DARK MATTER SEARCH

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23/5/2005
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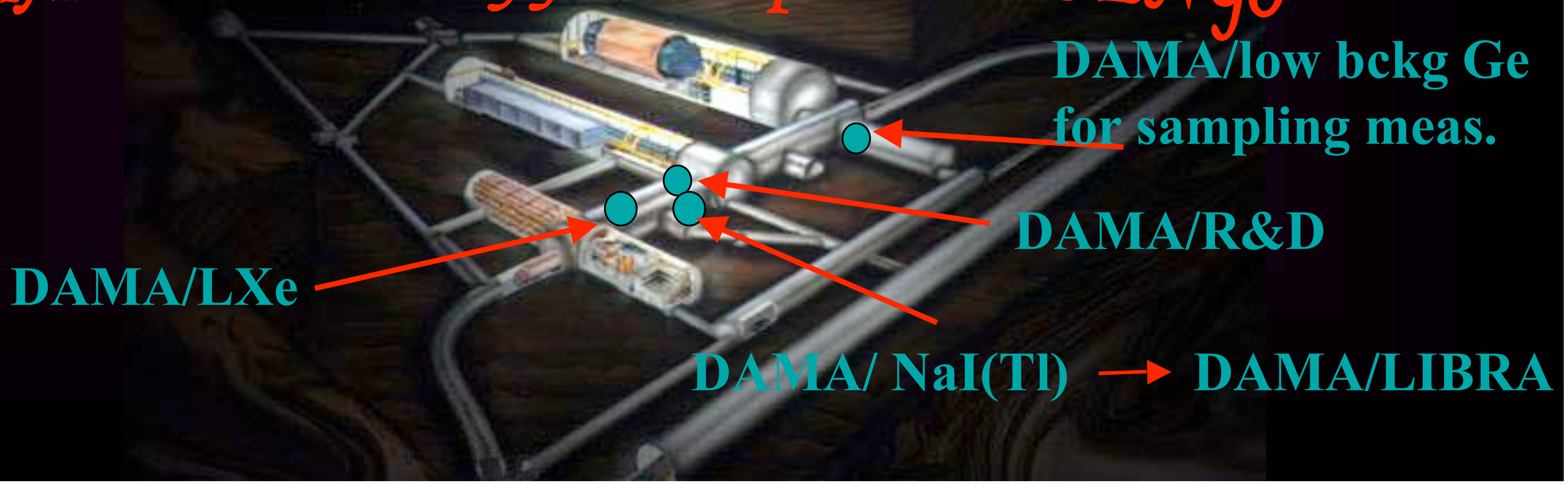
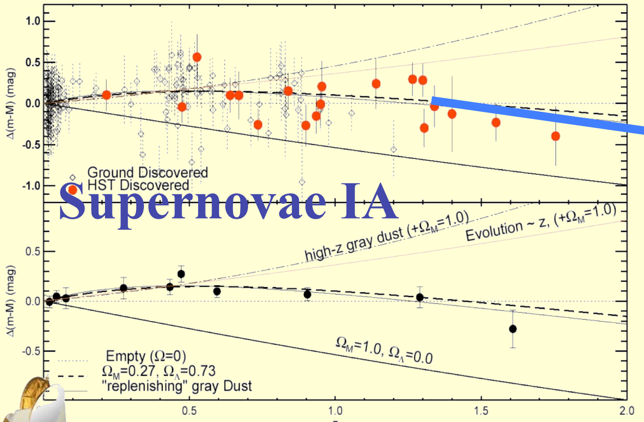
DAMA: an observatory for rare processes @LNGS

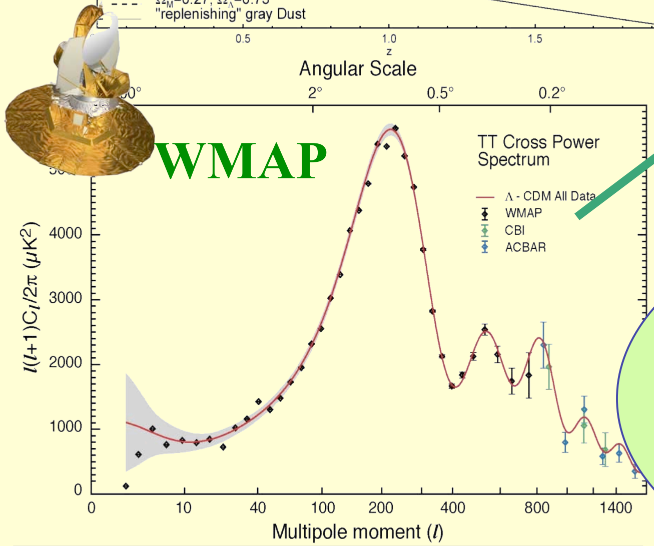


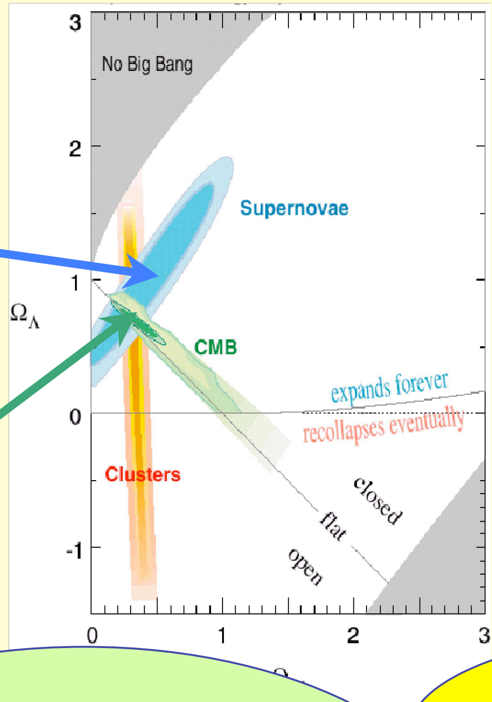
"Concordance model "



Supernovae IA

WMAP





The Universe is flat

$\Omega = \Omega_M + \Omega_\Lambda =$ 1.02±0.02

$\Omega_\Lambda \approx 0.73;$

$\Omega_M \approx 0.27;$

Observations on:
- light nuclei abundance
- microlensings
- rotational curves
- visible light.

Primordial Nucleosynthesis

Structure formation in the Universe

The baryons give "too small" contribution

$\Omega_b \sim 4\%$

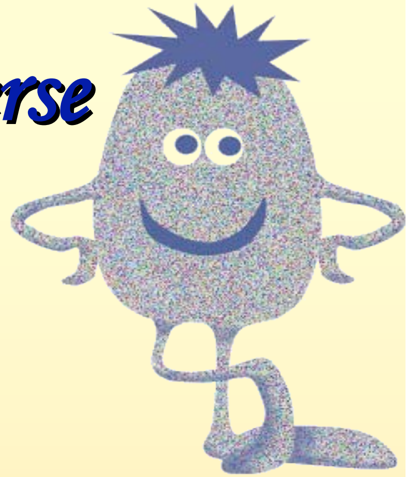
Non baryonic **Cold Dark Matter** is dominant

$\Omega_{CDM} \sim 23\%,$
$\Omega_{HDM,\nu} < 1\ \%$

~ 90% of the matter in the Universe is non baryonic

A large part of the Universe is in form of non baryonic Cold Dark Matter particles

Relic CDM particles from primordial Universe



Light candidates: axion, axion-like produced at rest

Heavy candidates:

- **In thermal equilibrium in the early stage of Universe**
- **Non relativistic at decoupling time (that is, COLD dark matter)**

  $<\sigma_{ann} \cdot v> \sim 10^{-26}/\Omega_{WIMP}h^2\ cm^3s^{-1} \quad \rightarrow \quad \sigma_{ordinary\ matter} \sim \sigma_{weak}$
- **Expected flux:** $\Phi \sim 10^7 \cdot (GeV/m_W)\ cm^{-2}\ s^{-1}$ $(0.2 < \rho_{halo} < 1.7\ GeV\ cm^{-3})$
- **Form a dissipationless gas trapped in the gravitational field of the Galaxy ($v \sim 10^{-3}c$)**
- **neutral**
- **stable (or quasi-stable with half life ~ age of Universe)**
- **massive**
- **weakly interacting**

the sneutrino in the Smith and Weiner scenario

SUSY
(R-parity conserved → LSP is stable)
neutralino or sneutrino

self-interacting dark matter

+

a heavy ν of the 4-th family

mirror dark matter

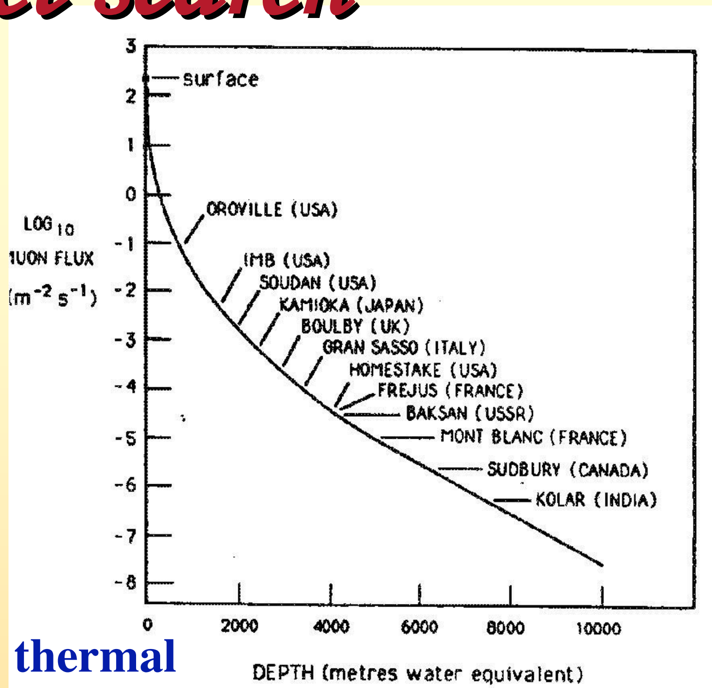
heavy exotic canditates, as "4th family atoms", ...

even a particle not yet foreseen by theories

Kaluza-Klein particles

For the DM direct search

- Underground site
- Low bckg hard shields against γ's, neutrons
- Lowering bckg: selection of materials, purifications, growing techniques, ...
- Rn removal systems



Background sources

- Background at LNGS:

muons → **$0.6\ \mu/(m^2h)$**

neutrons → **$1.08 \cdot 10^{-6}$ n/(cm²s) thermal**

$1.98 \cdot 10^{-6}$ n/(cm²s) epithermal

$0.09 \cdot 10^{-6}$ n/(cm²s) fast (>2.5 MeV)

Radon in the hall → **≈30 Bq/m³**

- Internal Background:

selected materials (Ge, NaI, AAS, MS, ...)

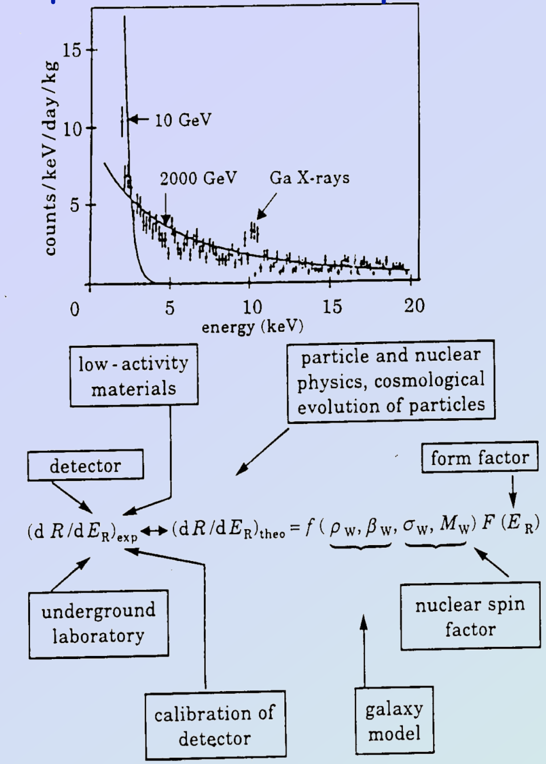
Shielding

Passive shield: Lead (Boliden [< 30 Bq/kg from ^{210}Pb], LC2 [<0.3 Bq/kg from ^{210}Pb], lead from old roman galena), OFHC Copper, Neutron shield (low A materials, n-absorber foils)

Active shield: Low activity NaI(Tl) surrounding the detectors

The "traditional" approach

- Experimental vs Expected spectra (with or without bckg rejection)

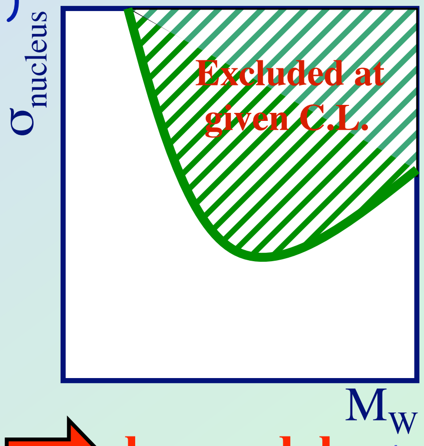


several assumptions and modeling required

+

experimental and theoretical uncertainties generally not included in calculations

Exclusion plot



by model: σ_p

An exclusion plot not an absolute limit. When different target nuclei, no absolute comparison possible.

- No discovery potentiality
- Uncertainties in the exclusion plots and in their comparison
- Warning: limitations in the recoil/background discrimination (always not event by event): PSD (τ of the pulse depends on the particle) in scintillators (NaI(Tl), LXe), Heat/Ionization (Ge), Heat/Scintillation (CaF_2(Eu), $CaWO_4$).

To have a potentiality of discovery a *model independent signature* is needed !

Direct search: A DM model independent signature is needed

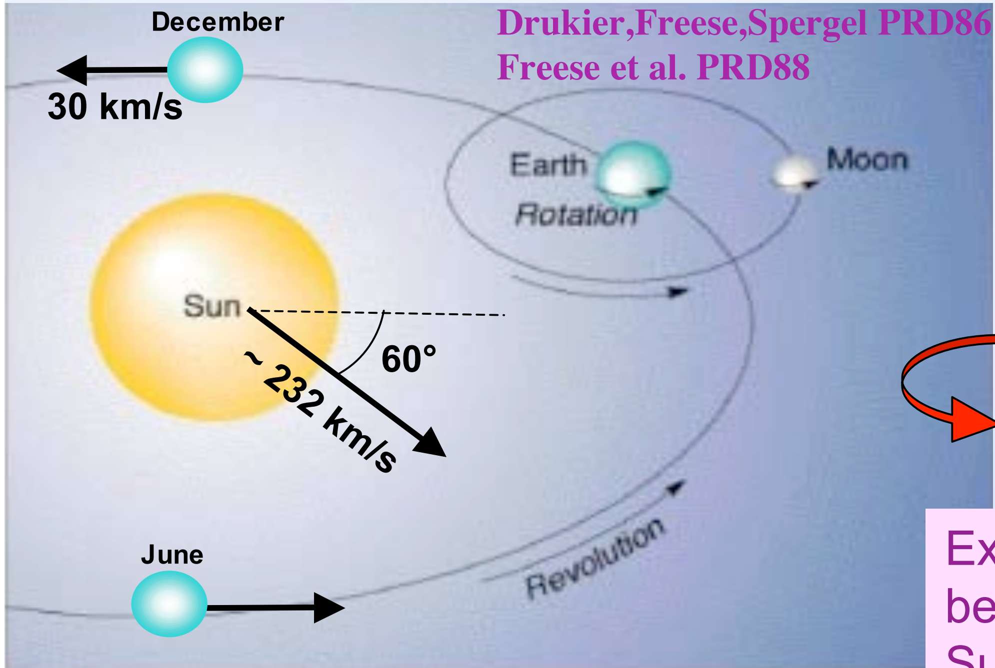
Directionality Correlation of nuclear recoil track with Earth's galactic motion due to the distribution of DM particle velocities very hard to realize

Nuclear-inelastic scattering Detection of γ's emitted by excited nucleus after a nuclear-inelastic scattering. very large exposure and very low counting rates hard to realize

Annual modulation Annual variation of the interaction rate due to Earth motion around the Sun. at present the only feasible one

Diurnal modulation Daily variation of the interaction rate due to different Earth depth crossed by the DM particle only for high σ

Investigating the presence of a DM particle component in the galactic halo by the model independent annual modulation signature



Drukier,Freese,Spergel PRD86
Freese et al. PRD88

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

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

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

Expected rate in given energy bin changes because of the Earth's motion around the Sun moving in the Galaxy

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) For single hit in a multi-detector set-up
6) With modulated amplitude in the region of maximal sensitivity < 7% (larger for DM particles with preferred inelastic interaction, PRD64 (2001)043502, or if contributions from Sagittarius, astro-ph/0309279)

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 these 6 requirements

First STEP

- The investigation on the annual modulation signature is model independent
- If all the signature's features are satisfied by the data this point out the presence of DM particles in the galactic halo at a certain C.L..

Second STEP

corollary quest for a candidate

To investigate the nature and coupling with ordinary matter of the possible DM candidate, an effective energy and time correlation analysis of the events has to be performed within given model frameworks

THUS

uncertainties on models and comparisons

?

ρ_W

DM particle's velocity distribution and its parameters

coupling: SI, SD, mixed SI&SD, preferred inelastic, ...

new contributions to DM particle-nucleus scattering? (see e.g. astro-ph/0309115)

scaling laws on cross sections

form factors and related parameters

spin factors etc.

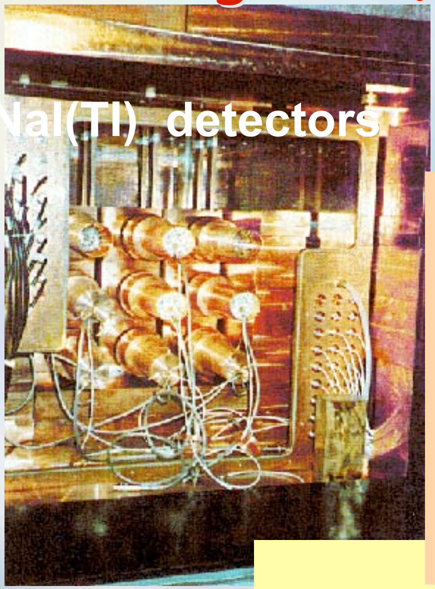
They can affect not only the corollary estimated regions following a positive effect from the DM annual modulation signature, but also results given as exclusion plots

\+

experimental parameters (typical of each experiment)

comparison within particle models

~100 kg NaI(Tl) DAMA set-up: data taking completed on July 2002



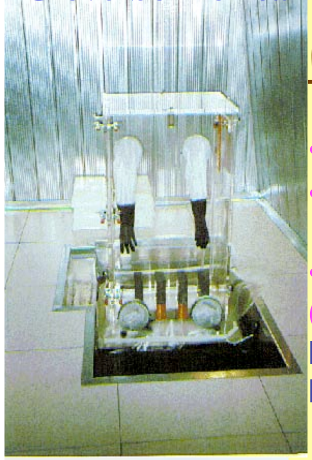
Performances:

N.Cim.A112(1999)545, EPJC18(2000)283
Riv. N. Cim. 26 n. 1 (2003) 1-73

Results on rare processes:

- Possible Pauli exclusion principle violation — PLB408(1997)439
- Nuclear level excitation of ^{127}I and ^{23}Na during CNC processes — PRC60(1999)065501
- Electron stability and non-paulian transitions in Iodine atoms (by L-shell) — PLB460(1999)235
- Exotic Dark Matter search — PRL83(1999)4918
- Search for solar axions by Primakoff effect in NaI(Tl) crystals — PLB515(2001)6
- Exotic Matter search — EPJdirect C14(2002)1
- Search for superdense nuclear matter — EPJA23(2005)7
- Search for heavy clusters decays — EPJA24(2005)51

Glove-box for calibration



Results on WIMPS:

- PSD: PLB389(1996)757
- Investigation on diurnal effect: N.Cim.A112(1999)1541
- Annual Modulation Signature (up to 57986 kg ·d - 4 cycles): PLB424(1998)195, PLB450(1999)448, PRD61(1999)023512, PLB480(2000)23, PLB509(2001)197, EPJ C18(2000)283, EPJ C23 (2002)61, PRD66(2002)043503, Riv. N. Cim. 26 n.1 (2003)1-73, IJMPD13(2004)2127 (astro-ph/0501412

during installation

total exposure collected during 7 annual cycles 107731 kg·d

Riv. N. Cim. 26 n. 1 (2003) 1-73
(astro-ph/0307403)

NaI(Tl) well suitable to investigate the annual modulation signature of DM particle

- Well known technology
- Large mass possible
- Small underground space needed
- High radiopurity by selections, chem./phys. purifications, protocols reachable
- Well controlled operational condition feasible
- Routine calibrations feasible down to keV range in the same conditions as the production runs
- Neither re-purification procedures nor cooling down/warming up (reproducibility, stability, ...)
- Absence of microphonic noise + effective noise rejection at threshold (τ of NaI(Tl) pulses hundreds ns, while τ of noise pulses tens ns)
- High light response (5.5 -7.5 ph.e./keV)(e.g. Xe has 1 ph.e./keV)
- Sensitive to SI, SD, SI&SD couplings and to other existing scenarios, on the contrary of many other proposed target-nuclei
- Sensitive to both high (by Iodine target) and low mass (by Na target) candidates
- High duty cycle
- etc.

A low background NaI(Tl) also allows the study of several other rare processes such as: possible processes violating the Pauli exclusion principle, CNC processes in ^{23}Na and ^{127}I, electron stability, nucleon and di-nucleon decay into invisible channels, neutral SIMP and nuclearites search, solar axion search, ...

High benefits/cost

The model independent result

107731 kg · d

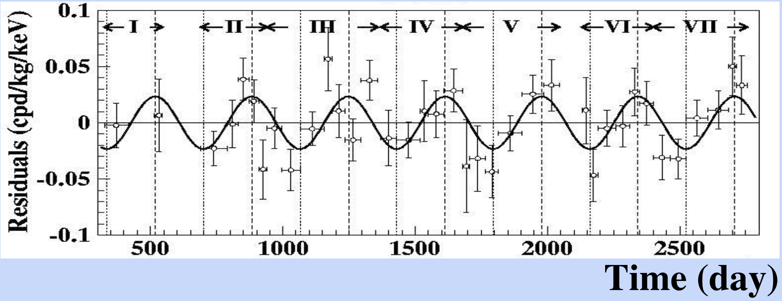
Annual modulation of the rate: DAMA/NaI 7 annual cycles

Riv. N. Cim. 26 n.1. (2003) 1-73

Experimental single-hit residuals rate vs time and energy

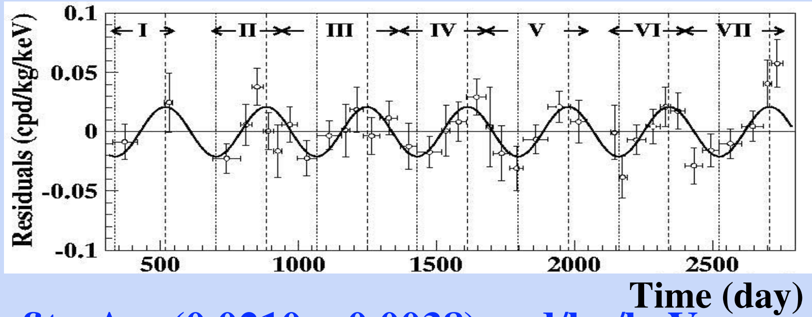
$A\cos[\omega(t-t_0)]$; continuous lines: t_0 = 152.5 d, T = 1.00 y

2-4 keV



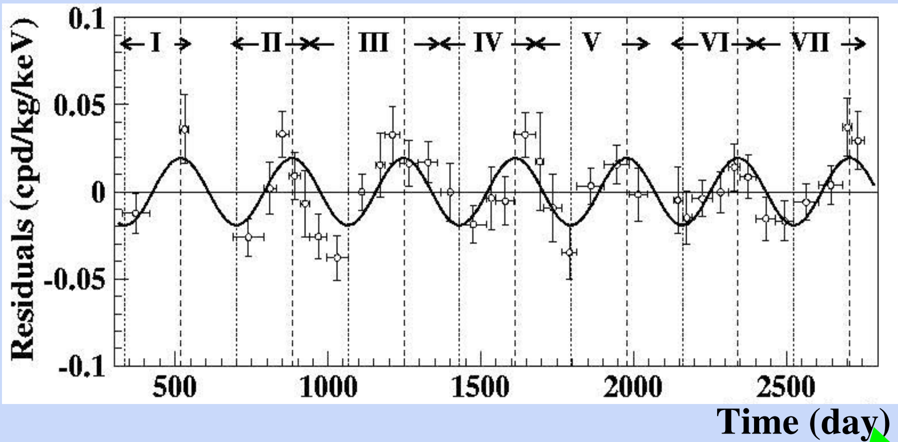
fit: A = (0.0233 ± 0.0047) cpd/kg/keV

2-5 keV



fit: A = (0.0210 ± 0.0038) cpd/kg/keV

2-6 keV



Absence of modulation? No

χ^2/dof=71/37 → P(A=0)=$7\cdot10^{-4}$

fit: A = (0.0192 ± 0.0031)cpd/kg/keV

fit (all parameters free):

A = (0.0200 ± 0.0032) cpd/kg/keV ;

t_0 = (140 ± 22) d ; T = (1.00 ±0.01) y

The data favour the presence of a modulated behaviour with proper features at 6.3σ C.L.

These residual rates are calculated from the measured rate after subtracting the constant part (the weighted mean of the residuals must obviously be zero over each period):

$$\left\langle r_{ijk} - flat_{jk} \right\rangle_{jk}$$

There the r_{ijk} is the rate in the considered i-th time interval for the j-th detector in the k-th considered energy bin, while $flat_{jk}$ is the rate of the j-th detector in the k-th energy bin averaged over the cycles. The average is made on all the detectors (j index) and on all the energy bins in the considered energy interval.

Model-independent residual rate for single hit events

Results of the fits keeping all parameters free:

(2-4) keV

$A = (0.0252 \pm 0.0050)$ cpd/kg/keV
$t_0 = (125 \pm 30)$ d
$T = (1.01 \pm 0.02)$ y

(2-5) keV

$A = (0.0215 \pm 0.0039)$ cpd/kg/keV
$t_0 = (140 \pm 30)$ d
$T = (1.01 \pm 0.02)$ y

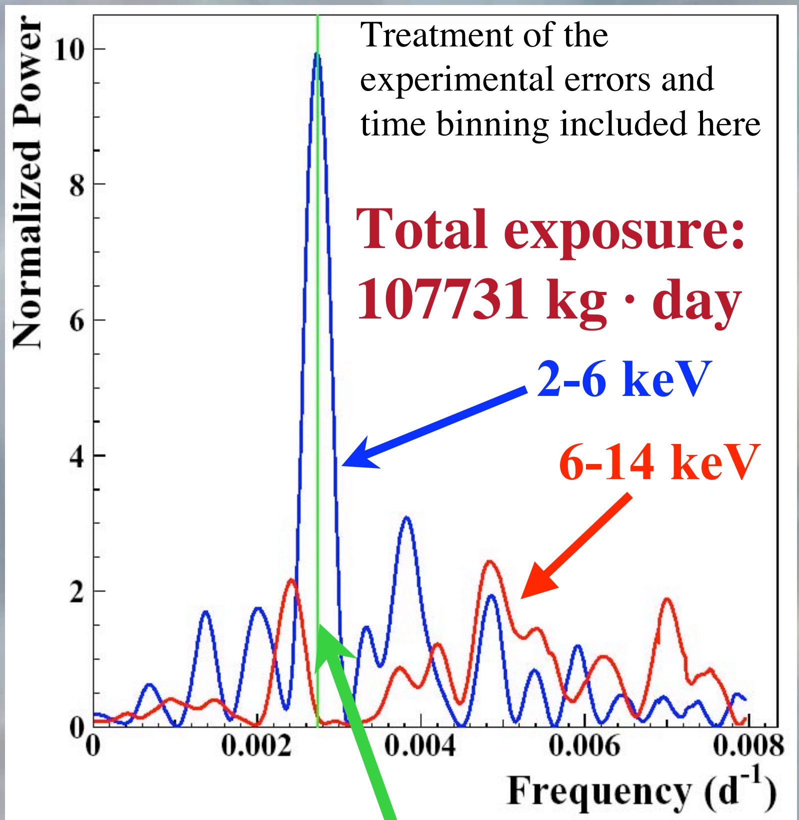
(2-6) keV

$A = (0.0200 \pm 0.0032)$ cpd/kg/keV
$t_0 = (140 \pm 22)$ d
$T = (1.00 \pm 0.01)$ y

Power spectrum of single-hit residuals

(according to Ap.J.263(1982)835; Ap.J.338(1989)277)

2-6 keV vs 6-14 keV



Principal mode in the 2-6 keV region
→ $2.737 \cdot 10^{-3}\ d^{-1} \approx 1\ y^{-1}$

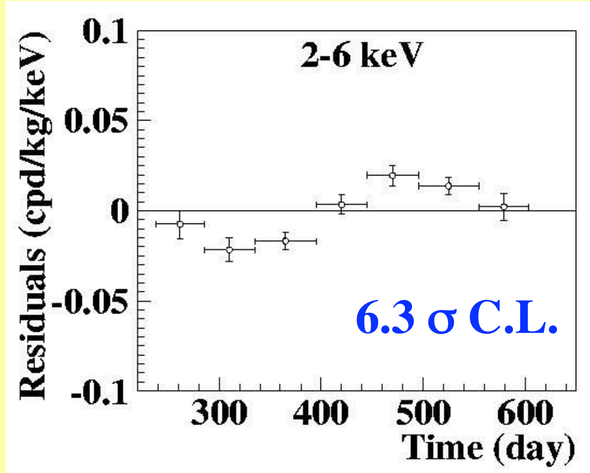
+

Not present in the 6-14 keV region (only aliasing peaks)

Single-hit residual rate as in a single annual cycle

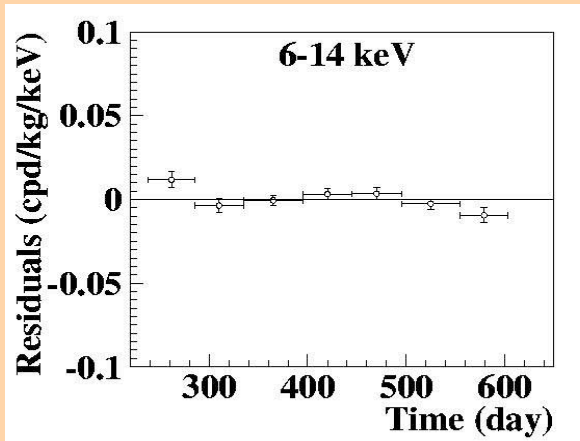
DAMA/NaI 7 annual cycles:107731 kg × day

Initial time August, 7



for t_0 = 152.5 day
and T = 1.00 y:
A=(0.0195 ± 0.0031) cpd/kg/keV

Initial time August, 7



for t_0 = 152.5 d
and T = 1.00 y:
A= -(0.0009 ± 0.0019) cpd/kg/keV

A clear modulation is present in the lowest energy region, while it is absent just above

Multiple-hits events in the region of the signal

- In DAMA/NaI-6 and 7 each detector has its own TD (multiplexer system removed) → pulse profiles of multiple-hits events (multiplicity > 1) also acquired (total exposure: 33834 kg d).
- The same hardware and software procedures as the ones followed for single-hit events

→ ***just one difference: recoils induced by WIMPs do not belong to this class of events,***

that is: multiple-hits events = DM particle events "switched off"

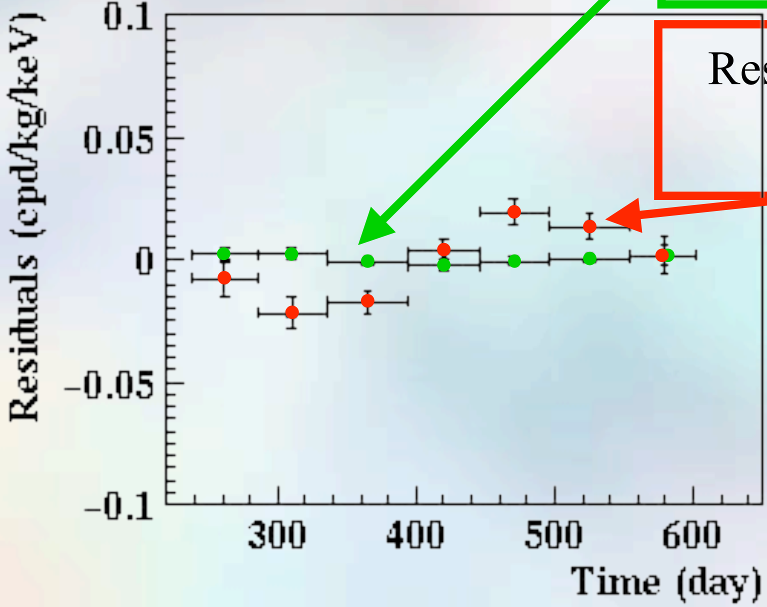
- **2-6 keV residuals**

Residuals for multiple-hits events (DAMA/NaI-6 and 7)

Mod ampl. = $-(3.9\pm7.9)\cdot10^{-4}$ cpd/kg/keV

Residuals for single-hit events (DAMA/NaI 7 annual cycles)

Mod ampl. = (0.0195 ± 0.0031) cpd/kg/keV



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

Summary of the results obtained in the investigation of possible systematics or side reactions

N. Cim. 26 n.1. (2003) 1-73 [astro ph/0307403], IJMPD13(2004)2127 and ref. therein

Source	*Main comment*	*Cautious upper limit (90%C.L.)*
RADON	Sealed Cu box in HP Nitrogen atmosphere	**<0.2% S_m^{obs}**
TEMPERATURE	The installation is air- conditioned+ detectors in Cu housings directly in contact with multi-ton shield→ huge heat capacity + T continuously recorded	**<0.5% S_m^{obs}**
NOISE	Effective noise rejection	**<1% S_m^{obs}**
ENERGY SCALE	Periodical calibrations+ continuous monitoring of ^{210}Pb peak	**<1% S_m^{obs}**
EFFICIENCIES	Regularly measured by dedicated calibrations	**<1% S_m^{obs}**
BACKGROUND	No modulation observed above 6 keV + this limit includes possible effect of thermal and fast neutrons + no modulation observed in the multiple-hits events in 2-6 keV region	**<0.5% S_m^{obs}**
SIDE REACTIONS	Muon flux variation measured by MACRO	**<0.3% S_m^{obs}**

+ even if larger they can not satisfy all the 6 requirements of annual modulation signature

→

Thus, they can not mimic the observed annual modulation effect

Summary of the DAMA/NaI *Model Independent* result

- Presence of modulation for 7 annual cycles at ~6.3σ CL with the proper distinctive features for a DM particle induced effect
- The deep investigation has shown absence of known sources of possible systematics and side processes able to account for the observed effect
- All the signature features satisfied by the data over 7 independent experiments of 1 year each one
- No other experiment whose result can be directly compared in model independent way with this one is available so far

corollary quest for a candidate

To investigate the nature and coupling with ordinary matter of the possible WIMP candidate, an effective energy and time correlation analysis of the events has to be performed within given model frameworks

THUS

uncertainties on models and comparisons

?

ρ_W

WIMP velocity distribution and its parameters

coupling: SI, SD, mixed SI&SD, preferred inelastic, ...

new contributions to WIMP-nucleus scattering? (see e.g. astro-ph/0309115)

scaling laws on cross sections

form factors and related parameters

spin factors etc.

They can affect not only the corollary estimated regions following a positive effect from the WIMP annual modulation signature, but also results given as exclusion plots

+

experimental parameters (typical of each experiment)

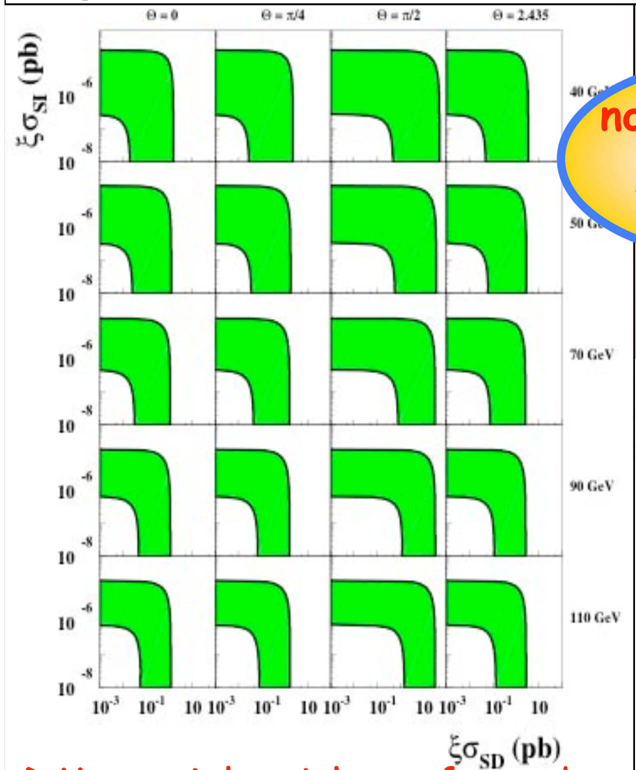
comparison within particle models

Few Examples of corollary quests for the candidate particle

(Riv. N.Cim. vol.26 n.1. (2003) 1-73, IJMPD13(2004)2127)

General case: DM particle with SI&SD couplings (Na and I are fully sensitive to SD interaction, on the contrary of e.g. Ge and Si)

Examples of slices of the allowed volume in the space ($\xi\sigma_{SI}$, $\xi\sigma_{SD}$, m_W, θ) for some of the possible θ ($tg\theta = a_n/a_p$, with $0 \leq \theta < \pi$) and m_W



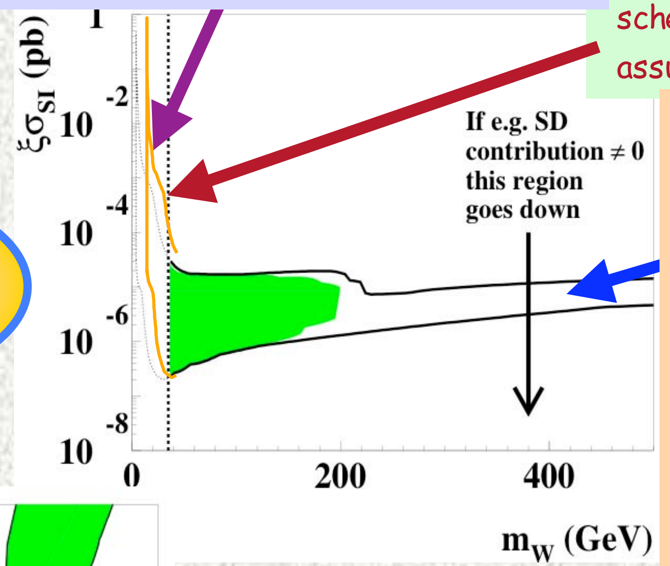
not exhaustive

+ different scenarios?

DM particle with dominant SI coupling

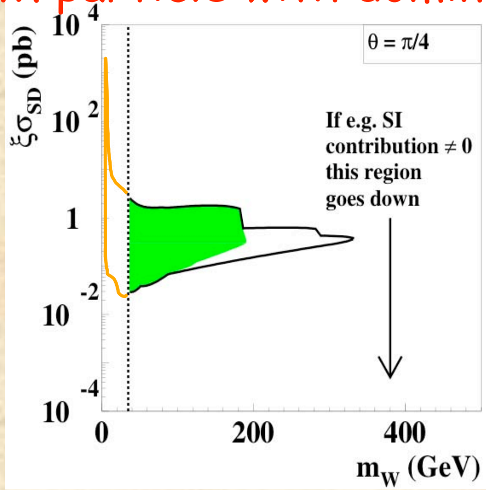
Region of interest for a neutralino in supersymmetric schemes where assumption on gaugino-mass unification at GUT is released and for "generic" DM particle

Model dependent lower bound on neutralino mass as derived from LEP data in supersymmetric schemes based on GUT assumptions (DPP2003)



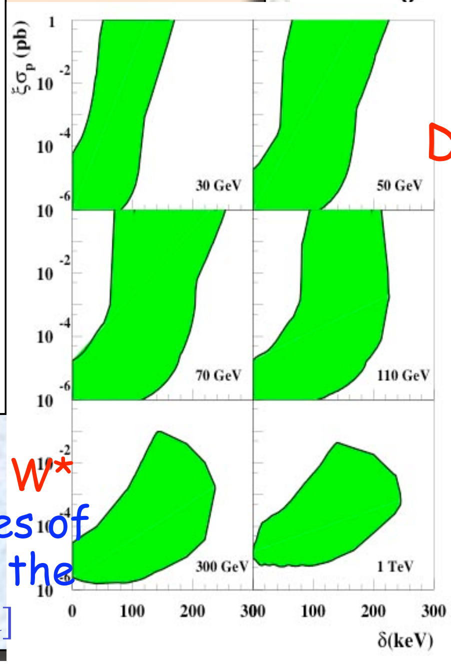
higher mass region allowed for low v_0, every set of parameters' values and the halo models: Evans' logarithmic C1 and C2 co-rotating, triaxial D2 and D4 non-rotating, Evans power-law B3 in set A

DM particle with dominant SD coupling



volume allowed in the space (m_W, $\xi\sigma_{SD}$, θ); here example of a slice for $\theta = \pi/4$ ($0 \leq \theta < \pi$).

Regions above 200 GeV allowed for low v_0, for every set of parameters' values and for Evans' logarithmic C2 co-rotating halo models



DM particle with preferred inelastic interaction: $W + N \rightarrow W^* + N$ (S_m/S_0 enhanced): examples of slices of the allowed volume in the space ($\xi\sigma_p$, m_W, δ) [e.g. Ge disfavoured]

Summary

Particle Dark Matter investigation can offer complementary information on Cosmology and Particle Physics beyond the standard model.

Annual modulation signature very effective method successfully exploited by DAMA/NaI over 7 annual cycles (~ 1.1 x 10^5 kg day) obtaining a 6.3σ C.L. model independent evidence for the presence of a Dark Matter particle component in the galactic halo

The complexity of model dependent results (either exclusion plots or allowed regions) and of model dependent comparisons have been pointed out

not exhaustive at all – many other possibilities under investigations

+ different scaling laws?
+ different scenarios?
+ different Dark Matter distributions? non-thermal contributions? existence of streams? either caustics or clumpiness?... and more

DAMA/LIBRA (~250 kg NaI(Tl)) now running since march 2003

... wait for an exposure larger than that of DAMA/NaI

...and beyond?

- multi-purpose NaI(Tl) ton set-up (R. Bernabei, IDM96)
- new ideas to fully exploit signal peculiarities and halo features

Some different kinds of approaches can offer complementary results

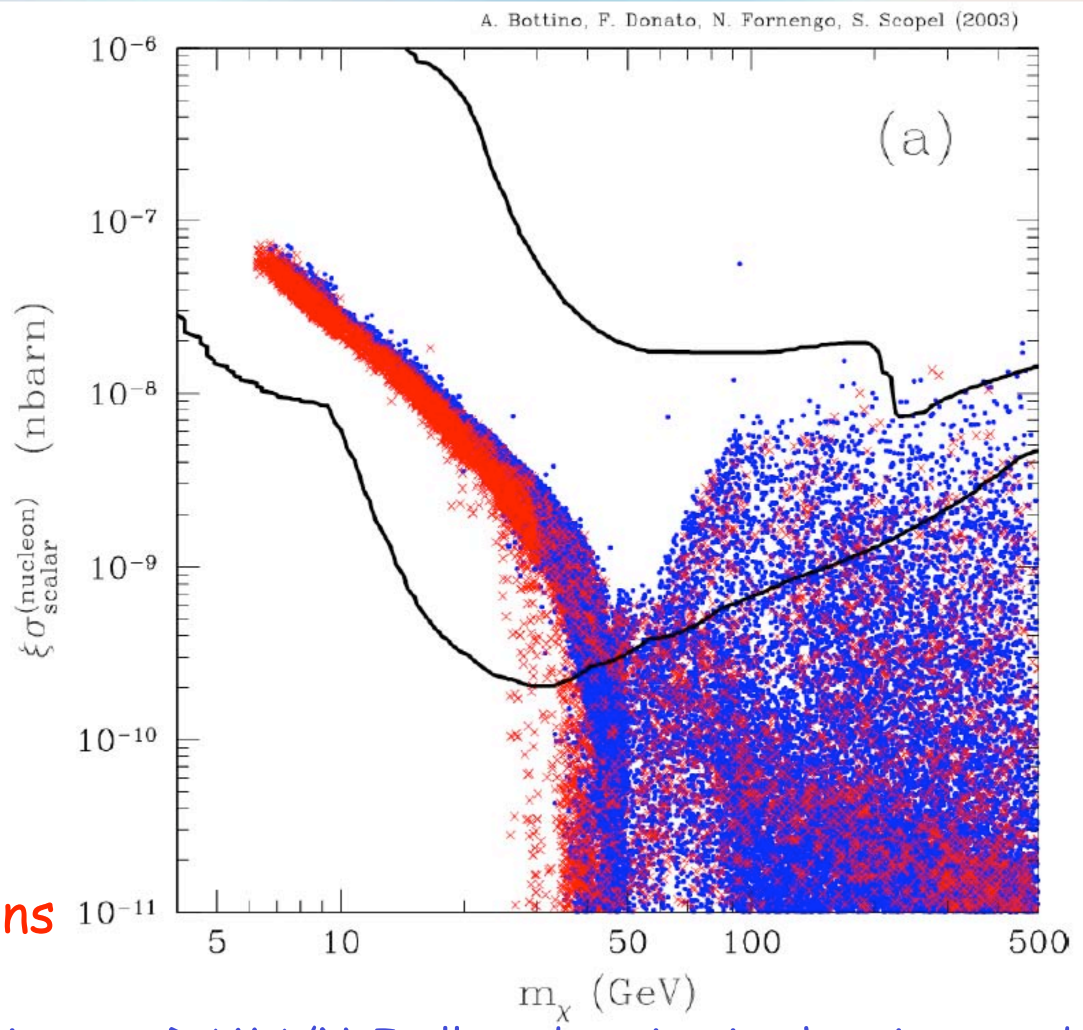
Supersymmetric expectations in MSSM

- Assuming for the neutralino a dominant purely SI coupling
- when releasing the gaugino mass unification at GUT scale:

  $M_1/M_2 \neq 0.5$ (<);

(where M_1 and M_2 U(1) and SU(2) gaugino masses)

low mass configurations are obtained



scatter plot of theoretical configurations vs DAMA/NaI allowed region in the given model frameworks for the total DAMA/NaI exposure (area inside the green line);

figure taken from PRD69(2004)037302 (for previous DAMA/NaI partial exposure see PRD68(2003)043506)

DAMA/NaI out of operation

The switching off of the ~100kg NaI(Tl) set-up at end of July 2002

Opening the shield

Dismounting the ~100kg NaI(Tl) set-up in August 2002 in HP N_2 atmosphere

DM particle-nucleus elastic scattering

SI+SD differential cross sections:

$$\frac{d\sigma}{dE_R}(v,E_R)=\left(\frac{d\sigma}{dE_R}\right)_{SI}+\left(\frac{d\sigma}{dE_R}\right)_{SD}=\frac{2G_F^2m_N}{\pi v^2}\left\{\left[Zg_p+(A-Z)g_n\right]^2F_{SI}^2(E_R)+8\frac{J+1}{J}\left[a_p\langle S_p\rangle+a_n\langle S_n\rangle\right]^2F_{SD}^2(E_R)\right\}$$

$g_{p,n}(a_{p,n})$ effective DM particle-nucleon couplings

$\langle S_{p,n}\rangle$ nucleon spin in the nucleus

$F^2(E_R)$ nuclear form factors

m_{Wp} reduced DM particle-nucleon mass

Generalized SI/SD DM particle-nucleon cross sections:

$$\sigma_{SI}=\frac{4}{\pi}G_F^2m_{Wp}^2g^2 \qquad \sigma_{SD}=\frac{32}{\pi}\frac{3}{4}G_F^2m_{Wp}^2\bar{a}^2$$

where: $g=\frac{g_p+g_n}{2}\bullet\left[1-\frac{g_p-g_n}{g_p+g_n}\left(1-\frac{2Z}{A}\right)\right]$ $\quad \bar{a}=\sqrt{a_p^2+a_n^2}$ $\quad tg\theta=\frac{a_n}{a_p}$

g: independent on the used target nucleus since Z/A nearly constant for the nuclei typically used in WIMP direct searches

Differential energy distribution: $\frac{dR}{dE_R}=N_T\frac{\rho_W}{m_W}\int_{v_{\min}(E_R)}^{v_{\max}}\frac{d\sigma}{dE_R}(v,E_R)vf(v)dv=N_T\frac{\rho_Wm_N}{2m_Wm_{Wp}^2}\cdot\Sigma(E_R)\cdot I(E_R)$

where: $\Sigma(E_R)=\left\{A^2\sigma_{SI}F_{SI}^2(E_R)+\frac{4}{3}\frac{J+1}{J}\sigma_{SD}\left[\langle S_p\rangle\cos\theta+\langle S_n\rangle\sin\theta\right]^2F_{SD}^2(E_R)\right\}$ $\qquad I(E_R)=\int_{v_{\min}(E_R)}^{v_{\max}}\frac{f(v)}{v}dv$

N_T: number of target nuclei

f(v): DM particle velocity distribution in the Earth frame (**it depends on v_e**)

$v_e=v_{sun}+v_{orb}\cos\omega t$

v_{max}: maximal DM particle velocity in the Earth frame

$v_{\min}=\sqrt{\frac{m_NE_R}{2m_{WN}^2}}$ minimal velocity providing E_R recoil energy

Halo modeling

- **Needed quantities for Dark Matter direct searches:**

→ DM local density $\rho_0 = \rho_{DM}(R_0 = 8.5\ \text{kpc})$

→ local velocity $v_0 = v_{rot}(R_0 = 8.5\text{kpc})$

→ velocity distribution $f(\vec{v})$

Isothermal sphere: the most widely used model only in the WIMP direct search (but not correct)

density profile: $\rho_{DM}(r) \propto r^{-2}$

gravitational potential: $\Psi_0 \propto \log(r^2)$

→ Maxwellian velocity distribution

Spherical ρ_{DM}, isotropic velocity dispersion

Evans' logarithmic
$$\rho_{DM}(r) = \frac{v_0^2}{4\pi G}\frac{3R_c^2 + r^2}{(R_c^2 + r^2)^2} \qquad \Psi_0(r) = -\frac{v_0^2}{2}\log(R_c^2 + r^2) \qquad v_{rot}^2(r) = v_c^2\frac{r^2}{(R_c^2 + r^2)}$$

Evans' power-law
$$\rho_{DM}(r) = \frac{\beta\Psi_a R_c^\beta}{4\pi G}\frac{3R_c^2 + r^2(1-\beta)}{(R_c^2 + r^2)^{(\beta+4)/2}} \qquad \Psi_0(r) = \frac{\Psi_a R_c^\beta}{(R_c^2 + r^2)^{\beta/2}},\ (\beta \neq 0) \qquad v_{rot}^2(r) = \frac{\beta\Psi_a R_c^\beta r^2}{(R_c^2 + r^2)^{(\beta+2)/2}}$$

Others:
$$\rho_{DM}(r) = \rho_0\left(\frac{R_0}{r}\right)^\gamma\left[\frac{1+(R_0/a)^\alpha}{1+(r/a)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

If spherical ρ_{DM} with non-isotropic velocity dispersion → $\beta_0 = 1 - \frac{\bar{v}_\phi^2}{\bar{v}_r^2}$

If Axisymmetric ρ_{DM} → q flatness $\Psi_0(r,z) = -\frac{v_0^2}{2}\log(R_c^2 + r^2 + \frac{z^2}{q^2})$

Triaxial ρ_{DM} → p, q, δ
$$\Psi_0(x,y,z) = -\frac{v_0^2}{2}\log\left(x^2 + \frac{y^2}{p^2} + \frac{z^2}{q^2}\right)$$

δ = free parameter → in spherical limit (p=q=1) quantifies the anisotropy of the velocity dispersion tensor
$$\frac{\bar{v}_\phi^2}{\bar{v}_r^2} = \frac{2+\delta}{2}$$

Constraining the models

$$v_0 = (220 \pm 50)km \cdot s^{-1}$$
$$1\cdot 10^{10} M_\oplus \leq M_{vis} \leq 6\cdot 10^{10} M_\oplus$$
$$0.8\cdot v_0 \leq v_{rot}(r = 100kpc) \leq 1.2\cdot v_0$$

Consistent Halo Models

- Isothermal sphere ⇒ very simple but unphysical halo model; generally not considered
- Several approaches different from the isothermal sphere model: Vergados PR83(1998)3597, PRD62(2000)023519; Belli et al. PRD61(2000)023512; PRD66(2002)043503; Ullio & Kamionkowski JHEP03(2001)049; Green PRD63(2001) 043005, Vergados & Owen astroph/0203293, etc.

Models accounted in the following

(Riv. N. Cim. 26 n.1 (2003)1-73 and previously in PRD66(2002)043503)

- **Needed quantities**
  - → DM local density $\rho_0 = \rho_{DM}(R_0 = 8.5\text{ kpc})$
  - → local velocity $v_0 = v_{rot}(R_0 = 8.5\text{kpc})$
  - → velocity distribution

- **Allowed ranges of ρ_0 (GeV/cm^3) have been evaluated for v_0=170,220,270 km/s, for each considered halo density profile and taking into account the astrophysical constraints:**

$$v_0 = (220 \pm 50) km \cdot s^{-1}$$
$$1 \cdot 10^{10} M_\oplus \le M_{vis} \le 6 \cdot 10^{10} M_\oplus$$
$$0.8 \cdot v_0 \le v_{rot}(r = 100kpc) \le 1.2 \cdot v_0$$

NOT YET EXHAUSTIVE AT ALL

Class A: spherical ρ_{DM}, isotropic velocity dispersion		
A0	Isothermal Sphere	
A1	Evans' logarithmic [101]	$R_c = 5$ kpc
A2	Evans' power-law [102]	$R_c = 16$ kpc, $\beta = 0.7$
A3	Evans' power-law [102]	$R_c = 2$ kpc, $\beta = -0.1$
A4	Jaffe [103]	$\alpha = 1, \beta = 4, \gamma = 2, a = 160$ kpc
A5	NFW [104]	$\alpha = 1, \beta = 3, \gamma = 1, a = 20$ kpc
A6	Moore et al. [105]	$\alpha = 1.5, \beta = 3, \gamma = 1.5, a = 28$ kpc
A7	Kravtsov et al. [106]	$\alpha = 2, \beta = 3, \gamma = 0.4, a = 10$ 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} [107] (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.	$\delta = 16$

The allowed local density values

- **Allowed intervals of ρ_0 (GeV/cm^3) for v_0=170,220,270 km/s, for the halo models considered in the model-dependent analyses given in the following**

	$v_0 = 170$ km s^{-1}		$v_0 = 220$ km s^{-1}		$v_0 = 270$ km s^{-1}	
Model	ρ_0^{min}	ρ_0^{max}	ρ_0^{min}	ρ_0^{max}	ρ_0^{min}	ρ_0^{max}
A0	0.18	0.28	0.30	0.47	0.45	0.71
A1 , B1	0.20	0.42	0.34	0.71	0.62	1.07
A2 , B2	0.24	0.53	0.41	0.89	0.97	1.33
A3 , B3	0.17	0.35	0.29	0.59	0.52	0.88
A4 , B4	0.26	0.27	0.44	0.45	0.66	0.67
A5 , B5	0.20	0.44	0.33	0.74	0.66	1.11
A6 , B6	0.22	0.39	0.37	0.65	0.57	0.98
A7 , B7	0.32	0.54	0.54	0.91	0.82	1.37
C1	0.36	0.56	0.60	0.94	0.91	1.42
C2	0.34	0.67	0.56	1.11	0.98	1.68
C3	0.30	0.66	0.50	1.10	0.97	1.66
C4	0.32	0.65	0.54	1.09	0.96	1.64
D1 , D2	0.32	0.50	0.54	0.84	0.81	1.27
D3 , D4	0.19	0.30	0.32	0.51	0.49	0.76

$$v_0 = (220 \pm 50) km \cdot s^{-1}$$

$$1 \cdot 10^{10} M_{\oplus} \le M_{vis} \le 6 \cdot 10^{10} M_{\oplus}$$

$$0.8 \cdot v_0 \le v_{rot}(r = 100 kpc) \le 1.2 \cdot v_0$$

Intervals evaluated considering the density profile and the astrophysical constraints

PRD66(2002)043503