Neutron background in dark matter experiments and new (α,n) cross-section measurements

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TIDPAN 2026: Taller de Instrumentación y Detectores en Física de Particulas, Astropartículas y Nuclear, Jun 15-26, 2026 (IFIC/CSIC-UV)

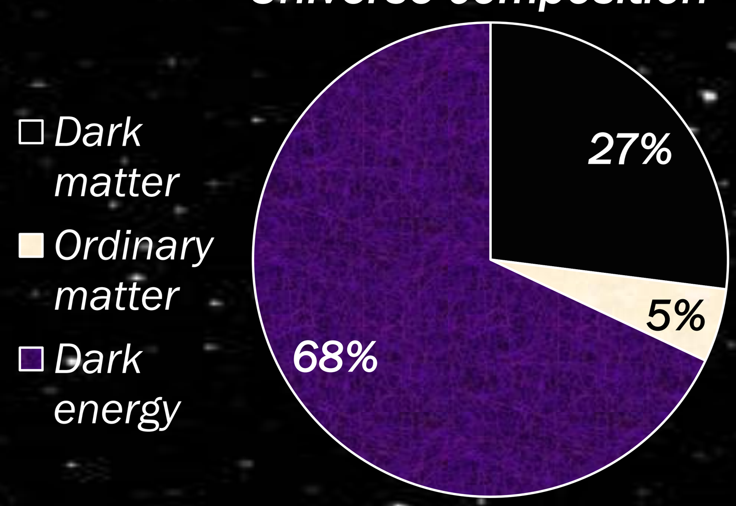
WIMPs: A Dark Matter candidate

Evidence of a **new type of matter** with astrophysical evidences:

- Curve of velocity rotation of spiral galaxies
- Gravitational lensing
- The Bullet Cluster
- ...

One possibility is that it is formed by particles which can interact with ordinary matter with a weak coupling

Universe composition



WIMPs: *Weakly Interacting Massive Particles*

Candidate for dark matter particles. They would be a thermal relic from the Early Universe from a freeze-out process, in which a decrease in the temperature of the Universe with its expansion caused a decoupling of the dark matter from ordinary matter, leaving a relic abundance. This abundance matches the abundance in the ΛCDM model, which is known as the *WIMP miracle*.

There are several ways to attempt a first measurement of a WIMP:

- **Direct detection**
- Indirect detection
- Collider searches

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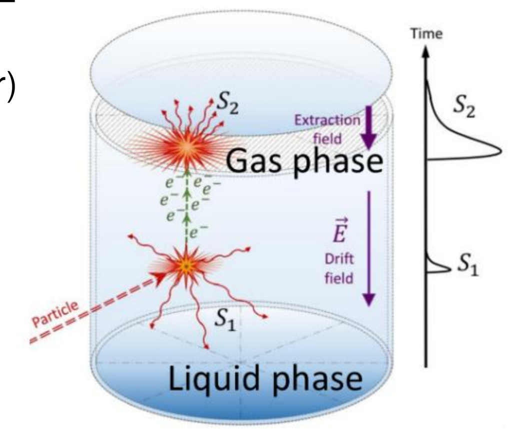
DarkSide-20k experiment

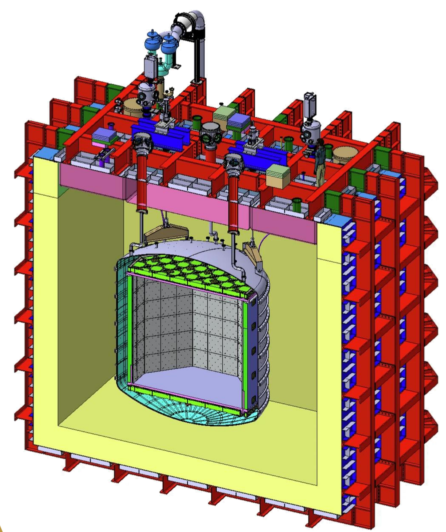
Global Argon Dark Matter Collaboration (GADMC)
Currently under construction at Hall C in **LNGS** (Italy)

Dual-phase TPC with 50 tonnes of low-radioactivity **underground Ar** (UAr)

Pulse Shape Discrimination: Nuclear Recoils vs Electronic Recoils

Extensive material assay campaign





- **ProtoDune-like cryostat**
- 21 m^2 of cryogenic **radiopure SiPM**
- **Active neutron veto (Inner Veto):** 32 tonnes of liquid UAr inside SS vessel
- **Cosmogenic muon veto (Outer Veto):** 700 tonnes of liquid AAr inside cryostat

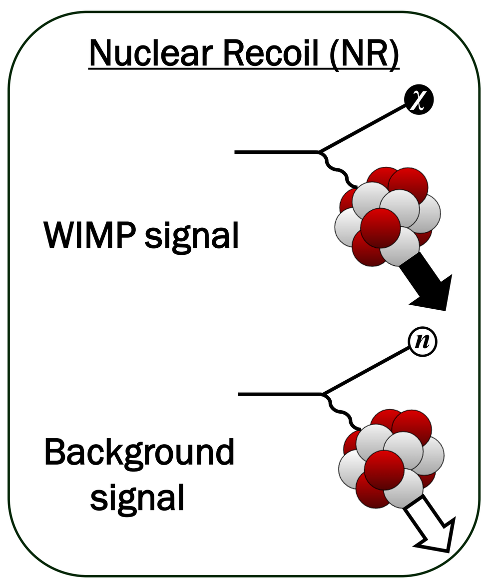
WIMP measurement:
Spin independent WIMP-nucleon interaction cross-section of 10^{-48}cm^2 at 90% CL for $m_\chi = 100$ GeV/c^2 in 200 tonne-year exposure

Neutron background calculation and its uncertainties

WIMP signal:
Single Nuclear Recoil in the fiducial volume in the WIMP energy range with no signal in veto-detectors in a given time window

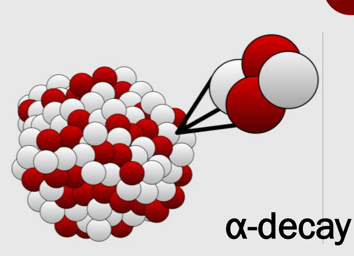
Background:
Neutrons producing single NRs in the keV energy range can mimic WIMP signals

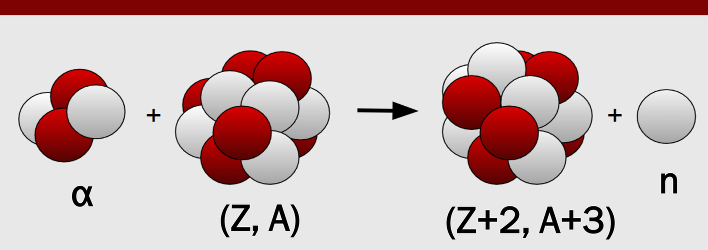
Current frontier in sensitivity
(α,n) neutrons coming from radiogenic α-activity



(α,n) reactions

Natural α-decay chains (^{238}U, ^{232}Th and ^{235}U) present in small proportions in the detector materials can produce neutron via the **(α,n) reaction**





Sources of uncertainty
Activity assay
Material composition
(α,n) yield: cross-section, stopping power

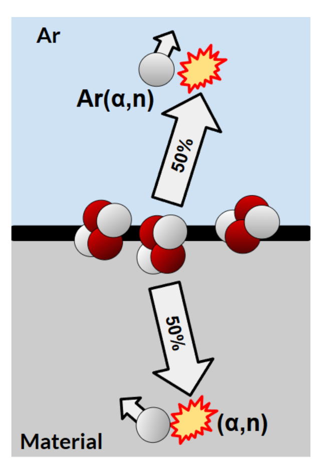
(α,n) neutrons for a Δt data-taking time

$$N_{ik} = \Delta t \, m_i \, \epsilon_k \sum_j a_{ij} \, y_{ij}$$

(α,n) yield calculation

$$Y_i(E_\alpha) = \frac{\eta_i}{\eta} \int_0^{E_\alpha} \frac{\sigma^i_{(\alpha,xn)}(E'_\alpha)}{S(E'_\alpha)} dE'_\alpha$$

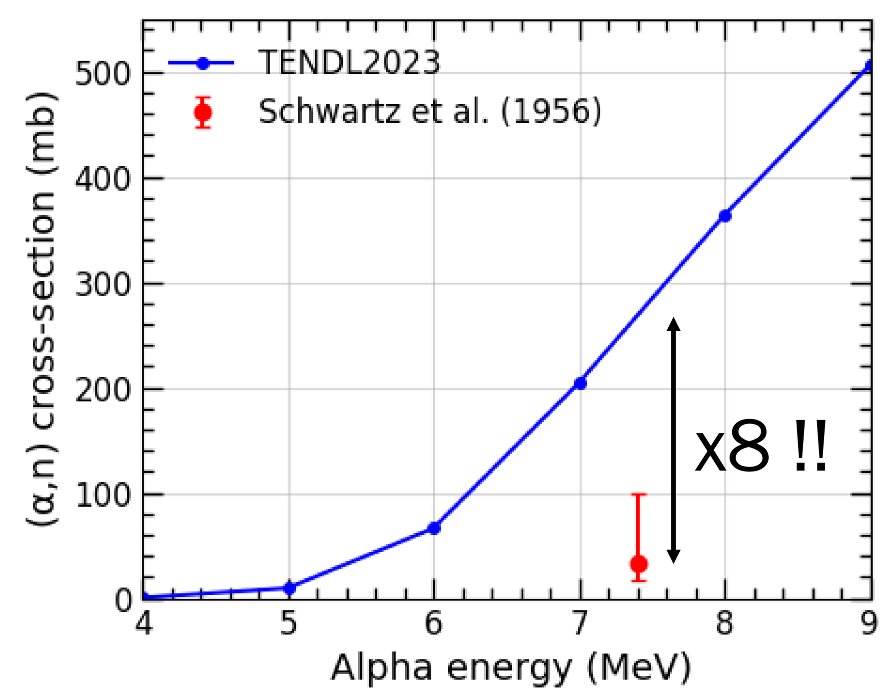
Some isotopes **lack** (α,n) experimental **data**



^{40}**Ar** is a special case because is the **main source** of (α,n) background coming from **surface activity** of the detector materials

The ^{40}**Ar(α,n) cross-section has never been measured** in the whole range of interest (4-9 MeV)

Rare-events experiments using **Ar** rely on ^{40}**Ar(α,n)** cross-sections based on evaluated theoretical calculations
These evaluated data show a **discrepancy** with the only available experimental point [1]



^{40}Ar(α,xn) measurement

First measurement ever of the ^{40}Ar(α,xn) reaction cross-section in the 4 – 9 MeV range

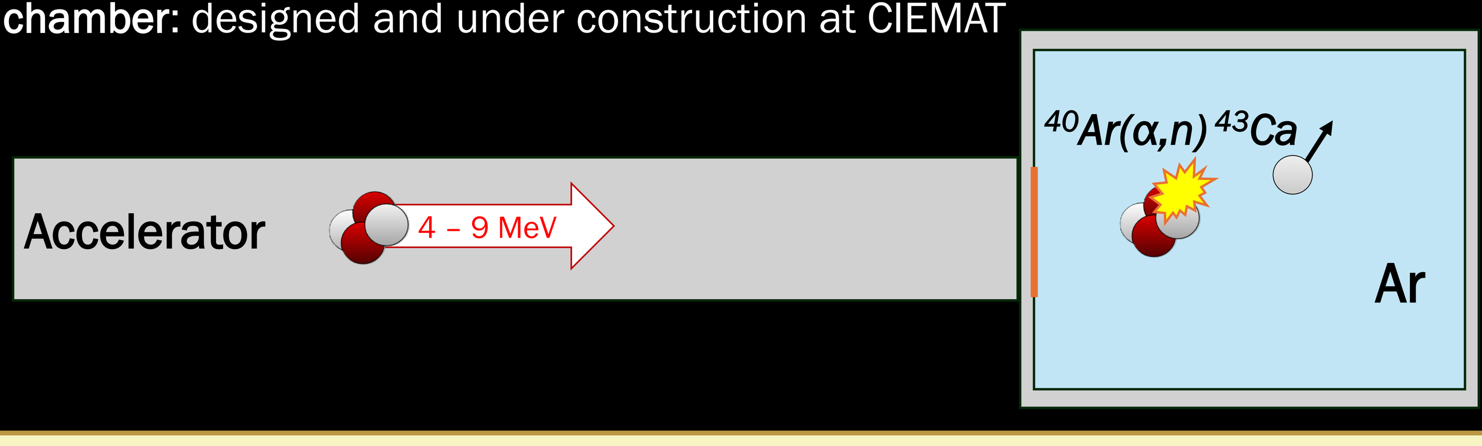
Idea: **α-beam** into an **argon gas chamber** ⟶ measure the **neutrons** produced

Some of the challenges:

- Low density of gaseous Ar may lead to low neutron counts
- **Ultra-thin** (~μm) vacuum window: transparent while withstanding the ΔP, and **low (α,n) cross-section**
- A gas circulation system: vacuum, refilling, and heat dissipation
- **Background** from the beam scattering to the walls

Current status: planning phase of the experiment

- **Thin argon target** (low pressure)
- A high-threshold material (Ta, W) is needed at the back to stop the α-beam
- **Gas chamber:** designed and under construction at CIEMAT

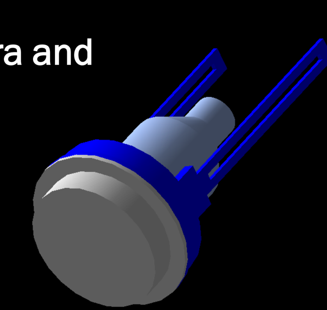


Neutron detectors

MONSTER: Neutron Time-of-Flight spectrometer

Results: **Neutron energy spectra and angle distribution**

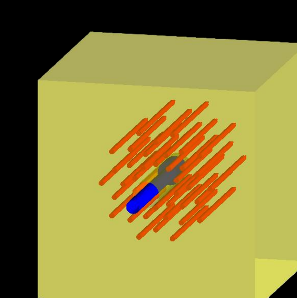
Energy spectra is obtained by unfolding



He-3 proportional counters in a neutron moderator:

Result: **yields** and **cross-section**

Higher total efficiency
Designed to be energy-independent ("flat efficiency")



Previous (a,n) measurements
Participation in ^{27}**Al(α,n) TOF** measurements using MONSTER at Centro de Micro-Análisis de Materiales (**CMAM**) in May 2026

Next steps:

- **Neutron background uncertainties calculation:** development of a Monte Carlo calculation which takes into account every source of uncertainty mentioned for the neutron background of DarkSide-20k.
- ^{40}**Ar(α,n) measurement:** detector selection and design, formal measurement proposal for beamtime in an accelerator facility.

[1] Schwartz, R. B., Corbett, J. W., & Watson, W. W. Alpha-Particle Bombardment of A^{36} and A^{40}. *Phys. Rev.*, *101*, 1370–1372. (1956)

Ayuda RED2024-153684-T financiada por MICIU/AEI/10.13039/501100011033

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