A review on the discovery reach of directional detection

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Outline

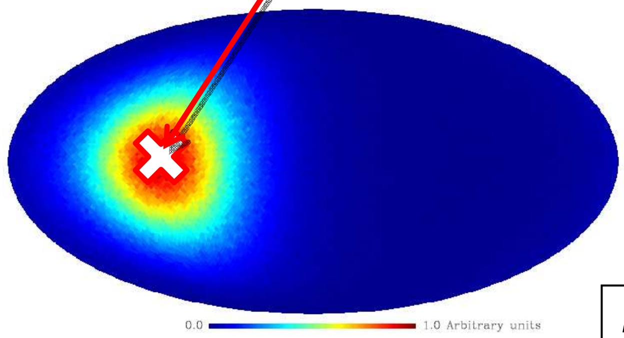
1. Review of the discovery reach of directional detection
   - Exclusion
   - Discovery
   - Identification
2. Interplay with latest LHC results
   - Heavy squarks
   - monophoton/monojet

Directional detection : expected signal

Constellation Cygnus (l = 90°,b = 0°)

WIMP flux
in galactic coordinates

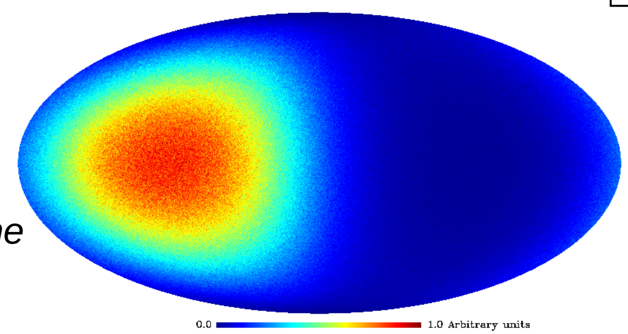
for a standard halo (isothermal and isotropic)



Elastic scattering
100 GeV/c² WIMP

WIMP signal (recoil map)

Angular distribution of Fluorine recoils [5;50] keV



Unambiguous difference between WIMP and background

Background

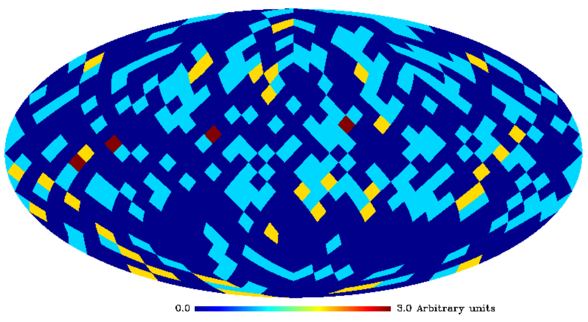
- low number of WIMPs (low exposure)
- large residual background
- poor angular resolution

1. Review of the discovery reach of directional detection

Exclusion

Discovery

Identification



0 WIMP + 300 Bckg

Can we exclude a Dark Matter signal ?

J. Billard *et al.*, PRD 2010

S. Henderson *et al.*, PRD 2008

Exclusion

Best limit on SD interaction (proton)

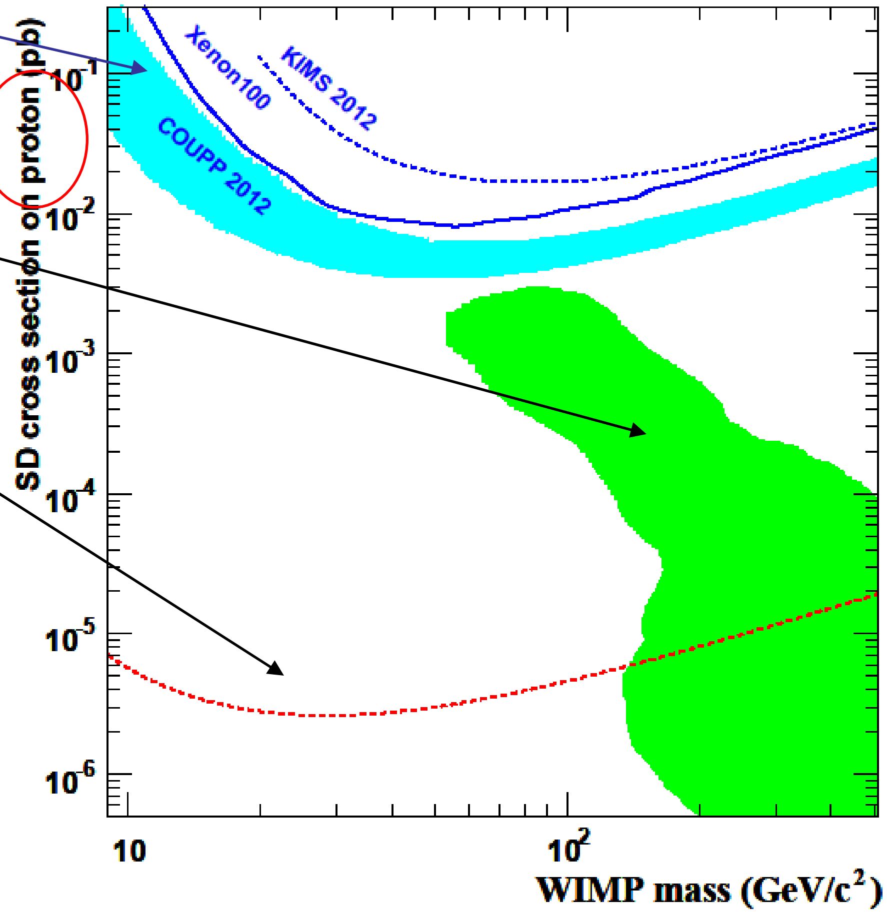
Your preferred SUSY model

Your preferred detector

Result depends on exposure,

residual background level,

threshold, …

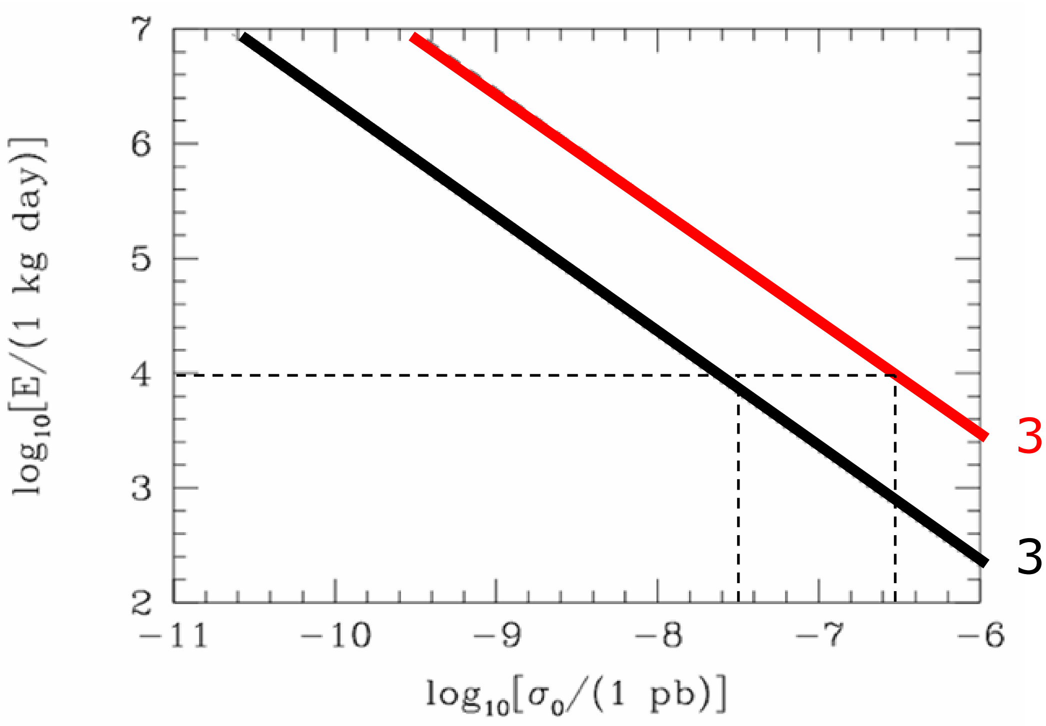


Goal : try to be competitive with ongoing/planned direct experiments devoted to Spin-dependent interaction (on proton)

Isotropy rejection

A. M. Green & B. Morgan, Astropart. Phys. 2007

The exposure required to reject isotropy
(and hence detect a WIMP signal) at 95% CL in 95% of exp.



Study done for a CS_2 target

3D without sense recognition

3D with sense recognition

With ~10^4 kg.days (CS_2) reach ~10^{-7} pb (SI)

1. Review of the discovery reach of directional detection

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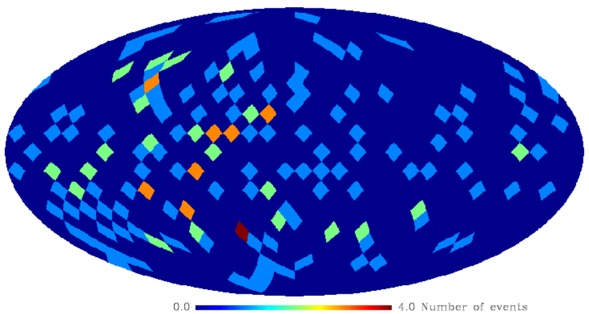


100 WIMPs + 100 Bckg

Can we claim a Dark Matter discovery ?

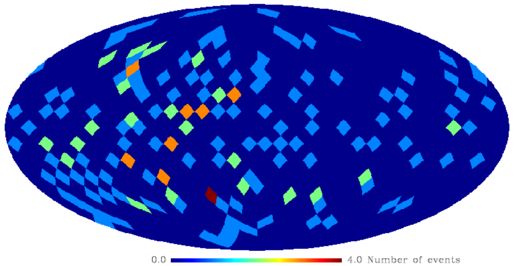
J. Billard *et al.*, PLB 2010, PRD 2012

A.M. Green & B. Morgan, PRD 2010

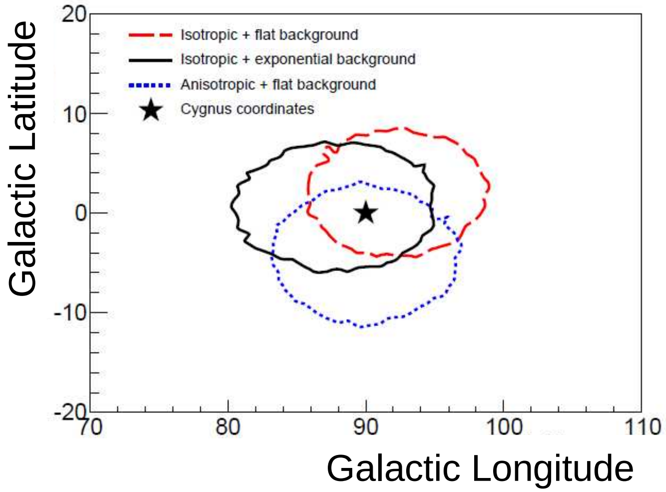
Discovery

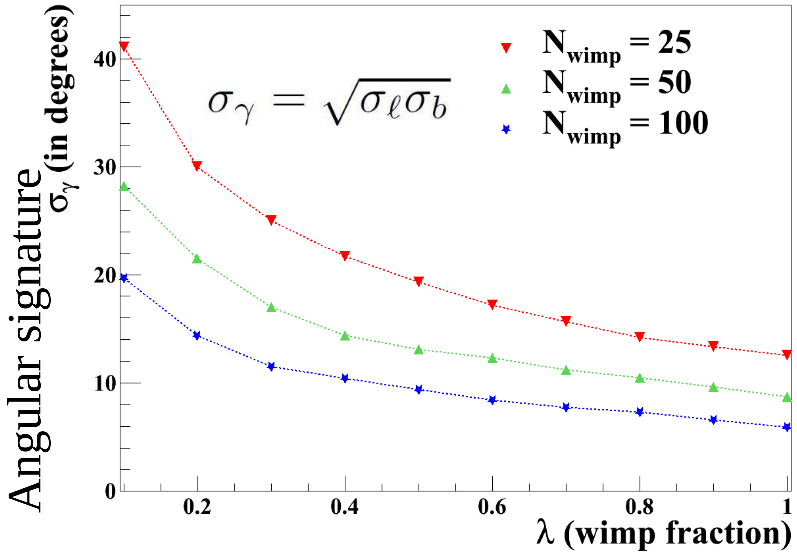
J. Billard *et al.*, PLB 2010, PRD 2012

Directional detection may be used to discover Dark Matter



Blind likelihood analysis





<u>Proof of discovery</u> : signal from Cygnus

Exclusion strategy

↓

Discovery strategy

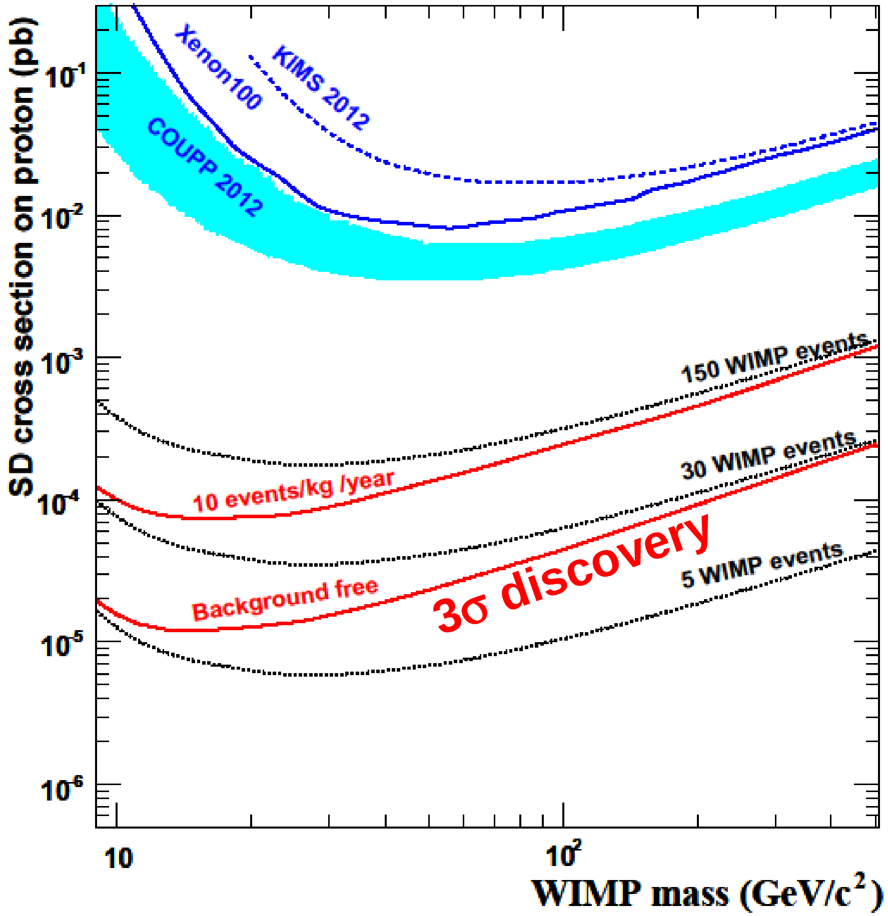
Estimation of the statistical significance…

Discovery

J. Billard *et al.*, PLB 2010, PRD 2012

Estimation of the discovery potential considering astrophysical uncertainties
=> *Profile likelihood method*

Detector characteristics
-10 kg CF_4
- DAQ : 3 years
- Recoil energy range [5, 50] keV



Discovery at 3σ: With BKG (300) / Without BKG

→ Even with a large number of background events, discovery is still possible

→ Only low number of WIMP events are required at low masses

→ ***A discovery (>3σ @90%CL) with BKG*** is possible down to ***10^{-3}-10^{-4} pb***

Discovery

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=> *Profile likelihood method*

J. Billard *et al.*, PLB 2010, PRD 2012

D. Albornoz-Vasquez *et al.*, PRD 2012

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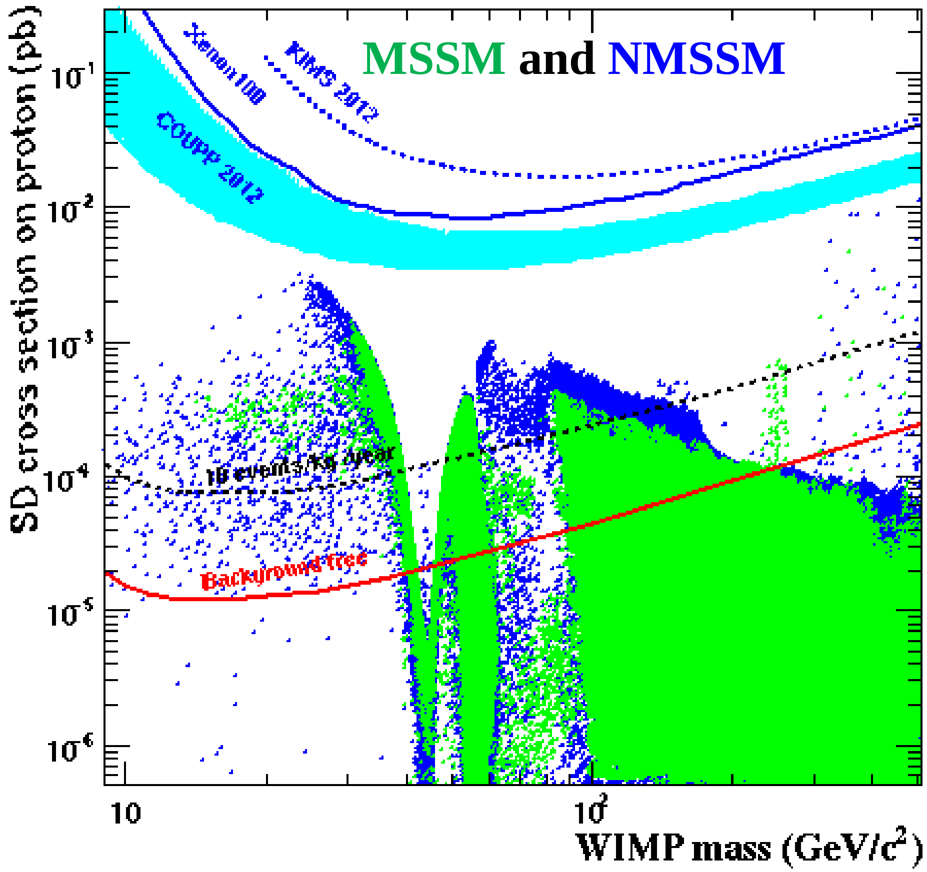

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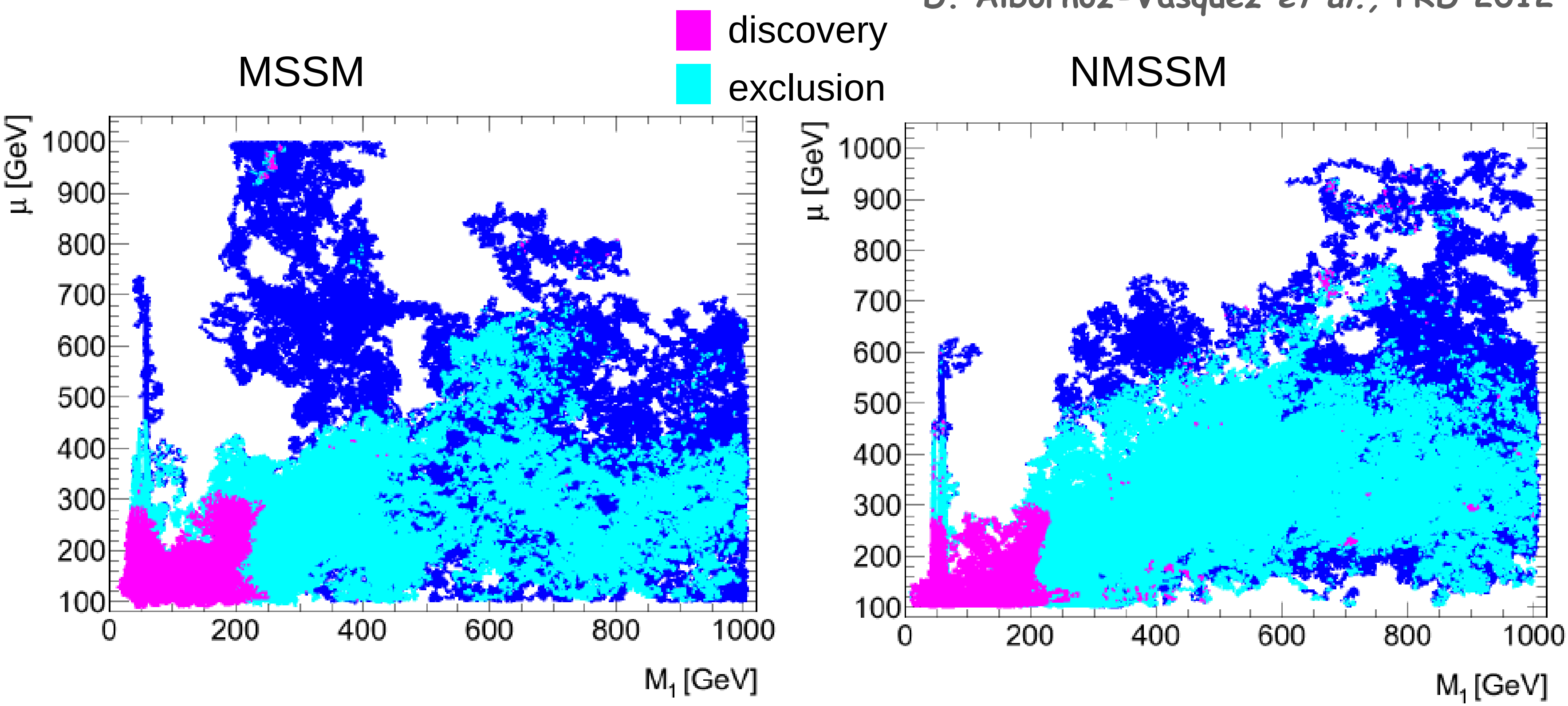
Directional reach in SUSY space

D. Albornoz-Vasquez *et al.*, PRD 2012



- (N)MSSM with 11(12) parameters defined at the weak scale
- Cosmology and Colliders constraints included (before Higgs discovery)

→ low μ and M_1 models would not escape a discovery with a large directional detector (30 kg.year).

Discovery : beyond the standard halo

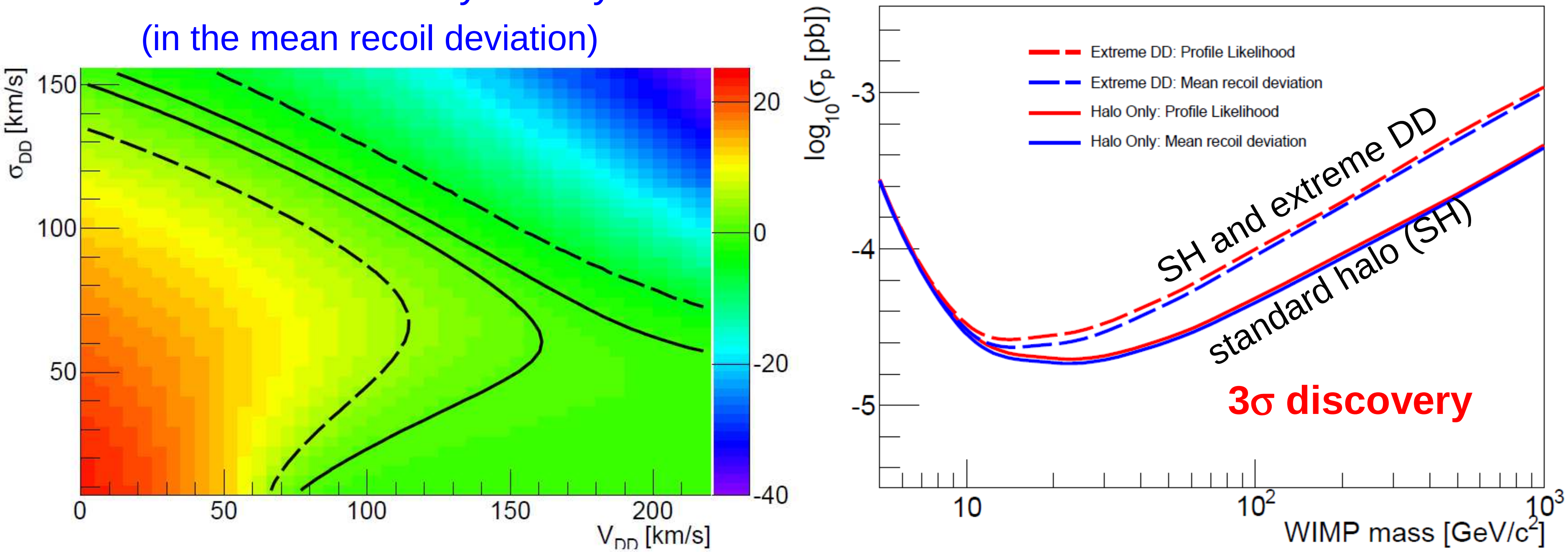
J. Billard *et al.*, PLB 2013

N-body simulations favor a co-rotating Dark Disk (10%-50% of local DM density)

→for a nul lag velocity, Dark Disk Wimps have an isotropic velocity distribution

Relative Asymmetry

(in the mean recoil deviation)



→only extreme Dark Disk parameters may affect the directional signal

→not a threat for directional detection

1. Review of the discovery reach of directional detection

Exclusion

Discovery

Identification

Can we infer Dark Matter properties from directional detection ?

J. Billard *et al.*, PRD 2011

Dark Matter identification

J. Billard *et al.*, PRD 2011

Directional detection may be used to identify Dark Matter

i.e. measure WIMP and halo properties

A Markov Chain Monte Carlo analysis dedicated to directional detection (10^{-3} pb)

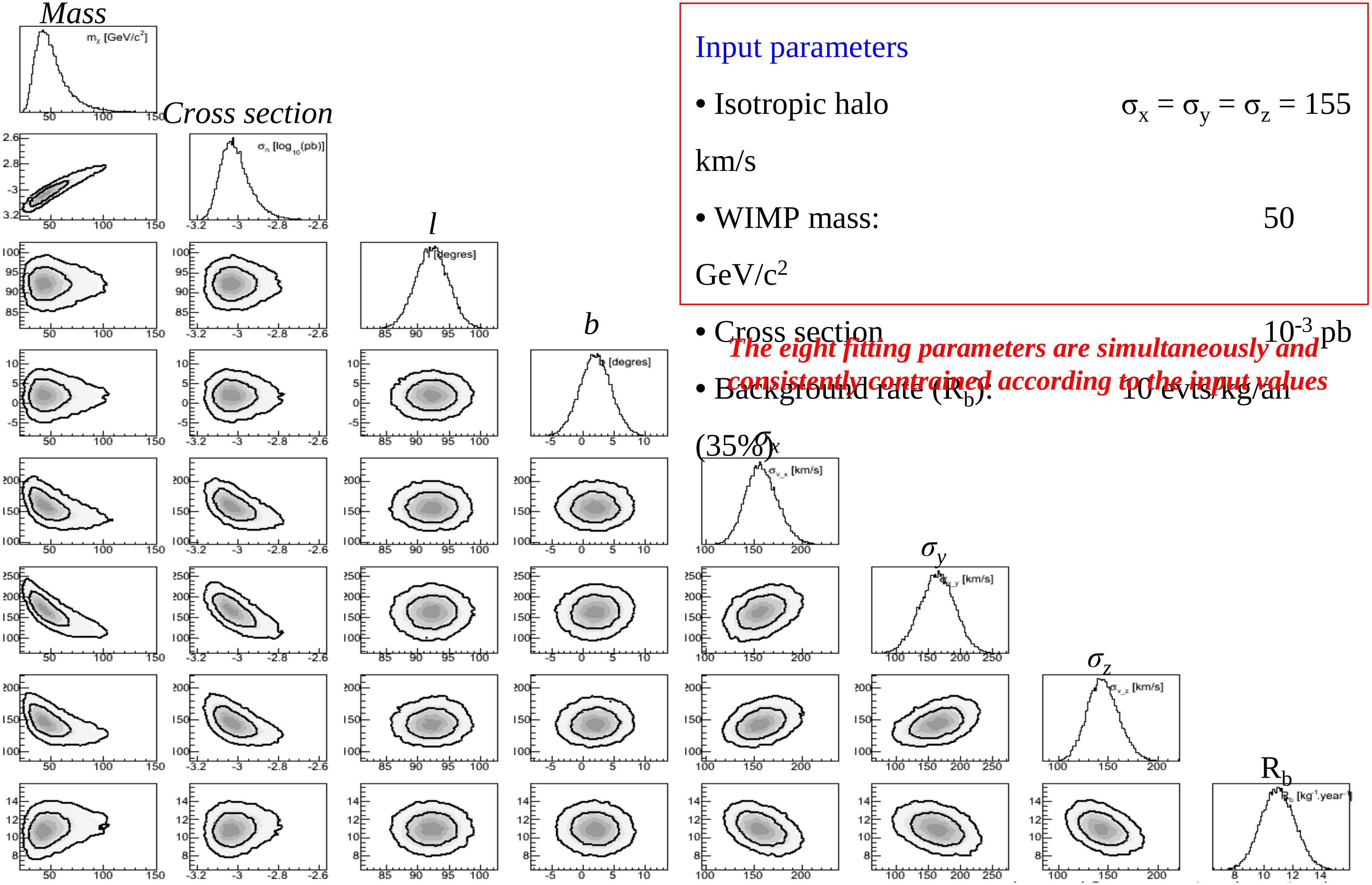
- Multivariate gaussian (triaxial halo)
- Simulated data : CF_4 detector (30 kg.year) + 35% background

- ***Eight free parameters constrain with the same set of directional data***

- The WIMP mass m_X
- The WIMP-nucleon cross section σ_n
- The main direction of the signal (l_O,b_O)
- The three velocity dispersions σ_x, σ_y et σ_z
- The background rate R_b

(WIMP mass and WIMP-nucleon cross section: WIMP properties; main direction of the signal and three velocity dispersions: Halo properties)

Dark Matter identification



Input parameters

• Isotropic halo $\sigma_x = \sigma_y = \sigma_z = 155$ km/s

• WIMP mass: 50 GeV/c^2

• Cross section 10^{-3} pb

• Background rate (R_b): 10 evts/kg/an (35%)

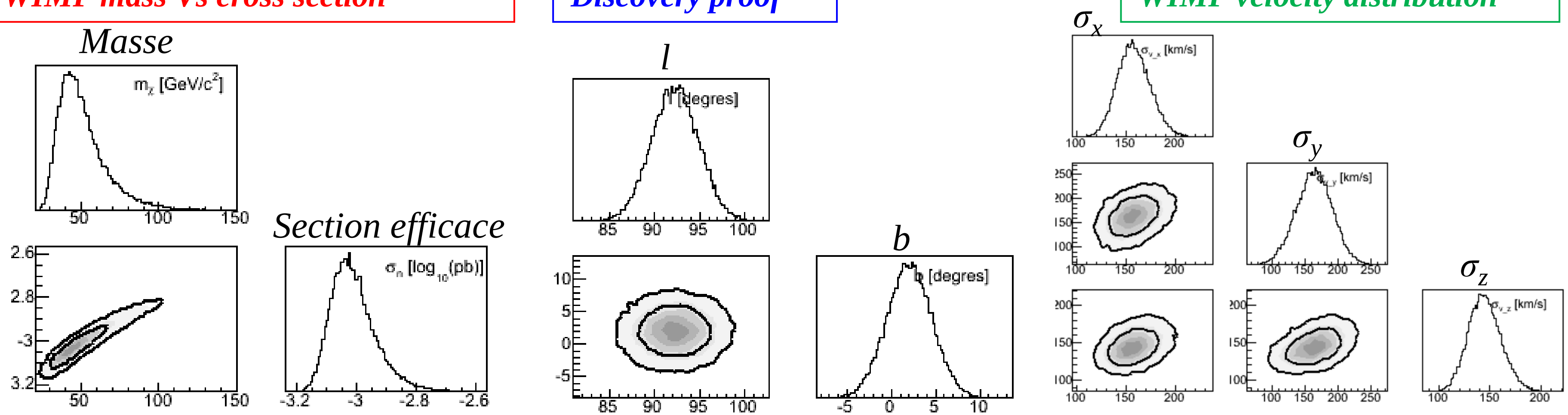
The eight fitting parameters are simultaneously and consistently contrained according to the input values

Dark Matter identification

J. Billard *et al.*, PRD 2011

The eight parameters are strongly constrained with only one directional data set.

WIMP mass Vs cross section | ***Discovery proof*** | ***WIMP velocity distribution***



	m_χ (GeV/c^2)	$\log_{10}(\sigma_n$ (pb))	$\ell_\odot$ (°)	$b_\odot$ (°)	σ_x (km.s^{-1})	σ_y (km.s^{-1})	σ_z (km.s^{-1})	β	R_b (kg^{-1}year^{-1})
Input	50	-3	90	0	155	155	155	0	10
Output	$51.8^{+5.6}_{-19.4}$	$-3.01^{+0.05}_{-0.08}$	$92.2^{+2.5}_{-2.5}$	$2.0^{+2.5}_{-2.5}$	158^{+15}_{-17}	164^{+27}_{-26}	145^{+14}_{-17}	$-0.073^{+0.29}_{-0.18}$	10.97 ± 1.2

Going further : Dark Matter 3D

D. S. M. Alves *et al.*, arXiv1204.5487

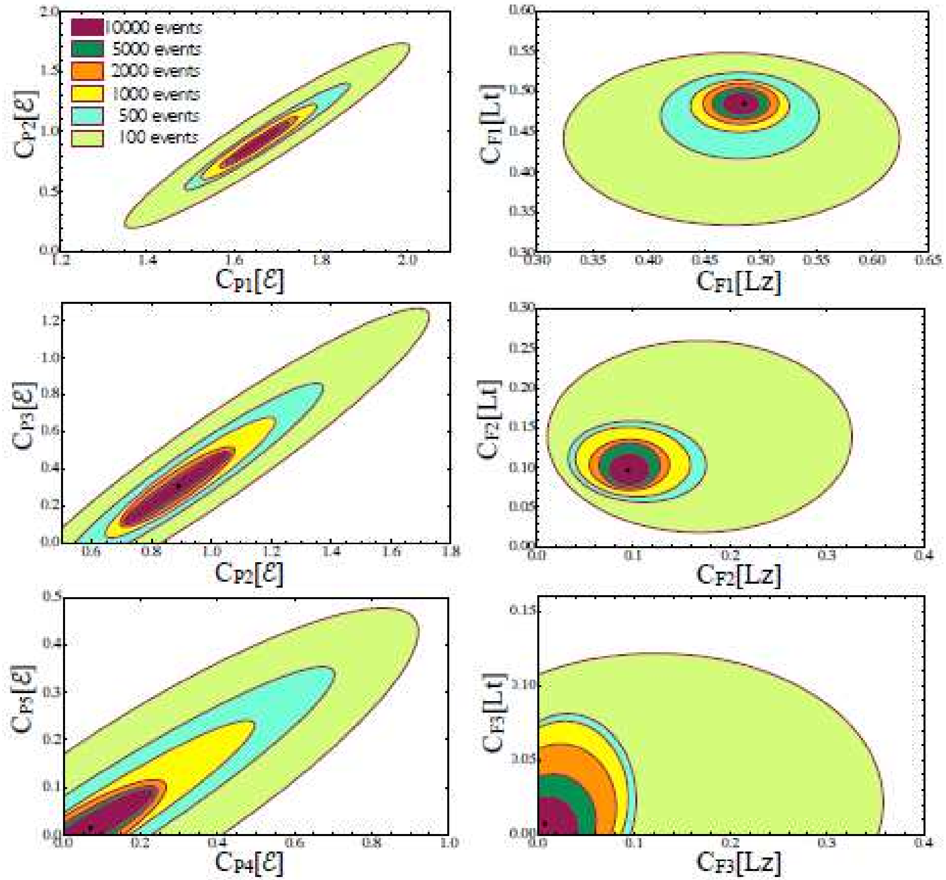
Post-discovery era : the WIMP mass and cross section are supposed to be known
Hence, after LHC discovery and/or other DM exp.

- A generic parametrization of DM distribution
- 3 integrals of motion decomposed on the basis of special functions

$$f_1(\mathcal{E}) = \sum_\ell c_{P_\ell} \tilde{P}_\ell \left(\frac{\mathcal{E}}{\mathcal{E}_{\rm lim}}\right),$$

$$f_2(L_t) = \sum_n c^t_{F_n} \cos\left(n\pi \frac{L_t}{L_{\max}}\right),$$

$$f_3(L_z) = \sum_m c^z_{F_m} \cos\left(m\pi \frac{L_z}{L_{\max}}\right).$$



~1000 events are required for a good measurement of the underlying DM distribution

2. Interplay with latest LHC results

Heavy squarks

monophoton/monojet

Is Xenon100 a threat to directional detection ?

A priori : no ! SD-neutron versus SD-proton, **but…**

D. Albornoz-Vasquez *et al.,* PRD 2012

Is LHC a threat to directional detection ?

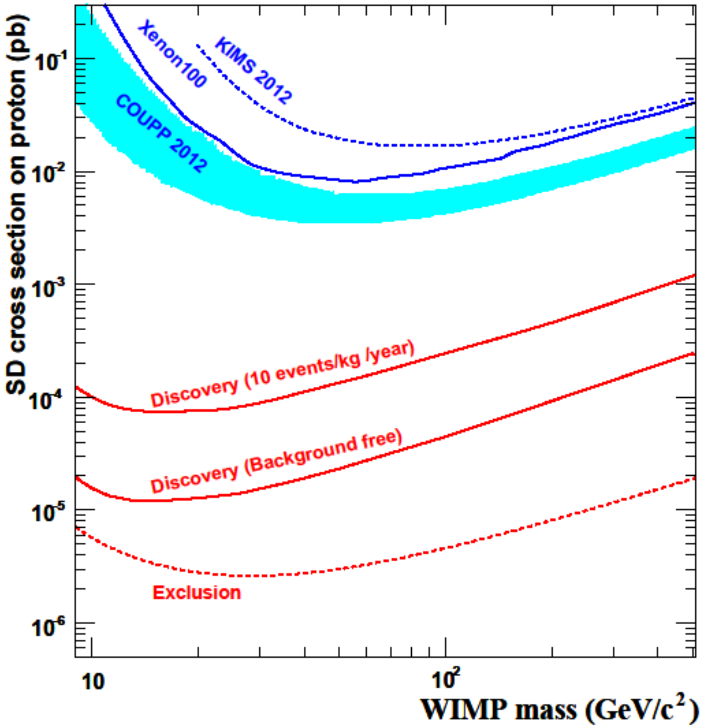
G. Bélanger *et al.,* in preparation

SD interaction

$$\sigma^{SD}(^{A}\mathrm{X}) = \frac{32}{\pi} G_F^2 \times \mu_A^2 \times \frac{J+1}{J} \Big(a_p < S_p > + a_n < S_n > \Big)^2$$

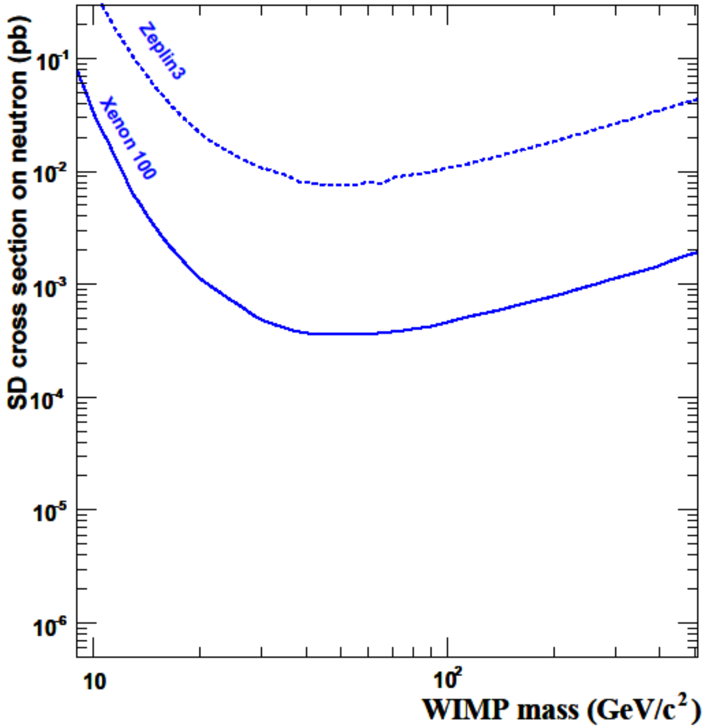
Proton SD interaction (a_n=0)

CF_4 detectors



Neutron SD interaction (a_p=0)

Xenon100, CDMS, Edelweis, ..

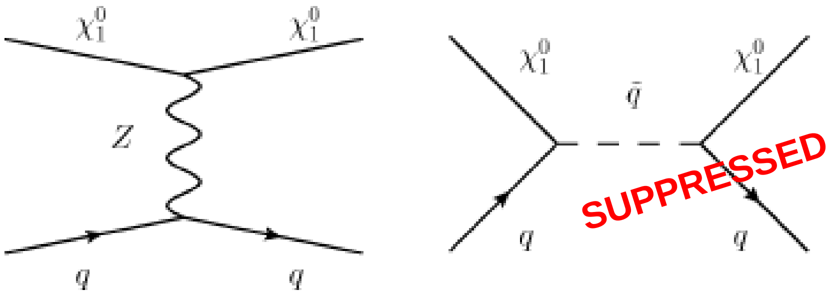


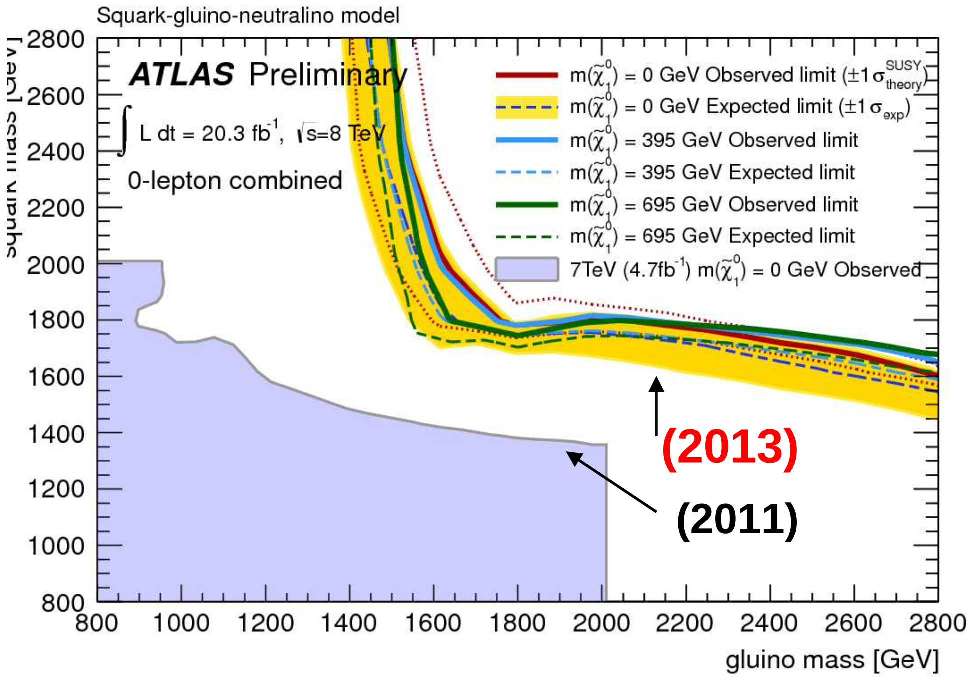
First caveat : model independent treatment requires to consider both cross-sections

D. R. Tovey *et al.*, PLB 2010

Recent results from LHC

ATLAS-CONF-2013-047





simplified phenomenological MSSM

- LHC => Heavy squarks (>TeV)
- Squark exchang diagramm : suppressed
- SD cross section :

→does not depend on quark flavor

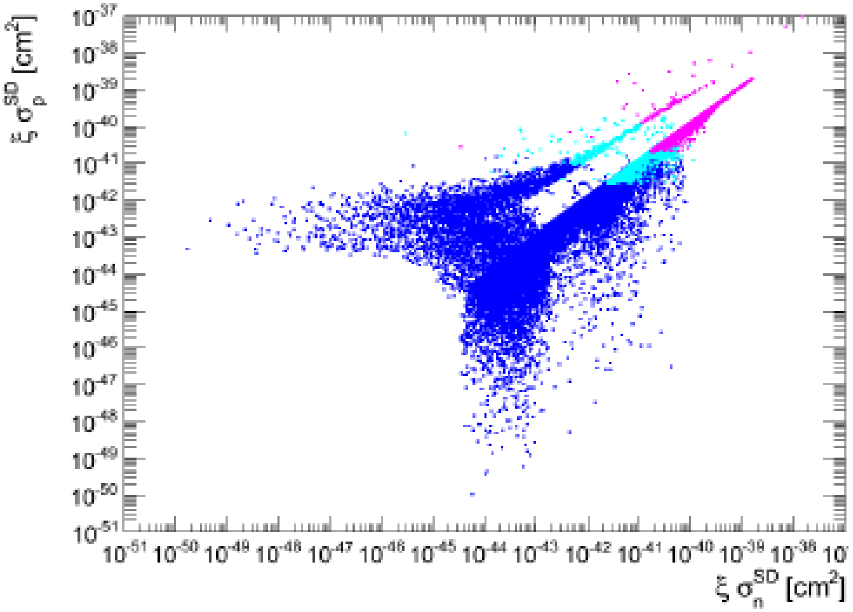
→only on the Z-neutralino coupling

SD cross section should be close ***(and should not depend on SUSY parameters)***

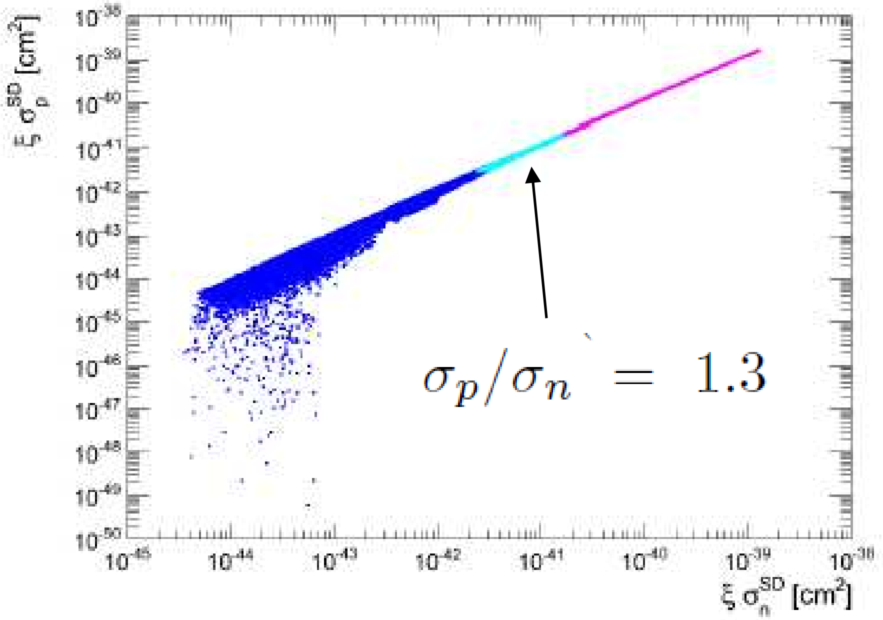
Consequences for Dark Matter

D. Albornoz-Vasquez *et al.*, PRD 2012

MSSM + collider & cosmology contraints



MSSM + … + LHC squark result



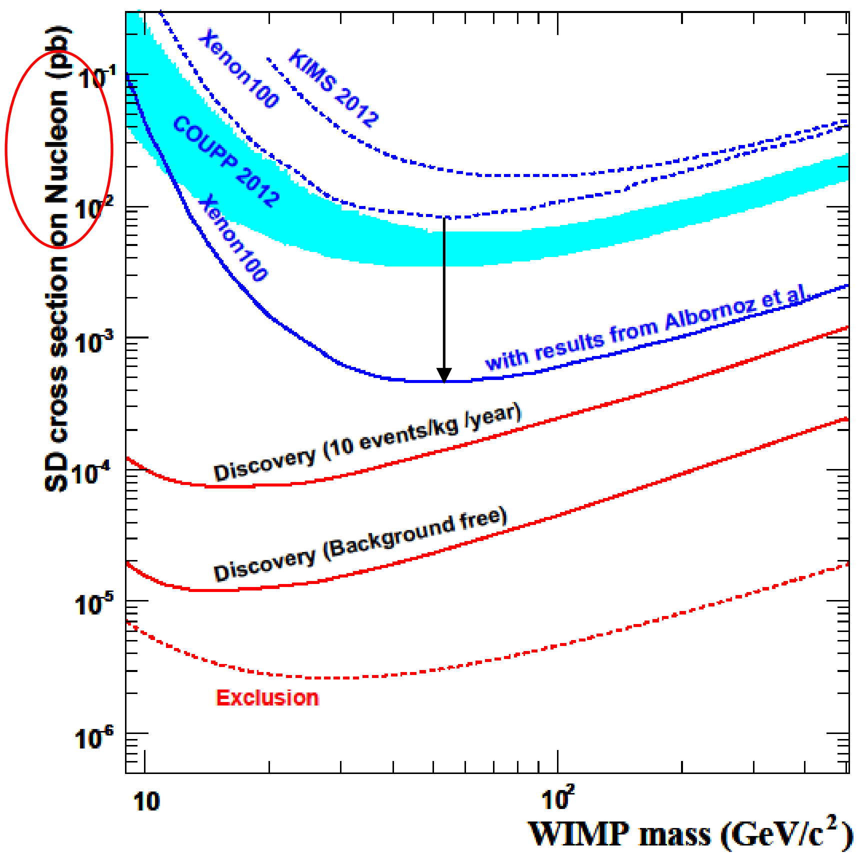
• SD cross-section on p and n can no longer be considered as independent

→All SD results apply to directional detection

e.g. large exposure experiments (Xenon, SuperCDMS, …)

SD interaction on Nucleon

We need to consider SD-nucleon cross section



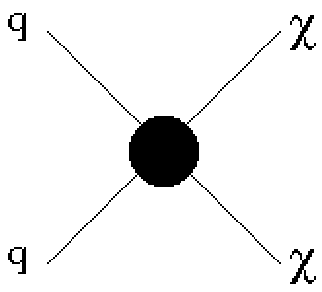
• All SI experiments have a not so small odd-nuclei fraction (^{129,131}Xe, ^{73}Ge, ^{29}Si)

3% in Si, 7% in Ge, 50% in Xe

• Upcoming SI results may close the directionnal window

Other searches : monophoton/monojet @LHC

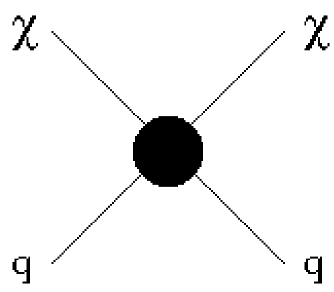
DM pair production



s-channel

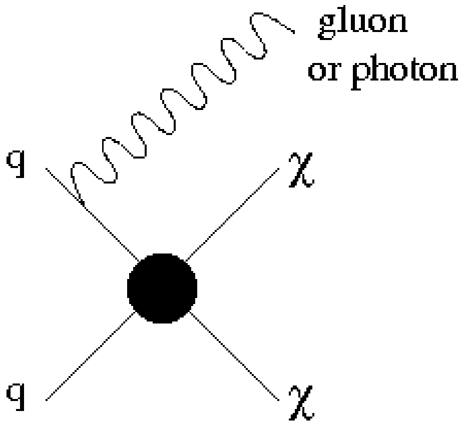
versus

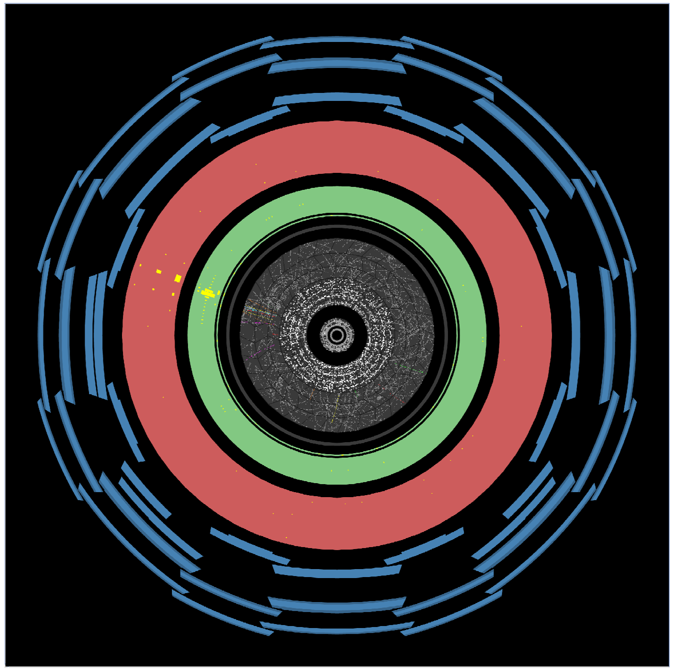
Elastic scatterring



t-channel

golden channel … no signal





make it visible…

→ consider ISR

→ one photon/jet and missing energy

ATLAS $\sqrt{s}$=7 TeV, $\int L\,dt = 4.6\ fb^{-1}$

ATLAS Col., JHEP 2013, PRL 2013

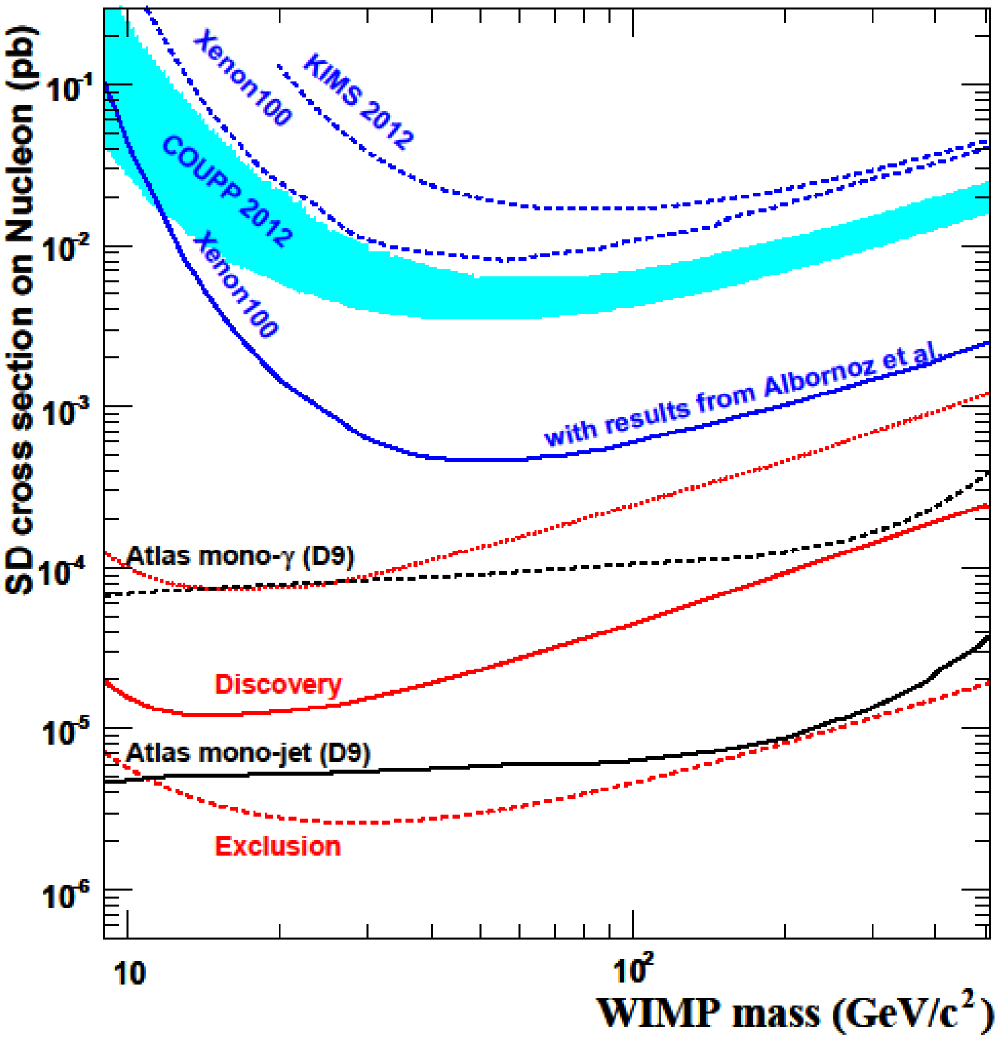
- **Effective theory**

4-fermion interaction *a la Fermi*

Point like interaction = heavy propagator

Question :

Is it really model independent ?



Conclusion

1) A large directional detector (30 kg.year) could lead either to a :

- constraint on DM properties (halo and particle), *~10^{-3} pb*
- conclusive discovery (with a high significance), *10^{-4}-10^{-5} pb*
- competitive exclusion, *10^{-5}-10^{-6} pb*

cannot be achieved by non-directional detectors

2) Most other Dark Matter searches seem to be relevant to the SD-neutron space

- Large exposure SI detectors
- LHC
- Neutrino telescope