Direct Detection of Dark Matter

Graciela Gelmini - UCLA

LNGS, October 22, 2014

Content of Lecture 3

- Halo independent data comparison Compare experiments without assuming a local WIMP density or velocity distribution

- Comment on DM searches at the LHC

- Comment on annually modulated backgrounds and ANDES

Scattering event rate: events/(kg of detector)/(keV of recoil energy)

$$\frac{dR}{dE_R} = \int \frac{N_T}{M_T} \times \frac{d\sigma}{dE_R} \times n v f(\vec{v}, t) d^3v$$

- For a WIMP-nucleus differential cross section $d\sigma/dE_R = \sigma(E_R)\ M_T/2\mu^2 v^2$

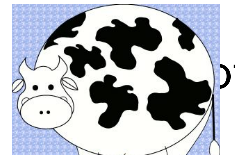
$$\frac{dR}{dE_R} = N_T \frac{\sigma(E_R)\rho}{2m\mu^2} \int_{v>v_{min}} \frac{f(\vec{v}, t)}{v} d^3v = N_T \frac{\sigma(E_R)}{2\mu^2} \frac{\rho\eta(v_{min})}{m}$$

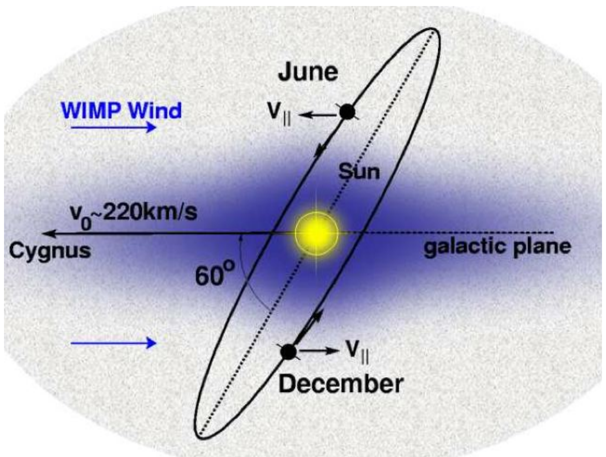
- $\frac{N_T}{M_T}$ = Avogadro's number per mol = Number of atoms per gram; $\mu = mM/(m+M)$
- For elastic scattering: $v_{min} = \sqrt{ME_R/2\mu^2}$ and E is the ion recoil energy .
-$\rho = nm$, $f(\vec{v}, t)$: local DM density, $\vec{v}$ distribution, depend on the Dark Halo Model.
- for spin-independent (SI) $\sigma(E_R) = \sigma_0 F^2(E_R)$ where

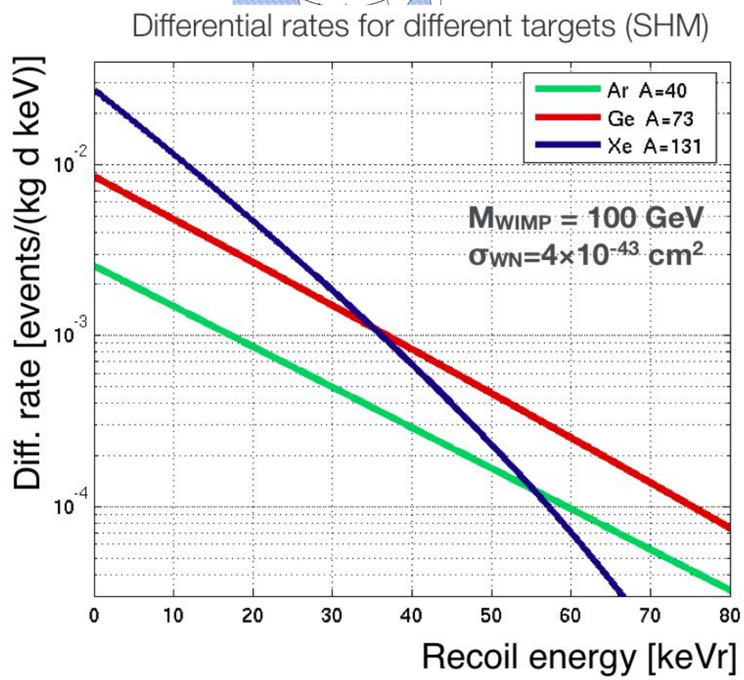
$\sigma_0 = \left[Z + (A-Z)(f_n/f_p)\right]^2 (\mu^2/\mu_p^2)\sigma_p = A^2(\mu^2/\mu_p^2)\sigma_p$ for $f_p = f_n$

"Halo dependent" data comparison in the $m, \rho\sigma_p$ plane given $\eta(v_{min})$

$\rho\eta(v_{min})$ encodes all the halo dependence and is common to all experiments-
"Halo independent" data comparison in the $v_{min}, \rho\eta/m$ plane (m fixed)!

Standard Halo Model (SHM) The  of halo models





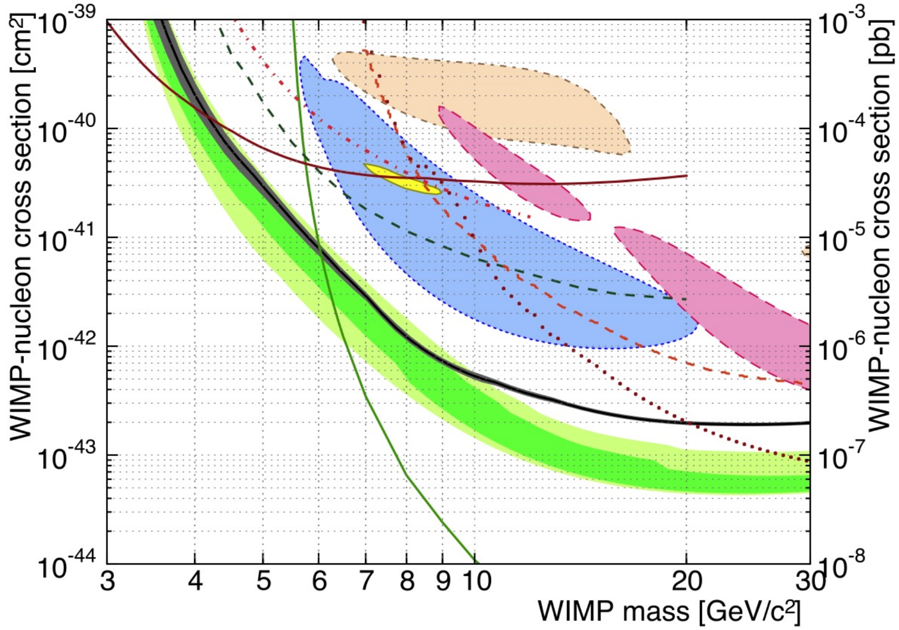
- $\rho_{SHM} = 0.3^{+0.2}_{-0.1}$ GeV/cm^3
- $f(\vec{v},t)$: Maxwellian $\vec{v}$ distribution

at rest with the Galaxy $v_\odot \simeq$220km/s (190 to 320km/s), $v_{esc} \simeq$500-650km/s

ANNUAL MODULATION: max in May, min in Dec.(Drukier, Freese, Spergel 1986)

Local ρ, v, modulation phase and amplitude could be very different if Earth is within a DM clump or stream or there is a "Dark Disk". Other: debris flows, anisotropic halo, velocity tails...

Usual "Halo Dependent" data comparison DAMA, CoGeNT, CRESST II, CDMS II-Si regions plus upper limits from negative searches.
Fig. from the SuperCDMS coll, 1402.7137 using the SHM and $f_n/f_p = 1$



"Halo Independent" data comparison Fox, Liu, Weiner 1011.1915

For a detector which consists of a single element, simply inverting the differential recoil rate for $v_{min} = \sqrt{m_T E_R / 2\mu^2}$

$$\tilde{\eta}(v_{min}) \equiv \sigma_p(\rho/m)\eta(v_{min}) = \frac{2\mu_p^2}{N_T\left[Z + (A-Z)(f_n/f_p)\right]^2 F^2(E_R)} \frac{dR}{dE_R}$$

Then if $E_R^{(1)} = \bar{E}_1$ **and** $E_R^{(2)} = \bar{E}_2$ **correspond to the same** v_{min} for two different targets, $\bar{E}_2 = \bar{E}_1 \mu_2^2 M_T^{(1)} / \mu_1^2 M_T^{(2)}$, the differential rates $dR^{(1)}/d\bar{E}_2$ **and** $dR^{(2)}/d\bar{E}_1$ **can be related.**

For regions and limits use energy integrated rates R

$R(t) = R_0 + R_1 \cos[\omega(t - t_0)]$ and plot it into

$\tilde{\eta}(v_{min}, t) = \widetilde{\eta}_0(v_{min}) + \widetilde{\eta}_1(v_{min}) \cos[\omega(t - t_0)]$

Notice, one value of $\widetilde{\eta}_0$ or $\widetilde{\eta}_1$ per bin. Fox, Liu, Weiner 1011.1915; Frandsen et al 1111.0292

Halo Independent analysis

Fox, Liu, Weiner 1011.1915 took efficiencies and form factors constant over the bin when integrating rates over bins, or at energies which minimize/maximize the ratio total rates to be compared for a putative signal or a constraint- $\varepsilon(E_R)$ is an energy-dependent efficiency.

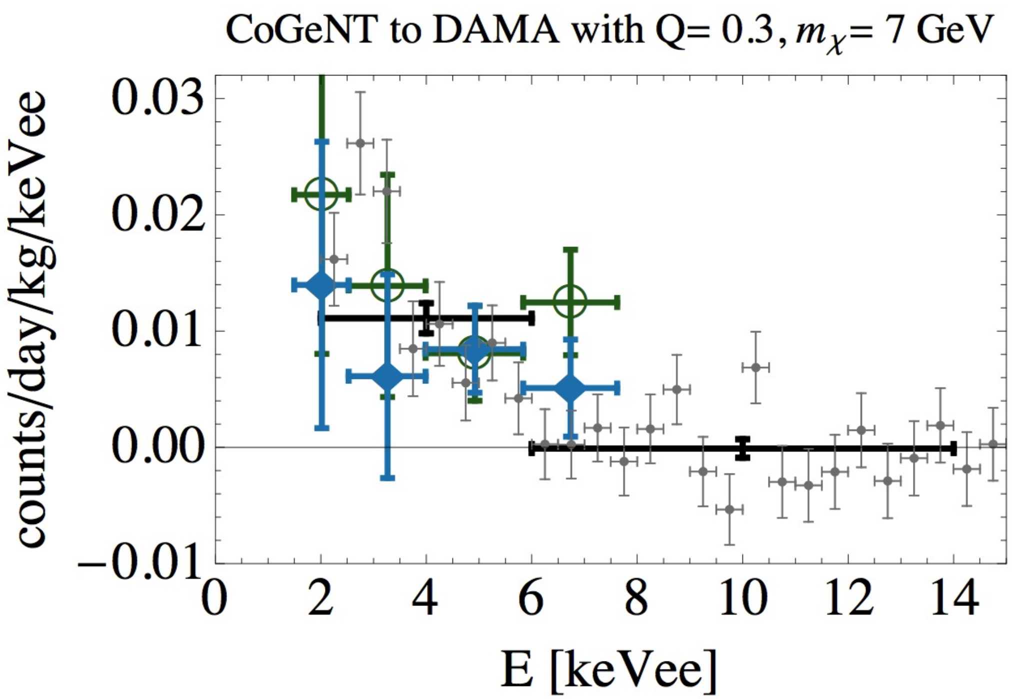
If $\bar{E}_2$ and $\bar{E}_1$ correspond to the same v_{min} for different targets, $\bar{E}_2 = \bar{E}_1 \mu_2^2 M_T^{(1)} / \mu_1^2 M_T^{(2)}$

$$R = \left(\frac{2 N_A \rho \, \sigma_p m_p}{m_\chi \, \mu_{n\chi}^2 \, f_p^2} \right) \left(\frac{\mu^2 C_T}{M_T} \right) \int_{v_{low}}^{v_{high}} dv \, \varepsilon(E_R) F^2(E_R(v)) v g(v)$$

Here $g(v) \equiv \eta(v)$, and assuming it is the same for both experiments for the same v_{min} interval

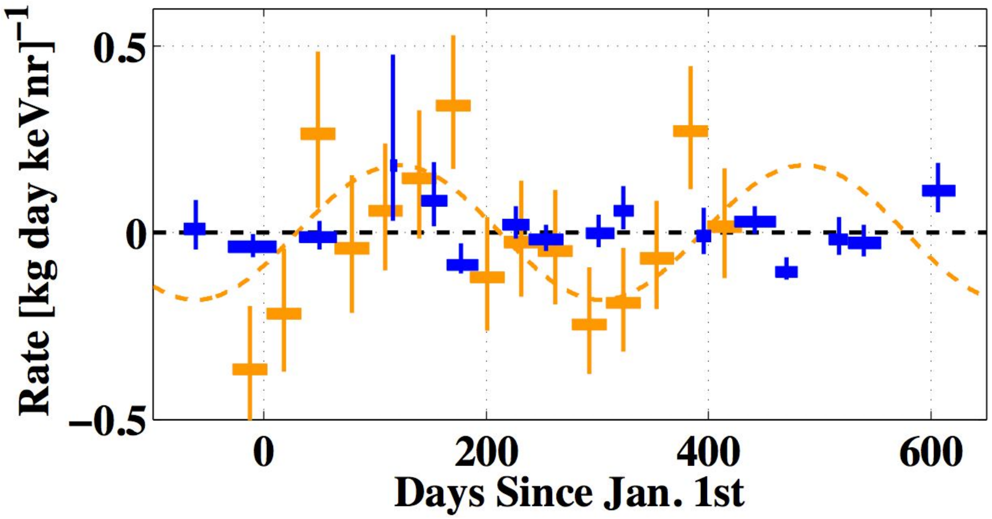
$$R_2 = \frac{\varepsilon_2(\bar{E}_2) F_2^2(\bar{E}_2)}{\varepsilon_1(\bar{E}_1) F_1^2(\bar{E}_1)} \frac{C_T^{(2)}}{C_T^{(1)}} \frac{M_T^{(1)}}{M_T^{(2)}} \frac{\mu_2^2}{\mu_1^2} R_1$$

Halo Independent analysis Fox, Kopp, Lisanti,Weiner 2011



CDMS negative annual modulation search

March 2012: 1203.1309 CDMS (Ge): no modulation > 0.06 ev./keVnr kg day in 5 to 11.9 keVnr (CoGeNT thres. 0.4 keVee $\simeq$ 1.6 keVnr) to 99%CL.



CoGeNT rate (orange)

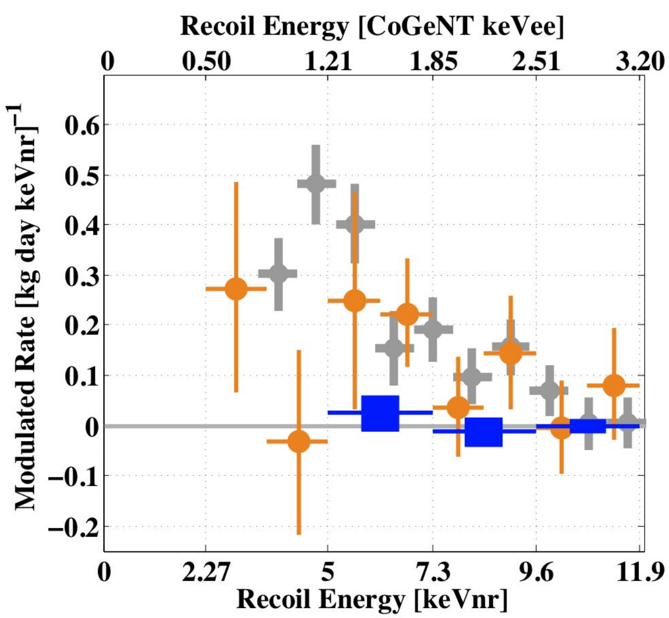
CDMS rate (blue)

CDMS II 1203.1309

Method of Fox, Liu, Weiner used e.g. by CDMS in its modulation bound paper .

CDMS negative annual modulation search

March 2012: 1203.1309 CDMS (Ge): no modulation > 0.06 ev./keVnr kg day in 5 to 11.9 keVnr (CoGeNT thres. 0.4 keVee $\simeq$ 1.6 keVnr) to 99%CL. Halo independent comparison:



Modulation amplitudes for $m = 10$ GeV
all plotted in Ge recoil energy
(energy resolutions not taken into account)
CoGeNT
DAMA ($Q = 0.3$)
CDMS-modulation

Cannot take into account full E dependence of efficiencies and energy resolutions.

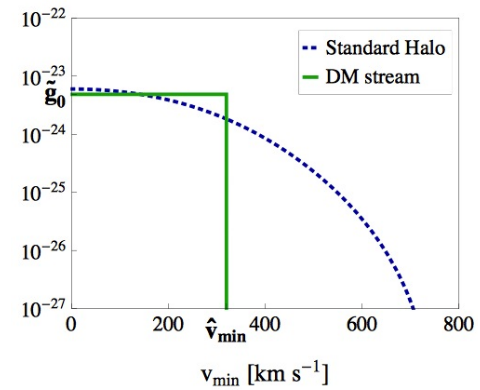
“Halo Independent” data comparison

Fox, Liu, Weiner 1011.1915 and Frandsen et al 1111.0292

For regions and limits use energy integrated rates R, taking efficiencies and form factors constant over the bin when integrating rates over bins.

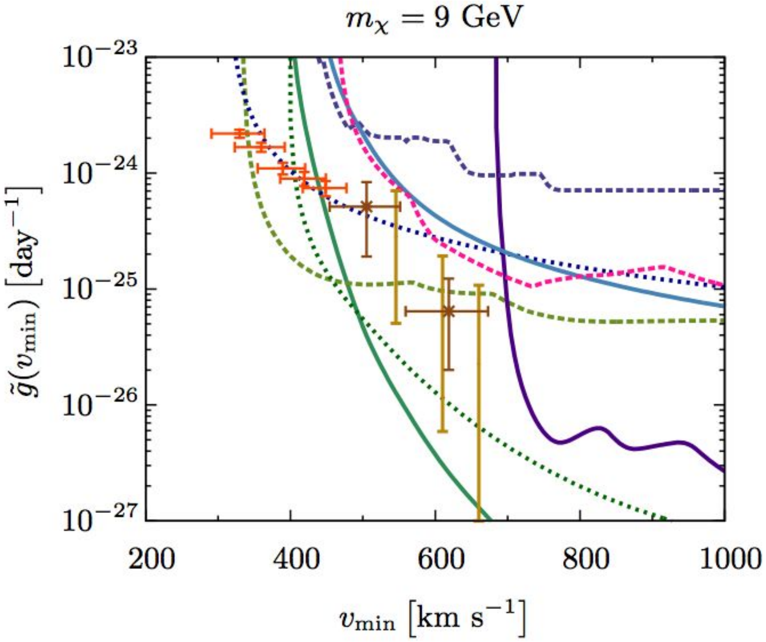
Signals: plot $R(t) = R_0 + R_1 \cos[\omega(t - t_0)]$ into $\tilde{\eta}(v_{min}, t) = \widetilde{\eta}_0(v_{min}) + \widetilde{\eta}_1(v_{min}) \cos[\omega(t - t_0)]$

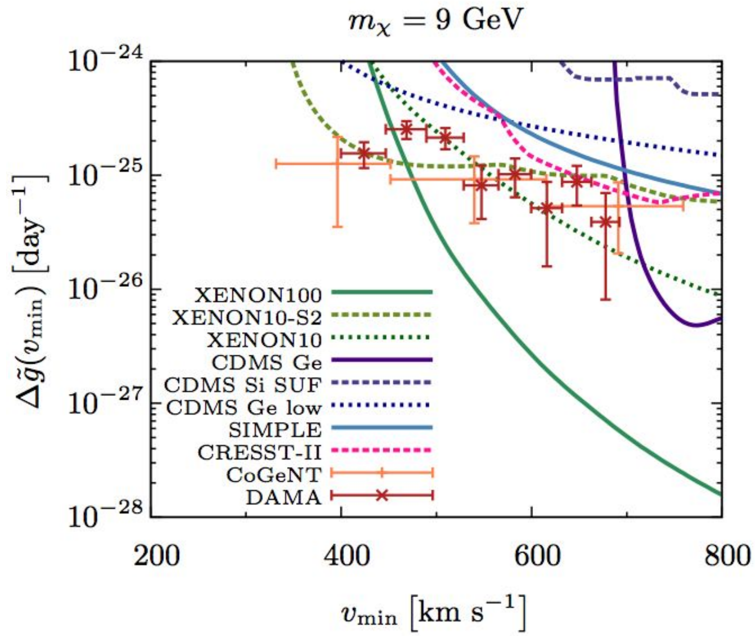
Upper limits: $\tilde{\eta}$ is a non decreasing function of v_{min}: the smallest possible with value $\widetilde{\eta}_0$ at $v_{min} = v_0$ is $\tilde{\eta} \geq \widetilde{\eta}_0 \Theta(v_0 - v_{min})$. Thus, compute the rate with this downward step function and ask for this rate to be at most equal to the measured limit for $\widetilde{\eta}_0 = \widetilde{\eta}_0^{\,lim}$.



"Halo Independent" data comparison Frandsen et al 1111.0292

Here LEFT: $\bar{g}(v_{min}) = \rho\eta(v_{min})\sigma_p/m$, RIGHT: $\Delta\bar{g}(v_{min})$ =annual mod. amp. of $\bar{g}$





Problems of original method: how to include isotopic composition and full energy dependence of energy resolutions functions and efficiencies for integrated rates over energy bins (they took efficiencies and form factors constant over the bin) and other interactions.

Halo Independent analysis These early versions of the method used the recoil spectrum dR/dE_R which is not directly accessible to experiments. Use instead experimentally accessible quantities, including isotopic composition and energy resolution and efficiency with arbitrary energy dependence Gondolo-Gelmini 1202.6359

Start with the differential rate in detected energy $E^{'}$(in keVee or number of PE)

$$\frac{dR}{dE^{'}} = \epsilon(E^{'}) \int_0^\infty dE_R \sum_T C_T \, G_T(E_R, E^{'}) \frac{dR_T}{dE_R}$$

- C_T: mass fraction in target nuclide T;
- $\epsilon(E^{'})$: counting efficiency or cut acceptance
- $G_T(E_R, E^{'})$: energy response function (includes the energy resolution $\sigma_E(E^{'})$ and the mean value $\langle E^{'} \rangle = E\, Q_T(E_R)$)

$$\frac{dR_T}{dE_R} = \frac{\sigma_T(E)}{2m\mu_T^2} \rho\, \eta(v_{min}, t)$$

Changing variable from E_R to v_{min}, $dE_R = (4\mu_T^2/m_T)v_{min}dv_{min}$ and using $\tilde{\eta}(v_{min}) = \sigma_p(\rho/m)\eta(v_{min})$ (recall $\sigma_T(E) \sim \sigma_p$) we get our final expression

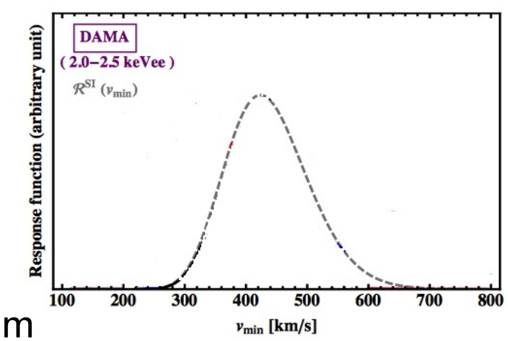
Halo Independent analysis Gondolo-Gelmini 1202.6359

Expected rate over a detected energy interval $[E_1^{'}, E_2^{'}]$

$$R_{[E_1^{'},E_2^{'}]} = \int_0^\infty dv_{min}\ \mathscr{R}^{SI}_{[E_1^{'},E_2^{'}]}(v_{min})\, \tilde{\eta}(v_{min})$$

$\mathscr{R}^{SI}_{[E_1^{'},E_2^{'}]}$: detector dependent response function for SI WIMP interactions

$$\mathscr{R}^{SI}_{[E_1^{'},E_2^{'}]}(v_{min}) = \sum_T \frac{2\, v_{min}\, C_T\, \sigma_T^{SI}(E_T)}{M_T\, \sigma_p\, (E_2^{'} - E_1^{'})} \int_{E_1^{'}}^{E_2^{'}} dE^{'}\ G_T(E_T, E^{'})\, \epsilon(E^{'})$$



is non zero only for an interval in v_{min} given a measured energy interval $[E_1^{'}, E_2^{'}]$ Every experiment is sensitive to a "window in velocity space" given by the response function $\mathscr{R}_{[E_1^{'},E_2^{'}]}$

In a simplified approach $\mathscr{R}^{SI}_{[E_1^{'},E_2^{'}]}(v_{min})$ is significantly different from zero only in the interval between $v_{min,1} = v_{min}(E_1^{'} - \sigma_E(E_1^{'}))$ and $v_{min,2} = v_{min}(E_2^{'} + \sigma_E(E_2^{'}))$

Halo independent analysis for general interactions

Apparent problem with more general cross sections?

$$\frac{dR}{dE_R} = \int \frac{N_T}{M_T} \times \frac{d\sigma}{dE_R} \times n v f(\vec{v},t) d^3 v$$

- For a WIMP-nucleus cross section $\sim 1/v^2$

$$\frac{d\sigma}{dE_R} = \frac{\sigma(E_R)\ M_T}{2\mu^2 v^2}$$

the rate depends on only ONE function $\eta(v_{min}) = \int_{v>v_{min}} [f(v,t)/v] d^3 v$

- But , e.g. for Magnetic Dipole DM, $L_{int} = (\lambda_\chi/2)\, \bar{\chi} \sigma_{\mu\nu} \chi F^{\mu\nu}$

$$\frac{d\sigma_T}{dE_R} = \frac{\alpha \lambda_\chi^2}{v^2} \left\{ Z_T^2 \frac{m_T}{2\mu_T^2} \left[\frac{v^2}{v_{min}^2} - \left(1 - \frac{\mu_T^2}{m^2} \right) \right] F_{SI,T}^2(E_R) + \widehat{\lambda_T^2} \frac{m_T}{m_p^2} \left(\frac{S_T + 1}{3 S_T} \right) F_{M,T}^2(E_R) \right\}$$

one term $\sim 1/v^2$ another $\sim 1/v_{min}^2$, with different detector dependent coefficients

so just integrating over v yields TWO different functions of v_{min}!?

Generalized Halo Independent analysis for ANY interaction

(Del Nobile, Gelmini, Gondolo and Huh, 1306.5273) We write the expected rate over a detected energy interval $[E_1^{'}, E_2^{'}]$ for any cross section in the same way we did for SI

$$R_{[E_1^{'},E_2^{'}]} = \int_0^\infty dv_{min}\; \mathscr{R}_{[E_1^{'},E_2^{'}]}(v_{min})\, \tilde{\eta}(v_{min})$$

With $\mathscr{R}^{SI}_{[E_1^{'},E_2^{'}]}$ an EXPERIMENT AND INTERACTION DEPENDENT response function

Generalized Halo Independent analysis for ANY interaction

(Del Nobile, Gelmini, Gondolo and Huh, 1306.5273)

Proof: Start from observed rate and change the order of integration in v and $E^{'}$ to get

$$R_{[E_1^{'},E_2^{'}]}(t) = \int_{E_1^{'}}^{E_2^{'}} dE^{'}\, \frac{dR}{dE^{'}} = \int_0^\infty dv\, \frac{\widetilde{F}(v,t)}{v}\, \mathscr{H}_{[E_1^{'},E_2^{'}]}(v) = -\int_0^\infty dv\, \frac{\partial\tilde{\eta}(v,t)}{\partial v}\, \mathscr{H}_{[E_1^{'},E_2^{'}]}(v)$$

with $\widetilde{F}(v) = \rho\sigma_{ref}F(v)/m$ and the usual function $\tilde{\eta}(v,t) = \int_v^\infty dv^{'}\, \rho\sigma_{ref}F(v^{'})/mv^{'}$

Now integrate by parts and use $\tilde{\eta}(v,t) = 0$ for $v \to \infty$ and $\mathscr{H}_{[E_1^{'},E_2^{'}]}(v) = 0$ for $v = 0$.

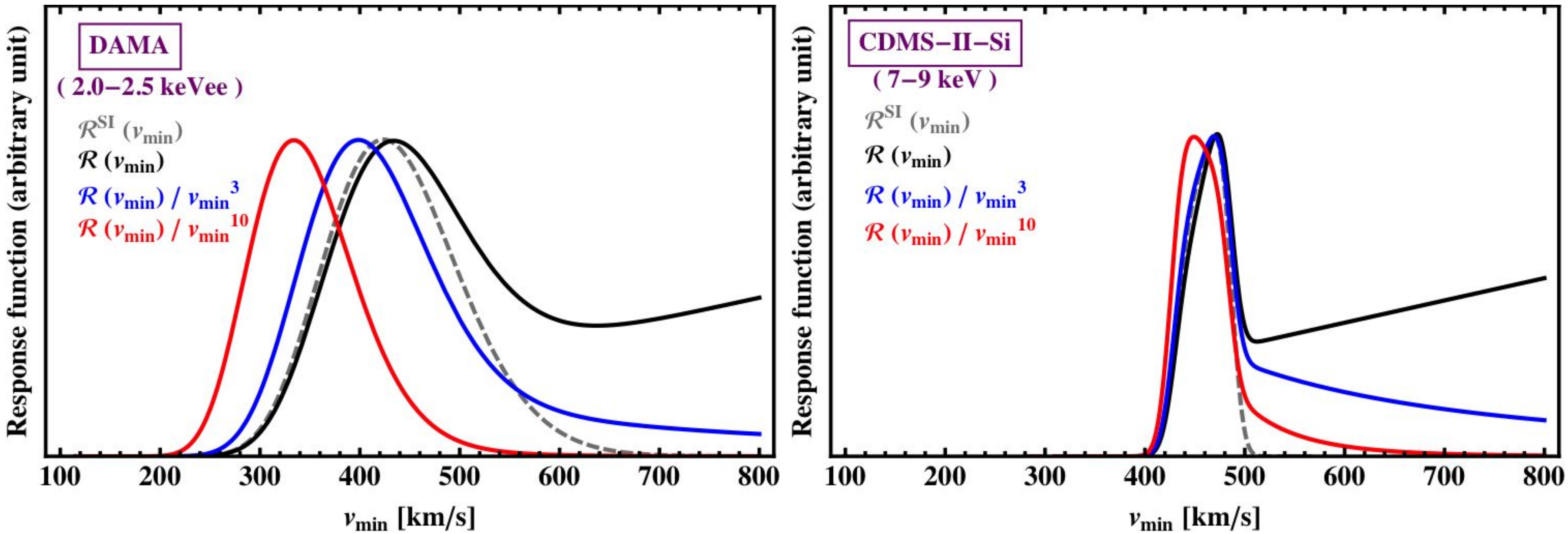
$$\mathscr{H}_{[E_1^{'},E_2^{'}]}(v) = \sum_T \frac{C_T}{m_T}\frac{4\mu_T^2}{m_T}\int_0^v dv_{min}\, \frac{v_{min}v^2}{\sigma_{ref}}\frac{d\sigma_T}{dE_R}\int_{E_1^{'}}^{E_2^{'}} dE^{'}\, \epsilon(E^{'})G_T(E_R(v_{min}),E^{'})$$

and define

$$\mathscr{R}_{[E_1^{'},E_2^{'}]}(v) \equiv \frac{\partial\mathscr{H}_{[E_1^{'},E_2^{'}]}(v)}{\partial v}$$

Generalized Halo Independent analysis: Examples of response functions for MDM

Del Nobile, Gelmini, Gondolo and Huh, 1306.5273



Halo Independent analysis Gondolo-Gelmini 1202.6359, Del Nobile, Gelmini, Gondolo and Huh, 1306.5273

- Rate measurements: translated into weighted averages of the $\tilde{\eta}$ function:

$$R^{measured}_{[E_1',E_2']} = \overline{\tilde{\eta}}_{[E_1',E_2']} \int_0^\infty dv_{min}\, \mathscr{R}_{[E_1',E_2']}(v_{min})$$

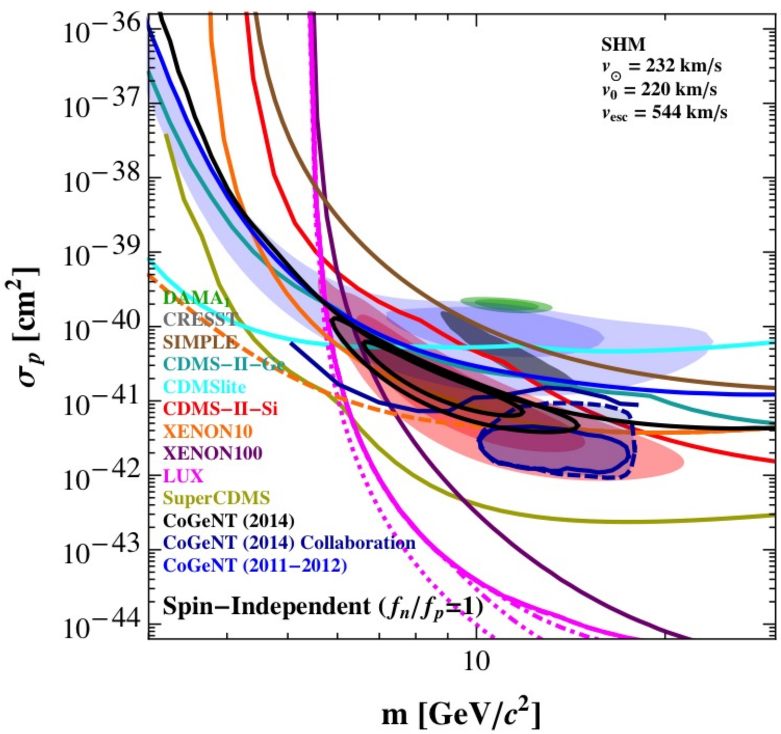
$\overline{\tilde{\eta}}_{[E_1',E_2']}$: weighted average of $\tilde{\eta}$ with weight $\mathscr{R}_{[E_1',E_2']}(v_{min})$

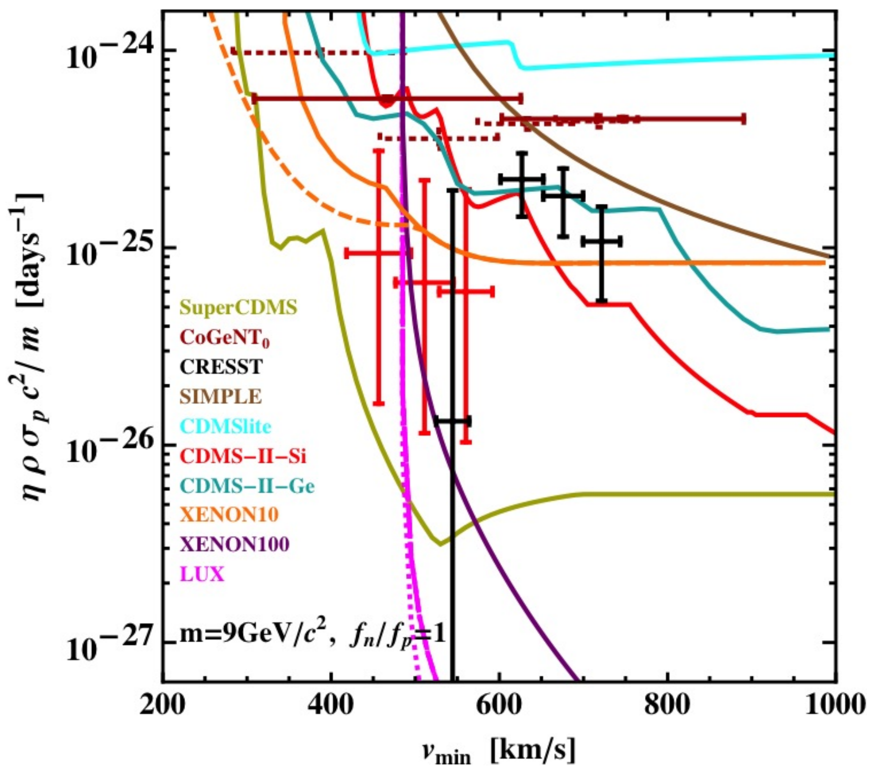
- Upper bounds: use that the smallest possible $\tilde{\eta}$ function having a value $\widetilde{\eta}_0$ at v_0 is the downward step-function $\widetilde{\eta}_0\, \Theta(v_0 - v_{min})$, we use the experimental upper limit $R^{limit}_{[E_1',E_2']}$ to get the upper limit $\tilde{\eta}^{limit}(v_0)$ as

$$R^{limit}_{[E_1',E_2']} = \tilde{\eta}_0^{limit}(v_0) \int_0^{v_0} dv_{min}\, \mathscr{R}^{SI}_{[E_1',E_2']}(v_{min})$$

Halo Dependent vs Independent comparison for SI IC

Rate only crosses, $\widetilde{\eta}_0$ Del Nobile, Gelmini, Gondolo, Huh 1304.6183, 1311.4247, 1405.5582

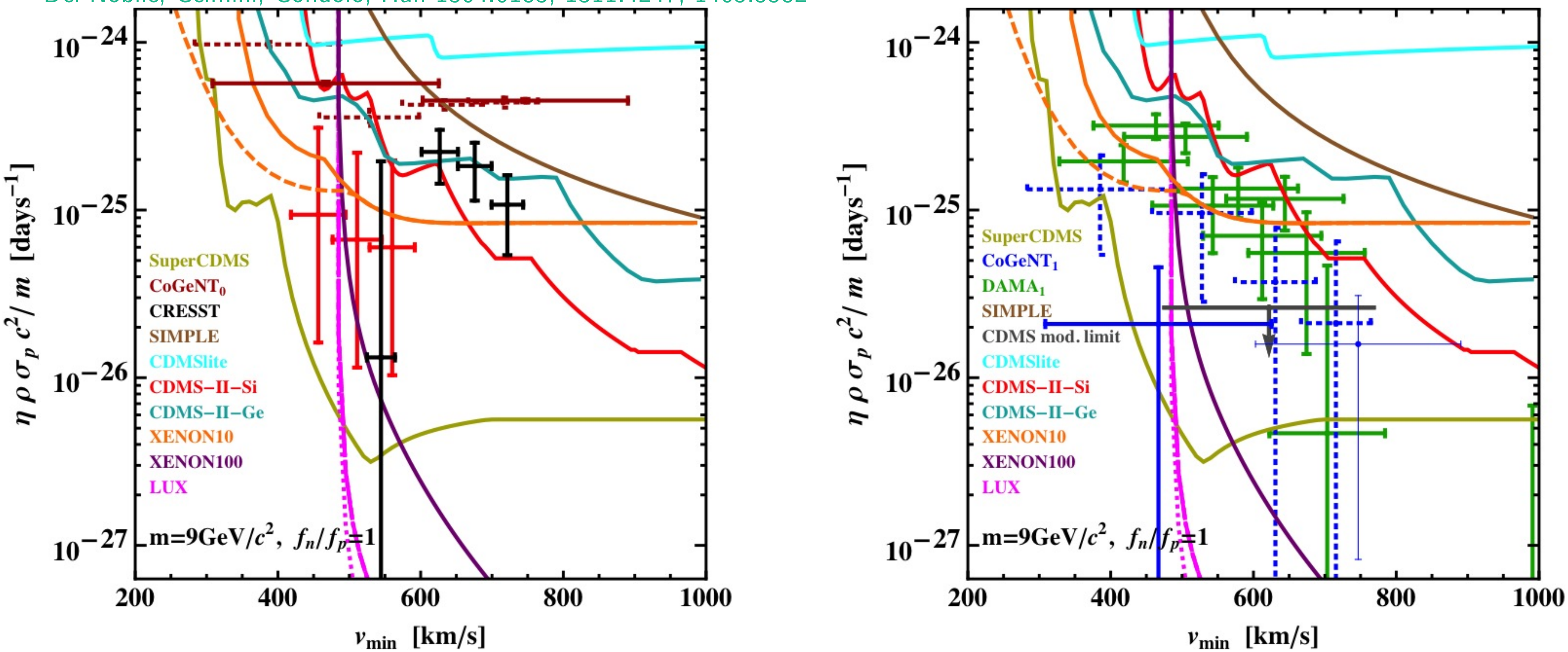




LEFT: CDMS-SI rejected by SuperCDSM bound in the SHM. RIGHT: $m = 9$GeV. CDMS-Si rate crosses are forbidden by the SuperCDMS limit in any halo model. But CDMSLite limit applies only in the SHM

Halo Dependent vs Independent comparison for SI IC

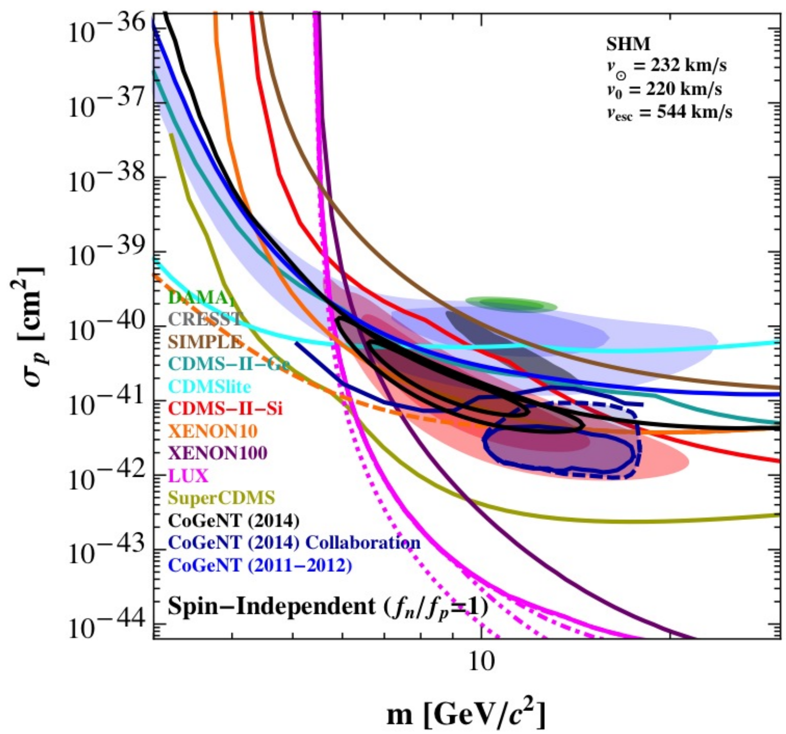
Del Nobile, Gelmini, Gondolo, Huh 1304.6183, 1311.4247, 1405.5582

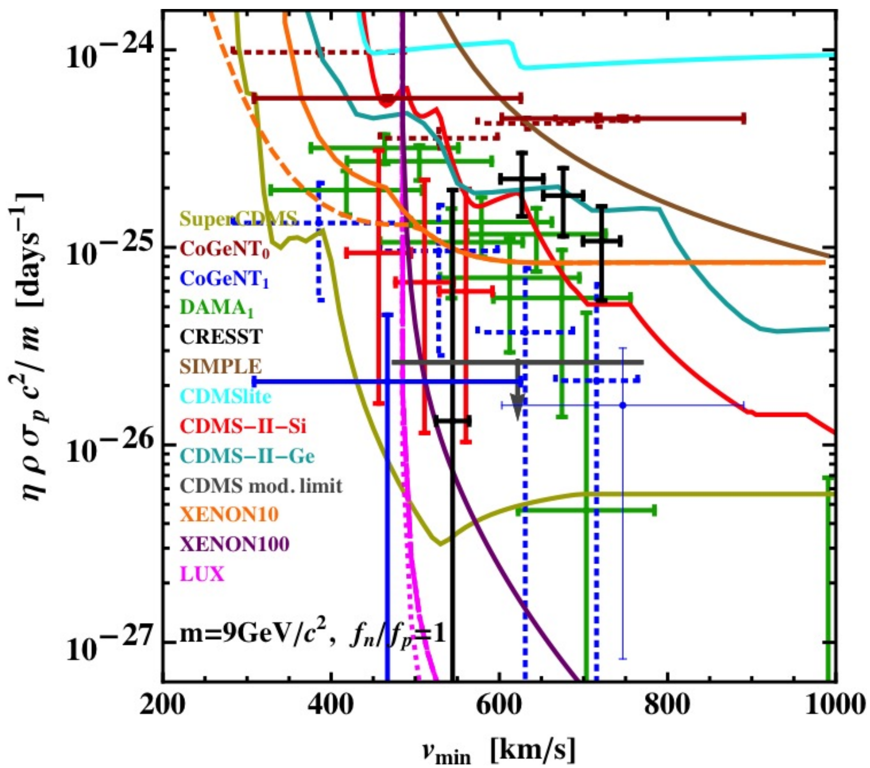


m = 9GeV. LEFT: Rate only crosses, $\tilde{\eta}_0$, and limits RIGHT: Modulation only crosses, $\tilde{\eta}_1$, of DAMA and CoGeNT and limits

Halo Dependent vs Independent comparison for SI IC

Both, $\widetilde{\eta}_1$ and $\widetilde{\eta}_1$ Del Nobile, et al. 1304.6183, 1311.4247, 1405.5582

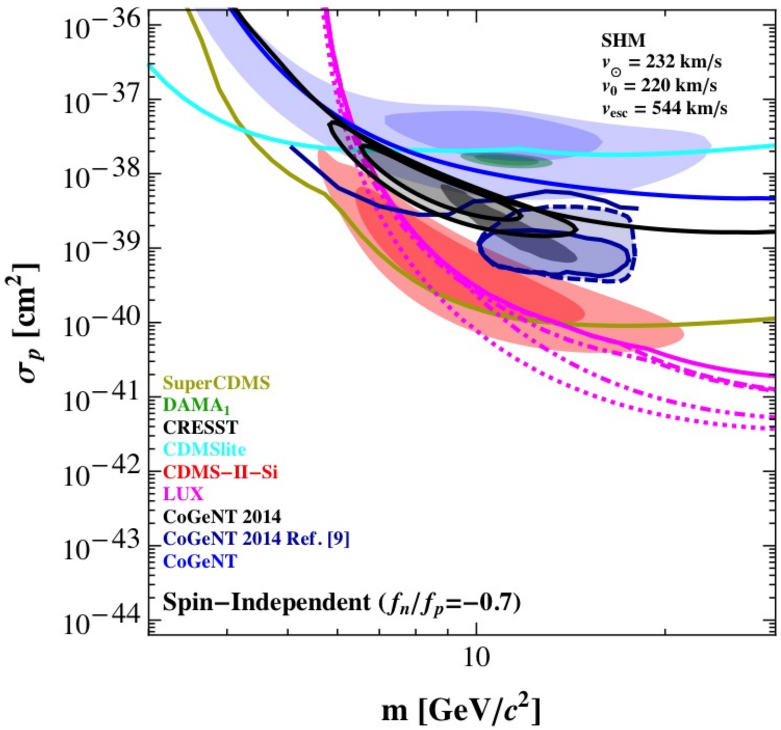


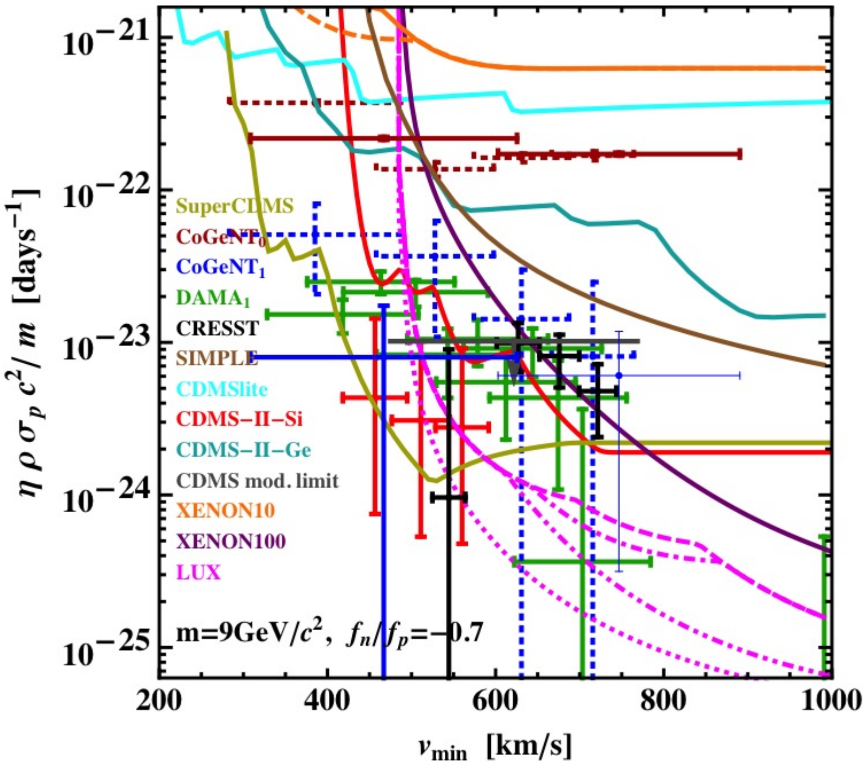


LEFT: CDMS-Si and CoGeNT compatible. RIGHT: $m = 9$GeV. CDMS-Si rate is too small for CoGeNT/DAMA mod. ($\widetilde{\eta}_1 > \widetilde{\eta}_0$ cannot be!). New CoGeNT modulation (solid blue cross) compatible with zero at $\simeq 1\sigma$, assuming the best fit phase of DAMA

Halo Dependent vs Independent comparison for SI IV

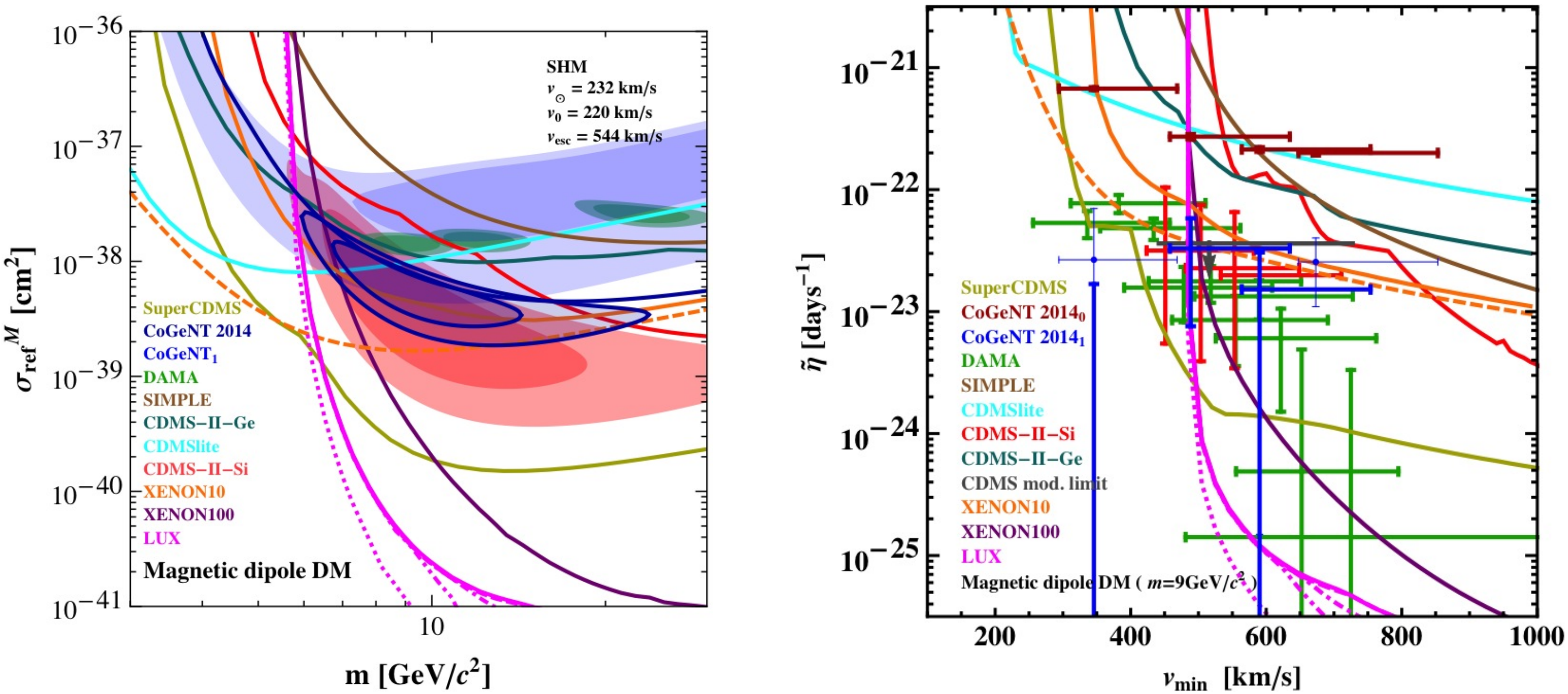
Del Nobile, Gelmini, Gondolo, Huh 1304.6183, 1311.4247, 1405.5582





CDMS-Si and CoGeNT regions separated and part of the CDMS-Si region survives the SuperCDMS limit in both. RIGHT: $m = 9$GeV. Again CDMS-Si rate small for CoGeNT/DAMA mod. and CoGeNT annual mod. compatible with zero at $\simeq 1\sigma$, with the best fit phase of DAMA,

Halo Dependent vs Halo Independent comparison for Magnetic Dipole DM Del Nobile, Gelmini, Gondolo, Huh 1401.4508



LEFT: DAMA, CoGeNT and CDMS-Si overlap! RIGHT: CDMS-Si rate too small for CoGeNT/DAMA modulations. Both: rejected by SuperCDMS, but importance of CDMSLite limit depends on the halo model

Generalized Halo Independent analysis also for inelastic scattering (Del Nobile, Gelmini, Gondolo and Huh, 1306.5273)

In inelastic scattering, the minimum velocity the DM must have to impart a nuclear recoil energy E_R depends on the mass splitting δ,

$$v_{min} = \frac{1}{\sqrt{2M_T E_R}}\left|\frac{m_T E_R}{\mu_T} + \delta\right|$$

Thus for a fixed DM velocity v: $E_R^-(v) < E_R < E_R^+(v)$, with

$$E_R^{\pm}(v) = \frac{\mu_T^2 v^2}{2M_T}\left(1 \pm \sqrt{1 - \frac{2\delta}{\mu_T v^2}}\right)^2$$

Call $\widehat{v}_\delta$ the minimum value v_{min} can take, $\widehat{v}_\delta = \sqrt{2\delta/\mu_T}$ for $\delta > 0$ and $\widehat{v}_\delta = 0$ for $\delta \leqslant 0$

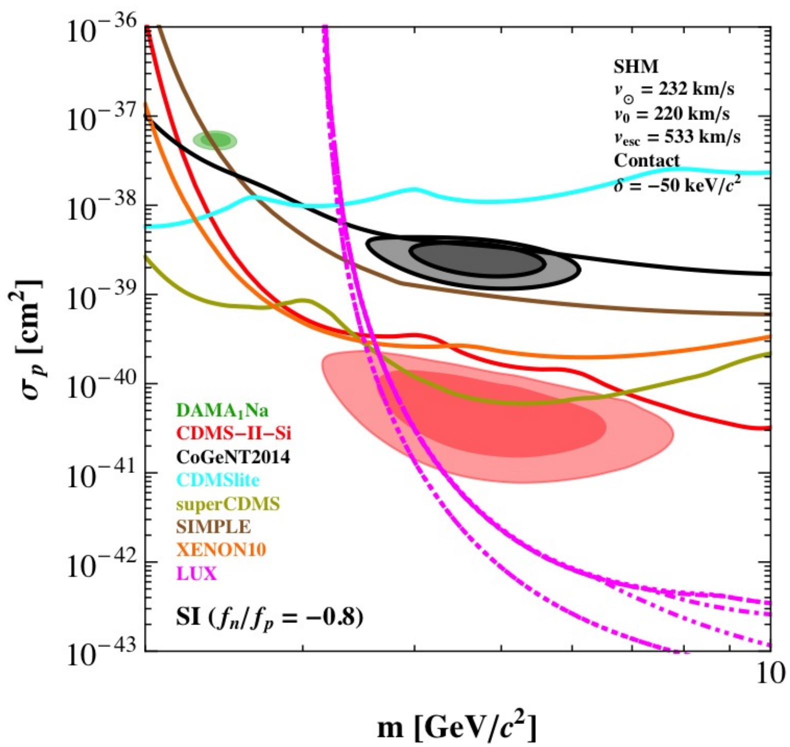
$$R_{[E_1',E_2']}(t) = \int_{v \geqslant \widehat{v}_\delta} d^3v \, \frac{\widetilde{f}(v,t)}{v} \, \mathscr{H}_{[E_1',E_2']}(v)$$

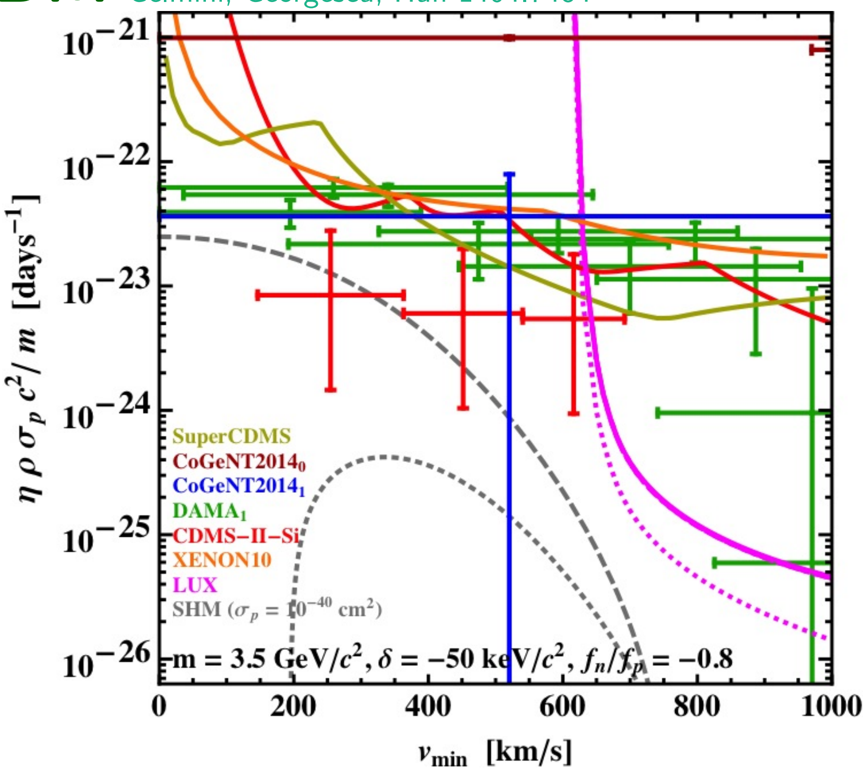
and

$$\mathscr{H}_{[E_1',E_2']}(v) \equiv \sum_T \frac{C_T}{M_T} \int_{E_R^-(v)}^{E_R^+(v)} dE_R \, \frac{v^2}{\sigma_{ref}} \frac{d\sigma_T}{dE_R}(E_R, v) \times \int_{E_1'}^{E_2'} dE' \, \epsilon(E') G_T(E_R, E')$$

Halo Dependent vs Independent comparison for Inelastic Exothermic SI "Ge-Phobic" DM

Gelmini, Georgescu, Huh 1404.7484

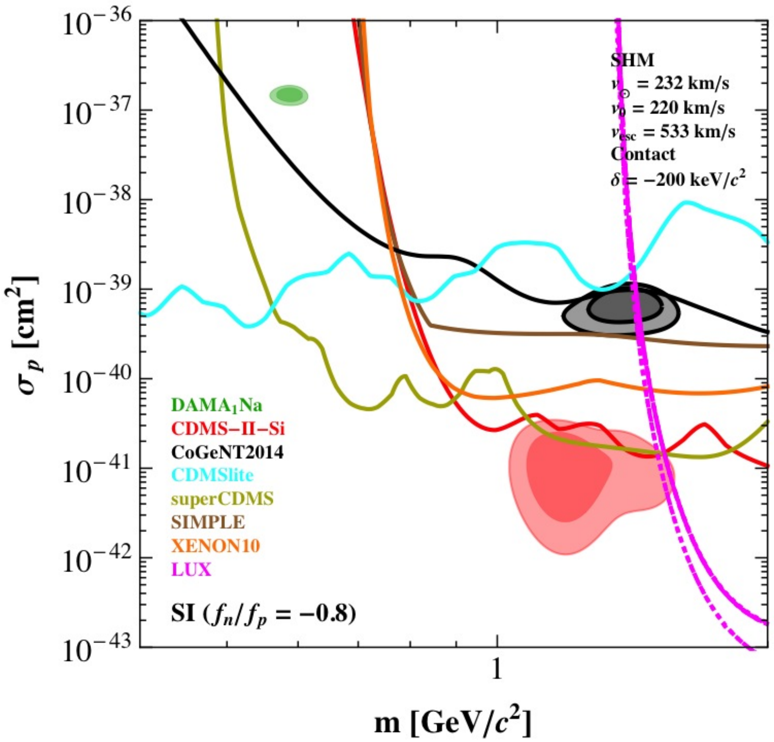


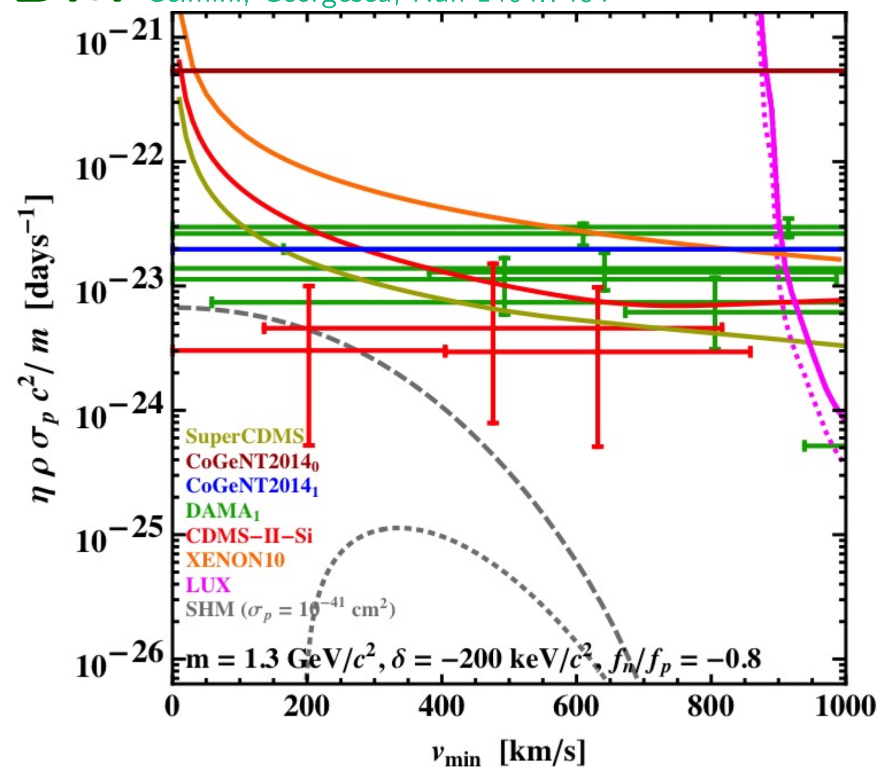


Exothermic $\delta = -50$ keV weakens Xe bounds, "Ge-Phobic" $f_n/f_p = -0.8$ weakens Ge bounds. LEFT: DAMA, CoGeNT and CDMS-SI disjoint! RIGHT: $m = 3.5$ GeV. CDMS-Si rate too small for CoGeNT and DAMA modulations (which overlap) Both: CDMS-Si allowed by all bounds

Halo Dependent vs Independent comparison for Inelastic Exothermic SI "Ge-Phobic" DM

Gelmini, Georgescu, Huh 1404.7484





LEFT: Exothermic $\delta = -200$ keV weakens Xe bounds, "Ge-Phobic" $f_n/f_p = -0.8$ weakens Ge bounds. LEFT: signal regions disjoint! RIGHT: $m = 1.3$ GeV. CDMS-Si rate too small for CoGeNT and DAMA modulations (which overlap). Both: CDMS-Si allowed by all bounds

Outlook on halo-independent data comparison method

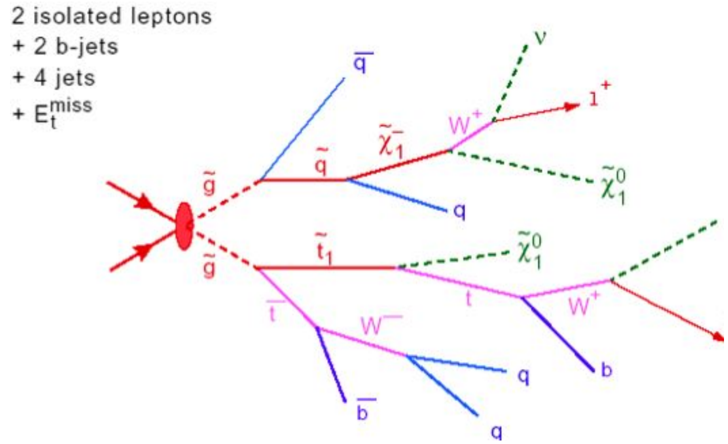
- The Halo Independent method to compare data of different direct DM searches is complementary to the usual comparison in the m, σ plane which must be done assuming a particular halo model. It shows when data cannot be made compatible with ANY choice of halo model- or not

- The Generalized Halo Independent method can be applied to ANY type of interaction, and not only to elastic but also to inelastic scattering (and can take fully into account all the characteristics of each experiment: energy resolutions, efficiencies etc)

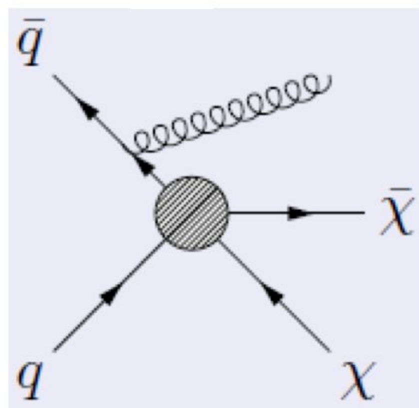
- The way in which we compare data up to now, i.e. comparing averages over v_{min} intervals for putative DM signal with upper bounds of negative searches, does not have a clear statistical meaning- More work is necessary to understand how to do it better.

Searches at the LHC

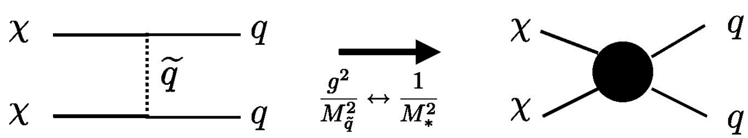
either DM through known decay chain
(specific models, SUSY, simplified)



or direct DM production plus a photon or gluon (monophoton or monojet signal) so far only for
CONTACT INTERACTIONS

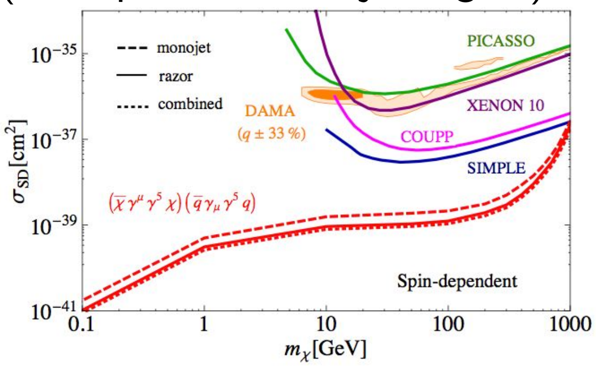


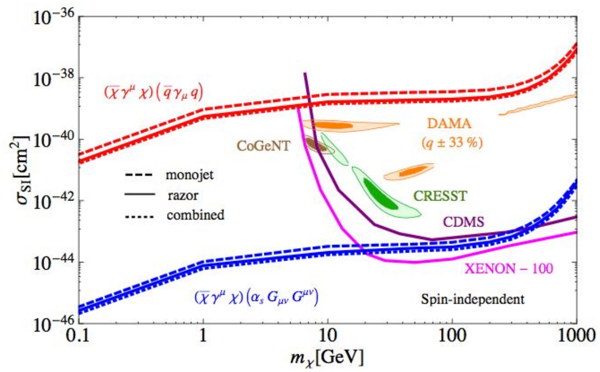
qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

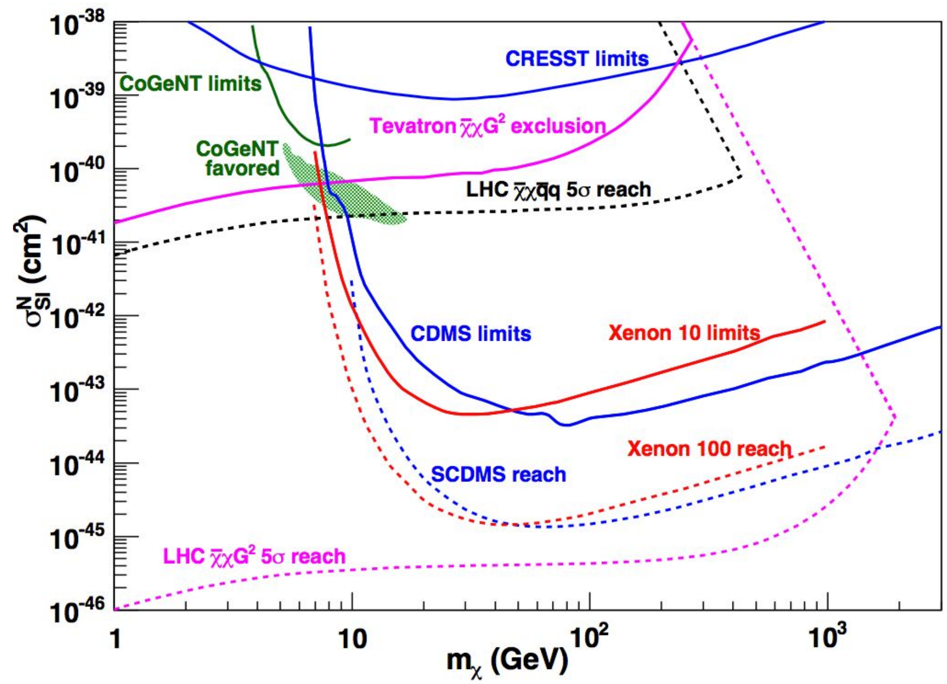


Graciela Gelmini-UCLA

Searches at the LHC direct production plus a photon or gluon (monophoton monojet signal) for CONTACT interactions Beltran et al 1002.4137; Fox et al 1203.1662







CAVEAT: in direct DM "contact interaction" if mediator M > q > MeV but here mediators mass > 100's GeV

Searches at the LHC

So far only effective operators with contact interactions, not only with mono-jets and mono-γ but what mono- whatever: mono-W's (leptons), mono-Z's (dileptons), or even mono-Higgs. The approach is limited (absence of possible interference between different operators, effect of lighter mediators than those necessary to have a contact interaction at the LHC...)

Now trying to use simplified models and classify classes of mediators in the s-channel and the t-channel, or by the way the DM relic density could occur (e.g. proposed "Benchmarks for DM detection at the LHC" De Simone, Giudice & Strumia 1402.6287). Lots of work to do in this direction...

DM signal or annually modulated backgrounds?

There have been many objections to the DAMA result over the years, none conclusive (extended to CoGeNT too could they be observing annually modulated backgrounds?

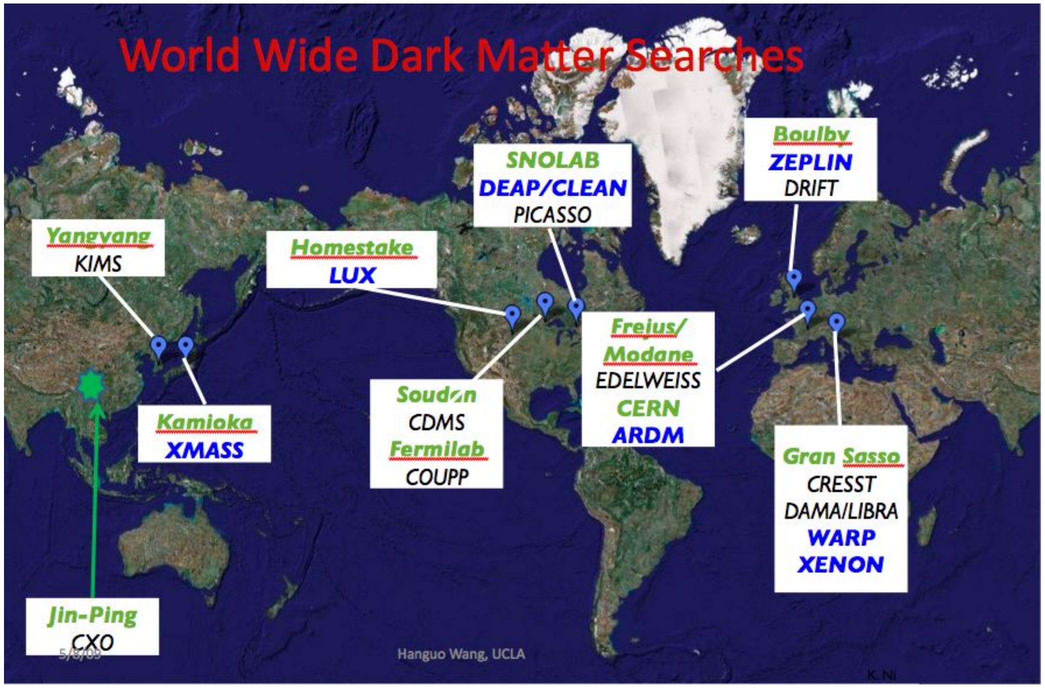
- O(10 MeV) ambient neutrons at the LNGS or Soudan Mine (via scattering or neutron capture and activation- Auger electrons) J. P. Ralston arXiv1006.5255

- >TeV cosmic ray μ's which reach the LNGS or Soudan Mine underground facility and
  -either produce secondary neutrons via spallation in the detector or surrounding rock J. P Ralston arXiv1006.5255, K. Blum arXiv1110.0857
  -or deposit their energy directly into the detector D, Nygren arXiv1102.0815 (2011)

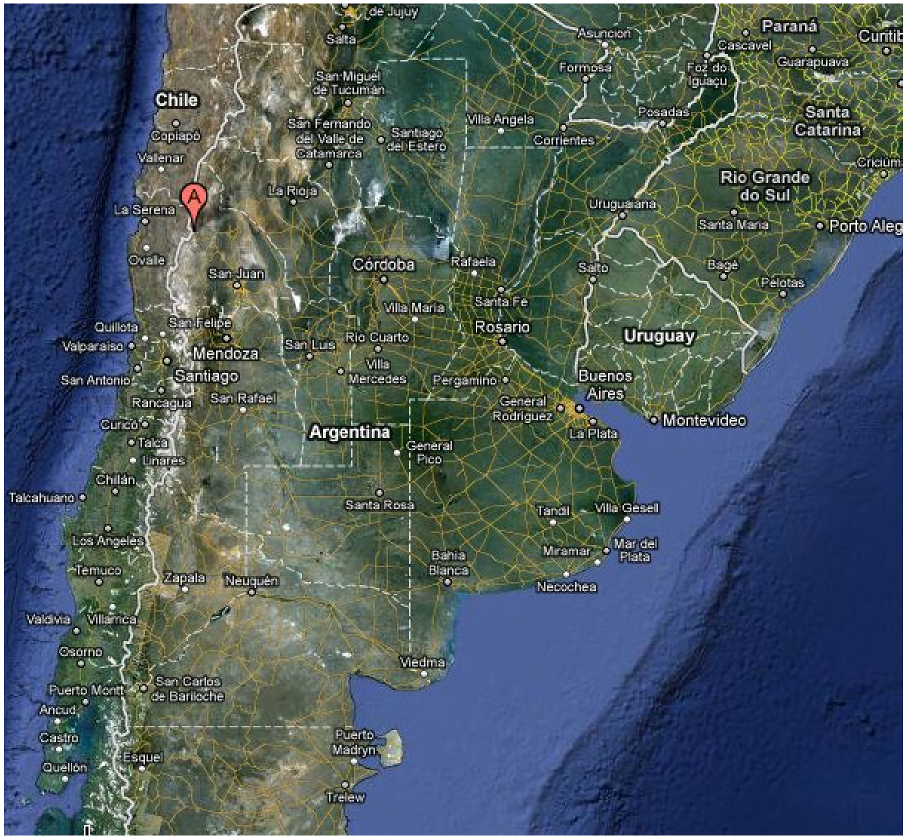
- DAMA refuted each claim...e.g. no modulation in multiple events (which n would produce)... phase of the modulation in DAMA is off with respect to the max T in the upper atmosphere S. Chang, J. Pradler and I. Yavin arXiv:1111.4222 - Could muons + solar ν at the right depth produce the phase in DAMA? Jonathan Davis, 1407.1052 Idea rejected in 1409.3185 and 1409.3516

DM signal or annually modulated backgrounds?

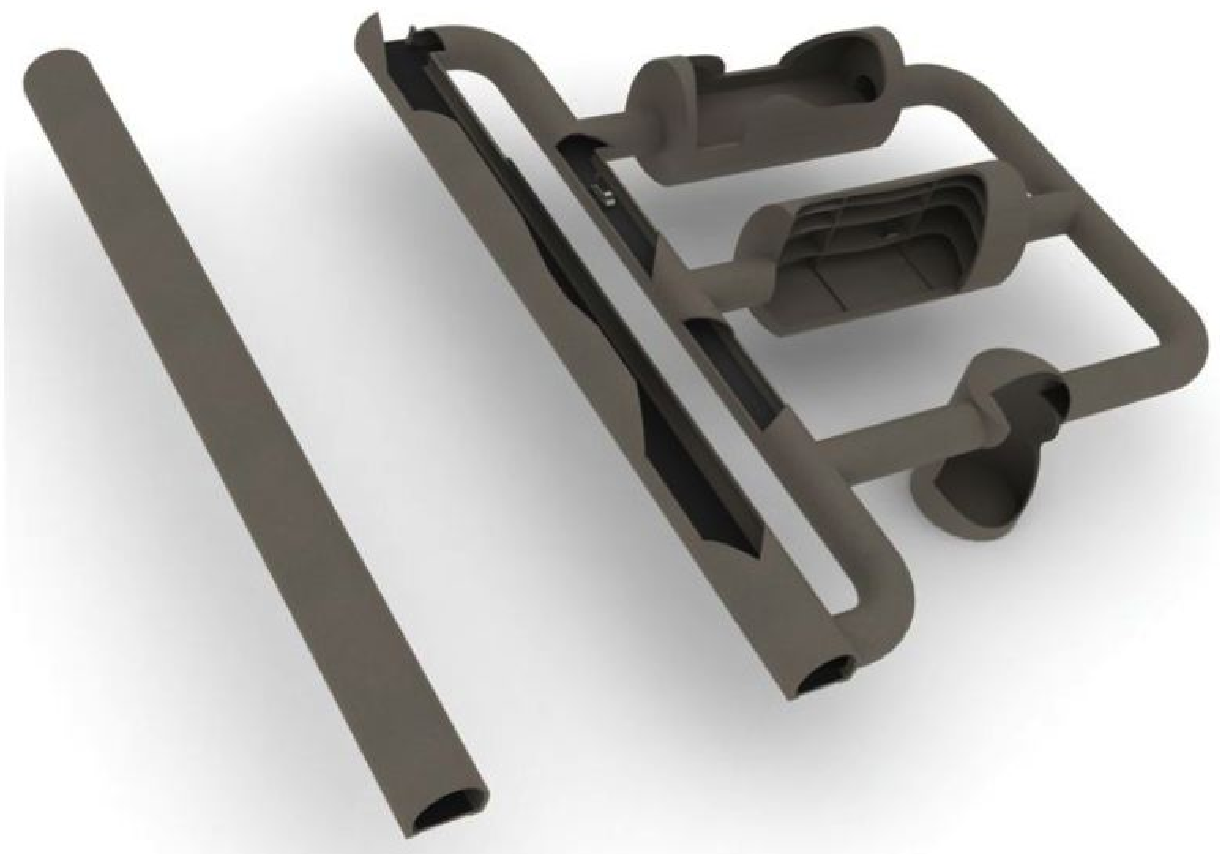
A definitive way to eliminate the doubt that the annual modulation in a direct DM detector is due to seasonal backgrounds: make the experiments in the Southern Hemisphere. Problem is, all underground laboratories are in the North



Opportunity to build ANDES at the Agua Negra Tunnel



ANDES Laboratory concept



ANDES, an underground laboratory in the Agua Negra tunnel

- 2 tunnels, 12 m diameter, separated 60 m, 14 km long
- Argentinian side at about 400 km N of Pierre Auger
- Entry in Argentina (close to the city of San Juan) at altitude 4085m, in Chile at 3600 m (close to La Serena)
- Cavities at $\simeq$ 3700m altitude
- Deepest point from surface at $\simeq$4800 mwe
- Rock: andesite, basalt, rhyolite; density $\simeq$ 2.7 g/cm^3
- Low radioactivity: 10^{-5} neutrons/kg s (Gran Sasso-10^{-4}, Modane 10^{-5});
  1.08 $\times 10^{-5}$ μ's/ m^2 sec; T$\simeq$ 30-40^o C
- Bidding finalized (in favor of Lombardi). Construction expected to start in 2015 and cavities will be ready within 2 years.