM.

Composed of 3 distinct detectores:

1. 7 tonne liquid xenon TPC;
2. 3 tonne xenon "skin" detector around the TPC;
3. 17.3 tonne Gd-loaded liquid scintillator Outer Detector.

Rare events experiment: WIMP's, Axions, Neutrinos, 0νββ decay.



LUX-ZEPLIN descriptions

Time Projection Chamber (TPC)

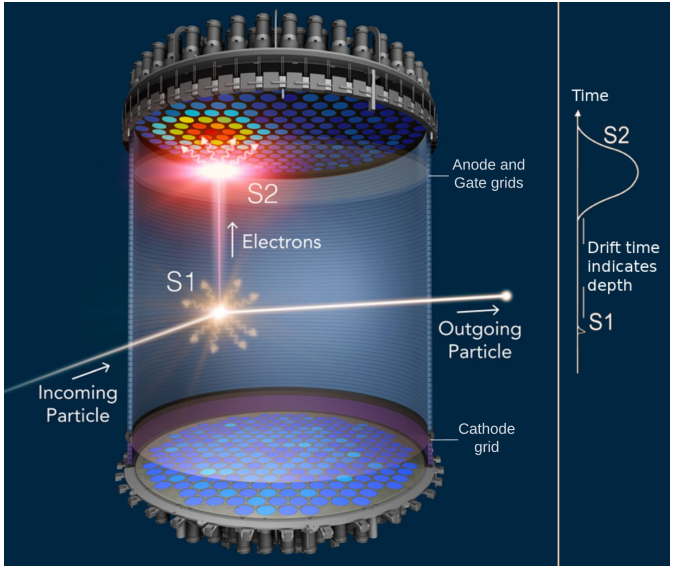
Record scintillation and ionization from interactions with the target allowing the discrimination of **electron recoils** (ER) or **nuclei recoils** (NR) of the target.

Detection process:

1. An interaction with the target produces **prompt scintillation light** (S1) and ionization electrons;

2. The electrons that do not recombine are drifted to the liquid-gas interface and extracted into the gas phase, creating **electroluminescence light** (S2);

3. Both S1 and S2 light are detected in the PMT's in the top and bottom part.



Find our data:

- The time difference indicates the **depth**;
- Light map of S2 indicates **XY position**;
- S1 and S2 sizes reconstruct the deposited **energy**;

Eletron and nuclear recoil discrimination

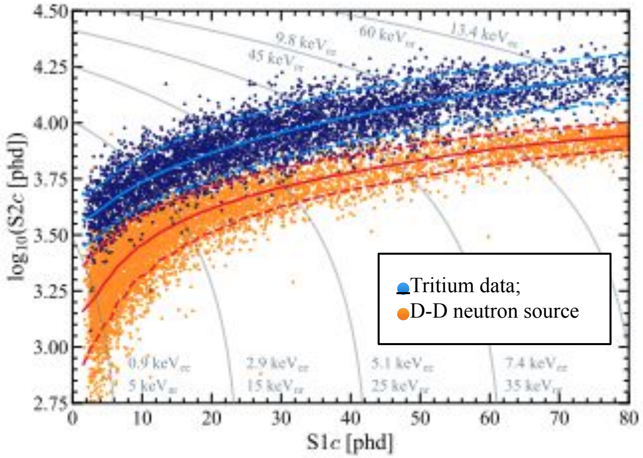
Electron recoils (ER) are produced by γ-rays, betas and neutrinos.

Nuclear recoils (NR) are produced by neutrons, neutrinos, alphas and hopefully WIMPs.

Each recoil produce different ratios of S2/S1 so it's possible to distinguish nuclear recoils from electron recoils.

- Nuclear Recoil: Short, dense tracks - more recombination;
- Electron Recoil: Long, less-dense tracks - less recombination.

So we expect S2/S1 from ER higher than S2/S1 from NR.



J. Aalbers, et al; 2022; First Dark Matter Search Results from the LUX-ZEPLIN (LZ) Experiment

Background

Such a sensitive experiment is very susceptible to noise despite the efforts to isolate it and make it as stable as possible.

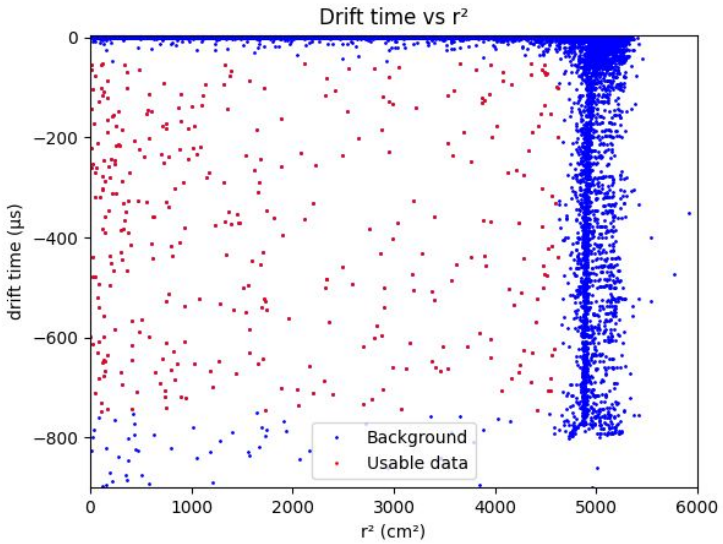
There are a lot of events detected that are background in our search for dark matter.

Those can be due to:

- Radioactive decays from the materials used on the TPC
- Contamination mixed in the Xe itself

Background events can be found mostly near the walls and grids of the detector.

- 50 < Drift Time (μs) < 800
- Radius (cm) < 68



Simulated WIMP Search Data
Background vs Usable Data

Corrections in Position (Xe-131m)

S2 shows a dependency with drift time, because of the possibility of the electrons recombining with ions and not reaching the extraction region (and producing S2 signals).

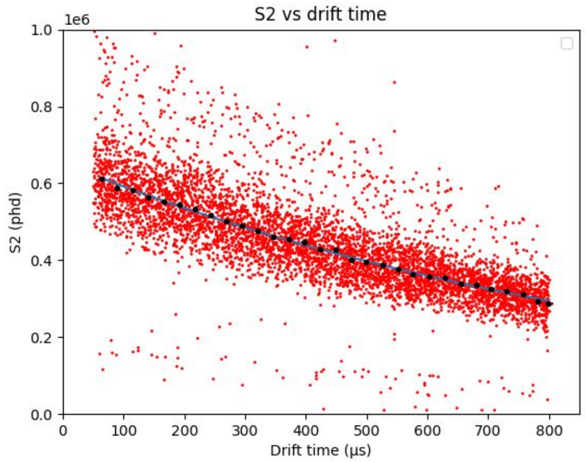
Doing a fit to this equation:

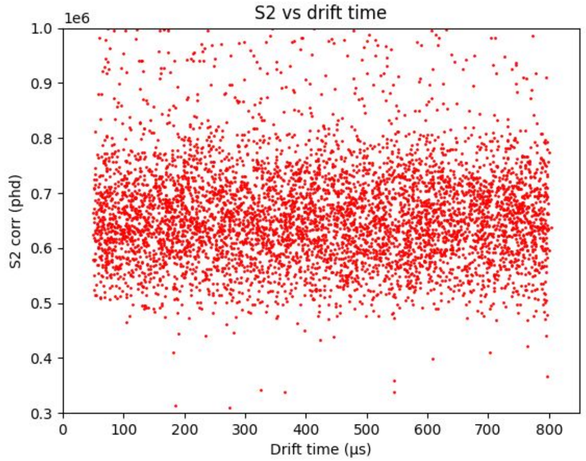
$$S2_{unc} = S2_{corr} \cdot e^{(-\tau/EL)}$$

We extract the value of EL (Electron Lifetime) = 1 ms.

Knowing this value, having τ (drift time) and using an equivalent equation we get the corrected values of S2.

$$S2_{corr} = S2_{unc} \cdot e^{(\tau/EL)}$$





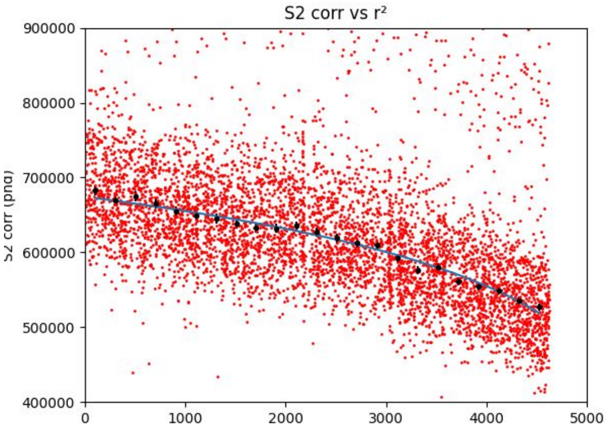
Corrections in Position (Xe-131m)

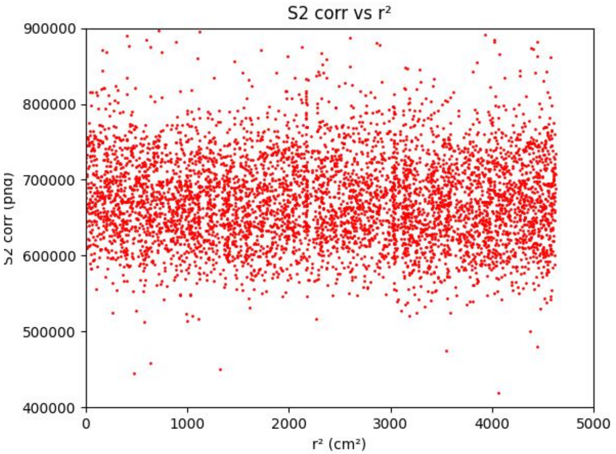
We came to realise that the S2 signal also shows a dependency with the radius squared.

This can have two causes:

- the solid angle subtended by the array of PMTs decreases the closer the sensors are to the walls of the detector.

- the material used in the walls of the array of gaseous Xe (kapton) absorbs light.





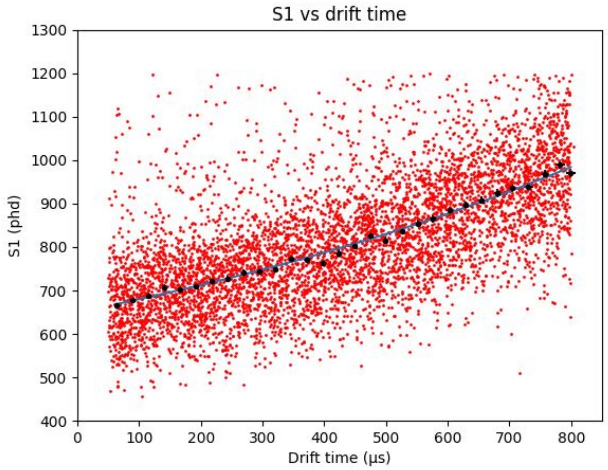
Corrections in Position (Xe-131m)

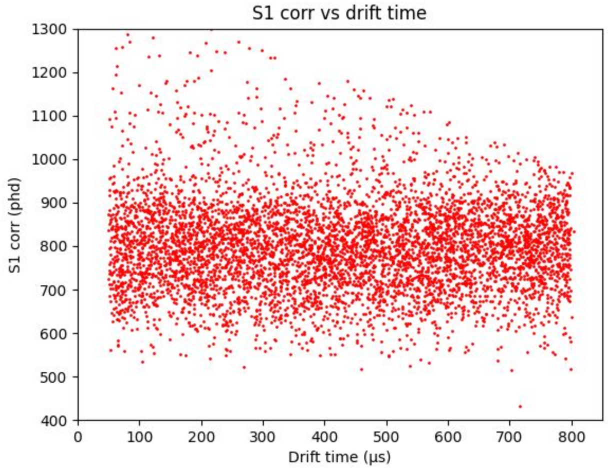
S1 varies with the depth/position of the interaction.

When drifting from the liquid Xe to the gaseous Xe at the top, there is a chance that the light is reflected back to the liquid phase.

Most of the S1 signal is detected at the bottom array where aren't as many reflections.

The S1 signal didn't show dependency with the radius squared so there was no need for that correction.





Energy Reconstruction (Xe-131m e Kr-83m)

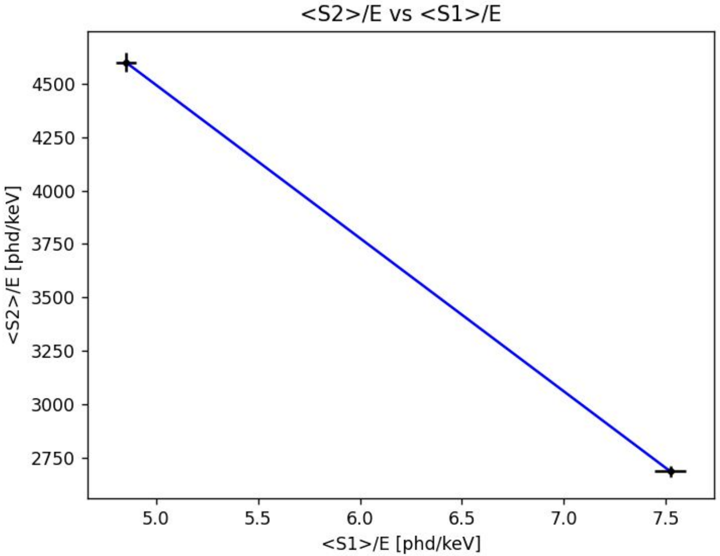
We identified the average values of the signals S1 and S2 from Xe-131m and Kr-83m and divided by the respective γ-decay energy (164 keV for Xe-131m and 41.5 keV for Kr-83m).

Then we made a linear fit with the two points, Xe-131m and Kr-83m using the equation:

$$E = \frac{W_q}{L(E)} \left[\frac{S1}{g_1} + \frac{S2}{g_2} \right]$$

Assuming: L(E) = 1 (electron recoils)

Wq = 13.7 eV



We obtained g1 = 0.154 phd/ph and g2 = 110 phd/e.

Determinate Electron Recoil Band (Rn-220)

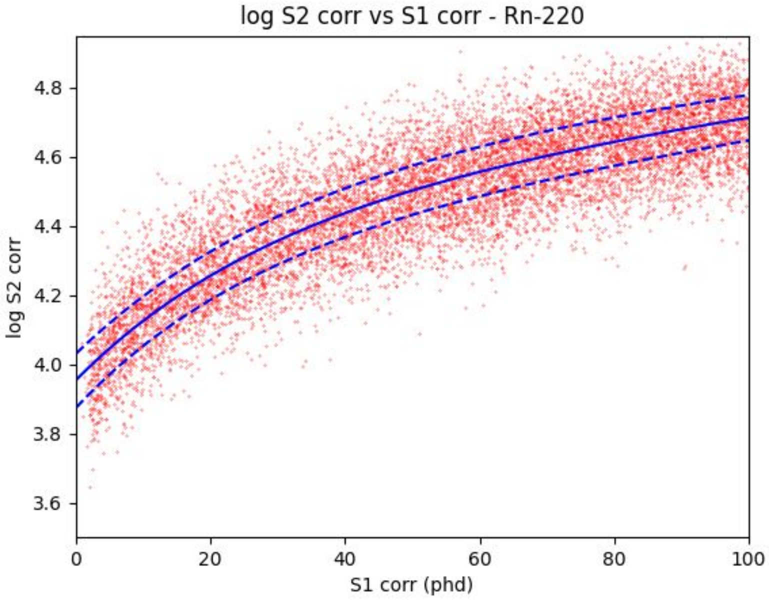
-Obtain the median and standard deviation by binning on corrected S1 values;

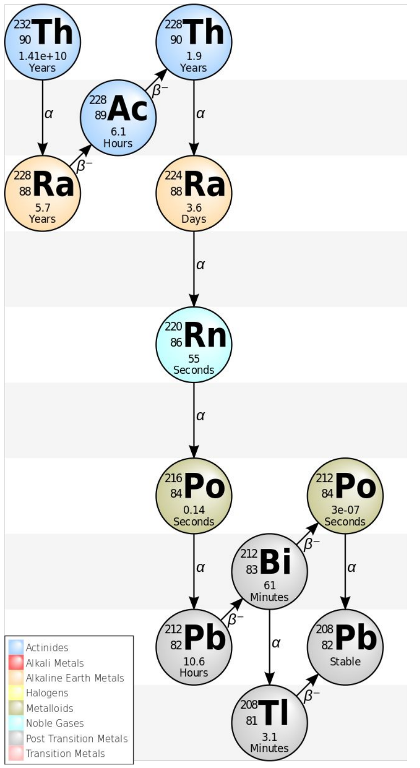
-Fit median to a curve;

-Fit median-0,64x(standard deviation) to another curve;

-Fit median+0,64x(standard deviation) to another curve;

-The band obtained has 80% of the events.

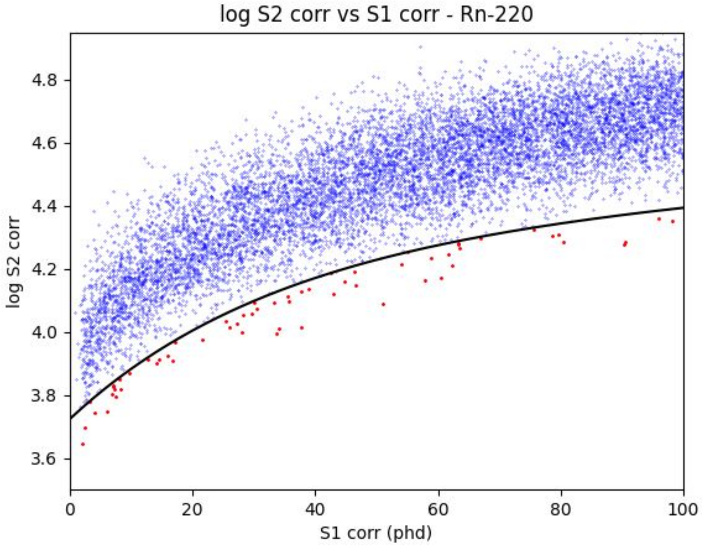


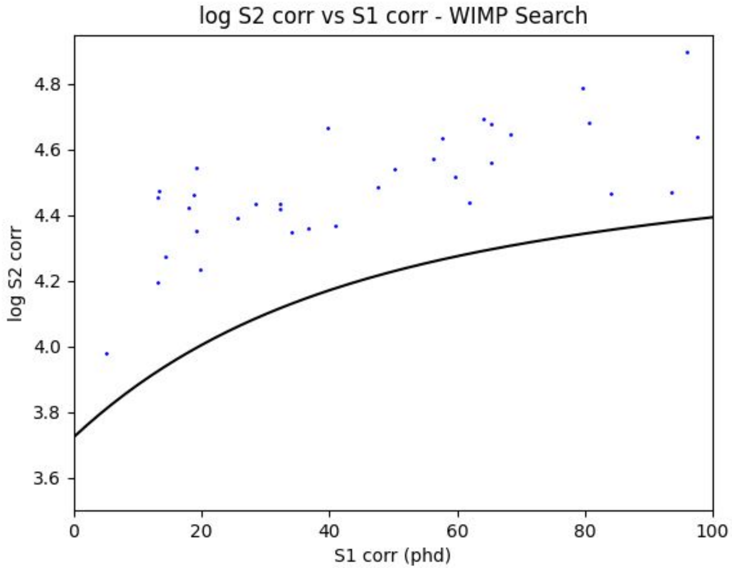


Th-232 chain decay

WIMP Search

Compare WIMP Search data, of 15 days, with nuclear recoil band (provided by the supervisors).





epsilon_ER=0.5% ER rejection=99.5% nBg=0

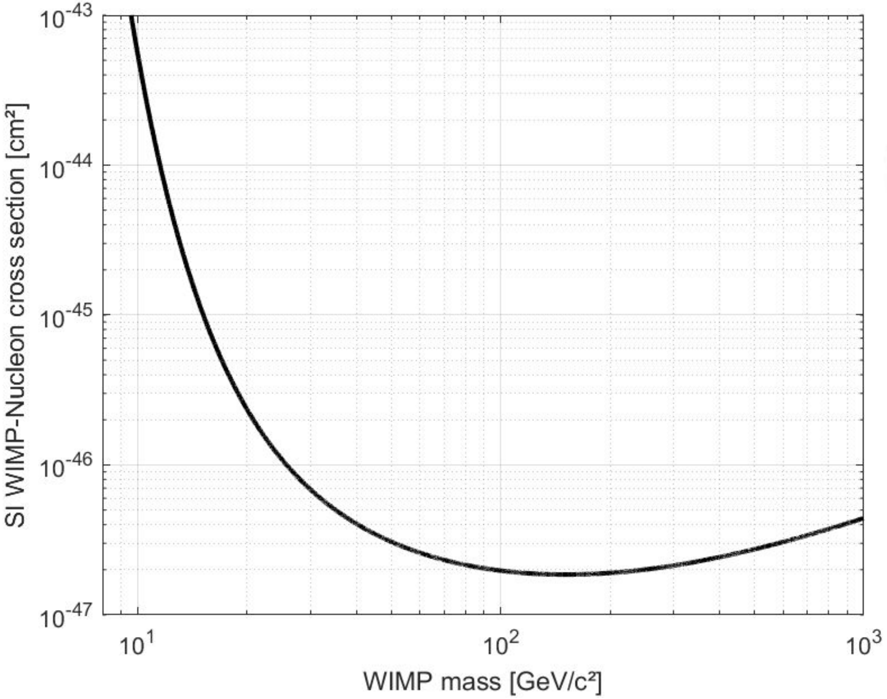
Cross section calculation

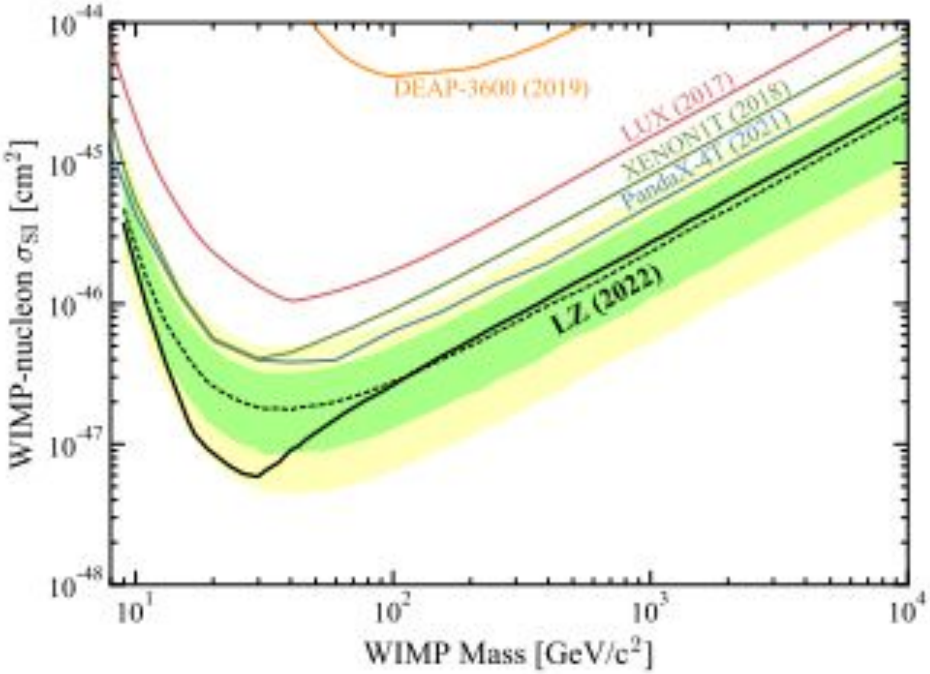
$$\sigma_{WN} = \widehat{R_0}\,\frac{\sqrt{\pi}}{2}\,\frac{A}{N_A}\,\frac{M_{DM}}{m_{FV}\,\rho_{DM}\,v_0\,t_{exp}\,\epsilon_0}$$

$$\epsilon_0 = e^{-\frac{E_{th}}{E_0 r}} \qquad E_0 = \frac{1}{2}M_{DM}v_0^2 \qquad r = \frac{4M_{DM}M_A}{(M_{DM}+M_A)^2}$$

$$\sigma_{Wn} = \frac{\sigma_{WN}}{A^2}\,\frac{\mu_{Wn}^2}{\mu_{WN}^2}$$

LUX-ZEPLIN Sensitivity





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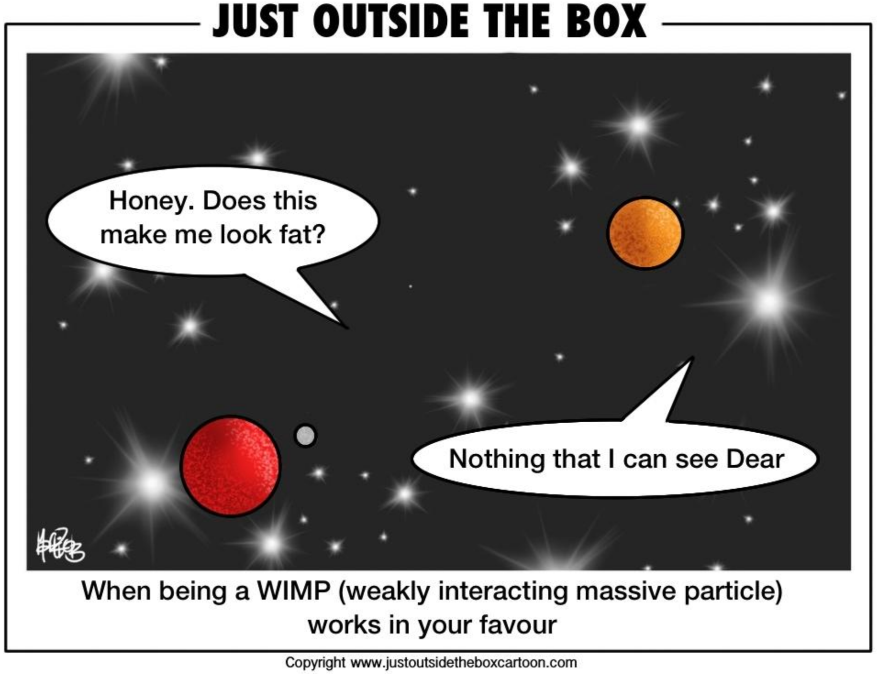
Conclusion

Unfortunately we won't win a Nobel, no dark matter has been found.

It is possible to discriminate between both recoils with a good efficiency.

We determined the sensitivity of LZ for the cross section spin-independent WIMP-Nucleon of 1.856x10^(-47) cm^2 for a WIMP mass of 150 GeV which is within the expected values for this exposition (5600 kg * 15 days).



Questions?