

Report to the LI LNGS Scientific Committee

The DarkSide Collaboration March 21, 2019



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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). The funding request included capital funding for DarkSide-20k infrastructure for €15M.

Following contacts between the INFN and IHEP 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 that is providing the acrylic for the JUNO experiment. IHEP collaborators already requested the necessary capital funding to the Chinese Ministry of Science.

Following contacts between the INFN and the US Department of Energy (DOE) leadership, 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 and on photoelectronics. The group at Laboratori Nazionali di Legnaro (LNL) has assumed on precision cleaning of copper on 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 $70 \text{ GeV}/c^2$ (by our DEAP colleagues) only in February of this year.

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. 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. In collaboration with the IHEP group in Beijing, we secured the acrylic needed for the DarkSide-20k TPC vessel from the same acrylic of the JUNO project produced by DonChamp inc in Changzhou China.

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 cryostat already fabricated and is currently located at CERN. The prototype TPC will be fabricated with low radioactive materials and then used 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 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/cm³ 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 ³⁹Ar 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 recirculation.

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 PE/KeV.

We have established a good contact with a Company 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 single dose SiPM, the DarkSide collaboration moved to the construction of a second

372 Motherboard, equipped with triple dose SiPMs. At
 373 the moment half of the SiPM tiles have been already
 374 mounted and successfully tested in Liquid Nitrogen.
 375 A 3 months delay in the delivery of the remaining
 376 SiPMs from FBK, reflected in a delay of the Motherboard production schedule. The remaining triple
 377 dose SiPMs were just shipped by FBK: We are confident to finalize this Motherboard by the end of April.
 378 The prototype boards of the opto-link system (optical driver and optical receiver board) have been
 379 just produced. The Optical receiver board (32 channels) was successfully tested in LN, while the optical
 380 driver board (25 channels) is at the moment under
 381 test.

386 The next step in the Photo-electronics schedule is
 387 the production of about 400 PDMs for the 1-ton
 388 Proto. These SiPMs will be produced by LFoundry:
 389 the first run is expected by the end of May. A first
 390 engineering run, finalized in September 2018 and
 391 tested shortly after, showed the capability of the silicon foundry to implement the FBK technology: the
 392 produced SiPMs showed a good performance both
 393 at room temperature and in Liquid Nitrogen. A second LFoundry engineering run, presently ongoing, is
 394 devoted to the TSVs making. This post-production
 395 rework requires the use of a thin layer (few hundreds
 396 of microns) of material on the top of the SiPMs: For
 397 the first time Fused Silica will replace glass, showing
 398 a too high level of radioactivity.

401 As far as the procurement of the equipment for the
 402 DarkSide 20k clean room massive production, the
 403 Cryogenic probe tender was just approved by the
 404 INFN Executive board and the Flip-chip bonder tender will follow in few weeks.

406 The DarkSide-20k SiPM packaging foresees the production of more than 10,000 PDMs in 2.5 years. This
 407 remarkable effort requires a large clean room, relying
 408 on cutting edge technology equipment and trained
 409 personnel.

411 The Tecnopolo clean room, selected as Darkside
 412 SiPM packaging facility, has a large area, already
 413 available, exceeding 700 m^2 . At the moment this
 414 space is being refurbished and will comfortably host
 415 the needed equipment and the personnel. This facility will be rented by INFN and GSSI: an agreement
 416 for the use of the Tecnopolo clean room has been
 417 already signed. The tender for the Cryogenic probe
 418 procurement has been finalized and the approval for
 419 the flip-chip bonder tender is expected to come in
 420 few weeks.

422 VI. DAQ

423 The DAQ and Trigger design for Darkside-20k has
 424 been consolidating taking care also of the advance-

425 ment on the design of the VETO detector. The main
 426 novel electronic device around which the readout architecture is built, ia new fast ADC developed for
 427 advanced digital signal processing, is close to completion. Few prototypes from CAEN will be available
 428 for testing in Summer while work in close cooperation between Darkside and CAEN firmware experts
 429 is ongoing to implement the needed DSP algorithms. In parallel, a DAQ system for the first phase
 430 of Darkside-Proto run is to be deployed in the next weeks at CERN to be able to acquire data from the
 431 first test of the small systems equipped with up to
 432 two MB and 50 channels.

438 VII. MATERIAL ASSAYS

439 The radioactive contamination of 17 samples has
 440 been measured during the first months of 2019, with
 441 20 assays in total. 60 results have been obtained
 442 concerning the contamination of the upper, middle
 443 and lower 238U and 232Th chains. The material
 444 database is now fully operational and includes all
 445 the results of the DarkSide assay campaign. The
 446 radioactive budget has been refined including the
 447 latest Monte Carlo results, allowing a detailed evaluation of the assay results. In parallel with the
 448 calculation of the background produced by the bulk
 449 contamination, the working group is now addressing
 450 the background given by the activation of the materials given by cosmic rays. Preliminary results have
 451 been produced for Copper, Stainless Steel and Argon and are now being evaluated. Finally, protocols
 452 for material protection and transportation are currently being defined in order to reduce the surface
 453 contamination given by Rn daughters plate-out and
 454 Rn diffusion inside the bulk.

459 VIII. ARGON PROCUREMENT AND PURIFICATION

461 A. Underground Argon Extraction and Purification: Urania

463 The Urania project has made significant strides
 464 in the last months, most importantly with the opening of the tender for the construction of the argon
 465 extraction plant by the INFN. The opening of the tender has officially marked the start date of the
 466 project, and the timeline for the extraction of the 50 t of UAr required for the DS-20k experiment has
 467 now been set and has been integrated with the overall schedule for DS-20k. it is now expected that
 468 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

1. Seruci-0

It is the pilot plant quite completely installed led in one of the outdoor assembly hall at Nuraxi Figus, ("outdoor - on surface")

"Papers"

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 authorizing process.

"Structures & Facilities"

Offices and storehouse: completed and operational. Close to the storehouse a protected area has been reserved to storing and using of gas-bottles need for the operations.

"Components"

All the column components have followed the agreed procedure: realized and tested c/o POLARIS, transferred at CERN, tested c/o CERN, delivered at CARBOSULCIS, tested c/o 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 assembling. In Summer 2018 the three main elements [Bottom, Module1 (Middle) and Top] have been assembled together in the devoted structure already erected 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 poured: they will host the Liquid Nitrogen Dewar + 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 March-April months.

2. Seruci-1

It is the complete column plant, 350m tall to be installed in one of the well at Seruci ("underground").

"Papers"

All the docs 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.

"Structures & Facilities"

In 2018 a complete cleaning and preparation of the well has been 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.

"Components"

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.

3. Management

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 under test, 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 ^7Be nucleus which accompany 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 anti-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, HyperKamiokande, 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.