A WIMP SEARCH EXPERIMENT

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The experiment

Consider a simplified WIMP-search experiment containing at its core a liquid xenon (LXe) target. The fiducial mass is 5,600 kg and the target operates for 1,000 days with 100% duty cycle in an underground laboratory. Natural abundance xenon is used.

The detector is instrumented as a LXe-TPC, capable of measuring scintillation (S1) and ionisation (S2) signals for each interaction. This allows 3D fiducialisation of the active volume and discrimination of interaction type: nuclear recoil (NR) events are signal candidates, electron recoils (ER) are background.

The experiment is searching for low-energy nuclear recoils in the range 5–50 keV. Let us simplify the problem by assuming that no recoil energy information is available within this energy range, i.e. treat this as a counting experiment. Given that there is some ER background in the xenon target, we must restrict our search to low values of the discrimination parameter S2/S1, thereby losing some NR signal acceptance – we assume this to be 50%. You may assume initially that the form factor $F^2(q)$ is unity.

We will work with a simplified dark matter halo model in which the Earth is stationary in the galactic frame and the galactic escape velocity is infinite. Reasonable values should be used for other parameters.

The observation

The mean number of background counts predicted in the region of interest ahead of unblinding the data is 1.5 ± 0. Upon unblinding the data, you observe 4 candidate events in this region.

The challenge

Calculate the spin-independent (SI) WIMP-nucleon scattering cross section for a 50 GeV/c^2 WIMP starting from the relation between the WIMP-nucle<u>us</u> cross section (σ_A) and the differential recoil rate per unit mass:

$$\frac{dR}{dE_R} = \frac{\rho_0 \sigma_A}{2 m_\chi \mu_A^2} F^2(q) \int_{v_{min}}^{v_{max}} \frac{f(\vec{v})}{v} d^3v.$$

0. [IF YOU HAVE TIME] Begin by calculating the velocity integral in order to normalise $f(\vec{v})$. Then find a simple expression for the differential rate of nuclear recoils (e.g. L&S 3.10). Use sensible units… (keV, kg, …)

1. Find the 90% confidence interval on the mean number of signal counts (μ) from Feldman-Cousins statistics. Would you claim a discovery? Justify.

2. Starting from L&S 3.10 or an equivalent expression for the expected nuclear recoil spectrum, calculate 90% CL upper limits on the WIMP-nucle<u>us</u> cross section for a 50 GeV particle (σ_A).

3. Calculate 90% CL upper limits on the WIMP-nucle<u>on</u> SI cross section (σ_p^{SI}).

4. [IF YOU HAVE TIME] Implement in Python the calculation of the SI sensitivity as a function of WIMP mass.

   a) Plot the recoil spectrum and the sensitivity curve for the approximations made so far.

   b) Then relax your approximations in turn, and explain how and why they influence the sensitivity curve. (use numerical methods for these calculations instead of deriving analytical solutions.)

5. What is the lightest particle this experiment is sensitive to? How might it reach lower masses?

References

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