Low-mass WIMP search with the EDELWEISS experiment

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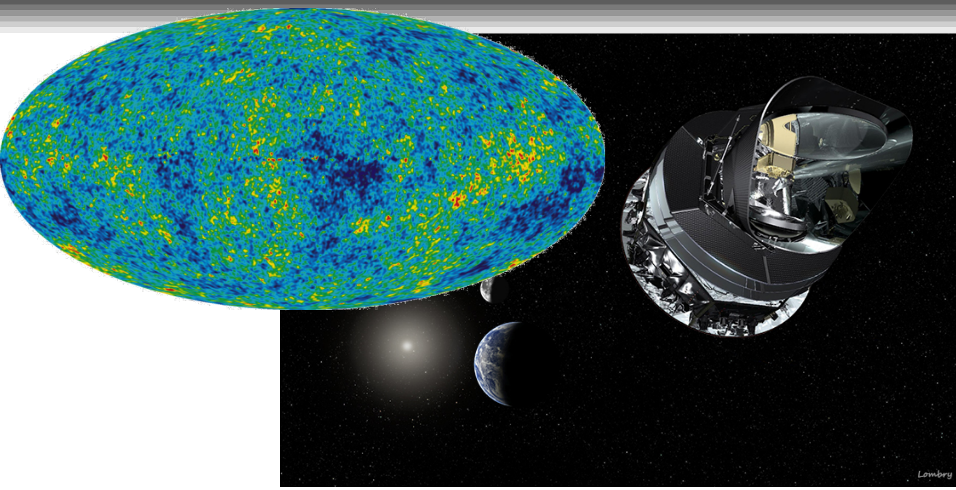
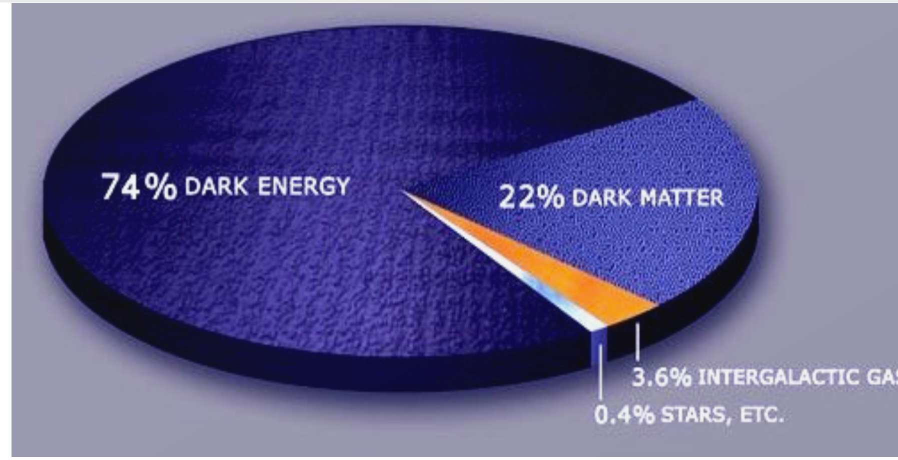
Expérience pour DEtecter Les WIMPs En Site Souterrain

IRN Terascale @ Montpellier – 3-5 July 2017

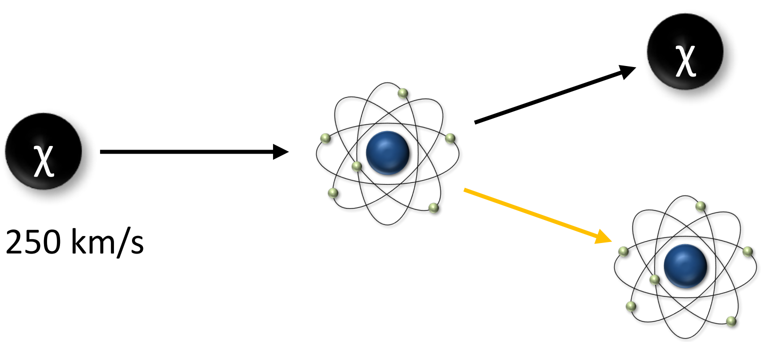
Direct detection of Dark Matter





How to detect a WIMP χ ?

- χ production within particles collisions → missing energy in final state,
- indirect detection within χ annihilation → annihilation products in cosmic rays,
- direct detection by elastic scattering of χ on nuclei → ionisation
  → heat
  → scintillation



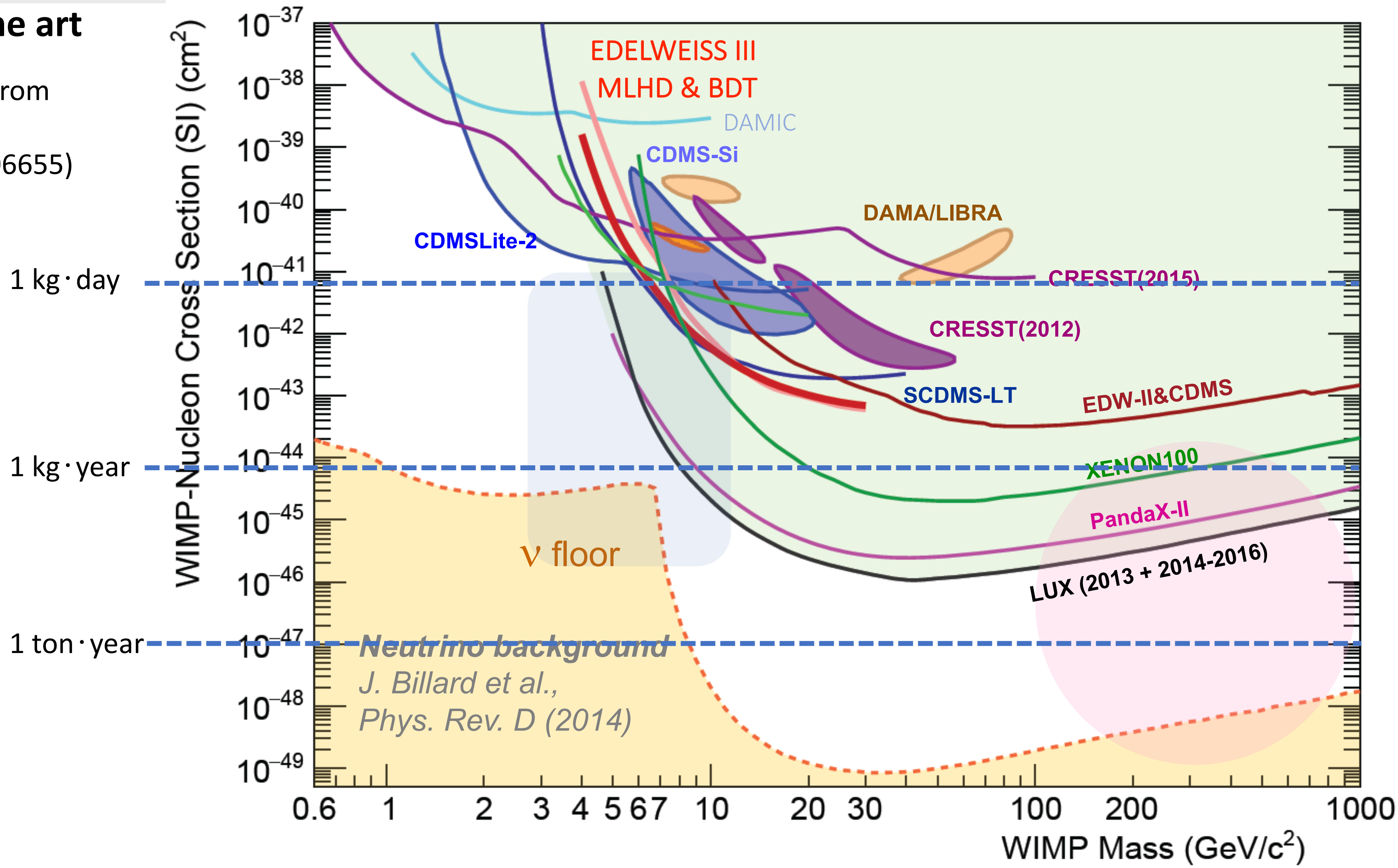
v ≈ 250 km/s

E_{recoil} ≈ 10 keV

Direct detection of Dark Matter

State of the art

New results from XENON1T (arXiv:1705.06655)



State of the art

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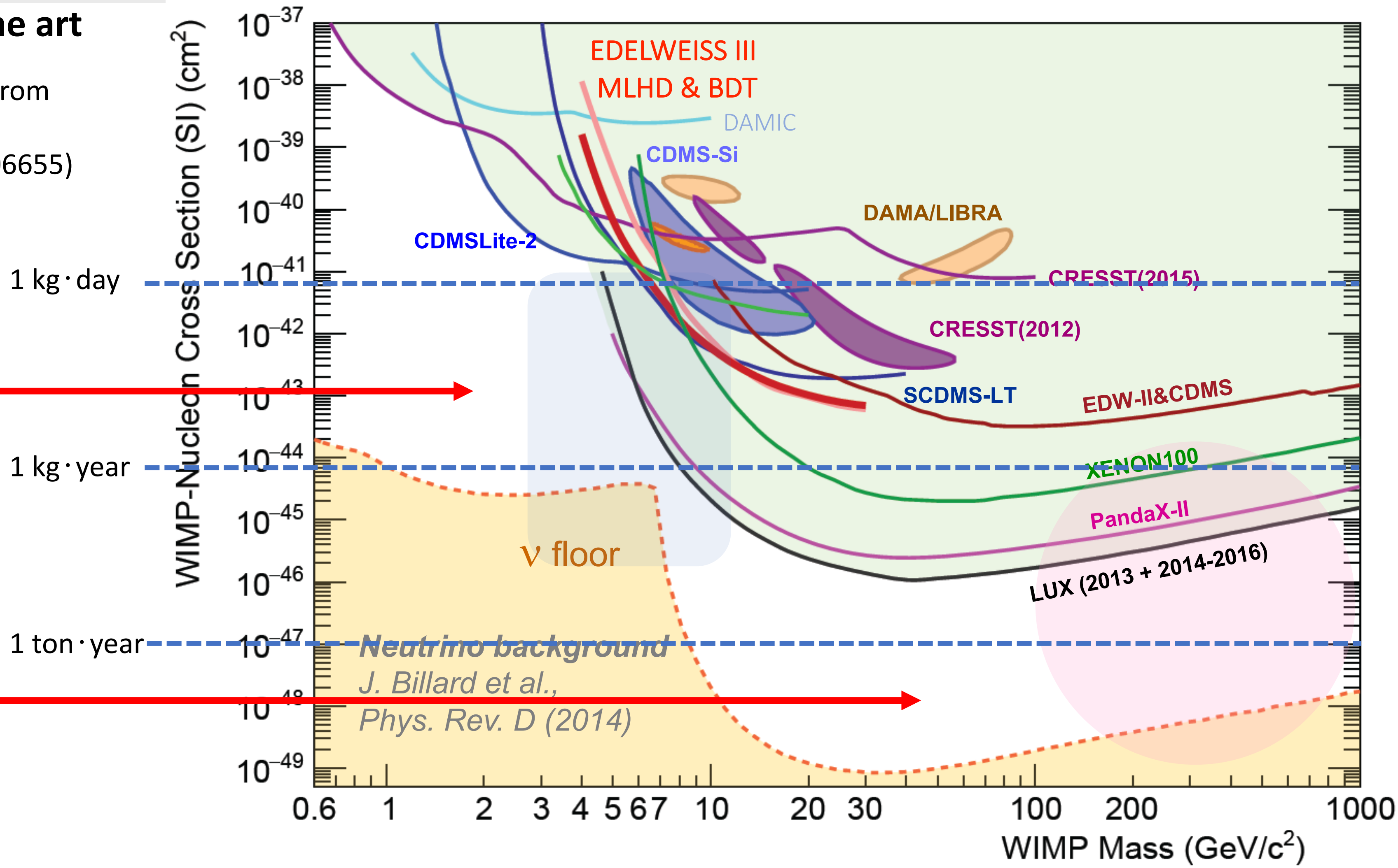


High-mass: large exposure and low background → use liquid noble gases.

Low-mass: low threshold (100 eV) and high resolution → use cryogenic detectors.

The EDELWEISS experiment

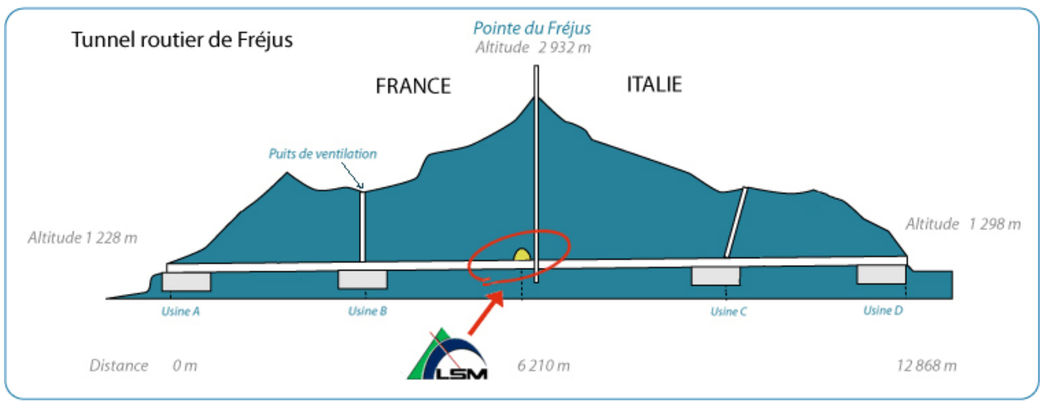
The EDW collaboration

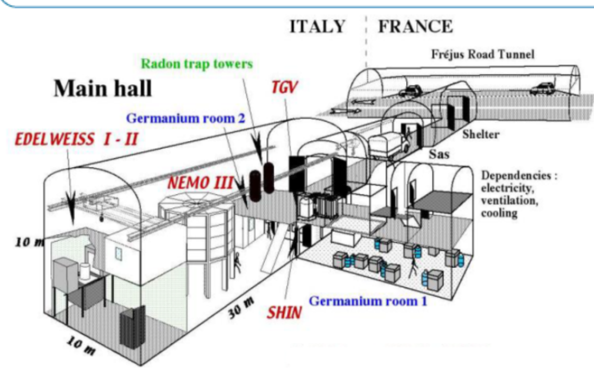
- CEA / Irfu / Iramis (Saclay)
- CSNSM (Orsay)
- Institut Neel (Grenoble)
- IPNL (Lyon)
- LPN (Marcoussis)

- KIT (Karlsruhe)
- JINR (Dubna)
- University of Oxford
- University of Sheffield


EDELWEISS 2016 @ Karlsruhe (De)

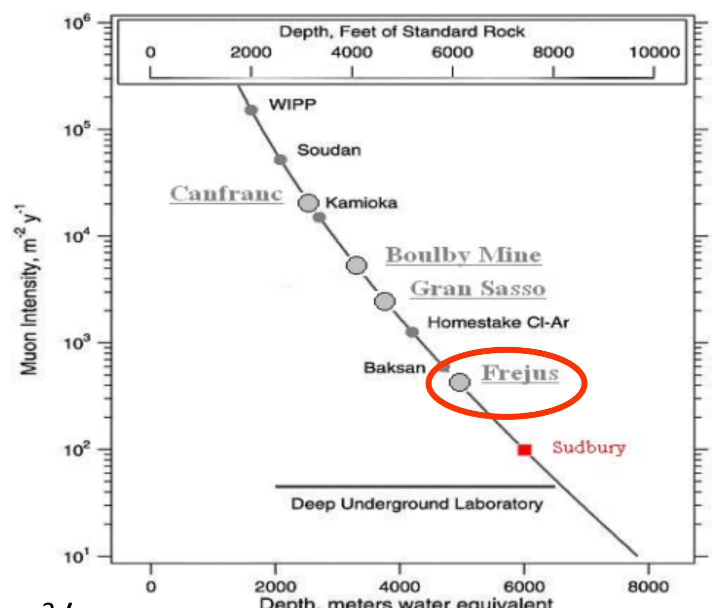
Laboratoire Souterrain de Modane





Muon flux attenuated by a factor **1 million** under ~2 km of rock.

Muon flux at sea level: $1.6 \cdot 10^{-2}$ /cm^2/s



The EDELWEISS experiment

The set-up

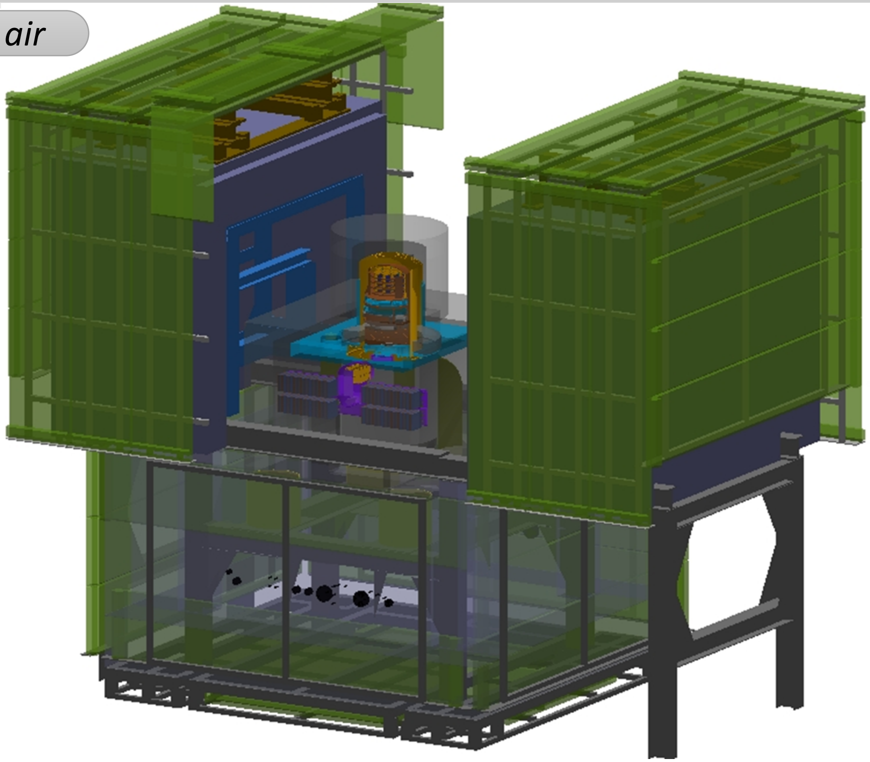
Deradonized air

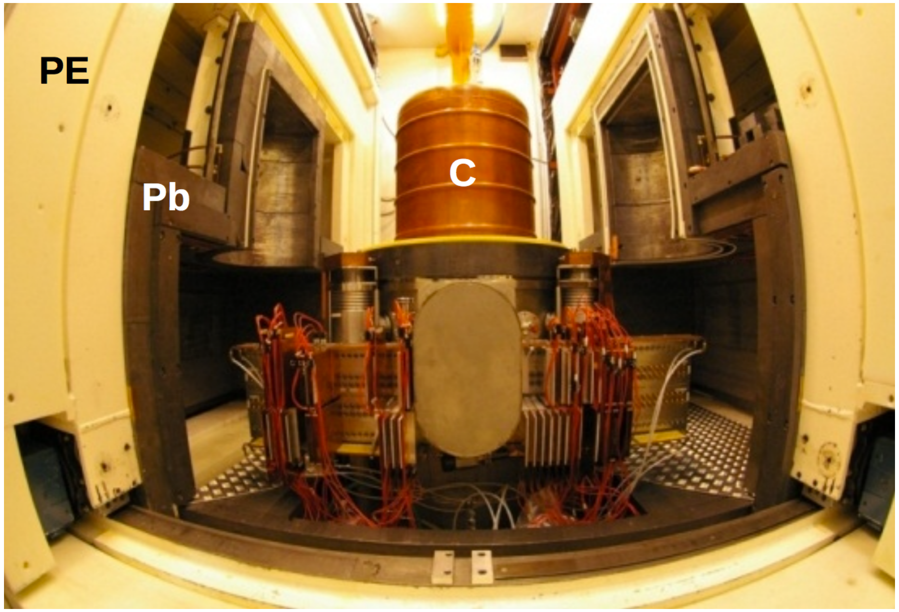
Shieldings:

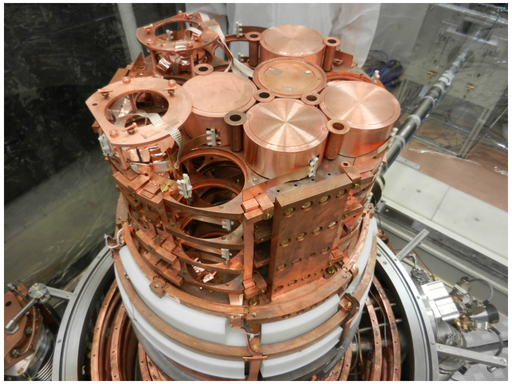
- Clean room,
- Muon veto (plastic scintillator modules),
- Polyethylene shield (external + internal),
- Lead shiel,
- Radiopure materials.

Towers:

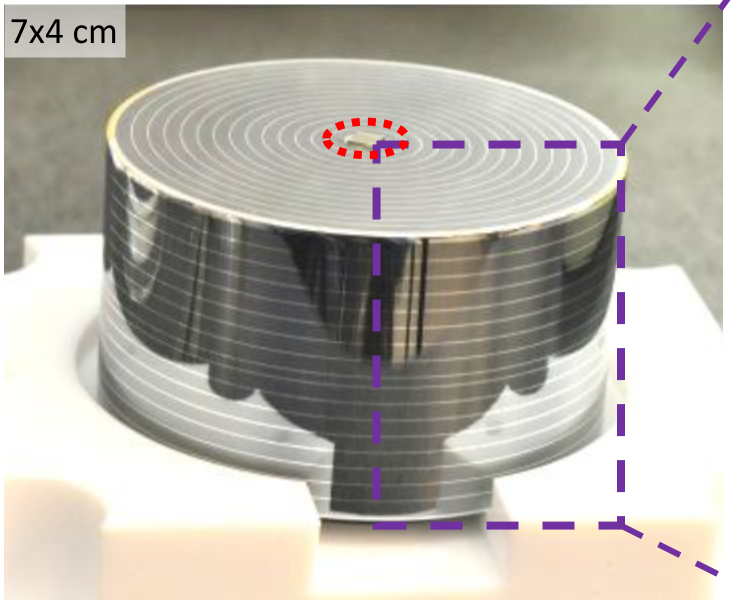
- 24 cryogenic detectors,
- T = 18 mK.

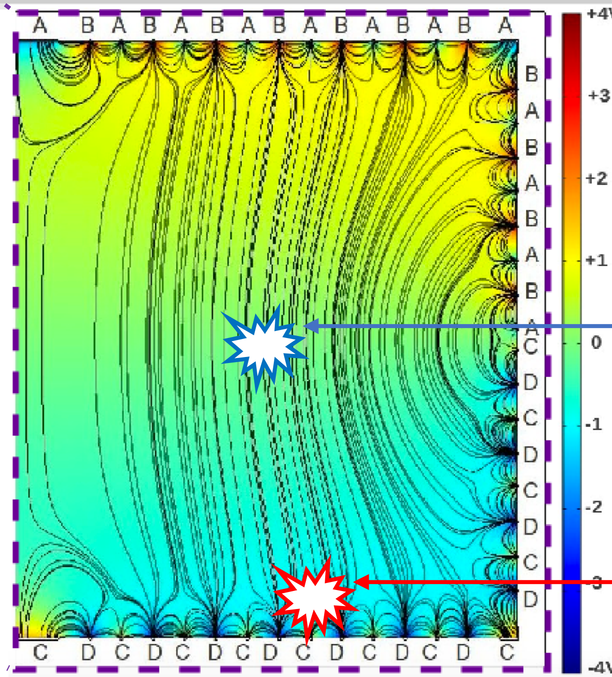






Full Inter-Digitized 800 g detector





Fiducial events:

- Collected by fiducial electrodes (B&D).

Surface events:

- Collected by veto electrodes (A/C) and their neighbour fiducial one (B/D).

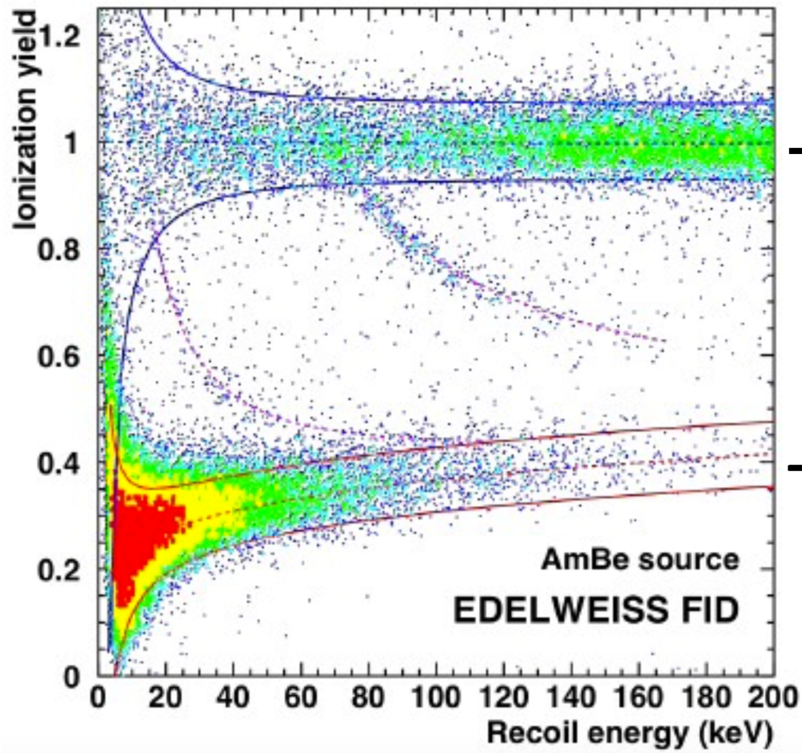
Heat channels:

- Measurement of phonon thermalization by two NTD (Neutron Transmutation Doped),
- **Δ**T = 0.1 μK/keV

Ionization channels:

- Charges collected by Al concentric electrodes (width = 150 μm, gap = 2 mm),
- Surface events rejection.

Detection within EDELWEISS-III

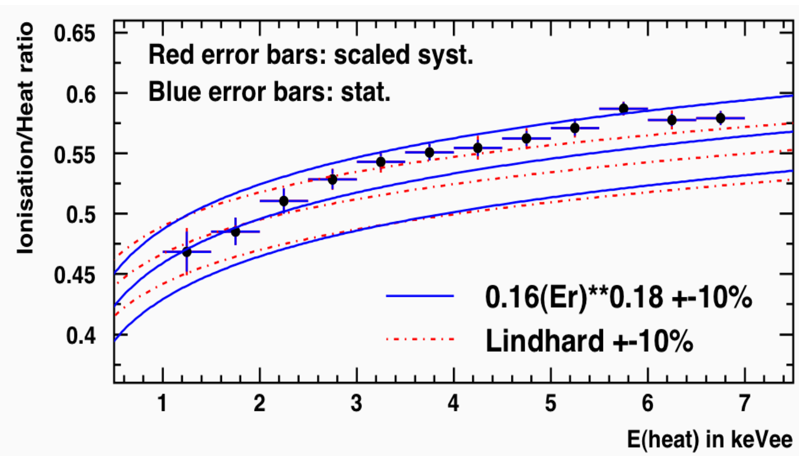


Nuclear recoil calibration and discrimination

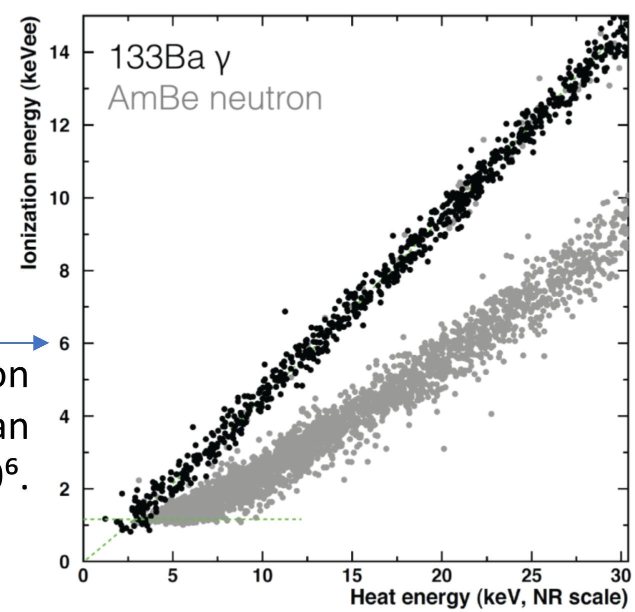
→ Electron recoil band

→ Nuclear recoil band

- Clear event-by-event separation down to 5 keV energy recoil,
- Response to nuclear recoils calibrated down to the analysis threshold for low-mass WIMP searches.
  (1 keV_{ee} heat = 2.5 keV nuclear recoil)



Our gamma rejection factor is lower than $2.5.10^6$.



EDELWEISS-III campaign

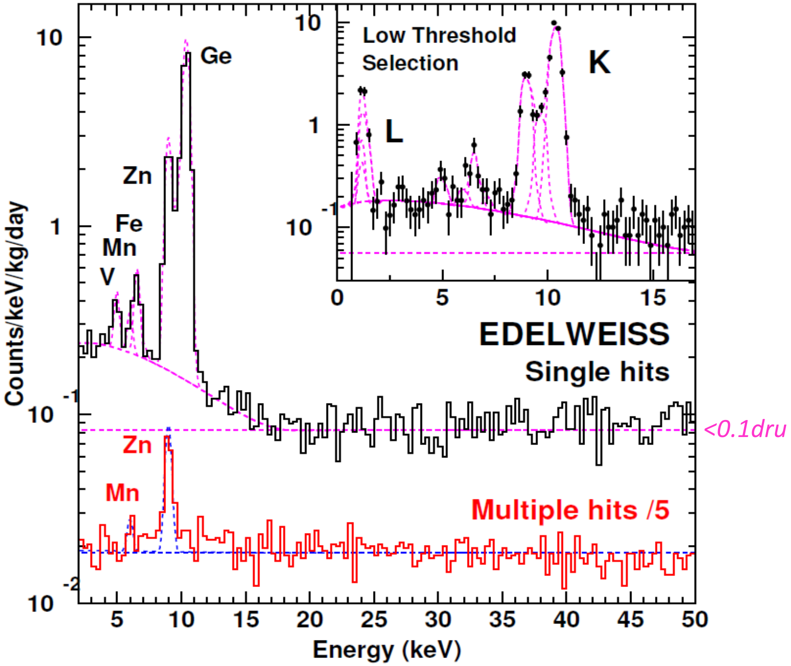
WIMP search in 2014-2015

arXiv:1607.04560

161 days of physics data with 24 FIDs > 3000 kg.day

- 19 detectors used in first measurement of cosmogenic production of ^{3}He in Ge,
- 8 detectors with lowest threshold used for low-mass WIMP search.

→ *Likelihood analysis*

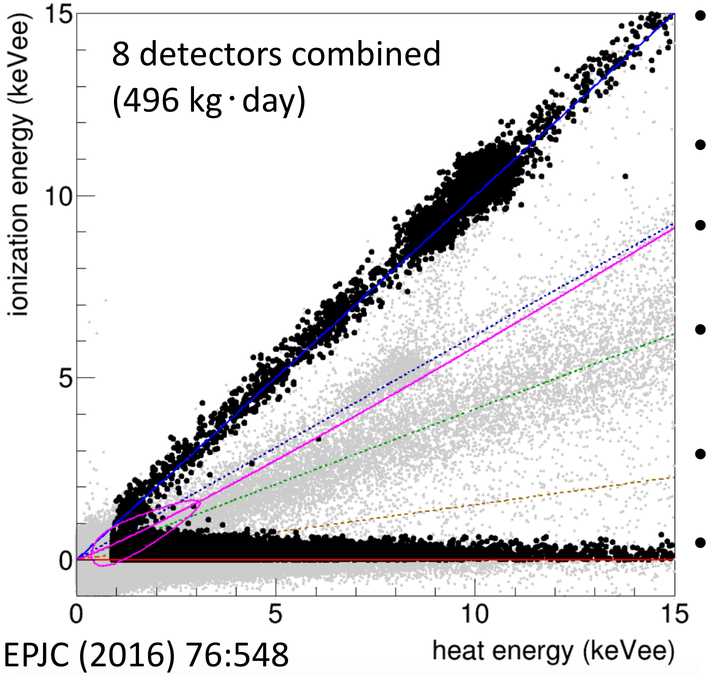


Thanks to low gamma background (<0.1 DRU), variation of cosmogenic exposure of its different detectors and ionization energy resolution (200 eV RMS).

EDELWEISS-III is the first Ge experiment to measure precisely the intrinsic tritium beta activation rate at the surface (Q_β = 18.6 keV, $T_{1/2}$ = 12.32 y): **P = 82 ± 21 nuclei/kg.d**

EDELWEISS-III – Likelihood analysis

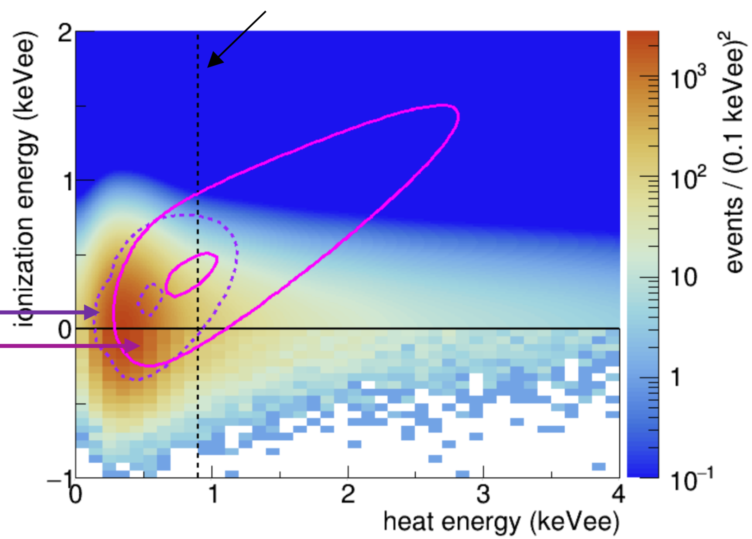
Description of the backgrounds



EPJC (2016) 76:548

- electron recoils from ^3H decay + Compton and cosmogenic gammas in the fiducial volume,
- surface gammas,
- nuclear recoils from neutron scattering,
- surface betas,
- ^{206}Pb recoils,
- Heat-only events.

analysis threshold in heat energy



10 % of the signal density for a WIMP of 5 GeV.
90 % of the signal density for a WIMP of 10 GeV.

Total PDF for each detector:

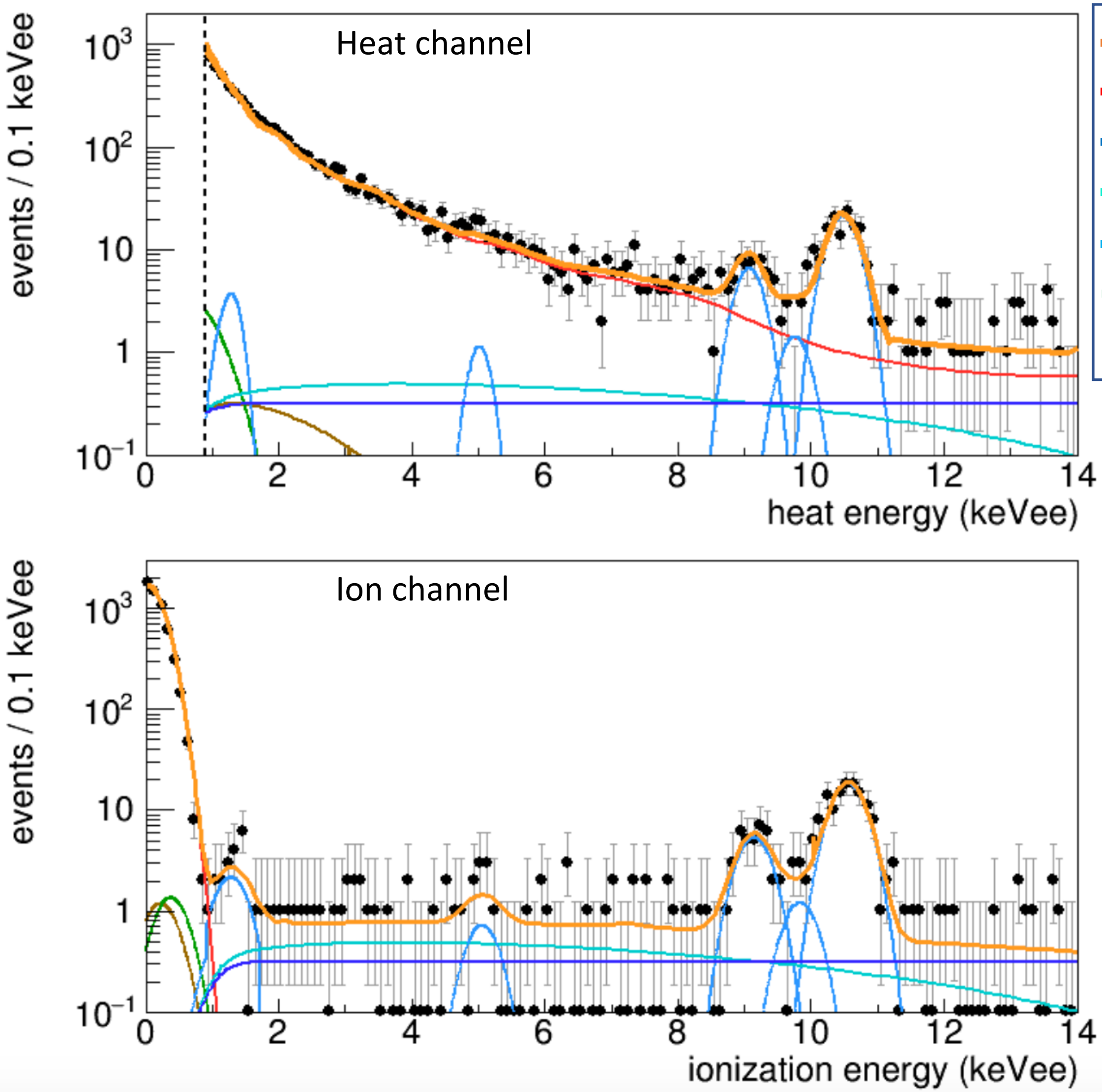
$$\mathcal{P}_{\mathrm{tot}}(\sigma, \boldsymbol{\mu} \mid m_\chi) = \frac{1}{\nu}\left[\mu_\chi \mathcal{P}_\chi(m_\chi) + \sum_{\mathrm{i}} \mu_{\mathrm{i}} \mathcal{P}_{\mathrm{i}}\right]$$

Extended likelihood function in heat and ionization energy:

$$\mathcal{L}(\sigma, \boldsymbol{\mu} \mid m_\chi) = \prod_{\mathrm{n}=1}^{N} \mathcal{P}_{\mathrm{tot}}\left(E^{\mathrm{n}}_{\mathrm{heat}}, E^{\mathrm{n}}_{\mathrm{ion}}\right)$$

$$\times \prod_{\mathrm{i}} \mathrm{Gauss}\left(\mu_{\mathrm{i}} \mid \mu_{\mathrm{i}}^{\mathrm{exp}}, \sigma_{\mathrm{i}}\right) \times \mathrm{Poisson}\left(N \mid \nu\right)$$

Energy spectra in the two observables



- ⇔ projection of the best fit PDF,
- ⇔ heat-only,
- ⇔ Compton gamma,
- ⇔ ^{3}H,
- ⇔ cosmogenic + combined L-shell peak,
- ⇔ β events,
- ⇔ ^{206}Pb recoils.

Heat channel:
Dominated by exponential heat-only spectrum at energies near the analysis threshold.

Ion channel:
Separation between Gaussian heat-only noise around 0 keV_{ee} and the electron recoil background.

Results from Likelihood

1.6×10^{-39} cm² at 4 GeV/c² to

6.9×10^{-44} cm² at 30 GeV/c².

(due to higher signal efficiency & background subtraction)

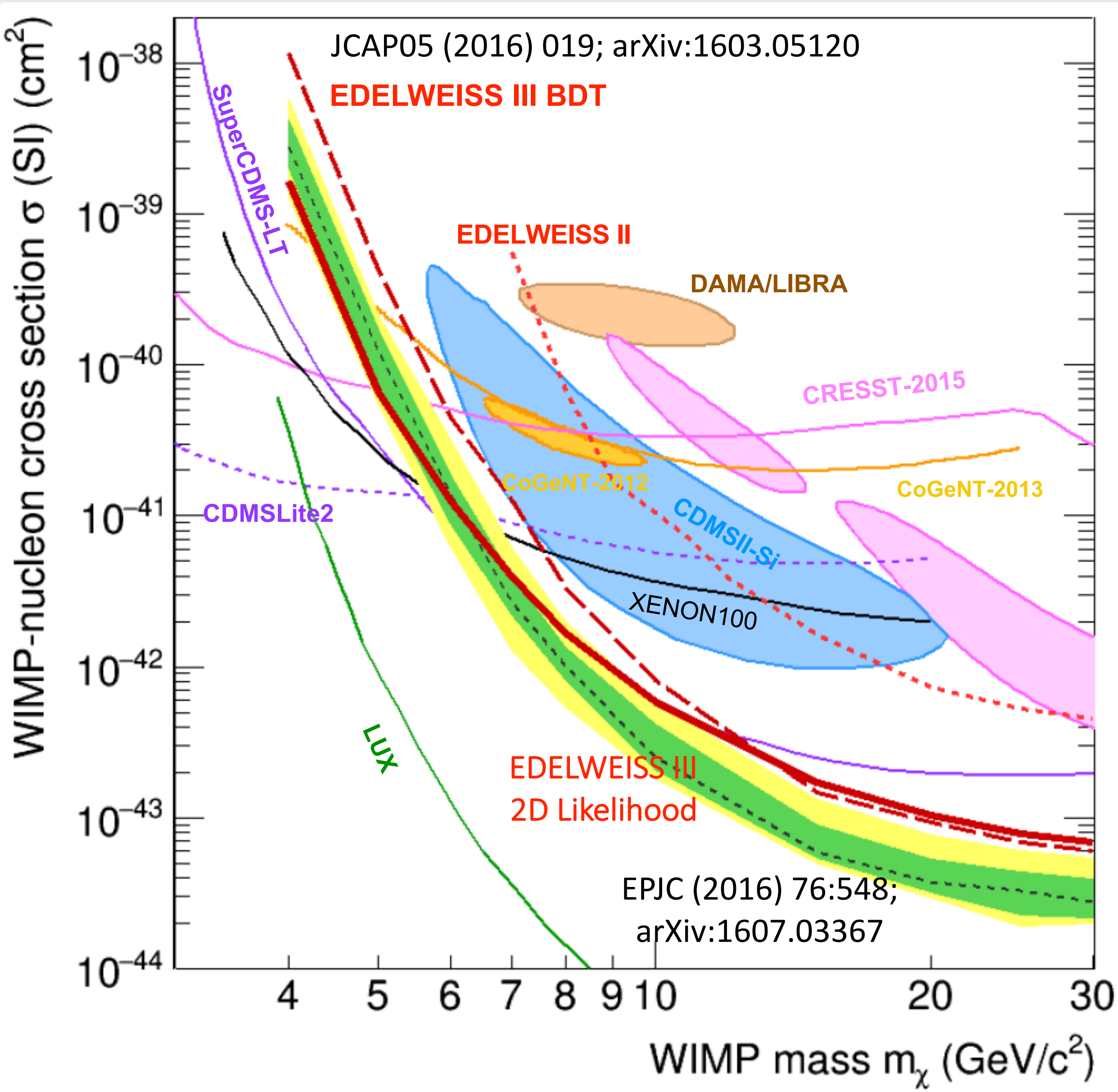
Improvement from the **BDT** analysis:

$1.1\cdot10^{-36} \rightarrow 1.6\cdot10^{-37}$ at 4 GeV/c²

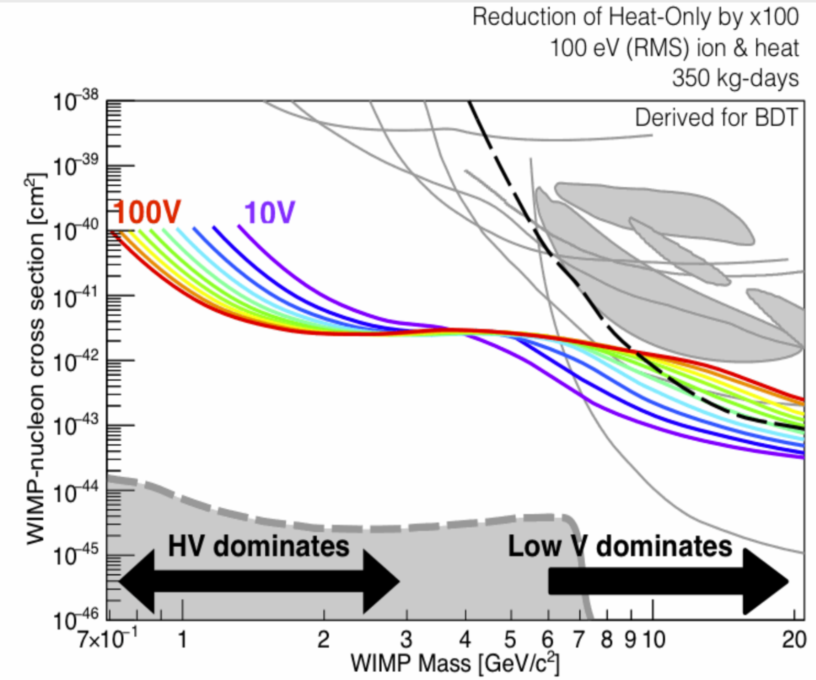
$3.34\cdot10^{-42} \rightarrow 1.66\cdot10^{-42}$ at 8 GeV/c²

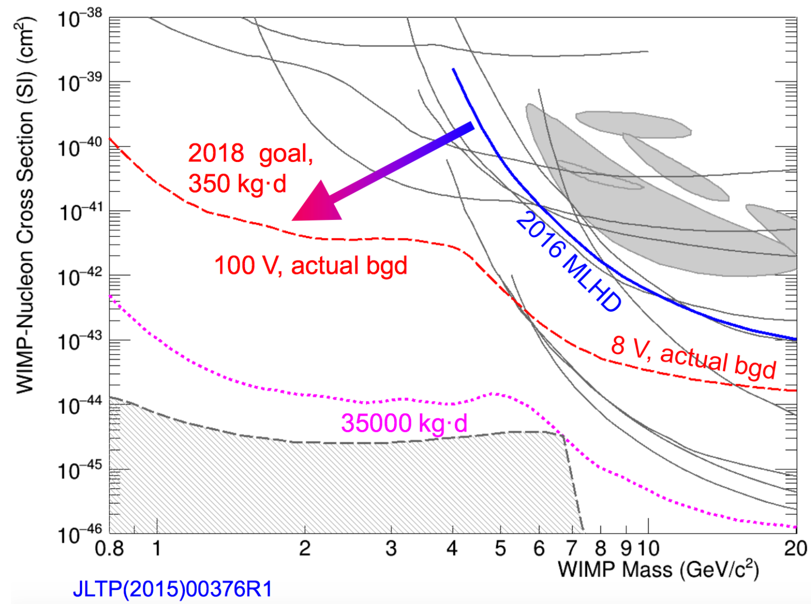
We are limited by heat-only background:

- Ionisation resolution to reject,
- Heat resolution for low thresholds.



New EDELWEISS goal: 4x100





EDELWEISS-LT

Physics with low threshold (<100 eV):

- Amplify signal → apply Neganov-Luke effect: V_{bias} = 8 ⇢ 100 V,
- Lower intrinsic heat threshold → improve heat sensor, σ_{phonon} = 500 eV ⇢ 100 eV,
- Heat-only background → reduction by factor 100.

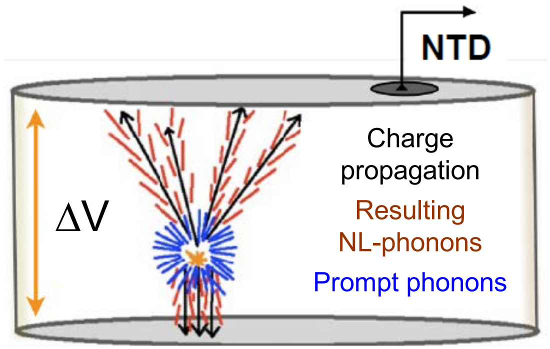
DMB8

Physics near the floor of ^{8}B:

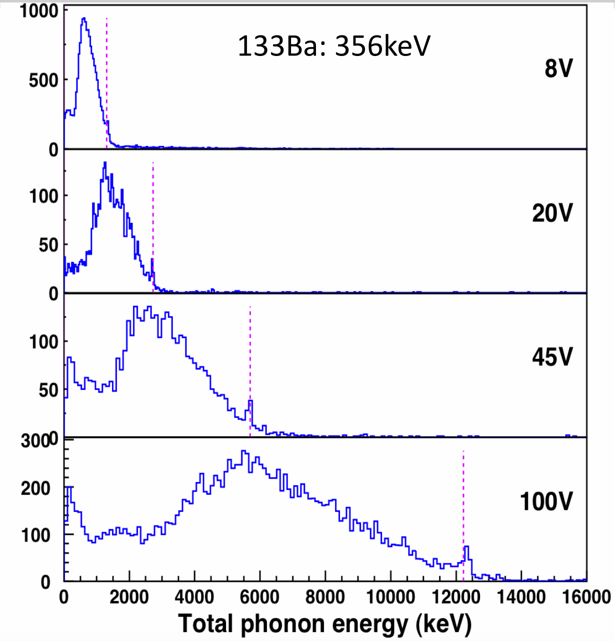
- Lower background at low energy → HEMT transistor read out, σ_{ion} = 200 eV ⇢ 100 eV.

R&D development: Neganov-Luke effect

High-voltage for Neganov-Luke amplification

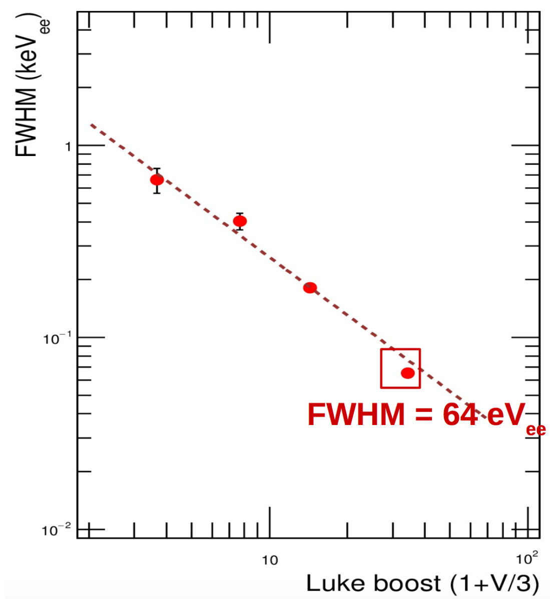


$$E_{\text{heat}} = E_{\text{recoil}} + E_{\text{Luke}}$$



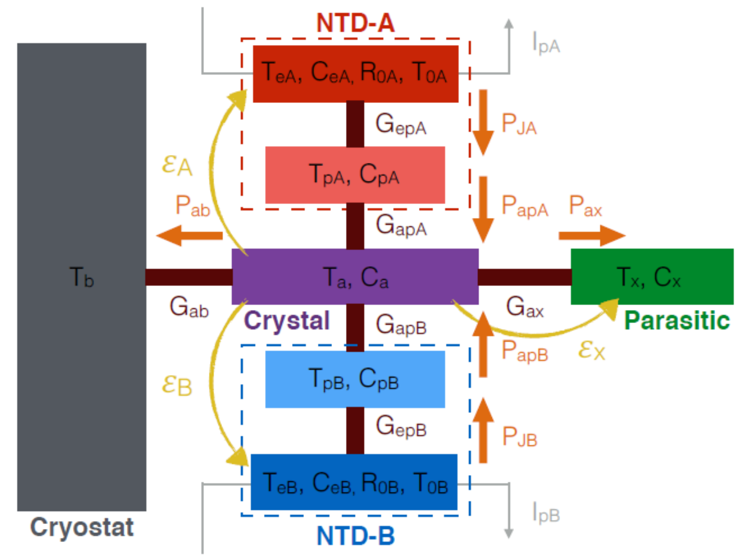
First measurement at the LSM with FID800 in 2015:

- Up to 100 V → boost by a factor of ~35,
- Heat resolution (keV_{ee}) improved by x35 best measurement of ionisation,
- Sensitivity goal: threshold < 100 eV_{NR} using improved phonon channel resolution,
- Ionisation signal redundant in HV mode (no particle discrimination) but provides detailed diagnostics of charge collection.



R&D development: heat sensor resolution

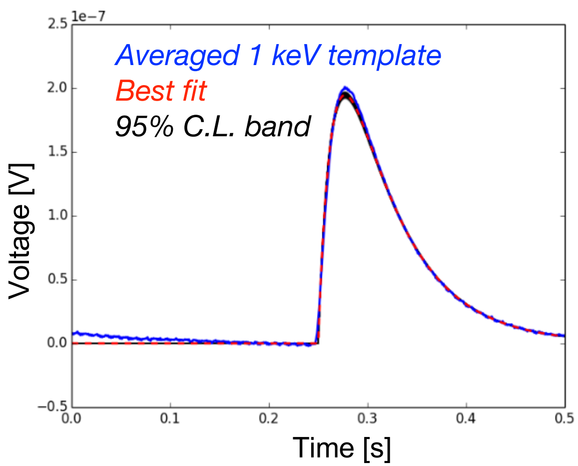
Optimisation of heat sensor – Thermal model



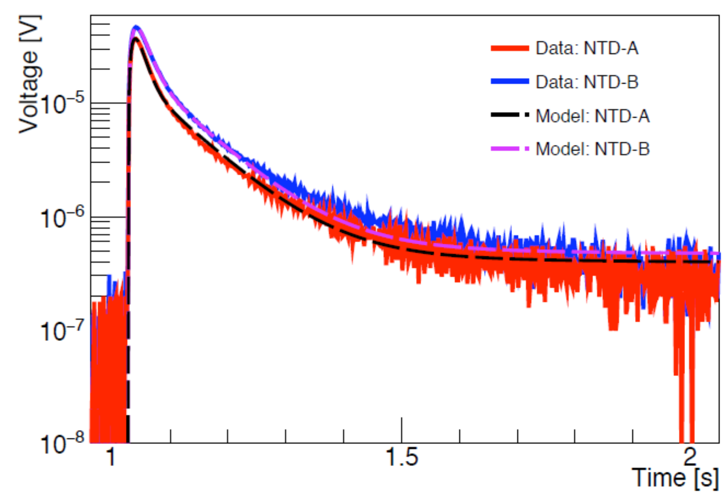
Better understanding of heat signal:

- Thermal modelling of signal,
- Identification of sensitivity to ballistic phonons,
- Identification of parasitic heat capacity.

Sensitivity of 200 nV/keV achieved with 200 g test detector.



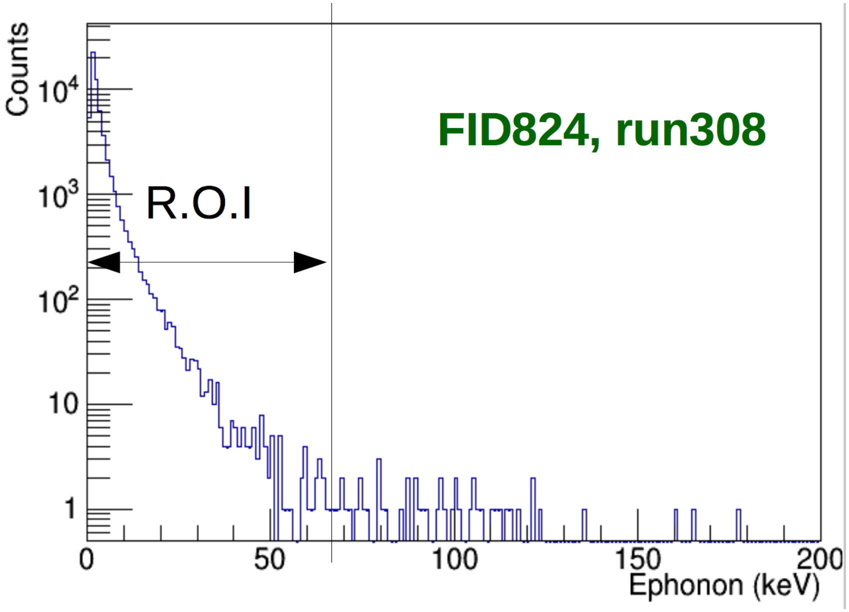
J. Billard et al., J. Low Temp. Phys. (2016)

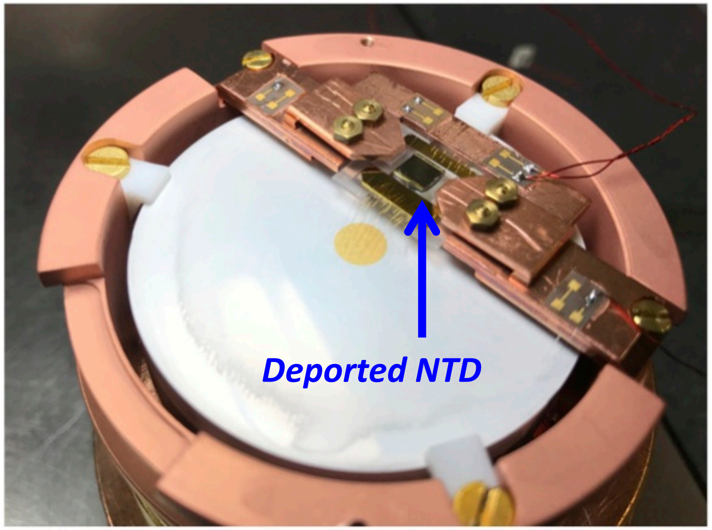


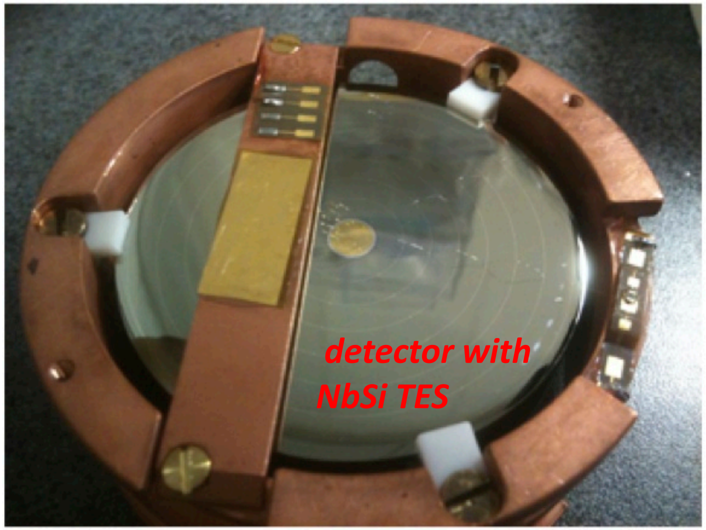
R&D development: heat-only events

Origins investigations

- HO background: dominant and reproducible at low energy,
- Studied hypotheses: noise, cryogenics, stress from detector suspension, glue…
- New detectors configurations and set-up to test hypotheses:
  - Deported NTD, glued on separated sapphire wafer,
  - Photo-lithographed high-impedance NbSi TES, sensitive to athermal phonons,
  - 4 new designed detectors have been tested at LSM.





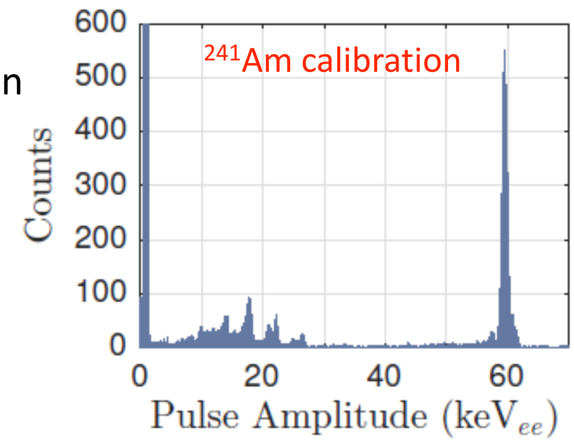


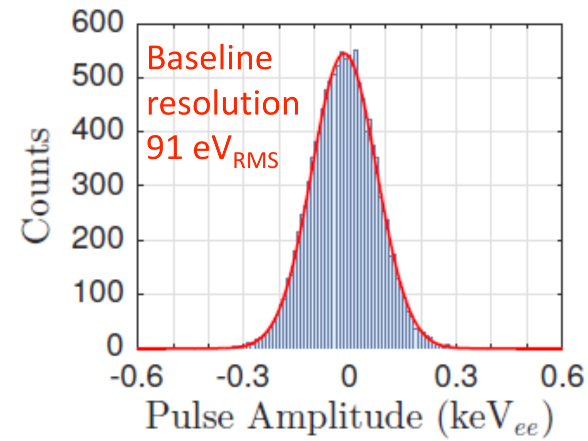
R&D development: HEMT read-out

Improvement of ionisation read-out

Change from JFET to HEMT (High Electron Mobility Transistor):

- Reduced intrinsic noise,
- Lower heat load,
- Operates at 4K stage:
  - shorter cabling,
  - reduced capacitance,
  - better signal-to-noise ratio.

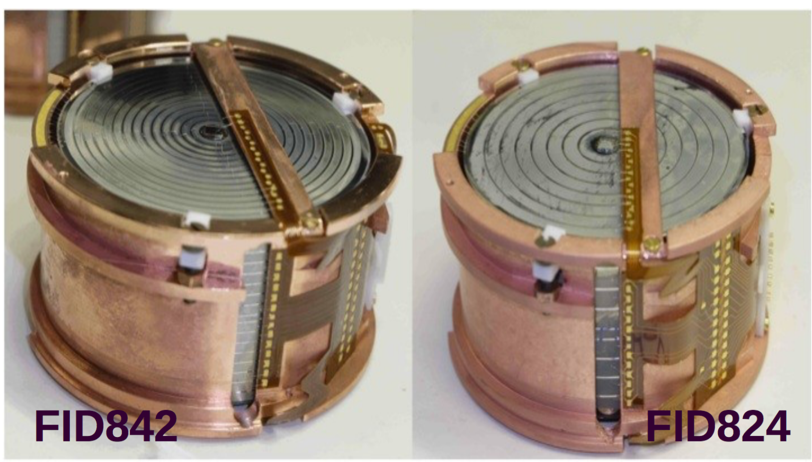


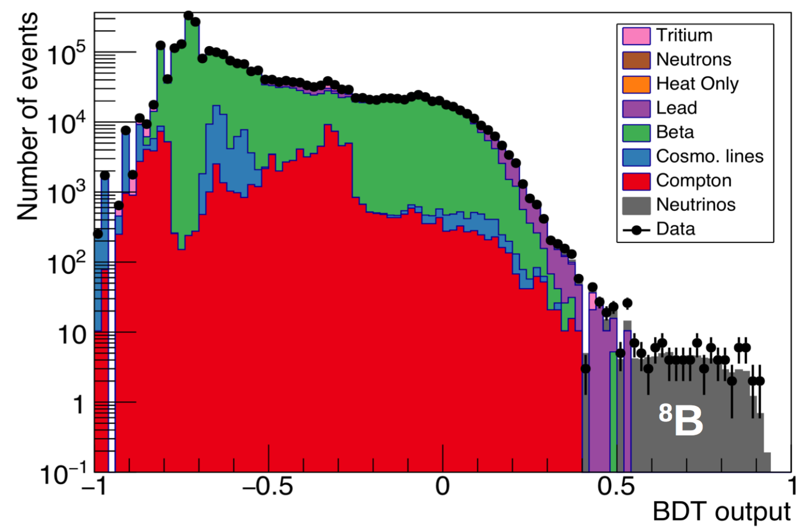


Successful HEMT amplifier with sub-100 eV_{RMS} ionisation resolution:

- Upgrade EDW ionisation read-out with this new design,
- Electrode design to reduce detector capacitance to reach 50 eV_{RMS}.

A. Phipps et al., arXiv:1611.09712
JLTP (2016) 184:505





Conclusion and outlook

Results and perspectives

EDELWEISS-LT:
- 2017-2018
- Low-mass program at LSM (350 kg·day)
- R&D on HV, HEMT, sensors, heat-only

EDELWEISS-DMB8:
- Beyond,
- Explore the ^{8}B region with discrimination.