Dark Matter group: P.N. 2022-2025

R.Santorelli
on behalf of DM-CIEMAT

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
cfp CIEMAT física de partículas
DARKSIDE

The CIEMAT DM people

Dark Matter-DD with argon and detector developments

Group members:

Pablo Garcia	(physicist) → 100%
Luciano Romero	(physicist) → 100%
Roberto Santorelli	(physicist) → 100%
Vicente Pesudo	(physicist) → 100%
Miguel Cardenas	(physicist) → ~50%
J.M. Cela	(physicist) → ~50%
Manuel Daniel	(engineer) → ~50%
Estefania Conde	(chemist) → ~50%
Ana Barrado	(chemist) → ~50%
Marta Fernandez	(chemist) → ~50%

Technicians:

J.J. Martinez (technician)
R. Lopez (technician)

PhD student:

L. Luzzi (2nd yr)

History

http://darkmatter.ciemat.es/funded-projects

- **PID2019-109374GB-I00** (MICINN).
  PI: Roberto Santorelli, Pablo García Abia.
  Title: *Direct WIMP search with the Global Argon Dark Matter Collaboration.*
  Validity period: 2020-2022.

- **FPA2017-92505-EXP** (Subprograma Estatal de Generación del Conocimiento/EXPLORA).
  PI: Roberto Santorelli.
  Title: *Discriminación de partículas con un detector de argón a alta presión para el estudio de materia oscura.*
  Validity period: 2019.

- **FPA2017-82647-P** (MINECO).
  PI: Roberto Santorelli, Luciano Romero.
  Title: *Dark matter direct search with the ArDM/DarkSide-20k experiments and R&D on argon detector technology.*
  Validity period: 2018-2019.

- **FPA2015-70657-P** (MINECO).
  PI: Roberto Santorelli, Luciano Romero.
  Title: *Participation of CIEMAT in the ArDM experiment.*

Nº	REFERENCIA	Propuesta de financiación (en euros)						
		Presupuesto total concedido	Por concepto de gasto		Por anualidades			
			Costes directos	Costes indirectos	2020	2021	2022	2023
482	PID2019-109374GB-I00	242.000,00	200.000,00	42.000,00	24.200,00	121.000,00	96.800,00	0,00

PID2019-109374GB: 200 k€ C. directos / 0 becas

Evaluation

1.Calidad y viabilidad de la propuesta	**Valoración de 0 a 55**	**: 50.25 (>40)**
1.1. Calidad	Valoración de 0 a 40	: 37.5
1.2 Viabilidad	Valoración de 0 a 15	: 12.75
2. Equipo de investigación	**Valoración de 0 a 30**	**: 25.5 (>20)**
3. Impacto	**Valoración de 0 a 15**	**: 13.94 (>5)**
3.1. Impacto CT de los resultados	Valoración de 0 a 10	: 9.56
3.2. Impacto social y económico	Valoración de 0 a 5	: 4.38
VALORACIÓN FINAL	**Puntuación de 0 a 100**	**: 89.69**

Scientific production (2019-2022)

http://darkmatter.ciemat.es/publications

1. *Time and band-resolved scintillation in time projection chambers based on gaseous xenon*, **S. Leardini et al.**, EPJ-C accepted (2022), DOI: 10.1140/epjc/s10052-022-10385-y, e-Print: arXiv:2112.04750 [physics.ins-det].
2. *Measurement of the muon flux in the bunker of Monte Soratte with the CRC detector*, **A. Candela et al.**, NIM-A 1031 (2022) 166514, DOI: 10.1016/j.nima.2022.166514, e-Print: arXiv:2106.02739 [physics.ins-det].
3. *Experimental Study of the Positive Ion Feedback from Gas to Liquid in a Dual-Phase Argon Chamber and Measurement of the Ion Mobility in Argon Gas*, **L. Romero, R. Santorelli, E. Sánchez García, et al.**, Universe 2022, 8,134. DOI: 10.3390/universe8020134, e-Print: arXiv:2112.14725 [physics.ins-det].
4. *High voltage pulse generator*, **R. López Manzano, L. Romero Barajas, E. Sánchez García**, Technical Note CIEMAT-DM 1/2021.
5. *Electronic driver for DArT platinum resistances*, **L. Romero, R. López Manzano, J.M. Cela Ruiz**, Informe Técnico CIEMAT 1504 (2021). ISBN/ISSN: 2695-8864.
6. *Pulse-shape discrimination against low-energy Ar-39 beta decays in liquid argon with 4.5 tonne-years of DEAP-3600 data*, **Adhikari, P., Ajaj, R., Alpizar-Venegas, M. et al.**, Eur. Phys. J. C 81, 823 (2021). DOI: 10.1140/epjc/s10052-021-09514-w.
7. *Spectroscopic analysis of the gaseous argon scintillation with a wavelength sensitive particle detector*, **R. Santorelli et al.**, Eur. Phys. J. C 81, 622 (2021). DOI: 10.1140/epjc/s10052-021-09375-3, e-Print: arXiv:2012.08262 [physics.ins-det].
8. *The novel Mechanical Ventilator Milano for the COVID-19 pandemic*, **A. Abba et al.**, Physics of Fluids 33, 037122 (2021). DOI: 10.1063/5.004444.
9. *Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos*, **The DarkSide-20k collaboration**, JCAP 03 (2021) 043. DOI: 10.1088/1475-7516/2021/03/043, e-Print: arXiv:2011.07819 [astro-ph.HE].
10. *SiPM-matrix readout of two-phase argon detectors using electroluminescence in the visible and near infrared range*, **The DarkSide-20k collaboration**, Aalseth, C.E., Abdelhakim, S., Agnes, P. et al., Eur. Phys. J. C 81, 153 (2021). DOI: 10.1140/epjc/s10052-020-08801-2, e-Print: arXiv:2004.02024 [physics.ins-det].
11. *Separating 39Ar from 40Ar by cryogenic distillation with Aria for dark-matter searches*, **The DarkSide-20k Collaboration**, P. Agnes et al., Eur. Phys. J. C 81, 359 (2021), DOI: 10.1140/epjc/s10052-021-09121-9, e-Print: arXiv:2101.08686 [physics.ins-det].
12. *The liquid-argon scintillation pulseshape in DEAP-3600*, DEAP Collaboration, P. Adhikari et al., Eur. Phys. J. C (2020) 80:303, DOI: 10.1140/epjc/s10052-020-7789-x, e-Print: arXiv:2001.09855 [physics.ins-det].
13. *Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon*, **The DarkSide-20k Collaboration**, C.E. Aalseth et al. 2020 JINST 15 P02024 (corresponding author **E. Sánchez Garcia**), February 2020, DOI: 10.1088/1748-0221/15/02/P02024, e-Print: arXiv:2001.08106 [astro-ph.IM].
14. *DArT, a detector for measuring the ^{39}Ar depletion factor*, **E. Sánchez Garcia**, 2020 JINST 15 C02044, LIDINE 2019 conference proceedings, February 2020, DOI: 10.1088/1748-0221/15/02/C02044, e-Print: arXiv:2001.08077 [physics.ins-det].
15. *AVOLAR: A high voltage generator for liquid argon time projection chambers*, **L. Romero, J.M. Cela, E. Sánchez García, M. Daniel, M. de Prado**, 2020 JINST 15 C03057, LIDINE 2019 conference proceedings, DOI: 10.1088/1748-0221/15/03/C03057, February 2020, e-Print: arXiv:2001.05268 [physics.ins-det].
16. *Neutron production induced by α-decay with Geant4*, **E. Mendoza, D. Cano-Ott, P. Romojaro, V. Alcayne, P. Garcia Abia, V. Pesudo, L. Romero, R. Santorelli**, NIM-A 960 (2020) 163659, DOI: 10.1016/j.nima.2020.163659, February 2020, e-Print: arXiv:1906.03903 [hep-ph].
17. *Electromagnetic Backgrounds and Potassium-42 Activity in the DEAP-3600 Dark Matter Detector*, **DEAP Collaboration, R. Ajaj et al.**, Phys. Rev. D 100, 072009 (2019), e-Print: arXiv:1905.05811 [nucl-ex].
18. *Neutrino Physics with the PTOLEMY project*, **PTOLEMY Collaboration, M.G. Betti et al.**, JCAP 1907 (2019) 047, DOI: 10.1088/1475-7516/2019/07/047, e-Print: arXiv:1902.05508 [astro-ph.IM].
19. *A Design for an Electromagnetic Filter for Precision Energy Measurements at the Tritium Endpoint*, **PTOLEMY Collaboration, M.G. Betti et al.**, *Progress in Particle and Nuclear Physics* Vol. 106 (2019) 120-131, DOI: 10.1016/j.ppnp.2019.02.004, e-Print: arXiv:1810.06703 [astro-ph.IM].

Eur. Phys. J. C (2021) 81:622
https://doi.org/10.1140/epjc/s10052-021-09375-3

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Spectroscopic analysis of the gaseous argon scintillation with a wavelength sensitive particle detector

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Abstract We performed a time-resolved spectroscopic study of the VUV/UV scintillation of gaseous argon as a function of pressure and electric field, by means of a wavelength sensitive detector operated with different radioactive sources. Our work conveys new evidence of distinctive features of the argon light which are in contrast with the general assumption that, for particle detection purposes, the scintillation can be considered to be largely monochromatic at 128 nm (second continuum). The wavelength and time-resolved analysis of the photon emission reveal that the dominant component of the argon scintillation during the first tens of ns is in the range [160, 325] nm. This light is consistent with the third continuum emission from highly charged argon ions/molecules. This component of the scintillation is field-independent up to 25 V/cm/bar and shows a very mild dependence with pressure in the range [1, 16] bar. The dynamics of the second continuum

performances better than the ones reachable with other technologies. In gas phase, their exceptional calorimetric properties are used for instance in [9,10].

A central aspect of either single or dual phase (gas-liquid) noble element detectors is their efficient collection and detection of the vacuum ultraviolet (VUV) scintillation photons, which provides calorimetric data, event time for the 3D event reconstruction, and particle identification capability [11,12]. Experimental information, obtained largely from the closely related fields of photo-chemistry, plasma and laser physics, allows attributing this characteristic scintillation to the bond created between excited and ground state atoms through 3-body collisions (see, e.g., [13]). The resulting singlet and triplet excimer states (Rydberg states with a dimer core and a binding electron) undergo radiative de-excitation, giving rise to the so-called *second excimer continuum*. It is typi-

Eur. Phys. J. C **81**, 622 (2021).

Scientific production (2019-2022)

http://darkmatter.ciemat.es/master-and-phd

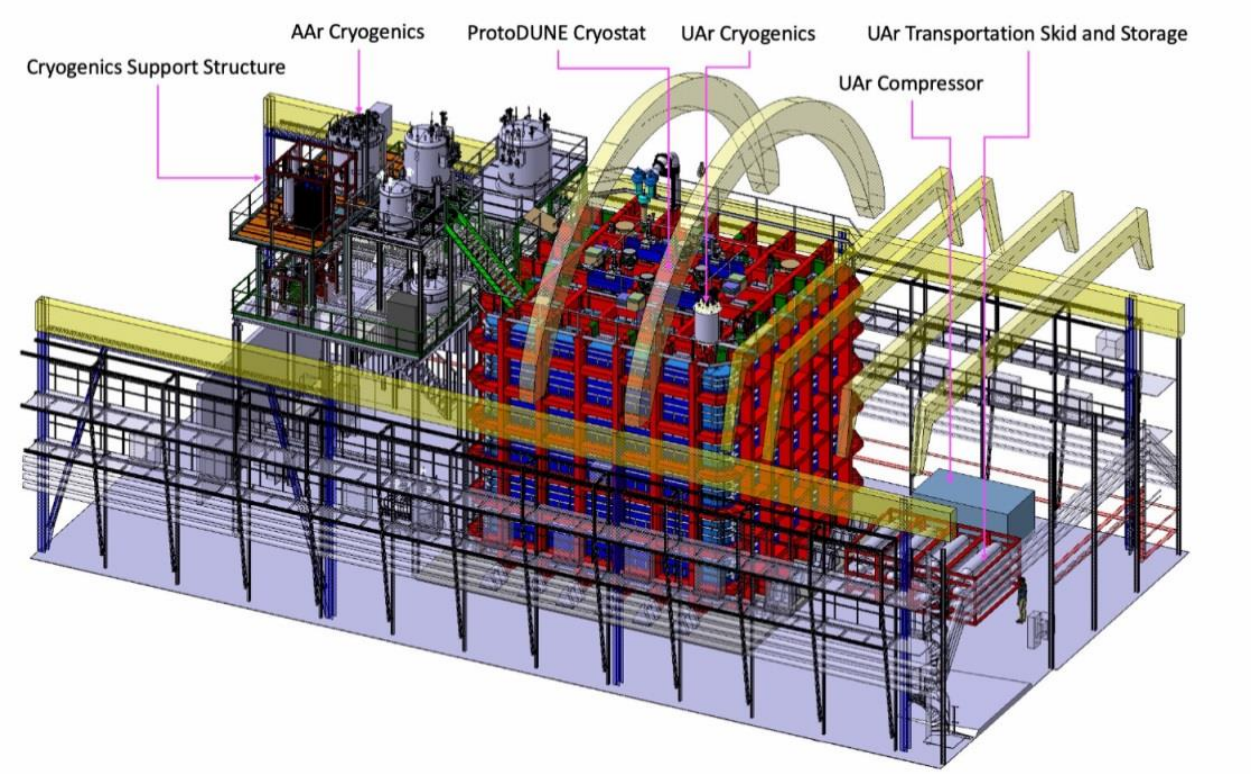
- 1 PhD thesis
- 8 Master thesis
- 28 talks (TAUP, La Thuile, DM, PANIC, CPAN..)
- 1 EXPLORA
- Step 2 for an ERC starting grant
- 2 Workshops organized
- 2 collaboration meetings
- 1 conference next year

A successful technology

'00s ~Kg-scale

'10s ~ton-scale

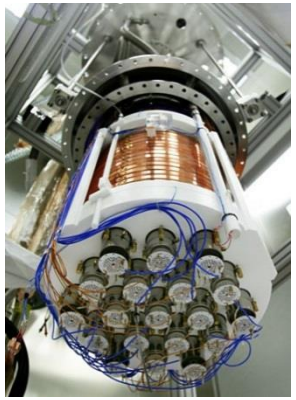
'20s ~tens of ton



GADMC: towards 200 t·yr

- There is a remarkable and unique opportunity for large exposures (~200 t·yr) in **background-free mode** with a massive argon TPC
- The dual-phase LAr-TPC is able to exceed the current experimental limits, reaching the neutrino floor
- ***GADMC***: Collaboration with groups from DS-50, ArDM, DEAP-3600 and MiniCLEAN (major expertise in Argon based detectors) ~500 people, about 100 Institutions

DarkSide-50@LNGS

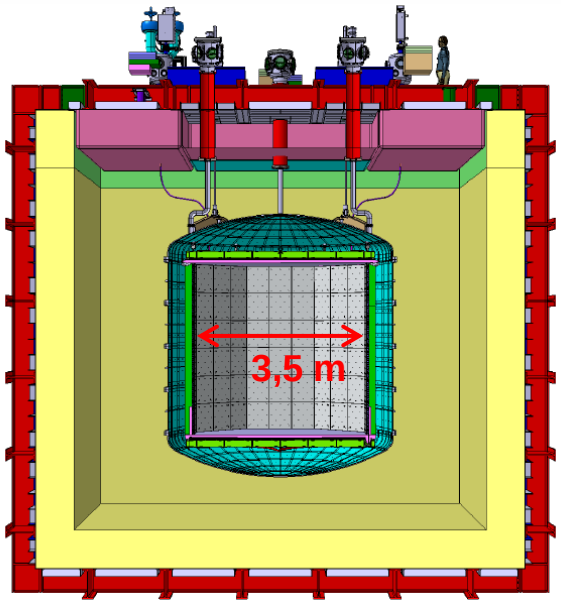


Mini Clean@SNOLAB

DEAP-3600@SNOLAB

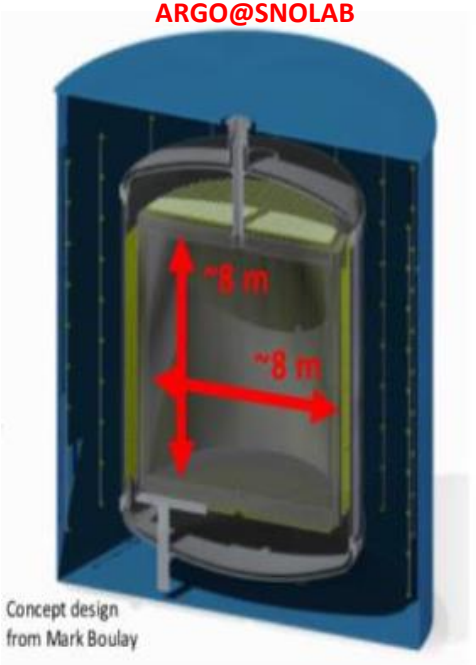
ArDM@LSC

DarkSide-20k@LNGS



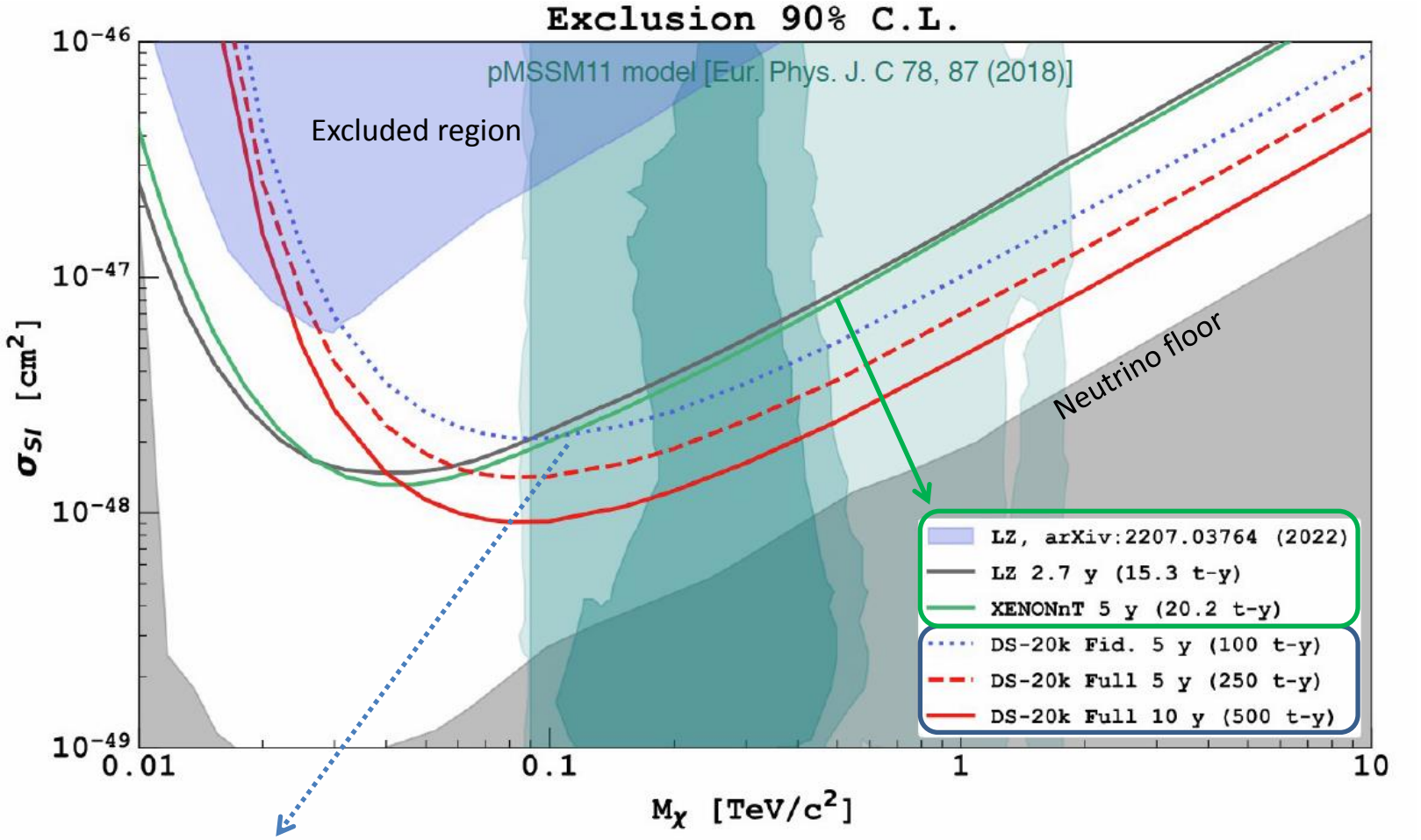
Data taking from 2025
51 t total mass
20 t × 10 yr

ARGO@SNOLAB



Conceptual studies in progress
3 kt x 10 yr

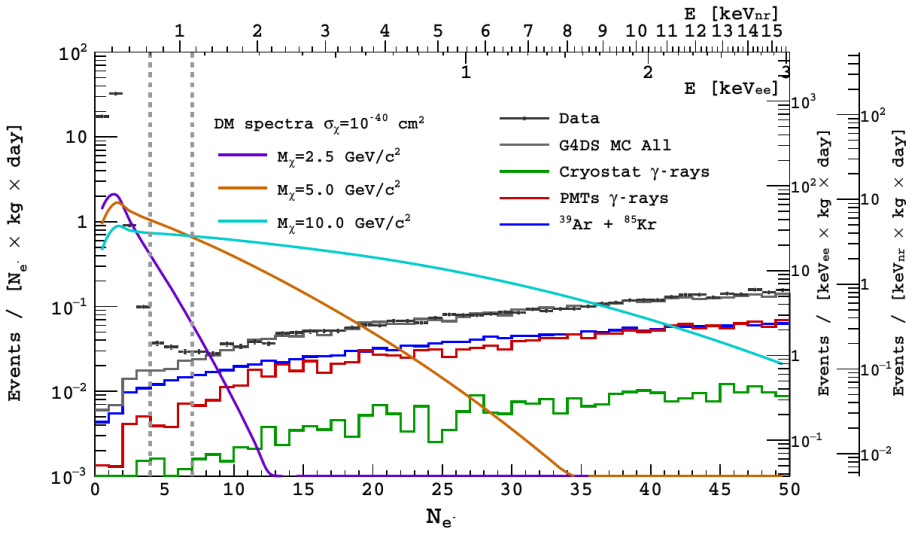
Sensitivity (SI)

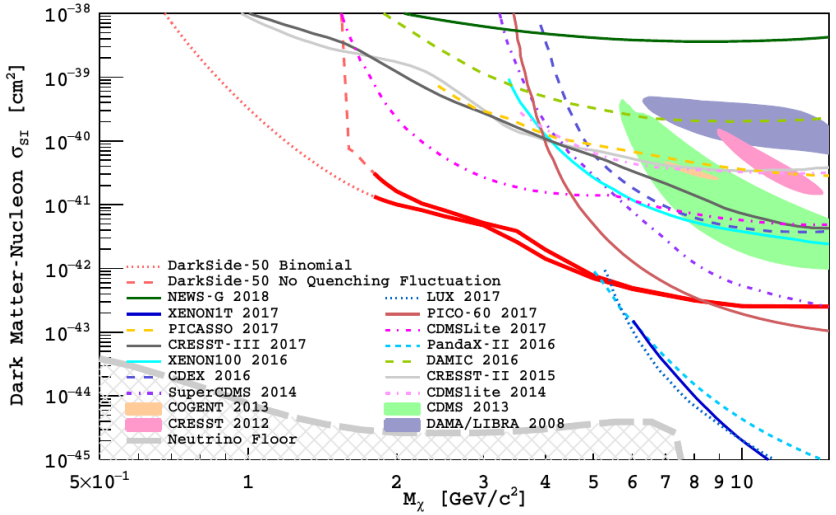


- **6.3×10^{-48} cm^2 for 1 TeV/c^2 WIMP (90% C.L.)**
- **2.1×10^{-47} cm^2 (5σ) discovery**
- **nominal exposure: (20×10) t·yr**
- **background: 0.1 events**

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

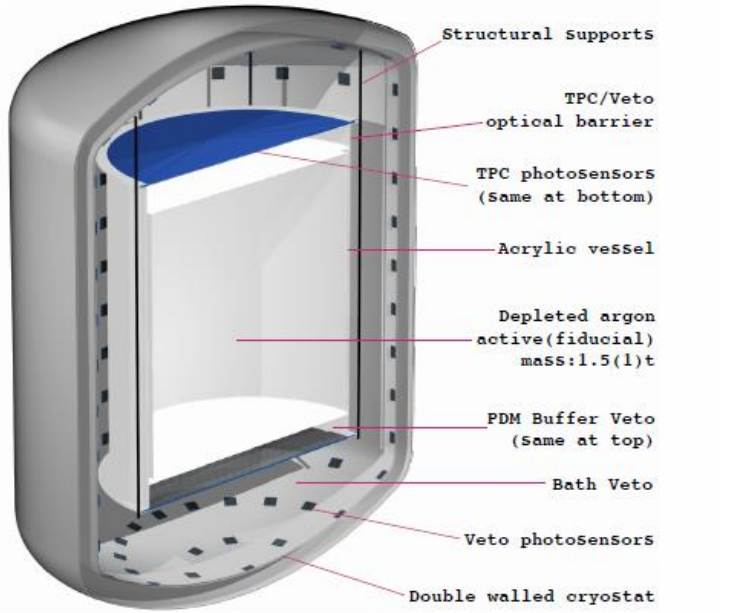
Low-mass, SN…





DarkSide-50@LNGS

Phys.Rev.Lett. 121 (2018)

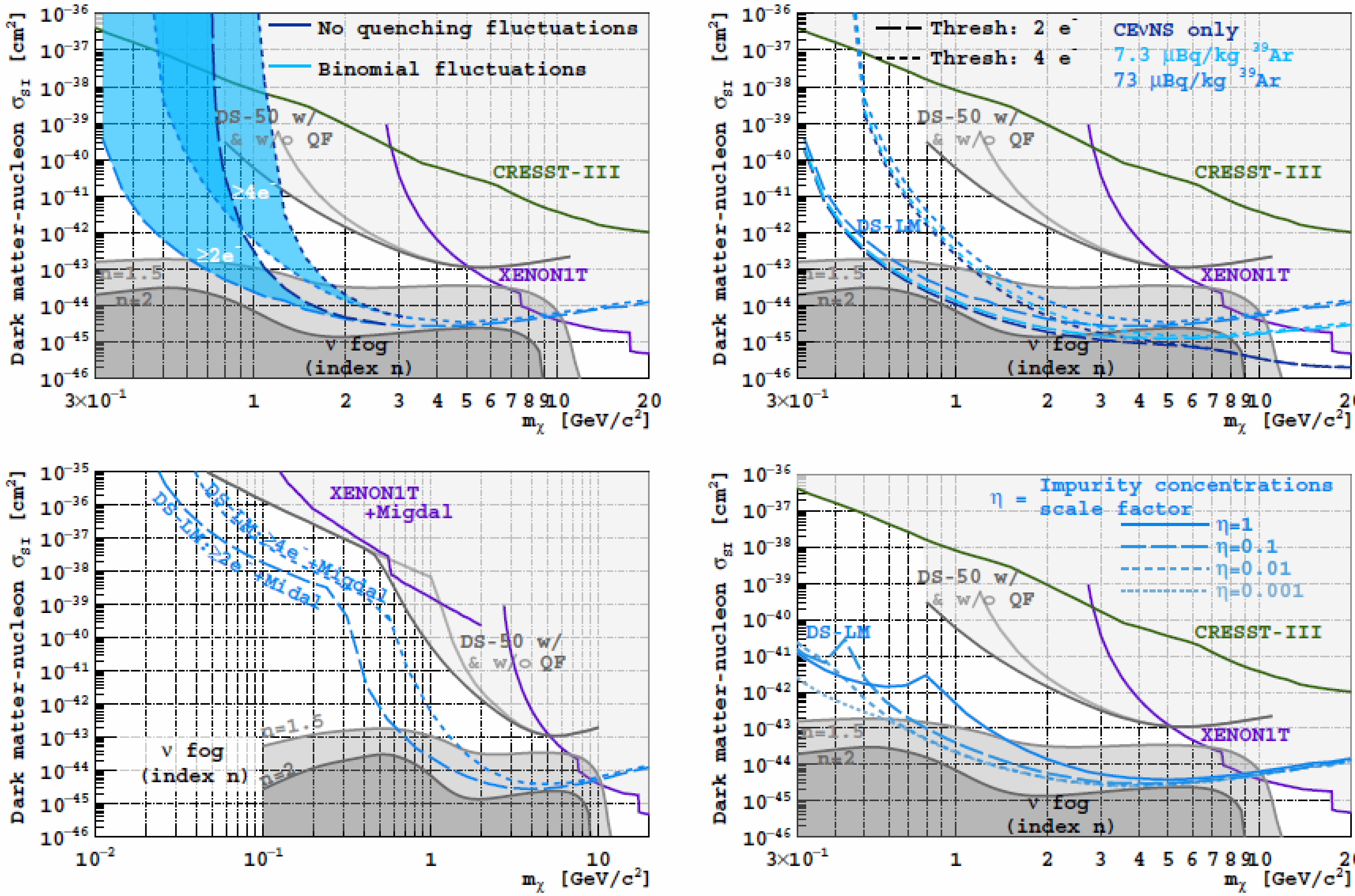


arXiv:2209.01177

- 1.5 t dual-phase Ar-TPC
- acrylic vessel
- 10 cm buffer vetoes
- UAr bath veto

Physics program beyond WIMPs:

- Exotic DM searches
- Low mass DM searches (DS-LowMass)
- Solar axions
- SuperNova neutrinos
- …. And more



No quenching fluctuations
Binomial fluctuations
DS-50 w/ & w/o QF
CRESST-III
XENON1T
≥4e⁻
≥2e⁻
n=1.5
n=2
ν fog (index n)
Dark matter-nucleon σ_SI [cm²]
m_χ [GeV/c²]
Thresh: 2 e⁻
Thresh: 4 e⁻
CEνNS only
7.3 μBq/kg ³⁹Ar
73 μBq/kg ³⁹Ar
DS-LM
XENON1T +Migdal
DS-LM:≥4e⁻+Migdal
DS-LM:≥2e⁻+Migdal
η = Impurity concentrations scale factor
η=1
η=0.1
η=0.01
η=0.001

Technology breakthrough: Radiopurity

Very demanding background requirements (< 0.1 in 10 yr exposure):
PSD alone is not sufficient

Strategy:

➢ Assay all materials of the detector

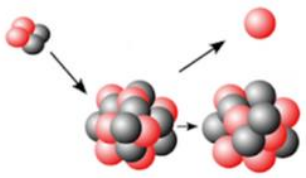
- Worldwide effort **Canada, Italy, France, Poland, Russia, Spain, UK, US**…
- Counting facilities in four Underground laboratories involved (Boulby, LNGS, LSC, SNOLAB)
- 3 different techniques employed: ICPMS, HPGe, Po extraction for Upper, Middle and Lower ^{238}U chain
- Hundreds of assays carried-out
- Platform to store and manage the results of the material assay campaign

➢ Full characterization and calculation of the materials background

- Control of the cosmogenic activation of materials
- Control of the surface contamination
- Evaluation of the radioactive budget of the experiment including activation UG
- Evaluation of the systematic uncertainty from the material composition
- New MC tools for (α, n) calculations

DarkSide is the first experiment with the (a,n) neutron background fully calculated with Geant4

Simple and versatile tool provided to the community **SaG4n**
(http://win.ciemat.es/SaG4n/)
"Neutron production induced by α-decay with Geant4",
Nucl. Instrum. Methods A 960, 163659 (2020)



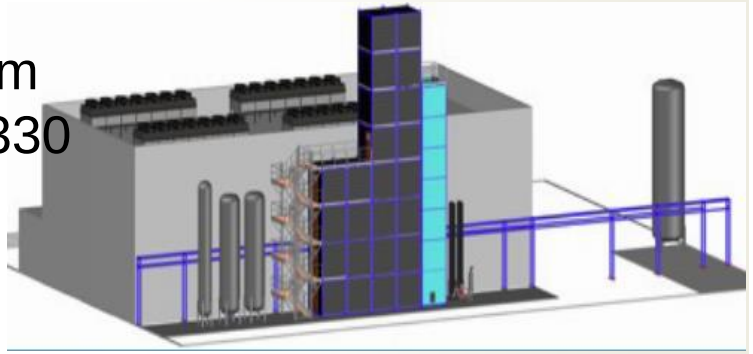

Deep underground laboratory support for global collaboration towards discovery of dark matter utilising liquid argon detectors.

To whom it may concern;

As hosts of the existing operational liquid argon direct dark matter detectors, and as proponents and supporters of the Underground-GRI initiative, the LNGS, SNOLAB and LSC deep underground research facilities are pleased to recognize the collaborative developments within the global liquid argon dark matter community. The DarkSide project at LNGS, the DEAP project at SNOLAB and the ArDM project at LSC are all developing new technologies and capabilities to search for WIMP dark matter, and are beginning to coalesce into one collaboration to develop future, larger generations of liquid argon direct dark matter detectors. We encourage and support the development of this global community, with a focus on the development of DarkSide-20k at LNGS in the first instance, and a larger detector at a location to be determined from scientific requirements, in the future. Using available assay and research infrastructure, the three deep underground research facilities will support the activities and development of the various generations of liquid argon detectors.

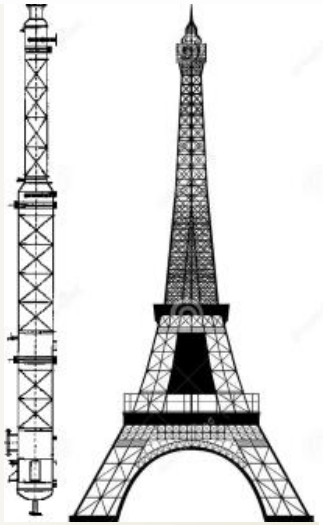
Technology breakthrough: radiopure Ar

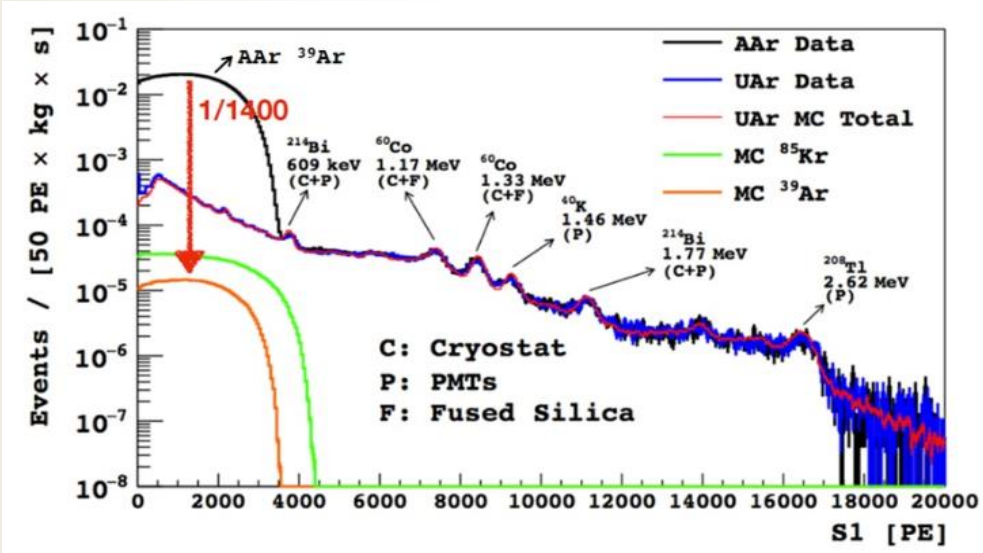
- **URANIA** project:
  Procurement of 50 ton of UAr extracted from the CO_2 wells at Cortez mine, Colorado (~330 kg/d, 99.99% purity)



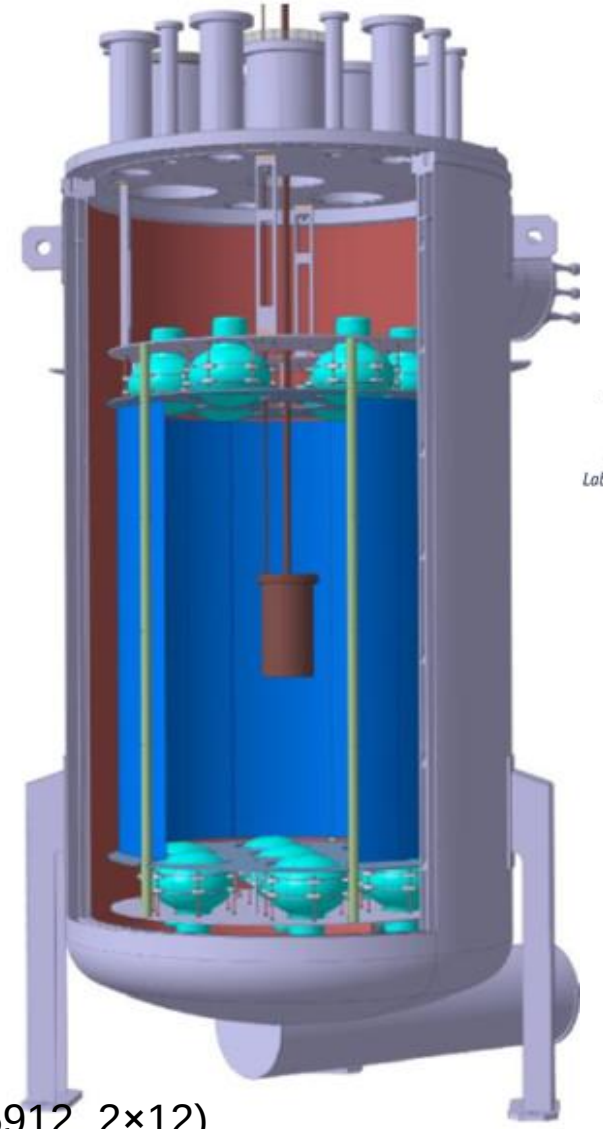
- **ARIA** project:
  - Seruci 1: chemical purification of the UAr by cryogenic distillation (reduction factor 1000 per pass, 1 t/d)
  - Seruci 2: Active Ar-39 depletion via isotope distillation

28 modules,
360 m in total

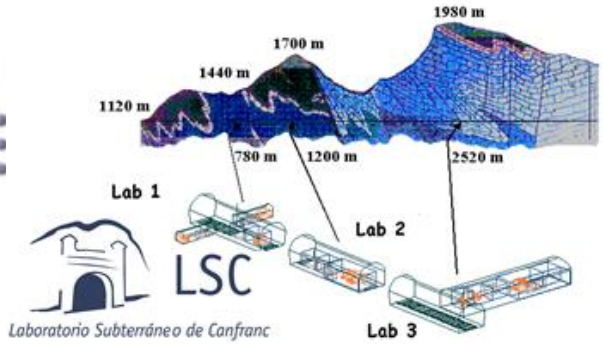




UAr radiopurity measurement: DArT in ArDM



LSC in Spain



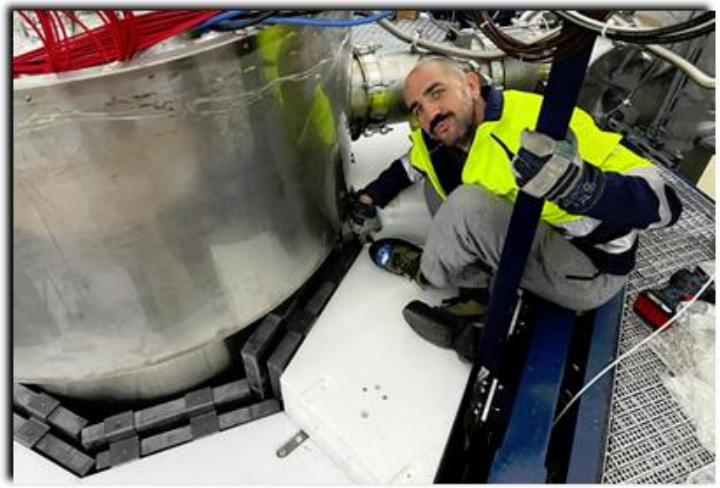
Main Lab under mount Tobazo

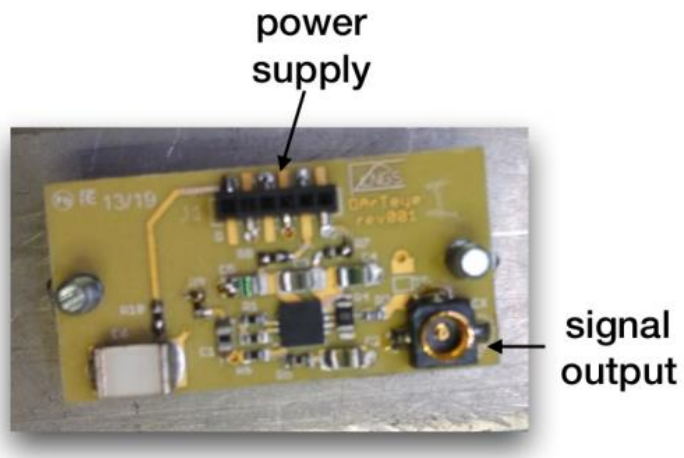
- ~850 m rock
- ~2400 mwe
- 1400 m^2

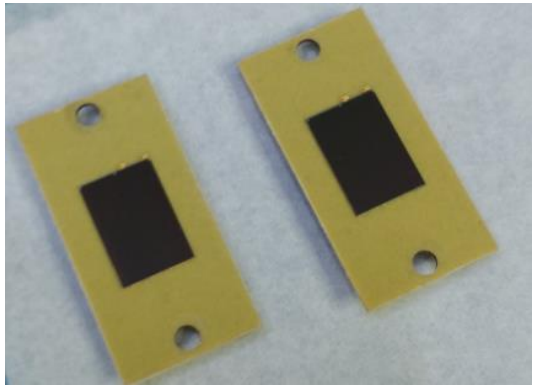
ArDM

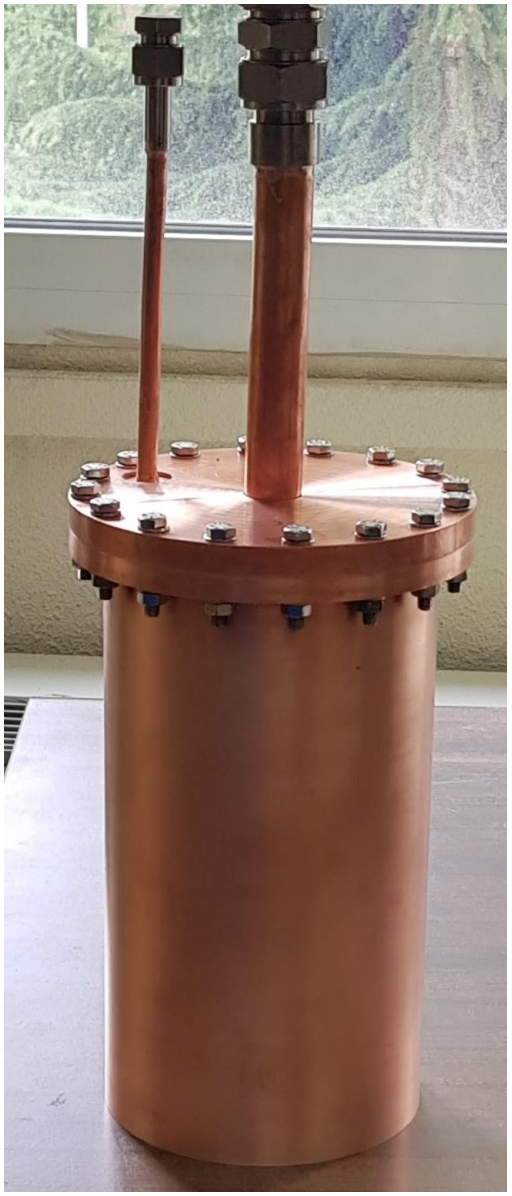
- Double-phase EL-TPC
- 850 kg active volume (≈2 t total)
- Cryogenic low rad. PMT arrays (R5912 2×12)
- 50 cm passive neutron shield (Poly, 20 ton)
- Data taken 2014-2018

UAr radiopurity measurement: DArT in ArDM




power
supply
signal
output





A Facility for Low-Radioactivity Underground Argon

Henning O. Back[1,*,†,‡], Walter Bonivento[2,§], Mark Boulay[3,‡,**], Eric Church[1,††], Steven R. Elliott[4,‡‡], Federico Gabriele[5,§], Cristiano Galbiati[6,7,§§], Graham K. Giovanetti[8,§§], Christopher Jackson[1,††], Art McDonald[9,§§,**], Andrew Renshaw[10,‡], Roberto Santorelli[11,***], Kate Scholberg[12,††,†††], Marino Simeone[13,‡], Rex Tayloe[14,†††], Richard Van de Water[4,‡‡‡]

1. Pacific Northwest National Laboratory, Richland, Washington 99352, USA
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9. Queen's University, Kingston, ON K7L 3N6, Canada
10. University of Houston, Houston, Texas 77204, USA
11. CIEMAT, Madrid 28040, Spain
12. Duke University, Durham, North Carolina 27708, USA
13. Università degli Studi di Napoli "Federico II", Napoli 80125, Italy
14. Indiana University, Bloomington, Indiana 47405, USA

* *Corresponding author. PNNL, 902 Battelle blvd., P.O. Box 999, MSIN J4-65, Richland, WA 99352 Email:henning.back@pnnl.gov*
† Representing environment and applied sciences
‡ Representing the Urania portion of GADMC/Darkside-20k
§ Representing the Aria portion of GADMC/Darkside-20k
** Representing the DEAP-3600 collaboration
†† Representing the DUNE-like detector
‡‡ Representing the LEGEND collaboration
§§ Representing the GADMC/Darkside-20k collaboration
*** Representing the DART portion of GADMC/Darkside-20k
††† Representing the COHERENT collaboration
‡‡‡ Representing the Coherent Captain-Mills (CCM) collaboration

Recent management positions

In the GADM collaboration:

- **Spanish representative** in the Global Argon Dark Matter Collaboration, 2017-present
- **Level-1 manager** of the DarkSide-20k project (responsible for the background of the experiment), 2016-present
- **DS-Mat/Bkg WG** convener
- Member of the **rules committee** 2017-2019
- Member of the DarkSide-20k **executive board / management board**, 2018-present
- **Chair** of the DarkSide-20k advisory committee (elected position), 2017-2021
- **Run coordinator** in DEAP-3600
- **Technical coordinator** of DArT

Goals of our proposal

Darkside-20k	• **Material analysis/Radiopurity** • **Construction** • **MC/Bkg calculation** • **DEAP-3600 analysis**
DArT in ArDM	• **Construction** • **Operations** • **Data taking / analysis**
R&D	• **Charge (AVOLAr/ArIon)** • **Light (LArDis/PILSNER)**

Funds request

- With the current funds our participation in GADMC is not viable
- Travels: constant presence @ LSC (2 people)
- Trips to LNGS for the next 3 y
- DS-20k construction funds (81 k€)

} ~250 k€

- Assay campaign (~ 50 k€)
- DArT construction/operation (~ 100 k€)
- R&D Charge/light (~ 100 k€)
- Personnel: student+postdoc for data analysis
- Common funds (~ 100 k€)

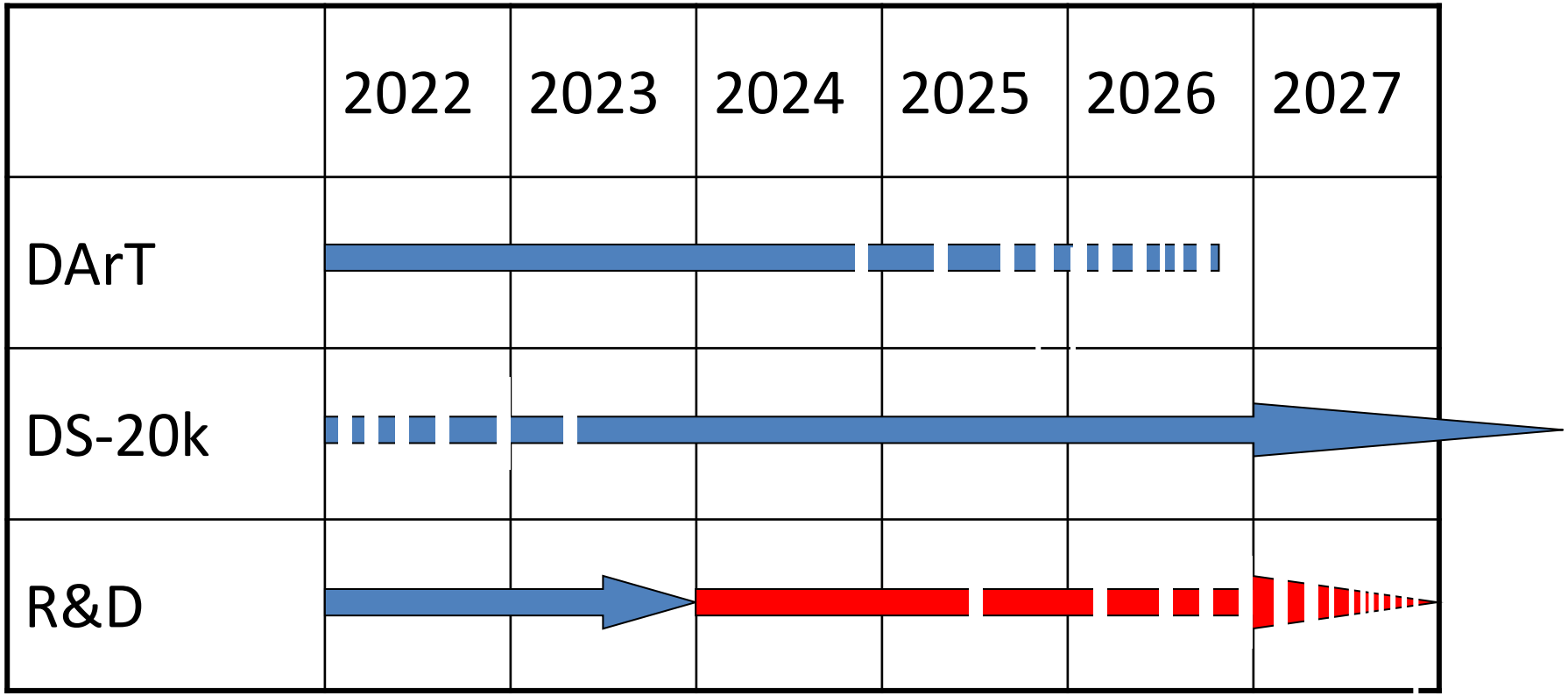
Conclusions / remarks

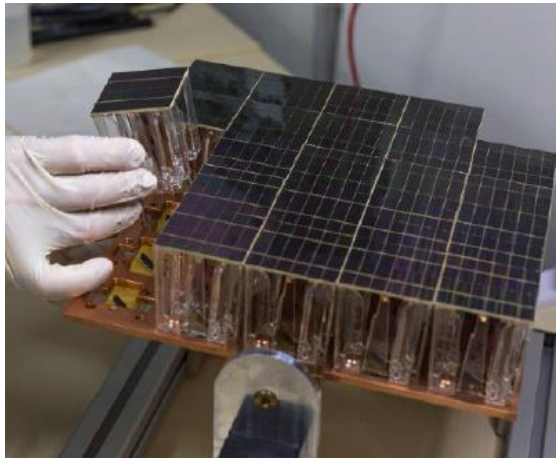
- Our group already demonstrated to be able to take a leading role in a huge international collaboration thanks to the specific expertise
- This expertise cannot be lost!
- We have a clear scientific plan with strong connection at international/national level
- Fundamental connection with an important Spanish ICTS
- Outstanding synergies at national level

Conclusions / remarks

- We are still pretty much in survival mode
- PID2019-109374GB only for travels
- Very limited budget for the R&D (Only Consumables?)
- No predoc contract (we need two)

- Coordinated project with Zaragoza (ANAIS group)
- Resource board representative


2022
2023
2024
2025
2026
2027
DArT
DS-20k
R&D



Backup

Goals of this proposal: A

Working Package	Name	Activity ID	Description	Goals and Milestones
A	**DarkSide-20k**	A1	Coordination of the material radiopurity assay campaign	• Material screening with mass spectroscopy at CIEMAT (>2 samples/month) • Material screening with high purity Ge crystals at LSC (>2 samples/month). • Analysis of surface and bulk contamination with large area foils deployed in BiPo-3 at LSC (1 samples/month). • Leading the cross-calibration campaign between the counting facilities in 4 different underground laboratories: Boulby, LNGS, LSC, SNOLAB. • Development of the material database with the results of all the assays. • Analysis of the screening results and definition of the impact on the background of the experiment.
		A2	Detector Construction	• Procurement of the raw materials. • Completing the construction of the mechanical pieces of TPC prototype (1 m). • Machining and construction of the mechanical pieces (4 m) of the DS-20k TPC. • Mechanical tests and shipment to LNGS.
		A3	Analysis and simulation	• Final Monte Carlo simulation for the estimation of the intrinsic detector background from the analysis of the material contamination results. • Consolidation of the new Geant4 tools recently developed for the (α,n) neutrons energy spectrum and flux calculation. • Radioactive budget consolidation: calculation of the expected irreducible neutron backgrounds (single scattering NR from fission or (α,n) neutrons). • Definition of the event reconstruction and particle discrimination algorithms. • Study of the DM sensitivities for SI WIMP-nucleus interaction.

Goals of this proposal: B

B	**DArT experiment at LSC**	B1	Commission the detector at LSC and measurement of the argon from Aria (2020-2021)	• Installation of DArT inside ArDM at LSC. • Commissioning of the detector, including the electronics and the cryogenic system. • Argon condensation in the DArT chamber, with argon gas from the Aria plant. • Measurement of the ^{39}Ar β spectrum and background studies.
		B2	Upgrade of the detector (lead shield) (2021)	• Construction and installation of the 6 t lead shield for external background mitigation. • Re-installation and commissioning of DArT. • Assessment of the reduced background level. Measurement of the ^{39}Ar activity in the new working conditions.
		B3	Measurement of the underground argon (2022)	• Reception at LSC of underground argon batches from Aria. • Underground argon condensation in DArT. • Long data-taking runs, depending on UAr purity. • Data analysis: determination of the residual background and measurement of the depletion factor of ^{39}Ar in UAr.

Goals of this proposal: C

C	**DEAP-3600**	C1	Run coordination	• Data taking, data quality and shift organization. • Calibration campaign organization. • Improvement of the DAQ tagging.
		C2	Analysis and new dark matter results	• Development of background mitigation techniques based on Neural networks to perform specific classifications of good-bad events. • Analysis of blind data with the application of new background mitigation techniques. • Rare event Physics analysis beyond WIMP searches. Detection of SuperNova neutrinos via the ^{40}Ar inverse-β-decay channel.

Goals of this proposal: D

D	**R&D in LAr detectors**	D1	Proof of concept of a MV power supply for Ar (AVOLAR)	• The design will be refined to achieve a stable and constant electric charge transfer. • Measurement of voltage and current limits. • Upgrade the system to allow long term operation. • First publication of the preliminary studies. • Study of the reliability for long term operations. • Installation of a high field drift chamber and measurements in high field.
		D2	Study of the dynamics of the ions in LAr (ARION)	• Publication of the latest results and detailed predictions for the future experiments. • Pulsed high voltage supply and measurement of the ions mobility in LAr.
		D3	Argon scintillation studies (ARDIS)	• Publication of the preliminary result concerning the wavelength resolved analysis of the excimers decay. • Commissioning of the new high pressure gas argon chamber at 20 bar. • Detection of the interactions with a ^{241}Am (alpha) and ^{90}St/^{90}Y (beta) sources at 20 bars. • Wavelength resolved analysis of the electroluminescent signal. • Study of possible upgrades and design of the new chamber for liquid operations.