Study and development of new detectors for the search of light dark matter with CRYOSEL

PhD days

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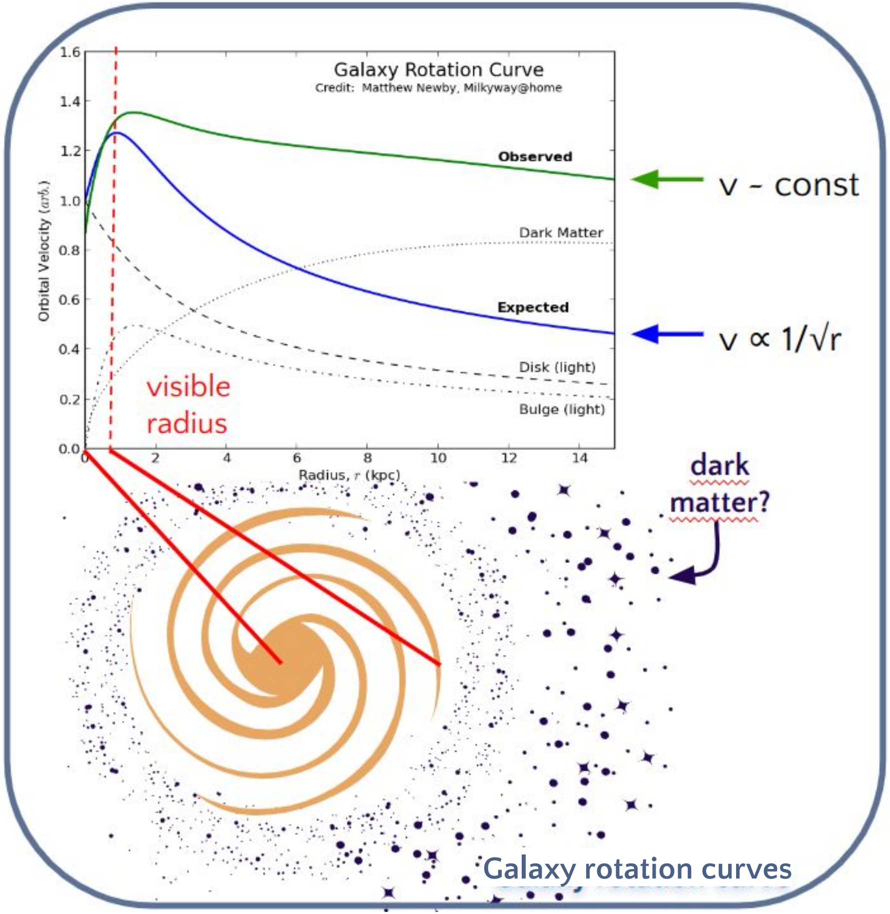
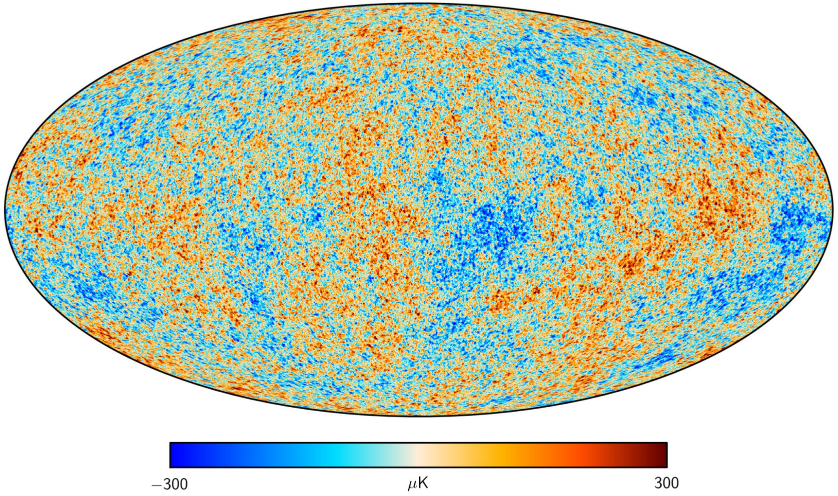
The problem of dark matter



Galaxy rotation curves



Planck, 2018

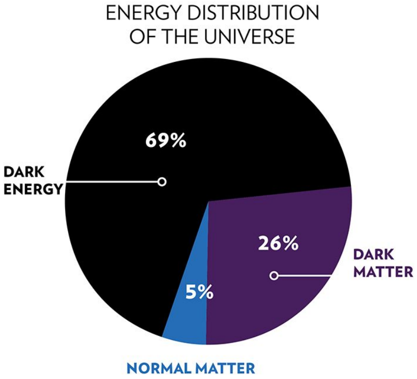
CMB measurements

Cosmological model ΛCDM

Λ → Dark energy

CDM → Cold Dark Matter

> ¼ of dark matter

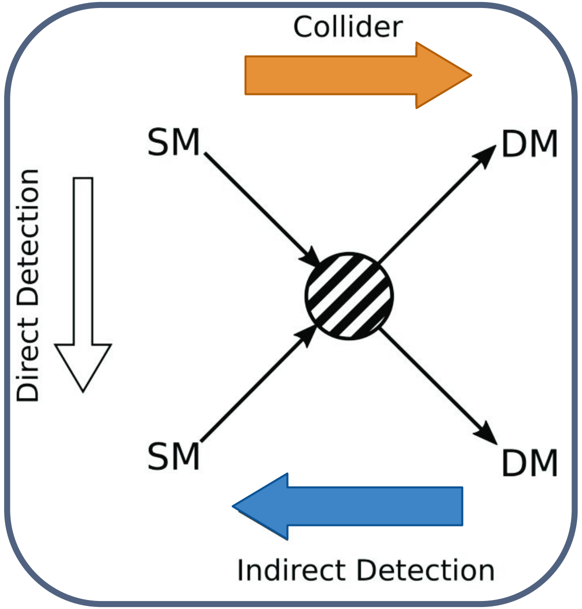


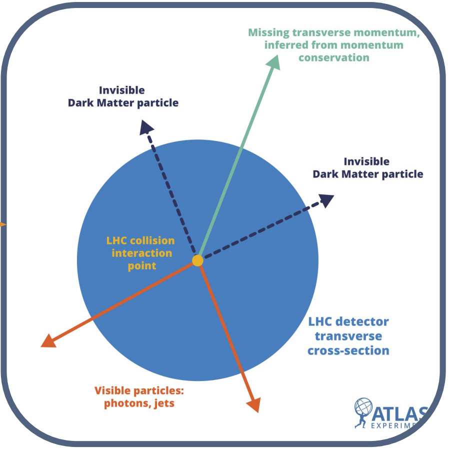
Detecting dark matter particles

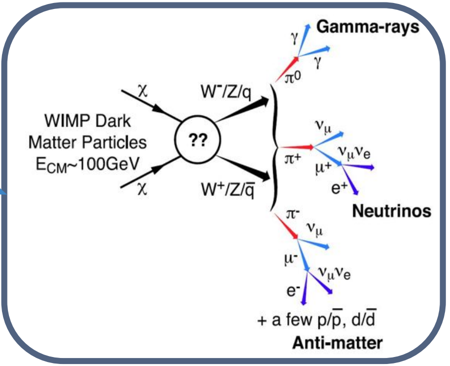
- → Production in collider
- → Indirect detection
- → Direct detection

Make it!

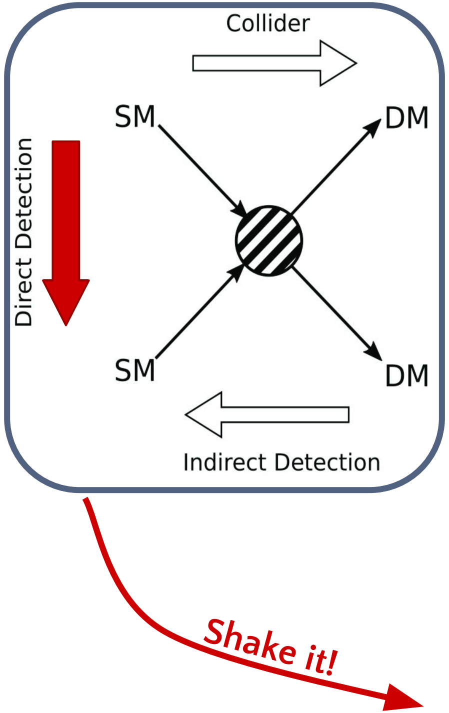
Break it!

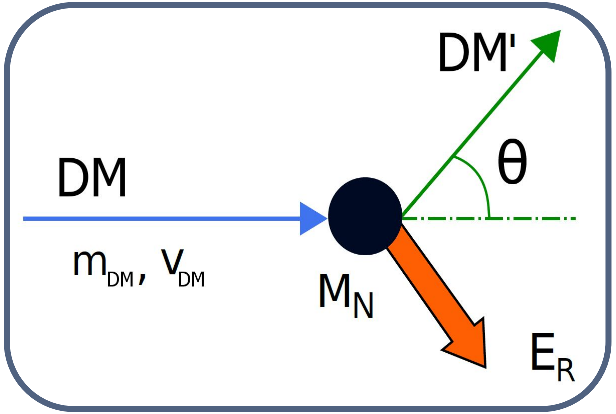


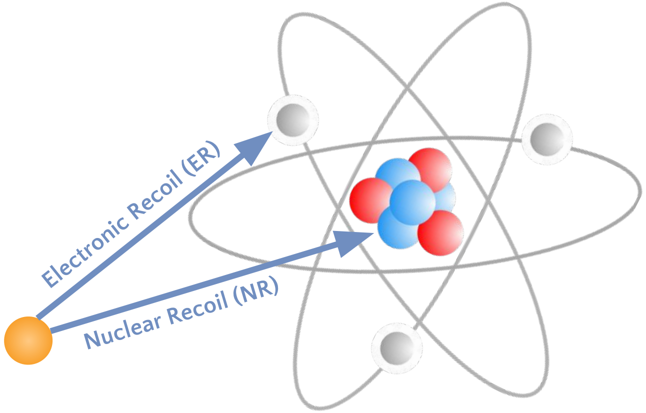




Detecting dark matter particles



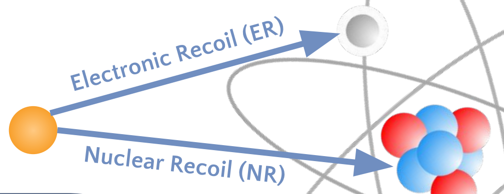


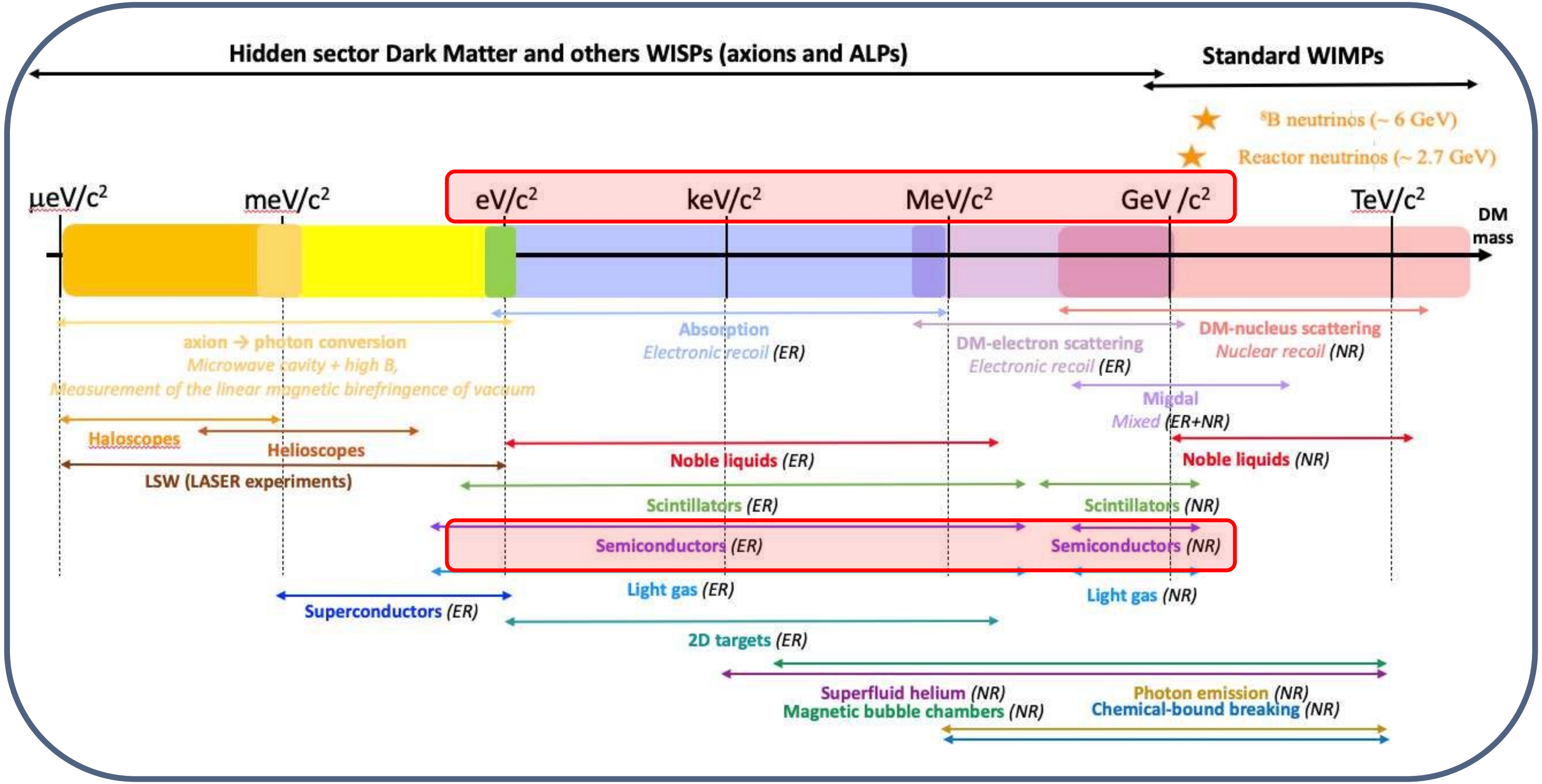


The interactions can produce:

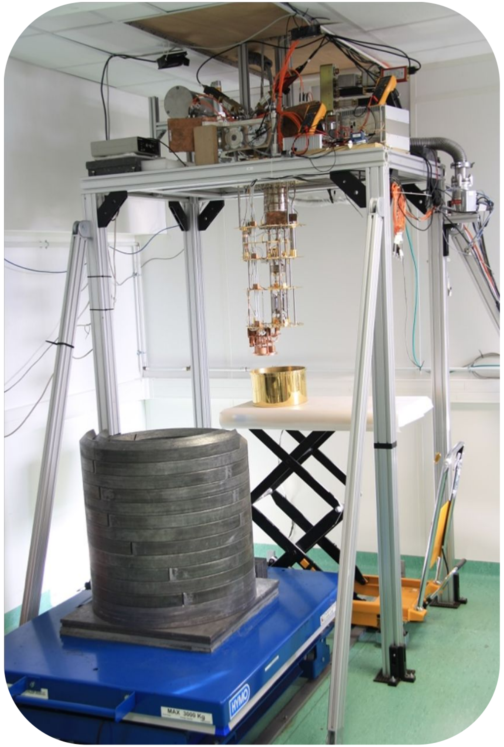
- motion → heat
- ionization → e^-/h^+ pairs
- excitation → scintillation

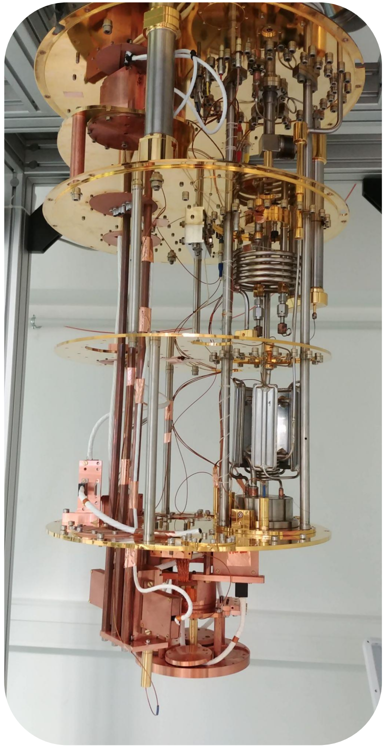
Detecting dark matter particles

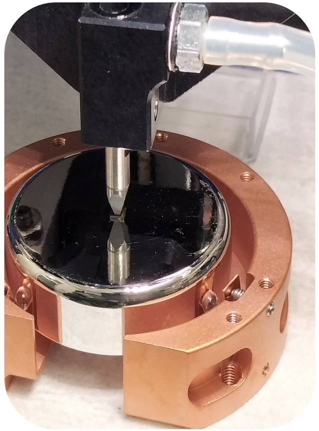


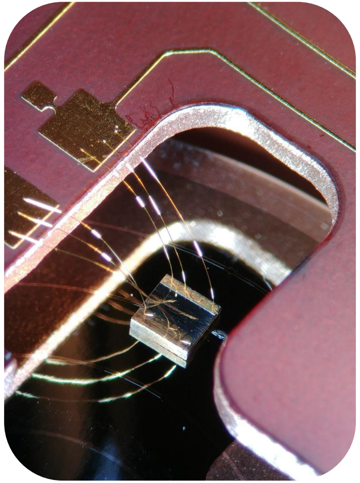


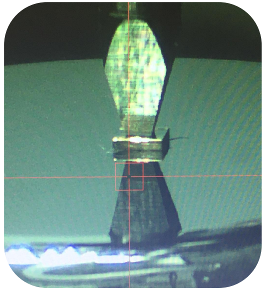
Setup at IP2I for cryogenic detectors study

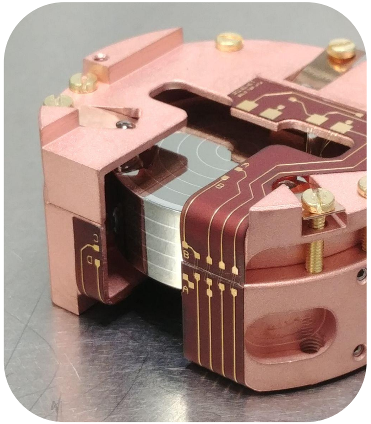












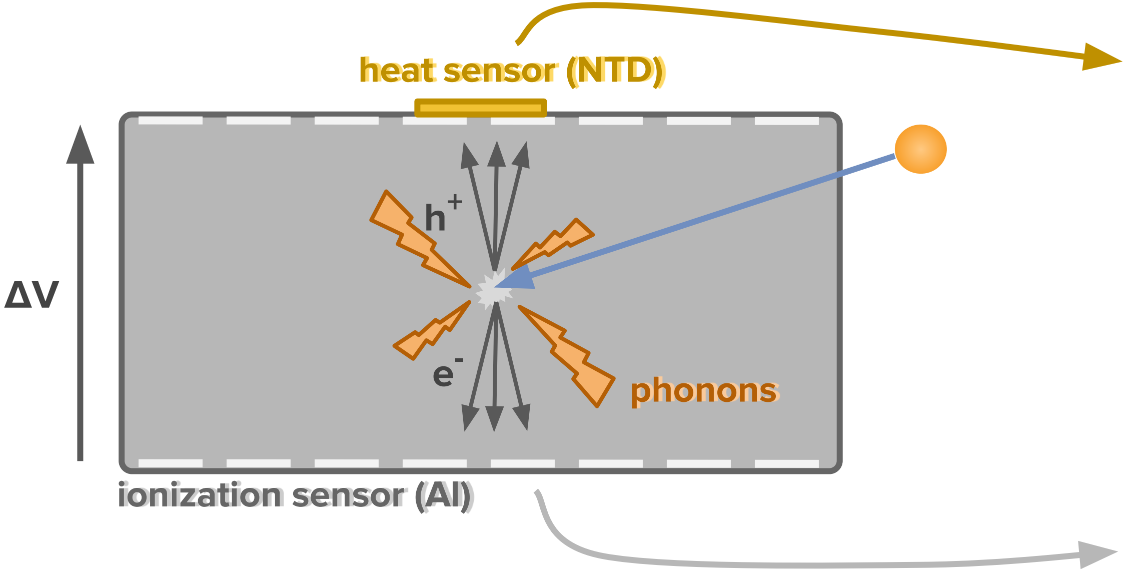
→3 m.w.e

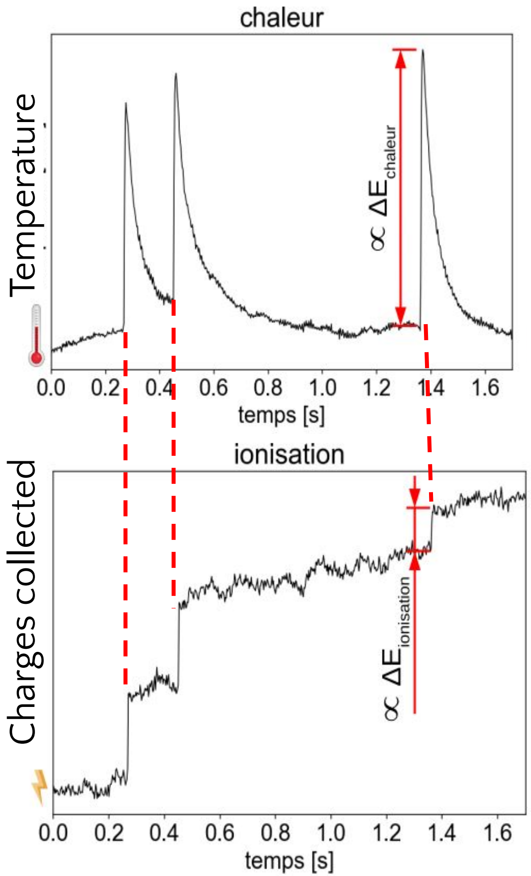
→ Lead shielding against γ

→ Operated ~ 16mK

Direct detection with EDELWEISS

→ Simultaneous measurement: **heat** & **ionization**
→ Ge semiconductor cylindrical crystals (4 → 800g)
→ Operated at cryogenic temperature ~16mK





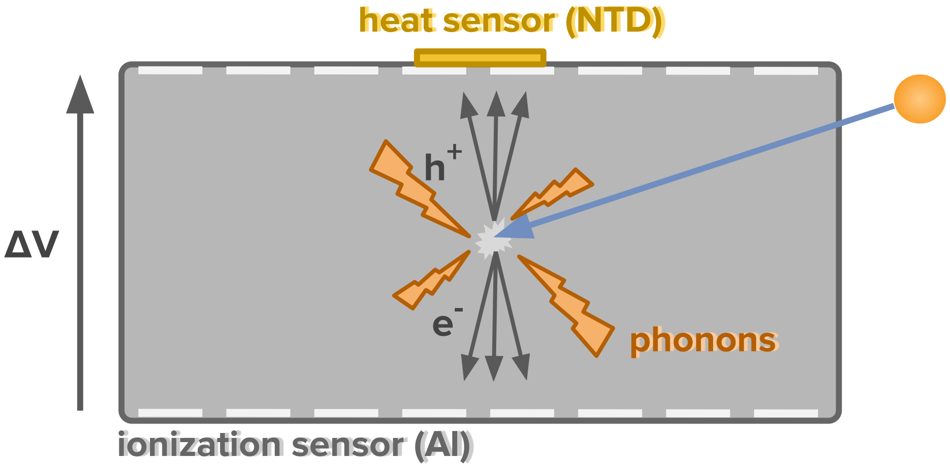
Direct detection with EDELWEISS

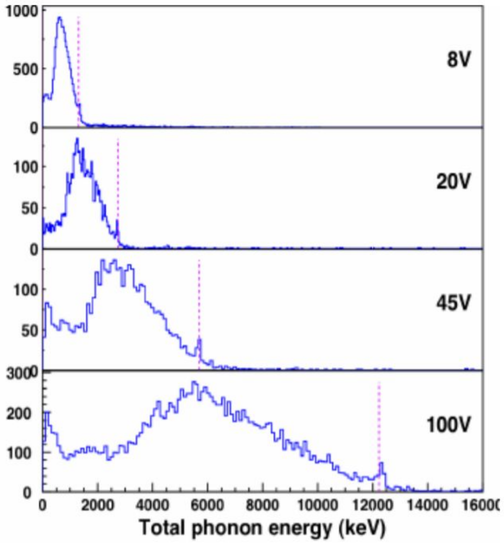
→ Simultaneous measurement: **heat** & **ionization**
→ Ge semiconductor cylindrical crystals (4 → 800g)
→ Operated at cryogenic temperature ~16mK

Luke amplification

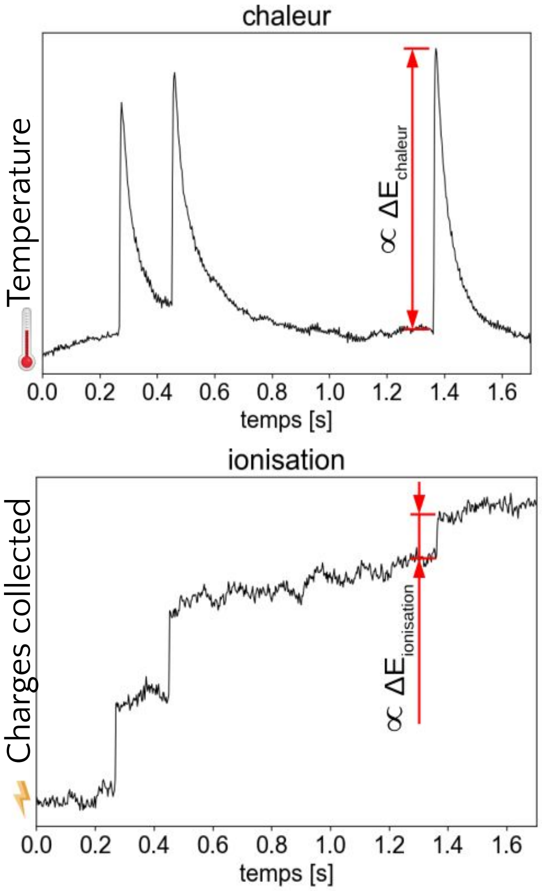
$$E_{heat} = E_{recoil} + E_{Luke} = E_{recoil} + N_p \Delta V$$

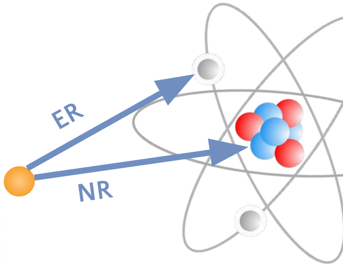
$$E_{heat} = E_{recoil}\left(1 + \frac{\Delta V}{\epsilon}\right)$$ *particle-ID dependent*

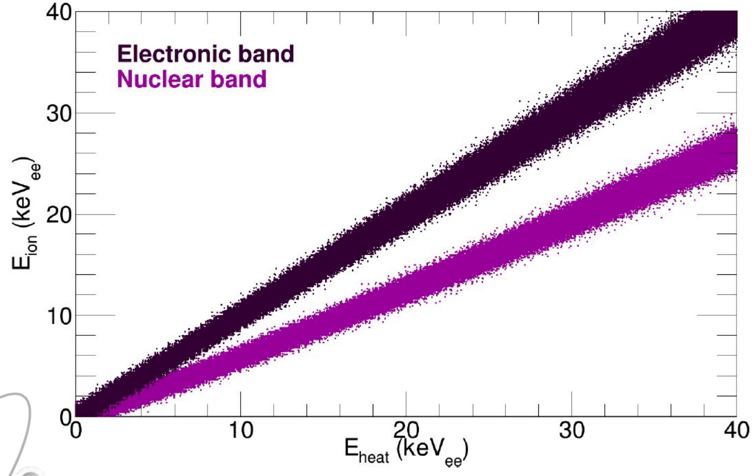


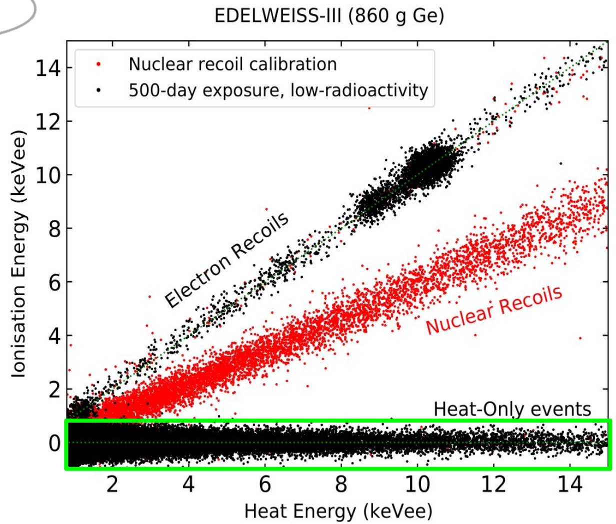


The problem of HO









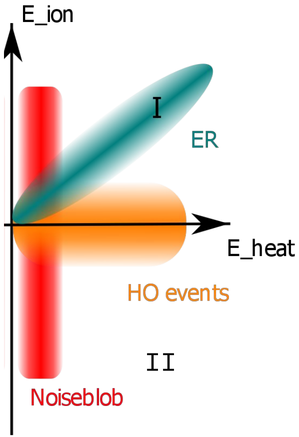
The problem of HO

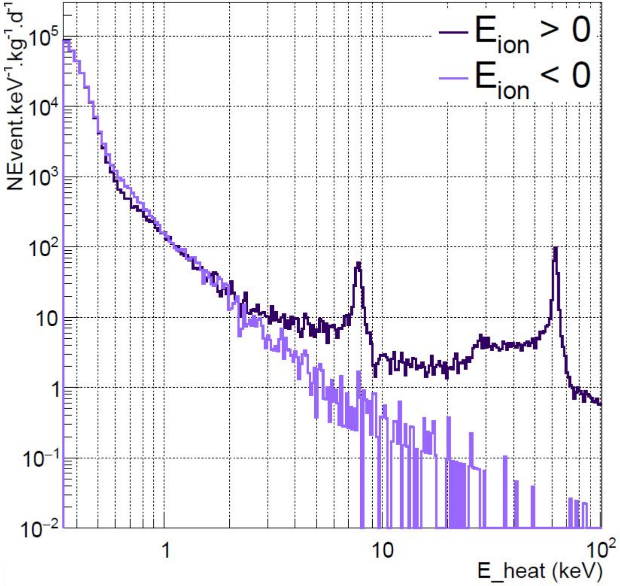
We know that,

→ no production of charges

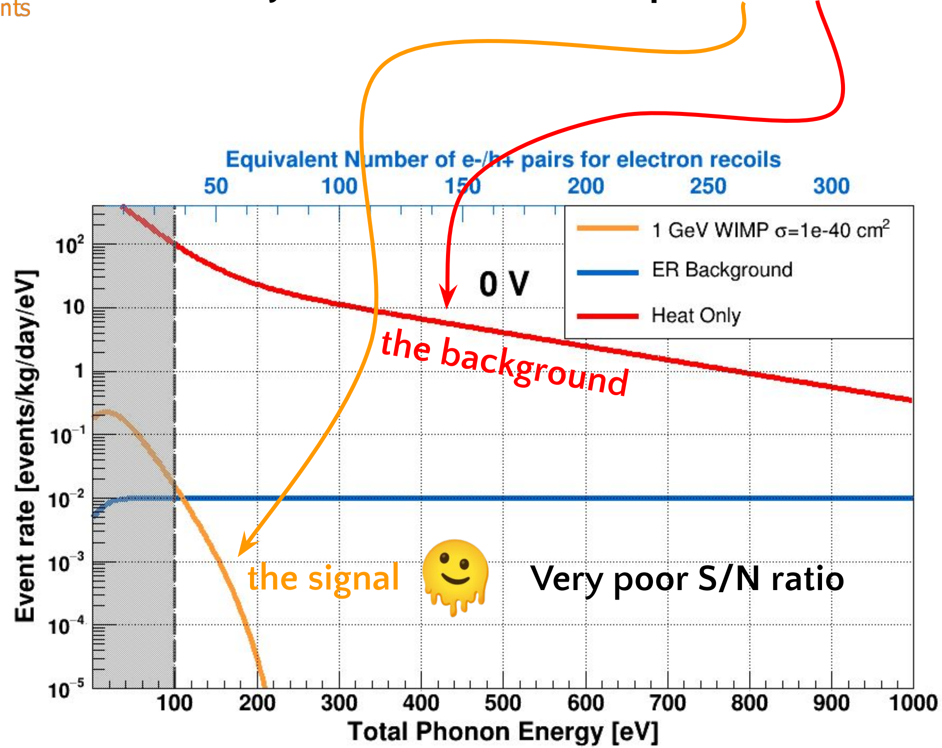
→ E_{ion} = 0 eV!

→ Isolate HO!





Why are HO events so **problematic**?



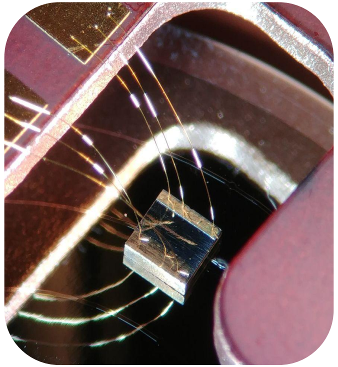
the background

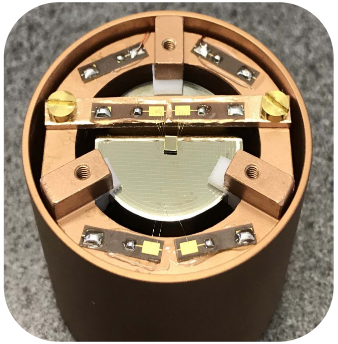
the signal

Very poor S/N ratio

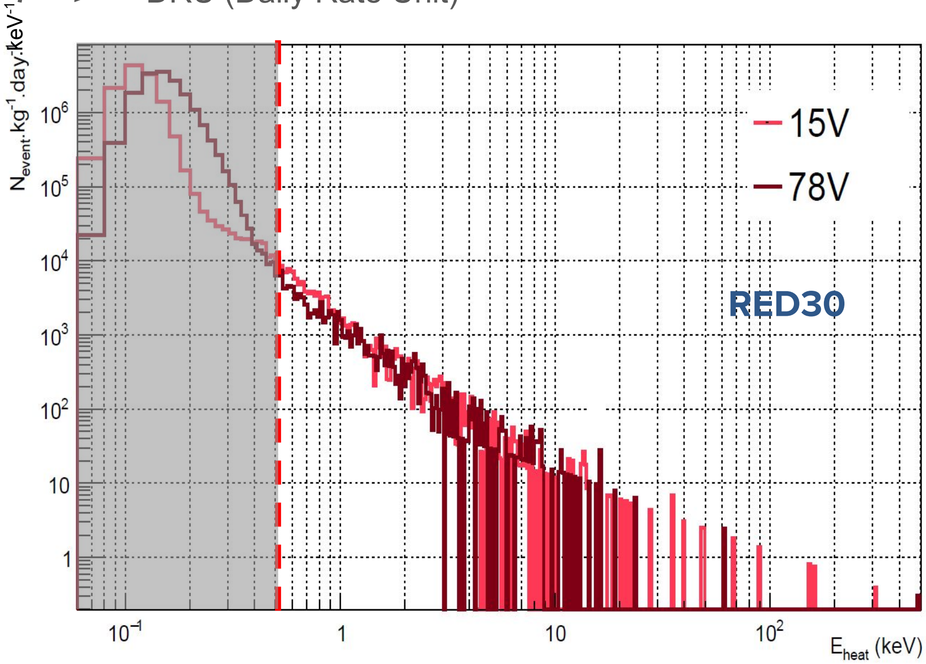
The problem of HO

We *also* know that,
→ no production of charges
→ not affected by Luke boost!





= DRU (Daily Rate Unit)



Event rate vs E_{heat} using NTD thermometer

Similar shape -> majority of events with no charges

Same behavior observed in other detectors in Lyon

Similar low energy excess observed in other cryogenic experiments → EXCESS workshop

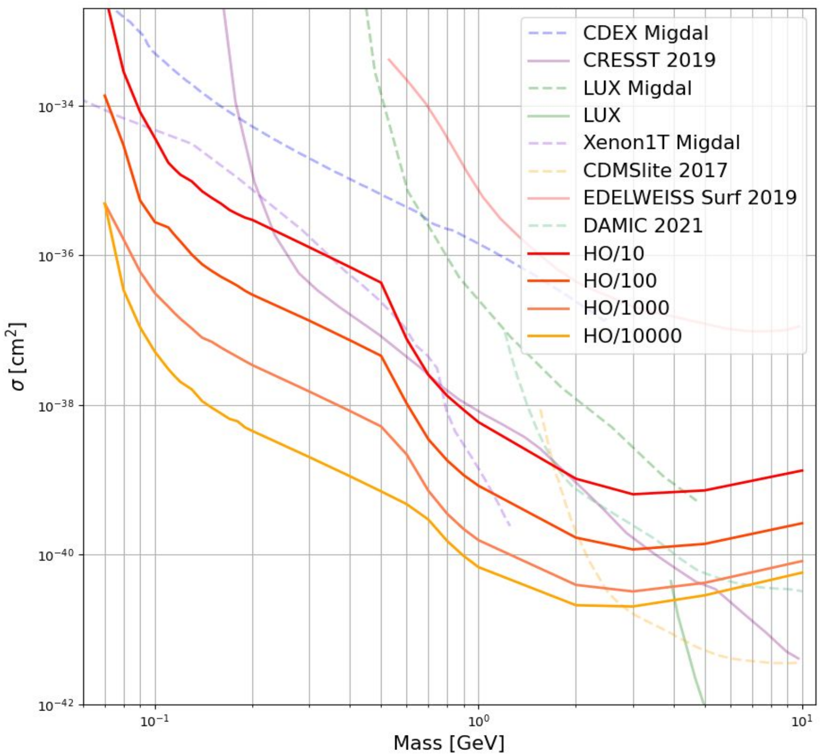
The problem of HO

→ Exclusion curve in the cross section vs. DM mass parameters space for DM particles interacting through NR

→ Projection plot of detector performance w/ various rates of HO

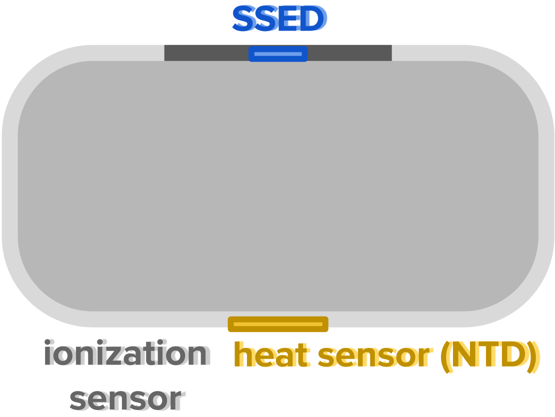
→ Working on reducing the HO background could be a real game changer!

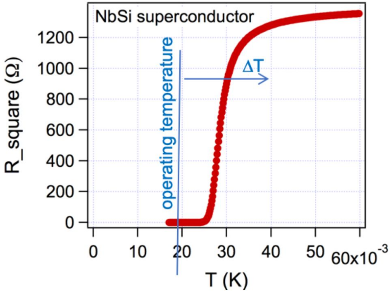
DM (NR) (1 kg.d)



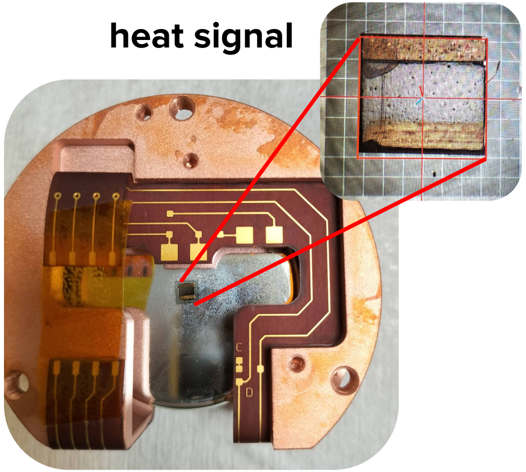
CRYOSEL design

- → Reduce HO -> tag production of charges
- → keep NTD thermistance as a reliable heat sensor
- → new sensor design: **SSED**
  “*Superconducting Single Electron Device*”
  sensitive to the production of a single e^-
- → 40g Ge detector, σ_{phonon} = 20 eV, 200 V bias,

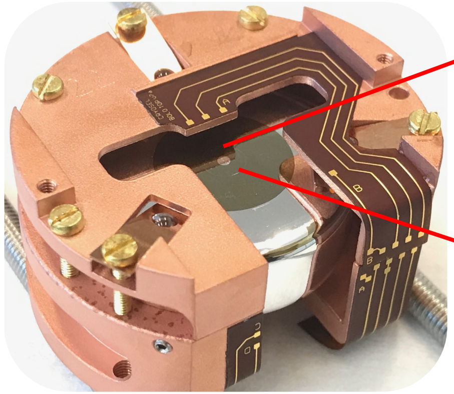




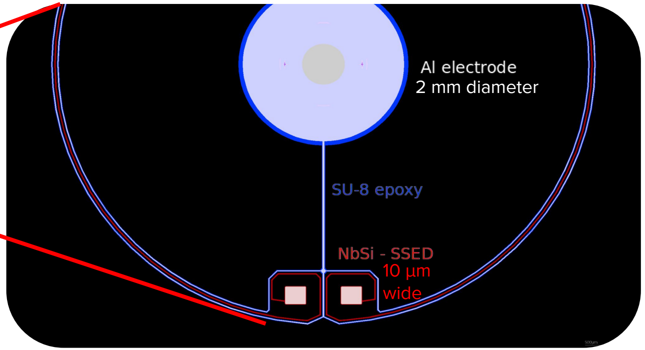
heat signal



ionization signal

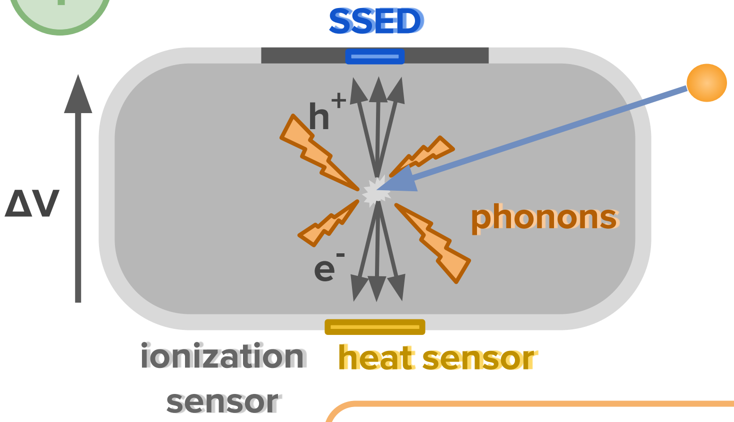


SSED signal

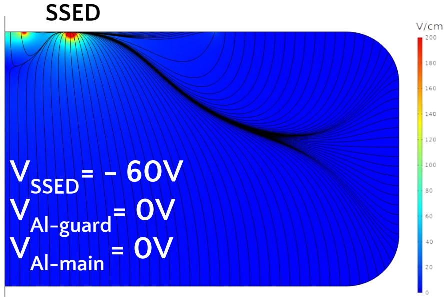


Principle of CRYOSEL

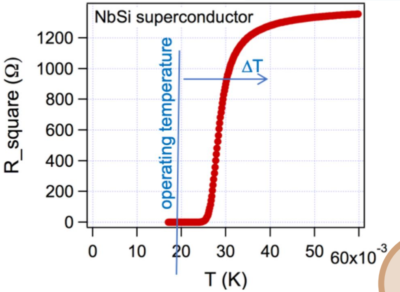
1



2

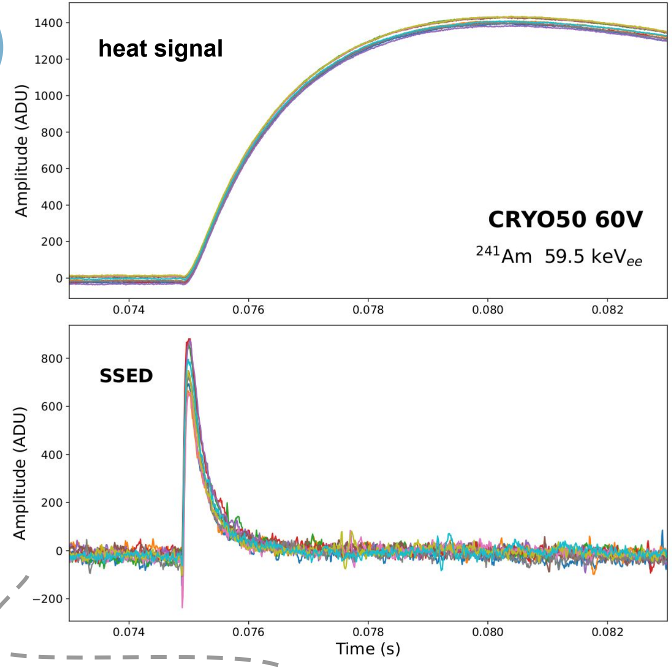


V_{SSED} = – 60V
$V_{Al\text{-}guard}$ = 0V
$V_{Al\text{-}main}$ = 0V



act as **HO veto**

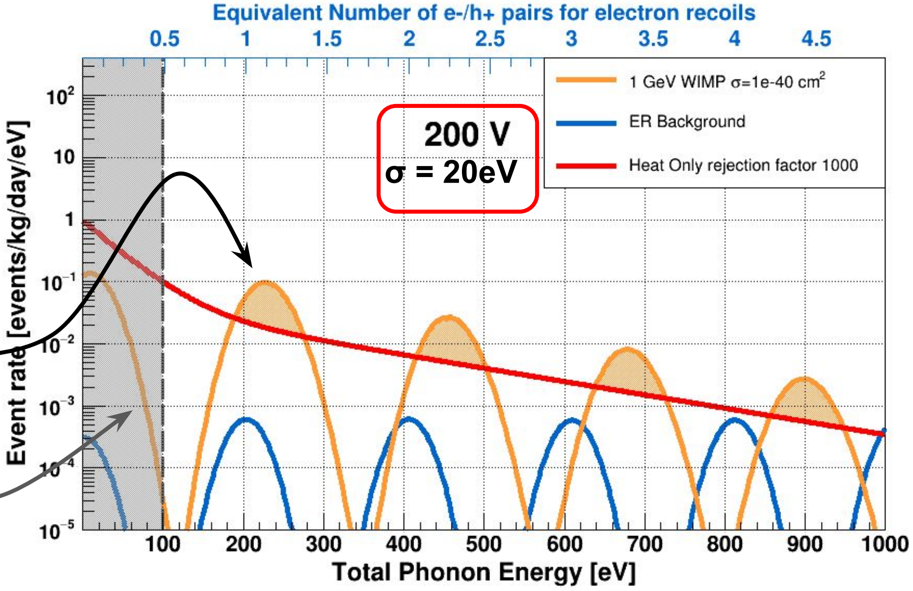
3



CRYO50, first prototype with operational SSED
→ need to **study SSED behavior**

CRYOSEL expected performance

- Mean energy to create one e^-/h^+ pair in Ge, $\epsilon \approx 3$ eV (ER)
- Use Luke boost to discretize the charges & amplify the energy deposited by single charge to energies that can be detected
- **At 200V**, E_{heat}= 3 x (1 + 200/3) = 203 eV, want σ = 20eV to be sensitive to a single e^-/h^+ pair → 5σ threshold at 100 eV
- <u>**Need:**</u> A detector that sustains **high voltage**, a **good heat resolution**, a **low SSED threshold** (single charge) for HO veto.



SSED expected behavior

- Detector that sustains high voltage:

→ For now, limited to 70V

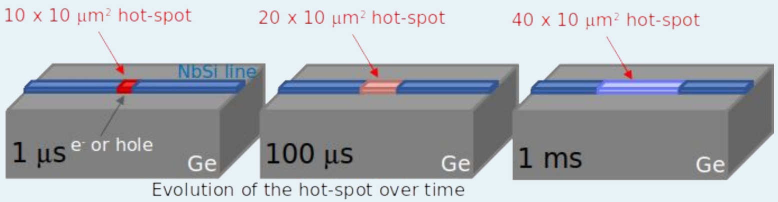
- Low threshold & good resolution:

→ SSED, new technology, needs **first demonstration** of working principle

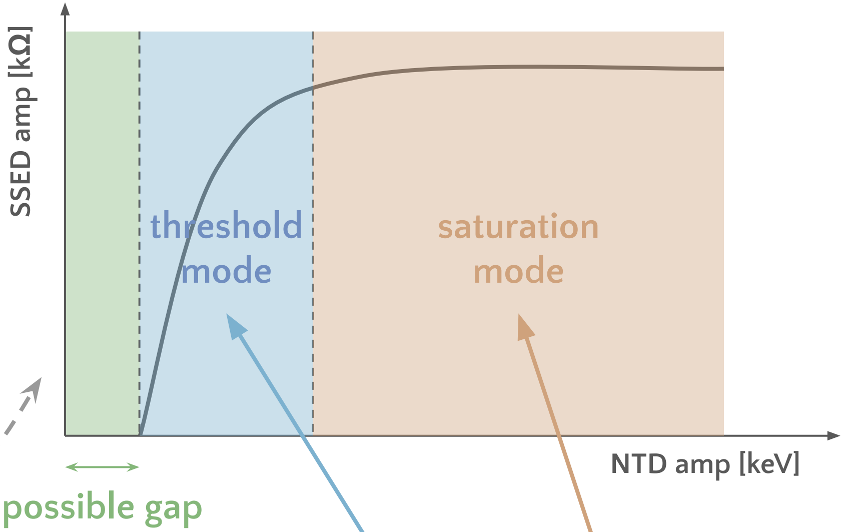
→ We already have an idea of what we expect to see:

SSED pulse amplitude in kΩ

→ $R_{SSED} \propto$ portion of NbSi film that transitions



(from S. Marnieros)



Region with R∝E?

Depending on operating temperature? Bias? Tc?

Constant R?

→ **Let's verify this behavior!**

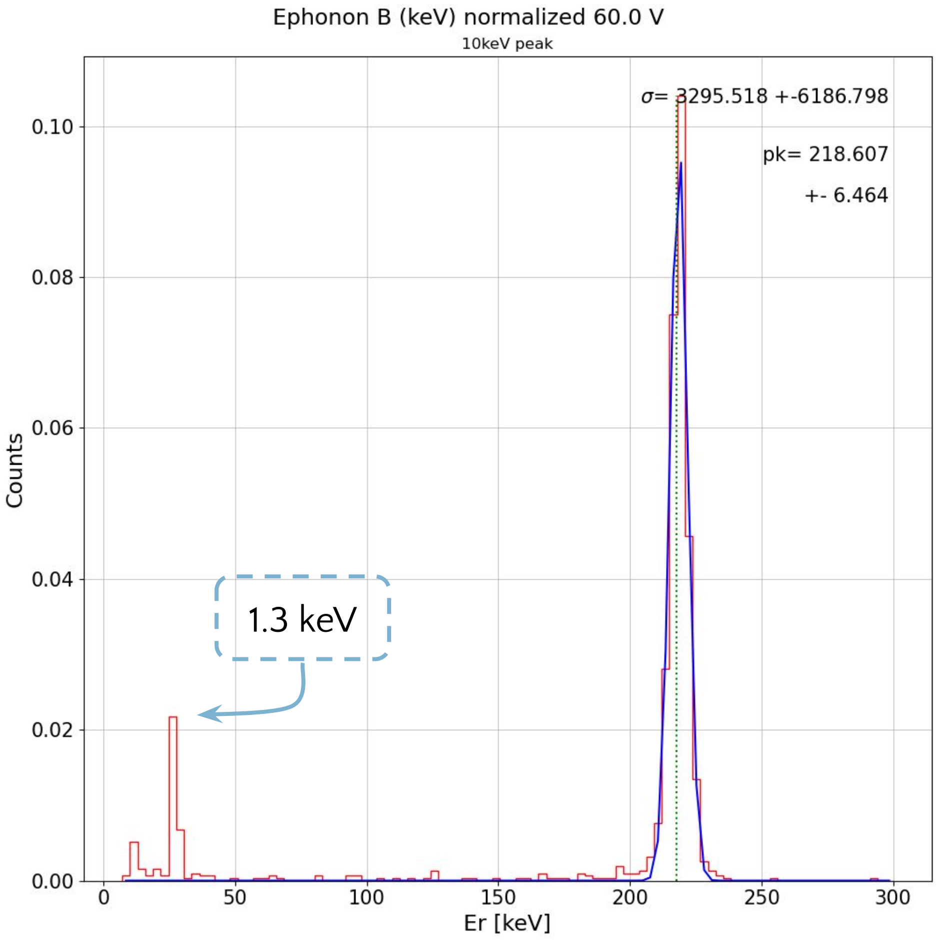
Heat pulse amplitude VS bias

1st step, the heat :

- To populate the plot we need characteristic peaks at known energy : 10.37 keV calibration peak from AmBe source
- Fit of the mean amplitude peak at various biases
- Thermistance, measures heat signal as a variation of resistance, known behavior, linear dependence of heat pulse amplitude wrt bias

$$E_{heat} = E_{recoil} \times (1 + \Delta V/3) \propto \Delta R_{NTD}$$

- What about the SSED ?



1.3 keV

SSED pulse amplitude (for 10.37 keV events) VS bias

2nd step, the SSED :

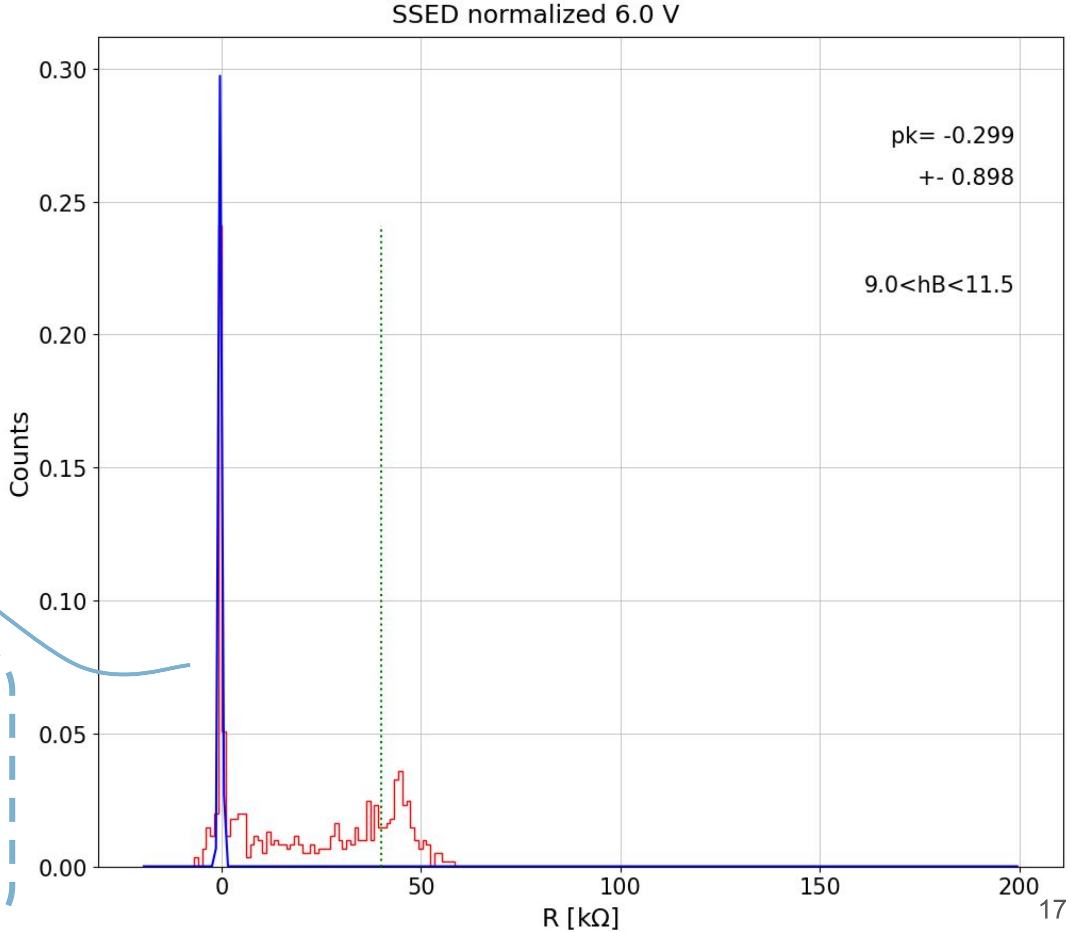
- NbSi line, measures heat signal as a variation of resistance,

  $\Delta R_{NTD} \propto$?

- How does the SSED behave wrt the deposited energy ?

- We consider a 5σ threshold for the SSED (~ 5 x 0.250 = **1.250 kΩ**)

SSED amplitudes spread over a wide range of values → not as easy as for the NTD… Not all events lead to a transition of the NbSi line.
→ compute **mean SSED amplitude**

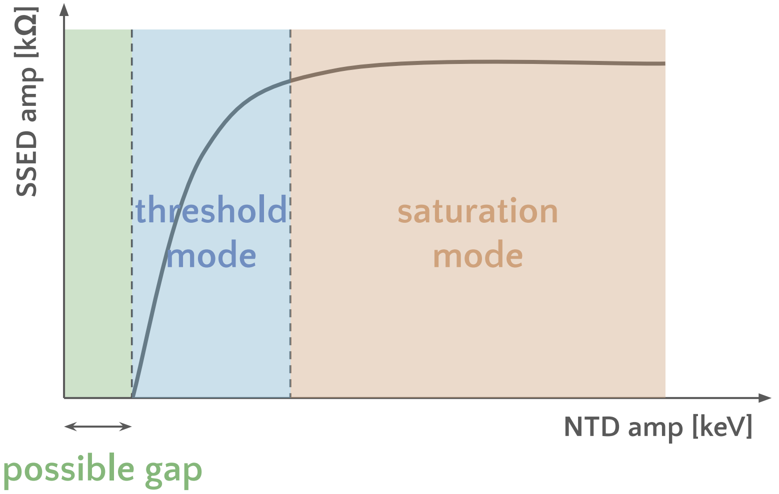


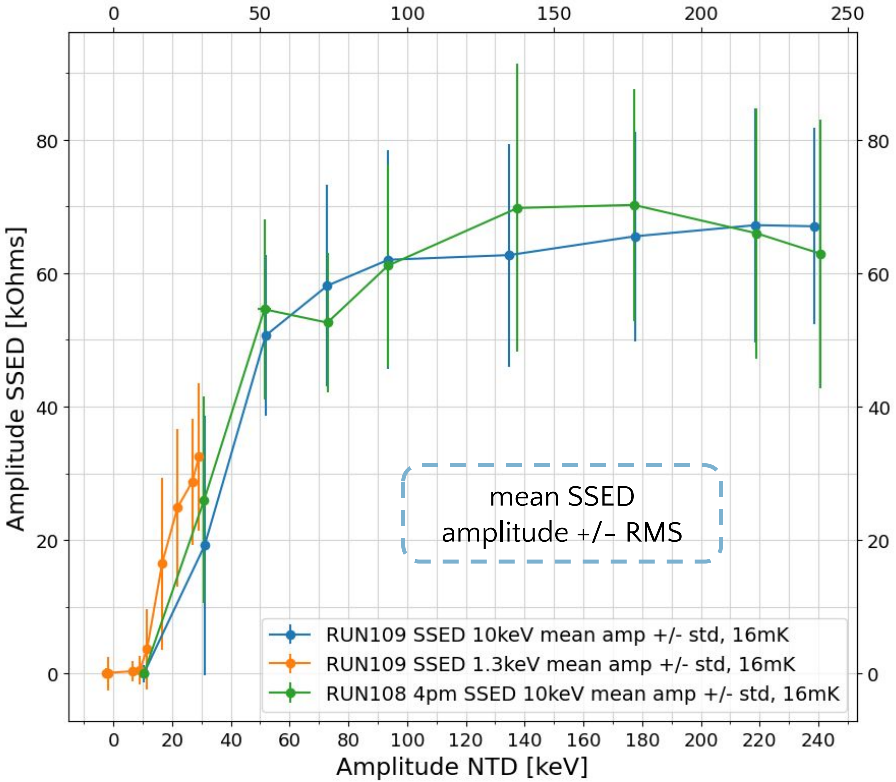
SSED VS NTD

Use calibration peaks (10.37 keV & 1.3 keV) as probes by using Luke amplification.

Three datasets :

- ● From RUN109 10.37 keV
- ● From RUN109 1.3 keV
- ● From RUN108 10.37 keV





mean SSED amplitude +/– RMS

→ We want a HO veto, what actual fraction of events trigger the SSED ?

SSED triggering efficiency

5σ threshold ~ **1.250 kΩ**

Three datasets :

- ● From RUN109 10.37 keV
- ● From RUN109 1.3 keV
- ● From RUN108 10.37 keV

Limitations in threshold characterization :

Only two exploitable characteristic peaks

Bias and E_{recoil} are intrinsically linked because of Luke effect

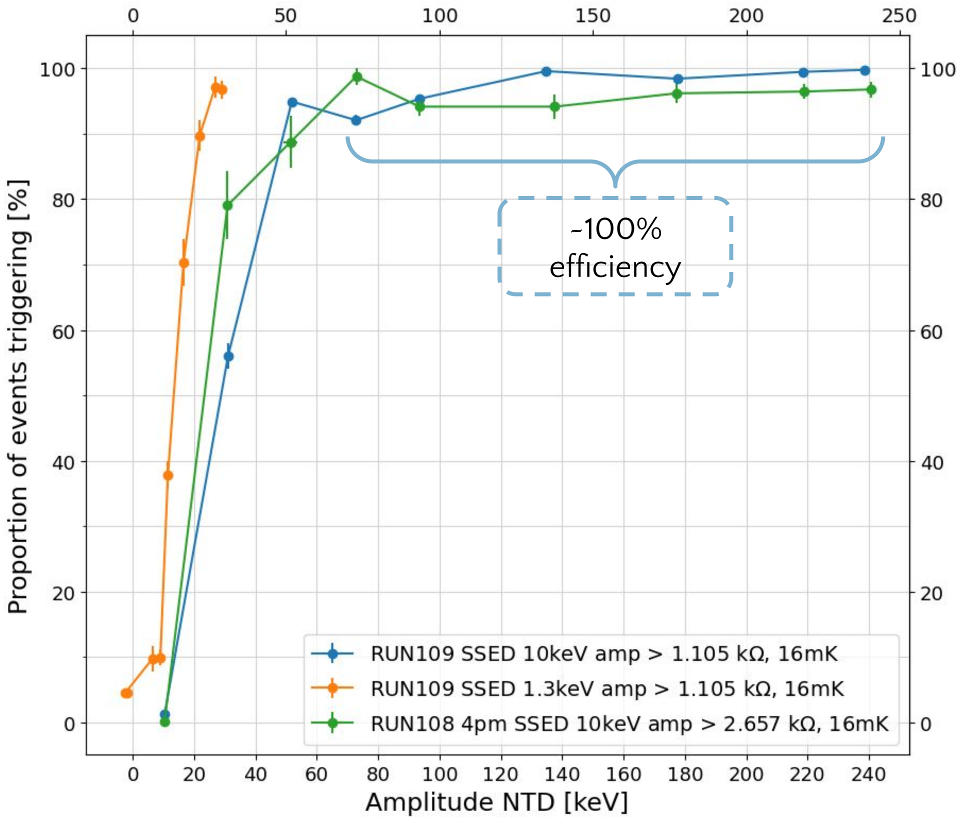
→ Low bias, low field, no triggering ?

→ Low bias, bad charge collection

Next step :

LASER probing

→ Allows to tune pulse energy at any operating temperature and bias



Conclusion and perspective

- With this first fully operational CRYOSEL prototype we have been able to :
  - → First confirmation that SSED behaves as expected,
  - → First characterization of the new SSED sensor,
  - → Results that will allow useful inputs to further improve CRYOSEL design

- Next step is the setup of the LASER probing system that will allow a much more rigorous study of the SSED
- Physics run at LSM in 2024 !

Thank you for your attention !