# Status and Prospects of the EDELWEISS-III Direct WIMP Search Experiment

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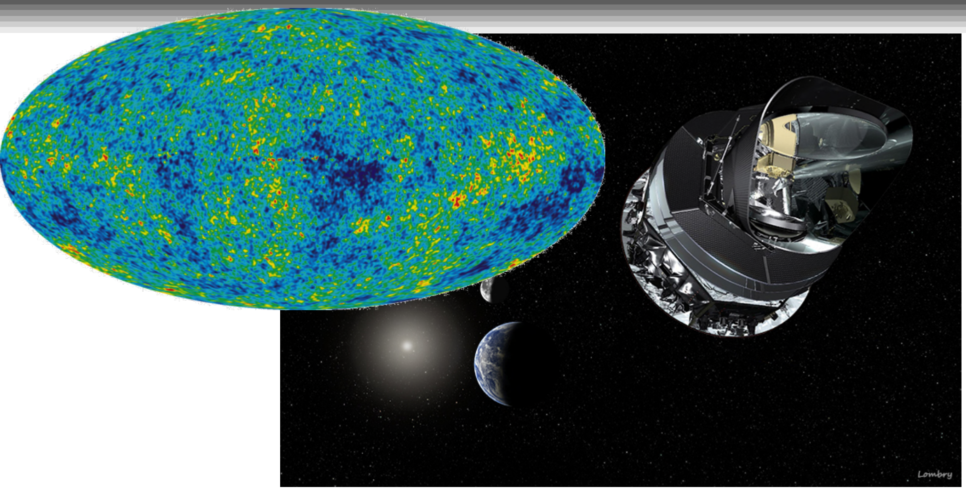
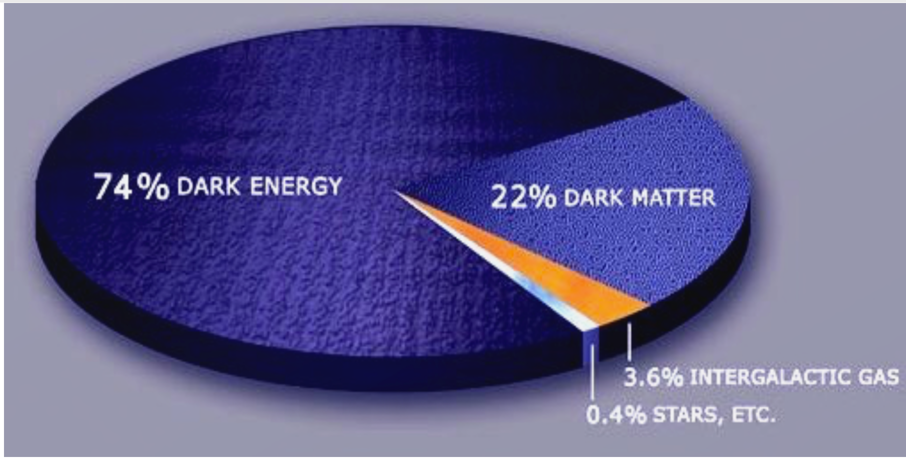
**17th International Workshop on Low Temperature Detectors,
Kurume, Japan, 17-21 July 2017**

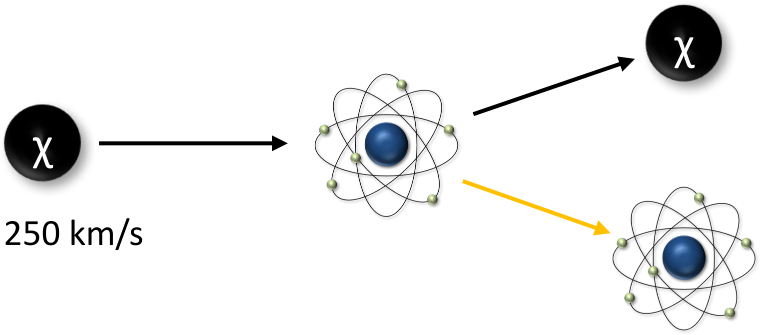
# Direct detection of Dark Matter






**How to detect a WIMP χ, candidate to Dark Matter ?**

- χ production within particle 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



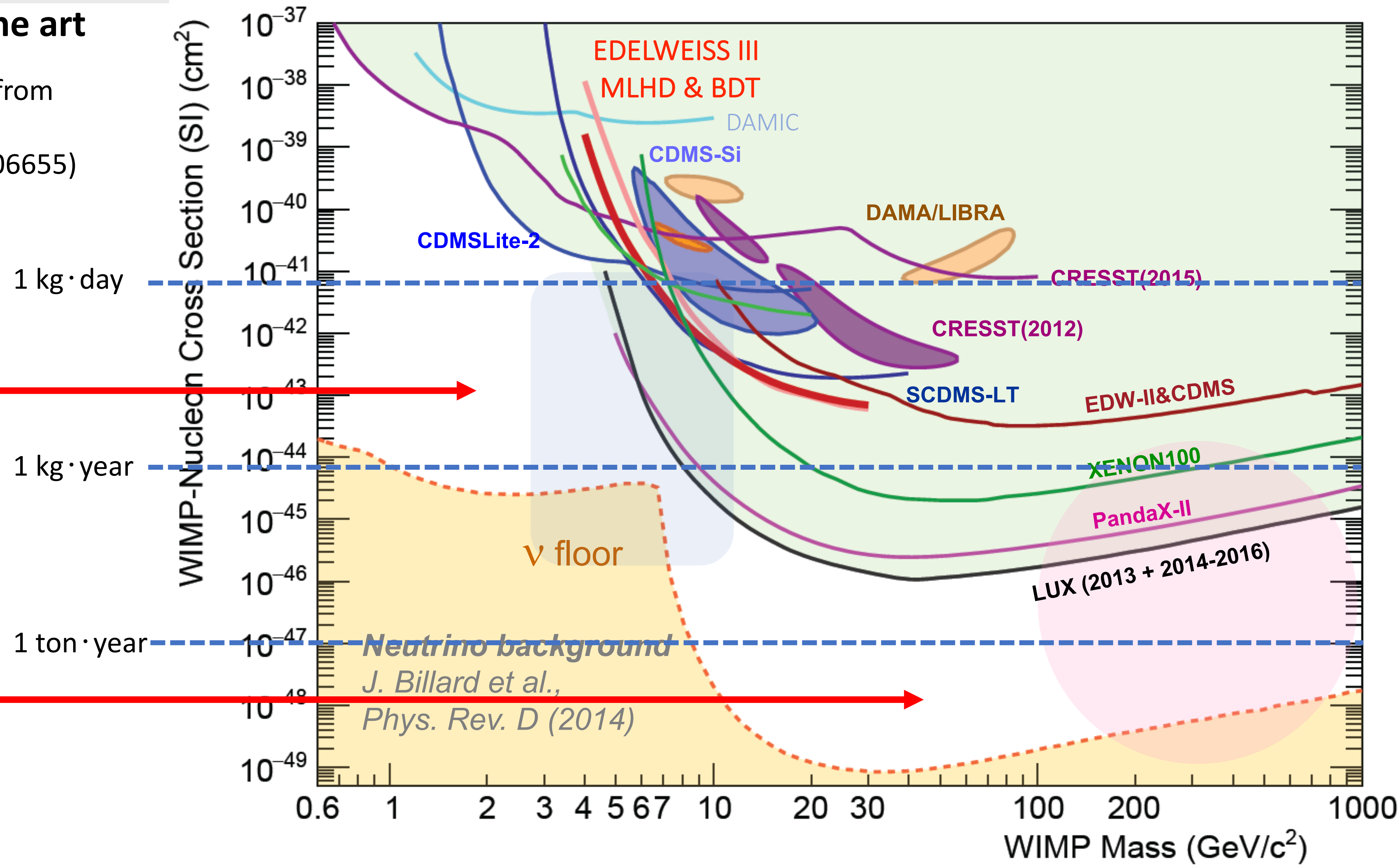

v ≈ 250 km/s

$E_{recoil} \approx 10$ keV

# Direct detection of Dark Matter

## State of the art

New results from XENON1T (arXiv:1705.06655)




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

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

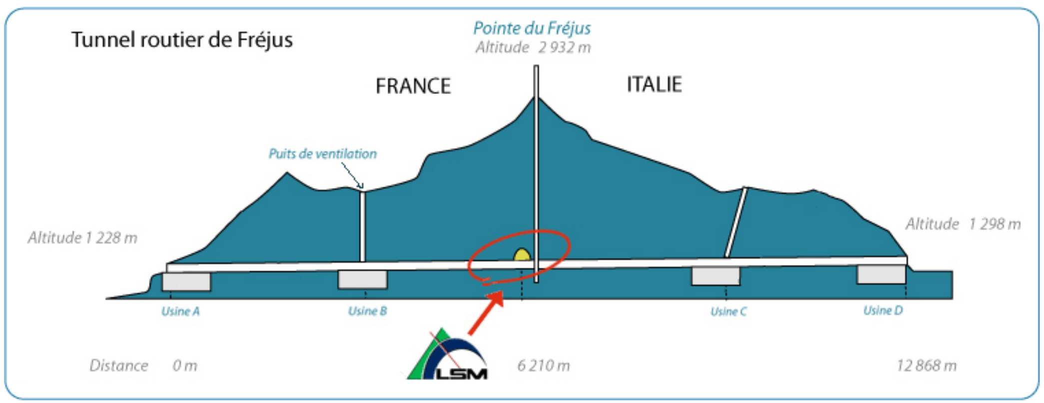
# The EDELWEISS experiment

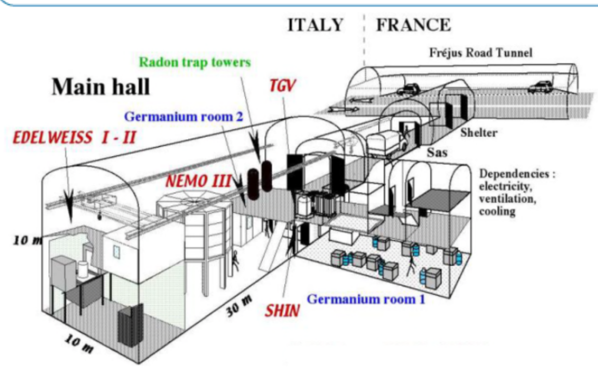
## The EDW collaboration

- 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)

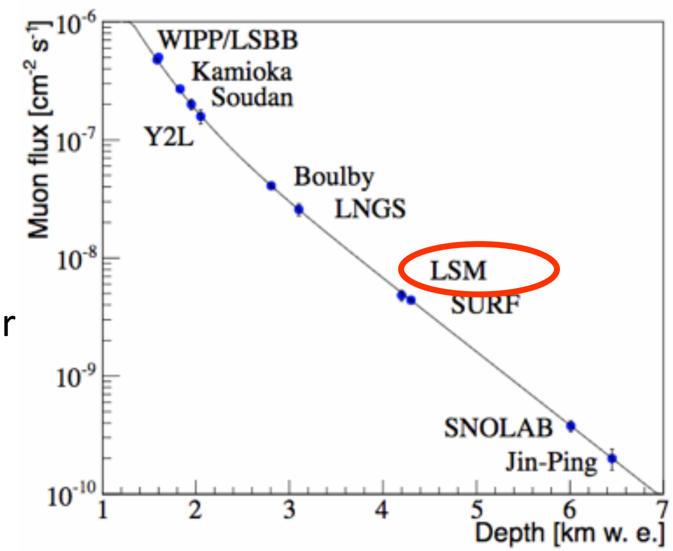
## Laboratoire Souterrain de Modane




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

Muon flux at sea level:
$1.6 \cdot 10^{-2}$ /cm²/s



# The EDELWEISS experiment

## The set-up

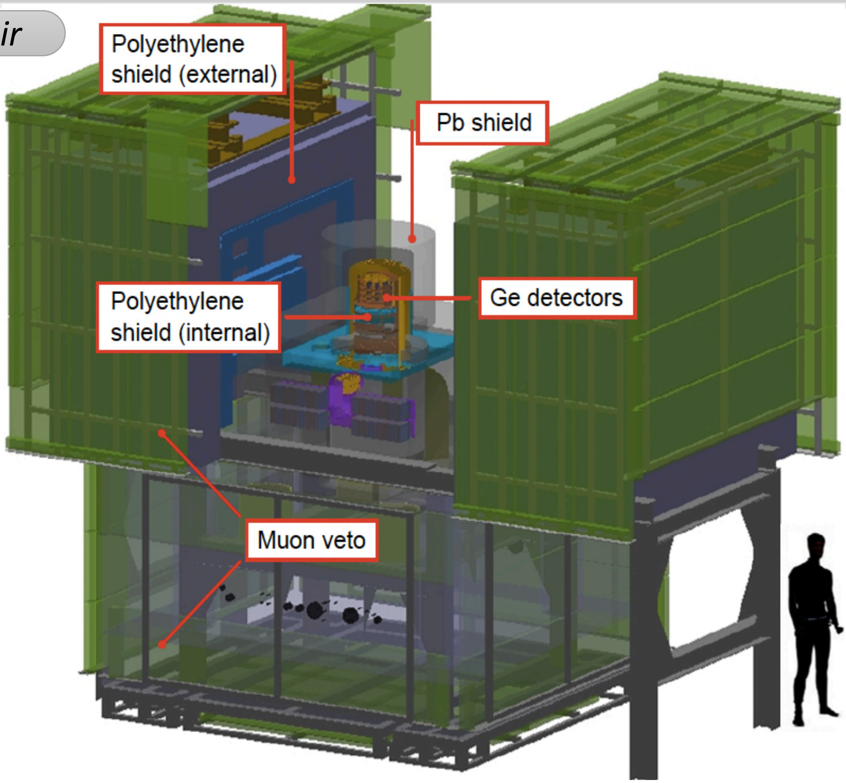
Deradonized air

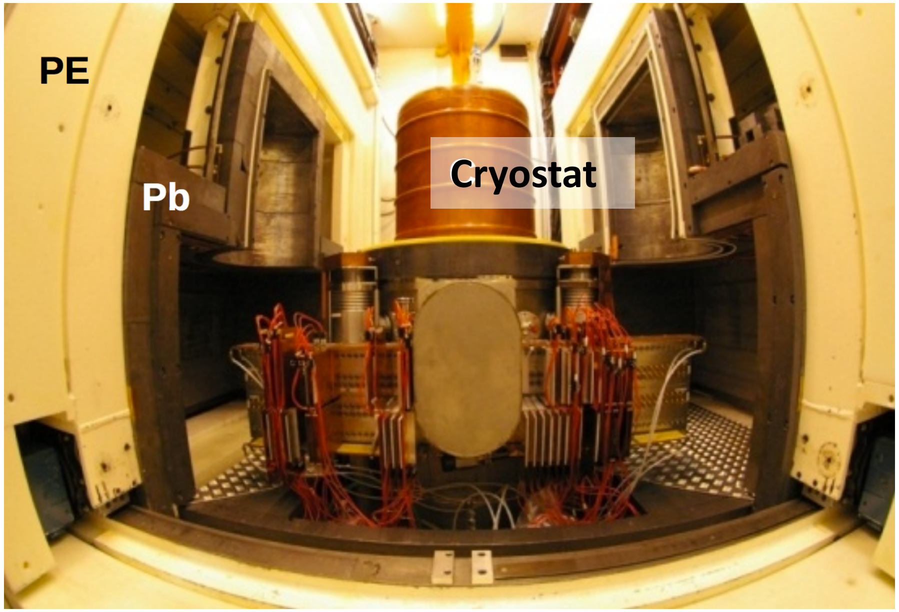
**Shieldings:**

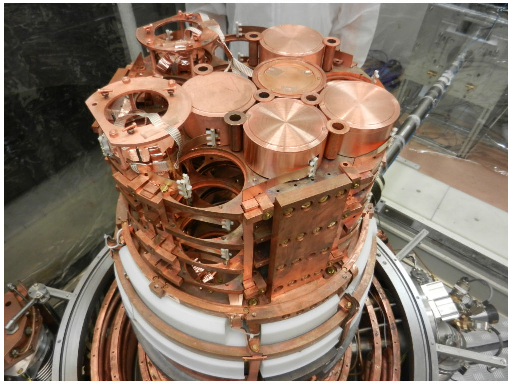
- Clean room,
- Muon veto (plastic scintillator modules),
- Polyethylene shield (external + internal),
- Lead shiel,
- Radiopure materials.

**Towers:**

- 24 cryogenic detectors,
- T = 18 mK.

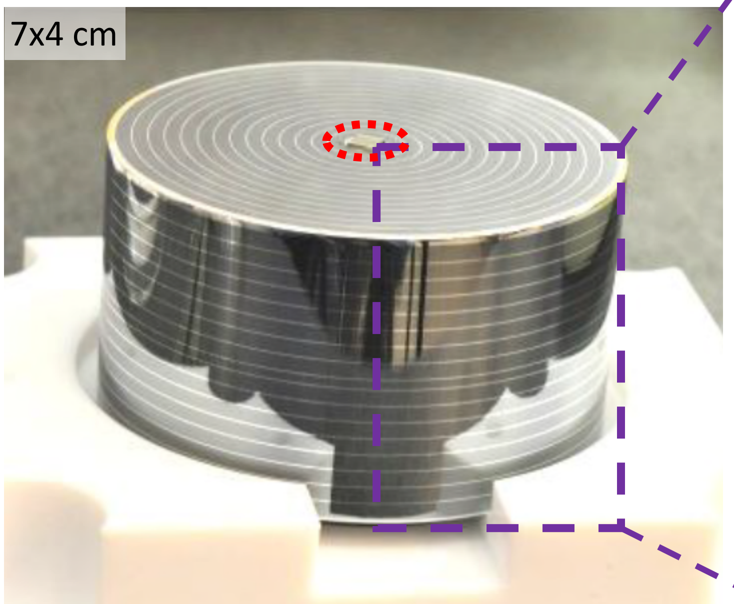


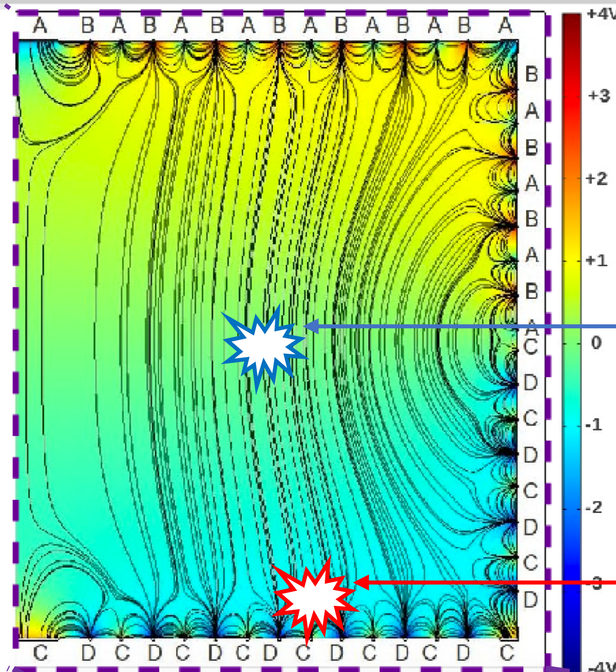



# The EDELWEISS detectors

## Full Inter-Digitized 800 g detector



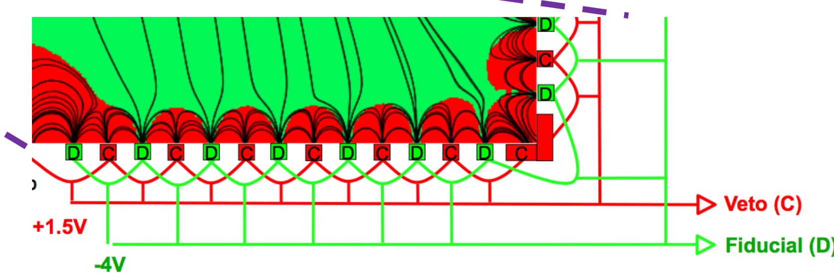




**Fiducial events:**

- Collected by fiducial electrodes (B&D).

**Surface events:**

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




**Heat channels:**

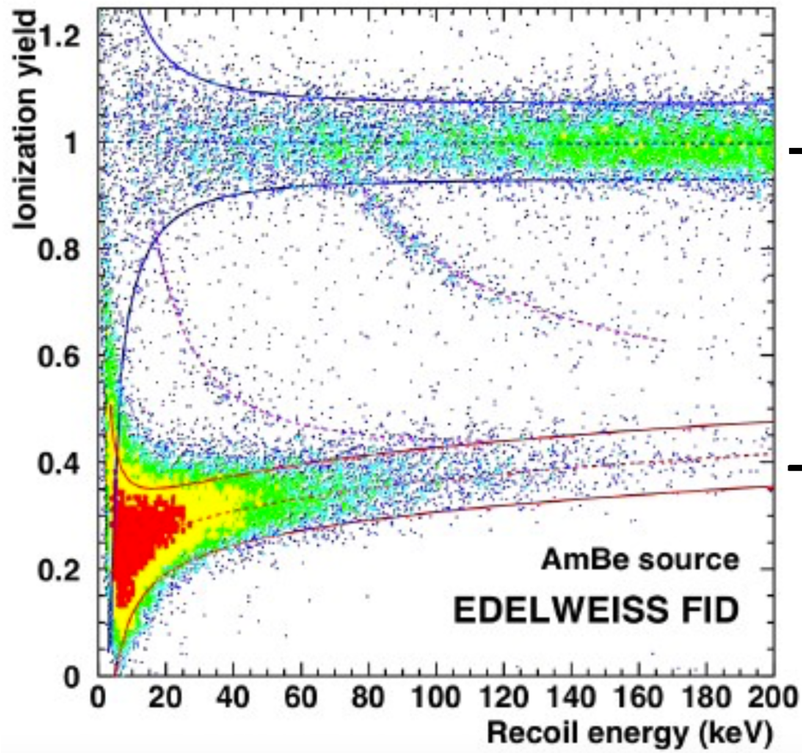
- Measurement of phonon thermalization by two NTDs (Neutron Transmutation Doped),
- **Δ**T = 0.1 µK/keV

**Ionization channels:**

- Charges collected by Al concentric electrodes (width = 150 µm, gap = 2 mm),
- Surface event rejection → ≈99% efficiency of fiducial event selection.

*EDELWEISS performance (2017), arXiv:1706.01070*

# Detection within EDELWEISS-III

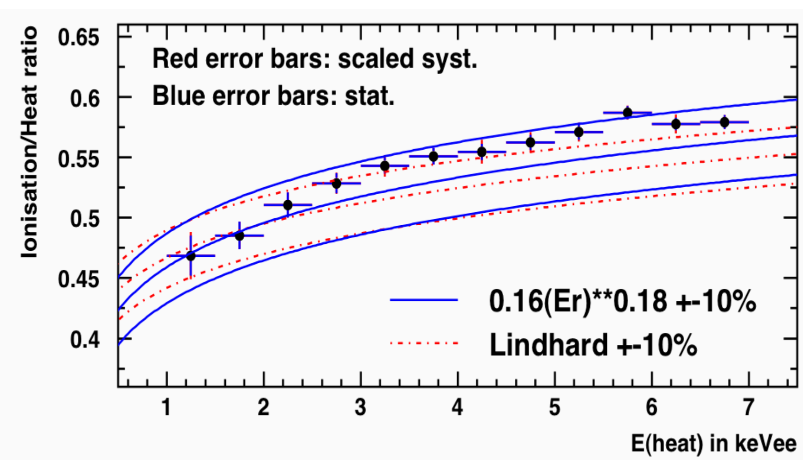



→ Electron recoil band

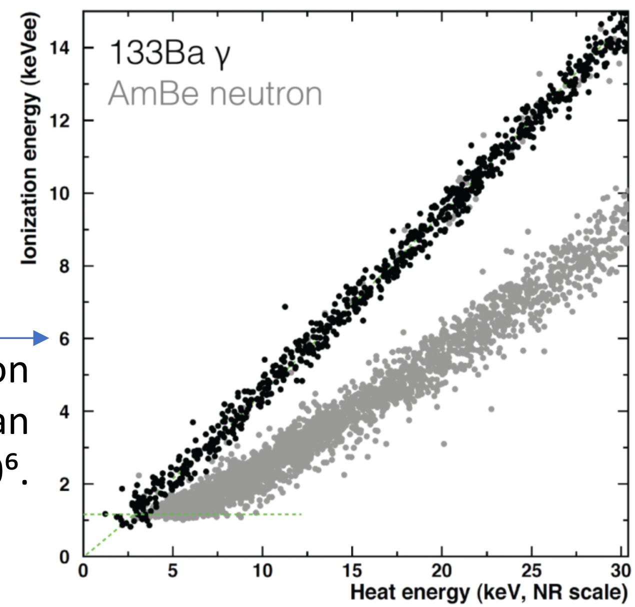
→ Nuclear recoil band

## Nuclear recoil calibration and discrimination

- Clear event-by-event discrimination 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

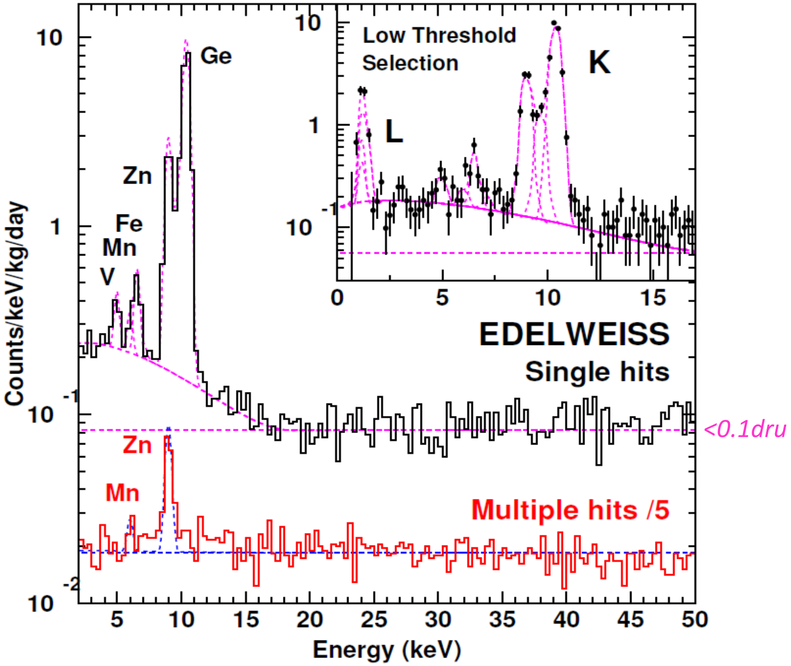
## WIMP search in 2014-2015

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.

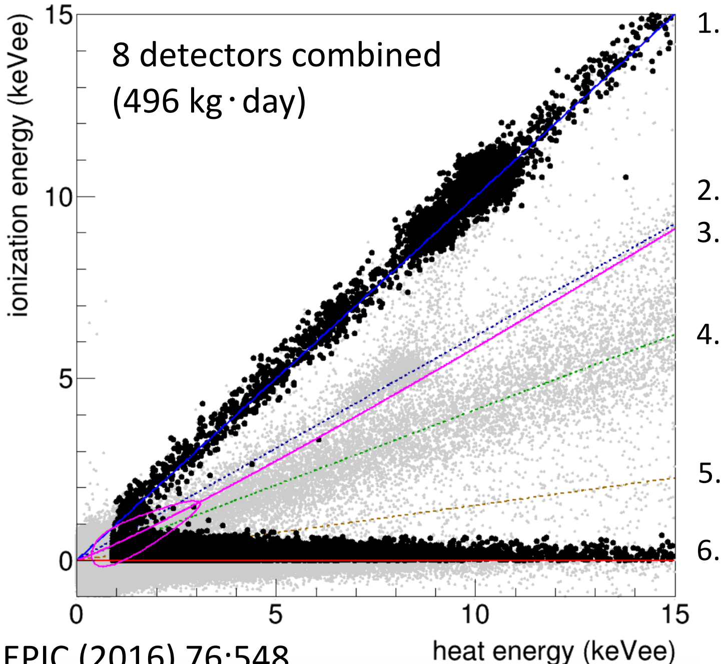
→ *Likelihood analysis*




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 ($Q_\beta$ = 18.6 keV, $T_{1/2}$ = 12.32 y): **P = 82 ± 21 nuclei/kg.d**

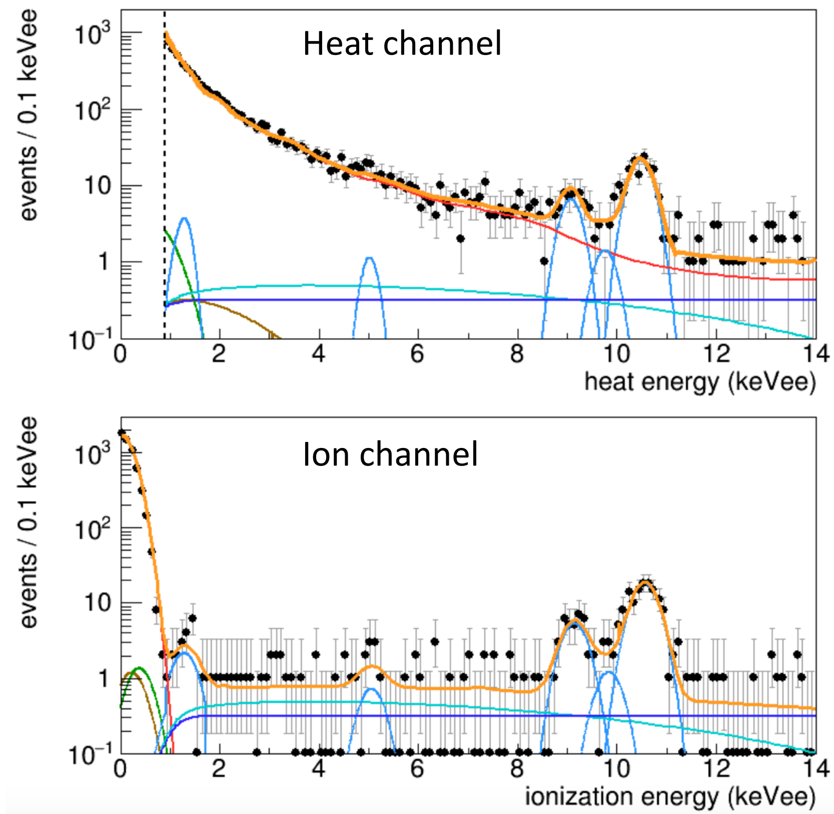
## Description of the backgrounds




EPJC (2016) 76:548

1. $e^-$ recoils from $^3$H decay + Compton and cosmogenic gammas in the fiducial volume,
2. surface gammas,
3. nuclear recoils from neutron scattering,
4. surface betas,
5. $^{206}$Pb recoils,
6. heat-only events.

## 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.

Total PDF for each detector: $\mathcal{P}_{\rm tot}(\sigma, \boldsymbol{\mu} \mid m_\chi) = \frac{1}{\nu}\left[\mu_\chi \mathcal{P}_\chi(m_\chi) + \sum_{\rm i} \mu_{\rm i} \mathcal{P}_{\rm i}\right]$

# EDELWEISS-III – Likelihood analysis

**Results from Likelihood**

$1.6 \cdot 10^{-39}$ cm$^2$ at 4 GeV/c$^2$ to

$6.9 \cdot 10^{-44}$ cm$^2$ at 30 GeV/c$^2$.

(due to higher signal efficiency & background subtraction)

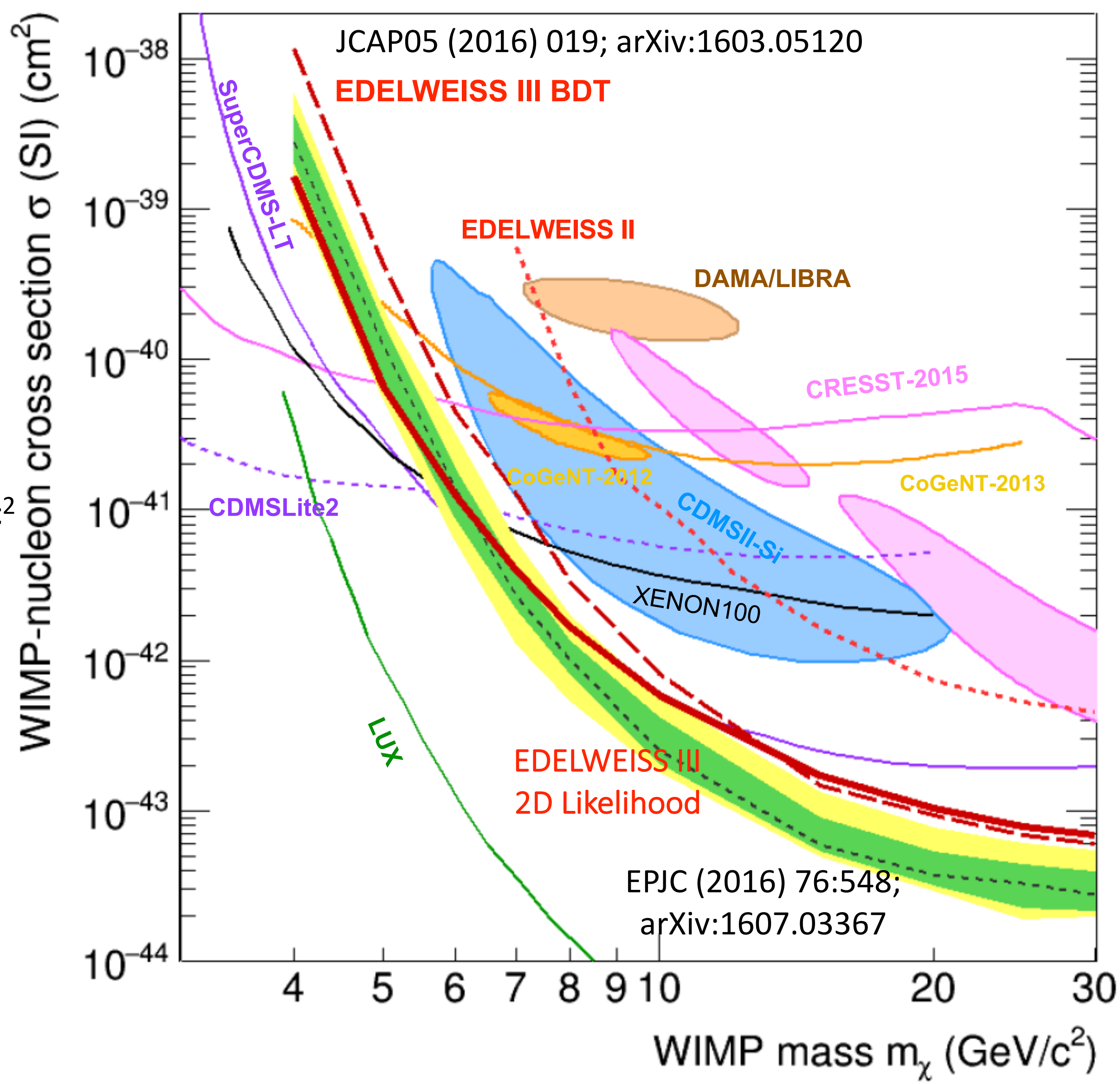
From the **BDT** to **Likelihood** analysis:

$1.1 \cdot 10^{-38}$ cm$^2$ → $1.6 \cdot 10^{-39}$ at 4 GeV/c$^2$

$3.34 \cdot 10^{-42}$ cm$^2$ → $1.66 \cdot 10^{-42}$ at 8 GeV/c$^2$

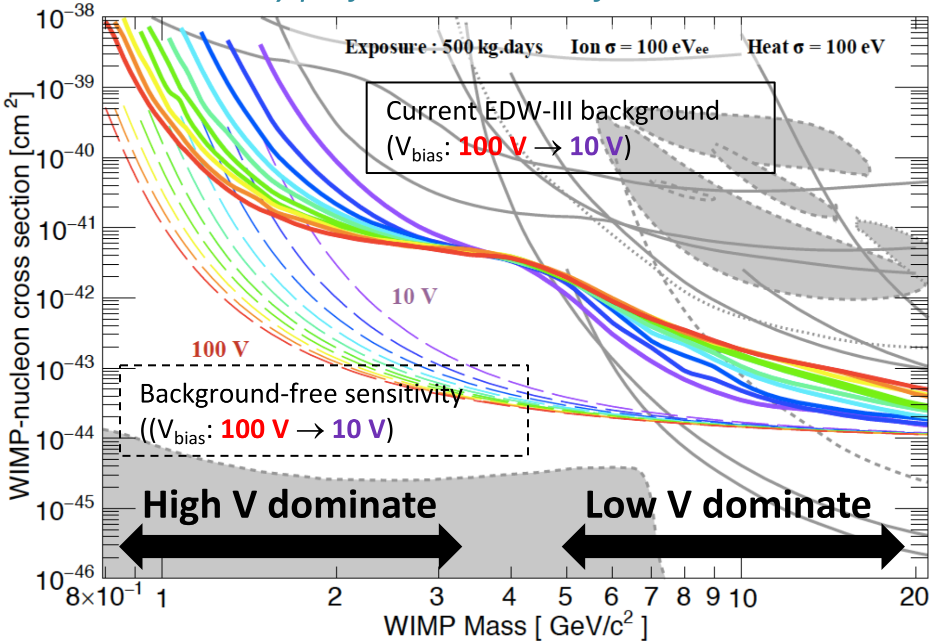
We are limited by heat-only background:

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

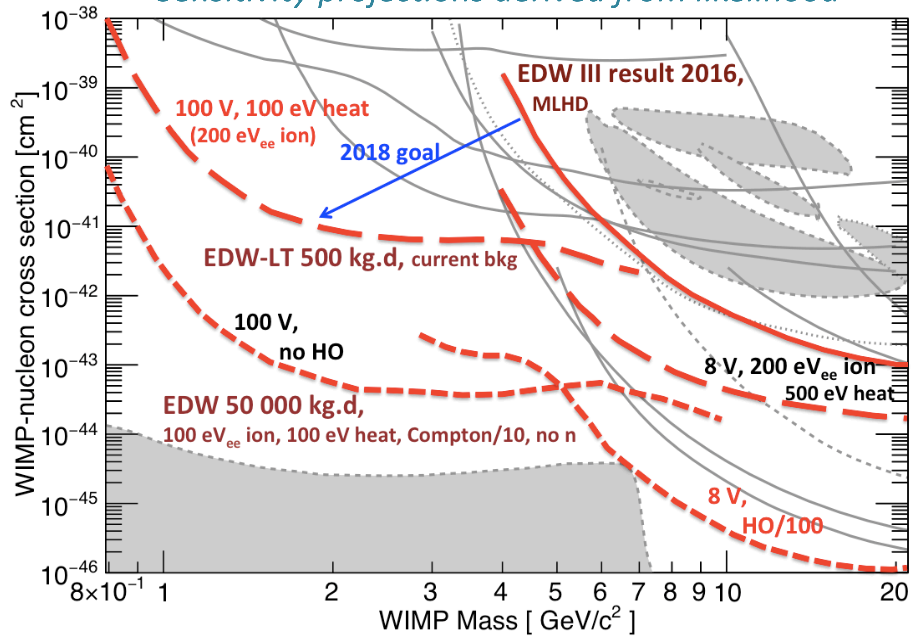


# New EDELWEISS goal: 4x100

*100 $eV_{ee}$ ion & 100 eV heat (RMS), 500 kg.d,*
*Sensitivity projections derived from likelihood*




*All resolutions are given RMS*
*Sensitivity projections derived from likelihood*




*EDELWEISS projections (2017), arXiv:1707.04308*

## 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, $\sigma_{phonon}$ = 500 eV ⇢ 100 eV,
- Heat-only background → reduction by factor 100.

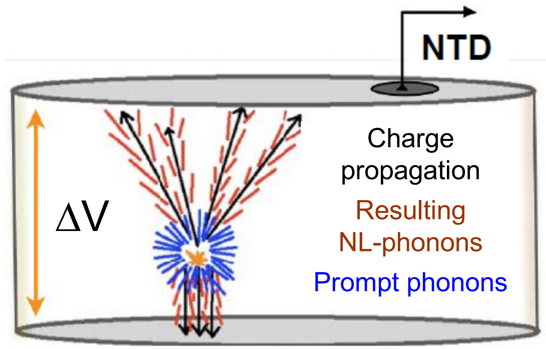
## DMB8

Physics near the floor of $^{8}B$:

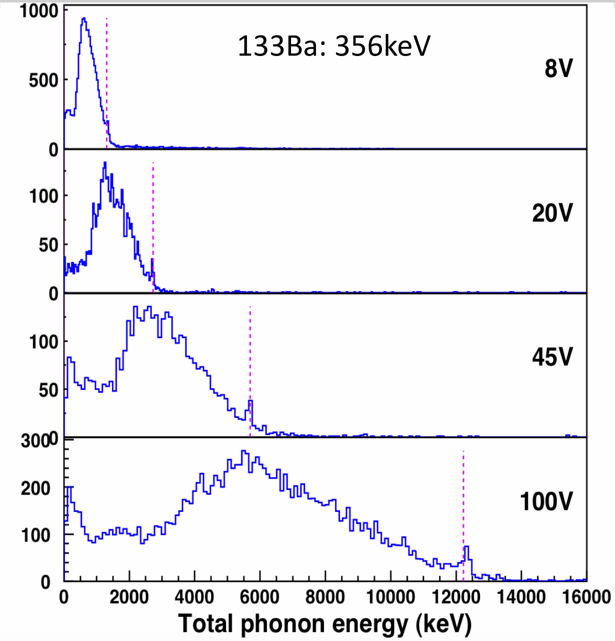
- Lower background at low energy → HEMT transistor read out, $\sigma_{ion}$ = 200 $eV_{ee}$ ⇢ 100 $eV_{ee}$.

# R&D development: Neganov-Luke effect

## High-voltage for Neganov-Luke amplification

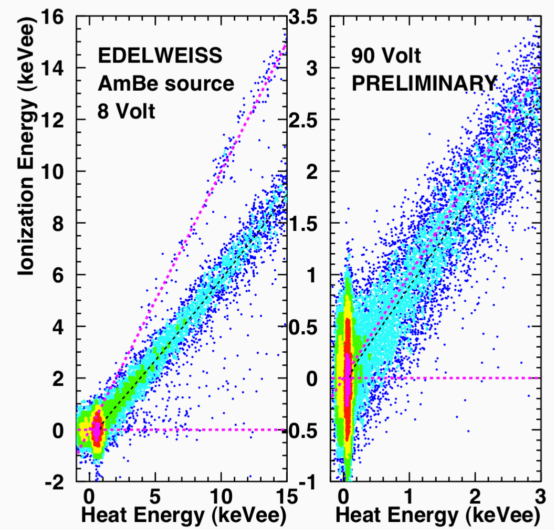



$$E_{\text{heat}} = E_{\text{recoil}} + E_{\text{Luke}}$$



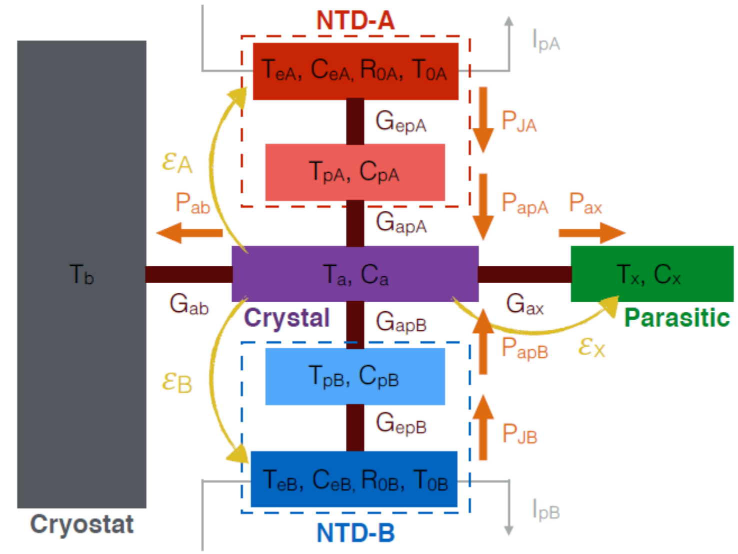

First measurement at the LSM with FID800 in 2015:

- Up to 100 V → boost by a factor of ~35,
- Best resolution for energy in $keV_{ee}$,
- 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

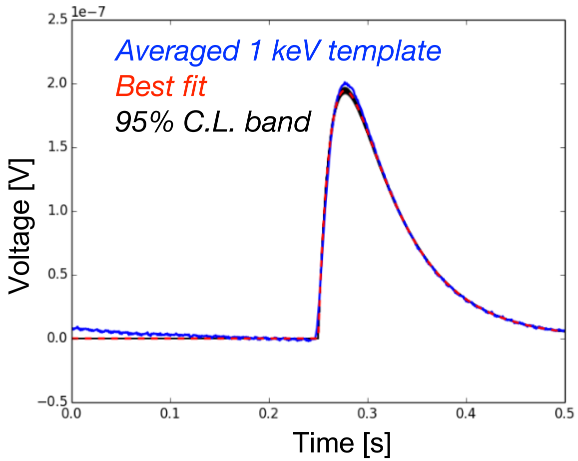
## Optimisation of heat sensor – Thermal model



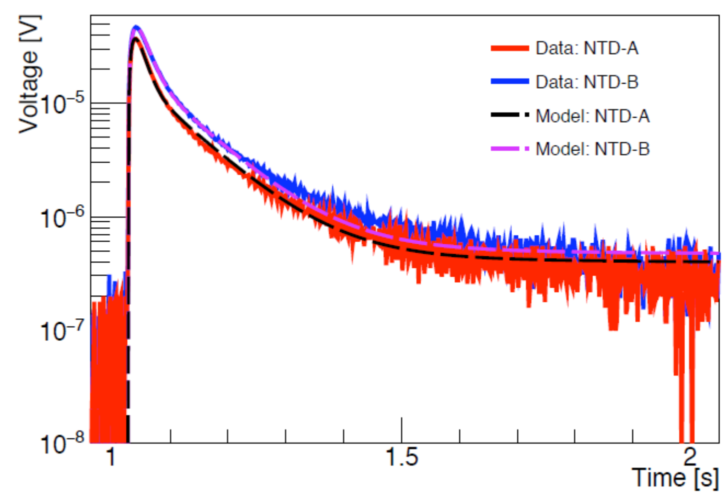

Better understanding of heat signal:

- 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.

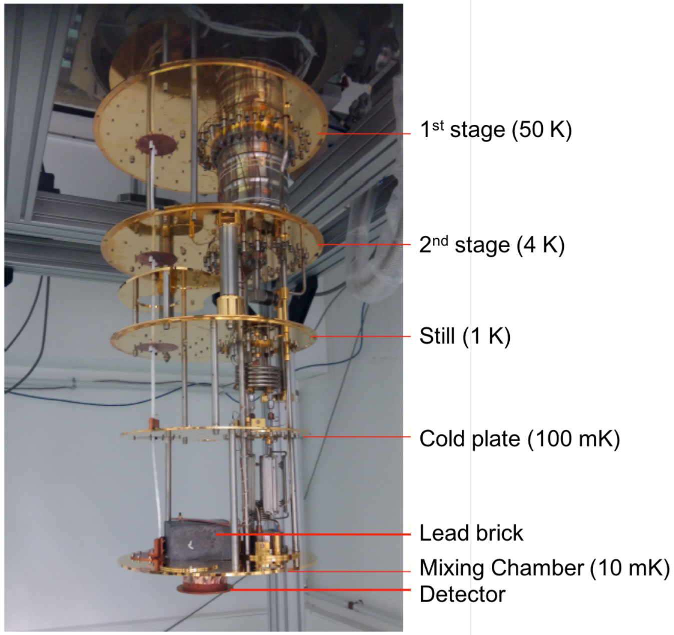



J. Billard et al., J. Low Temp. Phys. (2016)



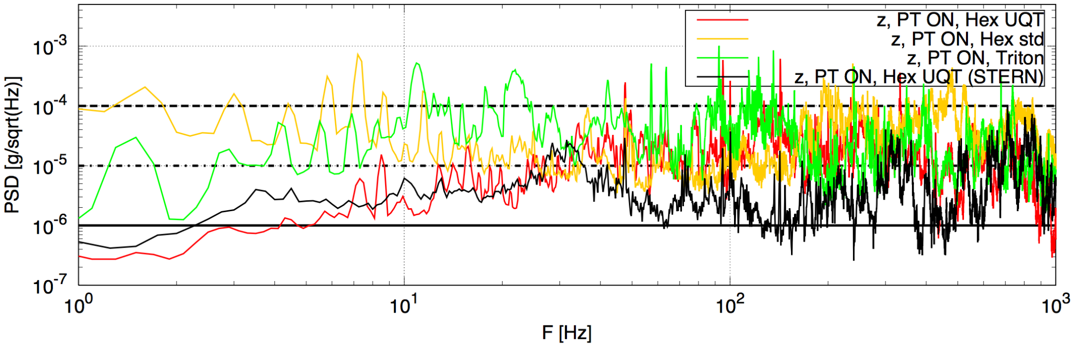
# R&D development: vibrations decoupling

## Dry cryostat @ IPNL for R&D

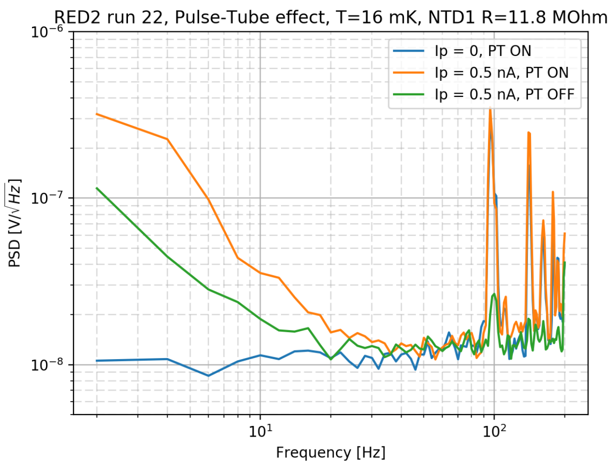



Cryostat **Hexadry Standard (Hex std)** produced by Cryoconcept with decoupling 50K/4K → **gas exchange**.

**Hexadry Ultra Quiet Technology (Hex UQT)** in order to attenuate vibrations from the pulse-tube system.




E. Olivieri, J. Billard, M. De Jesus, A. Juillard, A. Leder, Nucl. Instr. Meth. Phys. Res., A, vol. 858, June 2017, 73-79




Remaining harmonics with impact on heat channel signal of detectors.

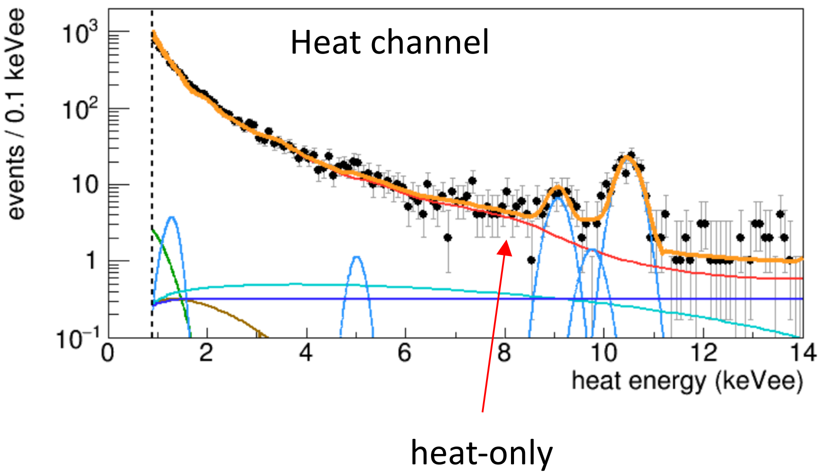
- ➢ Investigations for vibrations decoupling system.

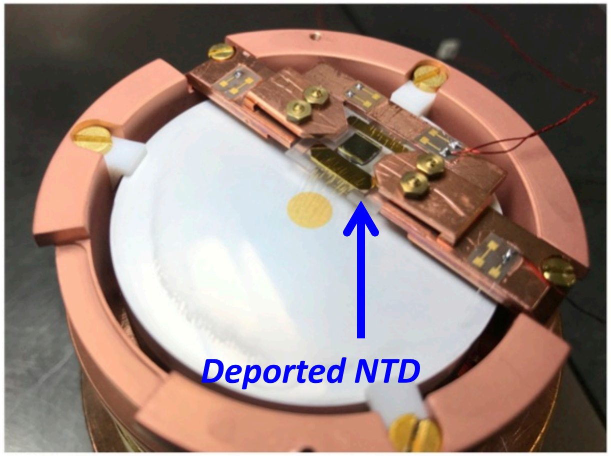
Poster LTD17-PD18

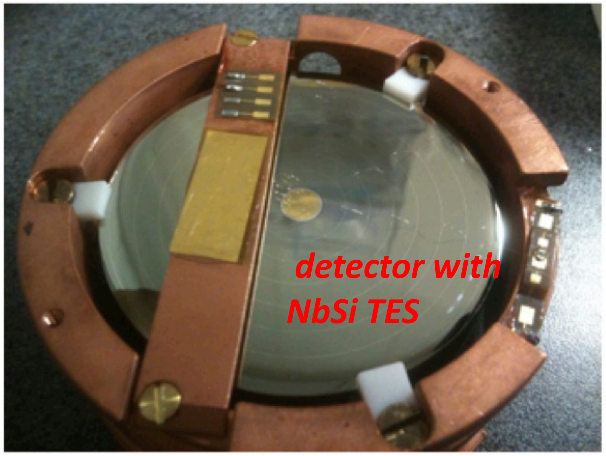
# R&D development: heat-only events

## 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.



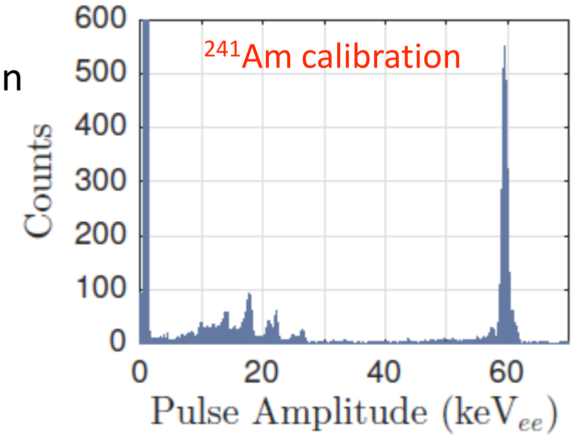



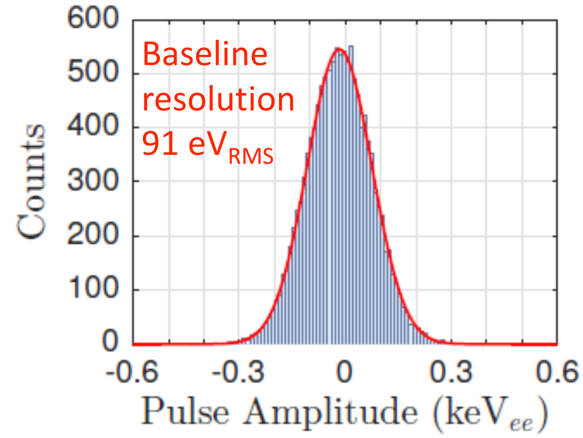



## Improvement of ionisation read-out

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.

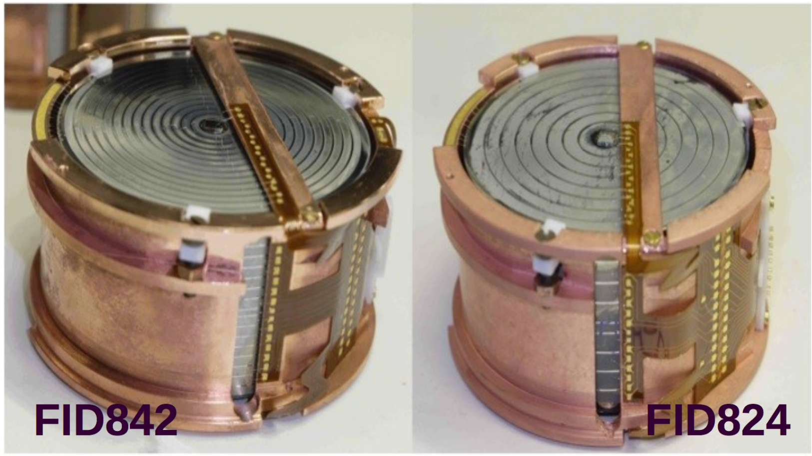


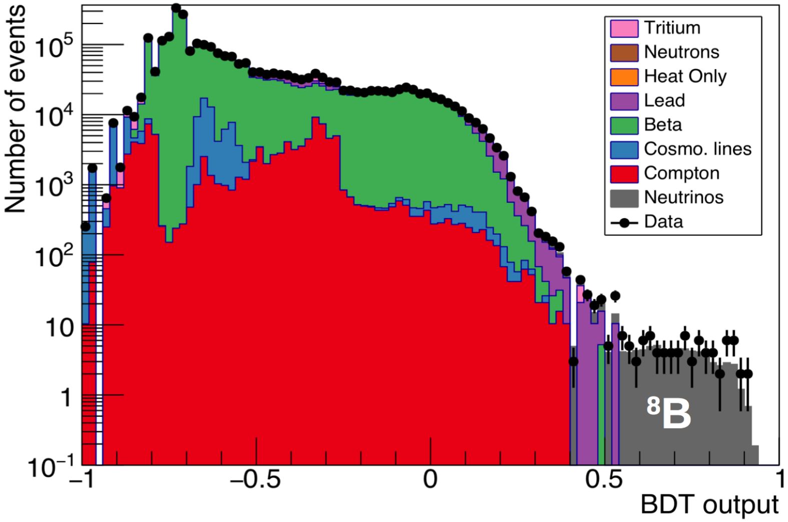




Successful HEMT amplifier with sub-100 $eV_{RMS}$ ionisation resolution:

- 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

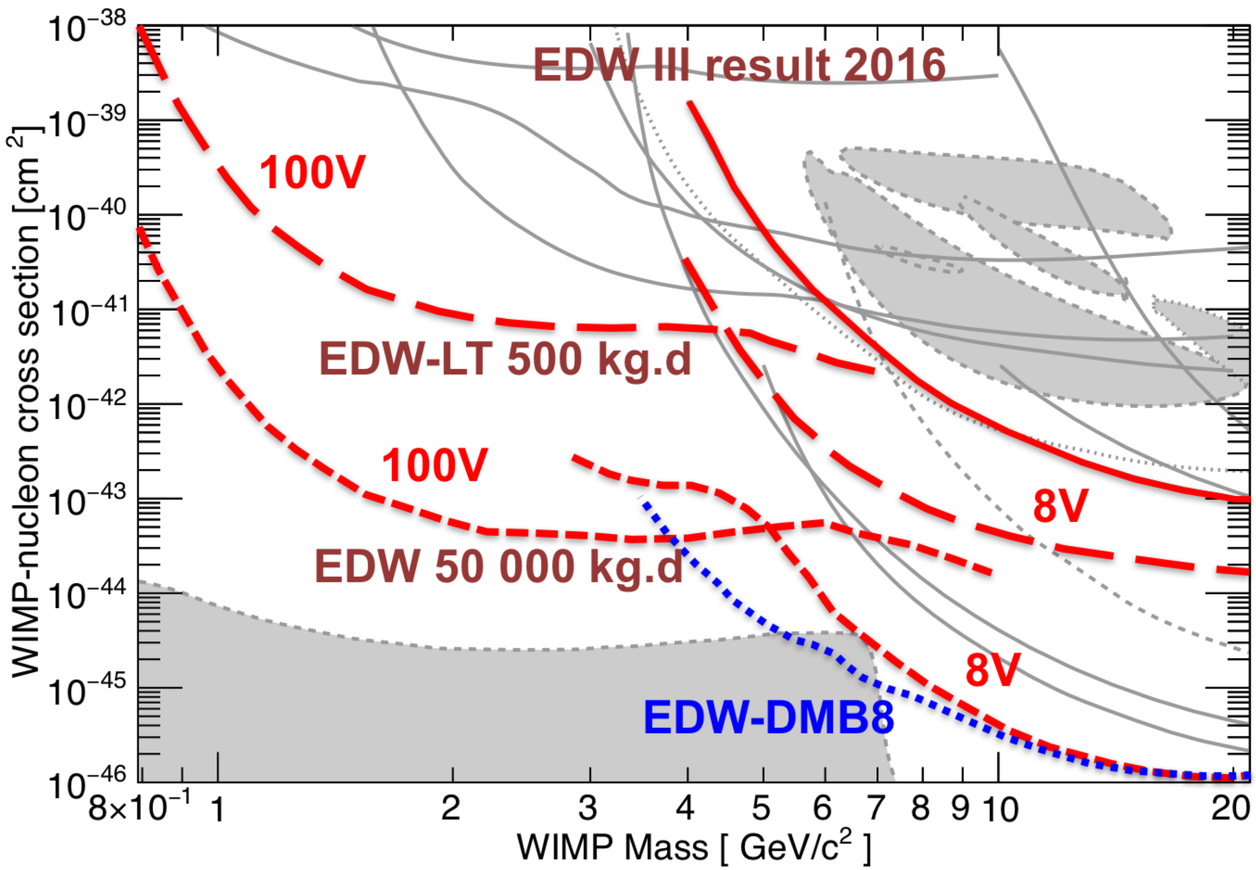
## Results and perspectives

**Analysis:**

- Likelihood analysis with improved results,
- Development of heat-only background model (*ongoing*).

**R&D with EDELWEISS-LT and DMB8:**

- Low-mass program at LSM,
- R&D on HV, HEMT, sensors, heat-only,
- Explore the $^8$B region with discrimination.




# Thanks for your attention