Direct detection of dark matter

An overview, not a review

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- Even if a new neutral particle is discovered at accelerators, one must still prove that it is the cold dark matter.

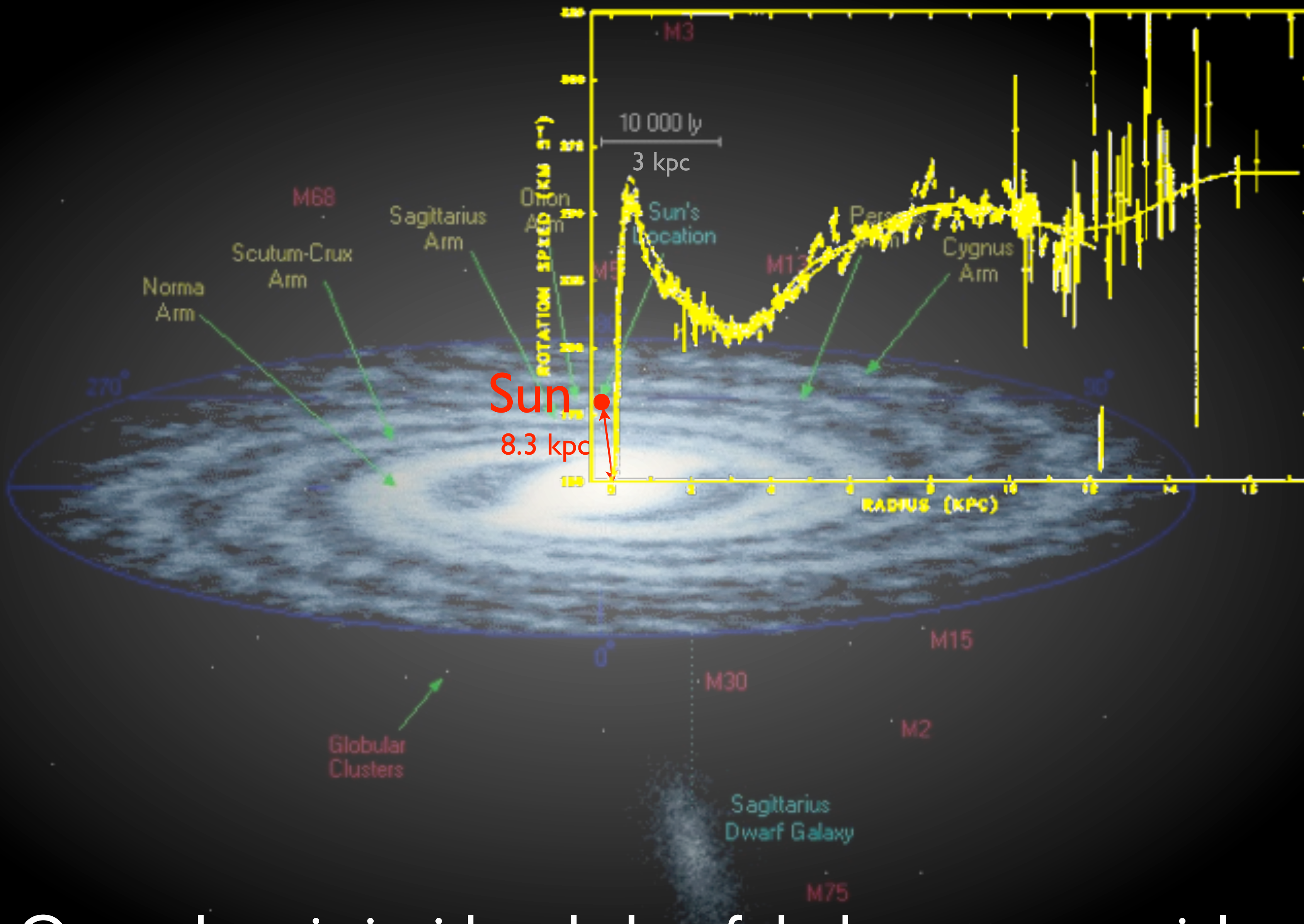
  Example: active neutrinos are neutral but are hot dark matter.

- Indirect detection of dark matter is subject to poorly known astrophysical backgrounds, so it is hard to claim an unconditional discovery (exception may be gamma-ray line).

- Direct detection seems the best way to prove the existence of particle dark matter.

The principle

Rotation curve (Clemens 1985)

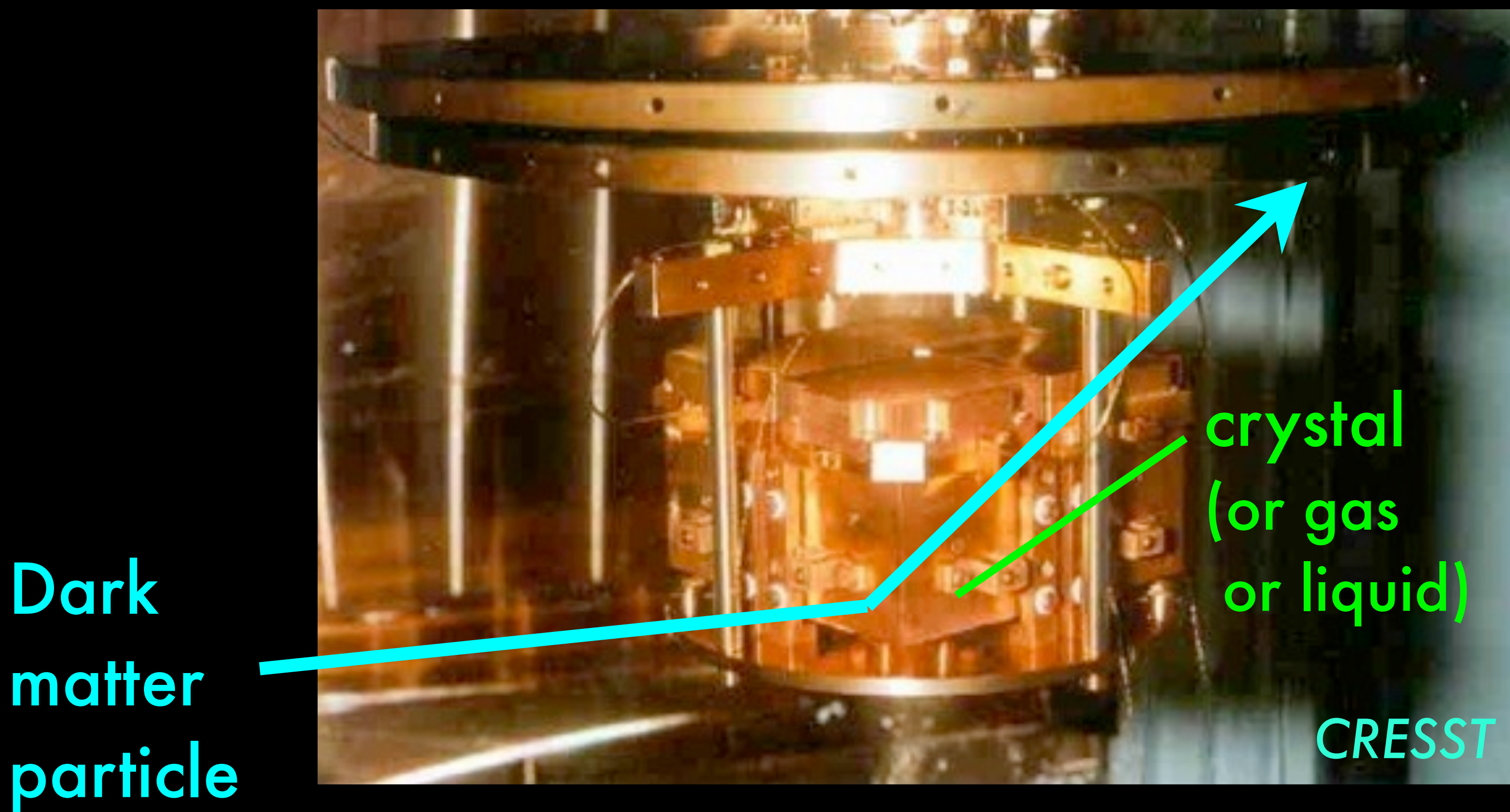


Our galaxy is inside a halo of dark matter particles

Image by R. Powell using DSS data

The principle

Dark matter particles that arrive on Earth scatter off nuclei in a detector

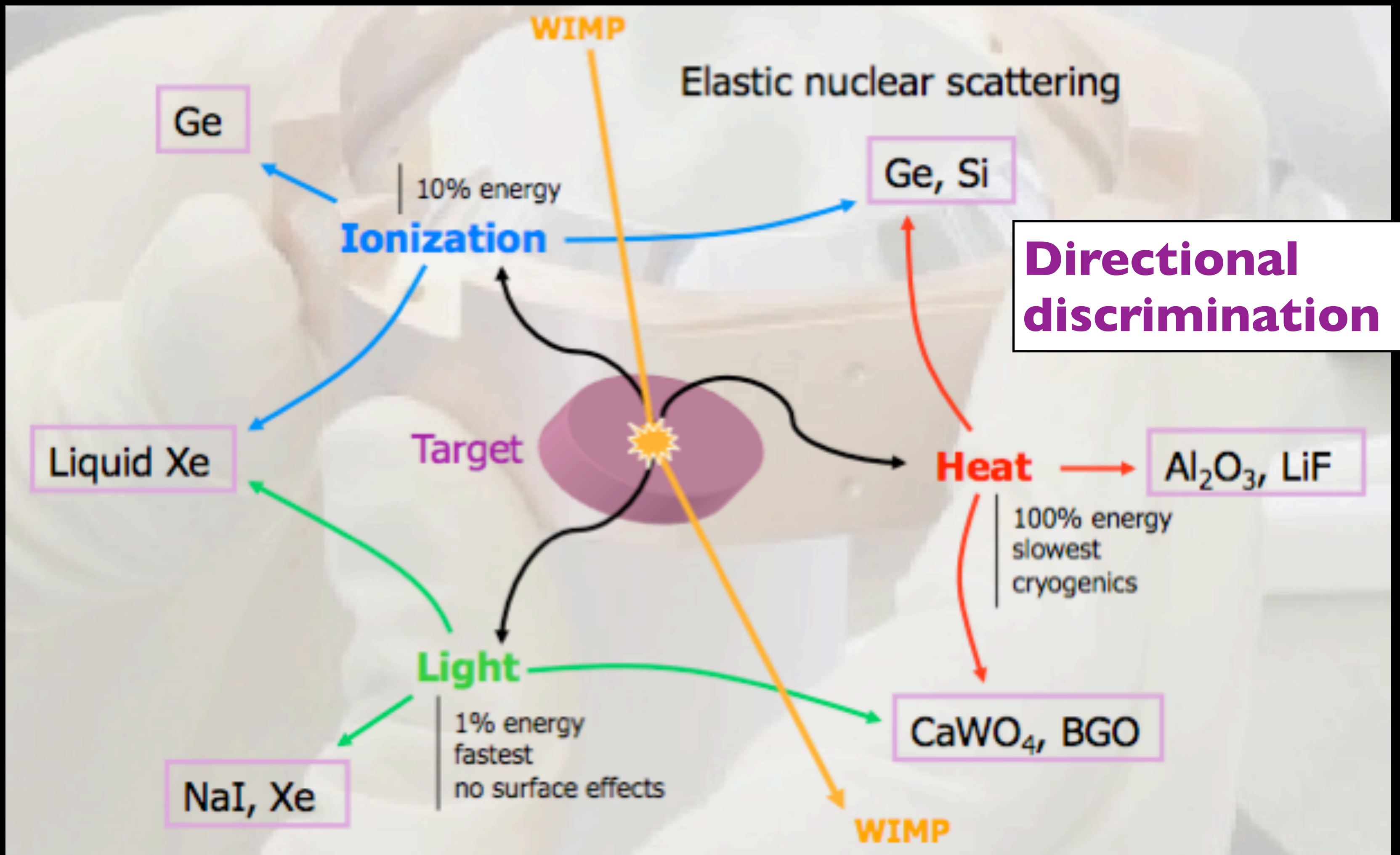


Low-background underground detector

CDMS
EDELWEISS
DAMA
CRESST
KIMS
DRIFT
XENON
COUPP
CoGeNT
TARP
DMTPC
TEXONO
.....

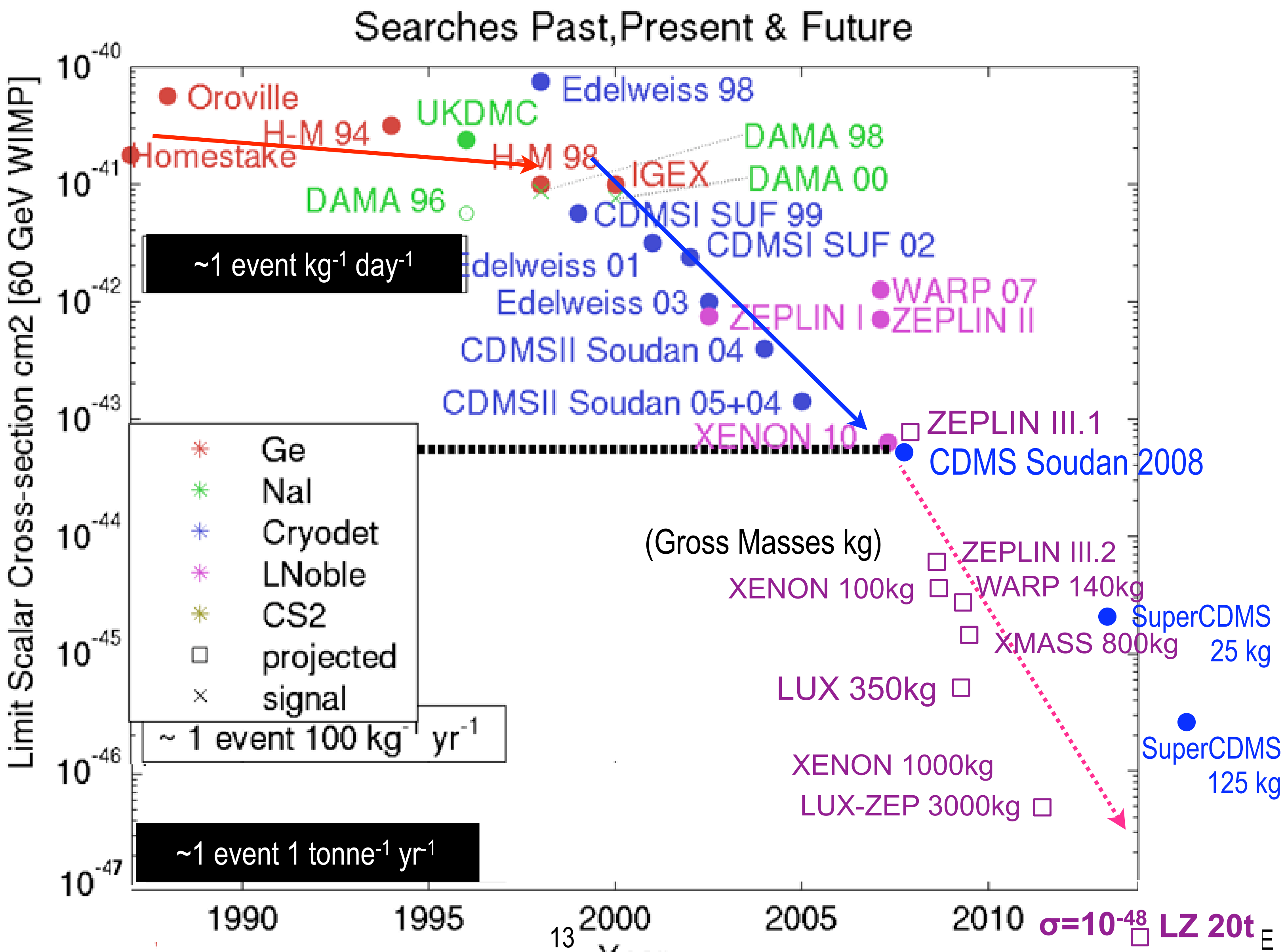
Background discrimination

Finding the dark matter particles is a fight against background



From Sanglard 2005

DM Direct Search Progress Over Time (2009)



Gaitskell 2009

Coming up......

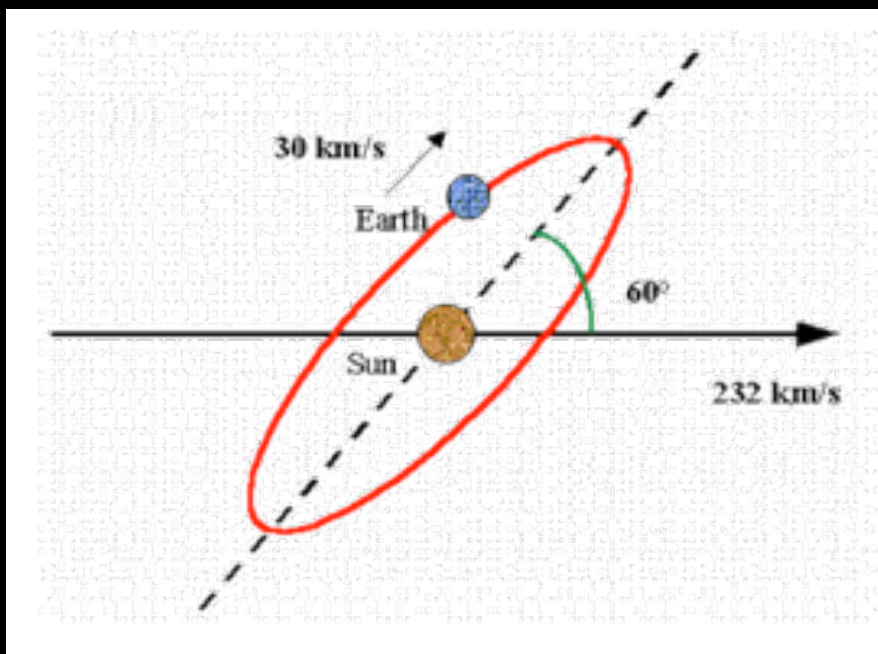
- XMASS (800 kg LXe, Kamioka, 2011-)
- SuperCDMS (25kg Ge, Soudan, 2012-)
- LUX (350 kg LXe, Homestake, 2012-)
- DarkSide (50 kg LAr, Gran Sasso, 2012-)
- COUPP (60 kg CF_3I, SNOLab, 2012-)
- XENON-1T (1 ton LXe, Gran Sasso, 2014-)
- DM-ICE, EURECA, DARWIN, and many many others

The annual modulation

Drukier, Freese, Spergel 1986

Annual modulation in WIMP flux and detection rate

$$S = S_0 + S_m \cos[\omega(t - t_0)]$$

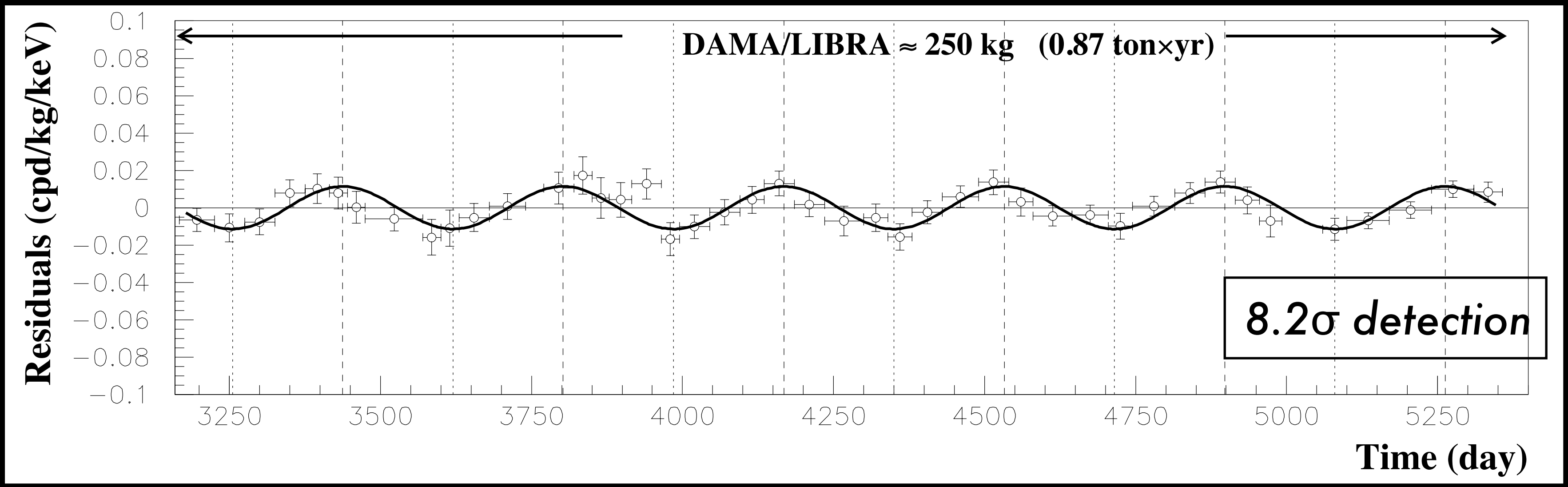


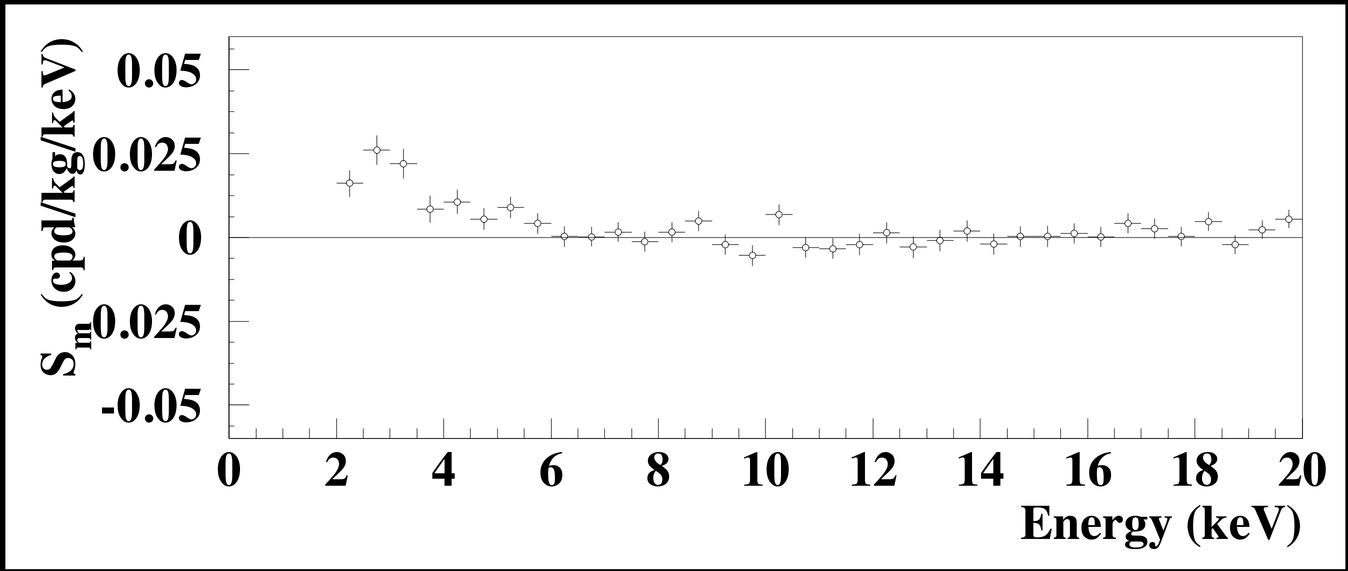
The WIMP bulk velocity w.r.t. Earth modulates from ~232+15 km/s to ~232-15 km/s with a period of one year

The DAMA modulation

DAMA finds a yearly modulation as expected for dark matter particles

Bernabei et al 1997-2012



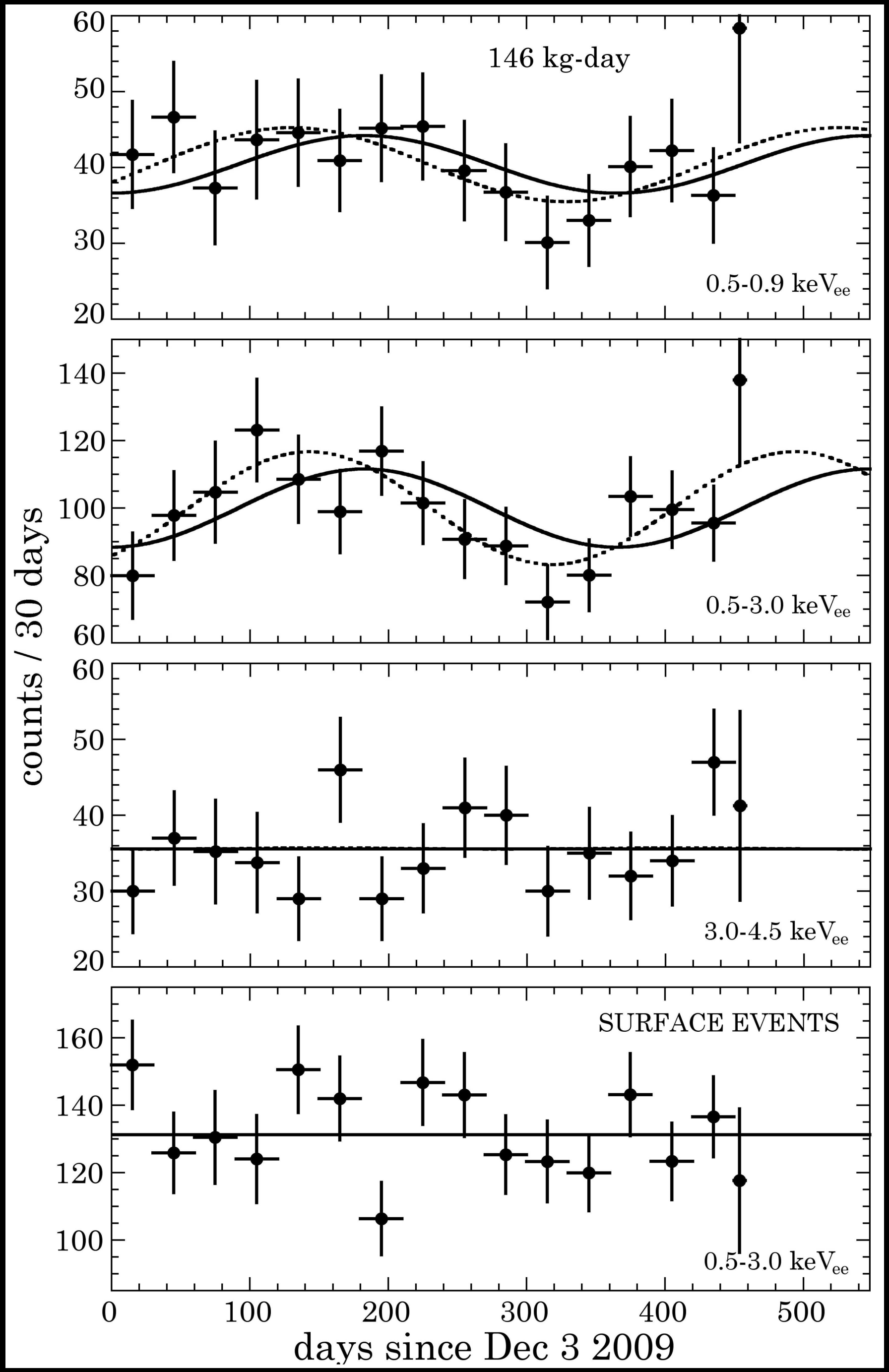


$$S = S_0 + S_m \cos[\omega(t - t_0)]$$

The CoGeNT modulation

The CoGeNT "irreducible excess" (*) modulates with a period of one year and a phase compatible with DAMA's annual modulation.

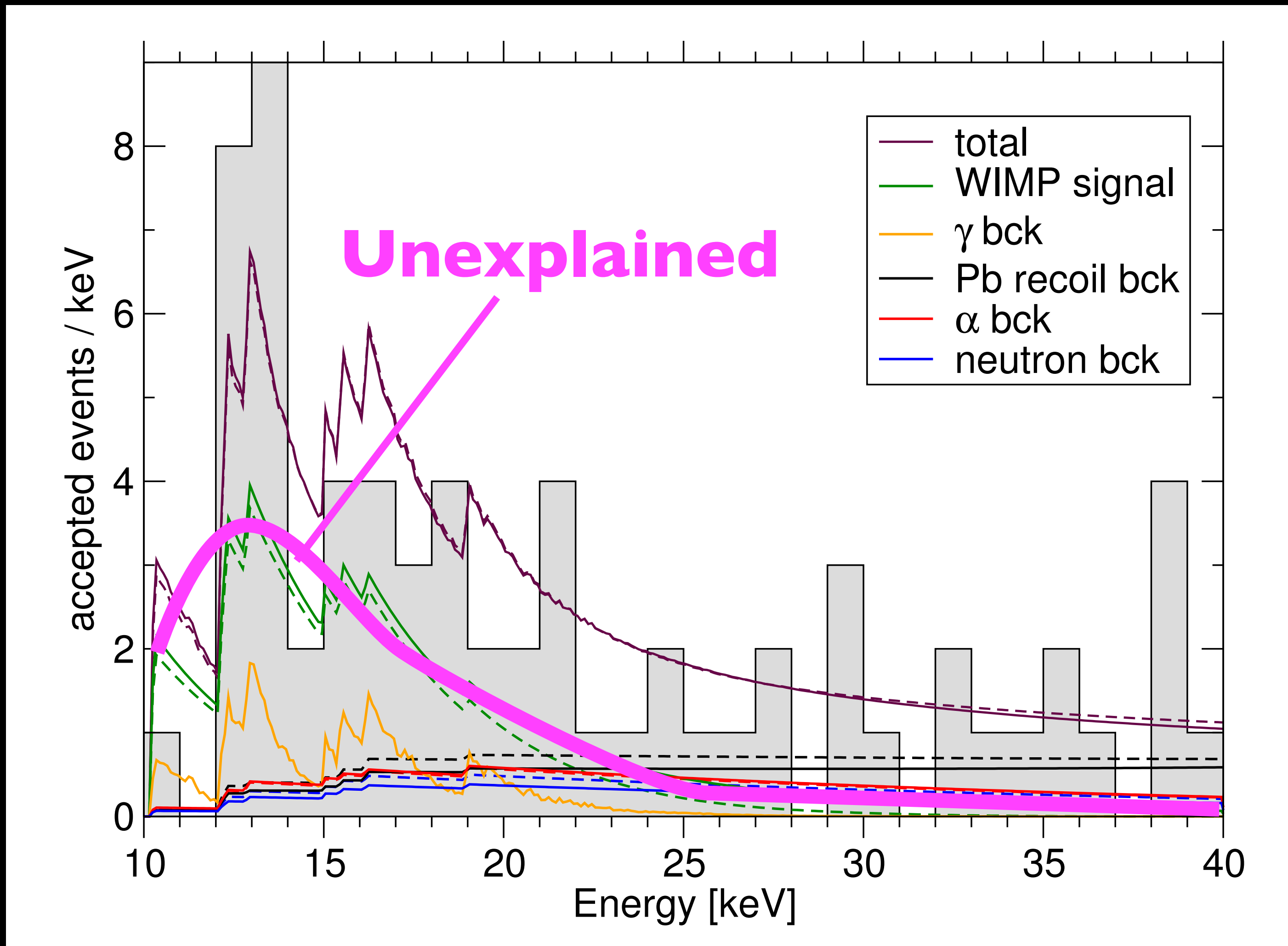
Aalseth et al 1106.0650



(*) Partly due to extra surface events

The CRESST unexplained excess

67 observed events cannot all be explained by background at 4σ



Adapted from Anglehor et al 2011

The CRESST unexplained excess

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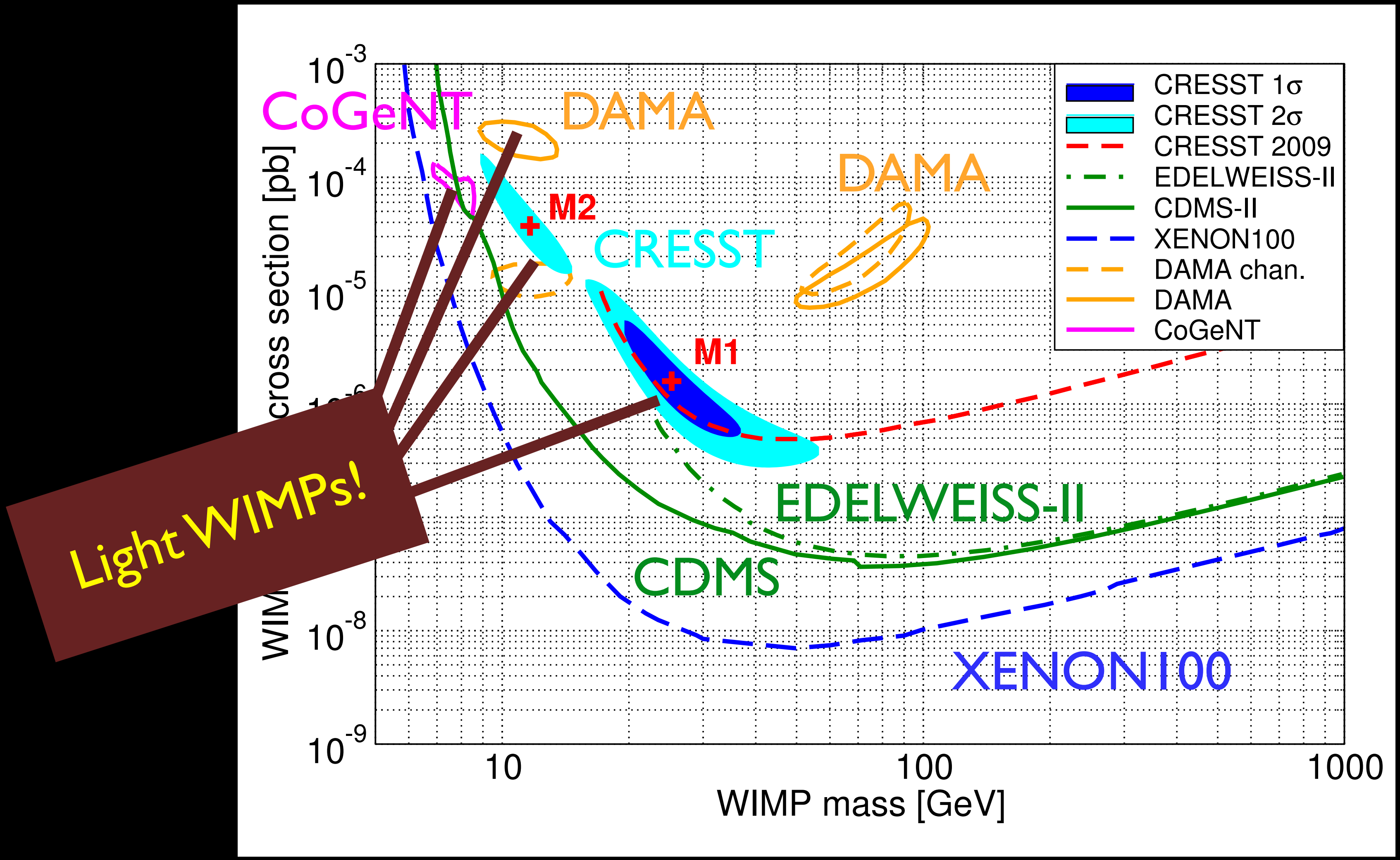
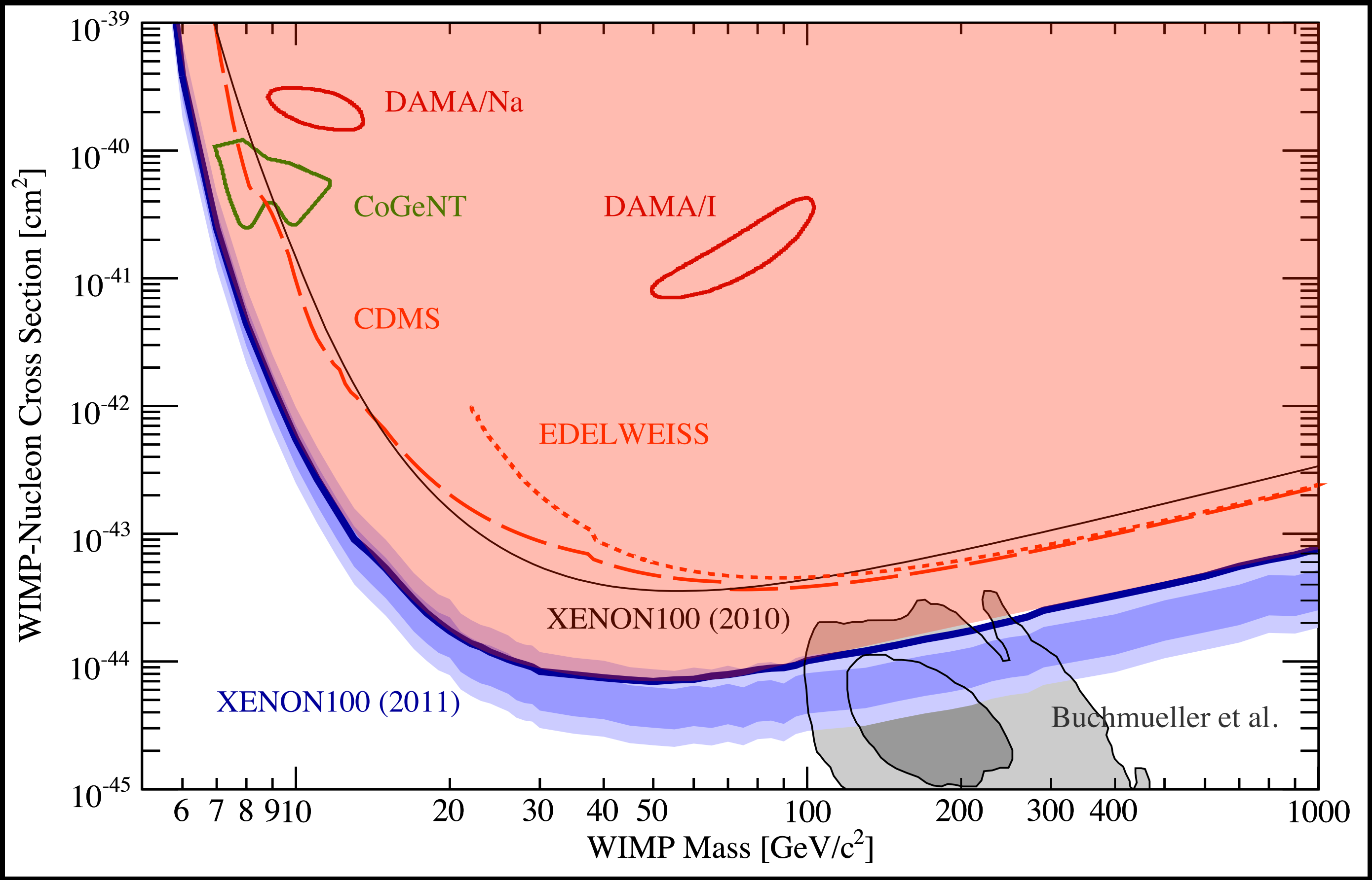


model-dependent

Adapted from Anglehor et al 2011

Limits from XENON-100, KIMS, CDMS, ...

Upper limit on WIMP-nucleon cross section
from XENON-100 (model dependent)



3 events observed

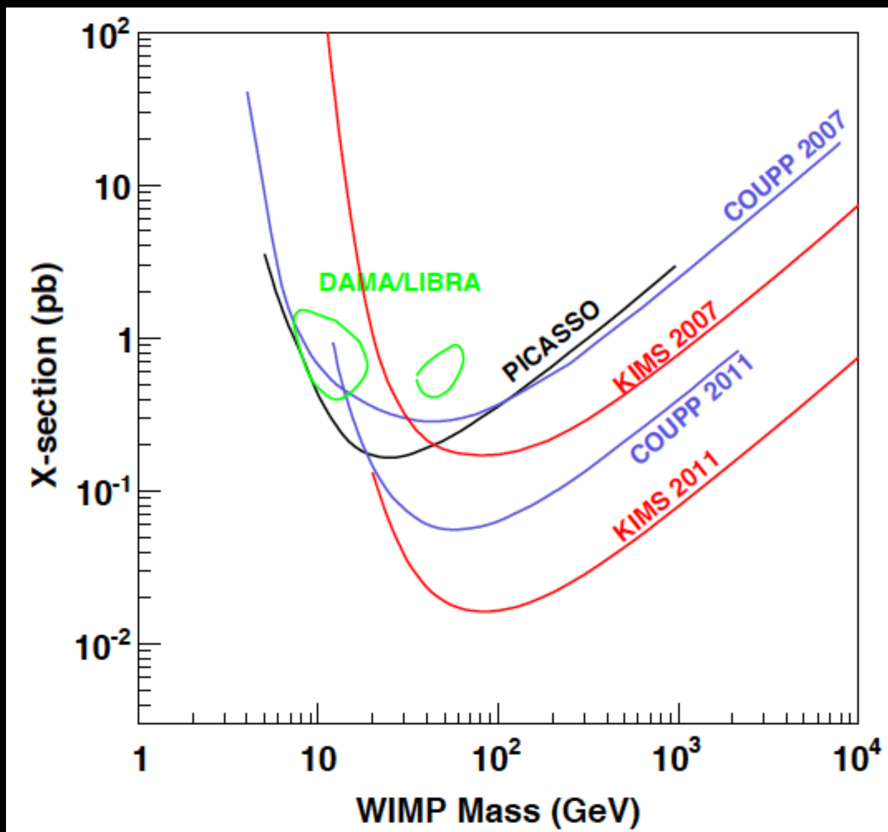
Aprile et al (XENON-100) 1104.2549

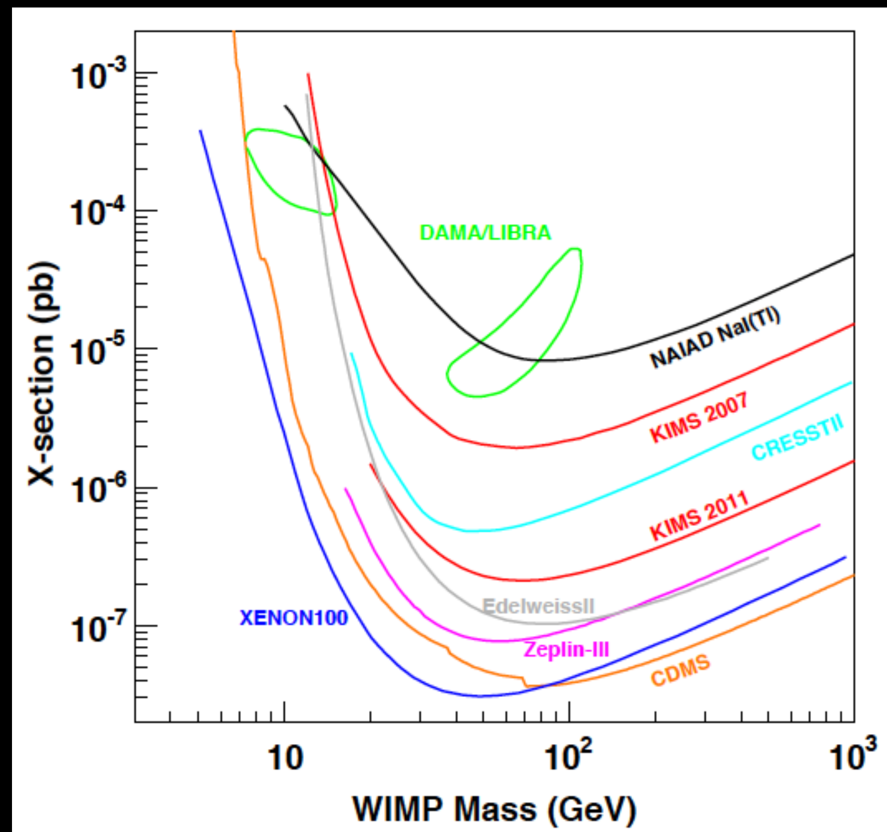
1.8±0.6 expected background

Limits from XENON-100, KIMS, CDMS, ...

KIMS: CsI scintillation detector
(similar to DAMA)

- *Excludes inelastic dark matter*
- *Excludes 60 GeV/c² DAMA region*

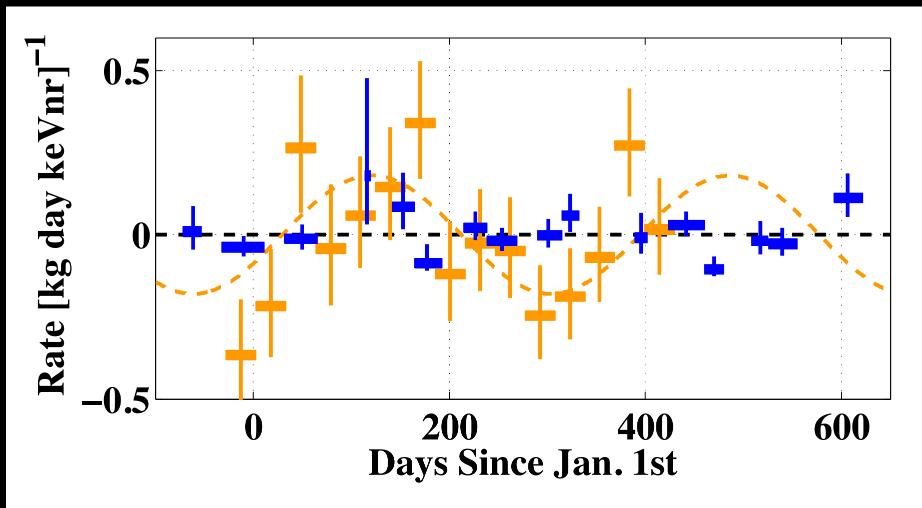




Without using detectors with large surface α background

Kim at TAUP 2011

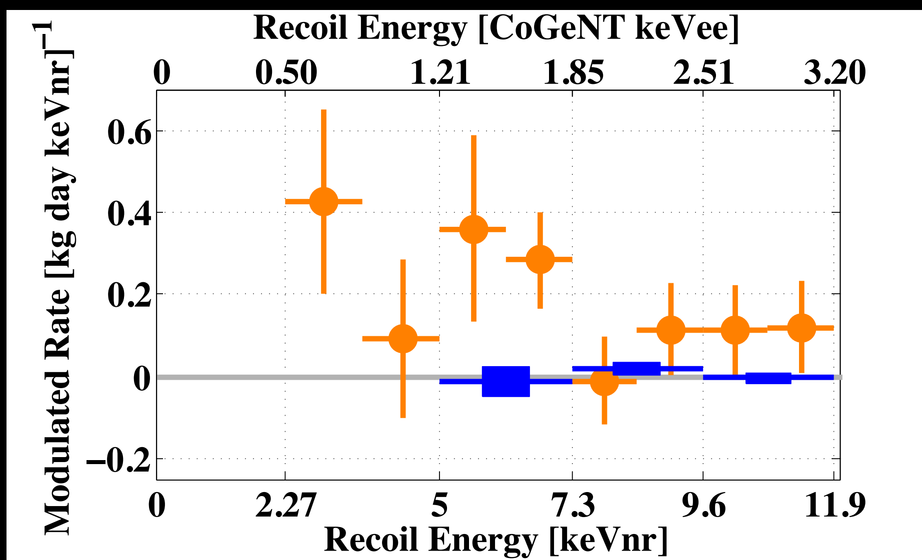
Limits from XENON-100, KIMS, CDMS, ...

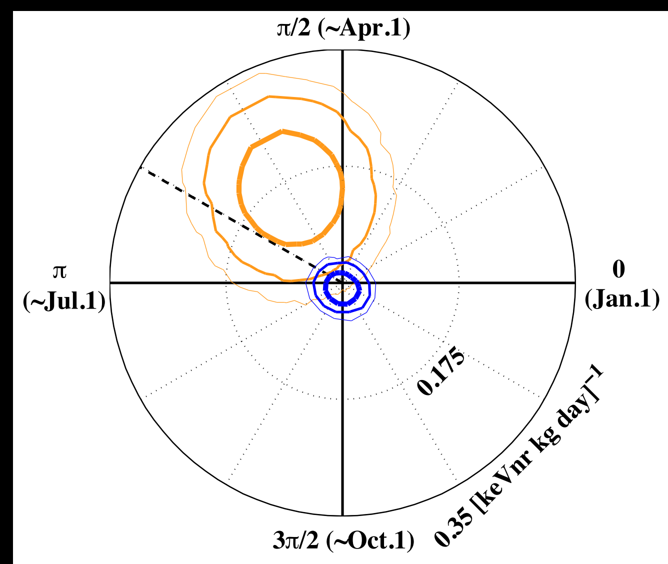


CDMS does not observe an annual modulation and constrains its amplitude

Ahmed et al 1203.1309

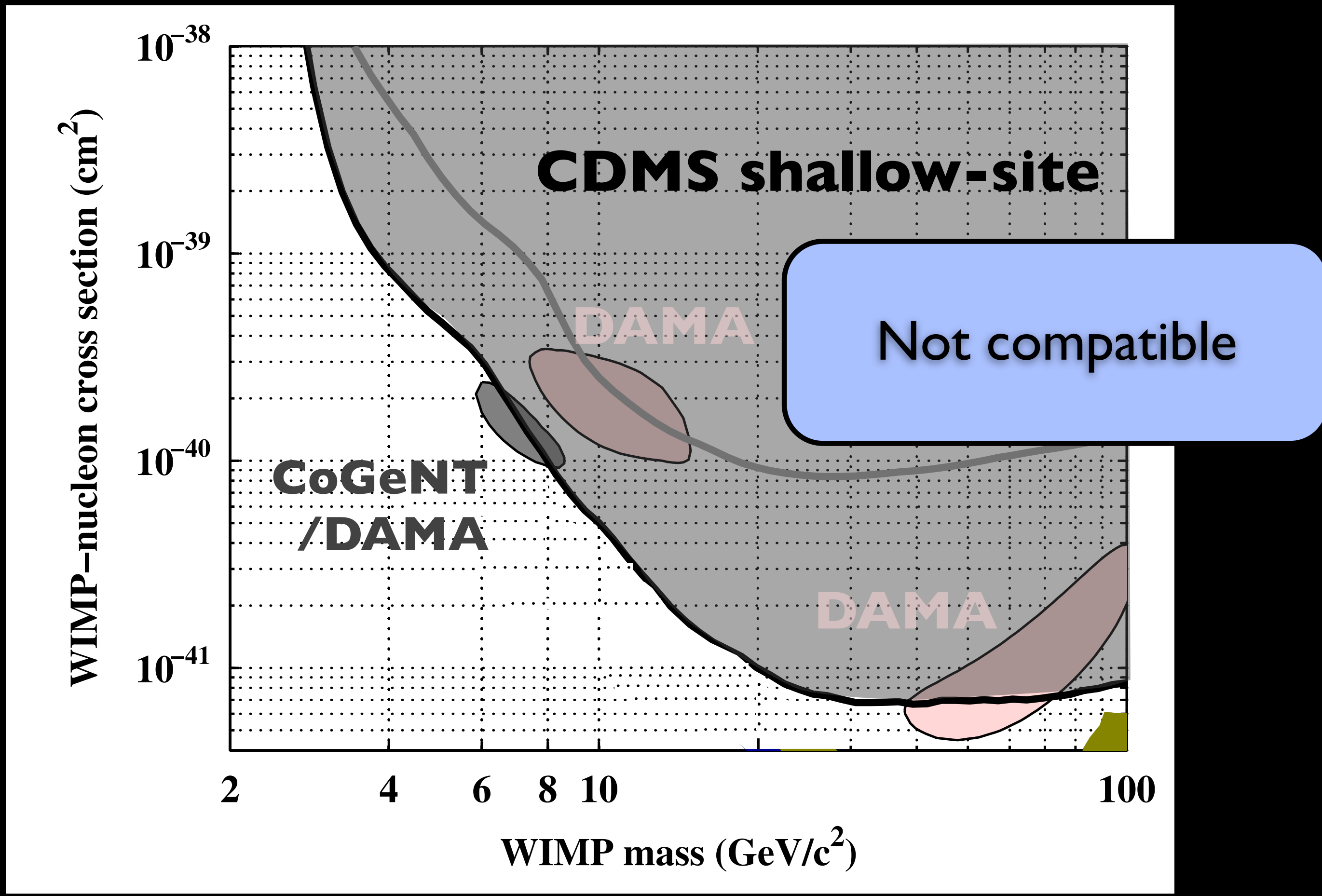
CoGeNT CDMS





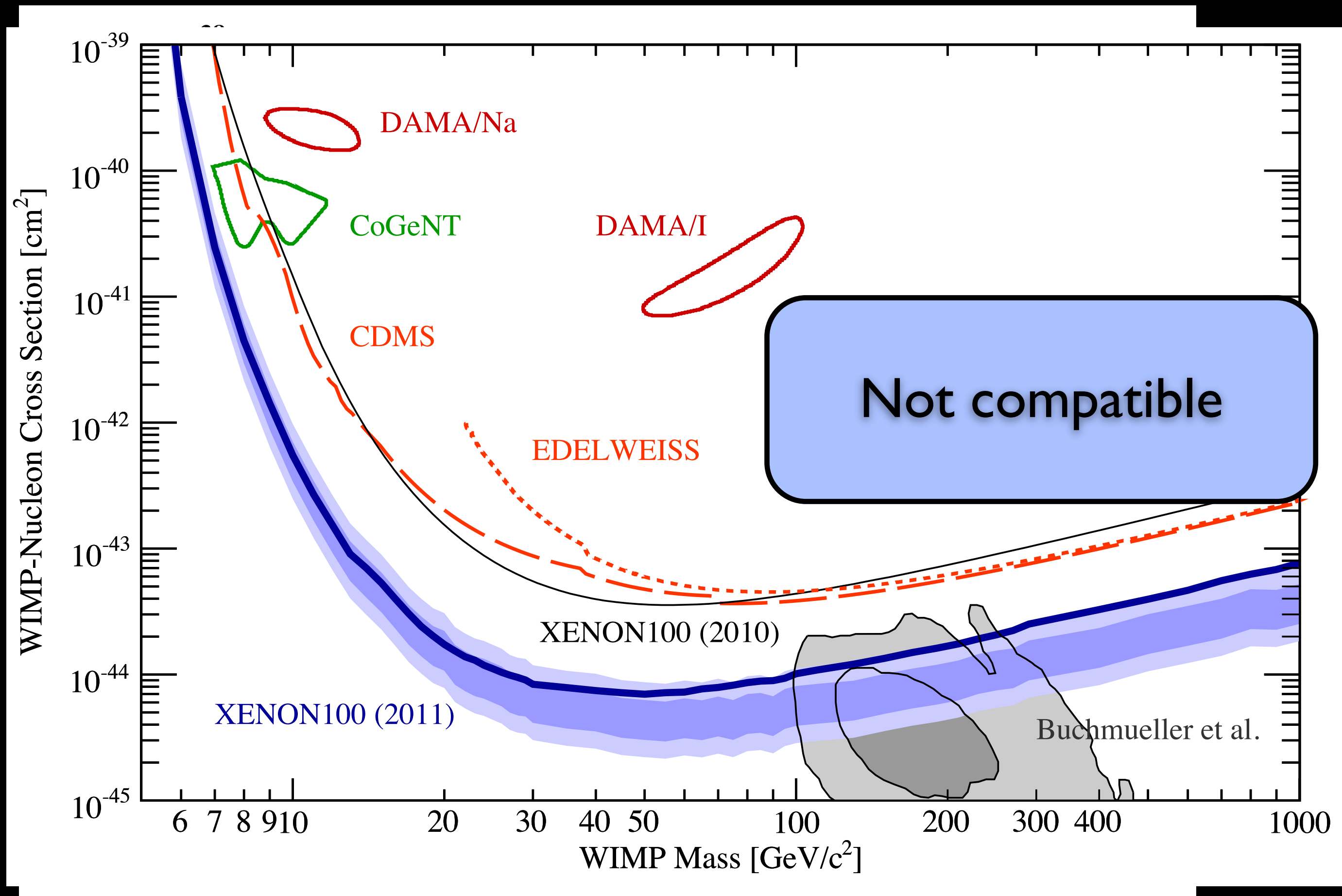
model-independent

CoGeNT & DAMA vs. XENON, CDMS, et al



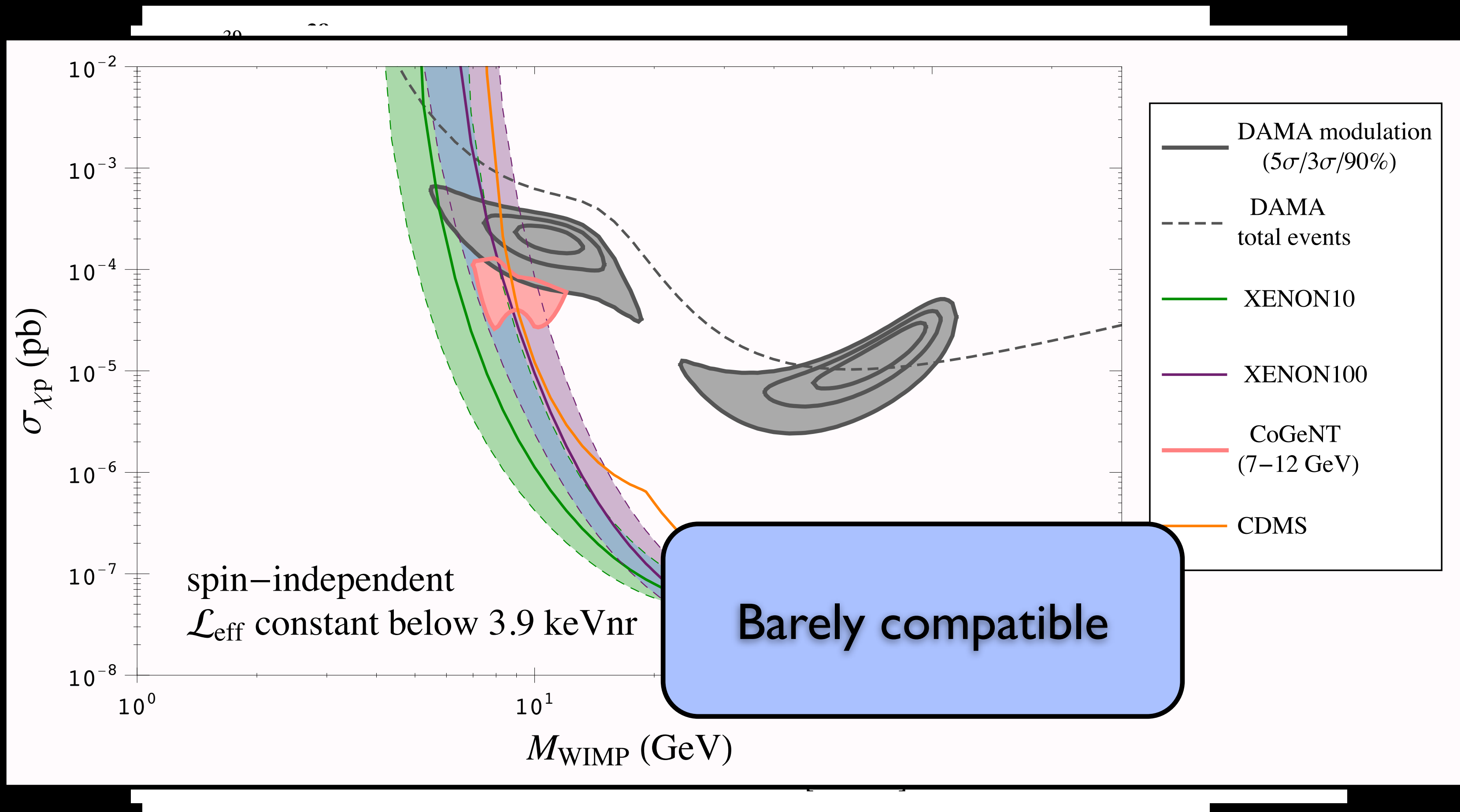
Akerib et al (CDMS) PRD82, 122004, 2010

CoGeNT & DAMA vs. XENON, CDMS, et al



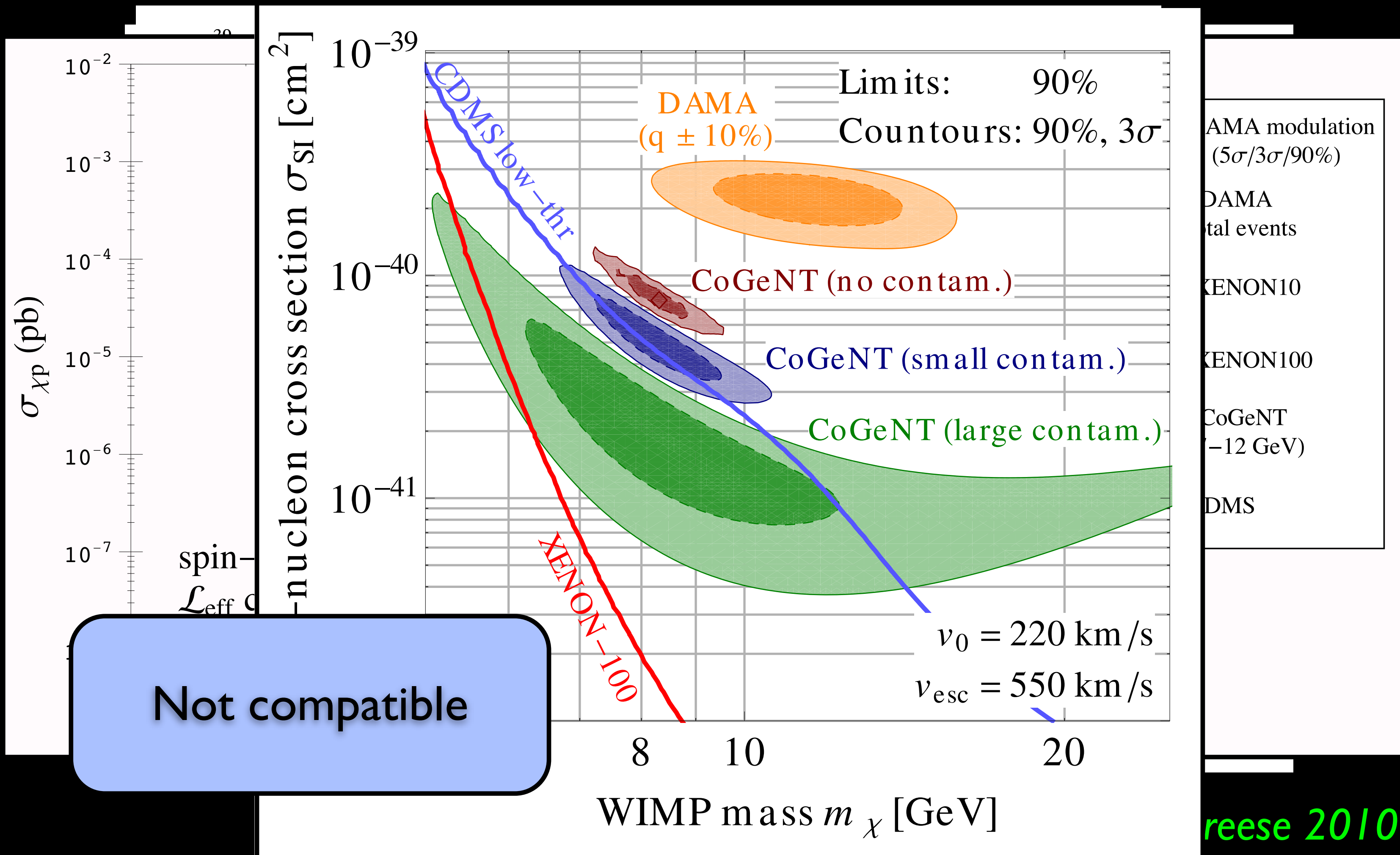
Aprile et al (XENON-100) 1104.2549

CoGeNT & DAMA vs. XENON, CDMS, et al



Savage, Gelmini, Gondolo, Freese 2010

CoGeNT & DAMA vs. XENON, CDMS, et al

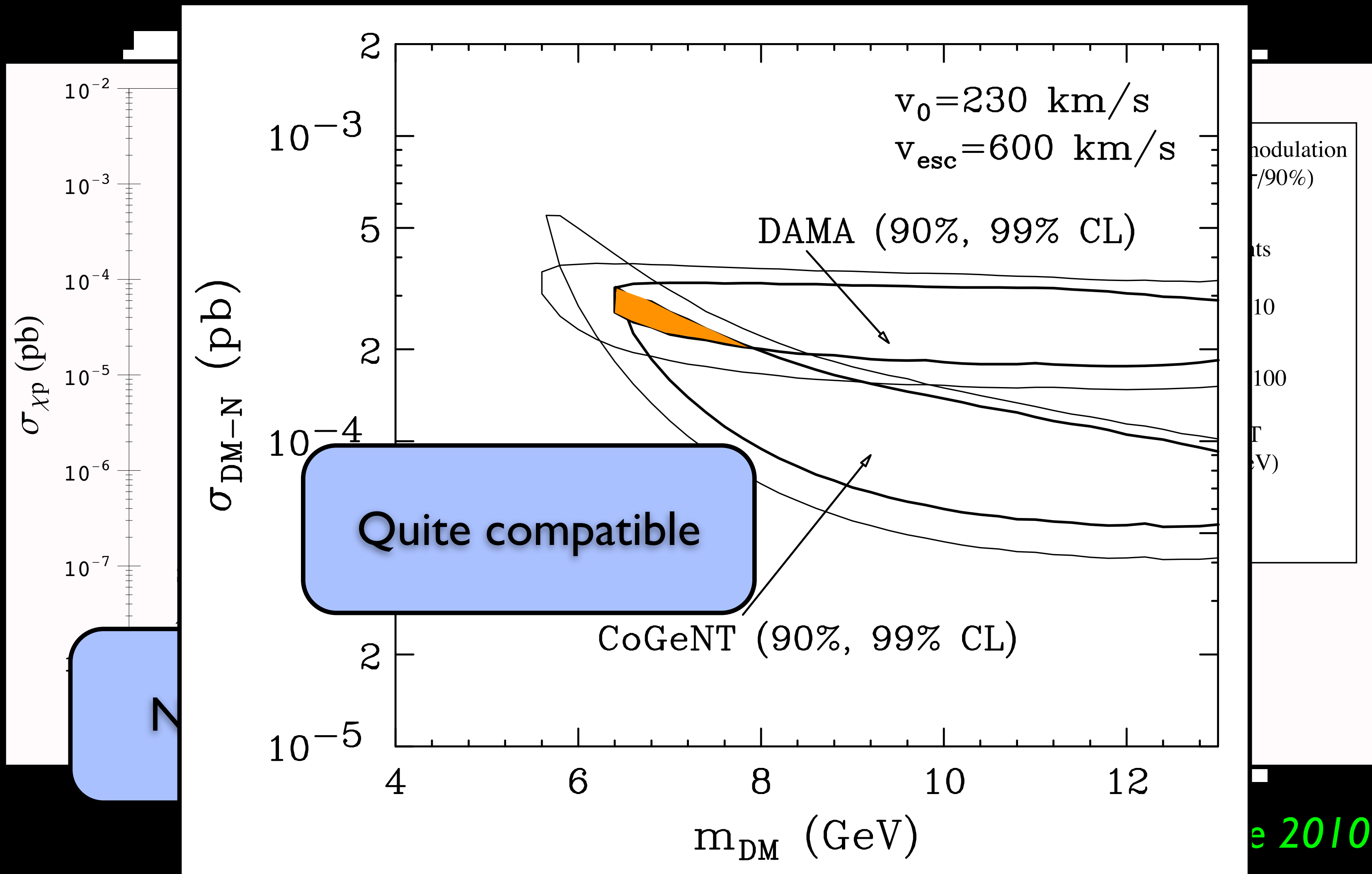


Not compatible

...reese 2010

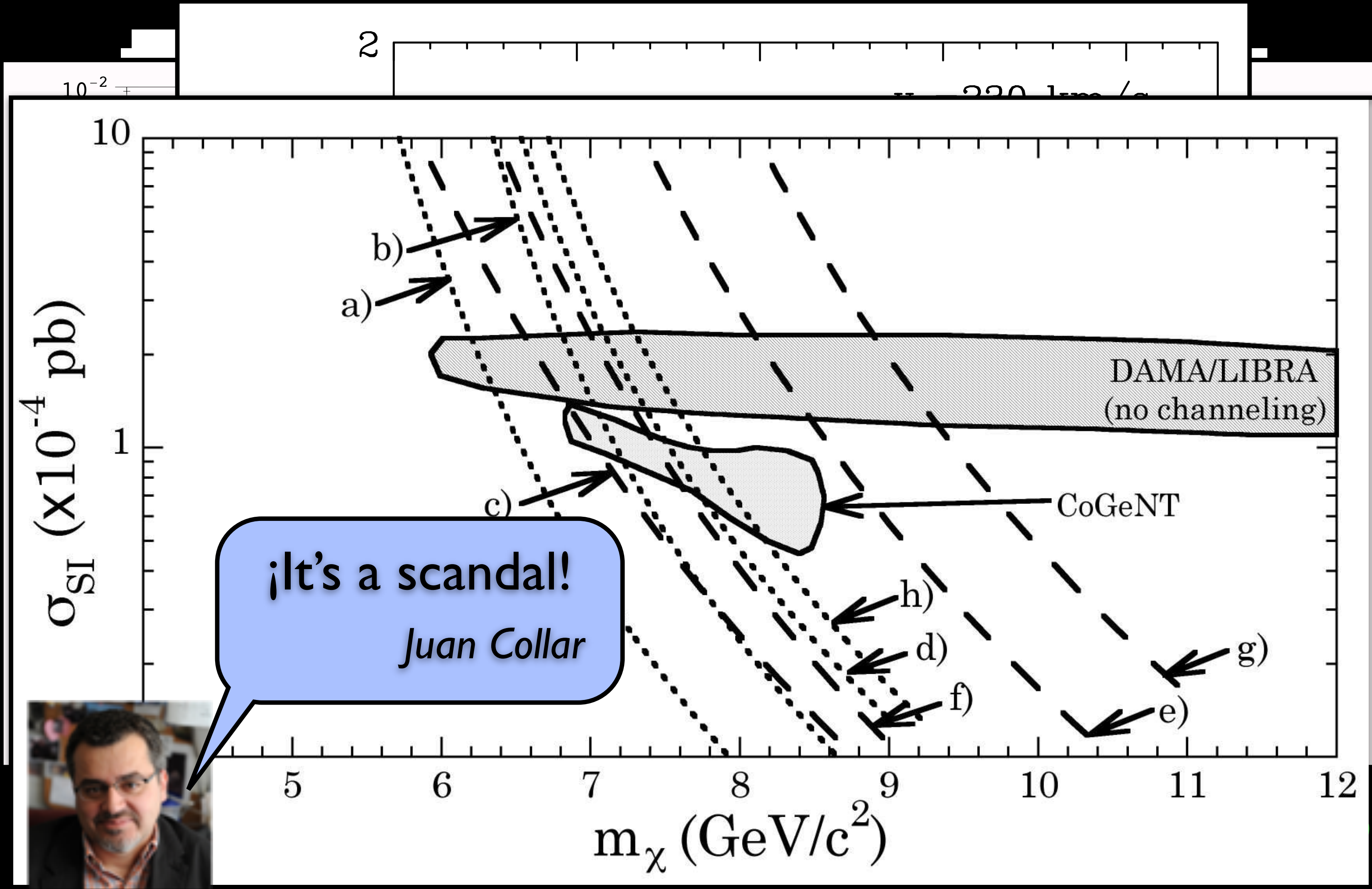
Kopp, Schwetz, Zupan 2011

CoGeNT & DAMA vs. XENON, CDMS, et al



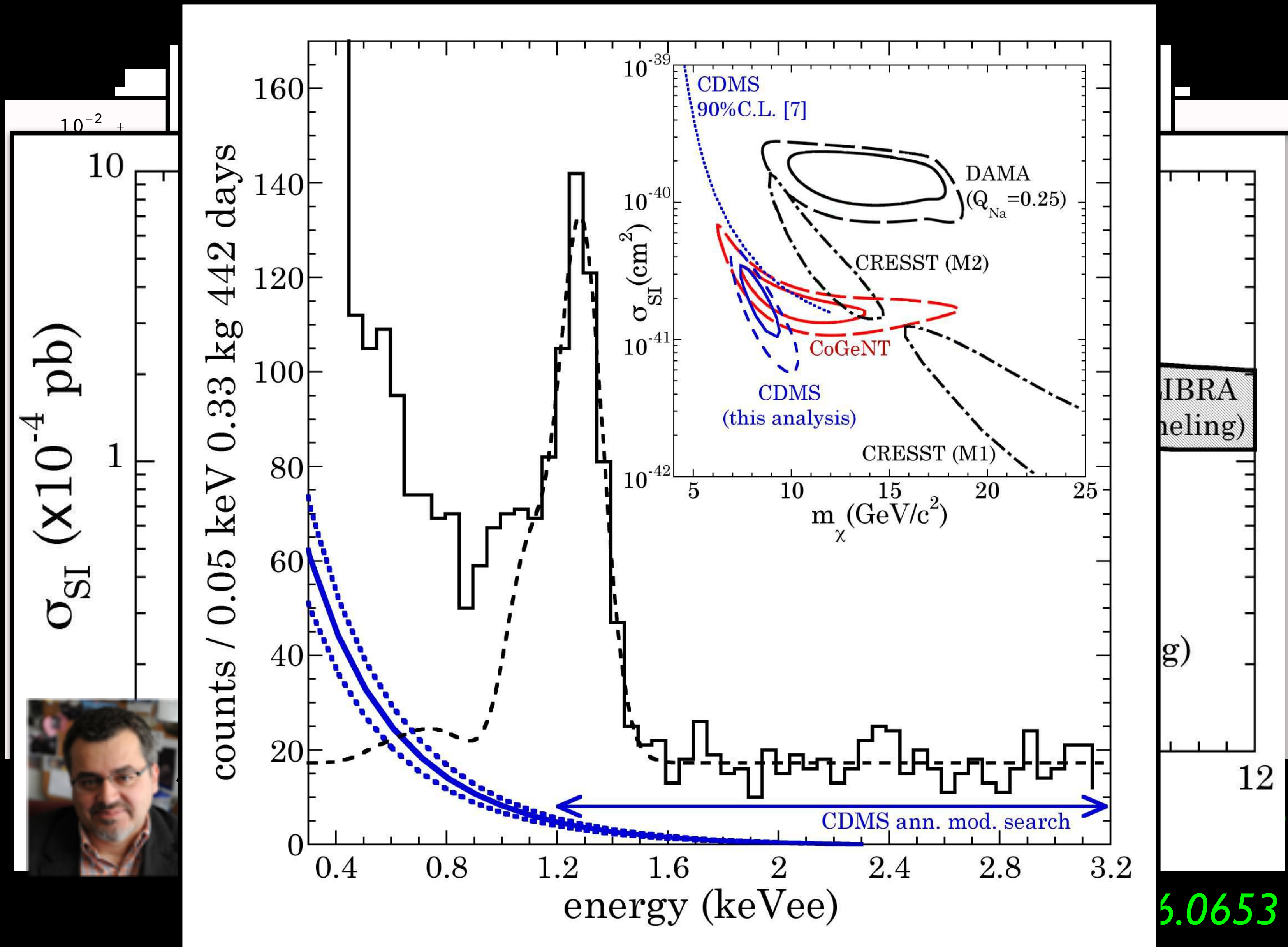
Hooper, Collar, Hall, McKinsey 2010

CoGeNT & DAMA vs. XENON, CDMS, et al



Collar 1106.0653

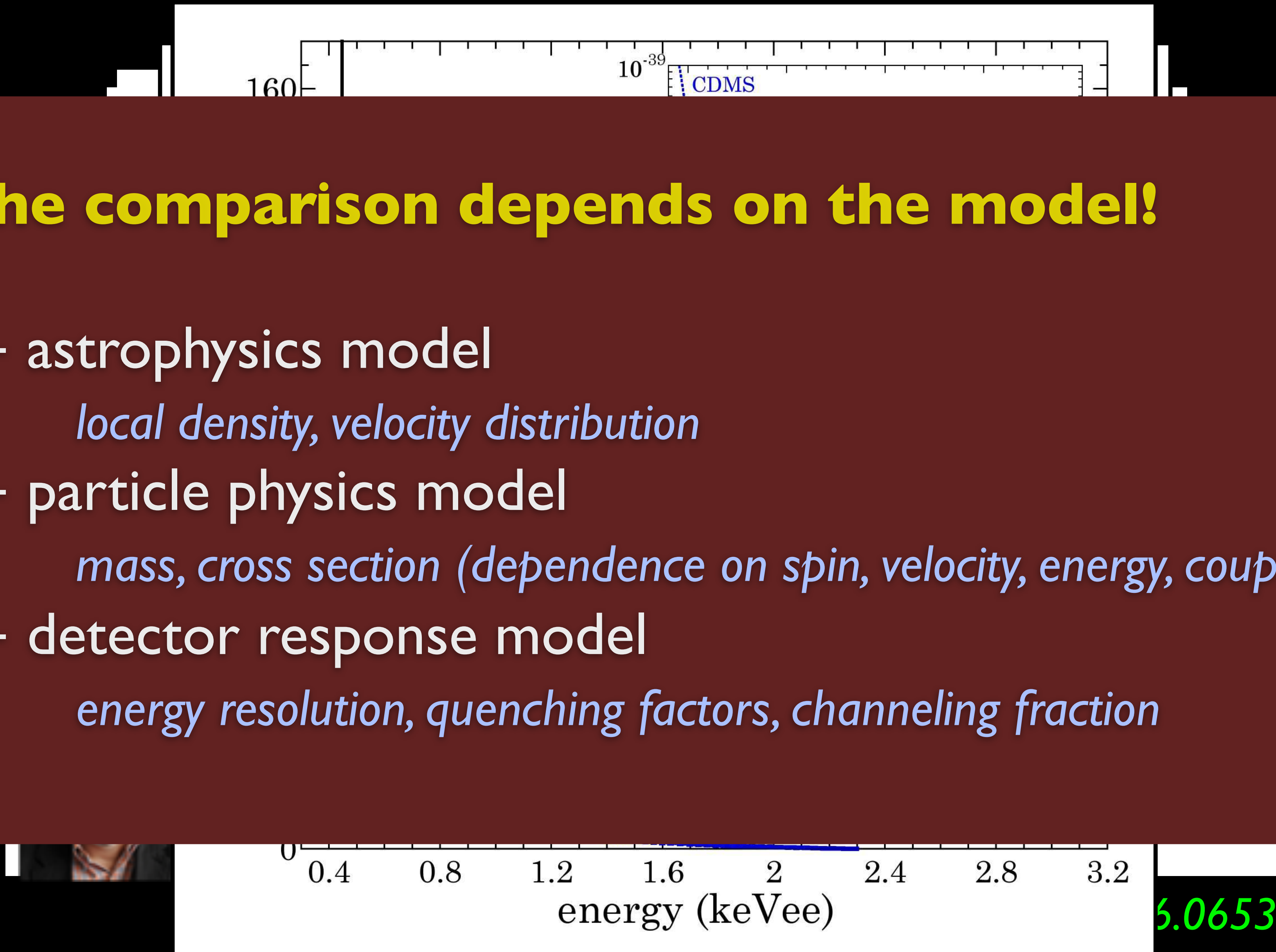
CoGeNT & DAMA vs. XENON, CDMS, et al



6.0653

Collar Fields 1204.3559

CoGeNT & DAMA vs. XENON, CDMS, et al



The comparison depends on the model!

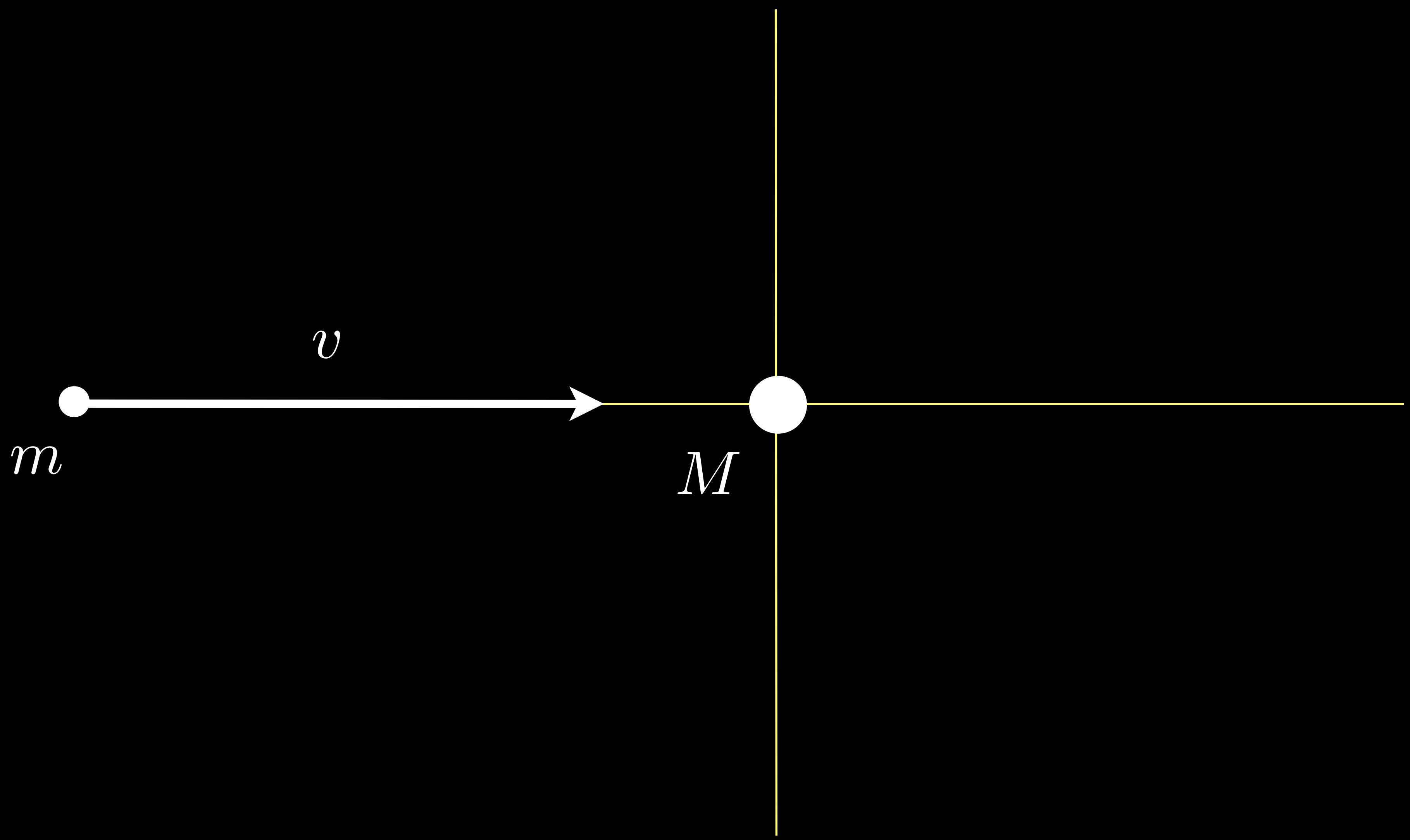
- astrophysics model
  local density, velocity distribution
- particle physics model
  mass, cross section (dependence on spin, velocity, energy, couplings)
- detector response model
  energy resolution, quenching factors, channeling fraction

…6.0653

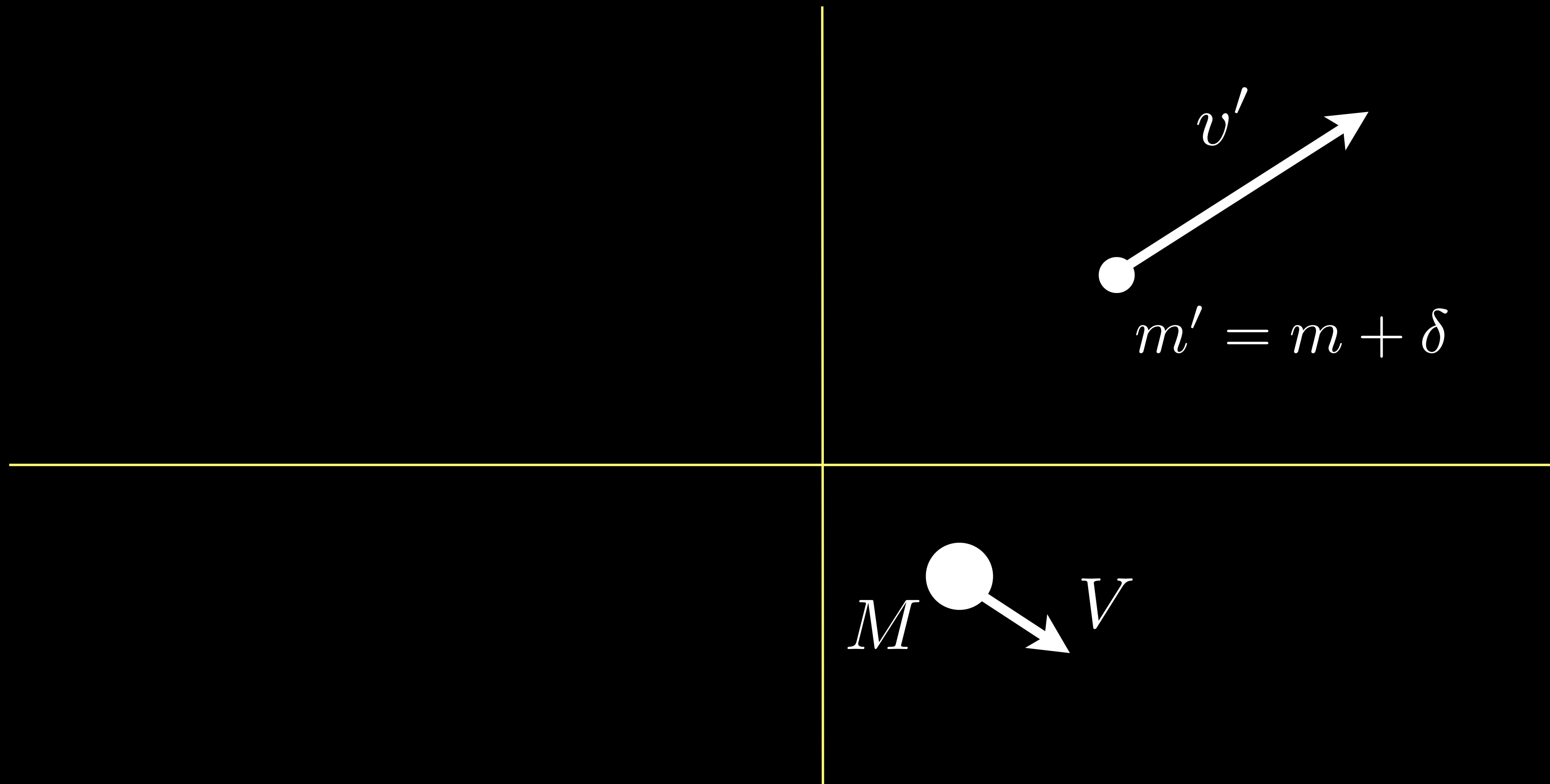
Collar Fields 1204.3559

Basic ideas

The expected number of events



The expected number of events



Recoil energy $E = \frac{1}{2} M V^2$

The expected number of events

Energy response function

Recoil spectrum

$$N = \sum_A M_A \int dt \int_{E_{\mathrm{ee},1}}^{E_{\mathrm{ee},2}} dE_{\mathrm{ee}}\, \varepsilon(E_{\mathrm{ee}})\, g(E_{\mathrm{ee}}, E)\, \frac{dR}{dE}$$

Exposure

Measured energy

Counting acceptance/efficiency

The recoil spectrum (scattering rate per unit target mass)

Differential scattering cross section

WIMP density

$$\frac{dR}{dE} = \frac{1}{m_A} \int \frac{d\sigma}{dE} \frac{\rho_\chi}{m_\chi} v\, f(\mathbf{v}, t)\, d^3v$$

WIMP velocity distribution

Recoil energy

$$= \frac{\rho_\chi}{2\mu^2 m_\chi} \int E_{\max} \frac{d\sigma}{dE} \frac{f(\mathbf{v}, t)}{v}\, d^3v$$

$$E_{\max} = \frac{2\mu^2 v^2}{m_A}$$

The expected number of events

$$\begin{pmatrix}\text{number of}\\ \text{events}\end{pmatrix} = (\text{exposure}) \times \begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} \otimes \begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix}$$

$$\begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} = \begin{pmatrix}\text{energy}\\ \text{response function}\end{pmatrix} \times \begin{pmatrix}\text{counting}\\ \text{acceptance}\end{pmatrix}$$

$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} \times (\text{astrophysics})$$

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$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} \times (\text{astrophysics})$$

Detector response model

From measured energy to recoil energy

$$\begin{pmatrix} \text{energy} \\ \text{response function} \end{pmatrix} = g(E_{\text{ee}}, E)$$

Recoil energy (keV)

Energy observed in detector, typically expressed in keV electron equivalent (keV_{ee})

Typically written as a single Gaussian with mean value

$$E_{\text{ee}} = \boxed{Q} E$$

Quenching factor

and standard deviation σ_E, but *may be different.*

Detector response model

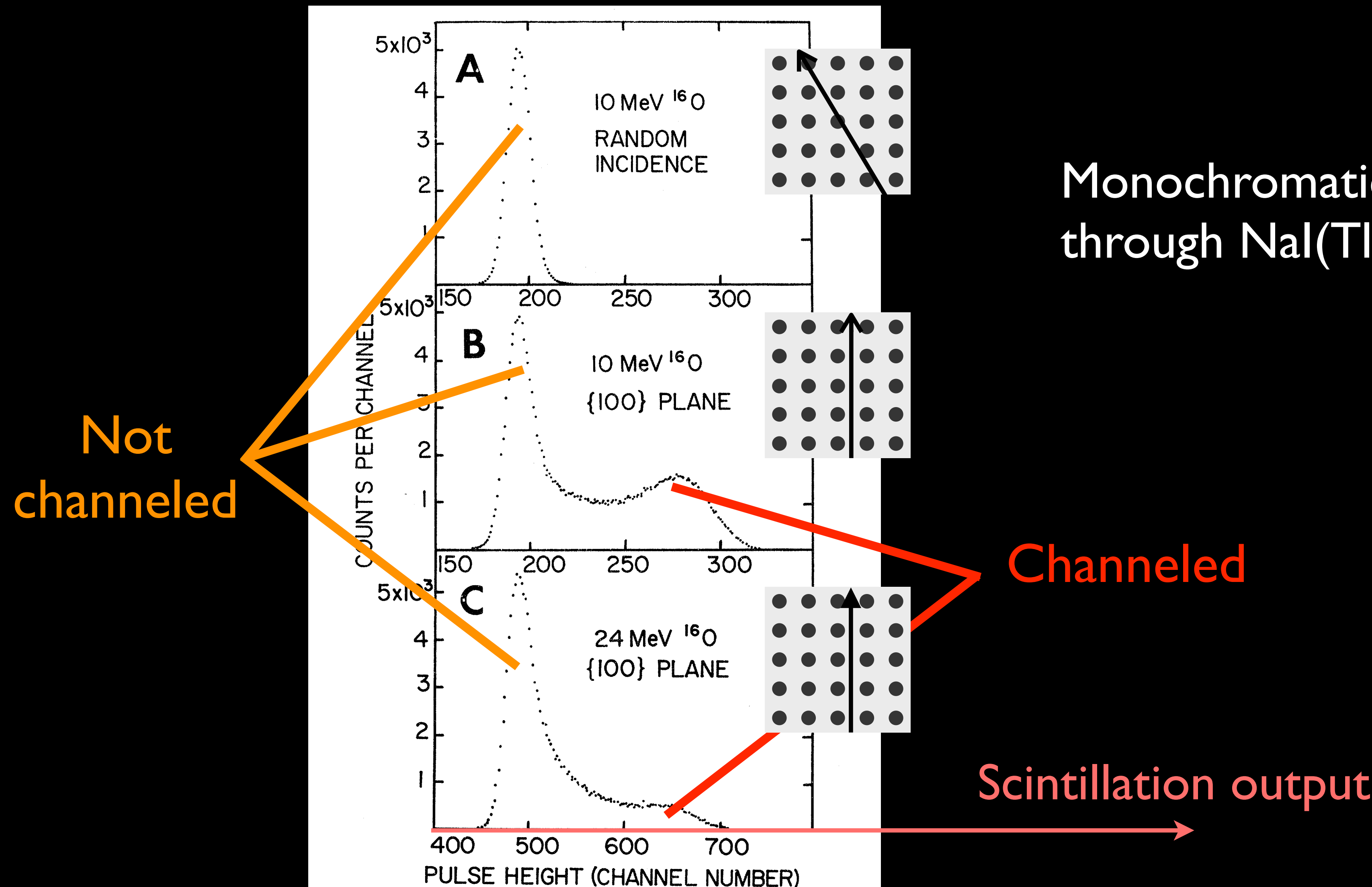


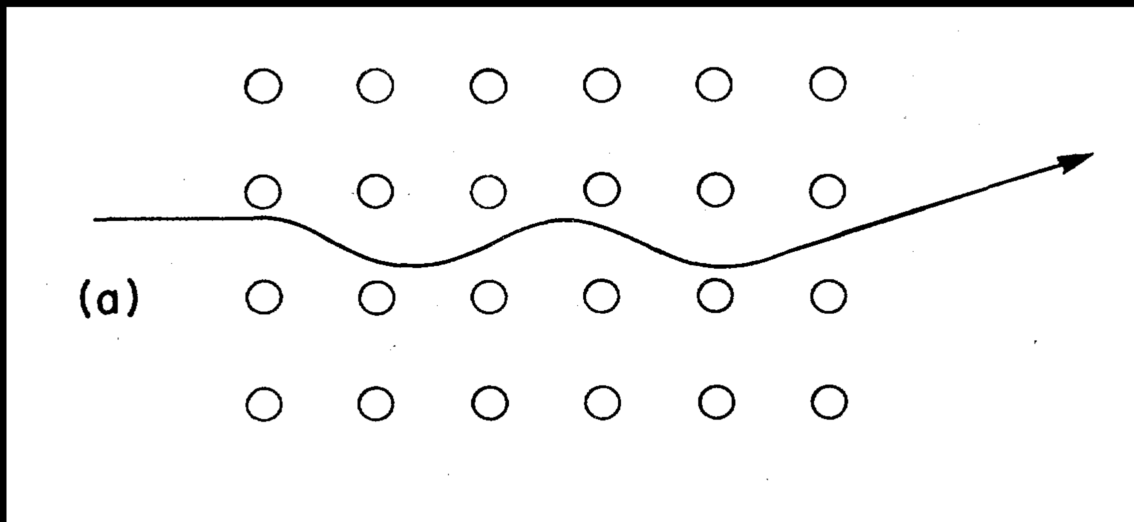
FIG. 2. (a) Pulse-height spectrum from 10-MeV ^{16}O on NaI(Tl) for incidence along a random direction. (b) Pulse-height spectrum from 10-MeV ^{16}O along a {100} plane. (c) Pulse-height spectrum from 24-MeV ^{16}O along a {100} plane. A light guide was used in all cases.

Monochromatic ^{16}O beam through NaI(Tl) scintillator

Altman et al 1973 (Phys.Rev. B7, 1743)

Detector response model

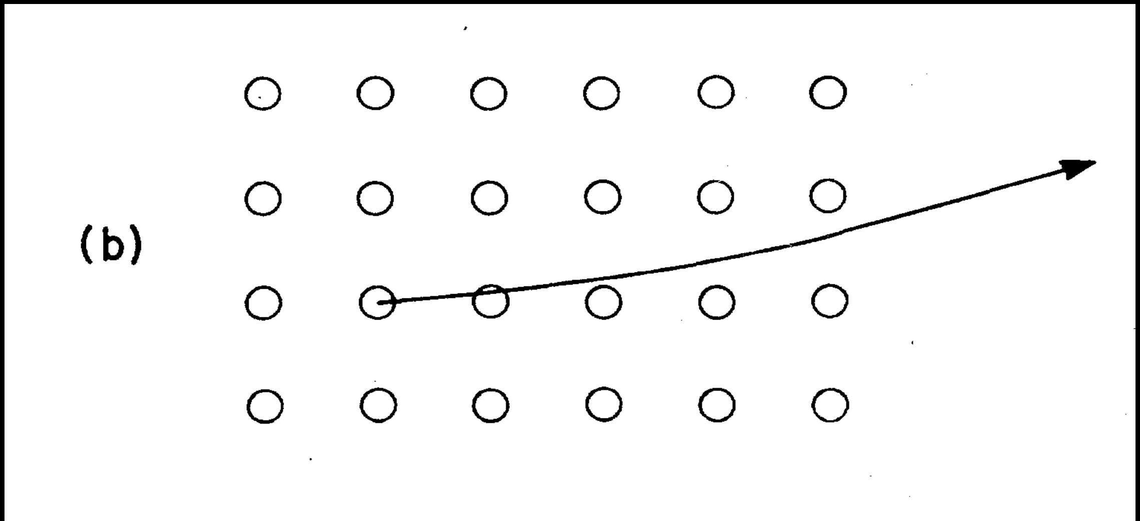
Channeling. If an ion incident onto the crystal moves in the direction of a symmetry axis or plane of the crystal, it has a series of small-angle scatterings which maintains it in the open channel. The ion penetrates much further into the crystal than in other directions.



From Gemmel 1974, Rev. Mod. Phys. 46, 129

Detector response model

Blocking. If an ion originating at a crystal lattice site moves in the direction of a symmetry axis or plane of the crystal, there is a reduction in the flux of the ion when it exit the crystal, creating a "blocking dip".

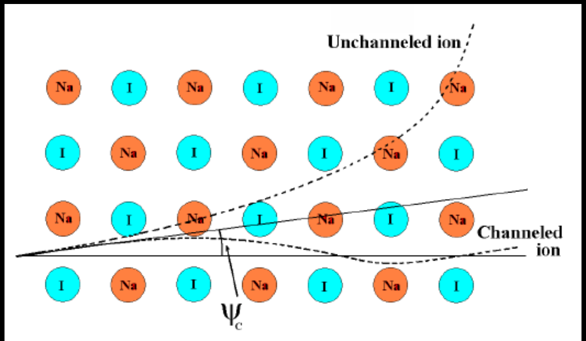


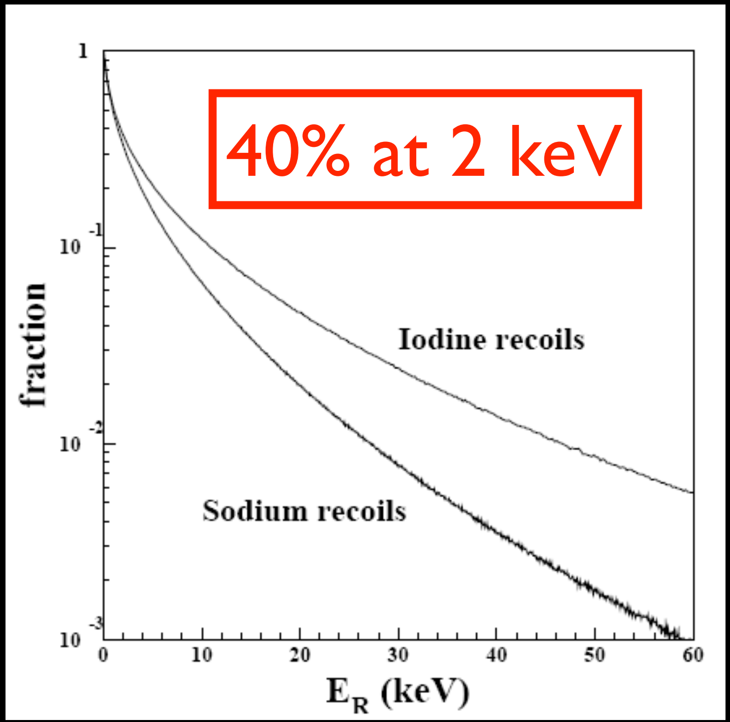
From Gemmel 1974, Rev. Mod. Phys. 46, 129

Detector response model

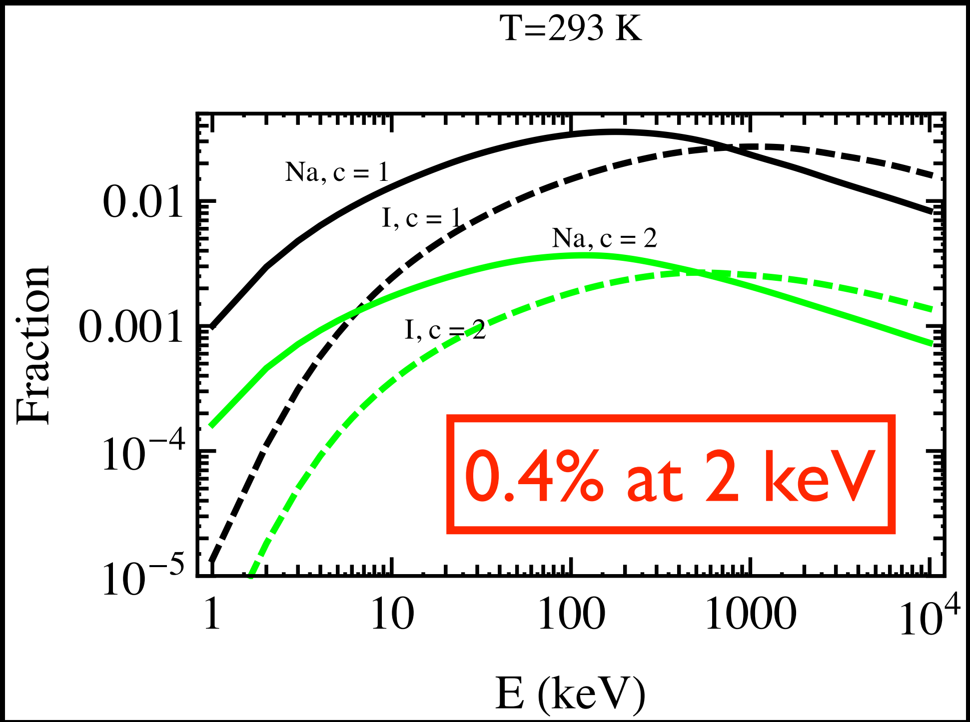
Channeling in DAMA's NaI(Tl) is much less than previously published

Bozorgnia, Gelmini, Gondolo 2010



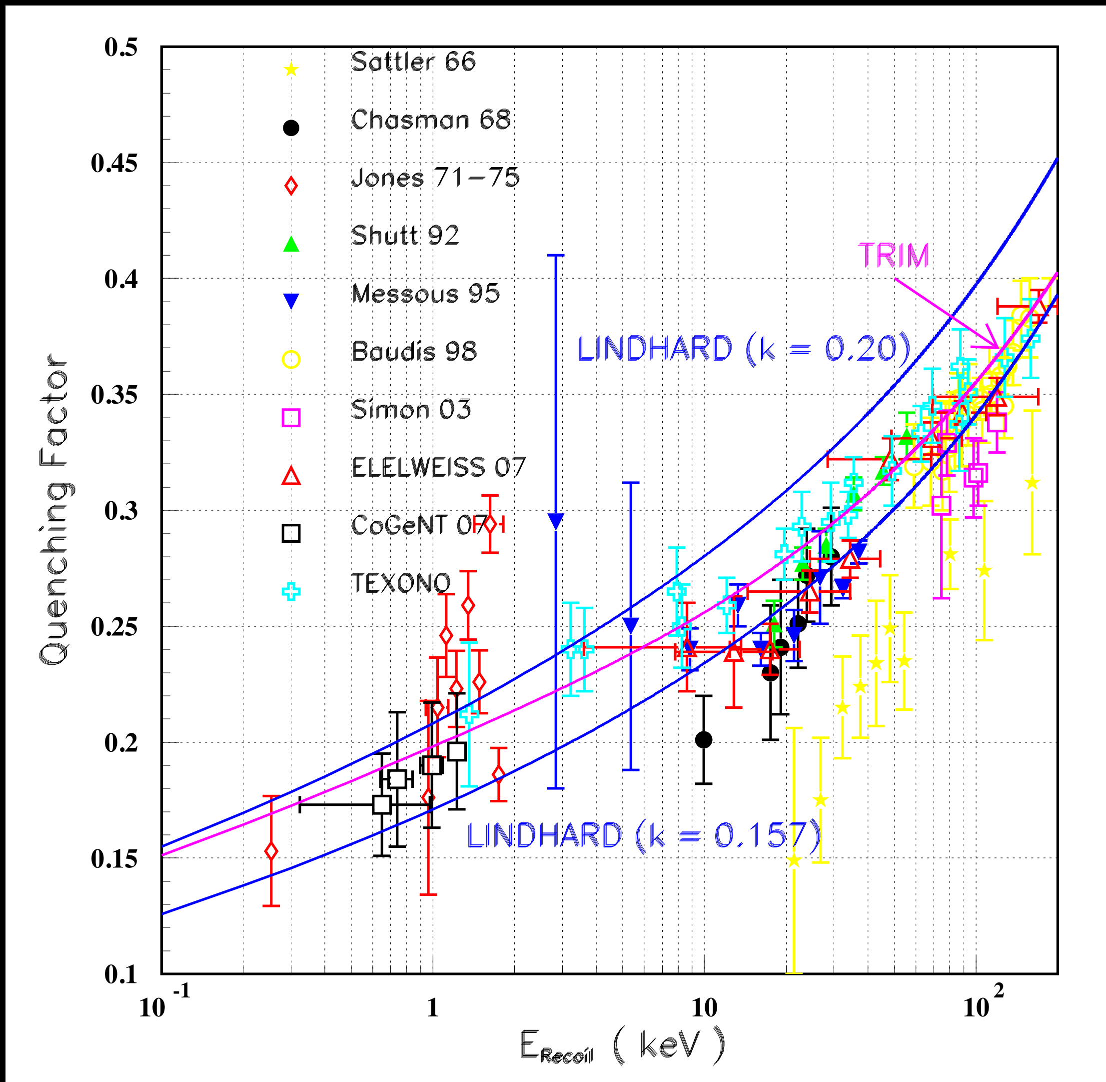


Bernabei et al. 2008



Bozorgnia, Gelmini, Gondolo 2010

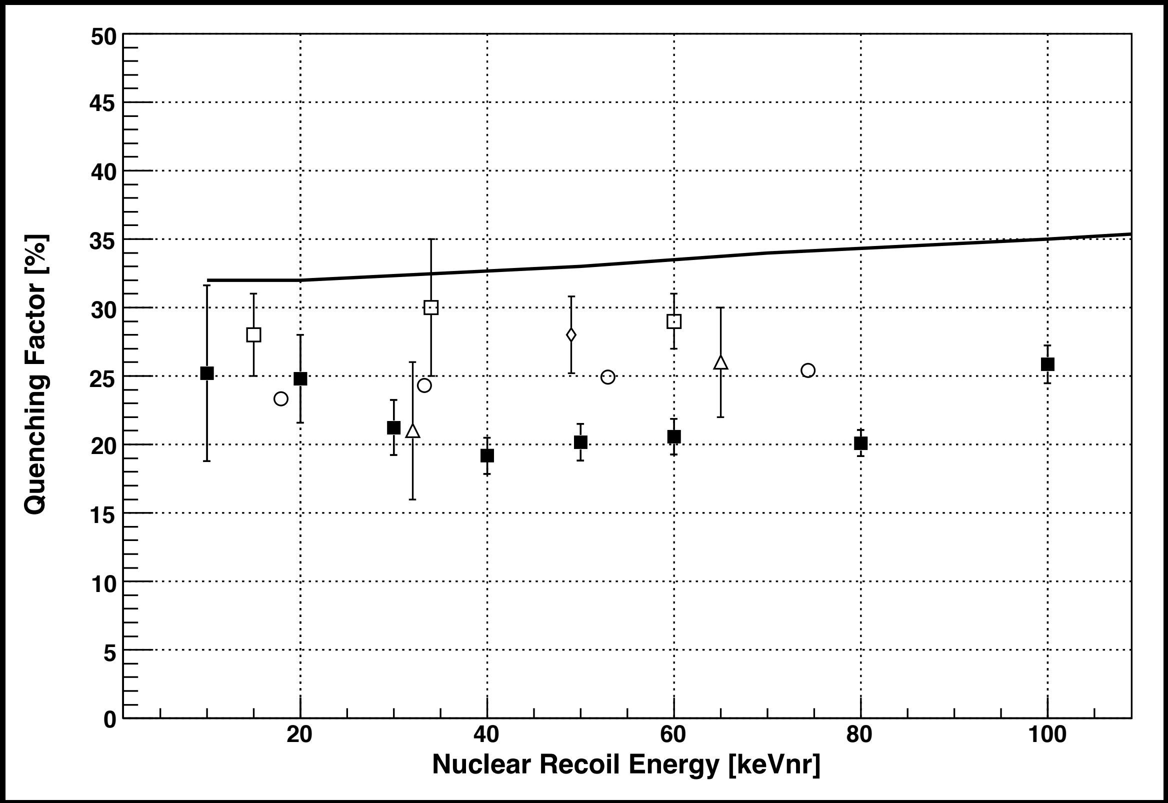
Detector response model



Compilation of measurements of the quenching factor *Q* in germanium

Lin et al (TEXONO) 2007

Detector response model



Chagani et al 0806.1916

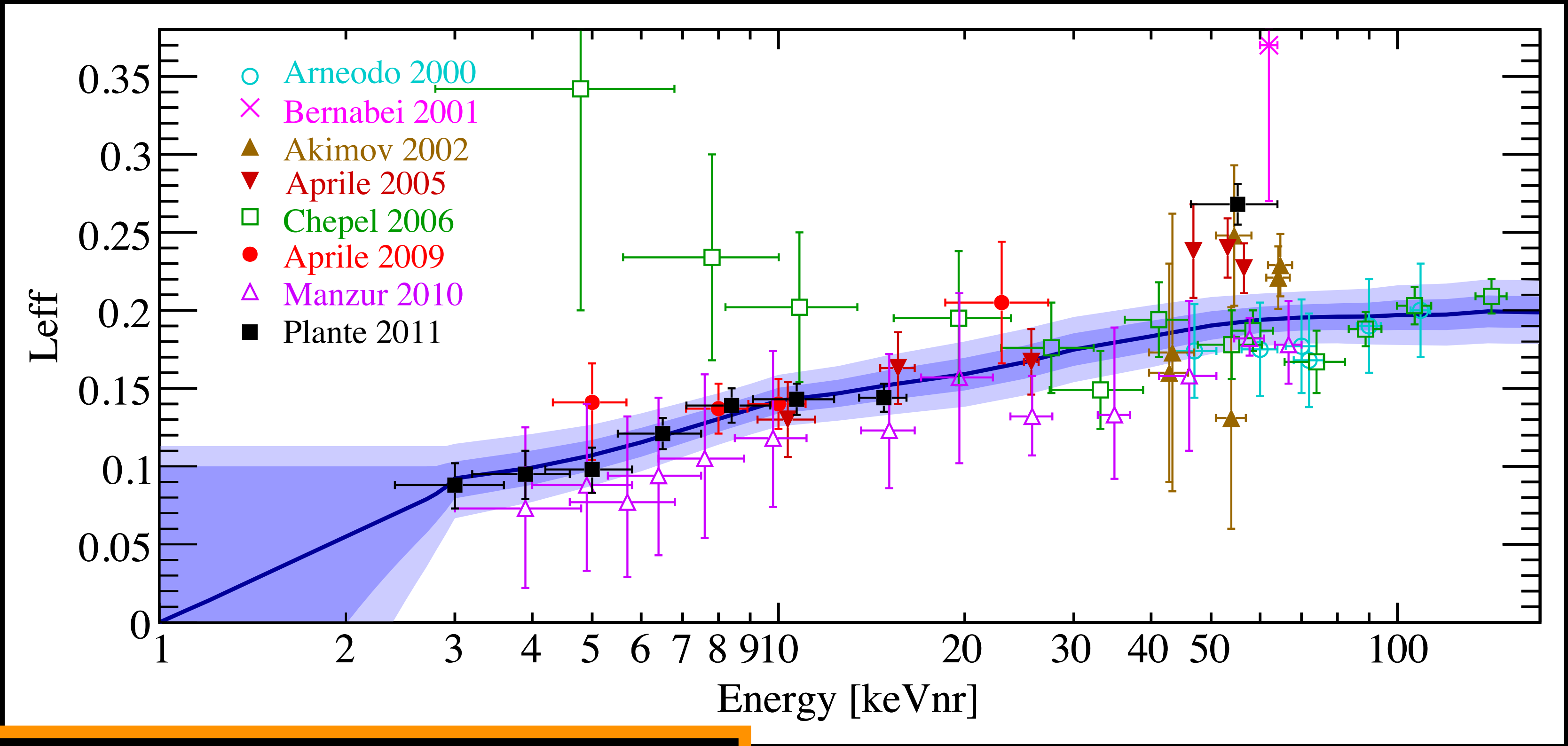
Compilation of measurements of the quenching factor *Q* in NaI(Tl)

This is where one can tweak to make DAMA and CoGeNT compatible.

Detector response model

Compilation of measurements of the light efficiency factor L_{eff} in liquid xenon

$$E_{\mathrm{ee}} = \mathrm{S1}/L_y(122\mathrm{keV_{ee}})$$
$$Q = L_{\mathrm{eff}}(S_{\mathrm{nr}}/S_{\mathrm{ee}})$$



This is where most of the CoGeNT/XENON debate is.

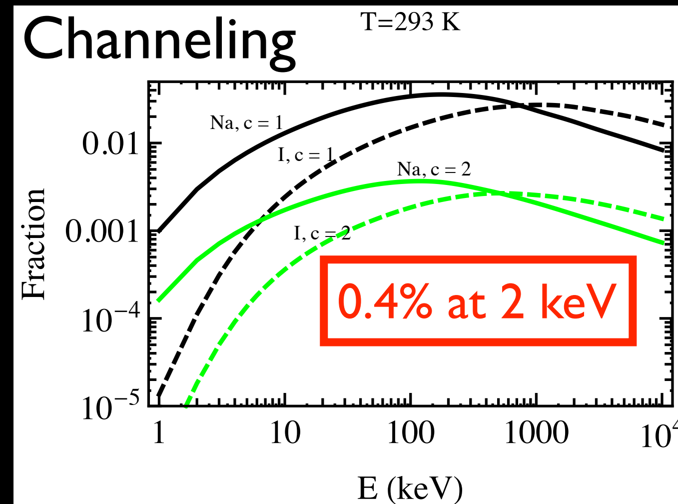
Aprile et al (XENON100), 1104.2549

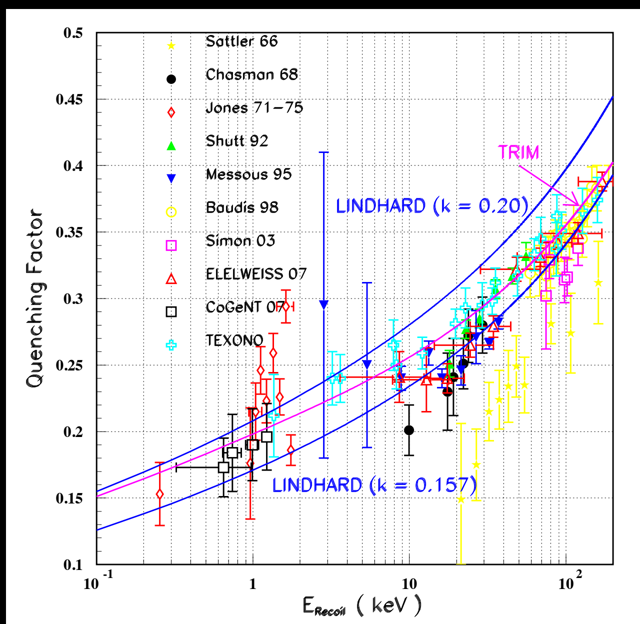
Detector response model

Quenching factor $E_{ee} = \boxed{Q} E$

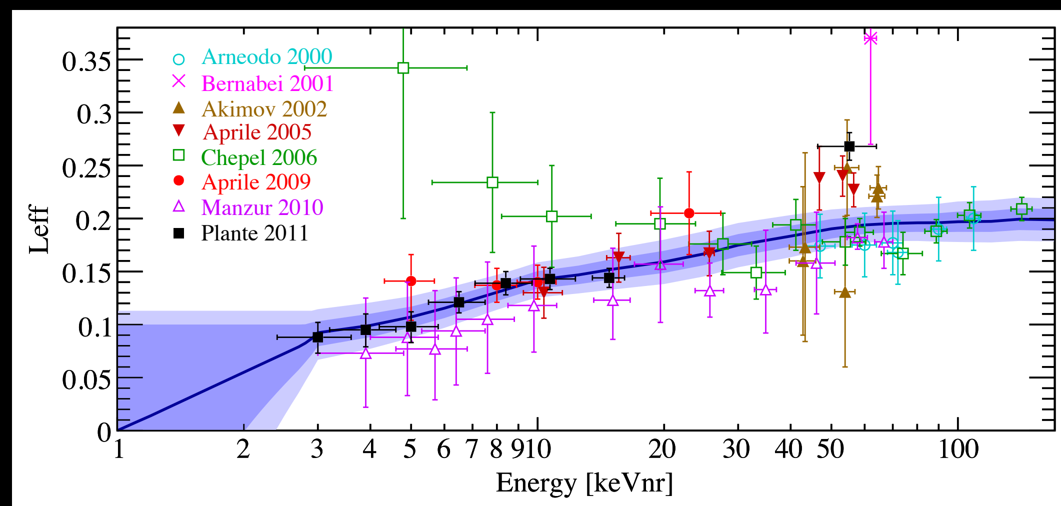
This is where one can tweak to make experiments compatible.

Bozorgnia et al 2010





Lin et al (TEXONO) 2007



Aprile et al (XENON100), 1104.2549

The expected number of events

$$\begin{pmatrix}\text{number of}\\ \text{events}\end{pmatrix} = (\text{exposure}) \times \begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} \otimes \begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix}$$

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$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} \times \boxed{(\text{astrophysics})}$$

Astrophysics model

How much dark matter comes to Earth?

Local halo density

Velocity distribution

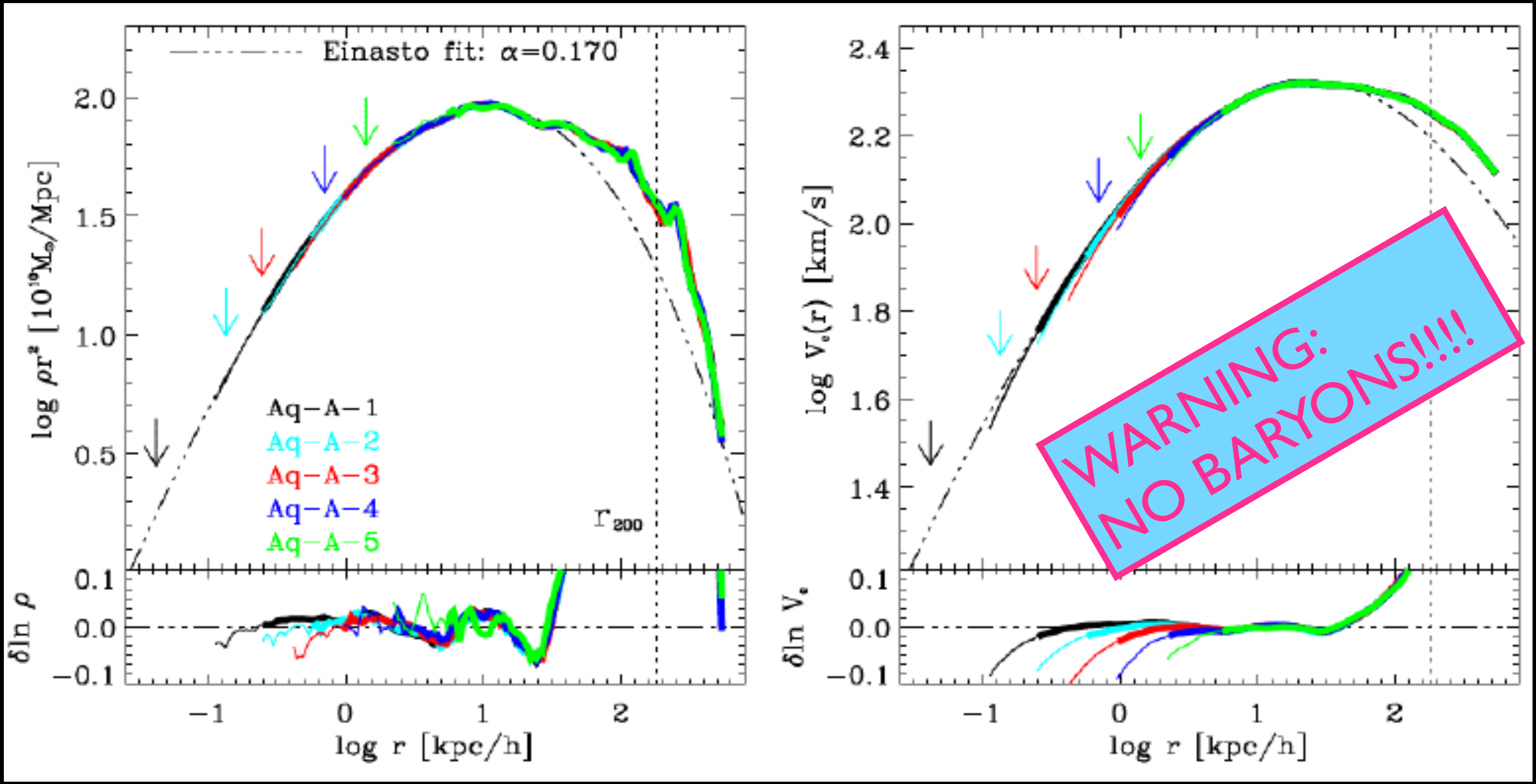
$$(\mathrm{astrophysics}) = \rho \int_{v > v_{\min}(E)} \frac{f(\vec{v}, t)}{v}\, \mathrm{d}^3 v$$

Minimum speed to impart energy $E,\ v_{\min}(E) = (ME/\mu + \delta)/\sqrt{2ME}$

Astrophysics model: local density

Galactic density profile from Aquarius simulations

$$\rho(r) \propto \exp\left(-Ar^{\alpha}\right).$$



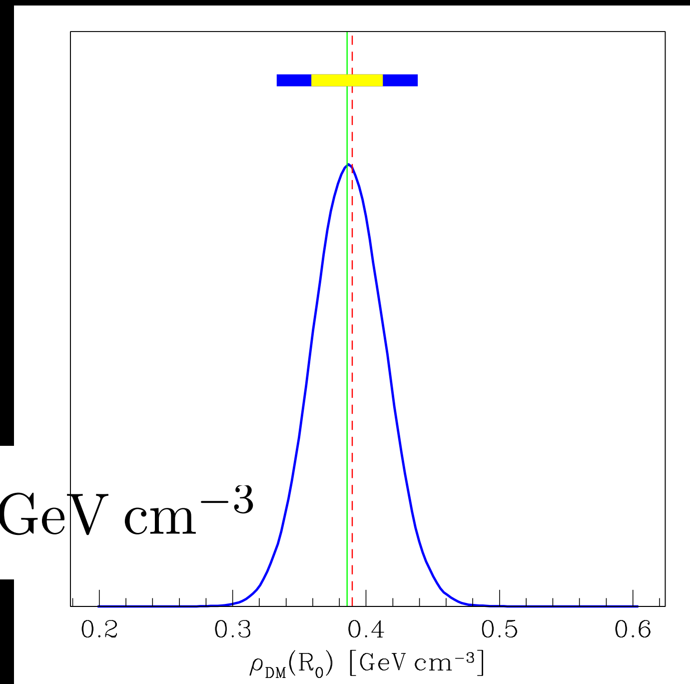
Astrophysics model: local density

$$\rho_\odot = \left(0.430 \pm 0.113_{(\alpha_\odot)} \pm 0.096_{(r_{\odot D})}\right)\frac{\mathrm{GeV}}{\mathrm{cm}^3}\,.$$

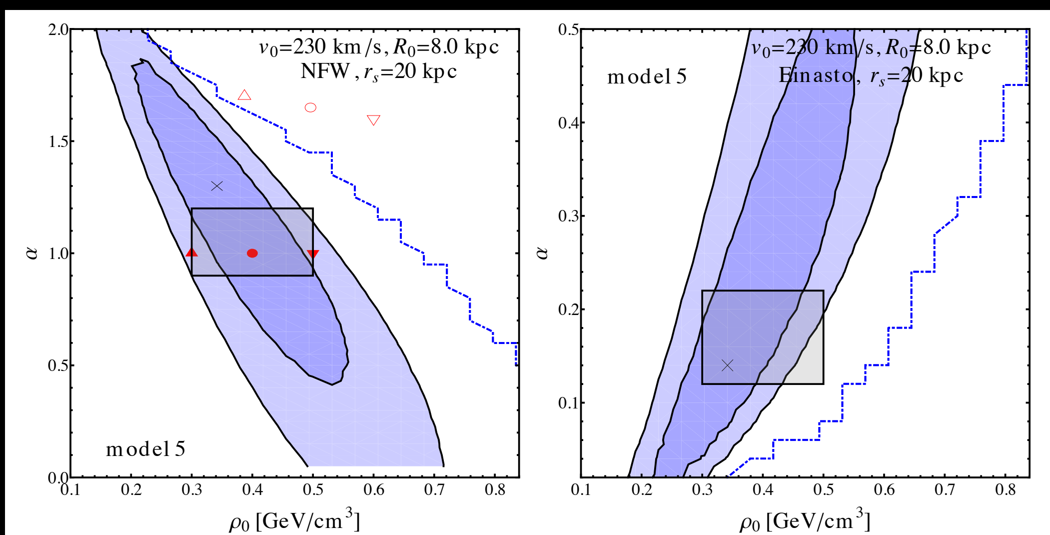
Salucci et al 2010

Local density from galactic modeling

$$\rho_{DM}(R_0) = 0.385 \pm 0.027\,\mathrm{GeV\ cm^{-3}}$$



Ullio, Catena 2009



$$\rho_0 = 0.20 - 0.55\ \mathrm{GeV/cm^3}$$

Iocco, Pato, Bertone, Jetzer 2010

Astrophysics model: velocity distribution

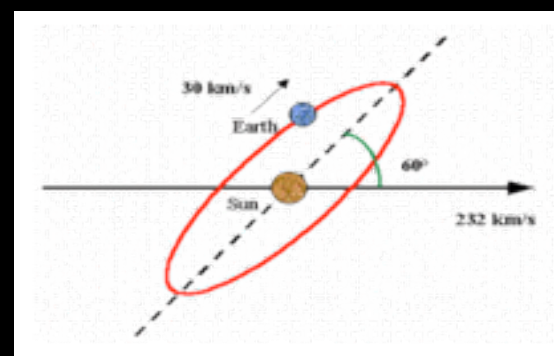
The velocity factor $\eta(E,t) = \int_{v>v_{\min}(E)} \frac{f(\vec{v},t)}{v}\, \mathrm{d}^3v$

- If $f(E,t)$ is non-truncated Maxwellian in detector frame, $\eta(E,t)$ is exponential in E

- $\eta(E,t)$ depends on time (unless WIMPs move with detector)

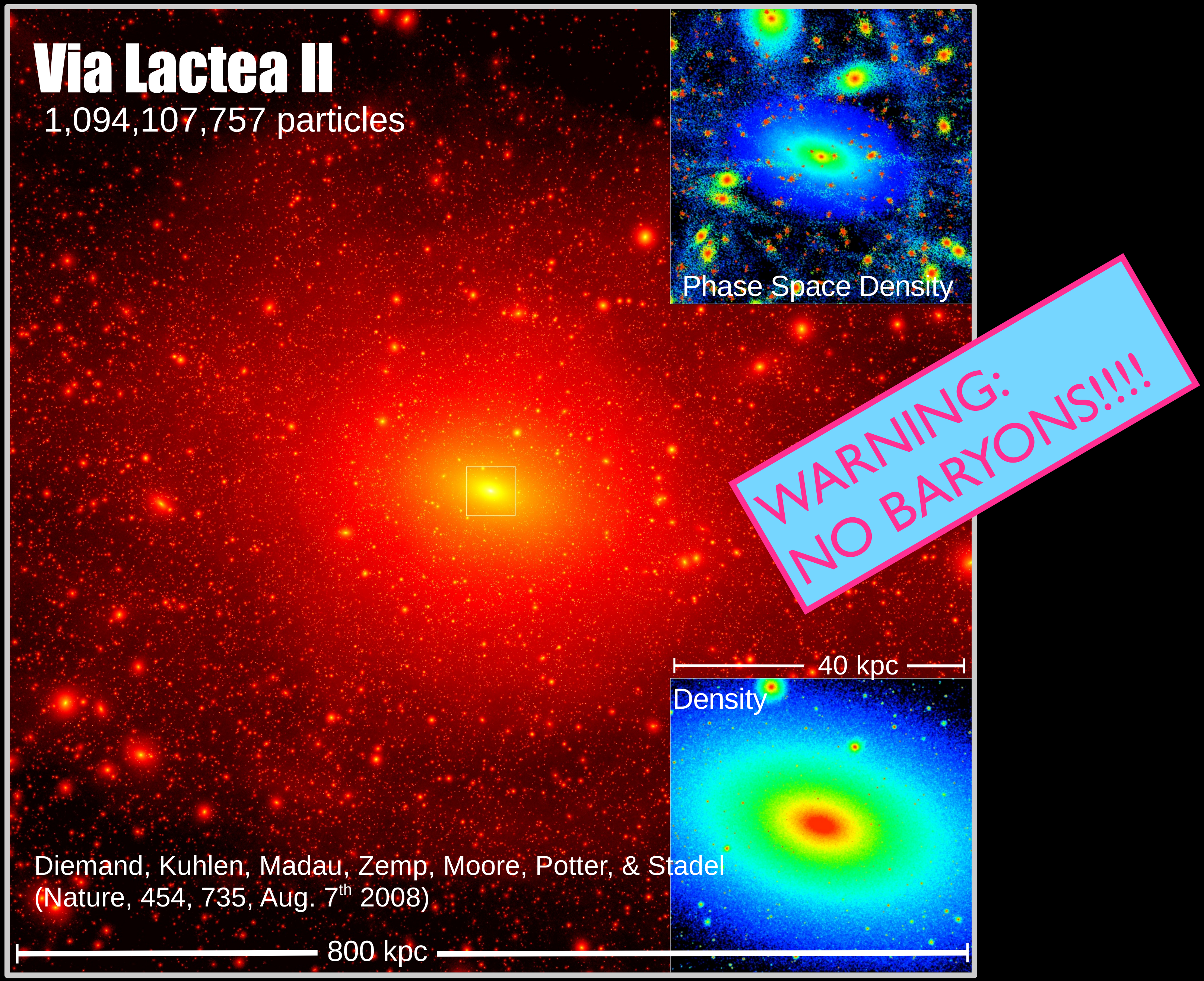
Example: annual modulation

$$\eta(E,t) = \eta_0(E) + \eta_{\mathrm{m}}(E) \cos\omega(t - t_0)$$



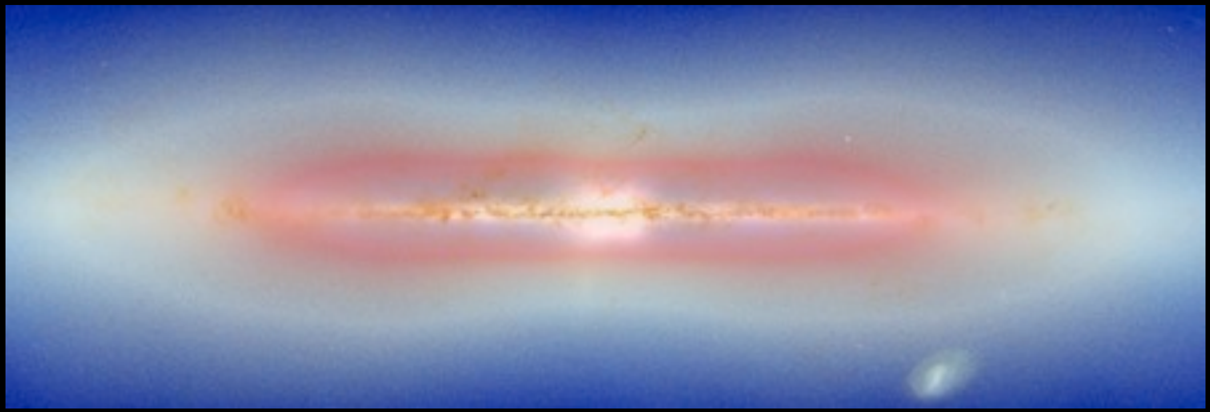
Drukier, Freese, Spergel 1986

Astrophysics model: velocity distribution



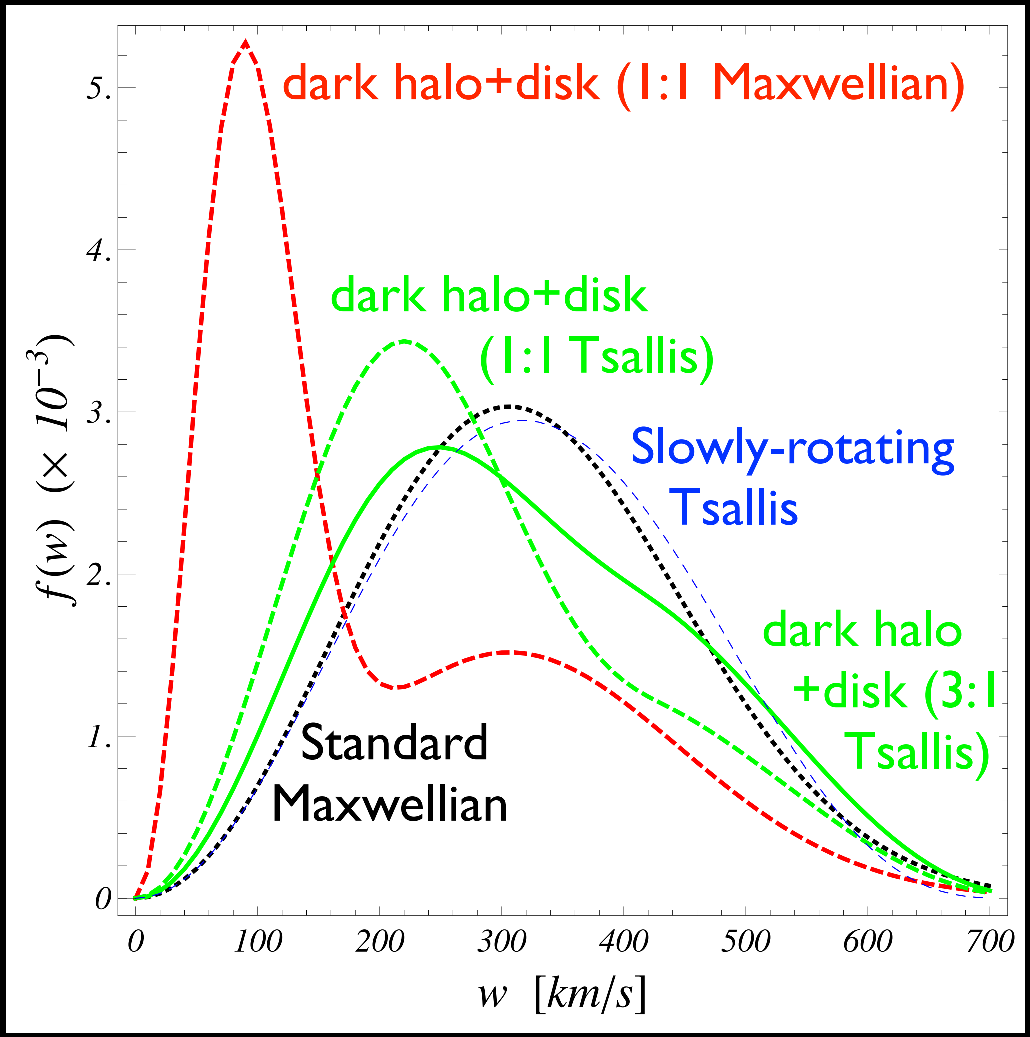
Astrophysics model: velocity distribution

Inclusion of baryonic disk may lead to a dark disk



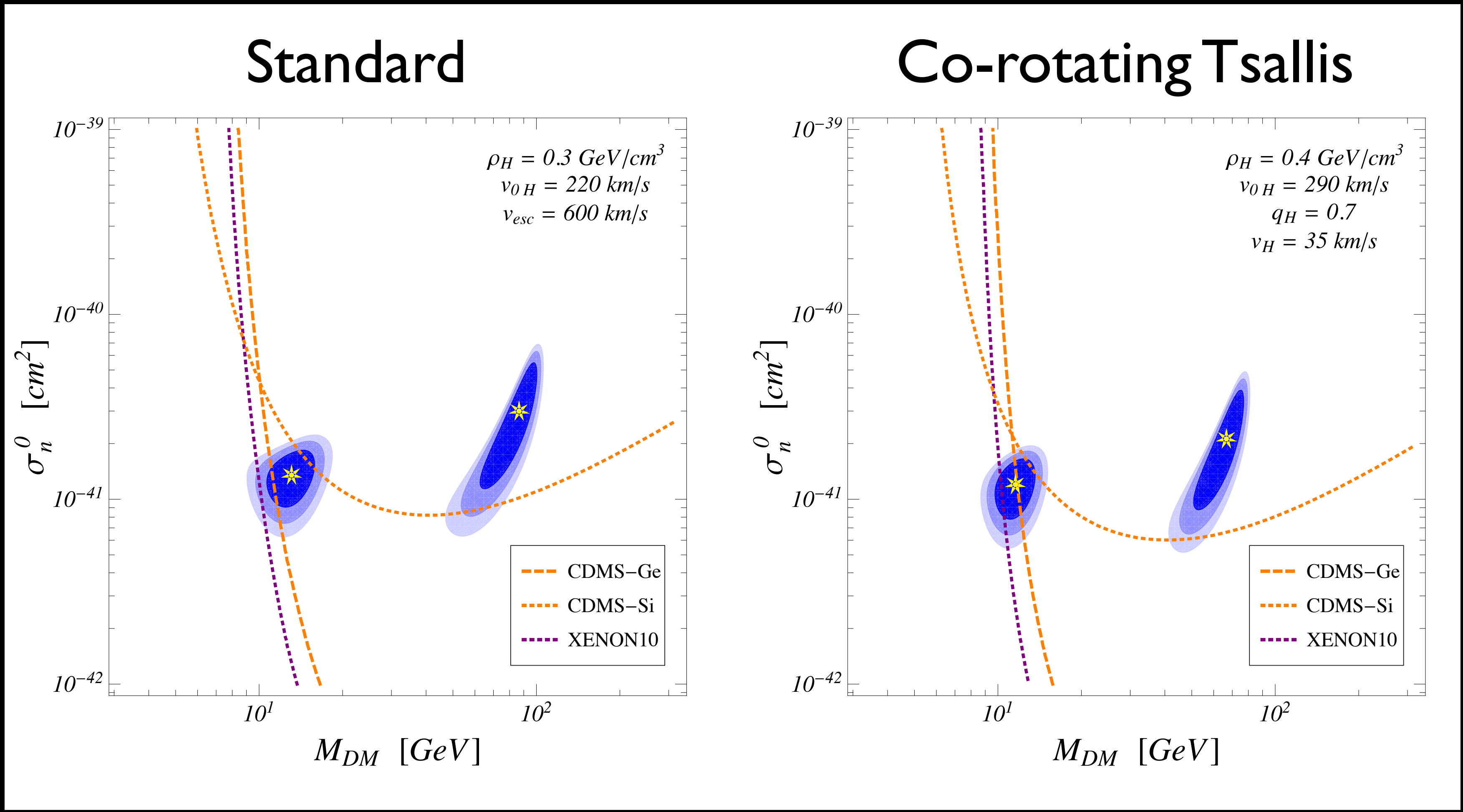
Read, Lake, Agertz, De Battista 2008

Astrophysics model: velocity distribution



Ling 2009

Astrophysics model: velocity distribution

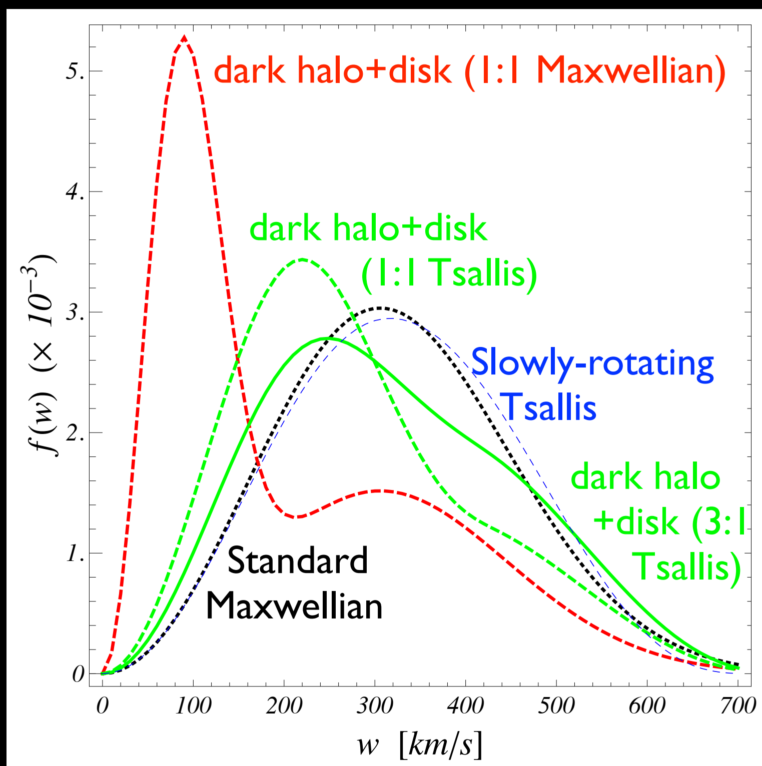


Ling 2009

Astrophysics model

The local density may be "known" within a factor of 2, but the velocity distribution is still an open question

Analytic models

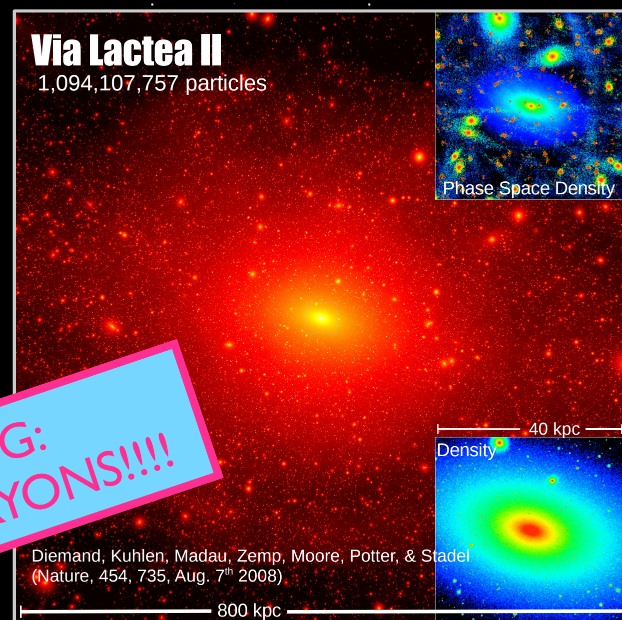


Ling 2009

N-body simulations

Read et al 2008

Kuhlen et al



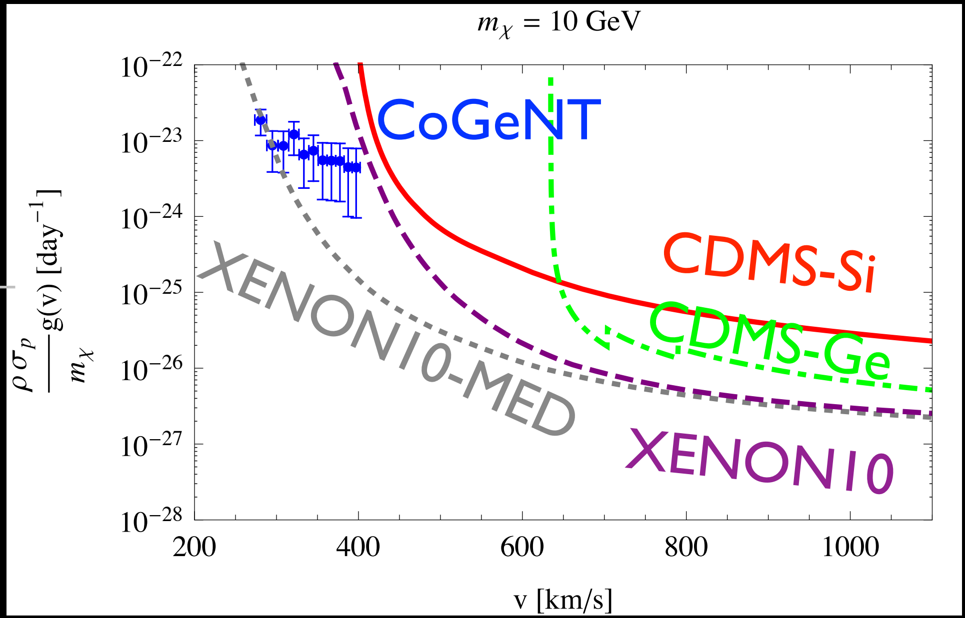
WARNING:
NO BARYONS!!!!

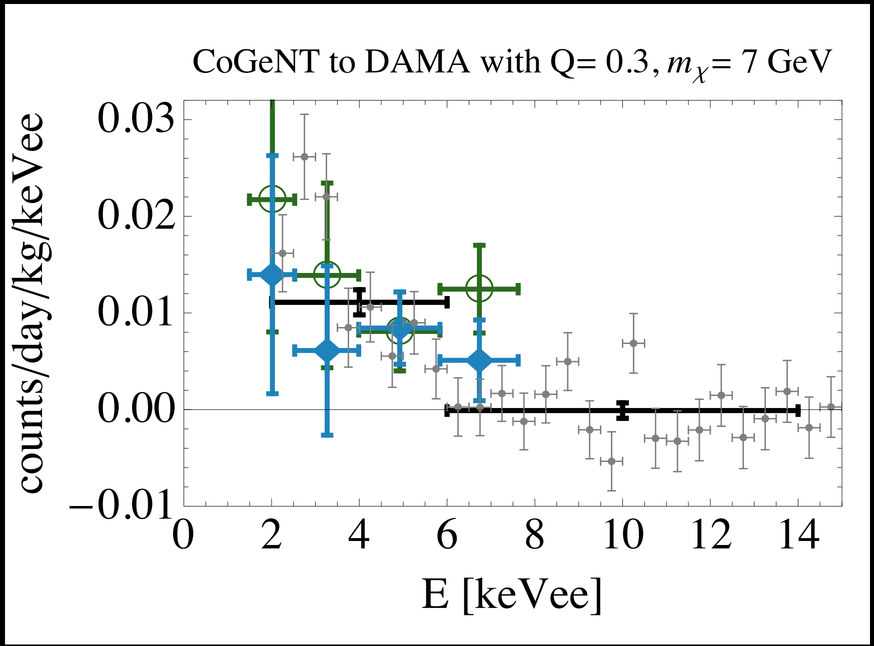
Astrophysics-independent approach

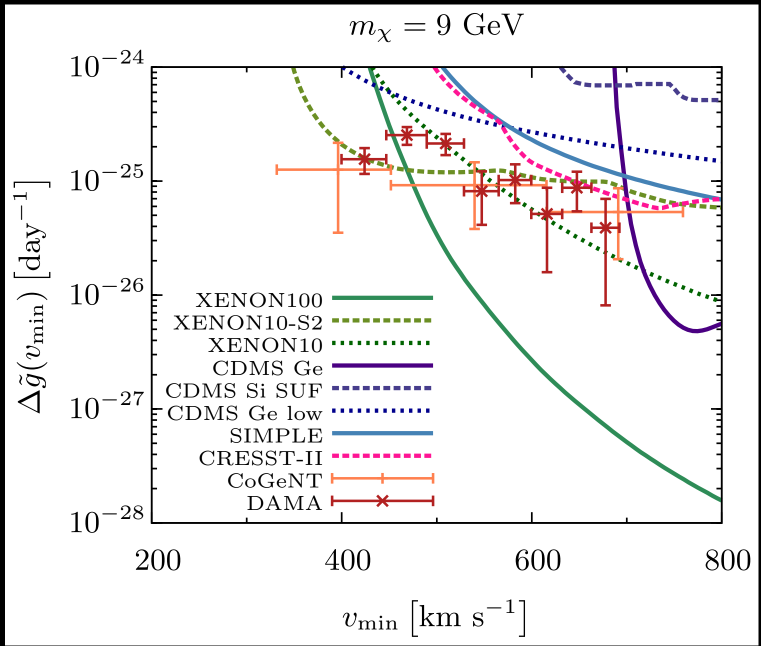
Fox, Liu, Weiner 2011

Astrophysics factor

$$\frac{\rho_\chi \sigma_{\chi p} c^2}{m_\chi} \int_v^\infty \frac{f(v')}{v'} dv'$$



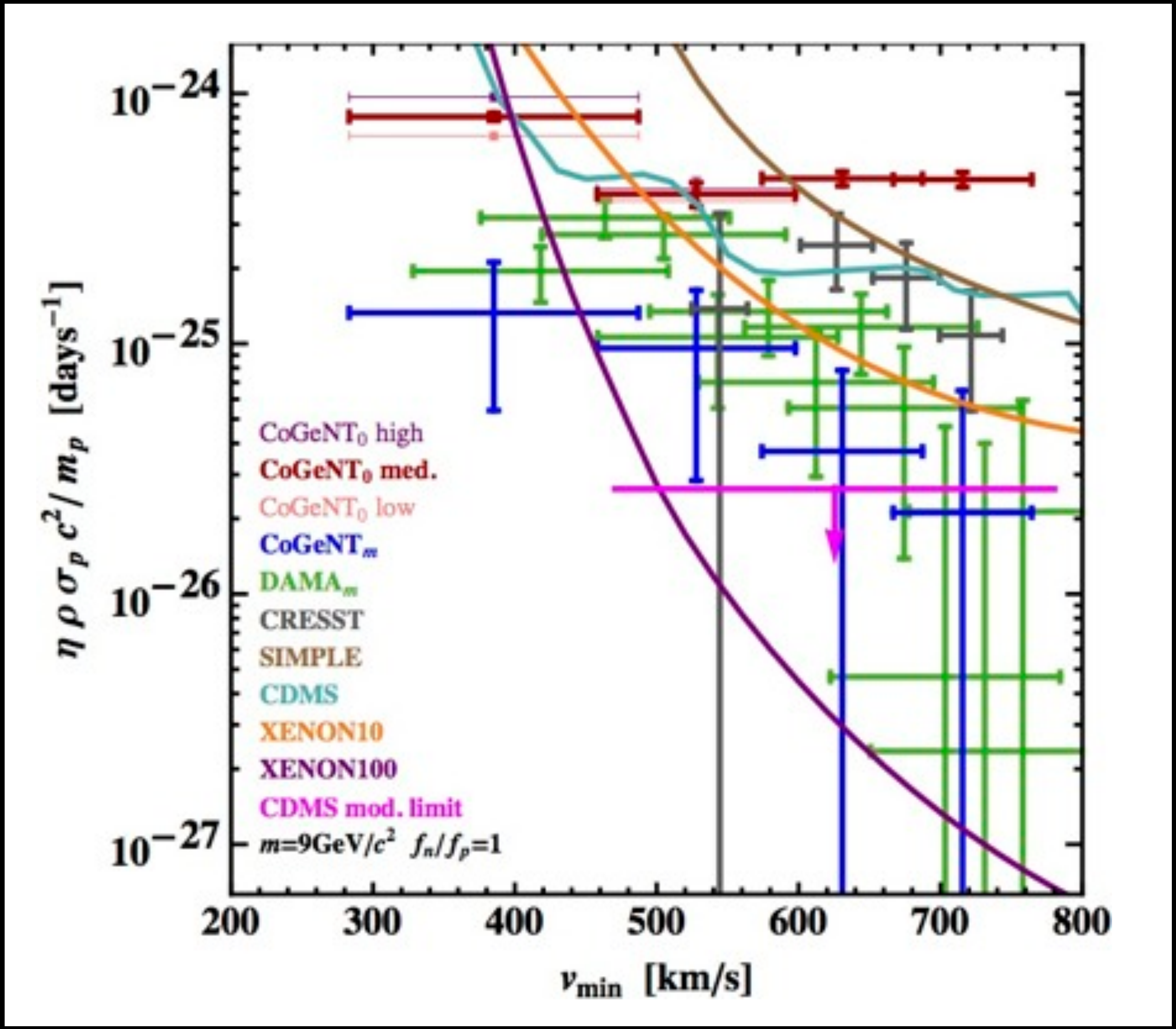




Fox, Kopp, Lisanti, Weiner 2011

Frandsen et al 2011

Astrophysics-independent approach



Still depends on particle model

Analysis extends Fox, Liu, Weiner method to include energy response function

Gondolo Gelmini 1202.6359

The expected number of events

$$\begin{pmatrix}\text{number of}\\ \text{events}\end{pmatrix} = (\text{exposure}) \times \begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} \otimes \begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix}$$

$$\begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} = \begin{pmatrix}\text{energy}\\ \text{response function}\end{pmatrix} \times \begin{pmatrix}\text{counting}\\ \text{acceptance}\end{pmatrix}$$

$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \boxed{\begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix}} \times (\text{astrophysics})$$

Particle physics model

What force couples dark matter to nuclei?

Spin-independent and spin-dependent cross sections

$$\begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} = \frac{\sigma_{SI}(E) + \sigma_{SD}(E)}{2m\mu^2}$$

Reduced mass $\mu = mM/(m+M)$

$$\sigma(E) = E_{\max}\frac{d\sigma}{dE} = \frac{2\mu^2 v^2}{m}\frac{d\sigma}{dE}$$

Particle physics model

Exchange scalar, vector, pseudovector, ... ?

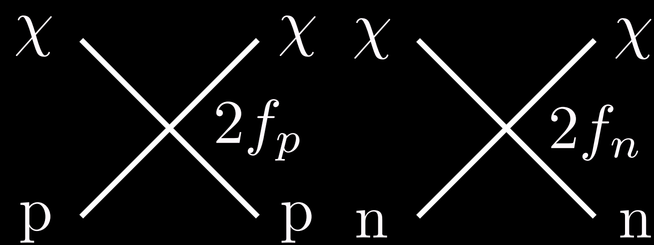
- Supersymmetry
- Extra U(1) bosons
- Extended Higgs sector
- Effective operator approach

Particle physics model

Scalar and vector currents give spin-independent terms

$$\sigma_{SI}(E) = \frac{4\mu^2}{\pi} \left| Z f_p + (A - Z) f_n \right|^2 \left| F(E) \right|^2$$

Effective four-particle vertices



Nuclear density form factor

Example: neutralino

$$2 f_p \simeq 2 f_n \simeq \sum_q \langle \bar{q} q \rangle \left[- \sum_h \frac{g_{h\chi\chi} g_{hqq}}{m_h^2} + \sum_{\tilde{q}} \frac{g_{L\tilde{q}\chi q} g_{R\tilde{q}\chi q}}{m_{\tilde{q}}^2} \right]$$

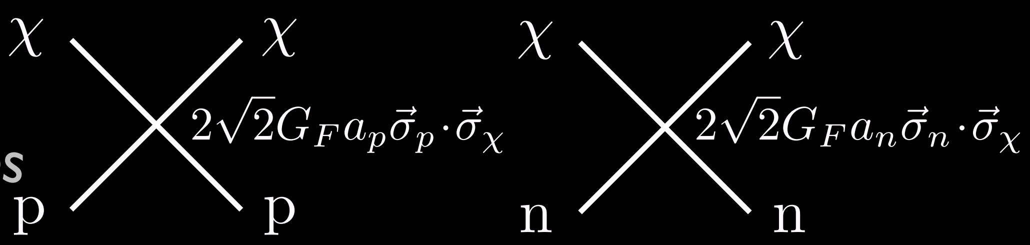
Main uncertainty is $\langle m_s \bar{s} s \rangle$ (strange content of nucleon)

Particle physics model

Axial and tensor currents give spin-dependent terms

$$\sigma_{SD}(E) = \frac{32\mu^2 G_F^2}{2J+1}\left[a_p^2 S_{pp}(q) + a_p a_n S_{pn}(q) + a_n^2 S_{nn}(q)\right]$$

Effective four-particle vertices



Nuclear spin structure functions

Example: neutralino

$$2\sqrt{2}G_F a_p = \sum_q \Delta q \left[\frac{g_{Z\chi\chi} g_{Zqq}}{m_Z^2} + \sum_{\tilde{q}} \frac{g_{L\tilde{q}\chi q}^2 + g_{R\tilde{q}\chi q}^2}{m_{\tilde{q}}^2}\right]$$

Main uncertainty is nuclear spin structure functions $S(q)$

What particle model for light WIMPs?

What particle model for light WIMPs?

- It should have the cosmic cold dark matter density
- It should be stable or very long-lived ($\gtrsim 10^{24}$ yr)
- It should account for the CoGeNT and DAMA modulations
- It should be compatible with collider, astrophysics, etc. bounds
- Ideally, it would justify apparent incompatibilities between direct detection experiments
- Ideally, it would explain some excessive emissions possibly observed in Galactic gamma-ray and radio maps

A few particle models for light WIMPs*

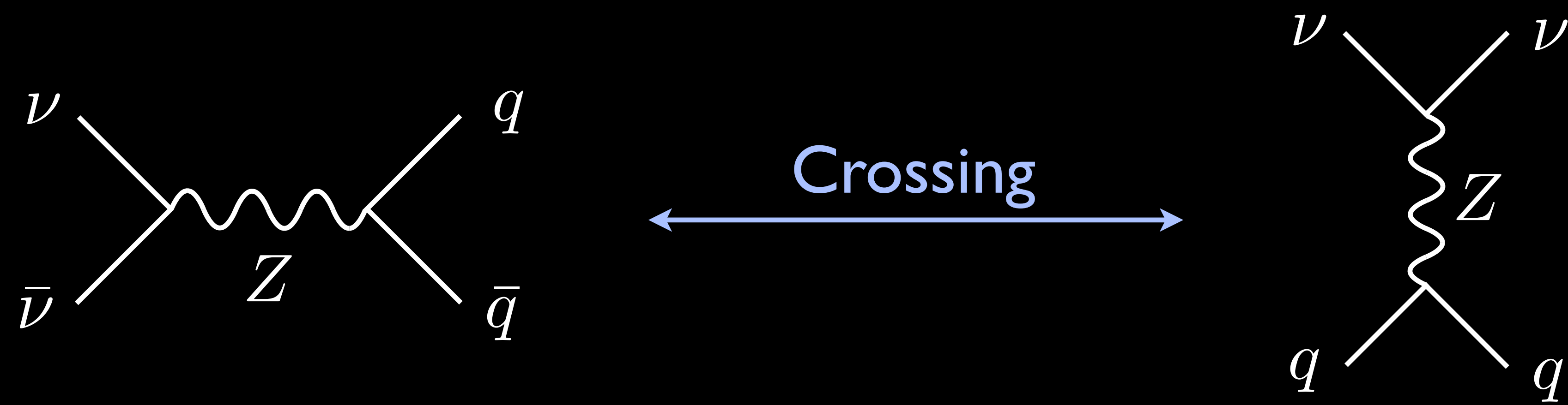
Models		References
SUSY	MSSM neutralino	*Goldberg 1983; Griest 1988; Gelmini, Gondolo, Roulet 1989; Griest, Roszkowski 1991; Bottino et al 2002-11; ~~Kuflik, Pierce, Zurek 2010~~; ~~Feldman et al 2010~~; ~~Cumberbatch et al 2011~~; Belli et al 2011; .....*
SUSY	beyond-MSSM neutralino	*Flores, Olive, Thomas 1990; Gunion, Hooper, McElrath 2005; Belikov, Gunion, Hooper, Tait 2011; Belanger, Kraml, Lessa 1105.4878; ......*
SUSY	sneutrino	*.....; An, Dev, Cai, Mohapatra 1110.1366; Cerdeno, Huh, Peiro, Seto 1108.0978; .....*
minimalist dark matter (real singlet scalar with Z_2)		*Silveira, Zee 1985; Veltman, Ydnurain 1989; McDonald 1994; Burgess, Pospelov, ter Veldhuis 2000; Davoudiasl, Kitano, Li, Murayama 2004; Andreas et al 2008-10; He, Tandean 1109.1267; .....*
technicolor and alike		*....; Lewis, Pica, Sannino 1109.3513; .....*
kinetically-mixed U(1)' (Higgs portal)		*.....; Foot 2003-10; Kaplan et al 1105.2073; An, Gao 1108.3943; Fornengo, Panci, Regis 1108.4661; Andreas, Goodsell, Ringwald 1109.2869; Andreas 1110.2636; Feldman, Perez, Nath 1109.2901; ......*
baryonic U(1)'		*Gondolo, Ko, Omura ; Cline, Frey 1109.4639; ......*
....		....

* 1-10 GeV WIMP; very incomplete references.

Phenomenological approach

Break the annihilation/scattering relation

Annihilation $\nu\bar{\nu} \to q\bar{q}$ Scattering $\nu q \to \nu q$



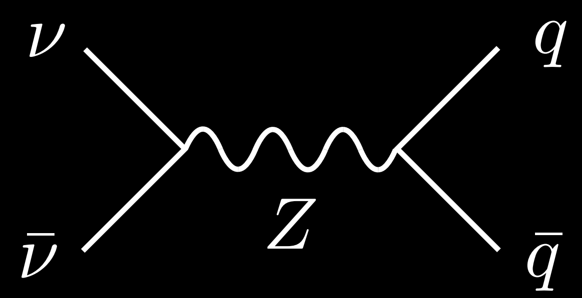
For example, for a ~4 GeV/c² dark matter neutrino, the scattering cross section is

$$\sigma_{\nu n} \simeq 0.01 \frac{\langle \sigma v \rangle}{c} \simeq 10^{-38}\,\mathrm{cm}^2$$

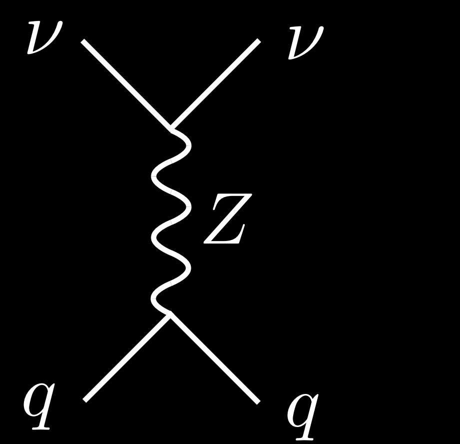
Break the annihilation/scattering relation

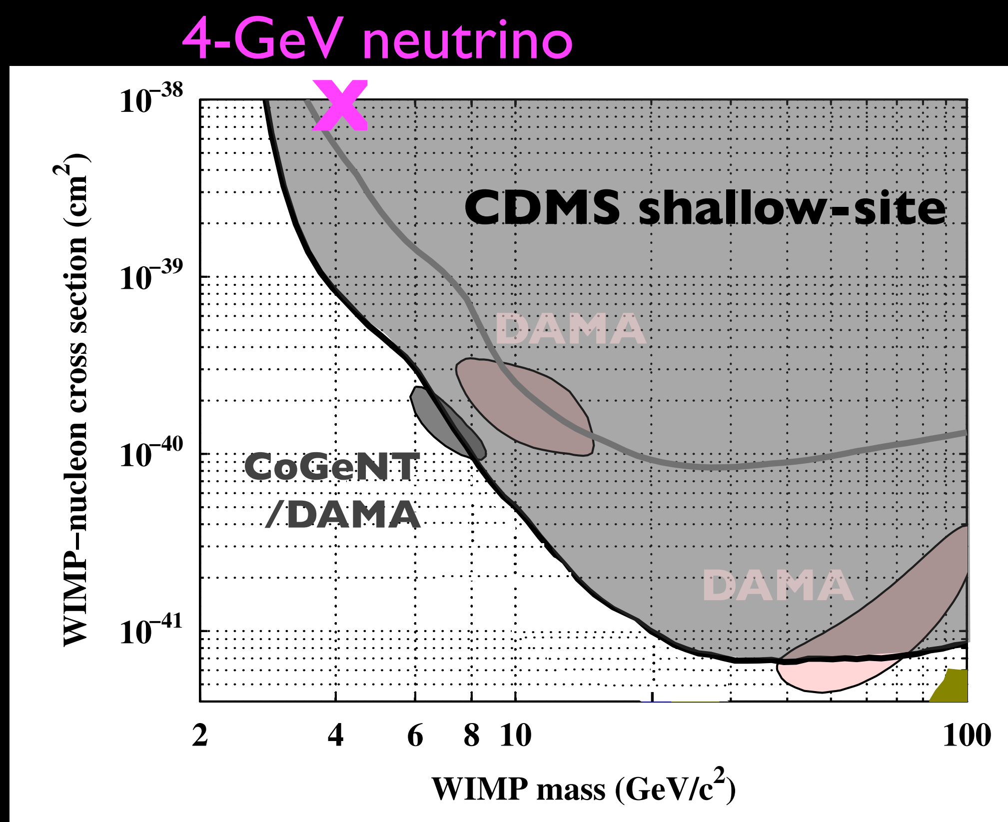
Annihilation $\nu\bar{\nu} \rightarrow q\bar{q}$

Scattering $\nu q \rightarrow \nu q$



Crossing ⟷

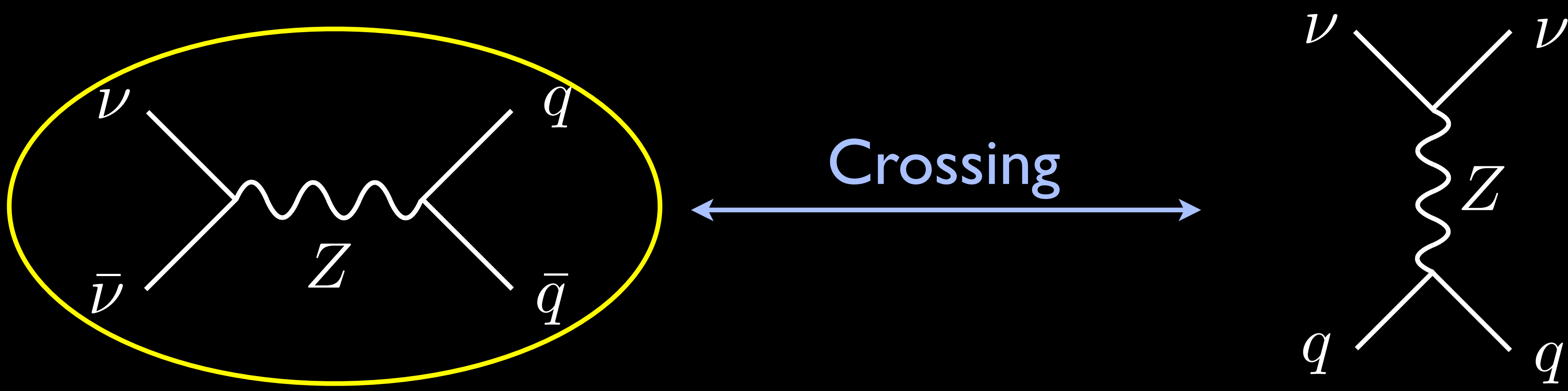




Akerib et al (CDMS) 2010

Break the annihilation/scattering relation

Annihilation $\nu\bar{\nu} \to q\bar{q}$ Scattering $\nu q \to \nu q$



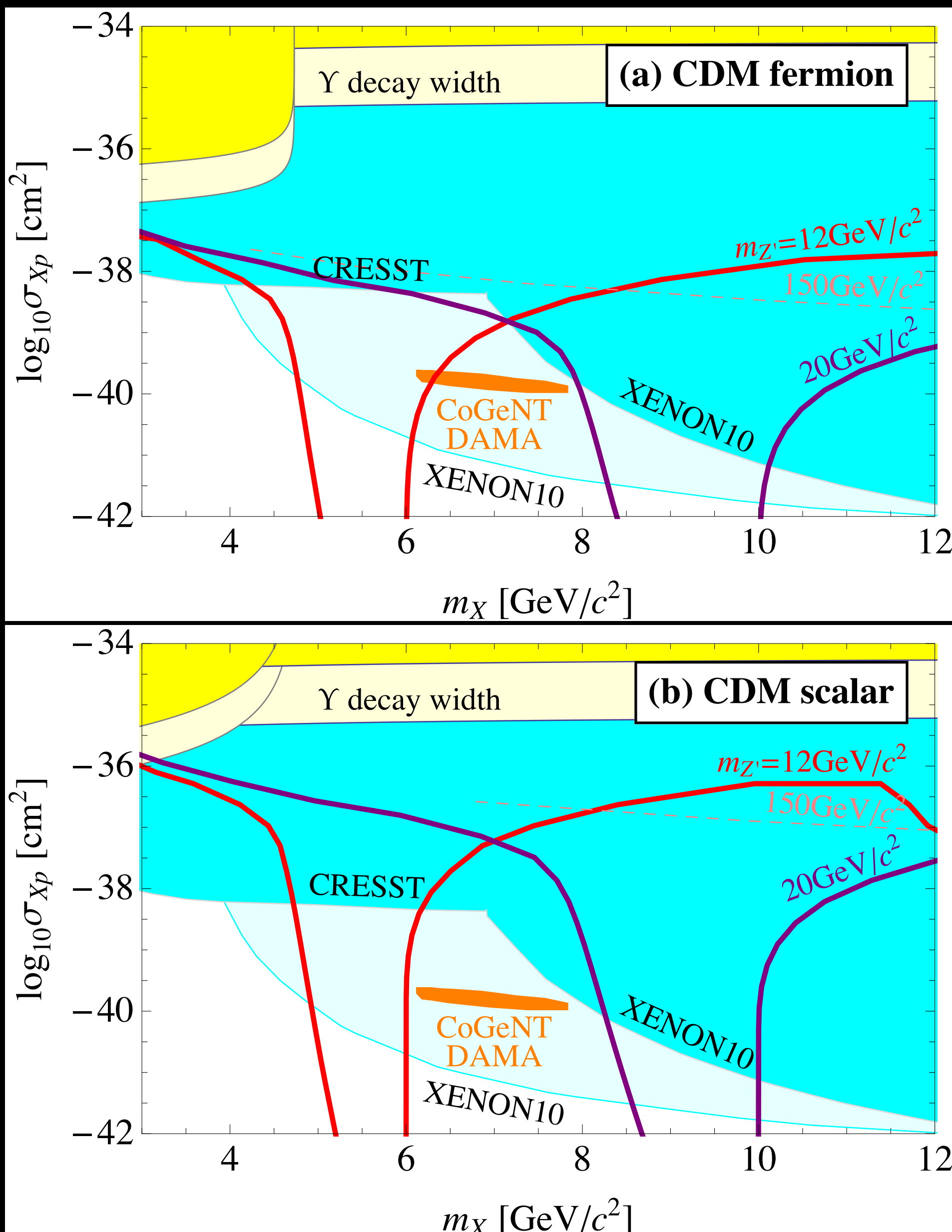
Resonant when $m_\nu \approx m_Z/2$

$$\sigma_{\nu n} \simeq \frac{0.02}{1 + m_n/m_\nu} \left(1 - \frac{4m_\nu^2}{m_Z^2}\right)^2 \frac{\langle \sigma v \rangle}{c}$$

$\sigma_{\nu n}$ would perhaps match DAMA/CoGeNT if m_Z were $\approx 2m_\nu$

Try a new particle χ and a new vector boson Z'

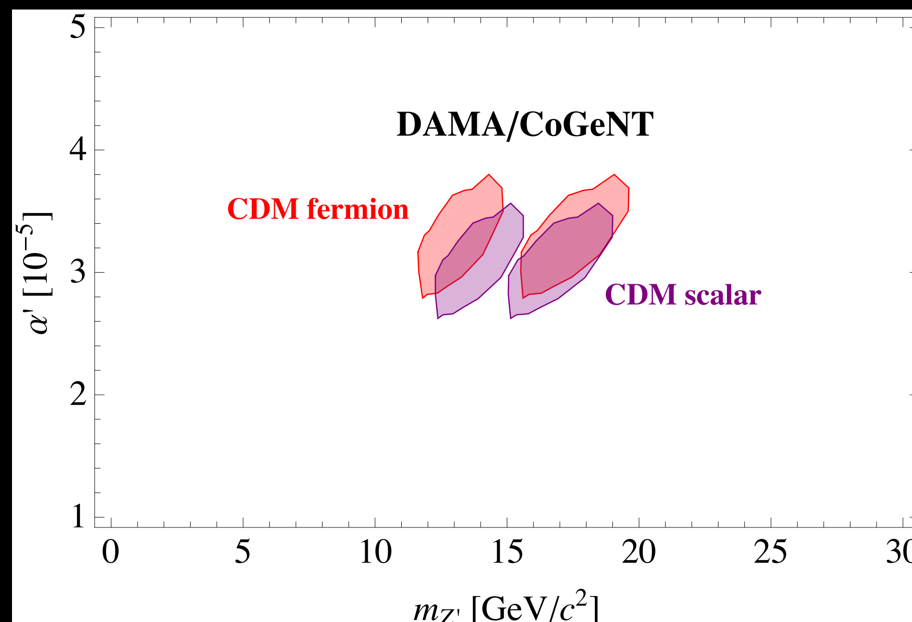
Break the annihilation/scattering relation



Example: Leptophobic Z'

- An extra U(1) gauge boson Z' coupled to quarks but no leptons, with no significant kinetic mixing
- Works for $m_{Z'}$~10-20 GeV and α'~10^{-5}

Gondolo, Ko, Omura 2011



Modify the scattering cross section

The recoil spectrum (scattering rate per unit target mass)

WIMP density

Differential scattering cross section

$$\frac{dR}{dE} = \frac{1}{m_A}\frac{\rho_\chi}{m_\chi}\int \frac{d\sigma}{dE}\, v\, f(\mathbf{v})\, d^3\mathbf{v}$$

WIMP velocity distribution

Recoil energy

$$= \frac{\rho_\chi}{2\mu^2 m_\chi}\int E_{\max}\frac{d\sigma}{dE}\,\frac{f(\mathbf{v})}{v}\, d^3\mathbf{v}$$

$$E_{\max} = \frac{2\mu^2 v^2}{m_A}$$

Traditionally, $E_{\max}\, d\sigma/dE = \mathrm{const} \times (\text{nuclear form factor})$, with the same coupling to protons and neutrons (spin-independent case)

Put additional velocity or energy dependence in $E_{\max}\, d\sigma/dE$

Set different couplings to neutrons and protons ("isospin-violating")

Modify the scattering cross section

Energy and/or velocity dependent scattering cross sections

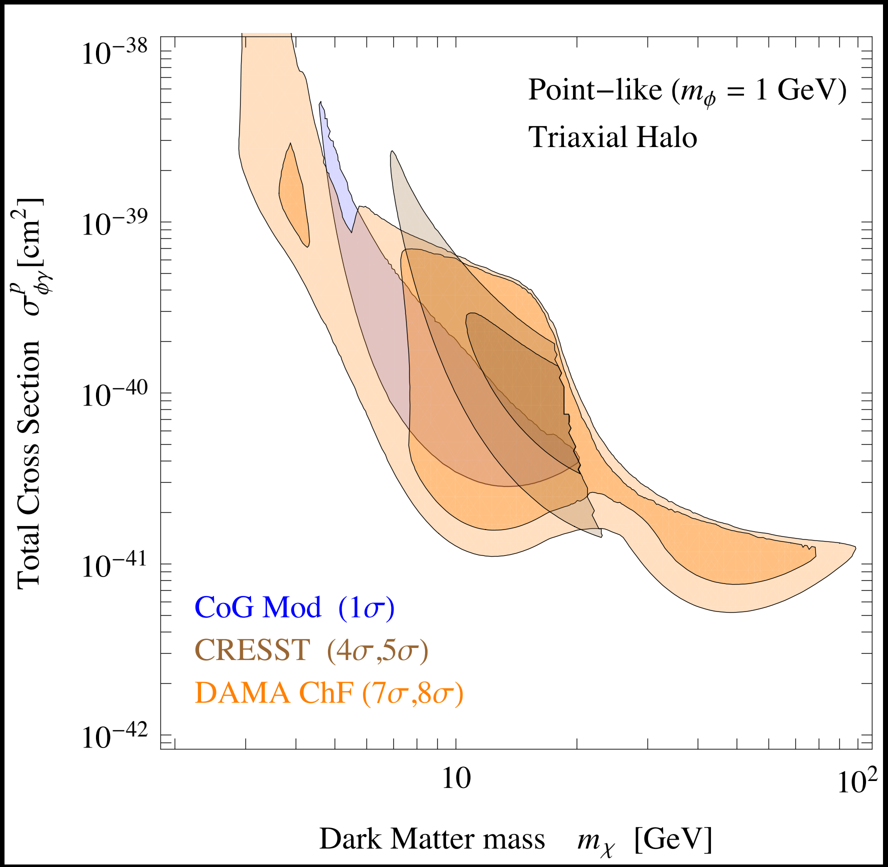
nucleus	DM	$E_{max}\, d\sigma/dE$	
		light mediator	heavy mediator
"charge"	*"charge"*	$1/E^2$	$1/M^4$
"charge"	*dipole*	$1/E$	E/M^4
dipole	*dipole*	$\text{const} + E/v^2$	E^2/M^4

All terms may be multiplied by nuclear or DM form factors $F(E)$

See e.g. Barger, Keung, Marfatia 2010; Fornengo, Panci, Regis 2011; An et al 2011

Modify the scattering cross section

Example:
a 1 GeV mediator can bring CoGeNT, DAMA, and CRESST together

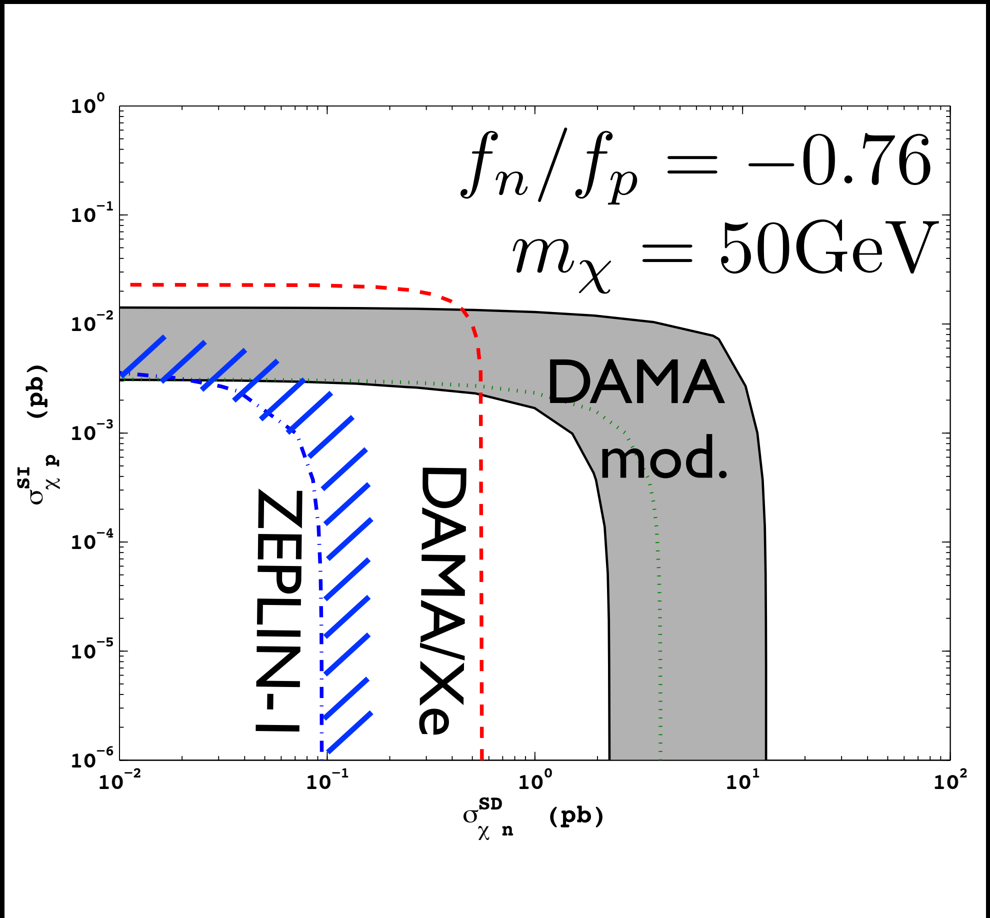


Fornengo, Panci, Regis 2011

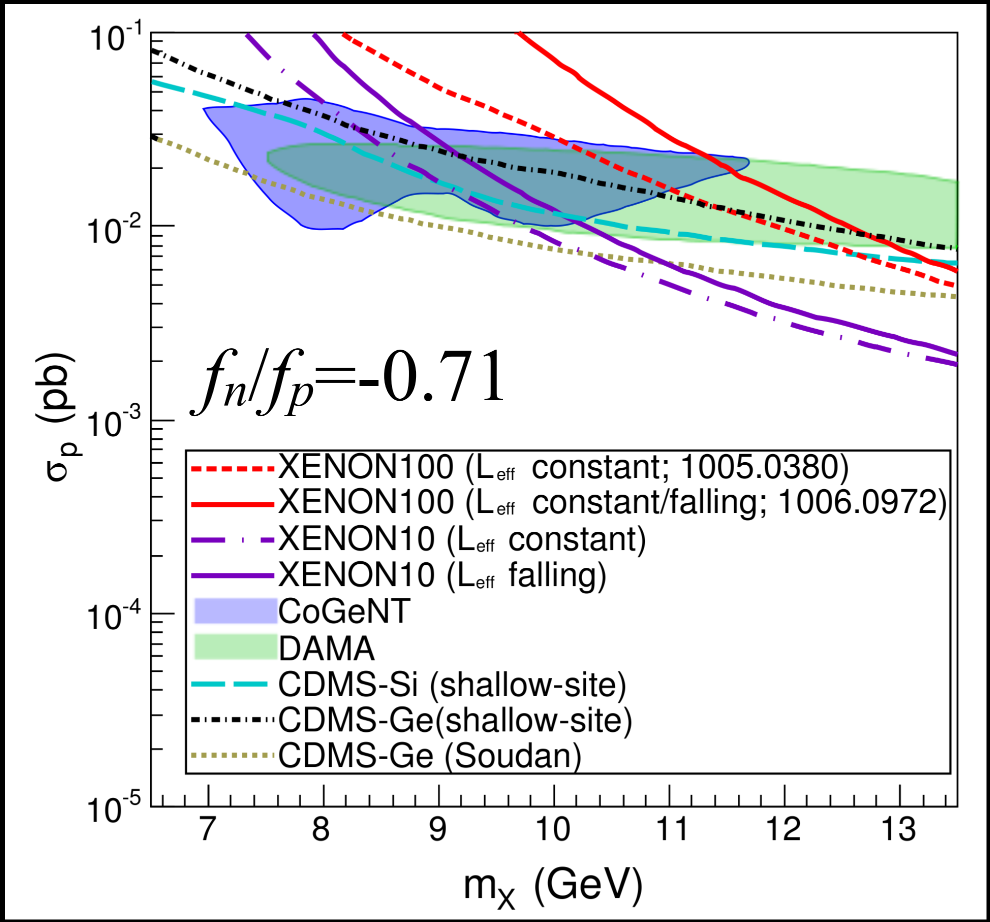
Isospin-violating dark matter

Spin-independent couplings to protons stronger than to neutrons allow modulation signals compatible with other null searches

Kurylov, Kamionkowksi 2003; Giuliani 2005; Cotta et al 2009; Chang et al 2010; Kang et al 2010; Feng et al 2011; Del Nobile et al 2011; .....



Kurylov, Kamionkowski 2003



Feng, Kumar, Marfatia, Sanford 2011

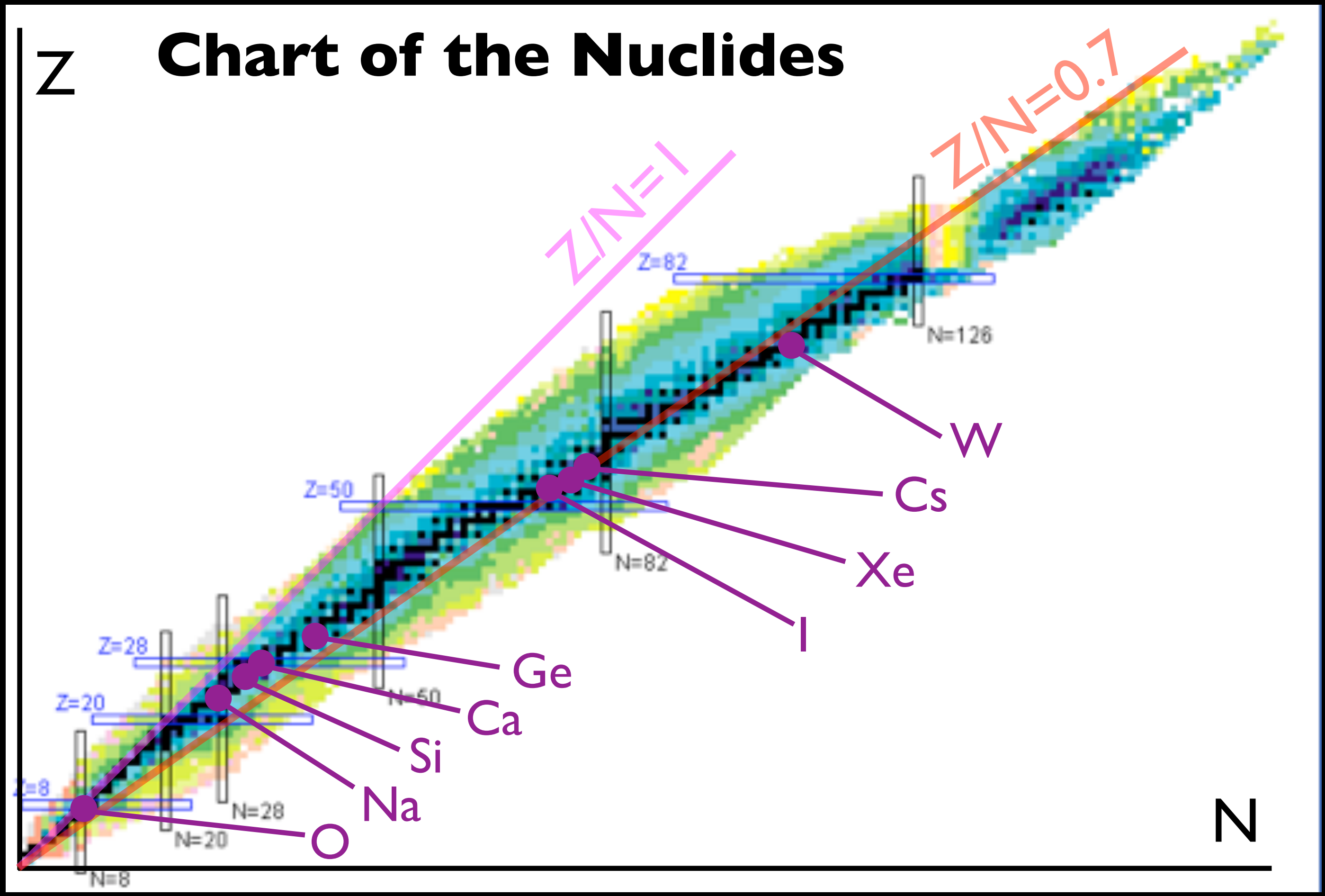
Isospin-violating dark matter

Spin-independent couplings to protons stronger than to neutrons allow modulation signals compatible with other null searches

Kurylov, Kamionkowksi 2003; Giuliani 2005; Cotta et al 2009; Chang et al 2010; Kang et al 2010; Feng et al 2011; Del Nobile et al 2011; .....

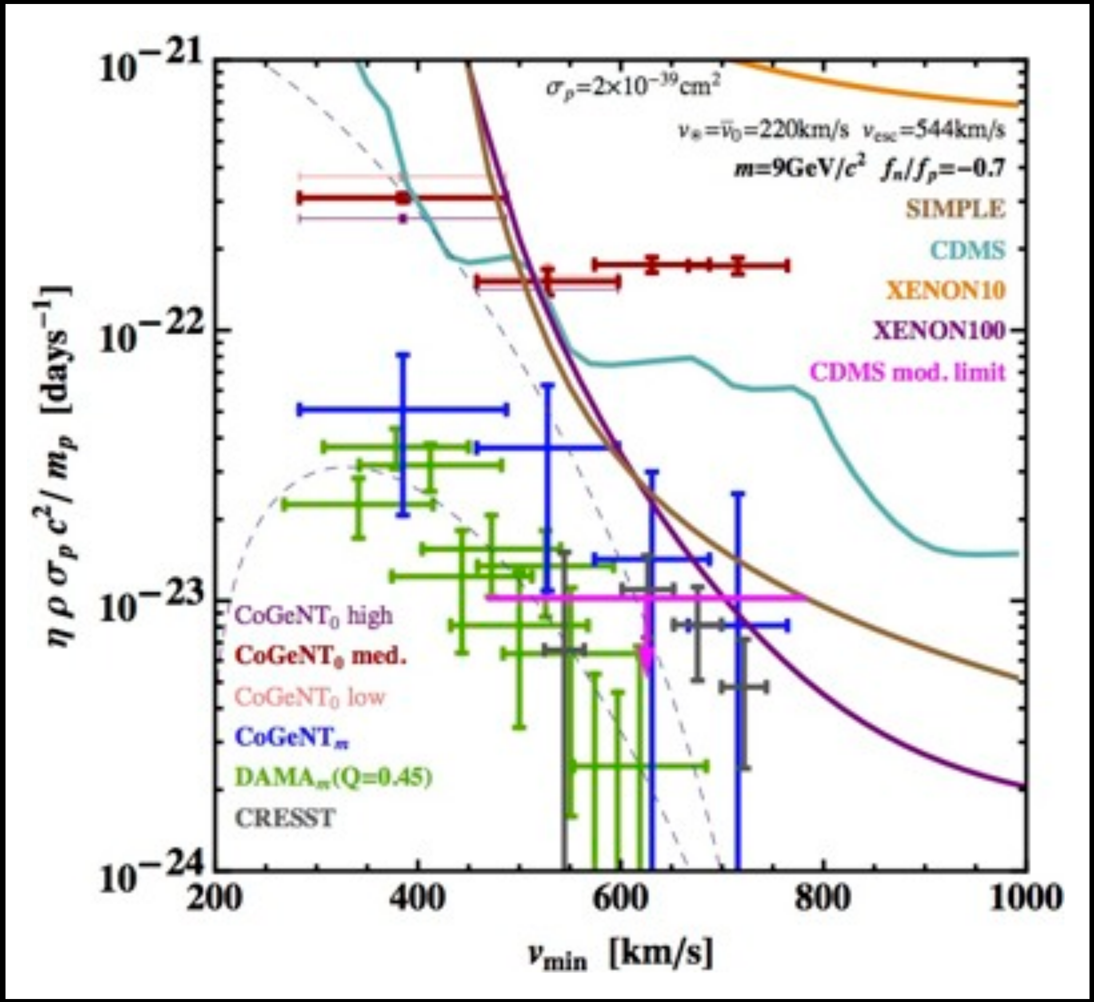
coupling $N f_n + Z f_p \approx 0$ for $f_n / f_p \approx -Z/N$

Why f_n/f_p=-0.7 suppresses the coupling to Xe



Isospin-violating dark matter

Spin-independent couplings to protons stronger than to neutrons allow modulation signals compatible with other null searches



Gondolo Gelmini 1202.6359

Isospin-violating dark matter

Spin-independent couplings to protons stronger than to neutrons allow modulation signals compatible with other null searches

Kurylov, Kamionkowksi 2003; Giuliani 2005; Cotta et al 2009; Chang et al 2010; Kang et al 2010; Feng et al 2011; Del Nobile et al 2011; .....

Models with $f_n/f_p = -0.7$ are possible through e.g. interference of two Higgs boson mediators, but require a new physics scale of 1-20 GeV............

Del Nobile et al 2011

Compositeness? Mirror baryons?

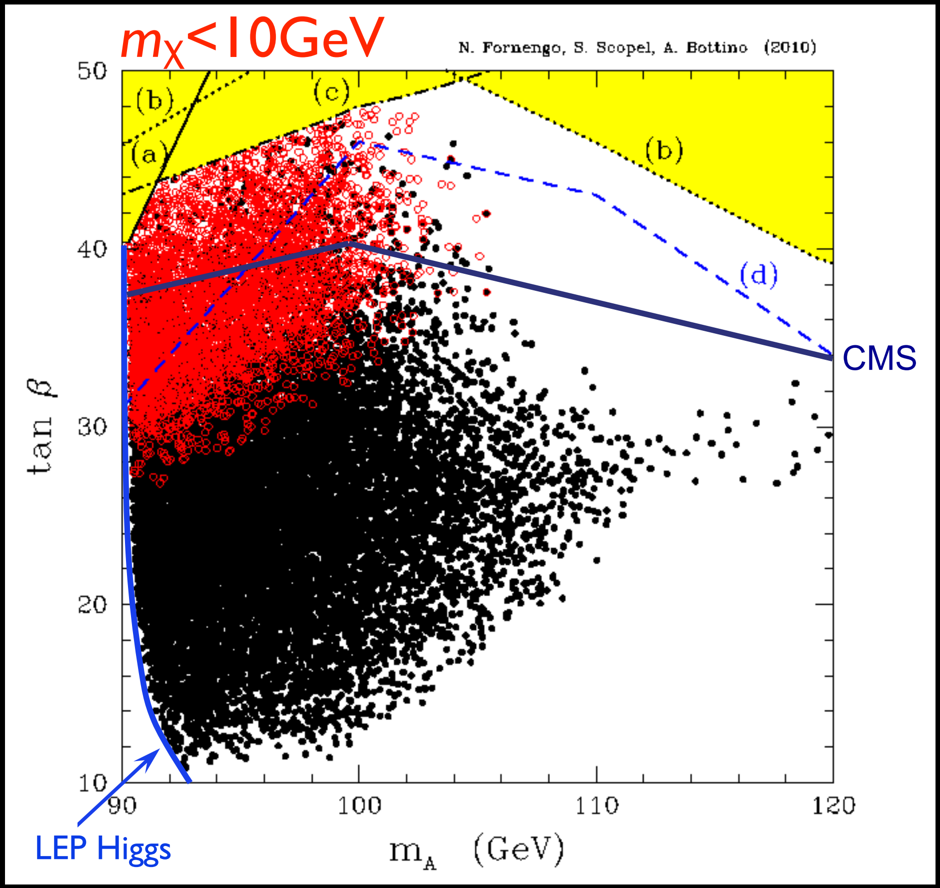
Light neutralinos

Light neutralinos

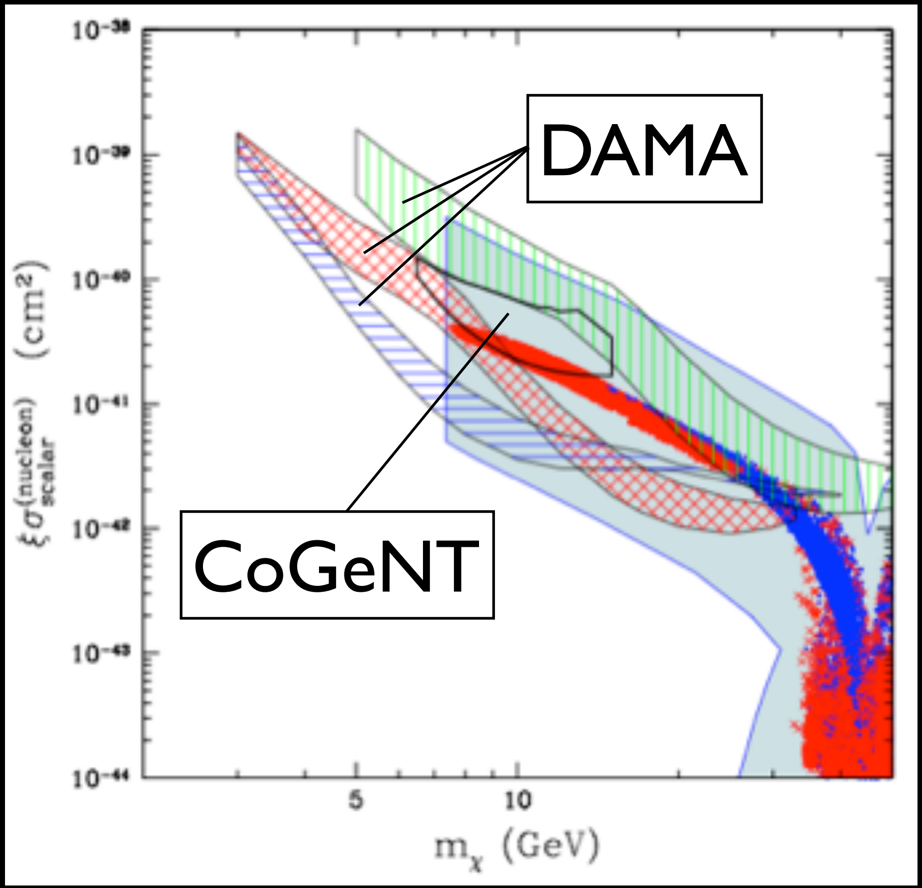
Bottino, Donato, Fornengo, Scopel 2003-2011 *Non-GUT MSSM*

~10 GeV neutralinos may account for DAMA, CoGeNT, and CRESST

Fornengo at TAUP 2011



Belli et al 1106.4667



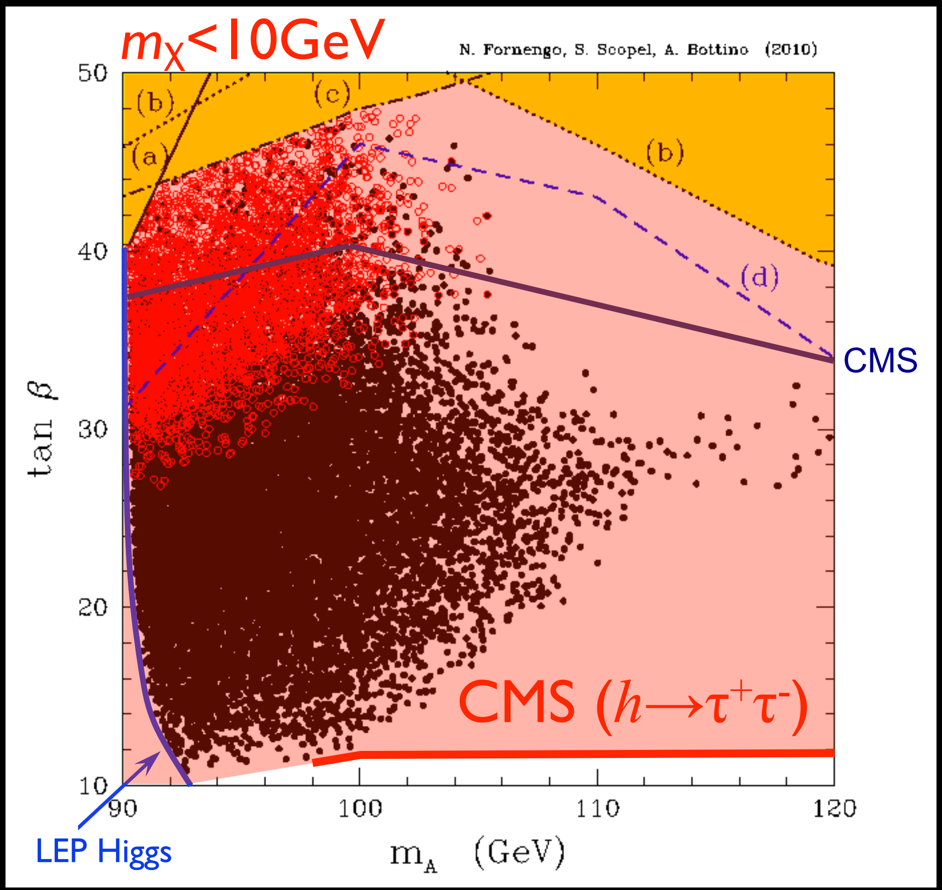
Light neutralinos

Bottino, Donato, Fornengo, Scopel 2003-2011 *Non-GUT MSSM*

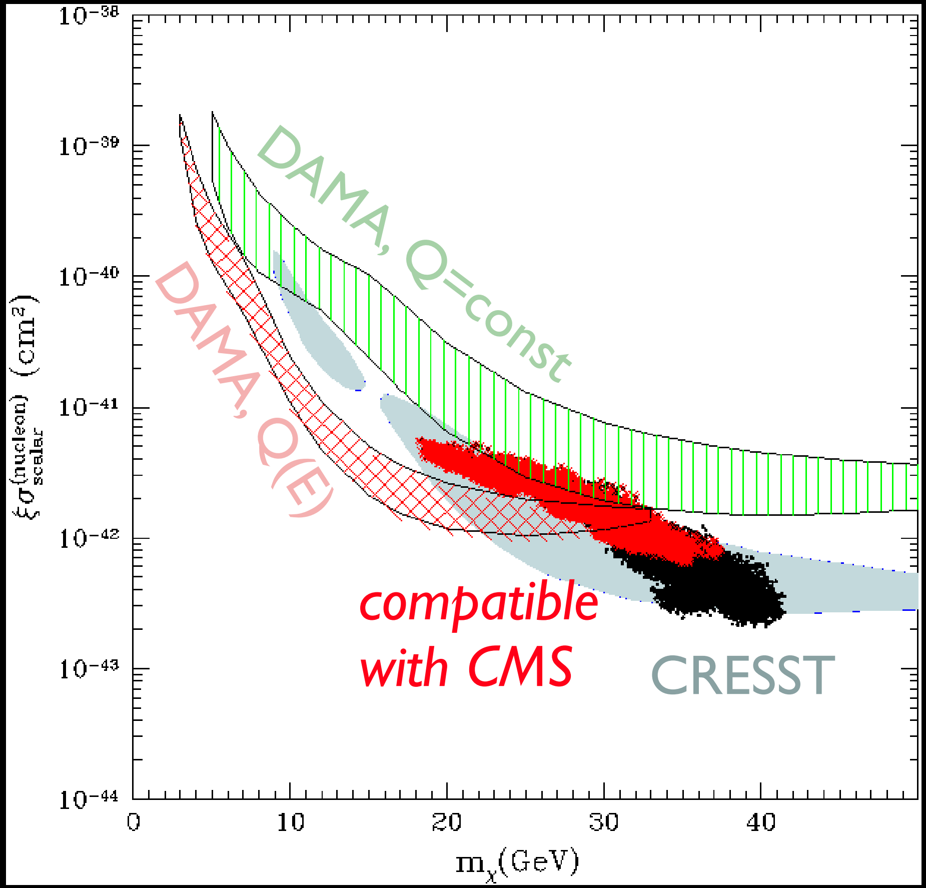
~10 GeV neutralinos may account for DAMA, CoGeNT, and CRESST

negative LHC Higgs searches impose m_χ >18 GeV

Fornengo at TAUP 2011



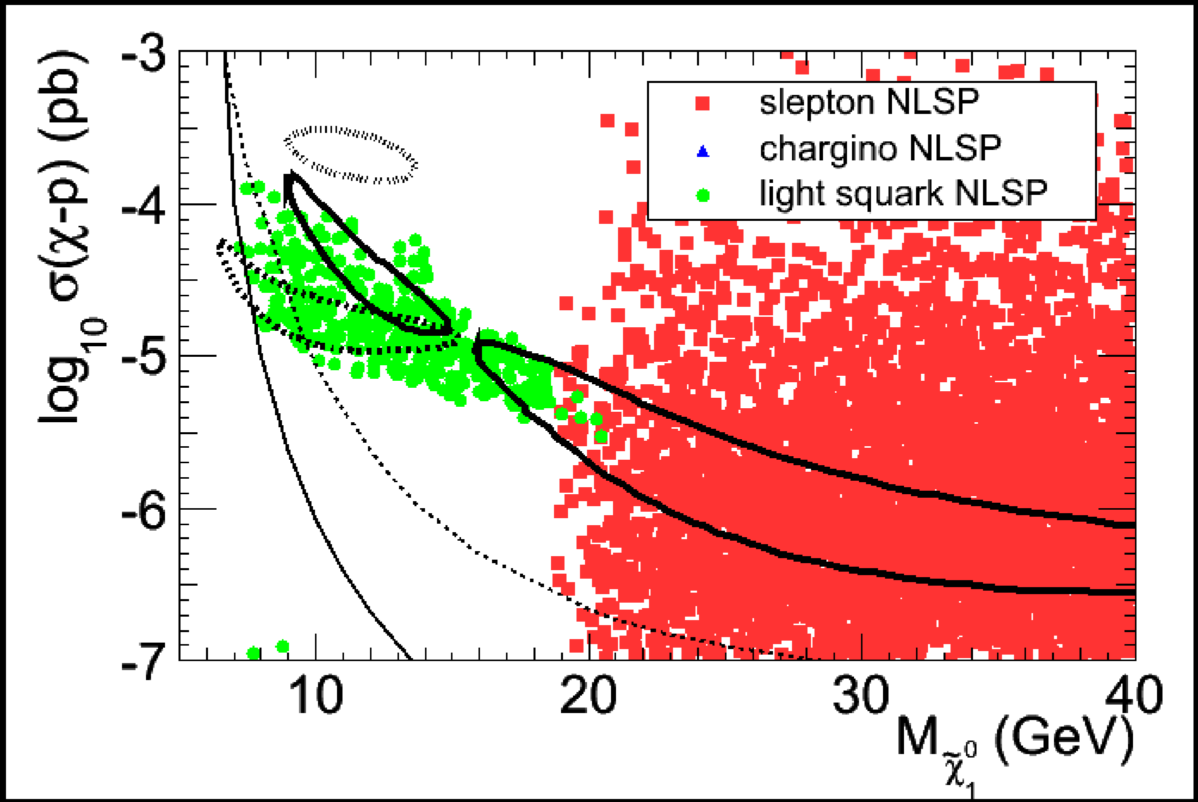
Bottino et al 1112.5666



Light neutralinos

Arbey, Battaglia, Mahmoudi 1205.2557

pMSSM



Light neutralinos seem possible in the pMSSM with 19 free parameters

Minimalist dark matter

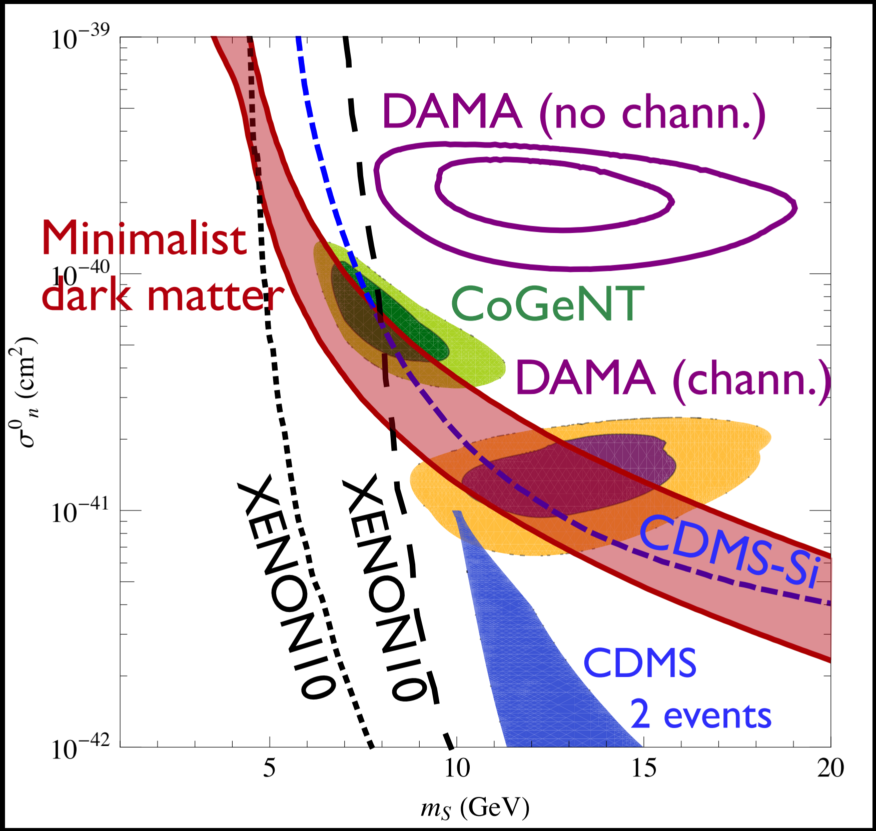
Minimalist dark matter

do not confuse with minimal dark matter

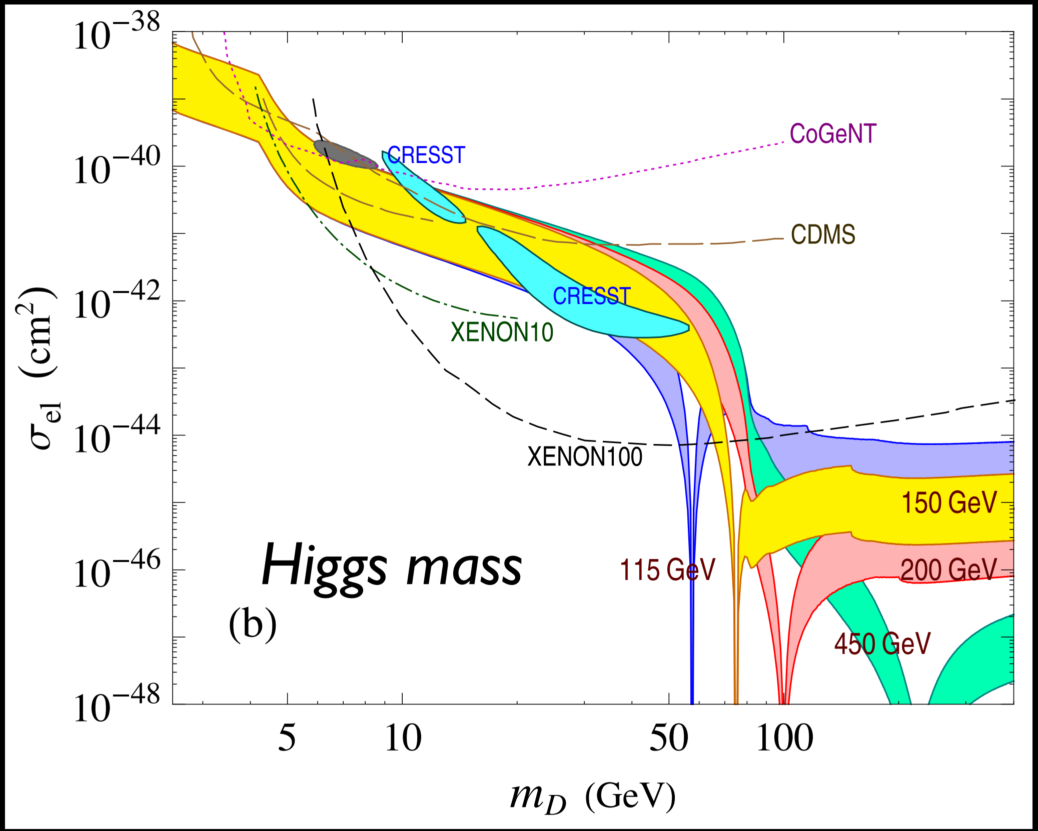
Gauge singlet scalar field S, stabilized by Z_2 symmetry

Silveira, Zee 1985

$$\mathcal{L}_S = \frac{1}{2}\partial^\mu S \partial_\mu S - \frac{1}{2}\mu_S^2 S^2 - \frac{\lambda_S}{4} S^4 - \lambda_L H^\dagger H S^2$$



Andreas et al 2010



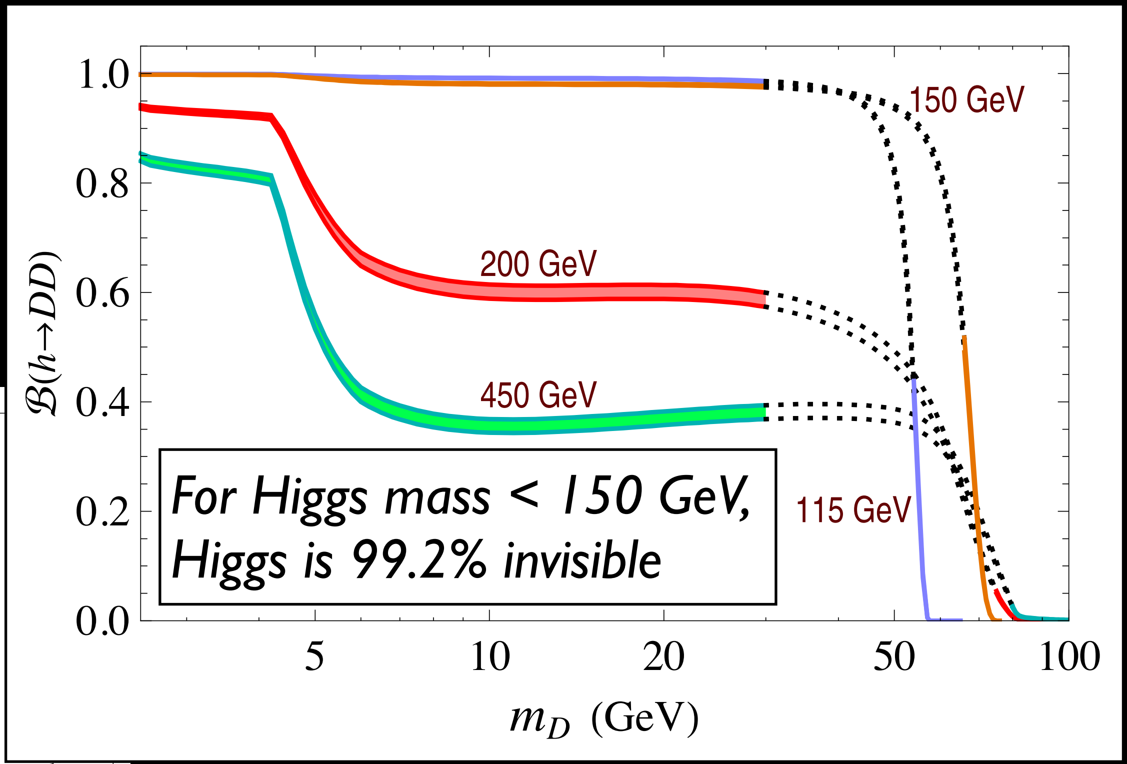
He, Tandean 2011

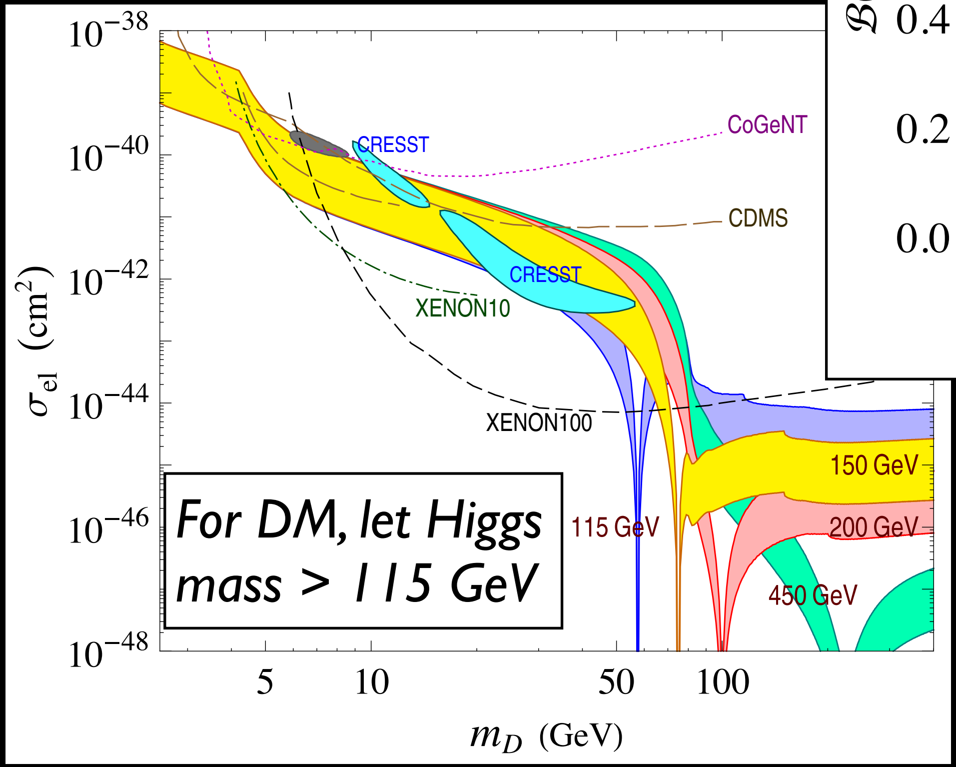
Minimalist dark matter

do not confuse with minimal dark matter

Constraints from the LHC: none

A Higgs mass of 125 GeV works!





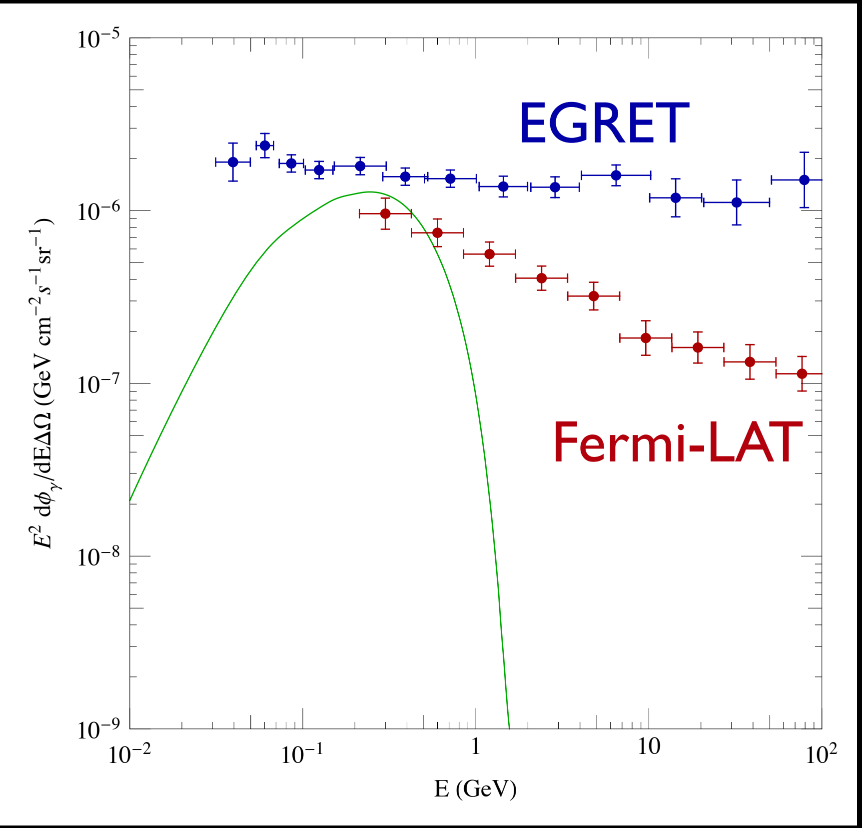
He, Tandean 2011

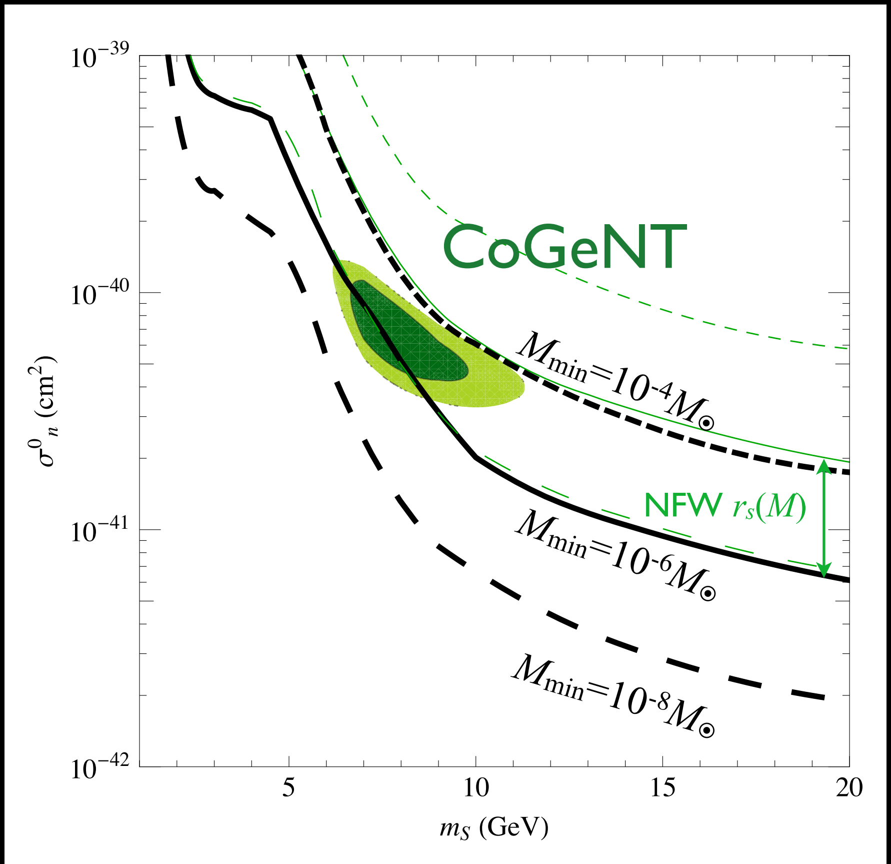
Minimalist dark matter

do not confuse with minimal dark matter

Constraints from diffuse Galactic gamma-rays

Very sensitive to unknown properties of small dark subhalos





Arina, Tytgat 2010

A few models of light dark matter*

Models		References
SUSY	MSSM neutralino	*.....; Griest 1988; Gelmini, Gondolo, Roulet 1989; Griest, Roszkowski 1991; Bottino et al 2002-11; ~~Kuflik, Pierce, Zurek 2010~~; ~~Feldman, Liu, Nath 2010~~; ~~Cumberbatch et al 2011~~; Belli et al 2011; .....*
SUSY	beyond-MSSM neutralino	*Flores, Olive, Thomas 1990; Gunion, Hooper, McElrath 2005; Belikov, Gunion, Hooper, Tait 2011; Belanger, Kraml, Lessa 1105.4878; ......*
SUSY	sneutrino	*.....; An, Dev, Cai, Mohapatra 1110.1366; Cerdeno, Huh, Peiro, Seto 1108.0978; .....*
minimalist dark matter (SM + real singlet scalar)		*Veltman, Ydnurain 1989; Silveira, Zee 1985; McDonald 1994; Burgess, Pospelov, ter Veldhuis 2000; Davoudiasl, Kitano, Li, Murayama 2004; Andreas et al 2008-10; He, Tandean 1109.1267; .....*
technicolor and alike		*....; Lewis, Pica, Sannino 1109.3513; .....*
kinetically-mixed U(1)'		*.....; Foot 2003-10; Kaplan et al 1105.2073; An, Gao 1108.3943; Fornengo, Panci, Regis 1108.4661; Andreas, Goodsell, Ringwald 1109.2869; Andreas 1110.2636; Feldman, Perez, Nath 1109.2901; ......*
baryonic U(1)'		*Gondolo, Ko, Omura; Cline, Frey 1109.4639; ......*
dynamical DM		*Dienes, Thomas 1106.4546, 1107.0721*

* 1-10 GeV WIMP; very incomplete references.

So many theoretical models!

My suggestion: pay theorists more, so they do not need to work so much.