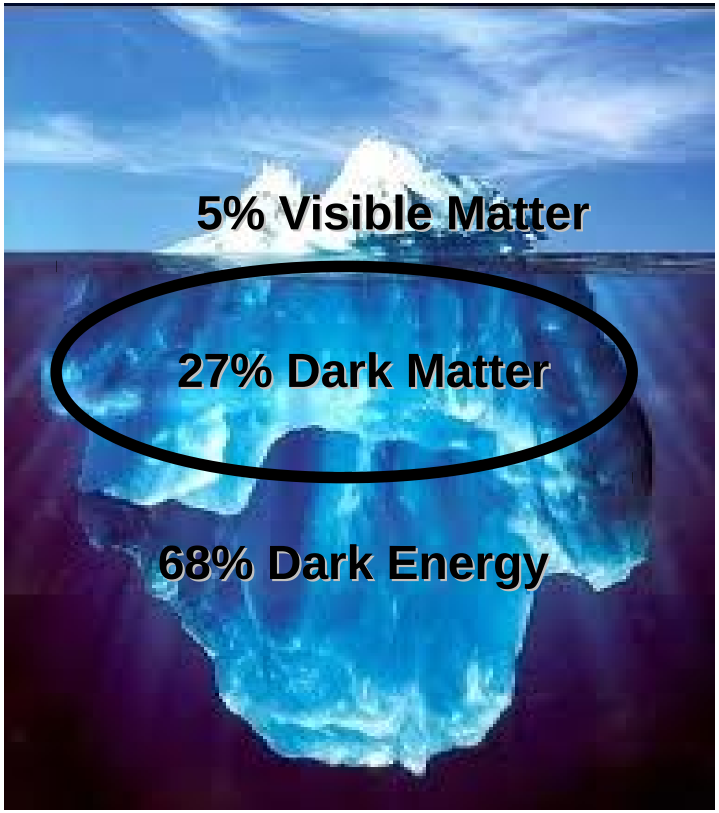
- **Nom:** de Boissière Thibault
- **Cursus:** Ecole Centrale
- **Motivations:** Exploring the frontier between cosmology and particle physics, many possibilities: experiments, analysis, phenomenology...

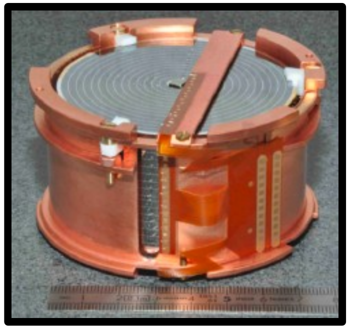
- Looking for Dark Matter with the EDELWEISS experiment



Galactic halo: a potential source of dark matter

WIMPs are the vanilla candidates

Direct detection in Ge bolometer

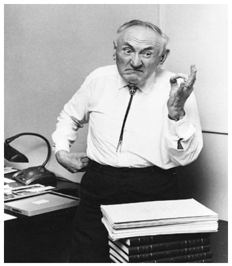


⇒ Detect **nuclear recoils** from WIMP scattering

Outline

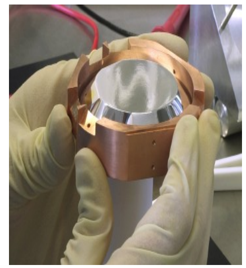
- **A lightning history of Dark Matter direct detection**
- **The EDELWEISS experiment**
- **Background analyses**
- **Extra sugar: axion searches**

A lightning history of Dark Matter direct detection



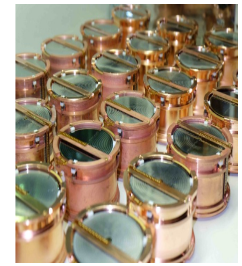
F. Zwicki
(1933)

Excess of gravitational mass



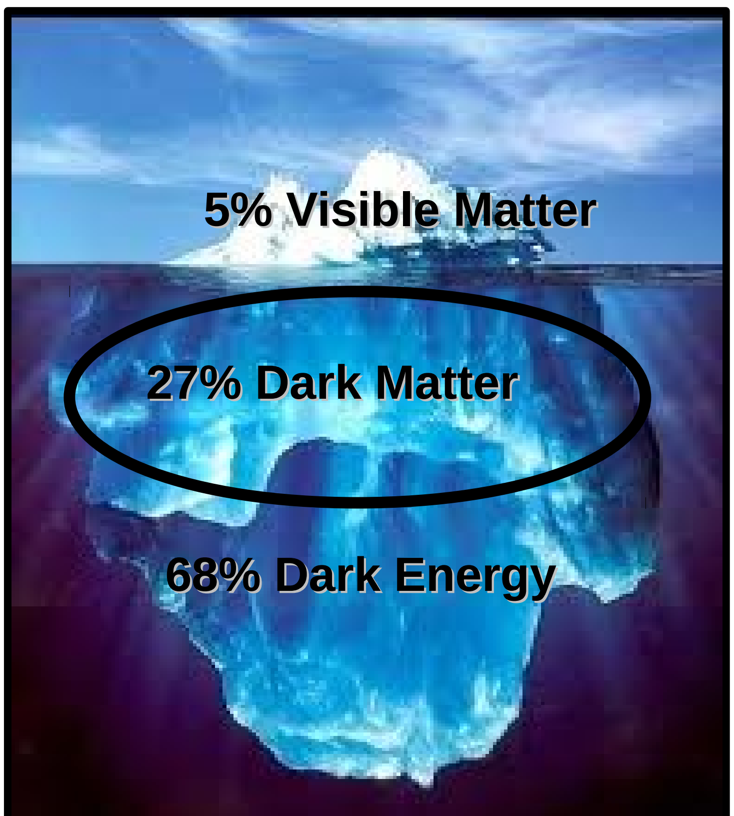
EDELWEISS I
(1988-2002)

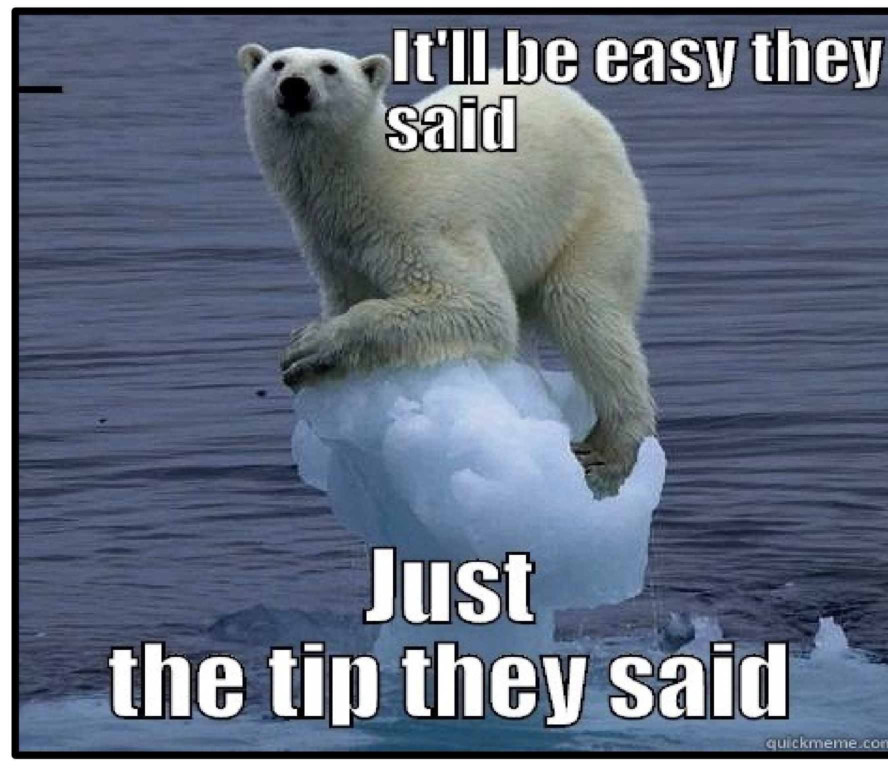
First cryogenic detectors



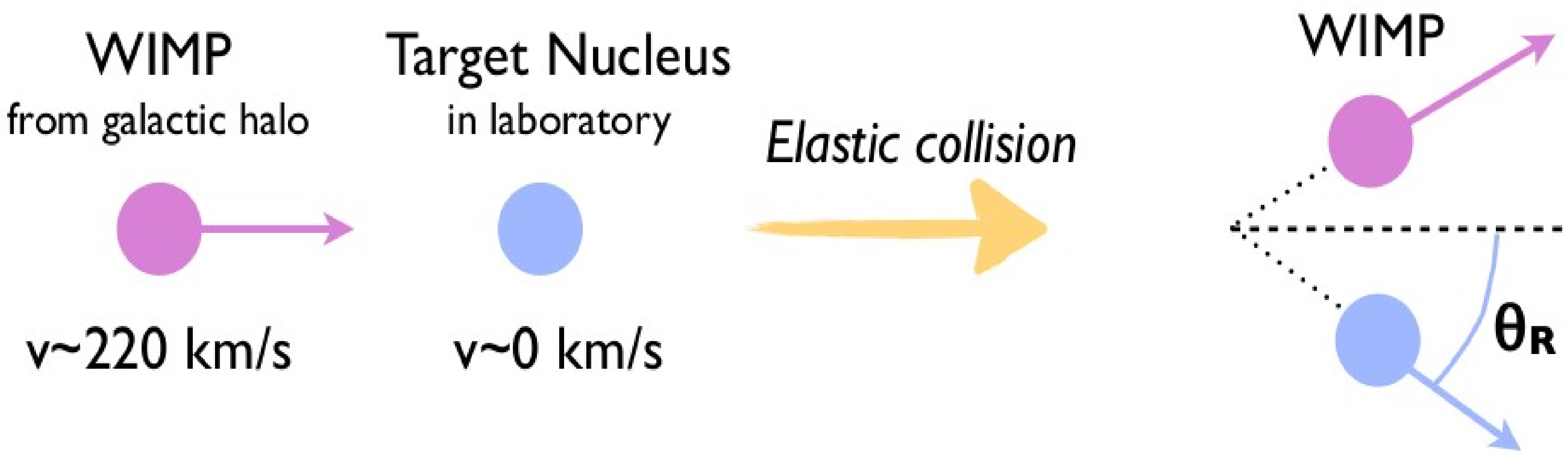
EDELWEISS III
(2014-)

36 detectors





A lightning history of Dark Matter direct detection



Typical energy: keV to < 100 keV

Expected WIMP event rate: < 0.1 per ton per day

Radioactive background: most materials give higher rate

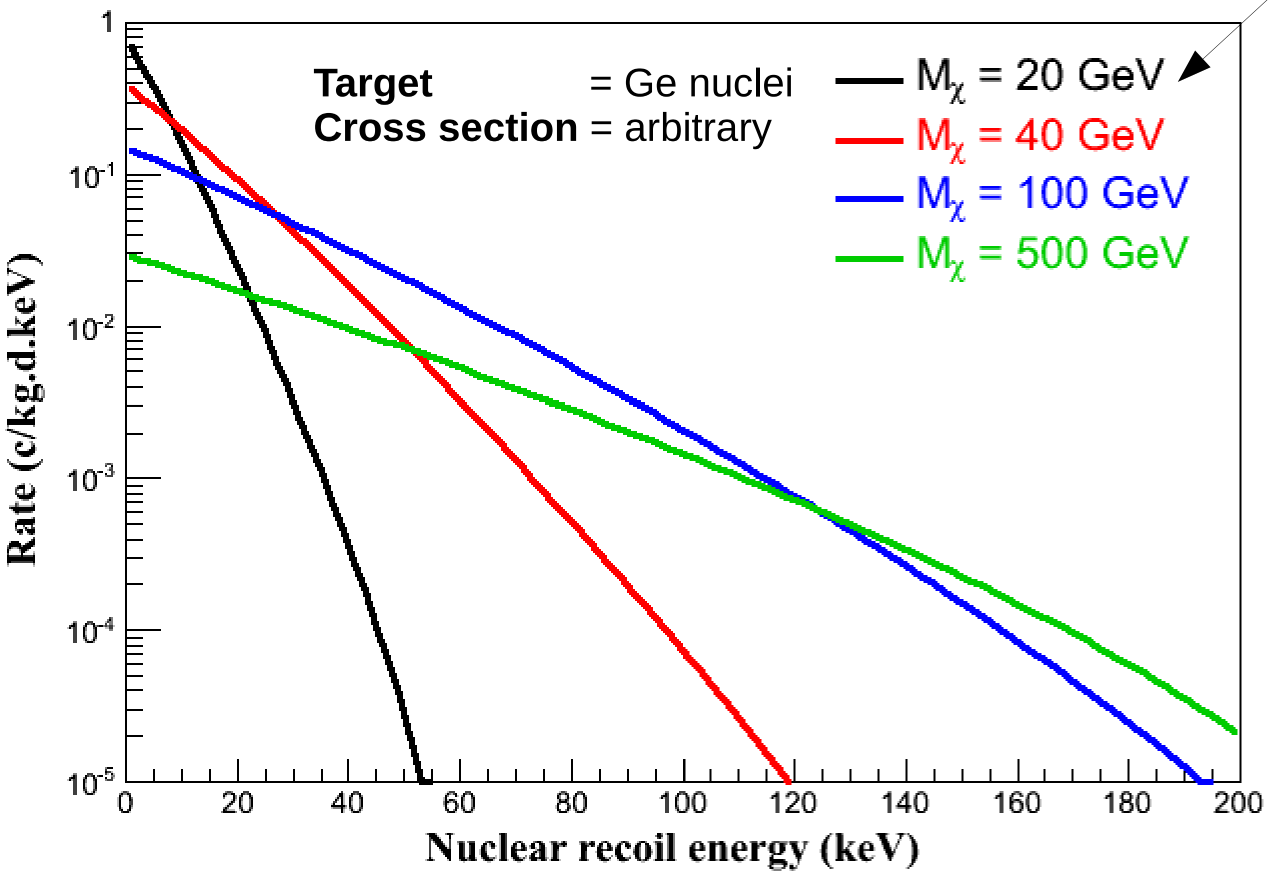
We need :

- Low thresholds
- High exposure
- Background rejection

A lightning history of Dark Matter direct detection

What do direct detection dark matter experiments expect?

WIMP masses

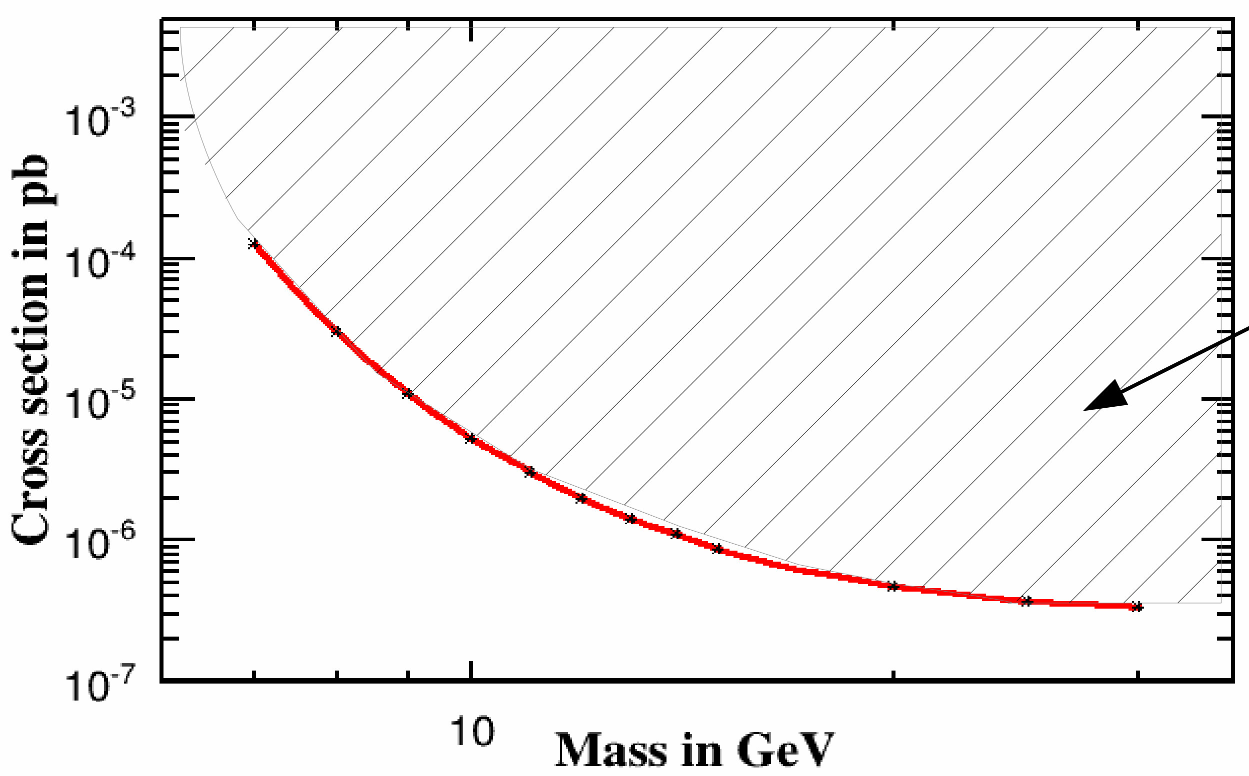


- **Exponential** spectrum
- 2 classes: **high masses** versus **low masses**
- **Low masses:** most of the signal near threshold

A lightning history of Dark Matter direct detection

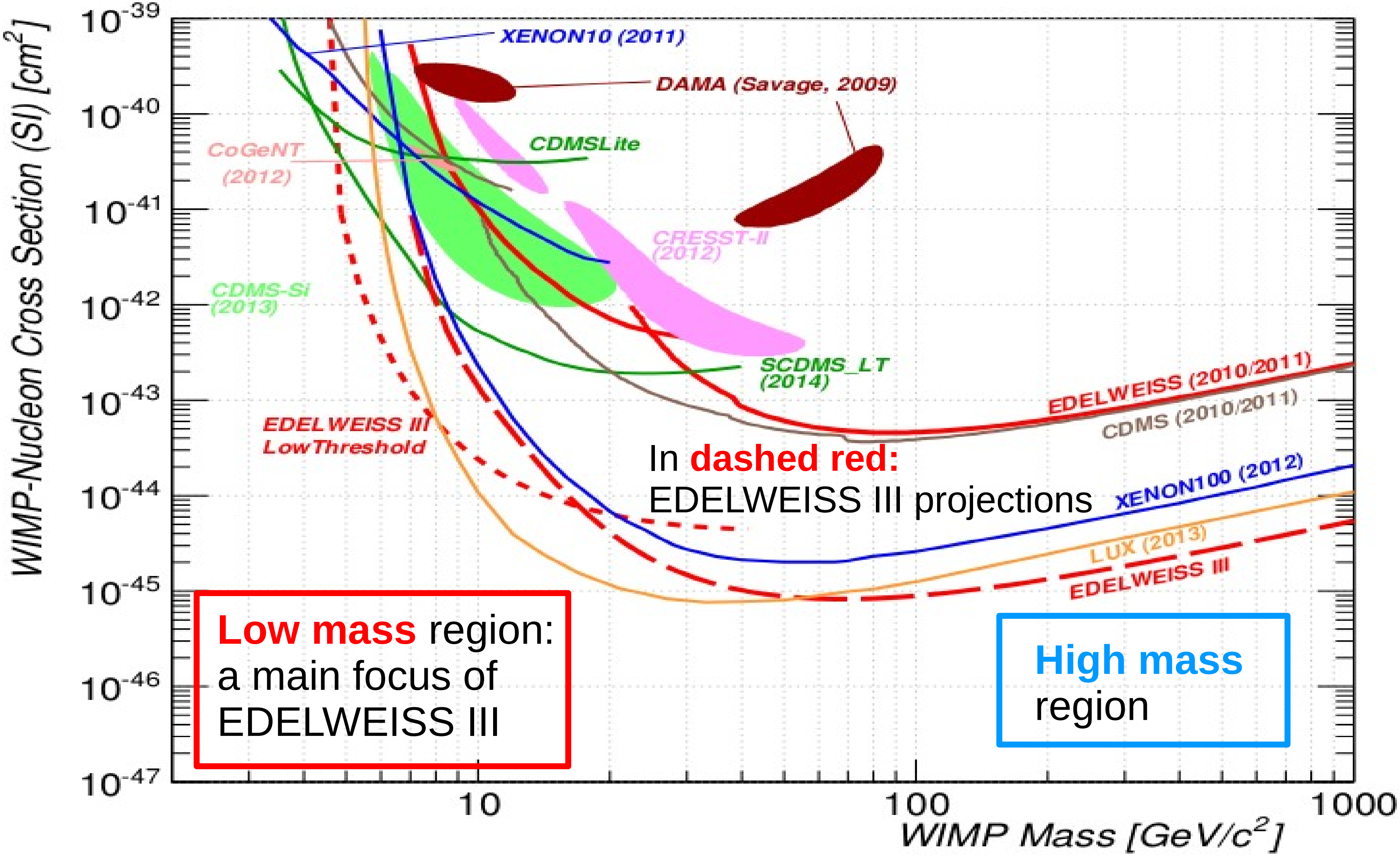
What do Dark Matter direct detection experiments see?

So far, Nothing! ⇒ Plot exclusion limit in the **(Mass, Cross section)** plane



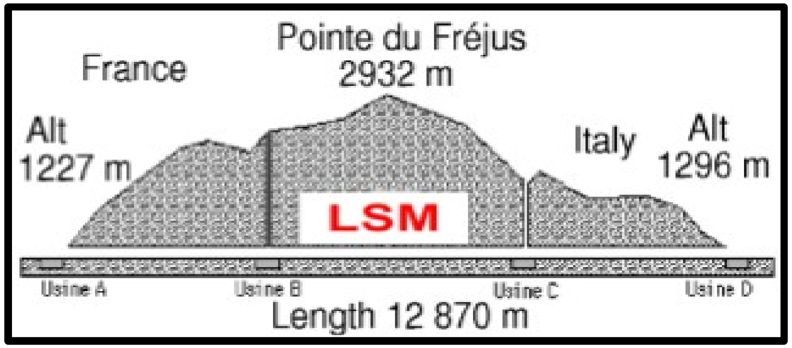
Excluded region

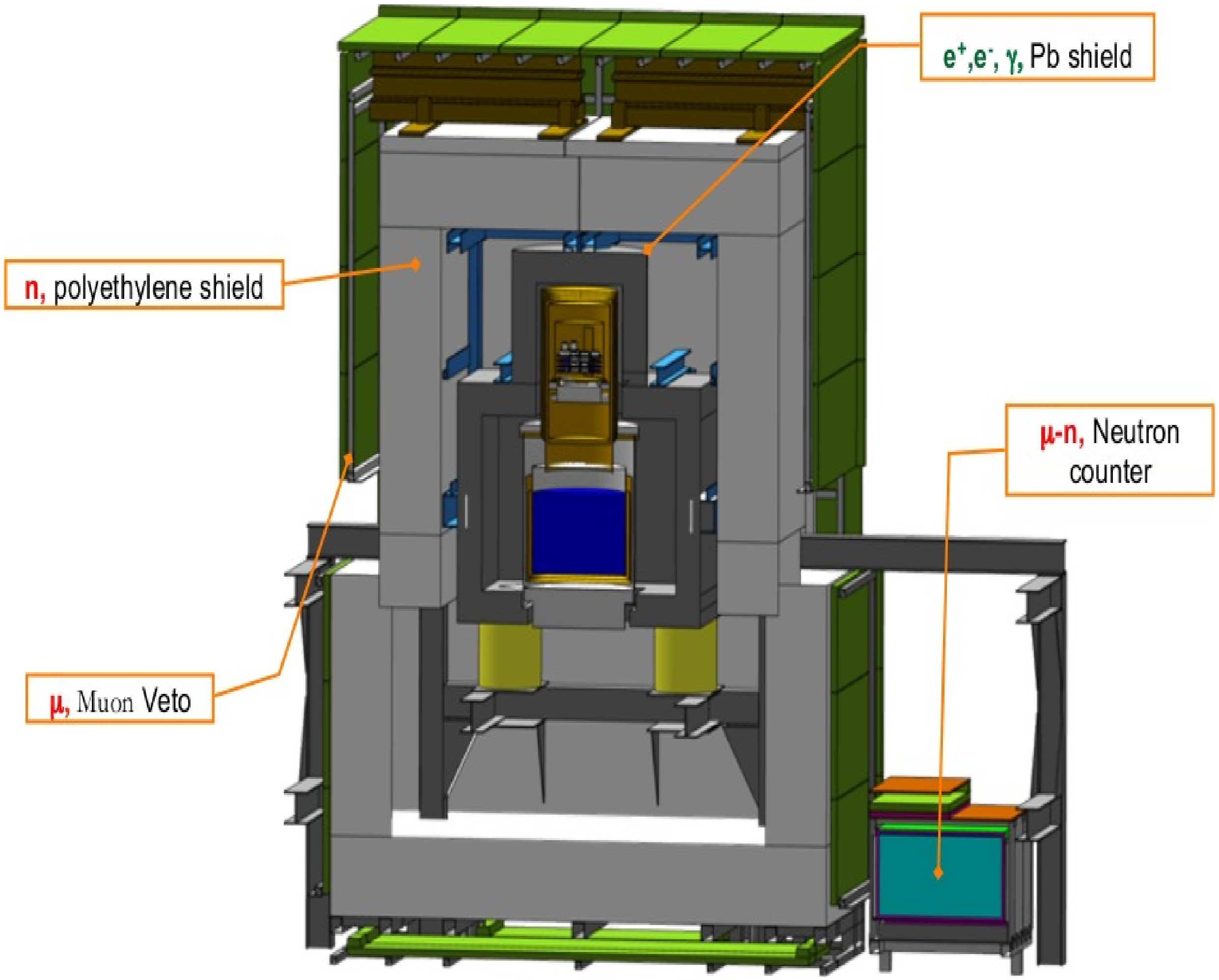
A lightning history of Dark Matter direct detection



The EDELWEISS experiment

The EDELWEISS experiment

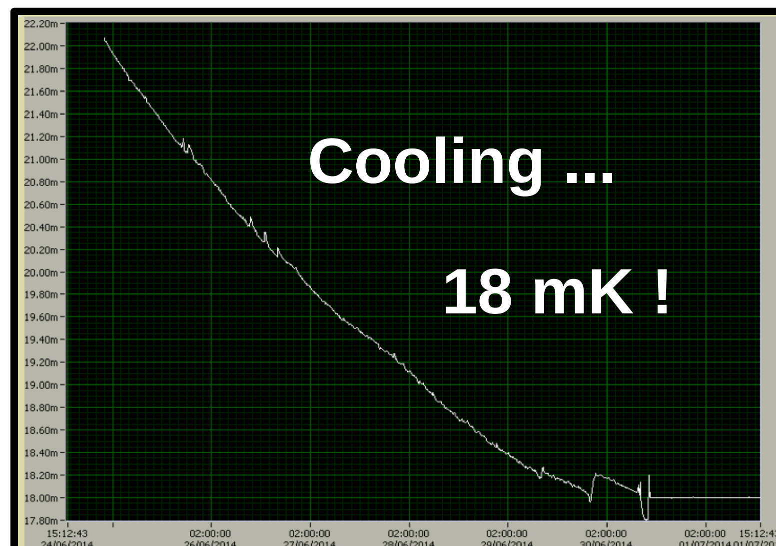




The EDELWEISS experiment

EDELWEISS III status

- 2012 to early 2014: detector fabrication, installation, first commissioning
- 2014 – 2016: physics run
- 36 detectors at the lab, 24 read out, current cool-down successful !
- Analyses in next slides based on 2013 commissioning data



Dealing with backgrounds in EDELWEISS: 2 arrows

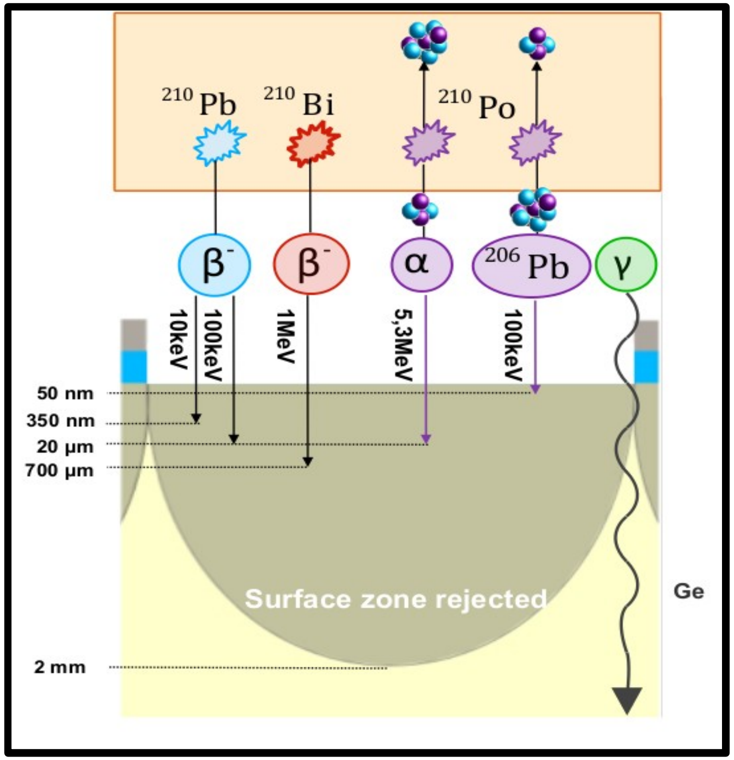
1st arrow : VOLUME versus SURFACE distinction

Many background events interact on the SURFACE of the detector:
γ, β, Pb, α

WIMPs, γ and neutrons interact in the VOLUME of the detector

⇒ **Tagging VOLUME versus SURFACE gives efficient background rejection**

(EDELWEISS uses 4 different electrodes for **VOLUME/SURFACE** rejection, see later)



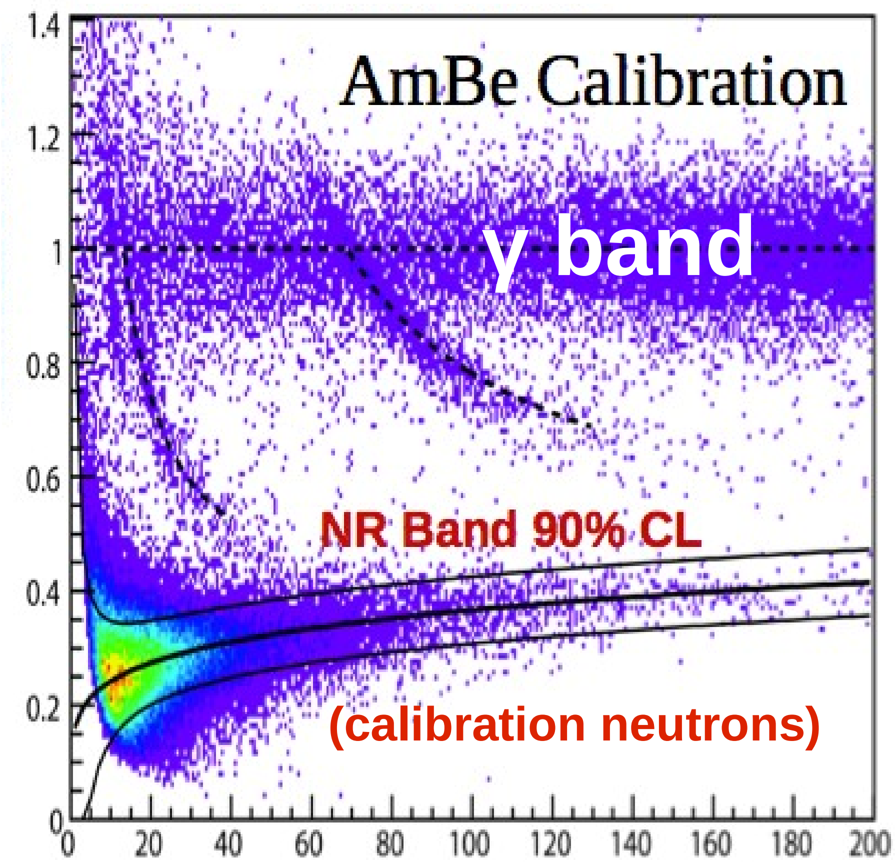
The EDELWEISS experiment

2nd arrow: DUAL SENSORS for event discrimination

- **We measure:**
  - the **heat**
  - the **ionisation**

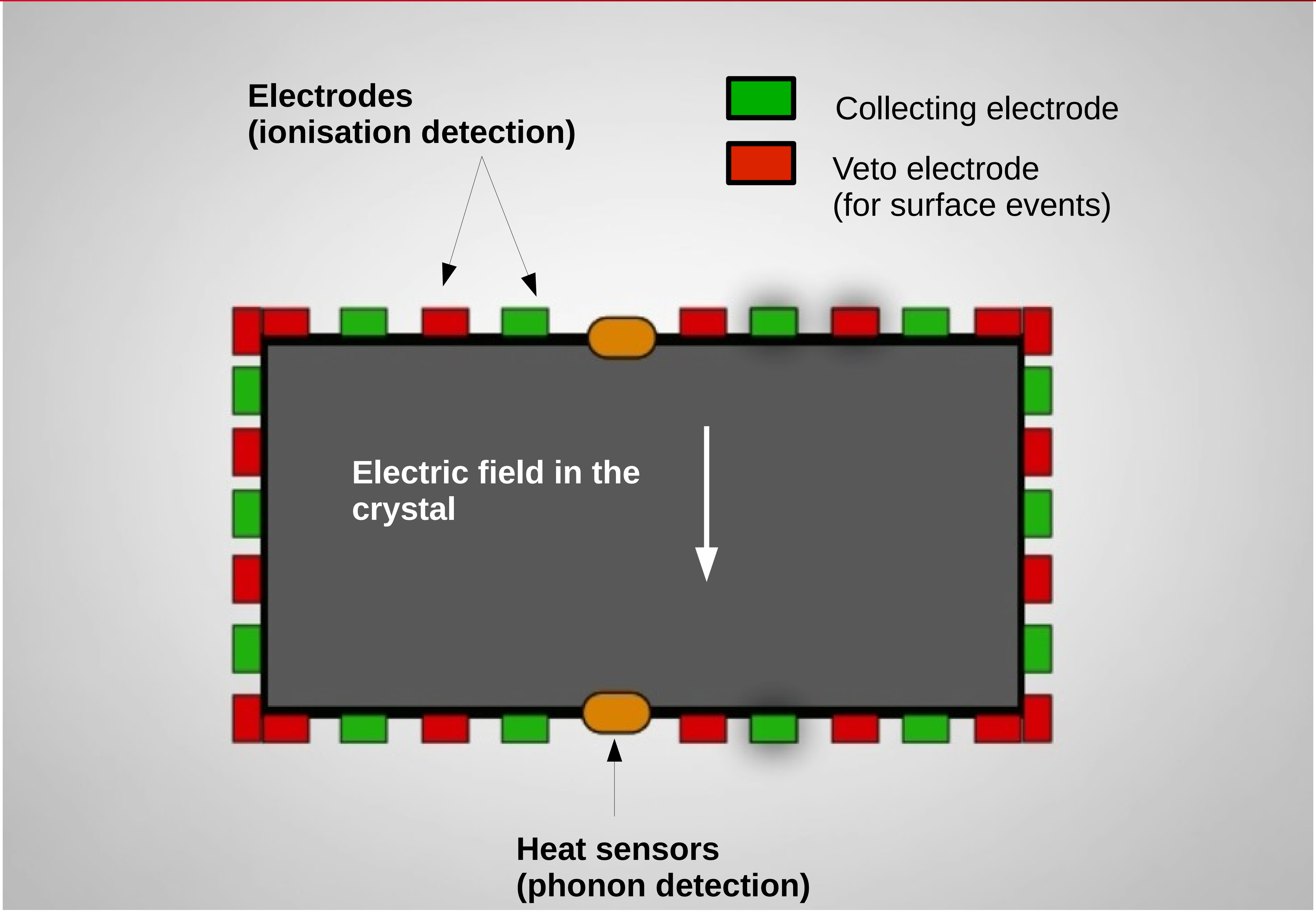
- **Combine them:**
  - Estimate the recoil energy: Erecoil
  - Derive a discriminating variable : **Q** = Eion/Erecoil

Q



Erecoil (keV)

The EDELWEISS experiment



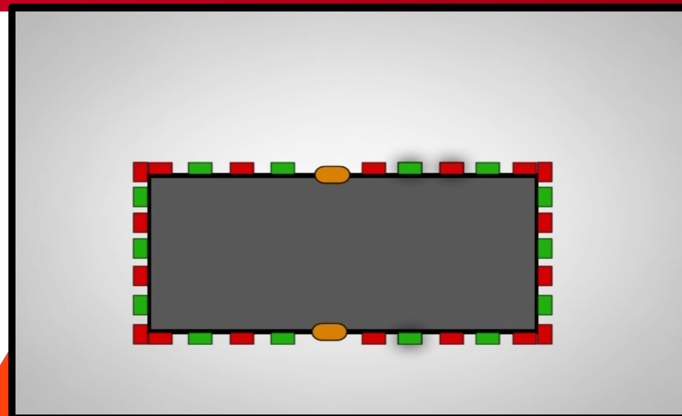
The EDELWEISS experiment

VOLUME events:
WIMPs, γ and neutrons

SURFACE events:
γ, β, Pb, α

Background analyses

Background analyses



Collecting electrode

Veto electrode
(for surface events)

Low mass WIMPs:
background rejection is
very difficult

Understanding the backgrounds is a key step of the analysis!

SIGNAL on collectrode
NO SIGNAL on Veto

This is a **VOLUME event**

SIGNAL on collectrode
SIGNAL on Veto

This is a **SURFACE event**

NO IONISATION SIGNAL

This is a **HEAT ONLY event**

Focus of my analyses

Compute
Q=Eionisation/Erecoil
to label the particle

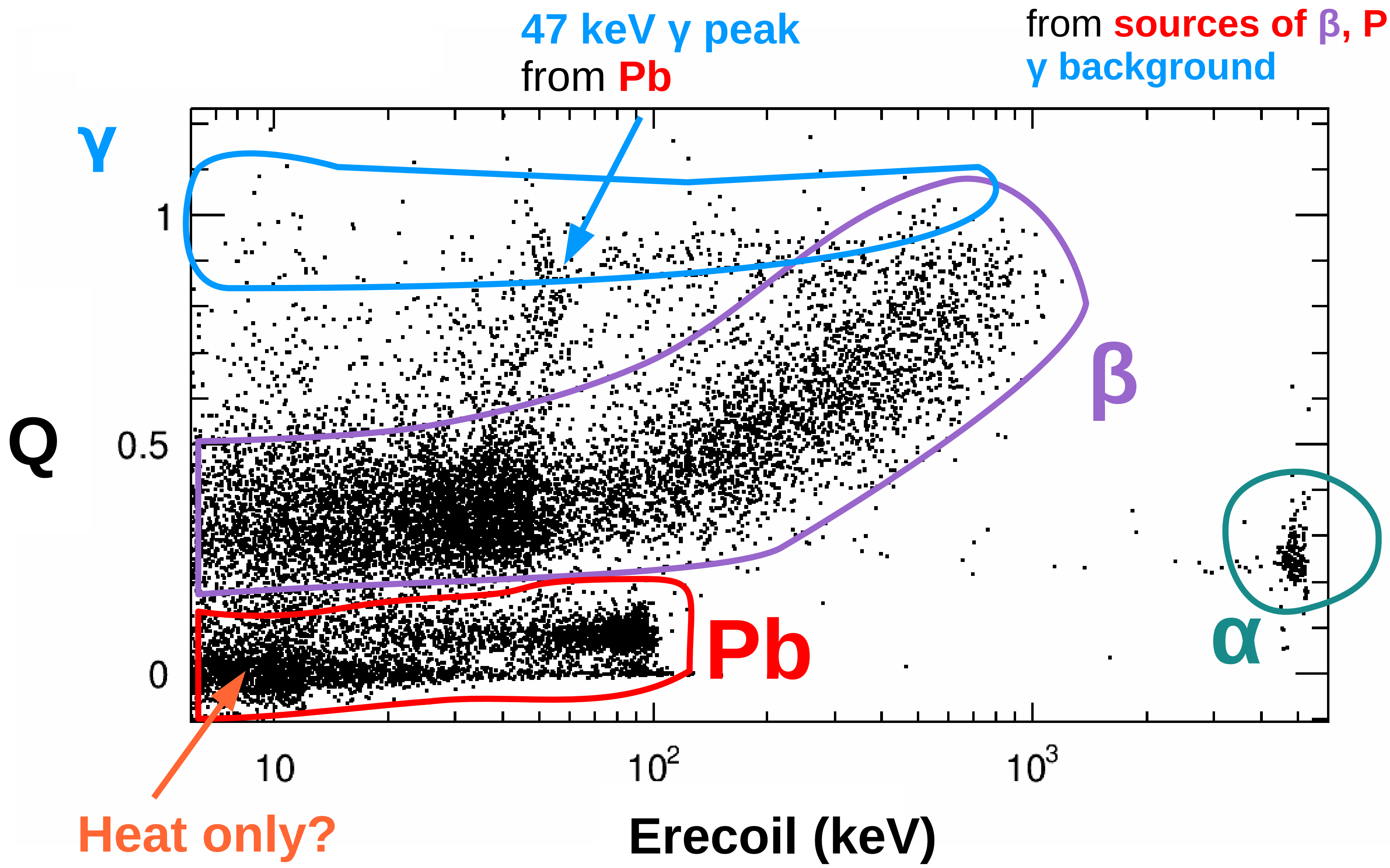
Q = 1 : γ
Q = 0.1: **Pb**
Q = 0.2: **neutrons/WIMPs**
Q = 0.4: **β**
Q = 0: **Heat-only**

Background analyses

SURFACE events

Surface Calibration data from 2013

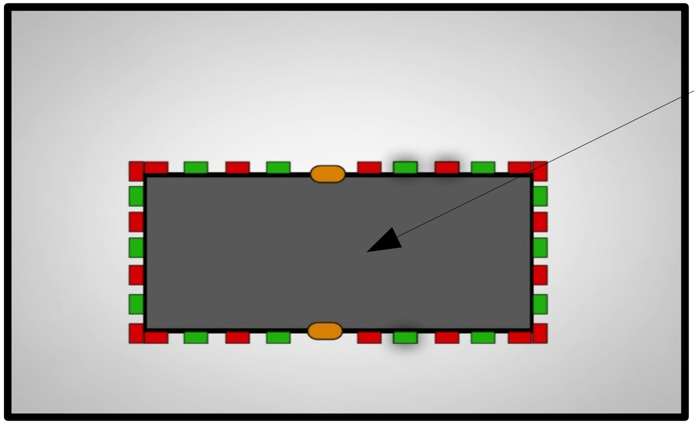
Shown here: surface events from **sources of β, Pb, α** + **γ background**



Background analyses

We can check we understand the surface events :

Recall the detector:



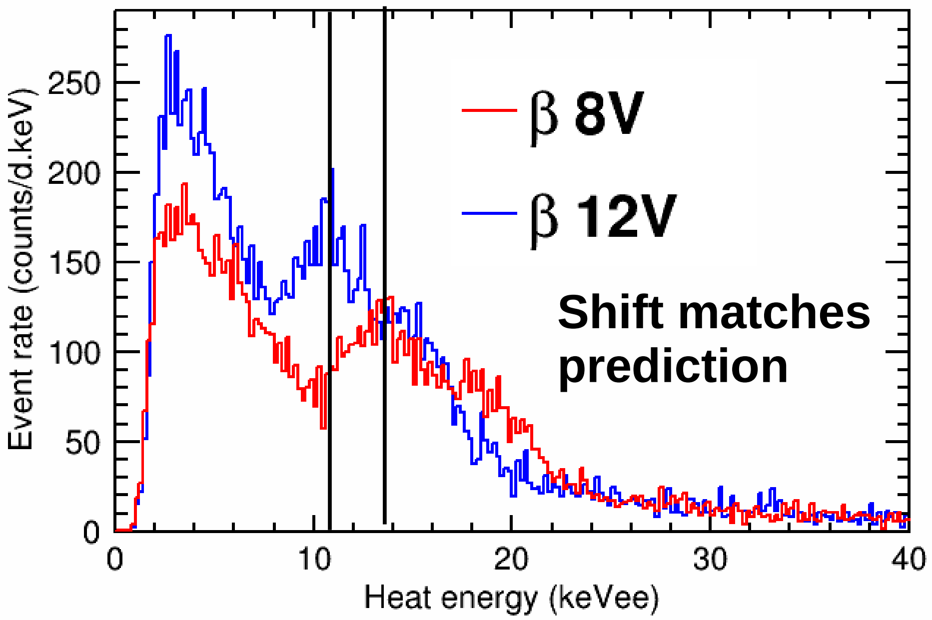
Electrons drift in the electric field of the crystal.

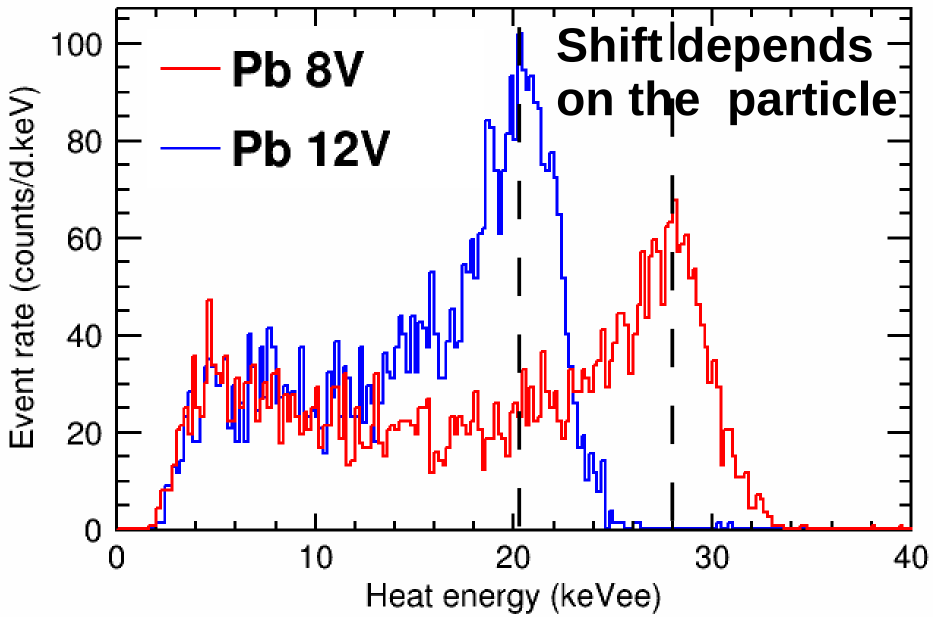
Joule effect !

The **heat energy** depends on:

- the **electric field**
- the **type of particle**

⇒ Changing the electric field **shifts the heat spectrum differently** for each particle.





Background analyses

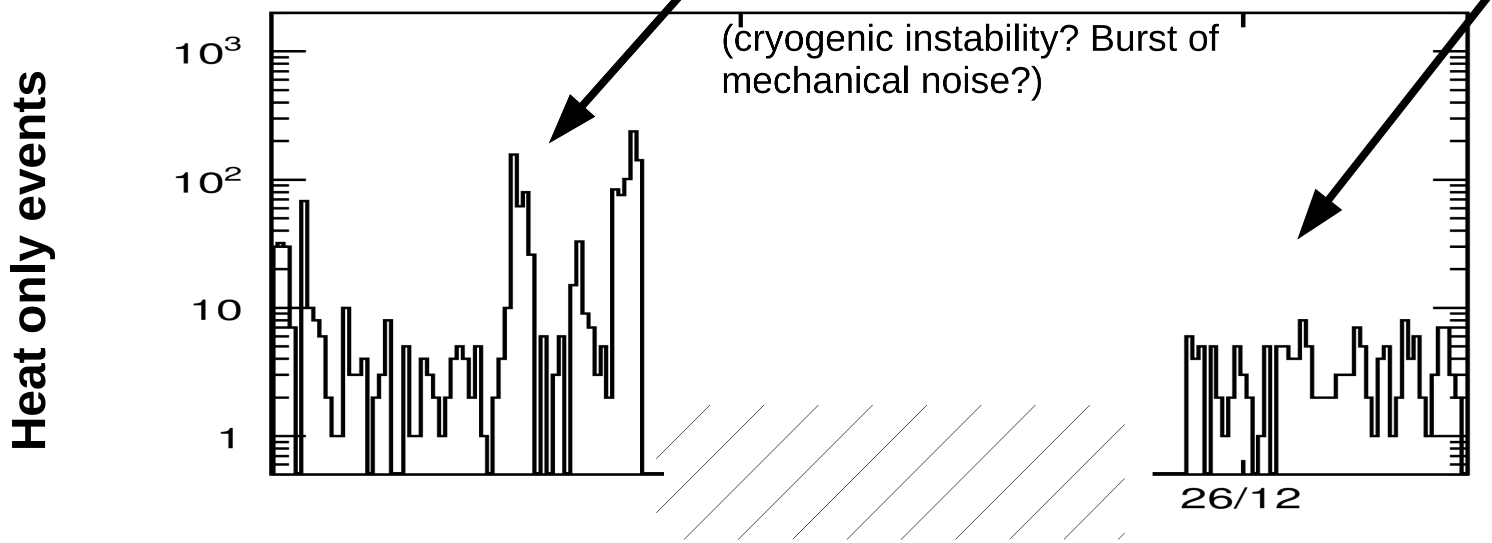
HEAT ONLY events

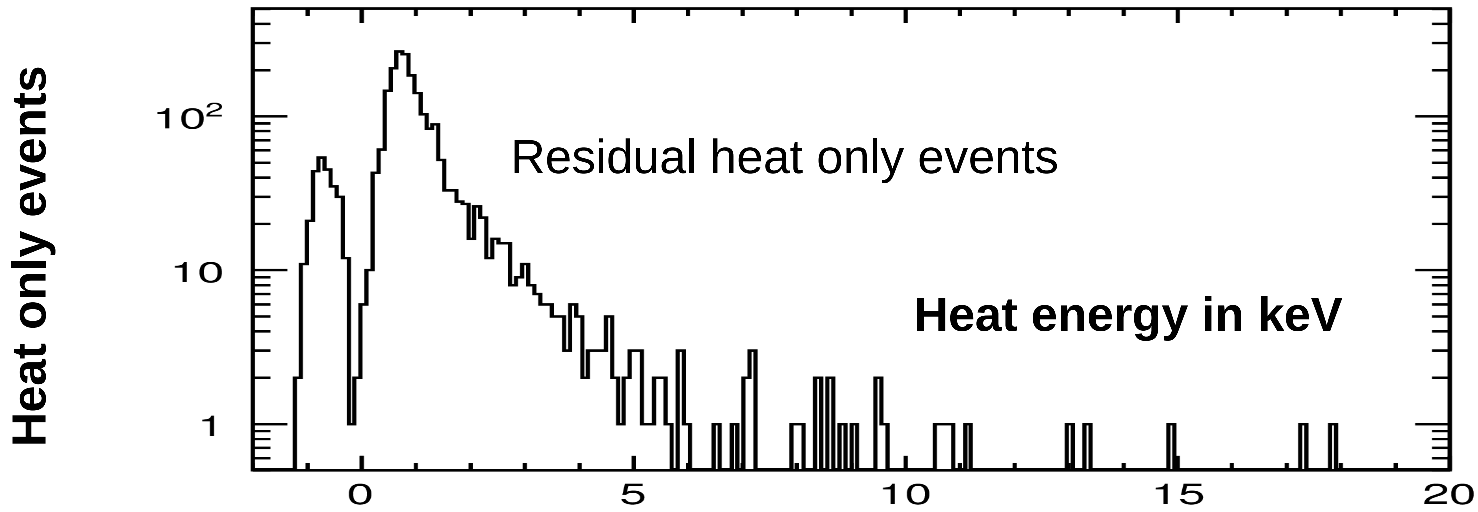
Burst of heat-only events

(cryogenic instability? Burst of mechanical noise?)

Residual heat-only events

(residual mechanical noise, residual surface events?)





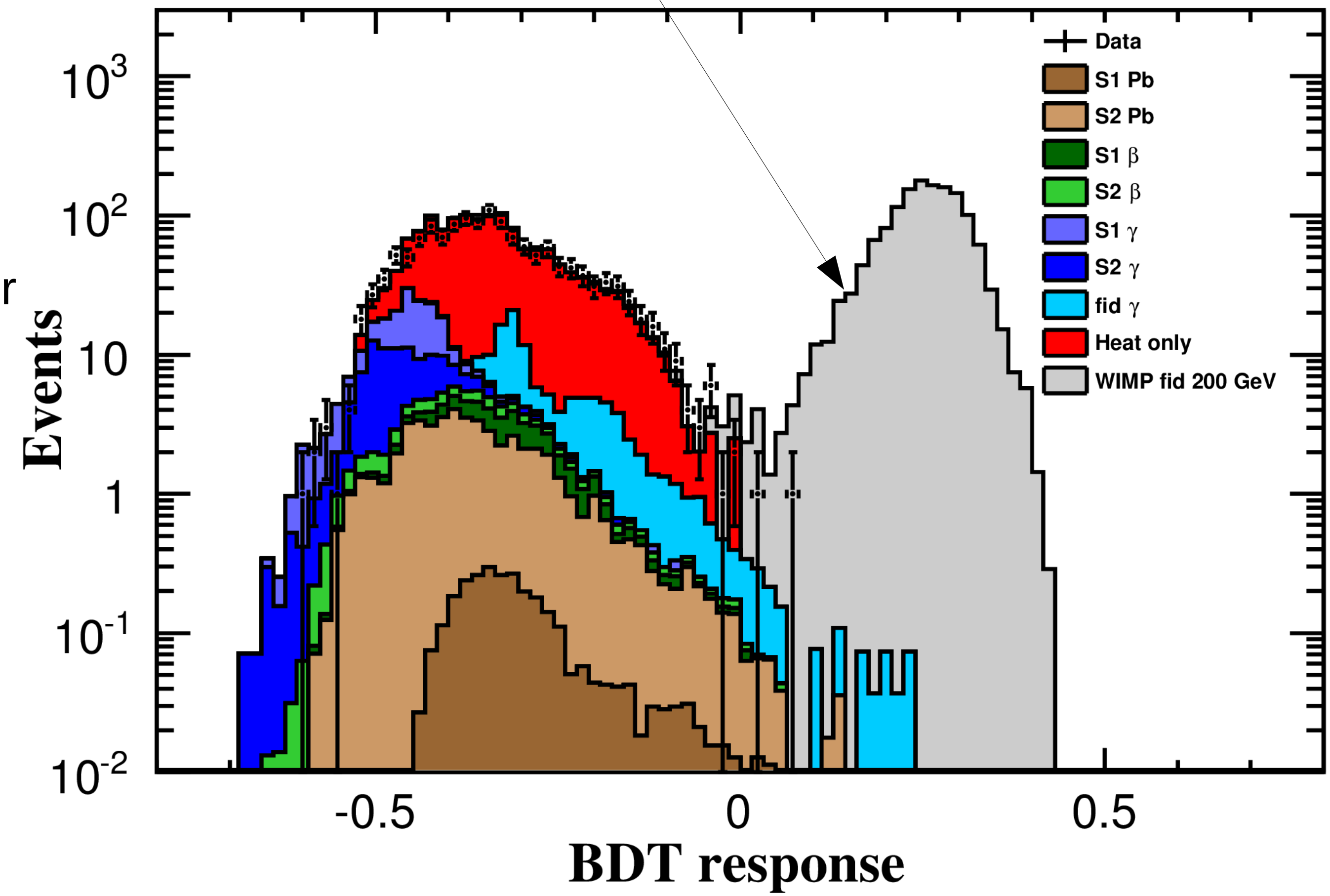
Background analyses:

Boosted trees / Neural networks

(Increasing efficiency at low energies)

Neural network / Boosted Tree

WIMP signal.
Mass: 200 GeV, **Cross section:** 10^{-2} pb, **Exposure:** 4 kg.d



High masses:

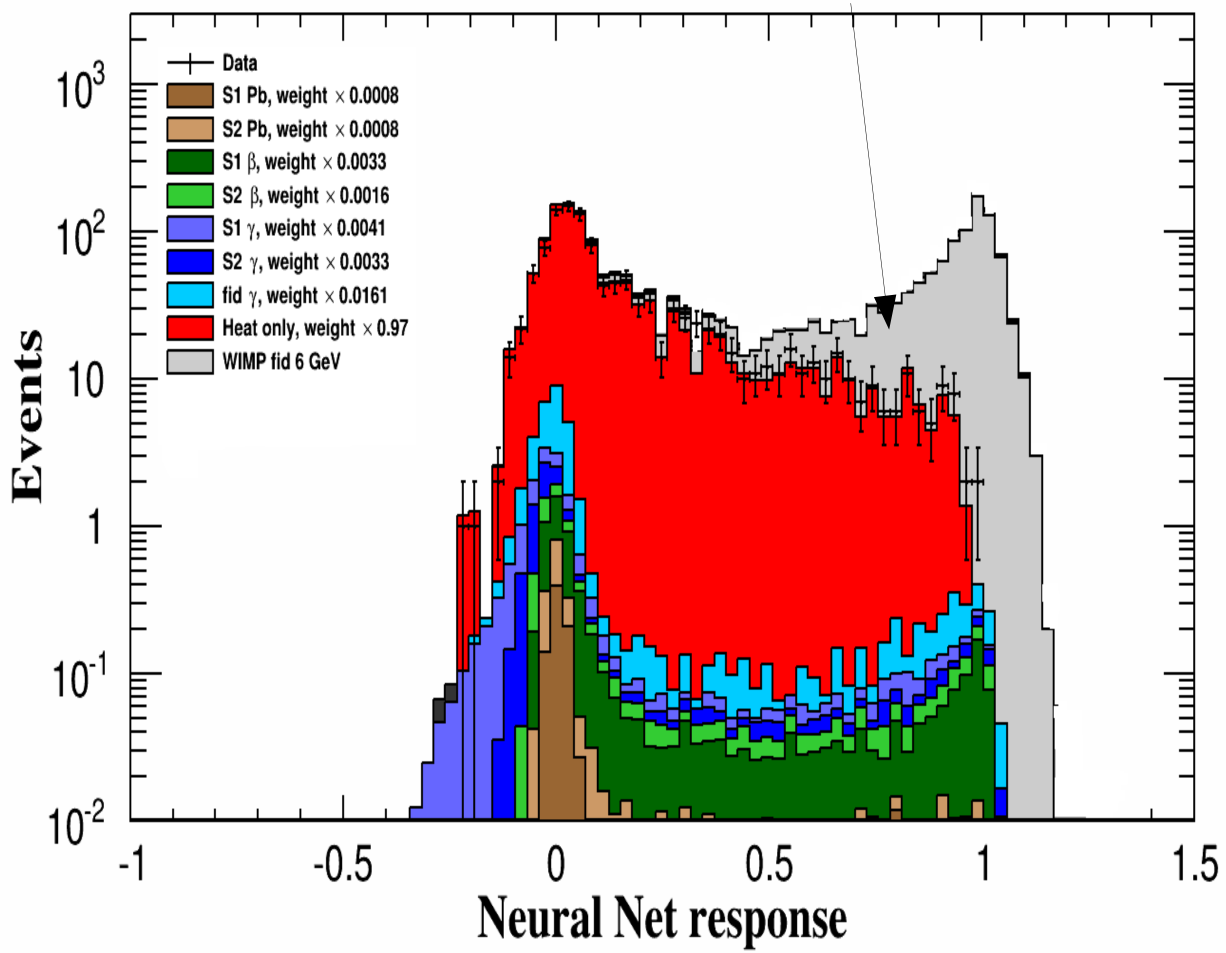
- Background are well rejected
- Small efficiency loss for perfect rejection
- Use 6 variables (4 ionisation, 2 heat)
- More variables will be added in subsequent analyses

Neural network / Boosted Tree

Low masses:

- Heat only events dominate
- Surface events are much harder to reject: efficiency loss
- Use 6 variables (4 ionisation, 2 heat)
- More variables will be added in subsequent analyses

WIMP signal.
Mass: 6 GeV, **Cross section:** 1 pb, **Exposure:** 4 kg.d



Extra sugar: axion searches

Extra sugar: axion searches

- **Axions** are elementary particles that solve the strong CP problem
- **Axions** are also a prime **Dark Matter** candidate
- **Axions** are predicted to interact with Standard Model particles, like electrons
- **EDELWEISS** bolometers are sensitive to **electronic recoils**

$$L = \left(\overline{\Theta} - \frac{\phi_A}{f_A}\right) \frac{\alpha_s}{8\pi} G^{\mu\nu a} \tilde{G}^{a}_{\mu\nu}$$

We studied **4 channels** involving:

- The axio-nucleon coupling: g_{aN}
- The axio-electron coupling: g_{ae}
- The axio-photon coupling: $g_{a\gamma}$

I used data from EDELWEISS II physics run

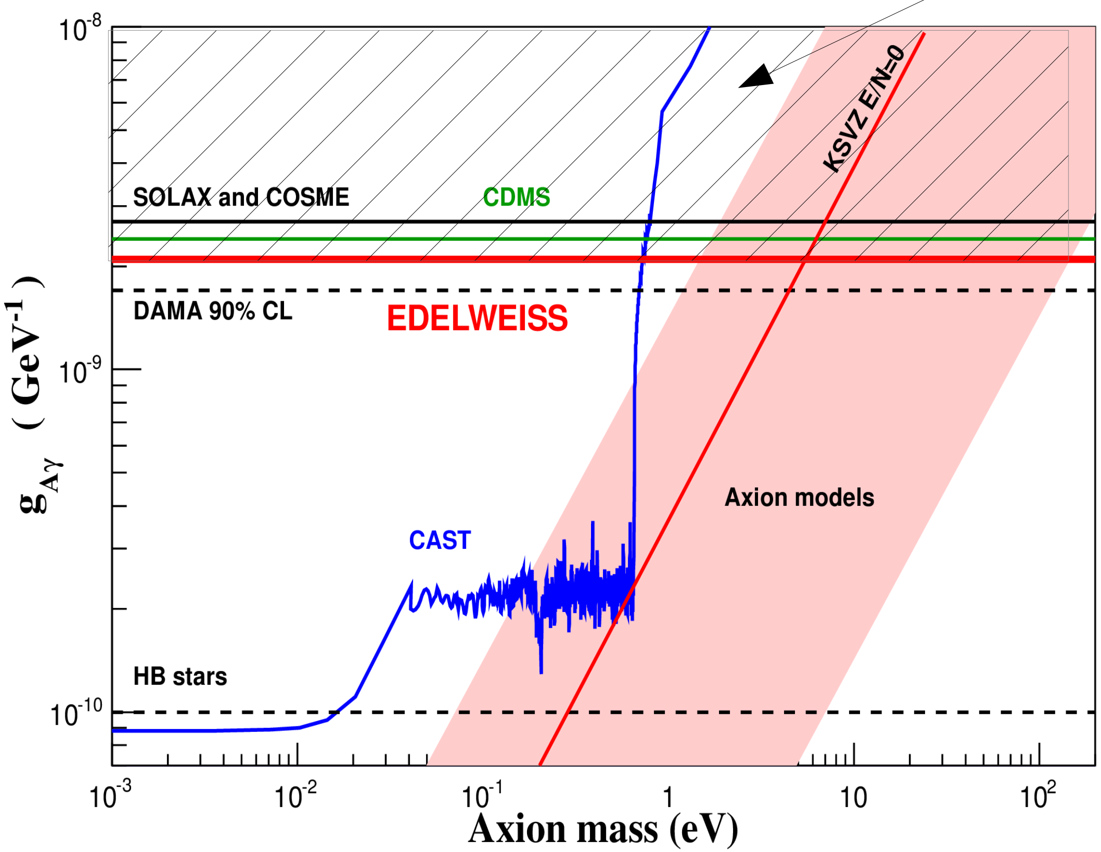
Extra sugar: axion searches

For the full paper:
JCAP 1311 (2013) 067

Results: limit on the coupling of axions to photons

$$g_{a\gamma} < 2.13 \times 10^{-9}\, GeV^{-1}$$

Hatched region excluded by EDELWEISS



We can **combine the 4 channels** and interpret this as **a constraint on the axion mass** within an axion model:

We can exclude **over 5 orders of magnitude** of the axion mass!

Conclusion

Ph.D time

- Used EDELWEISS II data to look for axions in 4 channels **JCAP 1311 (2013) 067**
- EDELWEISS II excludes DFSZ axions over 5 orders of magnitude

- Integration of the calibration procedure into a new framework
- Currently working on novel data analysis methods: multivariate analyses and pulse shape recognition
- Use Boosted Trees/Neural Networks to gain sensitivity in the critical **low-mass** region

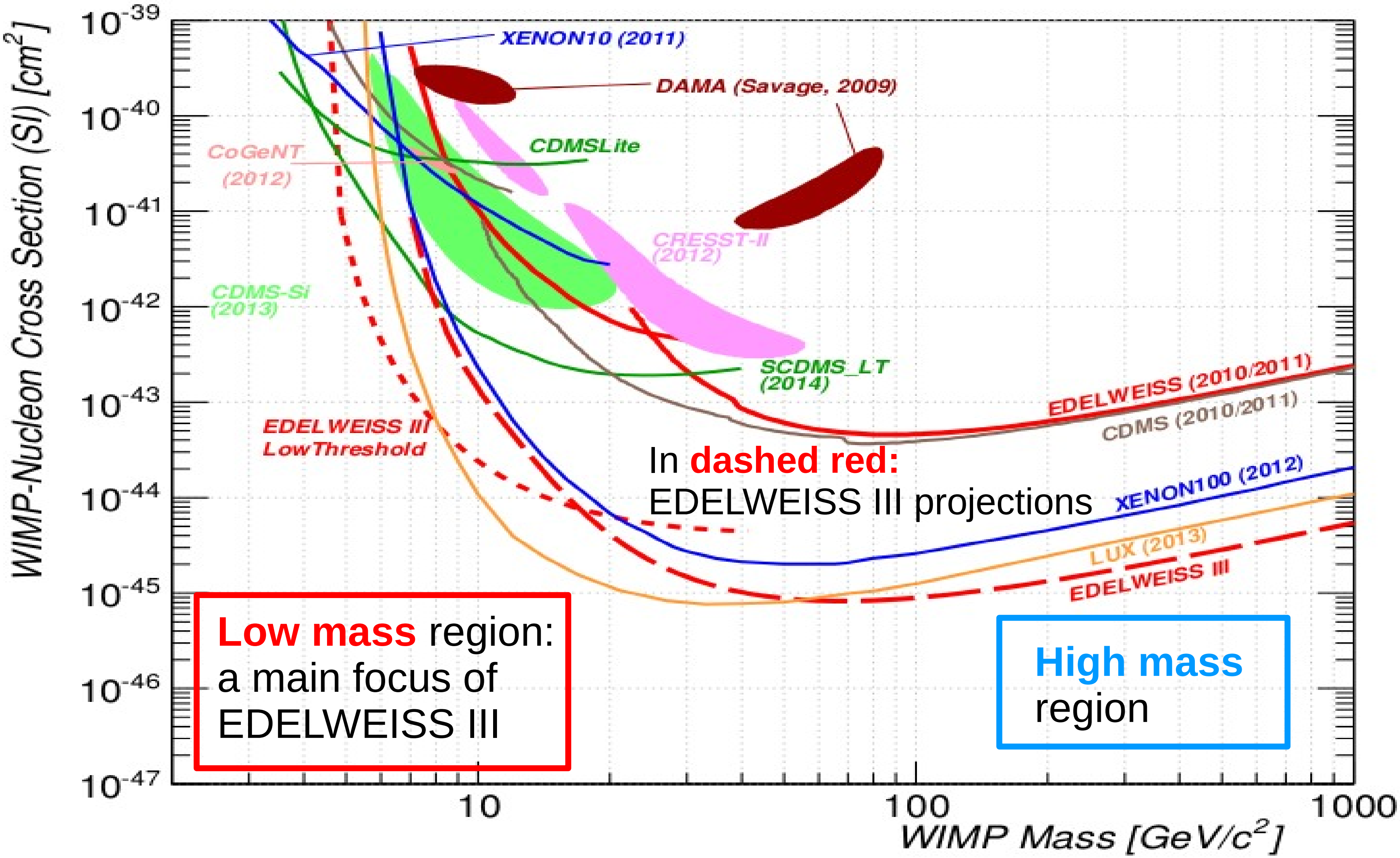
Now

Ph.D time

- New results on low mass WIMPs coming in 2015 (fingers crossed)
- Improve multivariate methods
- Dark Matter phenomenology

Backup

EDELWEISS III projections



In **dashed red:**
EDELWEISS III projections

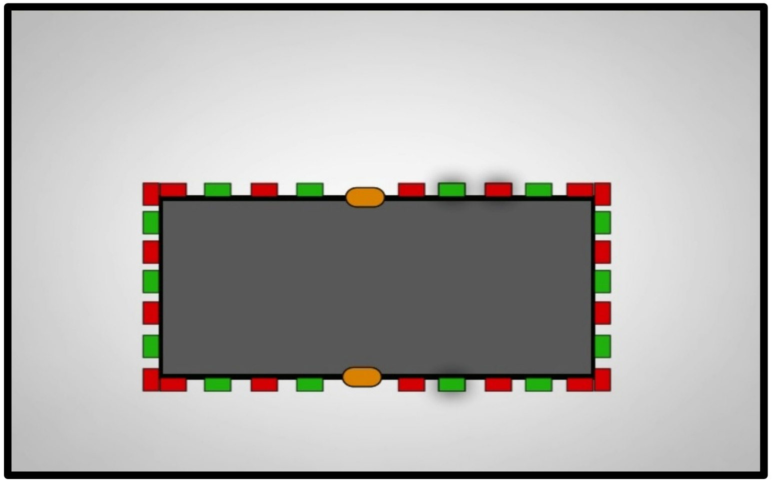
Low mass region:
a main focus of
EDELWEISS III

High mass
region

Summary: SURFACE events

Select events with:

- **SIGNAL on veto**

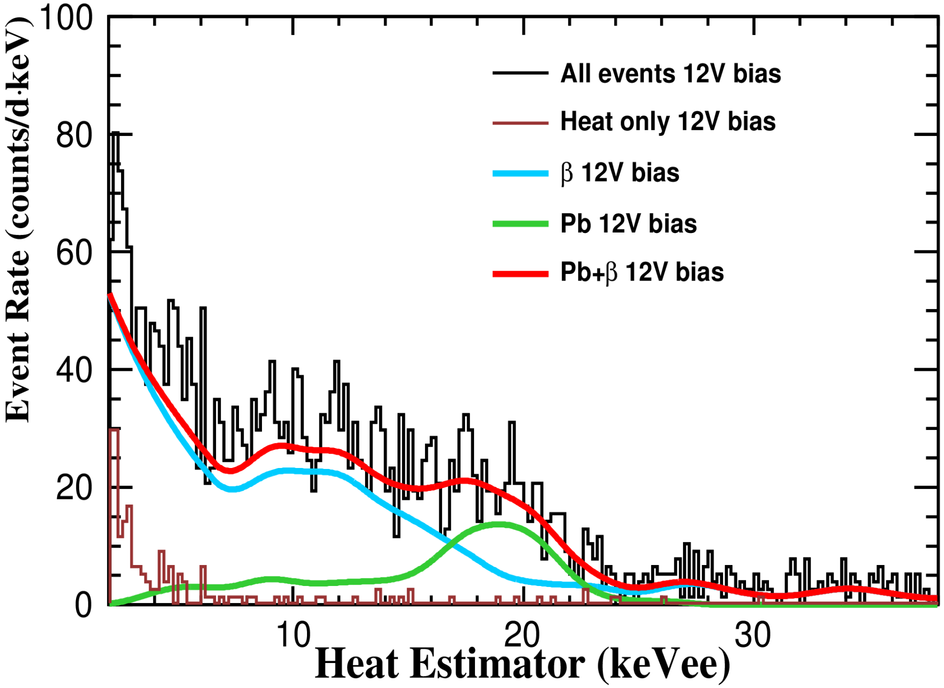


Collecting electrode

Veto electrode
(for surface events)

- Estimate the **recoil energy**
- Can look at the recoil spectrum

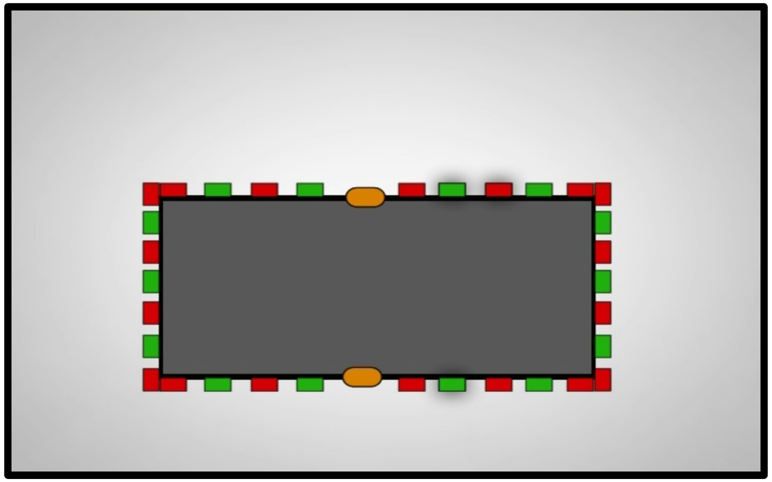
β, Pb and heat-only recoil spectrum



Background analyses

VOLUME events (γ)

Select events with:
- **NO SIGNAL on veto**
- **SIGNAL on collectrode**



Collecting electrode

Veto electrode
(for surface events)

- Estimate the **recoil energy**
- Can look at the recoil spectrum