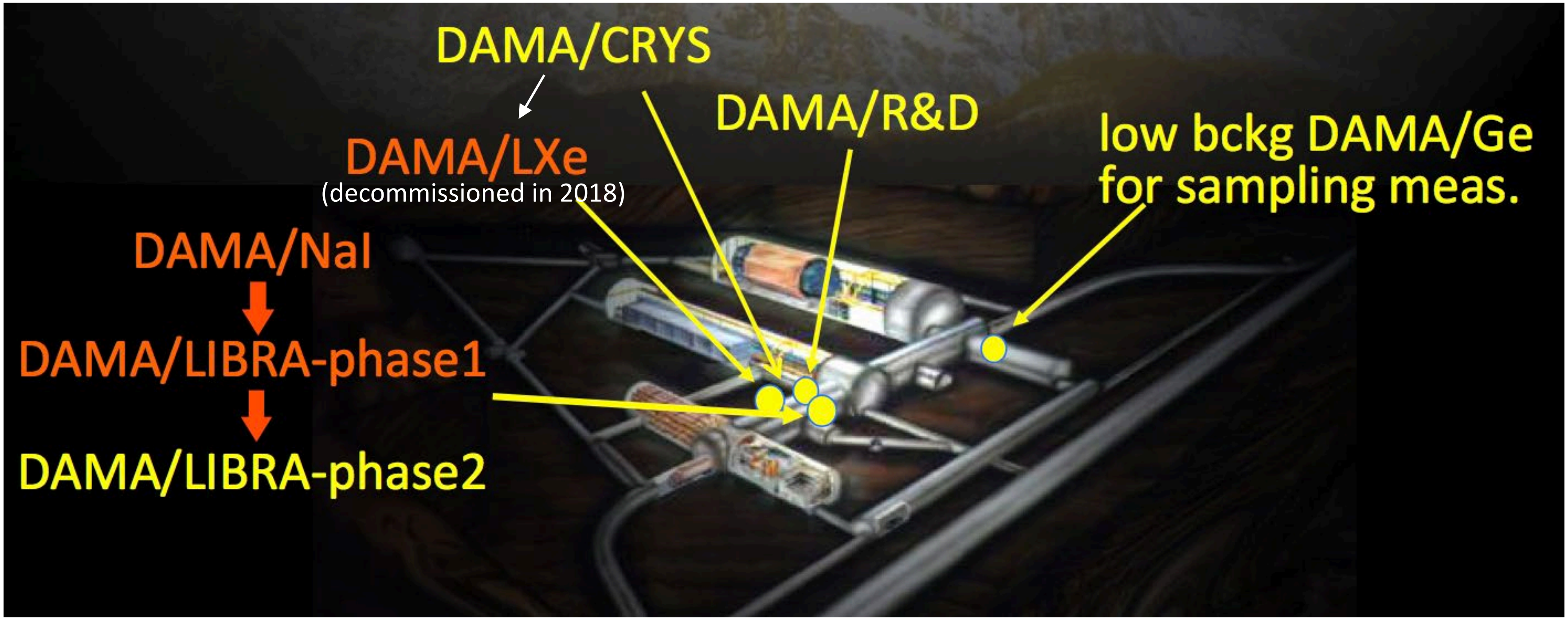
Implicazioni di DAMA/LIBRA-phase2 in vari scenari di materia oscura

105º Congresso Nazionale della Società Italiana di Fisica
L'Aquila, 23-27 settembre 2019

Vincenzo Caracciolo (Università di Roma "Tor Vergata" e INFN)
a nome della collaborazione DAMA

DAMA set-ups

an observatory for rare processes @ LNGS



Collaboration:

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

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

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

+ neutron meas.: ENEA-Frascati, ENEA-Casaccia

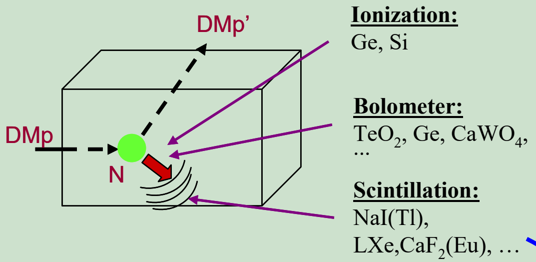
+ in some studies on ββ decays (DST-MAE and Inter-Universities project):

IIT Kharagpur and Ropar, India

Some direct detection processes:

- Scatterings on nuclei

  → detection of nuclear recoil energy



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

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

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

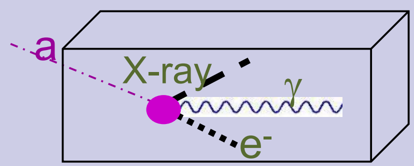
$$\frac{1}{2}\mu v^2 \geq \delta \Leftrightarrow v \geq v_{thr} = \sqrt{\frac{2\delta}{\mu}}$$

- Excitation of bound electrons in scatterings on nuclei

  → detection of recoil nuclei + e.m. radiation

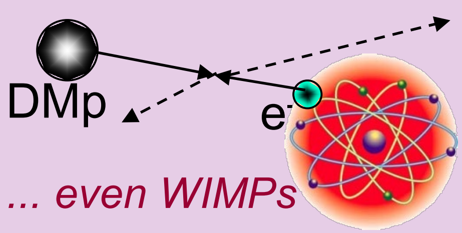
- Conversion of particle into e.m. radiation

  → detection of γ, X-rays, e$^-$



- Interaction only on atomic electrons

  → detection of e.m. radiation

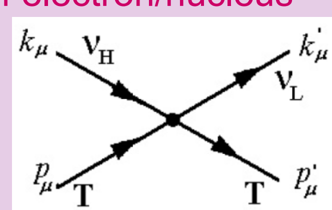


... even WIMPs

- 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

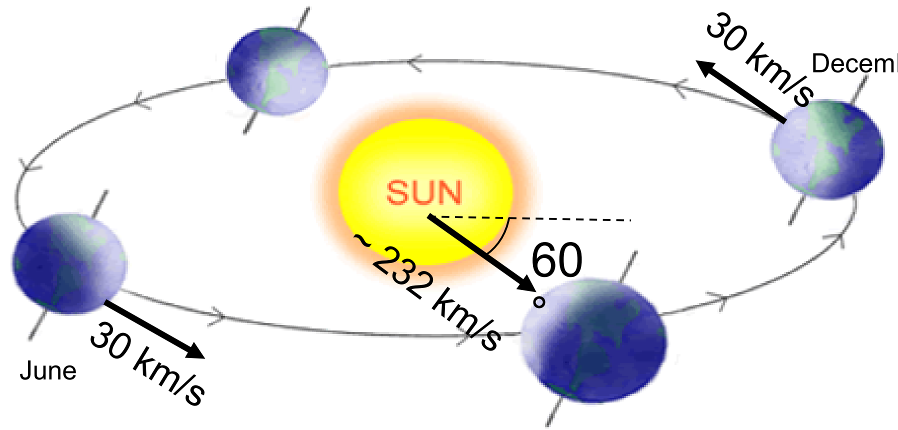
The annual modulation: a model independent signature for the investigation of DM particles component in the galactic halo

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.

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

Requirements:

1) Modulated rate according cosine
2) In low energy range
3) With a proper period (1 year)
4) With proper phase (about June 2)
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



- 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)

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

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

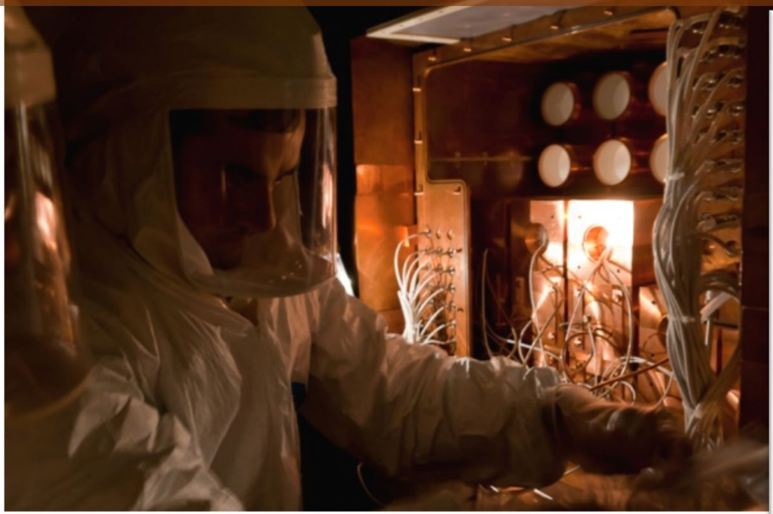
the DM annual modulation signature has a different origin and peculiarities (e.g. the phase) than those effects correlated with the seasons

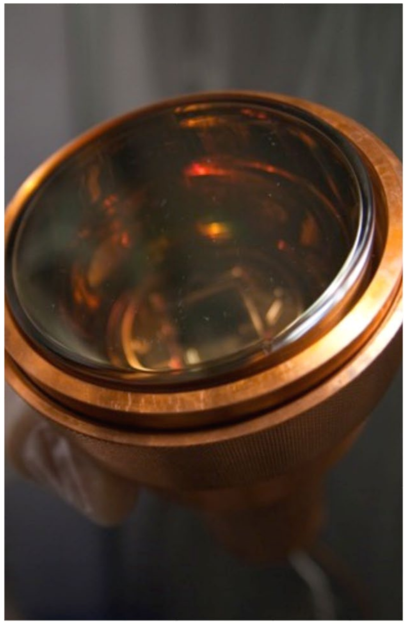
To mimic this signature, spurious effects and side reactions must not only be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

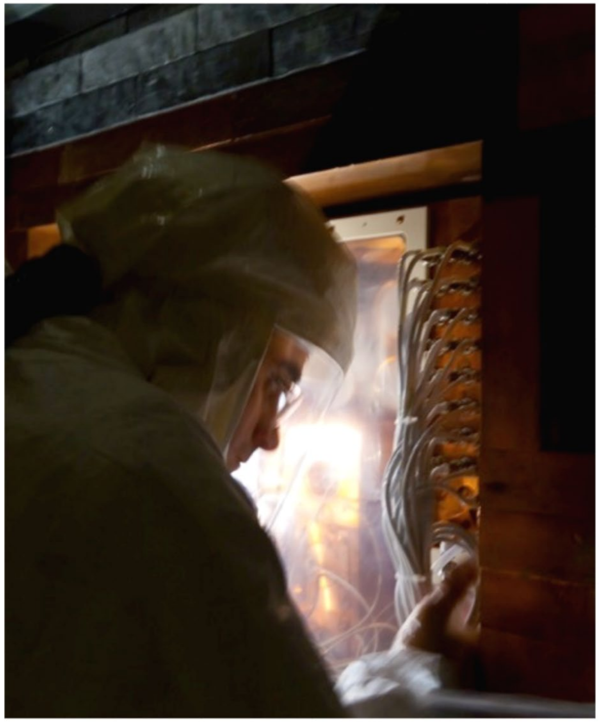
DAMA/LIBRA–phase2

JINST 7(2012)03009
Universe 4 (2018) 116
NPAE 19 (2018) 307
Bled W. in Phys.19 (2018) 27
arXiv:1907.06405

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





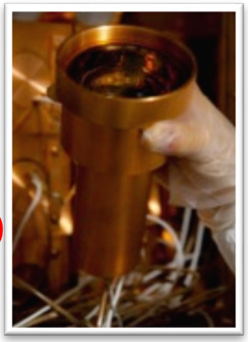


Q.E. of the new PMTs:
33 – 39% @ 420 nm
36 – 44% @ peak

DAMA/LIBRA-phase2 data taking

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

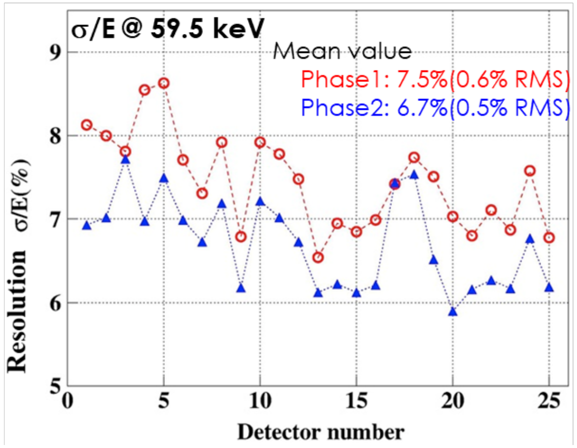
JINST 7(2012)03009



Energy resolution @ 60 keV mean value:

prev. PMTs 7.5% (0.6% RMS)
new HQE PMTs 6.7% (0.5% RMS)

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



Annual Cycles	Period	Mass (kg)	Exposure (kg×day)	$(\alpha-\beta^2)$
I	Dec 23, 2010 – Sept. 9, 2011	commissioning		
II	Nov. 2, 2011 – Sept. 11, 2012	242.5	62917	0.519
III	Oct. 8, 2012 – Sept. 2, 2013	242.5	60586	0.534
IV	Sept. 8, 2013 – Sept. 1, 2014	242.5	73792	0.479
V	Sept. 1, 2014 – Sept. 9, 2015	242.5	71180	0.486
VI	Sept. 10, 2015 – Aug. 24, 2016	242.5	67527	0.522
VII	Sept. 7, 2016 – Sept. 25, 2017	242.5	75135	0.480

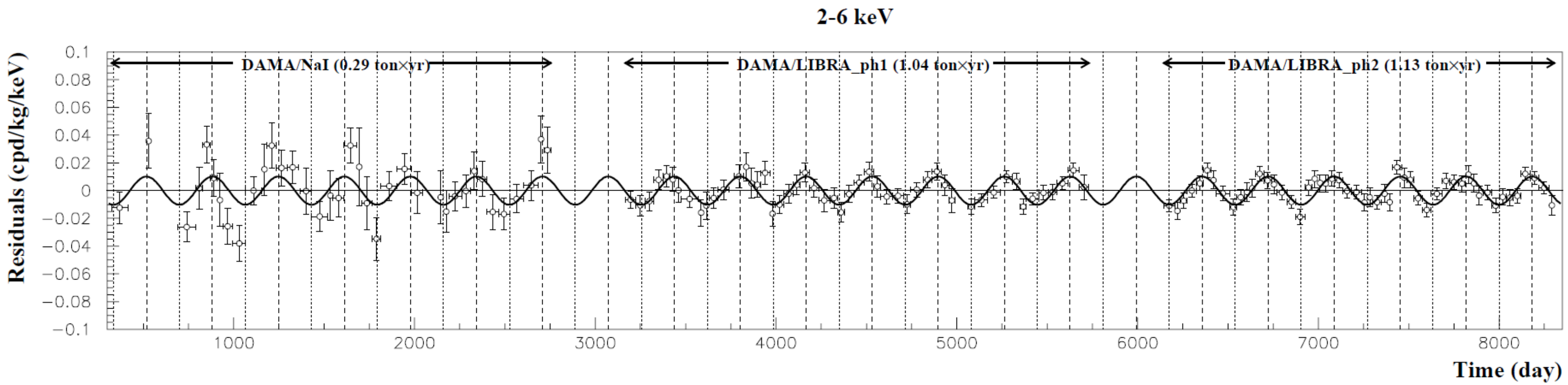
- ✓ Fall 2012: new preamplifiers installed + special trigger modules.
- ✓ Calibrations 6 a.c.: ≈ 1.3 x 10^8 events from sources
- ✓ Acceptance window eff. 6 a.c.: ≈ 3.4 x 10^6 events (≈1.4 x 10^5 events/keV)

Exposure first data release of DAMA/LIBRA-phase2: **1.13 ton x yr**
Exposure DAMA/NaI+DAMA/LIBRA-phase1+phase2: **2.46 ton x yr**

DM model-independent Annual Modulation Result

Experimental residuals of the single-hit scintillation events rate vs time and energy

DAMA/NaI+DAMA/LIBRA-phase1+DAMA/LIBRA-phase2 (2.46 ton × yr)



Fit on DAMA/NaI+ DAMA/LIBRA-ph1+ DAMA/LIBRA-ph2

$A\cos[\omega(t-t_0)]$;

continuous lines: t_0 = 152.5 d, T = 1.00 y

2-6 keV

A=(0.0102±0.0008) cpd/kg/keV

χ^2/dof = 113.8/138 **12.8 σ C.L.**

Absence of modulation? No

- 2-6 keV: χ^2/dof=272.3/142 ⇒ P(A=0) =3.0×10^{-10}

The data of DAMA/NaI + DAMA/LIBRA-phase1 +DAMA/LIBRA-phase2 favor the presence of a modulated behavior with proper features at 12.8 σ C.L.

Releasing period (T) and phase (t_0) in the fit

	ΔE	A(cpd/kg/keV)	$T=2\pi/\omega$ (yr)	t_0 (day)	C.L.
DAMA/LIBRA-ph2	(1-3) keV	0.0184±0.0023	1.0000±0.0010	153±7	8.0σ
	(1-6) keV	0.0106±0.0011	0.9993±0.0008	148±6	9.6σ
	(2-6) keV	0.0096±0.0011	0.9989±0.0010	145±7	8.7σ
DAMA/LIBRA-ph1 + DAMA/LIBRA-ph2	(2-6) keV	0.0096±0.0008	0.9987±0.0008	145±5	12.0σ
DAMA/NaI + DAMA/LIBRA-ph1 + DAMA/LIBRA-ph2	(2-6) keV	0.0103±0.0008	0.9987±0.0008	145±5	12.9σ

$A\cos[\omega(t-t_0)]$

DAMA/NaI (0.29 ton x yr)

DAMA/LIBRA-ph1 (1.04 ton x yr)

DAMA/LIBRA-ph2 (1.13 ton x yr)

total exposure = 2.46 ton×yr

The data has been analysed in many other ways (e.g. analysis in frequency, analysis for each detectors, for whole energy spectrum, to study the upper limit on S_0 component, investigations of possible systematics or side reactions suggest from different authors too, etc.): see the DAMA literature **(http://people.roma2.infn.it/~dama/web/publ.html).**

No modulation above 6 keV
This accounts for all sources of background and is consistent with the studies on the various components

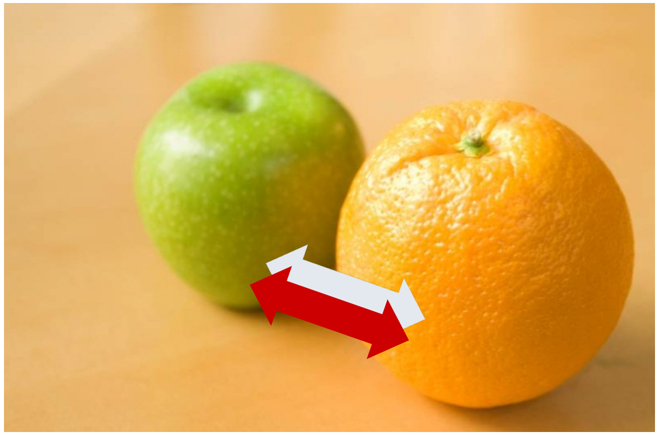
Summary of the results obtained in the additional investigations of possible systematics or side reactions – DAMA/LIBRA

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, IJMPA31(2017)issue31, Universe4(2018)03009, Beld19,2(2018)27

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**



About interpretations and comparisons

See e.g.: Riv.N.Cim.26 n.1(2003)1, IJMPD13(2004)2127, EPJC47(2006)263, IJMPA21(2006)1445, EPJC56(2008)333, PRD84(2011)055014, IJMPA28(2013)1330022

…models…

- Which particle?
- Which interaction coupling?
- Which Form Factors for each target-material?
- Which Spin Factor?
- Which nuclear model framework?
- Which scaling law?
- Which halo model, profile and related parameters?
- Streams?
- …

…and experimental aspects…

- Exposures
- Energy threshold
- Detector response (phe/keV)
- Energy scale and energy resolution
- Calibrations
- Stability of all the operating conditions.
- Selections of detectors and of data.
- Subtraction/rejection procedures and stability in time of all the selected windows and related quantities
- Efficiencies
- Definition of fiducial volume and non-uniformity
- Quenching factors, channeling, …
- …

Uncertainty in experimental parameters, as well as necessary assumptions on various related astrophysical, nuclear and particle-physics aspects, affect all the results at various extent, both in terms of exclusion plots and in terms of allowed regions/volumes. Thus comparisons with a fixed set of assumptions and parameters' values are intrinsically strongly uncertain.

No direct model-independent comparison among experiments with different target-detectors and different approaches.

arXiv:1907.06405

Model-dependent analyses for some DM candidates

Including DAMA/LIBRA/phase2

- A large (but not exhaustive) class of halo models is considered;
- Local velocity v_0 in the range [170,270] km/s;
- Halo density ρ_0 in the range:
  - [0.17, 0.67] GeV/cm^3 for v_0=170 km/s
  - [0.29, 1.11] GeV/cm^3 for v_0 = 220 km/s
  - [0.45, 1.68] GeV/cm^3 for v_0 = 270 km/s

  depending on the halo model
- v_{esc} = 550 km/s
  no sizable differences if v_{esc} in the range [550, 650]km/s
- And for DM candidates inducing nuclear recoils:
  - constants quenching factors, q.f., with respect to the recoil energy, E_R;
  - varying q.f. as a function of E_R [Astr.Phys.33, 40 (2010)];
  - channeling effect [EPJC 53, 205 (2008)]
  - Three different sets of values for the nuclear form factor and quenching factor parameters

Class A: spherical ρ_{dm}, isotropic velocity dispersion		
A0	Isothermal Sphere	
A1	Evans' logarithmic	$R_c = 5$ kpc
A2	Evans' power-law	$R_c = 16$ kpc, $\beta = 0.7$
A3	Evans' power-law	$R_c = 2$ kpc, $\beta = -0.1$
A4	Jaffe	$\alpha = 1$, $\beta = 4$, $\gamma = 2$, $a = 160$ kpc
A5	NFW	$\alpha = 1$, $\beta = 3$, $\gamma = 1$, $a = 20$ kpc
A6	Moore et al.	$\alpha = 1.5$, $\beta = 3$, $\gamma = 1.5$, $a = 28$ kpc
A7	Kravtsov et al.	$\alpha = 2$, $\beta = 3$, $\gamma = 0.4$, $a = 10$ kpc
Class B: spherical ρ_{dm}, non–isotropic velocity dispersion (Osipkov–Merrit, $\beta_0 = 0.4$)		
B1	Evans' logarithmic	$R_c = 5$ kpc
B2	Evans' power-law	$R_c = 16$ kpc, $\beta = 0.7$
B3	Evans' power-law	$R_c = 2$ kpc, $\beta = -0.1$
B4	Jaffe	$\alpha = 1$, $\beta = 4$, $\gamma = 2$, $a = 160$ kpc
B5	NFW	$\alpha = 1$, $\beta = 3$, $\gamma = 1$, $a = 20$ kpc
B6	Moore et al.	$\alpha = 1.5$, $\beta = 3$, $\gamma = 1.5$, $a = 28$ kpc
B7	Kravtsov et al.	$\alpha = 2$, $\beta = 3$, $\gamma = 0.4$, $a = 10$ kpc
Class C: Axisymmetric ρ_{dm}		
C1	Evans' logarithmic	$R_c = 0$, $q = 1/\sqrt{2}$
C2	Evans' logarithmic	$R_c = 5$ kpc, $q = 1/\sqrt{2}$
C3	Evans' power-law	$R_c = 16$ kpc, $q = 0.95$, $\beta = 0.9$
C4	Evans' power-law	$R_c = 2$ kpc, $q = 1/\sqrt{2}$, $\beta = -0.1$
Class D: Triaxial ρ_{dm} (q = 0.8, p = 0.9)		
D1	Earth on maj. axis, rad. anis.	$\delta = -1.78$
D2	Earth on maj. axis, tang. anis.	$\delta = 16$
D3	Earth on interm. axis, rad. anis.	$\delta = -1.78$
D4	Earth on interm. axis, tang. anis.	$\delta = 16$

arXiv:1907.06405

Model-dependent analyses

DM particles elastically interacting with target nuclei – SI interaction

Including DAMA/LIBRA/phase2

The point-like SI cross section of DM particles scattering off nucleus (A,Z):

$$\sigma_{SI}(A,Z) \propto m_{red}^2(A,DM)\left[f_p Z + f_n(A-Z)\right]^2$$

where f_p,f_n are the effective DM particle couplings to protons and neutrons

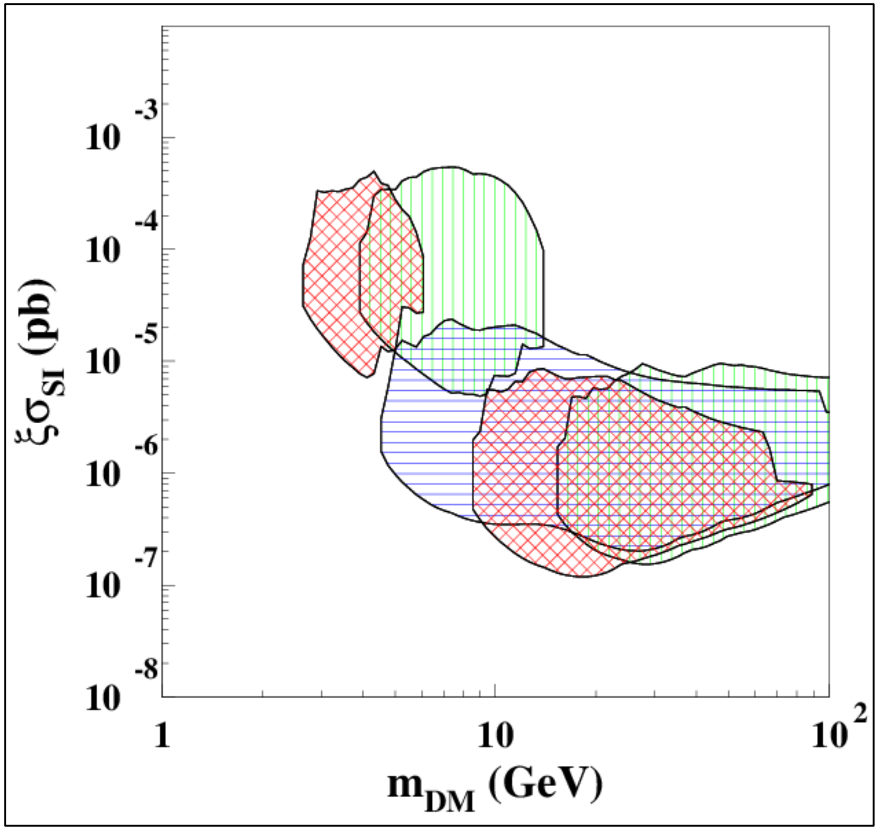
If $f_p=f_n$: $$\sigma_{SI}(A,Z) = \frac{m_{red}^2(A,DM)}{m_{red}^2(1,DM)} A^2 \sigma_{SI}$$

σ_{SI} SI point-like DM-nucleon cross section

ξ fractional amount of local density in terms of the considered DM candidate

$\xi\sigma_{SI}$ vs m_{DM}

1. Constants q.f.
2. Varying q.f.(E_R)
3. With channeling effect



Allowed DAMA regions:
Domains where the likelihood-function values differ more than 10σ from absence of signal

arXiv:1907.06405

Model-dependent analyses

DM particles elastically interacting with target nuclei

SI-IV interaction

Including DAMA/LIBRA/phase2

Case of isospin violating SI coupling:

$f_p \neq f_n$

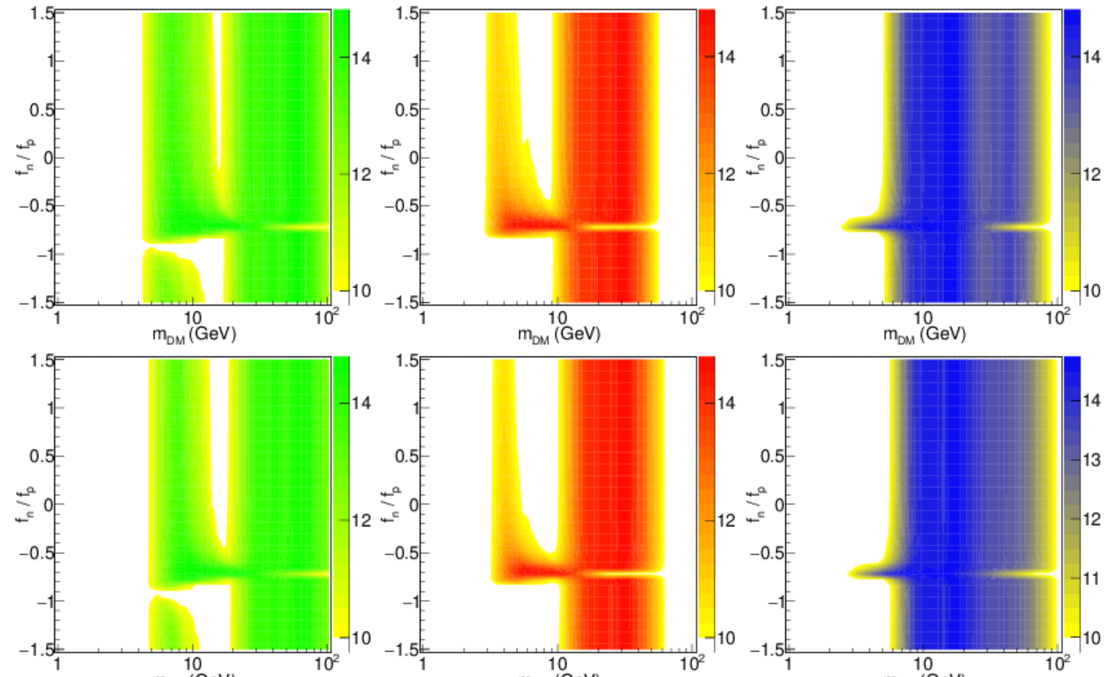
$$\sigma_{SI}(A,Z) \propto m_{red}^2(A,DM)\left[f_p Z + f_n(A-Z)\right]^2$$

f_n/f_p vs m_{DM}

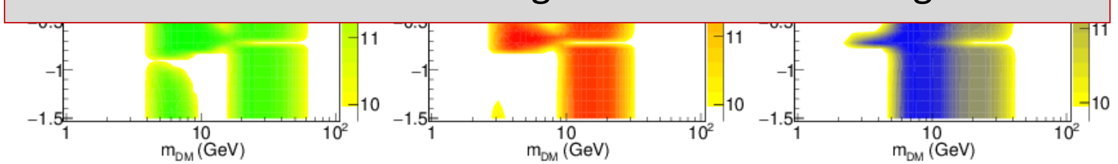
marginalizing on $\xi\sigma_{SI}$

1. **Constants q.f.**
2. **Varying q.f.(E_R)**
3. **With channeling effect**

Allowed DAMA regions for A0 (isothermal sphere), B1, C1, D3 halo models (top to bottom)



- Two bands at low mass and at higher mass;
- Good fit for low mass DM candidates at $f_n/f_p \approx$ -53/74 = = -0.72 (signal mostly due to ^{23}Na recoils).
- Contrary to what was stated in Ref. [PLB789,262(2019), JCAP07,016(2018), JCAP05,074(2018)] where the low mass DM candidates were disfavored for f_n/f_p = 1 by DAMA data, the inclusion of the uncertainties related to halo models, quenching factors, channeling effect, nuclear form factors, etc., can also support low mass DM candidates either including or not the channeling effect.



arXiv:1907.06405

Model-dependent analyses

DM particles elastically interacting with target nuclei – purely SD interaction

Including DAMA/LIBRA/phase2

Possible only for target nuclei with spin≠0

A further parameter, θ, is needed:

$$\tan\theta = \frac{a_n}{a_p}, \qquad \theta \text{ in } [0,\pi]$$

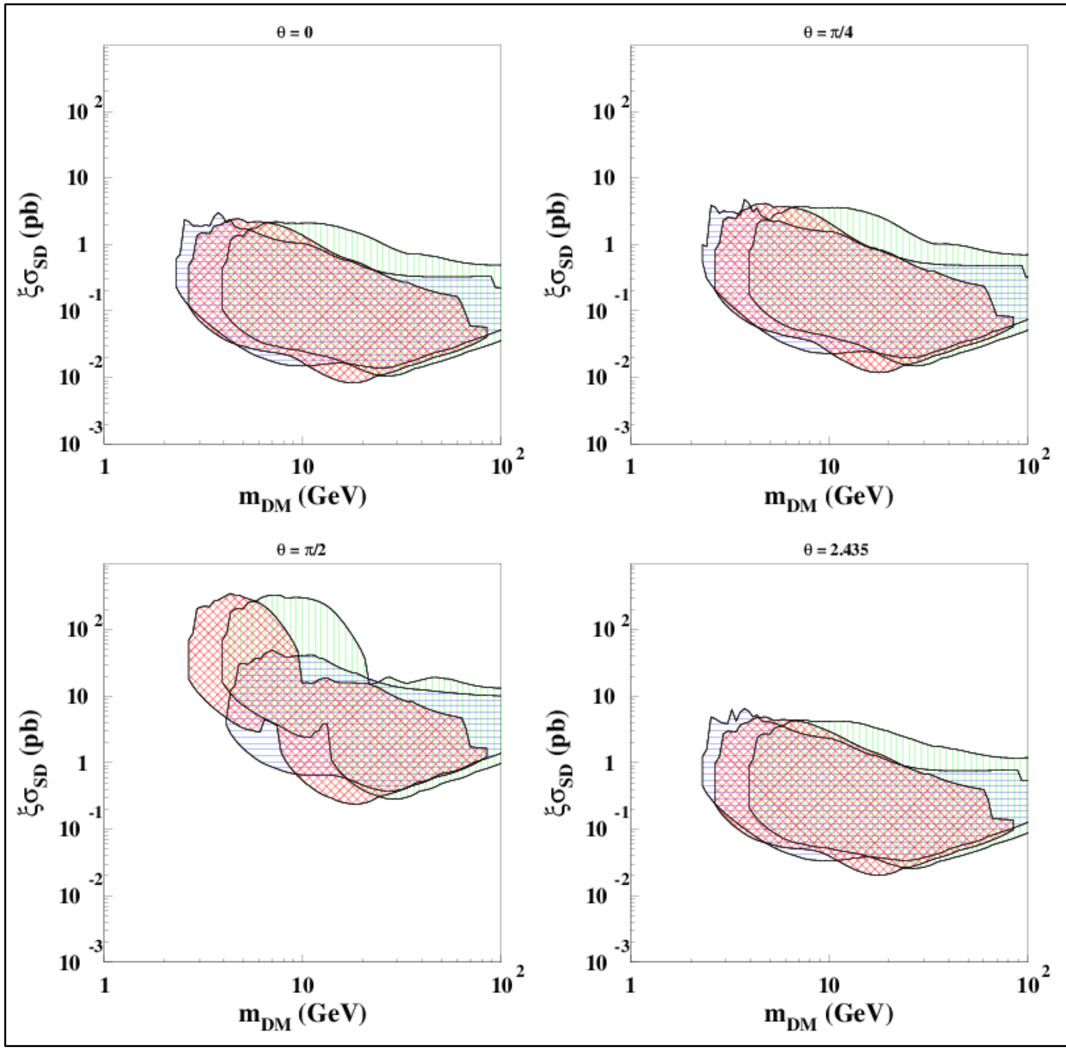
a_p and a_n are the effective DM-nucleon coupling strengths for SD interactions

Slices at fixed θ values of the 3-dim allowed volume ($\xi\sigma_{SD}$, θ, m_{DM})

$\theta = 0$ $\Rightarrow$ $a_n=0$, $a_p \neq 0$ or $|a_p|>>|a_n|$;
$\theta = \pi/4$ $\Rightarrow$ $a_n=a_p$;
$\theta = \pi/2$ $\Rightarrow$ $a_p=0$, $a_n \neq 0$ or $|a_n|>>|a_p|$;
$\theta = 2.435$rad $\Rightarrow$ $a_n/a_p=-0.85$, pure Z_0 coupling

$\xi\sigma_{SD}$ vs m_{DM}

1. Constants q.f.
2. Varying q.f.(E_R)
3. With channeling effect



Model-dependent analyses

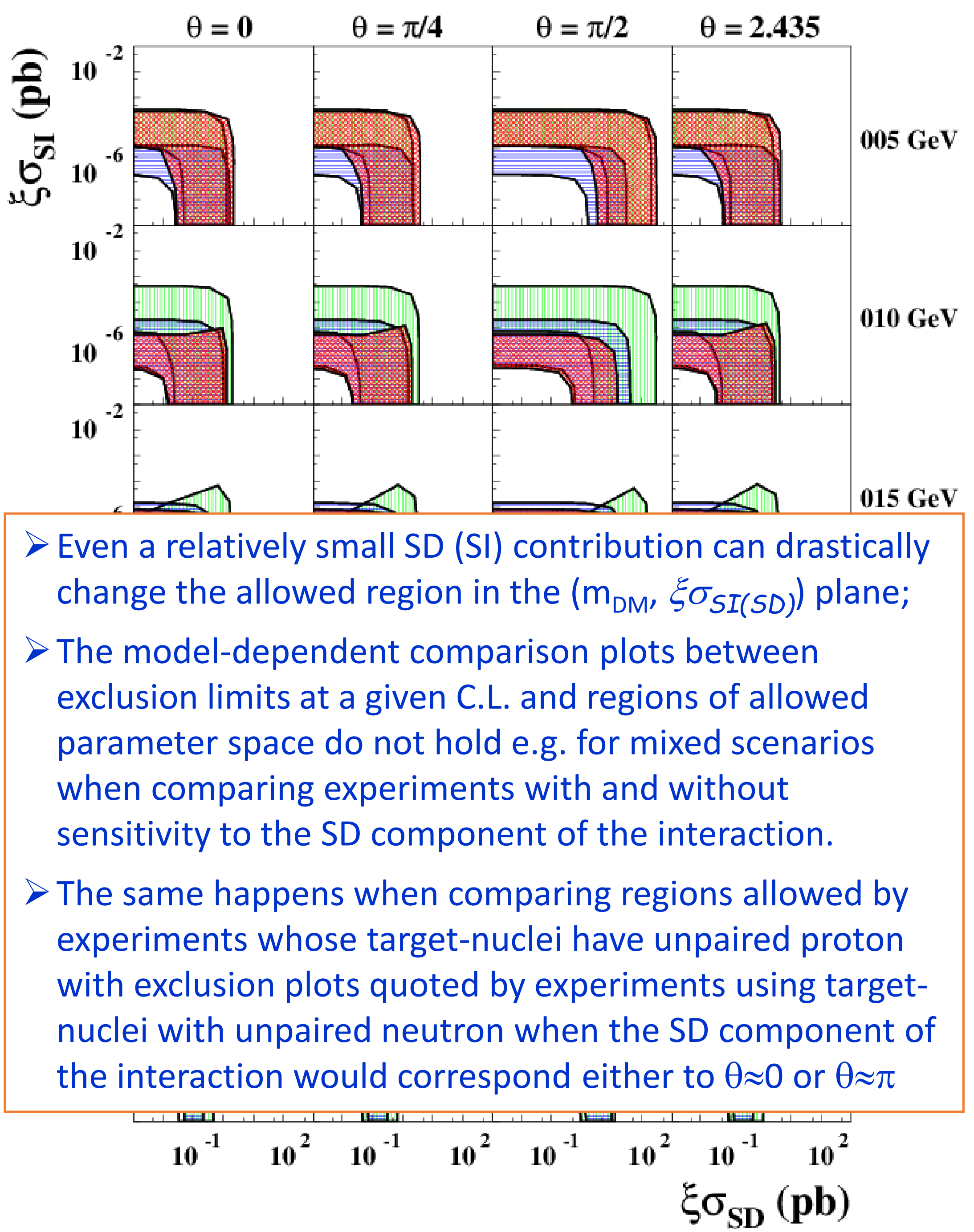
DM particles elastically interacting with target nuclei

Mixed SI-SD interaction

Including DAMA/LIBRA/phase2

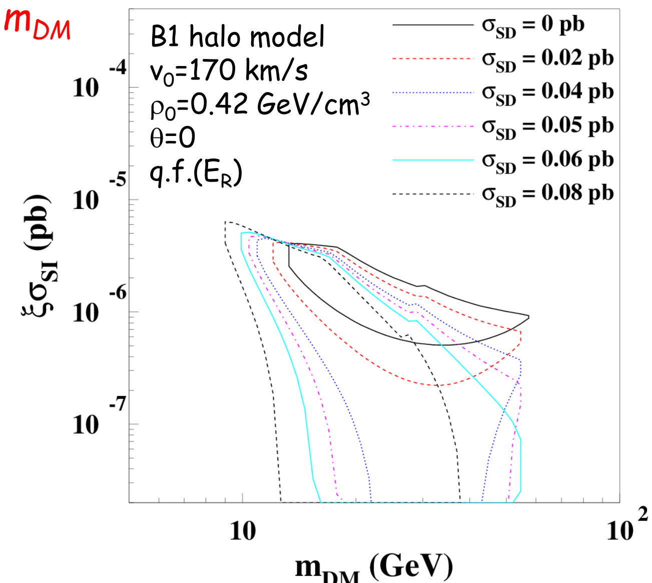
Slices of the 4-dim allowed volume ($\xi\sigma_{SI}$, $\xi\sigma_{SD}$, θ, m_{DM})

1. **Constants q.f.**
2. **Varying q.f.(E_R)**
3. **With channeling effect**



- Even a relatively small SD (SI) contribution can drastically change the allowed region in the (m_{DM}, $\xi\sigma_{SI(SD)}$) plane;
- The model-dependent comparison plots between exclusion limits at a given C.L. and regions of allowed parameter space do not hold e.g. for mixed scenarios when comparing experiments with and without sensitivity to the SD component of the interaction.
- The same happens when comparing regions allowed by experiments whose target-nuclei have unpaired proton with exclusion plots quoted by experiments using target-nuclei with unpaired neutron when the SD component of the interaction would correspond either to $\theta \approx 0$ or $\theta \approx \pi$

Effect induced by the inclusion of a SD component on allowed regions in the plane $\xi\sigma_{SI}$ vs m_{DM}



arXiv:1907.06405

arXiv:1907.06405

Model-dependent analyses

Inelastic DM in the scenario of Smith and Weiner [Phys. Rev. D 64, 043502 (2001)]

Including DAMA/LIBRA/phase2

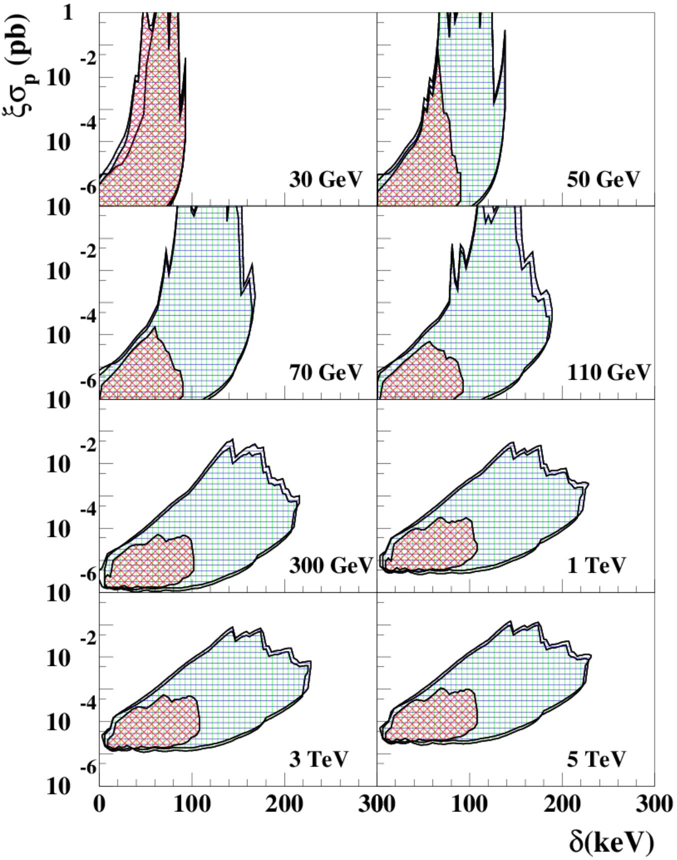
W + N → W* + N

→ W has 2 mass states $\chi+$, $\chi-$ with δ mass splitting

→ Kinematical constraint for the inelastic scattering of $\chi-$ on a nucleus (μ: χ-nucleus reduced mass)

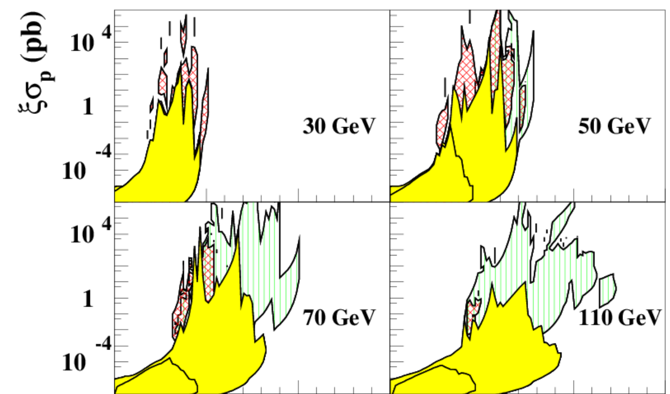
$$\frac{1}{2}\mu v^2 \geq \delta \Leftrightarrow v \geq v_{thr} = \sqrt{\frac{2\delta}{\mu}}$$

- Higher mass target-nuclei are favourites
- Enhanced S_m with respect to S_0



Slices of the 3-dim allowed volume ($\xi\sigma_p$, m_{DM}, δ)

1. Constants q.f.
2. Varying q.f.(E_R)
3. With channeling effect



Including Thallium: new allowed regions

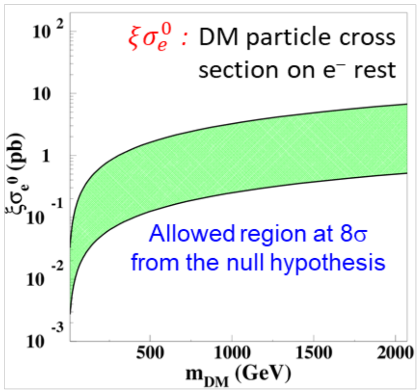
- New regions with $\xi\sigma_p > 1$ pb and $\delta > 100$ keV are allowed by DAMA after the inclusion of the inelastic scattering off Thallium nuclei.
- Such regions are not fully accessible to detectors with target nuclei having mass lower than Thallium.

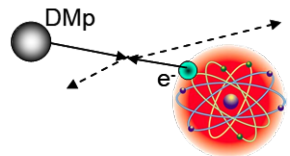
Other model-dependent analyses

Including arXiv:1907.06405
DAMA/LIBRA/phase2

DM particles with preferred electron interaction

They offer a possible source of the 511 keV photons observed from the galactic bulge





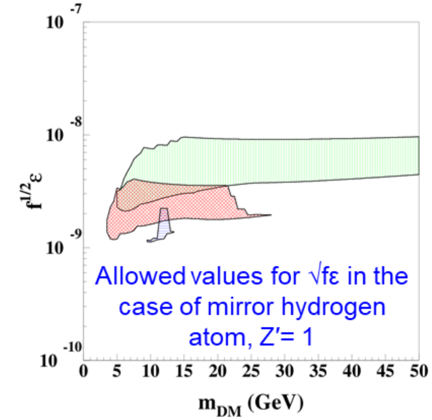
DM candidate particles with mass ≈ few GeV can interact on bound electrons with p ≈ few MeV/c and provide signals in the keV region

Mirror Dark Matter

Asymmetric mirror matter: mirror parity spontaneously broken ⇒ mirror sector becomes a heavier and deformed copy of ordinary sector

- Interaction portal: photon - mirror photon kinetic mixing $\frac{\epsilon}{2}F^{\mu\nu}F'_{\mu\nu}$
- mirror atom scattering of the ordinary target nuclei in the NaI(Tl) detectors of DAMA/LIBRA set-up with the Rutherford-like cross sections.

$\sqrt{f}\cdot\epsilon$ coupling const. and fraction of mirror atom

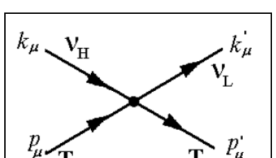


Allowed values for √fε in the case of mirror hydrogen atom, Z′= 1

Light Dark Matter

Elastic scattering of LDM (sub-GeV mass) particles both off electrons and off nuclei yields energy releases hardly detectable by the detectors

Investigation on the direct detection of LDM candidate particles by considering inelastic scattering channels on the electron or on the nucleus

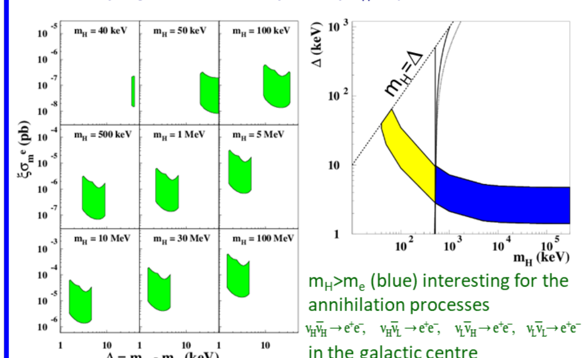


$\Delta = m_H - m_L$

ν_L is neutral, weakly interacting and can escape the detector

Electron interacting LDM

Examples of slices of the 3-dim allowed volume (m_H, $\xi\sigma_m^e$, Δ) and their projection on the plane (m_H, Δ)

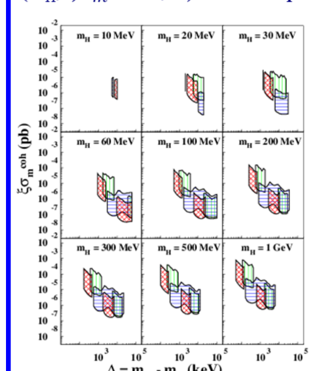


$m_H > m_e$ (blue) interesting for the annihilation processes
$\nu_H\bar{\nu}_H \to e^+e^-$, $\nu_H\bar{\nu}_L \to e^+e^-$, $\nu_L\bar{\nu}_H \to e^+e^-$, $\nu_L\bar{\nu}_L \to e^+e^-$
in the galactic centre

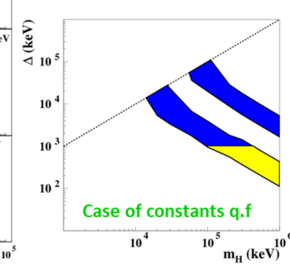
Electron interacting LDM in the few-tens-keV/sub-MeV range allowed by DAMA can be of interest, e.g., in the models of WDM particles (e.g. weakly sterile neutrino)

Nucleus interacting LDM

Example of slices (coherent case) of the 3-dim allowed volume (m_H, $\xi\sigma_m^{nucleus}$, Δ) and their projection on the plane (m_H, Δ)



Two volumes from inter. on:
- I (larger Δ at m_H fixed)
- Na (smaller Δ at m_H fixed)



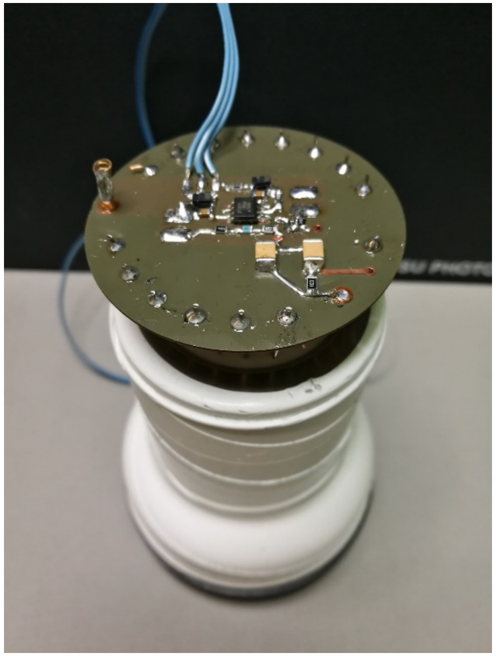
1. Constants q.f.
2. Varying q.f.(E_R)
3. With channeling effect

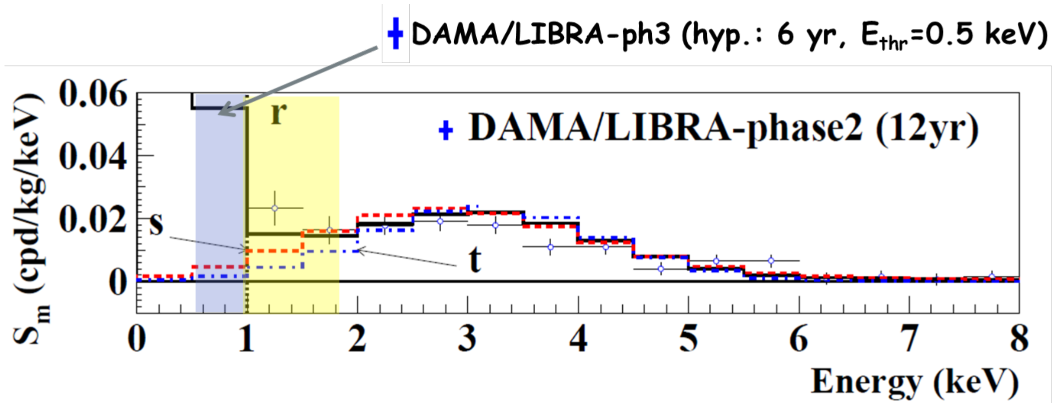
If $\Delta > 2m_e$ (blue): $\nu_H \to \nu_L e^+ e^-$ allowed

Toward DAMA/LIBRA-phase3

updating hardware to lower software energy threshold below 1 keV

new miniaturized low background **pre-amps** directly installed on the low-background supports of the **voltage dividers** of the new lower background high Q.E. **PMTs**





The presently-reached metallic PMTs features:

- Q.E. around 35-40% @ 420 nm (NaI(Tl) light)
- Radio-purity 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).

several prototypes from a dedicated R&D with HAMAMATSU at hand

Features of the DM signal investigated by DAMA at various levels; improvements foreseen with DAMA/LIBRA-phase3

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

High exposure and low energy threshold can allow 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**

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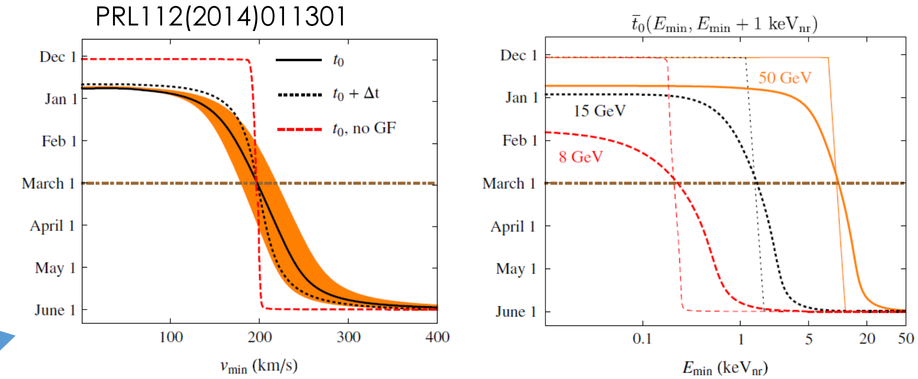
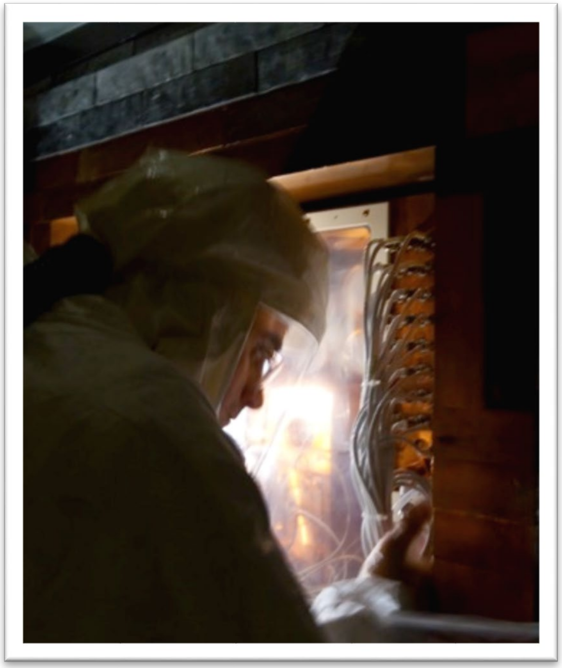
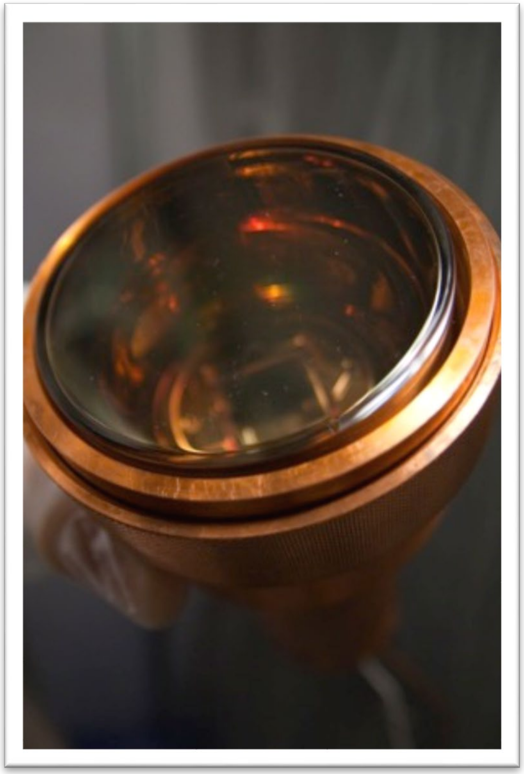


Conclusions



- Model-independent evidence for a signal that satisfies all the requirement of the DM annual modulation signature at **12.9σ** C.L. (20 independent annual cycles with 3 different set-ups: 2.46 ton × yr)
- Modulation parameters determined with increasing precision
- New investigations on different peculiarities of the DM signal exploited in progress



- 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**
- Model dependent analyses on new data allowed significantly improving the C.L. and restricting the allowed parameters' space for the various scenarios with respect to previous DAMA analysis
- DAMA/LIBRA–phase2 **continuing data taking**
- DAMA/LIBRA–phase3 **R&D almost concluded**
- Continuing investigations of **rare processes** other than DM