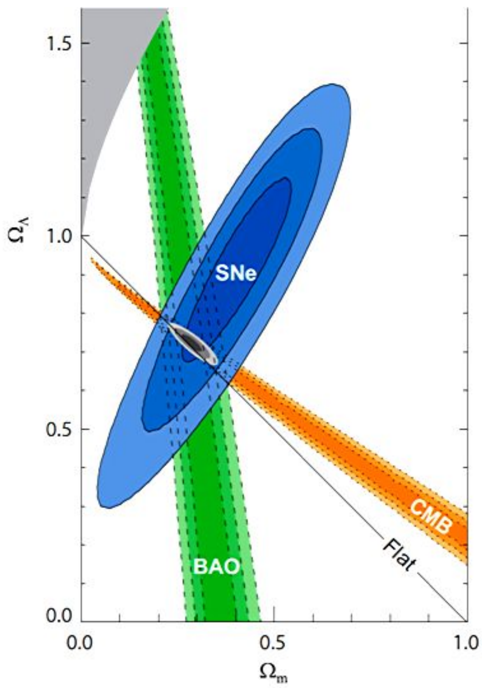
EDELWEISS-II
Recent results on search for WIMPs

Gilles Gerbier- CEA Saclay/IRFU
Andes 1st workshop
Buenos Aires 11-14 april 20011

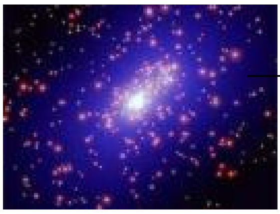
Expérience pour DEtecter Les Wimps En SIte Souterrainn

Which dark matter for ΛCDM ?



- New field(s) of « gravitationnal » nature = modified gravity (MOND etc)
  - justified by obs. galactic dynamics + Λ + …
  - no convincing theory yet
- New « particle-like » field(s), many possibilities among which:
- « SuperWIMPs » eg. gravitino, axino (SUSY)
- Supermassive relics (M_{Pl})
- Axions : Peccei-Quinn axions (QCD) or ALPs
- The « WIMP miracle » : *thermal relic hypothesis* :
  Ω_{DM}~ 0.3 ⇒ $<\sigma_{ann}v>$ ~ 3×10^{-26} cm^3/s weak interactions, M~100 GeV (Weakly Interacting Massive Particles)
  - neutralino [SUSY models]
  - LKP [UED models]
  - …

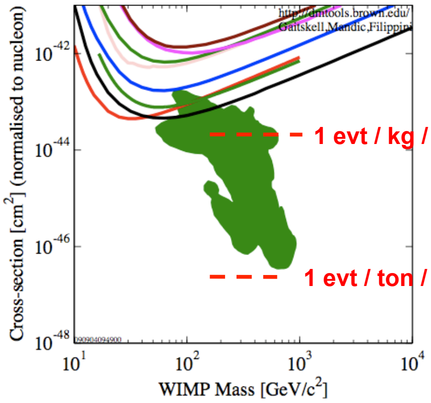
Principle of WIMP direct detection



Galactic WIMP → Interaction in a terrestrial detector

velocity v ~ 200 km/s
local density ρ_0

WIMP
θ_r
Energy deposition
Nuclear recoil E_r



- Relevant parameters:
- **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

- Non-relativistic diffusion:

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

- Interaction rate:

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

Principle of WIMP direct detection

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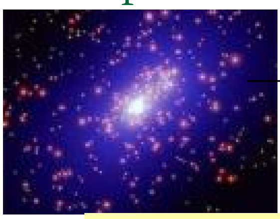
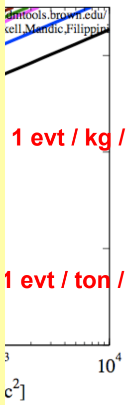




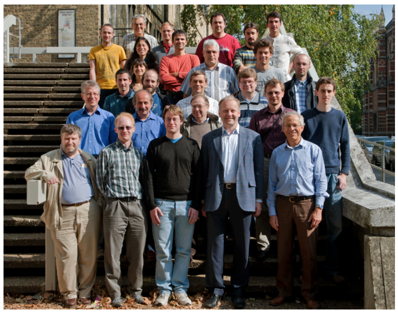
- **Low-threshold detectors**
- **Ultra-low-background detectors :**

- « Passive » bckgd reduction (shields, radiopurity, external vetos..)
- « Active » bckgd reduction (discrimination of electron recoils, multiple scatters..)

- **We consider only the « spin-independent » channel here → single WIMP-nucleon cross-section ∀ target**

The EDELWEISS collaboration

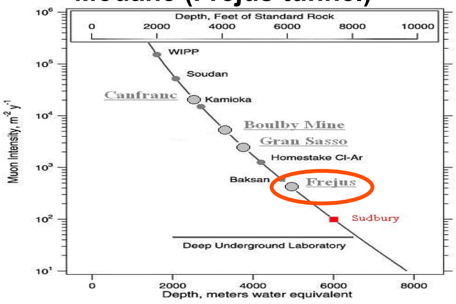
Karlsruhe - oct 09



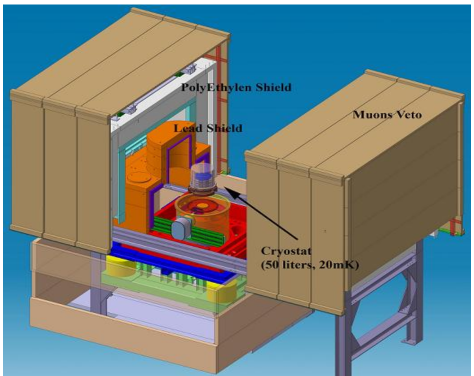
Oxford - sep 10

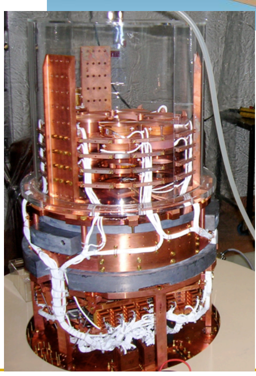
- CEA Saclay (IRFU and IRAMIS)
- CSNSM Orsay (CNRS/IN2P3 + Univ. Paris Sud)
- IPNLyon (CNRS/IN2P3 + Univ. Lyon 1)
- Institut Néel Grenoble (CNRS/INP)
- Karlsruhe Institute of Technology
- JINR Dubna
- Oxford University (joined in 2009)
- Sheffield University (joined in 2010)

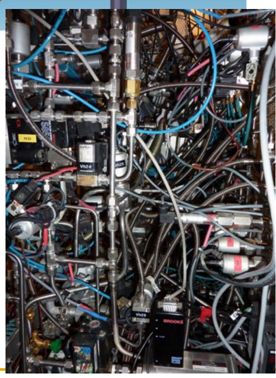
Laboratoire Souterrain de Modane (Fréjus tunnel)



The EDELWEISS-II infrastructure



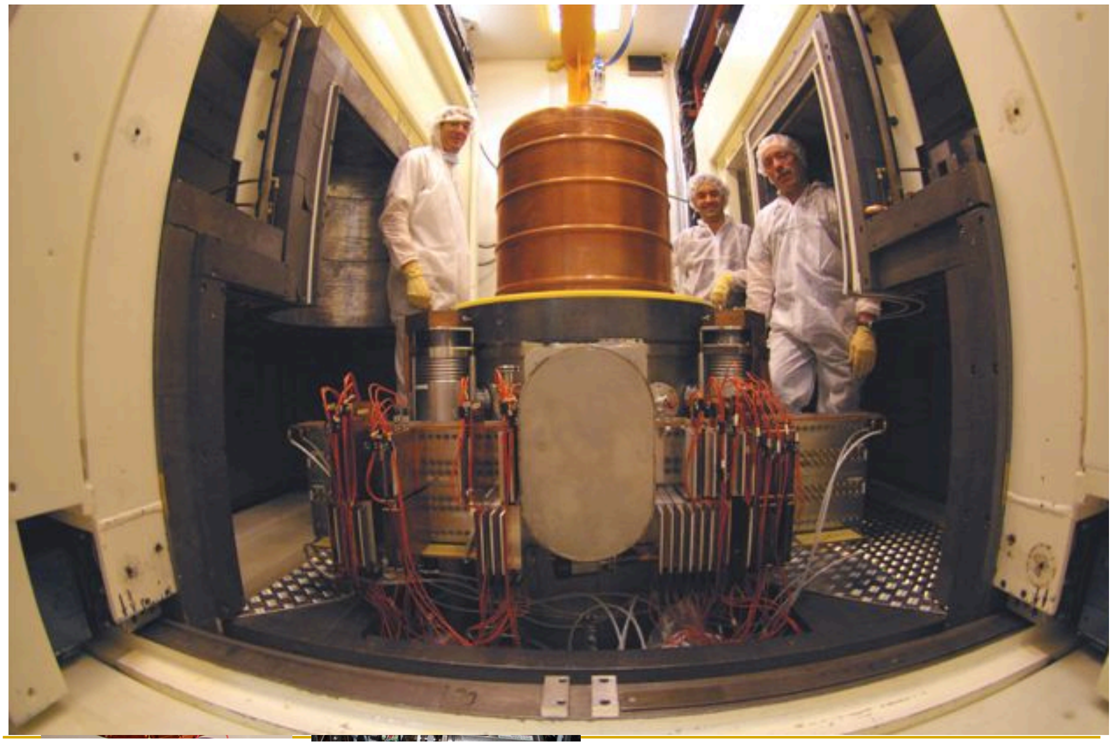




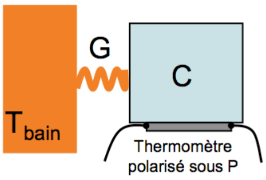
- Cryogenic installation (18 mK) :
  - Reversed geometry cryostat, pulse tubes
  - Remotely controlled
  - **Can host up to 40kg of detectors**
- Shieldings :
  - Clean room + deradonized air
  - Active muon veto (>98% coverage)
  - 50-cm PE shield
  - 20-cm lead shield

  ⇒ γ background reduced by ~3 wrt EDW1
- Other items:
  - Remotely controlled sources for gamma calibrations + regenerations
  - AmBe sources of neutron calibrations
  - Detector storage & repair within the clean room
  - **Radon detector down to few mBq/m^3**
  - **He3 neutron detector (thermal neutron monitoring inside shields) sensitivity ~10^{-9} n/cm^2/s**
  - **Liquid scintillator neutron counter (study of muon induced neutrons)**

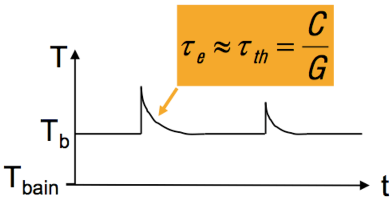
The EDELWEISS-II infrastructure



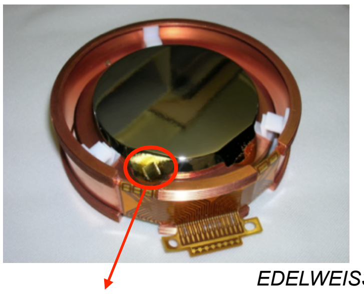
Bolometric energy measurement



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



Energy deposition E_0 in the absorber : $\Delta T = E_0/C$



NTD sensor

EDELWEISS Absorber ~ 400g

• <u>Working point @ T ~ 20 mK (for EDW):</u>
C(T) ~ T^3 (isolating) ⇒ sensitivity gain

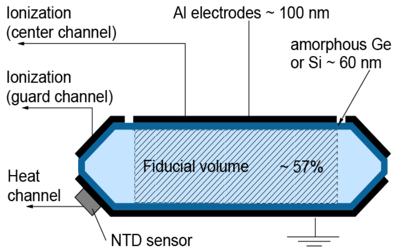
• Theoretical resolution limited by fluctuations of internal energy in the detector

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

• different sensor technologies
- EDW : NTD sensor = thermal phonons
- CDMS : sensitivity to athermal phonons

« EDELWEISS-I-like » detectors

- Germanium bolometers
- Ionization measurement @ few V/cm
- Heat measurement (**NTD sensor**) @ 20 mK:
  - heat signal = k x recoil energy + Luke effect



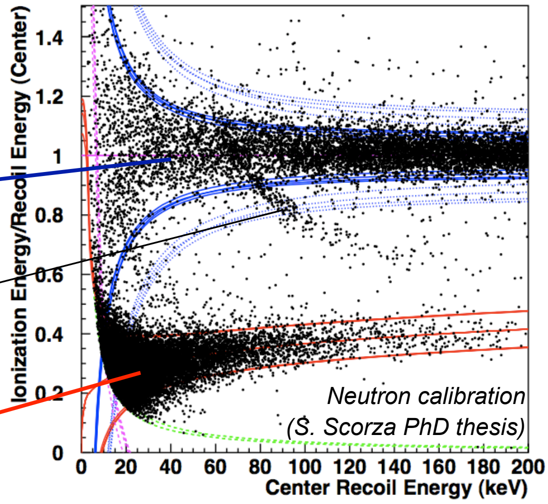
- *Discriminating variable between electronic and nuclear recoils :*
  « Q » = ionization/recoil energy

⇒ Full separation between ER and NR

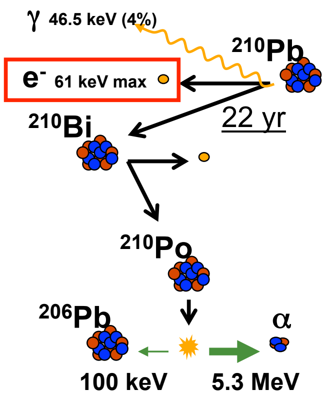
electron recoils

inelastic neutron diffusion

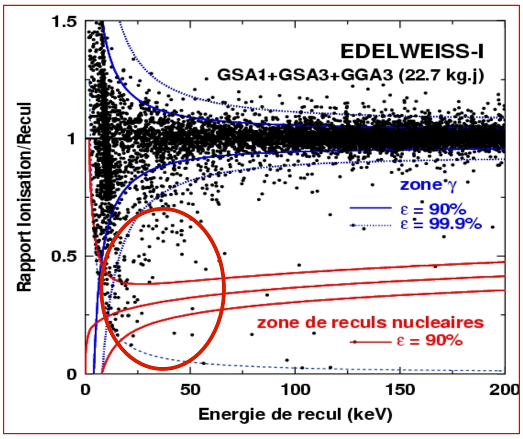
nuclear recoils



The issue of surface interactions

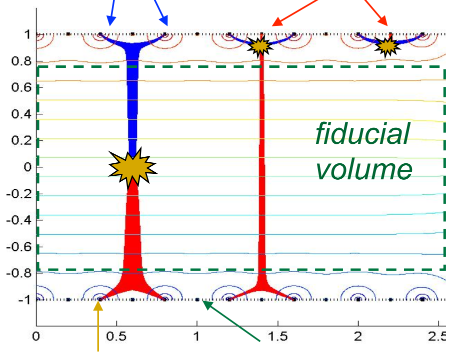


- Almost irreducible source of local radioactivity : beta rays from ^{210}Pb (a daughter of Radon present in the air)
- A beta interaction = electronic recoil, <u>at the detector surface</u> (penetration length ~ few microns)
  ⇒ **Incomplete charge collection at the electrodes** : impossible to discriminate with nuclear recoils

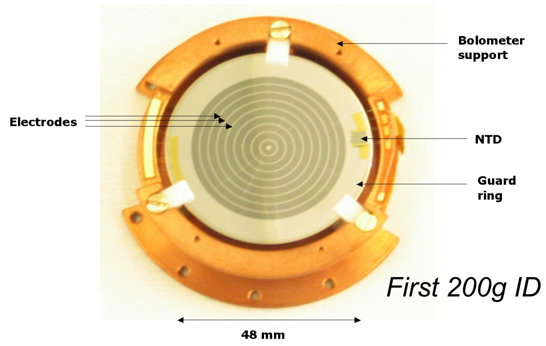


Edelweiss background run - 2003
Sensitivity limited by the beta background
Quantitative bckgd understanding published 2007
S. Fiorucci et al. - Astropart. Phys. 28:143-153.2007 (astro-ph/0610821)

Rejecting surface events with interleaved electrodes



the « ID » (interdigit) detector



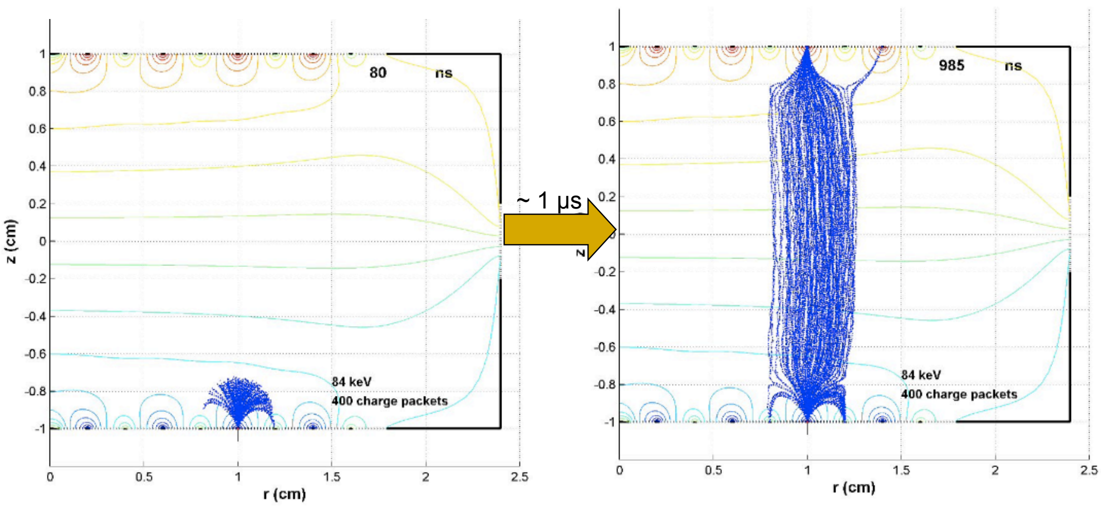
- Keep the EDW-I NTD phonon detector
- Modify the E field near the surfaces with interleaved electrodes
- Use 'b' and 'd' signals as vetos against surface events

- First detector built 2007
- 1x200g + 3x400g tested in 2008
- 10x400g **running 1 year 2009-2010**
- **800g detectors tested and running** 2010-2011

Charge propagation in an InterDigit detector

- Initial expansion of the charge cloud due to Coulomb interactions is sufficient to generate charges in the vetos even in
  - regions of low electric field
  - regions just under the collecting electrodes

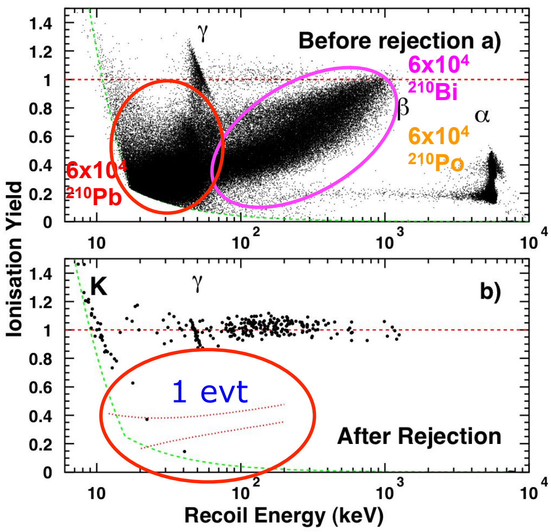
[PLB 681 2009 305]



Simulation : interaction under a collecting electrode
(no anisotropy effect taken into account)

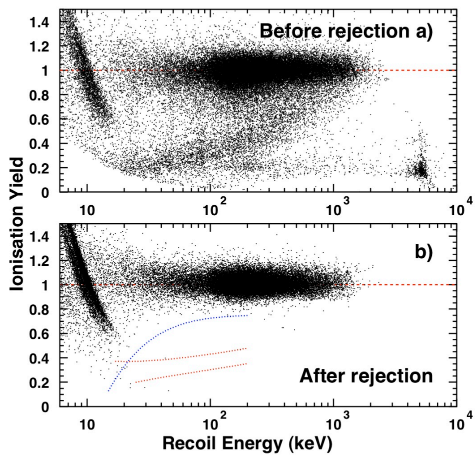
Ionization yield for surface events

^{210}Pb calibration (2008)

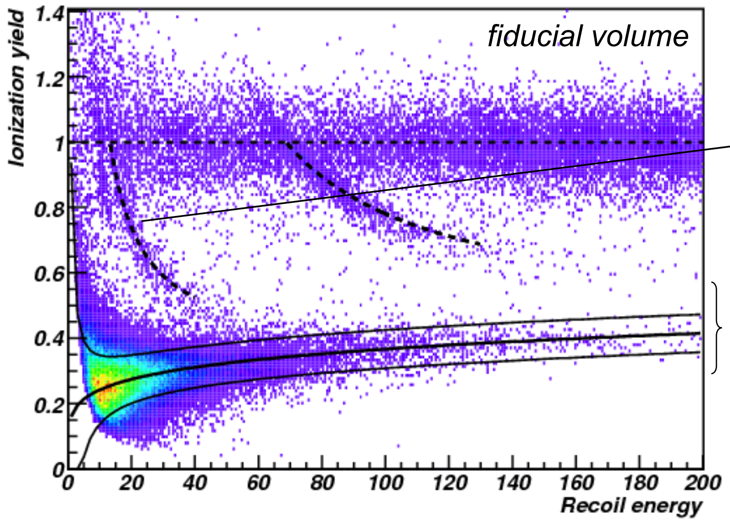


PLB 681 (2009) 305-309 [*arXiv:0905.0753]*

Background data



ID-400g : neutron calibration



inelastic neutron scattering (EM energy 13 and 69 keV)

90% CL NR (nucl. recoil) region :

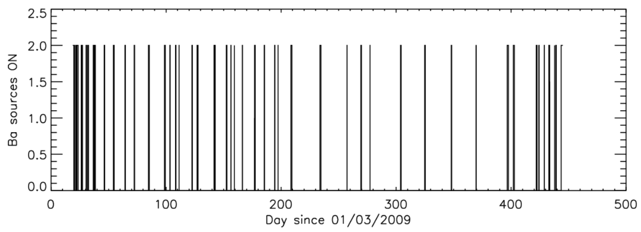
- high-stat confirmation of $Q = 0.16\ E_r^{0.18}$ from <10keV to 200keV

- cross-check of resolution effects on the NR band

- full efficiency to NRs even below 20keV

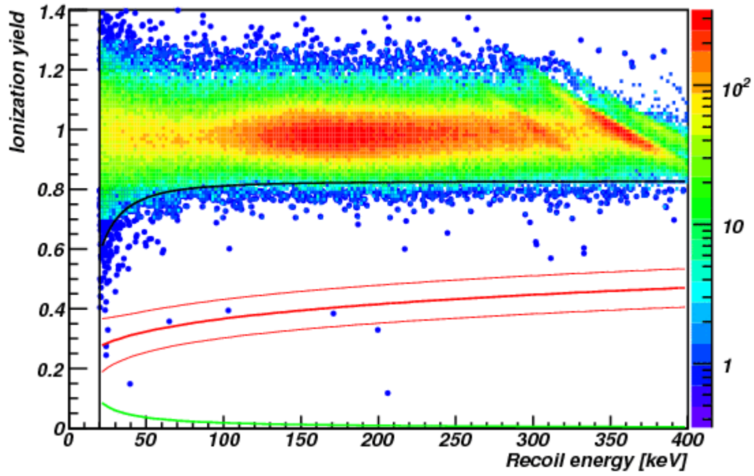
ID-400g : gamma calibration

• Regular calibrations between background runs with two motorized ^{133}Ba sources (356 keV)



• all IDs stacked
• same analysis/cuts as for bg data
• more than 350000 fiducial evts

• <u>anomalous events observed</u>:
- for 20<E<200keV ~ (3±1)x10^{-5} rejection
- study of possible mechanisms under way - may be related to the presence of a large non-fiducial volume



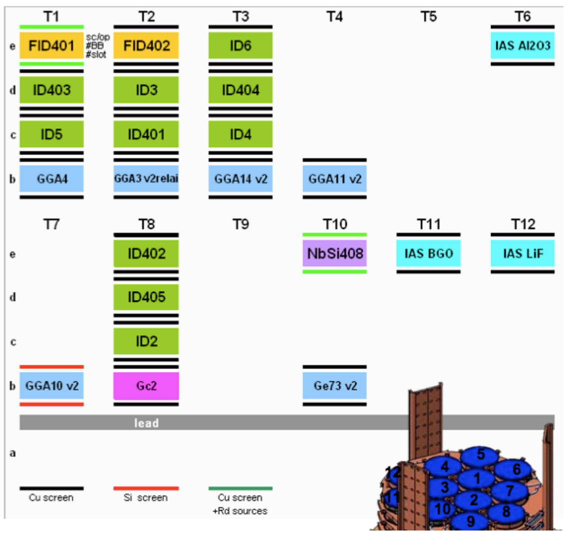
WIMP search with ID-400g detectors

~ 20 kg.d in 2008 during validation runs of ID detectors (2 detectors)

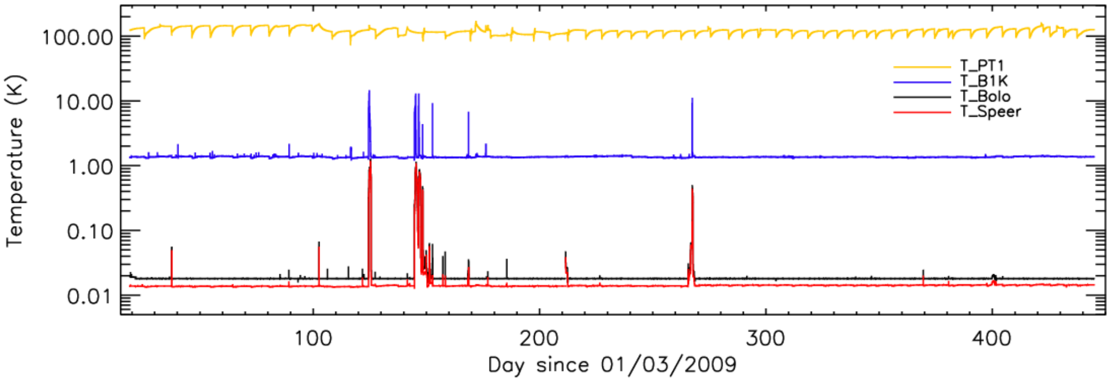
Physics run Apr 2009 - May 2010 (10 detectors) : ~ 360 kg.d

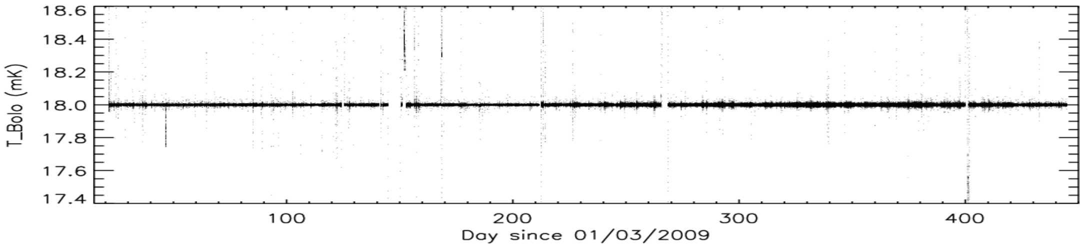
- Published : 2008 + 6 months 2009 = 160 kg.d - ***PLB 687 (2010) 294–298* [arXiv: 0912.0805]**
- Final results of the complete run presented here ***- submited [arXiv:1103.4070]***

- All heat sensors working
- 55/60 electronics channels working
  - *calibrations show we can use all detectors for WIMP search thanks to redundancy*



A 14 month-long WIMP-search run at 18 mK





Data processing and cuts

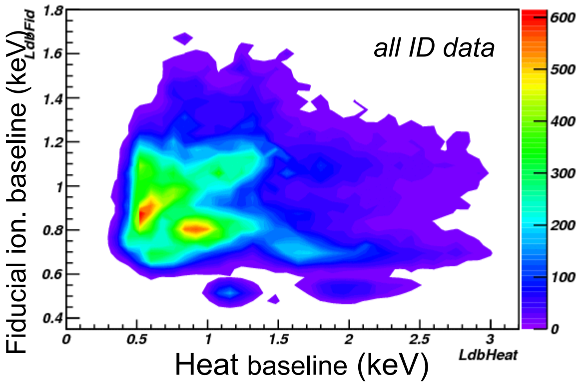
- Online trigger on heat pulses
  - Online threshold : tiny effect for E_{recoil} > 20 keV
- Two independent processings - analysis
  - Careful cross-checks, very similar results
- Optimal filtering of heat and ionization data samples
- Removal of « bad » periods from the measured baselines
  - Require FWHM heat < 2.5 keV, ion_fiducial < 2 keV, ion_guard < 2.5 keV
  - 17% exposure loss (concentrated on a few detectors)

- Quality of pulse reconstruction (chi2 cut) : 2.7% efficiency loss
- Select fiducial volume (160g)
- Reject coincidences + muon veto

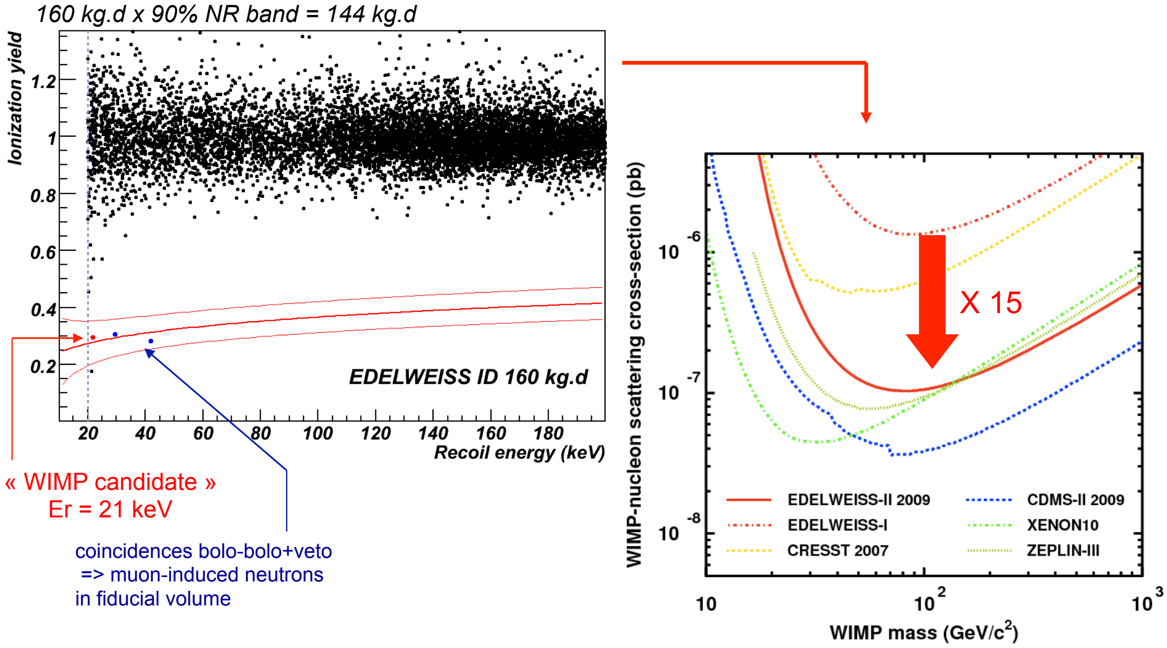
  ⇒ **427 kg.d**
- 99.99% gamma rejection + 90% nuclear recoil band selection + <u>set threshold at 20 keV</u>

  ⇒ 384 kg.d «useful»

  98.3% efficiency at 20keV

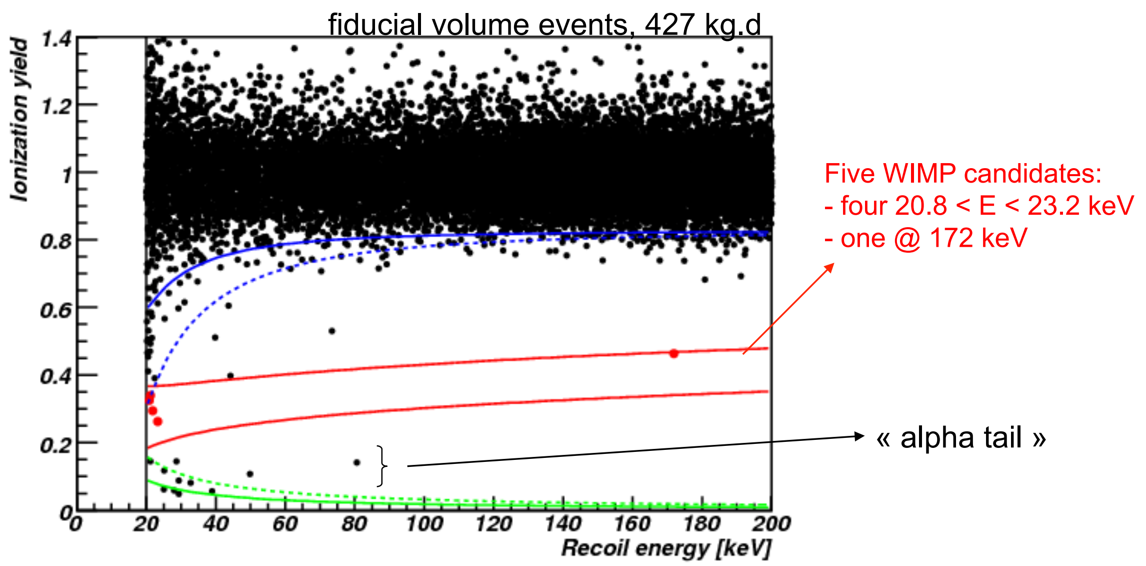


WIMP search : first six month result



PL B 687 (2010) 294–298 [arXiv:0912.0805]

WIMP search : final results



Elastic WIMP scattering limit

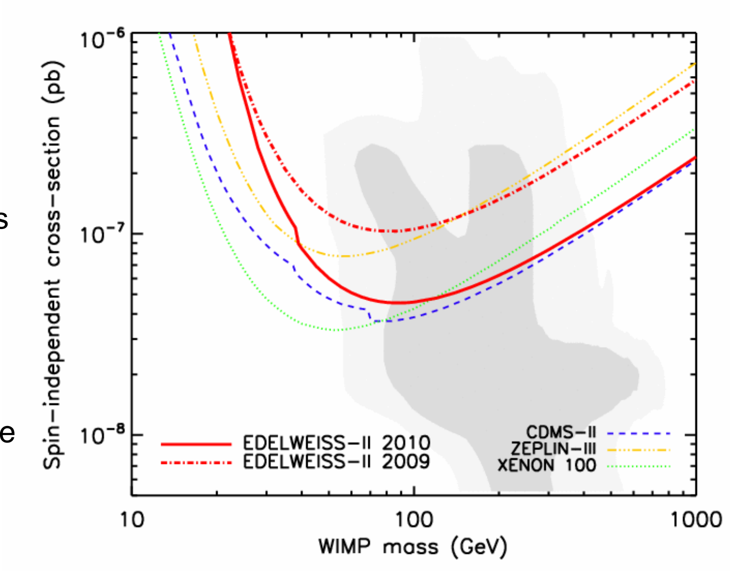
- 384 kg.d

4.4 x 10^{-8} pb at Mχ=85 GeV

(x2.7 better than 2009 result)

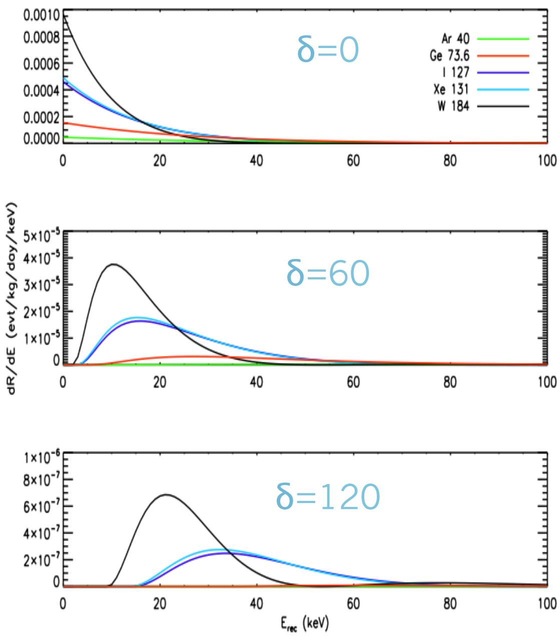
- Sensitivity limited at low mass due to background

- current work performed with CDMS collaboration to combine data of both experiments



arXiv:1103.4070

Inelastic dark matter

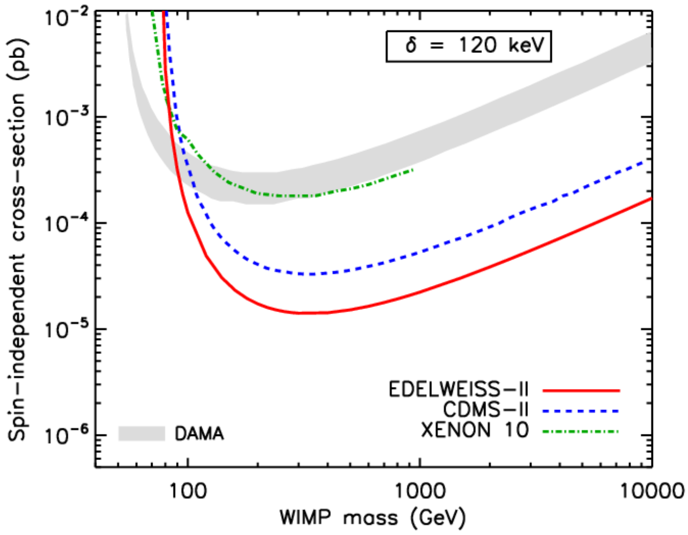


- Dark matter modulated signal claimed by DAMA/LIBRA vs. null detection in all the other direct detection experiments
- χ + m ➔ χ* + m (δ ~100 keV)

$$v_{min} = \underbrace{\frac{1}{c^2}\sqrt{\frac{1}{2mE_R}}\left(\frac{mE_R}{\mu}\right.}_{v_{min}^{el}} + \delta\Big)$$

- Signal globally reduced and suppressed at low recoil energies
- Heavier targets preferred
- Modulation is enhanced

Constraints on inelastic dark matter



arXiv:1103.4070

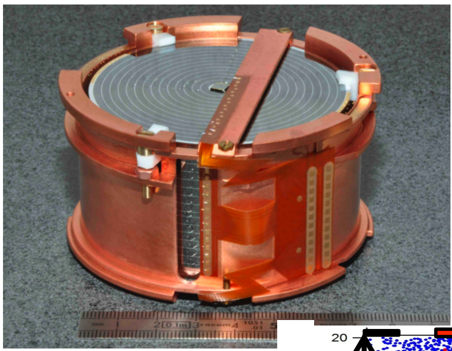
- same data & analysis as in the elastic case
- use v_{esc} = 544 km/s (RAVE survey, arXiv:0611671, 2007)
- **DAMA allowed region excluded for Mχ > 90 GeV (90%CL)**

What is the background ? Current status

- *Gamma*: ^{133}Ba calib rejection x observed bulk γ (3x10^{-5}) (18000) <0.9
- *Beta*: β source rejection x observed surface evts (6x10^{-5}) (5000) <0.3
- *Neutrons from* μ's: μ veto efficiency x observed muons (meas. > 92.8%) (0.008 evts/kgd) <0.4
- *Neutrons from rock*: measured neutron flux x Monte Carlo simu <0.1
  MC cross-check with outside strong AmBe source
- *Neutrons from Pb+PE+Cu+structure*:
  measured U limits x Monte Carlo simu <0.2
- *Other neutrons from within the cryostat (cables..)* <1.1

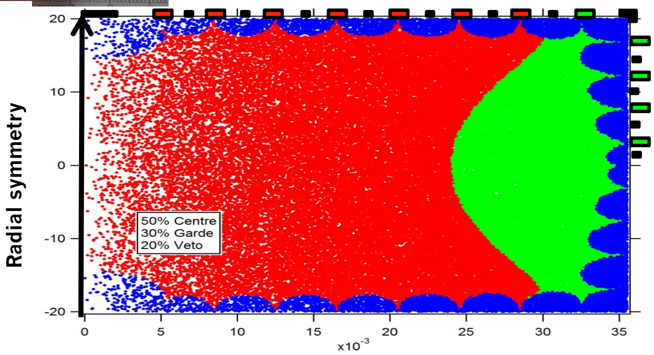
SUM < 3.0 for the whole WIMP run

What's next : the FID800 detector

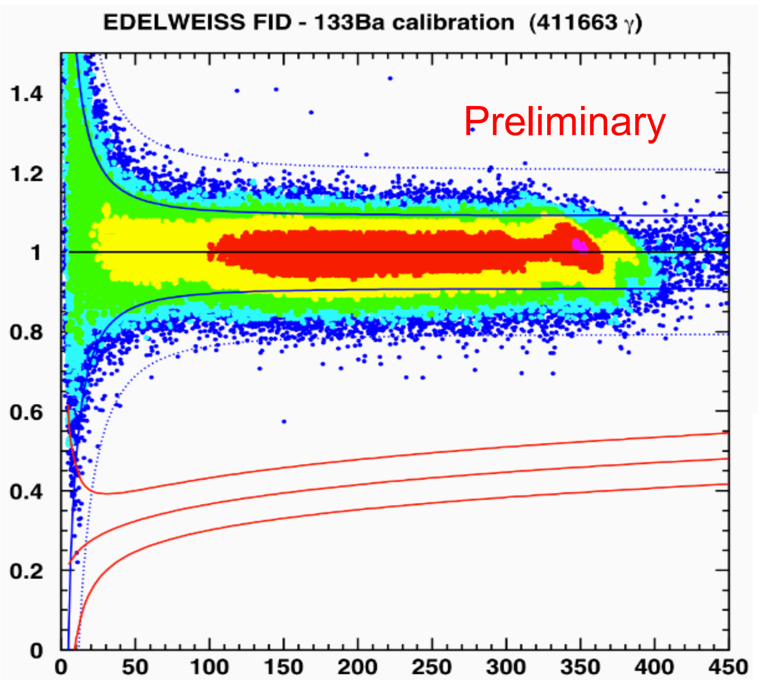


Increase mass + sensitivity :

- 800g crystal
- two NTD sensors per detector
- interleaved electrodes on all the surface : no « guard » region anymore, ~ 80% fiducial volume

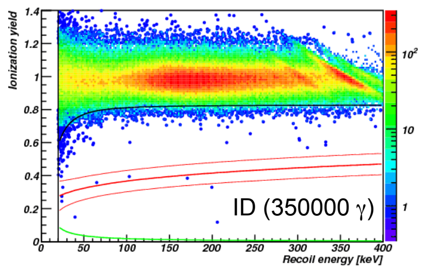


Gamma calibrations with FID800 (2010)



- All fiducial volume: more statistics than stacked ID-400 statistics
- No event in NR

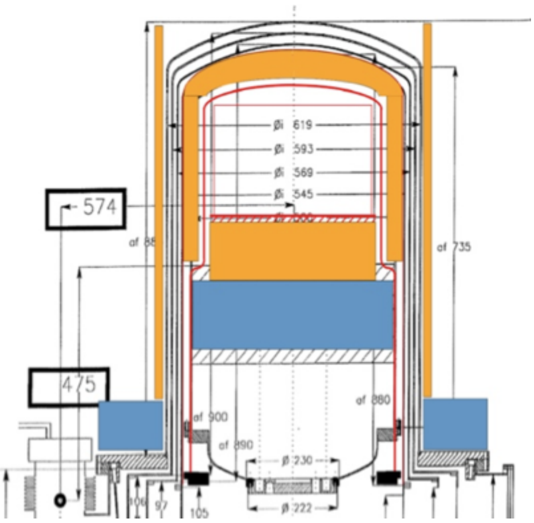
Looks better than IDs !



Towards $5x10^{-9}$ pb : EDELWEISS-III

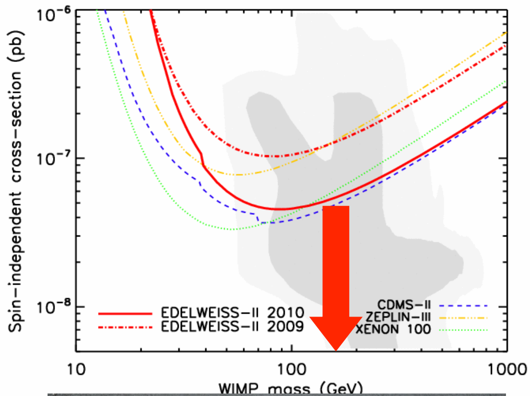
- Program under way, funded
- Infrastructure : Upgrades of cabling, cryogenics, acquisition and shielding **within the current EDW-II setup**
  - Special care with neutrons : additionnal inner PE shield
- Detectors : ~ 40 FID800 bolometers installed beginning 2012 : **26 kg fiducial**

  ⇒ 3000 kg.d by end 2012



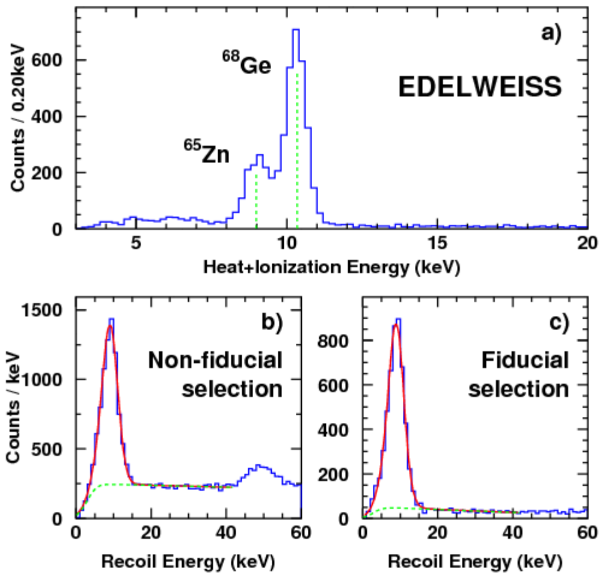
EDELWEISS : summary / prospects

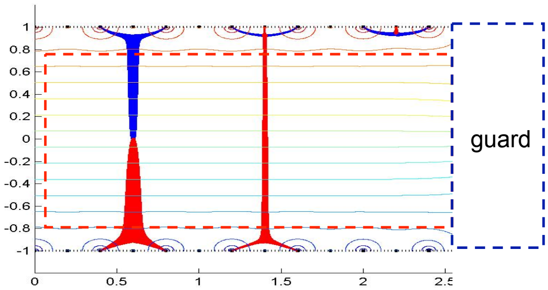
- EDELWEISS-II: final results with ID detectors
  - One year of WIMP search
  - $4.4x10^{-8}$ pb sensitivity achieved
  - Backgrounds start to appear
- EDELWEISS-III : project going on
  - New Goal $5x10^{-9}$ pb, 25 kg fiducial
  - Improvements wrt backgrounds
    - FID800 design
    - EM interactions : increased redondancy for ionisation and heat measurements
    - Neutrons : internal PE shield
  - New FID800 detectors now working at LSM
  - Build 40 detectors, upgrade set-up
    - 2012 = 3000 kg.d
- Then turn towards EURECA…



ID-400g : fiducial volume measurement

Data : 9 detectors - 6 month background runs (2009)



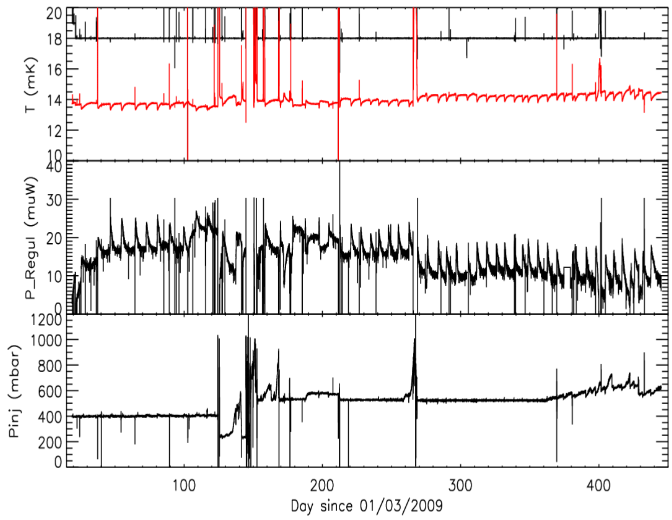


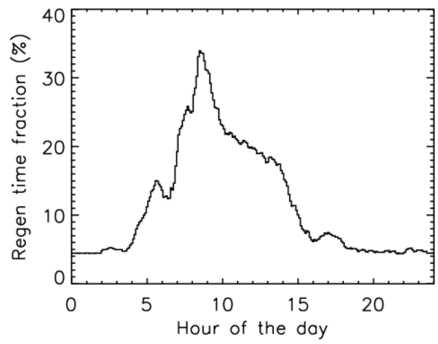
- Estimation with electrostatic models
- Measurement with cosmogenic lines:
  - ^{68}Ge and ^{65}Zn isotope lines at ~10keV, background electron recoil events
  - *Homogeneously distributed in the volume of the cristal*
  - *Real-condition measurement of fiducial cuts efficiencies at low energy in WIMP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

- **Fiducial volume measurement 160g, *primarily limited by the guard regions***

Routine running of cryogenics and bolometers

He refill ~ every week





« Regeneration » :
- strong gamma sources (Co)
- detector voltage bias = 0V
- cleans charges in the crystal

- 1h/day (+during He refills and unscheduled stops)

⇒ Overall ~ 15% detector « deadtime »