Review of the PhD dissertation of Iftikhar Ahmad

"Investigating backgrounds in dark matter searches: Argon-37 activation and cosmogenic neutron suppression in the DarkSide experiments"

General comments

Chapter 1 consists of a review of dark matter (DM) concepts, beginning with the explanation of the reasons for its existence, its origin and its different aspects. A revision on the different ways to detect DM is also made. It also summarizes the different and more significant experiments that are currently searching for DM. In the overall is a very complete review of all these topics.

Chapter 2 focuses on the Darkside program, a description of the system, the various prototypes, recent results and future perspectives.

In Chapter 3, data analysis of the runs in DS-50 was performed and the Ar activation due to the trip from US to LNGS was inferred. These results were compared with the simulation results performed by another group of the collaboration to infer about its precision. A summary of the most problematic backgrounds in the DarkSide experiment is also made together with a complete discussion of results. It was concluded that the results obtained are in agreement with the estimated Ar-37 activity, validating the model used for the estimation of the cosmic activation. This validation is important for confirming the reliability of the estimation models used in the DarkSide collaboration, and can eventually be used in other experiments using UAr.

In Chapter 4, the candidate presents the FLUKA simulation model of the detector DS-20k and the effectiveness of the shielding that will be used in the experiment, namely in vetoing cosmogenic neutron background. A thorough discussion of the results from the simulation is made and an important conclusion was made: the veto systems are valid in DS-20k.

Finally in Chapter 5, key components of the veto Photon Detection Units, vPDUs, and their testing setup at CEZAMAT are described in detail. It also includes the analysis of the vPDU testing, especially the PyReco reconstruction software, and analysis of the 2 vPDUs separately.
The candidate was responsible for the assembly of this testing system at CEZAMAT, for the data taking and for the development of part of the code that was used to analyze the data. This code was used afterwards by all the collaboration. The system is now ready for the testing of vPDUs at a larger scale.

The work developed within the scope of the PhD program represents valuable and original work performed by the candidate, showing that he has a solid knowledge in this scientific area and that he already has enough independence to undertake valuable scientific investigation on his own. There are different aspects developed within the scope of this thesis, from experimental to simulation work, together with data analysis that make this a very complete PhD thesis work.

Summing up, I consider the doctoral thesis of Iftikhar Ahmad to be a valuable contribution to the DarkSide collaboration and to other on-going experiments on dark matter detection and it clearly meets the criteria sought for in a doctoral dissertation. Therefore, I request that this dissertation to be admitted to a public defense.

(Filipa Melo Borges Belo Soares)

Associate Professor of the Physics Department of the University of Coimbra - Portugal

Comments to the author

Abstract – The phrase in brackets should be in the text, since it is important to justify the use of LAr in dark matter search. It seems to have been forgotten as a comment.

Chapter 1. This Chapter includes a revision of concepts of Dark Matter, beginning with the explanation of why it must exist; its origin and the different aspects of its existence. A revision on the different ways to detect DM is also made. It also summarizes the different and more significant experiments that are currently searching for DM. In the overall is a very complete review of all these topics. I felt sometimes lack of references in some topics and when using equations, sometimes not all the symbols used are defined, which makes it more difficult to follow. Examples: Section 1.3.3.2 (no reference indicated in the whole section, only on Fig. 1.8). But apart from that it shows a good knowledge of the background of DarkSide where the work is included.

Some questions and remarks:

Page 5 – Eq. 1.7 – is there a ½ term missing in this equation? To account for the double counting of masses? Or instead of an equal sign use a "approximately equal" one (~) …

Page 6 – Eq. 1.9 – what does M with a circle stands for? this means M inside or at the center of the cluster? the same for L.. The relation between this equation and the next phrase is not clear. Please clarify.

Page 11 – with a "red line", shouldn't it be "blue line"?
Page 12 – 2nd paragraph – "nor by" instead of "and" after the brackets

Page 14, 1st paragraph – the process of lower density is the same for SM and DM particles? Or are the processes dependent on one another? SM decrease implies DM decrease?

Pag. 20 – 2nd paragraph, last phrase: "the detector can collect the ions into a charge readout system". Are they ions or electrons? In which type of detector are you thinking of?

Chapter 2. Darkside Program overview

Some comments and remarks:

1st line – where is DarkSide installed? This information should be given, just like for the other experiments.

Page 28, ln 13 – The phrase "In addition … PSD capability" is out of context, because it is in between 2 paragraphs that are comparing the advantages of UAr with AAr. This characteristic of Lar (PSD) should be referred to before or after.

Page 29, 1st paragraph, ln 9 "While some of these… kinetic energy as heat", the statement that the recoiling nucleus will potentially scintillate, might give the impression that the scintillation is of nuclear origin, when it is atomic.

Page 29, 1st paragraph, ln11-17: These phrases until the equations (that should have a number!!) are confusing.

- Why introduce the exciton, meaning an excited atom, right? It is more commonly used in solid state physics..
- The decay is not of the order of ps, but micro-seconds. The formation of the dimer is eventually of that order.. but that is not stated in the text. This decay time is important since it will be used in PSD. It is ok in Section 2.5, but here may be misleading..

Page 30, Fig. 2.1 – is there any significant difference in light emitted due to recombination or de-excitation? Apart from the decay time? Maybe this should be mentioned.

Page 30, Section 2.5, 1st paragraph, line 10-11: can you explain briefly why a NR originates a larger amount of singlet states and a ER a larger amount of triplet states?

Page 37 – Fig. 2.7 – legends on the axes are too small!!

Page 38, Section 2.8.1.1 – What is the conversion efficiency of TPB?

Page 39 – Liquid scintillator veto: "The LSV provides shielding and anti-coincidence for neutrons, gamma rays, and cosmic muons." How are gamma-rays vetoed by anti-coincidence?

Question – is it important for Darkside to have a good energy resolution? Are events distinguished by the energy deposited? If so, what is the energy resolution limit for WIMP detection?

Page 46, last paragraph – improvements on DarkSide-low mass like:

- doping LAr consists of what?
- SiPM's sensitive to VUV are more efficient in detecting light? Is this related with TPB efficiency?

Chapter 3 - Data analysis and its comparison with simulation models of Ar 37 activation due to transport was performed. A summary of the most problematic backgrounds in the Darkside experiment is made. Then, a good discussion of results and a conclusion is also made. Apart from some comments above, it consists of very valuable work.

Some comments and remarks:

Section 3.3 Page 50, 1st line – why H3 in the list?

Section 3.4 – Background – important background, namely neutrons, alpha particles are produced by the detector materials and surroundings. Is there any special care with the material that is used in the detector construction, as is taken with the LAr, being chosen from underground instead of atmospheric? Should this be referred to?

Section 3.5 – Fig. 3.3 – what does Ne (extracted electrons) effectively represent? How was this obtained from the data? Is Ne proportional to the energy deposited in the detector?

Still in Fig. 3.3 – what does the colored bar represent? It should be clear in the graph and in the text. How is Ne extracted from the data?

Fig. 3.4 – 15000 s ~ 4h?

Fig. 3.5 and 3.6 – 500 day campaign: the lifetime is bigger for this, ~6h? This is adjusted when subtracting the background, right?

Fig. 3.8 – what is the difference between this graph and 3.3? Only a conversion in the xx' axis? Again the color scale is not useful, we have the graph all in blue! Maybe another color scale?

Fig. 3.9 – I do not understand the use of the information on this graph. Could you please explain?

Page 58 – Why write the 3 equations after Fig. 3.9? The last one is enough and should be numbered.

Fig. 3.10 - Since w-value in liquid Ar is ~26 eV, we would expect: Ne=2820/26 ~100 e-s. Why only 50? On the other hand, for the L-peak, 270/26~10 e-s, it looks ok. There is no linearity in the detector? The energy resolution is quite poor.. How does it affect the results? Could it be improved?

Page 59 – Again the equations are not numbered and are a little excessive. Eq. that gives N(t) and A(t)=dN/dt, would be enough and should be numbered. Tau (τ) is used but only defined some lines (paragraphs) below.

Page 61 – Line 2 and 3: how are the errors estimated? What parameters were taken into account?

Chapter 4 – Cosmogenic muons study: FLUKA simulation model of the detector DS-20k and the effectiveness of the shielding that will be used in the experiment, namely in vetoing cosmogenic neutron background.

Some comments and remarks:

Section 4.2 – is a little repeated from Chapter 3, maybe these could have been joined.

Section 4.6, Page 74, ln 5: why are 10 keV neutrons used in the simulation? This is the mean energy of neutrons that may enter the container? This should be clarified.

Fig. 4.12 – Again, the colored bar is not used in the graph and its meaning not explained. Why are most ER at f=0.3 and most NR at 0.7?? Shouldn't they be equally distributed in the areas?

Fig. 4.13 – it would be more clear if the same colors were used for the same materials in both graphs.

Fig. 4.19 – the percentages in the bars presented are due to the cuts performed sequentially? The sequence is the one presented in the graph? Or are these individually obtained, considering the cuts associated with each bar?

Page 86, 2nd paragraph, line 5: this analysis is different from what is presented in Fig. 4.19 and Table 4.6? If so, what are the main differences?

Fig. 4.21 and 4.22 – if efficiency of the veto is 90%, it means that there is 10% probability of particle not being vetoed?

Page 90 – A comment on Eq. 4.2, the meaning of its parameters, k and λ, and why it is due here should be presented.

General Comments on Chapter 4

- how close to DS-20k is the model used? Namely considering the OV and IV structure and materials? Were details of the vessels and radiopurity of materials considered? Is the decay of Ar37 considered?

- You concluded that applying these vetos will reduce the number of NR to almost zero. Does this mean that DS-20k will be a success in this issue, or should this model be refined?
- The position of the figures in the text is most of the times too far from the paragraph that analyses it, making it difficult to follow the discussion and verifying the figures. Could this be improved?

Chapter 5 – Veto readout system

The candidate was responsible for the assembly of this testing system at CEZAMAT, for the data taking and for the development of part of the code that was used to analyze the data.
The testing of vPDUs was made concerning several different aspects as I-V curves, voltage breakdown, dark current range, cross-talk, signal-noise ratio and the PyReco reconstruction software, a code used by all the collaboration. Analysis of the results and conclusions about the measurements are also presented. An upgrade of the system was also made. This will enable the testing of more vPDUs at the same time.

Some comments and remarks:

Page 92 – Line 2, the scintillation light referred to is due to the neutron interaction in the neutron moderator material? This should be clarified.

Page 98 – Fig. 5.7 – maybe just the reference of this item should be enough, the photo of it is not very useful.

Page 98 – Fig. 5.8 – “it arrived” is not needed in the legend.

Page 99 – Section 5.6.1 – at room temperature no charge spectra is measured, due to the dark current? It is referred that the power supply had an offset of 2.6 V. is this important? Was it considered, corrected? Just giving this information is not so clear..

Page 99 – “The signals from each vTile that make up a quadrant cannot be read out separately.” This is a permanent condition or it was assembled like this for testing? If permanent, won’t it deteriorate the position resolution?

Page 100 – Section 5.6.3 – why is the noise spectra calculated for both temperatures? It is not clear its importance in the text.

Page 101 – Figures 5.11 and 5.12 – the legend on the axis is not readable. Either there should be a larger legend for all the axes, or increase the size of the font used. Also, why do the peaks vary from tile to tile? Were the spectra repeated at different instants, at different times of the day?

Page 102 – Eqs. from 5.1-5.5 miss the explanation of some of the parameters used: what is R, fthr, d, how are the segments chosen.. these parameters and the method used should be more clearly explained.

Page 104 – Figs. 5.14 and 5.15 – why is the breaking voltage higher at room temperature?

Page 108 – Fig. 5.21 – quadrant 1 is also a little distorted when compared with quadrants 2 and 3. Is there a reason for this? Also, is there linearity in the response with LED intensity?

Page 110 – Fig. 5.23 – what is inferred from this distribution and dependence on LED intensity?

Page 113 – Fig. 5.29 – concerning DCR, some quadrants seem to have values above the requirements. Is this significant? Is it in agreement with previous measurements? Can it be related with experimental conditions?

Chapter 6 – Conclusion – a good summary of the work developed is made here. Maybe some more details on future work could have been given, apart from the vPDUs testing. But fine, in the overall.

(Filipa Melo Borges Belo Soares)

Associate Professor of the Physics Department of the University of Coimbra - Portugal