DarkSide program at CNAF

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Abstract.

DarkSide is a direct dark matter research program based at the underground Laboratori Nazionali del Gran Sasso (*LNGS*) and it is searching for the rare nuclear recoils (possibly) induced by the so called Weakly Interacting Massive Particles (*WIMPs*). It is based on a dual-phase Time Projection Chamber filled with liquid Argon (*LAr-TPC*) from underground sources. The prototype project is a LAr-TPC with a (46.4 ± 0.7)kg active mass, the DarkSide-50 (*DS-50*) experiment, which is installed inside a 30 t organic liquid scintillator neutron veto, which is in turn installed at the center of a 1kt water Cherenkov veto for the residual flux of cosmic muons. DS-50 has been taking data since November 2013 with Atmospheric Argon (*AAr*) and, since April 2015, has been operated with Underground Argon (*UAr*) highly depleted in radioactive ^{39}Ar. The exposure of 1422 kg d of AAr has demonstrated that the operation of DS-50 for three years in a background free condition is a solid reality, thank to the excellent performance of the pulse shape analysis. The first release of results from an exposure of 2616 kg d of UAr has shown no dark matter candidate events. This is the most sensitive dark matter search performed with an Argon-based detector, corresponding to a 90% CL upper limit on the WIMP-nucleon spin-indipendent cross section of $2 \times 10^{-44} cm^2$ for a WIMP mass of 100 GeV/c^2. DS-50 will be operated till the end of the year 2019. From the experience of DS-50, the DS-20k project has been presented based on a new LAr-TPC of more than 20 tonne.

1. The DS-50 experiment

The existence of dark matter is now established from different gravitational effects, but its nature is still a deep mystery. One possibility, motivated by other considerations in elementary particle physics, is that dark matter consists of new undiscovered elementary particles. A leading candidate explanation, motivated by supersymmetry theory (*SUSY*), is that dark matter is composed of as-yet undiscovered Weakly Interacting Massive Particles (*WIMPs*) formed in the early universe and subsequently gravitationally clustered in association with baryonic matter [1]. Evidence for new particles that could constitute WIMP dark matter may come from upcoming experiments at the Large Hadron Collider (*LHC*) at CERN or from sensitive astronomical instruments that detect radiation produced by WIMP-WIMP annihilations in galaxy halos. The thermal motion of the WIMPs comprising the dark matter halo surrounding the galaxy and the Earth should result in WIMP-nuclear collisions of sufficient energy to be observable by sensitive laboratory apparatus. WIMPs could in principle be detected in terrestrial experiments through their collisions with ordinary nuclei, giving observable low-energy <100 keV nuclear recoils. The predicted low collision rates require ultra-low background detectors with large (0.1-10 ton) target masses, located in deep underground sites to eliminate neutron background from cosmic ray muons. The DarkSide program is the first to employ a Liquid Argon Time Projection

Chamber (*LAr-TPC*) with low levels of ^{39}Ar, together with innovations in photon detection and background suppression.

The DS-50 detector is installed in Hall C at Laboratori Nazionali del Gran Sasso (*LNGS*) at a depth of 3800 m.w.e., and it will continue to taking data up to the end of 2019. The project will continue with DarkSide-20k (*DS-20k*) and *Argo*, a multi-ton detector with an expected sensitivity improvement of two orders of magnitude. The DS-50 target volume is hosted in a dual phase TPC that contains Argon in both phases, liquid and gaseous, the latter on the top of the former one. The scattering of WIMPs or background particles in the active volume induces a prompt scintillation light, called S1, and ionization. Electrons which not recombine are drifted by an electric field of 200 V/cm applied along the z-axis. They are then extracted into gaseous phase above the extraction grid, and accelerated by an electric field of about 4200 V/cm. Here a secondary larger signal due to electroluminescence takes place, the so called S2. The light is collected by two arrays of 19 3"-PMTs on each side of the TPC corresponding to a 60% geometrical coverage of the end plates and 20% of the total TPC surface. The detector is capable of reconstructing the position of the interaction in 3D. The z-coordinate, in particular, is easily computed by the electron drift time, while the time profile of the S2 light collected by the top plate PMTs allows to reconstruct the x and the y coordinates. The LAr-TPC can exploit Pulse Shape Discrimination (*PSD*) and the ratio of scintillation to ionization (S1/S2) to reject β/γ background in favor of the nuclear recoil events expected from WIMP scattering [4, 5].
Events due to neutrons from cosmogenic sources and from radioactive contamination in the detector components, which also produces nuclear recoils, are suppressed by the combined action of the neutron and cosmic rays vetoes. The first one in particular is a 4.0 meter-diameter stainless steel sphere filled with 30 t of borated liquid scintillator act as Liquid Scintillator Veto (*LSV*). The sphere is lined with *Lumirror* reflecting foils and it is equipped with an array of 110 Hamamatsu 8"-PMTs with low-radioactive components and high-quantum-efficiency photocathodes. The cosmic rays veto, on the other hand, is an 11m-diameter, 10 m-high cylindrical tank filled with high purity water act as a Water Cherenkov Detector (*WCD*). The inside surface of the tank is covered with a laminated *Tyvek-polyethylene-Tyvek* reflector and it is equipped with an array of 80 ETL 8"-PMTs with low-radioactive components and high-quantum-efficiency photocathodes.

The exposure of 1422 kg d of AAr has demonstrated that the operation of DS-50 for three years in a background free condition is a solid reality, thank to the excellent performance of the pulse shape analysis. The first release of results from an exposure of 2616 kg d of UAr has shown no dark matter candidate events. This is the most sensitive dark matter search performed with an Argon-based detector, corresponding to a 90% CL upper limit on the WIMP-nucleon spin-indipendent cross section of $2 \times 10^{-44} cm^2$ for a WIMP mass of 100 GeV/c^2 [6].

2. DkS-50 at CNAF

The data readout in the three detector subsystems is managed by dedicated trigger boards: each subsystem is equipped with an user-customizable FPGA unit, in which the trigger logic is implemented. The inputs and outputs from the different trigger modules are processed by a set of electrical-to-optical converters and the communication between the subsystems uses dedicated optical links. To keep the TPC and the Veto readouts aligned, a pulse per second (*PPS*) generated by a GPS receiver is sent to the two systems, where it is acquired and interpolated with a resolution of 20 ns to allow offline confirmation of event matching.

To acquire data, the DarkSide detector uses a DAQ machine equipped with a storage buffer of 7 TB. Raw data are processed and automatically send to CNAF farm via a 10 Gbit optical link (almost with approximately 7 hours delay). At CNAF data are housed on a server disk of about 1PBn capacity and on a 300TB tape for backup purposes, for a total of about more than 1 PByte of disk space and several kHS06 equivalent CPU. Raw data from CNAF, and processed ones from LNGS are then semi-automatically copied to Fermi National Laboratories Grid (*FNAL*) via a 100 Gbit optical link. Part of reconstructed data are send back to CNAF via the same link as before with a rate of about 0.5 TB/month (RECO files). Data processed and analyzed at FNAL, are compared with the analysis performed at CNAF. The INFN Roma 3 group has an active role to maintain and follow, step by step, the overall transferring procedure and to arrange the data management.

3. The future of DarkSide: DS-20k

Building on the successful experience in operating the DS-50 detector, the DarkSide program will continue with DS-20k, a direct WIMP search detector using a two-phase Liquid Argon Time Projection Chamber (LAr TPC) with an active (fiducial) mass of 23 t (20 t), which will be built in the next years. The optical sensors will be Silicon Photon Multiplier (*SiPM*) matrices with very low radioactivity. Operation of DS-50 demonstrated a major reduction in the dominant ^{39}Ar background when using argon extracted from an underground source, before applying pulse shape analysis. Data from DS-50, in combination with MC simulations and analytical modelling, also shows that a rejection factor for discrimination between electron and nuclear recoils of $> 3 \times 10^9$ is achievable. This, along with the use of the veto system and utilizing silicon photomultipliers in the LAr-TPC, are the keys to unlocking the path to large LAr-TPC detector masses, while maintaining an experiment in which less than < 0.1 events is expected to occur within the WIMP search region during the planned exposure. DS-20k will have ultra-low backgrounds than can be measured *in situ*, giving sensitivity to WIMP-nucleon cross sections of $1.2 \times 10^{-47}\ cm^2$ ($1.1 \times 10^{-46}\ cm^2$) for WIMPs of $1\ TeV/c^2$ ($10\ TeV/c^2$) mass, to be achieved during a 5 yr run producing an exposure of 100 t yr free from any instrumental background. DS-20k could then extend its operation to a decade, increasing the exposure to 200 t yr, reaching a sensitivity of 7.4 1048 cm2 (6.9 1047 cm2) for WIMPs of 1 TeV/c2 (10TeV/c2) mass. DS-20k will be more than two orders of magnitude larger in size compared to DS-50 and will utilize SiPM technologies. Therefore, the collaboration plans to build a prototype detector of intermediate size, called DS-Proto, incorporating the new technologies for their full validation. The choice of about 1t mass scale allows a full validation of the technological choices for DS-20k. DS-proto will be built at CERN laboratory, the data taking is foreseen to start in the year 2020.

4. DS-proto at CNAF

Data from DS-proto will be stored and managed at CNAF. The construction, operation, and commissioning of DS-proto will allow validation of the major innovative technical features of DS-20k. Data taking will start in the year 2020. The computing resources have been evaluated according to the data throughput, trigger rate and duty cycle of the experiment. A computing power of about 1kHS06 and 300TBn is needed to fully support DS-proto data taking and data analysis in the year 2020. In order to perform at CNAF the CPU demanding Monte Carlo production, 30TBn and 2kHS06 are needed. The DS-proto data taking has been foreseen for few years, requiring a total disk space of the order of PBn's and nkHS06.

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