Results of direct searches for dark matter with EDELWEISS and other experiments

Séminaire Greco - 22 mars 2010

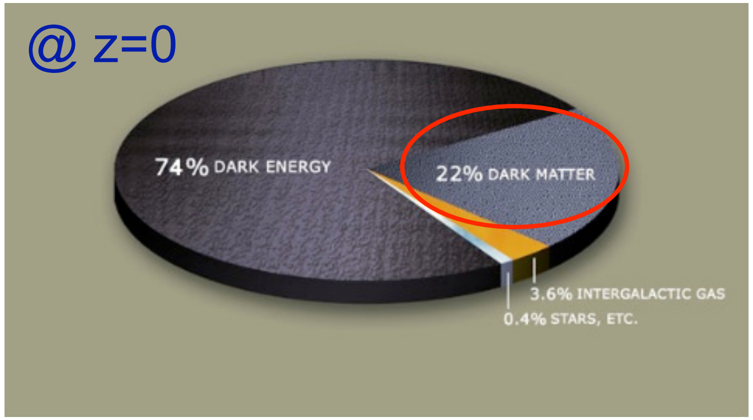
Eric Armengaud - CEA / IRFU

Edelweiss

Expérience pour DEtecter Les WIMPs En Site Souterrain

- « Phenomenology » of direct detection
  - Specifications / challenges for the experiments
- Noble liquids (XENON10 / current status of XENON100)
- Bolometers (latest results of EDELWEISS / CDMS)

Which dark matter for ΛCDM ?



- Galactic/cluster dynamics
- Structure formation $\delta \sim 10^{-5} \rightarrow \delta \sim 1$

⇒ Cold, collisionless, stable mass

- $\Omega_M > \Omega_b$ (primordial nucleosynthesis, CMB)

⇒ Non-baryonic mass, probably « out of Standard Model » ($\Sigma m_\nu \leq$ eV)

- New field(s) of « gravitationnal » nature = modified gravity (MOND etc)
  - justified by obs. galactic dynamics + Λ + …

- « SuperWIMPs » eg. gravitino, axino (SUSY)
- Supermassive relics (M_{Pl})
- Axions : Peccei-Quinn axions (QCD) or ALPs

- The « WIMP miracle » : *thermal relic hypothesis* :

  $\Omega_{DM} \sim 0.3 \Rightarrow <\sigma_{ann} v> \sim 3 \times 10^{-26}$ cm^3/s weak interactions, M~100 GeV (Weakly Interacting Massive Particles)
  - neutralino [SUSY models]
  - LKP [UED models]
  - …

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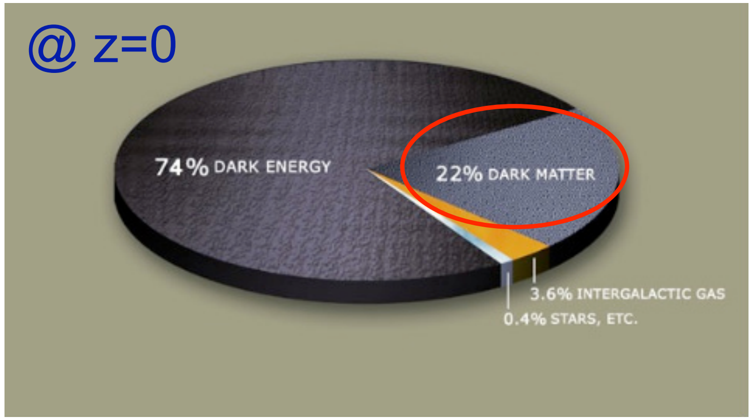
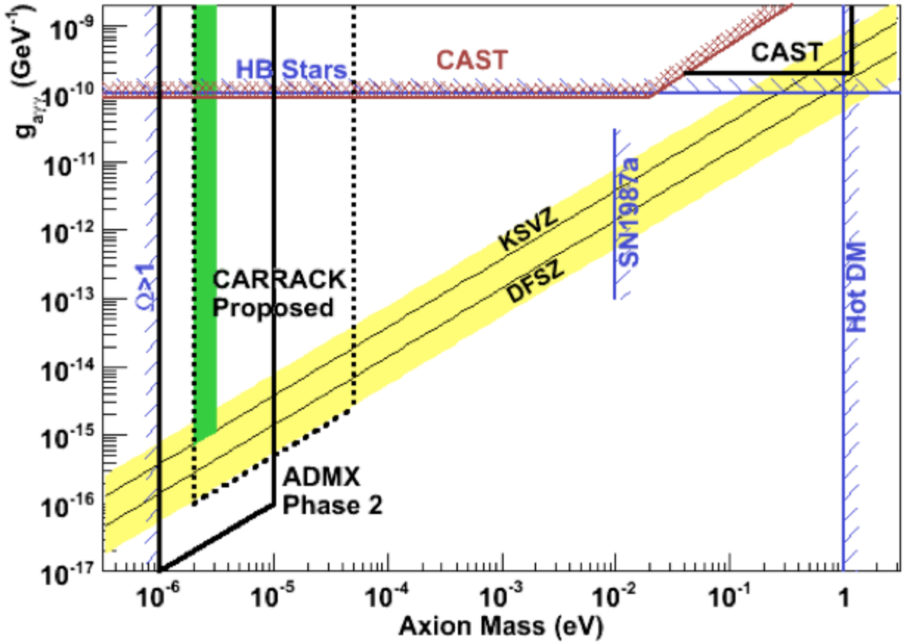


Direct detection of axions : resonant cavities



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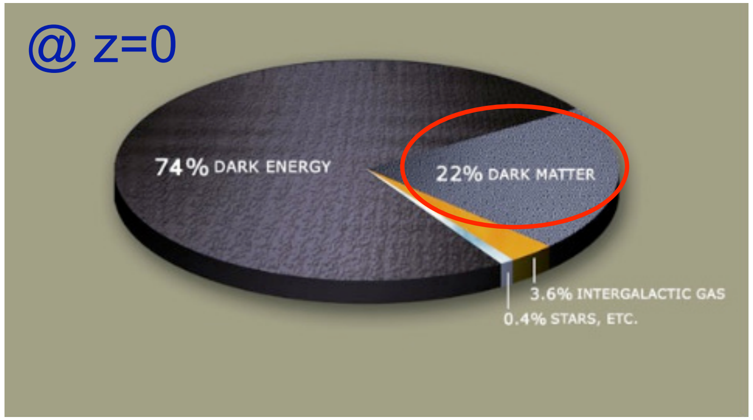

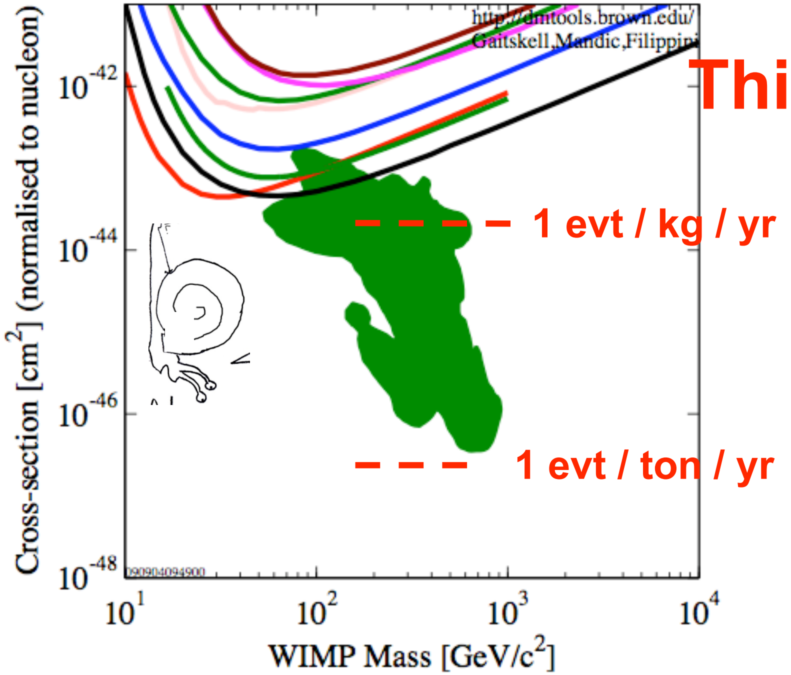

This talk

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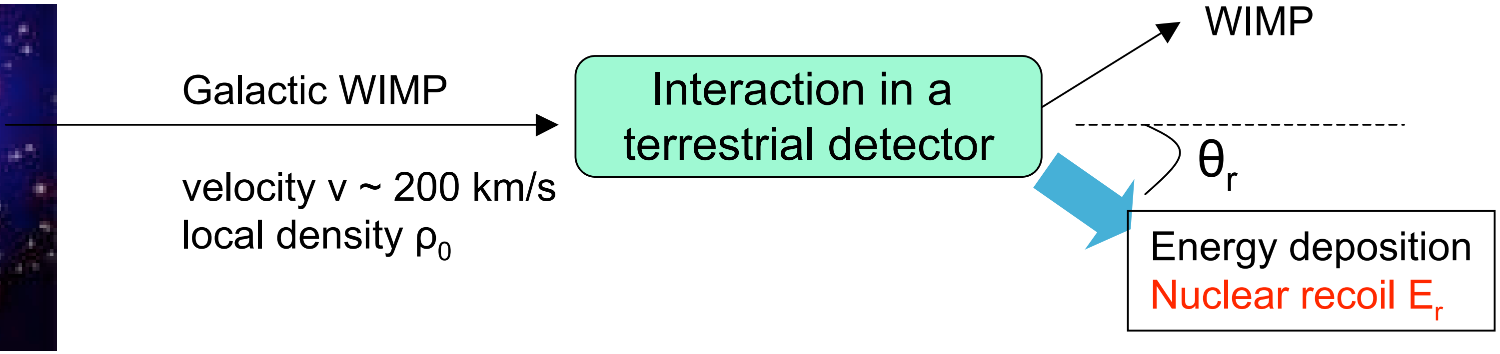
Principle of WIMP direct detection



Galactic WIMP

velocity v ~ 200 km/s
local density ρ_0

Interaction in a terrestrial detector

WIMP

θ_r

Energy deposition
Nuclear recoil E_r

- Relevant parametres:

- **mass m_χ ~ 10 GeV to 10 TeV** for usual extensions of the Standard Model
- **WIMP-nucleon cross-section σ**, weakly contrained but of the order of EW scale

Measure an interaction rate $R(E_{recoil}) \Rightarrow$ contraint on (m_χ,σ)

Non-relativistic diffusion:

$$E_r = \left(\frac{m_\chi}{2} v^2\right) \times \frac{4 m_N m_\chi}{(m_N + m_\chi)^2} \times \cos^2 \vartheta_r \quad \sim 1 - 100 \text{ keV}$$

➡ **Low-threshold detectors**
Ultra-low-background detectors

Interaction rate:

$$R \sim \frac{\rho_0 \sigma v}{m_\chi m_N} \sim 0.04 \left(\frac{100}{A}\right)\left(\frac{100\,GeV}{m_\chi}\right)\left(\frac{\sigma_0}{10^{-8}\,pb}\right)\left(\frac{\rho_0}{0.3\,GeV\,cm^{-3}}\right)\left(\frac{v_0}{230\ km\,s^{-1}}\right) \quad kg^{-1}day^{-1}$$

WIMP direct detection

- Cross-section: $$\frac{d\sigma}{dq^2} \equiv \frac{\sigma_0}{4\,m_r v^2} F^2(q)$$ *σ_0=total cross-section for F(q)=1 only*

- Local WIMP distribution: $$\frac{dn_{WIMP}}{dv\,d^3r} = \frac{\rho_0}{m_\chi} f_1(v)$$ *v = velocity relative to the observer*

⇒ $$\boxed{\frac{dR}{dE_r} = \frac{\sigma_0\,\rho_0}{2\,m_\chi m_r^2} F^2(q) \int_{v_{\min}}^{\infty} dv \frac{f_1(v)}{v}}$$ $$v_{\min} = \sqrt{\frac{m_N E_r}{2\,m_r^2}}$$

- Standard halo: $$f_1 = k \times \frac{v^2}{v_0^3} e^{-v^2/v_0^2}$$ with $$v_e = v_0(1.05 + 0.07\cos\omega t)$$

Galactic Sun rotation

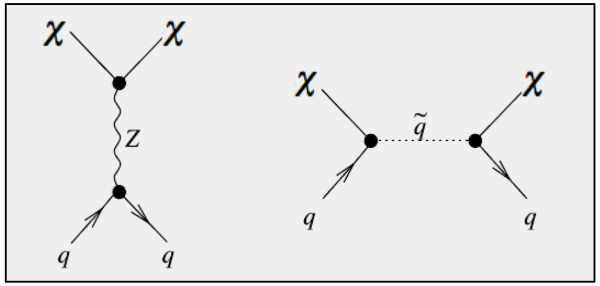
Earth annual rotation

⇒ $$\frac{dR}{dE_r} = \frac{\sigma_0\rho_0}{4v_e m_\chi m_r^2} F^2(q)\left[erf\left(\frac{v_{\min}+v_e}{v_0}\right) - erf\left(\frac{v_{\min}-v_e}{v_0}\right)\right]$$ *~ exponential shape*

- Correction due to galactic escape velocity : truncate f(v)
- **dR/dE depends on time : annual (quasi-sinusoidal) modulation expected ~ 7% (depending on Er)**

WIMP-nucleon cross-section : example of the neutralino

- Vector coupling (Z exchange) : none here (neutralino = Majorana fermion)
- « Axial » coupling :



$$L_{q\chi} = d_q\left(\bar{\chi}\gamma^{\mu}\gamma_5\chi\right)\left(\bar{q}\gamma_{\mu}\gamma_5 q\right)$$

Use $\langle n|\bar{q}\gamma^{\mu}\gamma_5 q|n\rangle = 2S^{\mu}\Delta q^{(n)}$ ↘

Hadron physics (lepton - proton diffusion)

$$\Rightarrow \quad L_{n\chi}^{eff} = \left(\bar{\chi}\gamma^{\mu}\gamma_5\chi\right)\left(\bar{n}\gamma_{\mu}\gamma_5 n\right)\underbrace{\sum_{q=u,d,s} 2d_q\Delta q^{(n)}}_{\equiv 2\sqrt{2}\,G_F a_{(n)}}$$

Summation over nucleons:

$$\frac{d\sigma}{dq^2} = \frac{8}{\pi v^2}G_F^2\,\Lambda^2 J(J+1)\frac{S(q)}{S(0)} \qquad \text{with} \qquad \Lambda = \frac{a_p\langle S_p\rangle + a_n\langle S_n\rangle}{J}$$

^{73}Ge : $S_p = 0$, $S_n = 0.23$
^{131}Xe : $S_p = -0.04$, $S_n = -0.24$
^{19}F : $S_p = 0.46$, $S_n = 0$

} *Use isotopes with appropriate spins*

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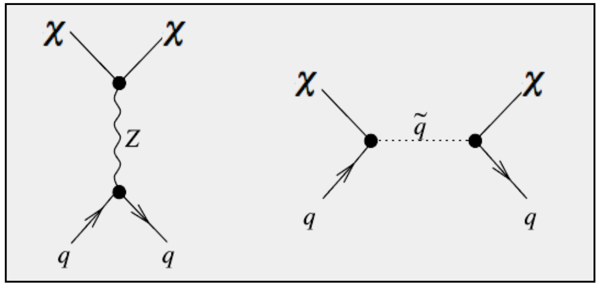

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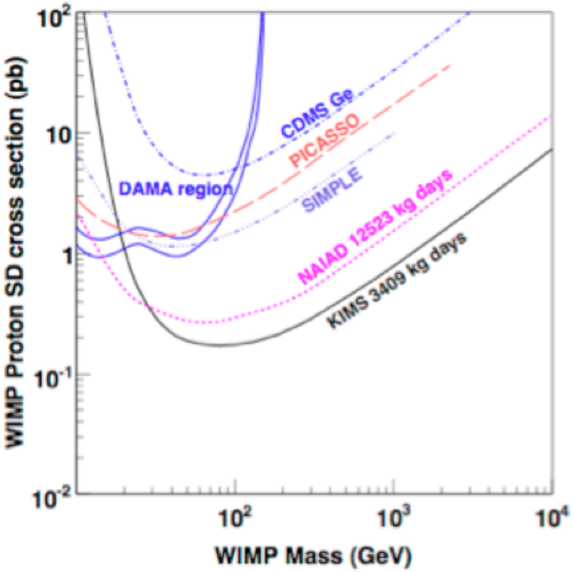
Constraint (σ_p,m) or (σ_n,m)



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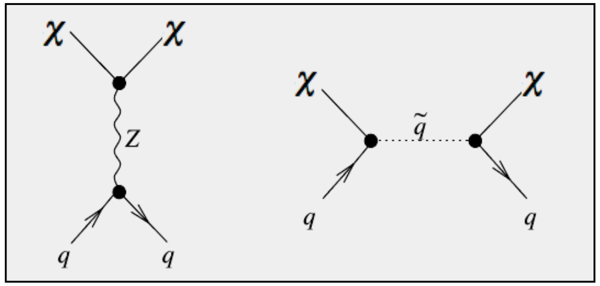

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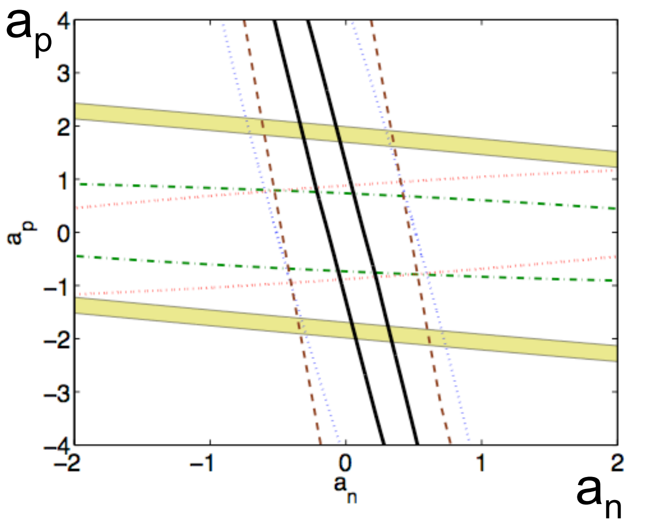
Equivalent : Constraint (a_p,a_n)



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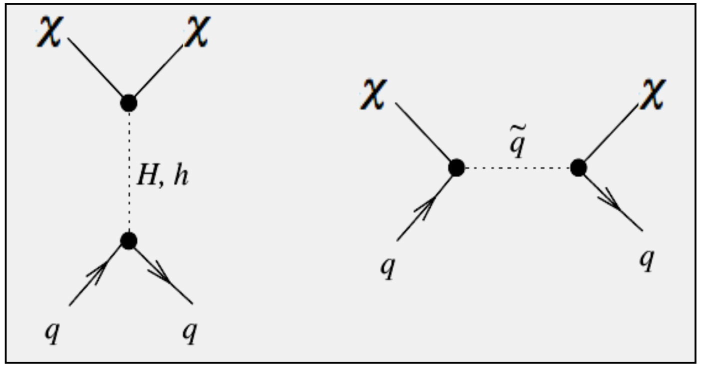
Use isotopes with appropriate spins

WIMP-nucleon cross-section : example of the neutralino

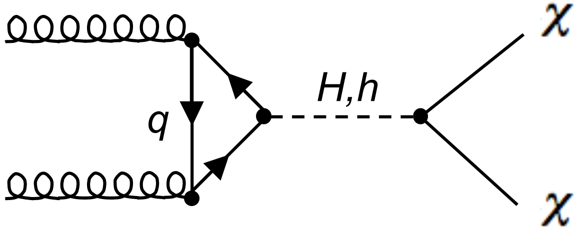
- Scalar coupling (« spin-independant »)

$$L_{q\chi} = f_q\left(\bar{q}q\right)\left(\bar{\chi}\chi\right)$$



- Use $m_q\langle n|\bar{q}q|n\rangle = m_{(n)}\underbrace{f_{Tq}^{(n)}}_{\textit{from pion-nucleon diffusion}}$ [q = u,d,s]

- Additional contribution from gluons and heavy quarks through QCD effects



⇒

$$L^{eff}_{n\chi} = \left(\bar{\chi}\chi\right)\left(\bar{n}n\right)\times \underbrace{m_{(n)}\left(\sum_{q=u,d,s} f_q \frac{f_{Tq}^{(n)}}{m_q} + \dots\right)}_{\equiv f_{(n)}}$$

Summation over nucleons:

$$\frac{d\sigma}{dq^2} = \left[Z f_p + (A-Z) f_n\right]^2 \frac{F^2(q)}{\pi v^2}$$

$f_p \approx f_n$:

- a single WIMP-nucleon cross-section σ_0

- coherence effect « A² » : <u>much better sensitivity for heavy targets than in the spin-dependant case</u>

Uncertainties in the prediction for interaction rate

- WIMP physics (eg. SUSY parameters…)
- Hadronic and nuclear physics
  - Spin-dependant diffusion :

$\Delta s^{(p)}$ = -0.09 to -0.16 $\langle S_n \rangle$ = 0.23 to 0.49 for ^{73}Ge

  - Spin-independent diffusion : f_{Ts} = 0.08 to 0.46

⇒ *Uncertainty of order unity on the WIMP-nucleus cross-section for a given WIMP model*

- Local structure of the dark matter halo
  - ρ_0~ 0.2 - 0.8 GeV/cm^3 from the MW rotation curve
  - Local velocity distribution : maxwellian, dispersion σ = 1.22 v_{circ}

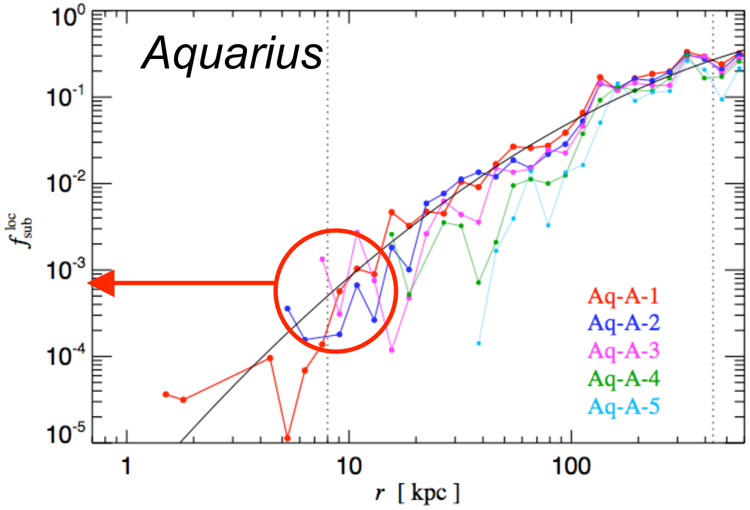
    with v_{circ} ~ 220 km/s [Kerr & Lynden-Bell]

    v_{circ} = (218 ± 7) (R_0/8kpc) km/s [HIPPARCOS]

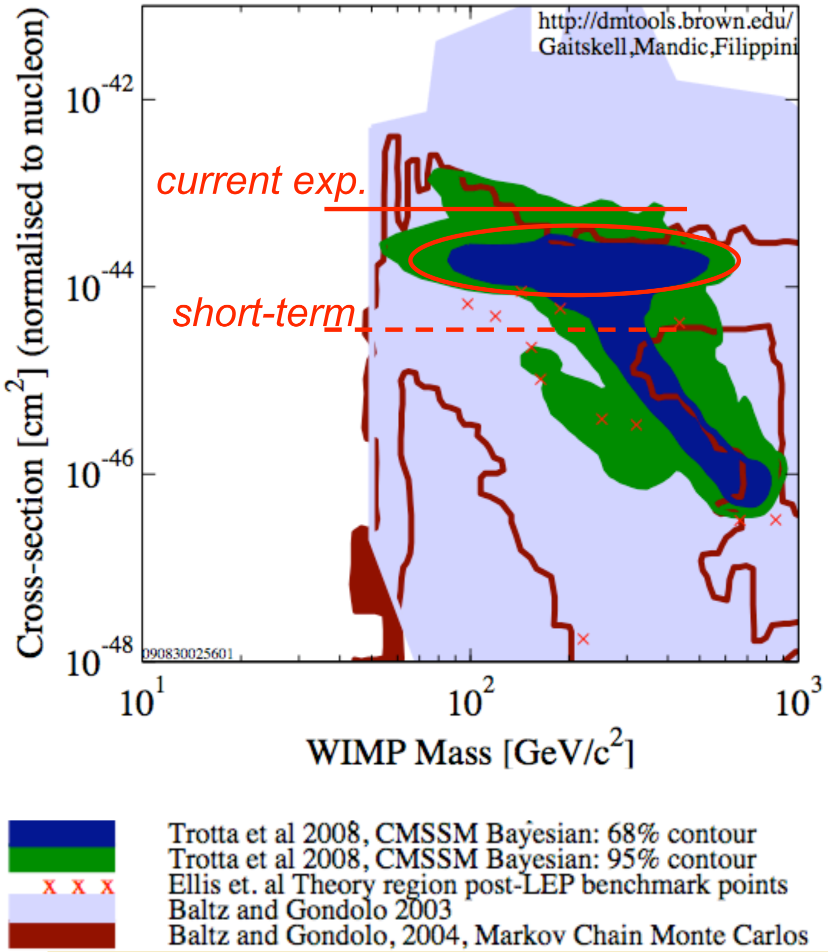
    v_{circ} = (254 ± 16) km/s [Reid - VLBA]

  - Substructures : weak probability for a local clump, but…
  - A dark matter disk from the interaction of sub-halos @ z<1 ?

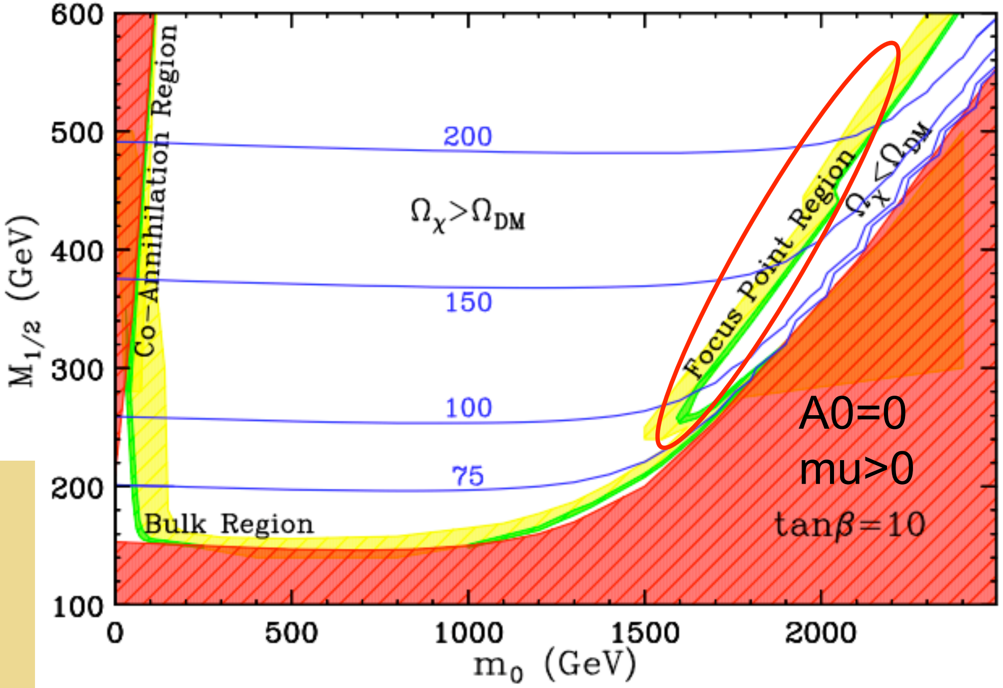
    ρ_{disk} ~ (0.25 - 1) ρ_{halo}



Cross-section predictions from SUSY scans



- Use of cMSSM (5 parameters) but other extended scans exist
- Scans (several algorithms are possibles)
  - strong impact of priors (eg. flat prior in linear or logarithmic scale)
  - strong impact of contraints from cosmo/accelerators (eg. Ω_m, b→sγ, etc)
- Use of « benchmark points », common to LHC



- <u>Focus Point region to be fully tested soon</u> (higgs exchange)

- Bulk region may require larger masses for detection

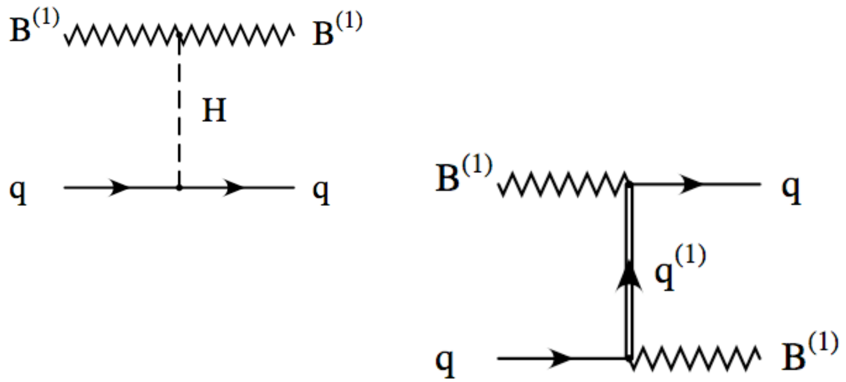
Direct detection of a LKP

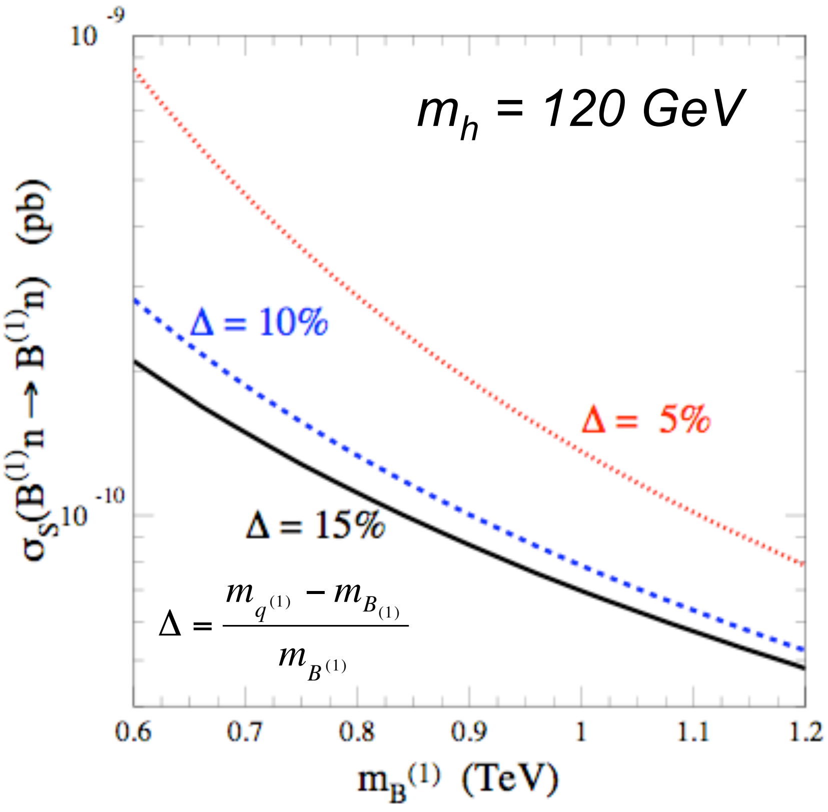
- UED models : all SM fields propagate in extra dimensions and get Kaluza-Klein modes
- KK parity (residual from Poincaré after compactification)

  ⇒ stable LKP
- Most studied LKP = $B^{(1)}$

- Cosmologic constraint : $M_{B(1)}$ ~ 600-1200 GeV

- Direct Detection predictions : similar to SUSY
  - (remplace squark by $q^{(1)}$, use one Higgs)
  - *Less parameters: m_{higgs}, M_{LKP} and m_{q}*





Cross-sections quite weak (<10^{-9} pb), but accessible with (multi)ton scale exp.

Summary : technical specifications for dark matter detectors

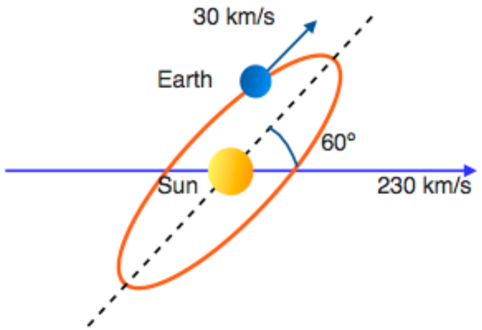
- Massive detectors (kg … multi-ton)
- Low detection threshold (recoils ~ few keV)
- Rejection of all radioactive backgrounds down to the desired sensitivity:
  - passive rejection (shieldings)
  - active rejection : discrimination WIMP recoils / other interactions

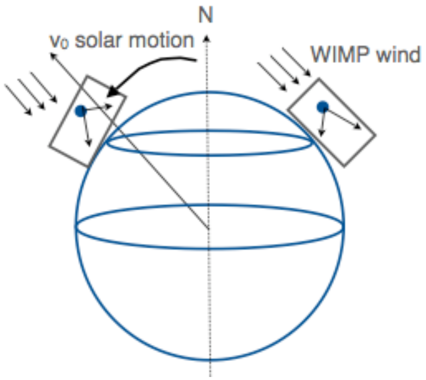
Signatures of a WIMP interaction :

- **Nuclear recoils** (not electronic)
- **Unique interaction** in the detector (no multiple diffusions)
- Interactions **uniformly distributed** within the detector volume
- Recoil spectrum ~ exponential
- Dependance « in A^2 » as a function of the nuclear target

- Annual modulation + directionnality

specific searches
- DAMA signal still there
- Lot of R&D effort on gazeous detectors





Backgrounds

- Gamma radioactivity : surrounding materials + detector radioactivity
  - Shielding + radiopurity of the whole experiment
  - *Interaction on the electrons* : active discrimination nuclear / electronic recoil

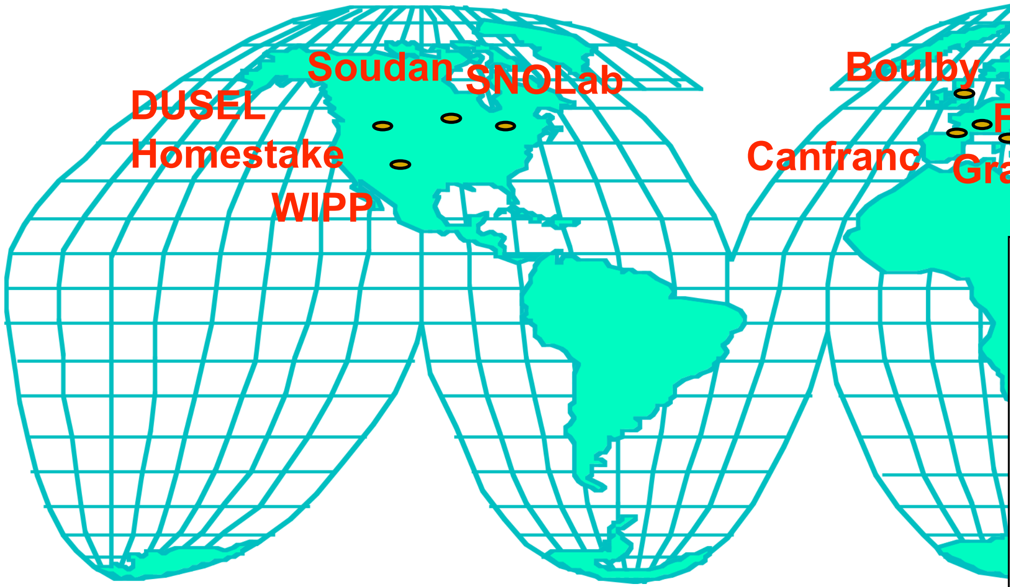
- Beta radioactivity : nearby environment
  - Interactions at the detector surface : position measurement of the interaction

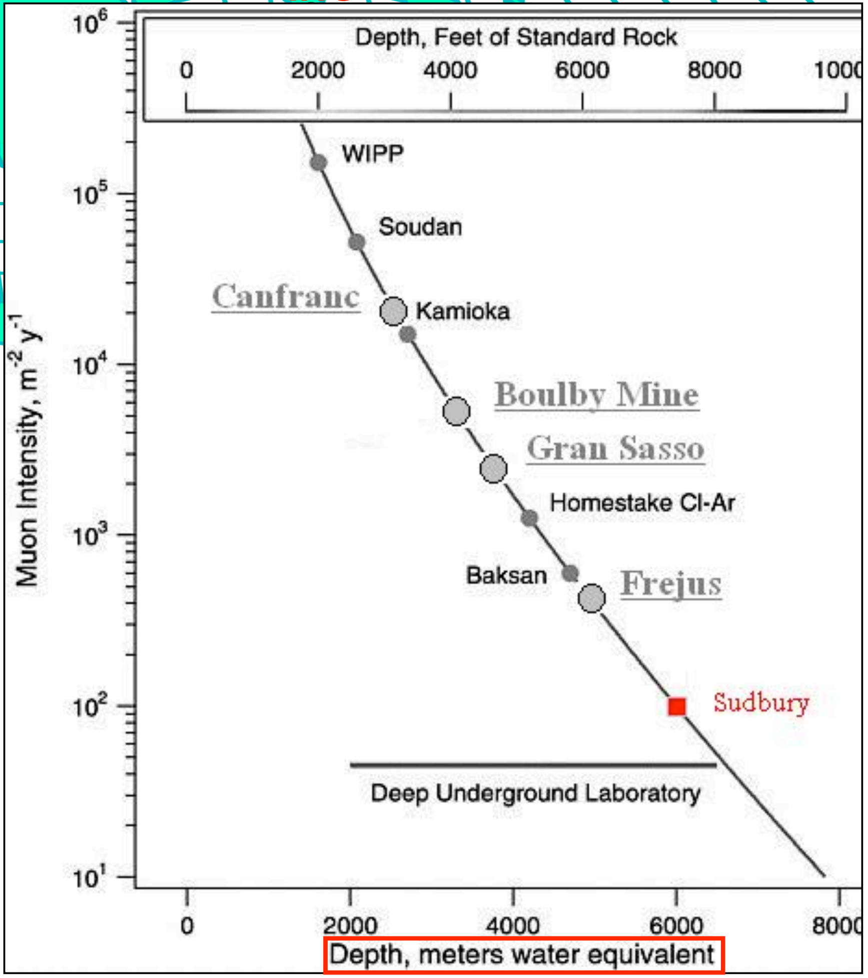
- Diffusion of fast neutrons : created by cosmic muons and the surrounding radioactivity ; nuclear recoils
  - Experiments in underground site : cosmic muon flux reduced
  - Radiopurity of the whole experiment
  - Muon vetos
  - Measurement of the interaction multiplicity (segmented detector)

- [Bonus : coherent diffusion from solar neutrinos
  - Interaction predicted within the SM, never detected yet
  - Mimics perfectly a WIMP signal (except for directionnality/annual modulation)
  - Relevant for future detectors >> ton]

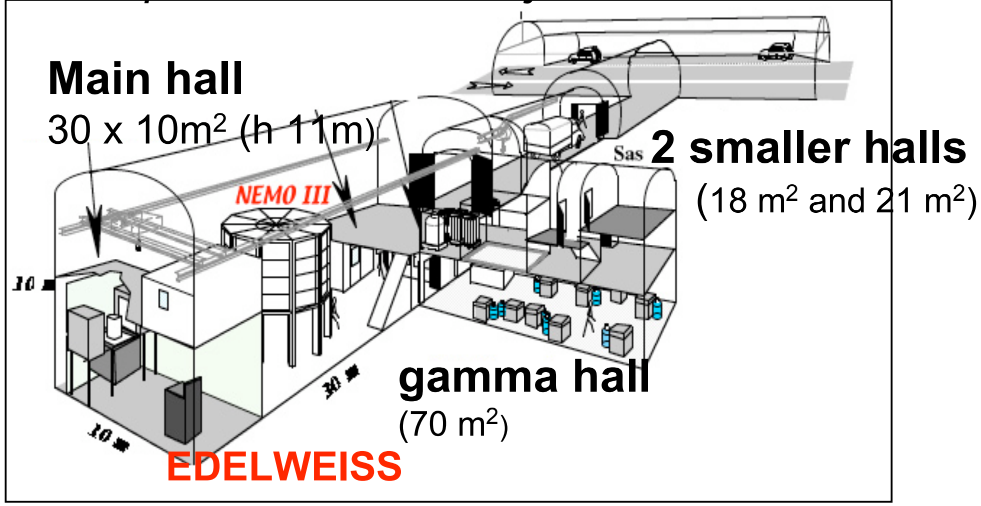
(Very) long-term R&D efforts

Underground laboratories





Example : Lab in the Fréjus tunnel



A wealth of WIMP search experiments

Solid scintillators

Directionality

Noble liquids

Bolometers

BPRS 🇫🇷

HDMS

ANAIS

IGEX

NaIAD

ZEPLIN

CDMS

DAMA

Mimac 🇫🇷

XENON-10

EDELWEISS 🇫🇷

DRIFT

CRESST

SIMPLE

KIMS

DMTPC

ZEPLIN-III

CDMS-II

TEXONO

LIBRA

XENON-100 🇫🇷

EDELWEISS-II 🇫🇷

CoGENT

WaRP

PICASSO

ROSEBUD 🇫🇷

SuperCDMS

ArDM

COUPP

XENON-1T 🇫🇷

CLEAN

XMASS

LUX

EURECA 🇫🇷

DEAP

DARWIN

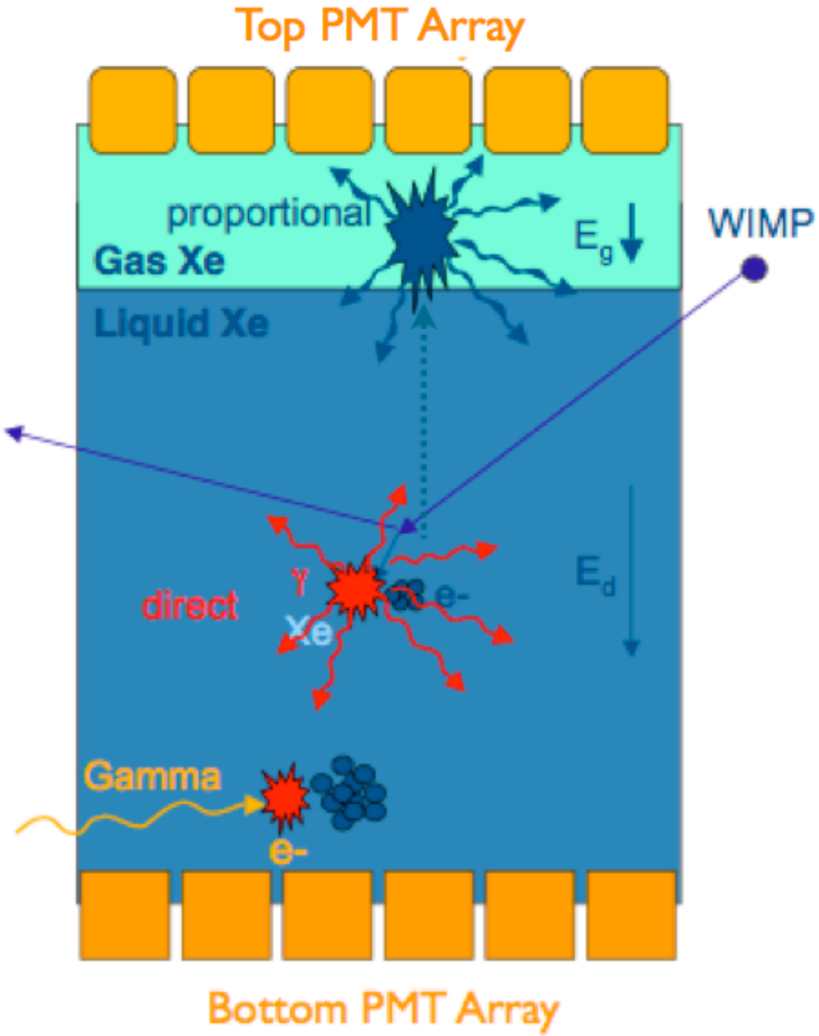
GeoDM

… and there are more …

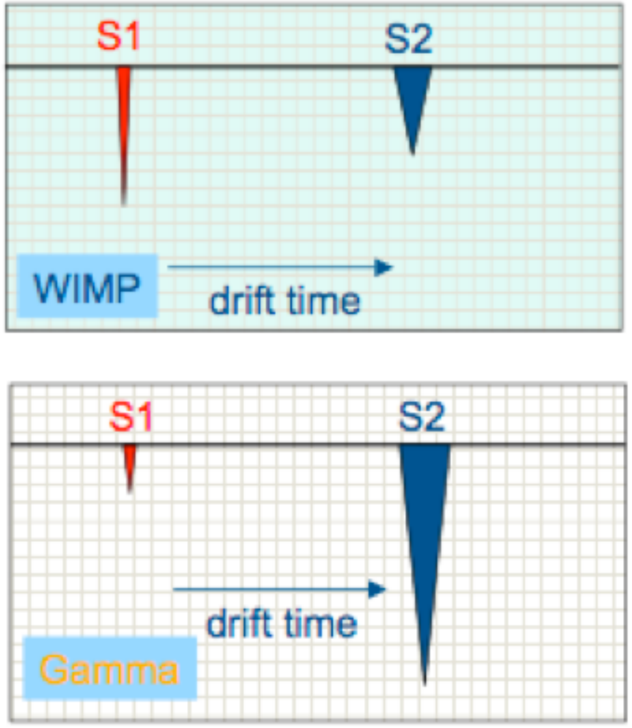
Noble liquid experiments (Xenon, Argon) : The example of Xenon10/100

The Time-Projection Chamber with dual-phase noble gaz

Example of Xenon 10 (2005-2007)



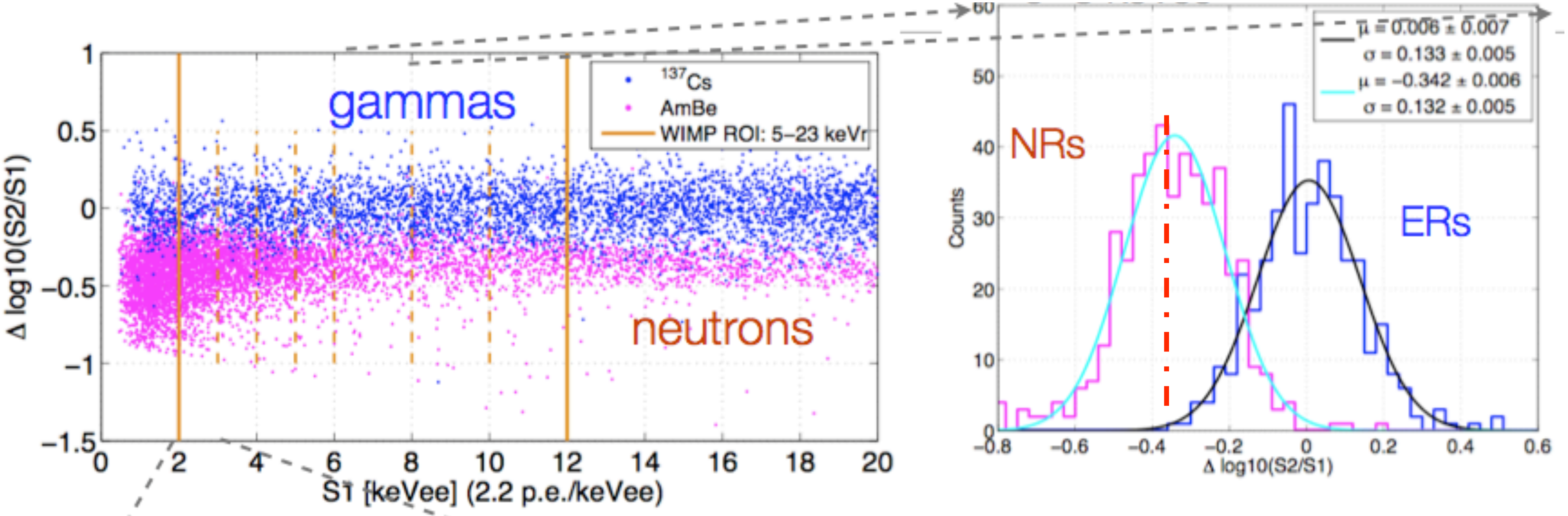
« S1 » = direct light, scintillation
« S2 » = light emitted when electrons reach the liquid/gaz, ionisation

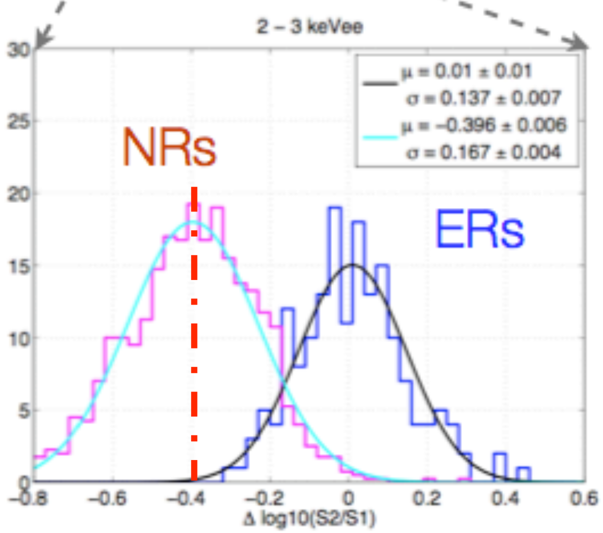


$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

Discrimination nuclear recoil / electronic recoil

NR/ER discrimination in XENON 10

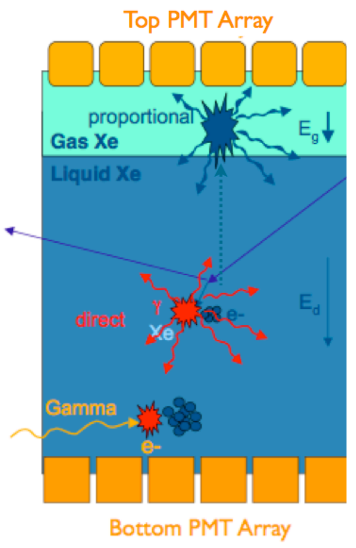


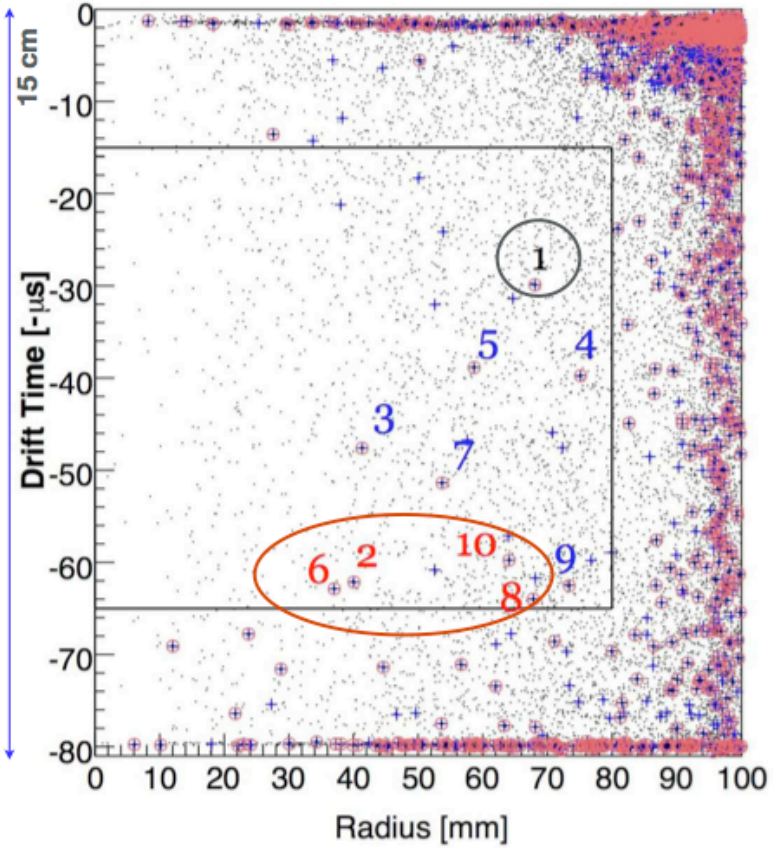


- Discrimination BUT both event populations overlap
- Discrimination ok down to the lowest energies (very lucky!)

- Select nuclear recoils only with Δlog(S2/S1) < -0.4 ⇒ <u>efficiency loss ~ 50%</u>

Fiducial cut in XENON10





- z-position : reconstructed from the electron drift time
- Radial position : good reconstruction using the signals from PMT array

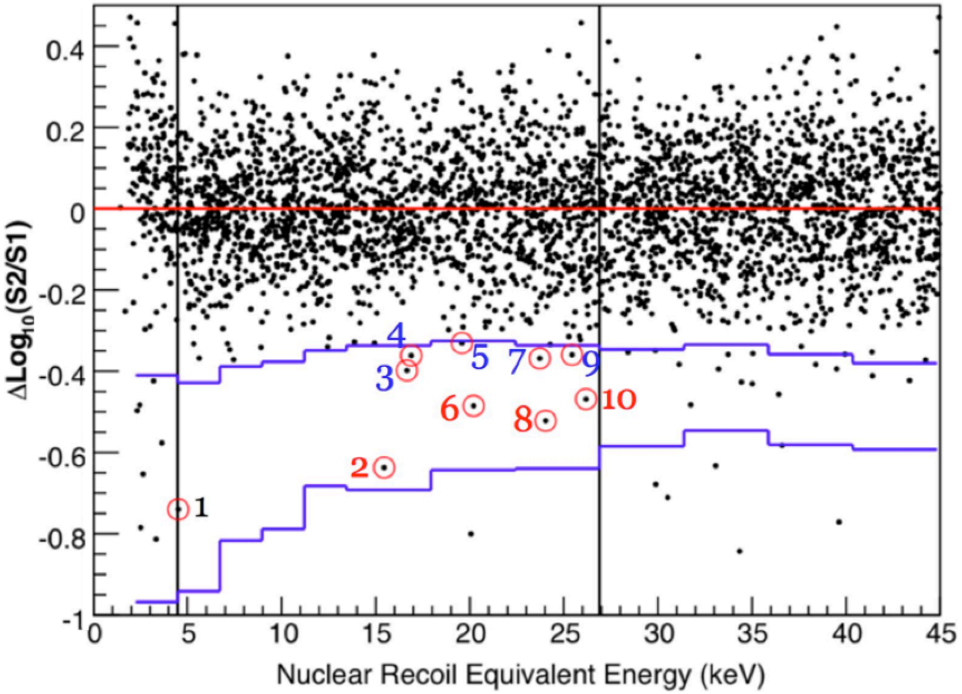
➢Definition of a fiducial volume within the TPC : 5.4 kg (for a total of 22kg of Xe)

➢Most of the radioactivity comes from surfaces (in particular from the PMTs)

⇒ **<u>Efficient self-shielding of the detector</u>**

➢ Self-shielding will improve for bigger detectors

XENON 10 results



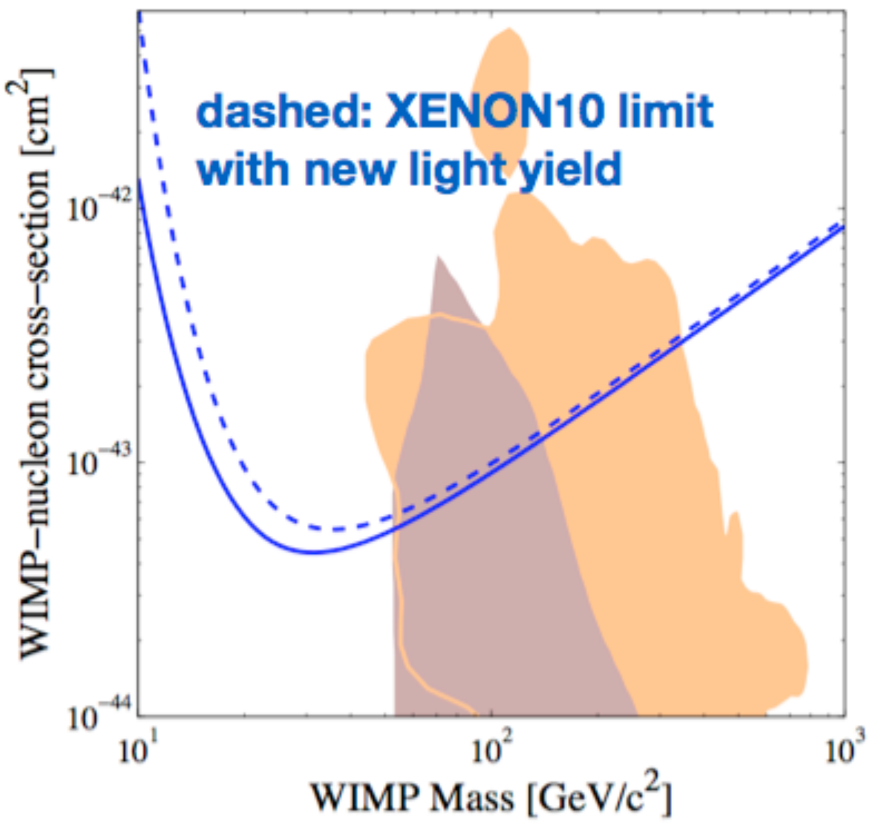
- Search in the energy window $4.5 < E_{recoil} < 27$ keV
- 136 kg.days = 58 days
  x 5.4 kg
  x 0.86 (cuts efficiency)
  x 0.5 (NR region selection)

Presence of background:

- « gaussian tail »
- Anomalous events

Hypothesis : double interactions with one in the dead volume of Xenon (with no S2)

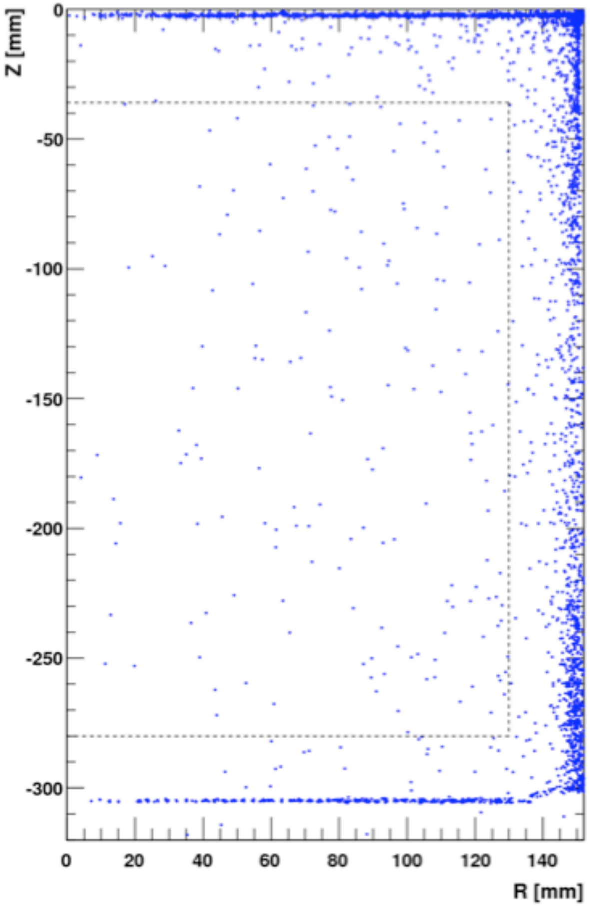
- *results arXiv:0706.0039*
- *experimental description arXiv:1001.2834*



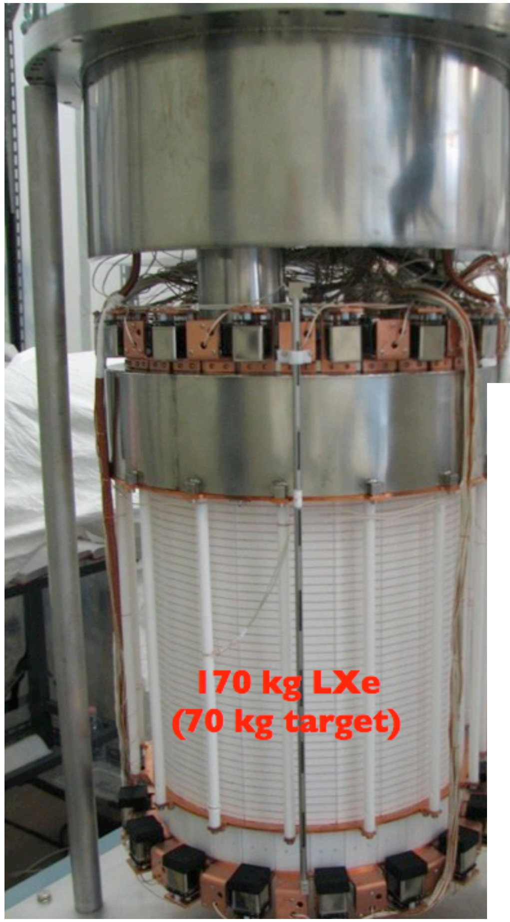
dashed: XENON10 limit with new light yield

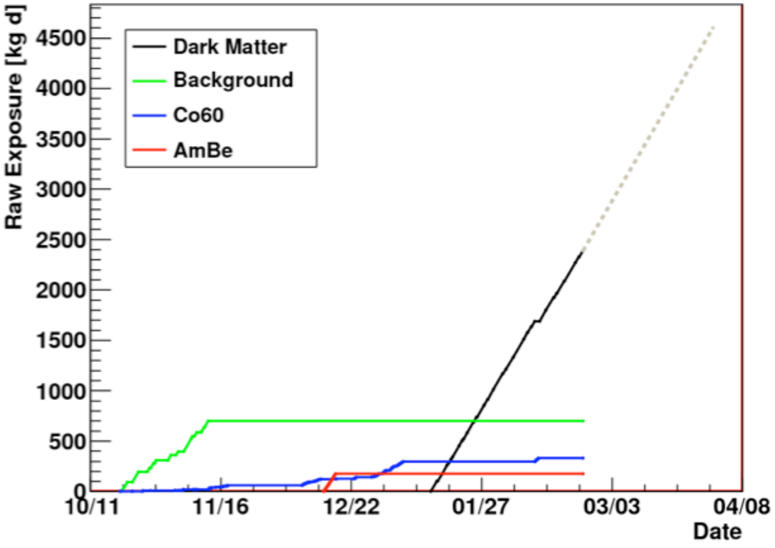
Running now : XENON 100 (2008-2010)

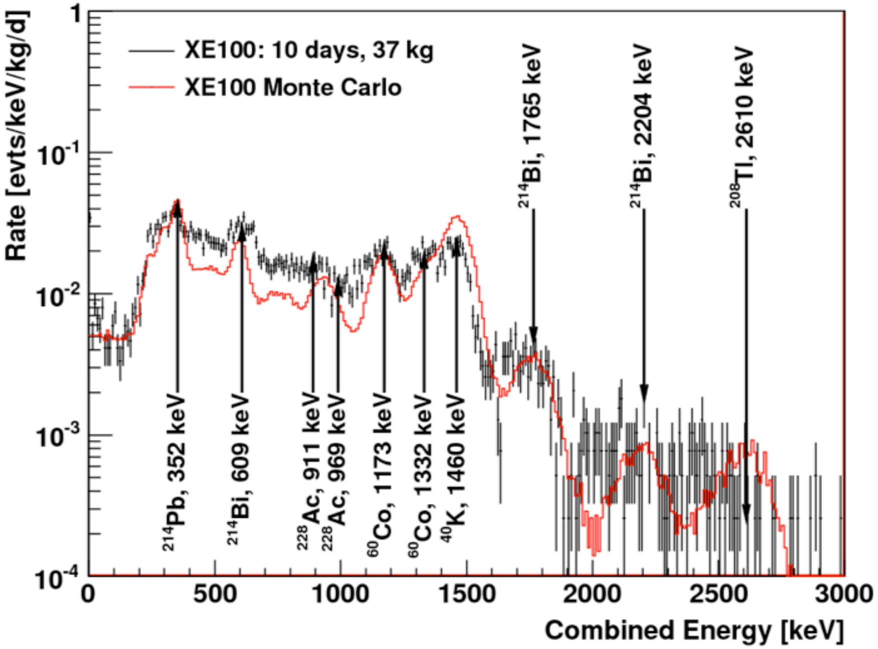
- Increase target volume : 30 to 50 kg fiducial
- Improve radiopurity (incl. PMTs)
- Side & bottom shieds, equipped with veto PMTs



XENON100, 4-60 keVee
37 kg fiducial, 10 d







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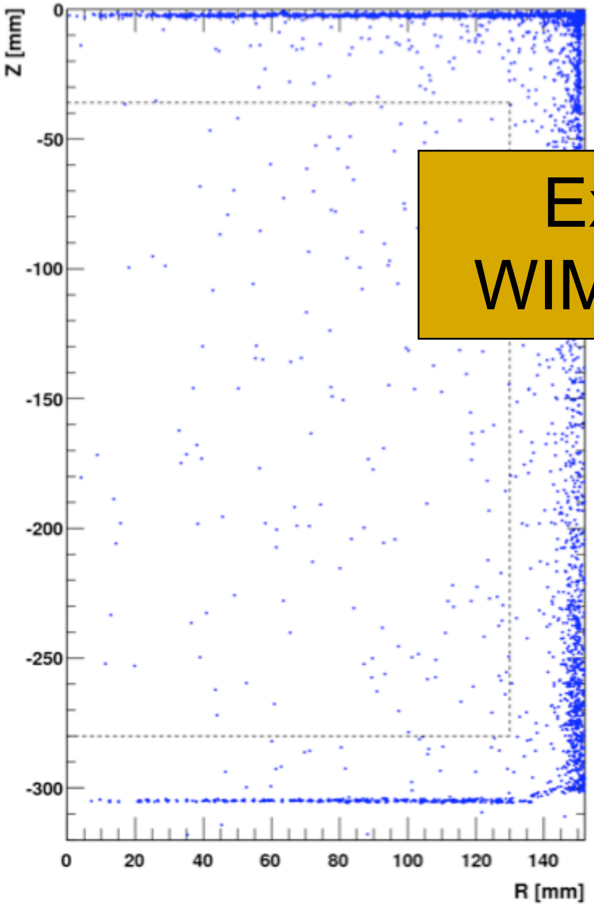

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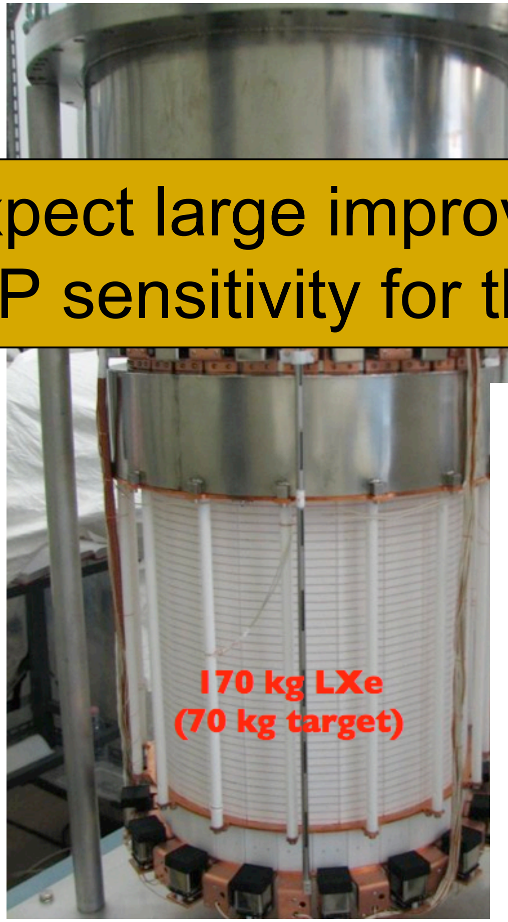
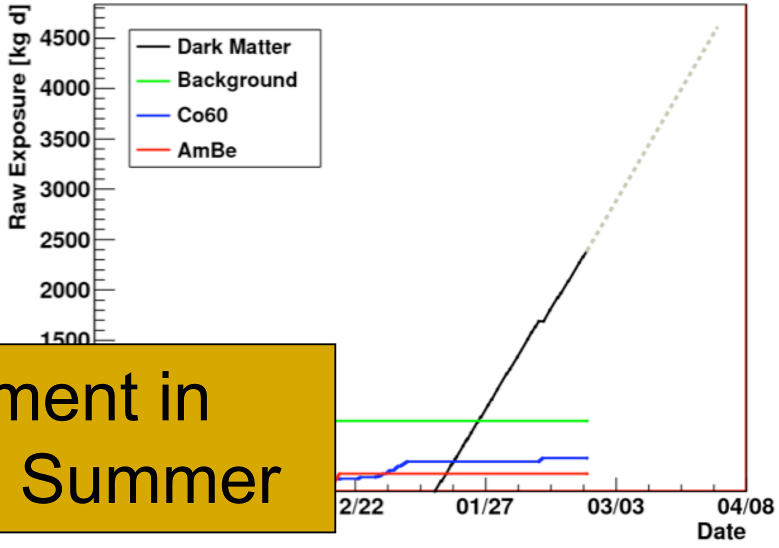
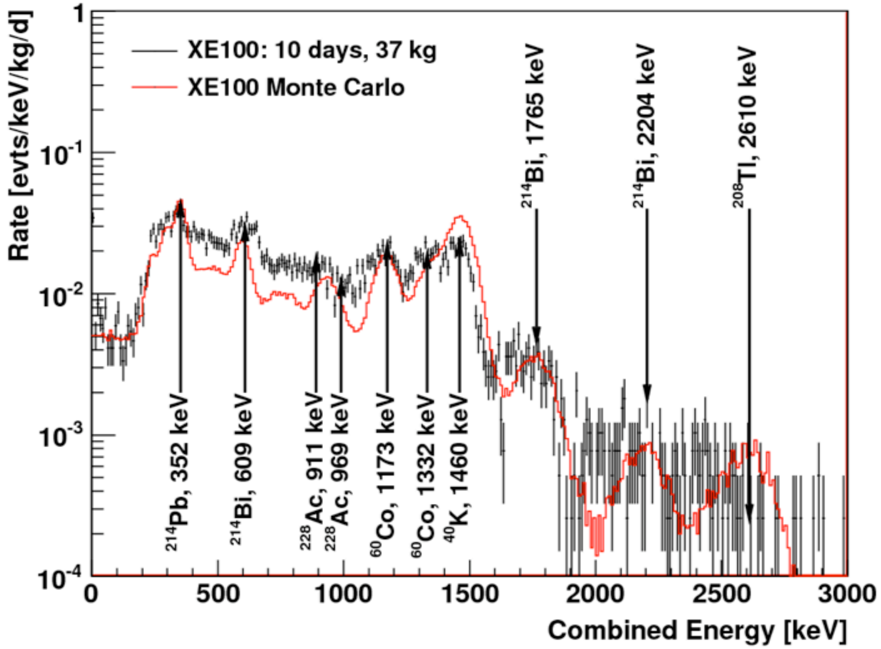




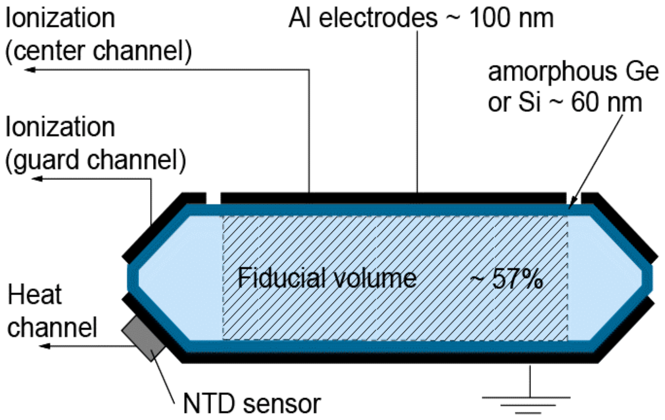
Expect large improvement in WIMP sensitivity for this Summer

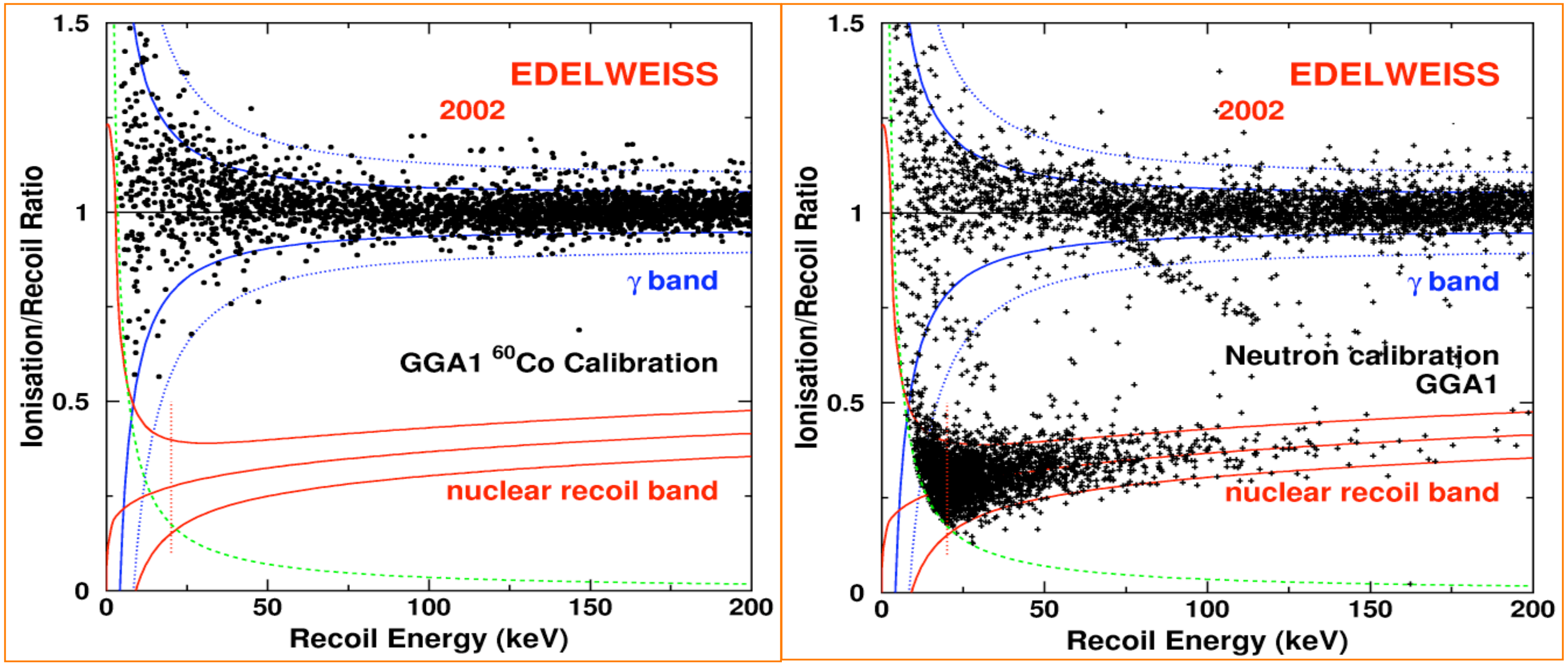


Bolometric experiments : EDELWEISS and CDMS

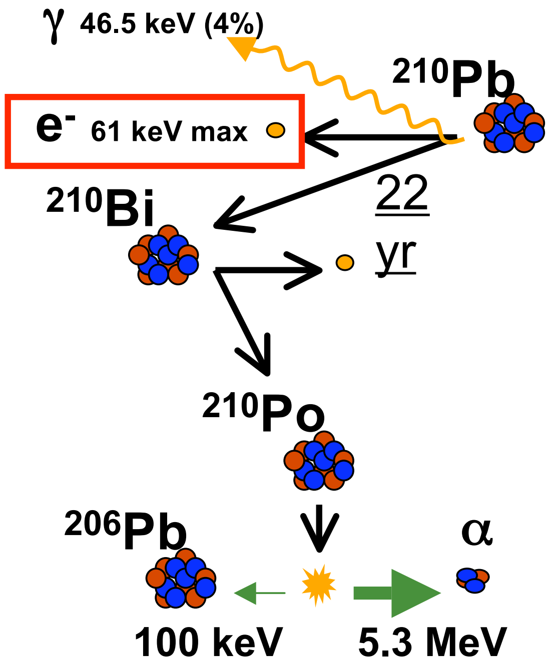
Edelweiss-I detectors

- Germanium bolometers
- Ionization measurement @ few V/cm
- Heat measurement (**NTD sensor**) @ 20 mK
- *Discriminating variable between electronic and nuclear recoils* : « Q » ~ ionization/heat



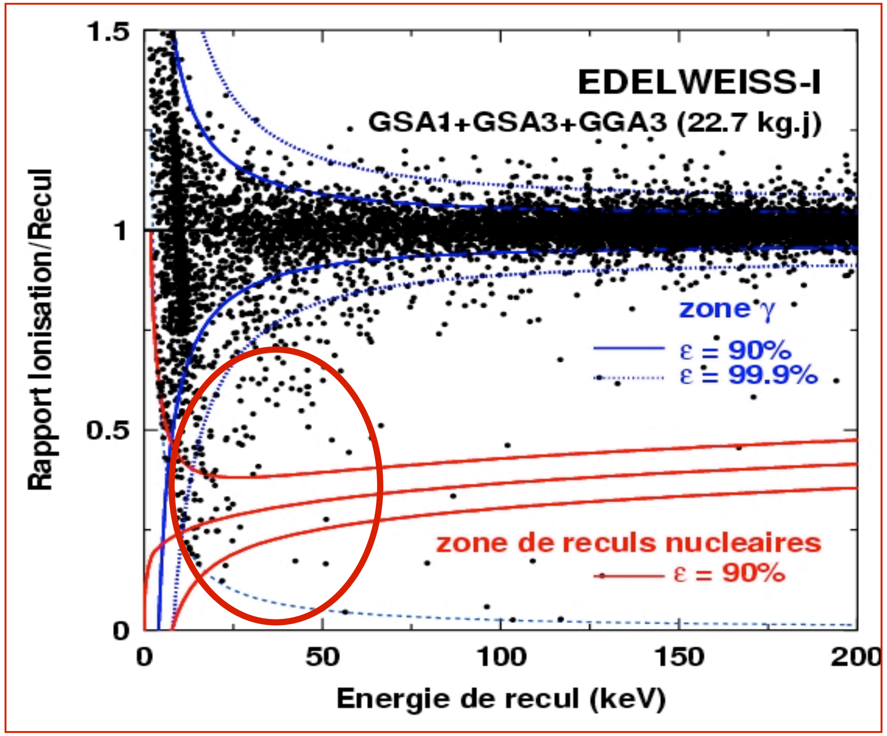


The issue of surface interactions



- Almost irreducible source of local radioactivity : beta rays from ^{210}Pb (a daughter of Radon present in the air)

- A beta interaction = electronic recoil, at the detector surface (penetration length ~ few microns)
⇒ **Incomplete charge collection at the electrodes** : impossible to discriminate with nuclear recoils



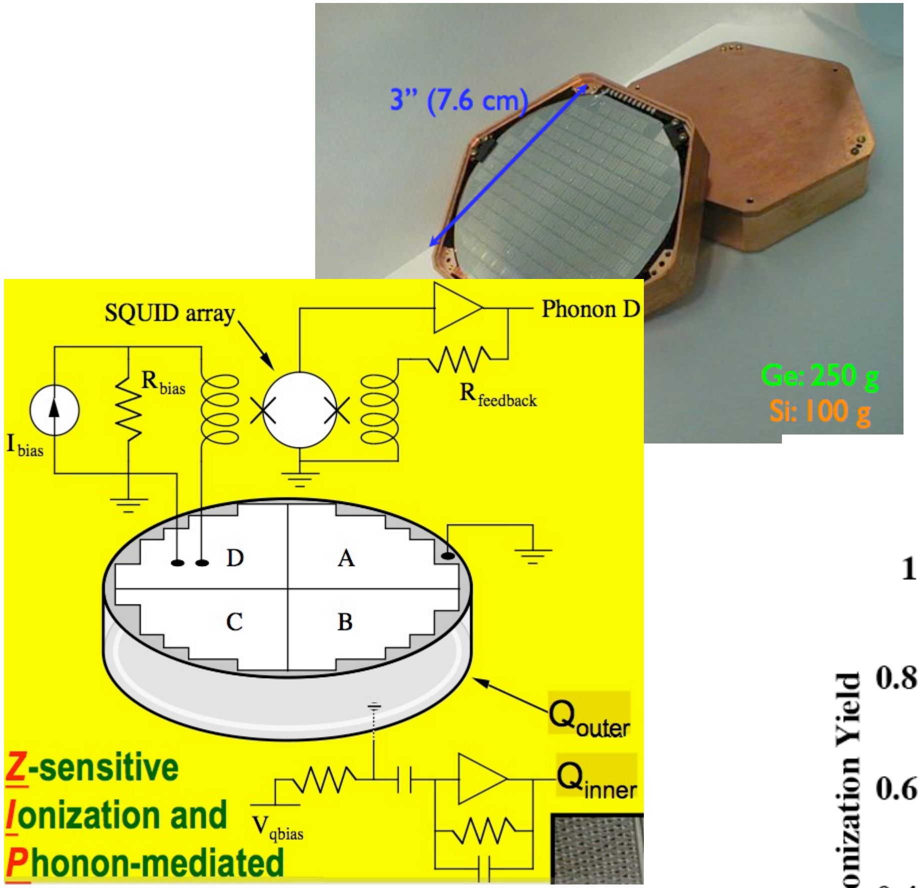
Edelweiss background run - 2003

Sensitivity limited by the beta background

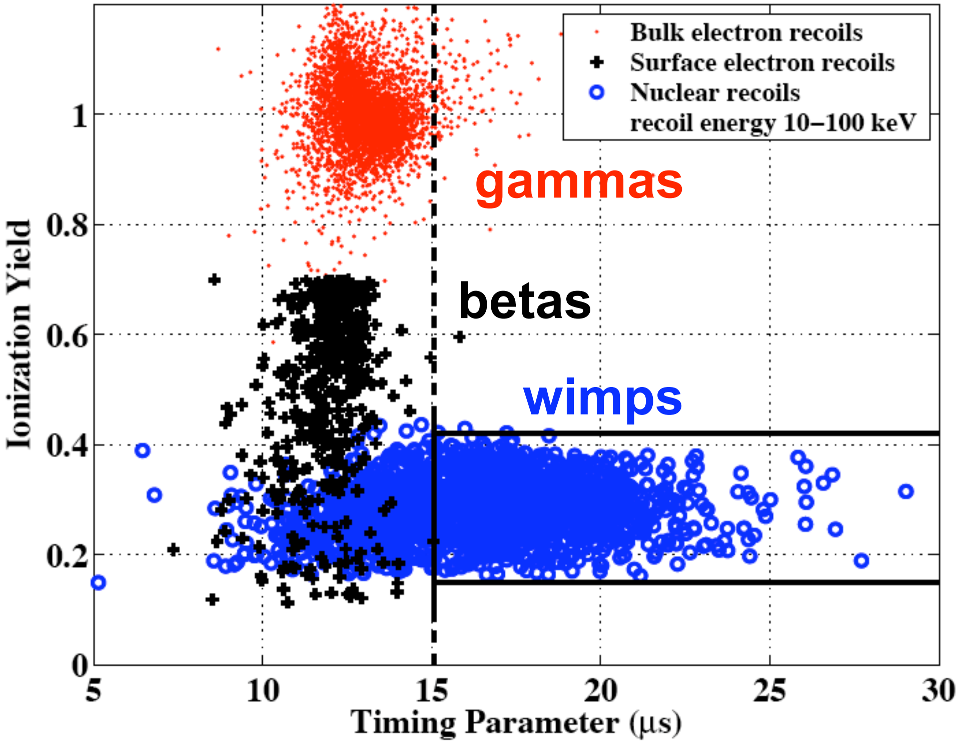
Quantitative bckgd understanding published 2007

S. Fiorucci et al. - Astropart. Phys. 28:143-153.2007 (astro-ph/0610821)

CDMS : surface event rejection with phonon measurement



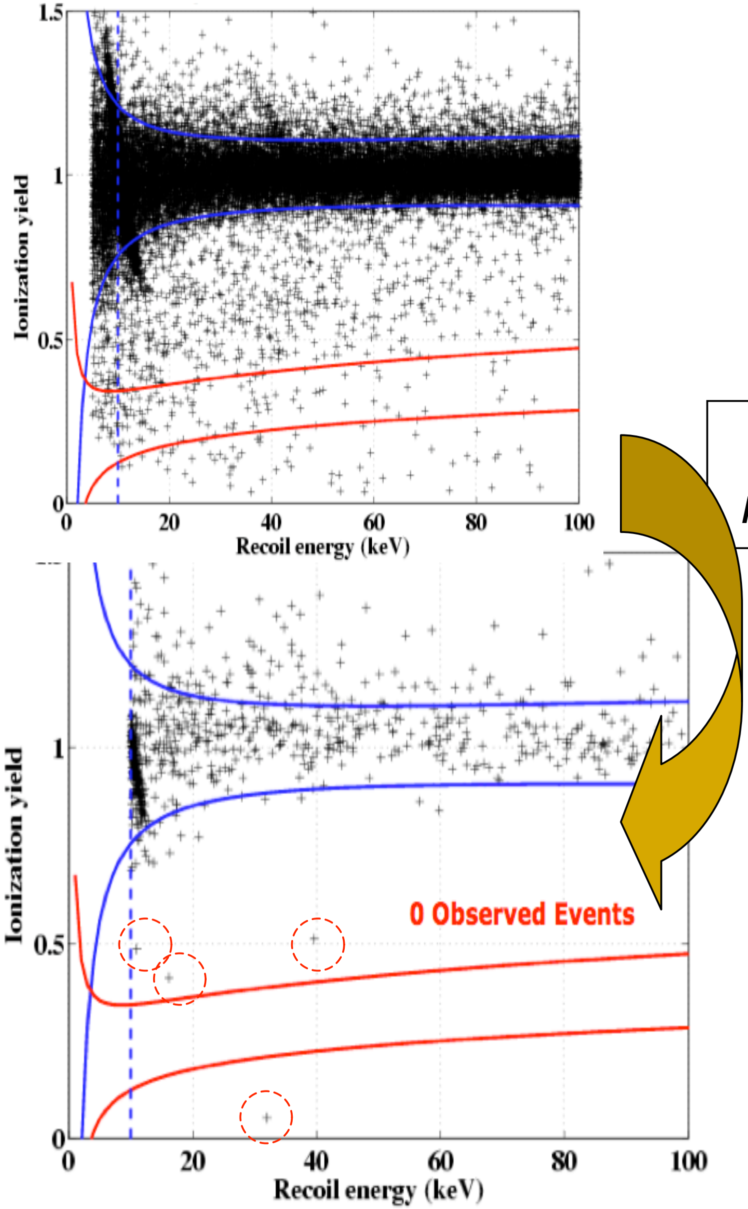
- US, installed @ Soudan mine
- Specific sensor measuring thermal and athermal phonons, with a complex division into many cells ⇒ partial reconstruction of the interaction location (athermal phonon signals faster for surface interactions)



- Additional « discriminating variable » : rejects betas at the price of 50% efficiency loss

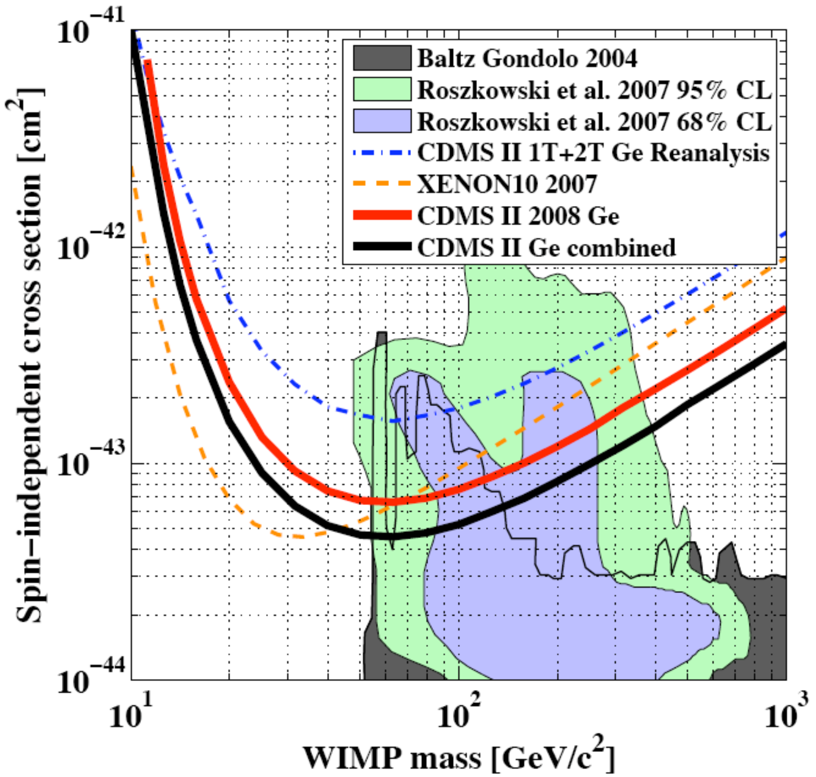
CDMS-II results : 2008

- 15 cristals used
- 654 kg.d « raw » analyzed, 121 kg.d post-cuts
- 0 event, ~ 0.5 expected



Beta rejection

arxiv:0802.3530

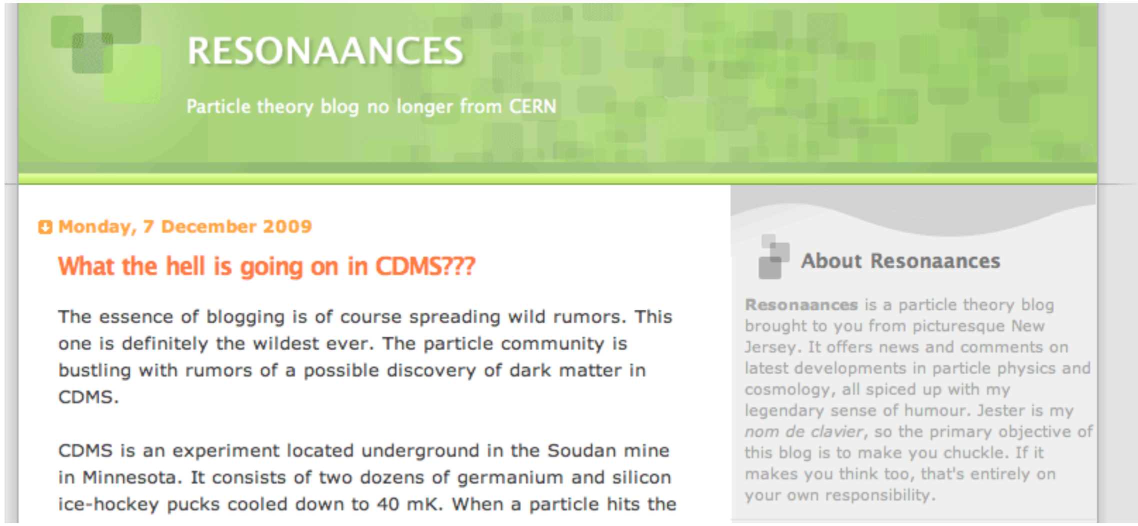


CDMS-II results : 2009

- Exposition x 2+
- Background « 0.8 (+0.5) evts »
- Observed 2 « WIMP candidates»

compatible with betas

- Final sensitivity (combine data 2002-2008) CDMS-II slightly improved : 3.8×10^{-8} pb @ M_x=70 GeV



RESONAANCES

Particle theory blog no longer from CERN

Monday, 7 December 2009

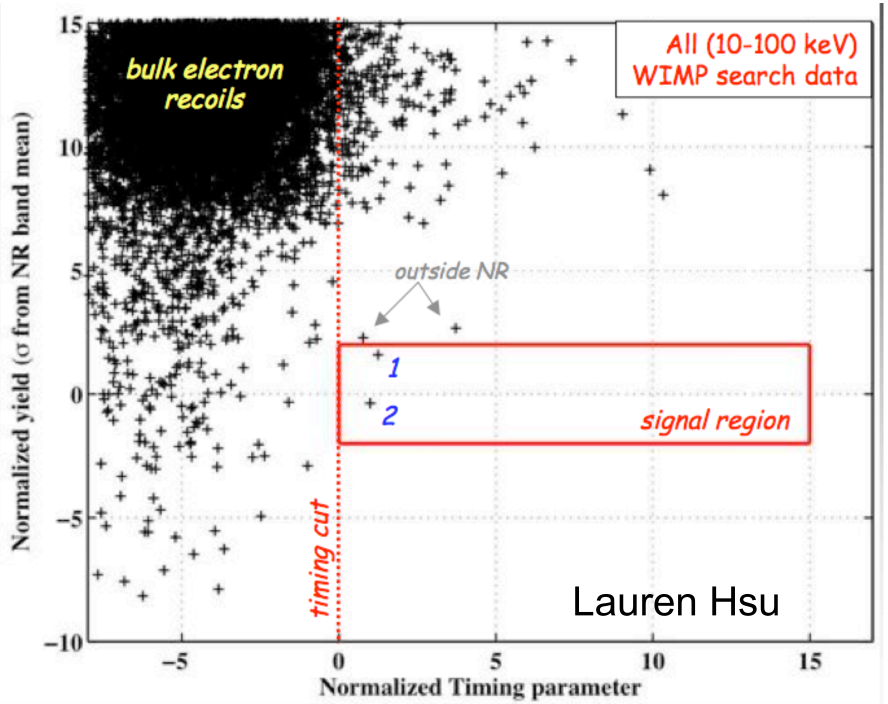
What the hell is going on in CDMS???

The essence of blogging is of course spreading wild rumors. This one is definitely the wildest ever. The particle community is bustling with rumors of a possible discovery of dark matter in CDMS.

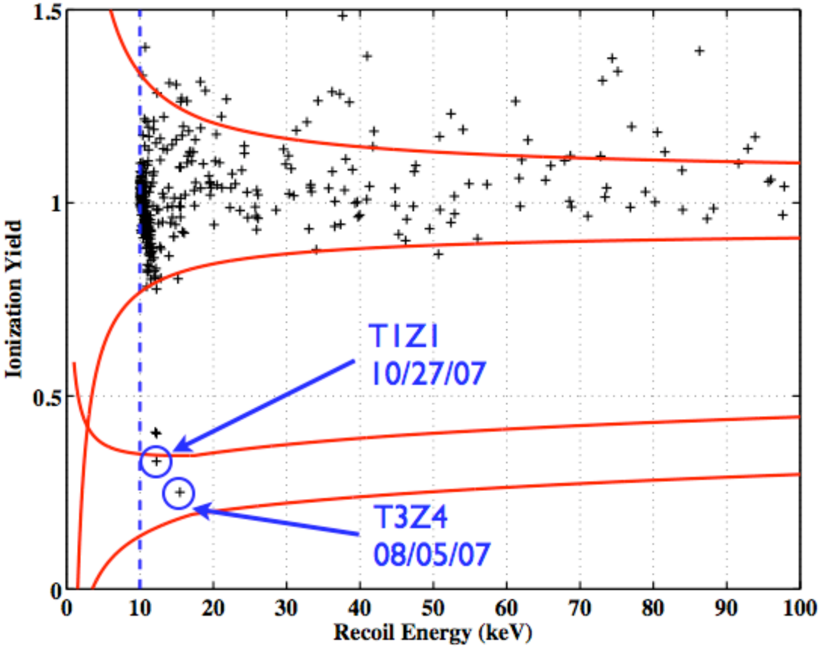
CDMS is an experiment located underground in the Soudan mine in Minnesota. It consists of two dozens of germanium and silicon ice-hockey pucks cooled down to 40 mK. When a particle hits the

About Resonaances

Resonaances is a particle theory blog brought to you from picturesque New Jersey. It offers news and comments on latest developments in particle physics and cosmology, all spiced up with my legendary sense of humour. Jester is my *nom de clavier*, so the primary objective of this blog is to make you chuckle. If it makes you think too, that's entirely on your own responsibility.

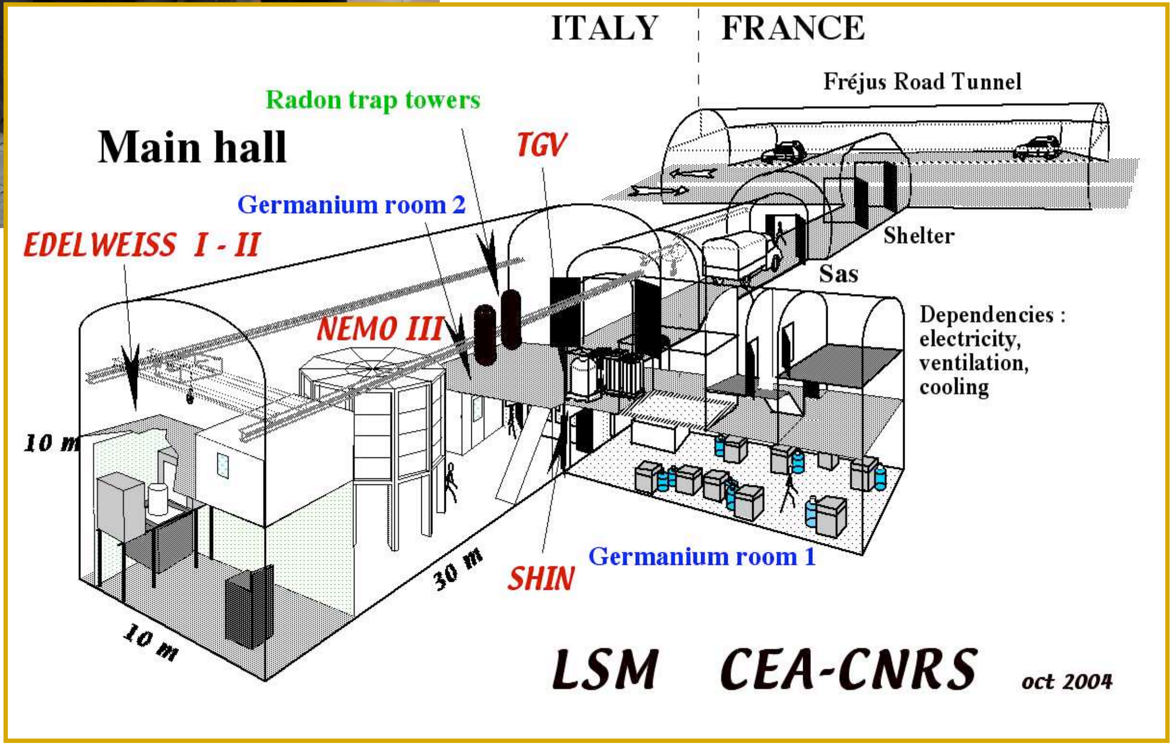


Lauren Hsu



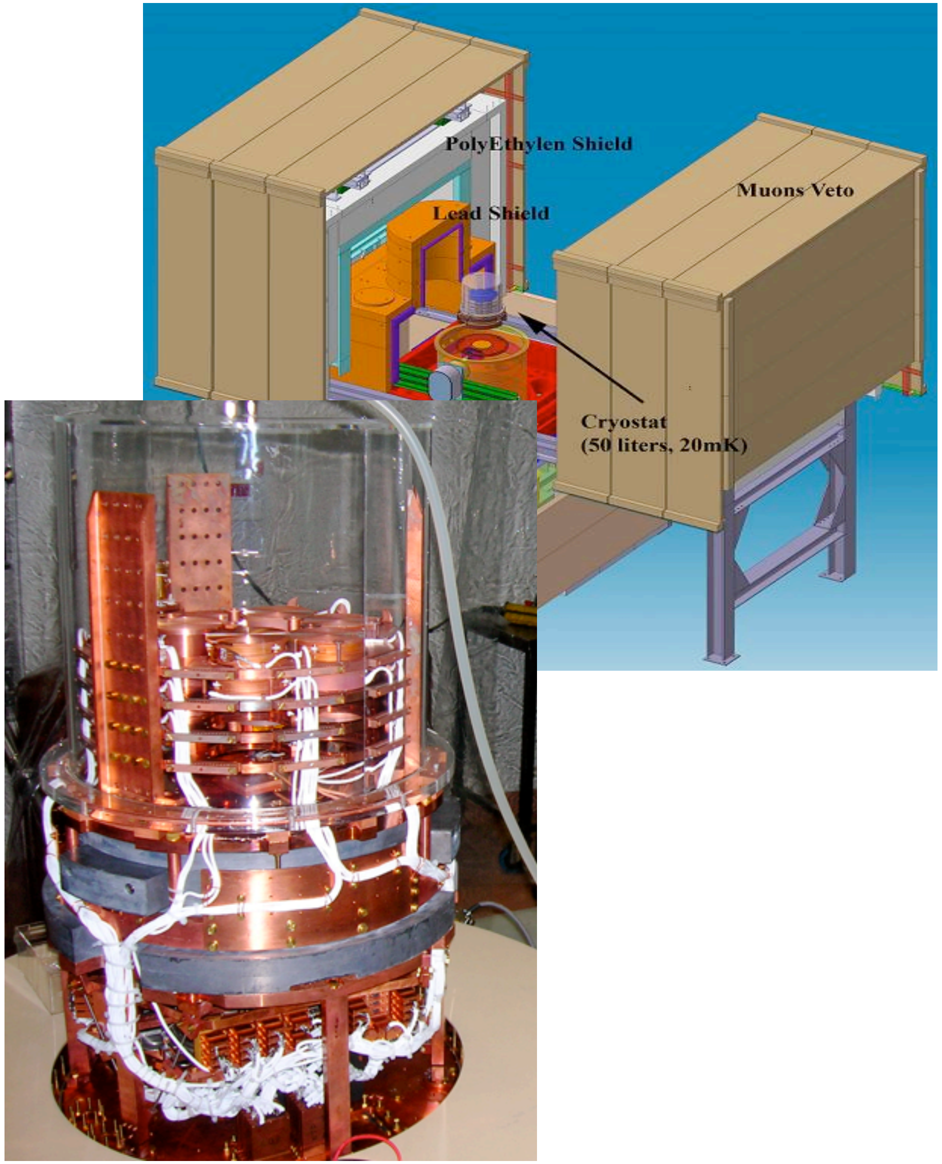
The EDELWEISS-II collaboration

Karlsruhe - oct 09



- **CEA Saclay (DAPNIA & DRECAM)**
- **CSNSM Orsay**
- **IPN Lyon**
- **Institût Néel Grenoble**
- **FZ/ Universität Karlsruhe**
- **JINR Dubna**
- **Oxford Univ.**

The EDELWEISS-II setup

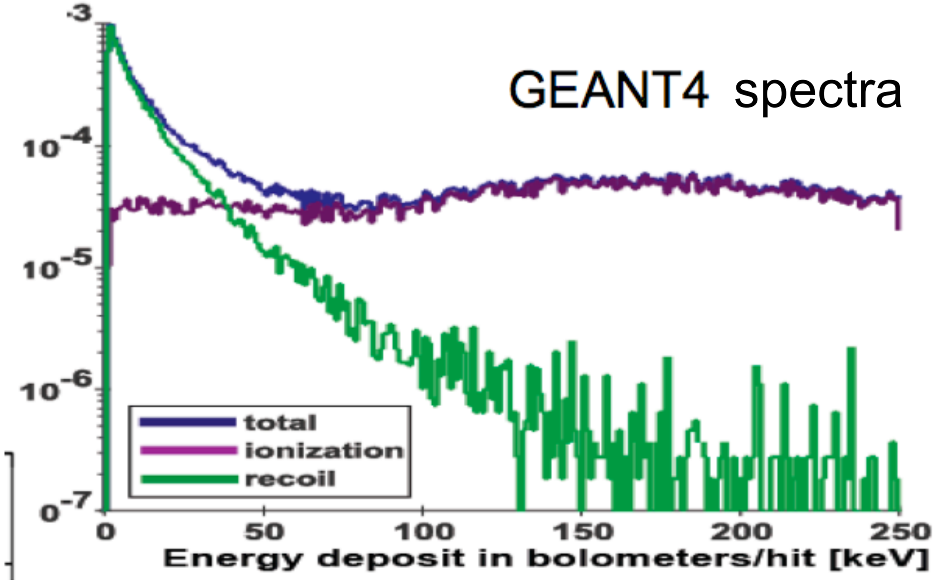


- Operated at the Underground Laboratory of Modane (4μ/day/m²)
- Cryogenic installation (18 mK) :
  - Reversed geometry cryostat, pulse tubes
  - Remotely controlled
- Shieldings :
  - Clean room + deradonized air
  - Active muon veto (>98% coverage)
  - PE shield
  - Lead shield

  ⇒ γ background reduced by ~3 wrt EDW1
- (Many) others :
  - Remotely controlled sources for calibrations + regenerations
  - Detector storage & repair within the clean room
  - Radon detector
  - He3 neutron detector (thermal neutron monitoring)
  - liquid scintillator neutron counter (study of muon induced neutrons)
- 12 cool-downs already operated

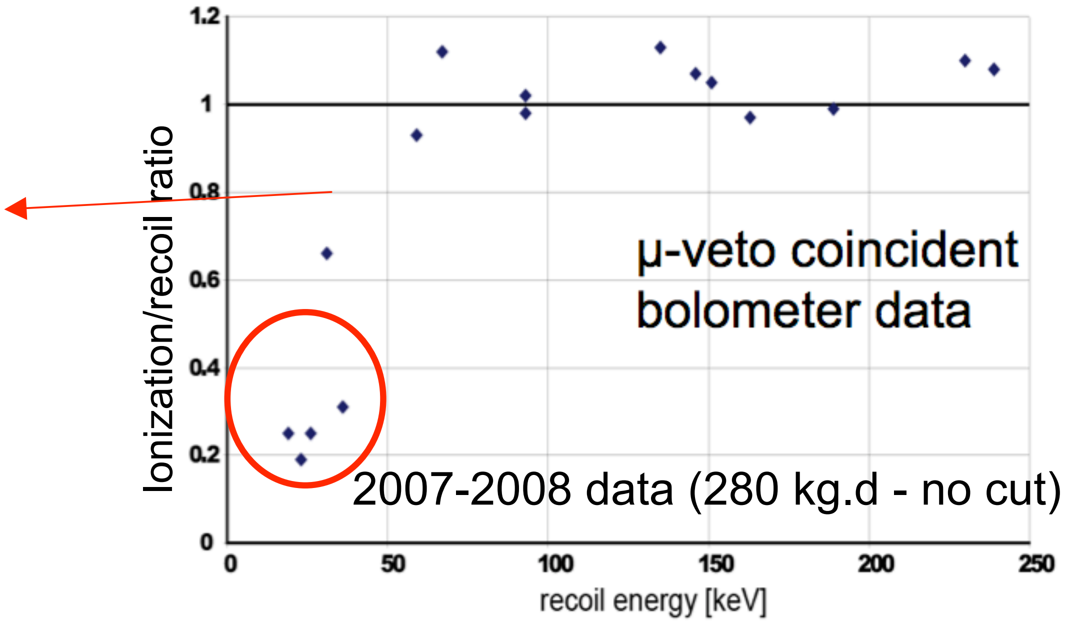
Rejecting muon-induced neutrons with the muon veto

- Interactions in detectors due to muon-induced neutrons inside the shields :
  - Geant4 - expected : ~0.03 evts / kg.d
  - Mostly nuclear recoils below 50 keV



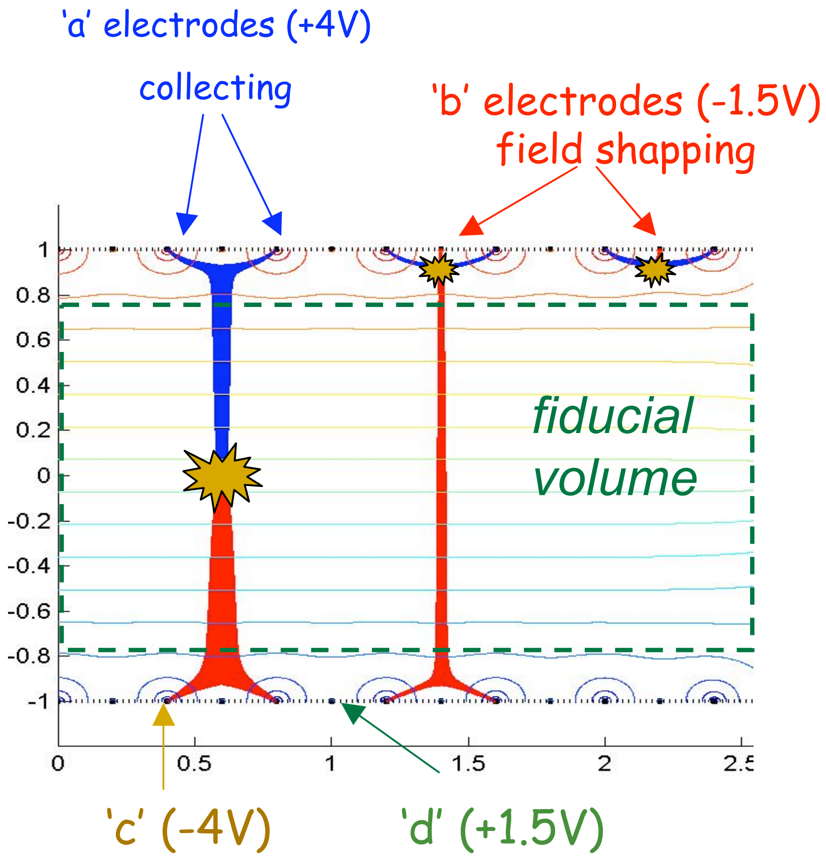
- Measured bolometer - muon veto coincidence rate : ~ 0.04 evts/kg.d

- The ionization yield distribution of coincidences is consistent with muon-induced events



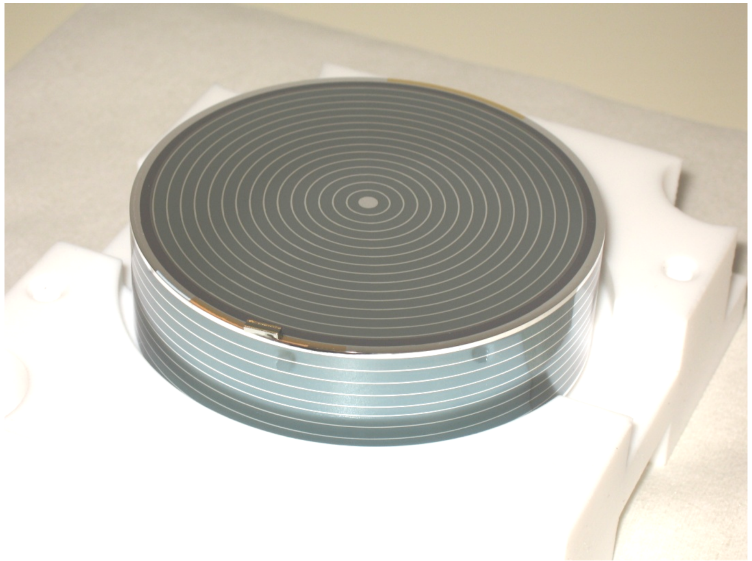
  - In addition: several neutron flux measurements carried out near the experiment

Rejecting surface events with interleaved electrodes



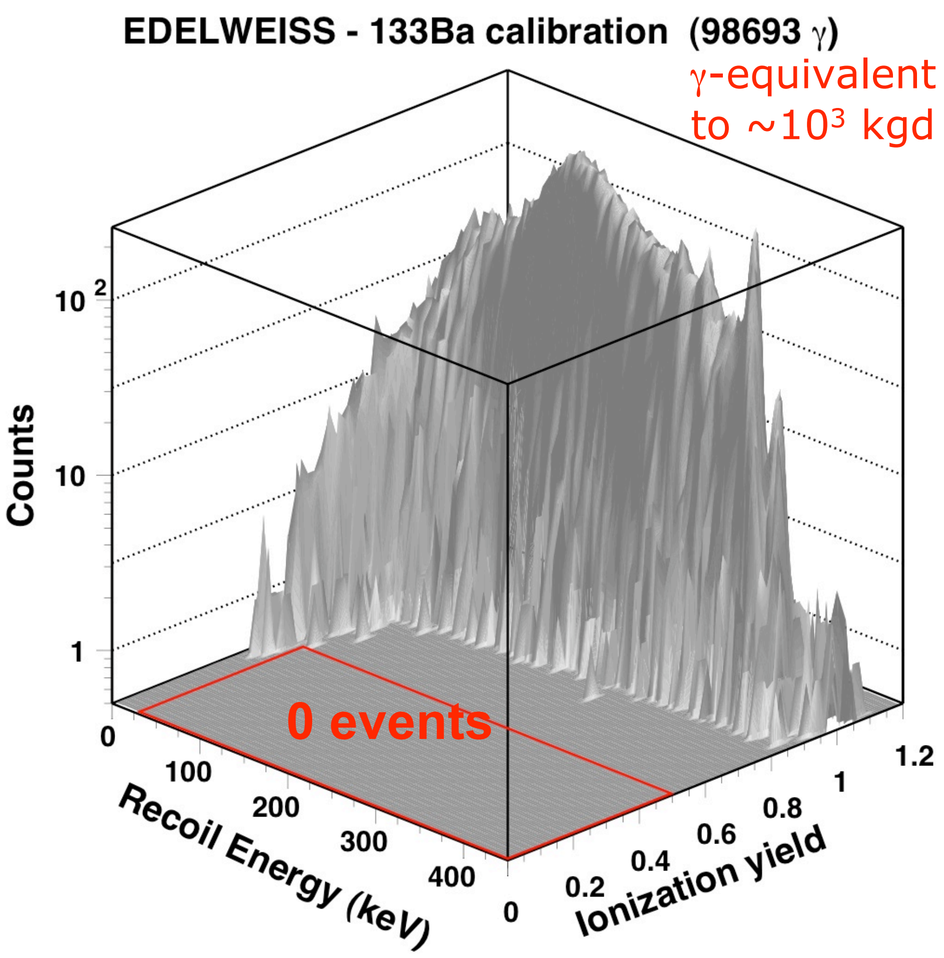
First detector built 2007
1x200g + 3x400g tested in 2008
10x400g running since beginning 2009
More coming 2010

the « ID » (interdigit) detector



- Keep the EDW-I NTD phonon detector
- Modify the E field near the surfaces with interleaved electrodes
- Use 'b' and 'd' signals as vetos against surface events

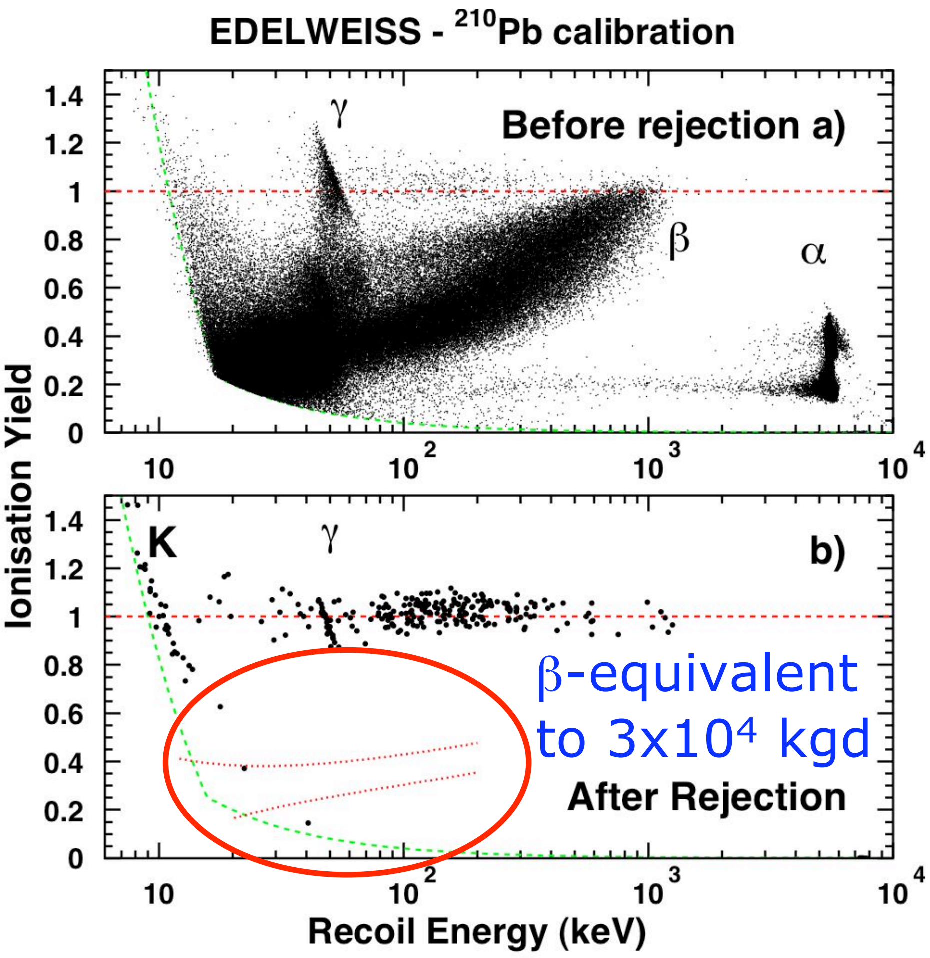
IDs : overall background rejection performances



EDELWEISS - 133Ba calibration (98693 γ)

γ-equivalent to ~10^3 kgd

0 events



EDELWEISS - ^{210}Pb calibration

Before rejection a)

b)

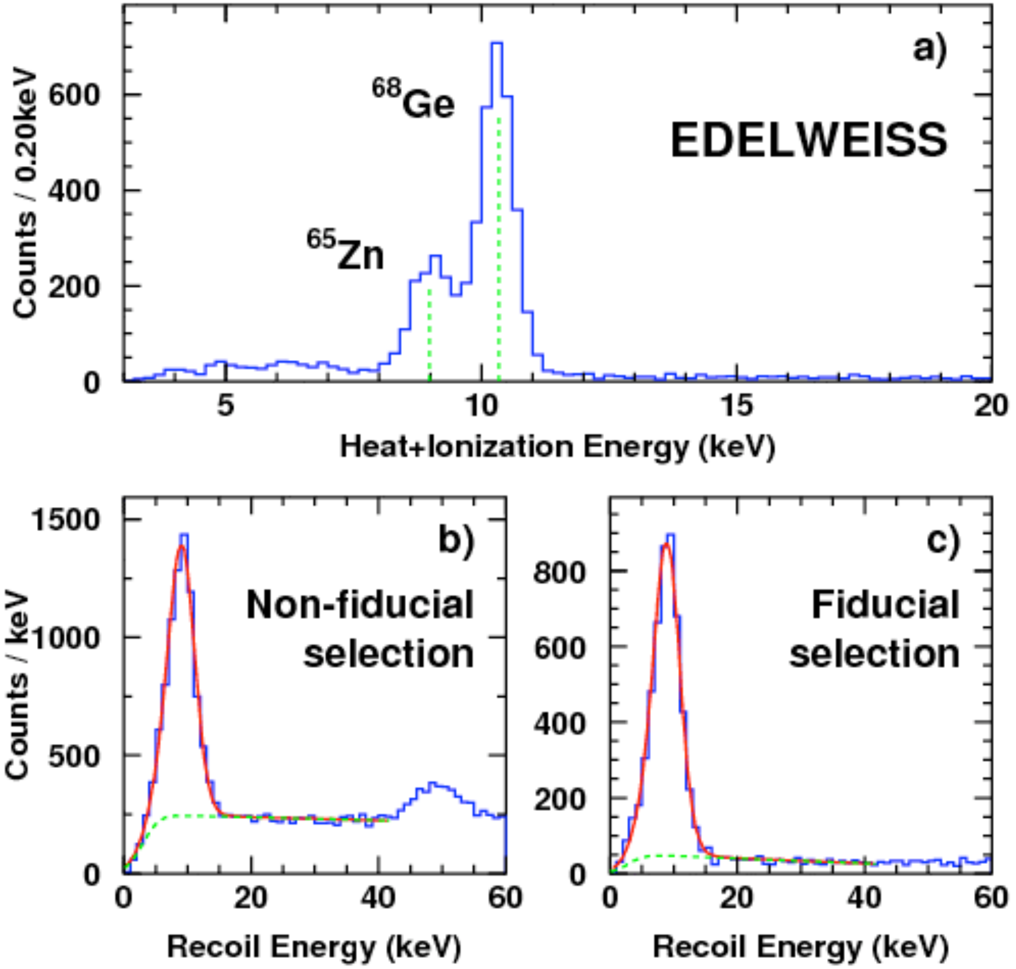
β-equivalent to $3x10^4$ kgd

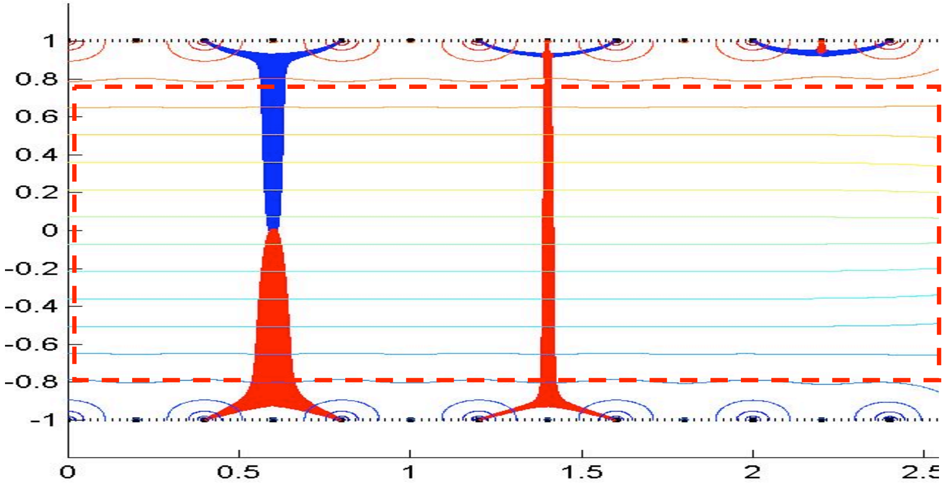
After Rejection

Phys Lett B 681 (2009) 305-309 [*arXiv:0905.0753]*

ID fiducial volume : well-controlled !

Data : all WIMP search (9 detectors)





- Estimation with electrostatic models

- Measurement with cosmogenic lines:
  - ^{68}Ge and ^{65}Zn isotope lines at ~10keV, background electron recoil events
  - *Homogeneously distributed in the volume of the cristal*
  - *<u>Real-condition measurement</u> of fiducial cuts efficiencies at low energy in WIMP search conditions (baselines, voltages…)*

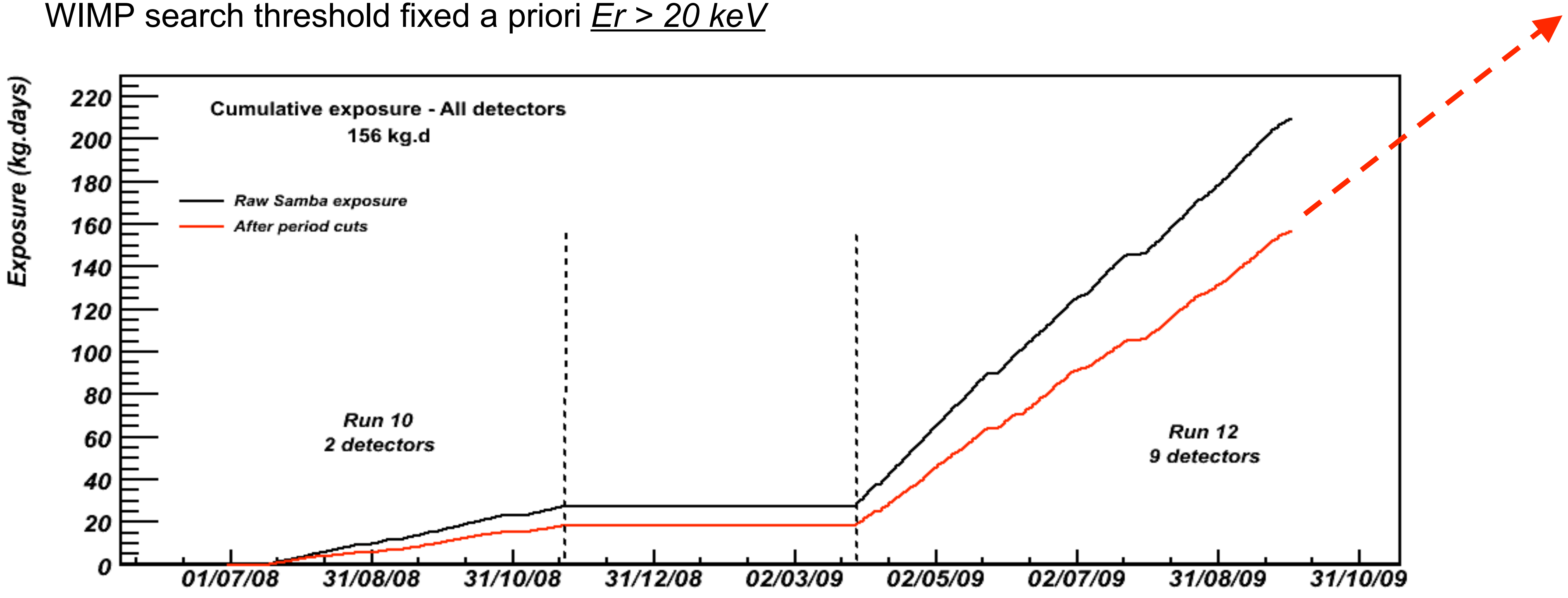
- Other measurement : using neutron calibration
- **Fiducial volume measurement 166g ± 6 => 160g, *primarily limited by the guard regions***

WIMP search with ID detectors

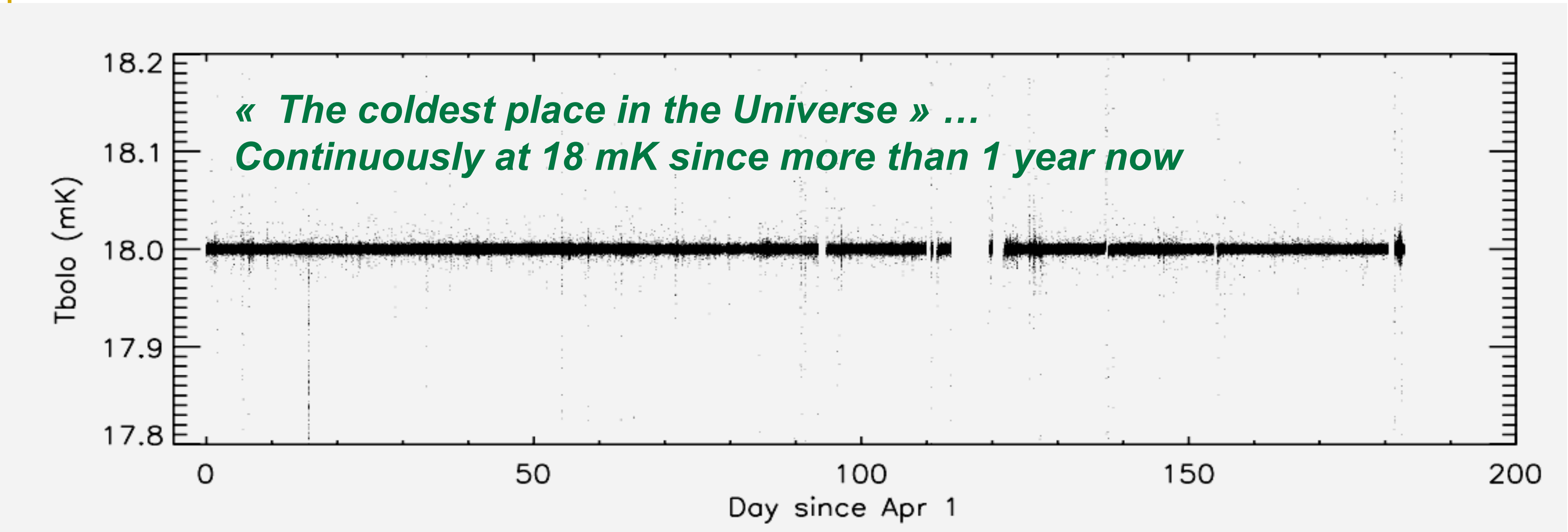
- 20 kg.d in 2008 during validation runs of ID detectors
- Physics run **Apr - Sept 2009** : **6 months data** presented
- Oct 2009 - Spring 2010 : run continuing

160 kg.d « post-cut » WIMP search

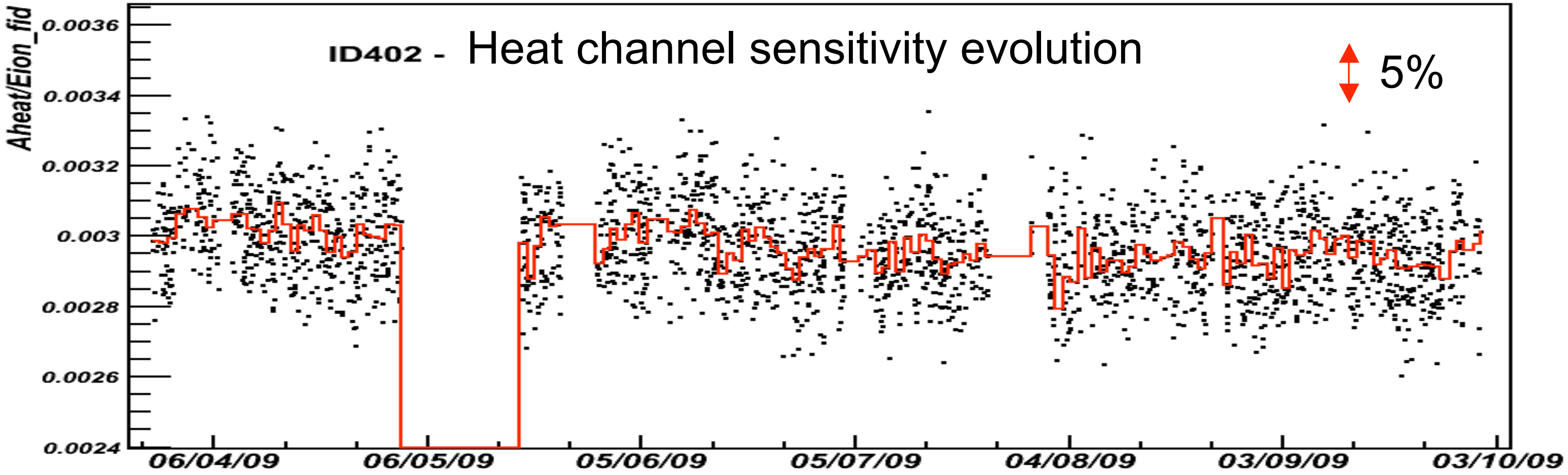
- Working detectors : heat + both « collectrodes » + 3 vetos and guards / 4
  - **9 detectors/10** ⇒ **reliability of IDs proved in real conditions**
- Period selection based on baseline noises : **80% efficiency**
- WIMP search threshold fixed a priori *Er > 20 keV*



Cryogenics performances & heat sensitivity



« The coldest place in the Universe » …
Continuously at 18 mK since more than 1 year now

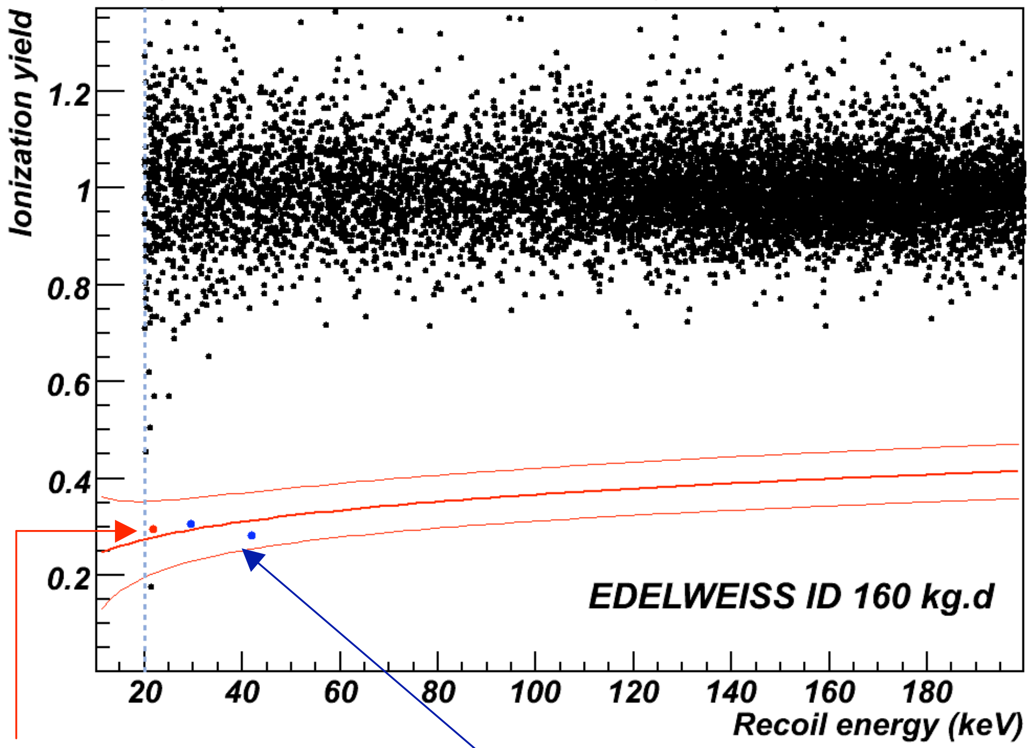


Heat channel sensitivity evolution

EDELWEISS-II WIMP search : first result

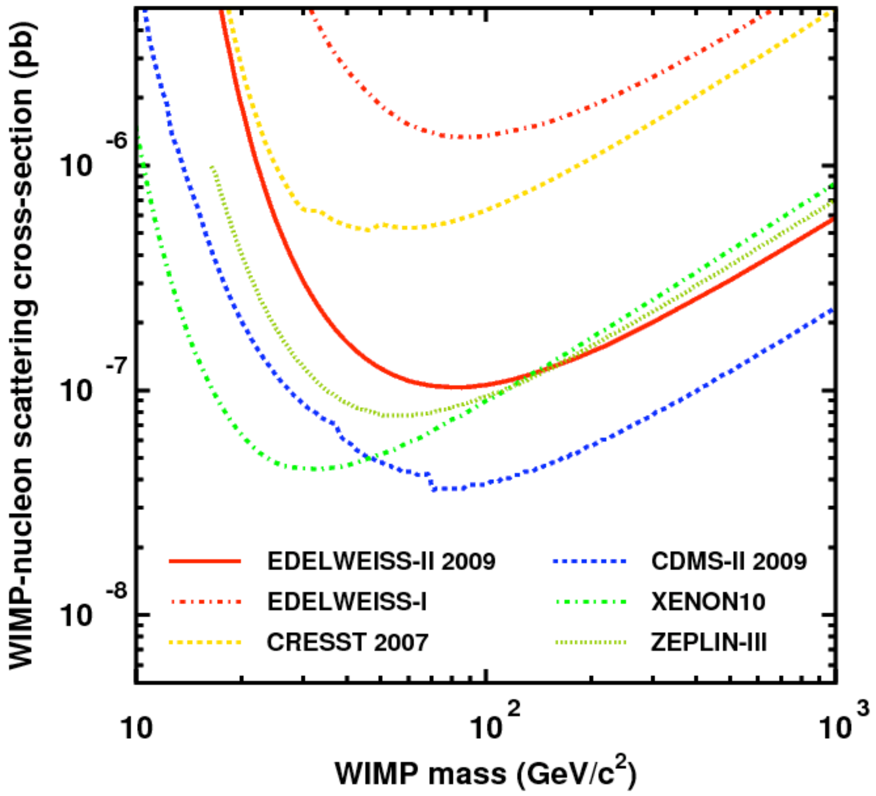
arXiv:0912.0805

160 kg.d x 90% NR band = 144 kg.d



« WIMP candidate »
Er = 21 keV

coincidences bolo-bolo+veto
=> muon-induced neutrons
in fiducial volume



Currently ~ x2 exposure

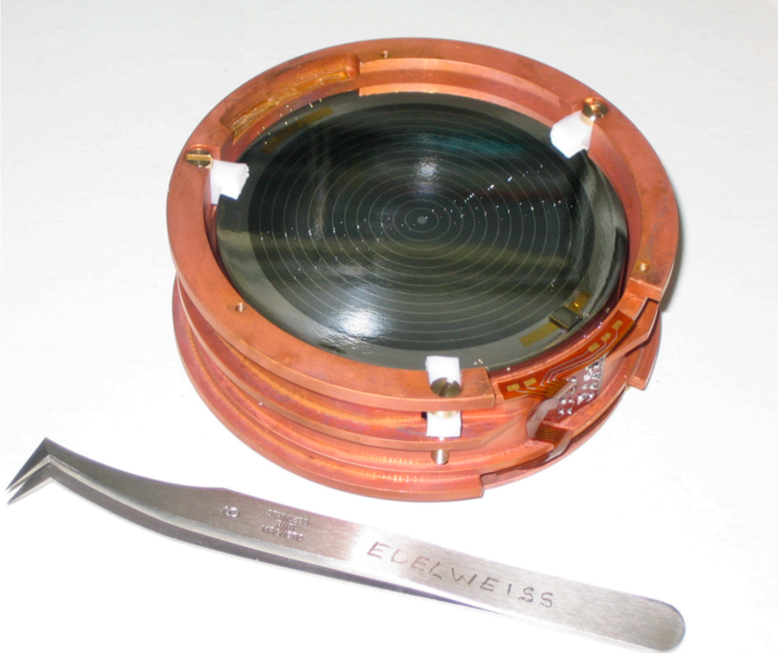
Background estimation : work in progress

First estimation *from previous calibrations/simulations*:

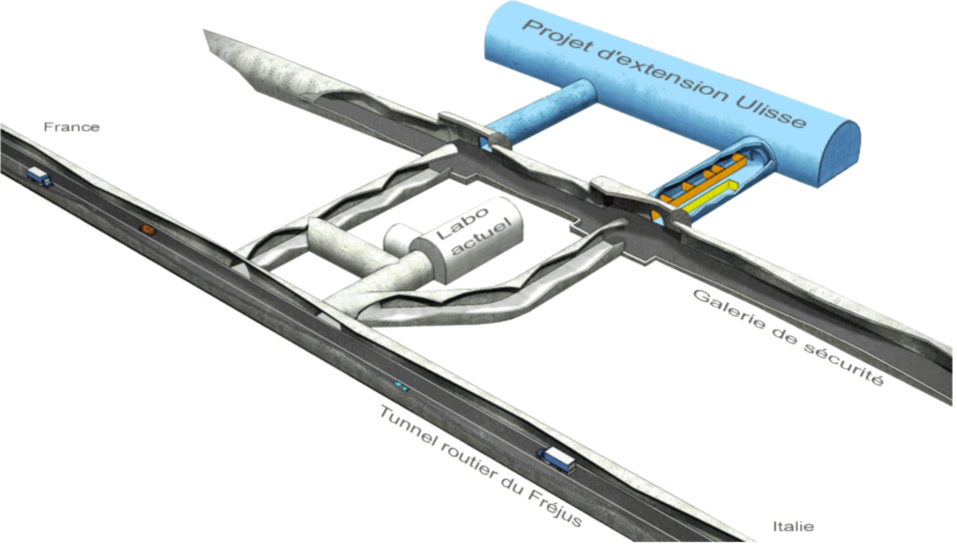
- gamma < 0.01 evt (99.99% rejection)
- beta ~ 0.06 evt (from ID201 calibration+obs. surf. evts)
- neutrons from ^{238}U in lead < 0.1 evt
- neutrons from ^{238}U+(α,n) in rock ~ 0.03 evt
- neutrons from muons < 0.04 evt

} < 0.23 evt

Edelweiss : summary / prospects



- EDELWEISS is currently finishing a first WIMP search with new-generation ID detectors
  - Robust detectors with redundancy and very high beta rejection
  - First 160kg.d => WIMP limit @ 10^{-7}pb, 1 evt observed
  - X2 exposure in Spring (+lower threshold & bg estimations)
  - Larger mass detectors to be installed in Spring



- Goals (including FIDs 400+800g)
  - 2011 = 1000 kg.d
  - 2012 = 3000 kg.d

  - Longer term Eureca@Ulisse, new LSM cavity

Global WIMP search : current status

- Current experiments already rule out a significant part of cMSSM parameter space
- *Short-term : $10^{-8/9}$ pb = major SUSY models probed*

XENON100, Edelweiss…

- *Long term : $10^{-10/12}$ pb = most WIMP models*

==> **require (multi)ton scale experiments**

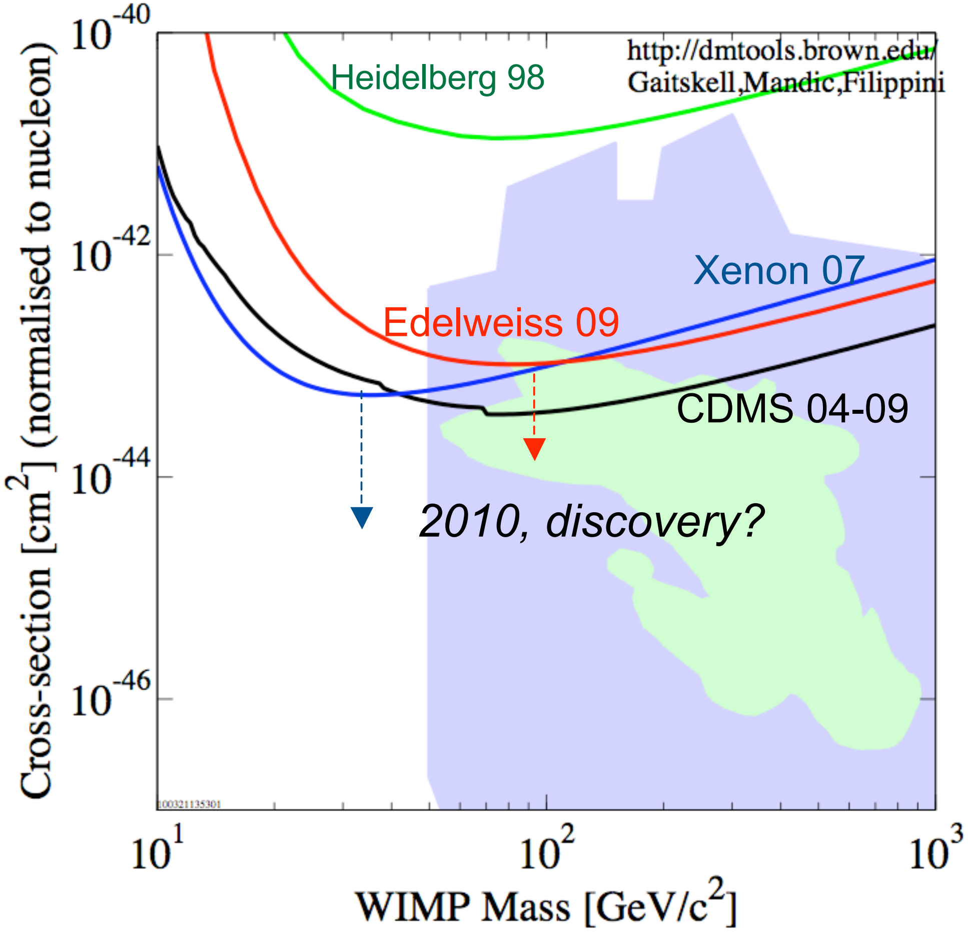
- **2 competitive technologies**

- Noble liquid TPCs = probably most appropriate to scale to large masses

Darwin, LUX…

- Bolometers = complementary, have better gamma rejection than Xe

Eureca, GeoDM…

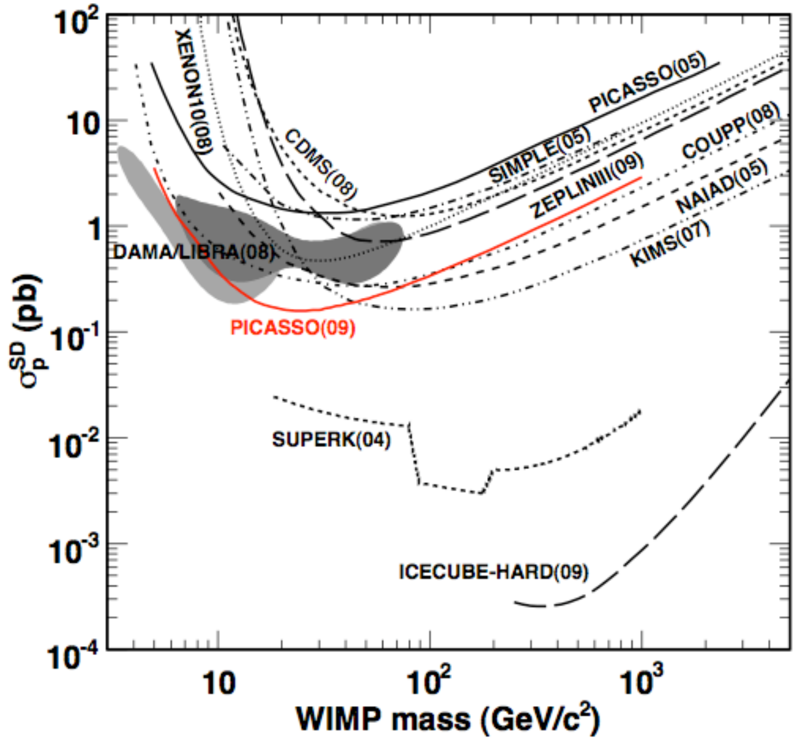


2010, discovery?

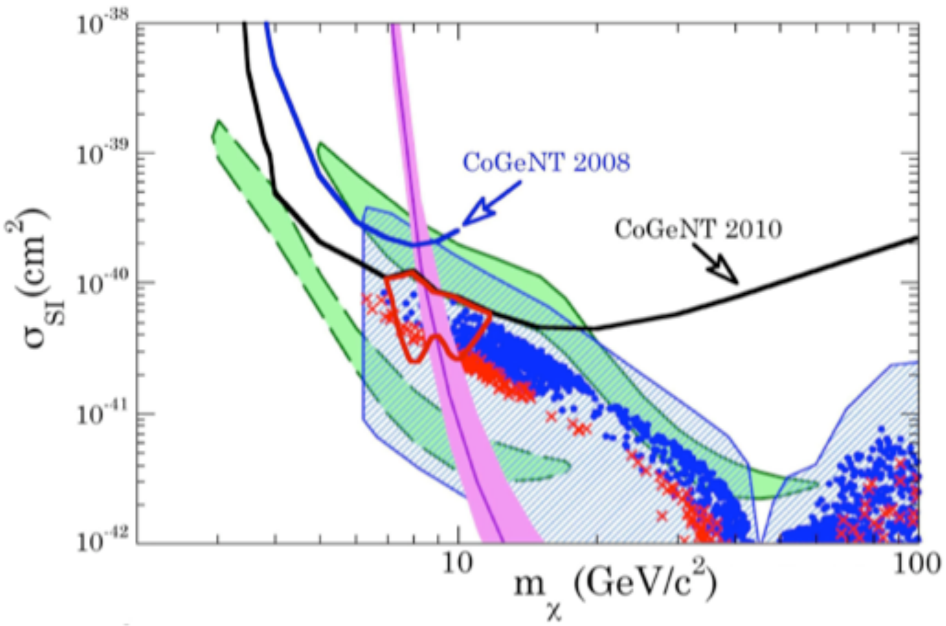
Global WIMP search : current status (b)

Several other channels, eg :

Spin-dependant coupling to proton
- several R&D technologies
- best sensitivity @ high mass = neutrinos from the Sun



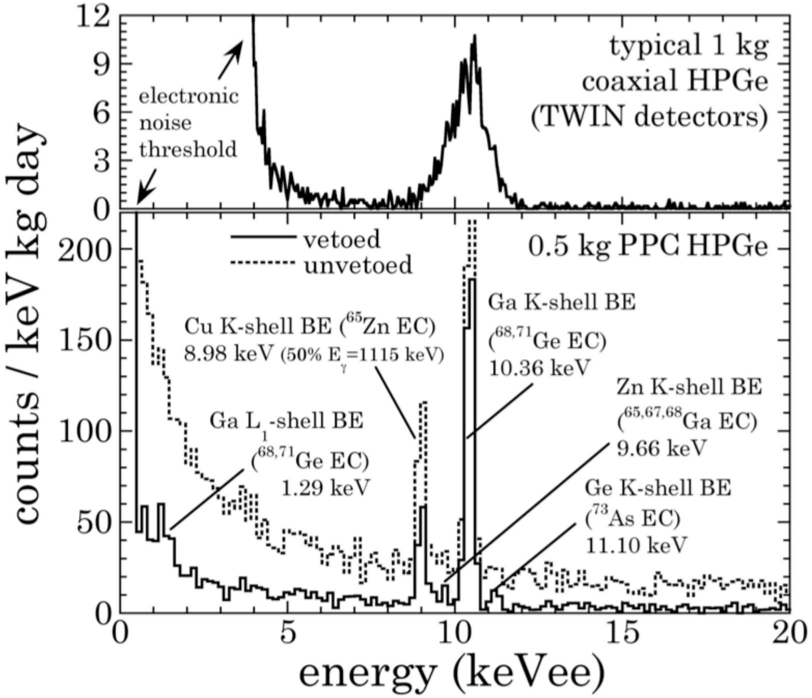
Low-mass WIMPs (~10 GeV)
- one of the last « windows » for DAMA
- need ultra-low threshold detectors



Résultats récents de détecteurs Germanium : CoGeNT

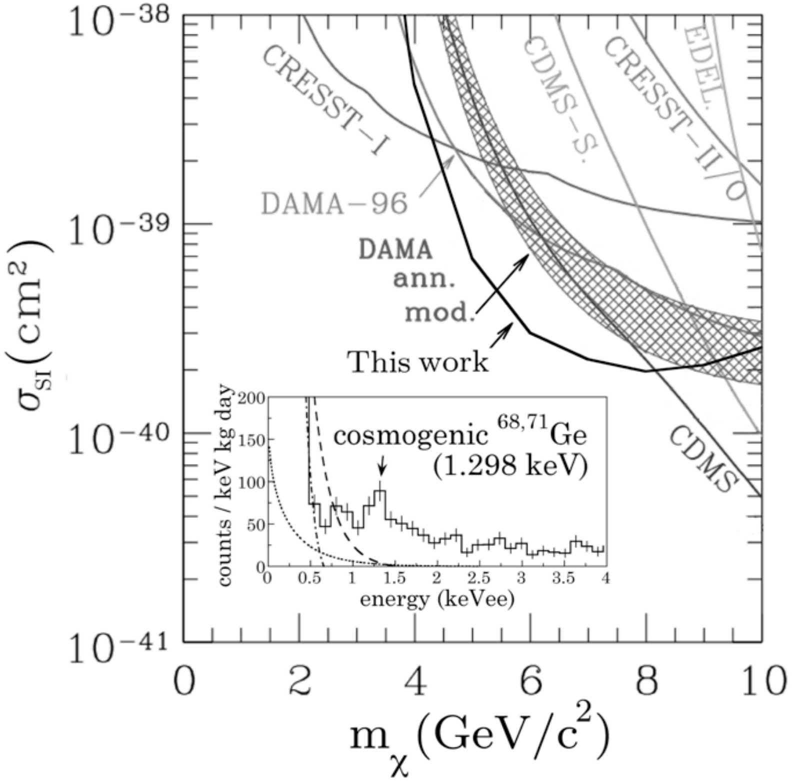
- ➢ Détecteurs Ge à ionisation seule, haute pureté (HPGe), améliorés (gain en seuil)
- ➢ Applications :
  - - diffusion cohérente de neutrinos
  - - **WIMPs à basse masse**

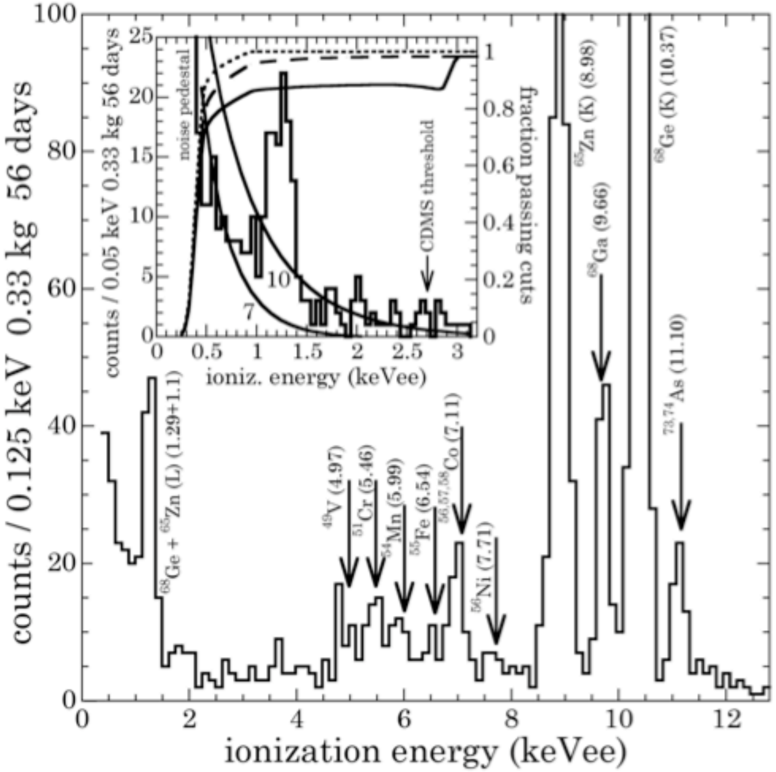
- • Pas de discrimination des bruits de fond, mais résultats pertinents à basse masse grâce au seuil bas
- • Résultats analogues par la collaboration TEXONO

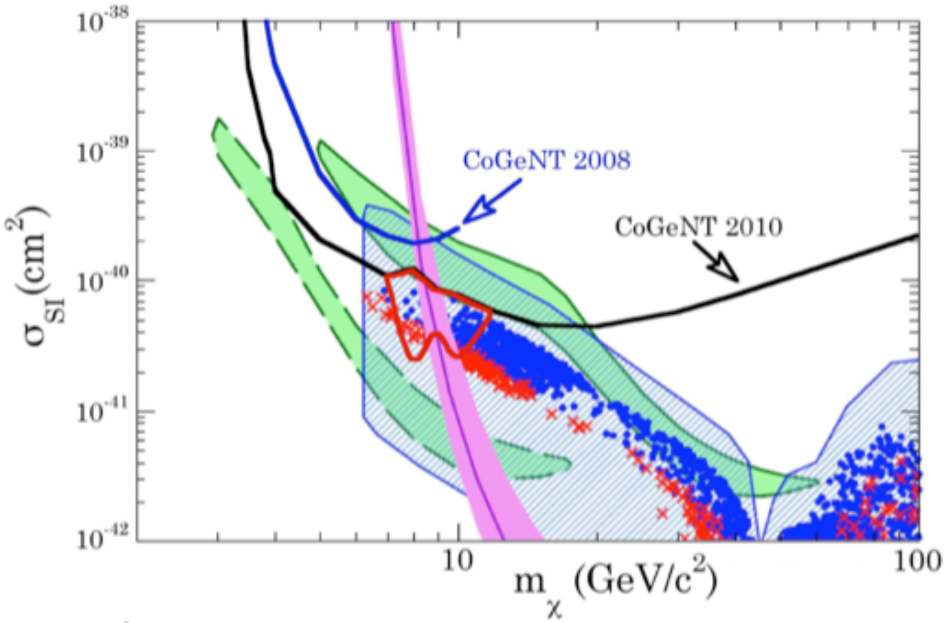


Description détecteur: Barbeau et al, JCAP 09 (2007) 009

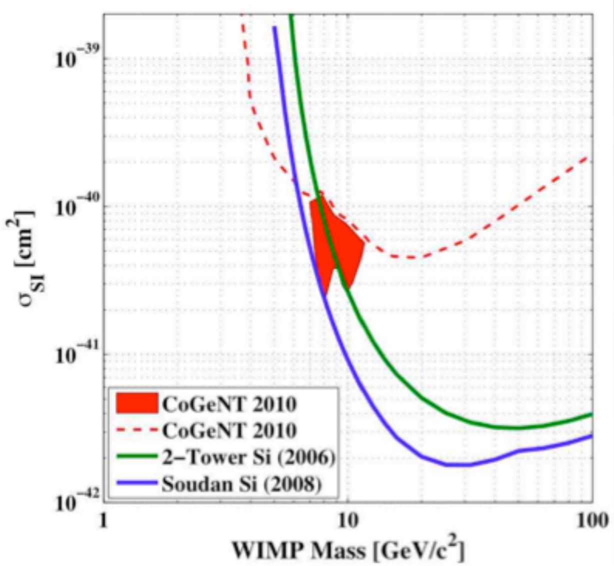
CoGeNT







Silicon Low Mass WIMP Limits (Comparison to CoGeNT)



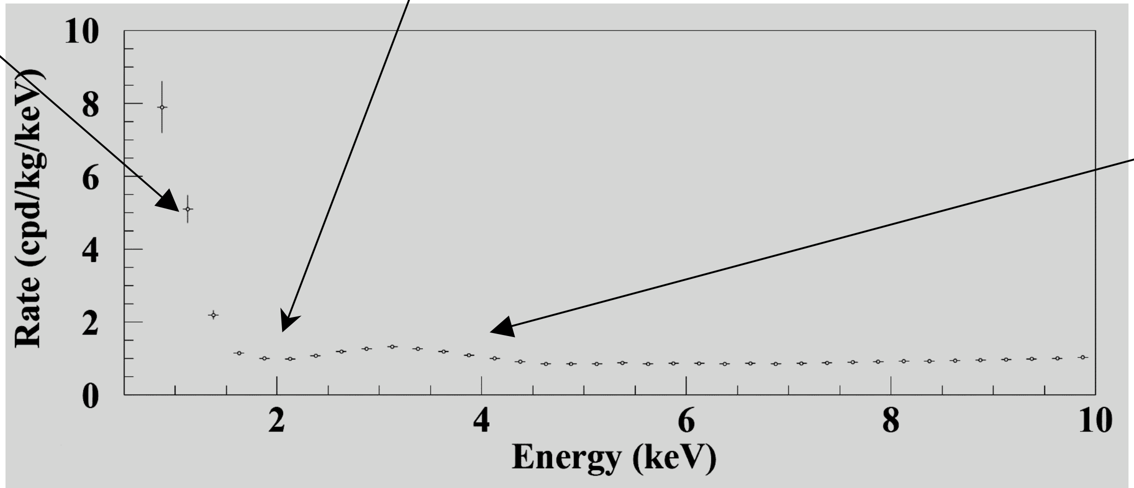
La modulation annuelle de DAMA/LIBRA

- ➢ Détecteur à scintillateur NaI
  - DAMA : 100 kg pendant 7 ans
  - DAMA/LIBRA : 250 kg, 4 ans

⇒ 0.82 tonne.an

- ➢ Pas de discrimination du fond
  (pas d'analyse forme des pulses)

Taux d'événements « brut » :



Bruit des PMTs (?)

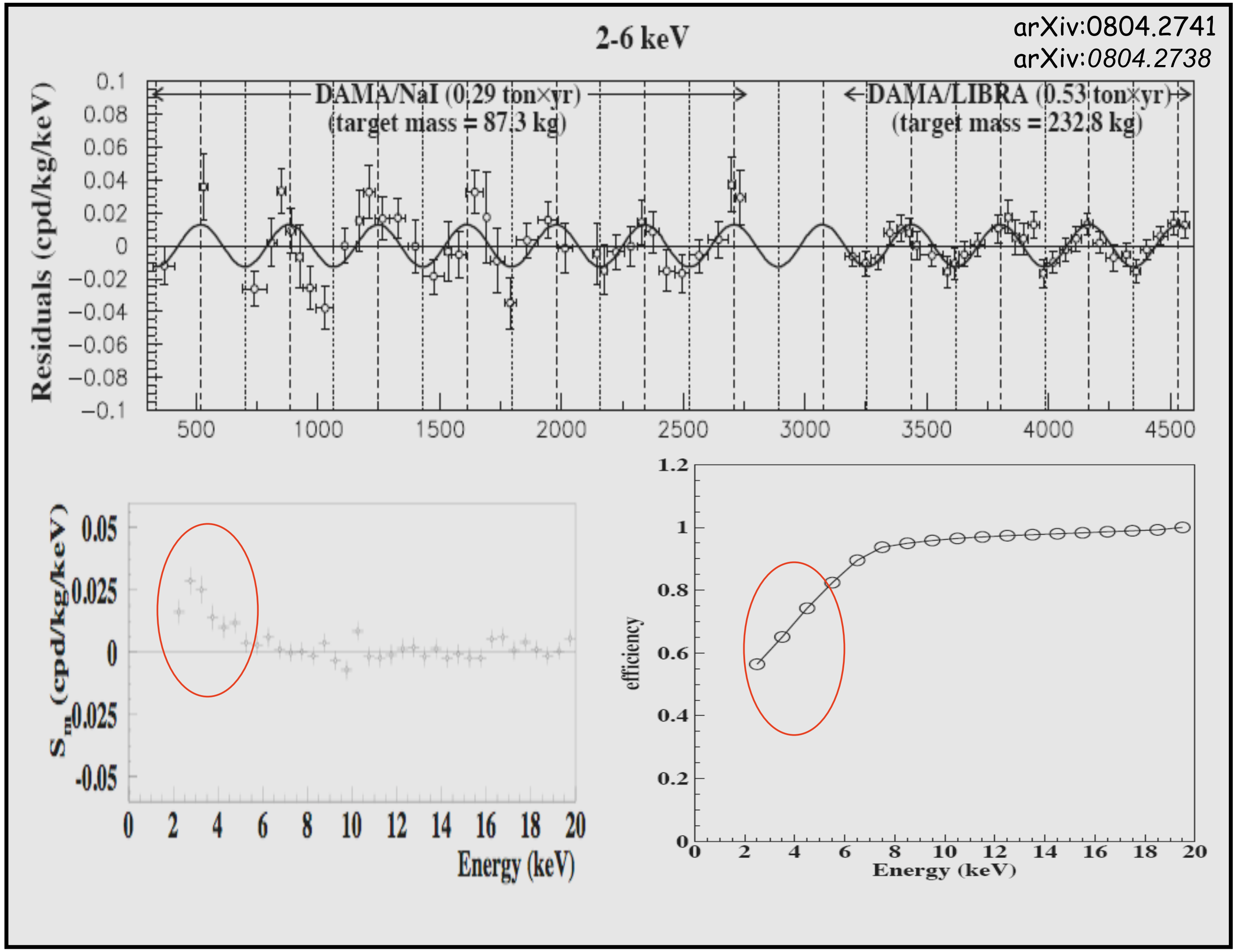
seuil d'analyse @ 2keV

- fond radioactivité gamma (dont raie K dominante @ 3keV)
- plus signal éventuel WIMPs [dont ~ 10% est modulé]

La modulation annuelle de DAMA/LIBRA

- **Modulation du taux d’évts @ basse énergie à 8σ**

- Phase correcte (début juin)
- Modulation observée seulement dans les *singles*
- Tout le signal modulé est vers 3keV:
  - pic du K
  - seuil d’acceptance

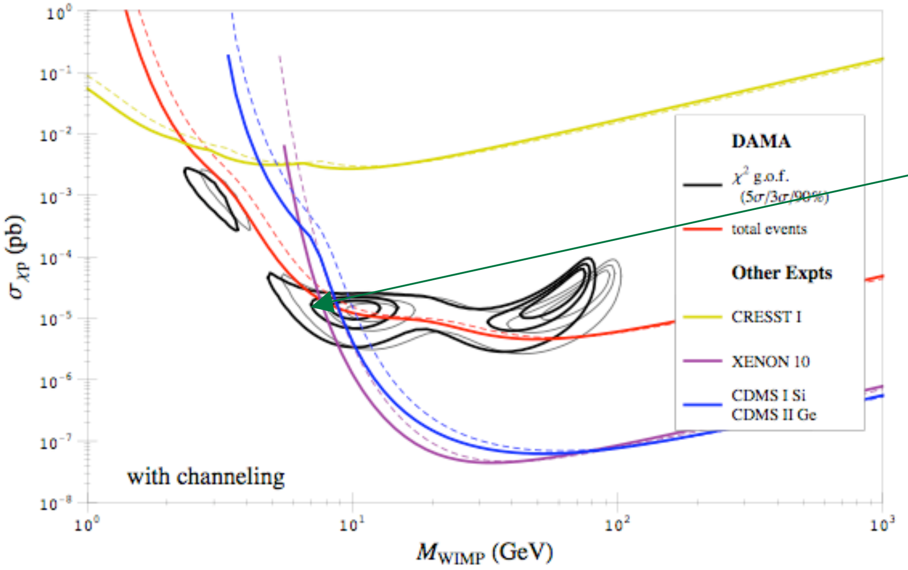


arXiv:0804.2741
arXiv:*0804.2738*

Résultat difficile à contrôler du point de vue des systématiques
En attente de résultats de KIMS (CsI - en modulation annuelle depuis 1 an)

Interprétation en WIMPs « standard » de DAMA/LIBRA

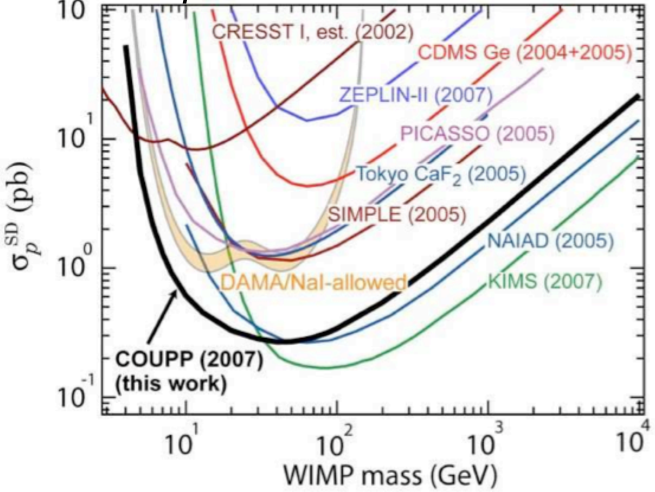
- Spin-indépendant (donc SUSY) : l’essentiel de l’espace compatible avec DAMA est exclu par les autres expériences depuis ~ 2002

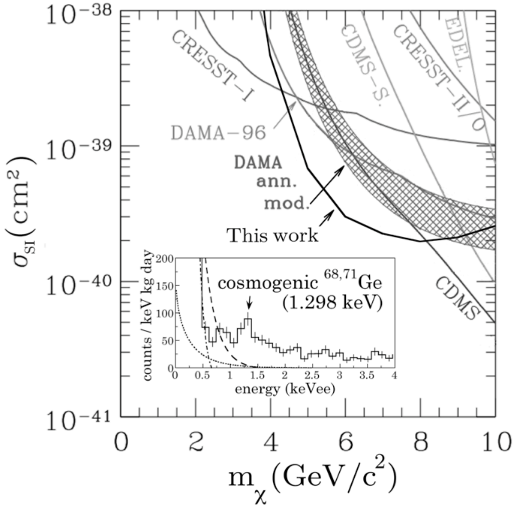


Fenêtre résiduelle à basse masse (avec l’effet hypothétique de channeling pris en compte)

- contrainte CoGeNT

- *Canal spin-dépendant quasiment exclu par COUPP + KIMS*





➡ Nécessité d’interprétations plus « exotiques » (littérature abondante)

Une interprétation plausible : matière noire inélastique (iDM)

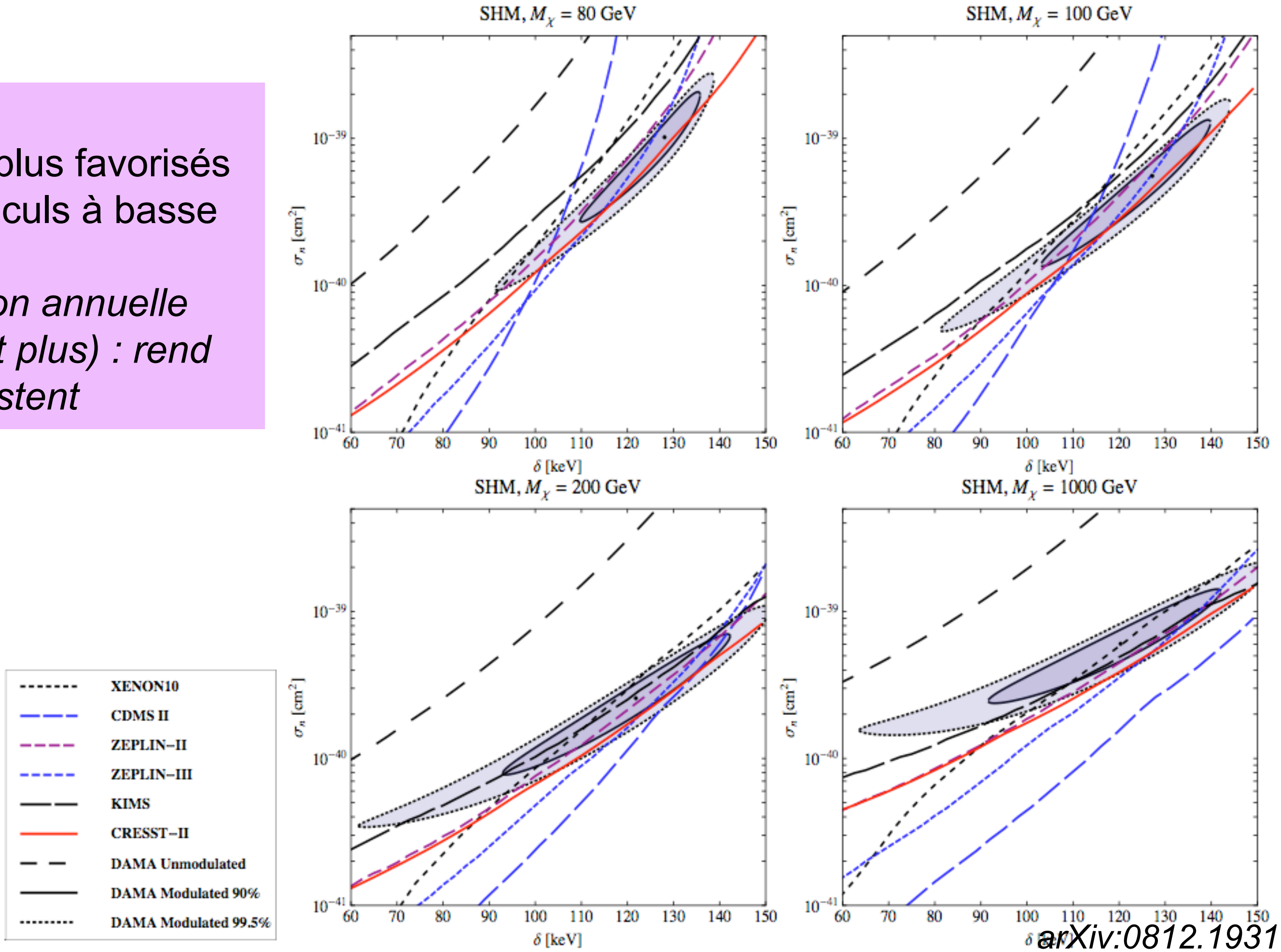
Changement de la cinématique de la diffusion :

$$\begin{cases} \chi + N \rightarrow \chi^{*} + N + E_{r} \\ m_{\chi^{*}} = m_{\chi} + \delta \end{cases}$$

avec δ ~ 100 keV

⇨ vitesse nécessaire plus importante pour générer un recul E_r

<u>Conséquences</u> :
- Noyaux cibles lourds encore plus favorisés
- Suppression du spectre de reculs à basse énergie
- *Augmentation de la modulation annuelle (les grandes vitesses comptent plus) : rend le signal DAMA plus autoconsistent*

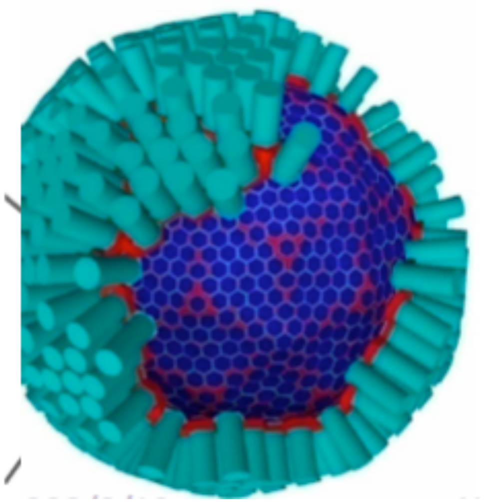


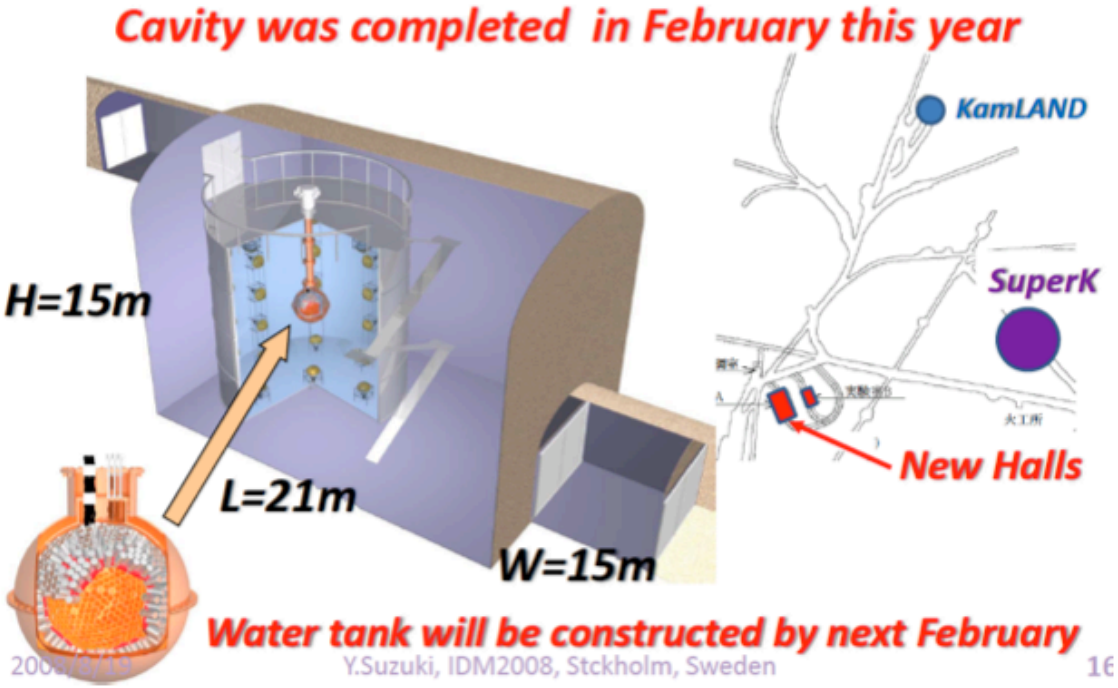
arXiv:0812.1931

- ➢ Le paramètre δ supplémentaire ouvre une petite fenêtre
- ➢ Contraintes fortes à venir des autres expériences (analyse des spectres de recul à énergie « élevée »)

Un détecteur Xenon à une seule phase : XMASS

- @ Kamioka
- Sphère de Xe ~ 900 kg
- Entourée de PMTs basse radioactivité (couverture photocathode 64%)
- Coupure fiducielle généreuse pour compenser le manque de discrimination des gammas.
- Blindage eau (neutrons)
- Vise ~10^{-4} dru soit 10^{-45} cm^2





Cavity was completed in February this year

Water tank will be constructed by next February

200

Y.Suzuki, IDM2008, Stckholm, Sweden

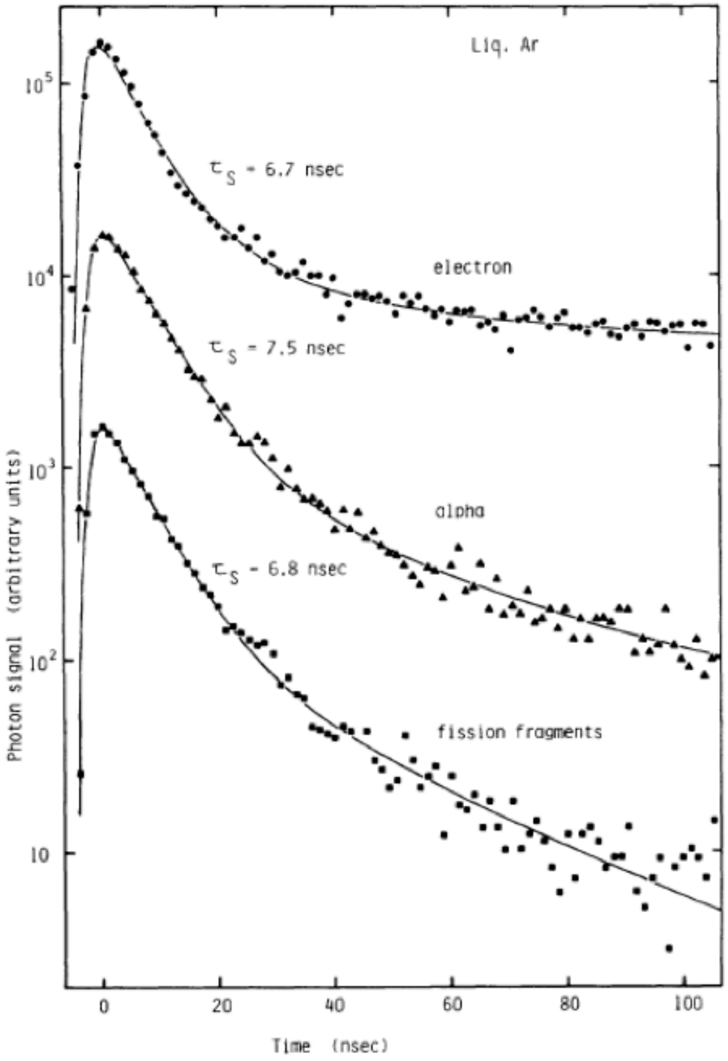
16

Détecteurs à l'Argon liquéfié

- Même principe que le Xenon

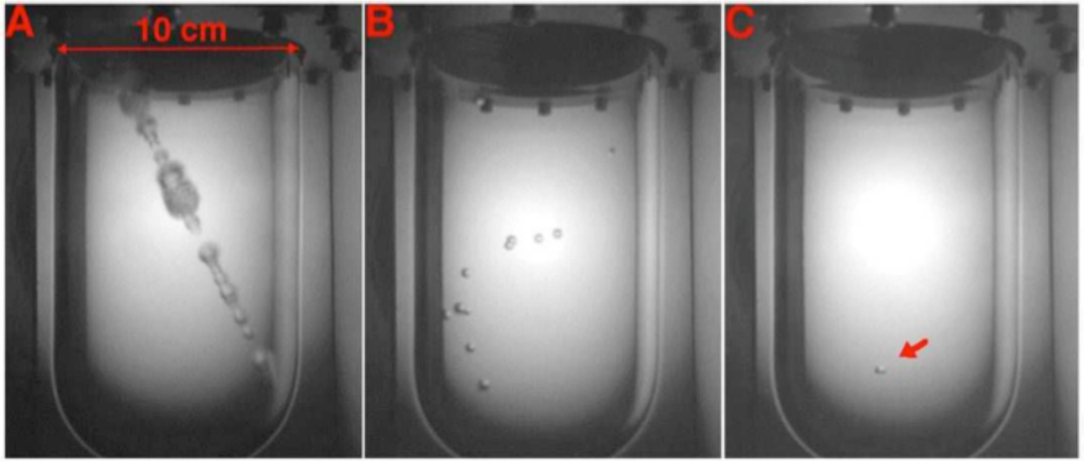
- Scintillation lente via l'état « triplet »
⇒ Comme le ratio singlet/triplet dépend du pouvoir ionisant de la particule, fournit une **seconde variable discriminante indépendante par mesure de la forme du pulse** (pulse shape discrimination == PSD)

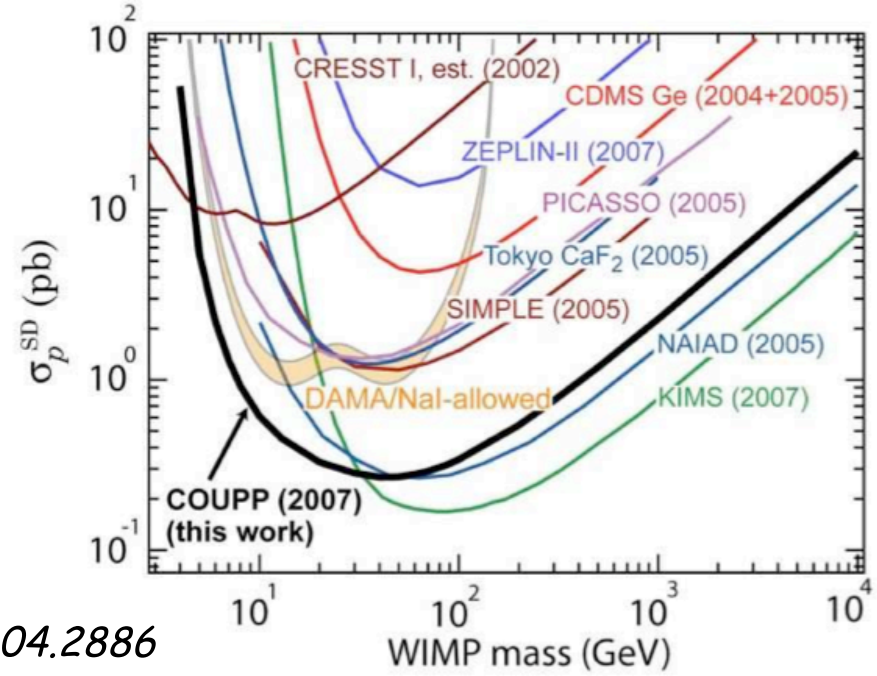
- Présence de l'isotope naturel radioactif ^{39}Ar : nécessité de trouver des sources à basse radioactivité (eg. réservoirs souterrains)



Canal spin-dépendant : COUPP

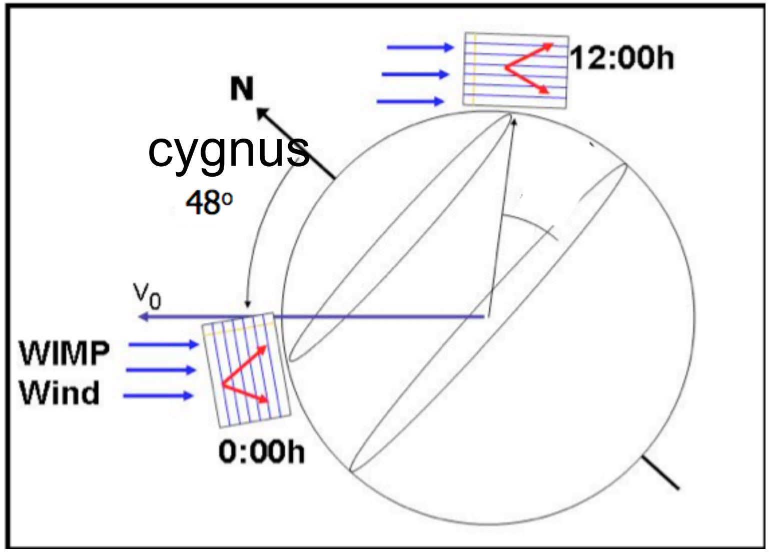
- R&D : le retour de la chambre à bulle?
- Aux bonnes conditions de pression sensible uniquement aux reculs nucléaires
- Scan (T,P) → scan en énergie
- 250 kg.j avec du CF_3I
  - Fluor : couplage au spin du proton





arXiv:0804.2886

Directionnalité des reculs de WIMPs

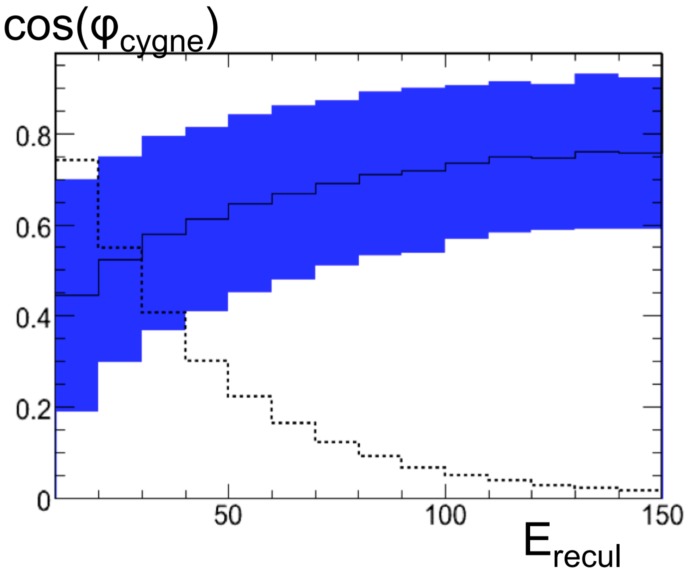


$$v_e = v_0\left(\boxed{1.05} + 0.07\cos\omega t\right)$$

- Mouvement relatif du système solaire par rapport au halo, à la vitesse v_0
- Distribution angulaire des reculs :

$$\frac{dR}{dE_r d\cos\varphi} \propto \exp\left(-\frac{(v_e\cos\varphi - v_{\min})^2}{v_0^2}\right)$$

Forte anisotropie dans la distribution des reculs par rapport à la « direction du Cygne » (effet d'amplitude ~ 80%)

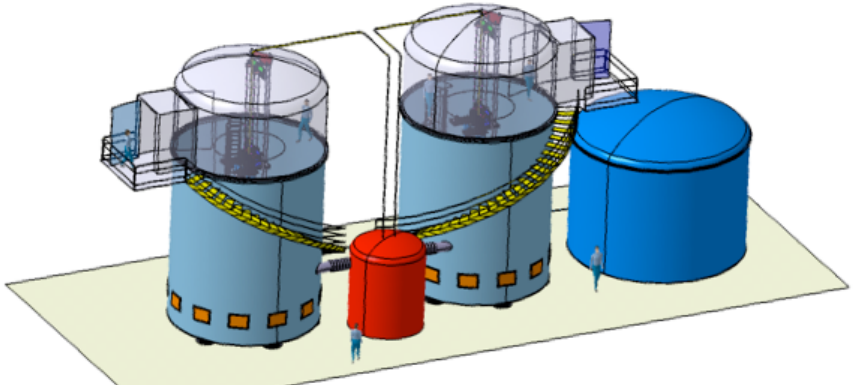


- Il faut pouvoir mesurer la direction des reculs : détecteurs gazeux (donc peu massifs / très volumineux…)

Projets de bolomètres « 100 kg - 1 tonne »

- ***Europe : projet EURECA***

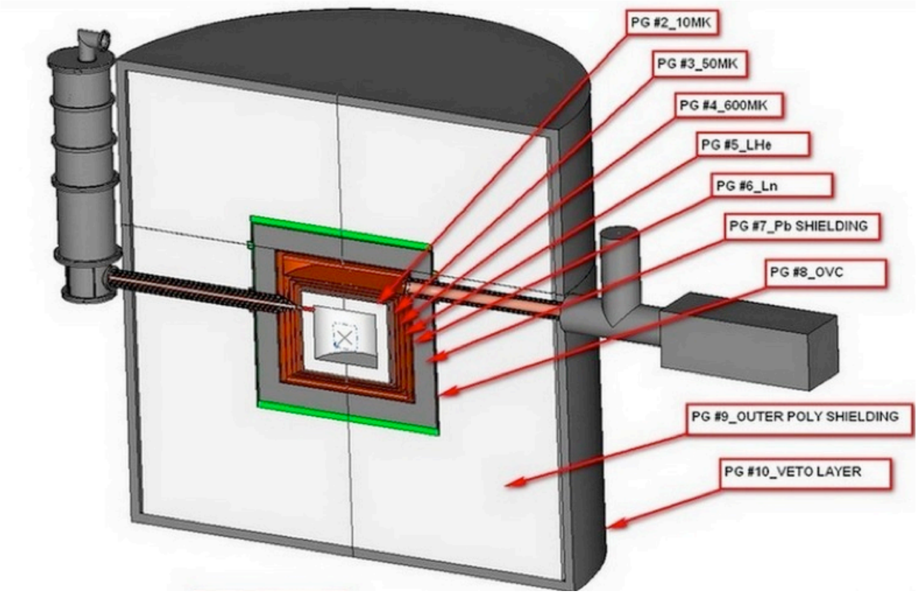
- à long terme
- « multi-cible » : germanium et scintillateurs
- nécessite des efforts importants en développement détecteurs et contrôle bruits de fond



EURECA : 2 cryostats in water tanks

- ***USA : suites de CDMS***

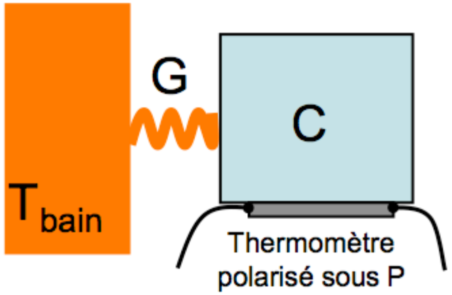
- Super-CDMS @ Soudan, 9kg, nouveaux détecteurs en R&D
- Super-CDMS @ SNOLab ~100kg
- Phase 1tonne @ DUSEL



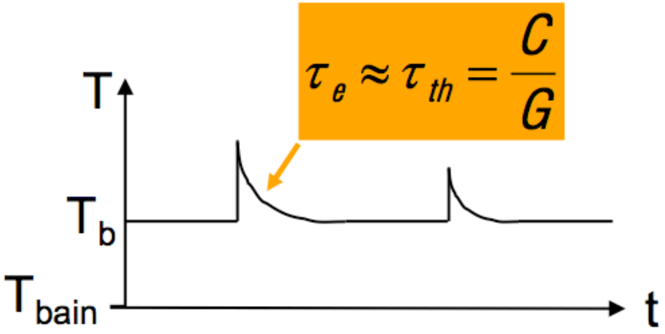
concept « Ice Box »

➡ *Techniquement envisageable, mais programmes lourds*

Principle of a bolometer for dark matter



C = heat capacitance
G = thermal leak
$P = G\,(T - T_{bath})$



$$\tau_e \approx \tau_{th} = \frac{C}{G}$$

Energy deposition E_0 in the absorber

⇓

$\Delta T = E_0/C$

⇓

Thermal measurement

- Working point @ T ~ 15 to 50 mK:

$C(T) \sim T^3$ (isolating) ou C ~ T (conducting)

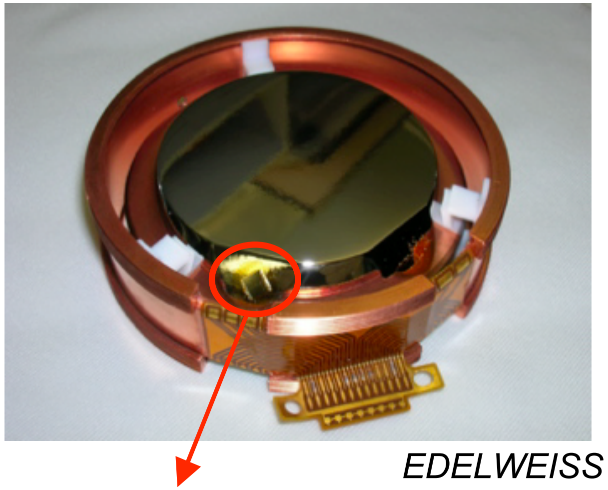
⇒ sensitivity gain

- Theoretical resolution limited by fluctuations of internal energy in the detector $\Delta U_{rms} = \sqrt{k_B T^2 C}$

- 2 uses :

- Dark matter, double beta decay, X-ray astro… : « impulse » mode (energy measurement)
- CMB, IR, … : « continuous » mode (power measurement)

- several types of thermometers (large R&D efforts)



EDELWEISS
Absorbeur ~ 400g