On Taxonomy, Taxidermy, and Dark Matter

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Super CDM

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MULTIDARK
Multimessenger Approach for Dark Matter Detection

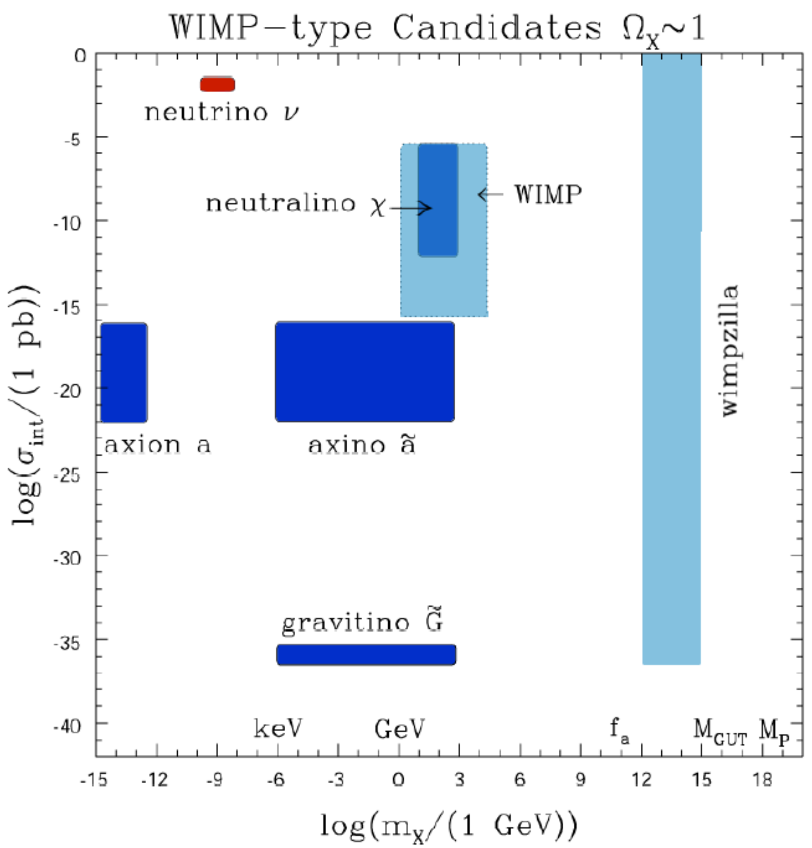
We don’t know yet what DM is... but we do know many of its properties

Good candidates for Dark Matter have to fulfil the following conditions

- Neutral (*)
- Stable on cosmological scales (*)
- Reproduce the correct relic abundance (*)
- Not excluded by current searches
- No conflicts with BBN or stellar evolution

Many candidates in Particle Physics

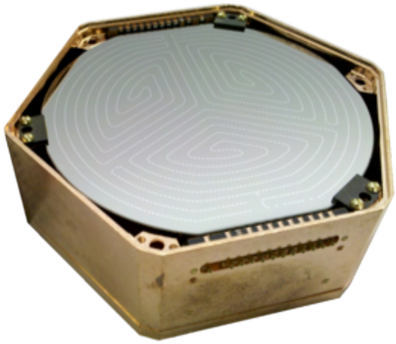
- Axions and ALPs
- **Weakly Interacting Massive Particles (WIMPs)**
- Sterile Neutrinos
- SuperWIMPs and Decaying DM
- WIMPzillas
- Asymmetric DM
- SIMPs, CHAMPs, SIDMs
- Bose Einstein Condensate …



... they have very different properties

Dark matter **MUST BE** searched for in different ways...

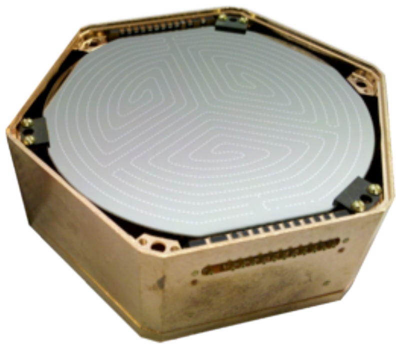
Direct DM detection



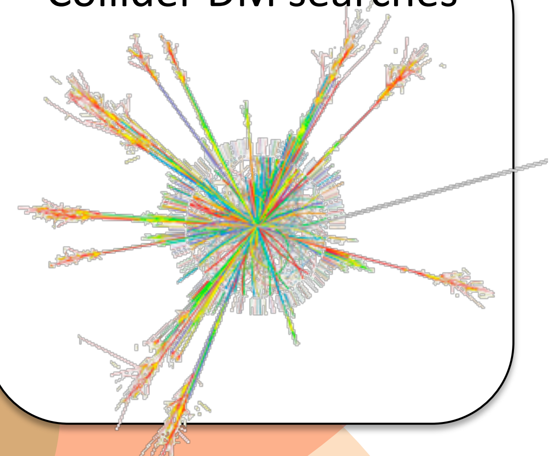
Weakly-Interacting Massive Particles
Inelastic DM
Axion-like particles
Millicharged particles

Dark matter MUST BE searched for in different ways…

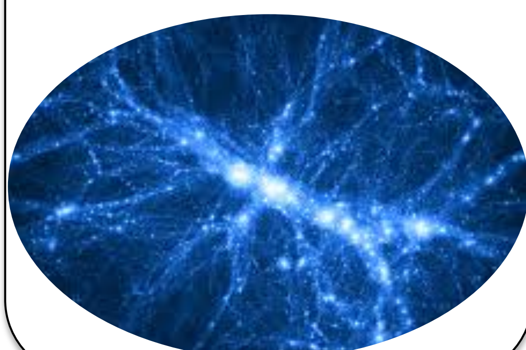
Direct DM detection



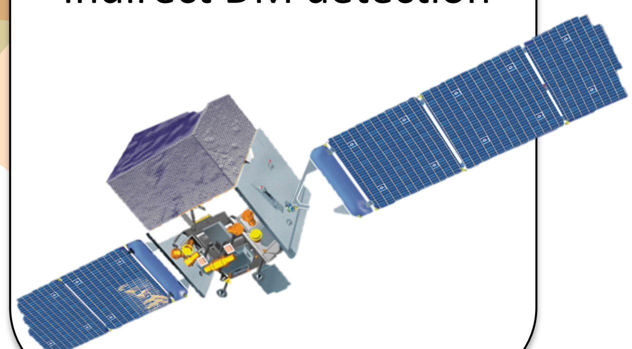
Collider DM searches



Astro/Cosmo probes

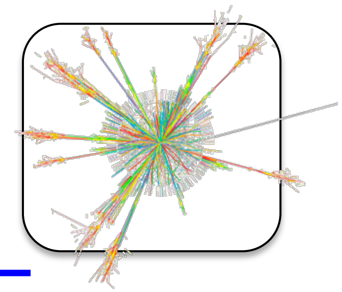


Indirect DM detection

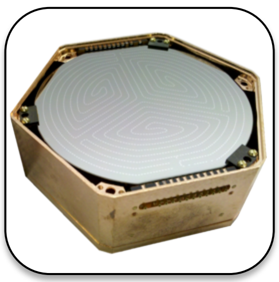


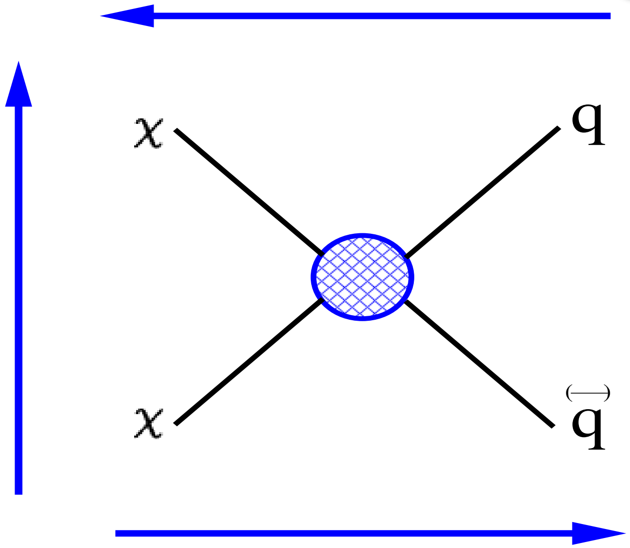
... probing **DIFFERENT** aspects of their interactions with ordinary matter

Accelerator Searches (production)



Direct Detection
(scattering)

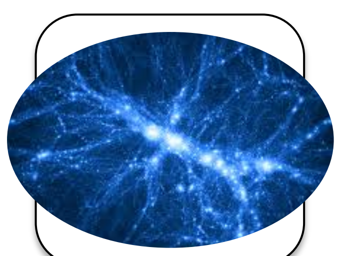


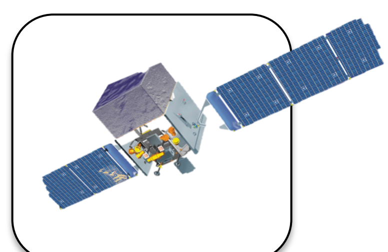


Constraints in one sector affect observations in the other two.

"**Redundant**" detection can be used to extract DM properties.

Indirect Detection
(annihilation or decay)





Current challenges for DARK MATTER

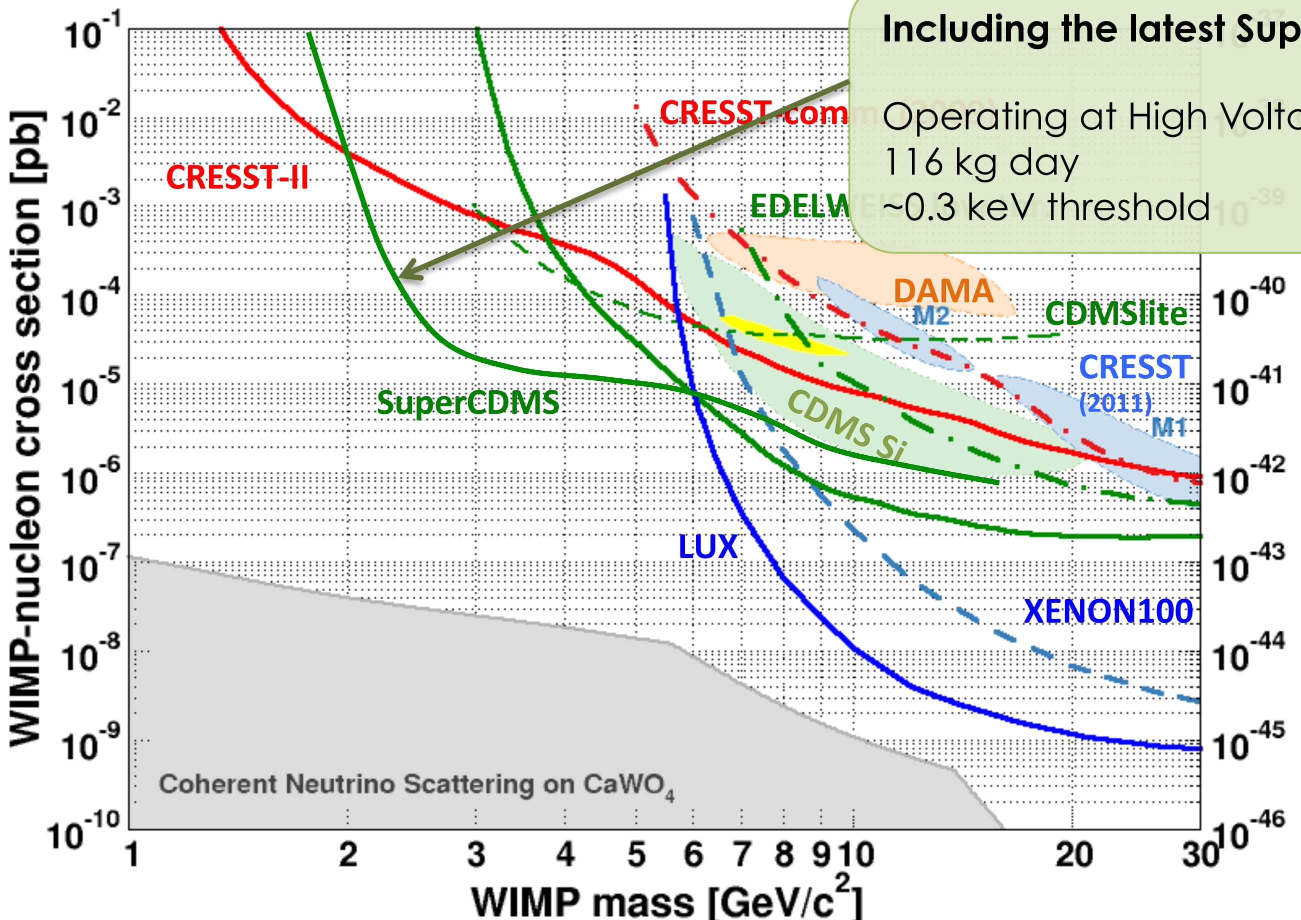
- **Experimental detection:**
  Does DM feel other interactions apart from Gravity?
  Is the Electro-Weak scale related somehow related to DM?
  How is DM distributed?

- **Determination of the DM particle parameters:**
  Mass, interaction cross section, etc…

- **What is the theory for Physics beyond the SM:**
  DM as a window for new Physics
  Can we identify the DM candidate?

Upper bounds on the SI cross section

XENON10, XENON100, LUX (Xe), CDMSlite, SuperCDMS, Edelweiss (Ge), COUPP (CF_3I), and CRESST ($CaWO_4$) have not observed any DM signal, which constrains the scattering cross section



Including the latest SuperCDMS low-mass results

Operating at High Voltage (~70V)
116 kg day
~0.3 keV threshold

From a plot by Raimund Strauss

Upper bounds on the SI cross section

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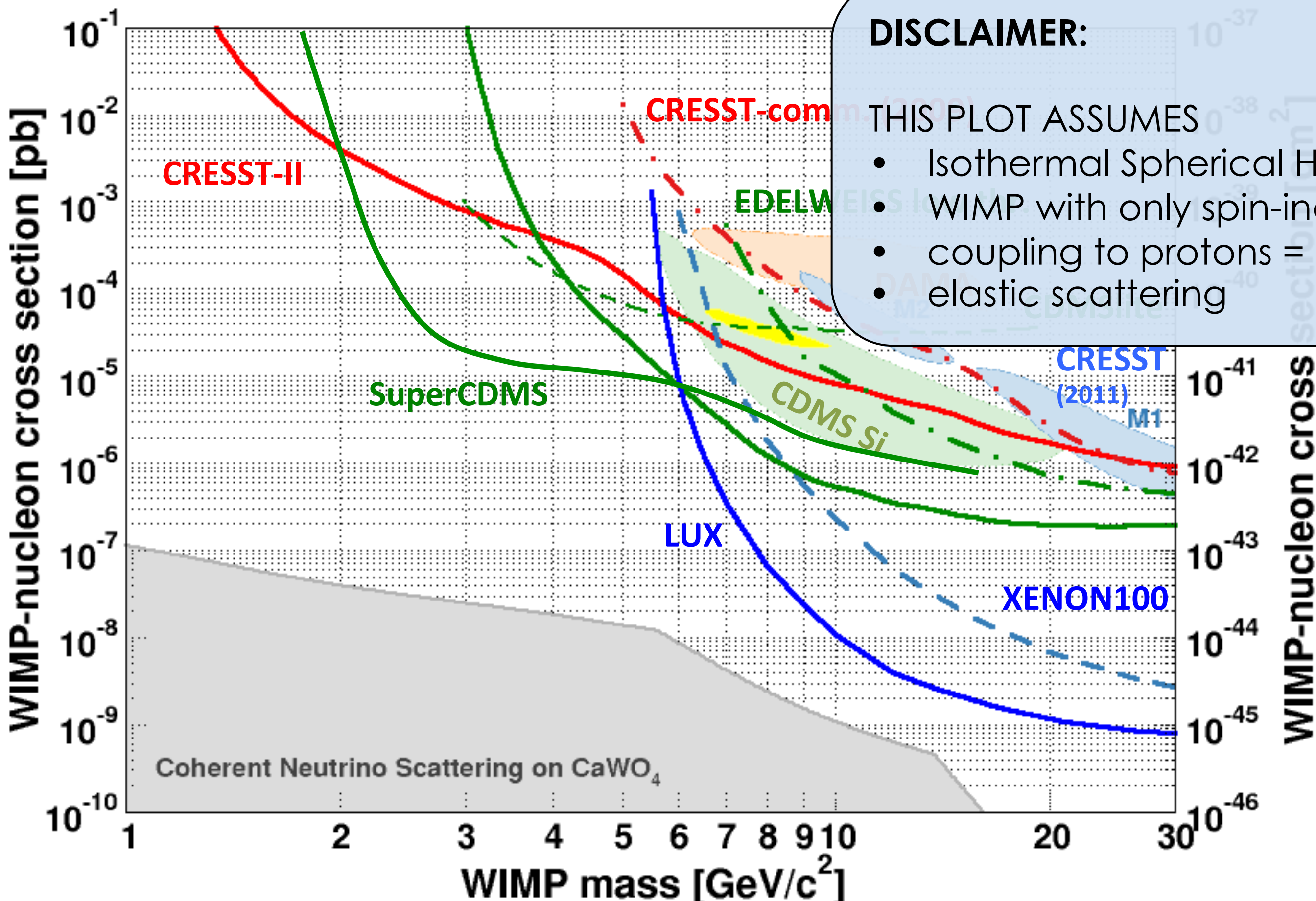


DISCLAIMER:

THIS PLOT ASSUMES

- Isothermal Spherical Halo
- WIMP with only spin-independent interaction
- coupling to protons = coupling to neutrons
- elastic scattering

From a plot by Raimund Strauss

Isospin-Violating Dark Matter can ease this discrepancy

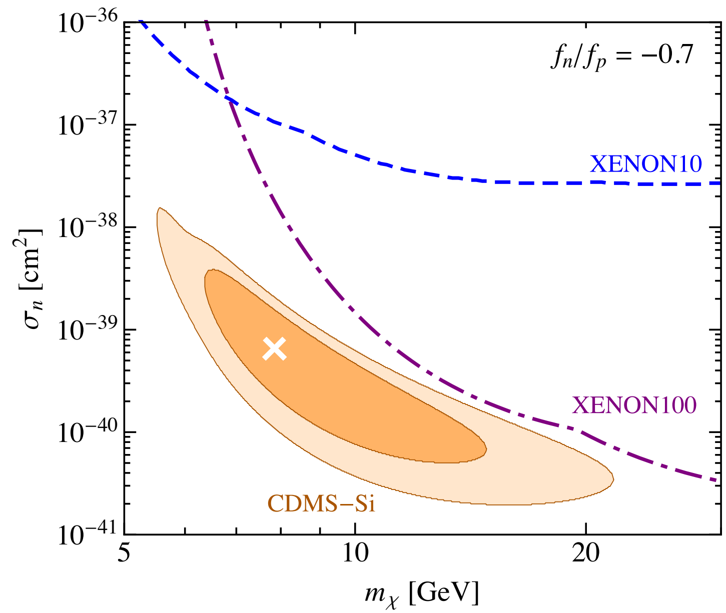
$$R = \sigma_p \sum_i \eta_i \frac{\mu_{A_i}^2}{\mu_p^2} I_{A_i} \left[Z + (A_i - Z) f_n/f_p\right]^2$$

The scattering amplitudes for proton and neutrons may interfere destructively

$$f_n/f_p = -Z/(A-Z)$$

The interference depends on the target nucleus

For Xe (Z=54, A~132) → $f_n/f_p = -0.7$



XENON100 (Xe) and CDMS II (Si) results can be "reconciled"

Frandsen et al. 2013

The effective interaction of DM particles with nuclei can be more diverse than previously considered

Fitzpatrick, Wick et al. 2012-2014

On Taxonomy and Taxidermy

Taxonomy (Theory–biased)

Construct a bestiary of "well motivated models"

Predictions are tested with experimental results

- "Standard" WIMPs
  - Supersymmetry (neutralinos, **sneutrinos**)
  - Kaluza-Klein DM
  - Inert Doublet Model
  - …

- Asymmetric DM
- Inelastic DM
- Decaying DM (e.g., gravitinos)
- Axions
- Self-interacting DM
- …

Particle Physics models for dark matter

Well motivated DM models in theories beyond the Standard Model (e.g., Supersymmetry)

Minimal SUSY extension

Squarks	$\tilde{u}_{R,L}$, $\tilde{d}_{R,L}$ $\tilde{c}_{R,L}$, $\tilde{s}_{R,L}$ $\tilde{t}_{R,L}$, $\tilde{b}_{R,L}$
Sleptons	$\tilde{e}_{R,L}$, $\tilde{\nu}_e$ $\tilde{\mu}_{R,L}$, $\tilde{\nu}_\mu$ $\tilde{\tau}_{R,L}$, $\tilde{\nu}_\tau$
Neutralinos	$\tilde{B}^0$, $\tilde{W}^0$, $\tilde{H}^0_{1,2}$
Charginos	$\tilde{W}^\pm$, $\tilde{H}^\pm_{1,2}$
Gluino	$\tilde{g}$

Neutralino

Good annihilation cross section. it is a WIMP

Goldberg '83

Ellis, Hagelin, Nanopoulos, Olive, Srednicki '83

Krauss '83

Sneutrino

Viable candidates in scenarios with Right-Handed sneutrinos

DGC, Muñoz, Seto 08

Arina, Fornengo 08

Gravitino (Superpartner of the graviton)

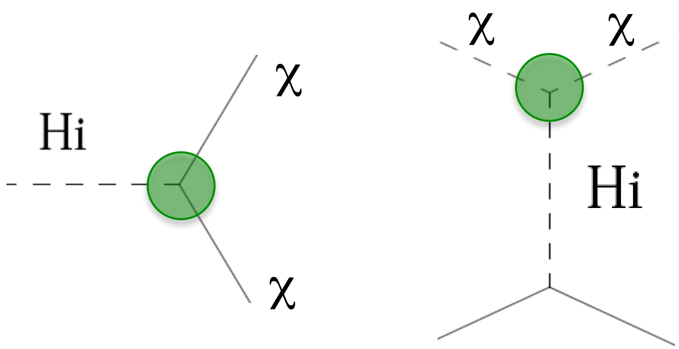
Axino (Superpartner of the axion)

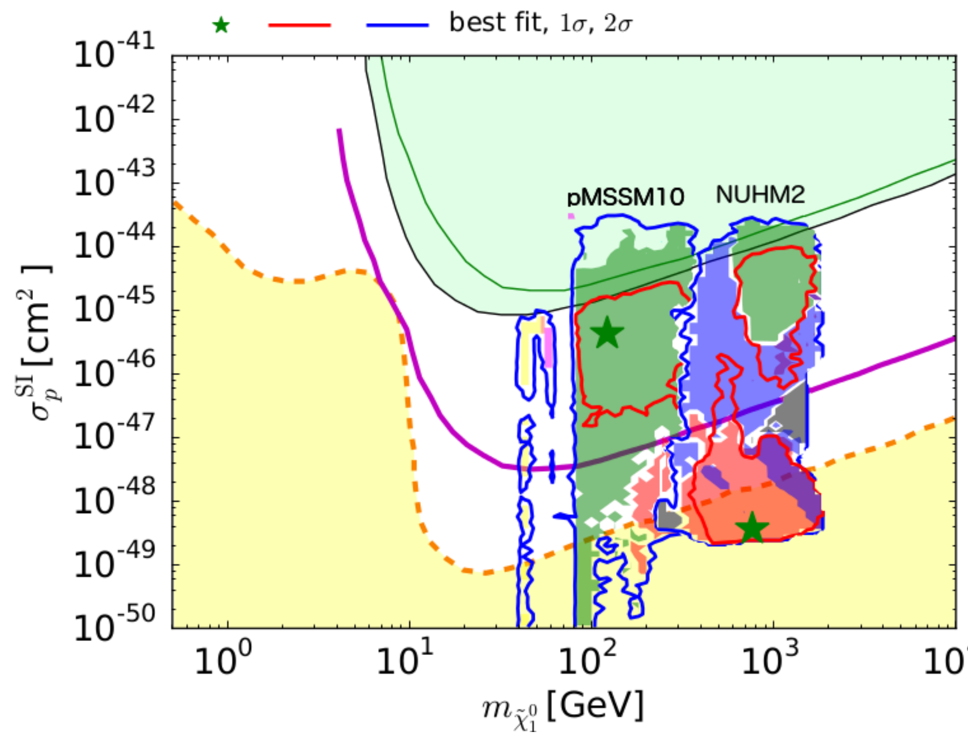
Extra-weakly interacting massive particles

Neutralino in the MSSM

Impose LHC1 bounds and explore the predictions of MSSM parameter space

- Bounds on SUSY masses
- Low-energy observables
- Invisible Higgs decay





MSSM after LHC1
Bagnaschi et al. 2015

The current bound on BR(H→ inv) sets constraints on the DM-Higgs coupling

This also translates into (upper) bounds for the scattering cross section of low-mass WIMPs

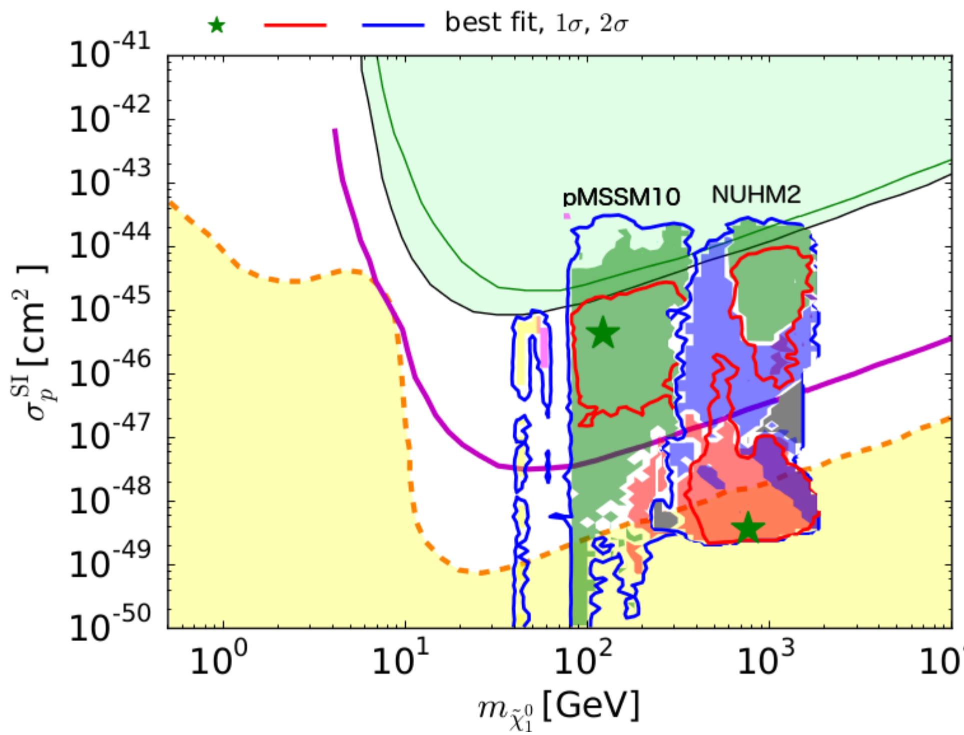
Neutralino in the MSSM

Impose LHC1 bounds and explore the predictions of MSSM parameter space

- Bounds on SUSY masses
- Low-energy observables
- Invisible Higgs decay
- Correct DM relic density

The predictions for the scattering cross section still span many orders of magnitude

(excellent motivation for more sensitive detectors)



MSSM after LHC1
Bagnaschi et al. 2015

Combined with LHC + Indirect searches → excellent coverage of SUSY parameter space

Right-handed sneutrino in the NMSSM

DGC, Muñoz, Seto 2007 , DGC, Seto 2009

- Addition of TWO new superfields, ***S***, ***N***, singlets under the SM gauge group

$$\mathrm{NMSSM} \quad = \quad \mathrm{MSSM} + \hat{S} \begin{cases} 2 \text{ extra Higgs (CP}-\text{even, CP}-\text{odd)} \\ 1 \text{ additional Neutralino} \end{cases}$$

$$+ N \begin{cases} 1 \text{ additional (right-handed) Neutrino} \\ \text{and sneutrino} \end{cases}$$

- New terms in the superpotential

$$W = Y_u\, H_2\, Q\, u + Y_d\, H_1\, Q\, d + Y_e\, H_1\, L\, e - \lambda\, S\, H_1 H_2 + \frac{1}{3}\kappa S^3$$

$$W \quad = \quad W_{\mathrm{NMSSM}} + \lambda_N S N N + y_N L\, H_2 N$$

- After Radiative Electroweak Symmetry-Breaking

$$\langle H_1^0 \rangle = v_1 \quad ; \quad \langle H_2^0 \rangle = v_2 \quad ; \quad \langle S \rangle = s$$

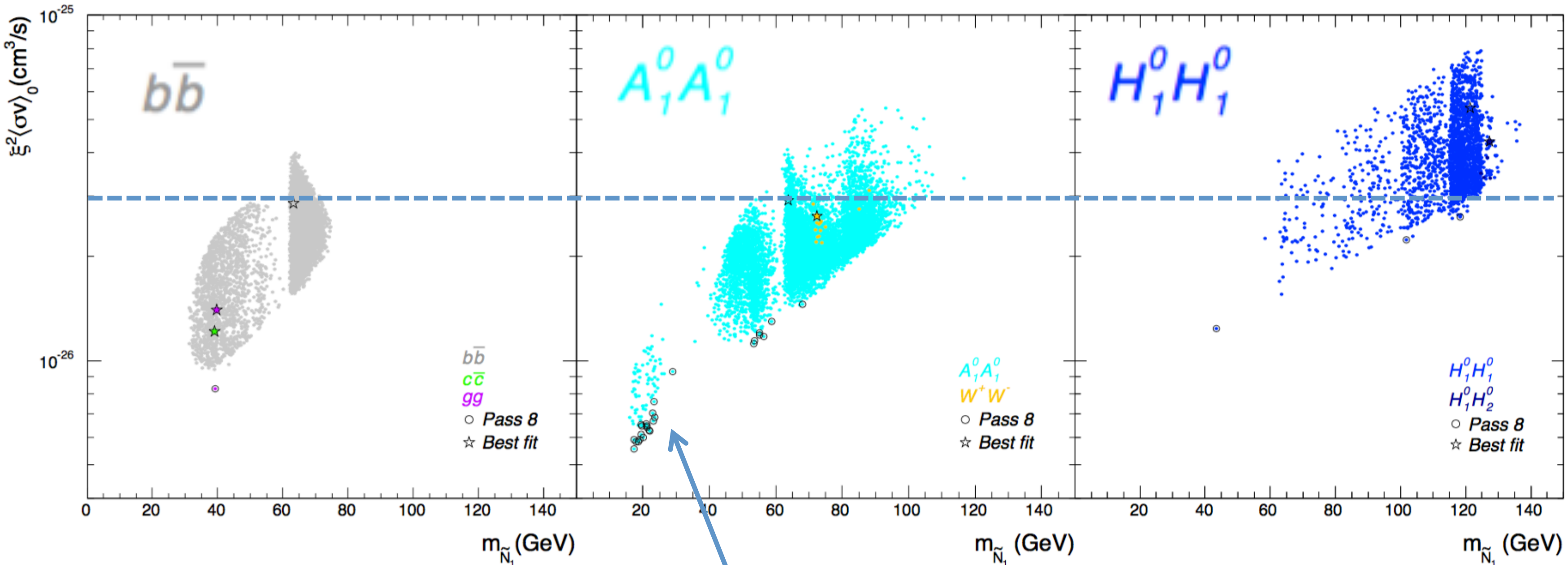
$$\begin{cases} \mu\, H_1\, H_2 \\ m_N\, N\, N \end{cases}$$

EW-scale Higgsino-mass parameter & Majorana neutrino mass

Right-handed sneutrino in the NMSSM and the GCE

- Scan in the parameter space imposing all constraints (direct, indirect and colliders)
- The full final state is studied
  Do not restrict the analysis to pure annihilation channels.

Points fitting the GCE at 90% CL

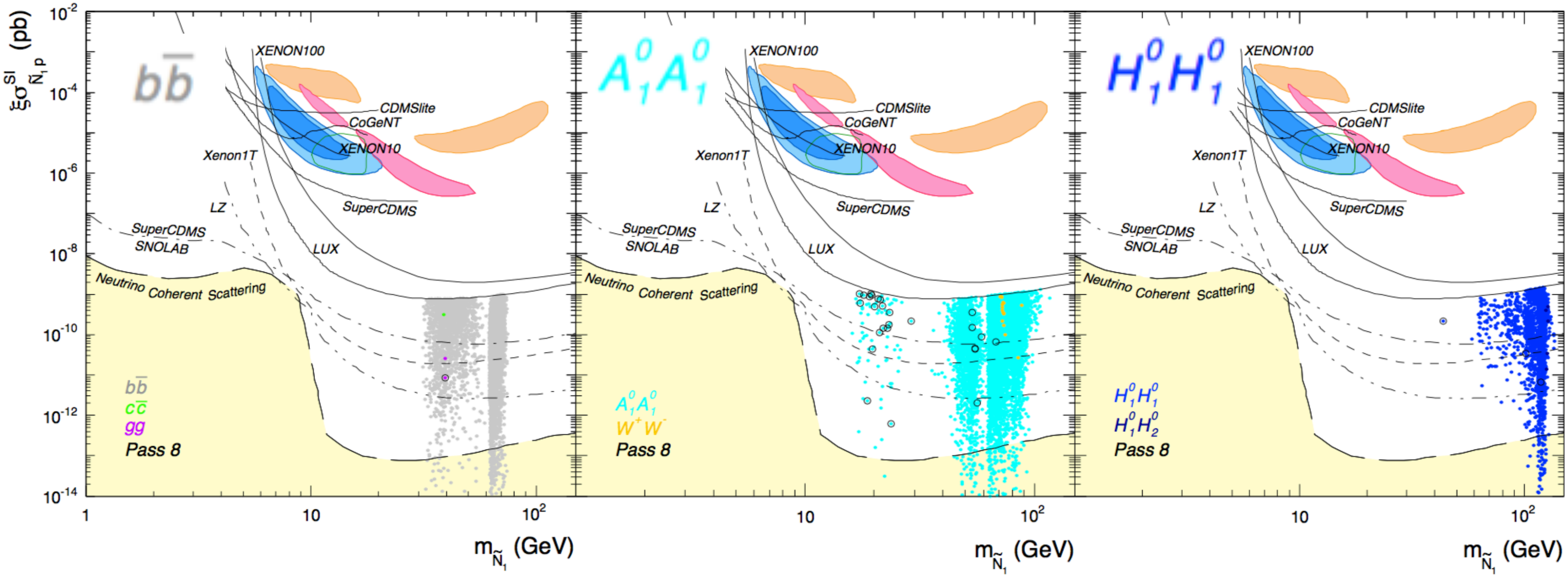


$$\tilde{N}_1\tilde{N}_1 \rightarrow 2A_1^0 \rightarrow 4\tau$$

DGC, Peiró, Robles JCAP 08 (2014) 005

Right-handed sneutrino in the NMSSM and the GCE

- Many of these points can be checked by G2 direct detection experiments



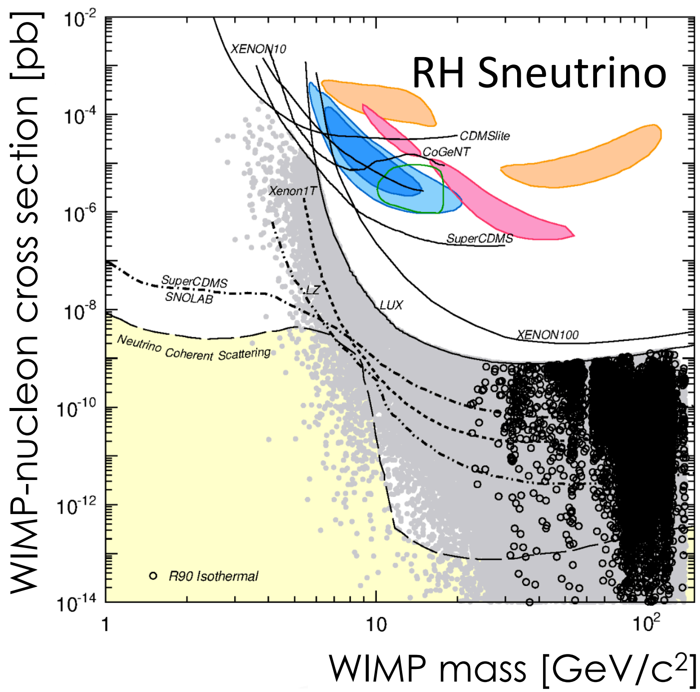
DGC, Peiró, Robles JCAP 08 (2014) 005

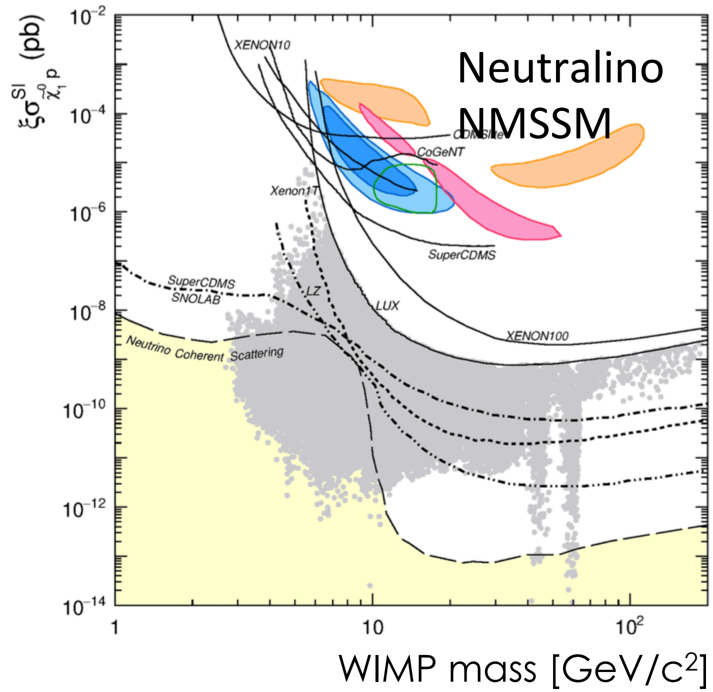
Once more: Complementarity of DM searches

Neutralino and Right-handed sneutrino in the NMSSM

Extensions of the MSSM can be more flexible (new light mediators)

Low-mass SUSY WIMPs are still viable (1-100 GeV)





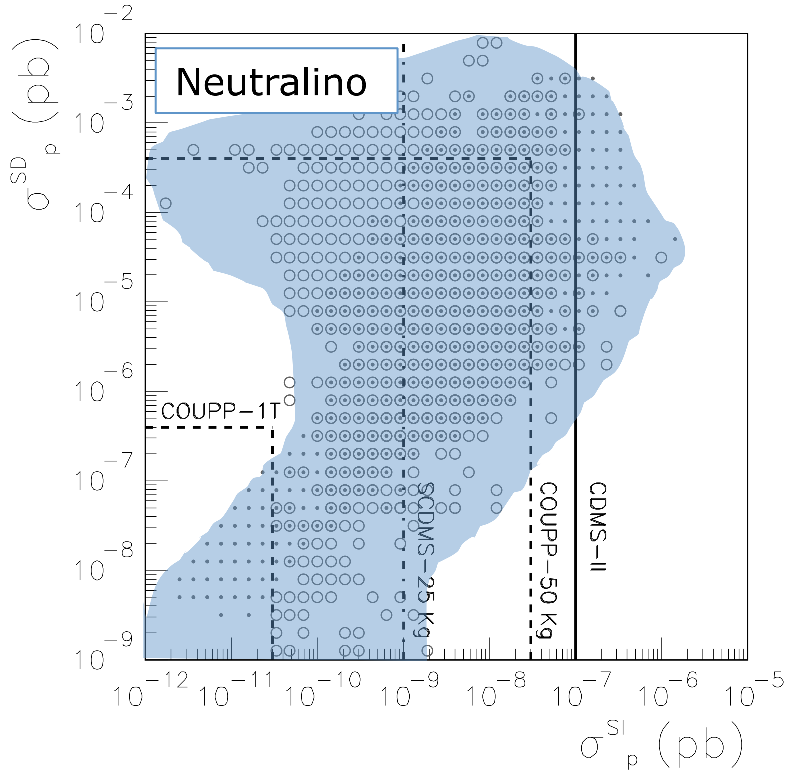
DGC, Peiró, Robles JCAP 08 (2014) 005
DGC, Peiró Robles, 2015

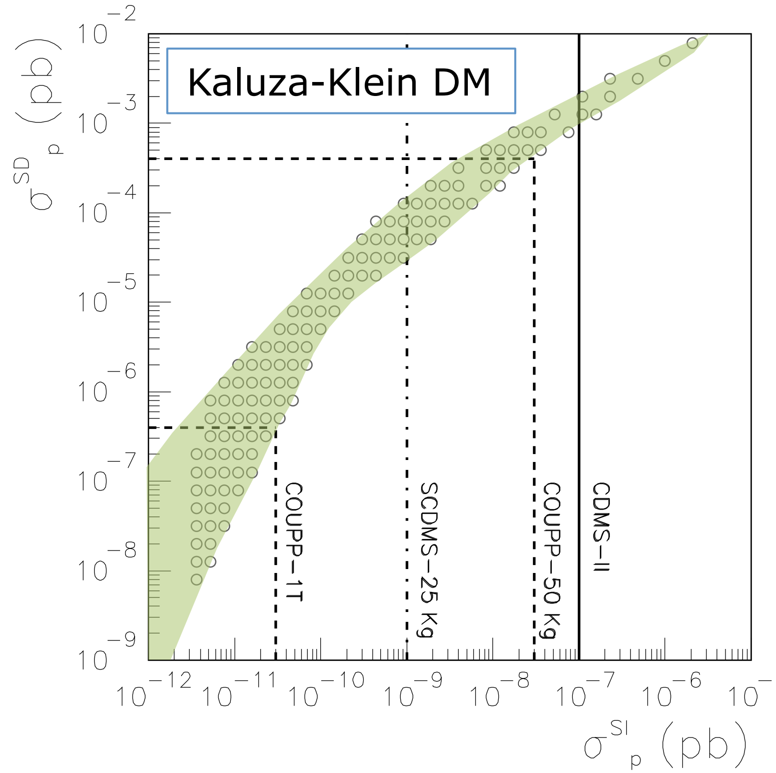
Excellent motivation for direct searches at low masses

WIMPs behave very similarly (not surprisingly)

There can be correlations in the “phenomenological parameters”

Information on spin-dependent WIMP couplings can prove important to distinguish models





Bertone, DGC, Collar, Odom ‘07

“Advance in both fronts” (spin-dependent and -independent) to gain discriminating power

If there is a positive detection of DM, can we identify the underlying model?

Problem:

- Experimental data allow us to reconstruct **"phenomenological parameters"**.

$$m_\chi,\ \sigma^{SI},\ \sigma^{SD},\ <\sigma v>_{ij}$$

- Theoretical models tend to produce similar results (e.g., most WIMPs are alike)

Solution:

- Data from different experiments has to be combined in order to remove degenerate solutions (and reduce the effect of uncertainties)

Strategies that allow the identification of DM from future data

On Taxidermy

Taxidermy **(Phenomenology-driven)**

Interpret experimental results in terms of simplified models or effective Lagrangians

Identify some basic features from a **positive observation**

(Galactic Centre Emission)

Taxidermy (Phenomenology-driven)

Identify some basic features from a **positive observation**

(Galactic Centre Emission)

Perform a **complementary measurement** with other search technique

(Signal in various direct detection targets or at the LHC)

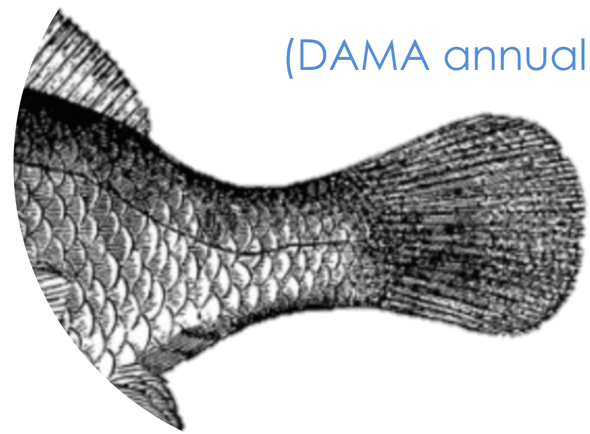
Taxidermy (Phenomenology-driven)

Identify some basic features from a **positive observation**

(Galactic Centre Emission)

Some data might be more difficult to explain in terms of "standard" DM models

(DAMA annual modulation)



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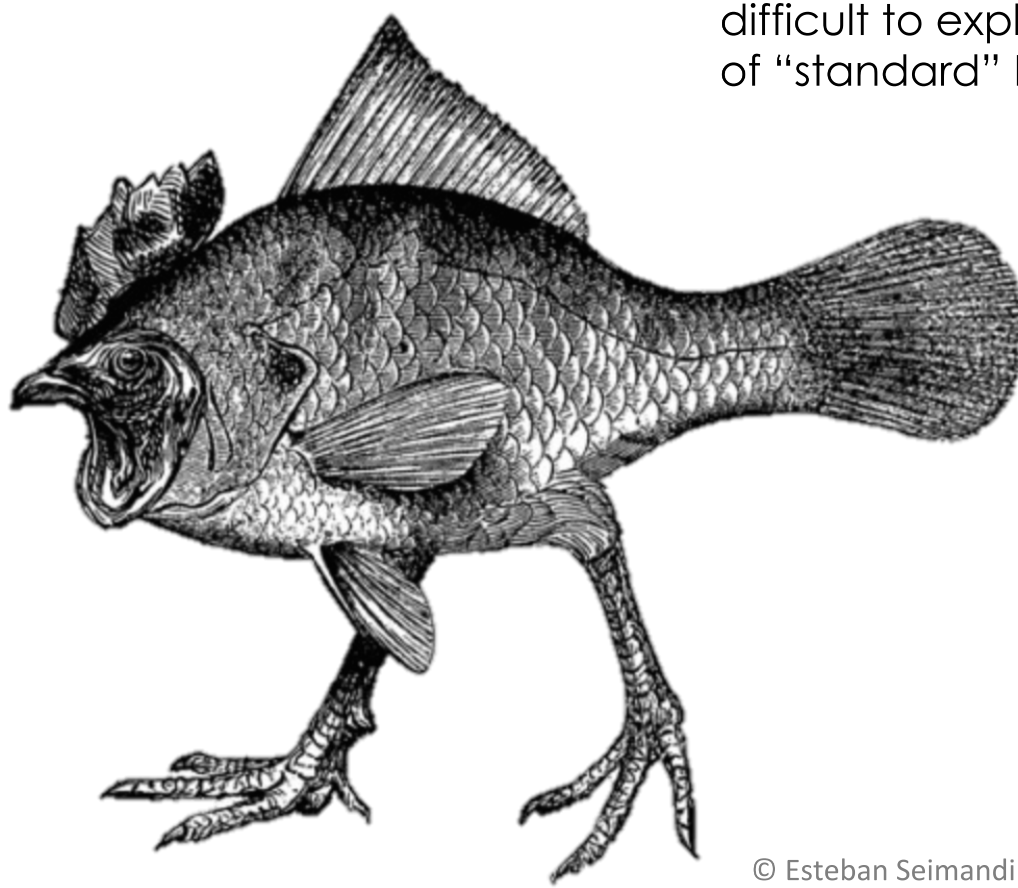


Perform a **complementary measurement** with other search technique

This motivates working with general frameworks, where little or nothing is assumed for the DM particle

Identification of Dark Matter

Given a DM direct detection, the DM mass and couplings can be determined from the observed number of events and energy spectrum.

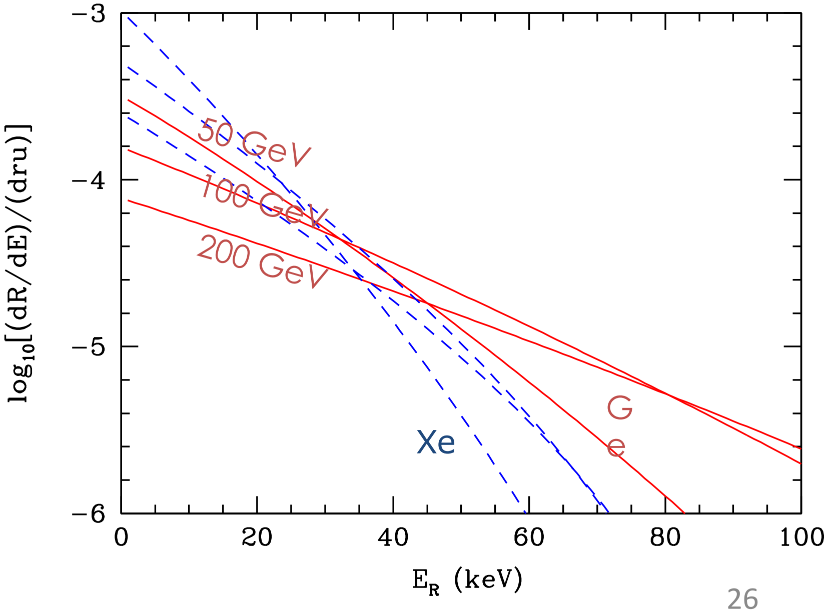
Theoretical input

$$R = \int_{E_T}^{\infty} dE_R \frac{\rho_0}{m_N\, m_\chi} \int_{v_{min}}^{\infty} v f(v) \frac{d\sigma_{WN}}{dE_R}(v, E_R)\, dv$$

$$\frac{d\sigma_{WN}}{dE_R} = \frac{m_N}{2\mu_N^2 v^2}\left(\sigma_0^{SI} F_{SI}^2(E_R) + \sigma_0^{SD} F_{SD}^2(E_R)\right)$$

Nuclear form factors

The energy spectrum depends on the WIMP mass and the mass of the target



Identification of Dark Matter with direct detection experiments

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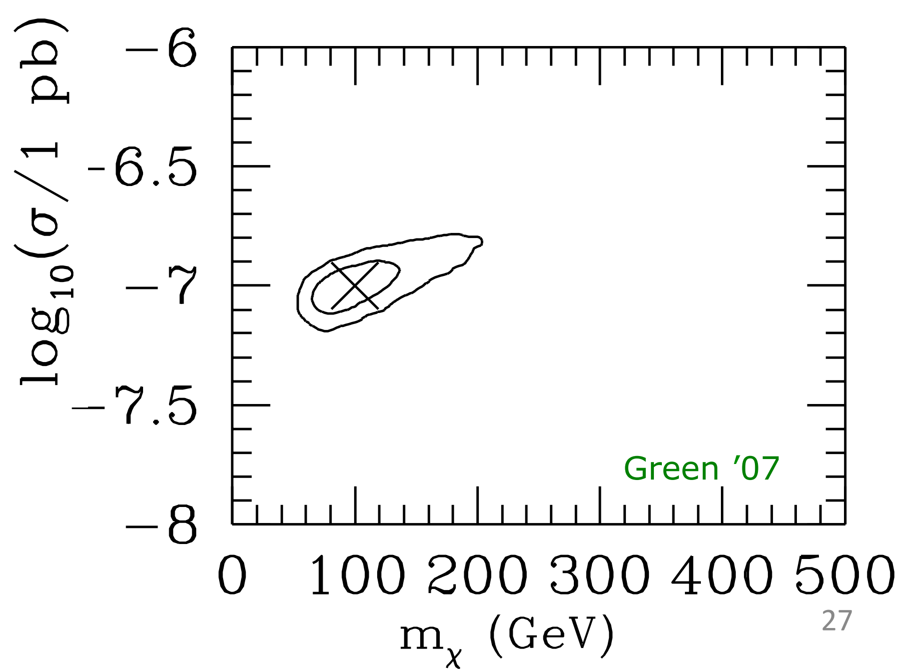
Nuclear form factors

The energy spectrum depends on the WIMP mass and the mass of the target

There are degenerate solutions



Example: m_χ=100 GeV
Exposure: 3000 kg day (Ge target)

Astrophysical uncertainties in direct DM searches

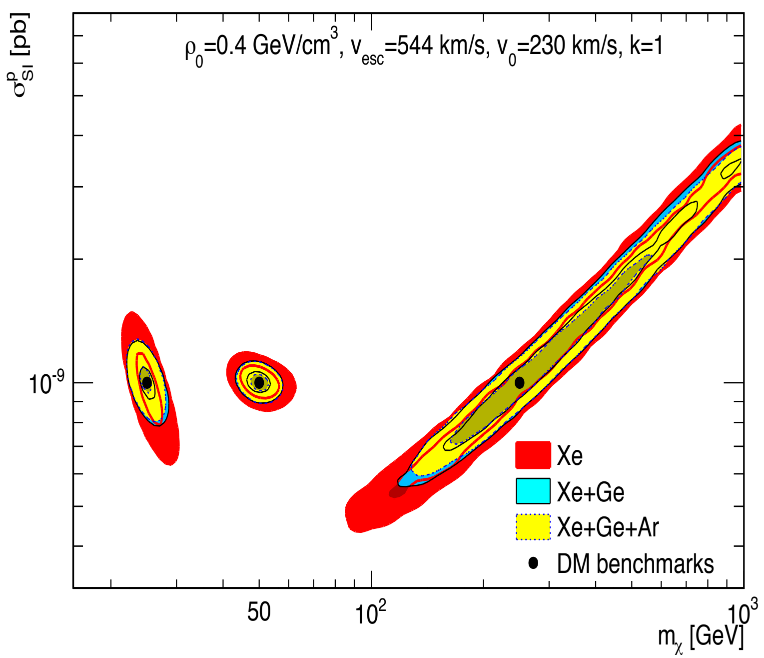
There are uncertainties in the parameters describing the Standard Halo Model

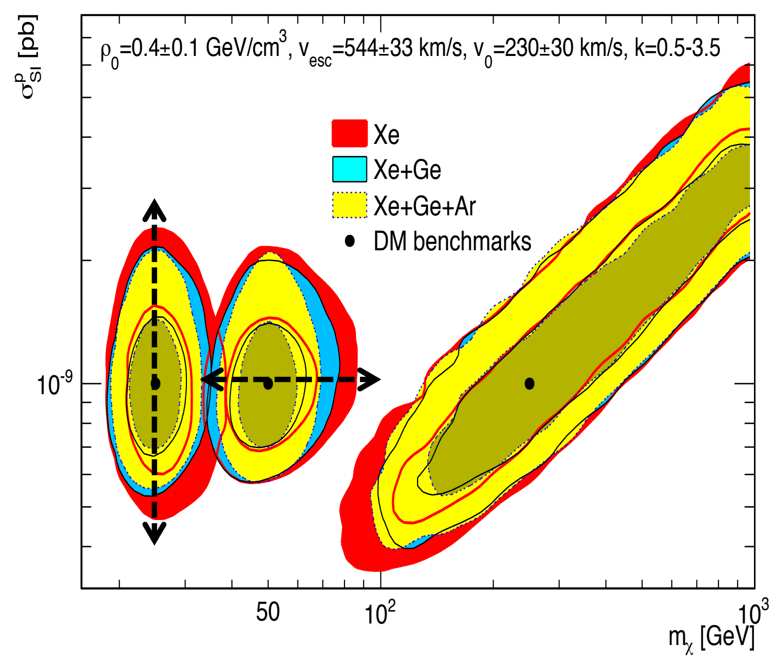
$$f(w) = \begin{cases} \frac{1}{N_f}\left[\exp\left(\frac{v_{esc}^2 - w^2}{k v_0^2}\right) - 1\right]^k & \text{if } w \leq v_{esc} \\ 0 & \text{if } w > v_{esc} \end{cases}$$

Binney, Tremaine '08

Nuisance parameter	Range
$\rho_{\mathrm{WIMP},\odot}$	$[0.2,\ 0.6]$ GeV cm^{-3}
v_{esc}	$[478,\ 610]$ km s^{-1}
$v_{\odot}$	$[170,\ 290]$ km s^{-1}
k	$[0.5,\ 3.5]$

Lisanti et al. '10





Pato, Baudis et al. '11

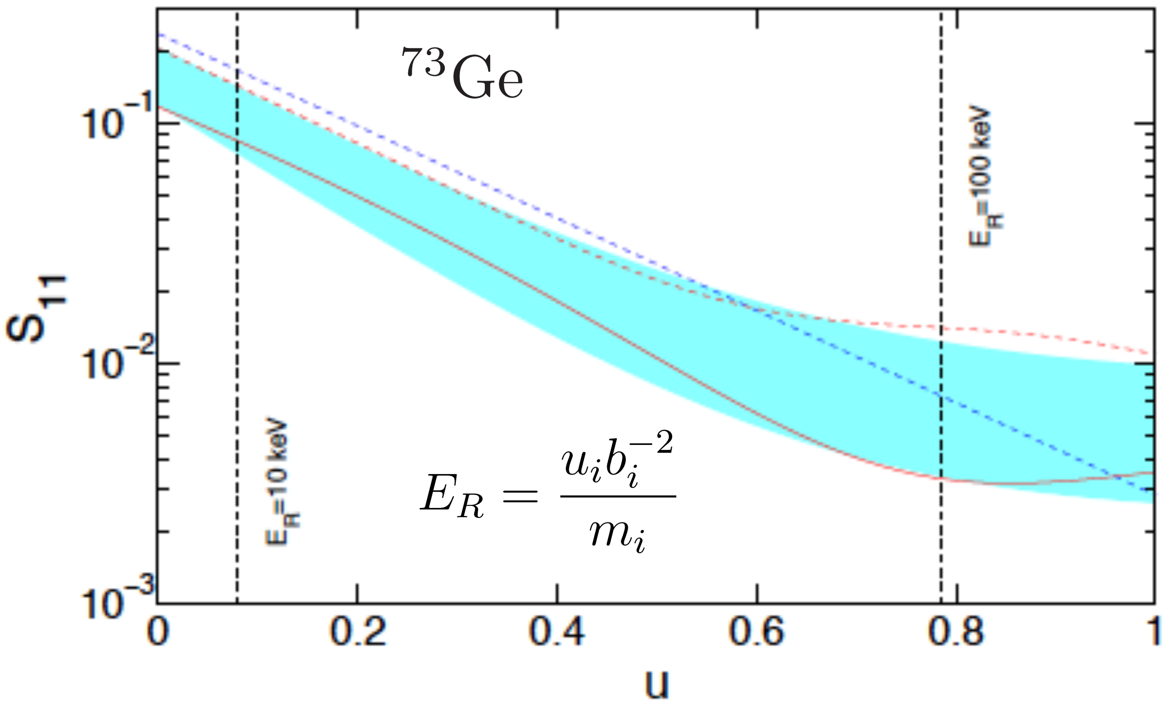
Uncertainties in the spin-dependent form factors

$$\left(\frac{d\sigma}{dE_R}\right)_{SD} = \frac{16\, G_F^2 m_N}{\pi v^2} \frac{(J+1)}{J} \left(a_p \langle S_p \rangle + a_n \langle S_n \rangle\right)^2 F_{SD}^2(E_R)$$

$$a_0 = a_p + a_n$$
$$a_1 = a_p - a_n$$

Spin-dependent structure functions:

$$S(q) = a_0^2 S_{00}(q) + a_0 a_1 S_{01}(q) + a_1^2 S_{11}(q)$$



Cerdeño, Fornasa, Huh, Peiro 2013

ShM COMPUTATIONS:

Ressel, et al. '93

Dimitrov, et al. '94

Variations in

- Zero-momentum value
- Slope
- Plateau

Degeneracies in reconstructing the phenomenological parameters.

The same detected rate can be due to different combinations of SI-SD interactions

$$R = \int_{E_T}^{\infty} dE_R \frac{\rho_0}{m_N\, m_\chi} \int_{v_{min}}^{\infty} v f(v) \frac{d\sigma_{WN}}{dE_R}(v, E_R)\, dv$$

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Nuclear form factors

Integrating in energies and velocities

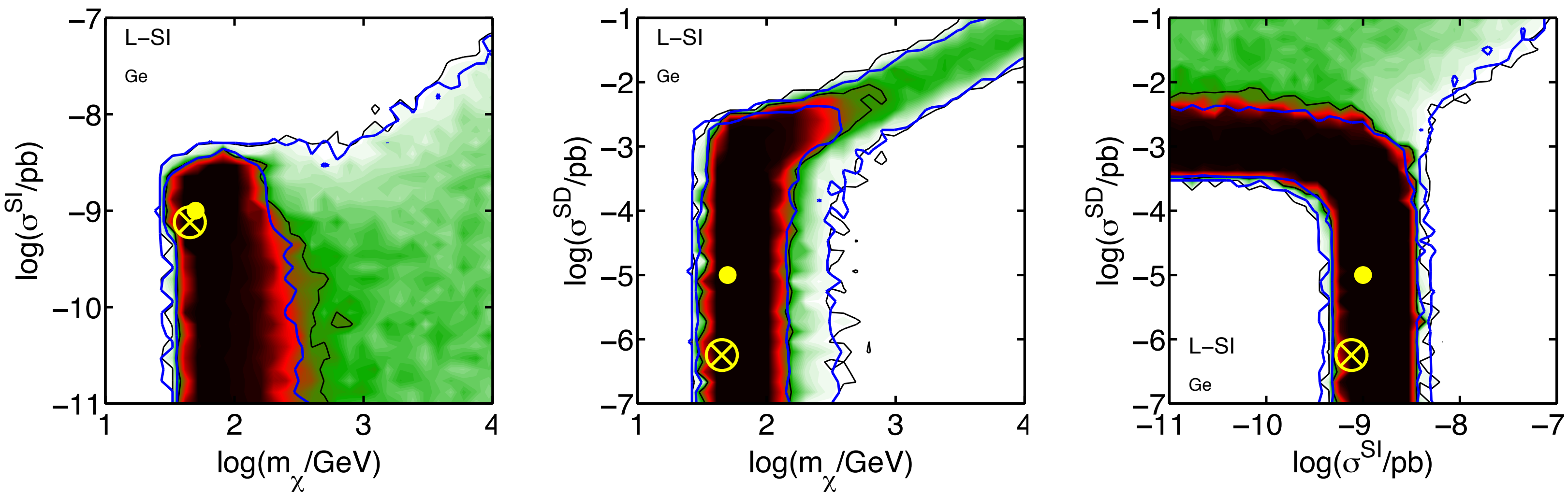
$$R_1 = A_1 \sigma_0^{SI} + \left(B_1^p \sqrt{\sigma_0^{SD,p}} + B_1^n \sqrt{\sigma_0^{SD,n}} \right)^2$$

Target-dependent

A single experiment cannot determine the three WIMP couplings (the shape of the differential rate allows a determination of the WIMP mass)

We need multiple experiments (with various targets)

A single experiment cannot determine all the WIMP couplings, a combination of various targets is necessary.



$$\sigma_0^{SI} = 10^{-9}\,\text{pb}$$
$$\sigma_0^{SD} = 10^{-5}\,\text{pb}$$
$$m_W = 50\,\text{GeV}$$
$$\epsilon = 300\,\text{kg yr}$$

We use simulated data to assess the reconstruction of DM parameters

Astrophysical and nuclear uncertainties included

Prospects for SuperCDMS (Ge)

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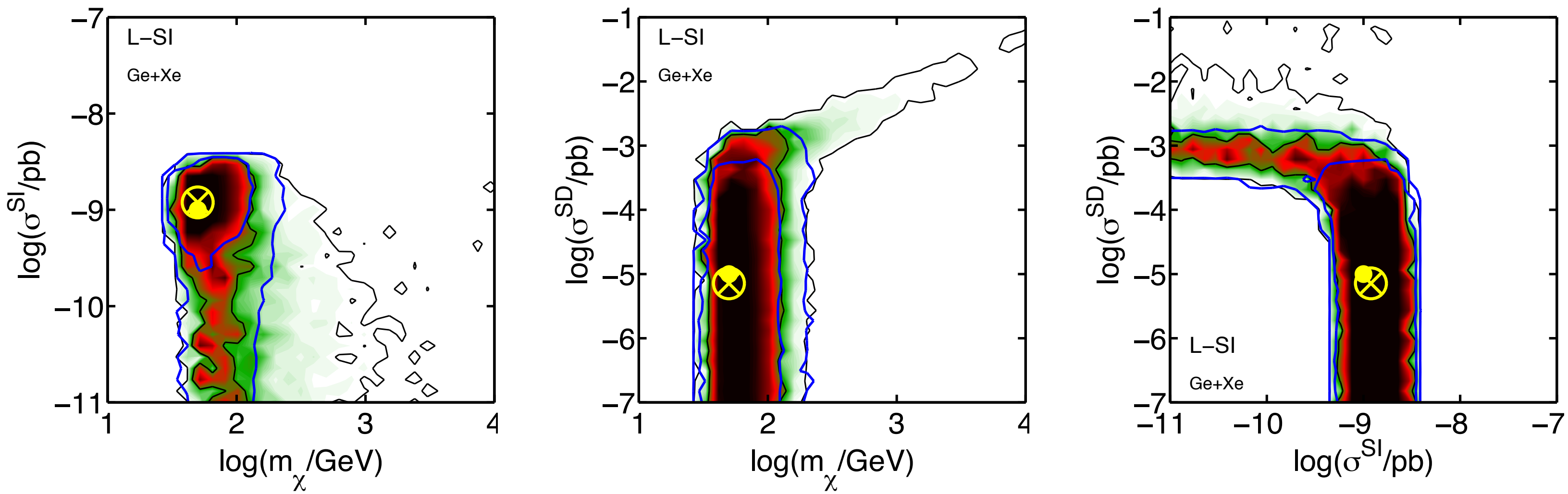

A combination of **Germanium and Xenon** greatly helps in reconstructing the DM parameters

Targets with different sensitivities to SI and SD cross section are needed (e.g., F, Al)

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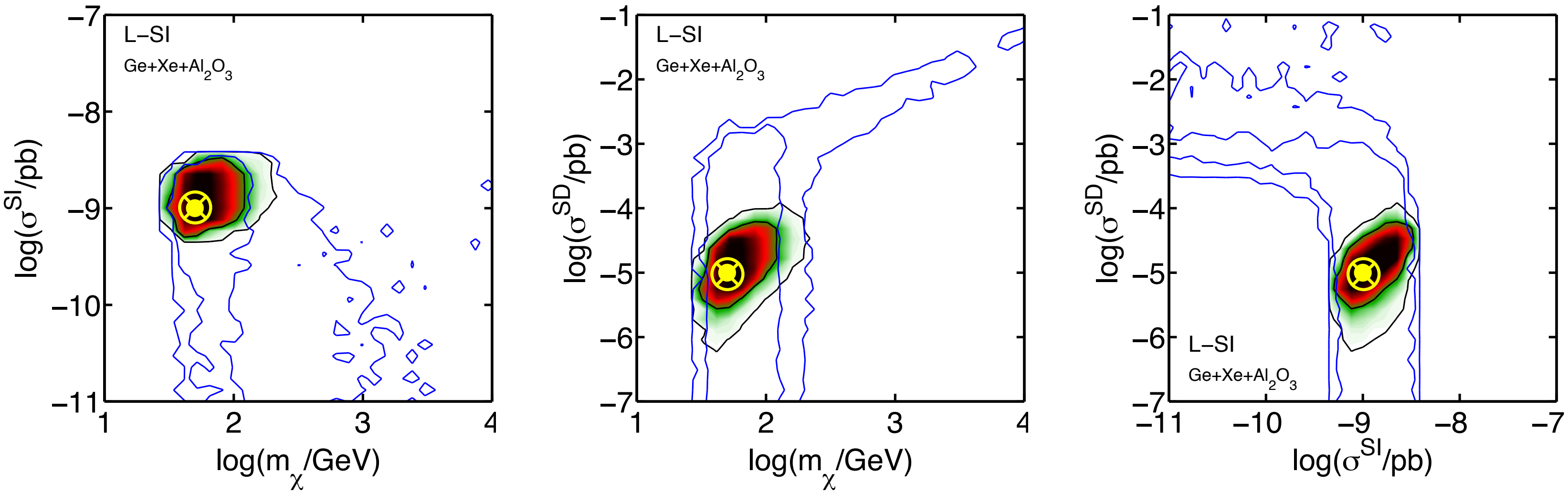


A combination of **Germanium and Xenon** greatly helps in reconstructing the DM parameters

Targets with different sensitivities to SI and SD cross section are needed (e.g., F, Al)

This is an excellent tool to help design future experiments.

Are we being too conservative in describing DM-nucleus interactions?

The most general effective Lagrangian contains up to 14 (x2) different operators that induce six types of response functions and two new interference terms

Haxton, Fitzpatrick 2012-2014

$$\mathcal{L}_{\text{int}}(\vec{x}) = c\ \Psi^*_\chi(\vec{x})\mathcal{O}_\chi\Psi_\chi(\vec{x})\ \Psi^*_N(\vec{x})\mathcal{O}_N\Psi_N(\vec{x})$$

Spin-Indep.

Spin-Dep.

Angular momentum of unpaired nucleon

Angular momentum and spin

$$\mathcal{O}_1 = 1_\chi 1_N$$

$$\mathcal{O}_3 = i\vec{S}_N \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$

$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$$

$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$

$$\mathcal{O}_6 = \left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$

$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$

$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$

$$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left[\vec{S}_N \times \frac{\vec{q}}{m_N}\right]$$

$$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$$

$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$

$$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left[\vec{S}_N \times \vec{v}^\perp\right]$$

$$\mathcal{O}_{13} = i\left[\vec{S}_\chi \cdot \vec{v}^\perp\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$

$$\mathcal{O}_{14} = i\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \vec{v}^\perp\right]$$

$$\mathcal{O}_{15} = -\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\left(\vec{S}_N \times \vec{v}^\perp\right) \cdot \frac{\vec{q}}{m_N}\right]$$

These operators can be obtained as the non-relativistic limit of relativistic operators (e.g., starting from UV complete models)

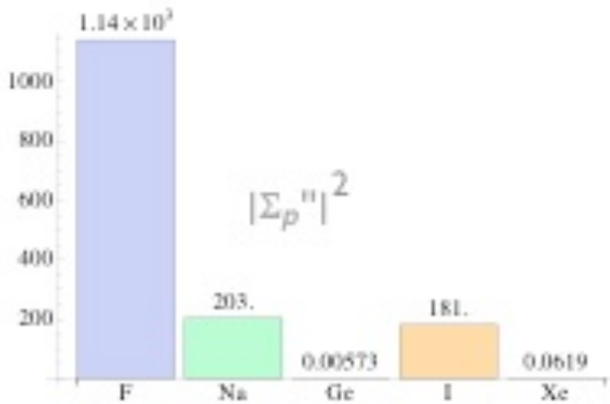
E.g., For a spin ½ particle

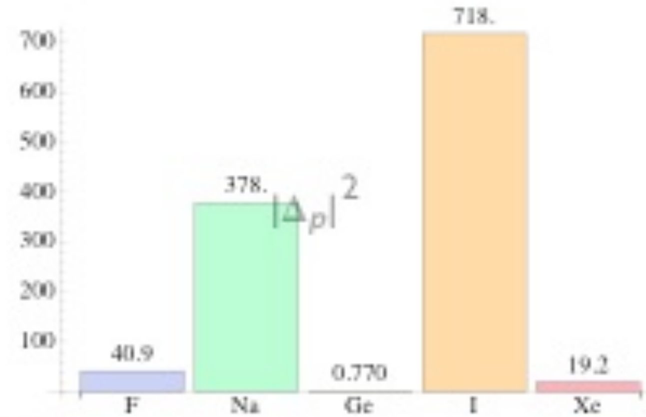
Scalar Mediator		
$\bar{\chi}\chi\bar{q}q$	$\longrightarrow$	$\left(\frac{h_1^N\lambda_1}{m_\phi^2}\right)\mathcal{O}_1$
$\bar{\chi}\chi\bar{q}\gamma^5 q$	$\longrightarrow$	$\left(\frac{h_2^N\lambda_1}{m_\phi^2}\right)\mathcal{O}_{10}$
$\bar{\chi}\gamma^5\chi\bar{q}q$	$\longrightarrow$	$\left(-\frac{h_1^N\lambda_2 m_N}{m_\phi^2 m_\chi}\right)\mathcal{O}_{11}$
$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	$\longrightarrow$	$\left(\frac{h_2^N\lambda_2 m_N}{m_\phi^2 m_\chi}\right)\mathcal{O}_6$
Vector Mediator		
$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$\longrightarrow$	$\left(-\frac{h_3^N\lambda_3}{m_G^2}\right)\mathcal{O}_1$
$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$\longrightarrow$	$\left(-\frac{2h_4^N\lambda_3}{m_G^2}\right)\left(-\mathcal{O}_7+\frac{m_N}{m_\chi}\mathcal{O}_9\right)$
$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$\longrightarrow$	$\left(-\frac{2h_3^N\lambda_4}{m_G^2}\right)(\mathcal{O}_8+\mathcal{O}_9)$
$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$\longrightarrow$	$\left(\frac{4h_4^N\lambda_4}{m_G^2}\right)\mathcal{O}_4$

Dent, Krauss, Newstead, Sabbharwal 2015

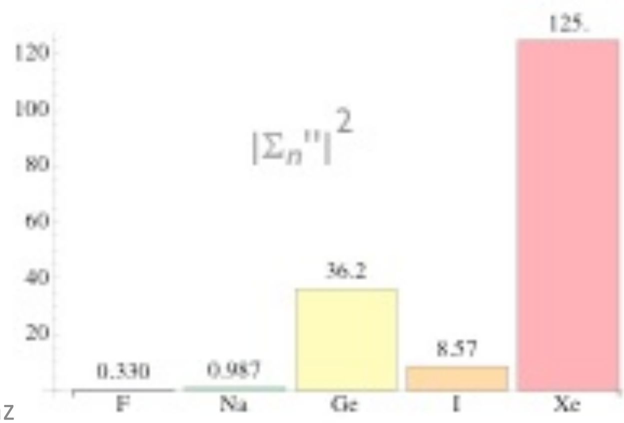
These are extremely sensitive to the choice of target material, being crucial in the design phase of new experiments.

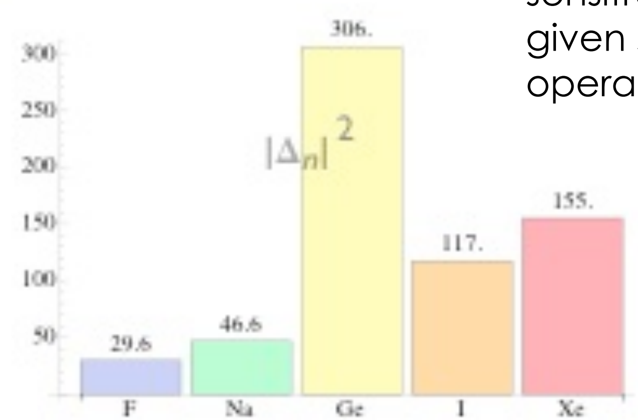
Vector, proton coupled: $\vec{\sigma}(i)$ vs. $\vec{\ell}(i)$





Vector, neutron coupled: $\vec{\sigma}(i)$ vs. $\vec{\ell}(i)$





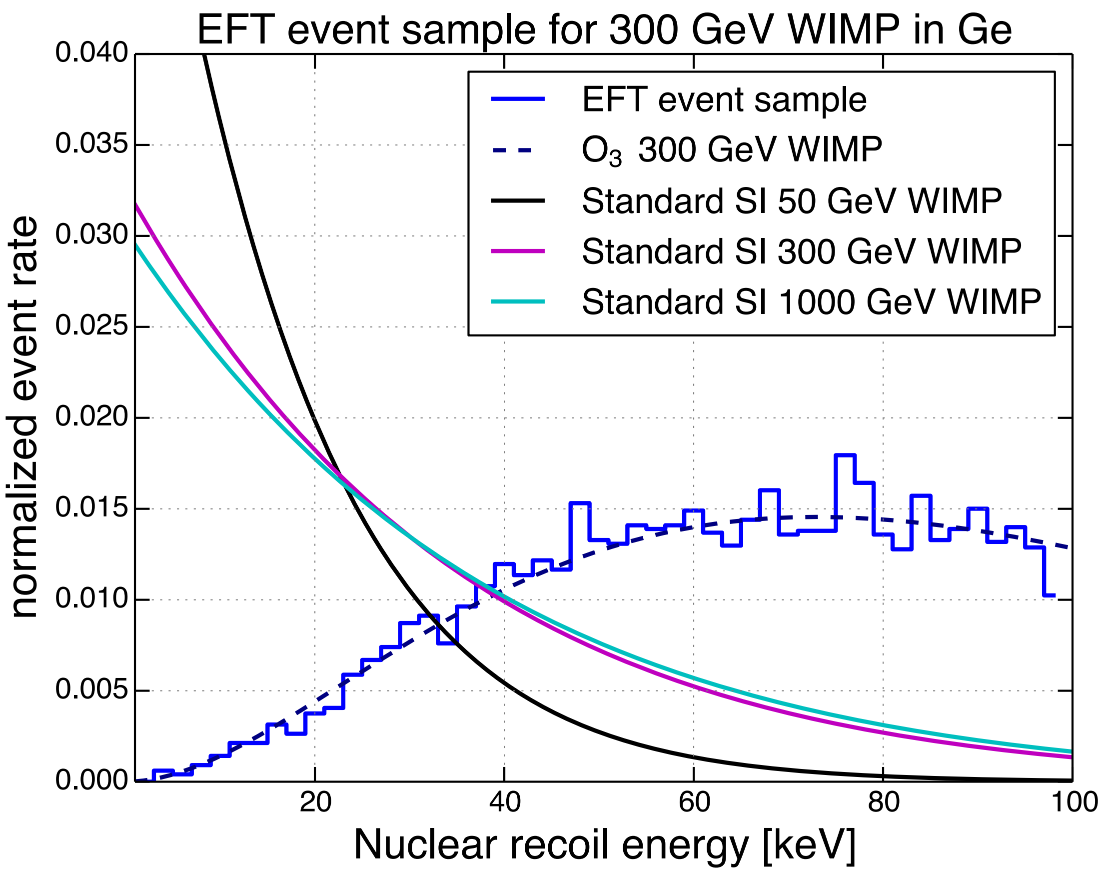
Some targets have enhanced sensitivities for a given set of operators

Limits on EFT operators (SuperCDMS)

K. Schneck et al. PRD 2015

- The spectrum differs from the expected for standard interactions

\- A DM signal could be misidentified as background



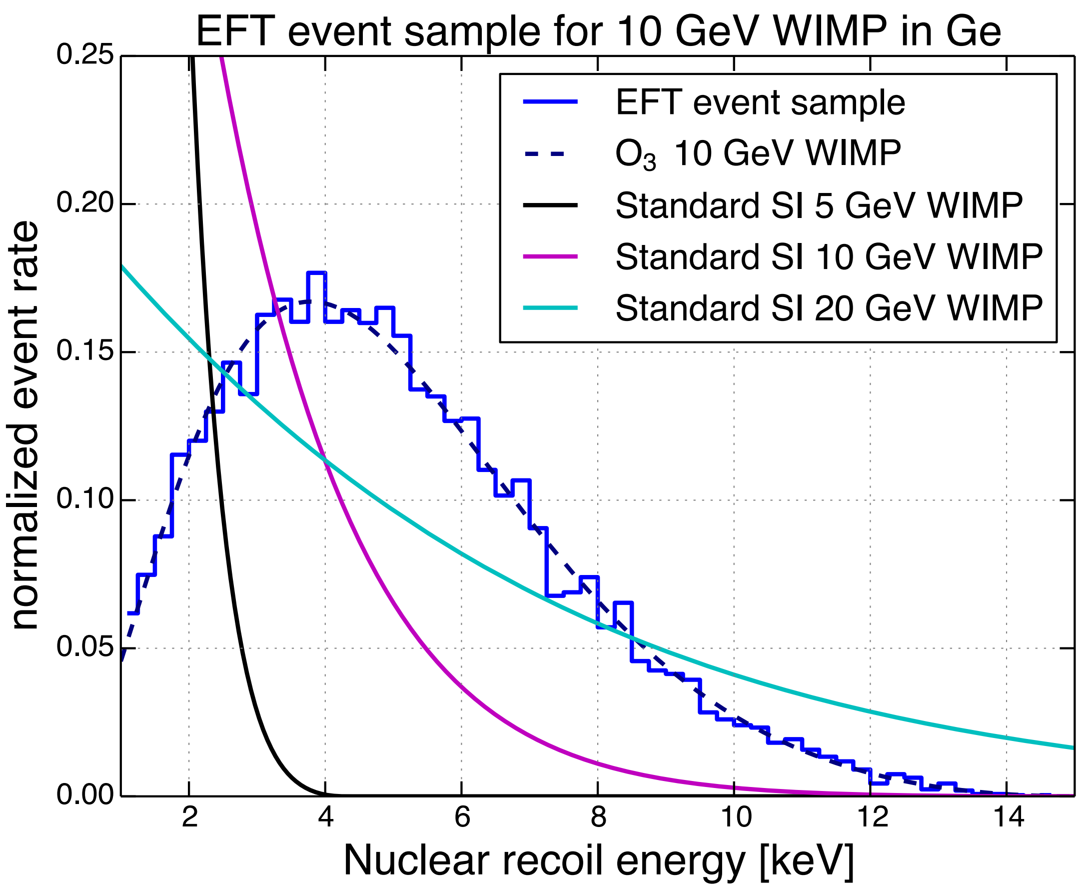
Limits on EFT operators (SuperCDMS)

K. Schneck et al. PRD 2015

- The spectrum differs from the expected for standard interactions

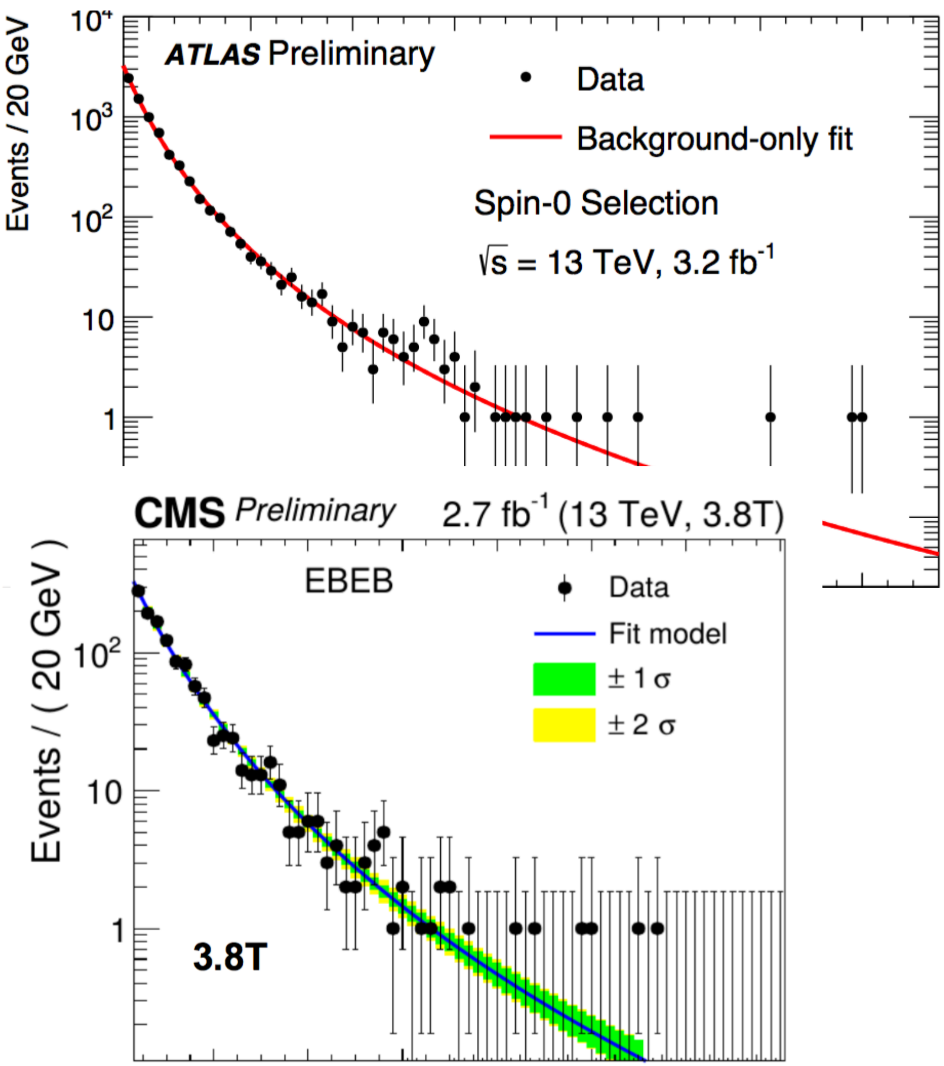
- A DM signal could be misidentified as background

- The reconstruction of a signal would point towards the wrong mass and couplings



Hints for a diphoton resonance at the LHC@13TeV

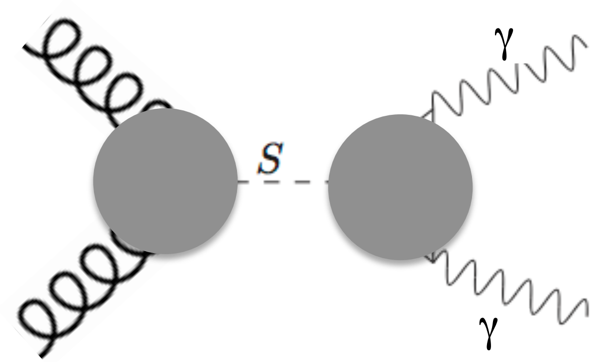
Both ATLAS and CMS have observed a potential feature at 750 GeV



- Not observed in any other channel
- Could correspond to the resonance of a spin-0 or spin-2 particle
- Large Width preferred by ATLAS (not necessarily CMS)

$$\Gamma/M \sim 0.06$$

- Large production cross section O(10 fb), presumably produced through its coupling to gluons

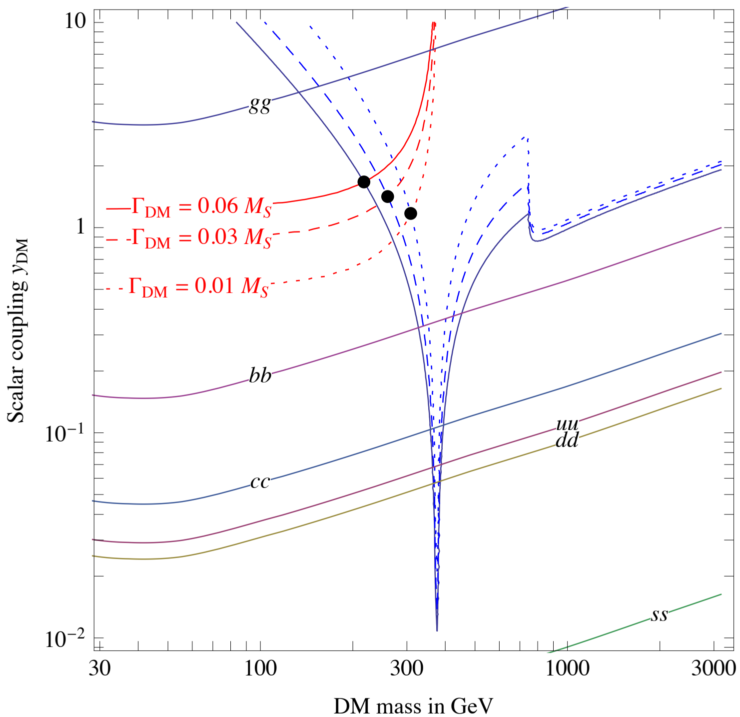


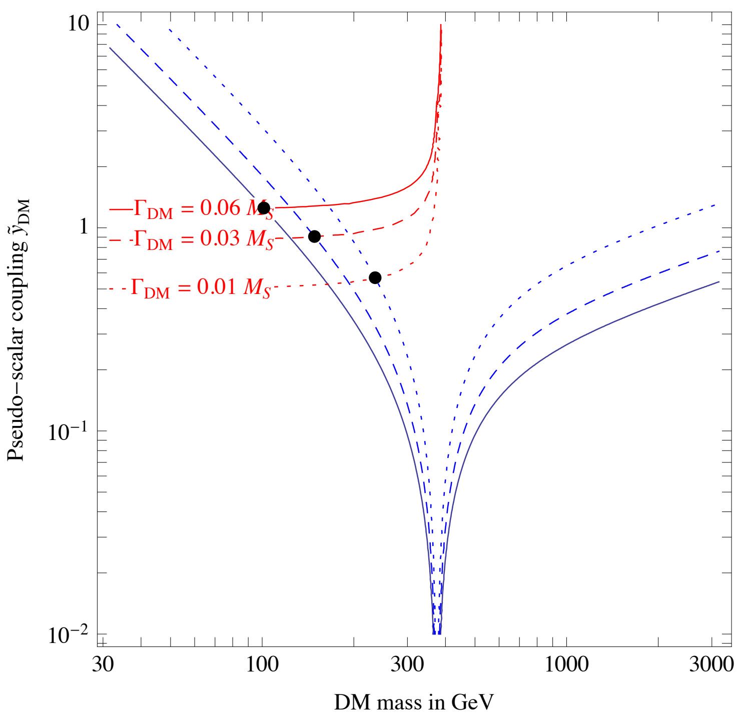
Can this have something to do with dark matter?

The large decay width of the resonance might imply new decay products.

Mambrini, Arcadi, Djouadi 1512.04913

Current direct/indirect detection constraints not too restrictive (**model dependent**)





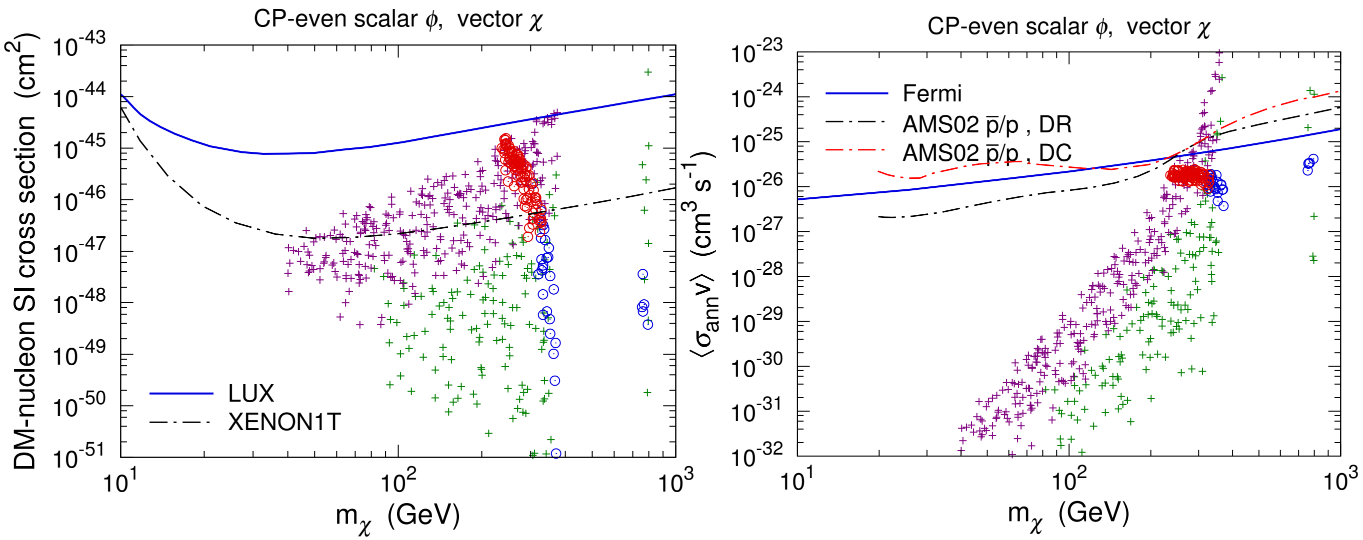
Can this have something to do with dark matter?

The large decay width of the resonance might imply new decay products.

Mambrini, Arcadi, Djouadi 1512.04913

Current direct/indirect detection constraints not too restrictive (**model dependent**)

If this observation is confirmed, the correlation with direct and indirect detection is crucial to determine the DM properties



Bi et al. 1512.06787

Conclusions

- **Is the WIMP paradigm in good health?**

  Certainly not dead yet, although it is becoming more constrained.

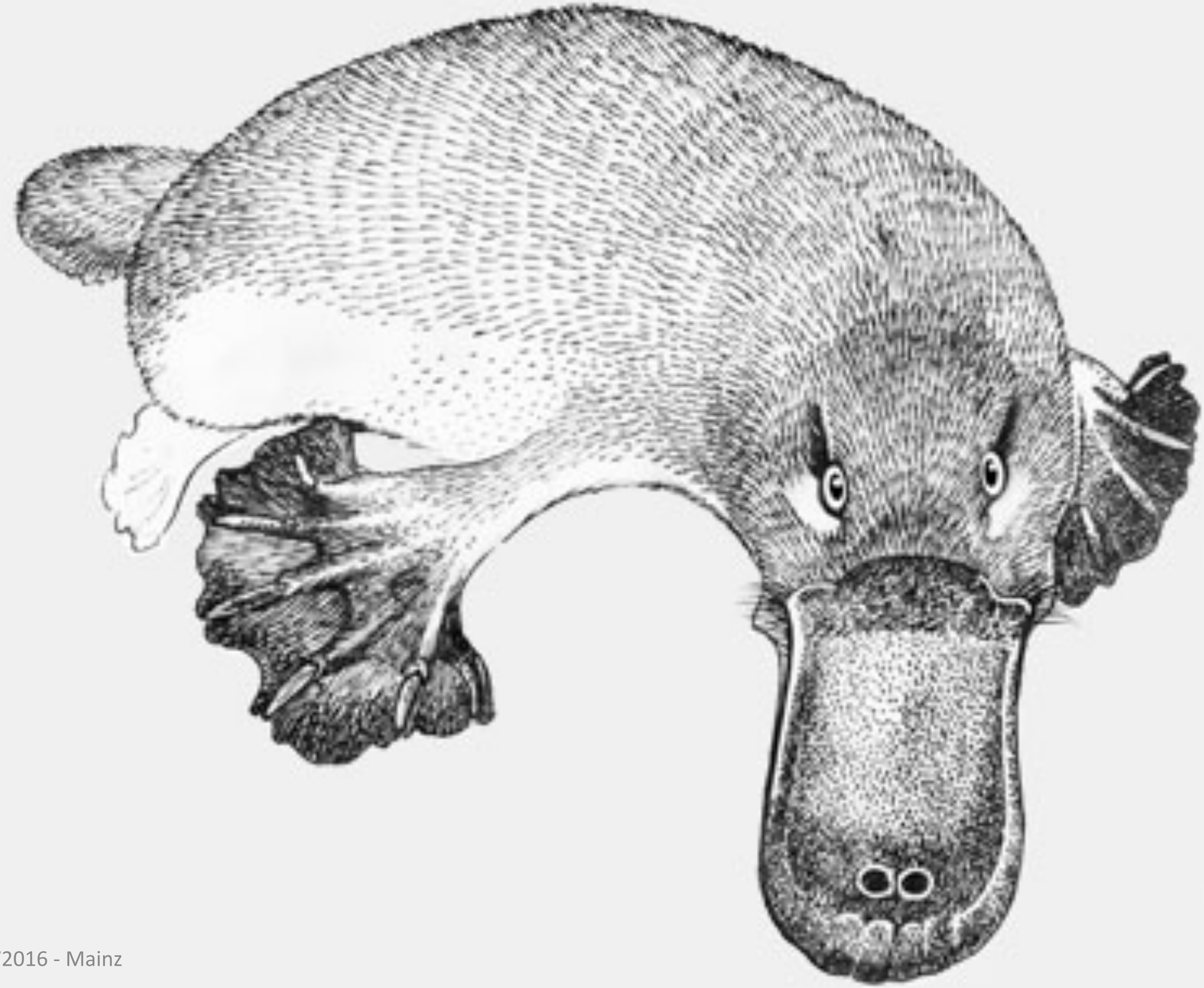
- **Will we ever detect WIMPs?**

  Exciting times ahead: G2 experiments → good coverage for WIMP models
  … if DM is not a WIMP? (sensitivity to axion-like particles and other exotics)

- **If so, can we reconstruct their properties?**

  Only through the combination of different experimental searches
  E.g., Direct detection and the Galactic Centre Excess
  Need to consider more general DM interactions and/or simplified models

- **How natural is the resulting Dark Matter model?**



Background		Rejection
• Bulk electron recoils Compton background 1.3 keV activation line	→	Yield = Ionization/phonon helps discriminating NR from ER
• Sidewall & surface events betas and x-rays from ^{210}Pb, ^{210}Bi, recoils from ^{206}Pb, outer radial Comptons, ejected electrons from Compton scattering	→	Z-Partition and Radial partition define a fiducial volume
• Neutrons (cosmogenic & radiogenic)	→	Use active and passive shielding. Cut on multiple hits. Simulation determines remaining irreducible rate

Analysis: Selection criteria and efficiencies

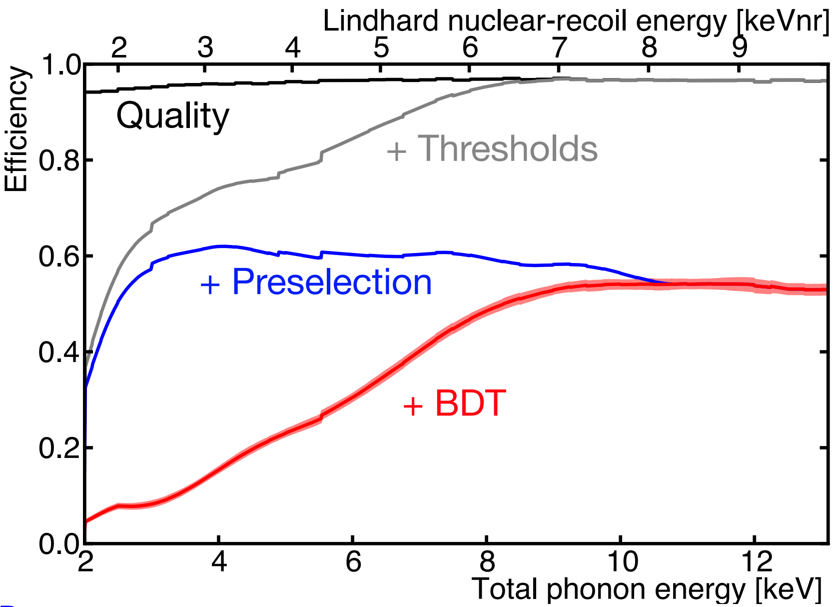
We carry out a blind analysis, with all singles in energy range removed from study, except data following ^{252}Cf calibration due to activation

Data Quality:
Reject periods with poor detector performance
Remove misreconstructed and noisy pulses
Measure efficiency with pulse MC

Trigger and analysis threshold:
Select periods with stable well-defined trigger threshold
Measure efficiency from ^{133}Ba calibration data

Preselection:
Single-detector scatter
Remove events coincident with muon veto
Ionization fiducial volume
Ionization and phonon partitions consistent with NR

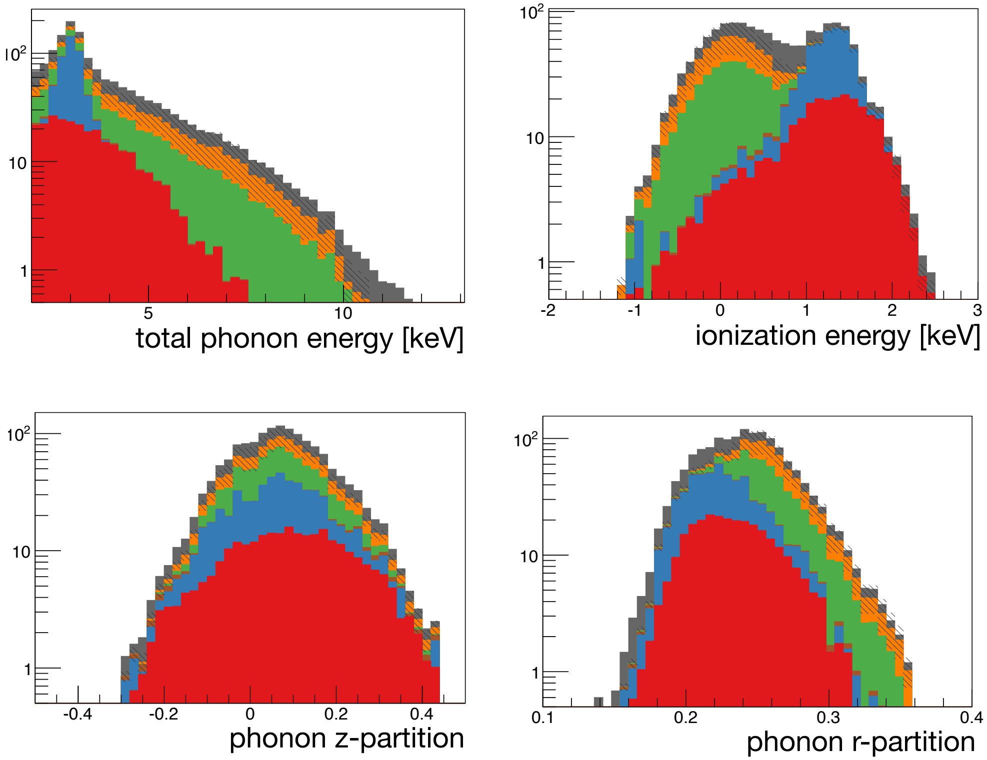
Boosted Decision Tree:
Optimised cut on the phonon fiducial volume and ionization yield at low energy
Efficiency estimated from fraction of ^{252}Cf passing



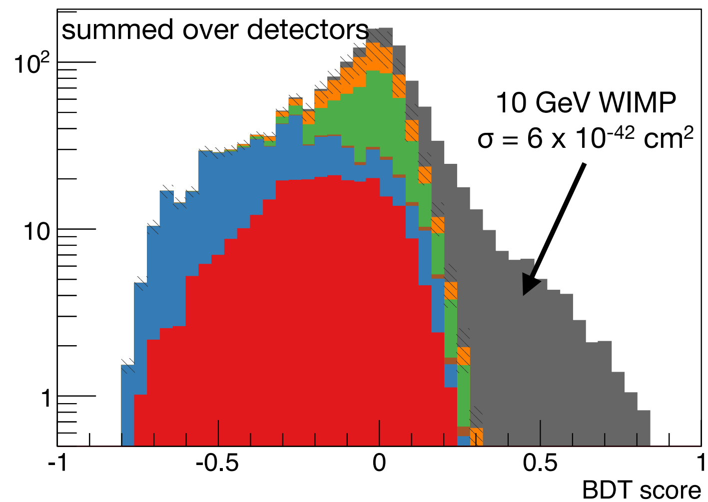
Efficiencies: measured for neutrons from ^{252}Cf. Corrected for multiple scattering with Geant4

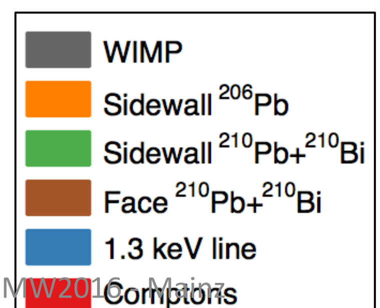
Boosted Decision Tree (BDT)

Inputs (per detector)



Output



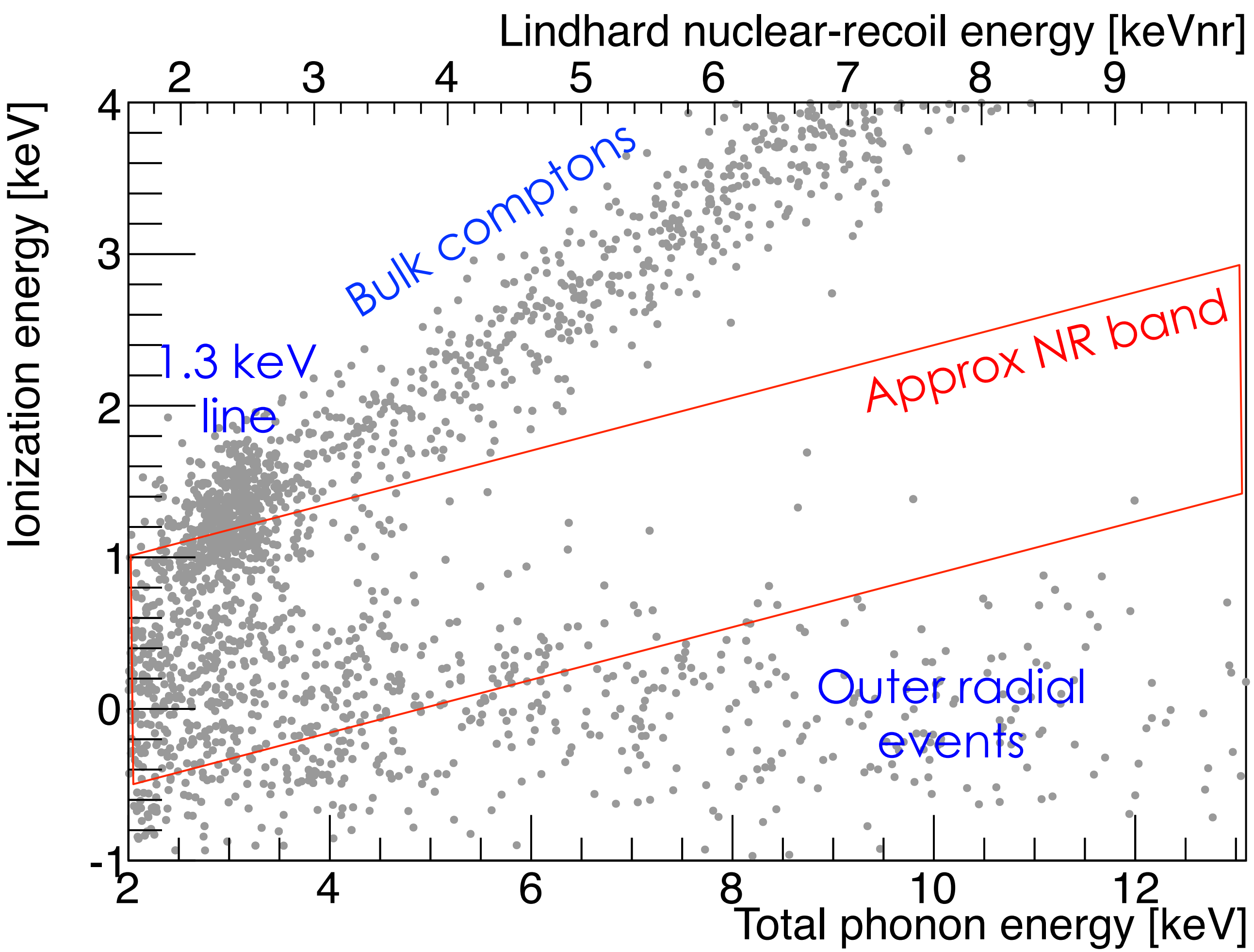


Background: Modelled with simulated data on sidebands and calibration.

WIMP Signal: Modelled with NR data from ^{252}Cf, then rescaled for WIMPs with mass 5, 7, 10, 15 GeV

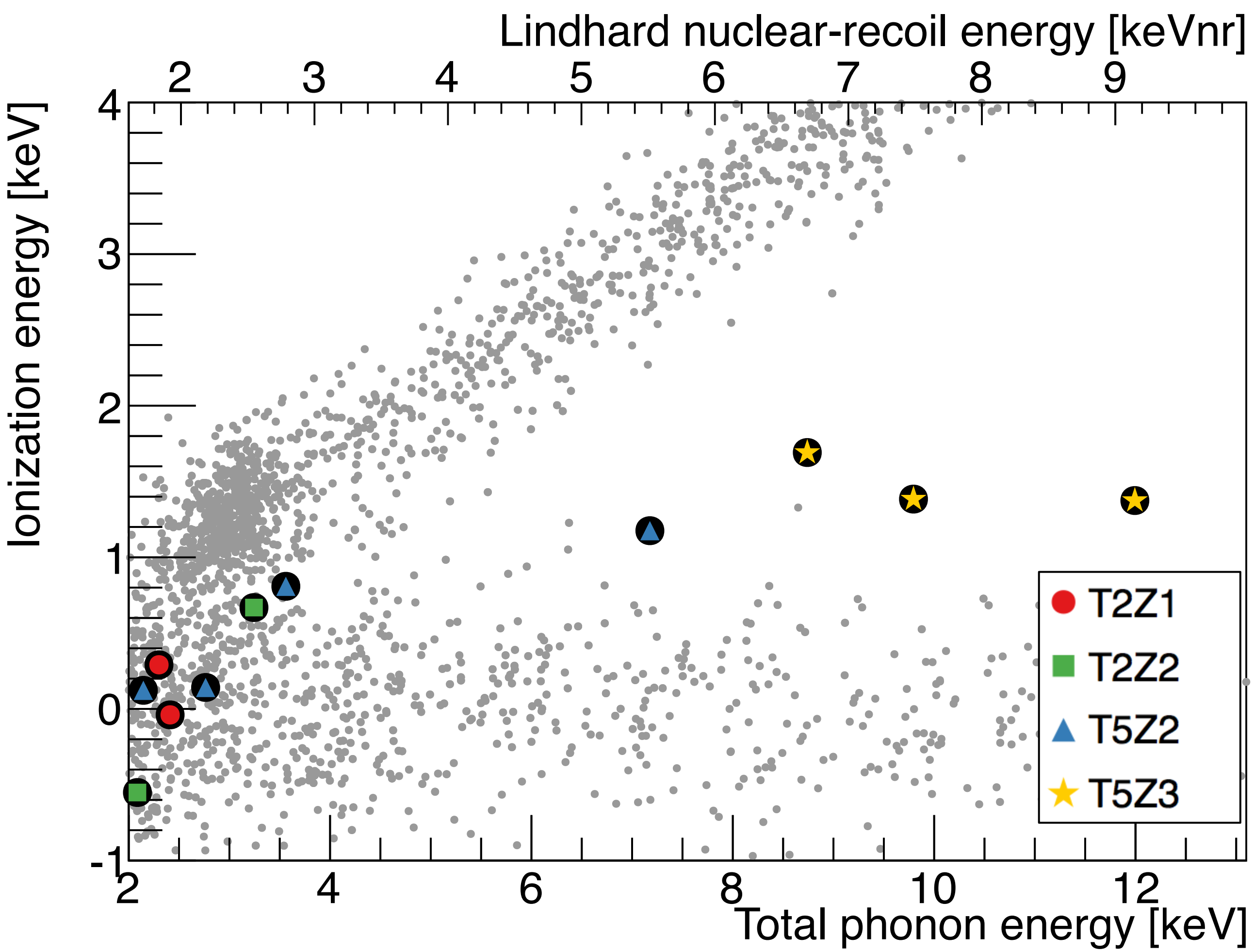
Unblinding: Before BDT cut

Events passing all the cuts prior to applying BDT



Unblinding: After BDT cut

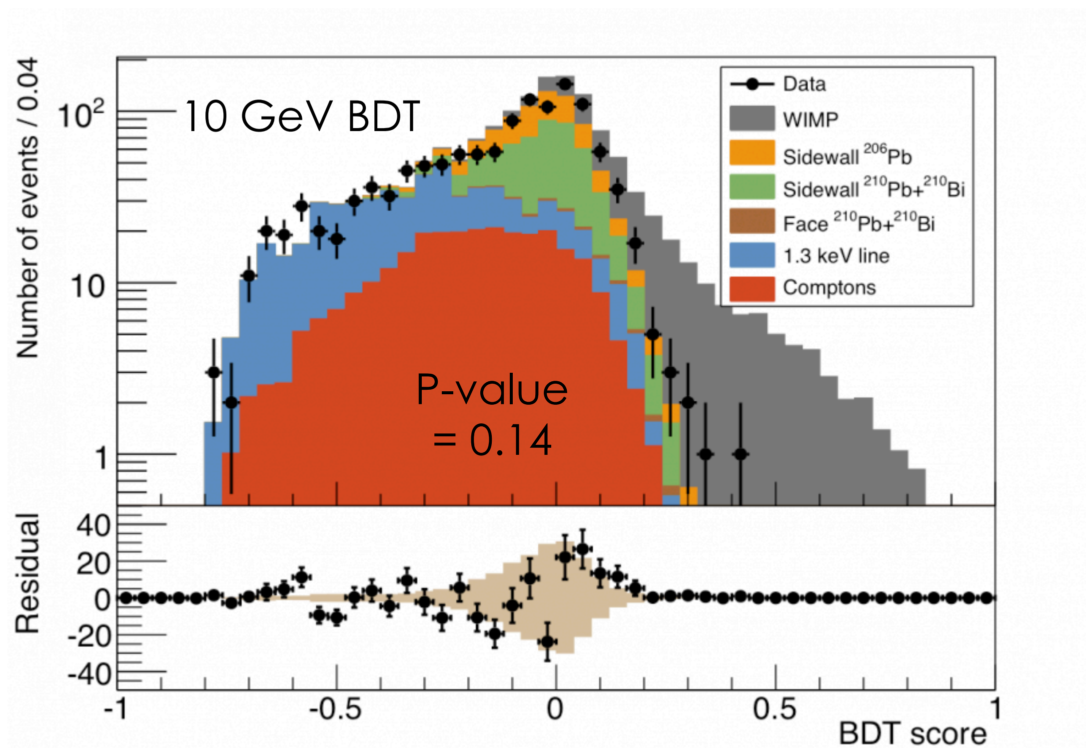
11 candidates (6.2 +1.1 -0.8 expected)



Post-unblinding discussion

Events are high in quality. Only the lowest energy candidate looks like spurious noise

- For most of the detectors there is good agreement with predicted background



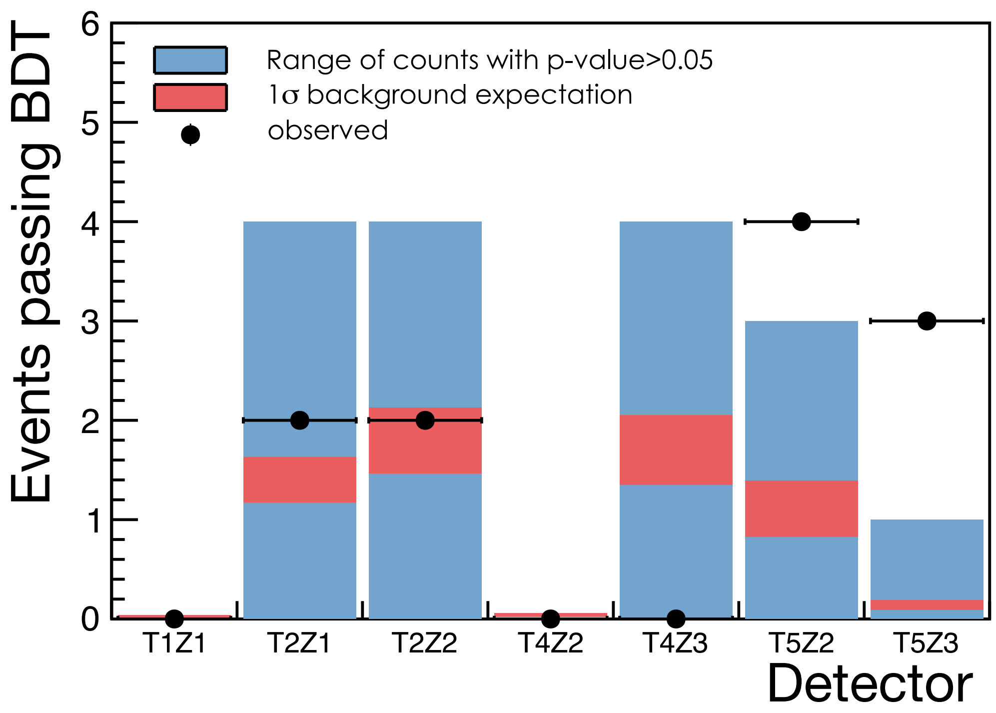
Post-unblinding discussion

Events are high in quality. Only the lowest energy candidate looks like spurious noise

- For most of the detectors there is good agreement with predicted background

- However, T5Z3 observes the 3 highest-energy events

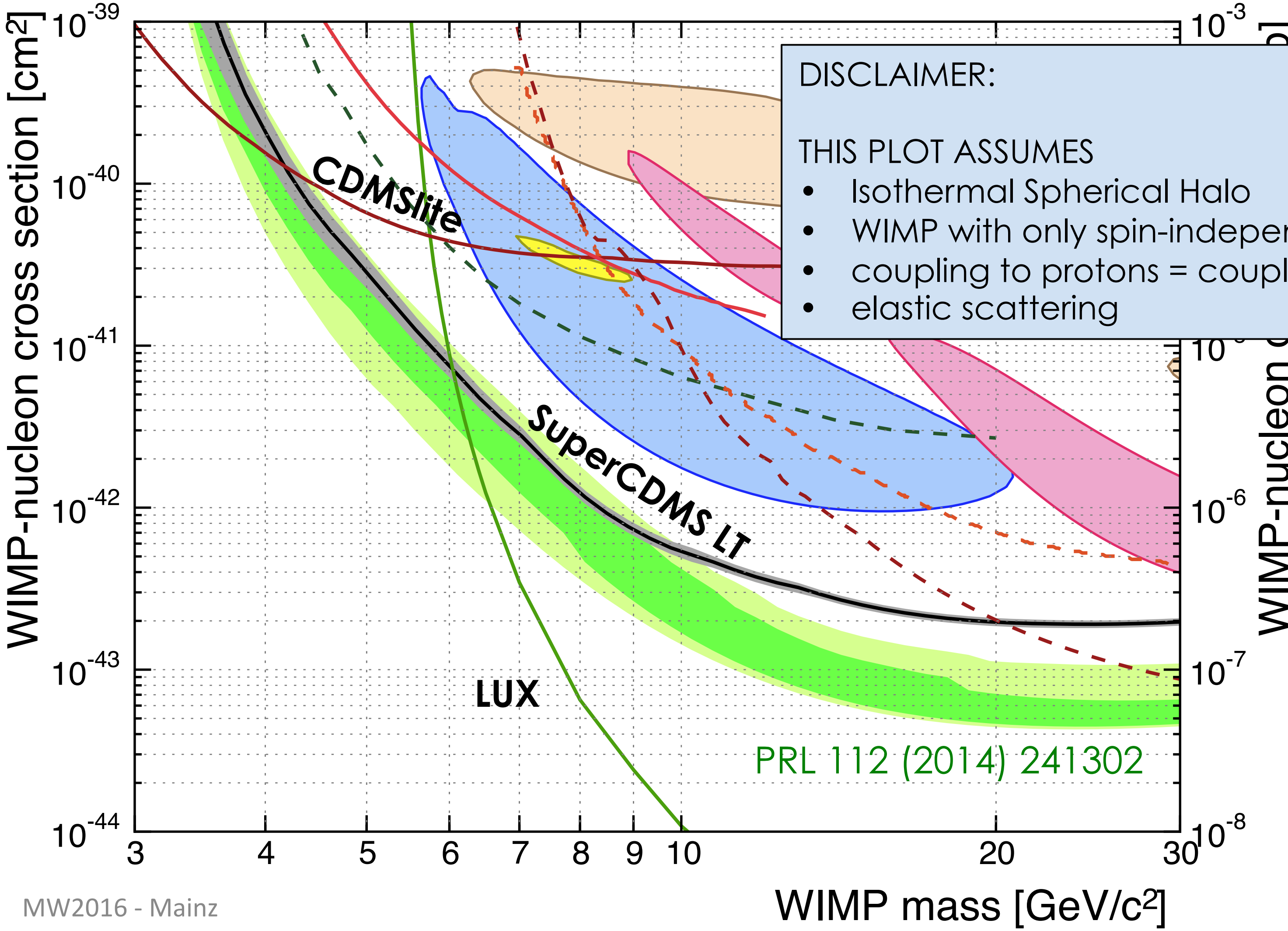
  (Poisson p-value is 0.04%)



T5Z3 has a shorted ionization guard. This may have affected the background model performance. Additional studies are ongoing.

Non-observation in other experiments set upper bounds on the cross section

XENON10, XENON100, LUX (Xe), CDMSlite, SuperCDMS, Edelweiss (Ge), COUPP (CF_3I) have not observed any DM signal, which constrains the scattering cross section

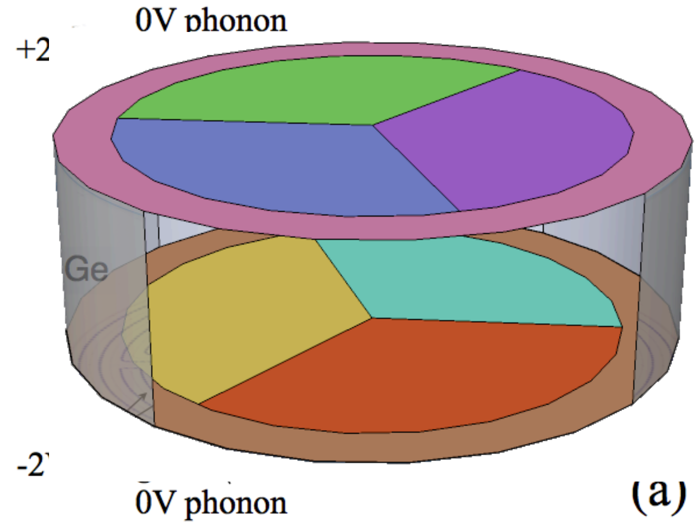


DISCLAIMER:

THIS PLOT ASSUMES
- Isothermal Spherical Halo
- WIMP with only spin-independent interaction
- coupling to protons = coupling to neutrons
- elastic scattering

iZIP discrimination of surface events

Ionization lines (±2V) interleaved with phonon sensors (0V) on a ~1mm pitch



Bulk events:
charges (e,h) drift to **both sides** of the crystal

Surface events:
charges (e,h) drift to **only one side** of the crystal

Z-PARTITION:
The resulting **symmetry**/**asymmetry** in charge collection in sides 1 and 2

Sidewalls

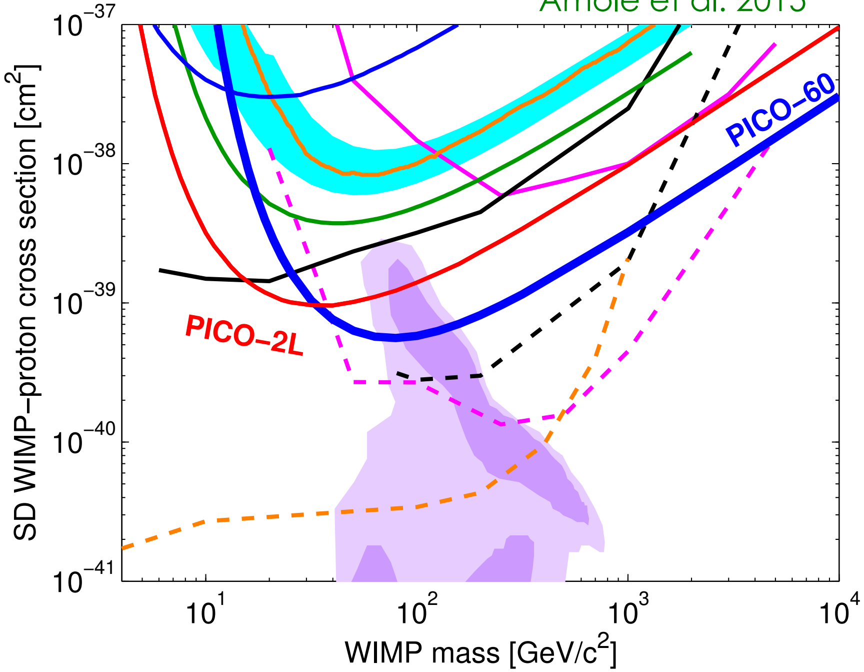
Surface events on the sides of the detector leave more energy in the outer sensors.

RADIAL PARTITION:
division of energy between inner and outer sensors

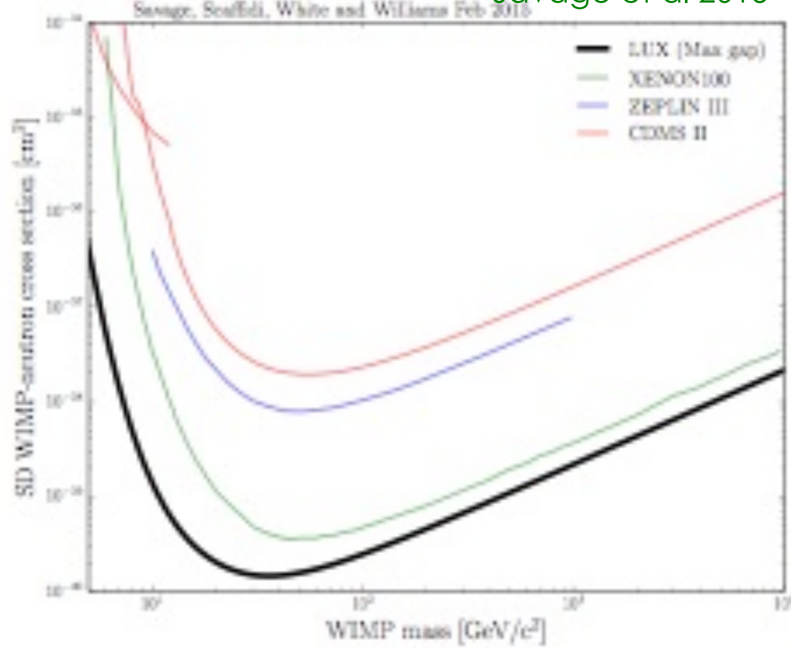
Upper bounds on the SD cross section

XENON100, LUX (Xe) for SD with neutron, PICO 60L (CF_3I) for SD proton

Amole et al. 2015



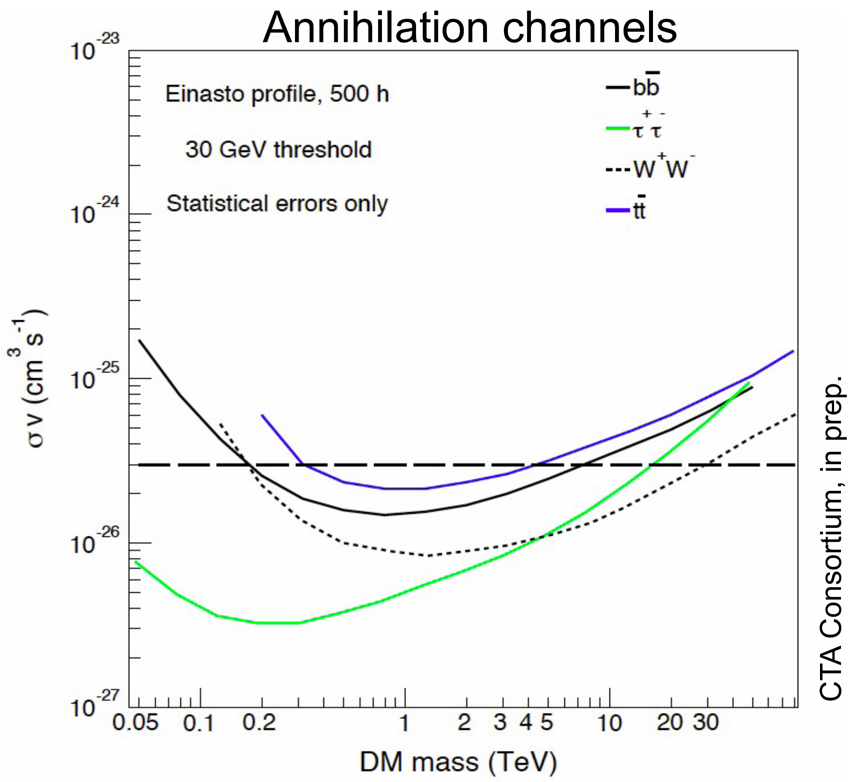
Savage et al 2015

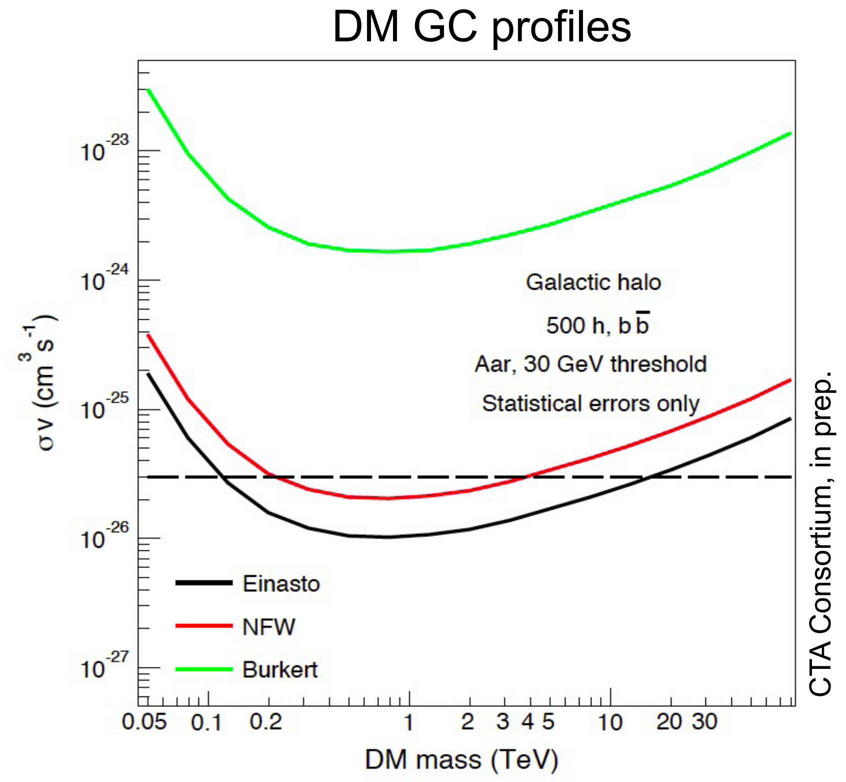


IceCube, Baksan and Antares also sensitive to DM capture rate in the Sun (mainly SD cross section with protons) and its subsequent annihilation in neutrinos.

CTA will further explore the heavy DM mass region

The thermal cross section can be probed up to ~10-30 TeV





These predictions (as well as current bounds) are extremely sensitive to the DM profile

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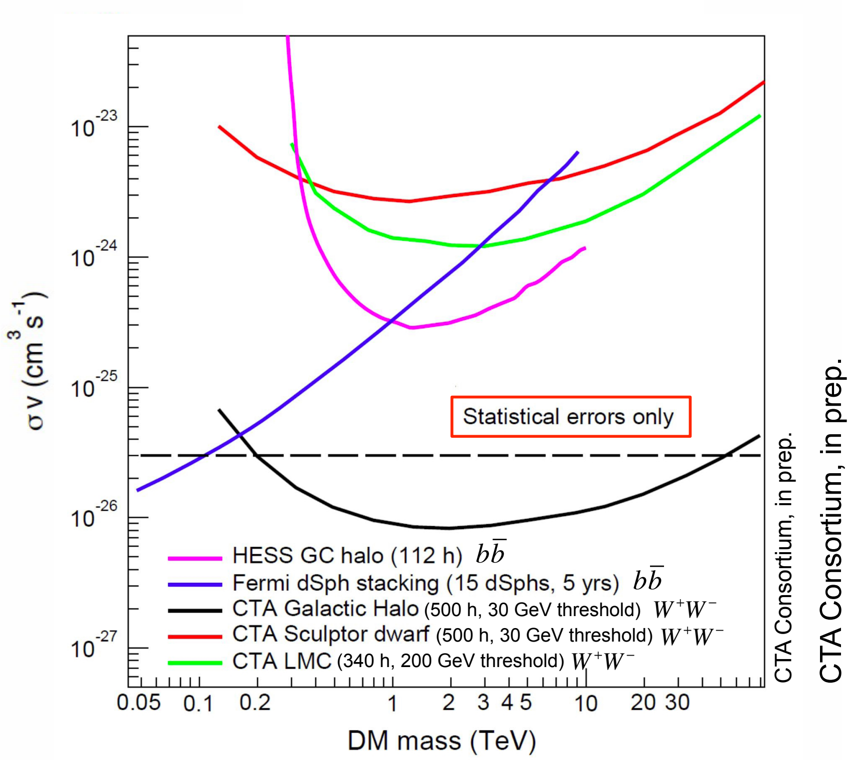

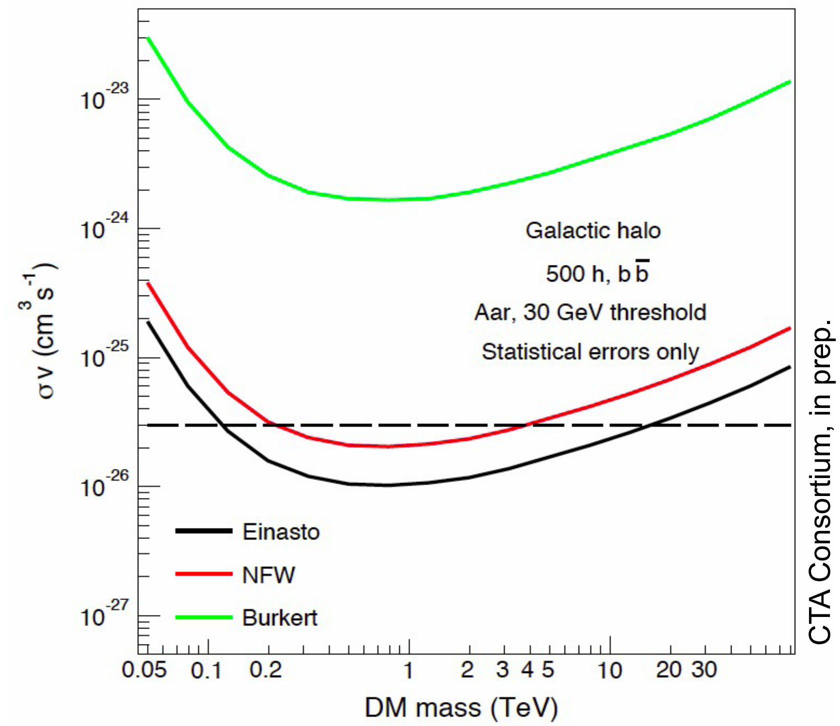

These predictions (as well as current bounds) are extremely sensitive to the DM profile