Complementarity of direct dark matter searches

David G. Cerdeño

UNIVERSIDAD AUTONOMA DE MADRID

ift

MULTIDARK
Multimessenger Approach for Dark Matter Detection

[arXiv:1208.6426] DGC, M. Fornasa, J.-H. Huh, M. Peiró

Work in progress with: M. Fornasa, J-H. Huh, M. Peiró, L. Robledo & ROSEBUD collaboration

Outline

- INTRODUCTION

  Direct DM detection... Where do we stand?

- RECONSTRUCTION OF DM PARAMETERS (direct detection experiments)

  The role of nuclear uncertainties (in the spin form factors)

- DM IDENTIFICATION and COMPLEMENTARY DM SEARCHES

  Complementary targets in direct detection

- CONCLUSIONS

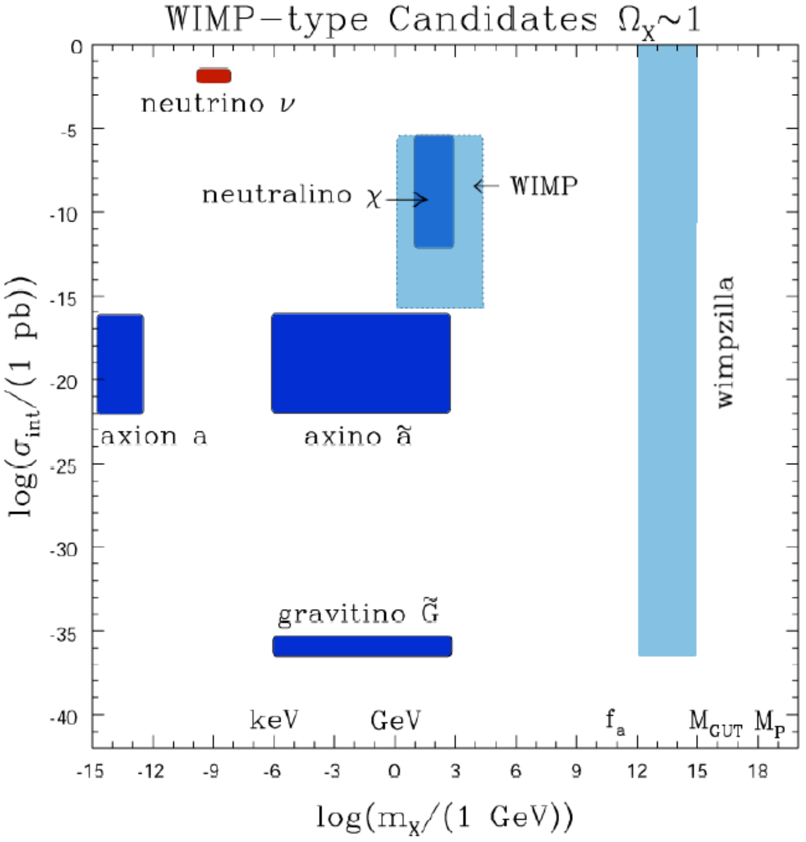
We don't know yet what DM is... but we do know many of its properties

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
- Weakly Interacting Massive Particles (WIMPs)
- SuperWIMPs and Decaying DM
- WIMPzillas
- SIMPs, CHAMPs, SIDMs, ETCs...



... they have very different properties

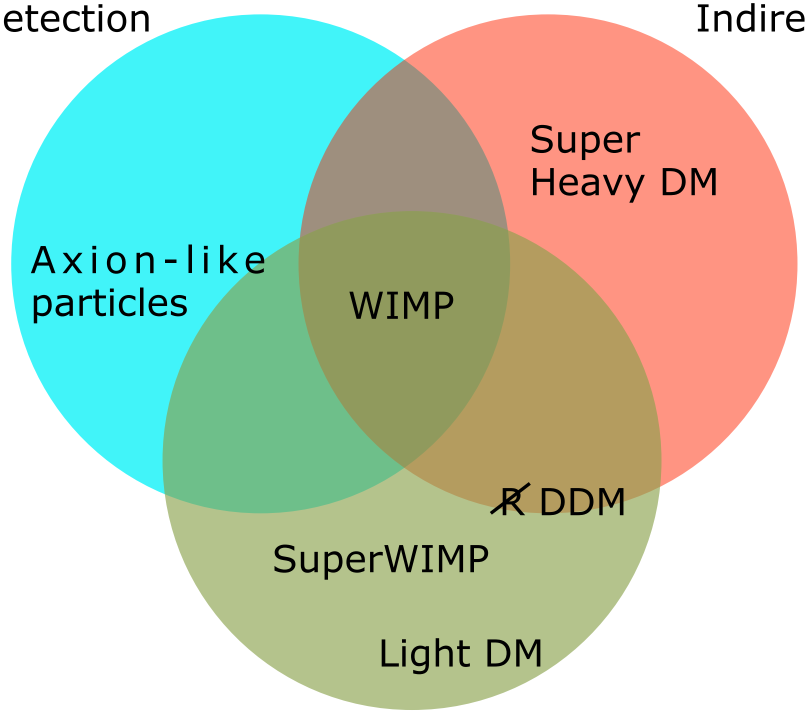
Complementarity of DM searches

Direct Detection

DAMA/LIBRA
CDMS
XENON
KIMS
COUPP
ZEPLIN
CoGeNT
CRESST
ANAIS
SIMPLE
...

Indirect Detection

PAMELA
Fermi
MAGIC
AMS
ANTARES
IceCube
CTA
WMAP
...



Axion-like particles

Super Heavy DM

WIMP

$\cancel{R}$ DDM

SuperWIMP

Light DM

Accelerator searches

LHC (ILC)

Many DM models can be probed by the different experimental techniques

"Redundant" detection can be used to extract DM properties

Direct detection, where do we stand?

DAMA/NaI (DAMA/LIBRA) signal on annual modulation

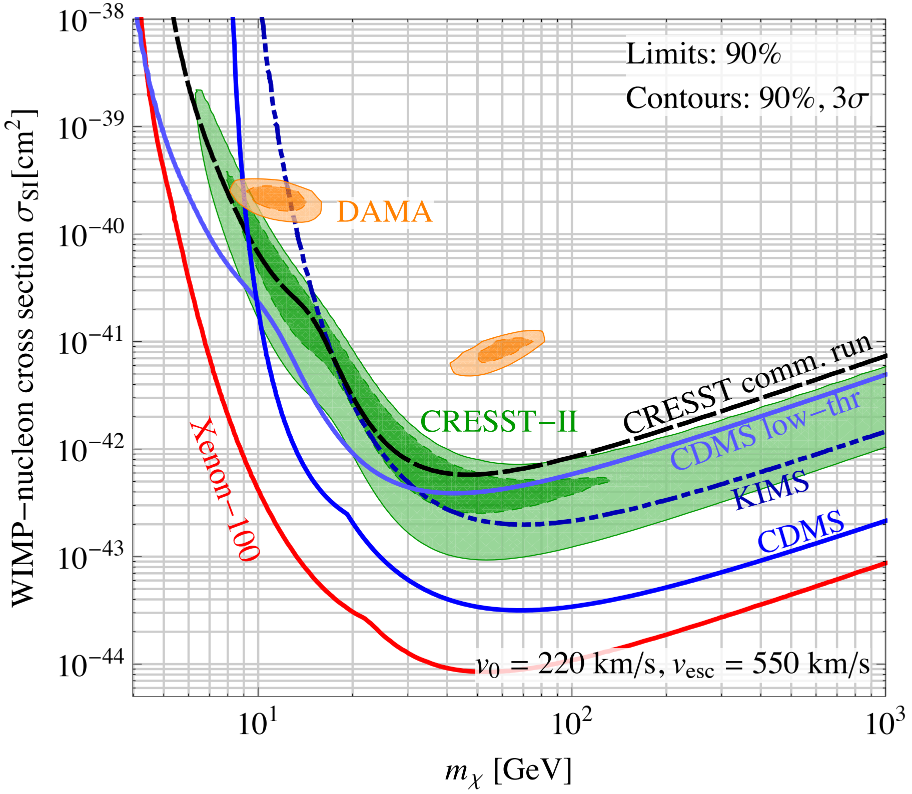
cumulative exposure 427,000 kg x day (13 annual cycles)

DAMA/LIBRA Coll. ‘10

... however other experiments (CDMS, Xenon, CoGeNT, ZEPLIN, Edelweiss, ...) did not confirm (its interpretation in terms of WIMPs).

Possible explanations in terms of “exotic” dark matter also constrained

- Spin-dependent WIMP couplings
- Pseudoscalar DM
- Inelastic Dark Matter
- Very light WIMPs
- None of the above...?



Kopp, Schwetz, Zupan ‘11

Hints of light WIMPs in recent experimental results...?

- **DAMA/LIBRA** region extended to very light WIMPs (channelling, quenching factors, ...)

Bottino, Fornengo, Scopel '09, DAMA/LIBRA '11

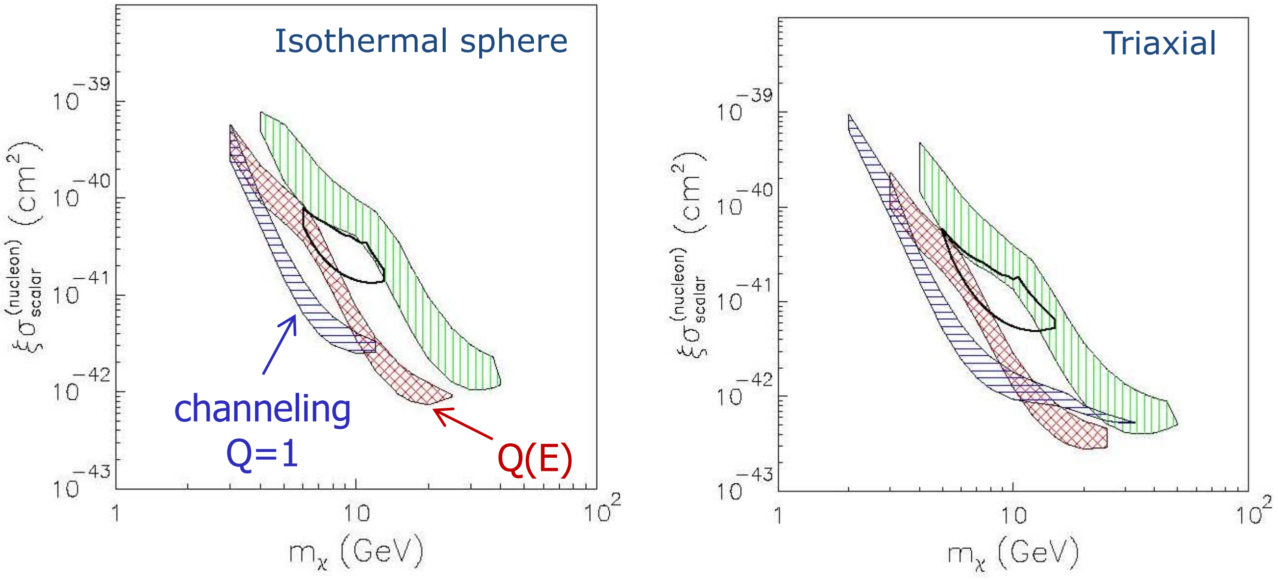
- **CoGeNT** finds irreducible background that can be compatible with 7-10 GeV WIMPs

... annual modulation (2.8 in 15 months data) in CoGeNT

Collar et al. '10, '11

- **CRESST** finds an excess over the expected background

CRESST '11



Belli et al. '11

Many efforts in reconciling these results

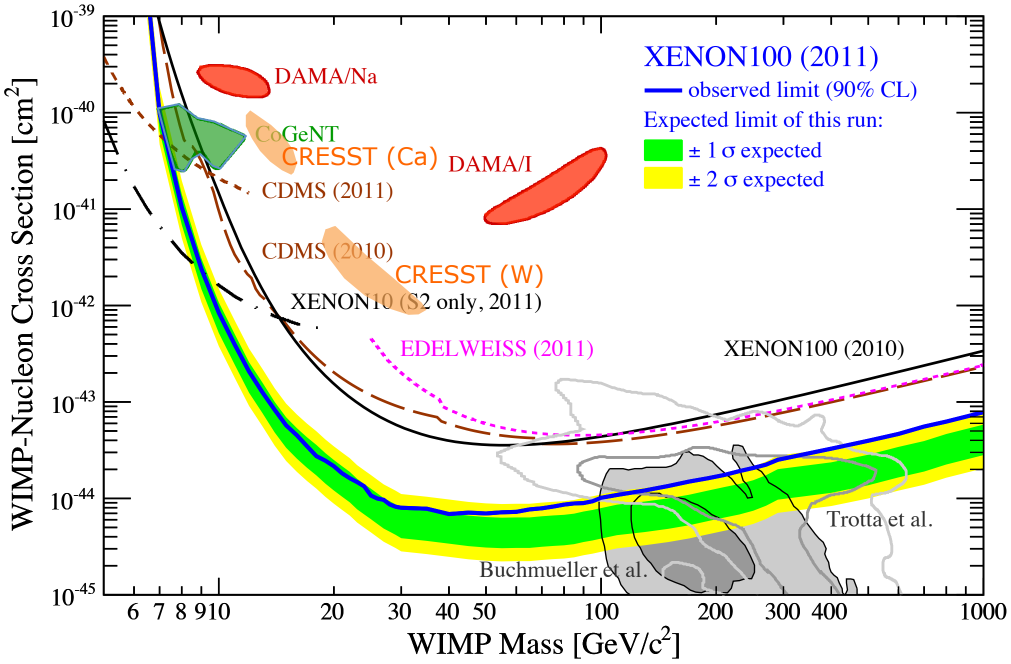
See, e.g., Andreas et al. '10;
Schwetz, Zupan '11;
Hooper, Kelso '11;
Farina et al. '11;
McCabe '11;
Arina et al. '11;
...

Uncertainties in determination of DM parameters

However very light WIMPs have not shown up in other experiments

- XENON finds no light WIMPs: issues with scintillation efficiency (L_{eff})?

XENON10, XENON100 '11-12



- CDMS: A low-energy reanalysis of the data is incompatible with CoGeNT region

CDMS '11

- SIMPLE: Further constraints on DAMA/LIBRA (but not in the CoGeNT region)

SIMPLE '11

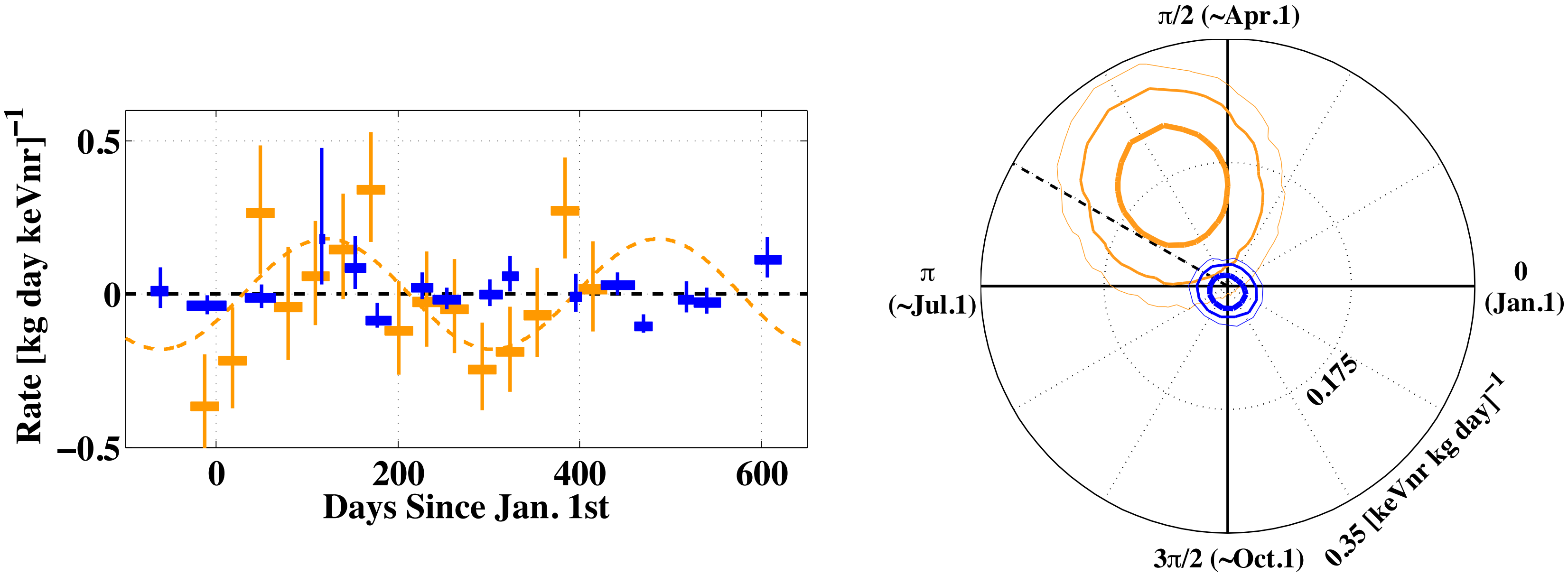
- DAMA-LIBRA interpretation in terms of channelling is challenged

Gelmini, Gondolo, Bozorgnia, '09 '10

CDMS does not see annual modulation

A recent analysis of CDMS II data has shown no evidence of modulation.

This means a further tension with CoGeNT observation

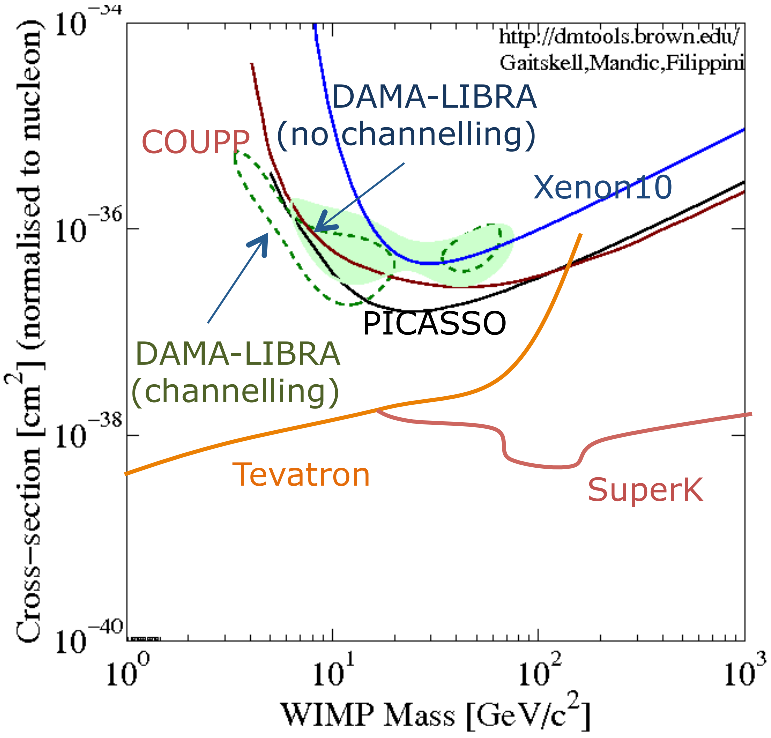


CDMS II 2012

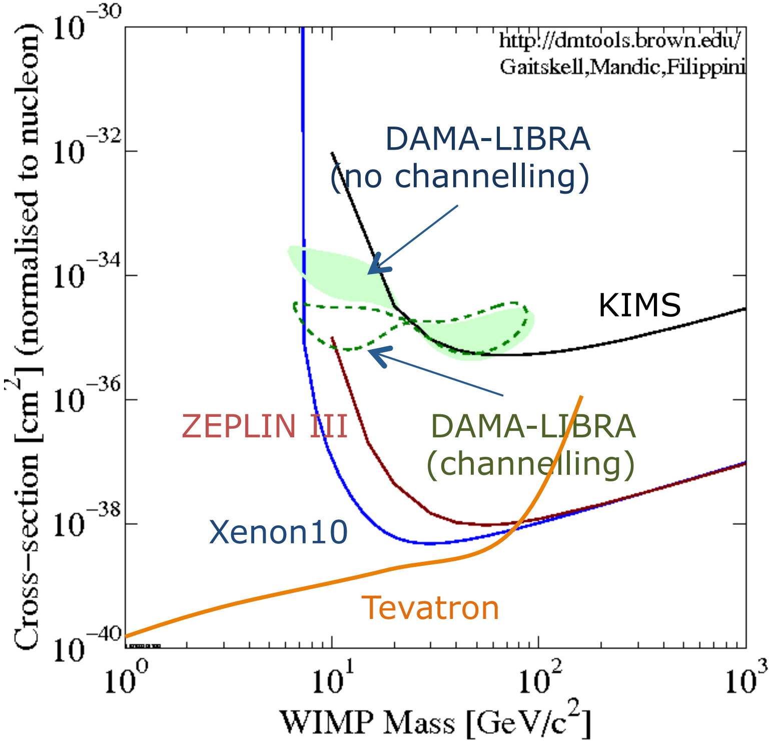
Spin-dependent searches have also become more sensitive

Dedicated experiments with targets sensitive to spin-dependent WIMP couplings

SD coupling to protons



SD coupling to neutrons



The DAMA-LIBRA interpretation in terms of spin-dependent couplings is not consistent with other detectors

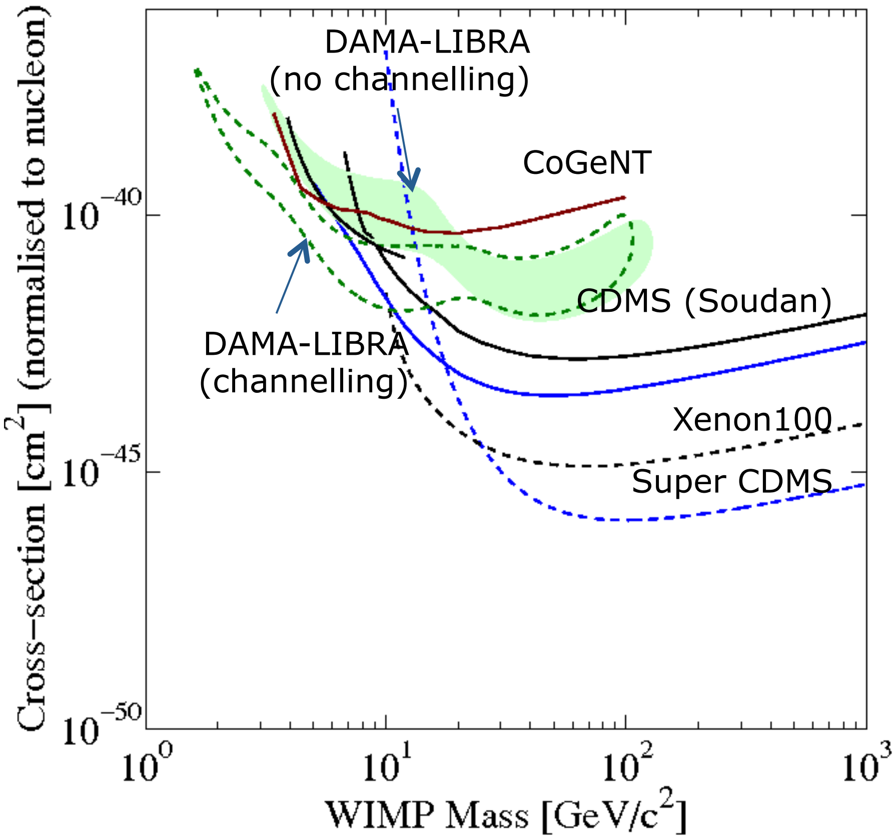
Future searches…

Future experiments (or upgrades of existing ones) will reach sensitivities ~ $10^{-9\ -10}$ pb

Advances in the light WIMP window are subject to improvements in low threshold experiments

(e.g., CDMS, CRESST or CoGeNT?)

How do these sensitivities compare with theoretical predictions for WIMP models?



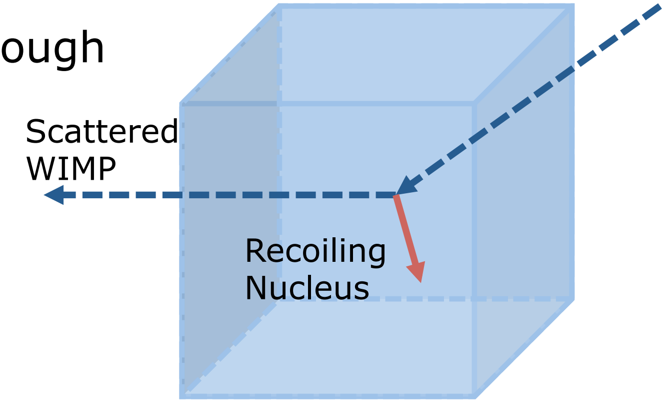
Plotted with DMTools

In case of a detection… (how well) can we determine the DM parameters?

Direct Detection of Dark Matter (main ingredients)

WIMP scattering with nuclei can be measured through

- Ionization
- Scintillation light
- Increase of temperature (phonons)
- Bubble nucleation



Detection rate

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

Experimental setup

Target material (sensitiveness to spin-dependent and –independent couplings)

Detection threshold

Astrophysical parameters

Local DM density

Velocity distribution factor

Theoretical input

Differential cross section (of WIMPs with quarks)

Nuclear uncertainties

The WIMP-nucleus cross section has two components

$$\frac{d\sigma_{WN}}{dE_R} = \left(\frac{d\sigma_{WN}}{dE_R}\right)_{SI} + \left(\frac{d\sigma_{WN}}{dE_R}\right)_{SD}$$

Spin-independent contribution: scalar (or vector) coupling of WIMPs with quarks

$$\mathcal{L} \supset \alpha_q^S \bar{\chi}\chi\bar{q}q + \alpha_q^V \bar{\chi}\gamma_\mu\chi\bar{q}\gamma^\mu q$$

Total cross section with Nucleus scales as A^2

Present for all nuclei (favours heavy targets) and WIMPs

Spin-dependent contribution: WIMPs couple to the quark axial current

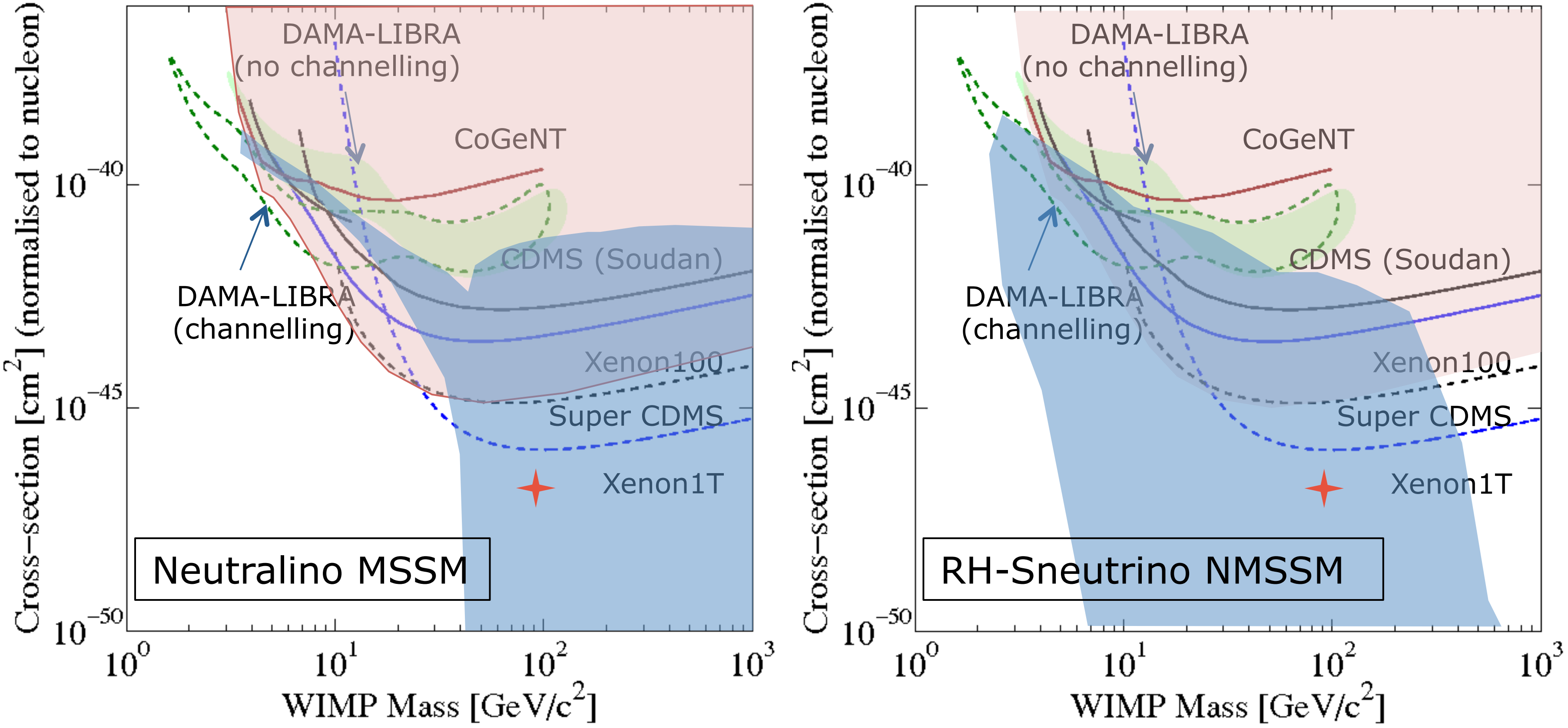
$$\mathcal{L} \supset \alpha_q^A (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{q}\gamma_\mu\gamma_5 q)$$

Total cross section with Nucleus scales as J/(J+1)

Only present for nuclei with J≠ 0 and WIMPs with spin

In general WIMPS... all seem to be alike

Supersymmetric WIMP Dark Matter:

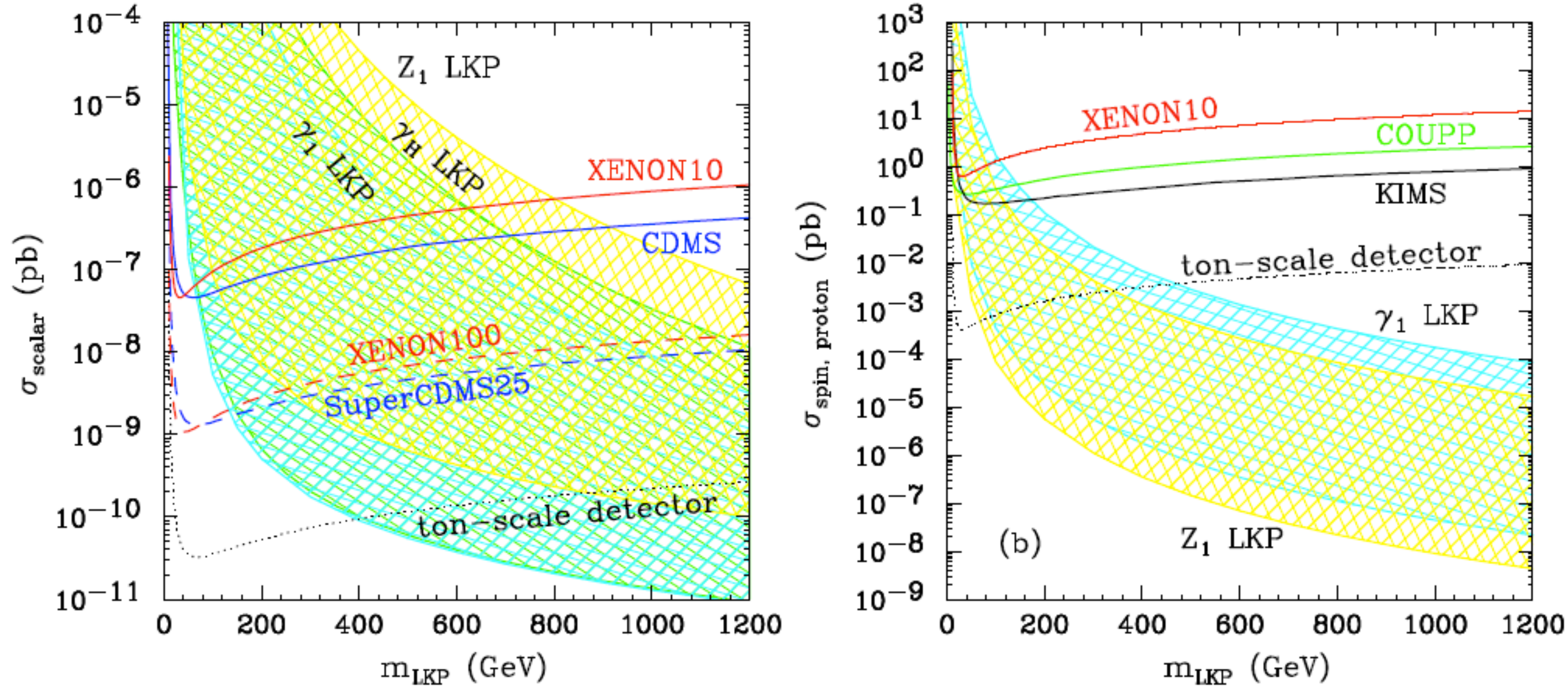


Bottino, Donato, Fornengo ’04-’11

DGC, Seto ‘08

In general WIMPS... all seem to be alike

Kaluza-Klein dark matter can have similar interaction cross section

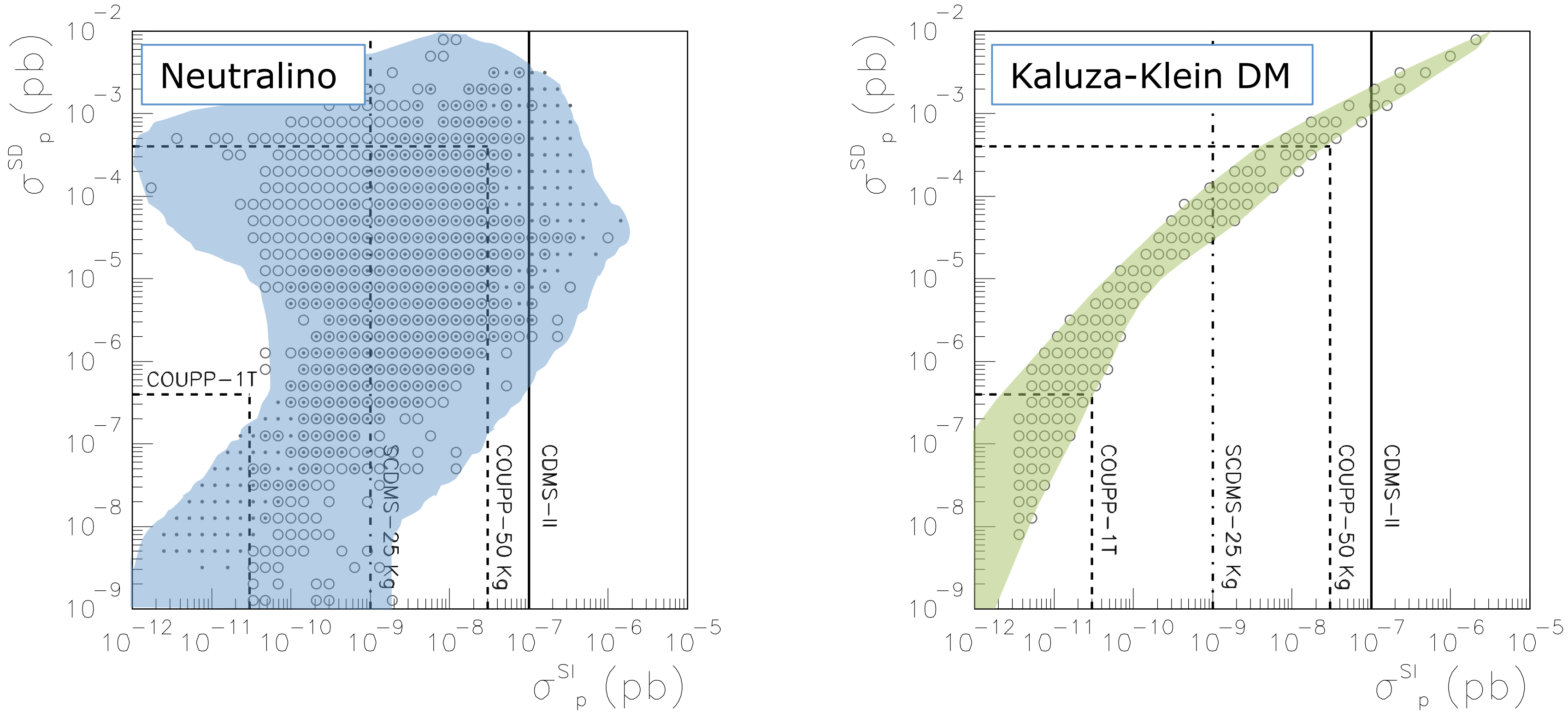


Arrenberg, Baudis, Kong, Matchev, Yoo ‘08

Not really if we look at the whole parameter space...

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

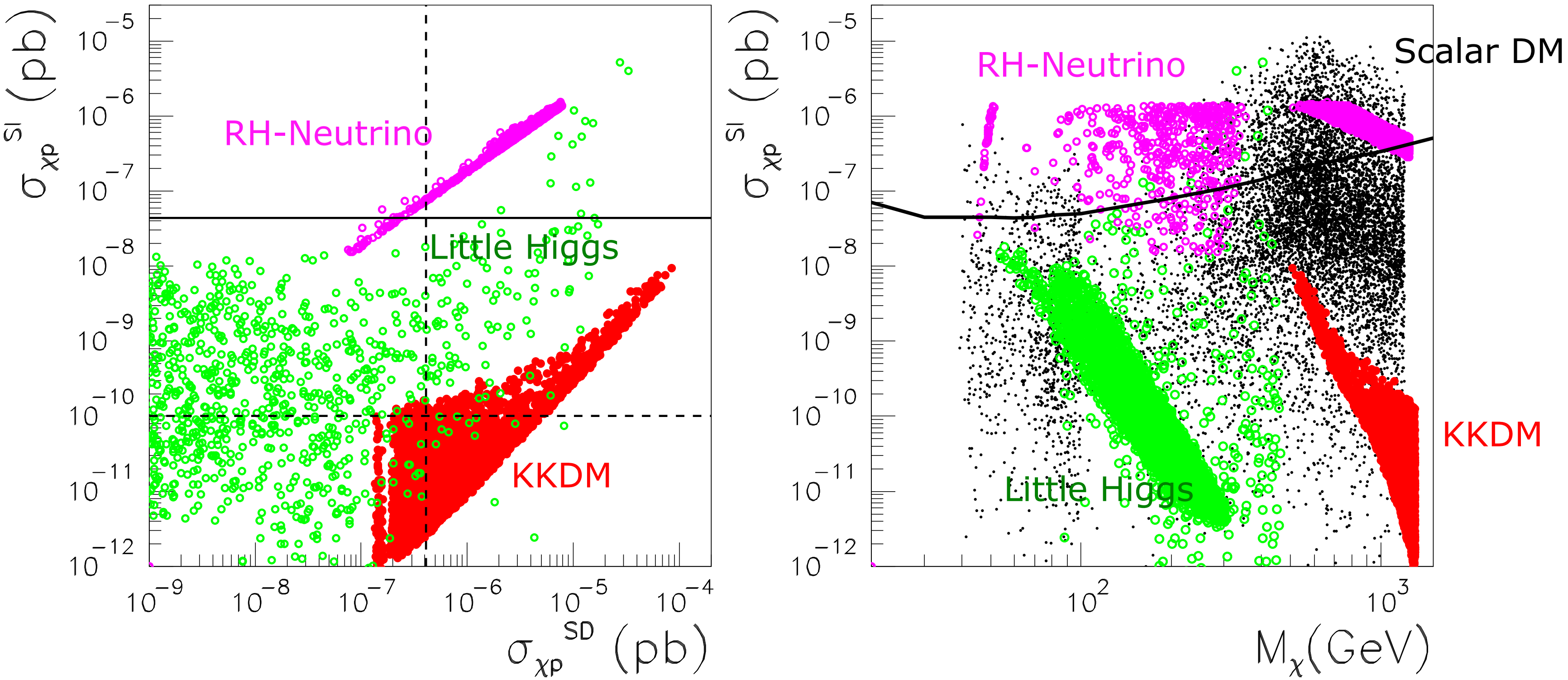
“Advance in both fronts” (spin-dependent and -independent) to gain discriminating power

Can we determine to which DM model it corresponds?

There can be correlations in the “phenomenological parameters”

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

Belanger, Nezri, Pukhov ‘08



Determining the full set of parameters provides crucial information

$$m_X \quad \sigma^{SI}_p \quad \sigma^{SD}_p \quad \sigma^{SD}_n$$

Can we determine the DM model from future data?

All WIMPs behave very similarly (not surprisingly)

The complete identification of the WIMP may not be possible from just the phenomenological parameters

Combination direct/indirect searches with LHC results

Determining the full set of phenomenological parameters

$$m_X \qquad \sigma^{SI}_{p} \qquad \sigma^{SD}_{p} \qquad \sigma^{SD}_{n}$$

Is nevertheless important to distinguish between different WIMP models

Direct searches with different targets

Combination from different experiments

If there is a positive detection the DM parameters can be determined

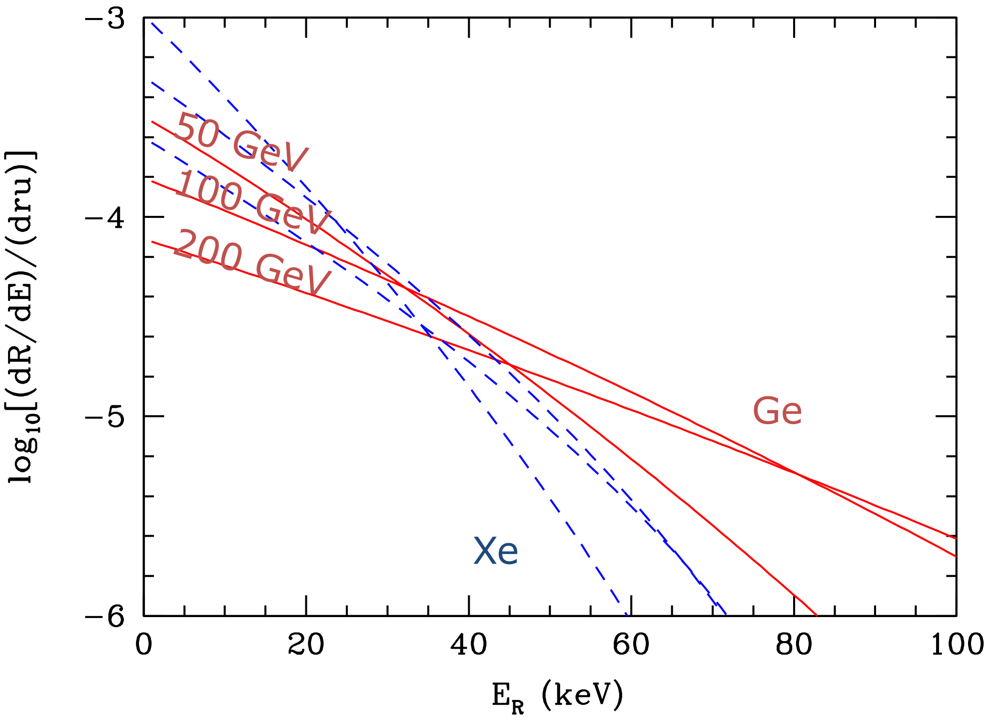
$$R = \int_{E_T}^{\infty} dE_R \frac{\rho_0}{m_N\, m_\chi} \int_{v_{min}}^{\infty} v f(v) \frac{d\sigma_{WN}}{dE_R}(v, E_R)\, dv$$

From the observed rate and differential rate the cross section and mass of the WIMP can be determined

Green '07-10; Drees et al. '08'09

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} \approx \left(\frac{\mathrm{d}R}{\mathrm{d}E_R}\right)_0 F^2(E_R)\exp\left(-\frac{E_R}{E_c}\right)$$

$$E_c = (c_1 2\mu_N^2 v_c^2)/m_N$$



If there is a positive detection the DM parameters can be determined

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

From the observed rate and differential rate the cross section and mass of the WIMP can be determined

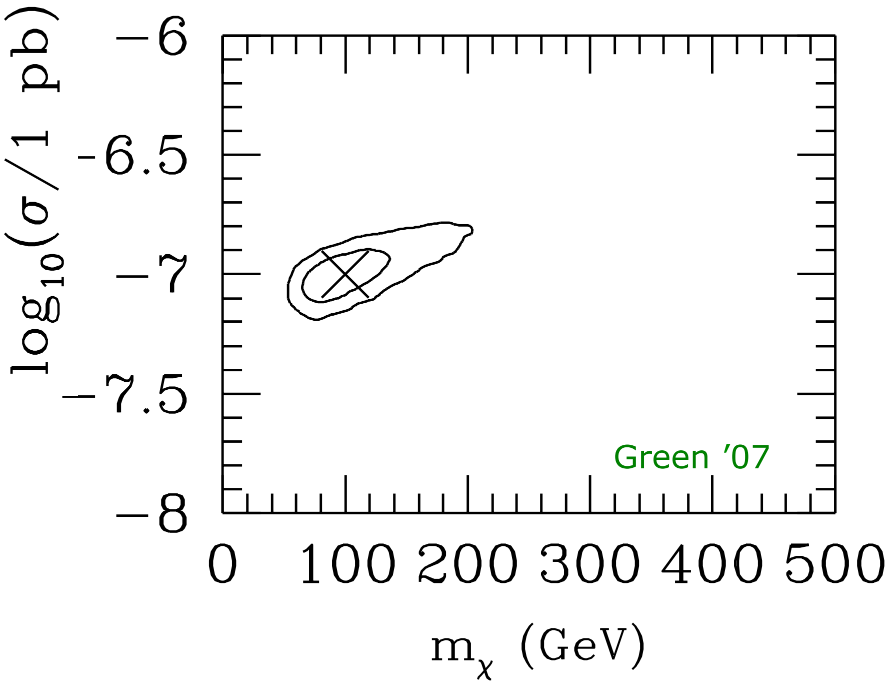
Green '07-10; Drees et al. '08'09

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} \approx \left(\frac{\mathrm{d}R}{\mathrm{d}E_R}\right)_0 F^2(E_R) \exp\left(-\frac{E_R}{E_c}\right)$$

$$E_c = (c_1 2\mu_N^2 v_c^2)/m_N$$

Direct detection can only determine "phenomenological" WIMP parameters

$m_X \quad \sigma^{SI}_p$

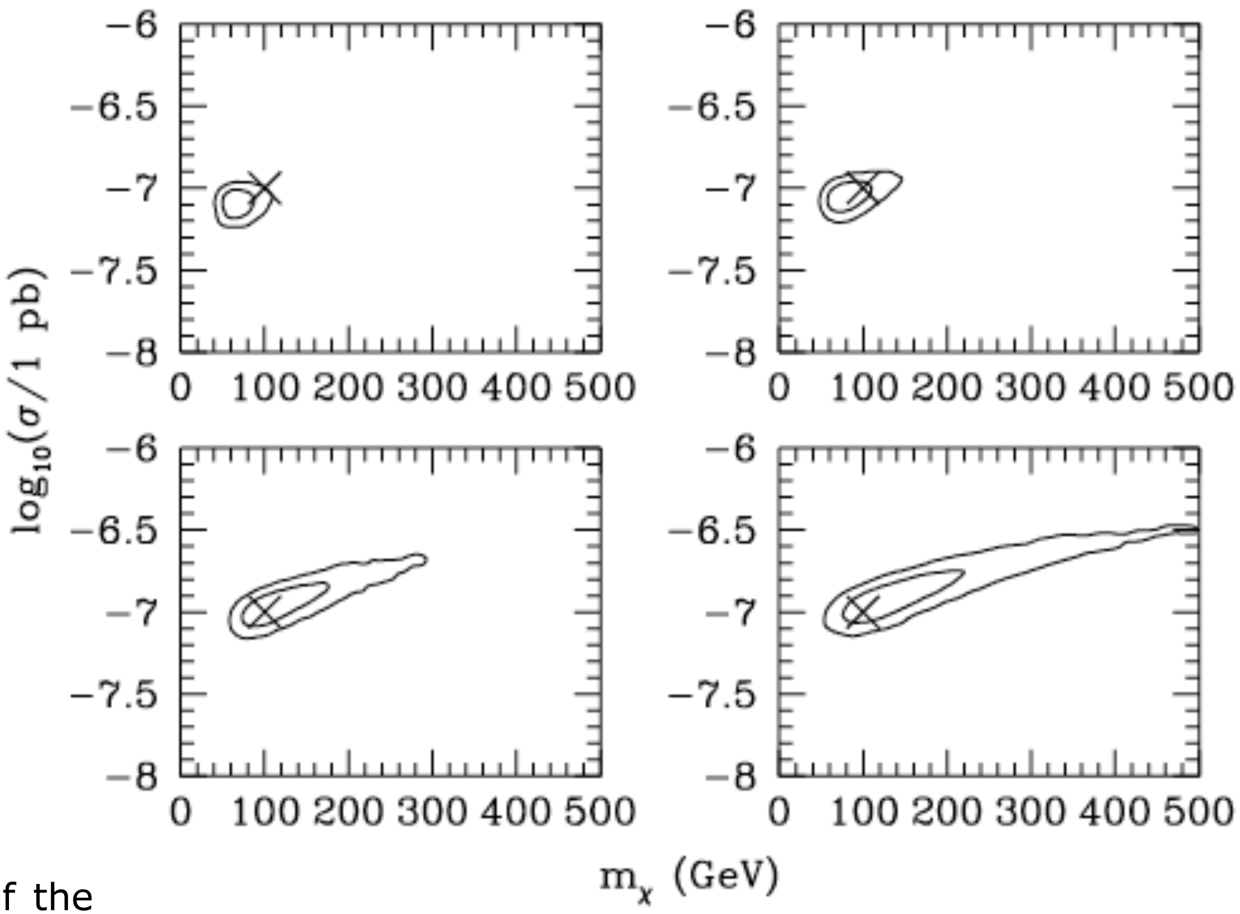


Example: m_X=100 GeV
Exposure: 3000 kg day (Ge target)

The determination is affected by uncertainties

Astrophysical uncertainties in direct DM searches

For example, on the central velocity of the DM halo



And also on the shape of the DM halo and the velocity distribution function.

Green '07

Parameterizing astrophysical uncertainties

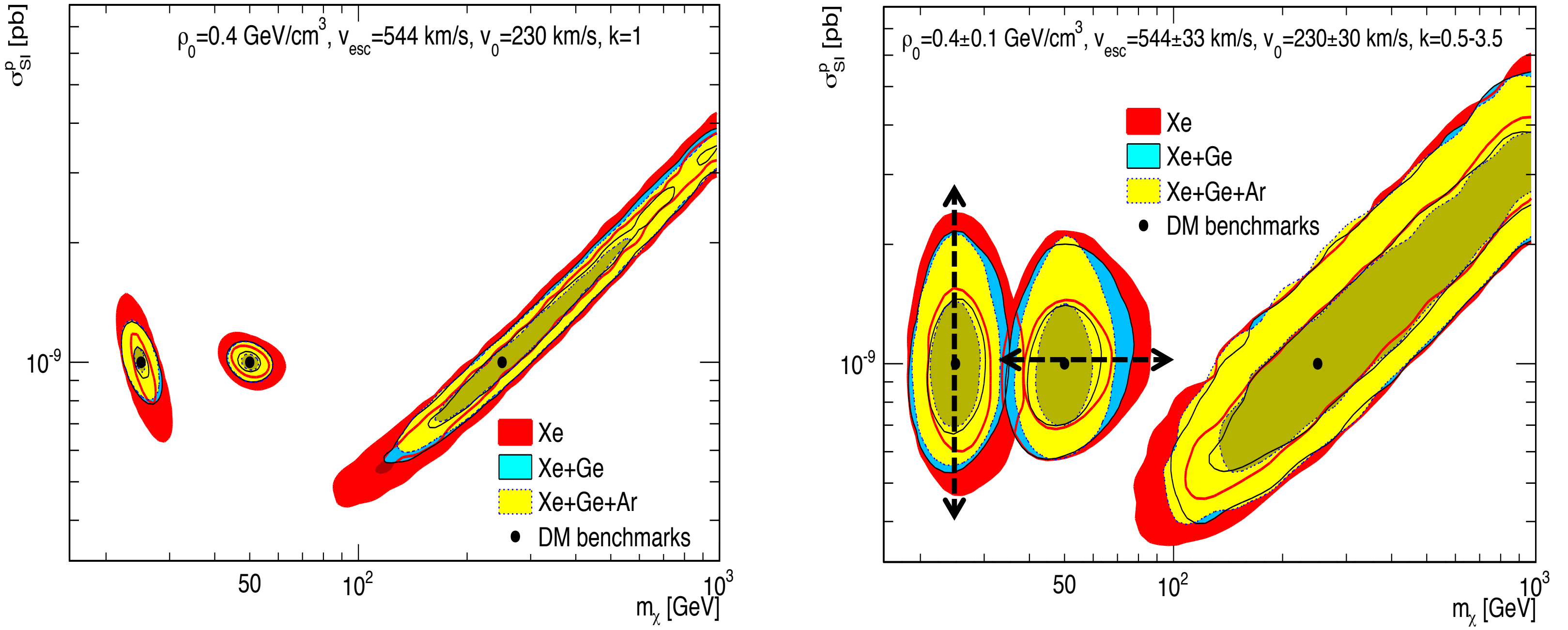
Generalization of the SHM for the velocity distribution function

Based on Binney, Tremaine '08

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

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

There are degeneracies in reconstructing the phenomenological parameters.

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

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

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

Nuclear form factors

Integrating in energies and velocities

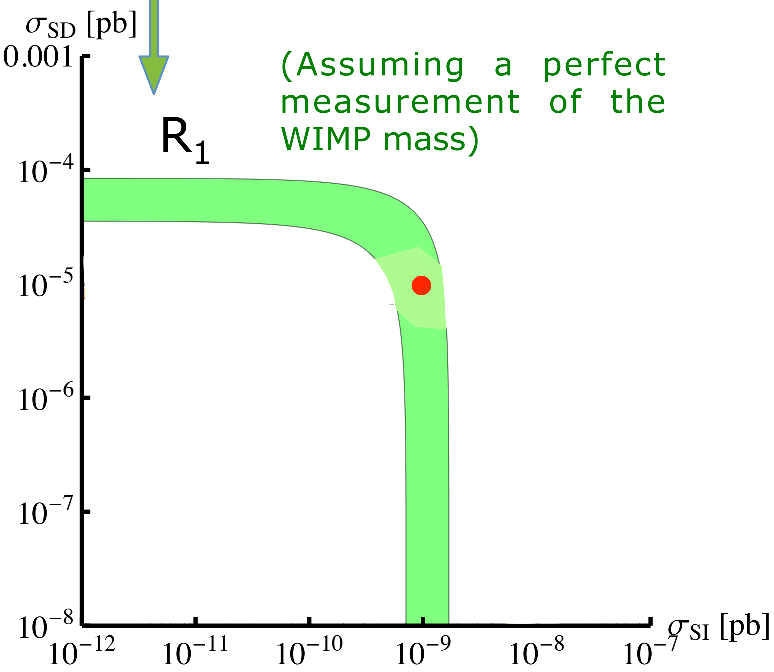
$$R_1 = A_1 \sigma_0^{SI} + \left(B_1^p \sqrt{\sigma_0^{SD,p}} + B_1^n \sqrt{\sigma_0^{SD,n}}\right)^2$$

Target-dependent

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

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

Determination of both SD and SI cross section



(Assuming a perfect measurement of the WIMP mass)

The same rate can be explained by a candidate with

Mostly spin-dependent interactions

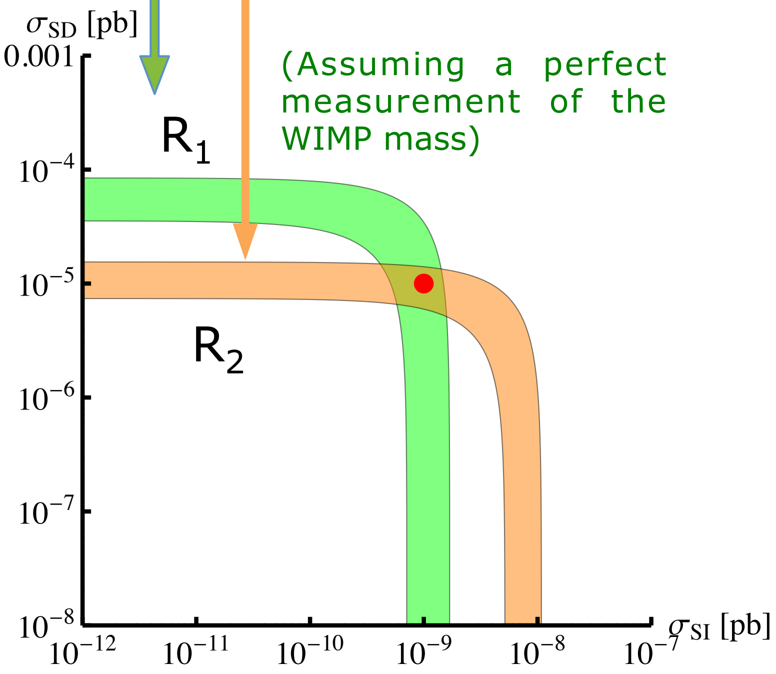
Mostly spin-independent interactions

NB: in fact we should take into account SD-interactions with protons and neutrons separately (i.e. 3D plots) – not in this talk.

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

$$R_2 = A_2\sigma_0^{SI} + \left(B_2^p\sqrt{\sigma_0^{SD,p}} + B_2^n\sqrt{\sigma_0^{SD,n}}\right)^2$$

Determination of both SD and SI cross section



(Assuming a perfect measurement of the WIMP mass)

Complementarity of targets

- One target mostly SI and the other mostly SD

Bertone, DGC, Collar, Odom 2007

- Large exposure → smaller area

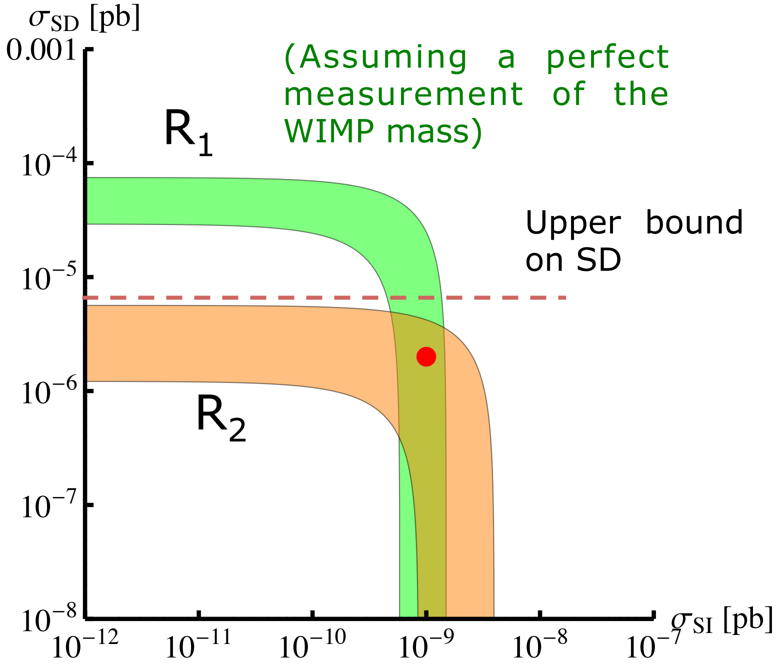
Analytical determination of the parameters without uncertainties (ideal)

Cannoni, Gómez, Vergados 2010
Cannoni 2011

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

$$R_2 = A_2\sigma_0^{SI} + \left(B_2^p\sqrt{\sigma_0^{SD,p}} + B_2^n\sqrt{\sigma_0^{SD,n}}\right)^2$$

Determination of only the SI cross section



The most common situation

- Most targets are more sensitive to the SI component
(e.g. Ge, Xe, I)
- Heavy targets or heavy WIMPs
- Small SD cross section

The inclusion of uncertainties is CRUCIAL

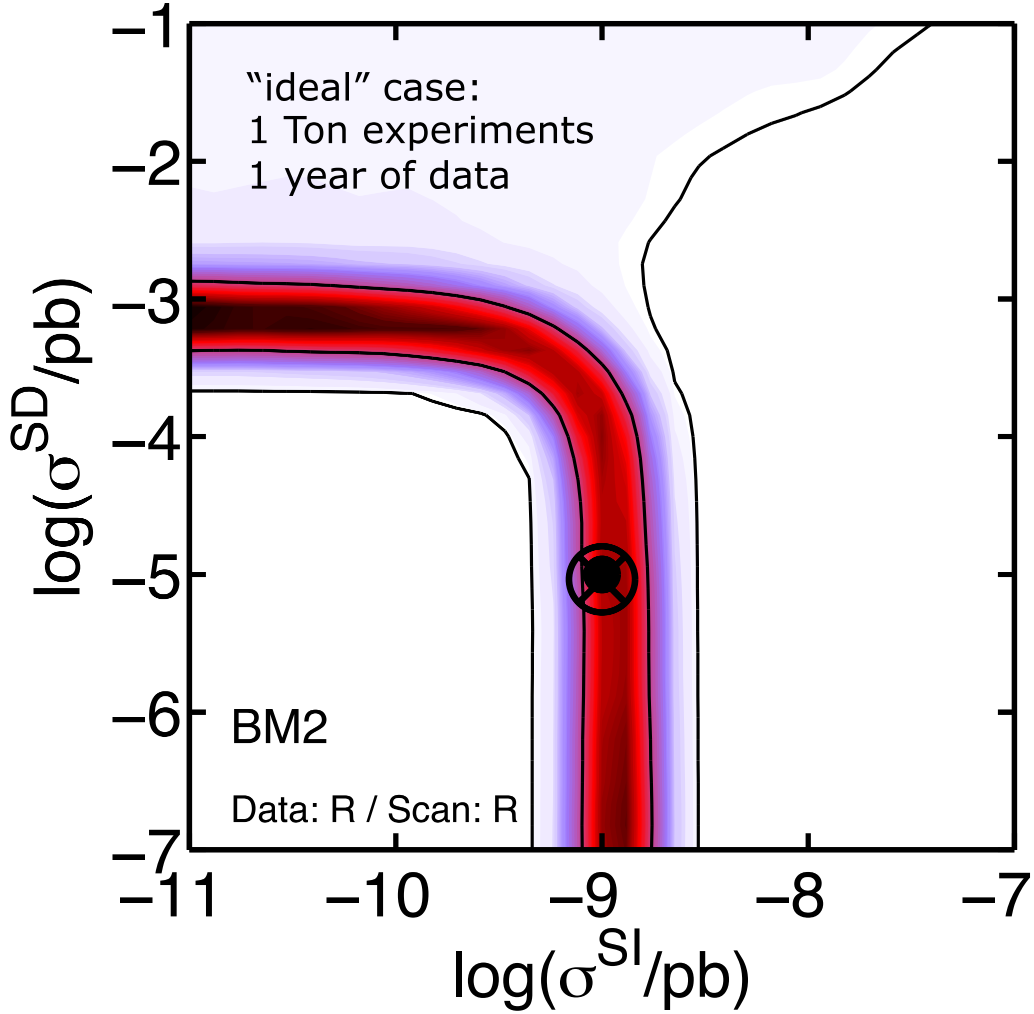
Astrophysical uncertainties

Nuclear uncertainties:
Uncertainties in the Spin-dependent form factor can lead to a misreconstruction of WIMP parameters

Detection with one experiment

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

Ge detector (e.g. Super CDMS)



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

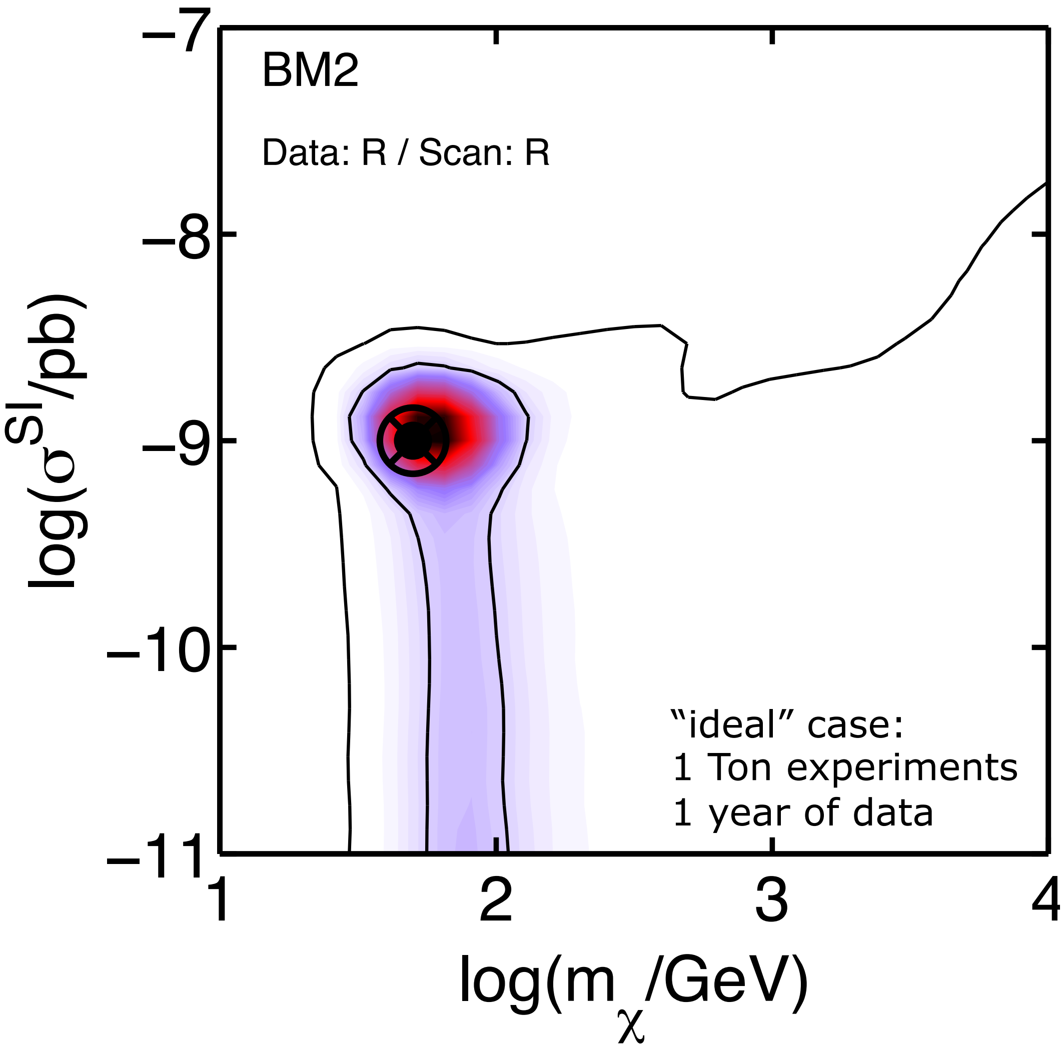
The degeneracy cannot be fully removed unless assumptions are made on the WIMP model

Uncertainties lead to a poorer reconstruction of parameters

Detection with one experiment

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

Ge detector (e.g. Super CDMS)



"ideal" case:
1 Ton experiments
1 year of data

$$\boxed{\begin{aligned} \sigma_0^{SI} &= 10^{-9}\,\mathrm{pb} \\ \sigma_0^{SD} &= 10^{-5}\,\mathrm{pb} \\ m_W &= 50\,\mathrm{GeV} \\ \epsilon &= 300\,\mathrm{kg\,yr} \end{aligned}}$$

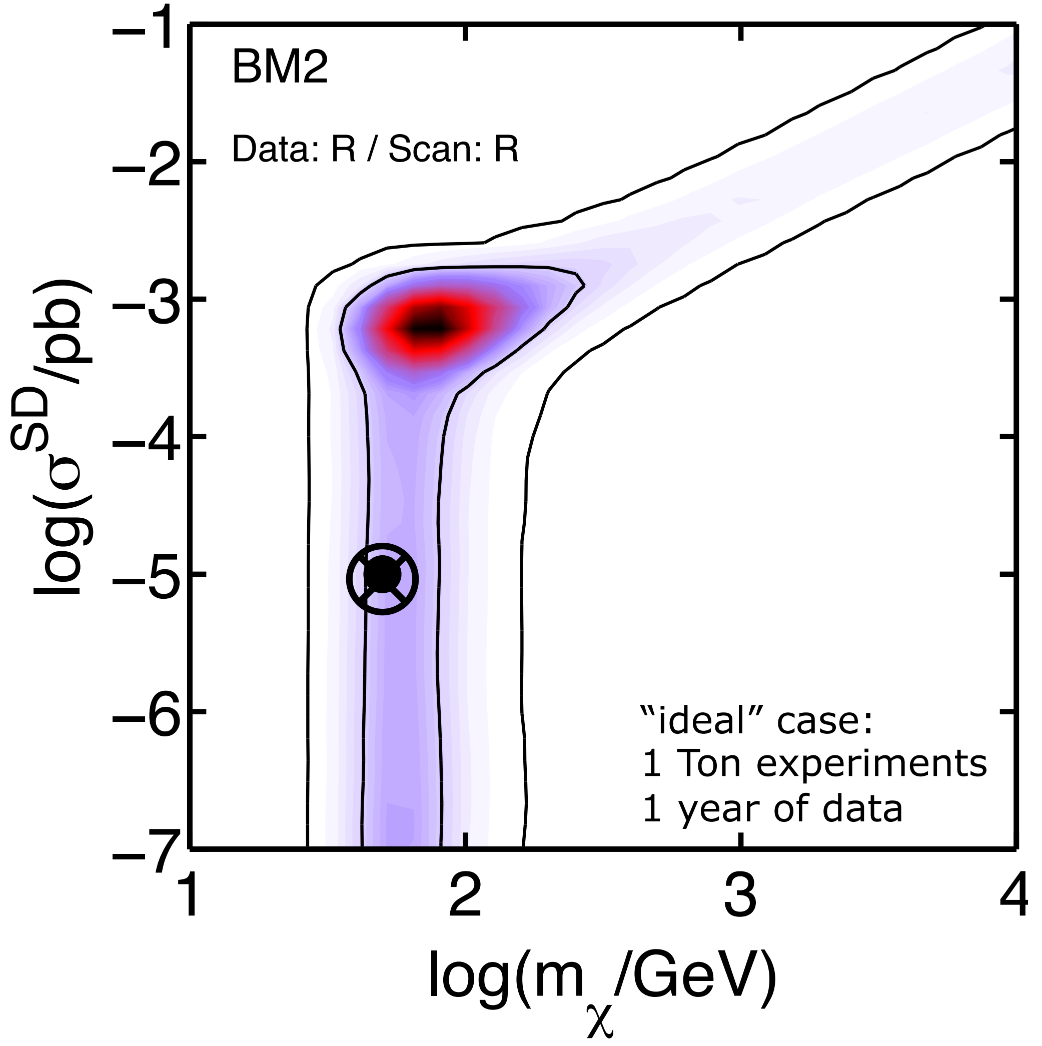
The degeneracy cannot be fully removed unless assumptions are made on the WIMP model

Uncertainties lead to a poorer reconstruction of parameters

Detection with one experiment

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

Ge detector (e.g. Super CDMS)



“ideal” case:
1 Ton experiments
1 year of data

$$\boxed{\begin{aligned}\sigma_0^{SI} &= 10^{-9}\,\mathrm{pb}\\ \sigma_0^{SD} &= 10^{-5}\,\mathrm{pb}\\ m_W &= 50\,\mathrm{GeV}\\ \epsilon &= 300\,\mathrm{kg\,yr}\end{aligned}}$$

The degeneracy cannot be fully removed unless assumptions are made on the WIMP model

Uncertainties lead to a poorer reconstruction of parameters

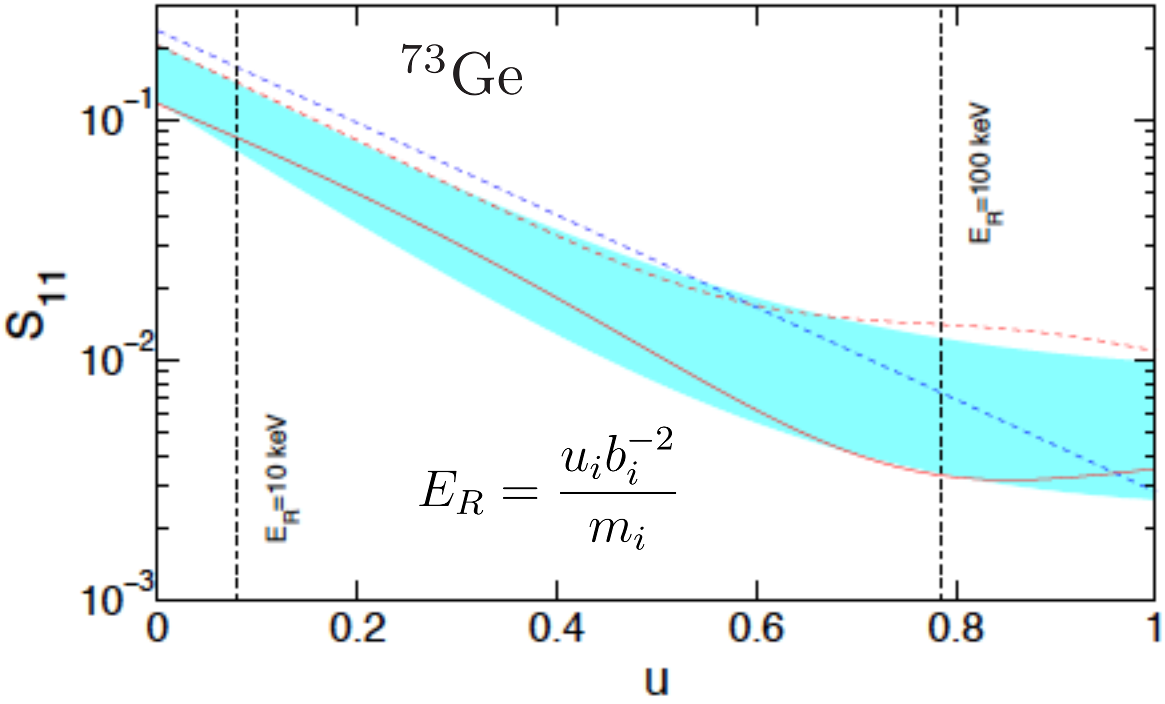
Uncertainties in the spin-dependent form factors

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

$$a_0 = a_p + a_n$$

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

$$a_1 = a_p - a_n$$



ShM COMPUTATIONS:

Ressel, et al. ‘93

Dimitrov, et al. ‘94

Variations in

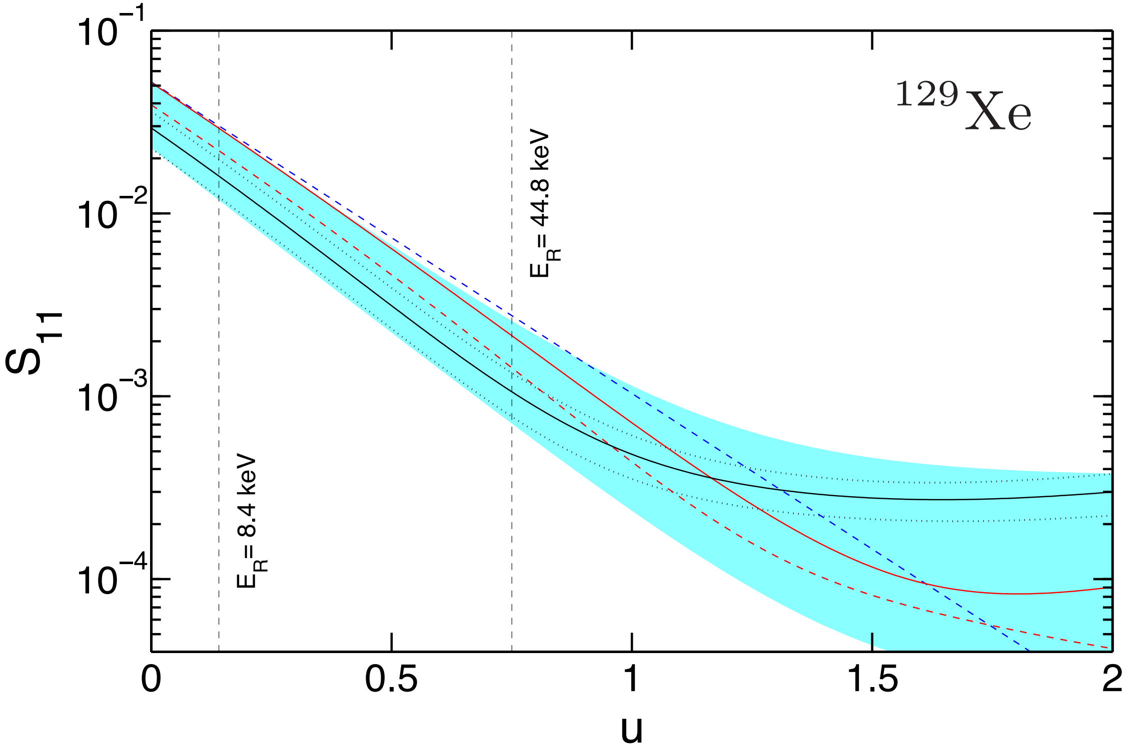
- Zero-momentum value
- Slope
- Plateau

Uncertainties in the spin-dependent form factors

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

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

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



ShM COMPUTATIONS:

Bonn A / Nijmegen II

Ressel, Dean '97

gcn5020 interaction

Menéndez, Gazit, Schwenk '12

Variations in

- Zero-momentum value
- Slope
- Plateau

Uncertainties in the spin-dependent form factors

We use an empirical fitting formula that allows interpolation between the various models

$$S_{ij}(u) = N\left((1-\beta)e^{-\alpha u} + \beta\right)$$

	N	α	β
^{73}Ge	$0.12 - 0.21$	$0.020 - 0.042$	$5.0 - 6.0$
^{129}Xe	$0.029 - 0.052$	$4.2 - 4.7$	$1.0 \times 10^{-3} - 7 \times 10^{-3}$
^{131}Xe	$0.017 - 0.027$	$4.3 - 5.0$	$4.2 \times 10^{-2} - 6.1 \times 10^{-2}$

The three fitting parameters are included as “nuisance parameters” in the scan of the parameter space

Of particular importance are the zero momentum value and slope (they affect the determination of the cross-section and mass, respectively)

Varitions in

- Zero-momentum value
- Slope
- Plateau

$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$

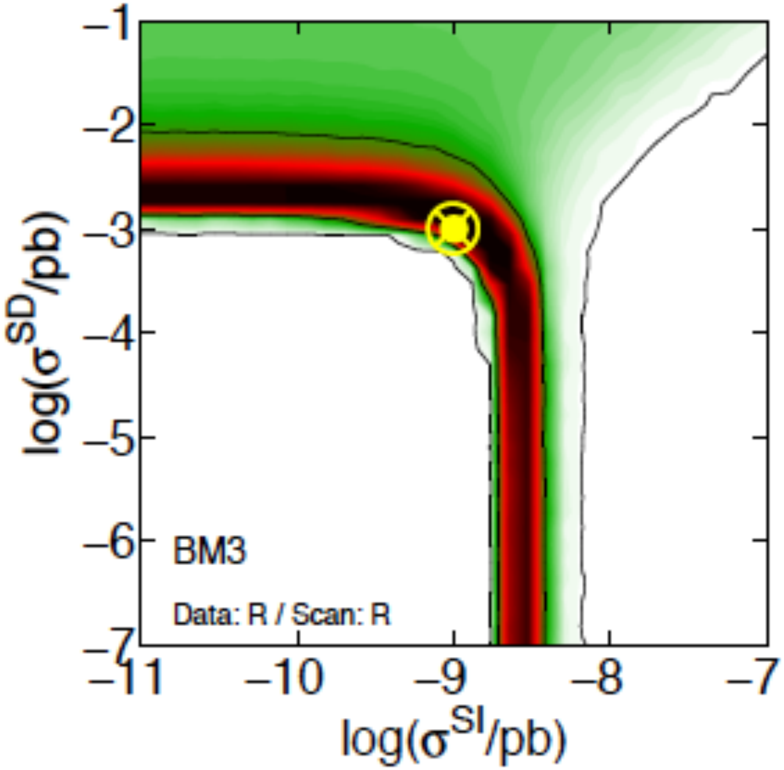
$$\sigma_0^{SD} = 10^{-3}\,\mathrm{pb}$$

$$m_W = 100\,\mathrm{GeV}$$

We introduce a 3-dimensional parametrization

$$S_{ij}(u) = N\left((1-\beta)e^{-\alpha u} + \beta\right)$$

	N	α	β
^{73}Ge	$0.12 - 0.21$	$0.020 - 0.042$	$5.0 - 6.0$
^{129}Xe	$0.029 - 0.052$	$4.2 - 4.7$	$1.0 \times 10^{-3} - 7 \times 10^{-3}$
^{131}Xe	$0.017 - 0.027$	$4.3 - 5.0$	$4.2 \times 10^{-2} - 6.1 \times 10^{-2}$



Reconstruction with a fixed model for the SD form factor

Variations in

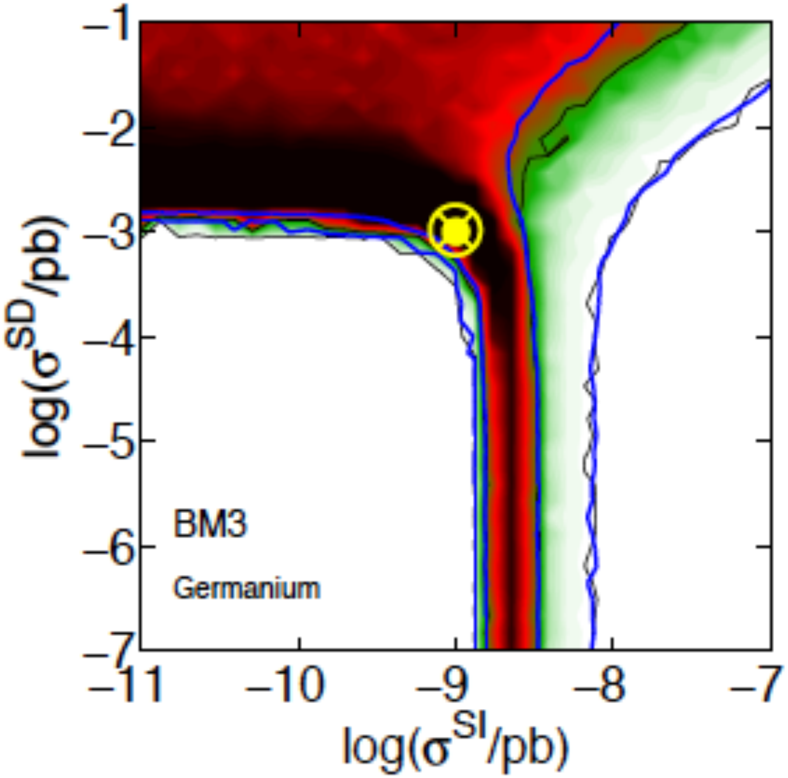
- Zero-momentum value
- Slope
- Plateau

We introduce a 3-dimensional parametrization

$$S_{ij}(u) = N\left((1-\beta)e^{-\alpha u} + \beta\right)$$

	N	α	β
^{73}Ge	$0.12 - 0.21$	$0.020 - 0.042$	$5.0 - 6.0$
^{129}Xe	$0.029 - 0.052$	$4.2 - 4.7$	$1.0 \times 10^{-3} - 7 \times 10^{-3}$
^{131}Xe	$0.017 - 0.027$	$4.3 - 5.0$	$4.2 \times 10^{-2} - 6.1 \times 10^{-2}$

$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$
$$\sigma_0^{SD} = 10^{-3}\,\mathrm{pb}$$
$$m_W = 100\,\mathrm{GeV}$$



BLACK = Reconstruction with uncertainties in the SD form factor

BLUE = Astrophysical uncertainties

Effects are only important when the SD contribution is sizable

Variations in

- Zero-momentum value
- Slope
- Plateau

We introduce a 3-dimensional parametrization

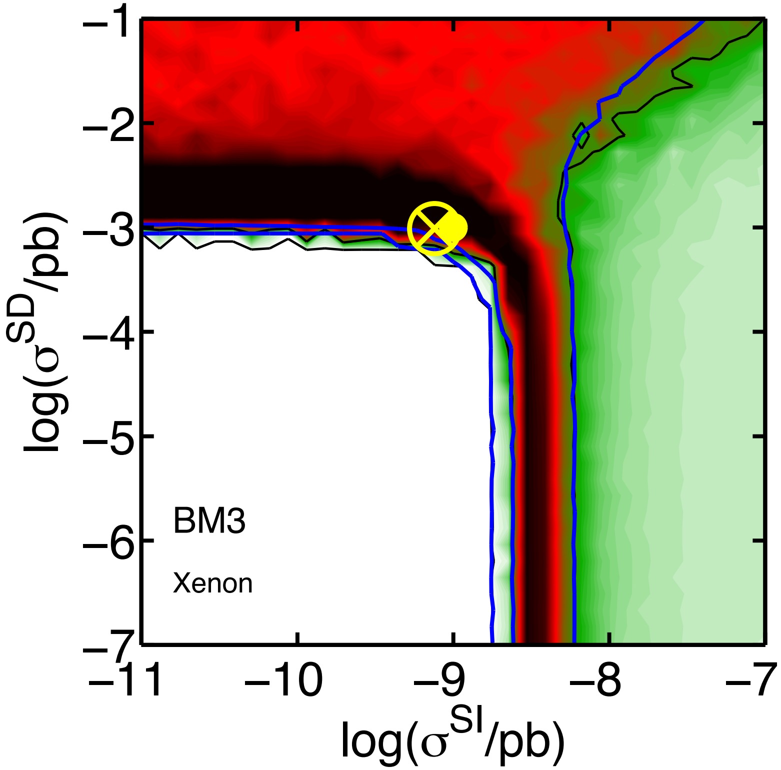
$$S_{ij}(u) = N\left((1-\beta)e^{-\alpha u} + \beta\right)$$

	N	α	β
^{73}Ge	$0.12 - 0.21$	$0.020 - 0.042$	$5.0 - 6.0$
^{129}Xe	$0.029 - 0.052$	$4.2 - 4.7$	$1.0 \times 10^{-3} - 7 \times 10^{-3}$
^{131}Xe	$0.017 - 0.027$	$4.3 - 5.0$	$4.2 \times 10^{-2} - 6.1 \times 10^{-2}$

$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$

$$\sigma_0^{SD} = 10^{-3}\,\mathrm{pb}$$

$$m_W = 100\,\mathrm{GeV}$$



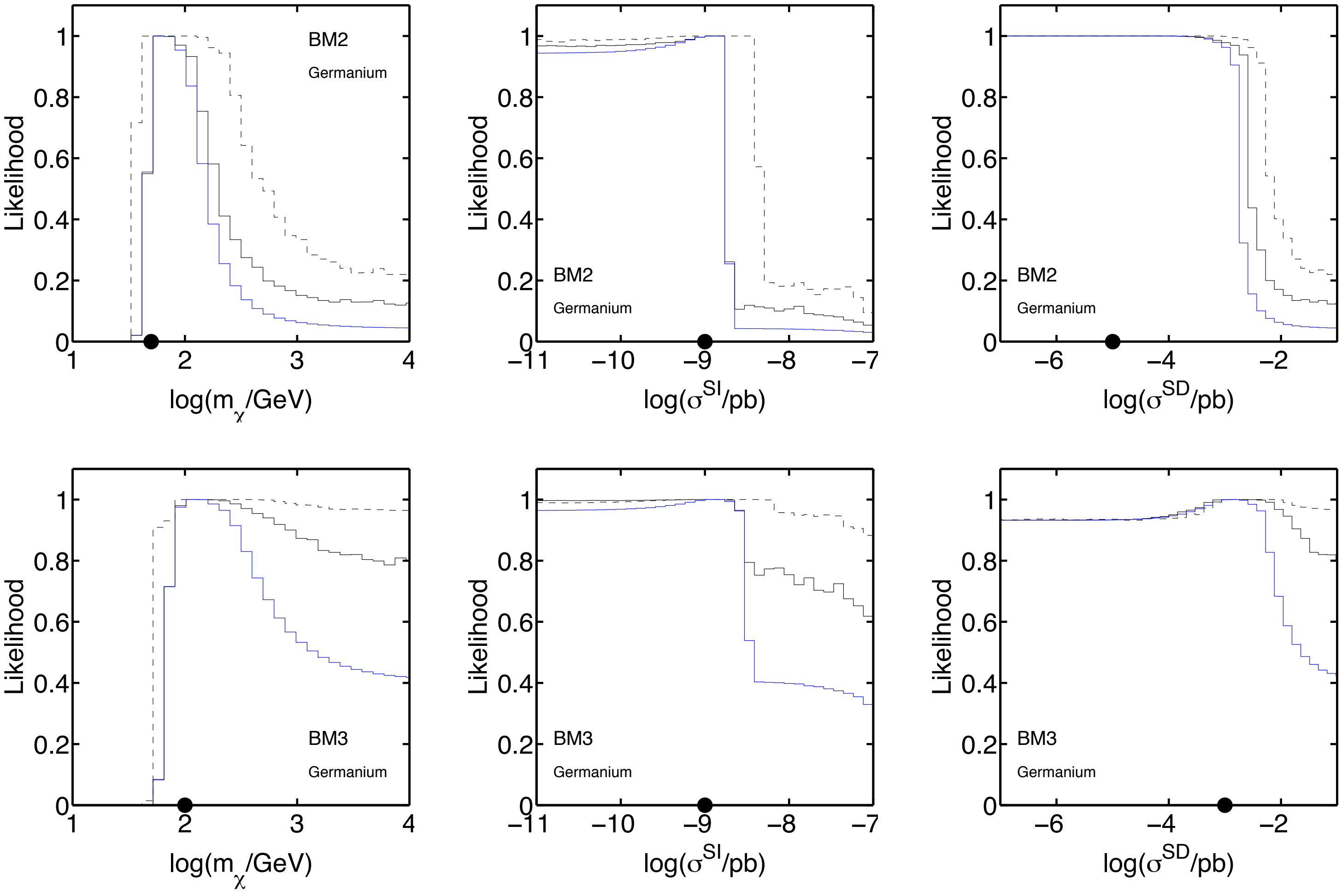
BLACK = Reconstruction with uncertainties in the SD form factor

BLUE = Astrophysical uncertainties

Effects are only important when the SD contribution is sizable

Quantitatively similar for XENON or CDMS

Uncertainties in the SD form factors affect the reconstruction of the WIMP mass and SD cross section



$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$
$$\sigma_0^{SD} = 10^{-5}\,\mathrm{pb}$$
$$m_W = 50\,\mathrm{GeV}$$

$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$
$$\sigma_0^{SD} = 10^{-3}\,\mathrm{pb}$$
$$m_W = 100\,\mathrm{GeV}$$

The effect of uncertainties in Spin-Independent form factors is negligible

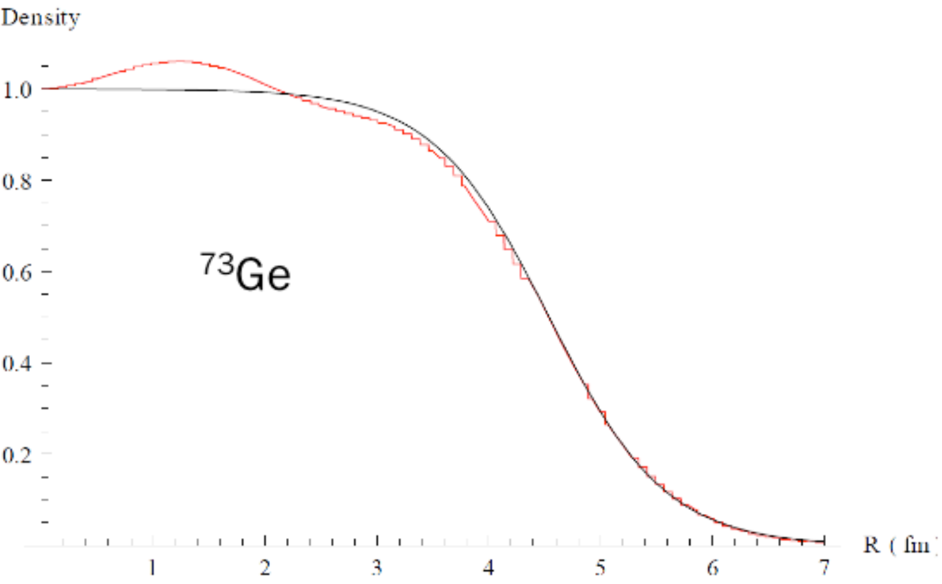
$$F_{SI}(q) = \int e^{-iqx}\rho_A(x)d^3x\,.$$

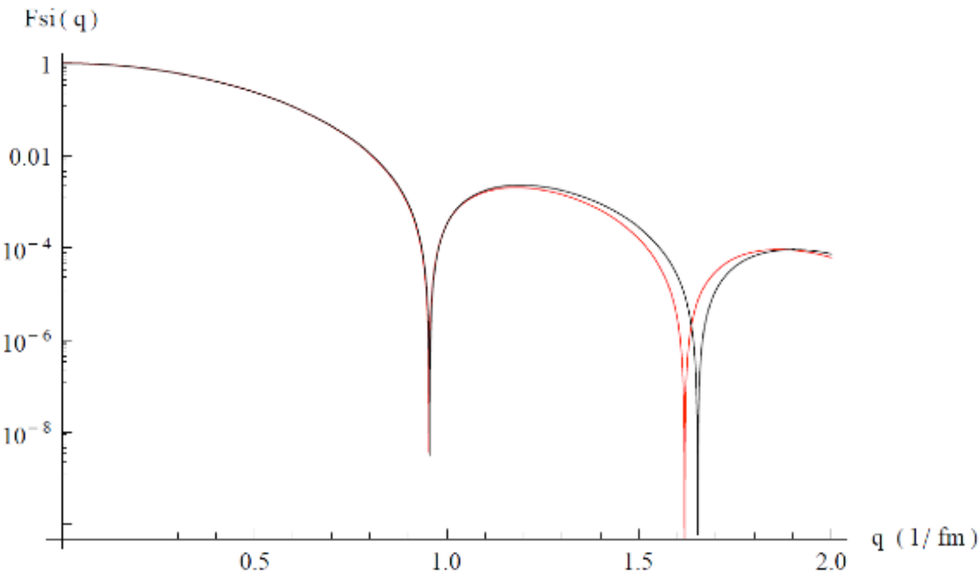
Fermi distribution

$$\boxed{\rho_A(x) = \frac{c}{1+\exp[(r-R_A)/a]},}$$

$$a = 0.52 \text{ fm}$$

$$R_A = (1.23A^{1/3} - 0.6) \text{ fm}$$



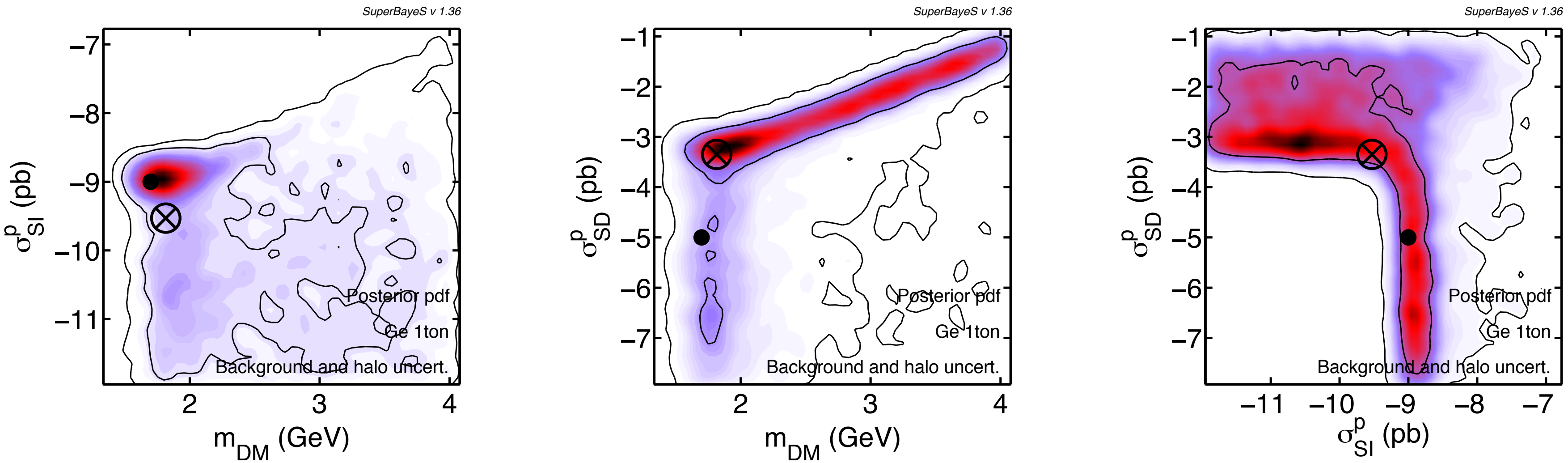


🟥 **Real data** ▬ **Fermi distribution**

Detection with one experiment

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

Ge detector (e.g. SuperCDMS)



$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$

$$\sigma_0^{SD} = 10^{-5}\,\mathrm{pb}$$

$$m_W = 50\,\mathrm{GeV}$$

$$\epsilon = 300\,\mathrm{kg\,yr}$$

The degeneracy cannot be fully removed unless assumptions are made on the WIMP model

(e.g., usually the SD contribution is considered negligible)

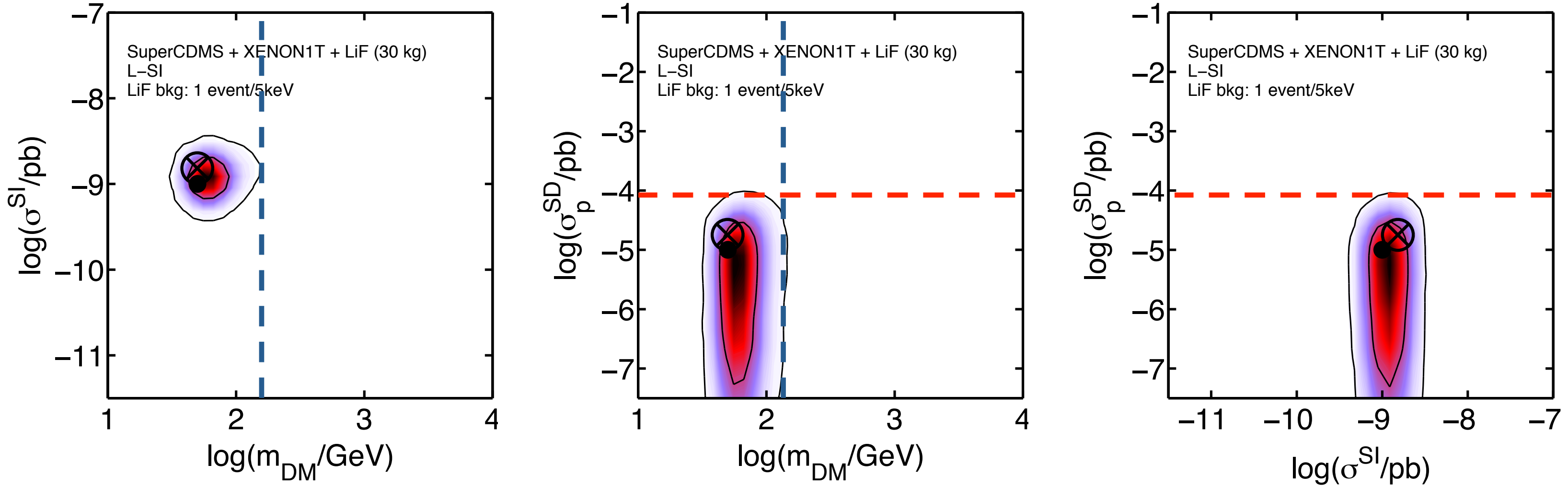
Detection with two experiments

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

$$R_2 = A_2 \sigma_0^{SI} + \left(B_2^p \sqrt{\sigma_0^{SD,p}} + B_2^n \sqrt{\sigma_0^{SD,n}} \right)^2$$

Ge detector (e.g. SuperCDMS)

Xe detector (e.g. Xenon)



$$\boxed{\begin{aligned} \sigma_0^{SI} &= 10^{-9}\,\mathrm{pb} \\ \sigma_0^{SD} &= 10^{-5}\,\mathrm{pb} \\ m_W &= 50\,\mathrm{GeV} \\ \epsilon &= 300\,\mathrm{kg\,yr} \end{aligned}}$$

Both experiments are mostly sensitive to the spin-independent component

Degeneracies cannot be completely removed but the upper bound on the spin-dependent component is more stringent

Better determination of the WIMP mass

Ideal for complementarity: targets which have large spin content

	^{3}He	^{19}F	^{29}Si	^{23}Na	^{73}Ge	^{127}I*	^{127}I**	^{207}Pb^{+}
$\Omega_0(0)$	1.244	1.616	0.455	0.691	1.075	1.815	1.220	0.552
$\Omega_1(0)$	-1.527	1.675	-0.461	0.588	-1.003	1.105	1.230	-0.480
$\Omega_p(0)$	-0.141	1.646	-0.003	0.640	0.036	1.460	1.225	0.036
$\Omega_n(0)$	1.386	-0.030	0.459	0.051	1.040	0.355	-0.005	0.516
μ_{th}		2.91	-0.50	2.22				
μ_{exp}		2.62	-0.56	2.22				
$\frac{\mu_{th}(spin)}{\mu_{exp}}$		0.91	0.99	0.57				

From Vergados '09

Ideally one also wants to further discriminate SD-proton and SD-neutron

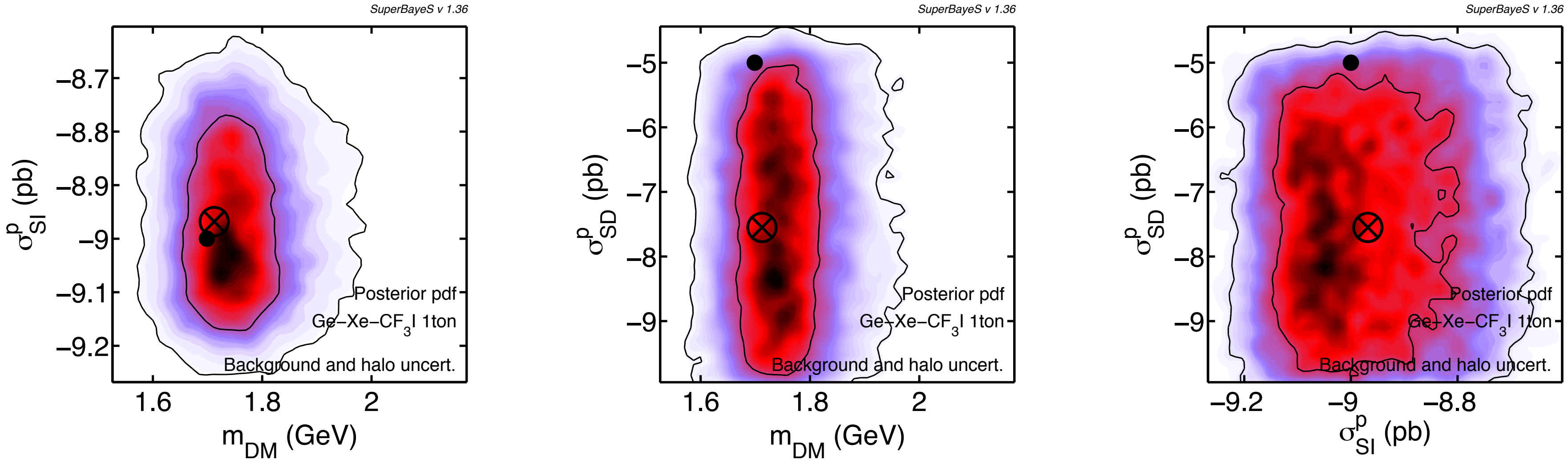
Fluorine? – e.g., used in COUPP

Detection with three experiments

Ge detector (e.g. Super CDMS)

Xe detector (e.g. Xenon)

+ COUPP (CF_3I) (no spectrum measurement – no mass reconstruction)



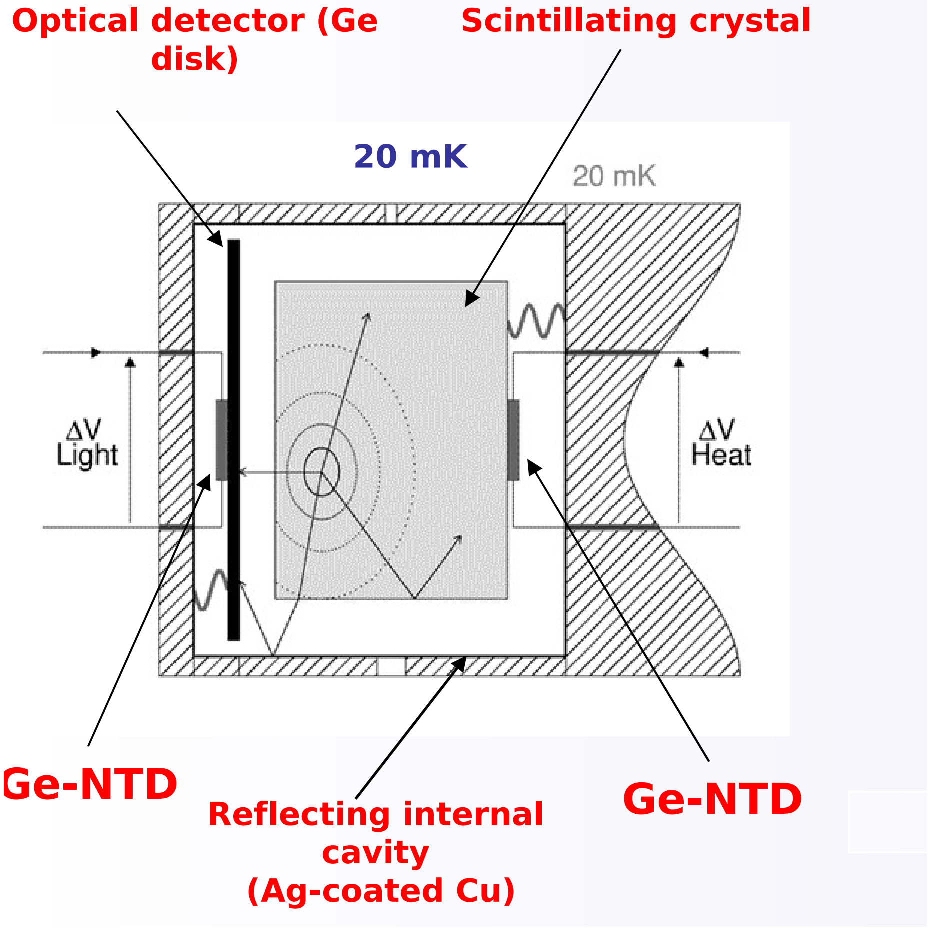
$$\boxed{\begin{aligned} \sigma_0^{SI} &= 10^{-9}\,\mathrm{pb} \\ \sigma_0^{SD} &= 10^{-5}\,\mathrm{pb} \\ m_W &= 50\,\mathrm{GeV} \\ \epsilon &= 300\,\mathrm{kg\,yr} \end{aligned}}$$

More stringent upper bound on the spin-dependent component

No improvement in the determination of the WIMP mass

How large do we need the target to be to obtain complementarity?

We studied scintillating-bolometric targets for the ROSEBUD collaboration



Optical detector (Ge disk)

Scintillating crystal

Ge-NTD

Reflecting internal cavity (Ag-coated Cu)

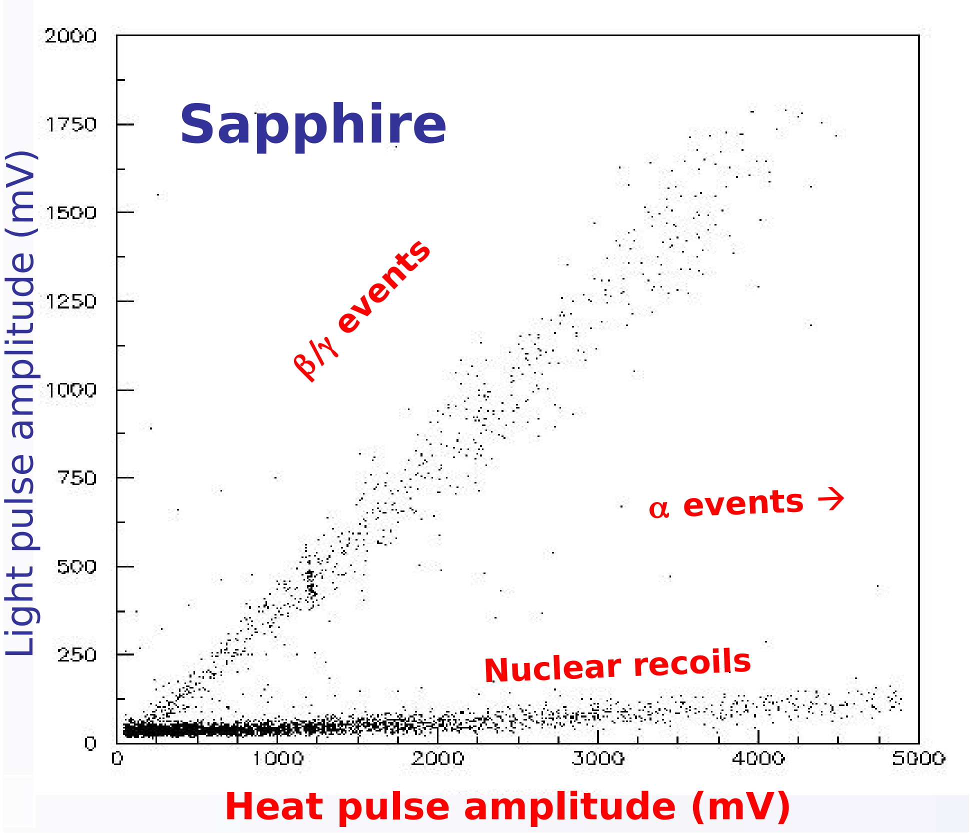
Ge-NTD

The signal is heat (phonons) and scintillation light

LiF
CaF
CaWO
Al_2O_3
BGO (Bi, Ge, O)
…

How large do we need the target to be to obtain complementarity?

We studied scintillating-bolometric targets for the ROSEBUD collaboration



The signal is heat (phonons) and scintillation light

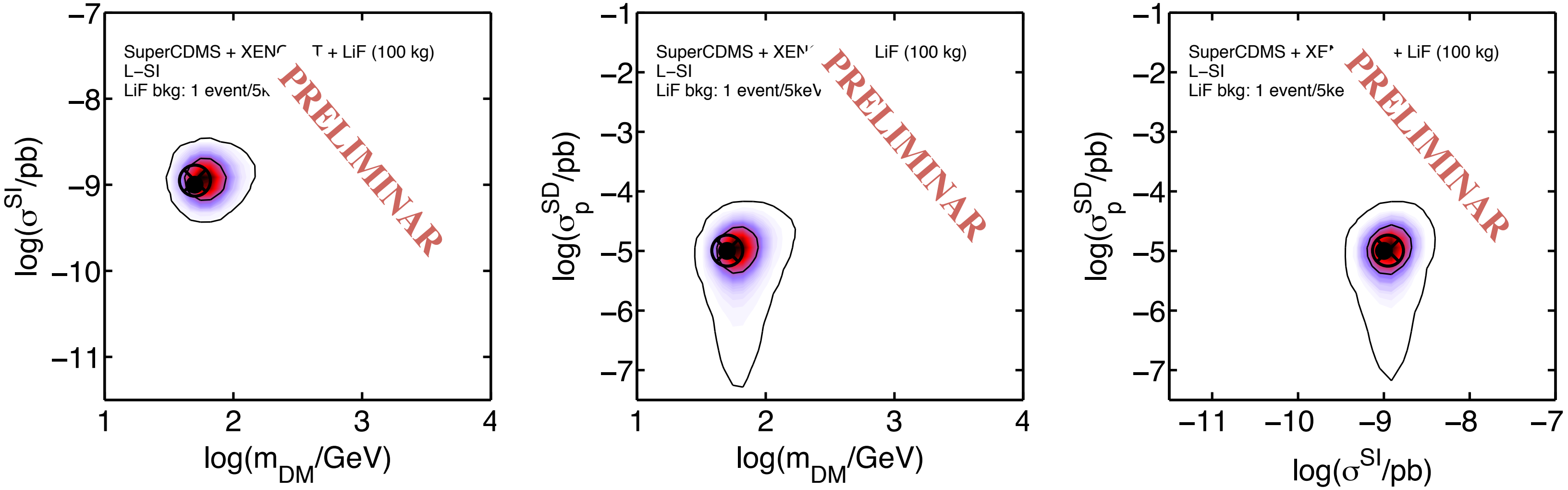
LiF
CaF
CaWO
Al_2O_3
BGO (Bi, Ge, O)
...

Detection with three experiments

Ge detector (e.g. SuperCDMS)

Xe detector (e.g. Xenon)

+ EURECA (LiF)
100 kg yr



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

Degeneracies can be removed and the phenomenological parameters determined

The needed exposure depends on the actual point in the parameter space

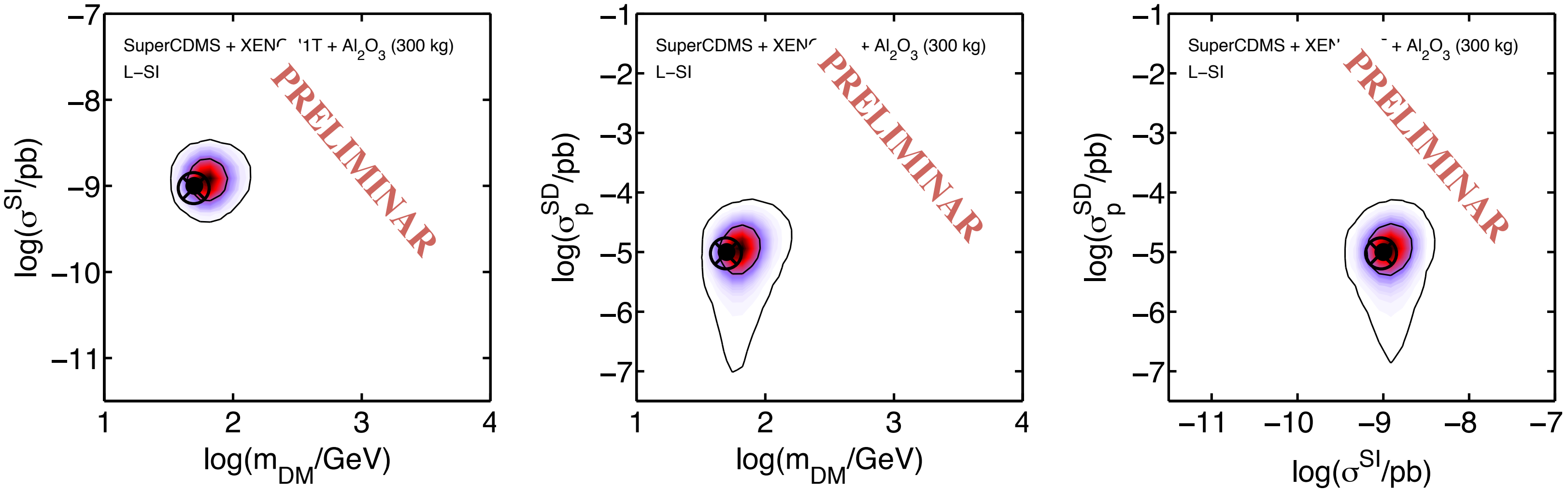
In progress: testing other possible targets and the whole parameter space

Detection with three experiments

Ge detector (e.g. SuperCDMS)

Xe detector (e.g. Xenon)

+ EURECA (Al_2O_3)
300 kg yr



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

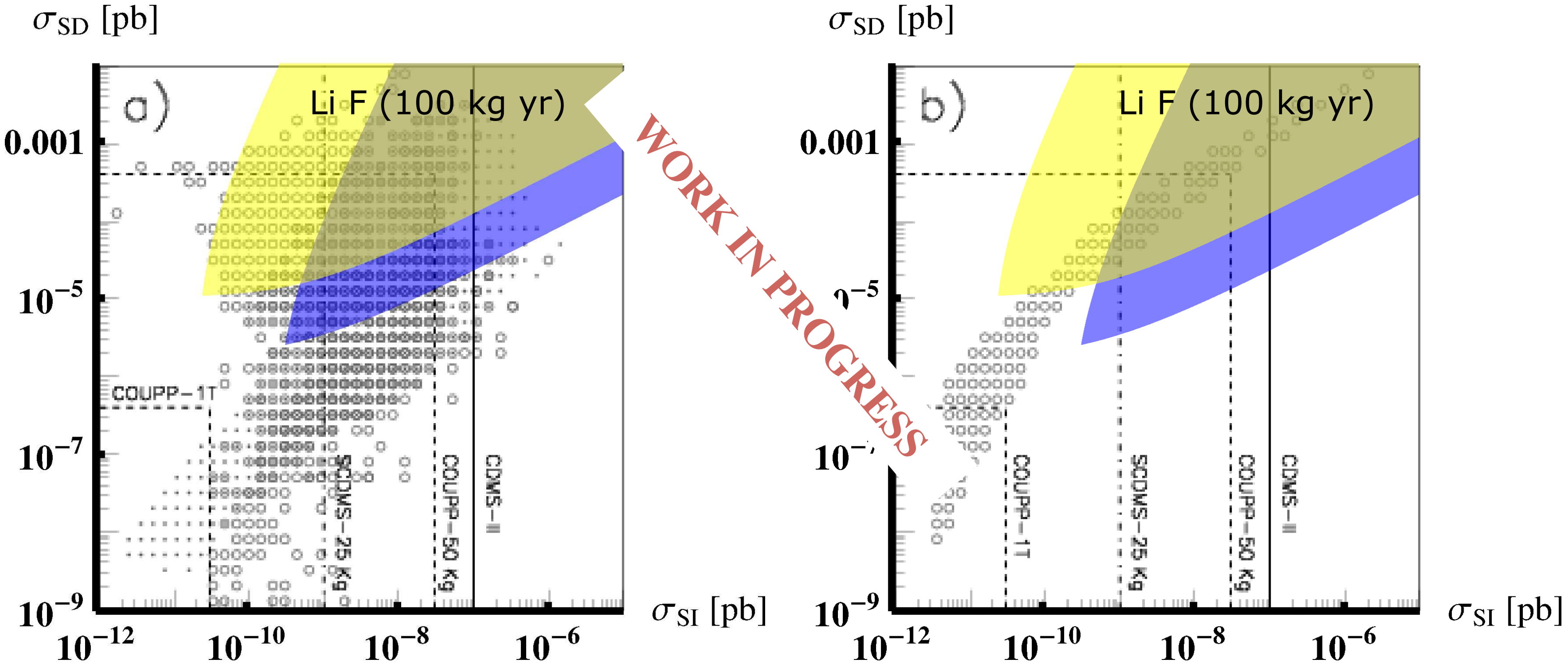
Degeneracies can be removed and the phenomenological parameters determined

The needed exposure depends on the actual point in the parameter space

In progress: testing other possible targets and the whole parameter space

The goal is to completely characterise these targets, determining for which regions of the parameter space they provide complementarity

These results depend on the mass and cross section of the WIMP



Conclusions

- We have studied the effect of UNCERTAINTIES in the spin-dependent form factors for the reconstruction of WIMP parameters

  They affect the determination of the WIMP mass and SD cross-section off nuclei

  Comparable to astrophysical uncertainties (if the SD contribution dominates)

- Spin-dependent sensitive targets can provide COMPLEMENTARY information to determine the WIMP phenomenological parameters

  Germanium and Xenon experiments might be unable to fully determine the WIMP phenomenological parameters (no measurement of the SD cross-section)

  ~100 kg of LiF or Al_2O_3 (bolometric targets that could be used in EURECA) can be complementary

New slides

Some of the SD targets used in Direct DM detection

isotope	Z	J^{π}	abundance (%)	experiment
^{3}He	2	$1/2^{+}$	$<<1$	MIMAC
^{7}Li	3	$3/2^{-}$	93	Kamioka
^{13}C	6	$1/2^{-}$	1.1	PICASSO, SIMPLE, COUPP
^{17}O	8	$5/2^{+}$	$<<1$	ROSEBUD, CRESST
^{19}F	9	$1/2^{+}$	100	SIMPLE, PICASSO, Kamioka, COUPP
^{21}Ne	10	$3/2^{+}$	$<<1$	CLEAN
^{23}Na	11	$3/2^{+}$	100	DAMA, NAIAD, ANAIS, LIBRA Kamioka
^{27}Al	13	$5/2^{+}$	100	ROSEBUD
^{29}Si	14	$7/2^{+}$	4.7	CDMS
^{35}Cl	17	$3/2^{+}$	76	SIMPLE
^{37}Cl	17	$3/2^{+}$	24	SIMPLE
^{43}Ca	20	$7/2^{-}$	$<<1$	CRESST-II, Kamioka
^{67}Zn	30	$5/2^{-}$	4.1	CRESST-II
^{73}Ge	32	$9/2^{+}$	7.8	HDMS, CDMS, GENIUS, EDELWEISS
^{127}I	53	$5/2^{+}$	100	DAMA , NAIAD, KIMS, ANAIS, LIBRA, COUPP
^{129}Xe	54	$1/2^{+}$	26	ZEPLIN
^{131}Xe	54	$3/2^{+}$	21	ZEPLIN
^{133}Cs	55	$7/2^{+}$	100	KIMS
^{183}W	74	$1/2^{-}$	14	CRESST-II
^{209}Bi	83	$9/2^{-}$	100	ROSEBUD

Example: Two targets in COUPP

The detection rate for a given target is a function of the spin-dependent and independent couplings of the WIMP

$$R_1 \sim A_1\, \sigma^{SI}{}_p + B_1\, \sigma^{SD}{}_p$$

$$R_2 \sim A_2\, \sigma^{SI}{}_p + B_2\, \sigma^{SD}{}_p$$

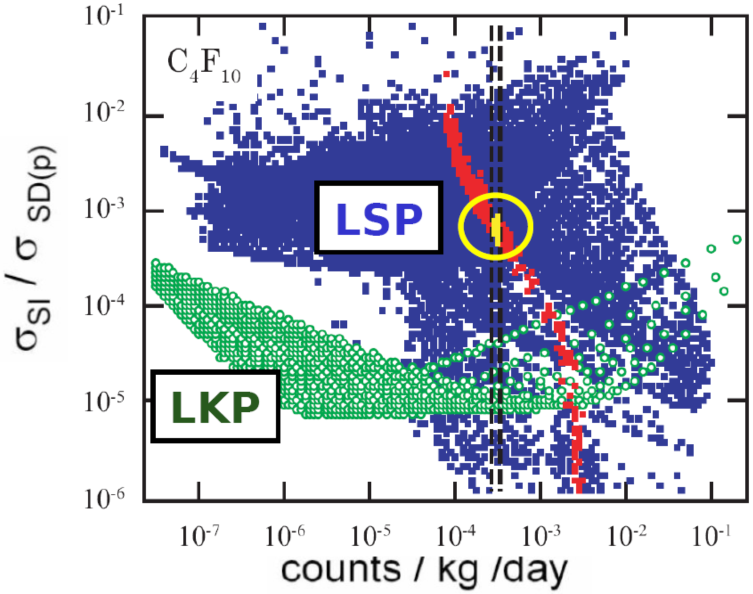
(use WIMP relation among $\sigma^{SD}{}_n$and $\sigma^{SD}{}_p$)

WIMP detection in two complementary targets can be used to discriminate WIMP models

Bertone, D.G.C, Collar, Odom '07

E.g., for COUPP with CF_3I and C_4F_{10}

(See also Belanger, Nezri, Pukhov '08)



Example: Two targets in COUPP

The detection rate for a given target is a function of the spin-dependent and independent couplings of the WIMP

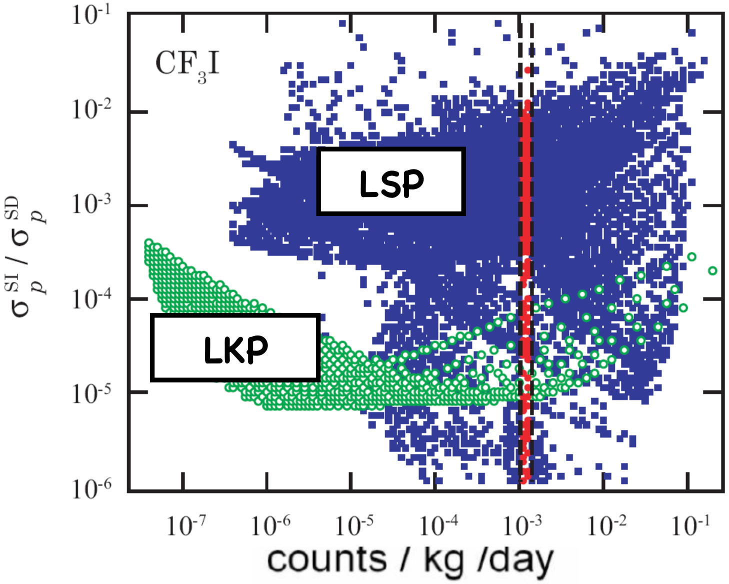
$$R_1 \sim A_1\, \sigma^{SI}_p + B_1\, \sigma^{SD}_p$$

(use WIMP relation among σ^{SD}_n and σ^{SD}_p)

WIMP detection in two complementary targets can be used to discriminate WIMP models

Bertone, D.G.C, Collar, Odom '07

E.g., for COUPP with CF_3I



Taking into account the background

For the inclusion of a background for CDMS we have assumed that the new interleaved detectors will make Surface Electron Recoils a negligible background.

Runs 125-8:	Bulk Electron Recoils	~5x10^{-4}
	Cosmogenic Neutrons	~0.04
	Radiogenic Neutrons	~0.04

from M. Fritts PhD Thesis

Estim. for 333 kg yr of Ge: (in the same site) ~16 Events

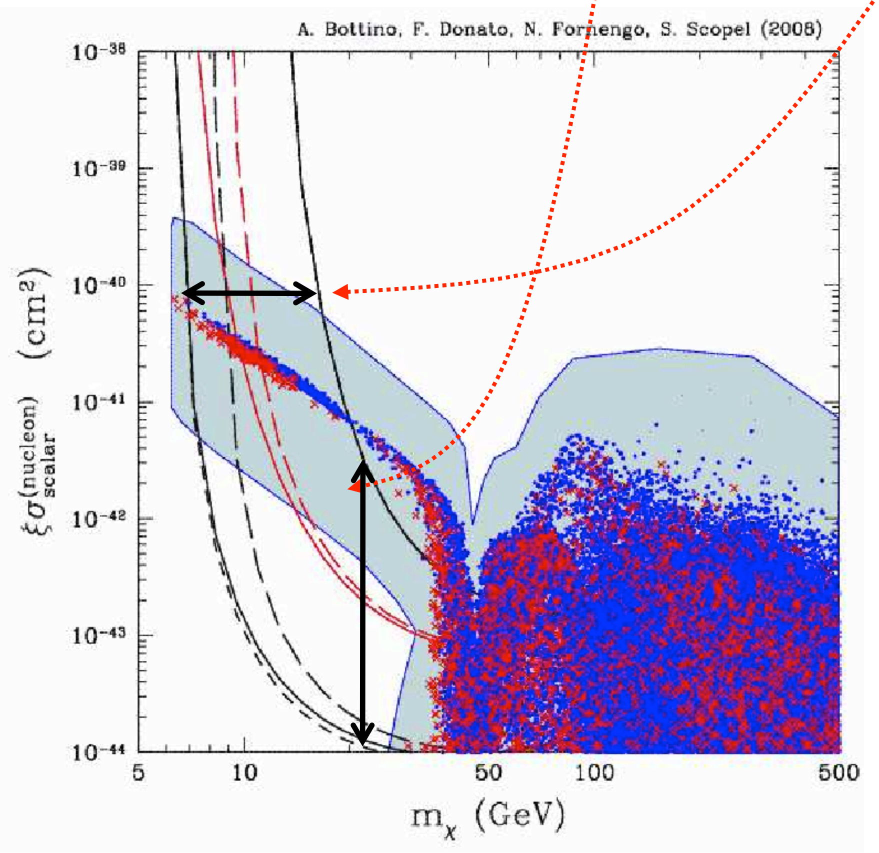
$$\lambda = \epsilon \int_{E_{\rm th}}^{E_{\rm max}} \frac{dR_\chi}{dE} + \frac{dR_{\rm back}}{dE}\, dE$$

Flat (energy-independent) background – conservative choice (worse parameter reconstruction)

For other experiments (Xenon and COUPP) we also assume a factor 10 improvement in the background

Astrophysical uncertainties in direct DM searches

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

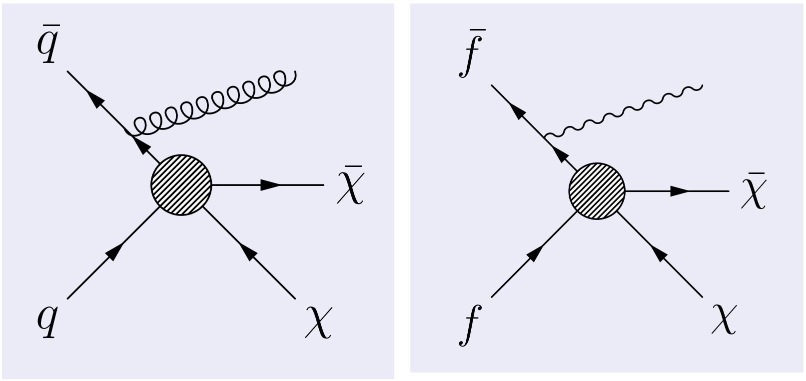

A. Bottino, F. Donato, N. Fornengo, S. Scopel (2008)

Uncertainty in the local density parameter leads to an indetermination of the total scattering cross section

Variations in the velocity distribution factor affect the potential reach for low mass WIMPs and the reconstruction of WIMP mass

Both effects are correlated

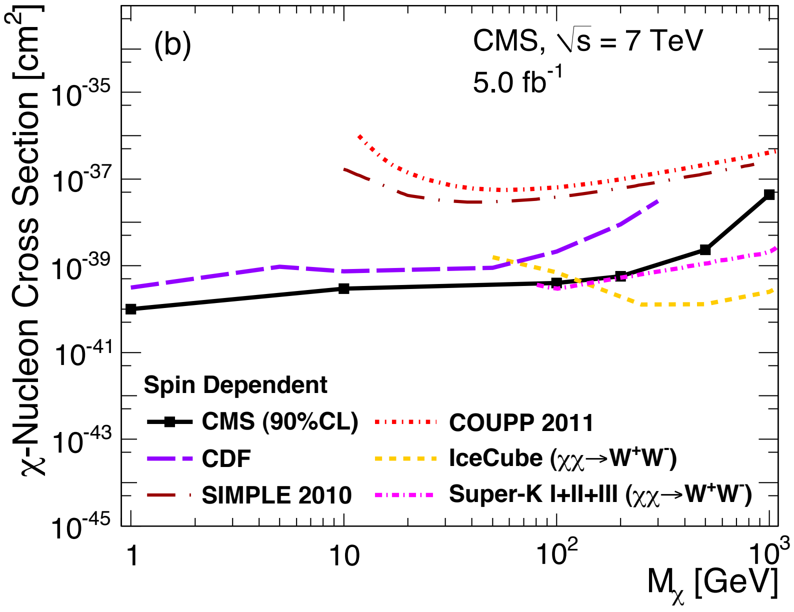
Mono-jet and Mono-γ (plus MET) searches constrain the region of light WIMPs

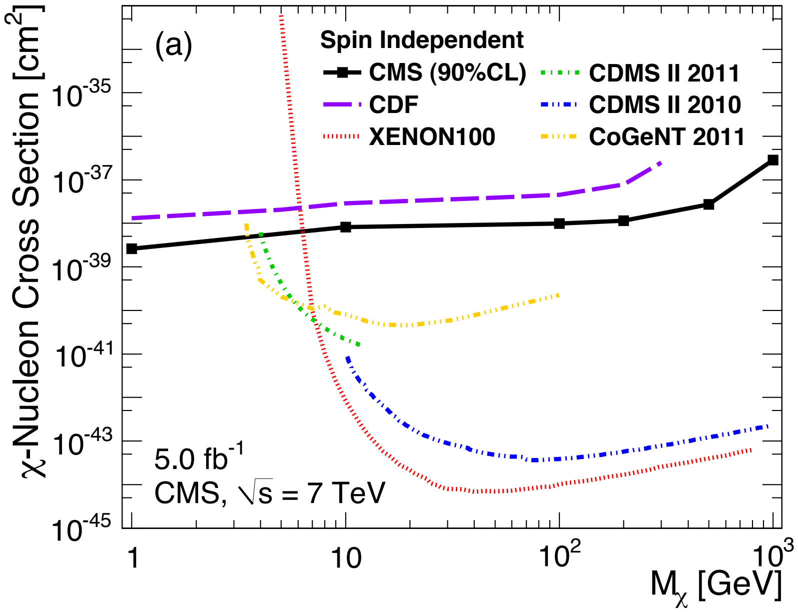


Dark matter production with initial state radiation

Bounds depend on the DM effective operators to fermions

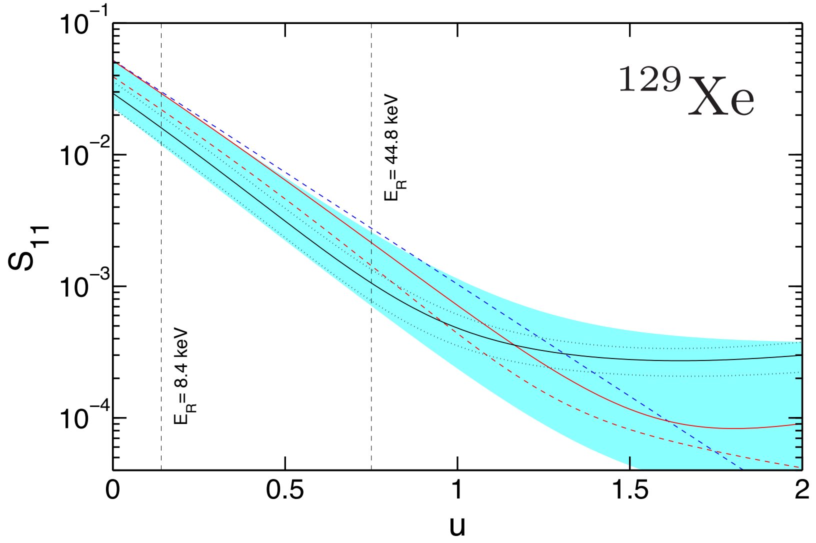
LHC data 2011 (see also previous results from Tevatron)

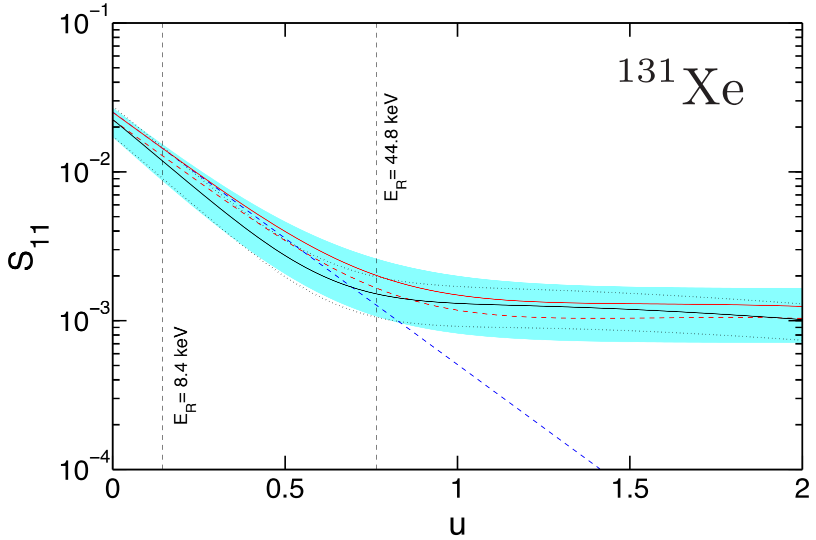


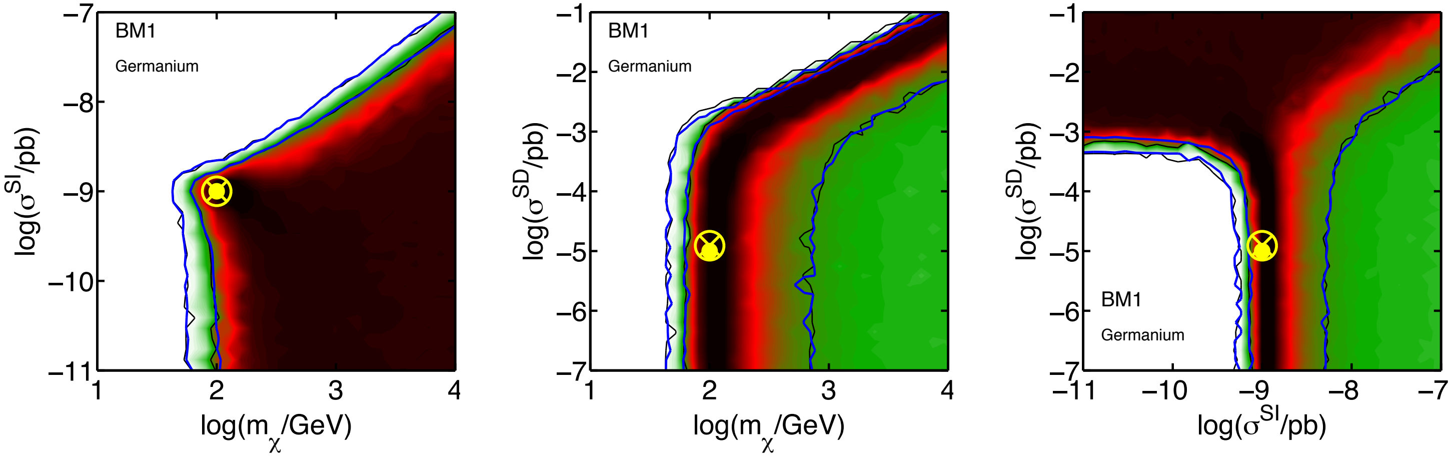


(CMS-PAS-EXO-11-096)

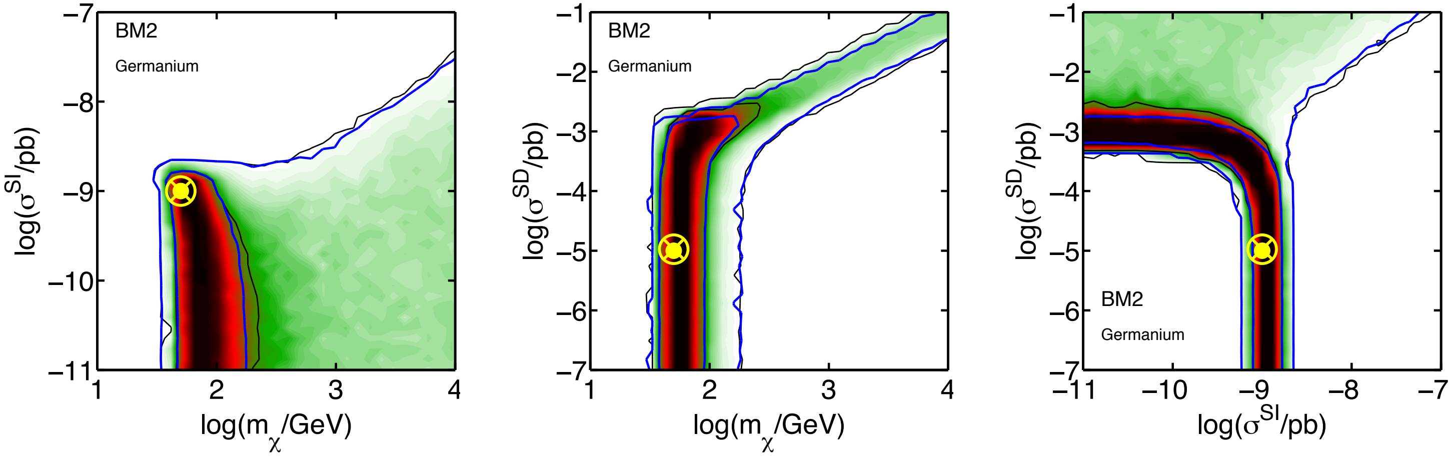
Uncertainties in Xenon SD Structure Functions



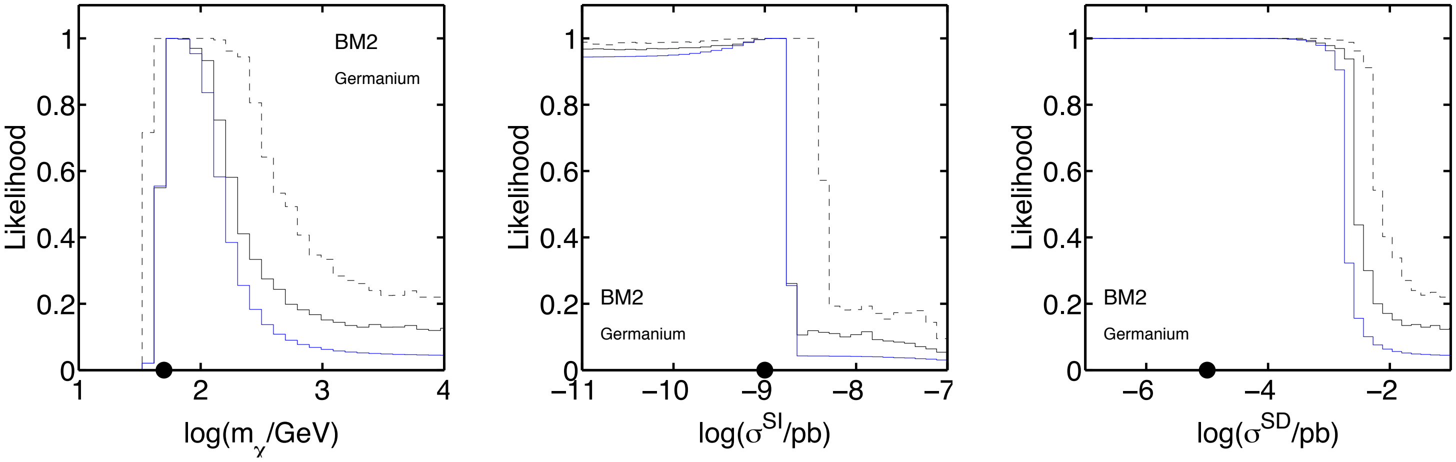




$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$
$$\sigma_0^{SD} = 10^{-5}\,\mathrm{pb}$$
$$m_W = 100\,\mathrm{GeV}$$



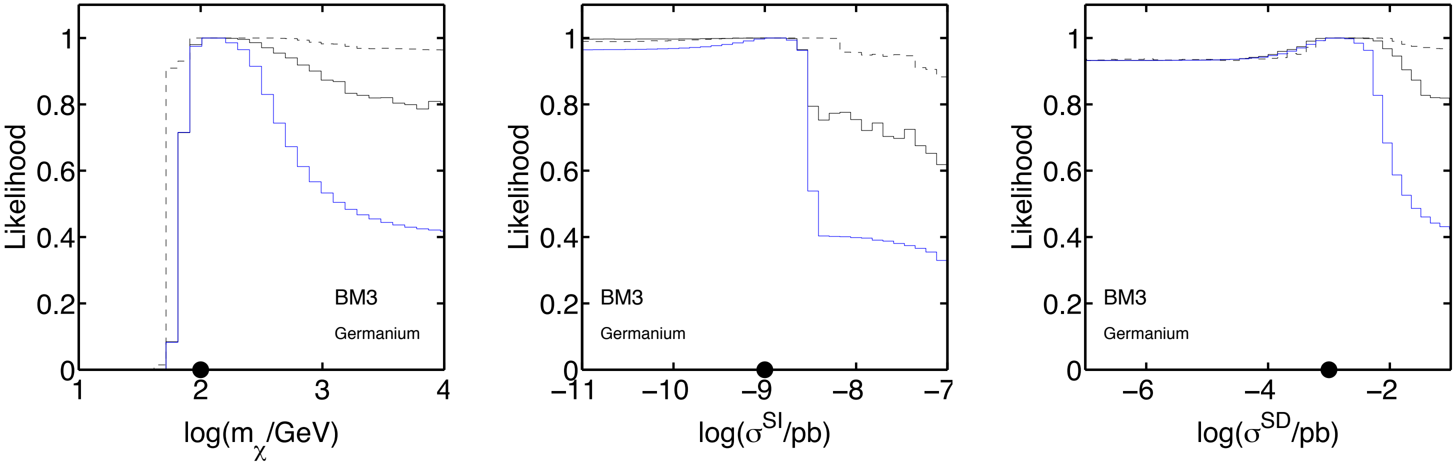
$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$
$$\sigma_0^{SD} = 10^{-5}\,\mathrm{pb}$$
$$m_W = 50\,\mathrm{GeV}$$



$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$

$$\sigma_0^{SD} = 10^{-5}\,\mathrm{pb}$$

$$m_W = 50\,\mathrm{GeV}$$



$$\sigma_0^{SI} = 10^{-9}\,\mathrm{pb}$$

$$\sigma_0^{SD} = 10^{-3}\,\mathrm{pb}$$

$$m_W = 100\,\mathrm{GeV}$$