Search for WIMPs with EDELWEISS

LPHNE - Seminar

01/12/2011

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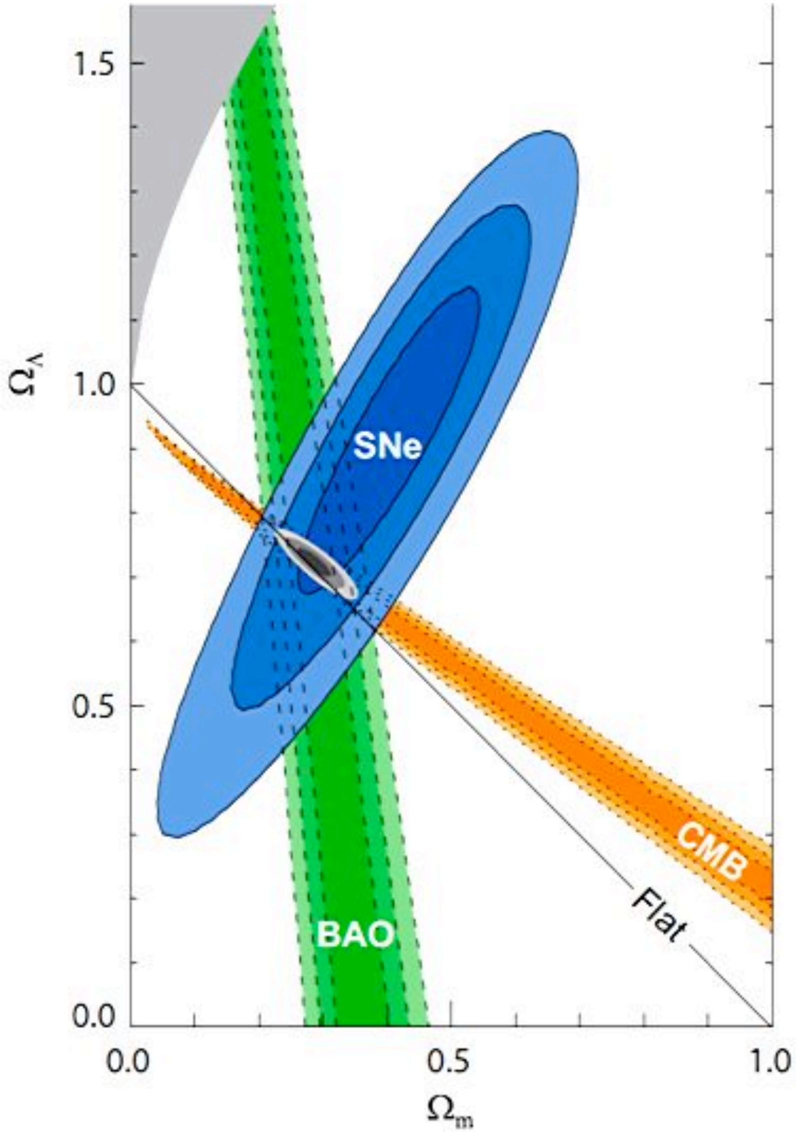
Edelweiss

Expérience pour DEtecter Les WIMPs En Site Souterrain

- Direct detection and EDELWEISS
- The « ID » detector principle and performances
- WIMP search with ID detectors (2009-2010 data)
- Ongoing and future projects
- Low-mass WIMPs

Dark matter exists: what is it ?



- New field(s) of « gravitationnal » nature = modified gravity (MOND etc)
  - justified by obs. galactic dynamics + Λ + …
  - no convincing theory yet

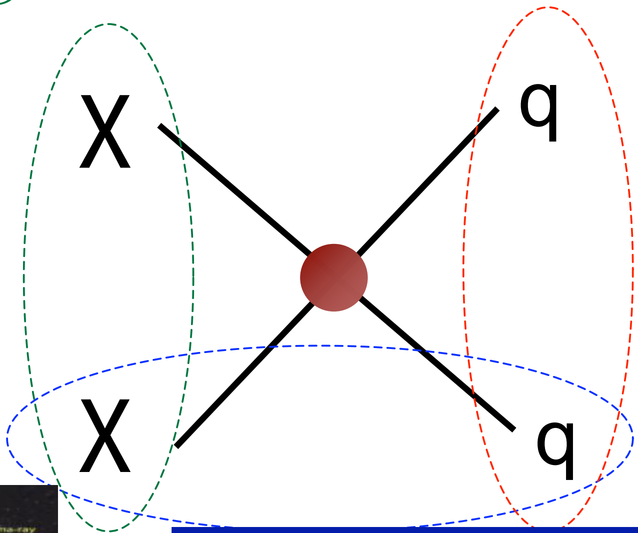
- New « particle-like » field(s), many possibilities among which:

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

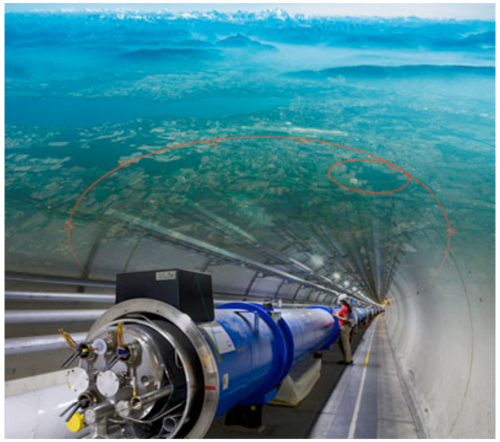
- The « WIMP miracle » : *thermal relic hypothesis* :
  $\Omega_{DM} \sim 0.3 \Rightarrow \langle\sigma_{ann}v\rangle \sim 3\times10^{-26}$ cm^3/s weak interactions, M~100 GeV (Weakly Interacting Massive Particles)
  - neutralino [SUSY models]
  - LKP [UED models]
  - …

Search strategies for WIMPs

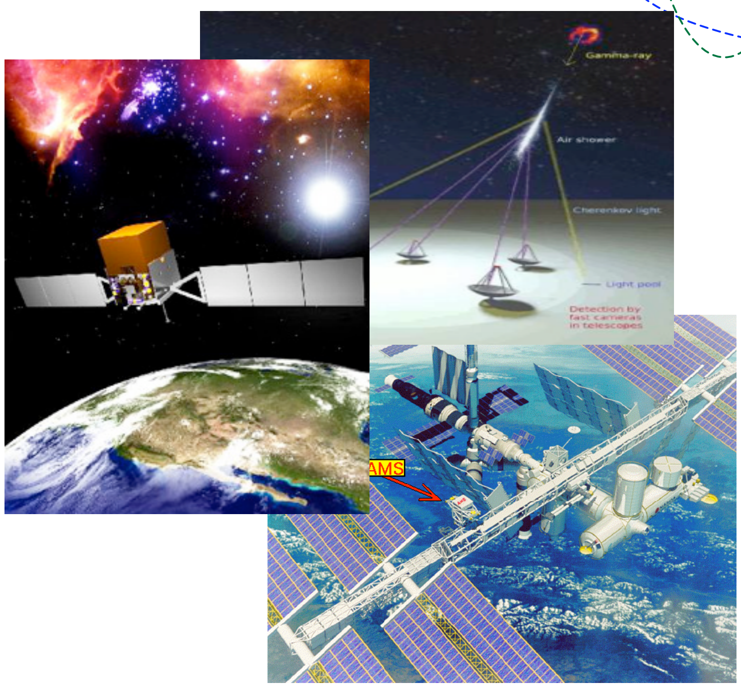
Indirect detection
- observation of WIMP annihilation products from astrophysical regions
- many « observatories » involved

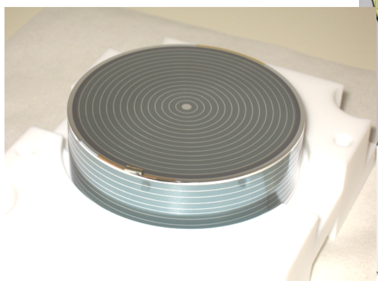


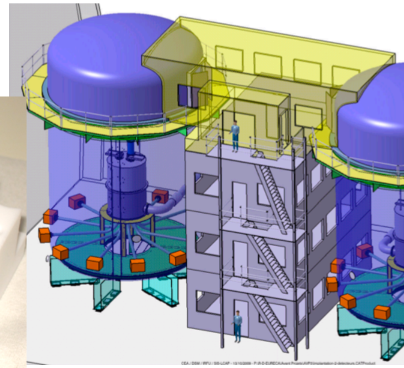
Colliders
- production of WIMPs, detection of missing energy
- LHC

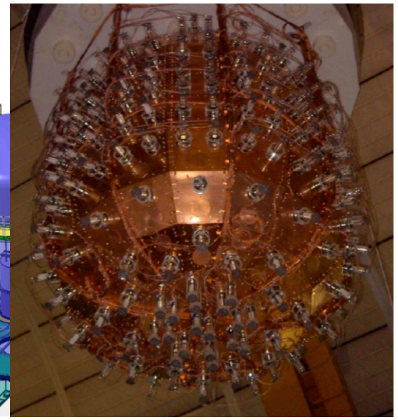


Direct detection
- observation of the interaction of local galactic WIMPs on a terrestrial detector
- several <u>dedicated</u> experiments

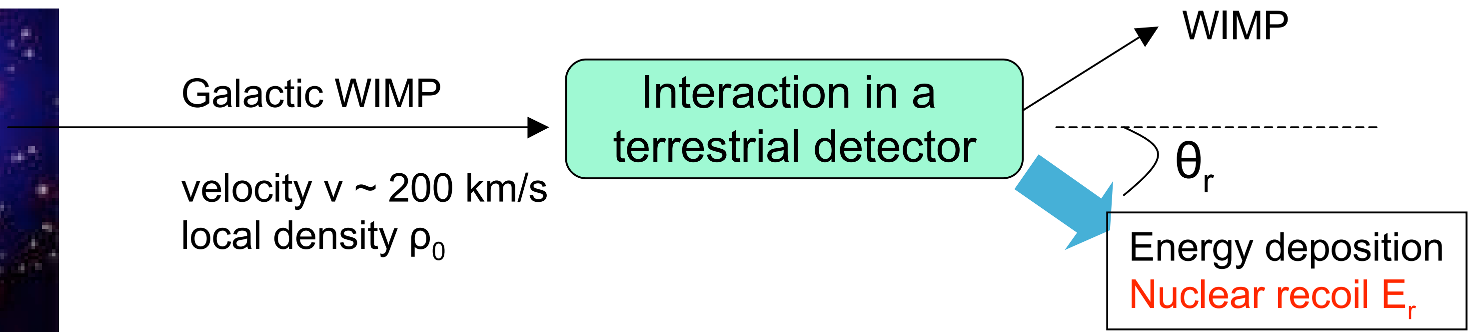








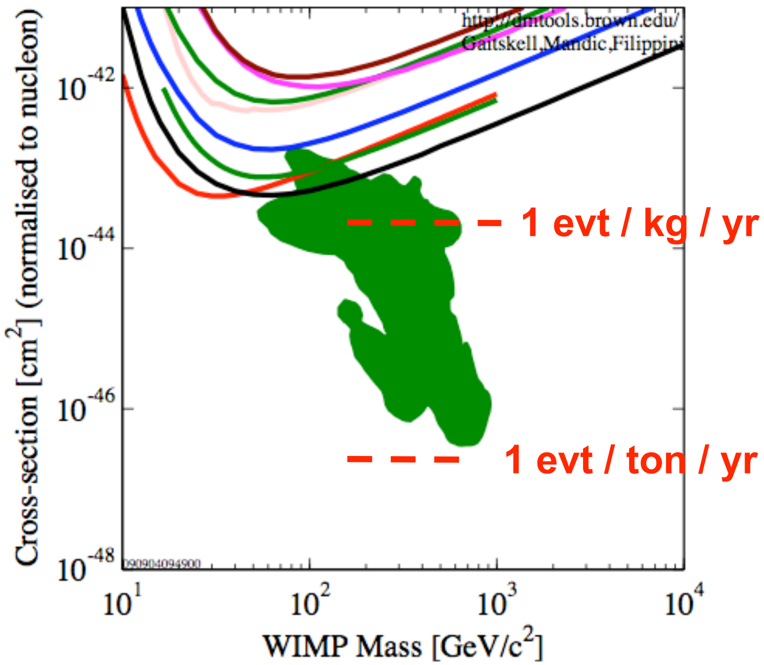
Principle of WIMP direct detection



• 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:

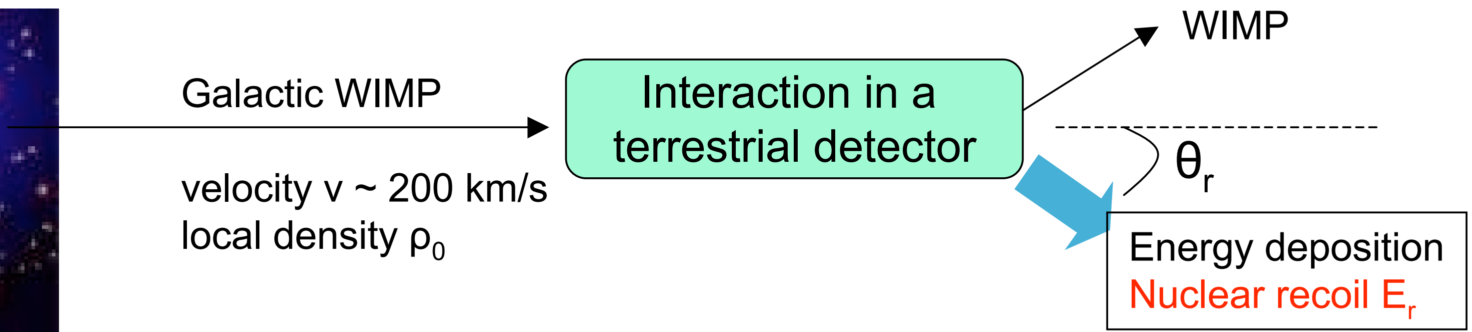
$$E_r = \left(\frac{m_\chi}{2} v^2\right) \times \frac{4 m_N m_\chi}{(m_N + m_\chi)^2} \times \cos^2 \vartheta_r \quad \sim 1 - 100 \text{ keV}$$



• 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



• Relev

- **mass**

extens

- **WIMI**

contrai

• Non-r

$E_r = \left(\frac{m}{2} \right.$

• Inter

$R \sim \frac{\rho_0 \sigma}{m_\chi m}$

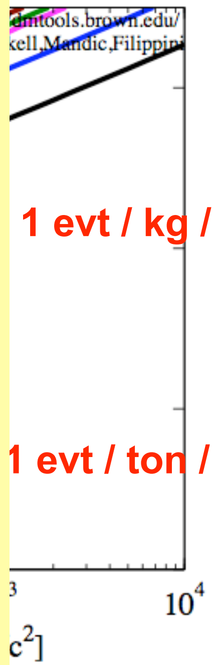
• Low-threshold detectors

• Ultra-low-background detectors :

- « Passive » bckgd reduction (shields, radiopurity, external vetos..)

- « Active » bckgd reduction (discrimination of electron recoils, multiple scatters..)

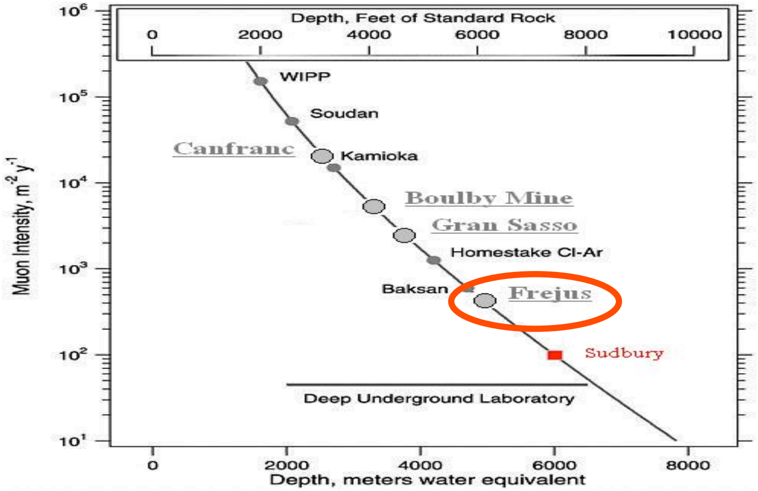
• We consider only the « spin-independent » channel here → single WIMP-nucleon cross-section ∀ target



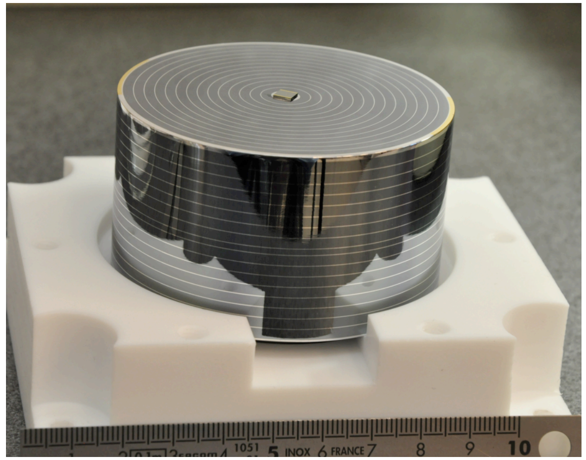
The EDELWEISS collaboration

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
- Sheffield University

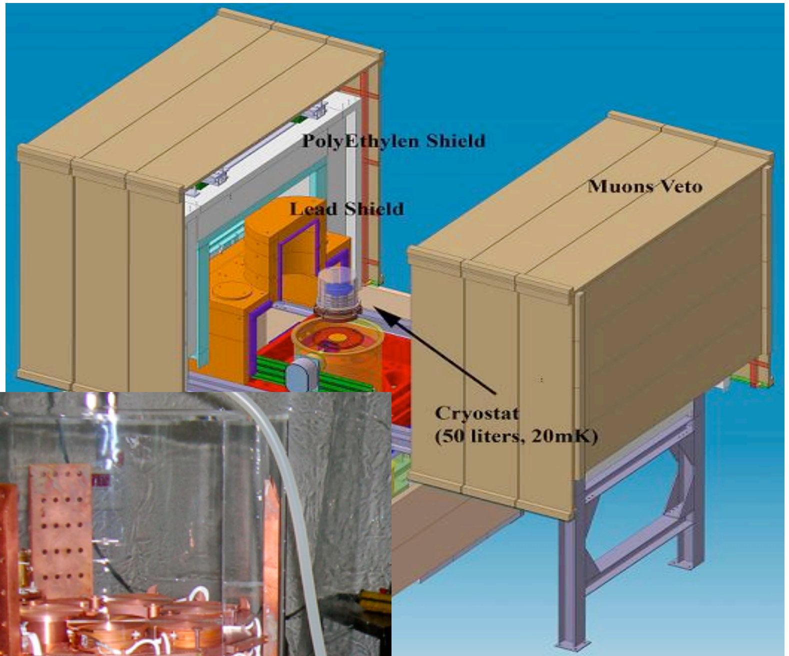


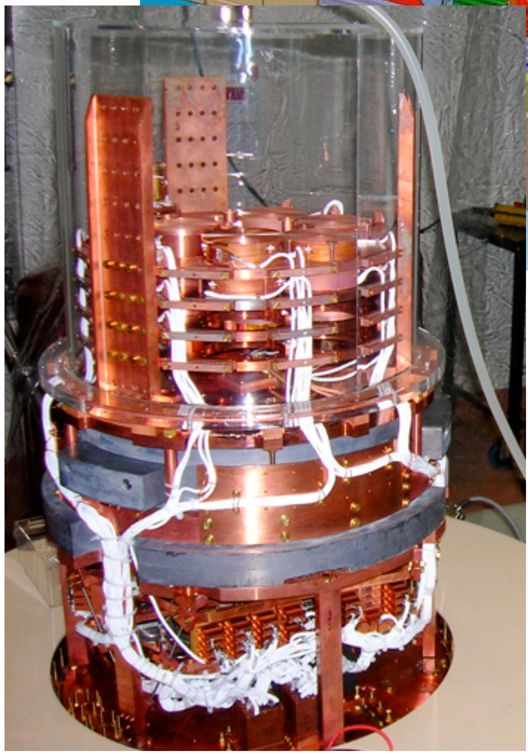
Laboratoire Souterrain de Modane (Fréjus tunnel)



Germanium bolometers

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)**

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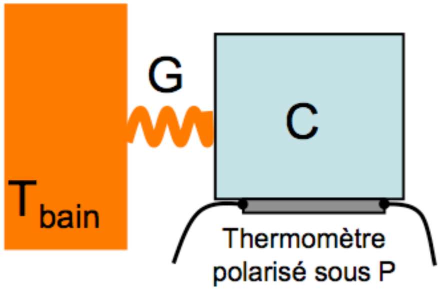
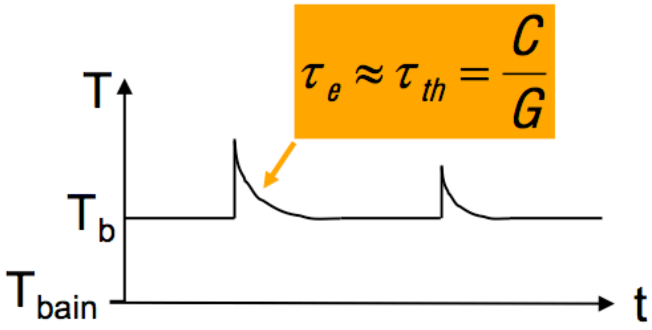
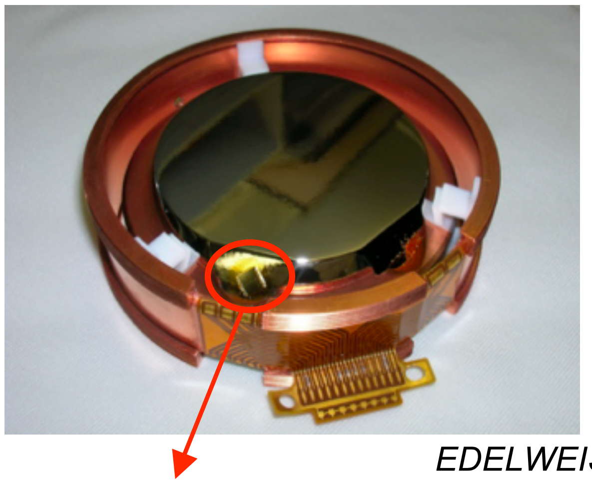
Bolometric energy measurement



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

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

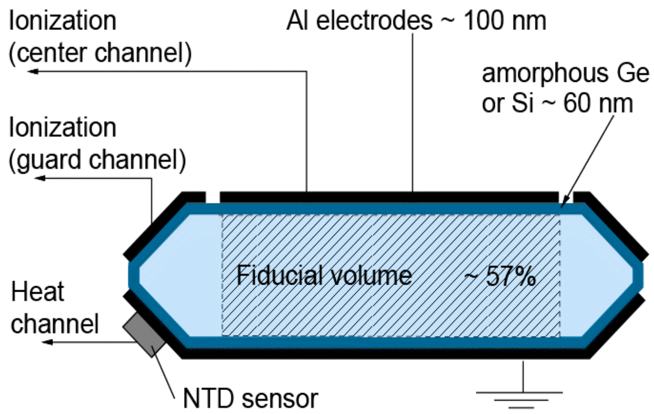
• Theoretical resolution limited by fluctuations of internal energy in the detector

• 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* :

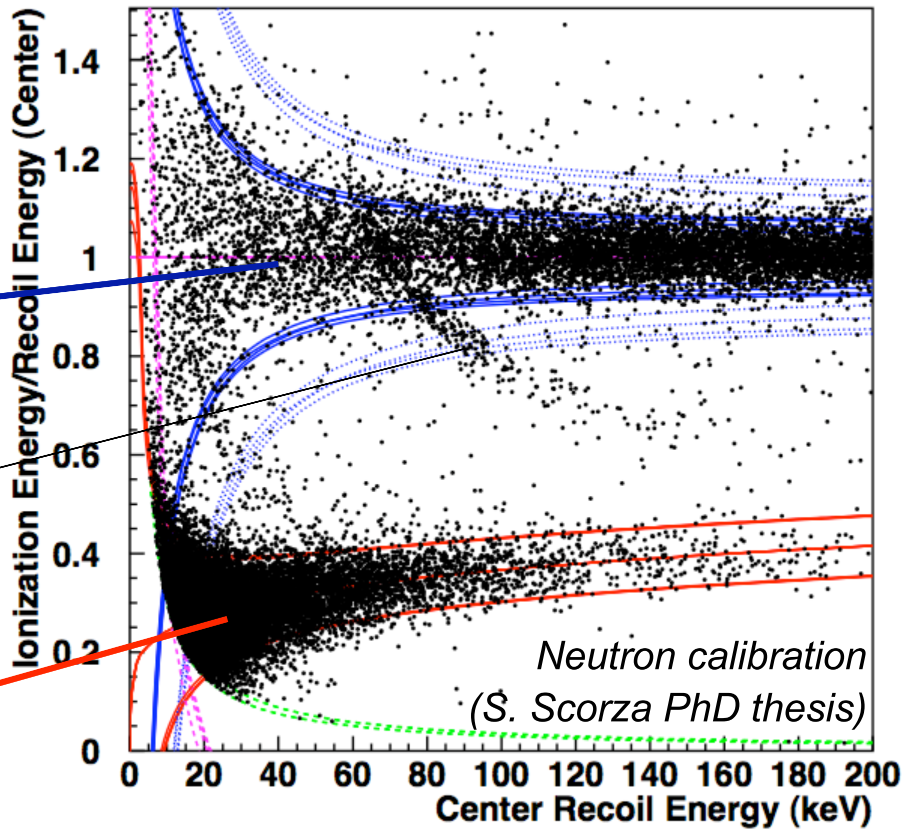
  « Q » = ionization/recoil energy

⇒ Full separation between ER and NR

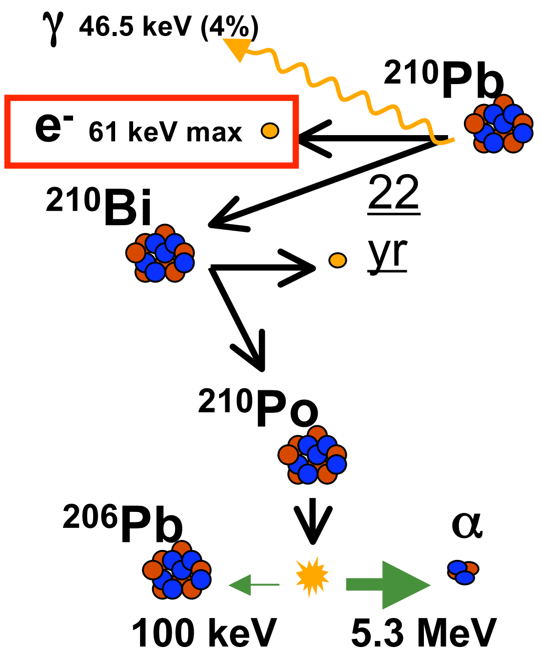
electron recoils

inelastic neutron diffusion

nuclear recoils

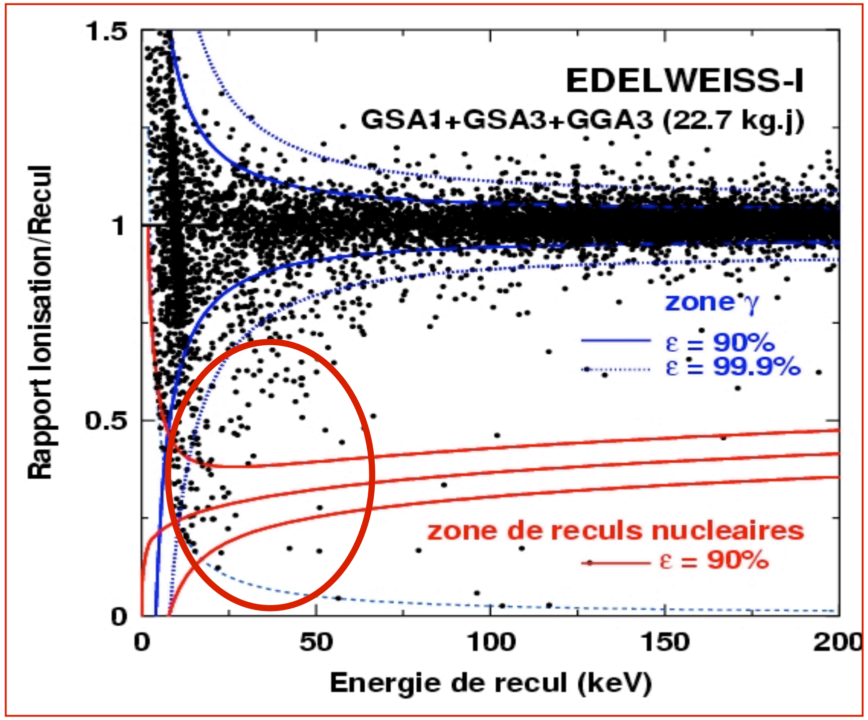


The issue of surface interactions



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

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



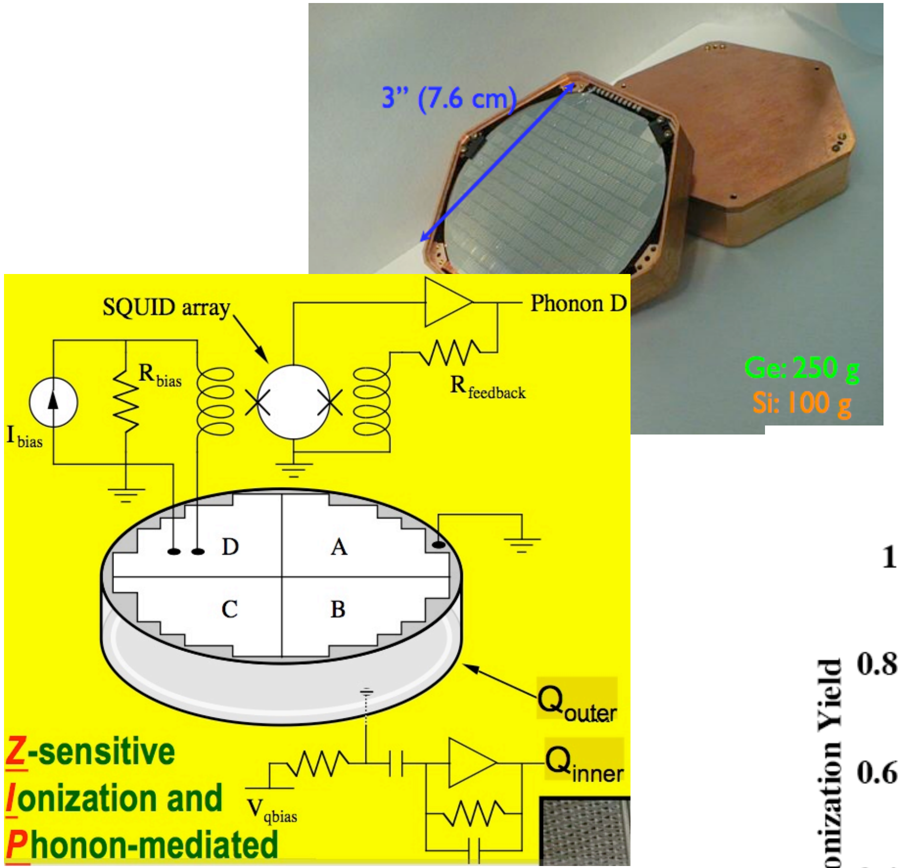
Edelweiss background run - 2003

Sensitivity limited by the beta background

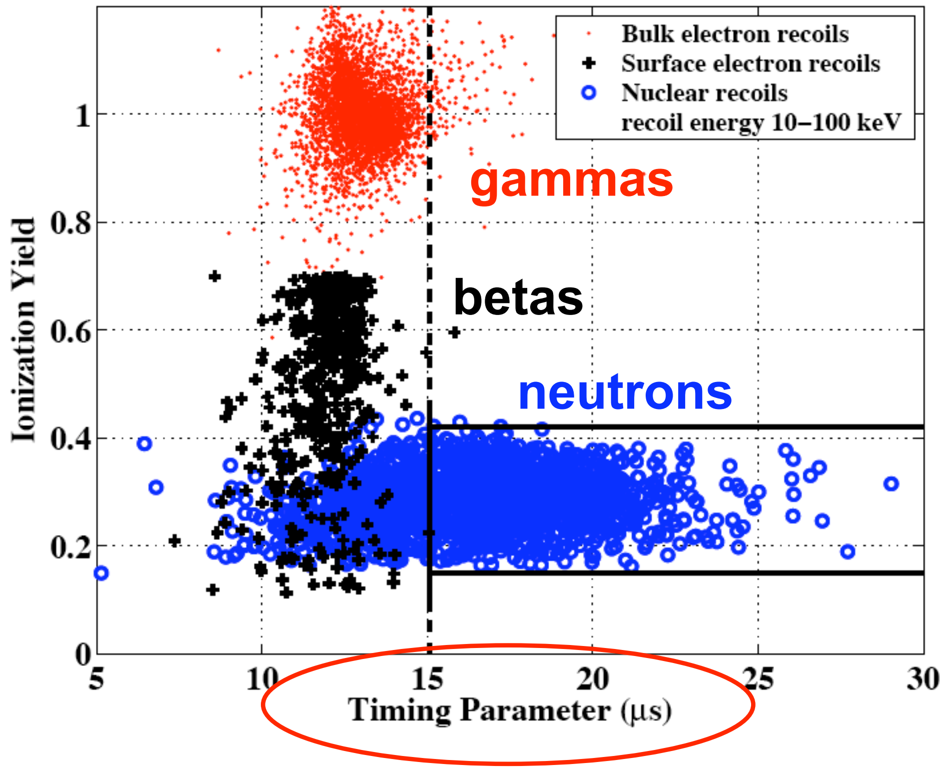
Quantitative bckgd understanding published 2007

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

CDMS : surface event rejection with phonon measurement



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



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

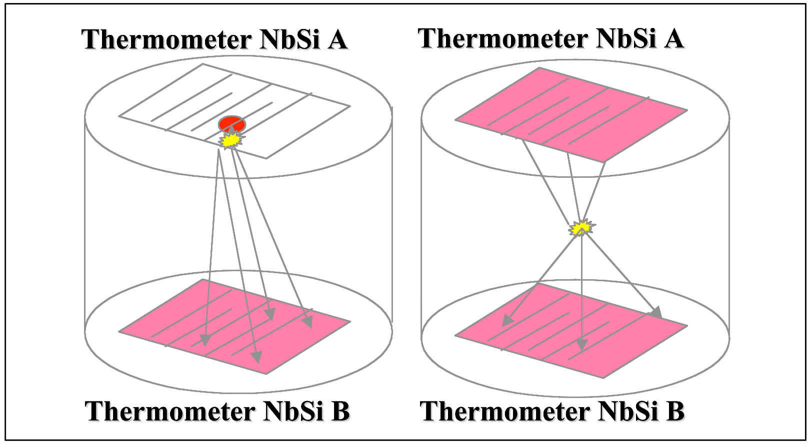
Surface event rejection with phonons : NbSi detectors

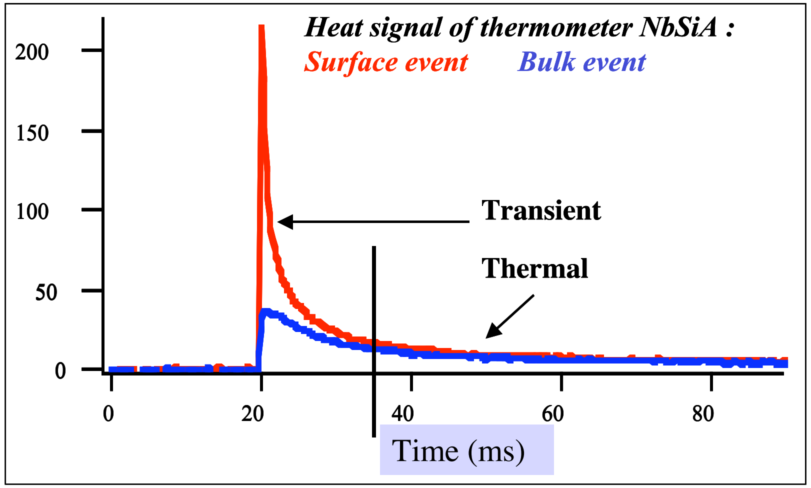
• 2 NbSi films measuring athermal phonons + ionization signals

• Surface event rejection correct

• Several generations of prototypes tested at Orsay + on EDW-II cryostat 2007-2009

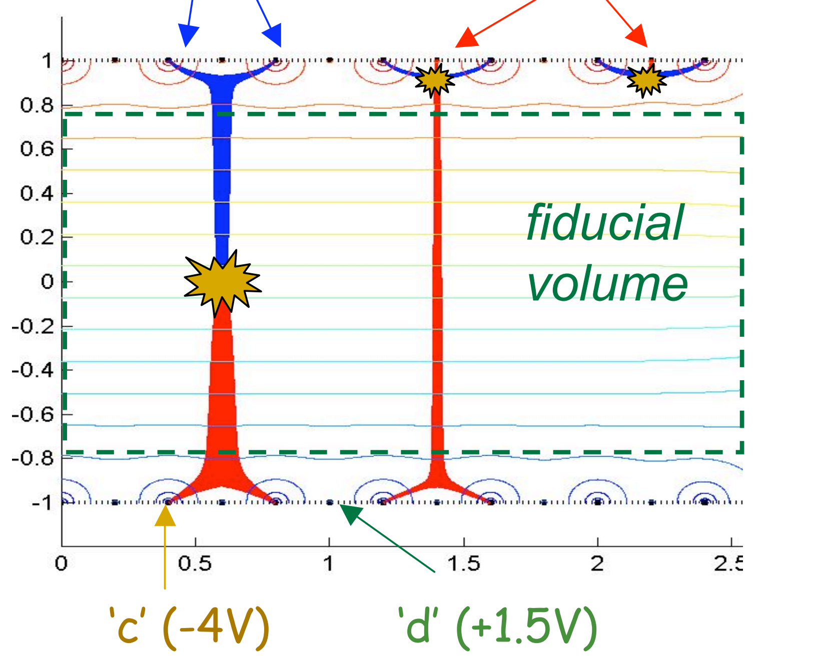
• Pbs of threshold / reproducibility



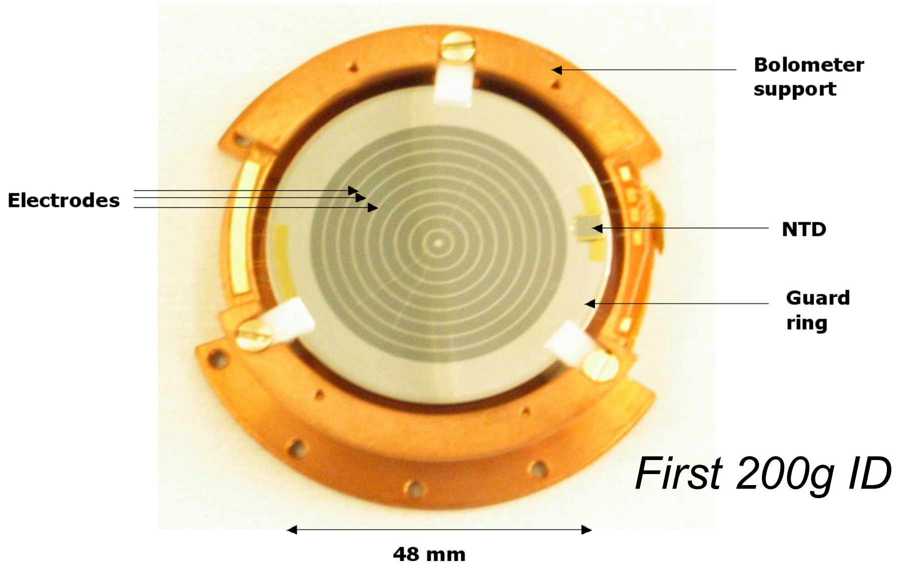


Currently still at R&D stage

Rejecting surface events with interleaved electrodes



the « ID » (interdigit) detector



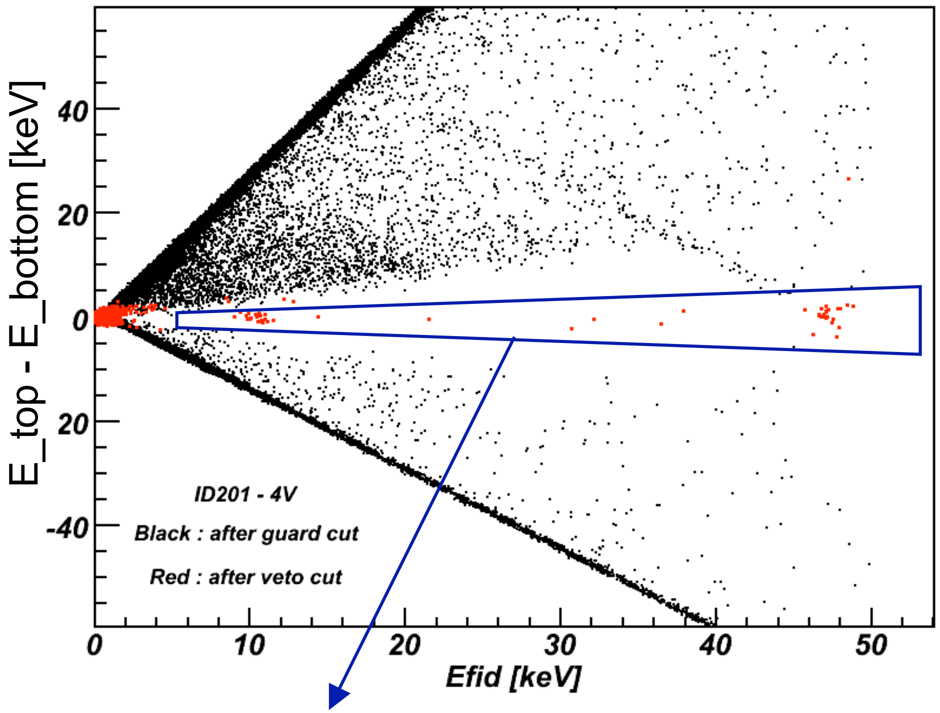
First 200g ID

- 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

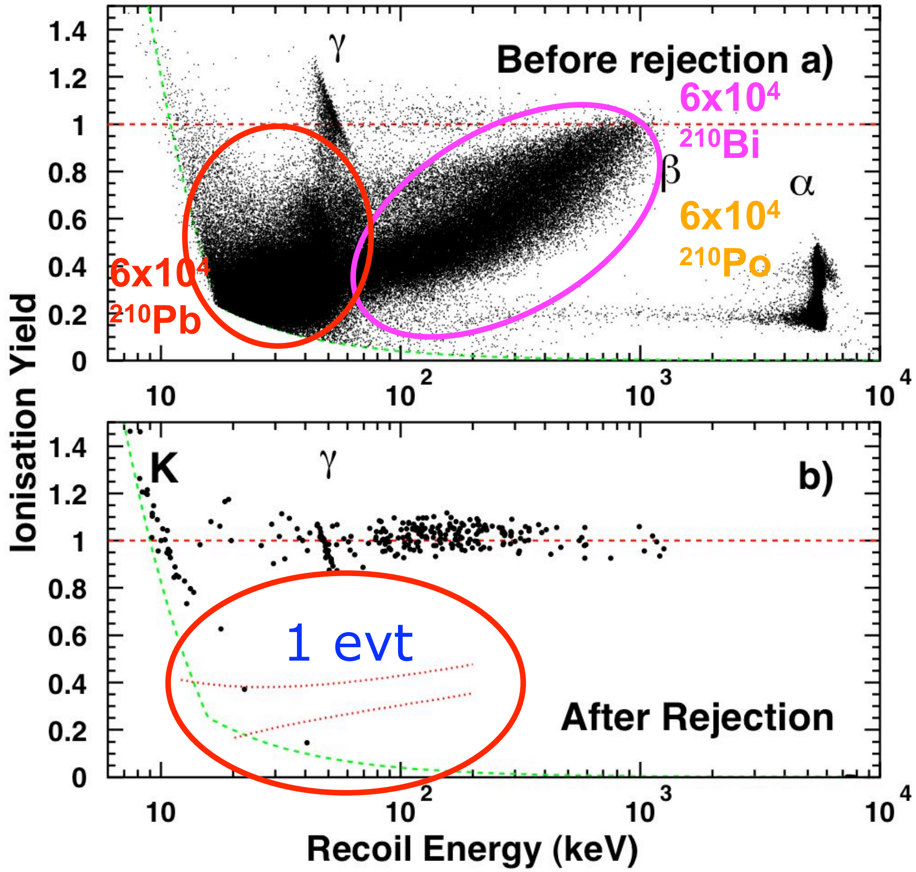
- First detector built 2007
- 1x200g + 3x400g tested in 2008
- 10x400g **running 1 year 2009-2010**
- **800g detectors tested and running** 2010-2011

An outstanding discrimination of surface events with IDs

Exposition to beta rays (^{210}Pb)



fiducial volume events
(including the 10 keV doublet
+ 46 keV gamma line)

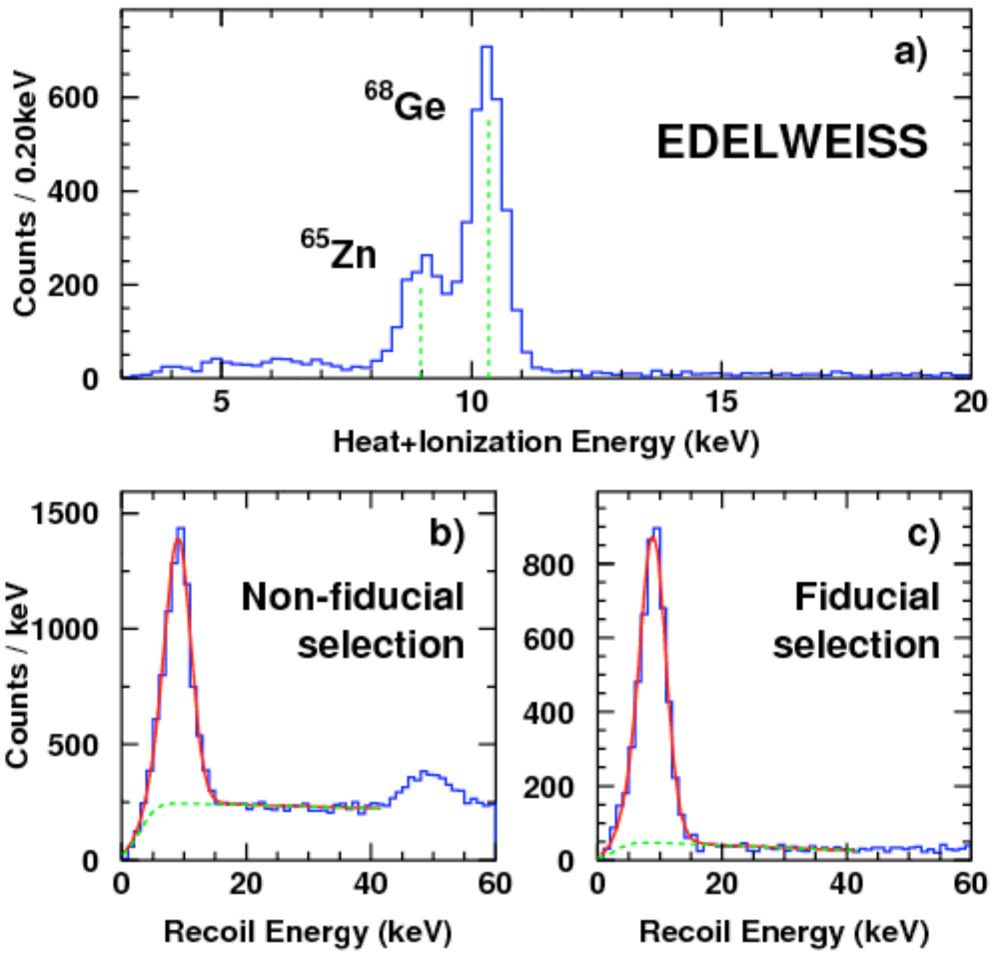


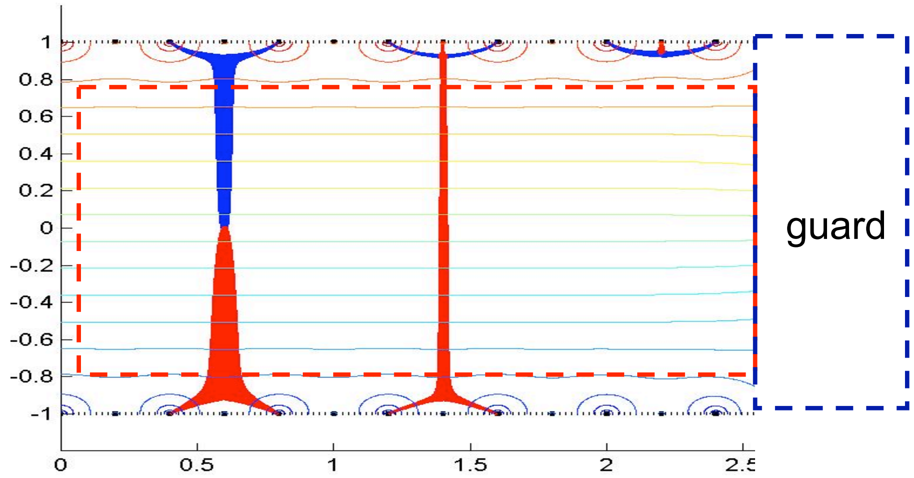
- *Redundant cuts on electrode signals*
- Surface and volume events are completely separated
- Overall beta rejection ~ 10^{-5}

PLB 681 (2009) 305-309

ID-400g : fiducial volume measurement

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



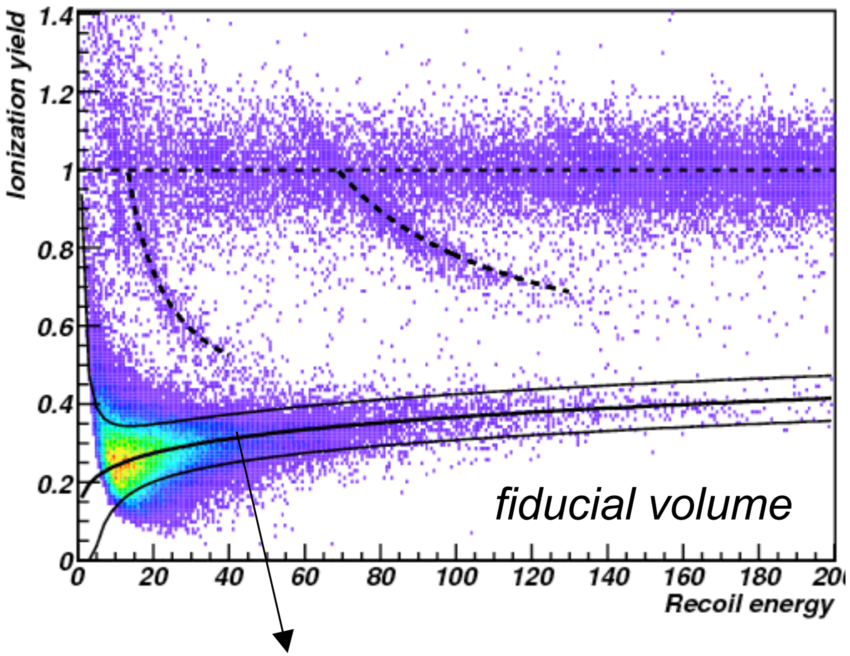


- Estimation with electrostatic models
- Measurement with cosmogenic lines:
  - ^{68}Ge and ^{65}Zn isotope lines at ~10keV, background electron recoil events
  - *Homogeneously distributed in the volume of the cristal*
  - *Real-condition measurement of fiducial cuts efficiencies at low energy in WIMP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

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

Calibrations of ID detectors

Neutrons (NR signal)



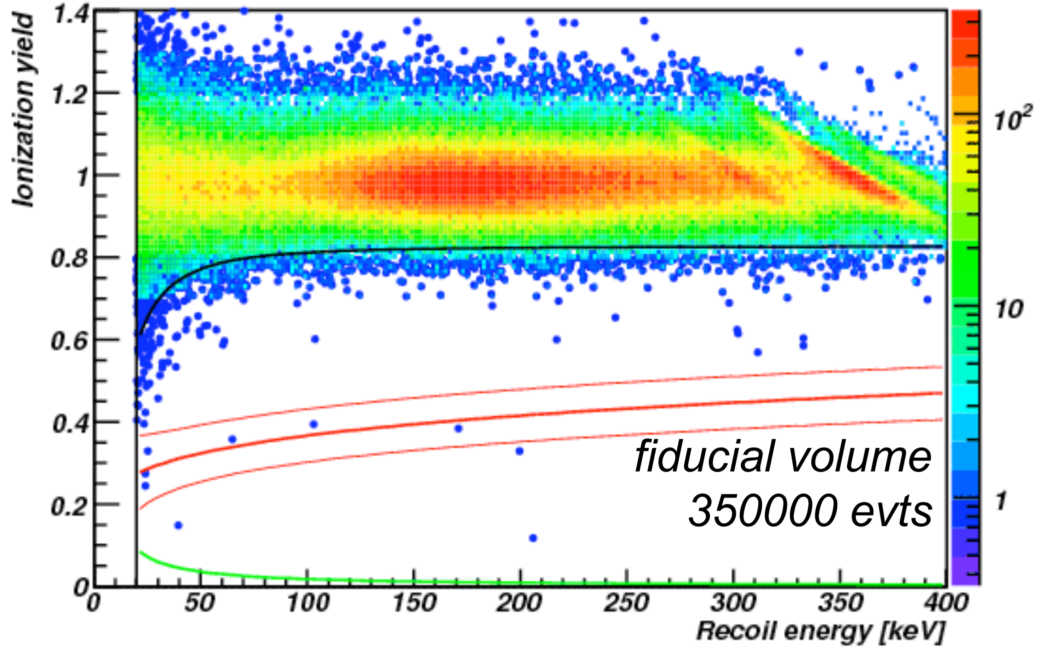
90% CL NR (nucl. recoil) region :

- 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

Gamma-rays (ER background)



• all detectors stacked, same analysis/cuts as for physics data

• anomalous events observed:

- for 20<E<200keV ~ $(3\pm1)\times10^{-5}$ rejection

- study of possible mechanisms under way

- Direct detection and EDELWEISS
- The « ID » detector principle and performances
- WIMP search with ID detectors (2009-2010 data)
- Ongoing and future projects
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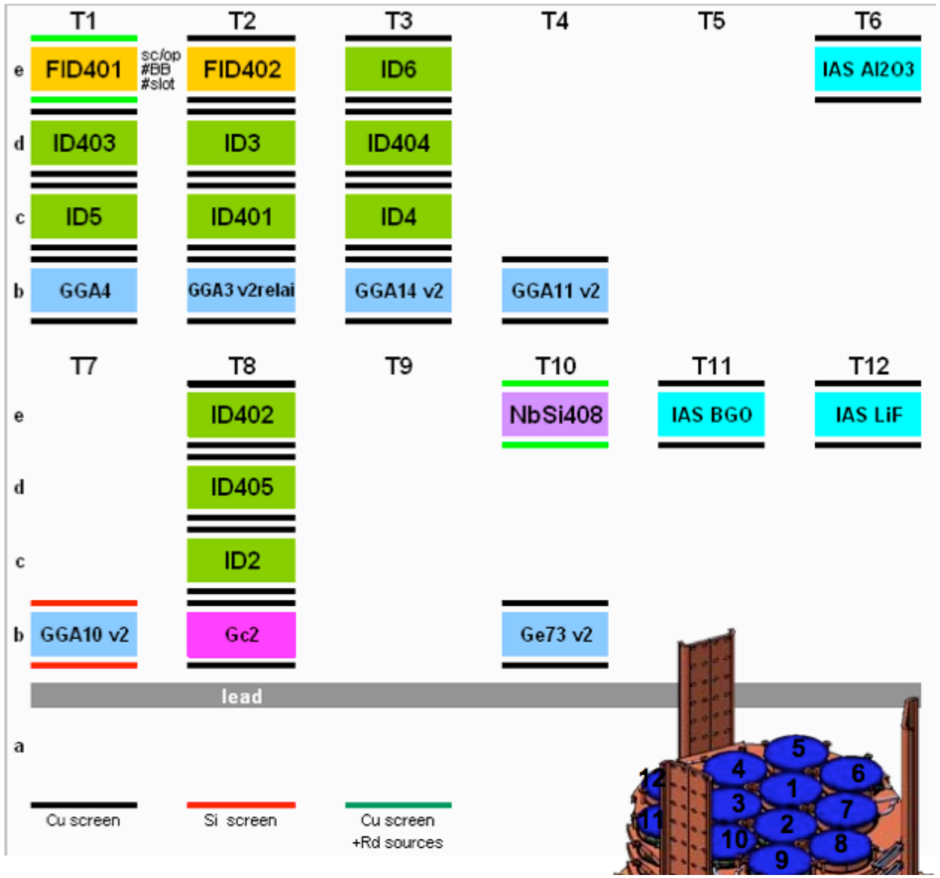
WIMP search with ID-400g detectors

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

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

- first 6 month data: **Phys. Lett. B687 (2010) 294-298**
- full dataset: **Phys. Lett. B702 (2011) 329-335**

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



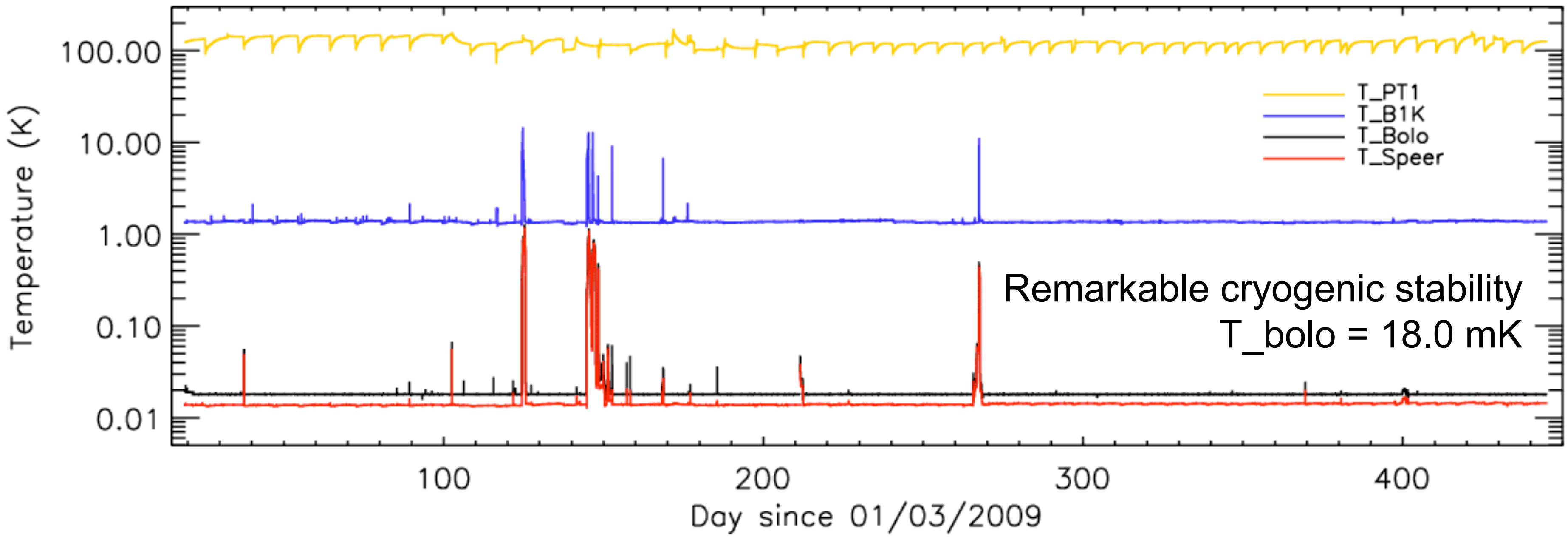
WIMP search : reconstruction / analysis steps

- Online trigger on heat pulses
- Two independent processings, using optimal filtering of heat and ionization data samples
- Removal of noisy periods : 17% exposure loss

  require FWHM heat < 2.5 keV, ion_fiducial < 2 keV, ion_guard < 2.5 keV
- Removal of misreconstructed pulses (chi2) : 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 exposure with 98.3% efficiency at threshold

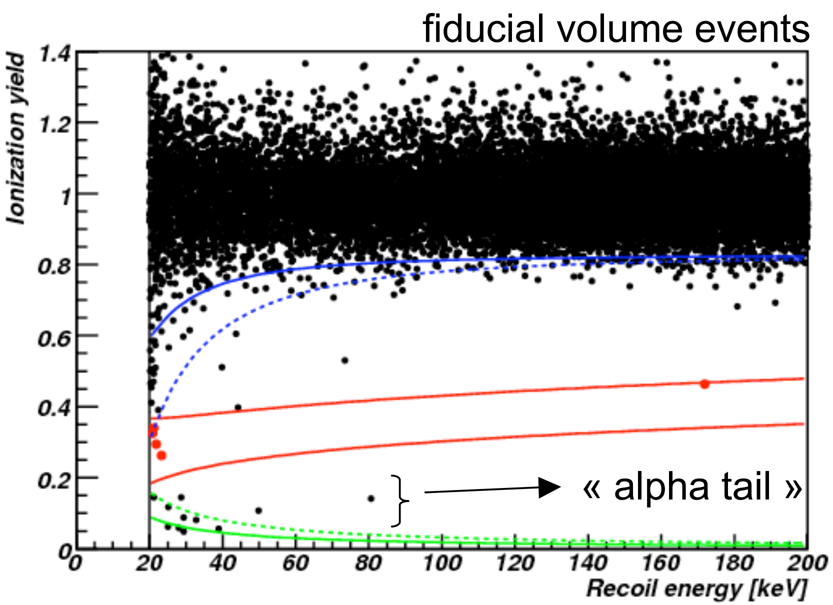


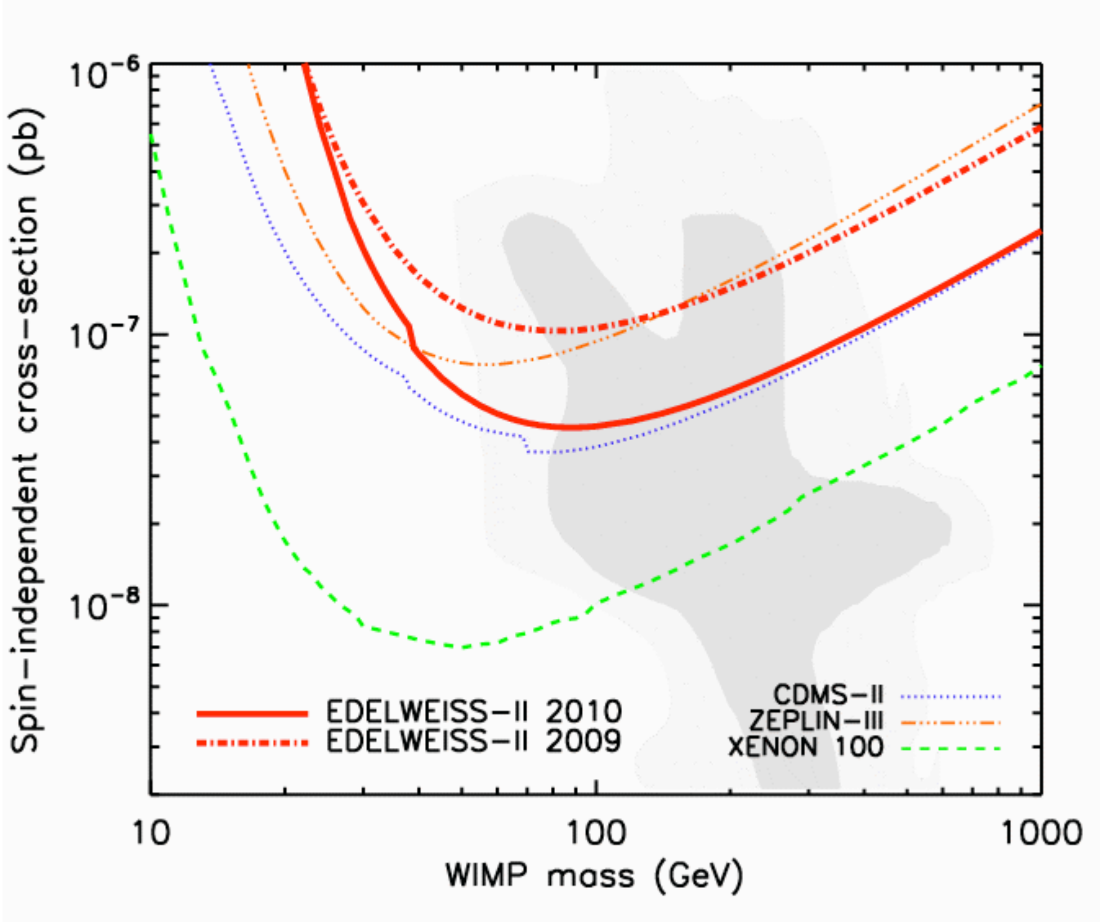
Expected backgrounds

Gamma:	^{133}Ba calib rejection x observed bulk γ	<0.9
	(3×10^{-5}) (18000)	
Beta:	β source rejection x observed surface evts	<0.3
	(6×10^{-5}) (5000)	
Neutrons from μ's:	μ veto efficiency x observed muons	<0.4
	(meas. > 92.8%) (0.008 evts/kgd)	
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

Background for the whole WIMP run: 3 evts

WIMP search with EDELWEISS-II : final results





Five WIMP candidates:
- four 20.8 < E < 23.2 keV
- one @ 172 keV

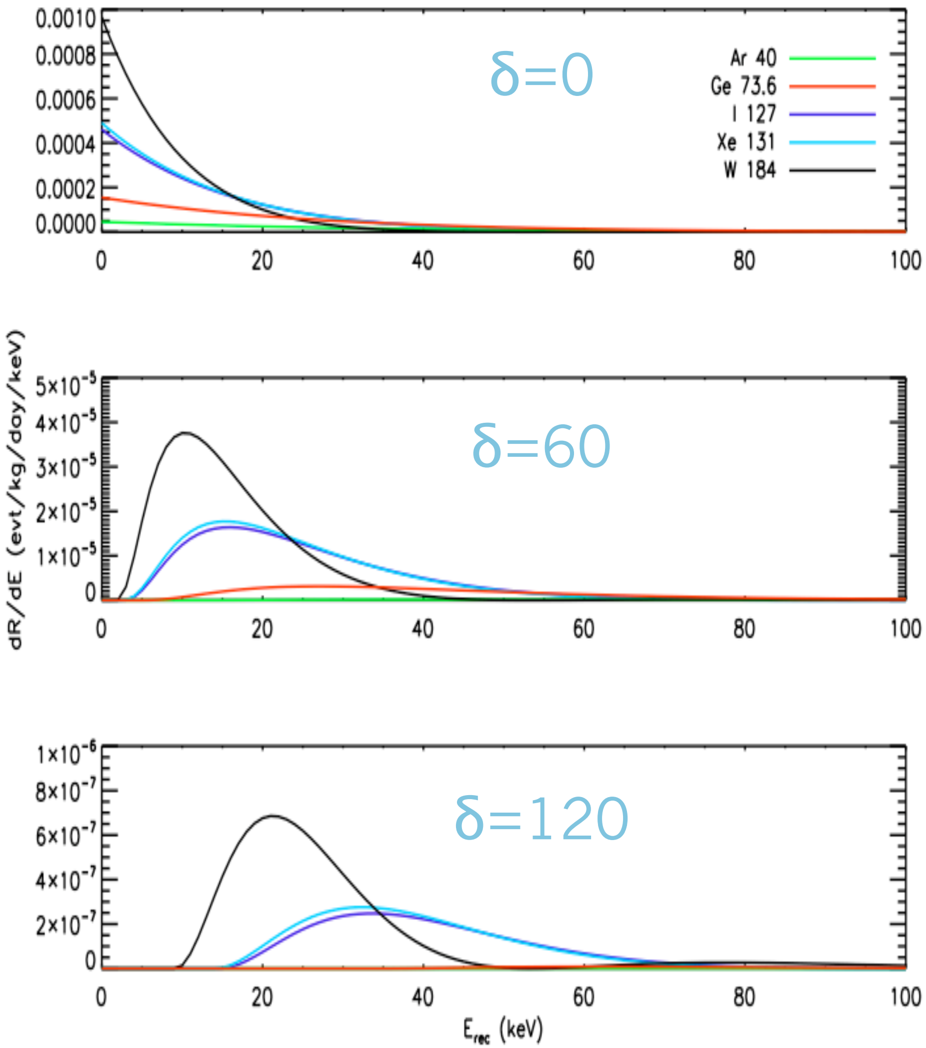
- 384 kg.d

4.4 x 10^{-8} pb at Mχ=85 GeV

- Sensitivity limited at low mass due to background

Phys. Lett. B 702 (2011) 329-335

Inelastic dark matter



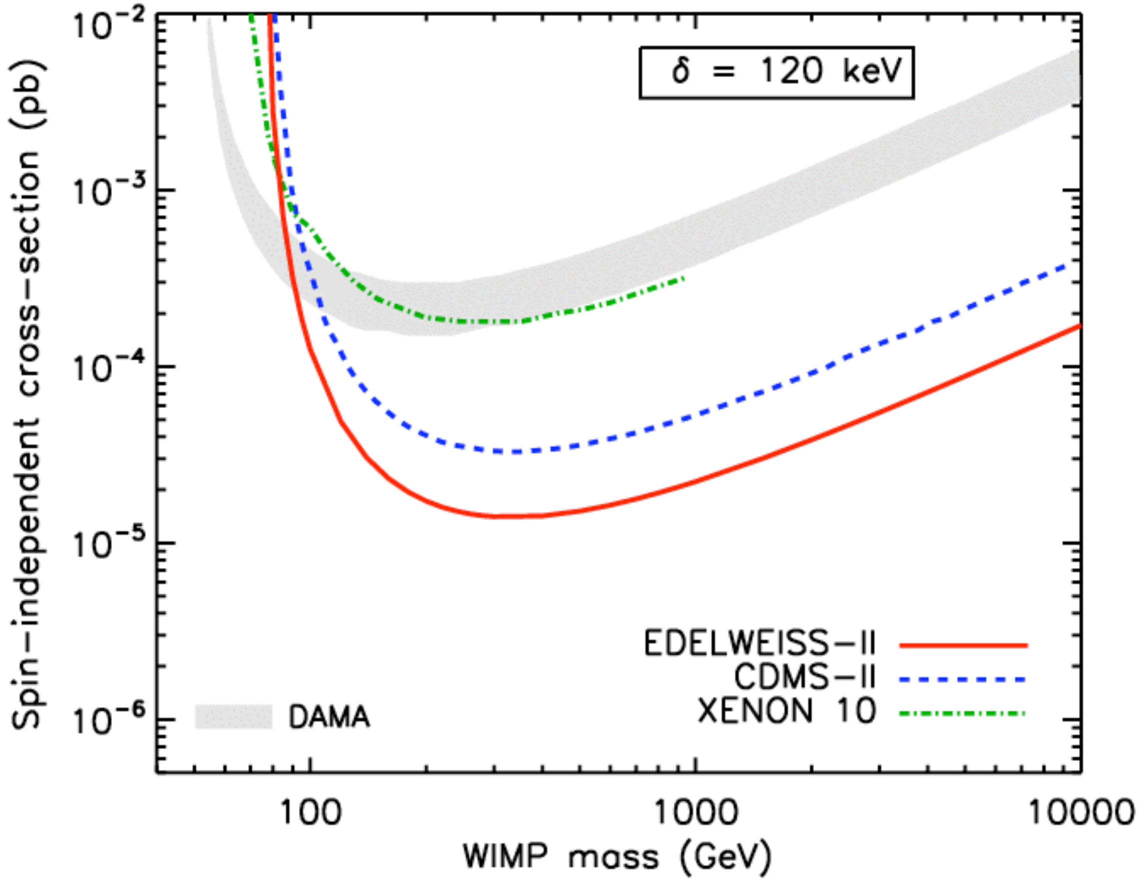
- Dark matter modulated signal claimed by DAMA/LIBRA vs. null detection in all the other direct detection experiments

- χ + m ➔ χ* + m (δ~100 keV)

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

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

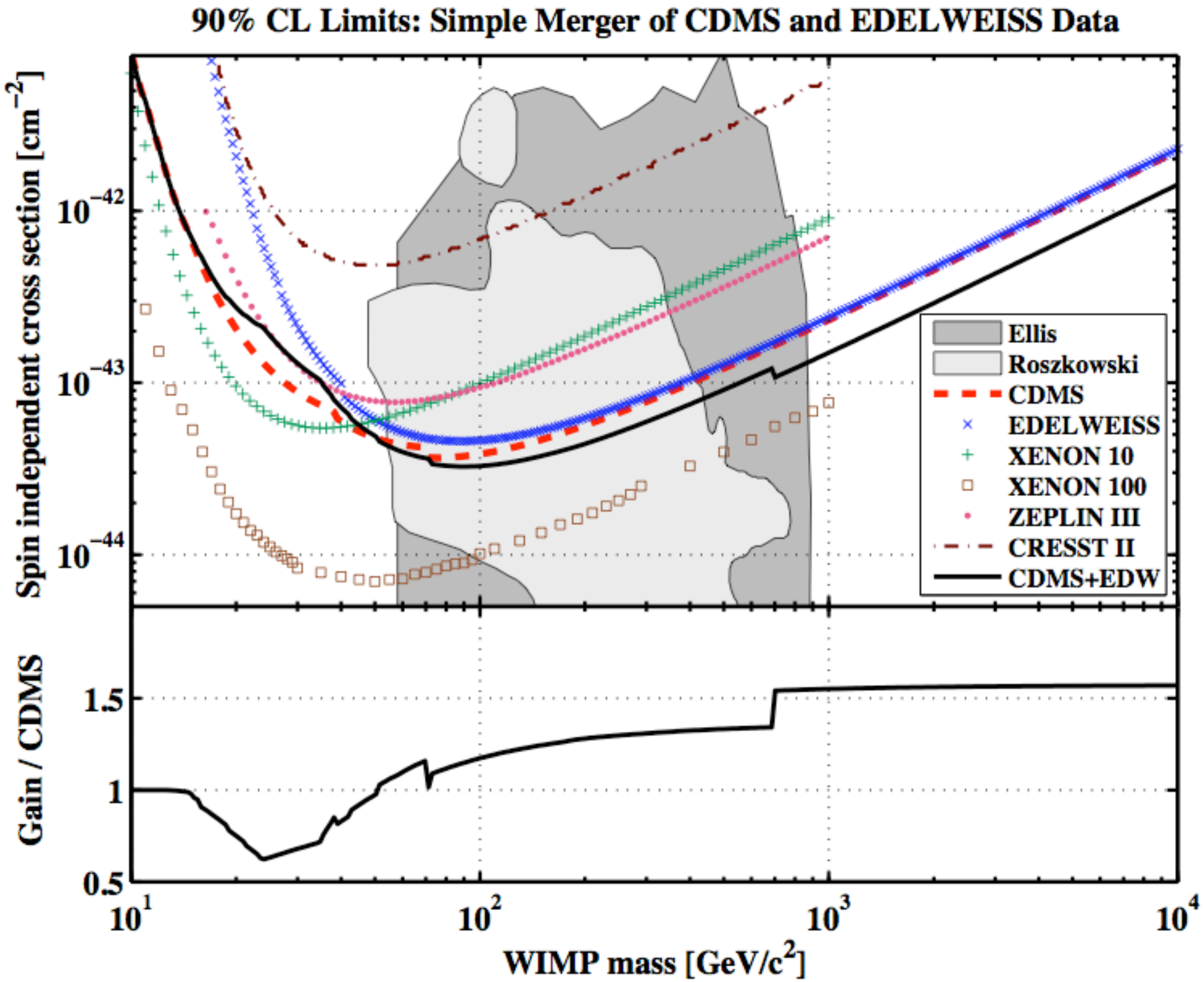
Constraints on inelastic dark matter



- same data & analysis as in the elastic case
- use v_{esc} = 544 km/s (RAVE survey)
- **DAMA allowed region excluded for $M\chi$ > 90 GeV (90%CL)**

EDELWEIS-CDMS combined analysis

- The use of the same target material allows simple combination of data.
- Simple merger of data sets was chosen prior to any analysis.
  - EDW: 384 kg.d, [20-200keV], 5 evts
  - CDMS: ~379 kg.d, [~10-100keV], 4 evts
- Other methods have also been tested.



~50% gain at high WIMP masses.

Phys. Rev. D **84, 011102 (2011).**

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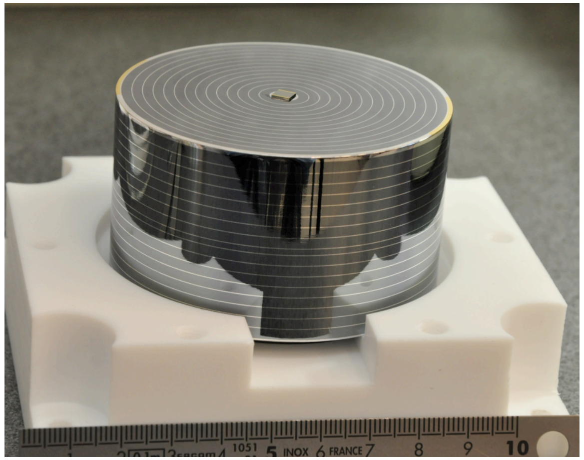
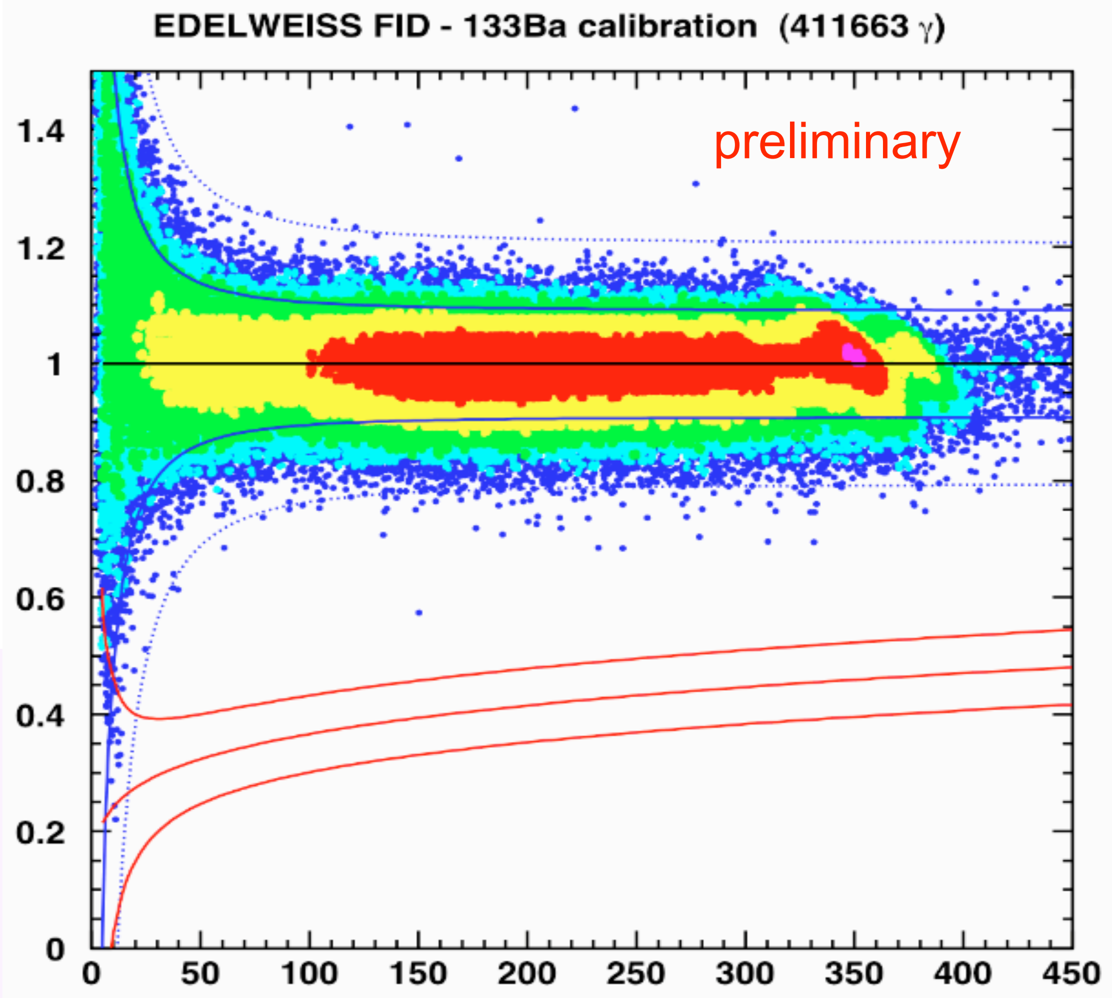
Better than ID : the FID800 detector





<u>Increase mass + sensitivity :</u>

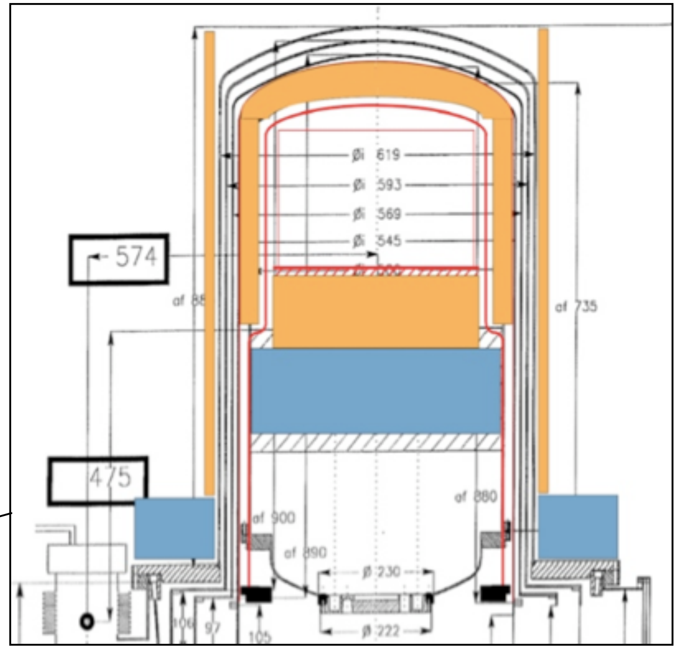
- 800g crystal

- two NTD sensors per detector

- interleaved electrodes on all the surface : no « guard » region anymore, ~ 75% fiducial volume

Strong improvement of the gamma-ray rejection over original ID detectors

Towards 5×10^{-9} pb : EDELWEISS-III



- Program under way, funded
- Infrastructure : Upgrades of cabling, cold electronics, cryogenics, acquisition and shielding **within the current EDW-II setup**
    - Lower thresholds due to reduced noises
    - Special care with neutrons : additionnal inner PE shield

- Detectors : ~ 40 FID800 bolometers installed 2012 : **24 kg fiducial**

  ⇒ 3000 kg.d by end 2012

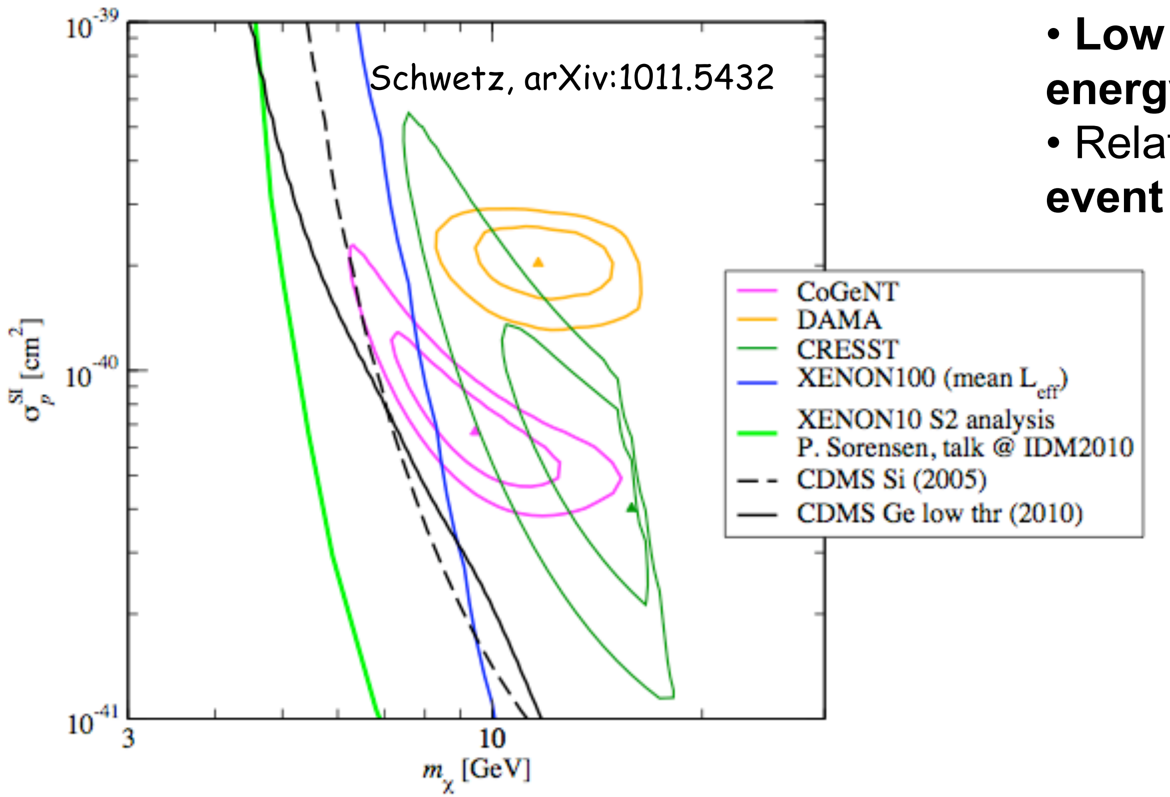
  (5×10^{-9} pb)

Longer term : EURECA project
CDR in redaction

- large cryogenic installation (ton-scale)
- multi-target : germanium and scintillators
- important efforts in infrastructure, detector developments and background control

- Direct detection and EDELWEISS
- The « ID » detector principle and performances
- WIMP search with ID detectors (2009-2010 data)
- Ongoing and future projects
- Low-mass WIMPs

Low-mass WIMPs : an interesting but messy window



• **Low mass (~10GeV)** : **very low-energy signals**
• Relatively large cross-section : **large event rates** wrt « standard WIMPs »

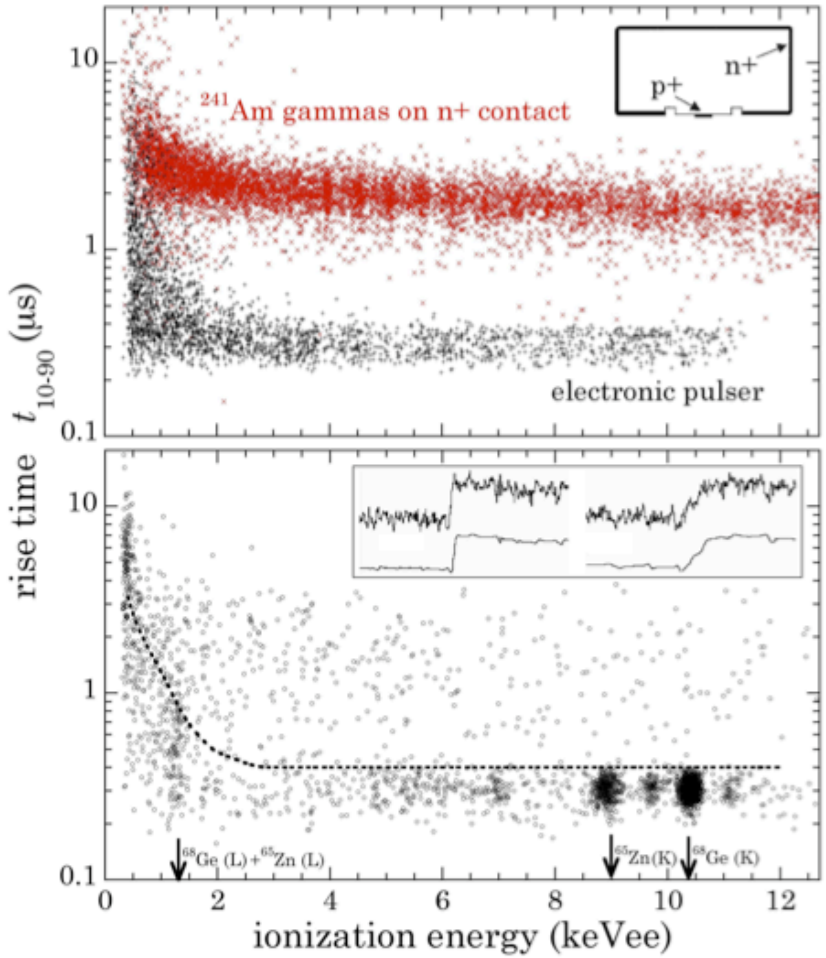
They see WIMPs:
- DAMA (modulation)
- CoGeNT (spectrum+modulation)
- CRESST (spectrum)

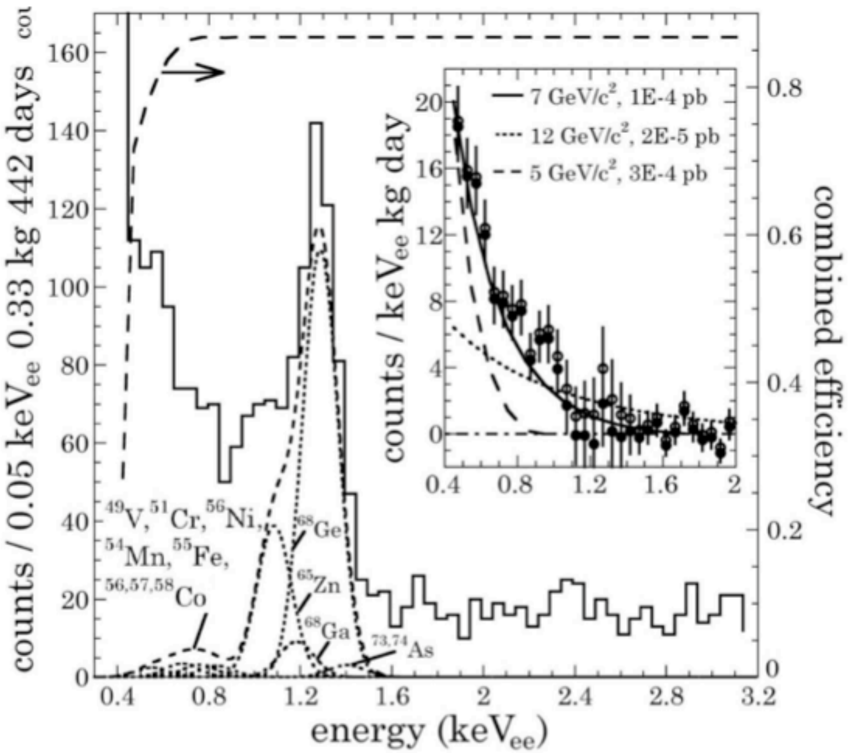
They don't see WIMPs:
- XENON 10
- XENON 100
- CDMS
- Edelweiss???

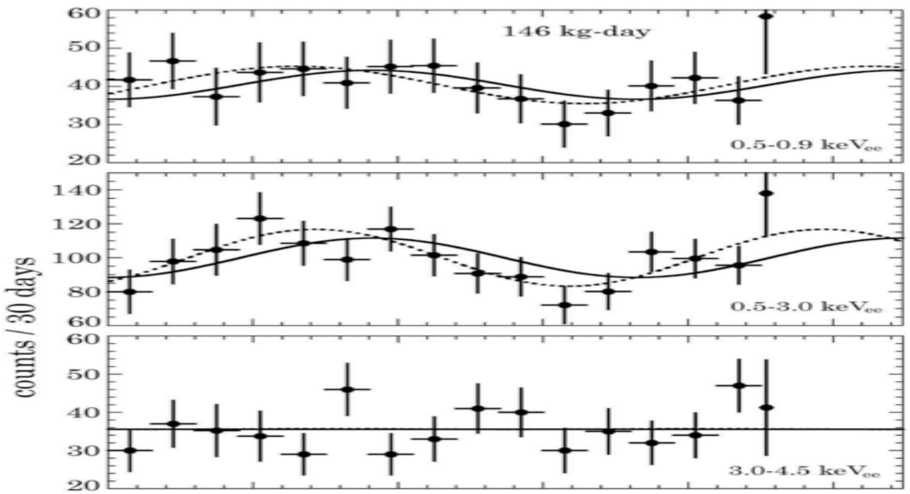
Constraints from other searches:
- colliders : M_X<40 GeV excluded for SUSY neutralinos *with universal couplings only*
- indirect search in dwarf galaxies by Fermi : M_X<40 GeV also excluded assuming standard annihilation branching ratios

The CoGeNT signal

Germanium, ionization only





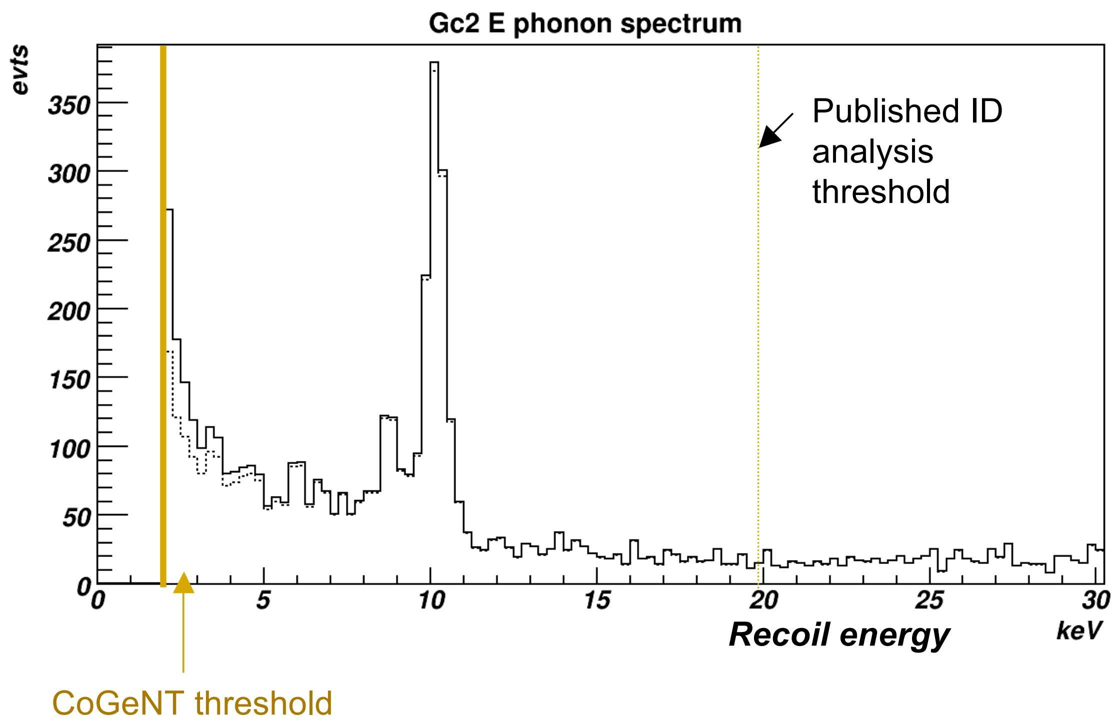


Going to lower thresholds with EDW

- Goal : have 2 parameters to separate nuclear/electron recoils and/or surface/volume events at 2 keVr
- R&D ongoing to reach few 100 eV thresholds on ionisation **and** heat

__Example: heat-only detector (330g), one NTD sensor, several-month exposure__

J. Domange thesis



- pure bolometric measurement
- NO discrimination between electron and nuclear recoil
- 2 keV analysis threshold
- Backgrounds: gammas, betas from Pb decay, heat noise fluctuations

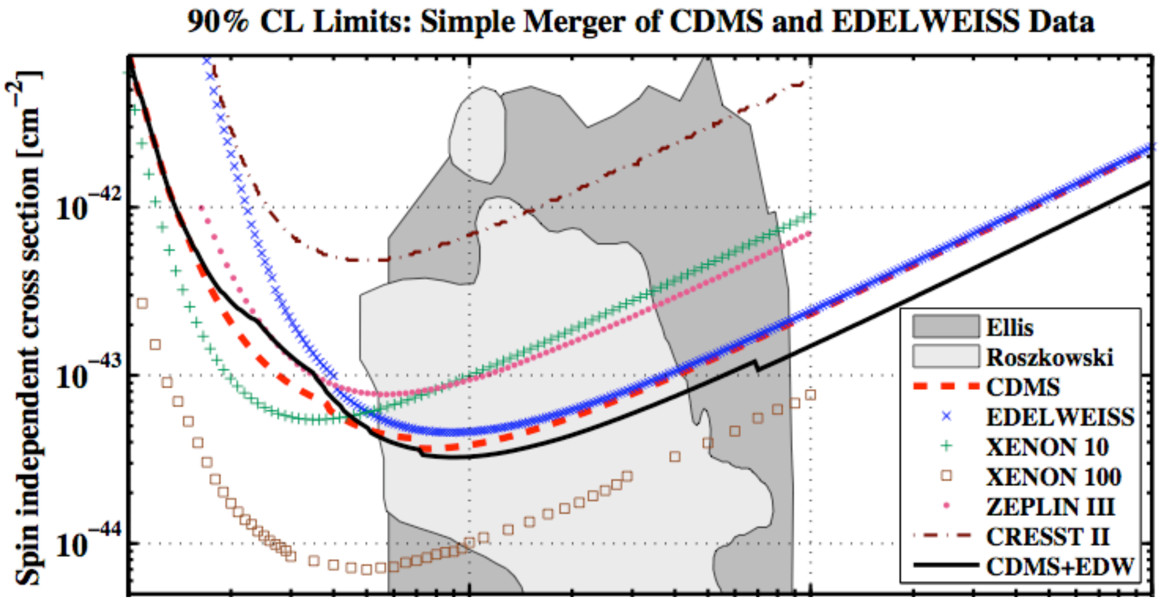
Summary / prospects

EDELWEISS-II : important progress with cryogenic Ge detectors

- One year of WIMP search
- <u>4.4×10^{-8} pb sensitivity achieved</u>
- <u>Data combined with CDMS</u>
- Backgrounds start to appear

EDELWEISS-III : project going on

- New Goal 5×10^{-9} pb, 25 kg fiducial
- Improvements wrt backgrounds
  - FID800 design
- Build 40 detectors, upgrade set-up
  - 2012 = 3000 kg.d



Low-mass WIMPs

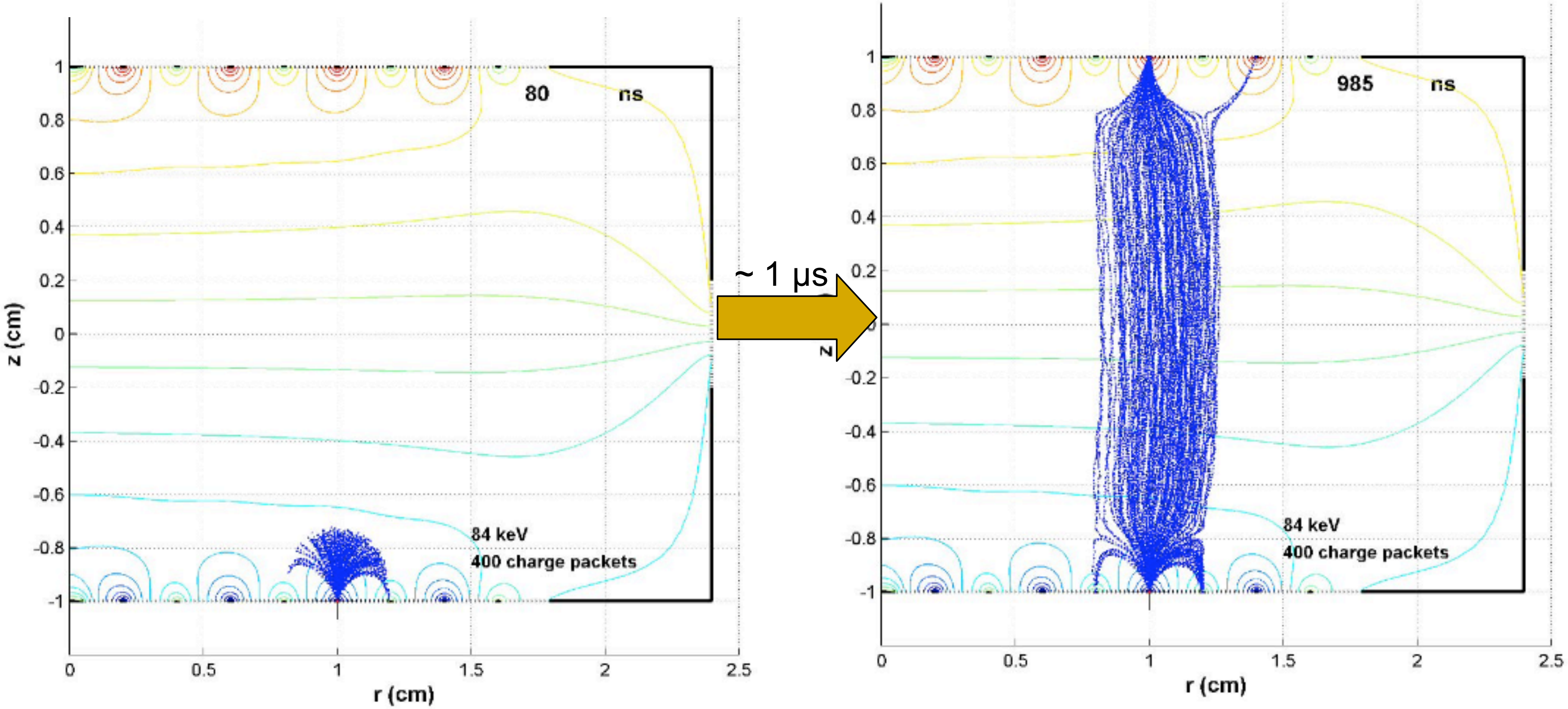
- Interesting region, with loose experimental constraints
- Current analysis going on
- Detector developments within EDW to lower thresholds

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)

Low-threshold reanalysis of CDMS data

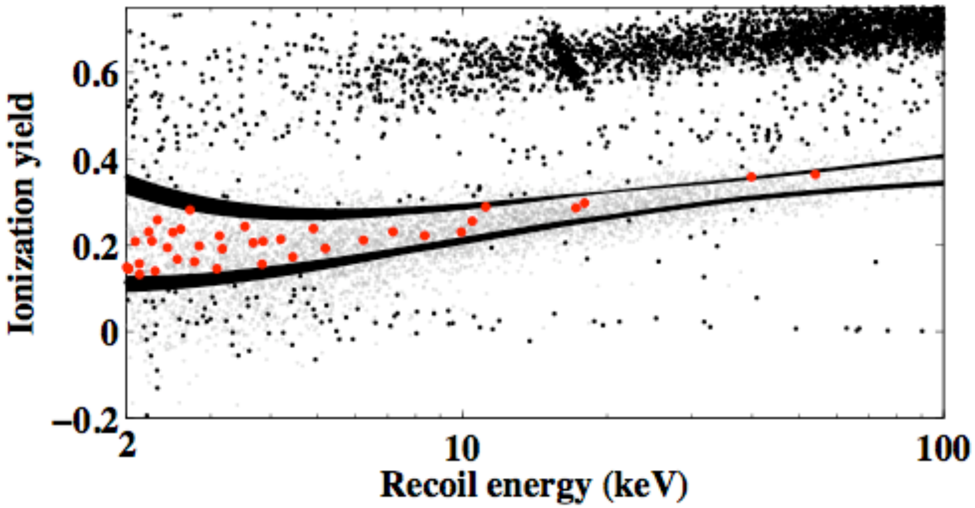
Phys.Rev.Lett.106:131302,2011

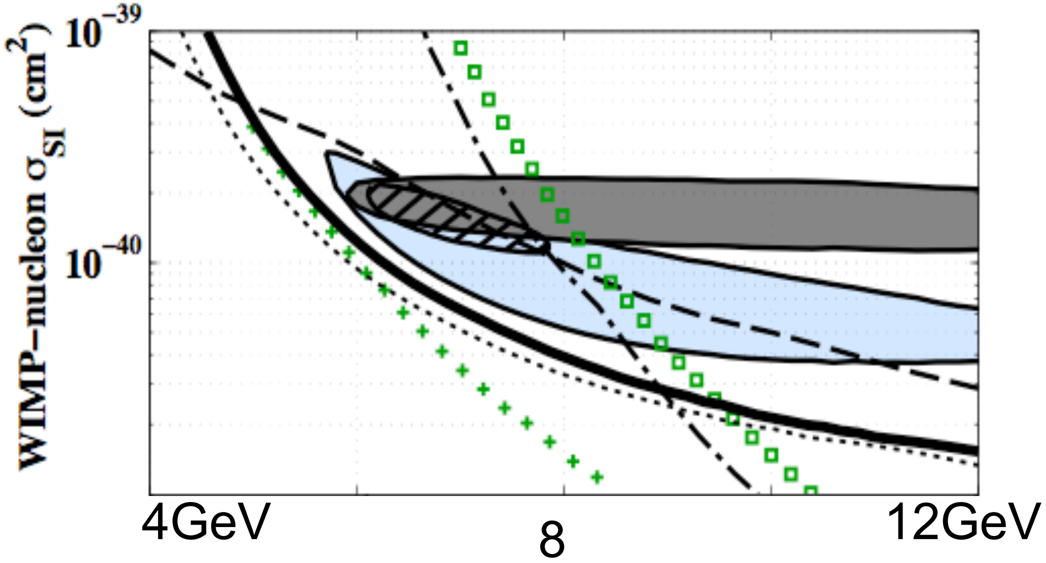
- Abandon some gamma discrimination power to gain sensitivity at low-energies

- Use several detectors but in practice the « best » detector dominates the sensitivity

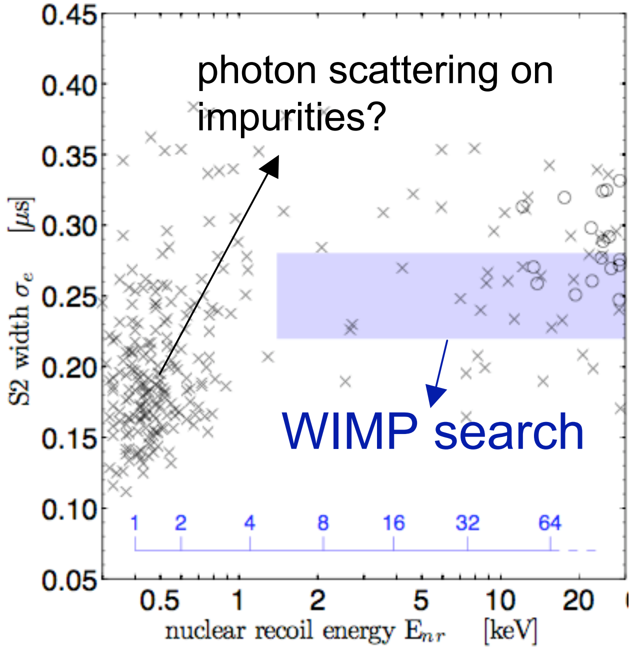
- Several backgrounds, difficult to quantify :
- unrejected gammas and betas
- « ionizationless events »

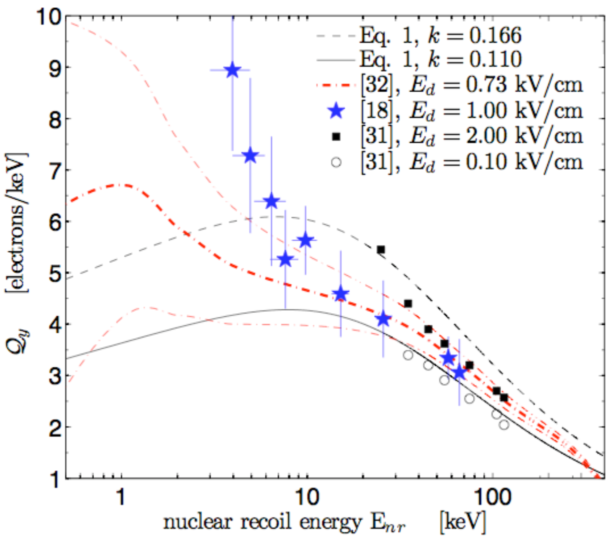
- Limit is set assuming the residual events are WIMPs





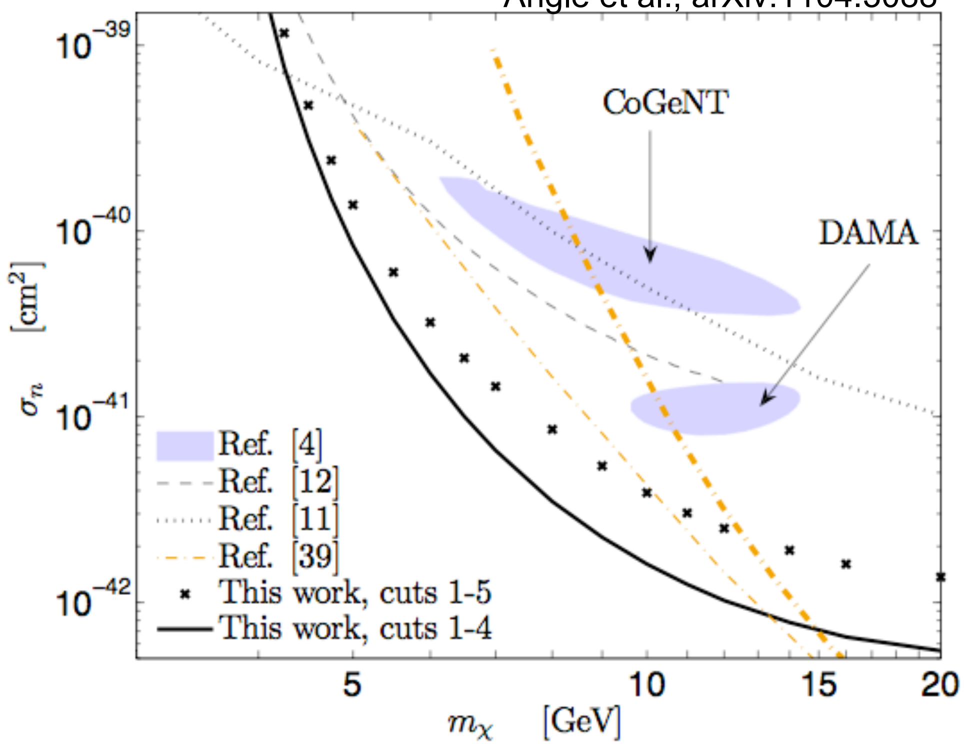
« S2-only » XENON10 data

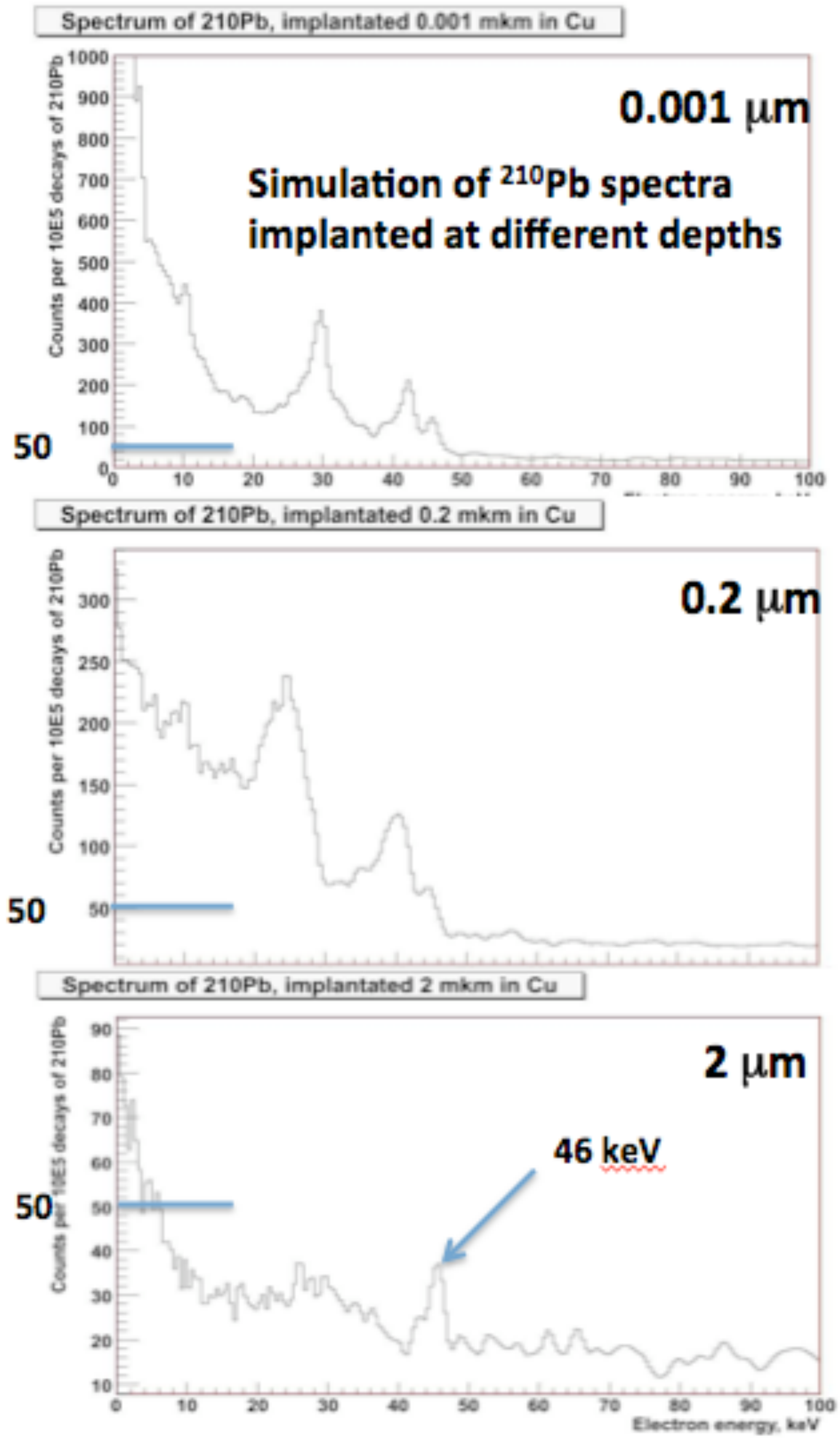




- Abandon some gamma rejection and position reconstruction
- A « z » cut is still possible (average efficiency 41%)
- Hardware trigger : S2, single electron
- Effective target mass 1.2kg, 15 kgd

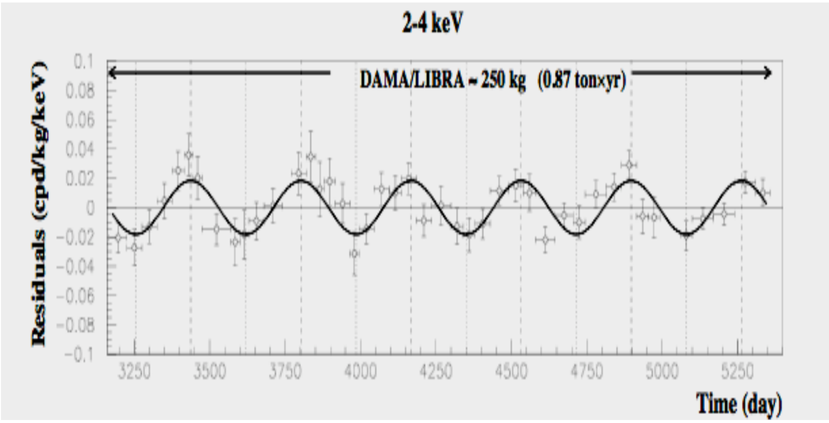
Angle et al., arXiv:1104.3088




Spectrum of 210Pb, implantated 0.001 mkm in Cu
0.001 μm
Simulation of 210Pb spectra
implanted at different depths
Counts per 10E5 decays of 210Pb
50
Spectrum of 210Pb, implantated 0.2 mkm in Cu
0.2 μm
50
Spectrum of 210Pb, implantated 2 mkm in Cu
2 μm
46 keV
50
Electron energy, keV

The DAMA signal

• NaI scintillating crystal : no rejection of electromagnetic background
• Search for annual modulation of the raw single interaction rate
• 1.17 ton.year (0.29 DAMA + 0.87 DAMA/LIBRA)



- Decrease of the modulation amplitude ??
- Phase ~ phase of LVD modulation of muon flux @ LNGS ??

CRESST results