Status and Perspectives of DAMA/LIBRA

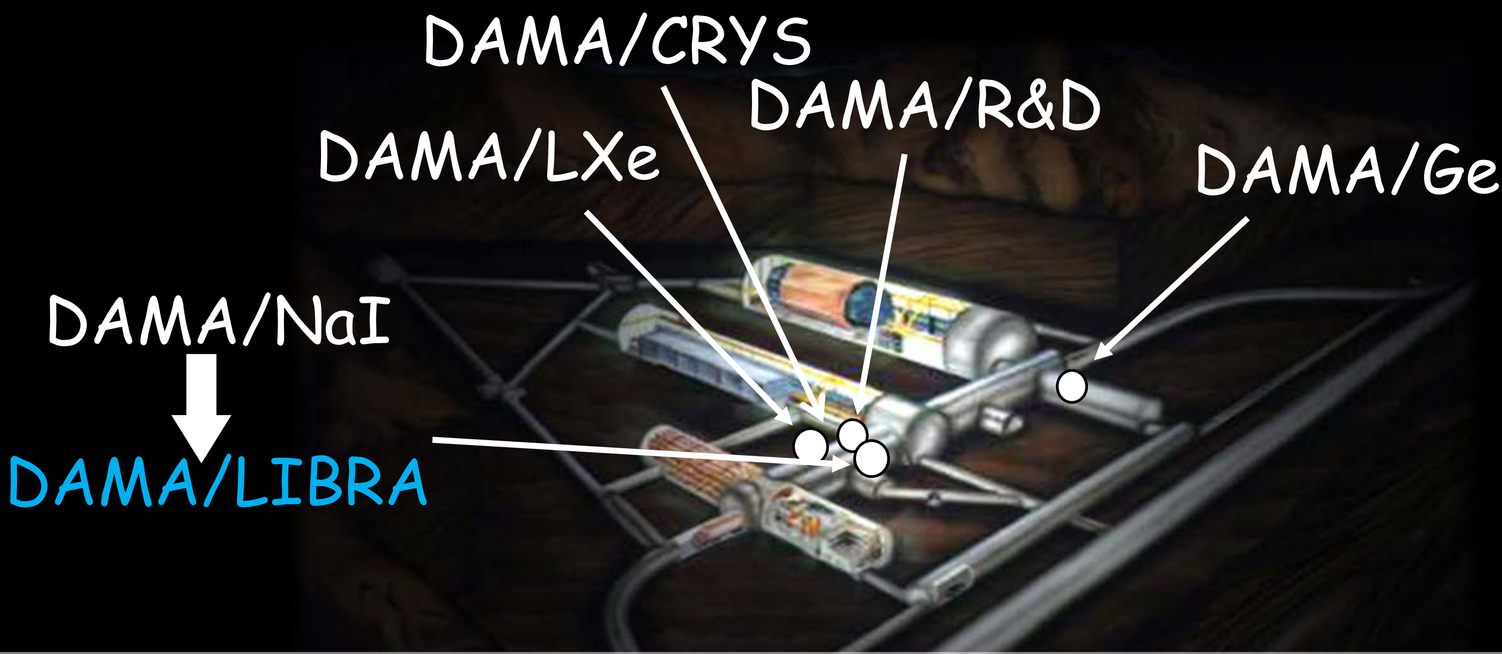
103º Congresso Nazionale della Società Italiana di Fisica

Trento, 11-15 Settembre 2017

Bernabei R., Belli P., d'Angelo S., Di Marco A., Montecchia F., d'Angelo A., Incicchitti A., Cappella F., Caracciolo V., Cerulli R., Dai C.J., He H.L., Kuang H.H., Ma X.H., Sheng X.D., Wang R.G., Ye Z.P.

DAMA Experimental Activities

DAMA Collaboration (spokesperson: prof. R. Bernabei):
Roma2, Roma1, LNGS-INFN, IHEP/Beijing
+ by-products and small scale expts.: INR-Kiev and others
+ neutron meas.: ENEA-Frascati e ENEA-Casaccia
+ in some studies on ββ decays (DST-MAE project): IIT Kharagpur/Ropar, India



DAMA: an observatory for rare processes @LNGS

http://people.roma2.infn.it/dama

Relic DM Particles from Primordial Universe

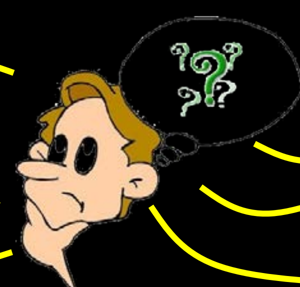
- SUSY (as neutralino or sneutrino In various scenarios)
- the sneutrino in the Smith and Weiner scenario
- sterile ν
- mirror dark matter
- invisible axions, ν's
- even a suitable particle not yet foreseen by theories
- axion-like (light pseudoscalar and scalar candidate)
- self-interacting dark matter
- electron interacting dark matter
- Kaluza-Klein particles (LKK)
- heavy exotic canditates, as "4th family atoms", ...
- Elementary Black holes, Planckian objects, Daemons
- etc...
- a heavy ν of the 4-th family

What Accelerators can do:
- to demonstrate the existence of some of the DM candidates

What Accelerators cannot do:
- to credit that a certain particle is a DM solution or the "only" DM particle solution...

+ DM candidates and scenarios exist (even for neutralino candidate) on which accelerators cannot give any information

&



- Composition? DM multicomponent also in the particle part?
- Right related nuclear and particle physics?
- etc... etc...
- Right halo model and parameters?
- Non thermalized components?
- Caustics?
- clumpiness?

Some Direct Detection Processes:

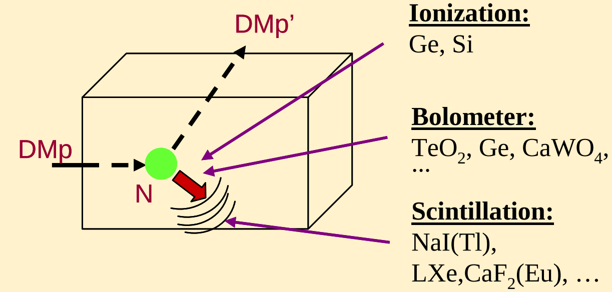
- Inelastic Dark Matter: W + N → W* + N

→ W has 2 mass states χ+ , χ- with d mass splitting

→ Kinematic constraint for the inelastic scattering of χ- on a nucleus

$$\frac{1}{2}\mu v^2 \geq \delta \Leftrightarrow v \geq v_{thr} = \sqrt{\frac{2\delta}{\mu}}$$

- Elastic scatterings on nuclei
→ detection of nuclear recoil energy

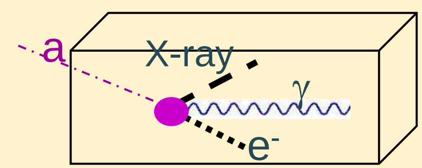


- Excitation of bound electrons in scatterings on nuclei

→ detection of recoil nuclei + e.m. radiation

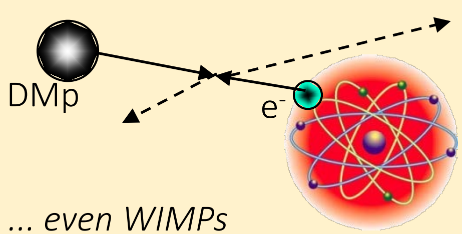
- **Conversion of particle into e.m. radiation**

→ detection of g, X-rays, e^-



- Interaction only on atomic electrons

→ detection of e.m. radiation

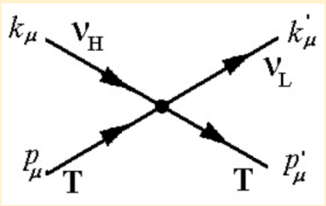


… even WIMPs

- Interaction of light DMp (LDM) on e^- or nucleus with production of a lighter particle

→ detection of electron/nucleus recoil energy

e.g. sterile ν



e.g. signals from these candidates are completely lost in experiments based on "rejection procedures" of the e.m. component of their rate

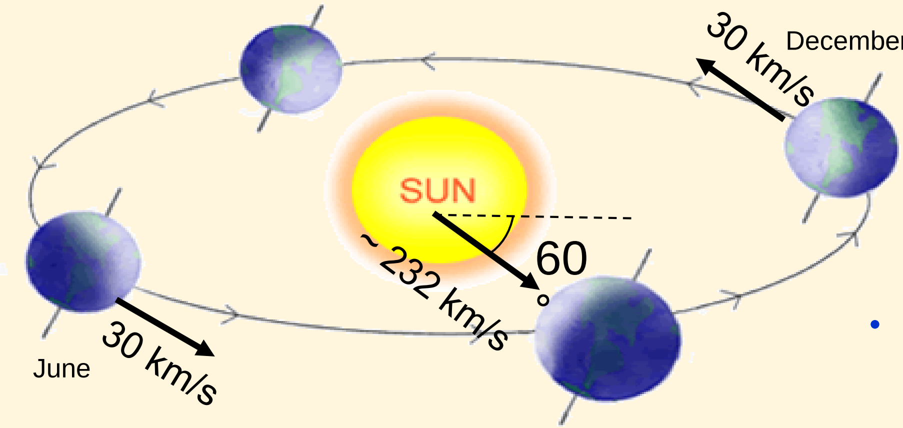
… also other ideas …

- … and more

The DM Annual Modulation: a Model Independent Signature to Investigate the DM Particles Component in the Galactic Halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions can point out its presence.

Drukier, Freese, Spergel PRD86; Freese et al. PRD88



- v_{sun} ~ 232 km/s (Sun vel in the halo)
- v_{orb} = 30 km/s (Earth vel around the Sun)
- $\gamma = \pi/3$, $\omega = 2\pi/T$, T = 1 year
- t_0 = 2nd June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb} \cos\gamma \cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

Requirements of the DM annual modulation

1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) Just for single hit events in a multi-detector set-up
6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

the DM annual modulation signature has a different origin and peculiarities (e.g. the phase) than those effects correlated with the seasons

To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

Complete DAMA/LIBRA-phase1

	Period	Mass (kg)	Exposure (kg×day)	$(\alpha - \beta^2)$
DAMA/LIBRA-1	Sept. 9, 2003 - July 21, 2004	232.8	51405	0.562
DAMA/LIBRA-2	July 21, 2004 - Oct. 28, 2005	232.8	52597	0.467
DAMA/LIBRA-3	Oct. 28, 2005 - July 18, 2006	232.8	39445	0.591
DAMA/LIBRA-4	July 19, 2006 - July 17, 2007	232.8	49377	0.541
DAMA/LIBRA-5	July 17, 2007 - Aug. 29, 2008	232.8	66105	0.468
DAMA/LIBRA-6	Nov. 12, 2008 - Sept. 1, 2009	242.5	58768	0.519
DAMA/LIBRA-7	Sep. 1, 2009 - Sept. 8, 2010	242.5	62098	0.515
DAMA/LIBRA–phase1	Sept. 9, 2003 - Sept. 8, 2010		379795 ≃ 1.04 ton×yr	0.518
DAMA/NaI + DAMA/LIBRA–phase1:			1.33 ton×yr	

- EPJC56(2008)333
- EPJC67(2010)39
- EPJC73(2013)2648

- calibrations: ≈96 Mevents from sources
- acceptance window eff: 95 Mevents (≈3.5 Mevents/keV)

a ton × yr experiment? done

DAMA/LIBRA-phase1:

- First upgrade on Sept 2008: replacement of some PMTs in HP N_2 atmosphere, new Digitizers (U1063A Acqiris 1GS/s 8-bit High-speed cPCI), new DAQ system with optical read-out installed

DAMA/LIBRA-phase2 (running):

- Second upgrade at end 2010: replacement of all the PMTs with higher Q.E. ones from dedicated developments
- commissioning on 2011

Goal: lowering the software energy threshold

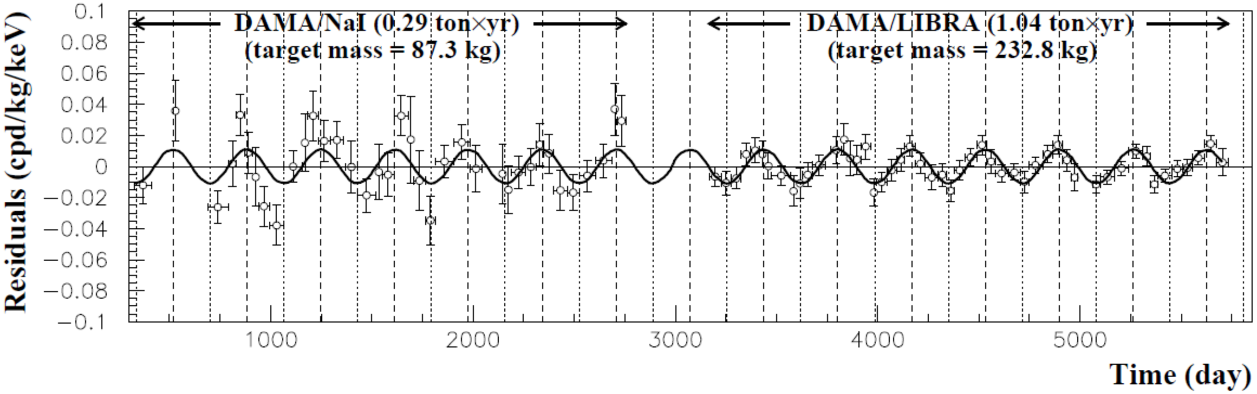
- Fall 2012: new preamplifiers installed + special trigger modules. Other new components in the electronic chain in development

Model Independent Annual Modulation Result

DAMA/NaI + DAMA/LIBRA-phase1 Total exposure: 487526 kg×day = **1.33 ton×yr**

Single-hit residuals rate of scintillation events *vs* time in 2-6 keV

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



continuous line: t_0 = 152.5 d, T =1.0 y

A=(0.0110±0.0012) cpd/kg/keV

χ^2/dof = 70.4/86 9.2 σ C.L.

Absence of modulation? No

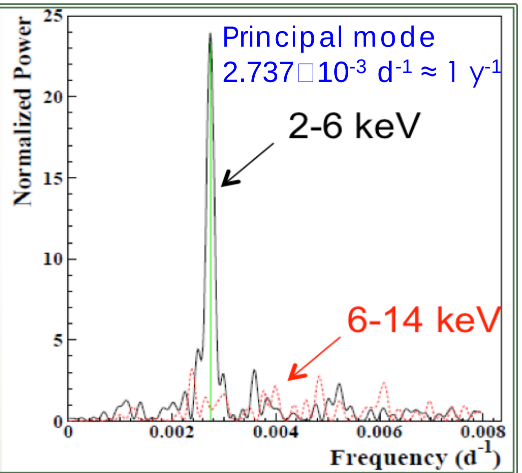
χ^2/dof=154/87 P(A=0) = 1.3×10^{-5}

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

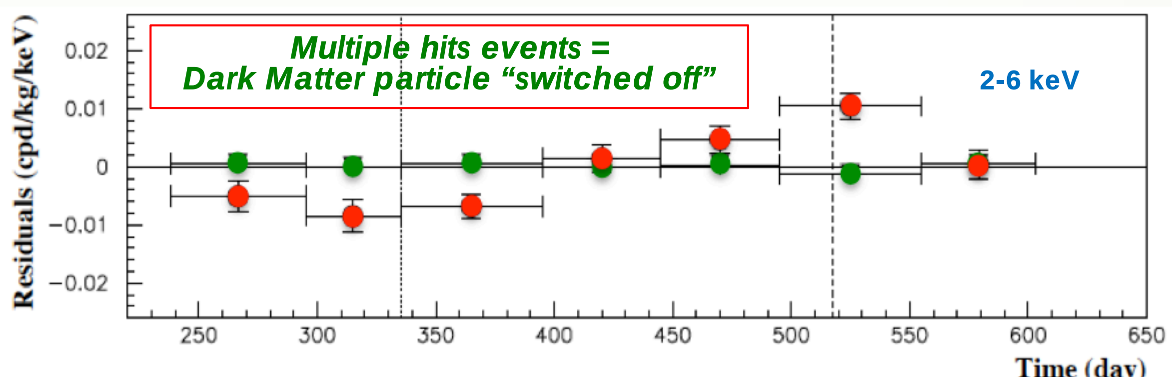
Power spectrum



No systematics or side reaction able to account for the measured modulation amplitude and to satisfy all the peculiarities of the signature

Comparison between **single hit residual rate (red points)** and **multiple hit residual rate (green points)**; Clear modulation in the single hit events; No modulation in the residual rate of the multiple hit events

A=-(0.0005±0.0004) cpd/kg/keV



This result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background

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.

Summary of the results obtained in the additional investigations of possible systematics or side reactions – DAMA/LIBRA-phase1

(NIMA592(2008)297, EPJC56(2008)333, J. Phys. Conf. ser. 203(2010)012040, arXiv:0912.0660, S.I.F.Atti Conf.103(211), Can. J. Phys. 89 (2011) 11, Phys.Proc.37(2012)1095, EPJC72(2012)2064, arxiv:1210.6199 & 1211.6346, IJMPA28(2013)1330022, EPJC74(2014)3196)

Source	Main comment	Cautious upper limit (90%C.L.)
RADON	Sealed Cu box in HP Nitrogen atmosphere, 3-level of sealing, etc.	$<2.5\times10^{-6}$ cpd/kg/keV
TEMPERATURE	Installation is air conditioned+ detectors in Cu housings directly in contact with multi-ton shield→ huge heat capacity + T continuously recorded	$<10^{-4}$ cpd/kg/keV
NOISE	Effective full noise rejection near threshold	$<10^{-4}$ cpd/kg/keV
ENERGY SCALE	Routine + intrinsic calibrations	$<1\text{-}2\times10^{-4}$ cpd/kg/keV
EFFICIENCIES	Regularly measured by dedicated calibrations	$<10^{-4}$ cpd/kg/keV
BACKGROUND	No modulation above 6 keV; no modulation in the (2-6) keV *multiple-hits* events; this limit includes all possible sources of background	$<10^{-4}$ cpd/kg/keV
SIDE REACTIONS	Muon flux variation measured at LNGS	$<3\times10^{-5}$ cpd/kg/keV

+ they cannot satisfy all the requirements of annual modulation signature

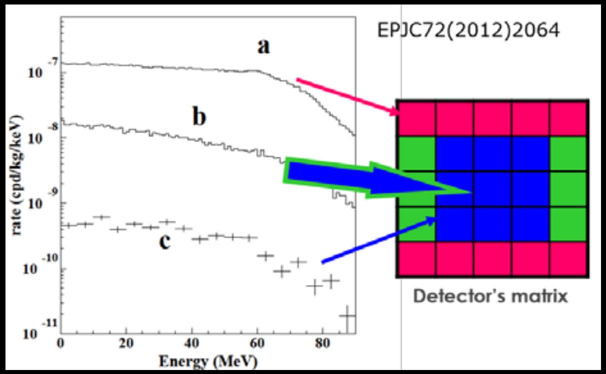
→ Thus, they cannot mimic the observed annual modulation effect

No role for μ in DAMA annual modulation result

✓ **Direct μ interaction in DAMA/LIBRA set-up:**

DAMA/LIBRA surface ≈0.13 m^2
m flux @ DAMA/LIBRA ≈2.5 μ/day

It cannot mimic the signature: already excluded by R_{90}, by *multi-hits* analysis + different phase, etc.



$S_m^{(m)} < (0.3\text{-}2.4) \times 10^{-5}$ cpd/kg/keV

✓ **Rate, R_n, of fast neutrons produced by μ:**

- Φ_μ @ LNGS ≈ 20 μ $m^{-2}d^{-1}$ (±1.5% modulated)
- Annual modulation amplitude at low energy due to **m modulation**:

$$S_m^{(m)} = R_n\, g\, e\, f_{DE}\, f_{single}\, 2\% /(M_{setup}\, DE)$$

Moreover, this modulation also induces a variation in other parts of the energy spectrum and in the *multi-hits* events

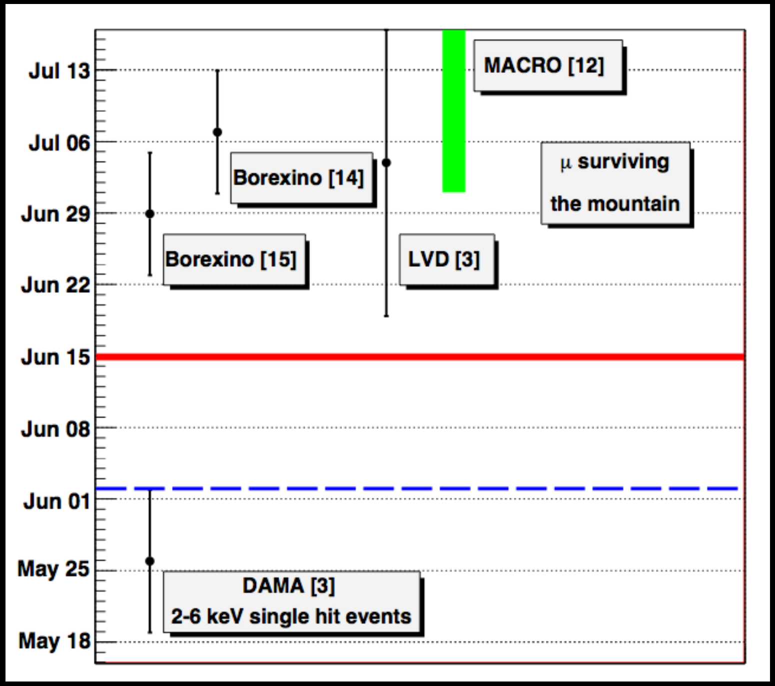
It cannot mimic the signature: already excluded by R_{90}, by *multi-hits* analysis + different phase, etc.

✓ **Inconsistency of the phase between DAMA signal and m modulation**

μ flux @ LNGS (MACRO, LVD, BOREXINO) ≈$3\cdot10^{-4}$ $m^{-2}s^{-1}$; modulation amplitude 1.5%; **phase**: July 7 ± 6 d, June 29 ± 6 d (Borexino)

The DAMA phase: May 26 ± 7 days (stable over 14 years)

The DAMA phase is 5.7σ far from the LVD/BOREXINO phases of muons (7.1 σ far from MACRO measured phase)



… many others arguments EPJC72(2012)2064, EPJC74(2014)3196

No role for n/μ/ν in DAMA annual modulation result

- Contributions to the total neutron flux at LNGS; → $\Phi_k = \Phi_{0,k}\left(1 + \eta_k cos\omega\left(t - t_k\right)\right)$
- Counting rate in DAMA/LIBRA for *single-hit* events, in the (2 – 6) keV energy region induced by: → $R_k = R_{0,k}\left(1 + \eta_k cos\omega\left(t - t_k\right)\right)$
  - neutrons,
  - muons,
  - solar neutrinos.

(See e.g. also EPJC 56 (2008) 333, EPJC 72(2012) 2064, IJMPA 28 (2013) 1330022) EPJC74(2014)3196

Modulation amplitudes

Source		$\Phi^{(n)}_{0,k}$ (neutrons cm^{-2} s^{-1})	η_k	t_k	$R_{0,k}$ (cpd/kg/keV)		$A_k = R_{0,k}\eta_k$ (cpd/kg/keV)	A_k/S_m^{exp}
SLOW neutrons	thermal n ($10^{-2} - 10^{-1}$ eV)	1.08×10^{-6} [15]	$\simeq 0$ however $\ll 0.1$ [2, 7, 8]	–	$< 8 \times 10^{-6}$	[2, 7, 8]	$\ll 8 \times 10^{-7}$	$\ll 7 \times 10^{-5}$
	epithermal n (eV-keV)	2×10^{-6} [15]	$\simeq 0$ however $\ll 0.1$ [2, 7, 8]	–	$< 3 \times 10^{-3}$	[2, 7, 8]	$\ll 3 \times 10^{-4}$	$\ll 0.03$
FAST neutrons	fission, $(\alpha, n) \to$ n (1-10 MeV)	$\simeq 0.9 \times 10^{-7}$ [17]	$\simeq 0$ however $\ll 0.1$ [2, 7, 8]	–	$< 6 \times 10^{-4}$	[2, 7, 8]	$\ll 6 \times 10^{-5}$	$\ll 5 \times 10^{-3}$
	$\mu \to$ n from rock (> 10 MeV)	$\simeq 3 \times 10^{-9}$ (see text and ref. [12])	0.0129 [23]	end of June [23, 7, 8]	$\ll 7 \times 10^{-4}$	(see text and [2, 7, 8])	$\ll 9 \times 10^{-6}$	$\ll 8 \times 10^{-4}$
	$\mu \to$ n from Pb shield (> 10 MeV)	$\simeq 6 \times 10^{-9}$ (see footnote 3)	0.0129 [23]	end of June [23, 7, 8]	$\ll 1.4 \times 10^{-3}$	(see text and footnote 3)	$\ll 2 \times 10^{-5}$	$\ll 1.6 \times 10^{-3}$
	$\nu \to$ n (few MeV)	$\simeq 3 \times 10^{-10}$ (see text)	0.03342 *	Jan. 4th *	$\ll 7 \times 10^{-5}$	(see text)	$\ll 2 \times 10^{-6}$	$\ll 2 \times 10^{-4}$
	direct μ	$\Phi^{(\mu)}_0 \simeq 20\ \mu$ m^{-2}d^{-1} [20]	0.0129 [23]	end of June [23, 7, 8]	$\simeq 10^{-7}$	[2, 7, 8]	$\simeq 10^{-9}$	$\simeq 10^{-7}$
	direct ν	$\Phi^{(\nu)}_0 \simeq 6 \times 10^{10}\ \nu$ cm^{-2}s^{-1} [26]	0.03342 *	Jan. 4th *	$\simeq 10^{-5}$	[31]	3×10^{-7}	3×10^{-5}

* The annual modulation of solar neutrino is due to the different Sun-Earth distance along the year; so the relative modulation amplitude is twice the eccentricity of the Earth orbit and the phase is given by the perihelion.

+ In no case neutrons (of whatever origin), muon or muon induced events, solar ν can mimic the DM annual modulation signature since some of the **peculiar requirements of the signature** would fail (and – in addition - quantitatively negligible amplitude with respect to the measured effect).

All are negligible w.r.t. the annual modulation amplitude observed by DAMA/LIBRA and they cannot contribute to the observed modulation amplitude.

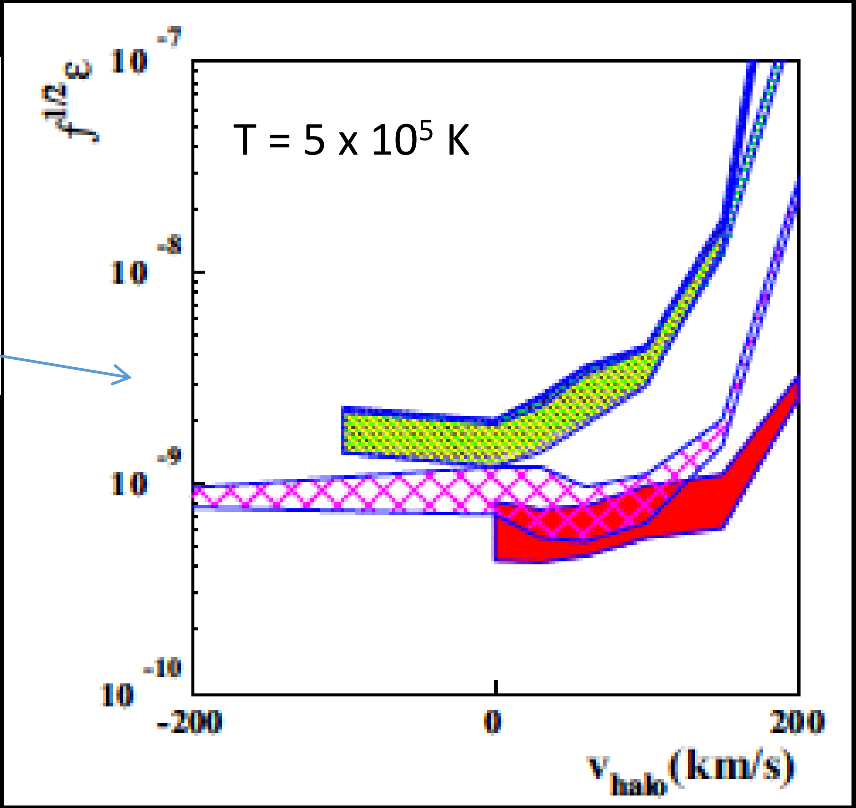
An example: the most recent corollary analysis: DAMA annual modulation effect and Symmetric mirror matter

Symmetric mirror matter:

Eur. Phys. J. C (2017) 77

- halo composed by a bubble of Mirror particles of different species; Sun is travelling across the bubble which is moving in the Galactic Frame (GF);
- the mirror particles in the bubble have Maxwellian velocity distribution in a frame where the bubble is at rest; cold and hot bubble with temp from 10^4 K to 10^8 K
- interaction via photon - mirror photon kinetic mixing

Mirror matter composition	H (%)	He (%)	C (%)	O (%)	Fe (%)
H′, He′	25	75	–	–	–
H′, He′, C′, O′	12.5	75.	7.	5.5	–
H′, He′, C′, O′, Fe′	20	74	0.9	5.	0.1

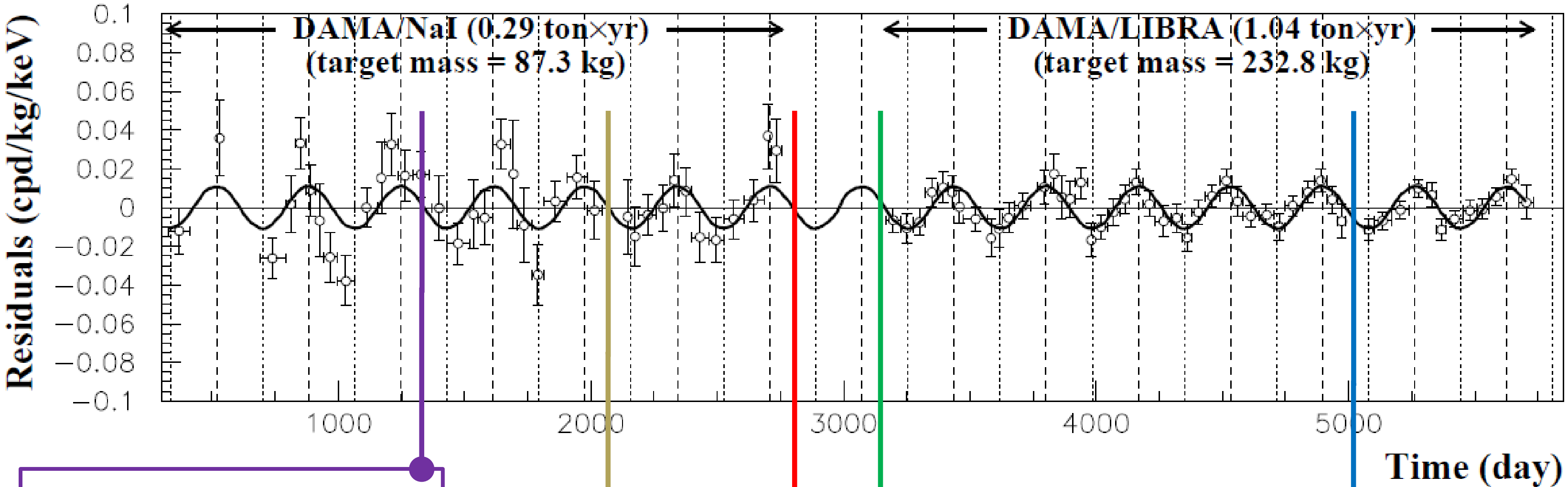


DAMA/LIBRA allowed values for √fε in different scenarios

coupling const. and DM fraction as mirror atom

Many configurations and halo models favoured by the DAMA annual modulation effect corresponds to couplings values well compatible with cosmological bounds.

DAMA/NaI & DAMA/LIBRA experiments main upgrades and improvements



PHASE2

Minimal upgrade in Fall

July 2000 new DAQ and new electronic chain installed (MULTIPLEXER removed, now one TD channel for each detector):

(i) TD VXI Tektronix;

(ii) Digital Unix DAQ system;

(iii) GPIB-CAMAC.

July 2002 DAMA/NaI data taking completed

On 2003 DAMA/LIBRA has begun first operations

Sept.-Oct. 2008 – DAMA/LIBRA upgrade:

① one detector recovered by replacing a broken PMT

② a new optimization of some PMTs and HVs performed

③ all the TD replaced with new ones (U1063A Acqiris 8-bit 1GS/s DC270 High-Speed cPCI Digitizers)

④ a new DAQ with optical read-out installed.

The second DAMA/LIBRA upgrade in Fall 2010:
Replacement of all the PMTs with higher Q.E. ones from dedicated developments
(+new preamp in Fall 2012 and other developments in progress)

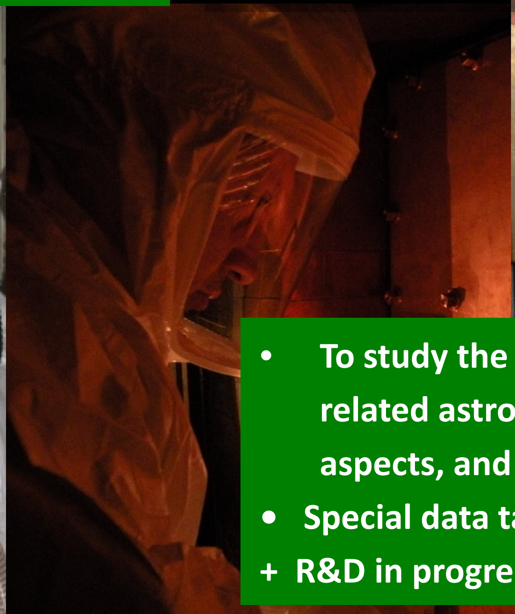
DAMA/LIBRA-phase2 *in data taking*

DAMA/LIBRA – phase2

After a period of tests and optimizations in data taking in this new configuration

Second upgrade on Nov/Dec 2010: all PMTs replaced with new ones of higher Q.E.

typically
DAMA/LIBRA-phase1: 5.5-7.5 ph.e./keV
→ DAMA/LIBRA-phase2: 6-10 ph.e./keV

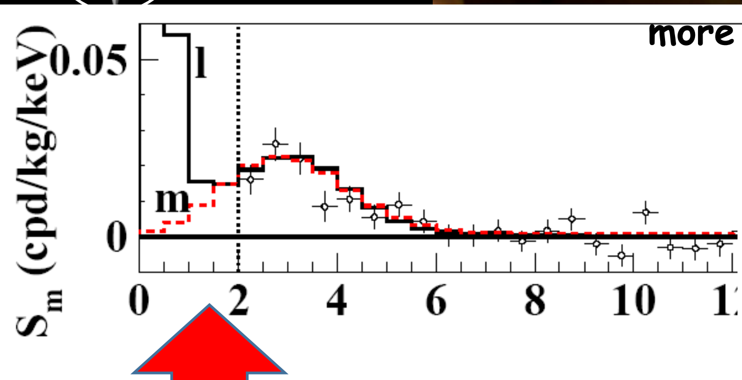


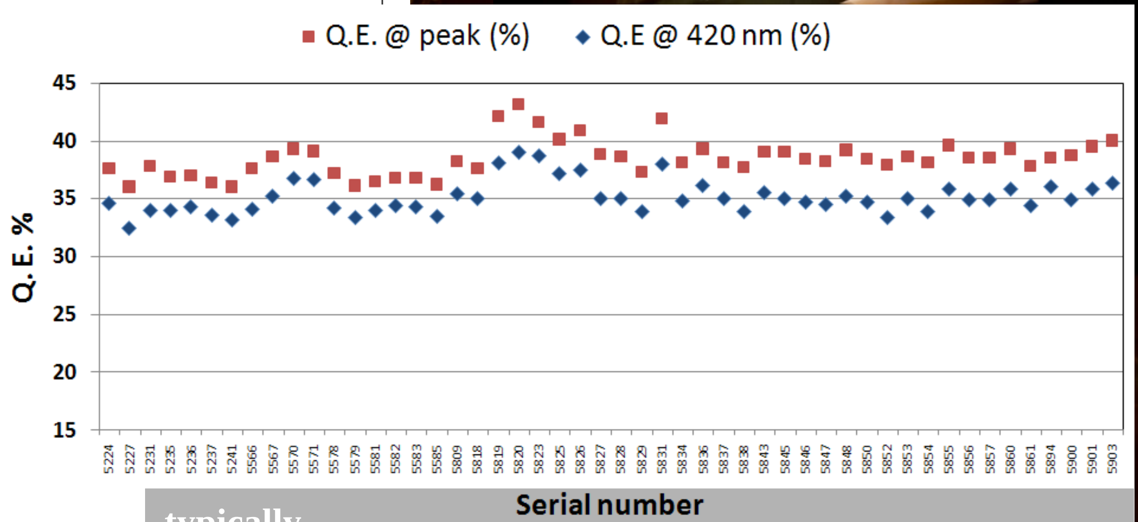
- To study the nature of the particles and features of related astrophysical, nuclear and particle physics aspects, and to investigate second order effects
- Special data taking for other rare processes

\+ R&D in progress towards more future phase3

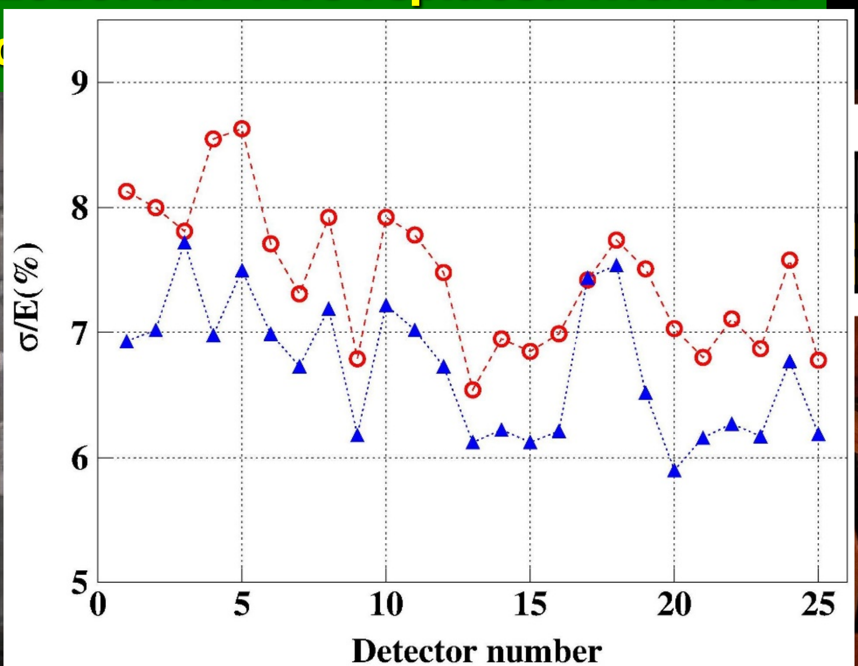
DAMA/LIBRA – phase2

After a period of tests and optimizations in data taking in this new configuration





Second upgrade on Nov/Dec 2010: all PMTs replaced with



typically
DAMA/LIBRA-phase1: 5.5-7.5 ph.e./keV
→ DAMA/LIBRA-phase2: 6-10 ph.e./keV

^{234m}Pa (Bq/kg)	^{235}U (mBq/kg)	^{228}Ra (Bq/kg)	^{228}Th (mBq/kg)	^{40}K (Bq/kg)	^{137}Cs (mBq/kg)	^{60}Co (mBq/kg)
-	47	0.12	83	0.54	-	-
-	10	0,02	17	0.16	-	-

- To study the nature of the particles and features of related astrophysical, nuclear and particle physics aspects, and to investigate second order effects
- Special data taking for other rare processes

+ R&D in progress towards more future phase3

DAMA/LIBRA phase 2 – data taking

Second upgrade at end of 2010:
all PMTs replaced with new ones of higher Q.E.

JINST 7(2012)03009

Energy resolution mean value: prev. PMTs 7.5% (0.6% RMS)
new HQE PMTs 6.7% (0.5% RMS)

- ✓ Fall 2012: new preamplifiers installed + special trigger modules.
- ✓ Calibrations 5 a.c.: ~ 1.03 x 10^8 events from sources
- ✓ Acceptance window eff. 5 a.c.: ~ 7 x 10^7 events (~ 2.8 x 10^6 events/keV)
- ✓ Exposure collected in the first 5 a.c. of DAMA/LIBRA-phase2: **0.92 ton x yr**

Annual Cycles	Period	Mass (kg)	Exposure (kg · day)	$(\alpha - \beta^2)$
1	Dec 2010 – Sept. 2011		Commissioning	
2	Nov. 2, 2011 – Sept. 11, 2012	242.5	62917	0.519
3	Oct. 8, 2012 – Sept. 2, 2013	242.5	60586	0.534
4	Sept. 8, 2013 – Sept. 1, 2014	242.5	73792	0.479
5	Sept. 1, 2014 – Sept. 9, 2015	242.5	71180	0.486
6	Sept. 10, 2015 – Aug. 24, 2016	242.5	67527	0.522
7	Sept 2016 –	242.5	running	

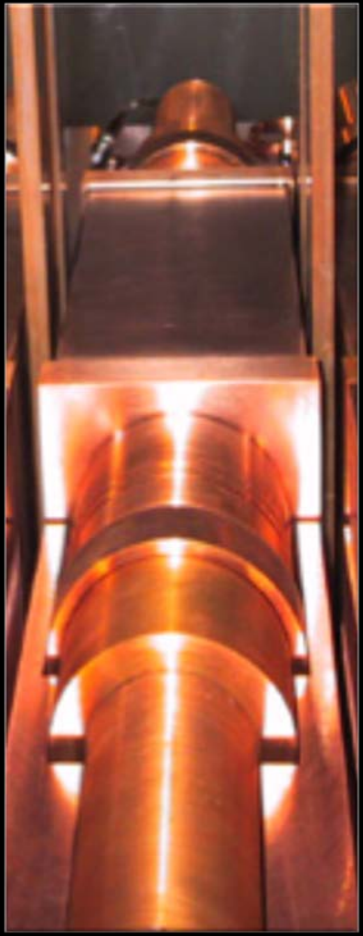
PRELIMINARY

Exposure expected for the first data release of DAMA/LIBRA-phase2, 6 a.c.: ≈ 1.1 ton x yr

Possible DAMA/LIBRA-phase3

- The light collection of the detectors can further be improved
- Light yields and the energy thresholds will improve accordingly

The strong interest in the low energy range suggests the possibility of a new development of **high Q.E. PMTs** with **increased radiopurity** to directly couple them to the DAMA/LIBRA crystals, **removing** the special radio-pure quartz (Suprasil B) light guides (10 cm long), which act also as optical window.



The presently-reached PMTs features:

- Q.E. around 35-40% @ 420 nm (NaI(Tl) light)
- radiopurity at level of 5 mBq/PMT (^{40}K), 3-4 mBq/PMT (^{232}Th), 3-4 mBq/PMT (^{238}U), 1 mBq/PMT (^{226}Ra), 2 mBq/PMT (^{60}Co).

R&D efforts to obtain PMTs matching the best performances… feasible

No longer need for light guides (a 30-40% improvement in the light collection is expected) → difficult protocols to remove them, which act also as optical windows of the detectors

Other signatures?

- *Second order effects*
- *Diurnal effects*
- *Shadow effects*
- *Directionality*
- *…*

Diurnal effects

A diurnal effect with the sidereal time is expected for DM because of Earth rotation

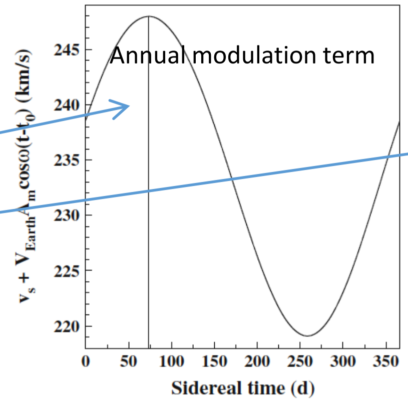
EPJC 74 (2014) 2827

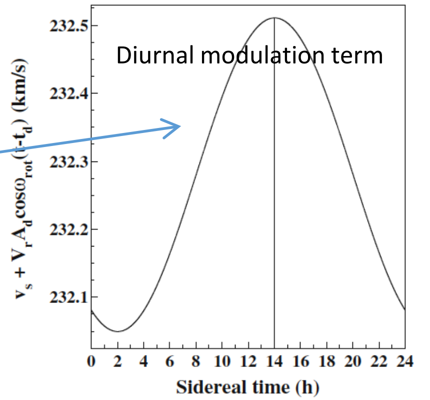
Velocity of the detector in the terrestrial laboratory: $\vec{v}_{lab}(t) = \vec{v}_{LSR} + \vec{v}_{\odot} + \vec{v}_{rev}(t) + \vec{v}_{rot}(t),$

Since:

- $|\vec{v}_s| = |\vec{v}_{LSR} + \vec{v}_{\odot}| \approx 232 \pm 50\ \mathrm{km/s},$
- $|\vec{v}_{rev}(t)| \approx 30\ \mathrm{km/s}$
- $|\vec{v}_{rot}(t)| \approx 0.34\ \mathrm{km/s}$ at LNGS

$$v_{lab}(t) \simeq v_s + \hat{v}_s \cdot \vec{v}_{rev}(t) + \hat{v}_s \cdot \vec{v}_{rot}(t).$$





Expected signal counting rate in a given k–th energy bin:

$$S_k\left[v_{lab}(t)\right] \simeq S_k\left[v_s\right] + \left[\frac{\partial S_k}{\partial v_{lab}}\right]_{v_s}\left[V_{Earth} B_m \cos\omega(t-t_0) + V_r B_d \cos\omega_{rot}(t-t_d)\right]$$

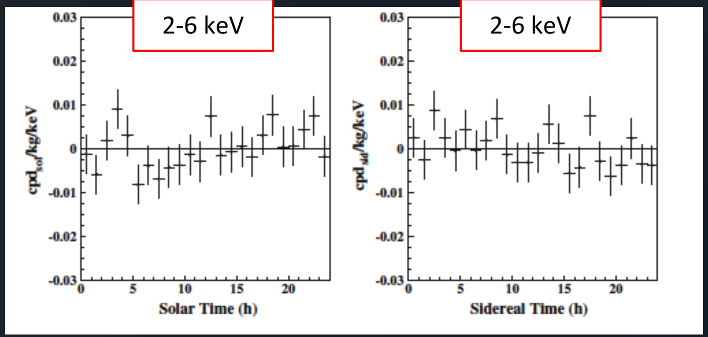
The ratio R_{dy} is a model independent constant:

$$R_{dy} = \frac{S_d}{S_m} = \frac{V_r B_d}{V_{Earth} B_m} \simeq 0.016$$ at LNGS latitude

- Observed annual modulation amplitude in DAMA/LIBRA–phase1 in the (2–6) keV energy interval: (0.0097 ± 0.0013) cpd/kg/keV
- Thus, the expected value of the diurnal modulation amplitude is $\simeq 1.5 \times 10^{-4}$ cpd/kg/keV.
- When fitting the *single-hit* residuals with a cosine function with amplitude A_d as free parameter, period fixed at 24 h and phase at 14 h: all the diurnal modulation amplitudes are compatible with zero.

A_d (2-6 keV) < 1.2×10^{-3} cpd/kg/keV (90%CL)

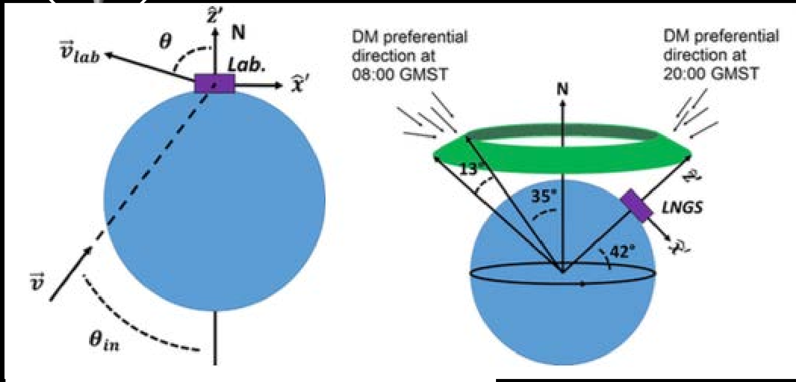
Model-independent result on possible diurnal effect in DAMA/LIBRA–phase1



Present experimental sensitivity more modest than the expected diurnal modulation amplitude derived from the DAMA/LIBRA–phase1 observed effect.

larger exposure DAMA/LIBRA–phase2 with lower energy threshold offers increased sensitivity to such an effect

Earth shadowing effect with DAMA/LIBRA–phase1



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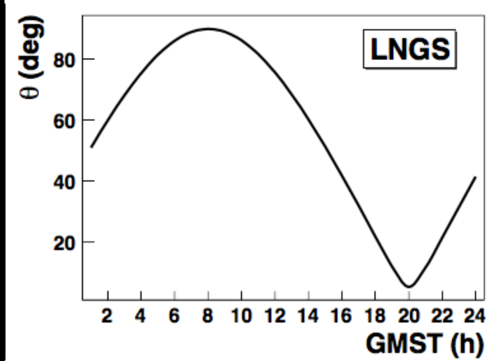
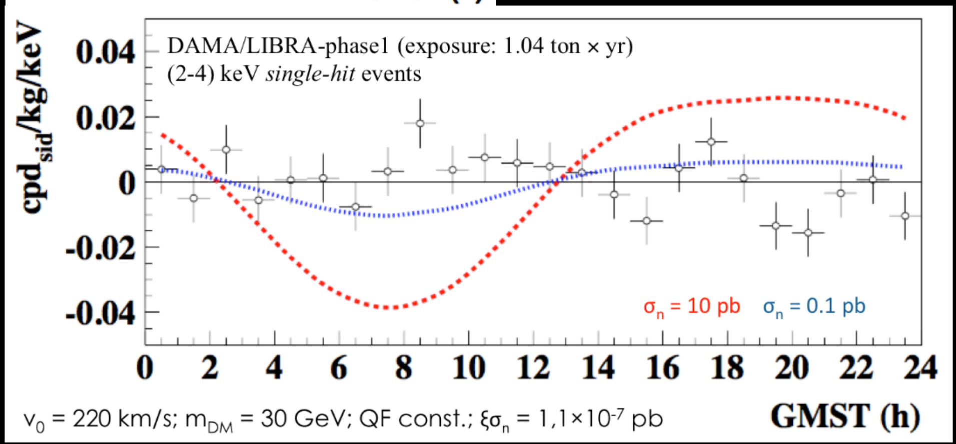
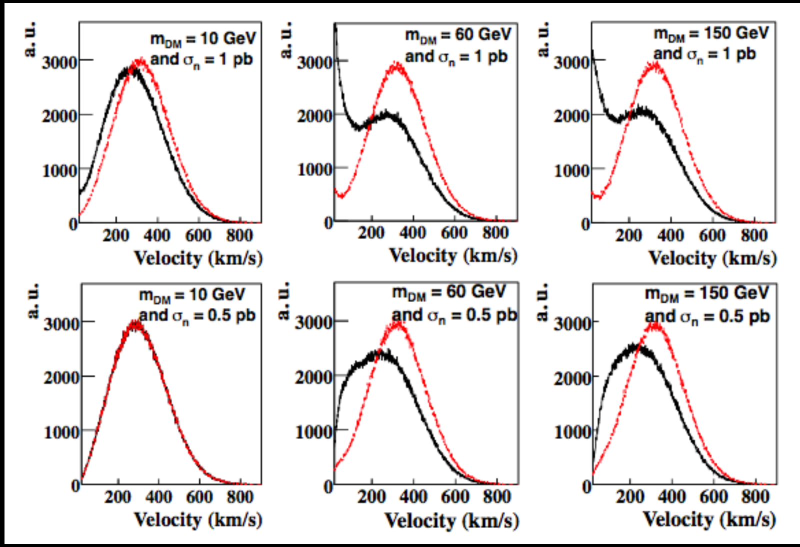
- **Earth Shadow Effect** could be expected for DM candidate particles inducing just nuclear recoils
- can be pointed out only for candidates with high cross-section with ordinary matter (low DM local density)
- would be induced by the variation during the day of the Earth thickness crossed by the DM particle in order to reach the experimental set-up



- DM particles crossing Earth lose their energy
- DM velocity distribution observed in the laboratory frame is modified as function of time (**GMST 8:00 black**; **GMST 20:00 red**)





Taking into account the DAMA/LIBRA DM annual modulation result, allowed regions in the ξ vs σ_n plane for each m_{DM}.

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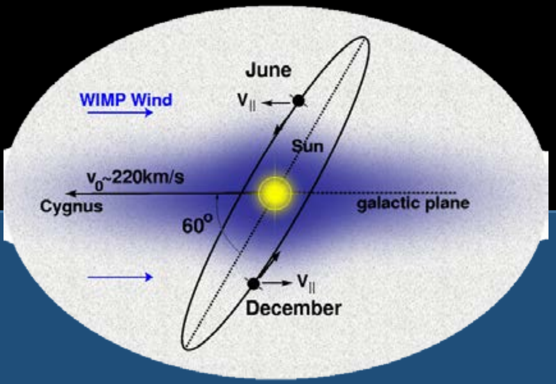
Development of detectors with anisotropic response

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 **just 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;

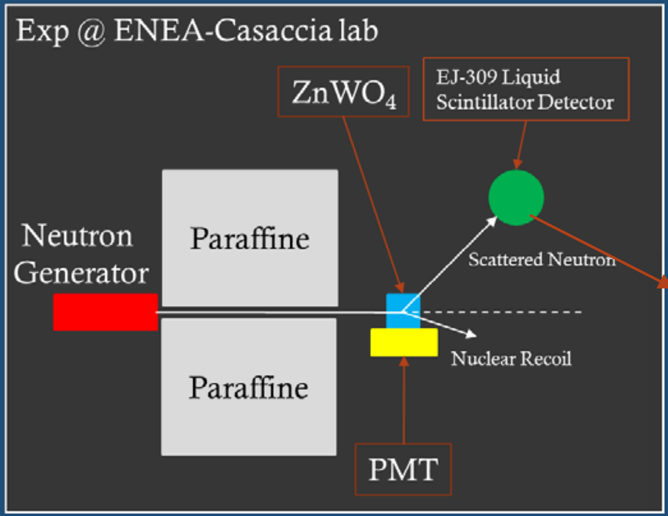
The detector response is expected to vary as a function of the sidereal time

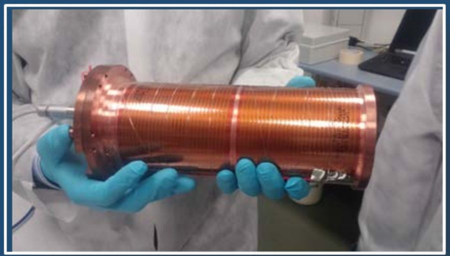
Development of $ZnWO_4$ scintillators

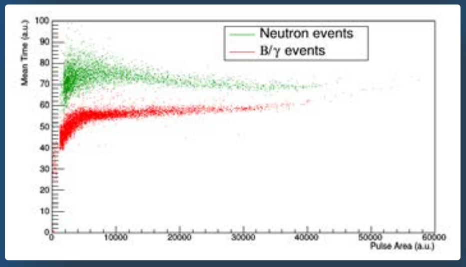
- ✓ Both **light output** and **pulse shape** have **anisotropic behavior** and can provide two **independent ways** to study **directionality**
- ✓ **Very high** reachable **radio-purity**;
- ✓ **Threshold** at **keV** feasible;
- ✓ O->light masses, Zn, W -> high masses

$ZnWO_4$ – work in progress…

- Cryostat for low temperature measurement with scintillation
- detectors realized
- Test of the Cryostat in progress
- Lowering the energy threshold (new PMT with higher QE, SiPM, APD, SDD, …)
- New purification techniques under study → NIMA 833(2016)77-811
- Measurements of anisotropy at low energy with Neutron Generator (E_n = 14 MeV) in progress at Casaccia ENEA lab
- Development of electronics







Conclusions

- Positive evidence for the presence of DM particles in the galactic halo at **9.3σ** C.L. (14 annual cycles DAMA/NaI and DAMA/LIBRA-phase1: 1.33 ton × yr)
- Modulation parameters determined with higher precision
- New investigations on different peculiarities of the DM signal exploited (**Diurnal Modulation** and **Earth Shadow Effect**)
- New corollary analysis on **Mirror Dark Matter**
- Full sensitivity to many kinds of DM candidates and interactions types (both inducing recoils and/or e.m. radiation), **full sensitivity to low and high mass candidates**

- **DAMA/LIBRA – phase2 in data taking** at lower software energy threshold (below 2 keV)
- Continuing investigations of rare processes other than DM
- **DAMA/LIBRA – phase3 R&D in progress**
- R&D for a possible DAMA/1ton set-up, proposed by DAMA since 1996, **continuing** as well as **some other R&Ds**