Decay rate and Activity of Argon-37 in DarkSide-50 Experiment (ISAPP-2021)

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Introduction

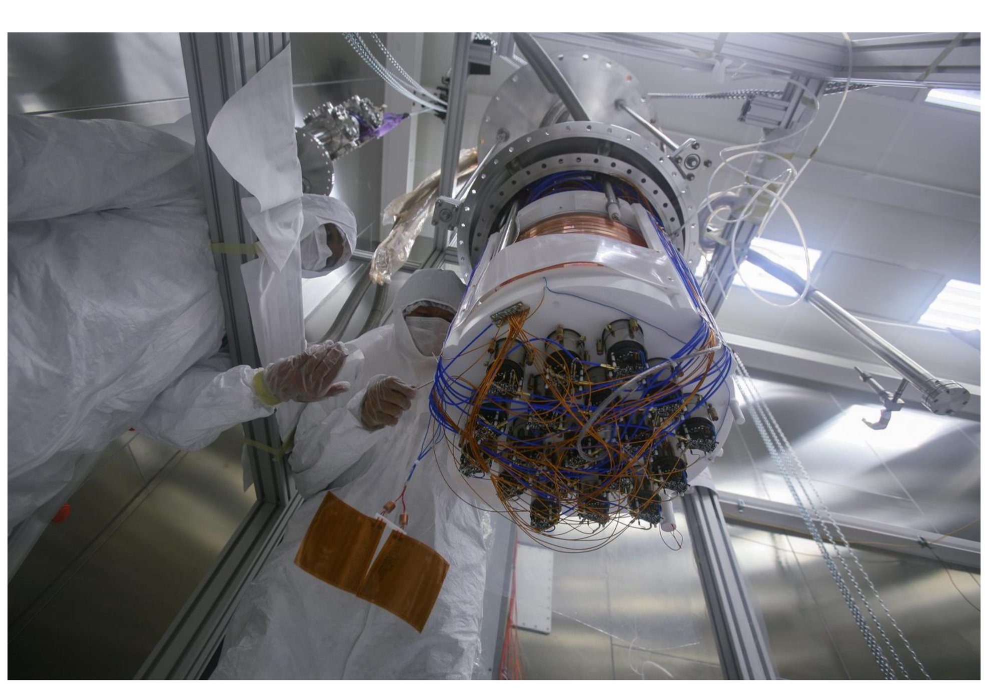
The DarkSide-50 (DS-50) experiment [1] deals with the detection of Dark matter, specifically WIMPs (Weakly Interacting Massive Particles). Liquid Argon (LAr) is used as a target in DS-50.

During refining and transport (from Colorado, US, to Gran Sasso, Italy) an impurity (^{37}Ar isotope) is produced in the underground argon (UAr) by cosmic rays. This ^{37}Ar was present in the experimental setup for almost 100 days. The half-life of ^{37}Ar is 35.04 ± 0.04 days [2] and the corresponding decay time is 50.5 ± 0.05 days. ^{37}Ar decays by electron capture (EC). It produces cascades of X-ray photons and Auger electrons. In both cases narrow peaks are visible in DS-50. The energy for the first peak is 0.2702 keV (L-shell) and for the second peak, it is 2.8224 keV (K-shell) [2]. The decay modes consists of ~99% of L-shell and K-shell capture while ~1% corresponds to M-shell (0.0175 keV) capture. The branching ratio for L, K, and M shell is 0.09, 0.90, and 0.009 respectively [3]. The theoretical branching ratio for the two channels (L/K) is 0.100 [4]. The previous study from Alden Fan shows the decay time of 51.6 ± 4.1 days for ^{37}Ar [5].

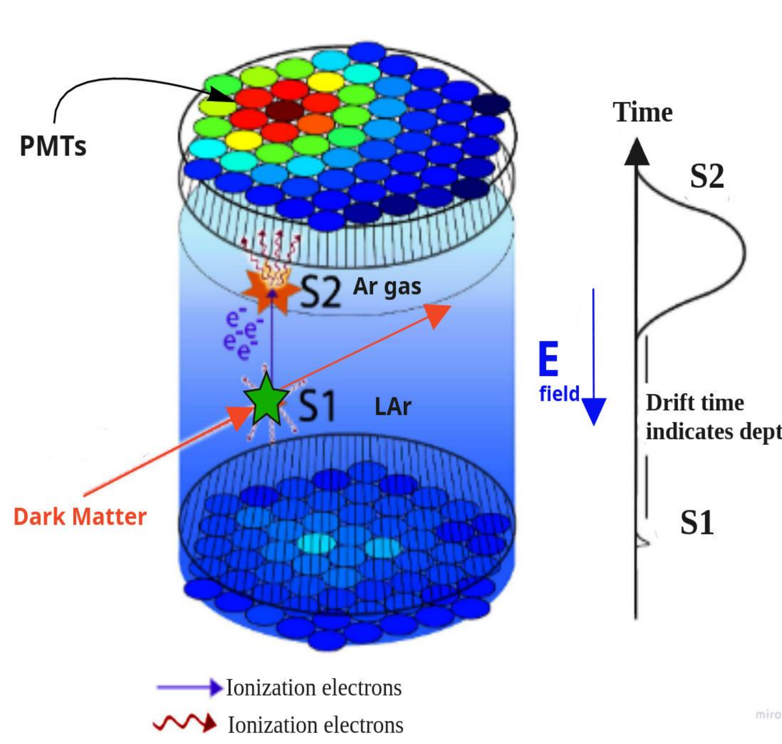
My task was to find the rate of decay based on DS-50 experiment data, project the initial activity, and independently perform a calculation for the expected activation. It will be compared with the estimated values and other experimental results.

DarkSide-50 Experiment

- The experiment is based on a dual-phase Liquid Argon Time Projection Chamber (LAr-TPC).
- Three nested detectors:
  - Liquid Argon Time Projection Chamber (TPC) (46.7 kg of underground Argon (UAr)): Inner detector for WIMP search
  - Liquid Scintillator Veto (LSV) (30 ton) : Active and neutron detector.
  - Water Tank (WT) (1 kiloton) : Active detector for muons
- 38 Photomultipliers tubes (PMTs), 19 at bottom and 19 on the top.



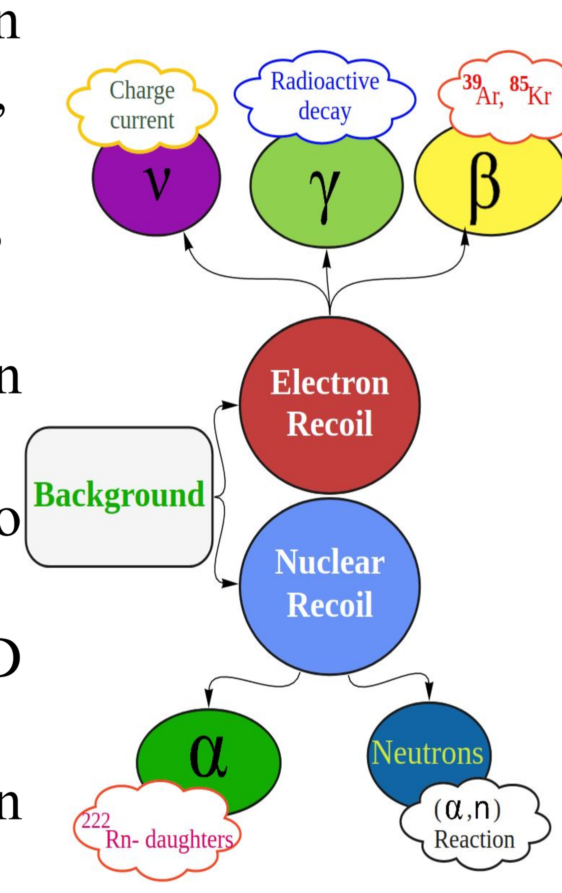
Detection Method

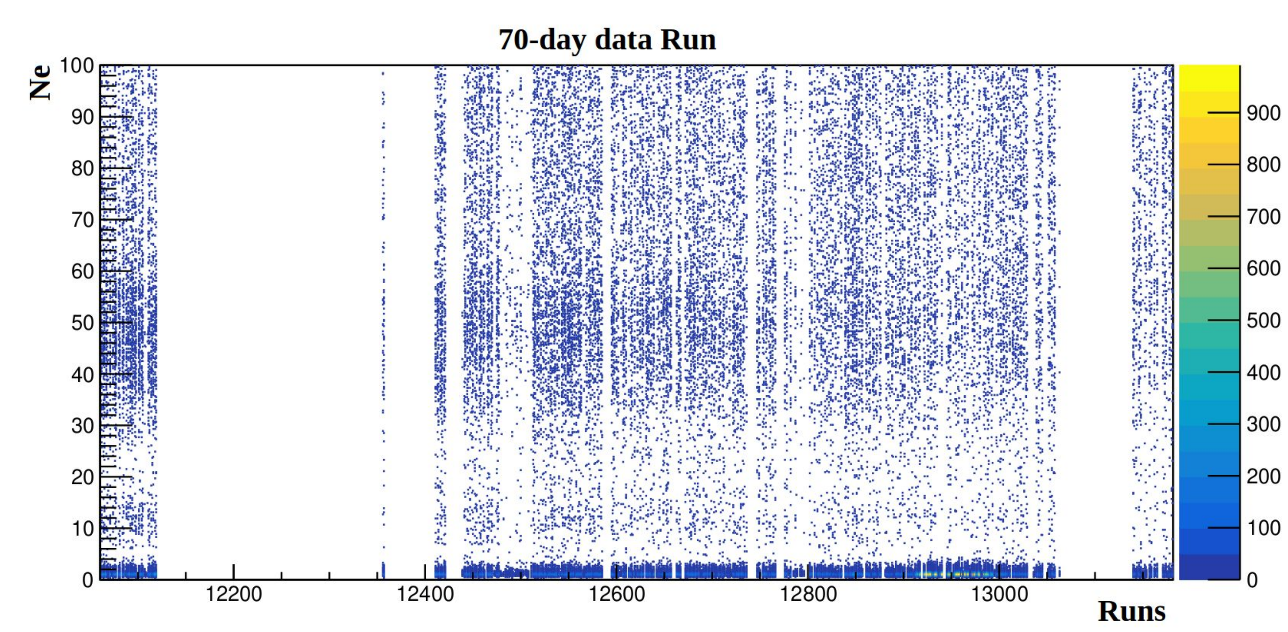


- S1 pulse: primary scintillation in LAr.
- S2 pulse: secondary scintillation in Ar gas phase.
- 3D position reconstruction.

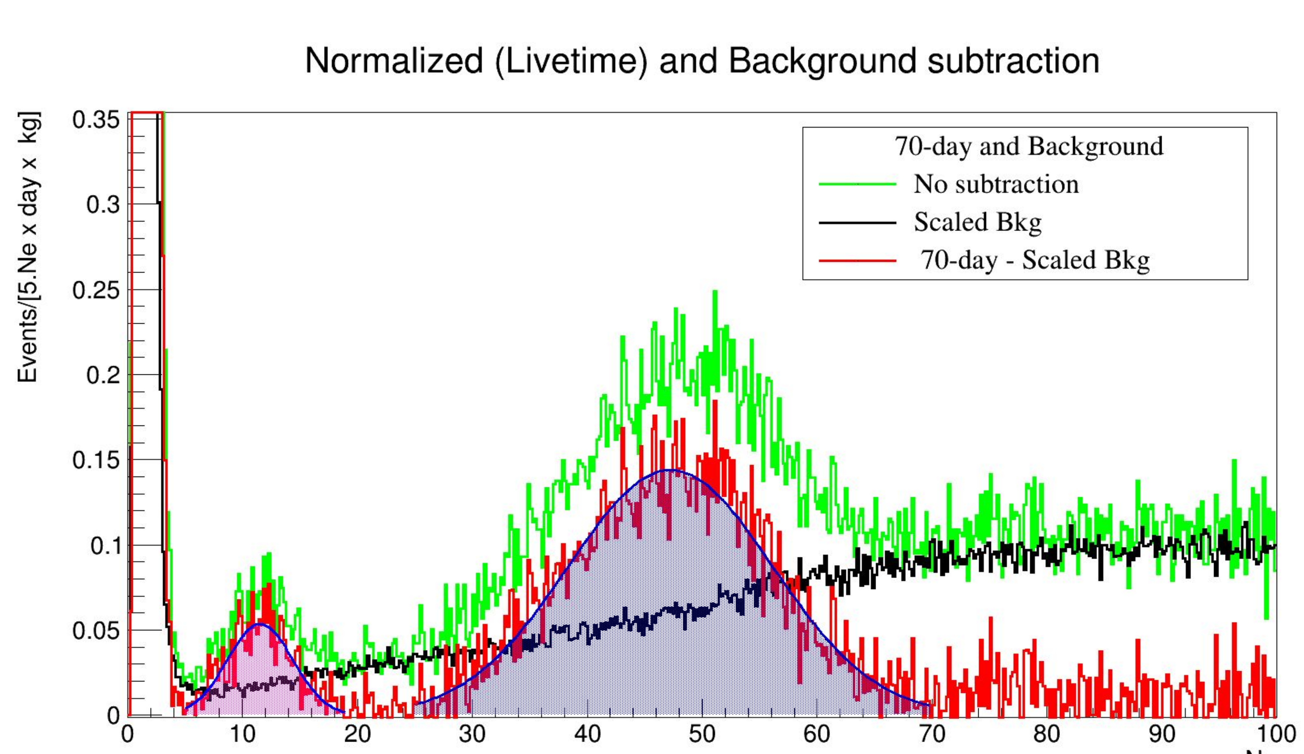
Main Backgrounds and its mitigation

- Use of underground argon (UAr) with reduced ^{39}Ar, which is a beta emitter.
- Deep underground at LNGS
- Low-background materials
- Pulse Shape Discrimination (PSD)
- Ionization/Scintillation ratio (S2/S1)
- Surface rejection using 3D position reconstruction
- Active neutron and muon vetoes

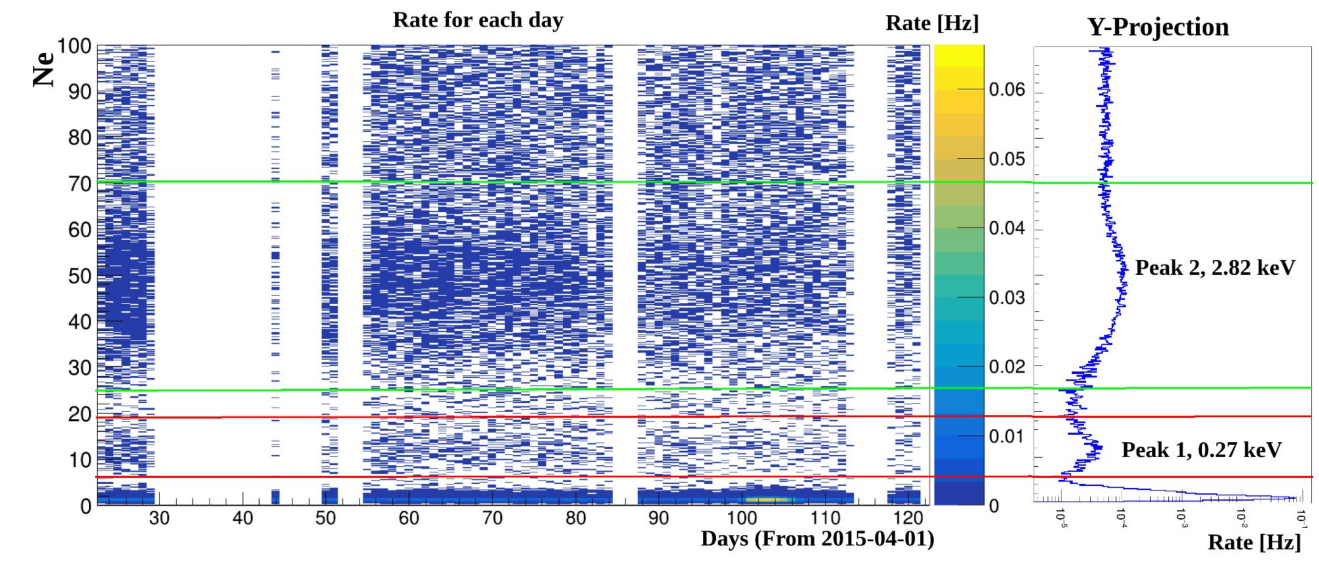




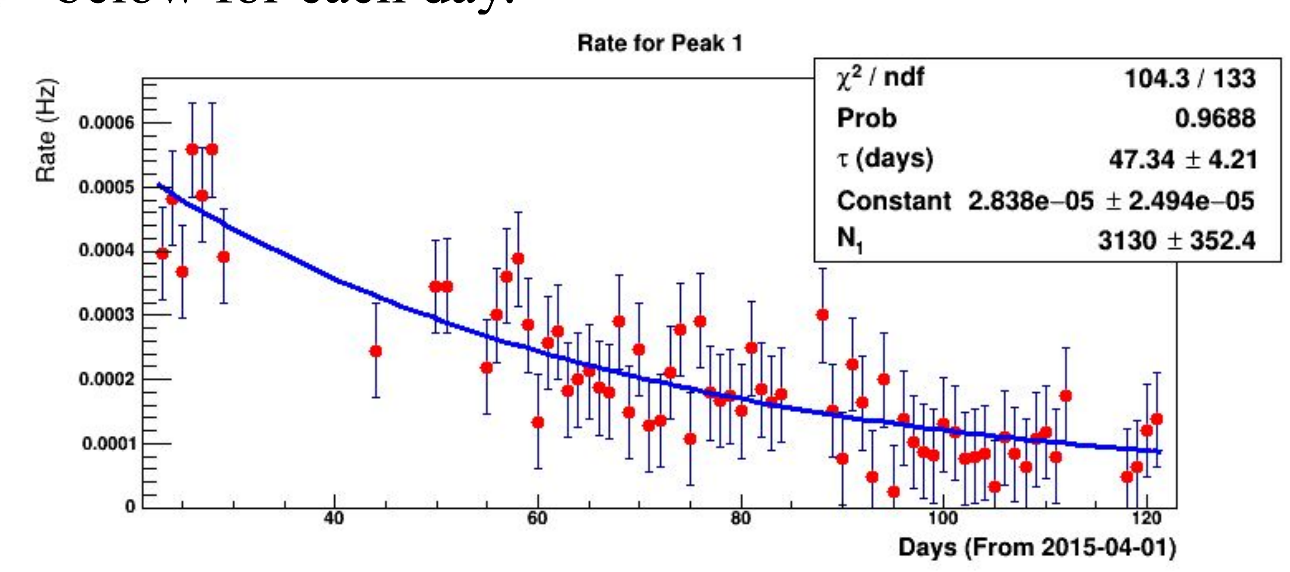
The figure shows data from the DarkSide-50 experiment for the 70-days after the UAr filling. Similarly, the 500 day background starts after the 70-day run. For the analysis the last 400 days are used from the 500 day background. It is because that the ^{37}Ar is decayed by this time [2]. The y-axis shows the number of extracted electrons (N_e) while the x-axis shows the runs .

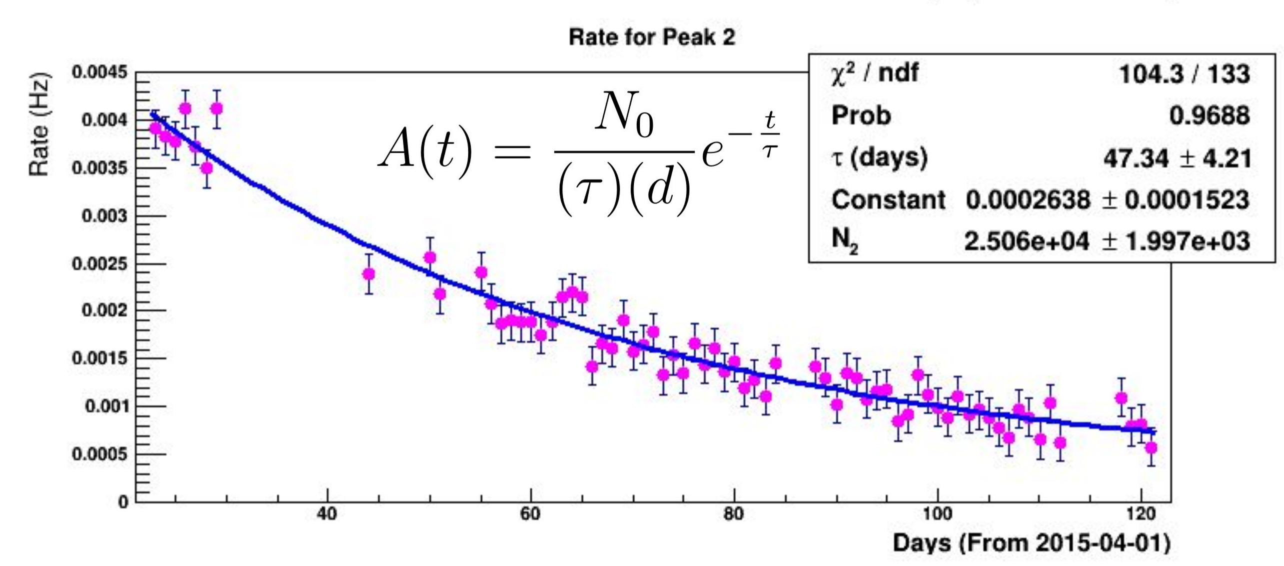


The figuret shows the whole 70-day dataset (green) and the background (black) while the red line shows the subtraction of the 70-day sample after subtracting the background. The plot is normalized by the livetime of the 70-day and 500-day background respectively. The 70-day sample shows two peaks, corresponding to the number of extracted electrons, Ne, that were attributed to the 0.2702 keV L-shell (magenta shaded) and the 2.8224 keV K-shell (blue shaded) radiation following electron capture in ^{37}Ar. This plot shows that the background level is stable over time.



The figure shows the 70 day data, the data is converted to days from runs. Similarly the livetime is converted into days. By dividing each day of the 70 day data by its respective livetime for each day, we get the rate for each day. By taking y-projection for each bin (day), subtracting the background and taking integral for peak 1 (from 6 to 19 Ne) and peak 2 (from 25 to 70 Ne). The rate (Hz) is plotted below for each day.





$$A(t) = \frac{N_0}{(\tau)(d)} e^{-\frac{t}{\tau}}$$

The above figure shows the fitting of the rate with the function A(t) shown on top of the plot, in the function τ is the decay time, d (conversion factor) is the number of seconds in a day and N_0 is the initial number of particles. The parameter τ is the common parameter for the rate of first peak and second peak. In the plot, $N_1=(Br_1)(N_0)$ and $N_2=(Br_2)(N_0)$ where N_0 are total number of particles i.e. $N_0= N_1+N_2$, the Br_1 and Br_2 are the branching ratios for each channel respectively. A correction for M-shell is also applied to have the total initial particles. By applying the correction, we can have the total activity for the three channels i.e L, K, and M.

Results and Conclusion

In conclusion, we see that the decay time is 47.34 ± 4.21 days, which is within 1 sigma with the expected decay time (50.5 ± 0.05 days). The L/K branching ratio is 0.12 ± 0.01 (N_1/N_2), which is within 2 sigma within the expected theoretical L/K branching ratio (0.100). The total activity (with correction of M-shell) of ^{37}Ar at 2015-04-01 is determined to be 6.89 ± 0.78 mBq.

References

1. P. Agnes et al arXiv:1802.06994v3 [astro-ph.HE] 28 Aug 2018.
2. V. I. Barsanov et al (2007). Artificial neutrino source based on the ^{37}Ar isotope.
3. E.M Boulton, et al arXiv:1705.08958v3 [physics.ins-det] 26 Jun 2017
4. Santos-Ocampo, A. G.; Conway (1960). for. Phys.Rev, 120(6),2196–2200. doi:10.1103/PhysRev.120.2196.
5. Internal note by Alden Fan.

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