





#### IDTM Workshop 14/09/2023 Lisbon

#### Sandro De Cecco Sapienza Università di Roma & INFN Roma

# Direct DM search future direction



## Liquid Argon double phase TPC



Sandro De Cecco

## The DarkSide program timeline



#### DarkSide-50 (end)

Sensitivity to WIMP -nucleon cross section 10<sup>-44</sup> cm<sup>2</sup> for a WIMP mass of 100 GeV/c<sup>2</sup>. Leading S2 only low mass limit (2018). -> Updated result in

-> Updated result in 2022



Acrylic TPC, test first PDM motherboard, S2 studies. Running @ Napoli:





Acrylic TPC to test NR response to low energy recoils



#### <u>TPC Mockup (2023)</u>

Scaled down DS20k version, 0.4t active LAr acrylic TPC.Test: final detector design & UAr cryogenics. CERN -> now LNGS:



#### Sandro De Cecco

#### DarkSide-20k @LNGS (2023-26)

50t UAr (20t fiducial) acrylic TPC, 8280 PDM channels. Acrylic+Gd n-veto in AAr protoDUNE cryostat.100 ton-yr exposure. TDR submitted dec.21, now baselined Sensitivity to WIMP-nucleon cross sec. of 2.10<sup>-48</sup> cm<sup>2</sup> at 100 GeV/c<sup>2</sup> WIMP mass.



Global Ar DM Collaboration, GADMC: ArDM, miniDEAP, DEAP-3600, DarkSide-50 ... and future 300t ARGO

## The proof of principle: DS50 with UAr





5

# DS50 results in high mass DM search

Before and After active neutron veto tagging: zero-background DM search



UAr DS50 TPC background-free for exposure of 44 ty -> DarkSide-20k scales to 200 ty

#### The Underground Argon road: URANIA and ARIA



Also of interest for other future experiments: LEGEND, COHERENT, Argo, DuNe R&Ds

# DS50 results in low mass DM search

DS50 2018 analysis updated in 2023 with new calibration, selection and MC.

Only S2 ionization signal (recoil energy too low to have scintillation S1).

Non zero background search. Limited by energy response at low energy and internal ER back.

World best sensitivity to GeV DM and sub-GeV adding Migdal effect [ 10<sup>-39</sup> ₩ Ŭ

σsı

Matter-Nucleon

10

10-42

10-43

10<sup>-44</sup> มษุ

 $10^{-45}$ 1.2

2.0

3.0

 $M_{\chi} [GeV/c^2]$ 

4.0

6.0

10.0



### DarkSide-20k construction in LNGS Hall-C



# DarkSide-20k inner detector design

- TPC:
  - Active UAr mass: 49.7 tonnes;
  - Fiducial UAr mass: 20.2 tonnes.
- · Active neutron veto
  - Gd-PMMA;
  - Active UAr mass: 32 tonnes.
- SiPM as the photosensor;
- Single readout channel size: 10 cm x 10 cm;
- TPC: 2112 channels:
  - Top and bottom optical plane (OP);
- Veto: 480 channels.



#### DS-20k Inner detector: nested TPC & neutron Veto

- Drift field: 200 V/cm;
- Extraction field: ≥2.8 kV/cm;
- Cathode voltage: -73.38 kV (min).
- Gas pocket thickness: 7.0±0.5 mm.
- LY (@null field) ~10 p.e./keVee;
- S2 yield > 20 p.e./e<sup>-</sup>.
- Acrylic as the main structure (pure and Gddoped);
- E-field:
  - Conductive polymer (Clevios<sup>™</sup>) coating as anode, cathode and field cage rings;
  - SS wire grid;
- ESR as reflector and TPB as wavelength shifter.



## Gadolinium loaded PMMA neutron veto

Gd(MAA)3-doped acrylic with 1 wt% Gd
 concentration —> new material (transparent)

- 15 cm thick panels, 4π coverage: TPC walls, top & bottom endcaps.
- 40 cm thick external UAr buffer with PEN w.l. shifters and SiPMs (+ UAr in TPC) to detect scintillation from Gd gamma's.





# DarkSide-20k cryogenic SiPMs

Technology change from PMT to low background SIPMs to cover large areas w high efficiency

Sandro De Cecco

Parameter	1 SiPM
Pixel pitch	<b>30 X 30 μm²</b>
Fill Factor	76.6%
Active area	689 μm²
Number of cells	94904
Total Area	11.7 x 7.9 mm2
Breakdown voltage[77 K]	26.8 +- 0.2 V
Internal Cross Talk Prob. [77 K]	<33% (7 V over voltage)
Dark noise rate [77 K]	<0.01 Hz/mm2 (7 V over voltage)
After Pulse prob. [77 K] within 5 μs	<10%
PDE [77 K] @420 nm	>40%
Single Cell Capacitance	62.5 +-2.5 fF

- NUV-HD-cryo SiPMs R&D by FBK & DarkSide
- Preproduction tested at cold in several sites
- Tech. Transfer and Production at LFoundry (SiPMs produced in 2022, currently tested
- Mass assembly is starting at LNGS

#### Dark noise rate



S/N ratio > 8; time res. ~ 10 ns PDE: Particle detection efficiency @420 nm 87K After a careful calibration of the light source and mea



13

#### Photo Detection Units production and test

Sandro De Cecco





TPC optical plane (  $\sim 21 \text{ m}^2$ ) 525 PDUs Photo-detection unit 16 tiles arranged into 4 channels Tile / photo-detector module 24 SiPMs + signal amplifier

SiPM (  $\sim 1 \text{ cm}^2$ )

16 Tiles

1 single PCB for the Tile and amplifier (signal peaking time few ns)

• 24 SiPM: 4s 6p + TIA amplifier based on discrete elements for TPC

24 SiPM: 4 X(2s3p) + ASIC amplifier (for the Veto)

1 single 20X20 Arlon based PCB with all functions implemented (MB+, Mother Board +) Thin structure

Sum of 4 amplified tile signals

Differential output

PDU mass **test at Napoli** cryogenic facility also now testing long term performances and PDU prototypes, proto0 for S2 reco + DAQ.





PDU assembly and mass production at NOA clean room, a 400 m<sup>2</sup> new infrastructure at LNGS







#### General neutron background budget in 200 t yr

Total NR background events from alpha-n neutrons in 200 t yr : 0.095

De clement d'anne	Bg events in ROI
Background type	$[200  t  yr]^{-1}$
$(\alpha, n)$ neutrons from U and Th	$9.5  imes 10^{-2}$
Fission neutrons from U-238	$<\!\!2.3 \times 10^{-3}$
Neutrons from Rn-222 diffusion and surface plate-out	${<}1.4 imes10^{-2}$
Cosmogenic neutrons	$<\!\!6.0  imes 10^{-1}$
Neutrons from the lab rock	$1.5  imes 10^{-2}$
Random surface $\alpha$ decay + S2 coincidence	${<}5.0 imes10^{-2}$
Correlated ER + Cherenkov	${<}1.8 imes10^{-2}$
Uncorrelated ER + Cherenkov	${<}3.0 imes10^{-2}$
ER	$< 1.0 \times 10^{-1}$

TABLE 26. Nuclear recoil (NR) backgrounds expected during the full DS-20k exposure, based on current data and Monte Carlo simulations. The right column is the total number of events surviving the veto cut, fiducial volume cut, and PSD.



... + 3.2 events from CEvNS (irreducible atmospheric v background))

Sandro De Cecco

### DarkSide-20k sensitivity



< 0.1 neutrons in Rol (30 - 200 keVnr) with 200 t-y exposure.

Sandro De Cecco

#### LHC and Direct DM search complementarity



Sandro De Cecco

# DarkSide-LowMass sensitivity

For a conceptual low background 1 ton UAr TPC ~ 1 year exposure:



DarkSide-20k sensitivity to low mass DM paper in preparation (will be very high)

# DarkSide-20k construction schedule



#### GADMC: the Global Argon Dark Matter Collaboration



**Global Argon Dark Matter Collaboration : 400 scientists - 14 countries** 

<u>Fundings for DarkSide-20k</u>: INFN, MIUR, CIPE, RA, RAS (Italy), NSF and DOE (U.S.), CFI and NSERC (Canada), STFC (UK), IN2P3 (France), Poland and Spain Ministries for Science and Education



#### DarkSide-20k Cryostat



**CERN - INFN** DARKSIDE COLLABORATION AGREEMENT **KR5321/RCS** Signed January 2022

Including: warm/cold membranes and AAr cryogenic system Installation started in Hall-C: Apr. 23 Sandro De Cecco -> ends in Dec. 2023

## DarkSide-20k in LNGS Hall-C



# DarkSide-20k TPC parameters

- Drift field: 200 V/cm;
- Extraction field: ≥2.8 kV/cm;
- Cathode voltage: -73.38 kV (min).
- Gas pocket thickness: 7.0±0.5 mm.
- LY (@null field) ~10 p.e./keVee;
- S2 yield > 20 p.e./e<sup>-</sup>.
- Acrylic as the main structure (pure and Gddoped);
- E-field:
  - Conductive polymer (Clevios<sup>™</sup>) coating as anode, cathode and field cage rings;
  - SS wire grid;
- ESR as reflector and TPB as wavelength shifter.



#### The Underground Argon road: URANIA and ARIA





## DS-20K keys/URANIA



- CO<sub>2</sub> wells in SW Colorado (near Cortez)
- Contains ~500 ppm Argon
- Air Products started operation of its helium extraction plant in June 2015
  - will provide ~20% of the production for the US National Helium Reservoir in Amarillo, TX
- Will exploit a slip-stream from the helium plant, the new Argon plant will be designed and built by Polaris SRL.

- Procurement of underground argon at the Cortez(Co) site from Kinder Morgan wells will be expanded
- Support by 2013 MIUR
   Progetto Premiale Urania
   (€2.3M) will provide a plant
   capable of extracting 100 kg/
   day of UAr



## DS-20K key points/URANIA

#### URANIA is a Pressure Swing Absorption plant (PSA)



#### Feedstock: 6500 Nm<sup>3</sup>/h; Pin=50bar; Tin=ambient

Gas	Concentration
CO <sub>2</sub>	95.50 %vol
N <sub>2</sub>	3.50 %vol
$CH_4$	0.92 %vol
O <sub>2</sub>	0 %vol
He	300 ppmv
Ar	440 ppmv
Hydrocarbons (*)	420 ppmv

(\*) ethane, propane, isobutane, n-butane, iso-pentane, n-penta

Product: ≅100 kg/d – 2.5Nm<sup>3</sup>/h; Target: Purity=99.9% - Recovery=90%

- Helium plant working, Urania plant engineering completed
- Modular units fabricated in Italy and shipped to US
- Installation in 2022 at Kinder Morgan site in Colorado

## DS-20K key points/ARIA



### DS-20K keys/ARIA



**ARIA:** 350 mt tall **cryogenic distillation column** in Carbo Sulcis Seruci well : Regione Sardegna & INFN initial capital investment

- Seruci-0 module in operation, run with Argon in October 2021

- First article on cryogenic distillation with Aria and results of Seruci-0 run III: published on EPJC: <u>https://link.springer.com/article/10.1140/epjc/s10052-021-09121-9</u>

- Industrial operation to improve availability and affordability of <sup>13</sup>C, <sup>15</sup>N, and <sup>18</sup>O, crucial for medical and nuclear energy applications

ize Comparison

# DarkSide-20k UAr cryogenic systems



#### DarkSide-20k UAr cryogenic system test at CERN



## DarkSide-20k TPC details

#### More TPC Details

Clevios + TPB

- 1. Optical plane support structure
- 2. Gd-Acrylic blocks
- 3. PDU+
- 4. Anode (pure acrylic)
- 5. Wire frame
- 6. Wire frame concentricity guide
- 7. Gd-Acrylic wall panel
- 8. Field cage groove (Clevios coated)
- 9. Reflector panel
- 10. Subassembly pin
- 11. Veto mounting pin sockets
- 12. Liquid ports (location to be confirmed by CFD analysis)





## DarkSide-20k TPC field rings



#### DarkSide-20k Inner detector parameters

TPC Parameter	Value
TPC drift length	$348\mathrm{cm}$
Octagonal inscribed circle diameter (87 K)	$350\mathrm{cm}$
Total LAr mass in titanium vessel	$99.2\mathrm{t}$
LAr mass in TPC	$51.1\mathrm{t}$
Active LAr mass	$49.7\mathrm{t}$
Vertical fiducial cut (nominal)	$70~{ m cm}$
Radial fiducial cut (nominal)	$30 \mathrm{cm}$
Fiducial LAr mass	$20.2\mathrm{t}$
Drift field	$200  \mathrm{V/cm}$
Extraction field	$2.8 \mathrm{kV/cm}$
Luminescence field	$4.2 \mathrm{kV/cm}$
Cathode operating voltage	$-73.38\mathrm{kV}$
Extraction grid operating voltage	$-3.78\mathrm{kV}$
Anode operating voltage	ground
Field cage ring vertical spacing	$4\mathrm{cm}$
Gas pocket thickness	$(7.0\pm0.5)\mathrm{mm}$
Grid optical transparency	97%
Electron drift lifetime for stable S2 generation	$>5\mathrm{ms}$
Projected light yield at null field (S1)	$10  \mathrm{PE/keV}_{ee}$
S2 yield	XX
xy resolution	XX
z resolution	XX
Veto Parameter	Value
Active mass	$32\mathrm{t}$
Light yield	$1988\mathrm{PE/MeV}$
Light yield uniformity	3.0%
Reflective surface	$174\mathrm{m^2}$
SiPM geometrical coverage	3.2%
Gd concentration in PMMA	XX
Ti vessel Parameter	Value
Vessel inner diameter	$4650 \mathrm{~mm}$
Vessel total internal volume	$80 \text{ m}^3$
Total UAr (with TPC inside)	$99.2\mathrm{t}$

#### DarkSide-20k background free strategy

#### **ER backgrounds :**

<sup>39</sup>Ar : expect 1.8x10<sup>8</sup> events in ROI with UAr (based on ) → push PSD to 10<sup>9</sup> (possible) higher LY (*SiPMs*) and/or further depletion factor DAr/UAr O(10-100) from ARIA

<sup>222</sup>**Rn:** if <2μBq/kg (like DS-50) would be 100k events in ROI but will be less due to larger volume/ surface ... and PSD!

**85Kr:** is x3 <sup>39</sup>Ar activity in DS-50  $\rightarrow$  ARIA <sup>85</sup>Kr depletion x1000 ok

v-electron scattering : 20k events in ROI  $\rightarrow$  negligible after PSD

Material radioactivity : subleading after <sup>39</sup>Ar → radiopure SiPMs and ultra clean SS vessel

#### NR backgrounds :

- cosmogenic neutrons ( $\mu$  induced): negligible after WCD and LS veto.
- Material radioactivity : total events in 100 t yr <</li>
   0.1 after veto → radiopure SiPMs and ultra clean
   SS vessel
- v-N CNNS scattering : 1.6 events in 100 t yr  $\rightarrow$  irreducible

DarkSide-20k Neutron background budget:

De allemanuel terre a	Bg events in ROI
Background type	$[200  t  yr]^{-1}$
$(\alpha, n)$ neutrons from U and Th	$9.5 \times 10^{-2}$
Fission neutrons from U-238	$<2.3 imes10^{-3}$
Neutrons from Rn-222 diffusion and surface plate-out	$< 1.4 \times 10^{-2}$
Cosmogenic neutrons	${<}6.0 imes10^{-1}$
Neutrons from the lab rock	$1.5  imes 10^{-2}$
Random surface $\alpha$ decay + S2 coincidence	${<}5.0 imes10^{-2}$
Correlated ER + Cherenkov	${<}1.8 imes10^{-2}$
Uncorrelated ER + Cherenkov	${<}3.0 imes10^{-2}$
ER	$< 1.0 \times 10^{-1}$

TABLE 26. Nuclear recoil (NR) backgrounds expected during the full DS-20k exposure, based on current data and Monte Carlo simulations. The right column is the total number of events surviving the veto cut, fiducial volume cut, and PSD.