Possible Dark Matter scenarios for DAMA/LIBRA results

Séminaire du SPP 12.01.2009

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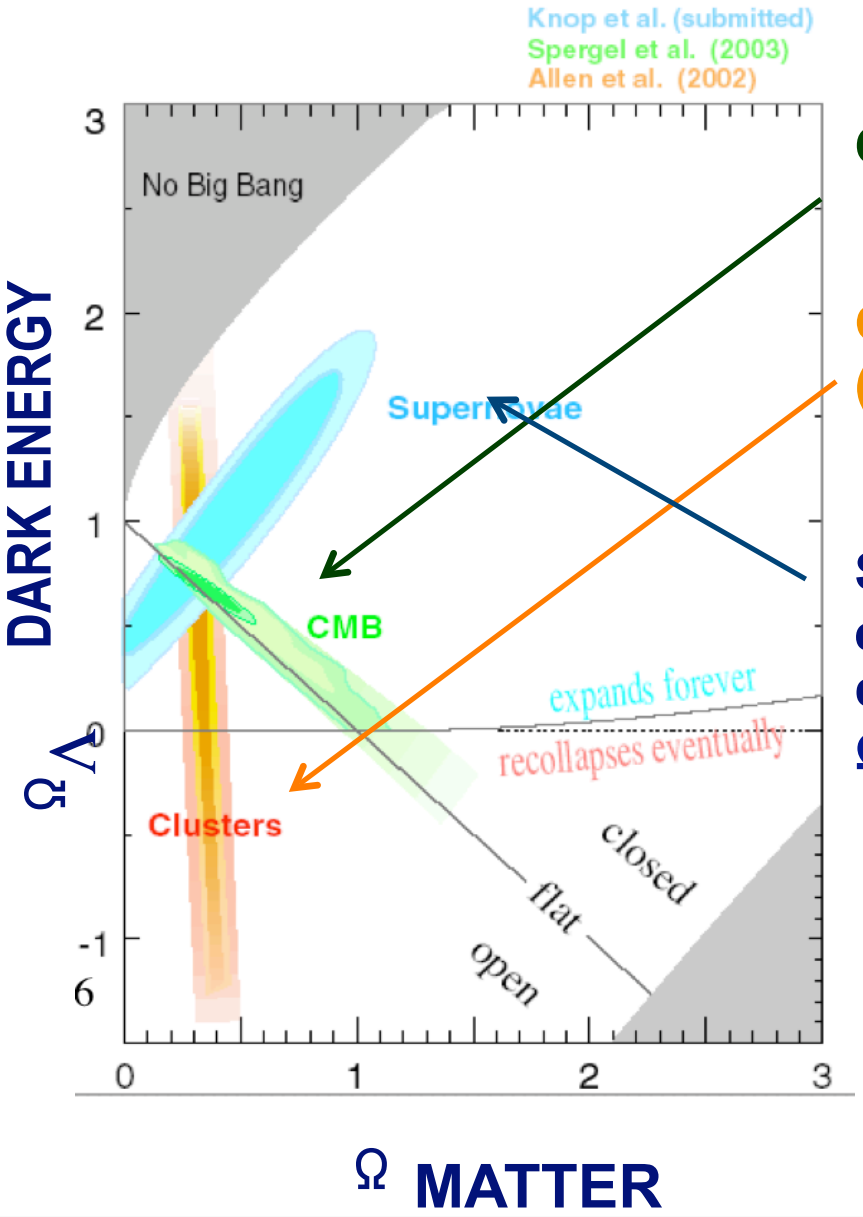
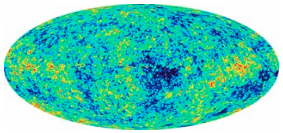
The Concordance model

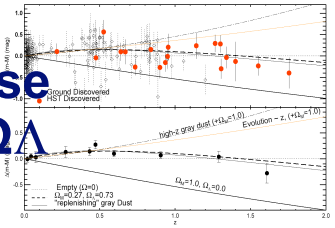


CMB : flat universe
ΩM + ΩΛ = 1.02 ±0.02



Galaxy clusters
(lenses, viriel, X rays) :
ΩM = 0.30 ± 0.03 (mainly d

Supernovae :
expansion of the universe
dependent on ΩM and ΩΛ
ΩΛ - ΩM ≈ 0.4



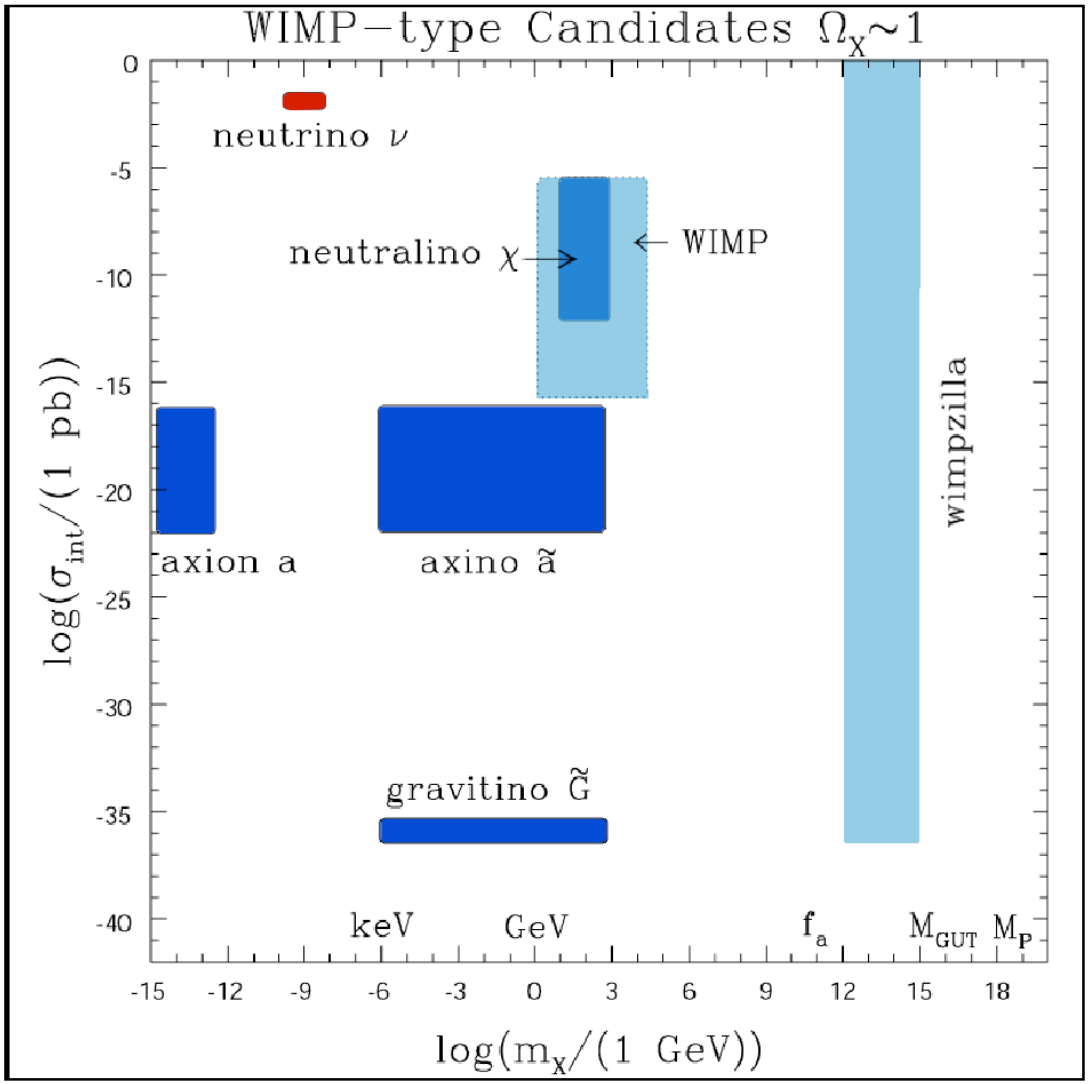
-**Big Bang Nucleosynthesis :**
Ω baryons = 0.05 ± 0.005
->Dark matter is non-baryonic
(Also from CMB)
- **Structure formation :**
Dark matter is cold

A few Dark Matter candidates

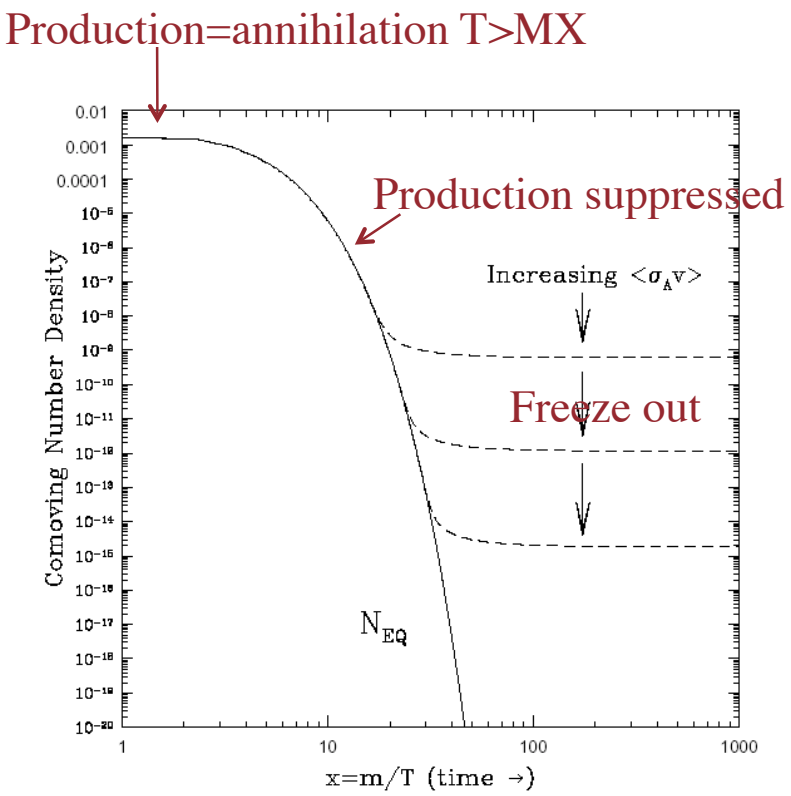
Covers a very large range of masses and cross sections

Most promising Candidates :

- **WIMPS**
- **Axions**

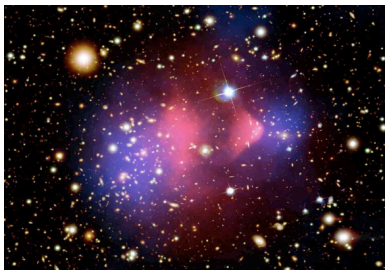


Weakly Interacting Massive Particle



WIMPs

« Bullet cluster » 1E0657-558



- Big bang relics

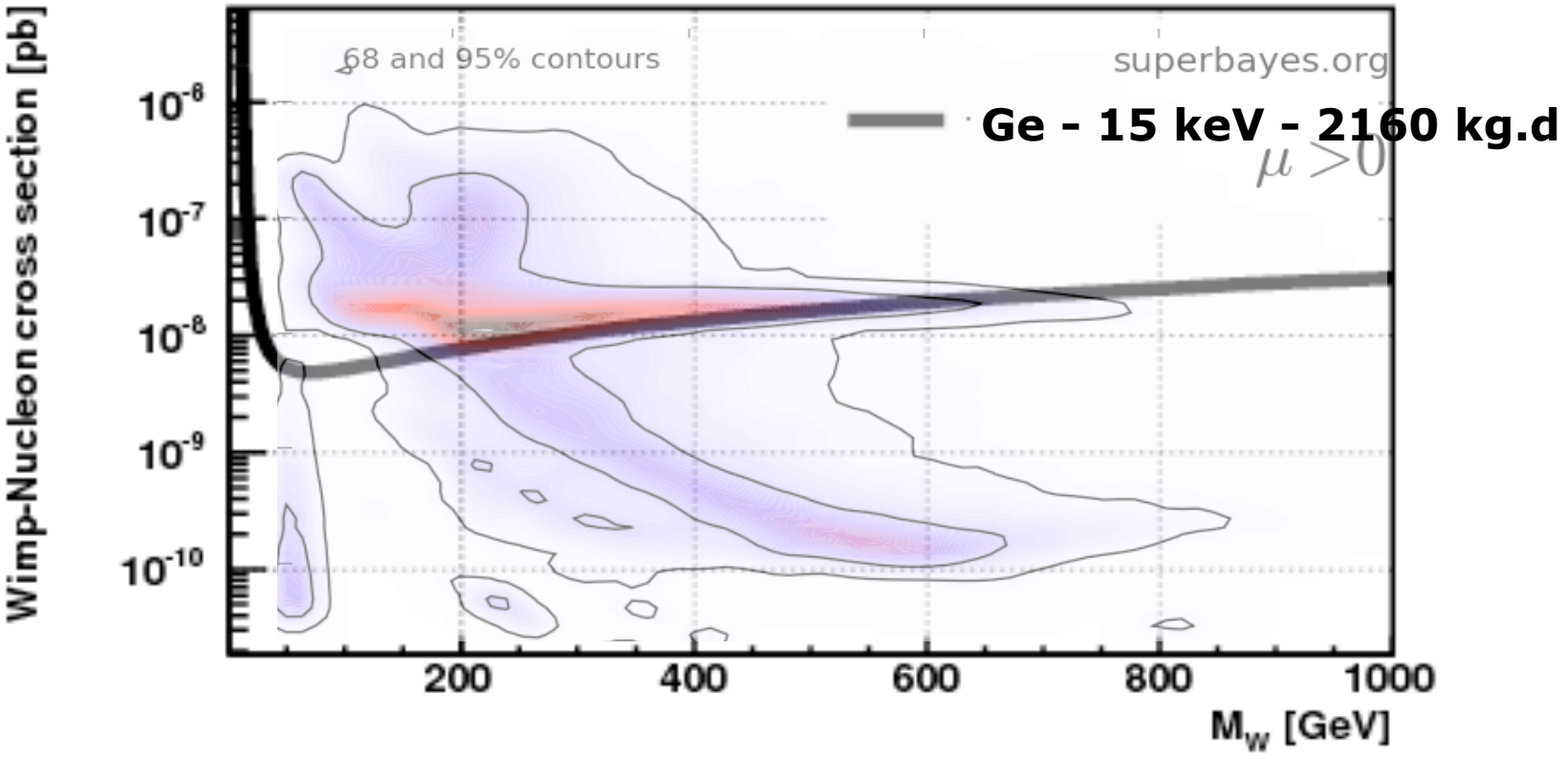
- **10 - 1000 GeV**
- **The annihilation cross-section giving the right relic density is around the electro-weak scale**

where one expects new physics

Freeze-out When annihilation rate = expansion rate

Neutralinos, Kaluza-Klein, etc

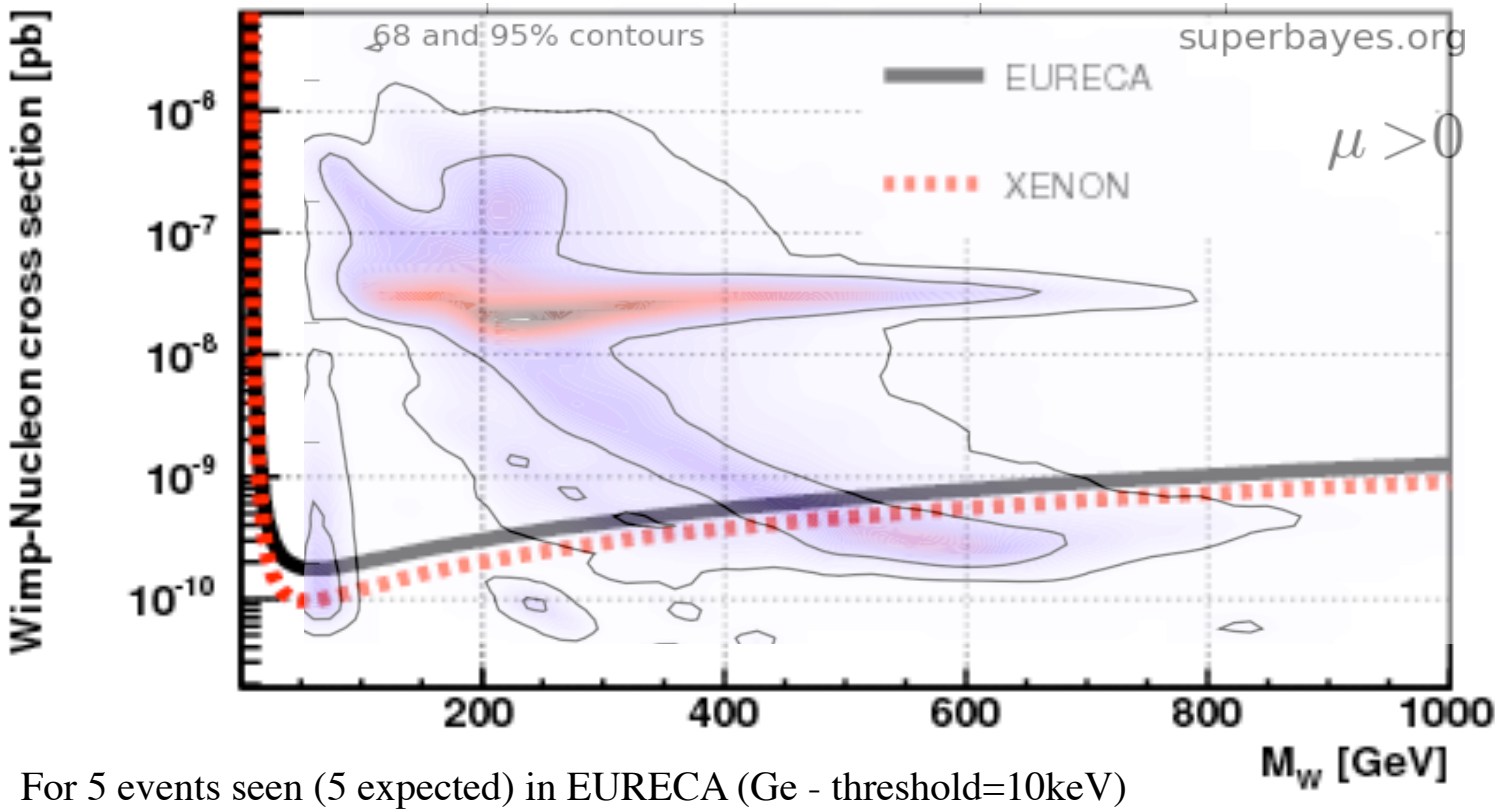
MSUGRA Neutralino (SuperBayeS scan)



Bulk of models reachable soon

Using Ilias dark matter web tools (DAMNED): http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/

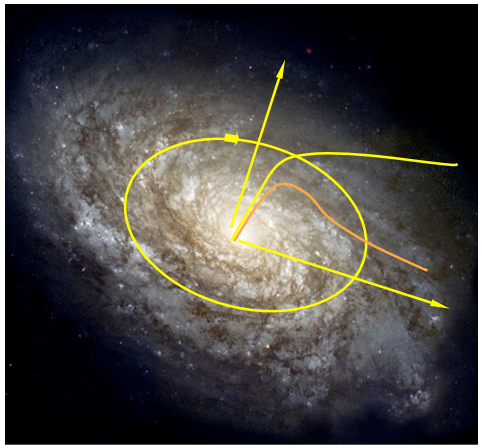
MSUGRA Neutralino (SuperBayeS scan)

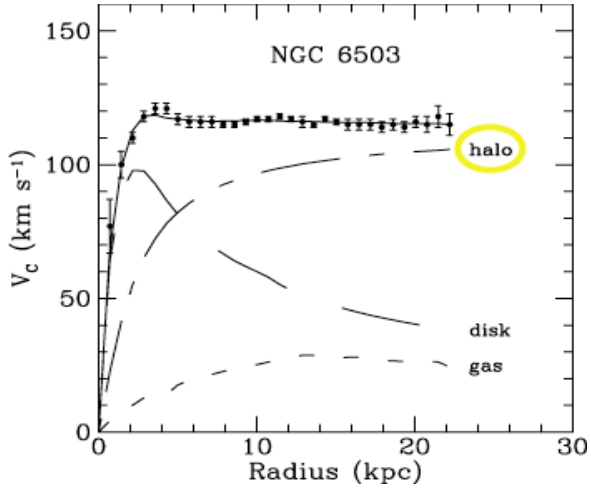


For 5 events seen (5 expected) in EURECA (Ge - threshold=10keV)
In XENON (Xe - threshold= 6.75 keV (3keVee)

Future experiments will probe most of the models

WIMPs in the galactic halo





Rotation curve of the galaxies point to Dark Matter

- EROS : Machos < 10% halos

From rotation curves:

Local density = 0.2-0.4 GeV/cm^3

For M_{WIMP} ~100 GeV/c^2

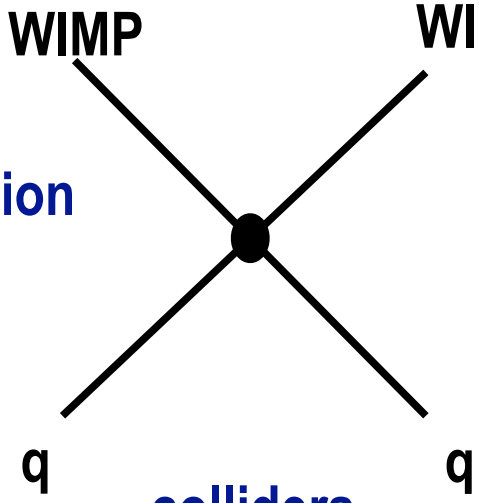
density = 3000 WIMPs/m^3,

velocity # 200 km/s:

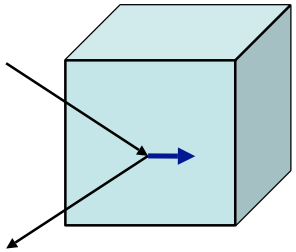
flux = 10^5 WIMP/cm^2/s

WIMP detection

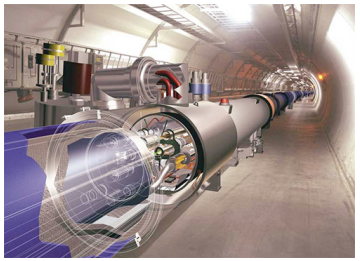
Indirect detection



direct detection



colliders



Indirect detection
WIMP annihilation in the galactic halo, the sun, the earth

Direct detection : nuclear recoil induced by a WIMP

Production in colliders: missing energy

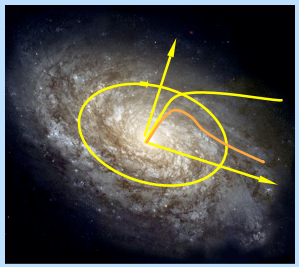
WIMPs detection rate

WIMP nature : eg Neutralino

σ = **WIMP-nucleus cross section (point-like)**
m_χ = **WIMP mass**
(μ = **WIMP-nucleus reduced mass**)

Galactic Halo

ρ = **density (0.3 GeV/cm3)**
$f(v)$ = **velocity distribution**
(v_0=200 km/s)



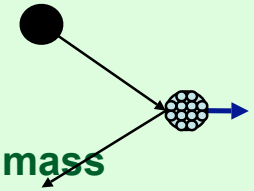
Detection rate :

$$\frac{dN}{dE} = \frac{\sigma \rho}{2\mu^2 m_\chi} F^2 \int_{v_{min}(E_r)}^{v_{esc}} \frac{f(v)}{v} dv$$

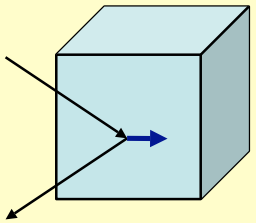
$$x\ \varepsilon_{(E)} / q_{(E)} \otimes r_{(E)}$$

Nucleus

F = **Nuclear form factor**
μ = **WIMP-nucleus reduced mass**



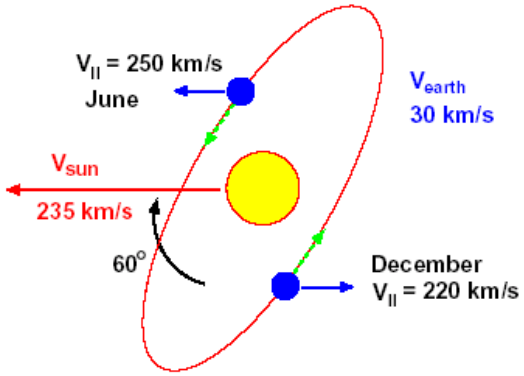
Detection
$q_{(E)}$ = **quenching**
$\varepsilon_{(E)}$ = **efficiency**
$r_{(E)}$ = **resolution**



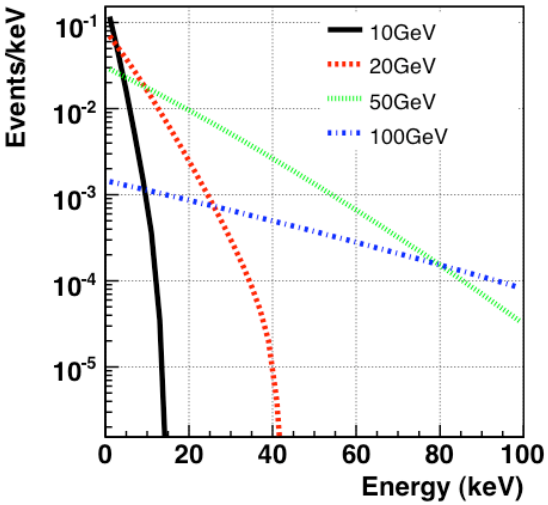
J. D. Lewin and P. F. Smith, Astropart. Phys. ***6****, (1996)87*

Signatures

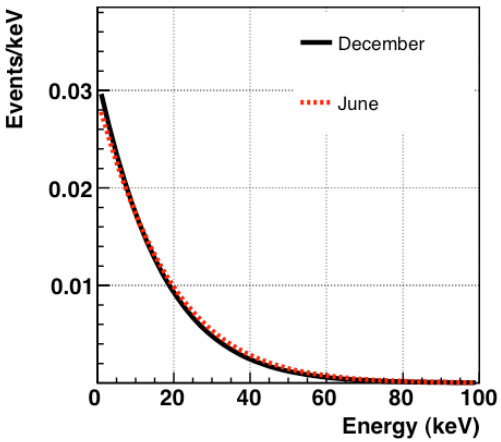
1. Recoil energy spectrum
2. Nuclear (and not electron) recoils
3. Coherence: μ^2A^2 dependence
4. Absence of multiple interactions
5. Uniform rate throughout entire volume
6. Annual modulation (… requires >~10^4 evts!)
7. Directonality (Gabriela Sciola seminar)



for different masses



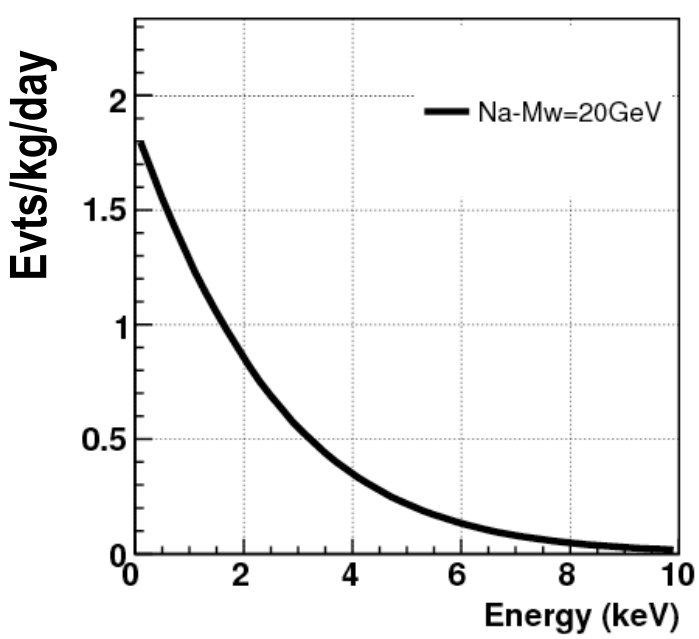
December-June signal

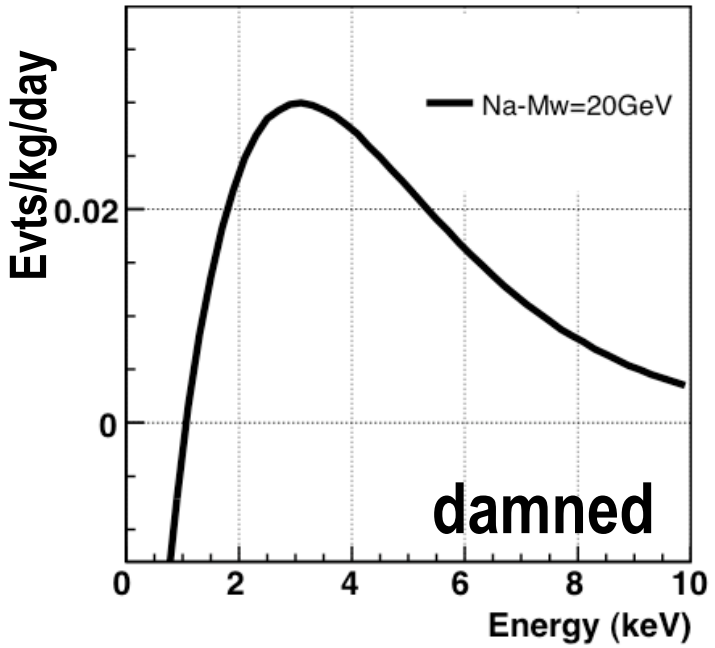


Signal harder as Earth moves in same direction as the Sun through the galactic halo at the level of only a few percents

Annual modulation signal

Example of a 20 GeV mass WIMP interacting on a Na nucleus with standard halo assumptions, seen in NaI(Tl)



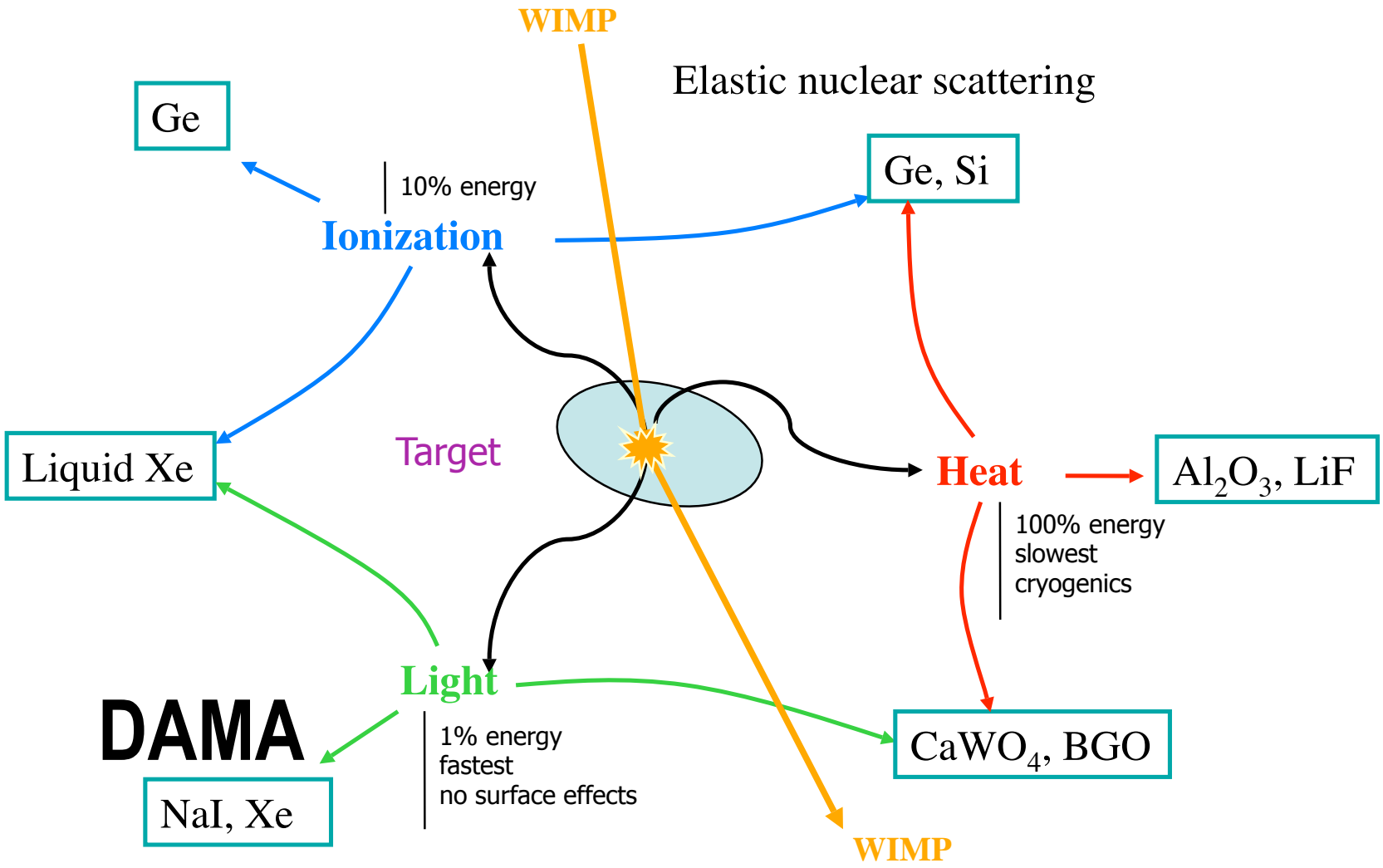


S_0 S_m

$$S = S_0 + S_m \cos(\omega t)$$

DAMA looks for the annual modulation of the signal which should vanish for the background

Detection techniques

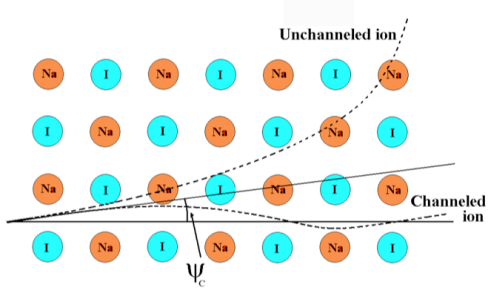


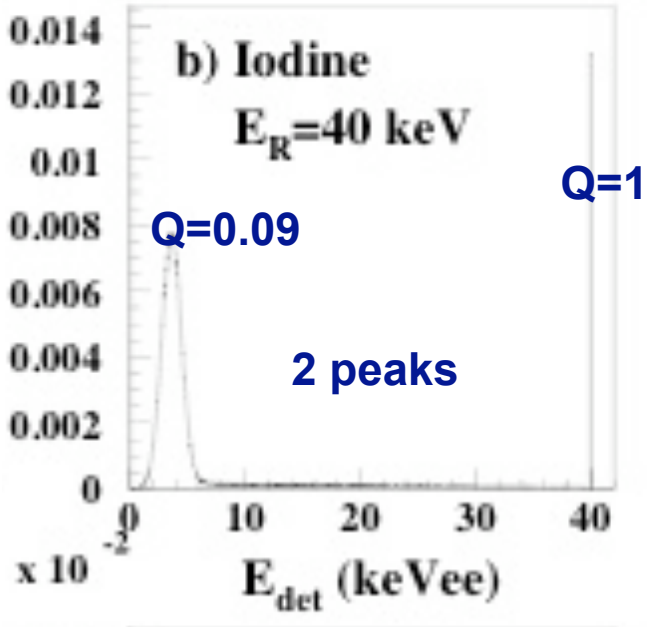
Quenching and Channeling

Light Yield (quenching) =0.09 for I recoil and 0.3 for Na recoils

arXiv:0710.0288 [astro-ph]

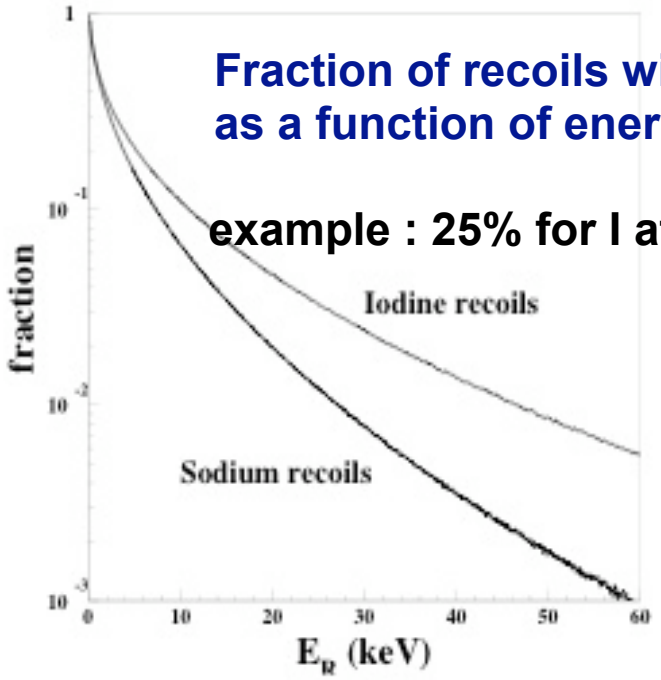
But Channeling Q=1 along lattice axes





Fraction of recoils with Q=1 as a function of energy

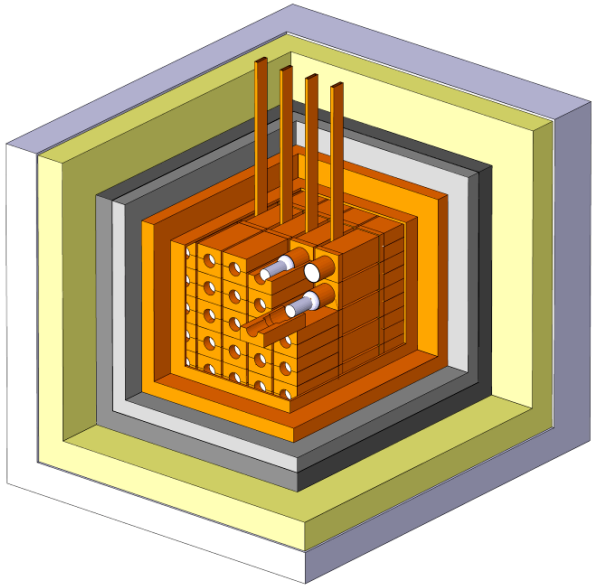
example : 25% for I at 3 keV



Channeling estimated by simulation
Usually results are quoted taking and not taking into account this effect

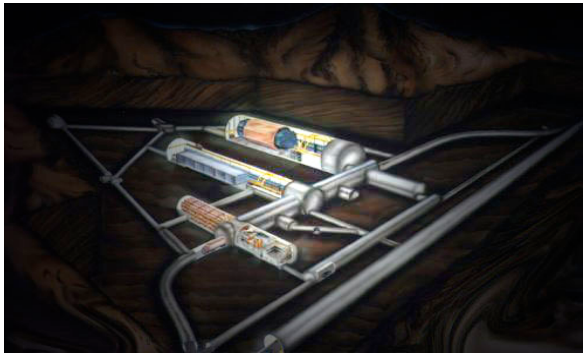
Background issues

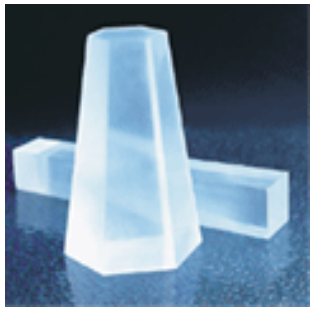
Rare event search (< 1 evt/kg/week)
at low energies (keV)



background reduction :

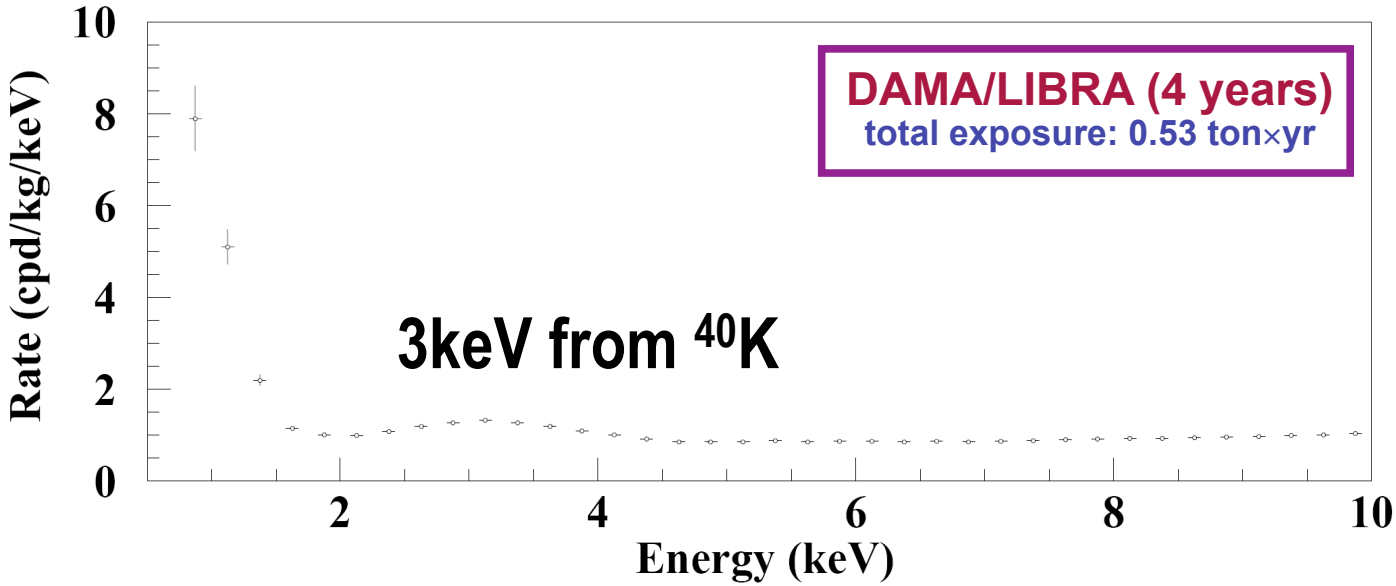
- Underground site (cosmic rays)
- Shieldings (radioactivity of the walls)
- Low radioactivity materials
  (selection and purification)
- Identification background events
  (electrons, gammas, neutrons, alphas)





DAMA/LIBRA Data Taking

25 modules of 9.7 kg
4 years data taking (09/03 to 07/07)
=> 192 000 kg.d = twice DAMA exposure

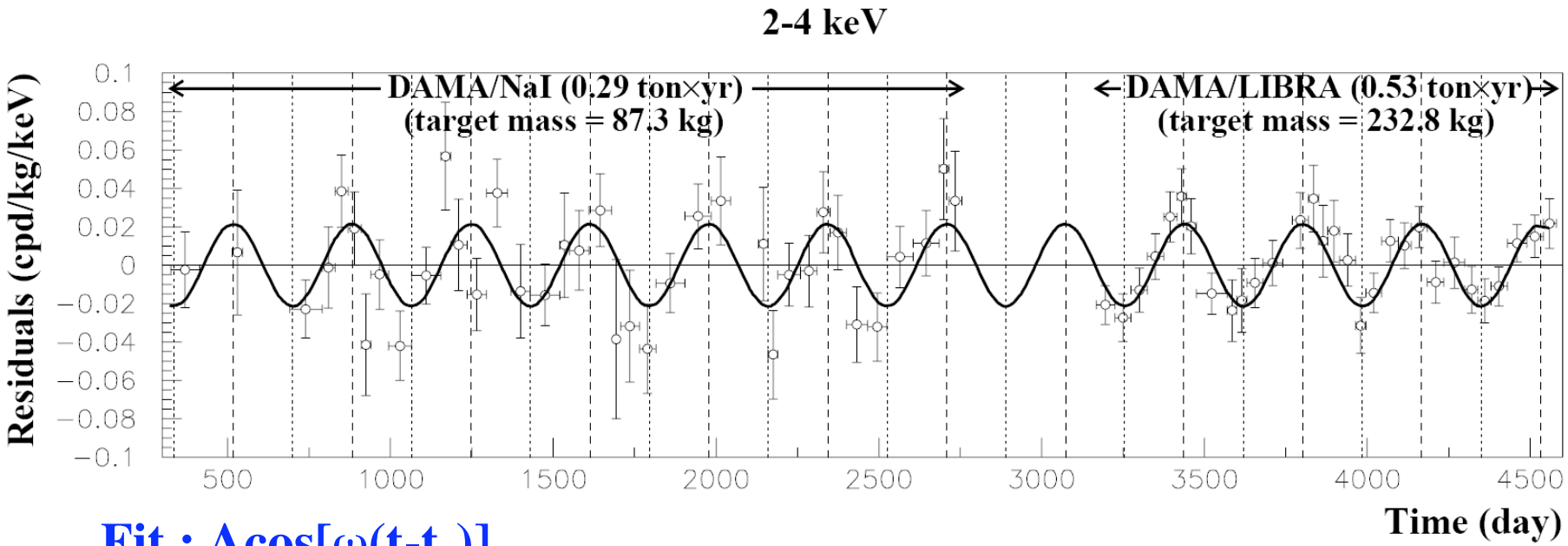


DAMA/NaI (7 years) + DAMA/LIBRA (4 years)

total exposure: 300555 kg×day = 0.82 ton×yr

Modulation Signal

DAMA/NaI (7 years) DAMA/LIBRA (4 years)



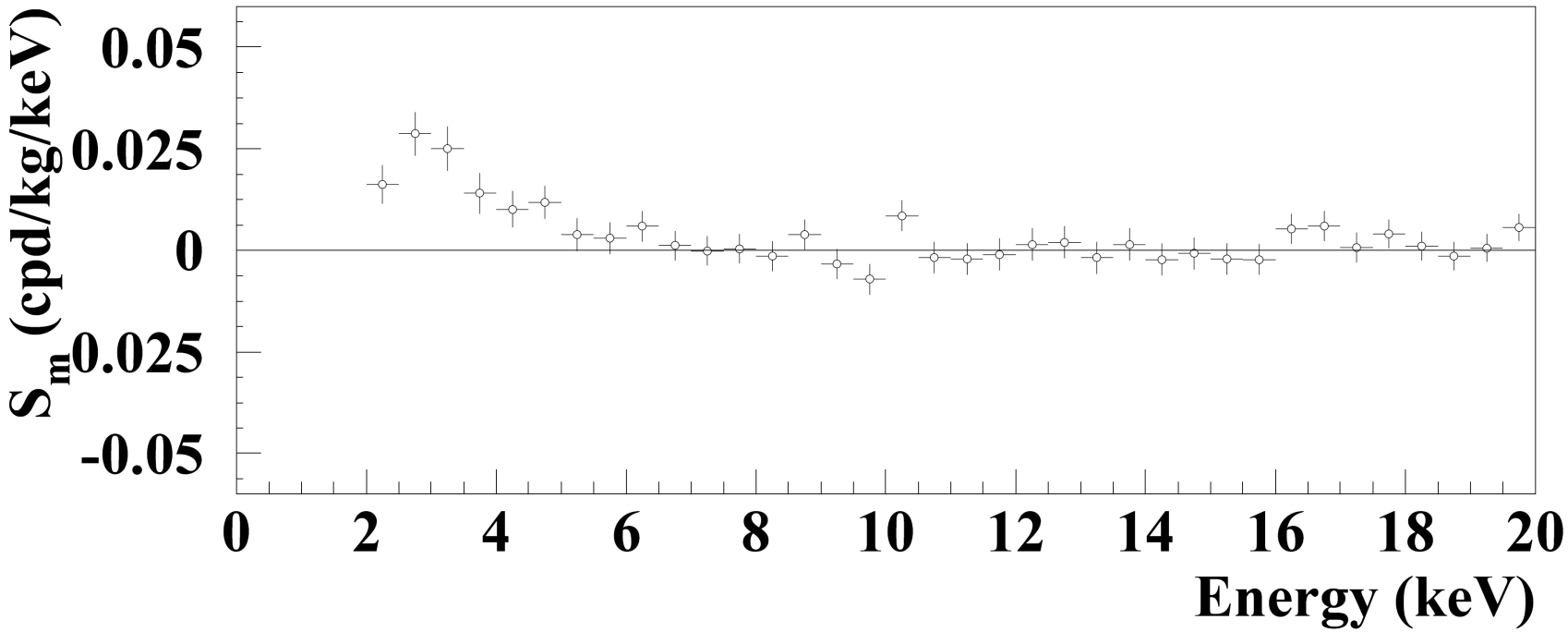
Fit : $A\cos[\omega(t-t_0)]$

	A (cpd/kg/keV)	Period (Year)	t_0 (day)	C.L.
DAMA/NaI	0.0252 ± 0.0050	1.01 ± 0.02	125 ± 30	5.0 σ
DAMA/LIBRA	0.0213 ± 0.0032	0.997 ± 0.002	139 ± 10	6.7 σ
COMBINED	0.0223 ± 0.0027	0.996 ± 0.002	138 ± 7	8.3 σ

χ^2/dof = 51.9/66

Signal = cosine shape (χ^2), with 1 year period, with maximum in june

Difference between summer and winter spectra

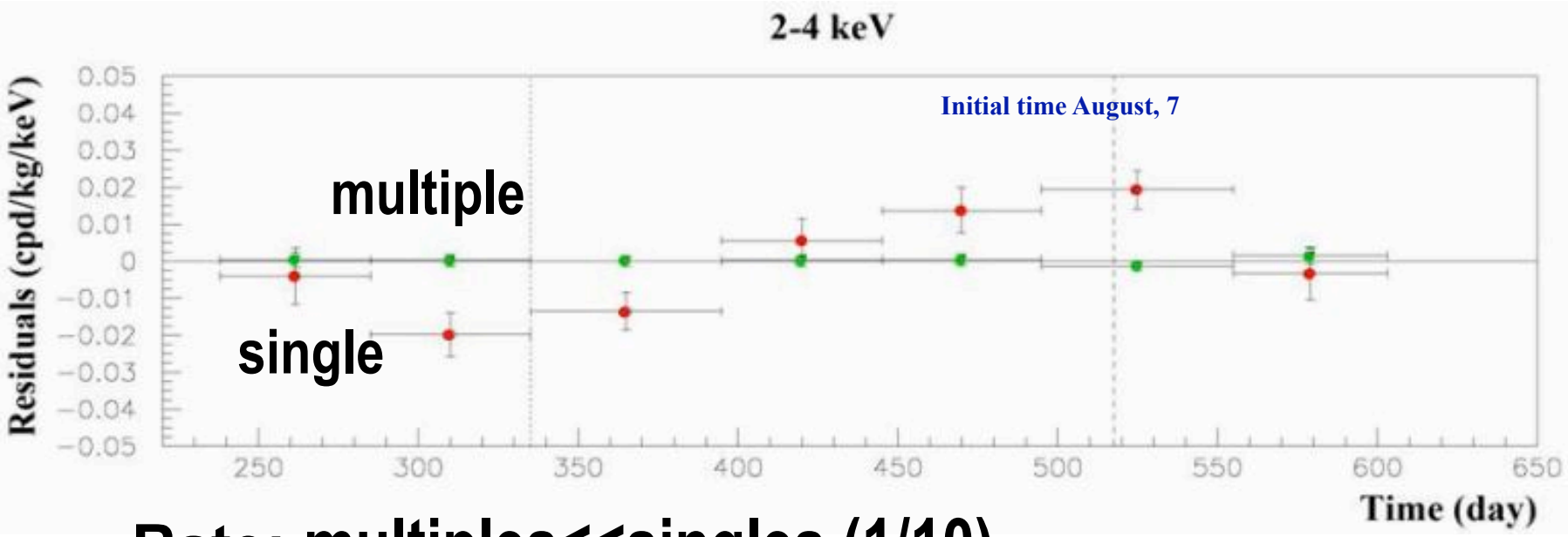


Modulation above 6 keV compatible with 0

X^2/dof = 24.4/28

Modulation of multiple hits

We don't expect multiple hits as dark matter is very weakly interacting



Rate: multiples<<singles (1/10)

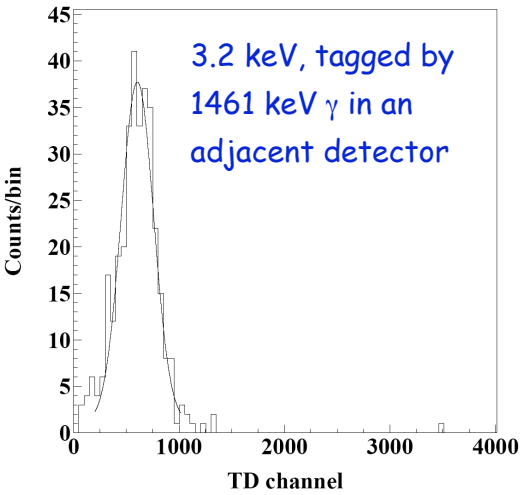
Modulation :

Multiple hits modulation compatible with 0

A=-(0.0004±0.0008) cpd/kg/keV
but with much lower CL as single hits

DAMA background and systematics

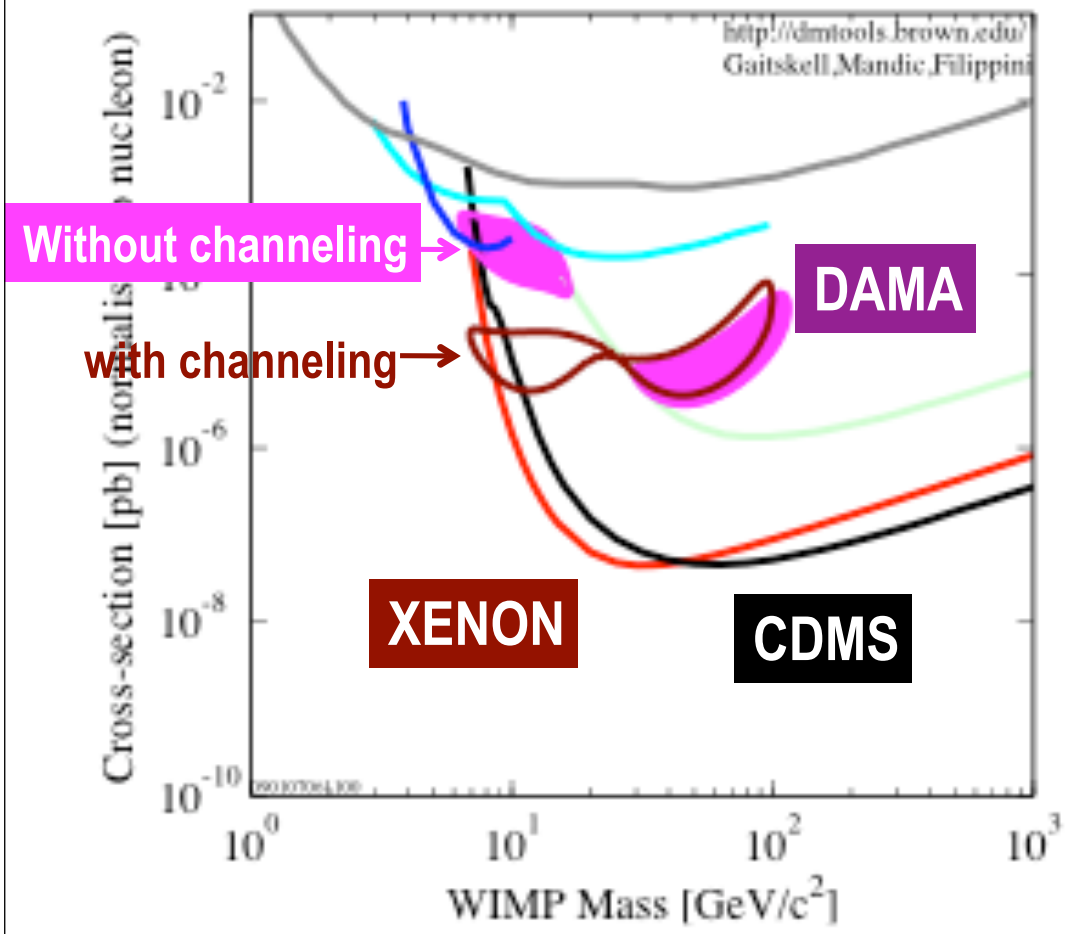
Source	Main comment (see also ref. [21])	Cautious upper limit (90%C.L.)
Radon	Sealed Cu Box in HP Nitrogen atmosphere, 3-level of sealing	$< 2.5 \times 10^{-6}$ cpd/kg/keV
Temperature	Air conditioning + huge heat capacity	$< 10^{-4}$ cpd/kg/keV
Noise	Efficient rejection	$< 10^{-4}$ cpd/kg/keV
Energy scale	Routine + intrinsic calibrations	$< 1 - 2 \times 10^{-4}$ cpd/kg/keV
Efficiencies	Regularly measured	$< 10^{-4}$ cpd/kg/keV
Background Including neutrons	No modulation above 6 keV; no modulation in the (2 – 6) keV *multiple-hit* events; this limit includes all possible sources of background	$< 10^{-4}$ cpd/kg/keV
Side reactions	From muon flux variation measured by MACRO	$< 3 \times 10^{-5}$ cpd/kg/keV



Modulation of ^{40}K peak?

No known systematics can mimic the signal
There is need for an independent observation
to identify the signal and further explore systematics

Spin independent WIMP interpretation



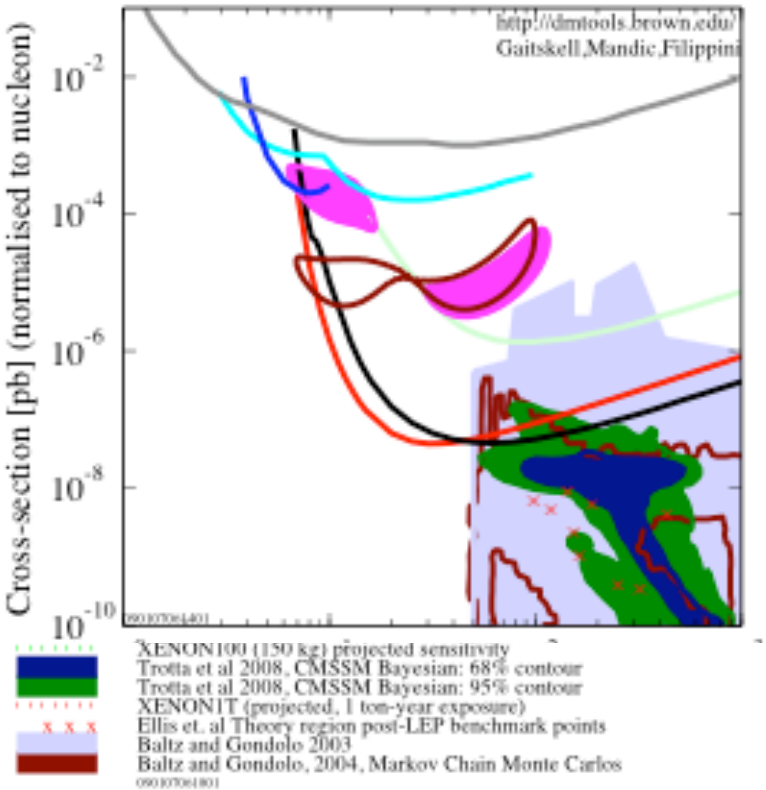
DAMA WIMP SI excluded by other experiments if no systematic effect

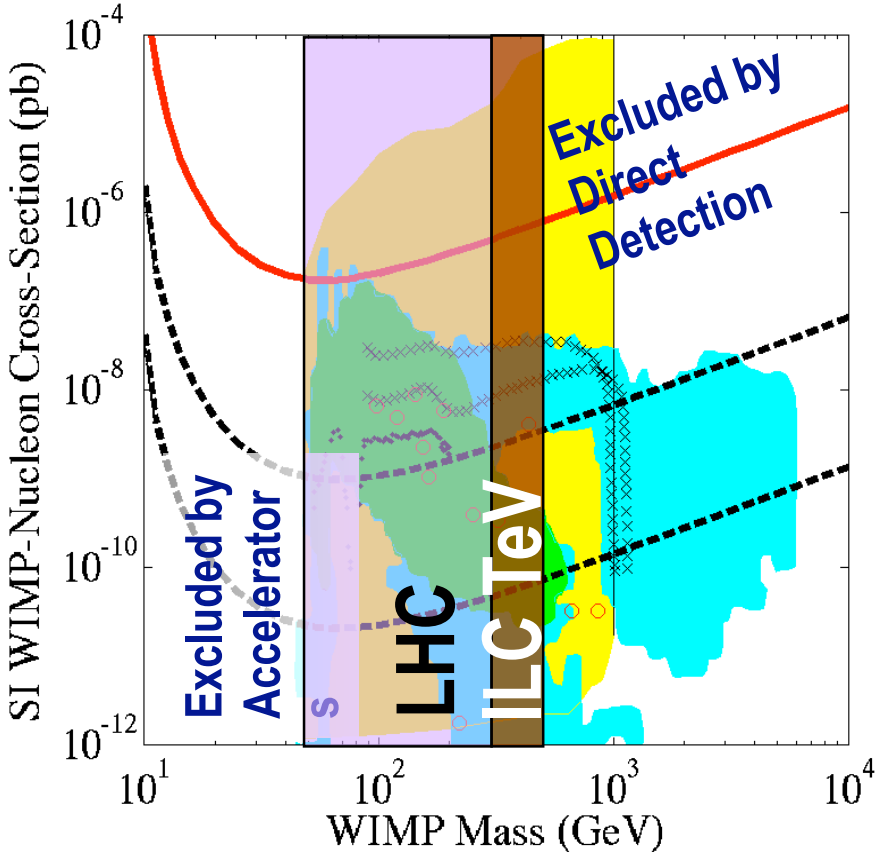
need for more data taking to overcome the edge of DAMA signal or assess a clear signal there

Neutralino dark matter

Coherent interactions usually dominate

($\sigma_p \sim \sigma_n$, $\sigma_{NUCLEUS} \sim \mu^2 A^2$)



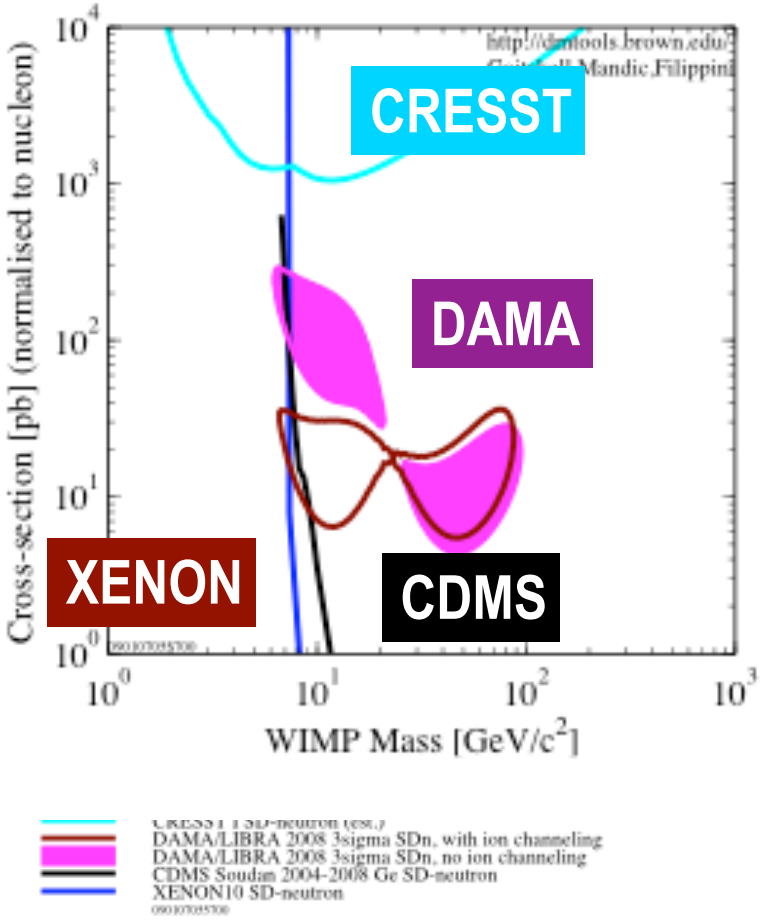


From Richard Schnee

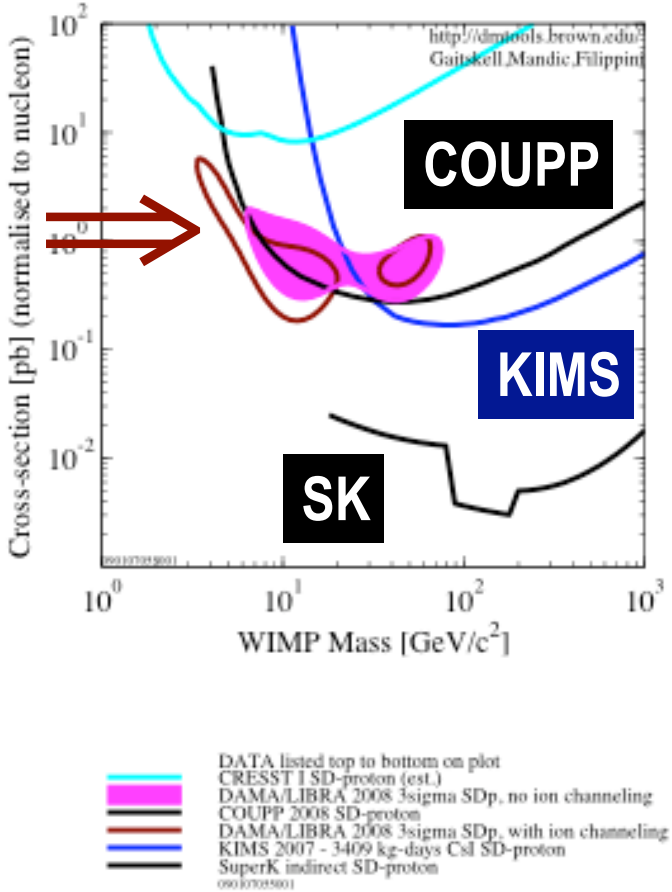
DAMA Signal is not expected from neutralinos

Spin Dependent Dark Matter

Pure neutron



Pure proton



Maybe some room for low mass region in proton SD

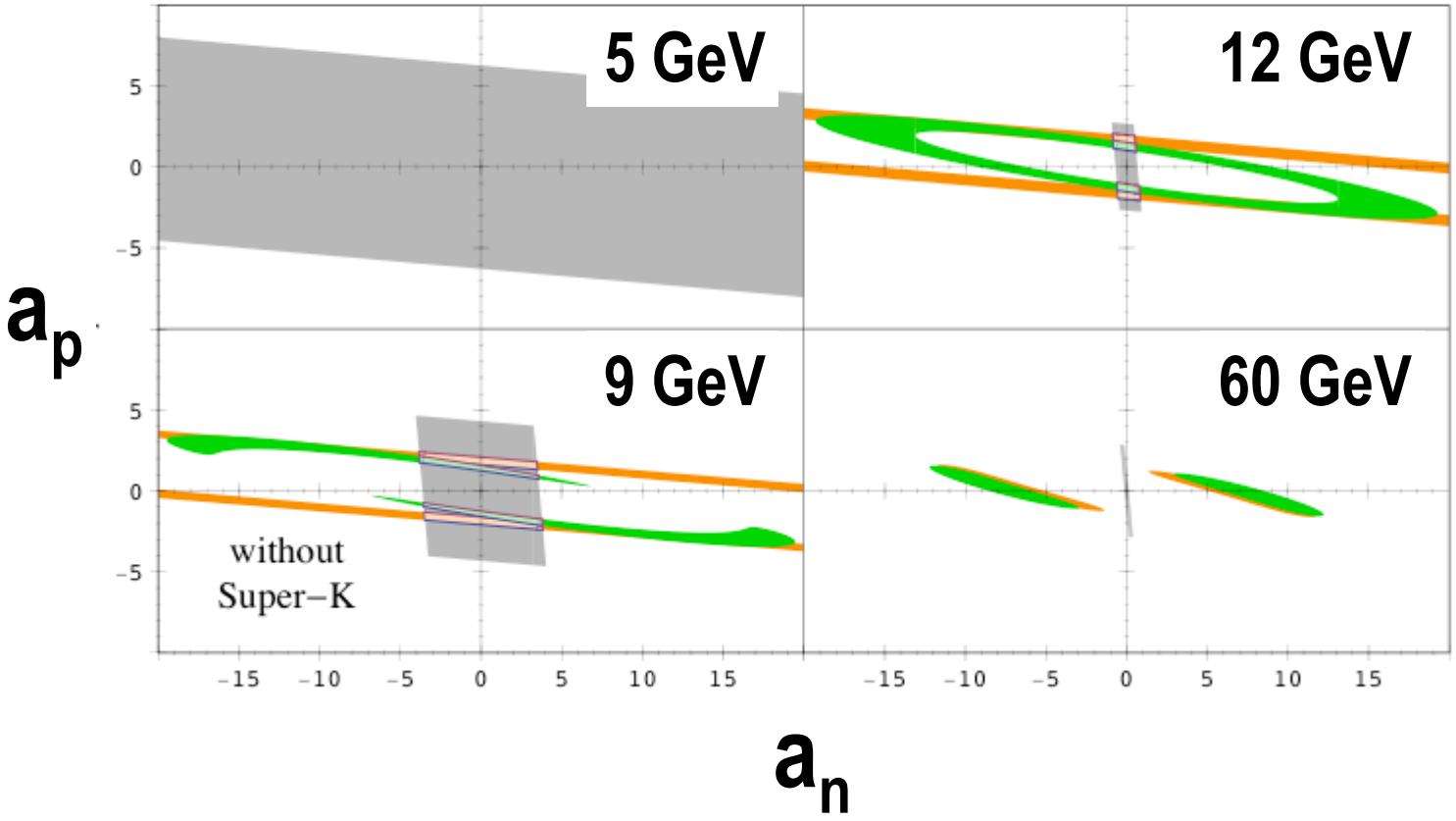
Spin Dependent Dark Matter

(Mixed proton and neutron coupling)

Dama (3σ)

Dama (3σ) with channeling

Other null results

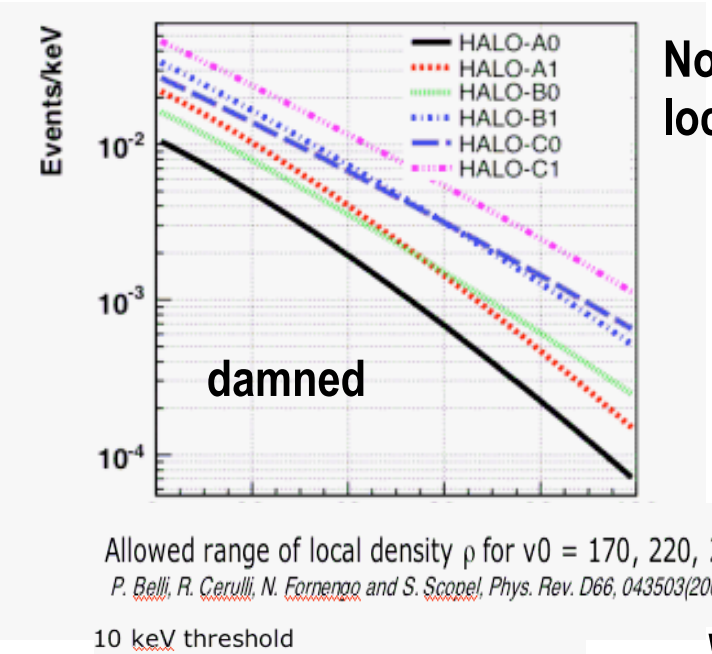


Again narrow window at low mass

ChristopherSavage, GracielaGelmini, PaoloGondolo, and Katherine Freese arXiv:0808.3607v2 [astro-ph]*

Non standard Halo models

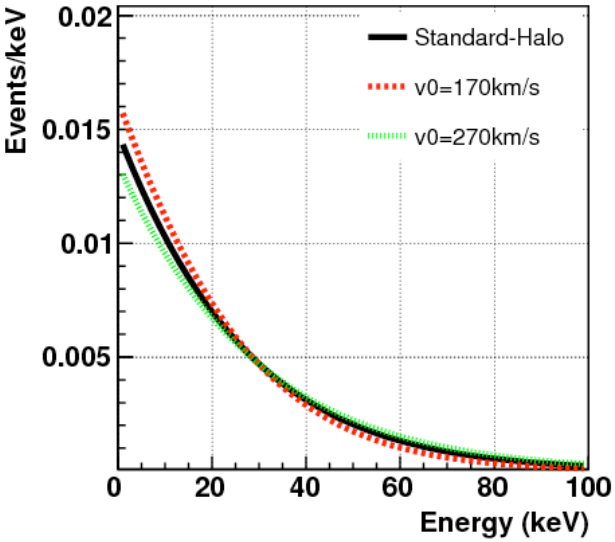
Varying local halo density and velocities within rotation curves constraints

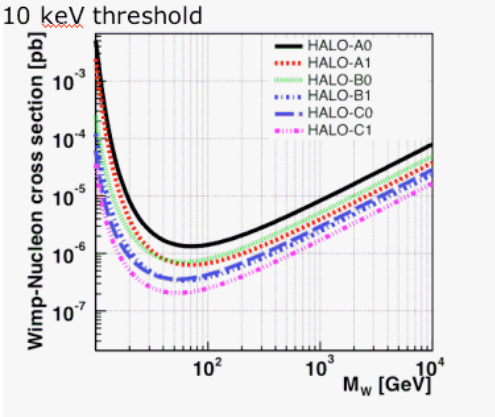


Allowed range of local density ρ for v0 = 170, 220, 270 km/s

P. Belli, R. Cerulli, N. Fornengo and S. Scopel, Phys. Rev. D66, 043503(2002)

Normalising to same local halo density



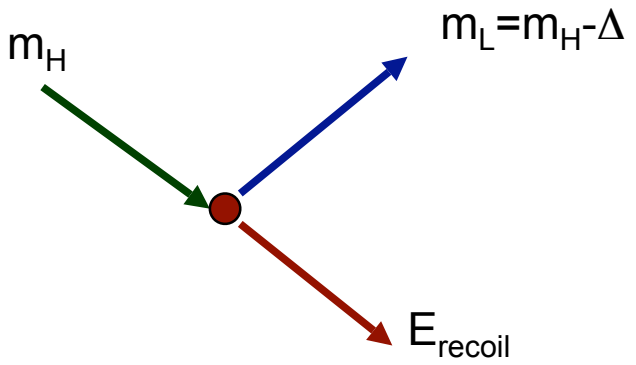


We measure actually limits on cross-section x local halo density
The velocity distributions doesn't affect compatibility of results

(see also arXiv:0808.0704 Fairbairn & Schwetz)

Light Dark Matter (considered by DAMA) *arXiv:0802.4336*

What about Light Dark Matter ?
-> inelastic reaction
(otherwise they cannot induce large enough recoil energies)



modulation of velocity

$$\langle v^2 \rangle \simeq \langle v_g^2 \rangle + v_\odot^2 + v_\odot v_{SE} cos(\omega(t-t_0))$$

Cross section as a function of velocity : $\sigma v \simeq a + bv^2$

Rate :

$$\frac{dR_T}{dE_R} \simeq \eta_T \frac{\rho_{\nu_H}}{v_0 m_H} \left(\sigma_0^T v_0^2 + \sigma_m^T \langle v^2 \rangle\right) \frac{\Theta(E_+^T - E_R)\Theta(E_R - E_-^T)}{E_+^T - E_-^T}$$

nuclei /kg — wimp density — Cross sections — Kinematics ≈ dirac peak

Position of the peak :

$$\langle E_R \rangle \simeq \frac{\bar{m}\,\Delta}{m_H + m_T}$$

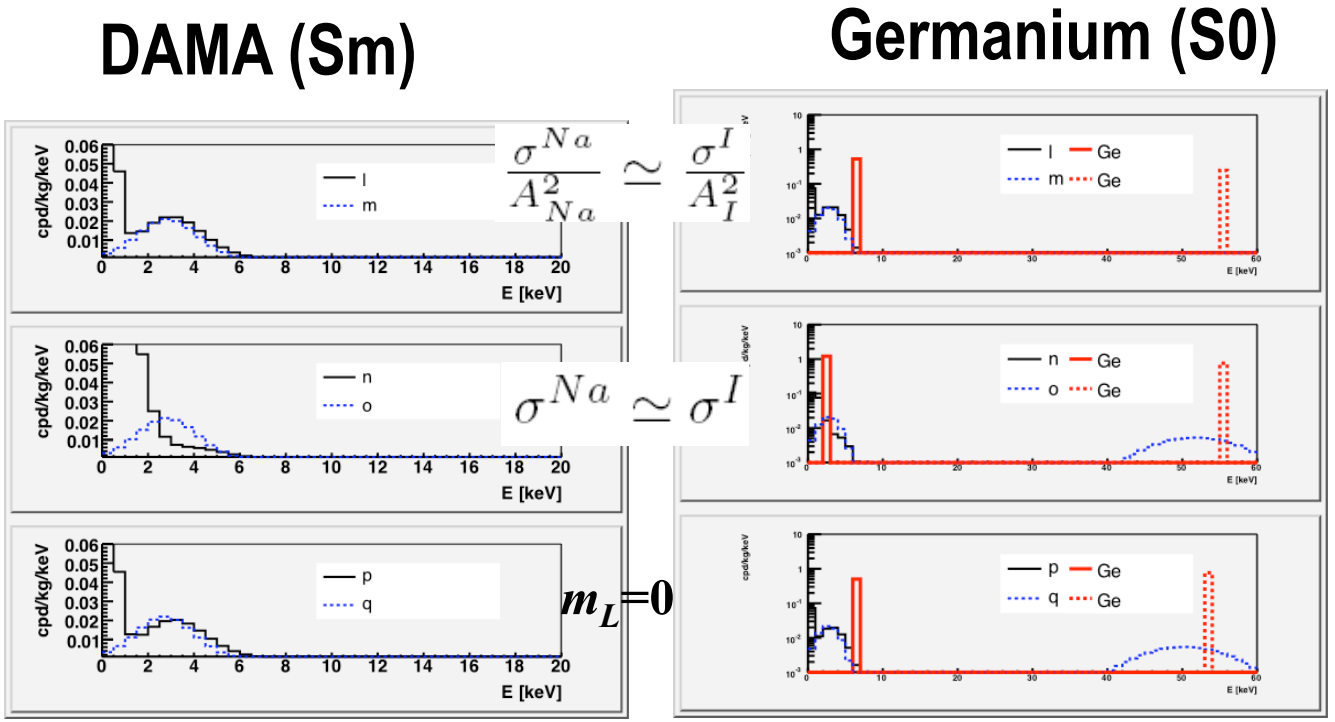
With :

$$\Delta = m_H - m_L \qquad \bar{m} = \frac{m_H + m_L}{2}$$

-> σ_0=0 Most favourable for Sm signal (modulation of 15%)

Expected rates

	M_H	Δ
l	30 MeV	18 MeV
m	100 MeV	55 MeV
n	30 MeV	3 MeV
o	100 MeV	55 MeV
p	28 MeV	28 MeV
q	88 MeV	88 MeV
r	60 keV	60 keV



2 cases : 3keV peak on quenched or unquenched recoil energies on I

High rate expected for Germanium but might be below threshold (low Δ, high cross-sections)

Scan of inelastic light dark matter

arXiv:0806.3989
Petriello, Zurek

DAMA and
null-experiments
allowed regions

Prefered regions

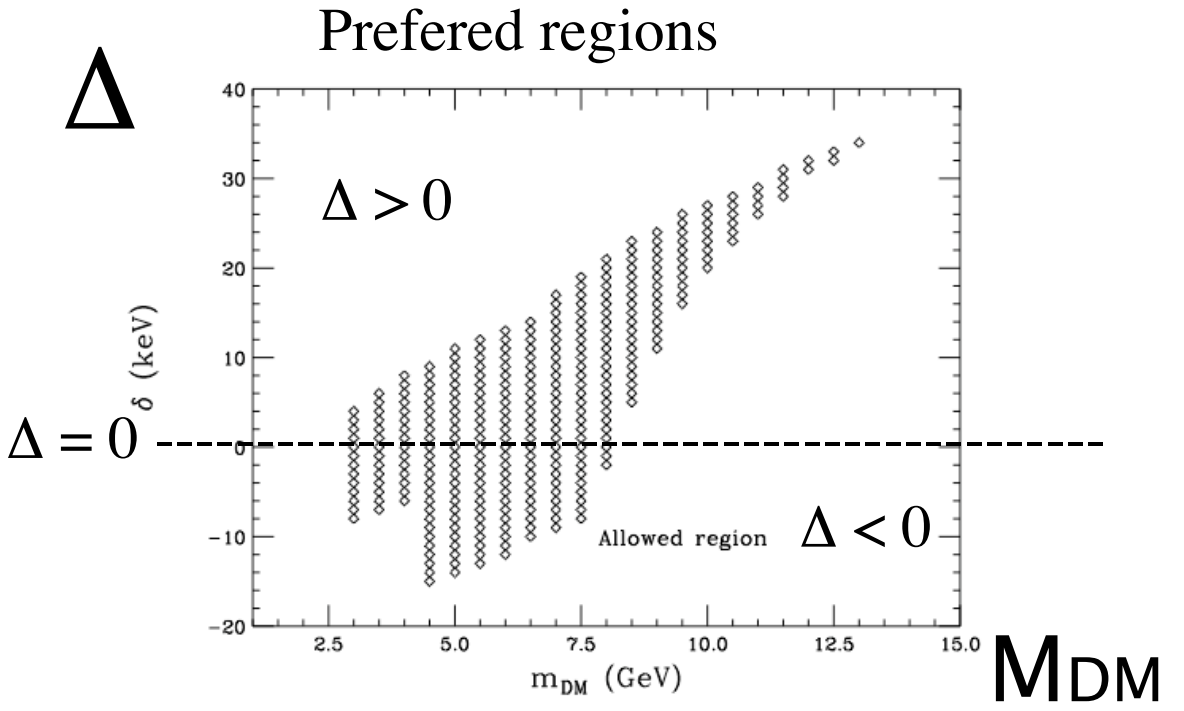


Figure 7: Region of parameter space in the m_{DM}, δ plane where the DAMA signal is consistent with the constraints from all null experiments. The widest allowed range of dark matter masses occurs where $\delta = 0$.

Inelastic processes doens't help reconciliation with null experiments

Conclusions

The DAMA modulation signal is statistically overwhelming

No systematic effect that can mimic this signal have been found yet

Unexpected (low mass, high cross-section) or exotic Dark Matter candidates are needed

WIMP candidates pointed by DAMA results are essentially ruled out by other experiments If no overlooked large systematic effect

Awaiting more results from KIMS CsI and other experiments at low threshold