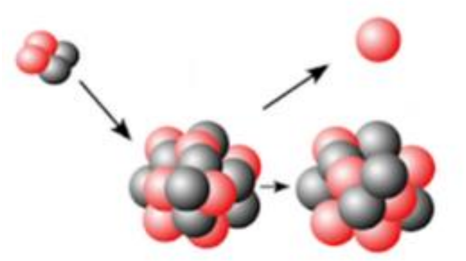
(a,n) neutron yields for direct search of Dark Matter



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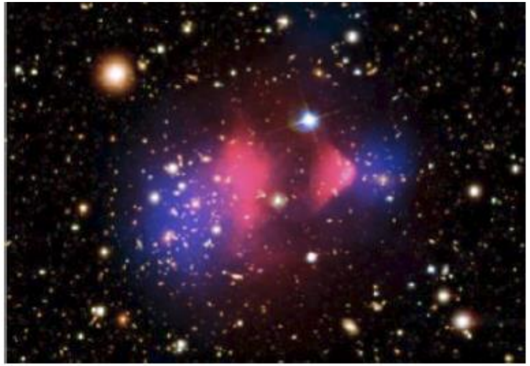
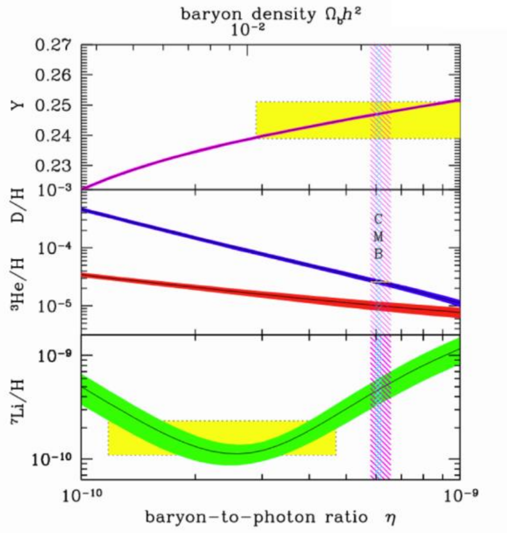
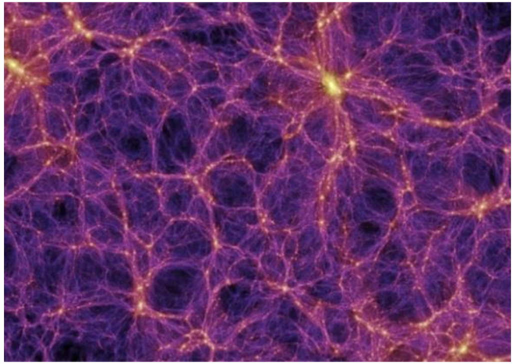
IAEA Technical Meeting on (α,n) nuclear data evaluation and data needs
08/11/2021

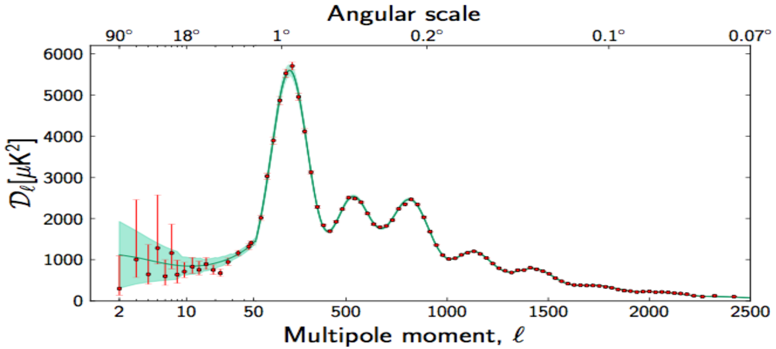
The Dark Matter problem ( )

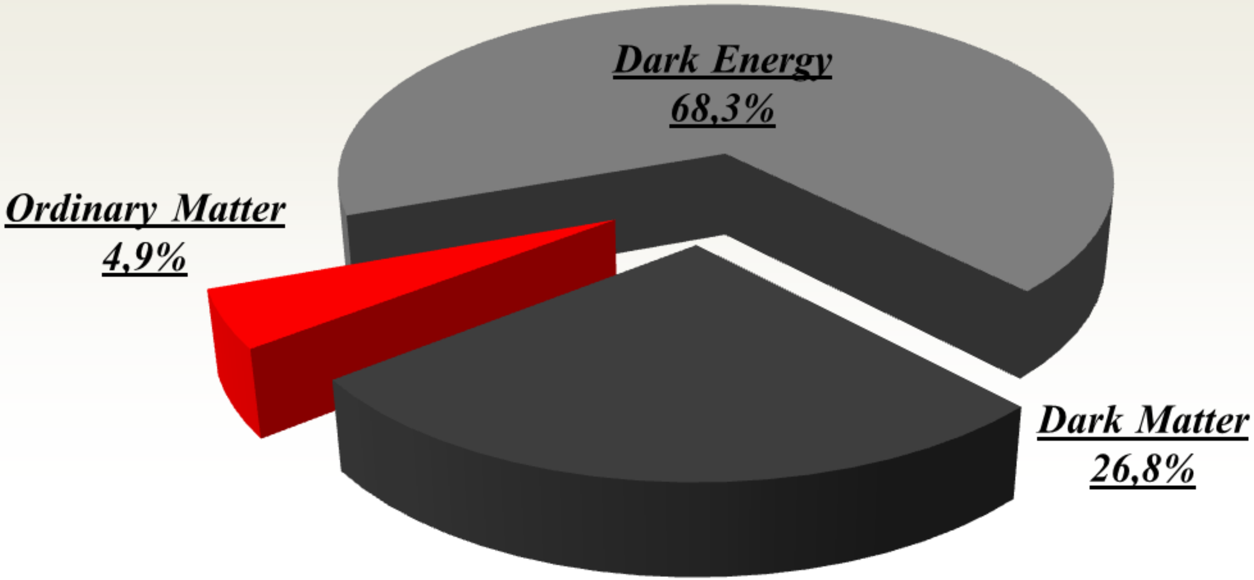
- The ΛCDM model has been successful explaining CMB, large scale structure etc..
- It fits all the observations with only 6 parameters
- A Cold Dark Matter model is necessary for the formation of structure and galaxies in the universe





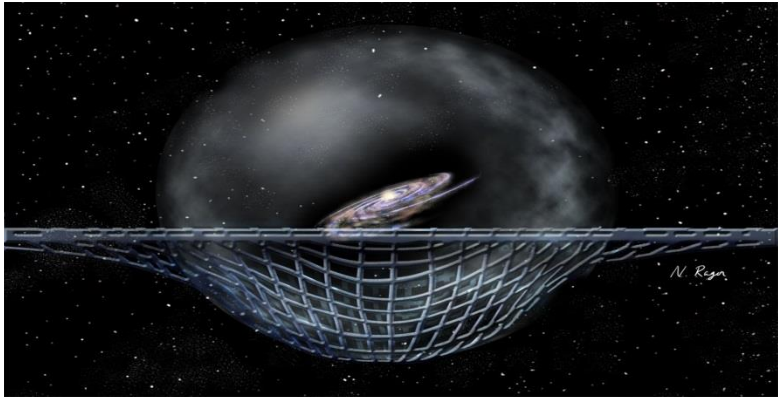






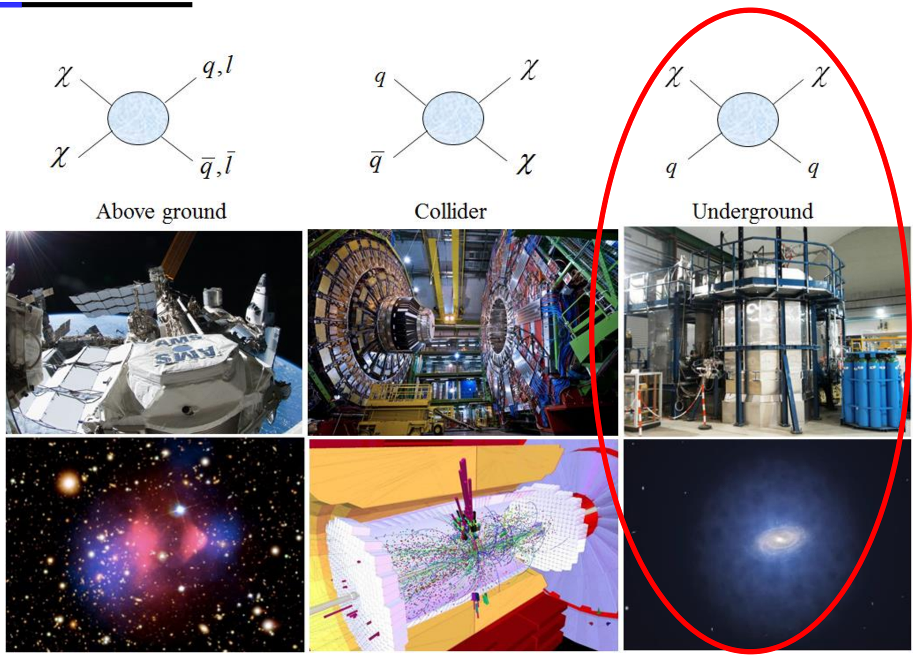
- Invisible dark matter makes up most of the universe – but we can only detect it from its gravitational effects
- The nature of dark matter is one of the most fundamental problems in modern physics and cosmology

WIMPs



Weakly Interactive Massive Particle

- stable
- slow
- relic from the Bing Bang
- with the “right” mass and abundance



The Galactic DM Halo

- Dark Matter distributed in a spherical halo around the Milky Way

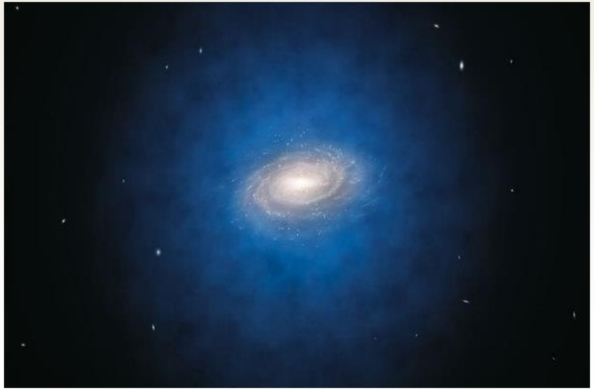
- Isothermal Maxwell-Boltzmann velocity distribution 220 km/s and V_{esc}=544 km/s

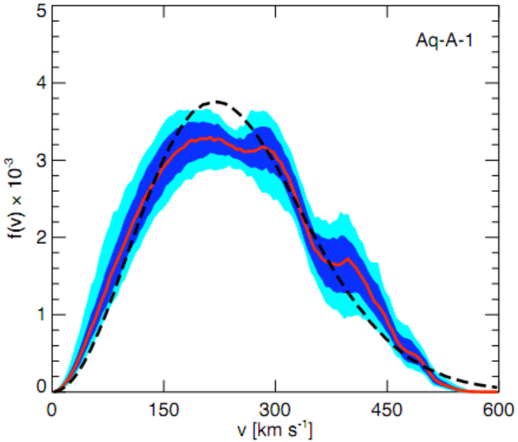
- V_e~245 km/s WIMP velocity relative to Earth

- Local density = 0.3 GeV/cm^3

J.Bovy S.Tremaine APJ 756 2012

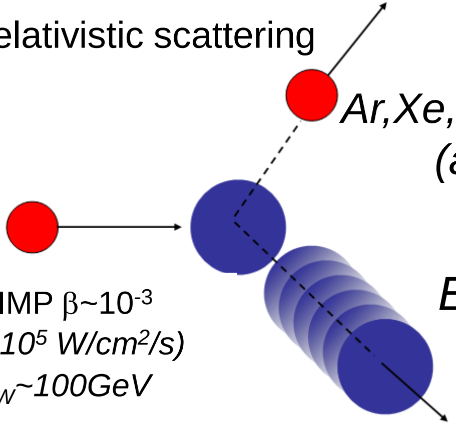
($1e^5$ $cm^{-2}s^{-1}$ for M_W=100 GeV/c^2)





GOAL: Low energy nuclear recoil

Non relativistic scattering



Ar,Xe,Ge…Nuclei (at rest)

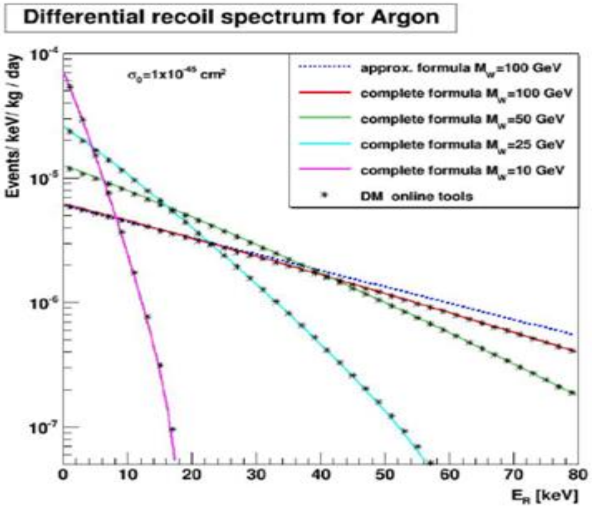
E_{recoil}

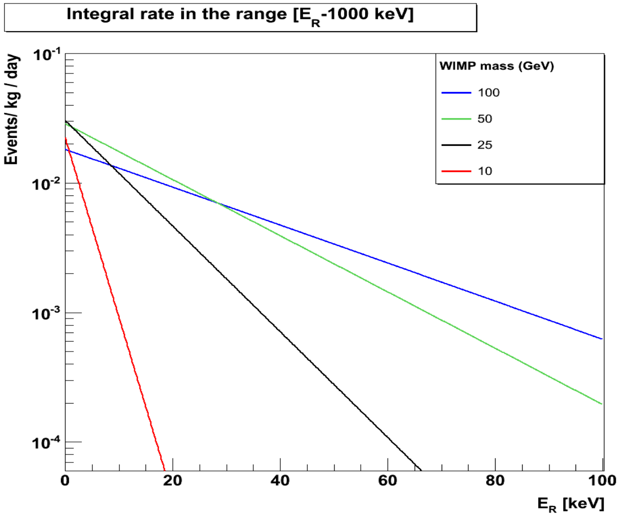
WIMP β~10^{-3}
(Flux ~10^5 W/cm^2/s)
M_W~100GeV

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

m_W = WIMP mass (~GeV-TeV)
σ = WIMP-nucleus and WIMP-nucleon scattering x-sec ($\leq 10^7$pb)
ρ_0 = local WIMP density

ρ_0~0.3GeV/cm^3 → 3000 wimp/m^3, m_W=100GeV

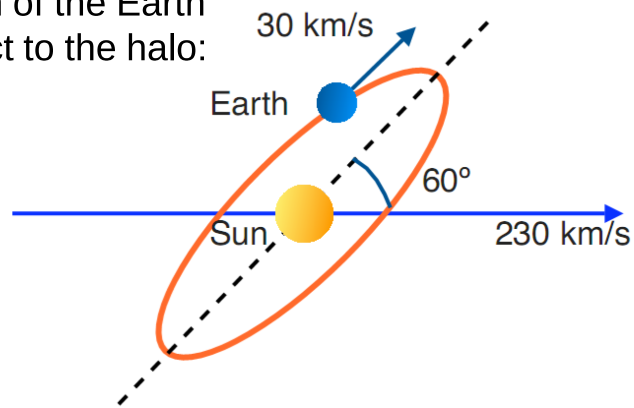




Experimental signature

- WIMPs are excellent candidates for particle DM
- WIMP mass ~1 GeV - 10 TeV and cross sections 10^{-40} - 10^{-50} cm^2
- Nuclear recoils ~ 10s keV
- Featureless recoil spectrum (no bump)
- Single scatters (uniform throughout the detector)

Motion of the Earth respect to the halo:



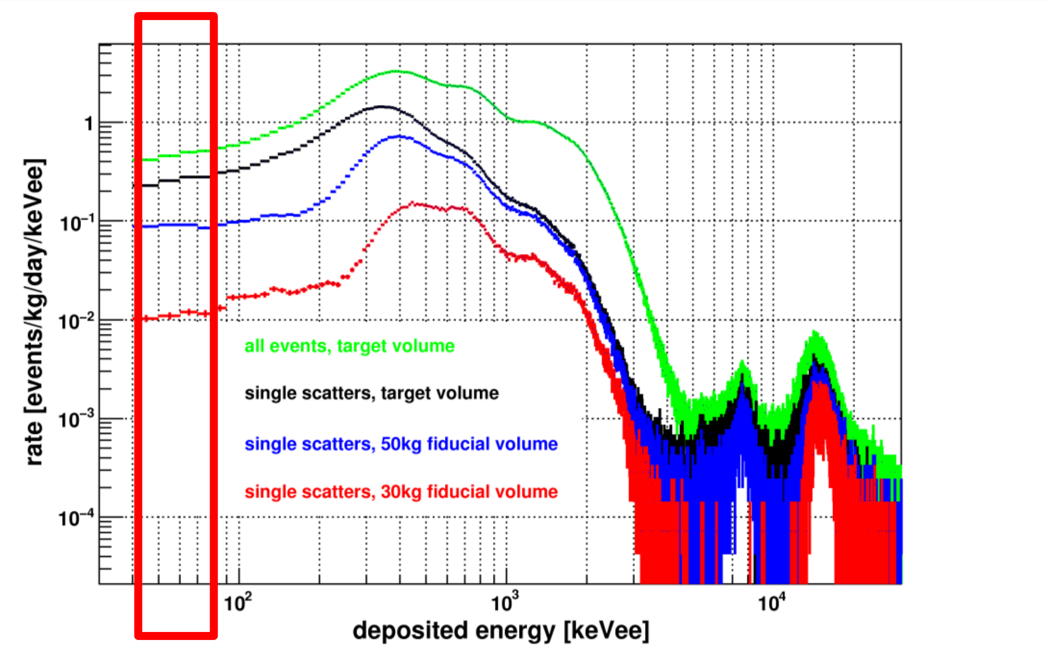
- Rate variation (June – December ~3%)
- Direction asymmetry (Daily rotation)

Annual modulation (~7%) → Additional signature

Signal vs Background

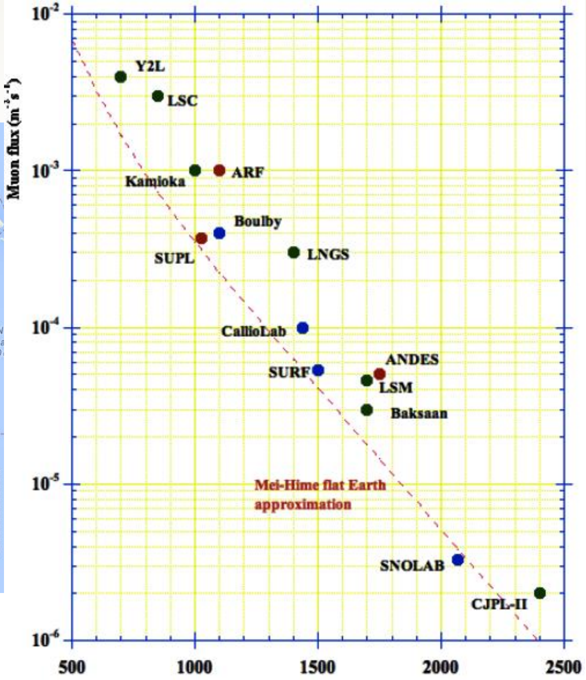
DD backgrounds: α

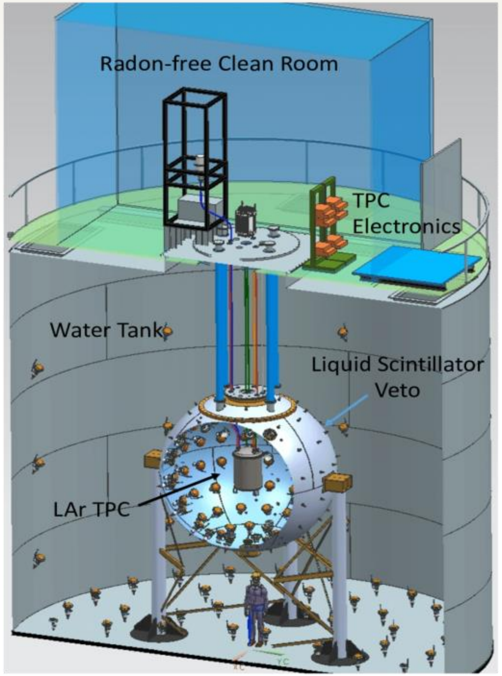
- α : *higher energy depositions*



DD backgrounds: μ

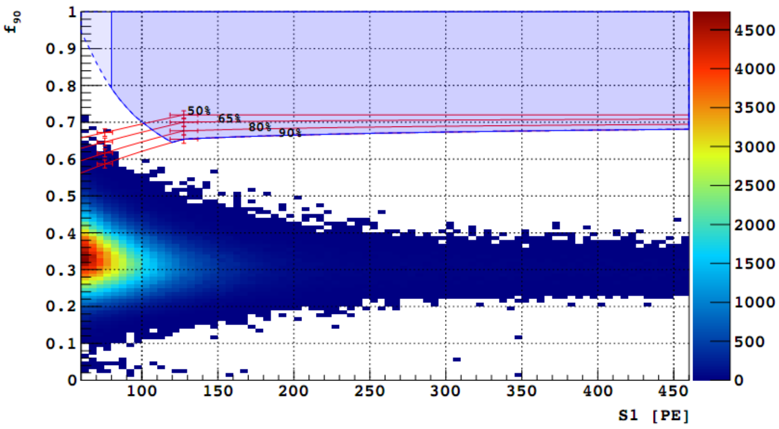
- α : *higher energy depositions*
- μ : ***underground + veto***

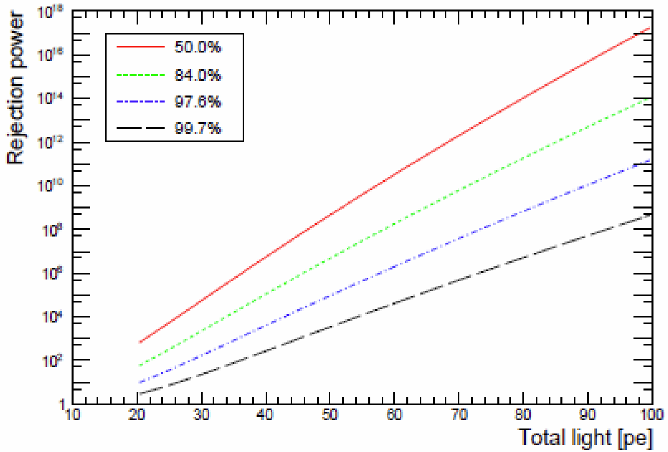




DD backgrounds: γ,β

- α : *higher energy depositions*
- μ : *underground + veto*
- ***γ,β : ER $\rightarrow$ shielding + discrimination***





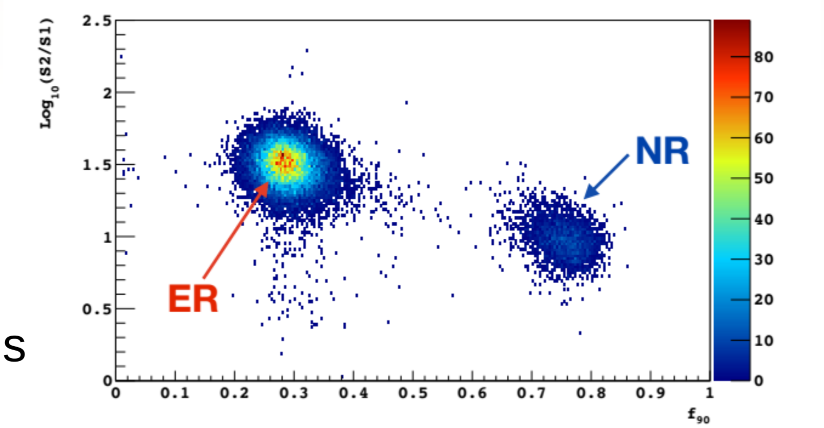
DD backgrounds: γ,β

- α : *higher energy depositions*
- μ : *underground + veto*
- γ, β **: *ER → shielding + discrimination***

DAMA (LNGS)
ANAIS (LSC)
COSINE (Yangyang)

} Light

SuperCDMS (SNOLAB) → Charge + phonons
CRESST (LNGS) → Light + phonons
DarkSide, XENON (LNGS) → Light + charge
LZ (SURF) → Light + charge

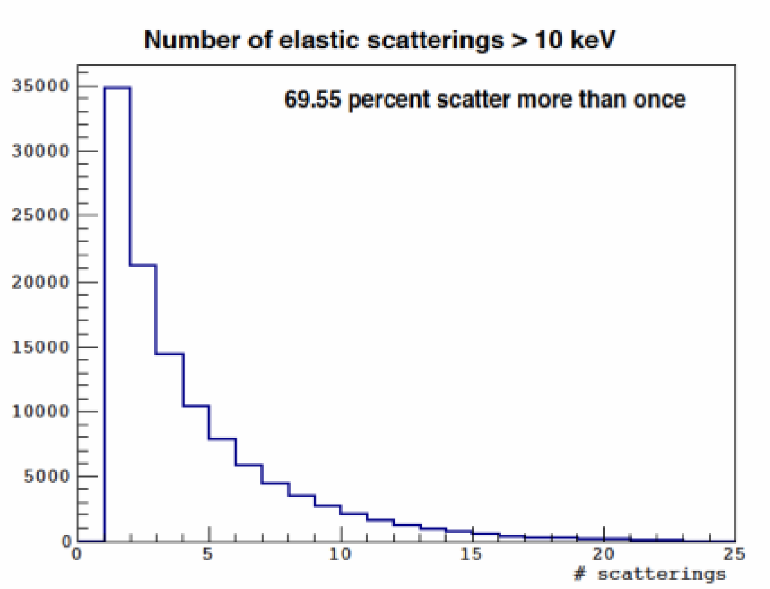


DD backgrounds: n

- α : higher energy depositions
- μ : underground + veto
- γ, β : ER $\rightarrow$ shielding + discrimination
- **n : neutrons can produce nuclear recoil in the WIMP search region of interest**

$\rightarrow$ ***Potential irreducible background***

- Tagging
- Multiplicity



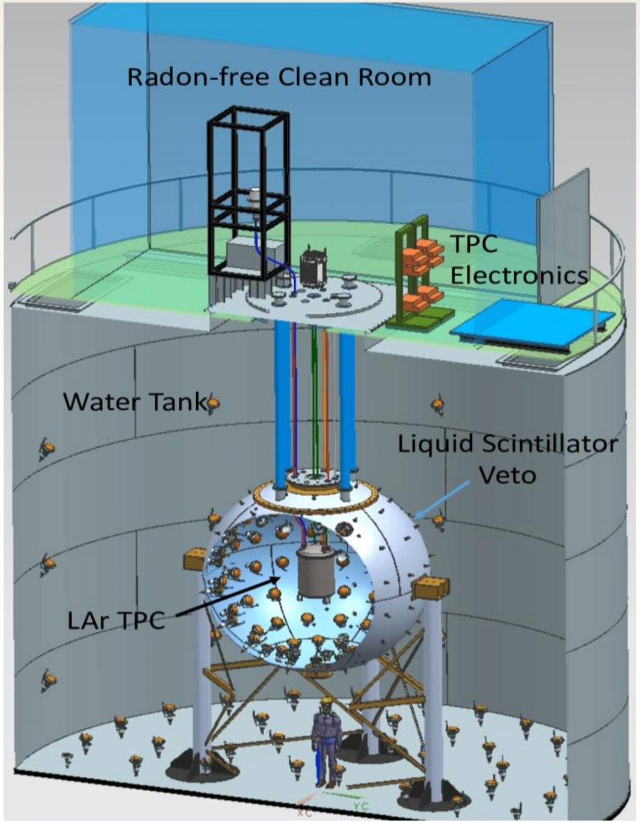
Simulated neutron multiple scattering:
~70% of neutrons produce multiple site events

DD backgrounds: n-produced externally

Passive and active shielding can mitigate

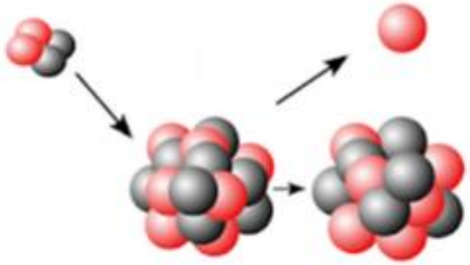
the impact of the neutrons produced externally

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



Radiogenic n from detectors materials

- *Radiogenic neutrons from the parts surrounding the active volume*
- *“Limited” tagging capability*



Strategy:

- ➢ Extensive material assay campaign
    - U-238, Th-232, U235… contamination
- ➢ (α,n) n-yields calculations
    - Codes (SOURCES4C, NeuCBOT, SaG4n)
    - Libraries (JENDL, TENDL…)
- ➢ MC simulation
    - G4, FLUKA…

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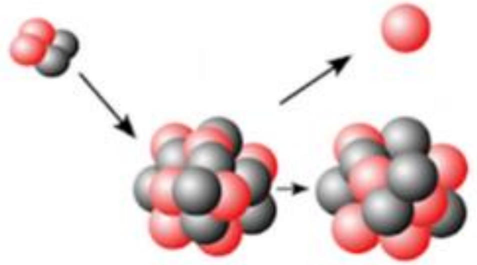

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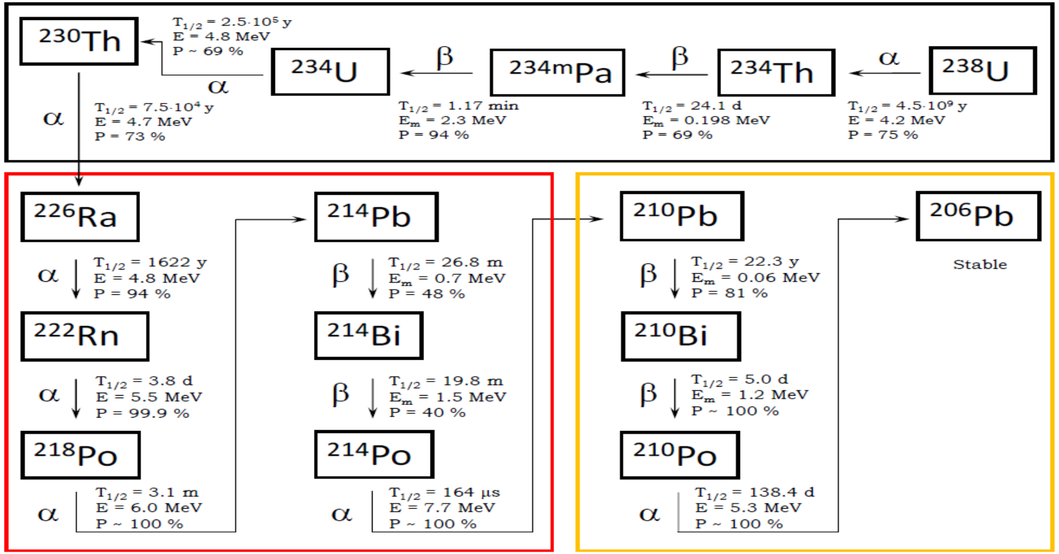
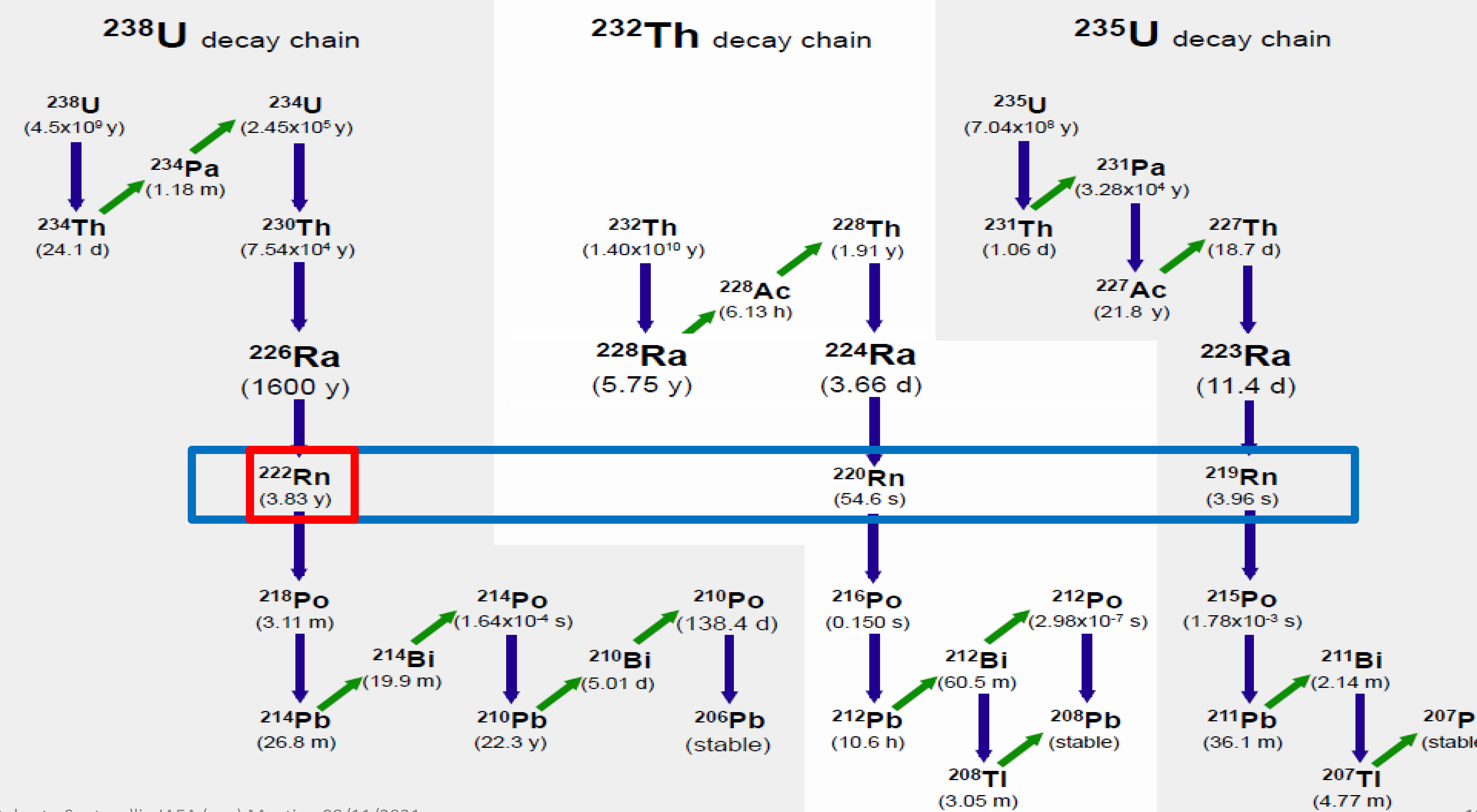
^{238}U chain

ICPMS

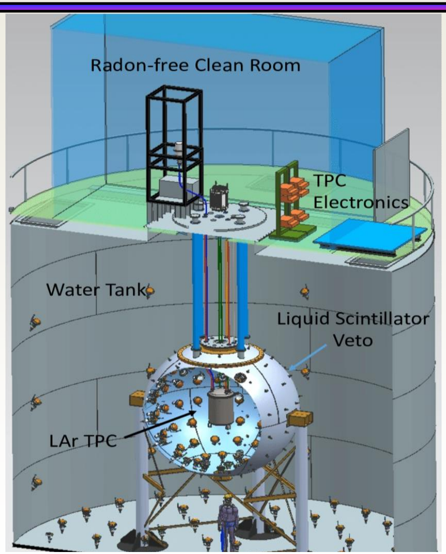
HPGe

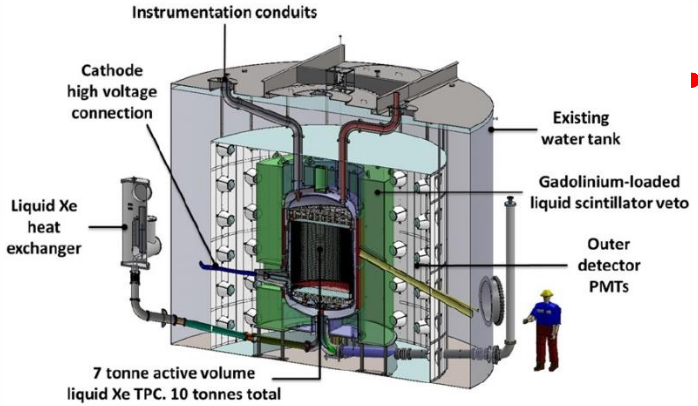


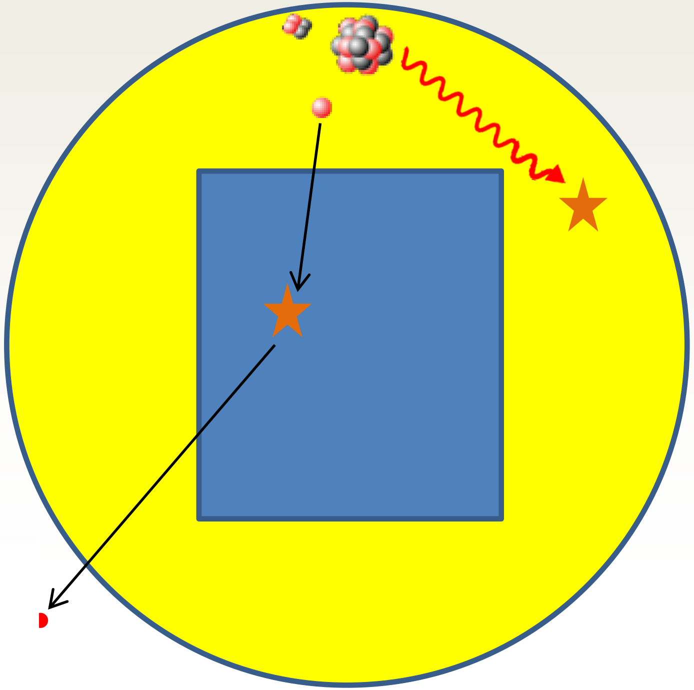
Radiochemical


238U decay chain
232Th decay chain
235U decay chain
238U (4.5x10⁹ y)
234U (2.45x10⁵ y)
234Pa (1.18 m)
234Th (24.1 d)
230Th (7.54x10⁴ y)
226Ra (1600 y)
222Rn (3.83 y)
218Po (3.11 m)
214Po (1.64x10⁻⁴ s)
214Bi (19.9 m)
214Pb (26.8 m)
210Po (138.4 d)
210Bi (5.01 d)
210Pb (22.3 y)
206Pb (stable)
232Th (1.40x10¹⁰ y)
228Th (1.91 y)
228Ac (6.13 h)
228Ra (5.75 y)
224Ra (3.66 d)
220Rn (54.6 s)
216Po (0.150 s)
212Po (2.98x10⁻⁷ s)
212Bi (60.5 m)
212Pb (10.6 h)
208Pb (stable)
208Tl (3.05 m)
235U (7.04x10⁸ y)
231Pa (3.28x10⁴ y)
231Th (1.06 d)
227Th (18.7 d)
227Ac (21.8 y)
223Ra (11.4 d)
219Rn (3.96 s)
215Po (1.78x10⁻³ s)
211Bi (2.14 m)
211Pb (36.1 m)
207Tl (4.77 m)

(a,nγ)

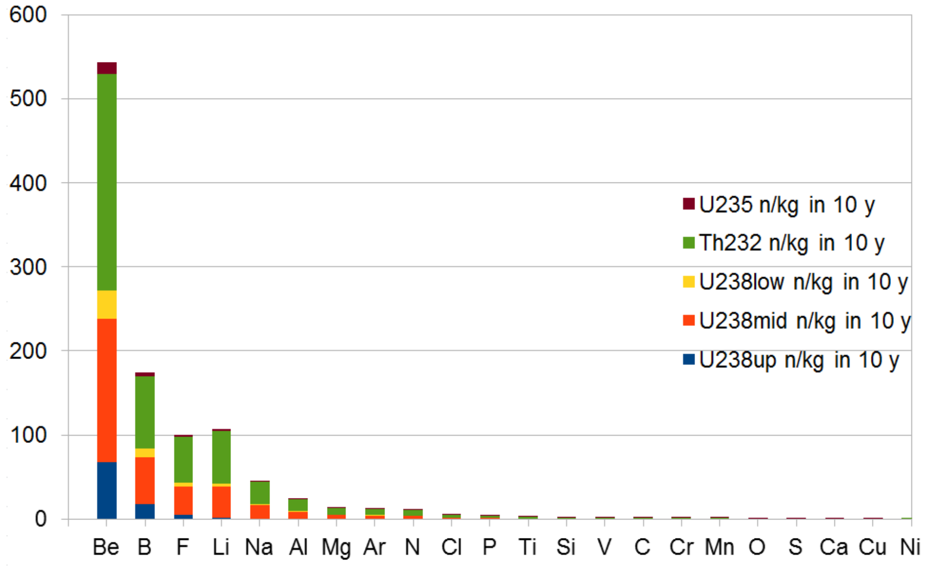


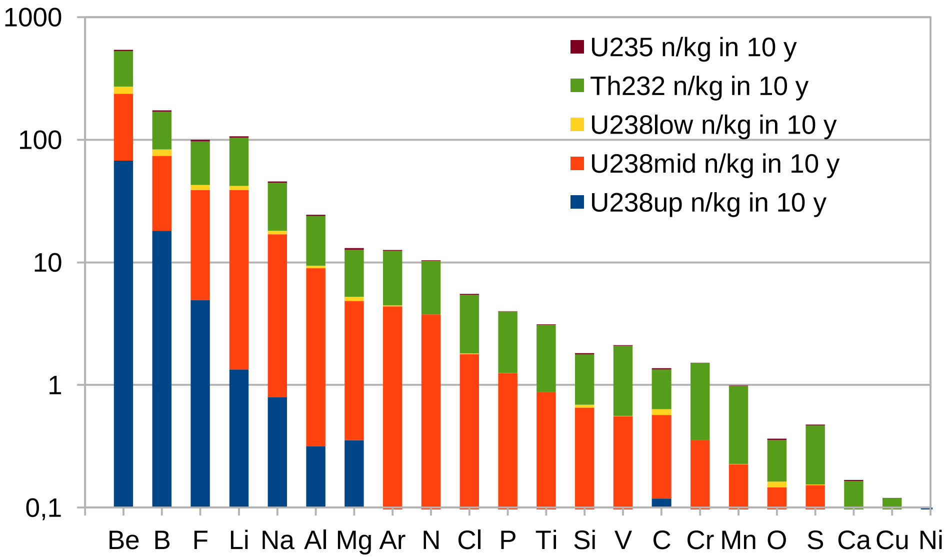




The correlated gamma emission is fundamental for understanding the background in Dark Matter

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



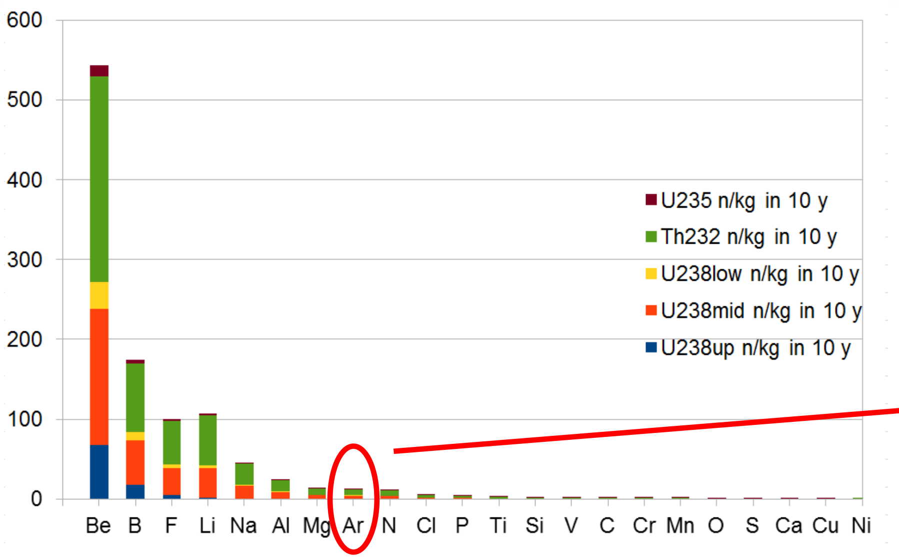


Typical elements

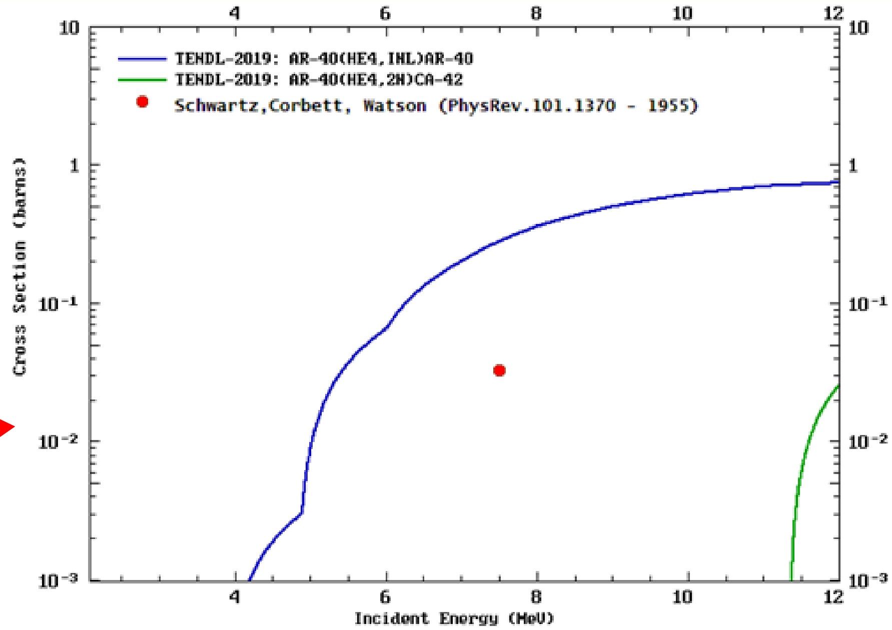
- Try to avoid Be and B, F (as much as possible)

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

(a,n) on Argon

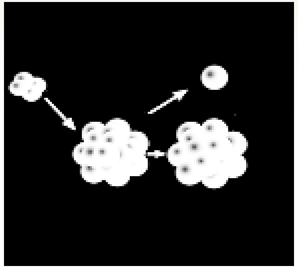


600
500
400
300
200
100
0
U235 n/kg in 10 y
Th232 n/kg in 10 y
U238low n/kg in 10 y
U238mid n/kg in 10 y
U238up n/kg in 10 y
Be B F Li Na Al Mg Ar N Cl P Ti Si V C Cr Mn O S Ca Cu Ni



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)
10
1
10⁻¹
10⁻²
10⁻³
4
6
8
10
12

(α,n) yield in low background experiments WG



- “(α,n) yield in low background experiments” Workshop
  21-22 November 2019, CIEMAT, Madrid, Spain
  https://agenda.ciemat.es/event/1127/

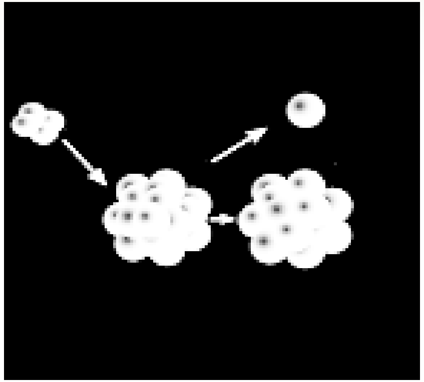
- WG including ~ 35 researchers from several experiments (ANAIS, CRESST, DarkSide, DEAP-3600, LZ, nEXO, XENON, PICO, SNO+, SuperCDMS,

- alphan@ciemat.es

- Snowmass2021 – LOI: “Neutron yield in (α,n)-reactions in rare-event searches”
  link.pdf

- “White paper on (α,n) neutron yields in low-background experiment” – in preparation

White paper



- Process description
- Key isotopes
- Cross-sections and available databases
- Calculations tools
- Significant uncertainties
- Impact of (a,nγ) on the background estimate
- …. Importance of new measurements

Conclusions