Detecting axions in the DEAP-3600 dark matter detector

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Abstract

Axions are natural dark matter candidates that have the ability to be detected via the axio-electric effect. The DEAP-3600 detector electron recoil spectrum caused by solar axio-electric interactions is predicted using the flux of solar axions incident at the surface of the Earth. Using this recoil spectrum, a method is formulated to eventually set a limit on the solar axion coupling using a ratio of toy data to a best fit function of the zero mass hypothesis.

Introduction

- Dark matter makes up ~25% of our universe.
- Up to 37% of this is made of axions, or axion-like-particles (ALPs).
- Axions are theorised pseudoscalar Nambu-Goldstone bosons that are a solution to the strong charge-parity problem, and are natural dark matter candidates.
- ALPs are like axions but don't necessarily solve the strong charge-parity problem.
- Axions could be detected via the axio-electric effect, which is analogous to the photoelectric effect.

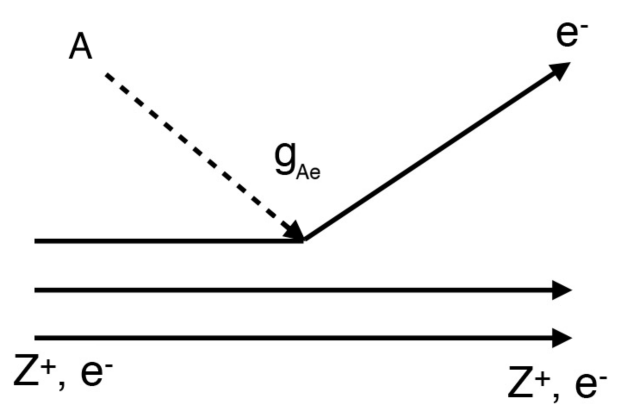

Figure 1: The axio-electric effect.

- The Dark Matter Experiment using Argon Pulse-shape (DEAP-3600) is a direct dark matter detector.
- The electron recoils caused by the axio-electric effect can be detected within the detector by measuring scintillation light.
- Electron recoil backgrounds exist in DEAP-3600, and argon-39 beta decay is the predominant background with a rate of 1 Bq/kg.
- The best fit of the argon-39 decay spectrum was calculated for the zero mass hypothesis.
- This was used to simulate toy background data.

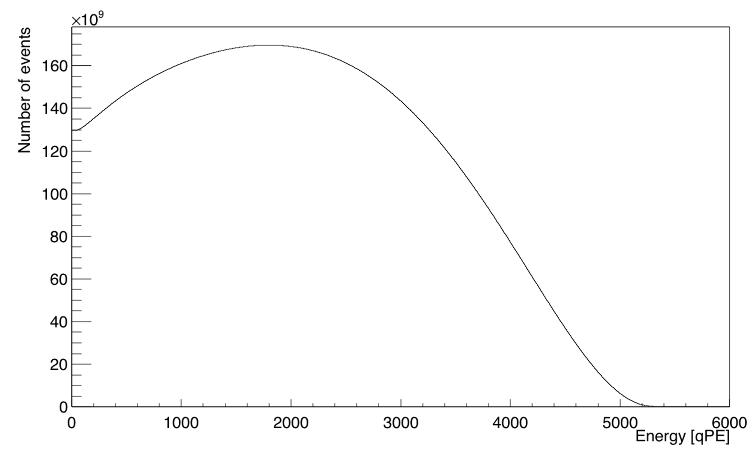

Figure 2: The best fit of the argon-39 decay spectrum.

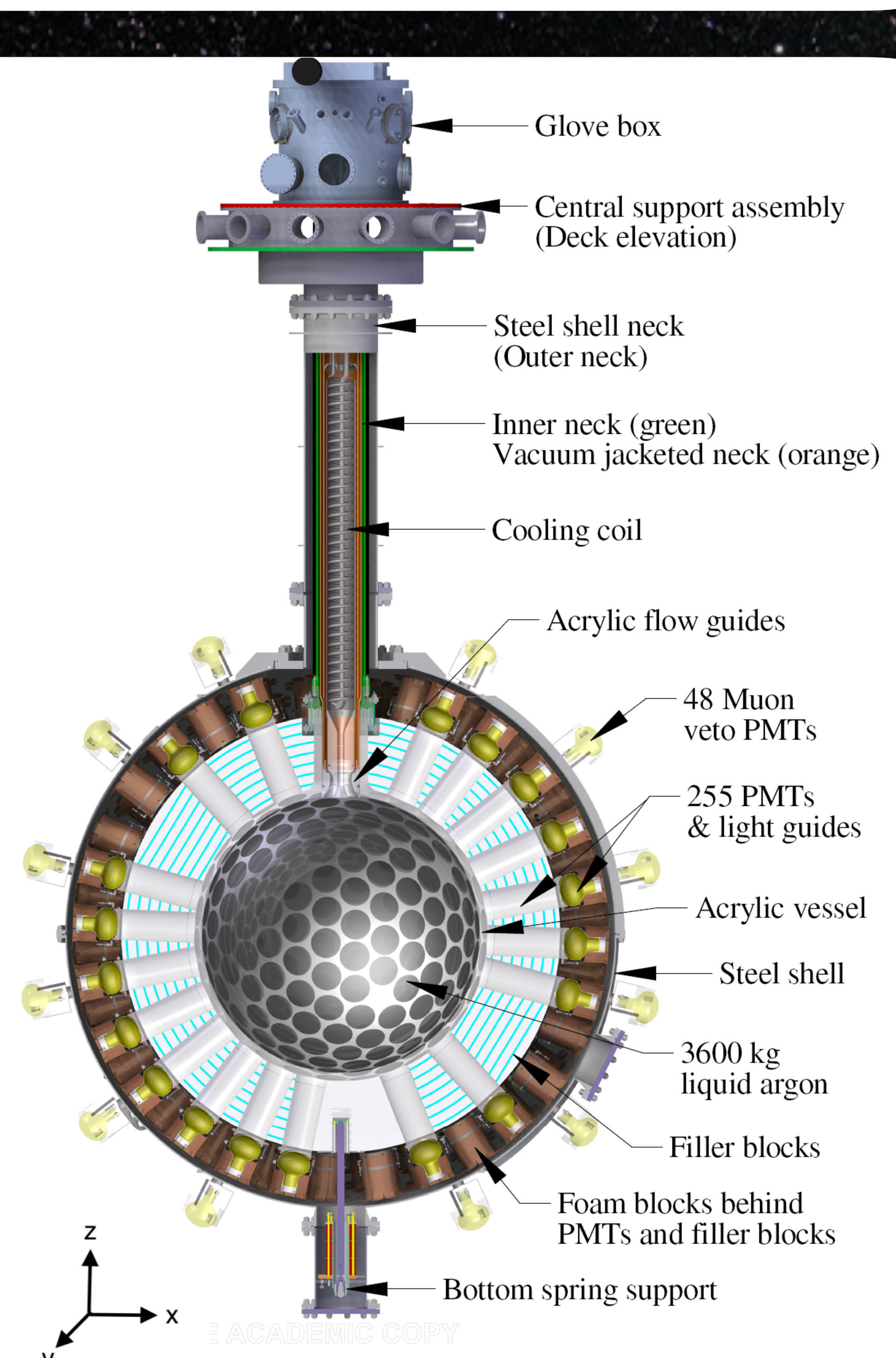

Figure 3: A schematic of the DEAP-3600 detector.

Prediction of the axion rate at DEAP-3600

- By multiplying:

1. The number of targets within DEAP-3600, $n \simeq 9.8 \times 10^{29}$
2. The predicted flux of solar axions at the detector.

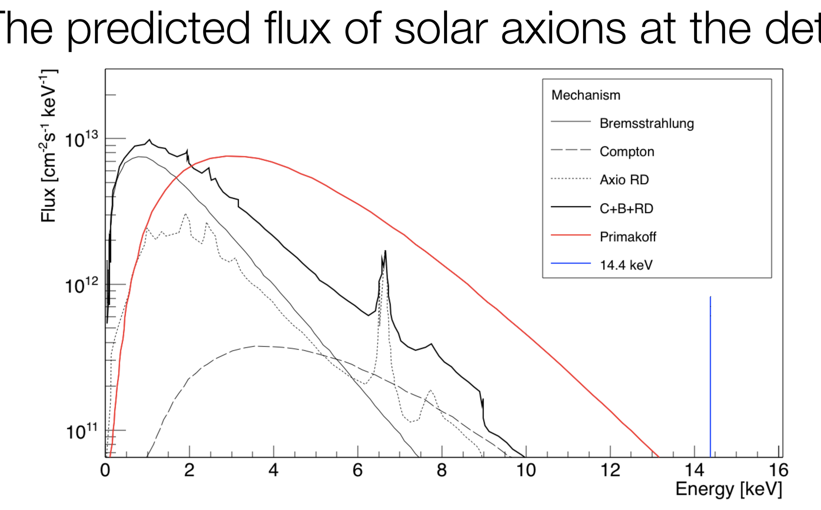

Figure 4: The predicted flux of axions at the surface of the Earth[1].

3. The axio-electric cross section[1],

$$\sigma_{Ae} = \sigma_{pe}(E_A)\frac{g_{Ae}^2}{\beta_A}\frac{3E_A^2}{16\pi\alpha_{em}m_e^2}\left(\frac{1-\beta_A^{2/3}}{3}\right)$$

- The rate at the surface of the Earth was calculated as a function of the incident axion mass:

$$\frac{dA}{dt} = n\,\Phi\,\sigma_{Ae}$$

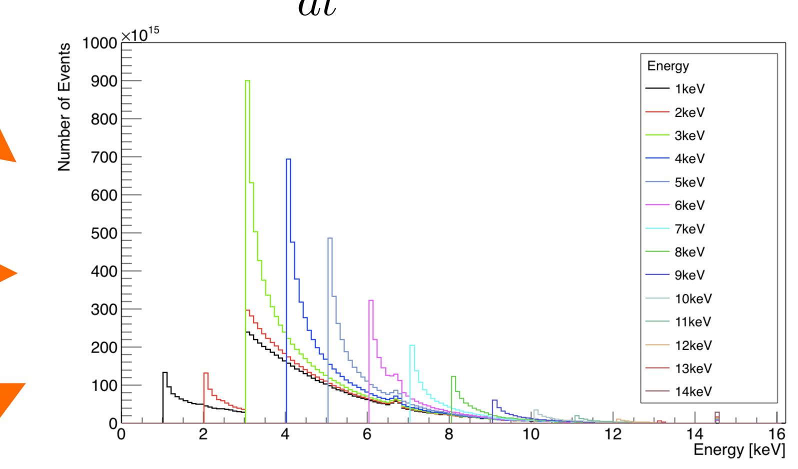

Figure 5: The predicted rate of axions at the surface of the Earth with an assumed coupling of $g_{Ae} = 1$

- This shows the rate for the electron recoil of axio-electric interaction to be highest for a solar axion of a 3 keV mass.

- The signal of axions at DEAP-3600 was simulated using a full detector simulation including event reconstruction.

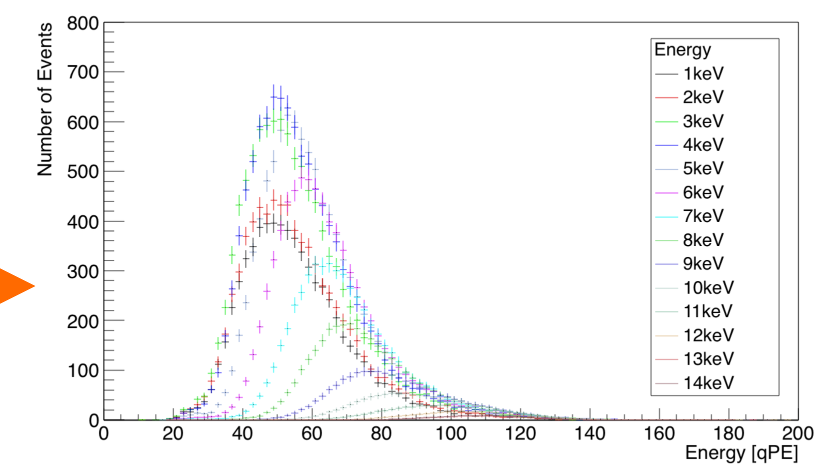

Figure 6: The predicted rate of axions detected within DEAP-3600, with an assumed coupling of $g_{Ae} = 7.7 \times 10^{-12}$ [2]

- Here the highest rate for an axio-electric event is for a solar axion of a 4 keV mass.

The method proposed to search for axions within data

1. Retrieve data.
   - Data = signal + background.
   - Here, signal is toy data signal from Figure 6 for axion mass of 4 keV.

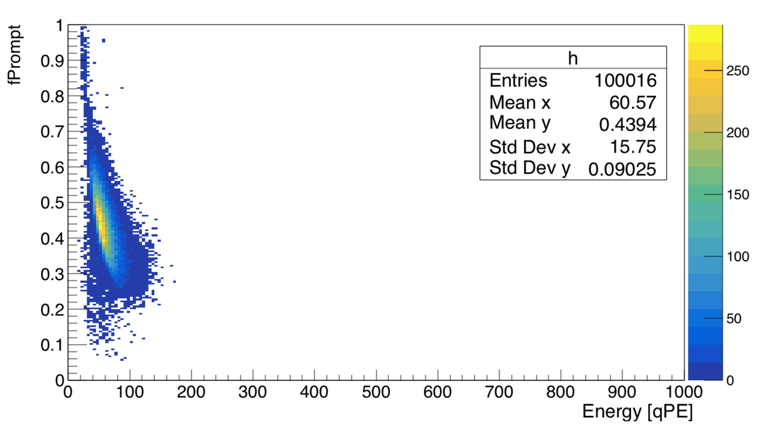

Figure 7: The fraction of prompt scintillation light to late light (fPrompt) versus energy, which identifies the type of recoil present. It is assumed that all events are electron recoils.

   - Background is the best fit of argon-39 from Figure 2, with errors.
   - The best fit of argon-39 is also used as an analytical model in the zero mass hypothesis.

2. Apply cuts to signal data to remove events other than the axio-electric effect electron recoils. Require:
   - ✓ the maximum fraction of charge detected by a PMT must be less than 40%.
   - ✓ a minimum of 200 μs between events.
   - ✓ that events must exist within a radius of 800 mm from the centre of the detector.
   - ✓ that events must exist $z \leq 550$ mm from the centre of the detector.

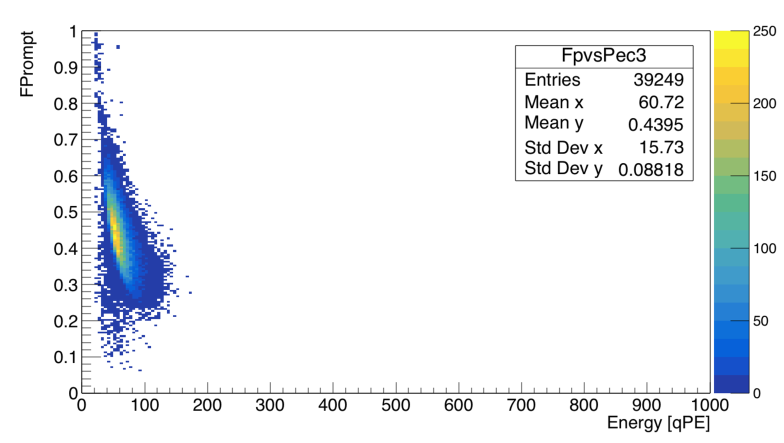

Figure 8: fPrompt versus energy, with all cuts applied.

3. Search for axions within the data using:

$$\text{signal} + \text{background} - \text{Argon39 bestfit}$$

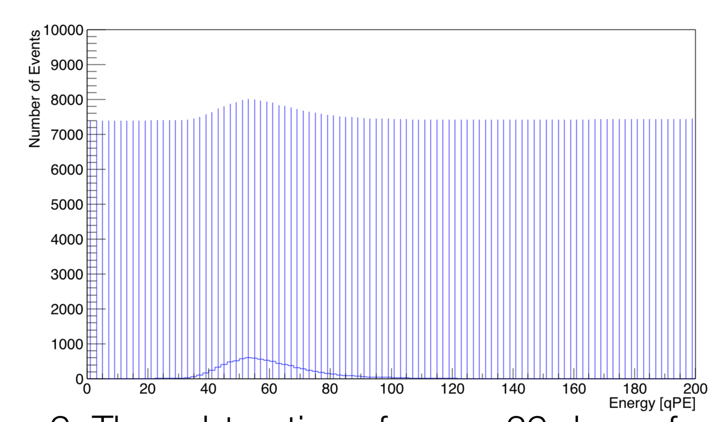

Figure 9: The subtraction of argon-39 decay from the data.

$$\frac{\text{signal} + \text{background}}{\text{Argon39 bestfit}} - 1$$

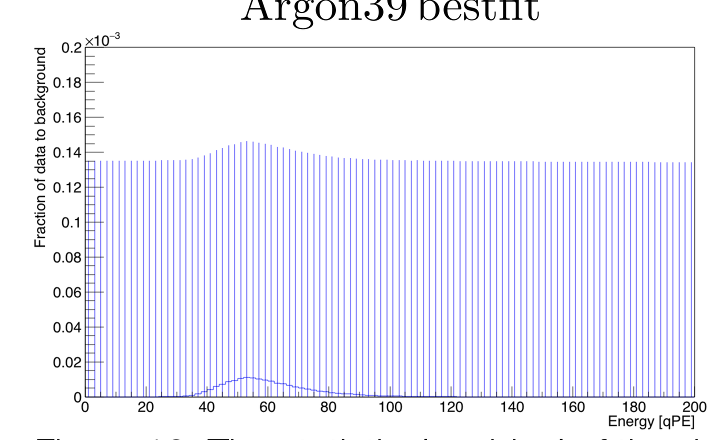

Figure 10: The statistical residual of the data.

References

[1] The EDELWEISS Collaboration: E. Armengaud *et al*. Axion searches with the EDELWEISS-II experiment. JCAP **1311** (2013); arXiv: 1307.1488v1.
[2] The XENON100 Collaboration: E. Aprile *et al*. First Axion Results from the XENON100 Experiment. Physics Review D **90** (2014); arXiv: 1404.1455v2.

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