State of the art in directional detection of Dark Matter

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Directional DM detection

D. N. Spergel, Phys. Rev. D **37** (1988) 1353

Motion of the Earth and the detection of weakly interacting massive particles

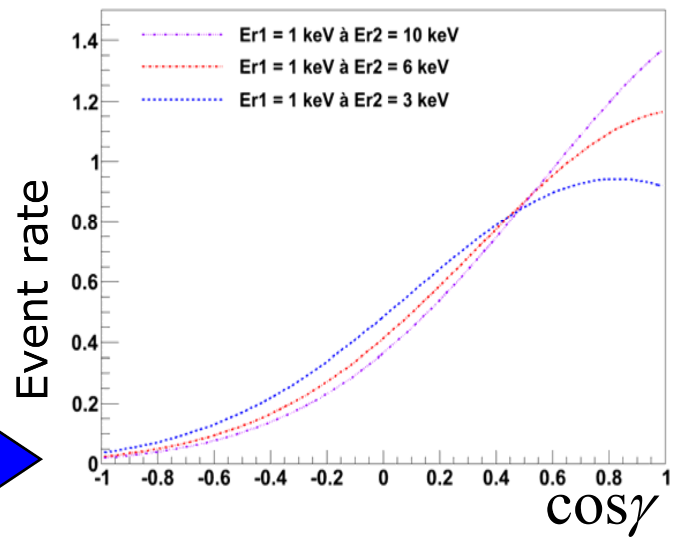
David N. Spergel*
Institute for Advanced Study, Princeton, New Jersey 08540
(Received 21 September 1987)

If the galactic halo is composed of weakly interacting massive particles (WIMP's), then cryogenic experiments may be capable of detecting the recoil of nuclei struck by the WIMP's. Earth's motion relative to the galactic halo produces a seasonal modulation in the expected event rate. The direction of nuclear recoil has a strong angular dependence that also can be used to confirm the detection of WIMP's. I calculate the angular dependence and the amplitude of the seasonal modulation for an isothermal halo model.

a very strong angular dependence. The number of events in the forward direction will significantly exceed the number of events in the backward direction for any energy threshold E_{th}. This strong effect suggests that even weak angular resolution would be a powerful tool that could discriminate between the dark-matter signal and the background.

Early idea :

forward/backward asymmetry



Directional DM detection

From the pionner work of David Spergel :

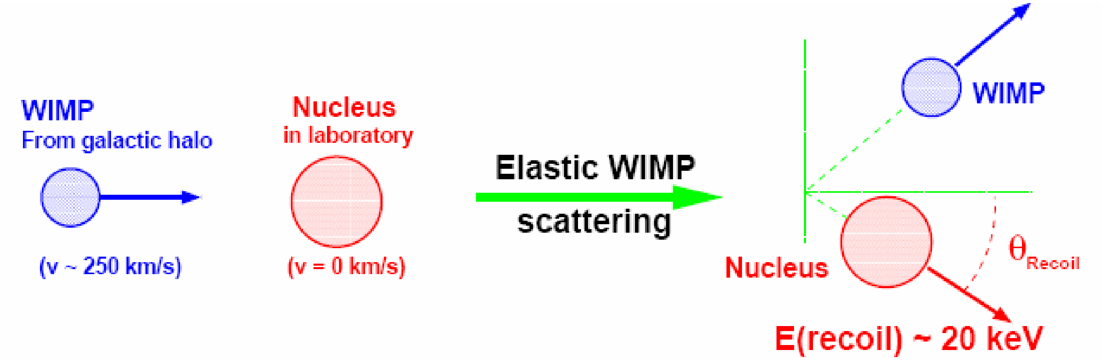
1. « Powerful tool » :

   How to fully exploit these upcoming data ?

2. « even a low angular resolution detector»

   What kind of detector is needed ?

   Which instrumental achievements are needed ?



Direct → Directional

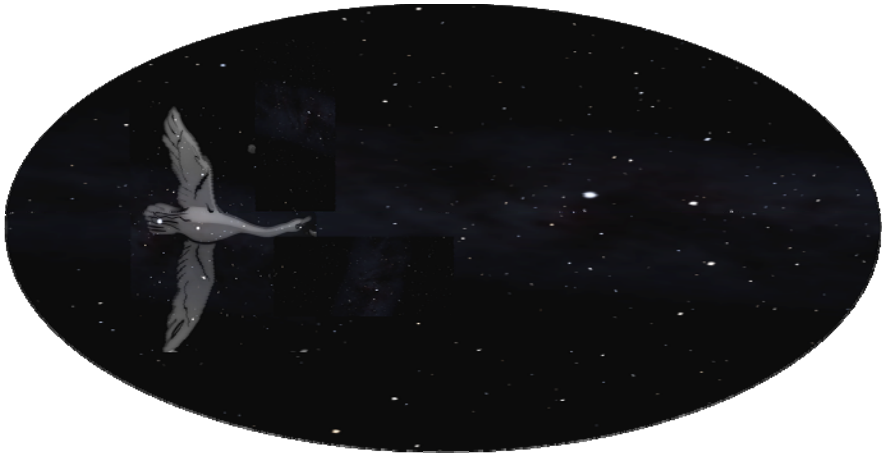
$$\frac{dR}{dE_R} \rightarrow \frac{d^2R}{dE_R d\Omega_R}$$

Directional detection requires to measure both

the recoil energy and the 3D track

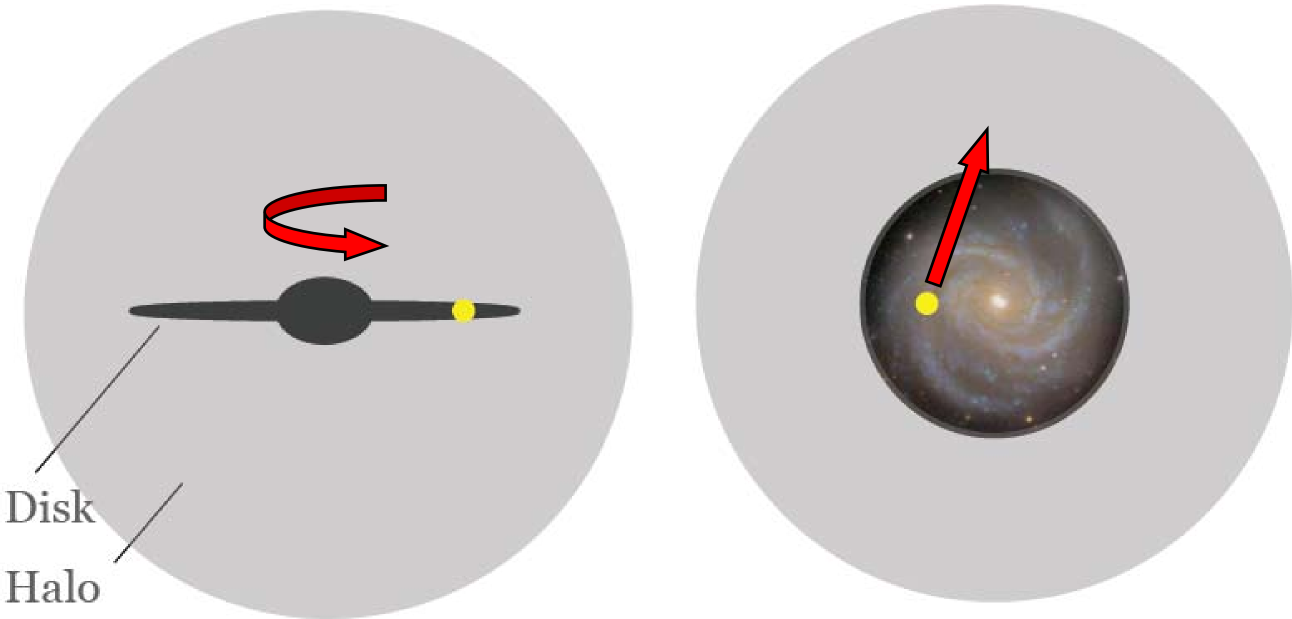
I Directional DM detection

a powerful tool ?



- *A wind of WIMPs form the Cygnus constellation ?*
- *Discrimination WIMP & background*
- *Exclusion/Discovery/Identification potential*

A powerful tool ? : principle



The Sun velocity vector ($\vec{v}_\odot$) is pointing towards ($\ell_\odot = 90°, b_\odot = 0°$) which happens to be roughly in the direction of the Cygnus constellation.

→ *« A wind of WIMPs from Cygnus »*

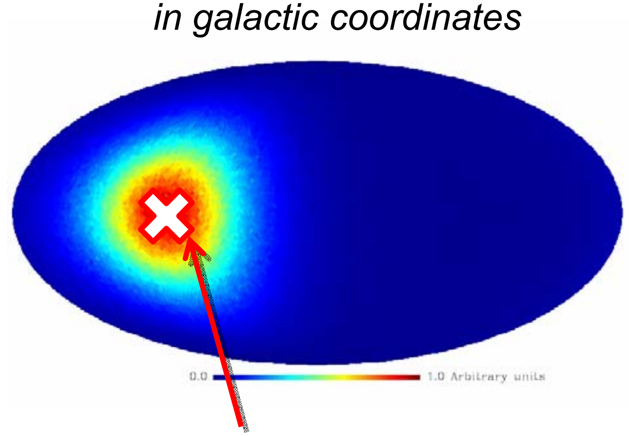
WIMP events = from Cygnus

Background events = isotropic

Directional detection : expected signal

For a standard halo (isothermal and isotropic)

WIMP flux in a earth-based detector in galactic coordinates

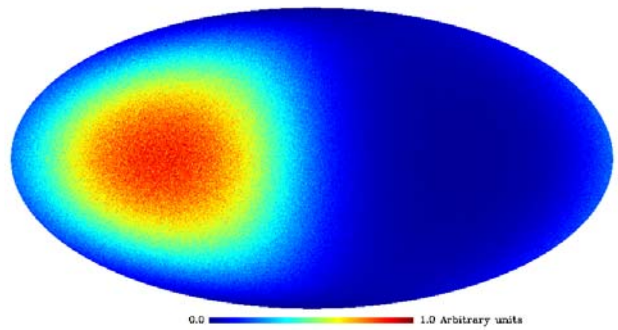


Cygnus Constellation (l = 90°,b = 0°)

After scattering

100 GeV/c² WIMP

Angular distribution of Fluorine recoils
Energy range : [5;50] keV



Expected WIMP-induced signal (recoil-map)

The recoil-map is still pointing toward Cygnus

also slightly broadenned

This will be the main result of directional detection.

→ *Need for recoil-map analysis*

Directional detection : which target ?

Need to measure low energy recoils

→ light target to maximize track length

→ focus on SD interaction (to be competitive with ongoing exp.)

Ideal target : light with non-vanishing spin

→ candidates = H, ^{3}He, ^{19}F

→ most projects have chosen CF_4

In the following we consider a MIMAC-like detector :

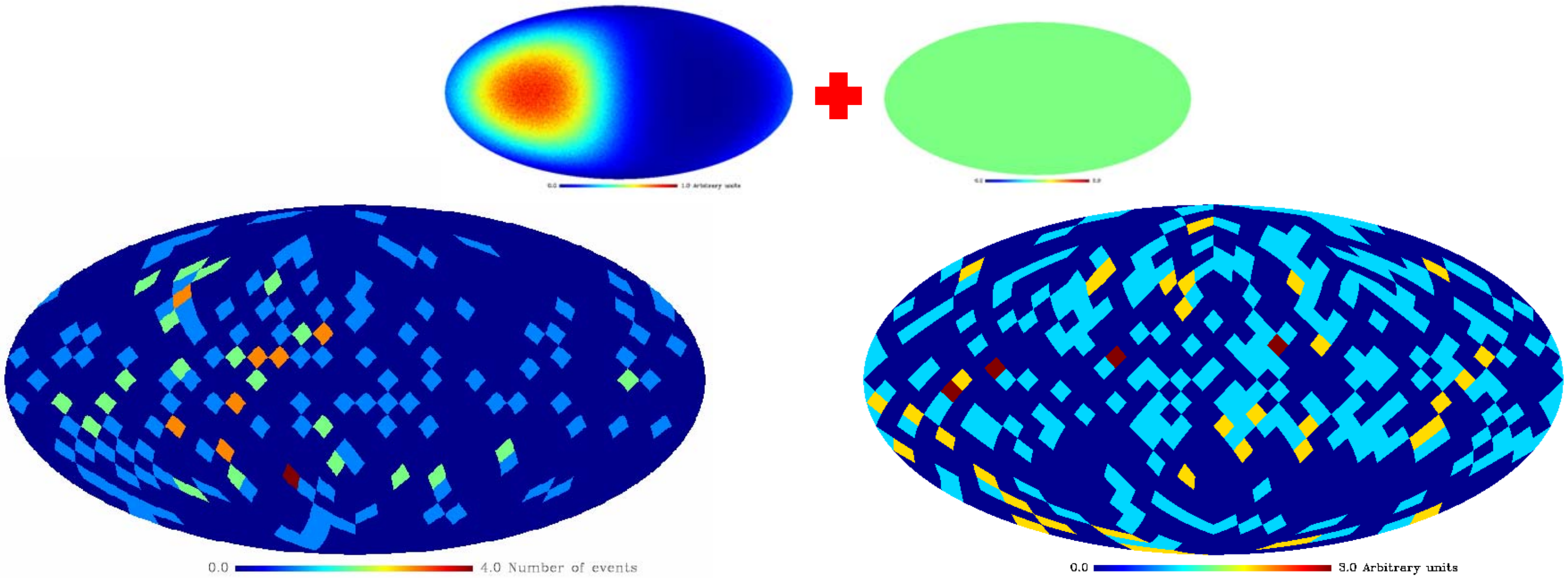
Pseudo data

- 10 kg CF_4
- Livetime : 3 years
- Recoil energy range : [5, 50] keV
- Measure both the energy and 3D track

Directional detection : expected signal

Characteristics of directional data

- Low number of WIMP events
- A large background fraction
- Rather low angular resolution



100 WIMP + 100 bck events

0 WIMP + 300 bck events

What can we conclude from such skymaps ?

Dedicated data analysis is needed…

Directional Detection : exclusion

Best limit in SD interaction (proton) : COUPP 2010

J. Billard *et al.*, PRD 2010

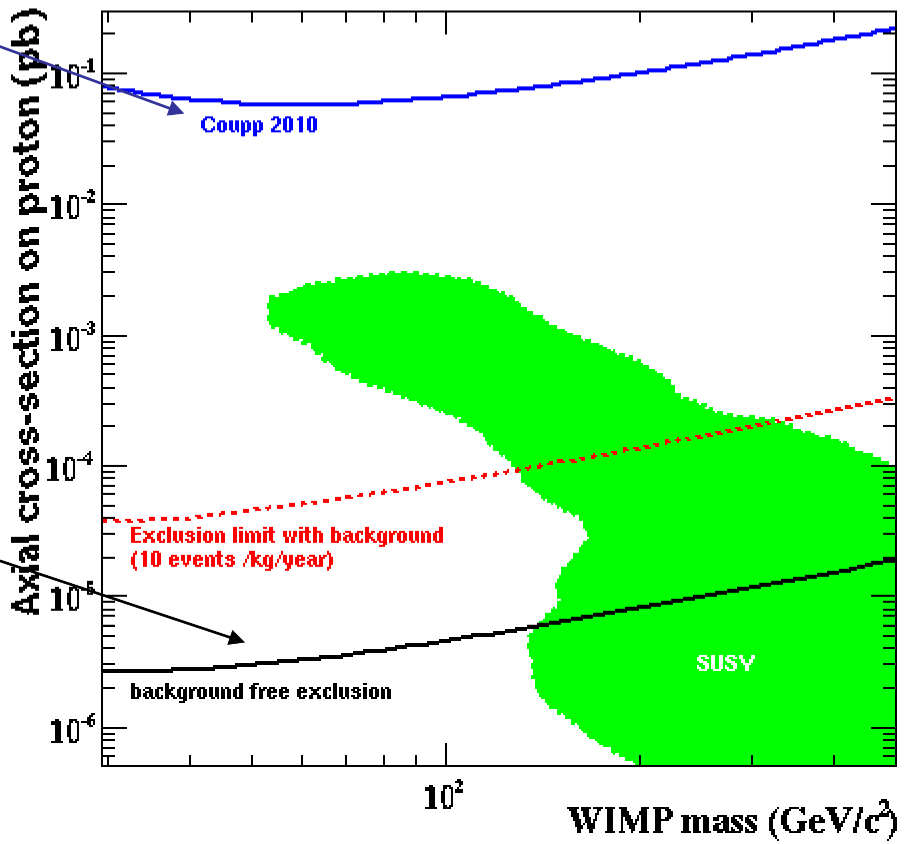
First idea :

Directional detection may

be used for exclusion

Sensitivity (no background)

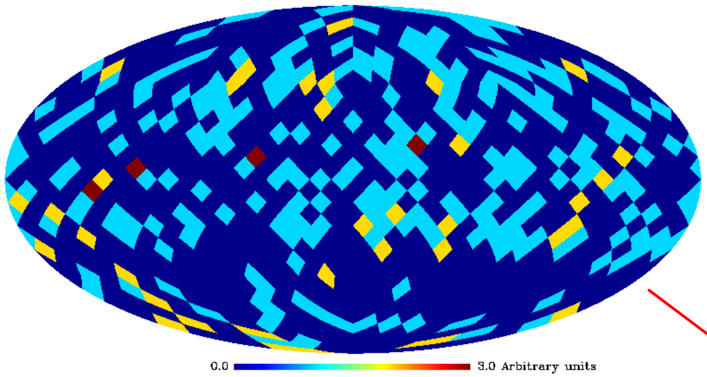
CF_4 30 kg.year



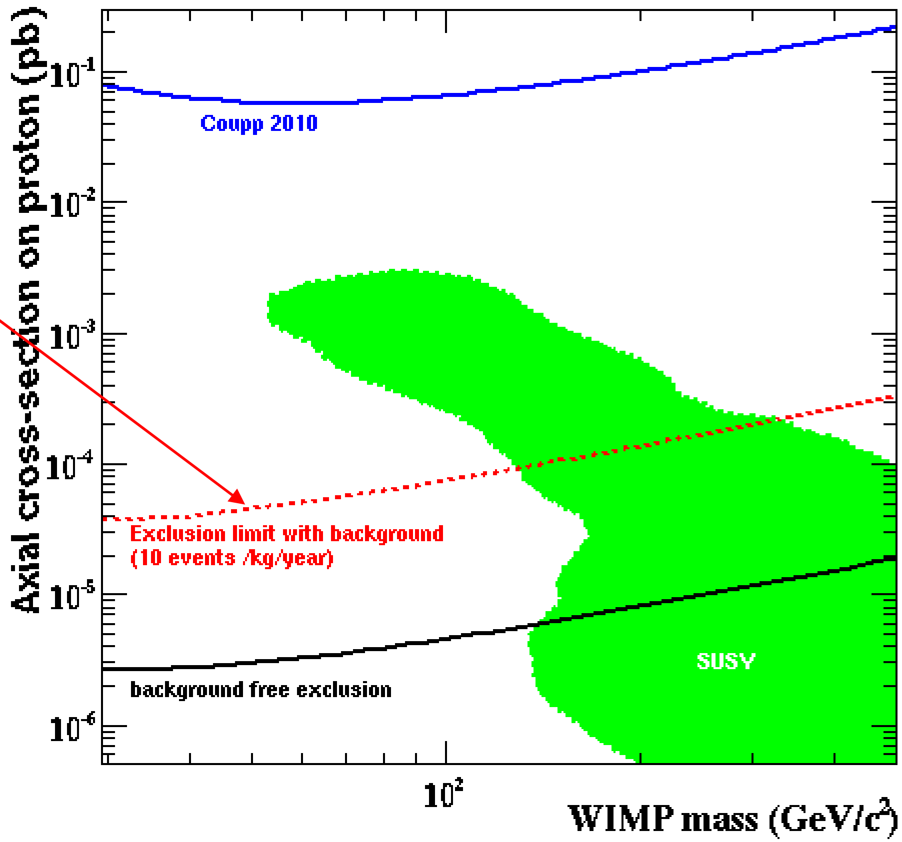
Sensitivity ~ 5 orders of magnitude lower than current SD-p limits
cover a large part of the « Susy region »

Directional Detection : exclusion

J. Billard *et al.*, PRD 2010



• 0 WIMP, 300 background
Background rate : 10 evts/kg/year



<u>Directional Likelihood method</u>

- Only the angular part of the event distribution
- *No assumption on the background energy spectrum*

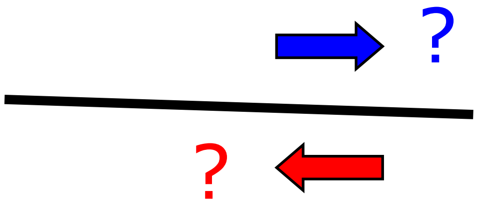
Even a rather large background fraction can be accounted for

Reducing the background rate is not the major issue in directional detection

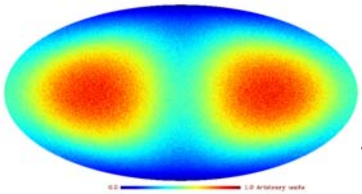
Directional exclusion : sense recognition

J. Billard *et al.*, PRD 2010

Sense recognition means :
(« *head-tail* »)

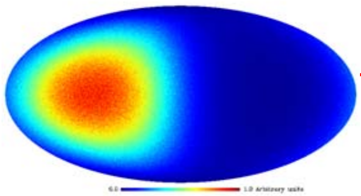


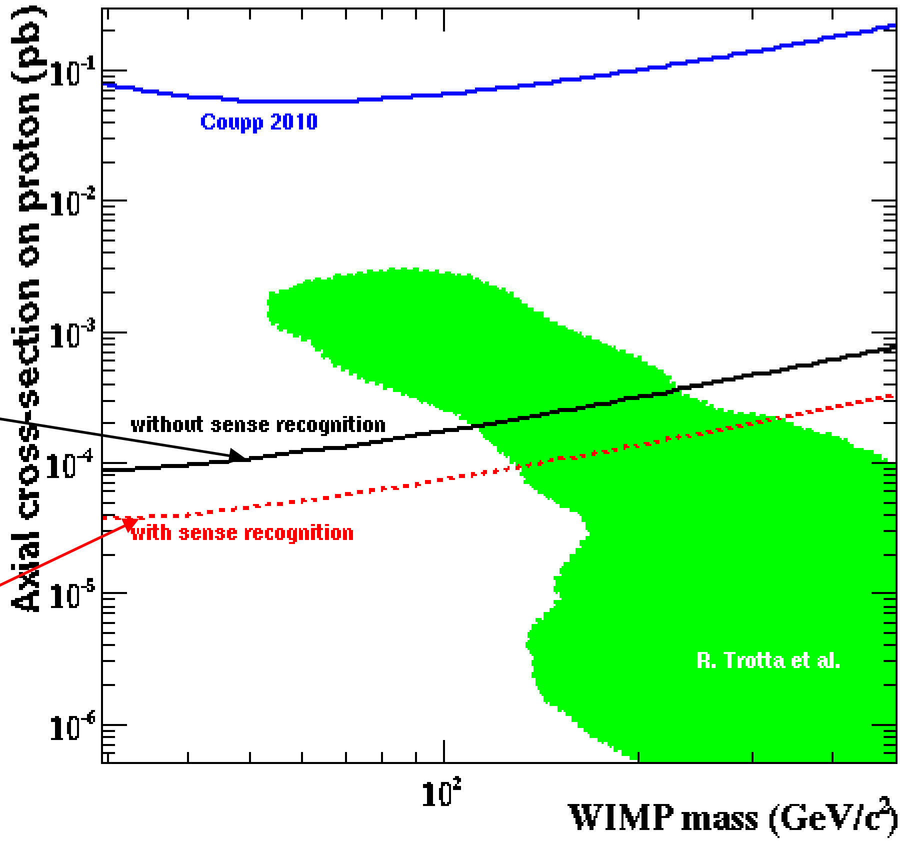
Without Sense Recognition



The WIMP distribution tends to isotropy

With Sense Recognition



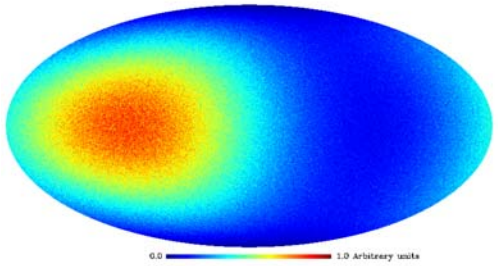


Loose about a factor of 2-3 → **Very important experimental issue**

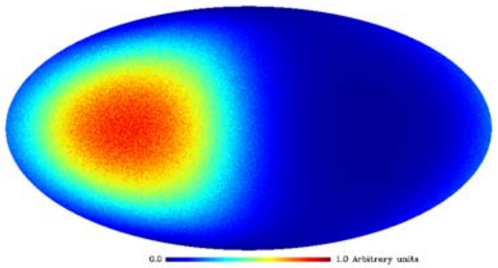
Directional exclusion : angular resolution

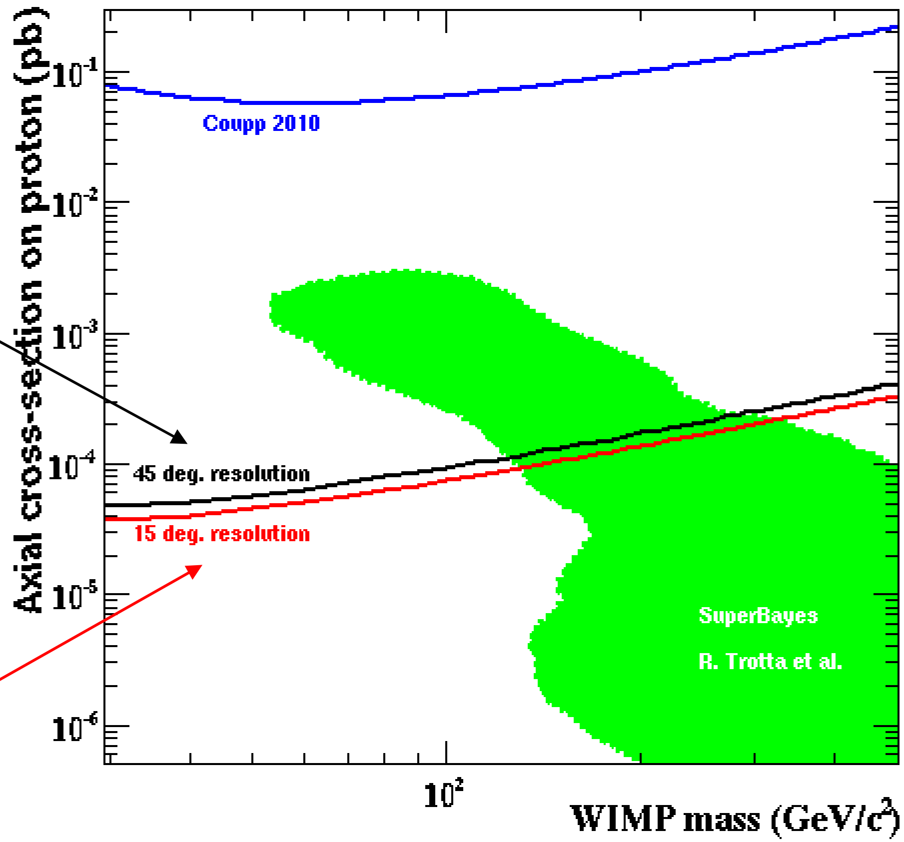
J. Billard *et al.*, PRD 2010

$\sigma_\Theta = 45\,°$



$\sigma_\Theta = 15\,°$



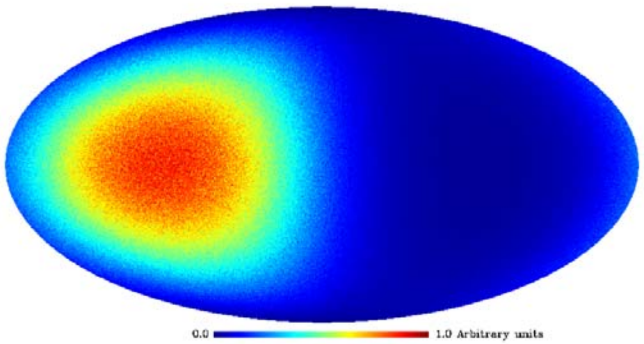


Minor experimental issue

Directional detection : going further

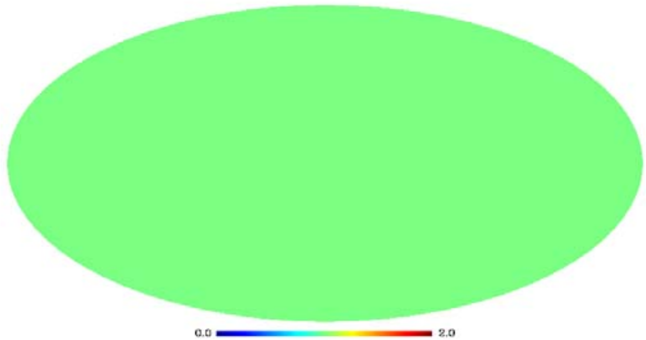
Second idea : Directional detection may be used to discover DM

WIMP signal



Vs

Background



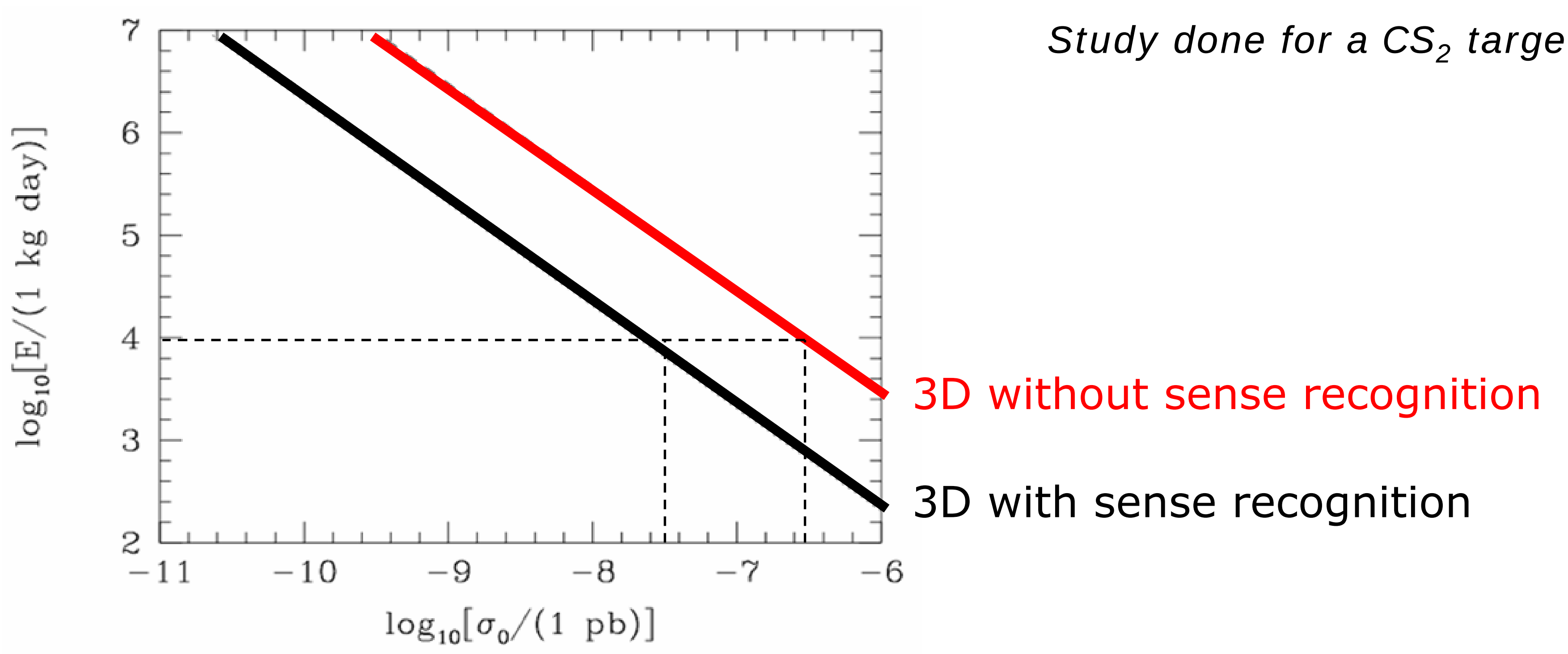
Clear and unambiguous difference between WIMP signal (left) and background (right)

Ref: A. Green and B. Morgan, Astropart. Phys. 2007, …
L. Krauss and C. J. Copi, PRD 2001, …
J. Billard, F. Mayet and D. Santos, PRD 2010, …

Directional detection : reject isotropy

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

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

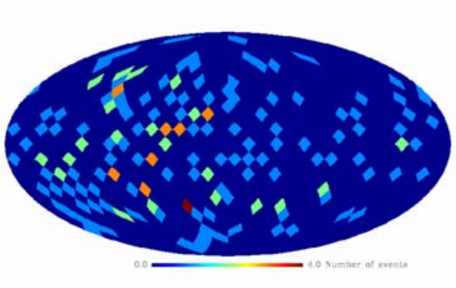


Study done for a CS_2 target

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

Directional detection : discovery

Pseudo-data



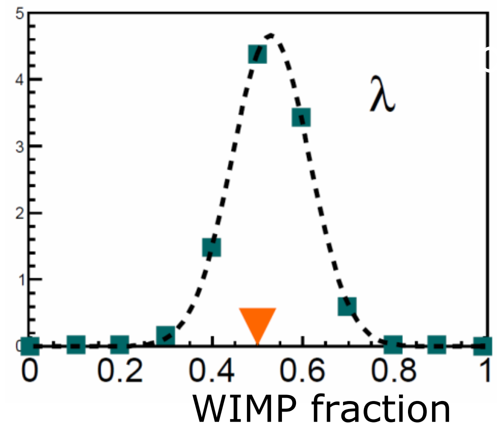
J. Billard *et al.*, PLB 2010

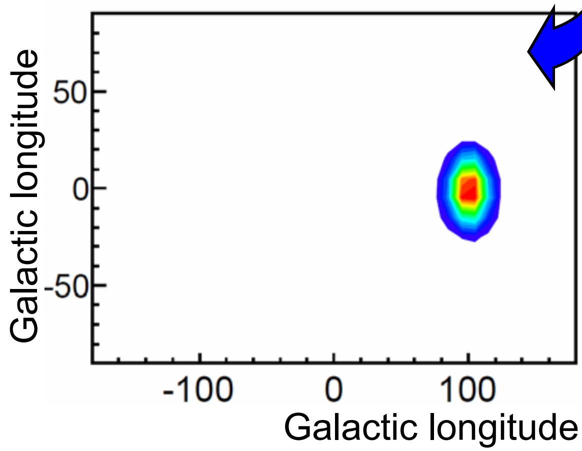
$$\mathscr{L}(m_\chi, \lambda, \ell, b)$$

A 4 parameter Likelihood analysis
- Wimp Mass
- WIMP fraction in the map
- Galactic Latitude et Longitude of WIMP signal

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)





<u>Conclusion for the recoil map analysis</u>
- Signal from Cygnus within 10° (68% CL)
- This map contains 106 WIMP : $N_{WIMP} = 106 \pm 15$ (68% CL)

→ A high significance discovery of galactic DM

Directional detection : discovery

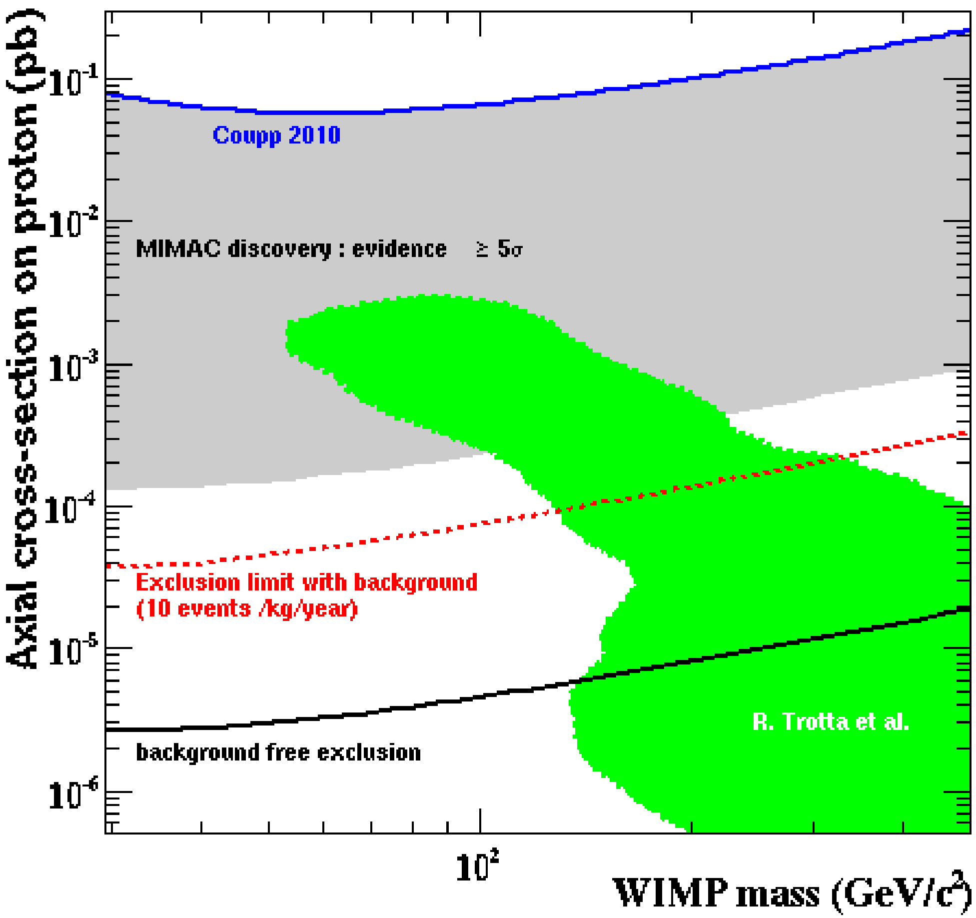
J. Billard *et al.*, PLB 2010

A 5 σ discovery of galactic DM may be achieved

down to 10^{-4} pb

(10^{-3} pb at large masses)

with a directional detector



Pseudo data

- 30 kg.year CF_4
- Bckg rate = 10 /kg/year
- Recoil energy [5, 50] keV
- Angular resolution : 15°

Directional detection : identification of DM

J. Billard *et al.*, PRD 2011

For large SD cross-section (10^{-3} pb) it is possible to go even further

Identification of DM

« Contraining the WIMP mass & cross-section together with the halo properties »

A MCMC analysis of directional data

8 free parameters :

- The WIMP mass
- The WIMP-nucleon cross- section
- The main incoming direction of the signal (l_o,b_o)
- The 3 velocity dispersions σ_x, σ_y et σ_z
- The background rate R_b

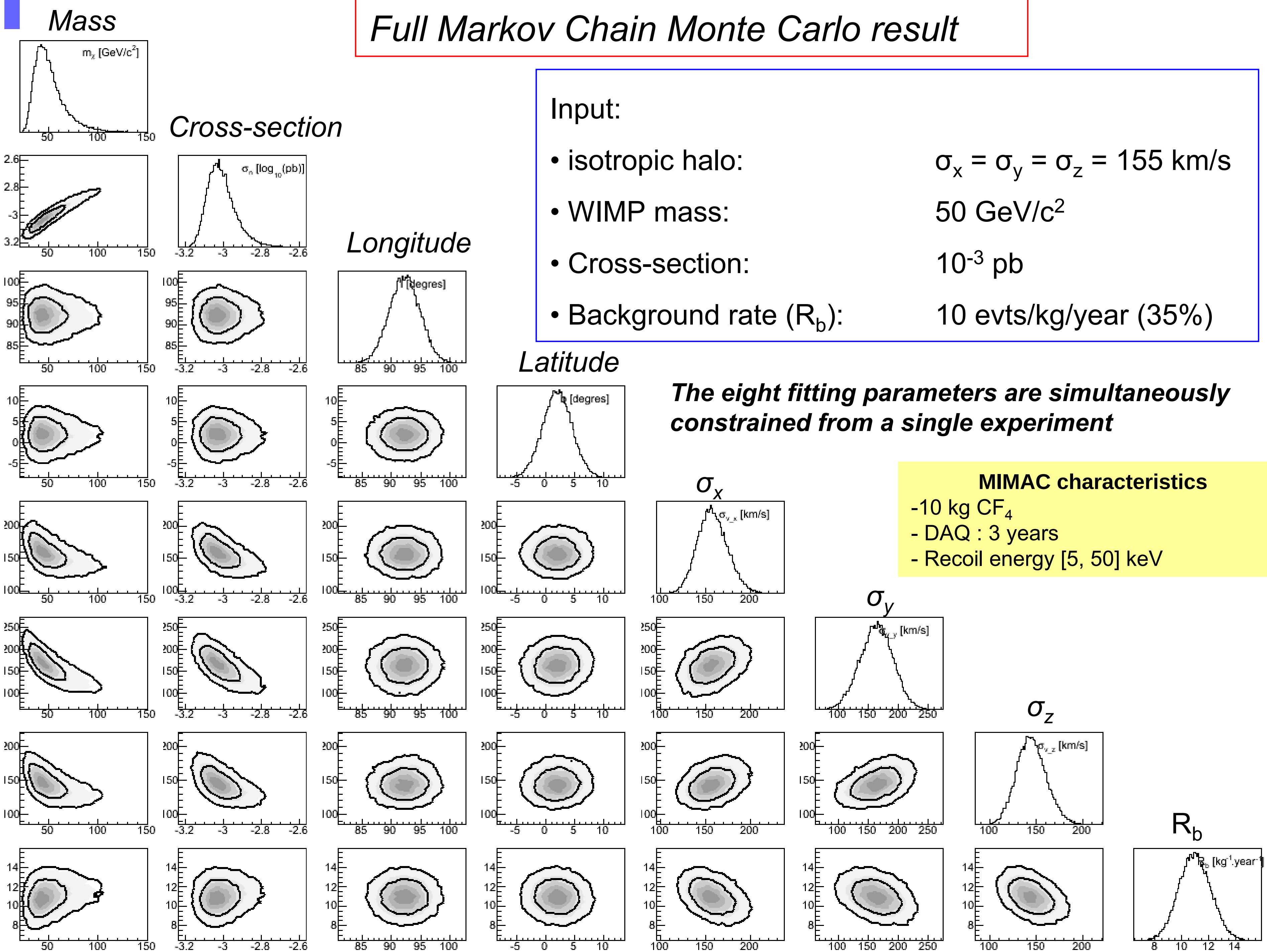
WIMP velocity distribution = *multivariate gaussian*

→ triaxial generalization of the standard isothermal sphere

→ consistent with recent numerical N-body simulations

[M. Vogelberger et al. 2009, M. Khulen et al. 2010, F. S. Ling et al. 2010]

Full Markov Chain Monte Carlo result



Input:

- 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/year (35%)

The eight fitting parameters are simultaneously constrained from a single experiment

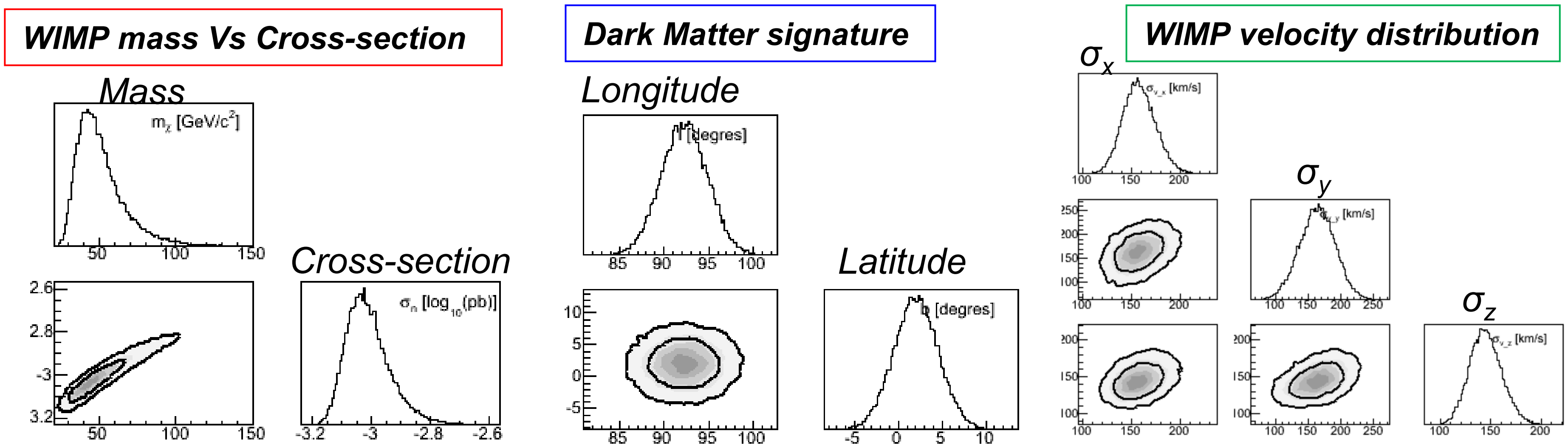
MIMAC characteristics

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

Directional detection : identification of DM

J. Billard *et al.*, PRD 2011

The 8 fitting parameters are strongly constrained with a single directional detection experiment:



	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

Holds true for most WIMP & haloes. Discrimination between halo models

Directional detection

A Directional DM detector may allow to :

- **Exclude :** ***several orders of magnitude below current SD limits***

- ***Discover galactic DM : high significance discovery down to 10^{-4} pb***

- ***Identify galactic DM : measurement of the properties of the WIMP (mass cross-section) and of the galactic halo may be achieved down to 10^{-3} pb***

with a single CF_4 experiment (30 kg.year)

II Which detector for directional detection ?

- Detector specifications
- State of the art
- The MIMAC project

based on *S. Ahlen et al., Int. Journal of Modern Physics A 25 (2010) 1-51*

Directional Detector wish list

- 3D track reconstruction & energy measurement
  - *low pressure TPC (50-200 mbar)*
  - *measure tracks of a few mm and a few keV*

    → major experimental issue. Compulsory
- Sense recognition
  - *If not achieved : could be carefully handled by data analysis (with an expected downgrade of performance)*

    → very important issue (for discovery/identification)

Directional Detector wish list

- 3D track reconstruction & energy measurement

  → major experimental issue. Compulsory

- Sense recognition

  → major experimental issue.

- Low energy threshold
  - *Nota Bene : it means measuring **both** energy and track…*

  → *the lower the better*

- Good angular/energy resolution

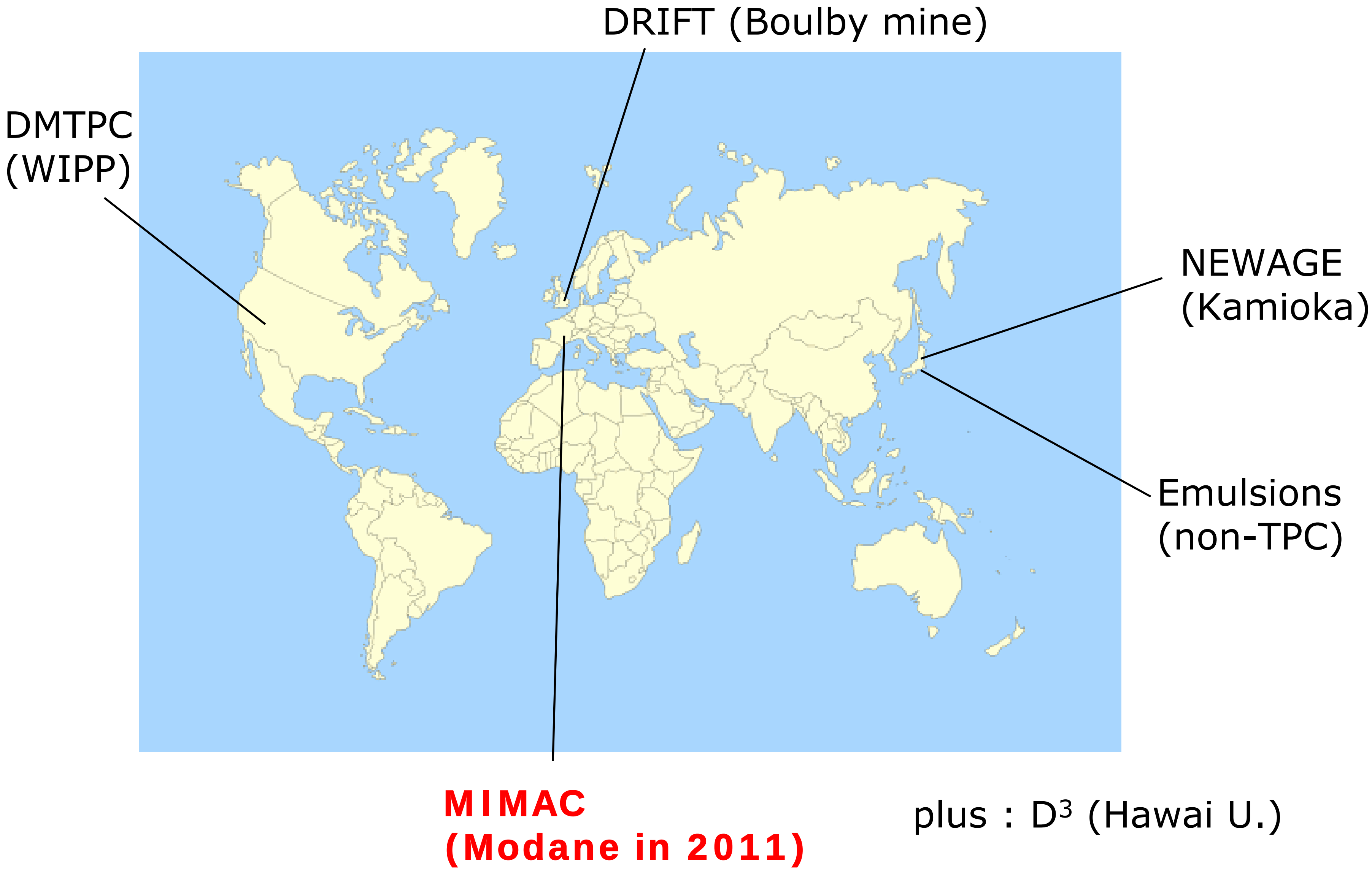
  → minor experimental issue.

- Zero background event rate

  → very minor experimental issue → *light shielding ?*

Directional Detection could handle a rather large residual background fraction (exclusion, discovery & identification)

State of the art : worldwide effort



plus : D^3 (Hawai U.)

State of the art : DRIFT

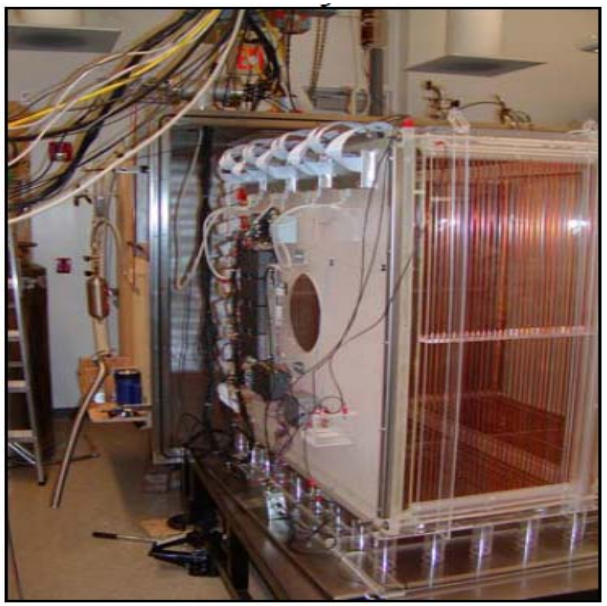
E. Daw *et al.*, arxiv:1010.3027

DRIFT

Rutherford, Imperial. Coll., London, Occidental. Coll, Sheffield U., Edimburg U., New Mexico U.

Piooner in directional detection

- 1 m^3 MultiWire Proportional Counter
- S target nucleus with CS_2 gaz
- Drift of negative ions to reduce diffusion
- 3D reconstruction (2D + timing)
- Large drift distance but poor spatial resolution
- Operational in the Boulby Mine (UK) since 2001
- Pressure : 53 mbar
- Recently add Fluorin target (SD interaction)



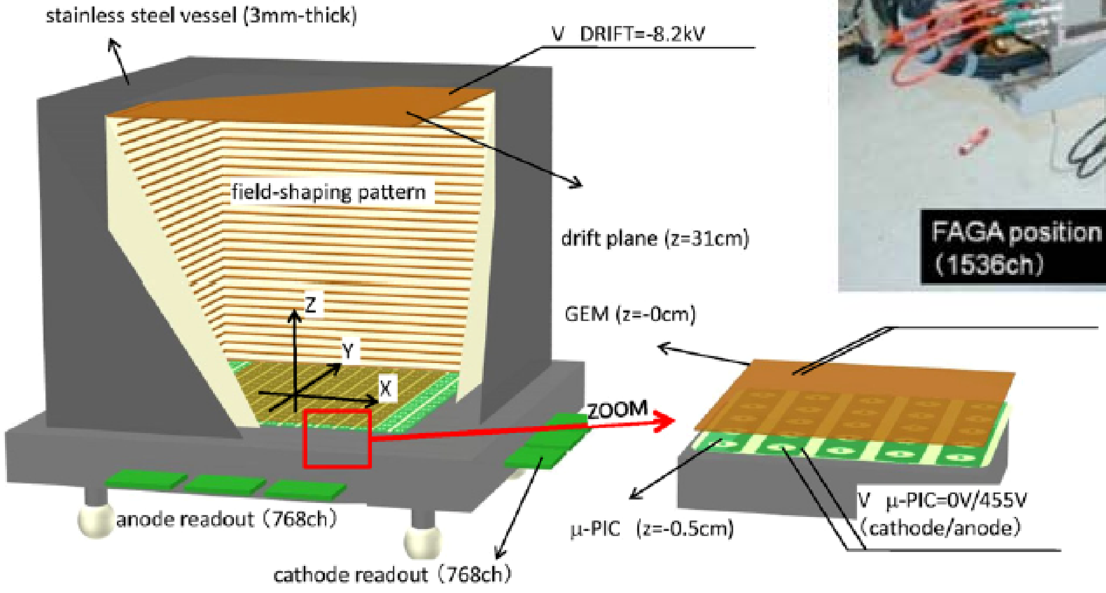
State of the art : Newage

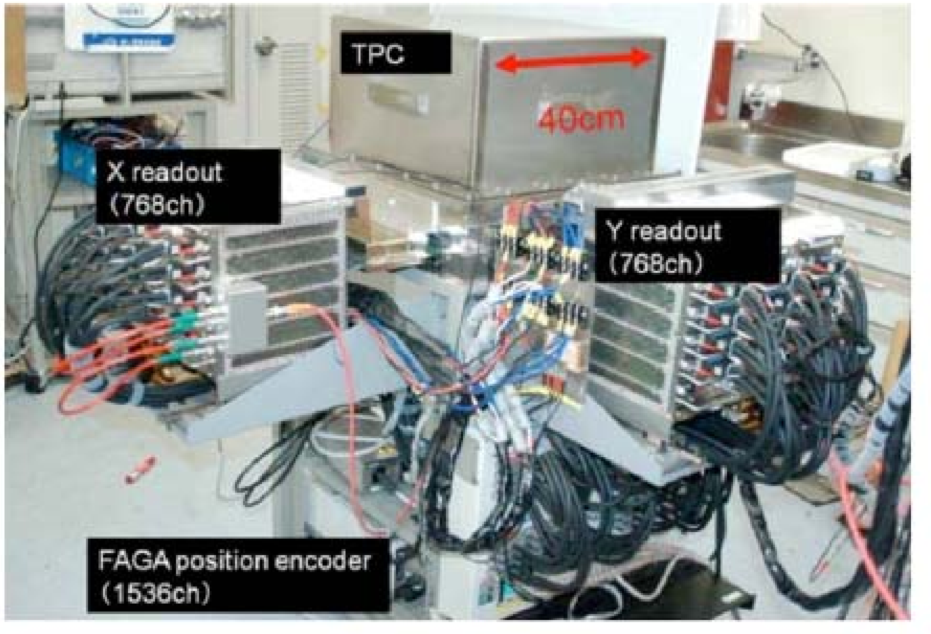
K. Miuchi *et al.*, PLB 2010

NEWAGE

Kyoto University, Tokyo University

- CF4
- 200 mbar
- 0.3 m³ TPC + pixelized anode + GEM
- 3D Reconstruction
- No sense recognition





State of the art : DM-TPC

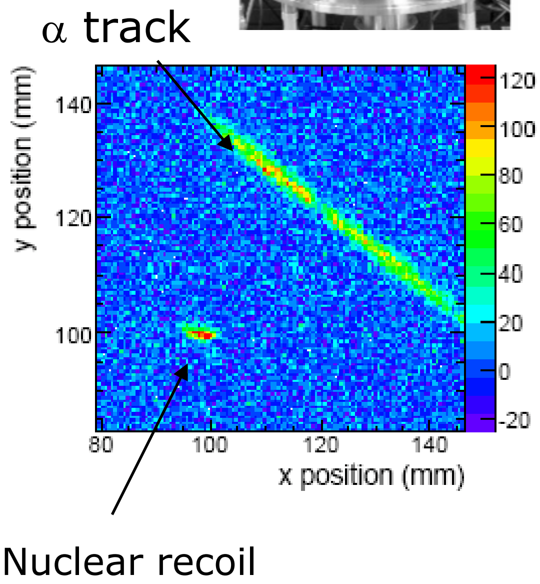
S. Ahlen *et al.*, PLB 2011

DM-TPC
MIT, Boston University, Brandeis University

- 10 L CF_4 (100 mbar)
- 6.2 g fiducial mass
- Dual TPC + 2 CCD

  →Charge & Optical (600 nm) readout
- 2D track Reconstruction
- Sense recognition above 100 keV
- Micromesh 256 µm pitch
- Energy [80-200 keV]

- funded for $1m^3$
- starting to take data underground (@ WIPP lab.)



State of the art : early directional results

Newage

- Underground run @ Kamioka
- Exposure : 0.5 kg.day
- [100-124 keV]
- 1244 events measured

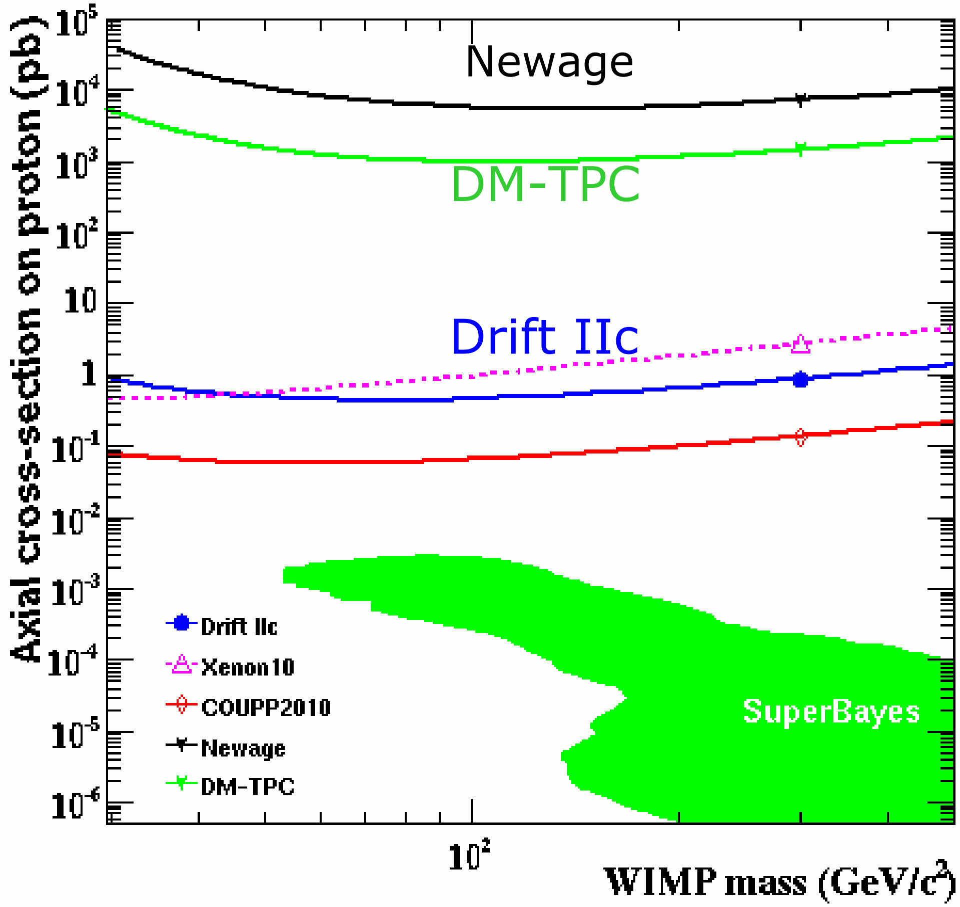
DM-TPC

- Surface run @MIT
- 10 L CF4 (6.2 g fiducial mass)
- Exposure : 35.7 g.day
- Energy range [80-200 keV]
- 105 events measured
- reject isotropy @ 75 % CL

Drift

- Underground run @ Boulby mine
- 0.8 m^3 ficudial volume
- 30 Torr CS2 + 10 Torr CF4
- Exposure : 74.4 live-days
- CAUTION : non-directional result

S. Ahlen *et al.*, PLB 2011
K. Miuchi *et al.*, PLB 2010
E. Daw *et al.*, arxiv:1010.3027



III The MIMAC project

measuring small tracks (few mm)

at low energies (few keV)

in a low pressure CF_4 TPC

to perform directional DM detection

The MIMAC collaboration

LPSC (Grenoble) :

J. Billard, F. Mayet, D. Santos

Technical Coordination : O. Guillaudin

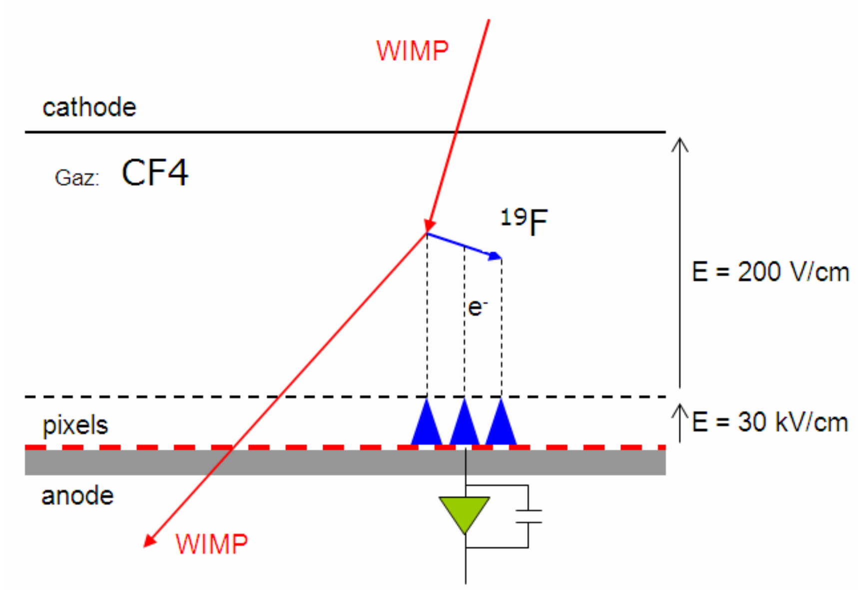
- Electronics : G. Bosson, J-P. Richer
- Gas detector : A. Pellisier
- Data Acquisition: O. Bourrion
- Mechanical Structure : Ch. Fourel
- Ion source : T. Lamy, P. Sole

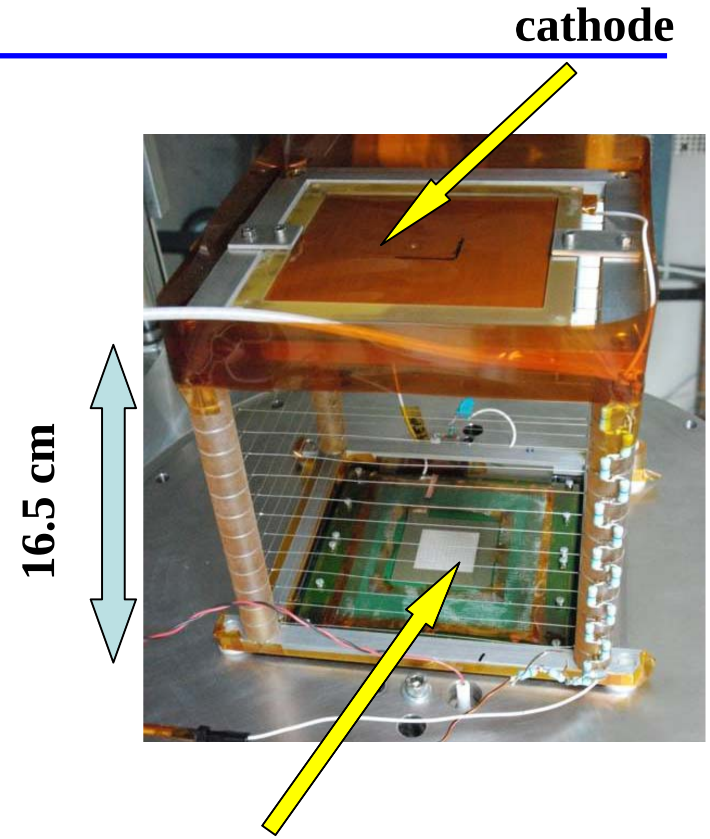
CEA-IRFU (Saclay) : P. Colas, E. Ferrer, I. Giomataris

IRSN (Cadarache): C. Golabek, L. Lebreton

The MIMAC project

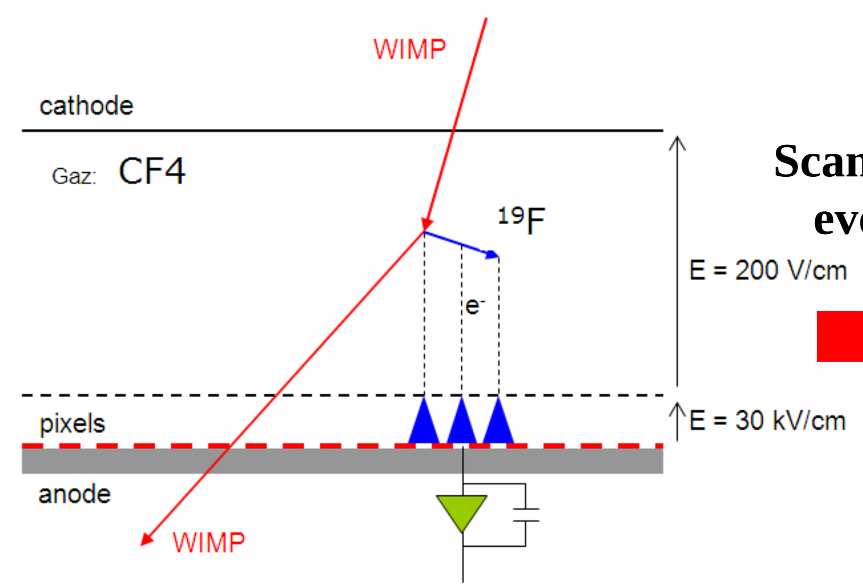
- a Matrix of micro-TPC
- Micromegas technology
- Measurement of energy and 3D track
- CF_4
- Gazeous mixture : ^3He, CH_4, C_4H_{10}, CF_4
- Low pressure operation (50 mbar)
- Goal : a 10 kg directional detector





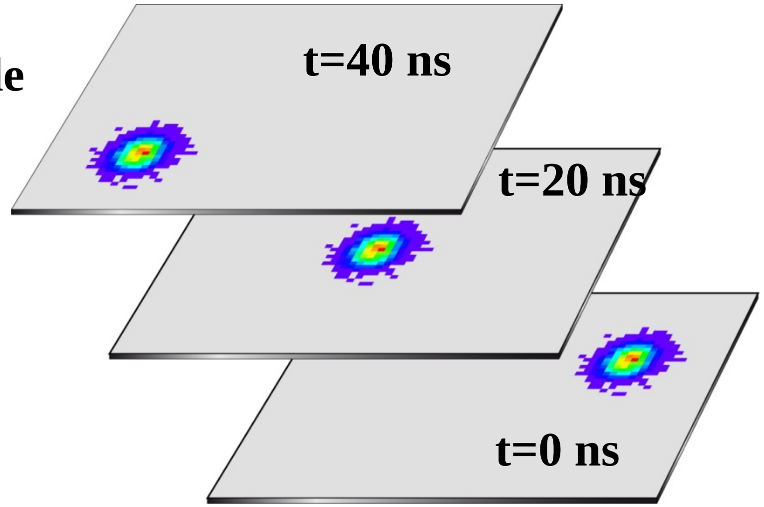
Micromegas & pixelized anode (x,y)
10 cm x 10 cm
Pixel = 350µm

The MIMAC project : 3D strategy



Representation of a MIMAC TPC

Scan the anode every 20 ns



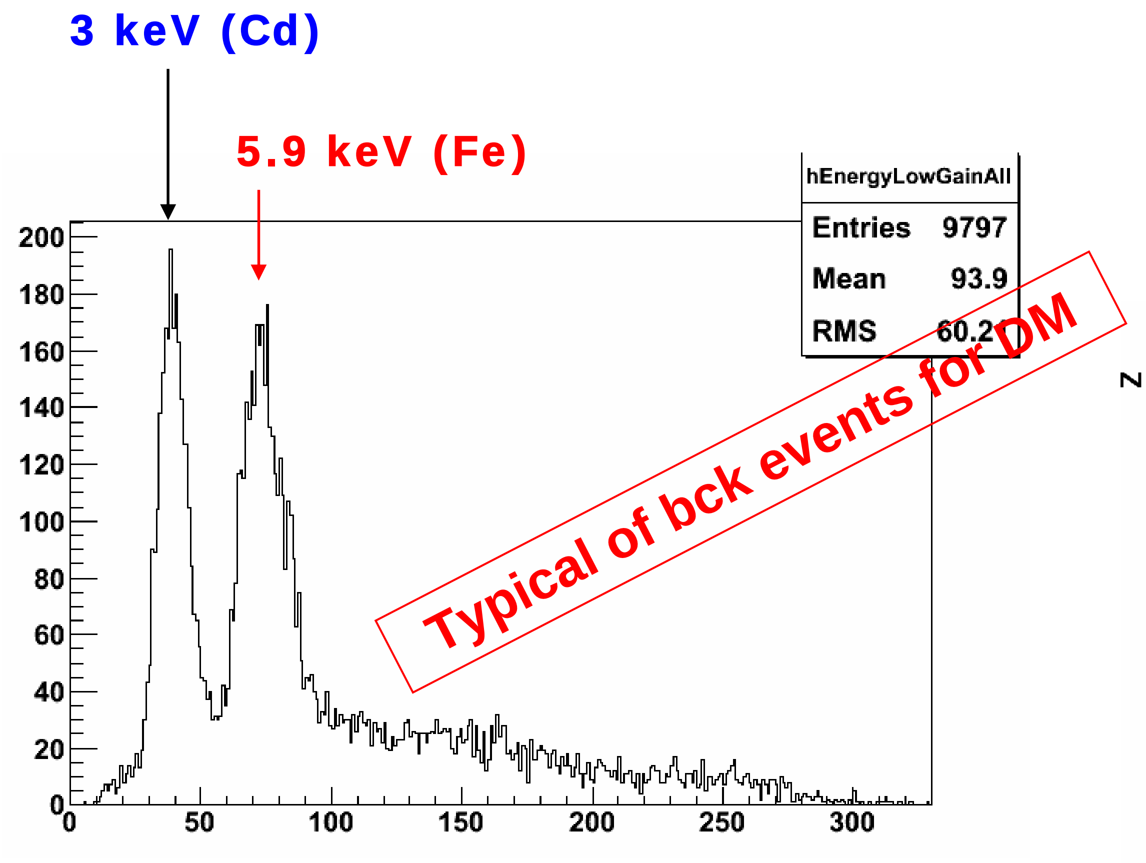
Evolution in time of the collected charges

Knowing the electron drift velocity in the gaz mixture,

It is then possible to get the third coordinate (Z) → 3D track

Typical electron drift velocity : 10-100 µm/ns

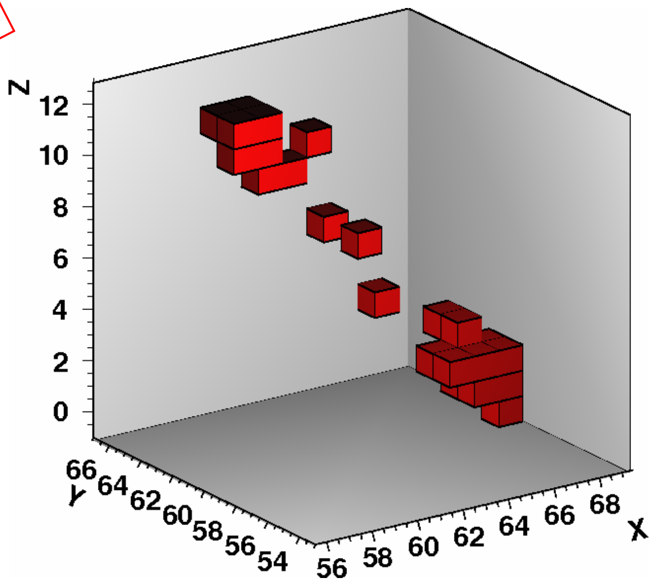
MIMAC : measuring track & energy



CF_4+CHF_3

(+C_4H_{10})

50 mbar



All events are measured with both energy and 3D track down to ~1 keV

→preliminary results but very encouraging

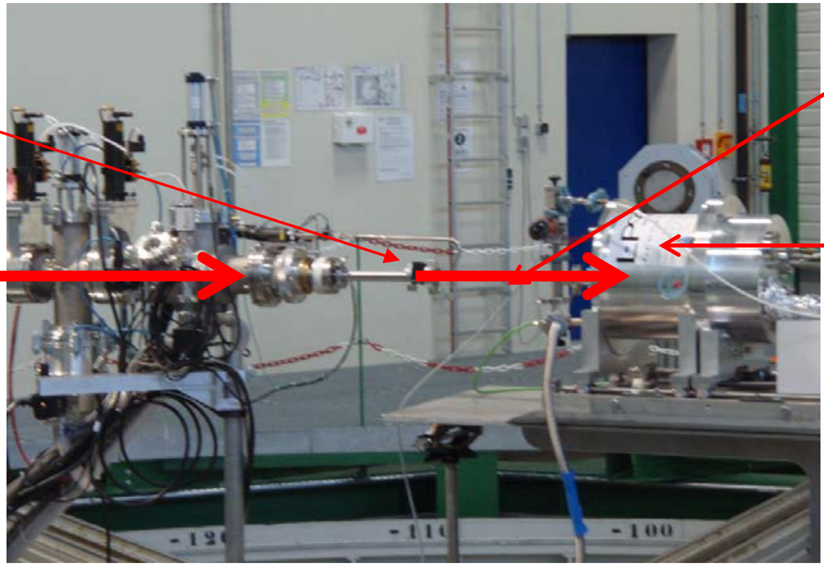
MIMAC : nuclear recoils

DATA

The Amande Facility (IRSN)

Target
Sc (8.2 keV n)
LiOH (144 keV n)

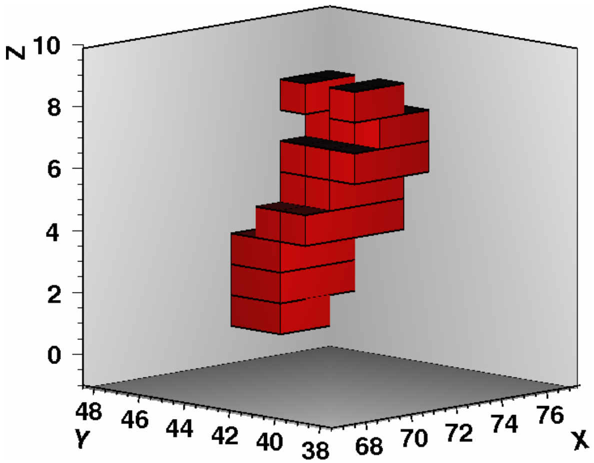
Beam
p/D



70 % CF_4 + 30% CHF_3

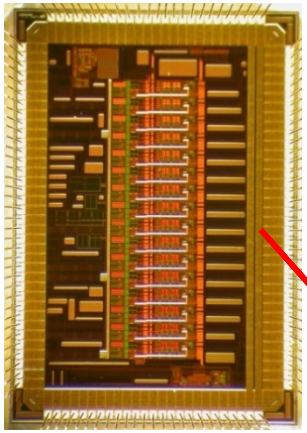
55 mbar,
170 V/cm

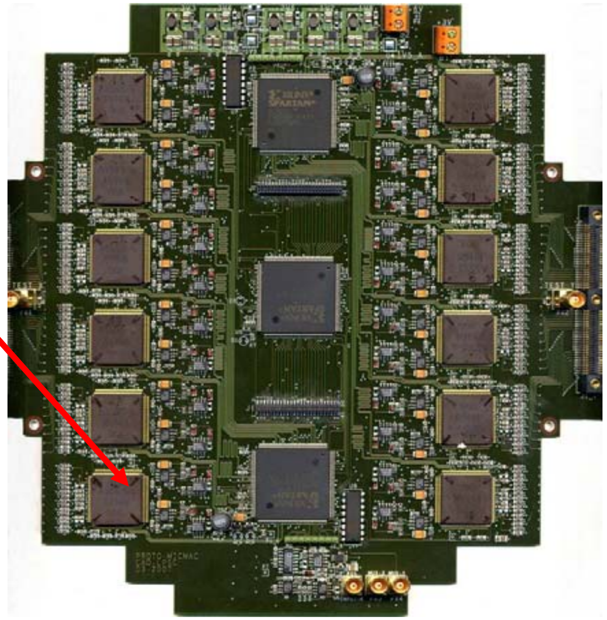
Fuorine Candidate
50 keV (ionisation)



MIMAC : electronics & DAQ

O. Bourrion *et al.*, NIM 2010
J. P. Richer *et al.*, NIM 2010





Self-triggered electronic for anode sampling @ 50 MHz

3250µm x 4700µm
[area ~ 15 mm^2]

Readout electronic comprises :

- 8 dedicated ASICs
- a FPGA
- a flash ADC (to monitor grid signal)
- an USB interface for DAQ.

New MIMAC electronics

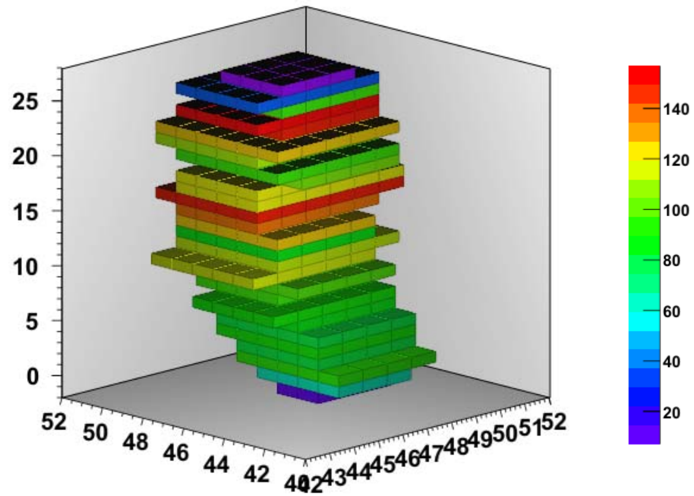
allows to get the charge

for each time slice

→ 4D track !!

→ Key-point for sense recognition

NEW

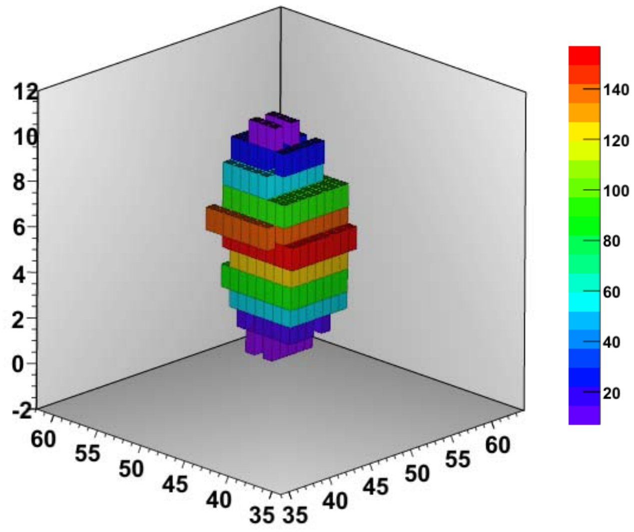


400 keV Fluorine (simulation)

MIMAC : 3D track reconstuction

How to retrieve information from a measured track ?

X, Y, Z, θ, ϕ and sense ??



<u>A likelihood-based track analysis</u>

- Data : track properties
  - → number of slices
  - → For each slice : X, Y, ΔX, ΔY and collected charge
- Fitting model : simulated tracks
  - → Using SRIM, Magboltz and full DAQ simulation

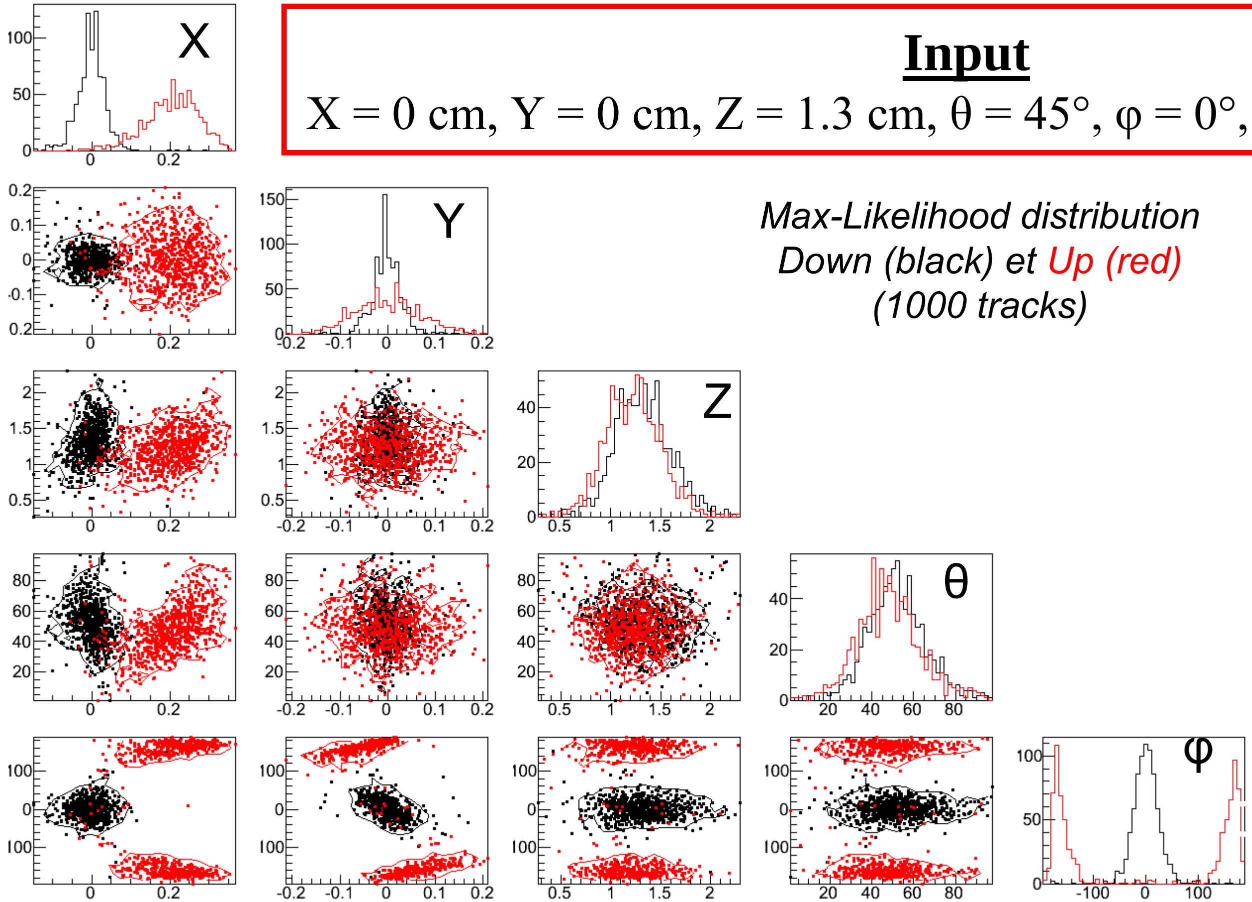
MIMAC : 3D track reconstuction

Preliminary results

1) Two hypothesis: Down-going & Up-going

Input

X = 0 cm, Y = 0 cm, Z = 1.3 cm, θ = 45°, φ = 0°, Sense = Down



Max-Likelihood distribution
Down (black) et Up (red)
(1000 tracks)

Down-going

Spatial resolution (X,Y)

$$\sigma_{x,y} = 314 \pm 10\ \mu\mathrm{m}$$

Z resolution

$$\sigma_z = 2.7 \pm 0.1\ \mathrm{mm}$$

Angular resolution

$$\sigma_\gamma = 23.7 \pm 0.6^\circ$$

2) **Boosted Decision Tree analysis**
allows to discriminate between **Down-going & Up-going**

77 %

MIMAC : conclusion

Very encouraging results from data analysis on simulated data

→ To be applied on real data

As of mid-2011 :

- 3D track and energy measurement → Ok

  thanks to dedicated DAQ and data analysis

- Sense recognition → on the way…

  thanks to the Flash ADC and BDT analysis

- Low energy threshold → on the way…
- Good angular/energy resolution → Ok

Conclusions

1) A 10 kg CF_4 TPC dedicated to directional DM detection

would allow to achieve major breakthrough in the field

Exclusion, Discovery or Identification of galactic DM
depending on the WIMP-nucleon cross-section

2) MIMAC project should be able to achieve 3D+sense reconstruction of low energy tracks

Next step :

A 2-chamber Module (2 μ-TPC equipped with 100x100 mm^2 Micromegas)

- 2 x 512 channels
- 4 L CF4 + 30% CHF3
- Going underground in 2011 (@LSM)

CYGNUS 2011

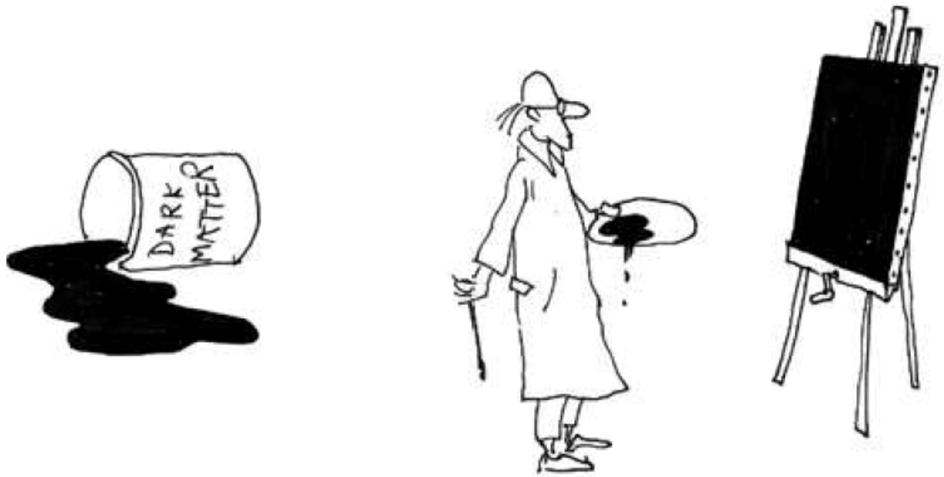
3rd Workshop on Directional Detection of Dark Matter

8-10 June 2011
in Aussois (France)
http://lpsc.in2p3.fr/Cygnus2011

This conference will focus on :

- **Technical progress on gaseous detectors,**
- **Directional data analysis**
- **Statistical methods to detect Dark Matter**
- **Experimental results from directional prototypes,**
- **Dark Matter theories (particle and galactic halo physics),**
- **Future of directional detection.**

Back-up slides



DATA

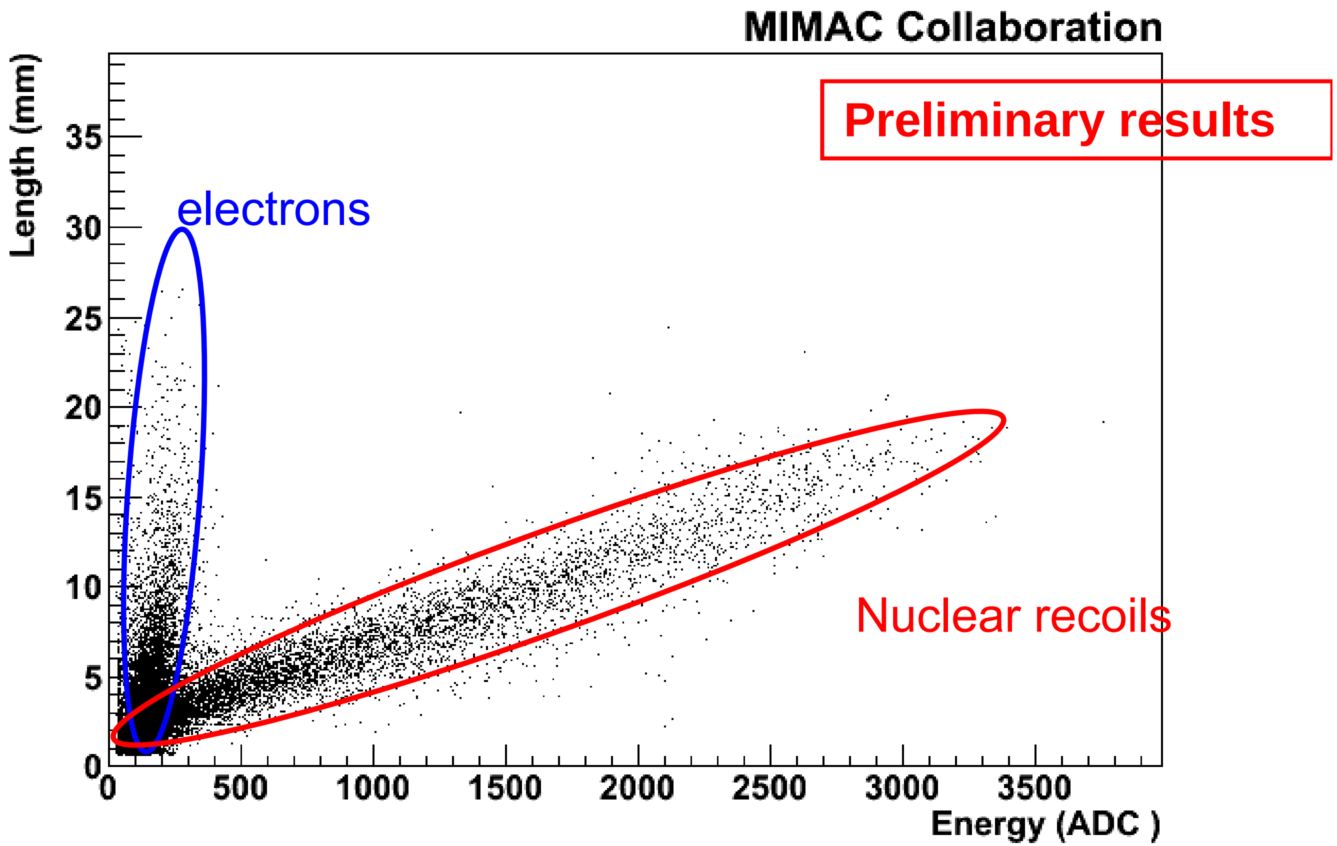
e/recoil discrimination : exp. result

He + 5% iC_4H_{10}

350 mbar,

150 V/cm

144 keV neutrons



144 keV

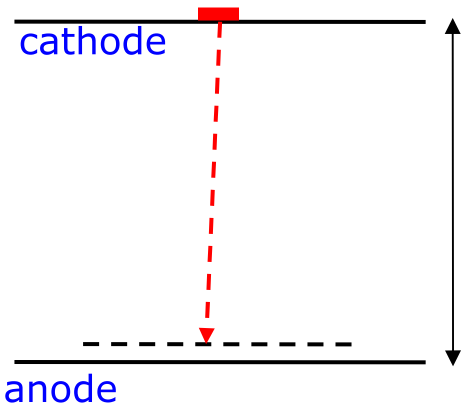
e/recoil discrimination in MIMAC

- High rejection power
- Low energies to be carefully studied

Track : Measurement of electron drift velocity

DATA

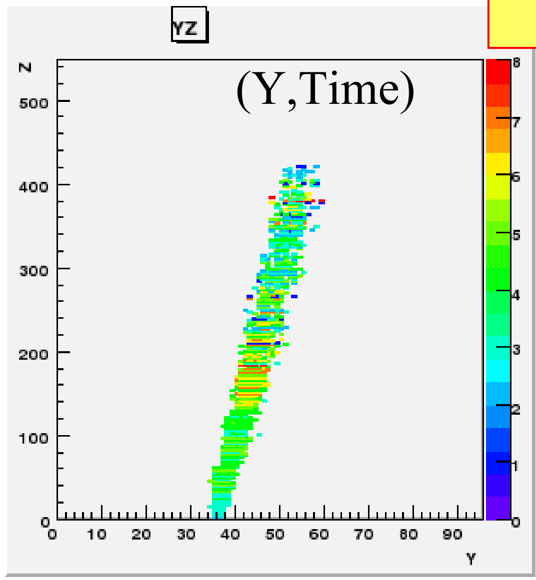
α source ^{241}Am + collimator (A ~ 1 Bq)

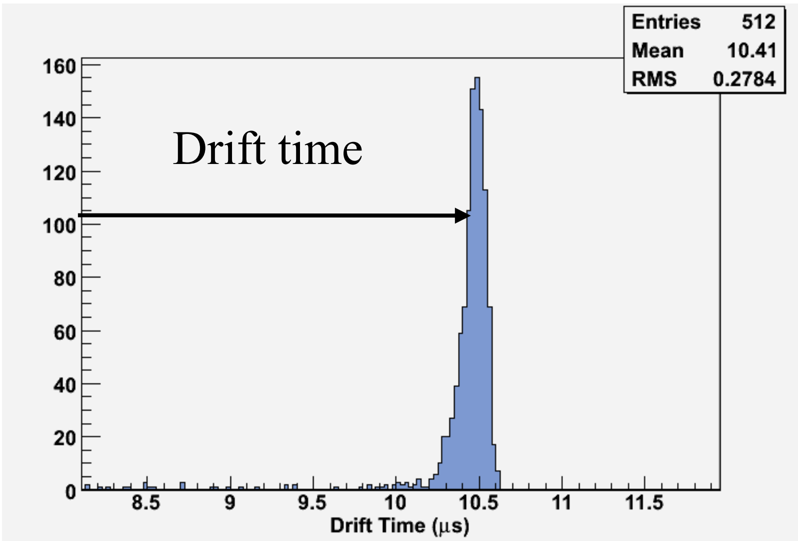


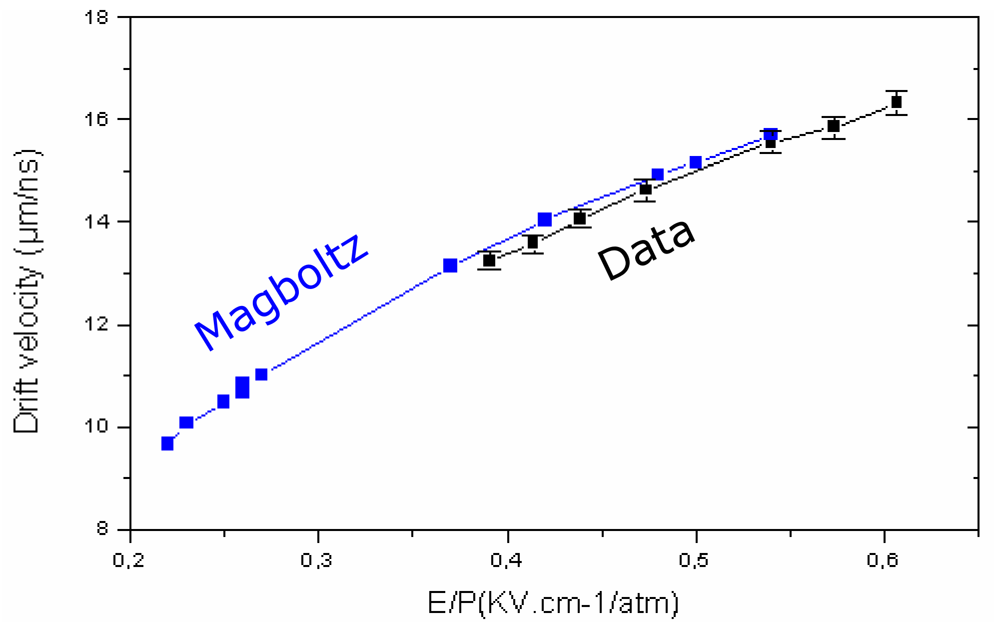
16.5 cm

Drift Time

(~10 μs)







Trace 3D : l'installation Amande

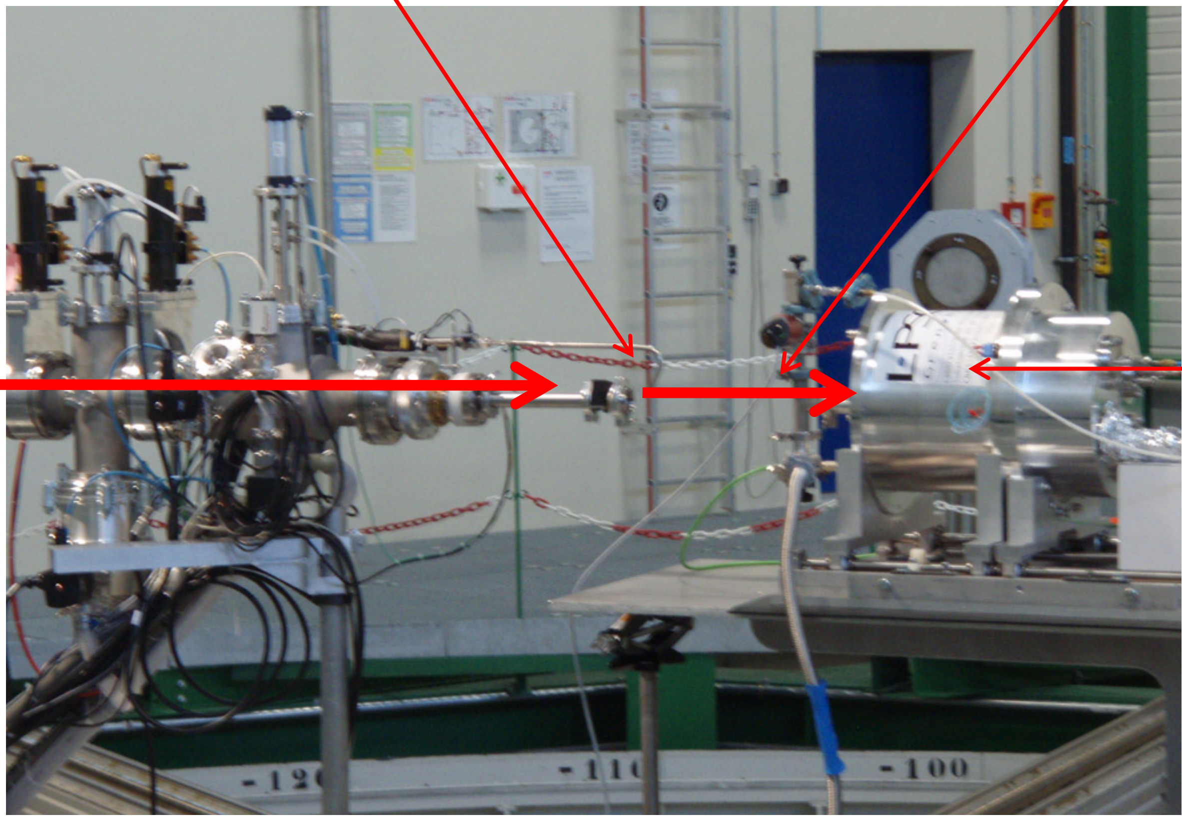
(IRSN Cadarache)

Cible
Sc (n de 8.2 keV)
LiOH (n de 144 keV)

Champ neutronique

Prototype MIMAC
(anode pixelisée)
+ Micromegas bulk

Faisceau
p/D



Trace 3D : l'installation Amande

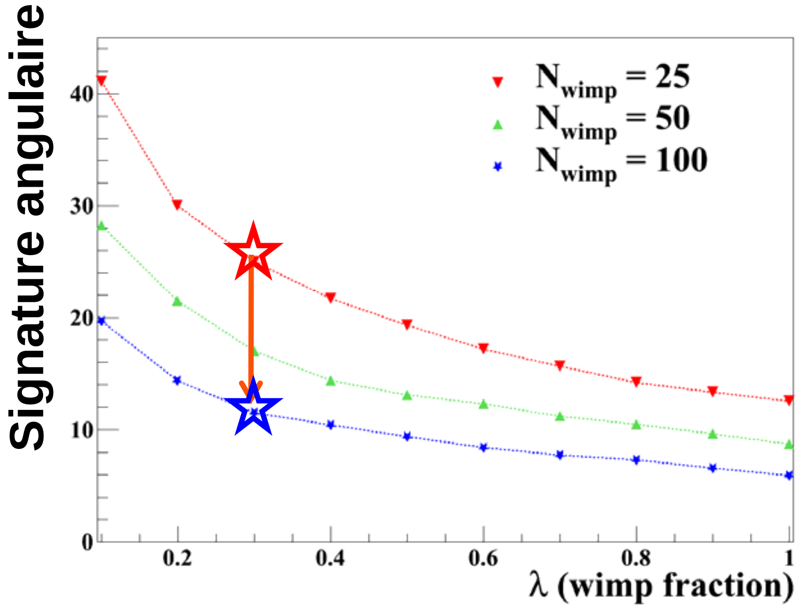
(IRSN Cadarache)

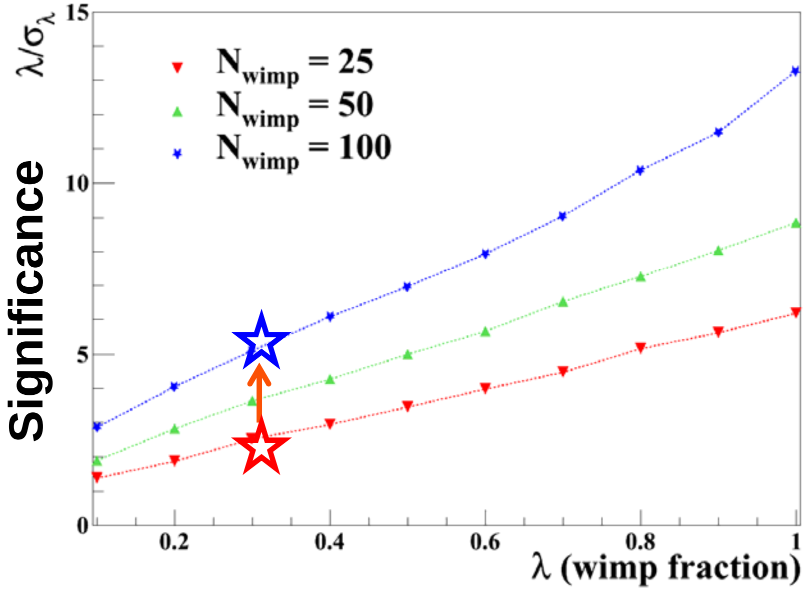
Etudes systématiques

Signature angulaire : $\sigma_\gamma = \sqrt{\sigma_\ell \sigma_b}$

Significance : λ/σ_λ

J. Billard et al., PLB 2010





Résultats satisfaisants sur une large gamme de N_{WIMP} et λ

☆ **Cas exposition faible** : *Détecteur CF4 et 1 kg.an = 25 WIMPs et 50 BDF*

Signal WIMP en direction du Cygne (25°) mais significance faible

➡ **Indication**

☆ **Cas exposition moyenne :** *Détecteur CF4 et 4 kg.an = 100 WIMPs et 200 BDF*

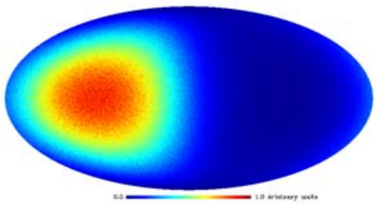
Signal WIMP en direction du Cygne (10°) + forte significance (5σ)

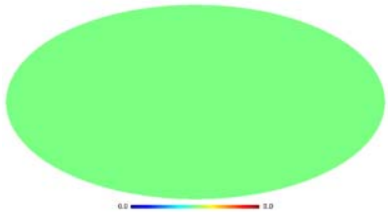
➡ **Découverte de la matière sombre galactique**

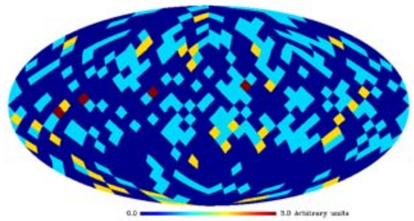
Directional Detection : exclusion

J. Billard *et al.*, PRD 2010

First idea : Directional detection may be used for exclusion







S: WIMP Signal WIMP

B: background

Flat priors and an extended likelihood function

$$L(\mu_s, \mu_b) = \prod_{i=1}^{N_{\text{pixels}}} P\left(\frac{\mu_s}{\mu_s + \mu_b} S_i + \frac{\mu_b}{\mu_s + \mu_b} B_i | M_i \right)$$

Estimate the expected number of WIMP events (μ_s) and Background events : μb

Directional Likelihood method

Considering only the angular part of the event distribution

→*No assumption on the energy spectrum of background*

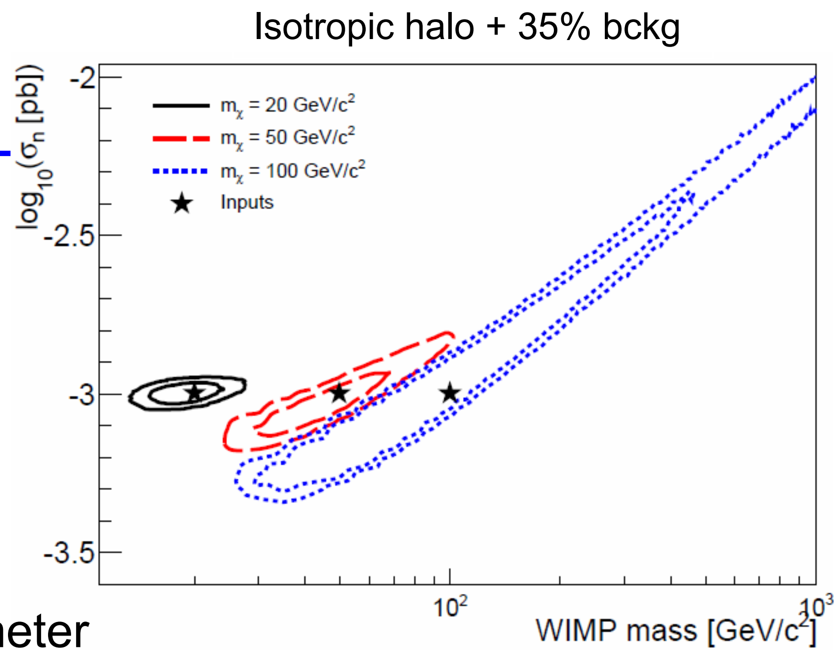
→ *the most conservative approach for optimal directional exclusion*

Identification of DM

J. Billard *et al.*, PRD 2011

Isotropic input halo
with three different masses:

- 20 GeV
- 50 GeV
- 100 GeV

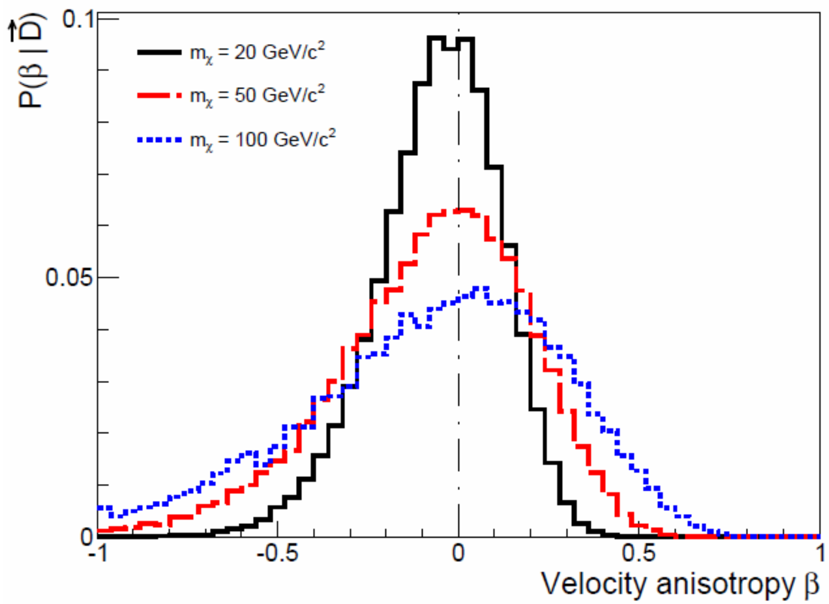


Constraints on the velocity anisotropy parameter

$$\beta(r) = 1 - \frac{\sigma_\theta^2 + \sigma_\phi^2}{2\sigma_r^2}$$

(Deduced from the full MCMC analysis)

Isotropic halo: ß = 0



Constraining the WIMP and halo properties with a single measurement

Identification of DM

J. Billard *et al.*, PRD 2011

Two input halo models

Isotropic (ß = 0)
Anisotropic (ß = 0.4)

→ Similar constraints on (m_X, $log_{10}(\sigma_n)$)

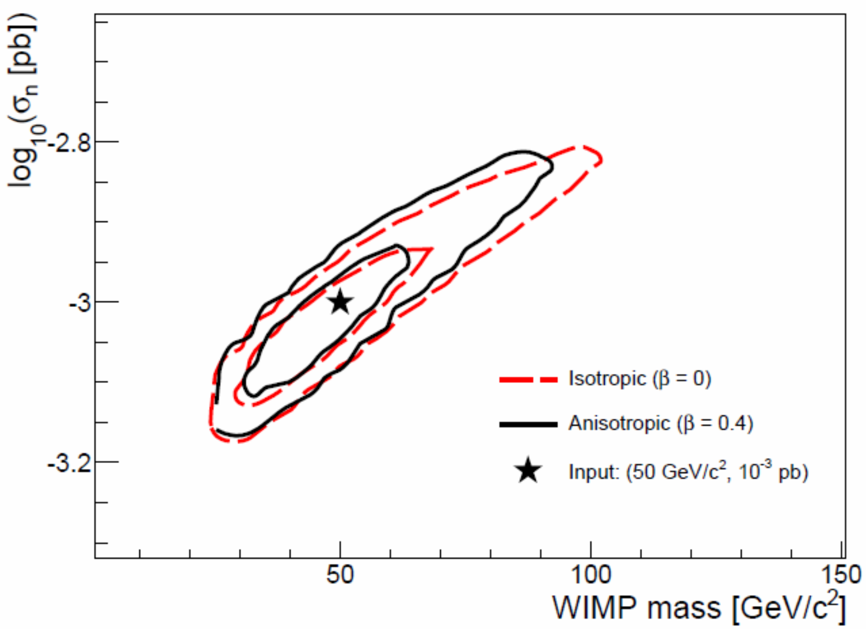
The ß parameter is well constrained:

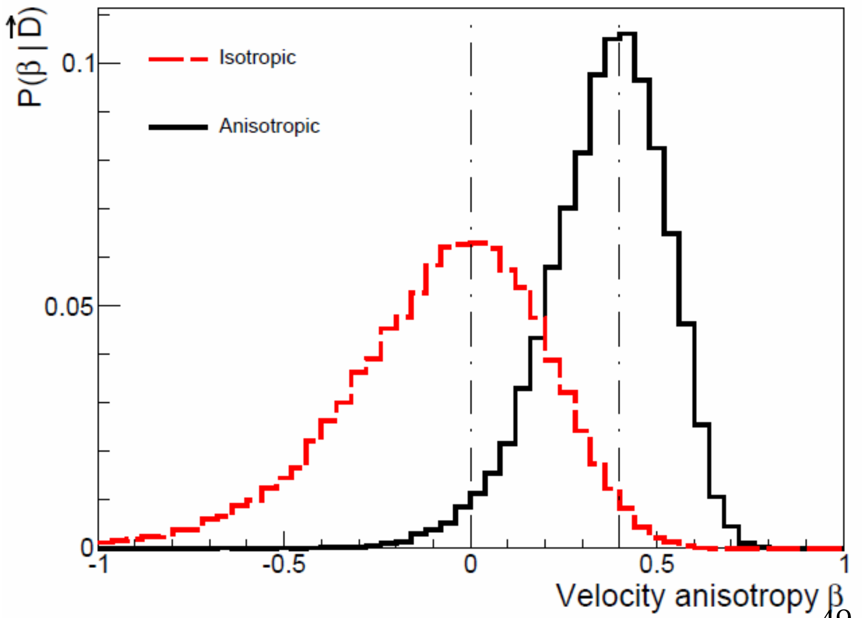
Isotropic → $\beta = -0.073^{+0.29}_{-0.18}$

Anisotropic → $\beta = 0.38^{+0.18}_{-0.10}$

Discrimination between various halo models could be achieved

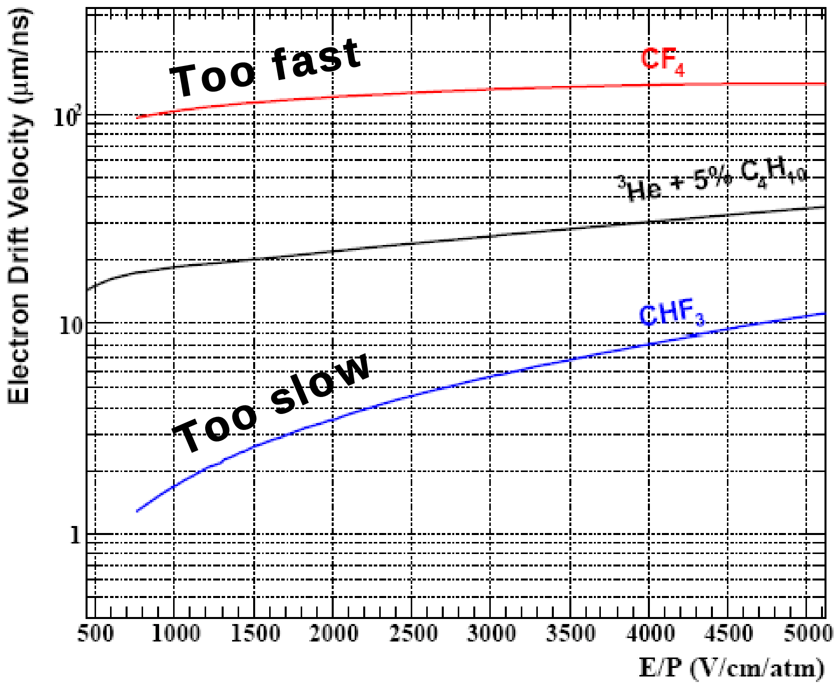
35% of bckg + 50 GeV/c²

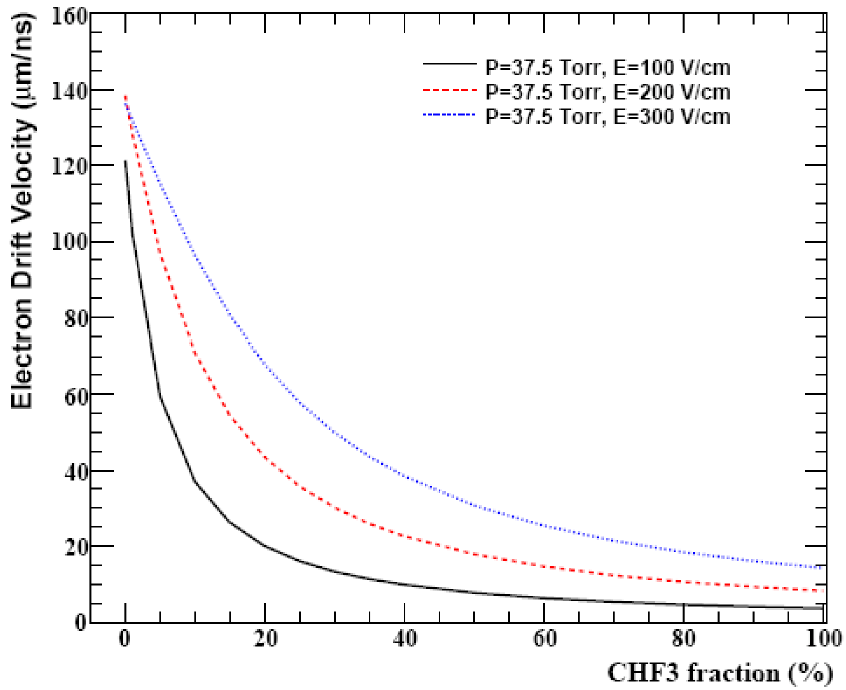




MIMAC : choosing the gaz mixture

Magboltz simulation





- New gaz mixture : CF_4 + 30% CHF_3
  - → *Choice of the electron drift velocity. Fluorine target dominates*
- Mesuaring electron drift velocity : *to be done soon*

SD interaction : spin content

Noyau	J^π	$< S_p >$	$< S_n >$	Ref.	frac. iso.	Expériences
^{3}He	$1/2^+$	-0,021	**0,462**	[42]	100 %	MIMAC
^{19}F	$1/2^+$	**0,441**	-0,109	[43]	100 %	MIMAC, COUPP [44], Picasso [45]
^{73}Ge	$9/2^+$	0,030	**0,378**	[46]	7,73 %	Edelweiss [47], CDMS [48]
^{127}I	$5/2^+$	**0,309**	0,075	[49]	100 %	KIMS [50]
^{129}Xe	$1/2^+$	0,028	**0,359**	[49]	26,4 %	Xenon [51], Zeplin III [52]
^{131}Xe	$3/2^+$	-0,041	**-0,236**	[53]	21,2 %	Xenon [51], Zeplin III [52]
^{133}Cs	$7/2^+$	**-0,370**	0,003	[54]	100 %	KIMS [50]

Détection directe : interaction axiale

Section efficace axiale WIMP-noyau :

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

Section efficace axiale WIMP-nucléon :

$$\sigma_{p,n} = \frac{24}{\pi} G_F^2 \times \mu_p^2 a_{p,n}^2$$

Approximation :

l'interaction est dominée par un des nucléons (a_p =0 ou a_n=0)

La limite obtenue sur un noyau peut être convertie
en limite sur le nucléon (->comparaisons)

$$\sigma_{p,n} = \frac{3}{4} \times \frac{\mu_p^2}{\mu_A^2} \times \frac{J}{J+1} \times \frac{1}{< S_{p,n} >^2} \times \sigma_{p,n}^A$$

Comparaisons indépendantes du modèles

E. Moulin, F. Mayet and D. Santos, Phys. Lett. B **614** (2005) 143
D. R. Tovey *et al.*, Phys. Lett. B **488** (2000) 17

Sans approximation, le résultat expérimental $\sigma^A < \sigma^{A(lim)}(m_\chi)$ devient, pour une masse de WIMP donnée :

$$\left(\langle S_p\rangle\sqrt{\sigma_p} \pm \langle S_n\rangle\sqrt{\sigma_n}\right)^2 < \frac{3}{4} \times \frac{\mu_p^2}{\mu_A^2} \times \frac{J}{J+1} \times \sigma_A^{lim}(m_\chi)$$

2 cas selon les signes relatifs de $a_n < S_n >$ et $a_p < S_p >$

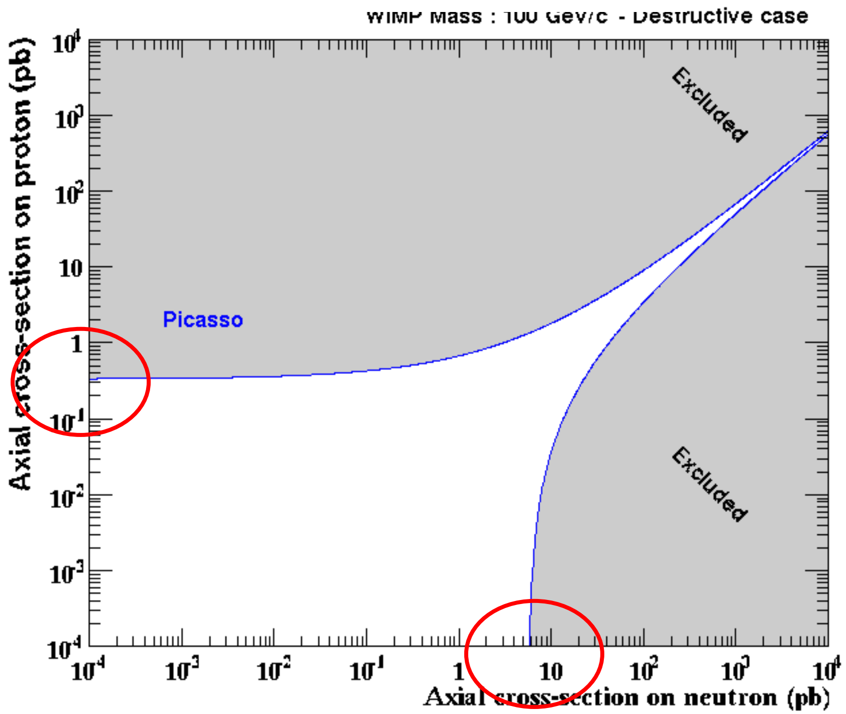
- Indépendant du modèle
- lourd à gérer (σ_p, σ_n, m_χ)

Comparaisons indépendantes du modèles

E. Moulin, F. Mayet and D. Santos, Phys. Lett. B **614** (2005) 143
D. R. Tovey *et al.*, Phys. Lett. B **488** (2000) 17

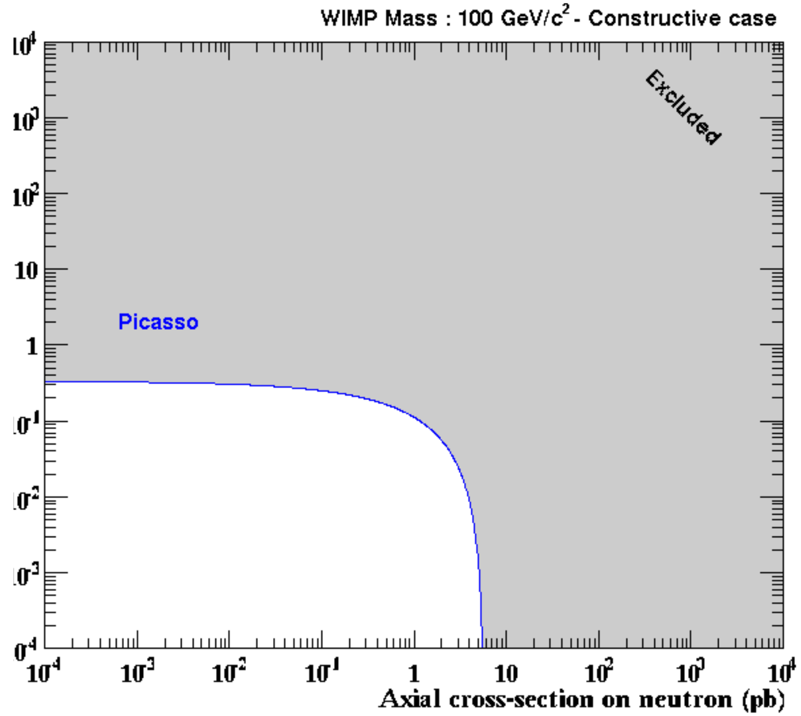
Cas destructif :

$a_p\langle S_p\rangle$ et $a_n\langle S_n\rangle$
de signes opposés



Cas constructif :

$a_p\langle S_p\rangle$ et $a_n\langle S_n\rangle$
de mêmes signes



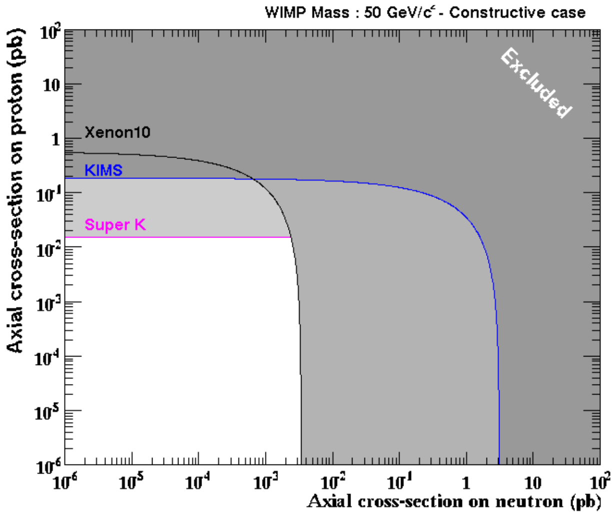
Détection directe : état de l'art (ap/an)

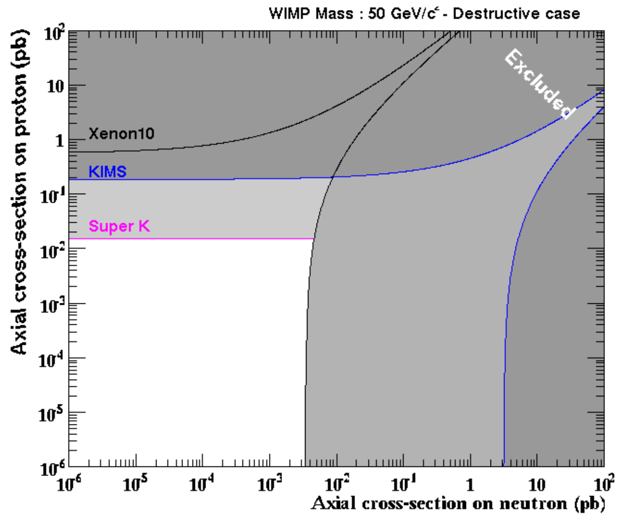
Cas constructif :

$a_p\langle S_p\rangle$ et $a_n\langle S_n\rangle$ de mêmes signes

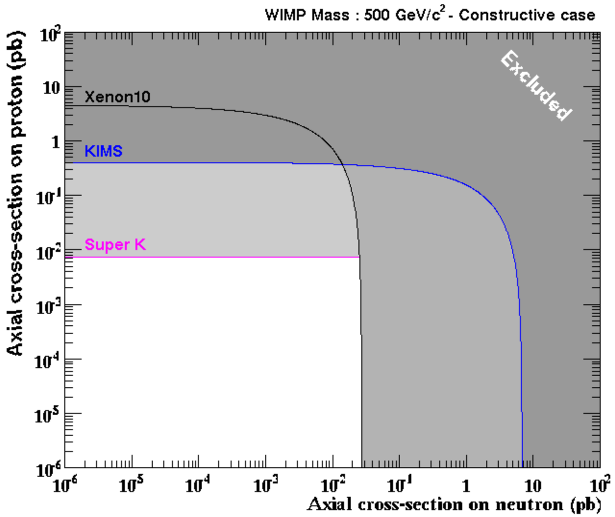
Cas destructif :

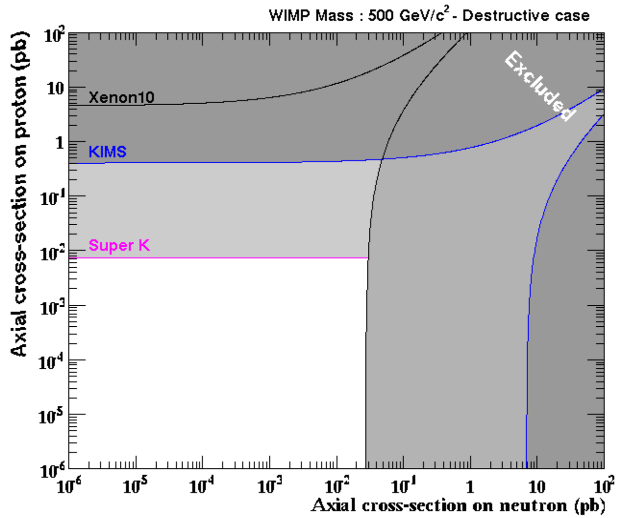
$a_p\langle S_p\rangle$ et $a_n\langle S_n\rangle$ de signes opposés





WIMP 50 GeV/c²





WIMP 500 GeV/c²

SD interaction

D. R. Tovey *et al.*, PLB 2000
E. Moulin *et al.*, PLB 2005

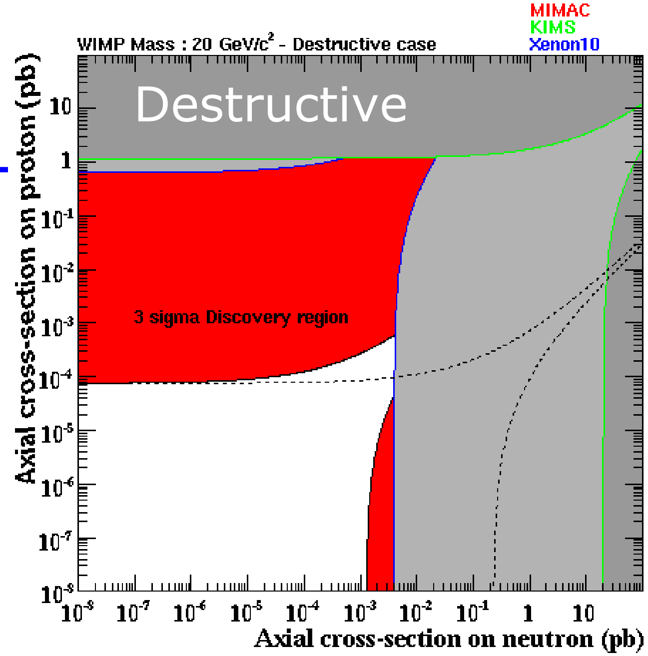
Results on SD interaction should be treated « à la Tovey », *i.e.* model-independent formalism

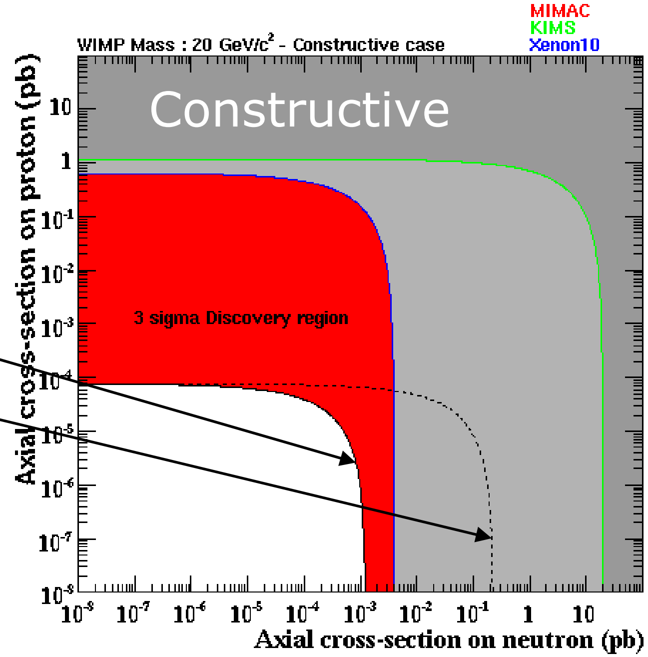
$$\left(\langle S_p\rangle\sqrt{\sigma_p} \pm \langle S_n\rangle\sqrt{\sigma_n}\right)^2 < \frac{3}{4} \times \frac{\mu_p^2}{\mu_A^2} \times \frac{J}{J+1} \times \sigma_A^{lim}(m_\chi)$$

→ constructive and destructive cases

^{19}F : spin content

Modèle	$< S_p >$	$< S_n >$
odd-group	0.5	0.
Pacheco & Strottman	0.441	-0.109
Divari *et al.*	0.475	-0.0087



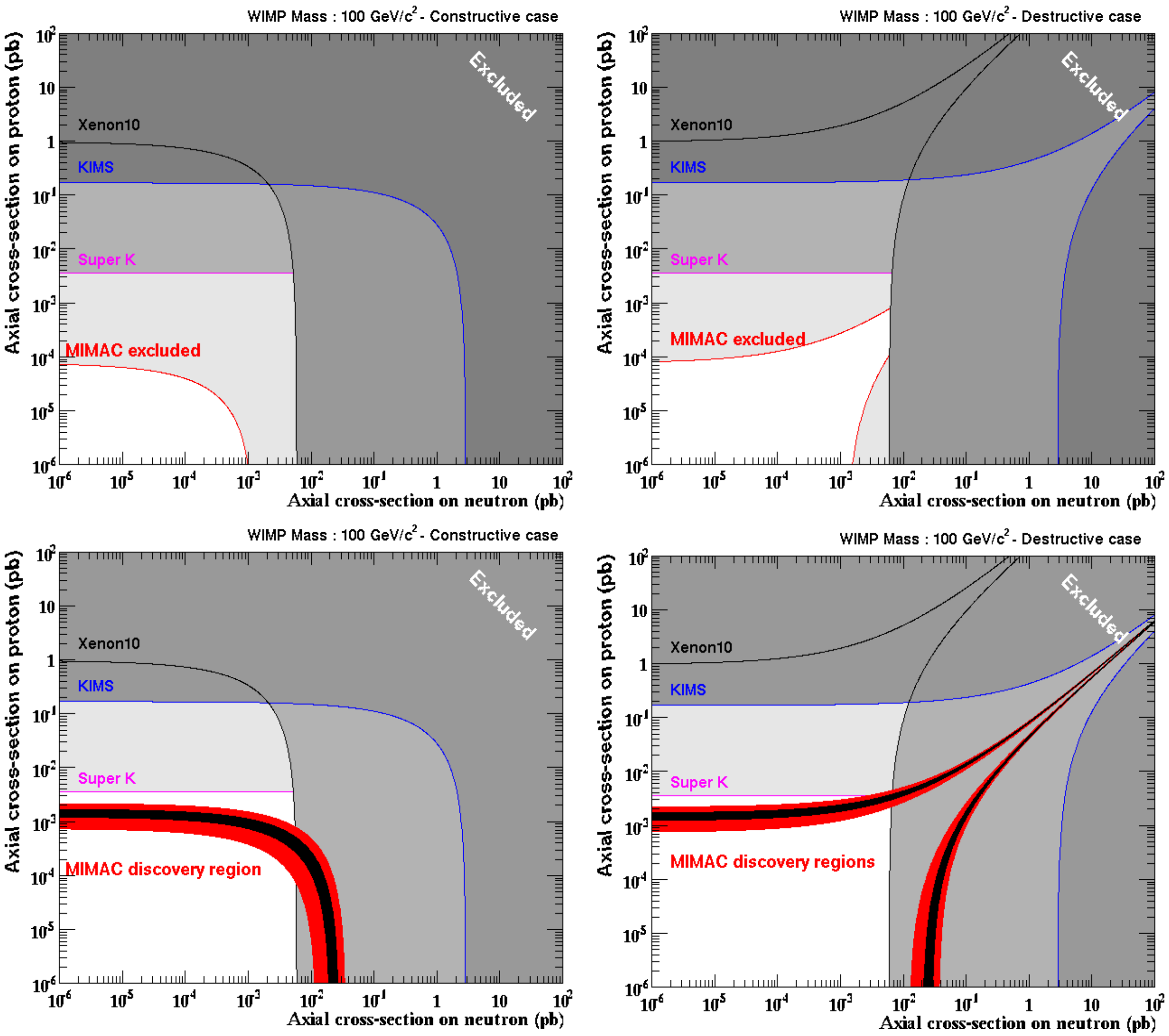


Knowledge of target spin content

Major issue (nuclear physics one)

… but not only for directional detection

Détection directionnelle : Exclusion/Découverte



- σ négligeable
- 300 BDF

- CF_4 10 kg 3 ans

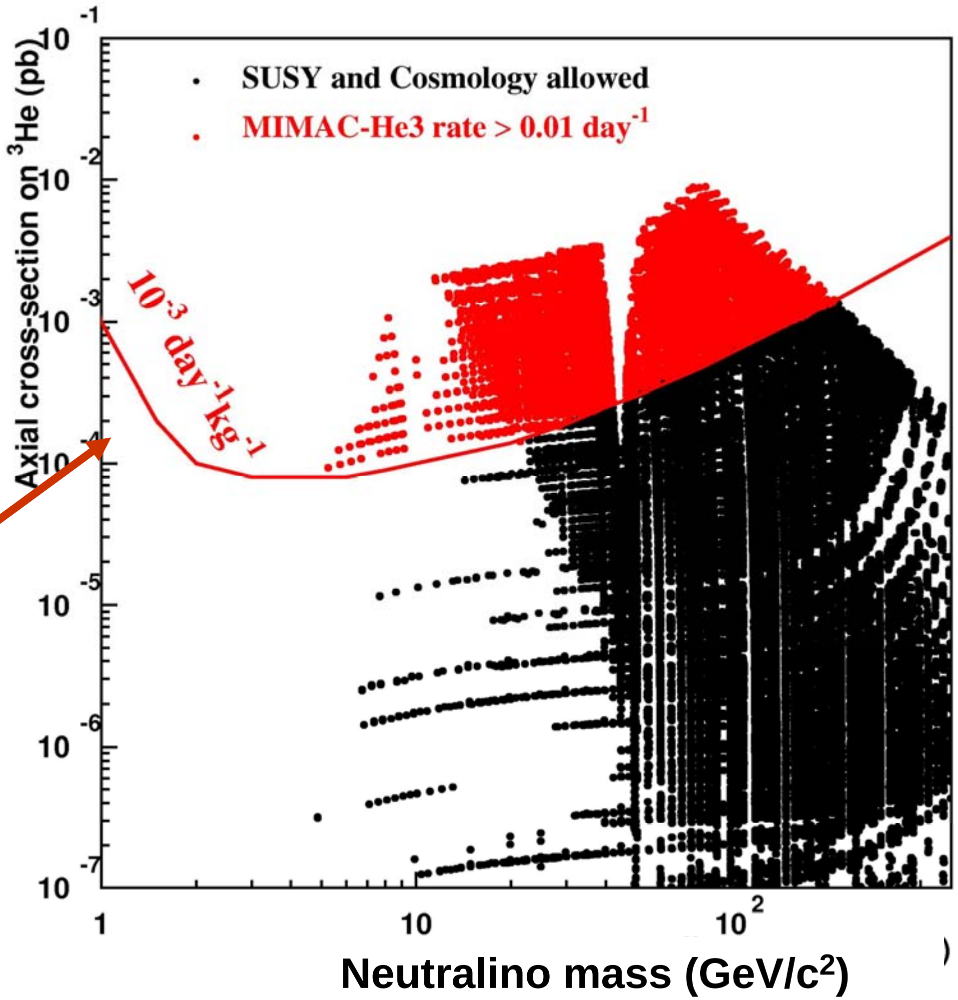
- σ=1.5x10^{-3} pb (proton)
- WIMP 100 GeV
- 100 BDF + 100 WIMP

- CF_4 10 kg <u>5 mois</u>

Cross section ^3He-χ and event rate in MIMAC-He^3 (10kg)

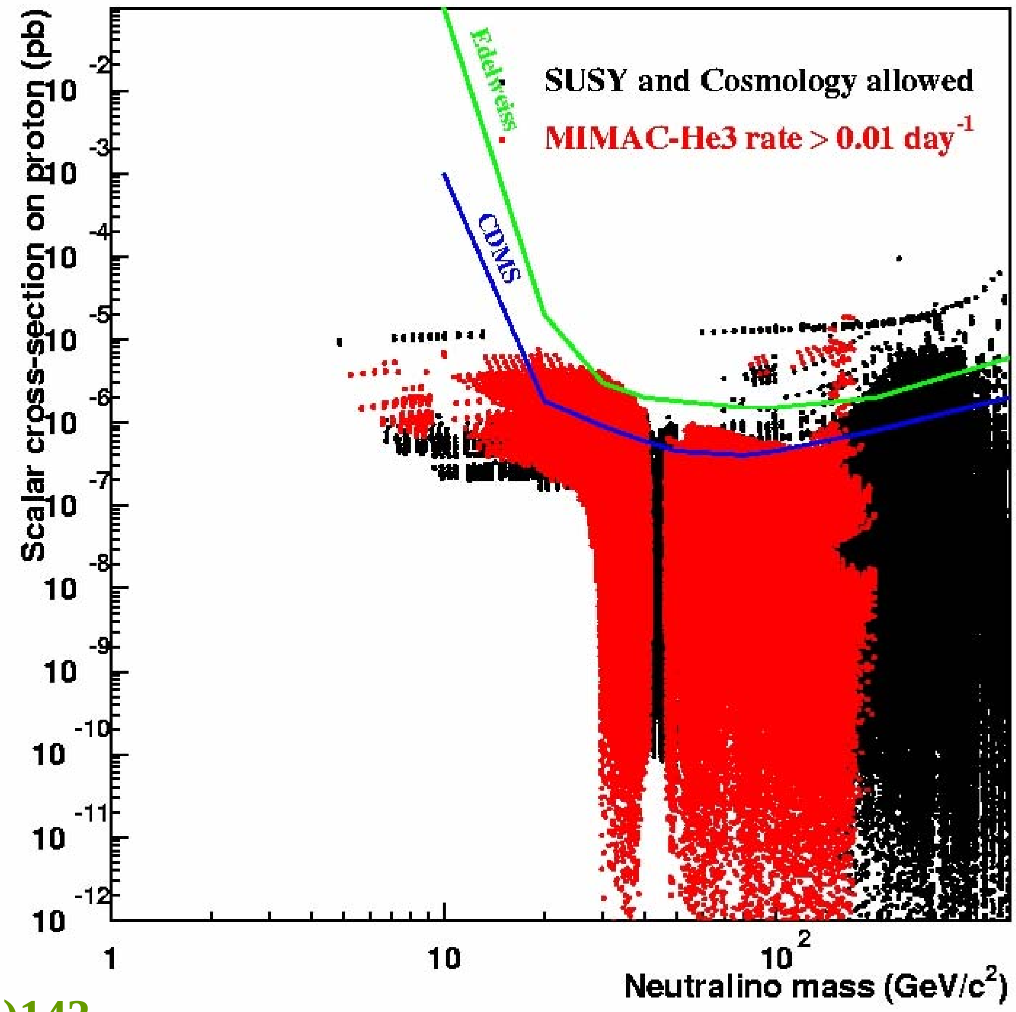
- $0.02 < \Omega_\chi h^2 < 0.15$
- Accelerator constrains

Exclusion curve for background 10^{-3} $kg^{-1}jour^{-1}$



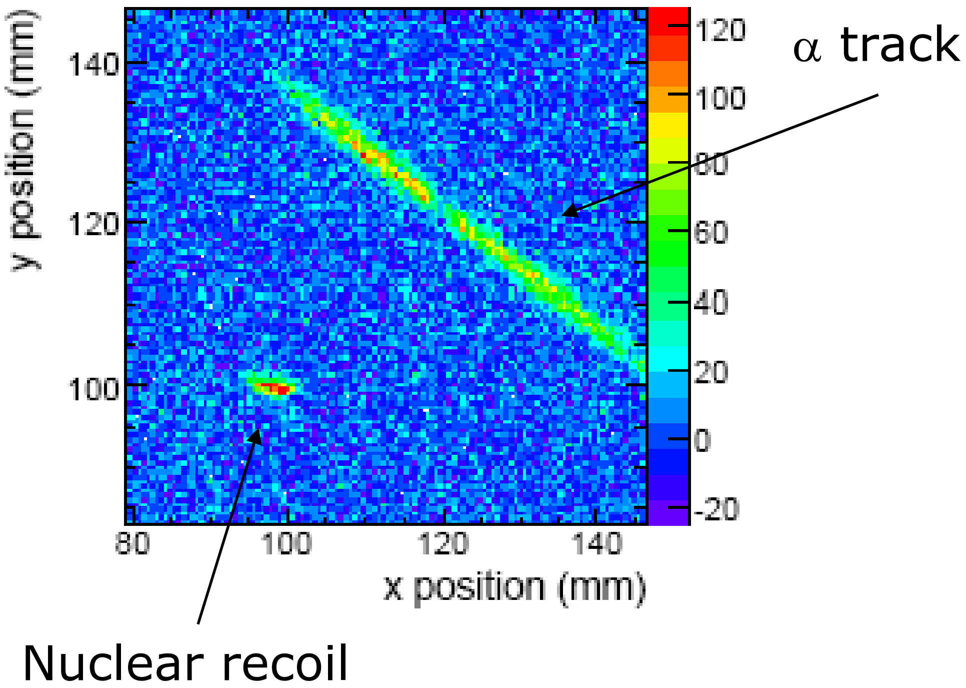
Complementarity with scalar detection

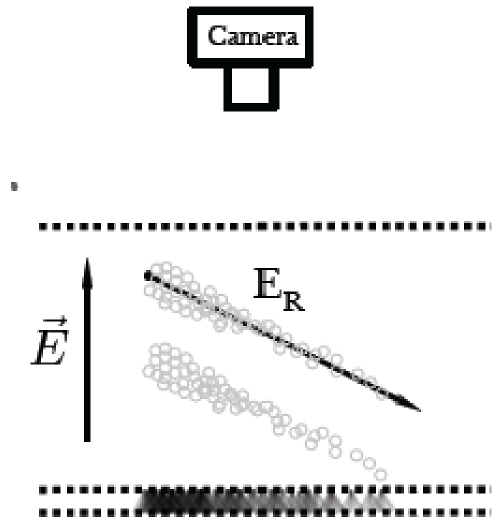
σ_{SD} and σ_{SI} not correlated



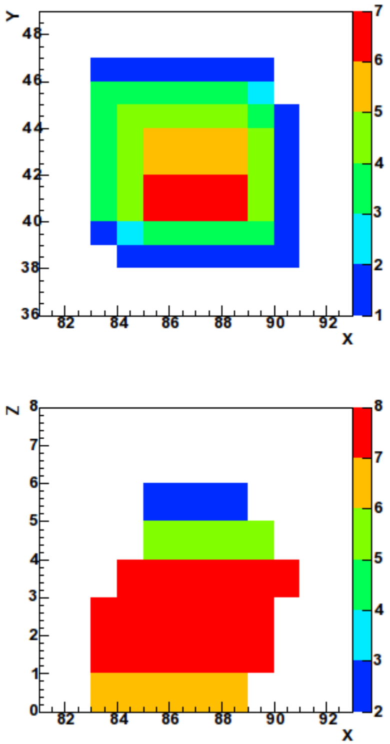
E. Moulin et al, PLB 614 (2005)143

State of the art : DM-TPC





Trace 3D : proton de 30 keV dans iC_4H_{10} pur

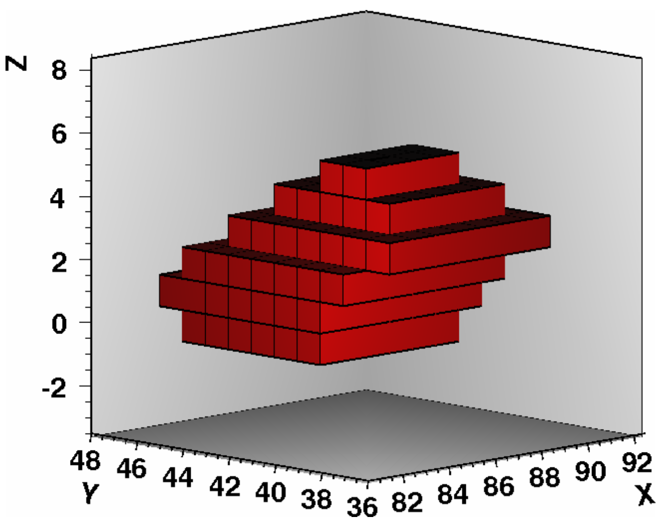


100% iC_4H_{10}

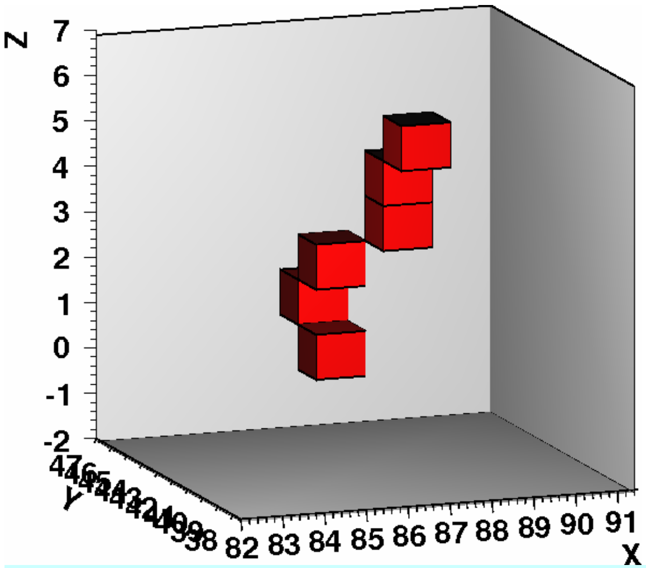
50 mbar,

150 V/cm

30 keV



Reconstruction brute



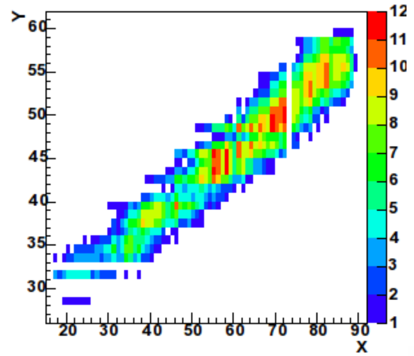
Reconstruction « barycentres »

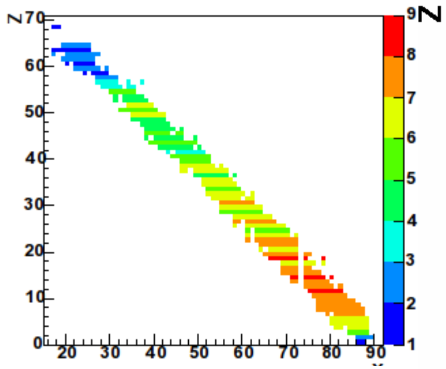
Trace 3D : **Alpha 5,5 MeV** (^{222}Rn)

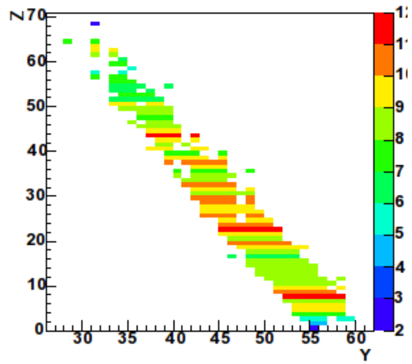
He + 5% iC_4H_{10}

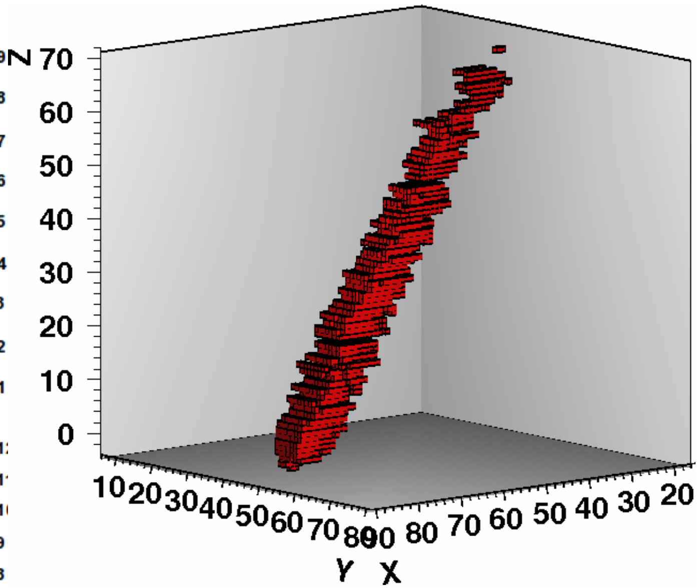
350 mbar,

150 V/cm

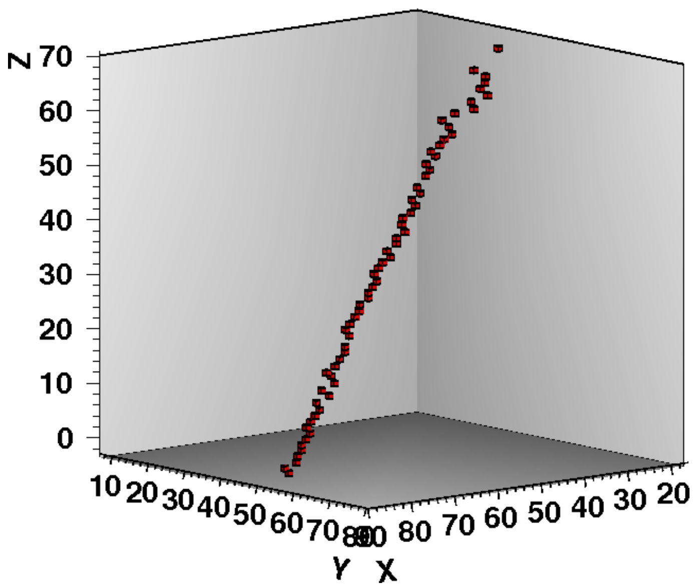








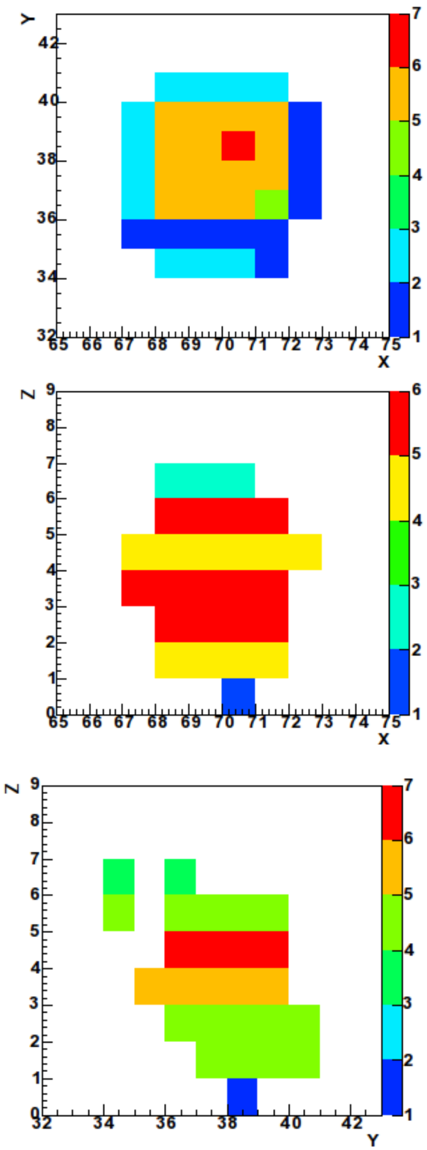
Reconstruction brute



Reconstruction « barycentres »

Basses energies ?

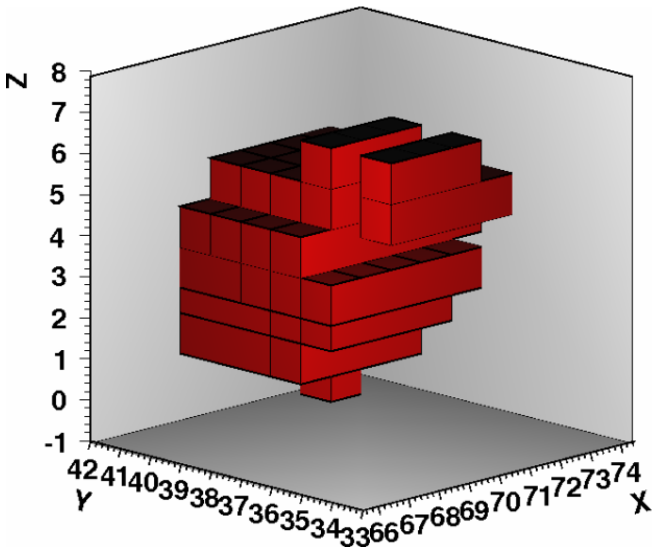
Trace 3D : proton 8 keV dans He + 5% iC_4H_{10}



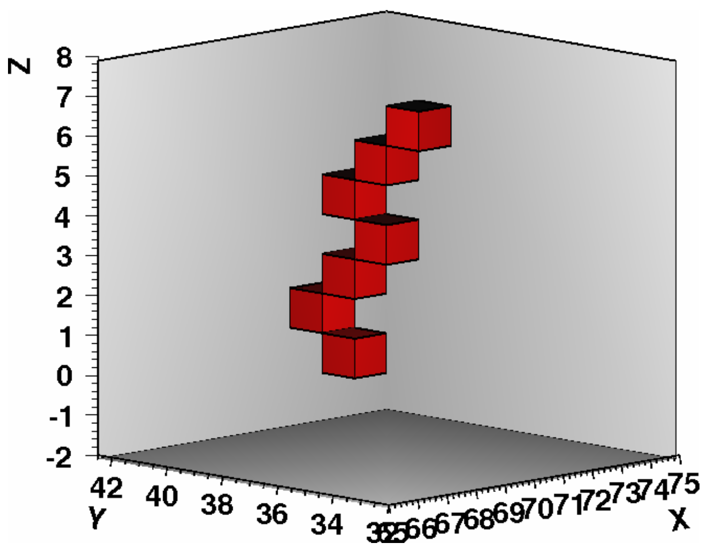
He + 5% iC_4H_{10}

350 mbar,

150 V/cm

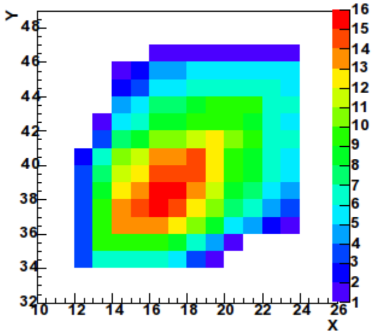


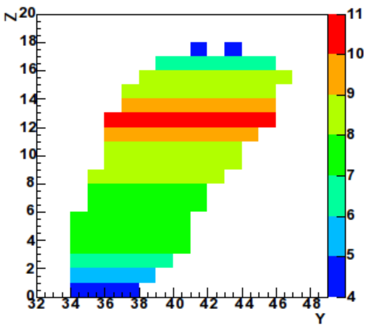
Reconstruction brute



Reconstruction « barycentres »

Trace 3D : proton 180 keV dans iC_4H_{10} pur



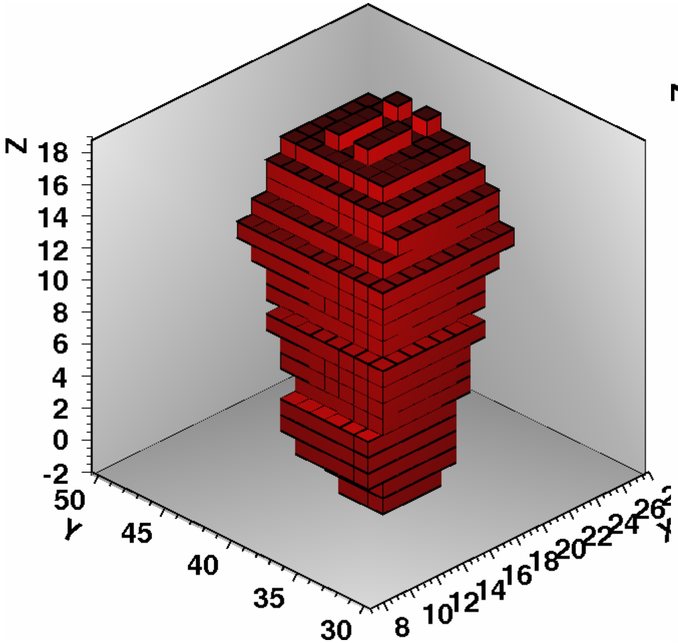


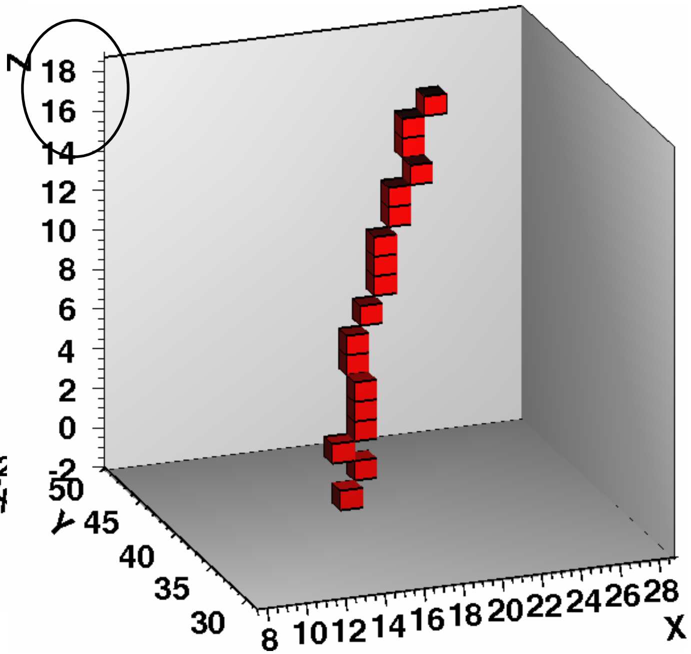
100% iC_4H_{10}

50 mbar,

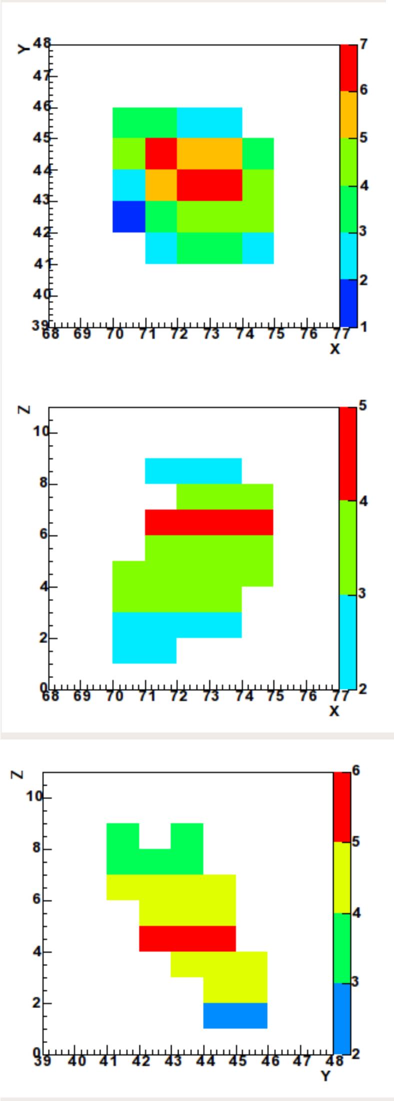
150 V/cm

Recul de ~180 keVl





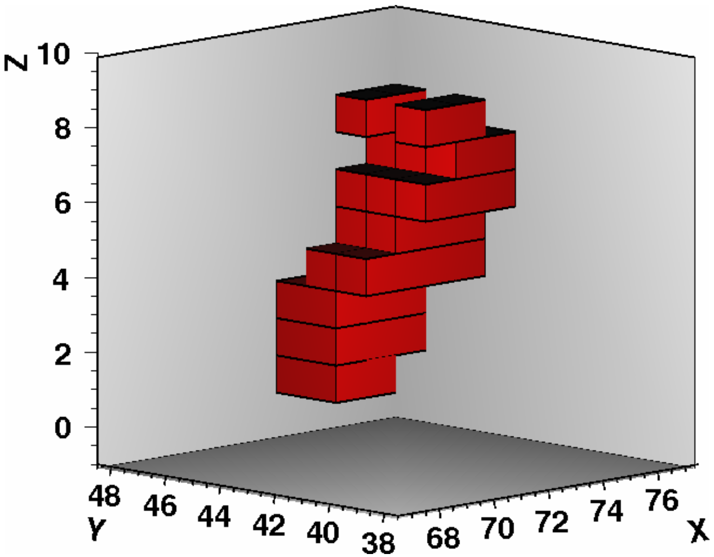
Trace 3D : **Fluor** dans 70 % CF_4 + 30% CHF_3

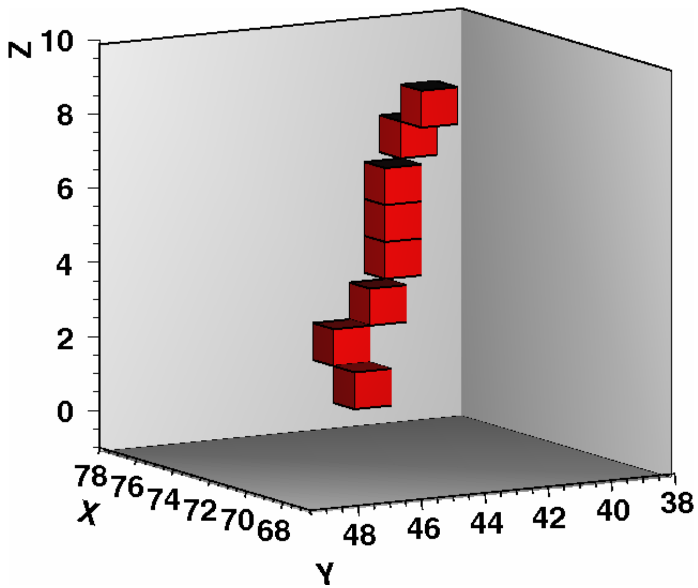


70 % CF_4 + 30% CHF_3

55 mbar,
170 V/cm

~50 keV (ionisation), 3 mm

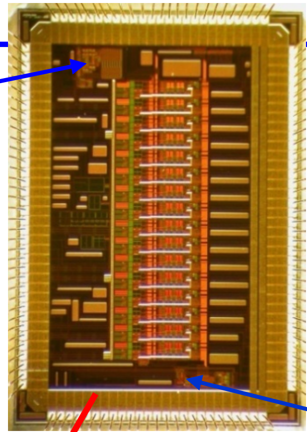




MIMAC : electronics & DAQ

O. Bourrion *et al.*, NIM 2010
J. P. Richer *et al.*, NIM 2010

Mixer & shaper → Energy



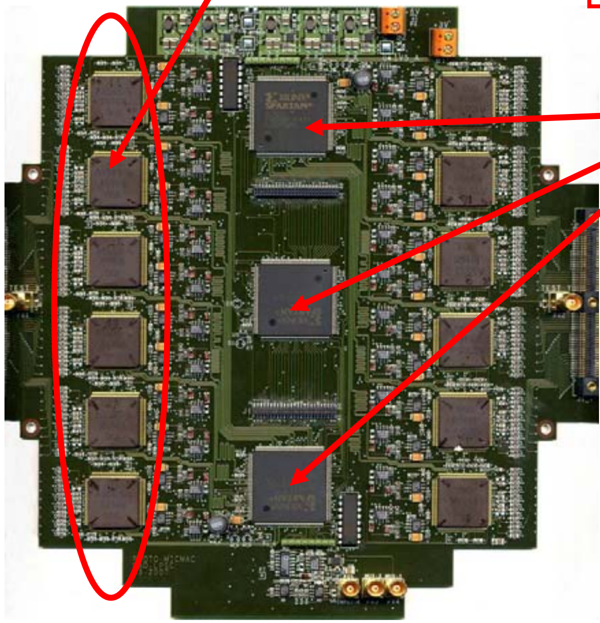
Self-triggered electronic for Anode sampling @ 50 MHz

16 channels:

Charge sensitive preamplifiers
+
Current comparators
+
5 bit DACs

3250µm x 4700µm
[area ~ 15 mm^2]

Serializer (Position)



X, Y and central FPGA

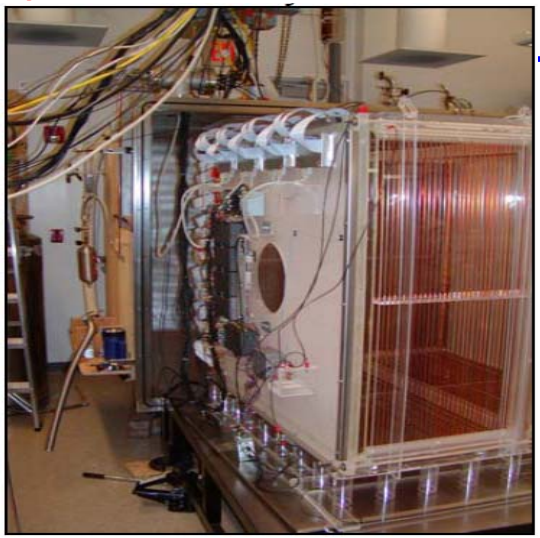
Six **ASIC** for each side

Total of 192 channels

The 3 **FPGA** process, concentrate and time sort data for each side

First version running (8 ASIC, total of 512 channels)

II. Current projects and detectors status

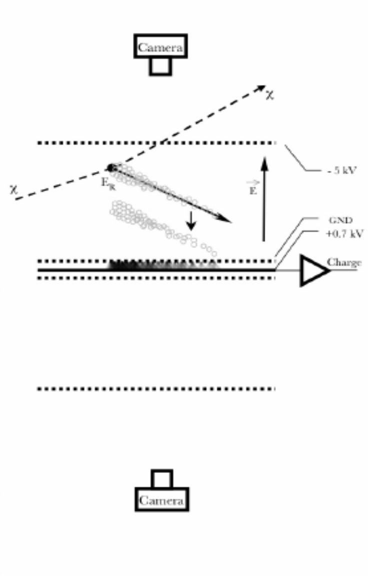


DRIFT *(Rutherford & Imperial. Coll., London & Occidental. Coll & Sheffield U. & Edimburg U. & New Mexico U.)*

m^3 MultiWire Proportional Counter

- S target nucleus with CS2 gaz
- Drift of negative ions CS2 with 3D reconstruction

DM-TPC *(MIT, Cambridge & Boston U., Boston & Brandeis U., Waltham)*



Time Projection Chamber (prototype)

- CF4 gaz at 75 torr
- Dual TPC with 2 CCD Camera read out => 2D track reconstruction

NEWAGE Results : Miuchi, PLB 2007

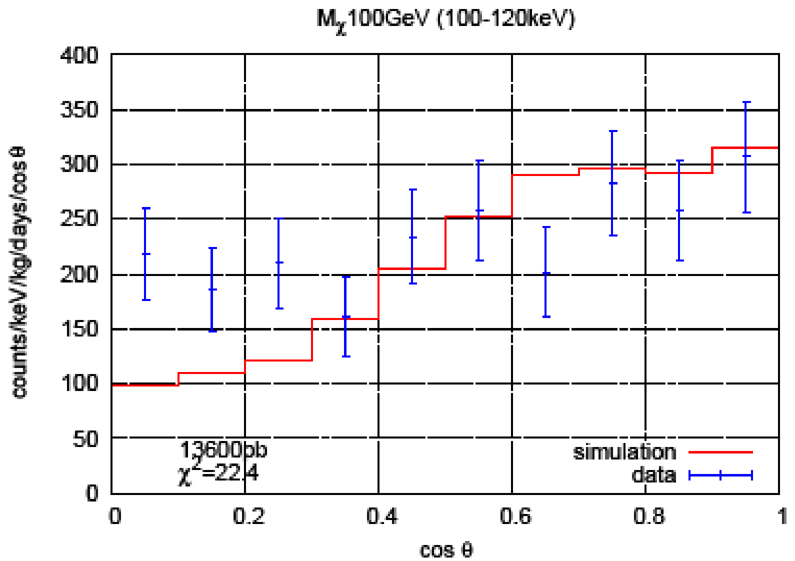


Fig. 8. Measured (with error bars) and expected (histogram) distribution of the angle between the recoil direction and the WIMP direction. The expected histogram is that with M_χ=100GeV, 100–120 keV bin, and 1.36×10^4pb.

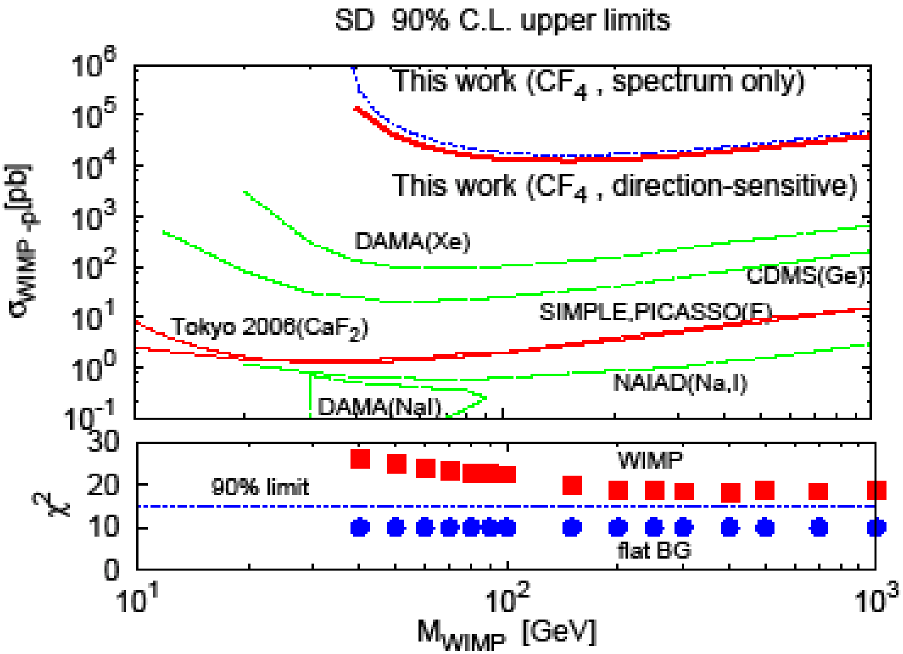
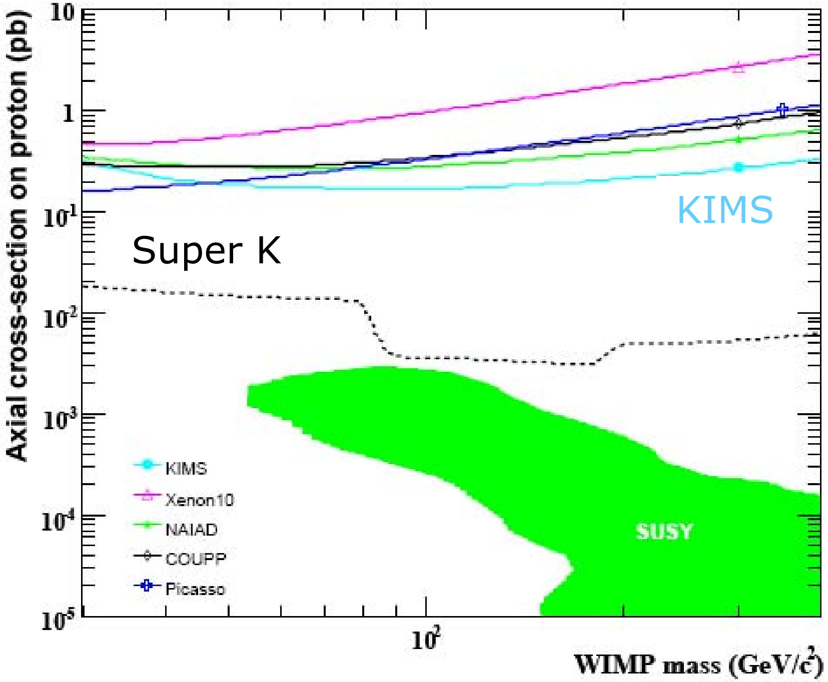


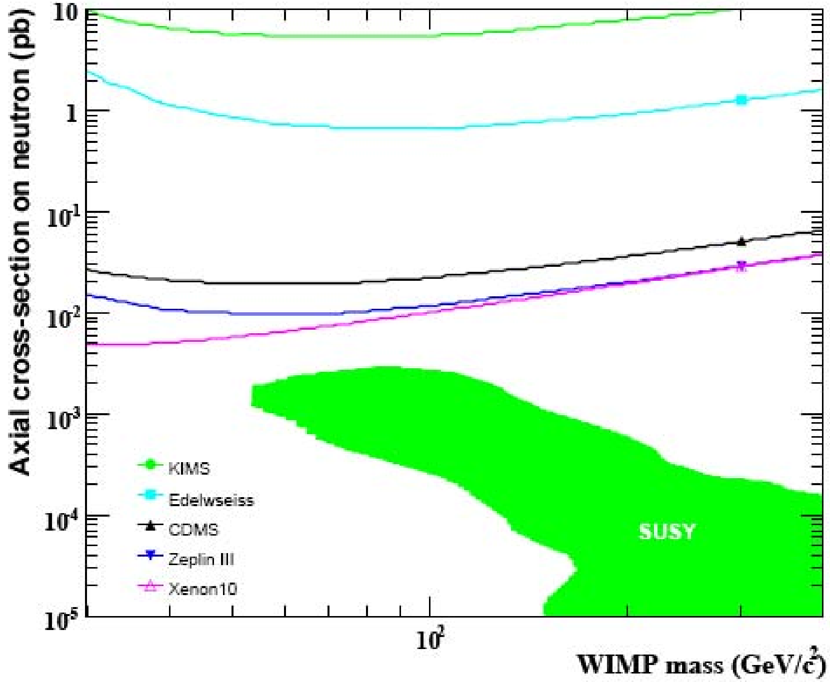
Fig. 9. 90% C.L. upper limits on the WIMP-proton spin-dependent cross section (upper) and χ^2 values (lower) as functions of the WIMP mass. The thick solid and dotted lines show the limits obtained with and without the direction information, respectively. Limits from other experiments (DAMA(Xe)[3], DAMA(NaI)[4], NAIAD[5], Tokyo CaF_2[7], SIMPLE 2005[10], PICASSO[11], and CDMS[12]) are shown for comparison. The filled squares show the χ^2 minimum values of the best–fit WIMP distribution, the filled-circles show the best-fit flat cos θ distribution, and the dotted line show the χ^2 values at the 90% C.L. upper limit.

SD interaction : state of the art

Proton SD interaction



Neutron SD interaction



SUSY Zone : SuperBayes (Trotta *et al.*)

MSugra + colliders + (WMAP)

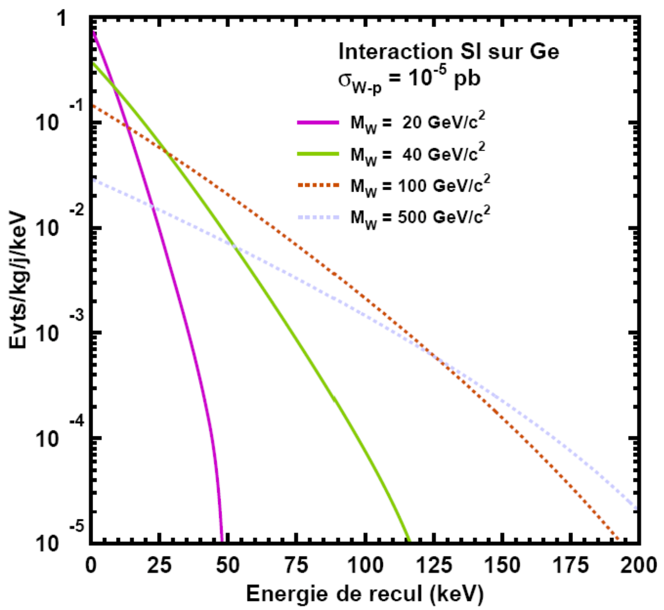
Détection directe : identification ?

Peut-on identifier un signal WIMP ?

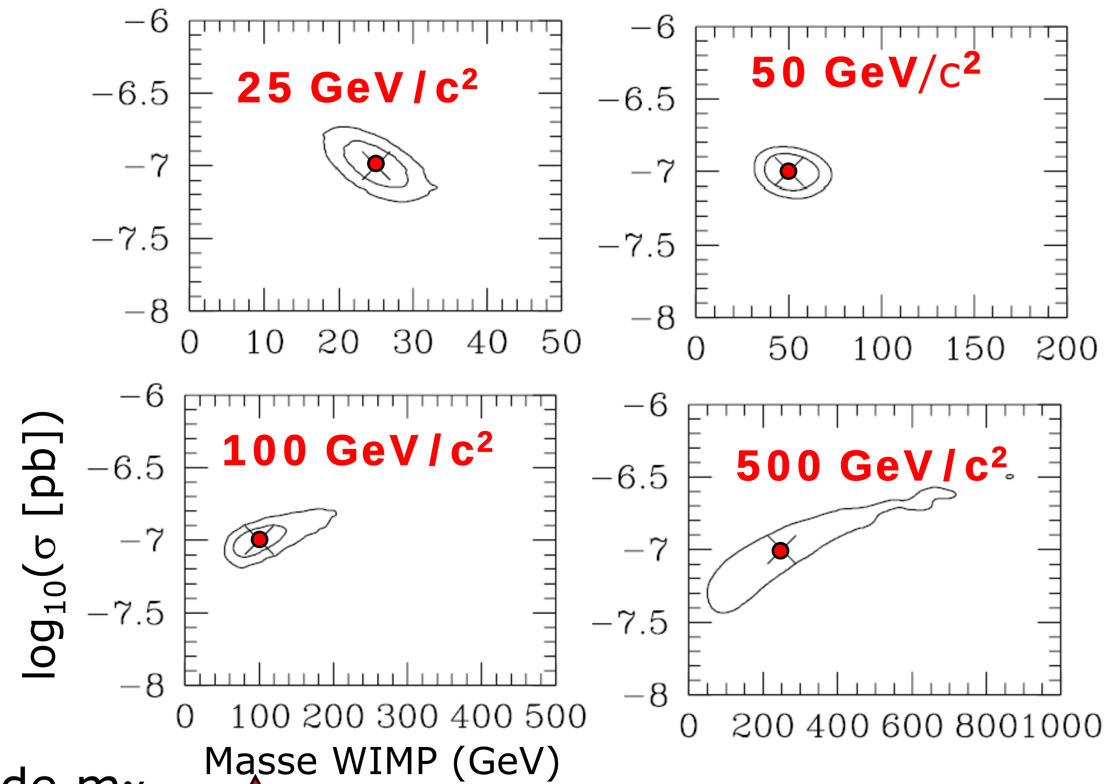
… et mesurer sa masse, sa section efficace ?

• Sans bruit de fond : **OUI**

Thèse V. Sanglard



A. M. Green, JCAP **0708** (2007) 022, JCAP **0807** (2008) 005



Ge + seuil 10 keV + 3000 kg.jour

dR/dE dépend fortement de mχ

Analyse de vraisemblance

Directional Detector specifications

To achieve such results, a directional detector should be able to :

Major experimental issues

- measure both the energy and the 3D track

  … down to low energy

  → low pressure TPC (50-200 mbar)

  → measure tracks of a few mm and a few keV

- perform sense recognition on tracks

  If not measured : need to be carefully handled by data analysis (with an expected downgrade of performance)

- use known (*i.e. measured*) values of the quenching factor ($E_{ioni} \rightarrow E_{recoil}$)

  Cf. debate on Xenon quenching factor…

Minor experimental issues

- mesure track (3D+energy) with a good angular/energy resolution