Analysis of the S1 triplet component in the DarkSide-50 dark matter experiment

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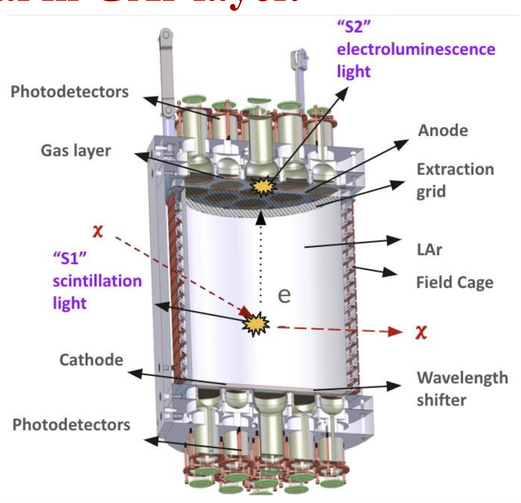
Abstract: Dark matter (DM) is hypothesized to be a cold, weakly interacting, non-baryonic particle. Several candidates exist for DM, including WIMPs, axions, MACHOs, etc. The Weakly Interacting Massive Particles (WIMPs) are a promising candidate, well-motivated by theories. DarkSide-50 is a dual-phase liquid argon time projection chamber (LAr TPC) designed for the direct detection of these WIMPs via nuclear recoil signatures. Primary scintillation (S1) occurs when ionizing events in LAr produce VUV photons (128 nm) with two components: the long-lived triplet state (~ 1.5 us) and short-lived singlet state (~ 6 ns). Impurities like O_2 and N_2 at ppm levels can quench scintillation, particularly suppressing the triplet component. A suppressed triplet lifetime indicates N_2 contamination in LAr. The results of this analysis are also used to test the hypothesis that spurious electrons (SEs) are caused by N_2, which is considered one of the prime suspects.

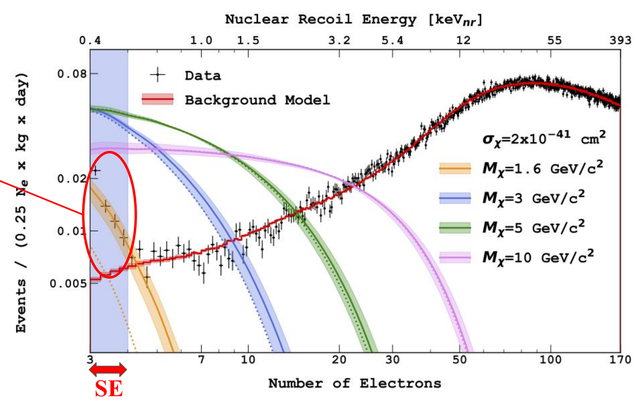
Direct detection of WIMPs in DarkSide-50

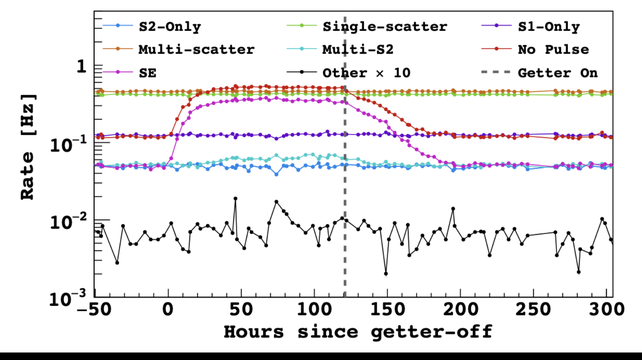
- Located at Gran Sasso National Laboratory (LNGS), Italy.
- 46.4 ± 0.6 kg of active Underground Argon (UAr).
- UAr data acquired between April 2015 and April 2018.
- **S1 - Primary scintillation signal in LAr.**
- **S2 - Secondary scintillation signal in GAr layer.**
- DM-induced nuclear recoils.
- Background-induced electron recoils.
- Excellent signal to background discrimination power.
- S1 light yield in DS-50 ➡ 7.9 PE/keV.



Hypothesis testing of SEs

- Observed an excess number of events at 1-4 Ne, **when the inline getter was bypassed (120 hours)**[1].
- **SE** event rate reduced after the getter re-installation.
  - Implies that the cause of SEs could be an impurity that exist in the gas phase.
  - N_2 is highly volatile at 87 K ➡ Prime suspect for causing SEs.





Impurities in DS-50 and its effects on S1

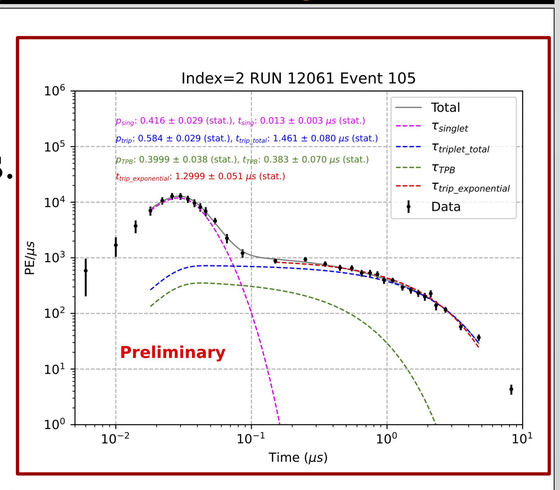
- Argon was constantly circulated through a circulation loop in gas phase containing a hot getter.
- For maintenance purposes, the inline getter was bypassed for about 5 days (120 hours).
- Major impurities in DS-50 ➡ N_2, O_2, H_2O, etc.
- Impurities at the ppm level causes reduction of scintillation[2].
- Quenching of light yield in N_2-contaminated LAr is expected.

$$Ar_2^* + N_2 \longrightarrow 2Ar + N_2$$

- N_2-contamination in LAr ➡ Suppression of triplet component.

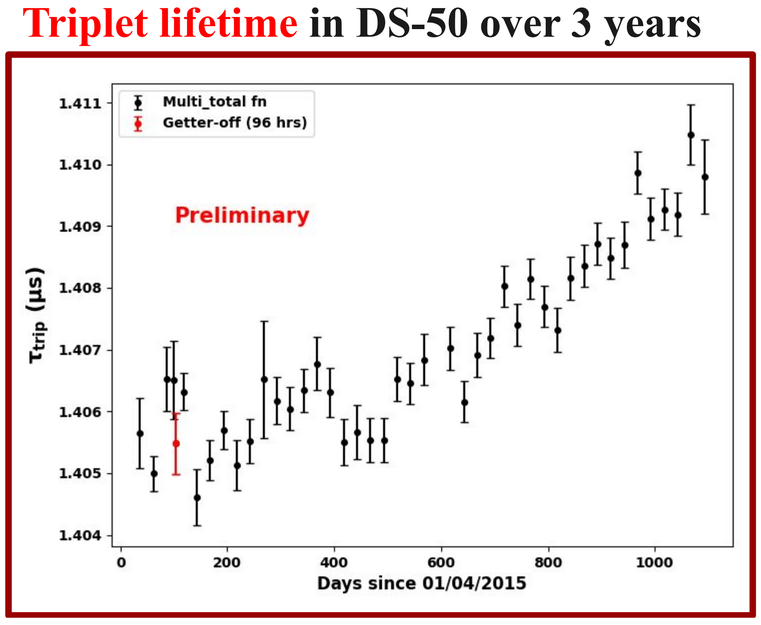
Triplet lifetime: Event-by-event analysis

- Suitable selection cuts are applied.
- Modelled the waveform using[3];
  a. Total fn. for the multi-components.
  b. Exponential fn. for the single-component.
- Chi-square fitted on each individual waveform.
- Similar analysis already done by **fitting on the average waveform** by a team from INFN Cagliari.



Results from event-wise analysis

Triplet lifetime in DS-50 over 3 years



- Event-by-event approach, τ_{trip} - 1.4070 ± 0.00006 μs
  Average wf approach, τ_{trip} - 1.375 ± 0.001 μs
- **Overall increase of τ_{trip} by ~ 0.43%** [4].
- **No degradation of τ_{trip} during getter-off period** is observed;
  - **N_2 concentration in DS-50 LAr < 1 ppm.**
  - **N_2 may not be the cause of SEs.**

Conclusions

Impurities can quench scintillation. A reduction in triplet lifetime of around 0.2 μs was expected during the getter-off period for around 1 ppm of N_2 contaminant[2]. From our analysis, no such degradation was observed, which may indicate that the concentration of N_2 in the LAr is less than 1 ppm. This may also imply that N_2 may not be the cause of SEs. The observed overall increase in the triplet lifetime may correspond to the increase in the purity of the LAr after re-installing getter.

References

1. P. Agnes, et al. (DarkSide-50 collaboration), Characterization of spurious-electron signals in the double-phase argon TPC of the DarkSide-50 experiment, arXiv:2507.23003 (2025).
2. R.Acciarri, et al. (WArP Collaboration), Effects of Nitrogen contamination in liquid Argon, JINST 5 P06003 (2010).
3. P. Agnes, et al., Characterization of the scintillation time response of liquid argon detectors for dark matter search,JINST 16 P11026 (2021).
4. C. Sunny (DarkSide-50 collaboration), Analysis of the S1 triplet component in the DarkSide-50 experiment, JINST 19 C07009 (2024).

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