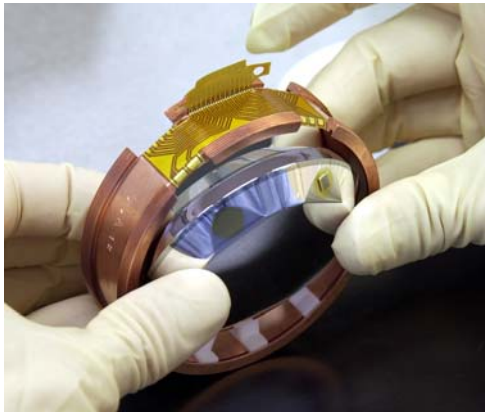




Recherche de matière noire avec l'expérience EDELWEISS

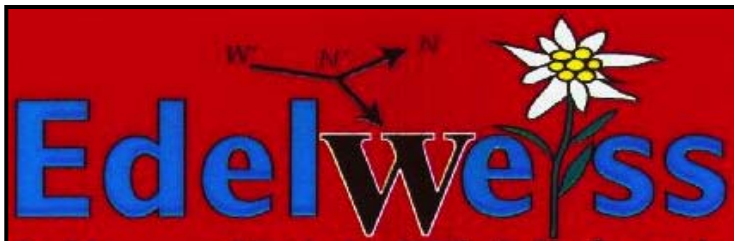


Contexte

Conclusions d'EDELWEISS-I

Avancement d'EDELWEISS-II

Perspectives

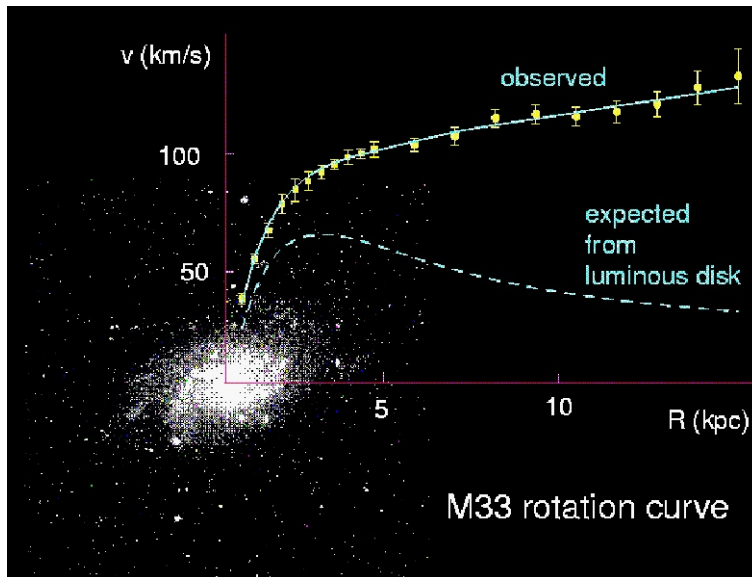
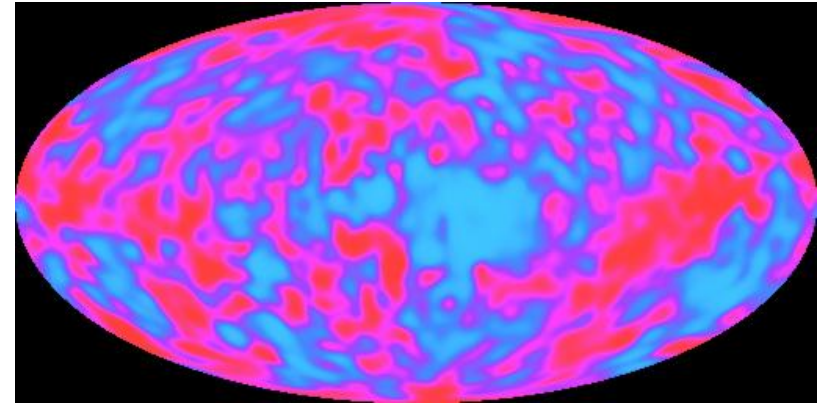


J. Gascon

UCB Lyon, CNRS/IN2P3/IPNL

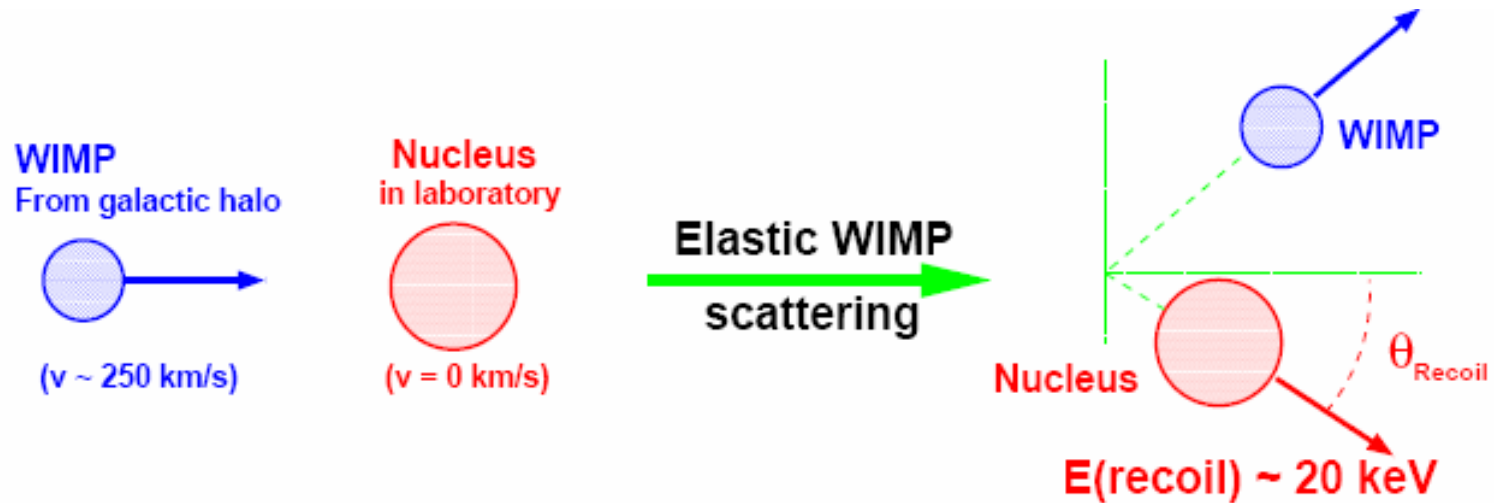
Matière Noire sous forme de WIMP

- Echelle cosmologique
(WMAP, Archeops, SNIa, ...)
 $\Omega_{\text{Cold Dark Matter}} \sim 0.22, \Omega_{\text{Baryon}} < 0.05$
- Formation de structures
→ Particules massives
- $\sigma_{\text{annihilation}} \sim \text{Weak force} \rightarrow \text{WIMPs}$



- Echelle galactique
Courbes de rotations:
 $\rho_{\text{CDM local}} = 0.2\text{-}0.4 \text{ GeV/cm}^3$
- Pour MWIMP $\sim 100 \text{ GeV}/c^2$
 - *$\sim 3000 \text{ WIMPs}/m^3$ ici présents,*
 - *$v \sim 200 \text{ km/s}$:*
 - *flux local $\sim 10^5 \text{ WIMP}/\text{cm}^2/\text{s}$*

Recherche directe



- WIMP scattering on nucleus in the laboratory (local ρ_{CDM})
- Kinetic energy of recoil ~ 20 keV
(for $M_{\text{WIMP}} \sim M_{\text{RECOIL}} \sim 100$ GeV and $v_{\text{WIMP}} \sim 200$ km/s)
- Direction of recoil? Difficult
Recoil travels ~ 20 nm in solid, ~ 30 μm in 1 atm gaz
- Calorimetric approach -> *Measure kinetic energy of recoil*

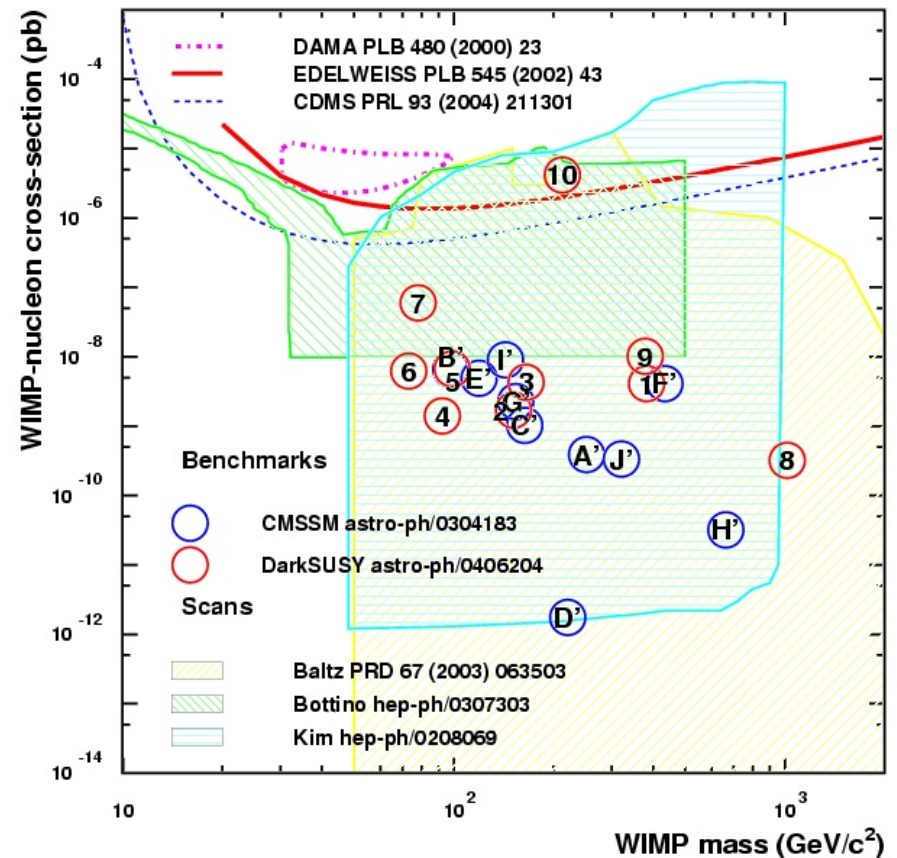
Taux de collisions

Rates depend on:

- WIMP density ($\sim 0.3 \text{ GeV/cm}^3$)
- WIMP velocity distribution ($\sim 200 \text{ km/s}$ +/- model)
 - > *Use Lewin & Smith prescriptions for comparing expt. sensitivities*
- WIMP scattering cross-section on nucleus
 - Depends on exact nature of WIMP
 - Large model dependence !*
 - Requires model: ex: in mSUGRA,
 - from 1 event/kg/week ...*
 - ... down to 1 event/ton/year*

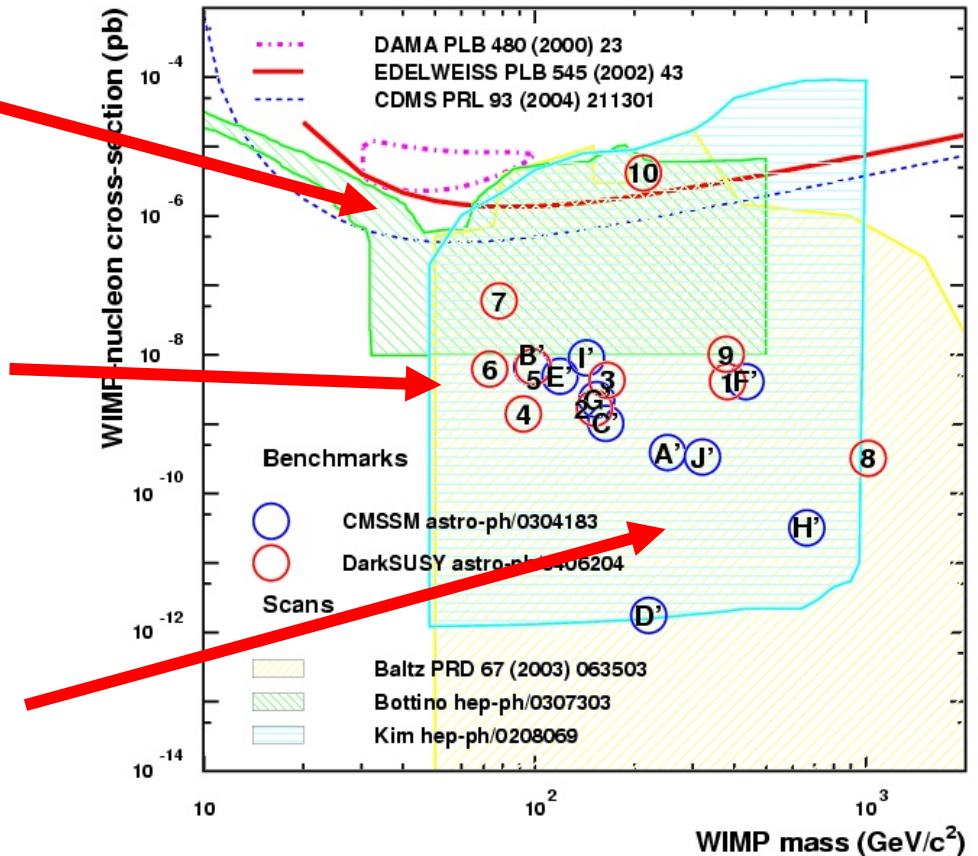
Prédictions MSSM

- Scans, or selected benchmarks
- Coherent interactions usually dominate ($\sigma_p \sim \sigma_n$, $\sigma_{\text{NUCLEUS}} \sim \mu^2 A^2$)
- Large variation of predicted rates
- Interesting range is factor $10^2 - 10^4$ below existing expt. limits



Prédictions MSSM et expériences

- $\sigma = 10^{-6}$ pb:
 ~ 1 event/kg/day
 ~ 0.1 now reached
- $\sigma = 10^{-8}$ pb:
 ~ 1 event/kg/year
*CDMS-II, CRESST-II and
 EDELWEISS-II goals*
- $\sigma = 10^{-10}$ pb:
 ~ 1 event/ton/year
*Next generation, requires
 further x100 improvement!*



Problème de fond

- Major problem! Typical radioactivity...
(ex.: human body $\sim 10^{+7}$ decays/kg/day)
... well above $\sim 10^{-4}$ event/kg/day ultimate goal!
- Extremely large reduction required
 - > tails of distributions, difficult to understand and simulate accurately.
- 20 keV \sim atomic X-ray (to compare with \sim MeV signal in large ν detectors)
 - > relatively un-charted background domain for rare event searches
- Aim for *background-free* expts (rejection, not subtraction)

1. Recoil energy spectrum
2. Nuclear (and not electron) recoils
3. Coherence: $\mu^2 A^2$ dependence
4. Absence of multiple interactions
5. Uniform rate throughout entire volume
6. Annual modulation (... requires $> \sim 10^4$ evts!)

... Cryogenic detector arrays designed to fully exploit all of these

Signatures

1. Recoil energy spectrum ← **Energy resolution**
2. Nuclear (and not electron) recoils ← **Discrimination**
3. Coherence: $\mu^2 A^2$ dependence ← **More than one A**
4. Absence of multiple interactions ← **Array**
5. Uniform rate throughout entire volume ← **Large array**
6. Annual modulation (... requires $> \sim 10^4$ evts!) ← **Large**

... Cryogenic detector arrays designed to fully exploit all of these

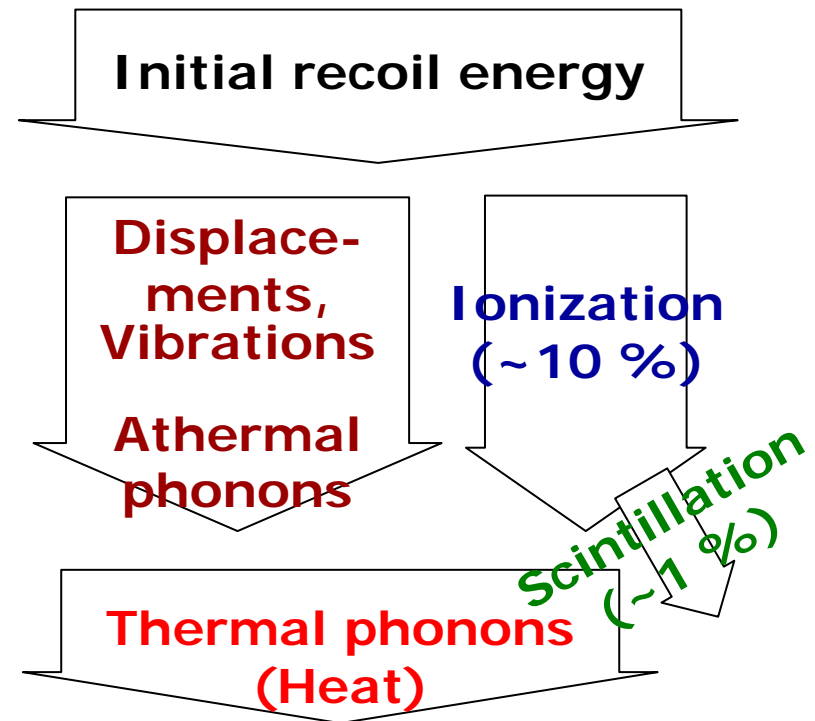


Détecteurs Cryogéniques

- Idea: Combine thermal (or phonon) measurement with ionization or scintillation measurement

- Thermal/phonon component: most accurate ***total energy*** measurement
- Ionization or scintillation yield (norm. to thermal/phonon) differs for
 - nuclear recoil (signal)
 - electron recoils (dominant background)

-> ***powerful rejection***

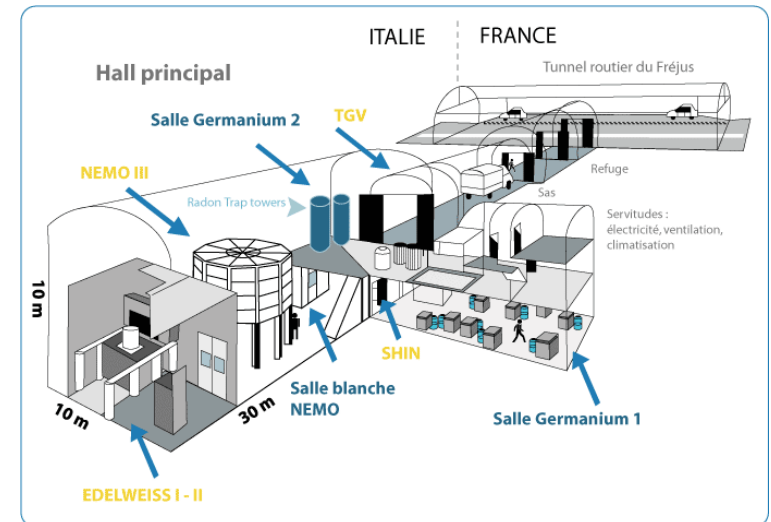


La collaboration EDELWEISS

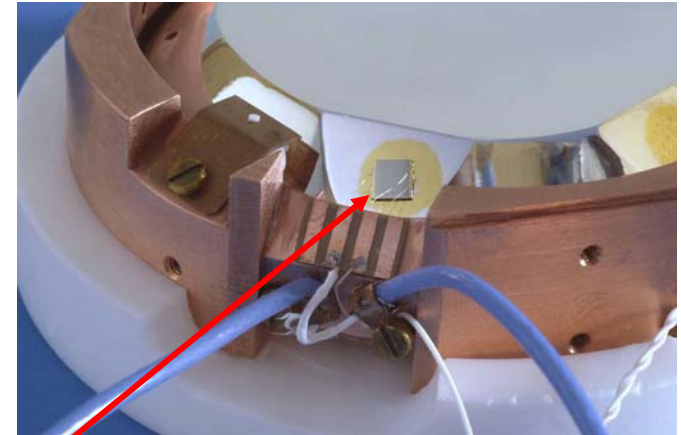
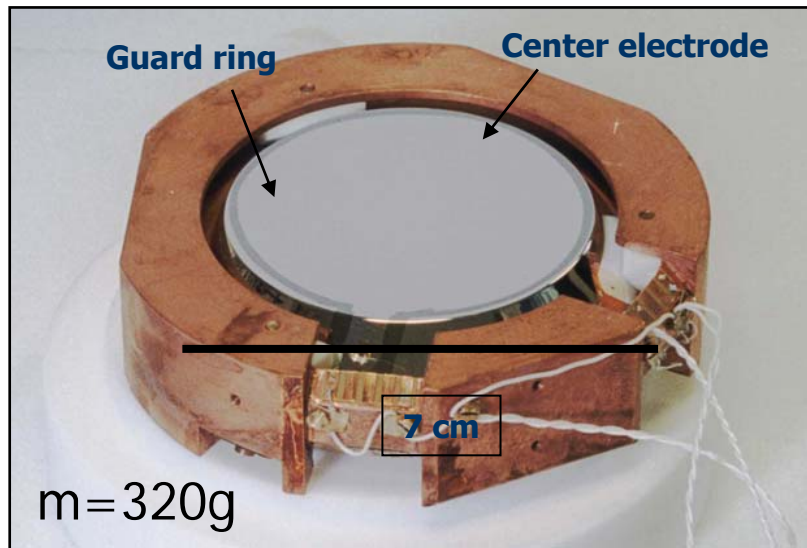
- CEA Saclay DAPNIA
DRECAM
- CNRS IN2P3/CSNSM Orsay
IN2P3/IPN Lyon
DSM/CRTBT Grenoble
INSU/IAP
- FZK/Univ. Karlsruhe (Allemagne)
- DUBNA (Russie)
- *Laboratoire Souterrain de Modane*
 - Sous 1700 m de roche (tunnel du Fréjus)
 - Flux de rayon cosmique réduit d'un facteur 10^6 ($4 \mu\text{m}^2/\text{d}$)



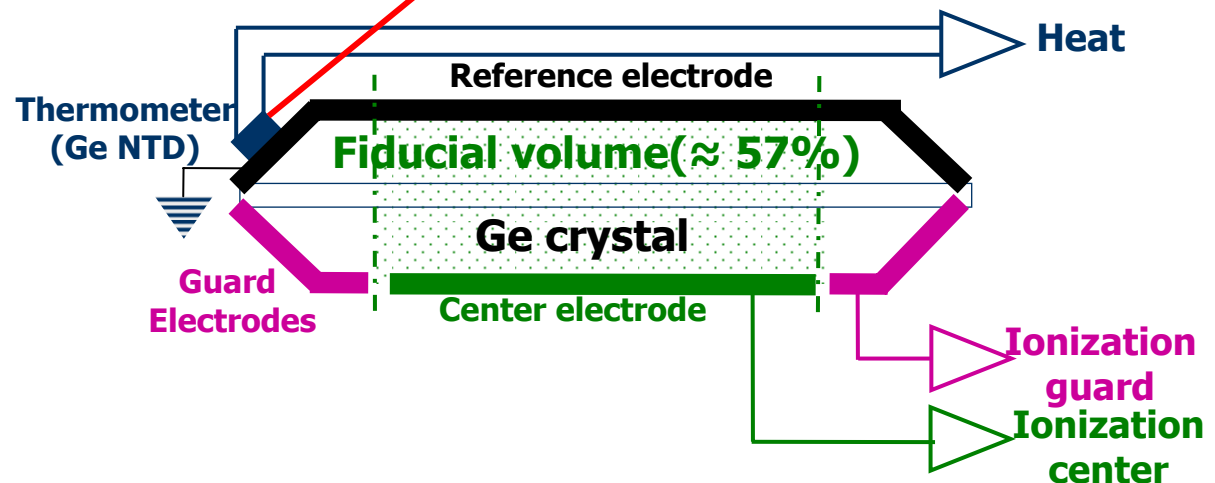
* Expérience pour Detecter Les WIMPs En Site Souterrain



Détecteurs EDELWEISS GeNTD

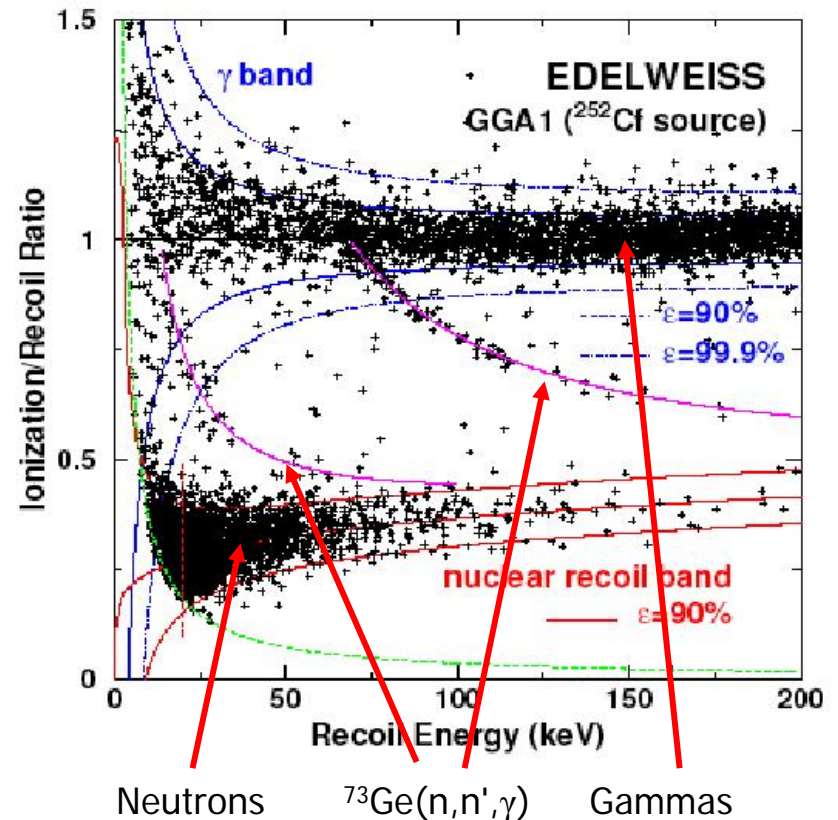
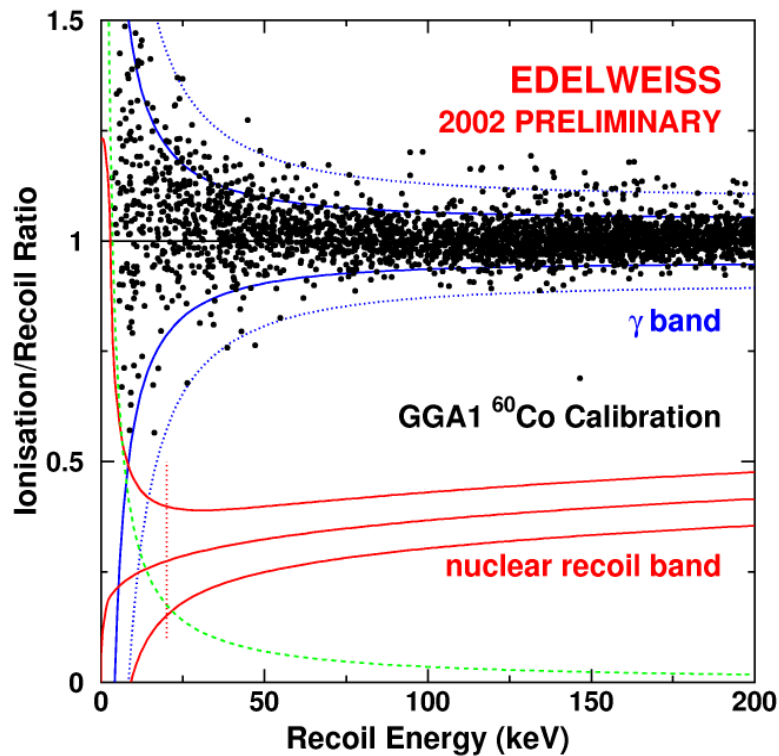


- Heat @ 17 mK
with Ge/NTD sensor
- Ionization @ few
V/cm with Al
electrodes
- Centre = Volume
Fiduciel (57%)

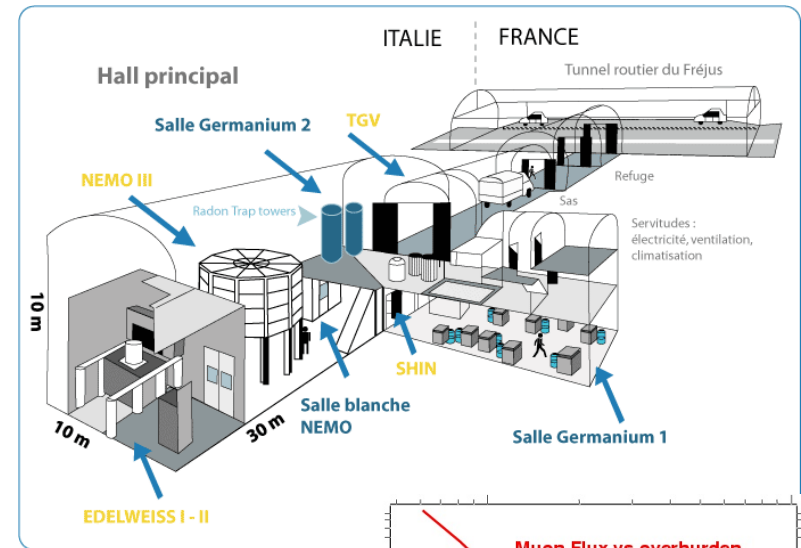


Discrimination EDELWEISS

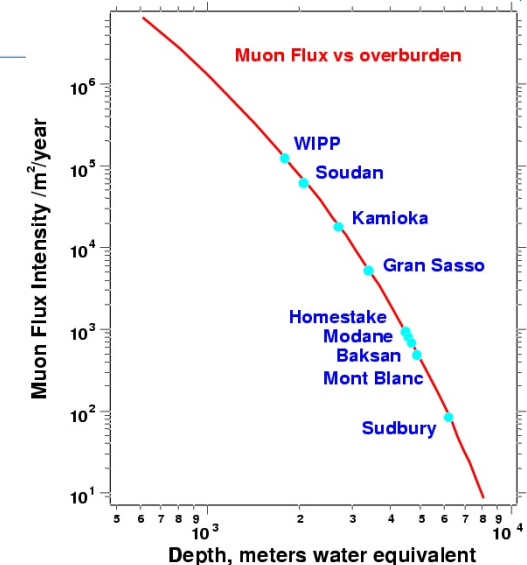
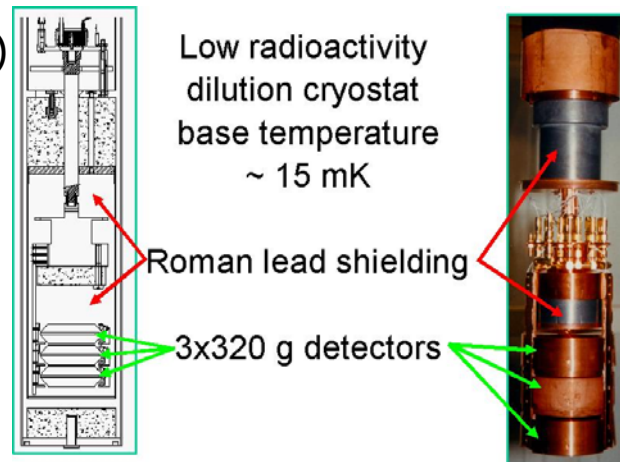
- Different charge/heat ratio for nuclear and electron recoils
- Evt-by-evt discrimination of electron recoils (main background: γ)



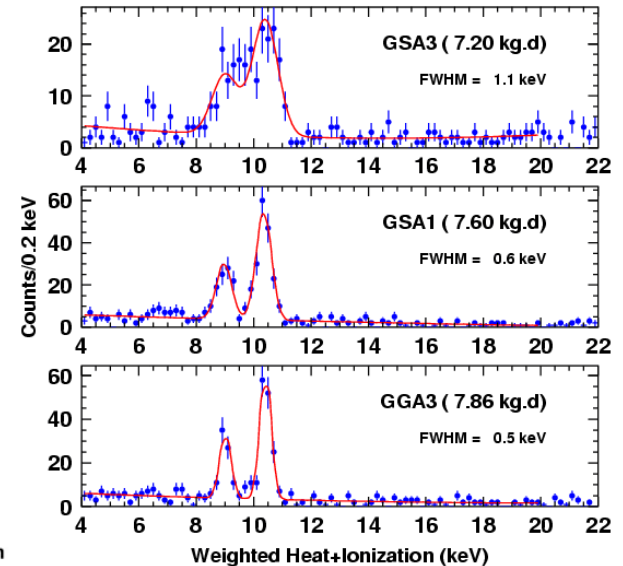
- Site du Laboratoire Souterrain de Modane
 - 1700 m de roche (Tunnel du Fréjus, 4800 mwe)
 - $4 \mu\text{m}^2/\text{jour}$ (10^6 moins qu'en surface)
 - 1500 neutrons ($> 1 \text{ MeV}$)/ m^2/jour (radioactivité naturelle: $(\alpha, n) + \text{fission}$)



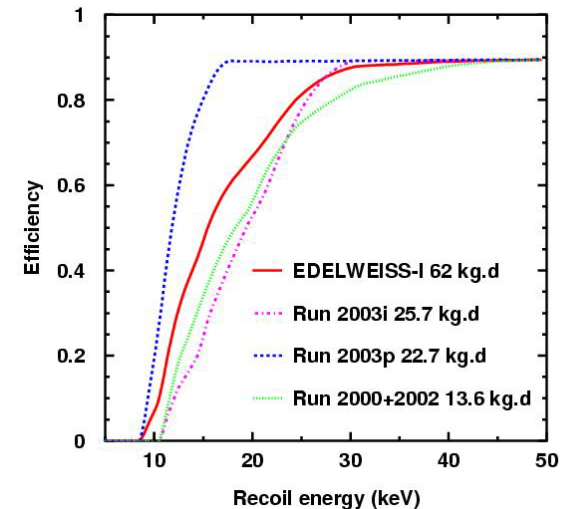
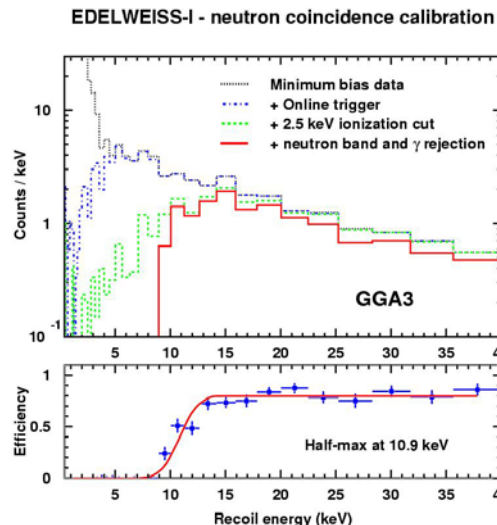
- 3 détecteurs (1 kg)
- Blindages:
 - 30 cm parafine
 - 15 cm plomb
 - 10 cm cuivre



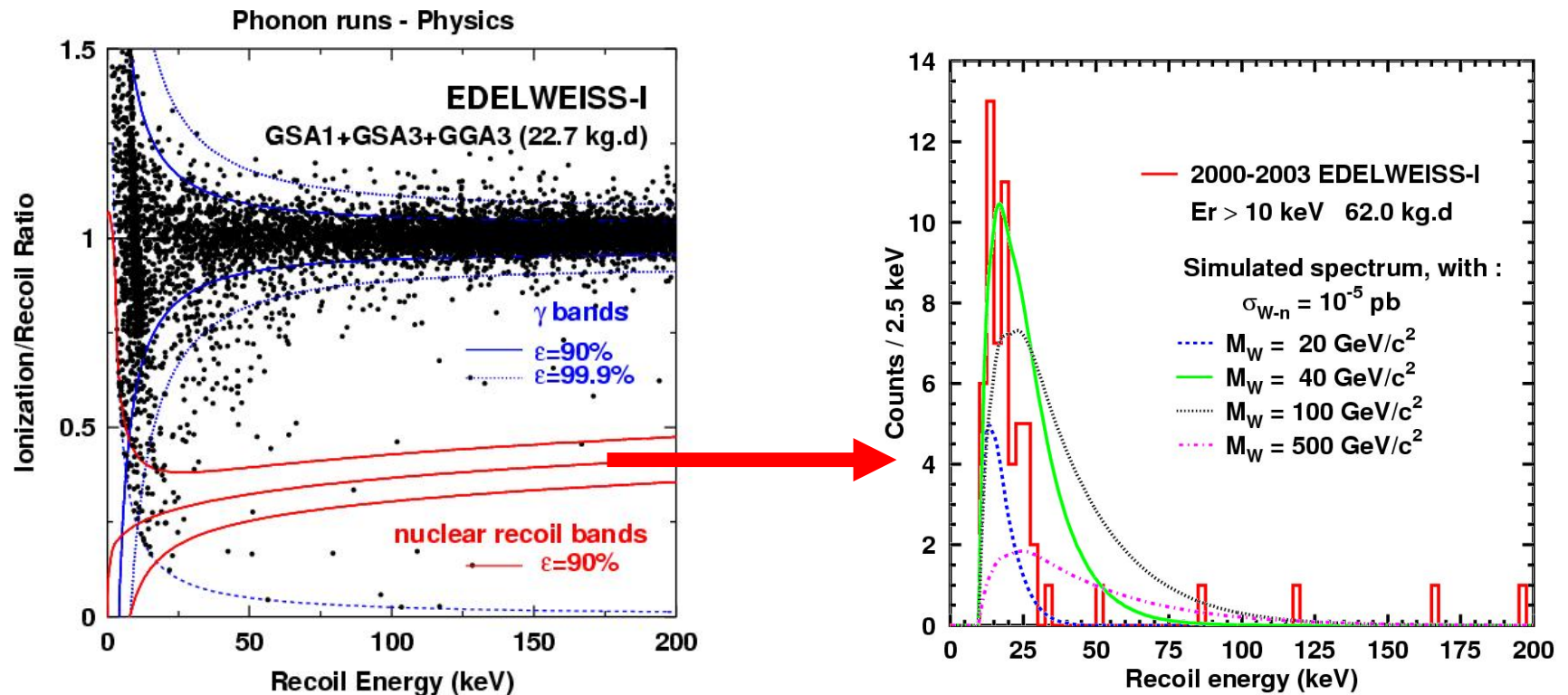
- Prises de données: 2000-2003
 - Temps considérable consacré à l'étalonnage: énergie, bande de reculs nucléaires, rejet gamma, zone fiducielle, seuil en énergie
- Dernier run (2003): 22 kg.d fid.
 - Déclenchement sur signal chaleur (plus lent, mais plus efficace à basse énergie: 50 % à 11 keV)
 - Excellente stabilité sur 4 mois



- Exposition totale:
 - **62 kg.d (fiduciel)**
 - **Efficacité @ 15 keV = 50%**

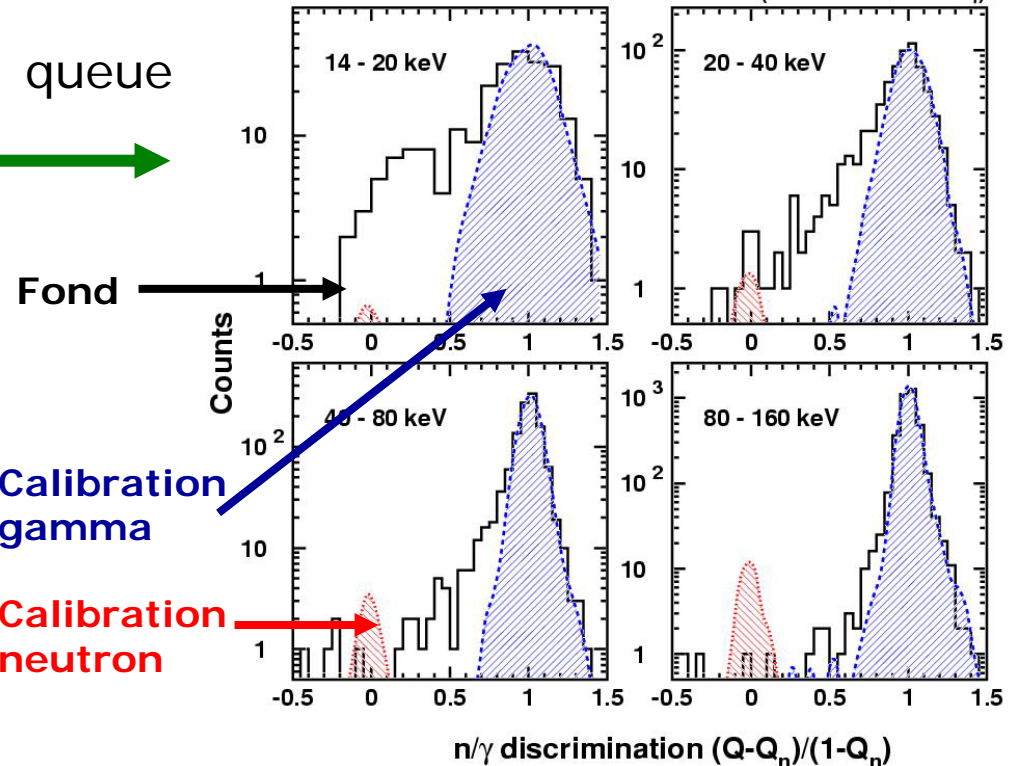
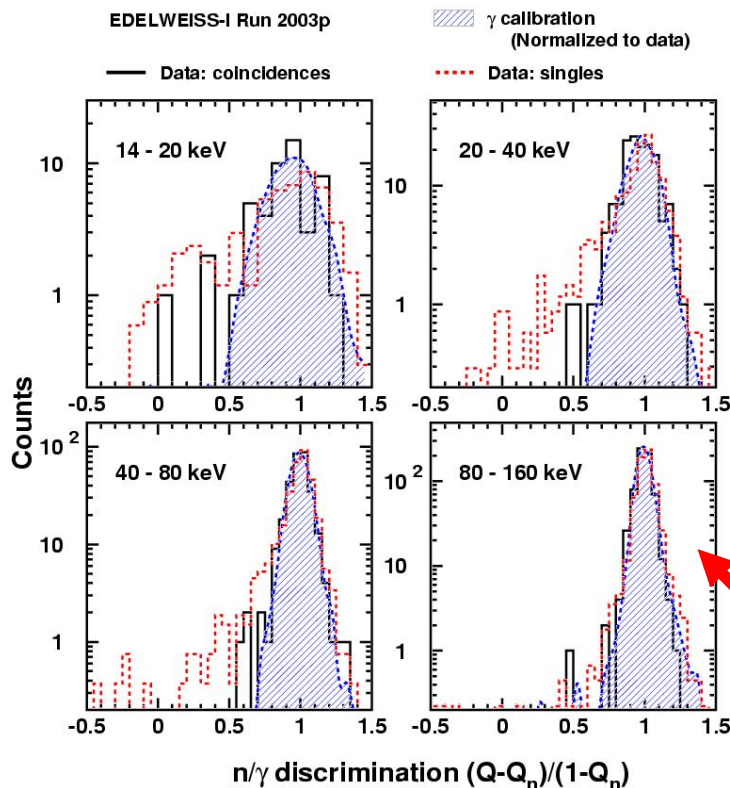


- Dans 62 kg.j (fid.), 40 candidats dans la bande de recul nucléaires > 15 keV, dont 3 avec $30 < E_R < 100$ keV
- Une coïncidence n-n observée: *fond neutron?*



Événements en surface EDELWEISS-I

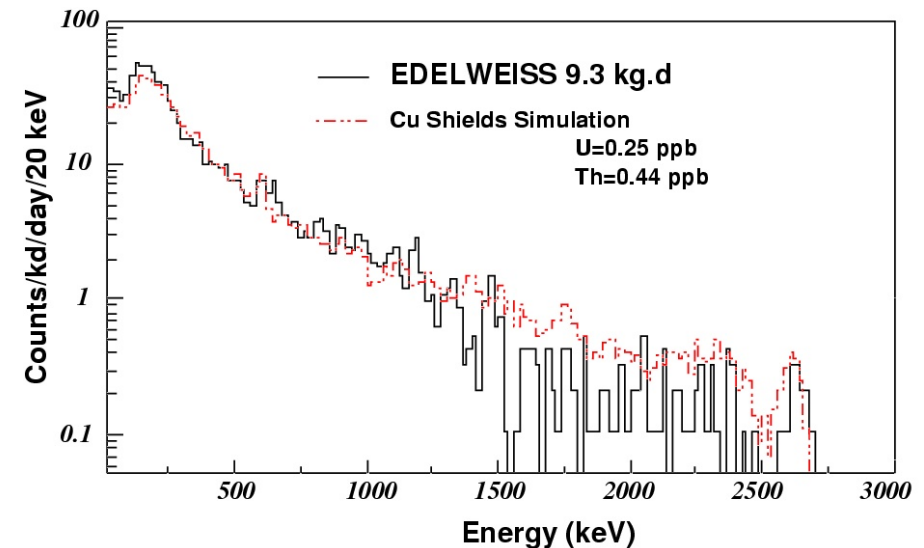
- Profil de collecte de charge: queue à basse énergie 



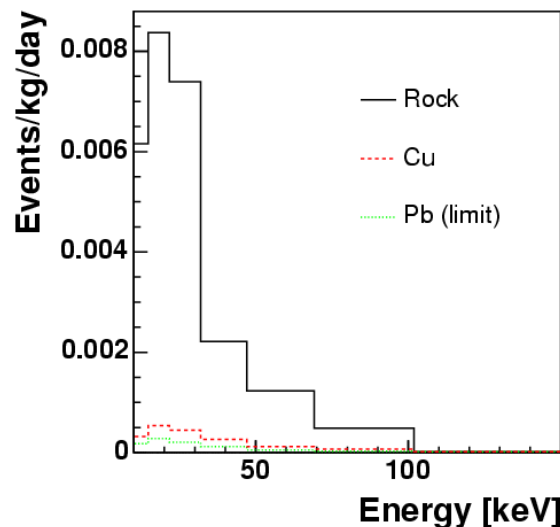
Coïncidences entre détecteurs: moins de queue. Radiation qui ne pénètre pas les capots entre les détecteurs (\sim mm Cu): β en surface?

■ Fond gamma

- 1.5 evt/kg/j/keV avant rejet
- Compatible avec mesure U/Th des blindages de Cu (pas utilisés dans EDW-II !).



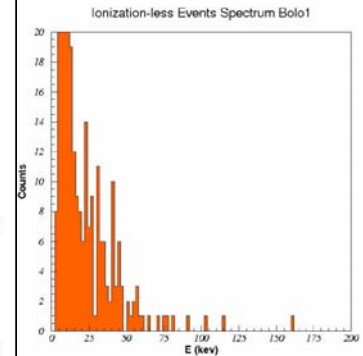
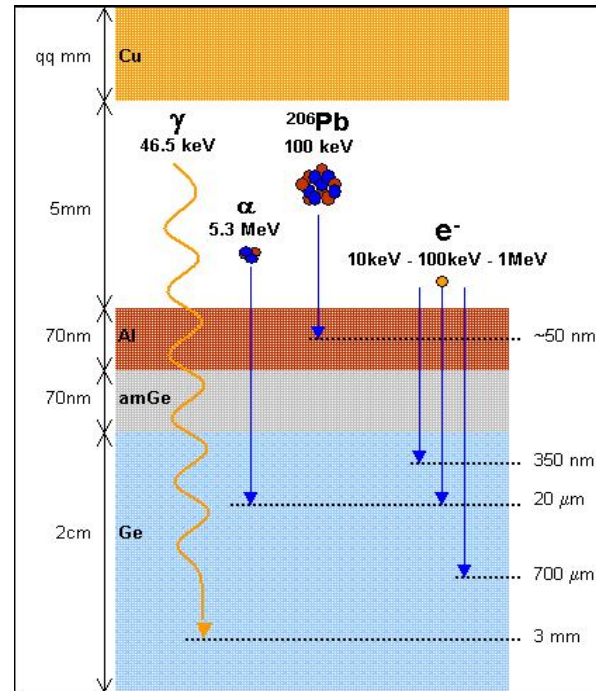
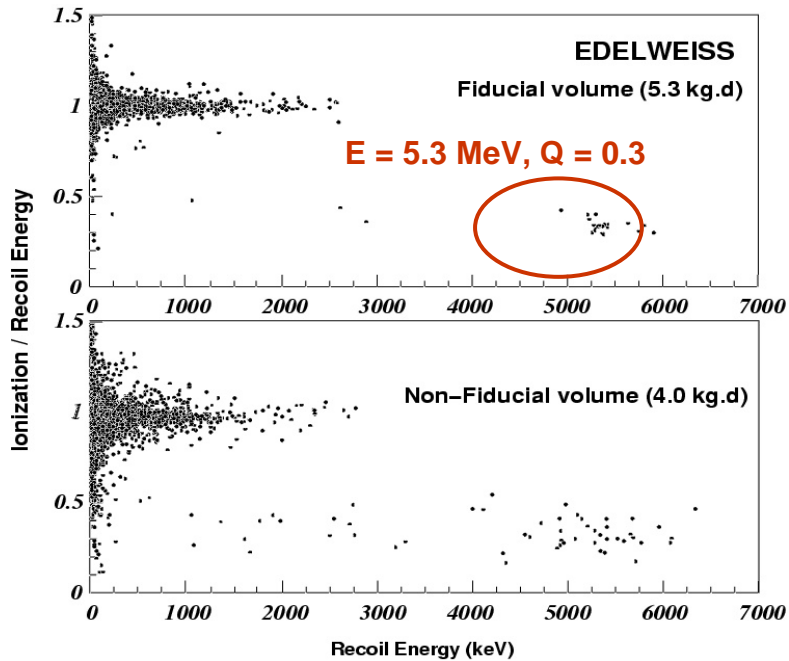
Neutron background in EDELWEISS-I detectors



Fond neutron

- Simulation du transport du flux issu de la roche à travers les blindage (MC vérifié sur calibration neutrons)
- ~2 reculs attendus en 62 kg.j, dont ~10% en coïncidence (compatible avec 1 coïnc. observée)

Fonds de surface

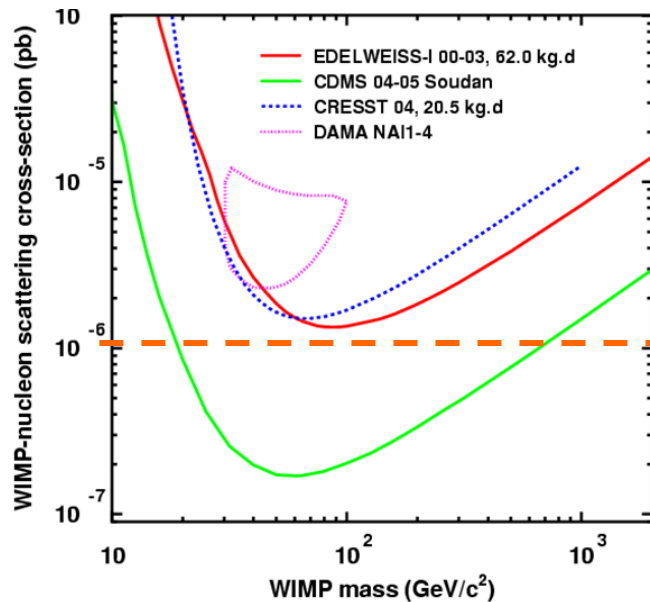


- α 's from ^{210}Po ($E_\alpha = 5.3 \text{ MeV}$)
 - $Q=0.3 \rightarrow \alpha$ decays near surfaces
 - Rate $\sim 400 / \text{m}^2/\text{d}$
 - As expected, non-fiducial part more exposed
- ^{210}Pb on Cu covers or Ge surfaces
 - Should see Pb recoils and β 's

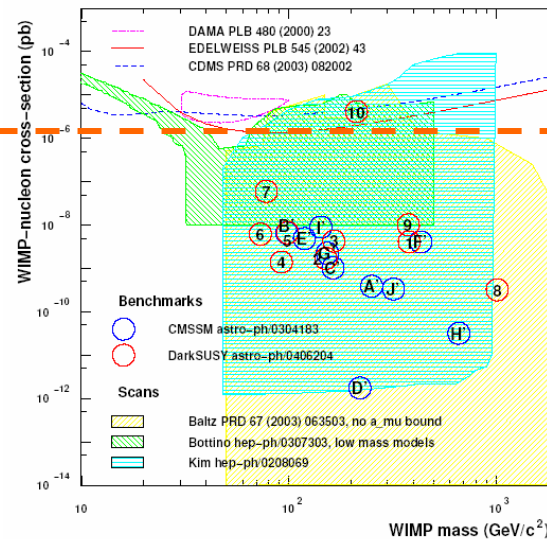
- No ^{206}Pb recoil peak at 100 keV observed as heat-only events: ^{210}Pb implanted in Cu, not Ge.
- Rate of $0.3 < Q < 1.0$ events at low energy consistent with expected surface β 's
- does not exclude contribution from ^{14}C
- By removing Cu between detectors, these events should disappear, or ID by coincidences

Conclusions EDELWEISS-I

- EDELWEISS 1 kg (3x320 g) complété en 2003
 - Expérience la plus sensible en 2001-2003: <0.2 reculs/kg/jour
 - Depuis, rattrapé (CRESST-II) et dépassé (CDMS-II) par d'autres cryodétecteurs
 - Limité par la taille du cryostat et le fond radioactif (neutron, β)



- Prochaine étape: EDELWEISS II



EDELWEISS-II
(sensibilité x100)

EDELWEISS-I → EDELWEISS-II

- EDELWEISS-II installé à Modane en 2005
- **But: gain x 100 en sensibilité**
 - ($\sigma \sim 10^{-8}$ pb, 0.002 evt/kg/j $E_R > 10$ keV)
 - **Plus de masse (=plus de détecteurs)**
 - **Plus de radiopureté, de blindage et de rejet**
- Nouveau cryostat
- Nouveaux détecteurs (28, puis 110):
 - 21 Ge-NTD, 7 NbSi
- Environnement bas-bruit radioactif
 - Salle blanche, air déradonisé
 - Sélection et tests systématiques des matériaux
 - Nouveaux blindages
- Nouvelle électronique (plus intégrée)

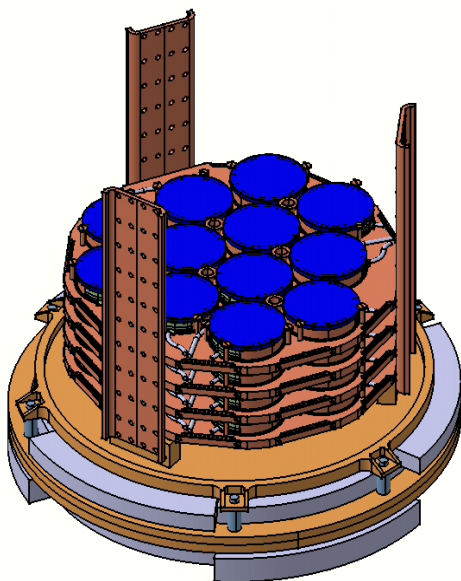
EDELWEISS-I



EDELWEISS-II



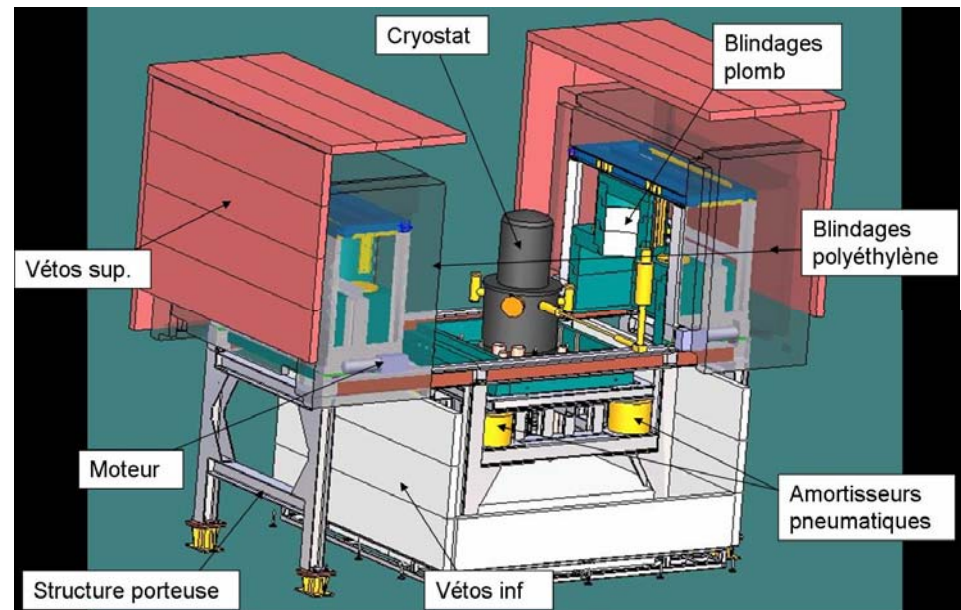
Cryostat EDELWEISS-II



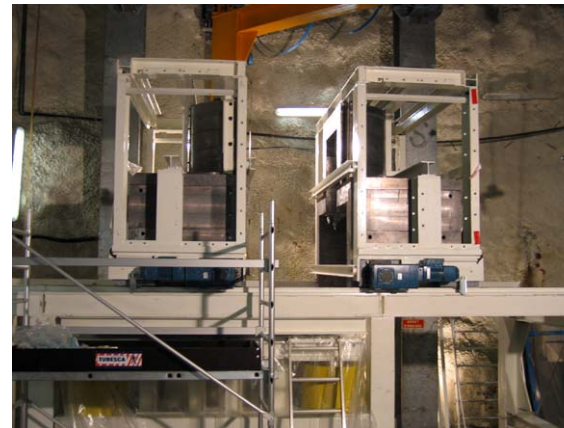
- Reversed geometry
- Nitrogen free : 3 Pulse tube (50K and 80K screens) and 1 He cold vapor reliquefier (consumption ≈ 0)
- Large volume 50l ⇒ Self shielding
- Up to ≈ 120 detectors ⇒ More statistics
- Compact and hexagonal arrangement ⇒ More coincidence (n bkg)

Blindage EDELWEISS-II

- Dedicated HPGe detectors for Systematic checks of radiopurity of all materials
- Clean Room (class 100 around the cryostat, class 10000 around the detectors)
- Deradonized air (from NEMO3) (0.1 Bq/kg)
- 20 cm Pb shielding
- Neutron Shielding
 - 50 cm polyéthylène
 - Full coverage
- μ veto (99% coverage)



Février 2005



Mars 2005



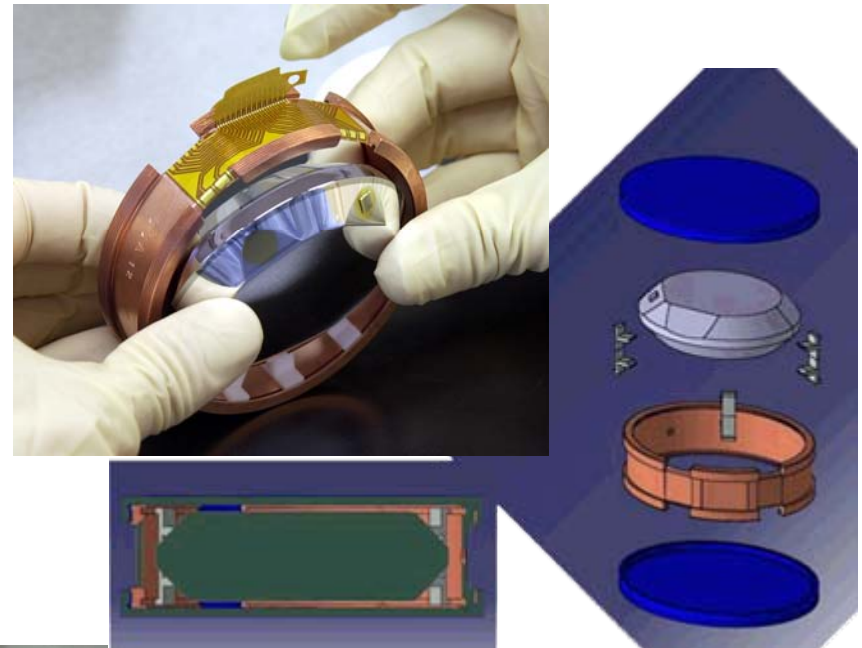
7 mars 2006

EDELWEISS

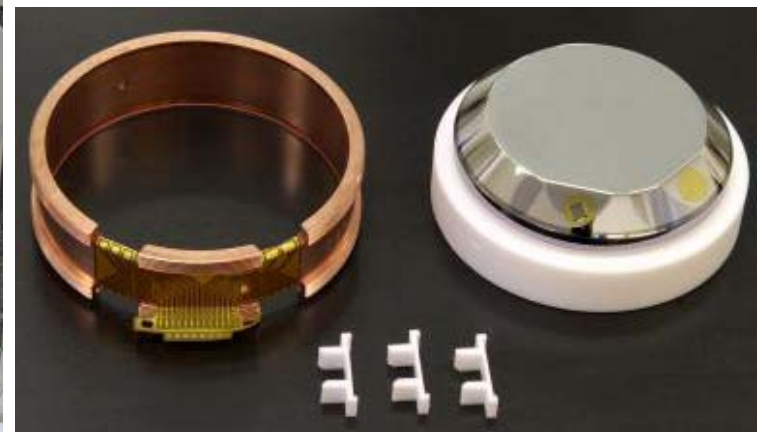
24

Détecteurs Ge-NTD

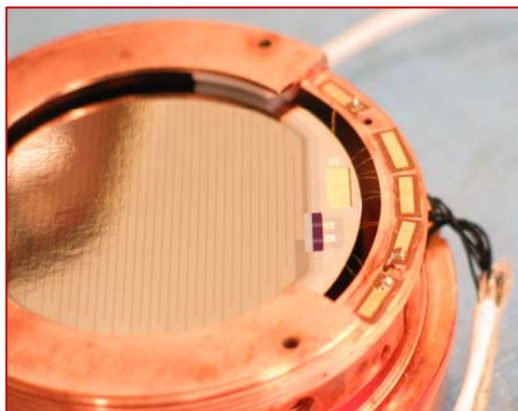
- Developed by CEA Saclay and Camberra-Eurisys
- Amorphous Ge and Si sublayer (better charge collection for surface events)
- Optimized NTD size and homogeneous working T (16-18 mK) : sub keV resolution



- 21 detectors
- New holders
- New connectors (Teflon and copper only)

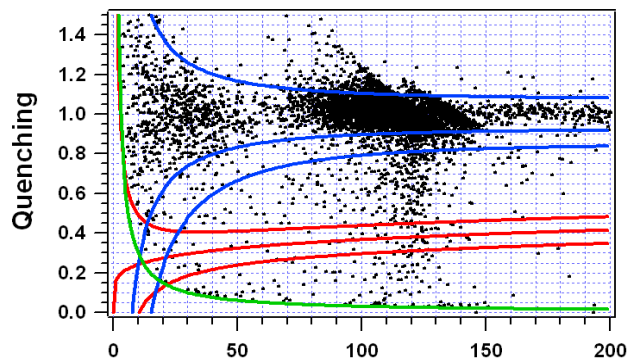
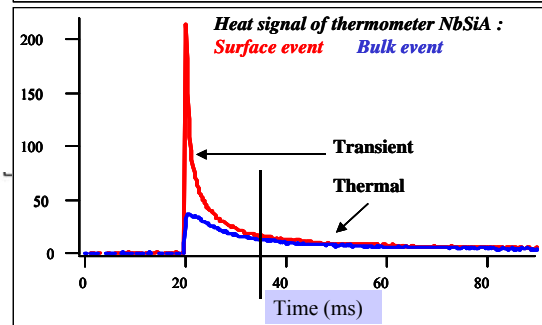
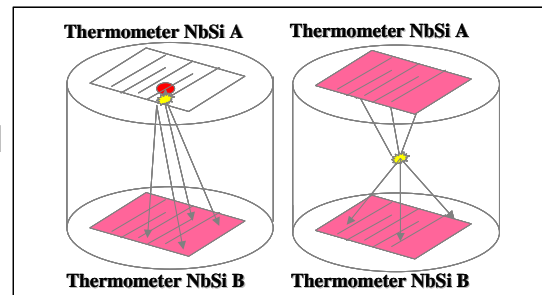


Identification of near surface events: athermal phonon measurement with NbSi thin film thermometers

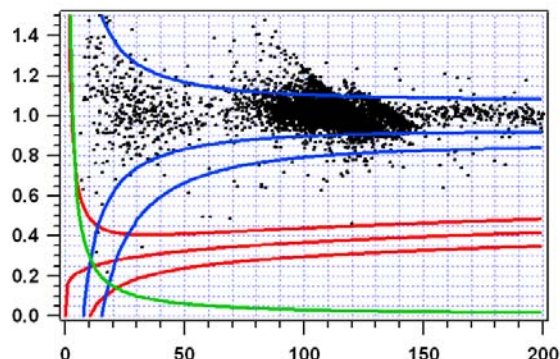


Heat and ionization Ge detectors

- Each signal = thermal + athermal component
- For surface events, athermal higher in NbSi
- Thermal signals proportionnal to the deposited energy

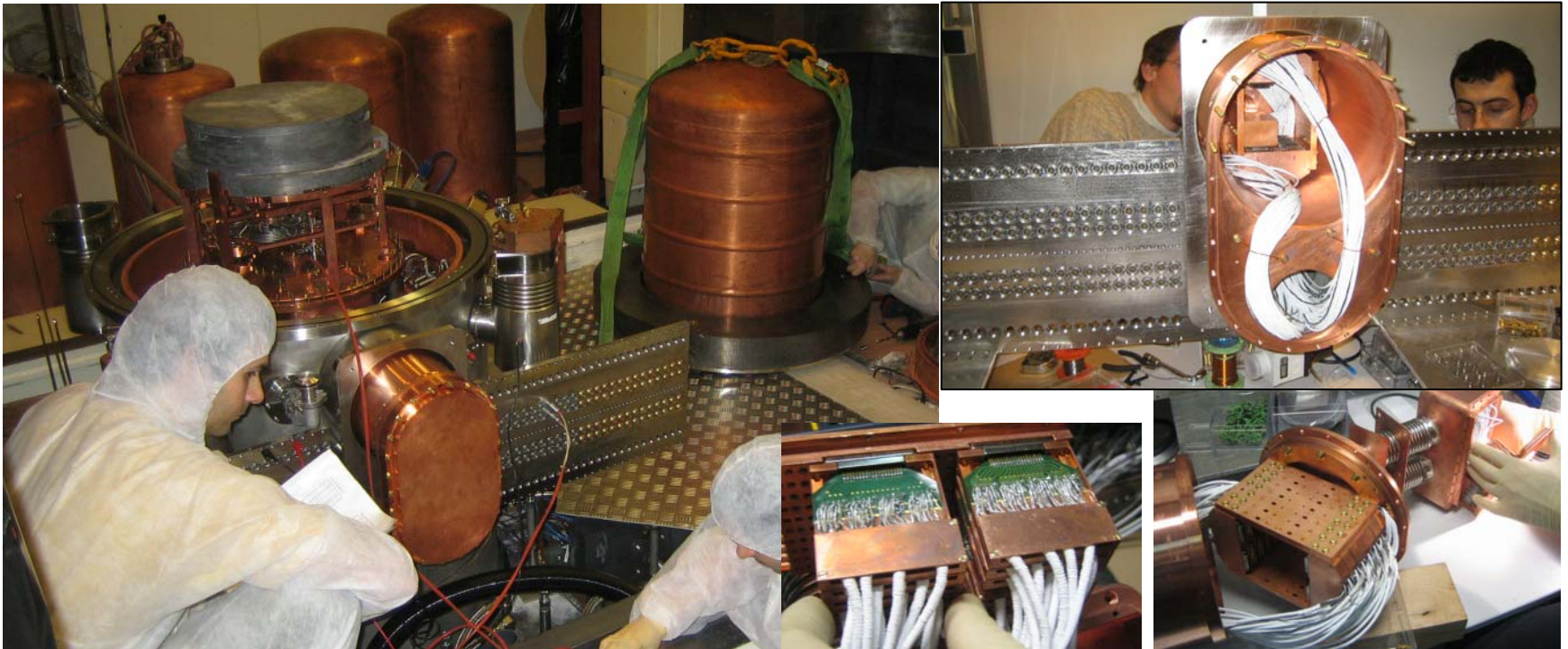
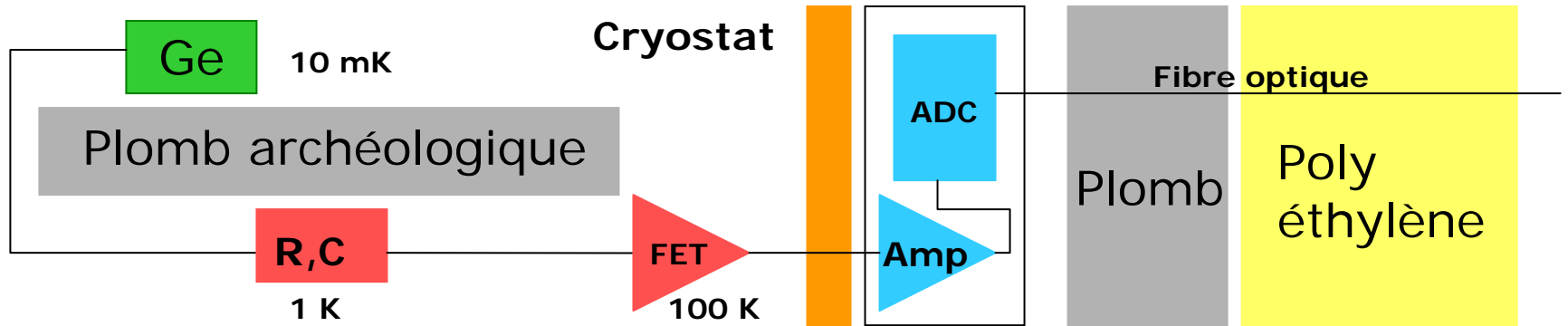


Before rejection



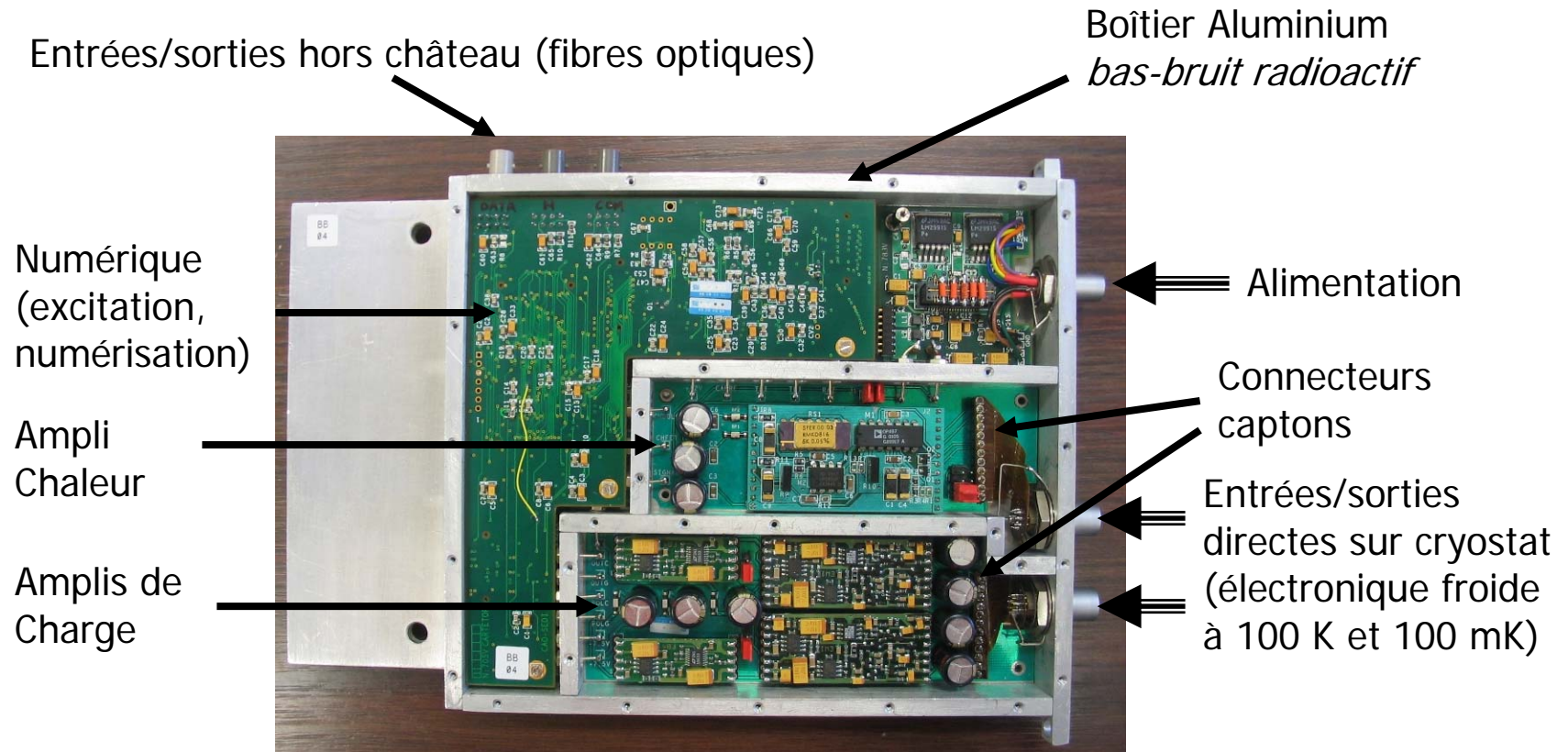
After rejection (1mm cut)

- Tests with 200g prototype in EDW-I
- Rejection X 20
- Fiducial volume reduction of 10 %



Electronique EDELWEISS-II

- Développement CEA/IPNL, + expertise CRTBT
- Solution « tout numérique » intégrée, avec numérisation dès la sortie du cryostat



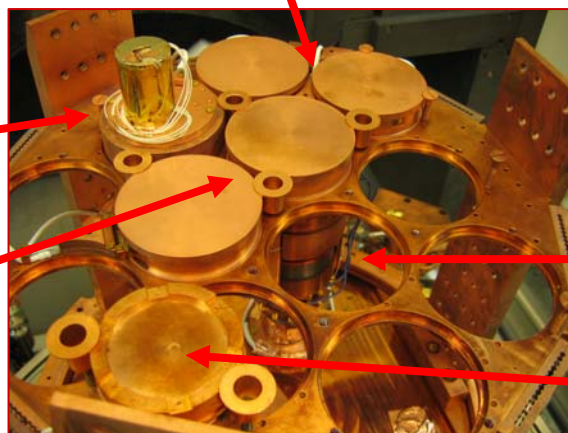
Etat d'avancement EDELWEISS-II

- Janv. 2005: Test cryogénique (avec écran Pb cryogénique, câblage et détecteurs)
 - Premiers signaux!
- Fév. 2005: Test de 8 détecteurs, supports, câblage, électronique, acquisition
 - Remise en froid très rapide

2x320 g Ge NTD
support EDW-II/Cu

50 g Al_2O_3 IAS
Scintillation-Chaleur

2x320 g Ge NTD
support EDW-II/Teflon



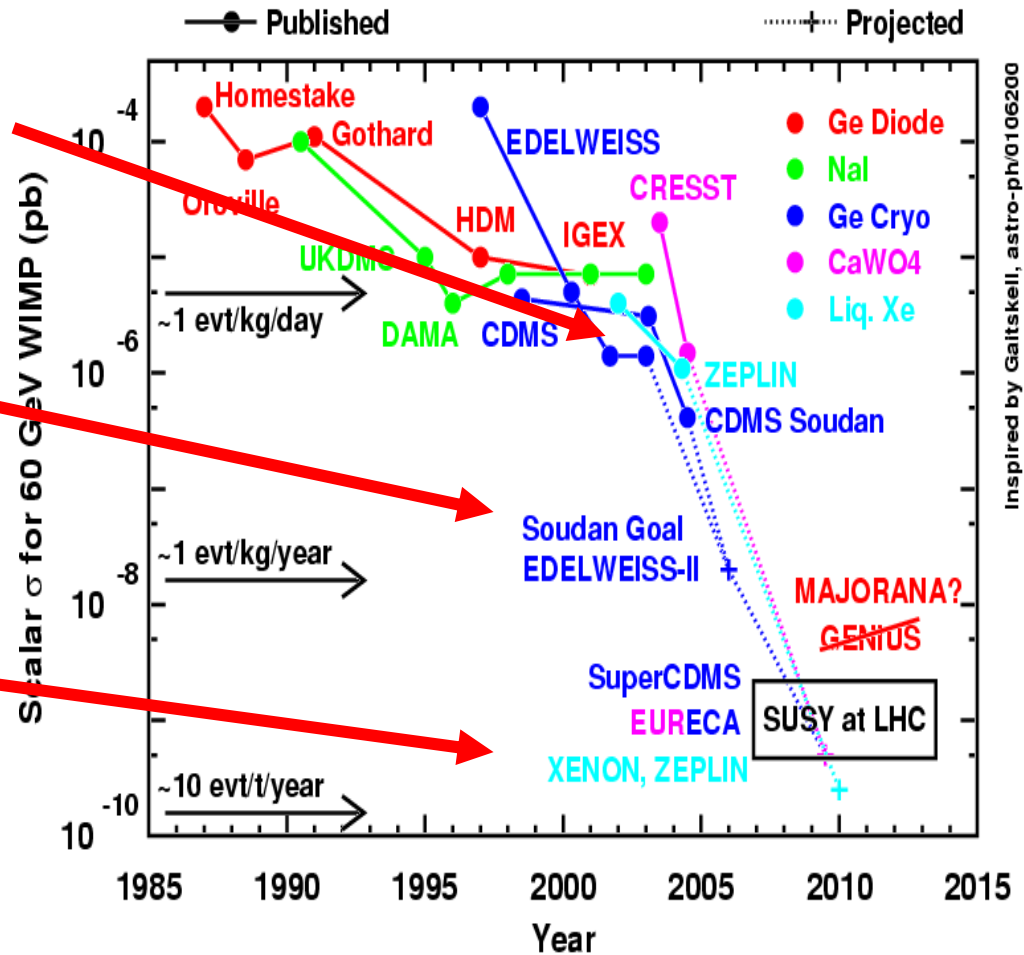
2 x 320 g Ge NTD
support EDW-I

200 g Ge NbSi

- Bad charge collection of near-surface events:
 - Study of charge diffusion, trapping and recombination
 - Passive rejection: improve charge collection for surface event
 - Optimization of Ge and Si amorphous sublayer
 - Detectors with thick electrodes
 - Active rejection: identification of the surface events
 - Pulse shape analysis of the charge signals (but high bandwidth \Leftrightarrow low noise)
 \Rightarrow localization of the event
 - Interdigitized electrodes
 - Detectors sensitive to athermal phonons \Rightarrow 8 Ge/NbSi detectors, 400 g
- Widen choice of target atomic mass? (CDMS: Ge and Si)
 - Low-A: neutron monitoring, sensitivity to spin-dependent σ
 - Al_2O_3 heat-and-scintillation detectors (SciCryo ANR, with IAS and MPP Munich)

Contexte international

- Hier: 10^{-6} pb
($< \sim 1$ evt/kg/jour)
 - *Démonstration technologique*
- Objectif actuel: 10^{-8} pb
(~ 1 evt/kg/an)
 - *Expériences CDMS-II, EDELWEISS-II, CRESST-II*
 - *Test de modèles SUSY intéressants*
- But ultime: 10^{-10} pb
(~ 10 evt/t/an)
 - *Couverture SUSY en phase avec physique au LHC*
 - *Défi technologique: projets SuperCDMS, EURECA*



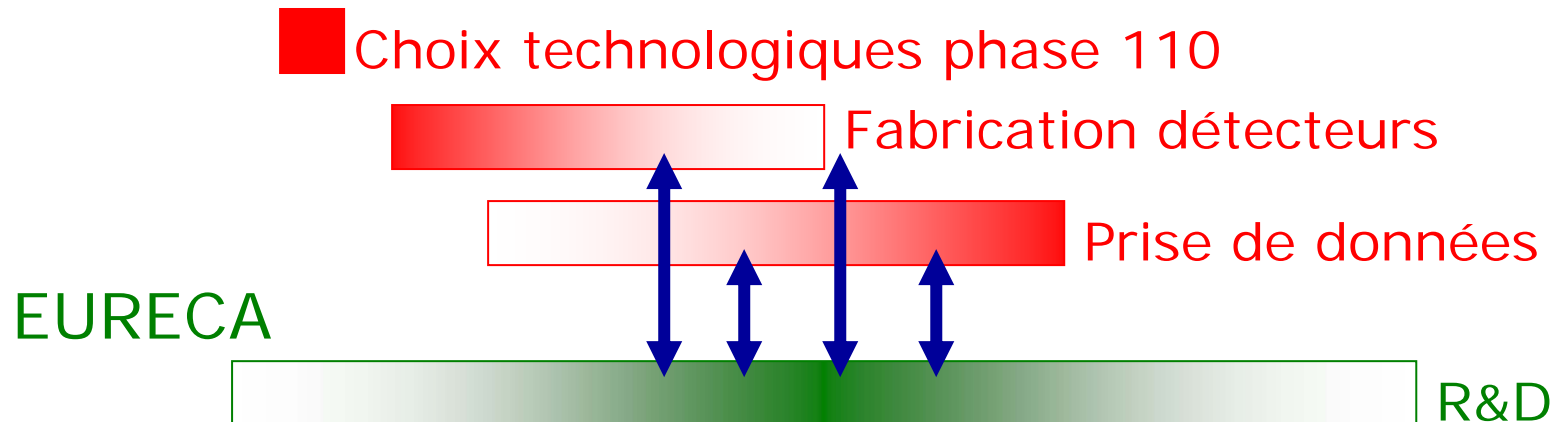
Calendrier EDELWEISS-II

2005 2006 2007 2008 2009 2010 2011 2012

EDELWEISS II-28 détecteurs



EDELWEISS II-110 détecteurs



- Proposition d'un *European Underground Rare Event Calorimeter Array*
 - Basée sur expérience acquise avec CRESST-II et EDELWEISS-II, avec forces additionnelles (CERN)
 - Variété de noyaux cibles: Ge, CaWO_4 (dépendance en A)
 - Masse: entre 100 kg et 1 tonne
 - Evolution: continuité de CRESST-II et d'EDELWEISS-II
 - avril 2005: Statement of Interest

- Recherche directe de la matière noire:
sujet important dans la décade LHC
- Détecteurs cryogéniques avec discrimination de recul nucléaires:
technique la plus performante à l'heure actuelle
- EDELWEISS-I
 - En tête en 2000-2003
 - A atteint ses limites, mais très riches en enseignements
- EDELWEISS-II démarre, objectif: 10^{-8} pb
- Objectif final (10^{-10} pb) très ambitieux
 - Détecteurs cryogéniques en constante amélioration de sensibilité,
avec encore un fort potentiel devant eux