The ArDM experiment

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on behalf of the ArDM collaboration

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MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
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Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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Eidgenössische Technische Hochschule Zürich
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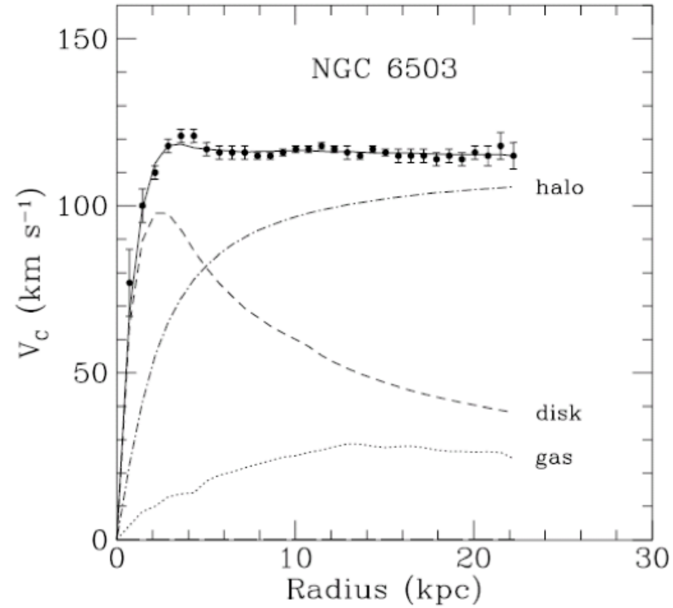
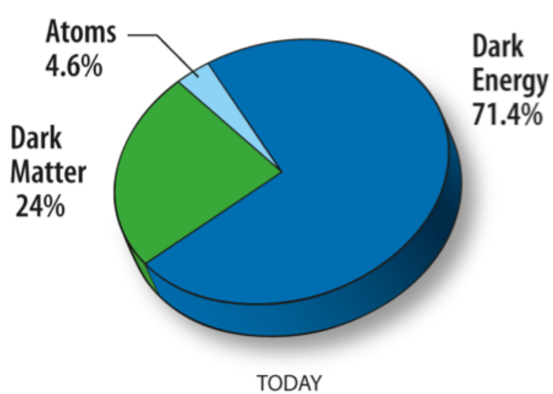
ArDM

Dark Matter

- **First hint**:
  - Fritz Zwicky (1930s) and Vera Rubin (1970s) measure **rotational velocities** of galaxies and clusters.
  - Galaxies rotating faster than predicted → **more matter required** for stability.



- WMAP results: **energy density** components of the Universe.



- **More hints**

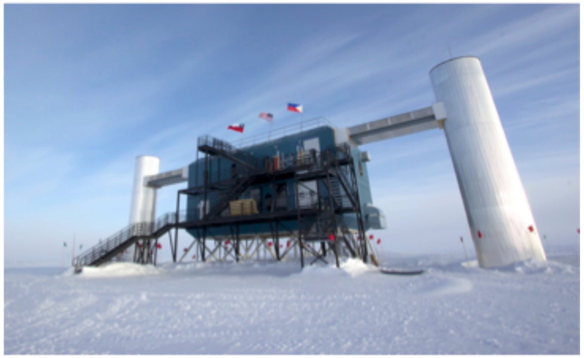
Gravitational lensing

Collision of galaxy clusters

Dark Matter observations and detection

- Dark Matter **candidates**:
  - **WIMPs** (Weakly Interacting Massive Particles)
    - Supersymmetry → neutralino.
  - Alternatives: axions, sterile neutrinos, ...

IceCube



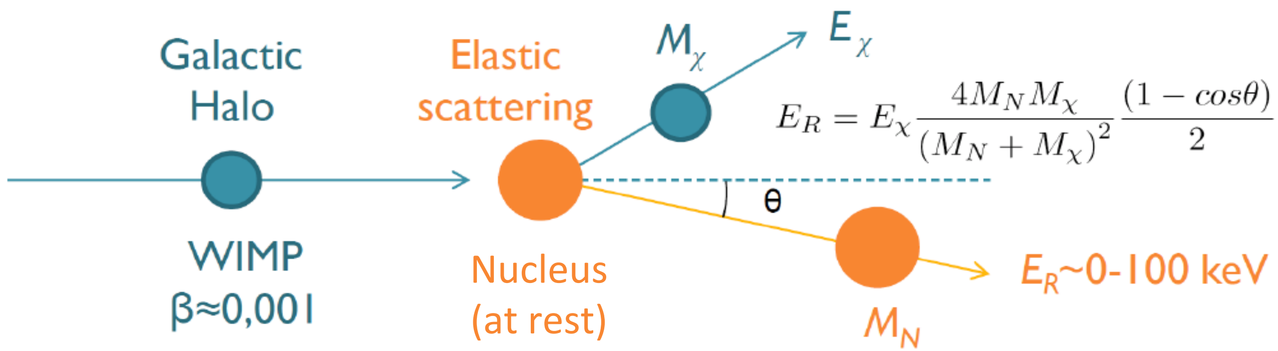
- **Detection**
  - **Direct** detection: nuclear recoil by WIMP scattering off ordinary matter (ArDM).
  - **Indirect** detection: gamma rays and antimatter from cosmic rays (IceCube).
  - **Accelerators**: production (LHC).

ArDM

LHC

Direct detection of DM

- Detection of **elastic scattering** of galactic WIMPs off target nuclei.
- The elastic scattering of a WIMP with mass M_χ produces the recoil of the target nucleus of a mass M_N with an energy E_R and an angle θ:



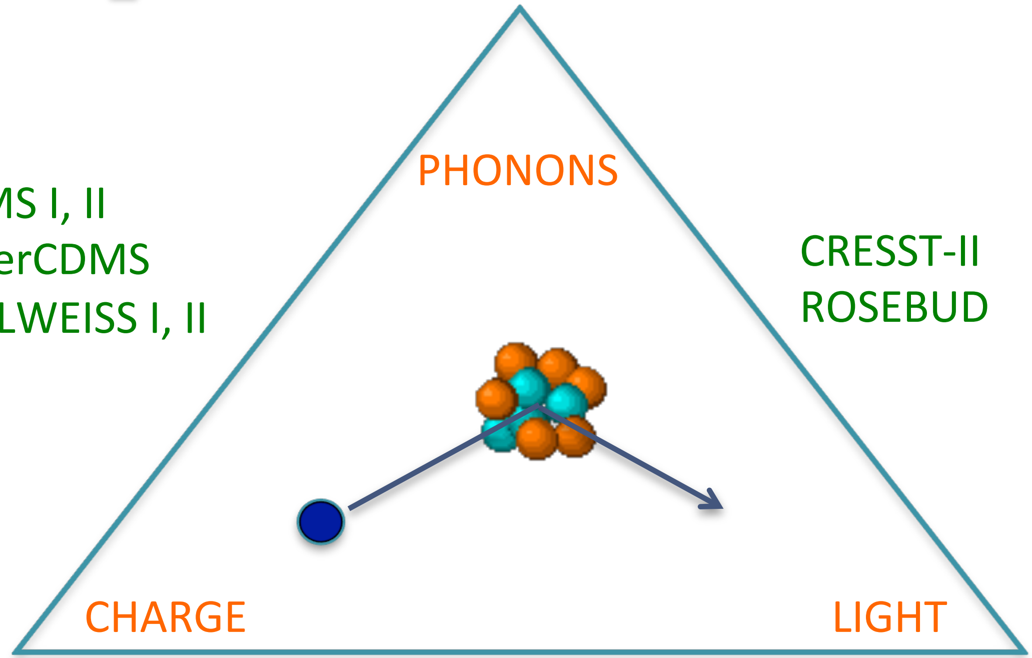
- WIMP speed ~ 220 km/s → expect **recoils** O(10 **keV**)
- Expect ~ **1 event/kg/year**
- Experimental requirements
  - Low energy **threshold**
  - Large **mass**
  - Ultra low **background** → underground operation
  - Event by event **discrimination**

Detection techniques

CRESST- I
COUPP
PICASSO

CDMS I, II
SuperCDMS
EDELWEISS I, II

CRESST-II
ROSEBUD

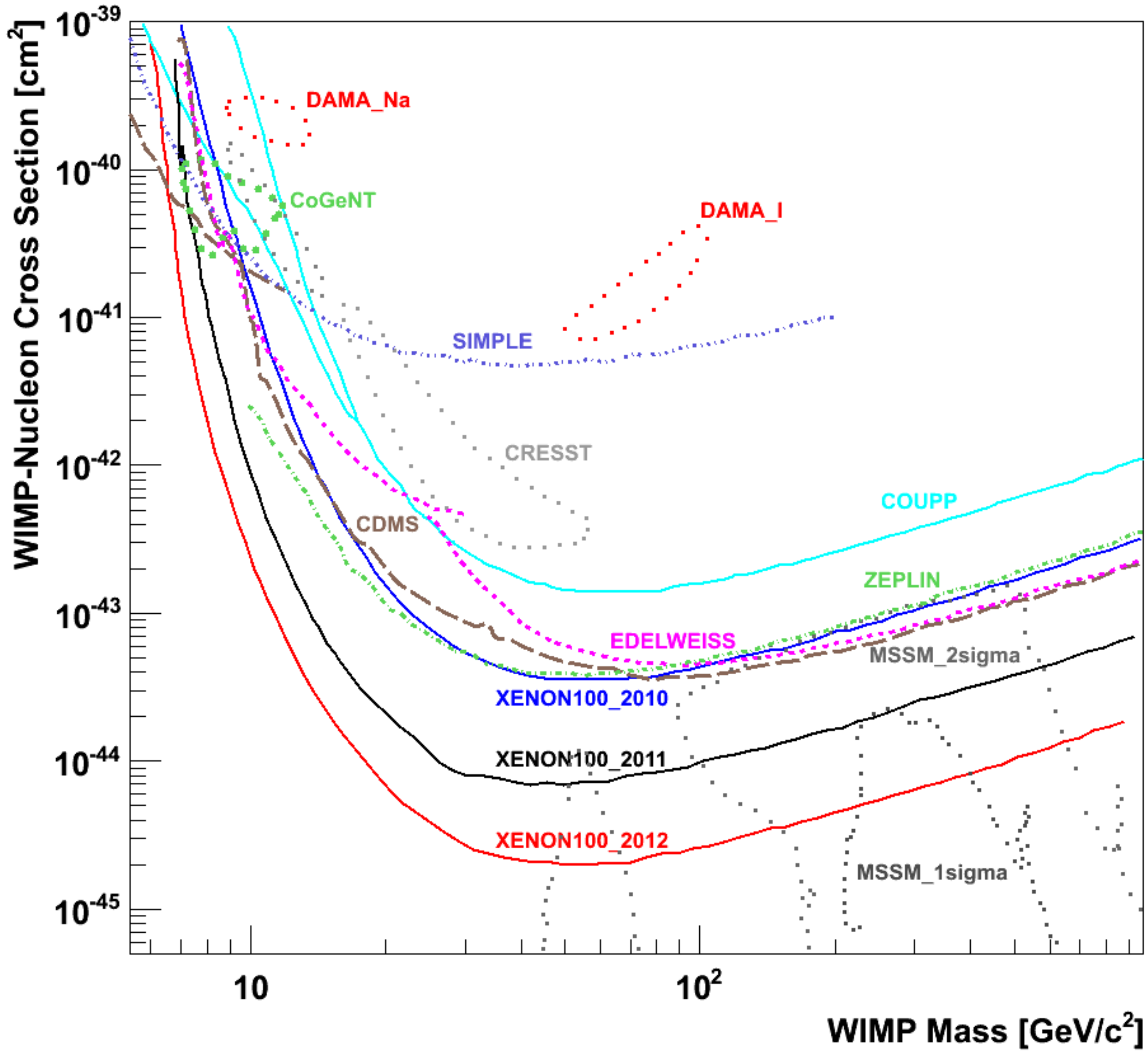


IGEX
GEDEON
GENIUS
GERDA
CoGeNT

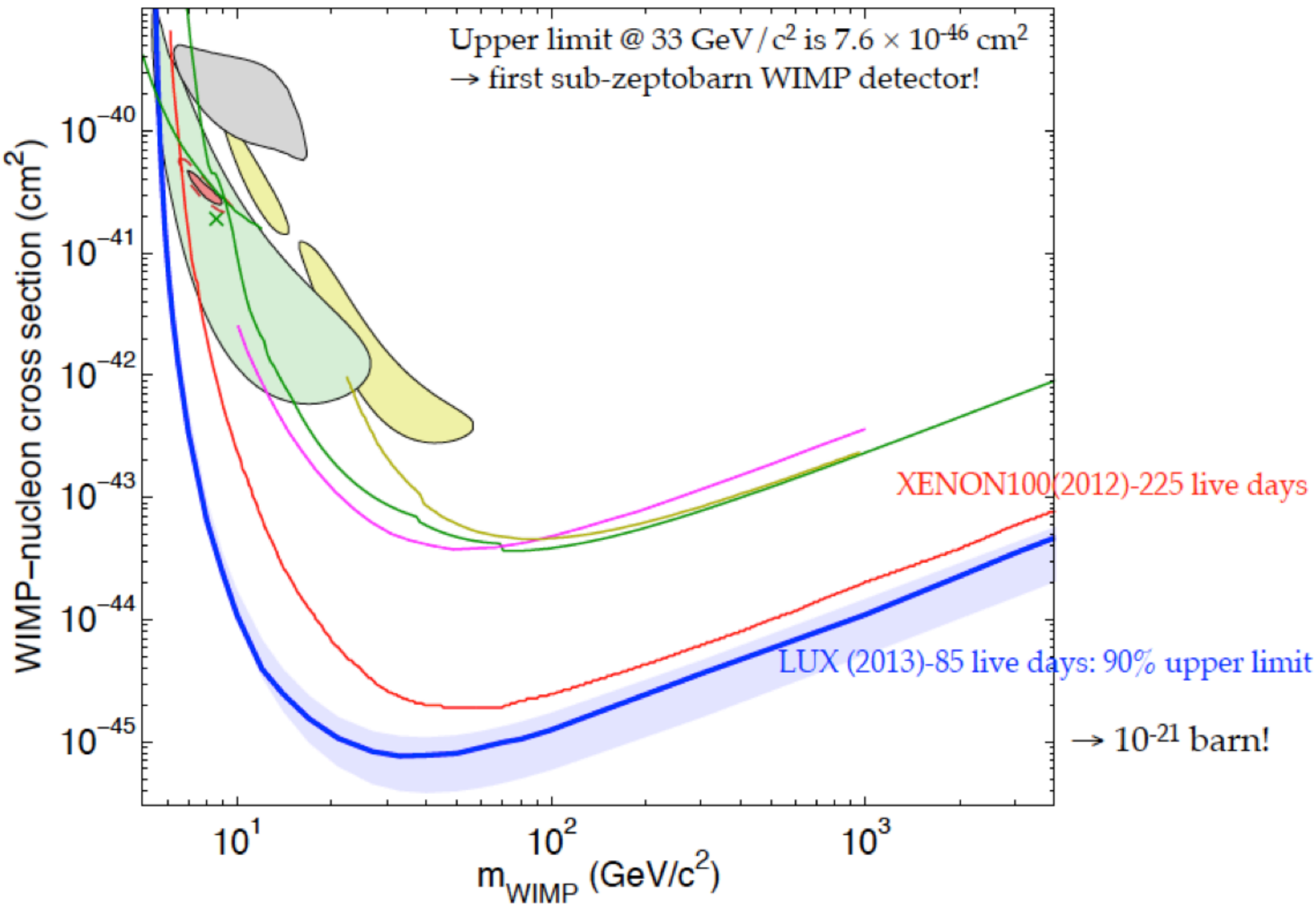
ZEPLIN II, III
XENON
LUX
WARP
ArDM
DarkSide

ZEPLIN I
DEAP
CLEAN
XMASS
DAMA/LIBRA
KIMS

Current experimental status



Latest results



EP Seminar
First results from the LUX Dark Matter Experiment
by Dr. Chamkaur Ghag (University College London)

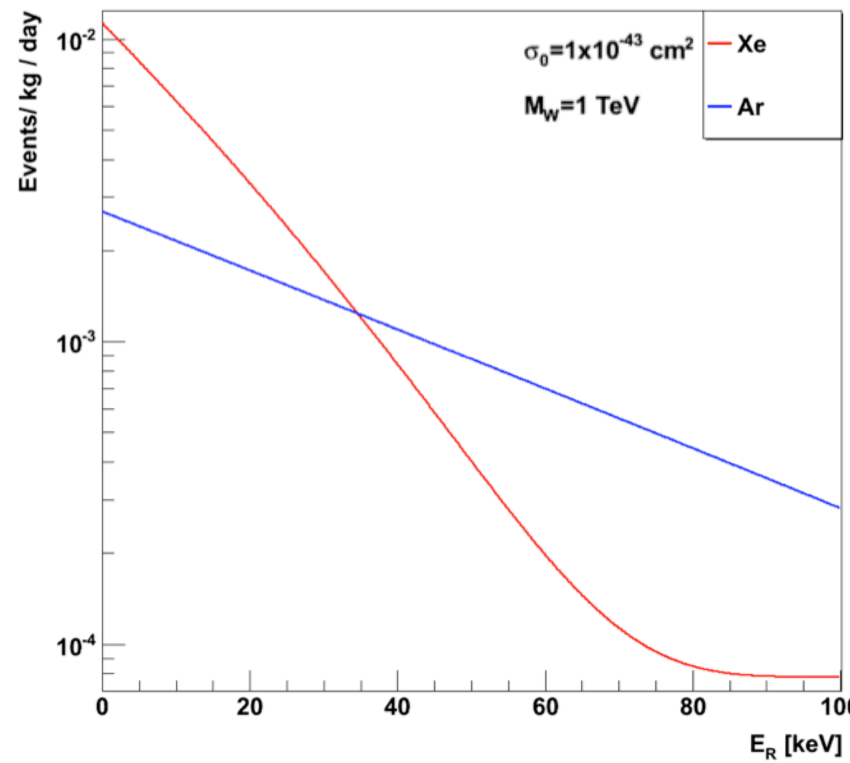
Noble liquids for DM detection

- Special properties for detecting nuclear recoils

1. **Scalable target** → build large detectors exploring low cross section values.
2. Ionization signal
   - **event position reconstruction** in a Time Projection Chamber (TPC)
   - fiducial volume cuts.
3. **High scintillation and ionization yield**
   - transparent to their own scintillation light.
4. **Discrimination methods** between electron like recoils and nuclear recoils
   - differences charge to light ratio
   - pulse shape discrimination [LAr]
5. Noble gases do not attach electrons and they can be **easily purified**
   - high electron mobility
   - long drift distances (D > 1m).
6. Available in large quantity (**affordable**).
7. **Safe** targets (inert and not flammable).

Characteristics of argon

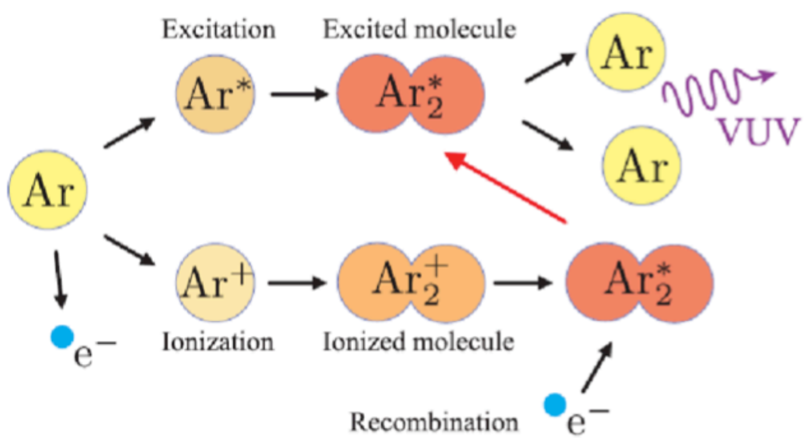
- Event rate in argon is **less sensitive to** the **threshold** on the recoil energy than it is for xenon.
- Xenon and argon recoil spectra are different due to kinematics (and form factor)
  - **Spin-independent or dependent interaction**
- Argon is much **cheaper** and **available** in large quantity than other noble gases.



- There is some **experience** in handling massive liquid argon detectors (ICARUS).
- Different methods for **background discrimination.**
- ^{39}**Ar** (β active isotope, T=269 years, rate ~1 Hz/kg).

Argon as detecting medium

- Many DM direct detection experiments **use noble liquids TPCs** that allow:
  - Detect **low threshold** events
    - **Elastic scattering** WIMP-argon nucleus → nuclear recoil $E_r \approx$10-100 keV
    - Estimated **event rate** on argon target: M_W=100 GeV/c^2, σ_{Wn} =10^{-43} cm^2, E_{th}=30 keV in 1 ton of argon is about 0.5 event/day.
  - **Background dicrimination**
  - Event **position reconstruction**

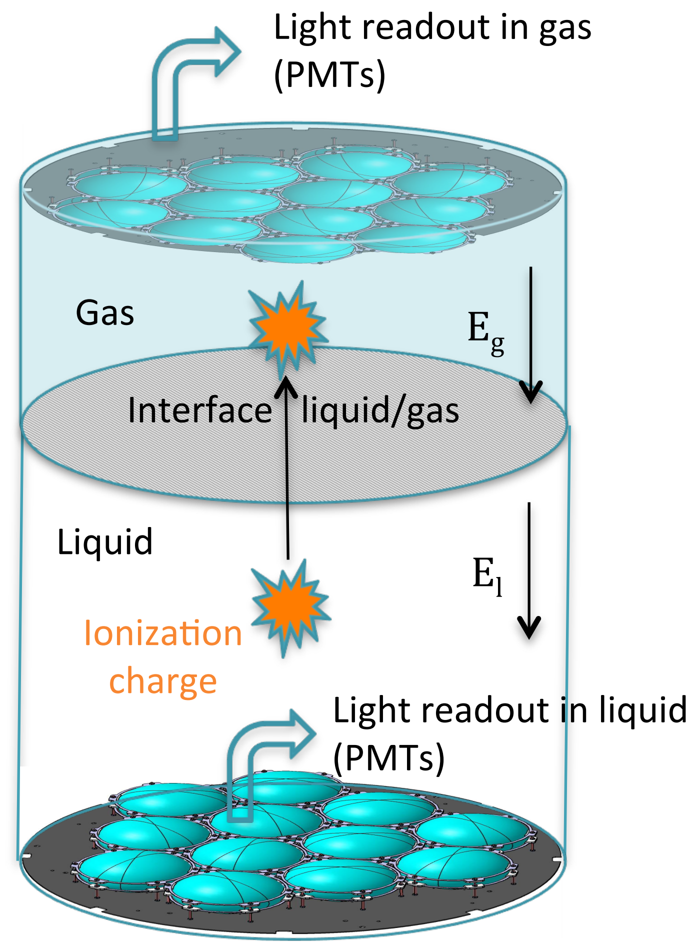


- **Scintillation signal in LAr**
  - **High scintillation yield** → 40 γ/keV
  - Ionization and excitation → excimers Ar_2^*. (singlet or triplet) → **primary scintillation light**, S1, 128nm (VUV).

Electroluminiscence time projection chamber

Ionization signal

- e^- from ionizing track are **drifted** by electric field. In **LAr TPC**:
  - E_l field: 1 kV/cm
  - Ionization yield → 42 e^-/keV
  - Drift velocity: ≈ 2mm/μs at 1 kV/cm
  - Small diffusion (≈mm after several m of drift)
- e^- **extracted** and accelerated from liquid into gas phase:
  - E_g field: 4 kV/cm
  - Produce **secondary electroluminescence** scintillation (S2)
  - S2 is proportional to the amount of charge reaching the gas phase.



- Event **position reconstruction**
  - Light pattern top PMT array → **x,y**
  - Delay S2 with respect to S1 → **z**

The ArDM collaboration

RE18 CERN experiment

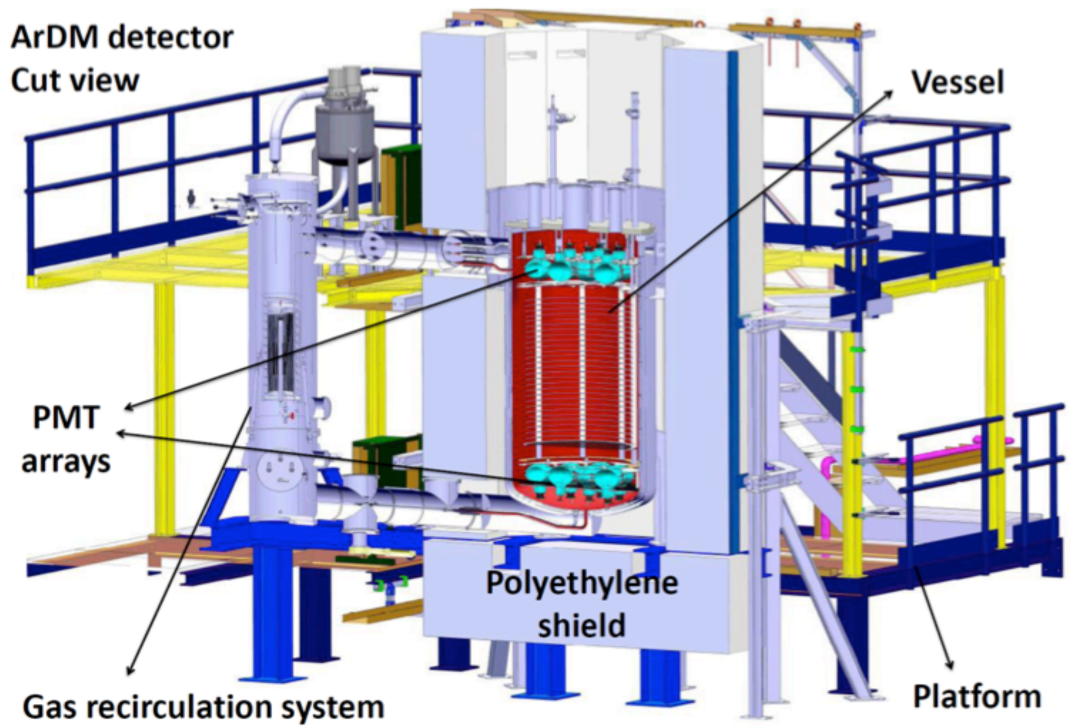
- ETH Zurich
  - F.Bay, C.Cantini, S.Di Luise, L.Epprecht, A.Gendotti, S.Horikawa, S.Murphy, K.Nguyen, K.Nikolics, L.Periale, C. Regenfus, F.Resnati, A.Rubbia, F.Sergiampietri, D.Sgalaberna, T.Viant, S.Wu
- CIEMAT
  - M. Daniel, B. Montes, L. Romero, R. Santorelli.

ArDM experiment

- **Double phase argon TPC** for direct DM searches.
- **Ton-scale** sensitive volume
- Goal: detect **nuclear recoils** produced by dark matter particles scattering off target nuclei.
- Tested on surface at **CERN** and currently installed in the Laboratorio Subterráneo de Canfranc (Spain).
- During 2013, the installation has been almost completed and several gas tests have been performed.

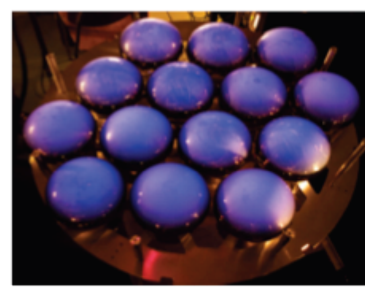
ArDM experiment

- **Drift length**: 120 cm.
- **Diameter**: 80 cm.
- **Target mass**: 850 kg.
- **Neutron shielding**: passive polyethylene.
- **Argon purification**: liquid and gas argon recirculation through getters.
- **Temperature control**: Vacuum insulation +two cryo-coolers.
- **Light readout**: 12 PMTs in LAr + 12 PMT in GAr (8“ Hamamatsu R5912-02MOD-LRI).

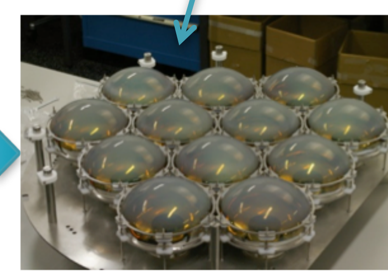


ArDM TPC

- **Two light signals** are produced and detected:
  - Liquid → primary scintillation light (**S1**).
  - Gas→ secondary electroluminescence scintillation (**S2**).
- **Wavelength conversion** 128 nm (VUV) → ~420 nm, optimal for detection on the photomultipliers (PMTs), using the wavelenth shifter tetraphenyl butadiene (TPB).
- Reconstruct xyz event **interaction position**.



UV light



Visible light

Canfranc Underground laboratory

- Located in the Central Pyrenees region in the Regional Community of Aragón (Northern Spain).
- Lab adjacent to two existing tunnel infrastructures: the Somport Road Tunnel, which connects Spain and France, and an old railway tunnel, which serves as emergency gallery for the road tunnel.

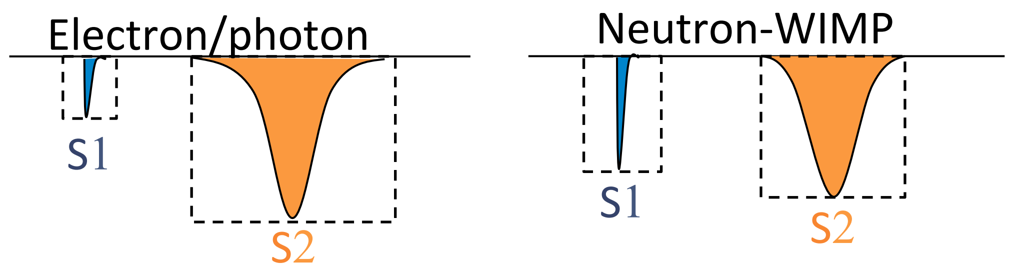
- Lab. space ≈ 4000 m^3 (main hall).
- Gamma flux ≈ 2×10^{-2} $\gamma/cm^2/s$.
- Neutron flux ≈ 10^{-6} $n/cm^2/s$ (CUNA).
- Radon ≈ 50-100 Bq/m^3.
- Temperature, pressure and humidity are carefully monitored.

Background

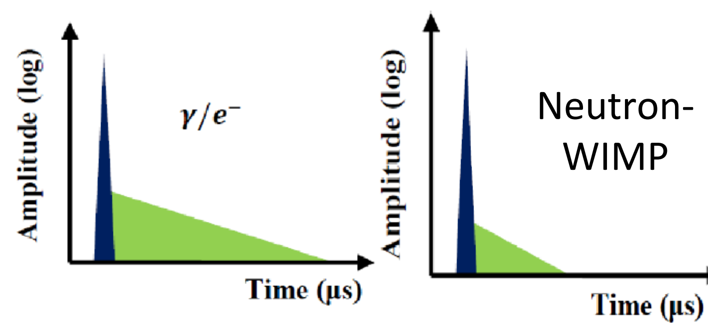
- **Low event rates** require:
  - powerful **background rejection.**
  - **underground** operation.
- **Electrons and photons**
  - Beta decay ^{39}Ar
  - Radioactive decay of the detector and laboratory materials
- **Neutrons**
  - Spontaneous fission: U/Th decay chains
  - (α,n) reactions
  - Cosmic muon spallation reactions
- **Two background discrimination methods**:
  - Charge to light ratio (S1/S2)
  - Pulse shape

Ratio S1/S2

Rejection $>10^8$



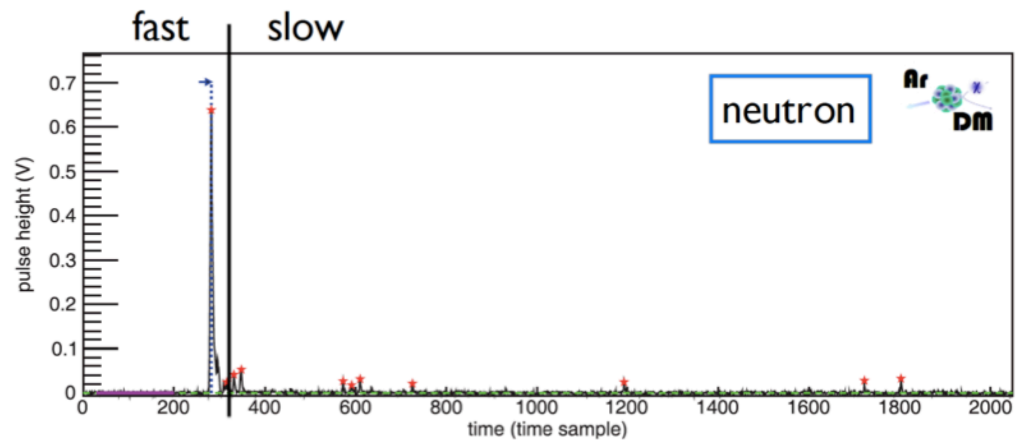
Pulse shape

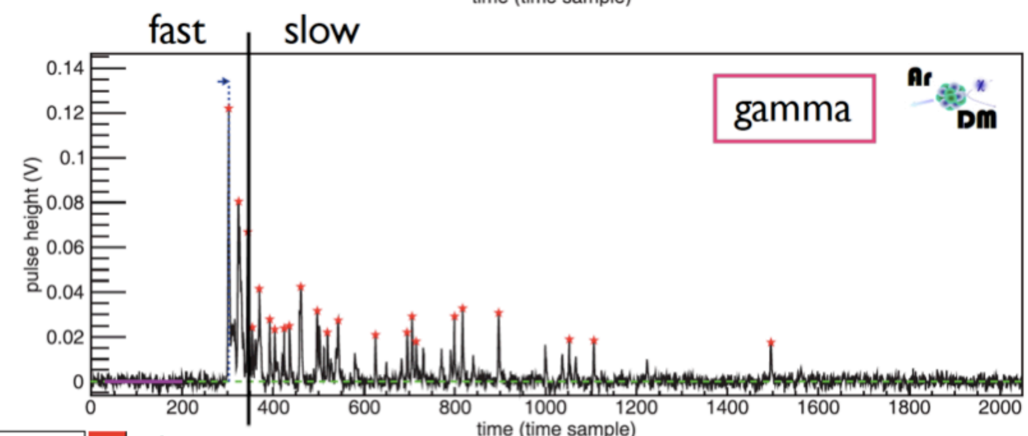


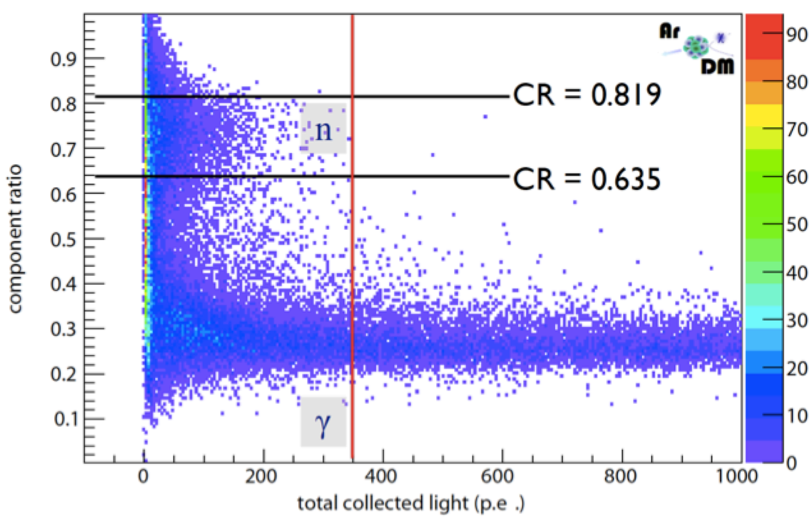
# photoelectrons	Rejection (E=0V/cm)
>10	$>10^2$
>20	$>5\times10^3$
>30	$>10^5$

Pulse shape discrimination

- **Data** taken on surface at CERN
  - ^{241}Am-Be source
    - $^{9}Be + \alpha \rightarrow 12C^{*} + n$
  - Externally triggered (NaI)
  - Sum of 14 PMTs
  - Single phase (LAr) mode







- **Component ratio**
  - **Electron-recoil** events: CR~0.3
  - Nuclear recoil events: CR~0.7
    - Maximum energy:350 p.e. (1.9 MeV_{nr})

U. Degunda, PhD thesis, ETHZ

Ar-39

- Produced from ^{40}Ar in the Earth's atmosphere by cosmic ray activity.
- It is a **radioactive** element that decays to ^{39}K by β^- desintegration.
- Half life: 269 years.
- The content of ^{39}Ar in natural argon is measured to be of $(8.0\pm0.6)\times10^{-16}$ g(^{39}Ar)/g(^{nat}Ar).
- The **activity** of ^{39}Ar in **liquid argon** is ~**1.4 Bq/L** (WARP)→ significant radioactive contamination → it could limit the sensitivity.
  - Integrated rate in 1 ton LAr ~1kHz
  - Required rejection power of 10^8
- ^{39}Ar background is well distinguishable, if a **precise** determination of the **ionization/scintillation ratio** is achieved.
- Alternative: use ^{39}Ar-**depleted argon** procured from underground well gases.

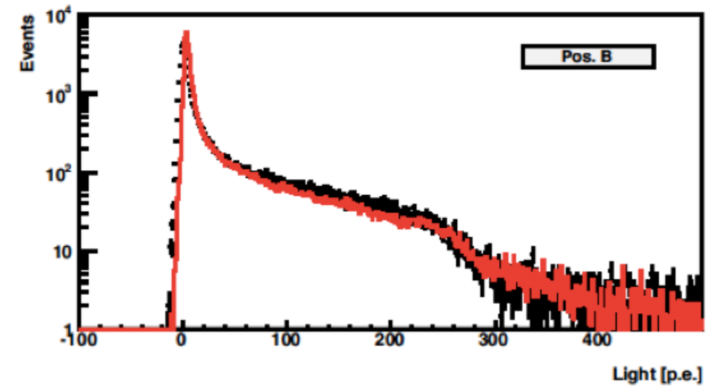
ArDM operation phases

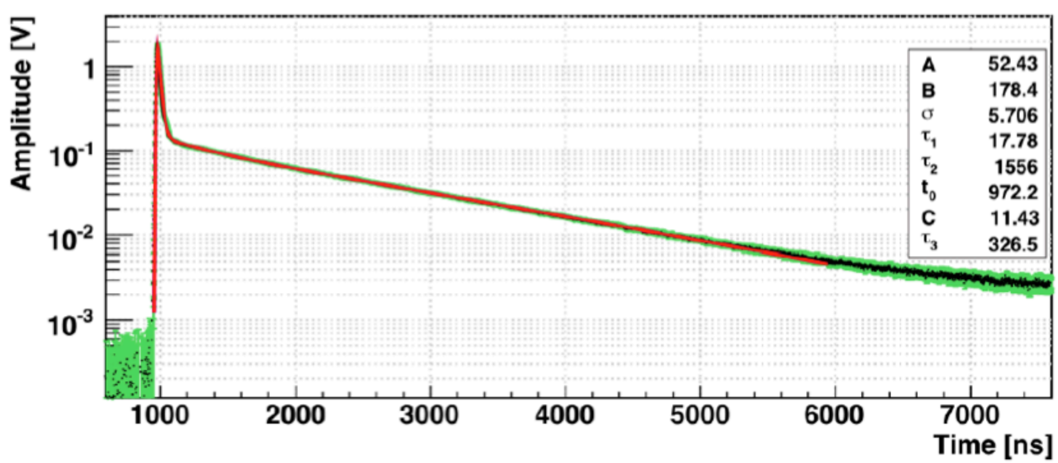
- **Surface** operation :
  - Build and assemble the ArDM prototype ✓
  - Commission the detector cryogenics, purification, HV, electronics,light readout and software ✓
- **Underground** operation I:
  - Construction and installation of the passive neutron shielding ✓
  - Installation of ArDM and its infrastructures ✓
  - Warm gas argon runs (test light readout system) ✓
  - Material screening → **Ongoing**
  - Neutron flux measurements → **Ongoing**
  - Cold gas argon runs (test cryogenics, light readout...). First half of 2014.
- **Underground** operation II (2014):
  - Liquid argon tests (commission HV, purification, cryogenics, ...).
  - Physics runs.

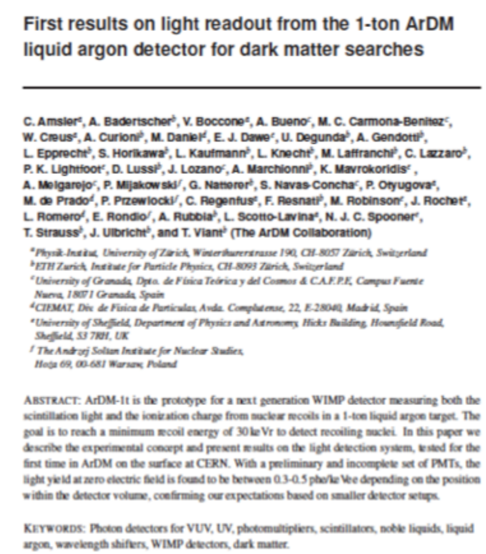
Surface operation at CERN

- Detector successfully operated in the single phase LAr operation mode in stable conditions.
- Several calibration runs with external sources taken (^{22}Na, AmBe).
- DAQ tested.
- Light collection and particle discrimination studies.

Na22







First results on light readout from the 1-ton ArDM liquid argon detector for dark matter searches

C. Amsler[a], A. Badertscher[b], V. Boccone[a], A. Bueno[c], M. C. Carmona-Benitez[c], W. Creus[a], A. Curioni[b], M. Daniel[d], E. J. Dawe[e], U. Degunda[b], A. Gendotti[b], L. Epprecht[b], S. Horikawa[b], L. Kaufmann[b], L. Knecht[b], M. Laffranchi[b], C. Lazzaro[b], P. K. Lightfoot[e], D. Lussi[b], J. Lozano[c], A. Marchionni[b], K. Mavrokoridis[e], A. Melgarejo[c], P. Mijakowski[f], G. Natterer[b], S. Navas-Concha[c], P. Otyugova[a], M. de Prado[d], P. Przewlocki[f], C. Regenfus[a], F. Resnati[b], M. Robinson[e], J. Rochet[a], L. Romero[d], E. Rondio[f], A. Rubbia[b], L. Scotto-Lavina[a], N. J. C. Spooner[e], T. Strauss[b], J. Ulbricht[b], and T. Viant[b] (The ArDM Collaboration)

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[b] ETH Zurich, Institute for Particle Physics, CH-8093 Zürich, Switzerland
[c] University of Granada, Dpto. de Física Teórica y del Cosmos & C.A.F.P.E, Campus Fuente Nueva, 18071 Granada, Spain
[d] CIEMAT, Div. de Física de Partículas, Avda. Complutense, 22, E-28040, Madrid, Spain
[e] University of Sheffield, Department of Physics and Astronomy, Hicks Building, Hounsfield Road, Sheffield, S3 7RH, UK
[f] The Andrzej Soltan Institute for Nuclear Studies, Hoża 69, 00-681 Warsaw, Poland

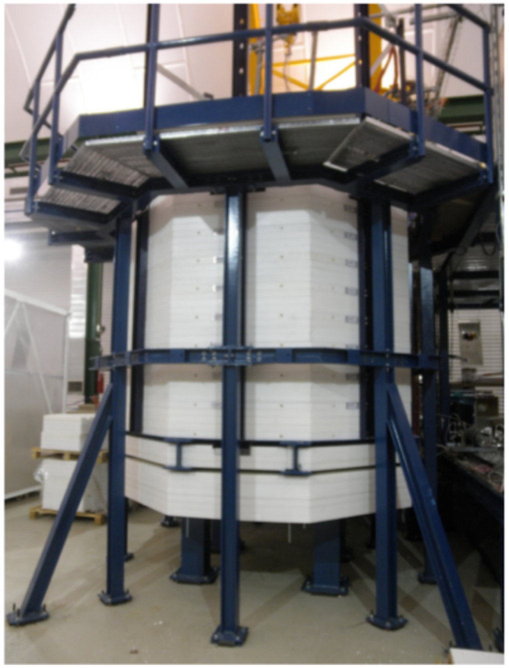
ABSTRACT: ArDM-1t is the prototype for a next generation WIMP detector measuring both the scintillation light and the ionization charge from nuclear recoils in a 1-ton liquid argon target. The goal is to reach a minimum recoil energy of 30 keVr to detect recoiling nuclei. In this paper we describe the experimental concept and present results on the light detection system, tested for the first time in ArDM on the surface at CERN. With a preliminary and incomplete set of PMTs, the light yield at zero electric field is found to be between 0.3-0.5 phe/keVee depending on the position within the detector volume, confirming our expectations based on smaller detector setups.

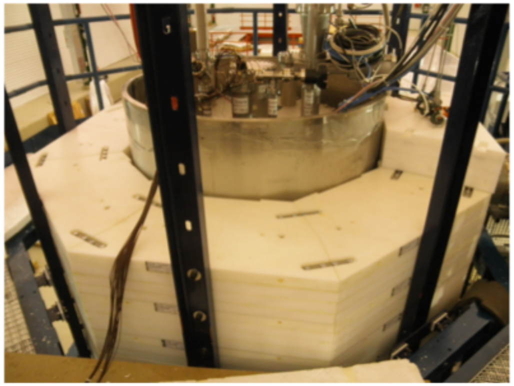
KEYWORDS: Photon detectors for VUV, UV, photomultipliers, scintillators, noble liquids, liquid argon, wavelength shifters, WIMP detectors, dark matter.

JINST 5:P11003,2010

Underground operation

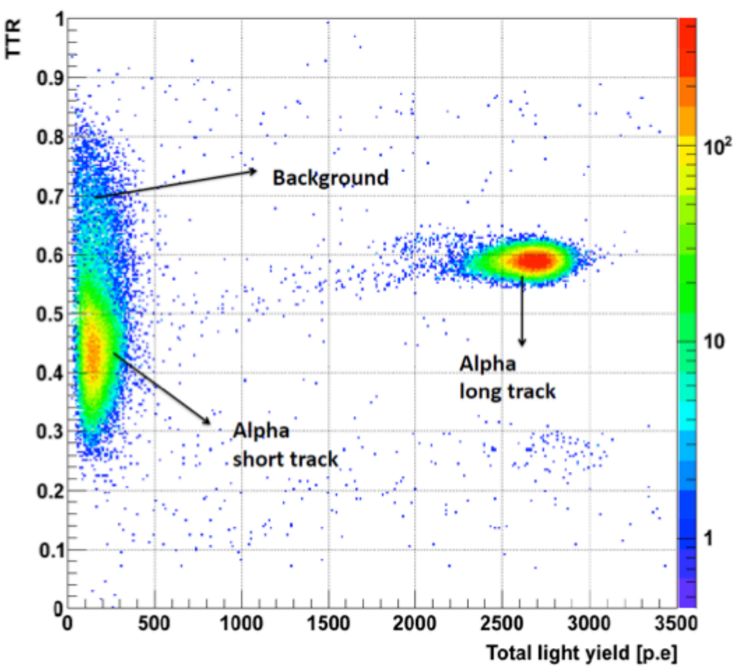
- ArDM underground operation started at LSC on 2012.
- **Polyethylene neutron shield**
  - 50 cm thick
  - Reduce ~10^5 the flux of neutron of less than 1 MeV.
  - Installed: bottom and most part of the lateral shield.
  - Top part: pending.
  - Liquid argon evacuation system.
- **Safety** → shield protection against accidental flame:
  - Fire-retardant paint.
  - Insulating layer + external aluminium sheet.

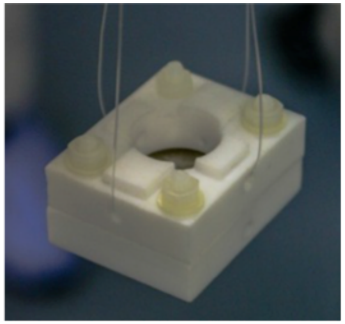




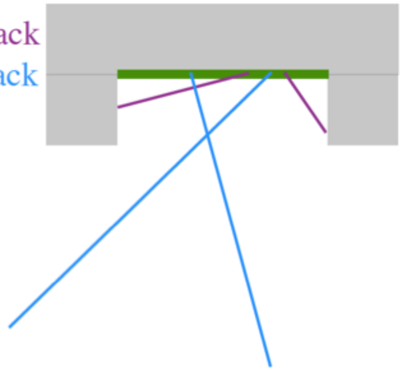
First measurement in gas

- First data taking at LSC was carried out in **April 2013**
  - **warm pure argon gas**
  - low-activity ^{241}**Am source** installed inside the detector vessel
  - goal: **evaluate light yield** and background.
- Top-to-total ratio: TTR = LY_{TOP} / LY_{TOTAL}.
- **Improvement** of a factor 3 **in the light yield** of the detector with respect to previous tests at CERN on a prototype having one PMT array at the bottom → **expected** LY in **liquid: 2p.e./keV$_{ee}$** at 0 kV/cm.





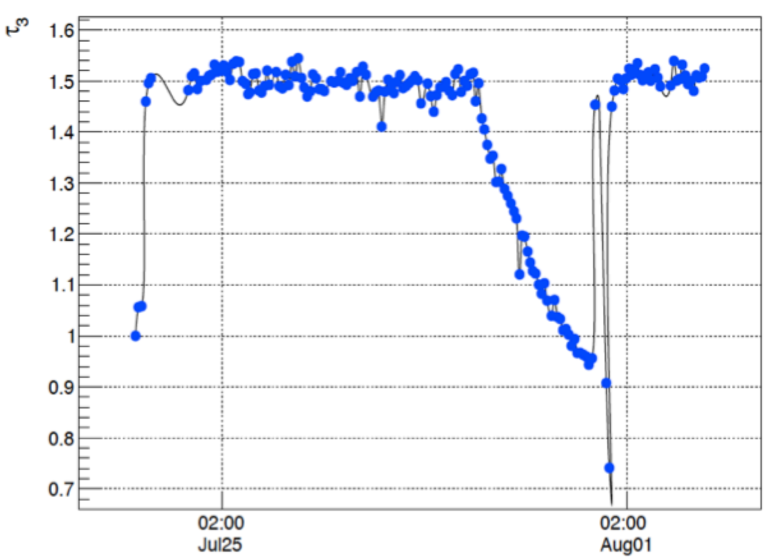
Source holder



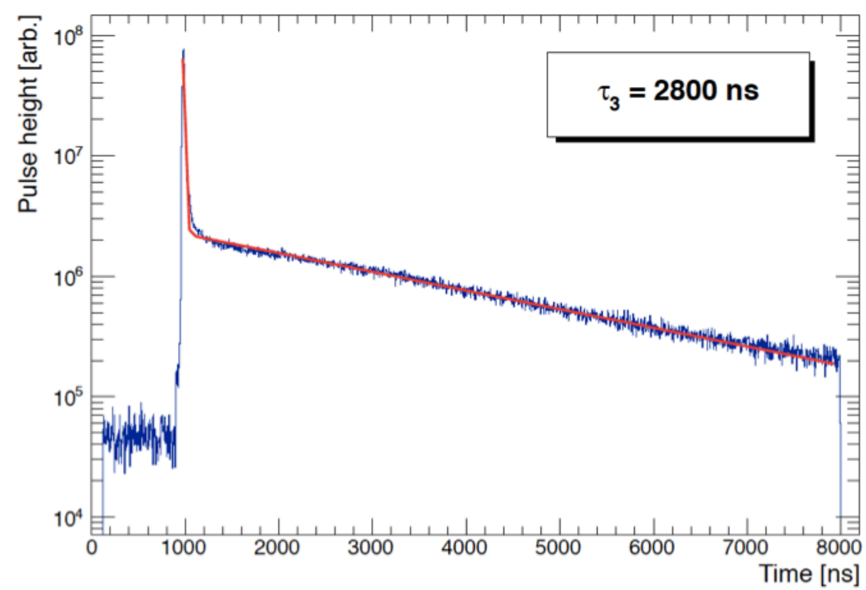
Track scheme

Gas test with recirculation

- Another comissioning data taking was carried on **July-August 2013**
  - **warm pure gas argon**
  - **no alpha source** inside the detector vessel
  - goal: observe **performance of gas recirculation** system and gain experience in continuous data taking.
- **Event rate** and slow scintillation component, τ_3 , **stable** with gas recirculation and decreased when stopping the system.



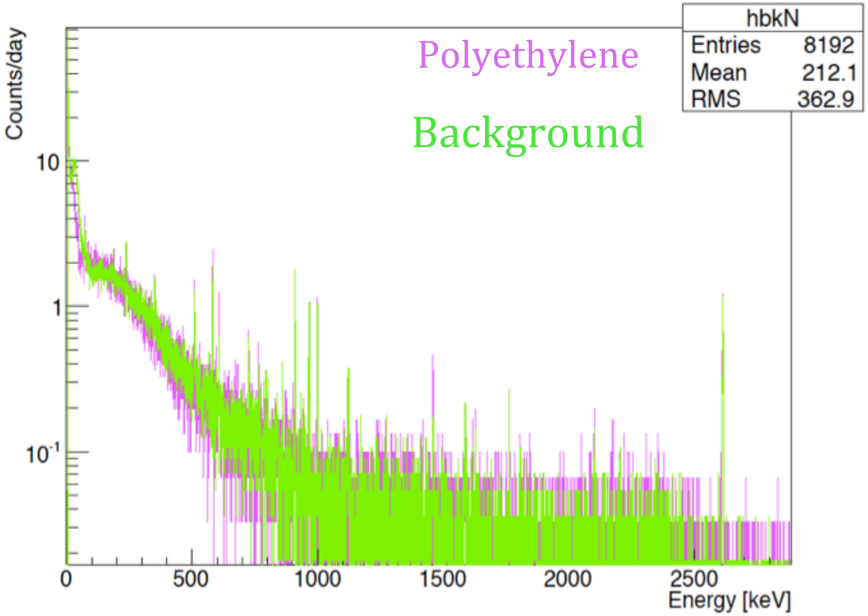
Waveform of argon scintillation in gas

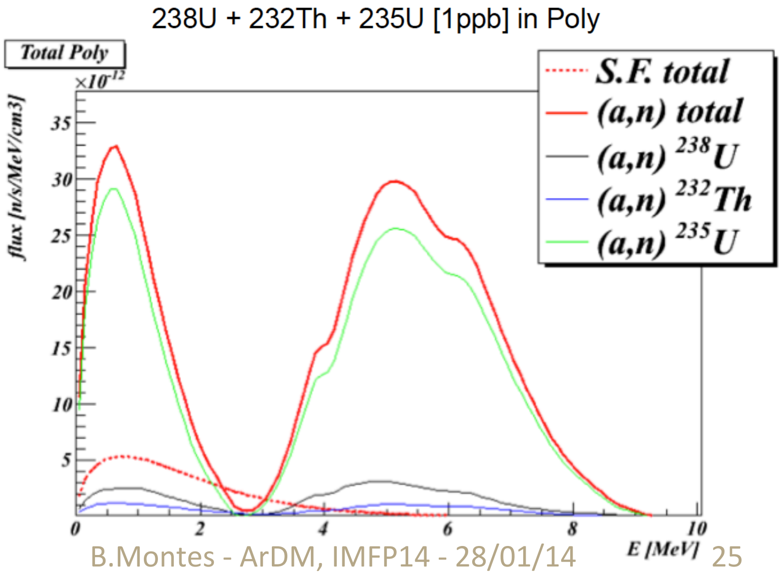


Ongoing activity: screening

- **Neutrons** coming from contamination of **detector materials** → irreducible background.
- Measurement campaign with **HPGe detector** supported by the LSC.
- Some **screened materials**
  - **PMT**: glass, electrodes, base, polyethylene for holder and base.
  - **HV resistors** for field cage.
  - **Polyethylene** for neutron shield.
  - **Perlite**

- Contaminations are input to evaluate the neutron flux inside the detector (irreducible background) → **Simulations** ongoing

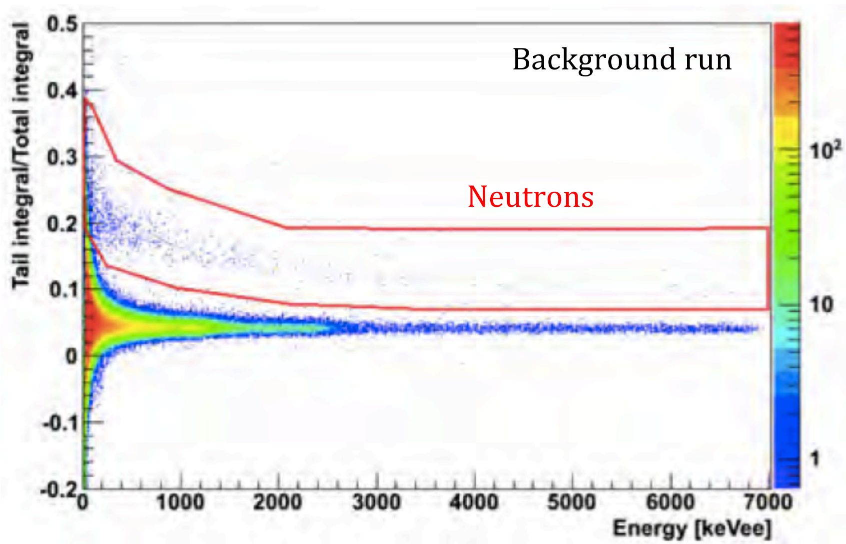


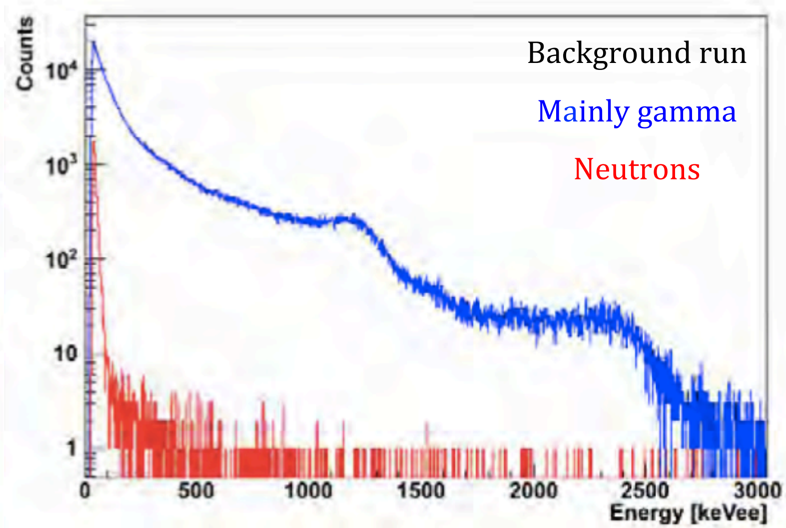


Ongoing activity: neutron measurements

- Neutron from natural radioactivity → nuclear recoils → **background contribution**.
- **Neutrons from surrounding rock**:
  - Natural isotopes: spontaneous fission and (α,n) reactions
  - Cosmic muon spallation reactions.
- Neutron flux and **energy spectrum "before the shielding"** → essential input parameters for Monte Carlo simulation → site-specific neutron flux measurements required.

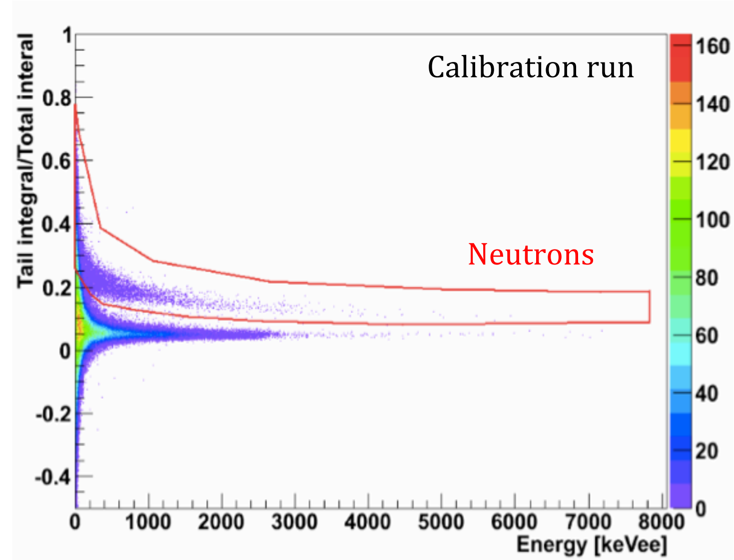
- Detectors fully characterized at **CIEMAT** (collaboration with the Nuclear Innovation Unit) with a proportional counter and two **BC501A liquid scintillators**.
- Digital charge integration discrimination method: **distinguish** between signals produced by **neutrons and gammas**.

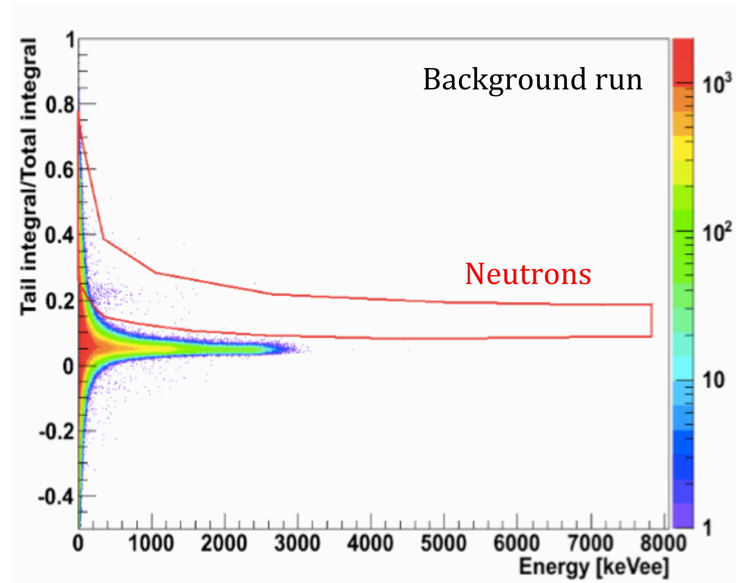


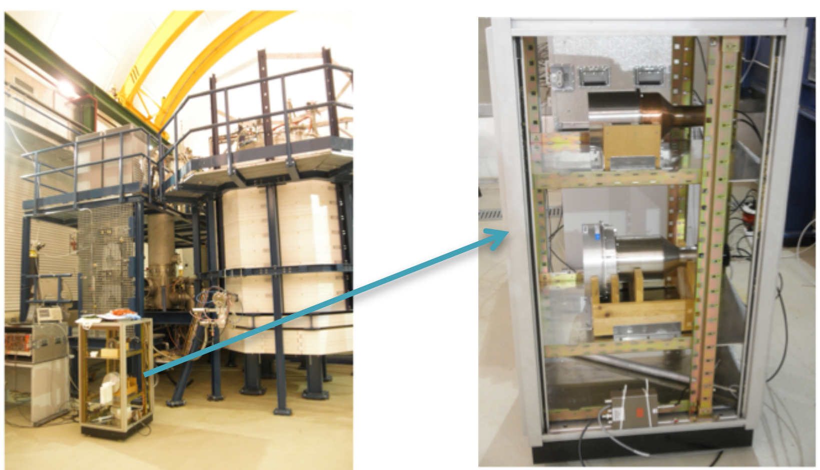


Ongoing: Neutron flux measurements at LSC

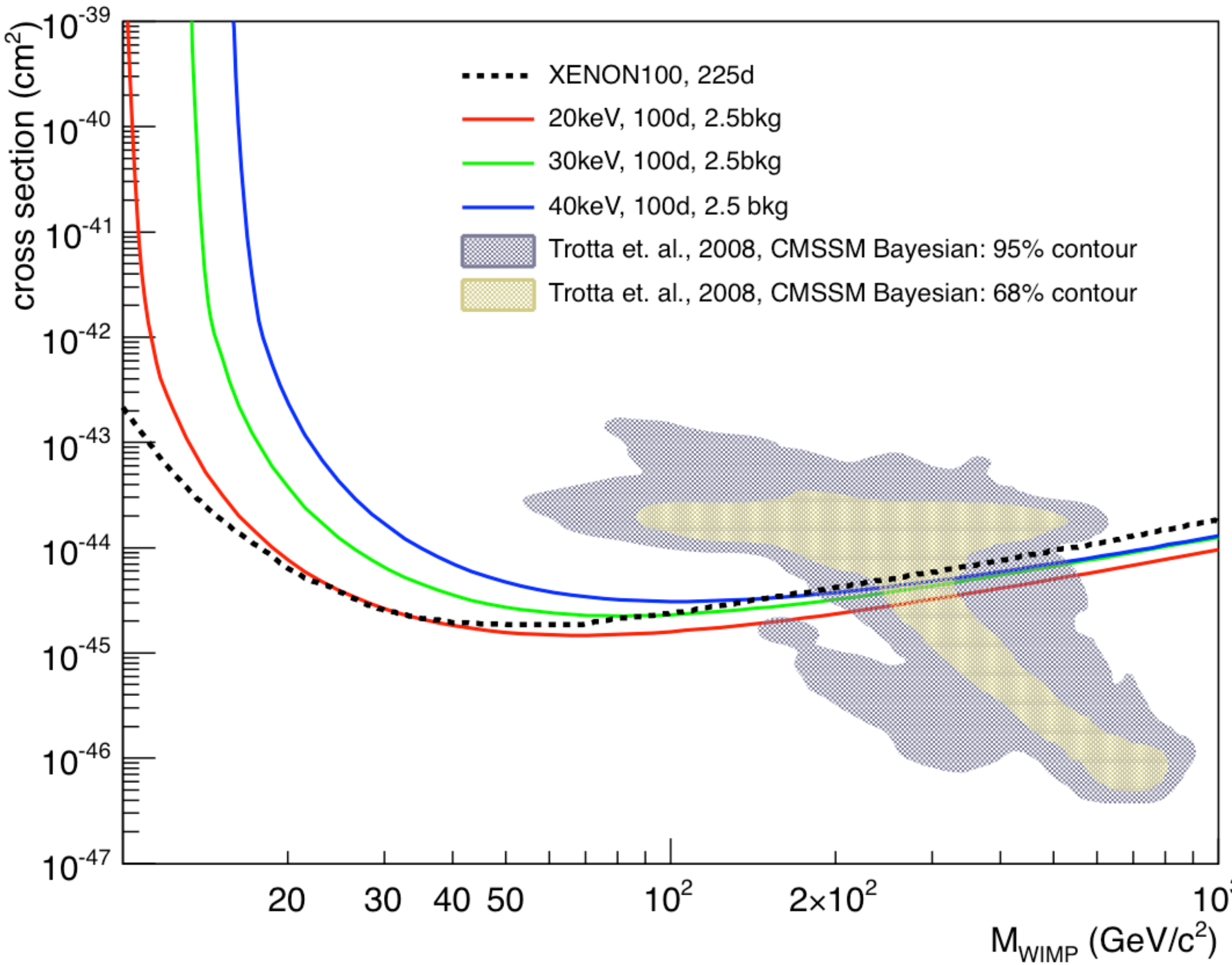
- Operations at LSC started in November 2013.
- Detectors and electronics **currently** installed **underground**, next to ArDM, and taking data:
  - Two BC501A **liquid scintillators** → fast neutron spectroscopy.
  - ^{3}He **proportional counter** → thermal neutron background.
- **Periodical calibrations** with gamma sources and a neutron source → check gain stability.
- **Data taking of several months** in collaboration with the Nuclear Innovation Unit from CIEMAT and **CUNA** is foreseen.







Goals after few months of operation



Conclusions

- The ArDM detector is **installed underground at LSC**.
- **First tests in gas** have been succesfully completed ✓
  - Study of detector response: signals from internal ^{241}Am source
  - PMT calibration
  - Light yield
- **Neutron flux** measurements → ongoing
- Expected in **liquid argon**:
  - Light yield at 0 kV/cm: 2p.e./keV_{ee}
  - 850 kg of Ar and 30 keV_{ee} threshold
- Rich measurement program on **2014**:
  - **Cold gas** argon runs.
  - Waiting for the green light from LSC to start operation in **liquid**.
  - After verification of the main detector parameters in liquid argon, we envisage the final preparation for the **physics runs**.

Thank you for your attention

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ArDM