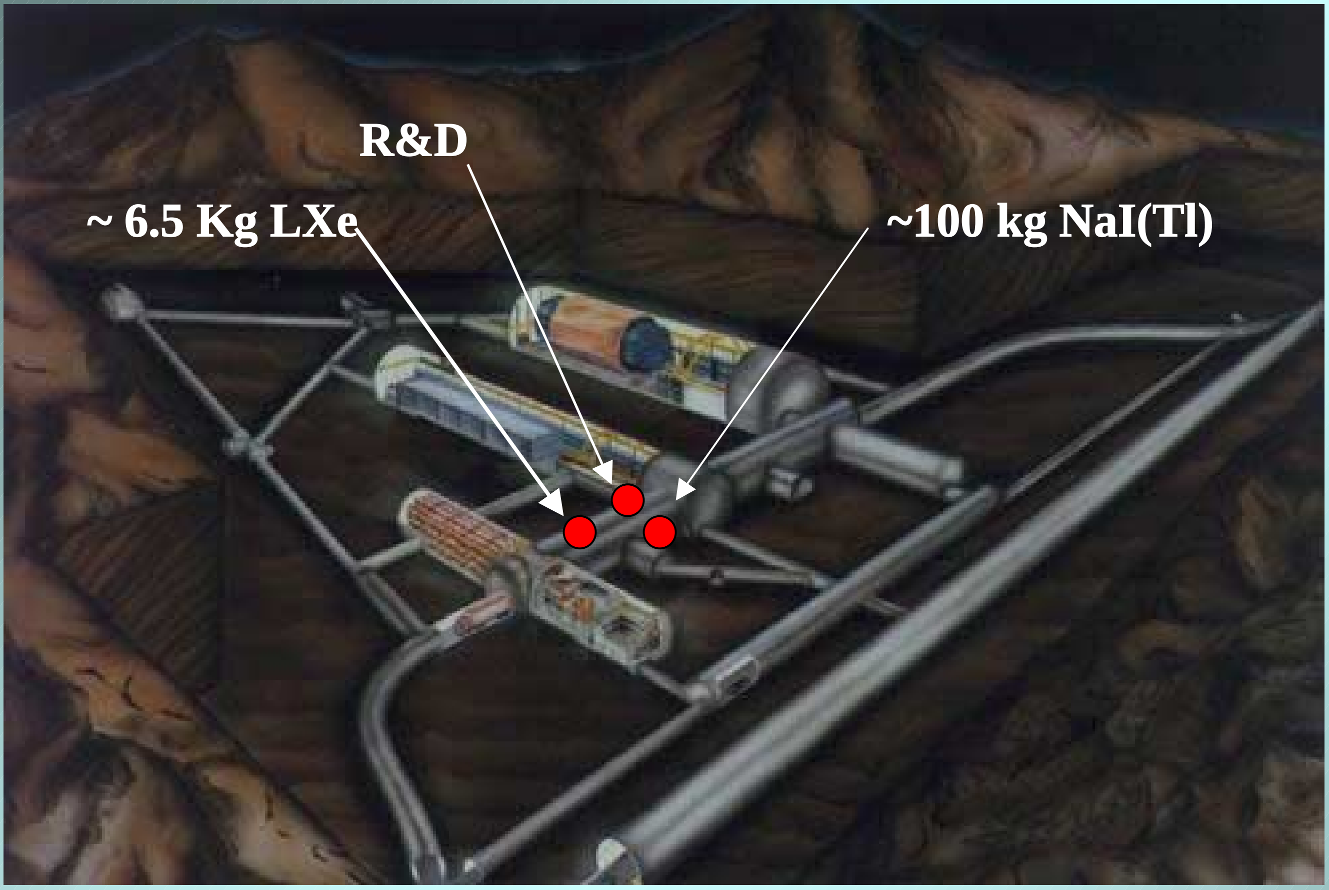
Results from the DAMA experiment at Gran Sasso

Roma2, Roma, IHEP/Beijing
(DAMA site on: www.lngs.infn.it)

R. Bernabei
The legacy of LEP and the SLC
Siena October 11, 2001

DAMA searches for rare processes @ LNGS



Recent References

• ~ 100 Kg NaI(Tl) :

PLB389 (1996) 757; PLB408 (1997) 439; PLB424 (1998) 195; PLB450 (1999) 448; N.Cim. A112 (1999) 545; PLB460 (1999) 236; PRL83 (1999) 4918; PRC60 (1999) 065501; PRD61 (2000) 023512; N.CimA112 (1999) 1541; PLB480 (2000) 23; Eur.Phys. J. C18 (2000) 283; PLB509 (2001) 197; PLB515 (2001) 6; ROM2F/2001-33.

• ~ 6.5 Kg LXe (^{129}Xe + ^{136}Xe):

N.Cim.C19 (1996) 537; PLB387 (1996) 222; Astrop.Phys.5 (1996) 217; PLB436 (1998) 379; PLB465 (1999) 315; PRD61 (2000) 117301; New Journal of Physics 2 (2000) 15.1-15.7; PLB493 (2000) 12; EPJdirect C11 (2001) 1; INFN/AE-01/02, to appear on NIM; ROM2F/2001-26.

• CaF_2(Eu) + others

Astrop.Phys.7 (1997) 73; Astrop.Phys.8 (1997) 67; N.Cim.A110 (1997) 189; Astrop.Phys.10 (1999) 115; NPB546 (1999) 235; NPB563 (1999) 97.

Recent DAMA activities

Dark Matter search

- Annual modulation DAMA/NaI-0 to 4 see later
- Upper limits on recoils from PSD with NaI(Tl) PLB389(1996)757
- Upper limits on recoils from PSD with LXe PLB436(1998)379
- Investigation of possible diurnal variation of the rate: excluded large-σ_p DM particle component with small halo fraction N.Cim.A112(1999)1541
- New limits on SIMP search PRL83(1999)4918
- New limits on the flux of neutral nuclearites PRL83(1999)4918
- New limits on SD WIMPs with CaF_2(Eu) NPB563(1999)97
- New limits on inelastic scattering in LXe NJP2(2000)15.1
- New measurements of light response to recoils in LXe EPJdirect C11(2001)1

Other searches

- New limits on the nuclear level excitation of ^{129}Xe during charge non-conservation (CNC) processes PLB465(1999)315
- New limits on 2β processes in ^{40}Ca and ^{46}Ca using low radioactive CaF_2(Eu) NPB563(1999)97
- New limits on the nuclear level excitation of ^{127}I and ^{23}Na during CNC processes PRC60(1999)065501
- New experimental limit on the electron stability and non-paulian transitions in Iodine atoms PLB460(1999)235
- New limits on $2\beta^+$ in ^{106}Cd Astr.Phys.10 (1999), 115
- New limits on electron decay $e^- \to \nu_e \gamma$ using LXe PRD61(2000)117301
- Search for nucleon and di-nucleon decay into invisible channels PLB493(2000)12
- Search for solar axions in NaI crystals PLB515(2001)6
- New limits on 2β decay in ^{136}Xe ROM2F/2001/26

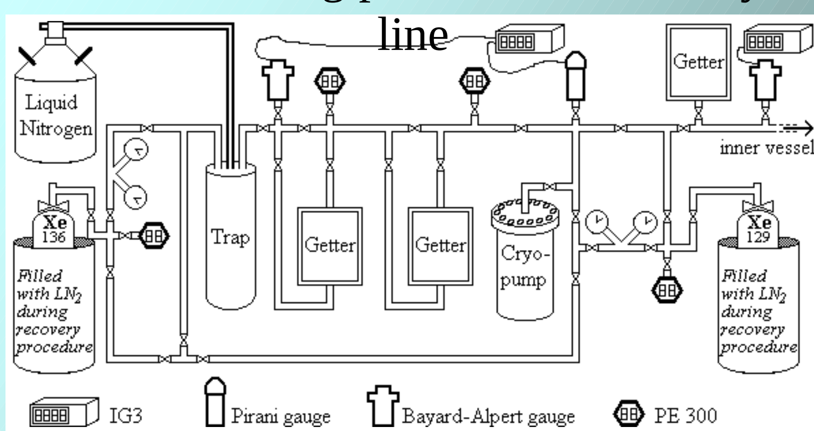
LXe set-up

Achieved results:

- Elastic scattering WIMP-^{129}Xe
- PSD
- Inelastic scattering WIMP-^{129}Xe
- Charge non-conserving processes in various channels
- Nucleon and di-nucleon stability (new approach)
- Search for ββ decay in ^{136}Xe

- measurement of quenching factor at ENEA neutron generator

vacuum/filling/purification/recovery line



Now running with Kr-free Xe enriched in ^{136}Xe

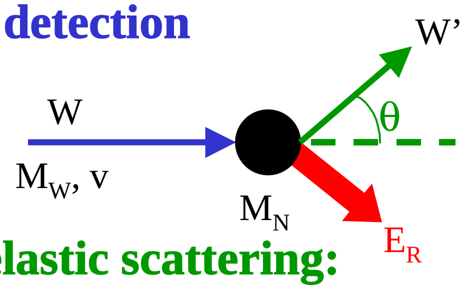
WIMP direct detection

- WIMPs: relic Cold Dark Matter particles from primordial Universe

- in thermal equilibrium in the early stage of the Universe
- non relativistic at the decoupling time
- $<\sigma_{ann}\, v> \sim (10^{-26}/\Omega_W h^2)\ cm^3 s^{-1}$ — $\sigma_{ordinary\ matter} \sim \sigma_{weak}$
- expected flux: $\sim 10^7\ (1GeV/m_W)\ cm^{-2}\ s^{-1}$ — $(0.2 < \rho_{halo} < 0.7\ GeVcm^{-3})$
- form a dissipationless (or quasi-) gas trapped in the gravitational field of Galaxy (velocity $\sim 10^{-3}$ c)

A candidate must be neutral, stable (or τ~age of Universe) and massive

- **Direct detection**



by inelastic scattering:

^{127}I (Eijiri et al.), ^{129}Xe (DAMA/LXe); good signature but very large exposure are necessary and very low counting rates.

^{127}I: NP B35 (1994) 400
^{129}Xe: PLB 387 (1996) 222
New Jou. of Phys. 2(2000)15.1

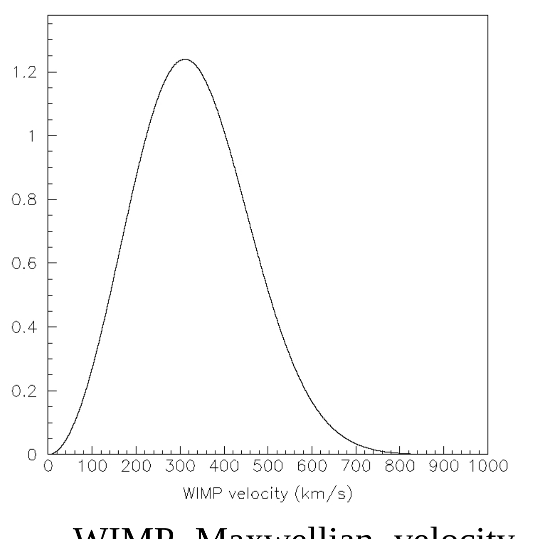
by elastic scattering:

$$\frac{dR}{dE_R} = N_T \frac{\rho_W}{M_W} \int_{v_{min}}^{v_{max}} v \cdot f(v \mid v_\oplus) \frac{\sigma_{point-like}}{E_{R\max}} F^2(E_R)\, dv$$

$$v_{min} = \sqrt{\frac{M_N \cdot E_R}{2 \cdot m_{red}^2}} \qquad E_{R\max} = \frac{2 \cdot m_{red}^2 \cdot v^2}{M_N}$$

$v_\oplus$ = Earth velocity in the galactic frame

Measured quantity : E_R in the keV region (quasi-exponential behaviour)

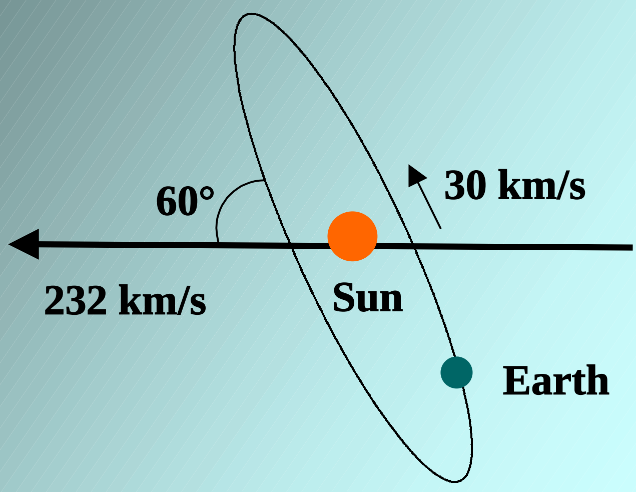


WIMP Maxwellian velocity distribution (v_0=220 km/s)

Searching for distinctive signature of WIMPs

- Annual modulation of the rate

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



- v = 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 = 2nd June (when $v_\oplus$ is maximum)

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

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

→ expected rate in given energy bin changes because the annual motion of the Earth around the Sun moving in the Galaxy

- Annual modulation is a distinct signature

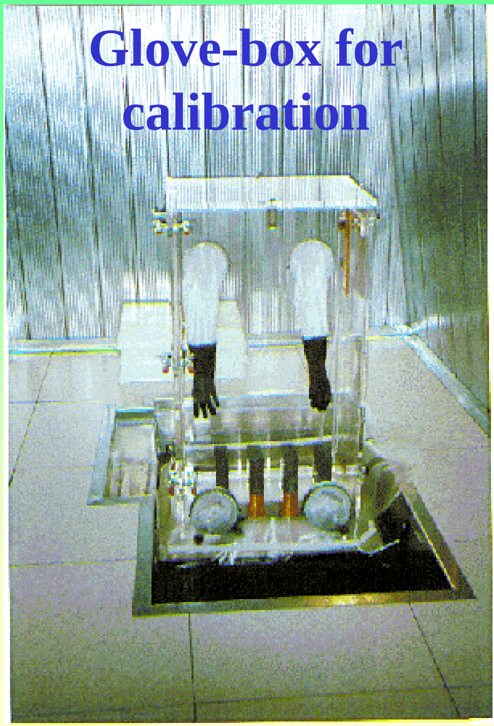
1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) For single hit in a multi-detector set-up
6) With modulated amplitude in the region of maximal sensitivity < 7%

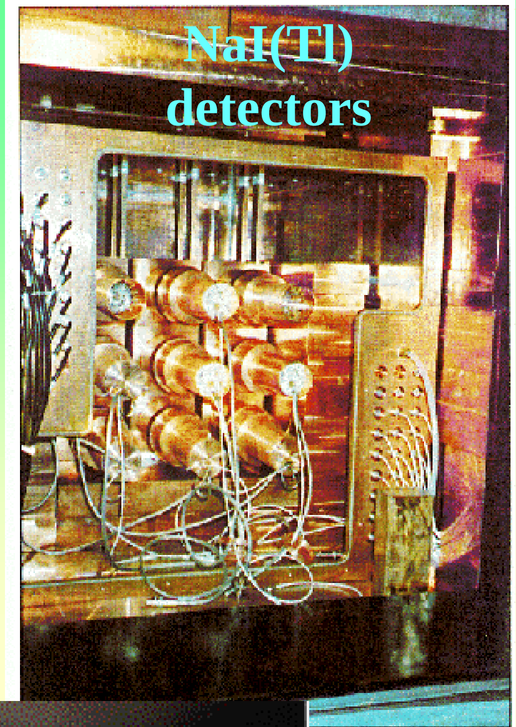
To mimic this signature, the spurious effects and side reactions must satisfy contemporaneously all these 6 requirements

Scintillator as target-detector

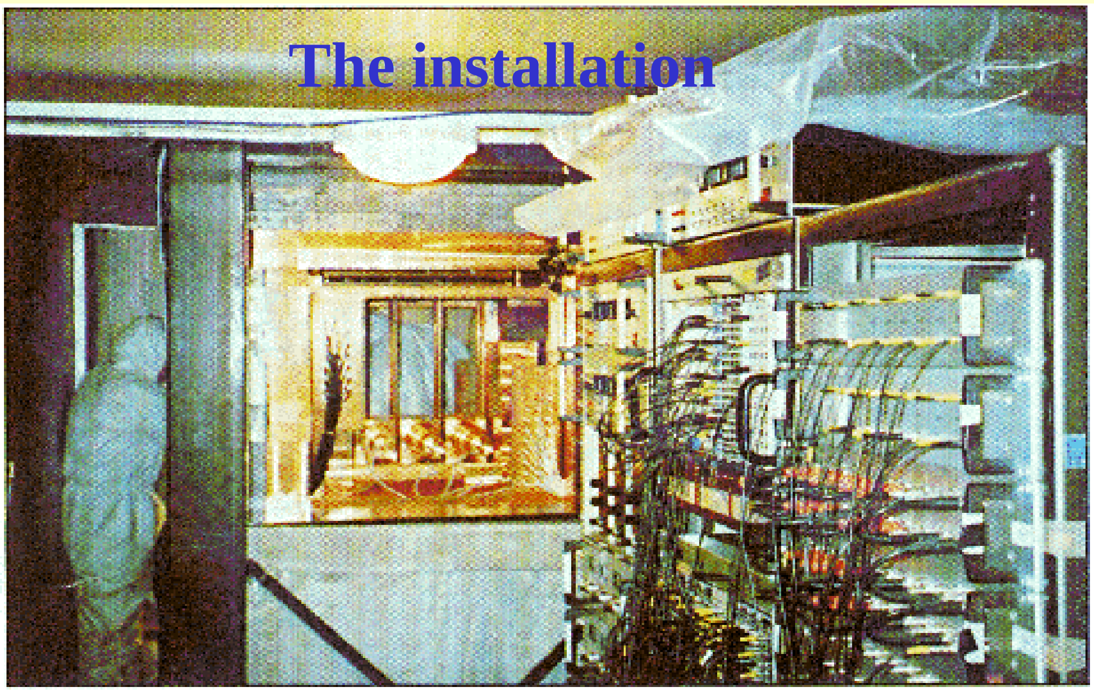
- Known technology
- Cost/Mass relatively low
- Full control of running conditions feasible
- Very high duty cycle
- Large mass $\rightarrow$ suitable statistics for annual modulation
- Statistical discrimination of recoil nuclei e.g. in NaI(Tl) and LXe
- Large set of target-detectors nuclei
- Sensitive also to spin-dependent interactions

DAMA @ LNGS
The ~100 kg NaI(Tl) set-up





Experimental details on:
Il N. Cim. A112 (1999) 545



Advantage of the ~100 kg NaI(Tl) expt

- **Knowledge of the physical energy threshold**

  (external keV range sources + low energy Compton electrons)

- **Noise identification**

  (high # ph.el./keV + pulse time structures)

- **Measurability of the software cut efficiencies**

  (by irradiating the crystal with γ sources and Compton e^-)

- **Knowledge of the needed efficiencies**

- **Knowledge of the sensitive volume**

- **Quenching factors well measured**

  (by irradiating a detector from the same growth with neutrons, inducing recoils in the whole sensitive volume)

The data released so far for the annual modulation search

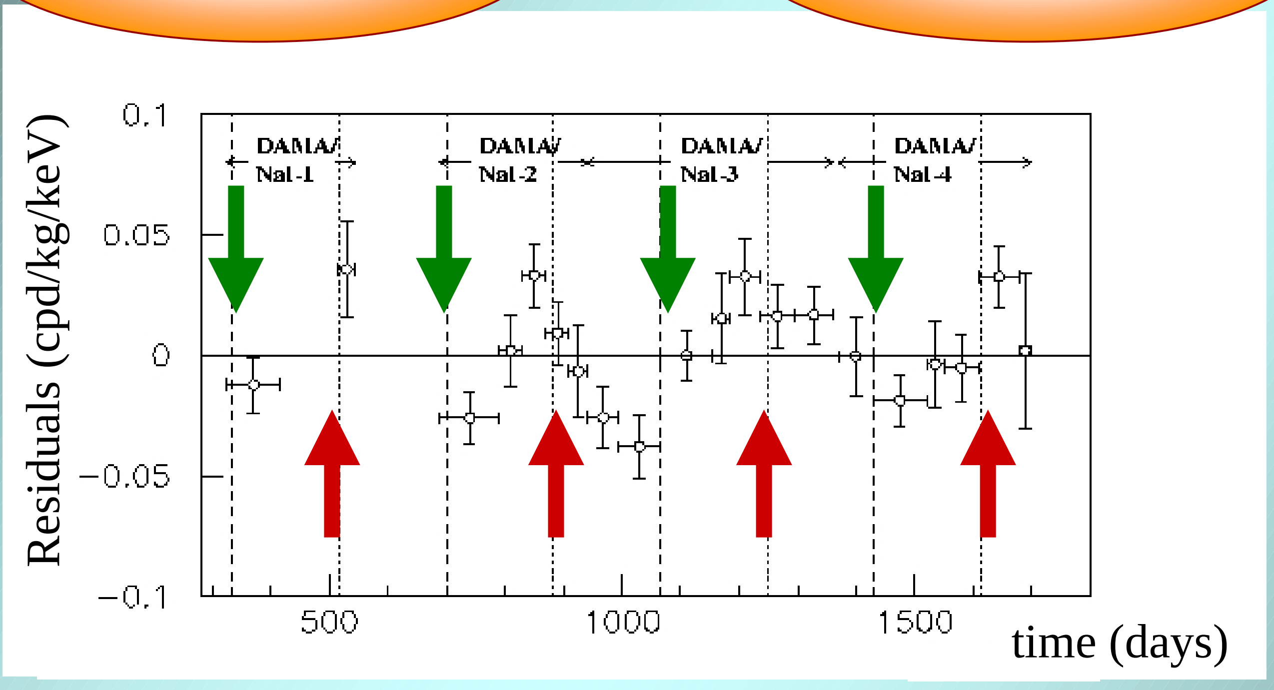
PERIOD	STATISTICS (kgday)	REFERENCES
DAMA/NaI-1	3363.8 winter + 1185.2 summer	PLB424(1998) 195
DAMA/NaI-2	14962 ~ November to end of July	PLB450(1999) 440 + PRD61(1999)023512
DAMA/NaI-3	22455 ~ middle August to end September	PLB480(2000) 23
DAMA/NaI-4	16020 ~ middle October to second half August	idem
TOTAL STATISTICS	57986	idem + PLB509(2001) 197 ROM2F/2001-33
+ DAMA/NaI-0 (properly included in the final result)	limits on recoil fraction by PSD	PLB389(1996) 757

The model independent result

2-6 keV residuals of the rate vs time

4 annual cycles

57986 kg day



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

χ^2_0 (A=0)/dof = 48/20 (P = 4 x 10^{-4})

1) t_0 = 152.5 days (fixed)
A=(0.022±0.005) cpd/kg/keV
T=2π/ω=(1.00± 0.01) years
χ^2 / dof = 23/18

2) T = 1 years (fixed)
A = (0.023 ± 0.005) cpd/kg/keV
t_0 = (144 ± 13) days
χ^2 / dof = 23/18

If all the 3 parameters kept free, similar values with slightly larger errors

Presence of annual modulation with characteristics of a WIMP candidate

POSSIBLE SYSTEMATICS?

Eur. Phys. J. C18 (2000), 283

RADON	Sealed Cu box in HP Nitrogen atmosphere	**<0.2% S_m^{obs}**
TEMPERATURE	The installation is air-conditioned	**<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 found in energy regions above 6keV	**<0.5% S_m^{obs}**
SIDE REACTIONS	Muon flux modulation by MACRO	**<0.3% S_m^{obs}**

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

Can the μ modulation measured by MACRO account for the observed effect?

Case of fast neutrons produced by muons

Φ_μ @ LNGS $\approx$ 20 μ m^{-2} d^{-1} (±2% modulated)

Neutron Yield @ LNGS: Y=1÷7 10^{-4} n /μ /(g/cm^2) (hep-ex/0006014)

R_n = (fast n by μ)/(time unit) = Φ_μ Y M_{eff}

Annual modulation amplitude at low energy due to μ modulation:

$$S_m^{(\mu)} = R_n\, g\, \varepsilon\, f_{\Delta E}\, f_{single}\, 2\% /(M_{setup}\, \Delta E)$$

where:	g = geometrical factor ε = detection efficiency by elastic scattering $f_{\Delta E}$ = energy window (E>2keV) efficiency f_{single} = single hit efficiency
Hyp.:	M_{eff} = 15 tons $g \approx \varepsilon \approx f_{\Delta E} \approx f_{single} \approx 0.5$ (cautiously)
Knowing that:	M_{setup}=100kg and ΔE=4keV

⇓

$S_m^{(\mu)} < (1÷7)\ 10^{-5}$ cpd/kg/keV (< 0.3% $S_m^{observed}$)

No

Moreover, this modulation also induces a variation in other parts of the energy spectrum

Excluded by R_{90} analysis

CONCLUSION #1

Presence of modulation with the proper features for a WIMP induced effect

+

Absence of known sources of possible systematics and side reactions able to fake this modulation

⇓

Presence of a WIMP contribution to the experimental rate is candidate by these data independently on its nature and coupling with ordinary matter

⇓

At this point one can investigate a possible candidate

For that a model is needed as well as an effective energy and time correlation analysis strategy

WIMP-nucleus elastic scattering

SI+SD differential cross sections:

$$\frac{d\sigma}{dE_R}(v,E_R) = \left(\frac{d\sigma}{dE_R}\right)_{SI} + \left(\frac{d\sigma}{dE_R}\right)_{SD} =$$

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

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

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

$F^2(E_R)$ nuclear form factors

m_{Wp} reduced WIMP-nucleon mass

Generalized SI/SD WIMP-nucleon cross sections:

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

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

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

Differential energy distribution:

$$\frac{dR}{dE_R} = N_T \frac{\rho_W}{m_W}\int_{v_{\min}(E_R)}^{v_{\max}} \frac{d\sigma}{dE_R}(v,E_R) v f(v) dv = N_T \frac{\rho_W m_N}{2 m_W m_{Wp}^2}\cdot \Sigma(E_R)\cdot I(E_R)$$

where: $$\Sigma(E_R) = \left\{A^2 \sigma_{SI} F_{SI}^2(E_R) + \frac{4}{3}\frac{J+1}{J}\sigma_{SD}\left[\langle S_p\rangle \cos\theta + \langle S_n\rangle \sin\theta\right]^2 F_{SD}^2(E_R)\right\}$$

$$I(E_R) = \int_{v_{\min}(E_R)}^{v_{\max}} \frac{f(v)}{v} dv$$

v_{max}: maximal WIMP velocity in the Earth frame

N_T: number of target nuclei

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

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

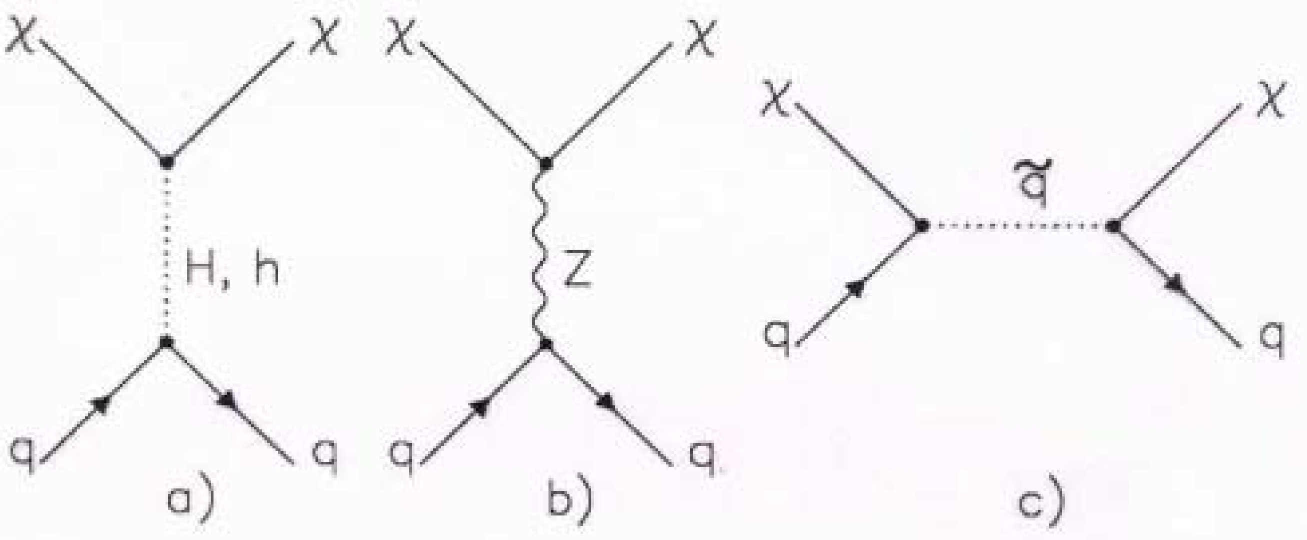
$v_e = v_{sun} + v_{orb}\cos\omega t$

The χ

- spin 1/2 - Majorana LSP

$$\chi = a_1\,\tilde{\gamma} + a_2\,\tilde{Z} + a_3\,\tilde{H}_1 + a_4\,\tilde{H}_2$$

- relevant diagrams for cross section on ordinary matter:



a) coherent contribution:

higgsino-Zino mixture: $\sigma \propto A^2$

b) spin-dependent contribution:

higgsino component: $\sigma \propto \lambda^2 J(J+1)$

c) spin and coherent contribution

Uncertainties on the models

- ρ_W
- **WIMP velocity distribution:** $f(\vec{v})$
- **parameters of** $f(\vec{v})$ **(in the usual case:** v_0 **and** v_{esc}**)**
- **couplings: SI, SD, mixed**
- **scaling laws on cross sections**
- **SI and SD form factors**
- **parameters of the form factors (in the usual case: r,s,b)**
- **etc.**

+ experimental parameters (typical of each experiment)

+ comparison within particle models

They can affect not only the annual modulation region but also the exclusion plots

First Model Framework

PLB480(2000) 23
PRD61(2000) 23512
PLB450(1999) 448
PLB424(1998) 195

- $\xi = \rho_W/(0.3 \text{ GeV cm}^{-3})$
- isothermal, maxwellian WIMP velocity distribution
- v_0 = 220 km/s and v_{esc} = 650 km/s

  Accounting for v_0 and v_{esc} uncertainties
- only SI
- $\sigma \propto \mu^2 A^2$
- Helm SI form factor
- $r = 1.2\ A^{1/3}$fm, s = 1fm
- parameters at fixed values
- physical constraints: $M_W > 30$ GeV

  Accounting for limit on recoils from PSD (DAMA/NaI-0)

Global analysis in the given scenario

- SI coupling
- Accounting for v_0 uncertainties

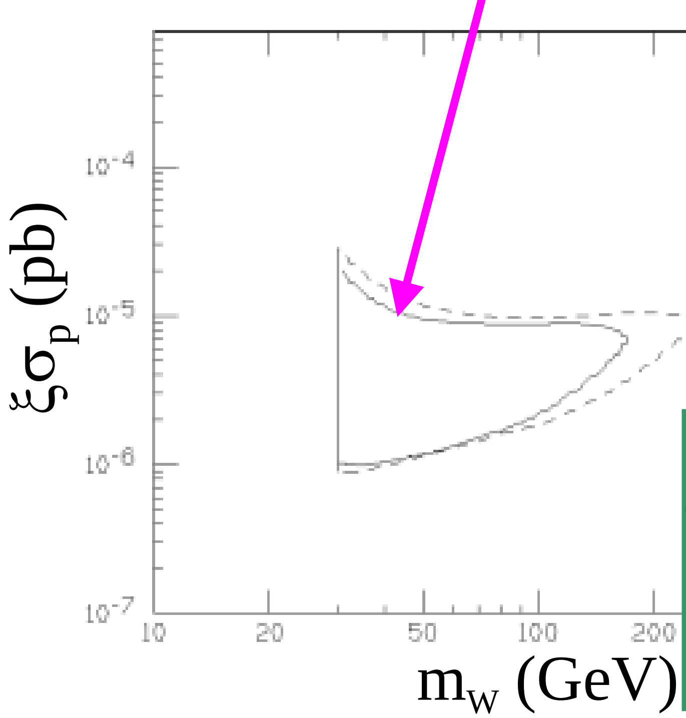
PLB480(2000), 23

Regions allowed a 3σ C.L. in the plane (m_W,$\xi\sigma_p$)

v_0 = (220 ± 50) km/s (90% C.L.)
(v_{esc}=(550±100)km/s (90% C.L.) ←negligible effect)
30 GeV ≤ m_W ≤ 105 GeV (1σ C.L.)

including possible Dark halo rotation
30 GeV ≤ m_W ≤ 132 GeV (1σ C.L.)

DAMA/NaI-0 to 4



v_0 (km/s)	m_W(GeV)	$\xi\sigma_p$(pb)
170	72^{+18}_{-15}	$(5.7\pm1.1)\cdot10^{-6}$
220	43^{+12}_{-9}	$(5.4\pm1.0)\cdot10^{-6}$
270	32^{+8}_{-7}	$(5.7^{+1.2}_{-1.1})\cdot10^{-6}$

In progress: investigation of the effect of halo models, WIMP velocity distributions, uncertainties associated to all experimental and theoretical parameters.

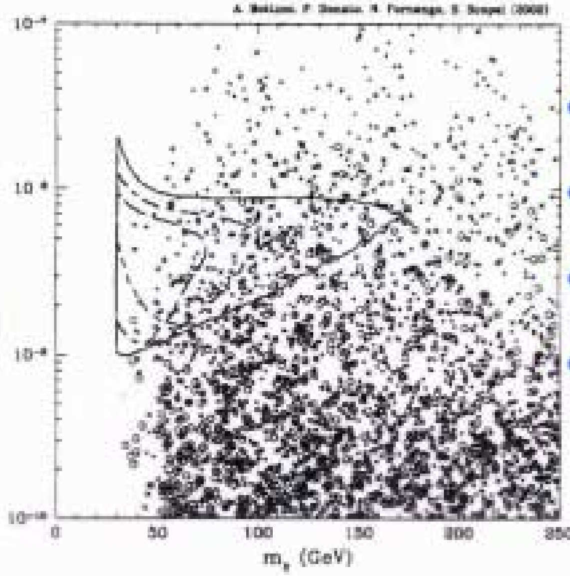
CONCLUSION #2

The comparison of the experimental data with the model of a SI coupled W IMP with m_W>30GeV (such as the neutralino) allows to put it as a candidate for the observed effect

Is a neutralino with mass and cross section in the region presently allowed by DAMA of cosmological interest?

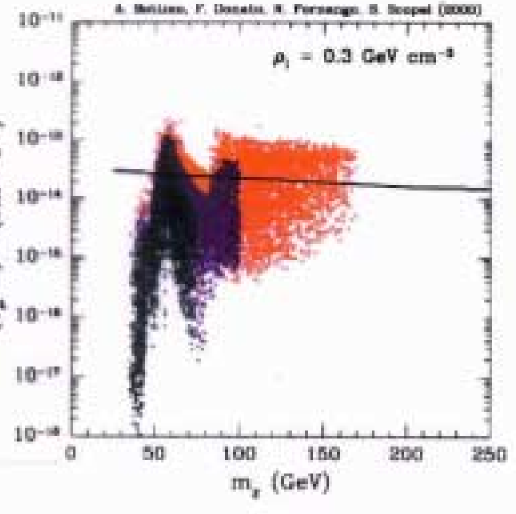
(see A. Bottino et al., R.W. Arnowitt and P. Nath, E. Gabrielli et al.)

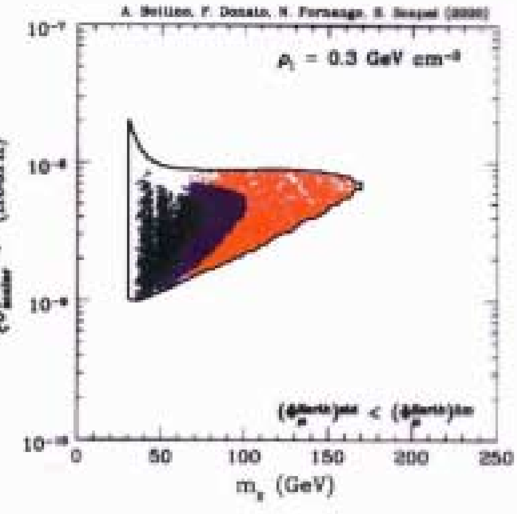
YES

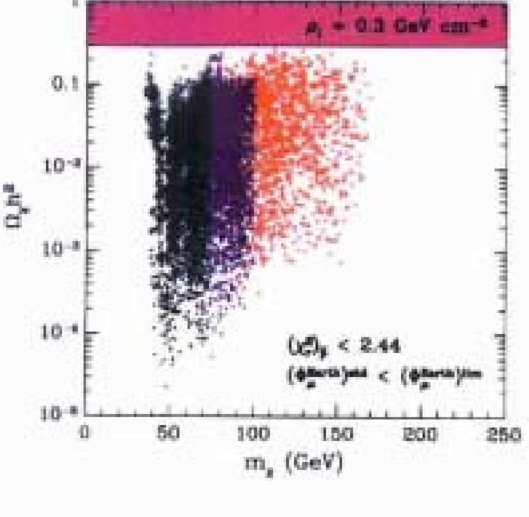


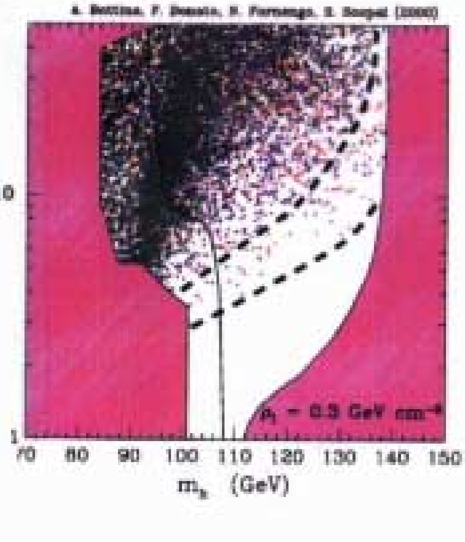
- MSSM
- Direct vs Indirect Searches
- Cosmological Abundance
- What expected from accelerators?

Bottino et al., PRD62(2000)056006



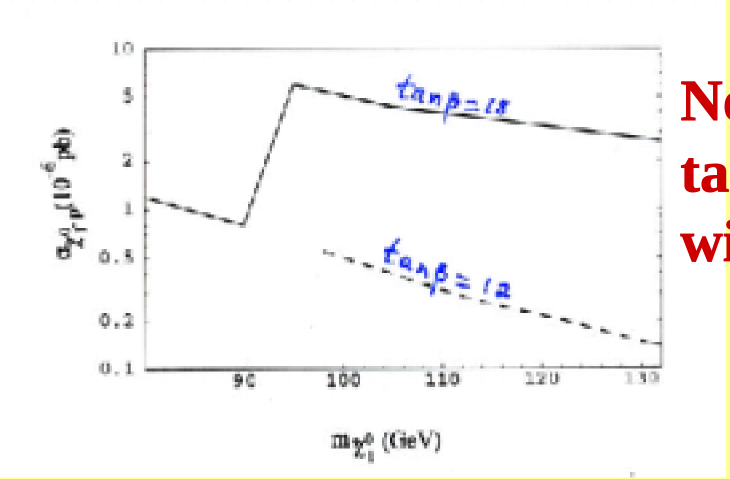






...and theories...

Arnowitt, Cosmo01

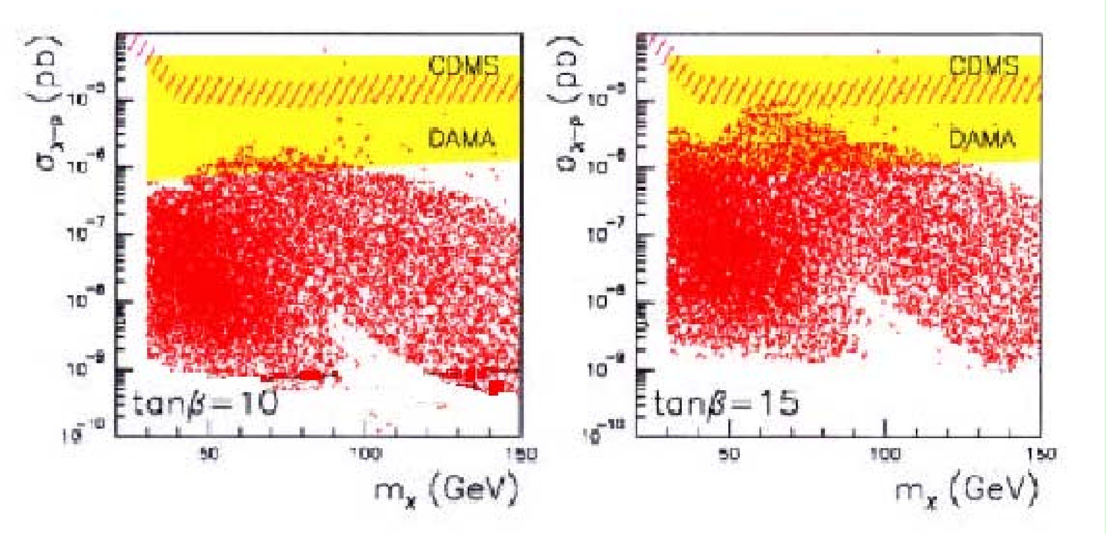


Non-Universal SUGRA
tanβ>15 ⇒ compatibility with DAMA

SUGRA tanβ>50 ⇒ possible compatibility with DAMA (strongly dependence on m_t and m_b)

Munoz, Cosmo01

Supergravity & Superstrings



tanβ>5 ⇒ compatibility with DAMA

General Model Framework for NaI(Tl)

PLB509 (2001) 197

- $\xi = \rho_W/(0.3 \text{ GeV cm}^{-3})$
- isothermal, maxwellian WIMP velocity distribution
- v_0 = 220 km/s and v_{esc} = 650 km/s

  Accounting for v_0 and v_{esc} uncertainties

- SI & SD
- $\sigma(SI) \propto \mu^2 A^2$, $\sigma(SD) \propto \mu^2 \Lambda^2 J(J+1)$
- Helm (SI) , Ressel et al. with Nijmegen potential (SD) form factors
- parameters at fixed values **+** *r*, *s*, *b* -20%
- physical constraints: $m_W > 30$ GeV

  Accounting for limit on recoils from PSD (DAMA/NaI-0)

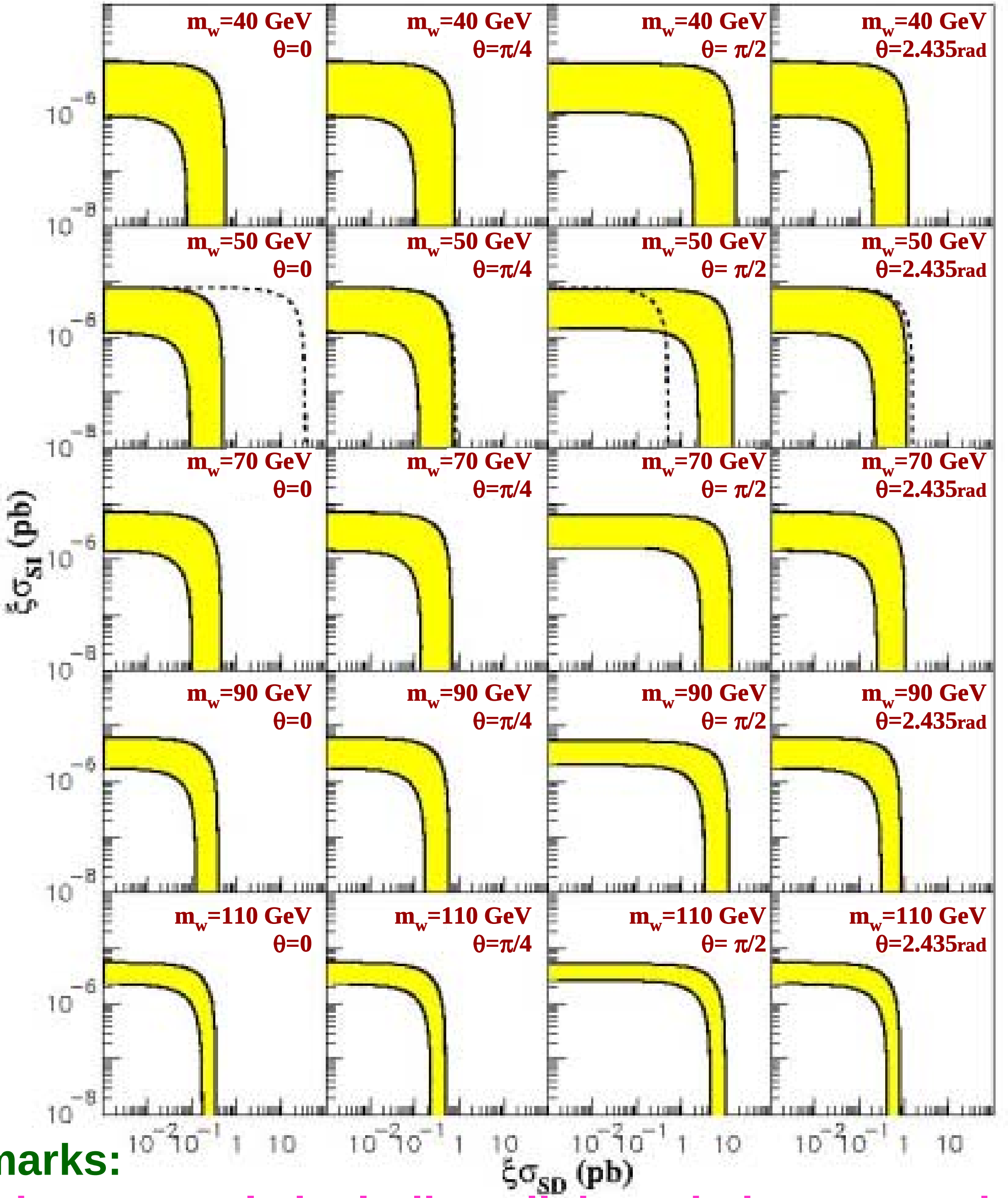
SI, SD mixed scenario

PLB509 (2001) 197

Allowed volume in the space (m_W, $\xi\sigma_{SI}$, $\xi\sigma_{SD}$) for each possible $tg\theta = a_n/a_p$ ($0 \leq \theta < \pi$)

Example of slices (3σ C.L.) for given m_W and θ

$a_p \neq 0$ $a_n = 0$ | $a_p = a_n$ | $a_p = 0$ $a_n \neq 0$ | $a_n/a_p = -0.85$



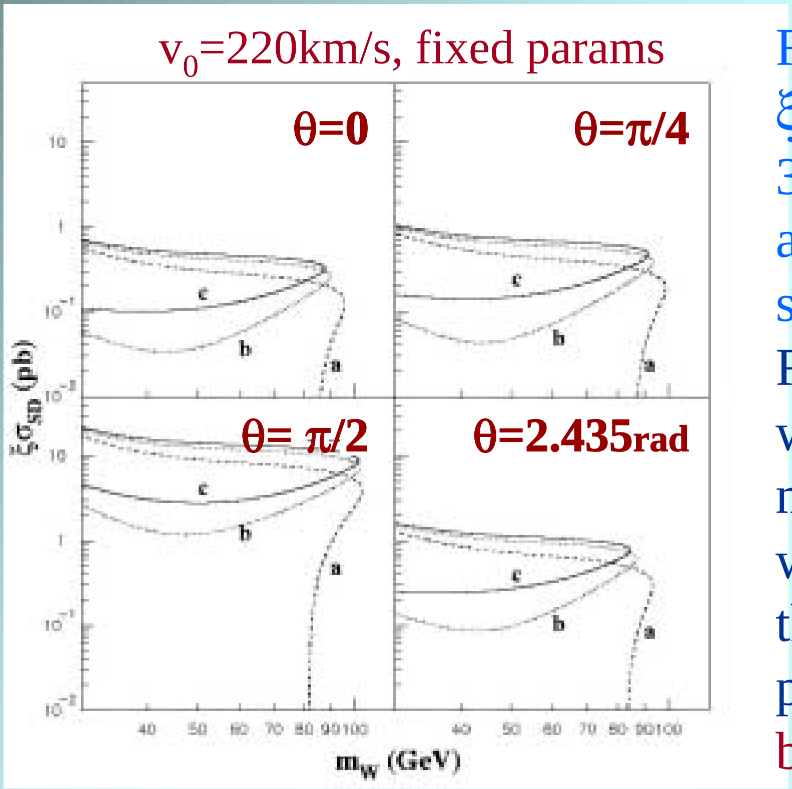
Remarks:

A) when properly including all the existing uncertainties much larger allowed regions are obtained for whatever model dependent scenario

B) other halo and particle models under investigation

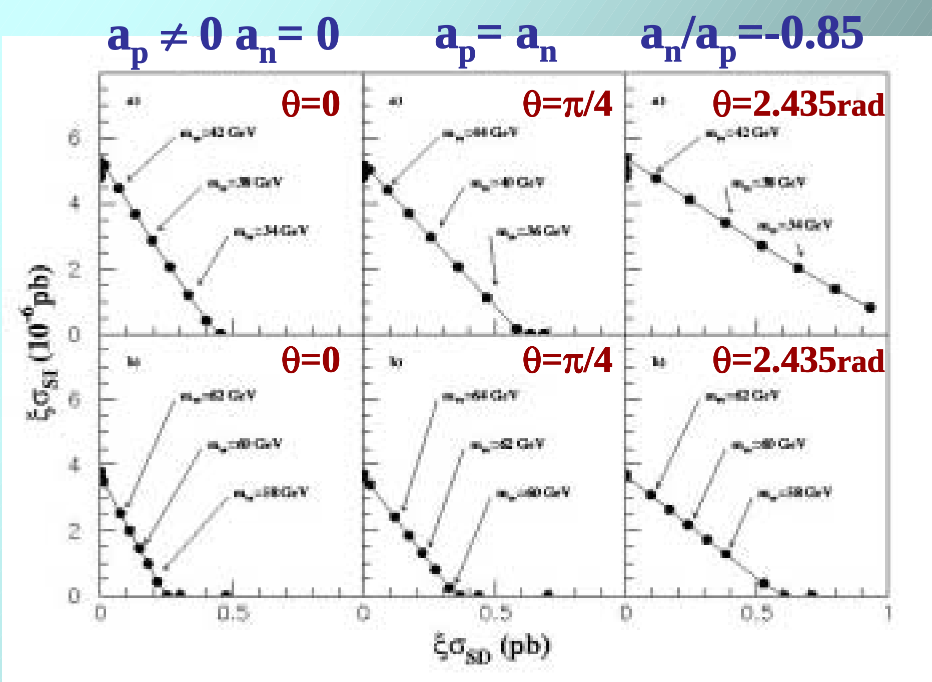
SI, SD mixed scenario

- If SD=0, interval not compatible with zero for $\xi\sigma_{SI}$
- If SI=0, interval not compatible with zero for $\xi\sigma_{SD}$
- Large regions allowed for mixed configurations also for $\xi\sigma_{SI} < 10^{-5}$ pb and $\xi\sigma_{SD} < 1$pb.



Finite values allowed for $\xi\sigma_{SD}$ even when $\xi\sigma_{SI} \cong 3\cdot10^{-6}$ (as in the region allowed in the pure SI scenario) (contour a)

Regions not compatible with zero in the $\xi\sigma_{SD}$ vs m_W plane allowed even when $\xi\sigma_{SI}$ much lower than those allowed in the pure SI scenario (contours b,c).



Minima of the *y* function with both $\xi\sigma_{SI}$ and $\xi\sigma_{SD}$ different from zero are present for some m_W and θ pairs (related C.L. ranges between 3 and 4 σ)

Comments

Open scenario

- SI: equal coupling on proton and neutron? (g_p=g_n?)
- SD: nuclear and particle physics degrees cannot be decoupled, that is the generalized SD FF depends on interacting particle (a_p, a_n) and of the chosen nuclear modellization.

Other scenarios are under study

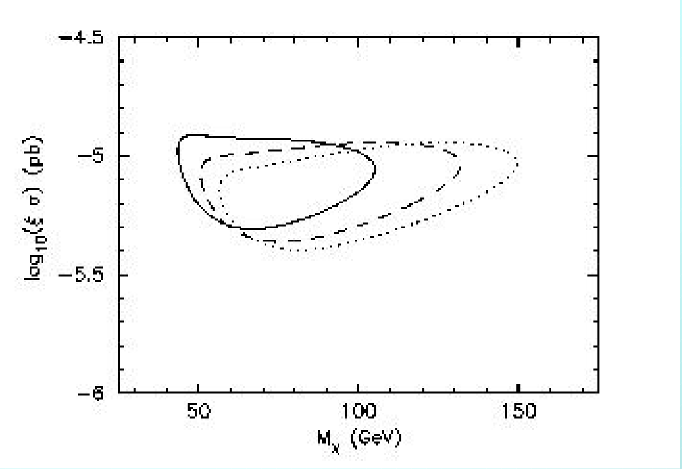
- Different halo modellizations and different WIMP velocity distributions
- Different interacting particles (such as inelastic WIMPs)
- ...

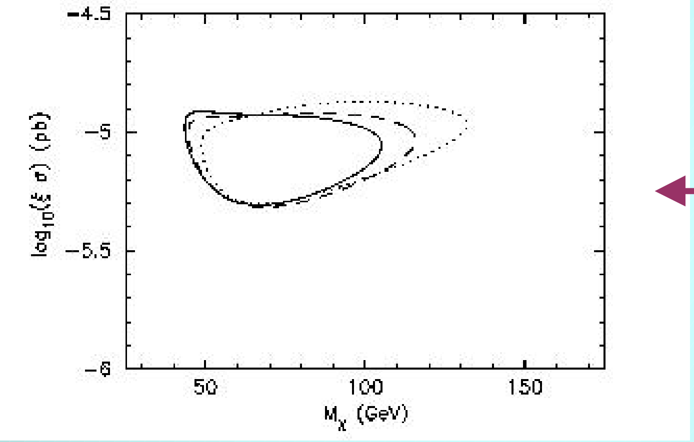
Example of nonstandard halo models

Qualitative approach by A.M. Green, PRD63 (2001) 43005

Asymmetric halo models with λ=0,0.5,1 (solid, dashed, dotted)

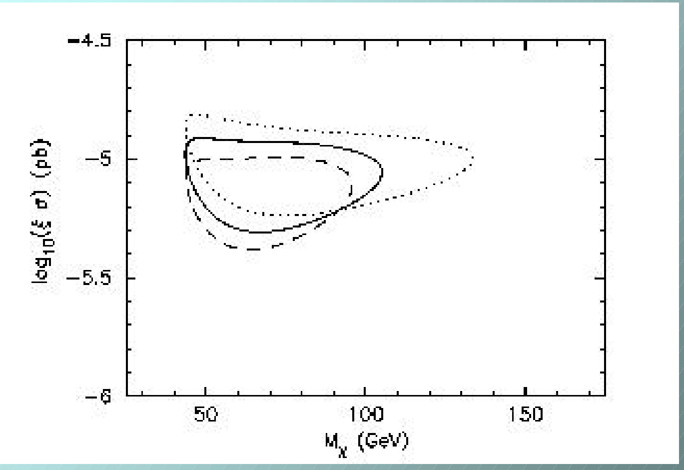
$$f(v) \propto e^{-\frac{v^2}{v_0^2}} \cdot e^{-\lambda\frac{v_\phi^2 + v_z^2}{v_0^2}}$$





Flattened halo models with the flattening parameter q=1.0,0.85,0.707 (solid, dashed, dotted)

Standard halo model with bulk rotation (see also PRD61(2000)23512) with a_{rot}=0.36,0.5,0.64 (dashed, solid, dotted)



Quantitative approach on real data in progress

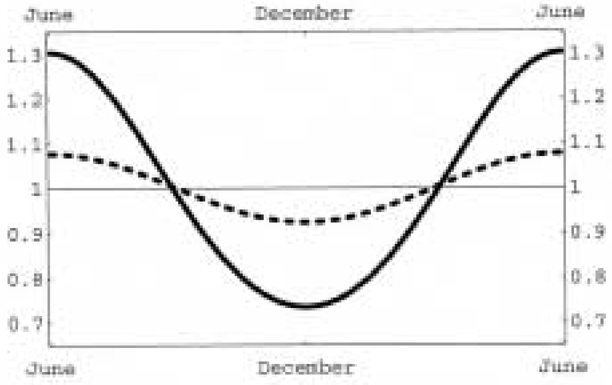
WIMPs with “preferred” inelastic scattering

D. Smith and N. Weiner, hep-ph/0101138

- **Two states χ_+ , χ_- with δ mass splitting WIMP**

- **Kinematical constraint for the inelastic scattering of χ_- on a nucleus with mass m_N:**

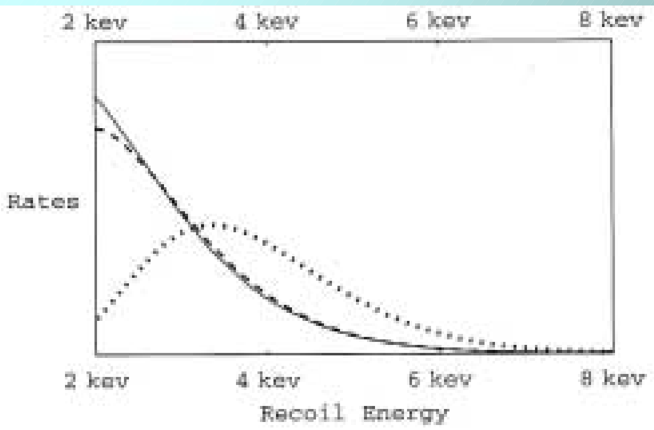
$$\frac{1}{2}\mu v^2 \geq \delta \quad \Rightarrow \quad v \geq v_{thr} = \sqrt{\frac{2\delta}{\mu}} \qquad \text{where} \qquad \mu = \frac{m_W m_N}{m_W + m_N}$$



Annual modulation of event rate with average normalized to one in the inelastic WIMP scenario (solid line) and standard WIMP scenario (dashed), with $\delta = 100$keV and $m_\chi = 50$GeV.

Ex. m_W =100 GeV

m_N	μ
70	41
130	57



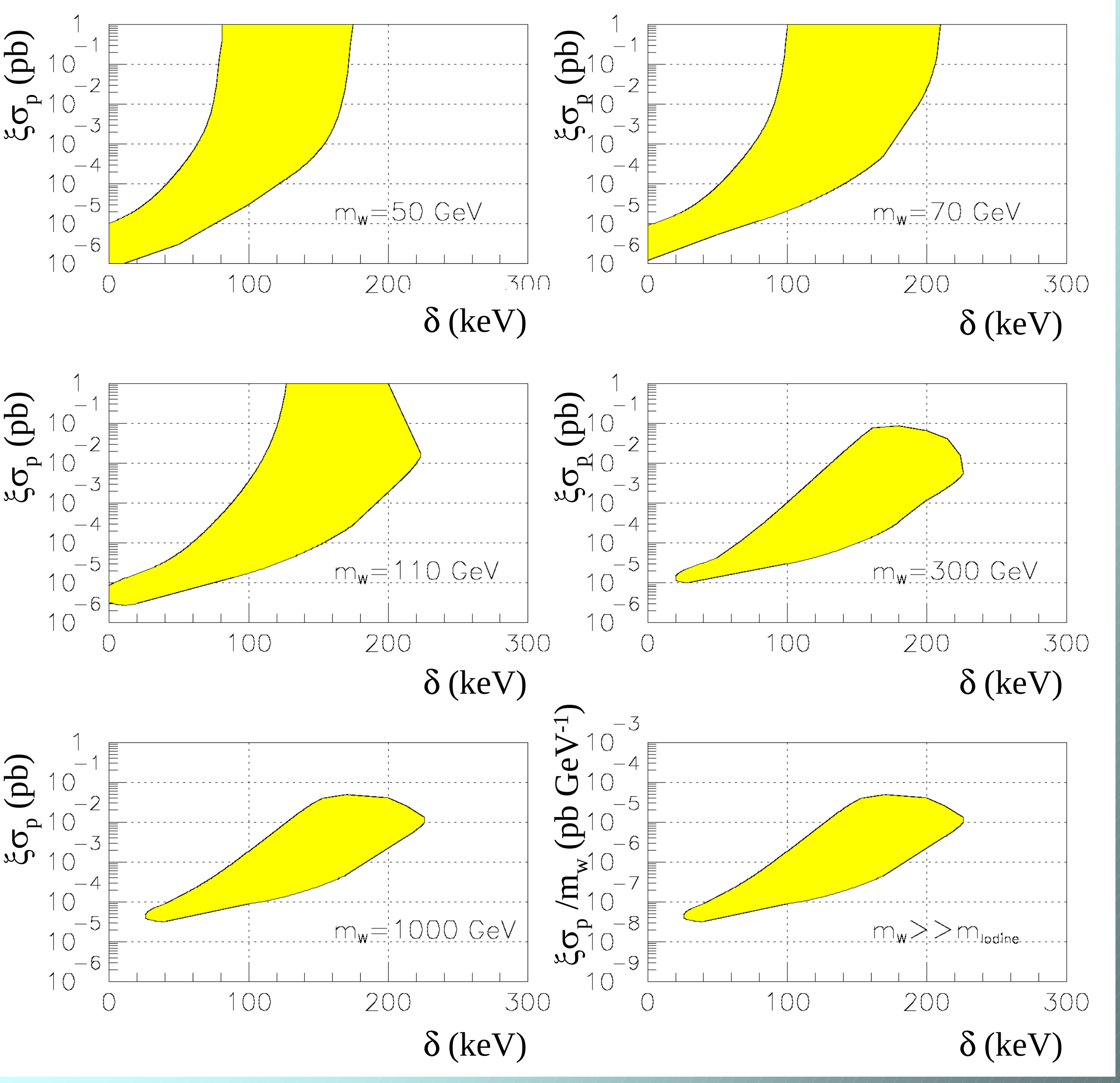
Normalized modulation (S_m) as a function of energy for ordinary WIMP scenario (solid), inelastic WIMP scenario with $\delta = 100$keV (dashed), and inelastic WIMP scenario with $\delta = 150$keV (dotted), all with $m_\chi = 60$GeV.

Examples of regions allowed by DAMA results for different WIMP masses (3σ C.L.) for inelastic Dark Matter

ROM2F 2001-33

Energy-Time correlation analysis of the events

Model framework: accounting for v_0 and v_{esc} uncertainties: v_0=170-270 km/s; v_{esc}=450-650 km/s; parameters at fixed values + *r*, *s*, *b* -20%. Accounting for limit on recoils from PSD (DAMA/NaI-0).



Reliable Proofs and Disproofs

Model independent comparisons

- No model independent comparison is possible with others
- Proof in DAMA: 4 independent cycles give consistent results

NO DISPROOF

Model dependent comparisons

Direct detection:

- **Pure SI?** CDMS (and similars) $\rightarrow$ Ge, background rejection uncertainties, stability, calibration, data "selection" and "handling", + other nucleus $\leftrightarrow$ uncertainties on scaling laws, on different sensitivity to different interactions, on used values for theoretical and experimental parameters, on astrophysical assumptions and model framework.
- **Pure SD?** (Ullio et al. hep-ph/0010036): wrong approach: use of SI model dependent S_m as SD one $\rightarrow$ arbitrary regions given + only two of many possible cases considered for a_n vs a_p, DAMA/LXe exclusion plot (as always) model dependent (uncertainties on scaling laws, on FF, on spin factors, on parameters, ...) $\rightarrow$ quantitative comparison arbitrary
- **Mixed coupling:** no comparison available
- **Our data often quoted uncorrectly**, e.g.: i) 2σ region (Baudis et al. PRD63(2001)022001) $\rightarrow$ estimates of different C.L. region than published by DAMA requires knowledge of behaviour of the log-lik function around the minima at various v_0 values; ii) DAMA/NaI-0 constraint not always considered; iii) the quantitative comparison between allowed DAMA region accounting for v_0 uncertainties and exclusion plots at fixed v_0 is uncorrect; ...

NO DISPROOF + many other scenarios possible

Indirect detection:

- No reliable quantitative comparison are possible, because it depends on assumptions and on the considered model framework.
- Biunivocal correspondence between the observables of direct/indirect detection (SI-SD cross sections / flux of secondary particles) depends on the given model framework: e.g. SK, MACRO, Baksan, ...
- Positron excess in cosmic rays? (see for example hep-ph/0108138)

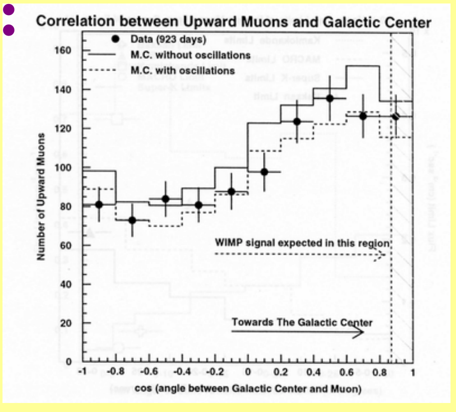
NO DISPROOF; PROOF?

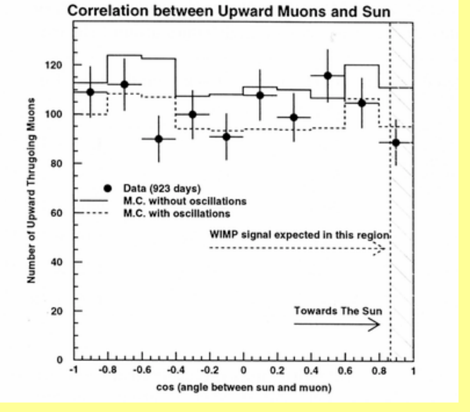
... and theory?

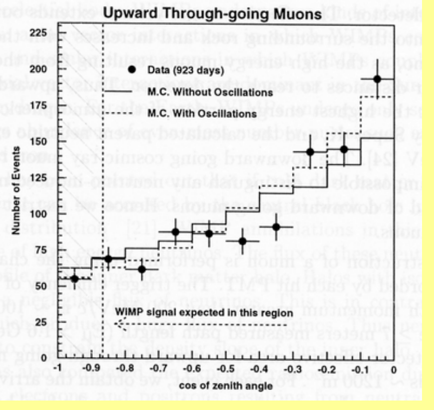
DAMA model independent and model dependent result not based on the candidate nature. If χ with dominant SI coupling $\rightarrow$ region compatible with MSSM expectations. "Constrained" models possible, but ...?

Recent results of up-going μ searches

Superkamiokande :





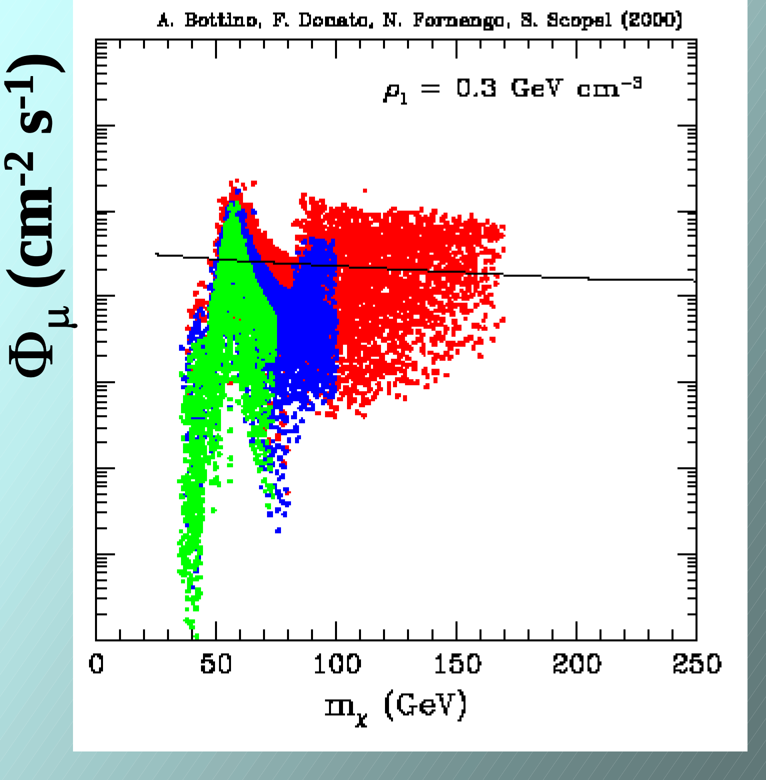


Similar results from MACRO, Baksan, ...

... exploring DAMA region:

PRD62(2000)056006

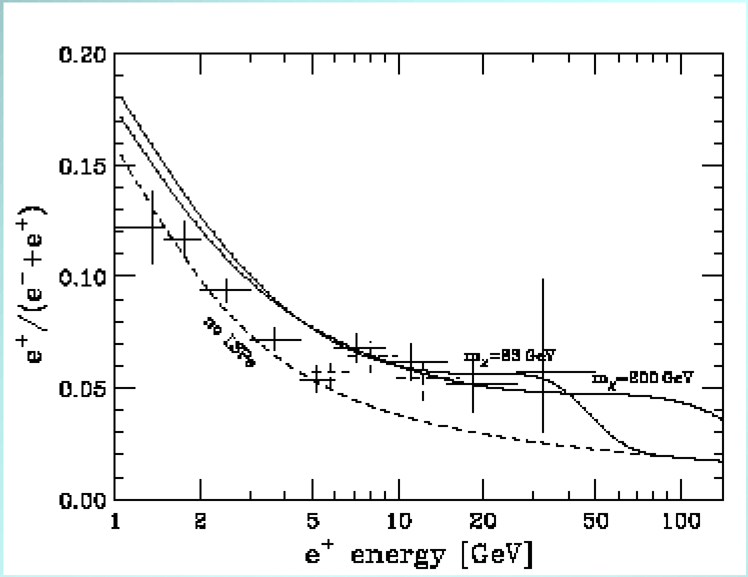
- Expectation of up-going muon flux from the center of the Earth in the MSSM versus χ mass.
- The MSSM configurations are selected by the DAMA region.
- Different colors refer to different v_0 values.



Positron excess in cosmic rays

Kane et al., hep-ph/0108138

- **Data analysis of the HEAT balloon experiment.**
- **Data set of 2000 (new and different instrument) confirms data set of 1994/95.**
- **Excess of high-energy positrons**



- Positron fraction as a function of the energy.
- The lower dashed line is the expected signal fraction with no χ annihilation.

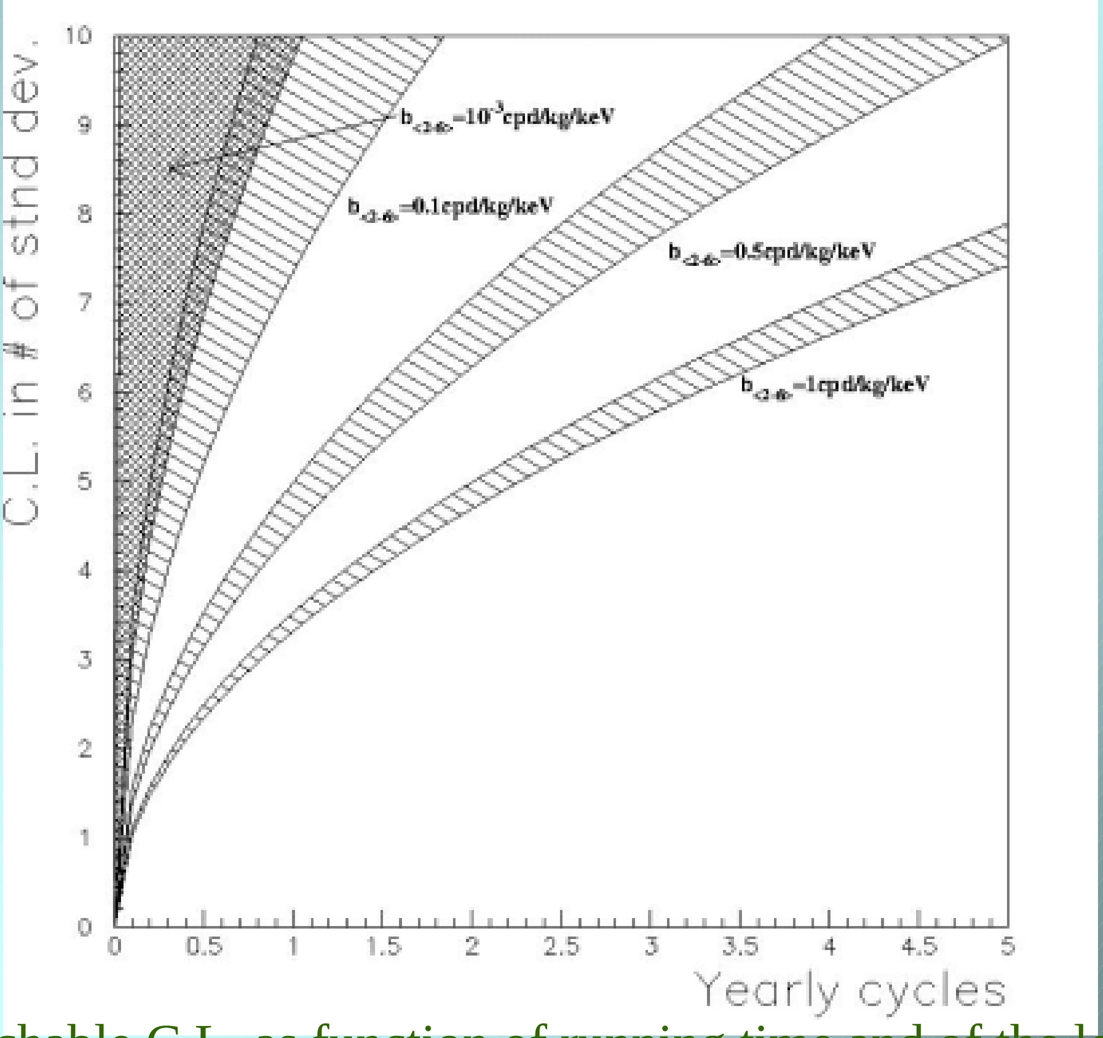
- The solid lines also include positrons and electrons from χ annihilation (m_χ=83 and 200 GeV)
- Data sets: 1994-1995 and 2000.

Compatible with DAMA result

What next on DAMA

~100 kg NaI(Tl)
further investigation on models in progress, 5th and 6th annual cycles at hand, 7th annual cycle in progress.

~250 kg NaI(Tl) LIBRA set-up under construction

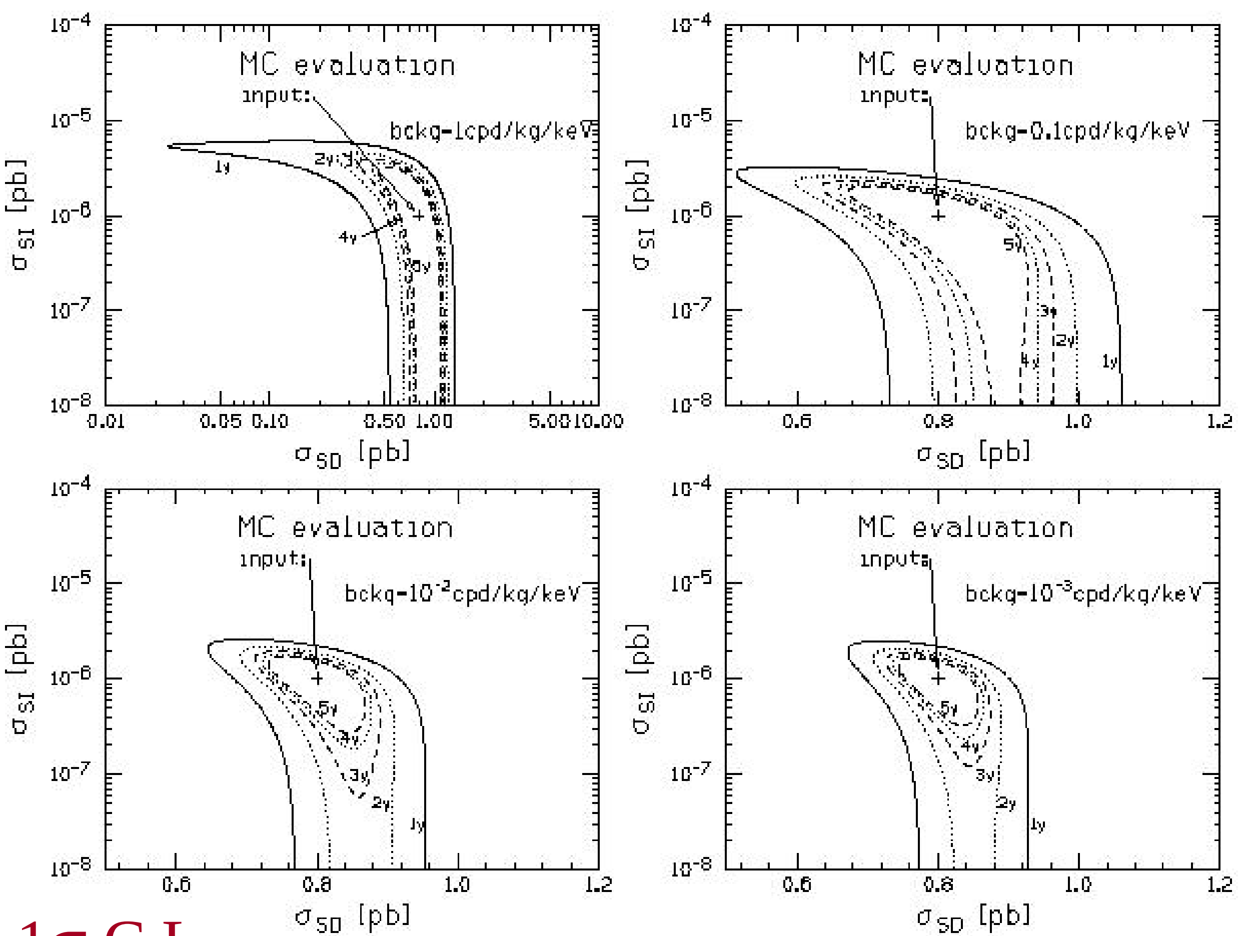


Reachable C.L. as function of running time and of the low energy bckg rate. The shaded regions account for several model frameworks

Example of the reachable sensitivity with the ~250kg NaI(Tl) set-up

Role of the increase of statistics and of the improvement in the bckg rate to identify a possible SI/SD coupled WIMP.

- **Allowed regions evaluated by simulating the response of the ~250kg NaI(Tl) set-up to a WIMP having m_W=60GeV, $\sigma_{SI}=10^{-6}$ pb, σ_{SD}=0.8 pb and θ=2.435rad.**
- **Various exposure times are considered (from 1 to 5y).**
- **In each panel different bckg rate.**



- 1σ C.L.
- v_0=220km/s, fixed params

Conclusions on DAMA

- **LXe and small scale expts are in progress**
- **NaI(Tl): 4 annual cycles released (57986 kg day)**
  consistent results from each independent experiment of 1 year cycle

Model independent presence of an annual modulation with the proper features

No systematics and side reactions able to account for observed modulation and to satisfy all distinctive features

Model dependent pure SI + mixed SI/SD + inelastic WIMPs + studies on the uncertainties of parameters and model frameworks

- **Further investigations on models in progress**
- **5th and 6th annual cycles at hand**
- **7th annual cycle running**

~250kg NaI(Tl) set-up to improve the experimental sensitivity. New radiopure detectors result of a dedicated R&D.

LIBRA set-up

(Large sodium Iodine Bulk for RAre processes) in the DAMA experiment