The direct dark matter detection with the EDELWEISS experiment and few words on low mass WIMPs

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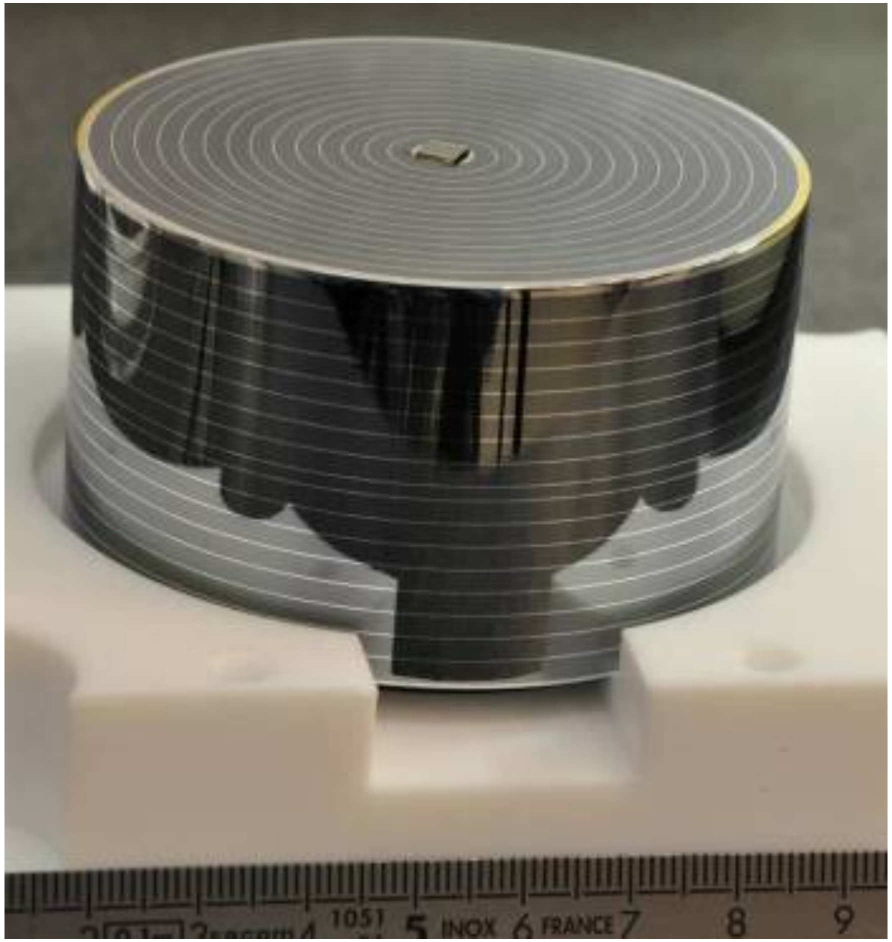
Outline

- WIMP direct detection in a nutshell
- The EDELWEISS-II collaboration
- The set-up and the detectors
- WIMP hunting: run 12
- From EDW-II to EDW-III
- The next future: EURECA
- Low-mass WIMP search
- Conclusions & Perspectives



WIMP direct detection

Galactic WIMP

velocity v ~ 200 km/s
local density ρ_0

Interaction in a terrestrial detector

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 scattering:

$$E_{recoil} = E_{WIMP} \frac{4 M_{nucleus} M_{WIMP}}{(M_{nucleus} + M_{WIMP})^2} \cos^2 \theta_{recoil} \qquad \sim 1 - 100 \text{ keV}$$

- **Interaction rate**:

$$R = \phi \, \sigma \, N$$

φ WIMP flux
σ cross section
N target nuclei

WIMP direct detection

Galactic WIMP

velocity v ~ 200 km/s
local density ρ_0

Interaction in a terrestrial detector

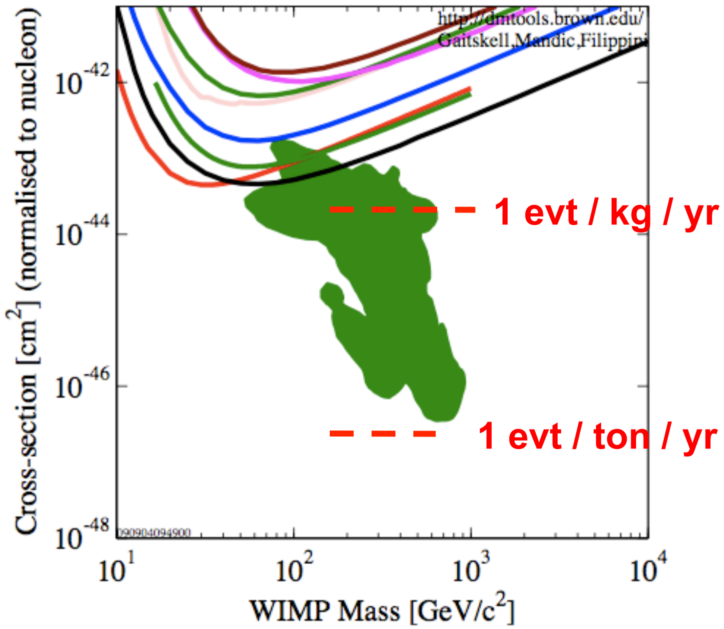
WIMP

θ_r

Energy deposition
Nuclear recoil E_r

- Low-threshold detectors
- Ultra-low-background detectors :
  « Passive » bkg reduction (shields, radiopurity, external vetos..)
  « Active » bkd reduction (discrimination of electron recoils, multiple scatters..)

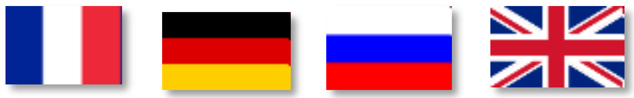
- We consider only the « spin-independent » channel here → single WIMP-nucleon cross-section ∀ target

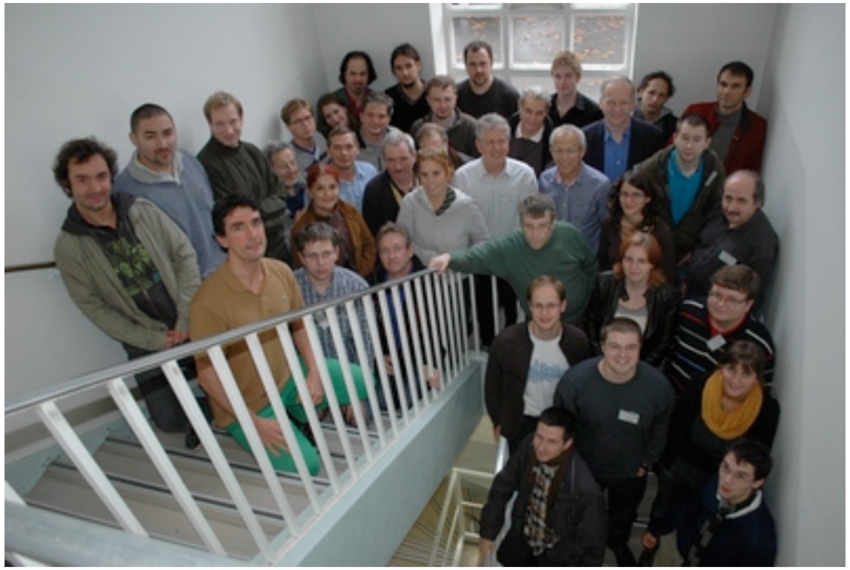


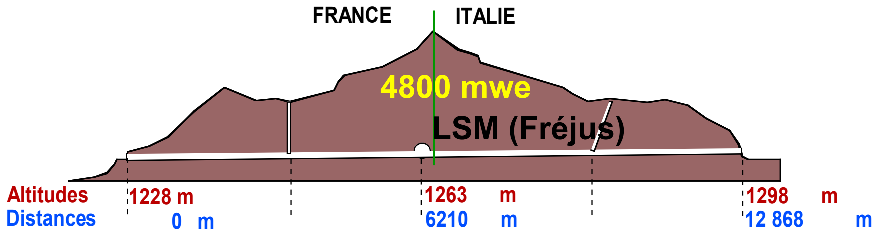
EDELWEISS-II: the collaboration

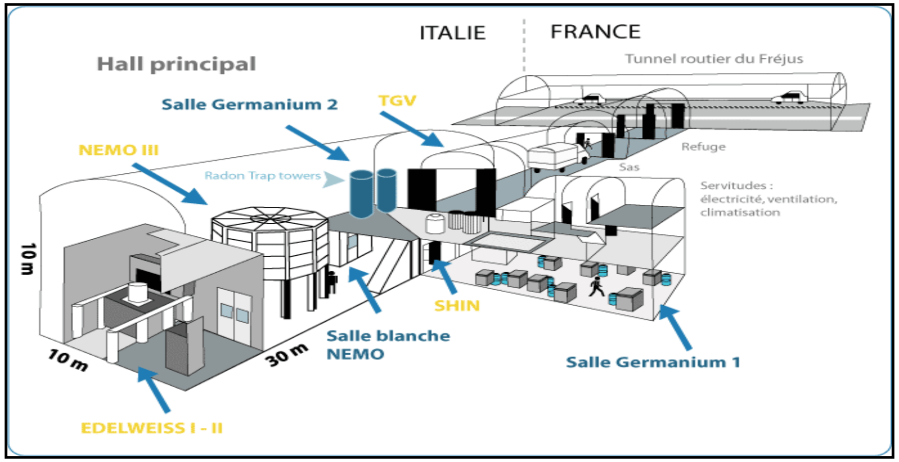
- CEA Saclay (IRFU & IRAMIS) — Detectors, electronics, acquisition, data handling, analysis
- CSNSM Orsay — Detectors, cabling, cryogenics
- IPN Lyon — Electronics, cabling, low radioactivity, analysis,detectors, cryo.
- Institut Néel Grenoble — Cryogenics, electronics
- Karlsruhe KIT + IPE — Vetos, neutron detectors, background
- JINR Dubna — Background, neutron and radon detectors
- Oxford University — Detectors, cabling, cryogenics, analysis
- Sheffield University — MC simulation

~ 50 people / 4 countries

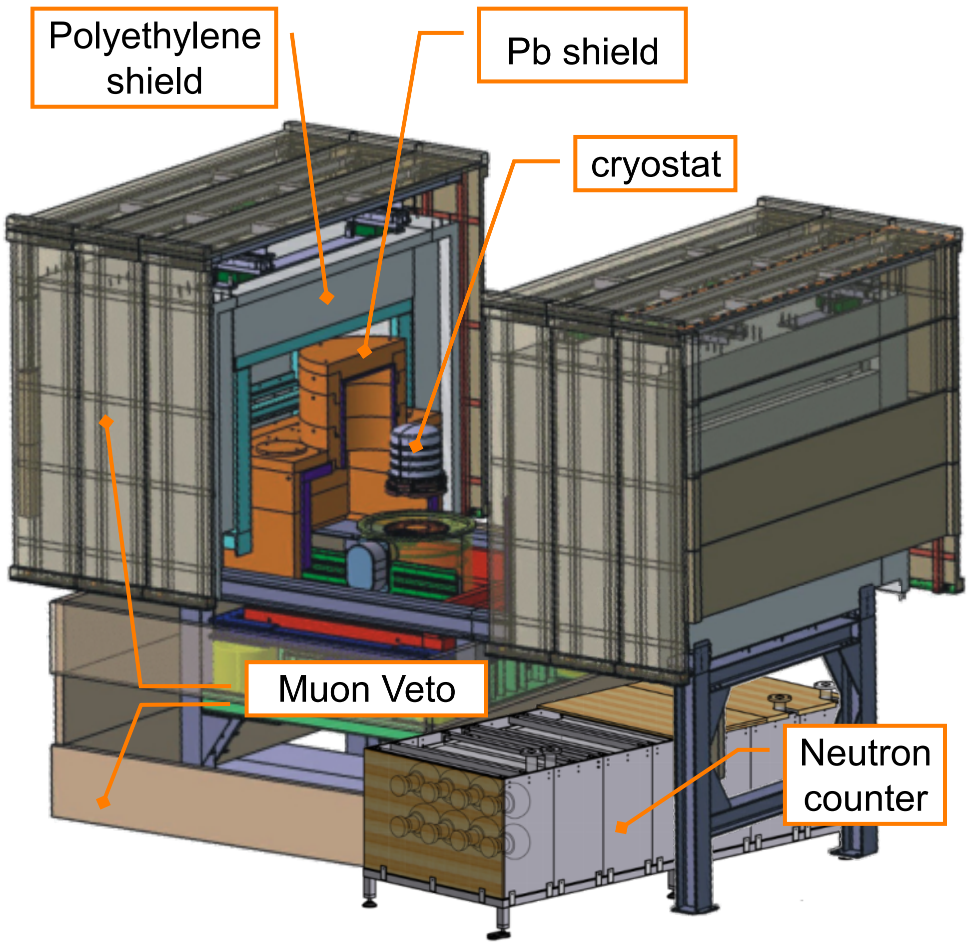








EDELWEISS: the set-up

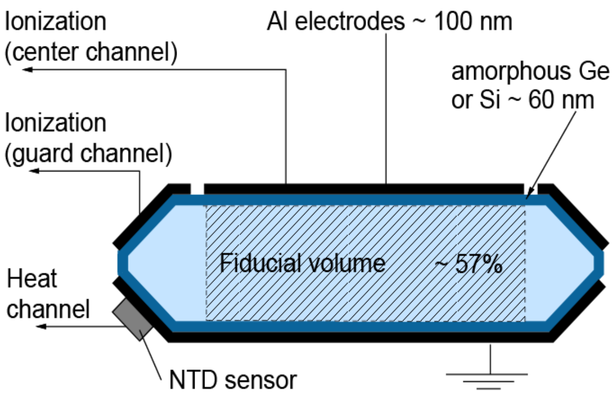


- **Cryogenic installation (18 mK) :**
  - Reversed geometry cryostat
  - **up to 40 kg of detectors**
- **Shieldings :**
  - Clean room + deradonized air (10 mBq/m^3)
  - Active muon veto (>98% coverage)
  - **50 cm PE** shield
  - **20 cm Lead** shield
- **(Many) others :**
  - Remotely controlled sources for calibrations + regenerations
  - Radon detector sensitive down to few mBq/m^3
  - He^3 neutron detector: thermal neutron monitoring inside shields – sensitivity 10^{-9} n/cm^2/s)
  - liquid scintillator 1 m^3 neutron counter: study of muon induced neutrons

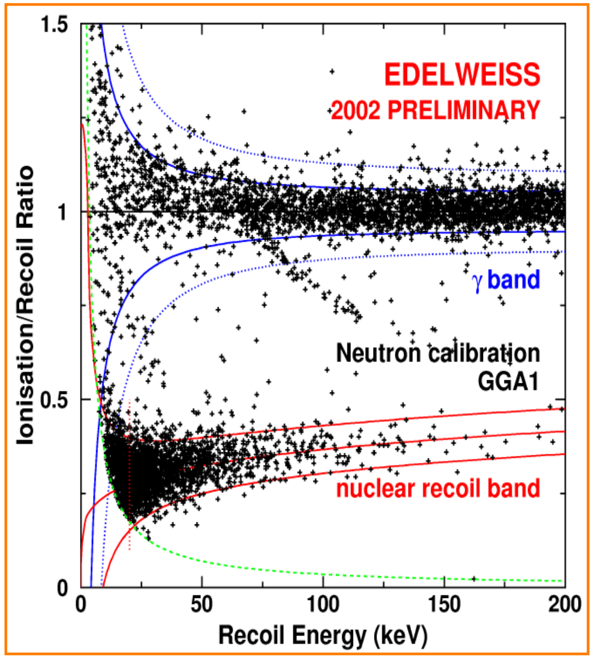
The EDELWEISS detectors: basic principle

1st generation – GeNTD

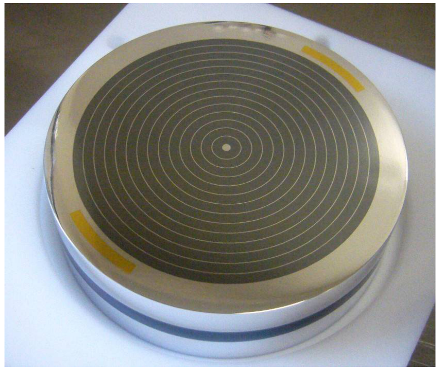
320 gr - All planar electrodes



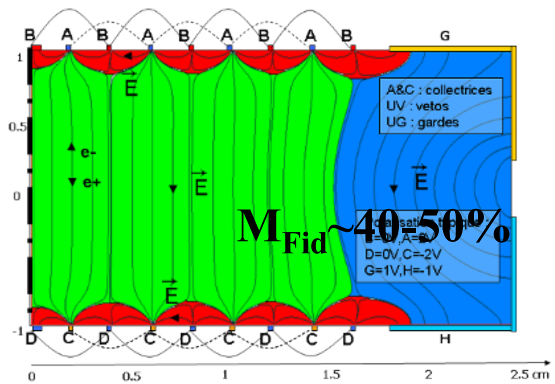
- **Simultaneous measurement**
  - **Heat @ 20 mK** with Ge/NTD thermometer
  - **Ionization @ few V/cm** with Al electrodes
- **Evt by evt identification** of the recoil
- $Q = E_{ionization}/E_{recoil}$
  - **Q=1 for electron recoils**
  - **Q≈0.3 for nuclear recoils**



2nd generation - ID400



Φ 70mm, H 20mm, 410g
14 concentric electrodes (width 100µm, spacing 2mm) without beveled edge.

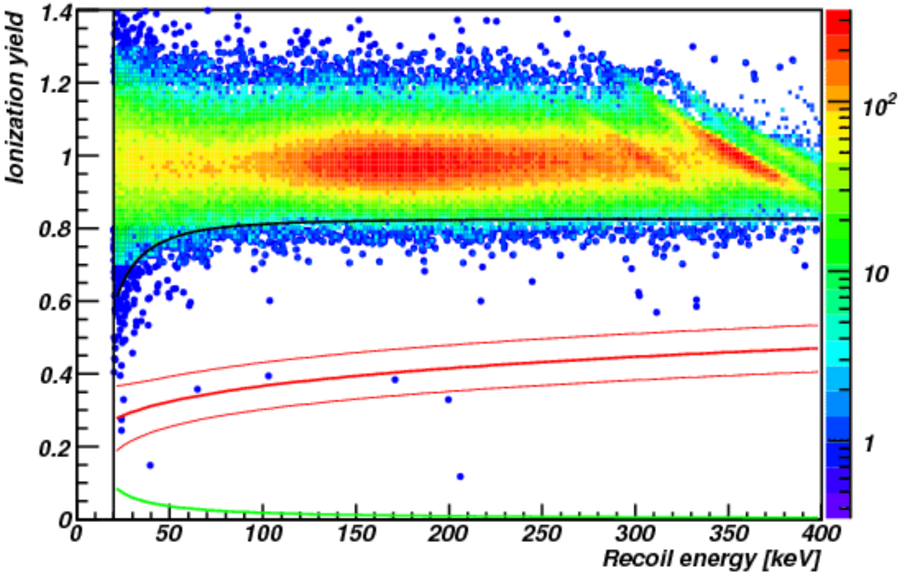


- Keep the EDW-I NTD phonon detector
- Modify the E field near the surfaces with interleaved electrodes:
  - Biases to have an electric field
    ~ horizontal near the surface and
    ~ vertical in the bulk
- The rings are alternately connected by ultra-sonic bonded wires.

→ Easy cuts on « veto » + guard electrodes define the fiducial zone

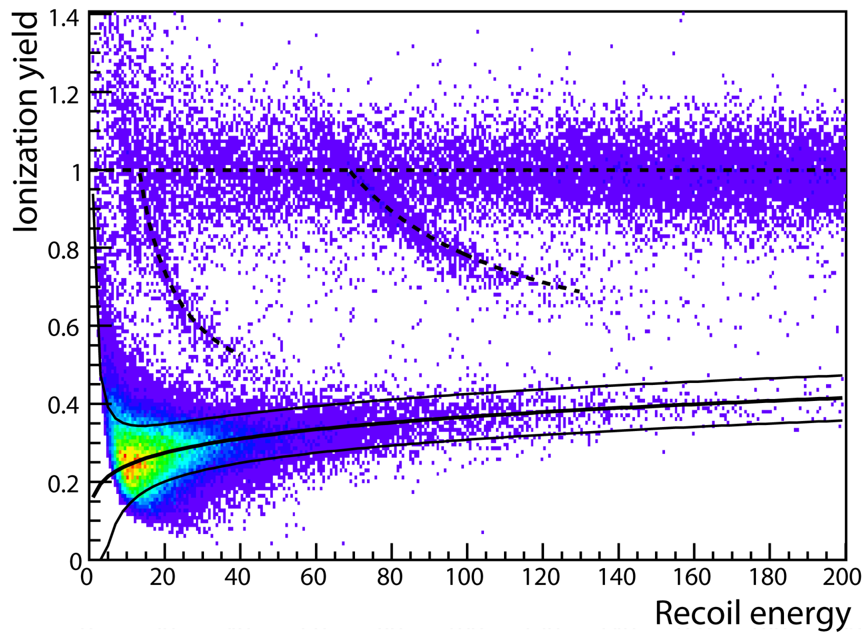
Gamma and neutron calibrations

γ calibrations with 133Ba



More than 350000 γ
γ suppression factor 3x10^{-5}
1 « NR » for every 30k γ (20-200 keV)

n calibrations with AmBe



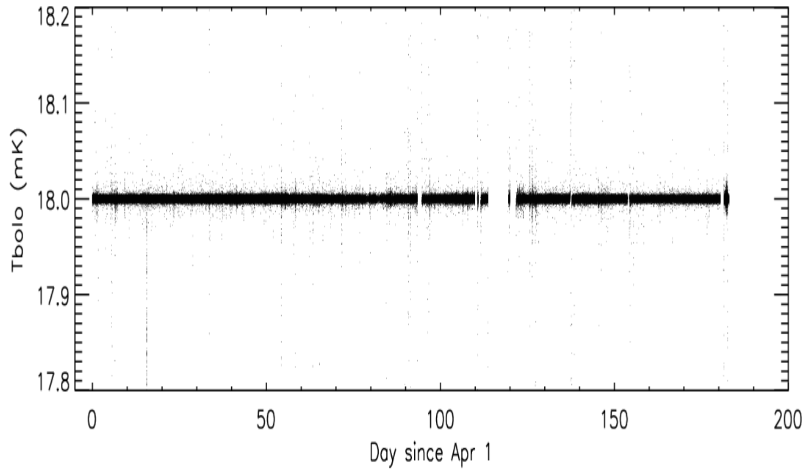
90% CL signal region
Q= 0.16 $E_r^{0.18}$
from <10 to 200 keV
(detection efficiency below 20 keV)

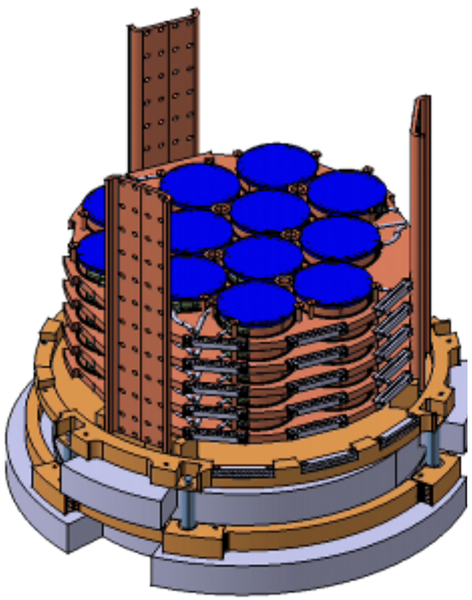
WIMP hunting with ID detectors

Run 12 (1^{st} april 2009 – 20 may 2010): stability over 14 months

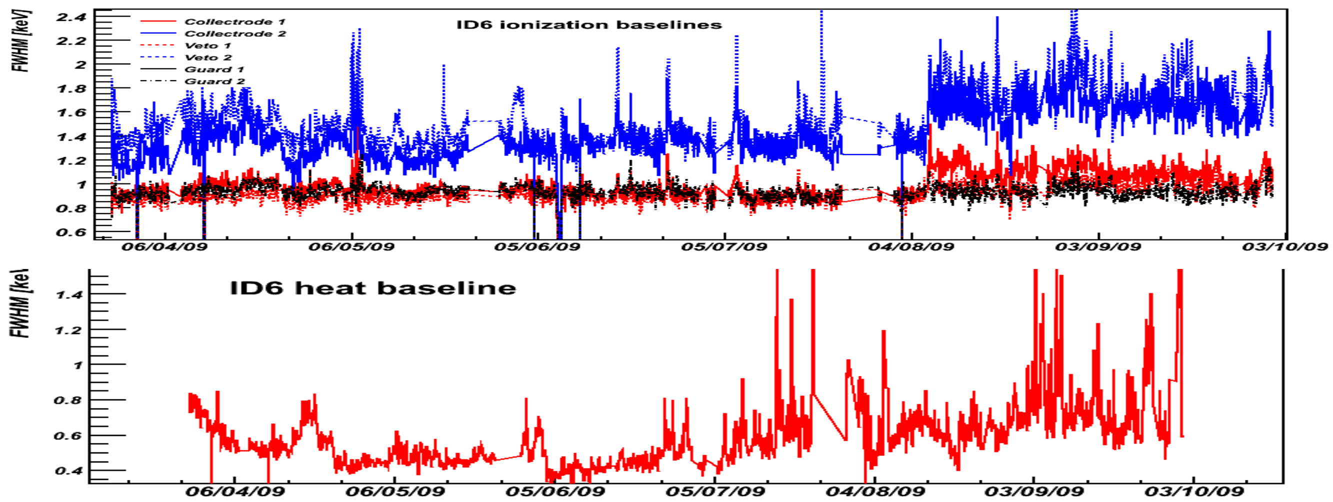
- 418 days
- 322 data (77% of 418)
- 305 physics (73% of 418)
- All bolo working, 90% electronics channels ok
- 9/10 bolo for Physics
- 8 d gamma
- 5 d neutron
- 4,5 d «other»
  - Incl. PE tests

« One of the coldest place in the Universe »
Continuously at 18 mK during more than 1 year !





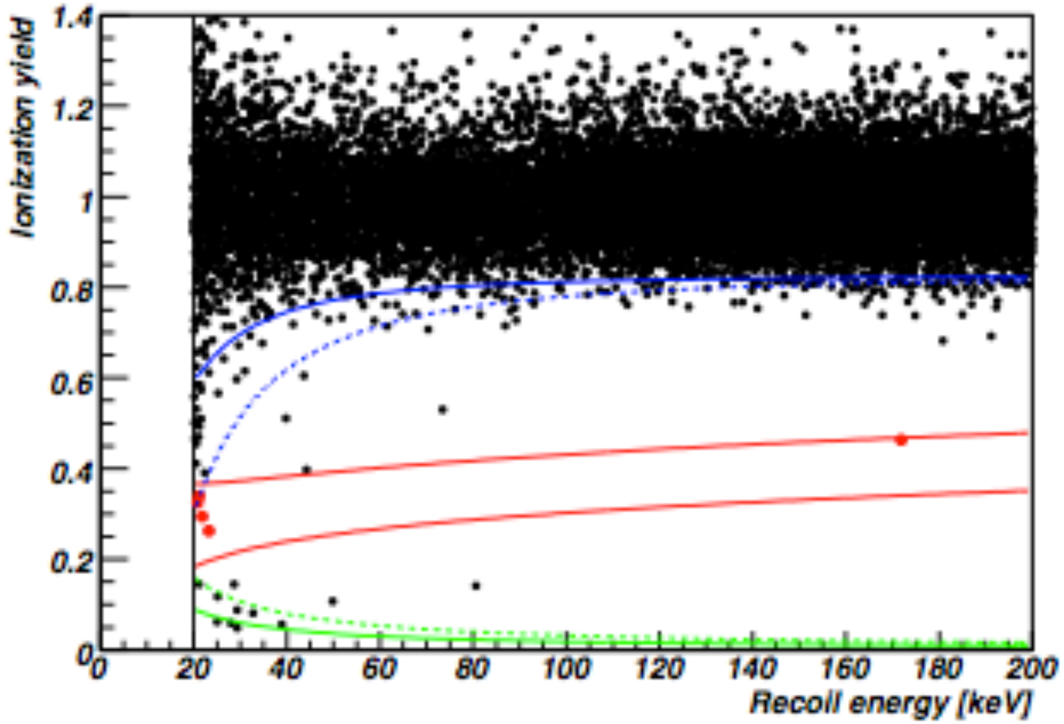
Ionisations baseline



Heat baseline

EDELWEISS-II: the final result (E_{rec}>20 keV)

Phys. Lett. B 702 (2011) 329 - arXiv: 1103.4070



NO indication for a WIMP signal

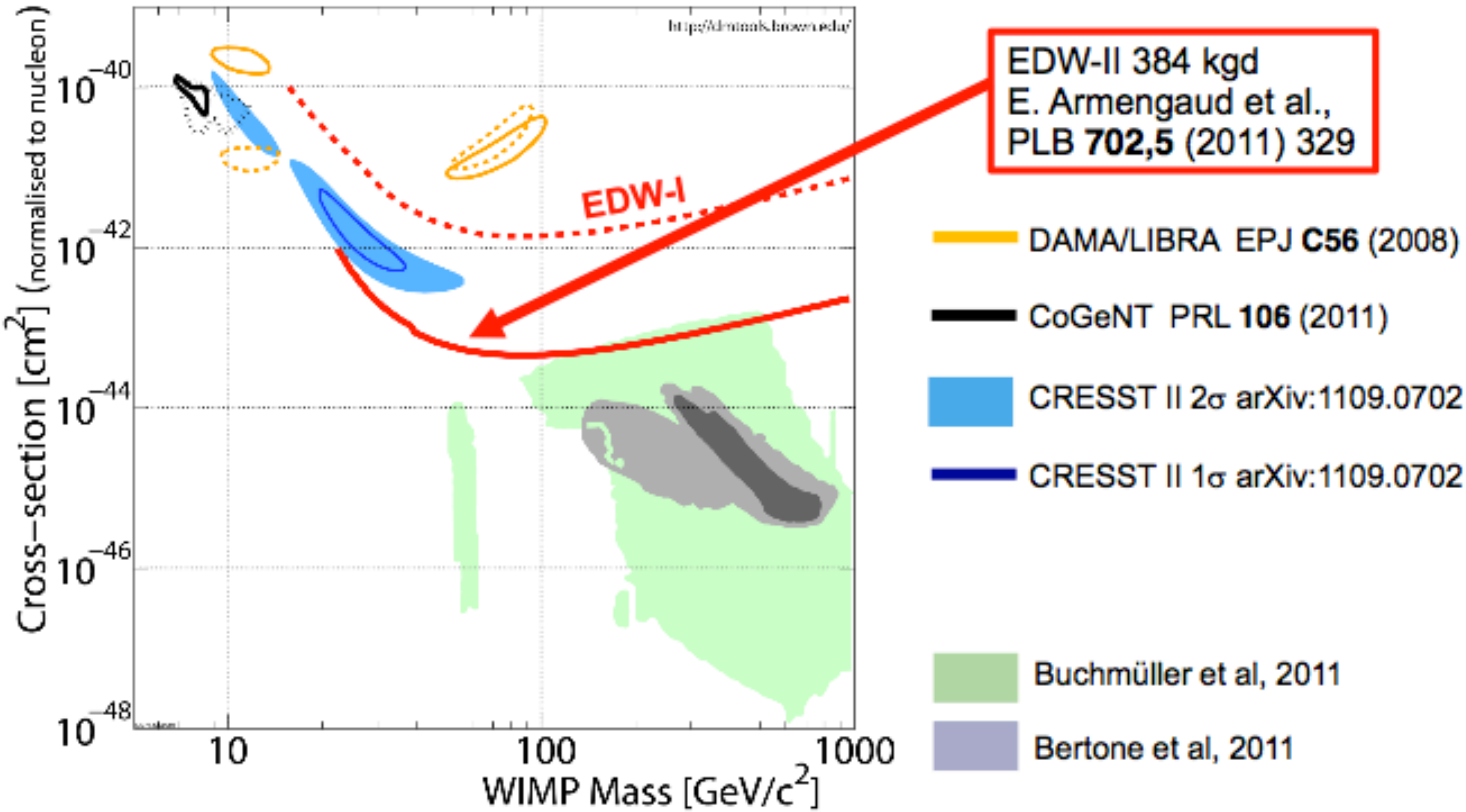
- 10 ID 400-g detectors
  1.6 kg fiducial mass
- Total exposure: **427 kg.d**
  in 90% NR band, i.e. WIMP RoI :
  384 kg.d
- **5 events observed:**
  - 4 with E < 22.5 keV
  - 1 with E = 172 keV
- Expected background [20-100 keV]
  < 5.1 (90% CL)

WIMP Halo:
local density of 0.3 GeV/c^2
Maxwellian velocity distribution
v_{rms} = 270 km/s
v_{Earth} = 235 km/s
v_{escape} = 544 km/s

standard halo: σ_{SI} < 4.4x10^{-8} pb at 90% C.L. for M_{WIMP} = 85 GeV/c^2

EDELWEISS-II: σ_χ vs. m_χ

EDW (384kgd; [20-200keV], 5evts -> σ_{SI} < 4.4×10^{-8} pb; M_{WIMP} = 85 GeV/c^2)
From EDW-I to EDW-II: x20 improvement



EDELWEISS-II: low-mass WIMP search

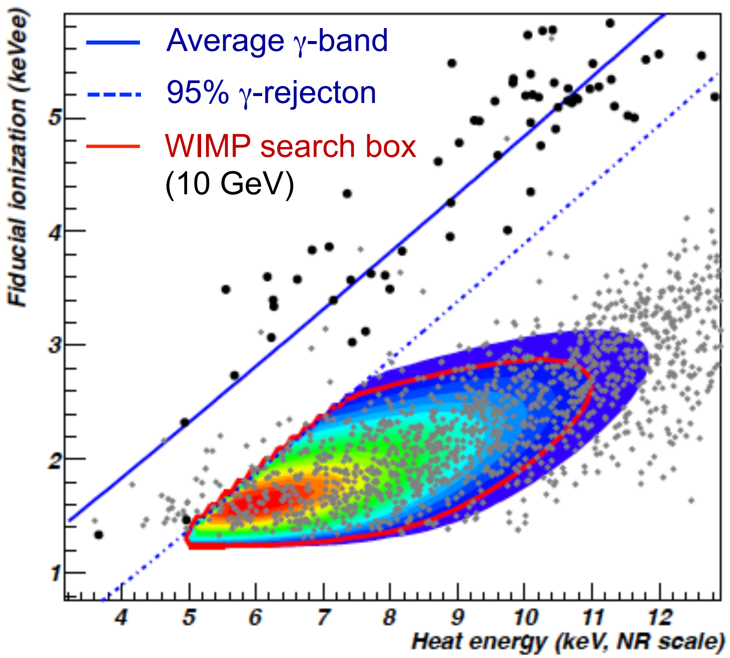
- Analysis of new data sets with E_R < 20 keV
- Select ID detectors sensitive to nuclear recoils down to 5 keV
- General strategy to select the data set :
  - Keep 4 detectors with sub-keV ionisation and heat baseline resolutions (removed those with missing electrodes, ^{210}Pb pollution, large low energy gamma bkg)
  - Remove noisy periods
  - χ^2 based cut
  - Exclude coincidences (muon veto, other bolometers)
  - Fiducial cut based on ionisation signal – energy independent

- Best energy estimator to search for nuclear recoils near the threshold:

$$E_{heat} = \frac{E_{rec}}{1+V/3}\left(1+\frac{V}{3}Q_n\left(E_{rec}\right)\right), \quad Q_n\left(E_{rec}\right) = 0.16\,E_{rec}^{0.18}$$

O.Martineau et al.
NIM A530 (2004) 426

- Good trigger efficiency @ low energy :
  78 % @ 5 keV, 90 % @ 6.3 keV



Phys. Rev. D 86, 051701(R) (2012)

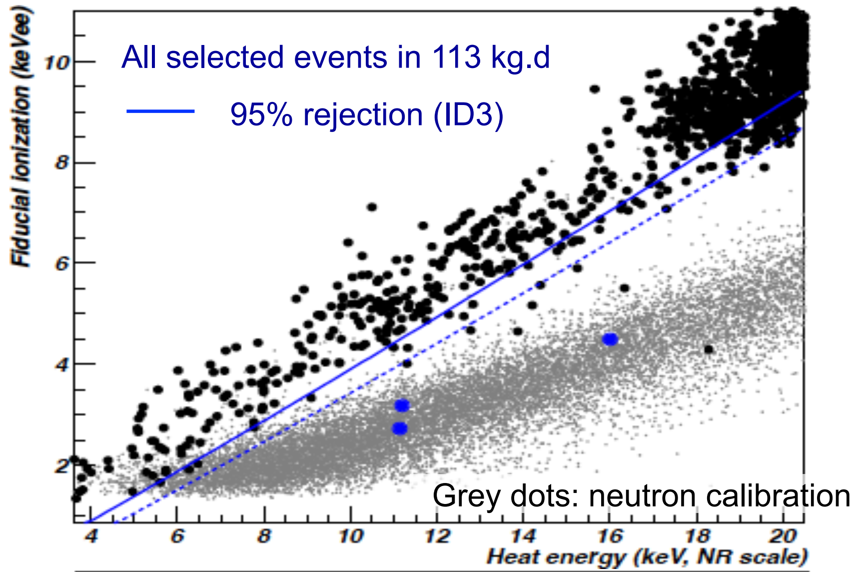
EDELWEISS-II – low mass WIMP: σ_χ vs. m_χ

- Total fiducial exposure : **113 kg.d**

– **3 evts** observed in the WIMP box

  (one event for $M\chi$ = 10 GeV)

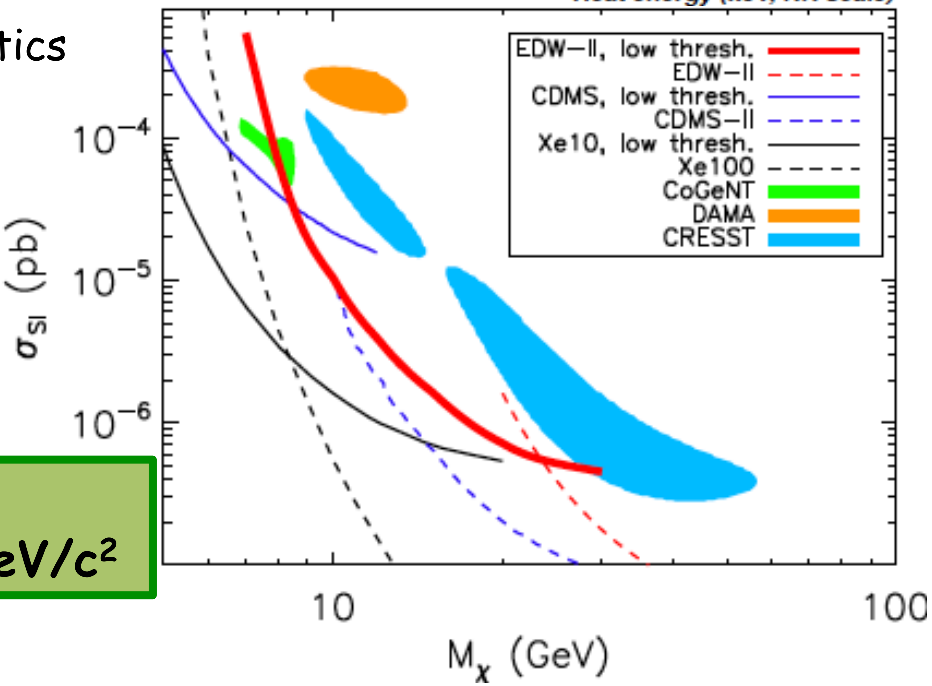
- Estimated background (5-20 keV):
  - Neutron < 1.7 evt, most probable 1.0 evt
    (based on Monte-Carlo + activity meas.)
  - Gamma = 1.2 evt



- Limits on σ_{SI} derived from Poisson statistics

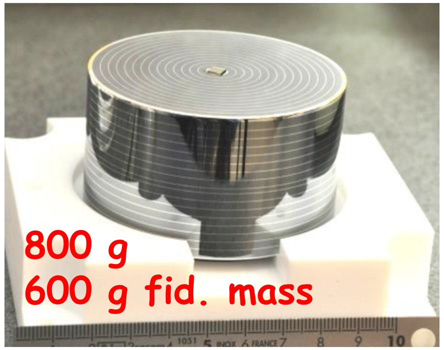
- Significantly extends EDW limits
  for $M\chi$ = 7-30 GeV

- Good rejection of surface events!



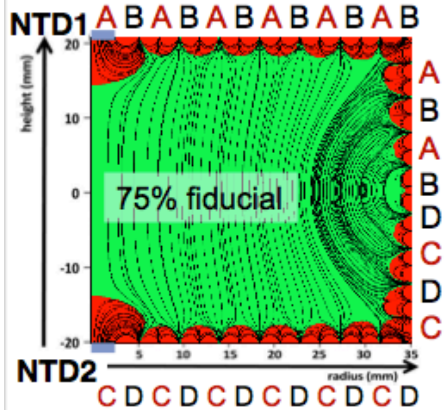
113 kgd; [5-20keV], 1-3 evts
→ σ_{SI} < 1.0 × 10^{-5} pb; M_{WIMP} = 10 GeV/c^2

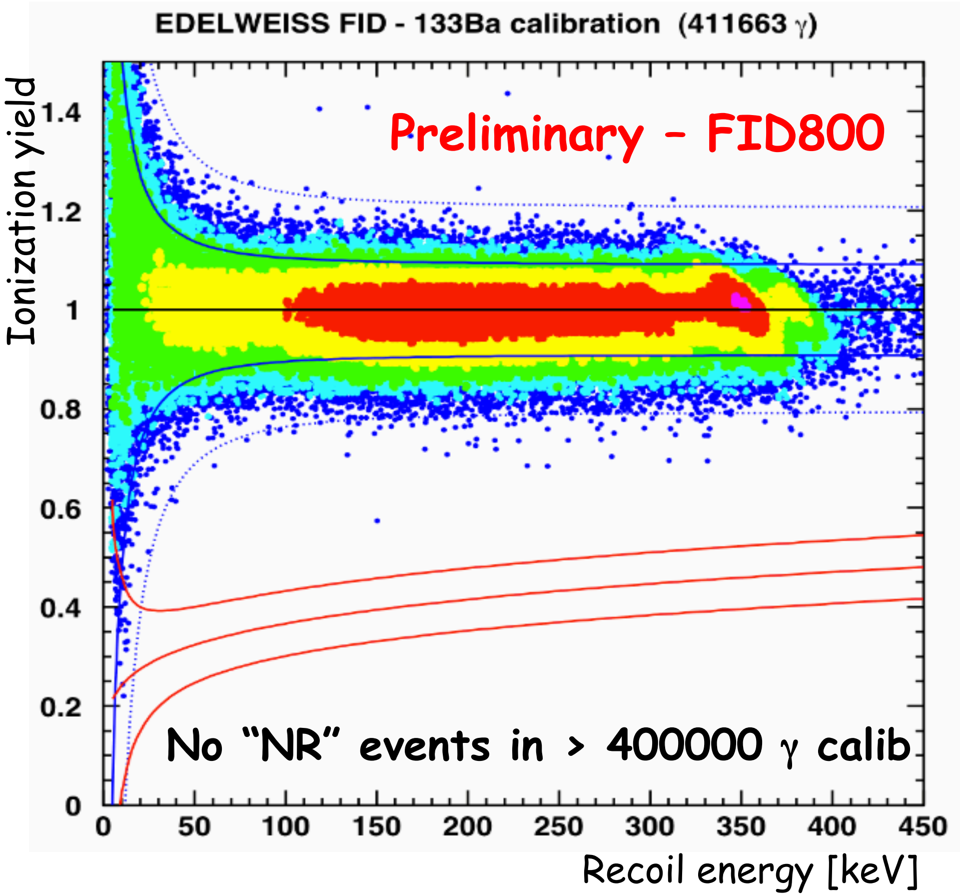
From EDELWEISS-II to EDELWEISS-III



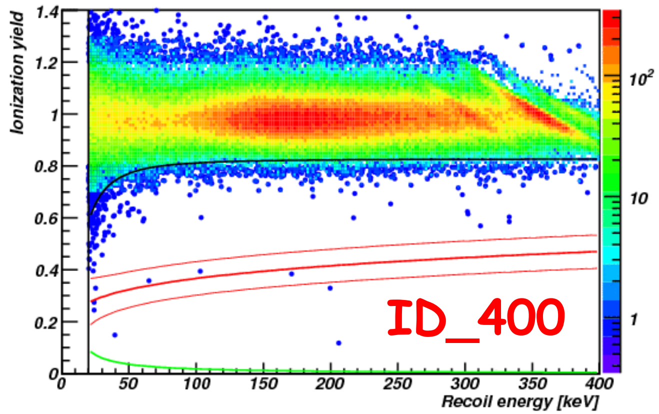
1) Increase detector mass

Fiducial mass		x2		x4
ID200 => ID400	=>	FID400	=>	FID800



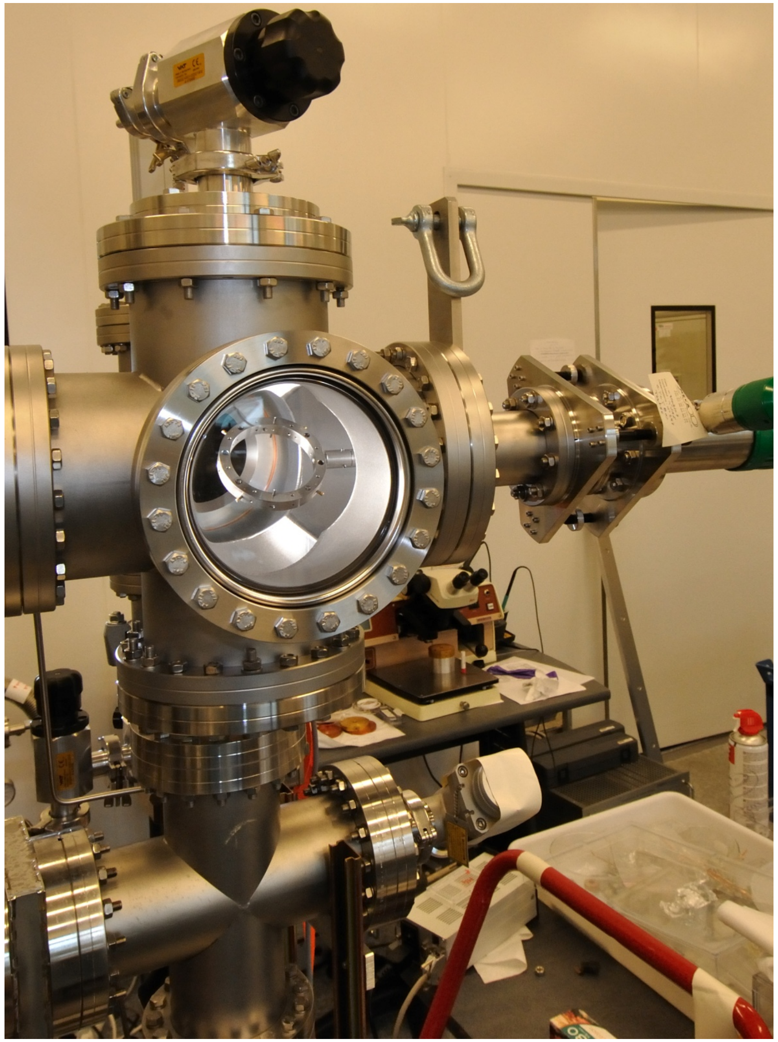


- All fiducial volume: more statistics than stacked ID-400 statistics
- No event in NR
- Expected to be and indeed better than IDs !

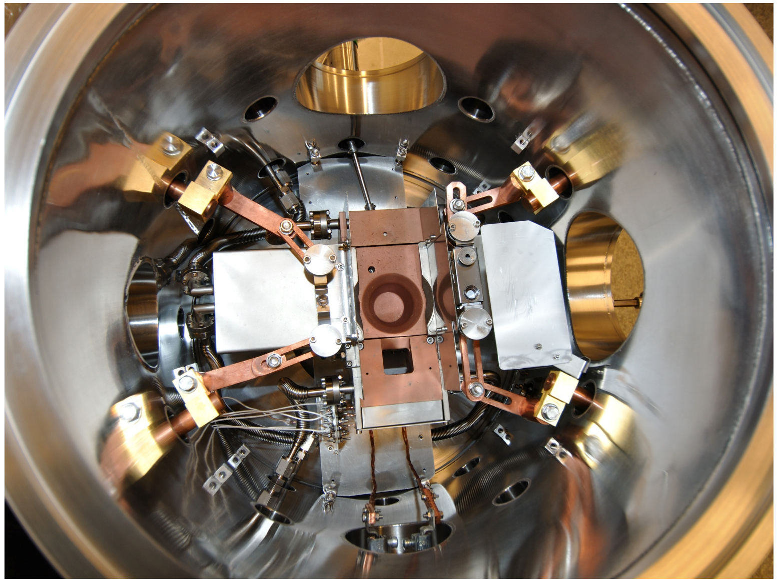


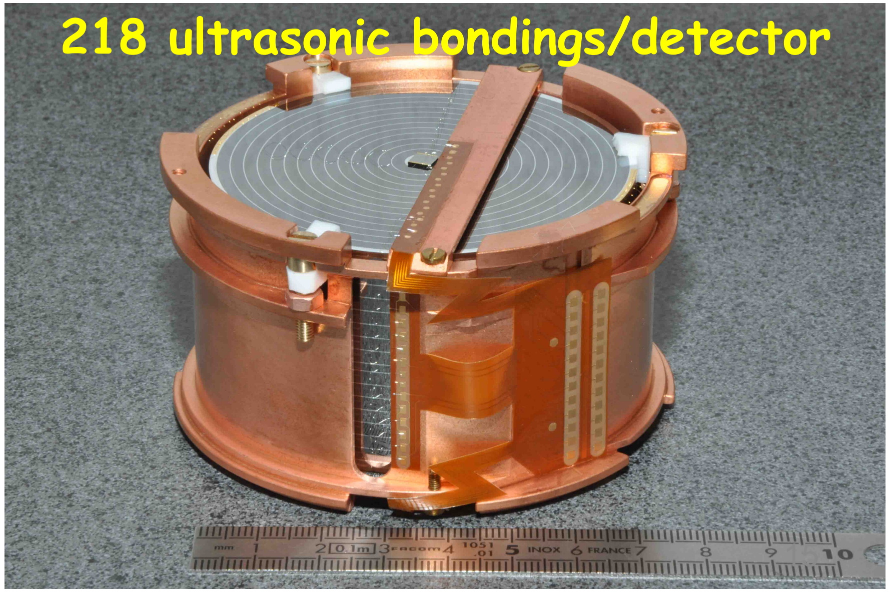
6 "NR" events in 350000 γ calib

FID production @ CSNSM-Orsay



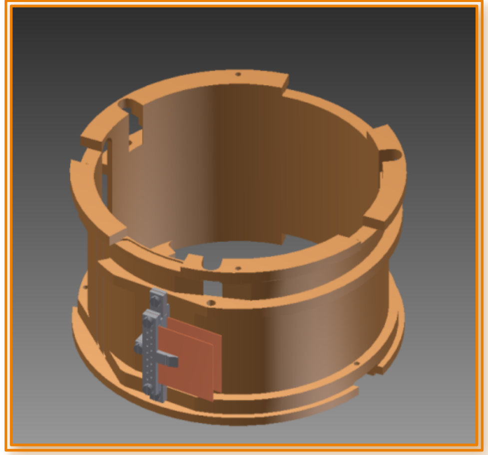
Production of FID detectors performed @ CSNSM-Orsay in a dedicated evaporator.





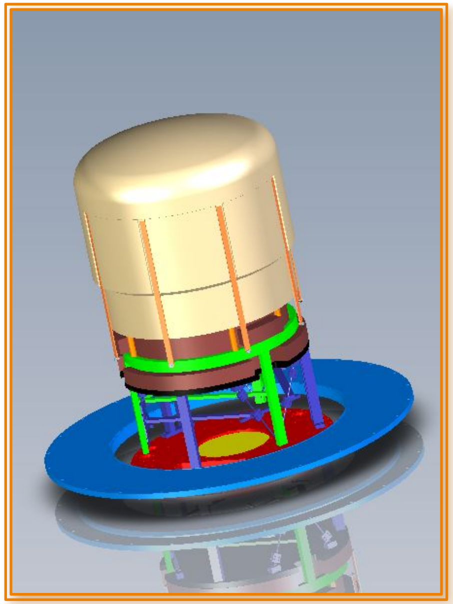
From EDELWEISS-II to EDELWEISS-III

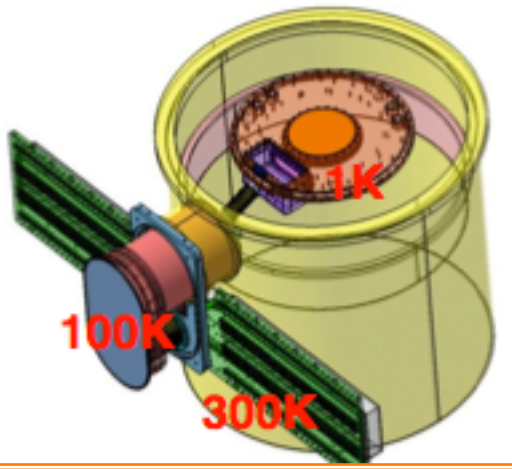
2) Decrease the background

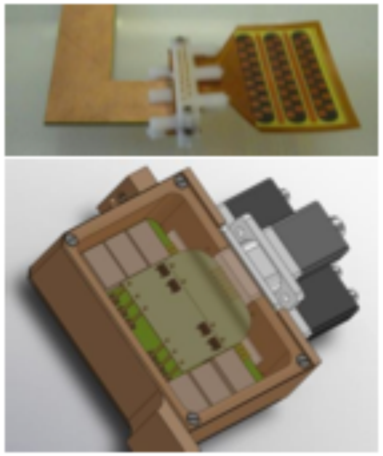


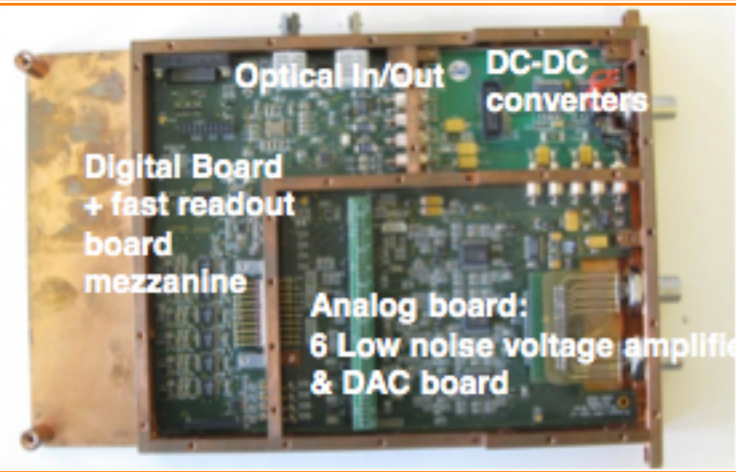
Major upgrade:

- inner part of the cryostat
- new arrangement of Ge bolometers
- new Cu mounting & thermal shields
- new internal PE shield @ 1 K







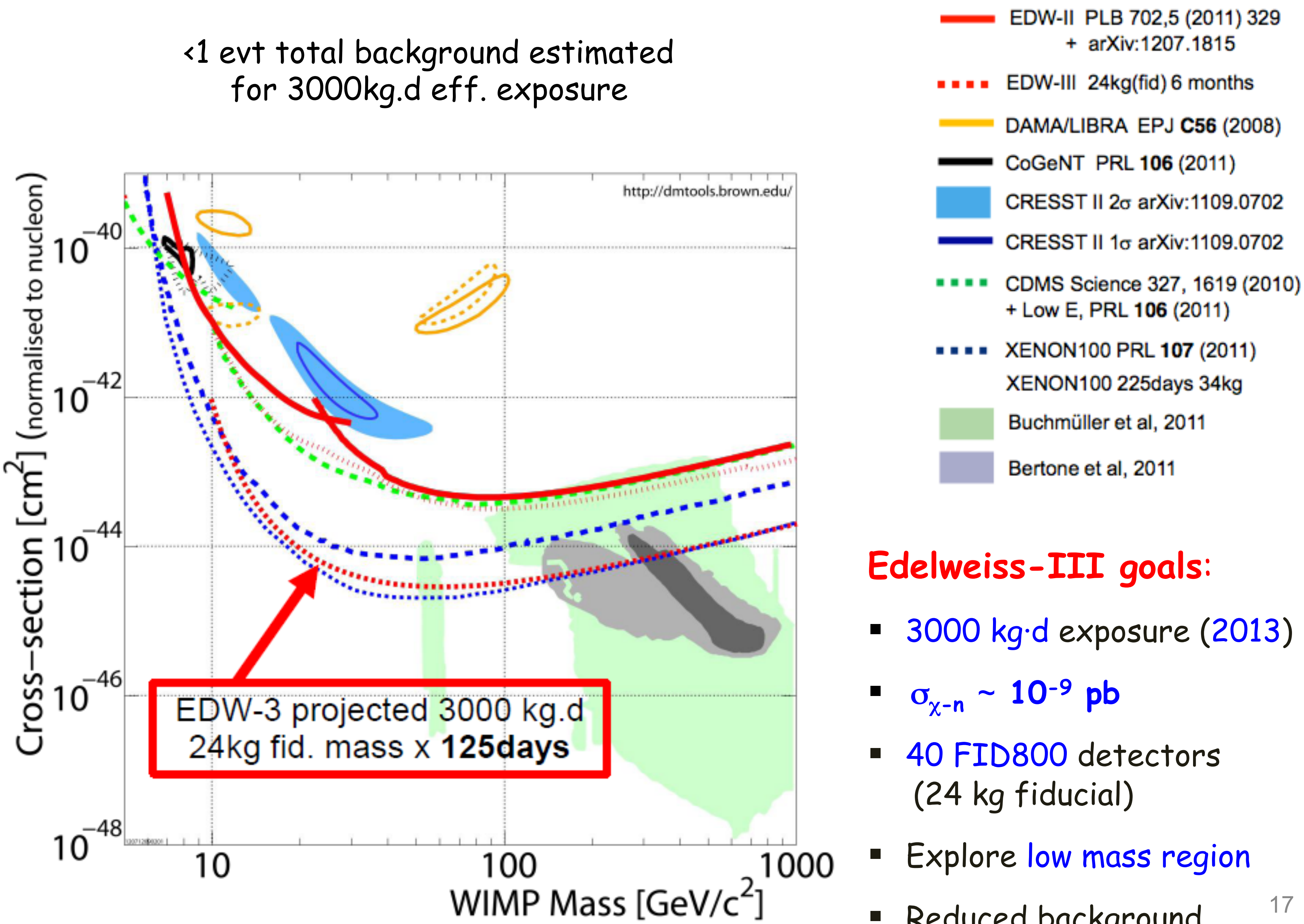


Upgrade of electronics & cabling

Upgrade of DAQ & data structure

EDELWEISS-III goal for 2013

<1 evt total background estimated
for 3000kg.d eff. exposure



Edelweiss-III goals:

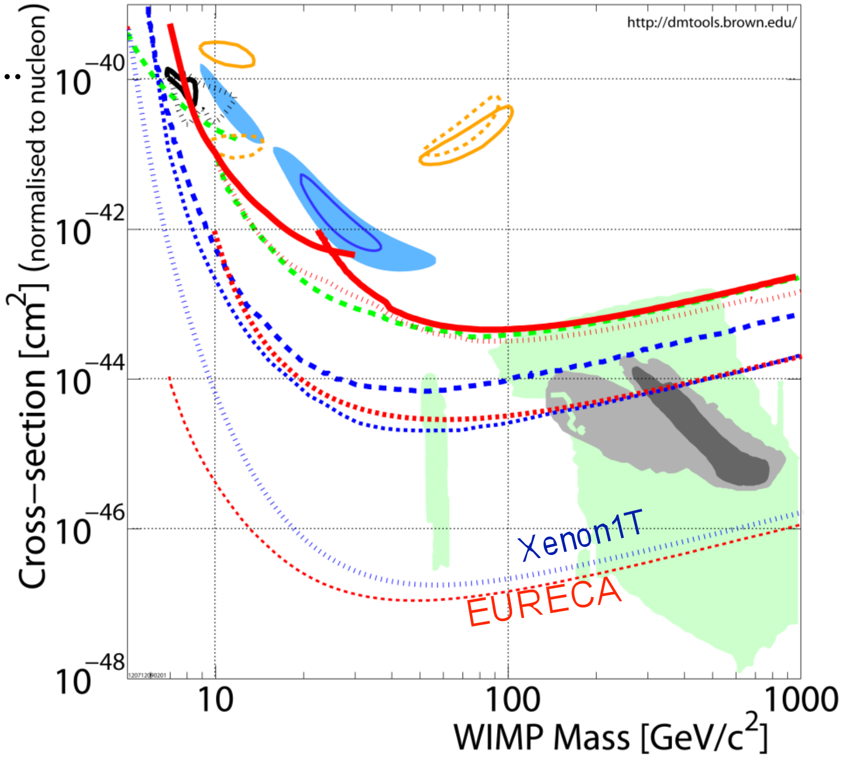
- 3000 kg·d exposure (2013)
- $\sigma_{\chi\text{-}n} \sim 10^{-9}$ pb
- 40 FID800 detectors
  (24 kg fiducial)
- Explore low mass region
- Reduced background

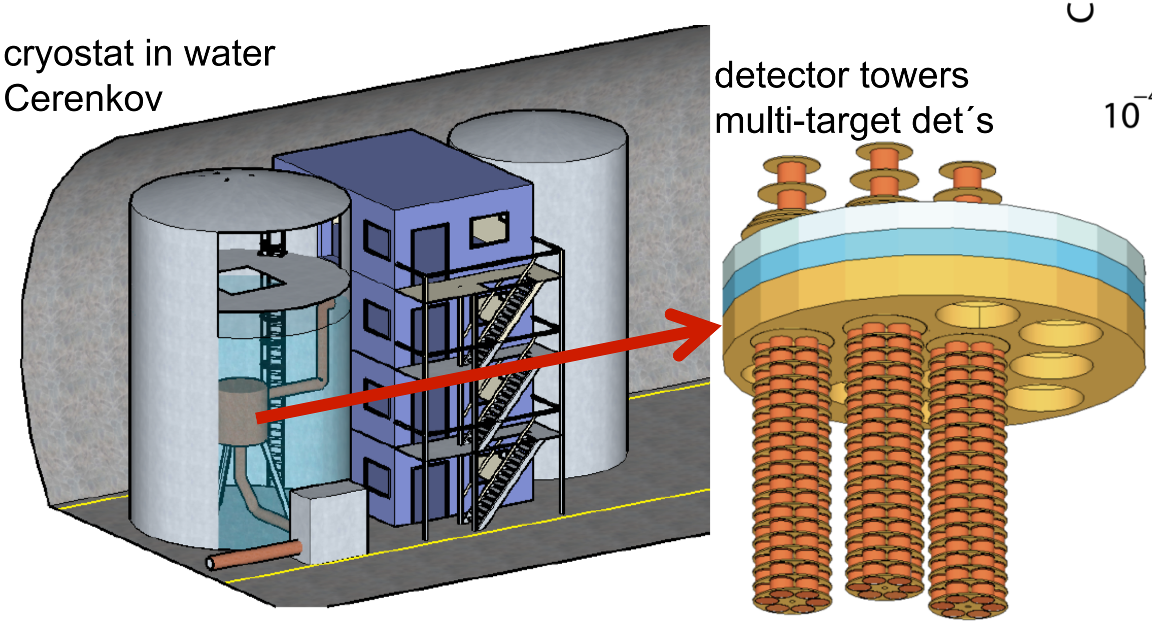
Beyond EDELWEISS-III: EURECA

EURECA: European Underground Rare Event Calorimeter Array

- Joint European collaboration of teams from EDELWEISS, CRESST, ROSEBUD, CERN, + others...
- **The goal: 10^{-10} pb**, 500 kg – 1 ton cryogenic experiment.
  2nd generation experiment with huge efforts in background reduction, detector development and build infrastructures.

2 experiments
(**different nuclei, different techniques**)
e.g. **1 bolometric**, 1 noble liquid





- coordinated cooperation with SuperCDMS
- CDR in summer 2012
- facility type (DM, $0\nu\beta\beta$,...)

Conclusions and perspectives

✧ EDELWEISS - ID detectors

- Robust detectors with a very high beta rejection
- 1 year of data analysis

  No evidence of WIMPs
  384kgd; [20-200keV], 5evts → $\sigma_{SI} < 4.4 \times 10^{-8}$ pb; $M_{WIMP} = 85$ GeV/c^2
  113 kgd; [5-20keV], 1-3 evts → $\sigma_{SI} < 1.0 \times 10^{-5}$ pb; $M_{WIMP} = 10$ GeV/c^2

✧ Next goal: ~10^{-9} pb

- Background improvement and comprehension

  Increased redundancy for both heat and ionisation channels
  Fast readout (multisite, pile-up)
  Internal PE shield
  Upgrade of inner cryostat, new internal shield
  Upgrade of cabling and electronics

- New FIDs - 40 detectors

  $m_{det} = 800$ g; $m_{fid} = 600$g → 24 kg_{fid}
  2013 = 3000 kg*d in 6 months (no bkg expected)

✧ The next future: EURECA- $10^{-10}/10^{-11}$ pb

Few words on low mass WIMPs

<u>The beginning of the history:</u>

DAMA/LIBRA: modulation with a significance of 8.9σ, consistent with elastically scattering dark matter (annual variation of the number of detection events, caused by the variation of the velocity of the detector relative to the dark matter halo as the Earth orbits the Sun).

Possible interpretation: very light dark matter particles (<~ 10 GeV) to accommodate this signal consistently with limits from other experiments

<u>Some years later (recently):</u>

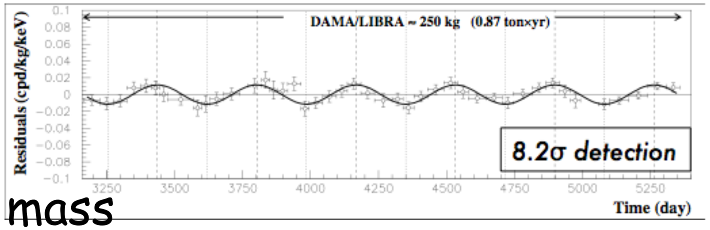
The situation has recently gained in complexity with the observations from **CoGeNT** and **CRESST**, which may point at a light-WIMP parameter space.

CAVEAT:

light-WIMP signals fall uncomfortably close to detector thresholds, a region where systematic effects can lead to rushed claims of exclusion or detection.

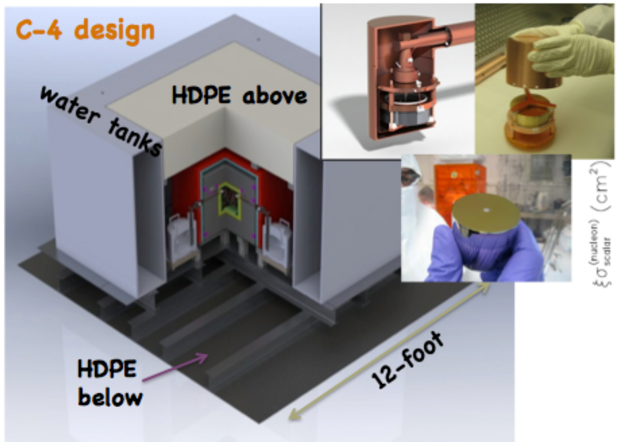
The main actors

DAMA and its annual modulation

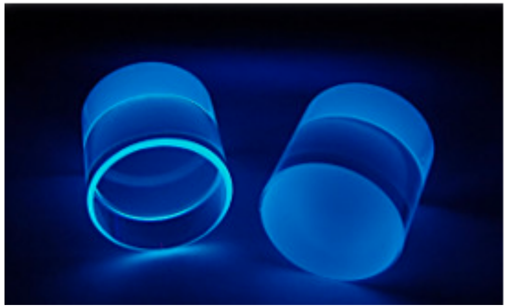


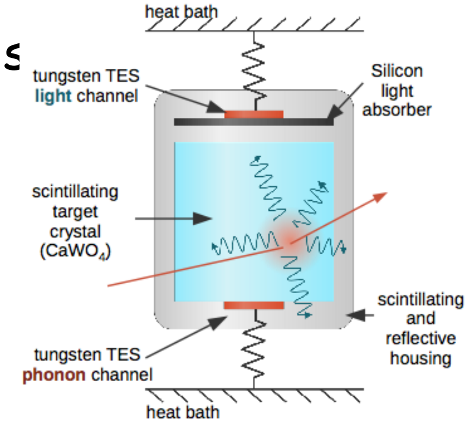
Detector: ~250 kg highly radiopure NaI(Tl)
No nuclear recoil identification but large sensitive mass
Location: LNGS

COGENT: a dedicated search for low mass WIMPs
No nuclear recoil identification but very low threshold
Location:Soudan

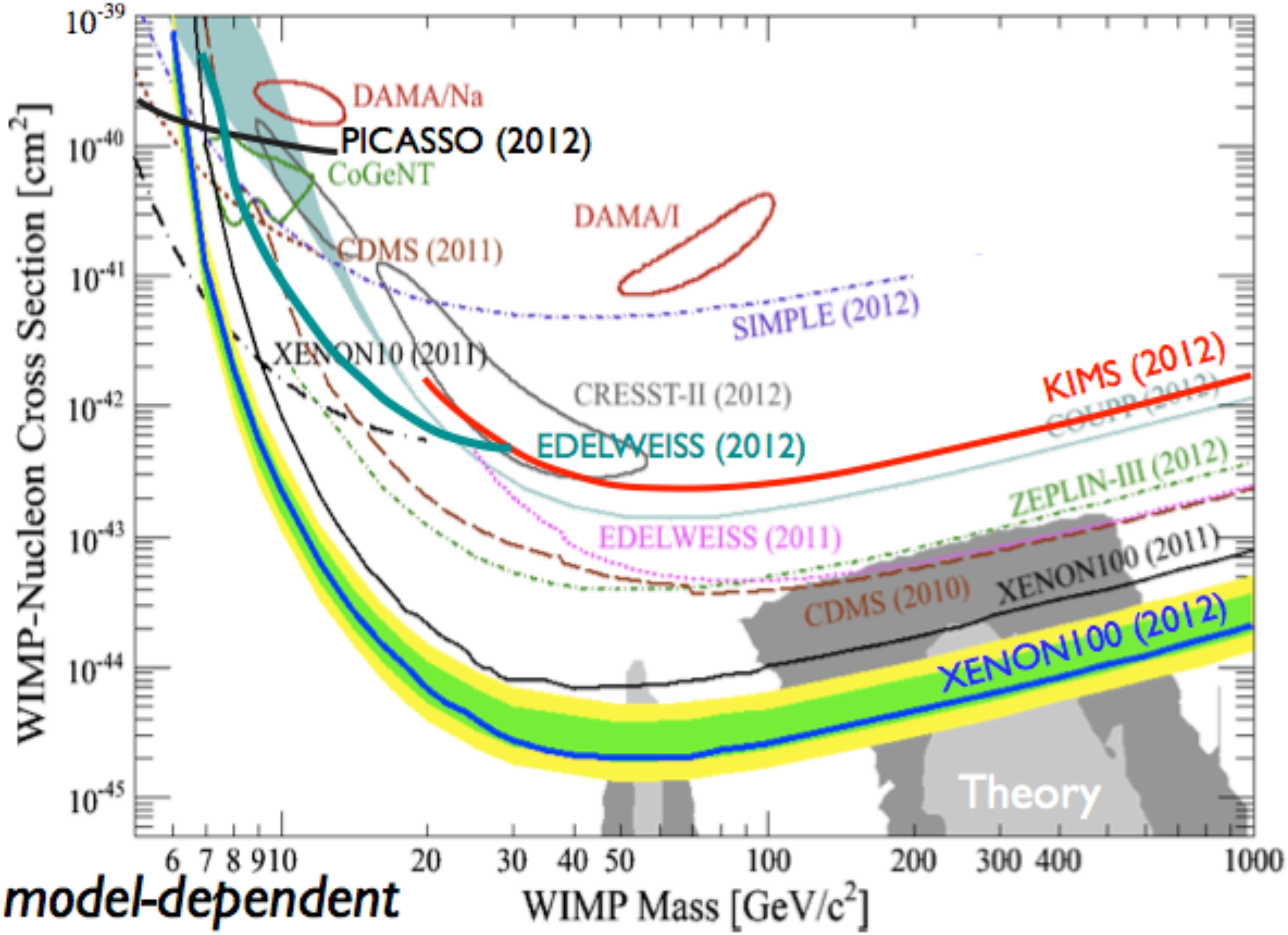


CRESST: cryogenic detectors with $CaWO_4$ scintillating crystals
Nuclear recoil discrimination
Location: LNGS



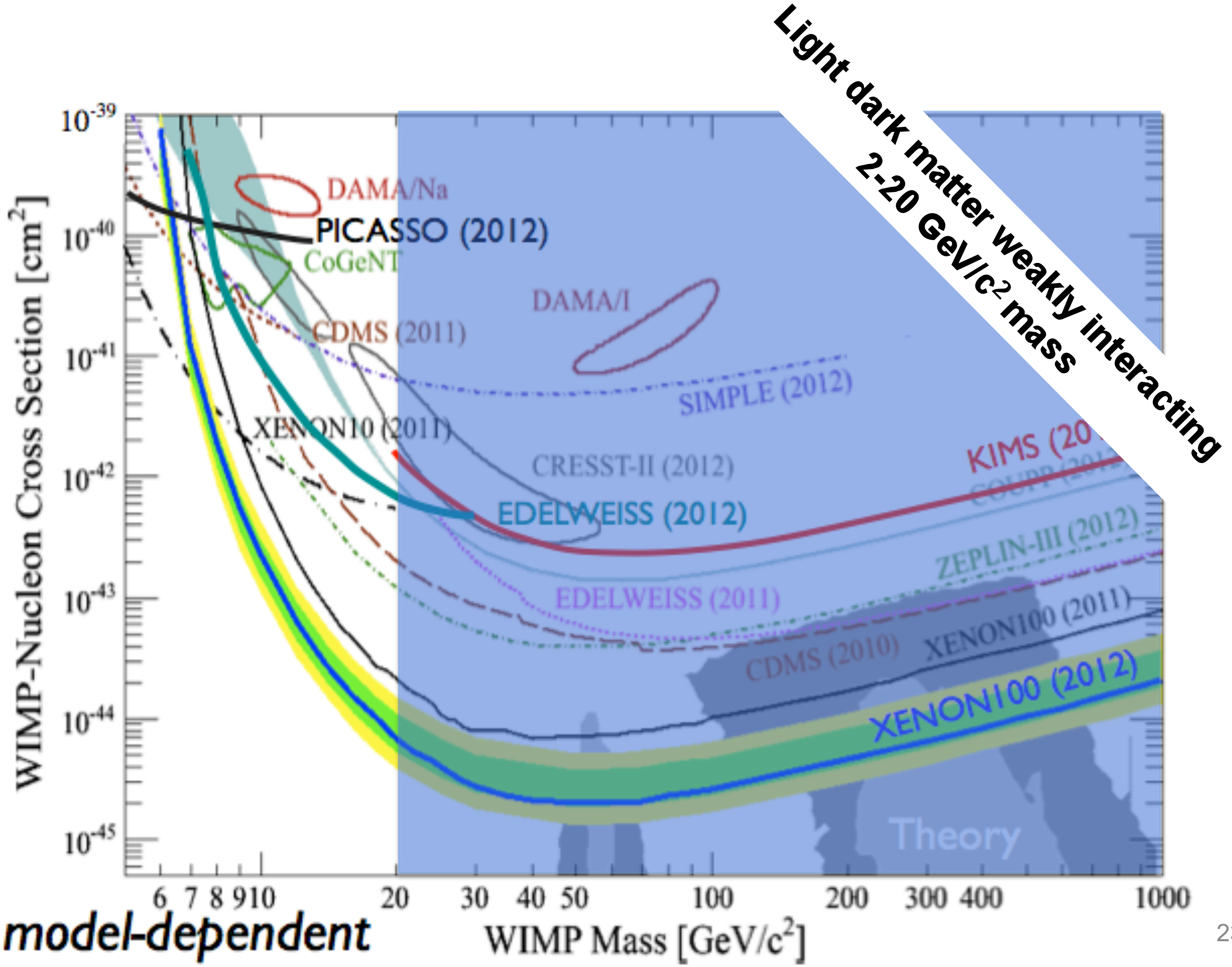


The low mass WIMPs story…



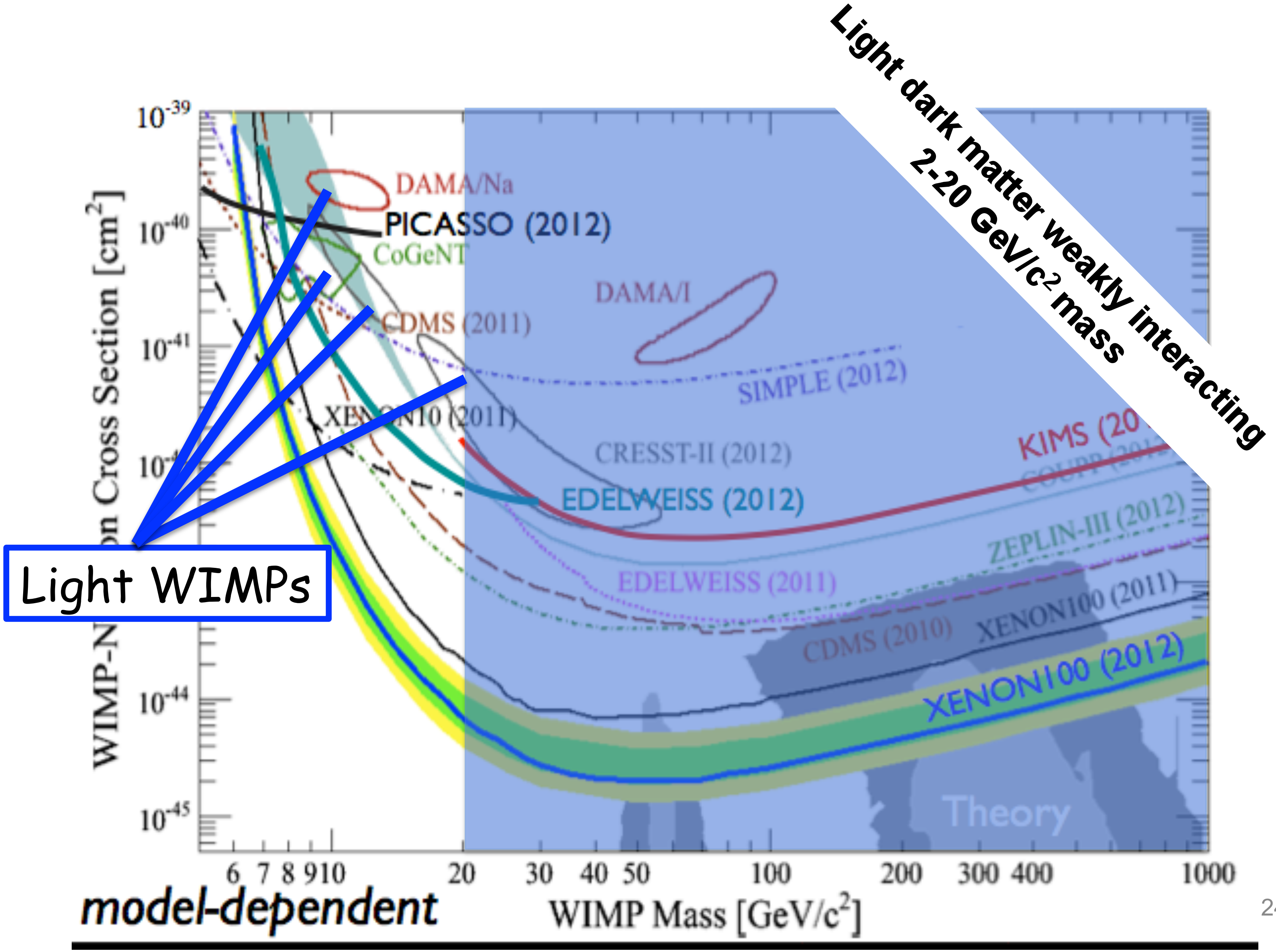
model-dependent

The low mass WIMPs story…



model-dependent

The low mass WIMPs story…



How to make a comparison

The comparison depends on the model

$$\begin{pmatrix}\text{number of}\\ \text{events}\end{pmatrix} = (\text{exposure}) \times \begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} \otimes \begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix}$$

$$\begin{pmatrix}\text{detector}\\ \text{response}\end{pmatrix} = \begin{pmatrix}\text{energy}\\ \text{response function}\end{pmatrix} \times \begin{pmatrix}\text{counting}\\ \text{acceptance}\end{pmatrix}$$

$$\begin{pmatrix}\text{recoil}\\ \text{rate}\end{pmatrix} = \begin{pmatrix}\text{particle}\\ \text{physics}\end{pmatrix} \times (\text{astrophysics})$$

Detector response model: energy resolution, quenching factors, channeling fractions

Astrophysics model: local density, velocity distribution

Particle physics model: mass, cross section

Conclusions from an expert…

From Paolo Gondolo's talk @ IDM2012 – Last July

Conclusions from an expert…

From Paolo Gondolo's talk @ IDM2012 – Last July

Conclusions

None.

Confusion

Maximal.