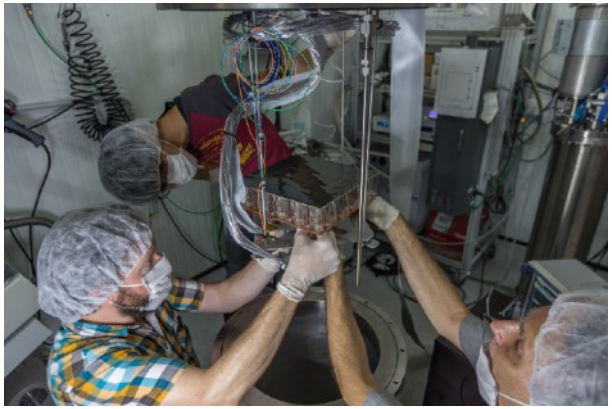
DarkSide project

Past, Present, Future





Yury Suvorov

(*University of Naples*)

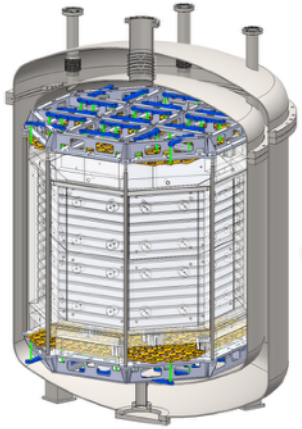
on behalf of the DarkSide collaboration

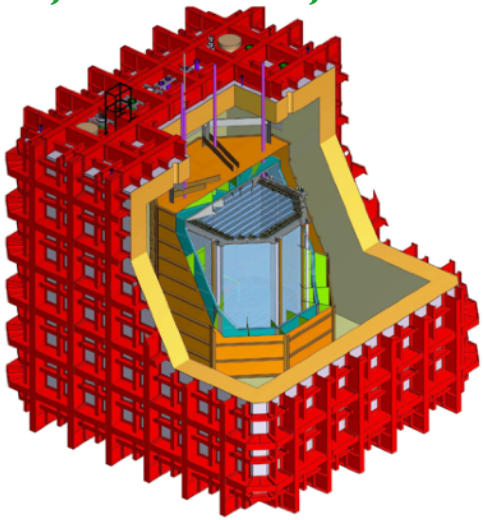
INSTR'20, 24-28 February, Novosibirsk, Russia

Past. Present. Future

2017 - Global Argon Dark Matter Collaboration (GADMC)

DarkSide, DEAP-3600, miniCLEAN, ArDM





ARGO
300t
detector

Proto 1t *(from 2020)*

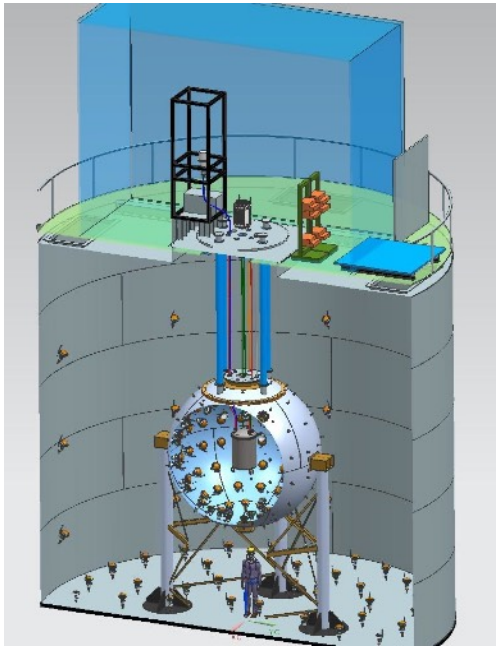
DarkSide-20k *(from 2024)*

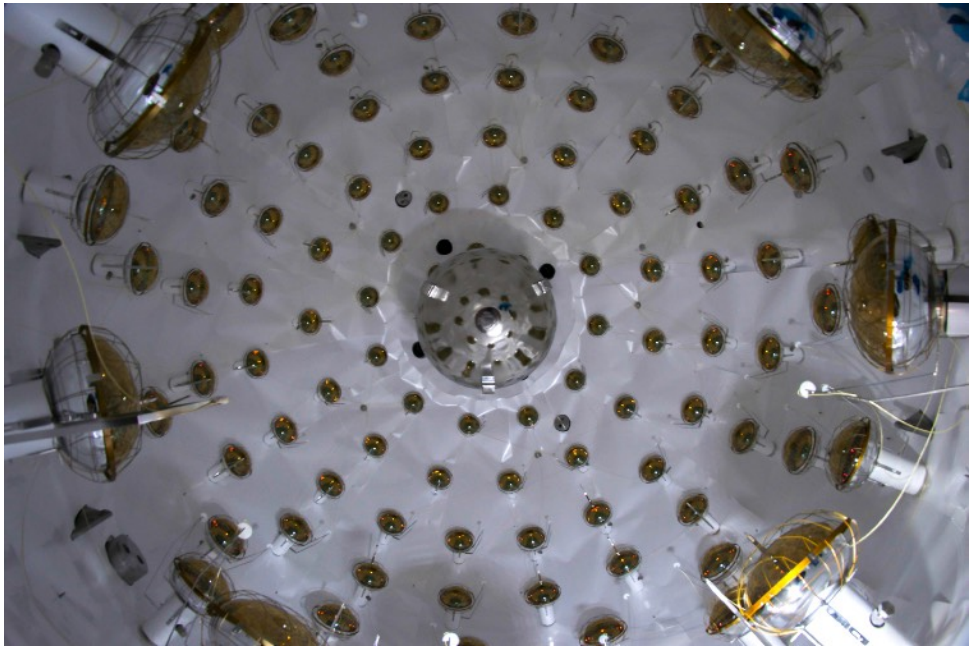
Argo *(from 2028)*

Canada, Cina, Europe, **Russia (Budker INP, SINP MSU, NRC Kurchatov Inst., MEPHI, JINR Dubna, Belgorod Univ.)**, USA

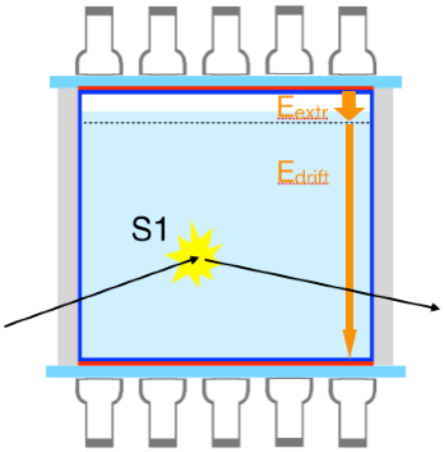
DM Direct Search with DS-50

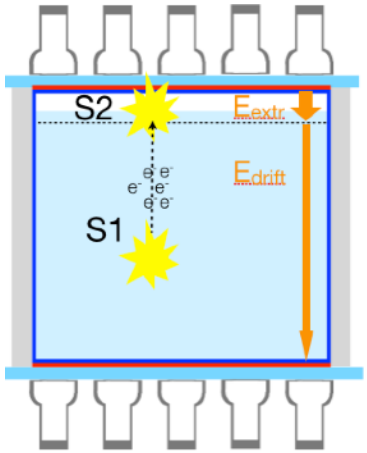
- **Deep underground location** ▻ INFN-LNGS (3800 m.w.e.) Italy.
- **TPC** ▻ Two phase Time Projection Chamber (scintillation S1 + ionization S2).
- **UAr** ▻ Argon from underground sources, depleted in ^{39}Ar (factor ~**1000** to AAr).
- **Active n-veto** ▻ Liquid Scintillator Detector. 30t of borated liquid scintillator.
- **Active μ-veto** ▻ Water Cherenkov Detector. Ultra-pure water.

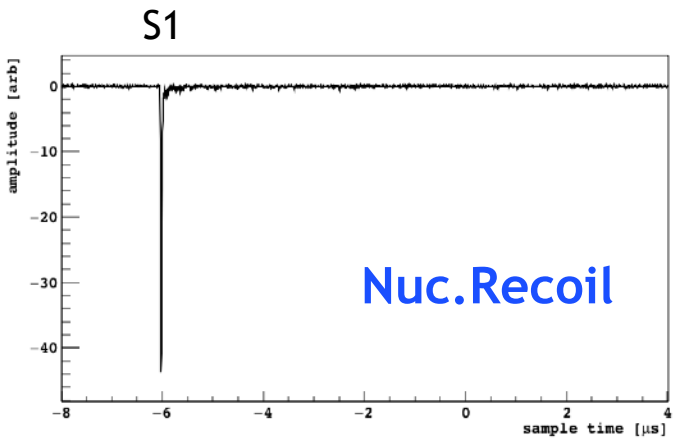


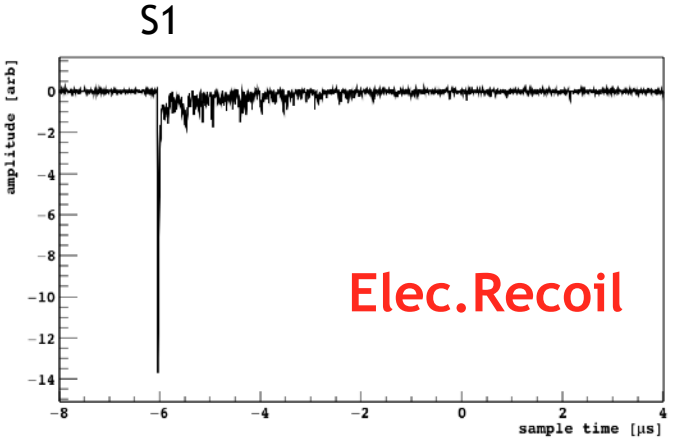


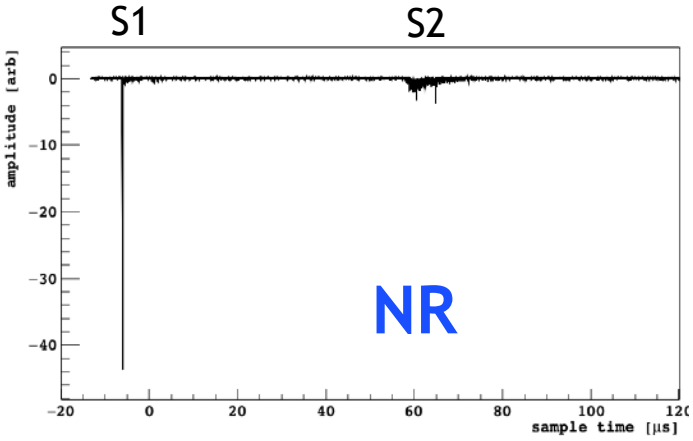
Two Phase TPC. Detection Principle

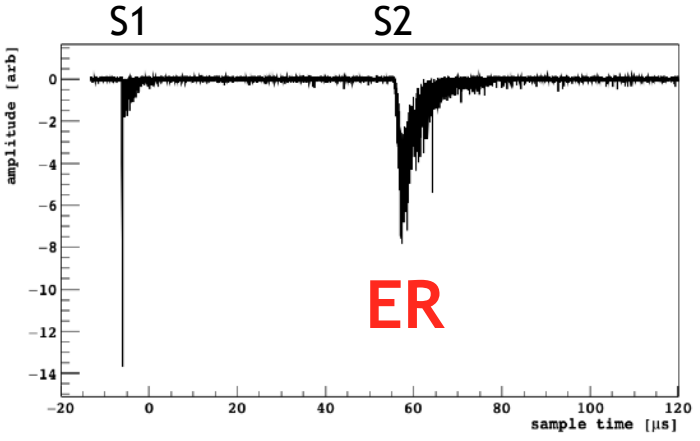










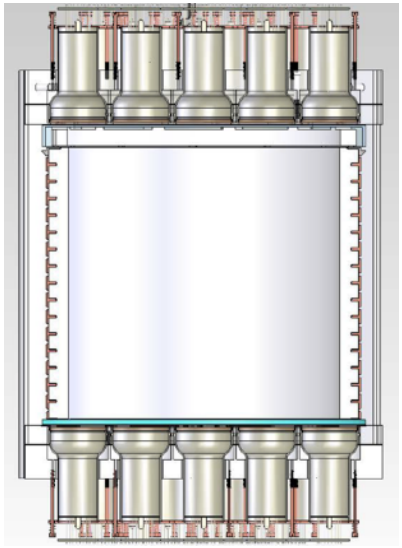


- Z position from drift time (*in DS-50 maximum drift time is 376* μs *@ 200V/cm*).
- XY position is determined by the top PMT array with S2.

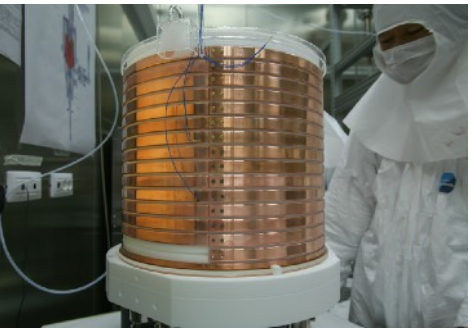
→ 3D positioning

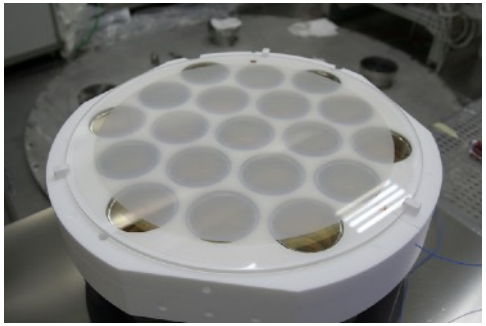
PSD (7ns singlet & 1600ns triplet) temporal pulse shape of S1 (first 90 ns - $\mathbf{f_{90}}$) provides powerful discrimination between NR & ER)

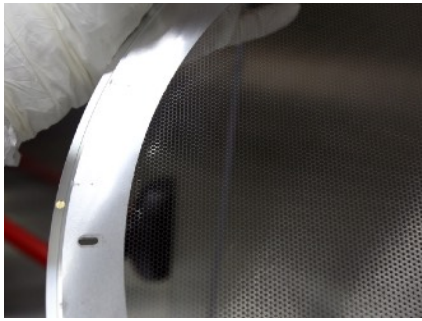
Two Phase TPC. Mechanics



- **PTFE cylinder 2.5 cm-thick**: (36 x 36) cm => 46 kg active (37 kg fiducial).
- **PMT**: 38 3" Hamamatsu R11065. 19(top) + 19(bottom). Coupled with specially designed **cold amplifiers** in order to work under the nominal HV value (cause instabilities and unwilling photon reemission);
- **Field**: Copper field shaping rings. Hexagonal mash as the grid. Standard field configuration: E_{drift} = 200V/cm, E_{extrac} =~ 2.8kV/cm, $E_{mult.}$ = 4.2 kV/cm.
- **Cathode & Anode**: Indium Tin Oxide (ITO) 15 nm fine conductive transparent layer on the fused silica windows. The f. s. diving bell to maintain 1 cm gas pocket.
- **TPB**: All inner surfaces are coated with WaveLength Shifter Tetra-phenyl Butadiene, to shift the Argon scintillation of 128 nm to 420 nm.

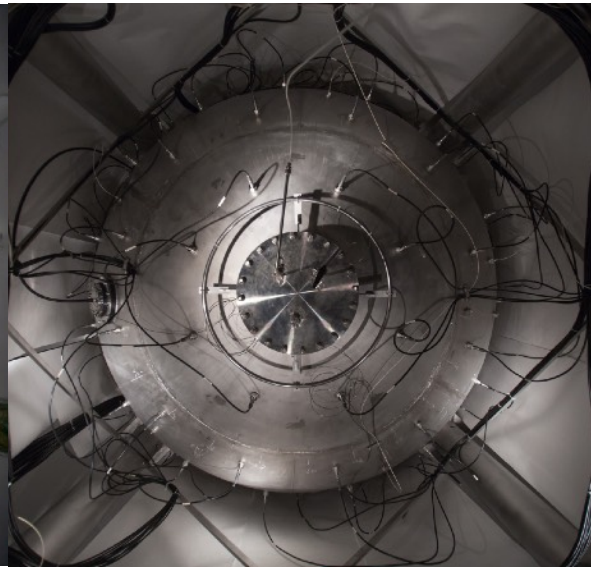






TPC-LSV-WCD





TPC: 46 kg of active LAr inside the SS double wall cryostat. 38 3" PMTs.

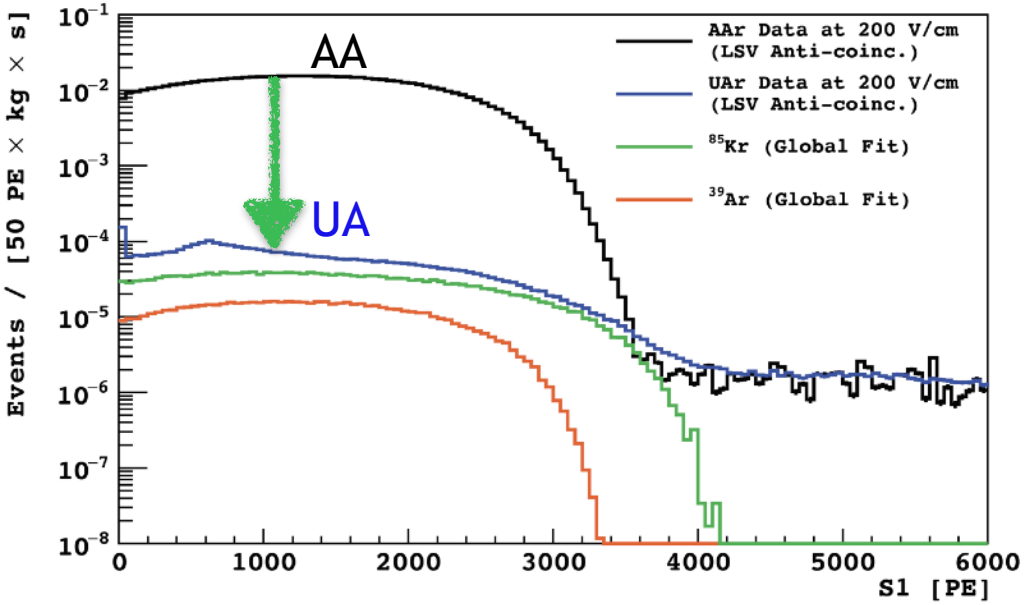
LSV: The 4 m Stainless Steel Sphere. 30 ton of boron-loaded liquid scintillator. 110 8" PMTs. Lumirror reflective foil.

WCD: The 11 m in d & 10 m high SS cylinder. The 1 kton of high purity water, 80 8" PMTs. Tyvec reflector.

Underground Argon

- The ^{39}Ar gives 1Bq/kg of bkg events ($^{39}Ar/^{40}Ar$ ~$8x10^{-16}$ in AAr mixture). Looking for Ar from the deep underground CO_2 sources. Activity starts in 2009. Exploration of wells in Cortez, Colorado looks very promising. First in situ extraction and enrichment plant, from 400ppm to 5%.
- Colorado ▻ Fermilab for further purification in 3.2m tall cryogenic distillation column (purification rate: 1kg/d). The content of CO_2, O_2, N_2 and He all <100ppm.
- Finally the UAr was shipped to Gran Sasso National Laboratory (LNGS), Italy. DS-50 fill with Zr getter as the very last stage of purification.

Six Years Effort! 155 kg produced



The (1.4±0.2)x10^3 less ^{39}Ar with respect to atmospheric Argon

DarkSide-50 Results

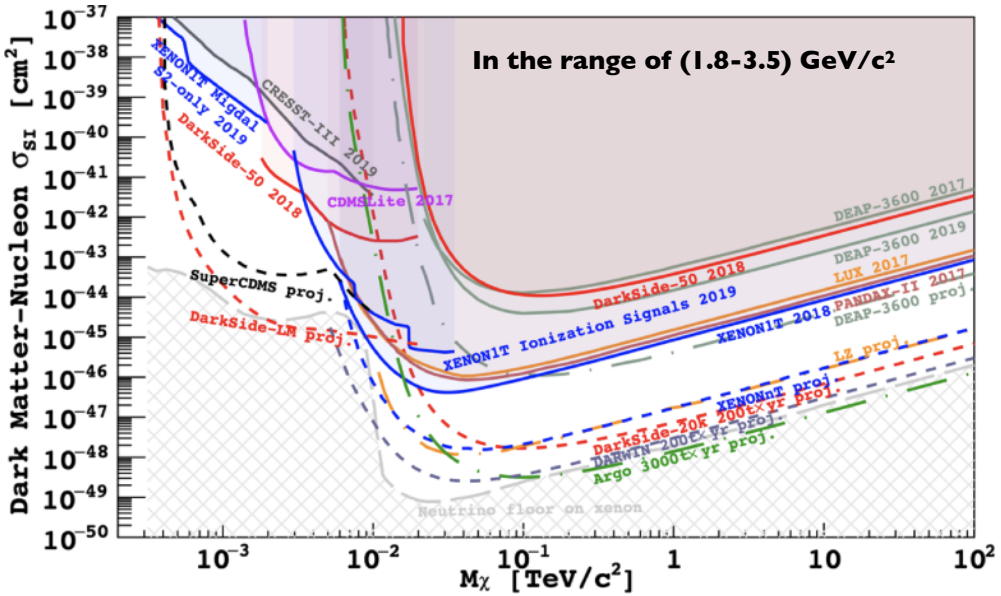
The DarkSide-50 is running with UAr since Aprile 2015.

Over 15 published papers, more are coming.

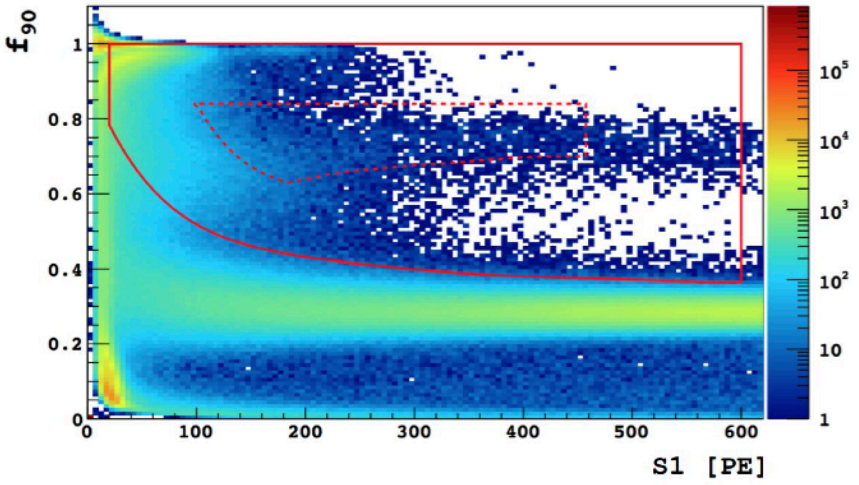
High Mass Analysis
Physical Review D 98 (10), 102006 (2018)

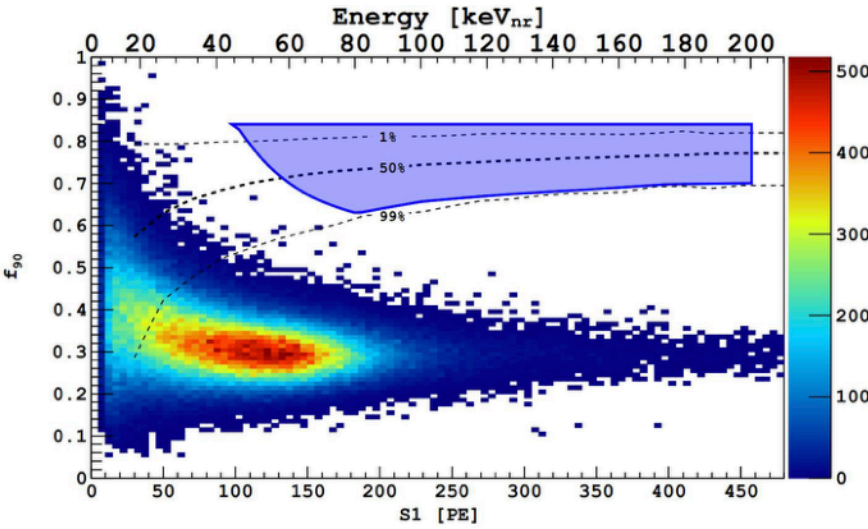
Low Mass Analysis
Physical Review Letters 121 (8), 081307 (2018)

Spin-independent DM-nucleon cross section 90% C.L. exclusion limits



The 532 live days x 46kg results (16660 ± 270)kg d exposure.
Cuts are studied on 70 live days + AAr data.





DarkSide-50 → DarkSide-20k

Restrictions for Liquid Scintillator use at LNGS.

New design: No liquid scintillator. No water. **LAr only**! Great simplification. Overall need: AAr ~(700 +120) tonnes plus 50 tonnes of UAr.

PMTs ▻ **SiPM**s designed and developed for LAr use in collaboration with FBK.

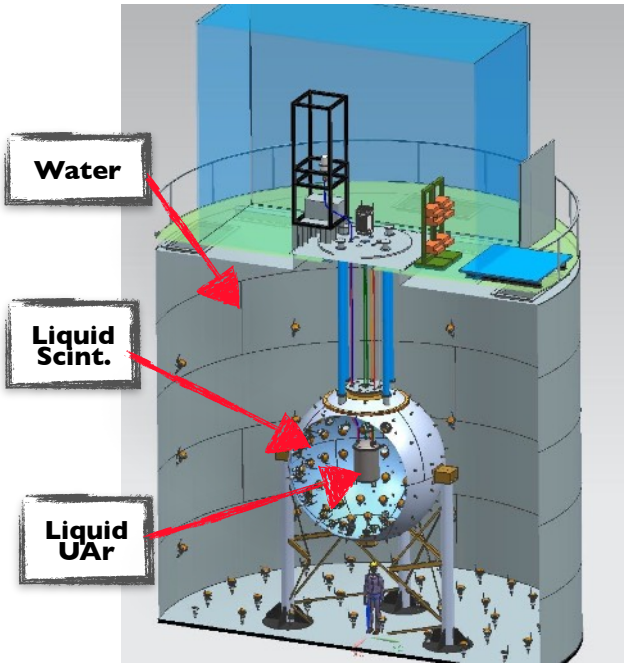
Acrylic TPC. Move from teflon to octagonal sealed acrylic vessel surrounded by the acrylic Veto.

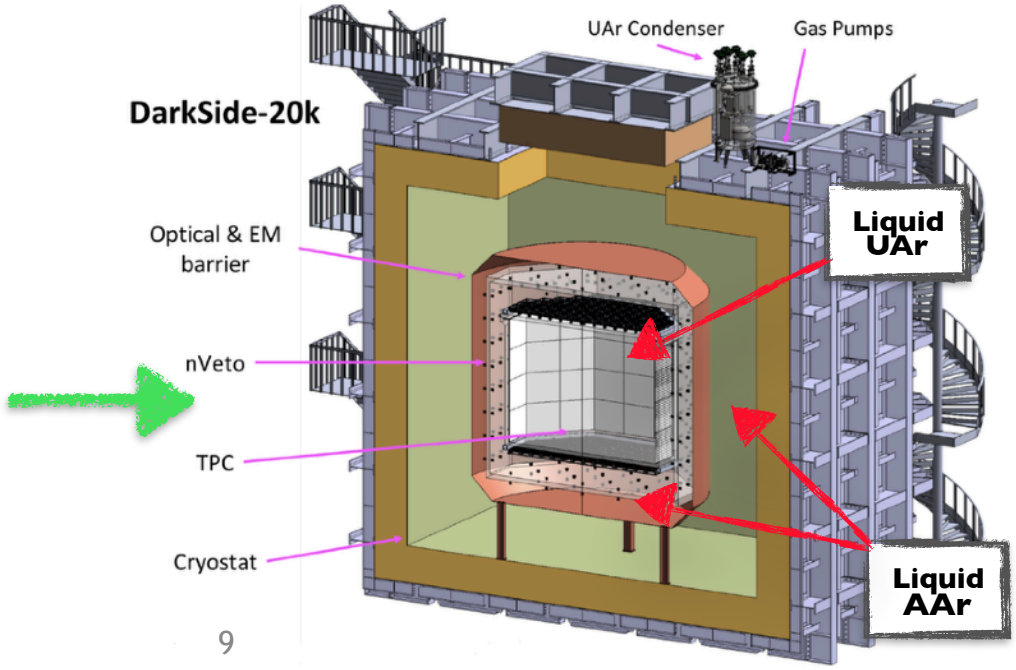
Enhanced Speculare reflector (ESR) to improve the light collection in the TPC & Veto.

ITO ▻ **Clevios**, new conductive polymer, no copper rings.

UAr as target material. New global community, joint effort towards the DS-20k & later ARGO (URANIA, ARIA).

ProtoDUNE type **cryostat** (*DarkSide-20k is a recognised experiment at CERN*).





DarkSide-20k R&D. SiPM

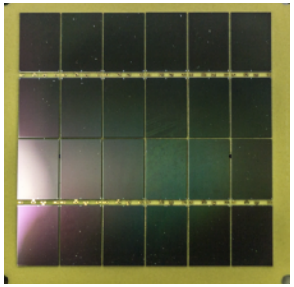
New type of SiPMs suitable for LAr temperature were developed in collaboration with Foundation Bruno Kessler (FBK).

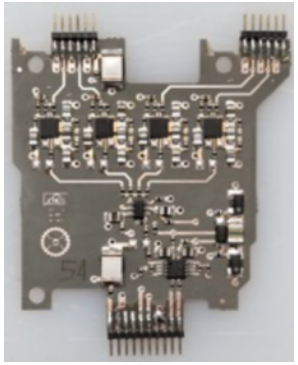
The 24 rectangular SiPMs assembled in 5x5 cm^2 tile, coupled with Front End Board (Photo Detecting Module). PDE of ~50%. S/N >20. Time resolution <10ns. Gain >10^6. Dark count rate at cold 0.1 Hz/mm^2. Compact & radioactively pure.

The 25 PDMs form a motherboards. All power is provided by the steering module. Individual optical readout, every PDM is coupled with an LED and the LED-to-Fiber optical adapter. DS-20k needs 30m^2 coverage, ~300 MBs in total.

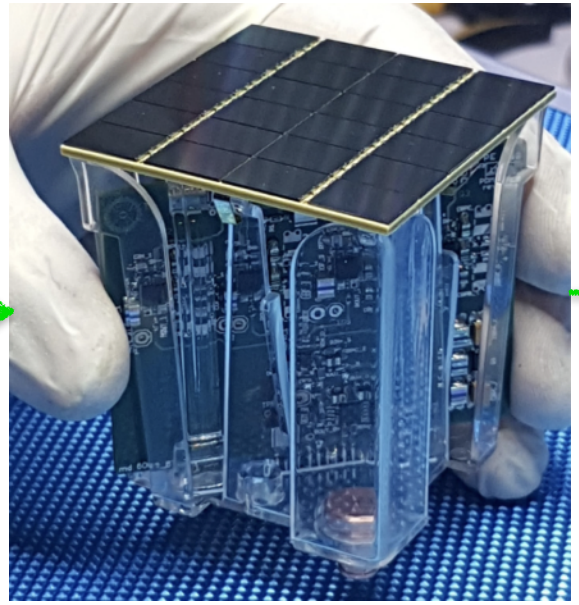
Controlled mass production of the raw wafer in LFoundry company and assembly in a dedicated special clean room at LNGS (NOA). The 30m^2 coverage of the TPC (8280 channels) + 3000 channel for Veto detector.

Compact size ▻ High Coverage efficiency,
High PDE & Signal to Noise ratio, **Low radioactivity** of the components.

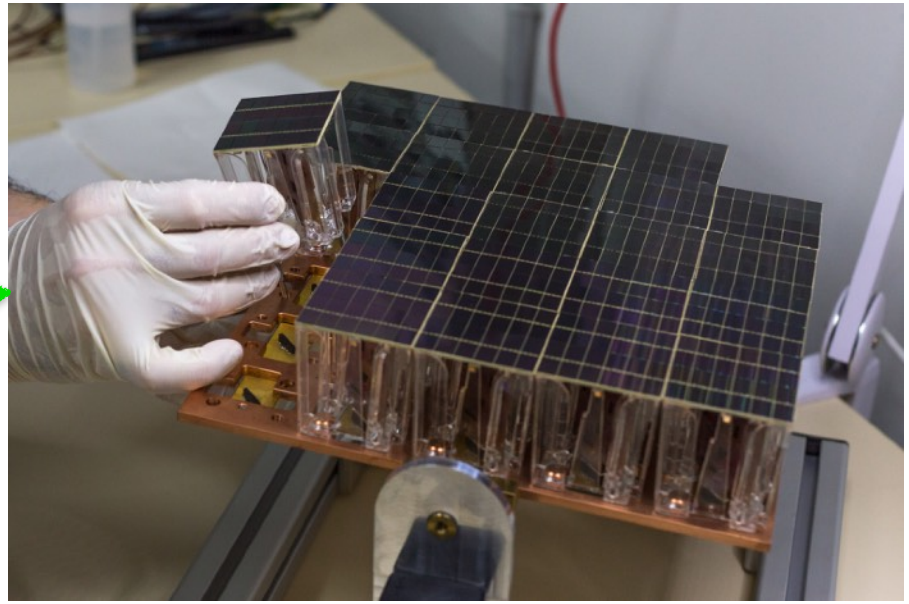




5x5cm SiPMs tile+FEB makes one PDM



25 PDMs make one Motherboard



DarkSide-20k. SiPM

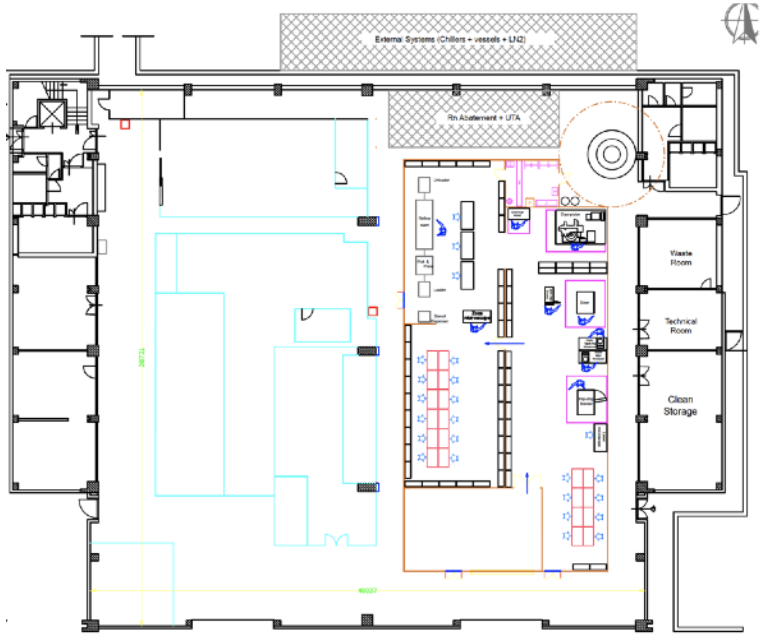
Towards the Mass Production

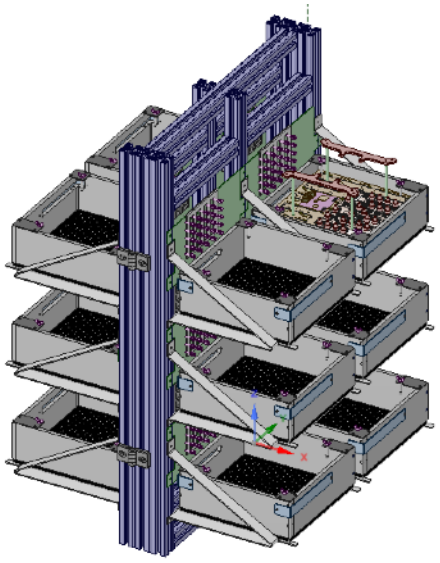
Nuova Officina Assergi (NOA). To cut the raw Si wafer, package the 5x5 cm tiles, couple them with cold electronics (FEB) to obtain the PDM, assemble 25 PDM to the Motherboard (MB). Over 300 MBs overall. Clean room equipment procurement is ongoing.

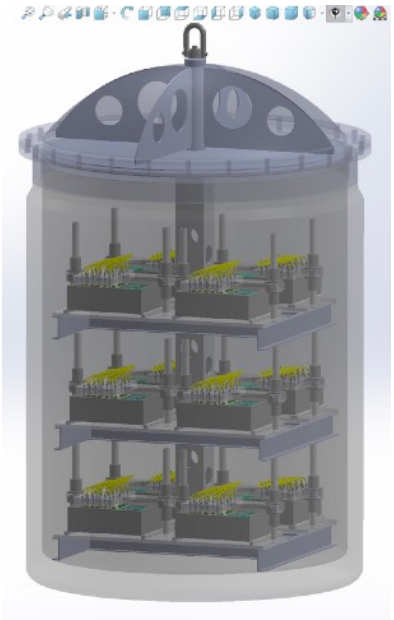
All MB fabricated in NOA will then pass to the Facility in Naples for the test.

Naples Test Facility to be constructed and assembled inside the existing clean room in Naples. Testing period is 2 years (12 MB per week). Tander for the cryostat fabrication ends on 24rd, then we pass to construction.

Special holding structure to host three floors of MBs, 4 in each. Fibers for signals and power lines.
Fully equipped DAQ for 300 channels, NI PXI based Slow control to manage the system. Some of the equipment is already under testing in Naples.







Naples facility Clean Room

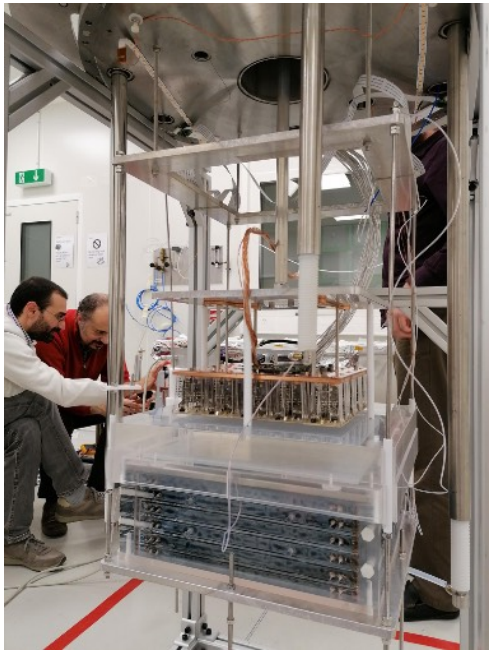
DarkSide-20k. SiPM tests

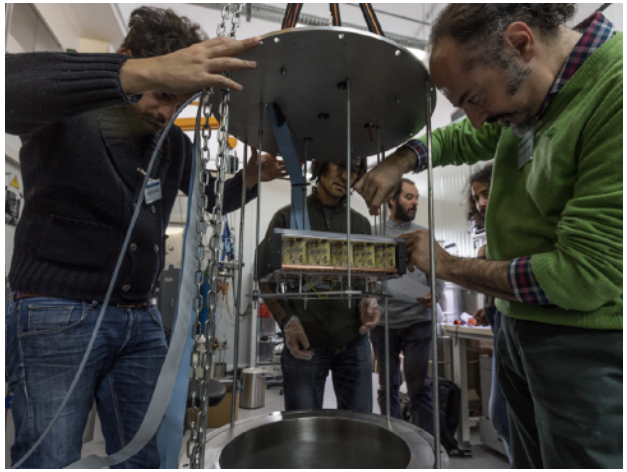
Mother Boards assembly & cold tests @ LNGS and CERN

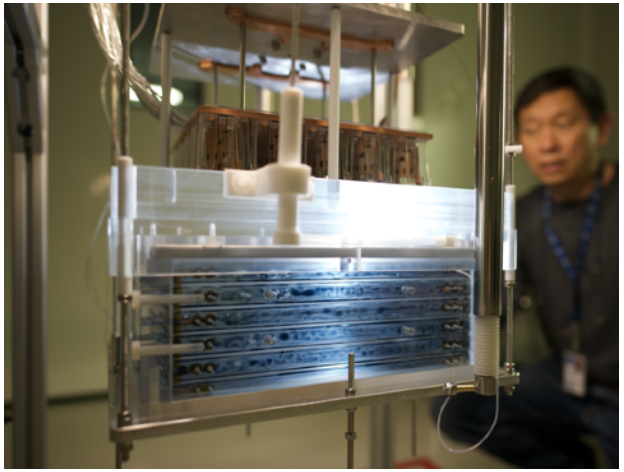
1st Mother board was assembled at LNGS (Sep 2018), tested at cold at LNGS (Nov 2018) and at CERN (Jul 2019).
All but one PDMs worked correctly (IV curves are fine).

2nd mother board together was assembled at LNGS (Aug 2019), tested at cold at LNGS (Sep 2019) and at CERN (Oct 2019).

All PDMs worked correctly (I-V curves are fine), some issue with the steering module, will be fix in the next version.







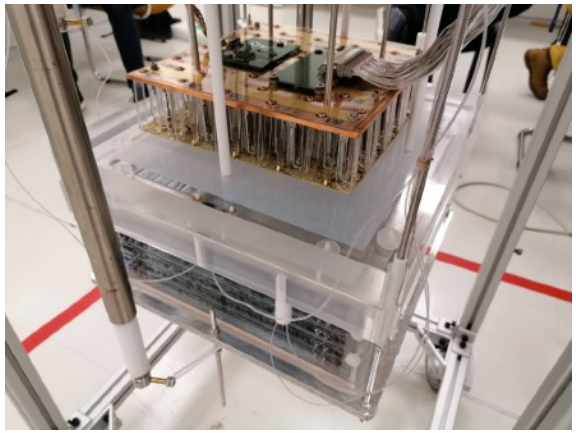
DS-20k R&D. Proto-0, Proto-1 ton

Two motherboards are already tested separately in LN_2 at LNGS & CERN.

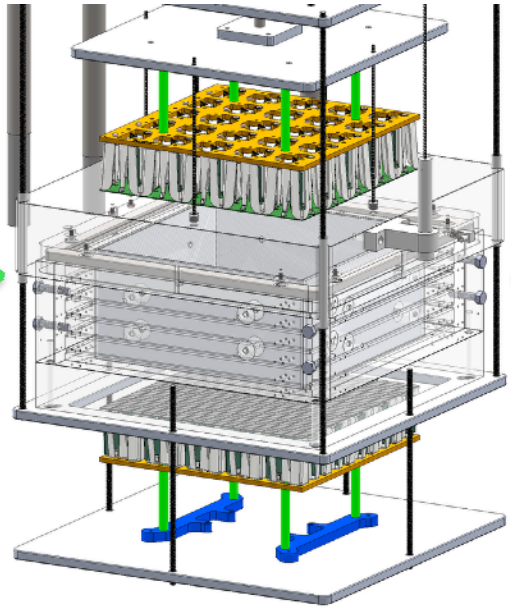
Proto-0 *(spring 2020)*. **MB1 + MB2** mounted on the Proto-0 TPC at CERN for the integration test, the S2 study and the adjustable Gas Pocket tests. From ITO to Clevios polymer.

Proto-1t *(from summer 2020)*. Tests of the scaled version of DS-20k, 5+5 MBs and octagonal acrylic vessel, at CERN and later on possibly at LNGS.

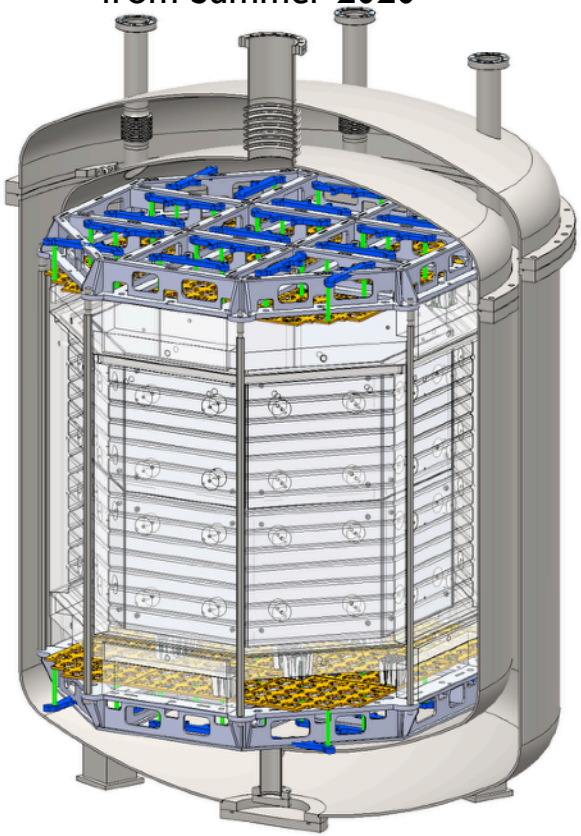
October 2019



spring 2020



from Summer 2020



DarkSide-20k R&D. TPC

Octagonal vessel **3.5m** H x **3.5m** W, made of **6cm** acrylic sheets bonded together. Similar acrylic sheets to build the Anode and Cathode windows. DEAP-3600 experts.

Clevios conductive polymer on top and bottom acrylic windows to make Anode and Cathode and on the walls (no copper rings to shape the drift field).

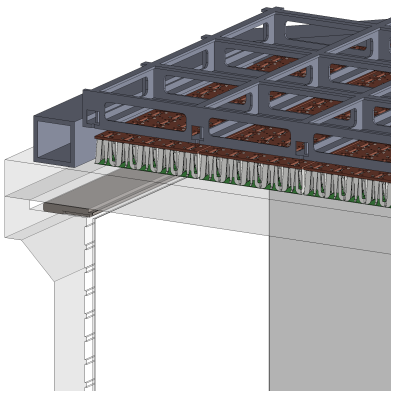
ESR on the inner side of the TPC walls to improve light collection.

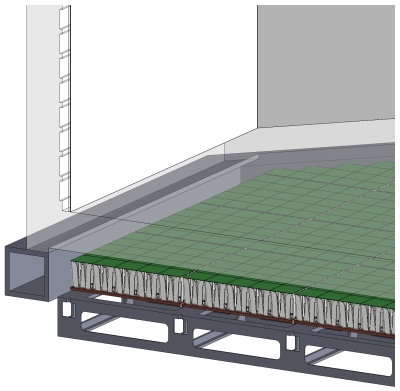
About 50 tonnes of Underground Argon (20t Fiducial).

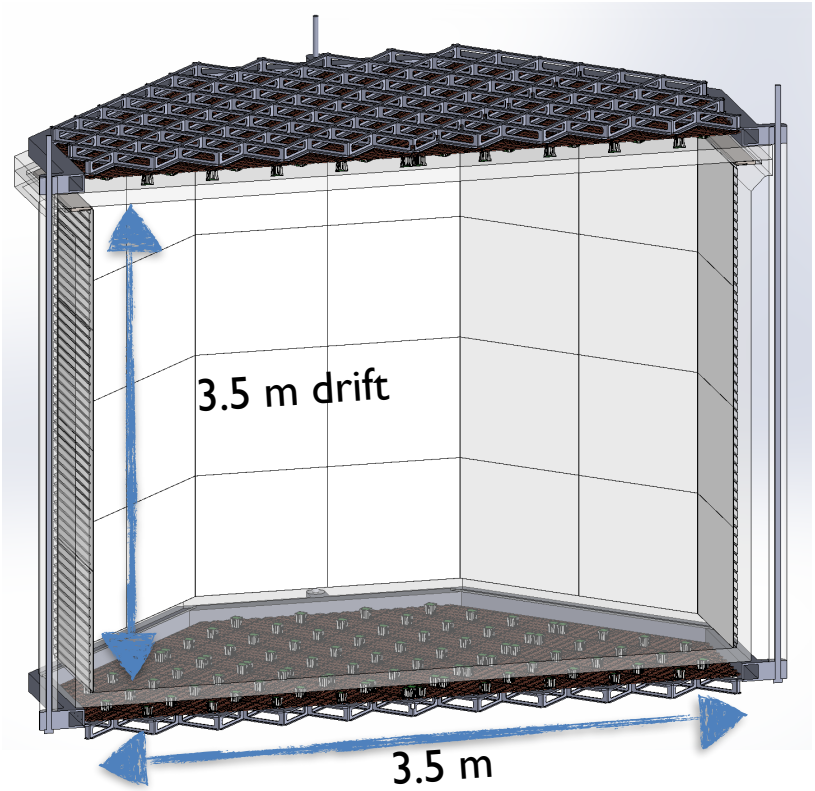
The SS frame with wires as grid.

The 8280 PDMs mounted on top and on the bottom assemblies (4140 each).

TPB coating as the WaveLength Shifter to shift the 128nm to 420 nm.

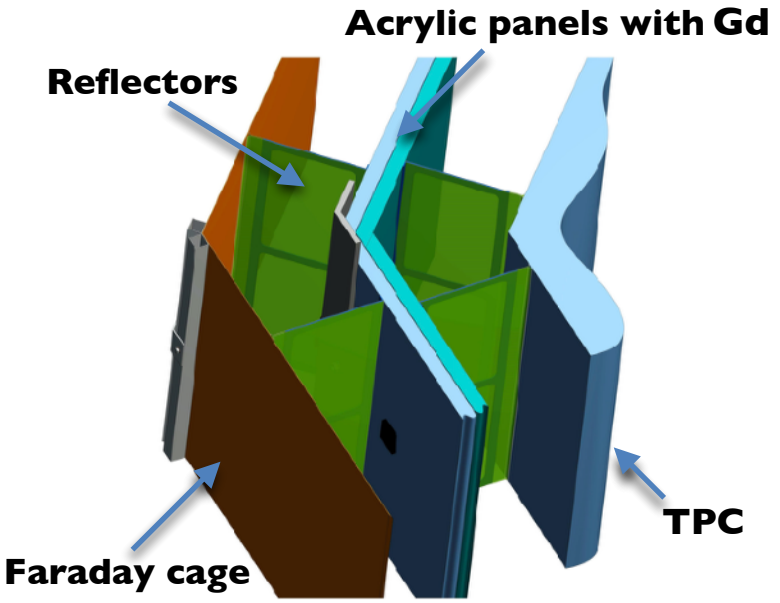


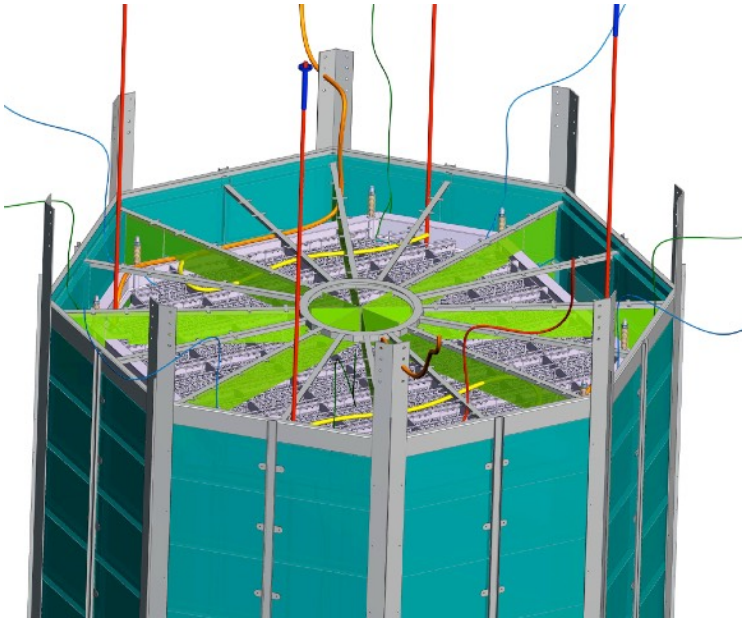




DarkSide-20k R&D. Neutron veto

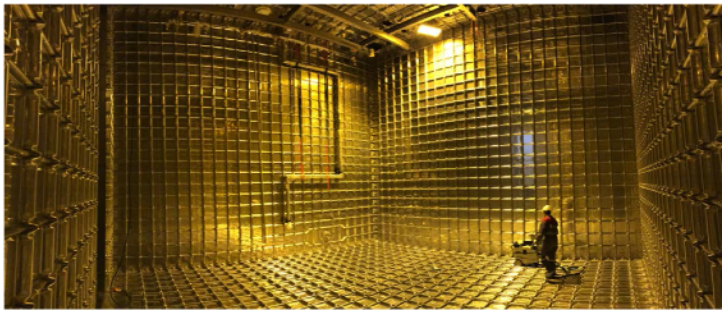
- The 10 cm thick vessel made of a PMMA+Gd_2O_3 sheets to be build around the TPC to moderate and capture neutrons. The 1-2% of Gd oxide in mass.
- Gives 40 cm thick inner (towards the TPC) and outer (towards the Faraday Cage) active liquid AAr volumes to detect gamma cascade due to neutron capture on Gd;
- The 3000 channels (single PDMs) coupled with ASIC FEE (in collaboration between Genova and Torino INFN groups). 4π coverage;
- Faraday cage to optically and electrically isolate veto and TPC detectors;
- Vertical segmentation to reduce pile-up rate of ^{39}Ar (1Bq/kg in AAr) event from AAr. ESR to maximize light collection;
- TPB (wavelength shifter) coated on all internal surface of each sector.



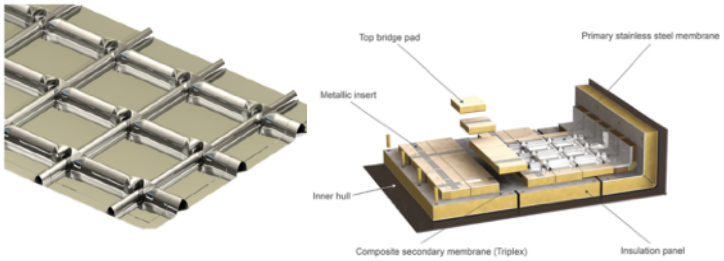


DarkSide-20k. Cryostat

ProtoDUNE type cryostat build with use of the Mark III membrane technology developed by GTT company for the Liquified Natural Gas transport ships.



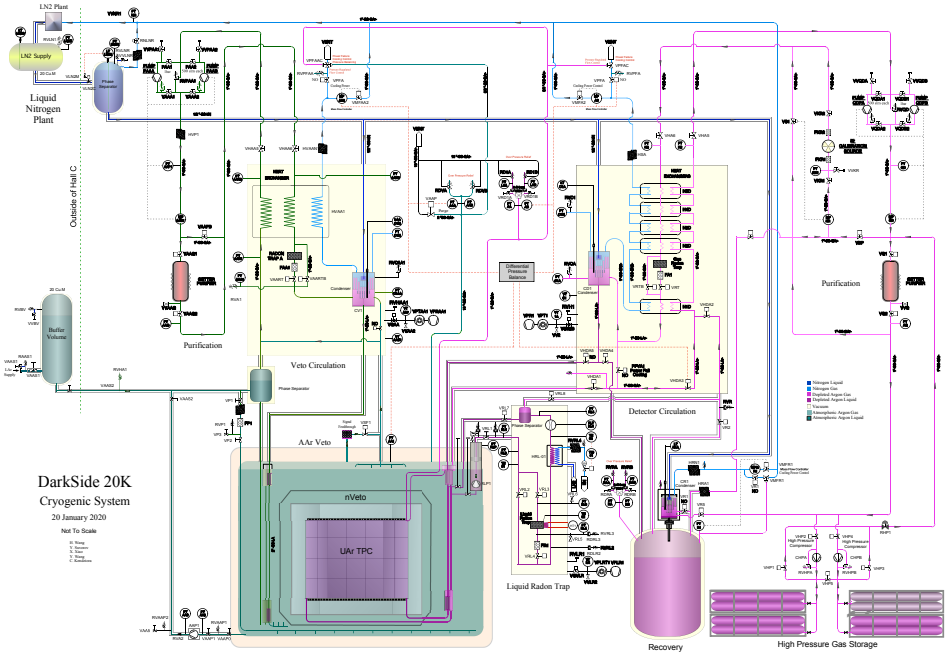
Modular system employs standard prefabricated components.
Designed for mass production techniques and easy assembly.

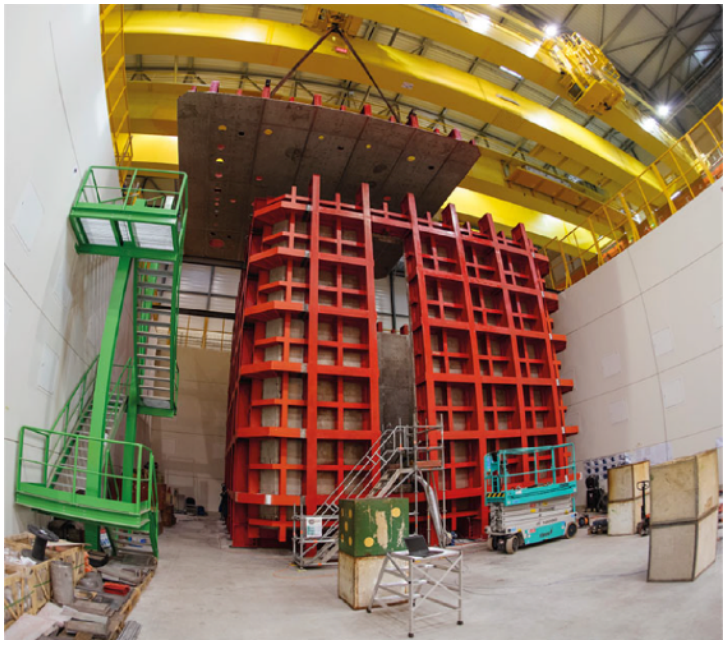


Internal dimensions: (8.5 x 8.5 x 7.9) m;
External dimensions: (11.4 x 11.4 x 10.7) m;
Overall volume: 557m3 of LAr.

DS-20k cryogenics

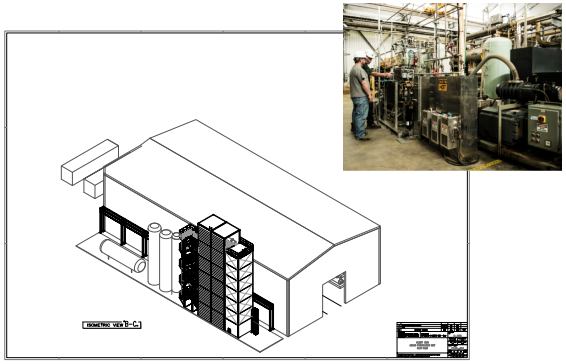
Two separate loops: one for UAr and one for AAr.





Underground Argon

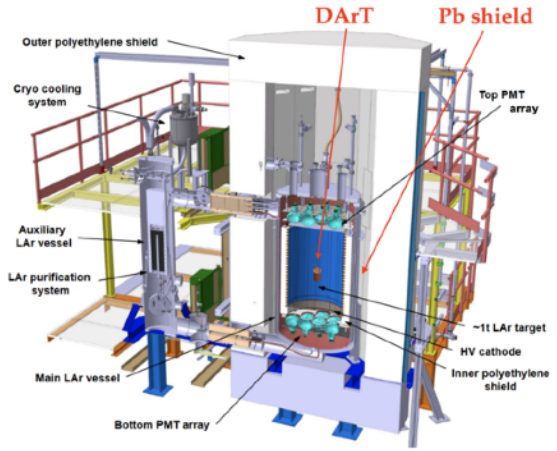
URANIA: We need ~50t of UAr. New extraction plant at Cortez, Colorado (same location as for DS50).
Estimated production rate: 330 kg/day.
The 7.8M are already assigned.
Outcome purity: 99.99%
Recovery: 98%
Installations starts on Jan-Feb 2021. Ready to operate from Nov 2021.



ARIA: New **350m** tall (0.32m inner diameter) distillation column installed in the coal mine well in Sardinia. Purification speed of **1t per day**.

Demonstrator column **Seruci-0** (**25m**) made of three modules (reboiler, condenser and middle module) was successfully tested in July-Oct 2019 with LN_2.

Assembly of the final column **Seruci-1** (350m) is ongoing. Should be complete by **June 2021**.

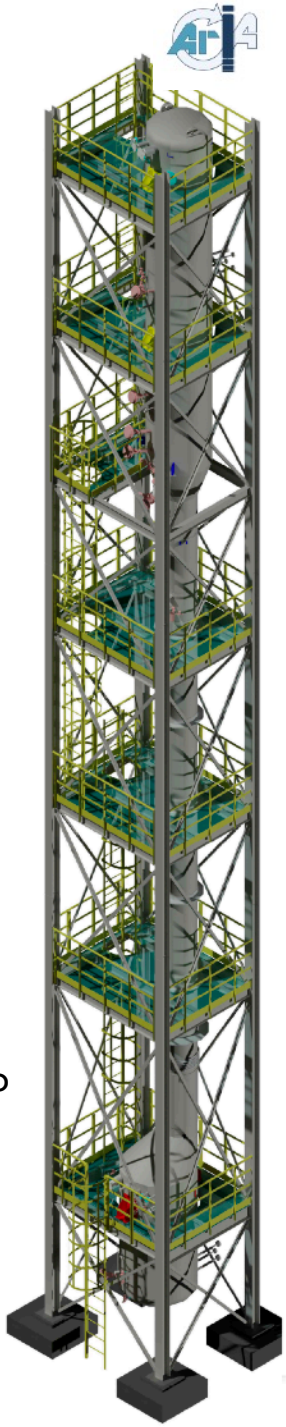


DArT is a single phase low-background detector designed to measure the ^{39}Ar depletion factor of different underground argon batches (URANIA+ARIA).

Made of 99.99% OFHC Cu cylinder, 1ℓ active volume, PMMA support structure with TPB coating, Readout two PDMs (1 cm^2 SiPMs) from DS-20k (DArTeye).

It will be located at LSC inside ArDM, LAr TPC (850 kg AAr) to be used as active veto.

"Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon"
Journal of Instrumentation https://doi.org/10.1088/1748-0221/15/02/P02024



Underground Argon. ARIA

Seruci-0.
The 25m tall prototype column to verify the separation capability.
Number of distillation runs from July till October 2019

Nitrogen (N_2) is the diatomic molecule.

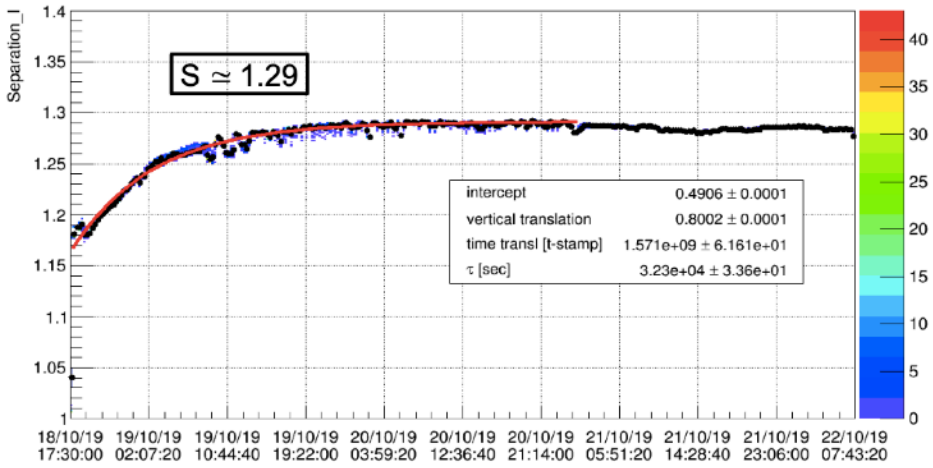
Two stable isotopes: ^{14}N and ^{15}N.

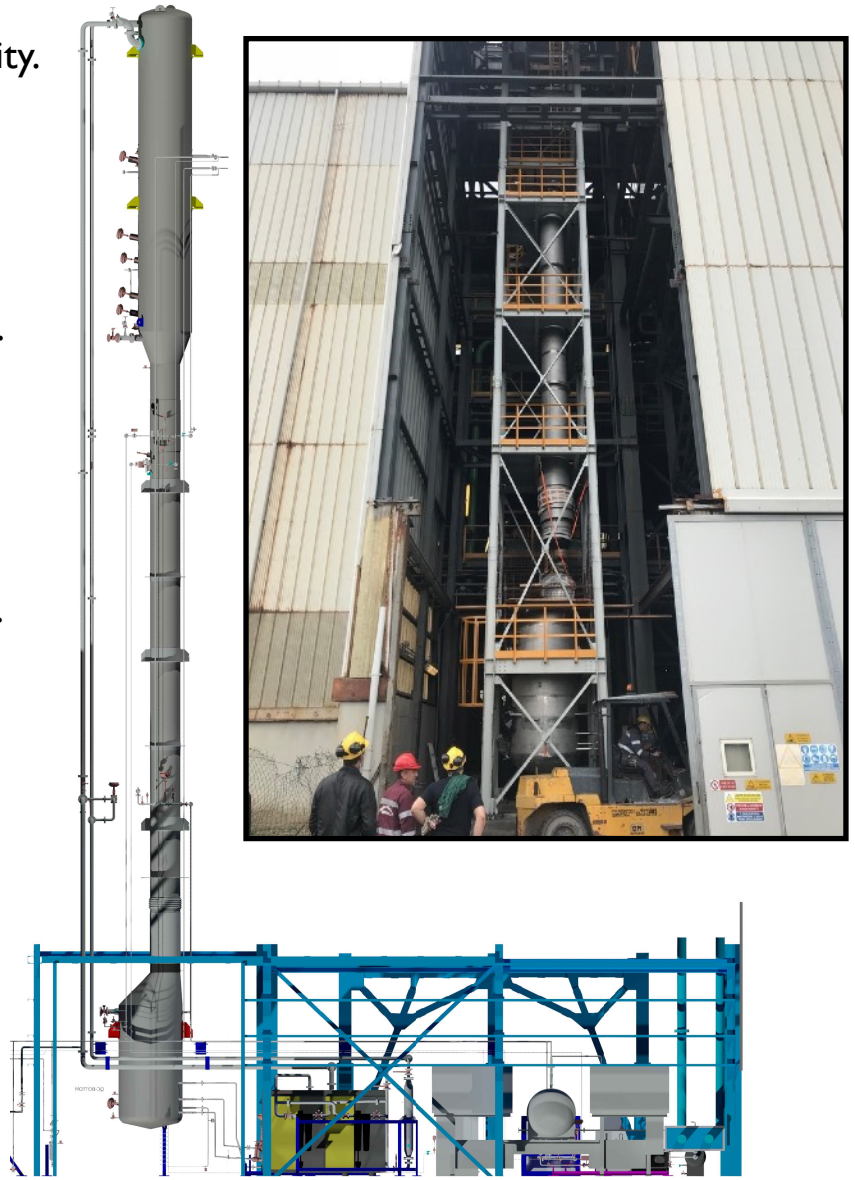
Looking for the separation between: ^{14}N-^{14}N (^{28}N) and ^{14}N-^{15}N (^{29}N).

Relative concentrations in the air: $^{28}N \simeq 99.27\%$ & $^{29}N \simeq 0.73\%$.

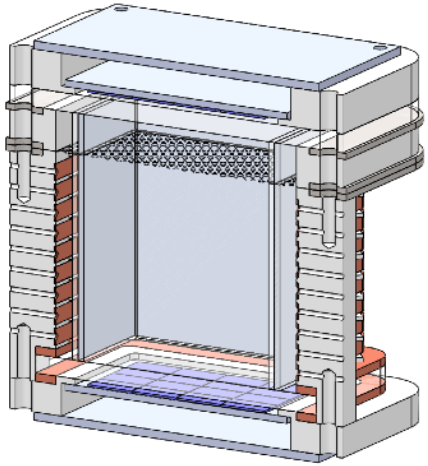
$$S := \frac{\left.\frac{[^{29}N]}{[^{28}N]}\right|_{Bottom}}{\left.\frac{[^{29}N]}{[^{28}N]}\right|_{Top}} = \alpha^n$$

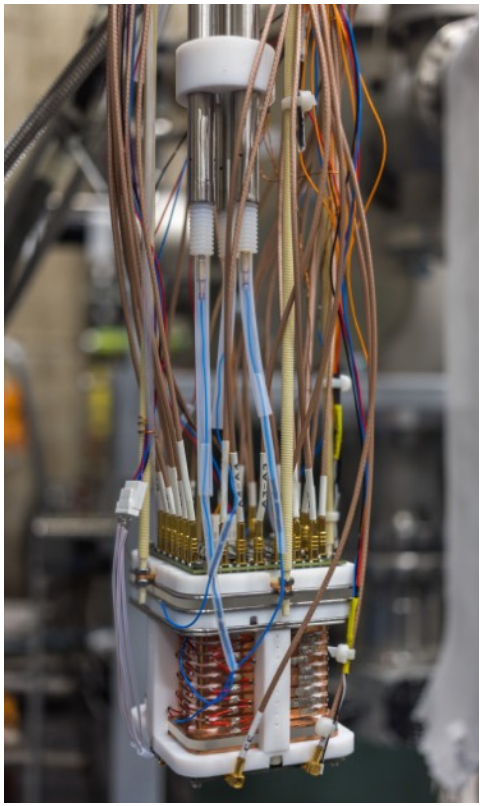
S: "separation" factor;
α: relative volatility;
n: number of distillations stages.





DS-20k. ReD





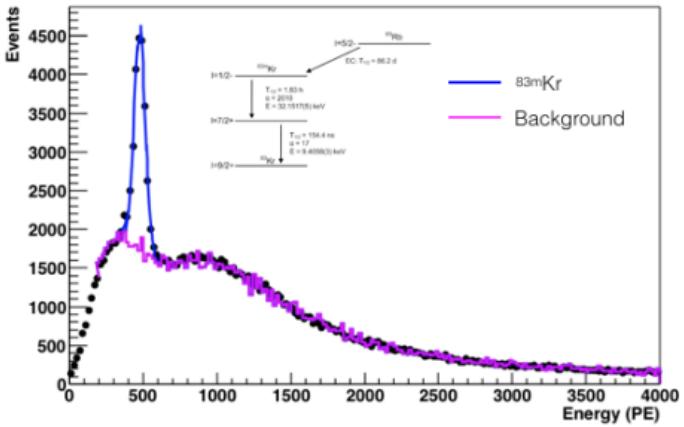
Miniaturized version of the DS-20k TPC (5W x 5L x 6H)cm designed in UCLA.

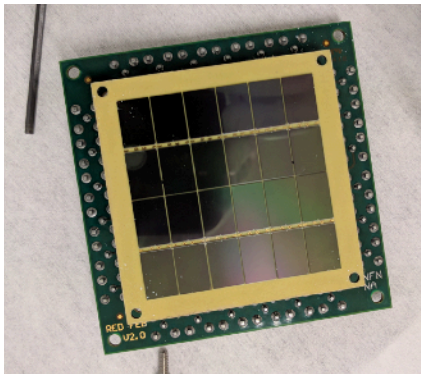
Main goal is to study the LAr TPC response to the neutron induced Ar recoils using the key features of the future detector.

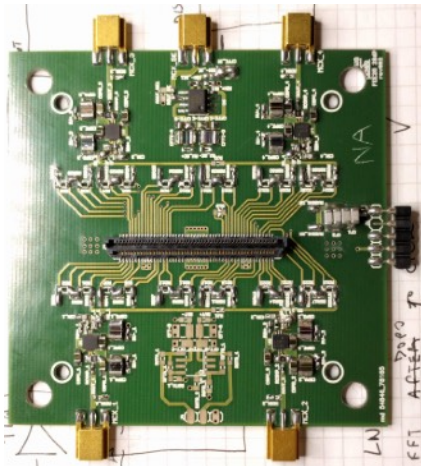
Two SiPM tiles coupled with dedicated FEBs (24ch on top + 4ch on bottom) design and fabricated in INFN-Naples, LNGS & INFN-Bologna.

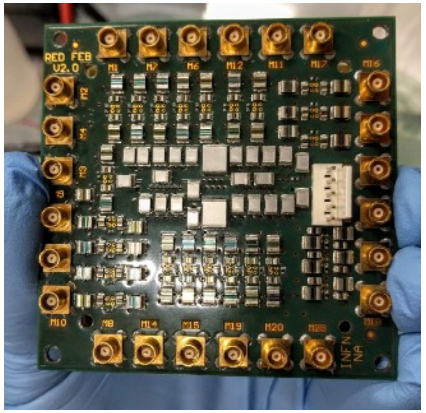
Acrylic inner chamber and reflective foil ESR. Acrylic windows for Anode and Cathode both coated with 15nm ITO and then with TPB.

Long characterisation campaign in Naples. Detailed study of the S1&S2. Multiple calibrations with radioactive sources, neutron DD gun & laser.



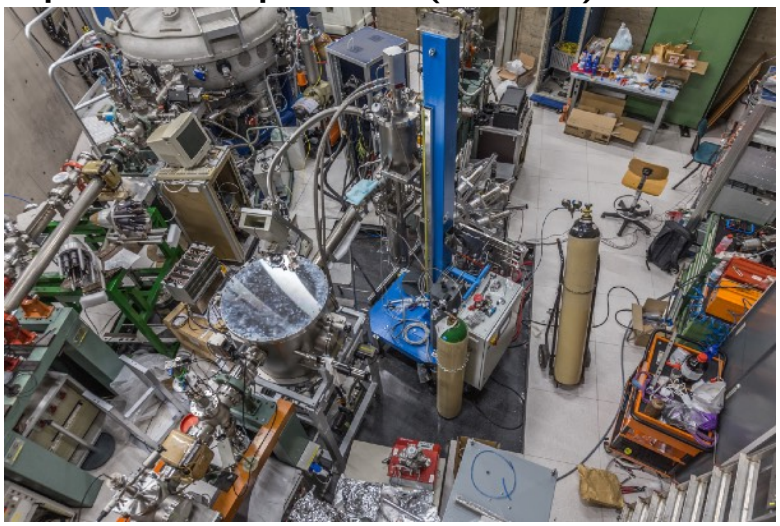


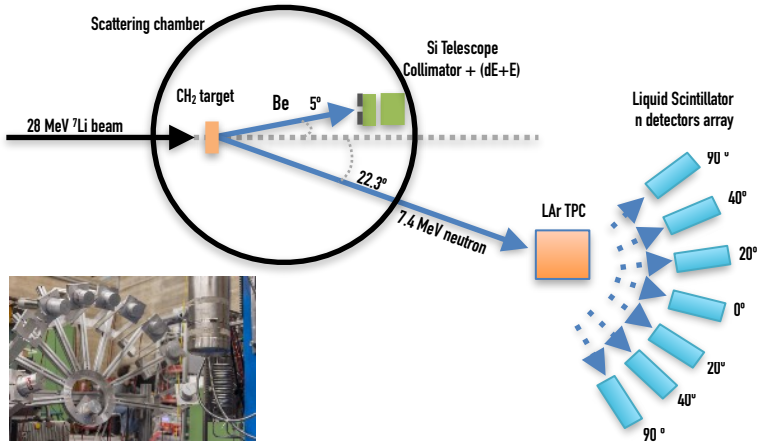




DS-20k. ReD

Experimental setup in Catania (INFN-LNS)





Two weeks beam run in Catania (INFN, LNS, Italy) ended on 14th of Feb.2020.

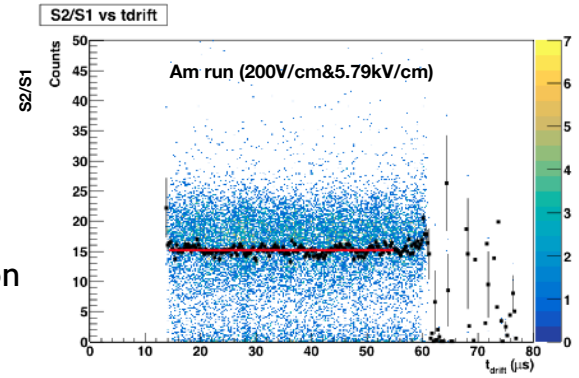
^{7}Li beam of 28 MeV. Neutrons of 7MeV from p(^{7}Li,^{7}Be)n reaction on polyethylene target (CH_2). 22.3° with respect to the beam. 70 KeV_{nr} of recoil energy.

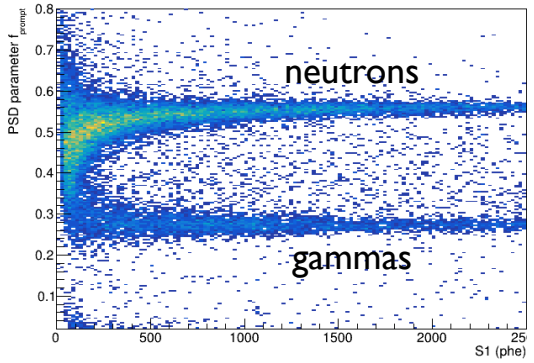
Looking for the triple coincidences: Si Telescopes+TPC+LScint. Rate ~ 150 ev/day.

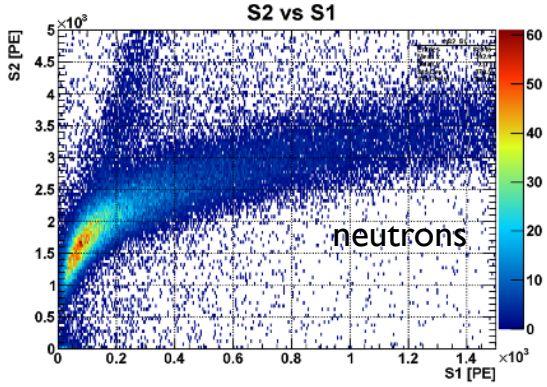
L.Y. of ~9 phe/keV_{ee} (at null field), S2/S1~23 , ~60us drift time, Working configuration:
A: +5.5kV,
C: -850kV,
1st ring: +100V,
G: @ GRD.

Electron lifetime is >1ms.

Clean sample due to the 7Be tagging and the PSD in TPC and in LScint.







Analysis are ongoing!!

Summary

- The DarkSide-50 LAr TPC filled with UAr is running in INFN-LNGS since Aprile 2015. This technology has proven to be competitive for a wide range of WIMP masses. Over 15 publications, more are coming;

- Global Argon Dark Matter Collaboration. Together towards the neutrino floor!

- Very rich R&D program: SiPM, Octagonal acrylic TPC, Modular acrylic Veto, Two loops cryogenic system and protoDUNE like external cryostat.

- Very promising achievement in Seruci-0. Seruci-1 column assembly in the well is undergo.

- URANI fully funded, design phase is almost complete.

- DarkSide-Proto-0 spring of 2020, DarkSide-Proto-1t from summer 2020, DarkSide-20k from 2024, ARGO from 2028-2029.

- ReD final run of the beam in Catania is just ended. Work is in progress, stay tuned!