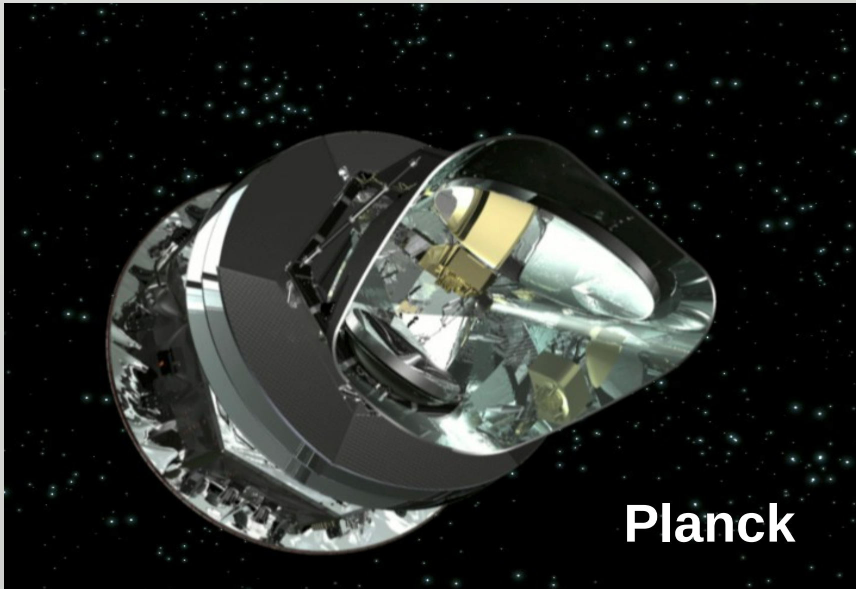
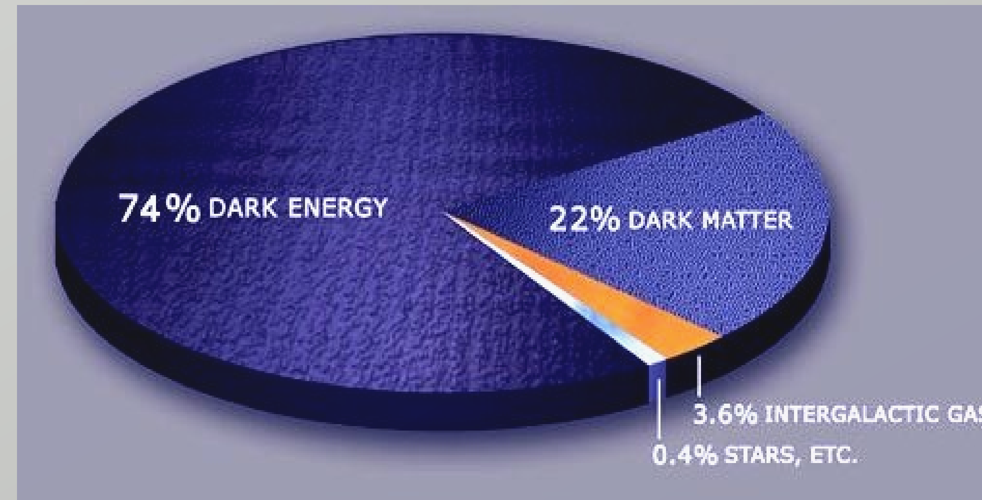
Low-mass WIMP search with the EDELWEISS experiment : Latest results and developments

Emeline Queguiner
for the EDELWEISS collaboration

Les rencontres de Blois 2017

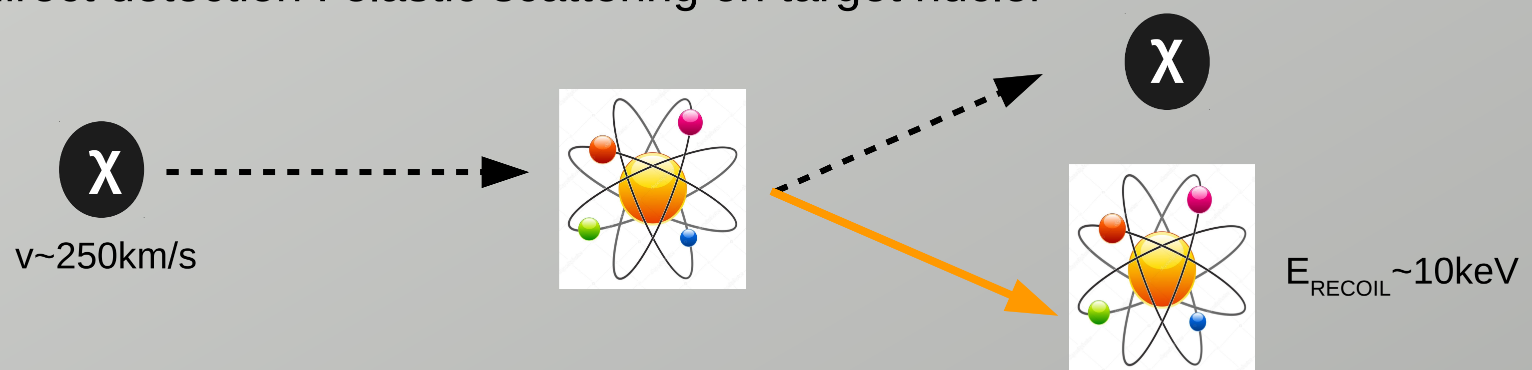
Direct detection of dark matter





Detection :

- Collider production : production of dark matter.
- Indirect detection : detection of annihilation product in cosmic rays
- direct detection : elastic scattering on target nuclei



Measurement :

- Ionization
- Heat
- Scintillation

EDELWEISS (Ionization + Heat)

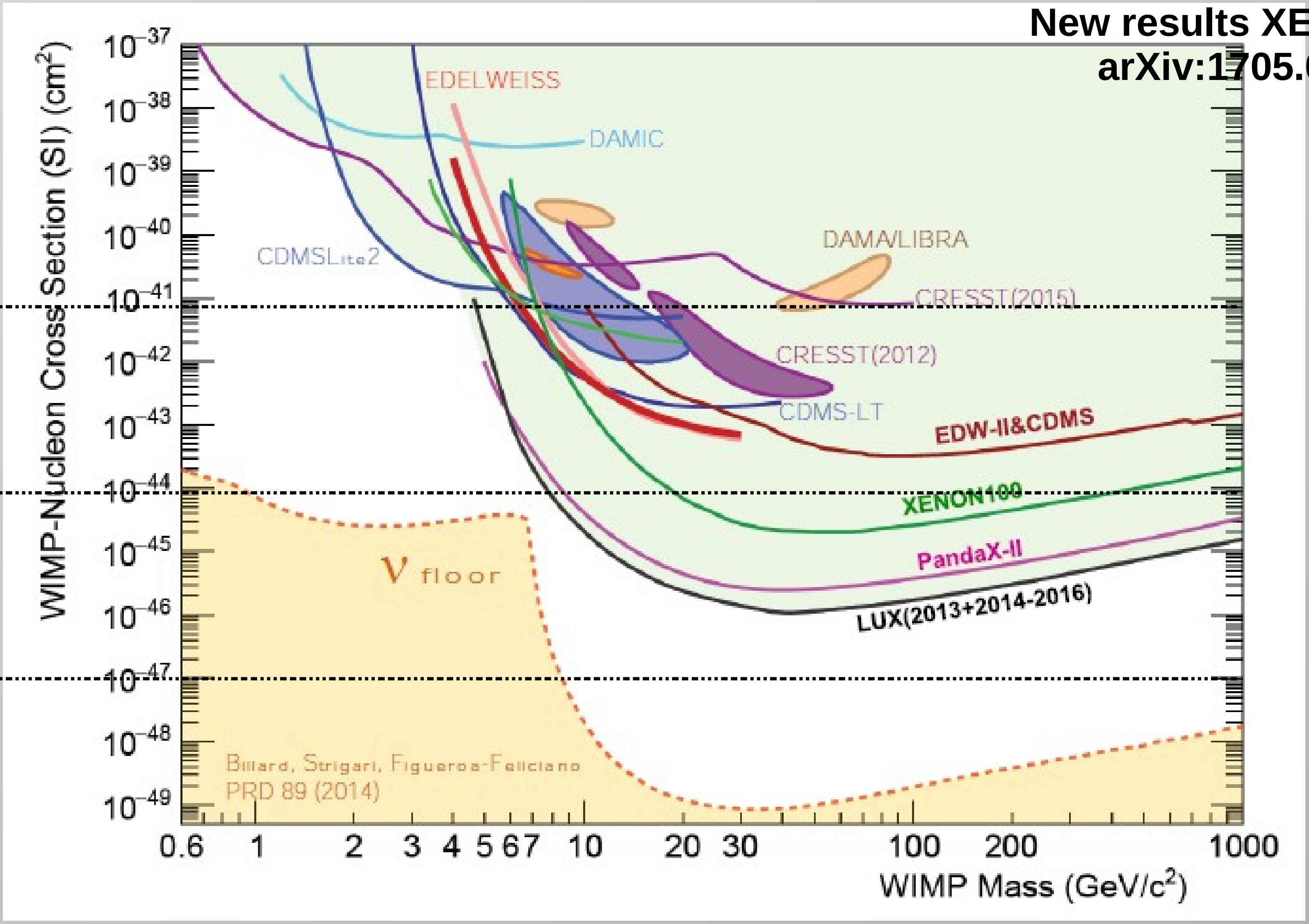
State of the art

New results XENON1T : arXiv:1705.06655

1 kg.day

1 kg.year

1 ton.year



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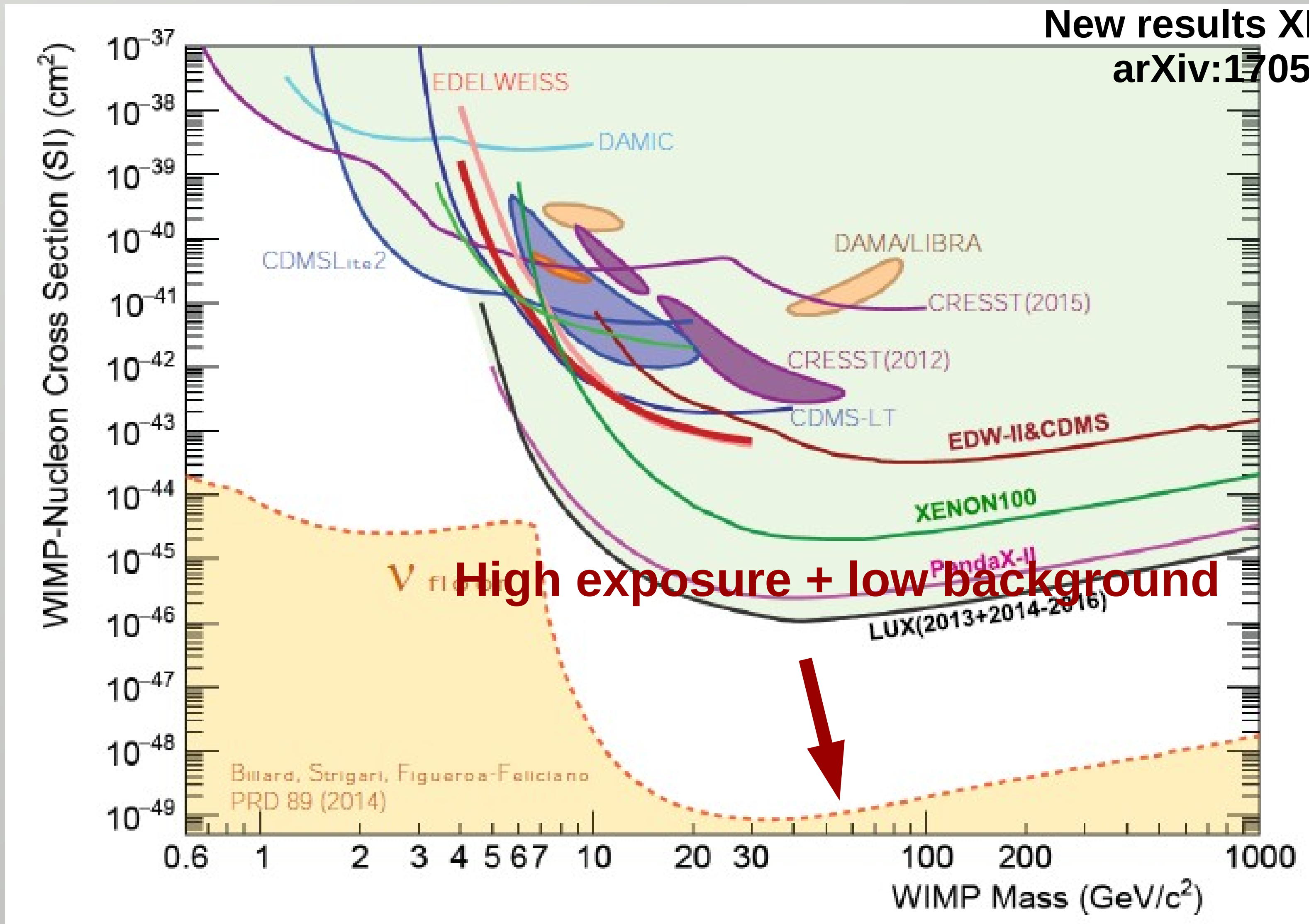

High exposure + low background

- **Liquid noble gases**

State of the art

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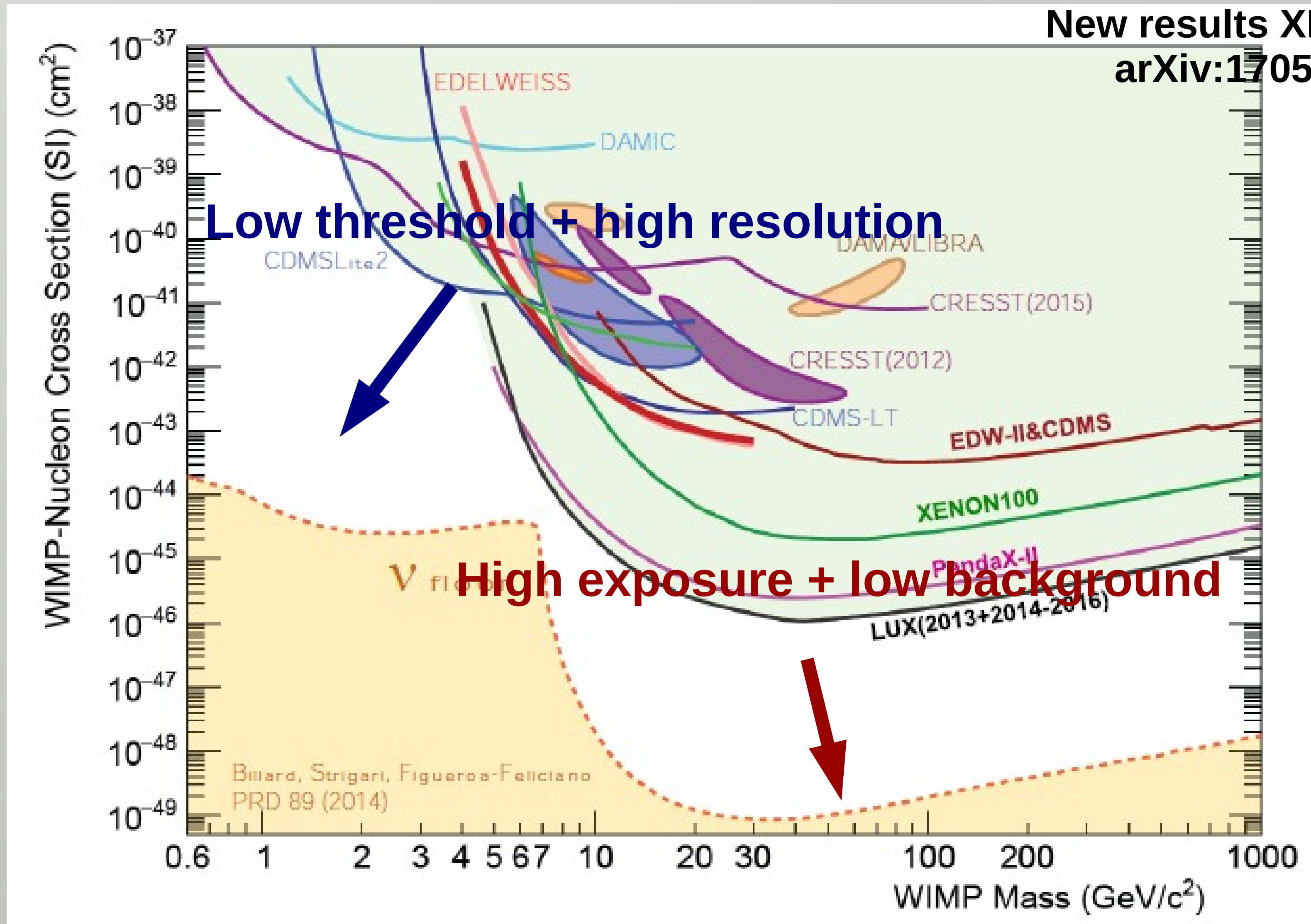


- **Liquid noble gases**
- **Cryogenic detectors**

→Threshold < 100eV
→Reduce background to the level of 1kg.year

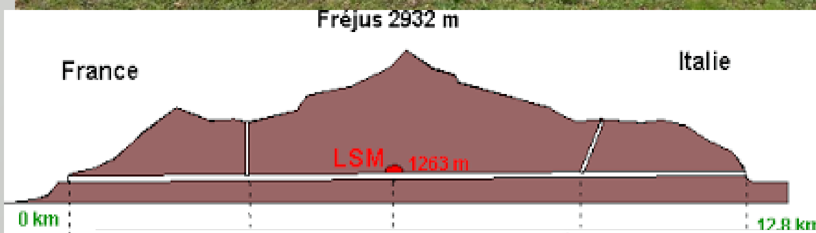
EDELWEISS collaboration

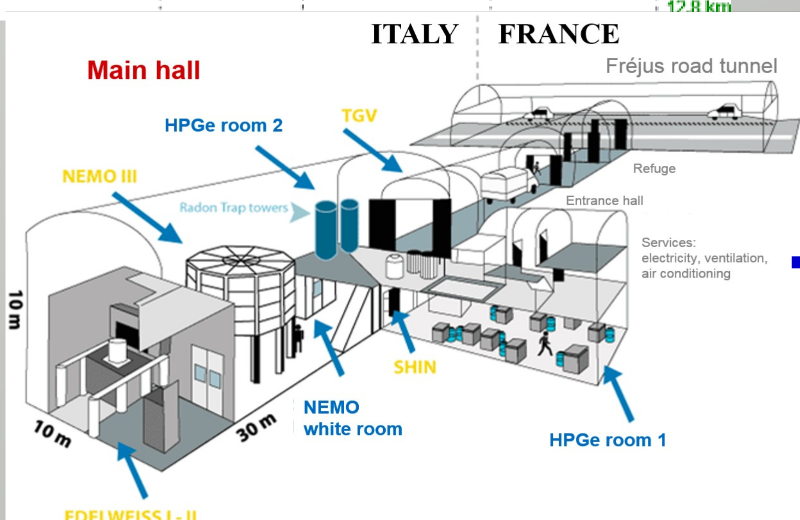
- CEA (Saclay)
- CSNSM (Orsay)
- IPNL (Lyon)
- Institut Neel (Grenoble)
- LPN (Marcoussis)

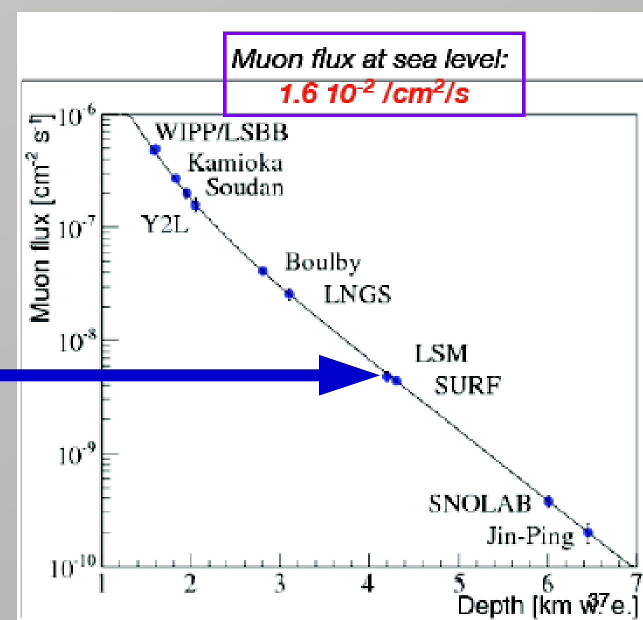
- KIT (Karlsruhe)

- JINR (Dubna)

- University of Oxford
- University of Sheffield







EDELWEISS III : → largest cryogenic Ge target with nuclear recoil discrimination [30kg]
→ to be updated for low thresholds

EDELWEISS III : Set up

•**Cryogenic installation (18 mK) :**

Reversed geometry cryostat

24 detectors in the cryostat

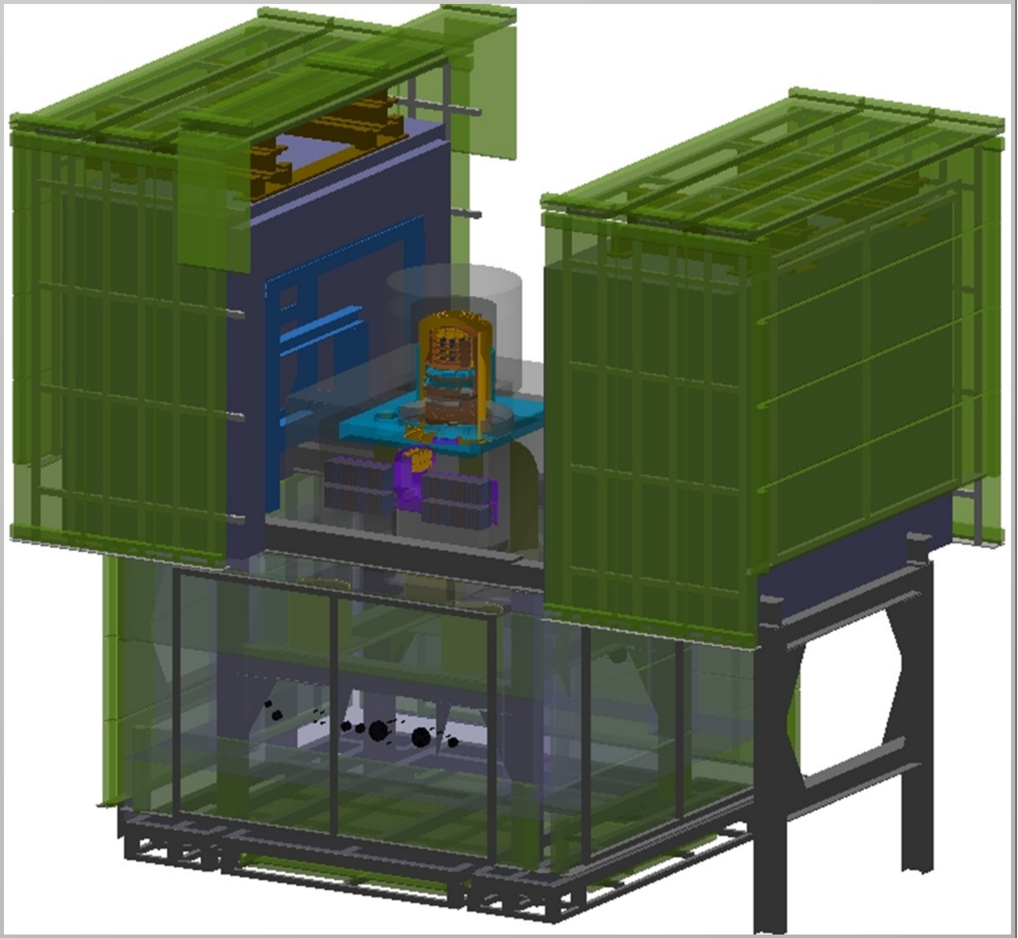
• **Shielding** :

Clean room + deradonized air: 10Bq/m³ → 30mBq/m³

Active muon veto (>98% coverage)

PE shield internal + external (50cm)

Lead shield 20 cm (18cm + 2cm ancient lead)



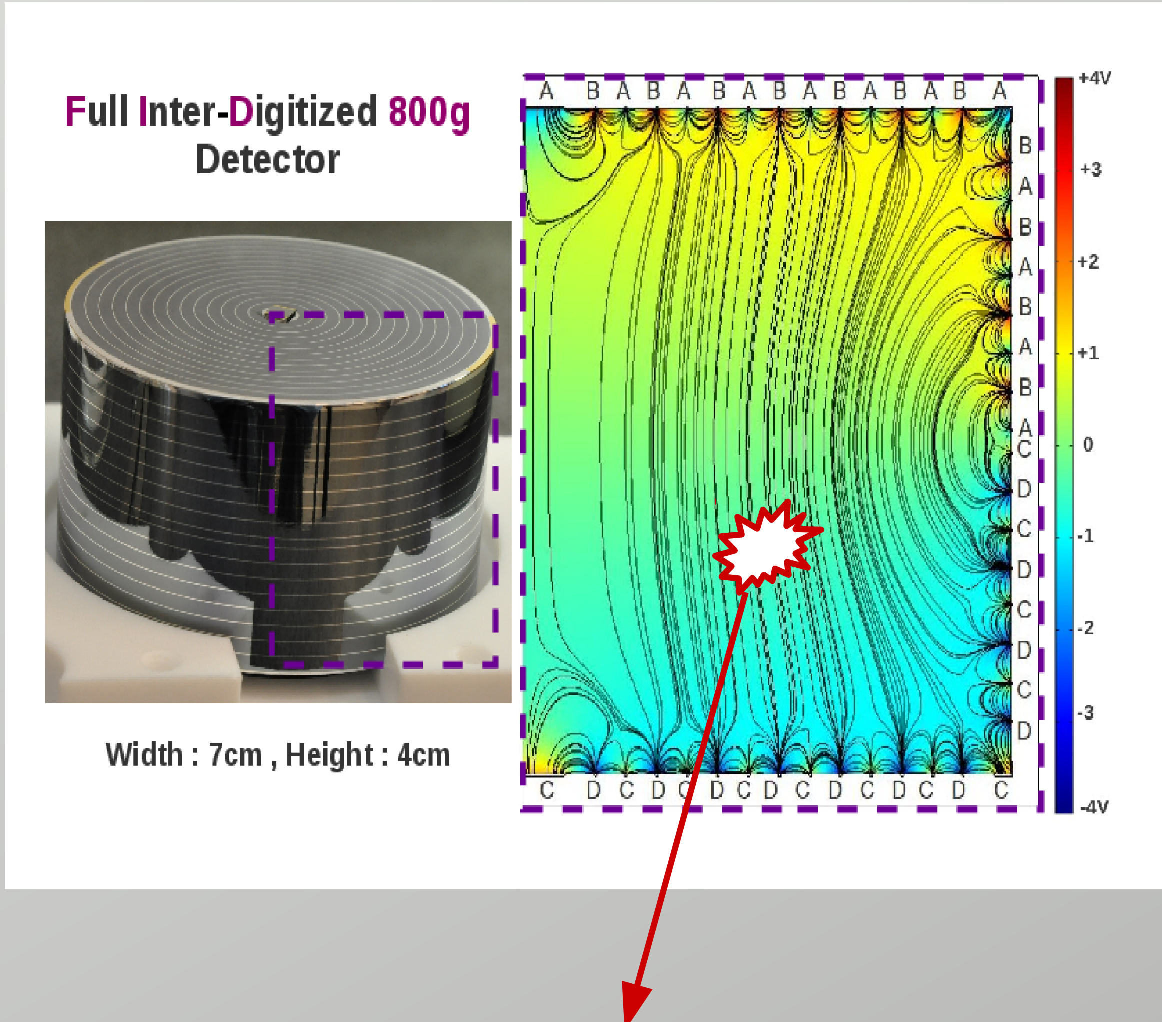
• **(Many) others :**

Remotely controlled sources for calibrations + regenerations

Radon detector down to few mBq/m³

thermal neutron monitoring (3He det.)

EDELWEISS experiment : FID800 detectors

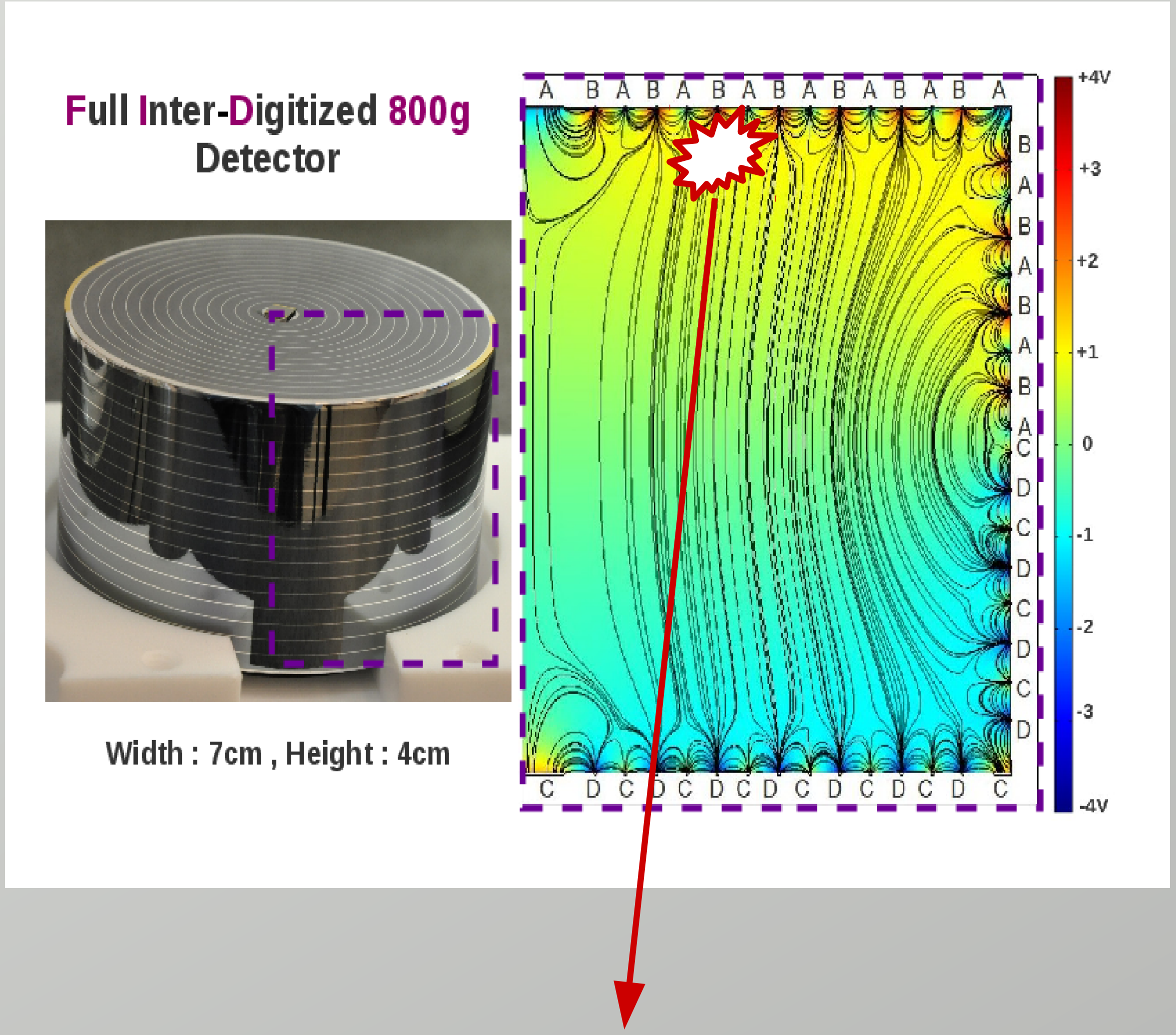


- Fully InterDigitized ~ 870g detectors
  T_{opt}=18mK
- Heat measurement : 2 GeNTDs heat sensors
- Electrodes : concentrics Al rings (2mm spacing) covering all faces
  XeF2 surface treatment: to ensure low leakage current (<1 fA) between adjacent electrodes
  J Low TempPhys(2014) 176: 182-187

<u>Bulk/fiducial event</u>

Charge collected on fiducial electrodes (top and bottom)

EDELWEISS experiment : FID800 detectors



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  J Low TempPhys(2014) 176: 182-187
- Surface events rejection (^{210}Pb+^{210}Bi, ^{210}Po α, ^{206}Pb recoils) < 4 10^{-5}

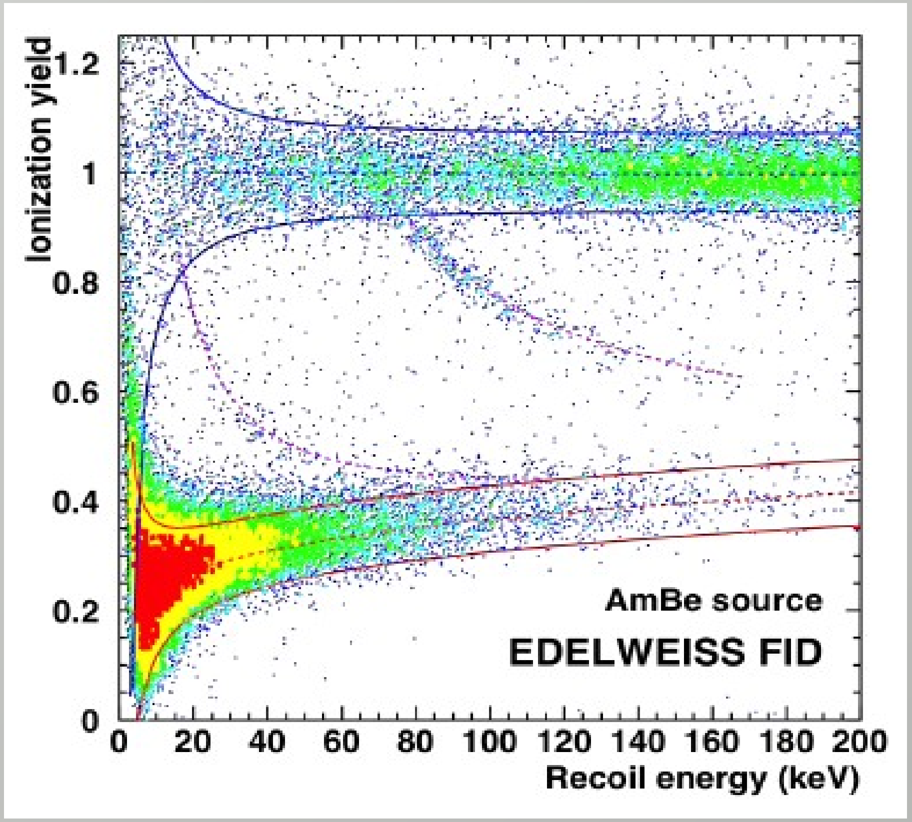
Surface event

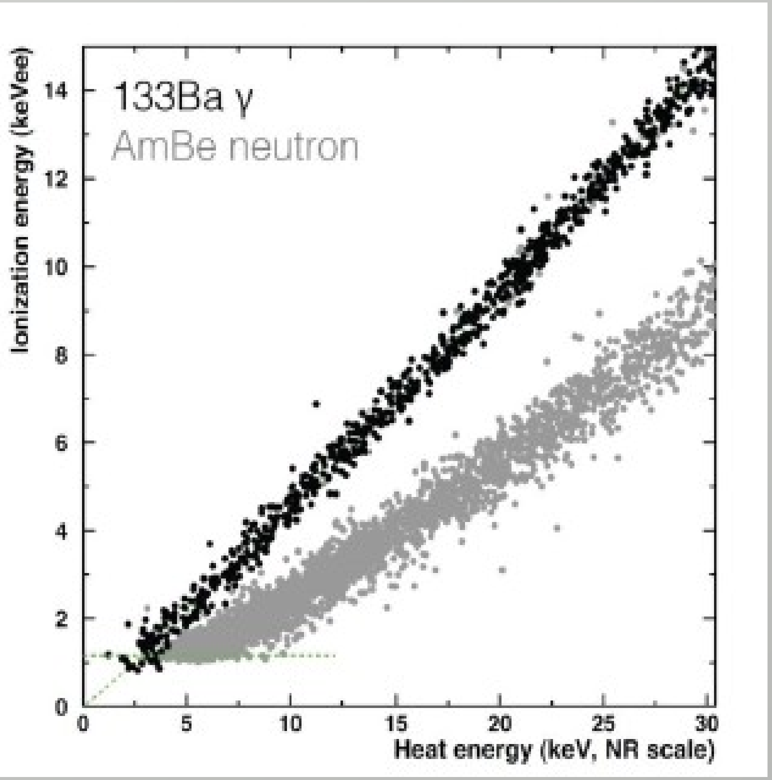
Charge collected on fiducial and veto electrodes (top)

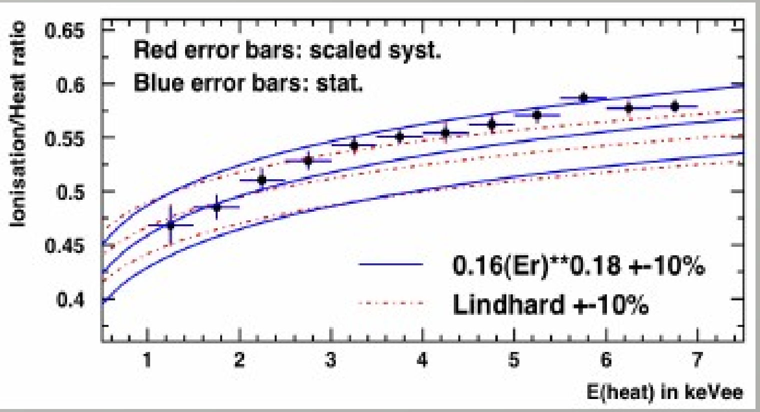
EDELWEISS III : detection

• Clear event-by-event separation down to 5keV energy (nuclear recoils)
• Response to nuclear recoils calibrated down to the analysis threshold for low-mass WIMP searches

• γ rejection factor < 2.5 10^{-6}

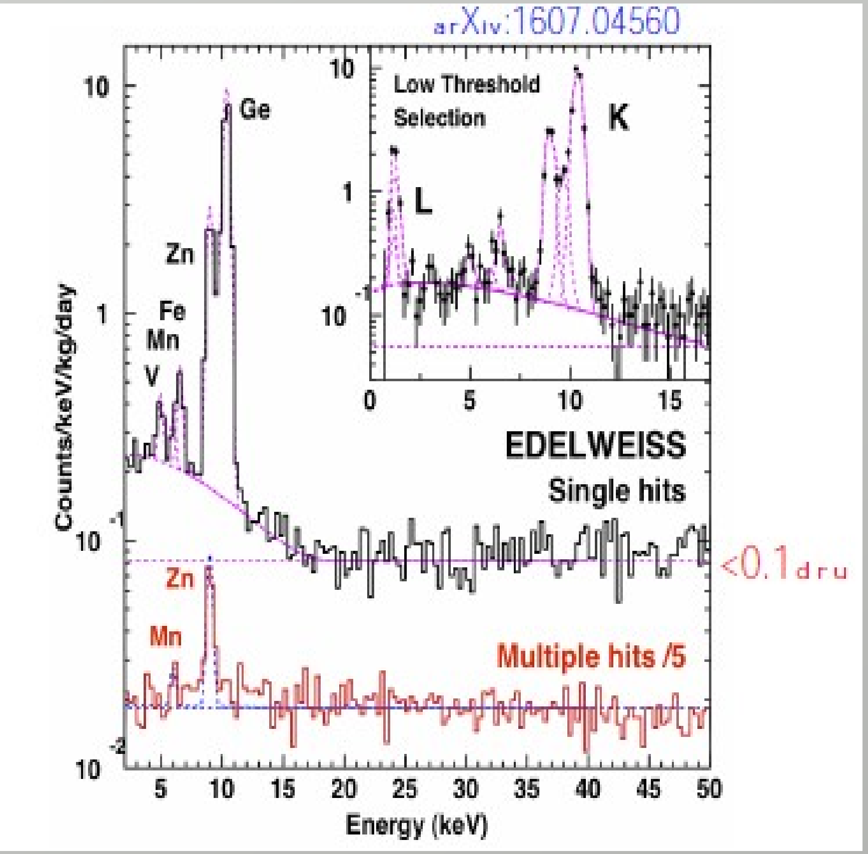






EDELWEISS III : 2014-2015 WIMP search

• 161 days of physics data with 24 FIDs > 3000 kg.days
→ Low Er background : 19 FIDs used in first measurement of cosmogenic production of ^{3}H in Ge

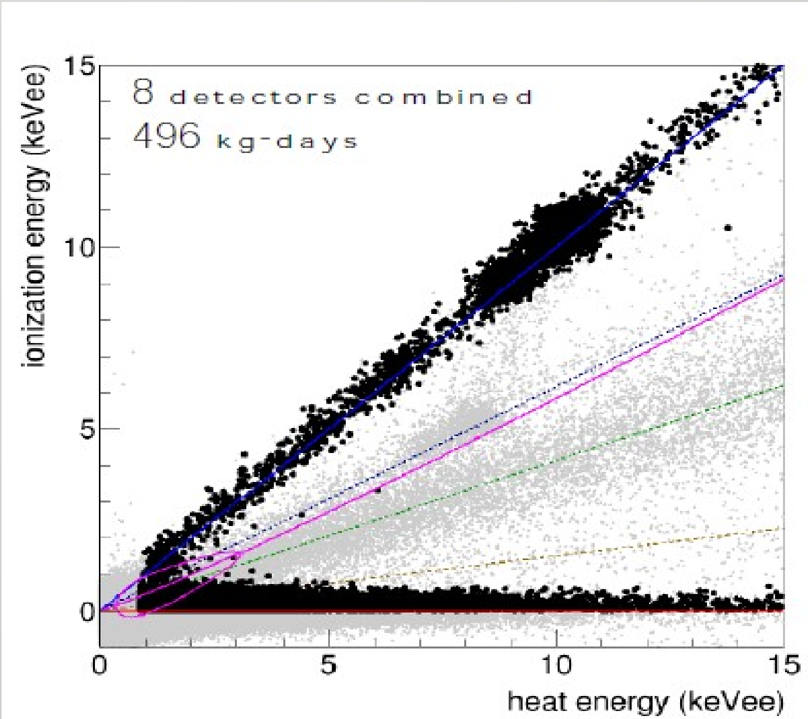


→ 8 lowest threshold FIDs used for low-mass WIMP search

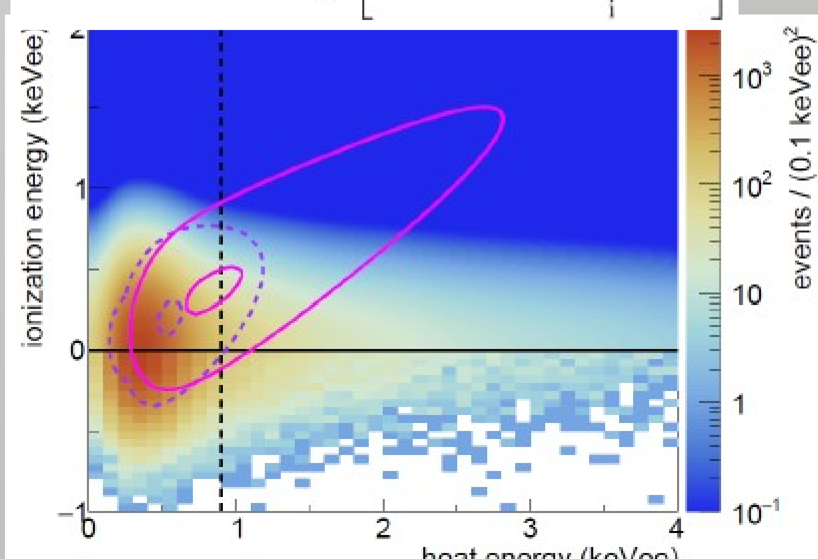
Thanks to low gamma background (<0.1 DRU), variation of cosmogenic exposure of its differents detectors and ionization energy resolution (200 eV RMS)

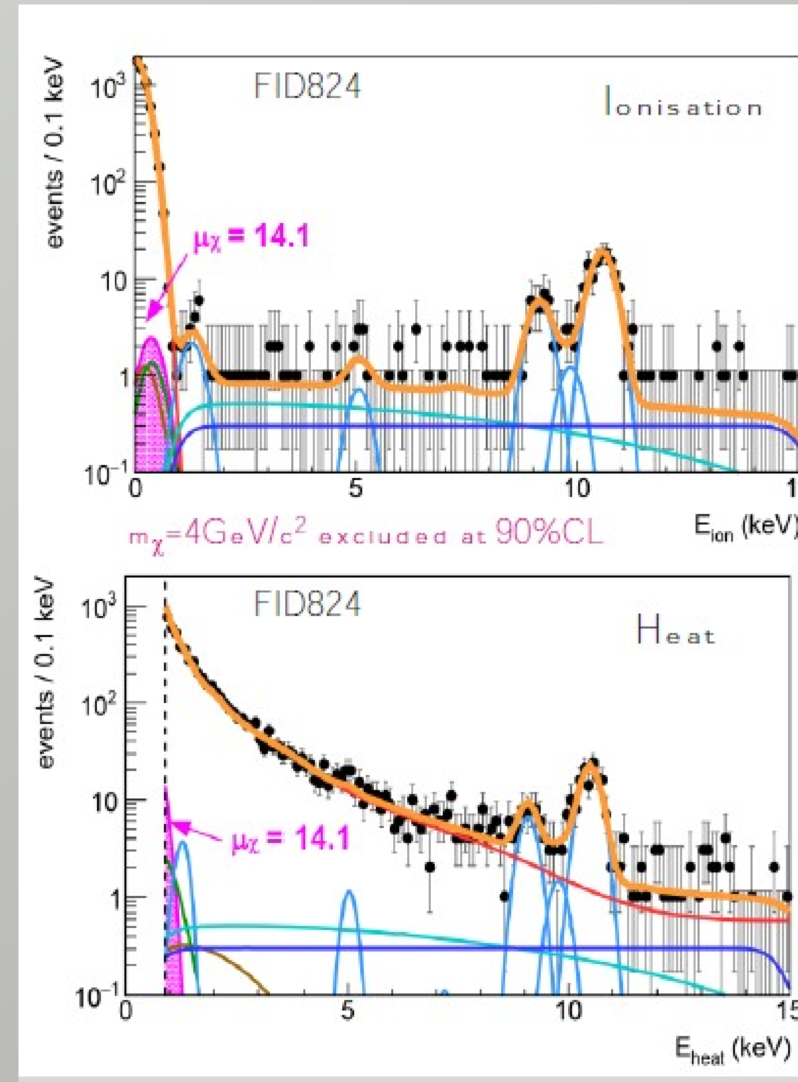
EDELWEISS-III is the first Ge exp.to measure precisely the intrinsic tritium beta activation rate at the surface (Q_β = 18.6 keV, $T_{1/2}$ = 12.32 y): **P = 82 ± 21 nuclei/kg.d**

EDELWEISS III : Low mass WIMP search with likelihood analysis



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





$$\mathcal{L}(\sigma, \boldsymbol{\mu} \mid m_\chi) = \prod_{\rm n=1}^{N} \mathcal{P}_{\rm tot}\left(E^{\rm n}_{\rm heat}, E^{\rm n}_{\rm ion}\right)$$
$$\times \prod_{\rm i} {\rm Gauss}\left(\mu_{\rm i} \mid \mu_{\rm i}^{\rm exp}, \sigma_{\rm i}\right) \times {\rm Poisson}\left(N \mid \nu\right)$$

EDELWEISS III : Low mass WIMP search with likelihood analysis

• Likelihood:

1.6×10^{-39} cm^2 at 4 GeV/c^2 to

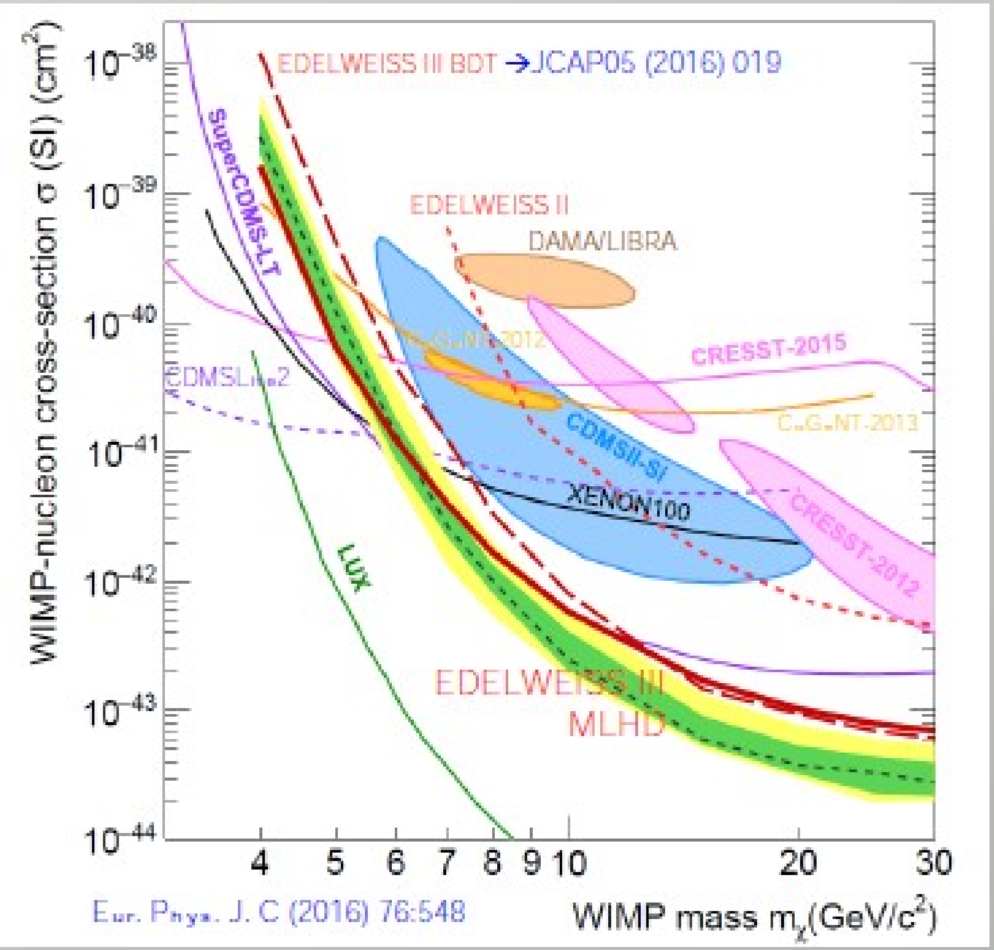
6.9×10^{-44} cm^2 at 30 GeV/c^2.

(due to higher signal efficiency & background subtraction)

→ Improvement wrt BDT analysis :

1.1×10^{-36} → 1.6×10^{-37} at 4 GeV/c^2

3.34×10^{-42} → 1.66×10^{-42} at 8GeV/c^2

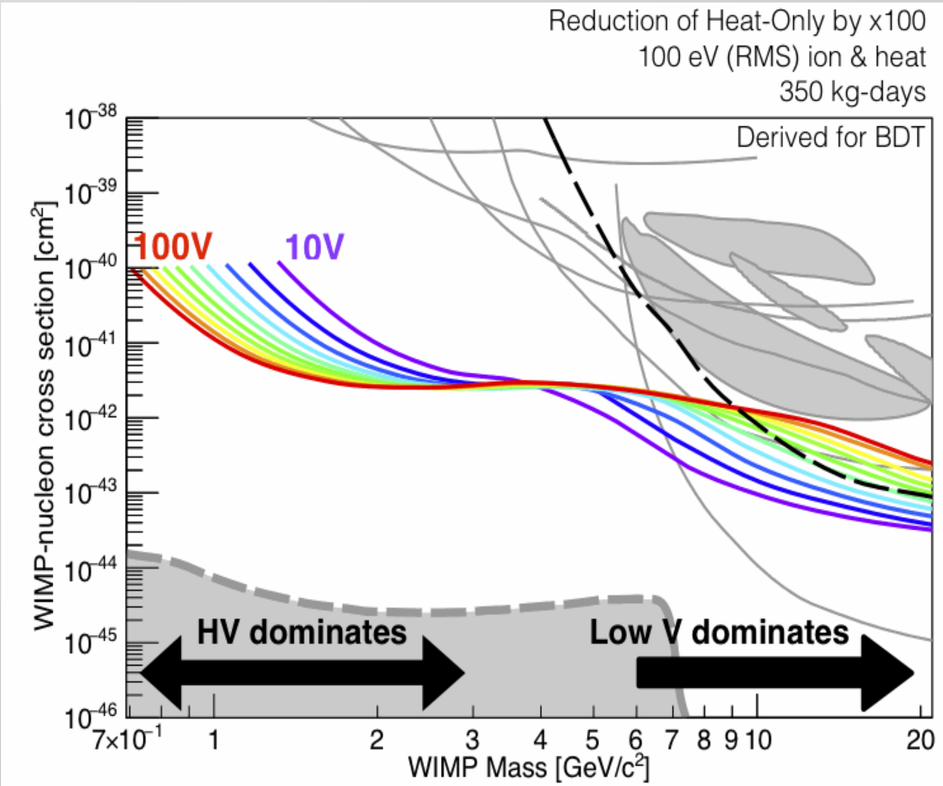


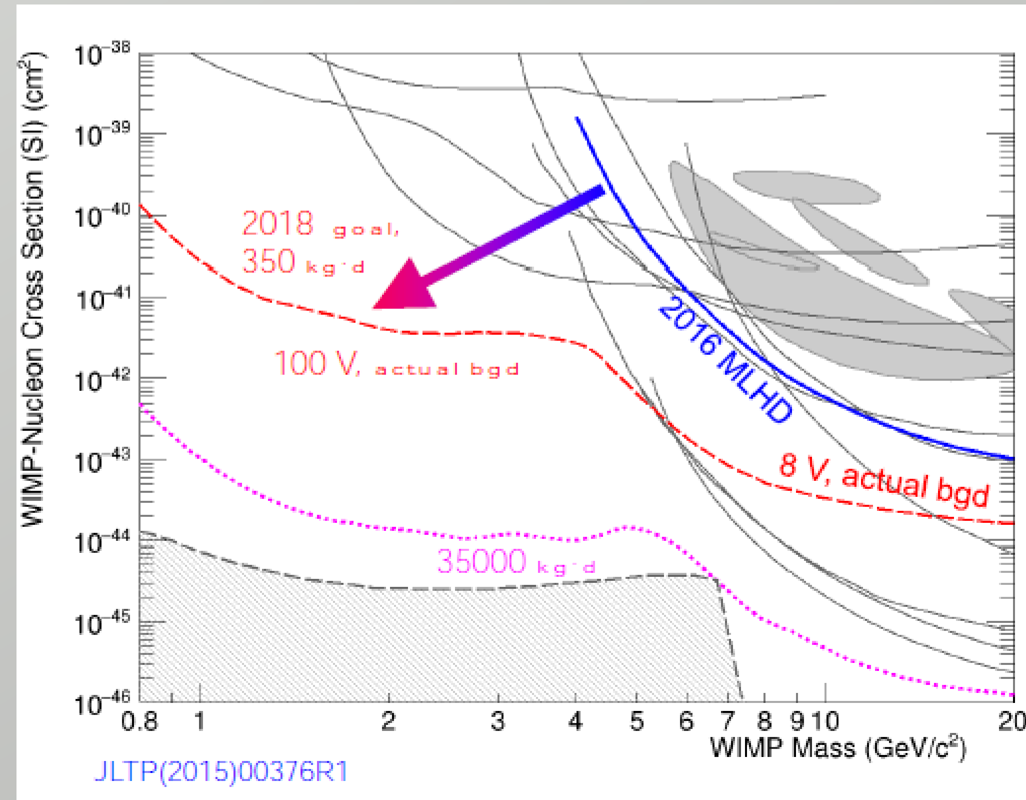
We are limited by Heat-only background : ID and rejection using the σ_{ion}=230 eV

→ Ionization resolution is key for rejection

→ Heat resolution is key for low thresholds

EDELWEISS-LT goal : 4x100





Physics with low threshold (<100eV): **EDELWEISS-LT**

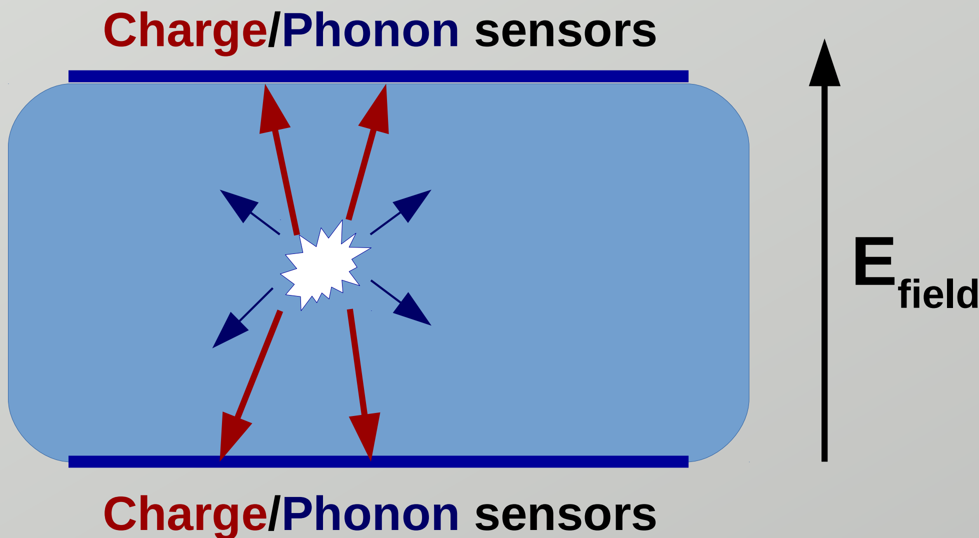
- Amplify signal to reduce threshold → apply Neganov-Luke effect : Vbias = 8V → 100V
- Lower the intrinsic heat threshold → Improved heat sensors : σ_{phonon} = 500eV → 100eV
- Heat-only background : x100 reduction (not included in the prediction shown here)

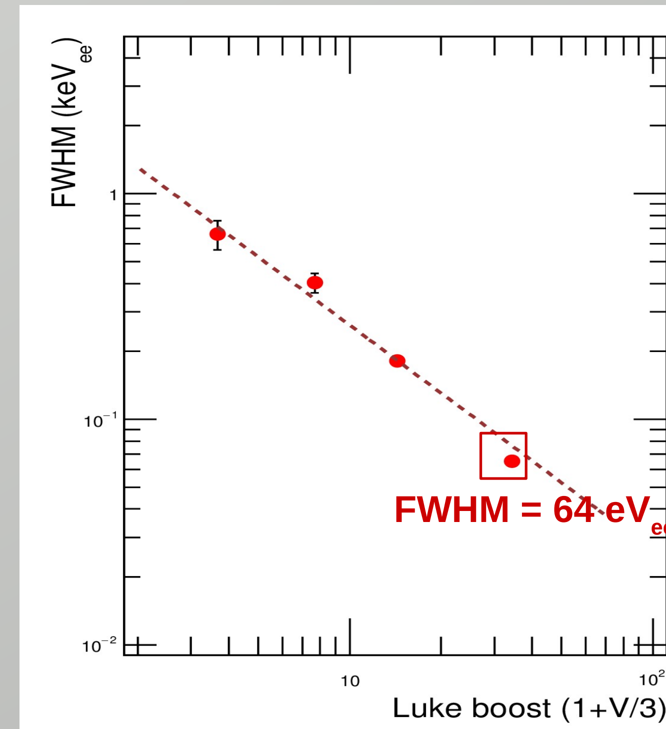
DMB8 :

- Background ID at lower energy → HEMT transistor read out : σ_{ion} = 200eV → 100eV

First R&D item : High voltage for Luke-Neganov amplification

- Neganov-Luke : $E_{total} = E_{recoil} + 1/3\ E_Q \Delta V$





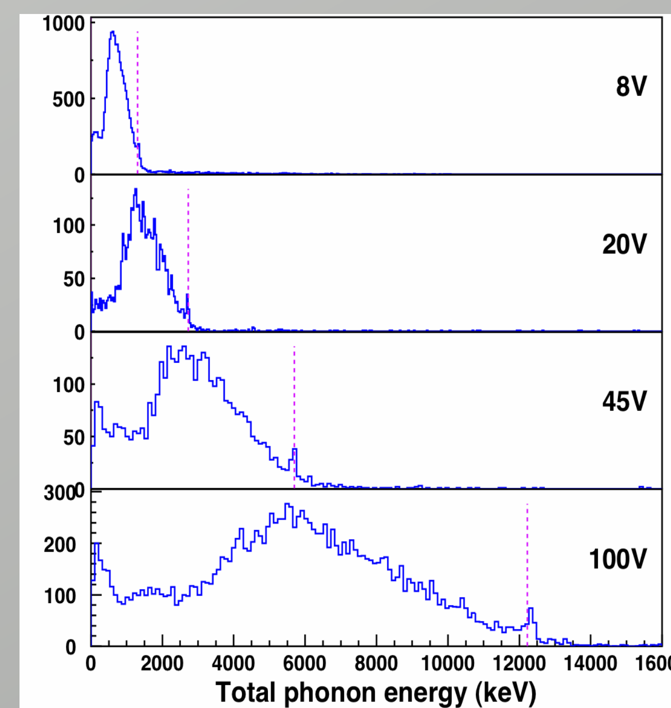
First measurements in LSM with FID800 in 2015 :

→Up to 100V working ~boost x35

→ heat resolution in keVee improved by x35
best measurement of ionization

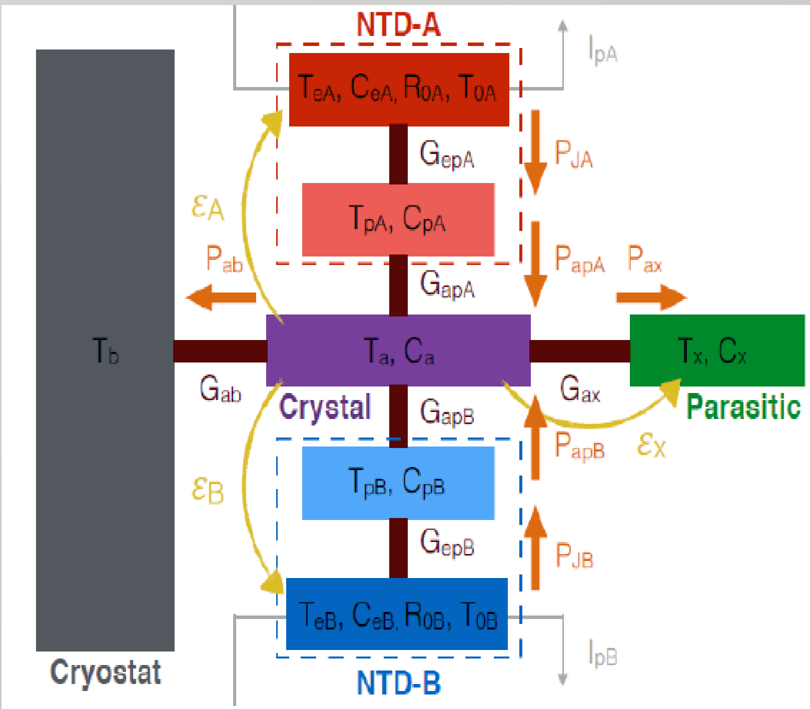
→ Sensitivity goal : threshold < $100eV_{NR}$
using improved phonon channel resolution

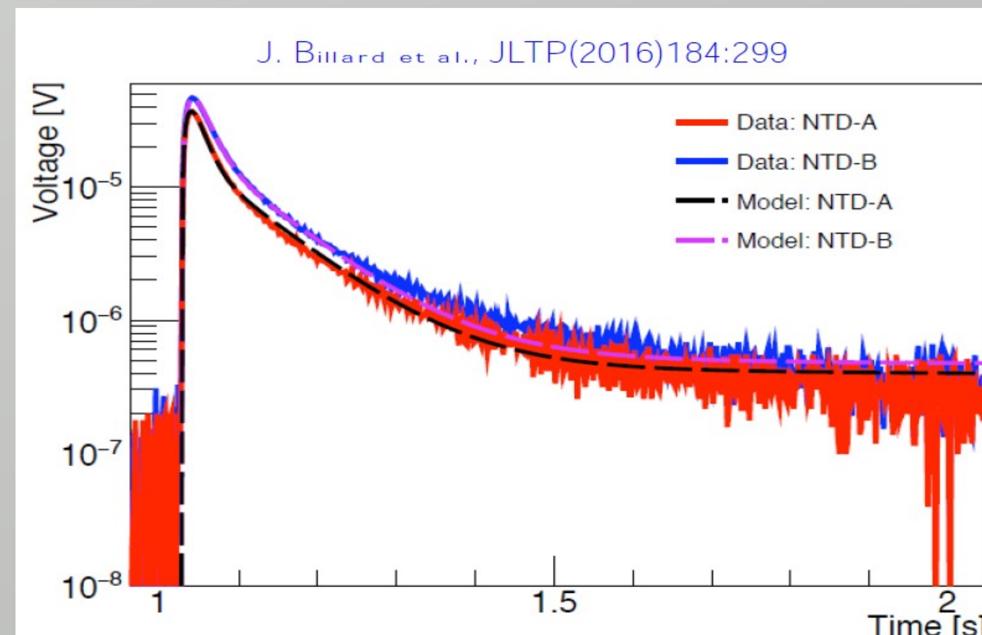
→ Ionization signal redundant in high voltage mode
(no particle discrimination), but provides
Continous + detailed diagnostics of charge collection



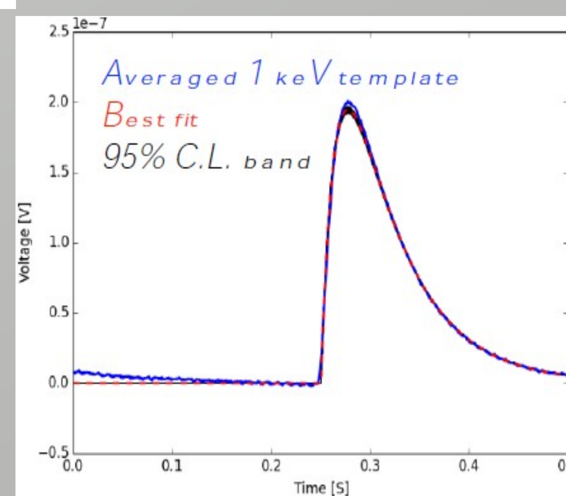
Second R&D item : Heat sensor resolution

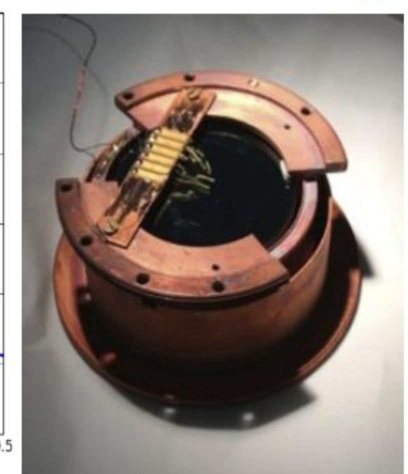
- Better understanding of heat signal
  - → Thermal modeling of signal, verified with dedicated R&D
  - → Identification of sensitivity to ballistic phonons
  - → Identification of parasitic heat capacity





- Sensitivity of 200 nV/keV
  - → achieved on 200g test detectors

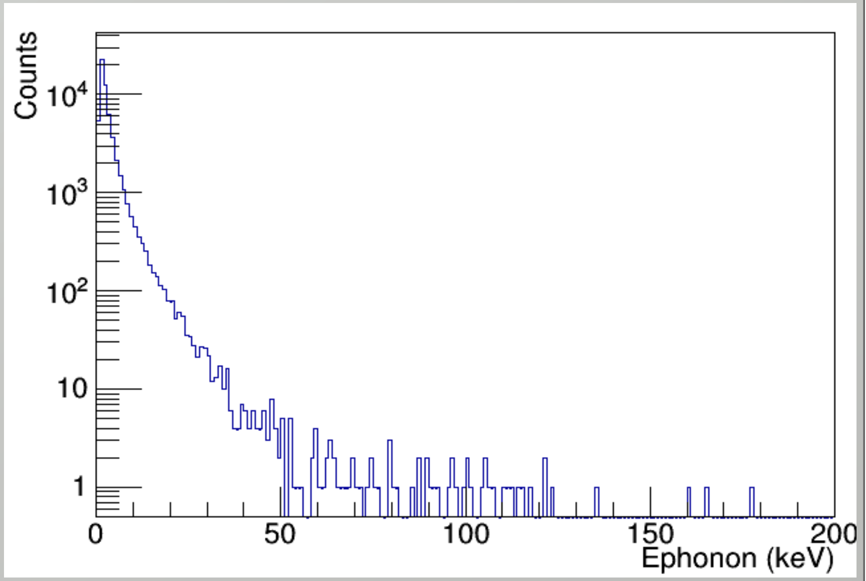




Third R&D item : Heat-only events

• Dominant (and reproducible) background at low energy

• Noise, cryogenics, stress from detector suspension or glue, etc... are being studied

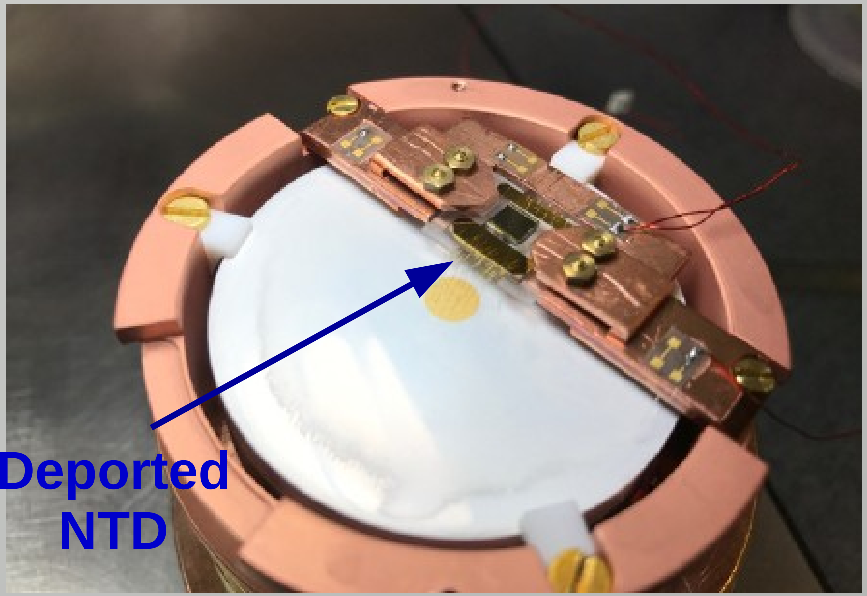


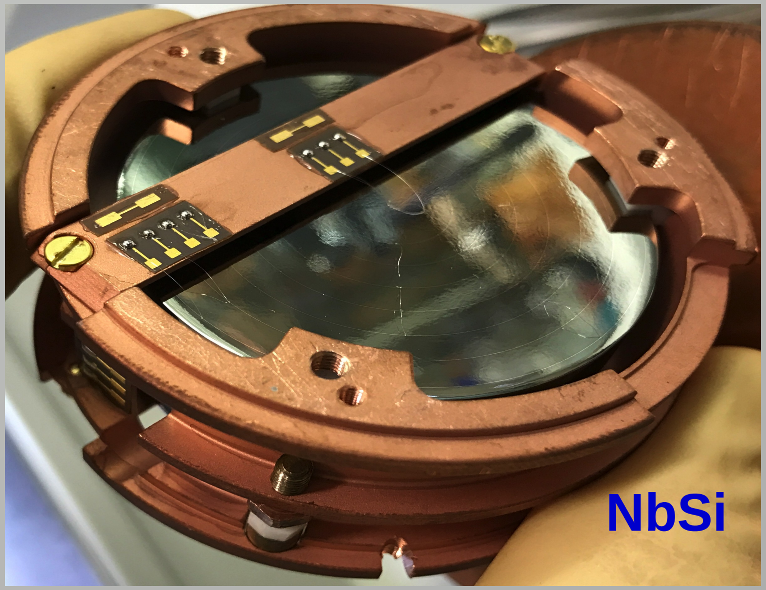
• Hypotheses tested with new sensor designs :

→ Deported NTD, glued on separate sapphire wafer

→ Photo-lithographed high-impedance NbSi TES, sensitive to athermal phonons

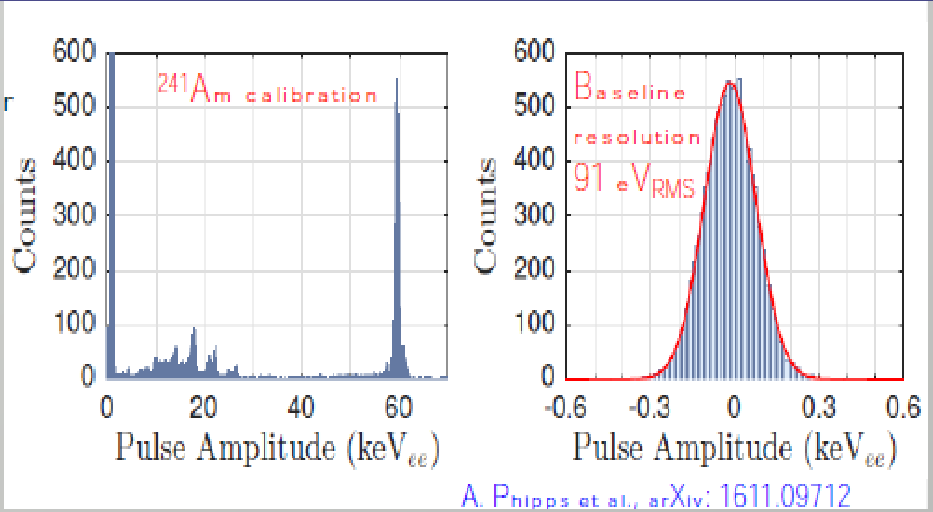
→ 4 detectors of these new designs have been studied in the last run at LSM





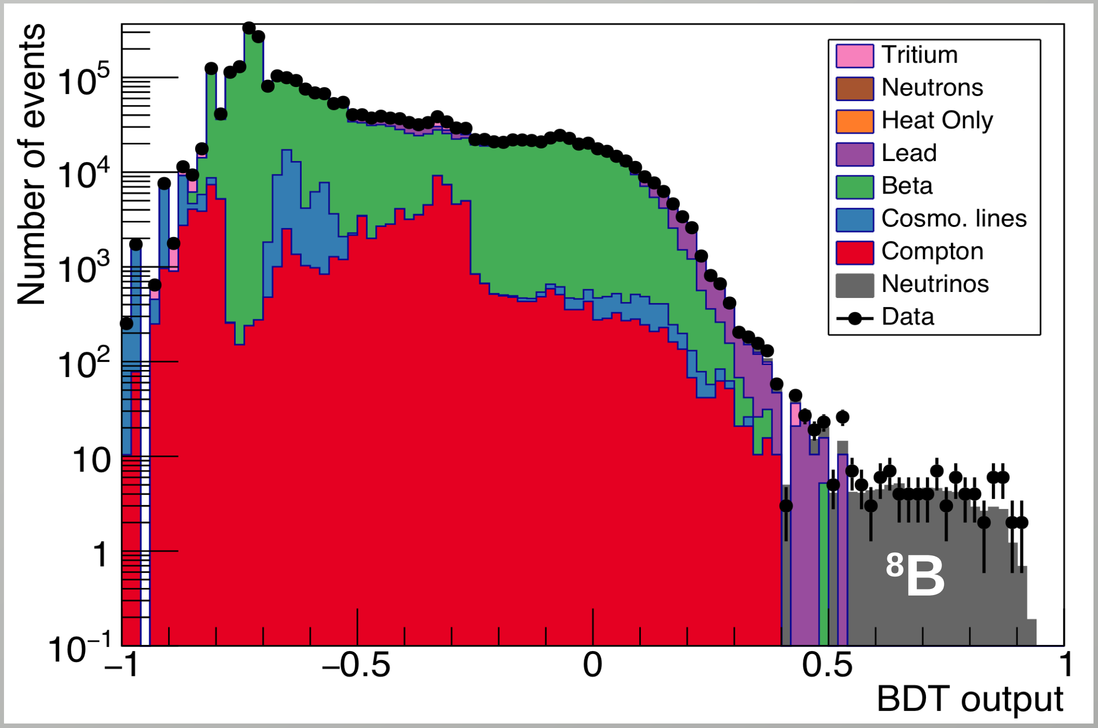
Fourth R&D item : HEMT read out

- JFET → HEMT (High Electron Mobility Transistor) :
  - → Reduced intrinsic noise
  - → Lower heat load
  - → Operates at 4K stage :
    - → shorter cabling
    - → Reduced capacitance
    - → Better Signal-to-Noise Ratio

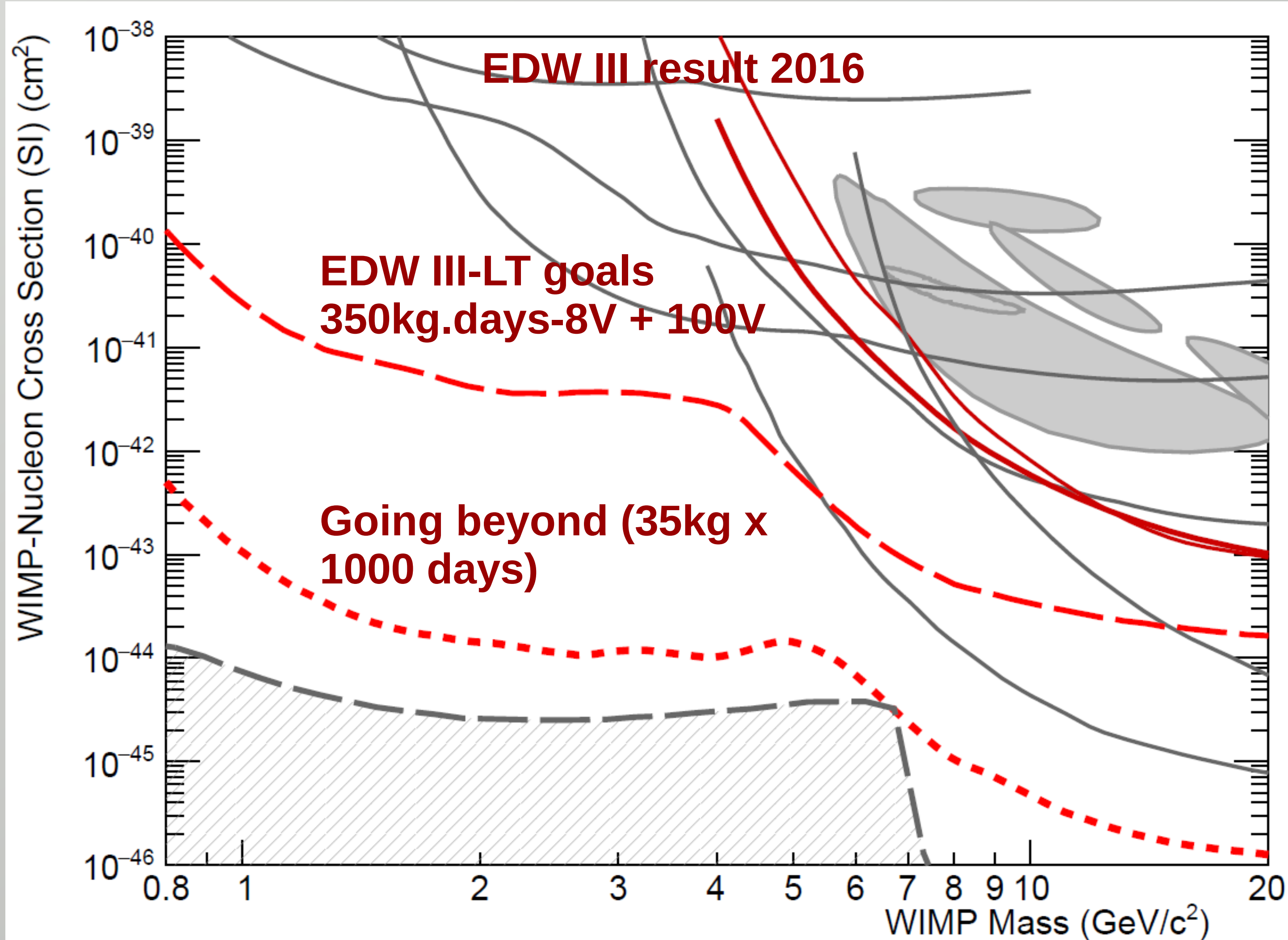


- Successful HEMT amplifier with sub-100 eVRMS ionization resolution
  [A. Phipps, arXiv:1611.09712, collaboration between SuperCDMS and EDW]
  - → Upgrade EDW ionization readout with this new design
  - → Electrode design to reduce detector capacitance to reach 50 eV$_{RMS}$

Increase of electrode spacing from 2 to 4 mm already successfully implemented



Conclusion and outlook



- 2017-2018, **EDELWEISS-LT** :Low-mass program in LSM (350 kg.d)

  R&D on HV, HEMT, sensors, heat-only

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