Directional detection of Dark Matter

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J. Billard, F. Mayet, J. F. Macias-Perez and D. Santos, **arXiv:0911.4086**

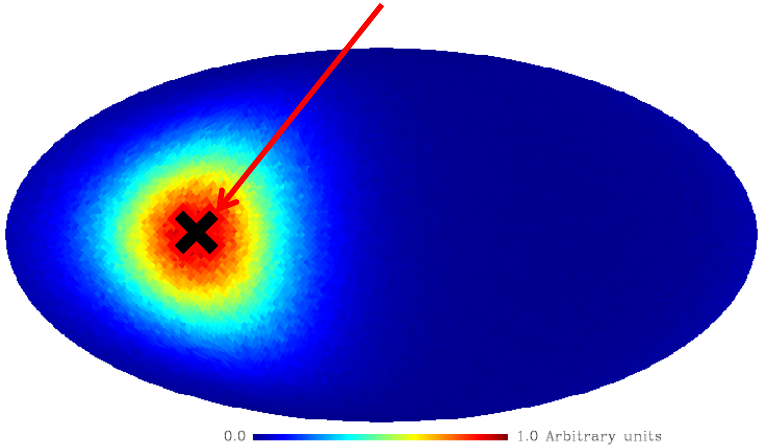
Moriond ElectroWeak 2010

I. Why a directional detection?

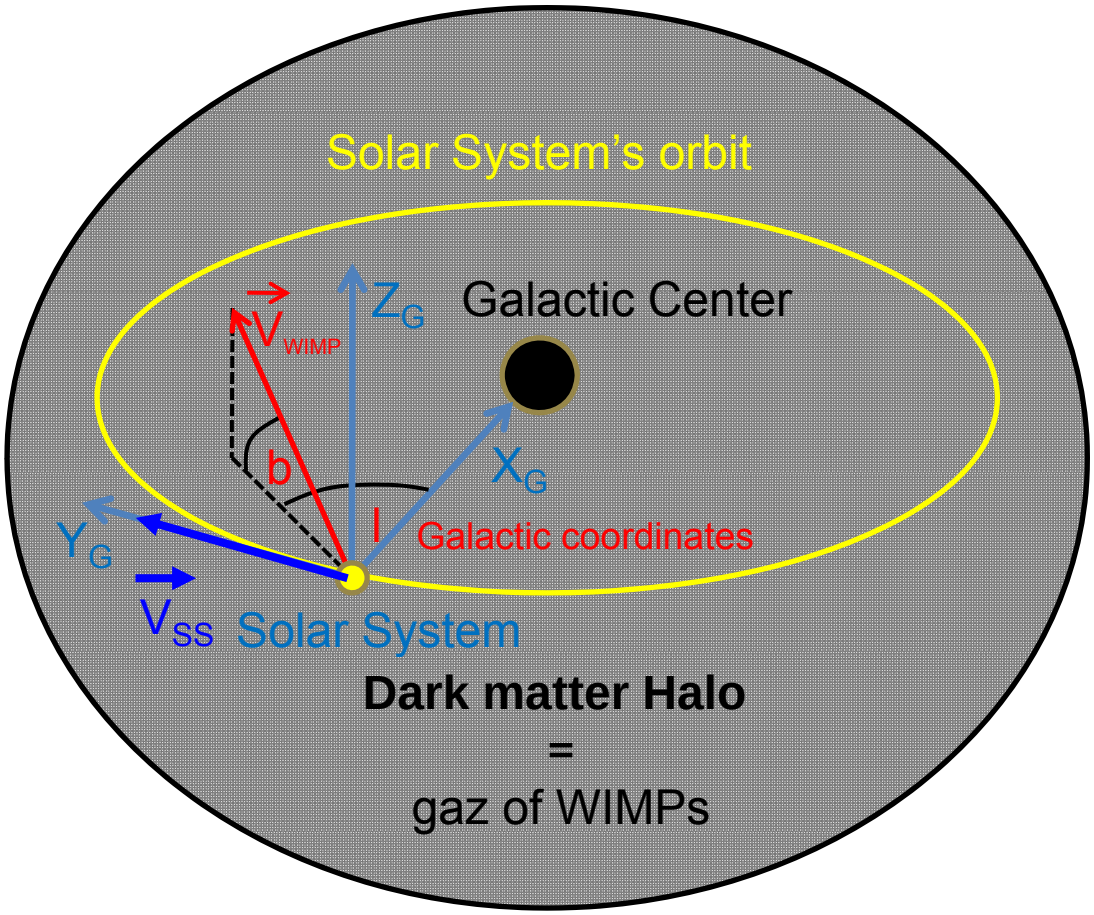
Directional detection is a direct detection of dark matter which is also interested in the recoil direction distribution

WIMPs should mainly come from the direction to which points $\vec{v}_{SS}$, i.e. :

Cygnus Constellation (l = 90°,b = 0°)



WIMP flux entering a terrestrial detector represented in Galactic coordinates



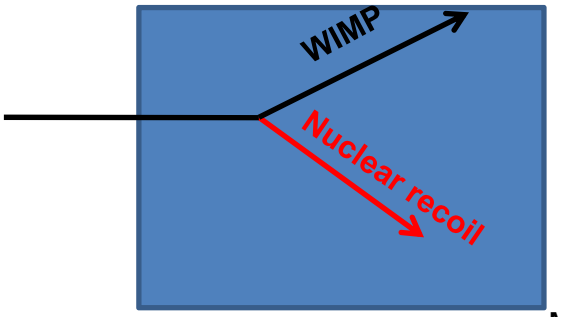
Representation of the Milky Way

II. WIMP signal

Directional detectors aim at measuring the WIMP induced recoil with :

- Gaseous detectors and TPC
- High background rejection
- Low treshold

Elastic scaterring



- Recoil direction
- Track length
- Energy

- *3D track reconstruction*
- *Sens recognition*

Current projects: **MIMAC**, DRIFT, DM-TPC and NEWAGE

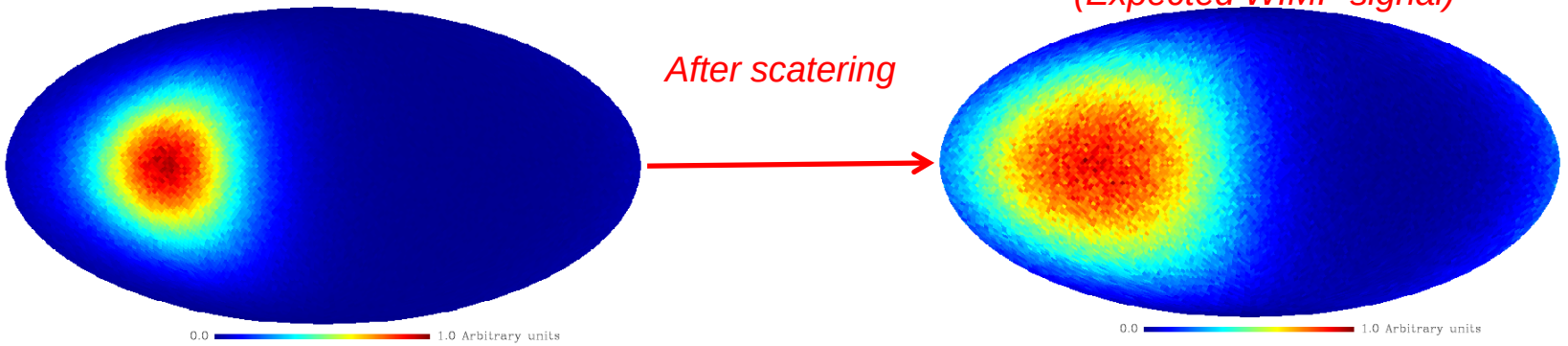
More details: S. Ahlen *et al., International Journal of Modern Physics A25 (2010)*

WIMP flux

WIMP induced recoil distribution

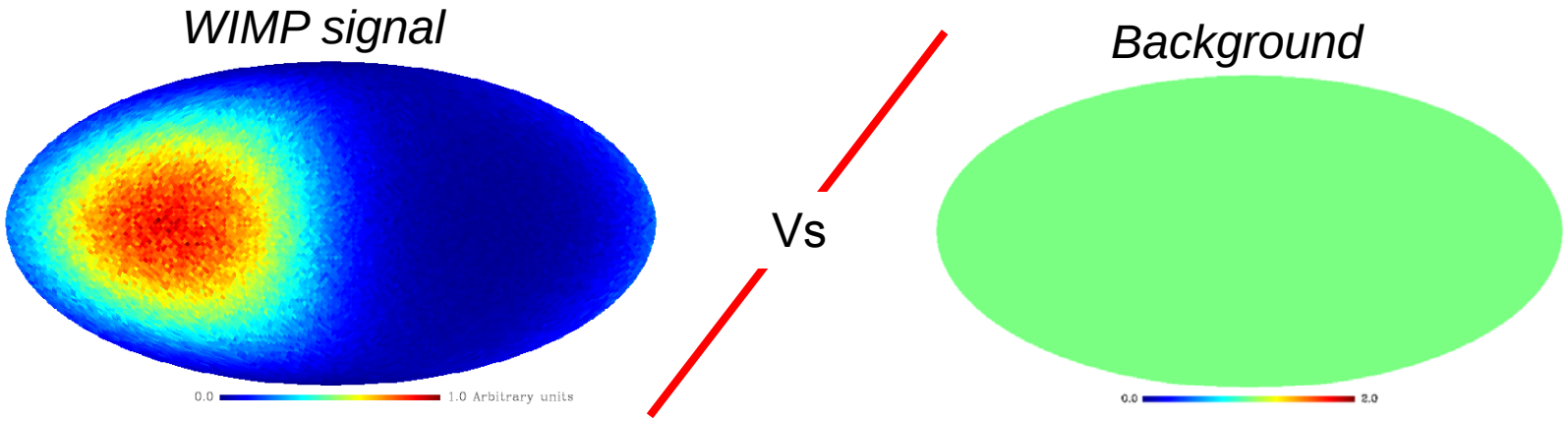
(Expected WIMP signal)

After scatering



III. Interest of the directional detection

Background is supposed to be isotropic



Clear and unambiguous difference between WIMP signal (left) and background (right)

Background hypothesis should be rejected at high CL even with a low number of WIMP events:

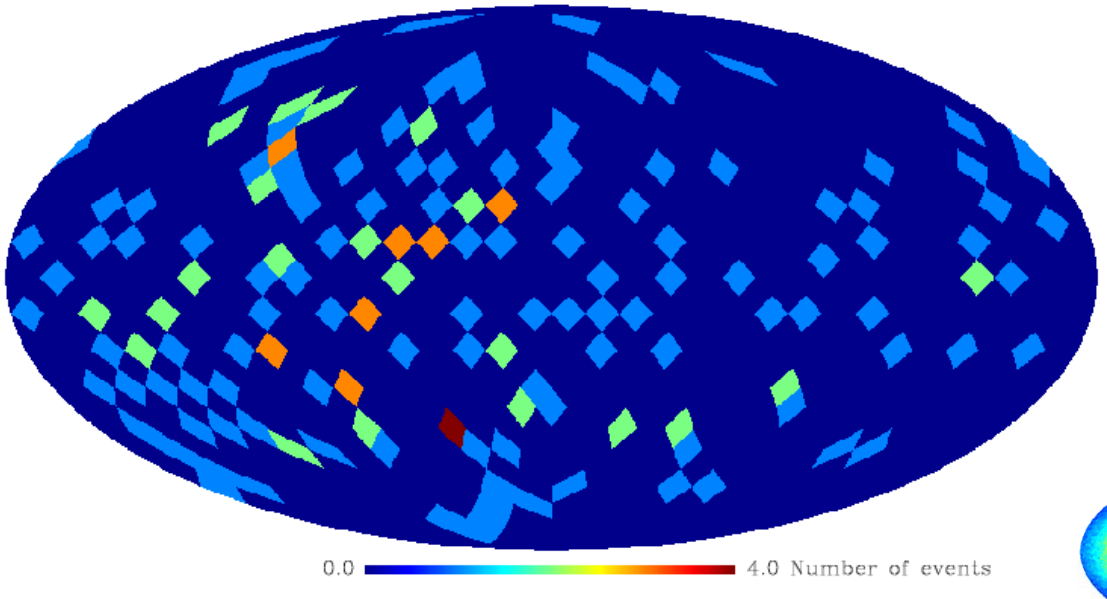
Ref: A. Green and B. Morgan, Astropart. Phys. **27** (2007) 142, …
L. Krauss and C. J. Copi, Phys. Rev. D **63** (2001) 043507, …

But, is it possible to clearly identify a genuine WIMP signal even at low exposure and with an important background contamination?

IV. A typical measurement of upcoming directional detectors

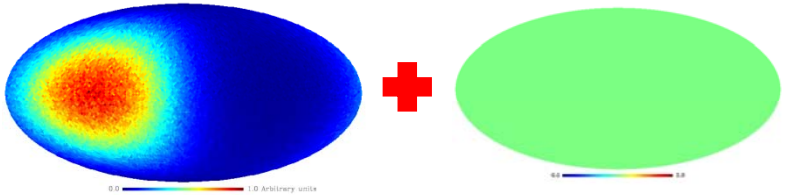
Characteristics of directional data

-Low number of WIMP events
-Eventually, a large background fraction
-Rather low angular resolution



Simulated Data

-10 Kg CF4 during 5 months
-A 1.5×10^{-3} pb SD WIMP cross-section
-WIMP mass of 100 $GeV.c^{-2}$
-100 WIMP
-100 Background events (after non nuclear recoils rejection)
-Angular resolution: 15° (FWHM)



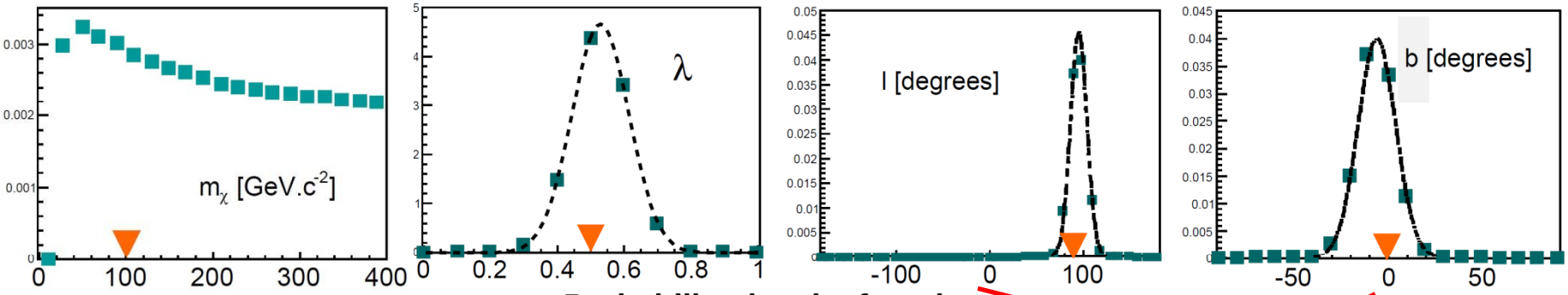
What can we conclude from such a measurement ?

A careful data analysis strategy is needed…

V. A map based likelihood analysis

$$\mathscr{L}(m_\chi, \lambda, \ell, b)$$

$$\lambda = S/(B+S)$$



Probability density functions

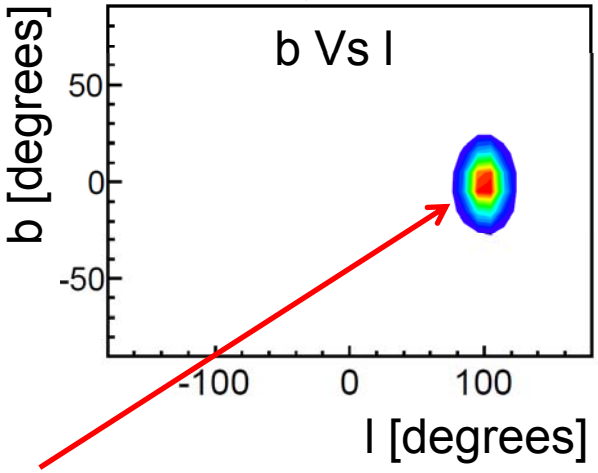
Likelihood analysis

WIMP mass: $m_\chi > 10$ GeV.c^{-2}

WIMP fraction: $\lambda = 0.53 \pm 0.085$ (1σ CL)

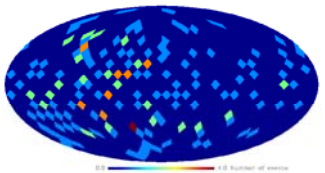
Galactic latitude: $l = 95^\circ \pm 10^\circ$ (1σ CL)

Galactic Longitude: $b = -6^\circ \pm 10^\circ$ (1σ CL)



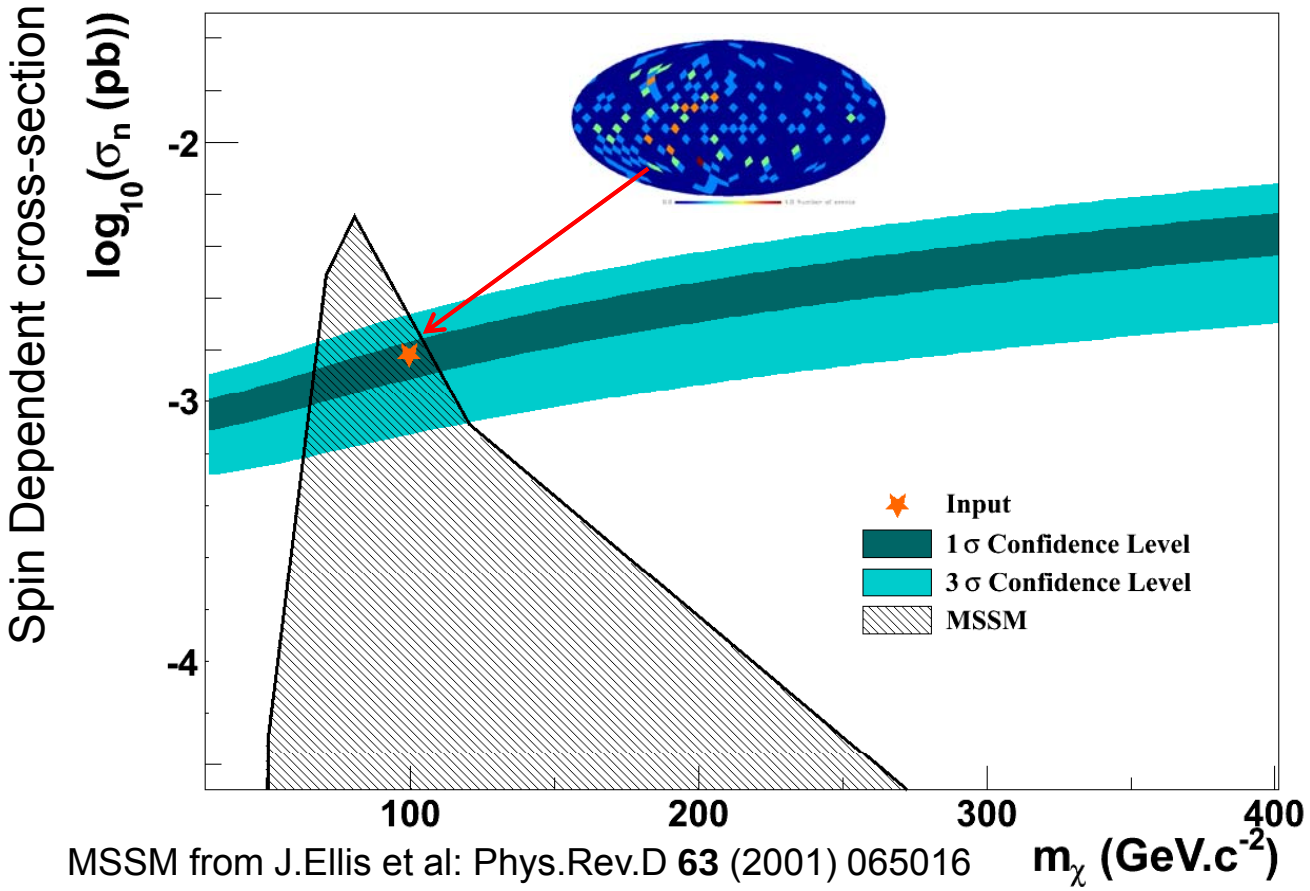
Conclusions of the map analysis:

- The signal is pointing toward the Cygnus Constellation within 10° (68% CL)
- $N_{WIMP} = 106 \pm 15$ (68% CL)



VII. Constraining the WIMP mass and cross-section

Constraint on the λ parameter also implies a constraint on the WIMP-nuleon cross-section:



MSSM from J.Ellis et al: Phys.Rev.D **63** (2001) 065016

Allowed regions deduced from the likelihood analysis

Conclusion

To conclude,

- Directional detection is an interesting way to distinguish WIMP events from background ones

- Using this presented analysis tool, we can identify a galactic WIMP signal rather than rejecting the background hypothesis

- This analysis tool is ready to be applied on any upcoming data!

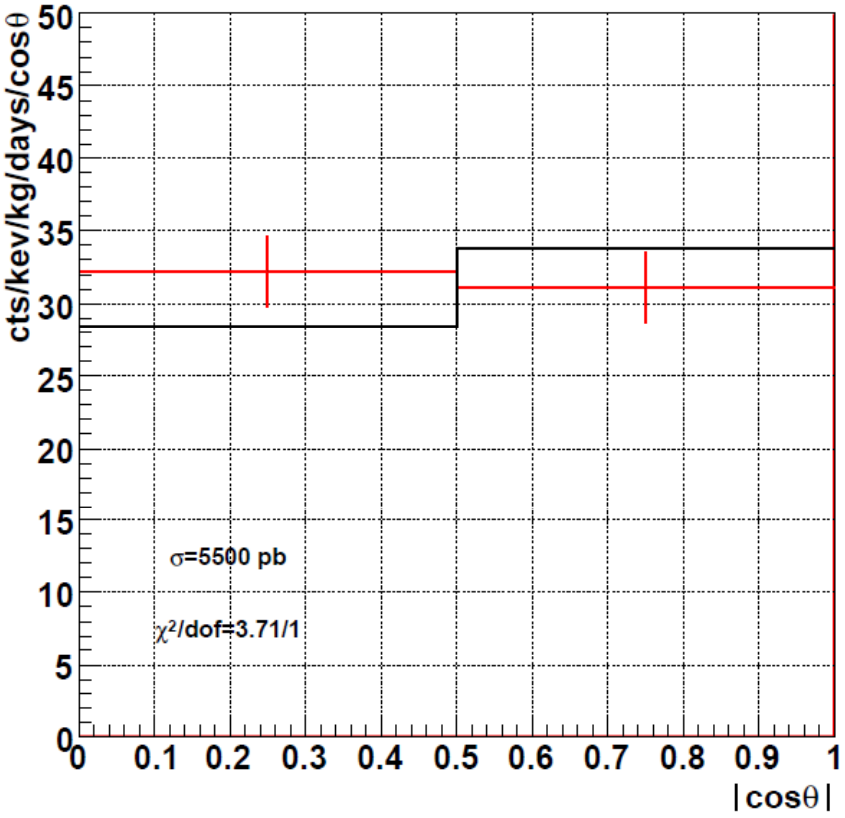
- Systematic studies have shown that this method gives satisfactory results on a large range of exposures and background contaminations.

Thank you for your attention

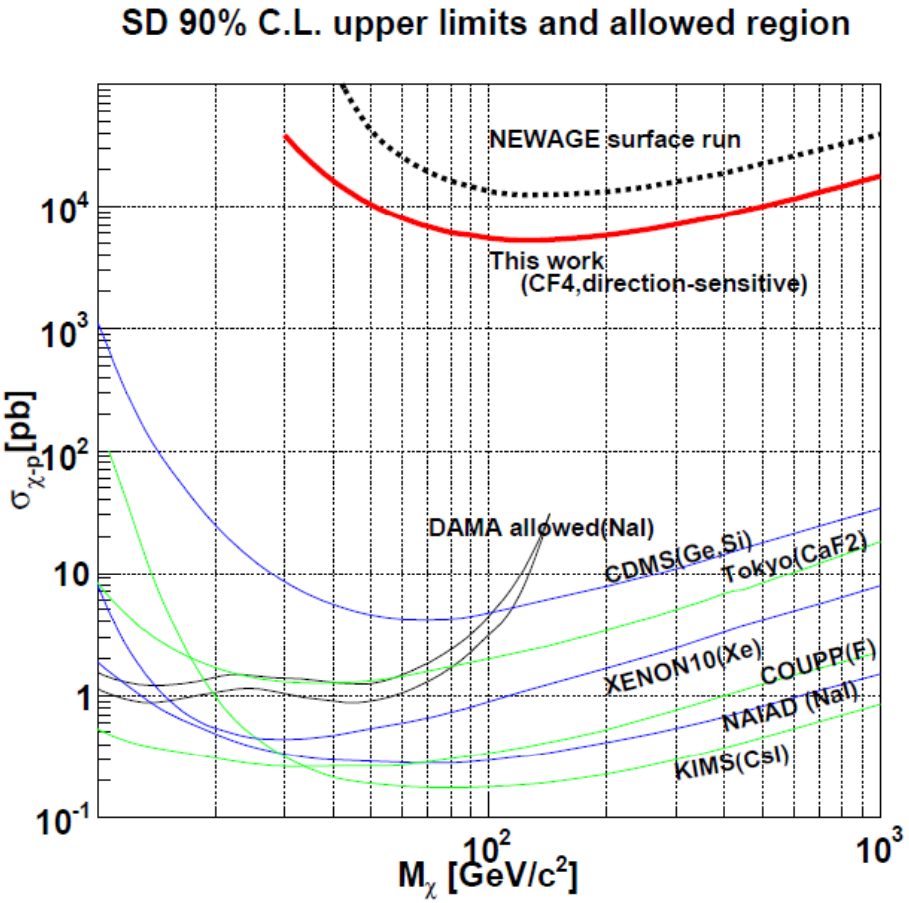
More details in : arXiv:0911.4086

Backup slides

Exlusion limit for SD interaction



NEWAGE results



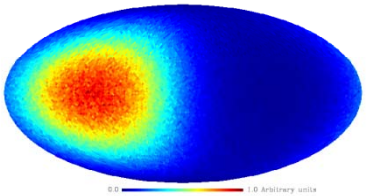
Exclusion limits for different SD sensitive experiments

Likelihood definition

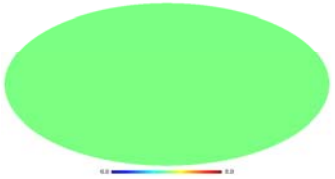
$$\mathscr{L}(m_\chi, \lambda, \ell, b) = \prod_{i=1}^{N_{\rm bins}} P([(1-\lambda)B_i + \lambda S_i(m_\chi; \ell, b)]|M_i)$$

P is evaluated using a Poissonian statistic

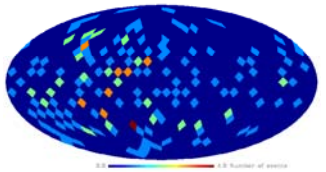
C: Theoretical WIMP signal
B: Background signal (isotropic)
M: Measurement



C



B



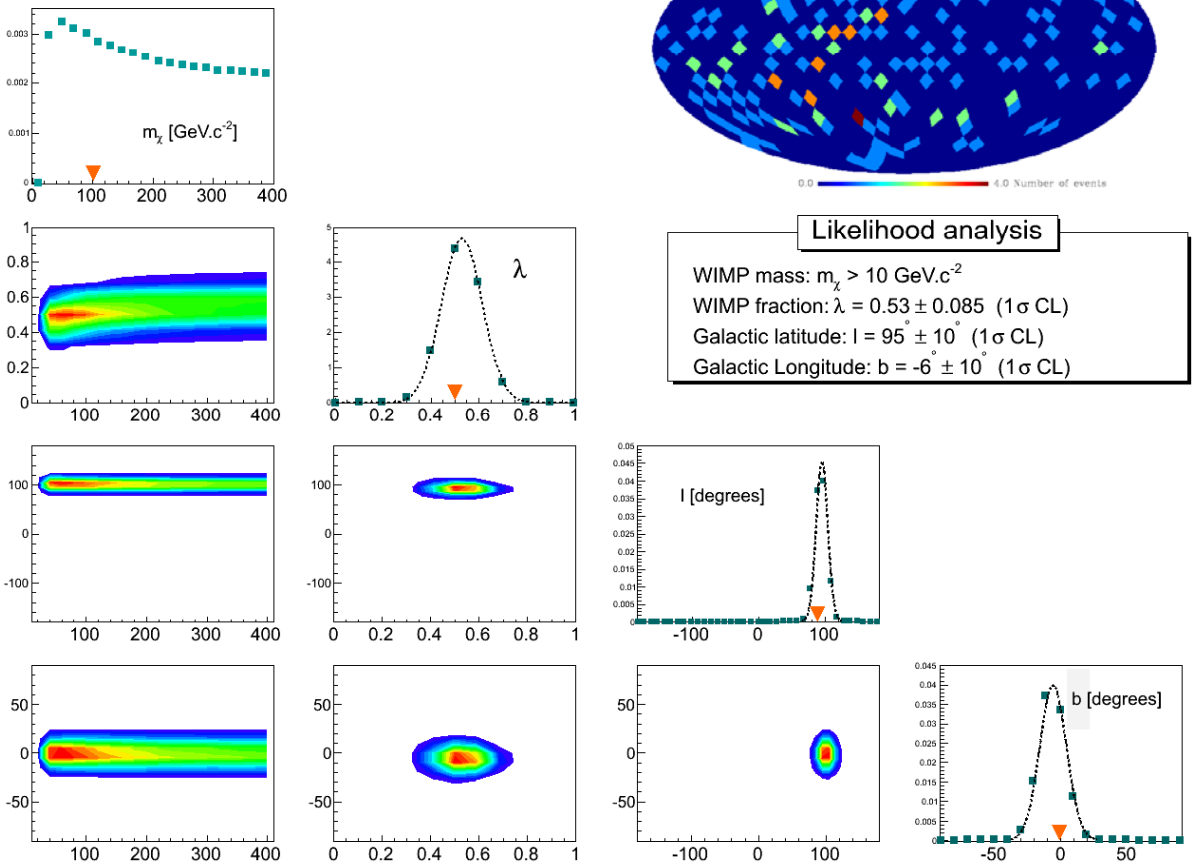
M

- Needs a carefull rotation of the theoretical WIMP signal: $S(m_\chi; \ell, b)$
- The WIMP fraction parameter is defined as: $\lambda = S/(B+S)$

Likelihood analysis result

$$\mathscr{L}(m_\chi, \lambda, \ell, b) = \prod_{i=1}^{N_{\mathrm{bins}}} P([(1-\lambda)B_i + \lambda S_i(m_\chi; \ell, b)]|M_i)$$

P is calculated using Poissonian statistics



Likelihood analysis

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WIMP fraction: $\lambda = 0.53 \pm 0.085$ (1σ CL)
Galactic latitude: $l = 95^\circ \pm 10^\circ$ (1σ CL)
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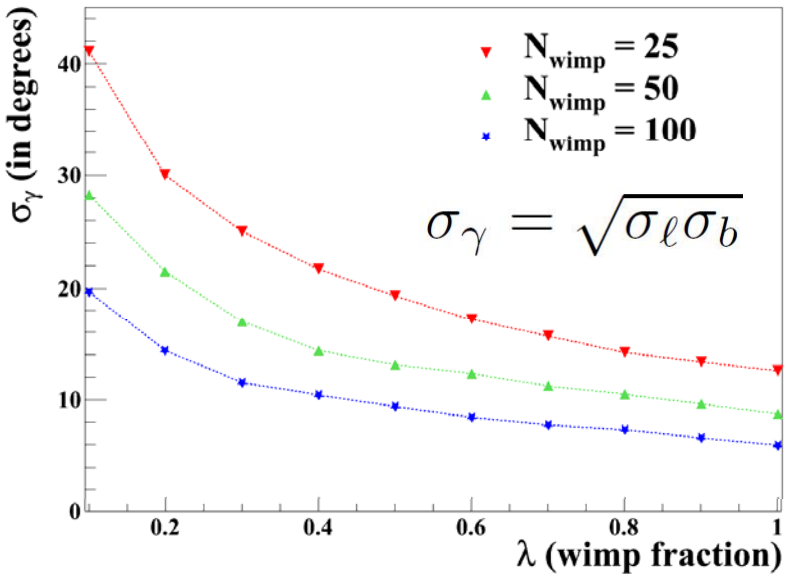
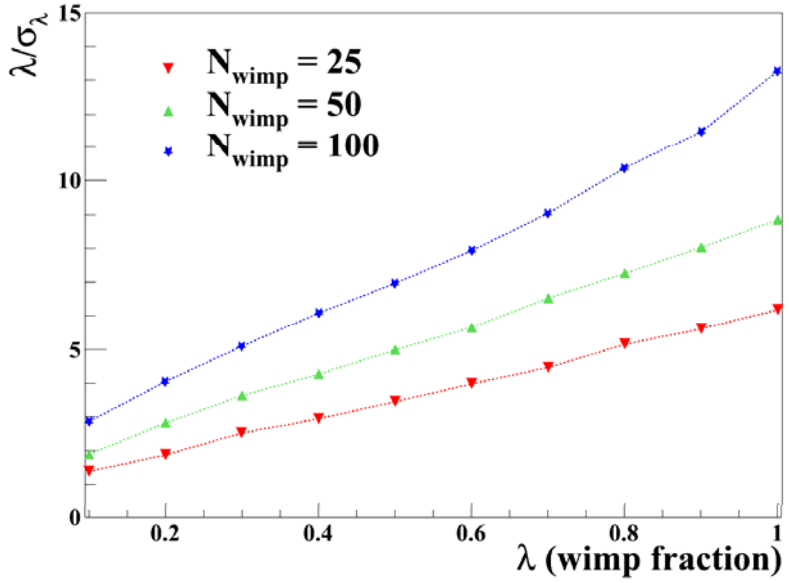
Evolution of the directional accuracy and significance in function of the WIMP fraction λ



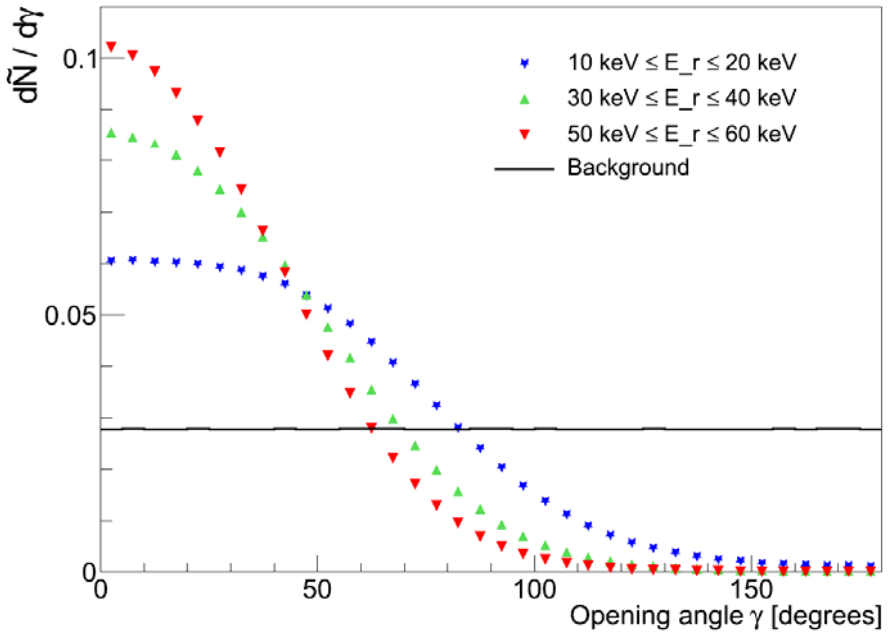


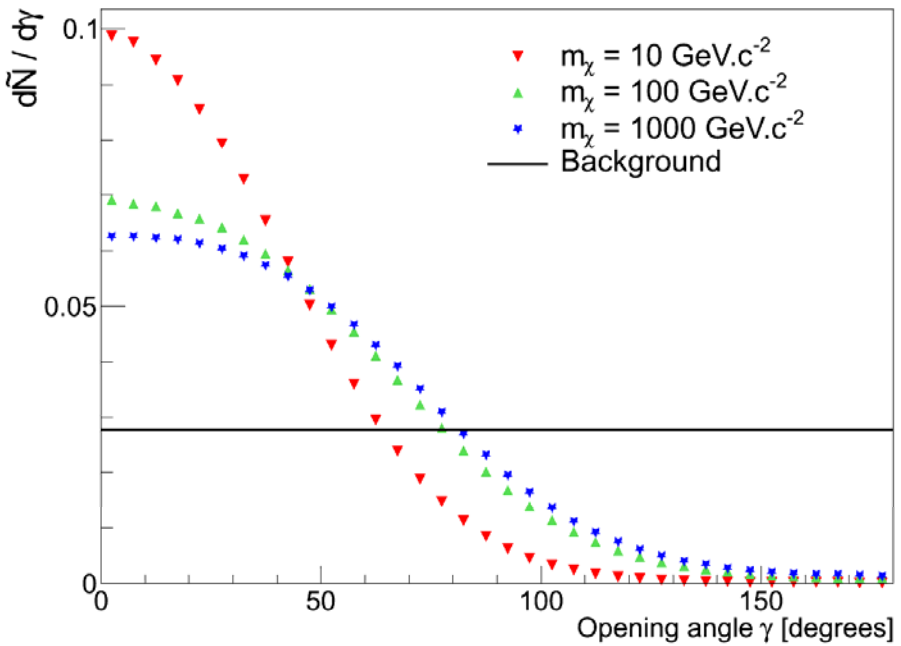
$$\lambda = S/(B+S)$$

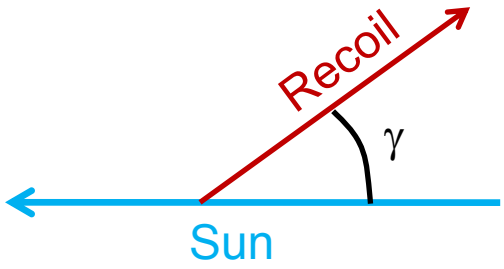
Systematic study has been done with 10^4 experiments

Evolution of the 1D angular spectrum in function of the energy range (left) and the WIMP mass (right)

Fraction of events per solid angle as a function of the opening angle γ

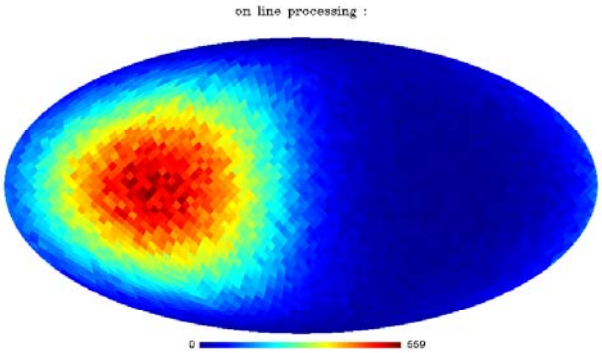




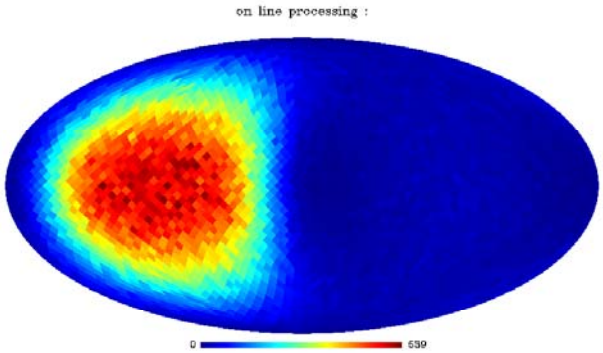


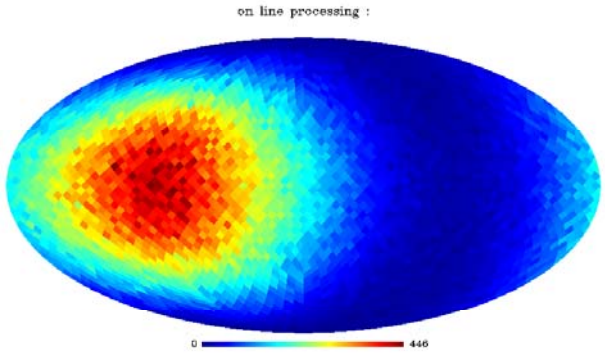
Evolution of the 2D angular distribution in function of the halo model

Sphère isotherme



Halo triaxial (ellipsoidal)

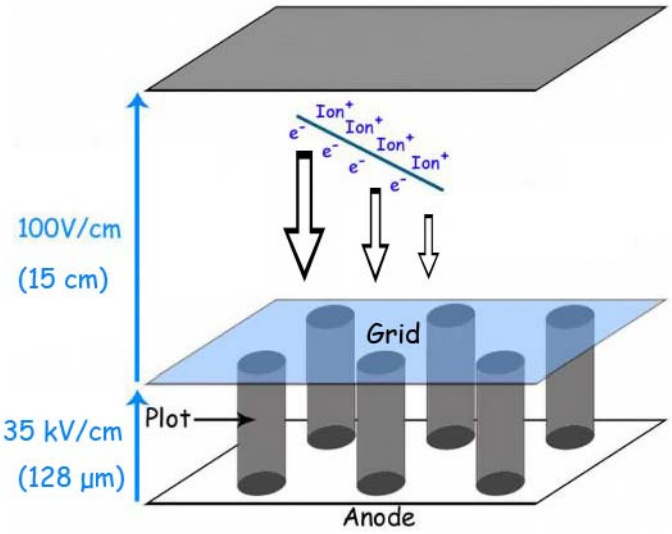




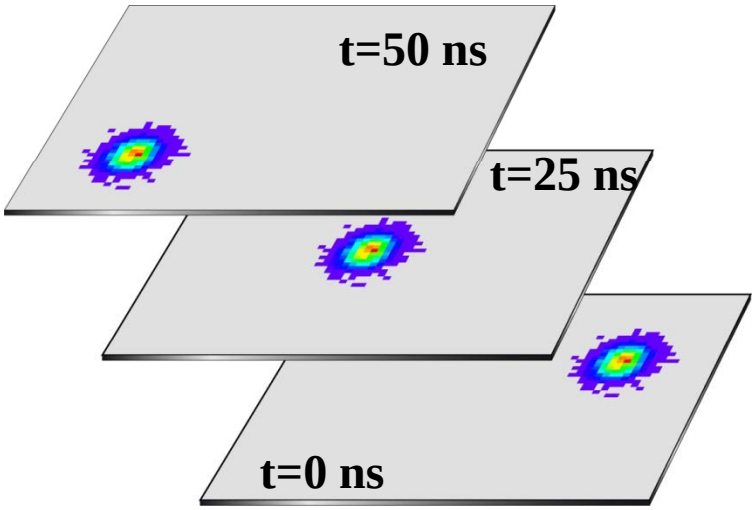
Extreme cases

Still pointing toward the Cygnus Constellation

Track reconstruction with the MIMAC detector



Scan the anode every 25 ns



3D track is reconstructed from 25 ns scan of the (x,y) anod

L, θ and ϕ

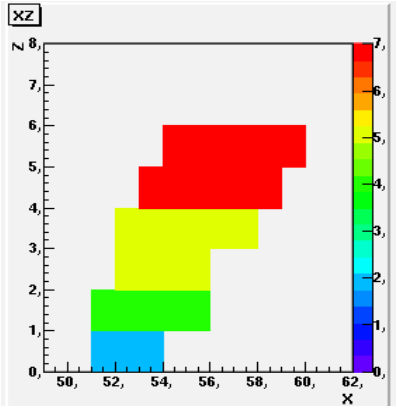
C. Grignon et al. 2009 (to appear)

Length Vs Energy: electron/nuclear recoil discrimination

Amande facility at IRSN Cadarache: neutron field of 144 keV

Pure isobutane

100 mbar



H recoil