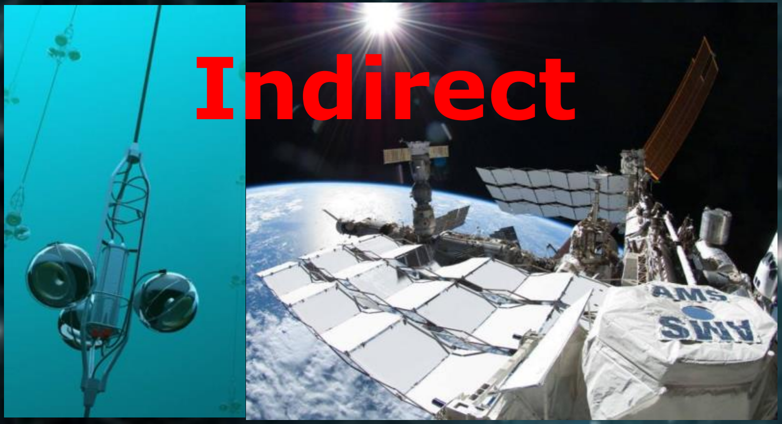
Attivita` in sezione

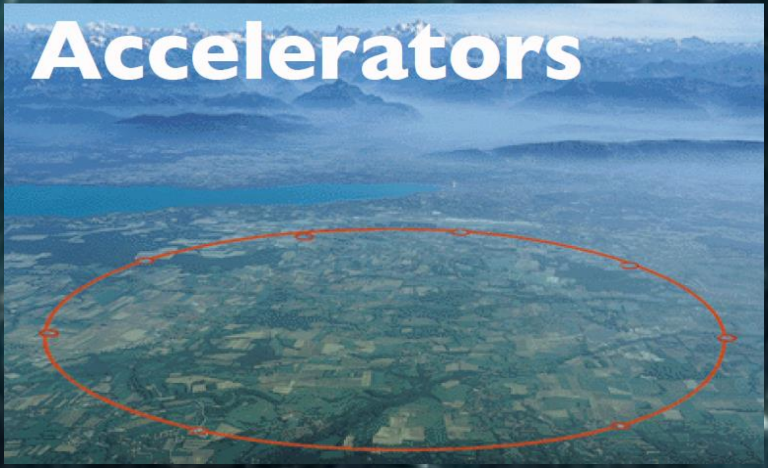
e prospettive

Primo pomeriggio di Discussione su Materia Oscura, 20 gennaio

A. Incicchitti
INFN Roma

Investigating the Dark Matter particles





No model independent comparison is possible

Investigating the Dark Matter particles

see P. Belli talk

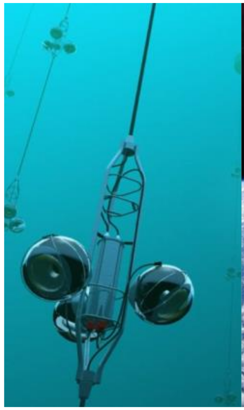
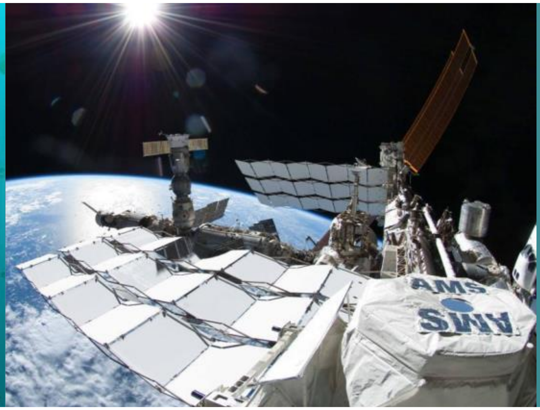
see F. Donato talk

see S. Rahatlou talk

Investigating the Dark Matter particles (Indirect)

Space experiments: AGILE, AMS2, CALET, DAMPE, FERMI, GAMMA-400, JEM-EUSO-RD, WIZARD(PAMELA), …
Surface (high altitude): ARGO-JBJ, HAWC, LHAASO, MILAGRO,…
Surface: AUGER, KASCADE Grande, DECOR, LOFAR, CODALEMA,….
Telescopes (Cherenkov detectors): CTA-RD, HESS, MAGIC,VERITAS, …
Underice: ICE-CUBE,…
Underwater: KM3(ANTARES,NEMO), Baikal-GVD,…
Underground: SUPER-KAMIOKANDE,…

- **Experiments@INFN-Roma, T Experiments@CSN2**

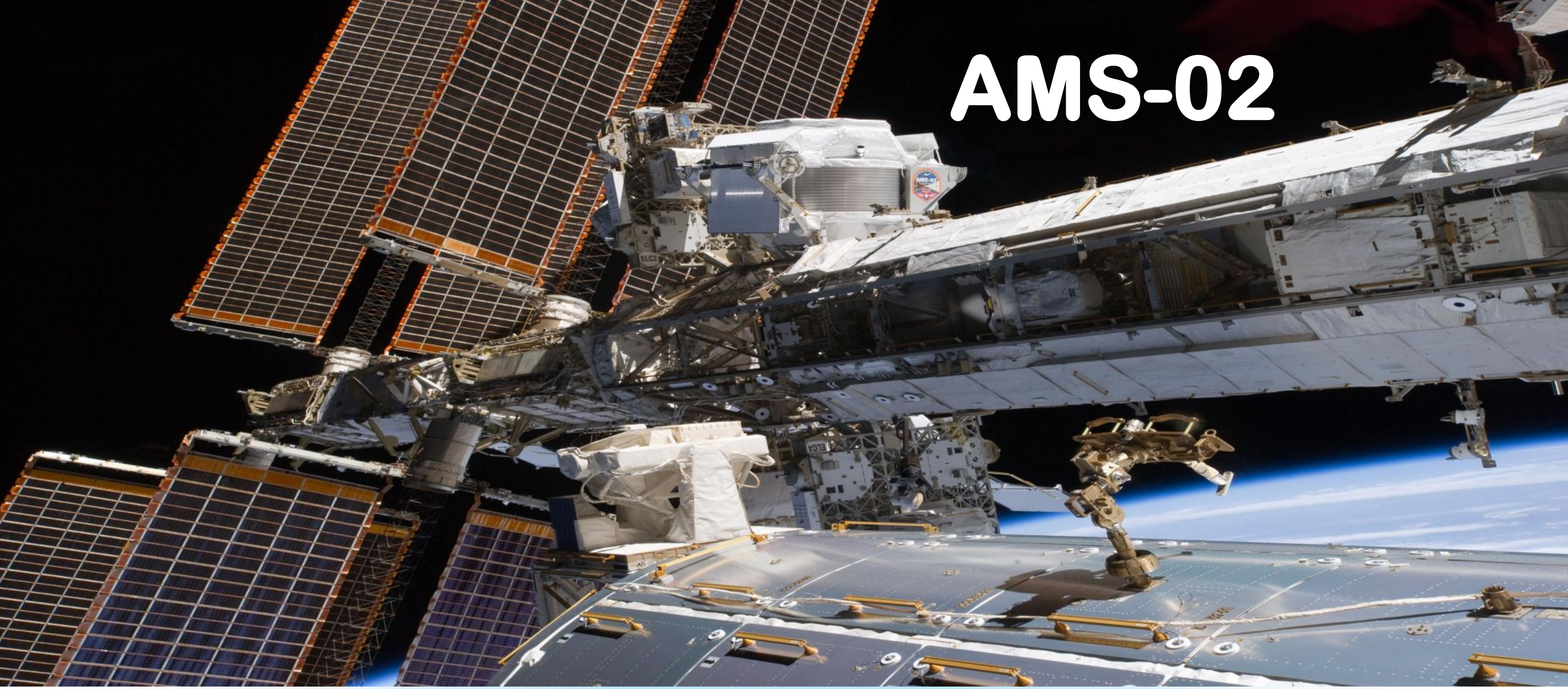



- High-energy neutrinos
- Gamma-rays
- Antimatter in the space (positrons, anti-protons)
- Effects of DM on astrophysical objects

- model dependent results, sensitive to some DM candidates and/or scenarios
- strong modeling of the background is needed
- other sources of positrons/gamma-rays/anti-matter/… are present

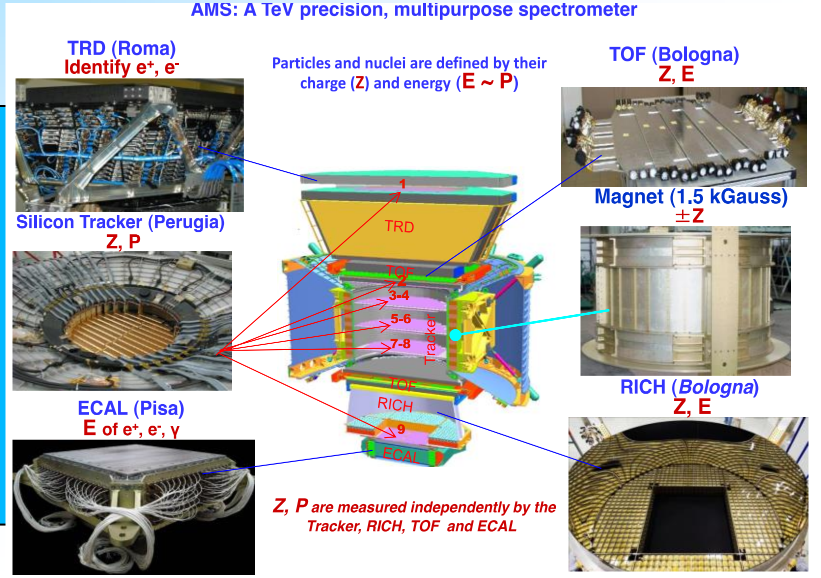
Key point: to look for channels and energy range where the background from ordinary astrophysical processes can be reduced

AMS-02



In data taking since May 2011

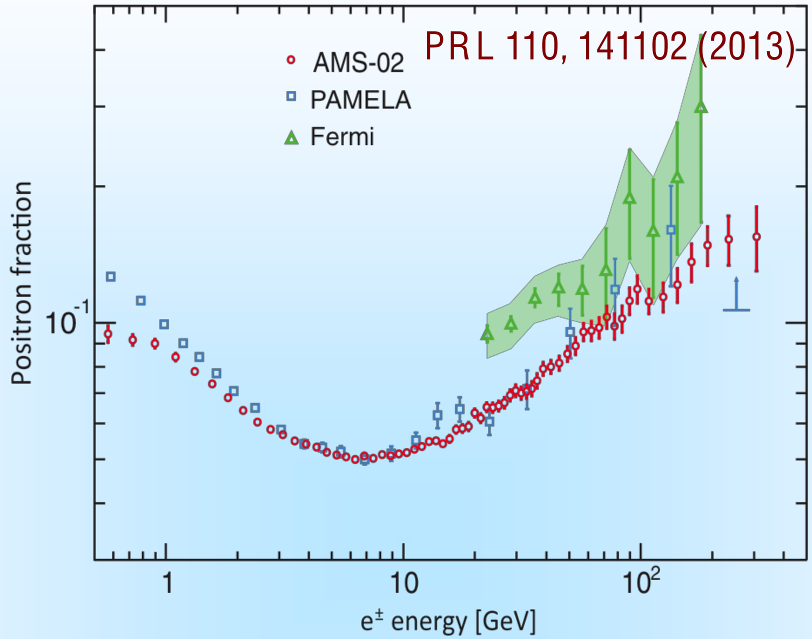
Fields of research: CR spectroscopy, Antimatter, some DM candidates. Results on e^-, e^+, p, He, B/C (energy spectra and fluxes), studies on solar variation on p flux, analysis on anti-p, anti-d, anti-He, solar physics, ion flux, photons, and more.



6.8 x 10^6 e^+ and e^- events (18 months of operations on the ISS up to December 2012). 8% of the expected AMS data sample.

AMS-02

Below 10 GeV good agreement with the behaviour expected from the secondary production of cosmic rays by collision with the interstellar medium.



It increases over 10 GeV. From 20 to 250 GeV, the slope decreases by an order of magnitude.

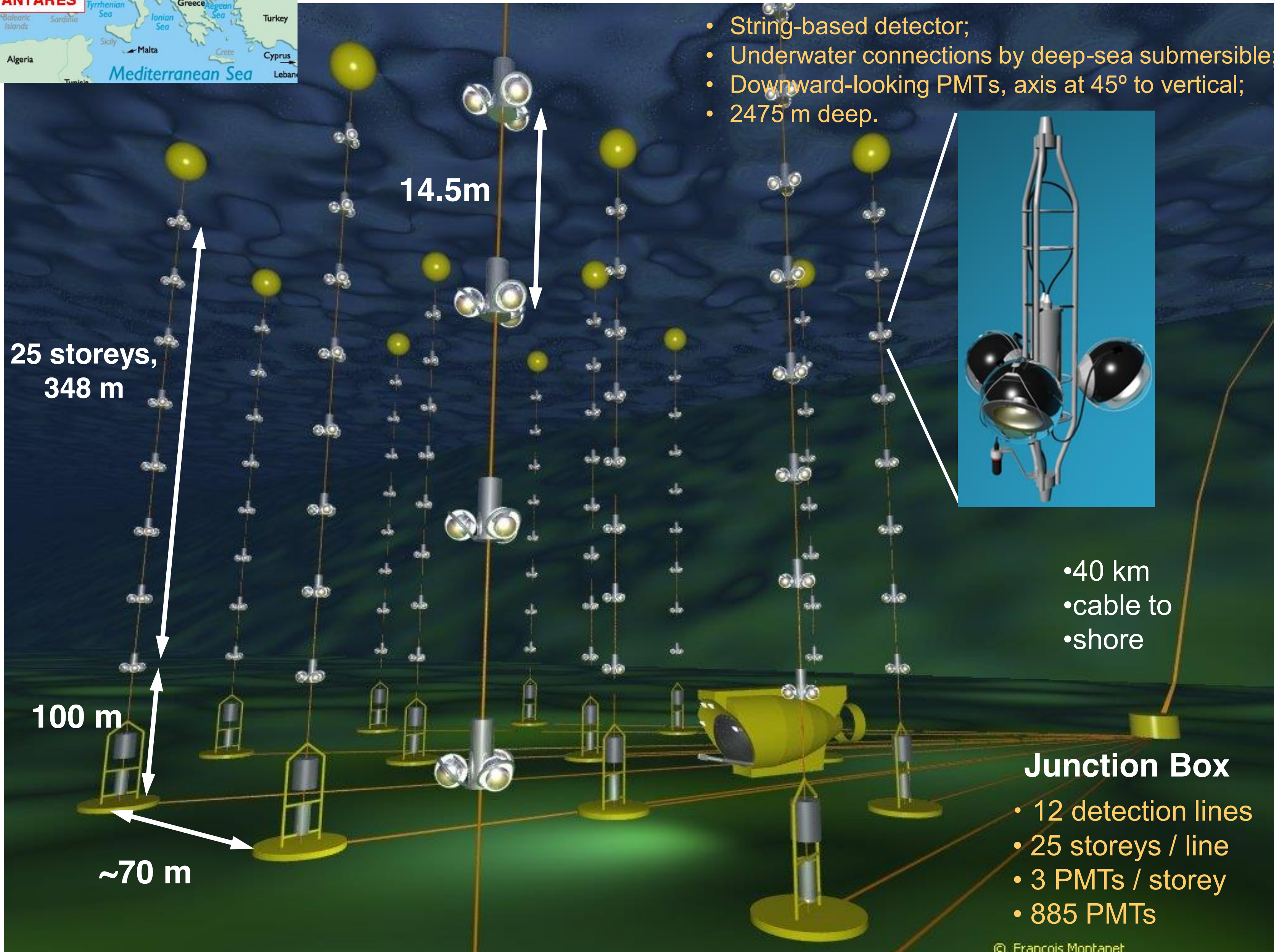
A DM model would need:

- **σ_{ann} (~10^{-24} cm^3/s), 100 times larger than the one required for a DM thermal relic;**
- **A leptophilic DM with σ_{ann} mostly into leptons (no excess in the CR anti-p spectrum is observed) or more exotics.**

- **A leptophilic DM is in tension with the g-ray flux from GC and dwarf galaxies.**
- **Nearby pulsars can be responsible for the observed behaviour of the positron fraction.**

PROSPECTS of AMS-02: In ten more years positron fraction up to 1 TeV + info on other subjects.

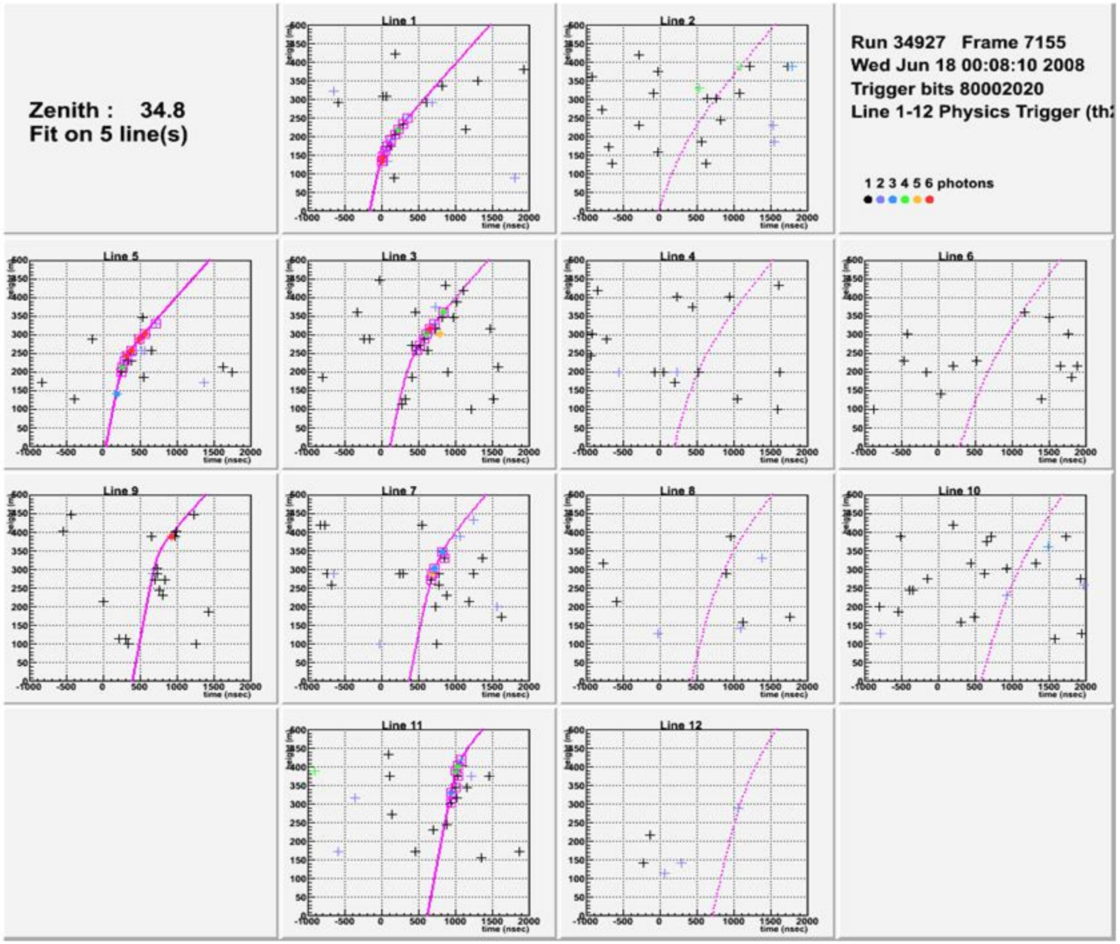
The ANTARES experiment



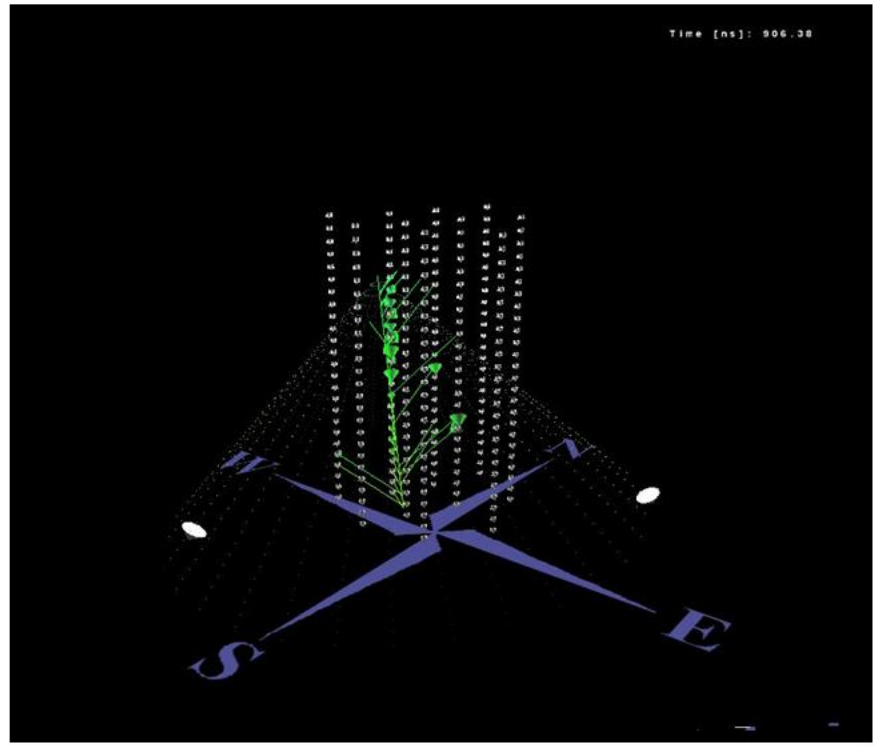
- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking PMTs, axis at 45º to vertical;
- 2475 m deep.

- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

Up-going track: a neutrino candidate

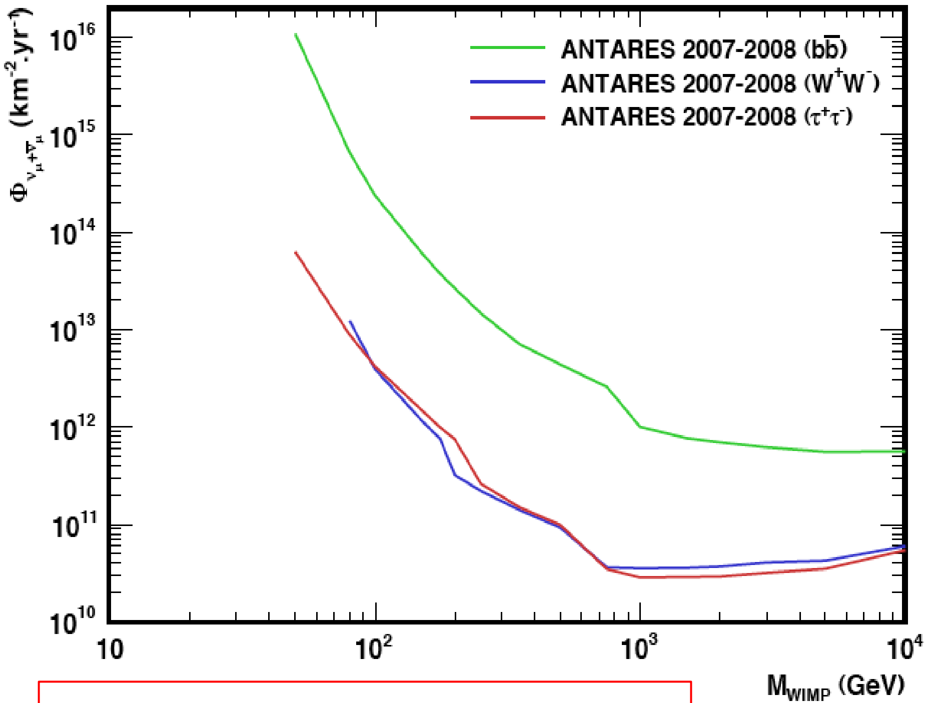


Example of a reconstructed up-going muon (i.e. a neutrino candidate) detected in 6/12 detector lines:

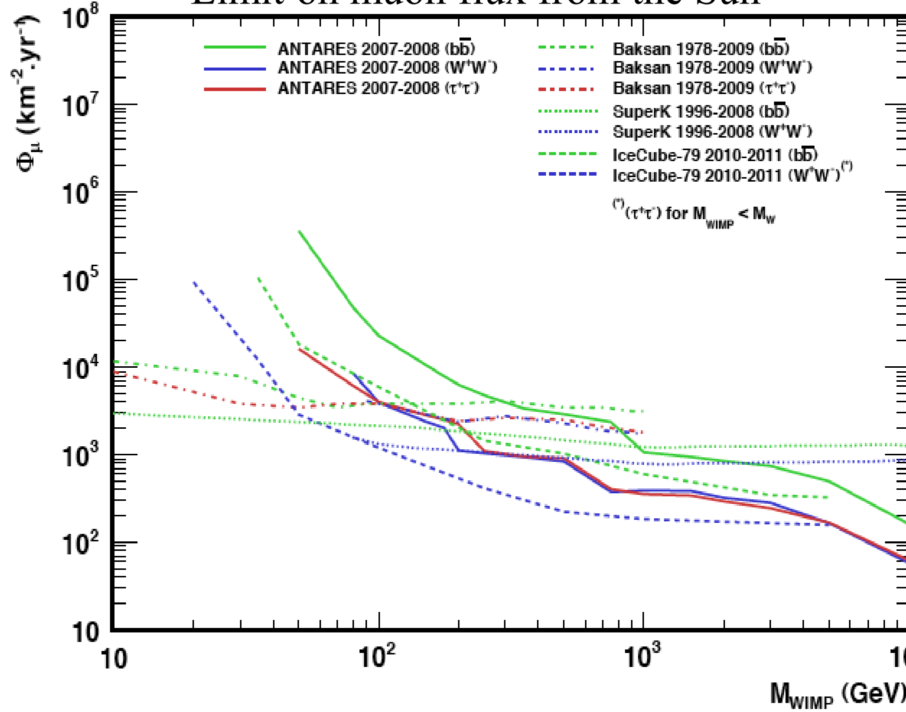


ANTARES: indirect search for Dark Matter

Limit on neutrino flux from the Sun



Limit on muon flux from the Sun



Differential neutrino flux is related with the annihilation rate as:

$$\frac{d\phi_\nu}{dE_\nu} = \frac{\Gamma}{4\pi d^2}\frac{dN_\nu}{dE_\nu},$$

If we assume equilibrium between capture and annihilation in the Sun:

$$\Gamma \simeq \frac{C_\otimes}{2}.$$

where the capture rate can be expressed as:

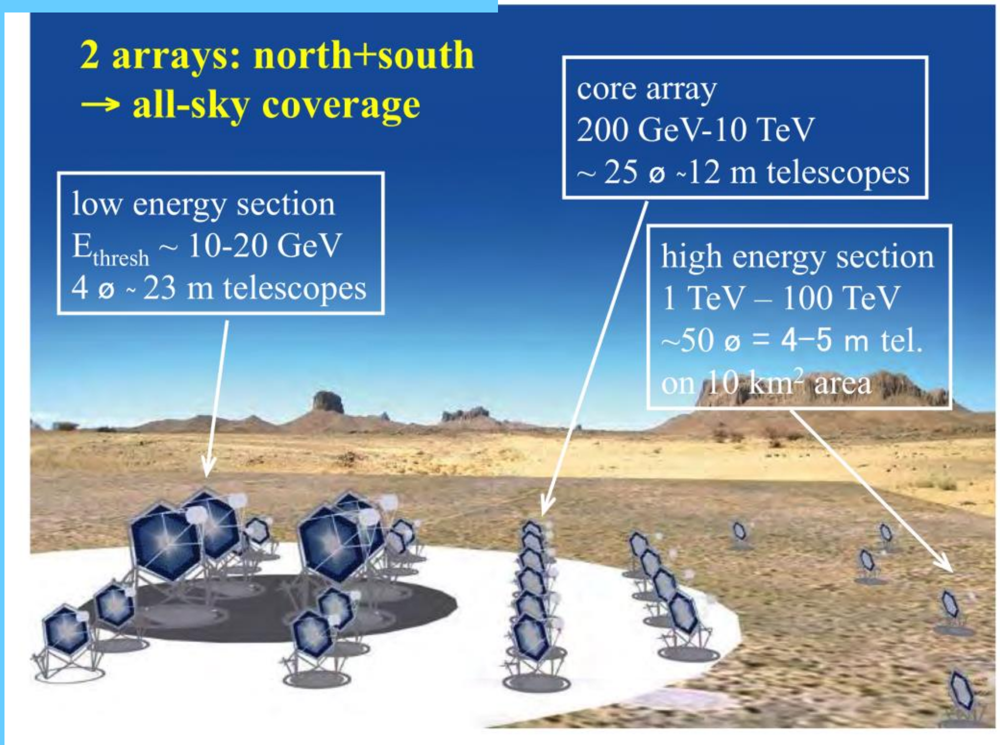
$$C_\otimes \simeq 3.35\times 10^{18}\mathrm{s}^{-1}\times\left(\frac{\rho_{\mathrm{local}}}{0.3\,GeV\cdot cm^{-3}}\right)\times \times\left(\frac{270\,\mathrm{km}\cdot\mathrm{s}^{-1}}{v_{\mathrm{local}}}\right)\times\left(\frac{\sigma_{H,SD}}{10^{-6}\,\mathrm{pb}}\right)\times\left(\frac{TeV}{M_{\mathrm{WIMP}}}\right)^2,$$

Analogous plots for neutrino flux from GC
See e.g. arXiv: 1312.4308 (contributions to ICRC2013)

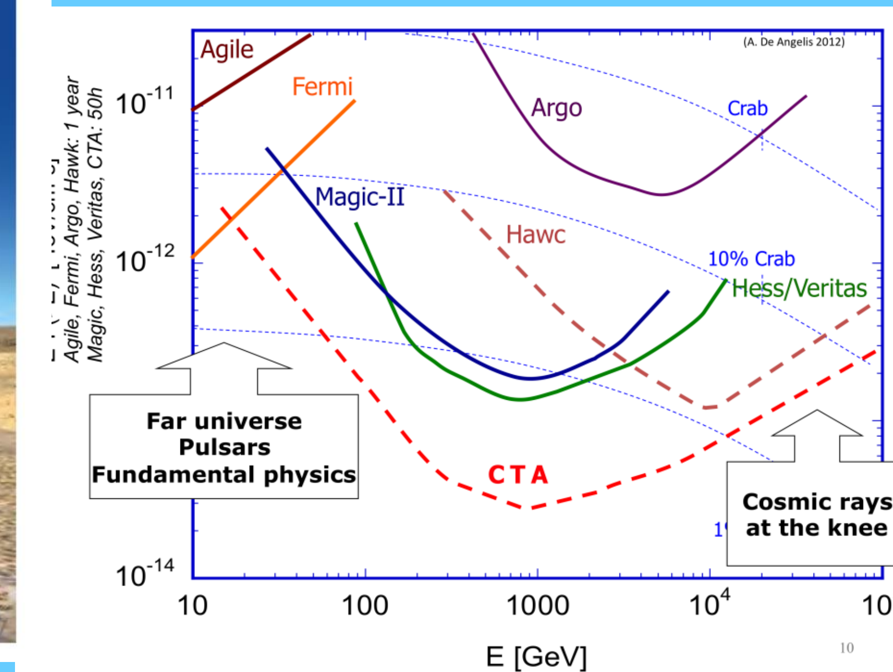
PROSPECTS of ANTARES: better statistics
In case of KM3: increased sensitivity depending on the final set-up

CTA

(a possible design)

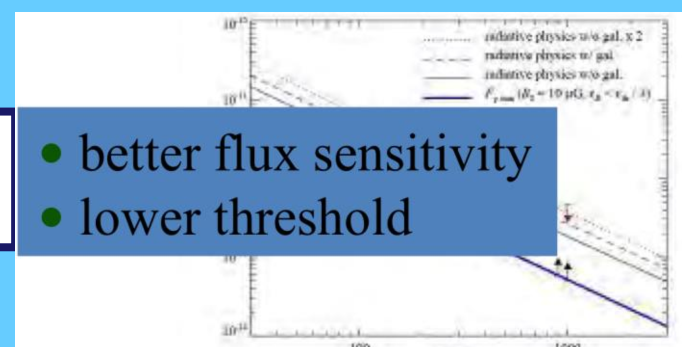


Fields of research: CR sources, photon propagation and more with better sensitivity



Possible sites: Tenerife, Namibia, Argentina, Arizona, Chile, Mexico

PROSPECTS for CTA:
New particles, new phenomena

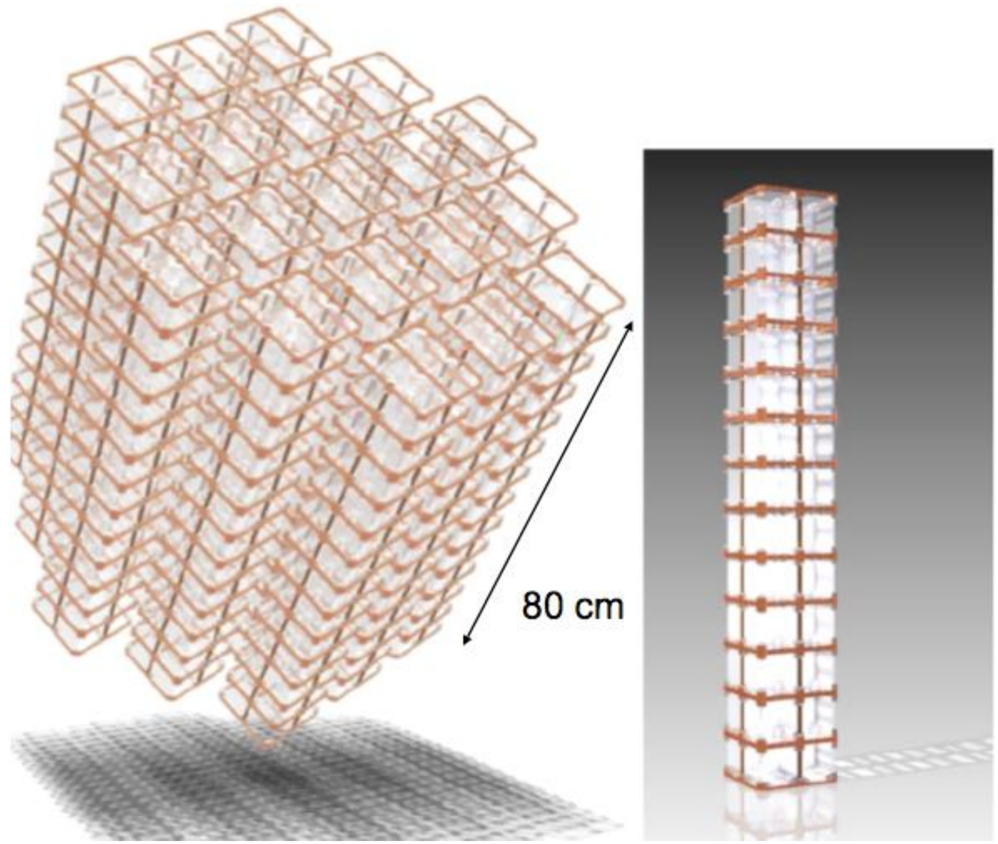


- better flux sensitivity
- lower threshold

CUORE

Bolometric experiment to search the neutrinoless double beta decay of ^{130}Te

- 988 TeO_2 crystals, 19 towers of 52 crystals each
- 750 g per crystal, 741 kg TeO_2
  - 592 kg Te (206 kg ^{130}Te)
  - 149 kg O
- Start data taking in 2015
- CUORE-0, the first CUORE tower started to take data in march 2013.



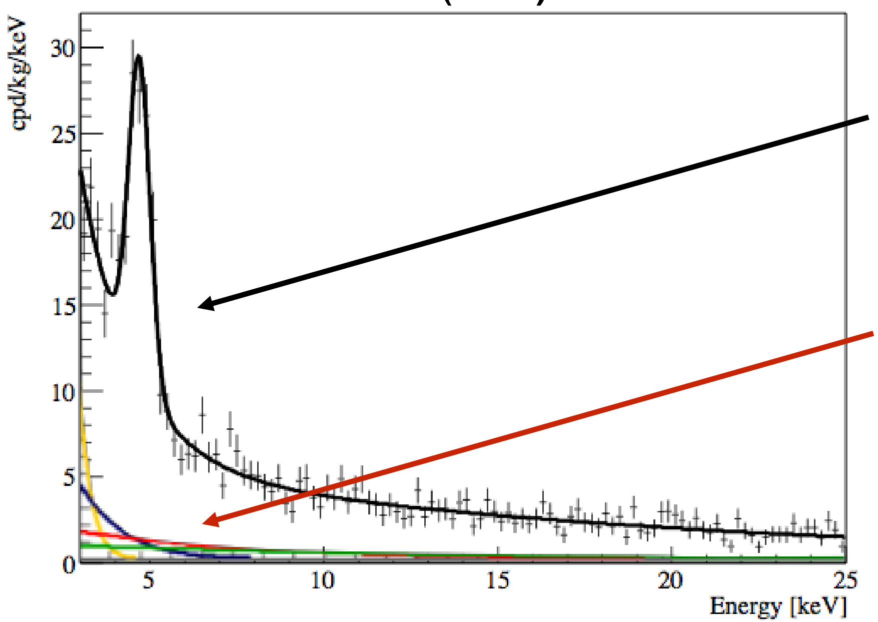
Hosted @ Laboratori Nazionali del Gran Sasso, Italy,
a natural shield of 1400 m of rock (equivalent vertical depth: 3100 m.w.e.)

Expected DM signal and bkg.

TeO_2 bolometers do not scintillate: the nuclear recoil identification via double readout (heat+light) is not possible:

- the only measurable signal is the annual modulation, à la DAMA.

JCAP 01 (2013) 038



Bkg at low energy as measured by a 4-bolometer test detector.

Expected signal from the DAMA result and the WIMP hypothesis.

The energy threshold is determined by the detector noise, which is dominated by vibrations of the detector.

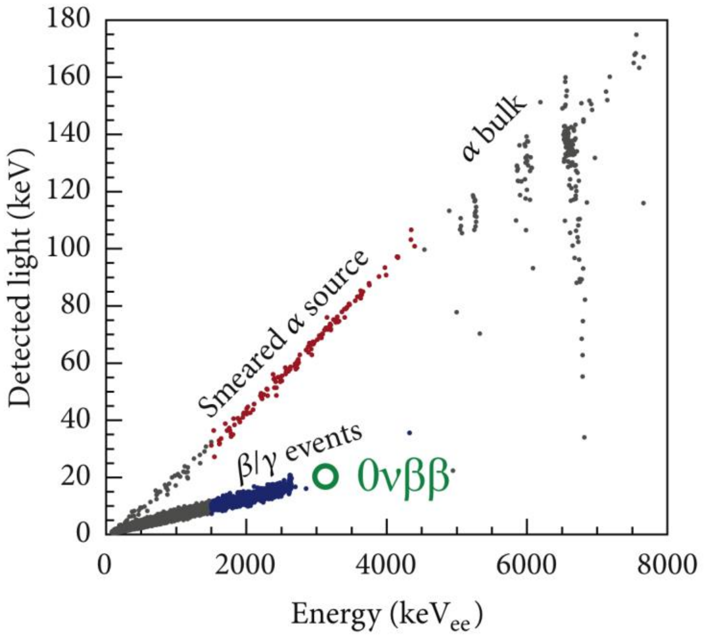
Noise optimization and low energy analysis ongoing in CUORE-0.

PROSPECTS of CUORE: Annual modulation investigation foreseen by the experiment. The CUORE sensitivity will depend on the noise seen, suitable stability etc.

LUCIFER

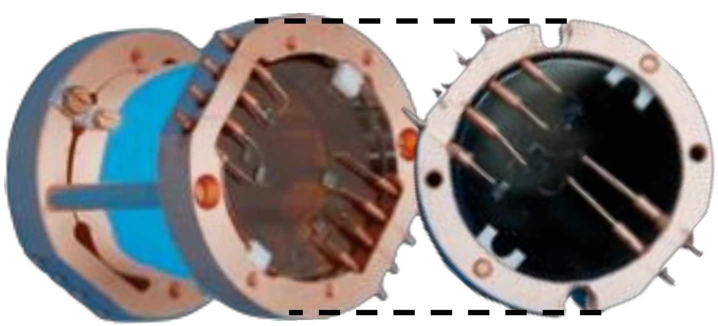
Bolometric experiment to search the neutrinoless double beta decay of ^{82}Se

- 36 crystals of $Zn^{82}Se$.
- 470 g per crystal, 17 kg ZnSe.
- Start data-taking: 2015.
- Unlike TeO_2, ZnSe scintillates, enabling particle ID via double read-out (heat+light).



High energy region (0νββ)

5cm

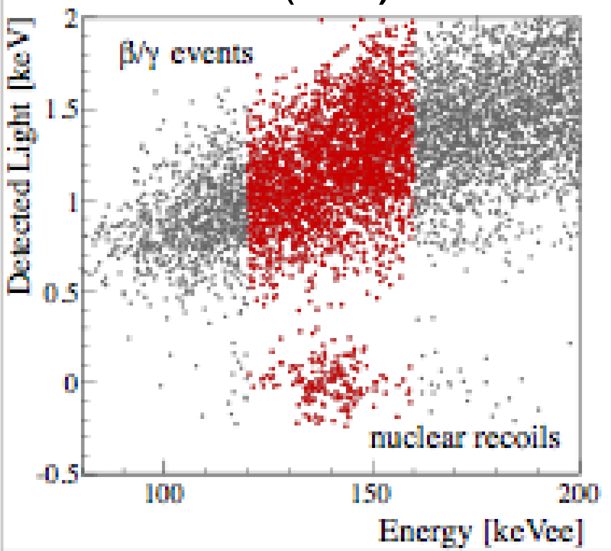


ZnSe bolometer surrounded by the light reflector

Light detector: germanium disk operated as bolometer

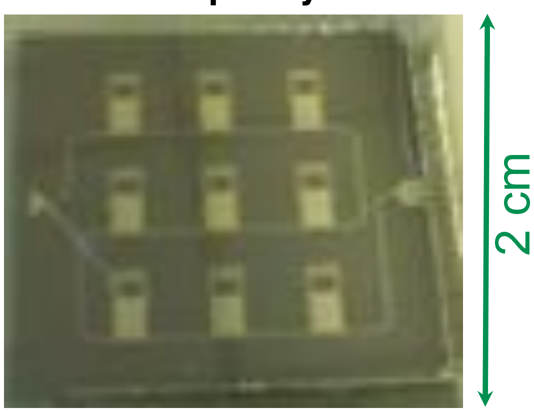
DM with LUCIFER (à la CRESST)

JINST 08 (2013) P05021



- WIMP Dark Matter induces nuclear recoils in the energy range 0-20 keV.
- Only 90 eV of light emitted by the β/γ background at 10 keV:
  - need light detectors with ΔE = 20 eV RMS, a factor 4-5 better than bolometers.

J. Low. Temp. Phys. 2014

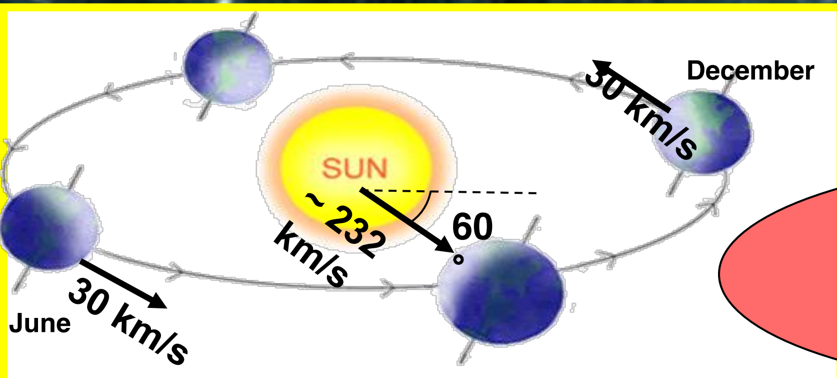


- R&D (CALDER, ERC granted) for new light detectors based on KIDs (Kinetic Inductance detectors). (c.f.r. Also RIC – INFN CSN5 – 2006-2009)
  - First prototypes with aluminum sensors work (we see pulses…).
  - Next step: new materials (TiN, NbSi,…) with high sensitivities.

A model independent signature is fundamental

A reliable technology to investigate a model independent signature:

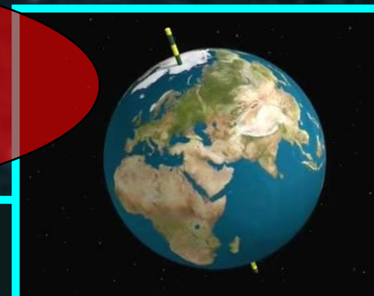
- High duty cycle
- Well controlled operational conditions
- Reproducibility (no re-purification procedures or cooling down/warming up)
- Long term stability
- Effective routine calibrations down to keV in the same conditions as production runs
- Sensitive to many candidates, interaction types and astrophysical, nuclear and particle physics scenarios



Annual modulation Annual variation of the interaction rate due to Earth motion around the Sun.

Fully model independent

Diurnal modulation Daily variation of the interaction rate due to Earth rotational velocity.



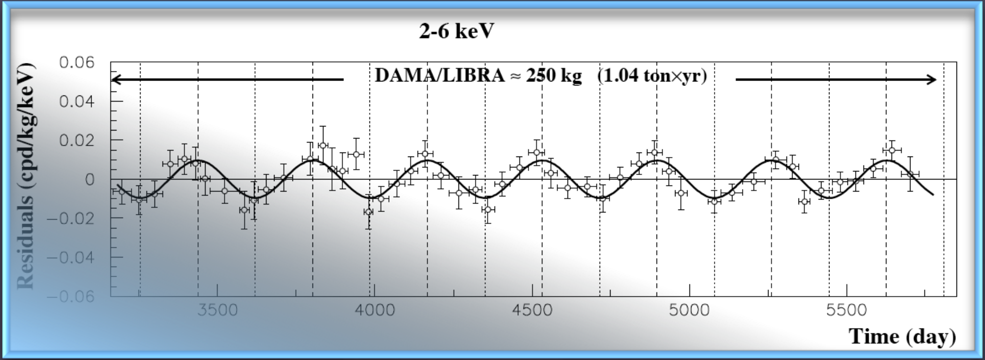
For some DM candidates

Directionality Correlation of Dark Matter impinging direction with Earth's galactic motion due to the distribution of Dark Matter particles velocities

Other investigations on diurnal modulation

Perspectives of DAMA/LIBRA

- Data of the 7 annual cycles of DAMA/LIBRA –phase1 released.
- Presence of annual modulation at 9.2σ C.L. in single hit events at (2-6) keV satisfying all the peculiarities of a DM signal and compatible with many scenarios (see talk P. Belli).



- DAMA/LIBRA upgrading to lower software energy threshold completed in 2010, new preamplifiers installed in 2012 and new electronics ready
- DAMA/LIBRA -phase2 in data taking
- Large exposure needed to deeper study the nature of the particles and features of related astrophysical, nuclear and particle physics aspects

- New investigation on dark matter peculiarities and second order effects
- Special data taking for other rare processes
- Possible a DAMA/LIBRA phase3
- Possible a DAMA/1 ton experiment (proposed since 1996)

INVESTIGATION OF POSSIBLE DIURNAL EFFECTS

- ✓ daily modulation on the sidereal time due to the Earth rotation velocity contribution
- ✓ daily effect on the sidereal time expected in case of DM candidates inducing nuclear recoils in anisotropic scintillator
- ✓ daily effect on the sidereal time expected in case of high cross section DM candidates (shadow of the Earth)
- ✓ daily effect on the sidereal time due to the channeling in case of DM candidates inducing nuclear recoils.

Phys.Atom.Nucl.72(2009) 2076,
ROM2F/2013/16 subm.
(N.Cim.15C(1992)475, EPJC28 (2003)203 +Int. Workshop IDM, World Sci. (1997)481,PLB571(2003) 132,NIMA496(2003)347, EPJC73(2013)2276)

PLB275(1992)181, N.Cim.A112(1999)1541

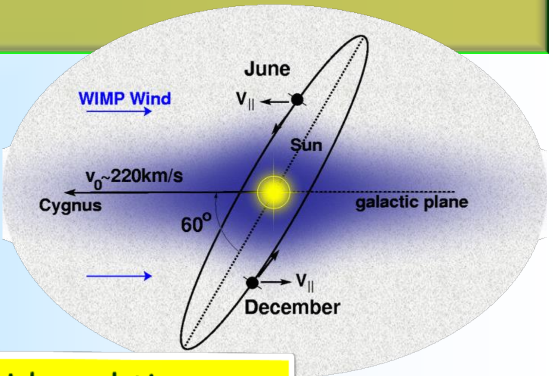
Eur. Phys. J.C53 (2008)205

An example: development of detectors with anisotropic response

Eur. Phys. J. C 73 (2013) 2276

Anisotropic detectors are of great interest for many applicative fields, e.g.:

⇒ they can offer a unique way to study directionality for Dark Matter candidates that induce nuclear recoils



Taking into account:

- the correlation between the direction of the nuclear recoils and the Earth motion in the galactic rest frame;
- the peculiar features of anisotropic detectors;

The detector response is expected to vary as a function of the sidereal time

Two strategies

Development of $ZnWO_4$ scintillators

✓ Both light output and pulse shape have anisotropic behavior and can provide two independent ways to study directionality

✓ Very high reachable radio-purity;

✓ Threshold at keV feasible;

Development of Carbon Nano Tubes (CNT) detectors

The detection principle is based on variation of the transport properties due to the particle irradiation

The intrinsic 1-D nature of CNTs makes them very promising for the study of directionality

➢ Spin-off and patents

➢ 3D detectors multi-wire chamber-like with nanotechnology

➢ Possible other applications:
  - Particle Physics;
  - Health Physics;
  - etc..

Heavy Neutral Leptons (HNL)@CERN SPS

CERN-SPSC-2013-024/SPSC-EOI-010
07/10/2013 (referee assigned)
Place: CERN - NA
Proposed schedule: 3-4 years construction
5 years data taking
https://cds.cern.ch/record/1606085/files/SPSC-EOI-010.pdf

Model νMSM: The three Standard Model ν have three right-handed partners (HNL) (N_i masses ~ 1 GeV) with some possible couplings to stardard ν.
N_1 sufficiently stable to be DM candidate, while N_2, N_3 could decay with very long lifetime.

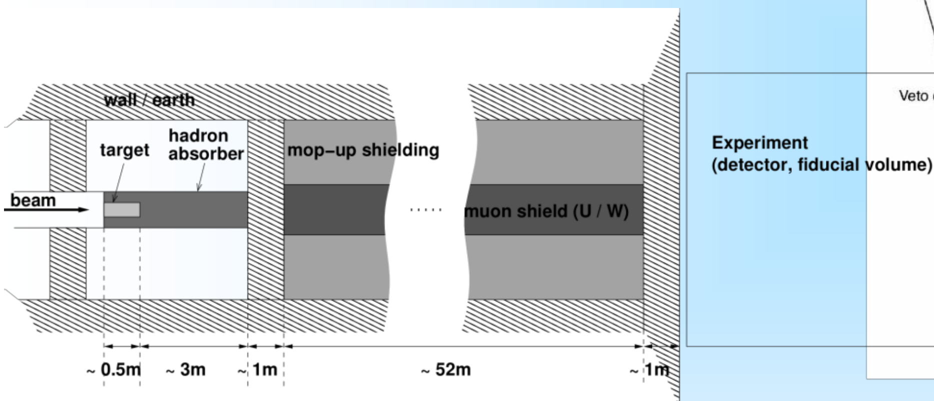


Figure 7: Schematic view of the target, hadron absorber and muon shield in front of the experiment. The total length from the target to the entrance of the fiducial volume is ~ 60 m.

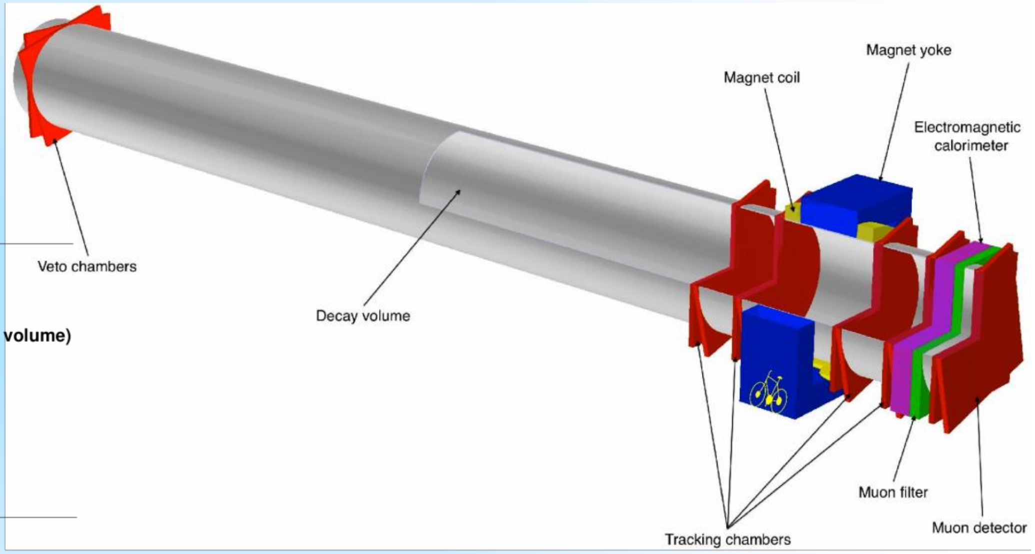


Figure 10: Three-dimensional sketch of the fiducial volume and detector arrangement.

PROPOSAL: fixed target, 400 GeV p beam of CERN SPS ($2x10^{20}$ p.o.t. within 5 years) + a hadron absorber, a muon shield, a decay volume and two magnetic spectrometers, a calorimeter, a muon detector
Apparatus to reconstruct exclusive NHL decays to measure NHL masses.

Conclusions

Activities:

- **DM investigation is challenging in all the research fields: astrophysics, cosmology, astroparticle physics, elementary particle physics.**
- **Many activities@INFN-ROMA are operative in the international framework (some will be presented in a second meeting).**
- **Complementary info from the different fields is fundamental**
- **The DAMA evidence is a benchmark**

Prospects:

- In cosmology: CMB peculiarities and experimental challenges
- In elementary particle physics: new frontier beyond the SM
- In indirect investigation: more info on DM annihilation products
- In direct investigation: signatures and peculiarities, low threshold
- In theoretical physics: creativity and freedom from paradigms
- In technological research: new frontier detectors

Thank you to our line II community for the fruitful discussions and the provided slides.

A second meeting will follow soon

on further DM topics