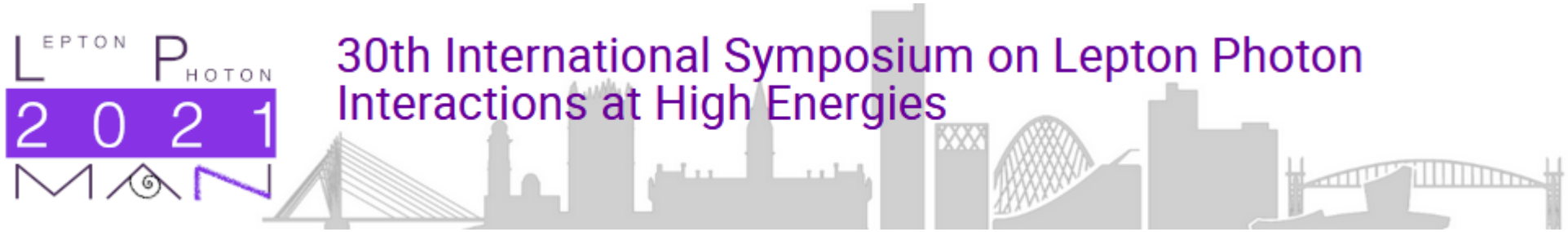



# DarkSide-20k and the Future Liquid Argon Dark Matter Program

Gemma Testera, on behalf of the GADM Collaboration

(INFN Genova- Italy)

# Direct search of Dark Matter with liquid Argon: GADMC Global Argon Dark Mater Collaboration

>500 people, about 100 Institutions
Join the expertise about low background liquid Argon based detectors
Multi step program towards WIMP dark matter detection

- Gained experience

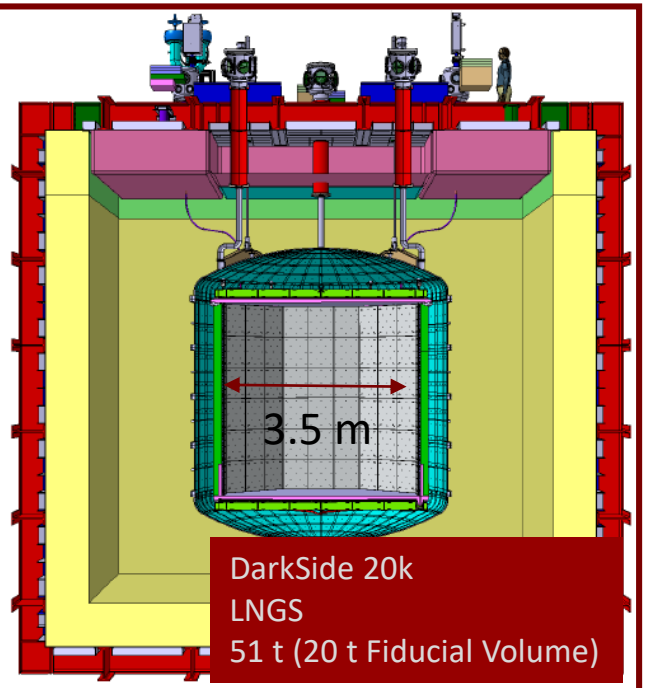
DarkSide 50
LNGS

DEAP 3600
Snolab

Mini Clean
Snolab

ArDM
Canfranc

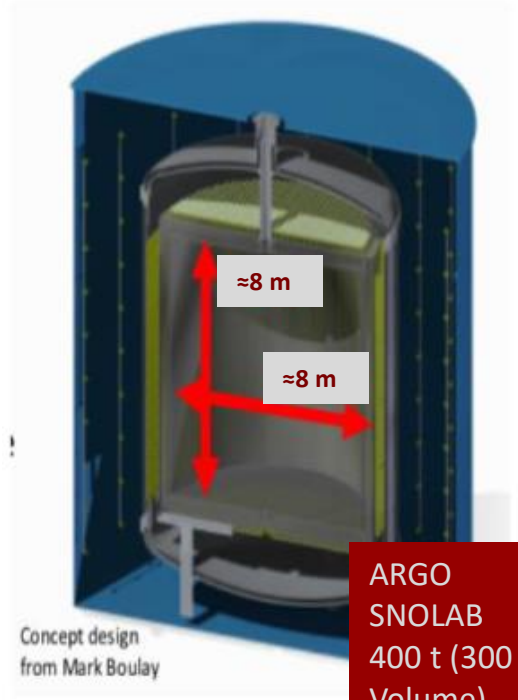
- **Present goal: DarkSide 20k @LNGS**
  **(+ ReD, Prototypes, R&D towards Low Mass WIMP sensitivity)**




DarkSide 20k
LNGS
51 t (20 t Fiducial Volume)

Construction starts in 2022
Data taking from 2025
Nominal run time: 10 years

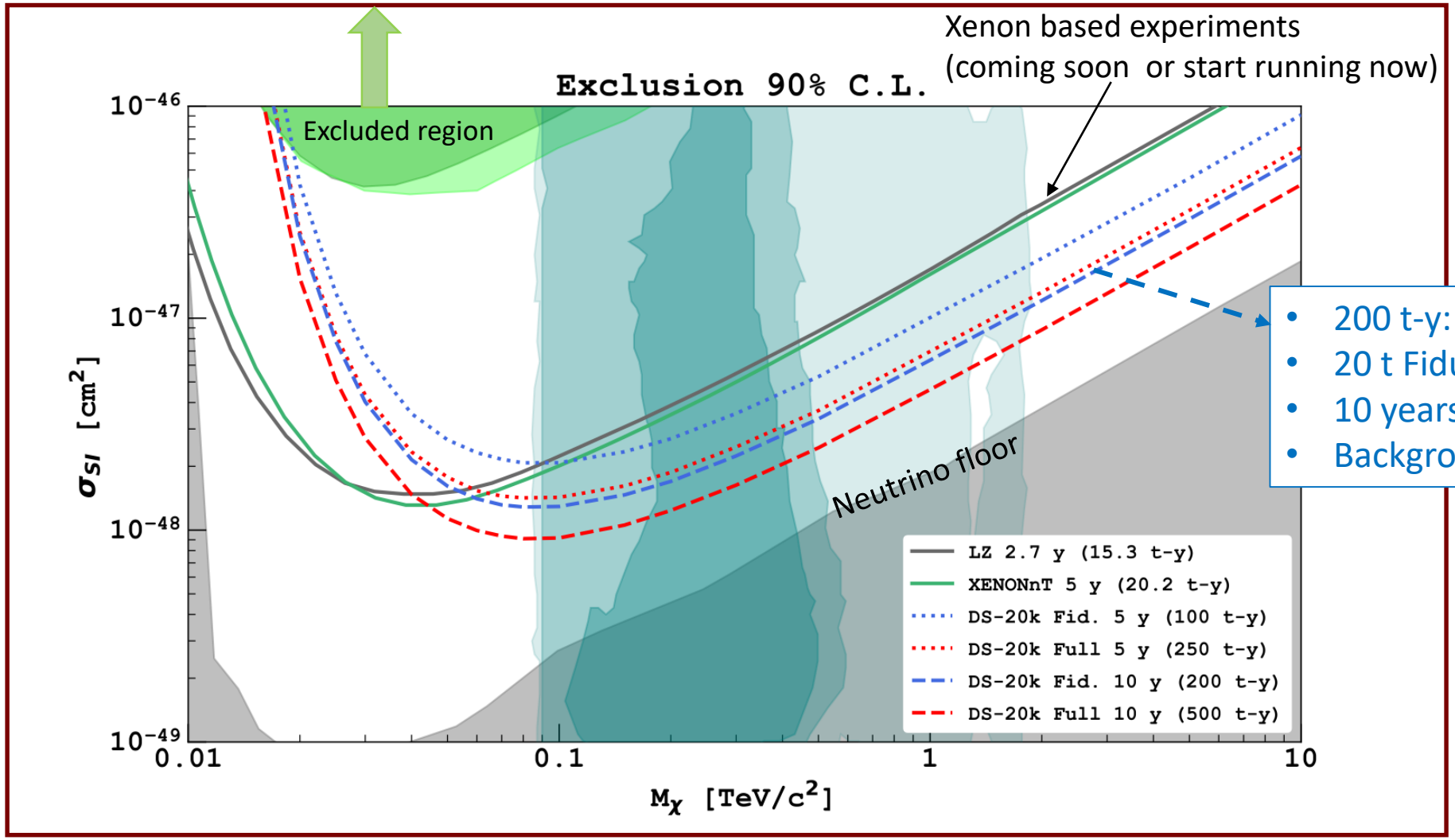
- Future goal: ARGO@SNOLAB



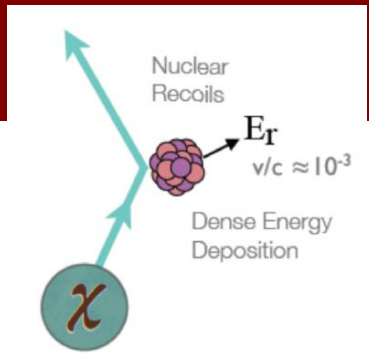

ARGO
SNOLAB
400 t (300 t Fiducial Volume)

Conceptual studies in progress
Nominal run time: 10 years (3 kt x year)

# Expected DS20k sensitivity




- 200 t-y: nominal exposure
- 20 t Fiducial Mass
- 10 years
- Background: 0.1 events




WIMP signal:
Nuclear Recoil (NR)
(≈1 to ≈100 keV)

Turquoise filled contours are from pMSSM11 model, E. Bagnaschi et al., Eur. Phys. J. C 78, 87 (2018).

# Dual Phase TPC (Time Projection Chamber) and unique Ar pulse shape discrimination

## Scintillation (S1)

**1**

Formation of excited molecular states $Ar^{2*}$ and decay

Singlet $\tau$= 6.7 ns

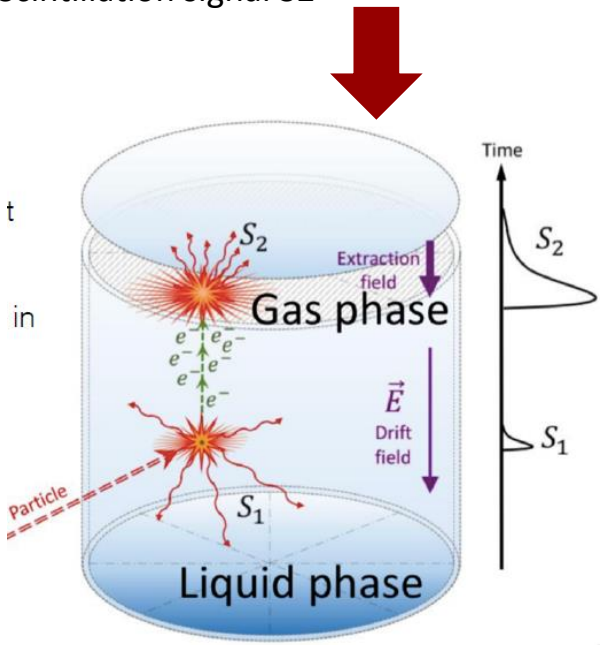
Triplet $\tau$ =1600 ns

## Ionization (S2)

Drift of ionization e- (E field in the liquid)

Extraction in gas

Scintillation signal S2



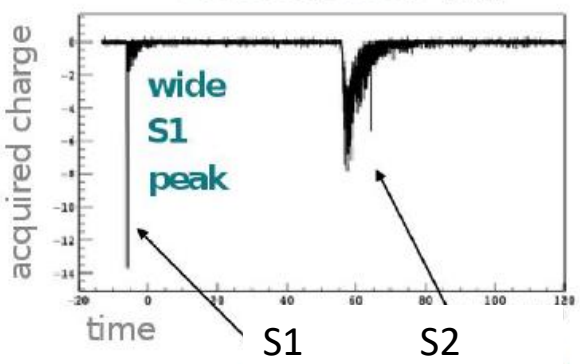

Dual Phase TPC: 3D space reconstruction

## Nuclear recoils (NR) vs e-, γ (ER) signal discrimination

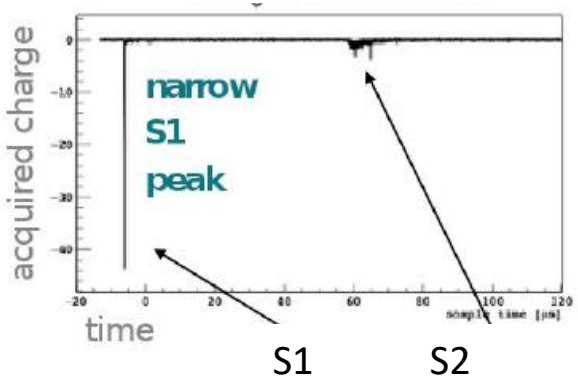
**2**

Fraction of prompt ($F_{prompt}$, $f_{90}$) and delayed light + S1/S2 ratio

Electron recoils:
Small prompt S1 light
Large late S2 light

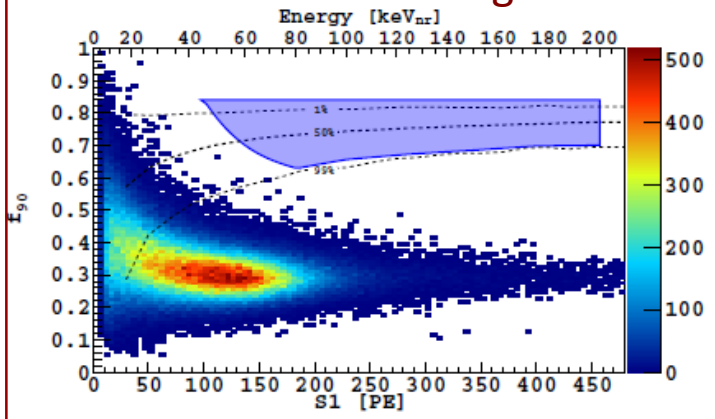



Nuclear recoils
Large prompt S1 light
Small late S2 light

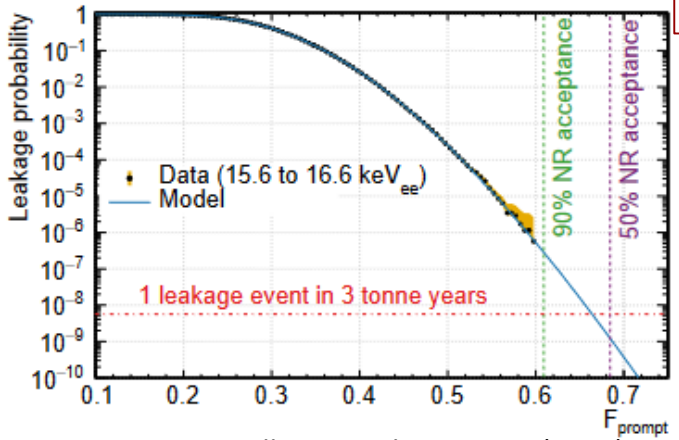



## Signal discrimination results

**3**




DS50 Coll., Phys. Rev. D 98 102006 (2018)




DEAP Coll., Euro. Phys. J. C 81 (2021)

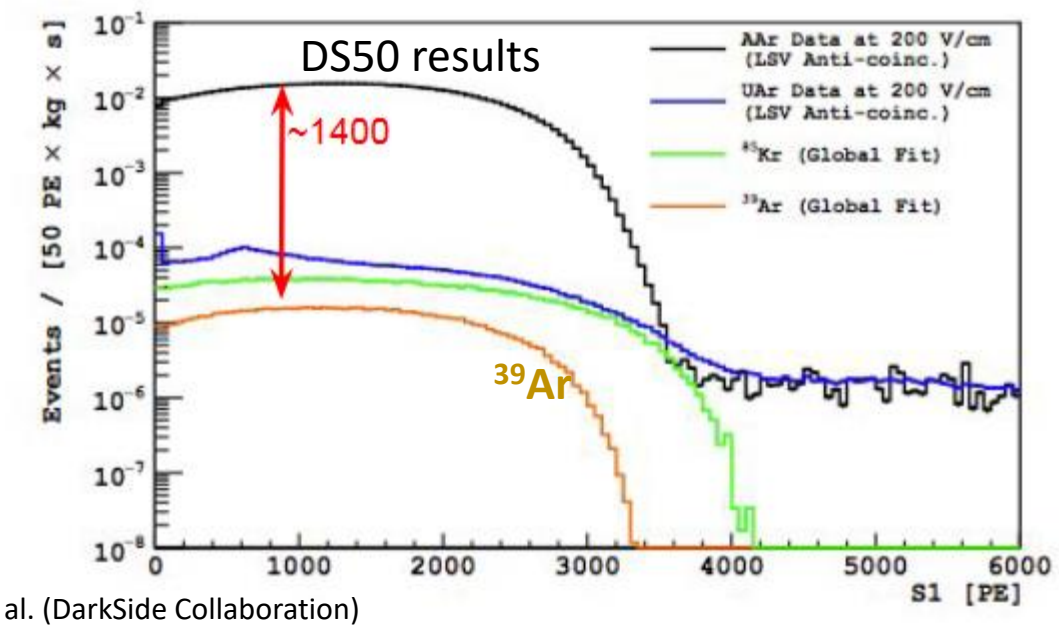
# Radiopure Ar from underground sources

- $^{39}$Ar β decay, $t_{1/2}$= 269 y
- End point: 570 keV
- Produced in the atmosphere $^{40}$Ar(n,2n)
- ≈1 Bq/kg in Argon from atmospheric origin

DS50: extraction of Ar of underground origin (UAr)

**$^{39}$Ar depletion factor: 1400+- 200**

Extraction of 157 Kg of UAr (50 Kg fiducial mass)




P. Agnes et al. (DarkSide Collaboration)
Phys. Rev. D 93, 081101(R) (2016)

DS20k filled with UAr
+ excellent Ar Pulse Shape Discrimination

**< 0.1 events /(200 t year)**
of residual
background due to Electron recoil (ER)

# The path towards radiopure Ar: URANIA +ARIA+DArT

**Scale up the UAr extraction from ≈100 Kg to ≈100 t**


See the poster of L. Luzzi

## URANIA: UAr extraction 1

- $CO_2$ well in Cortez, CO, USA;
- Industrial scale extraction plant;
- UAr extraction rate: 250-330 kg/day;
- Purity 99.99%
- Plant ready to be shipped
- Civil work ongoing

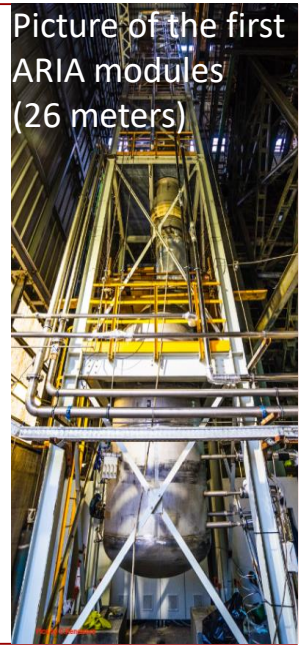
## ARIA: UAr distillation 2

- Cryogenic distillation column in Sardinia (Italy)
  bottom reboiler
  + 28 central modules (12 m each) 350 m in total
  + top condenser
- Chemical purification rate: 1 t/day
- First module operated according to specs with Nitrogen in 2019

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

- Run completed with Ar at the end of 2020:

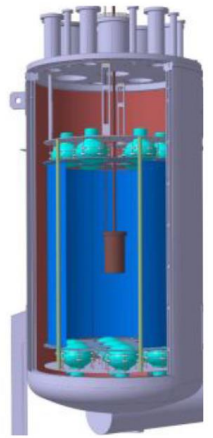
results to be published soon


Picture of the first ARIA modules (26 meters)

## DArT : Measurement of the activity of the $^{39}$Ar 3

- LSC, Canfranc Spain
- Single-phase inner detector for 1.42 kg of liquid UAr
- Inside 1 tonne ArDM detector acting as an active veto for background radiation
- $^{39}$Ar depletion factor sensitivity: U.L 90% CL. $6 \times 10^4$

2020 JINST 15 P02024.



# Signal and Background

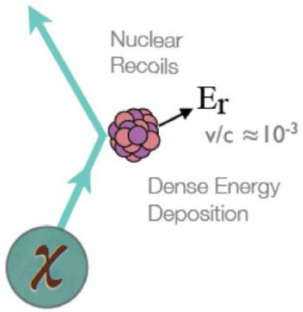
## Signal

- Nuclear recoil (NR): 1 to 100 keV
- Single scattering

Shape of the recoil spectrum

Annual modulation

Directionality (see previous talk of L. Pandola)




| Background source | Mitigation strategy |
|---|---|
| $^{39}$Ar β decay | Use Ar from Underground source (UAr)<br>+ Pulse Shape Discimination (PSD) |
| γ from rocks and γ, e- from materials | Pulse Shape Discrimination (PSD)<br>Selection of materials & procedures |
| **Neutrons**<br>**Radiogenic n (α,n) with a from material contaminants** | Material screening.<br>Definition of Fiducial Volume in the TPC + active VETO to reject n signal. |
| Surface contamination due to Rn progeny | Surface cleaning<br>Reduce the number of surfaces<br>Installation in Rn abated air |
| Neutrino coherent scattering | irriducible |

# The design of the DS20k detector

- **Two-phase TPC LAr (WIMP target & detector)**
  filled with 50 t (20 t FV) low-radioactivity Ar from underground source (UAr)
- 21 $m^2$ cryogenic SiPMs (top and botton readout)

- TPC surrounded by **a single phase (S1 only) detector (Veto) in UAr** to identify and veto neutron signals
- 5 $m^2$ cryogenic SiPMs (Veto readout)

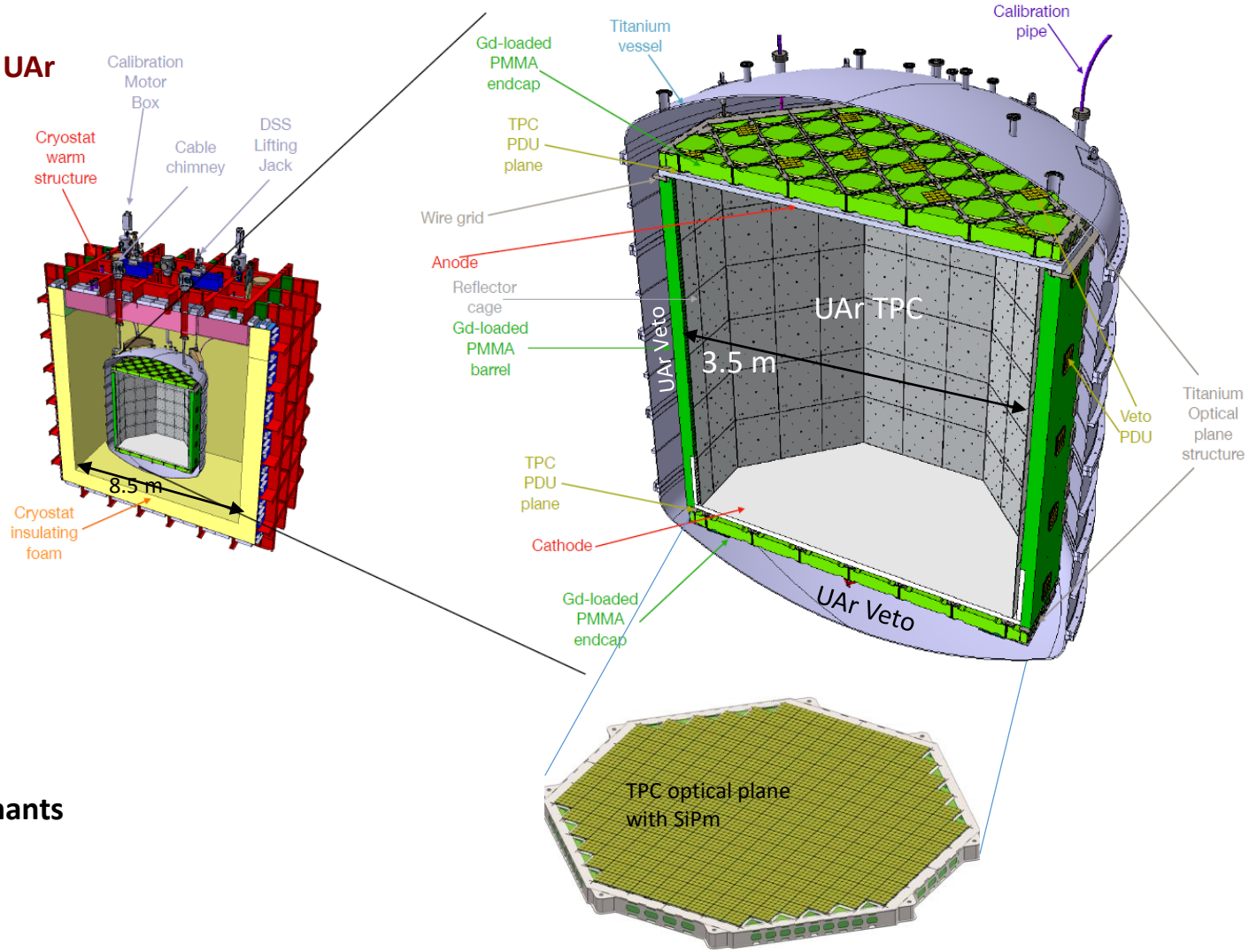
- Integration of TPC and VETO in a single object

- 99 t UAr in total contained in a hermetic Ti vessel

- TPC anode&cathode: transparent pure acrylic
- TPC lateral walls + additional top&bottom planes in Gd loaded acrylic (PMMA)
  - to thermalize n (acrylic is H rich)
  - high energy $\gamma$ emitted by Gd after neutron capture
  - minimize the amount of material

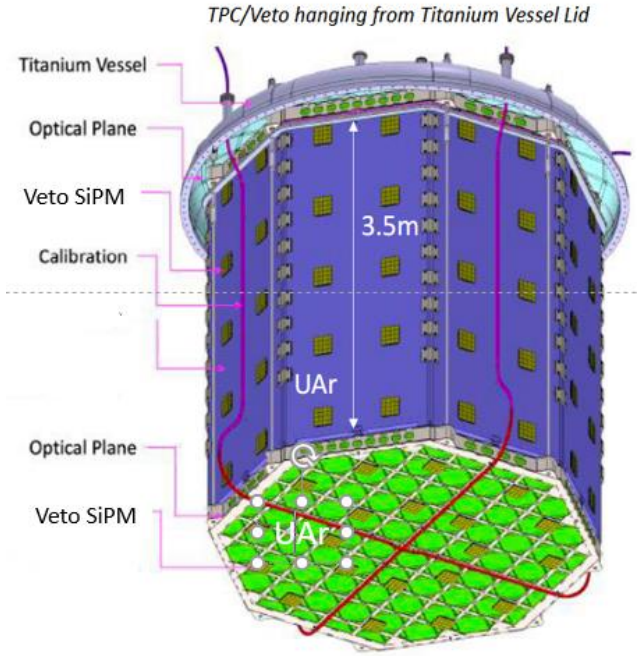
- ≈650 t AAr in a membrane cryostat, proto-DUNE like
- 2 independent cryogenics purification loops

- Selection and screening of all the materials
- Dominant n background: **$(\alpha,n)$ with $\alpha$ from material contaminants**

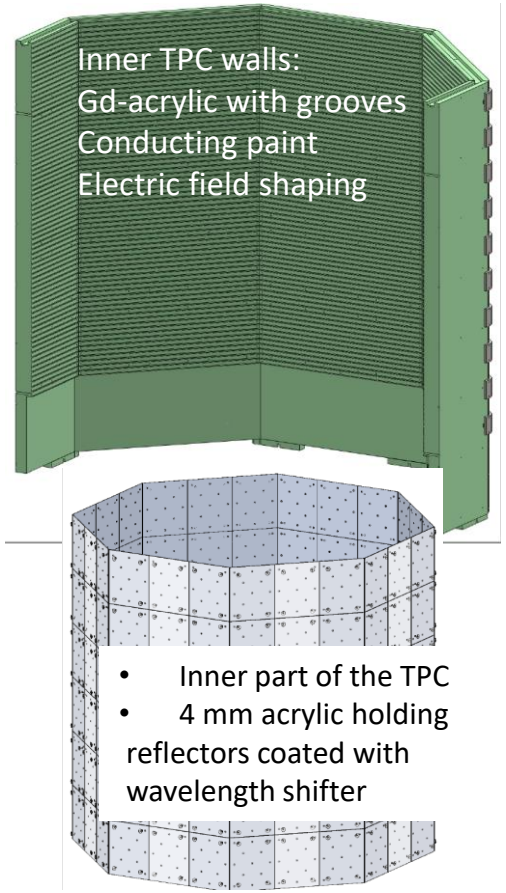


# The design of the DS20k detector: more details

- Reflectors and wavelengh shifters
  - inner TPC walls (TPC light)
  - outer TPC walls (Veto light)
  - innet Ti walls (Veto light)
- Cathode and anode coated with new transparent conductor (Clevios) and wavelength shifter
- TPC lateral walls: grooves with Clevios for shaping the field cage (no copper rings)




- Gas pocked 7.0±0.5 mm
- Drift field 200 V/cm
- Cathode -73.38 kV
- Extraction grid -3.78 kV
- >10 phe/keV in the TPC
- 2 phe/keV in the Veto




- Inner part of the TPC
- 4 mm acrylic holding reflectors coated with wavelength shifter

# Veto working principle

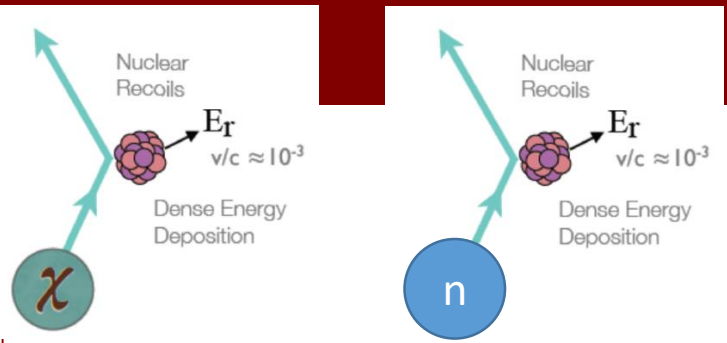
n identification:

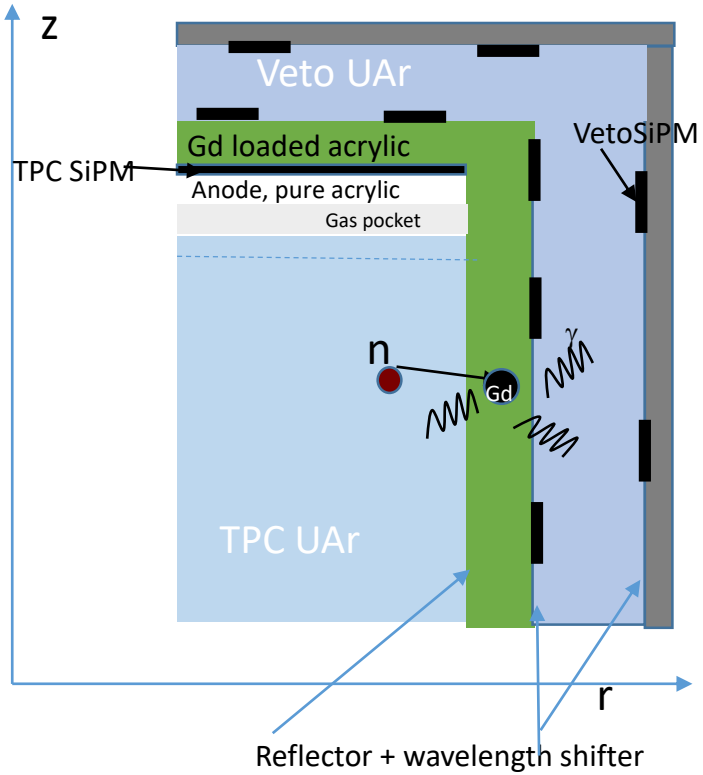
WIMP like event in the TPC (single cluster, PSD as Nuclear recoil 7.5 - 50 keV, r-z cut)

AND

event in the VETO with $E>E_{th1}$ and /or event Electron Recoil in the TPC with $E>E_{th2}$

within 800 μs




**2 recipes to produce a new material: Gd loaded PMMA**

- **$Gd_2O_3$: nanoparticle dispersion,**
  $Gd_2O_3$ commercially available
- **$Gd(acac)_3$ solution**
- R&D in progress to setup the production of $Gd(acac)_3$

**Both are**

- working at laboratory scale
- satisfying the radiopurity requirements
- under test with industry

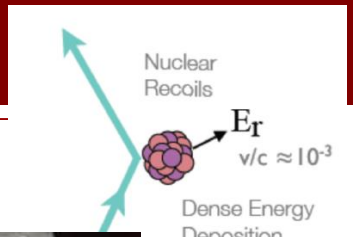
**Efficient suppression of the most dangerous n background: radiogenic neutrons**

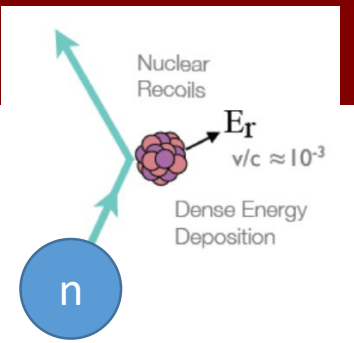
- Selection of materials
- Monte Carlo simulations
- Analysis cuts (TPC+Veto)
- 1% Gd by weight in acrylic
- Very low ineff.
  $2.2\ 10^{-6}$ for n coming from TPC SiPM, smaller for other n sources

→ **≈0.1 n/200 t y from (α,n) reactions**

12 cm tall,
acrylic loaded with $Gd_2O_3$ ,
2% Gd by weight

# Veto working principle



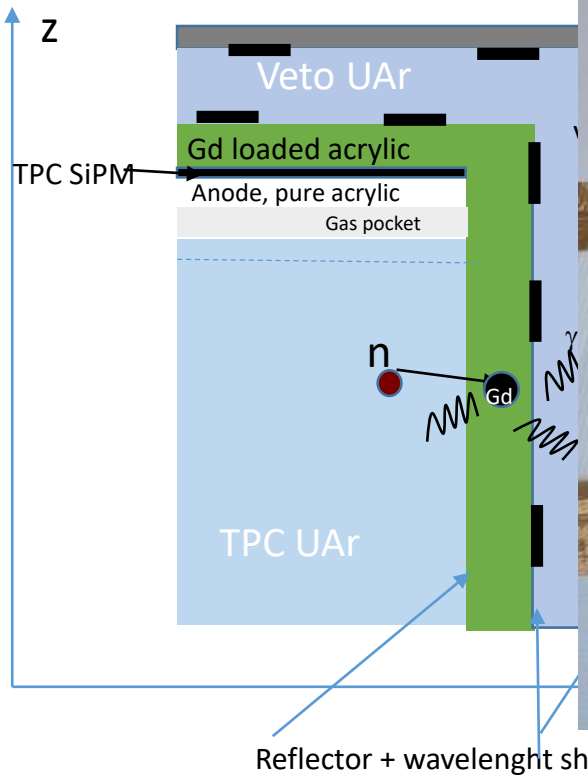



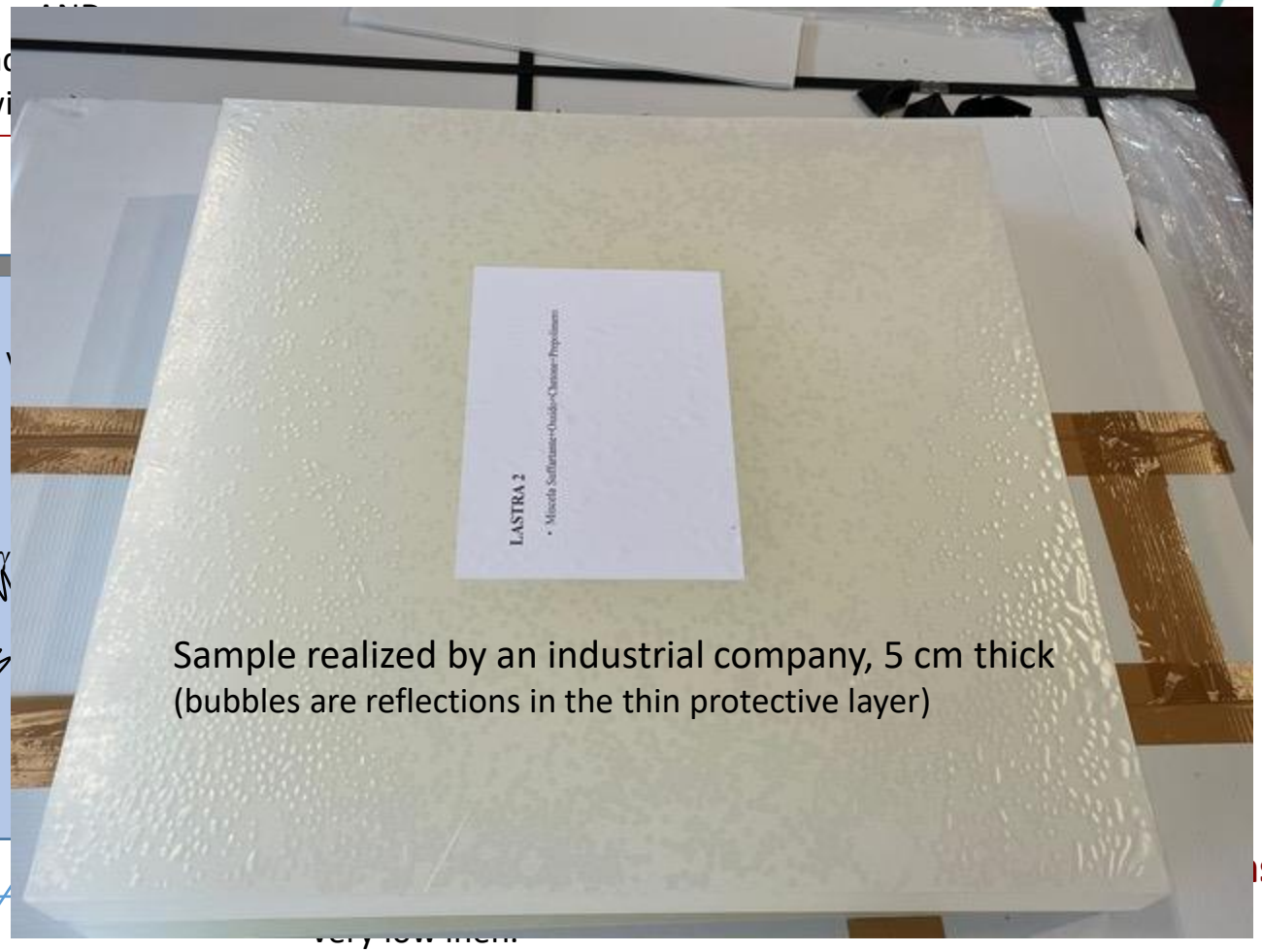

n identification:

WIMP like event in the TPC (single cluster, PSD as Nuclear recoil 7.5 - 50 keV, r-z cut)

event in the VETO with $E>E_{th1}$ and

wi



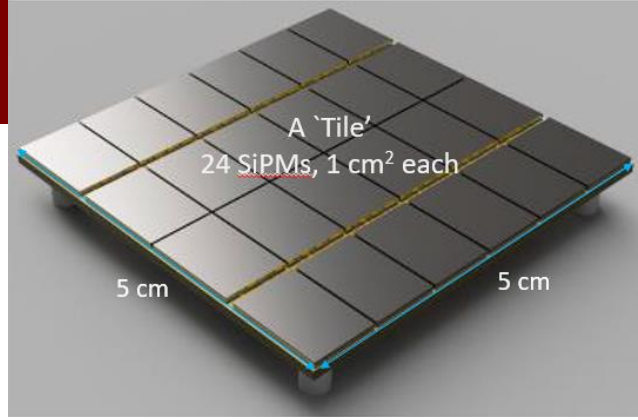

Sample realized by an industrial company, 5 cm thick
(bubbles are reflections in the thin protective layer)

12 cm tall,
acrylic loaded with $Gd_2O_3$ ,
2% Gd by weight

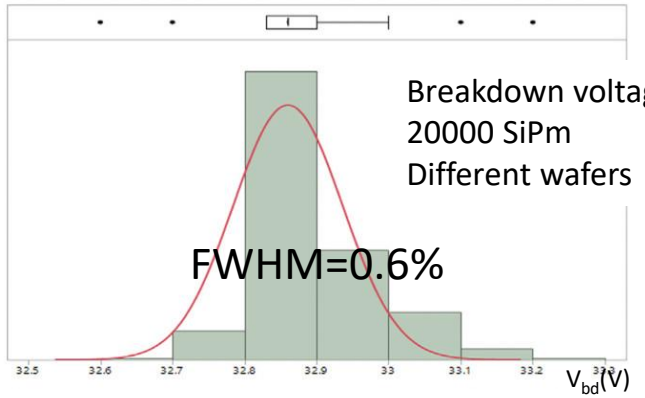
ns

2.2 $10^{-6}$ for n coming from TPC SiPM,
smaller for other n sources

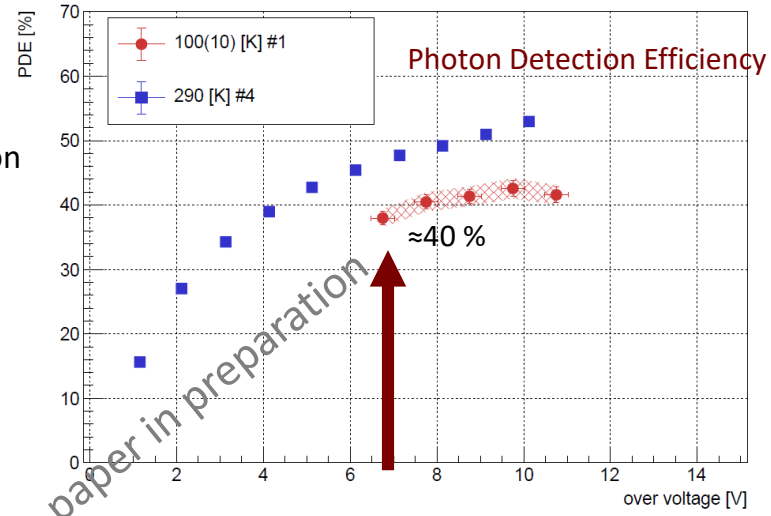
# Photosensors: development of large area cryogenic SiPMs

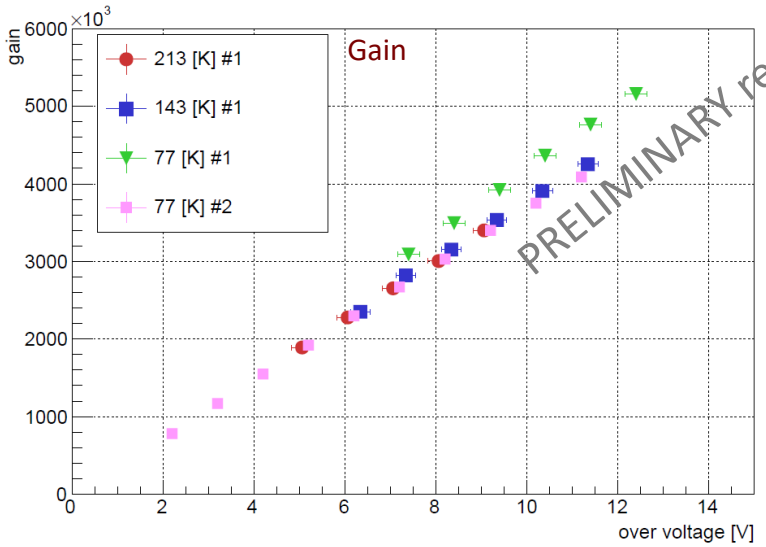



- Very high uniformity of the breakdown voltage (crucial for tiles of 24 SiPms and single Vbias)

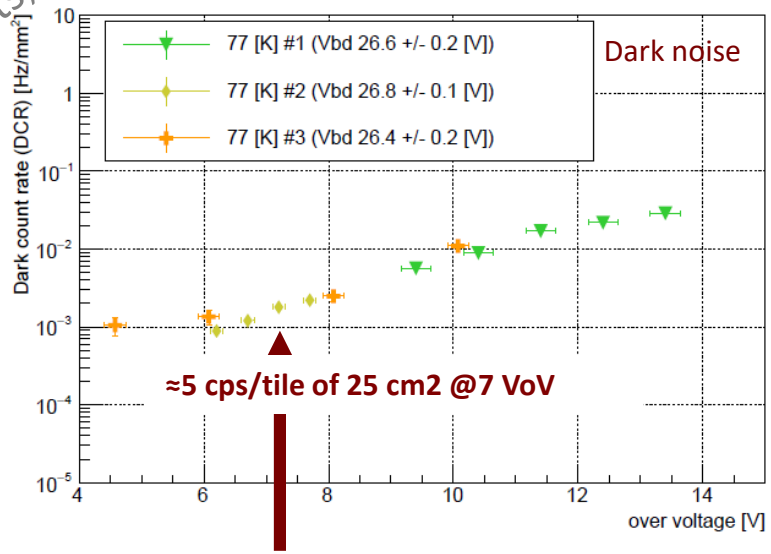



32.7




PRELIMINARY results, paper in preparation




+ measurements of
Correlated Avalanche
Direct Cross Talk
.....

and inclusion of the
data in the detector
Monte Carlo

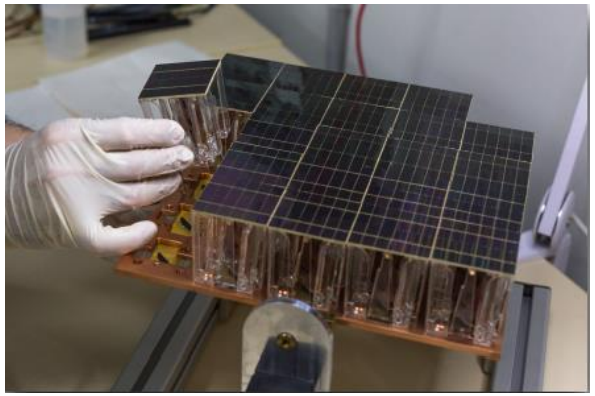
- R&D concluded
- Full SiPM procurement in progress
- Delivery during the first months of 2022

# Photosensors: grouping SiPMs into a large matrix

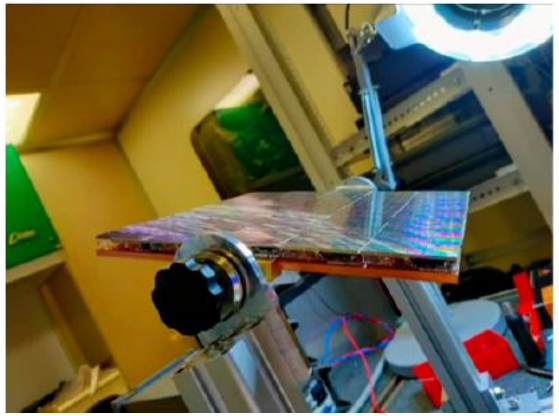
Development of cryogenic amplifiers (Trans Impedance Amplifier (TIA) scheme )

- Discrete elements
- ASIC

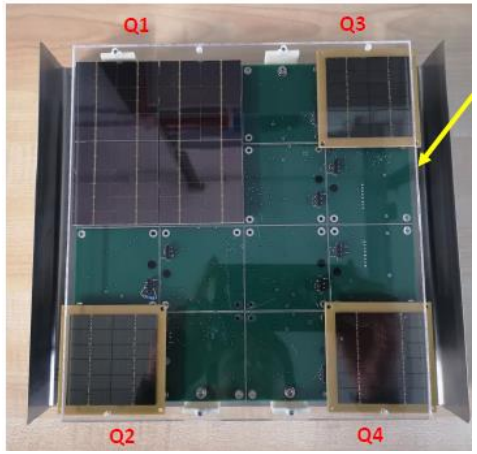
- Tested different solutions for assembling tiles into a large matrix, distribute power and control signals, route the output

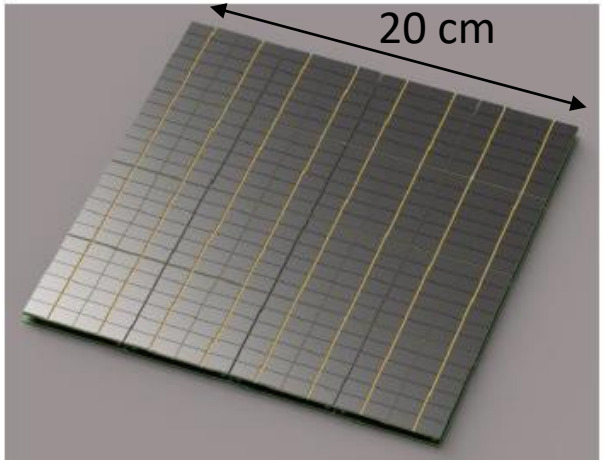


- The first prototype
- 25 Tiles
- Separate PCBs for various functions
- Thick structure (15 cm thick)
- Discrete elements amplifiers
- 25 outputs

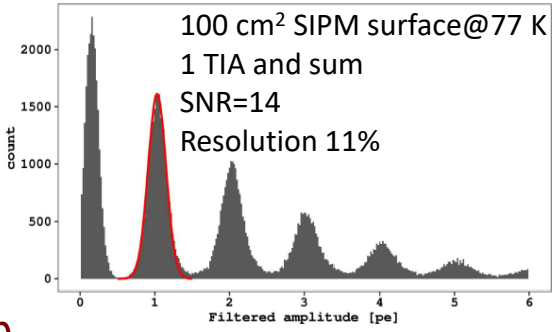


- 25 Tiles
- Separate PCBs for various functions
- Thin structure
- ASIC amplifier
- Sum of two amplified tile signals



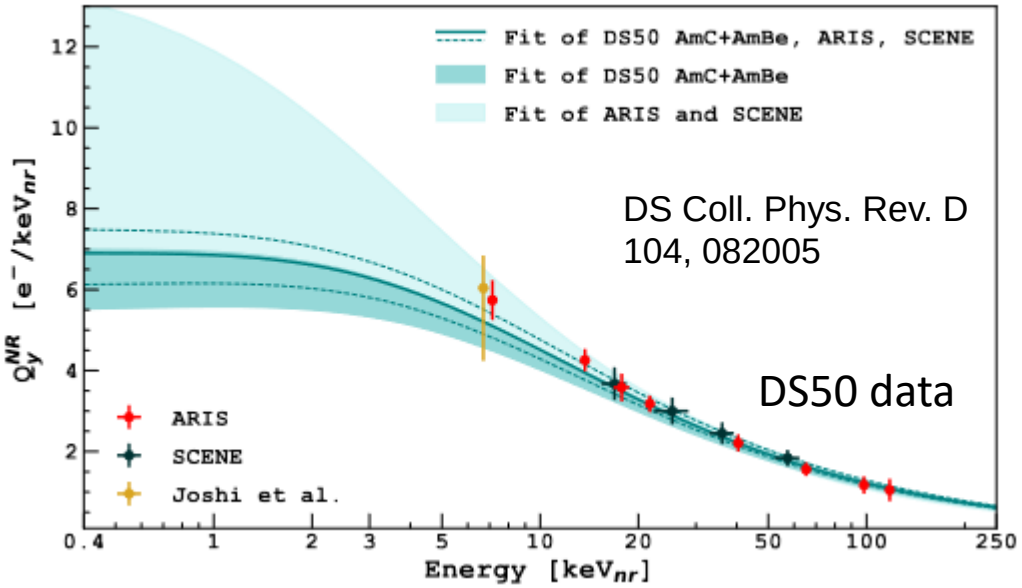



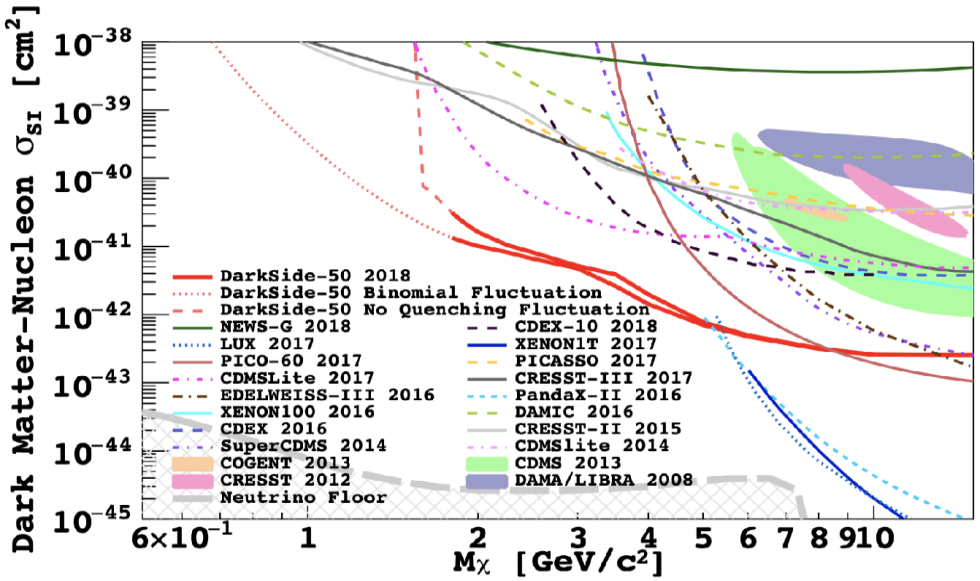

- 16 Tiles
- Single PCB for Tile & amplifier+
- 1 large PCB for control signals
- Thin structure
- Discrete elements (for TPC) and ASIC ( for Veto) amplifier
- Sum of 4 amplified tile signals
- 4 outputs




Baseline solution

# Sensitivity to light dark matter candidates




**High potential of Dual Phase TPC**

S2 signal larger than S1

**S2 only events** allow to identify nuclear recoil with keV and sub keV energy

Sensitivity to low WIMP mass values (few GeV)

- DarkSide-50 ionization-only analysis
  - world-best limit below 5 GeV/c2
  - recent new calibration of ionization response down to ~0.5 keVnr
  - soon new limits on WIMP-nucleon with/without Migdal, WIMP-electrons, solar and galactic axions, sterile neutrinos
- DarkSide-20k sensitivity evaluation in progress

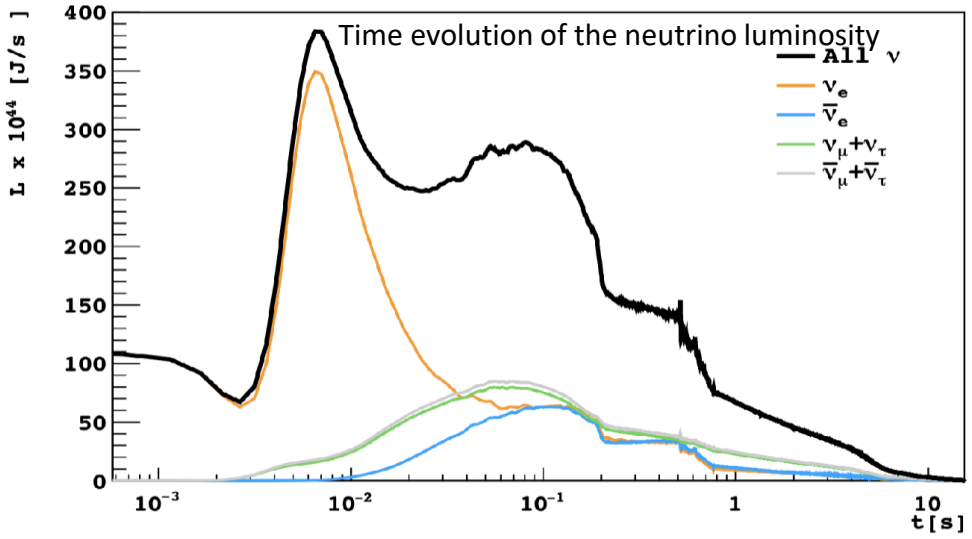
(with high statistics simulations, new observables under definition)

DS Coll. PRL 121 (2018) 081307, DS50 results

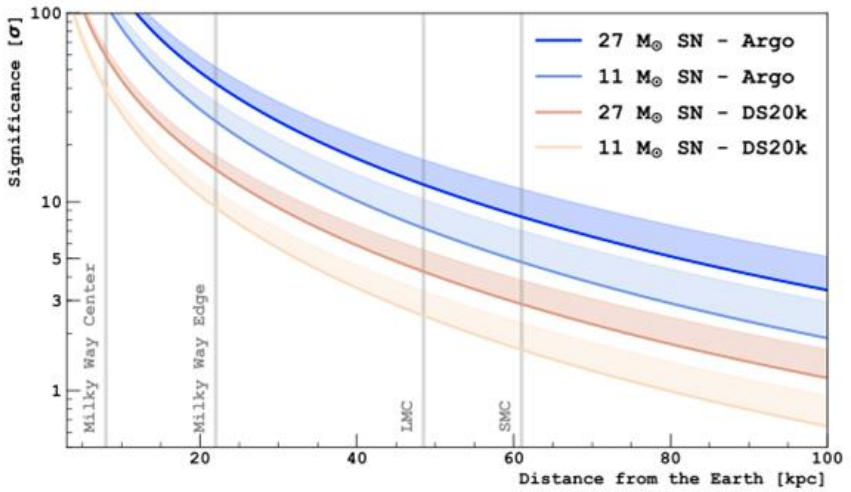
# Sensitivity to core collapse supernova via CENνS

DS20k Coll, JCAP 2021 (2021)

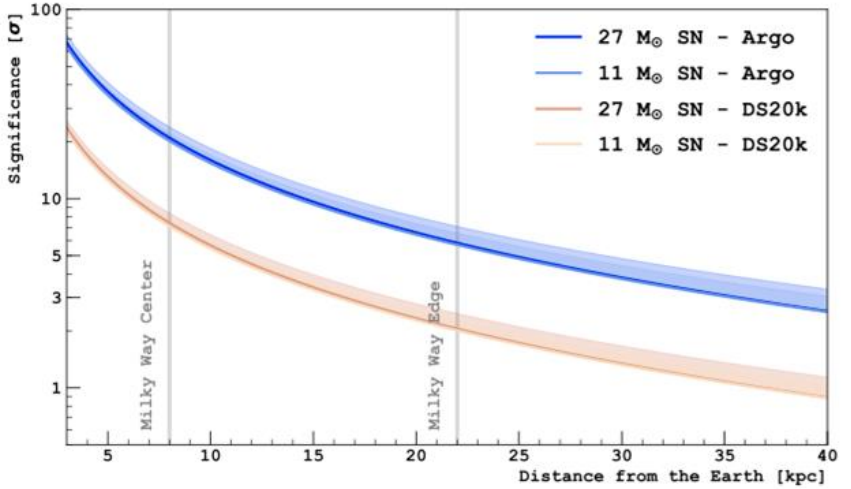
- Detection based on the ionization signal only (S2)
- Threshold down to 0.4 $keV_{nr}$
- Coherent scattering:
  - neutrino flavor insensitive
  - highest neutrino cross section
- Advantages of CENνS in LAr TPC:
  - Sensitive to the entire unoscillated neutrino flux
  - Sensitive to the neutronization burst (the electronic flavor is highly suppressed by oscillations)




Sensitivity to the entire SN neutrino flux




Sensitivity to neutrinos from SN neutronization burst



# Conclusions

- The Global Argon Dark Matter Collaboration (GADMC), with joint global expertise,
  has completed the R&D phase for the DS20k detector
- The Technical Design Report of the DS20k detector has been delivered to INFN on Dec 1, 2021
- Construction of the cryostat will start in 2022
- Full production of SiPMs already started
- URANIA & ARIA ongoing
- Several technologies have been developed :
  - procurement of large amount (≈100 t) UAr
  - acrylic TPC vessels
  - conductive polymers
  - wavelength-shifters
  - reflectors
  - Gd-doped acrylic
  - cryogenics SiPMs
  - cryogenics low noise amplifiers
  - selection of low background materials

- Data taking expected in 2025