Report to the LI LNGS Scientific Committee

The DarkSide Collaboration

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CONTENTS

I. COLLABORATION MATTERS

We highlight three important developments that took place since the last Scientific Committee meeting.
We have been informed that the Italian Ministry for Education, University and Research (MIUR) approved a grant of €18.4M in response to the INFN-LNGS proposal submitted to the "Programma Obiettivo Nazionale" (PON), see http://www.ponricerca.gov.it/media/395531/m_piaoodpfsrregistro-decreti-r-000046114-03-2019.pdf. The funding request included capital funding for DarkSide-20k infrastructure for €15M.
Following contacts between the INFN and IHEP, China, leadership, an agreement was reached to produce the acrylic material for both the TPC and the Veto detectors in China. The production will be carried out by the company DonChamp inc in Changzhou, that is providing the acrylic for the JUNO experiment. IHEP collaborators already requested the necessary capital funding to the Chinese Ministry of Science for purchasing the acrylic for the VETO.
Following contacts between the INFN and the US Department of Energy (DOE) leaderships, detailed discussions are ongoing to establish a possible capital funding contribution from DOE to the DarkSide-20k experiment, through Brookhaven National Laboratory (BNL) and Fermilab (FNAL).
Three new groups were admitted officially in the DarkSide Collaboration.
The Brookhaven National Laboratory (BNL) group has assumed responsibilities in the areas of photoelectronics, TPC, and offline calibrations. The group at *Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi*, has assumed responsibilities on Construction Database, photoelectronics and outreach. The group at Laboratori Nazionali di Legnaro (LNL) has assumed responsibilities on precision cleaning of copper and on the establishment of cleaning protocols and in data analysis.
At present, the DarkSide collaboration is composed of 59 institutions and 371 scientist from 14 nations: Brasil, Canada, China, France, Greece, Italy, Mexico, Poland, Romania, Russia, Spain, Switzerland, United Kingdom, United States of America.
The Collaboration voted to choose Argo as the name of the future, ultimate detector with a mass in the range of the multi-hundred tonnes.
The document entitled *Future Dark Matter Searches with Low-Radioactivity Argon* was submitted as *Input to the European Particle Physics Strategy Update 2018-2020*, and can be found at the link https://indico.cern.ch/event/765096/contributions/3295671/.

II. DARKSIDE-50

The DarkSide-50 high-mass WIMP search using the blind analysis of 532.4 live-days of data has been published in Physical Review D. It was surpassed as the most sensitive WIMP limit in Argon for masses above $70\,\mathrm{GeV}/c^2$ (by our DEAP colleagues, that are now DarkSide-20k collaborators) only in February of this year.
World-leading limits from DarkSide-50 were also published in Physical Review Letters, for interactions of low-mass WIMPs and for dark matter particles coupling primarily to electrons.
DarkSide-50 operations continue, primarily to diagnose problems that occurred during the February 2018 blackout. The experiment is functional, but the data quality is marginal due to contamination whose nature and origin is still not understood. While the impact of this contamination has been mitigated with continued purification, the rate of improvement is extremely slow, and, after a year, the data are still not of physics quality.
Currently, the limited resources and manpower available to the project are focused on the commissioning of the system that would allow permanent, safe storage of the full inventory of underground argon currently deployed in DarkSide-50.

III. DARKSIDE-20K INNER DETECTOR

A. TPC

The conceptual design of DarkSide-20k is being finalized with acrylic as underground argon vessel surrounded with regular argon which act as veto.
The design concept of the TPC will be verified with a staged effort using a small prototype at CERN and the TPC parts are being fabricated by members of the collaboration. The small prototype will be tested at CERN using the CERN existing cryogenics system. A 1-ton prototype with full features of the DarkSide-20k TPC has been designed with a cryostat already fabricated and is currently located at CERN. The prototype TPC will be fabricated with low radioactive materials that will enable its potential use as a dedicated detector for low mass WIMP search at LNGS. An engineering team from the DarkSide-20k collaboration is currently actively working at CERN together with the CERN neutrino platform engineering team to finalizing the design requirement of the TPC for the protoDUNE style cryostat.
The major change in the DarkSide-20k TPC design is the field shaping electrode construction. Instead of low background copper ring, we are planning to use a conductive transparent polymer, Clevios, to form both the field cage ring and the cathode and anode. This work is actively being worked on at CERN.

B. Cryogenics

Pending a safety review for both CERN and LNGS requirements, two cryogenics systems will be built for testing: a full scale cryogenics system for DarkSide-20k, and a dedicated system for the 1-ton prototype TPC. The full cryogenics system test is expected to be completed mid 2019 and the cryogenics system for the prototype will be completed later in 2019.

IV. VETO

The design of the veto is based on the concepts already reported into the Report to the XLX LNGS Scientific Committee. The veto detector is composed by three volumes:

- an inner volume of active liquid atmospheric argon (Inner argon Buffer, IAB) surrounding the TPC;
- a passive shell of acrylic (PMMA) loaded with gadolinium with octagonal shape (GdA) mounted around the TPC. The IAB is in between the TPC and GdA. The acrylic shell loaded with Gd surrounds the TPC in all the directions (lateral, top and bottom with the exception due to the service holes).
- an outer active volume of atmospheric argon (Outer Argon Buffer, OAB)

A copper cage (Faraday cage) provides the optical insulation from the rest of the argon external to OAB and, at the same time, it realizes the necessary electric shield. We have performed a series of Monte Carlo studies and, based on that, we have established that the required thickness of both the IAB and OAB is 40 cm, with no performance penalty for a thickness increase. The required thickness of GdA is 10 cm. The mass fraction of Gd in the acrylic should be between 1% and 2%.

The TPC and GdA are shaped as polyhedron with octagonal cross section. The apothem of the inner face of GdA octagon is 225 cm; the internal height of the GdA is 400 cm. Assuming a density of 1.18 g/cm^3 the mass of the acrylic loaded with gadolinium is 11.7 tons.

Neutrons are moderated by collisions (mostly with hydrogen) in the acrylic. The presence of Gd ensures the emission of multiple high energy γ-rays after the neutron capture. With Gd concentration between 1 and 2% by weight, capture of neutrons in Gd happens with about 54% probability and in argon with 24%. The remaining neutrons are caught in hydrogen with 16% probability and copper (8%). Note that the GdA acts as moderator and neutron capture agent and then there are no requests about its transparency to the scintillation light. γ-rays following the n capture interact in the IAB and OAB producing scintillation light that is detected by light sensors mounted on the two sides of GdA and facing both the IAB and OAB.

The IAB and OAB are segmented into vertical sectors using thin acrylic panels. The sectorization has the purpose of reducing the pile-up event rate due to the decay of ^{39}Ar and to obtain a sufficiently high photoelectron yield.

The precise number of sectors is going to be optimized; as a reference we assume to have 5 sectors along each edge of the octagon, both in the IAB and in the OAB volumes.

A sandwich made of a proper 3M foil (reflector) attached to a thin acrylic sheet on which we make TPB coating on the face opposite to the one with 3M foil will be built. This will be attached to the copper cage and to the external wall of the TPC. The panels of the sectors will be realized by 2 sandwiches coupled together.

Sectors are not liquid tight and the proper argon flow should be ensured both during filling and re-circulation. The argon light is detected by SiPM tiles (2000 in the IAB and 1000 in the OAB) with the same size as the one of the TPC. Montecarlo simulations show that the expected light yield is about 2 photoelectrons/keV.

The same company that will produce the acrylic panels is available to make small scale laboratory tests to mix a proper Gd compound with the acrylic and then produce the necessary amount for DarkSide. As we do not require the doped plastic to be transparent, several difficulties faced with metal loading of organic materials to make scintillators are reduced. However the selection of the proper Gd compound requires some R&D work that will start during the next weeks. Assays of the acrylic produced by this company performed by another collaboration shows that the the U and Th contamination should be acceptable for the VETO (ppt level). Additional assays will be performed by DarkSide-20k together with the assay of Gd compounds and of the final doped acrylic.

V. PHOTOELECTRONICS

After the completion of the first motherboard, equipped with 25 PDMs containing each 24 single dose SiPM's, the DarkSide collaboration moved to the construction of a second Motherboard, equipped with triple dose SiPMs. At the moment half of the SiPM tiles have been already mounted and successfully tested in liquid nitrogen. A 3 months delay in the delivery of the remaining SiPMs from the FBK company, Trento, Italy, reflected in a delay of the motherboard production schedule. The remaining triple dose SiPMs were just shipped by FBK. We are confident to finalize this motherboard by the end of April.

The prototype boards of the opto-link system (optical driver and optical receiver board) have been just produced. The optical receiver board (32 channels) was successfully tested, while the optical driver board (25 channels) is at the moment under test.

The next step in the photo-electronics schedule is the production of about 400 PDMs for the 1-ton prototype. These SiPMs will be produced by the LFoundry company, Avezzano, Italy: the first run is expected by the end of May. A first engineering run, finalized in September 2018 and tested shortly after, showed the capability of the silicon foundry to implement the FBK technology: the produced SiPM's showed a good performance both at room temperature and in liquid nitrogen. A second LFoundry engineering run, presently ongoing, is devoted to the true silicon via's (TSV) making. This post-production rework requires the use of a thin layer (few hundreds of microns) of material on the top of the SiPM's. For the first time fused silica will replace glass, showing a too high level of radioactivity.

As far as the procurement of the equipment for the DarkSide-20k clean room massive production is concerned, the cryogenic probe tender was just approved by the INFN Executive Board and the flip-chip bonder tender will follow in few weeks.
The DarkSide-20k SiPM packaging foresees the production of more than 10,000 PDM's in 2.5 years. This remarkable effort requires a large clean room, relying on cutting edge technology equipment and trained personnel.
The Tecnopolo's (AQ) clean room, selected as DarkSide-20k SiPM packaging facility, has a large area, already available, exceeding $700\,\mathrm{m}^2$. At the moment this space is being refurbished and will comfortably host the needed equipment and the personnel. This facility will be rented by INFN and GSSI: an agreement for the use of the Tecnopolo clean room has been already signed. The tender for the cryogenic probe procurement has been finalized and the approval for the flip-chip bonder tender is expected to come in few weeks.

VI. DAQ

The DAQ and Trigger design for DarkSide-20k has been consolidating taking care also of the advancement on the design of the VETO detector. The main novel electronic device around which the readout architecture is built, a new fast ADC developed for advanced digital signal processing, is close to completion. Few prototypes from the CAEN company, Viareggio, Italy, will be available for testing in summer while work in close cooperation between Darkside and CAEN firmware experts is ongoing to implement the needed DSP algorithms. In parallel, a DAQ system for the first phase of DarkSide-Proto run is to be deployed in the next weeks at CERN to be able to acquire data from the first test of the small systems equipped with up to two motherboards and 50 channels.

VII. MATERIAL ASSAYS

The radioactive contamination of 17 samples has been measured during the first months of 2019, with 20 assays in total. 60 results have been obtained concerning the contamination of the upper, middle and lower ^{238}U and ^{232}Th chains. The material database is now fully operational and includes all the results of the DarkSide assay campaign. The radioactive budget has been refined including the latest Monte Carlo results, allowing a detailed evaluation of the assay results. None of the measured samples has been identified as a showstopper. The analysis of acrylic sheets directly provided by the supplier is ongoing. This is a critical measurement given the large amounts of this material both in the TPC and in the veto. In parallel with the calculation of the background produced by the bulk contamination, the working group is now addressing the background given by the activation of the materials due to cosmic rays. Preliminary results have been produced for copper, stainless steel and argon and are now being evaluated. Finally, protocols for material protection and transportation are currently being defined in order to reduce the surface contamination given by Rn daughters plate-out and Rn diffusion inside the bulk.

VIII. ARGON PROCUREMENT AND PURIFICATION

A. Underground Argon Extraction and Purification: Urania

The Urania project has made significant strides in the last months, most importantly with the opening of the tender for the construction of the argon extraction plant by the INFN. The opening of the tender has officially marked the start date of the project, and the timeline for the extraction of the 50 t of UAr required for the DS-20k experiment has now been set and has been integrated with the overall schedule for DS-20k. It is now expected that the tender process will close at the beginning of the fourth quarter in the 2019 calendar year, and at that point a contract will be signed for the construction and delivery of the plant to the extraction site in Colorado, USA.
The Urania project team had an on-site meeting with the Kinder Morgan team on March 5, 2019. The meeting was a re-kick off of the project work that will take place at the Kinder Morgan Doe Canyon facility, in preparation for the installation of the plant that will take place towards the fourth quarter of the 2020 calendar year. This meeting was a huge success in getting the point of contacts established between the two parties, and action items have been assigned which will be covered by the end of the 2019 summer. The current plan is to install and commission the plant between the end of 2020 and the fourth quarter of the 2021 calendar year, allowing for extraction of the 50 t of UAr by the middle of the 2022 calendar year.

B. Final Argon Purification: Aria

Seruci-0 is the pilot plant almost completely installed in one of the outdoor assembly hall at Nuraxi Figus, Italy In the 2018 there were some meetings with the fire brigades and with local authorities in order to clarify some details and to continue in the authorization process. Offices and storehouse are completed and operational. Close to the storehouse a protected area has been reserved to storing and using of gas-bottles need for the operations.
All the column components have followed the agreed procedure: realized and tested at Polaris, transferred and tested at CERN, delivered and tested at CarboSulcis, and installed. All the Seruci-0 components and most of the accessory plants reached Sardinia in Spring 2018. They have been stored in the warehouse before assembly. In Summer 2018 the three main elements [Bottom, Mod-

ule1 (Middle) and Top] have been assembled together in the devoted structure already built and put in place. In the following months all leak-check tests have been performed in order to guarantee the foreseen and designed tightness to the whole apparatus. Moreover, most of the plants have been installed and assembled in the area surrounding the column itself. To date, two concrete platform have been built: they will host the liquid nitrogen dewar and the accessory plants, the cooling machine (chiller) and a box needed to host people on duty-shift and to organize the slow control. The above cited components will be assembled in the months of March-April. Concerning Seruci-1, the complete column plant, 350m tall to be installed in one of the well at Nuraxi-Figus, all the documents needed for the authorization request have been sent in May 2018 to the competent authorities. In the last months several meetings have been held, both with Fire Brigades and with other local and county offices and entities.

In 2018 a complete cleaning and preparation of the well was performed. A well defined coring procedure has been ended by January 2018. After the examination of the rocks samples, the design for the Seruci-1 supporting structure has been detailed. The tender has been completed in Autumn 2018: at the beginning of 2019, a "carbon steel sample platform" has been delivered to Seruci and installed in the well: the test has been successful; it has been very useful in order to define all the needed details. The goal is to receive all the platforms by the end of April 2019 and to install them inside the devoted them by the end of 2019.

An additional storehouse has been selected in order to provide "confined area" for storing and operation at Seruci site. It has been completely refurbished and equipped with TV-CC system for security reason.

The elements composing Seruci-0 and all the modules for Seruci-1 have been successfully tested at CERN and delivered to CarboSulcis by the end of 2018. To date, 15 modules have been "parked" in the Seruci-0 warehouse and 12 of them in the Seruci-1 warehouse.

As far as funding is concerned, in 2017 the first (RAS1) agreement that involves INFN and Regione Autonoma della Sardegna (RAS) has been officially signed. The agreement is focused on the relationship between the Sardinia Region and the INFN and it deals with the realization of the Seruci-plant in the "Iglesiente County" and with the possible industrial and commercial spin-off that the research project Aria might create in the future in different fields of applied technology. In 2018, two additional agreements (RAS2 and RAS3) have been signed. In 2018 several meetings of the so-called "comitato d'indirizzo" (Steering Committee) have been held.

C. Argon radioactivity assessment: DArT

An Expression of Interest for the experiment, re-using the ArDM detector at LSC, Spain, to host a small 1 litre detector containing the argon to be tested, with sensitivity to ^{39}Ar depletions larger than 10,000 compared to atmospheric argon, was submitted and presented at the Scientific Committee of the LSC on December 12th. The Committee recommended to proceed to a Technical Design Report. The document is ready to be submitted to the laboratory in Spain and is in the latest approval phases by the DarkSide-20k Collaboration.

In the meantime hardware activities have already started and the preparation of the experiment is in full steam.

IX. RED

After the LNS, Italy, test beam of September 2018, the ReD TPC has been transported back to Naples, to complete the characterization and commissioning. Tests have been performed to characterize the basic TPC performance in terms of light yield, uniformity, electric field configuration and S2/S1 ratio in double phase. The system was calibrated with ordinary γ-sources and with an internal ^{83m}Kr source, which generates a uniform distribution of mono-energetic events. Activities are still ongoing to characterize the extraction and multiplication fields.

A new test beam is planned in Spring 2019 at LNS, aiming for a more detailed characterization of the neutron beam. This test will be performed without the TPC, but only with the Si telescope, to detect ^{7}Be nucleus which accompanies the neutron, and the liquid scintillator cells as neutron detectors. The test is targeted to improve the layout used in the September 2018 test beam, and specifically the alignment of the system, the beam-correlated neutron background and the beam divergence. After the completion of the test beam, and if the key requirements are met, the TPC and the cryogenic system will be shipped back to LNS, for a re-assembly of the entire ReD setup. One week beam-time for a physics measurement will be likely planned in June-July.

The ReD project got a scientific approval by the Scientific Committee of LNS (PAC). A five-week beam allocation was granted for 2019.

X. CALIBRATIONS

While the goals of calibration of DarkSide-20k has not changed, the actual implementation is being revisited due to the changes in the TPC design as well in the veto design that calibration interfaces to. In addition to radioactive sources used in DarkSide-50, the collaboration has been investigating alternative ways of injecting low energy neutrons for low energy nuclear recoil calibration. Recently investigated method that will also be utilized in the DUNE experiment is utilization of the 57 keV neutron scattering resonance in argon, that makes argon nearly transparent to 57 keV neutrons. This feature will allow injection of neutrons deep into the veto, close to TPC for the TPC nuclear recoil calibration with low energy neutrons. 57 keV neutrons are produced via moderation of 2.45 MeV neutrons from the DD generator. In parallel, plans are being developed for the calibration needs of the DarkSide-20k prototype detectors for x-y positioning, light yield and nuclear recoil calibration.

XI. SCIENCE AND SIMULATION

DarkSide-20k Monte Carlo code is in an advanced status: the Geant4-based package (g4ds) is currently completed, and undergoes frequent updates following the changes of the detector design. Recently, we have also implemented a preliminary version of the electronics simulation, which has allowed the development of the event reconstruction code. ReD data are used to test reconstruction. Simulations are widely employed for different aspects of the experiment (e.g. background budget, optical response, neutron veto optimization), witnessing the advanced status of the code.

From the "Science" side, we are very active in the determination of the sensitivity of DarkSide-20k and ARGO to Supernova neutrinos exploiting the flavor insensitive coherent scattering channel. Such detection has a unique potential in providing information on total energy emitted by the supernova neutrino when compared with results from large scale detectors like DUNE, Hyper-Kamiokande, and JUNO, which are mostly sensitive to electron neutrinos. At the same time, we are still investigating potential in extending the low-mass WIMP limit with different configurations of the DarkSide-20k prototype and vetoes.