

A la recherche de la matière noire:

Résultats récents de l'expérience CDMS

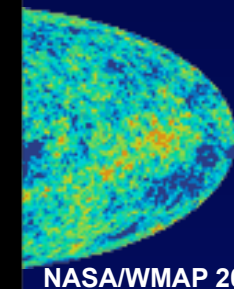
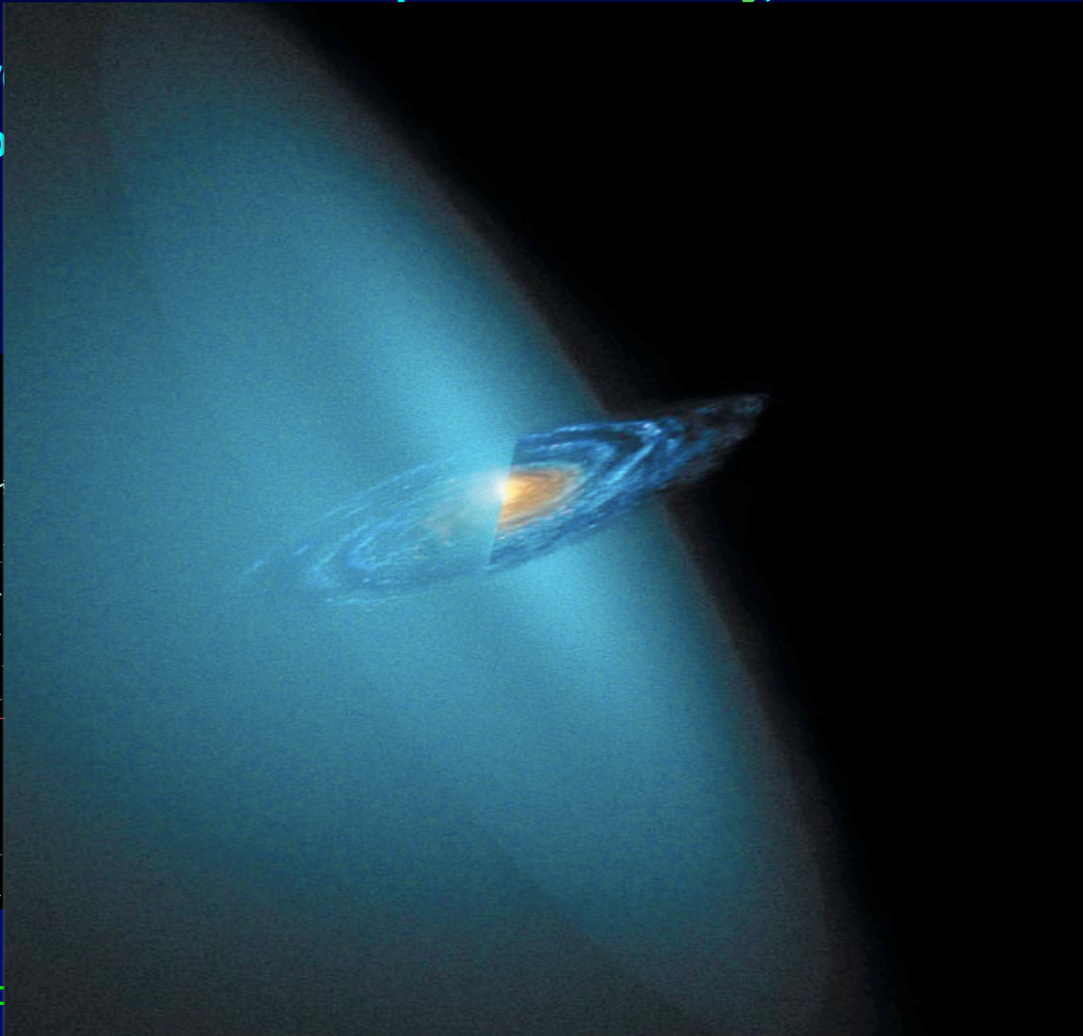
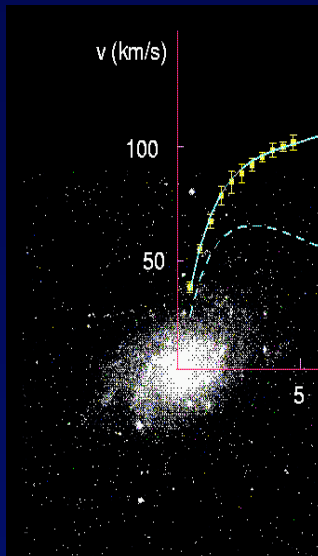
Bruno Serfass - UC Berkeley
CDMS collaboration

Existence de la Matière Noire

Depuis la mesure en 1933 des vitesses anormales des galaxies dans le grand amas de Coma par Fritz Zwicky,...

... de nombreux autres amas à différentes échelles, montrant...

matières



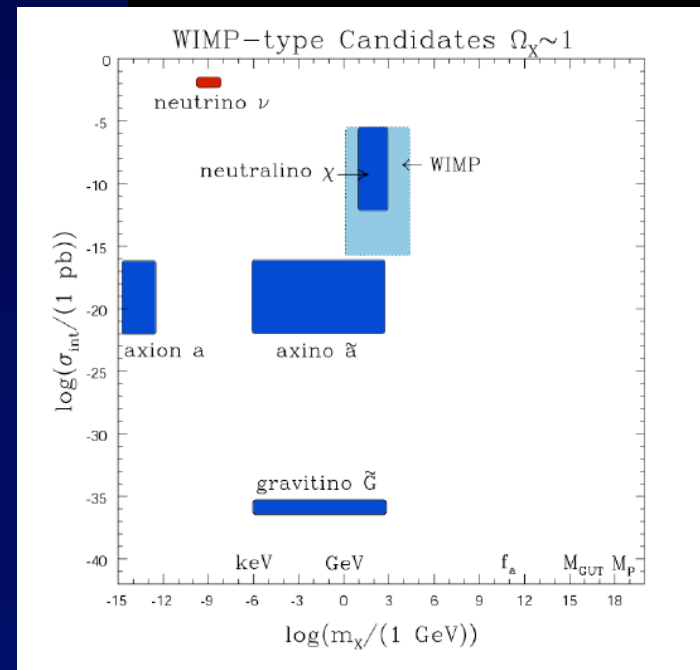
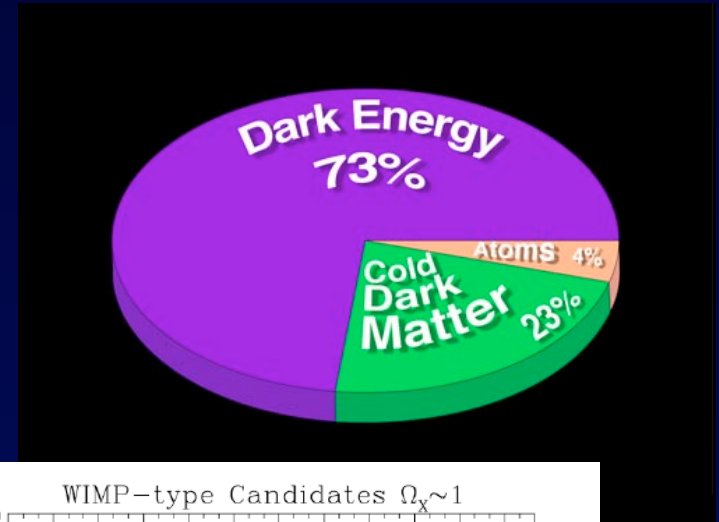
NASA/WMAP 2003

8, 109

Les Particules de Matière Noire

Matière noire: stable, non baryonique, non relativiste, interagissant faiblement

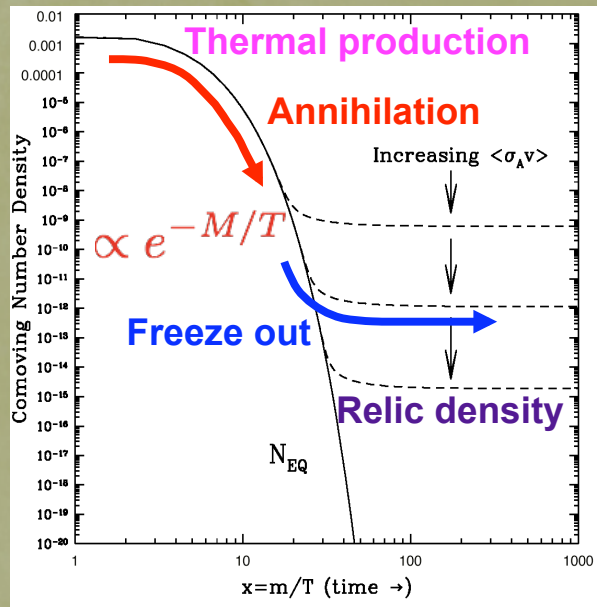
- **Weakly Interacting Massive Particles (WIMPs)**
 - particule interagissant très faiblement avec la matière ordinaire
 - Ex: SUSY neutralino, Kaluza-Klein (dimension supplémentaire)
- **Axions**
- **Neutrinos**
- **SUSY gravitinos, axinos,...**



(Roszkowski 2004)

Les WIMPs

Cosmology



$$\Omega_\chi \approx \frac{10^{-27} \text{ cm}^3 \text{ s}^{-1}}{\langle\sigma_{\chi\chi} v\rangle}$$

Weakly Interacting Massive Particles

- Particules stable, massives, produites dans l'univers primitif
- Section efficace d'annihilation doit être a l'échelle électrofaible pour expliquer la densité relic observée

$$\Omega_\chi \approx 1 \Rightarrow \left\{ \begin{array}{l} \sigma_{\chi\chi} \approx 0.1 \text{ pb } (10^{-37} \text{ cm}^2) \\ \sigma_{\chi\chi} \approx \frac{\alpha^2}{M_\chi^2} \Rightarrow M_\chi \approx 100 \text{ GeV}/c^2 \end{array} \right\}$$

Les WIMPs

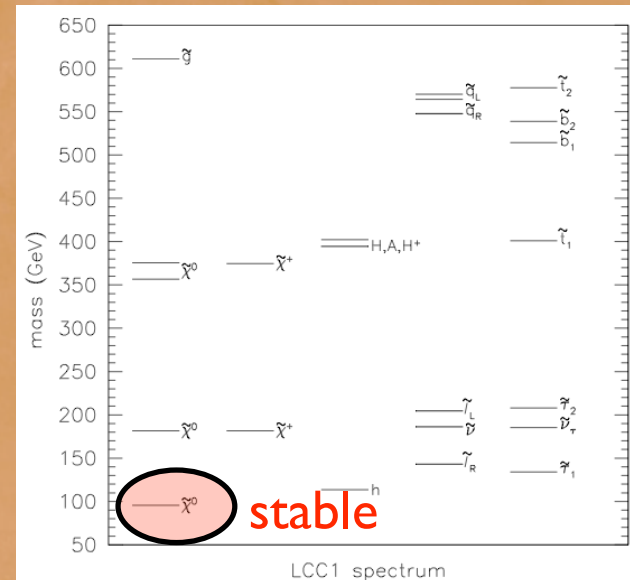
➤ Nouvelle physique nécessaire pour résoudre les problèmes du modèle standard, calcul de la masse du boson de Higgs, etc.

- Supersymétrie
- Dimensions supplémentaires
- ...

➤ Ces théories apportent des candidats stables, interagissant faiblement avec la matière

- LSP (neutralino)
- LKP
- ...

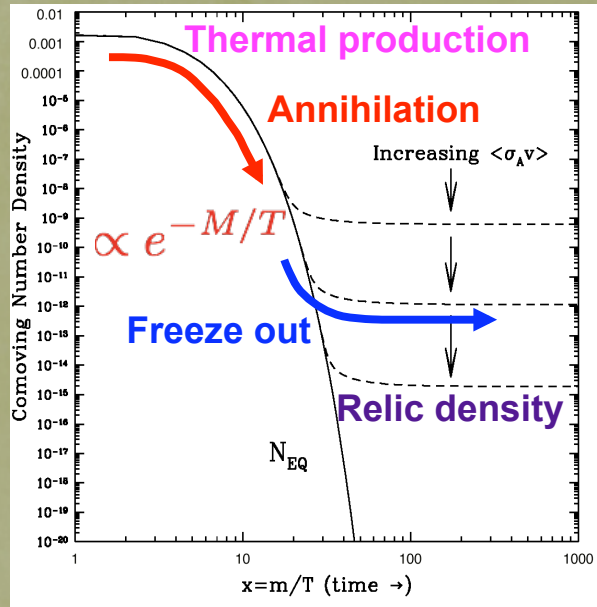
Particle Physics



Baltz et al., PRD 74, 103521 (2006)

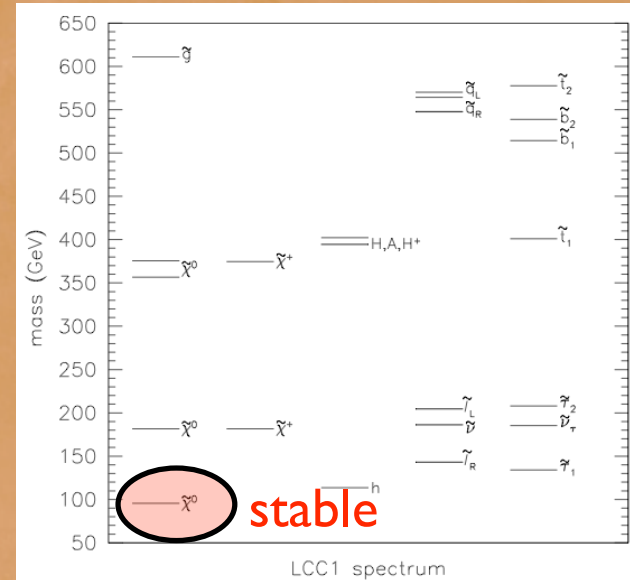
Les WIMPs

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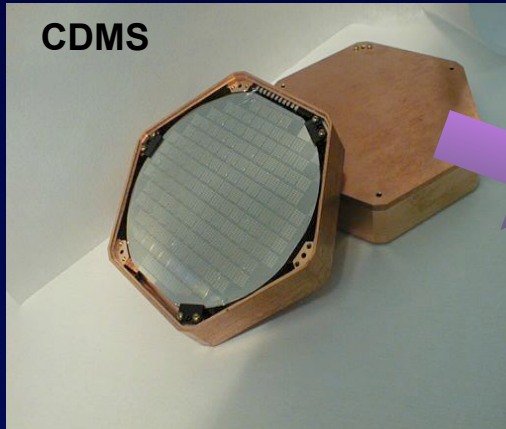


Baltz et al., PRD **74**, 103521 (2006)

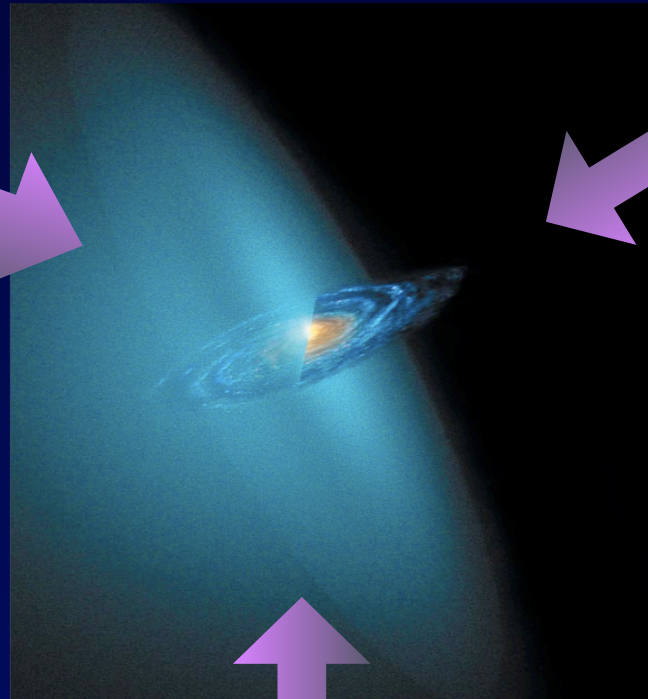
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Grande motivation pour la recherche des WIMPs

A la recherche des WIMPs



Mesure directe: interactions des WIMPs avec une cible dans un laboratoire



Mesure indirecte: annihilation des WIMPs



Production des WIMPs par un accélérateur

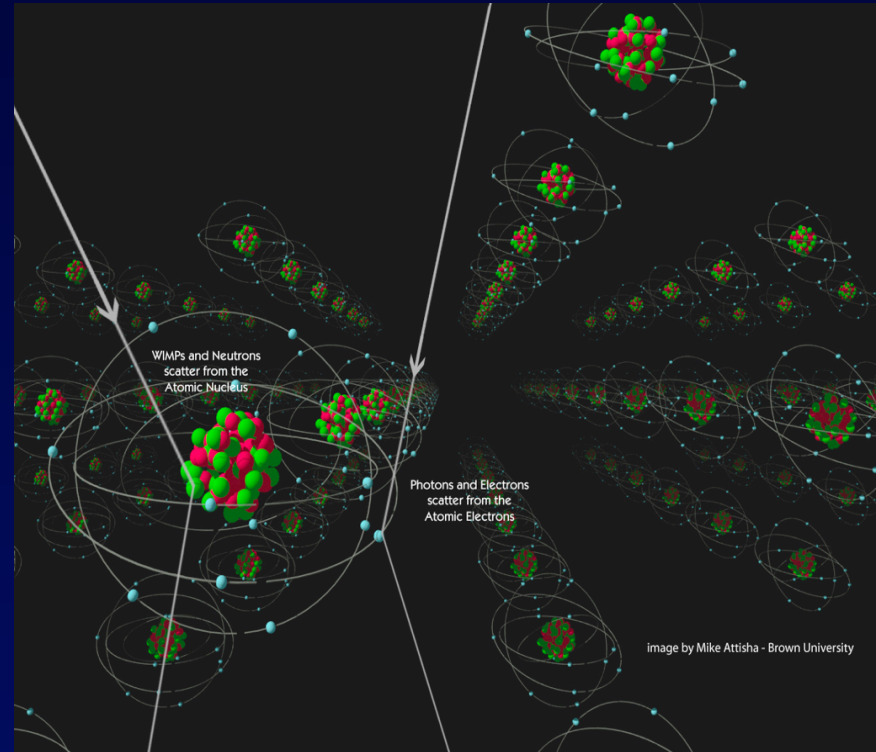
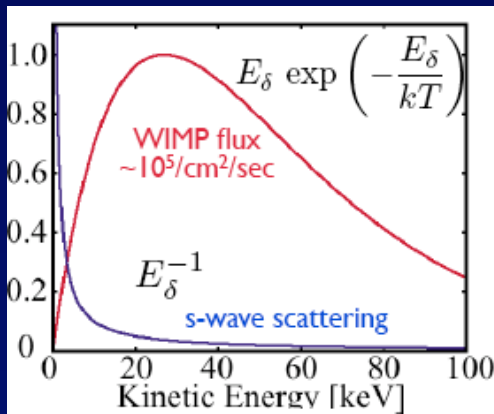
Détection Directe des WIMPs

Diffusion élastique des WIMPs sur des noyaux cibles (reculs nucléaires)

Le spectre d'énergie et le taux d'interaction dépendent de la masse du noyau et de la distribution des WIMPs dans le halo

Modèle standard de halo:

- Supposé sphérique, gaz parfait isotherme
- distribution Maxwellienne des vitesses
 $\langle V \rangle = 270 \text{ km/s}$, $\rho = 0.3 \text{ GeV / cm}^3$



- Spectre de recul: $\langle E \rangle \sim 15 \text{ keV}$
- Taux d'événements $\ll 1 \text{ évt/kg/jour}$

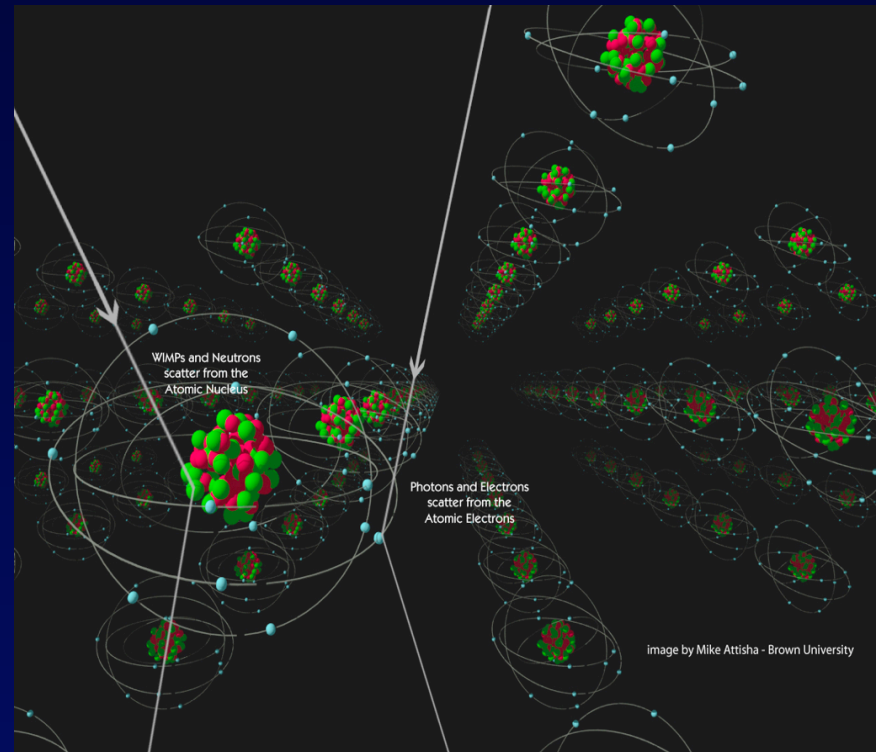
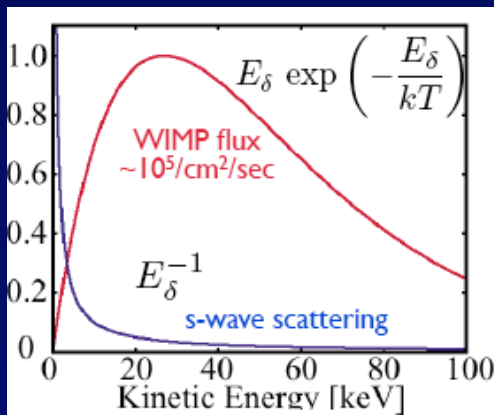
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- Supposé sphérique, gaz parfait isotherme
- distribution Maxwellienne des vitesses
 $\langle V \rangle = 270 \text{ km/s}$, $\rho = 0.3 \text{ GeV / cm}^3$



- Faible seuil de détection (~10 keV)
- Bonne rejection du bruit de fond
- Nécessité d'une très grande masse exposée

Méthodes de Détection Directe

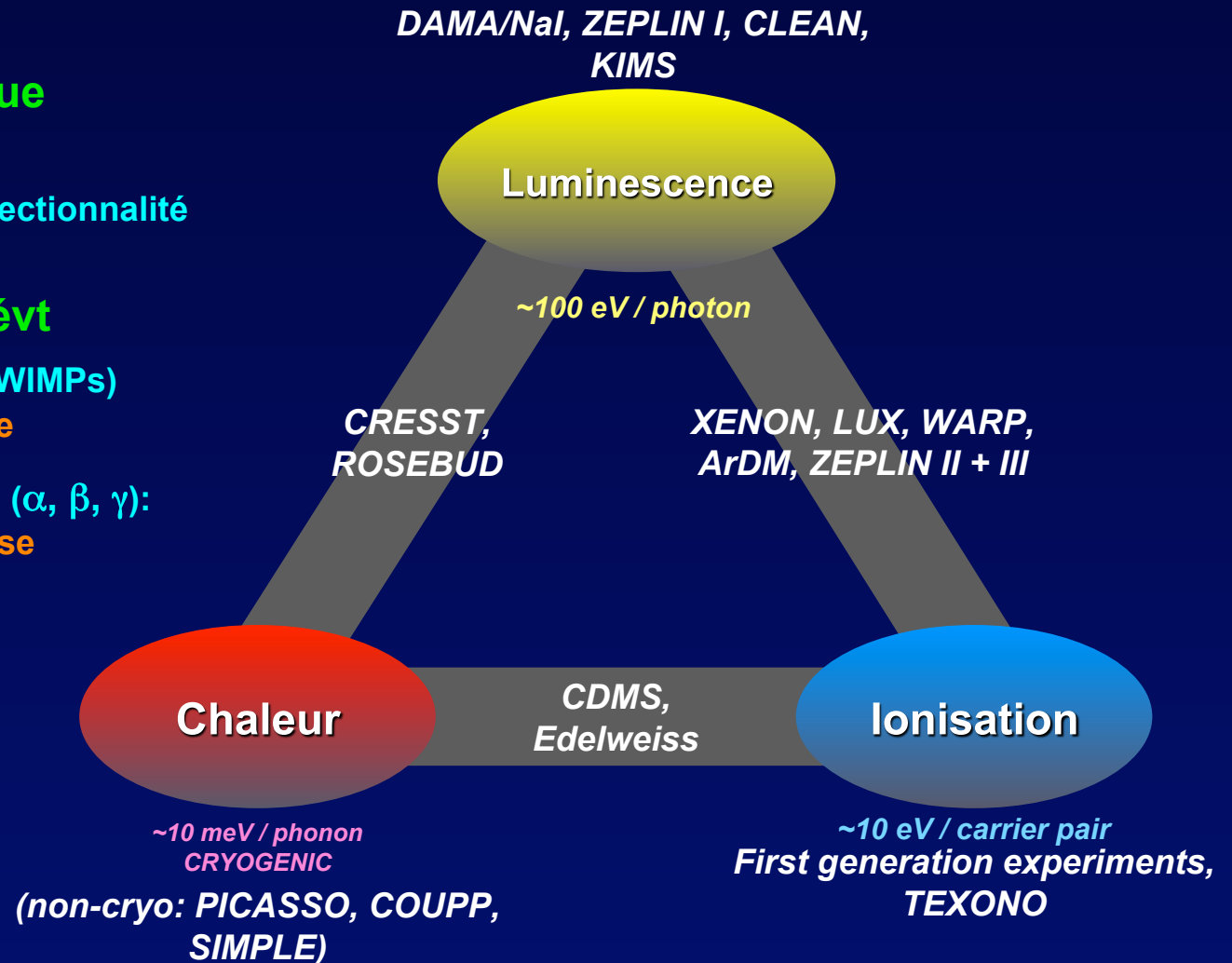
Techniques:

➤ Signatures statistique

- modulation annuelle
- asymétrie dans la directionnalité

➤ Signatures évt par évt

- Reculs nucléaire (n, WIMPs)
dépôt d'énergie dense
- Reculs électroniques (α , β , γ):
dépôt d'énergie épars



The Cryogenic Dark Matter Search

CDMS Collaboration

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* new collaborators or new institutions in SuperCDMS

Stratégie de CDMS

Combinaison de blindage, veto muon, et discrimination événement par événement pour maintenir un niveau de bruit de fond très bas

➤ Mesure de l'énergie de recul: vibrations du réseau cristallin du Ge (phonons hors équilibre)

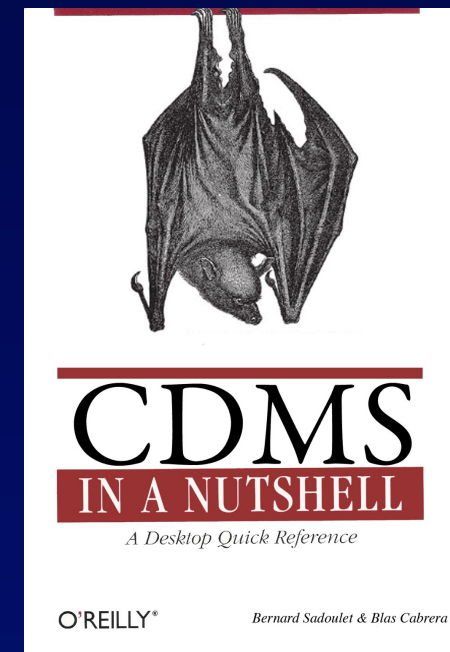
→ Excellente résolution

→ Seuil de détection très bas

➤ Mesure **simultanée** de l'ionisation

→ Discrimination événement par événement

Mais: complexité de l'expérience
(besoin d'appareil cryogénique)

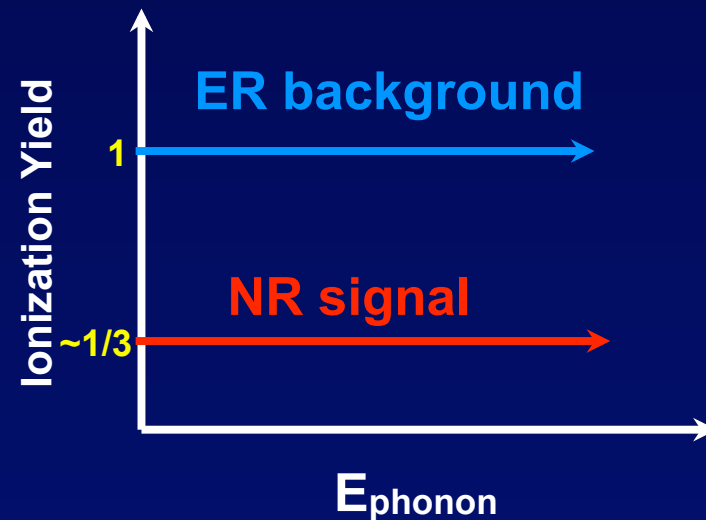
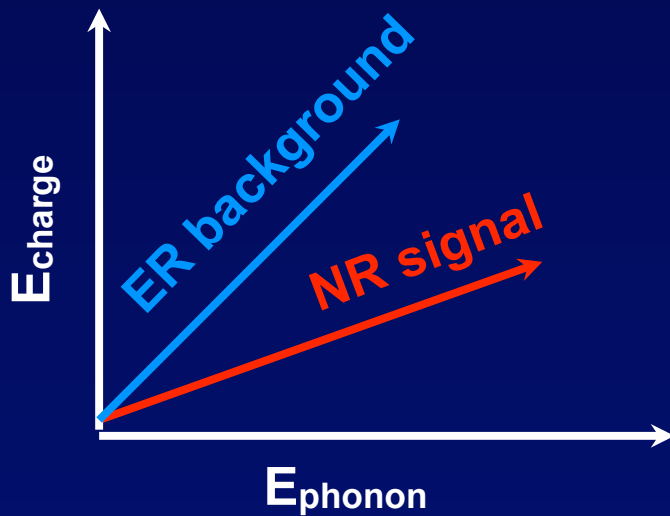


Discrimination événement par événement

- La quantité d'ionisation dans le semi-conducteur dépend du type d'interaction: facteur de Quenching Q
- Recul nucléaire (WIMPs, neutron) crée ~ 3 fois moins de paires électron/trou qu'un recul électronique (α, β, γ)

$$Q = \frac{E_{\text{charge}}}{E_{\text{phonon}}}$$

("Yield")

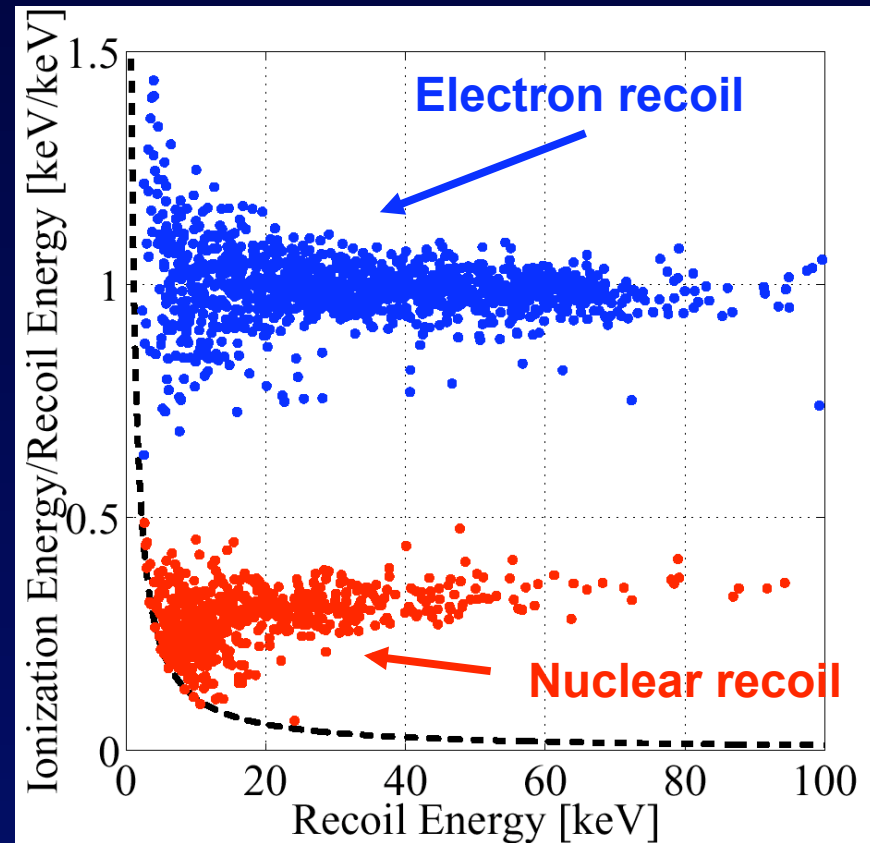
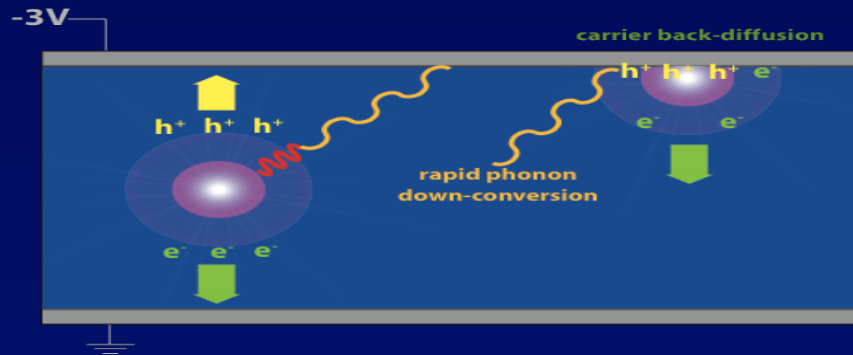


Discrimination événement par événement

Les événements proche de la surface peuvent avoir une collecte incomplète des charges et être confondus avec des événement reculs nucléaires

Solution:

- Utilisation du temps de montée des phonons athermiques (CDMS-II)

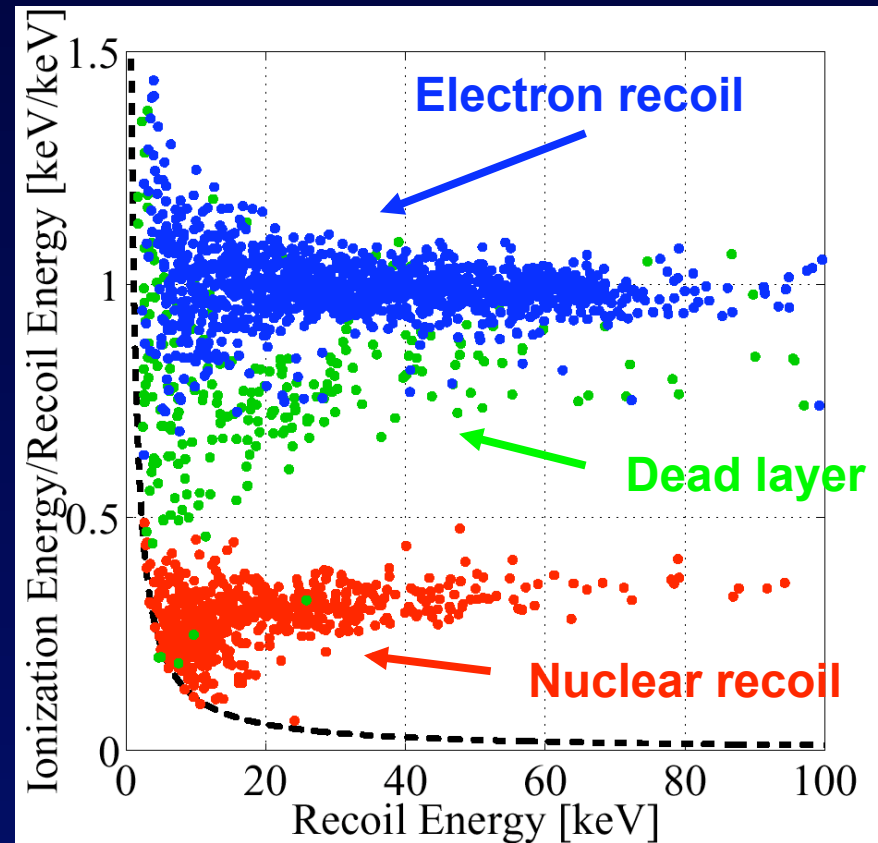
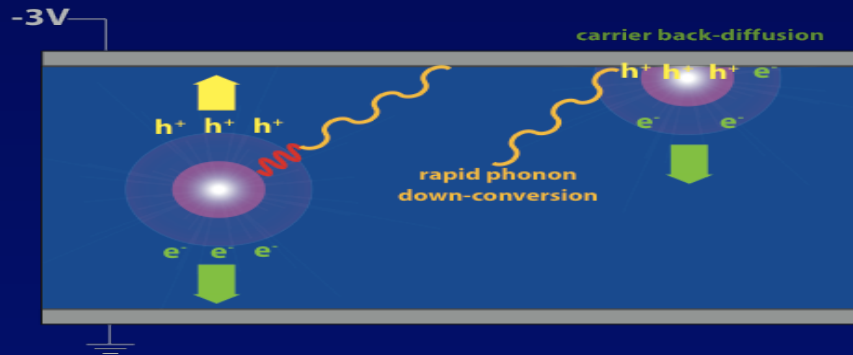


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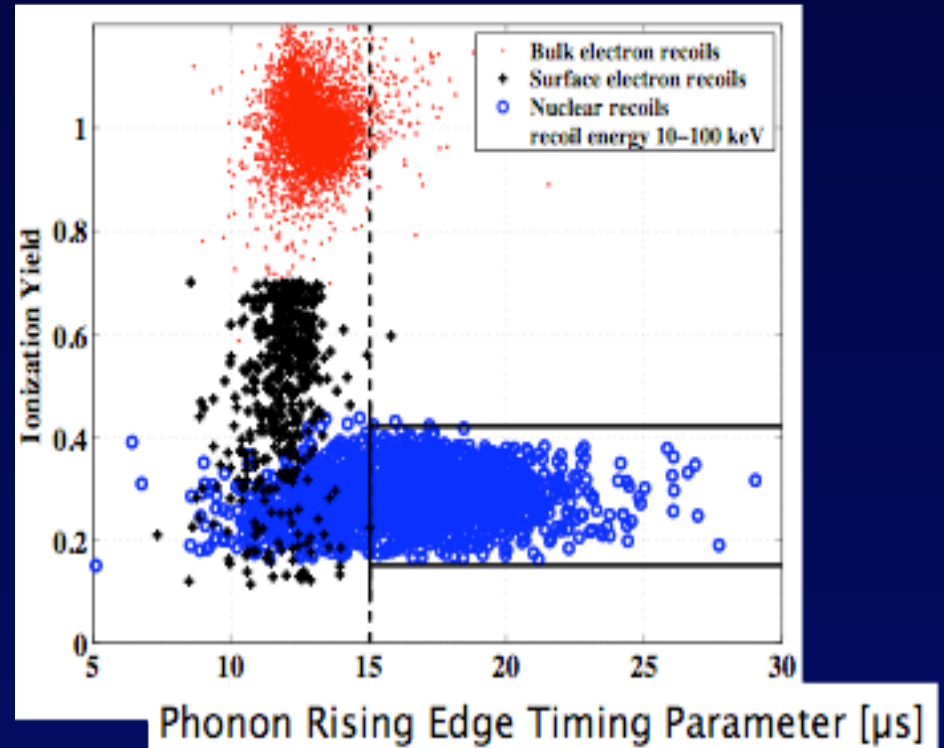
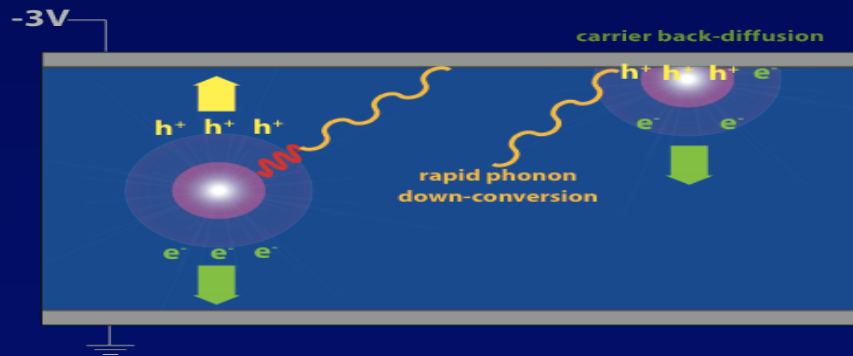


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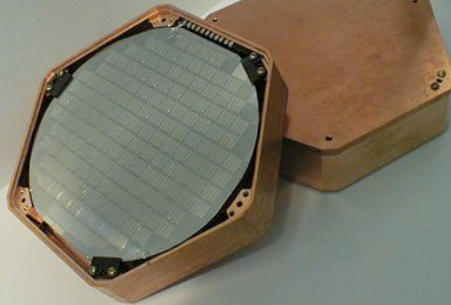
Solution:

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Détecteurs ZIP CDMSII (Z-sensitive Ionization and Phonon)

250 g Ge or 100 Si

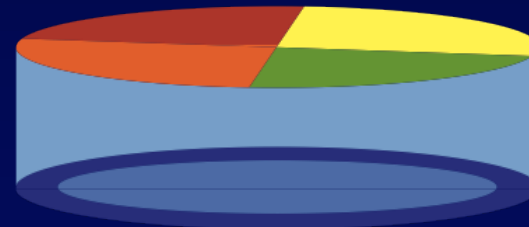


1cm thick x 7.5 cm diameter



Phonon sensors on one face

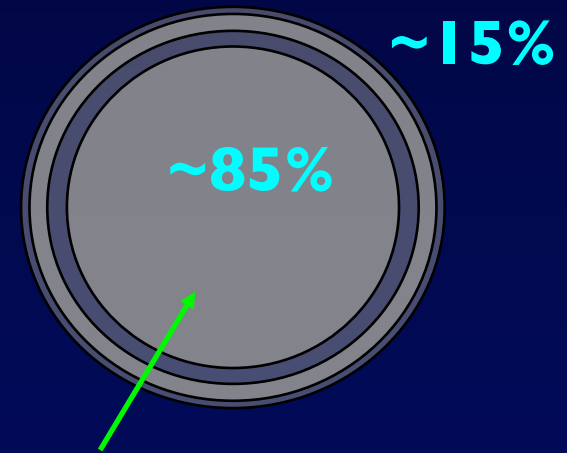
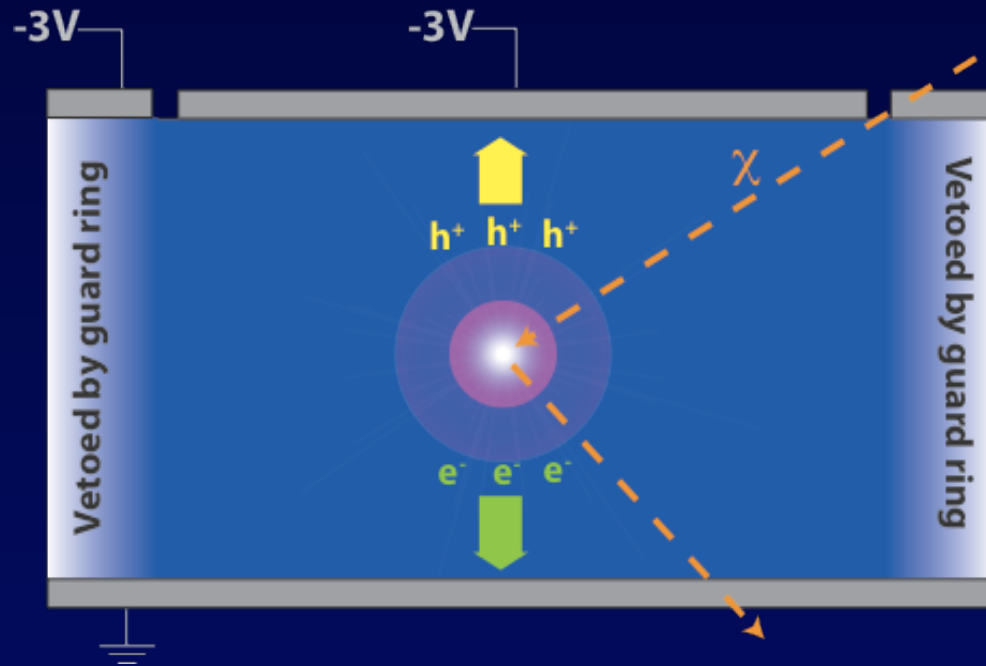
- Sensors divided in 4 quadrants
- Measurement of the energy



Charge readout in the other face

- divided into inner fiducial volume and outer guard ring
- measure ionization in low E field (\sim volts/cm)

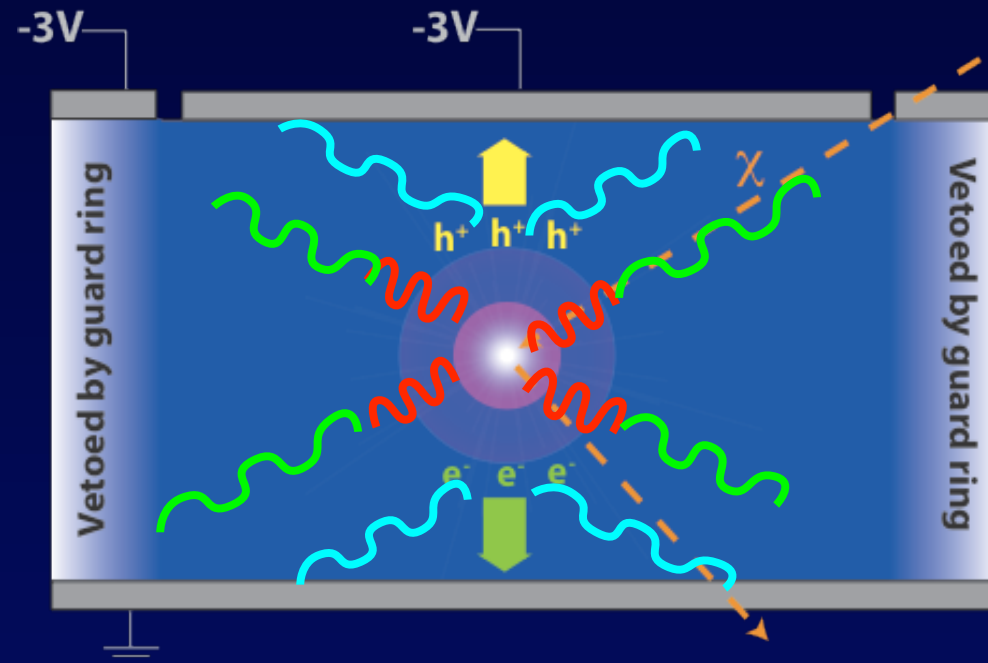
Mesure d' ionisation



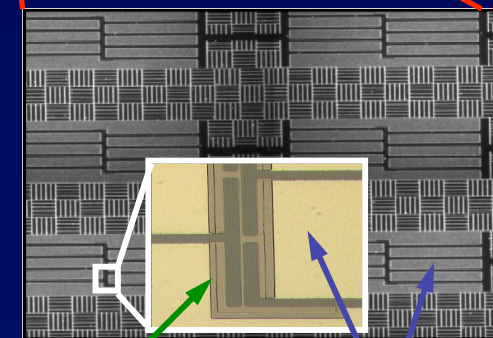
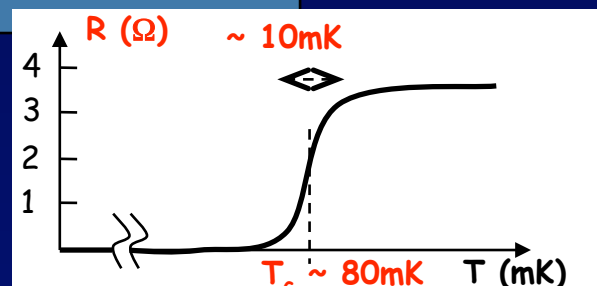
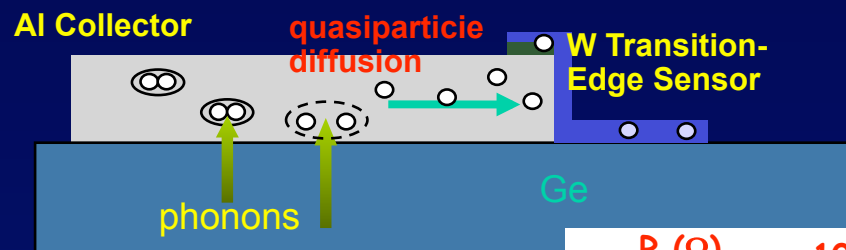
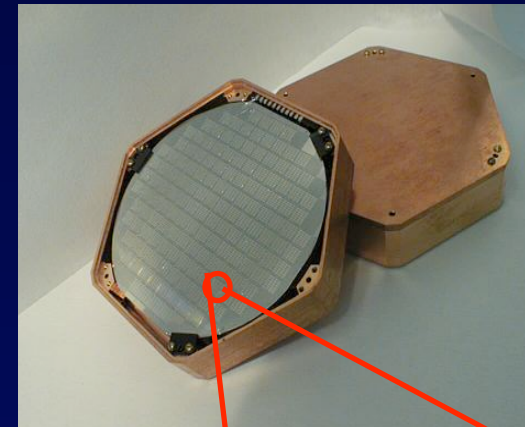
Fiducial volume cut

- Essentially complete collection at $3V/cm$ (after trap neutralization)
- Low-noise JFET amp at 140 K: Zero-energy resolution ~ 250 eV (~ 3 keV @ 511 keV)

Mesure des phonons



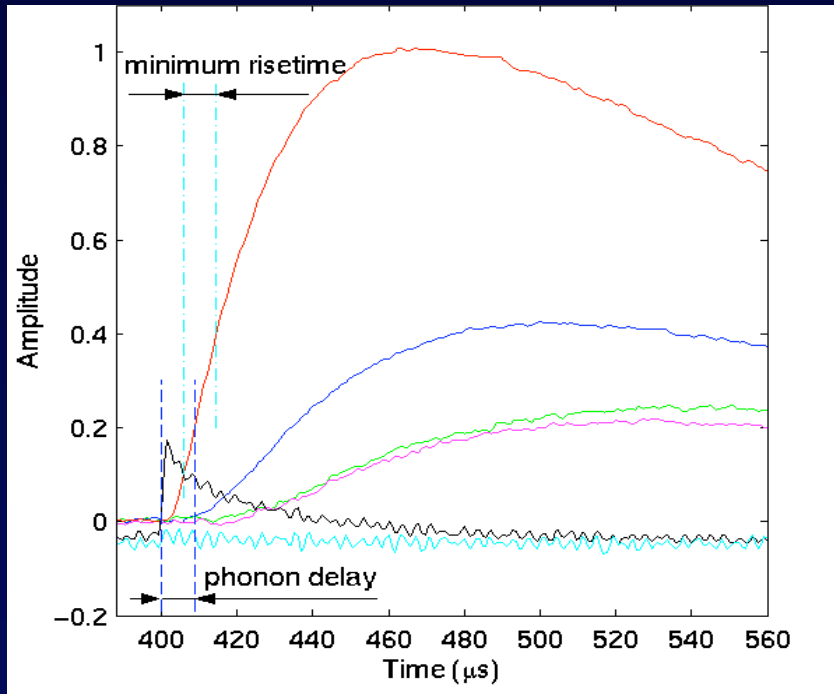
- 888 sensors (TES) per quadrant
- TES: 1- μm -thick strip of W connected to 8 Al collection fins



1 μ tungsten

380 μ x 60 μ aluminum fins

Reconstruction de la position

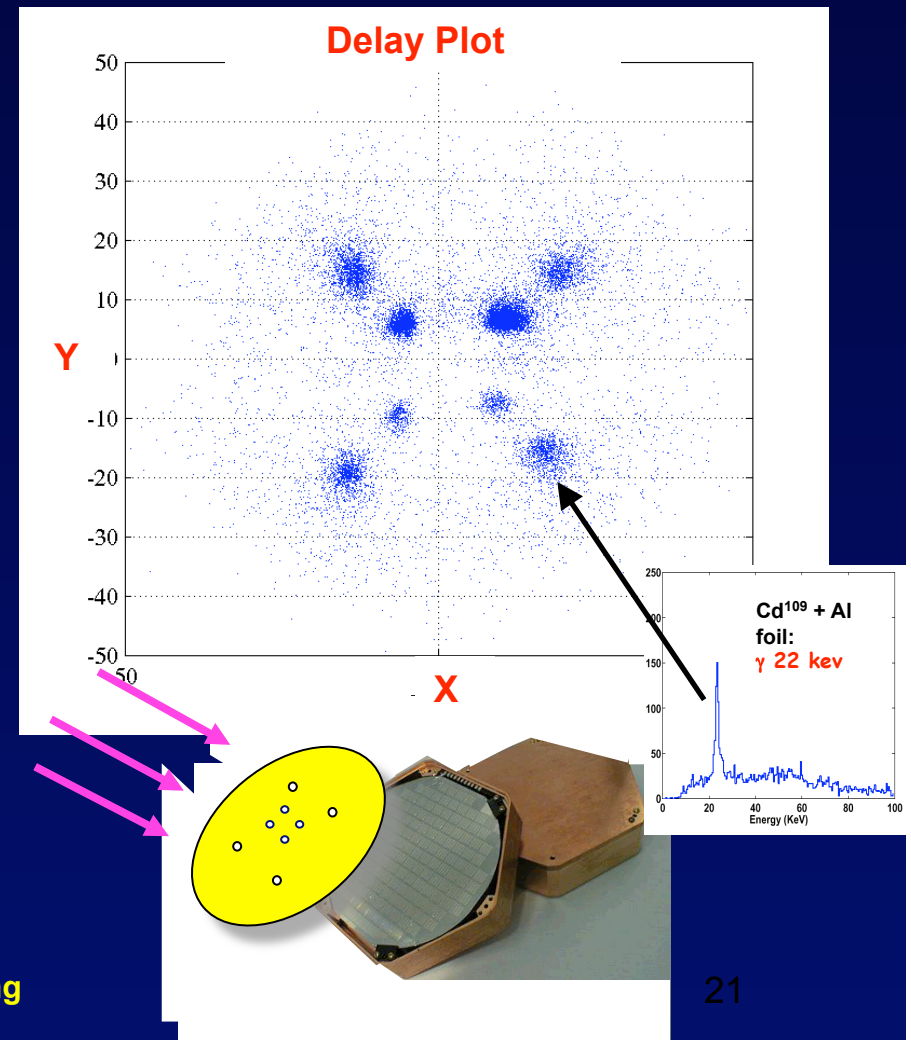


➤ Phonon sensors provide measurement of xy position:

- Phonons propagate at $0.5 \text{ cm}/\mu\text{s}$ in Ge crystal \rightarrow measurable delays between the pulses of the 4 phonon channels
- Able to measure x,y coordinates of interaction
- Demonstrate by shining sources through a collimator

➔ We can correct the phonon energy/timing position dependence

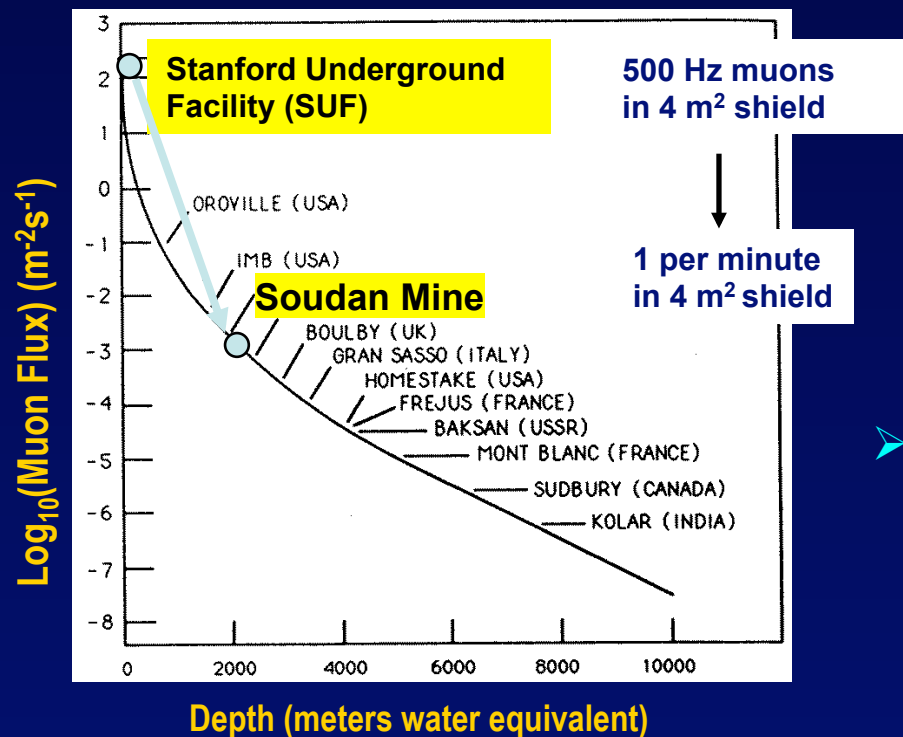
➤ Informations on phonons pulse shape (ex. risetime), delay between charge and phonon pulses



De Stanford à Soudan...

➤ 2001-2002 run at Stanford (17 mwe of rock)

- 28 kg-day exposure of 4x 250g Ge detectors (and 2x 100g Si detectors)
- 20 nuclear-recoil candidates consistent with expected neutron background *PRD 68:082002 (2003)*



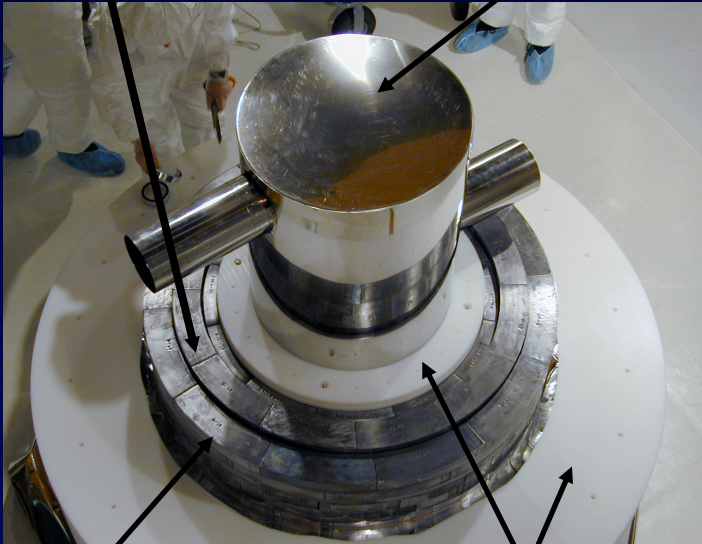
➤ Since 2003 in Soudan Mine (Minnesota)

- Depth 713 m (2090 mwe)
- Reduce neutron background:
 $\sim 1/\text{kg}/\text{day}$ to $\sim 1/\text{kg}/\text{year}$

Blindage, Veto à Soudan

Ancient lead

mu-metal (with copper inside)



Lead

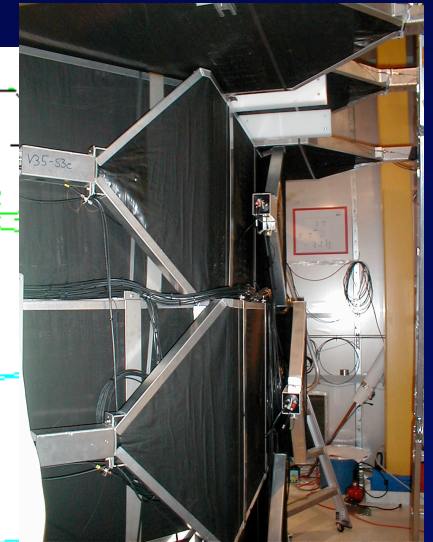
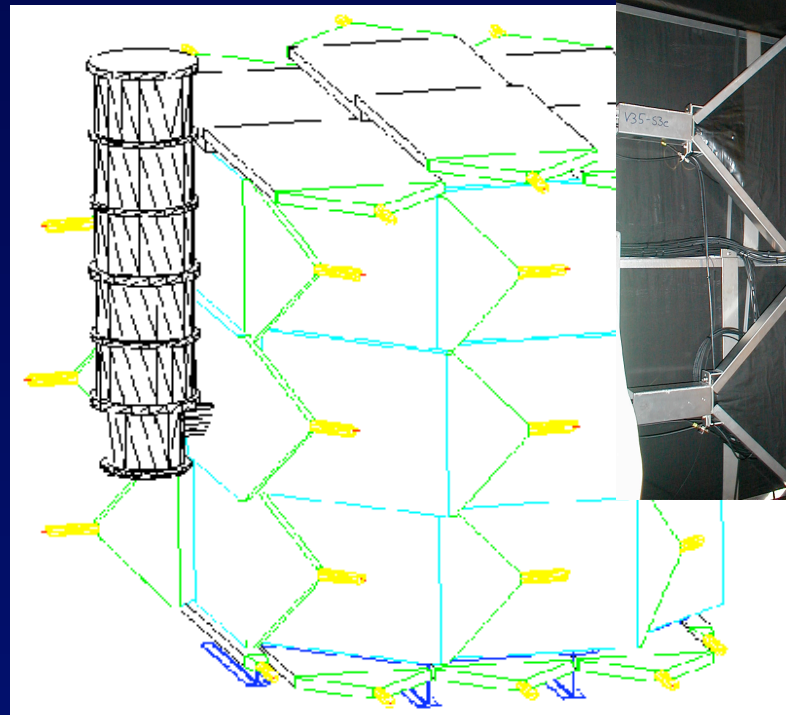
Polyethylene

□ Layered shielding (reduce γ , β , neutrons)

- 40 cm outer polyethylene
 - Removes neutrons from (α, n)
- 22.5 cm Pb, inner 5 cm is “ancient”
- 10 cm inner polyethylene
 - Removes neutrons from muons
- ~0.5 cm Copper walls of cold volume

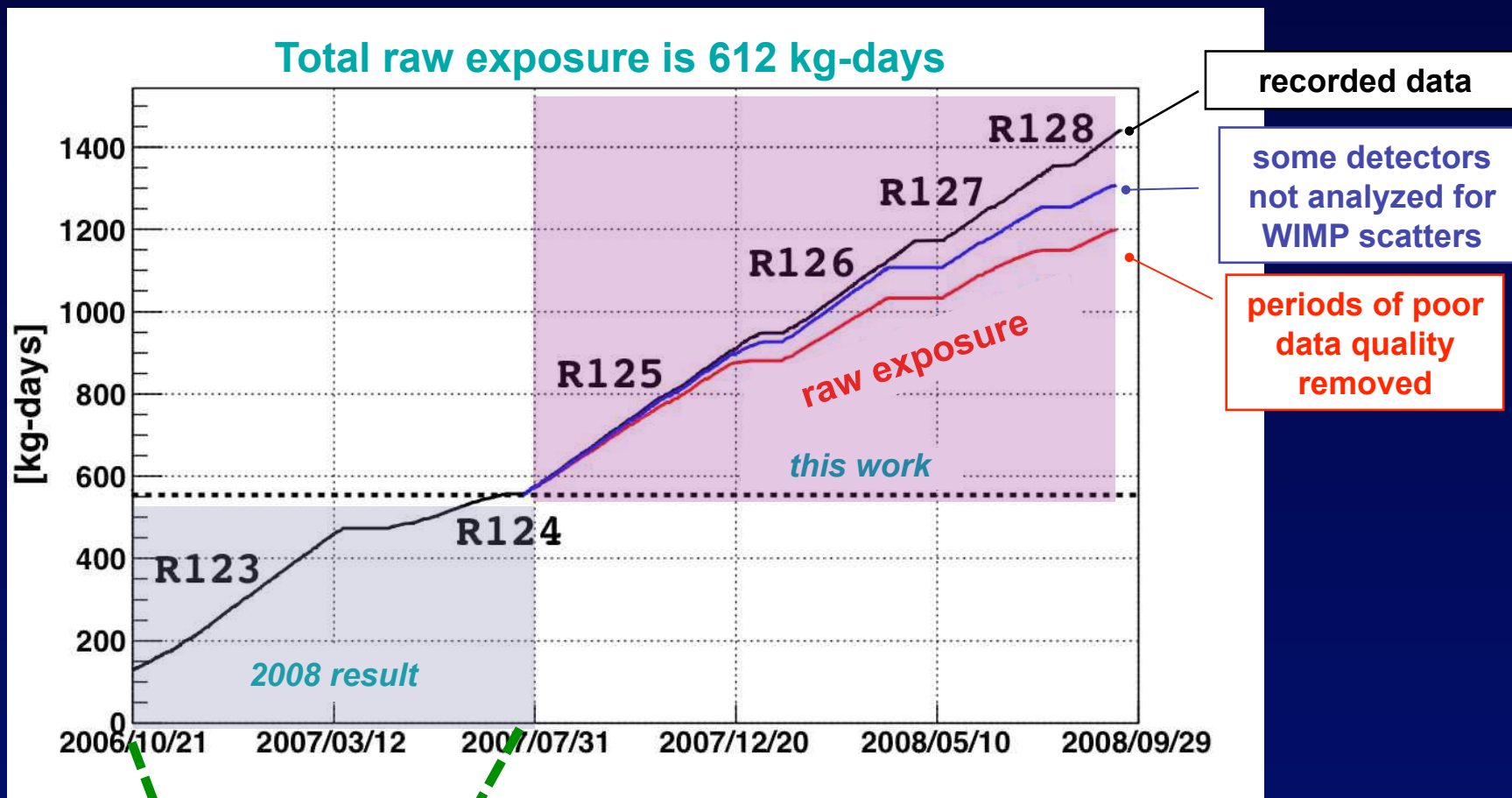
□ Active Muon Veto

- Hermetic, 2” thick plastic scintillator veto wrapped around shield
- Reject residual cosmic-ray induced events
- Veto rate ~600Hz
- One muon per minute is incident on the veto



Prise de données CDMS II depuis 2006

4 runs separated by partial warmups of cryostat
Dates of data taking: 7/2007 - 9/2008



ZERO Events Observed in
Signal Region!

^{133}Ba and ^{252}Cf calibration data taken
throughout the runs

Analyse des données 2007-2008

Blind analysis: Low yield singles masked



1. Reconstruction

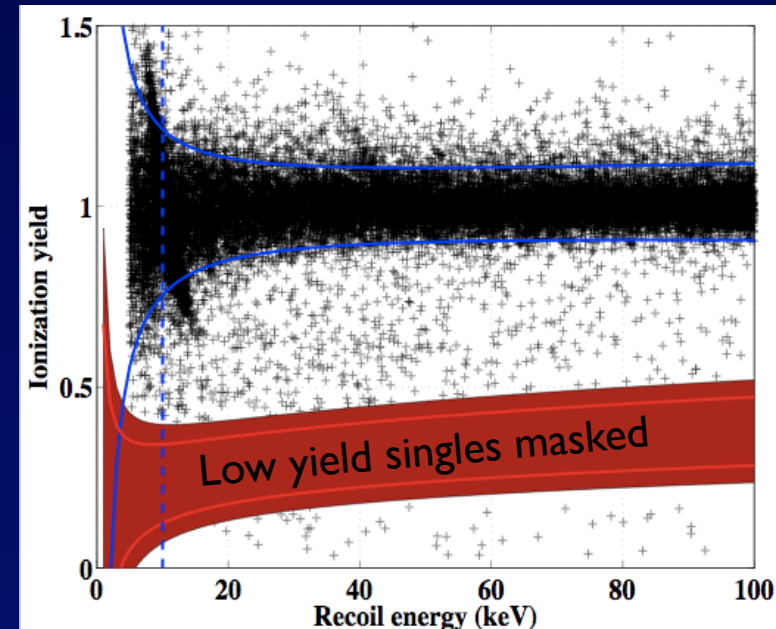
- pulse reconstruction (fits, etc.)
- position correction
- energy calibration

2. Data quality

- cuts pile-up, period of poor noise or detector performance, bad neutralization
- reconstruction failure

3. Physics

- veto anti-coincidence cut
- single scatter
- Q_{inner} (fiducial volume)
- ionization yield
- Phonon timing



Analyse des données 2007-2008

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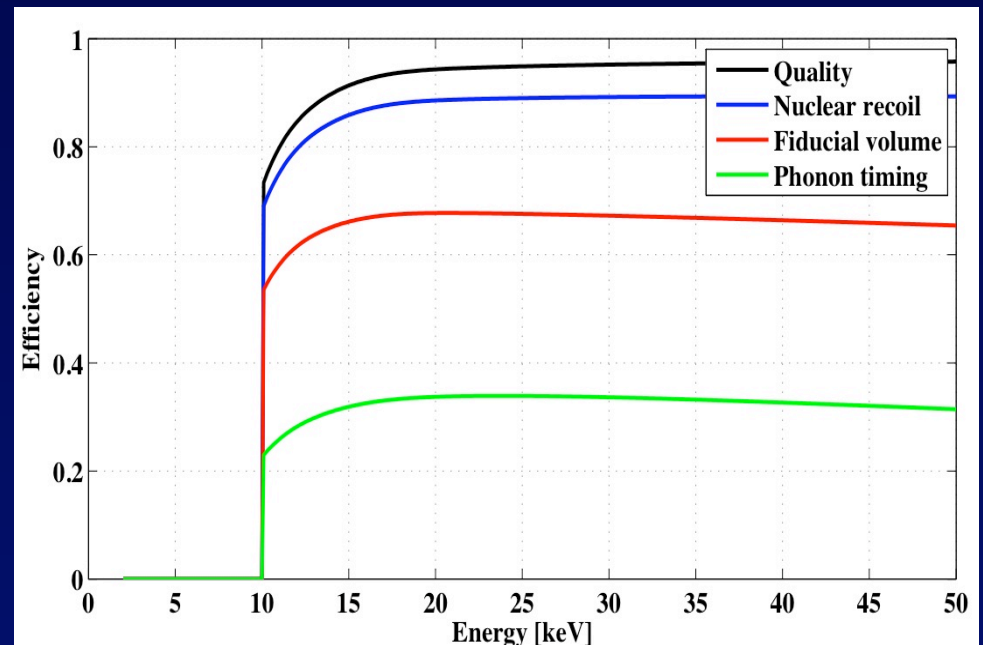
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- single scatter
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Estimation du bruit de fond: neutrons

➤ Cosmogenic Neutron Estimate:

$$\frac{N_{\text{unvetoed, single NR}}^{\text{MC}}}{N_{\text{vetoed, single NR}}^{\text{MC}}} * N_{\text{vetoed, single NR}}^{\text{data}} * \epsilon_{\text{neutron}} = 0.04^{+0.04}_{-0.03} \text{ (stat) events}$$

From GEANT4 and FLUKA simulations

3 vetoed, single NR (in Soudan dataset)

correct for efficiency and exposure

➤ Radiogenic Neutron Estimate:

0.03 - 0.06 events ● *fission, (α ,n) in Cu, Poly, Pb*

Detector contamination measured with HP Ge detector + global gamma simulation

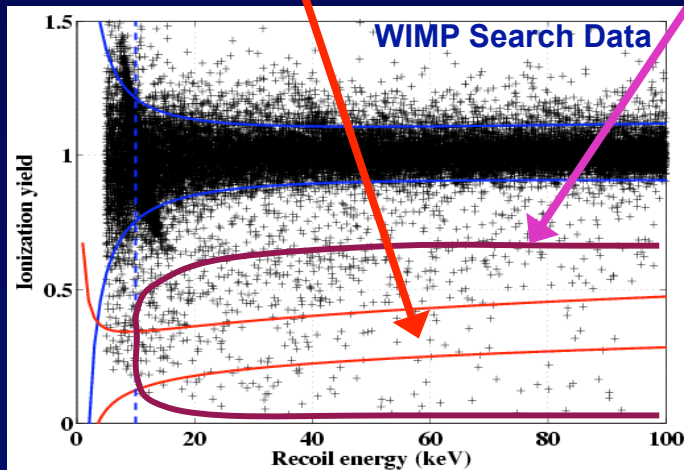
→ GEANT4 simulation of U/Th chains in detector materials

Estimation du bruit de fond: événements de surface

$$\text{Expected surface leakage} = \frac{N_{\text{sideband passing cut}}}{N_{\text{sideband failing cut}}} * N_{\text{data failing cut}}$$

Method 1

Use multiple-scatters
in NR band



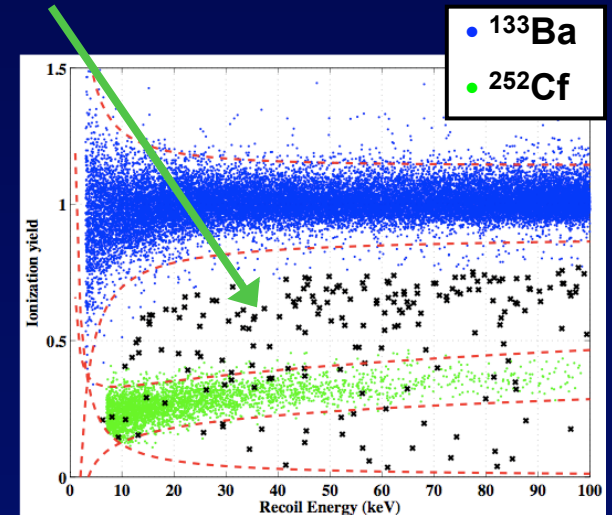
Method 2

Use singles and multiples
just outside NR band

Correct for systematic
effects due to different
distributions in energy
and yield

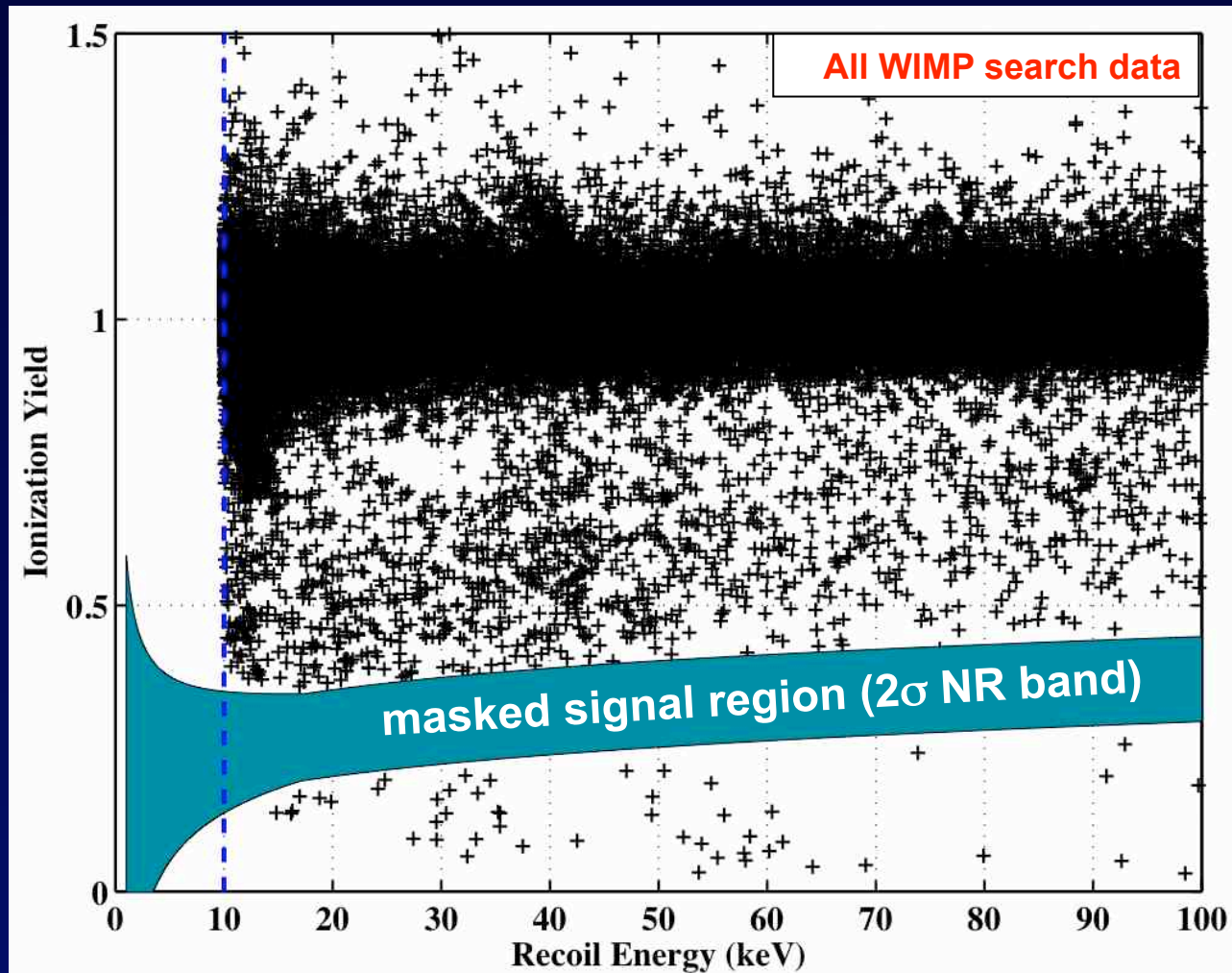
Method 3

Use singles and multiples from Ba
calibration in wide region



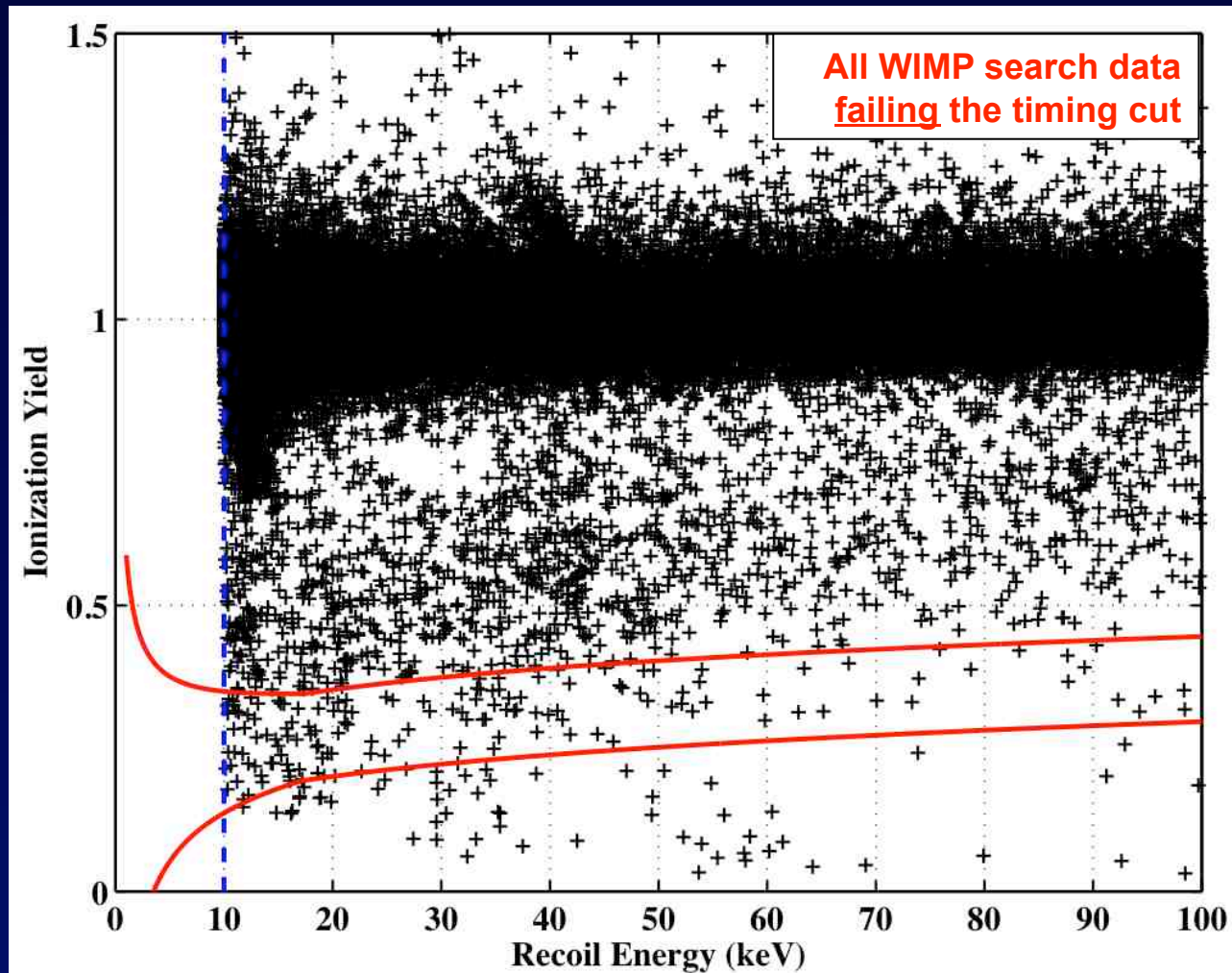
All 3 consistent, blind estimate = 0.6 ± 0.1 (stat) events

Résultats (“unblinding”)



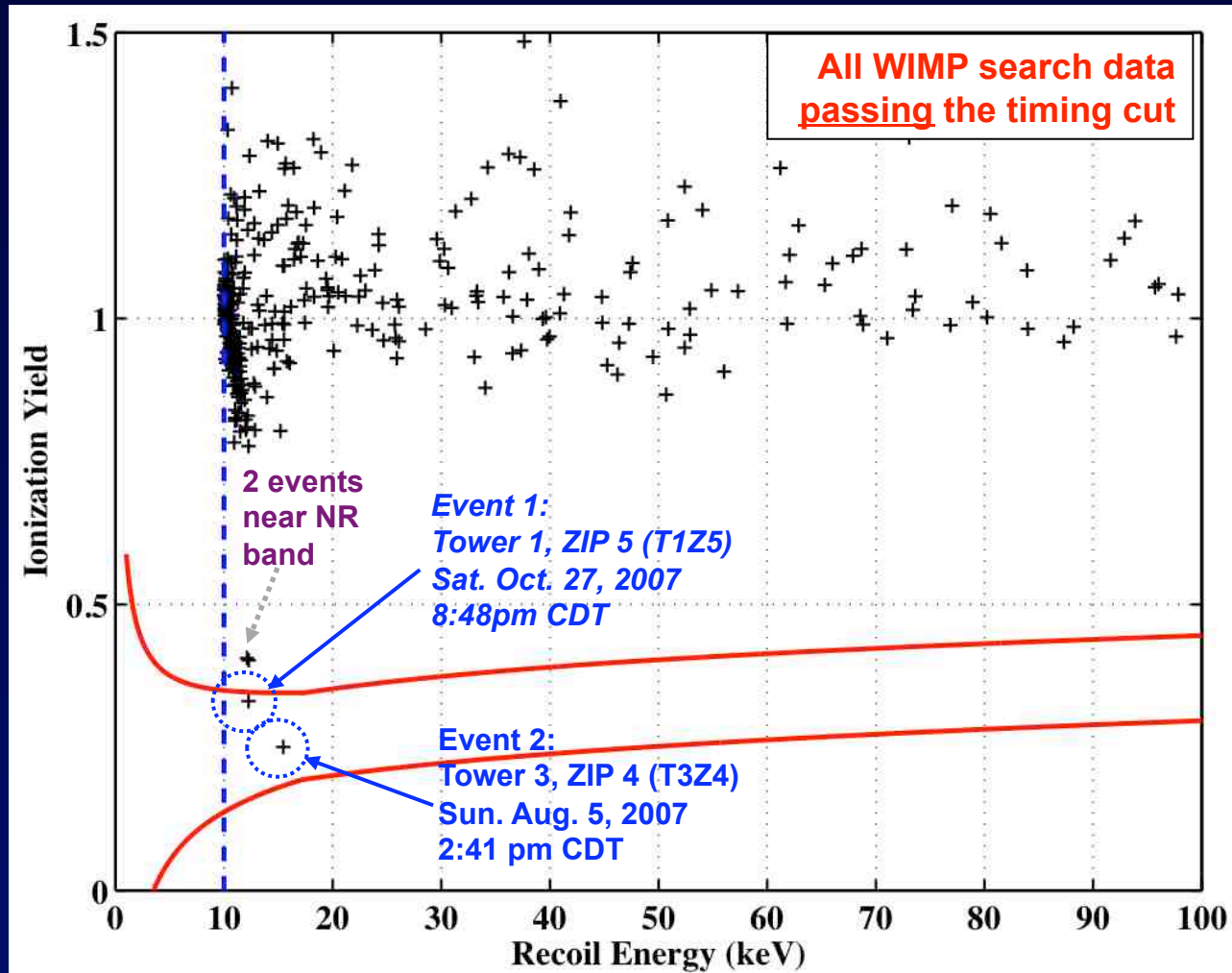
We unblinded the signal region November 5, 2009

Résultats (“unblinding”)



150 events in the NR band fail the timing cut, consistency checks deemed ok

Résultats (“unblinding”)



2 events in the NR band pass the timing cut!

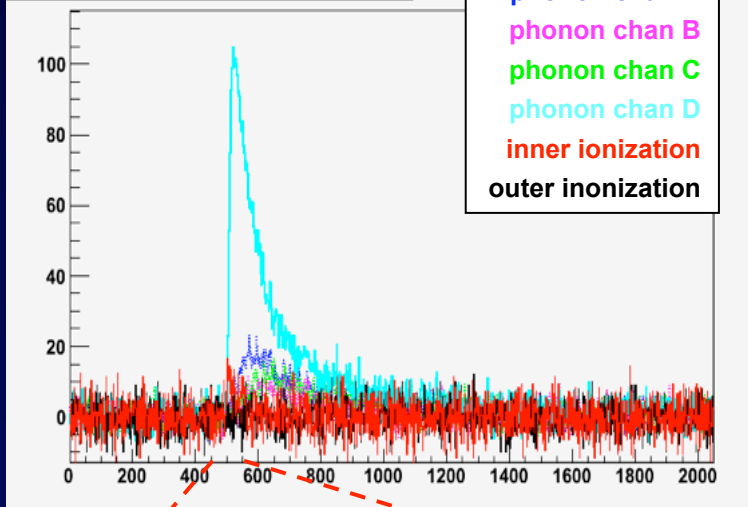
Qualité des données

Data Quality Item	Result
muon veto performance	✓ <i>good</i>
neutralization	✓ <i>good</i>
KS tests	✓ <i>normal</i>
noise levels	✓ <i>typical</i>
pre-pulse baseline rms	✓ <i>typical</i>
background electron-recoil rate	✓ <i>typical</i>
surface event rate	✓ <i>typical</i>
radial position	✓ <i>well-contained</i>
single-scatter identification	✓ <i>good</i>
special running conditions	✓ <i>no</i>
operator recorded issues	✓ <i>no</i>

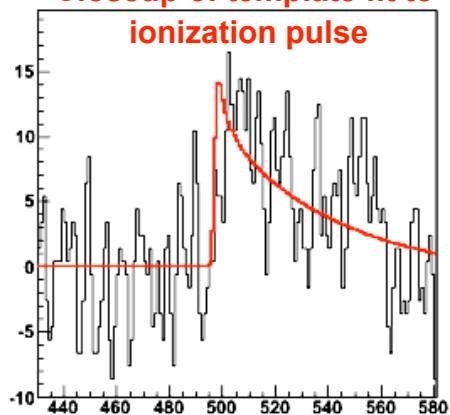
At the recorded time of both events, the experimental performance was excellent

Reconstruction des impulsions

Candidate 2 (on det T3Z4)

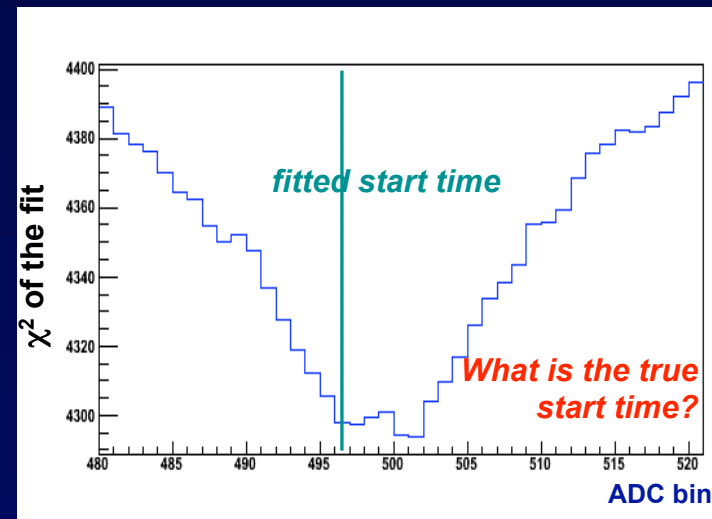


Closeup of template fit to ionization pulse



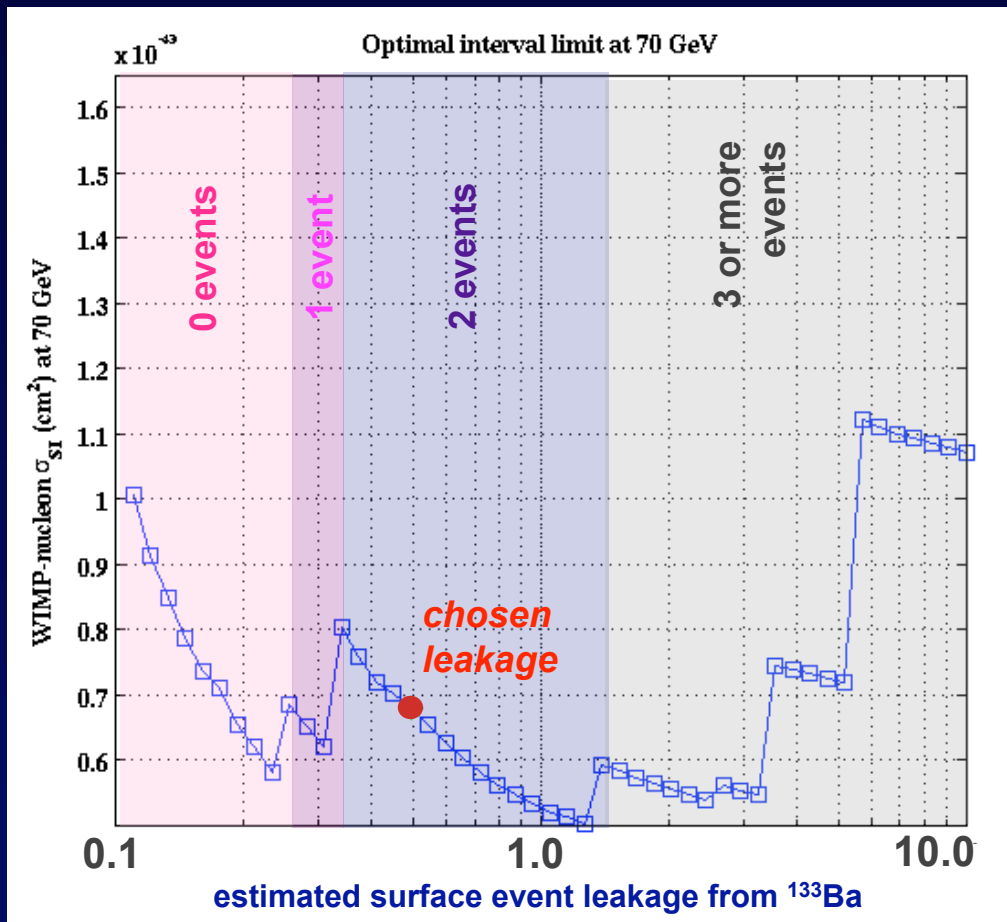
ionization and phonon energies look good, phonon timing looks good...

Could there be a problem with the start time of the charge pulse? (affects timing parameter)



This effect is strongly correlated with the ionization energy (affects events with < 6 keV ionization energy) and was mostly accounted for in the pre-unblinding leakage estimate.

Stabilité de la coupure



➤ Tightening cut to $\sim 1/2$ the expected leakage, removes all events from the signal region and reduces the exposure by $\sim 28\%$

➤ Additional events appear in the signal region after loosening the cut to $\sim 2X$ the expected leakage

The calculated limit doesn't depend strongly on chosen surface-event rejection cut value

Bruit de fond ou Signal?

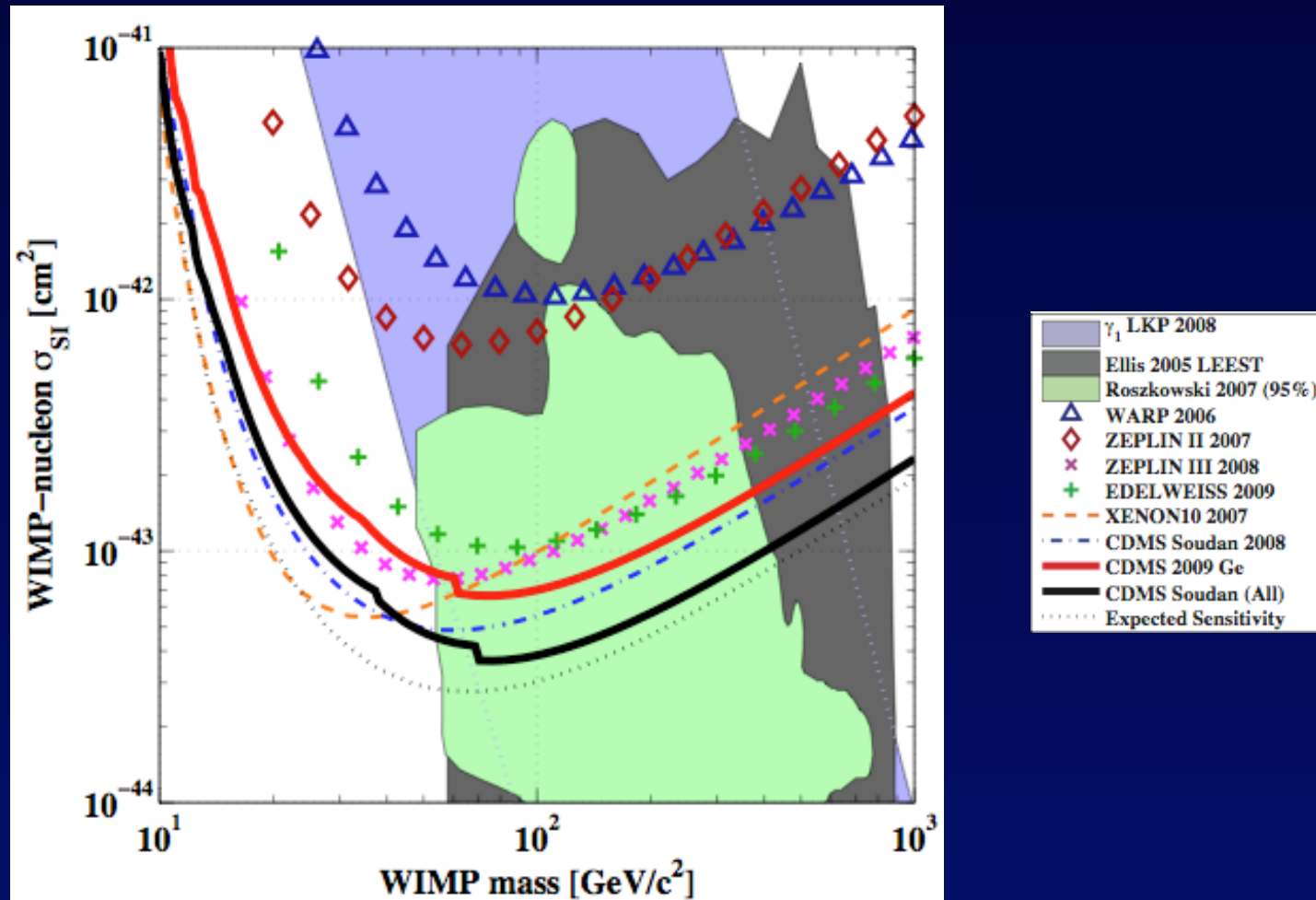
Après avoir finalisé l'erreur systématique, l'estimation du nombre d'événements de surface devient:

0.8 ± 0.1 (stat) ± 0.2 (syst) événements

Avec cette estimation du bruit de fond, la probabilité d'observer 2 ou plus événements de surface est de 20%

Le résultat de cette analyse ne peut donc pas être interprété comme une preuve de la présence de WIMPs, mais on ne peut pas rejeter la possibilité que ces deux événements soient bien un signal

90% C.L. Spin-Independent Limit

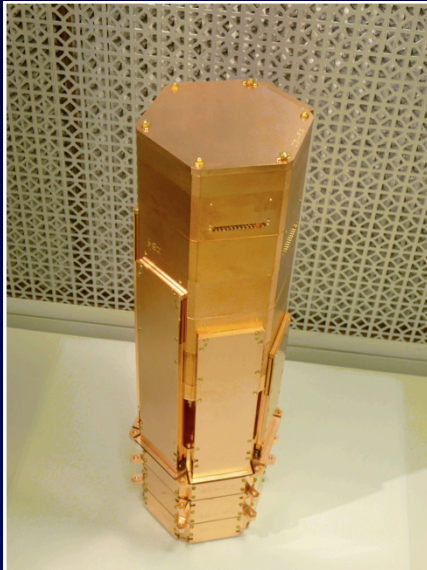


Upper limit at the 90% C.L. on the WIMP-nucleon cross section :

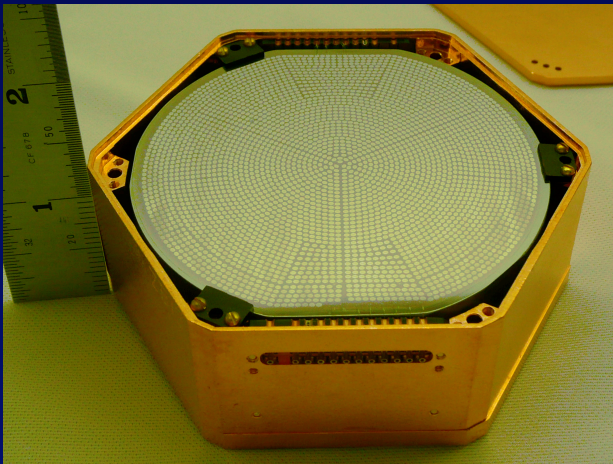
$3.8 \times 10^{-44} \text{ cm}^2$ for a WIMP of mass $70 \text{ GeV}/c^2$

SuperCDMS

SuperCDMS Soudan 15 kg



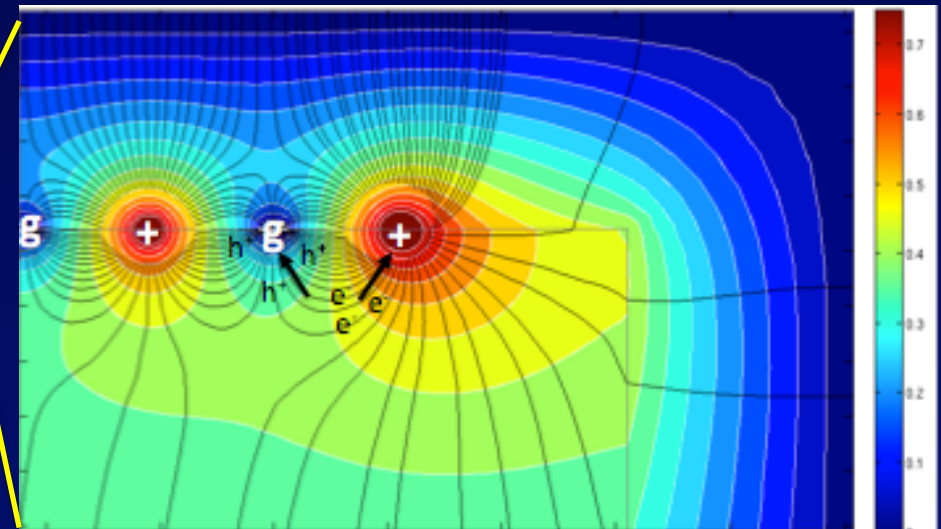
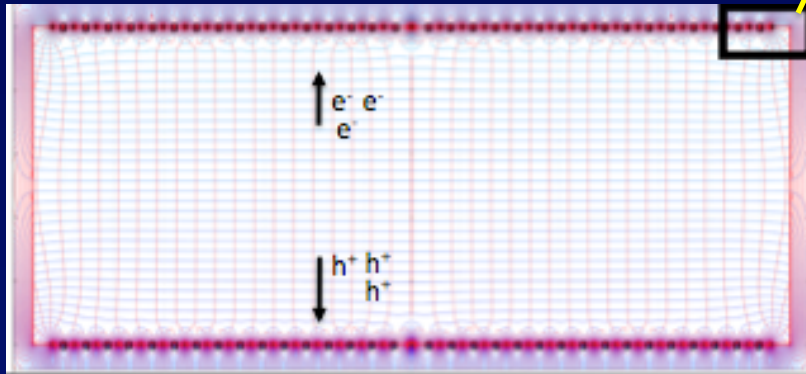
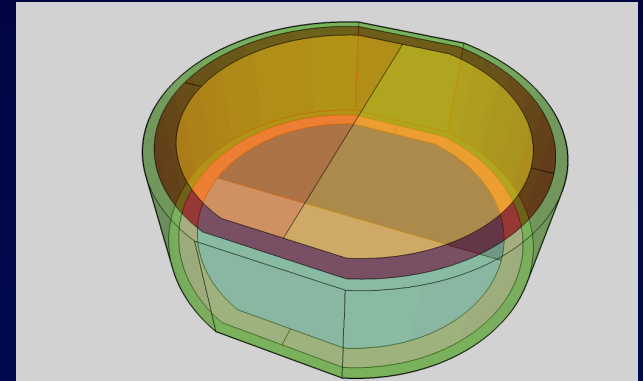
- **New 1 inch thick detectors : 0.64 kg**
 - improved phonon readout geometry
 - 2.5 × bulk/surface
 - Studied at the CDMS TF
- **SuperTower: 5 × 1 inch detectors + 2 × 1 cm veto detectors**



- **Data taking with ST1 at Soudan from July 2009-February 2010**
- **ST2 & 3: fabricated, testing nearly complete**
- **ST 4 & 5 on hold. Considering change of plan to use higher performance iZIP (see next slide)**

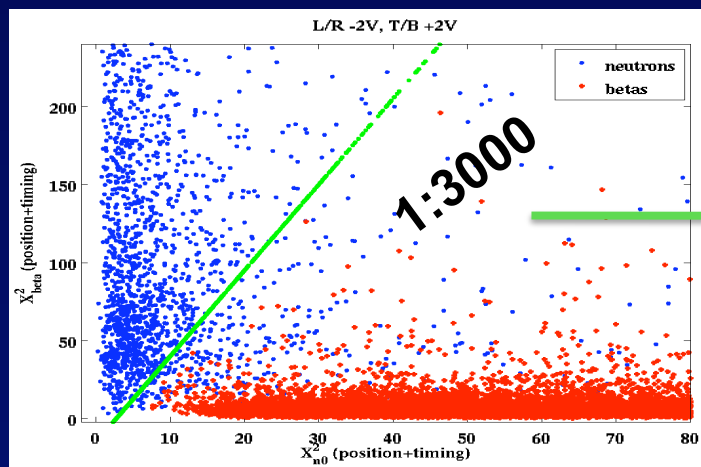
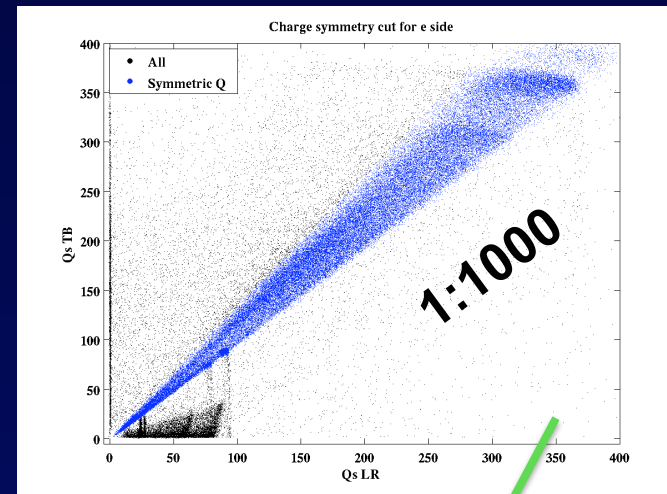
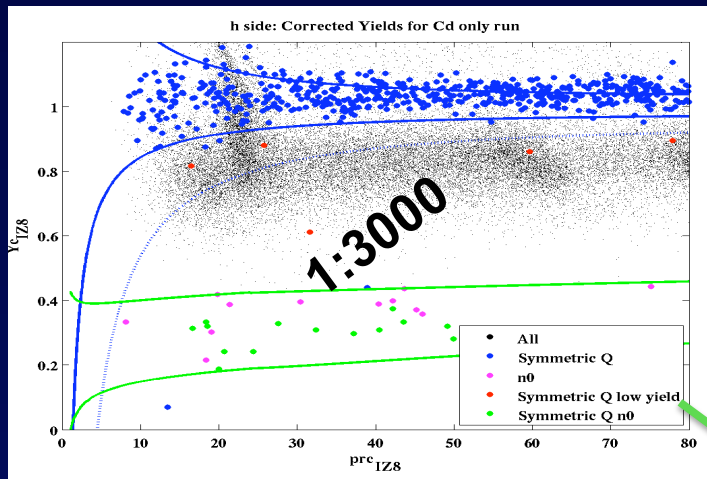
iZIP: Événements de surface, du passé?

- Interleaved electrodes on both sides
- Alternating +2 V & ground (phonon sensors) on one side -2V and ground on the other side
- Transverse E field ~ 20 V/cm on the surface
- Athermal phonon sensors cover both side



iZIP: Événements de surface, du passé?

- Near surface events: Ionization appears only on one side
- Bulk events: equal but opposite signal on both sides.



**Total Surface-NR leakage:
1:3e6-1e10 depending on correlations**

SuperCDMS SNOLab et GEODM

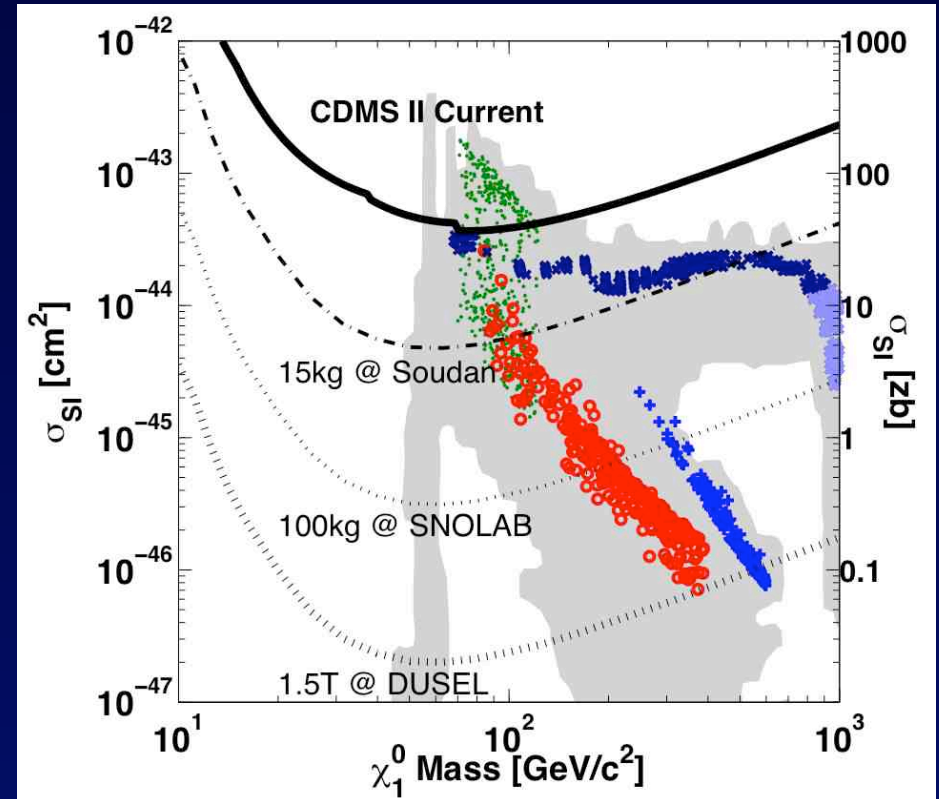
CDMS SNOLAB 100 kg: 100 K kg-d

DUSEL: Germanium Observatory
for DM (GEODM) 1500 kg: 1.5 M kg-d

3"x1 cm: 250g (CDMS II)

6"x2": 5kg

Large Ge substrate studies



Conclusion

- 2 événements ont été observés dans les données 2007-2008. Estimation du bruit de fond: 0.8 événements de surface et <0.1 neutrons

On ne peut pas interpréter, d'une manière statistiquement significative, ces deux événements comme étant un signal de matière noire mais on ne peut pas rejeter la possibilité que ces événements soient bien un signal

- CDMS donne actuellement la meilleure limite de la section efficace WIMP-nucléon $\sigma=3.8 \times 10^{-44} \text{ cm}^2$ à 90% CL (pour une masse WIMP de $70 \text{ GeV}/c^2$)

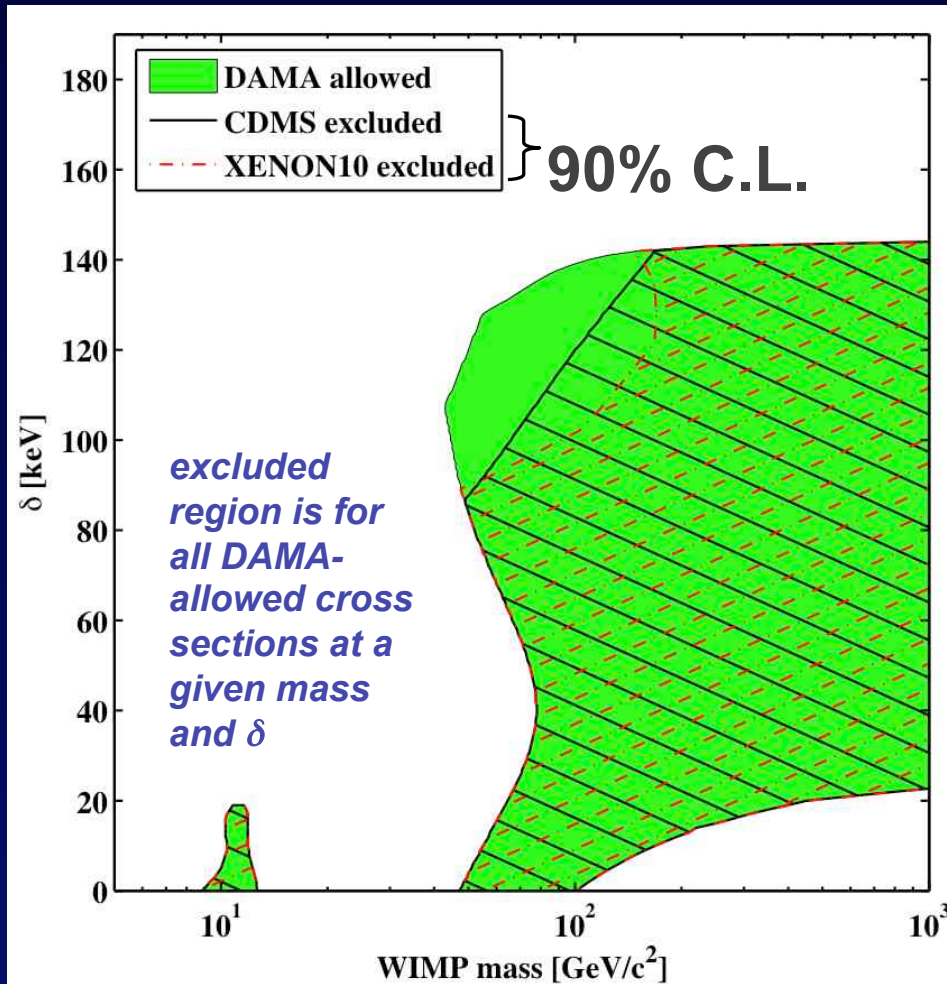
Et bientôt,

- 15-kg de détecteurs SuperCDMS en opération dès 2010-2011
- Préparation de SuperCDMS SNOlab avec 100 kg de détecteurs
- Et bientôt des résultats d'autres expériences....



Merci!

Matière Noire Inélastique



channeling not considered here

Has been invoked by Weiner et al. to explain DAMA/LIBRA data, among other things. [Phys. Rev. D 64, 043502 (2001)]

➤ Scattering occurs via transition of WIMP to excited state (with mass splitting δ)

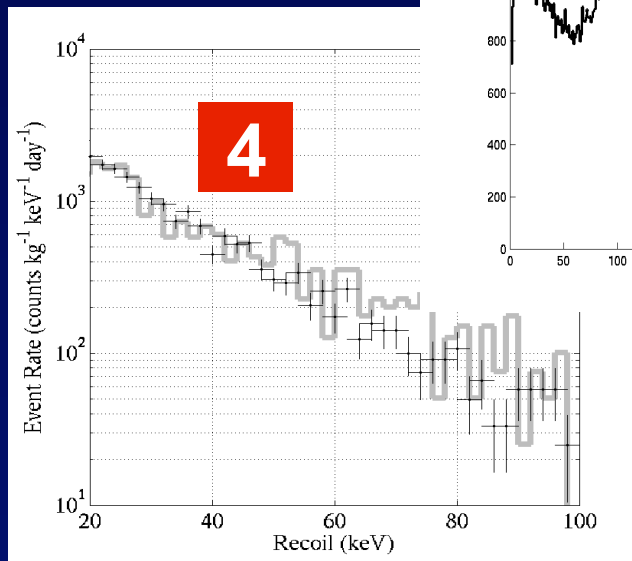
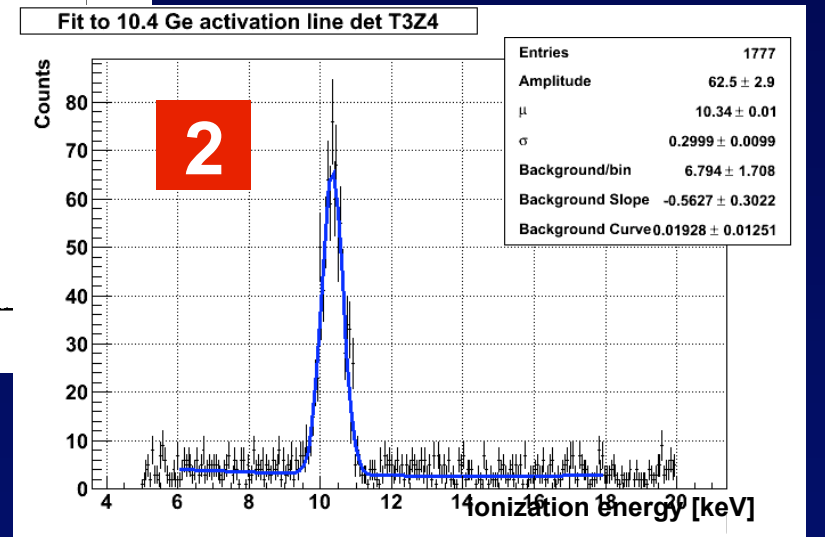
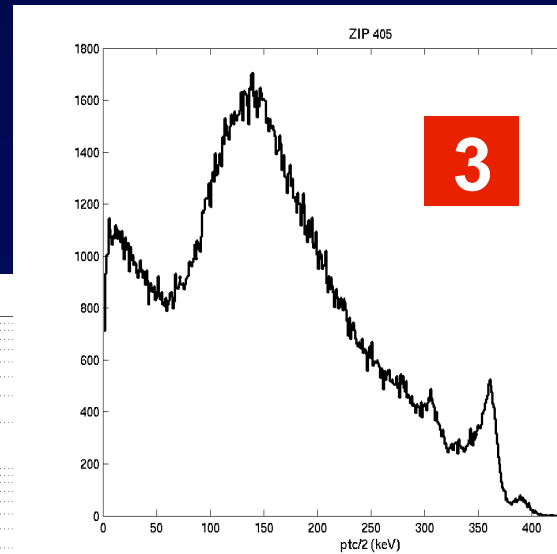
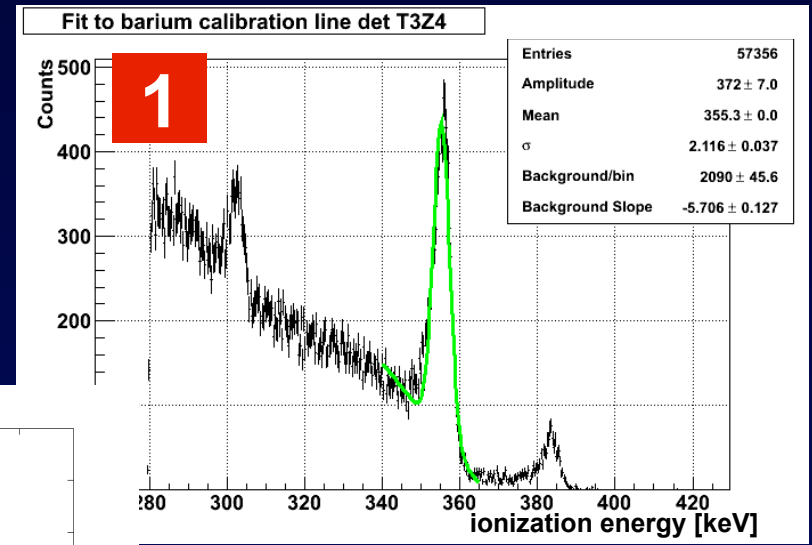
➤ spectrum peaks at higher recoil energies

➤ DAMA, allowed regions (at 90% C.L.) computed from χ^2 goodness-of-fit and standard truncated halo-model

[JCAP 04 (2009) 010]

Energy calibration

- 1) Use 356 keV ^{133}Ba lines to calibrate Ionization
- 2) 10.4 keV (Ge activation), 303 keV, and 384 keV lines confirm linearity
- 3) Calibrate Phonons against Charge
- 4) Nuclear recoils (^{252}Cf) consistent with MC



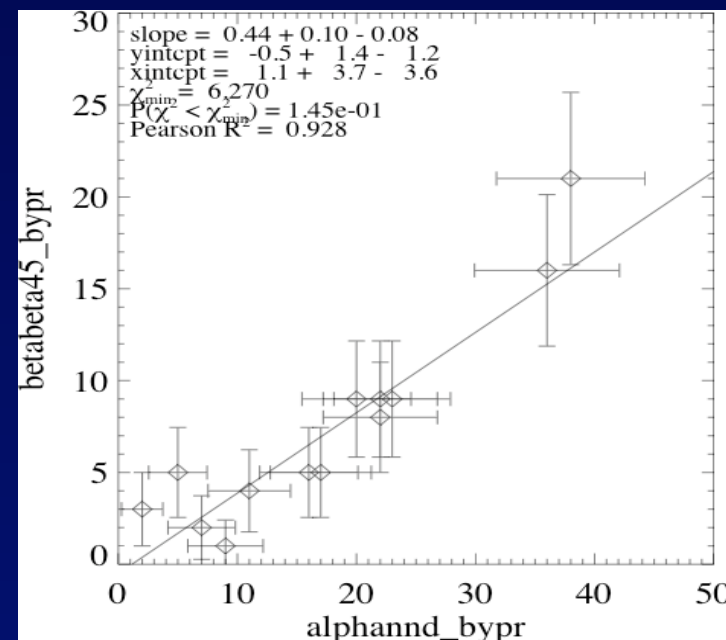
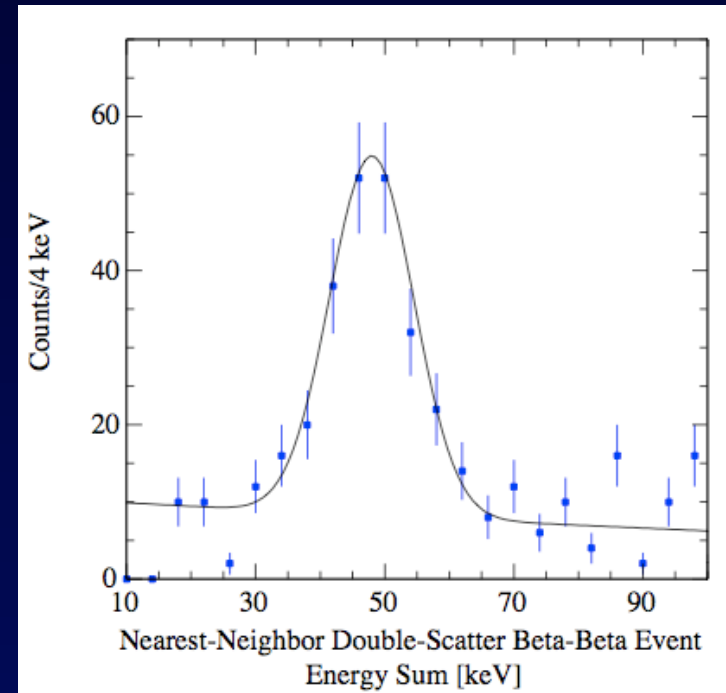
Background from ^{210}Pb

- Airborne ^{222}Rn decays to ^{210}Pb (1/2 life 22 years)
- ^{210}Pb decays to stable ^{206}Pb
 1. One electron per decay + Auger electrons and/or X-rays with total E near 46.2 keV
 2. One alpha with E=5.3 MeV an nucleus recoil with E=0.1 MeV

- 2 experimental handles to measure this background: 45.6 keV line and 5.3 MeV alpha
- measure correlation between both measurement

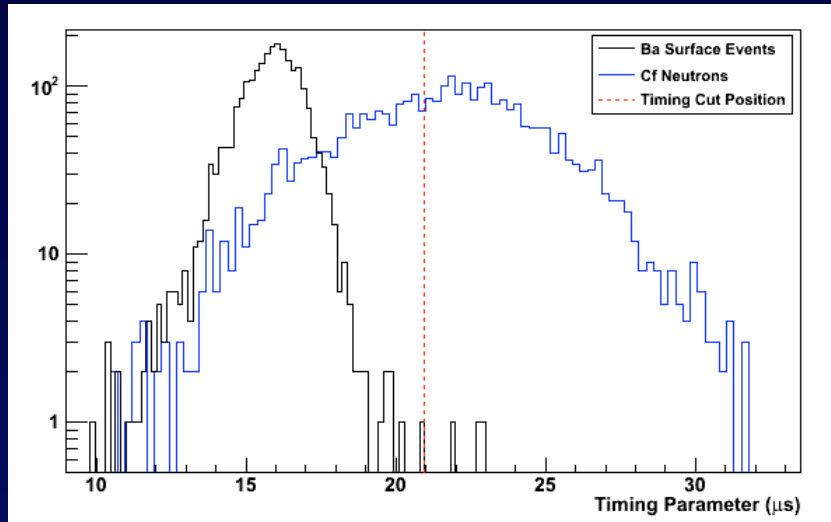


~75% of our contamination is ^{210}Pb
=> Already reduced by improved handling



Surface Event Background

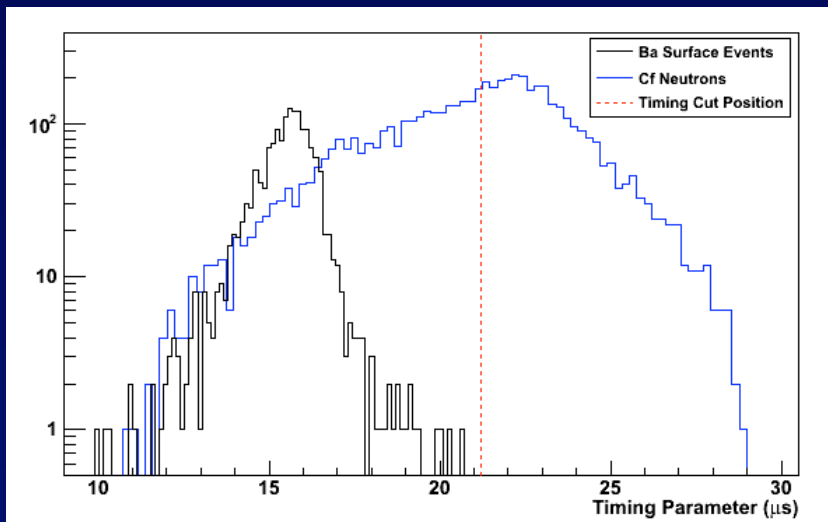
^{133}Ba provides surface events for tuning the surface event rejection cut.



We optimized for the best sensitivity
(results in < 1 expected background)

Challenges (!)

- Setting the cut on the tails of the distribution
- Accounting for systematic differences between surface events in ^{133}Ba and WIMP-search datasets

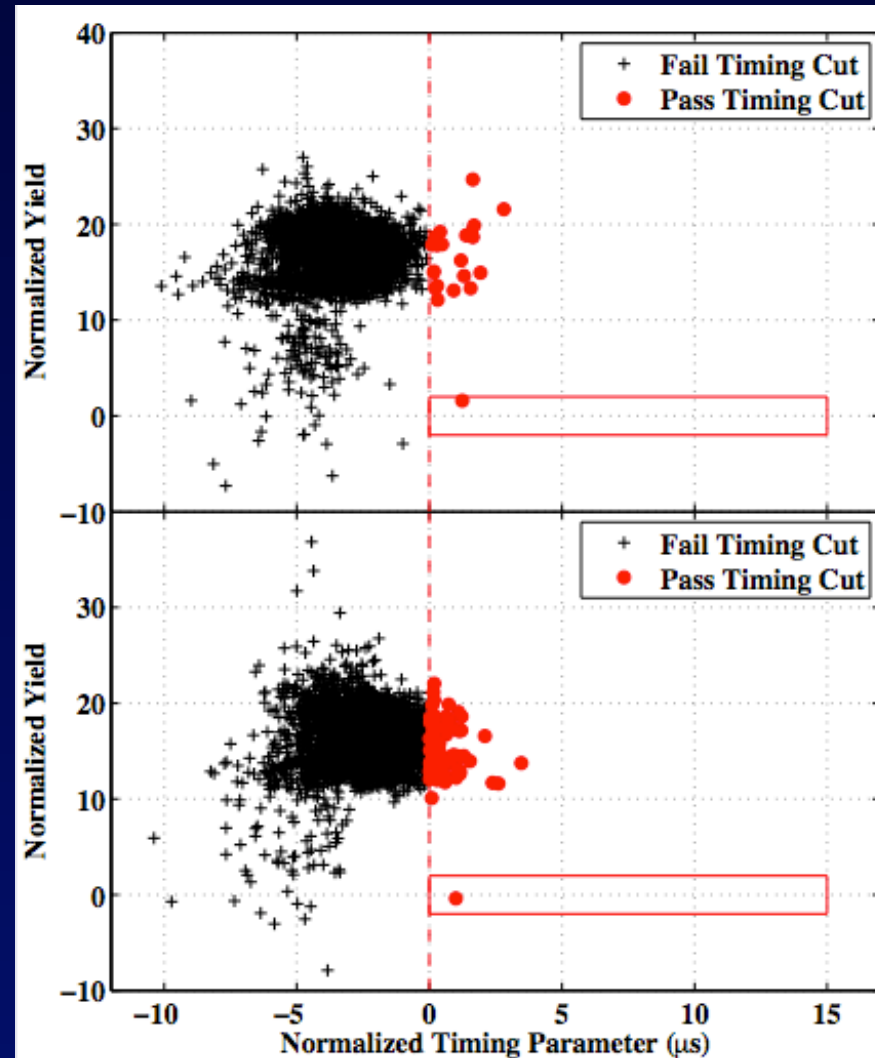


Résultats: 2 événements

Saturday Oct, 27th 2007



Sunday Aug, 5th 2007



Events happened in two different detectors in two different towers at well separated times