XII International Conference on New Frontiers in Physics

10-23 July 2023, OAC, Kolymbari, Crete, Grece

The search for Dark Matter: the DarkSide-20k Experiment

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on behalf of the DarkSide Collaboration

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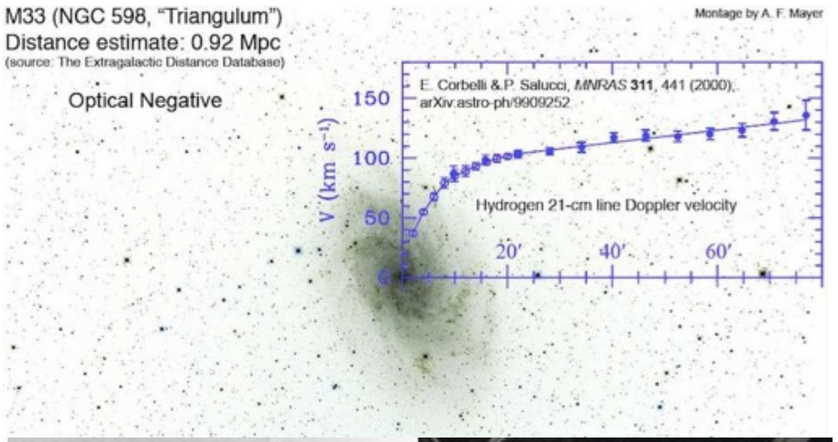
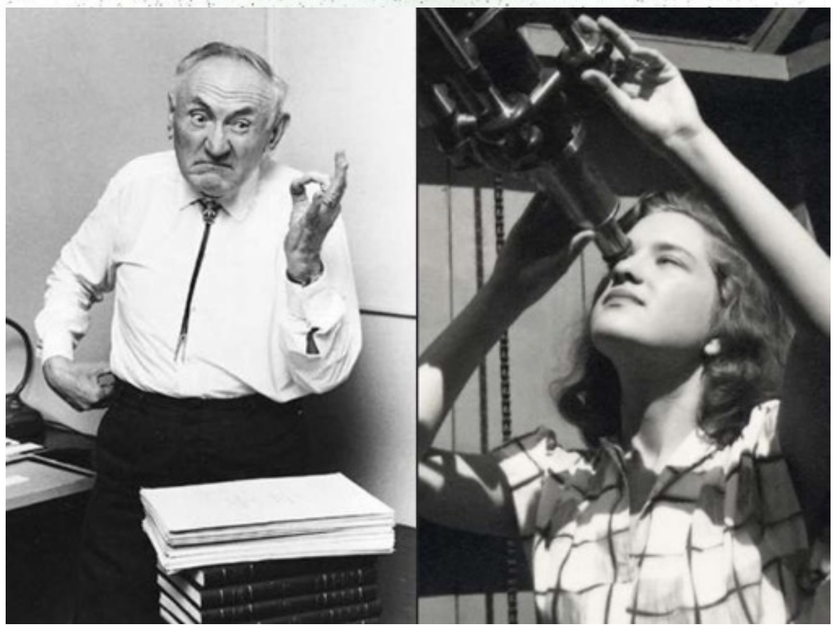
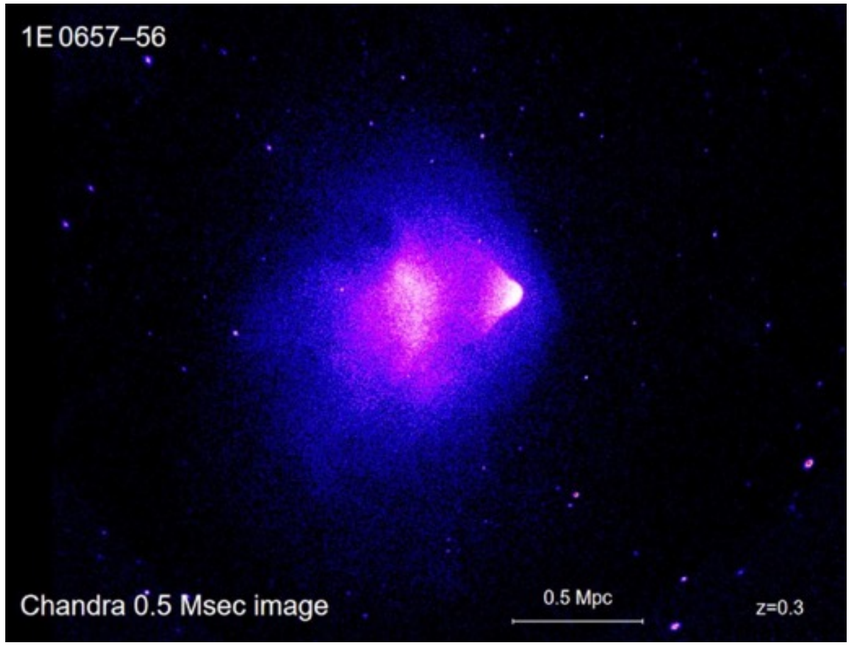
  - The future DarkSide-20k detector

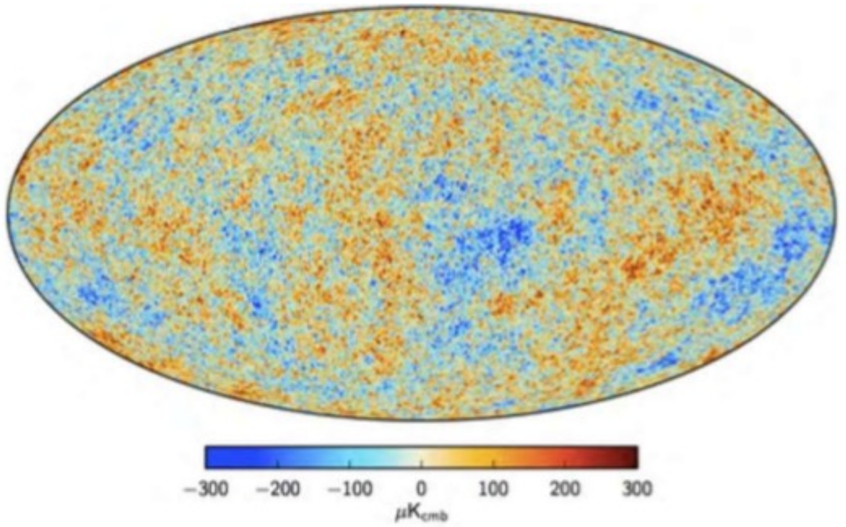
Experimental evidences of Dark Matter in the Universe





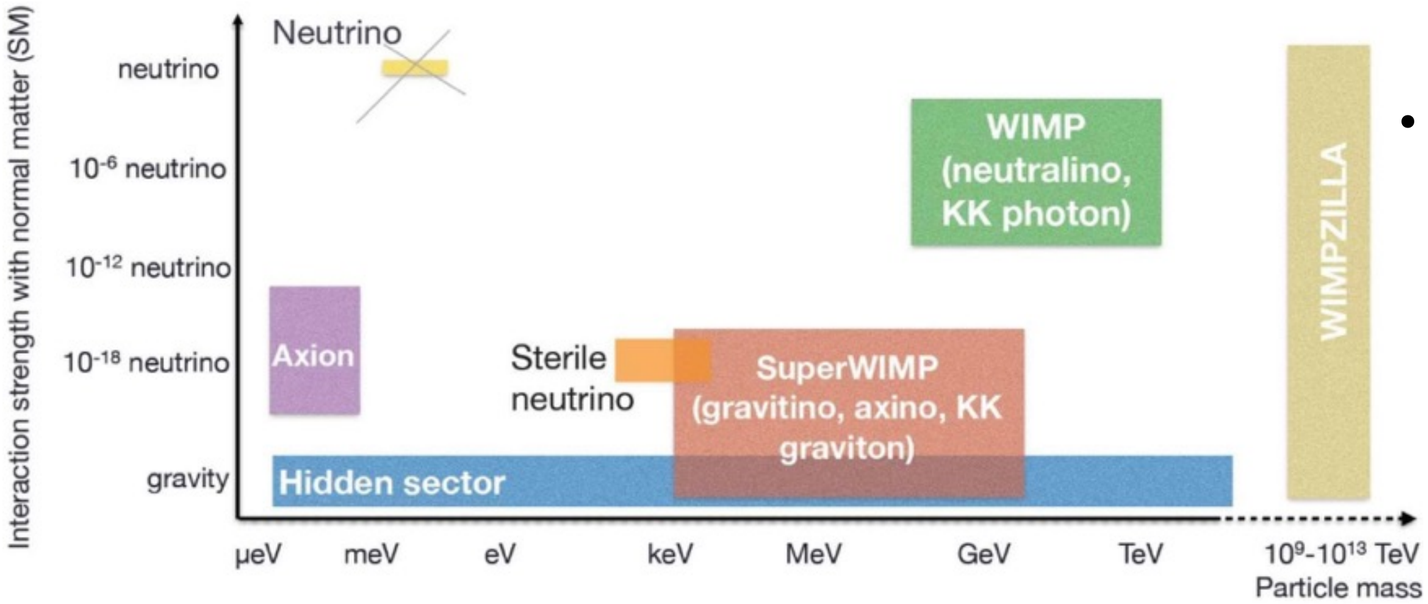
- **Galaxy clusters and gravitational lensing effect (Zwicky, 1933):**
  - Velocity dispersion measurements in Coma galaxy cluster
  - Measurements incompatible (1500-2000 km/s) with the average velocity (80 km/s) retrieved from the viral theorem;
- **Anomalies in the rotational curves of spiral galaxies (Rubin & Ford, 1970):**
  - Strong deviation of star velocity from the expected Keplerian law
  - The rotation curves are flat up to the outer region
  - Hypothesis: halo of non-luminous matter surrounding the galaxy with M(r) prop to r to explain velocity profile
- **Anisotropies in the Cosmic Microwave Background (CMB)**





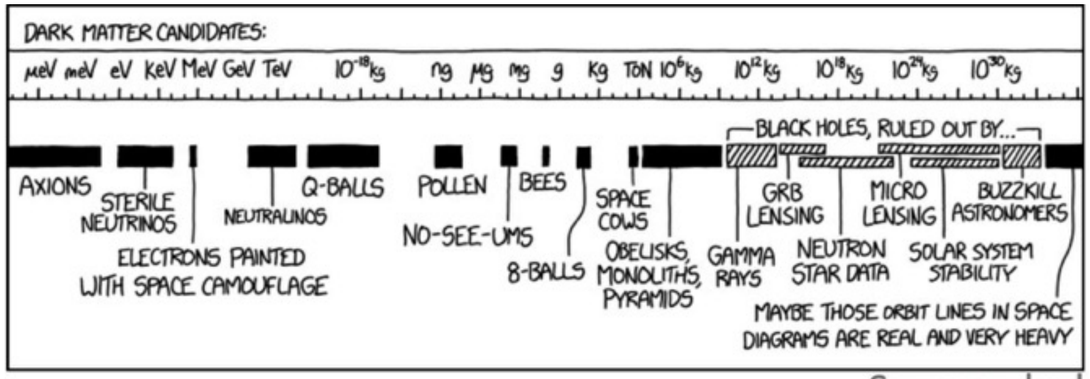
Dark Matter Candidates

The mass range of dark matter particle candidates spans over many orders of magnitude



- **Weakly Interacting Massive Particles (WIMPs) could form Cold Dark Matter:**
  - Predicted some theories beyond the standard model of particle physics
  - Correct relic density for an annihilation rate at ~ weak scale (***WIMP miracle***)

Dark matter could be non-weakly-interacting or a completely different type of particle

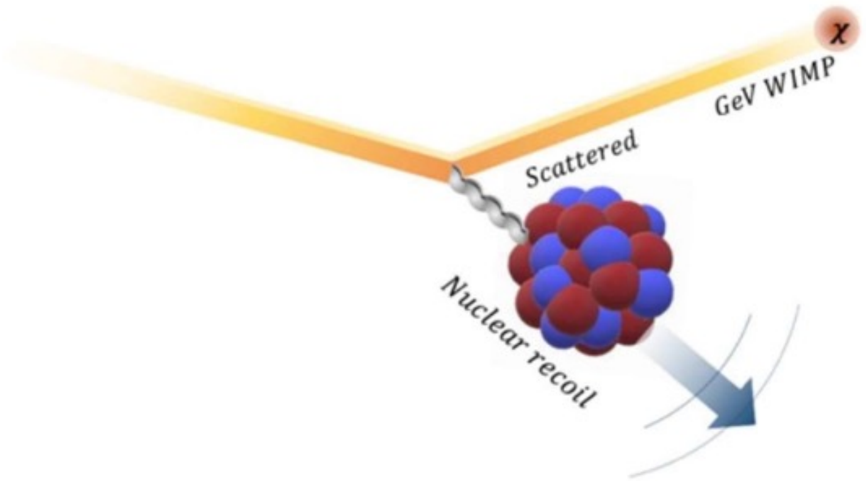


Source:xkcd

WIMPs

Too good to be true?

Expected rate in direct detection



Cross section

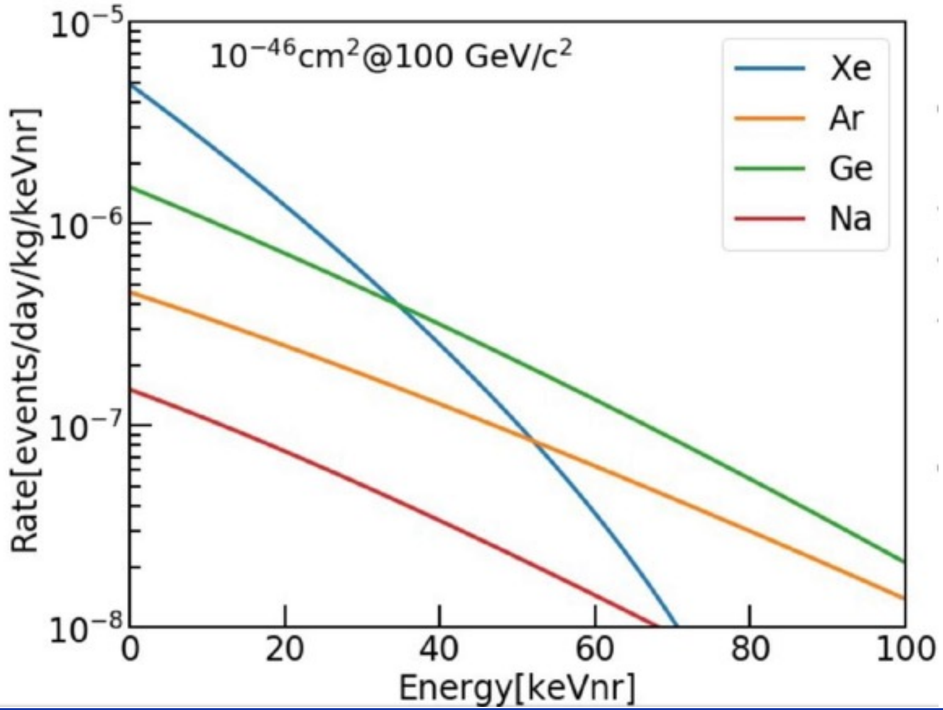
Nuclear Form Factor

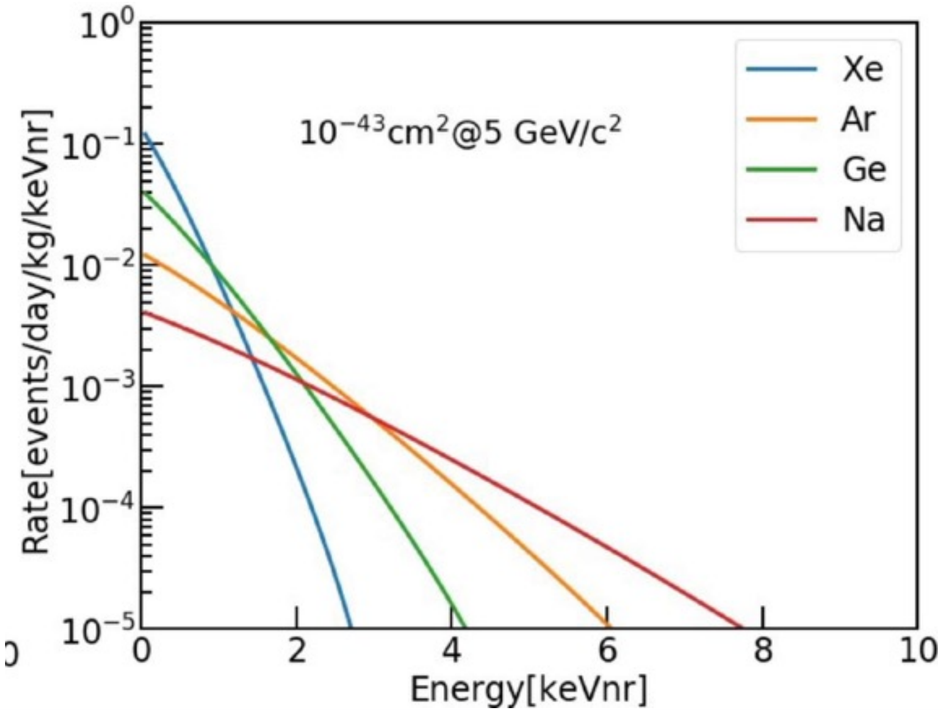
Astrophysics

$$\frac{dR^{NR}}{dE_R} = \sigma_n \frac{\rho_\chi}{M_\chi} \frac{m_A}{2\mu_{n\chi}^2} A^2 F_A(q)^2 \int_{v_{min}(E_R)}^{v_{esc}} d^3v \frac{f(v, v_E)}{v}$$

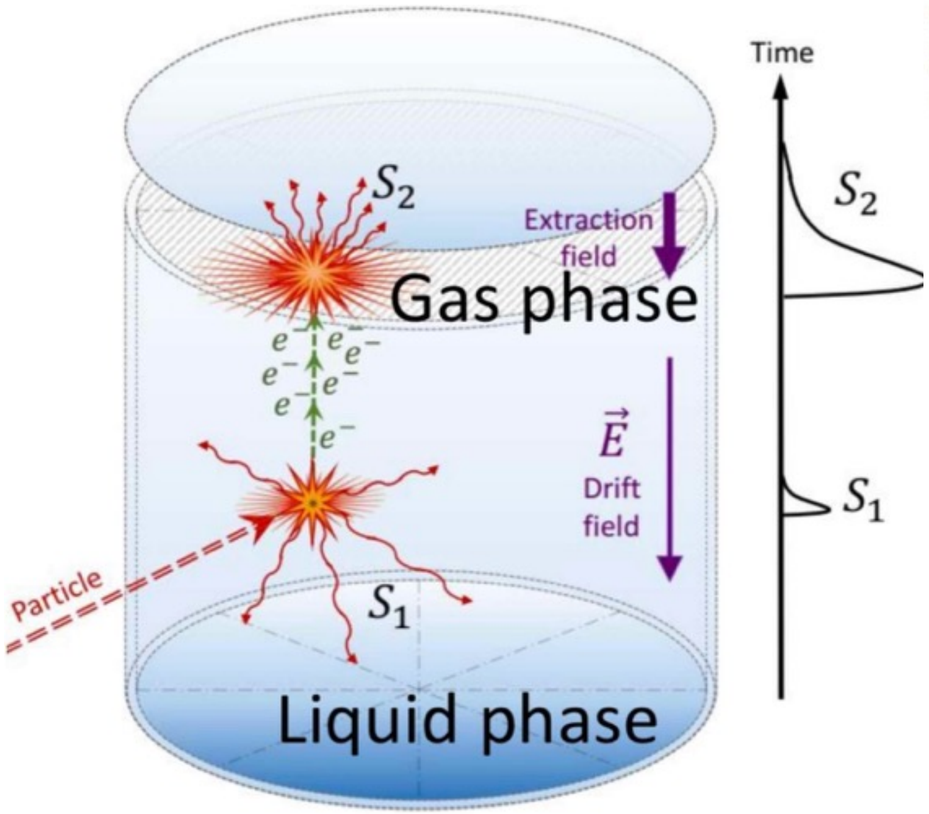
Dark Matter Properties

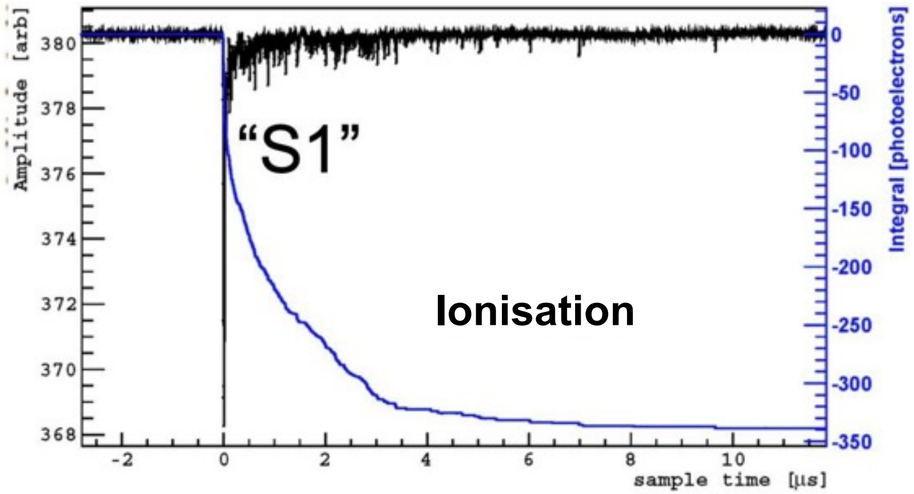
Target

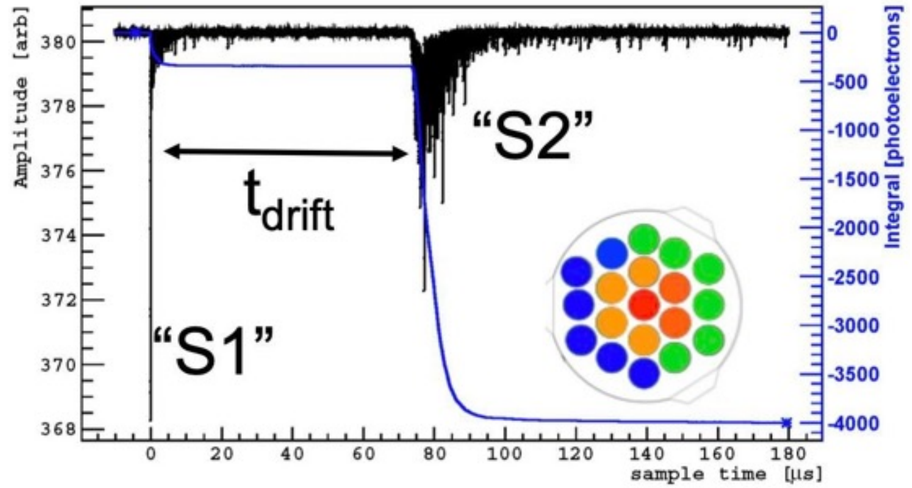




Dual-phase TPCs: working principle







3D vertex reconstruction (surface events, multi-sited events)

- A recoil excites and ionises liquid argon, producing prompt scintillation light (S1) that is detected by the optical sensors
- Thanks to electric fields, ionisation electrons drift to the gas region where they induce electroluminescence (S2)
- From the electron drift time (difference between the S2 and S1 signals) the vertical position of the event is reconstructed
- X-Y position of the event is on the contrary retrieved from the fraction of S2 light pattern in each optical sensor

Why Argon?

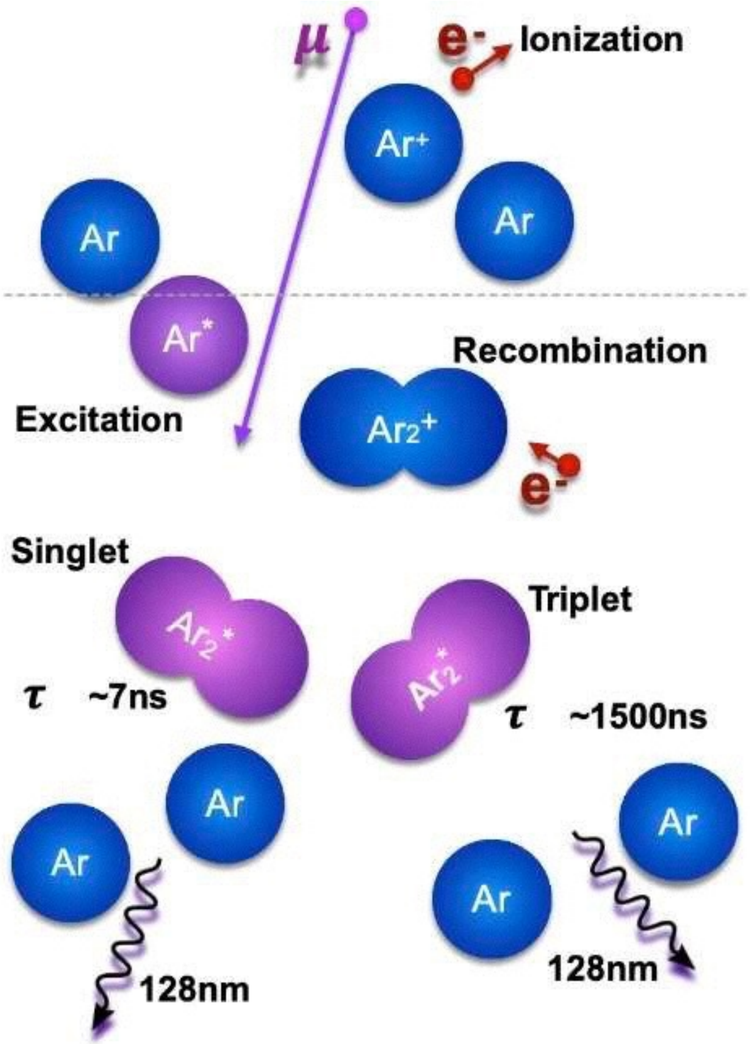
- **Good dark matter target material** because:
  - is relatively dense and easy to purify allowing to scale the experiment to large volumes
  - is a good scintillator (transparent to its own light)
  - has exceptional discrimination power against electron recoil (ER) backgound, provided by pulse shape discrimination (PSD)

but..

- atmospheric argon (AAr) contains ^{39}Ar, a cosmogenically activated isotope, whose β-decay in τ~269 yrs (Q~565 keV)

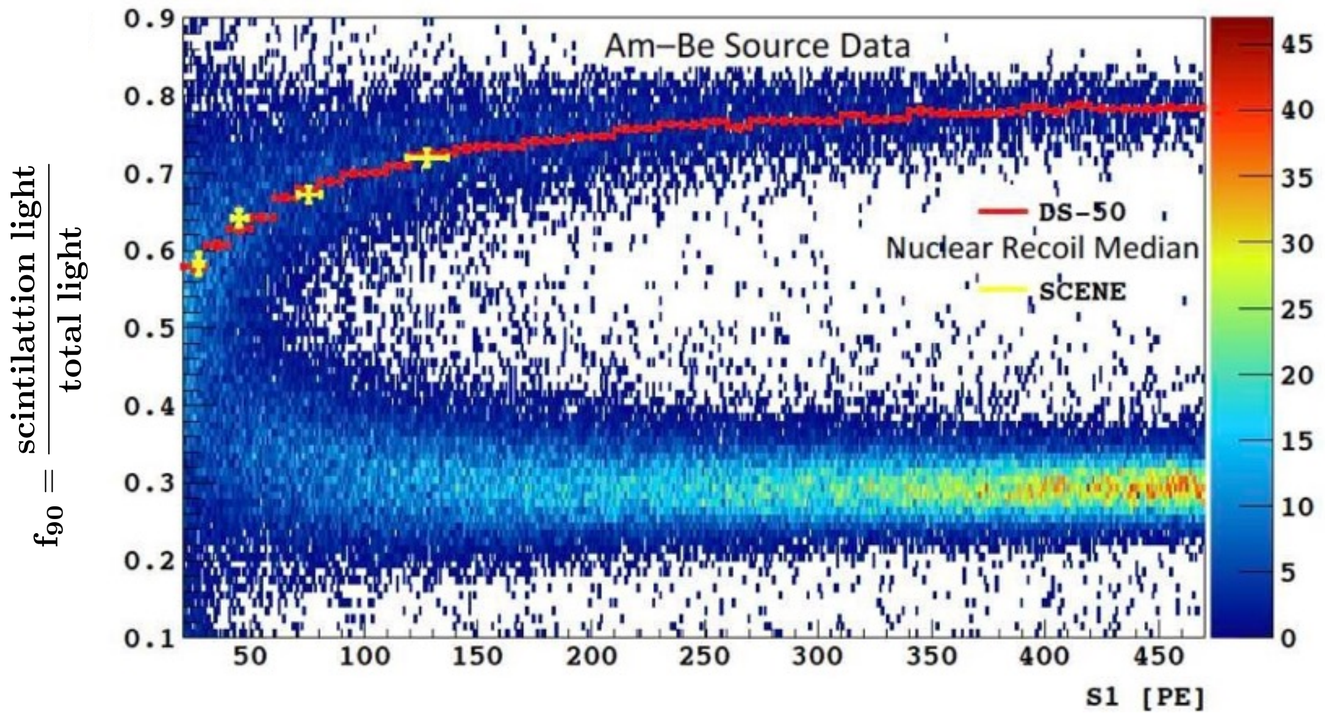
so..

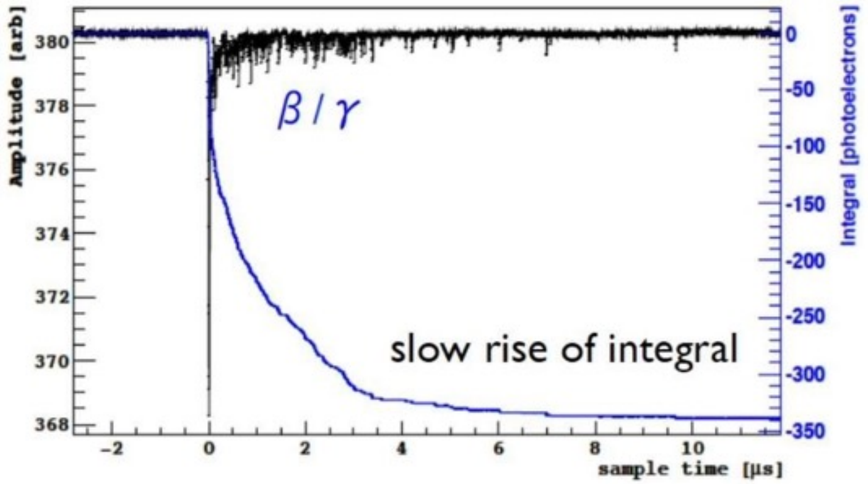
- use of Ar from underground reservoir (UAr), extracted from CO_2 wells, “ad hoc” distillated, and shipped to LNGS by sea

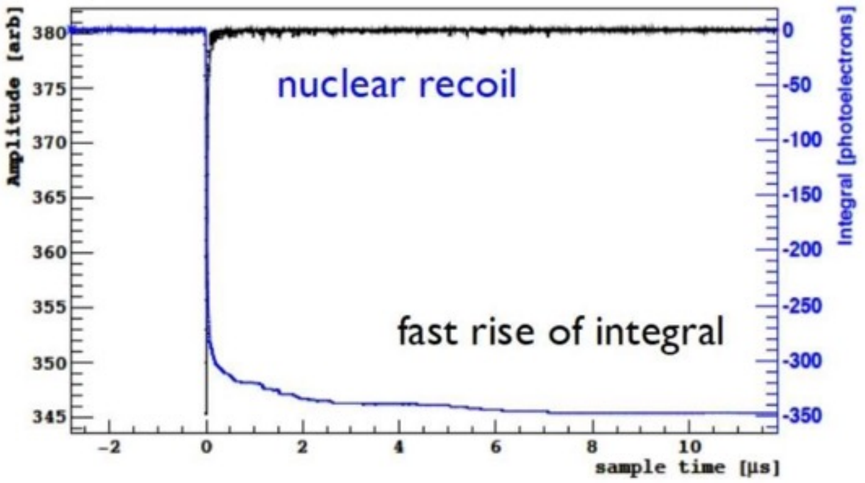


Pulse Shape Discrimination in Liquid Argon

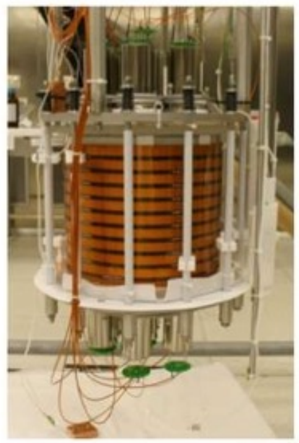
- Decay constant for triple state much longer than for singlet
- Nuclear Recoils (NRs) characterised by much larger dE/dx than Electron Recoils (ERs):
  - Scintillation light from triplets is highly suppressed in case of NRs wrt REs
- **Using scintillation light time profile in order to distinguish between:**
  - NRs (neutrons, WIMPs)
  - ERs (β/γ background)





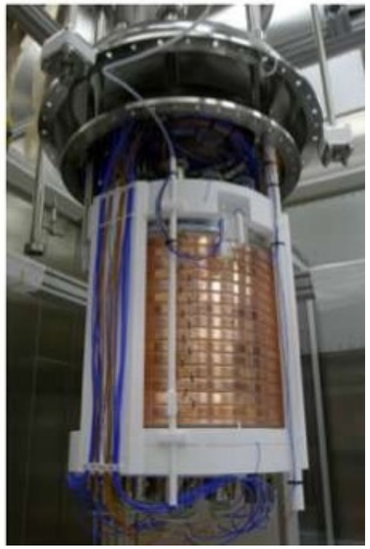


The DarkSide long-term programme



DarkSide-10

2011

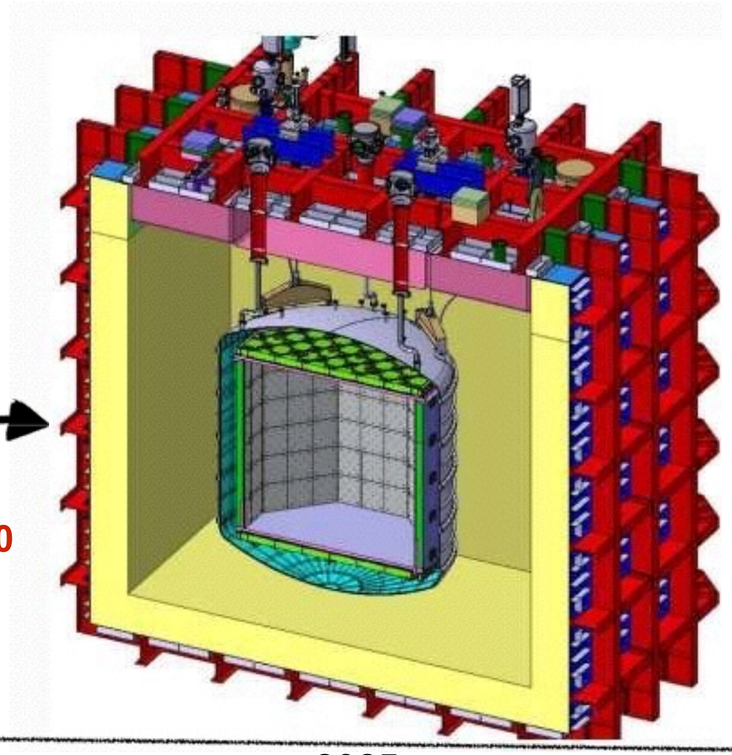


DarkSide-50

2013-2018 at LNGS

0.03 t.yr exposure

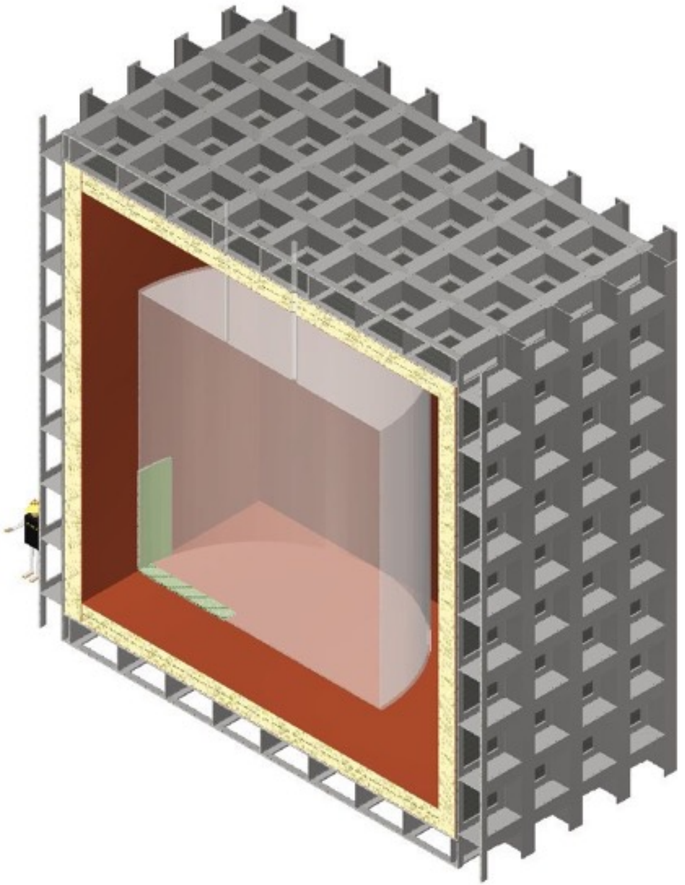
x 1000



DarkSide-20k

2025+

200 t.yr target exposure



ARGO

2030+

3000 t.yr target exposure

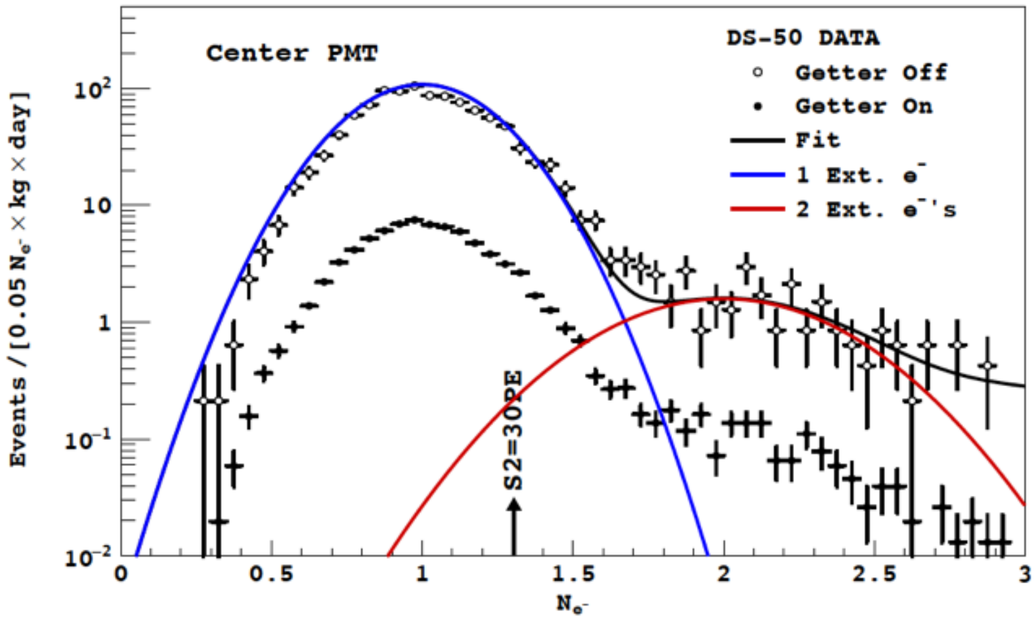
DarkSide-50: Low-mass new results

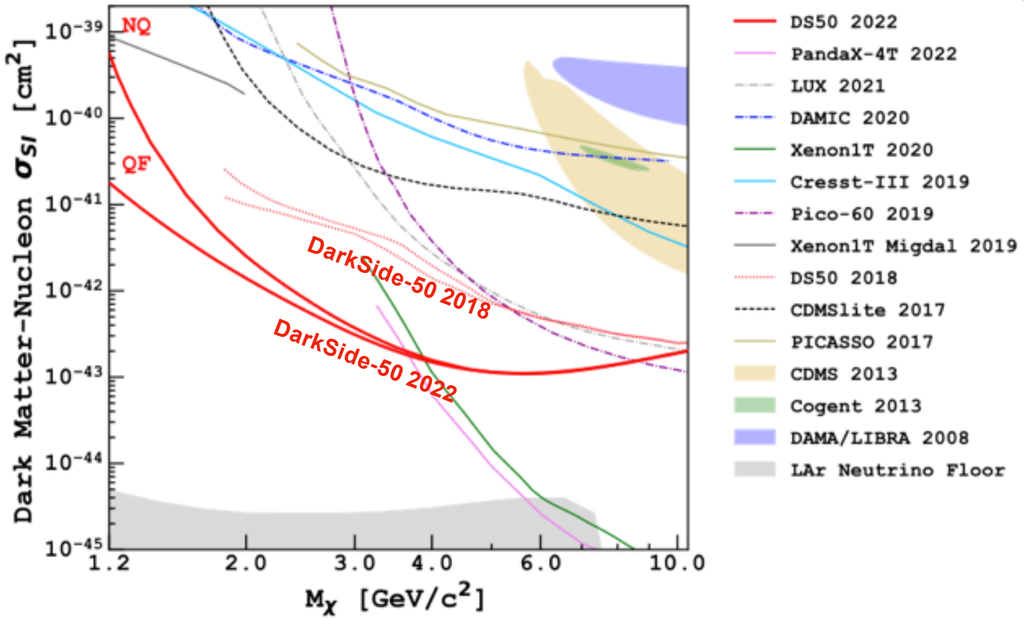
Look at the ionization only spectrum
(W_{ion} = 23.5 eV, gain in the gas: 23 PE/e^-)
Below 3 keV_{ee}: give up the scintillation signal
(too small to trigger the detector), and thus

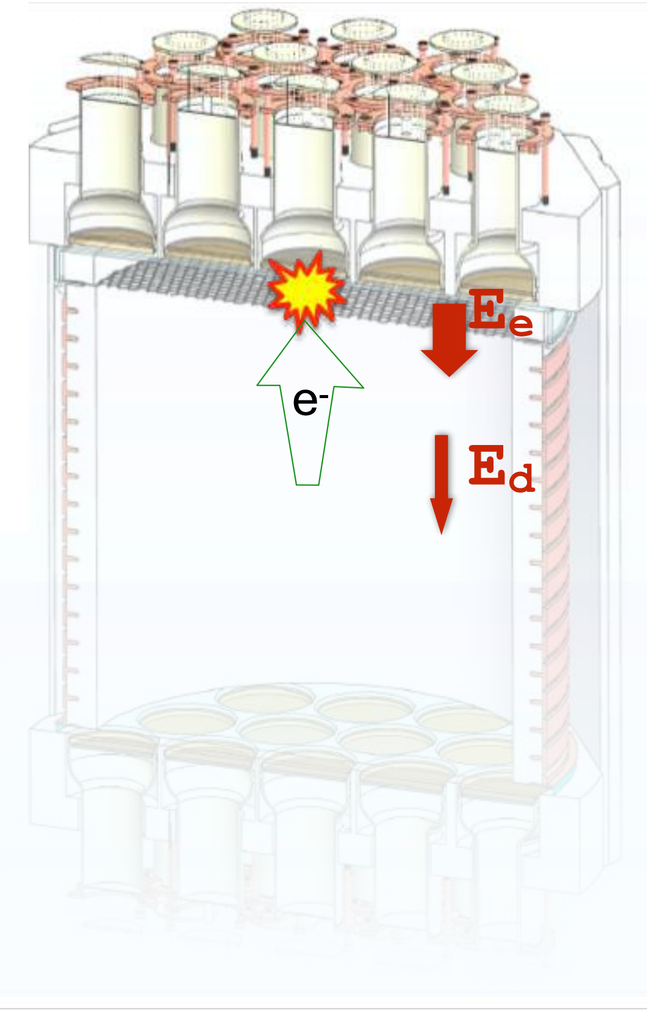
- minimal fiducialization (only radial)
- no PSD

No more background free

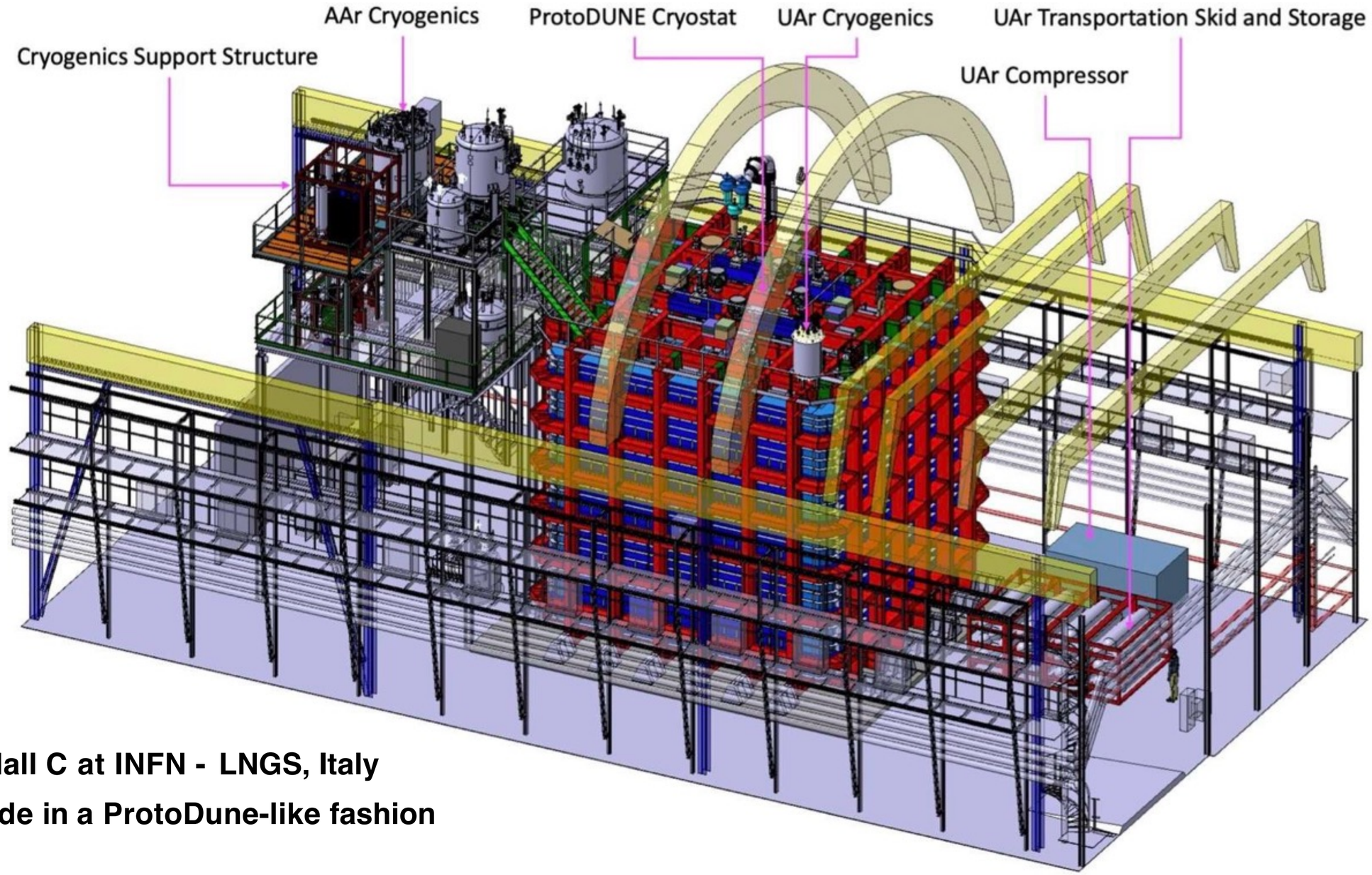
- *Background model* for DarkSide-50
  - First analysis in 2018, recently updated !
    - WIMP-N 10.1103/PhysRevD.107.063001
    - Migdal effect 10.1103/PhysRevLett.130.101001
    - WIMP-electron 10.1103/PhysRevLett.130.101002







DarkSide-20k

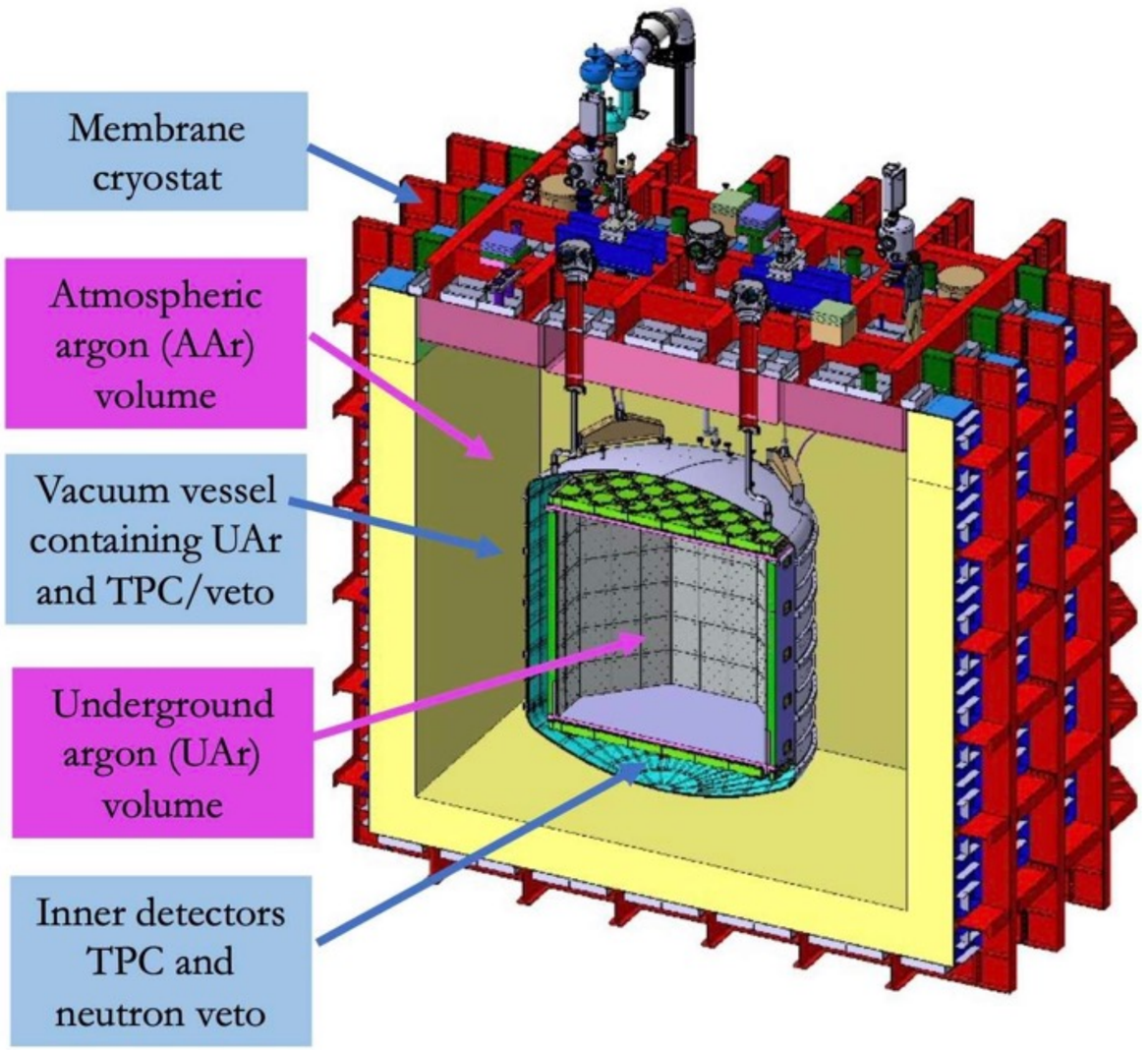


Installation started in Hall C at INFN - LNGS, Italy

Membrane cryostat made in a ProtoDune-like fashion

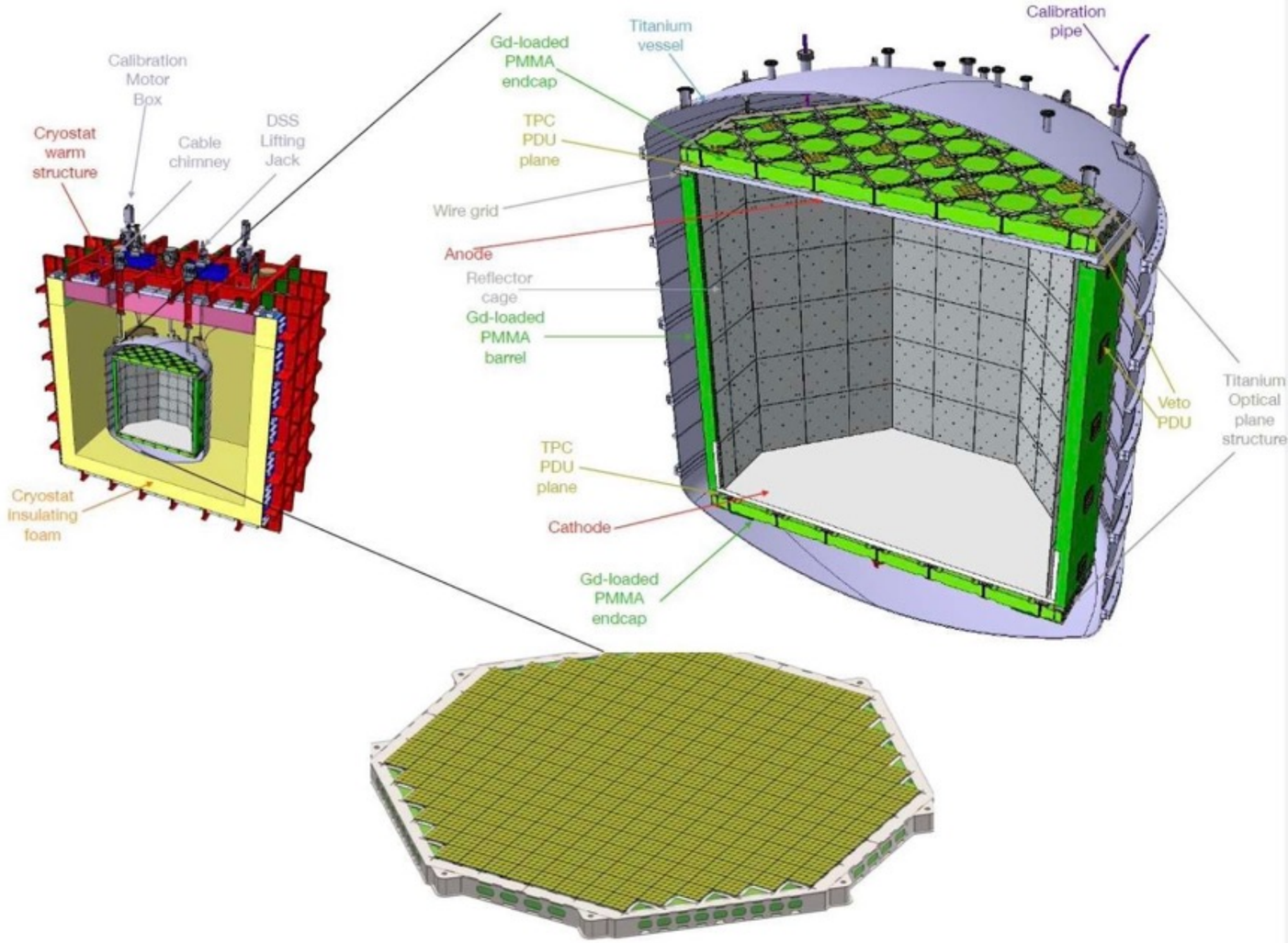
DarkSide-20k: overview

- **Nested structure of the detector:**
  - ProtoDune-like cryostat instrumented like a muon veto (8x8x8 m^3)
  - Titanium vessel separating Atmospheric Argon (AAr) from Underground Argon (UAr)
  - WIMP detector fiducial volume of ~ 20 tonnes (~ 50 tonnes total) of UAr, depleted in ^{39}Ar
  - Active neutron veto integrated into the TPC structure via gadolinium-loaded acrylic (PMMA)
  - **Silicon PhotoMultipliers (SiPMs) as photo detection devices (total area ~ 26 m^2)**
  - UAr and AAr will use separate cryogenic systems

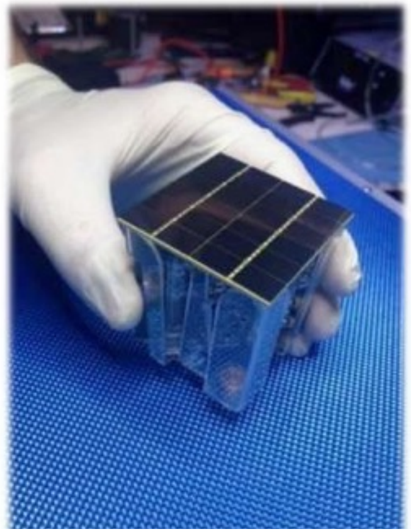


DarkSide-20k: inner detector

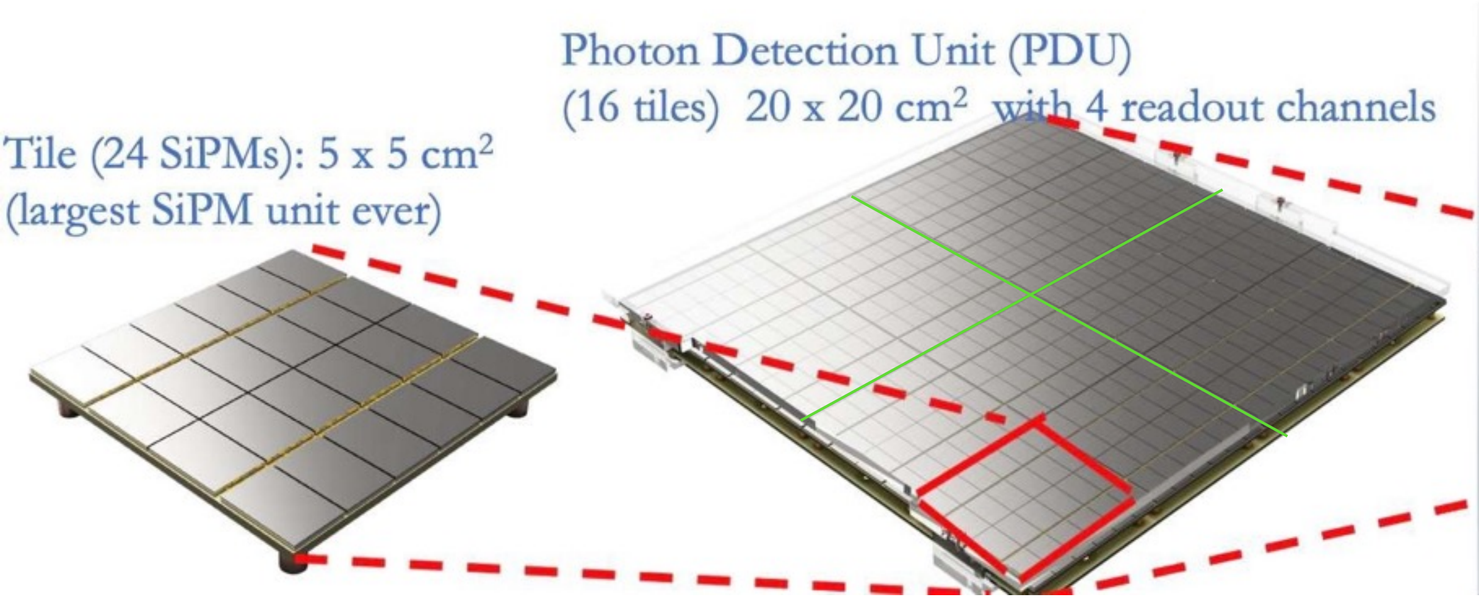
- **Integration of TPC and VETO into a single object**
- TPC Vessel:
  - Top and bottom windows made of pure transparent acrylic
  - Lateral walls made by PMMA + reflector + WLS
  - Anode, cathode and field cage coated with Clevios conductive paint
  - TPC readout by a total of *21 m^2 cryogenic SiPMs*
- **VETO:**
  - TPC surrounded by a single phase detector in UAr
  - TPC lateral walls + additional top/bottom planes in PMMA
  - VETO readout by a total of *5 m^2 cryogenic SiPMs*

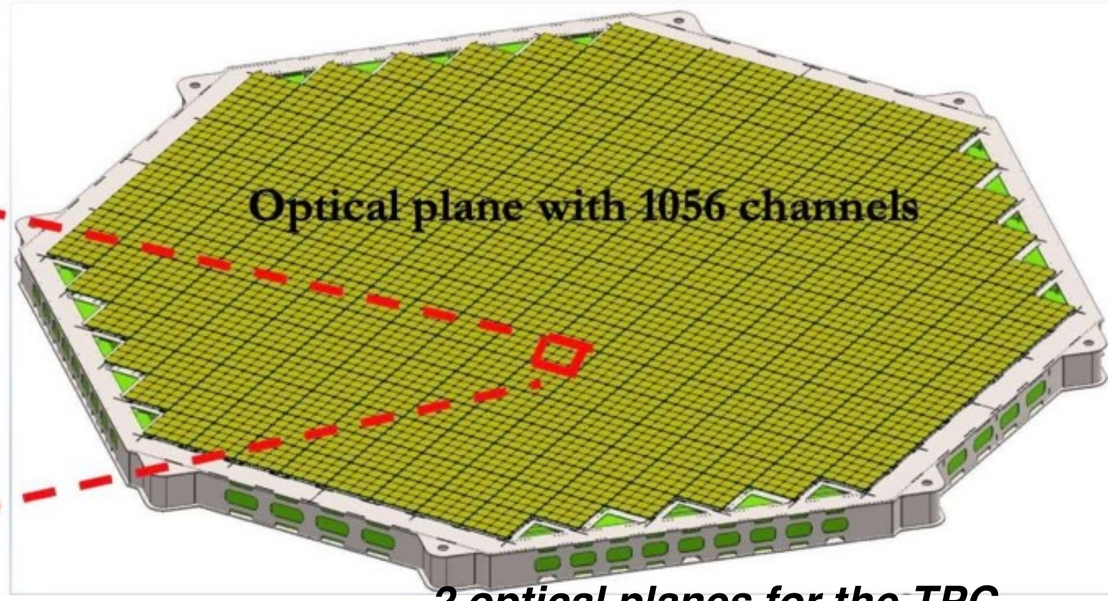


From PMTs to SiPM arrays



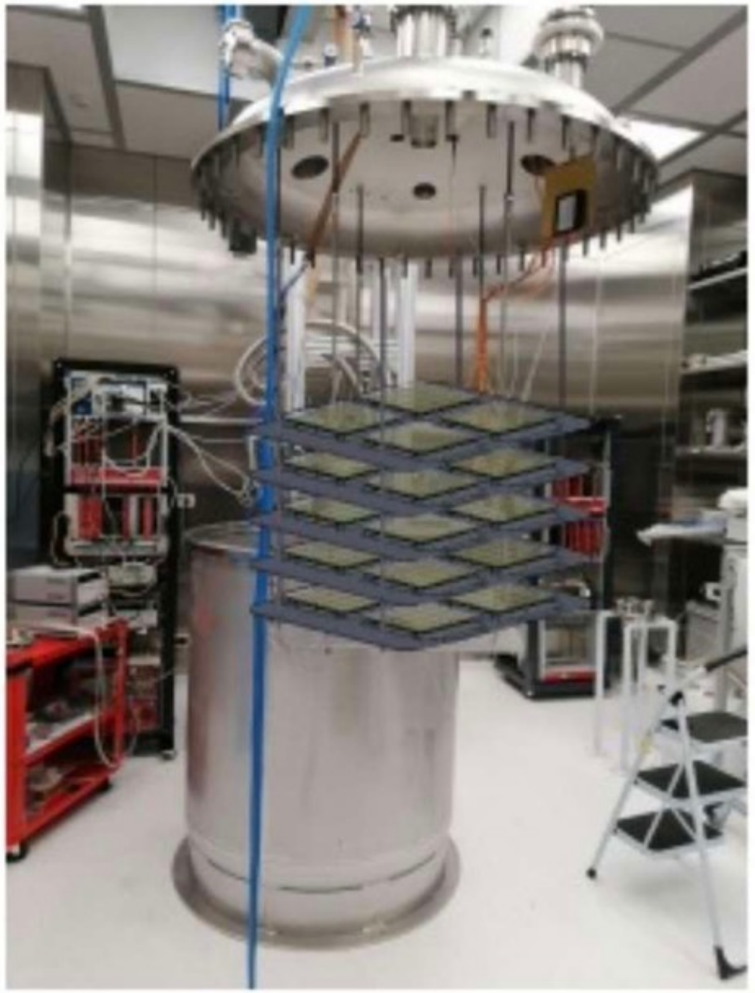
- **PROS**
  - Cryogenic temp stability
  - Better single photon resolution
  - Higher photo-detection efficiency
  - Low voltage operation
  - Lower background (Si intrinsically radiopure)
  - Lower cost
- **CONS**
  - Small area ≈ cm² (group them)
  - High dark rate (solved, operated at 87K)
  - High output capacitance for large devices (~0.5 μs recharge time)





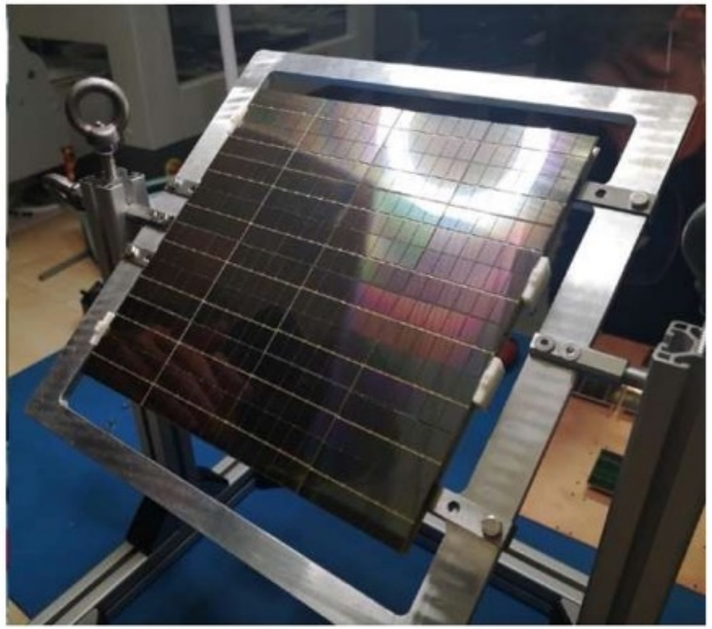
2 optical planes for the TPC
+ 480 channels to instrument the UAr veto

Photo Detection Units (PDUs) mass production and testing

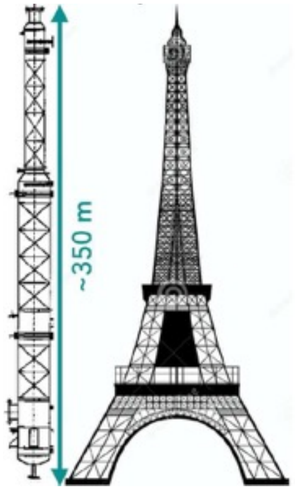


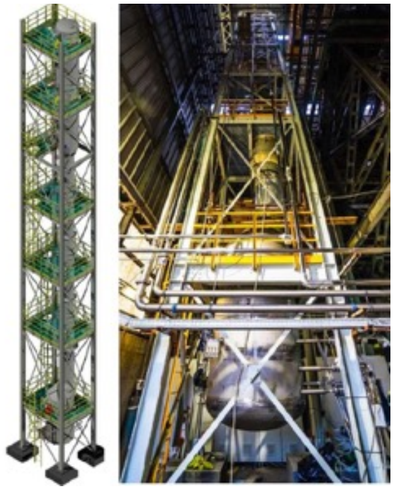
- **SiPMs production at LFoundry, Italy.** Wafer delivery started in 2022
- **Packaging and assembly for TPC** sensors: Nuova Officina Assergi (**NOA**), about to start operations
- **Packaging and assembly for Veto sensors: RAL and Liverpool, UK**
- **Several test facilities to qualify production: Naples, Liverpool, Edinburgh, AstroCent…**

See talk by Dr. Yury Suvorov later today

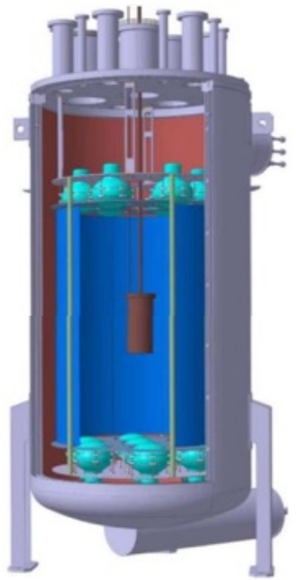


The UAr target: URANIA & ARIA

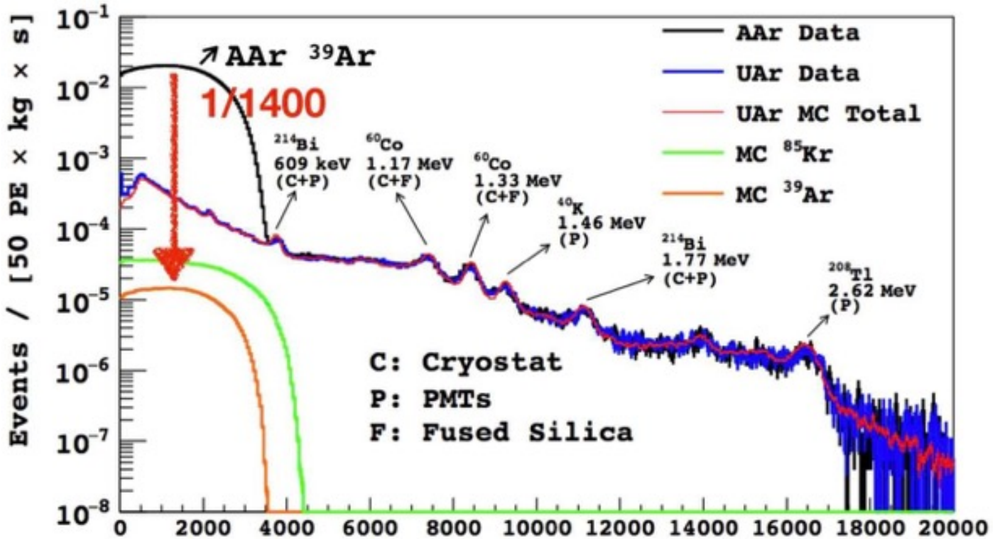




(*Eur. Phys. J. C (2021) 81:359*)



- **Urania:** Industrial CO_2 extraction plant in Cortez, Colorado, USA
- **Aria:** UAr shipped to Sardinia, Italy, for chemical purification via a 350 m tall cryogenic distillation column in the former Seruci Mine:
  - Process ~1 tonnes/day with ~1000 reduction factor of all chemical impurities and isotopically separate ^{39}Ar from ^{40}Ar
  - First module operated according to specs with nitrogen
  - Full assembly about to start
- **Qualification at Canfranc, Spain, DArT in ArDM:**
  - A single-phase LAr detector with active volume ~1L, capable of measuring UAr to AAr ^{39}Ar depletion factors of the order of 1000



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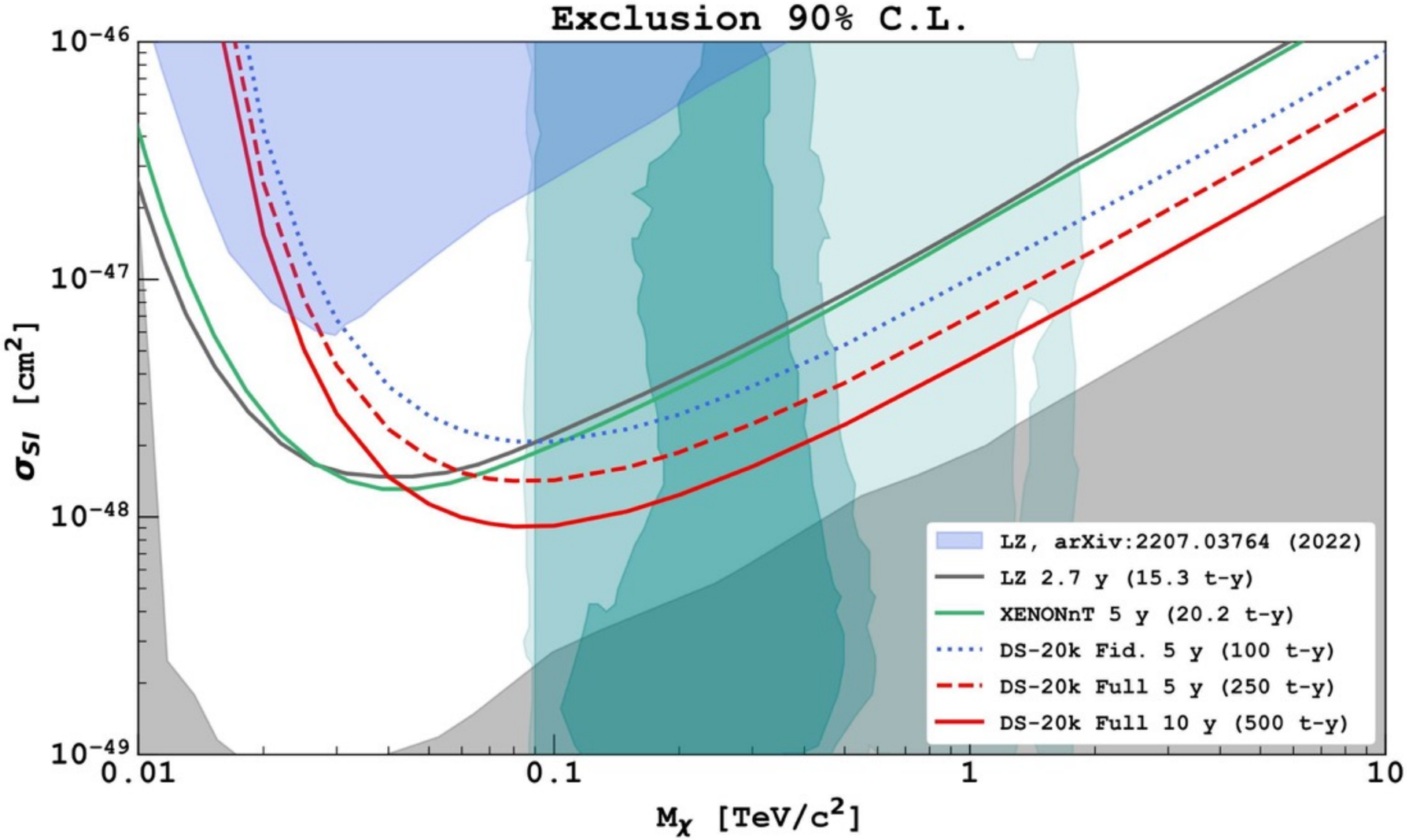
DarkSide-20k: Projected sensitivity

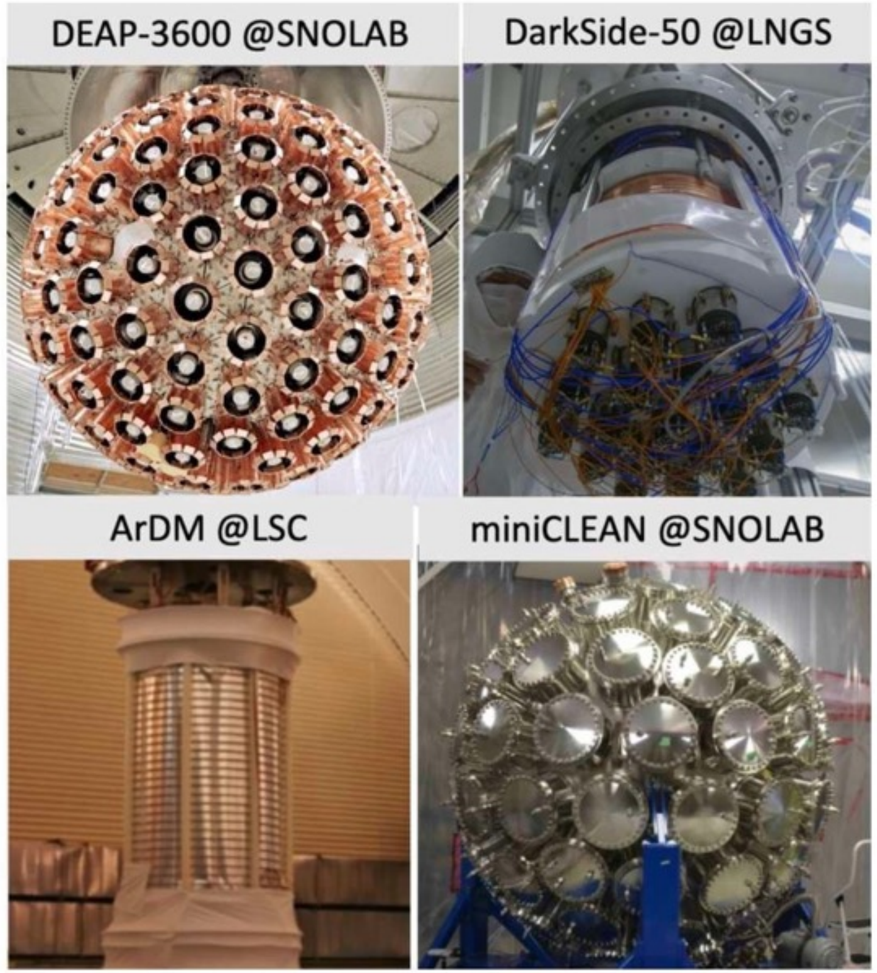


Projected sensitivity based on nearly instrumental background-free exposure (**<0.1 events in 200 t.yr**) using the fiducial volume (innermost 20 tonnes of UAr) AND using **the full active volume** (PLR approach, background pdfs known)

Main backgrounds (in 200 t.yr)**: CEvNS (3.2 ν_e),** radiogenic and cosmogenic neutrons, ER + Cherenkov, S1 + S2 accidental coincidence…

Global Argon Dark Matter Collaboration (GADMC)

All LAr-based experiments joined together in 2017 to pursue multi-ton-scale DM detectors



> 500 Collaborators, > 100 institutes distributed across 14 countries

ENJOY THE DARK SIDE!