Report on JINST_057P_0520

Date: June 6, 2020

Author(s): Eric Church, Christopher Jackson, Richard Saldanha

Title: Dark Matter Detection Capabilities of a Large Multipurpose Liquid Argon Time Projection Chamber

Received: 2020-05-12 02:33:18.0

Referee report

This manuscript explores the potential for the fourth DUNE far detector to be sensitive to nuclear recoils from WIMP dark matter. Starting from the dual phase far detector design, changes are proposed to allow better control over backgrounds to the dark matter search, including the use of low-radioactivity argon extracted from underground sources, known as underground argon (UAr).

Using UAr in the fourth DUNE module is an idea that has been floating around the community for some time (see for example Kate Scholberg's contribution to ["The Low-Radioactivity Underground Argon Workshop: A workshop synopsis", arXiv:1901.10108], which should be cited here). Nevertheless, to this reviewer's knowledge this is the first time the possibility is explored formally with a detector design study.

The key development allowing to seriously consider this possibility is a new opportunity, mentioned in this manuscript, to procure UAr in large quantities: "A major U.S. gas producer/supplier estimates [Private communication, Henning Back, PNNL, November 2019] that approximately 5 kt/year of UAr may be deliverable at a cost as low as three times that of atmospheric argon."

Confirming low 39Ar activity from such a high-yield, low-cost source could be a game-changer for the particle physics community, UAr being a very valuable resource for many low-background experiments (archeological lead and underground-electroplated copper are other such low-radioactivity materials that come to mind). The authors are therefore urged to pursue this opportunity whether or not UAr is to be used in DUNE. For instance, members of the Global Argon Dark Matter Collaboration may be interested to contribute their expertise from the URANIA project, to this enterprise. DArT in ArDM [JINST 15, 02, P02024, arXiv:2001.08106] could be used to assay UAr from this new supply.

The proposal presented in this manuscript is well-researched and well-written. Some design elements could be better supported by more detailed background estimate studies, although this could come later in a future Technical Design Report. In particular, it is unclear whether some of the chosen shielding thickness values are in fact optimal (3.5 m of UAr outside the fiducial region on all sides, 5 cm acrylic walls), so the 1 kT fiducial mass sounds arbitrary. Could it be made larger in the transverse dimension?

Part of this answer is provided in Figure 3 on the dominant reducible neutron backgrounds: it would be best to show how, based on this simulation, the dark matter sensitivity (based on total background estimates at a given threshold) depends on the transverse dimension of the fiducial region.

The photon counting study seems sound to first order, given the assumptions stated. Attenuation in argon is explicitly neglected on page 9, however for a detector of this size the effect may actually be significant: for example [Neumeier, A. et al. EPJC 72, 2190 (2012)] measured an effective attenuation length on the order of 1.6 m. It would be worth quantifying the impact of this effect on the ability to reach the required PE yield at the photodetectors.

Expected background studies are thorough for some sources, namely radiogenic neutrons, as well as beta and gamma rays, and the irreducible neutrino background. They are however incomplete or absent for other sources, e.g.
- Cherenkov backgrounds are very briefly mentioned on page 11 as neglected. They could be a very significant source of high-f90, low-PE background for a detector with this technology and size, and deserve further study.
- Alpha decays with unusual topologies, either with limited path length in LAr leading to smaller energy depositions, or with light-shadowing effects, can provide significant backgrounds that are not considered here. Without necessarily going into much detail, they would be important to mention too.

Overall, this contribution contains significant new material, is of high quality and scientific interest, is written in good, scientific English and is on subject matter covered by the Journal of Instrumentation. It is therefore recommended for publication, with revisions addressing the above points (in a manner reasonable for such a preliminary study).

Minor text revisions are also recommended, as follows.

Throughout
"Darkside" –>"DarkSide" including on Figure 6

page 2
"DP phase" –>"DP" as P stands for phase

page 4
"The motivation of the size of the inner volume is largely cost-based": this may be true for directions along the photodetector plane, but not perpendicular to it?

page 5
"Darkside50" –>"DarkSide-50" with dash

page 6
7.3*10^-4 Bq/kg * 4.3*10^6 kg = 3.1 kBq, suggesting to write this number explicitly
"12 events" pileup over which period of time?

page 8
Figure 2 x-axis quantity missing "neutron energy [MeV]"

page 14
Footnote: please write km/sec unit after each speed value

page 15
Figure 6: DEAP-3600 curve does seem to reflect their latest results, although the correct reference is [DEAP Collaboration, Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB. Physical Review D, 100 (2019) 022004]: please add in caption and References section.
Reference missing in Figure 6 caption for XENONnT expected sensitivity.
Figure 6 title and caption: after "90%" add "C.L."
Figure 6 y-axis would be clearer as "Spin-independent WIMP nucleon cross section [cm^2]"
Figure 6 x-axis unit should be [TeV/c^2]

page 16
The clarity of Table 1 would be greatly improved with three distinct columns for the three threshold scenarios (100 keVr, 75 keVr, 50 keVr). A row with "total" background estimates would be nice to have as well. "bPSD" and "aPSD" acronyms are unnecessary, please spell out "before PSD" and "after PSD". If necessary, making the table orientation landscape would give more space to implement these suggestions.

References
For consistency, please cite as collaboration names where appropriate, i.e.
Ref 4: DarkSide-50 Collaboration
Ref 15: DarkSide-50 Collaboration
Ref 16: DEAP Collaboration