DarkSide-20k and the Future Liquid Argon Dark Matter Program

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on behalf of the DarkSide-20k Collaboration

EPS-HEP 2021 - online conference - 27th July 2021

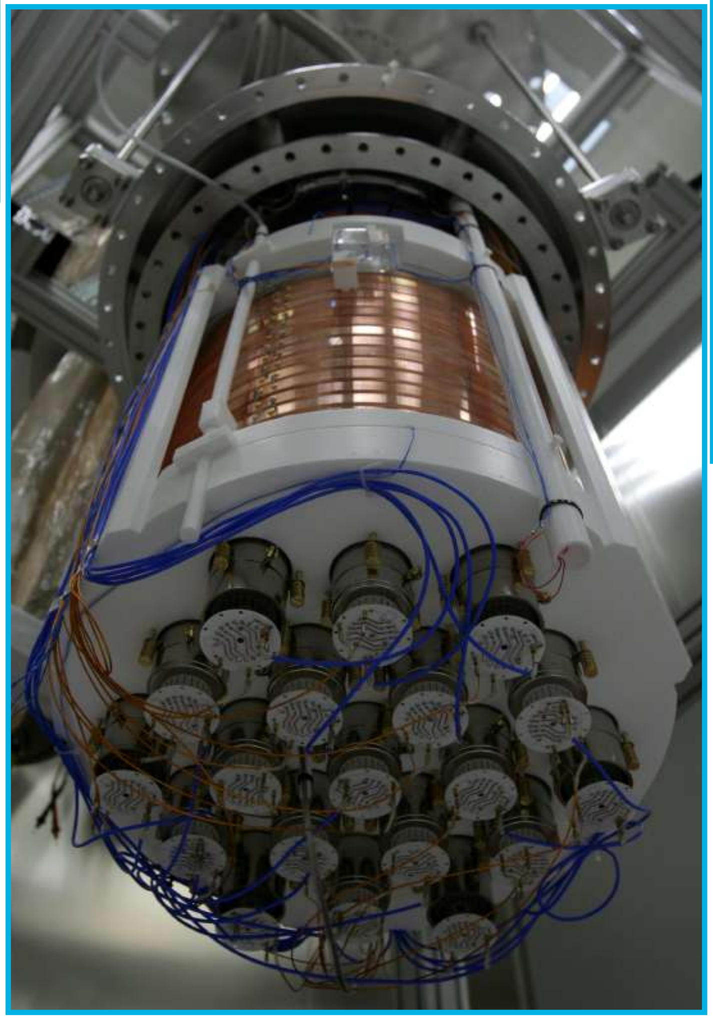
The DarkSide project

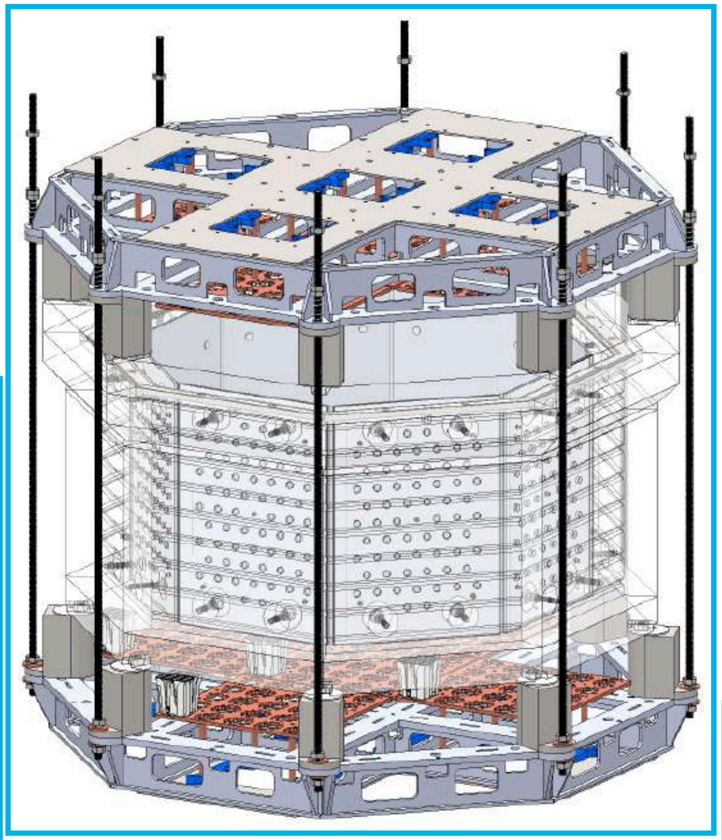
DarkSide-10

2011-2013

DarkSide-50

2015-2020



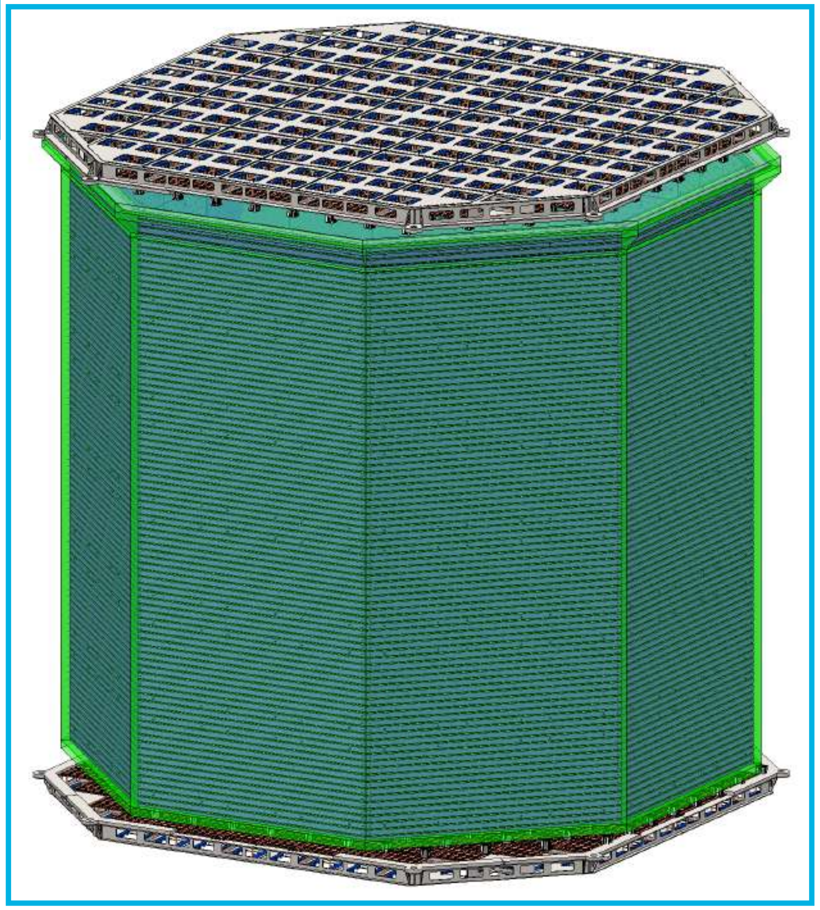


Proto-1t

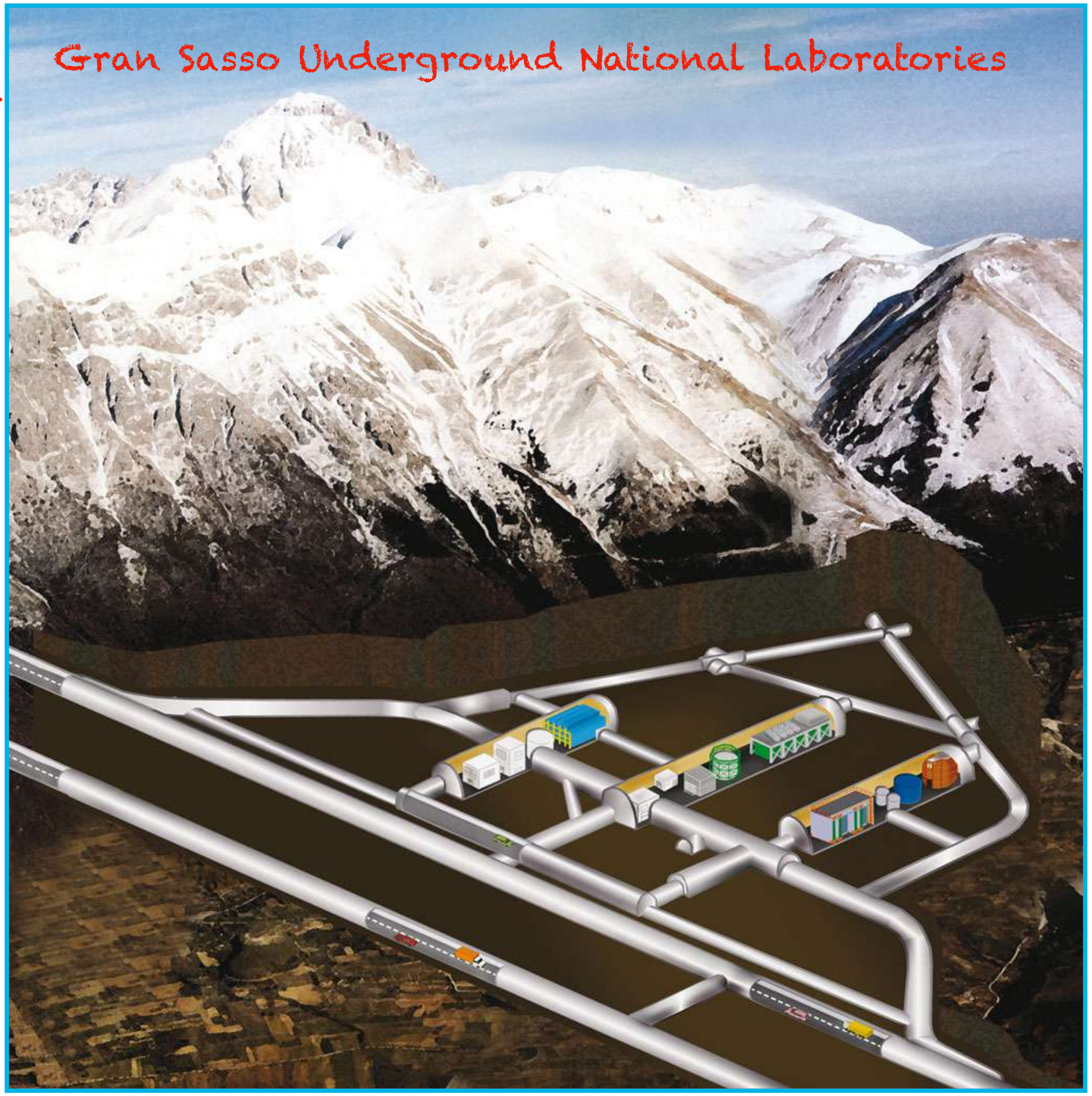
2021-2022

DarkSide-20k

2024-20XX



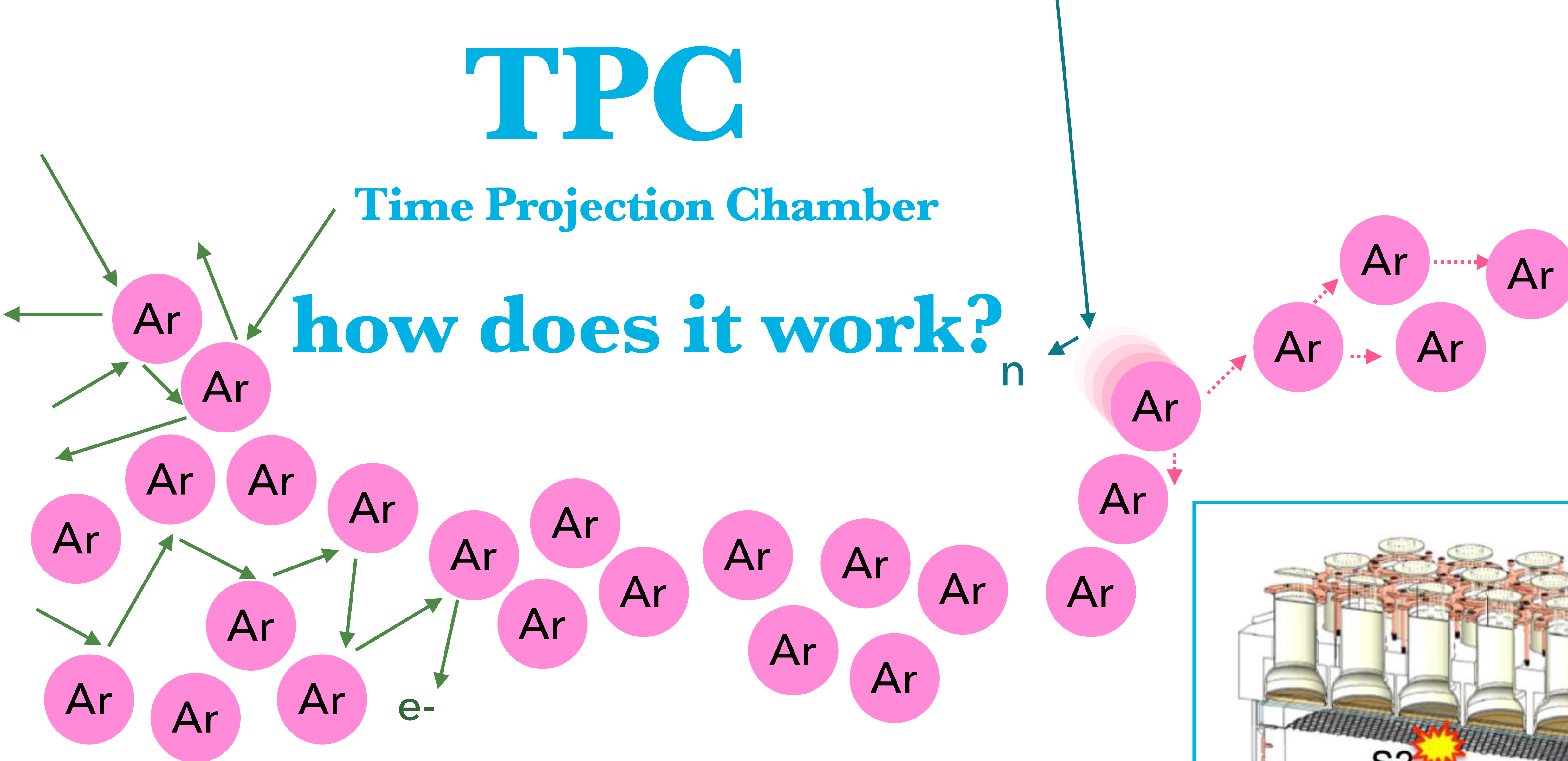
The DarkSide project

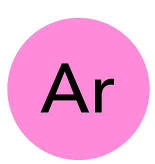


TPC

Time Projection Chamber

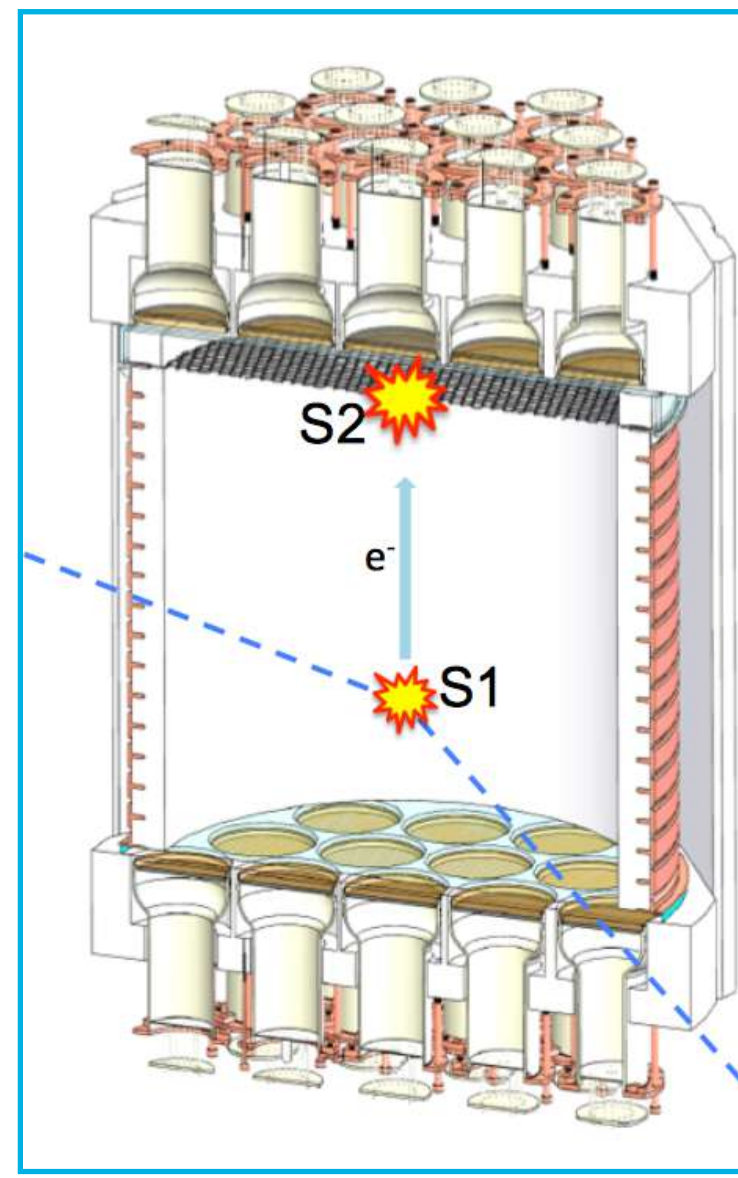
how does it work?





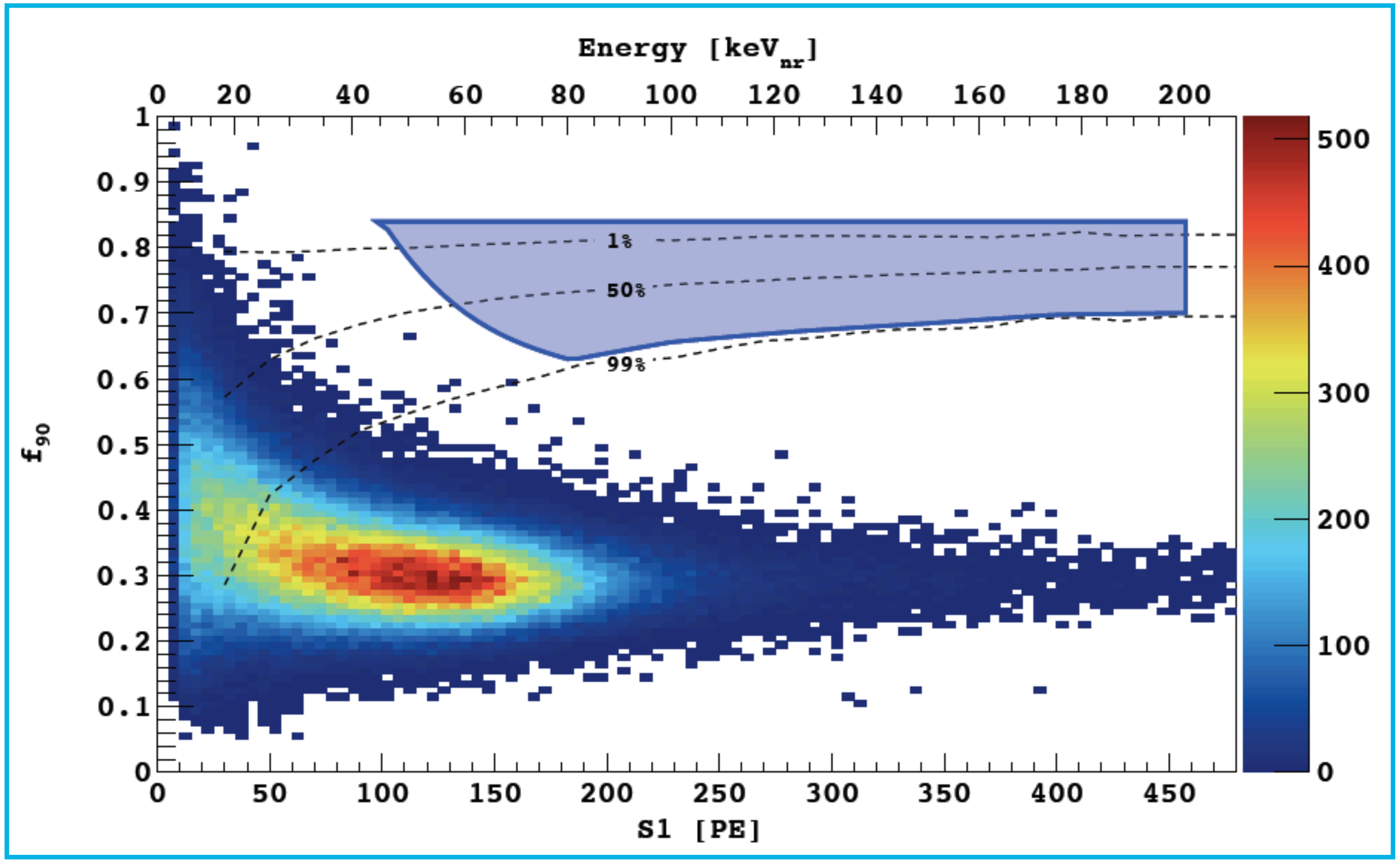
Detection of two signals:

- **S1**: produced in the liquid by the scintillation light due to both the excited Ar atoms, and the recombined fraction of ionized atoms.
- **S2**: produced in the gas layer by the free electrons escaped from recombination and drifted up to the liquid surface.



Why argon?

1. Dense and cheap
2. Cold and easy to purify
3. Good ionization yield and electron mobility
4. High scintillation yield (~40,000 PE/MeV) and transparent to its own light
5. Exceptional discrimination power:
   - light (S1)/charge (S2)
   - **PSD**: Pulse Shape Discrimination



PSD is one of the key features that allowed DarkSide-50 to reach < 0.1 background events in the region of interest

Physical Review D 98 (10), 102006 (2018)

Pulse shape discrimination

Two scintillation time constants in liquid argon:

- Singlet ~ 6 ns
- Triplet ~ 1.6 μs

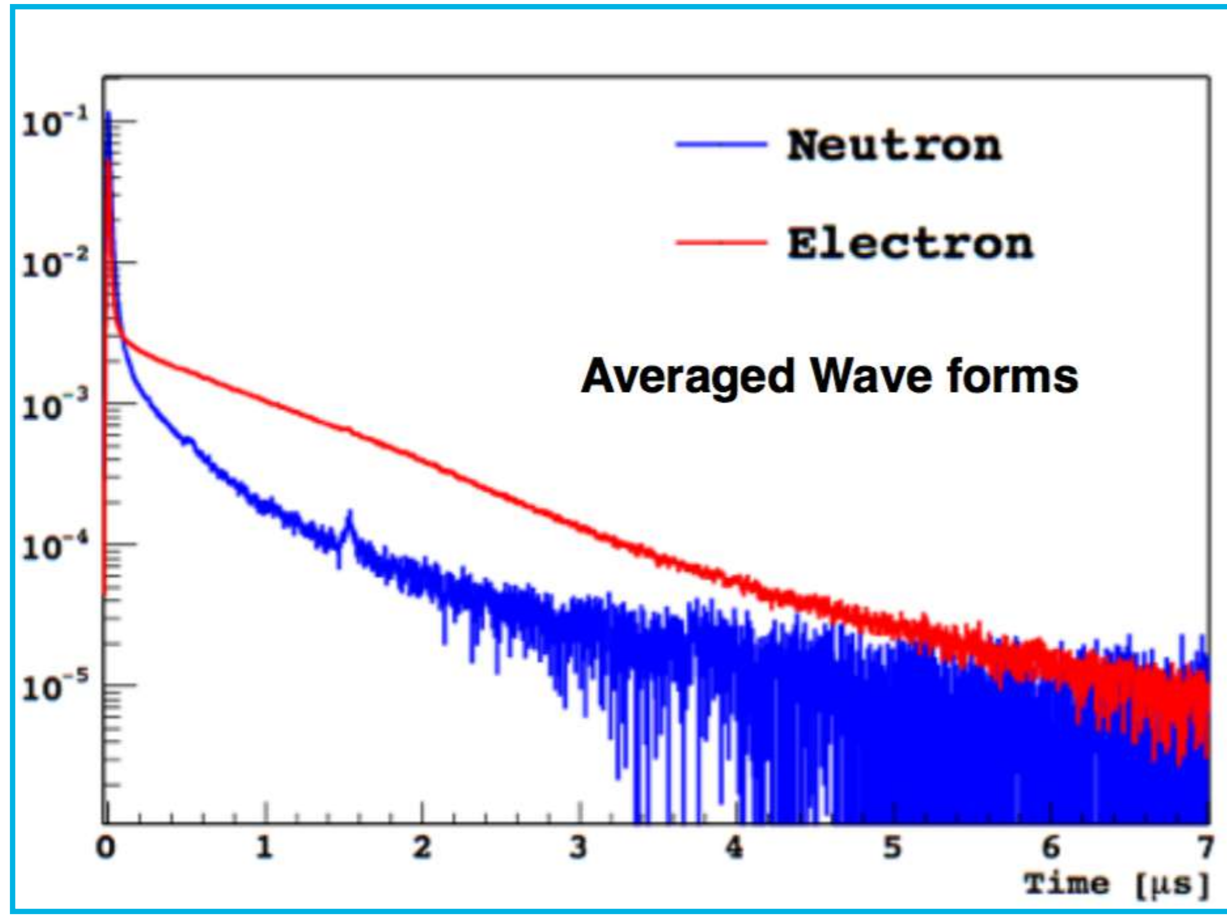
Nuclear and electron recoils have different ratios of singlet and triplet states.

↓

The signals generated by electron recoil and nuclear recoil have a different shape in time.

↓

This opens the possibility to distinguish between nuclear and electron recoil.



Discrimination parameter

$$f_{prompt} = \frac{\text{Light in the first tens of ns}}{\text{Total light}}$$

In DarkSide-50 we use f_{90}

Underground argon

PROBLEM

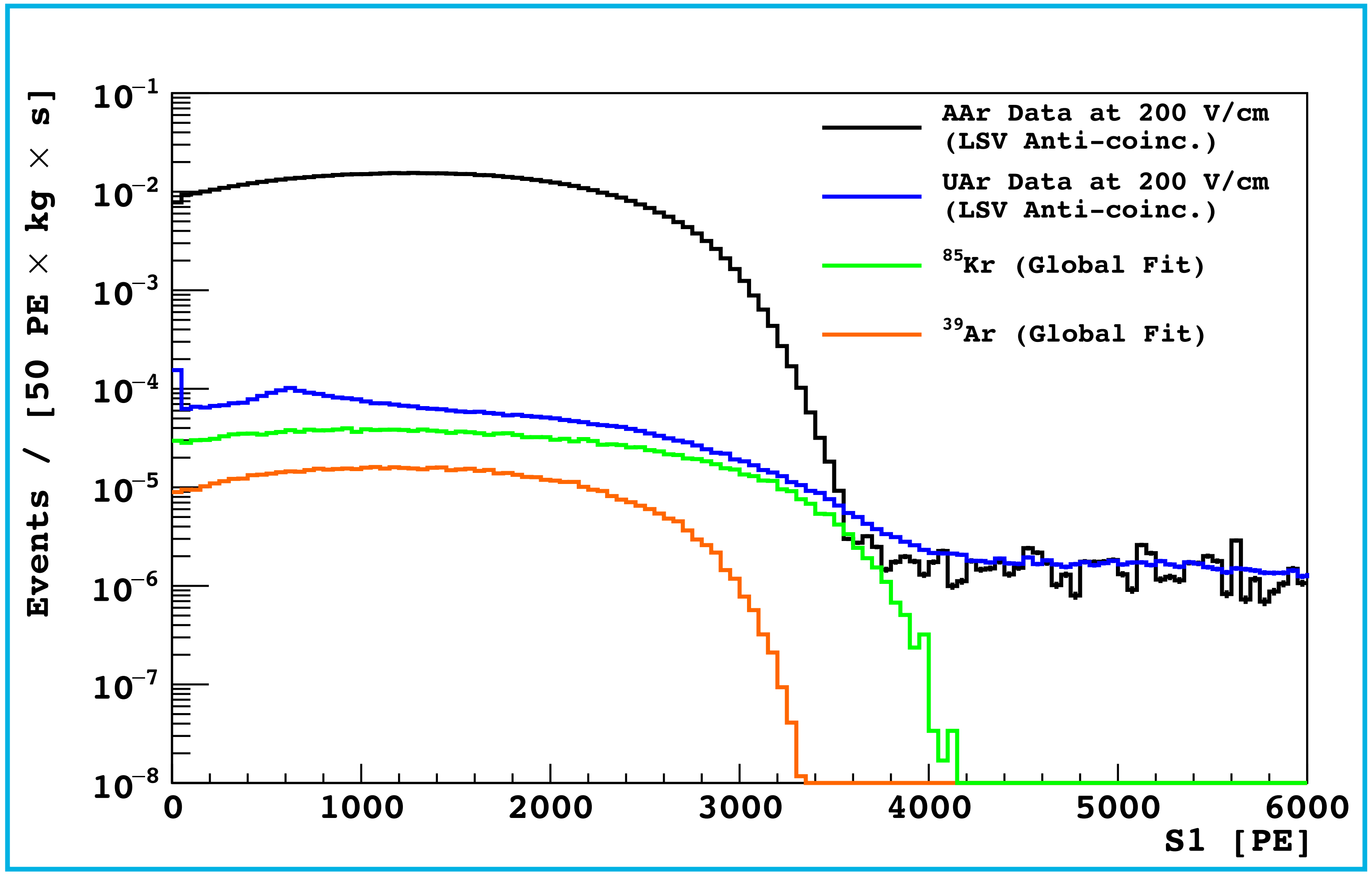
Atmospheric argon is contaminated with ^{39}Ar radioactive isotope, produced by cosmogenic activation.

^{39}Ar emits β with τ=269 years and Q-value=565 keV → Limits the sensitivity

SOLUTION

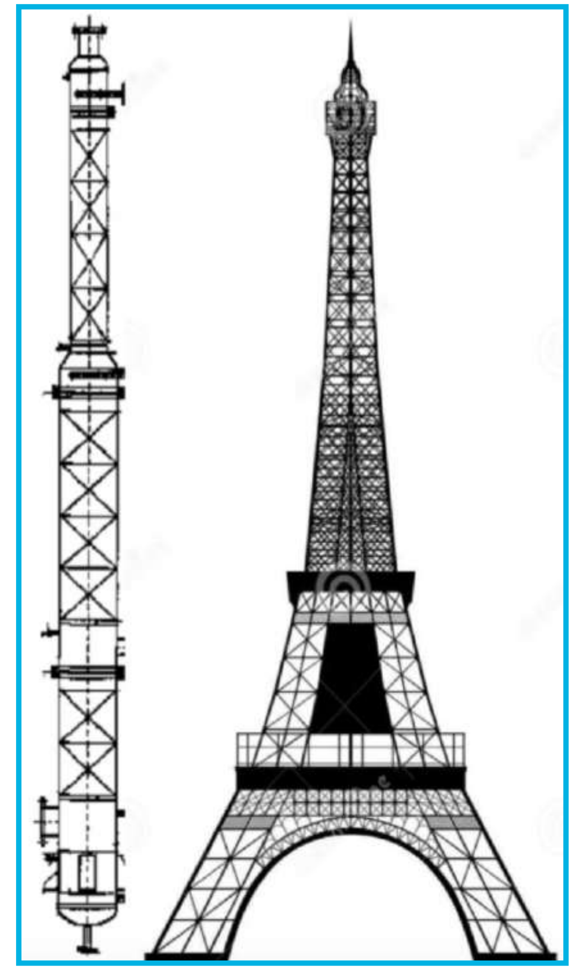
Use underground argon (UAr), extracted from deep sources.

The ^{39}Ar content is 1400 times less than in atmospheric argon, as proved by DarkSide-50.



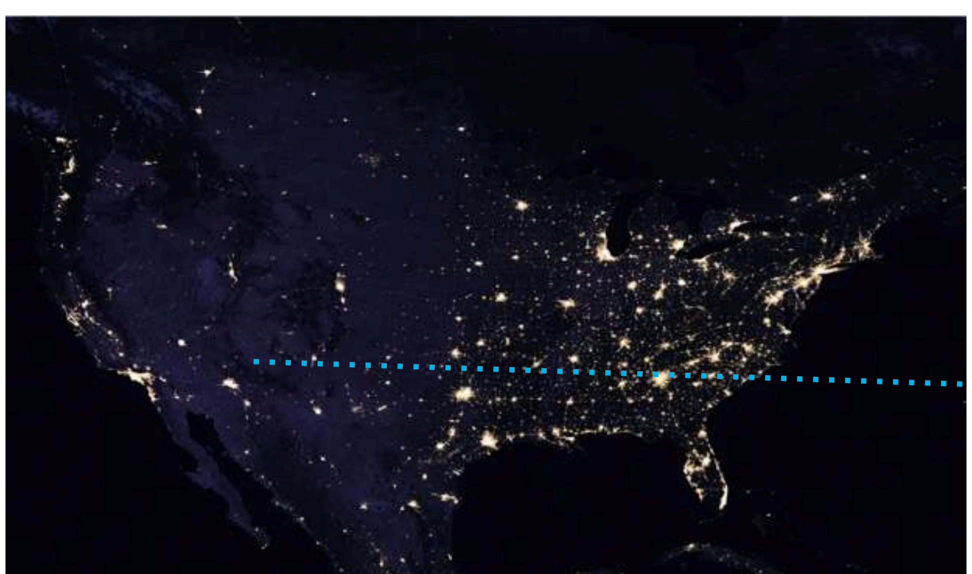
Physical Review D 93 (8), 081101 (2016)

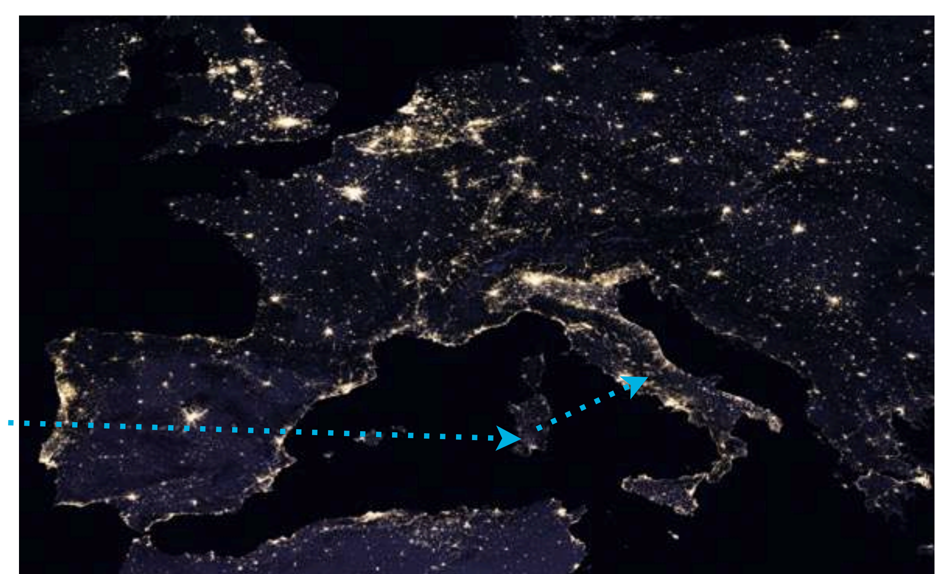
How to get the UAr?



Urania - Argon extraction and purification plant in Cortez, Colorado. Capable to provide 330 kg/d of UAr with a 99.99% purity.

Aria - final chemical purification plant in Seruci, Sardinia, Italy. Capable of separating isotopes using a 350 m cryogenic distillation column.



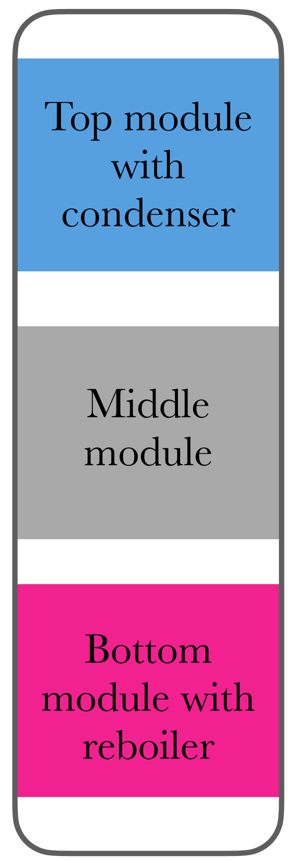


Aria

The Aria project consists of a plant, hosting a 350 m cryogenic isotopic distillation column, currently in the installation phase in a mine shaft at Carbosulcis, in Sardinia, Italy.
Aria is designed to further reduce the isotopic abundance of ^{39}Ar in underground argon by a factor 10 per pass.

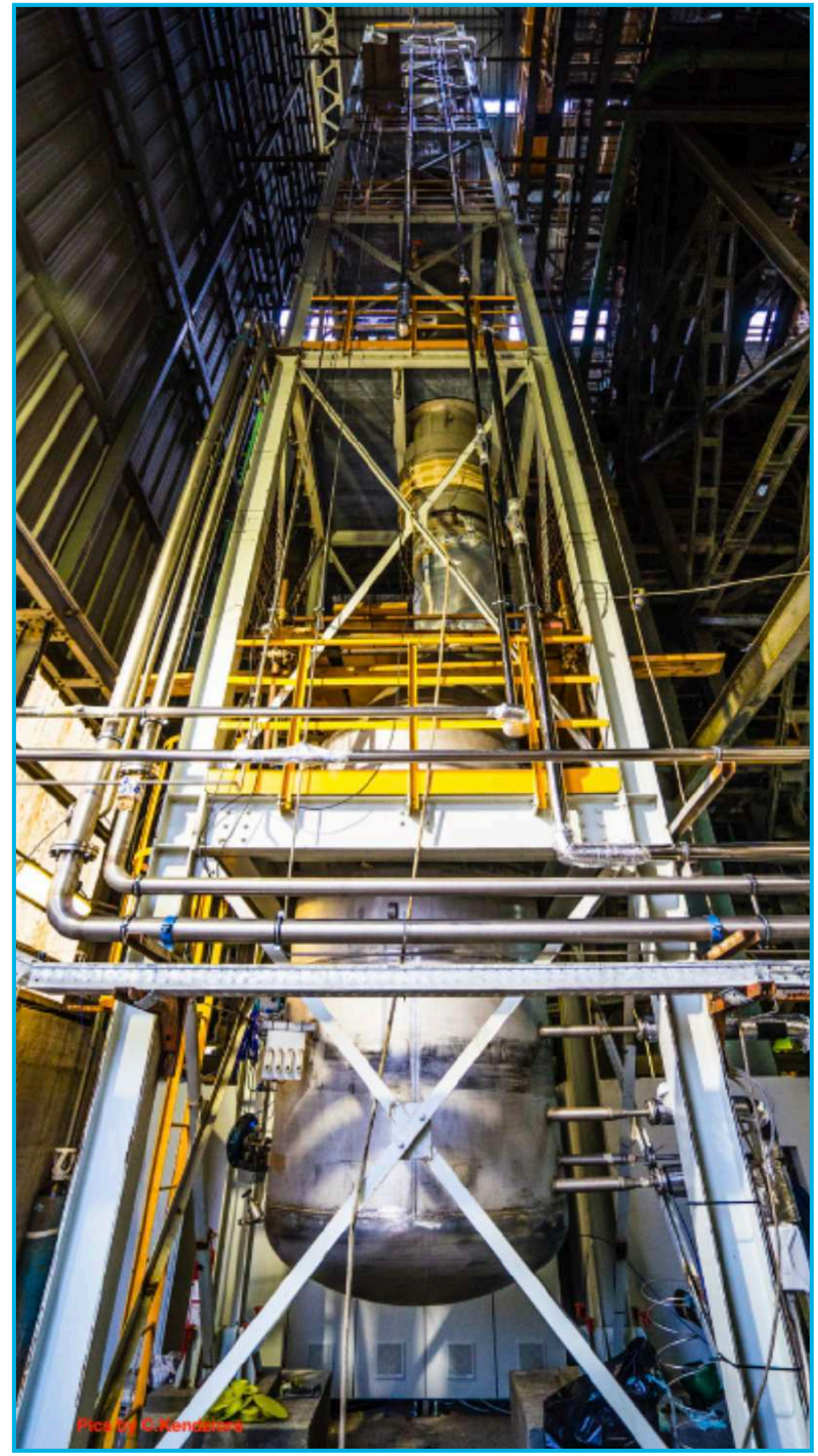
A prototype of the Aria column was already installed and operated.

Aria prototype:
- 26 m tall
- Built on the surface
- Just 3 modules
- Test run with nitrogen, instead of argon



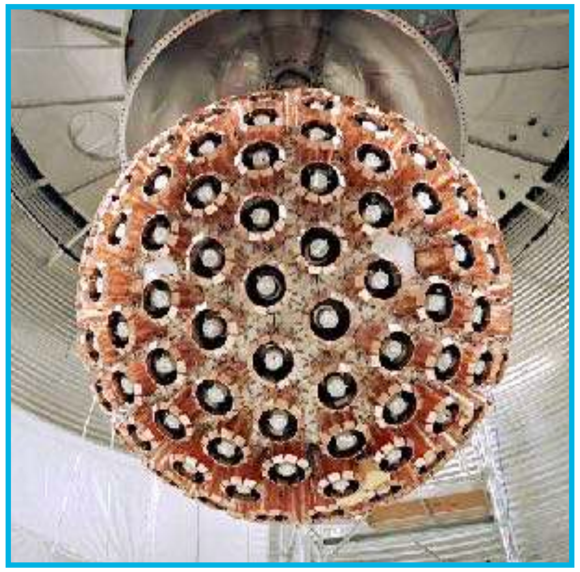
The results obtained are in agreement with the expectations and this represents a validation of the concept of cryogenic distillation with this plant.

Eur. Phys. J. C 81, 359 (2021)



Prototype Aria plant

Global Argon Dark Matter Collaboration



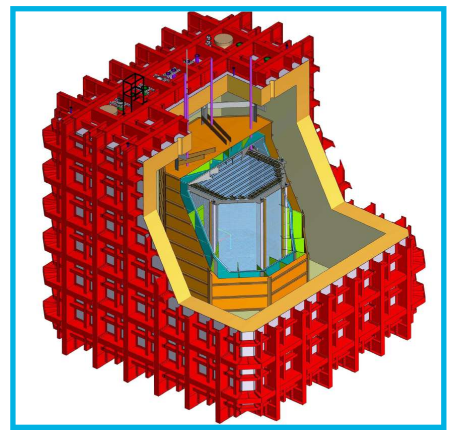
DEAP-3600

MiniCLEAN

More than 400 scientists from past and present argon-based experiments in a single international argon collaboration: **GADMC**

A sequential, two-steps program:

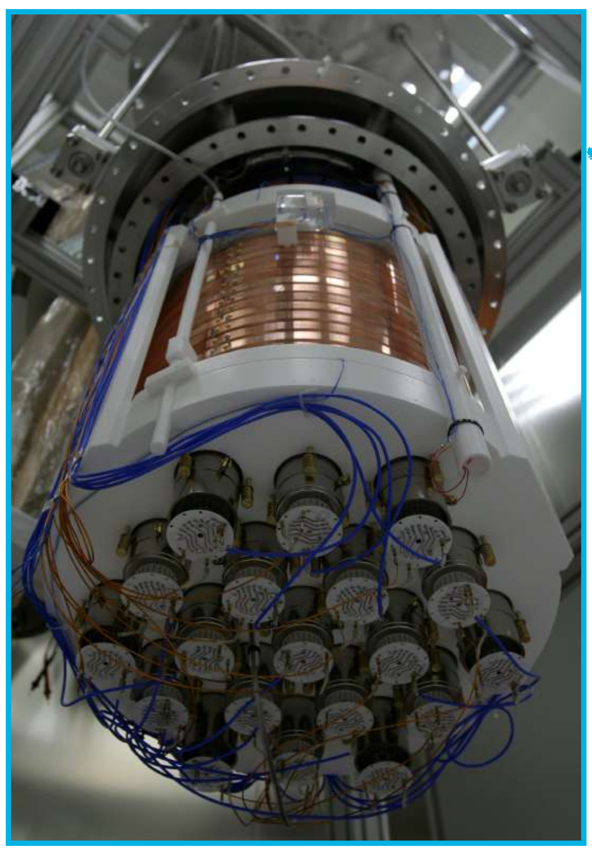
- DarkSide-20k (200 tonne X yr fiducial)



- Argo (3,000 tonne X yr fiducial)

At SNOLAB
From 2029

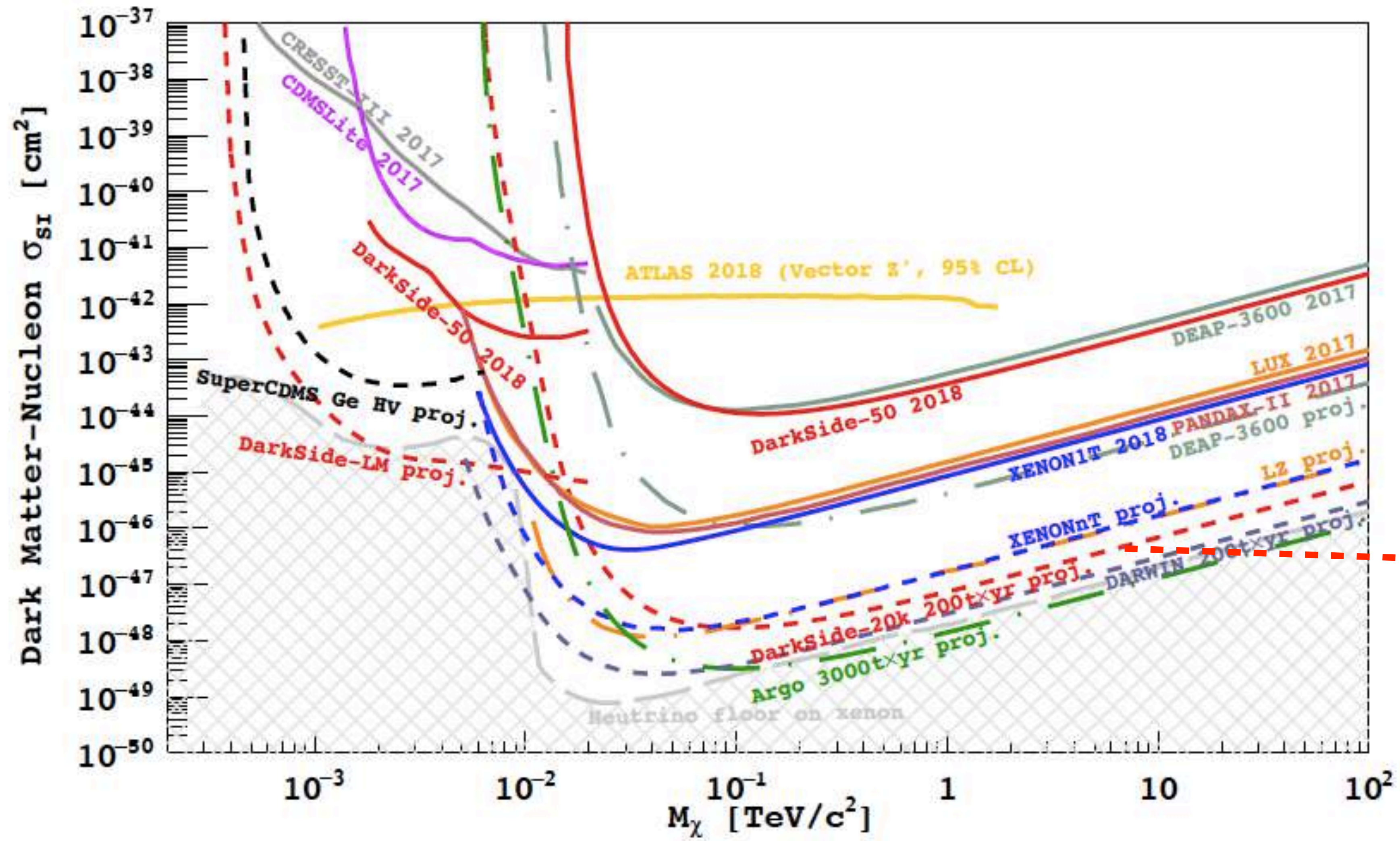
The goal: explore heavy dark matter to the neutrino floor and beyond with extremely low instrumental background



DarkSide-50

ArDM

DarkSide-20k goal



Ultra low background

+

Ability to measure background in situ

Expected sensitivity
7.4 x 10 $^{-48}$ cm^2
for 1 TeV/c^2 WIMP
with a 200 t yr exposure

To achieve this goal all sources of **instrumental background are reduced to < 0.1 events over a 200 t yr exposure.**

Background

Two background categories

Electron recoil induced background

- Use of UAr with low ^{39}Ar content
- Dual - phase TPC to tag multi-site events
- Pulse shape discrimination
- Very strict material selection and protocols to machine, store and assembly the components

How do we reduce the contribution?

Nuclear recoil induced background

- Dedicated neutron veto detector
- Very strict material selection and protocols to machine, store and assembly the components

MATERIAL SELECTION

For each component:
- Radiopurity
- Composition
- Position in the detector

\+ MonteCarlo efficiency for rejecting the background

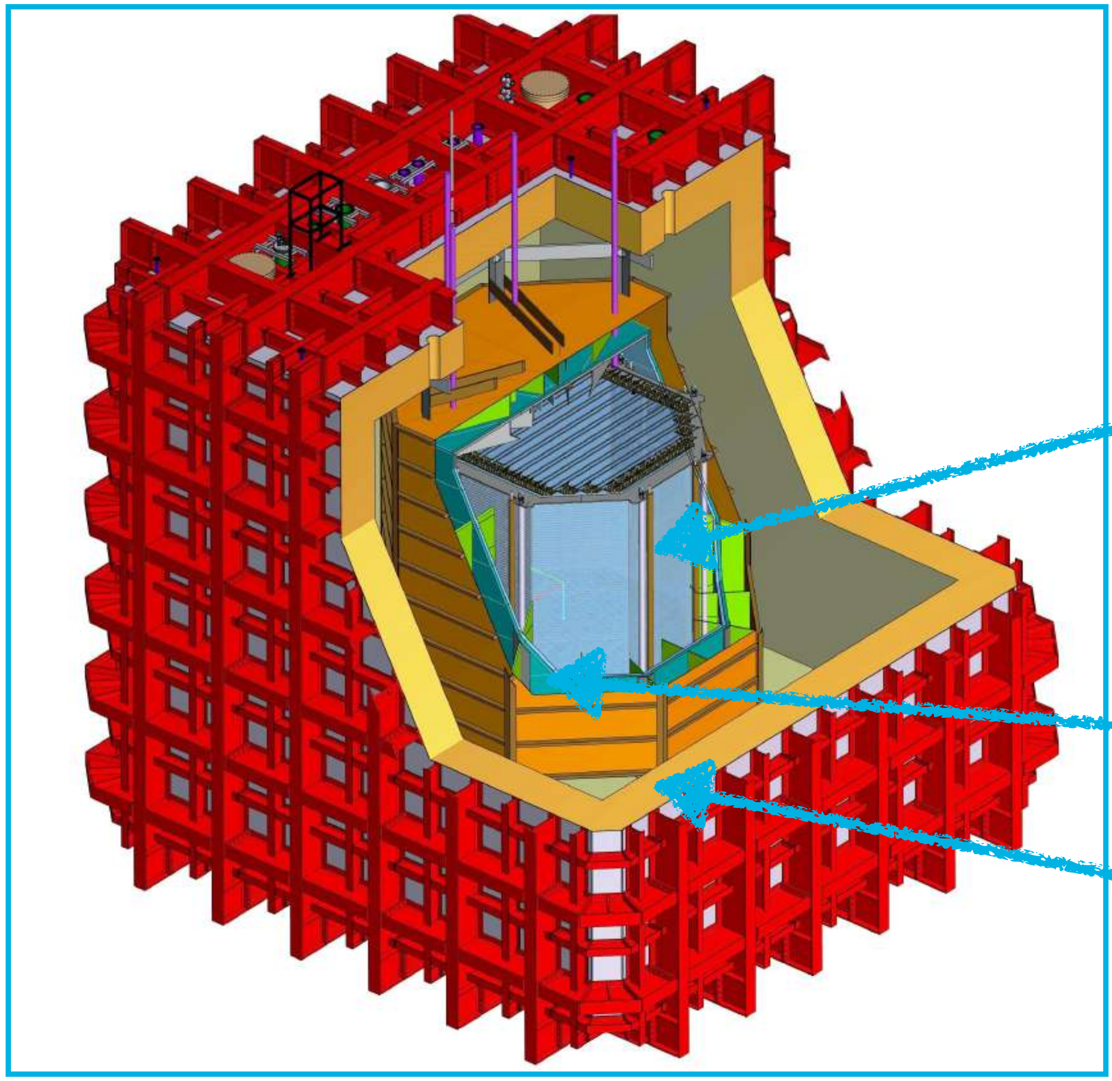
= Background budget

→ Decision if the component is acceptable or not

Nuclear recoil backgrounds expected during the full exposure

Background type	Bg events in ROI $[200\,\mathrm{t\,yr}]^{-1}$
(α,n) neutrons from U and Th	0.084
Fission neutrons from U-238	<0.001
Neutrons from Rn-222 diffusion and surface plate-out	<0.004
Cosmogenic neutrons	<0.030
Neutrons from the lab rock	<0.003
Random surface α decay + S2 coincidence	<0.005

DarkSide-20k detector



DarkSide-20k will be installed underground at the Gran Sasso National laboratories, in Italy.

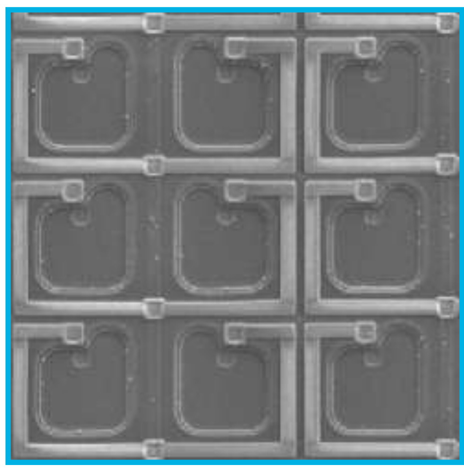
The detector has a nested structure:

- Sealed acrylic TPC filled with 50 t of UAr
- Neutron veto
  - Two liquid atmospheric argon buffers
  - Gadolinium loaded shell between the buffers
- Membrane cryostat like the ProtoDune one

Both TPC and veto signals are read with low-background, cryogenic photosensors based on silicon photomultipliers (SiPMs).

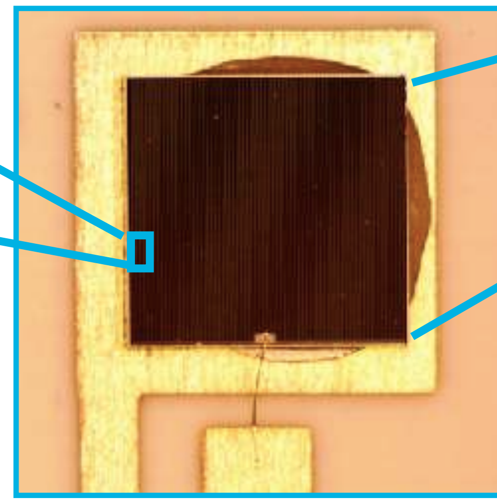
DarkSide-20k photosensors

Custom cryogenic SiPMs developed in collaboration with Fondazione Bruno Kessler (FBK), in Italy.



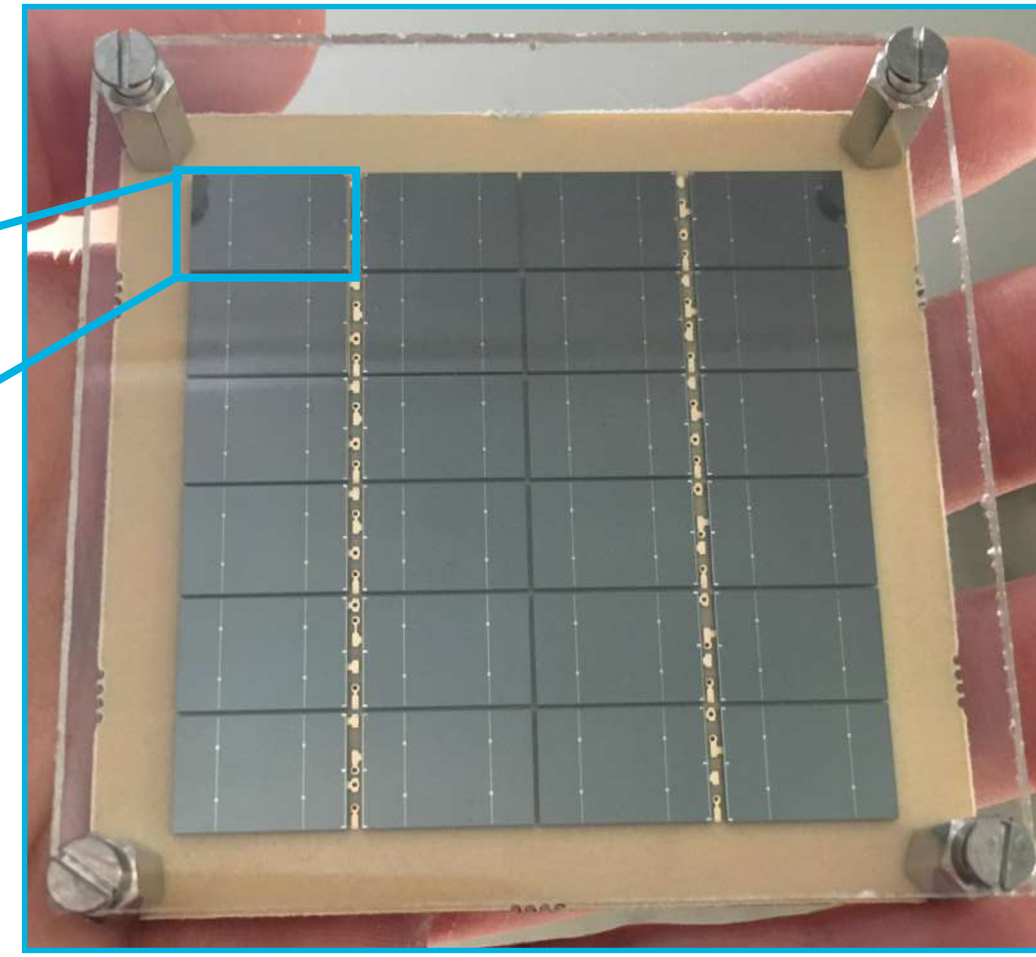
Single SPADs

~25-30 μm²



Single SiPM

~1 cm²



Tile = matrix of 24 SiPMs
5 x 5 cm²
Read as a single channel

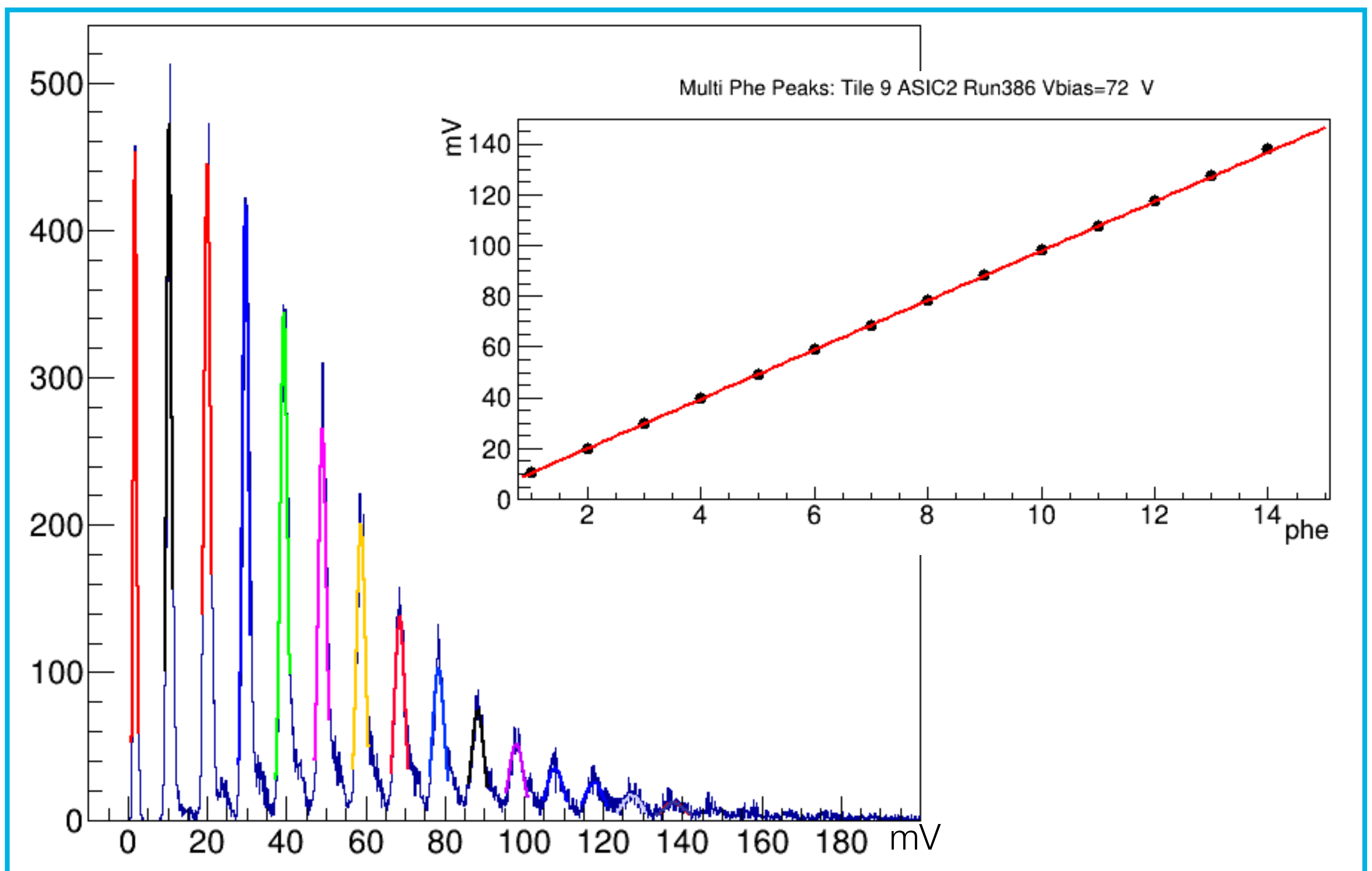
KEY FEATURES OF THE TILE

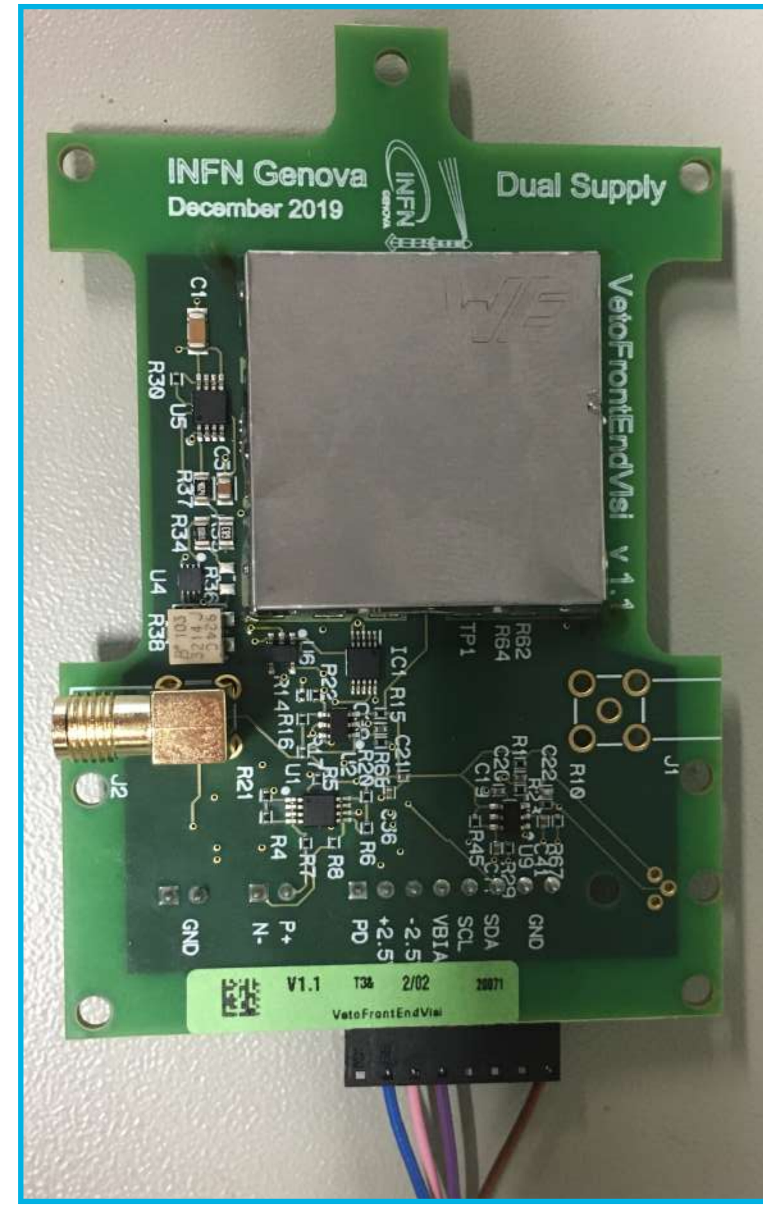
- Photon detection efficiency (PDE) ~45%
- Low dark-count rate < 20 cps
- Timing resolution ~ 10 ns

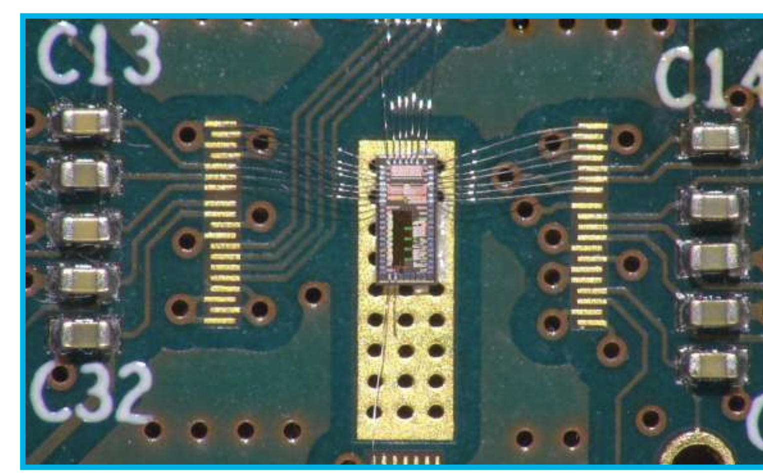
For more details see Izabela Kochanek's talk

The Veto detector readout

- The photo-detection module for the Veto is made of the front end board (FEB) and the SiPMs tile;
- The FEB is mounted **parallel** to the tile;
- The FEB is equipped with the analog CMOS **integrated electronics,** developed by the INFN Torino group;
- On each FEB there is also the **optical transmitter to drive the signal.** The signal can also be read with a coaxial cable or with a differential pair.





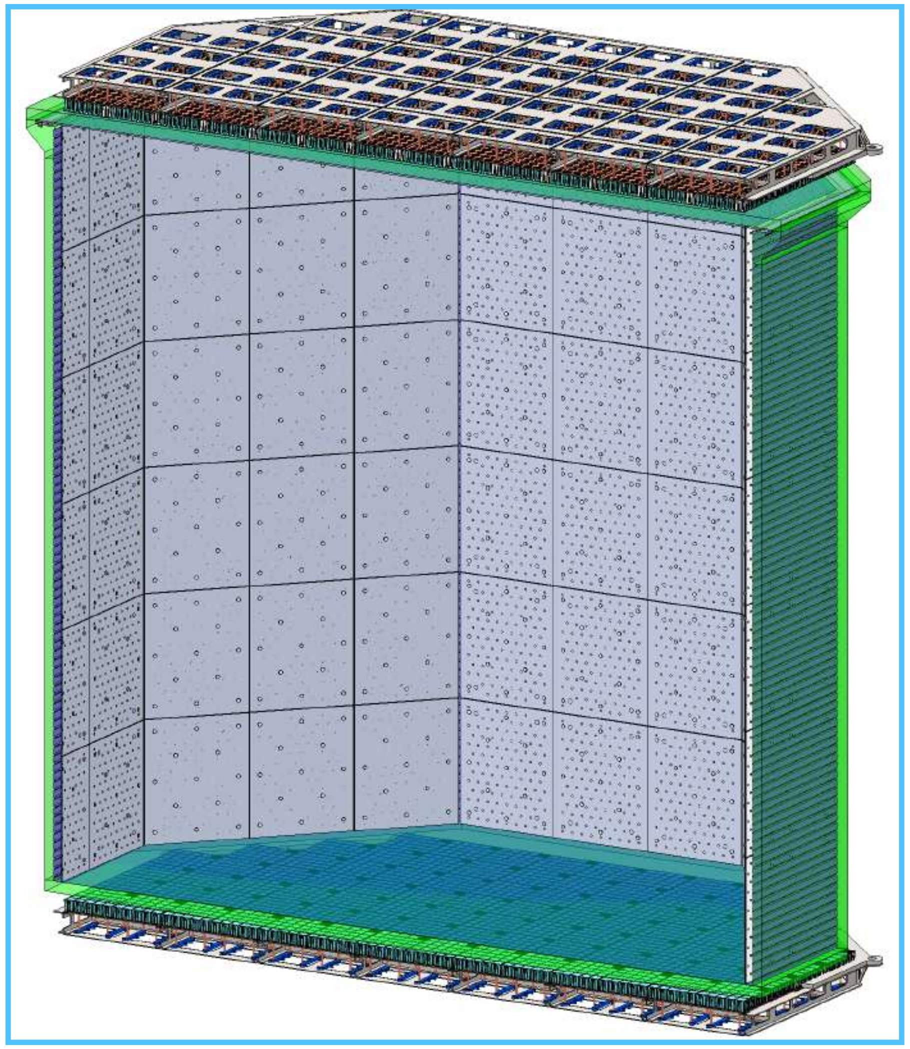


The TPC

- Ultra pure acrylic vessel, sealed with the bonding technique
- Octagonal shape
- Cathode and anode coated with new transparent conductor (Clevios) and wavelength shifter
- No copper rings ⟶ grooves with Clevios
- Wire grid
- Sides covered with multilayer polymeric reflector evaporated with wavelength shifter
- SiPMs planes external to anode and cathode

Parameter	Value
TPC drift length	350 cm
Octagonal inscribed circle diameter (87 K)	350 cm
Total LAr mass	51.1 t
Active LAr mass	49.7 t
Vertical fiducial cut (nominal)	70 cm
Radial fiducial cut (nominal)	30 cm
Fiducial LAr mass	20.2 t
Drift field	200 V/cm
Extraction field	2.8 kV/cm
Luminescence field	4.2 kV/cm
Cathode operating voltage	−73.8 kV
Extraction grid operating voltage	−3.8 kV
Anode operating voltage	ground
Gas pocket thickness	(7.0 ± 0.5) mm
Grid wire spacing	3 mm
Grid optical transparency	97 %

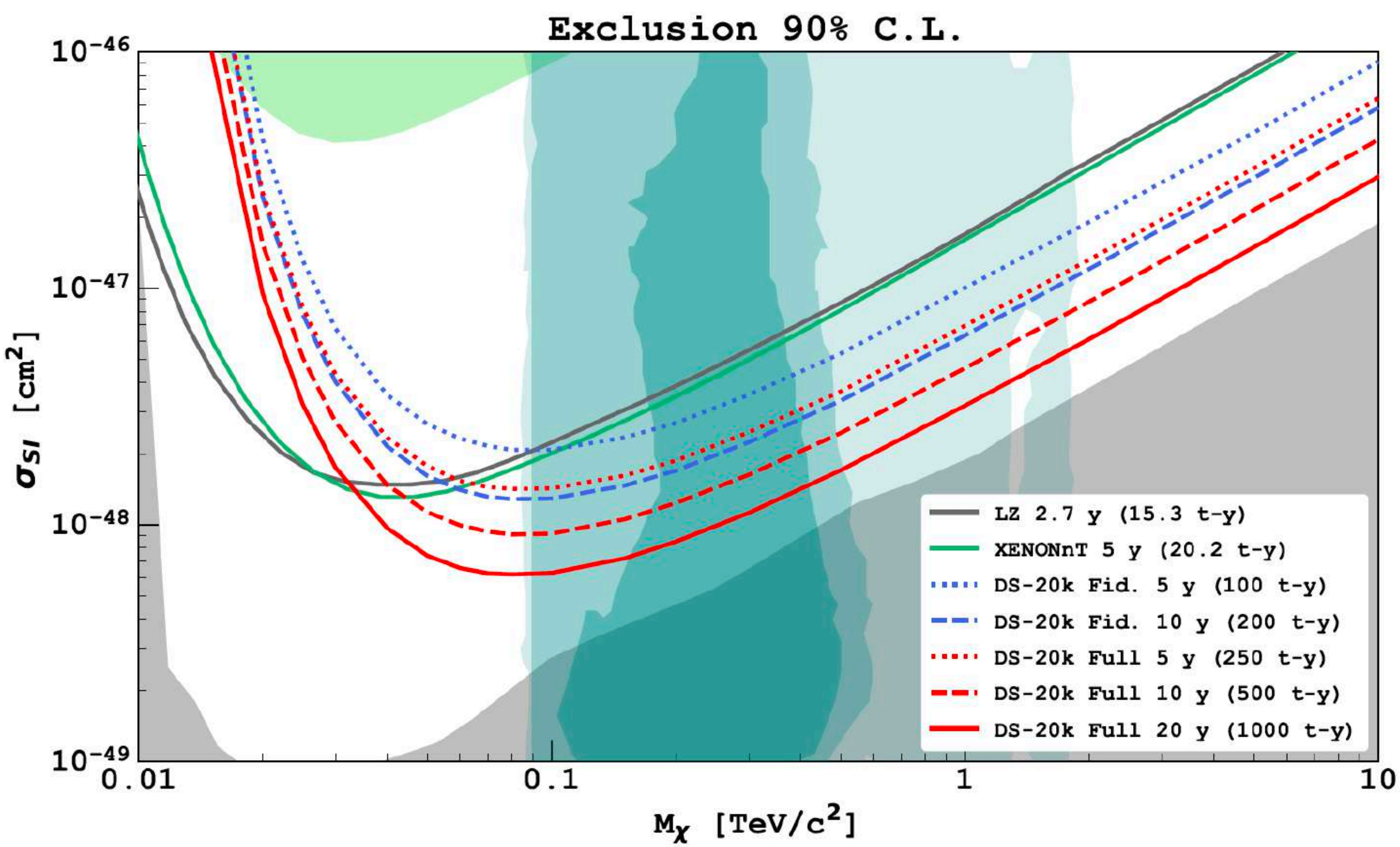
PROTO-0



DARKSIDE-20K

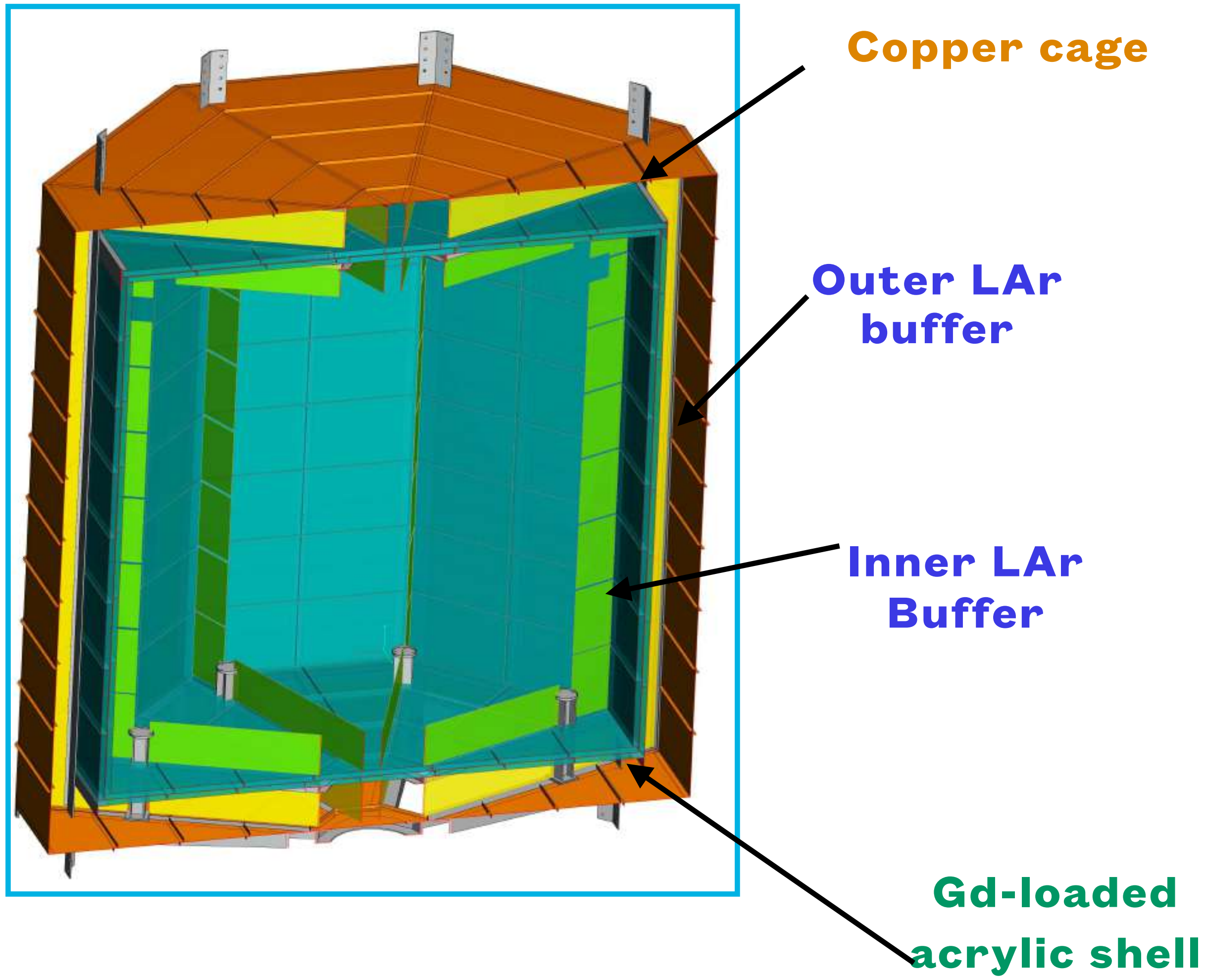
Expected sensitivity

The sensitivity of DS-20k to spin independent WIMPs for different lengths of runs, with the full exposure and with the fiducial cuts applied, compared to LZ and XENONnT.



The present projection - based on a 10 yr run, giving a full volume exposure of 500 t yr - is 4.6 x 10^{-48} cm^2 for 1 TeV/c^2 WIMP for the 90% C.L. exclusion

The Veto detector

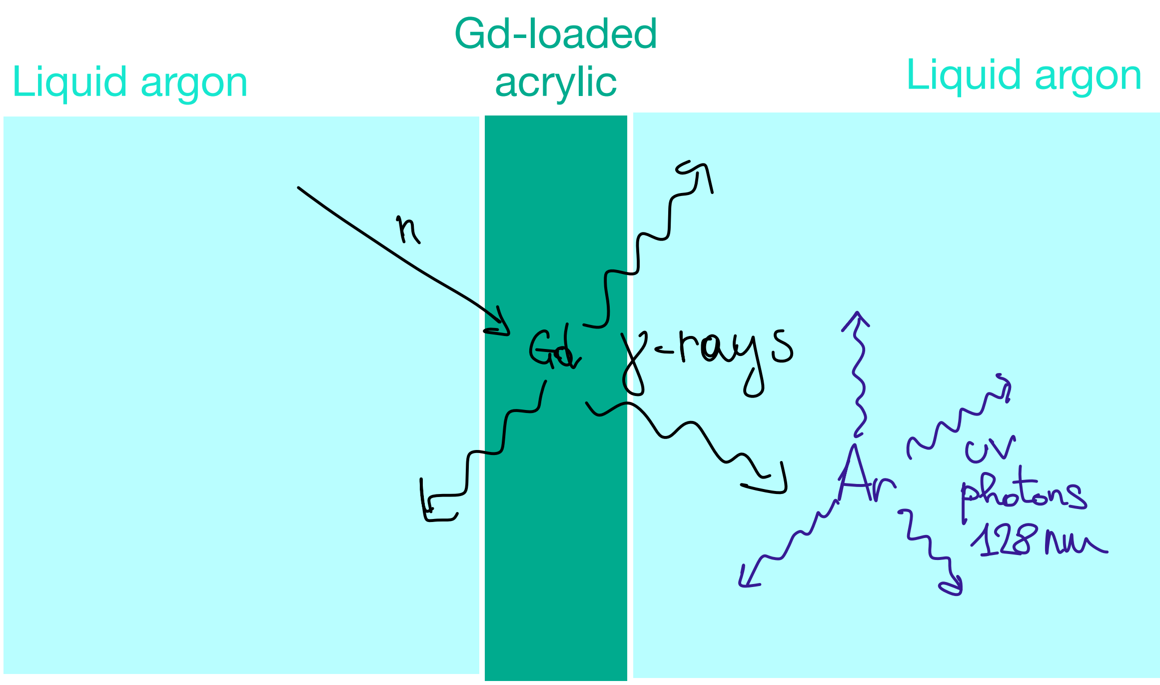


WHY WE NEED A NEUTRON VETO

Neutrons elastically scattering from argon nuclei are indistinguishable from WIMPs. We can not discard neutron events using PSD.

VETO STRUCTURE

- 424 panels of acrylic loaded with gadolinium, form a shell around the TPC. Total acrylic thickness: 10 cm.
- The shell is sandwiched between two atmospheric liquid argon buffers, each ~ 40 cm thick. Both buffers are divided in 8 sectors
- Reflector with WLS on all the surfaces



VETO WORKING PRINCIPLE

1. Neutrons are moderated in the acrylic shell and then captured by gadolinium;
2. Gd emits multiple γ-rays, with energy up to 8MeV;
3. γ-rays interact in the liquid argon buffers;
4. LAr scintillation light is shifted and detected by 3000 SiPM-based photosensors.

The Gd-loaded acrylic

REQUIREMENTS

- Mechanical stability at 87 K
- Very strong radio-purity
- Gd concentration between 1% and 2% , that means about 300 kg
- Good uniformity of the Gd, maximum 50% in the same panel

STRATEGY

Since almost no gadolinium compound is soluble in liquid methylmetacrylate, make a dispersion of nano grains, before polymerization occurs.

We identified a special kind of nano grains (~30 nm of diameter), from a Japanese company as the **most clean on the market.**

The number of neutrons produced considering the yields in PMMA is **fully compatible with the experiment requirements**.

We developed a mixing procedure and obtained **samples up to 7 cm in thickness.** The Gd distribution was uniform and the concentration between 1% and 2% as expected.

	^{238}U mBq/kg	^{232}Th mBq/kg	N bg / 200 t yr	
First sample	13.6	27	3.9×10^{-4}	In pure Gd_2O_3
			3.7×10^{-3}	In PMMA
Second sample	6.6	19	2.5×10^{-4}	In pure Gd_2O_3
			1.9×10^{-3}	In PMMA

Thank you for your attention