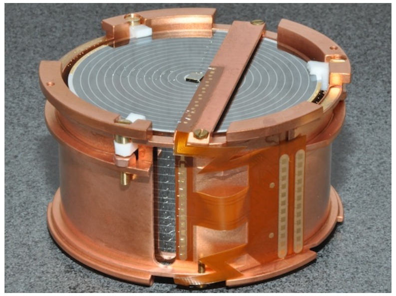
EDELWEISS-III progress report

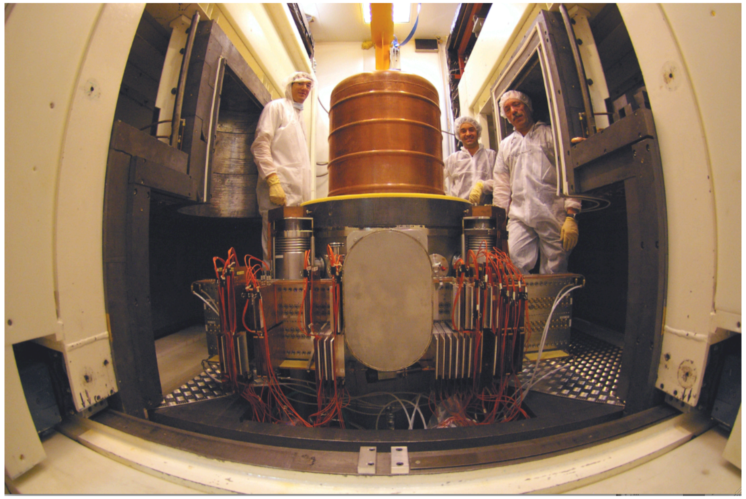


The project

Evolution of the scientific context

Progress report

Calendar, people and budget



J. Gascon
UCB Lyon 1, CNRS/IN2P3/IPNL

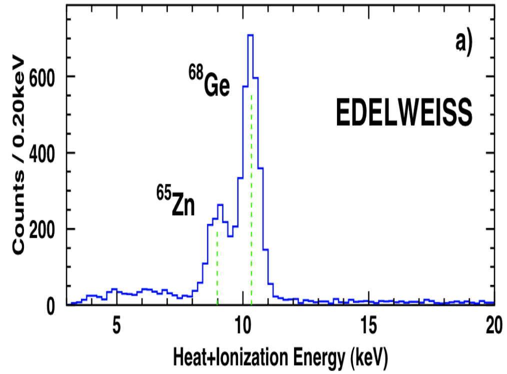
THE EDELWEISS-III PROJECT

The EDELWEISS collaboration objectives

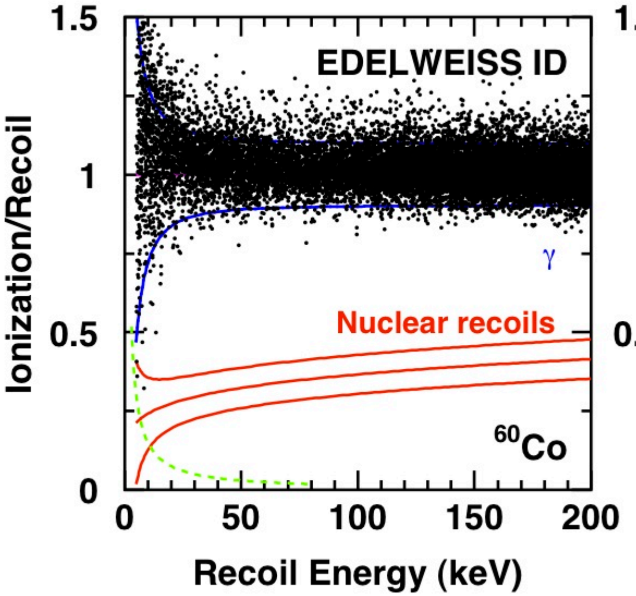
- *Exploit the advantages of germanium cryogenic detectors for Direct Dark Matter searches*
  - Germanium radiopurity
  - Superior energy resolution on both heat and ionization channels:
    - Distinct, event-by-event discrimination between nuclear electron recoils using ionization yield relative to heat signal
    - Low thresholds
    - Precise spectroscopy of any remaining backgrounds
- *Obtain significant limits on WIMP with spin-independent interactions*
- *Develop a simple and robust detector unit that keeps all the advantages and can be adapted to larger scale project*
  - Recognized expertise for heat-and-ionization detector design, fabrication and for understanding the physics of these device.

Germanium heat+ionization principle

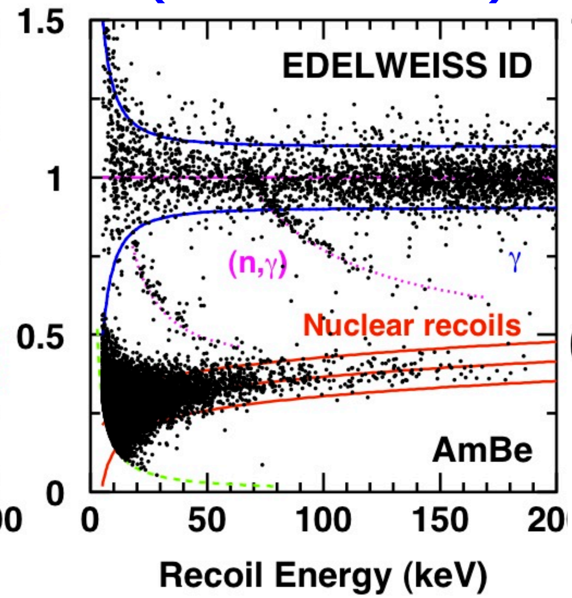
- Heat = true calorimetric measurement of recoil energy (independent of slowing-down process)
- Sub-keV resolution for ionization and heat signals
- Ion. yield for nuclear recoils ~1/3 of e⁻ recoils
- *Limitation: charge collection near surface => different rejection strategy for CDMS & EDELWEISS*



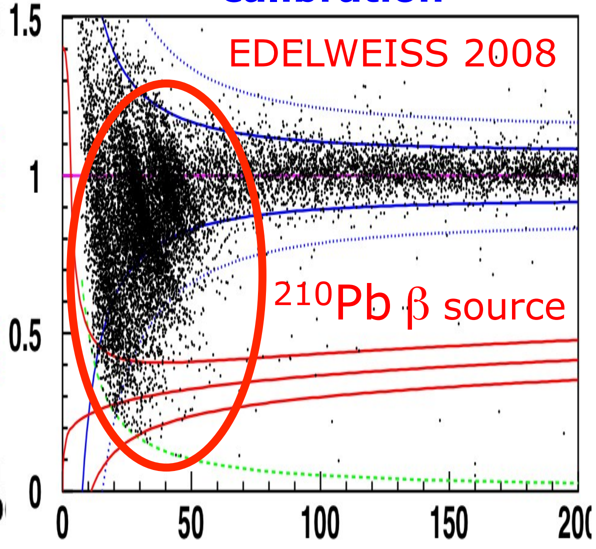
Gamma calibration



Nuclear recoil calibration (neutron source)

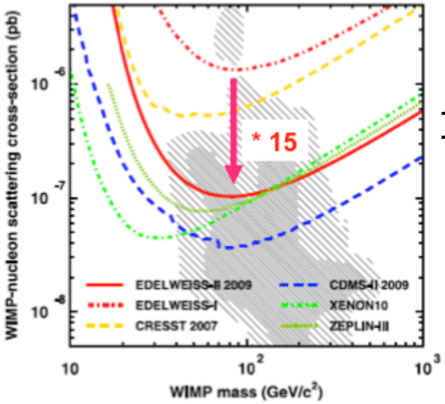


Surface recoil calibration

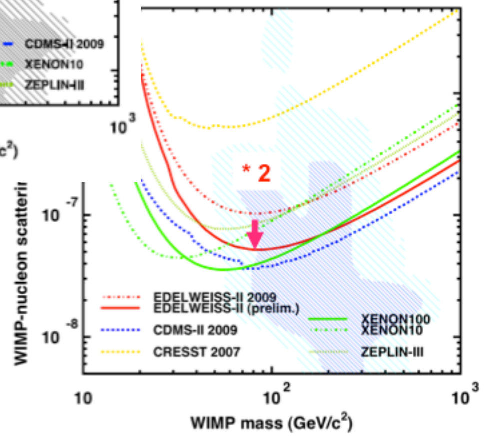


Motivation for the EDELWEISS-III project (1)

… as presented to the July 2010 IN2P3 Scientific Council



160 kgday

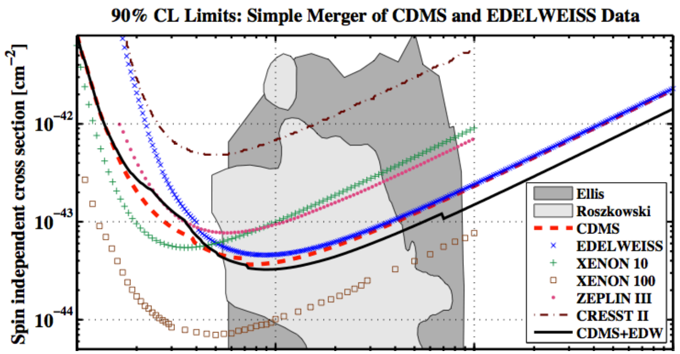


322 kgd

- With 10 x 400 g detectors (1.6 total fiducial mass) of the newly developped “ID” design, EDELWEISS improves x30 its previous background suppression performance and catches up with CDMS in terms of sensitivity
- *First direct proof that “ID” electrode design can efficiently remove background from surface events*

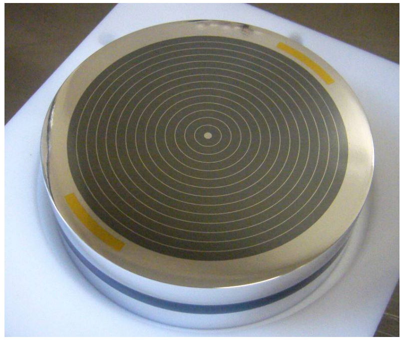
Update since 2010:

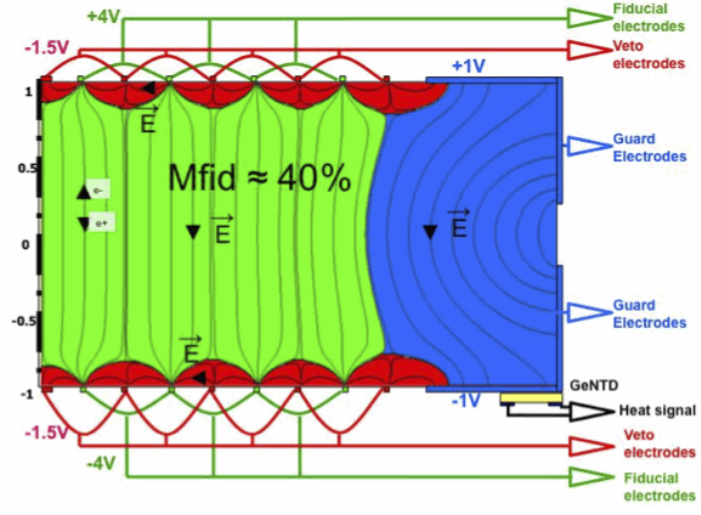
- Publication of final exposure (384 kgd)
- Combination with CDMS (379 kgd), improves best limits by x1.5 at high mass: joint paper
- *CDMS decides on an ID-inspired design for the electrodes of all its future detectors.*



Surface event rejection with ID electrodes

Φ 70mm, H 20mm, 410g
14 concentric electrodes
width 100µm, spacing 2mm





- Interleaved electrodes + guards
- Biases to have an electric field
~ horizontal near the surface and
~ vertical in the bulk

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

Improved understanding of detector physics

Surface event selection:

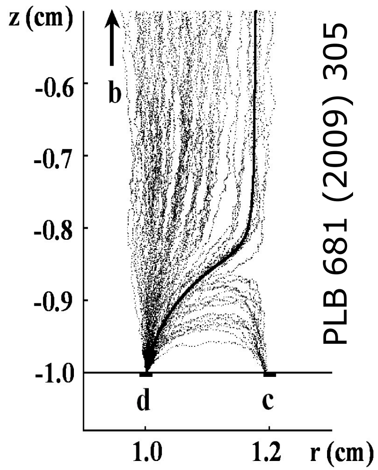
- First criteria: absence of signal on "veto" rings
- *Redundancy:* requires equality between "fiducial" rings on both sides

"Grid effect":

- High-field region close to fiducial electrodes improves charge collection in the region that needs it the most (surface)

Charge transport effects:

- Diffusion (T=20mK) and charge repulsion removes problems that could have arisen from low-field regions

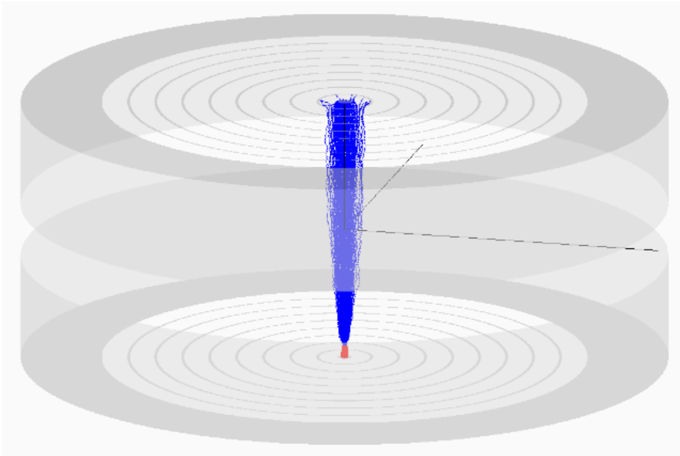


PLB 681 (2009) 305

Charge transport in cryogenic germanium

Broniatowski, LTD14

a) Simulation includes impurity scattering but neglects electron transport anisotropy



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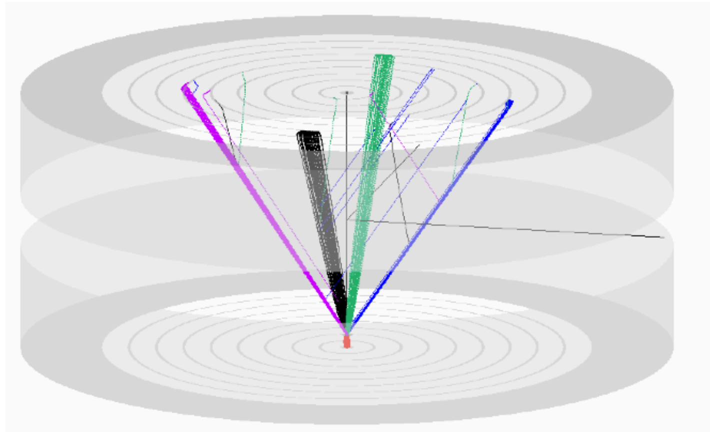
ID203: $N_{scatt} = 1.5 \times 10^{10} cm^{-3}$, $V_a = 1V$.

LTD14 Heidelberg, Germany Aug. 1-5, 2011

ID203
Height 20 mm
Diam. 50 mm
Ge p-type
doped to
10^{11} cm^{-3}
Field: 0.5V/cm

b) Simulation treats electron transport anisotropy, but neglects impurity scattering



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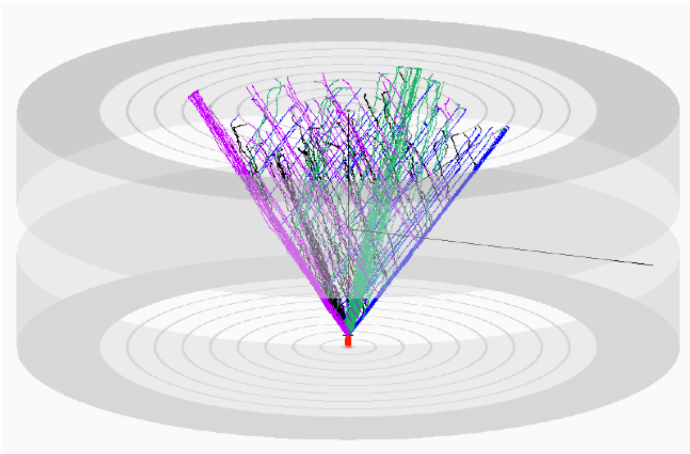
ID203: $N_{scatt} = 0$, $V_a = 1V$.

LTD14 Heidelberg, Germany Aug. 1-5, 2011

c) Simulation treats the combined effects of impurity scattering and electron transport anisotropy



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ID203: $N_{scatt} = 1.5 \times 10^{10} cm^{-3}$, $V_a = 1V$.

LTD14 Heidelberg, Germany Aug. 1-5, 2011

Since 2010:

Better understanding of detector physics

Confirmation of the benefit of covering all detector surfaces with ID electrodes

Reduction of backgrounds (1)

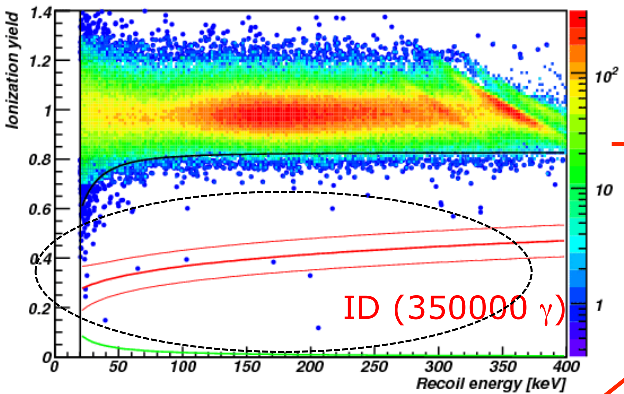
Good understanding of the limiting backgrounds in EDELWEISS-II

- Gamma-ray background (~1 bkg event in EDWII)

  Compton with part in the guard region (low field + poor charge collection)

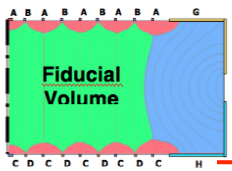
  - Improve rejection with detector fully covered with interleaved electrodes
    - Reduction of non-fiducial volume from 60% to 20%
    - Better charge collection for surface events due to grid effect

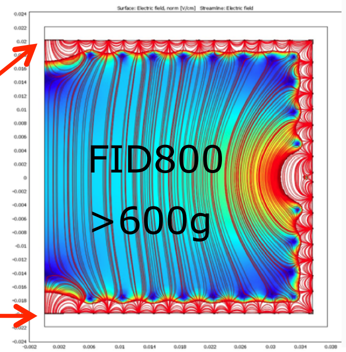
Since 2010: rejection improvement observed in FID800 γ calibrations

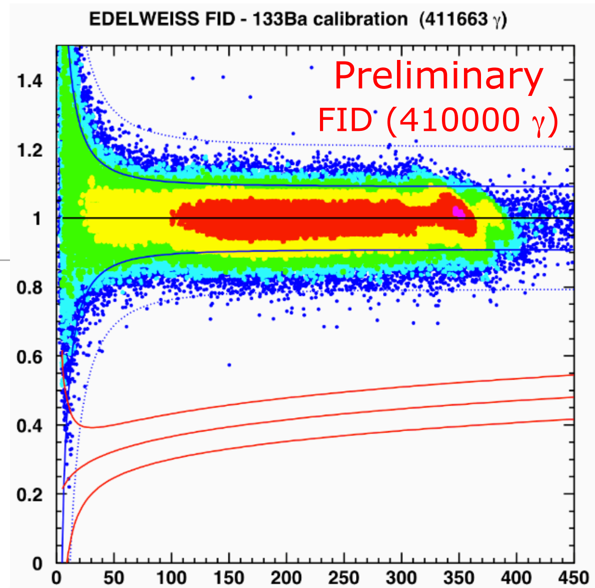


ID400

160g







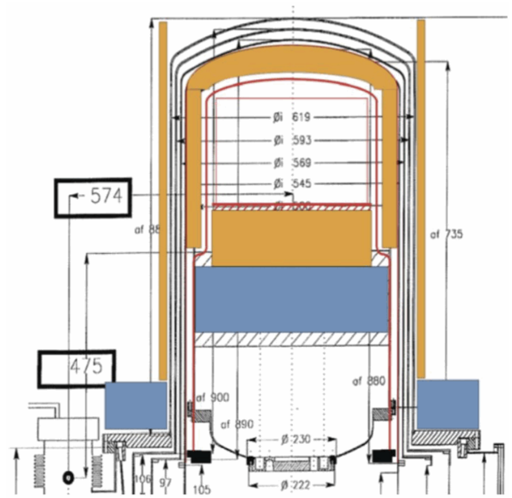
Reduction of backgrounds (2)

Good understanding of the limiting backgrounds in EDELWEISS-II

- Neutron background (~3 events in EDWII)

  alpha-n reaction in material inside polyethylene shield

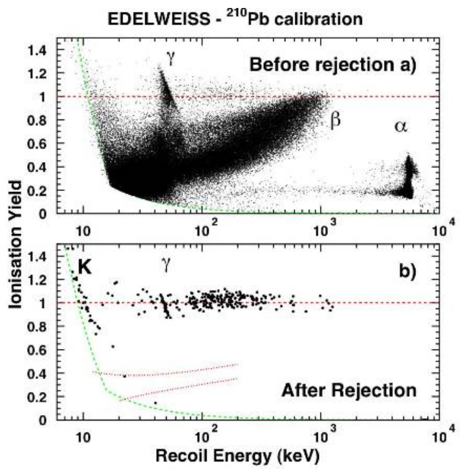
  - better material selection
  - ~10 cm internal polyethylene shield

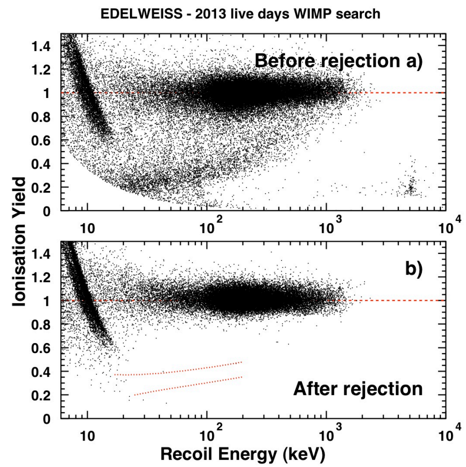


Surface events background

(<0.2 events in EDWII)

- Material selection
- Improved ionization resolution





FIDSUSY proposal (2010)

- Science goal: have a Ge array able to get 3000 kgd (with <1 bkg event) in 6 months (=5×10^{-9} pb)
- **40 x FID800 [ANR]** can do this (… as early as 2012):
  - X4 fiducial mass/detector wrt EDWII ID
  - Surface rejection of ID already ok
  - Need to improve on the γ-rejection wrt EDWII: has been confirmed in 2011 Run15
  - Need x10 improvement in neutron rejection: **internal shield**
- Assumed 20 keV_NR “sharp” threshold (reminder: EDW-II was 20 keV at the time)
  - Need improved/more reliable **cabling**, **electronics** (ionization resolutions >1 keV not acceptable) and **cryogenics** (main source of noise / deadtime due to excessive heat noise)

EDELWEISS-III collaboration and tasks

CSNSM — CNRS/IN2P3
IPNL — CNRS/IN2P3
Néel institut — CNRS/INP
Irfu — CEA/IRFU
IRAMIS — CEA/IRAMIS
KIT Karlsruher Institut für Technologie — IK, IEK, IPE
JINR — JINR DUBNA
University of Oxford — Univ. OXFORD
The University Of Sheffield — Univ. SHEFFIELD

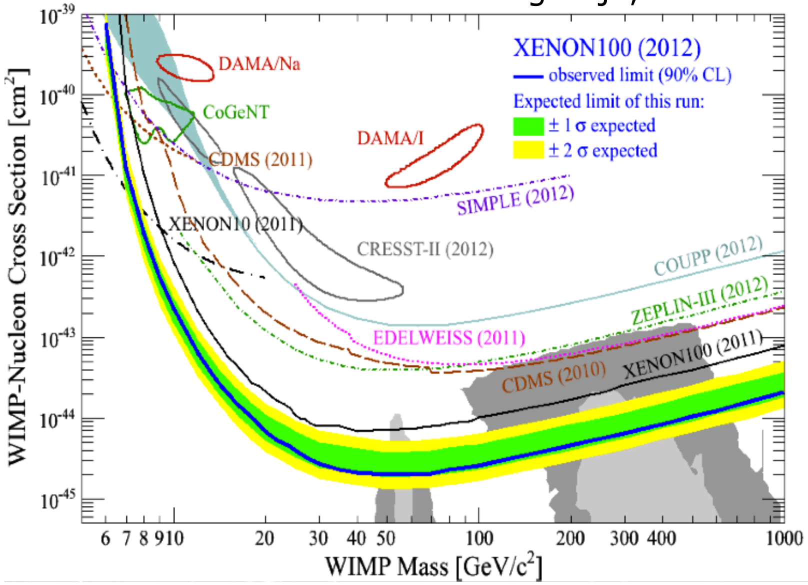
- Spokesman: *J. Gascon* (IPNL)
- Technical coordination: *A. Juillard* (IPNL)
- Relations with EURECA and CDMS: *G. Gerbier* (IRFU)

Task	Coordinators
Cryogenics	A. Benoit (Neel)
Detectors	S. Marnieros (CSNSM), X.F. Navick (IRFU)
Cryogenic cabling	A. Juillard (IPNL), H. Kraus (Oxford)
Electronics & DAQ	B. Paul + M. Gros (IRFU), M. Kleifges (IPE)
Low radioactivity and shielding	V. Kudryavtsev (Sheffield)
Muon veto and ancillary detectors	K. Eitel (IK), E. Yakushev (Dubna)
Offline and Monitoring	E. Armengaud (IRFU), J. Gascon (IPNL)
Database and documentation	A. Cox + V. Kozlov (IK)

EVOLUTION OF THE SCIENTIFIC CONTEXT

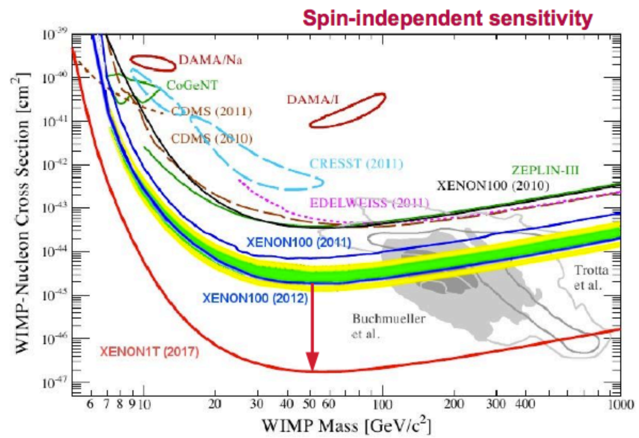
XENON-100 results

Melgarejo, IDM2012



- 224 days
- 38 kg fiducial mass
- 2 observed events
  (predicted: 1)
- New limits: 2×10^{-9} pb
  at M_{WIMP}=50 GeV

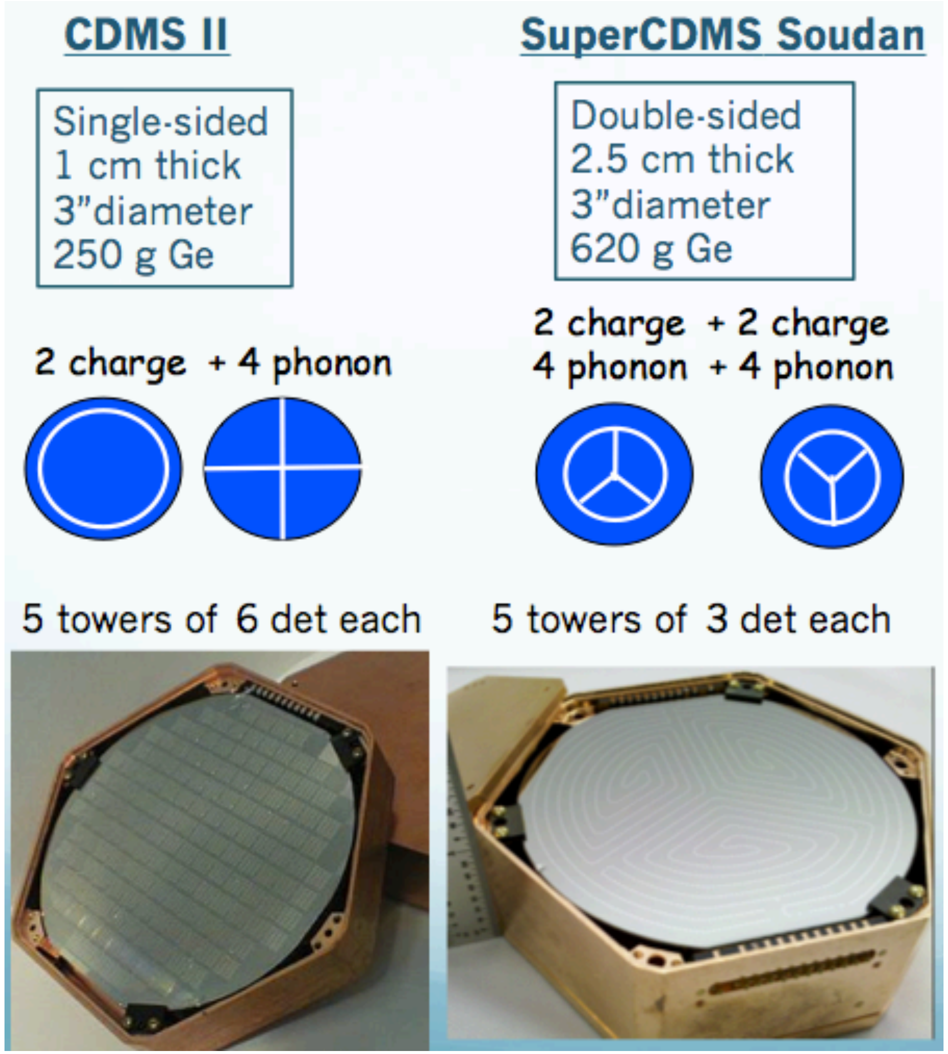
Budnik, IDM2012



- XENON 1t construction started
- 2400 kg Xe (XENON100 x 15)
- Data taking to start in 2015
- With x100 background reduction, goal of 2×10^{-11} pb in 2017.

SuperCDMS Soudan: 650g iZIPs

- Phonon timing + phonon symmetry + ID electrodes *(but no veto electrode readout)*
- 9 kg (6 kg fiducial)
- Data started in 2012, 2200 kgd by 2014 6×10^{-9} pb for 100 GeV/c^2
- Goals of low thresholds for low-mass WIMPs (at the expense of surface event rejection from phonon timing)



Cushman, IDM2012

Future Project: SuperCDMS at SNOLAB

- 1.38 kg iZIPs
- R&D to be completed in 2013
- Goal: 200 kg Ge
  140 000 kgd
  (4 year run)
  10^{-10} pb in ~2017

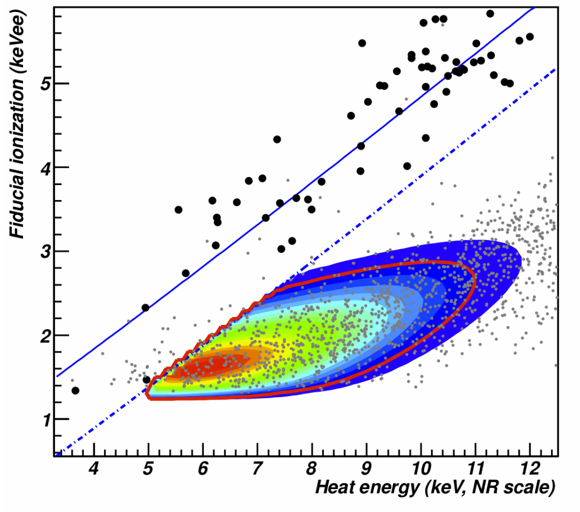
~EURECA time scale

Cushman, IDM2012

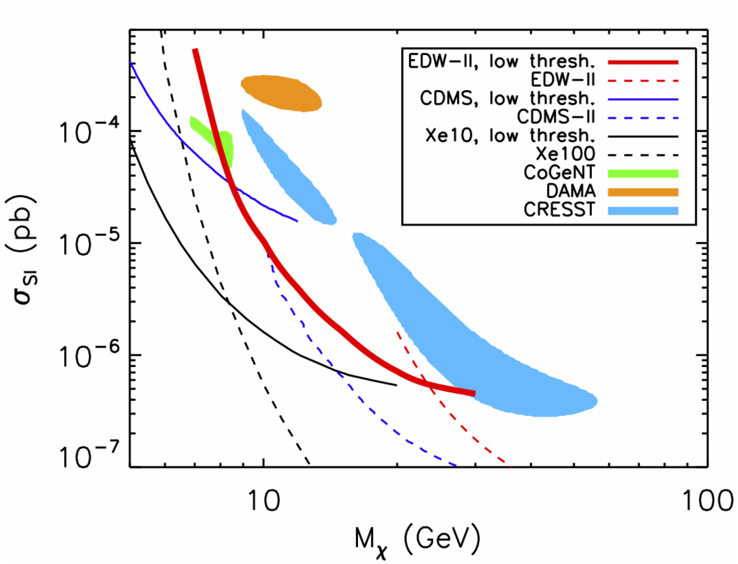
Recent EDELWEISS low mass analysis

PRD 86 (2012) 051701R

- Realization that, despite being tuned for M_{WIMP}~100 GeV, EDELWEISS-II had significant efficiency down to 5 keV recoil
- *Significant background rejection with ID electrodes down to low energy: EDELWEISS-ID limit better than CDMS in 8-10 GeV range*

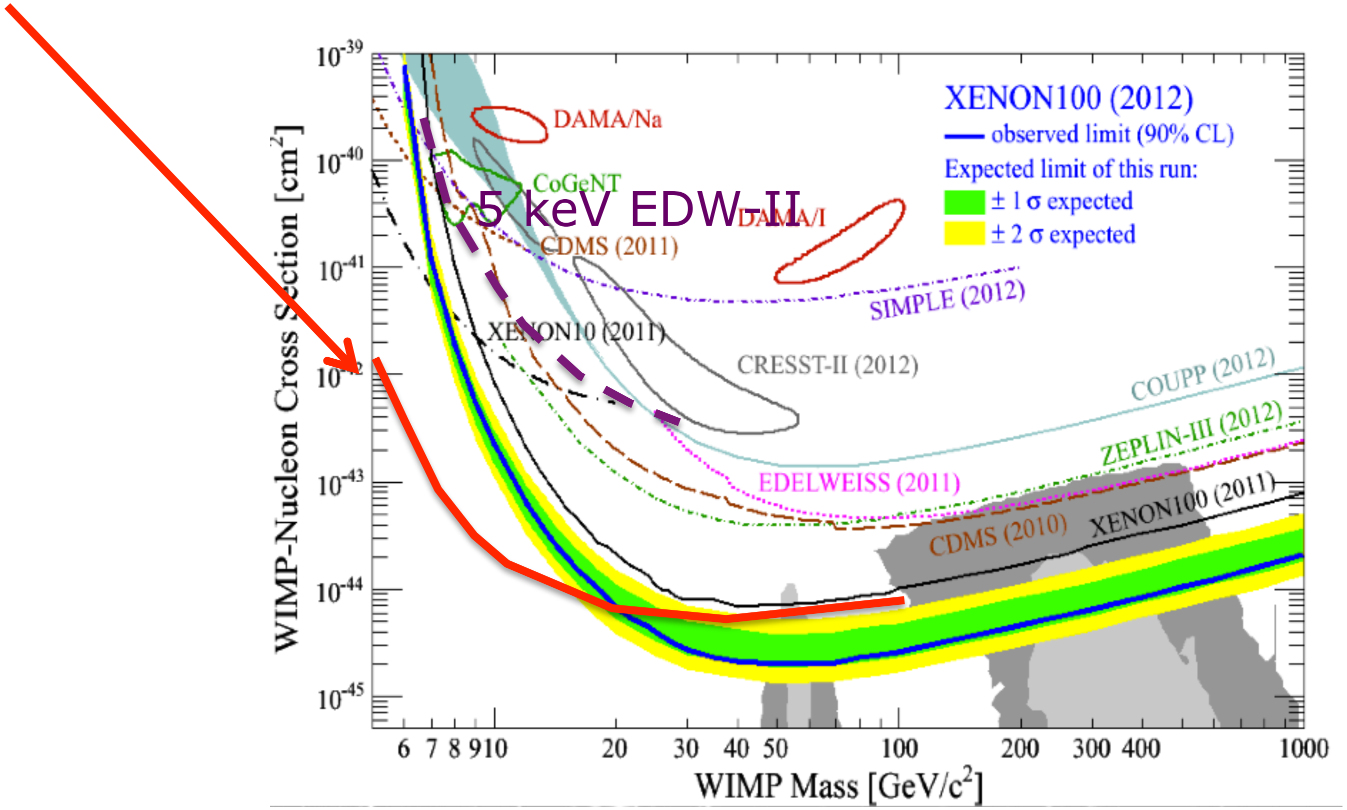


- Resolutions are improving with new electronics (900 eV -> 650 eV for ionization, 1.25 -> <1 keV for heat)
- 500 eV achieved in tests (HEMT R&D to go down to 300 eV?)
- EDW-III will have more aggressive goals concerning thresholds



Motivation for low thresholds

- Coverage of low-mass region with 4 FID detectors with 300 eV FWHM resolutions (1200 kgd)

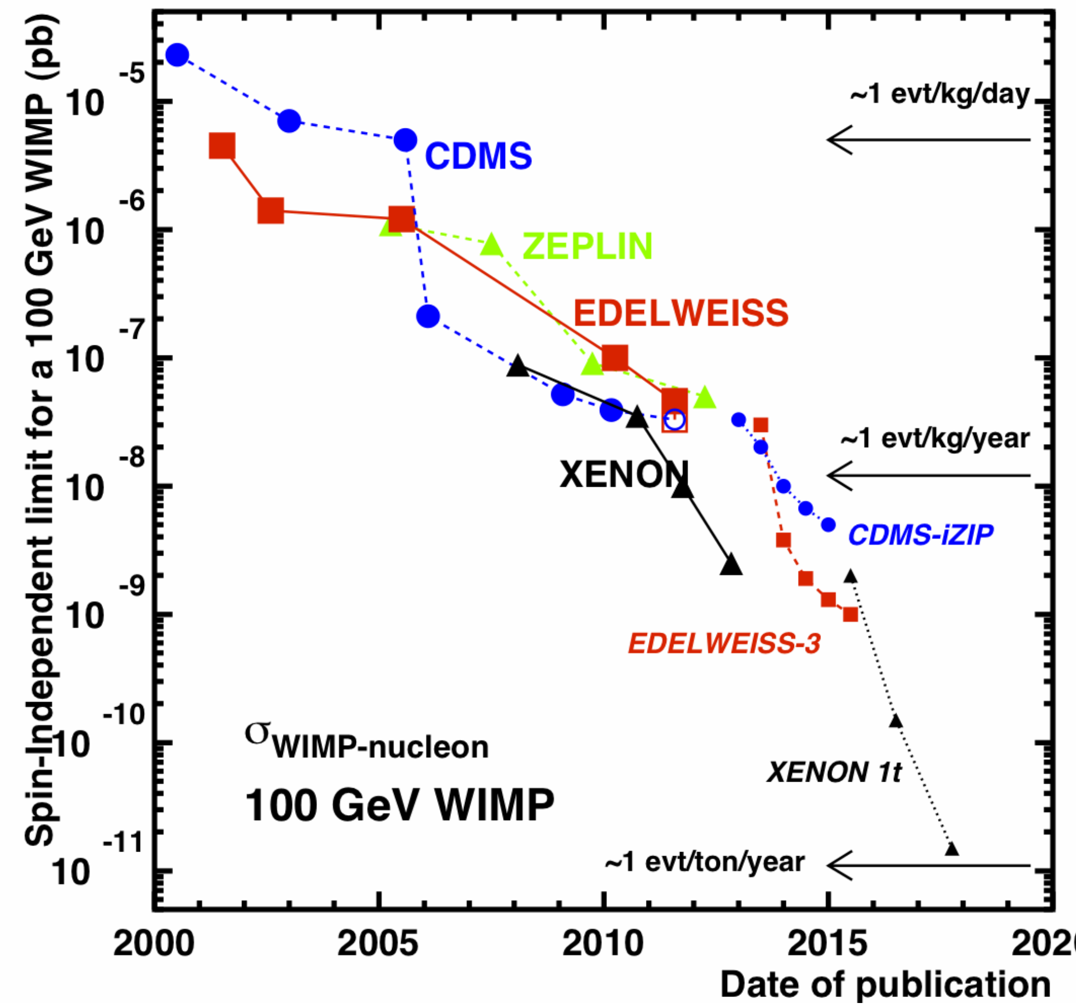


EDELWEISS-III Objectives Update

- One year late (mainly: leakage current problem discussed later)
- Slope of 3000 kgd / 6 month should be reached mid-2013
- Achieved improvements in resolution show that an average 10 keV threshold is possible, with significant efficiency down and little backgrounds down to 5 keV
  - Improves sensitivity for 3000 kgd to 3-4x10^{-9}pb instead of 5x10^{-9}pb
  - 3 keV thresholds on a few R&D detectors is possible (HEMT)
- Range of background from internal neutrons limits total exposure to 4500 kgd (2.5x10^{-9} pb at 15 keV) to 12000 kgd (10^{-9} pb at 15 keV)
- *Depending on backgrounds, EDELWEISS-III could reach 1 to 2.5x10^{-9} pb before the start of XENON-1t and SuperCDMS SNOLAB*

- Need to address low mass WIMPs
  - Recent paper: better than CDMS at 8-10 GeV/c^2
  - ~5 keV threshold already possible with good IDs
  - significant surface event rejection with cut on veto signals

Present limits vs CDMS/EDW3 predictions

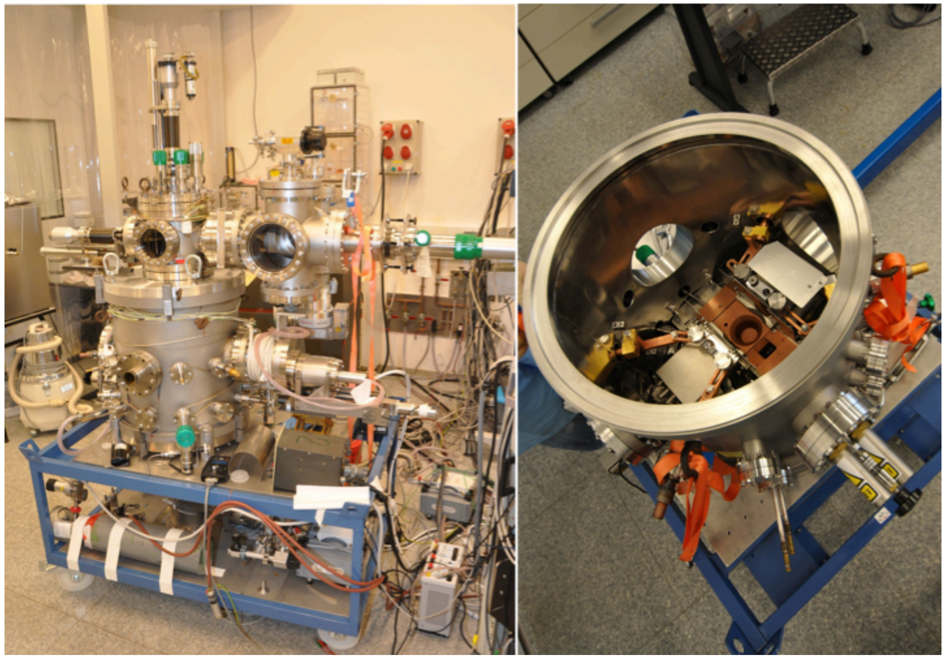


PROGRESS REPORT

EDELWEISS electron-beam evaporator (CSNSM)

FID detector processing

- 810 g Ge crystals are received already polished & etched
  - 10 Canberra + 24 BSI received
  - Additional 10 BSI purchased
- α-Ge underlayer deposition
- Al electrodes & contact pads deposition
- Au heat link pads deposition
- Ion beam cleaning (Ar) prior to each deposition
- Mask positioning outside the evaporator
- Ge-NTD heat sensor gluing
- Process shortened to 2.5 day by using same mask for α-Ge and Al
- *Planning based on 1 FID / week*



FID production

- Challenge wrt to ID: lateral evaporation
- First 3 FID800 could handle +-4V polarizations with no leakage current (<<1 fA)
- Production of next 10 FIDs: all but the second one suffer from leakage between adjacent electrodes, on either curved or flat surfaces or both.
- Intensive study to understand the origin of this problem, and to find a solution
- One year delay in detector production

Leakage current: solution

Need a solution that keeps the simplicity of the process, is ~100% efficient and ideally can be used to repair detectors *after* the leakage diagnostic

- Several detector processing alternatives have been tested:
  - *Electrodes under-layer material (H-αGe, αGe, SiO, no under-layer)*
  - *Ion-beam cleaning optimization*
  - *Ammonium sulfide surface passivation*
  - *Chemical etching (selective etch of Ge relative to Au and Al)* [CSNSM bolometer matrices R&D]
- After these studies and consulting experts (including CDMS, facing similar problems): problem most probably related to surface defects of Ge between Al electrodes, possibly linked to the initial mechanical polishing and chemical etching.

The selected chemical etching procedure *after the detector fabrication* is 100% efficient in removing leakage currents problems (11/11 detector treated)

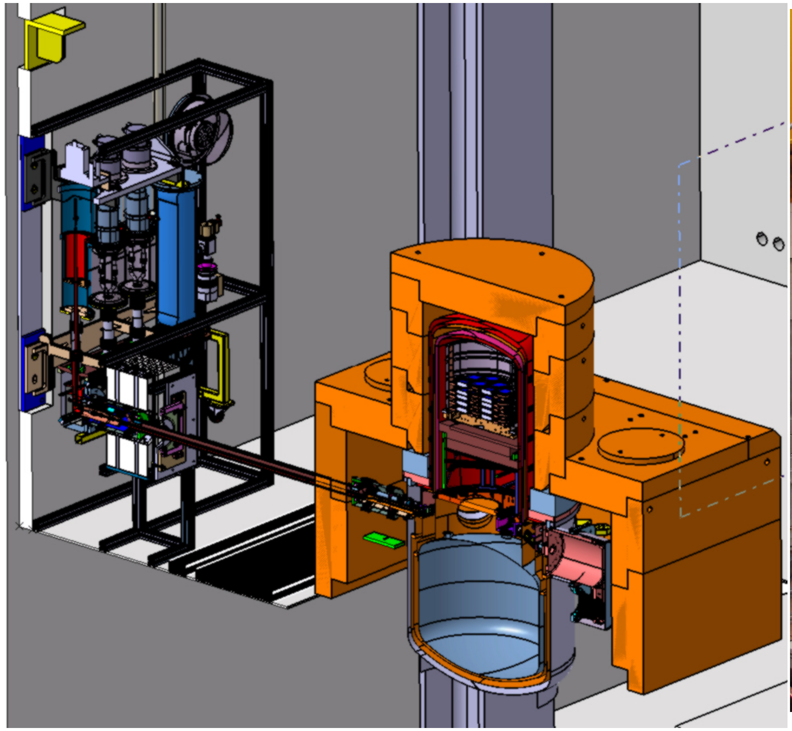
- A procedure has been optimized: it can be applied to the entire past production (without ungluing the NTD sensors) and preserves FID performances
- Actual procedure to be the object of a publication next year

2011-2012 calendar (1)

- 2011: Runs in Modane to help understand the leakage problems, and to study the performance of the three working FID800
  - Very good reproducibility
  - Fiducial volume conforms expectations
  - Improved gamma rejection than ID over entire fiducial volume
  - Better charge collection in non-fiducial regions than ID
- End 2011: Test new electronics, cabling and new NTD sensors
  - Baseline resolutions on fiducial ionization improves from ~1 keV (in EDELWEISS-II ID) to 0.65 keV FWHM
- Spring/Summer 2012: Upgrade of cryogenics
  - Lower and more consistent microphonics noise level to obtain a more homogeneous data sample with <1 keV heat resolution

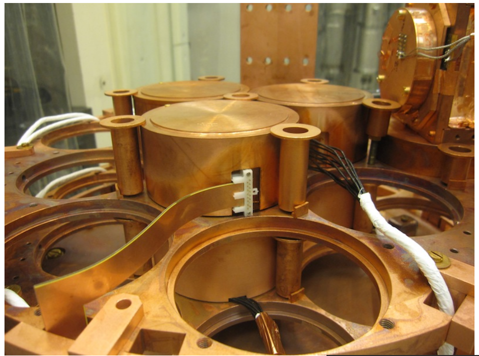
New Cryogenics machines

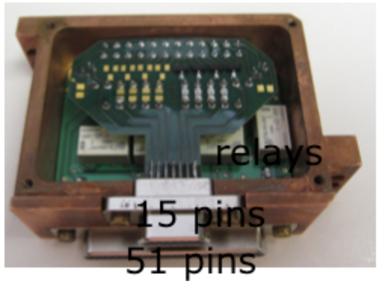
- Objective: move "noisy" pulse-tube out of inner shields
- Replace with thermal machines on LSM wall
- Cold transported via fluids in caloduc

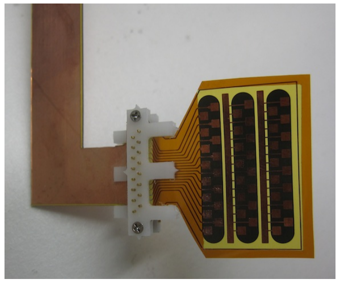


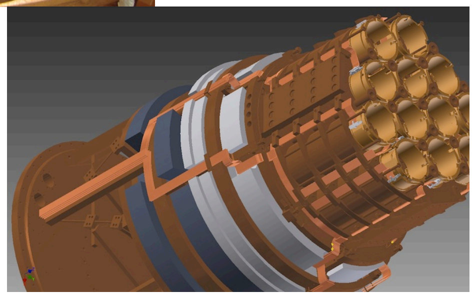
2011-2012 calendar (2)

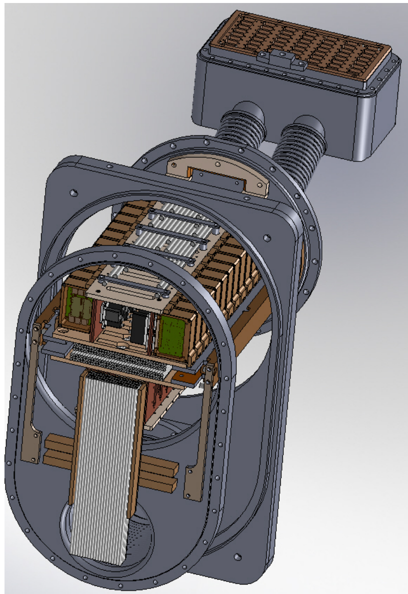
- Autumn 2012: Test of new Cu screens adapted to new PE shield
- Test of new kapton for 10-100 mK connection
- Preparation in IPNL of cabling for full detector array





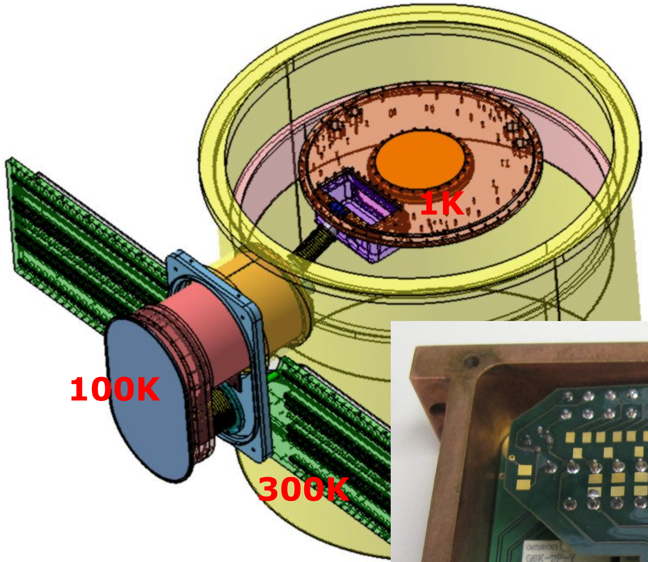


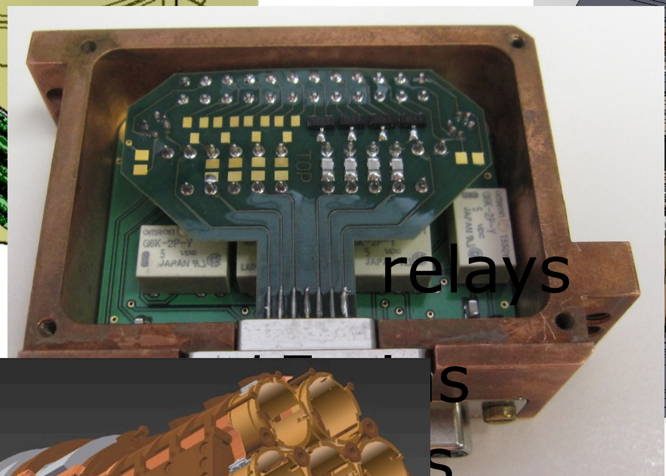




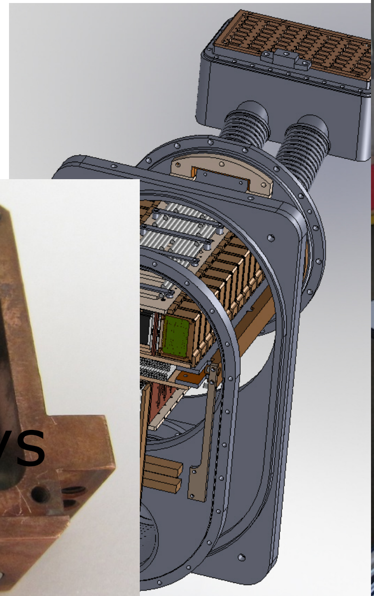
- Also at LSM: test of ZnMo detectors (A. Giuliani, ANR LUMINEU)

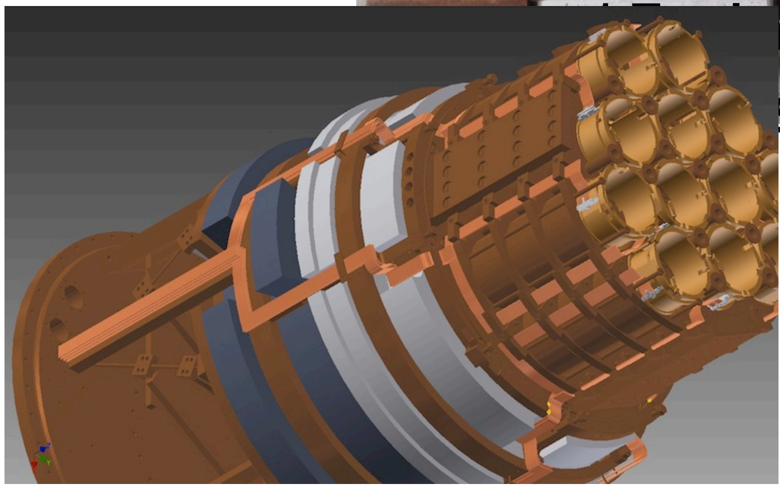
Cryogenic cabling status

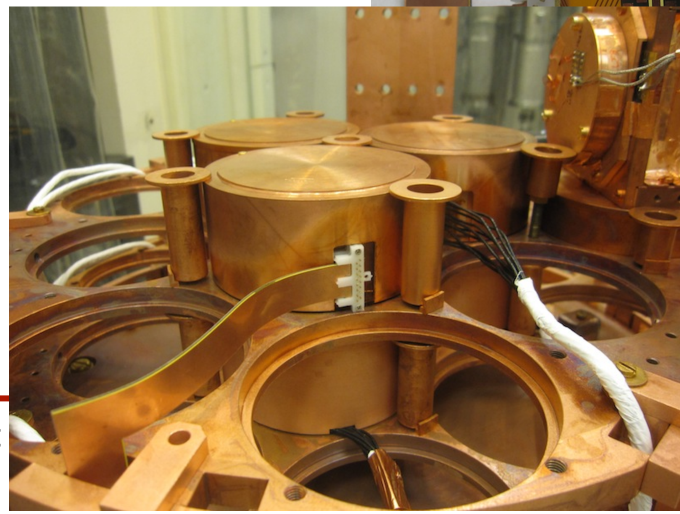




relays







Calendar for the coming years

- Run 20 (started october 2012): 6 FIDs
  - Final confirmation of performance of detectors with new surface treatment (done)
  - High-statistics beta calibration of FID800
- Start now final production of FIDs (1/week)
- Installation of new cabling and shields in December
- Run with 15 FIDs starting January 2013
  - Commissioning, large-statistics gamma calibration
- Run with 40 in summer 2013
- First 3000 kgd in winter 2013 (3000 kgd per 6 months)
- >10 000 kgd before end 2015

PEOPLE AND BUDGET

Edelweiss-III project: Budget

- We're within budget
- Savings on detector helped electronics + shields
- Investments spending 92% completed in 2012.

	2010 projection	Budget 2010-2013	2013 part	ANR part	in2p3 part
Detectors +NTDs	900 kE	810 kE	0	694 kE	0
Cryogenics	100 kE	138 kE	0	0	50
Electronics + cabling	330 kE	387 kE	110 kE	146 kE	30
Shields	30 kE	139 kE	0	0	0
Operations*	150 kE/y	112 kE/y	145 kE	0	~60 kE/y
4-year Total	2070 kE	1921 kE	255 kE	840 kE	330 kE

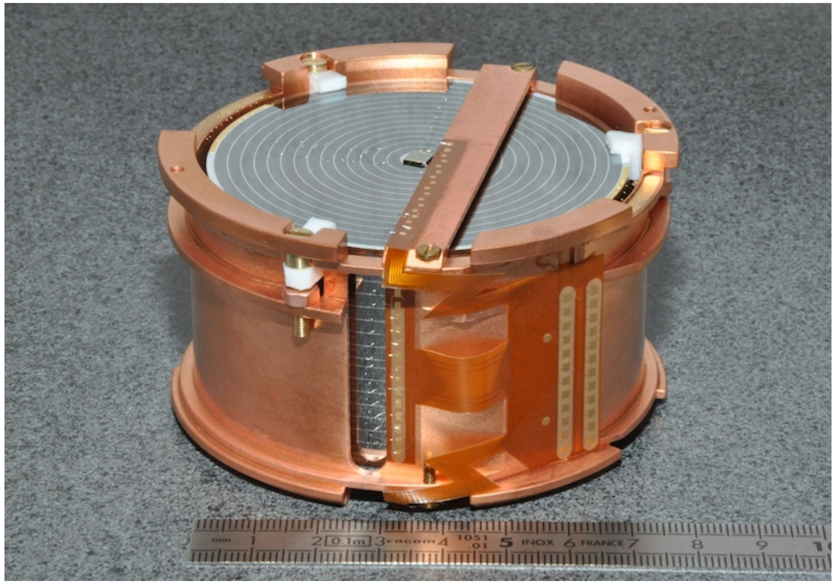
* Costs of operations in LSM. Do not include travels (~40 kE/y for in2p3) and operations and R&D in in2p3 labs (~45 kE/y)

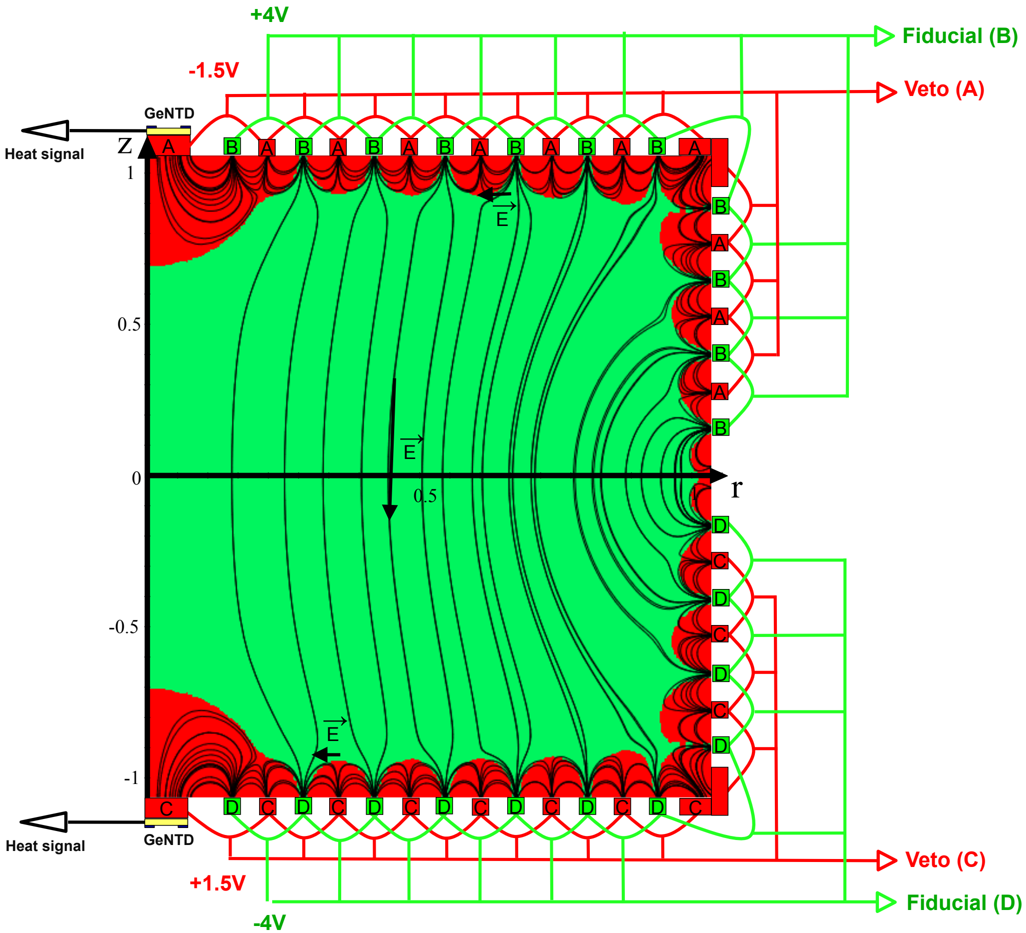
- More people than ever…
  - New group on DAQ electronics (IPE-Karlsruhe)
  - Excellent integration of recent members: IPE, and also Oxford (since 2010, cryogenic cabling) and Sheffield (since 2011, radioactive background and simulations)
  - 3 Postdocs (1 Paris, 2 KIT) + …
  - 8 PhD (4.5 KIT, 1.5 Lyon, 1 Paris, 1 Oxford) + …
  - 2 Diploma + …
  - Since 2011, +2 permanents in IPNL, +1.5 in CSNSM, +1 in CEA, …

Conclusion

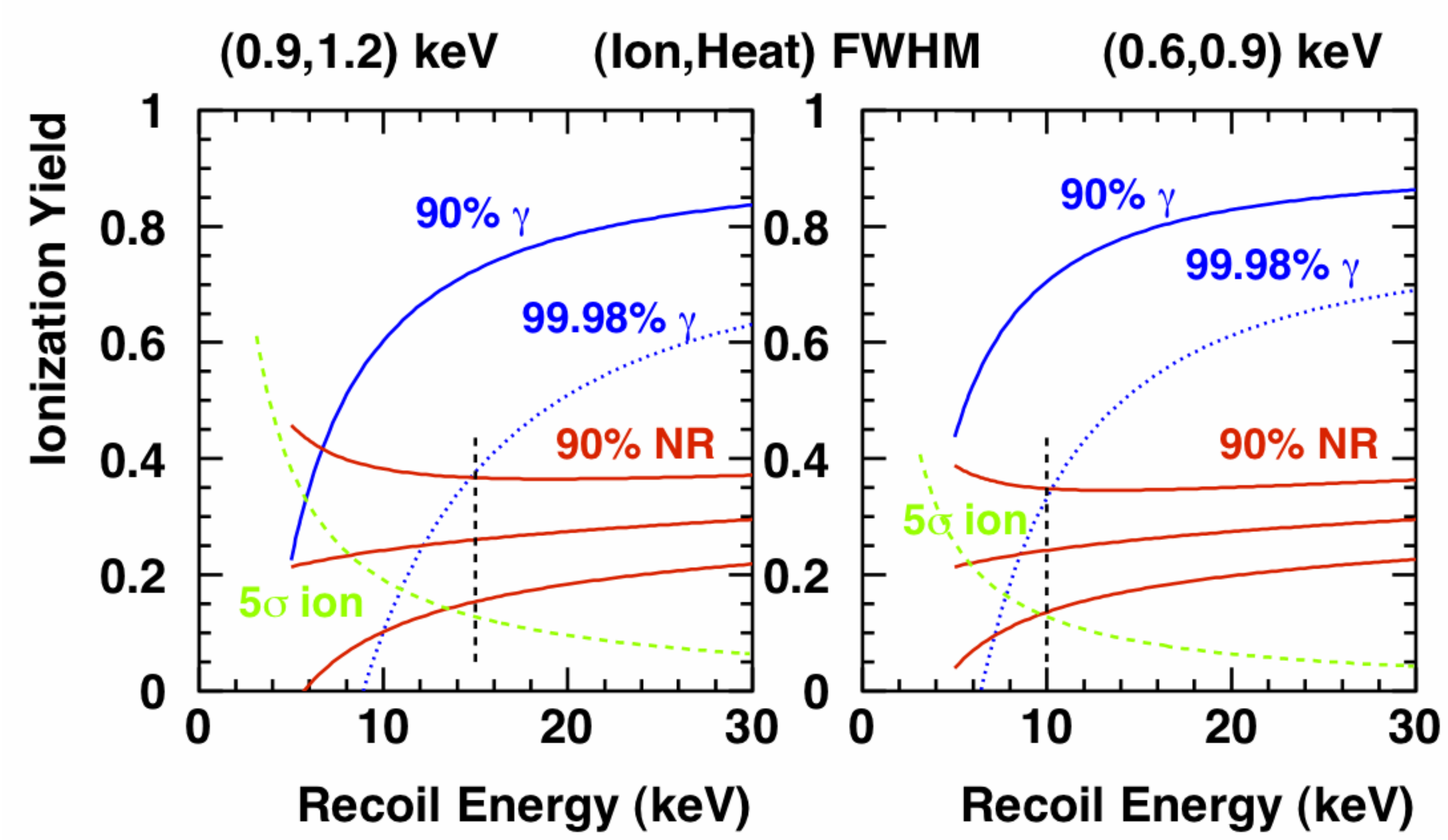
- After a year delay solving leakage current problems, detector production can now resume
- The delay was used to progress on the upgrade of the environment (cryogenics, cabling, electronics, shielding)
  - New electronics and cryogenics have resulted in >30% improvements in resolutions with respect to EDELWEISS-II. The average threshold should move down from 20 to 10 keV, with significant efficiency down to 5 keV or less.
- The goal of 3000 kgd/ 6 month will be reached in 2013
- Background level estimates allow for a two year run, resulting in a sensitivity of $>1\times10^{-9}$ pb
  - Establish our simple & reliable FID technology as the best starting point for future large-scale cryogenics Ge projects, in Europe or with American partners

EDELWEISS FID detectors





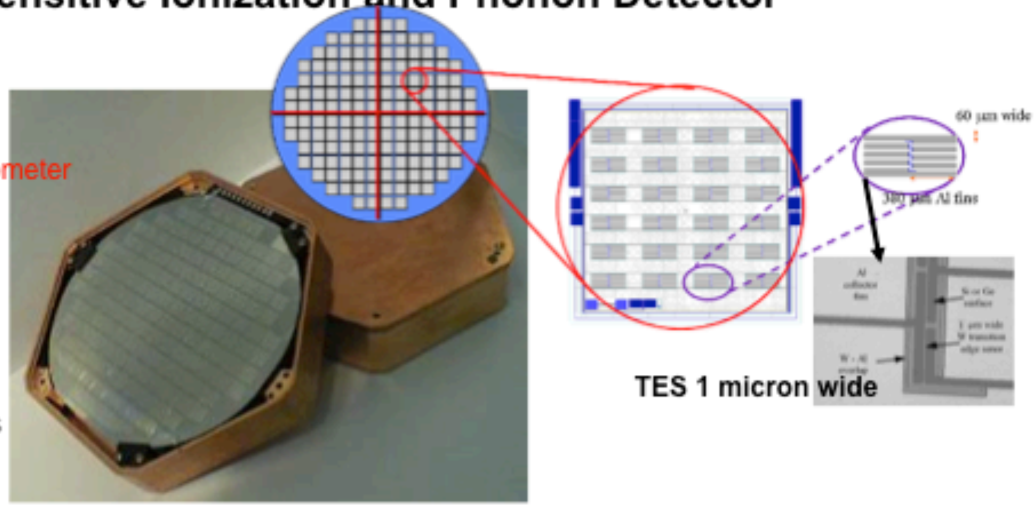
- EDW-II *average* FWHM keV: 0.9 Ion + 1.2 Heat
- (worse EDWII: 1.5 keV + 2 to 3 keV)



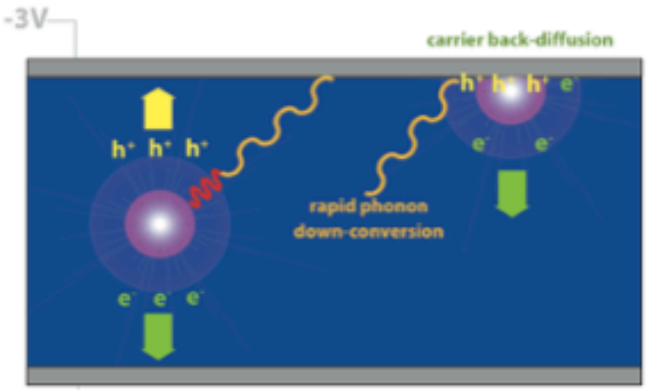
CDMS ZIP detectors

ZIP: Z-sensitive Ionization and Phonon Detector

Detectors :
- 250 g Ge or 100 g Si crystal
1 cm thick x 7.5 cm diameter
- Phonon Sensors : Superconducting W thermometer
Photolithographic patterning
4 quadrants
37 cells per quadrant
6x4 array of 250µm x 1µm W TES per cell
Each W sensor "fed" by 8 Al fins
- Ionization Sensors
2 electrodes (+ ground) allow rejection of events near outer edge
- Low impedance electronics with Squids
+ FETs pour Ionisation



TES 1 micron wide



A. Reisetter, UMinn
PRL 96, 011302 (2006)

Physics of phonons degradation : surface events have faster rise time.

→ 2 parameters used for cuts :

- Primary risetime (delay 10% - 40% phonon amp.)
Primary delay delay 20% charge amp and 20% phonon amp.)

46