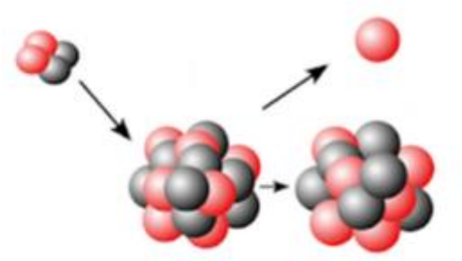
(α, n) yields for rare-event search experiments: a collaborative effort to understand the backgrounds

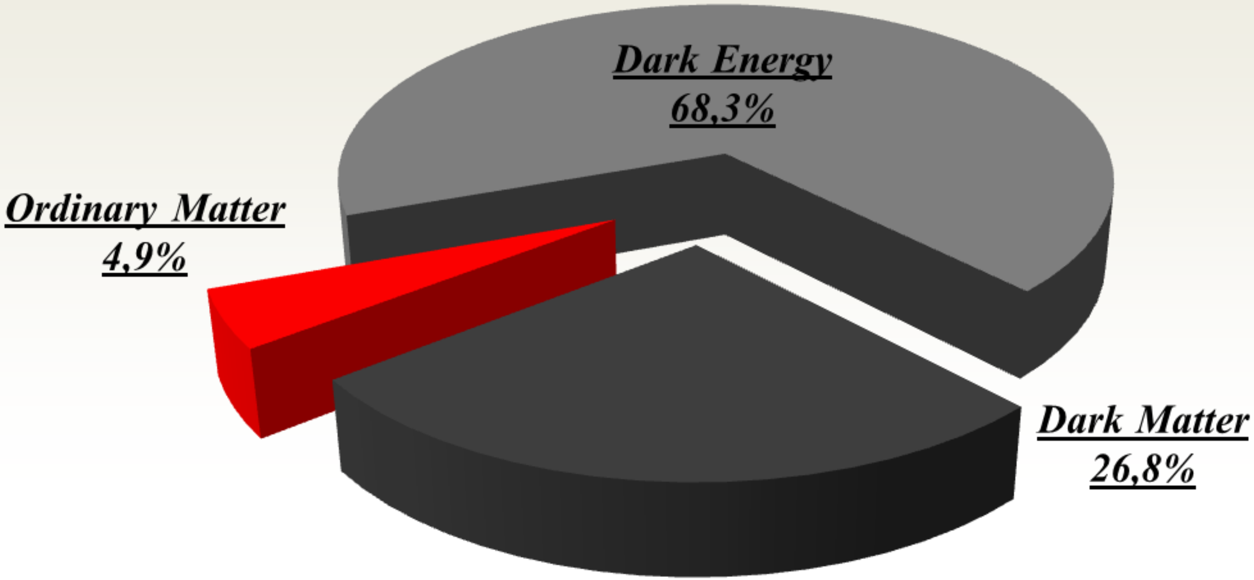


Roberto Santorelli

CIEMAT

IAEA Technical Meeting on (α,n) nuclear data evaluation and data needs
30/11/2023

Reminder

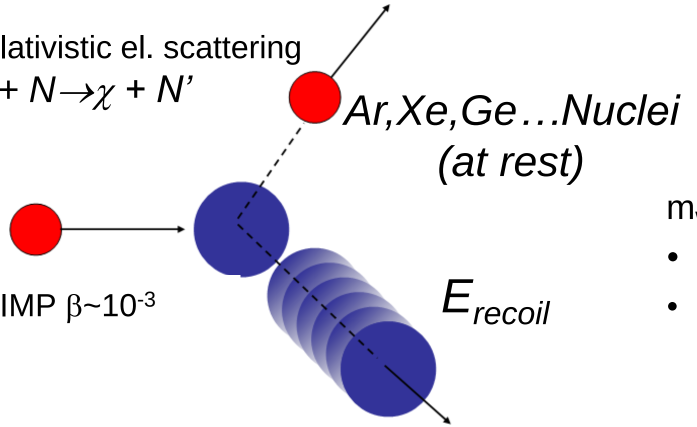


- Invisible dark matter makes up most of the universe
- The nature of dark matter is one of the most fundamental problems in modern physics and cosmology

Direct Detection of DM: Low energy nuclear recoil

Non relativistic el. scattering

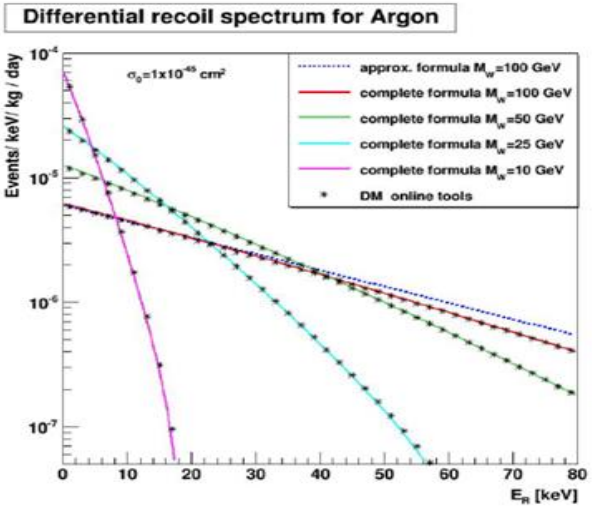
$\chi + N \rightarrow \chi + N'$

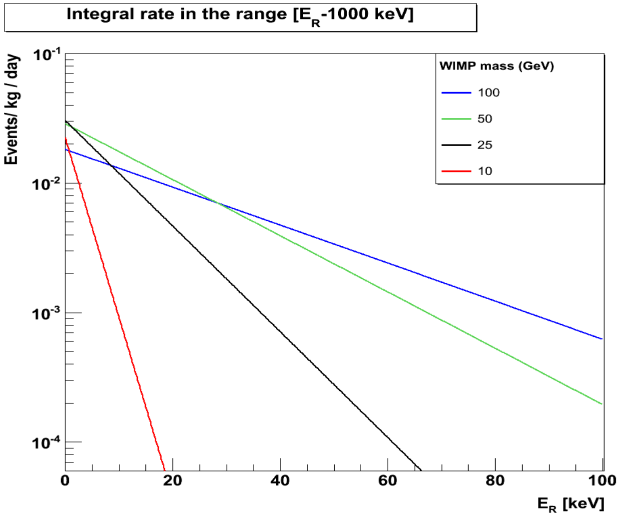


Possible scalar (coupling to the mass of the nucleus) and spin-spin interactions (coupling to the nuclear spin)

m_W = WIMP mass (~GeV-TeV) -- For M_W~100GeV:

- σ = WIMP-nucleus and WIMP-nucleon scattering x-sec ($\leq 10^{-47}$cm²)
- ρ_0 = local WIMP density *ρ_0~0.3GeV/cm³→ Flux ~10⁵ WIMPs/cm²/s)*

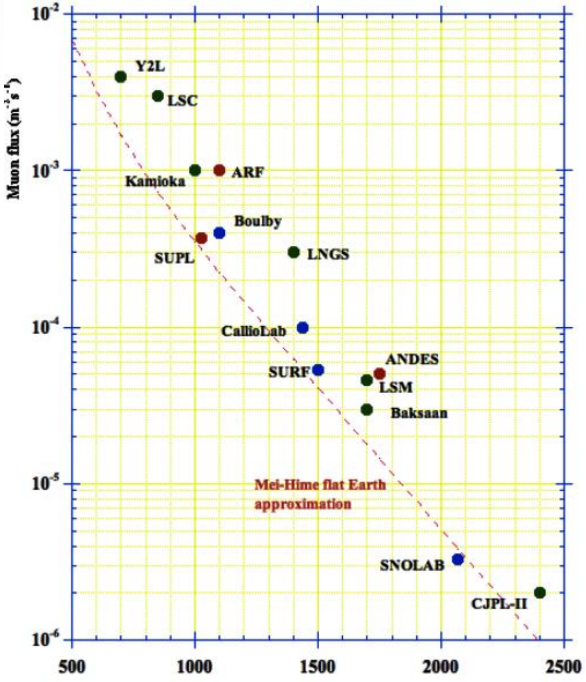




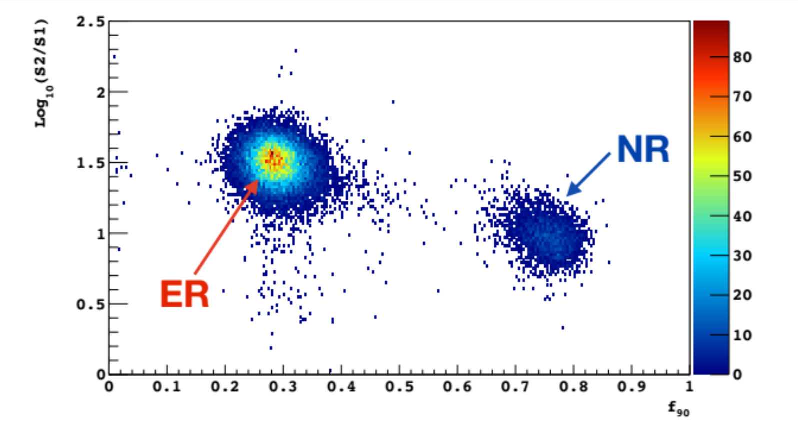
Signal vs Background

DD backgrounds: γ,β

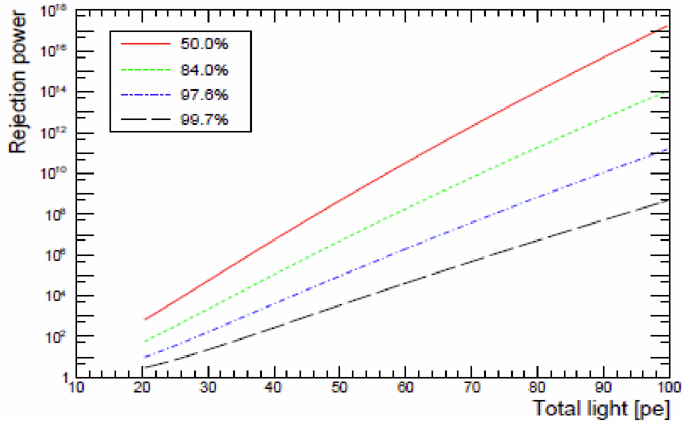
- α : *higher energy depositions*
- μ : *underground + veto*



- ***γ,β : ER $\rightarrow$ shielding + discrimination***



JCAP 12 (2018) 011

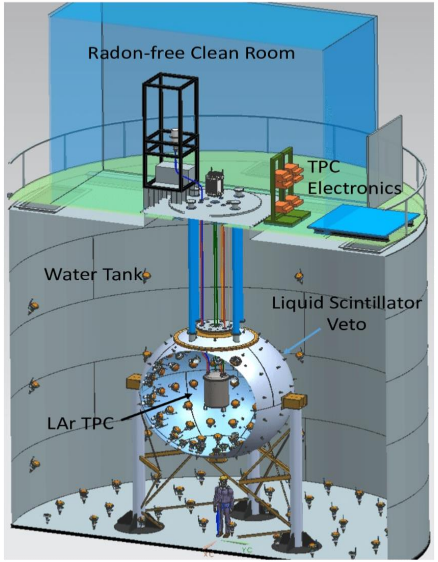


DD backgrounds: n

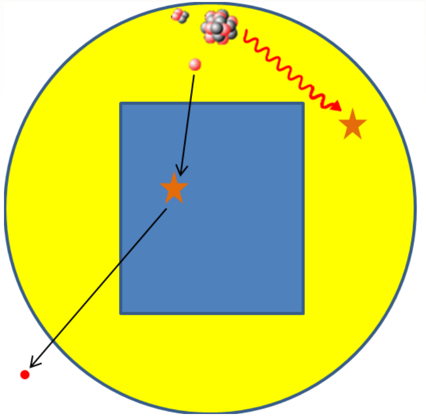
n : neutrons can produce nuclear recoil in the WIMP search region of interest

→ ***Potential irreducible background***

- Tagging
  - *Cosmogenic (spallation, βn…)*
  - *Neutrons from the rock*
  - *Radiogenic neutrons from distant materials*

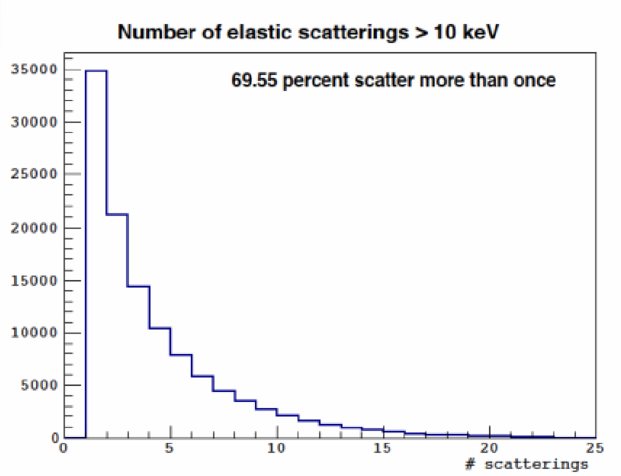


(α,nγ)



(α,nγ) might be subdominant in most of the cases with respect to (α,n) but is still very relevant for us

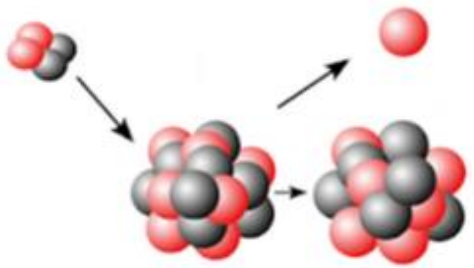
- Multiplicity



Simulated neutron multiple scattering:
~70% of neutrons produce multiple site events

Radiogenic n from detectors materials

- *Limited tagging capability for the radiogenic n from the parts surrounding the active volume (and in the active volume)*



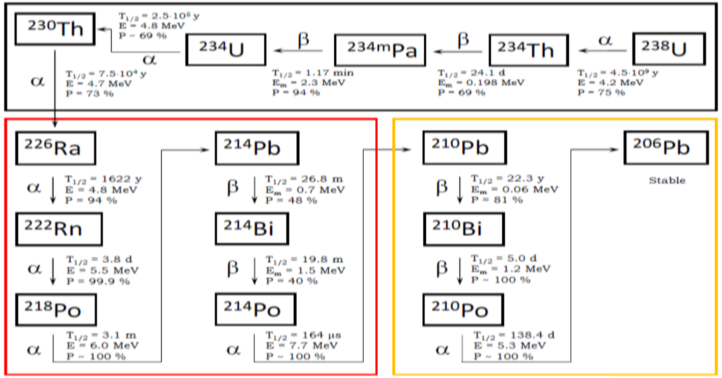
➢ <u>Strategy: Assay all materials of the detector</u>

- 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

^{238}U chain

ICPMS

HPGe



Radiochemical

ID	Report	Name	Reference	Method	Sample	Date	^{227}Ac	^{228}Ac	^{210}Po	^{210}Po, gross alpha activity	^{226}Ra	^{228}Ra	^{220}Rn	^{222}Rn	^{46}Sc	Th	^{228}Th	^{232}Th	^{234}Th	^{44}Ti
				SNOLAB),																
2124	289	Gadolinium sulfate 301 Decision pending	DarkSide-20k	HPGe GeOroel (Iulian Catalin Bancac, *LSC CANFRANC*),	complete	2019-08-27		387±24 [mBq/kg] (1 sigma)			9.4±1.4 [mBq/kg] (1 sigma)						274±14 [mBq/kg] (1 sigma)			
2121	288	OPA838 284 More assays needed	PDM module	Polonium-210 chemical extraction (Grzegorz Zuzel, *IF UJ*),	complete	2019-08-27			5.64±0.69 [Bq/kg] (1 sigma)											
2112	286	Harwin clips (clamp) 272 Satisfactory	PDM module	HPGe GeMPI (Matthias Laubenstein, *LNGS, INFN*),	complete	2019-08-13					30±9 [mBq/kg] (1 sigma)	<36 [mBq/kg] (2 sigma)					<27 [mBq/kg] (2 sigma)		<0.95 [Bq/kg] (2 sigma)	
2105	286	OPA838 284 More assays needed	PDM module	HPGe GeMPI (Matthias Laubenstein, *LNGS, INFN*),	complete	2019-08-13					77±8 [mBq/kg] (1 sigma)	25±10 [mBq/kg] (1 sigma)					19±6 [mBq/kg] (1 sigma)		<0.95 [Bq/kg] (2 sigma)	
2119	287	Silver loaded epoxy EJ2189 294 Decision pending	PDM module	HR-ICP-MS (Stefano Nisi, *LNGS, INFN*),	complete	2019-08-13										850±300 [ppt] (30 %)				

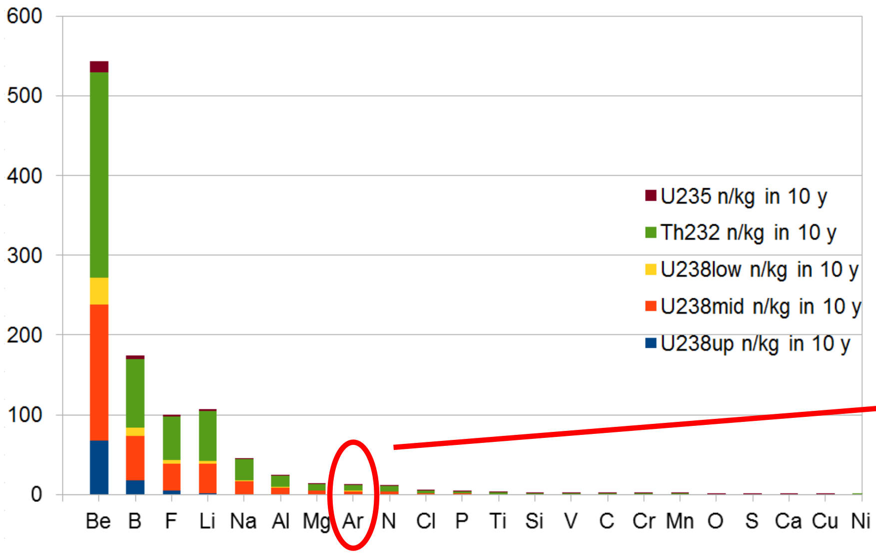
- Hundreds of assays carried-out
- Platform to store and manage the results of the material assay campaign

Typical elements

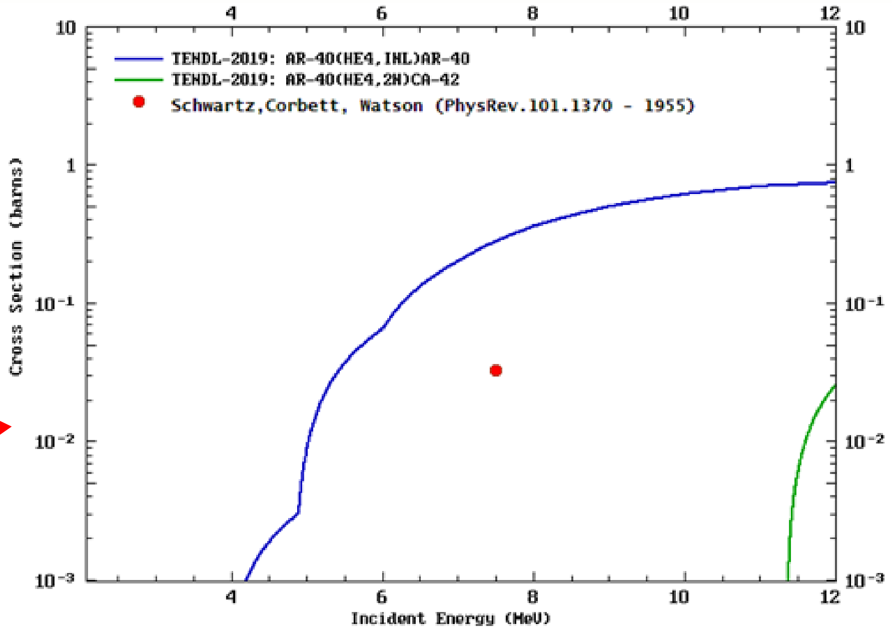
- Try to avoid Be and B, F (as much as possible)

- Resistors → Al, N, B (+Si, Mg…)
- PCB → C, N, O…
- Acrylic → C, O
- ~~Teflon → C, F~~
- Mechanical parts → SS, Cu, Ti…
- Sensors → Si…
- Target → Ar, Xe, Ge….

(a,n) on Argon



600
500
400
300
200
100
0
U235 n/kg in 10 y
Th232 n/kg in 10 y
U238low n/kg in 10 y
U238mid n/kg in 10 y
U238up n/kg in 10 y
Be B F Li Na Al Mg Ar N Cl P Ti Si V C Cr Mn O S Ca Cu Ni



TENDL-2019: AR-40(HE4,INL)AR-40
TENDL-2019: AR-40(HE4,2N)CA-42
Schwartz,Corbett, Watson (PhysRev.101.1370 - 1955)
Cross Section (barns)
Incident Energy (MeV)

SaG4n

Neutron yield ∝ $\int \Theta_\alpha(E)\, \sigma_{(\alpha,xn)}(E)\, dE$

(SRIM+ TALYS
… orEMPIRE, truly evaluated cross sections and secondary particle products)

SaG4n is a code fully based on Geant4 that we have developed to calculate neutron yields.

"Neutron production induced by α-decay with Geant4", Nucl. Instrum. Methods A 960, 163659 (2020) (**http://win.ciemat.es/SaG4n/**)

Use of a single Monte Carlo code

- flexible in the selection of the data libraries
- it needs a Geant4 installation but it can easily executed only by editing an input file

Advantages:

- it allows for almost arbitrarily complicated geometries
- Surface effects and boundary between different materials
- α transportation (electromagnetic processes)

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

(α,n) yield in low background experiments WG

- The calculation and the mitigation of the background minimization for the new generation of low-background experiments (DM, 0νββ) demand an unprecedented effort.
- This endeavor requires a collective commitment from the entire rare event physics community, leveraging diverse synergies and expertise.

- "(α,n) yield in low background experiments" Workshop 21-22 November 2019, CIEMAT, Madrid, Spain https://agenda.ciemat.es/event/1127/
- WG including ~ 35 researchers from several experiments (ANAIS, CRESST, DarkSide, DEAP-3600, LZ, nEXO, XENON, PICO, SNO+, SuperCDMS…)
- alphan@ciemat.es
- Snowmass2021 – LOI: "Neutron yield in (α,n)-reactions in rare-event searches" link.pdf

White paper

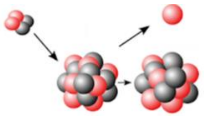
White paper on (α, n) neutron yields calculation

Authors[1]

[1]Somewhere

(Dated: Thursday 30th November, 2023- 12:59, Version: F1.0)

Understanding the radiogenic neutron production rate through the (α, n) reaction is essential in many fields of physics like dark matter searches, neutrino studies, nuclear astrophysics and medical physics. This white paper provides a review of the current landscape of (α, n) yields, neutron spectra, and correlated γ-rays calculations, and describes the existing tools and the available cross sections. The uncertainties that contribute to (α, n) yield calculations are also discussed with the plans for a program to improve the accuracy of the estimates. Novel ideas to measure (α, n) cross sections for a variety of materials of interest are presented. The goal of this study is to reduce the uncertainty in the expected sensitivity of next-generation physics experiments with keV–MeV measurements.



CONTENTS

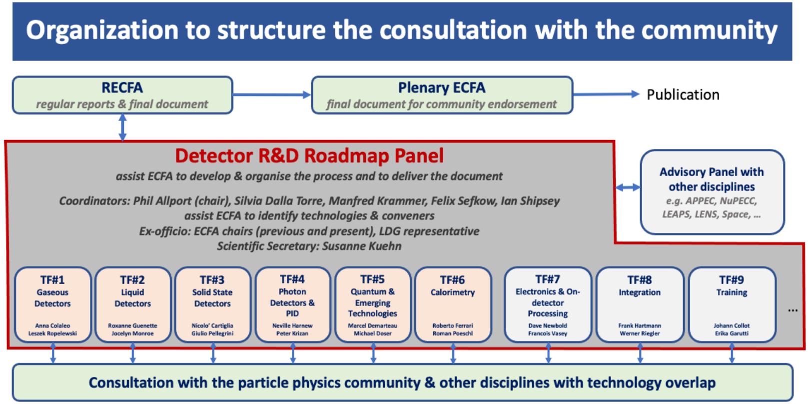
A little spoiler

- Discussion on the need of multiple assays
- Material composition
- Uncertainty in the calculation
- Uncertainty from the input parameters (Ar-40 x-section with TALYS)
- Comparison between different codes
- Need of more data …

ECFA Detector R&D Roadmap

"A roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields. The roadmap should identify and describe a diversified detector R&D portfolio that has the largest potential to enhance the performance of the particle physics programme in the near and long term".

"The mandate is to focus on the technical aspects to realise the research facilities in a timely fashion, and to provide strategic guidance for detector development at large, in synergy with neighbouring fields and industrial applications"



DRD2: Liquid Detectors v4

New tools/materials for the evaluation/suppression of backgrounds Neutrons are one of the main sources of background in rare-event search experiments. For the accurate calculation of radiogenic neutron production rates, it will be crucial to measure the (α,n) production cross-section in those materials relevant to the construction of low-background detectors for which experimental measurements are not available (e.g., argon). In parallel, significant research efforts are expected in the coming years to investigate innovative configurations of active veto technologies based on new materials for neutron background mitigation, e.g. R&D is currently ongoing aimed at producing a large amount (few tens of tons) of radiopure acrylic loaded with a gadolinium compound.

Conclusions

- The new generation of rare-event research experiments requires very careful **background characterization**

- The detailed calculation of the **(α,n) yields is the key aspect** to understand the background in this type of experiments.

- A working group of particle physicists has been formed

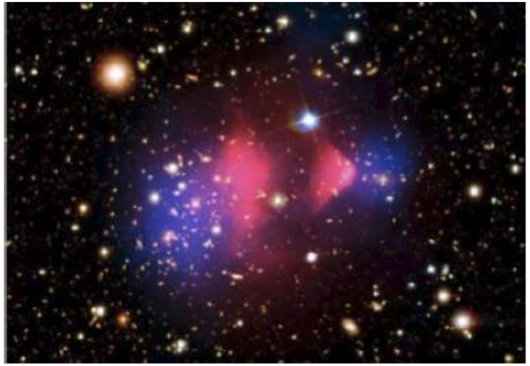
- White paper almost finalized (internal review)

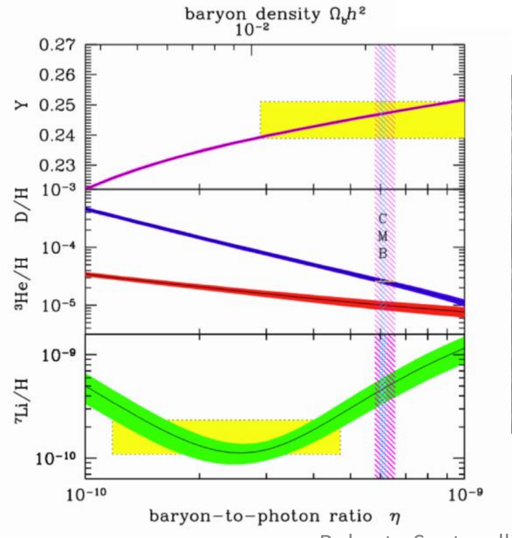
- ECFA detector R&D: our community is starving for **new measurements and new data**

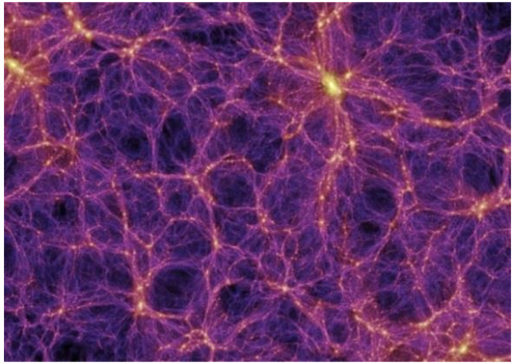
Backup

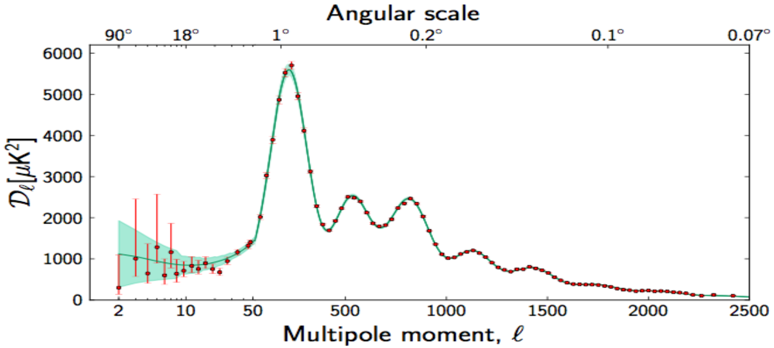
The Dark Matter problem ( )

- The ΛCDM model has been successful explaining CMB, large scale structure etc..
- It fits all the observations with only 6 parameters
- A Cold Dark Matter model is necessary for the formation of structure and galaxies in the universe



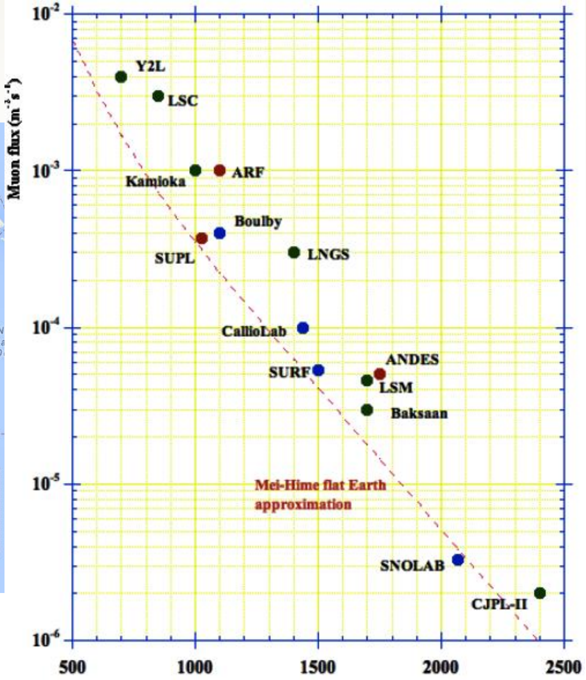


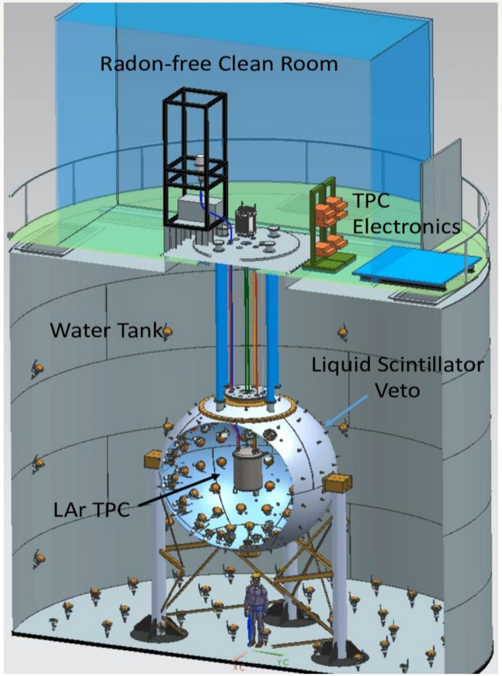




DD backgrounds: μ

- α : *higher energy depositions*
- μ : ***underground + veto***

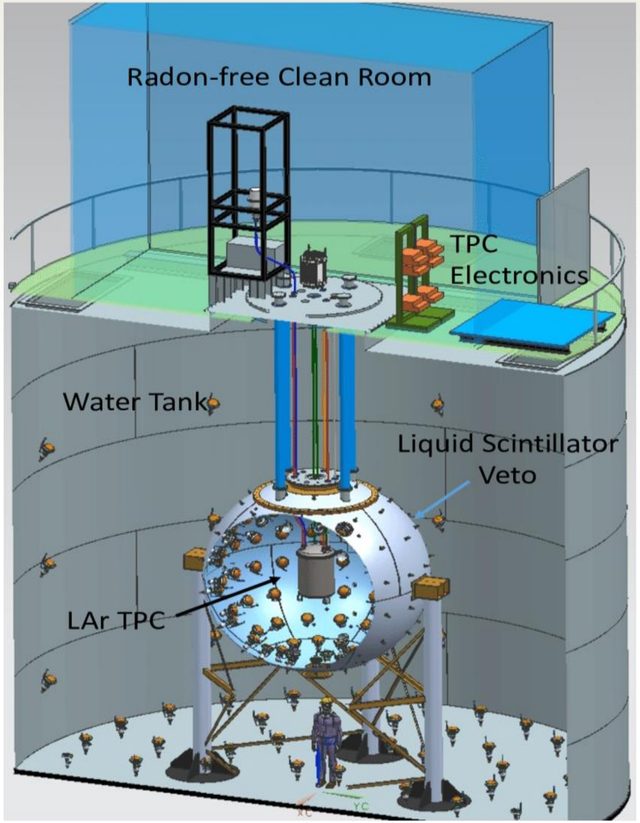




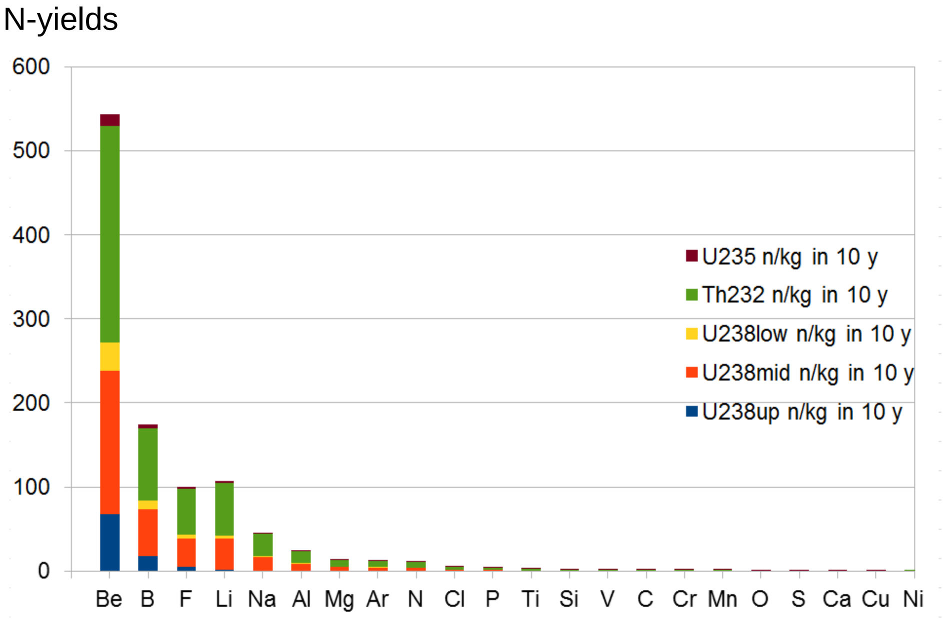
DD backgrounds: n-produced externally

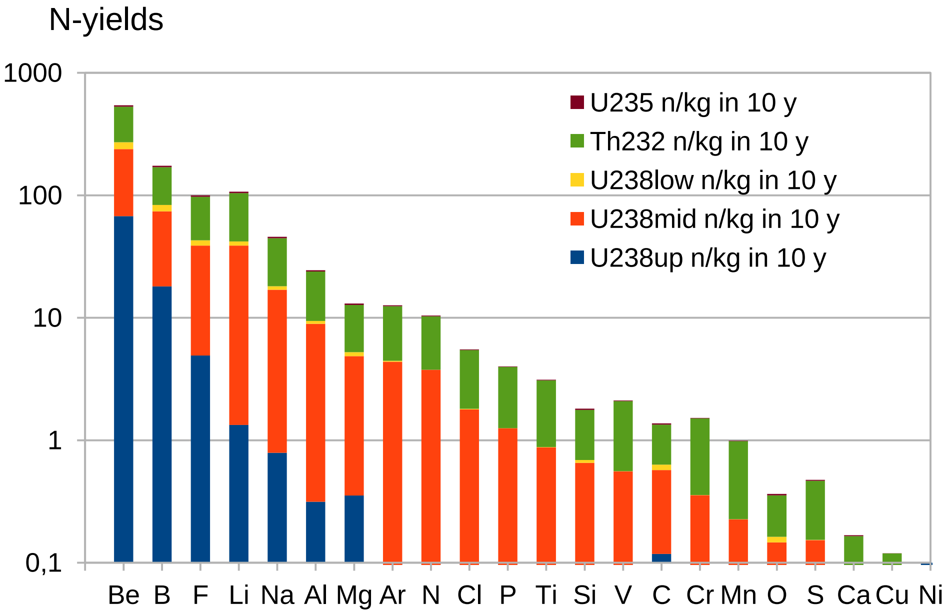
Passive and active shielding can mitigate the impact of the neutrons produced externally

- *Cosmogenic (spallation, βn…)*
- *Neutrons from the rock*
- *Radiogenic neutrons from distant materials*



N-yields: Values for 1 ppb Th-232 and U-238
(U-235 with its natural abundance)



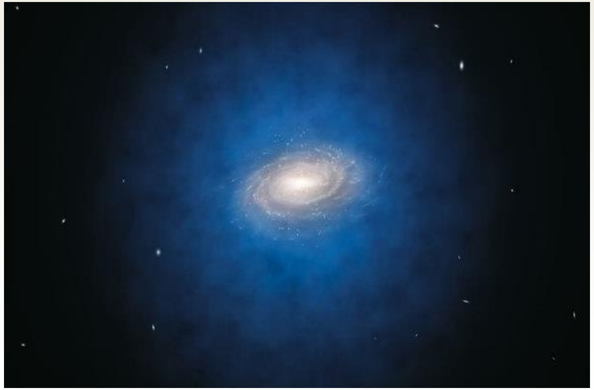


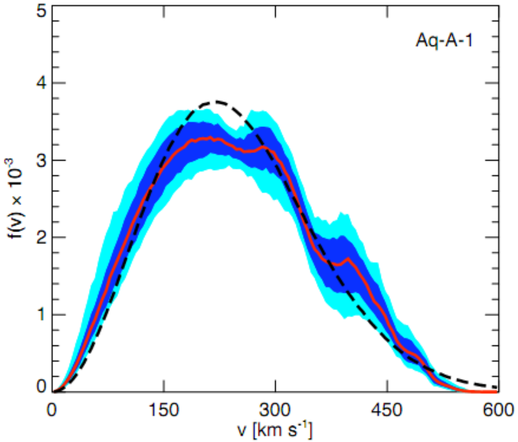
The Galactic DM Halo

- Dark Matter distributed in a spherical halo around the Milky Way
- Isothermal Maxwell-Boltzmann velocity distribution 220 km/s and V_{esc}=544 km/s
- V_e~245 km/s WIMP velocity relative to Earth
- Local density = 0.3 GeV/cm^3

J.Bovy S.Tremaine APJ 756 2012

(3000 wimp/m^3 , m_W=100GeV)





Radiogenic n from detectors materials

➢ Full control of the radioactive contamination

- Control of the bulk contamination
- Control of the surface contamination
- Rn exposure
- Storage

➢ Detailed calculation of the materials background

- New tools for (α, n) calculations -> SaG4n
- MC Simulation -> G4 + FLUKA
- Evaluation of the systematic uncertainty from the material composition