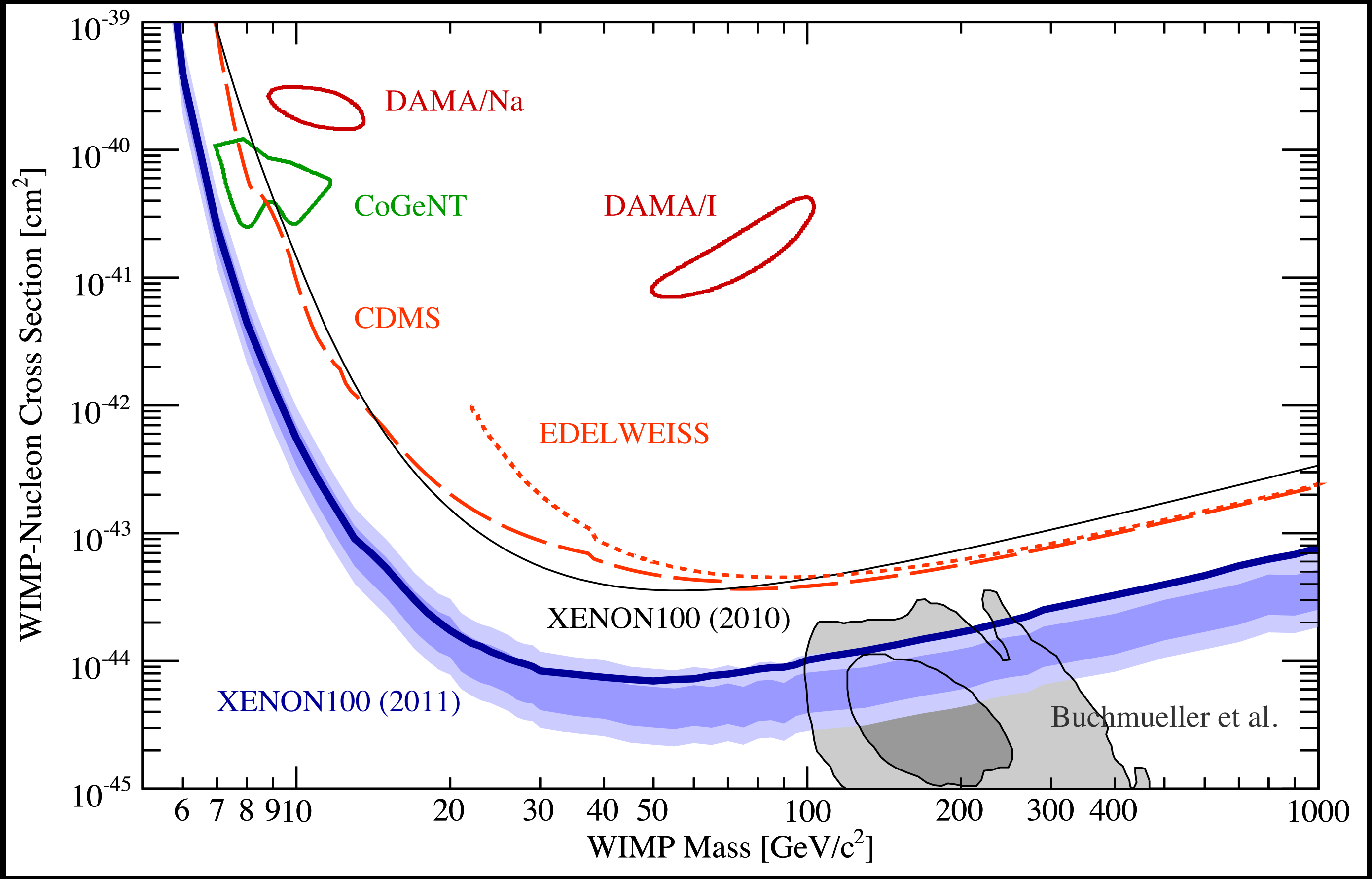
Direct detection of dark matter

An overview, not a review

Paolo Gondolo
University of Utah

Strong limits from XENON-100



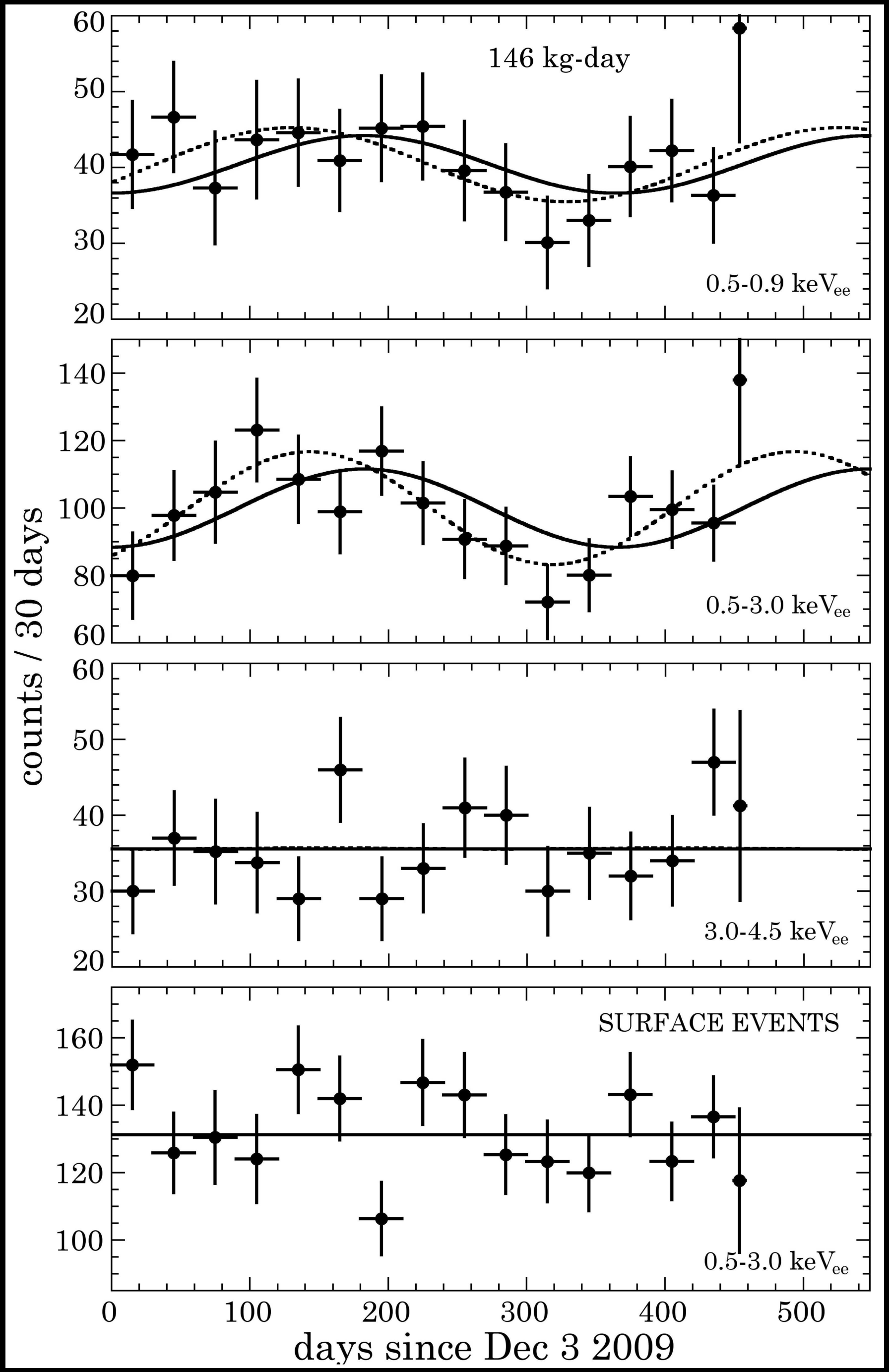
Aprile et al (XENON-100) 1104.2549

3 events observed

1.8±0.6 expected background

The CoGeNT modulation

Events in the CoGeNT ``irreducible excess" modulate with a period of one year and a phase compatible with DAMA's annual modulation.



Aalseth et al 1106.0650

Some headlines this past year.......

physicsworld.com

CoGeNT findings support dark-matter halo theory

Jun 15, 2011 4 comments

Cosmic Variance

Dark Matter is Just Messing With Us Now

by Sean

tuesday, may 10, 2011 ...

CoGeNT sees seasons (and maybe dark matter)

listen now

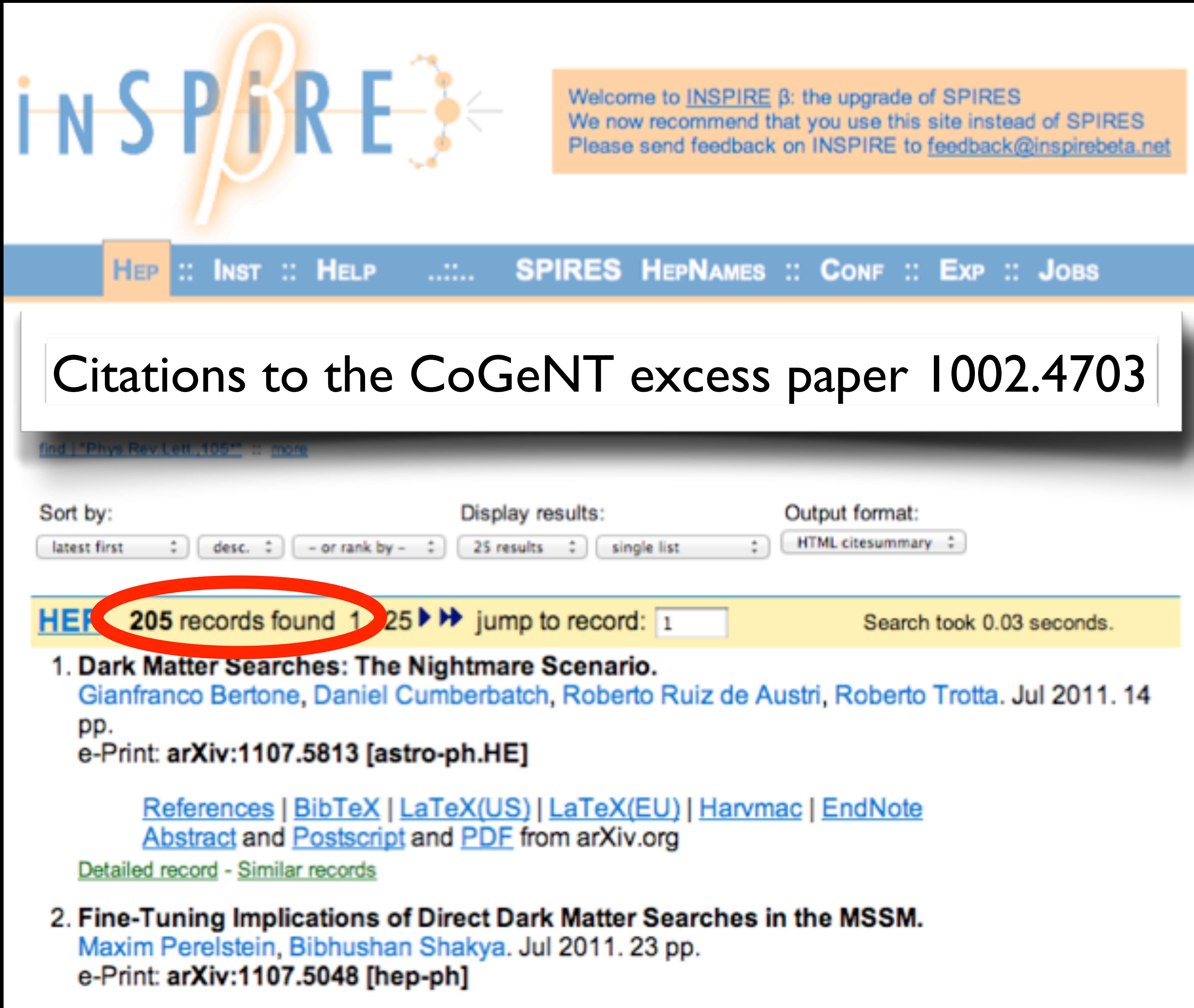
Résonaances

Saturday, 1 May 2010

More dark entries

Science journalists should be careful not to stoke the remarkable and scientific hype that has characterized theoretical high-energy physics for decades. [Note that I am not criticizing experimental hep.] *Robert Oldershaw*

In the age of instant information......



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Citations to the CoGeNT excess paper 1002.4703

Sort by: latest first | desc. | - or rank by -
Display results: 25 results | single list
Output format: HTML citesummary

HEP 205 records found 1 - 25 jump to record: 1 Search took 0.03 seconds.

1. **Dark Matter Searches: The Nightmare Scenario.**
Gianfranco Bertone, Daniel Cumberbatch, Roberto Ruiz de Austri, Roberto Trotta. Jul 2011. 14 pp.
e-Print: **arXiv:1107.5813 [astro-ph.HE]**

References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
Abstract and Postscript and PDF from arXiv.org
Detailed record - Similar records

2. **Fine-Tuning Implications of Direct Dark Matter Searches in the MSSM.**
Maxim Perelstein, Bibhushan Shakya. Jul 2011. 23 pp.
e-Print: **arXiv:1107.5048 [hep-ph]**

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Citations to the XENON100 first-results paper 1005.0380

find j "Phys.Rev.Lett.,105*" :: more

Sort by: latest first | desc. | - or rank by -
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Output format: HTML brief

HEP 209 records found 1 - 25 ▸ ▸▸ jump to record: 1 Search took 0.01 seconds.

1. **Dark Matter Searches: The Nightmare Scenario.**
Gianfranco Bertone, Daniel Cumberbatch, Roberto Ruiz de Austri, Roberto Trotta. Jul 2011. 14 pp.
e-Print: **arXiv:1107.5813 [astro-ph.HE]**

References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
Abstract and Postscript and PDF from arXiv.org
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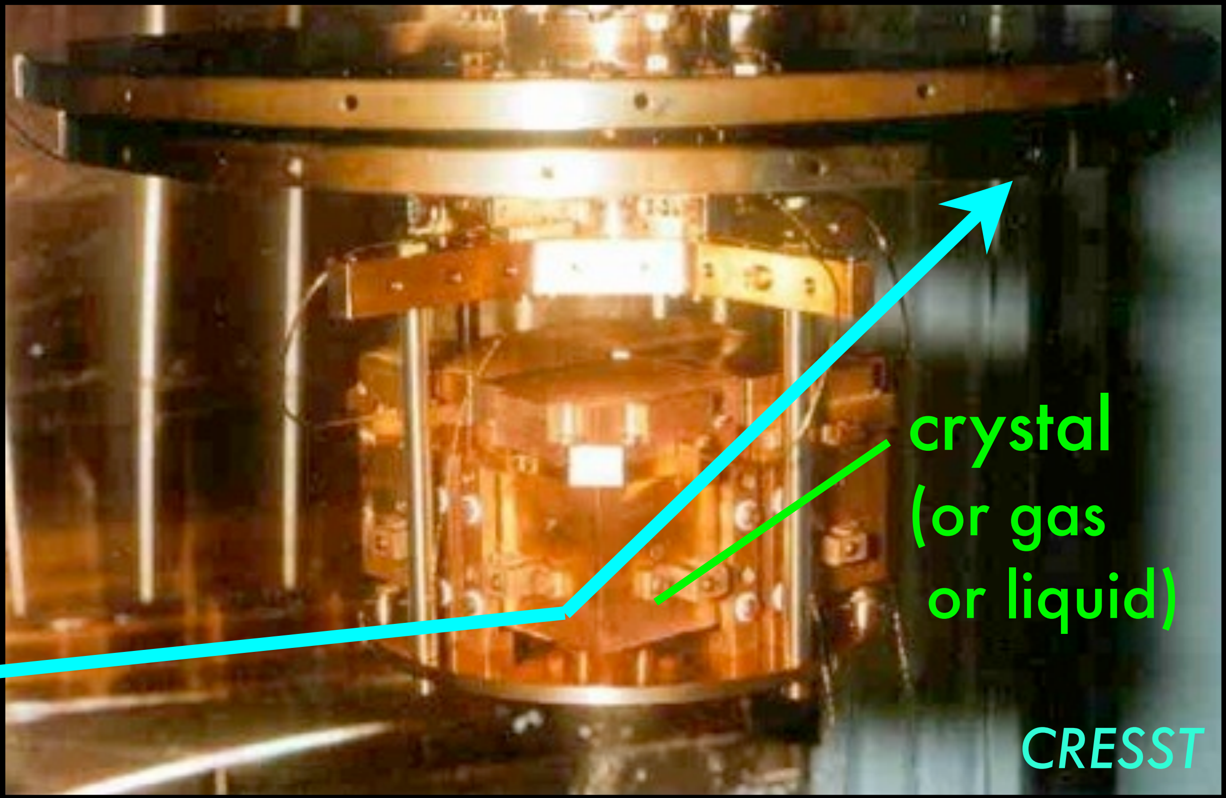
Maxim Perelstein, Bibhushan Shakya. Jul 2011. 23 pp.
e-Print: **arXiv:1107.5048 [hep-ph]**

Basic ideas

The principle

Dark matter particles scatter off nuclei in a detector

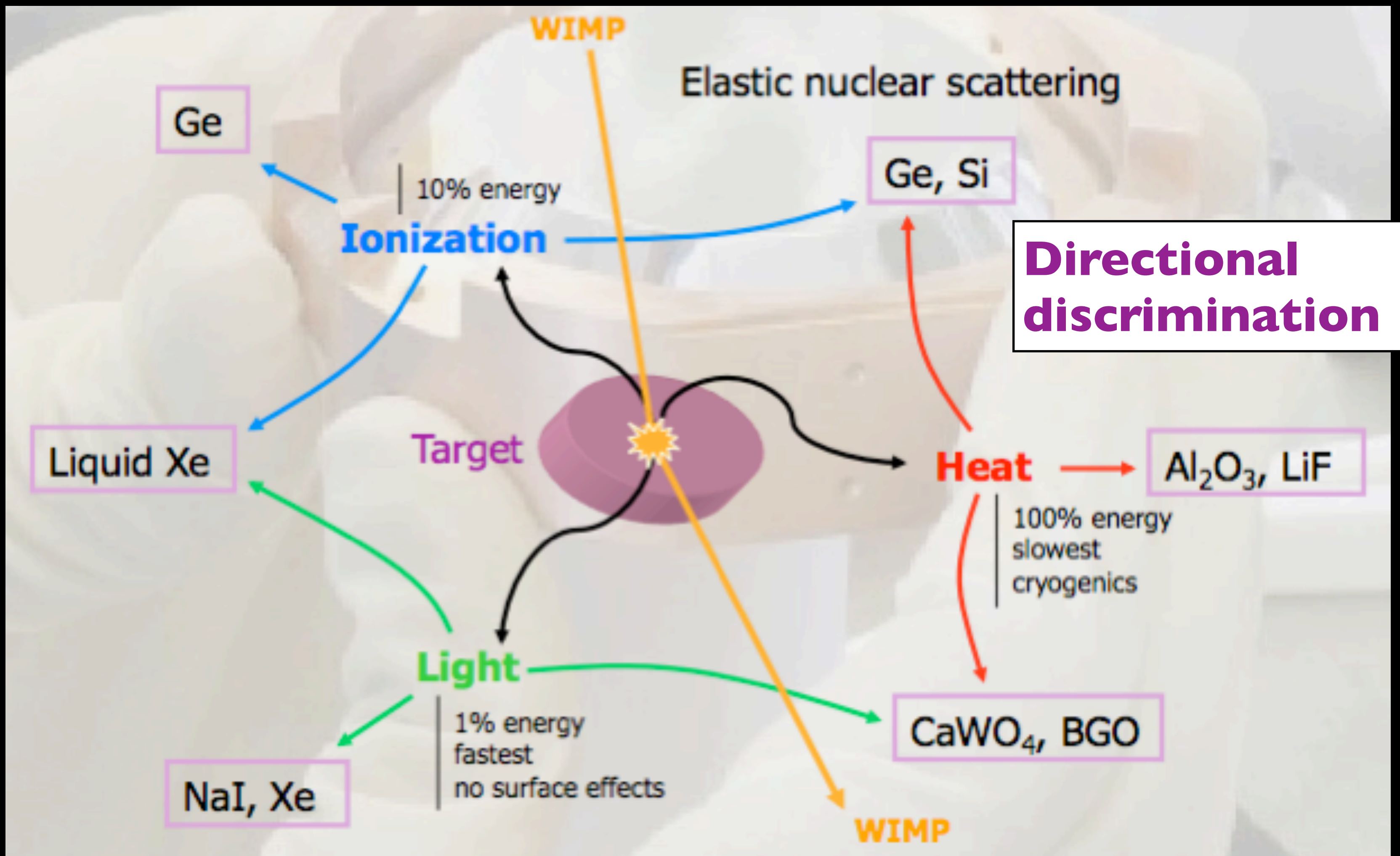
Dark matter particle



Low-background underground detector

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

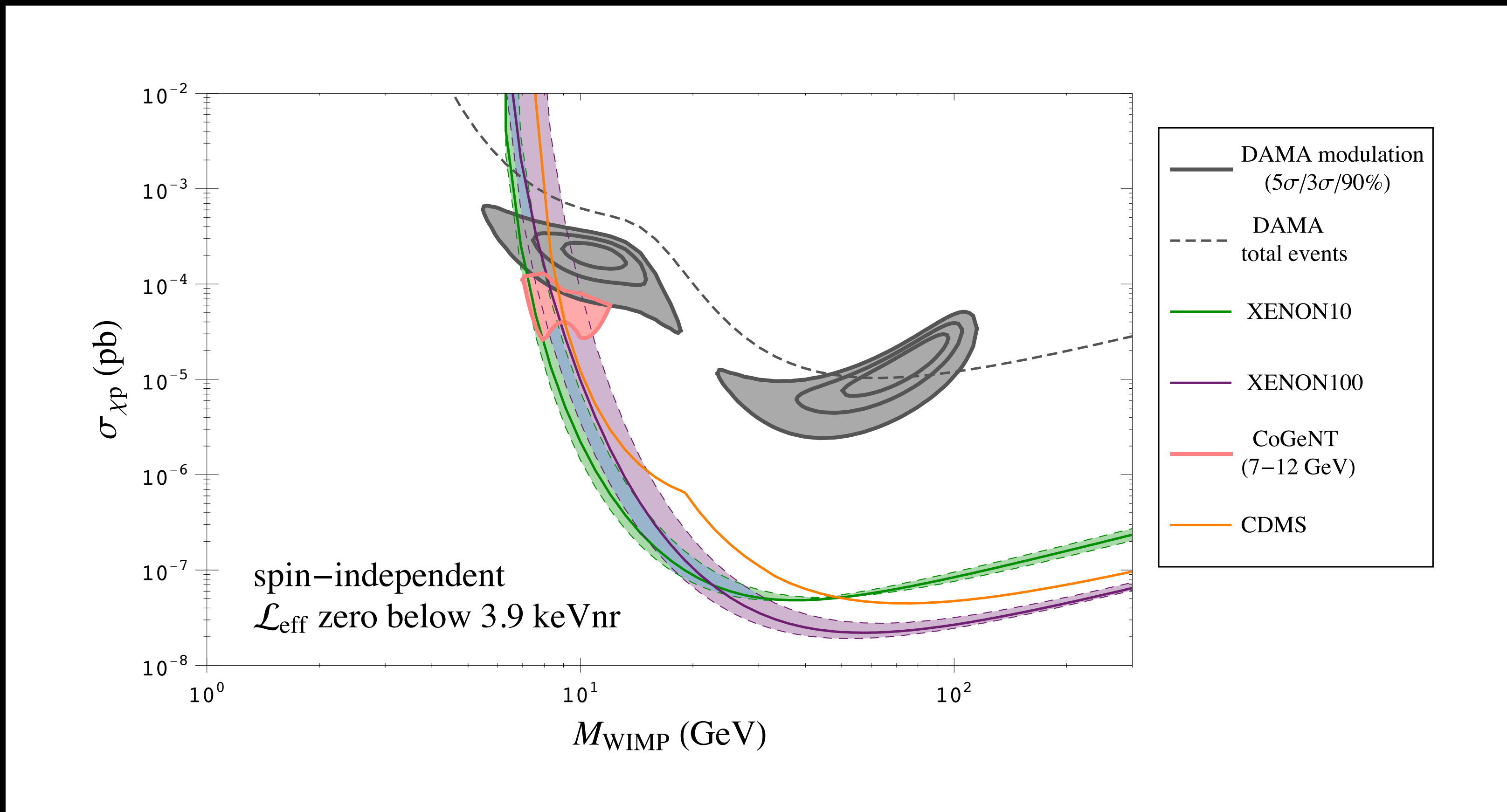
Background discrimination



From Sanglard 2005

Standard presentation of results

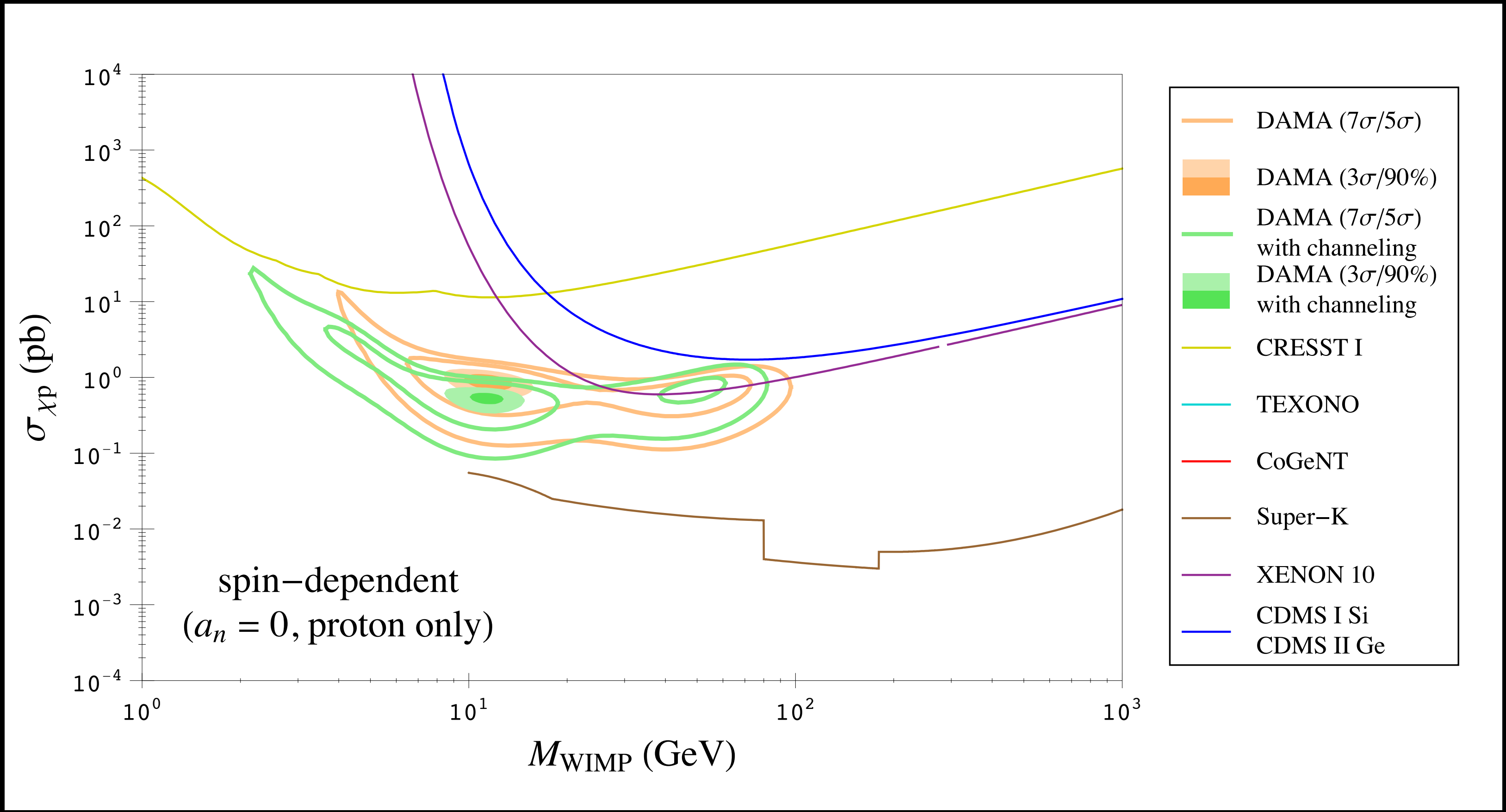
Spin-independent interactions



Savage, Gelmini, Gondolo, Freese 2010

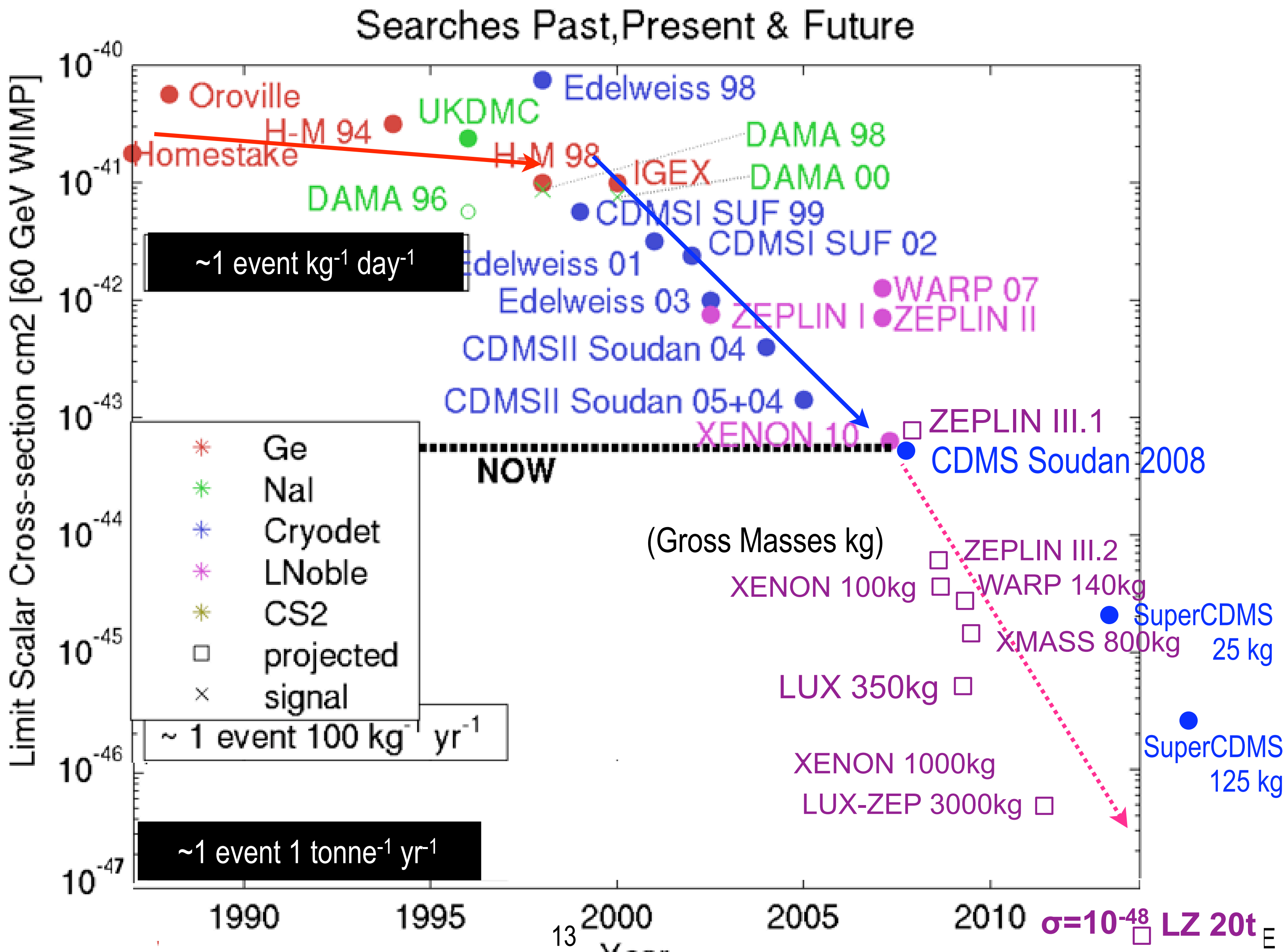
Standard presentation of results

Spin-dependent interactions



Savage, Gelmini, Gondolo, Freese 2009

DM Direct Search Progress Over Time (2009)

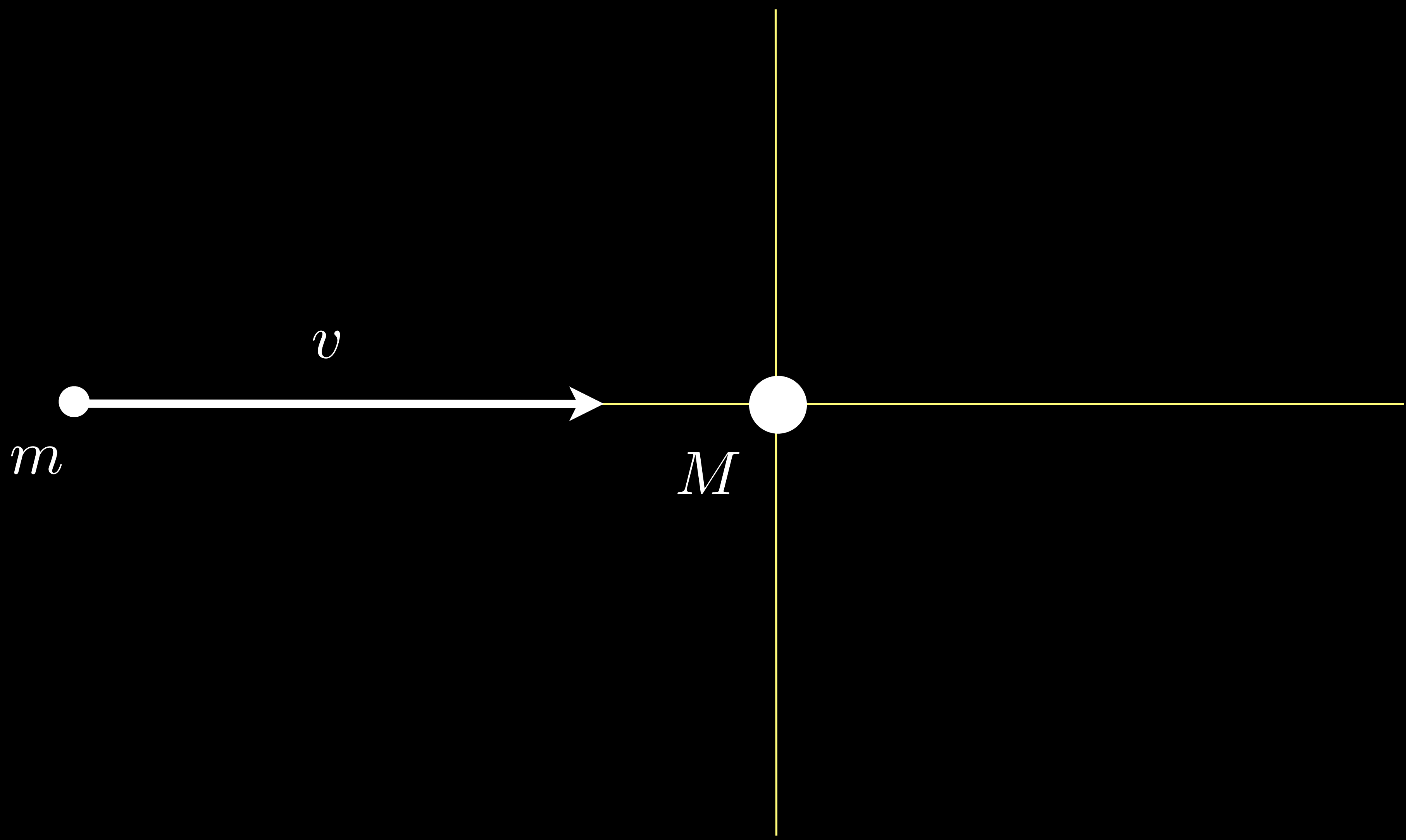


Dark Matt

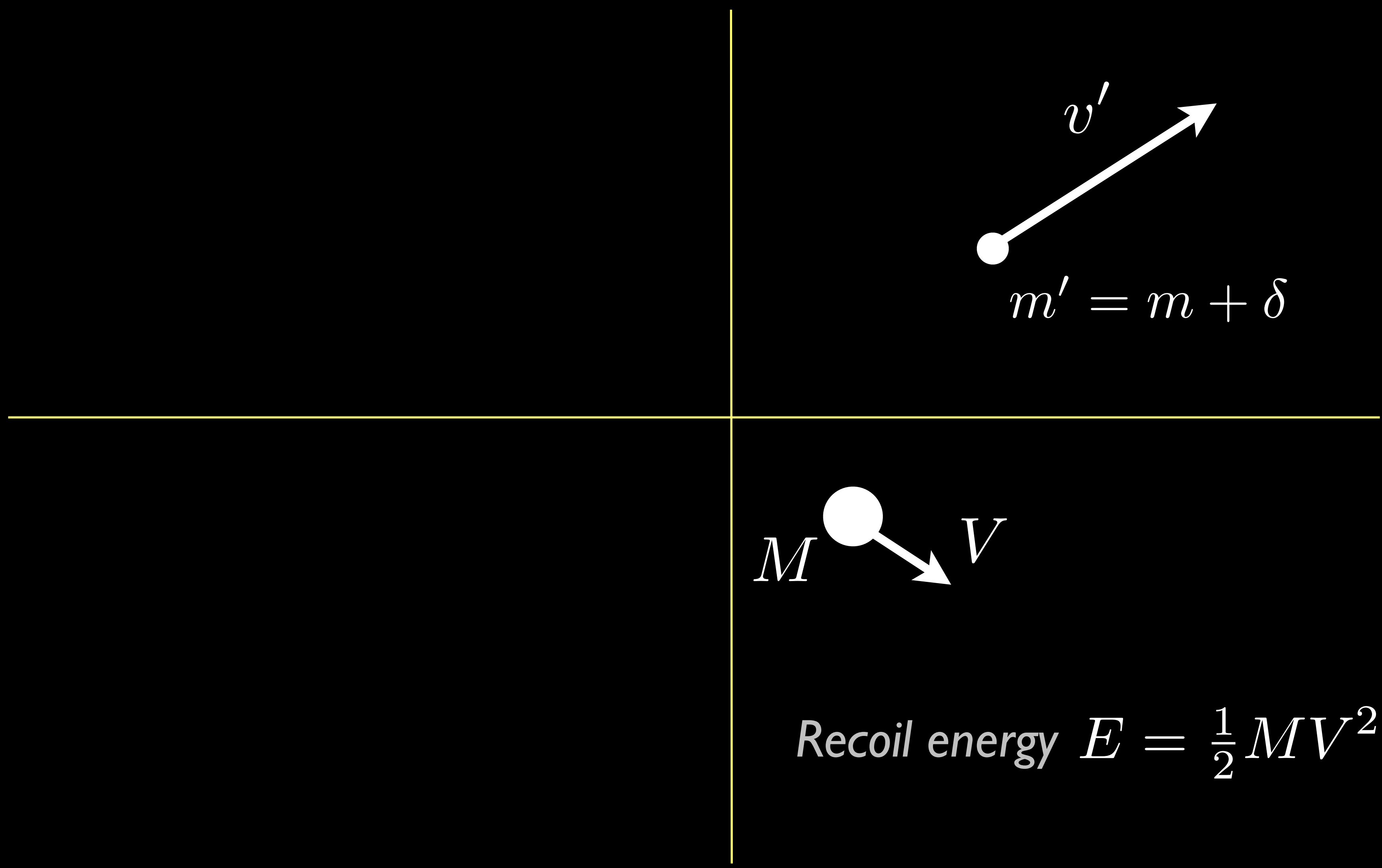
13

Gaitskell 2009

The expected number of events



The expected number of events



The expected number of events

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

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

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

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 factor

How much dark matter comes to Earth?

Local halo density

Velocity distribution

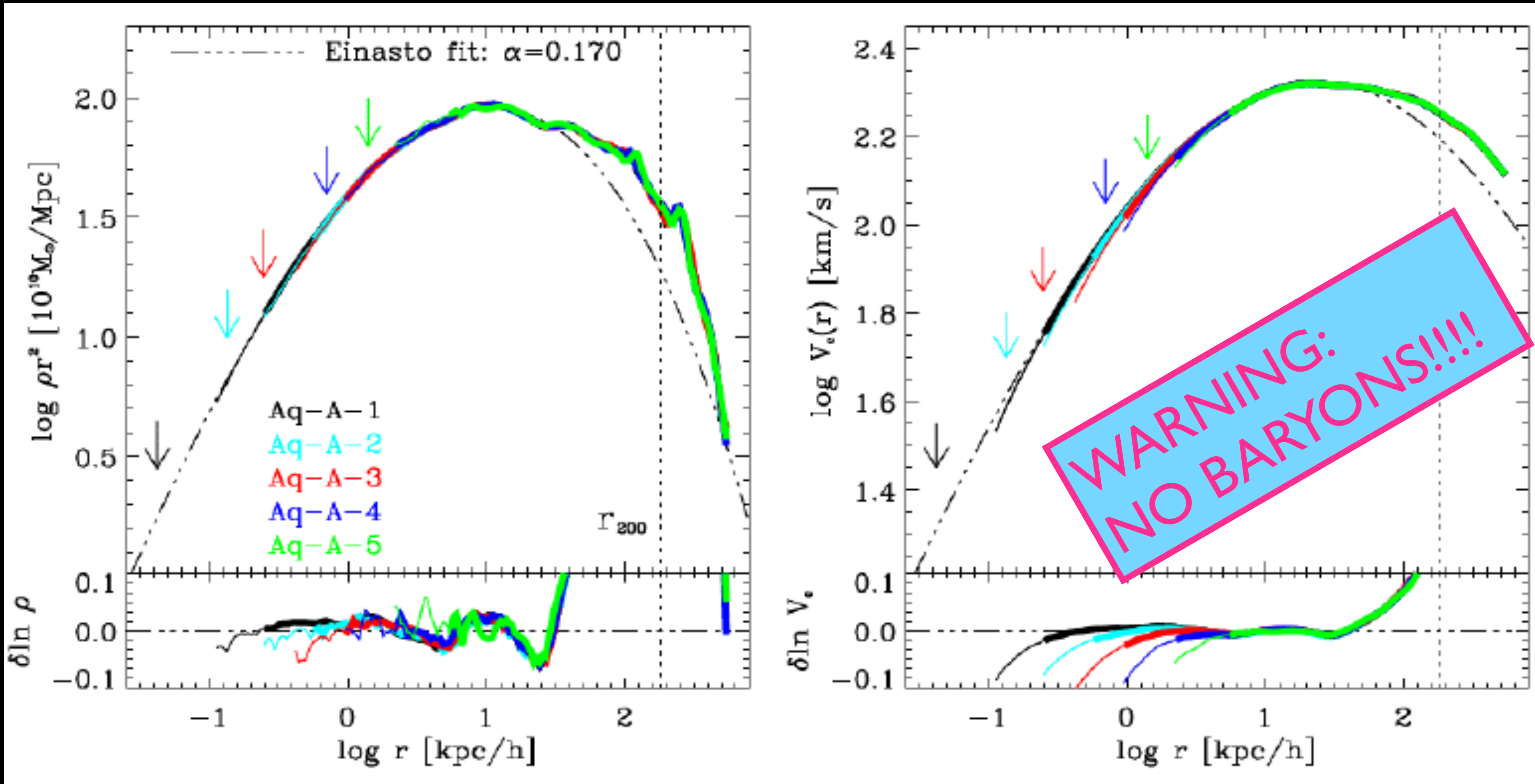
$$(\text{astrophysics}) = \rho \int_{v > v_{\min}(E)} \frac{f(\vec{v}, t)}{v} \, \mathrm{d}^3 v$$

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

Astrophysics factor: local density

Galactic density profile from Aquarius simulations

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



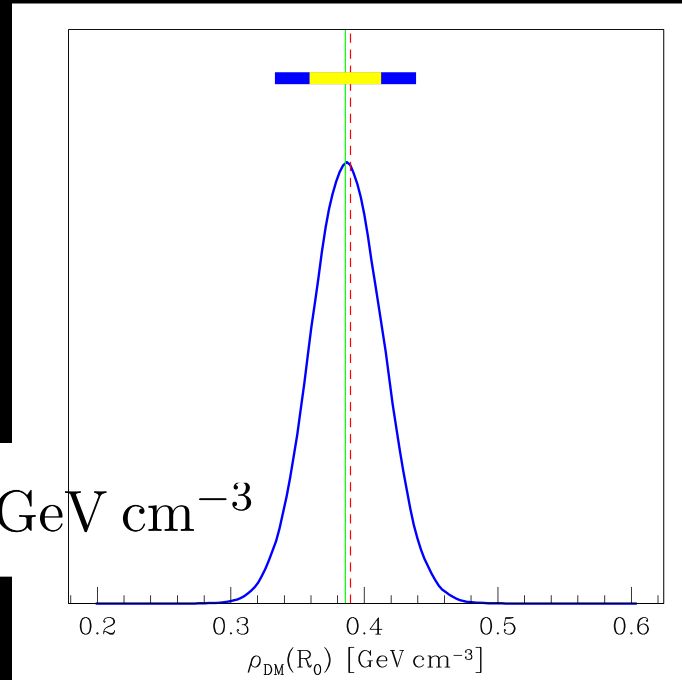
Astrophysics factor: local density

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

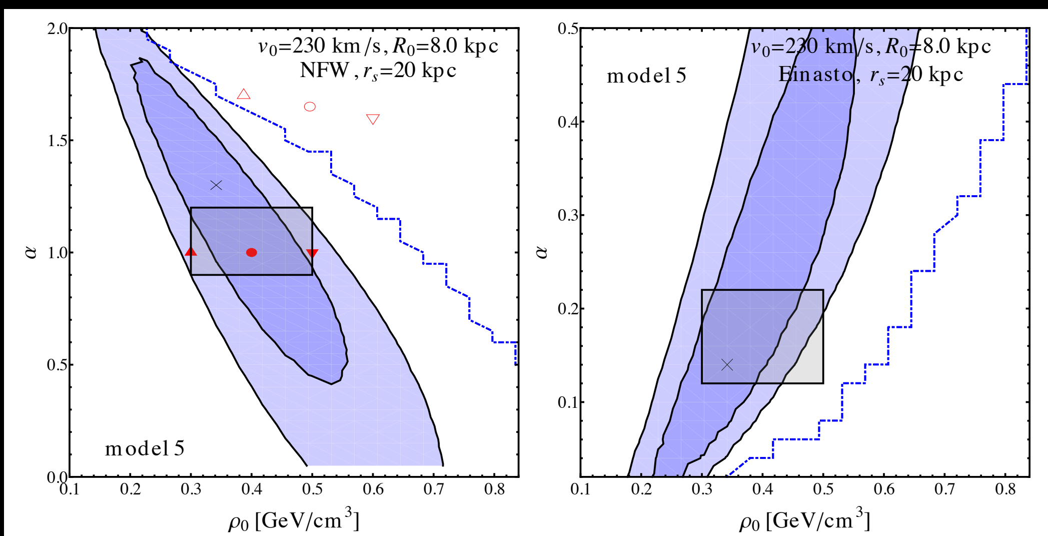
Salucci et al 2010

Local density from galactic modeling

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



Ullio, Catena 2009



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

Iocco, Pato, Bertone, Jetzer 2010

Astrophysics factor: velocity distribution

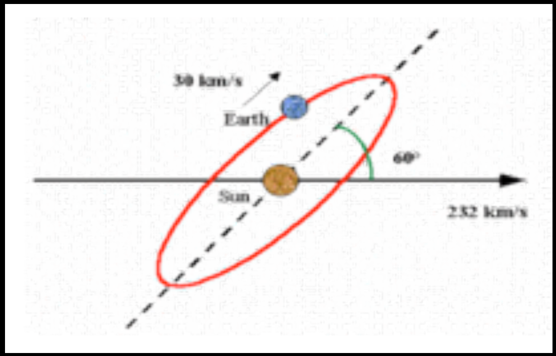
The velocity factor $\eta(E,t) = \int_{v > v_{\min}(E)} \frac{f(\vec{v},t)}{v} \, \mathrm{d}^3 v$

- 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)

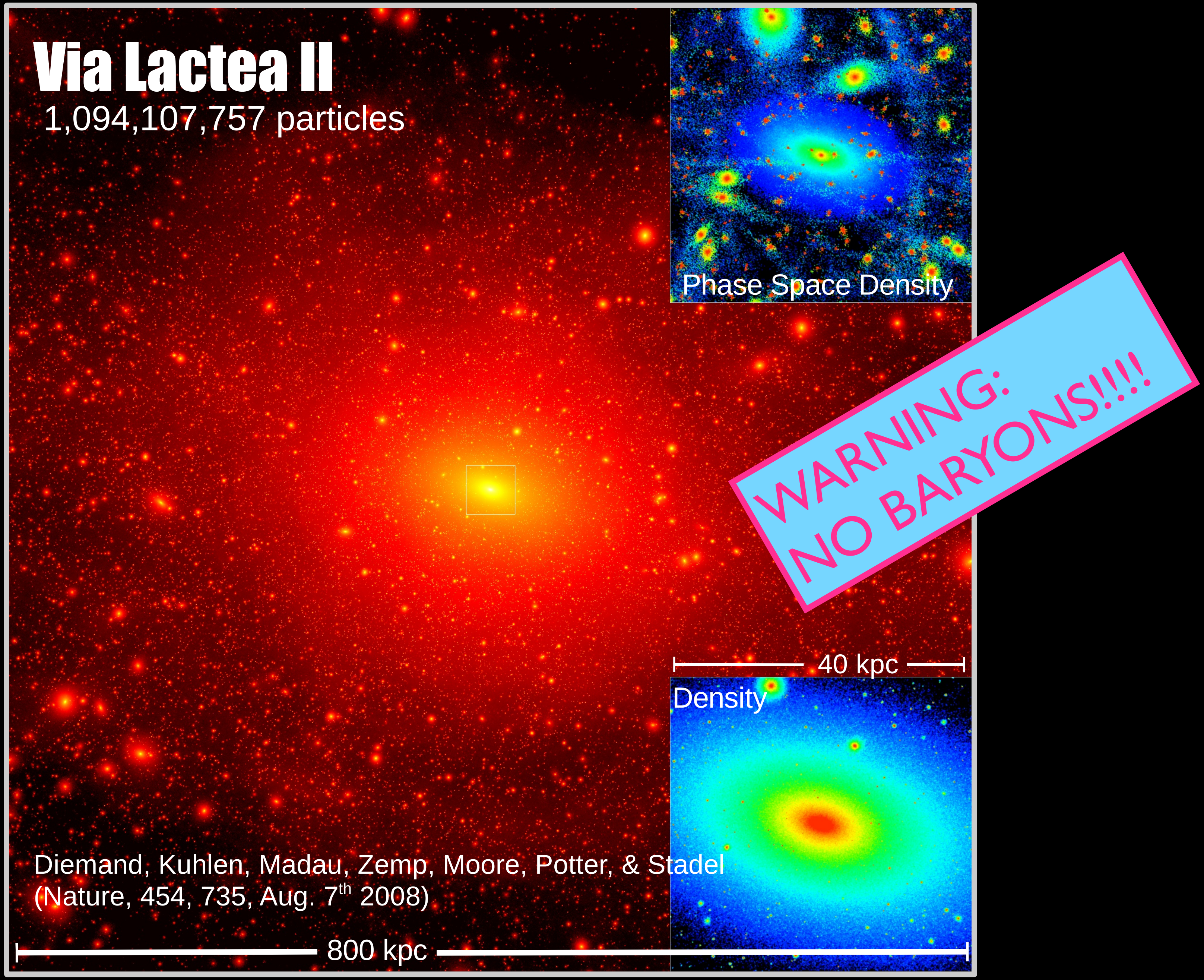
Example: annual modulation

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



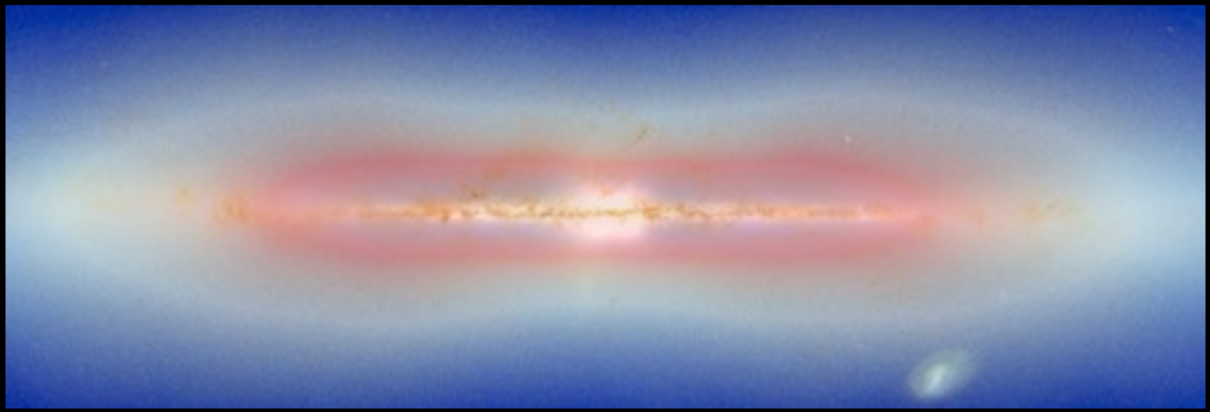
Drukier, Freese, Spergel 1986

Astrophysics factor: velocity distribution



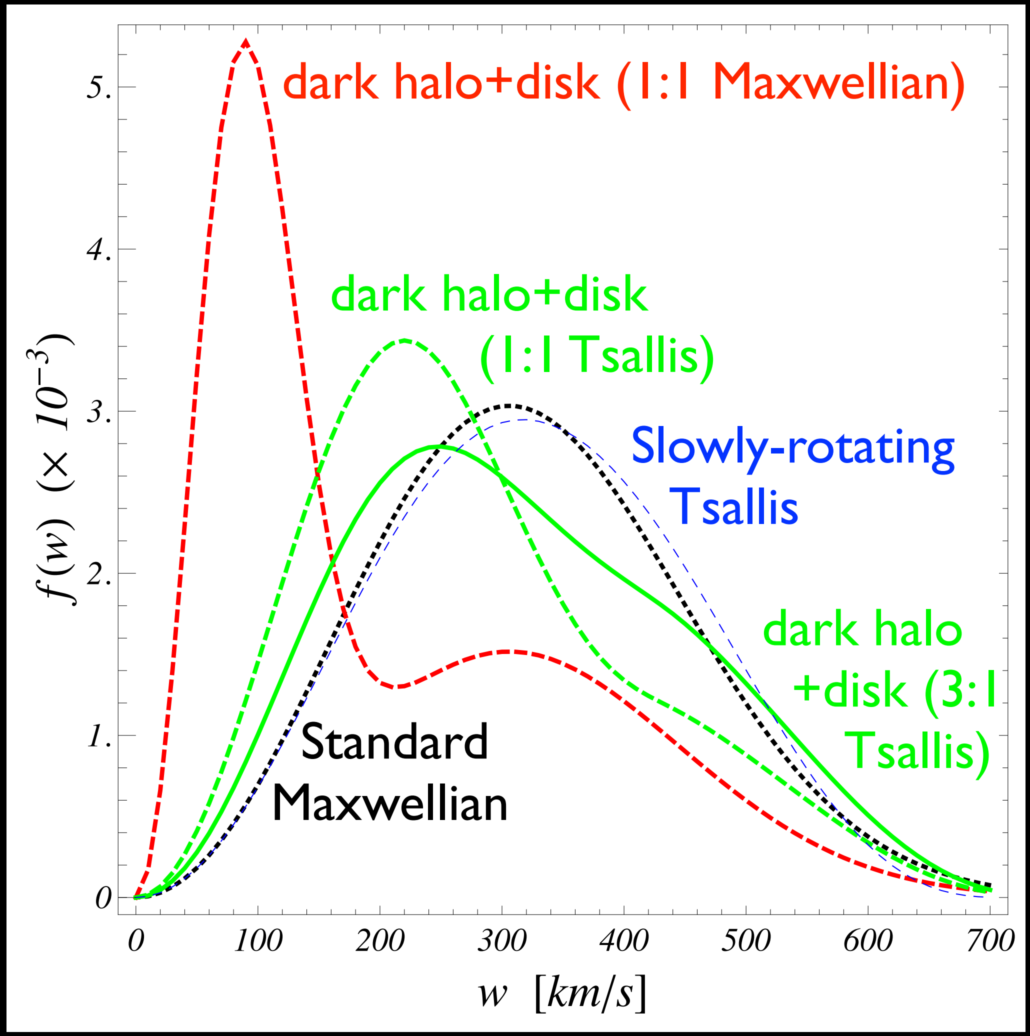
Astrophysics factor: velocity distribution

Inclusion of baryonic disk may lead to a dark disk



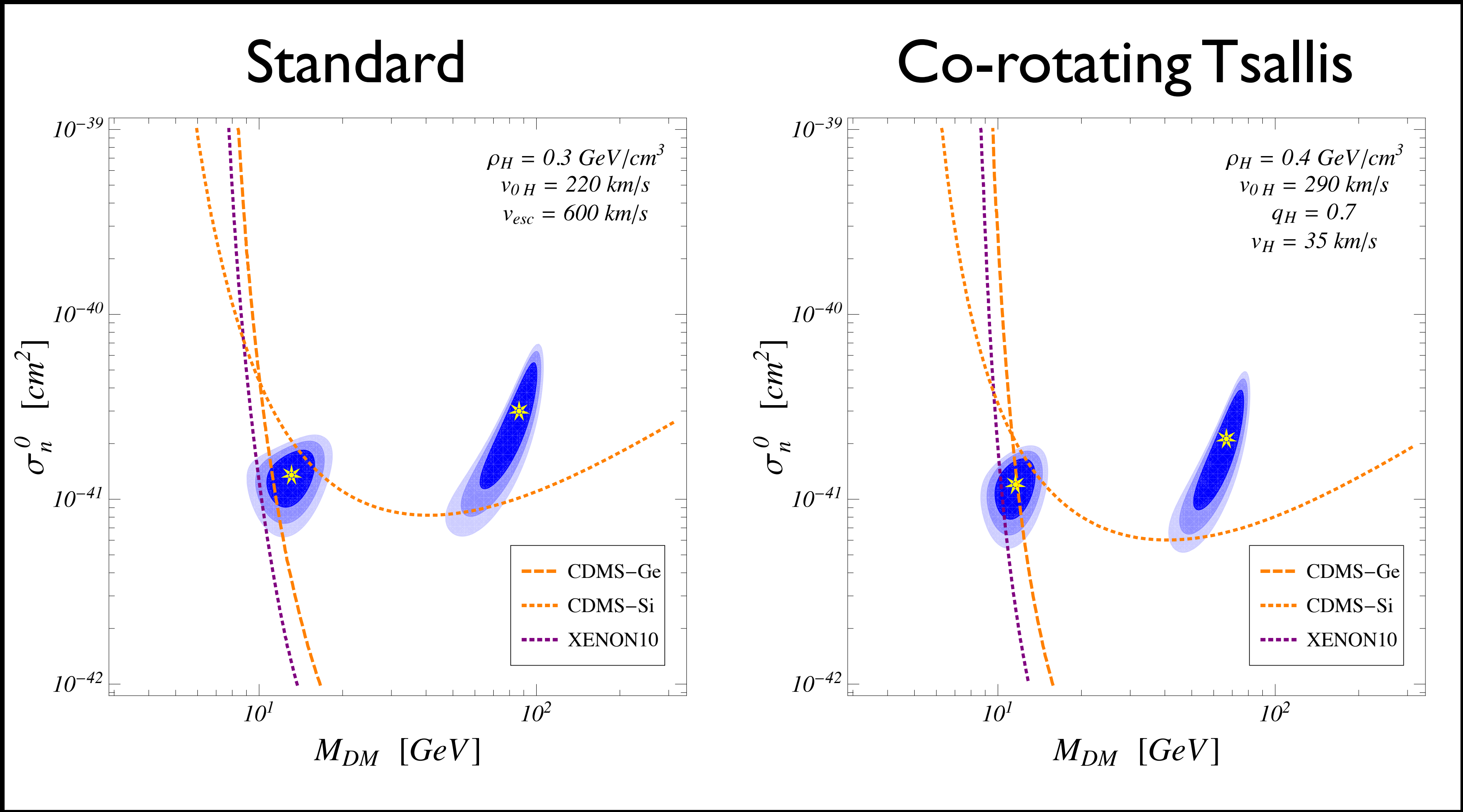
Read, Lake, Agertz, De Battista 2008

Astrophysics factor: velocity distribution



Ling 2009

Astrophysics factor: velocity distribution



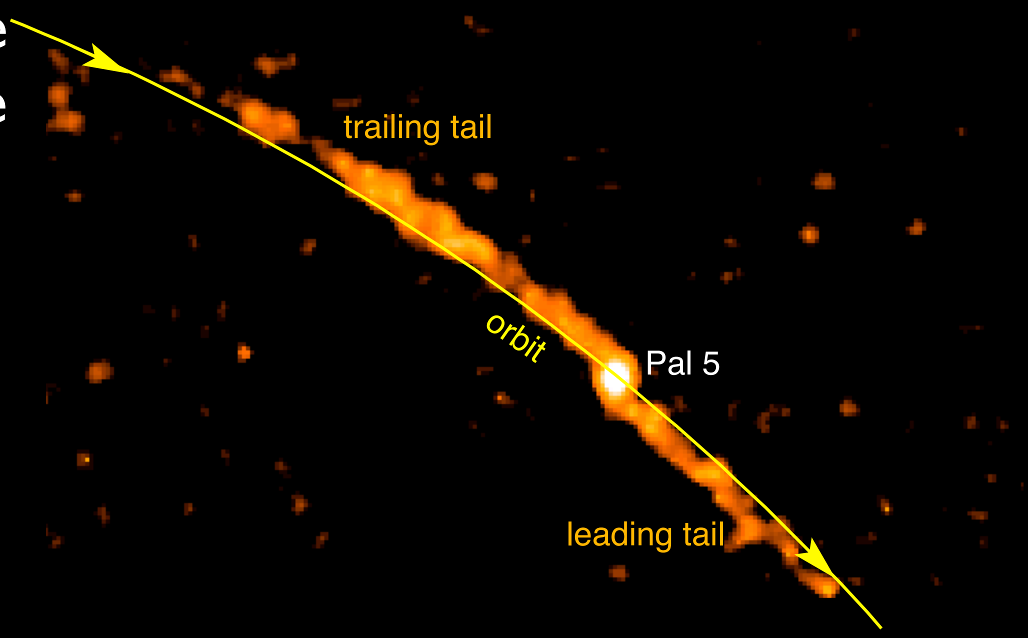
Ling 2009

Astrophysics factor: velocity distribution

Tidal forces can destroy subhalos and generate tidal streams

Streams of stars have been observed in the galactic halo

SDSS-1
2MASS
SEGUE
....



Odenkirchen et al 2002 (SDSS)

Astrophysics factor: velocity distribution

Stellar streams near the Sun

Table 1. Current census of solar neighborhood halo streams

Stream	$\langle v_\phi \rangle$ (km s^{-1})	σ_{v_ϕ} (km s^{-1})	$\langle$[Fe/H]$\rangle$	$\sigma_{\mathrm{[Fe/H]}}$	N	References
C2	-75	24	-1.6	0.4	53	Klement et al. (2009)
S_3	-48 [a]	14	-1.6	0.4	33	Klement et al. (2009)
Kapteyn	-46 [b]	63	-1.5	0.3	14	Wylie-de Boer et al. (2010)
ω Cen	-30	...	...	...	56	Dinescu (2002)
C3	-24	14	-1.7	0.4	44	Klement et al. (2009)
C1	-16	9	-1.5	0.2	32	Klement et al. (2009)
S_3	-9 [a]	10	-1.9	0.5	10	Dettbarn et al. (2007)
S_2	-7	4	-1.9	0.1	4	Dettbarn et al. (2007)
S_1	21	2	-1.7	0.5	4	Dettbarn et al. (2007)
SKOa	43	25	-2.0	0.2	6	Smith et al. (2009)
R2	59	15	-1.4	0.3	19	Klement et al. (2009)
KFR08	69	11	-0.7	0.3	19	Bobylev et al. (2010)
Groombridge 1830	71 [c]	18	...	...	5	Eggen and Sandage (1959)
RHLS	99	25	-2.0	0.2	3	Re Fiorentin et al. (2005)
H99	140	33	-1.8	0.4	33	Kepley et al. (2007); Klement et al. (2009)
C4	173	9	-2.3	0.3	20	Klement et al. (2009)

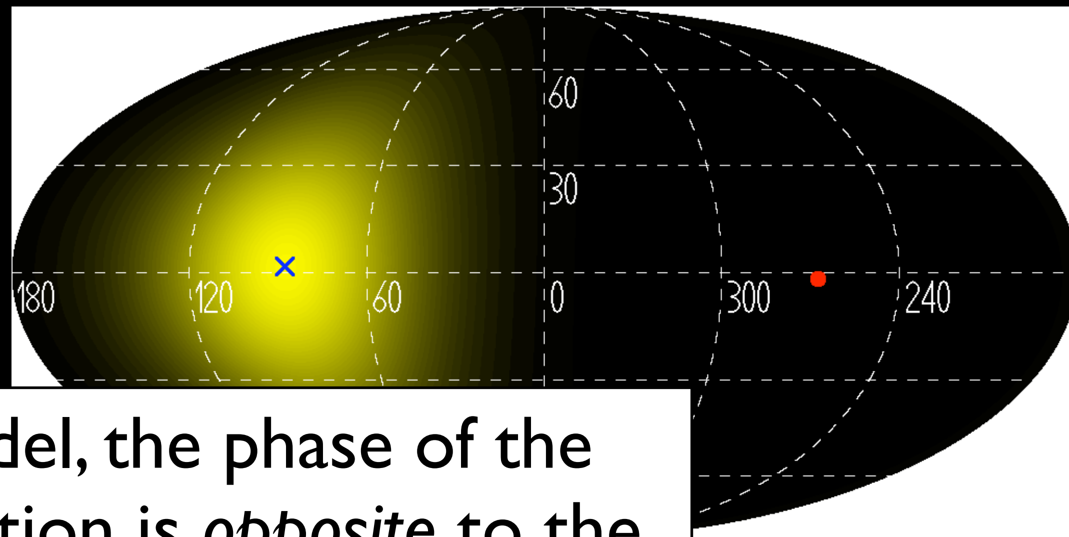
Klement 2010

Astrophysics factor: velocity distribution

WIMP arrival directions

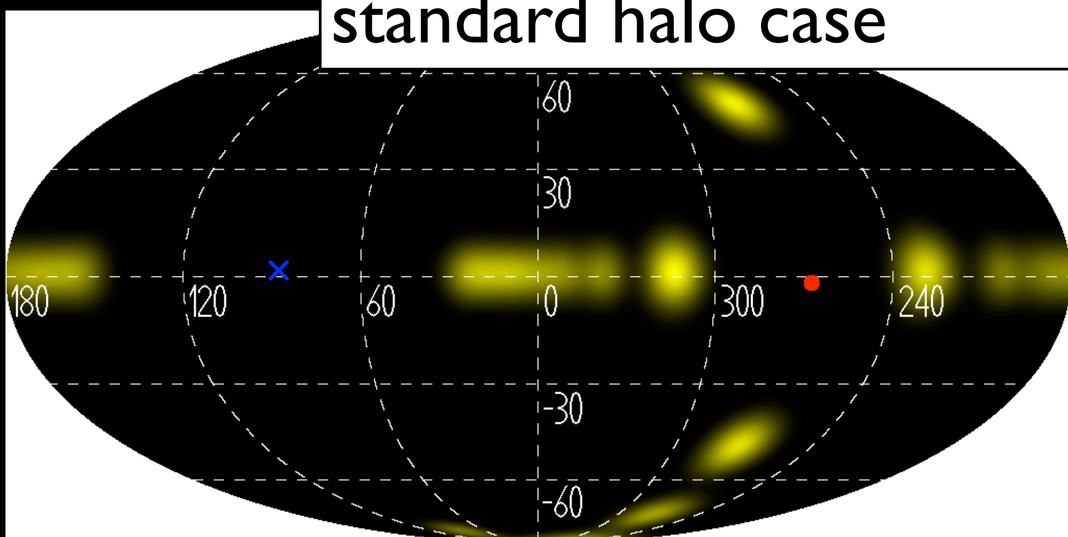
Standard halo

$$\frac{dF}{d\Omega} = \int v\, f(\mathbf{v})\, v^2 dv$$



In Sikivie's model, the phase of the annual modulation is *opposite* to the standard halo case

ni, Gondolo 2001



CAUTION
Extreme model

Sikivie's model

Astrophysics factor

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

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

Particle physics factor

What force couples dark matter to nuclei?

Spin-independent and spin-dependent cross sections

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

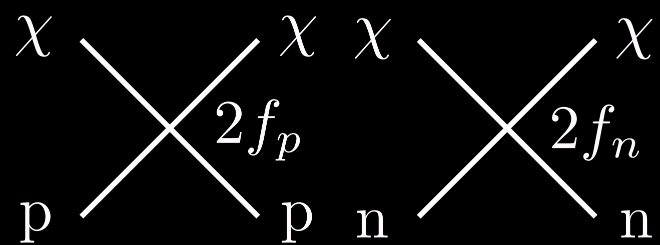
Reduced mass $\mu = mM/(m+M)$

Particle physics factor

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

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

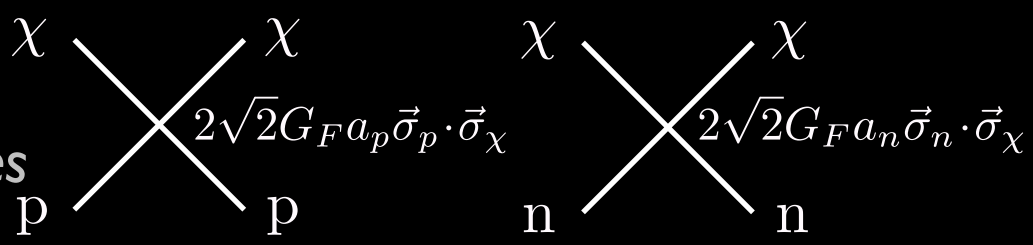
Main uncertainty is $\langle m_s \bar{s} s \rangle$ (strange content of nucleon)

Particle physics factor

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

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

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

Exchange scalar, vector, pseudovector, ... ?

1. Come up with an idea, possibly explaining more than one experiment.

2. Test it against existing data. If it passes all tests, go to 3.

3. Make predictions for upcoming experiments.

4. Post your findings on arxiv.org.

5. Go to 1.

Exchange scalar, vector, pseudovector, ... ?

- Supersymmetry
- Extra U(1) bosons
- Extended Higgs sector

Just too many theoretical models to mention here.

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

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

The energy response function

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

Recoil energy (keV)

Energy observed in detector, typically expressed in keV electron equivalent (keV$_{\text{ee}}$)

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.*

The energy response function

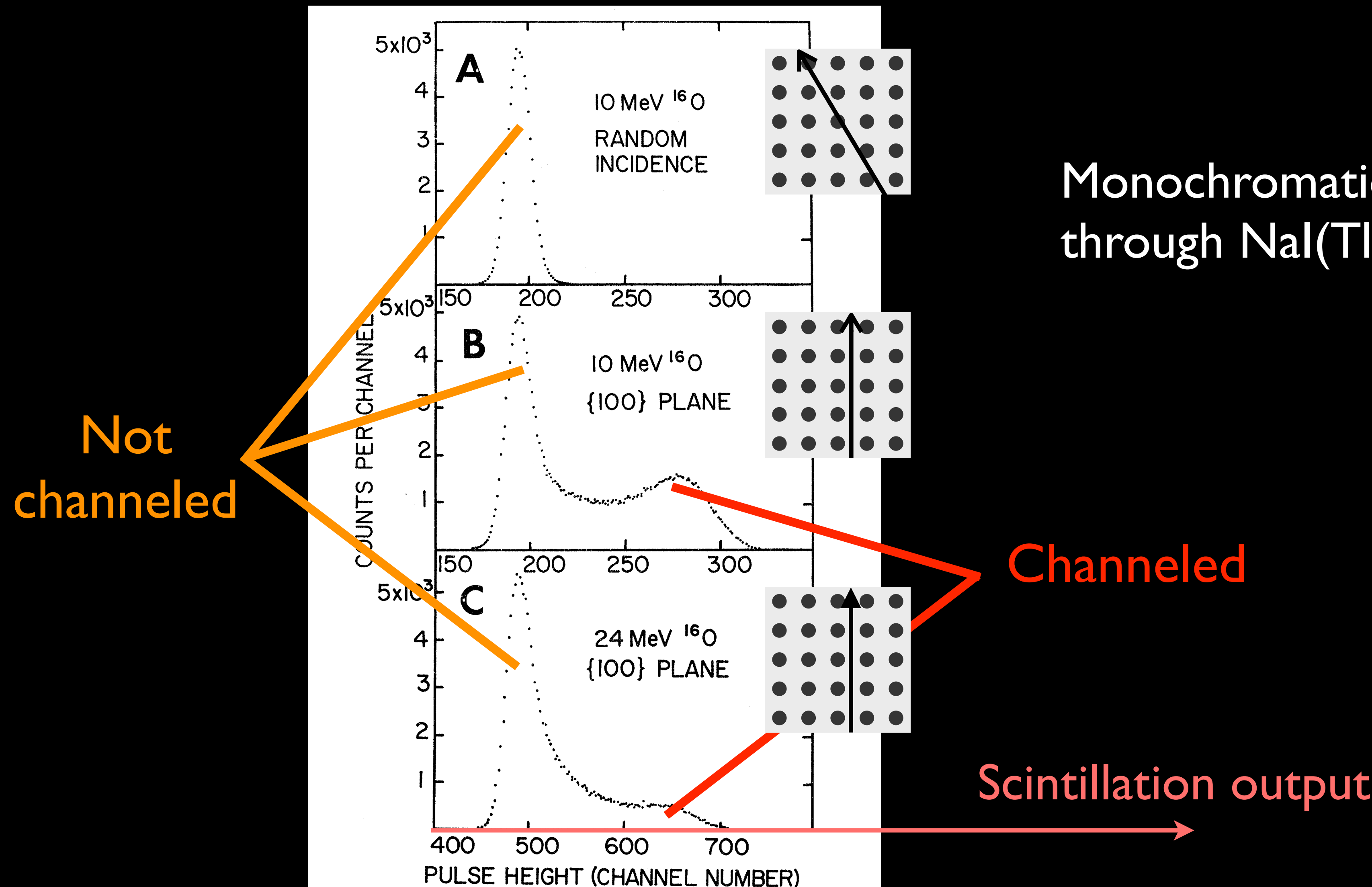


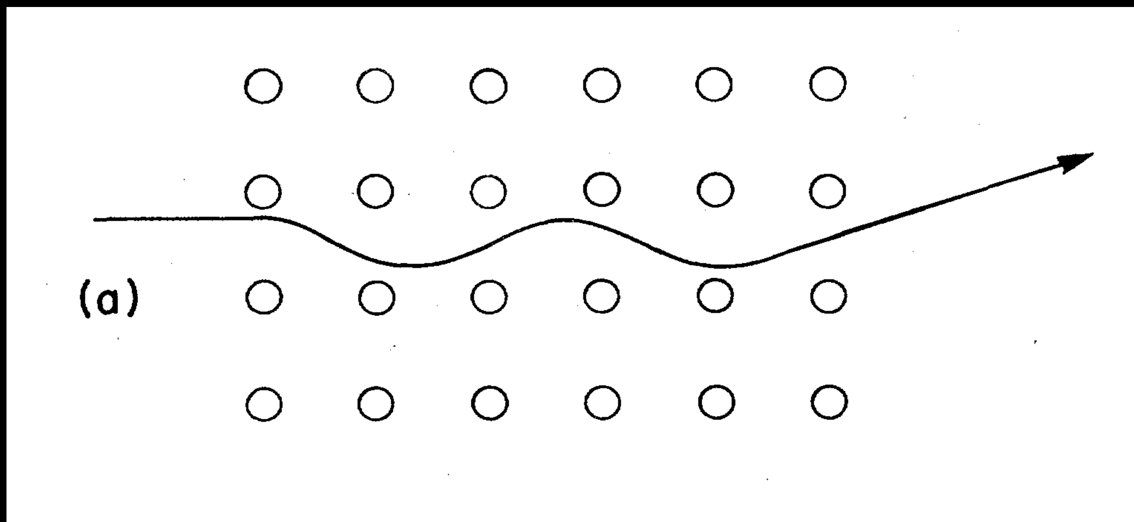
FIG. 2. (a) Pulse-height spectrum from 10-MeV ^{16}O on NaI(Tl) for incidence along a random direction. (b) Pulse-height spectrum from 10-MeV ^{16}O along a {100} plane. (c) Pulse-height spectrum from 24-MeV ^{16}O along a {100} plane. A light guide was used in all cases.

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

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

The energy response function

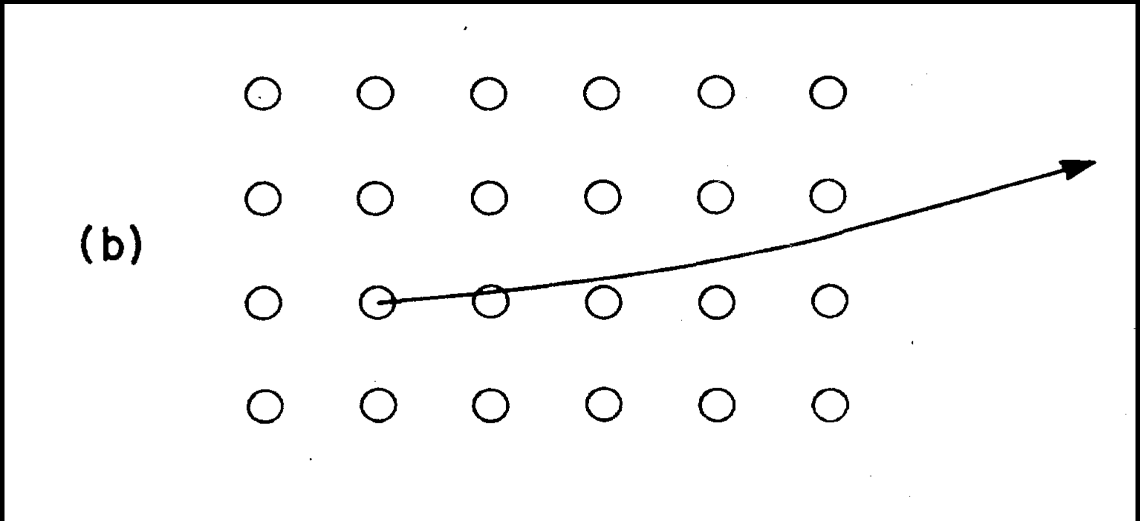
Channeling. If an ion incident onto the crystal moves in the direction of a symmetry axis or plane of the crystal, it has a series of small-angle scatterings which maintains it in the open channel. The ion penetrates much further into the crystal than in other directions.



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

The energy response function

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”.

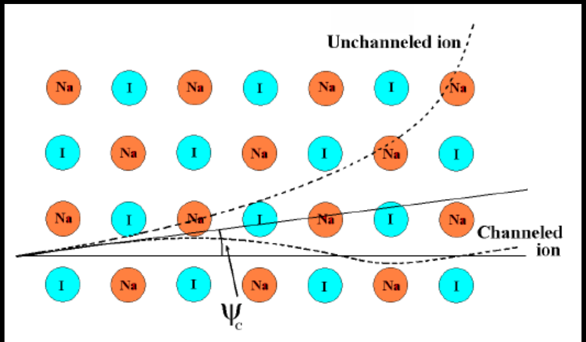


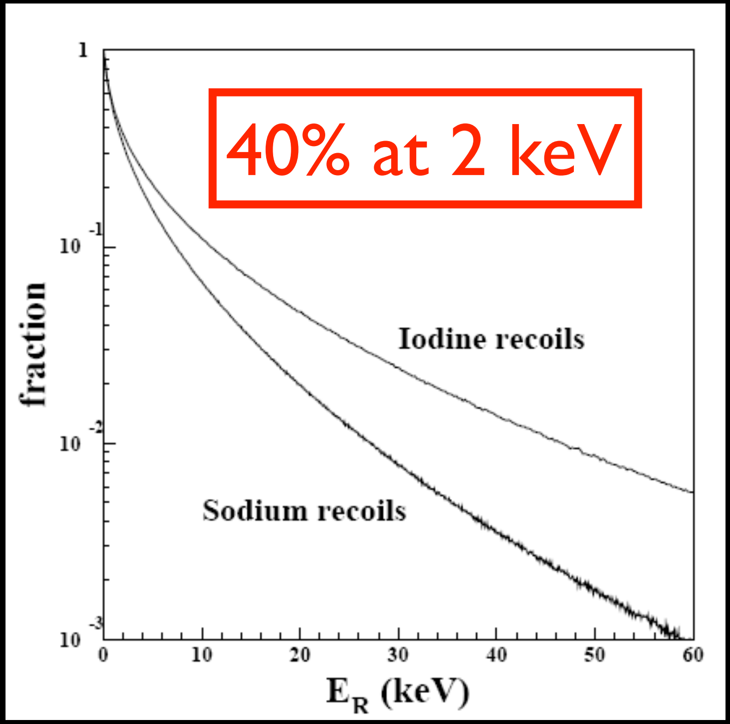
From Gemmel 1974, Rev. Mod. Phys. 46, 129

The energy response function

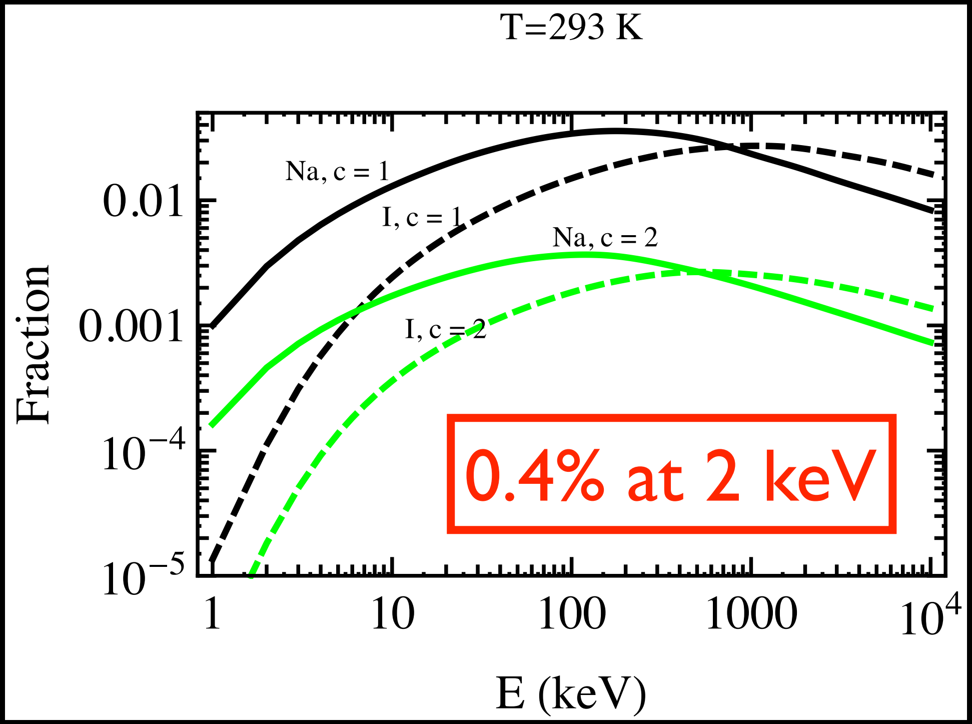
Channeling in DAMA's NaI(Tl) is much less than previously published

Bozorgnia, Gelmini, Gondolo 2010



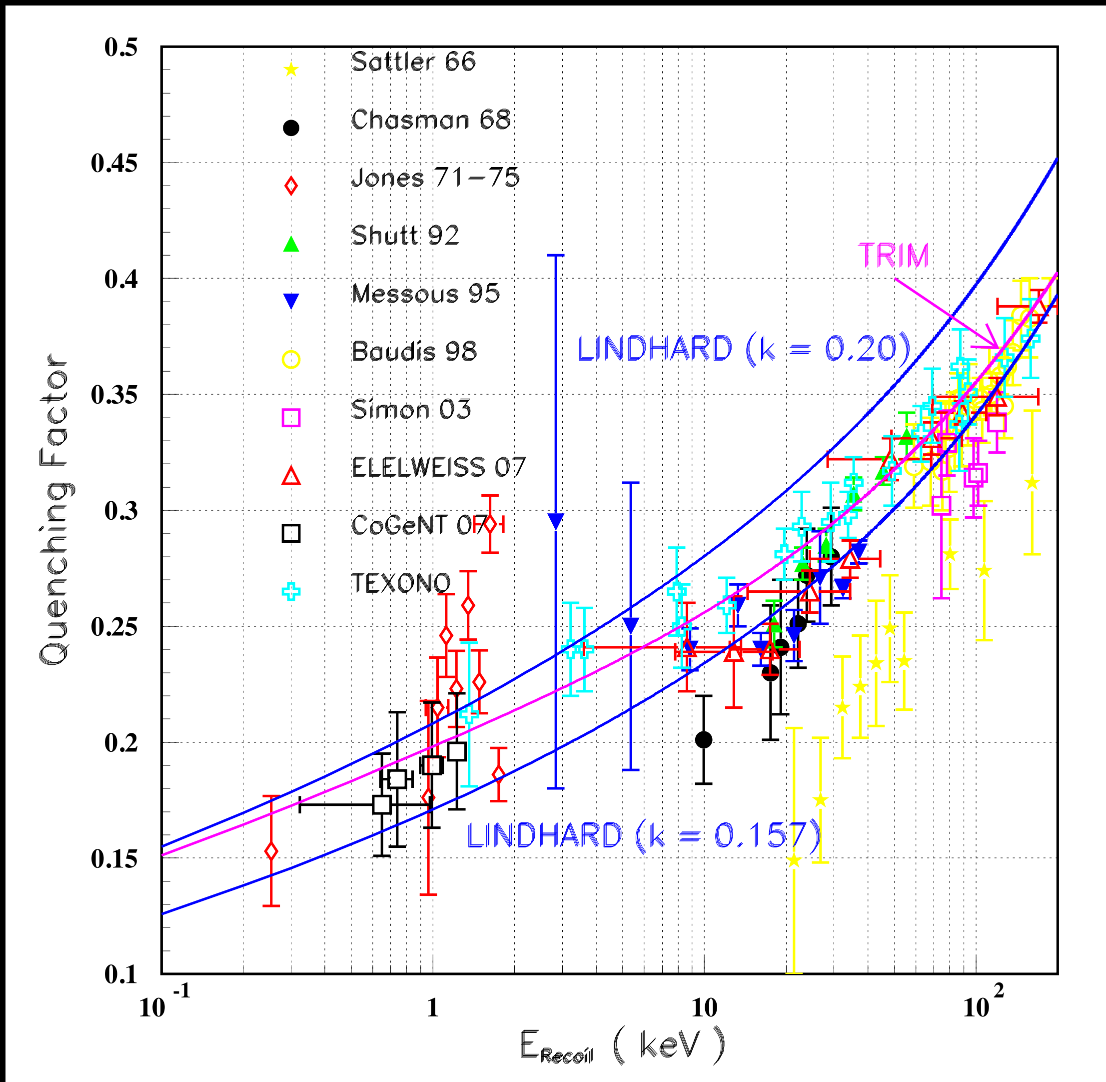


Bernabei et al. 2008



Bozorgnia, Gelmini, Gondolo 2010

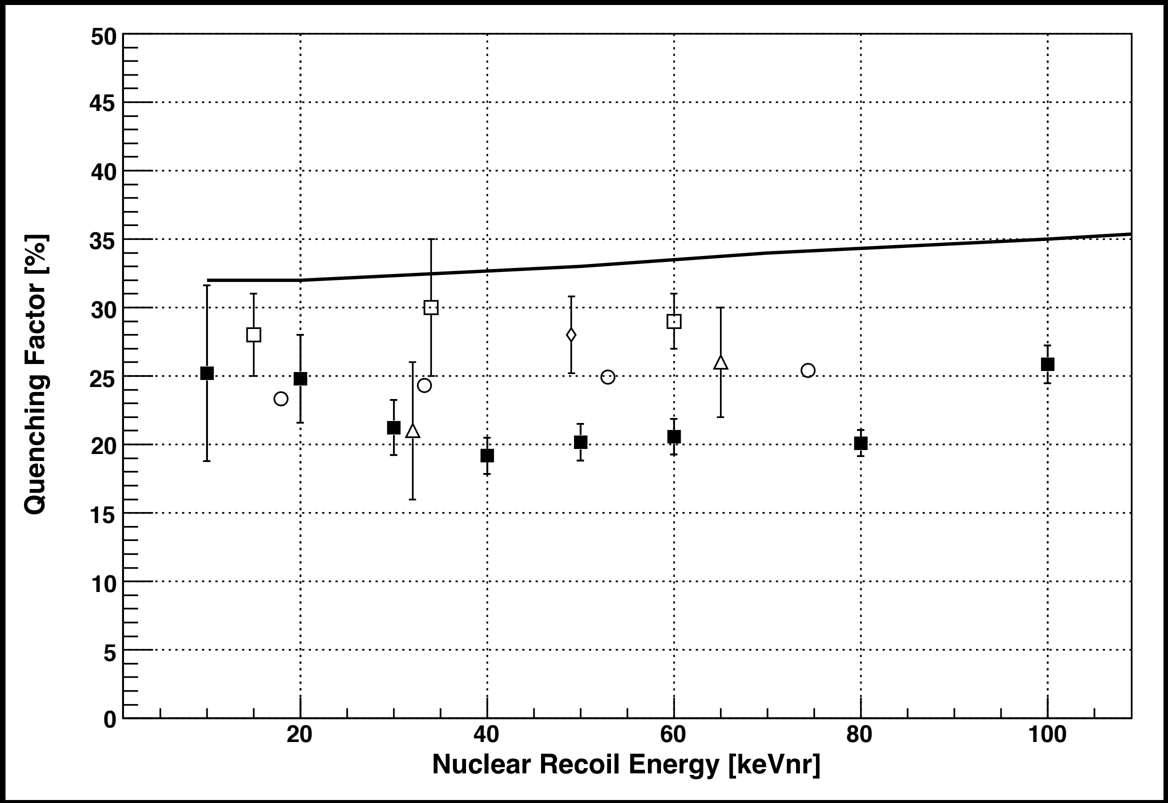
The energy response function



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

Lin et al (TEXONO) 2007

The energy response function



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

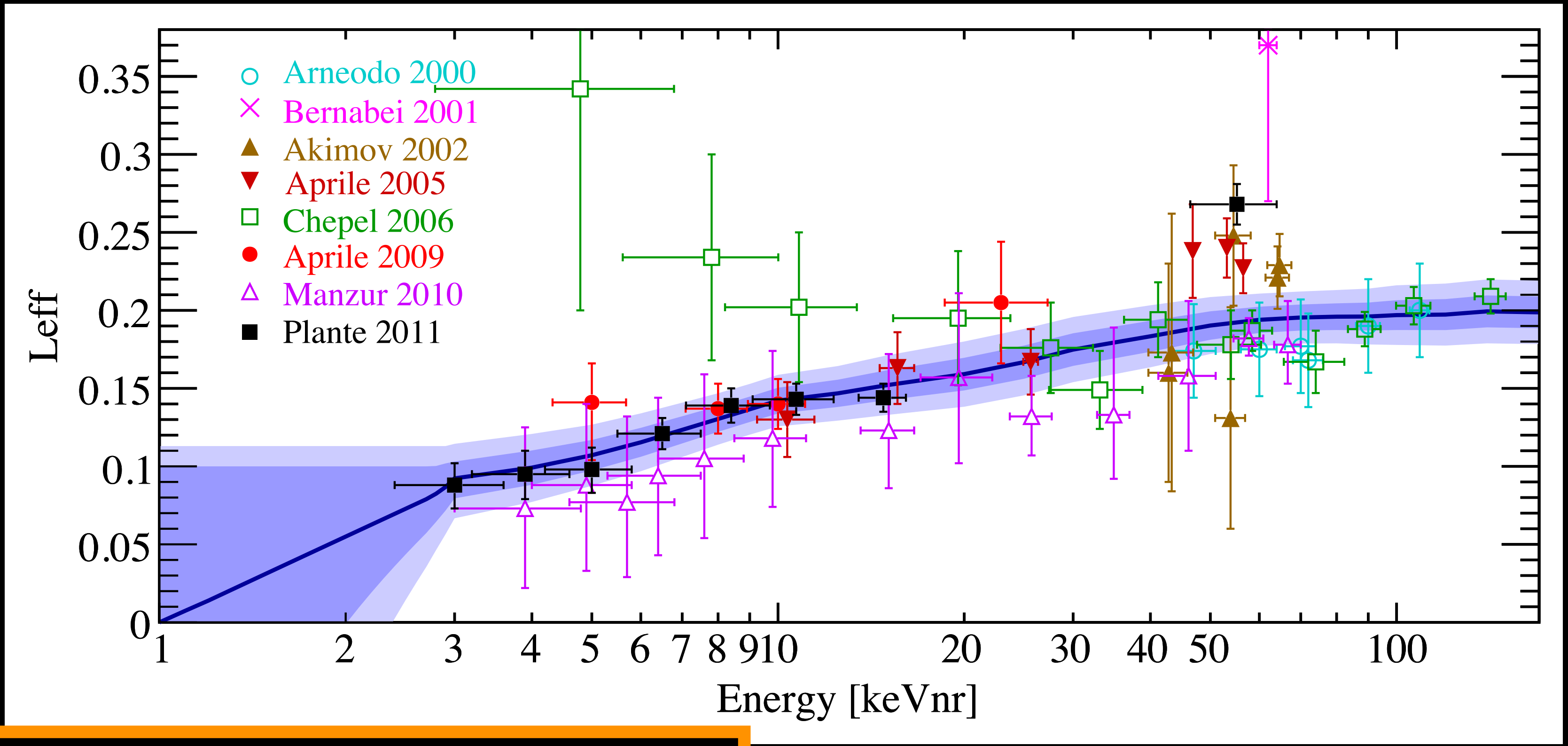
Chagani et al 0806.1916

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

The energy response function

Compilation of measurements of the light efficiency factor *Leff* in liquid xenon

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



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

Aprile et al (XENON100), 1104.2549

Finding dark matter

Finding a needle in a haystack

Hunts Needle in a Haystack

HOW LONG does it take to find a needle in a haystack? Jim Moran, Washington, D. C., publicity man, recently dropped a needle into a convenient pile of hay, hopped in after it, and began an intensive search for (a) some publicity and (b) the needle. Having found the former, Moran abandoned the needle hunt.

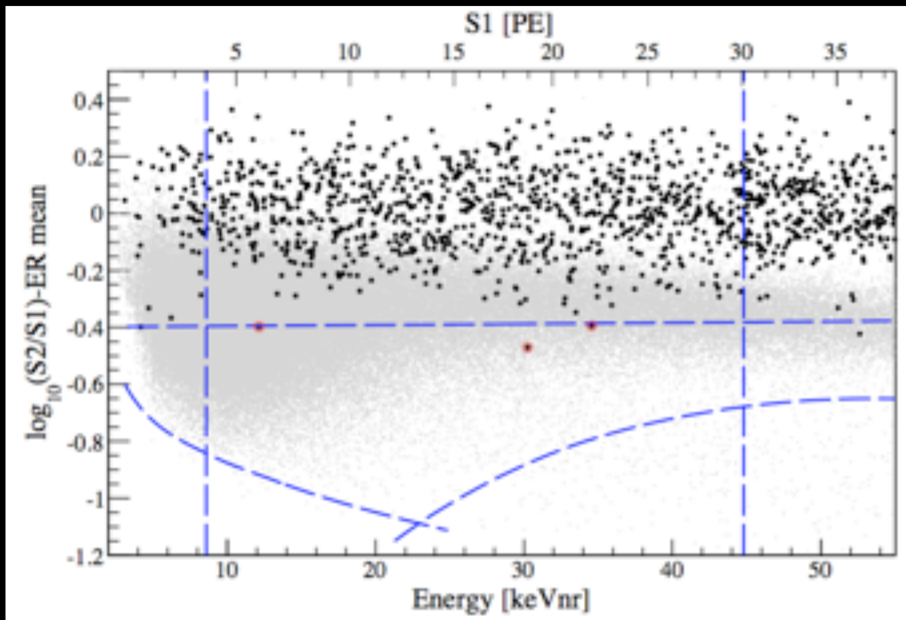
Popular Science magazine
July 1939

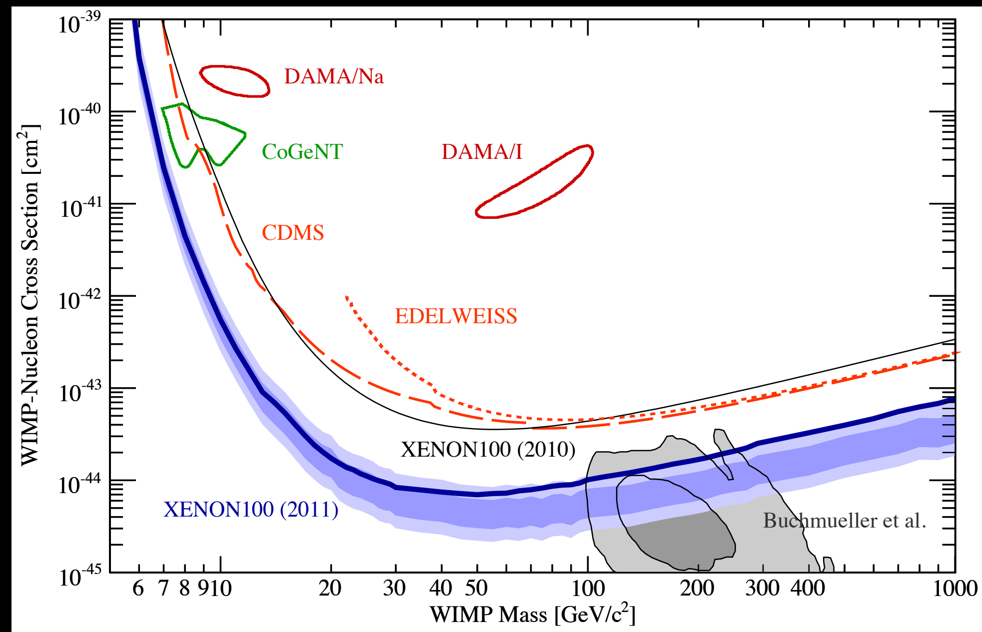
- Experiments with e.m./nuclear discrimination observe events
  - Limits are placed using
    - the "optimum interval" method, if backgrounds are not modeled
    - likelihood analysis, if backgrounds are modeled
- Two experiments without e.m./nuclear discrimination observe an annual modulation
  - Regions of interest are drawn with chi-squared fits to temporal behavior, or with likelihood analyses, or etc.
- Experiments with directional discrimination are still too small

Limits

XENON-100

3 events observed 1.8±0.6 expected background



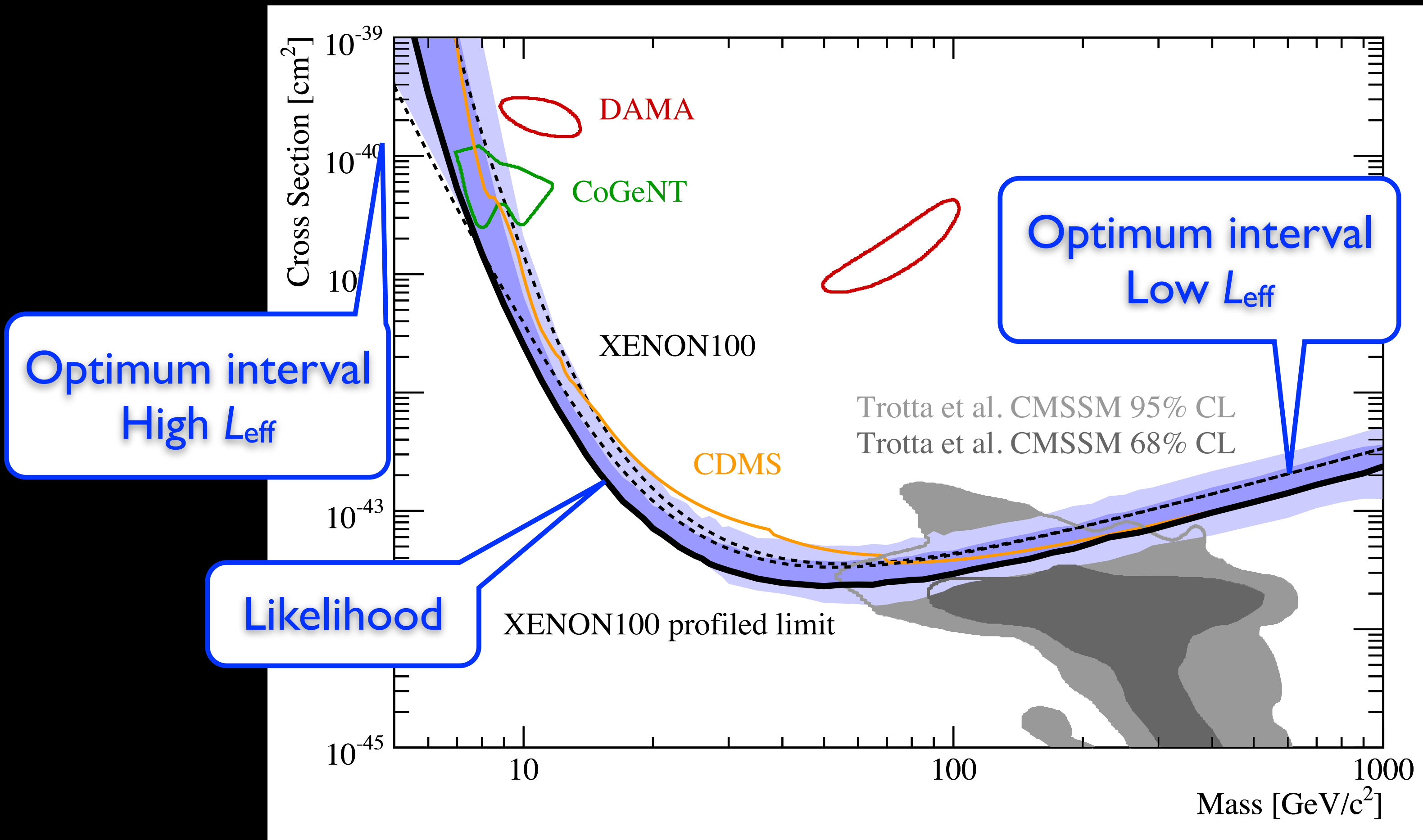


Likelihood

Aprile et al (XENON-100) 1104.2549

XENON-100

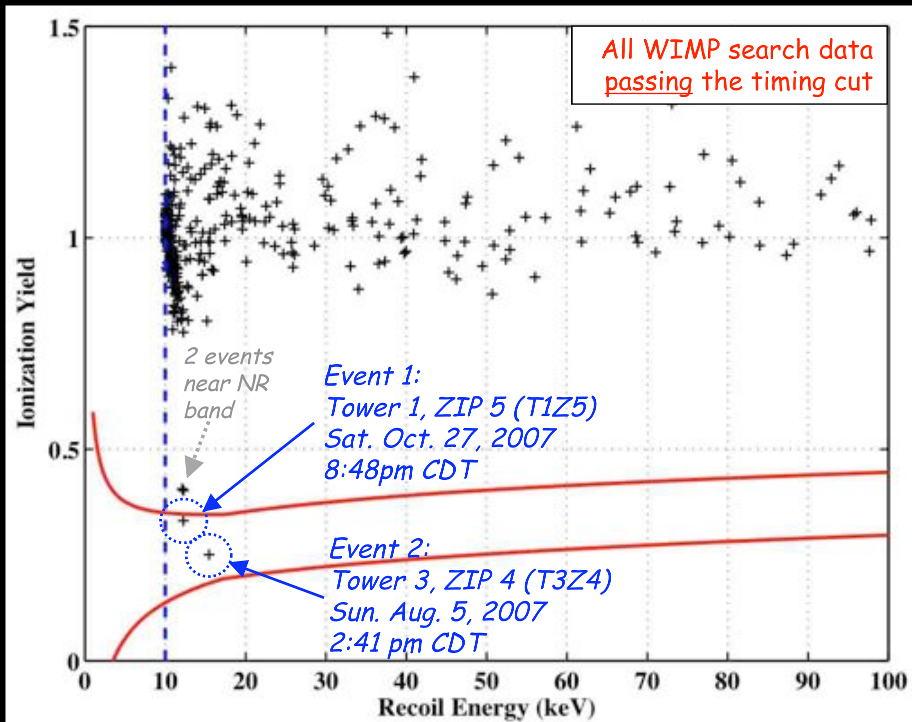
Likelihood vs optimum interval

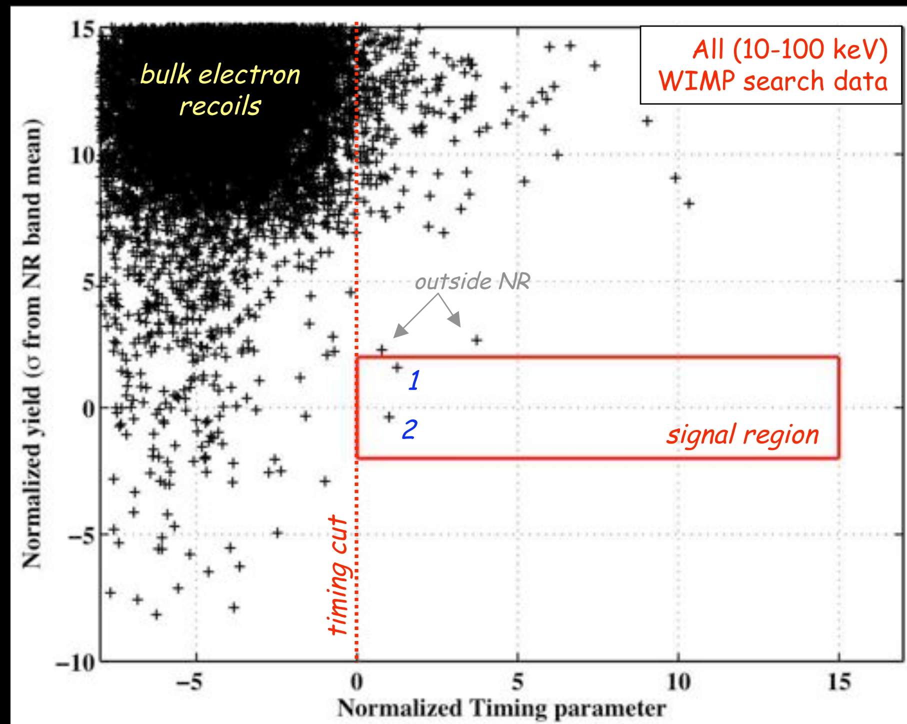


Aprile et al (XENON100), 1103.0303

CDMS

2 events observed 0.8±0.1±0.2 expected background

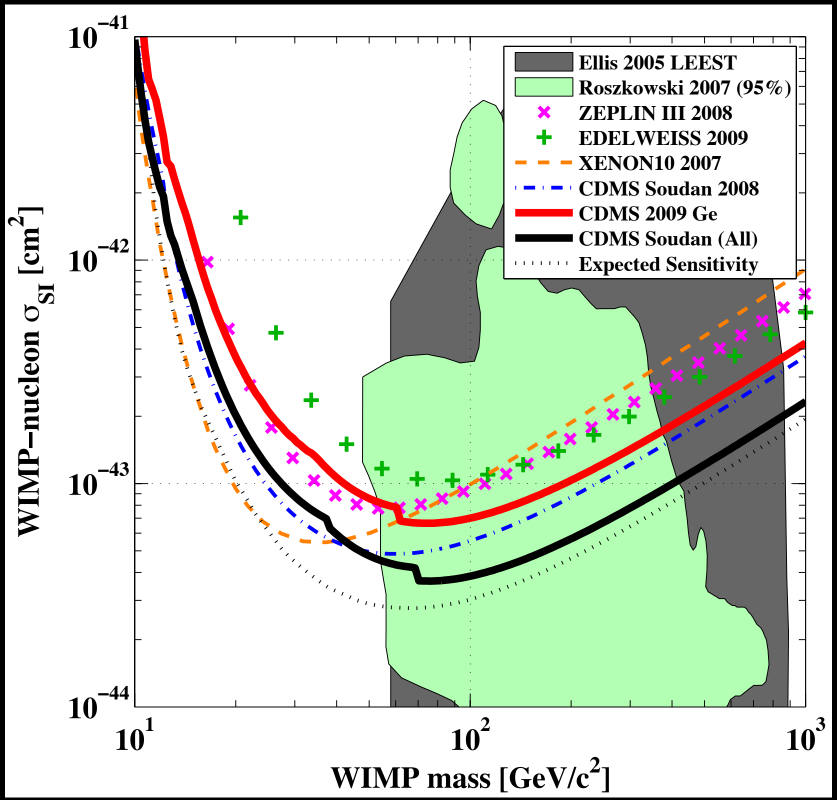




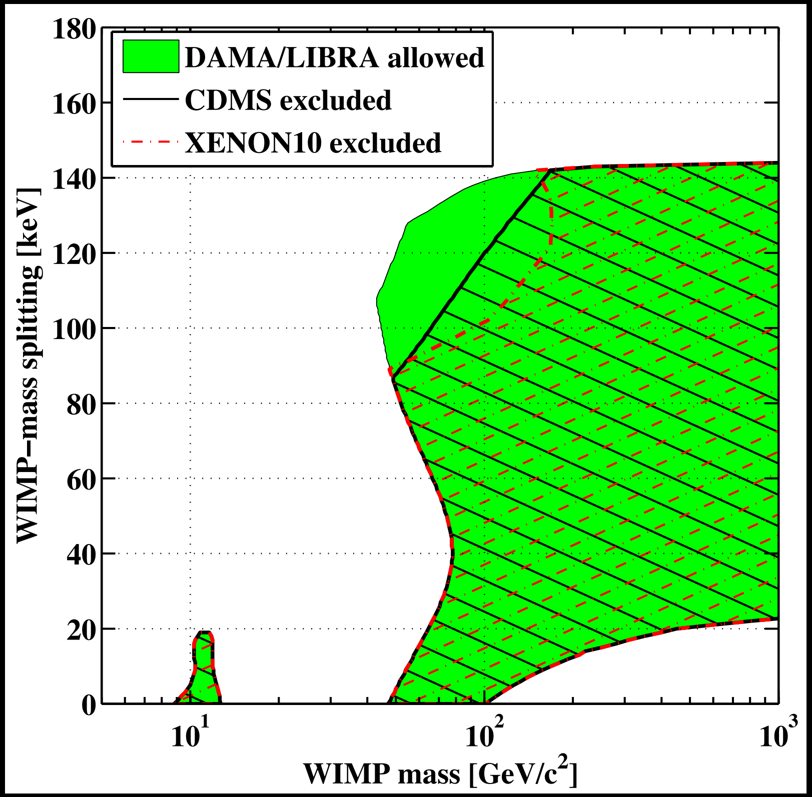
Hsu 2009

CDMS

Optimum interval



Elastic spin-independent

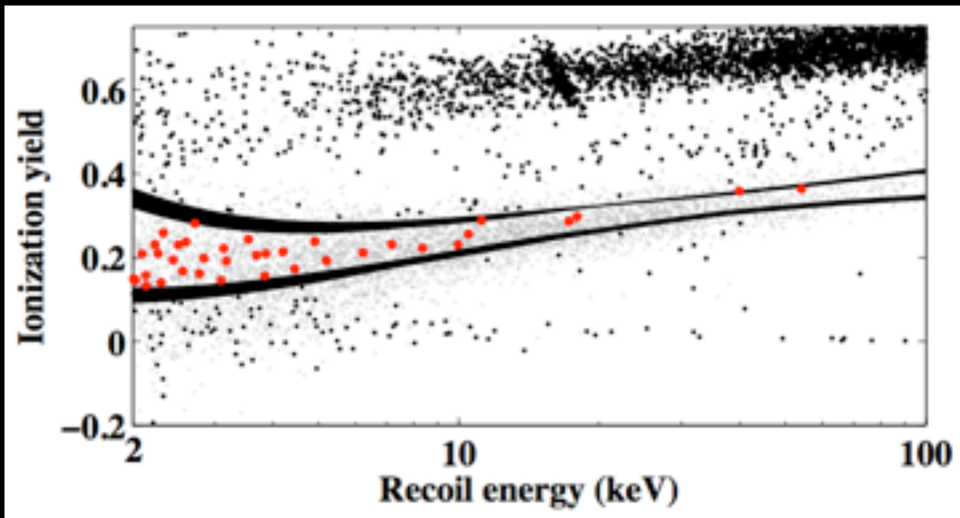


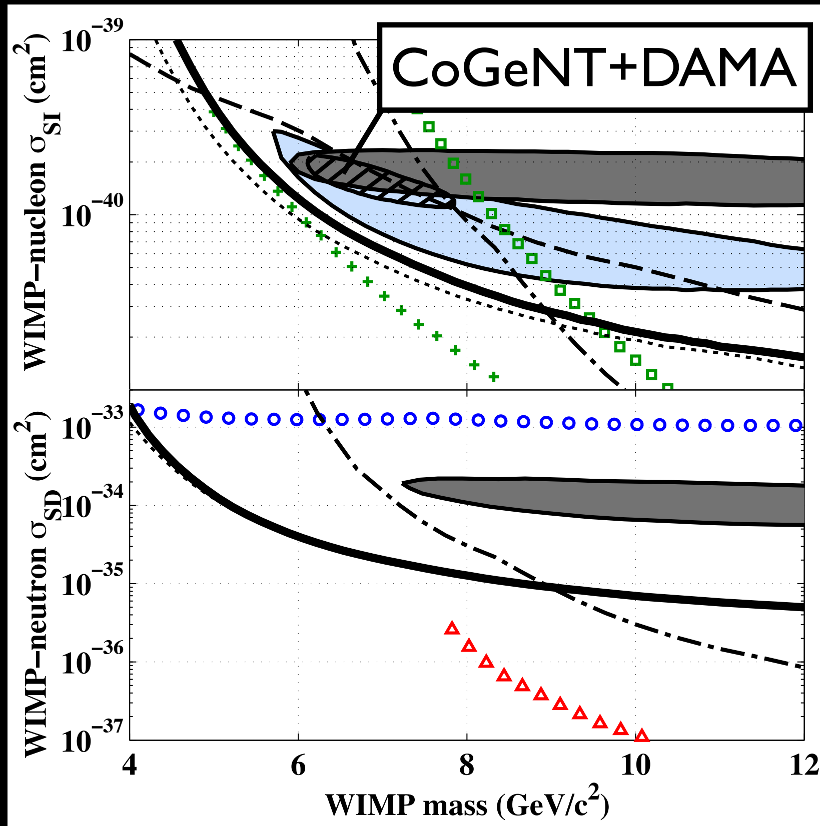
Inelastic

Ahmed et al (CDMS) 0912.3592

CDMS (low-threshold)

>34 events observed





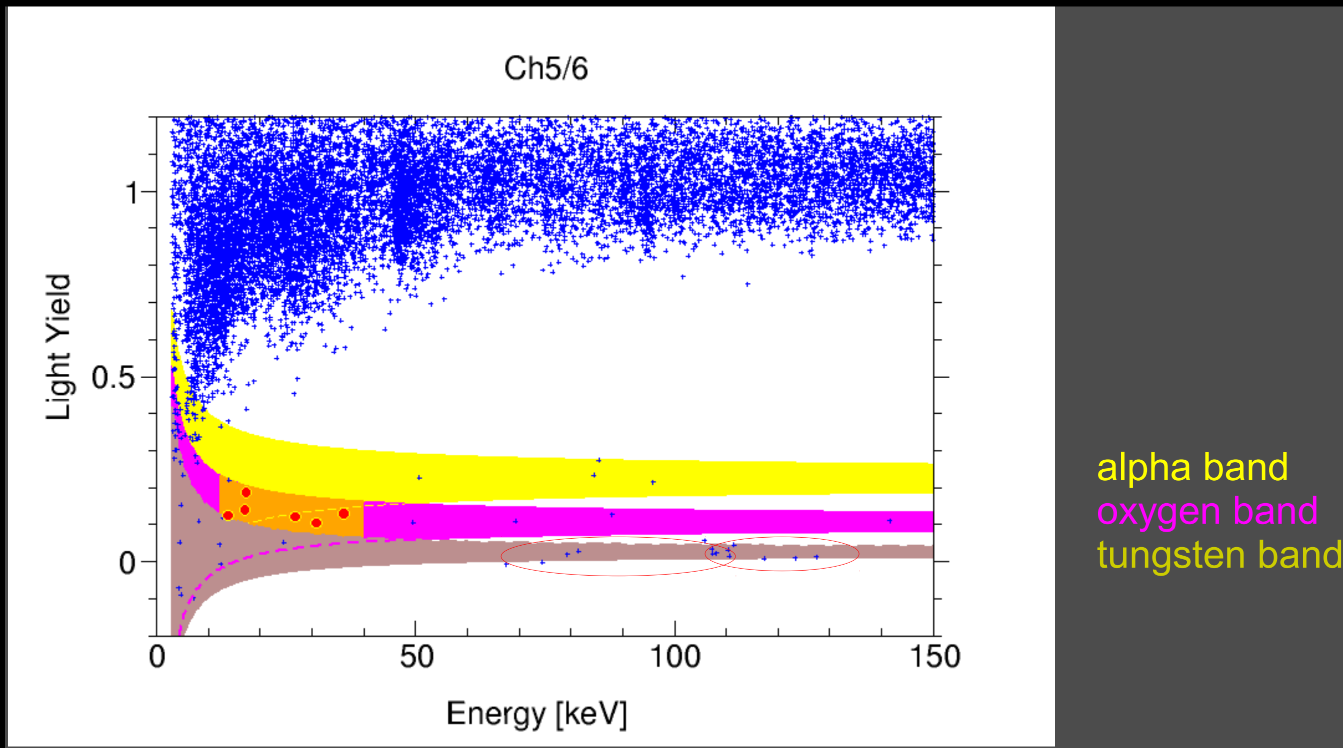
Optimum interval

Ahmed et al (CDMS) 1011.2482

CRESST

32 events observed

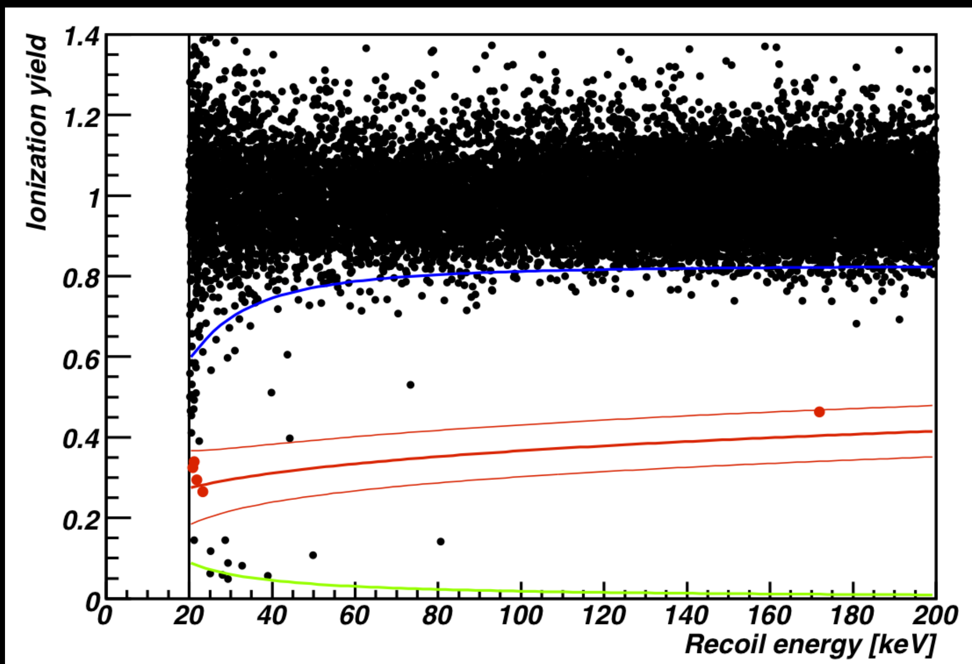
8 expected background



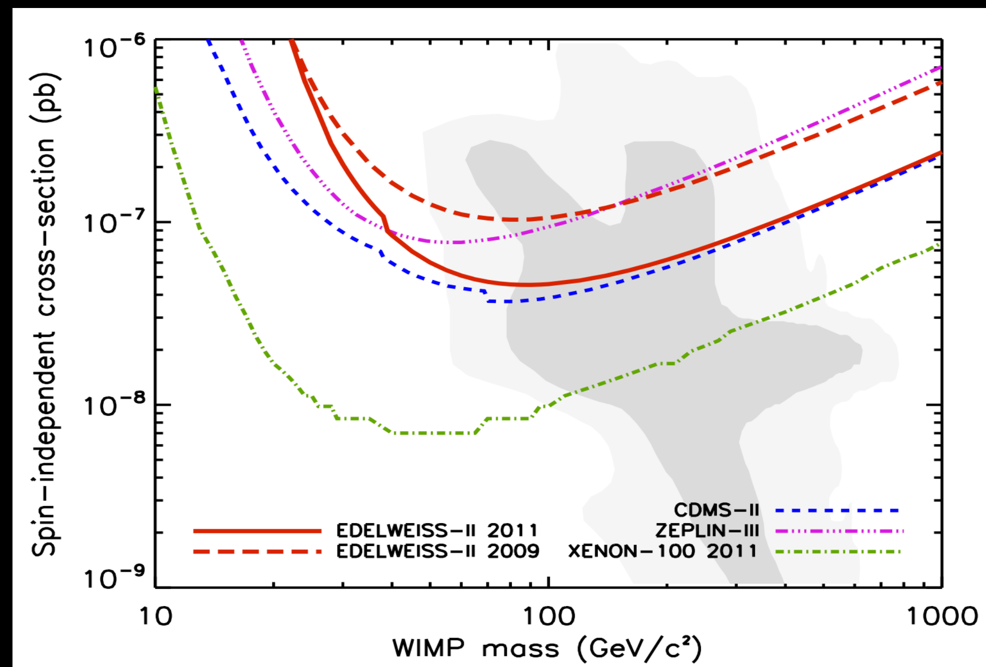
Probst 2010

EDELWEISS-II

5 events observed



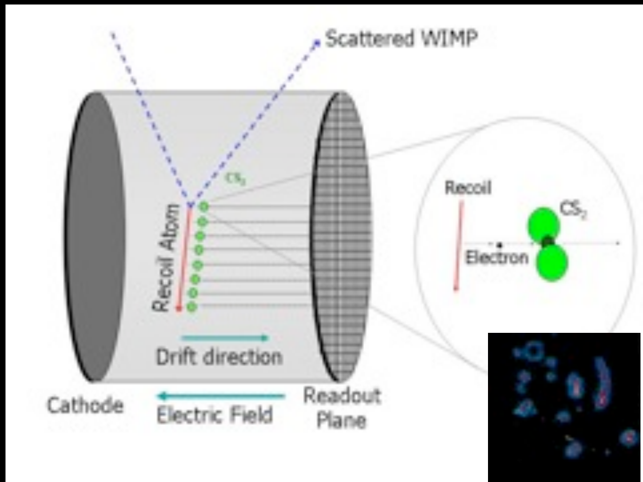
<3 expected background



Optimum interval

Torrento-Coello 1106.1454

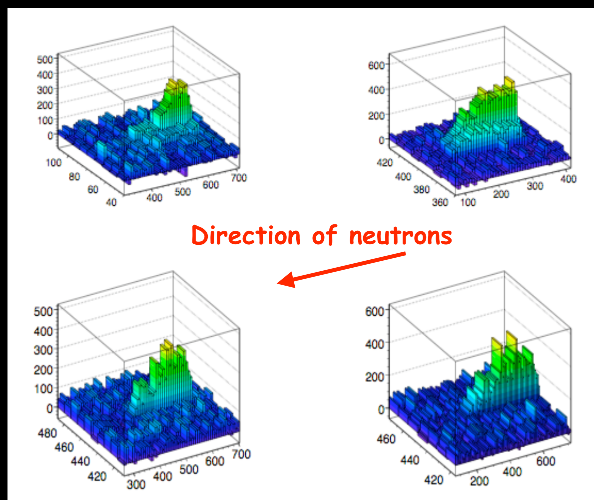
Directional detectors



DRIFT

- Background discrimination
- Able to measure dark matter velocity distribution

WIMP Astronomy

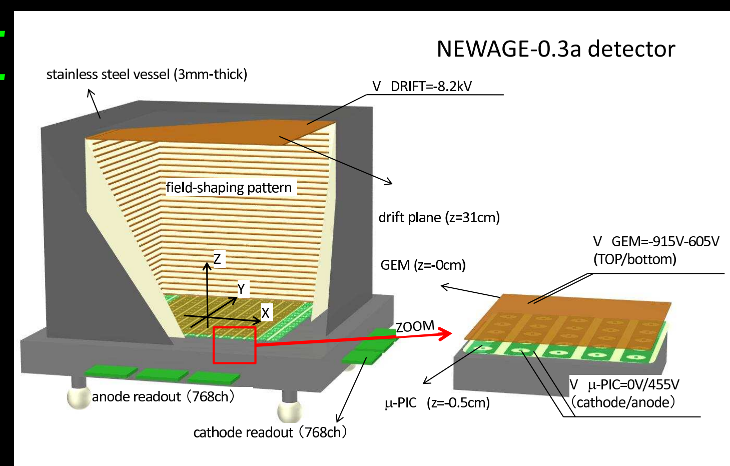


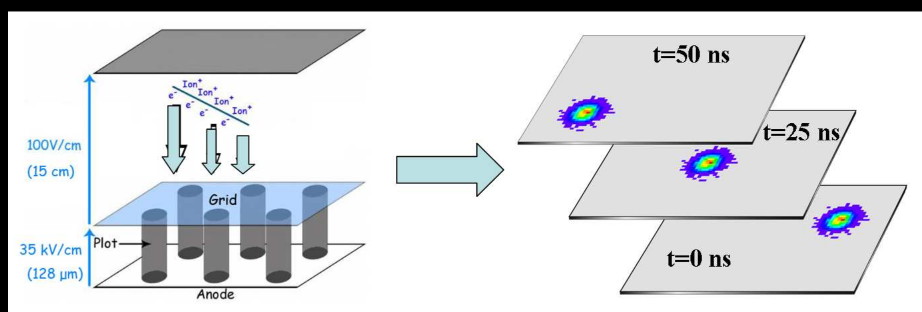
DM-TPC

Theory

Spergel 1988
Copi et al 1999-05
Morgan et al 2005-09
Gondolo et al 2002-08

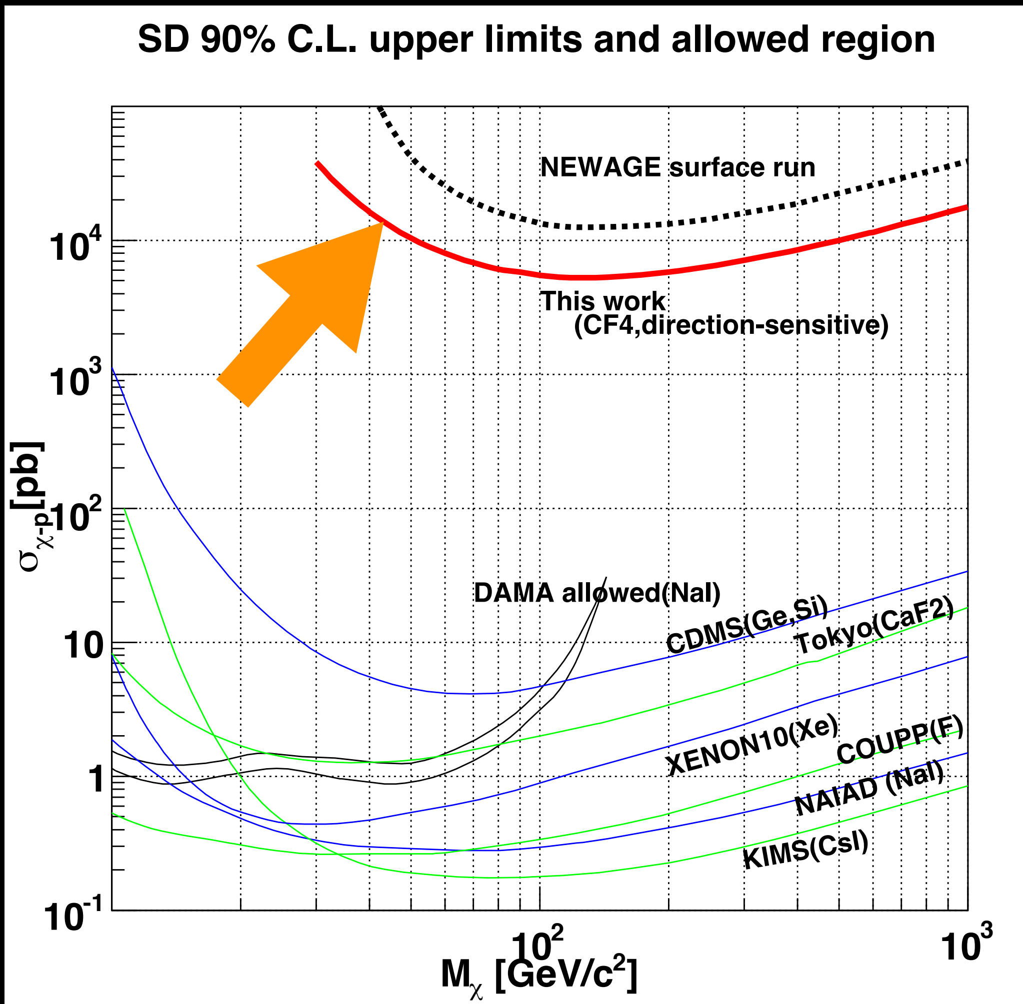
NEWAGE

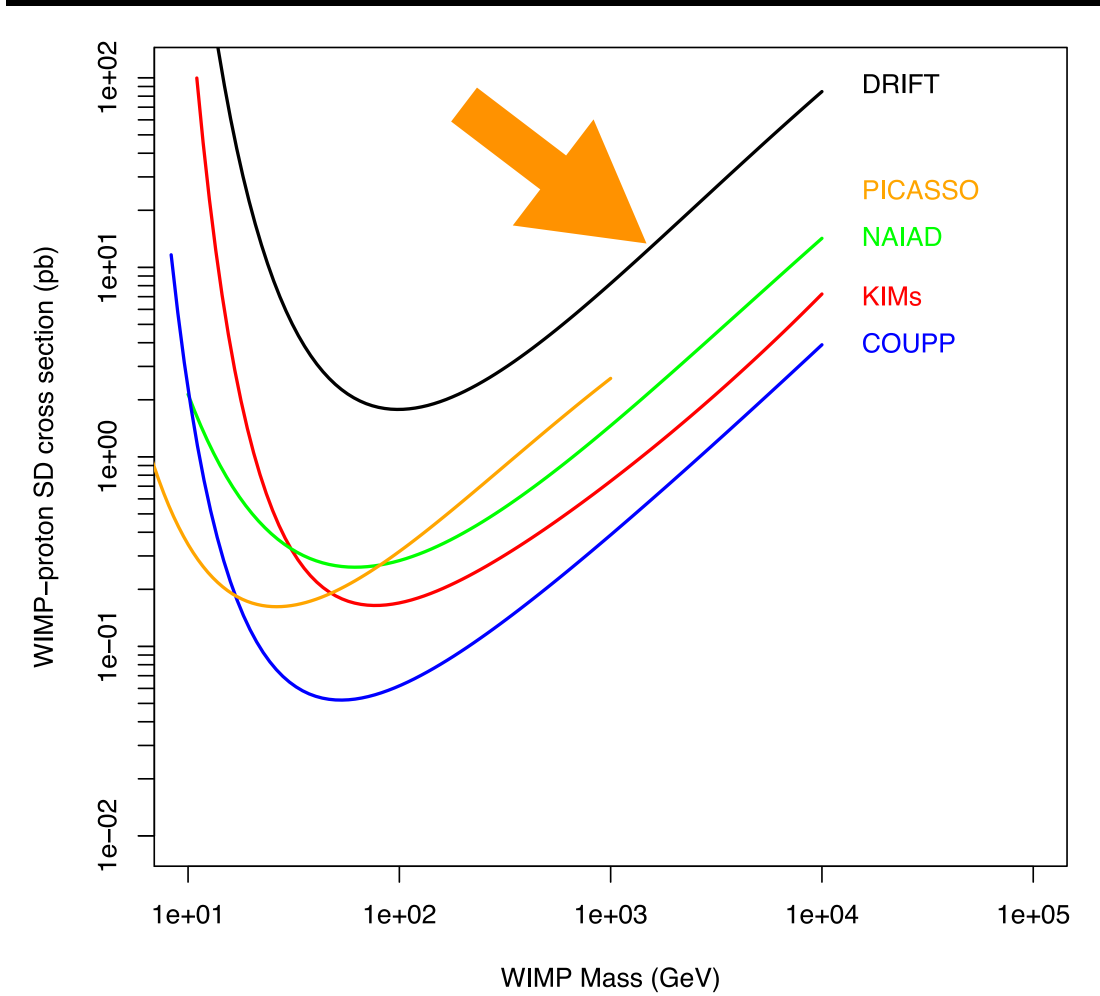




MIMAC

Directional detectors





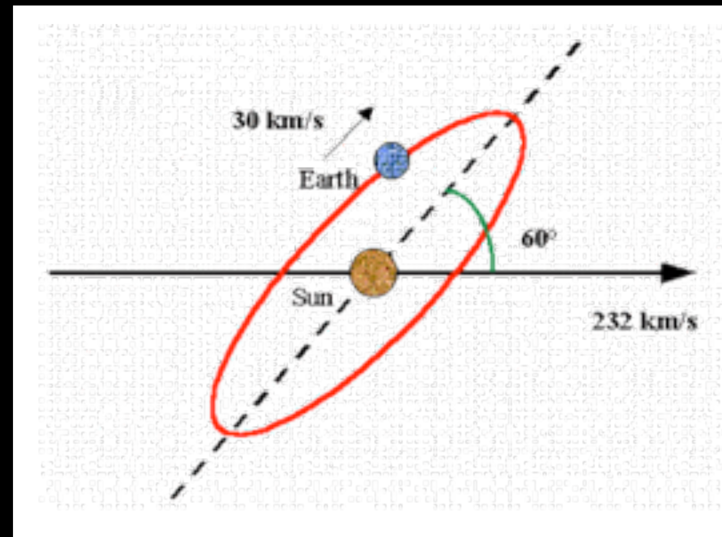
Miuchi e al (NEWAGE) 2010

Daw et al (DRIFT-II) 2010

Claims of detection

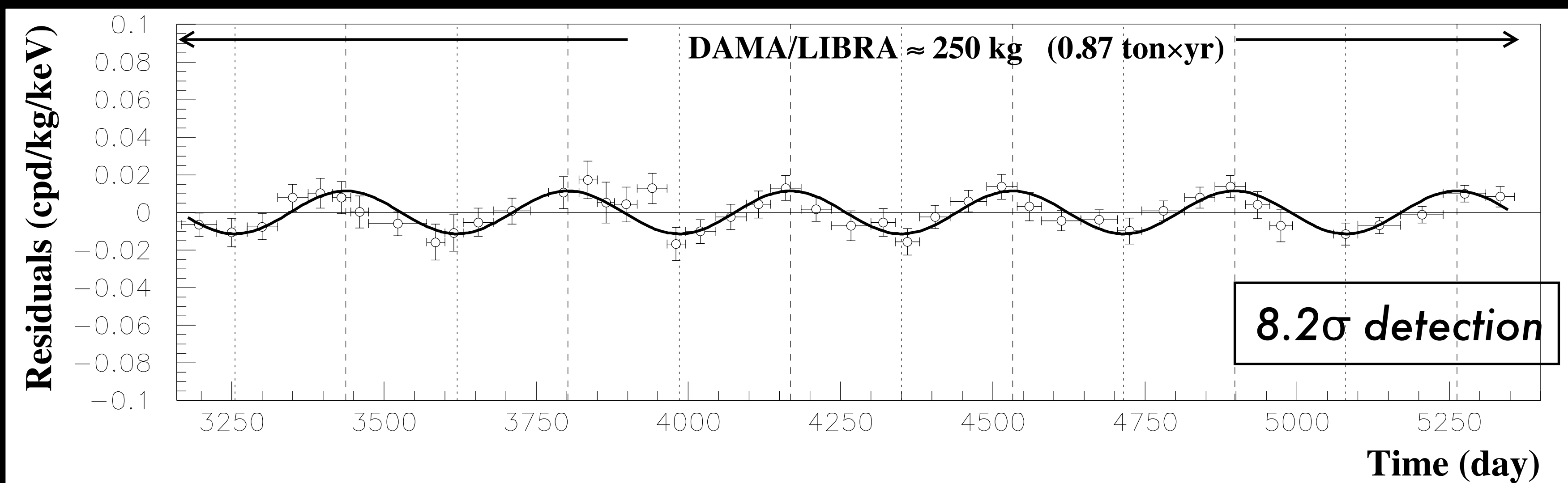
The DAMA modulation

DAMA finds a yearly modulation as expected for dark matter particles



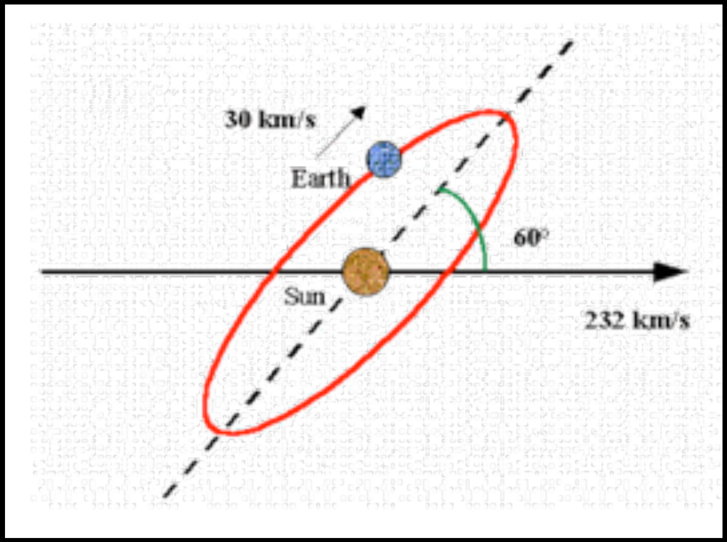
Drukier et al 1986

Bernabei et al 2003-10



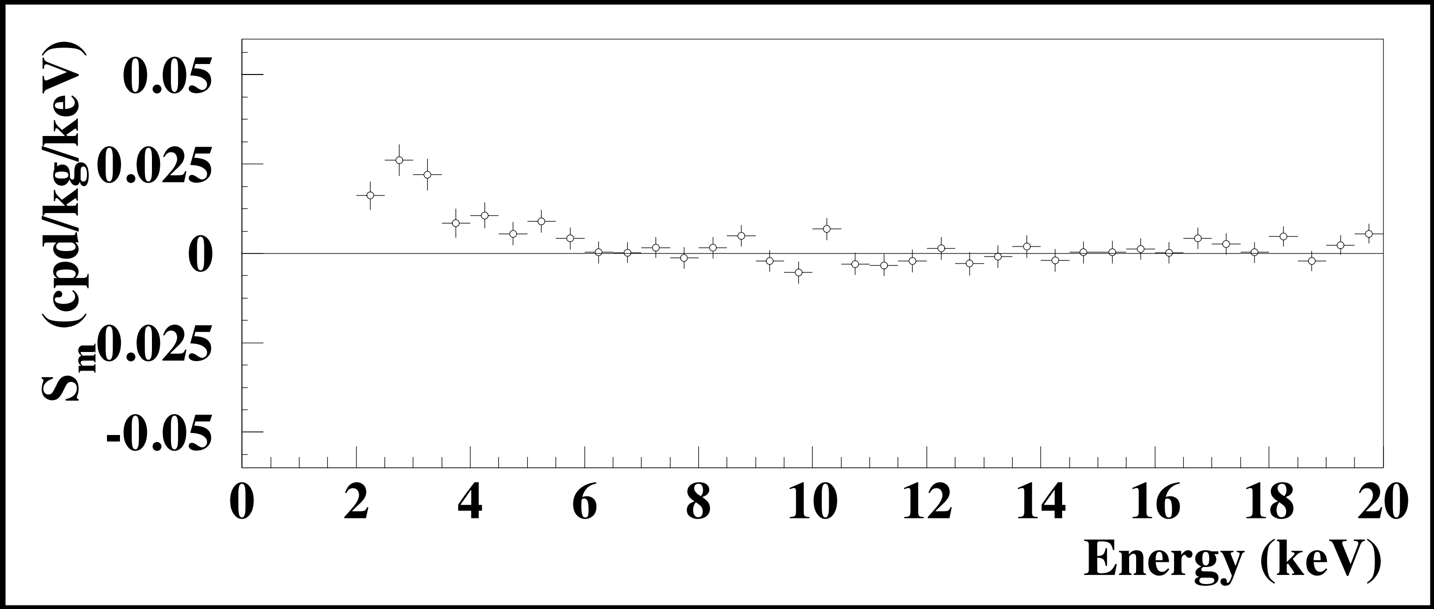
The DAMA modulation

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



Drukier et al 1986

Bernabei et al 2003-10



The DAMA modulation

Summary of the results obtained in the additional investigations of possible systematics or side reactions
(DAMA/LIBRA – arXiv:0804.2741 to appear on EPJC)

Source	*Main comment*	*Cautious upper limit (90%C.L.)*
RADON	Sealed Cu box in HP Nitrogen atmosphere, 3-level of sealing, etc.	**$<2.5\times10^{-6}$ cpd/kg/keV**
TEMPERATURE	Installation is air conditioned+ detectors in Cu housings directly in contact with multi-ton shield→ huge heat capacity + T continuously recorded	**$<10^{-4}$ cpd/kg/keV**
NOISE	Effective full noise rejection near threshold	**$<10^{-4}$ cpd/kg/keV**
ENERGY SCALE	Routine + instrinsic calibrations	**$<1\text{-}2\times10^{-4}$ cpd/kg/keV**
EFFICIENCIES	Regularly measured by dedicated calibrations	**$<10^{-4}$ cpd/kg/keV**
BACKGROUND	No modulation above 6 keV; no modulation in the (2-6) keV *multiple-hits* events; this limit includes all possible sources of background	**$<10^{-4}$ cpd/kg/keV**
SIDE REACTIONS	Muon flux variation measured by MACRO	**$<3\times10^{-5}$ cpd/kg/keV**

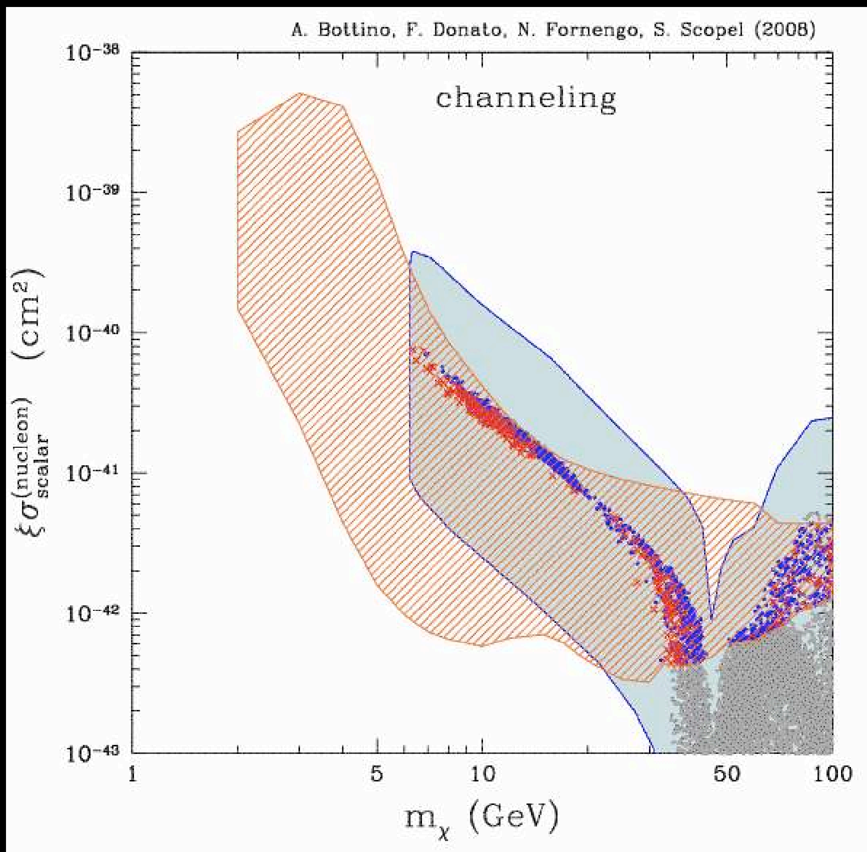
+ even if larger they cannot satisfy all the requirements of annual modulation signature → **Thus, they can not mimic the observed annual modulation effect**

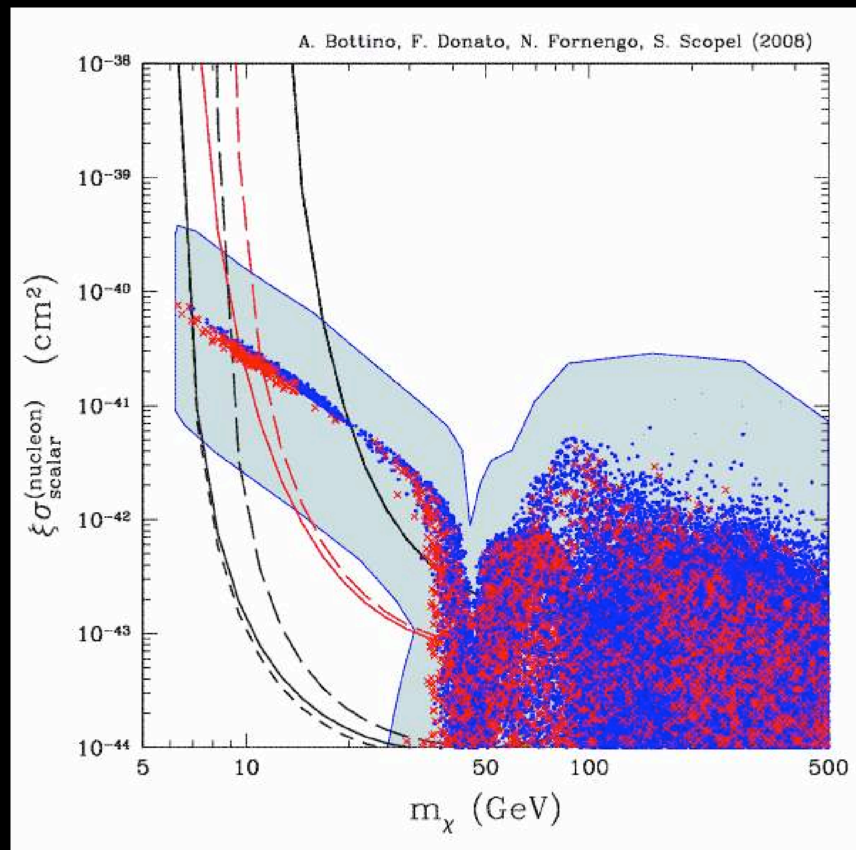
Slide by Belli (DAMA)

Interpretation of DAMA modulation

A neutralino with mass between ~5 GeV and ~100 GeV, when all uncertainties are included

Bottino, Donato, Fornengo, Scopel 2003-2011

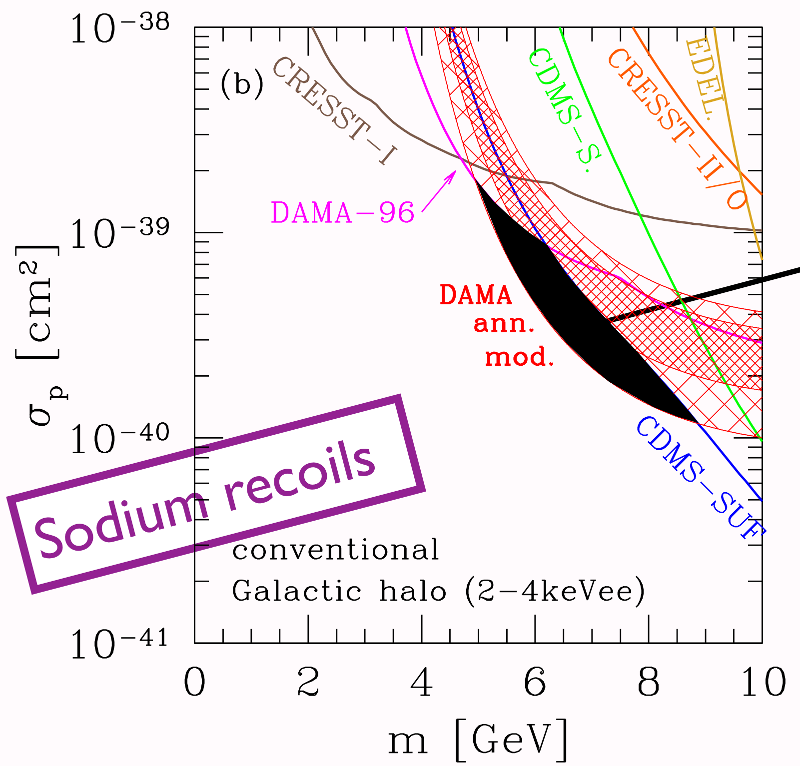




Interpretation of DAMA modulation

Are low mass WIMPs compatible with other experiments?

Gondolo, Gelmini 2004, 2005; Petriello, Zurek 2008; Bottino et al 2008; Chang, Pierce, Weiner 2008; Fairbairn, Schwetz 2008; Hooper, Petriello, Zurek, Kamionkowski 2008; Chang, Kribs, Tucker-Smith, Weiner 2008; Savage, Gelmini, Gondolo, Freese 2008, 2010; .....



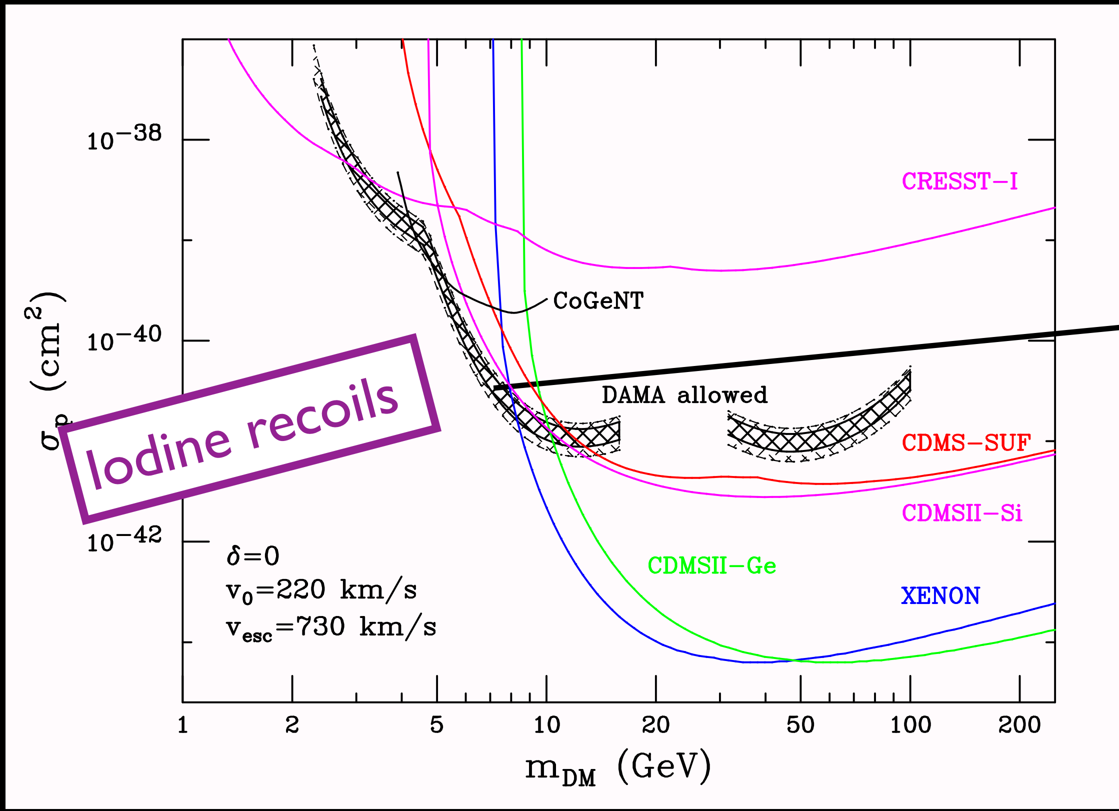
- "Raster scan" gives region compatible with DAMA modulation and all other experiments (as of 2004).
- Standard Maxwellian velocity distribution
- No channeling

Gondolo, Gelmini hep-ph/0405278

Interpretation of DAMA modulation

Are low mass WIMPs compatible with other experiments?

Gondolo, Gelmini 2004, 2005; Petriello, Zurek 2008; Bottino et al 2008; Chang, Pierce, Weiner 2008; Fairbairn, Schwetz 2008; Hooper, Petriello, Zurek, Kamionkowski 2008; Chang, Kribs, Tucker-Smith, Weiner 2008; Savage, Gelmini, Gondolo, Freese 2008, 2010; .....



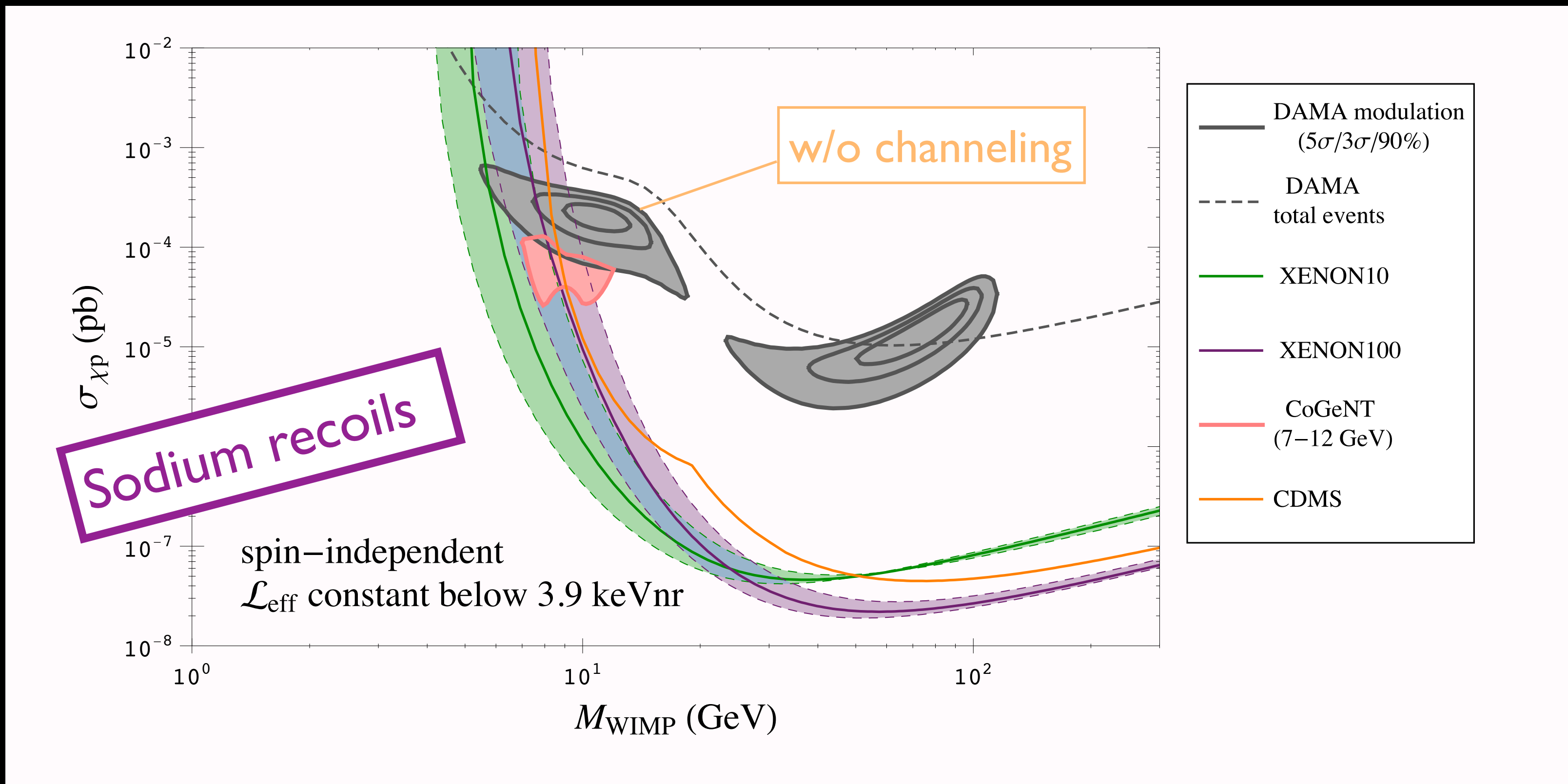
- Repeat analysis with channeling.
- But "raster scan" is no longer appropriate for new DAMA/LIBRA data.

Petriello, Zurek 2008

Interpretation of DAMA modulation

Low mass WIMPs are compatible with other experiments

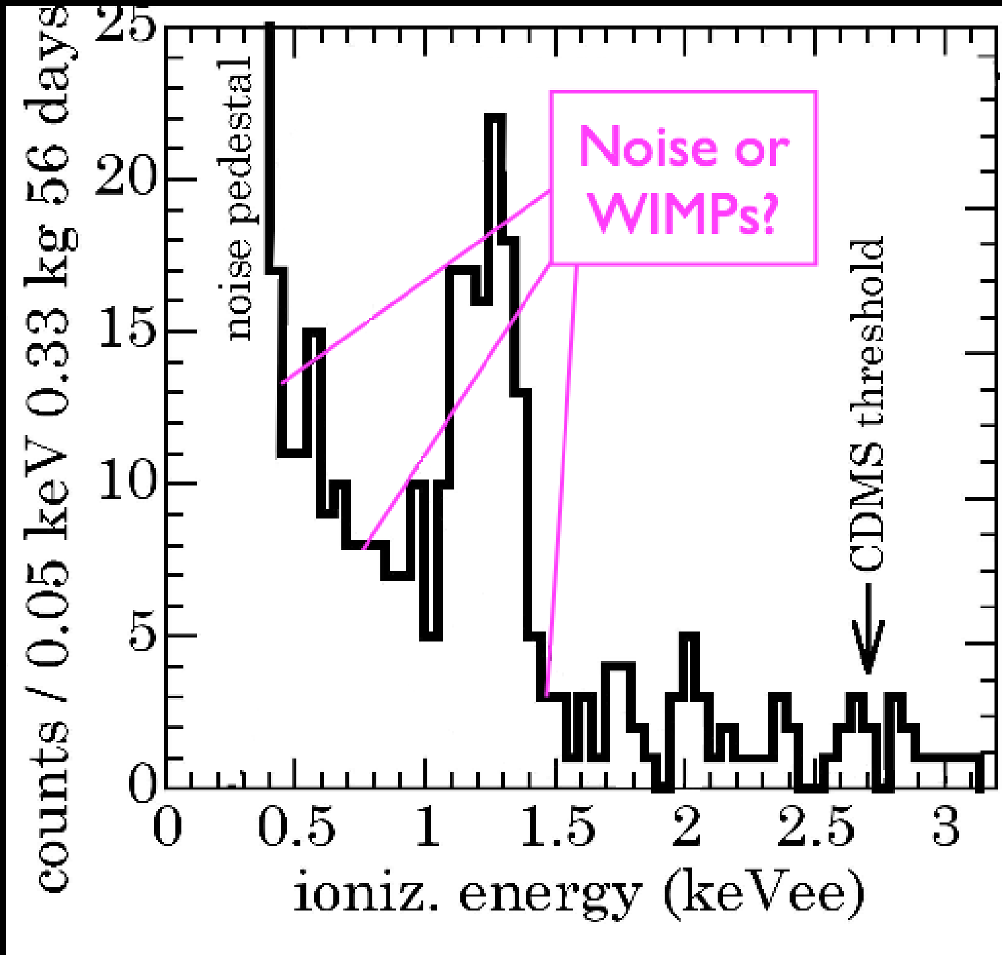
Gondolo, Gelmini 2004, 2005; Petriello, Zurek 2008; Bottino et al 2008; Chang, Pierce, Weiner 2008; Fairbairn, Schwetz 2008; Hooper, Petriello, Zurek, Kamionkowski 2008; Chang, Kribs, Tucker-Smith, Weiner 2008; Savage, Gelmini, Gondolo, Freese 2008, 2010; .....



Savage, Gelmini, Gondolo, Freese 2010

The CoGeNT "irreducible excess"

- CoGeNT, a low-electronic-noise Ge detector, finds an "irreducible excess of events"

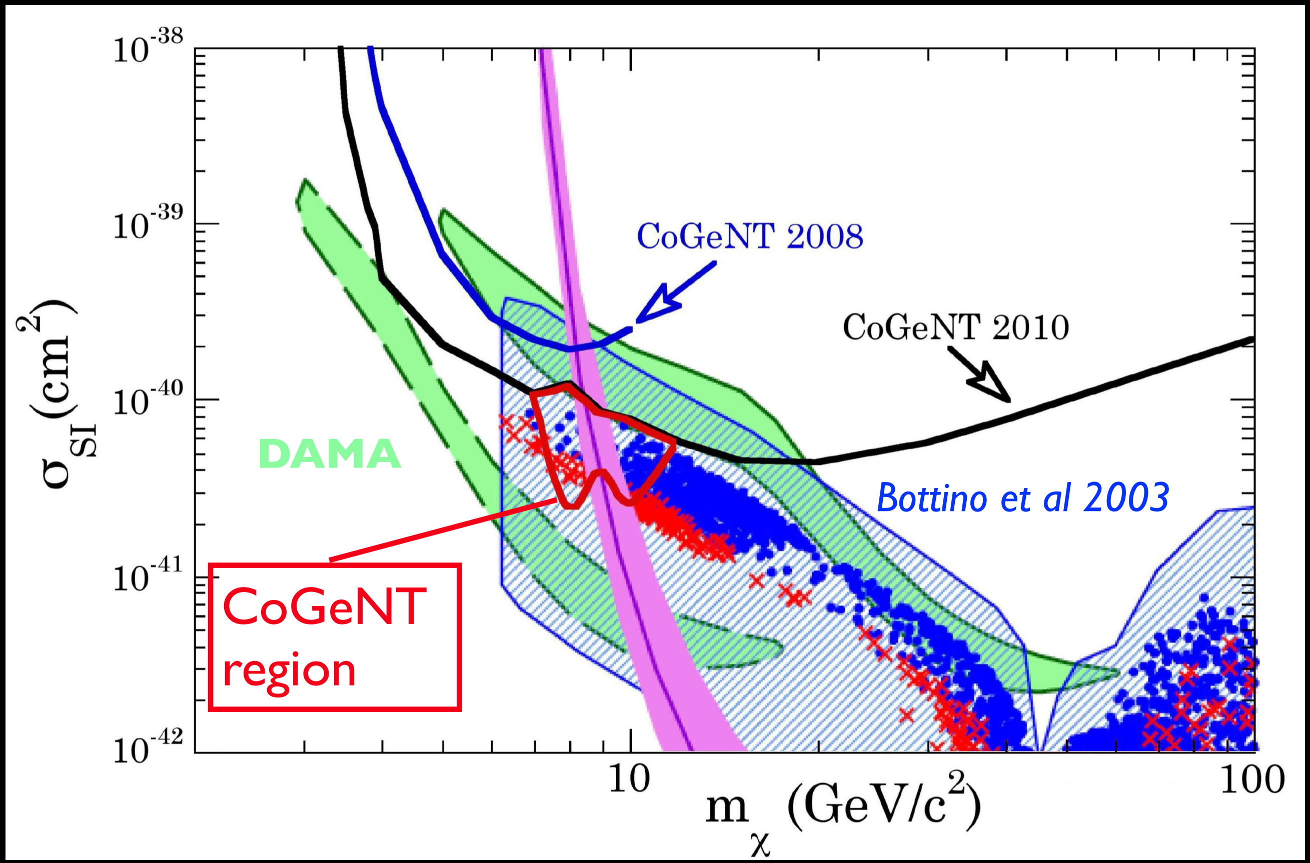


Aalseth et al 2010

Degeneracy between exponential background and exponential signal

Interpretation of CoGeNT excess

- A dark matter particle with mass around 10 GeV?
- It might also explain DAMA!

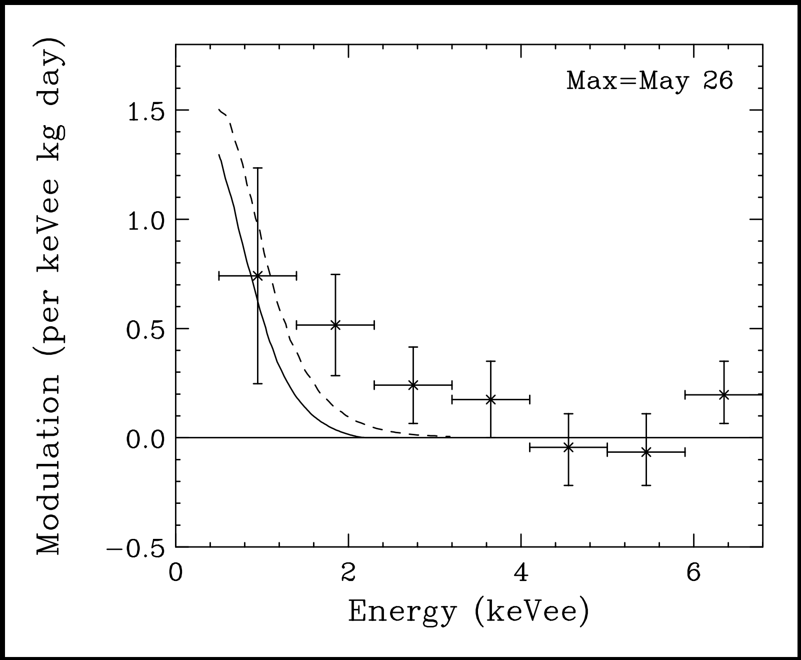


Aalseth et al 2010

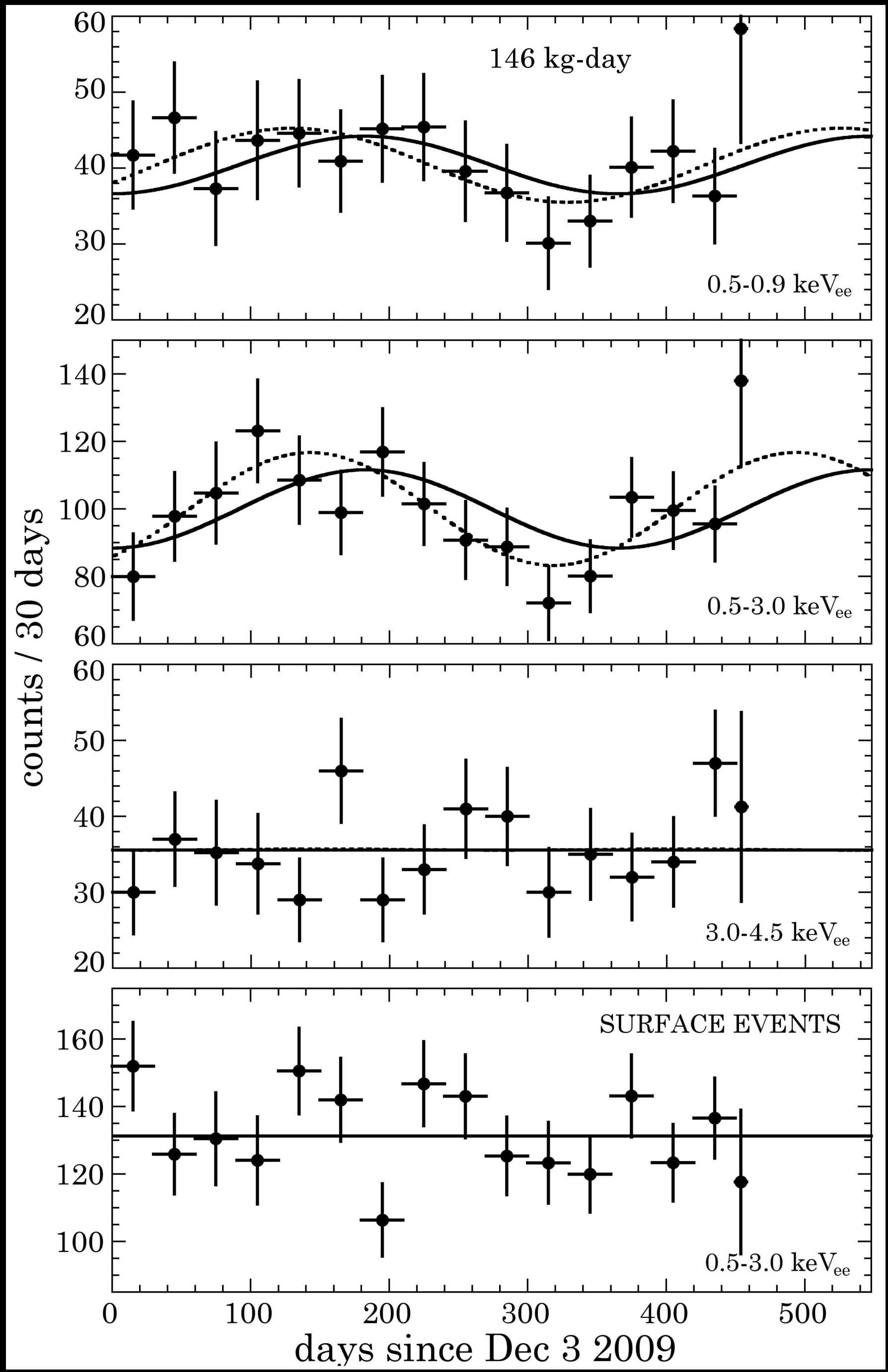
The CoGeNT modulation

- 442 live days, interrupted by fire
- 146 kg-day exposure

- Period of one year
- Phase compatible with DAMA's (within errors)
- 2.8 σ



Kelso, Hooper 1106.1066

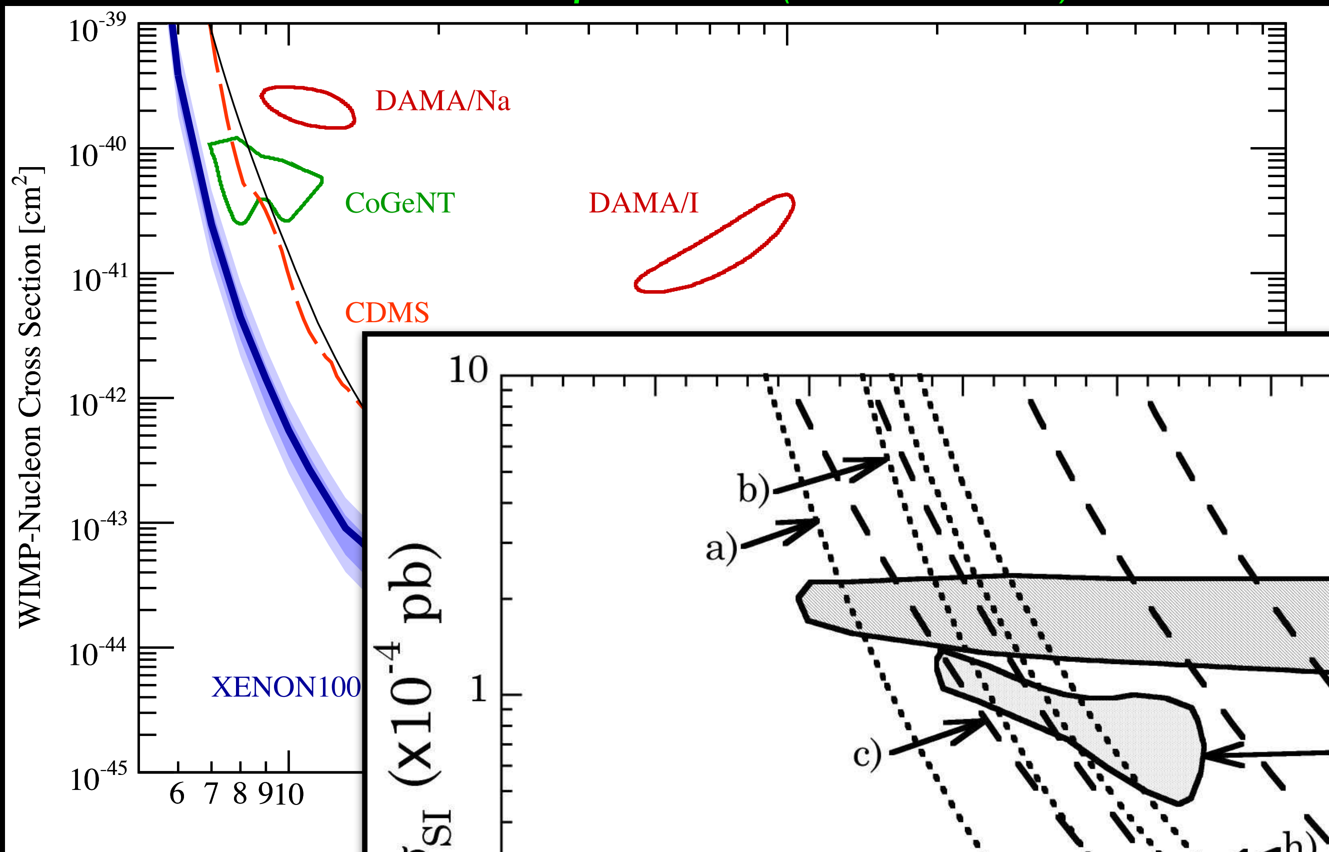


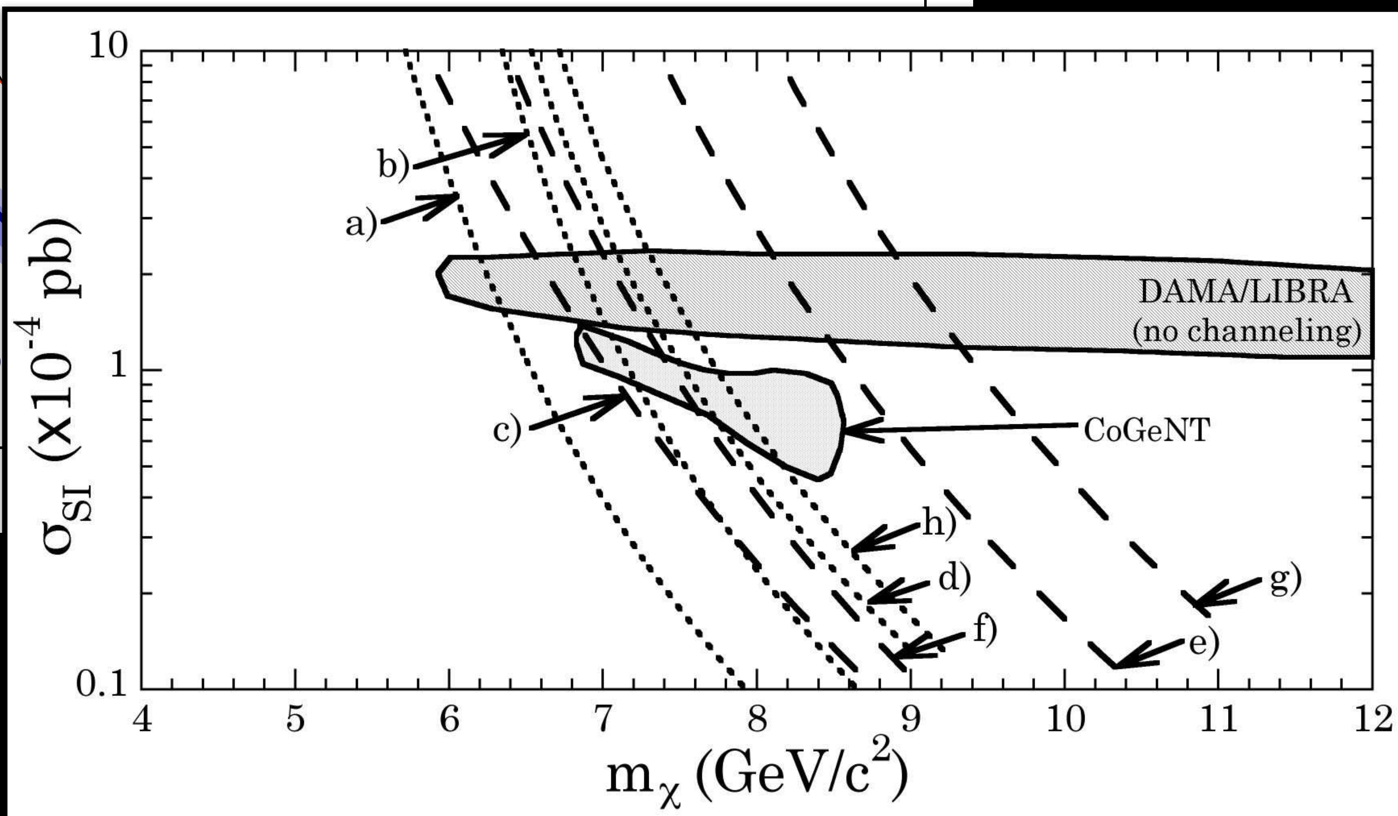
Aalseth et al 1106.0650

The devil is in the details

XENON-100 vs CoGeNT

Aprile et al (XENON-100) 1104.2549



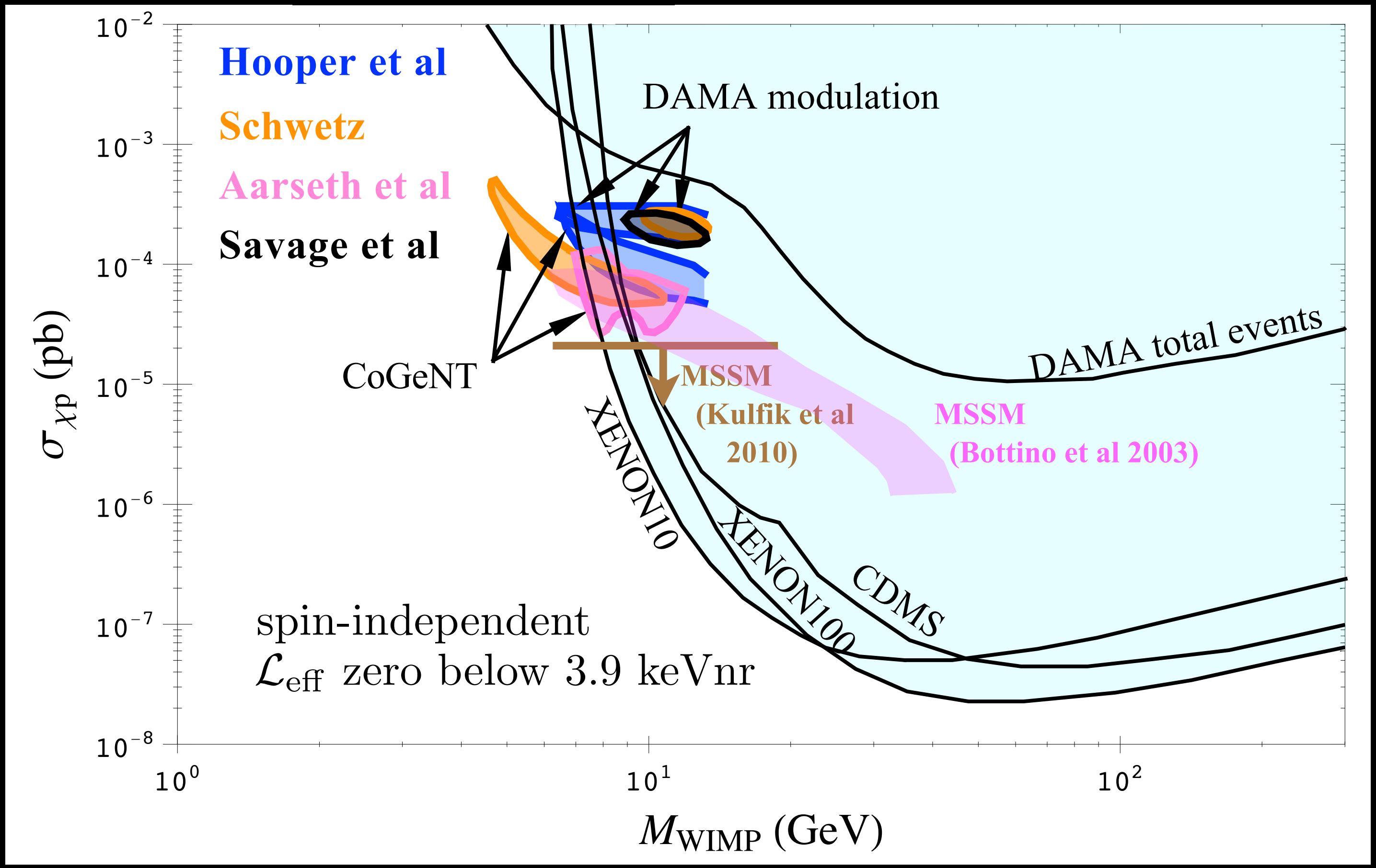


"It's a scandal!"
Juan Collar

Collar 1106.0653

~10 GeV dark matter?

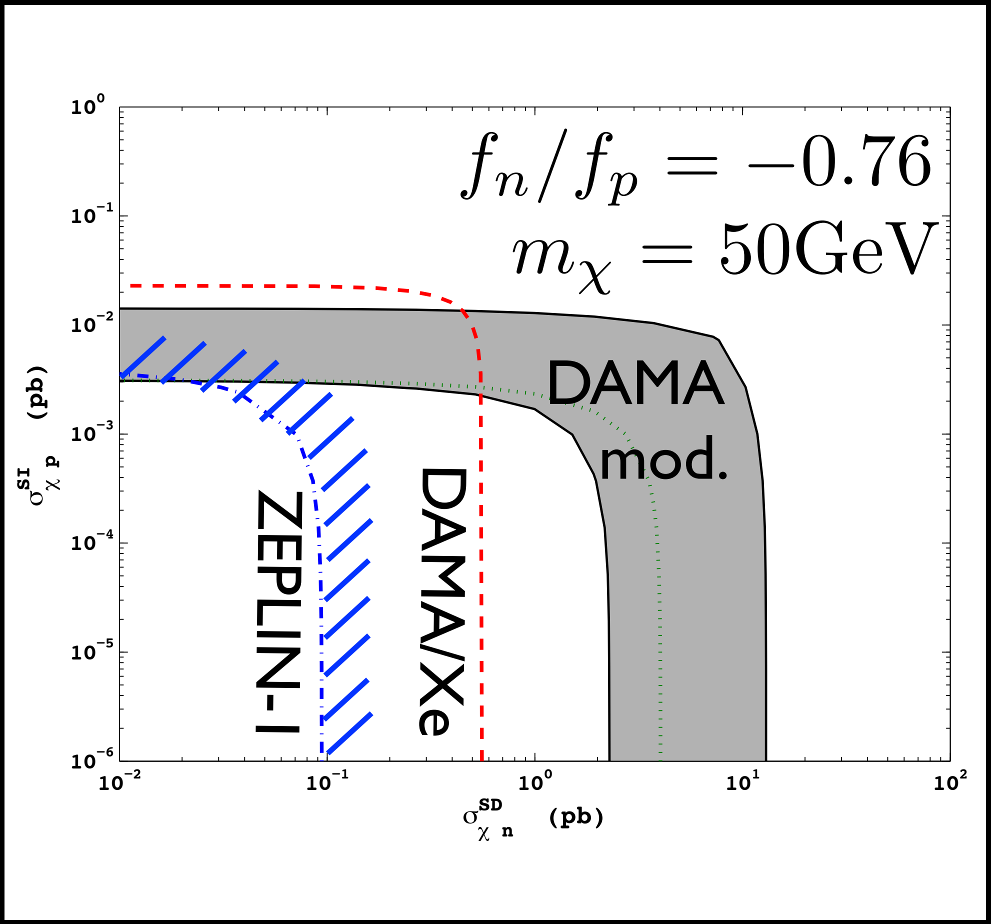
- Degeneracy between exponential background and exponential signal in CoGeNT
- Different analyses find opposite results (from compatible to incompatible)
- Theoretically challenging



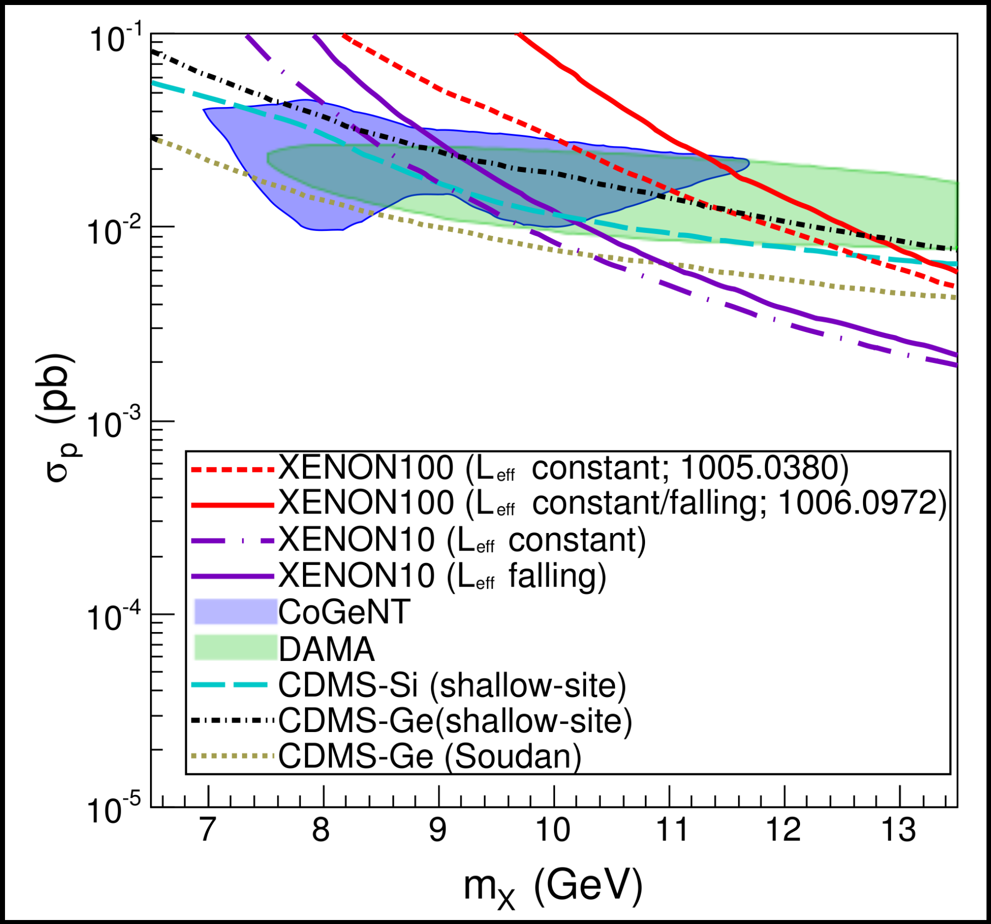
Couple more to protons than neutrons

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; .....



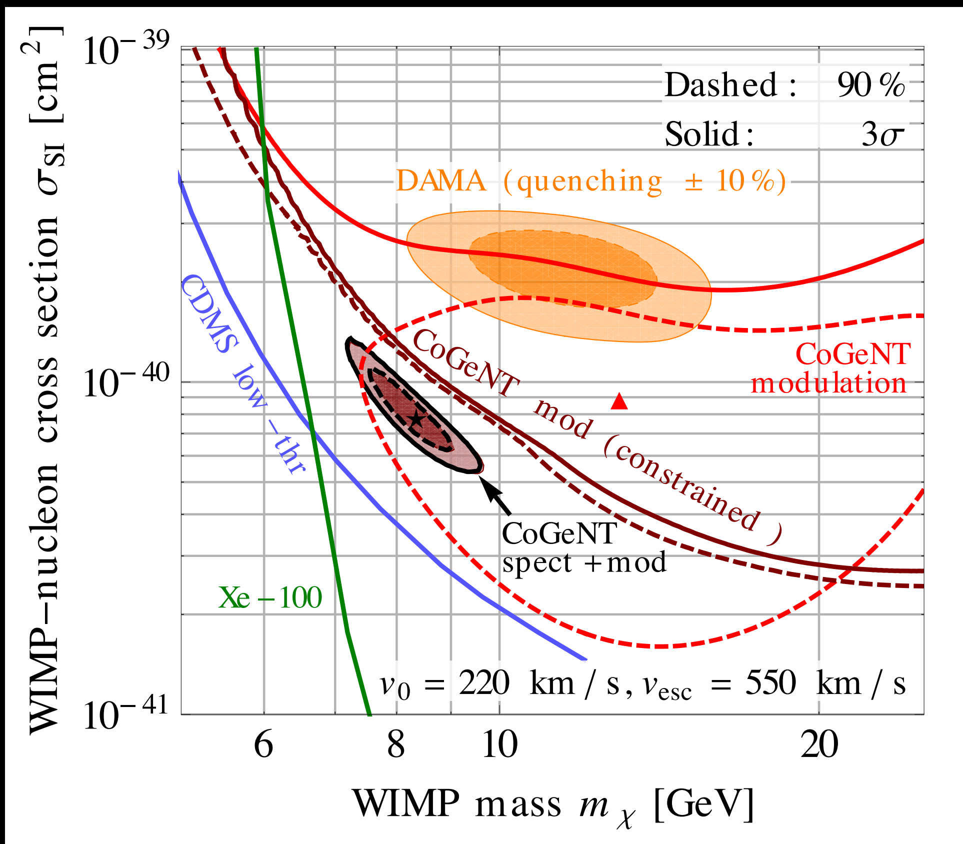
Kurylov, Kamionkowski 2003

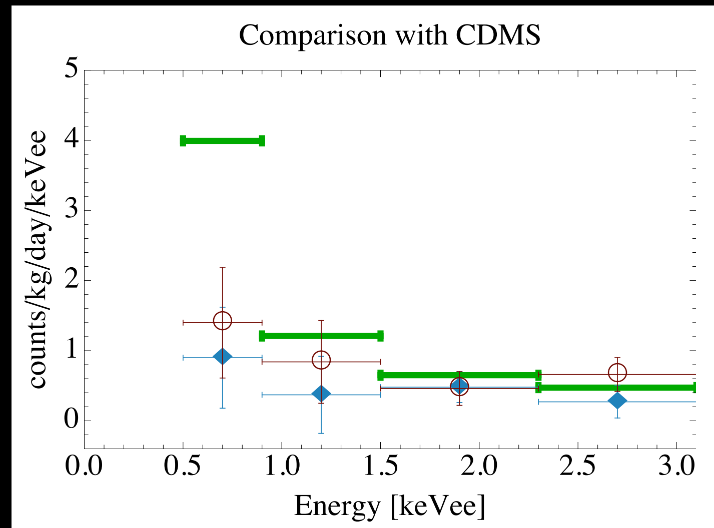


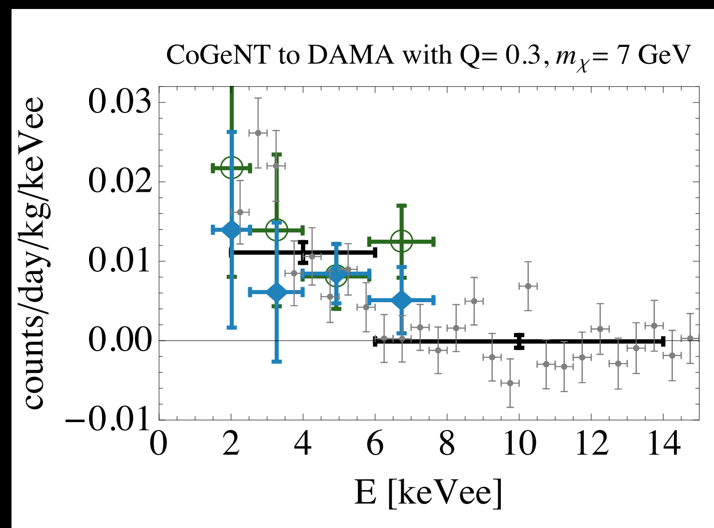
Feng, Kumar, Marfatia, Sanford 2011

A CoGeNT modulation analysis

Fox et al 1107.0717



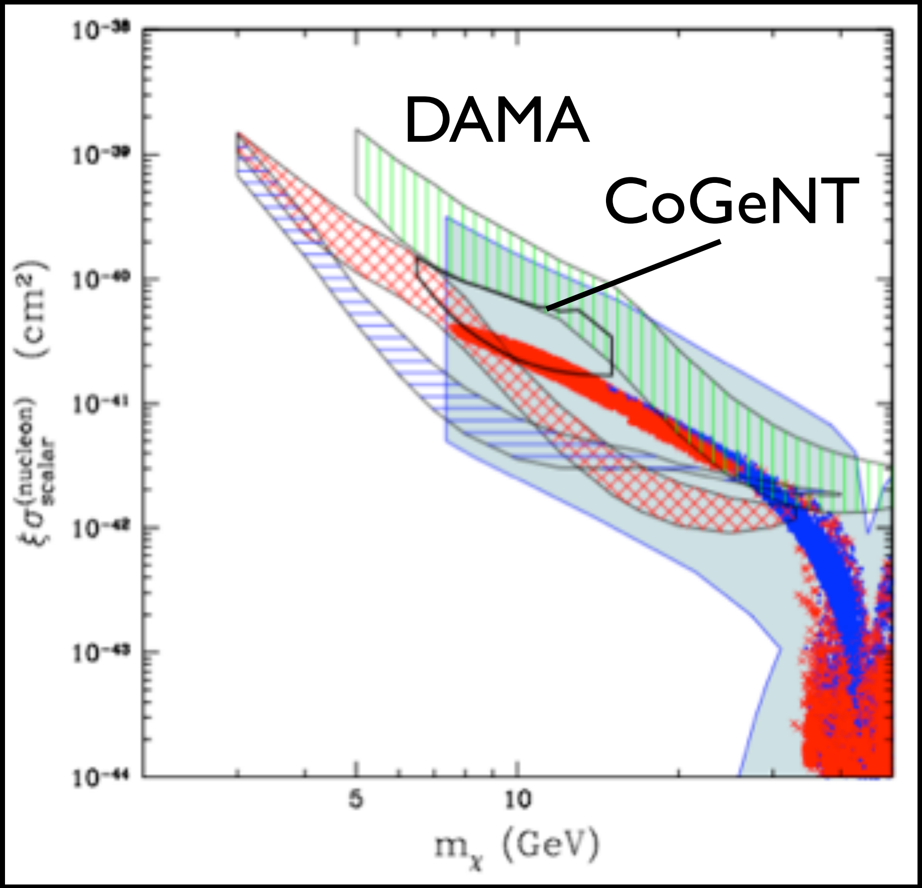


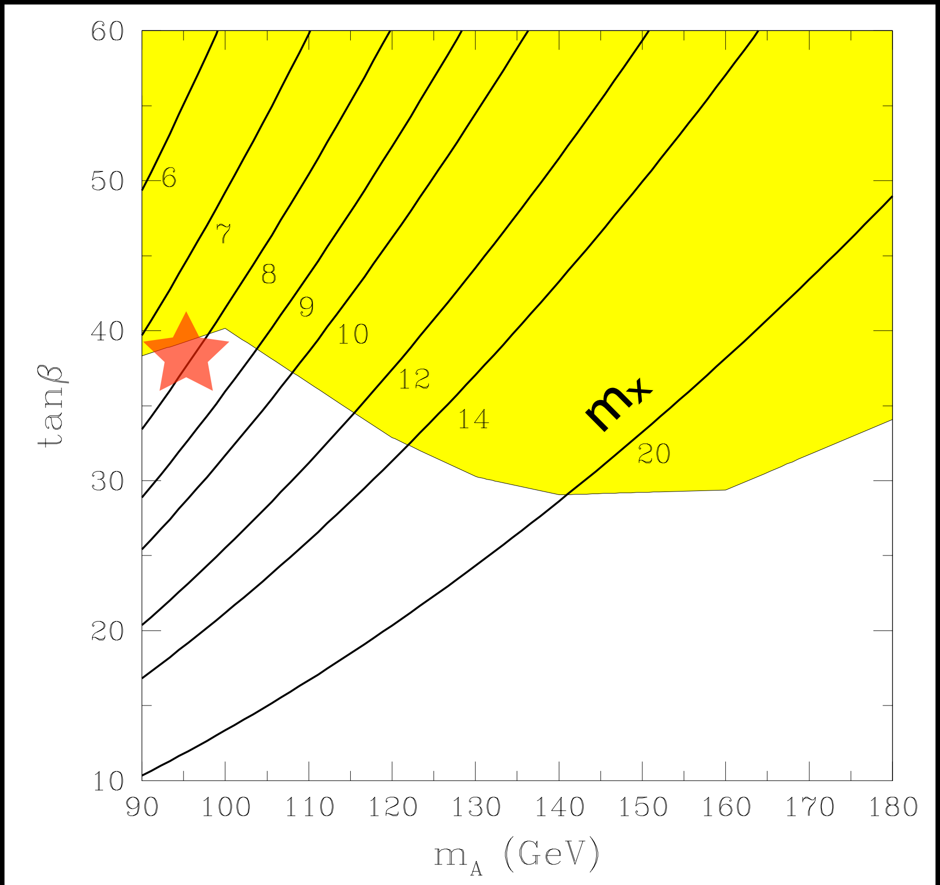


Light neutralinos

Bottino, Donato, Fornengo, Scopel 2003-2011

May escape ATLAS/CMS bounds
(see Baglio, Djouadi 2011)





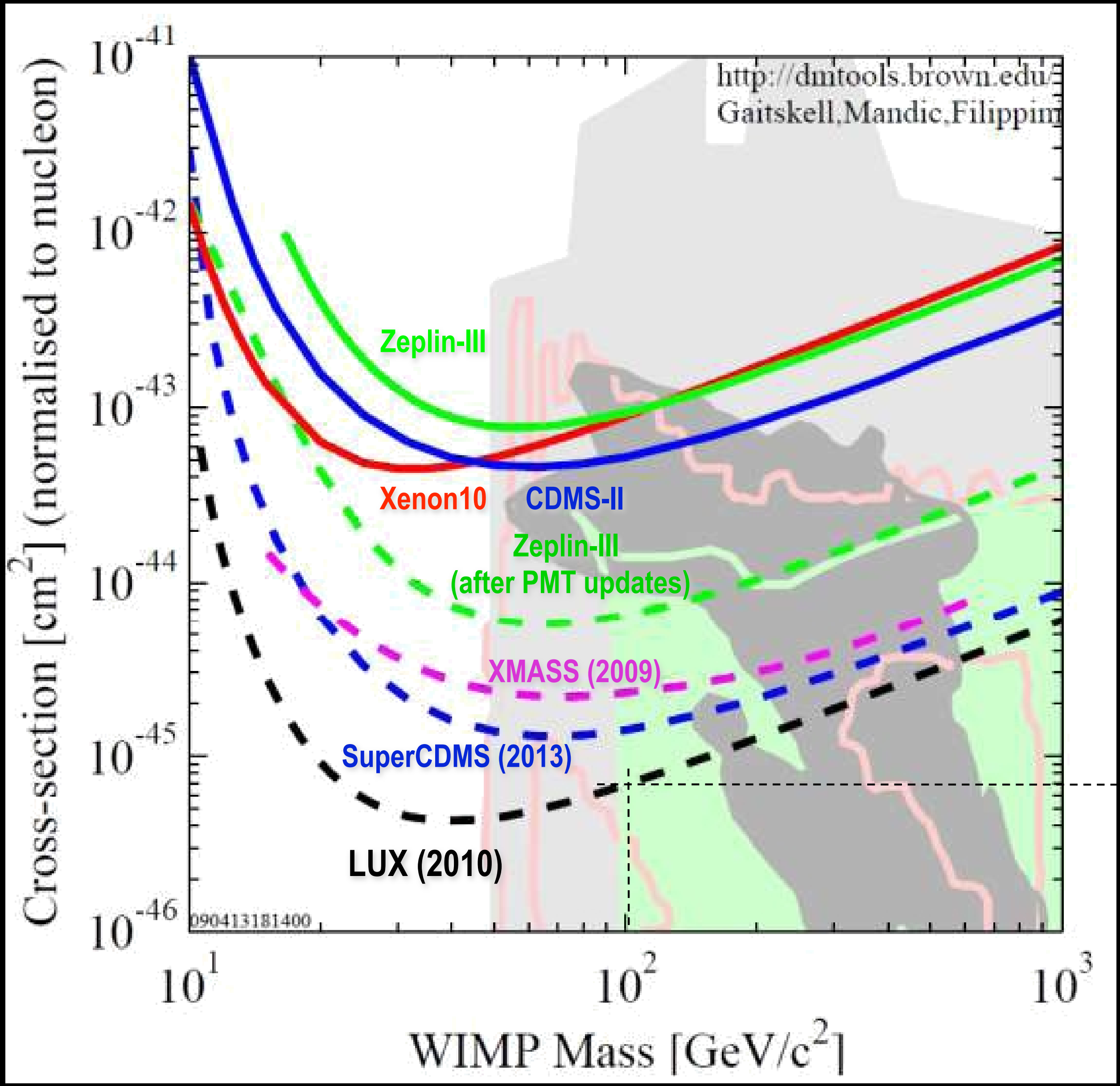
Belli et al 1106.4667

Interesting times

Coming up......

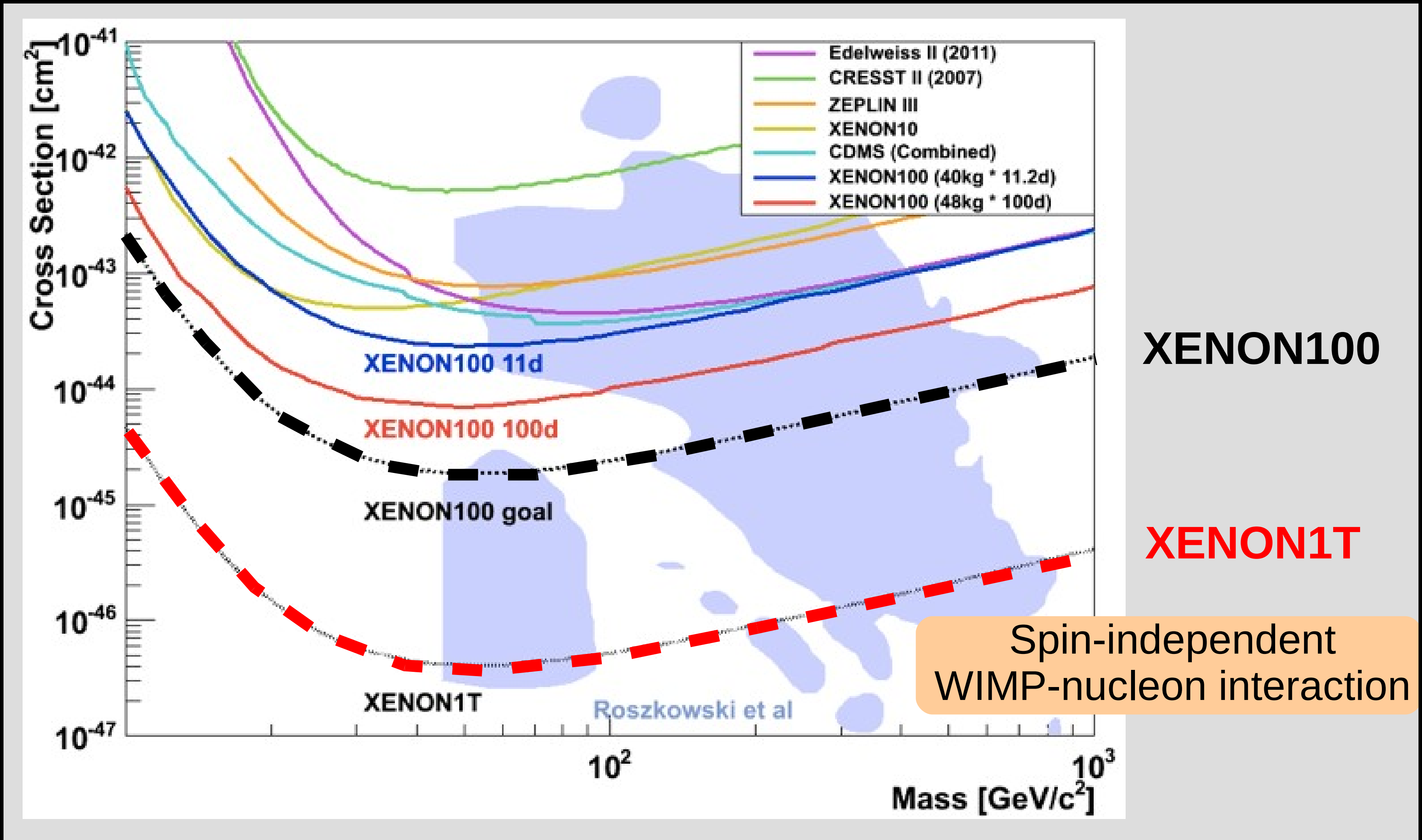
- XMASS
- EDELWEISS III
- XENON-1ton
- Super CDMS
- DM-ICE
- EURECA
- and many many others

Coming up.......



Gaitskell 2009

Coming up.......



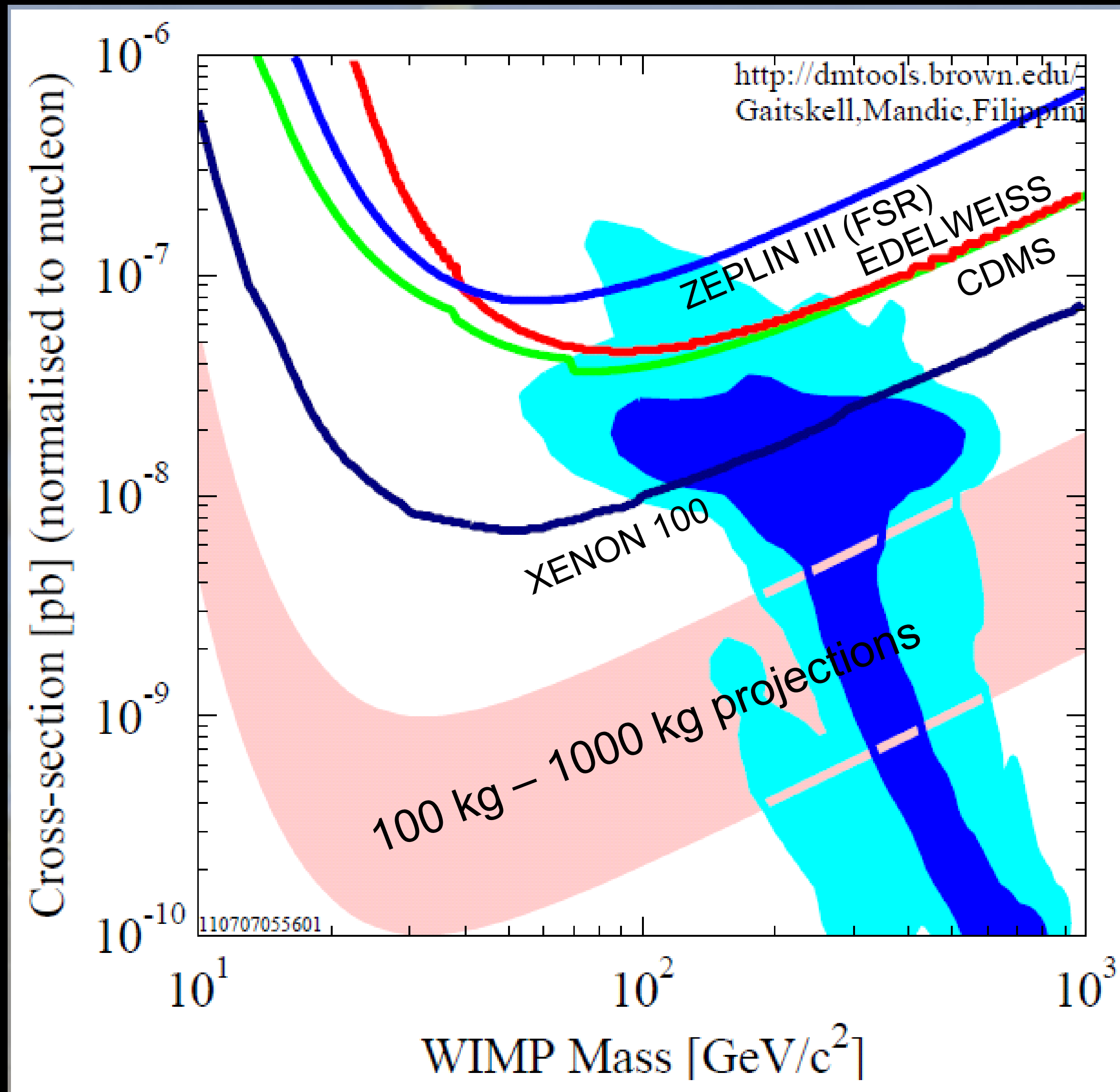
Schumann 2011

Coming up.......

EURECA

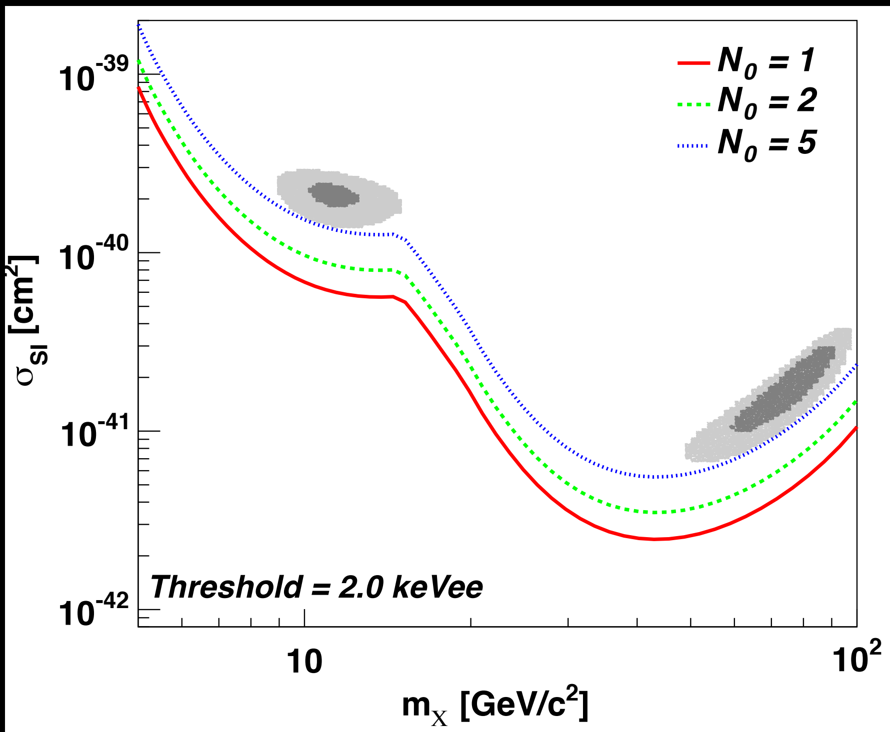
Ge, $CaWO_4$, ...

150 kg 2015
1 ton 2018



Kudryatsev 2011

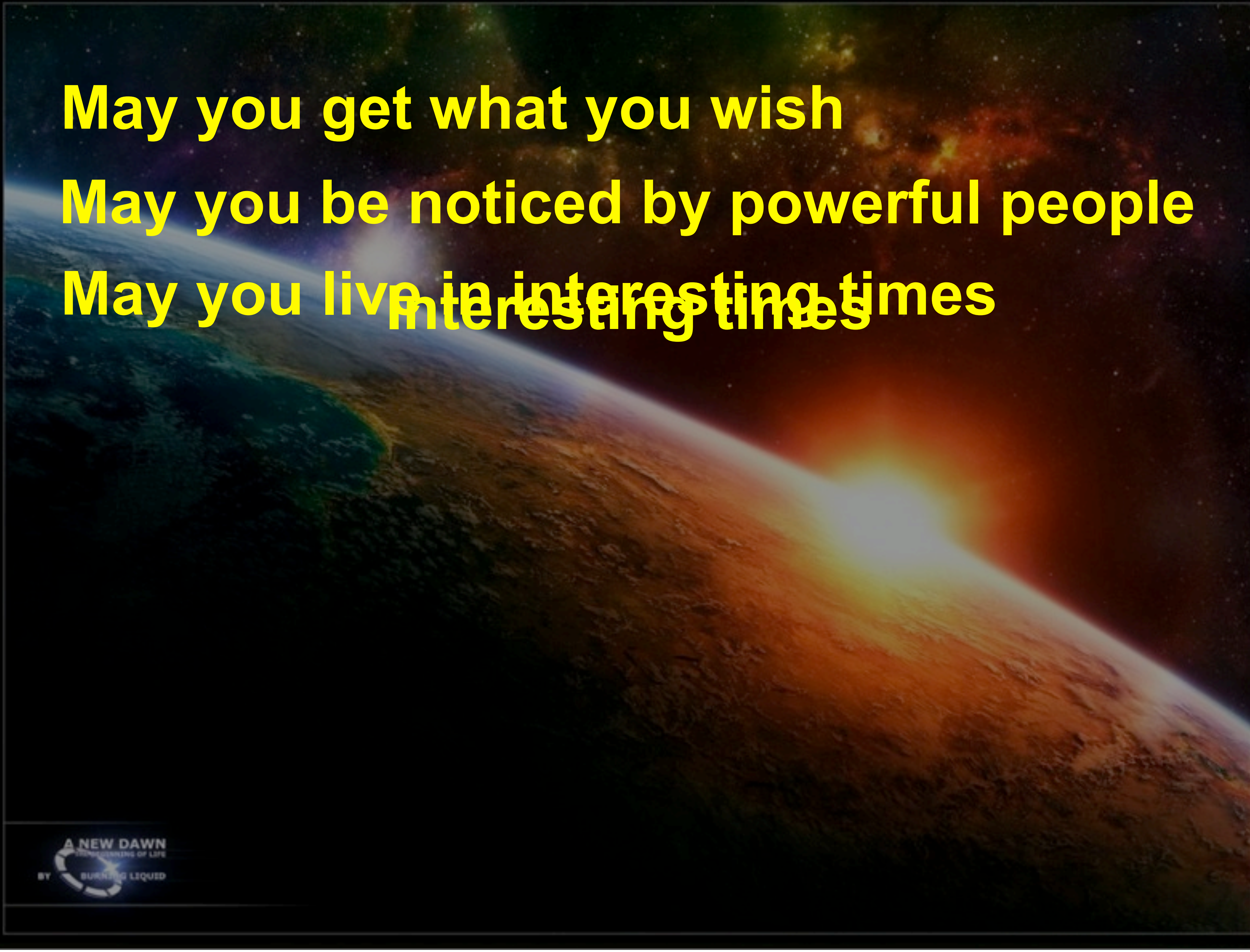
Coming up.......



Cherwinka et al 1106.1156

DM-ICE

Checking the annual modulation without seasons!


May you get what you wish
May you be noticed by powerful people
May you live in interesting times
interesting times
A NEW DAWN