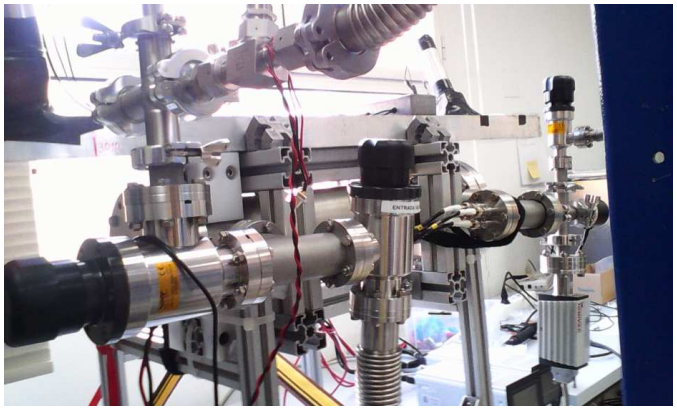
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
EXCELENCIA MARÍA DE MAEZTU
cfp CIEMAT física de partículas

The CIEMAT-DM group: current activity and plans


Roberto Santorelli
On behalf of the CIEMAT-DM group

RENATA thematic meeting on Dark Matter @ LSC
Feb 5-7, 2017

The CIEMAT DM-group

Noble liquids technology
R&D on charge-light

Dark Matter

Laboratorio Subterráneo de Canfranc

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

Staff:

Pablo Garcia	(physicist) →	100%
Luciano Romero	(physicist) →	100%
Roberto Santorelli	(physicist) →	100%
Manuel Daniel	(engineer) →	>50%
Abel Yllera	(chemist) →	>50%

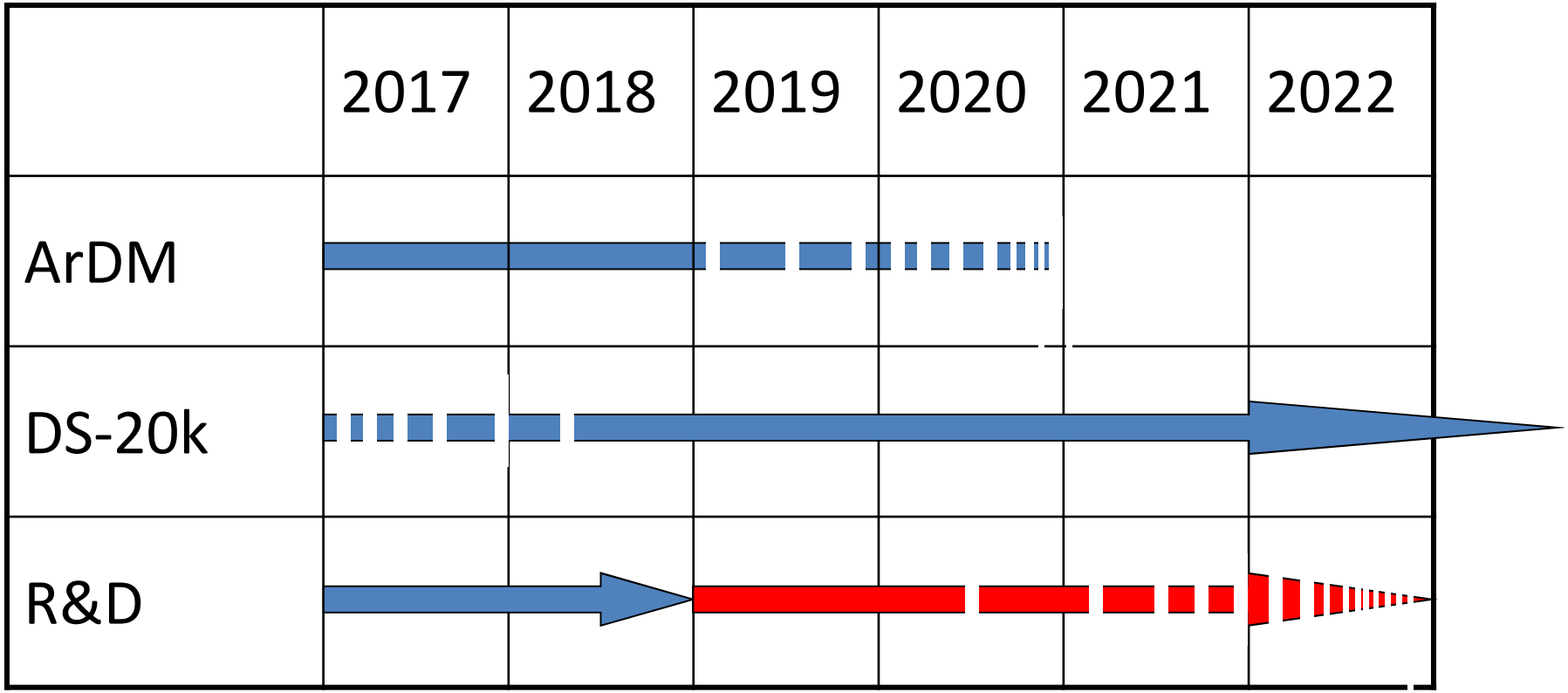
Postdoc:

Vicente Pesudo	(physicist) →	100%

PhD student:
Edgar Sanchez (1st yr)
PhD2 (start 2018)

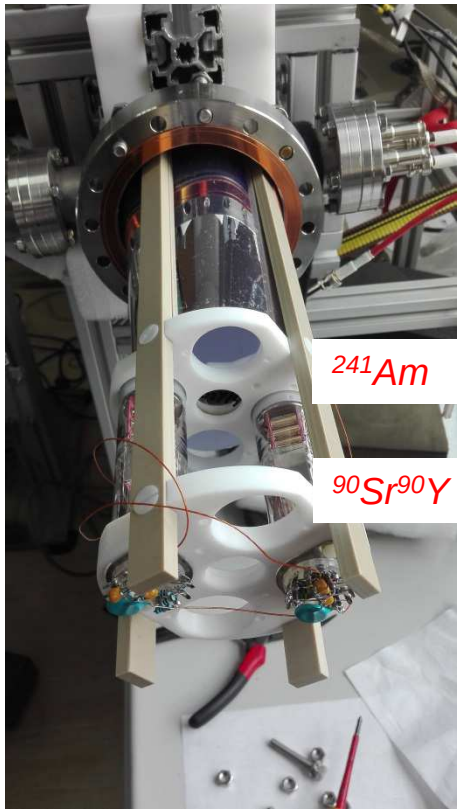
MS 2018:
Carmen Milla Pardo
Irene Jiménez Cuesta
María Ruiz Ortega

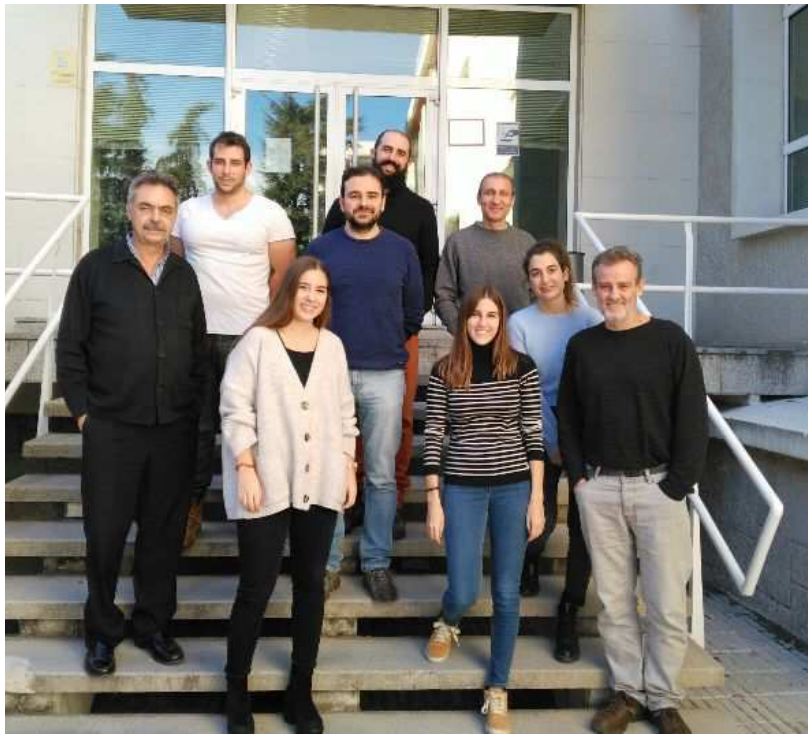
Current activity and funds

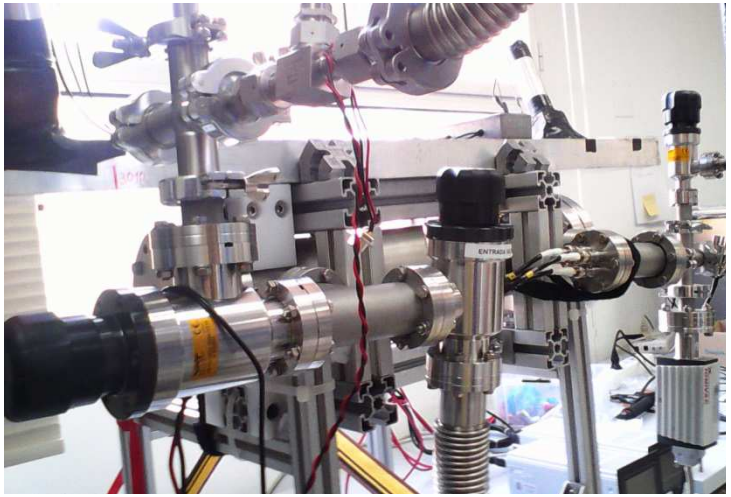


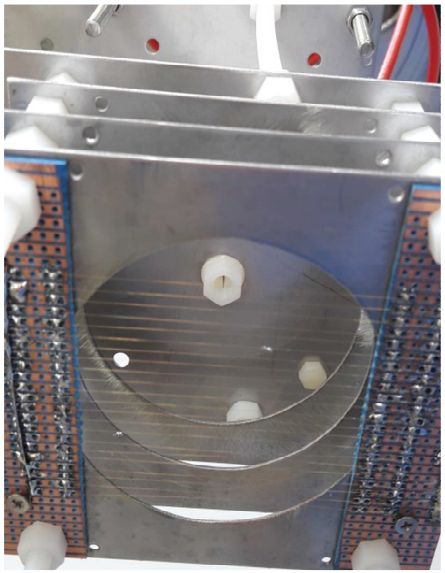
- Current fund: FPA2015-70657-P (MINECO) → 2016-2017
- New project: FPA2017-82647-P (MINECO) → 2018-2019
- MdM-CFP grant: MDM-2015-0509

- Subprograma Estatal de Generacion del Conocimiento/ EXPLORA FPA2017-92505-EXP


^{241}Am
$^{90}Sr^{90}Y$







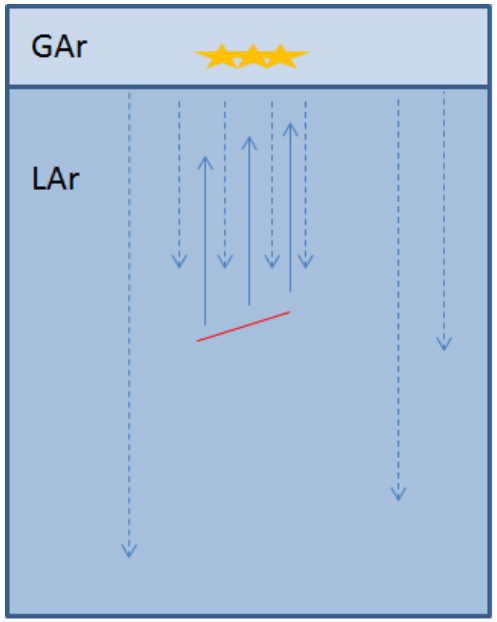
R&D Topics

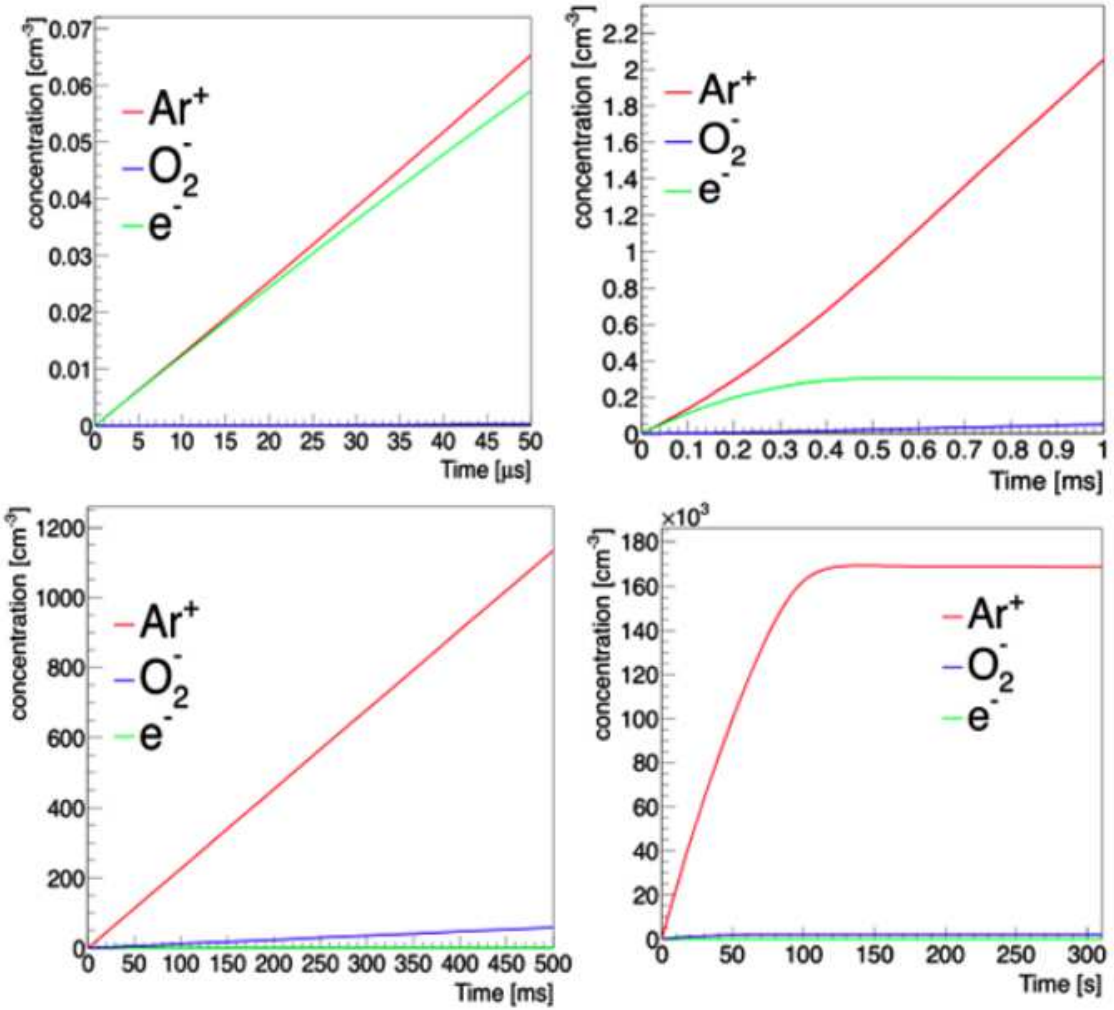
Novel ideas on

- light detection / transmission
- detector calibration
- detector design developments
- charge readout: studying the dynamics of the positive charge

- SiPM characterization at cryogenic temperature
- Ar scintillation studies and HP-TPCs
- New high voltage system for future large LAr detectors
- Measurement of the ion feedback from the gas and the ion velocity in liquid

Study of the dynamics of the ions in LAr





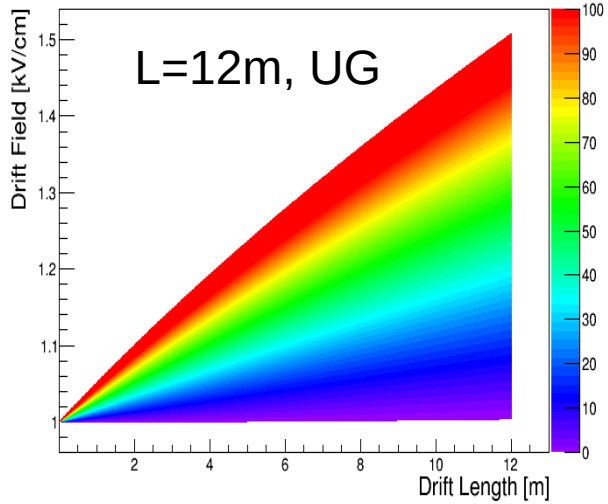
E_d= 0.5-1 kV/cm
$v_e \approx$ 2 mm/μs
$v_i \approx 1.6 \cdot 10^{-5}$ mm/μs

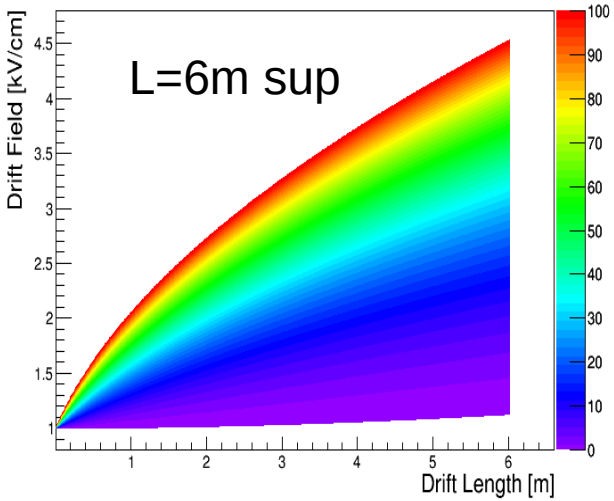
$v_i << v_e \rightarrow d_i >> d_e$

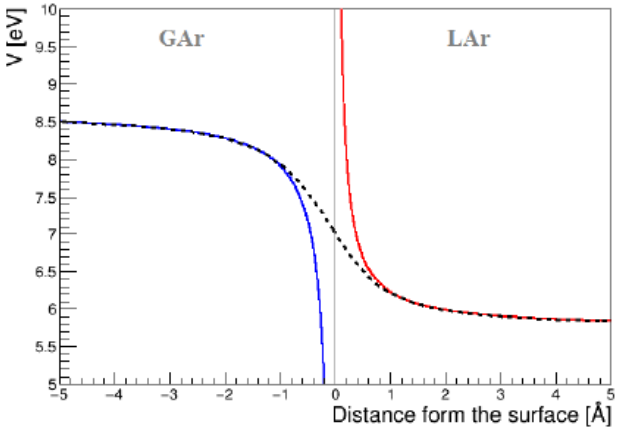
R. Santorelli, S. di Luise, E. Sanchez Garcia, P. Garcia Abia, T. Lux, V. Pesudo, L. Romero
"**Impact of the positive ion current on large size neutrino detectors and delayed photon emission**" To be published in JINST

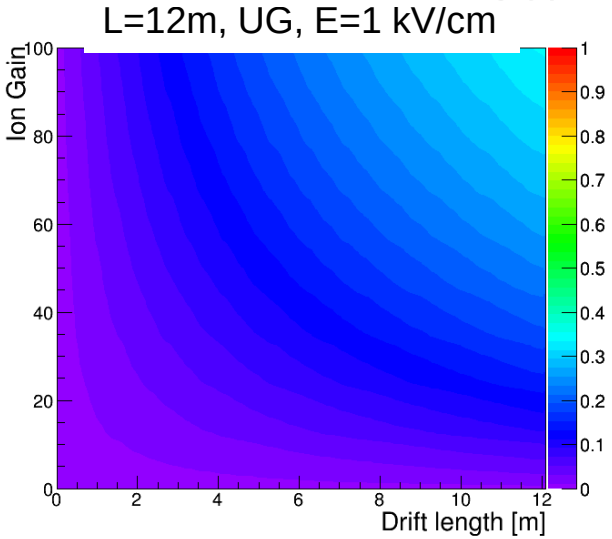
Impact of the positive charge current

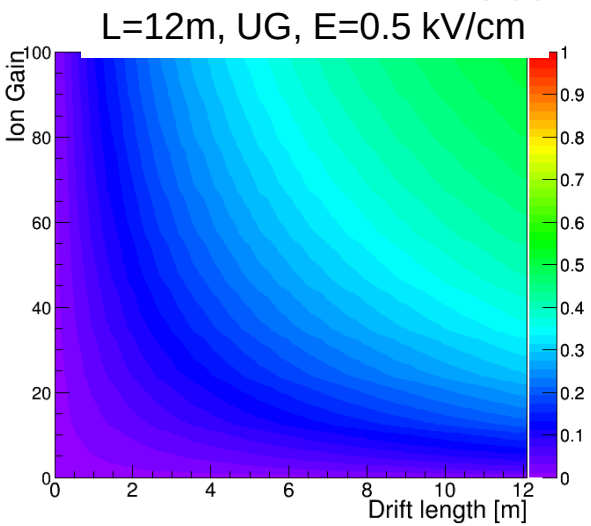
L. Romero, R. Santorelli, B. Montes:" Dynamics of the ions in Liquid Argon Detectors and electron signal quenching"
Astropart.Phys. 92 (2017) 11-20





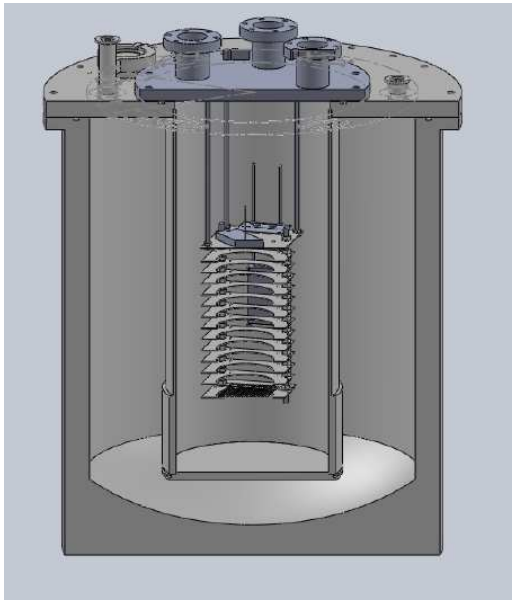






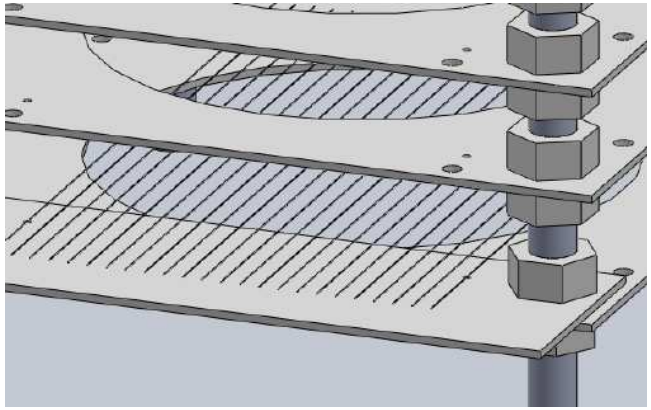
Study of the ion-feedback from the gas

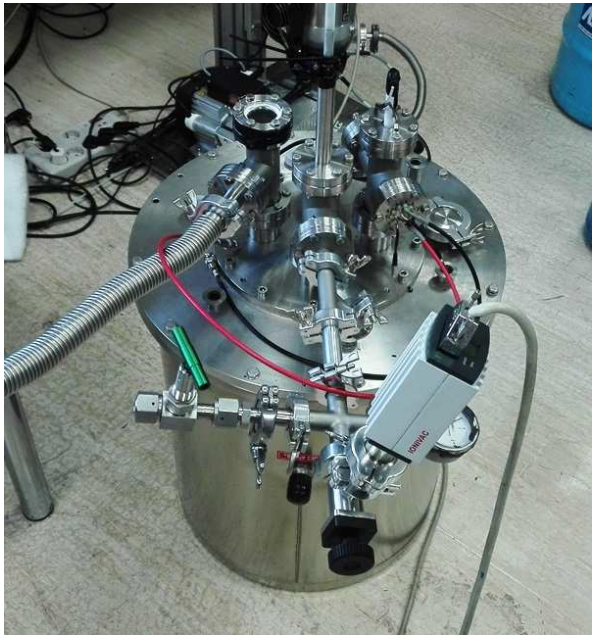
Dynamics of the ions at the GAr/LAr interface

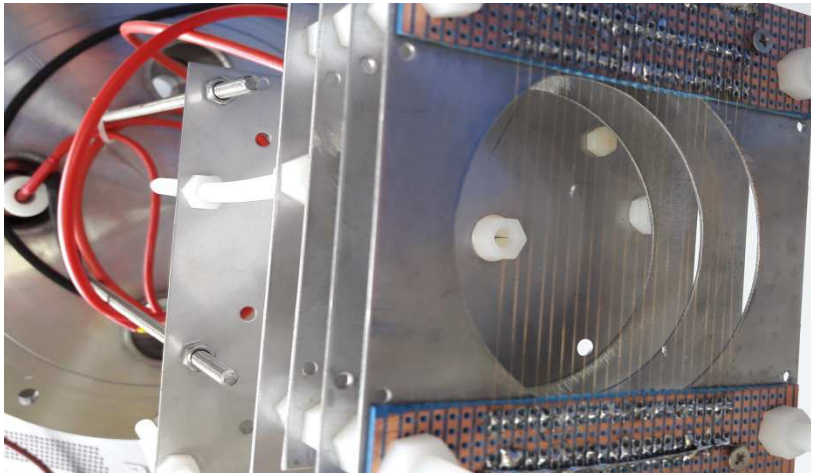


Collaboration with IFAE

Operative by the end of 2017!

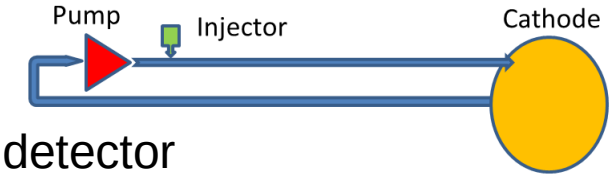


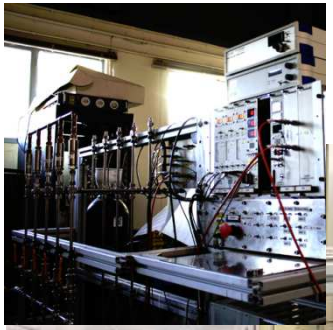




AVOLAR

- Megavolts ranges HV sources required by the future detectors, with several meters drifts
- Efficient removal of the positive charge cloud
- Novel approach: to generate the HV directly inside the detector
- AVOLAR project:
  - ➢ 2017 commissioning with LN2
  - ➢ 2017 first ev. of charge transportation
  - ➢ 2018 first LAr test

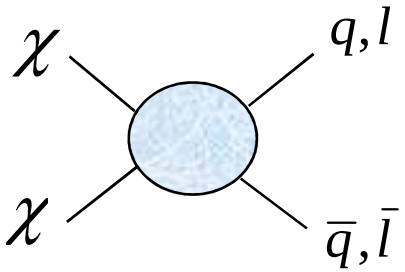




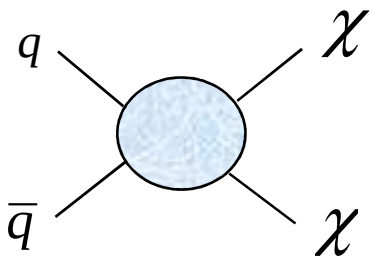
Calculation output

Flow medium:	Argon / liquid
Volume flow::	0.02 l/s
Weight density:	1400 kg/m³
Dynamic Viscosity:	300 10-6 kg/ms
Element of pipe:	circular
Dimensions of element:	Diameter of pipe D: 4 mm
	Length of pipe L: 10 m
Velocity of flow:	1.59 m/s
Reynolds number:	29709
Velocity of flow 2:	-
Reynolds number 2:	-
Flow:	turbulent
Absolute roughness:	0.005 mm
Pipe friction number:	0.03
Resistance coefficient:	66.39
Resist.coeff.branching pipe:	-
Press.drop branch.pipe:	-
Pressure drop:	1177.21 mbar
	1.18 bar

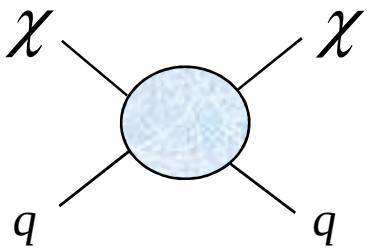
Detection



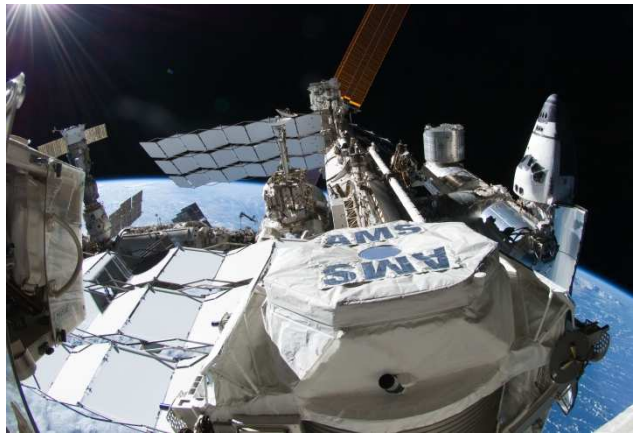
Above ground

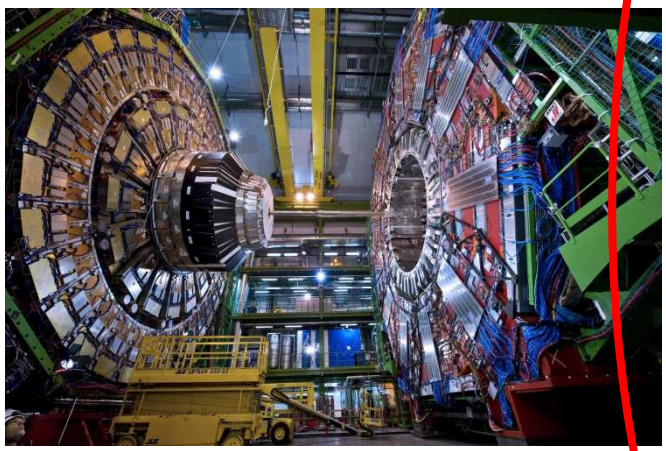


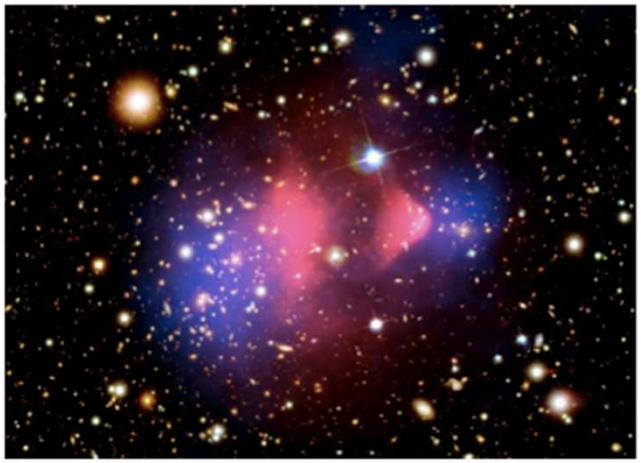
Collider

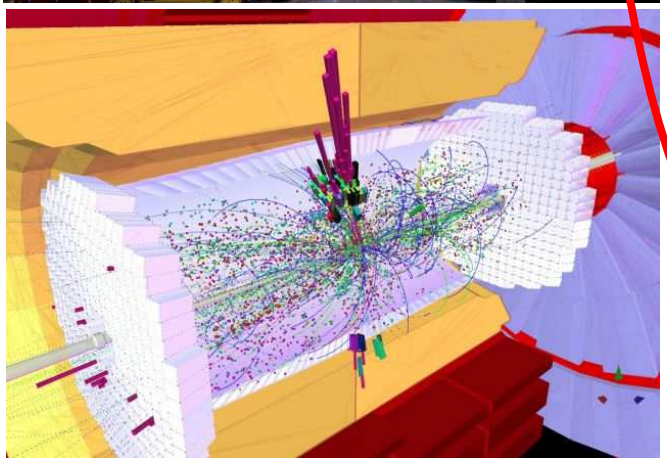


Underground









Challenging tasks

- Large Exposure (Mass $\times$ Time) : 100s ton $\times$ year
- Low Energy Threshold : ~10 keV_{NR}
- Event topology : γ/β, α, μ
- 3D Event Reconstruction : neutrons
- Discrimination between Signal and Background

  : > 99.9…%
- Low Background Rate : <0.1 evt in the exposure

LAr vs LXe: why LAr?

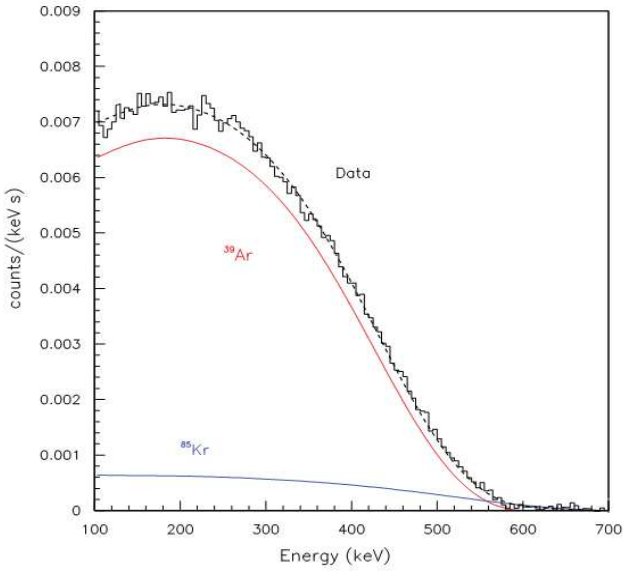
LXe:

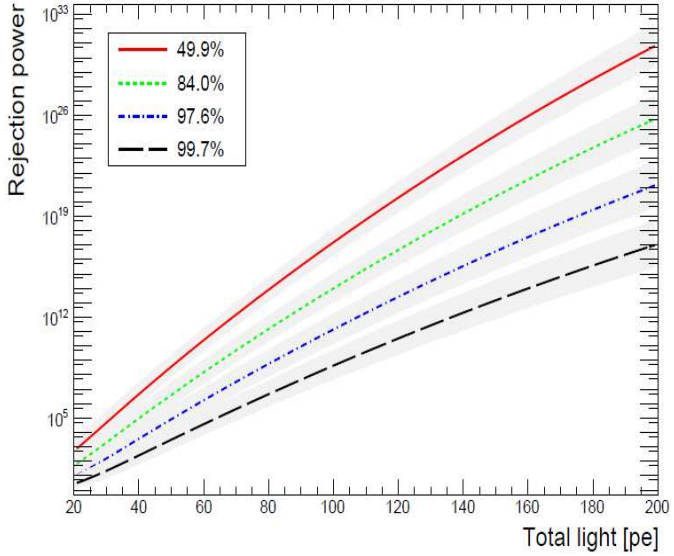
- ✓ *Density*
- ✓ *~50% odd isotopes (^{129}Xe, ^{131}Xe) for spin dependent interactions*
- ✓ *No long-lived radioactive isotopes*
- ✗ *Price*
- ✗ *ER discrimination*

LAr:

- ✓ *Available in large quantity*
- ✓ *ER background discrimination*
- ✗ *Radioactive isotopes*
  $^{39}Ar \rightarrow 1.01$ Bq/kg

NIM-A 574 (2007) 83–88





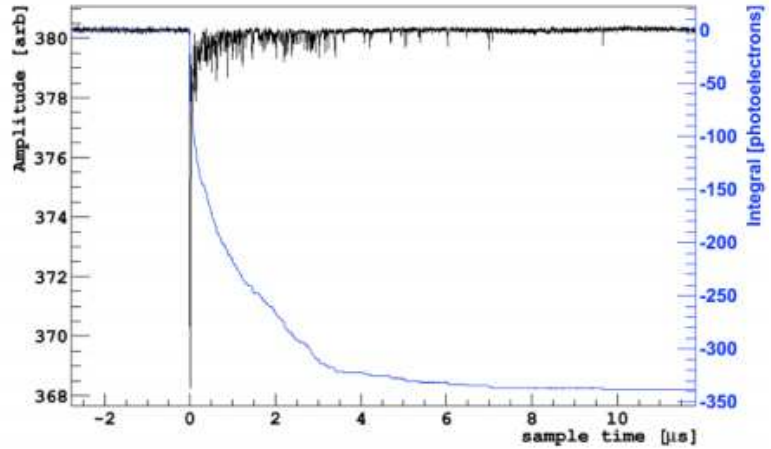
"Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC" arXiv:1712.01932

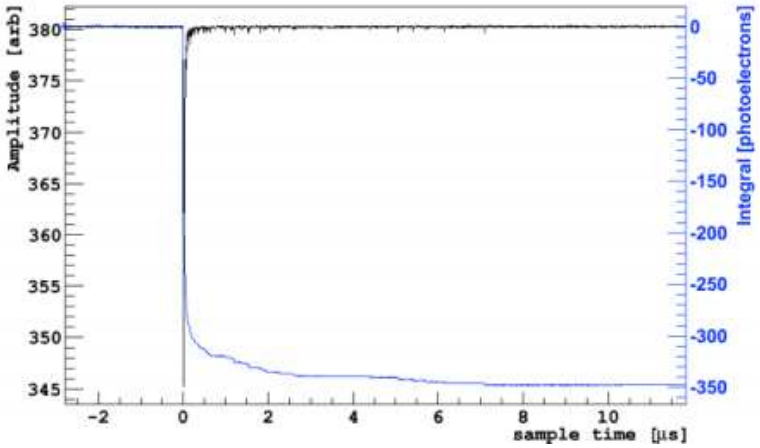
Event discrimination in Ar

ER-like event

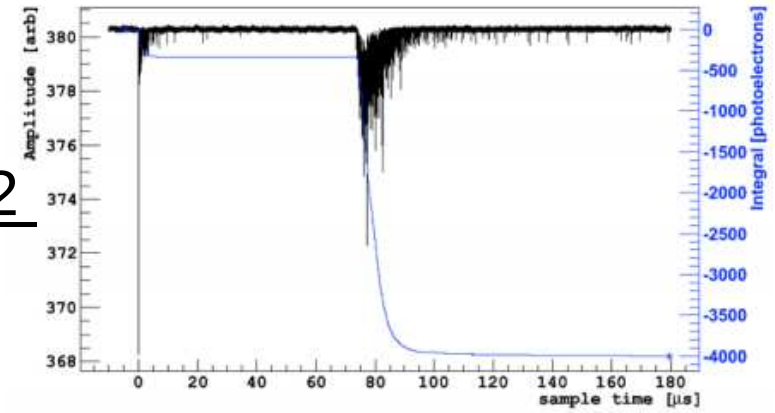
NR-like event

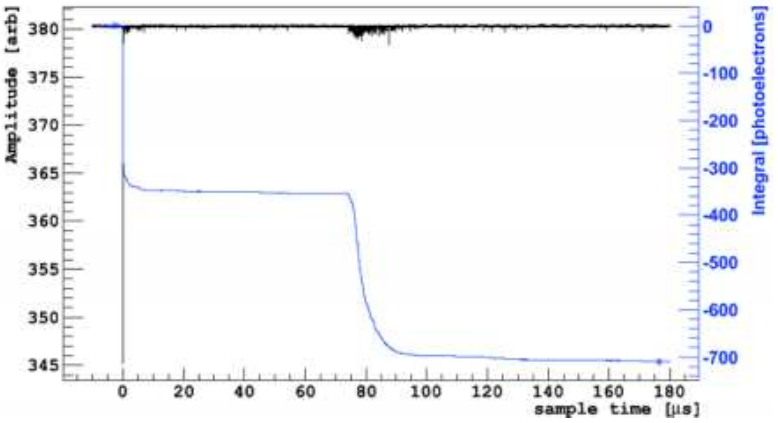
S1 only





S1/S2

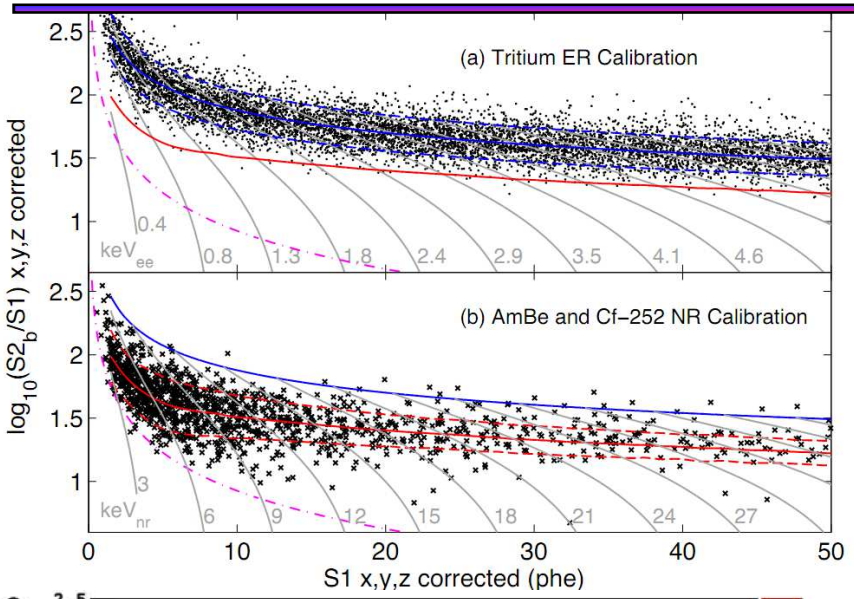


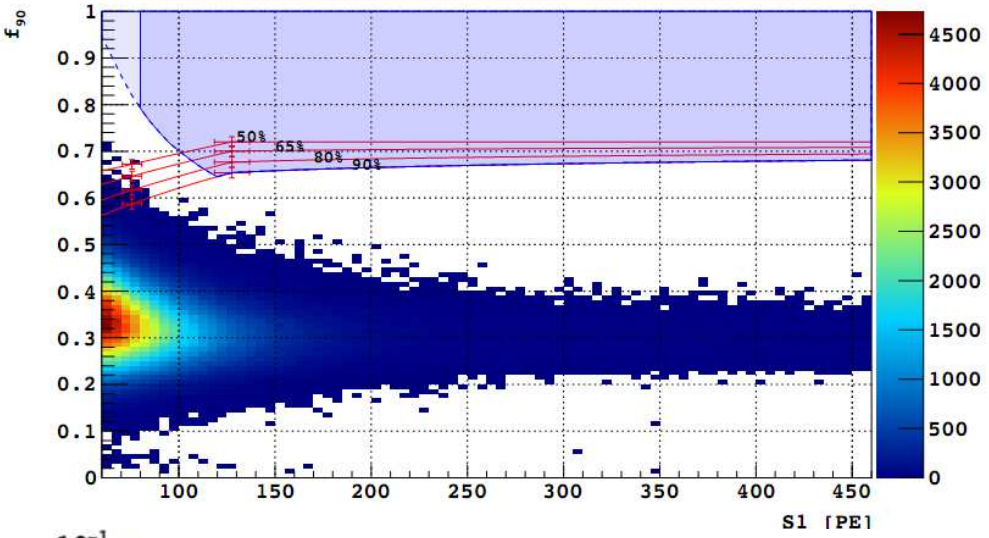


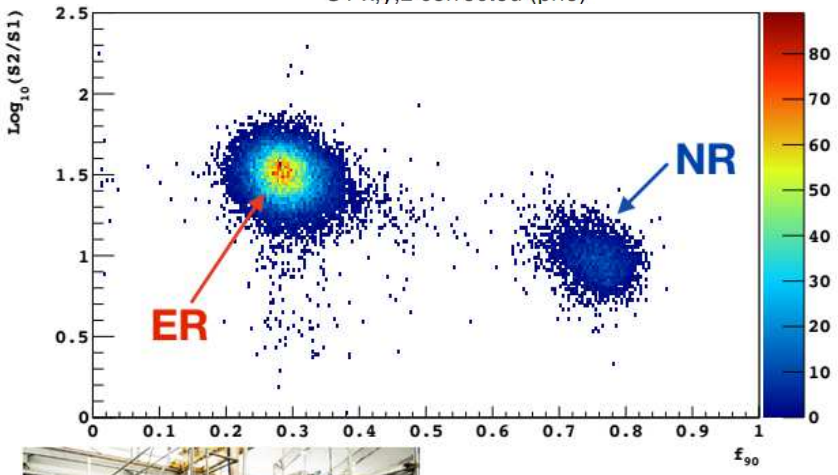
$$\left.\frac{S_2}{S_1}\right|_{ER} > \left.\frac{S_2}{S_1}\right|_{NR}$$

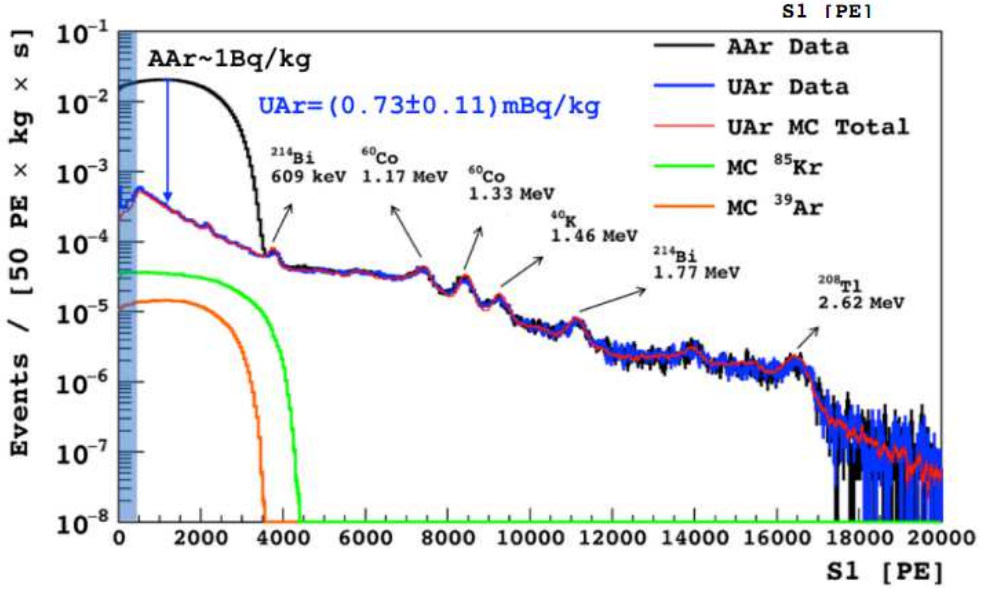
Due to an enhancement of the recombination process

ER discrimination and bkg









- Crude Argon from CO_2 well in Colorado
- Ar-39 suppressed by a factor 1400 (before analysis)
- Cryostat and PMTs main RA components of the detector

Physics case

- There is a remarkable and unique opportunity of having large exposures (~100 kg·yr) in background free mode with an argon TPC: **the future scientific program of the DM direct search community must include a dedicated worldwide effort based on this technology!**

- At the moment, the dual-phase **LAr TPC is the only technology** able to exceed the current experimental limits, reaching the neutrino floor

- A DM search with xenon requires a “background-free” exposure of 300 ton×yr to reach the neutrino floor

- Considering a β/γ rejection power in xenon of the order of 99.5% and 300 ton×yr. Sensitivity limited by
  - *pp* neutrinos (20 events/ton×yr in the 0-10 keV_{ER})
  - ^{222}Rn (15 events/tonne×yr for every 1 mBq of ^{222}Rn)

Status

- In 2015, the CIEMAT-DM group was one of the original proponents of the new DarkSide-20k Collaboration (DS-20k), which plans to build a **20 tonne fiducial** dual-phase Ar-TPC at LNGS, reaching an exposure of **100 ton×yr**

- The experiment plans to **take data from 2021,** and is designed to be the most sensitive detector for massive WIMPs (**up to 10 TeV/c^2**)

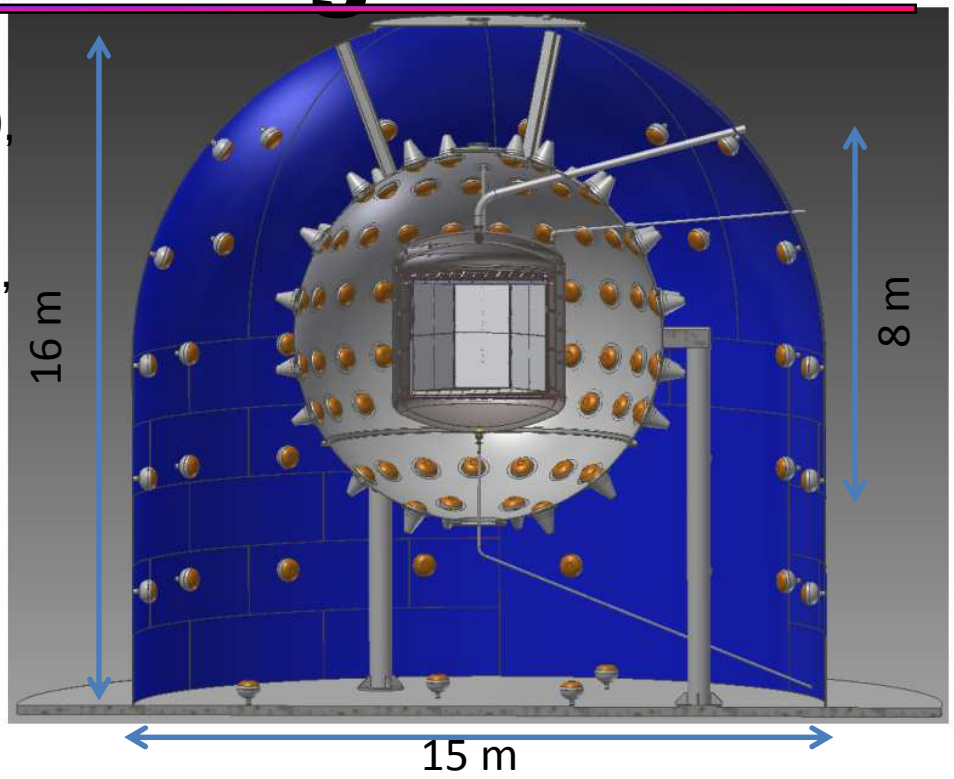
- In a second stage, the program foresees the construction and operation of the **ARGO experiment**, with an exposure of **1000 ton×yr** (a 300-tonne detector with a 200-tonne fiducial mass) in background free mode

- **The sensitivity expected is three orders of magnitude greater than the best result achieved today**

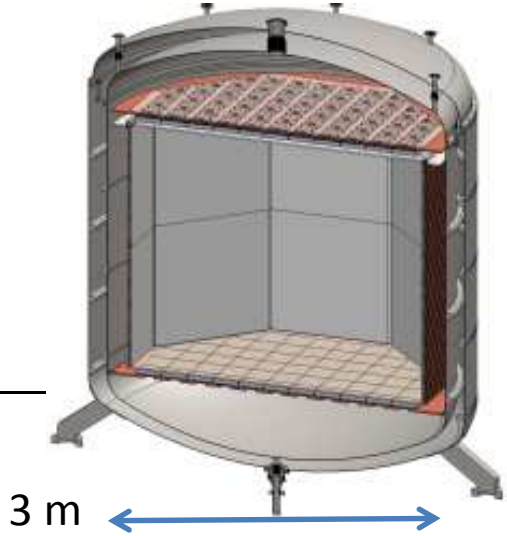
- April 2015: LOI to LNGS
- March 2016: proposal reviewed by a INFN and the NSF joint panel
- April 2016: proposal reviewed by the NSF Particle Astrophysics ranking panel (earning a rating of “Excellent" in both merit categories “Intellectual Merit" and “Broader Impact".
- April 2017: funding approval form INFN (40 M€ contribution)
- Positive review of the proposal submitted to the US-NSF, capital funding of 13 M$

Baseline design

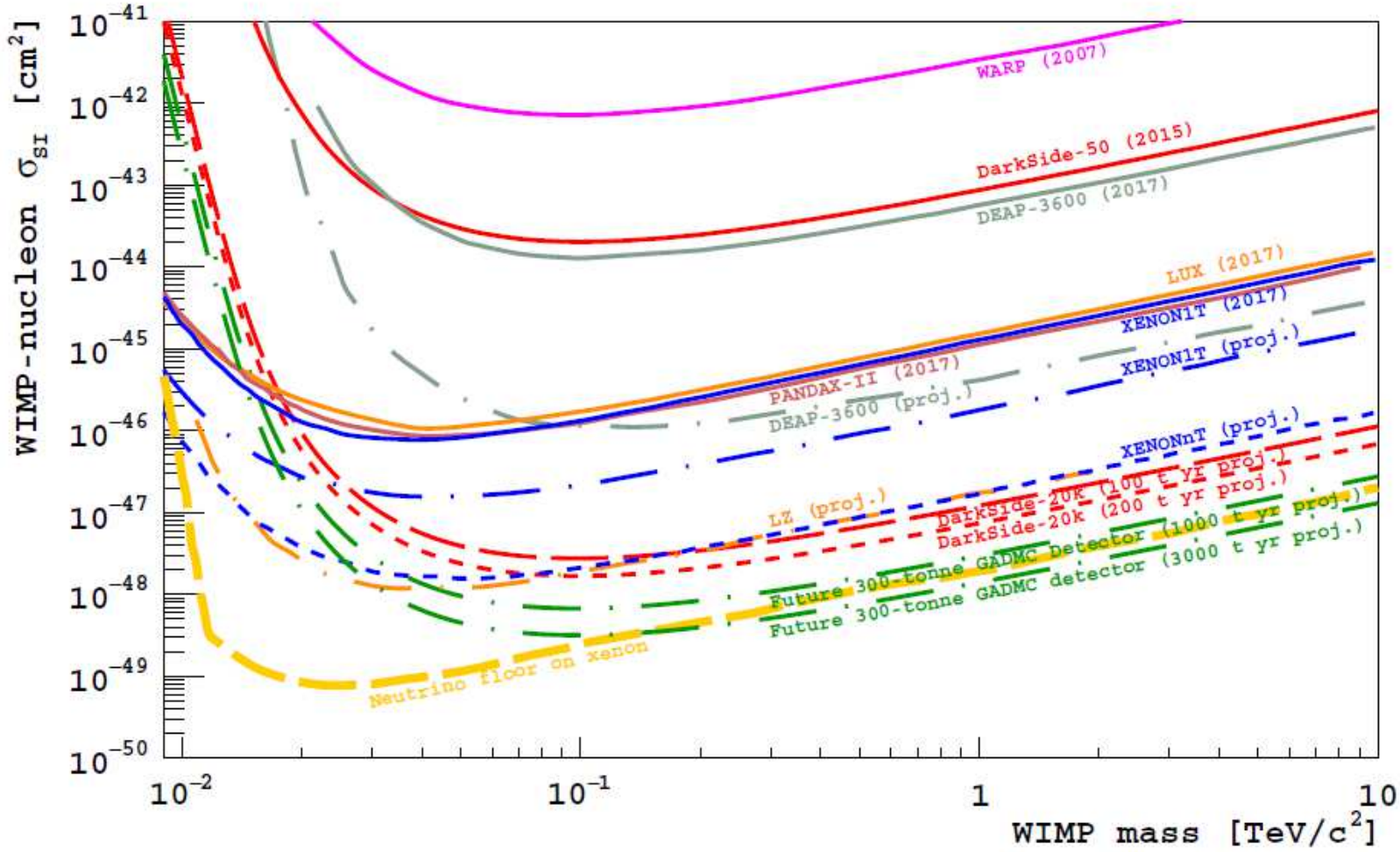
- New collaboration with groups from DS-50, ArDM and DEAP-3600.
- More than 70 institutions, 350 researchers, 12 countries
- Data taking from 2021
- 100 ton×yr exposure with < 0.1 evt bkg
- Sensitivity ~10^{47} for 1 TeV/c^2 WIMP mass



- 30 ton UAr, 20 ton fiducial
- Hexagonal shape
- 13 m^2 SiPM, LY above 8 PE/keV
- More than 5 ms mean electron lifetime
- ~~WCV (100 × 20" MCP-PMTs developed for JUNO)~~
- ~~LSV (130 × MCP, 13 % photocathode cov, ^{10}B)~~
- Extended Argon project: ARIA and URANIA

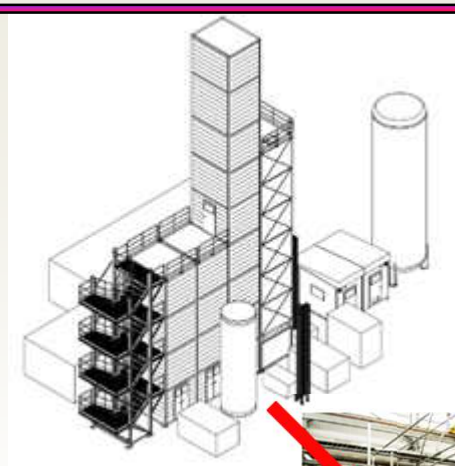


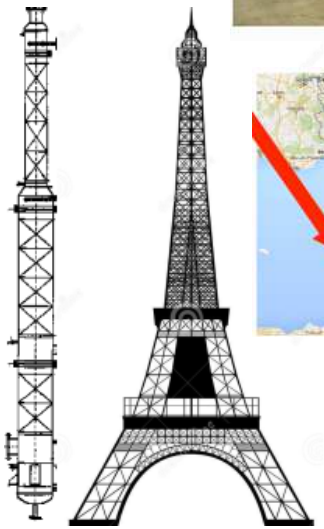
Sensitivity



Radiopure Ar procurement

- **URANIA** project:
  Procurement of 50 ton of UAr extracted from the CO2 wells at Kinder Morgan facility in Cortez, Colorado (100 kg/d)
- **ARIA** project:
  - Seruci 1: chemical purification of the UAr by cryogenic distillation (reduction factor 1000 per pass, 150 kg/d)
  - Seruci 2: Active Ar-39 depletion of the UAr via isotope distillation (factor 10/pass)



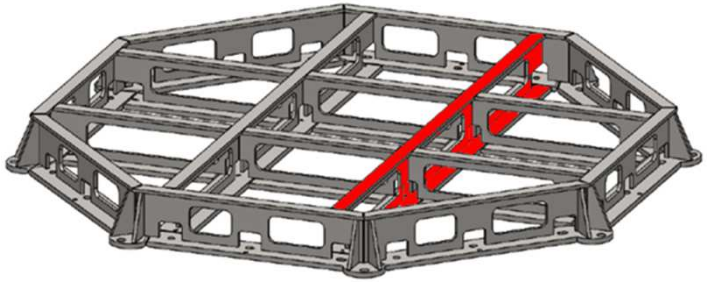


28 modules,12 m each,
360 m in total
Currently tested at CERN

CIEMAT at DS-20k

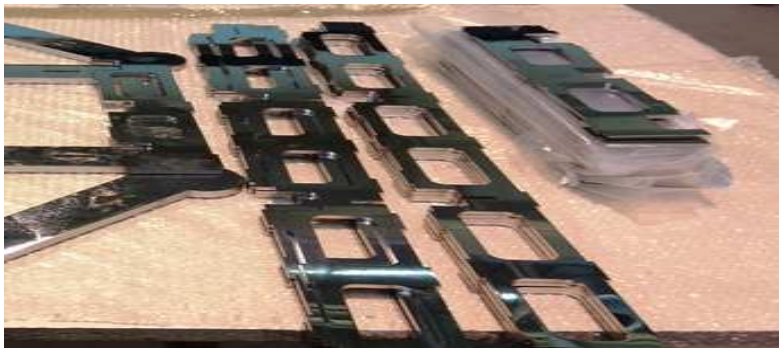
- Mechanical construction
- Material screening → Manager of the WG
- Monte Carlo, RA budget
- Sensitivity studies, computing, calibration sources ….
- ArDM @ LSC: ton-scale detector demonstration and UAr studies

The CIEMAT at DS-20k: mechanics



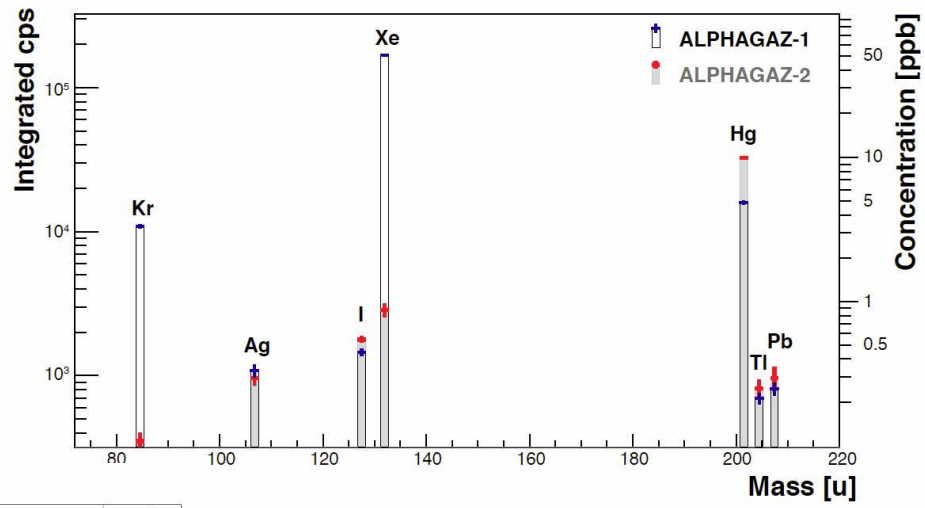
4×1×1 m Mill

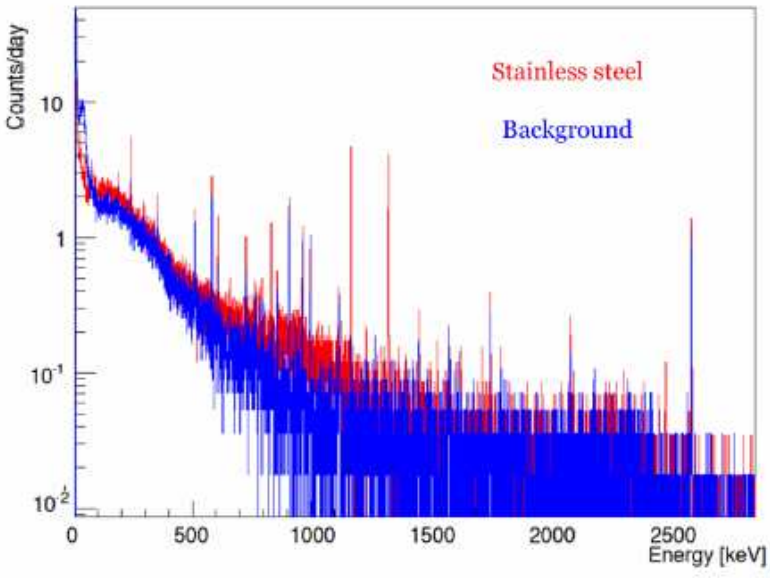
Tungsten Inert gas (Ar) welding with SS 316L

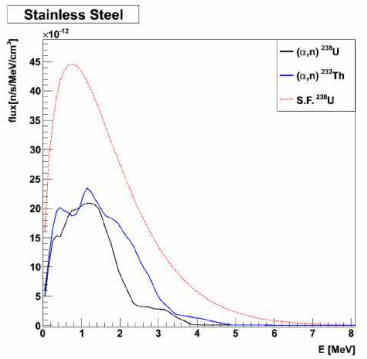


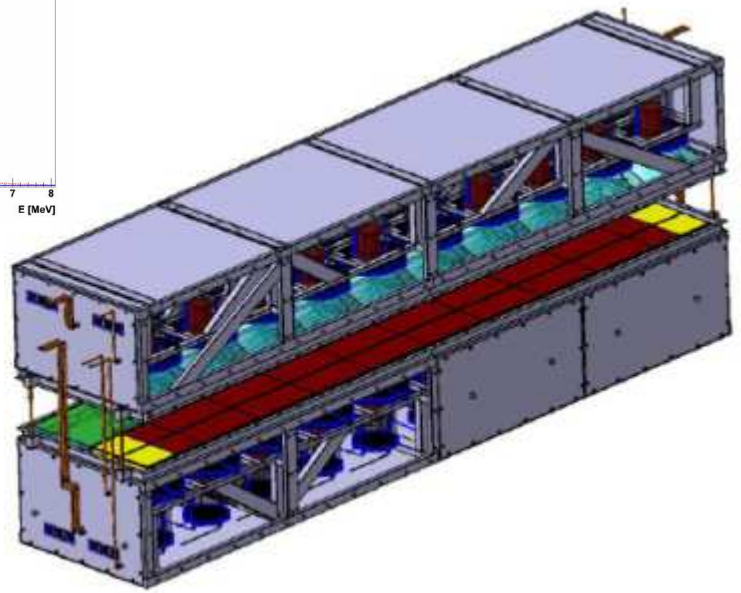
The CIEMAT at DS-20k: Mat. assay

- ICP-MS at CIEMAT
- HPGe / ICP-MS at LSC
- BiPo (surface contamination) at LSC

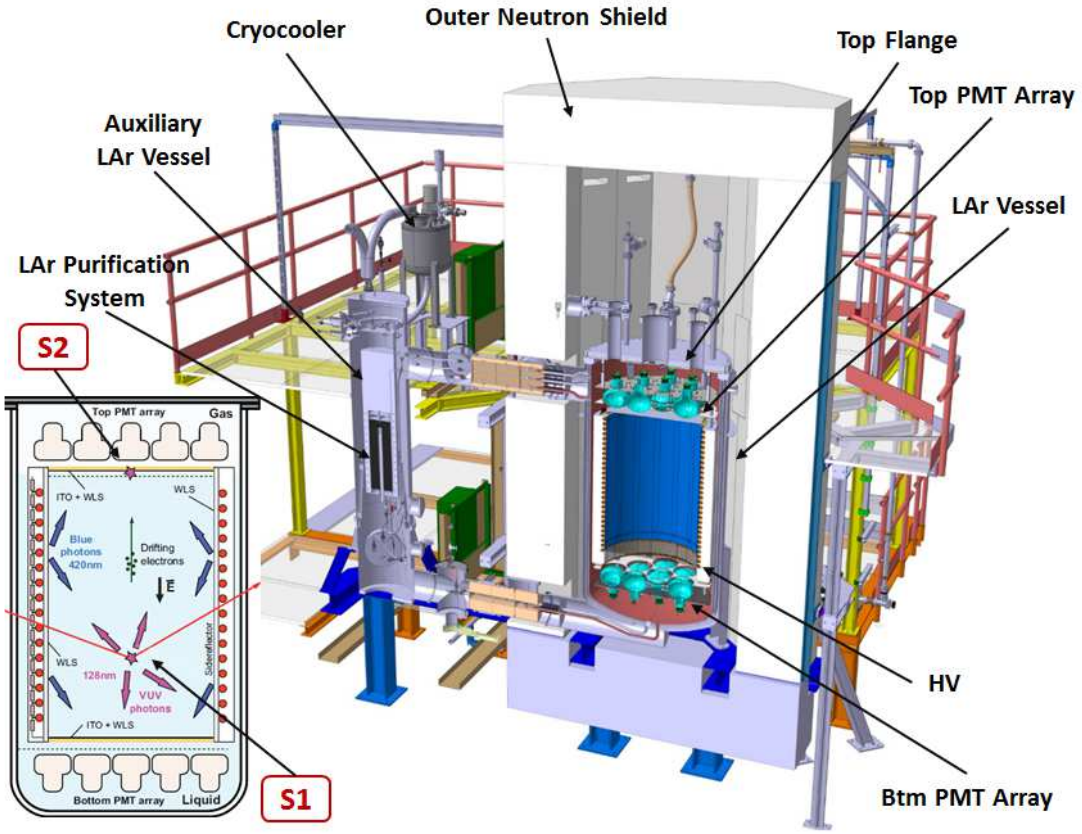






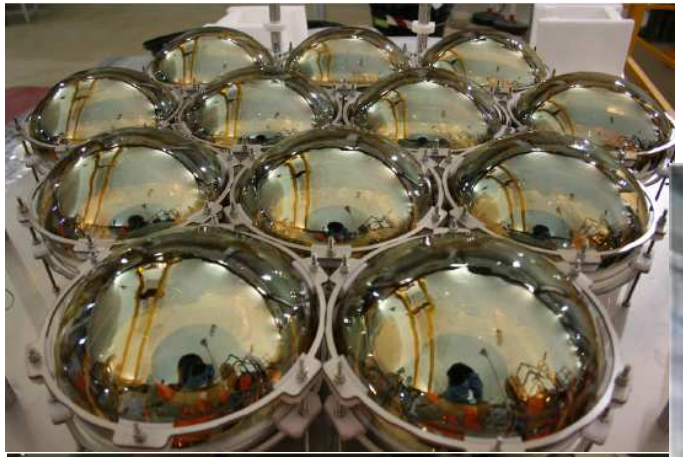


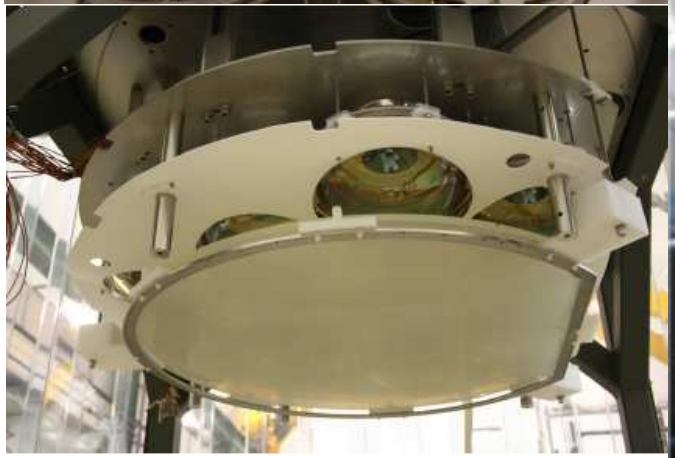
ArDM: tonne-scale LAr-TPC at LSC



- Collaboration between CIEMAT, ETH and LSC (RE18)
- Low background setup (LSC underground lab)
- 2015-2016 Data taking and analysis of the first physics run in single-phase
  - Validation of detector performances
  - LY
  - Study of the backgrounds

- **Double-phase EL-TPC**
- **850 kg** active volume (≈2 t total)
- Cryogenic low radioactive PMT arrays (R5912 2×12)
- 50 cm passive neutron **shield (Poly, 20 ton)**
- Control of the cryocoolers and cryogenic system fully integrated in the existing PLC
- 4x ADC V1720, 8ch, 12bit, 2Vpp, 250MS/s (up to 2.2 kHz trigger rate (289 MB/s – 8 μs digitalization)



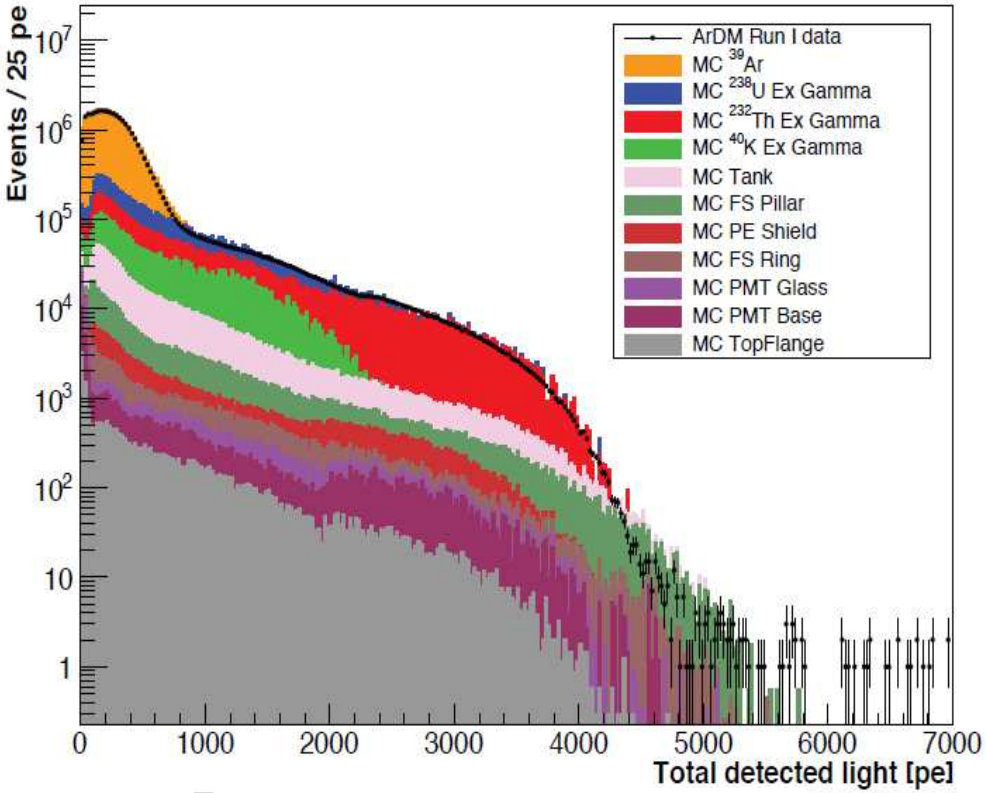


LSC
Laboratorio Subterráneo de Canfranc

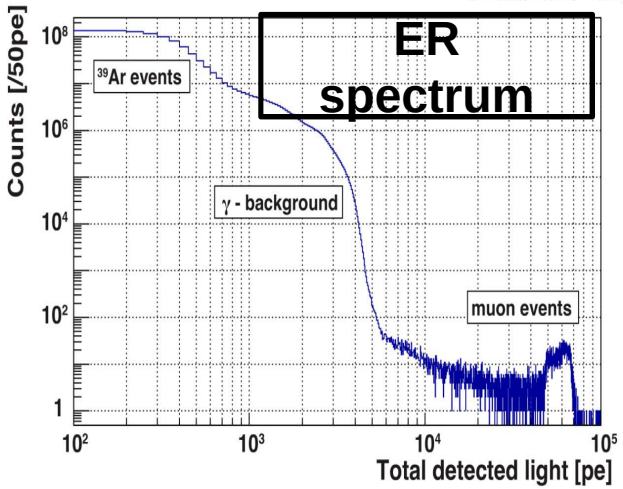
ArDM Phases of the project

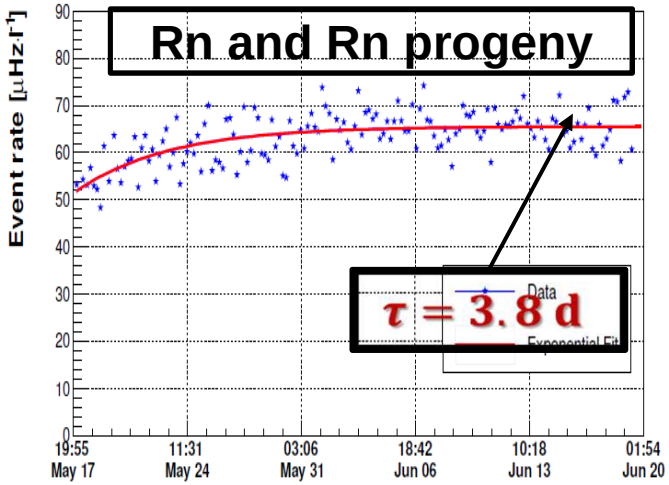
- **Surface** operations :
  - Building the ArDM prototype
  - Commissioning the detector cryogenics, purification, HV, electronics, light readout and software
- **Underground** - commissioning and RUN-I:
  - Construction and installation of the passive neutron shield
  - Full material screening campaign at LSC
  - Warm/cold GAr and LAr runs
    - 4.7 billion triggers (10% calibration)
    - ^{83m}Kr, ^{57}Co, ^{22}Na, ^{252}Cf calibrations
    - Gamma background assessment
    - LY and attenuation length studies
    - ER/NR discrimination through pulse shape
- **Underground** - double-phase operations and RUN-II:
  - Hardware upgrades
  - Run in Double-phase
- Integration ArDM/DarkSide-20k
- UAr measurements

Assessment of the gamma bkg



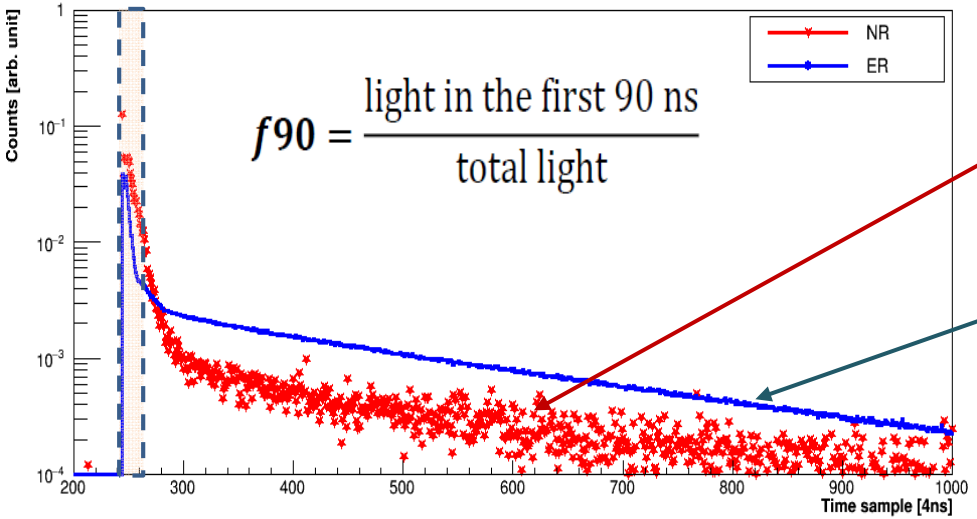
- Good data/MC agreement
- ER background
  - Ar-39: the dominant background, 0.95 Bq/kg
  - γ ray: amount to 26% ER background
- High energy background
  - Muon: $3.5 \times 10^{-3} m^{-2} s^{-1}$
  - Rn emanation: 65.6± 0.4 μHz/liter

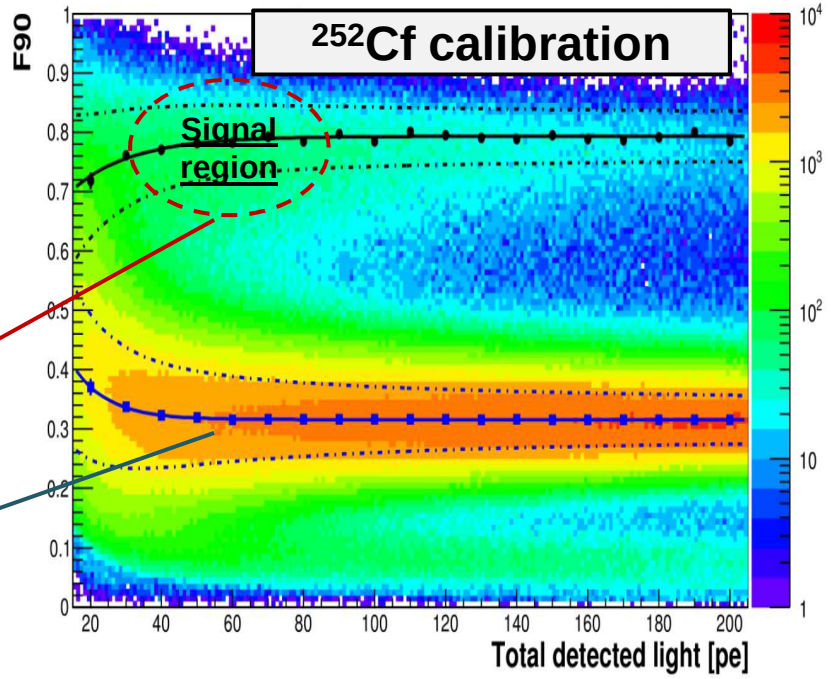




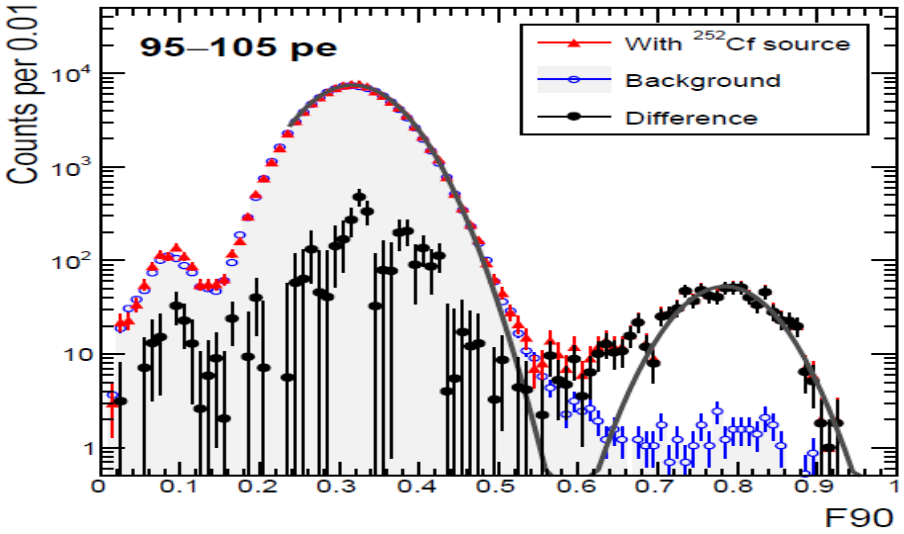
ER/NR discrimination

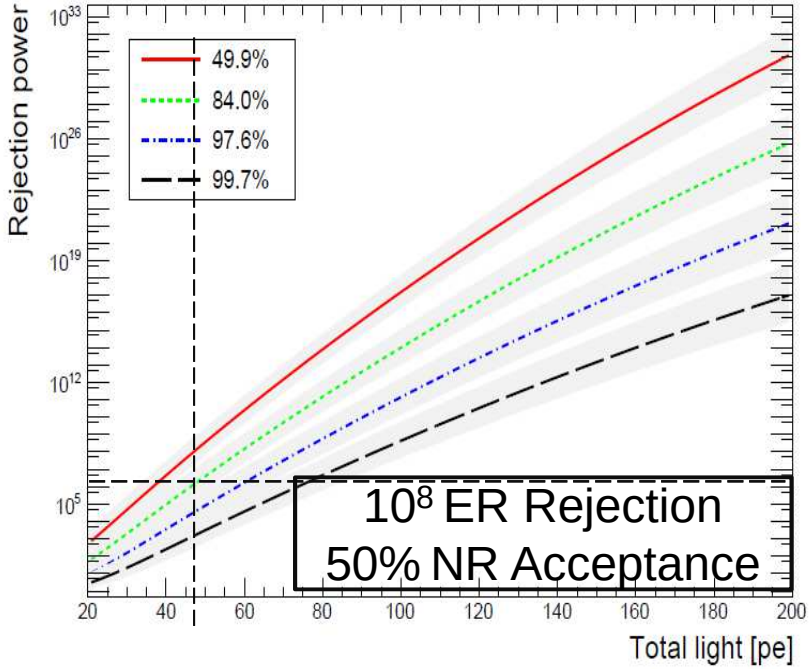
- Scintillation pulse shape discriminator:





- Rejection power: statistical separation





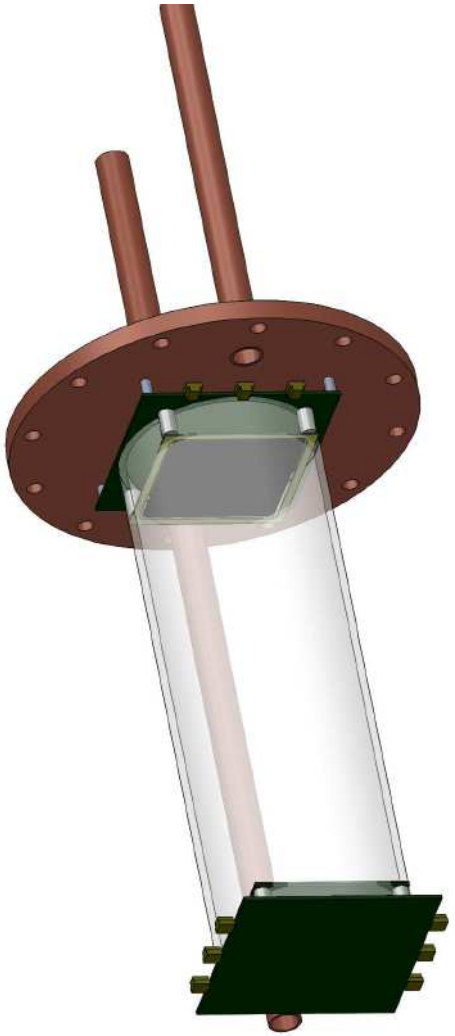
Calvo, J., et al. *JCAP* 2017.03 (2017)

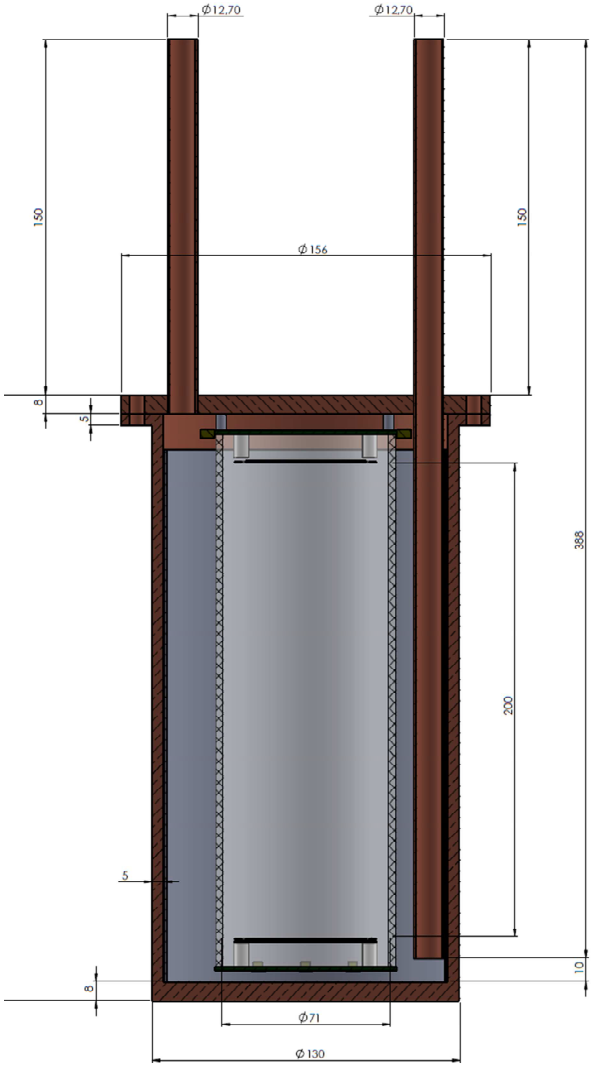
More results

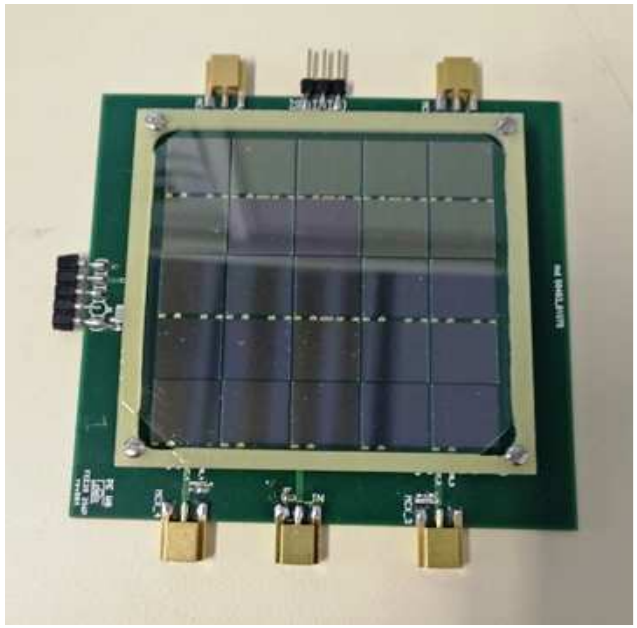
- *"Measurement of the attenuation length of argon scintillation light in the ArDM LAr TPC"* ArDM *Collaboration Nov 8, 2016. 11 pp. Astropart.Phys. 97 (2018) 186-196*
- *"Commissioning of the ArDM experiment at the Canfranc underground laboratory: first steps towards a tonne-scale liquid argon time projection chamber for Dark Matter searches"* ArDM Collaboration Dec 19, 2016. 30 pp. JCAP 1703 (2017) no.03, 003
- *"Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC"* ArDM Collaboration Dec 2, 2017. 18 pp. e-Print: arXiv:1712.01932

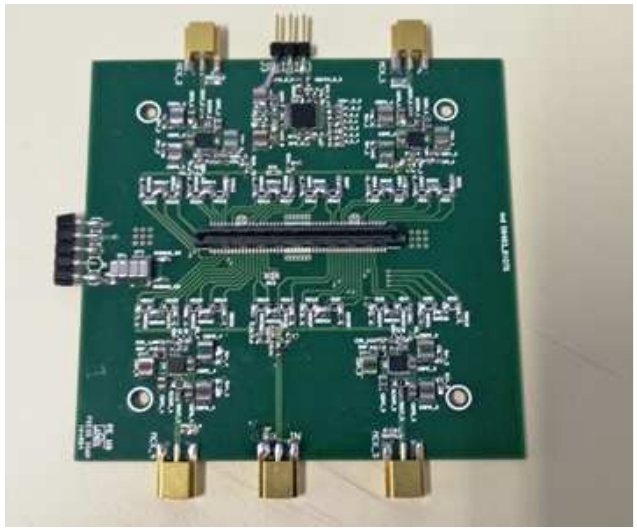
ArDM to DART : UAr studies (SiPM tests at LSC)

Vessel/detector design (on-going) and construction (2018) in Madrid

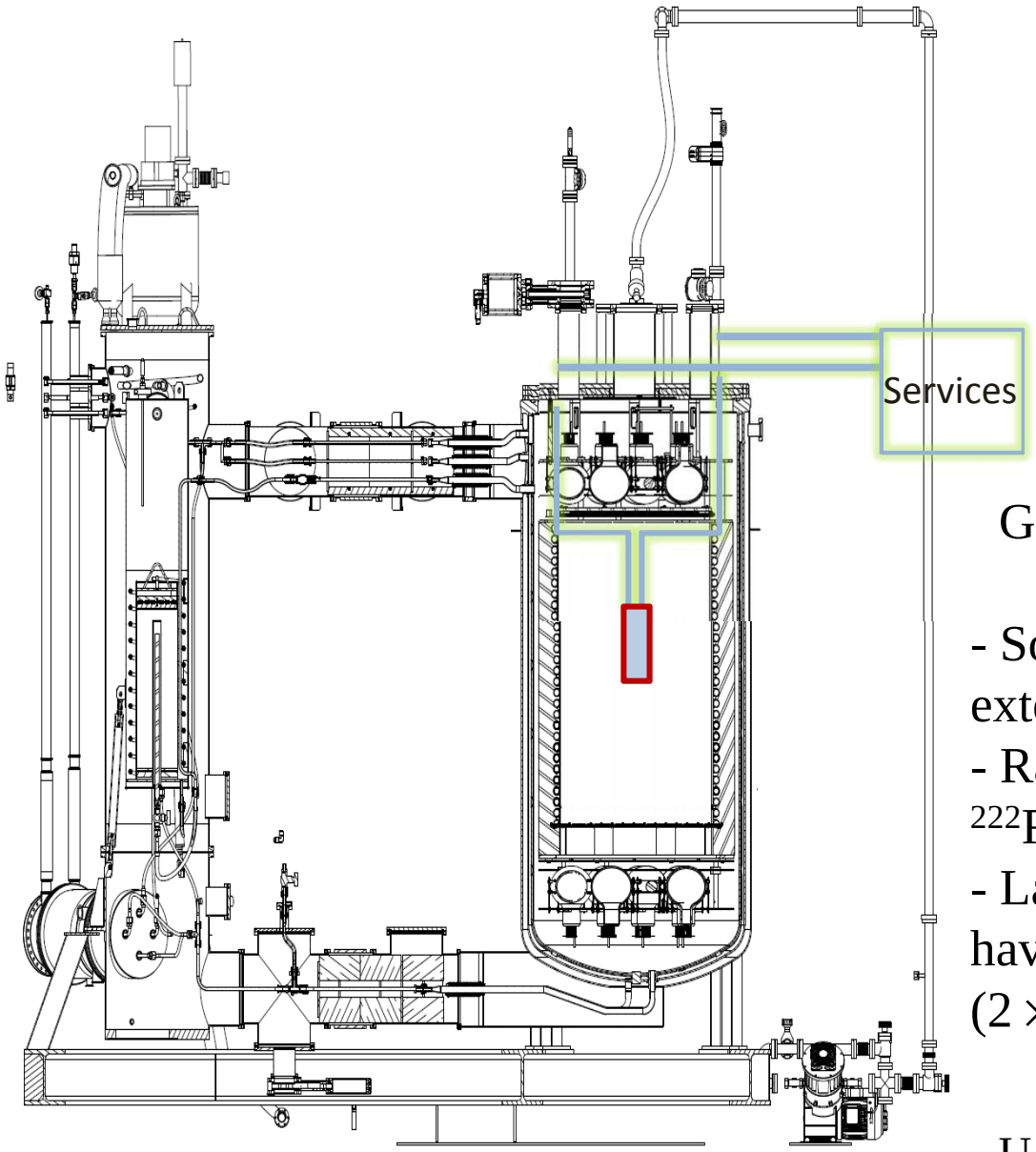


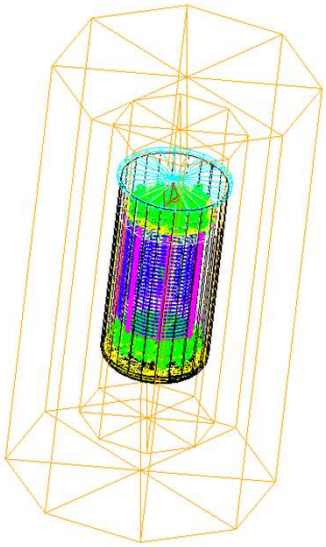






ArDM to DART : UAr studies at LSC





Geant4 simulations of the background

- Sources: SiPM, PCB, copper, steel, external...
- Radioactive chain of ^{40}k, ^{232}Th, ^{238}U, ^{222}Rn
- Large number of events simulated to have a significant spectrum in Dart (2×10^{12}).

UAr ~ 0.7 mBq/kg : 5σ ~0.2 weeks
DAr ~ 0.07 mBq/kg : 3σ ~7.7 weeks

	Activity	Responsible	2018				2019				2020			
ArDM														
A.a	ArDM RUN-II Data taking at LSC	L. Romero												
A.b	ArDM RUN-II Data analysis	R. Santorelli												
A.c	Underground Ar runs	P. Garcia												
DS-20k														
B.a	Detector construction	M. Daniel		Mockup						DS-20k				
B.b	Radiopurity assay at CIEMAT/LSC	A. Yllera Del Llano												
B.c	LS veto analog electronics and calibration	R. Santorelli												
B.d	Monte Carlo simulation and Computing infrastructure	P. Garcia												
B.e	Analysis code development	P. Garcia												
LAr-R&D														
C.a	LAr-HV power supply (AVOLAR)	L. Romero												
C.b	Study of the electron/ion recombination in argon (ARION)	L. Romero												
C.c	Argon scintillation wavelength studies (ARDIS)	R. Santorelli												
C.d	VUV-SiPM	R. Santorelli												

Conclusions

- We are fully aware of the financial problems experienced in Spain during the recent years
- We started doing first our homework at CIEMAT: group firmly committed and able to capitalize the relatively small investment of the past years
- **Very solid proposal and larger DM group in Madrid** (6 FTEs)
- We are open to scientific discussion, at the same time we recognize that, at least in Spain, there is only one major and viable path in the high mass WIMP search field
- LAr-EL TPC gives an extraordinary and unique opportunity of having large exposures (~100 kg·yr) in background free mode: **a striking worldwide effort based on this technology started!**
- We are already part of this effort, with a significant contribution! **Remarkable opportunity for other Spanish groups**: room to increase the visibility and maximize the investment.

Backup

Strategy

- **Dual-phase electroluminescent Ar-TPC** based on the DS-50 and ArDM designs (3D reconstruction and fiducialization and multiplicity)
- Electron recoil suppression by a factor in excess of **10^7 at low energy** (internal γ/β contamination)
- **Active vetoes** (WC+LS / LAr?) (μ and cosmogenics neutrons)
- Optimization of the detector in terms of total mass and setting very stringent limits in terms of **radiopurity** of the materials (internal fission and α,n neutrons)
- Radiopure **silicon-based photosensors** (SiPM), with an internal area above 14 m^2
  - Radiopurity
  - Photon counting
  - Detection efficiency
  - Segmentation, sub-centimeter position resolution and fiducialization
- Threshold **<30 keV_{NR}** and the neutron **background free** mode