Dark Matter Search with the EDELWEISS-II experiment

- Scientific context
- The experiment
- First commissioning results

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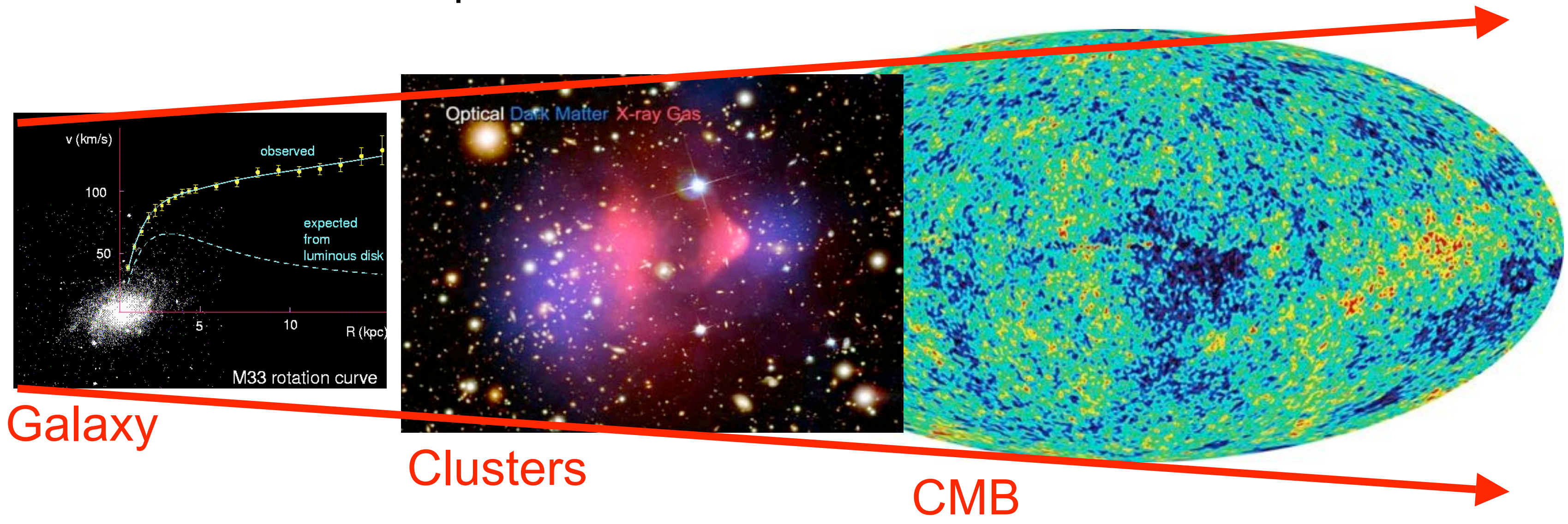
Outline

- Context
  - Dark Matter
  - Direct Searches
  - Some Experiments: Xenon, CRESST, CDMS
    - Spin-independent bias: PICASSO not discussed here!
- EDELWEISS
  - EDELWEISS-I successes and limitations
  - EDELWEISS-II: installation and commissioning; first data with new InterDigit detectors
  - The future: EURECA and ULISSE

Motivation for Dark Matter Searches

- Cold Dark Matter present at all scales in the Universe…



- … and soon, maybe also in collider experiments (LHC)
  - Natural candidates arise from New Physics scenarii, such as SUSY

- Direct Searches: linking the two worlds
  - The Dark Matter in our Galaxy is indeed Weakly Interacting Particles
  - The new particles found in colliders are indeed in our halo

Direct searches for WIMPs

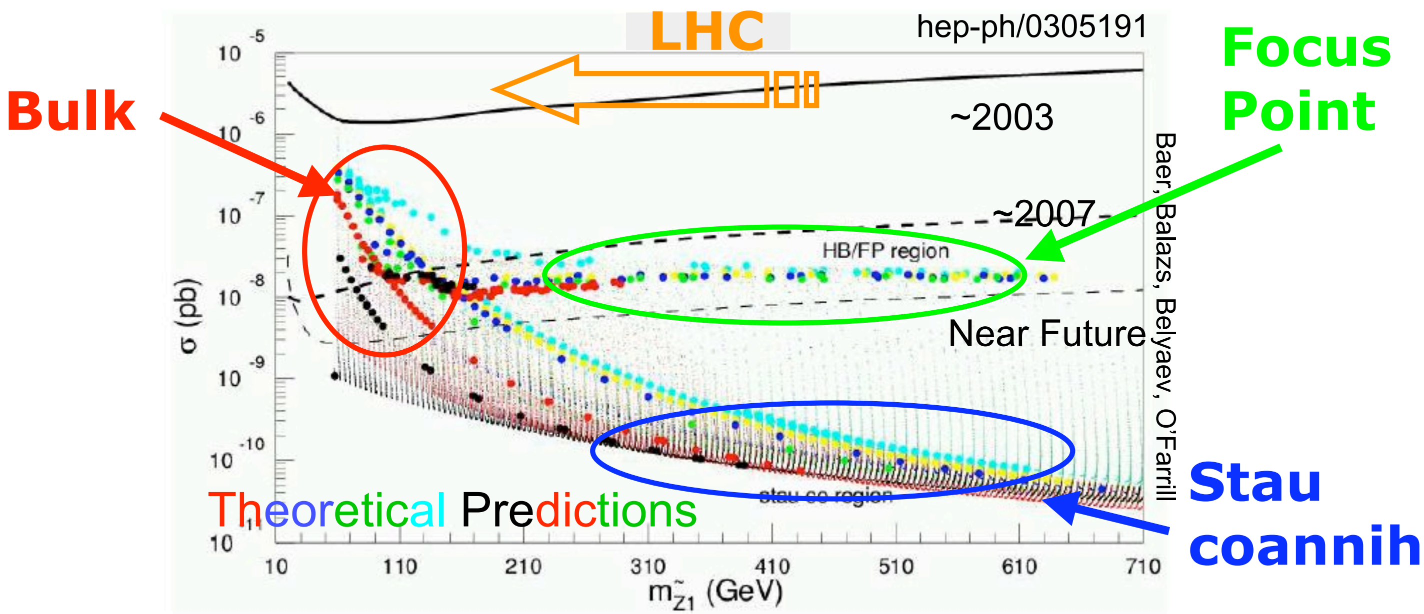
- If the Mass of Weakly interacting massive particles (WIMPs) forming our Galactic halo is ~100 GeV:
  - >1000 WIMPs/m^3 in this room
  - Wimp-nucleus collisions produce 10-50 keV nuclear recoils

- If WIMP ~ SUSY neutralino (σ prediction):
  - as many as 1 WIMP-nucleus collision per kg per month (or as few as 1 per ton and per year)

- Direct search: detect these energy deposits
- Main challenge: background from natural radioactivity (people = 10^{10} decay/kg/year)

Direct Searches and SUperSYmmetry

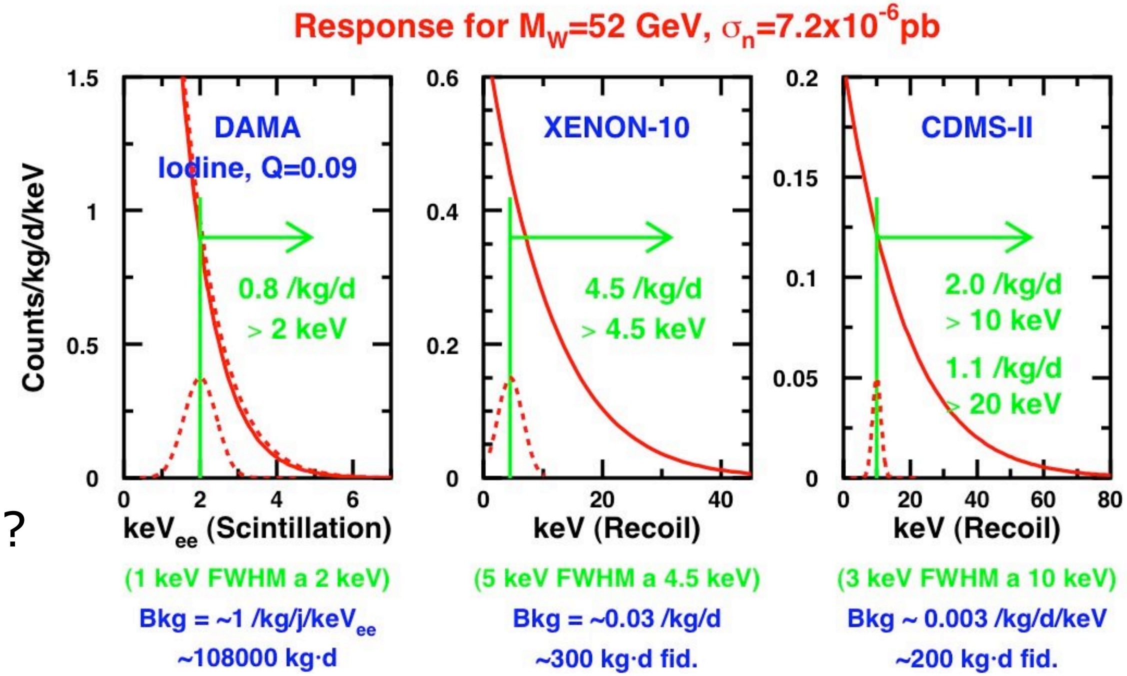
- 10^{-8} pb is an extremely significant goal for direct detection: Test of cosmologicaly + SUSY motivated "Focus Point" region



- 10^{-9} to 10^{-10} pb even more interesting (but significantly more challenging, experimentaly)

Signal in direct searches

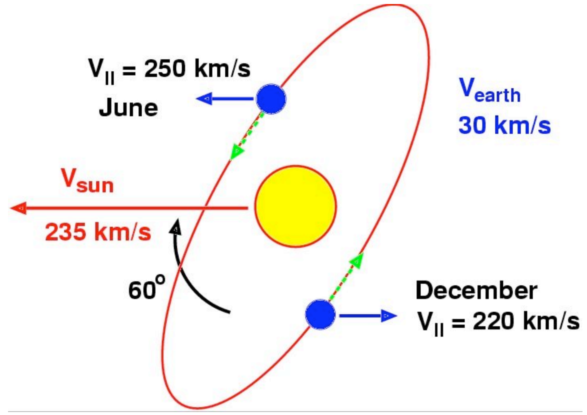
- Exponential spectrum (threshold)
- Nuclear recoil identification (wrt electron recoils):
  >100 reduction in background (caveat: neutron background)
- A^3-dependence of rate
- Examples:

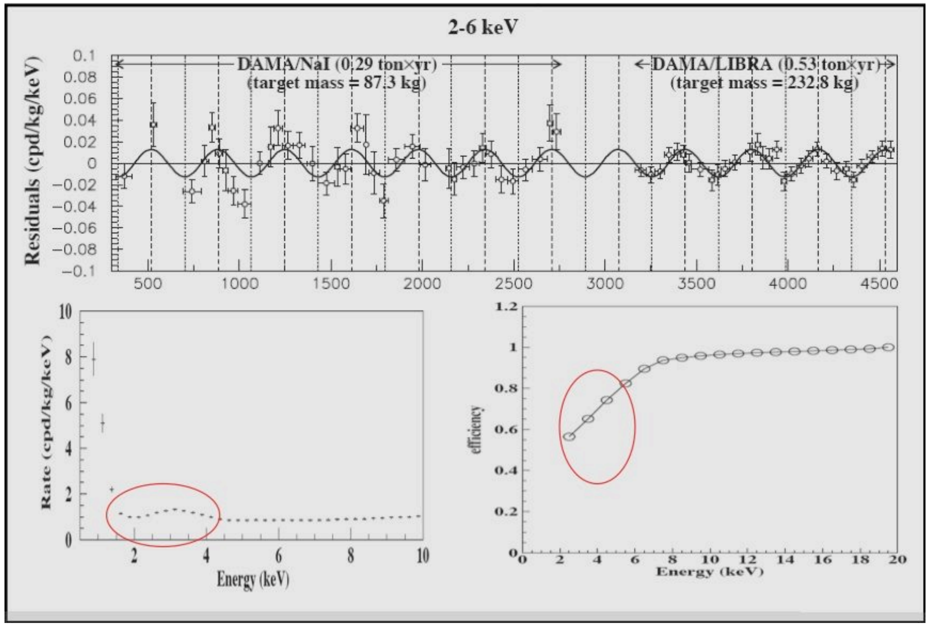


- Annual modulation?
- Directionality?

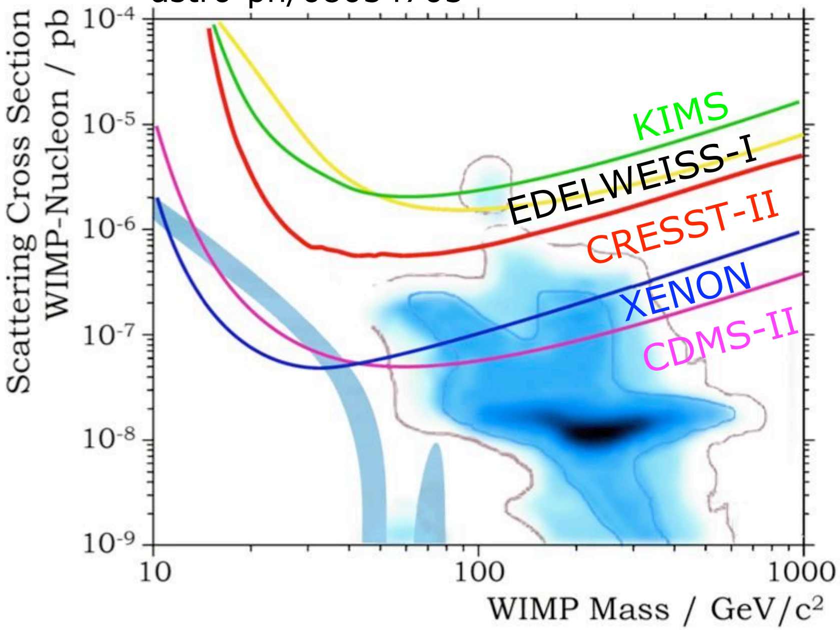
Annual modulation?

- Effect of Sun/Earth velocities addition in flux
- Claimed to be observed at low-energy in NaI (DAMA)
- Non-modulating component (~1 evt/kg/day, ~total rate in NaI) not observed in Ge (EDELWEISS, CDMS), Xenon, CsI (KIMS): opens the door to (too many?) new models
- Signal in low-efficiency, near-threshold region
- No "source off" (like all searches): observation of signal in different detectors/targets essential for credibility!





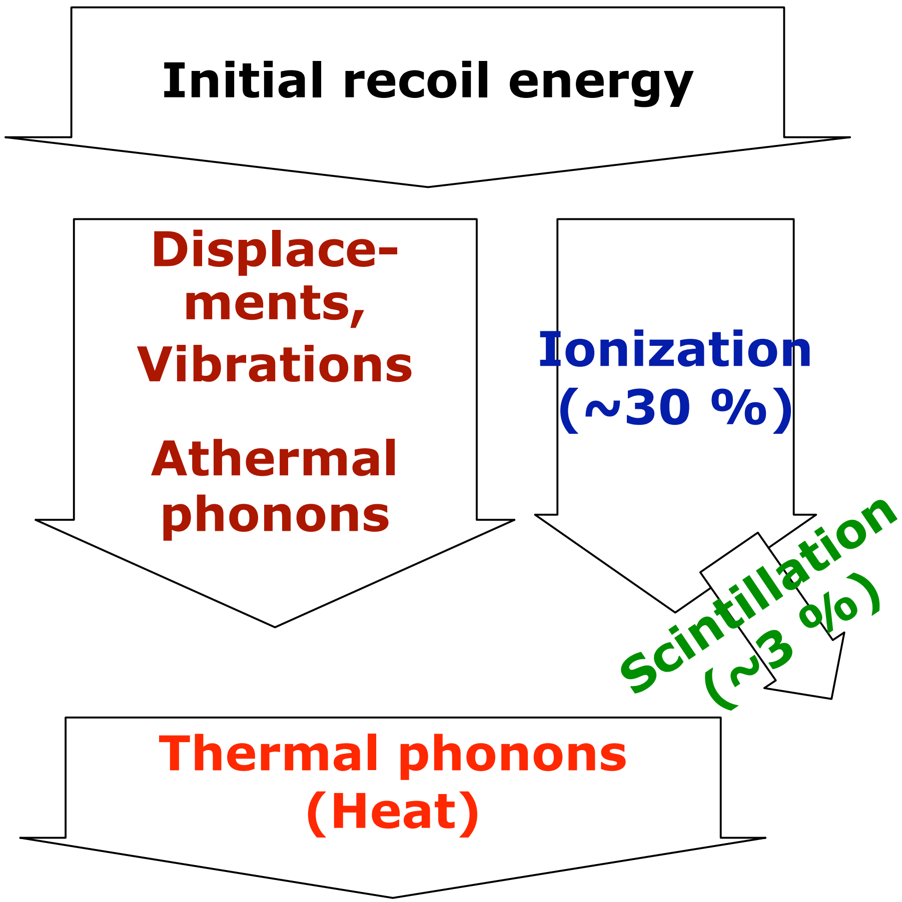
Spin-Independent Direct Searches



- Four most sensitive expts use different technologies

- CDMS: Ge Phonon+Ionisation
- Xenon-10: Xe Ionisation+Scintillation
- CRESST-II: CaWO4 Heat+Scintillation
- EDELWEISS: Ge Heat+Ionisation

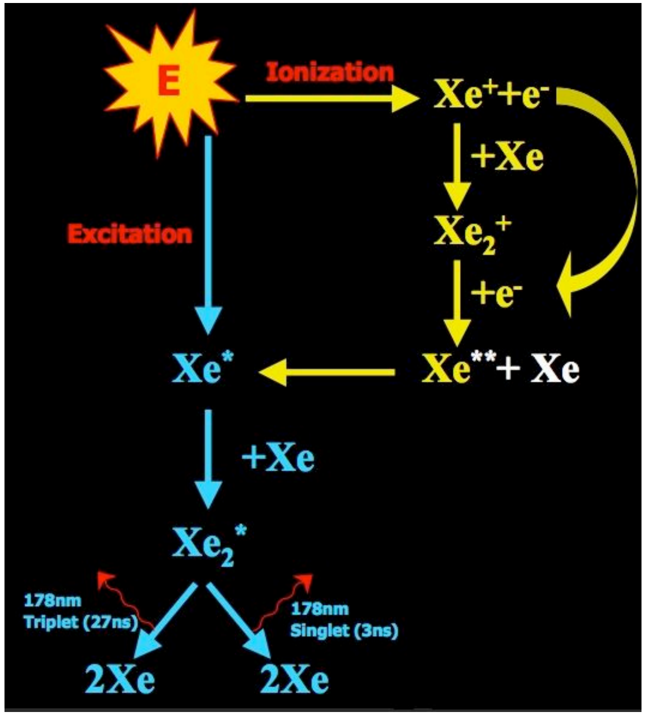
Nuclear vs electronic recoil discrimination

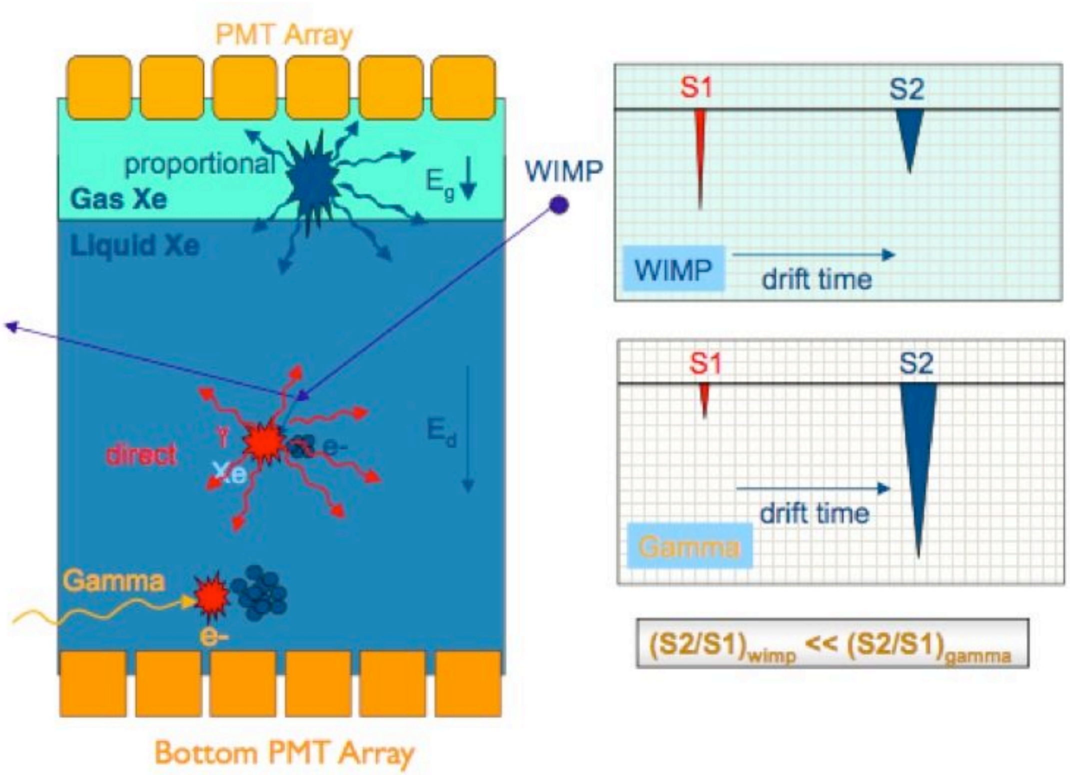


- Large difference of dE/dx of electron and ion recoils
- Nucl. recoil length: 20nm in solid
  - directionality of flux hard to measure
- Ionization/Scintillation yield depends on recoiling particle
  (ion or electron)
- Phonon (heat): most precise total energy measurement
- Simultaneous measurement to extract
  - total energy
  - ion/phonon yield

Xenon

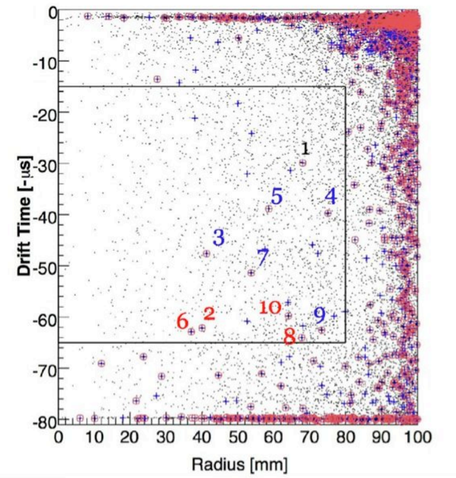
- Different scintillation (S1) and ionisation (S2) yields for nuclear and electronic recoils
- PMT array for (x,y), drift time for z : fiducial volume

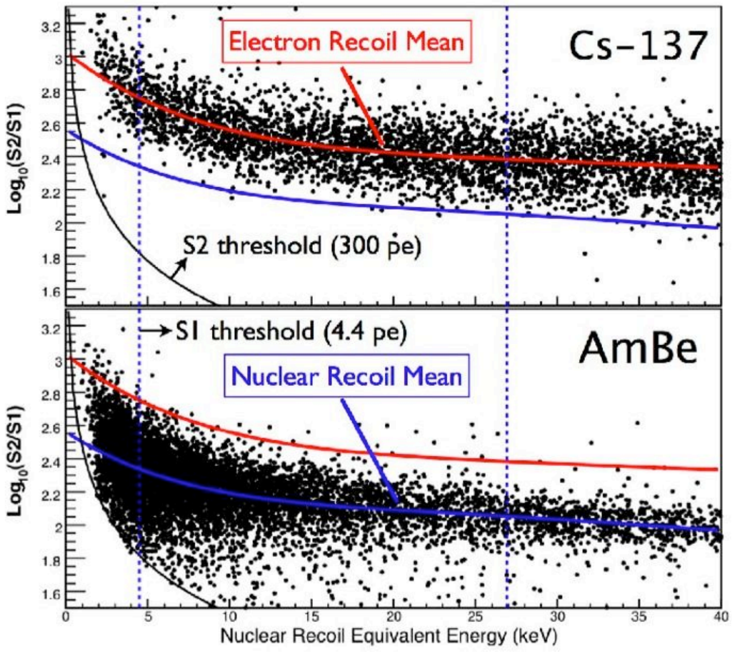


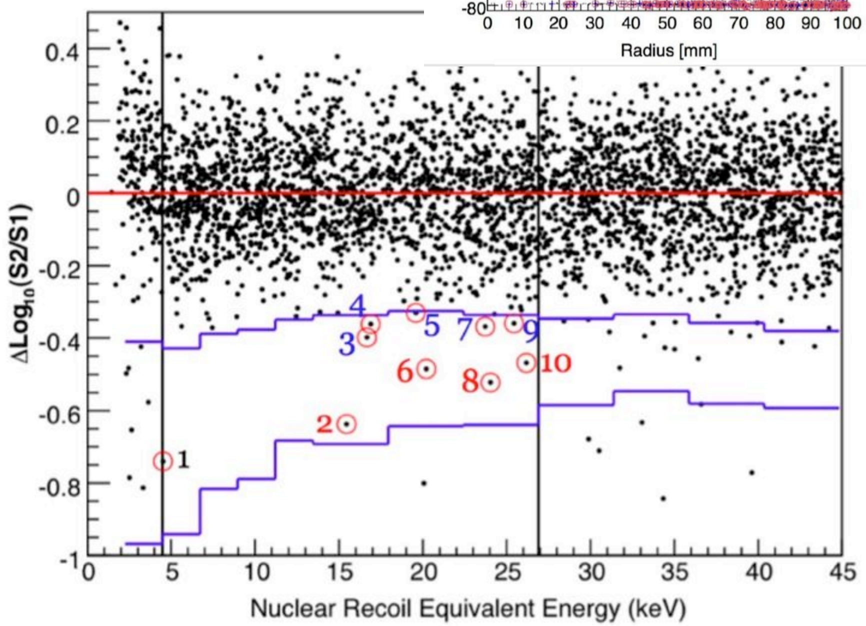


Xenon-10

- Large mass of Xe (10 kg) + purification
- Located at Gran Sasso
- 59 days x 5.4 kg fiducial
- ~ 10 evts (Compton?)





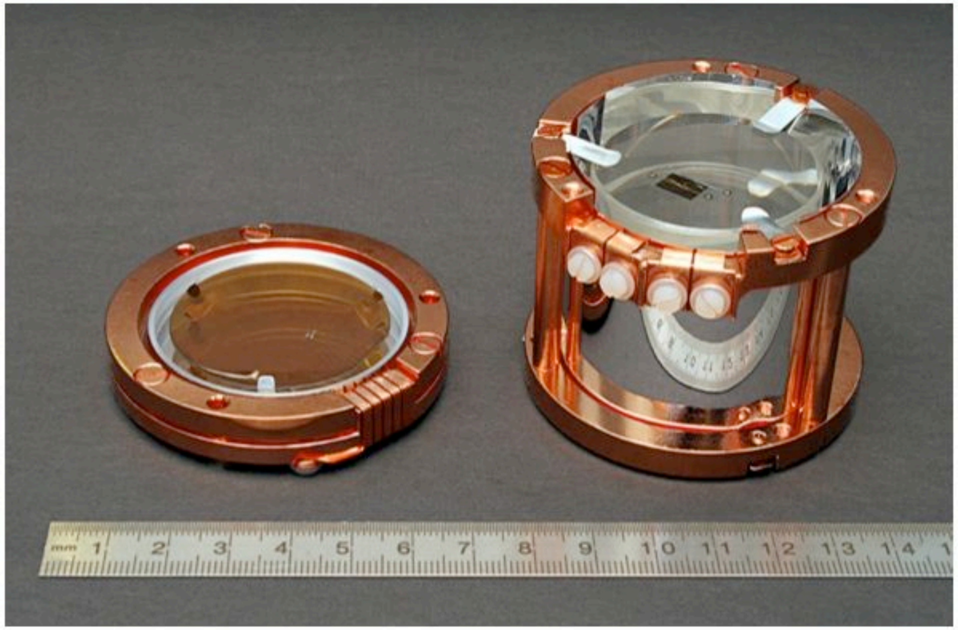


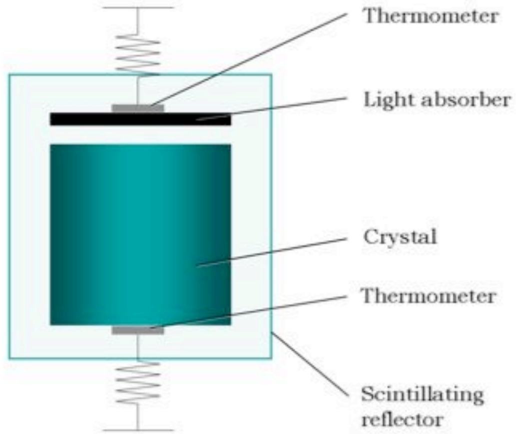
Xenon-100

- (10 →) 170 kg LXe, (5 →) ~50 kg fiducial
- (89 →) 242 low-activity PMTs, (15 →) 30 cm drift

CRESST: Scintillation vs heat

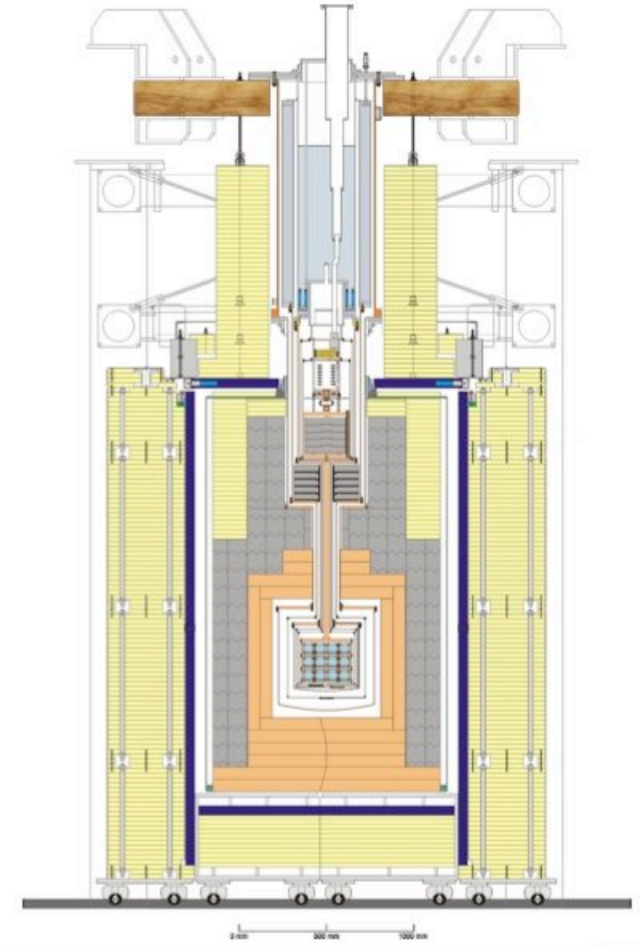
- 17 x 300 g modules installed in Gran Sasso
- W films: Superconducting Transition Edge temperature sensors + SQUID read-out
- Absorber: CaWO4 cristal (Wimps = W recoils, neutrons = O, Ca recoils)





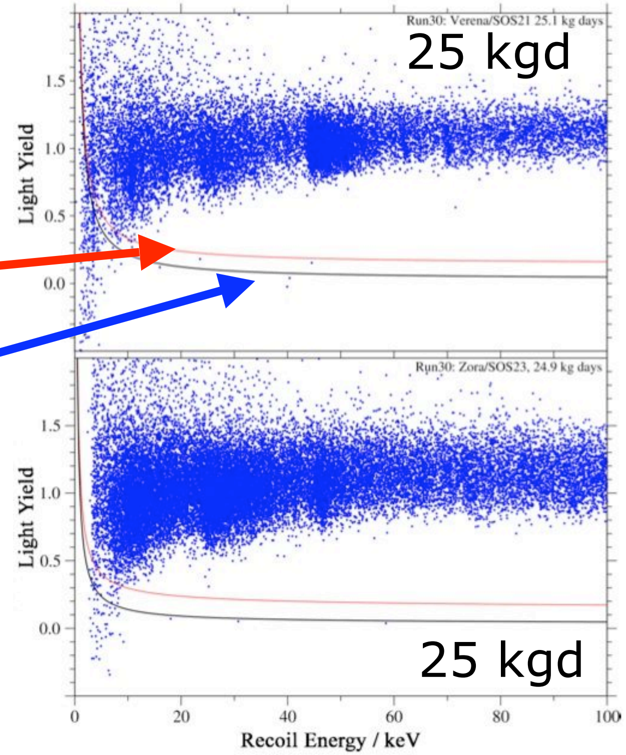
CRESST-II

- PolyEthylene+Pb+Cu shields
- Muon veto
- Commissioning runs completed



90% O recoils

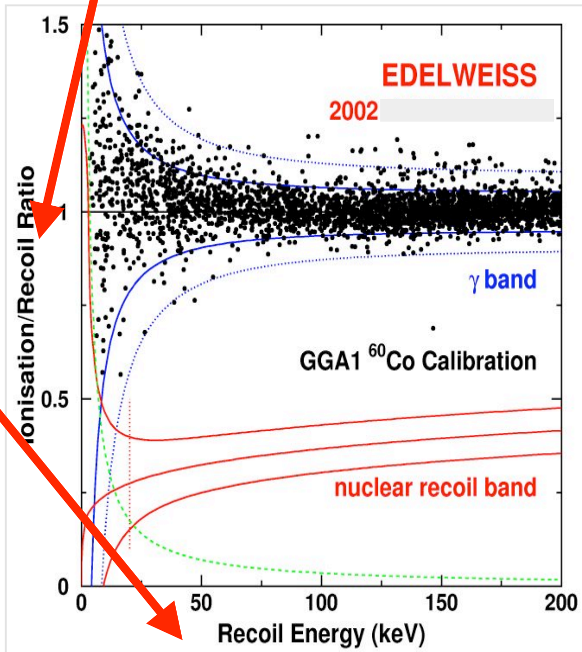
90% W recoils

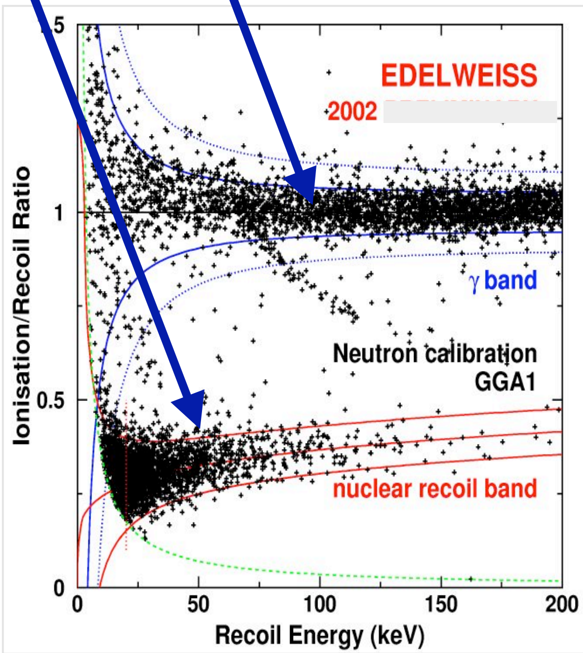


Cryogenic Germanium detectors

- Ge: Very pure material
- True calorimetric measurement of recoil energy using very-low temperature sensors

- Different ionization yields for nuclear recoils (WIMP or neutron scattering) and electronic recoils (β,γ decays)
  - discrimination of dominant background

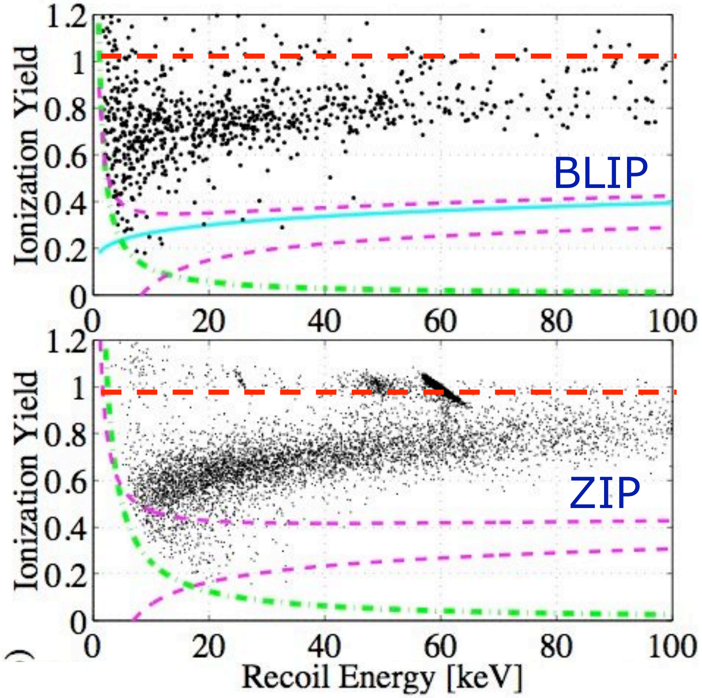




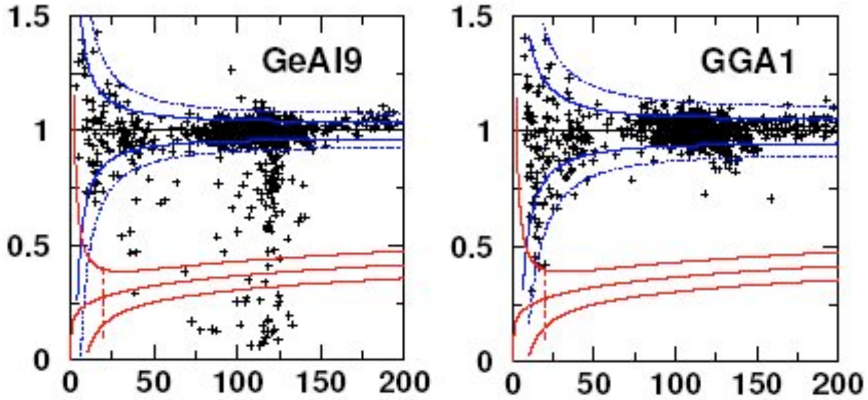
Potential limitations

- Radioactivity of environment (and surface)
- Neutron background (PE, muon veto, coincidences)
- Deficient charge collection (mostly surface β's)

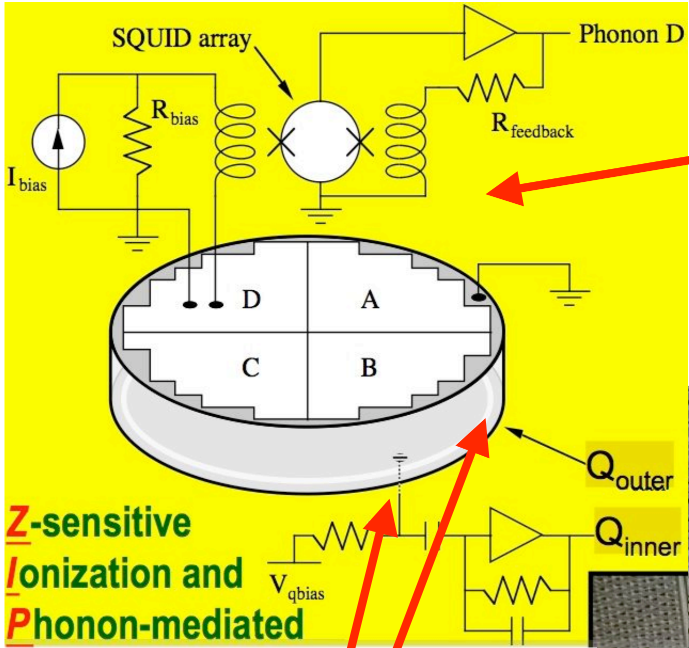
CDMS β calibration



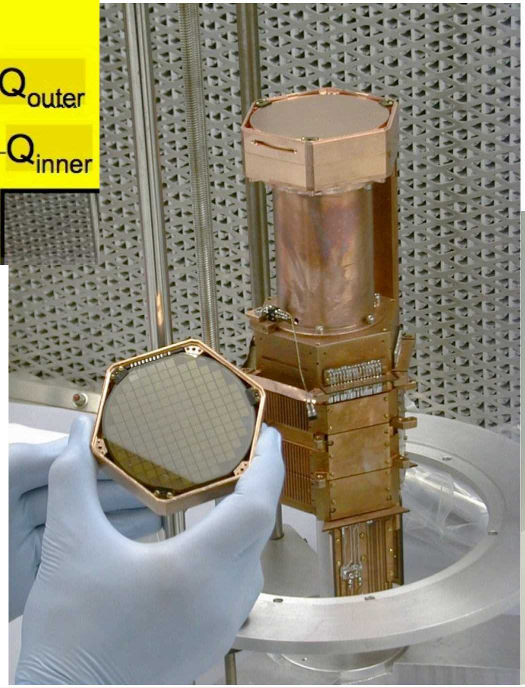
EDELWEISS γ calibration: detectors without/with Ge amorphous layer under Al electrode



CDMS Ge detectors

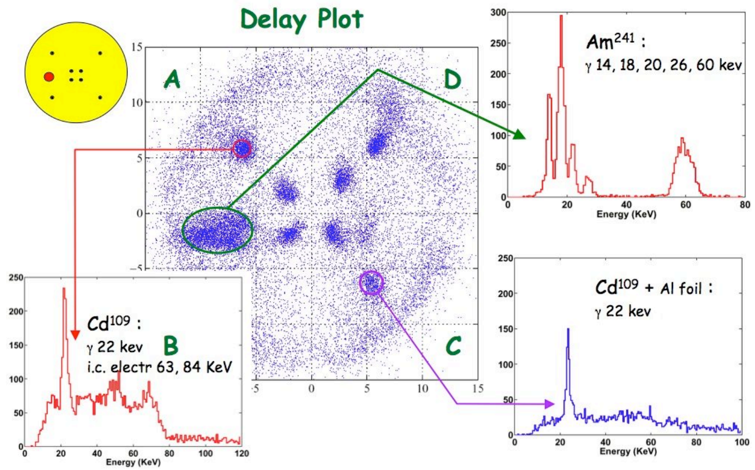


- Athermal phonon measurement with 4 quadrants of ~1000 transition-edge W sensors
  - Phonon risetime and delay wrt ionization: detects proximity from surface ("Z")
- Charge measurements: centre and guard ring

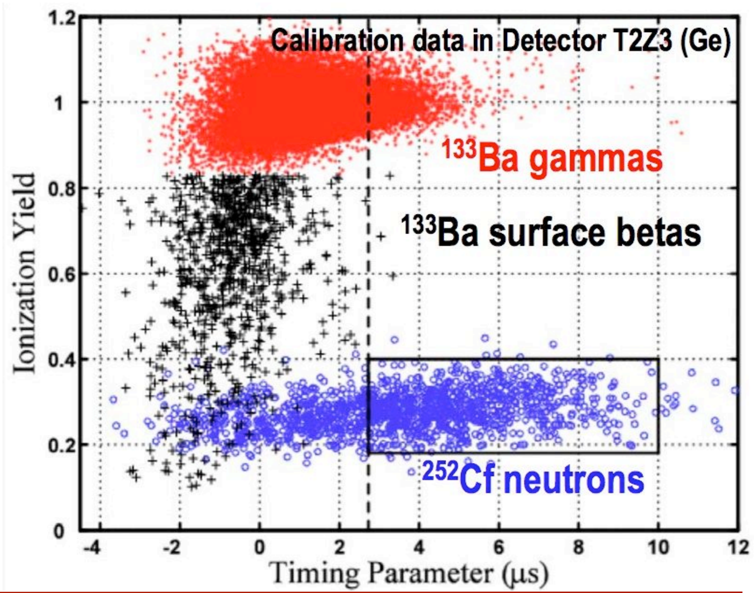


CDMS detectors

- (x,y) position-dependent signals
  - From relative quadrant timing and intensities



- Ionization yield + phonon timing: surface β rejection
  - Phonon risetime
  - Phonon delay wrt ionisation
  - Difference due to physics of different types of phonons (not directly z-position): a single film can veto both surfaces



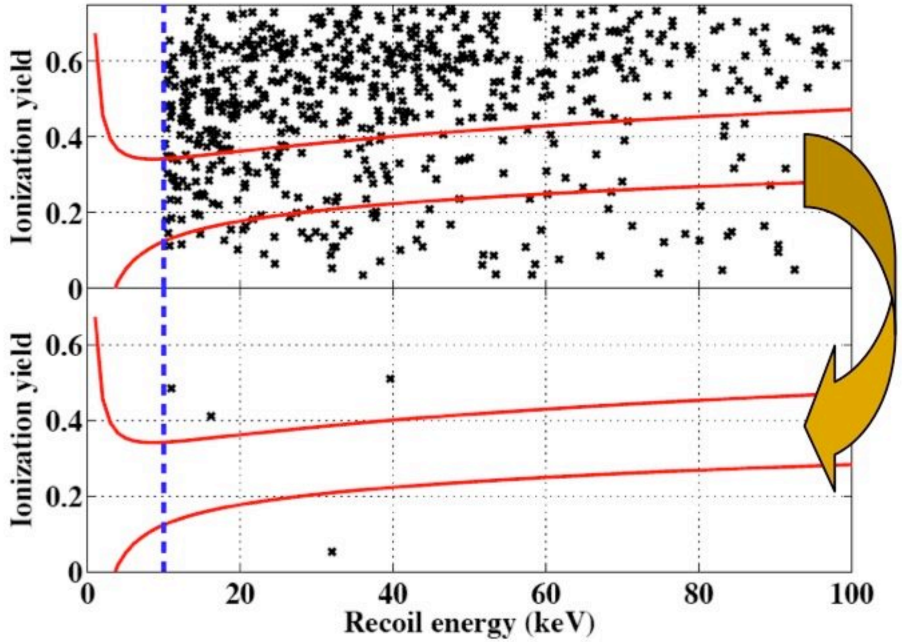
CDMS-II

- 2008: 1000 kg.d raw data with 15x250g Ge
- So far 650 kg.d analyzed
- 400 kg.d after quality cuts
- 121 kg.d after fiducial/acceptance cuts.

- 97 evts in nuclear recoil band before timing cut

- 0 evts after timing cut

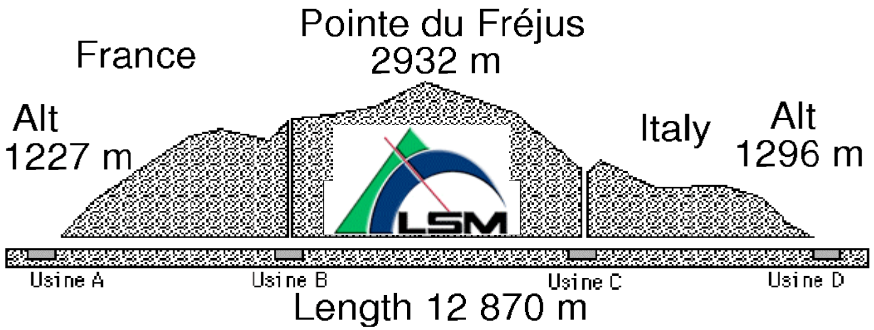
- Expected 0.6 +- 0.3

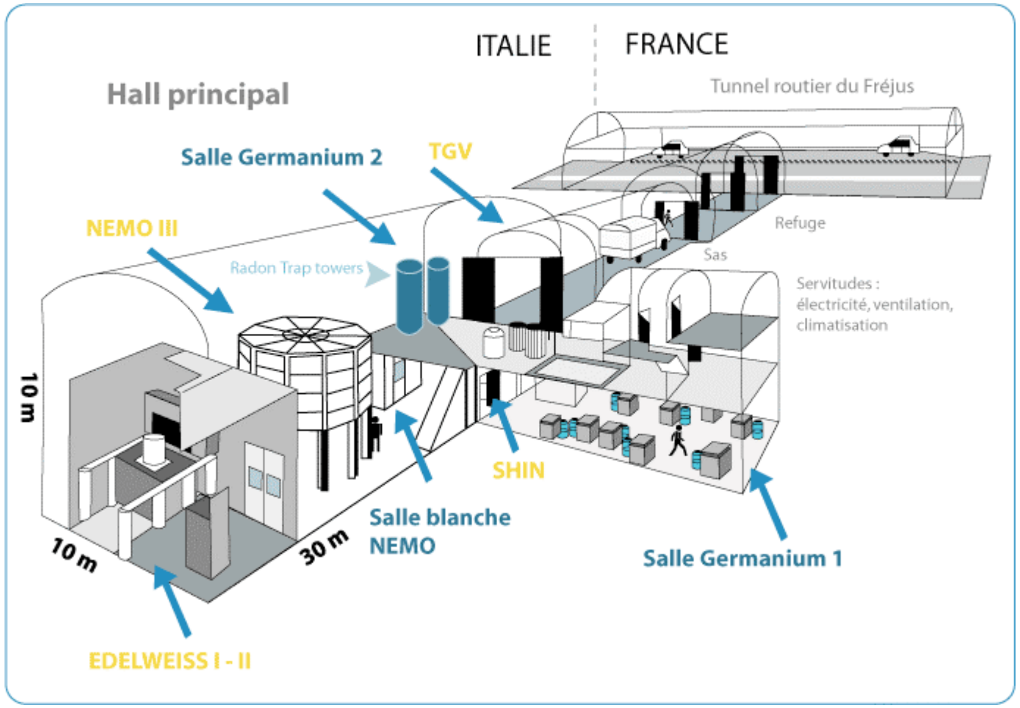


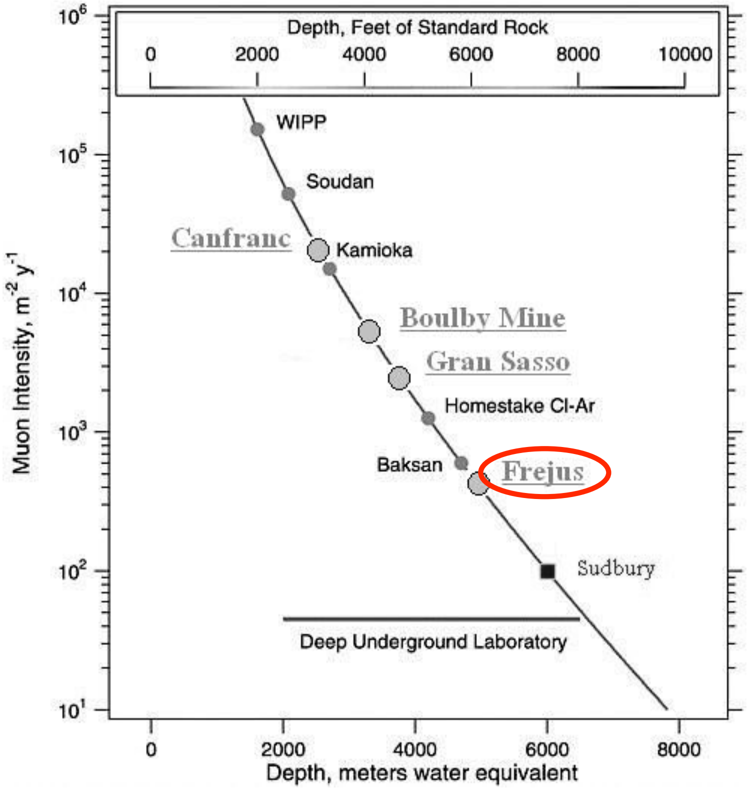
EDELWEISS-II Collaboration

- CEA Saclay
- CSNSM Orsay
- IPN Lyon
- Institut Néel Grenoble
- FZ/ Universität Karlsruhe
- JINR Dubna

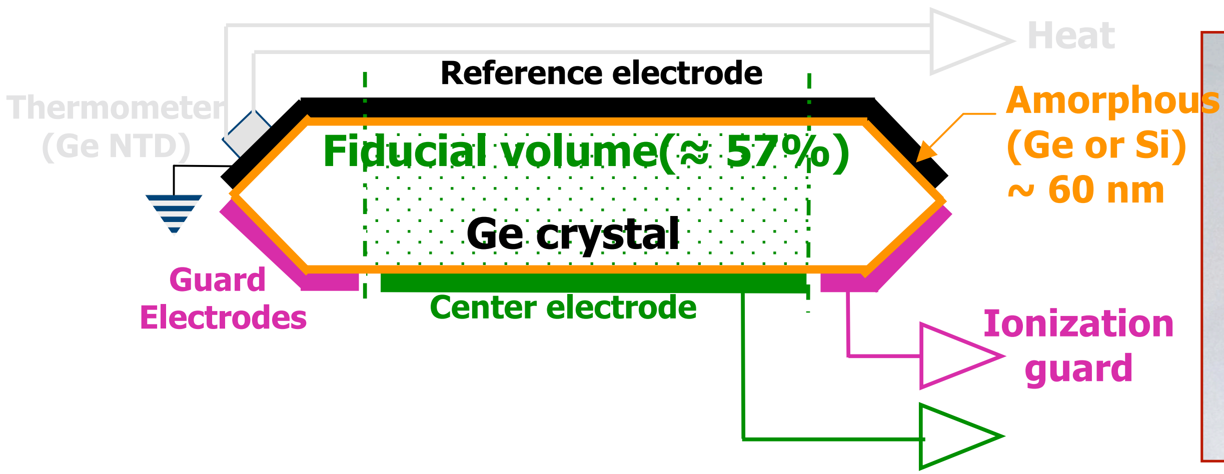
Laboratoire Souterrain de Modane

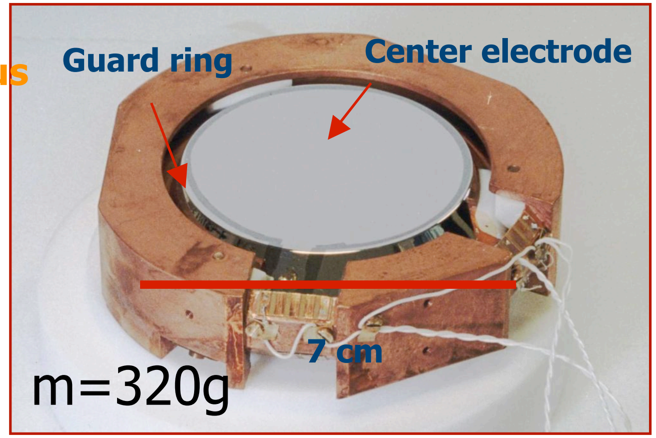






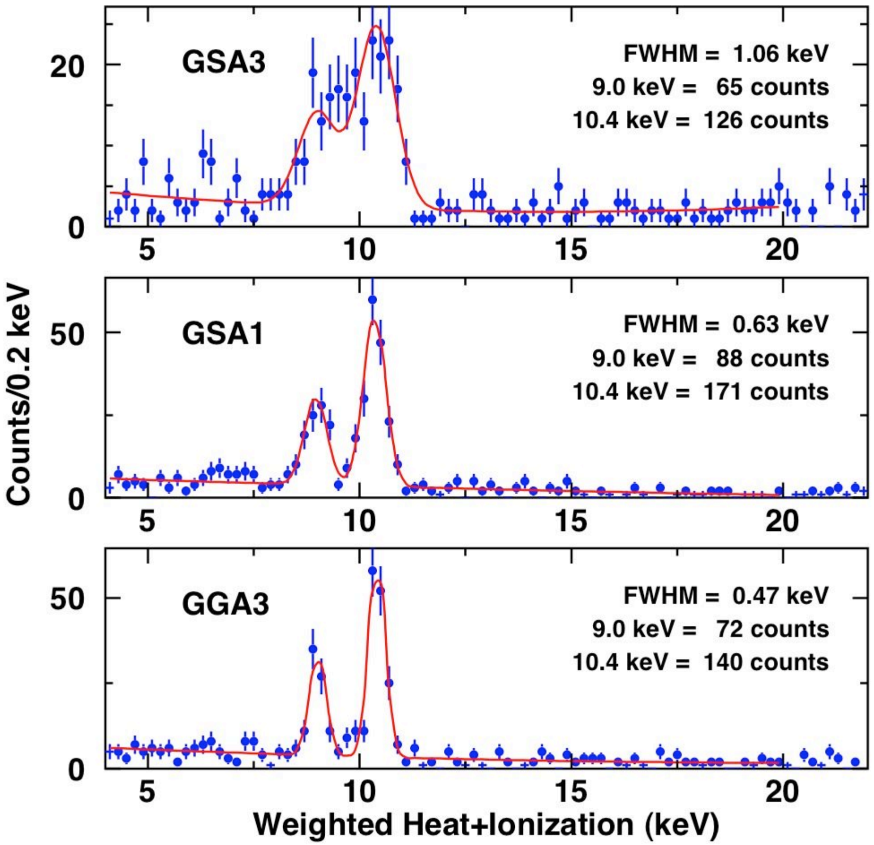
EDELWEISS-I GeNTD detectors





- Simultaneous measurement of
  - Heat @ 17 mK with Ge/NTD sensor (slow: ~10 ms risetime, full thermalisation)
  - Ionization @ few V/cm with Al electrodes
- Ion./Recoil set to 1 for electronic recoils
- Ion./Recoil = 0.3 for nuclear recoils
- Event-by-event discrimination of electron recoils (main background)

Energy resolution

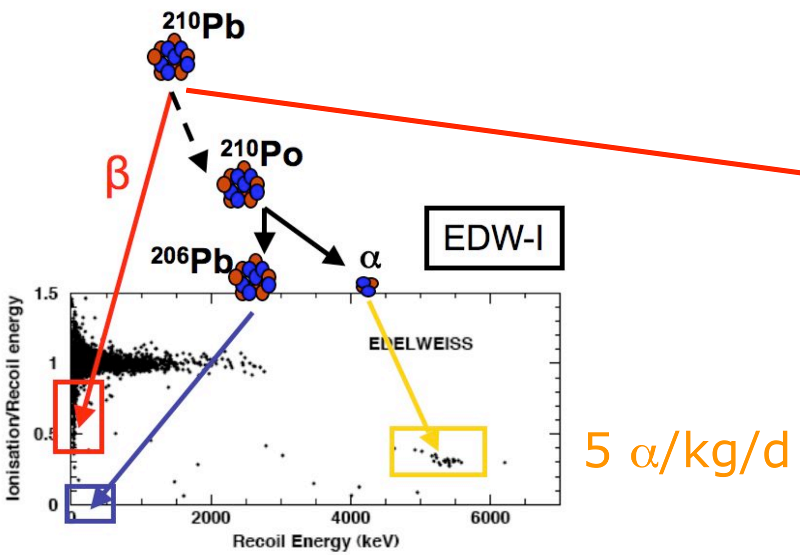


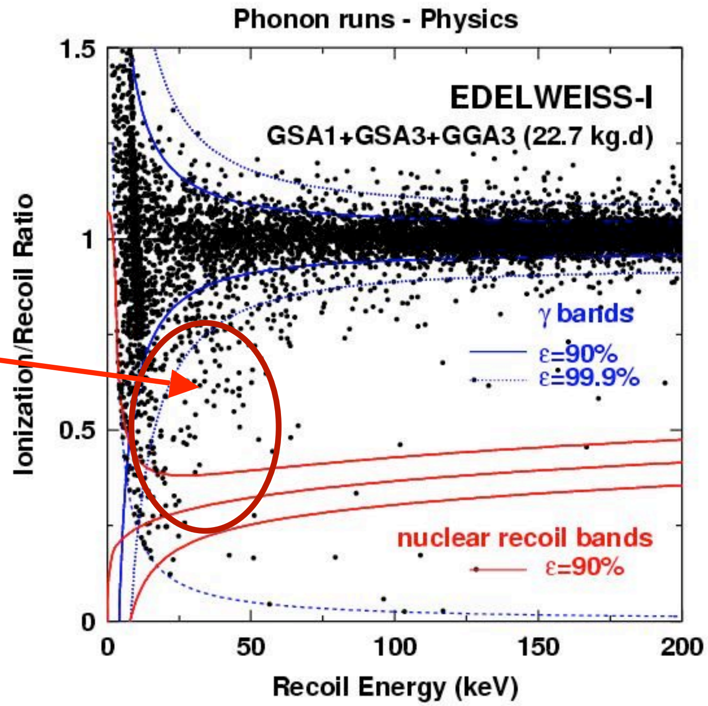
- Heat and ionisation energy resolution helps diagnostics
- Example: X-ray peaks due to cosmogenic population of ^{65}Cu and ^{68}Ge + neutron activation of ^{71}Ge, also used for low-energy calibration

EDELWEISS-I

- 62 kg.d with 3x320g detectors
- Observed 1 neutron-neutron coincidence (MC expects 2 singles)
- Tail of events with bad charge collection (limits sensitivity)

Attributed to surface contamination from β from ^{210}Pb decay (α from associated chain observed)

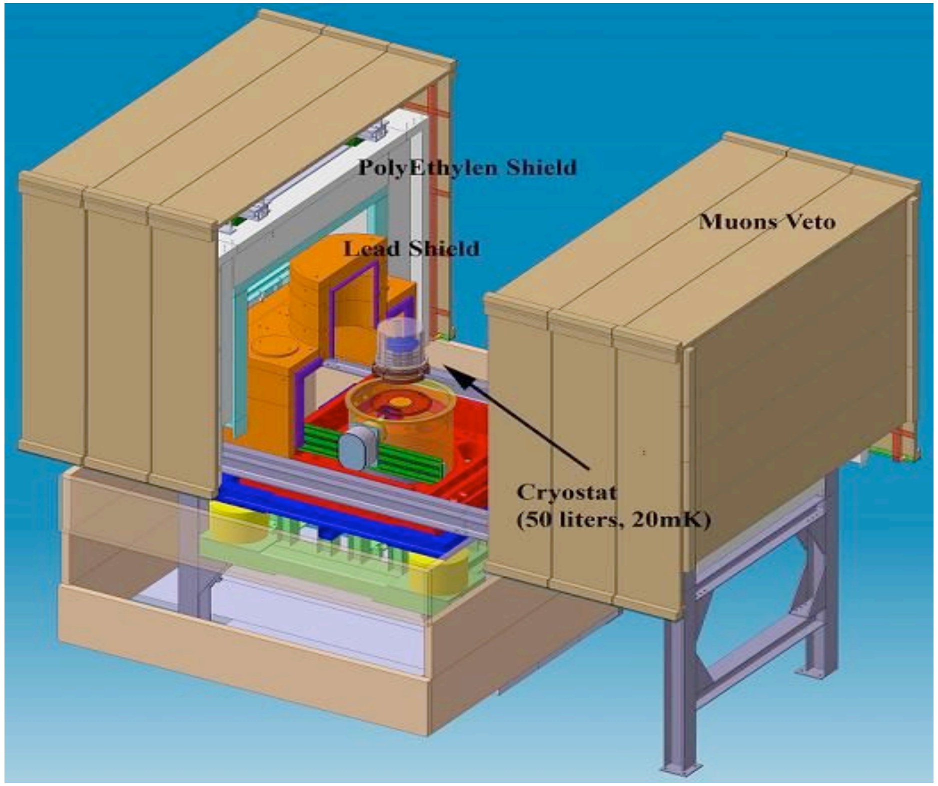




EDELWEISS-II Goals

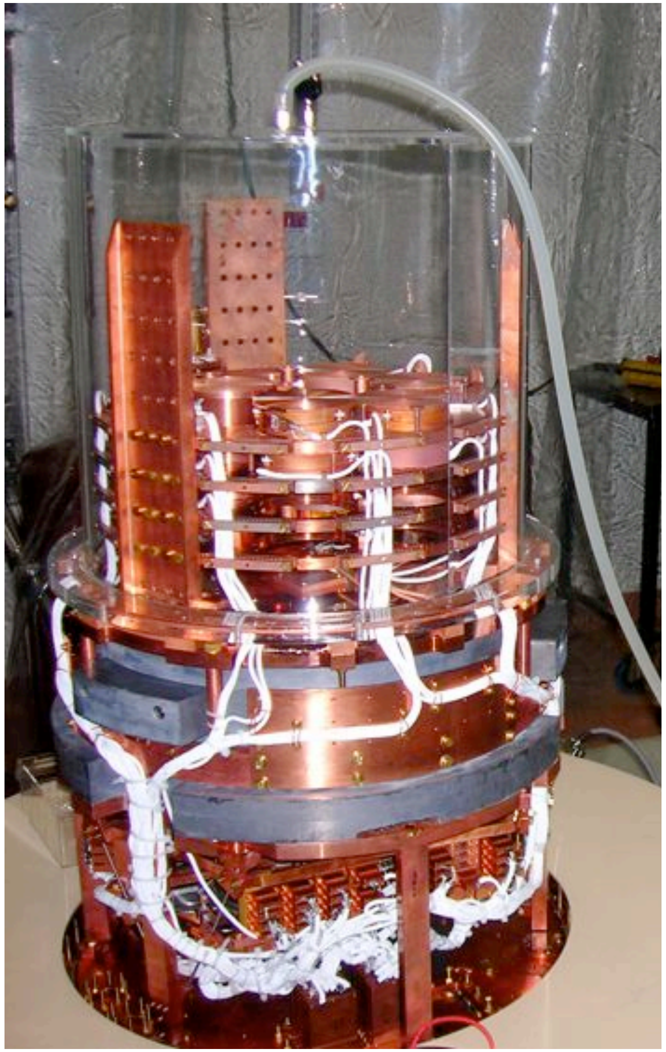
- Goal: 10^{-8}pb, <0.003 evts/kg/day
- More mass
- Better shielding agains neutrons
  - From U/Th in rock: more polyethylene, solid angle
  - From muons in Pb shield/ in rock: muon veto
- Better control of backgrounds
  - Material selection / Cleaning procedure / Environment
- Better control of surface events
  - Develop new detectors

New EDELWEISS-II setup



- Cryogenic installation (~ 20 mK)
  - Reversed geometry cryostat
  - Dilution refrigerator + pulse tube
  - Room for up to 120 detectors
- Shielding (Goal: <0.003 evt/kg/d)
  - Clean room + deradonized air (15 mB/m^3)
  - 20 cm Pb
  - 50 cm PE
  - Active μ veto (> 98% coverage)
- Remote operation (cryogenics, DAQ, calibrations, regeneration)
- 9 cool-downs since January 2006

EDELWEISS detectors

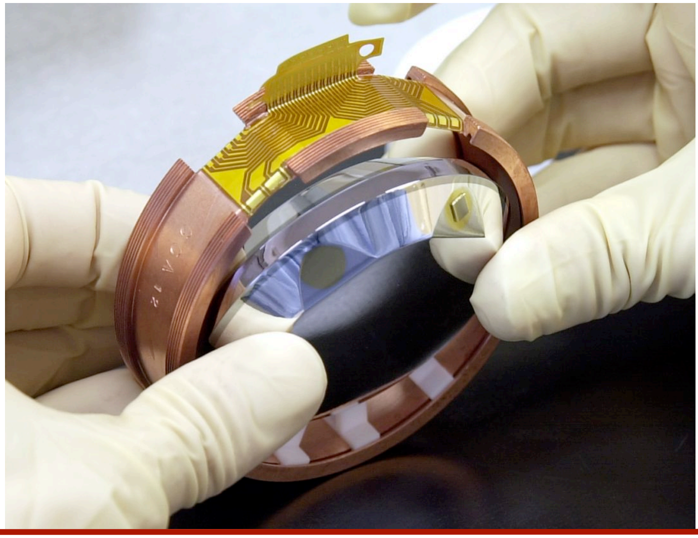


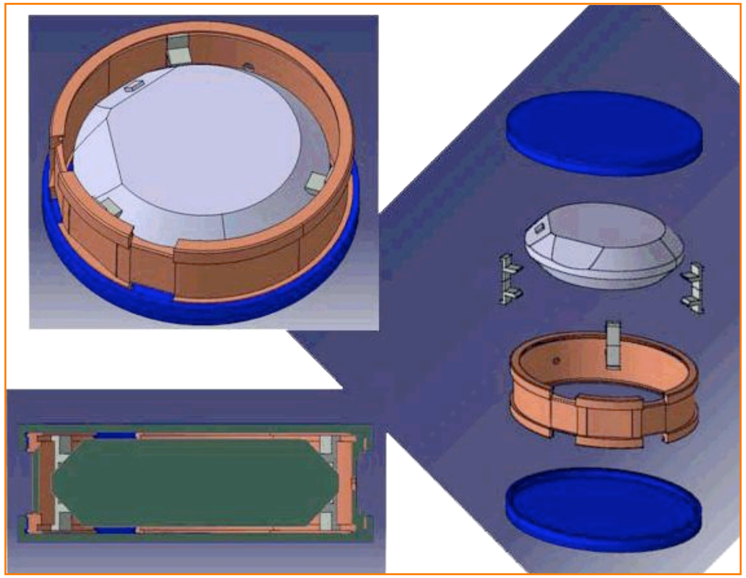
~10 kg of Ge:

- 23 “standard” Ge/NTD bolometers
- 5 “NbSi” bolometers
- 4 “Interdigit” bolometers

EDELWEISS Ge-NTD detectors

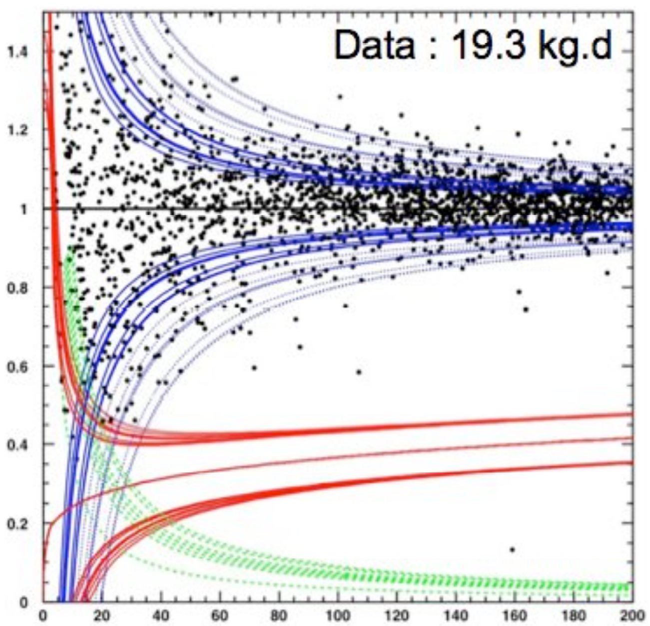
- 23 x 320 g Ge, 17 mK (3 detectors only in EDELWEISS-I)
- Simple design, uniform heat and ionisation response:
  - *Thermal* measurement (Ge-NTD heat sensor)
  - Bevelled guard ring (uniform field)
- Amorphous Ge or Si sublayer
- Radiopurity: Cu+Teflon holder

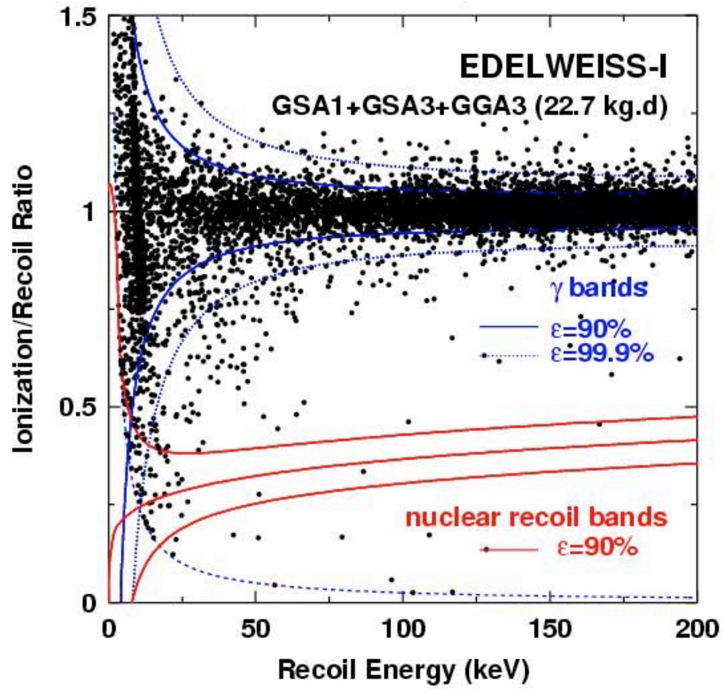




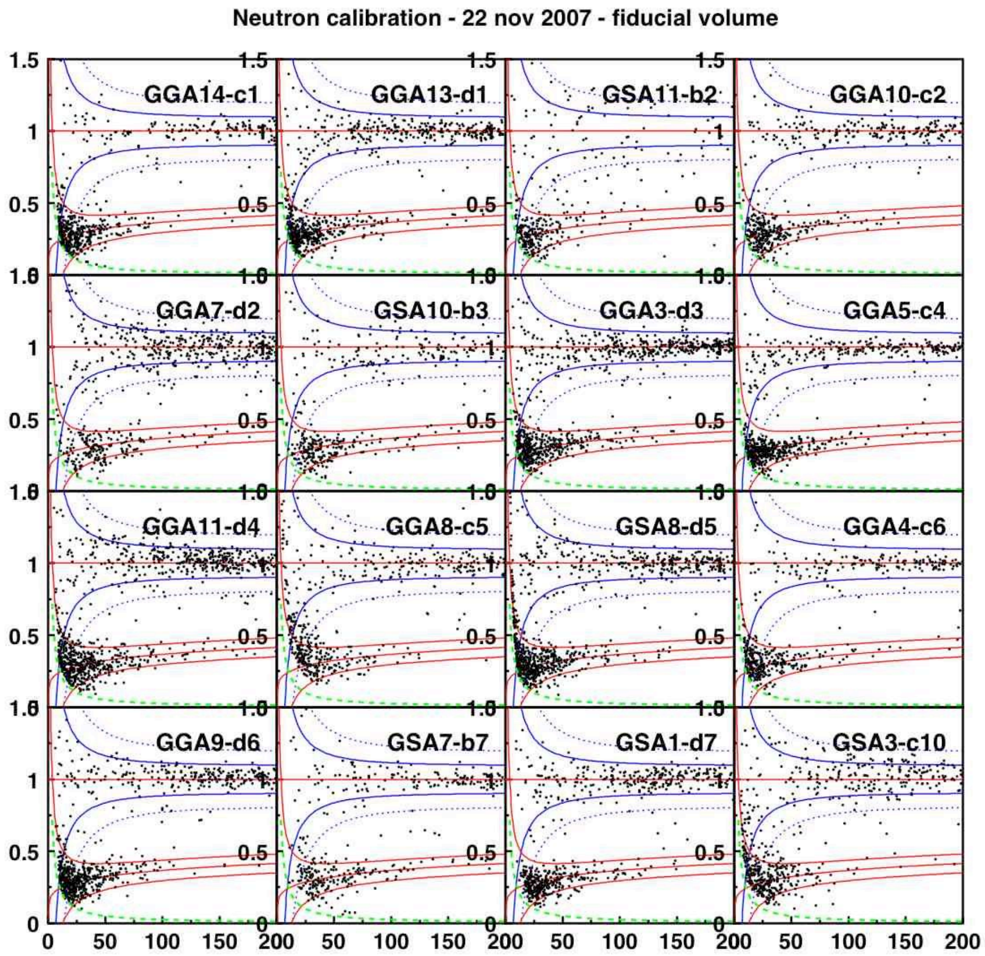
Results from standard GeNTD detectors

- Commissioning background run (spring 2007) ~ 19 kg.d
- 8 lowest threshold detectors selected
- Reduction of factor 3 of α and β backgrounds



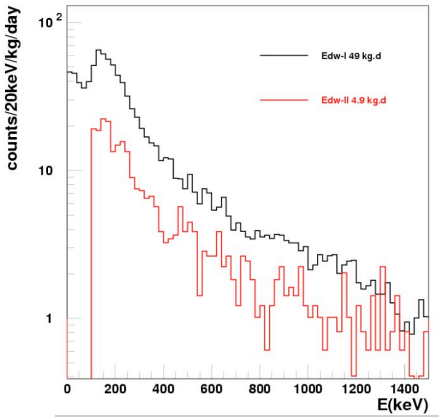


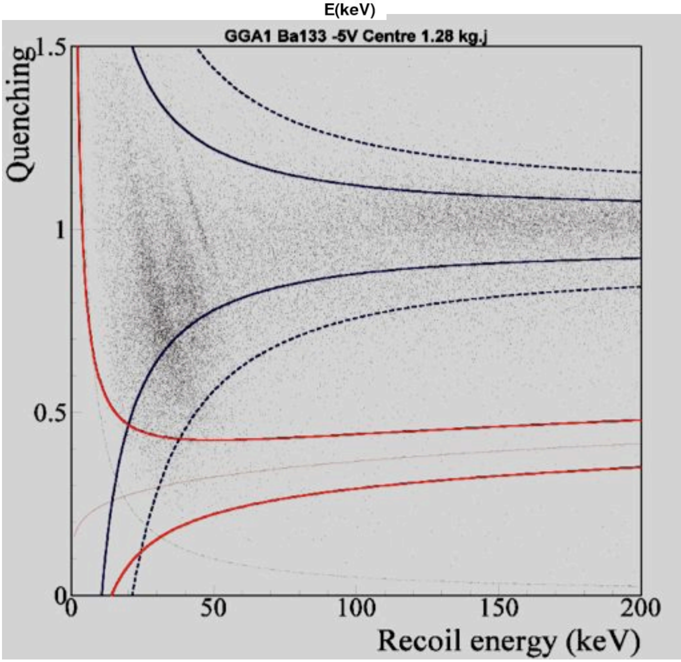
Operation of large number of detectors



- Start of physics run: november 2007
- More than 15 operational GeNTD detectors
- Choose a 30 keV threshold (see α bkg, expect β bkg)

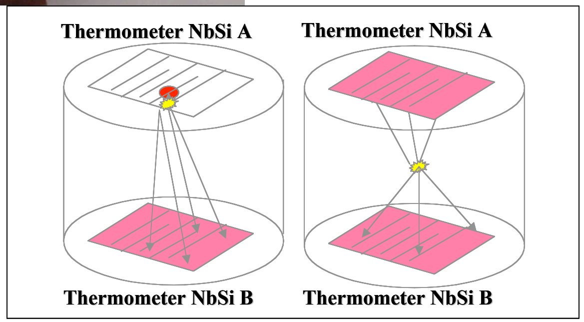
Results from standard GeNTD detectors

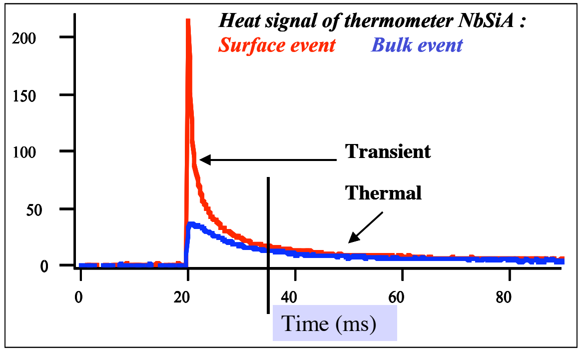




- Significant reduction of the γ background
- Calibration with β source (^{210}Pb) to study the detector's response to surface events
- ~ 100 kg.d of fiducial exposure accumulated after quality cuts (analysis underway)

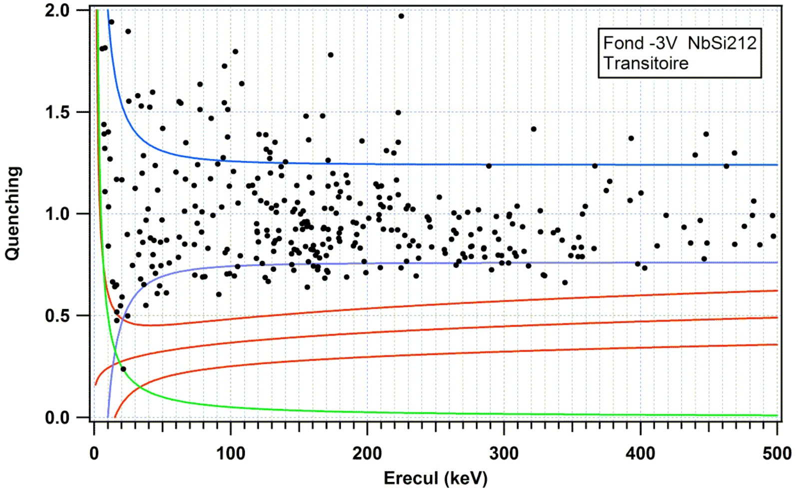
EDELWEISS NbSi detectors

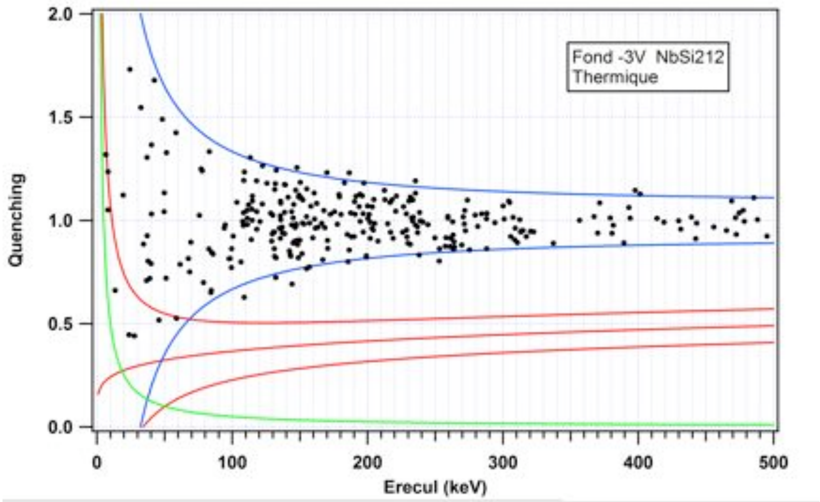




- Developed @ CSNSM since 2003
- Identification of surface events using athermal phonon measurement with NbSi thin film thermometers
- Two components: thermal + athermal
  - In surface events, extra athermal in corresponding film
  - Thermal signals = total energy
- Discrimination parameter = asymmetry of the top/bottom athermal components

EDELWEISS NbSi detectors

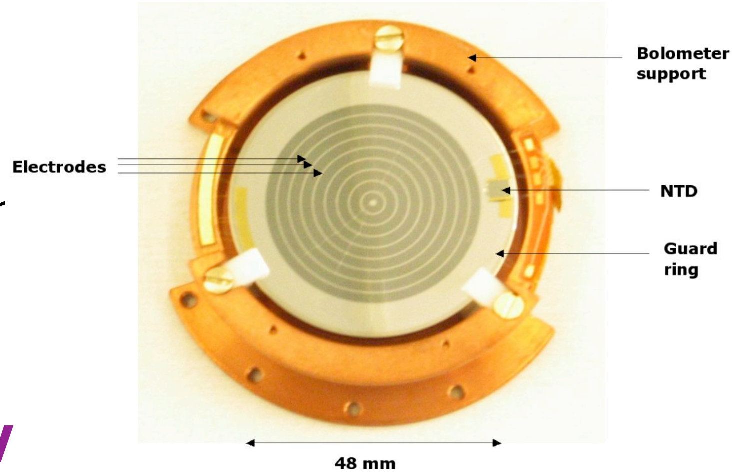


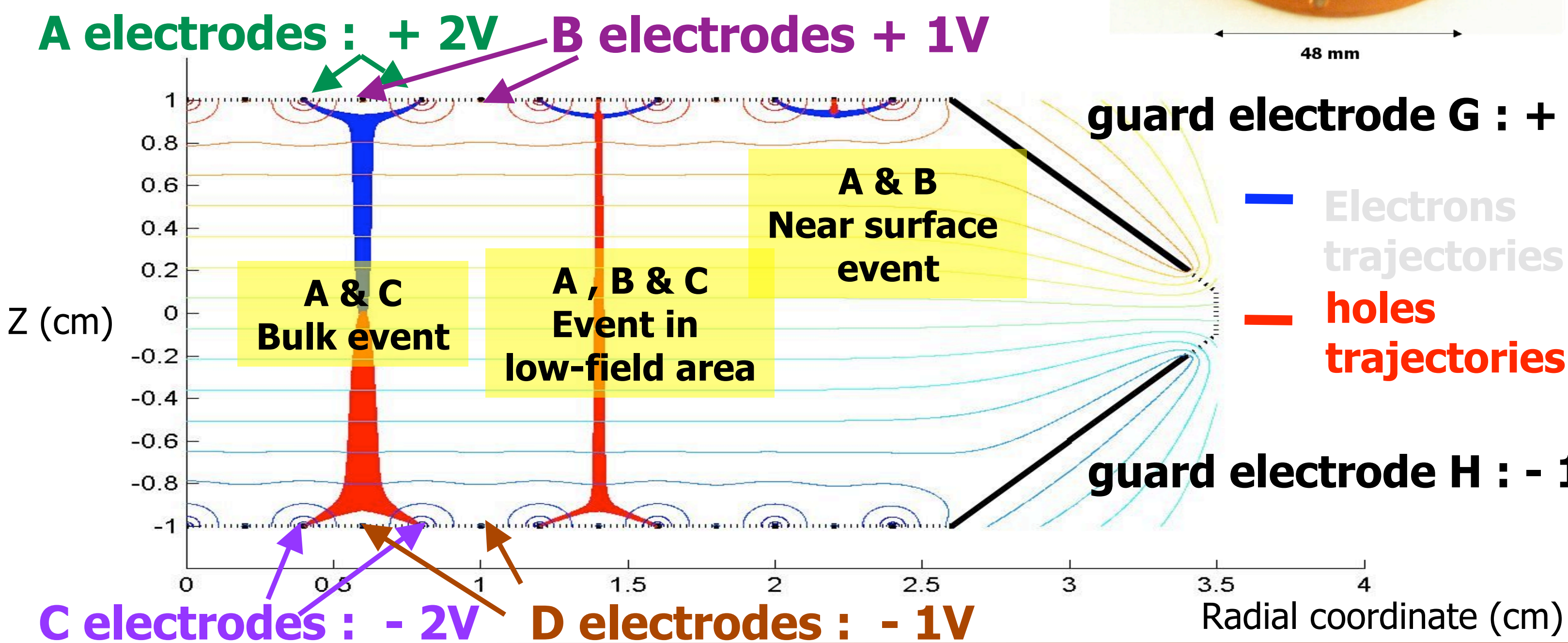


- Surface rejection ok
- Some problems in 2007 with film reproductibility, contacts, leakage currents
- Resolutions hasn't reached Ge/NTD performances

EDELWEISS: InterDigit Detectors

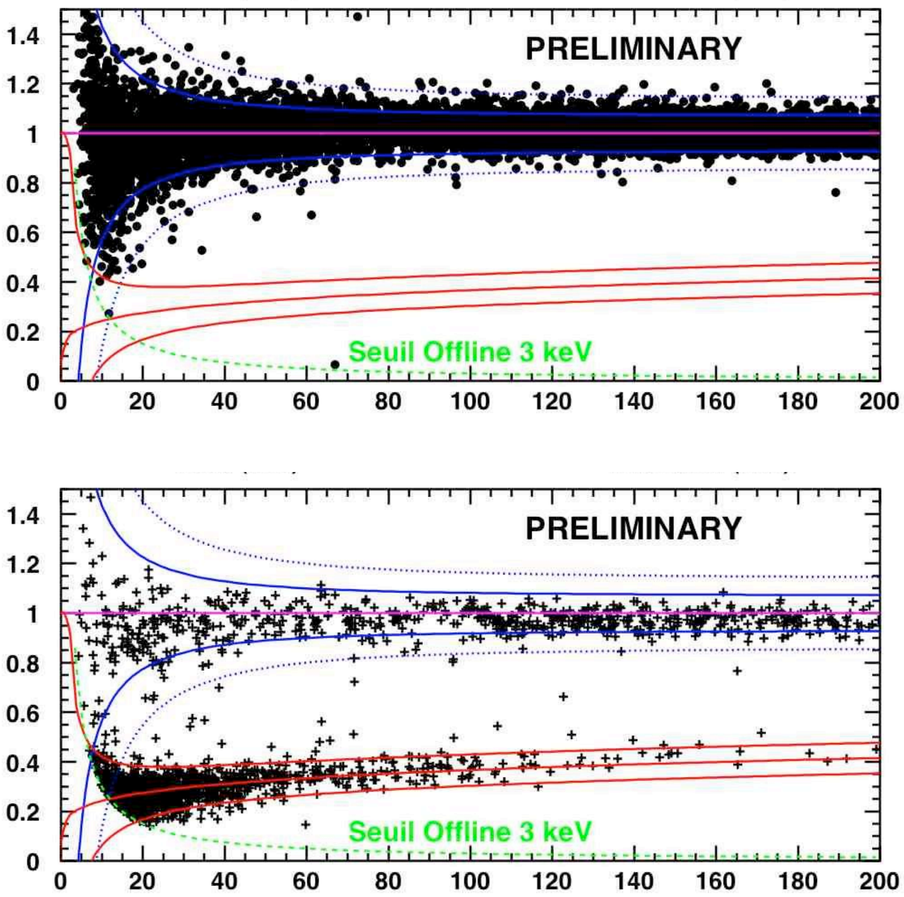
- GeNTD heat sensor
- E-field modified near surface with interleaved electrodes
- B + D signals = vetos against surface ever
- Preliminary sea-level measurements:
  Surface event rejection > 95 %,
  Fiducial volume ~ 50 %





Results from Ge/Interdigit detector

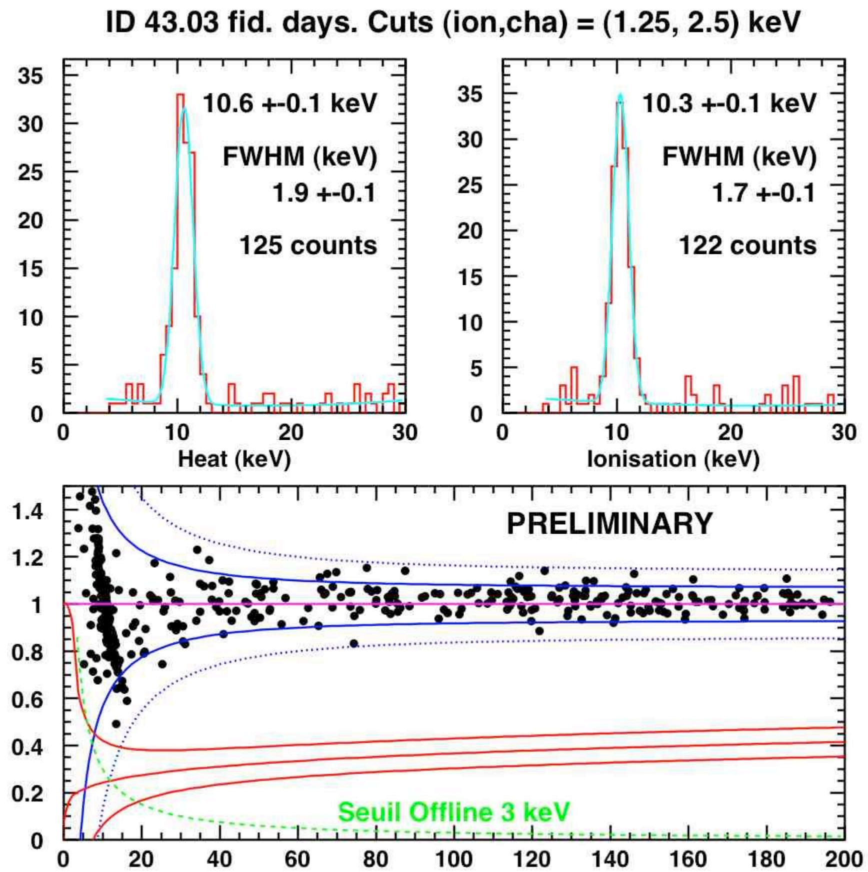
γ calibration



Neutron calibration

- 200g prototype test at Modane
- Good resolution
- 100 g fiducial volume
- Low threshold (<20 keV) possible again

Results from Ge/Interdigit detector



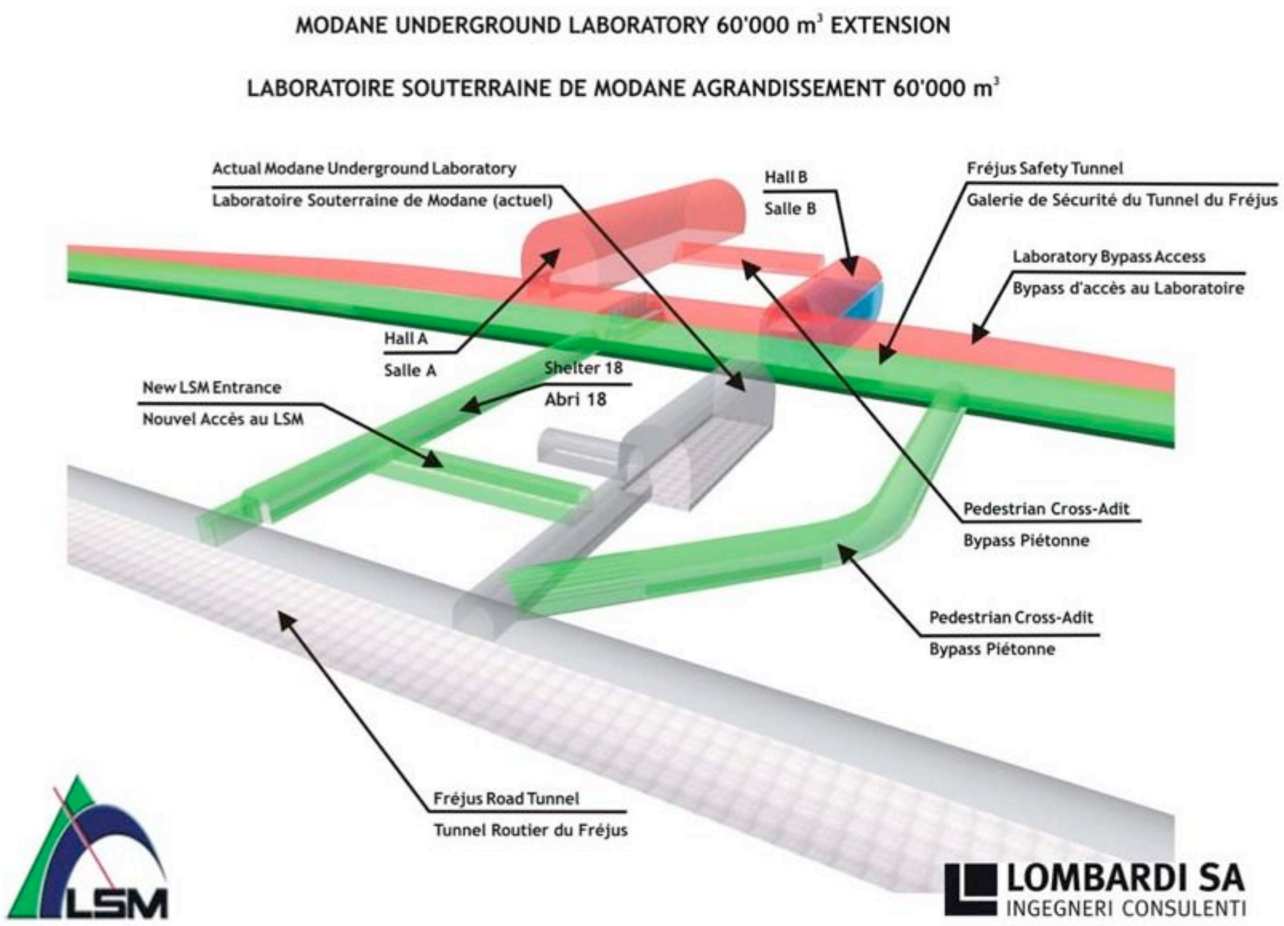
- ~4 kg.d low-background physics data
- No nuclear recoils down to <20 keV
- Currently
  - 3 new 400g detectors
  - Precise measurement of β rejection
- Very promising!

Future: EURECA

- EURECA: beyond 10^{-9} pb
- Major effort in background control and detector development
- Joint effort from teams from EDELWEISS, CRESST, ROSEBUD, CERN, +others…
- >>100 kg cryogenic experiment, multi-target
- Part of ILIAS/ASPERA European Roadmap

EURECA preferred site: ULISSE

- 60 000 m^2 extension of present LSM
- Linked to safety tunnel construction for Frejus
- To be dig in 2011-2012



EDELWEISS Conclusions

- "standard" Ge/NTD detectors
  - Show a significant reduction of α, β and γ background
  - 100 kg.d available for analysis
- Ge/NbSi detectors
  - Surface rejection ok but not resolution: pause
- Ge/Interdigit detectors
  - December 2008 : 9 additional detectors
  - July 2009 : 120 kg.d fid. exposure with thresh. <20 keV
  - Up to 35x320g Ge crystal available for reconfiguration as Ge/Interdigit -> largest Ge mass; 10^{-9} pb range?
- EURECA: federation of efforts
- ULISSE: great opportunity

Conclusions for SI searches

- XENON is serious competition
  - Will 100 kg detector design succeed in reducing bkg?
- CDMS is still leading
  - More kg.d coming, aiming $2x10^{-8}$pb with current 5 kg Ge at SOUDAN
  - No bkg so far (plan to adjust cuts to reduce it)
  - Sophisticated detector: price?
- CRESST
  - Should start accumulate kgd
- EDELWEISS
  - ID technology should bring it back in the competition
  - 15 kg Ge on hand, to be instrumented ID