DAMA/LIBRA-phase1
e prospettive future – What Next?

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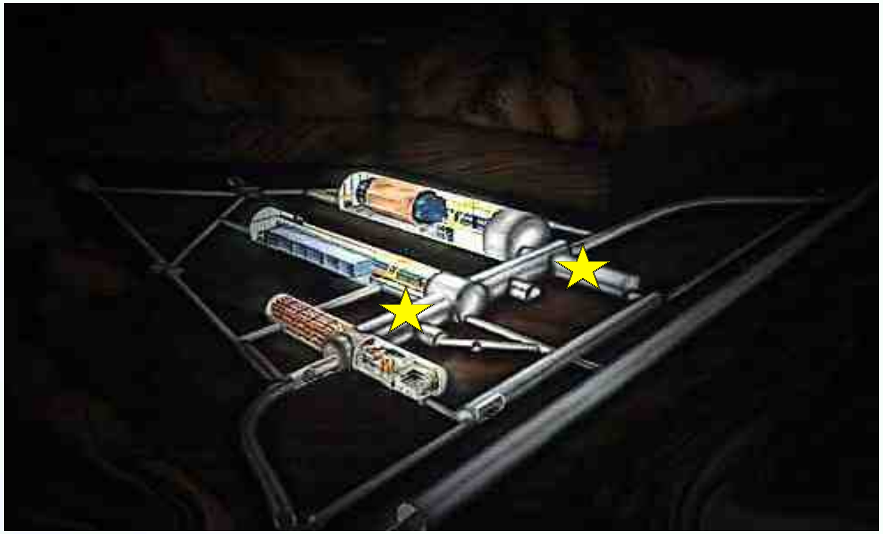
INFN – Roma Tor Vergata

What Next
Tor Vergata, 21 Marzo 2014

DAMA set-ups

an observatory for rare processes @ LNGS



- DAMA/LIBRA (DAMA/NaI)
- DAMA/LXe
- DAMA/R&D
- DAMA/Crys
- DAMA/Ge

Collaboration:

Roma Tor Vergata, Roma La Sapienza, LNGS, IHEP/Beijing

+ by-products and small scale expts.: INR-Kiev

+ neutron meas.: ENEA-Frascati

+ in some studies on ββ decays (DST-MAE and Inter-Unversities project): IIT Kharagpur and Ropar, India

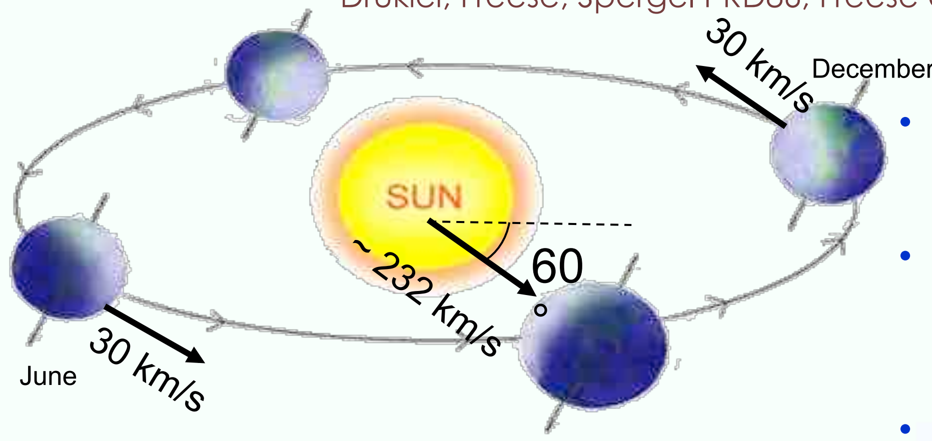
The annual modulation: a model independent signature for the investigation of DM particles component in the galactic halo

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.

Requirements of the 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

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
- $t_0 = 2^{nd}$ June (when $v_\oplus$ is maximum)

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

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

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

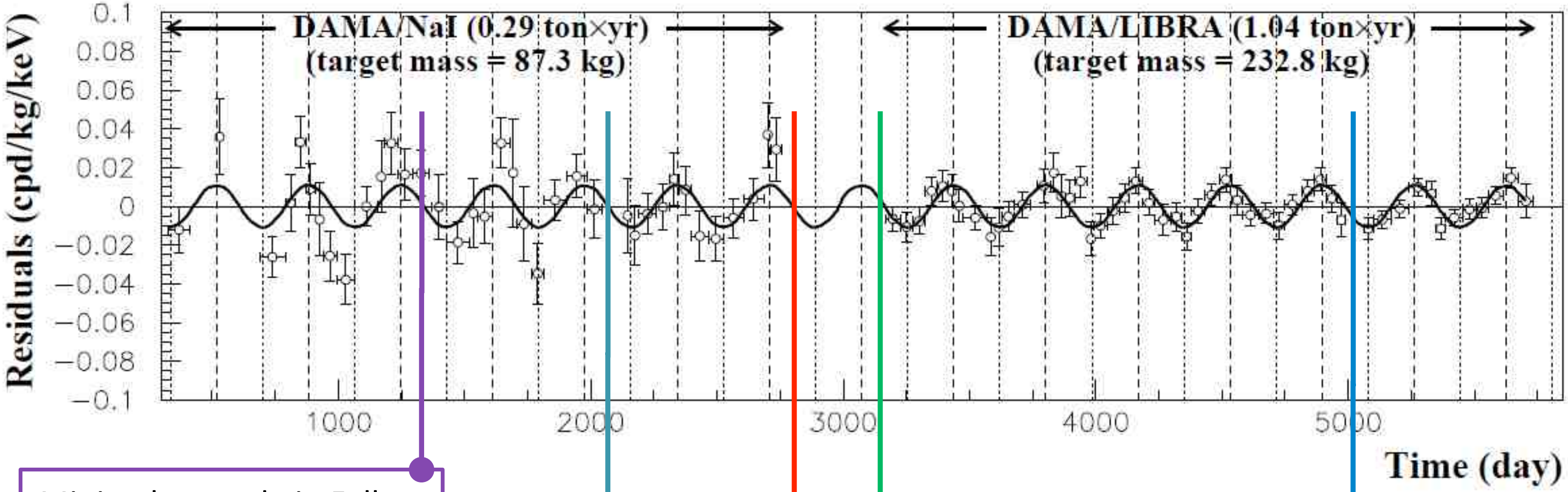
The DAMA/LIBRA set-up ~250 kg NaI(Tl) (Large sodium Iodide Bulk for RAre processes)

As a result of a 2nd generation R&D for more radiopure NaI(Tl) by exploiting new chemical/physical radiopurification techniques
(all operations involving - including photos - in HP Nitrogen atmosphere)

Residual contaminations in the new DAMA/LIBRA NaI(Tl) detectors: ^{232}Th, ^{238}U and ^{40}K at level of 10^{-12} g/g

- Radiopurity, performances, procedures, etc.: NIMA592(2008)297, JINST 7 (2012) 03009
- Results on DM particles, Annual Modulation Signature: EPJC56(2008)333, EPJC67(2010)39, EPJC73(2013)2648.
  Related results: PRD84(2011)055014, EPJC72(2012)2064, IJMPA28(2013)1330022
- Results on rare processes: PEP violation: EPJC62(2009)327; CNC in I: EPJC72(2012)1920; IPP in ^{241}Am decay: EPJA49(2013)64

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*

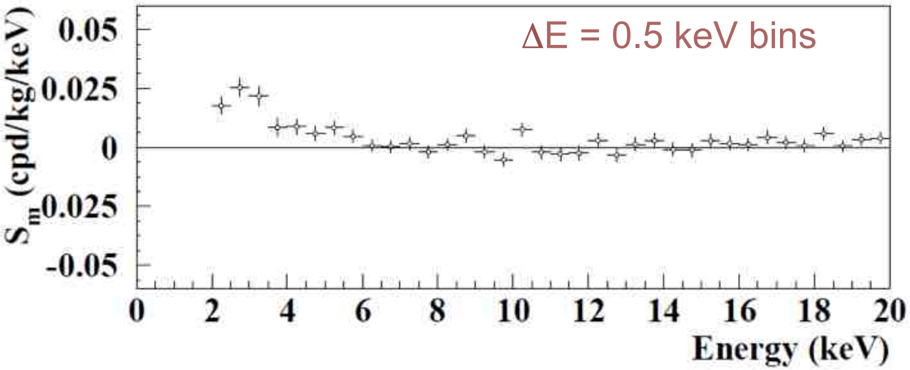
Model Independent Annual Modulation Result

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

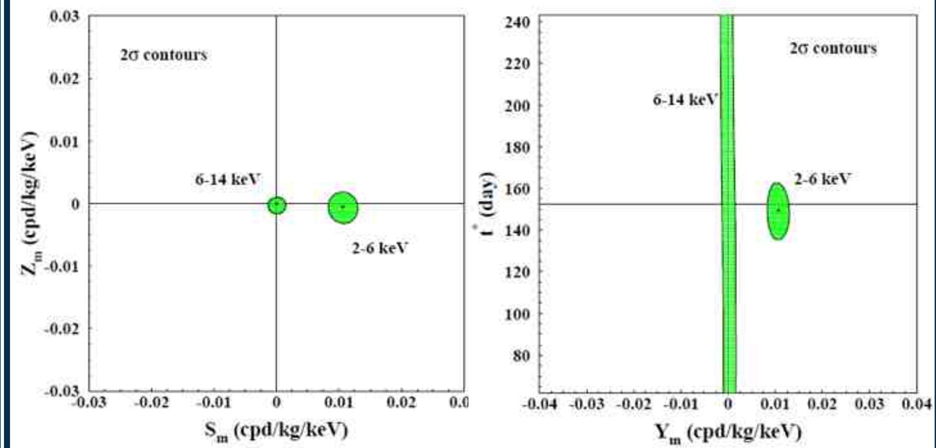
EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648

$$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$$

here $T=2\pi/\omega=1$ yr and $t_0= 152.5$ day



$$R(t) = S_0 + S_m \cos[\omega(t - t_0)] + Z_m \sin[\omega(t - t_0)] = S_0 + Y_m \cos[\omega(t - t^*)]$$



- No modulation above 6 keV
- No modulation in the whole energy spectrum
- No modulation in the 2-6 keV multiple-hit events

No systematics or side processes able to quantitatively account for the measured modulation amplitude and to simultaneously satisfy the many peculiarities of the signature are available.

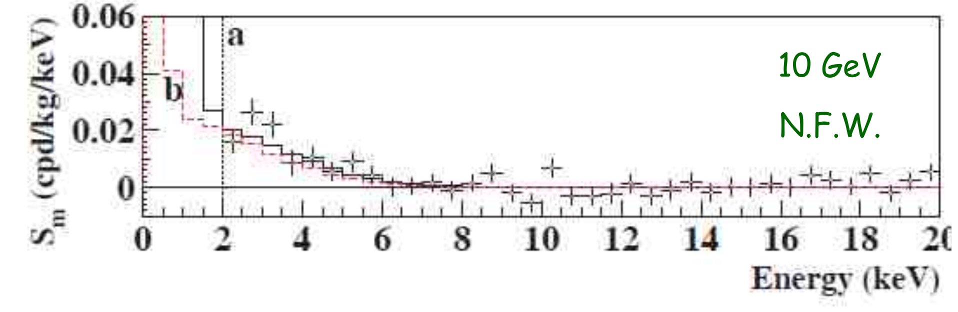
✓ Compatibility with many low and high mass DM candidates, interaction types and astrophysical scenarios, and in particular with recent positive model dependent hints from direct or indirect searches

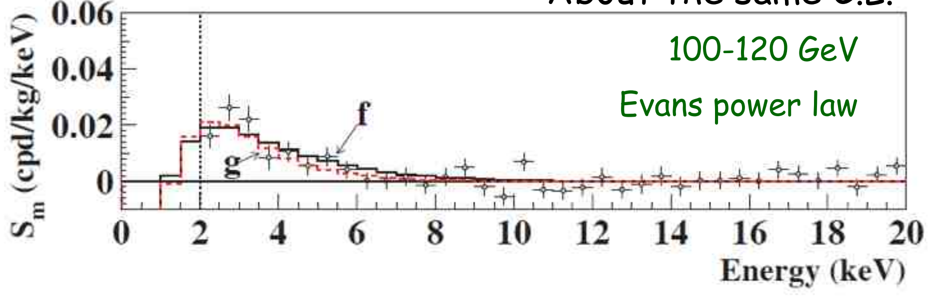
✓ No other experiment exists whose result can be – at least in principle – directly compared in a model-independent way with those by DAMA/NaI & DAMA/LIBRA-phase1

Just few <u>examples</u> of interpretation of the annual modulation in terms of candidate particles in <u>some scenarios</u>

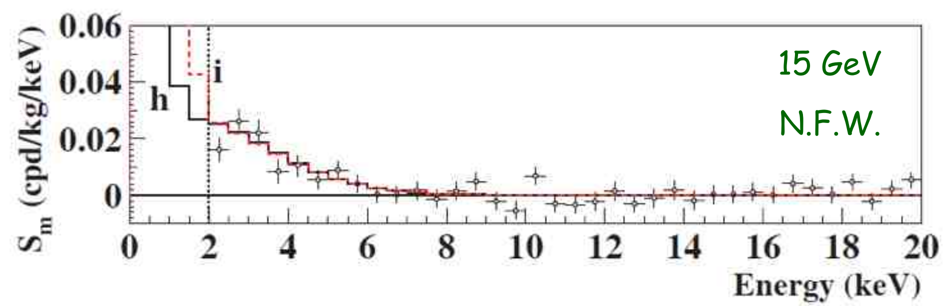
WIMP: SI

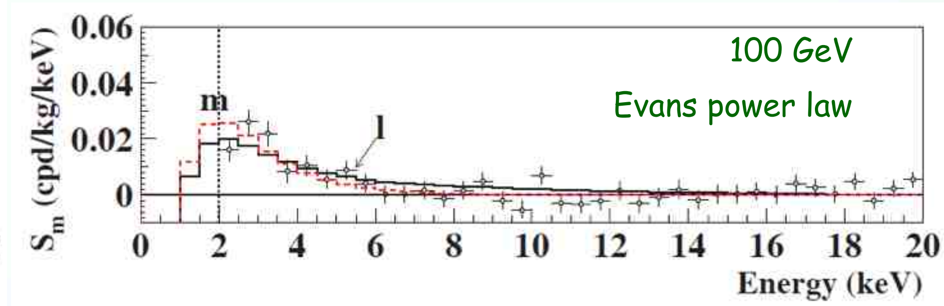
- Not best fit
- About the same C.L.



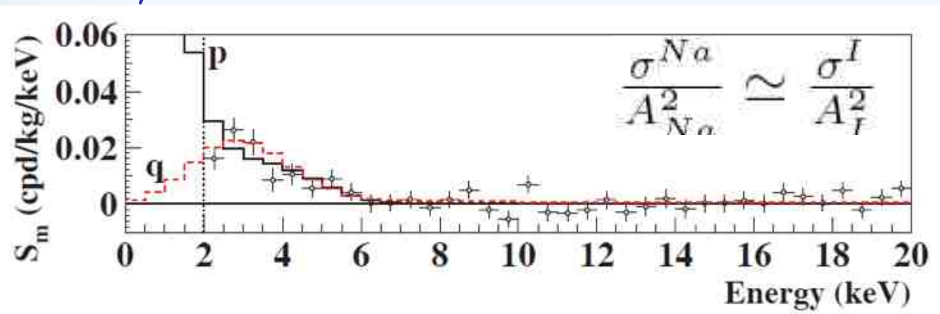


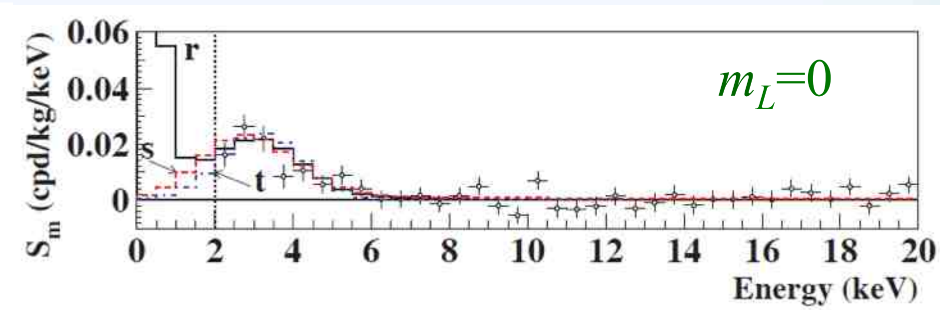
WIMP: SI & SD $\theta = 2.435$





LDM, bosonic DM



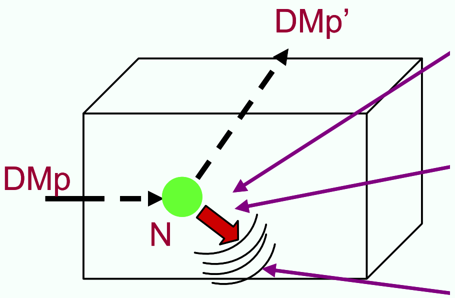


EPJC56(2008)333
IJMPA28(2013)1330022

Compatibility with several candidates; other ones are open

... an example in literature...

Case of DM particles inducing elastic scatterings on target-nuclei, SI case



Regions in the nucleon cross section vs DM particle mass plane

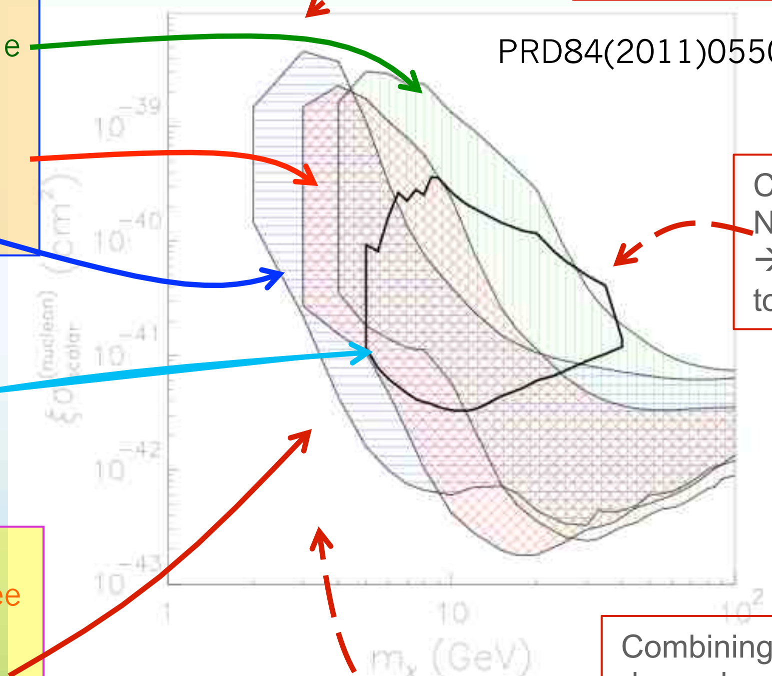
- Some velocity distributions and uncertainties considered.
- The DAMA regions represent the domain where the likelihood-function values differ more than 7.5σ from the null hypothesis (absence of modulation).
- For CoGeNT a fixed value for the Ge quenching factor and a Helm form factor with fixed parameters are assumed.
- The CoGeNT region includes configurations whose likelihood-function values differ more than 1.64σ from the null hypothesis (absence of modulation). This corresponds roughly to 90% C.L. far from zero signal.

Including the Migdal effect
→Towards lower mass/higher σ

DAMA allowed regions for a particular set of astrophysical, nuclear and particle Physics assumptions without (green), with (blue) channeling, with energy-dependent Quenching Factors (red);

7.5 σ C.L.

PRD84(2011)055014, IJMPA28(2013)1330022



Co-rotating halo,
Non thermalized component
→ Enlarge allowed region towards larger mass

CoGeNT; qf at fixed assumed value

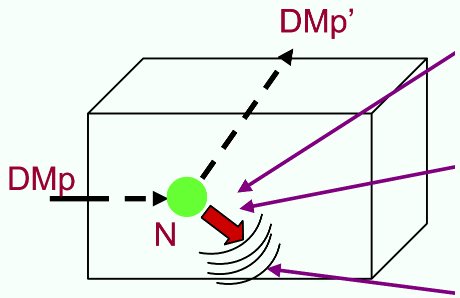
1.64 σ C.L.

Compatibility also with CRESST and CDMS, if the two CDMS-Ge, the three CDMS-Si and the CRESST recoil-like events are interpreted as relic DM interactions

Combining channeling and energy dependence of q.f. (AstrPhys33 (2010) 40)
→Towards lower σ

... an example in literature...

Case of DM particles inducing elastic scatterings on target-nuclei, SI case



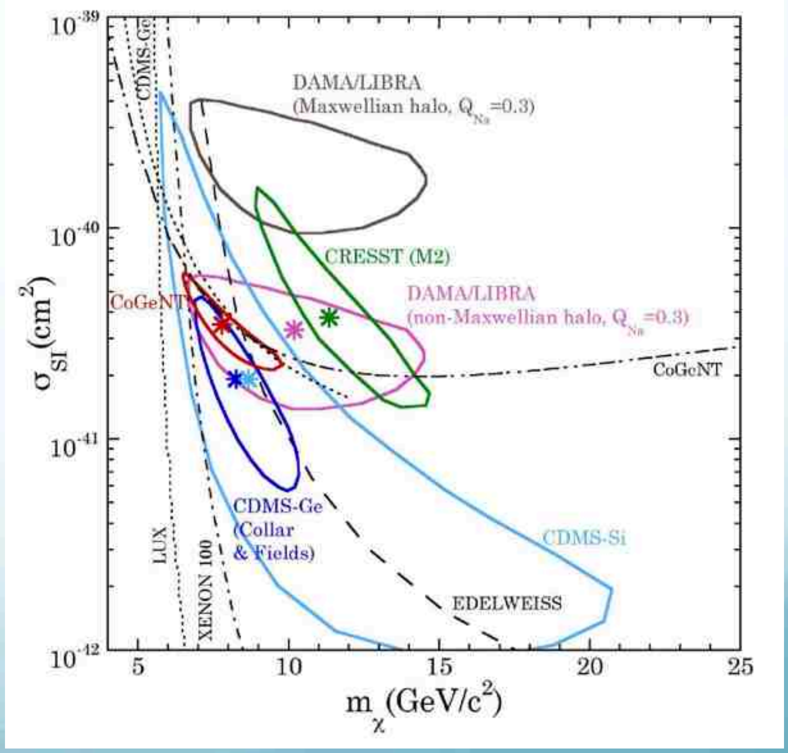
Regions in the nucleon cross section vs DM particle mass plane

... a recent conjecture ...

arXiv:1401.3295

- Non-Maxwellian halo model is considered.
- The DAMA regions are for both Maxwellian and non-Maxwellian halo models.
- Na quenching factor taken at the fixed value 0.3
- A fractional modulation amplitude corresponding to that found for CoGeNT data is assumed for DAMA.
- For CoGeNT a fixed value for the Ge quenching factor and a Helm form factor with fixed parameters are assumed.
- The CoGeNT region includes configurations whose likelihood-function values differ more than 1.64σ from the null hypothesis (absence of modulation). This corresponds roughly to 90% C.L. far from zero signal.

nium data [69] would be insensitive to up to a 100% modulation amplitude in a possible CDMS-Ge signal [63]. Liquid xenon (LUX, XENON-100) sensitivity to $m_\chi < 12$ GeV/c^2 is presently under test, using an ^{88}Y/Be neutron source [61].



Another example of compatibility

DM particle with preferred inelastic interaction

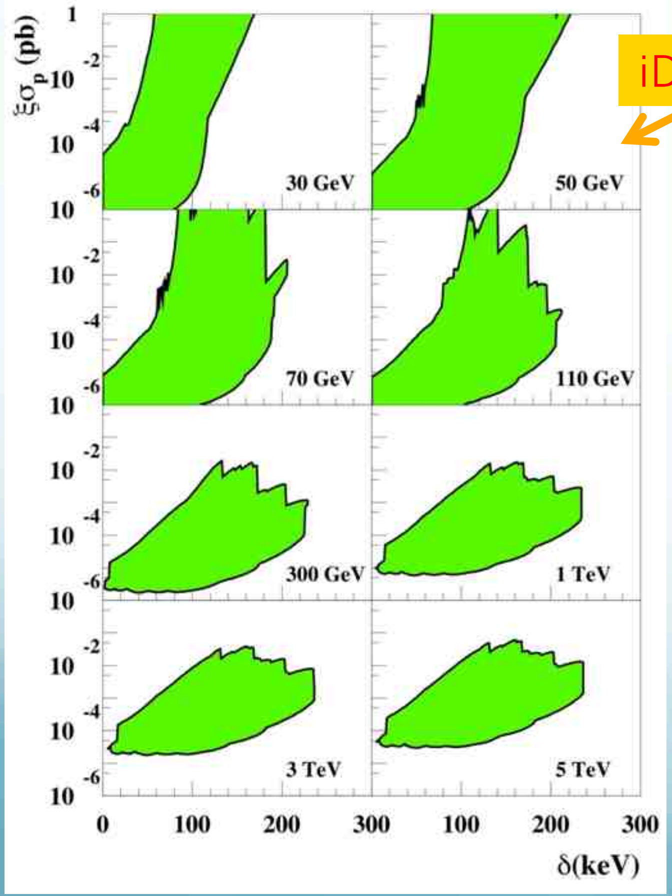
In the Inelastic DM (iDM) scenario, WIMPs scatter into an excited state, split from the ground state by an energy comparable to the available kinetic energy of a Galactic WIMP.

$$\chi^{-} + N \rightarrow \chi^{+} + N$$

- iDM has two mass states χ^{+}, χ^{-} with δ mass splitting
- Kinematical constraint for iDM

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

DAMA/NaI+DAMA/LIBRA Fund. Phys. 40(2010)900
Slices from the 3-dimensional allowed volume



iDM interaction on Iodine nuclei

iDM interaction on Tl nuclei of the NaI(Tl) dopant?

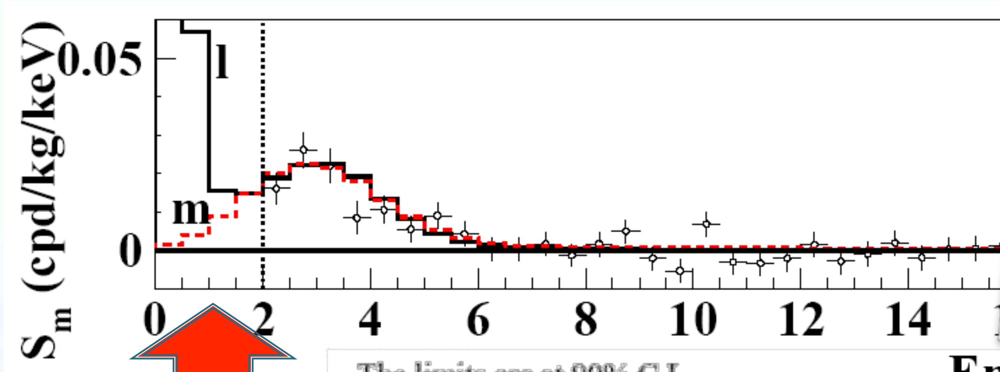
arXiv:1007.2688

- For large splittings, the dominant scattering in NaI(Tl) can occur off of Thallium nuclei, with A~205, which are present as a dopant at the 10^{-3} level in NaI(Tl) crystals.
- Inelastic scattering WIMPs with large splittings do not give rise to sizeable contribution on Na, I, Ge, Xe, Ca, O, … nuclei.

… and more considering experimental and theoretical uncertainties

DAMA/LIBRA phase 2 - running

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

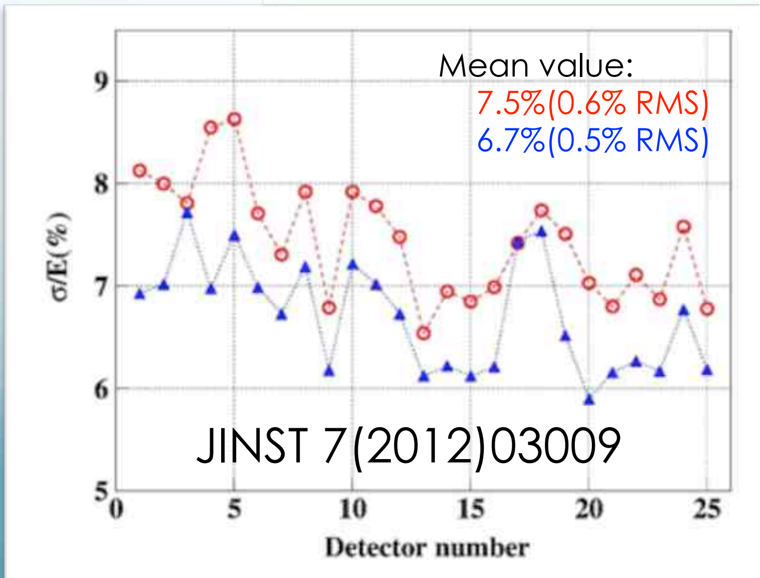


Residual Contamination

The limits are at 90% C.L.

PMT	Time (s)	Mass (kg)	^{226}Ra (Bq/kg)	^{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)
Average			*0.43*	-	*47*	*0.12*	*83*	*0.54*	-	-
Standard deviation			*0.06*	-	*10*	*0,02*	*17*	*0.16*	-	-

Energy resolution



σ/E @ 59.5 keV for each detector with new PMTs with higher quantum efficiency (blu points) and with previous PMT EMI-Electron Tube (red points).

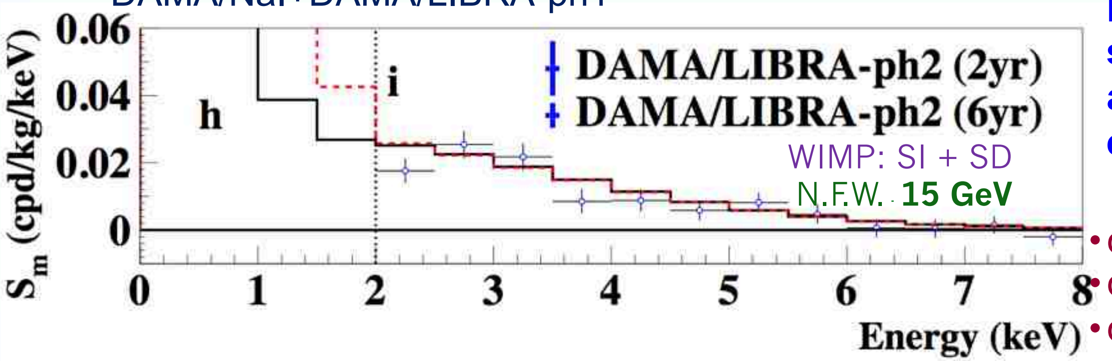
The light responses

Previous PMTs:	5.5-7.5 ph.e./keV
New PMTs:	up to 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*

Just few examples about the discrimination power of DAMA/LIBRA-phase2 under some given set of astrophysical, nuclear and particle physics assumptions

DAMA/NaI+DAMA/LIBRA-ph1



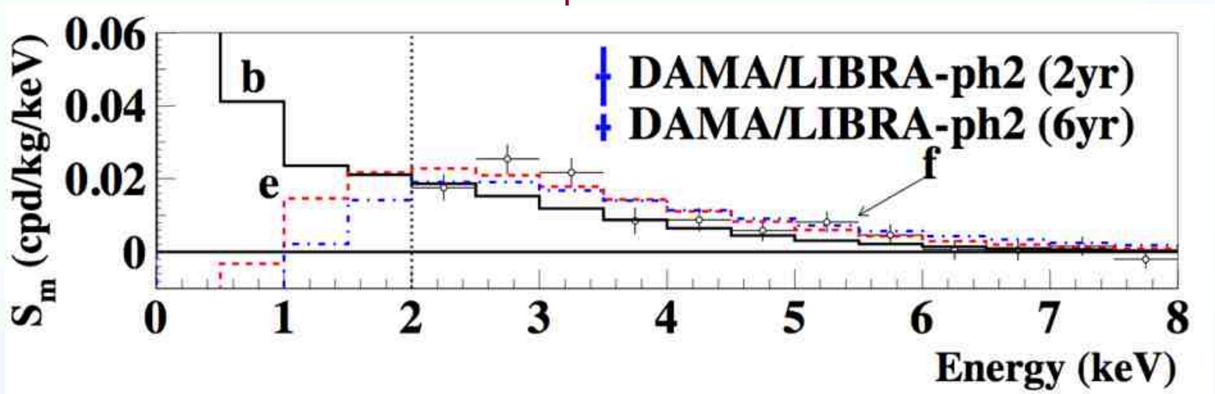
Not best fit cases, same C.L., see table above for cross sections and other assumptions in theor. expectations (i.e. labels).

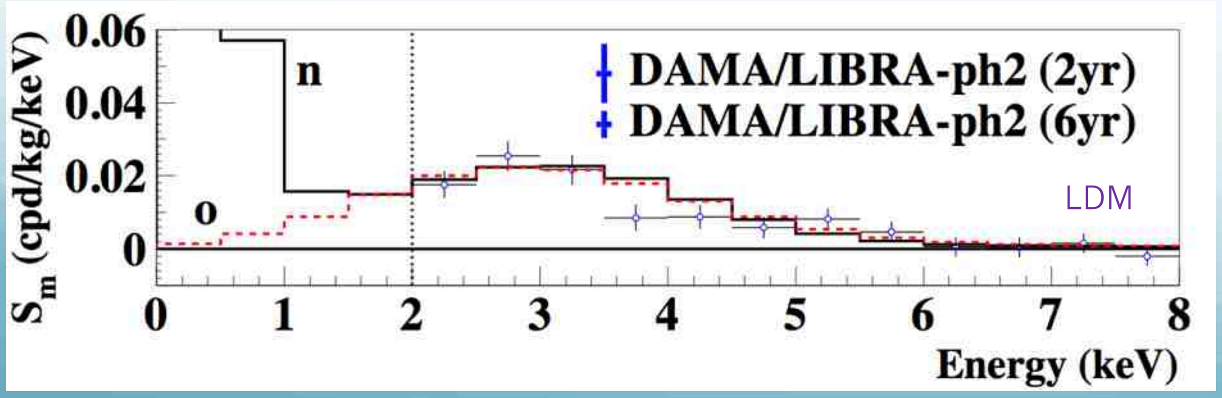
- discrimination among w/wo channeling
- discrimination among WIMP's masses
- discrimination among DM models

here q.f. vs E assumed constant

Assuming MT(6a.c.) = 464000 kg day

$$\sigma(S_m) = \sqrt{\frac{\langle R\rangle}{M\cdot T\cdot \Delta E\cdot \varepsilon\cdot(\alpha-\beta^2)}}$$





WIMP: SI

b) 10 GeV-ch

e) 60 GeV

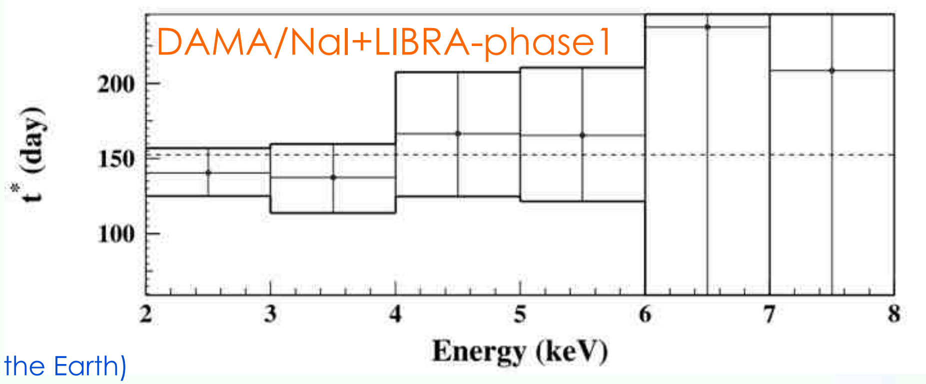
f) 100 GeV

Features of the DM signal

The importance of studying second order effects and the annual modulation phase

High exposure and lower energy threshold can allow further investigation on:

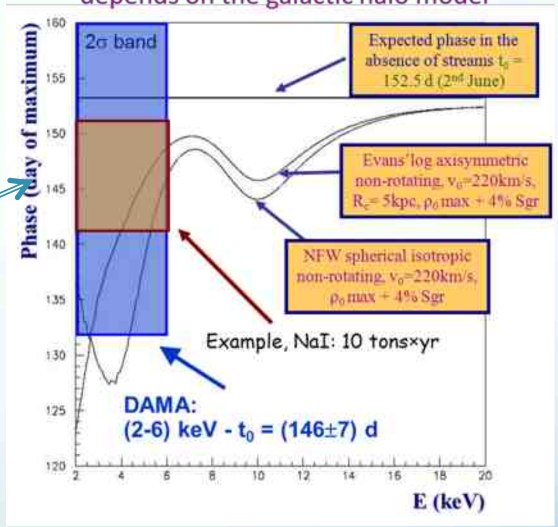
- the nature of the DM candidates
  - ✓ to disentangle among the different astrophysical, nuclear and particle physics models (nature of the candidate, couplings, inelastic interaction, form factors, spin-factors …)
  - ✓ scaling laws and cross sections
  - ✓ multi-component DM particles halo?
- possible diurnal effects on the sidereal time
  - ✓ expected in case of high cross section DM candidates (shadow of the Earth)
  - ✓ due to the Earth rotation velocity contribution (it holds for a wide range of DM candidates)
  - ✓ due to the channeling in case of DM candidates inducing nuclear recoils.
- astrophysical models
  - ✓ velocity and position distribution of DM particles in the galactic halo, possibly due to:
    - satellite galaxies (as Sagittarius and Canis Major Dwarves) tidal "streams";
    - caustics in the halo;
    - gravitational focusing effect of the Sun enhancing the DM flow ("spike" and "skirt");
    - possible structures as clumpiness with small scale size
    - Effects of gravitational focusing of the Sun

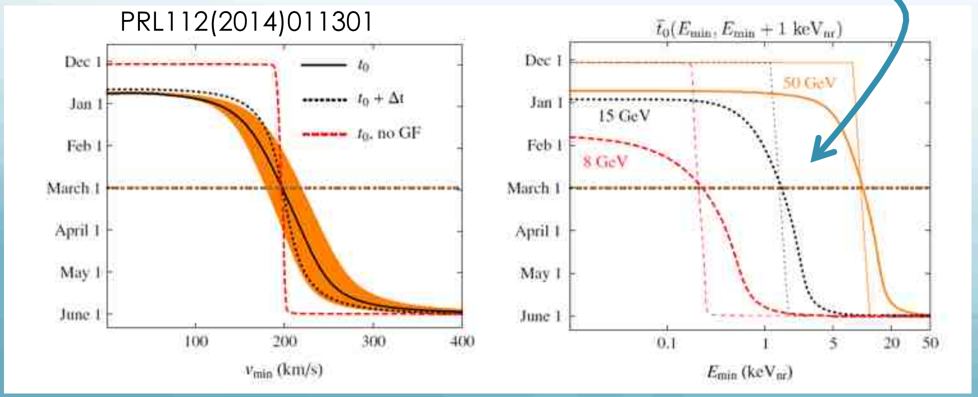


The annual modulation phase depends on :

- Presence of streams (as SagDEG and Canis Major) in the Galaxy
- Presence of caustics
- Effects of gravitational focusing of the Sun

The effect of the streams on the phase depends on the galactic halo model





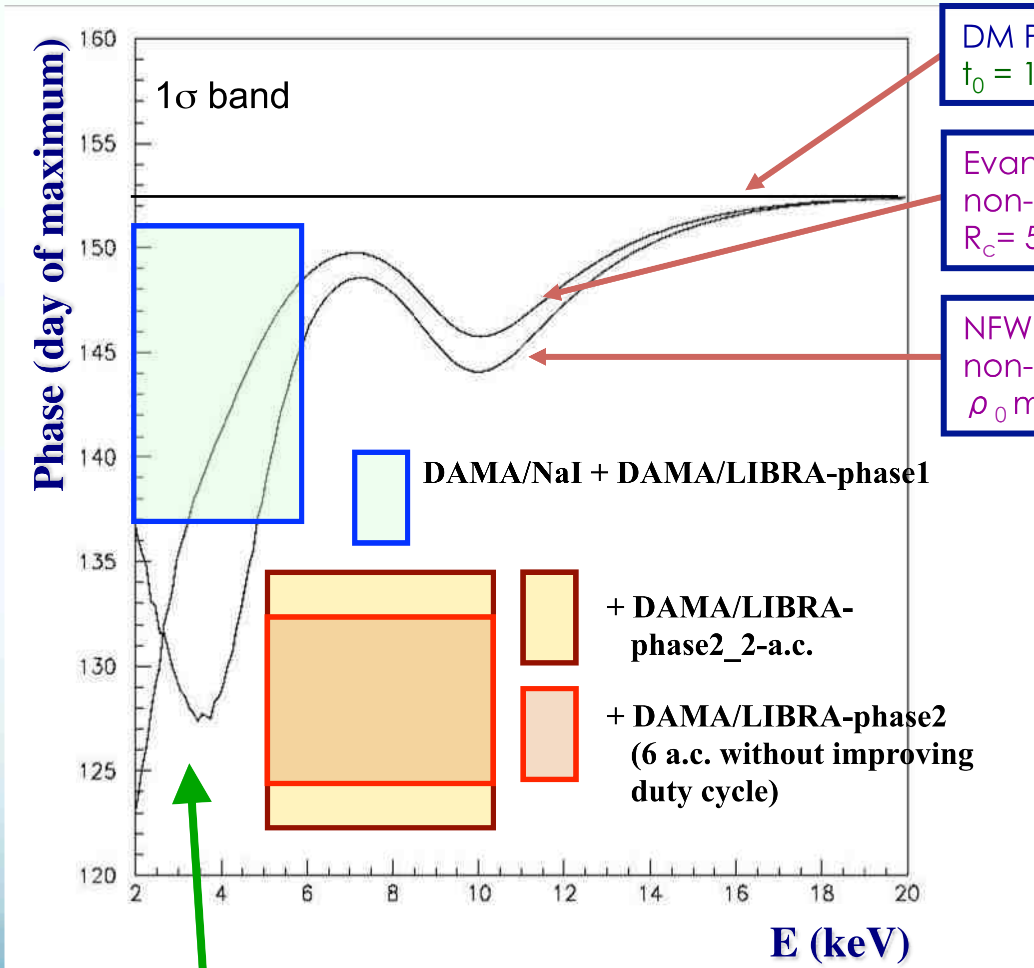
A step towards such investigations:

➔**DAMA/LIBRA-phase2**

with lower energy threshold and larger exposure

Towards signatures for the presence of streams in the Galactic halo

The effect of the streams on the phase depends on the galactic halo model



DM Phase with no streams
t_0 = 152.5 d (2nd June)

Evans'log axisymmetric non-rotating, v_0=220km/s, R_c= 5kpc, ρ_0 max + 4% Sgr

NFW spherical isotropic non-rotating, v_0=220km/s, ρ_0 max + 4% Sgr

The higher sensitivity of **DAMA/LIBRA-phase2** will allow the further investigation of possible contributions of streams in the galactic halo

If the sensitivity on the phase can be in DAMA/1ton at level of ~1 d, discrimination power on the local velocity, V_0, will be obtained:

- v_0 = 170 km/s → t_0-$t_{equinox}$ = 71.7 d
- v_0 = 220 km/s → t_0-$t_{equinox}$ = 73.2 d
- v_0 = 270 km/s → t_0-$t_{equinox}$ = 74.2 d

Eur. Phys. J. C 73(2013) 2648
Eur. Phys. J. C 47(2006) 263

DAMA/NaI & DAMA/LIBRA-ph1 (2-6) keV: t_0 = (144±7) d

Expected sensitivities:

DAMA/NaI & DAMA/LIBRA-ph1 & DAMA/LIBRA-ph2 (2 a.c.) (1-6) keV: 6 d

DAMA/NaI & DAMA/LIBRA-ph1 & DAMA/LIBRA-ph2 (6 a.c.) (1-6) keV: 4 d

Assuming MT(6yr) = 464000 kg day

Perspectives for the near and the far future

1. **DAMA/LIBRA–phase2 to reach the proposed goals**

2. **Possible phase3 at the end of phase2 (or data taking dedicated to other rare processes)**

   - The strong interest in the low energy range suggests the possibility of a new development of high Q.E. PMTs with increased radio-purity, directly coupled to the DAMA/LIBRA crystals, removing the special quartz light guides which act also as optical window.
   - Very high light response (ph.e./keV).
   - Technology for the ULB PMTs at hand (we have a prototype in TOV).
   - … and/or many other rare processes can be investigated

   At the end of DAMA/LIBRA underground data taking at LNGS: new precise measurements of q.f., channeling, etc. for each detector at Tor Vergata and neutron beams.

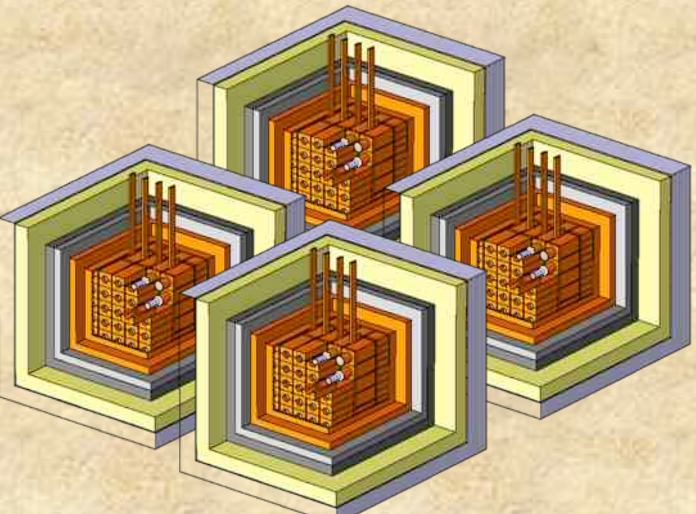
3. **Multi-purpose fully-sensitive mass DAMA/1ton**

   Proposed by DAMA since 1996 (DAMA/NaI and DAMA/LIBRA intermediate steps, some R&D's funded and carried out)

3) multi-purpose full sensitive mass DAMA/1ton

1) Proposed since 1996 (DAMA/NaI and DAMA/LIBRA intermediate steps+some R&D and POR fellowships)
2) Technology largely at hand and still room for further improvements in the low-background characteristics of the set-up (NaI(Tl) crystals, PMTs, shields, etc.)
3) 1 ton detector: the cheapest, the highest duty cycle, the clear signature, fast realization in few years

Design: DAMA/1 ton can be realized by adding 3 replicas of DAMA/LIBRA:



- the detectors of similar size than those already used
- the features of low-radioactivity of the set-up and of all the used materials would be assured by many years of experience in the field
- electronic chain and controls would profit by the previous experience and by the use of compact devices already developped, tested and used.
- new digitizers will offer high expandibility and high performances
- the daq can be a replica of that of DAMA/LIBRA

- **Some R&Ds carried out**

Perspectives
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3. **Multi-purpose fully-sensitive mass DAMA/1ton**

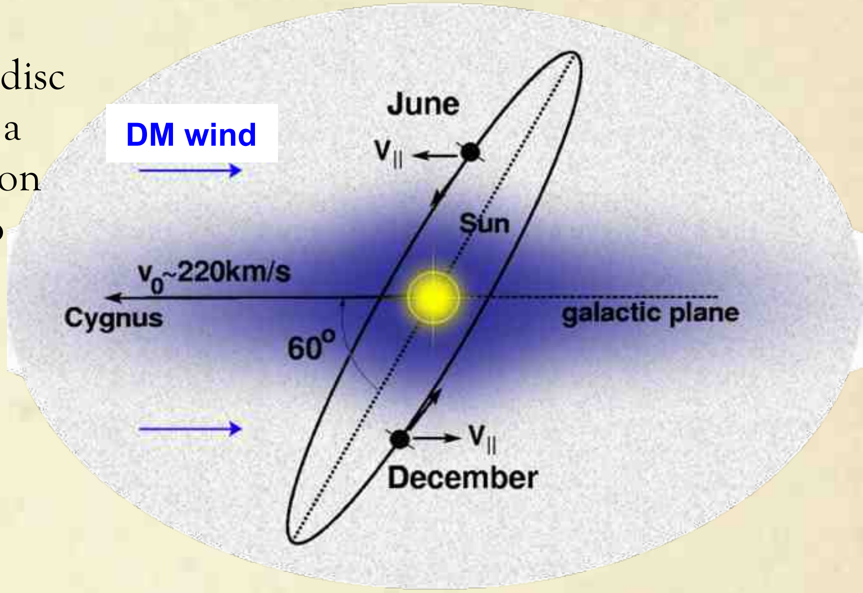
    Proposed by DAMA since 1996 (DAMA/NaI and DAMA/LIBRA intermediate steps, some R&D funded and carried out)

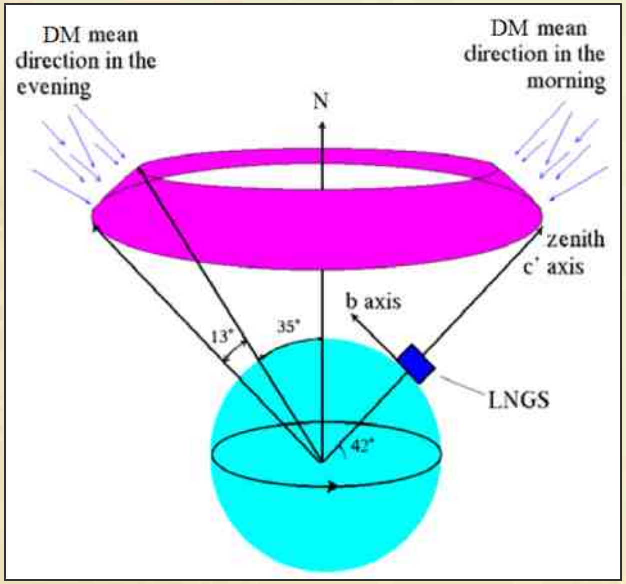
4. **New anisotropic scintillator/nanotube detectors for directionality**

The directionality approach

Based on the study of the correlation between the Earth motion in the galactic rest frame and the arrival direction of the Dark Matter (DM) particles able to induce nuclear recoils

The dynamics of the rotation of the Milky Way galactic disc through the halo of DM causes the Earth to experience a wind of DM particles apparently flowing along a direction opposite to that of solar motion relative to the DM halo





... but because of the Earth's rotation around its axis, the DM particles average direction with respect to an observer fixed on the Earth changes during the sidereal day

The **direction of the induced nuclear recoils** can offer a way for pointing out the presence of those candidate particles; in fact the nuclear recoils are expected to be **strongly correlated** with their **impinging direction**, while the background events are not

Directionality sensitive detectors: TPC

- Detection of the tracks' directions

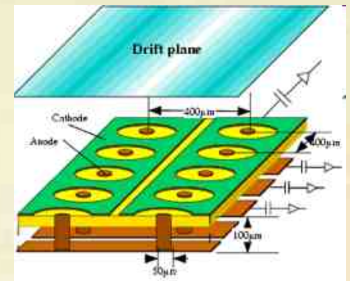
⇒ Low Pressure **Time Projection Chamber** might be suitable; in fact the range of recoiling nuclei is of the order of mm (while it is ~μ m in solid detectors)

In order to reach a significant sensitivity, a realistic TPC experiment needs e.g.:

1. extreme operational stability
2. high radiopurity
3. extremely large detector size
4. great spatial resolution
5. low energy threshold

Not yet competitive sensitivity

NEWAGE



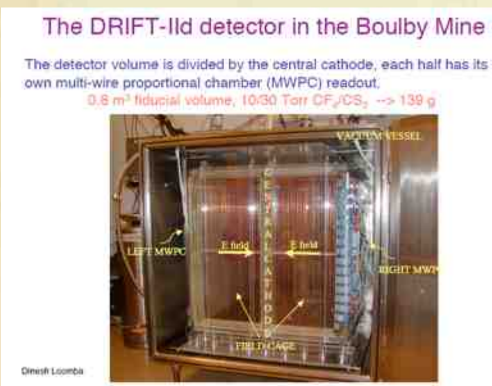
μ-PIC(Micro Pixel Chamber) is a two dimensional position sensitive gaseous detector

	Current	Plan
Detection Volume	30×30×31cm^3	>1m^3
Gas	CF_4 152Torr	CF_4 30 Torr
Energy threshold	100keV	35keV
Energy resolution(@ threshold)	70%(FWHM)	50%(FWHM)
Gamma-ray rejection(@threshold)	8×10^{-6}	1×10^{-7}
Angular resolution (@ threshold)	55° (RMS)	30° (RMS)

⇒Internal radioactive BG restricts the sensitivities

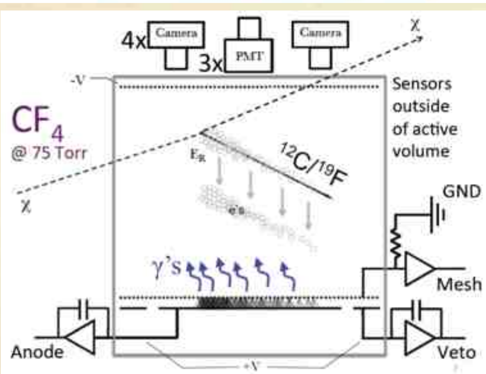
⇒We are working on to reduce the backgrounds!

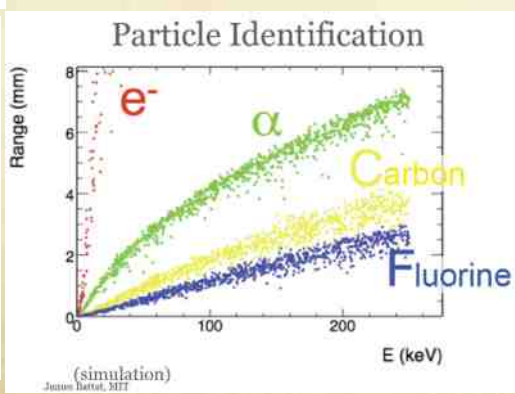
DRIFT-IId



Backgroud dominated by Radon Progeny Recoils (decay of ^{222}Rn daughter nuclei, present in the chamber)

DM-TPC





- The "4--Shooter" 18L (6.6 gm) TPC 4xCCD, Sea-level@MIT
- moving to WIPP
- Cubic meter funded, design underway

Directionality sensitive detectors overcoming the track measurement difficulties: anisotropic scintillators

- Study of the variation in the response of **anisotropic scintillation detectors** during sidereal day. In fact, **the light output and the pulse shape of these detectors depend on the direction of the impinging particles** with respect to the crystal axes

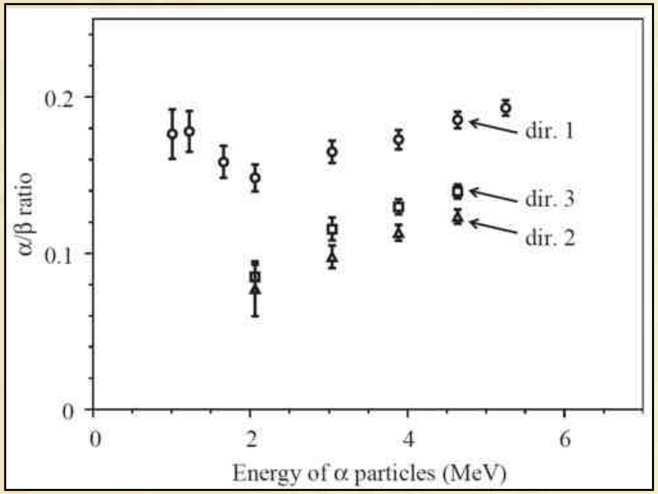
  - The use of anisotropic scintillators to study the directionality signature was proposed for the first time in refs. [P. Belli et al., Il Nuovo Cim. C 15 (1992) 475; R. Bernabei et al., Eur. Phys. J. C 28 (2003) 203], where the case of anthracene detector was preliminarily analysed; some preliminary activities have been carried out [N.J.C. Spooner et al, IDM1997 Workshop; Y. Shimizu et al., NIMA496(2003)347]

  - In the comparison with the anthracene the **$ZnWO_4$ anisotropic scintillator** offers a higher atomic weight and the possibility to realize crystals with masses of some kg, with high level of radio-purity, with threshold at few keV feasible **(Eur. Phys. J. C 73 (2013) 2276)**

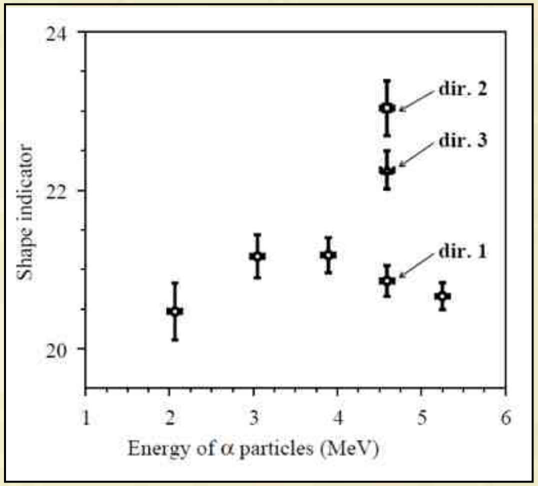
Anisotropic features in $ZnWO_4$

The reachable sensitivity of the directionality approach depend on the anisotropic features of the detectors in response to the low energy nuclear recoils induced by the DM particles

Measurements with α particles have shown that the **light response** and the **pulse shape** of a $ZnWO_4$ depend on the impinging direction of α particles with respect to the crystal axes



Such effects are absent in case of electron excitation



These anisotropic effects are ascribed to preferred directions of the excitons' propagation in the crystal lattice affecting the dynamics of the scintillation mechanism

Similar effect is expected in the case of low energy nuclear recoils
⇒ Dedicated measurements are in preparation

Both the anisotropic features of the $ZnWO_4$ detectors can provide two independent ways to exploit the directionality approach

Performances of the $ZnWO_4$ crystal scintillator

- *Summarizing*

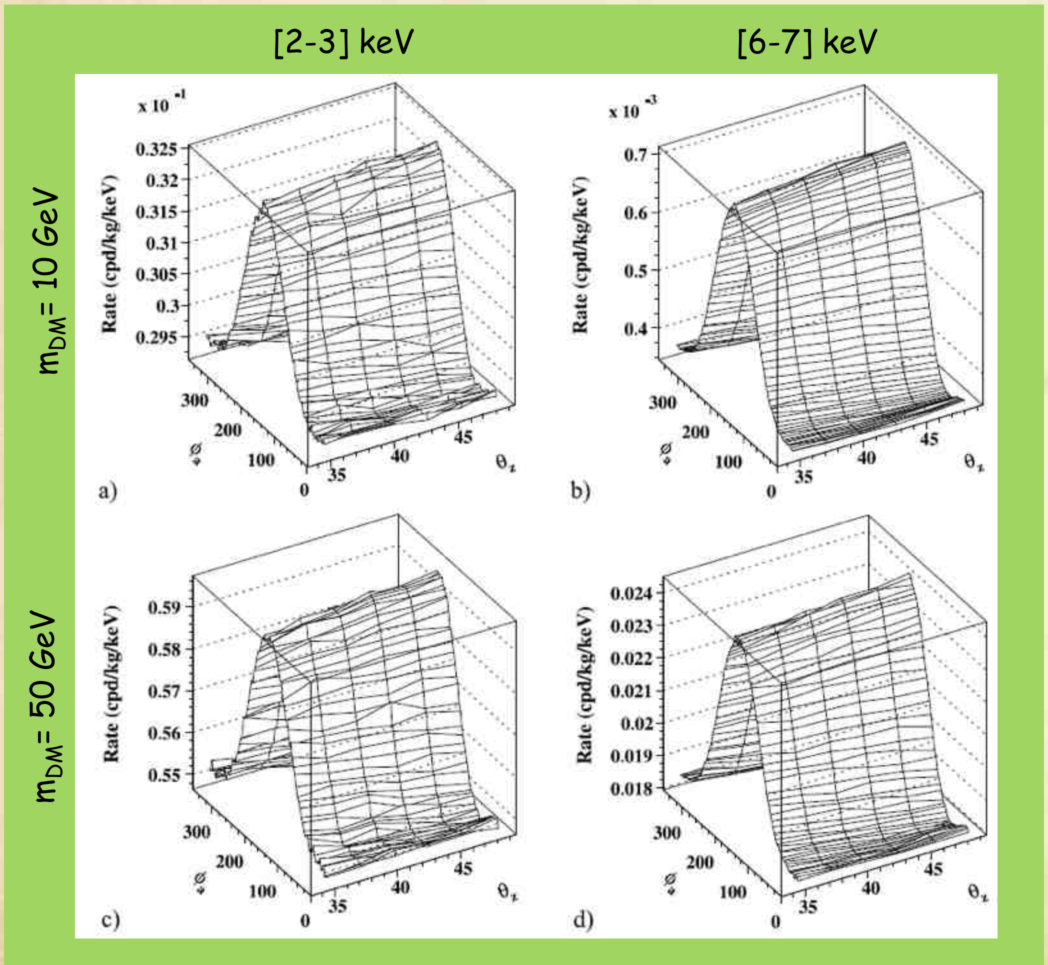
  - ✓ Large mass crystals
  - ✓ High level of radiopurity
  - ✓ Suitable light output
  - ✓ keV energy threshold
  - ✓ Pulse shape discrimination
  - ✓ Sensitivity to different DM masses (with Zn, W and O)
  - ✓ High stability of the running conditions
  - ✓ Suitable anisotropic features

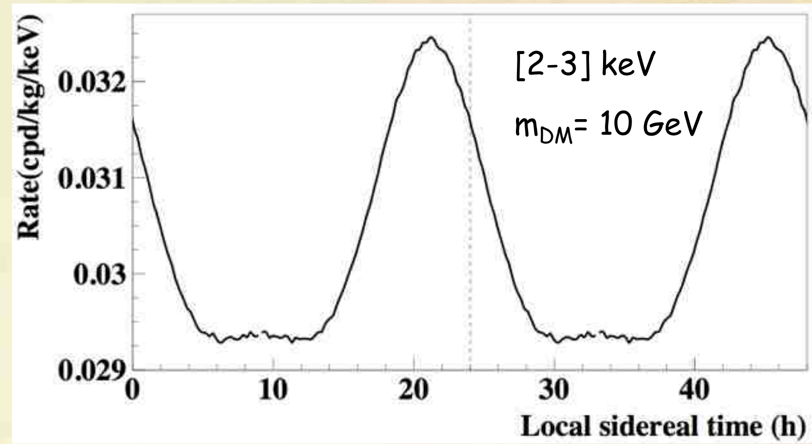
Since θ_z is always near 40°, it is convenient to consider:

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

- ✓ $ZnWO_4$ crystals with the axis having the largest q.f. in the vertical direction, and with the axis having the smallest q.f. towards the North

Expected counting rate as a function of $_d$ in the given model framework for σ_p=5×10^{-5} pb





- ✓ Strong dependence on the "polar-azimuth" ϕ_a that induces a diurnal variation of the rate
- ✓ Diurnal variation of the energy spectrum expected
- ✓ Diurnal variation of the nuclear recoils induced by DM interaction

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Considering an experiment with:

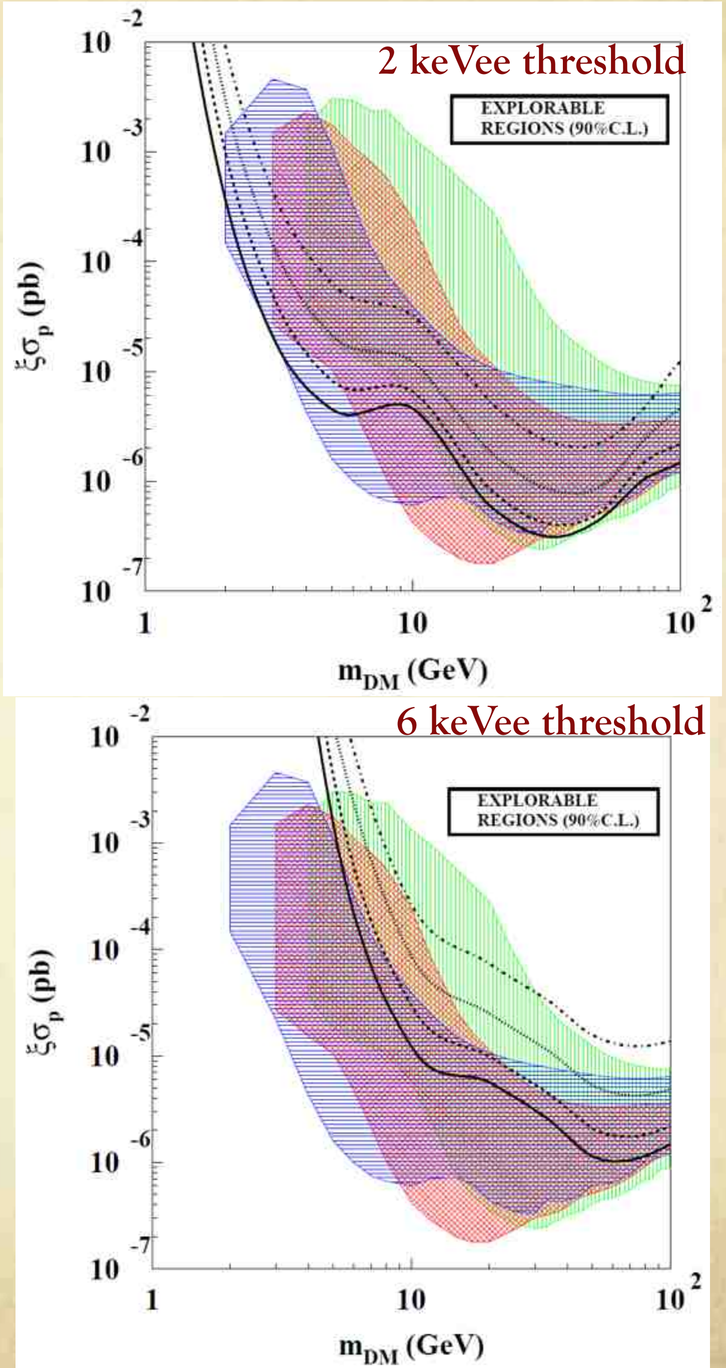
- 200 kg of $ZnWO_4$;
- 5 years of data taking.

The reachable sensitivity has been calculated considering four possible time independent background levels in the low energy region:

- 10^{-4} cpd/kg/keV
- 10^{-3} cpd/kg/keV
- 10^{-2} cpd/kg/keV
- 0.1 cpd/kg/keV

The directionality approach can reach in the given scenario a sensitivity to the cross section at level of 10^{-5} – 10^{-7} pb, depending on the particle mass

For comparison, there are also shown (green, red and blue) allowed regions obtained with a corollary analysis of the 8.9 σ C.L. DAMA model independent result in terms of scenarios for the DM candidates considered here

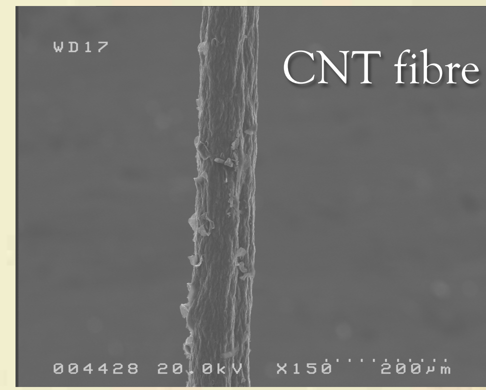


Directionality sensitive detectors: carbon nanotube fibers (CNT)

- New conceptual detector: 3D detectors with carbon nanotube fibers (CNT)

  ✓ The CNT are thin graphene foils, rolled as tubes with l-100 nm diameters and lengths well above one μm; they can be aligned by chemical process to obtain fibres

  ✓ The intrinsic 1-D nature of CNTs fibers makes them very promising for the study of directionality (diameter ~ 10-100μm; length ~ m); metallic material can be deposited on them



  ✓ The physical characteristic to be measured for the detection of the passage of dark matter: **alteration of the electrical characteristics** induced by the interaction with high-energy particles, which determines a **change of resistivity** in CNTs.

  ✓ Three possible nano-devices: bare CNT, CNT coated with standard materials, CNT coated with superconducting materials as Nb and NbN. These new detectors can realized as grid of oriented bundles of CNT or fibers, with spatial resolution comparable to the width of the components themselves (1 μm to 100 μm). Fibers of CNT will be used for a sort of multi-wire chamber detector configuration with a high spatial resolution.

Perspectives for the near and the far future

1. **DAMA/LIBRA–phase2 to reach the proposed goals**

2. **Possible phase3 at the end of phase2 (or data taking dedicated to other rare processes)**
   - The strong interest in the low energy range suggests the possibility of a new development of high Q.E. PMTs with increased radio-purity, directly coupled to the DAMA/LIBRA crystals, removing the special quartz light guides which act also as optical window.
   - Very high light response (ph.e./keV).
   - Technology for the ULB PMTs at hand (we have a prototype in TOV).
   - … and/or many other rare processes can be investigated

   At the end of DAMA/LIBRA underground data taking at LNGS: new precise measurements of q.f., channeling, etc. for each detector at Tor Vergata and neutron beams.

3. **Multi-purpose fully-sensitive mass DAMA/1ton**

   Proposed by DAMA since 1996 (DAMA/NaI and DAMA/LIBRA intermediate steps, some R&D funded and carried out)

4. **New anisotropic scintillator/nanotube detectors for directionality**

MOREOVER: with our international partners developments and use of many low background/new/isotopically-enriched scintillators/samples to deeply investigate rare processes with the realization of specific high mass set-ups

DAMA – Some of the main recent and planned activities (foreseen time schedule)- 1

Set-up	Activity	Period	Sensitivity/comments
DAMA/LIBRA	Phase-1 (concuded)	2003-2010	7 annual cycles: six released giving 9σ CL for DM annual modulation; other rare processes. Various analyses in progress.
	Phase-2	2011-2017	6 years of DM annual modulation data with the new configuration (PMTs with higher QE, lower energy threshold) & analyses before first data release; other rare processes
		2017-2022	Increasing sensitivity to better disentangle further scenarios, second order effects, very high precision determination of parameters, other DM features; dedicated data taking for other specific rare processes, etc.; at end detectors at surface for specific measurements
DAMA/LXe	^{129}Xe, ^{136}Xe	ongoing-2018	Investigation of several rare processes with ^{129}Xe and ^{136}Xe. When all the goals will be reached the set-up will be brought in surface at Tor Vergata University to be used for tests and for students' applications until the cryogenic system will be operative
DAMA/R&D	past	2011-2012	$ZnWO_4$, BaF_2, $CeCl_3$, $^{106}CdWO_4$: mainly $\beta\beta$ decay searches ($T_{1/2}$ ~10^{21} yr); resonant channels; the best sensitivities in $2\beta^+$ processes
	Aurora, ^{116}Cd	2012-2017	After 5 yr of data taking, the estimated sensitivity of the $0\nu2\beta^-$ decay will be: $T_{1/2}$ ~ $(0.5–1.5)\times10^{24}$ yr ($\langle m_\nu \rangle$ ~ (0.4–1.4) eV); then, in GeMulti
	future	2017-2022	Other measurements planned, with new $ZnWO_4$ + enriched $CdWO_4$ depleted in ^{113}Cd, and with the other developed scintillators (radiopure GSO and BaF_2) after preliminary screening in DAMA/CRYS + data analyses

→

DAMA – Some of the main recent and planned activities - 2

Set-up	Activity	Period	Sensitivity/comments
DAMA/CRYS		2012-on-going	$LaCl_3(Ce)$, further R&D of radiopure $^{116}CdWO_4$ and $ZnWO_4$. During 2013 improvements in the shield handling, installation of Peltier cells (for studying the responses of some scintillators at low temperature). Many measurements on different scintillators/samples/new-detectors
DAMA/Ge and STELLA	past	2011-2013	LiF(W), $^{7}LiI(Eu)$, $SrI_2(Eu)$, Dy, Pt, Ru samples: mainly $\beta\beta$ decay searches (up to $T_{1/2}$ ~10^{21} yr); resonant channels; first observation of α decay of ^{190}Pt; solar axions
	^{106}Cd in GeMulti	2012-2015	Reachable sensitivity to $\beta\beta$ decay: $T_{1/2}$ up to 10^{21} yr, in the range of theoretical expectations for two neutrino 2ε, $\varepsilon\beta^+$, $\beta^+\beta^+$.
	Os	2012-2013	Present sensitivity to $\beta\beta$ decay searches: $T_{1/2}$ up to ~10^{19} yr; resonant channels. First observation of α decay of ^{184}Os (?)
	future	2013-2022	More sensitive measurements on $SrI_2(Eu)$, Ru, $CaF_2(Eu)$, Pt, Nd_2O_3, CeO_2, Er_2O_3, Os, Yb_2O_3, Sm_2O_3, GSO samples to investigate many rare processes; preparation and measurements of enriched $CdWO_4$ depleted in ^{113}Cd, search for γ accompanied channels of 2βdecay in ^{116}Cd

Detectors/radiopurified samples developments present & future on-going
+ development towards multi-purpose DAMA/1ton & anisotropic detectors