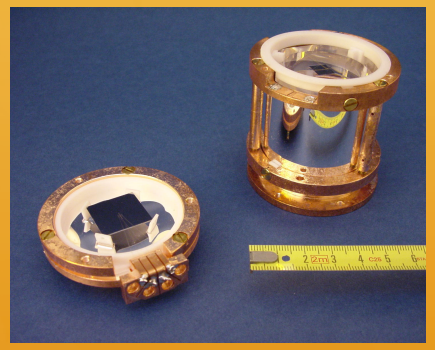
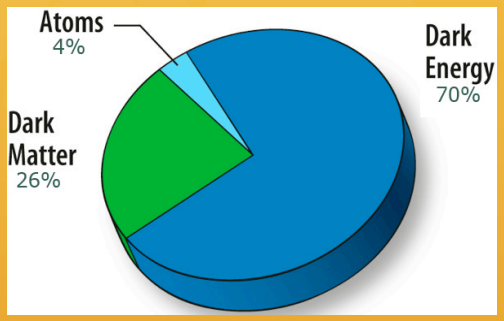
Direct Dark Matter Search



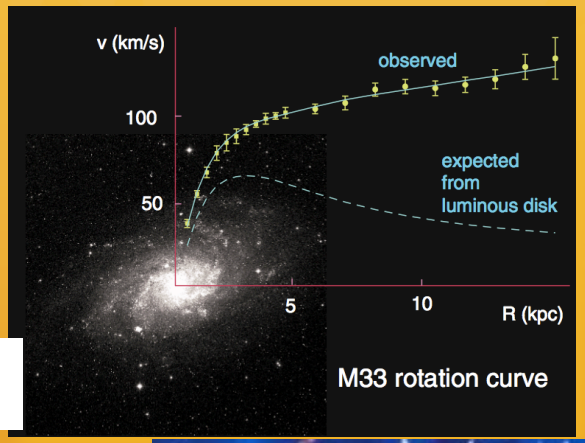
Marco Razeti – INFN Cagliari

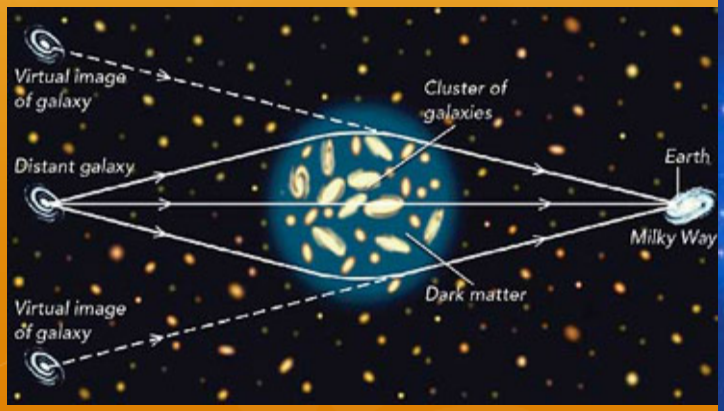
Dark Matter Evidences

Different measurements indicate that ~26% of our Universe is composed of Dark Matter



$$v = \sqrt{\frac{GM_{(R)}}{R}} \qquad M_{(R)} = \int_0^R \rho_{(r)} 2\pi r h * dr$$





Map of dark matter (light blue), digitally superposed on a photograph made by the Hubble Space Telescope, shows that a giant ring of invisible mass surrounds the dense core of a giant cluster of galaxies called ZwC10024+1652, about 5 billion light-years from Earth. Astronomers mapped the distribution of mass in the galaxy cluster by observing the effects of gravitational lensing on background galaxies.

NASA, ESA, M.J.Jee and H. Ford (Johns Hopkins University)

Dark Matter particles (WIMPs) are: stable, not charged, non-barionic, non-relativistic.

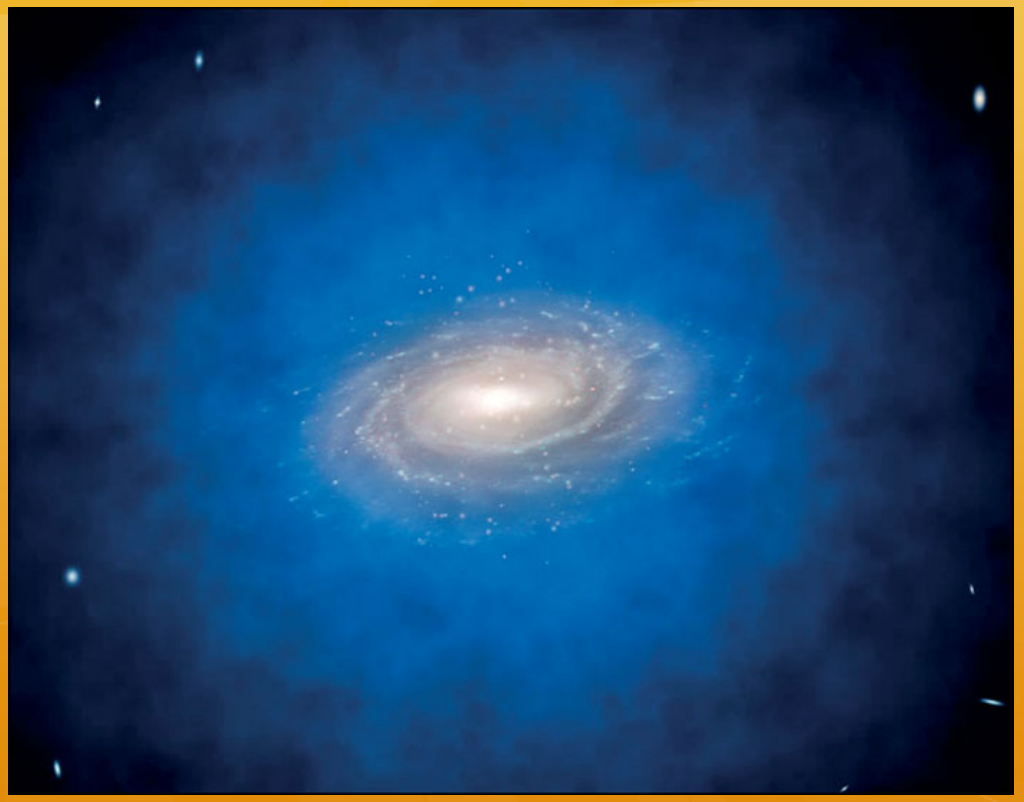
Many colliding/interacting objects out there…

Colliding Clusters: Strong Dark Matter evidence!

Observations of the “Bullet cluster” at z=1.3 in the optical and x-ray fields combined with gravitational lensing provide compelling evidence that dark matter is made of particles (WIMPs)

DM in our Galaxy

- ✓ Is surrounding our Galaxy as a spherical halo
- ✓ V(WIMP) ~240 Km/s with respect to the Earth
- ✓ Local density: 0.3 GeV/ cm^3

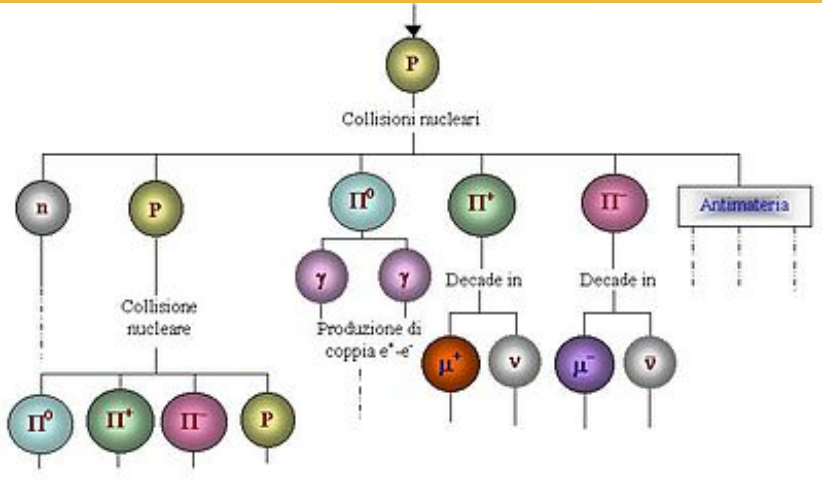


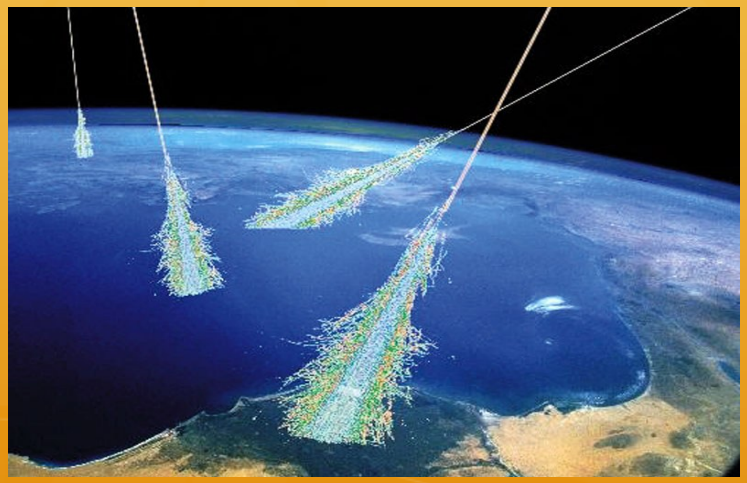
Assuming a WIMP mass of 100 GeV/c^2 ->
~10 million go through your hand every second!
(~without interacting)

How can we detect Dark Matter ???

Cosmic Rays & Radioactivity

- Primary cosmic rays are mainly protons: they interact with atoms in the upper layers of the atmosphere creating secondary cosmic ray showers.





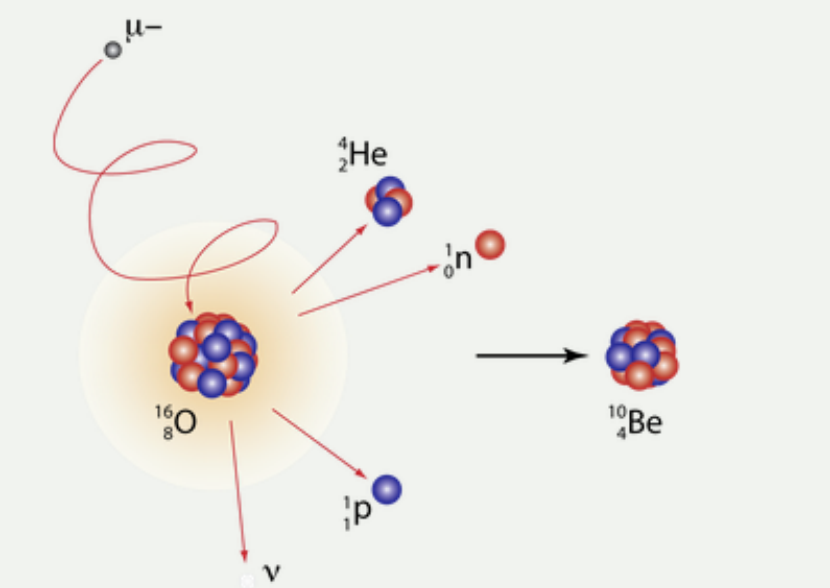
Rate at ground level ~ 1 particle/cm^{2}s (for energy ~GeV)

- Natural radioactivity is everywhere around us and produces an unwanted source of background

We look for a signal given by ~few events in a year: need to shield our detector(s) from all those particles!

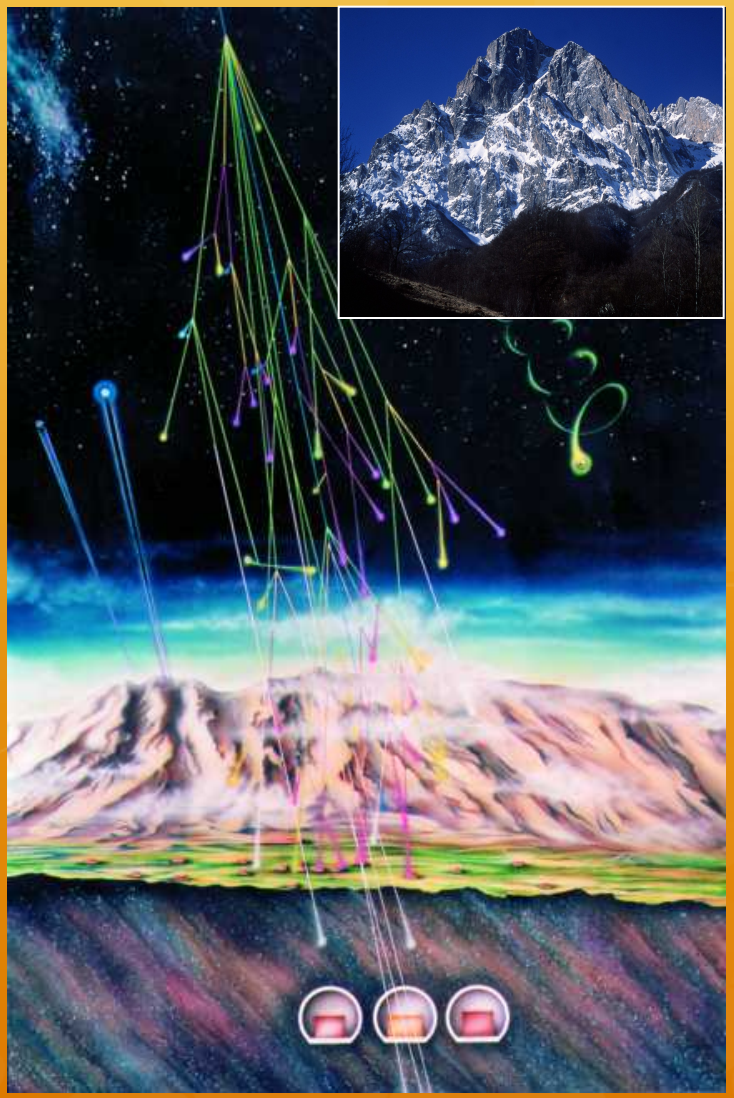
We have then four problems…

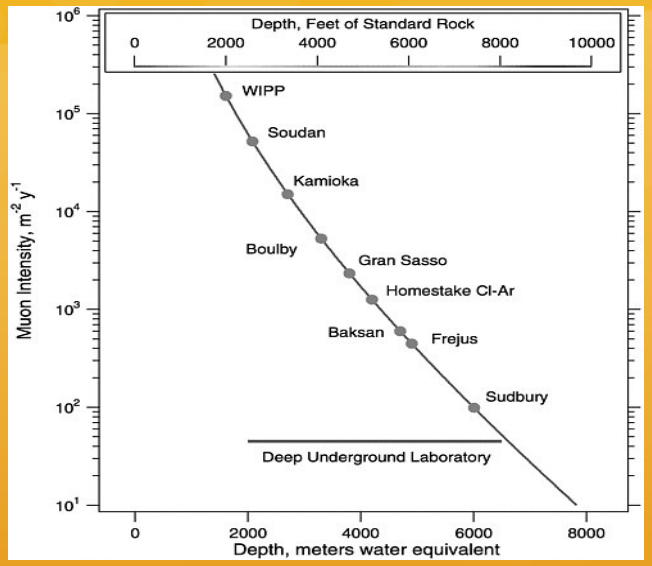
① **Cosmic muons may induce fast neutrons. Muons are difficult to shield, need to sit the experiment *deep underground* to reduce them (*not eliminate* –> muon coincidence veto).**

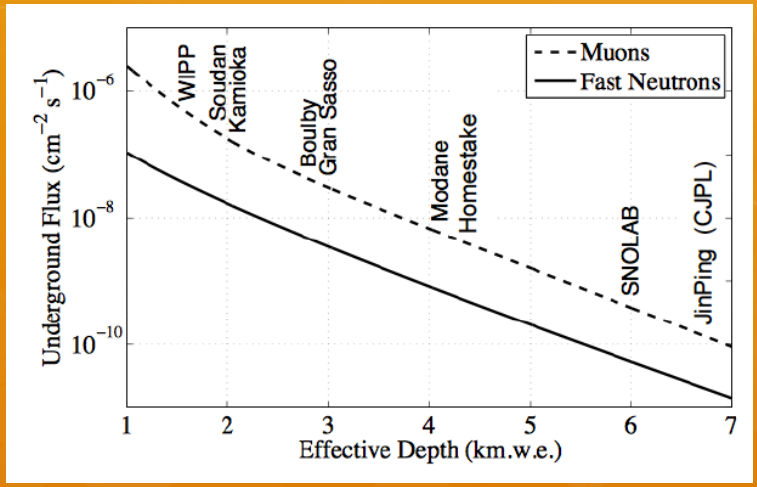


Negative muon capture reaction on an oxigen nucleus leading to the production of cosmogenic ^{10}Be.

Use of Deep Underground Sites





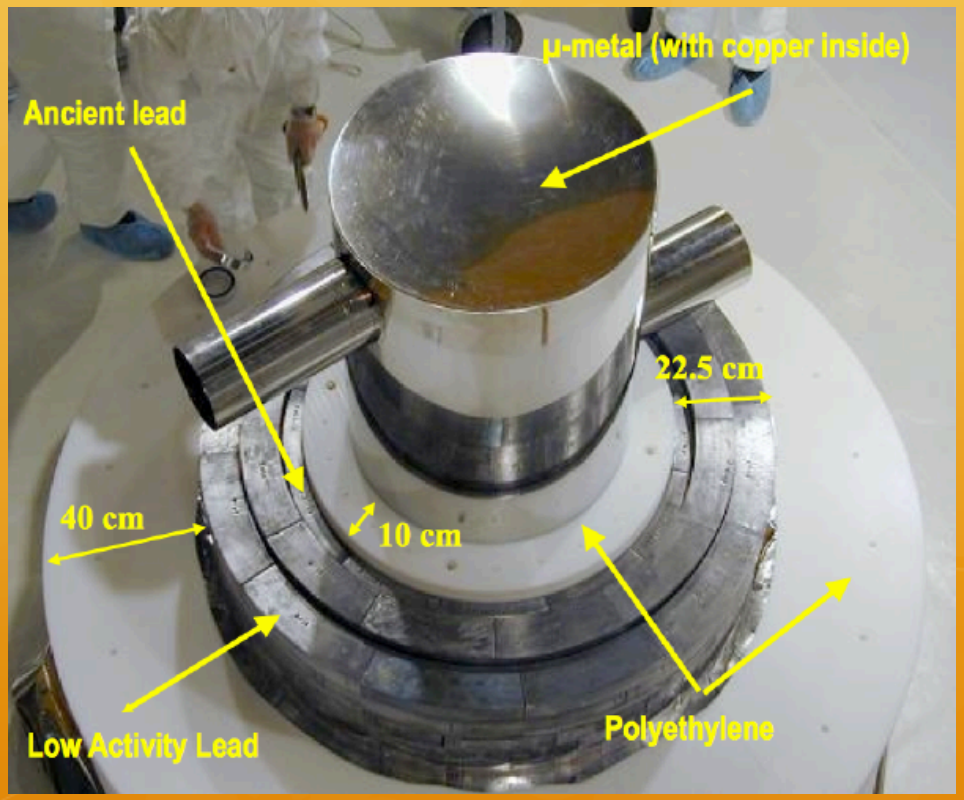


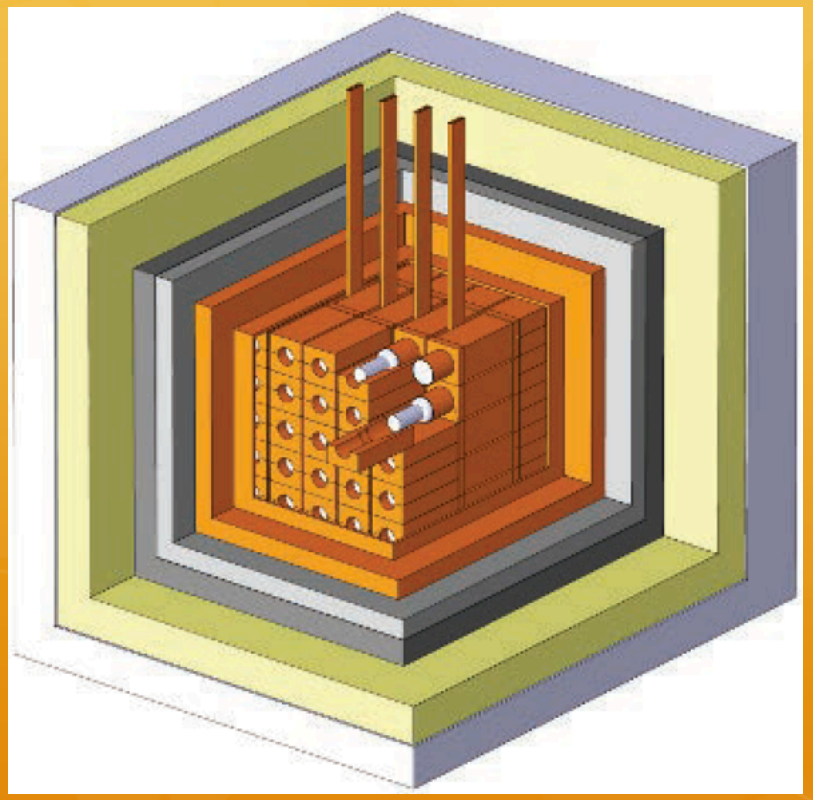
We have then four problems…

① Cosmic muons produce fast neutrons via spallation process. They are difficult to shield, need to sit the experiment deep underground to reduce them *(not eliminate!)*.

② **Even underground there is plenty of local natural radioactivity -> shield the experiment with radiopure materials (e.g., very low in Th/U chains and K). They may be passive or active shields.**

Passive shielding (SuperCDMS, DAMA)



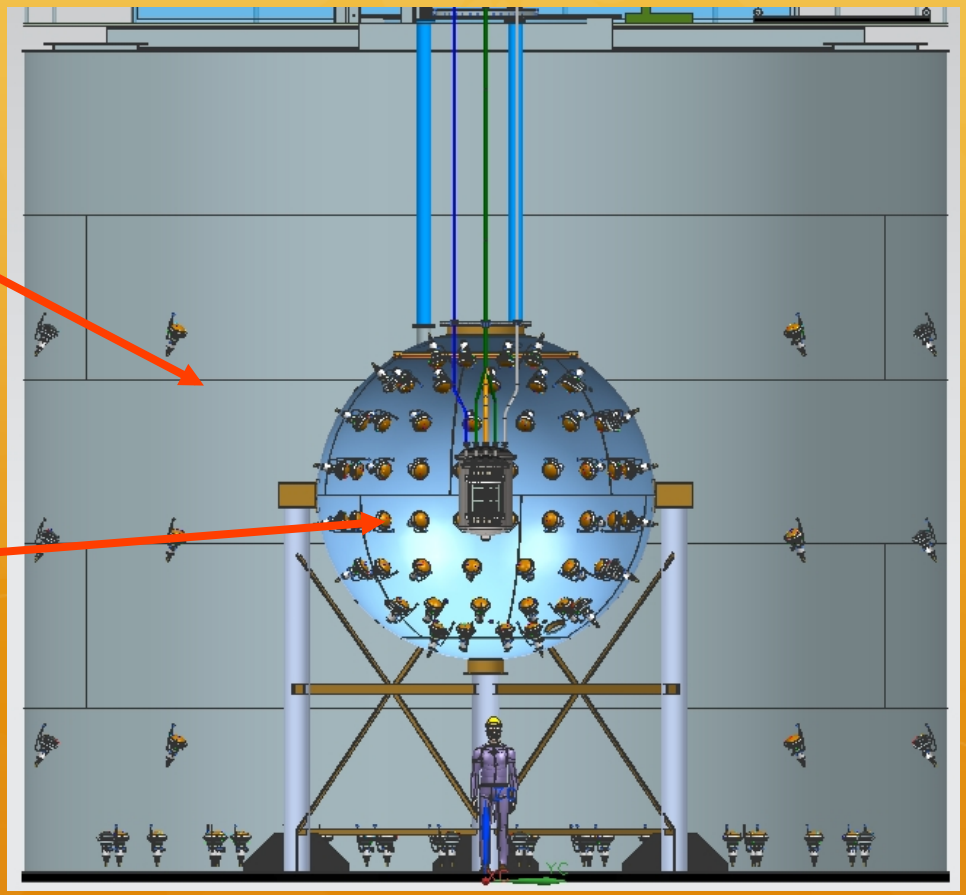


HP Copper: surrounds the detector.
Roman Lead: stops ^{210}Pb radioactivity in lead.
Lead: stops gammas from surroundings.
Polyethylene moderate neutrons below experiment threshold.

Active shielding (Darkside)

Water Cherenkov Muon Veto (moderate also muon induced fast neutrons)

Liquid scintillator Neutron Veto – Boron loaded (moderate and captures neutrons emitting gamma-ray)



If a neutron (for any reason) interact in our detector it will most probable interact also in the neutron veto -> signal rejection with >99% efficiency!

We have then four problems…

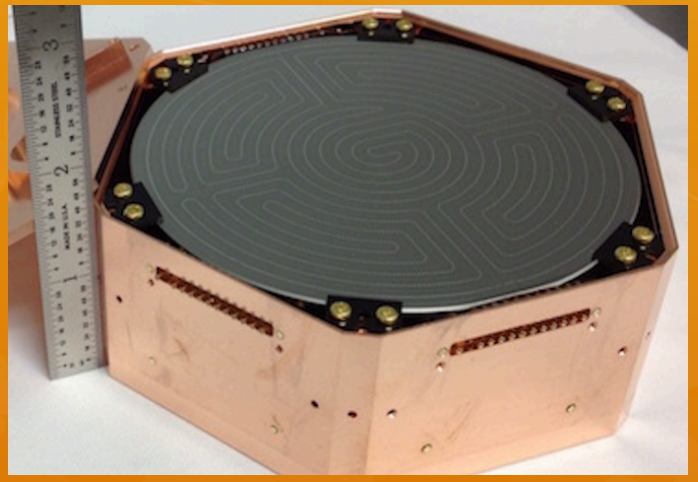
① Cosmic muons produce fast neutrons via spallation process. They are difficult to shield, need to sit the experiment deep underground to reduce them *(not eliminate!)*.

② Even underground there is plenty of local natural radioactivity -> shield the experiment with radiopure materials (very low in Th-232/U-238 chains and K-40). They may be passive or active shields.

③ Also the target itself may have traces of radioactive impurities: purification processes, detector fabrication in clean rooms (class 100, Rn free,…), use of pure N_2 gas overpressure to protect detectors against possible radioactive pollution,…

DAMA shielding cage and detectors: they are protected by overpressure of High Purity N2 gas

SuprCDMS HP Ge detectors are fabricated in 100 class clean room.



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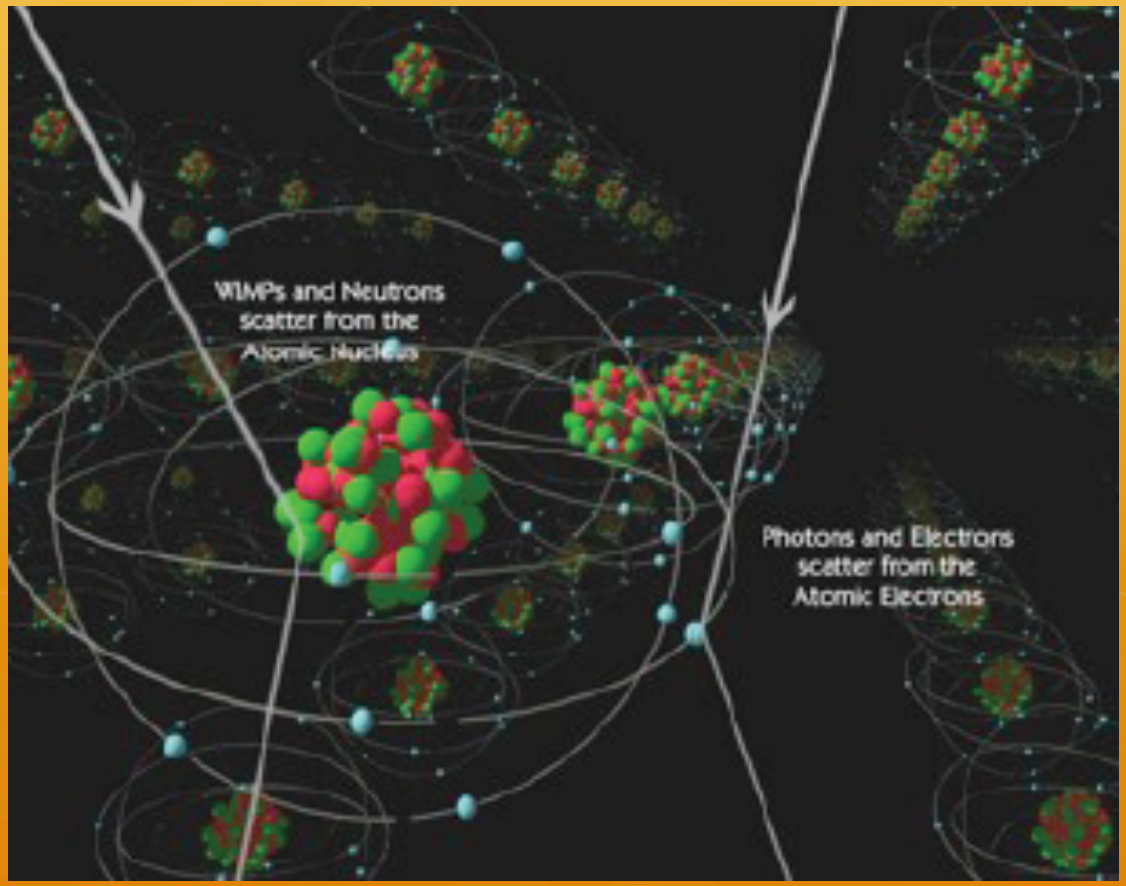
③ Also the target itself may have traces of radioactive impurities: purification processes, detector fabrication in clean rooms (Rn free), use of pure N_2 gas overpressure to protect detectors against possible pollution,…

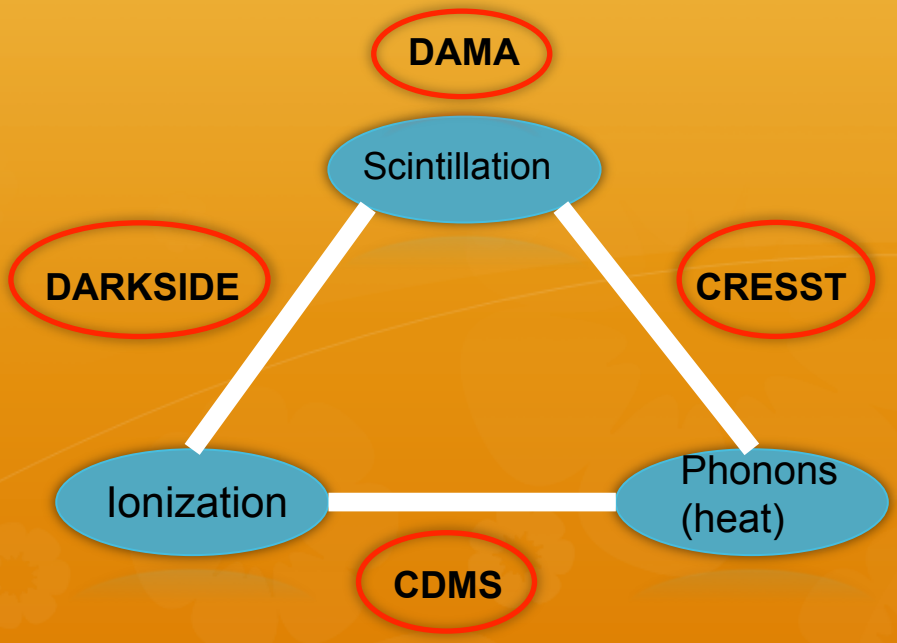
④ **The expected WIMP rate is so low that we will see many events due to electron recoils during the data taking: discrimination between ER and NR at a level of ~10^7 or higher.**

Discrimination between Nuclear and Electron Recoils (ER/NR)



Background Discrimination: Different Techniques

Several experiments using different techniques for background suppression -> *target material selection*.
(E.g. good scintillator materials are needed to produce high scintillation light).

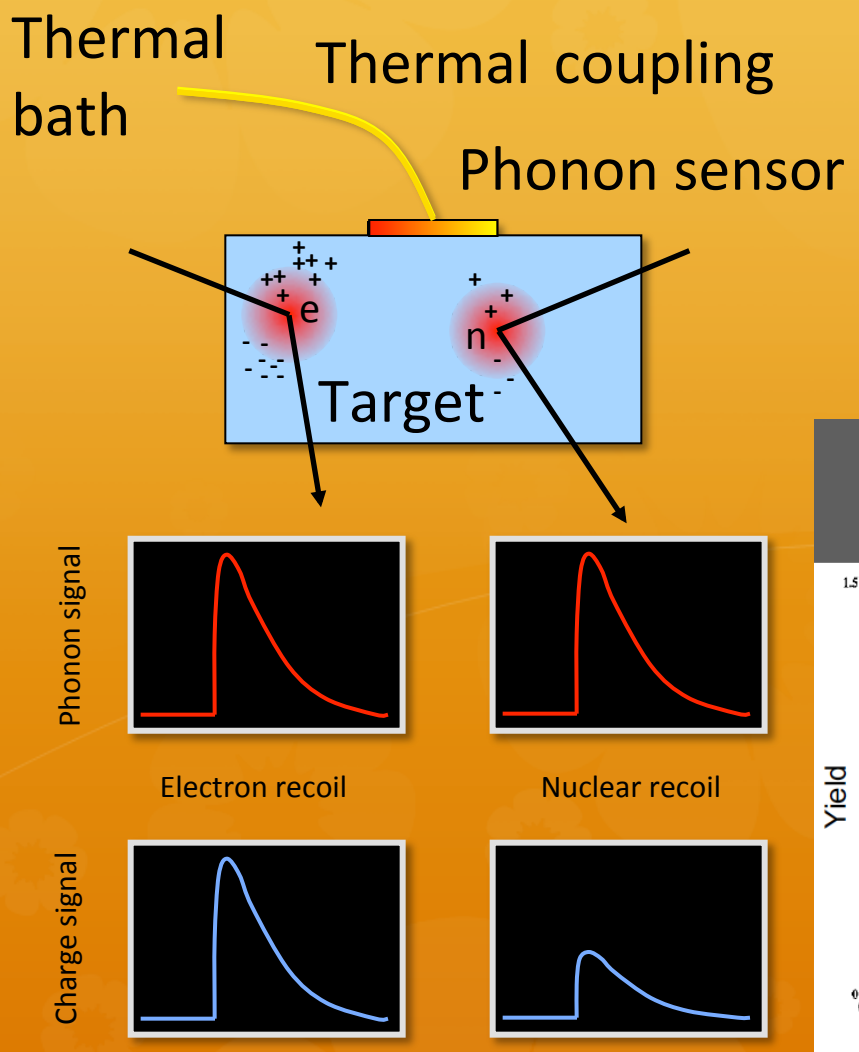


1) ER and NR give different scintillation and ionization signals (but same phonon signal) if the same energy is deposited in the detector (CDMS, CRESST)

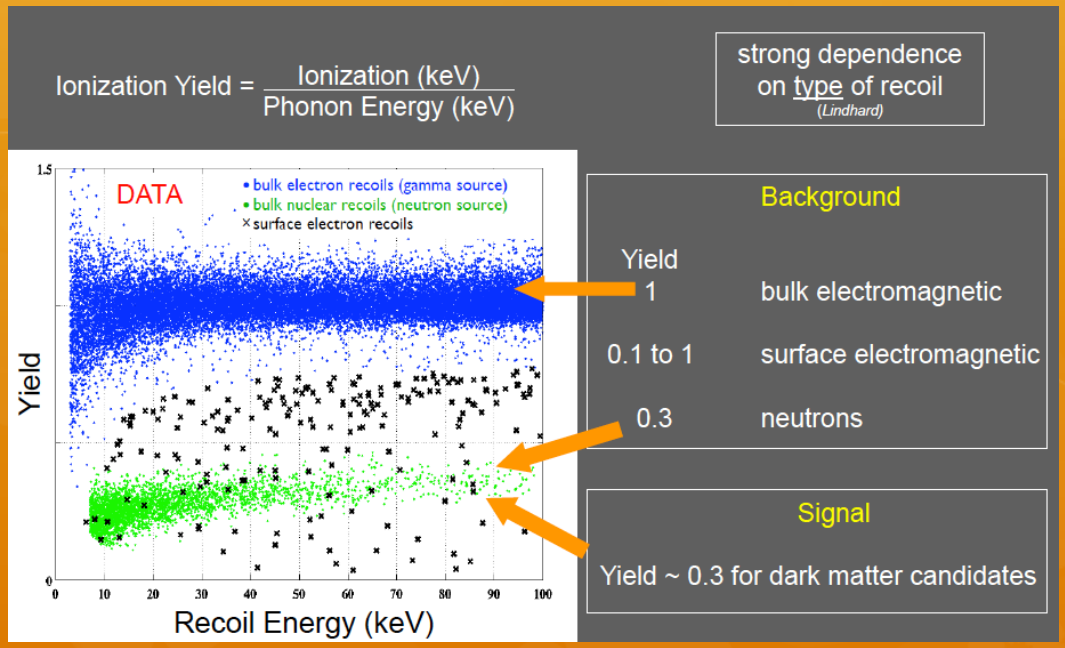
2) Scintillation and ionization signal may be different for ER and NR (DARKSIDE)

3) Scintillation signal alone may differ from ER and NR (DARKSIDE and DAMA).

SuperCDMS BKGD Rejection

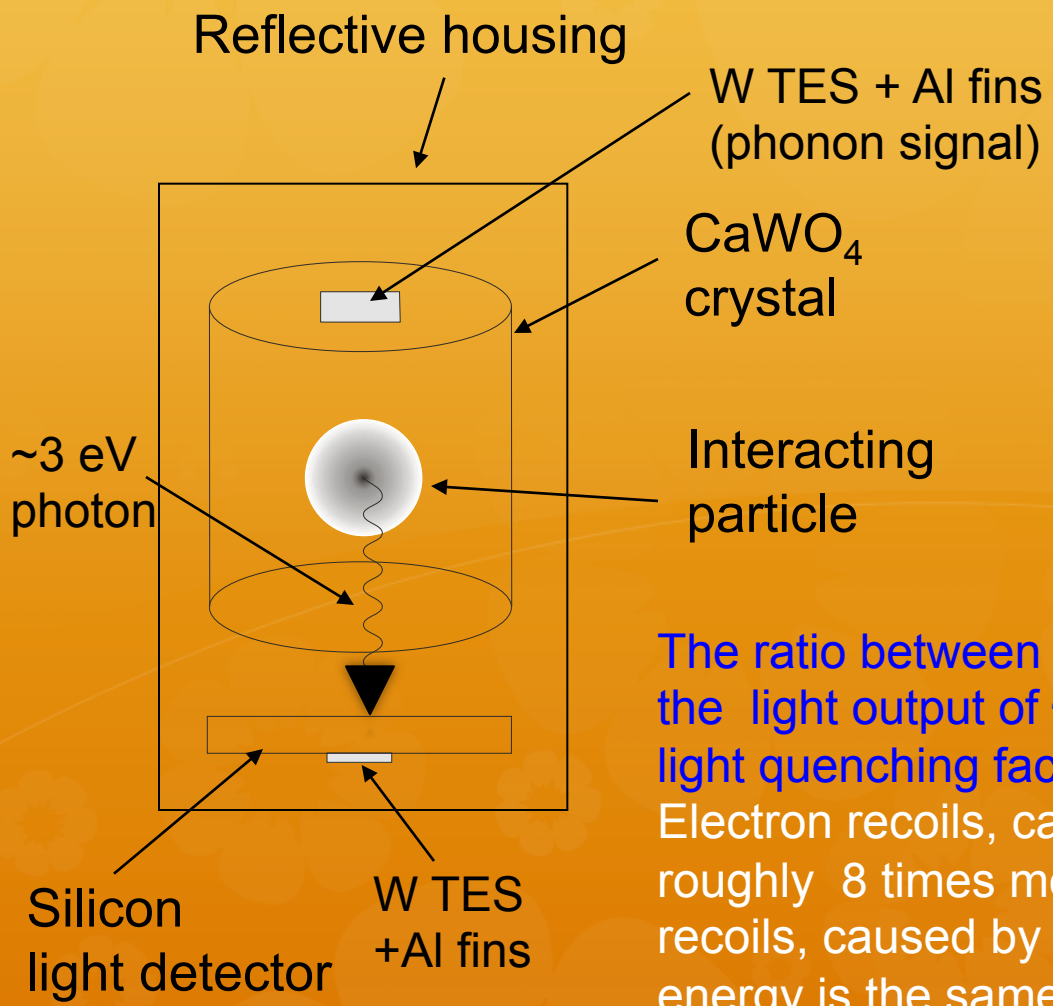


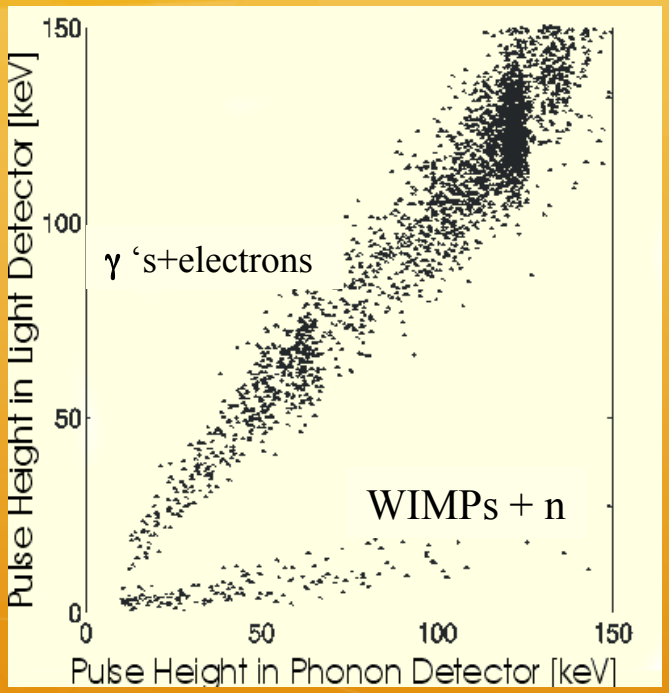
- Phonon signal: measures energy deposition
- Ionization signal: distinguishes between electron (large) and nuclear recoils (small)



CRESST BKGD Rejection

Principle of discrimination





The ratio between the light output of nuclear recoils and the light output of γ's of the same energy is known as the light quenching factor.

Electron recoils, caused by γ's and electrons, produce roughly 8 times more scintillating light than nuclear recoils, caused by WIMPs or neutrons, when the thermal energy is the same ⟶ main bkgd discrimination.

The Darkside Experiment

- Searches for **dark matter** (WIMPs) using a direct detection method in the underground laboratories in Gran Sasso (LNGS – Hall C)

- Is the new research program worldwide using liquid argon, as all the research groups have joined the DS-20k experiment (while still completing their current research programs):

Darkside
DEAP
ArDM
MiniCLEAN

→ DS-20k → multi-100 ton scale experiment

The Darkside Experiment

To this new collaboration will take part:

- 68 Research Institutes and Universities
- 350+ Researchers, Engineers and Technicians
- 12 Countries: Brazil, Canada, China, France, Greece, Italy, UK, Poland, Romania, Spain, Switzerland, USA.

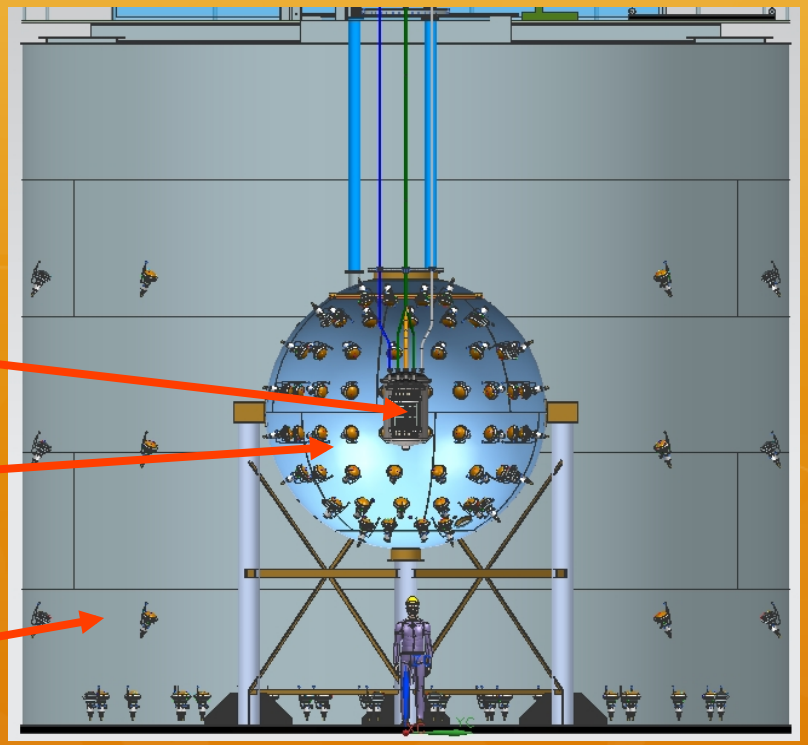
The Darkside Experiment

- Employs a double phase **Liquid Argon** Time Projection Chamber (**TPC**) capable of 3D event localization
- Provides a very powerful background suppression through the Pulse Shape Discrimination (**PSD**) and the Scintillation (S1) and Ionization (S2) channels: **S2/S1** parameter
- Operates with active Muon and Neutron Vetoes
- Aims to run in background free mode (<0.1 event in total exposure): **a necessary condition for a discovery program.**

Liquid Argon TPC as DM target

Liquid scintillator Neutron Veto

Water Cherenkov Muon Veto



The Darkside Experiment

Appealing **Argon properties** as dark matter target:

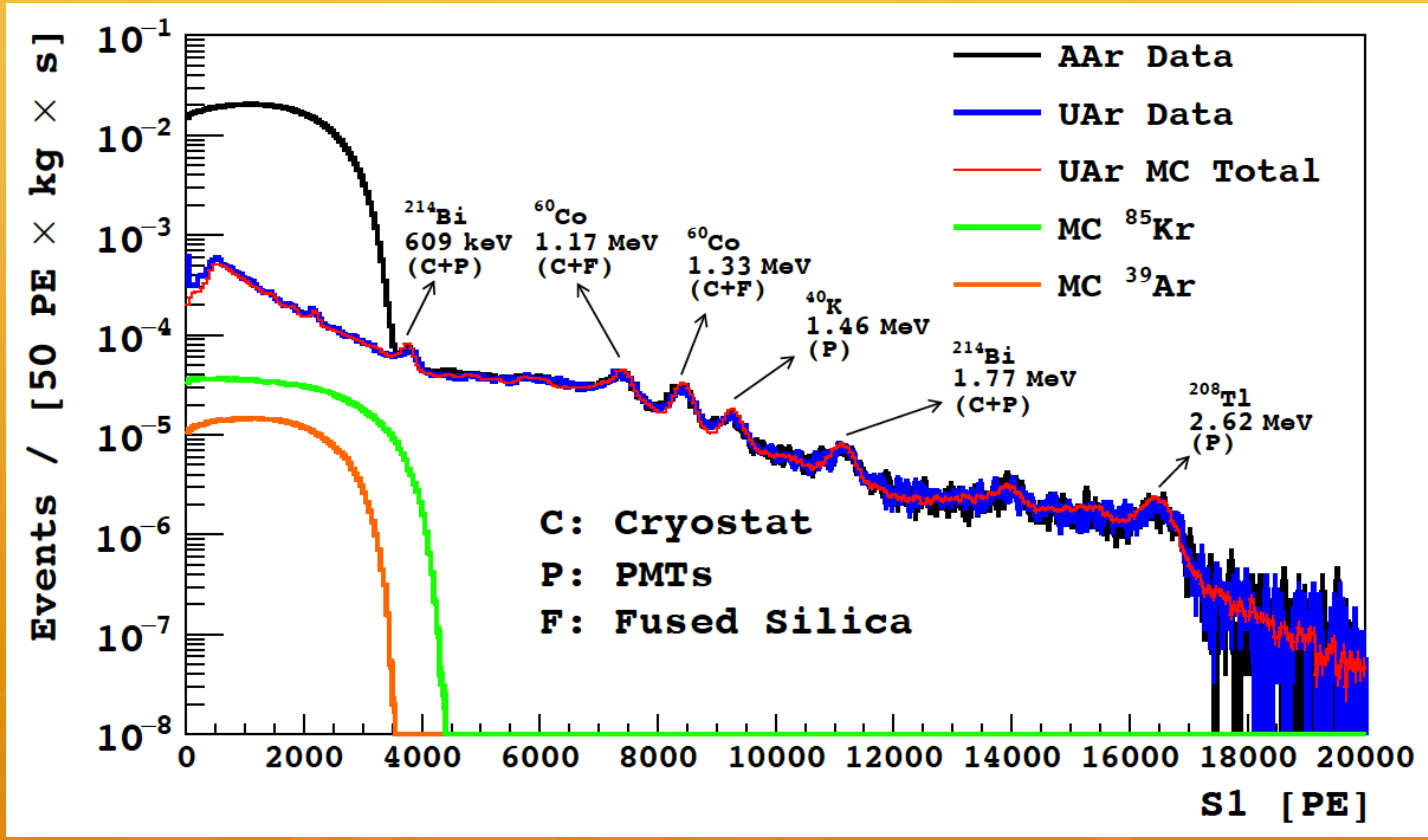
- Liquefies at 87 K, simply using LN_2 or cryogen free techniques
- Purification: contaminants/impurities may be easily trapped (e.g. Rn)
- May be scaled to larger masses
- Sufficiently high A (WIMP-nucleon cross section goes as A^2 for spin-independent interaction)
- Scintillates with high scintillation yield (40k photons/MeV) and is transparent to the emitted light.
- High ionization signal (electroluminescence in Ar gas)
- **Excellent background discrimination power**

One only drawback: cosmogenic production of the unstable isotope ^{39}Ar in the atmospheric Ar (AAr) via the **^{40}Ar(n, 2n)^{39}Ar** reaction.
^{39}Ar is present in traces (1 part in 10^{15}) and β-decays (Q=565 keV, $T_{1/2}$=269 y) -> a=1 Bq/kg.

Solution: Underground Argon (UAr) from deep underground wells (Cortez, CO).
Depletion factor of ^{39}Ar measured by DS-50 is $(1.4\pm0.2)\times10^3$ with respect to AAr.

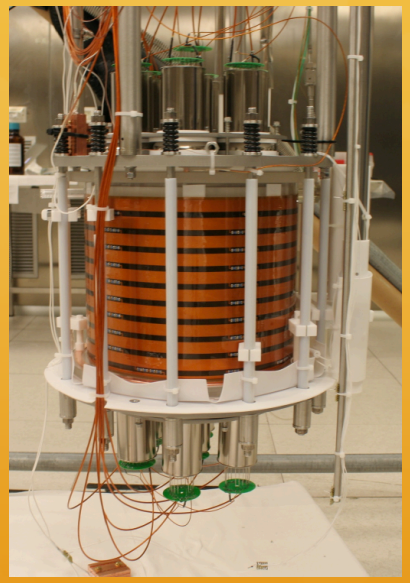
The Darkside Experiment

UAr depleted in ^{39}Ar of a factor 1400 with respect to AAr



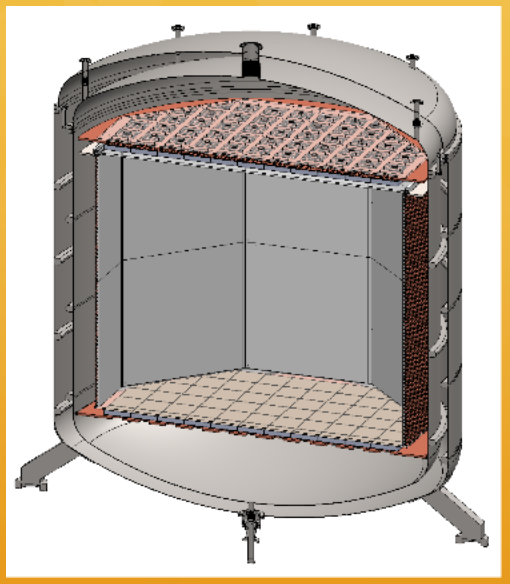
Fitted ^{85}Kr activity in UAr: 2.05 ± 0.13 mBq/kg
Fitted ^{39}Ar activity in UAr: 0.73 ± 0.11 mBq/kg
^{39}Ar activity in AAr: 1000 mBq/kg

The Darkside Experiment



DS-10
(2011-13)

DS-50 (2013 - presently running)

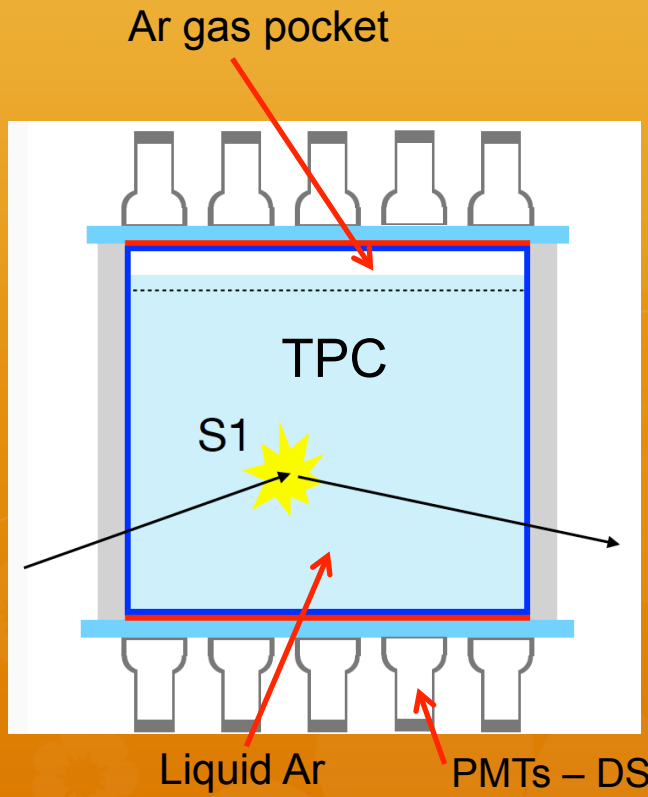


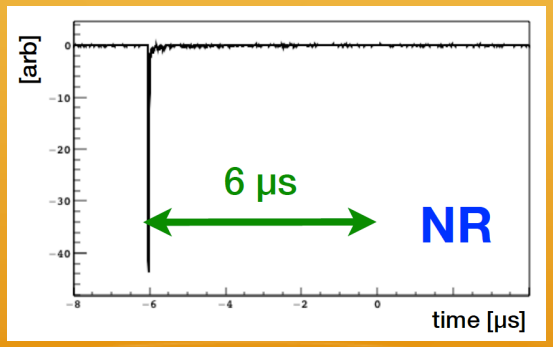
DS-20k (Data taking starts in 2021)

Darkside 50 is currently running with UAr in bkgd free mode.
Next steps:
DS-20k: 20 t (FV) of liquid UAr and **SiPM instead of PMTs (for bkgd reduction)**

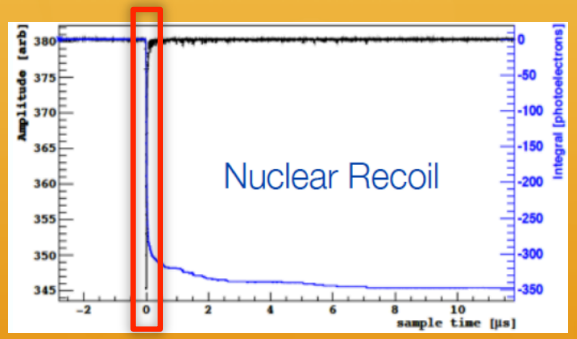
Background Rejection

Background Rejection:
S1 (scintillation signal) - Pulse Shape Discrimination (**PSD**) using the $\mathbf{f_{90}}$ parameter (fraction of light in the first 90 ns).



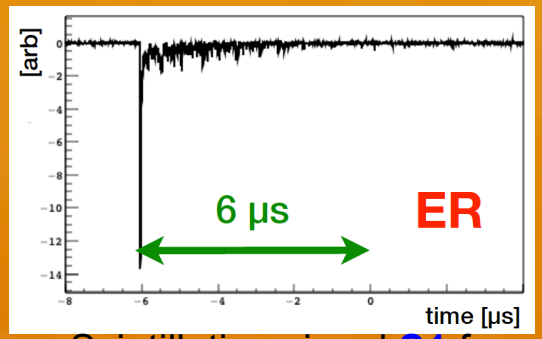


Scintillation signal **S1** for **NR**

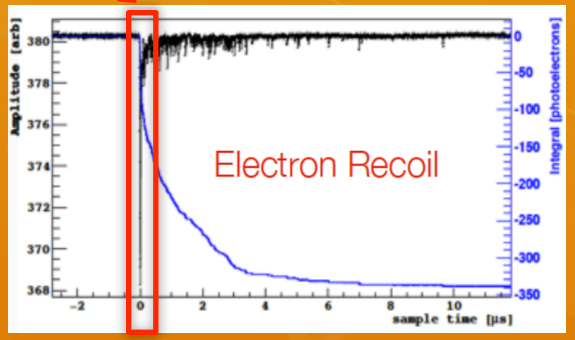


S1 integral for **NR**

90 ns windows



Scintillation signal **S1** for **ER**

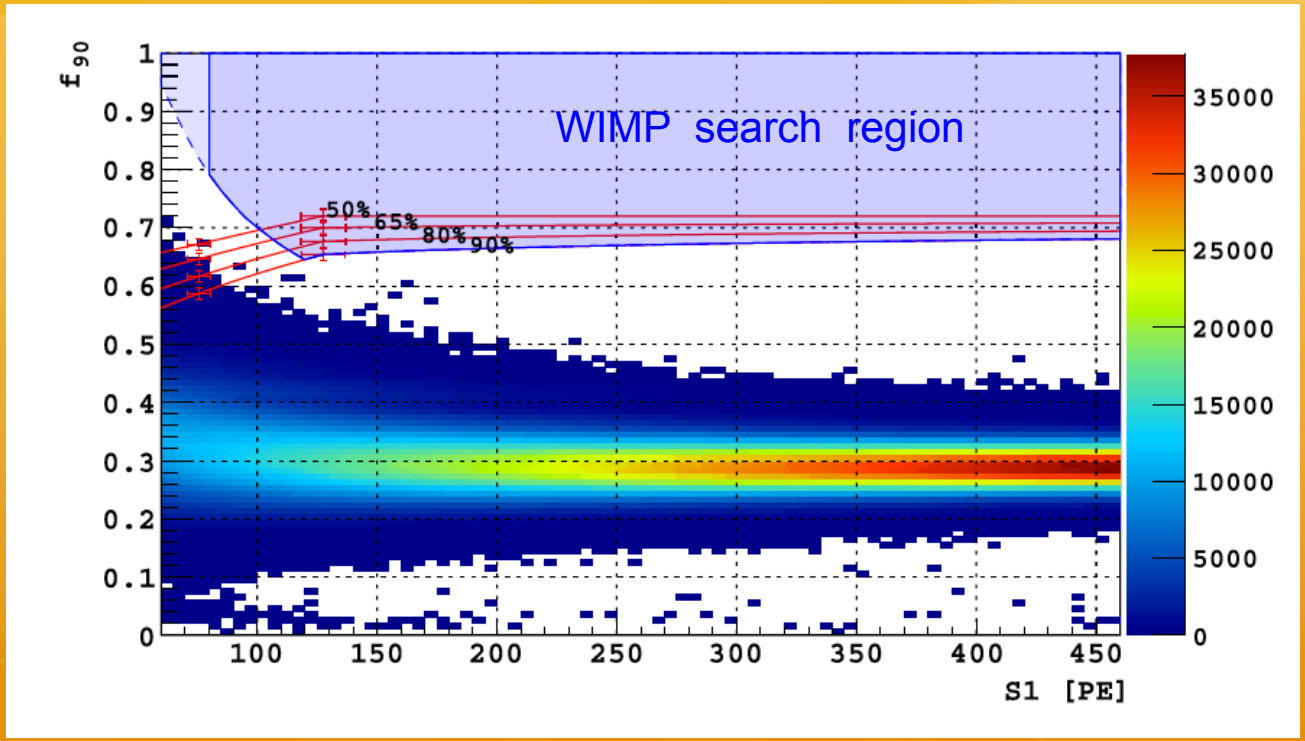


S1 integral for **ER**

Background Rejection

Atmospheric Argon: 1422±67 kg day exposure - Phys. Lett B 743 (2015) 456

f_{90} vs S1 plot after applying all quality and physics cuts: **1.6 ×10^7 events remain (mainly ^{39}Ar)**

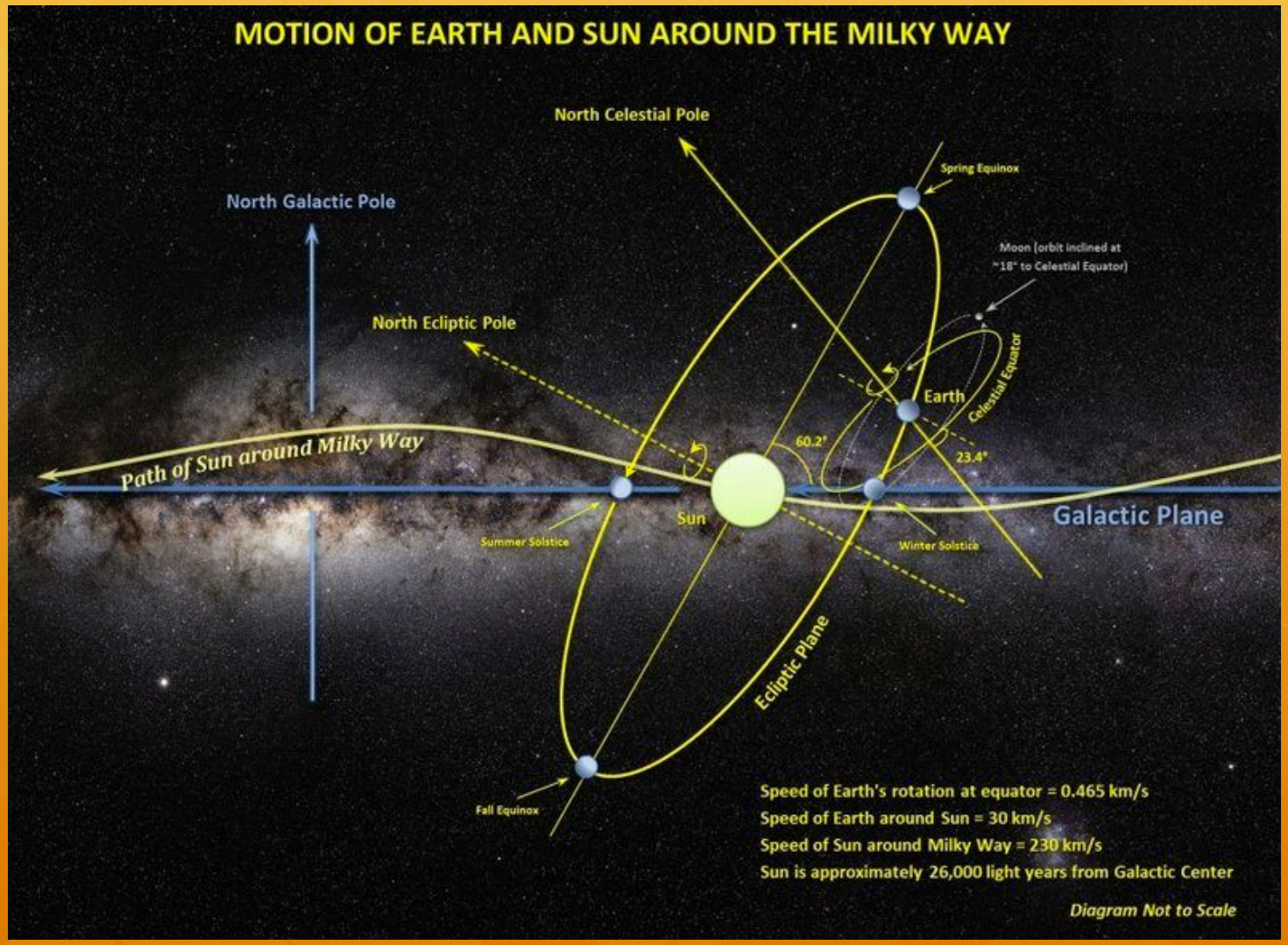


No events in the WIMP Search Region at 90% C.L. -> β/γ rejection power is greater than 1/1.6×10^7 -> DS-20k may run in bkgd free mode for 5.5 t×yr.

Monte Carlo study -> DS-20k may run bkgd free for the 100 t×yr exposure.

DAMA Experiment

Relative motion of the Earth wrt the the Sun

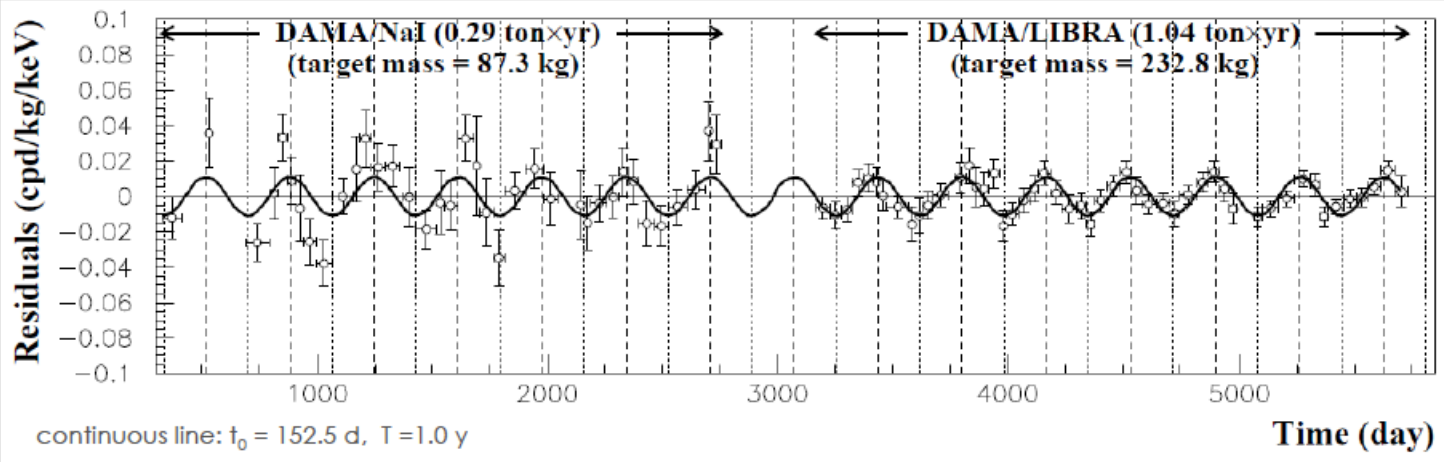


Model Independent Annual Modulation Result

DAMA/NaI + DAMA/LIBRA-phase1 Total exposure: 1.33 ton×yr

EPJC 56(2008)333,
EPJC 67(2010)39,
EPJC 73(2013)2648

residual rate of the 2-6 keV single-hit scintillation events *vs* time



Absence of modulation? No

χ^2/dof=154/87

P(A=0) = 1.3×10^{-5}

Fit with all the parameters free:

A = (0.0112 ± 0.0012) cpd/kg/keV

t_0 = (144±7) d - T = (0.998±0.002) y

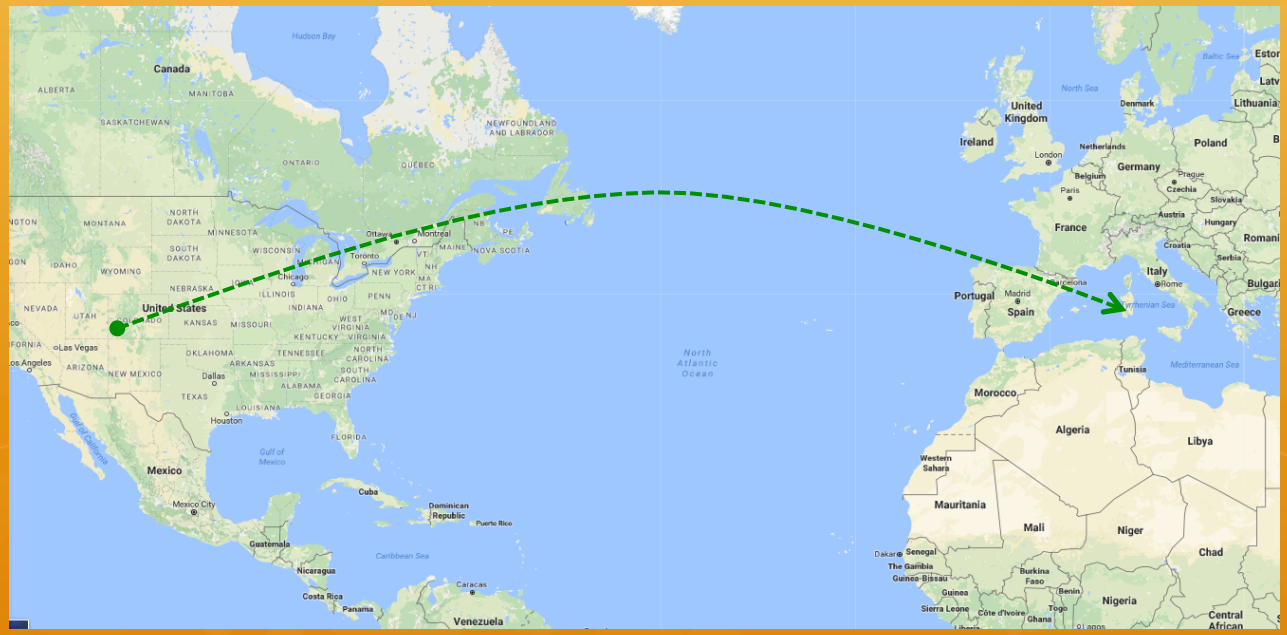
The data favor the presence of a modulated behaviour with all the proper features for DM particles in the galactic halo at about 9.2σ C.L.

SOME SEASONAL EFFECT ???

Two *identical* new experiments (SABRE) one in **LNGS** and the other in **Australia** will start soon taking data (they should be 6 months out of phase to confirm if this result is due to some seasonal effect!)

Aria: Ar process and stable isotope production

The Aria project, located at the Seruci mine in Sardinia, has the aim to perform chemical purification of the UAr extracted from the Doe Canyon CO_2 wells at Cortez (CO) for the DS20k experiment.



It will be also the test bench to develop active depletion of ^{39}Ar from the UAr.

Depletion of ^{39}Ar will be needed for the ARGO (multi-100 ton experiment).

Aria: Ar process and stable isotope production

Uses of stable isotopes ^{13}C, ^{15}N and ^{18}O:
Nuclear medicine: non radioactive, safe to use also in children and pregnant women as tracers.

Examples:

- ^{13}C labeled urea used in breath tests to detect Helicobacter pylori infection
- ^{13}C for studying metabolic changes in the brain by MRI to diagnose neuropsychiatric disorders
- Study of metabolic transformations of drugs in pharmaceutical industry using ^{13}C, ^{15}N, ^{17}O and ^{18}O.

Such isotopes will be produced by Aria, entering in a market that is now constrained by supply and their costs dominated by the energy required for separation.

THE END