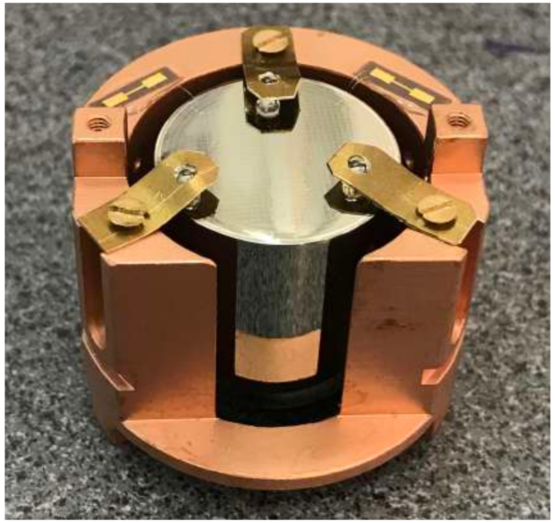
EDELWEISS (+Ricochet Ge) Low-energy spectrum studies



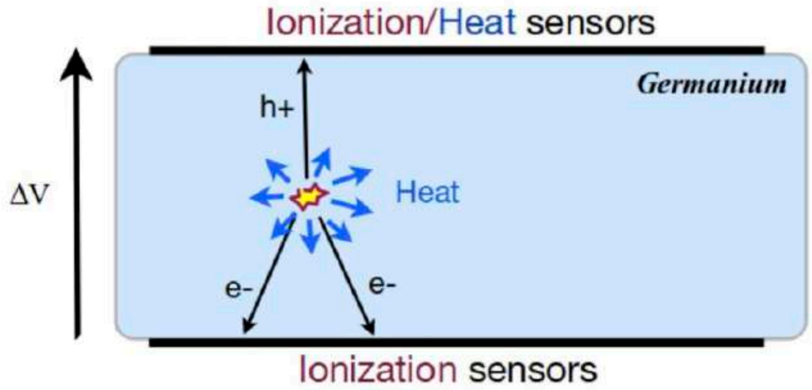
The answers to the quiz:

- *Detector*
- *Energy scale uncertainties*
- *Background model measurement*
- *Low-energy Spectra*
- *Time dependence?*
- *Explanation?*

J. Gascon
Lyon 1, CNRS/IN2P3/IP2I

Edelweiss-Ricochet detector principle

- High-purity Ge
- Heat channel: Ge-NTD thermistance
  - Total energy
  - Glued on electrode or Ge surface
  - Signal independent of hit position
- Ionization channel: electrode
  - Al evaporation or lithography
  - Electron Recoils: $N_{pairs} = E_{recoil} / 3$ eV



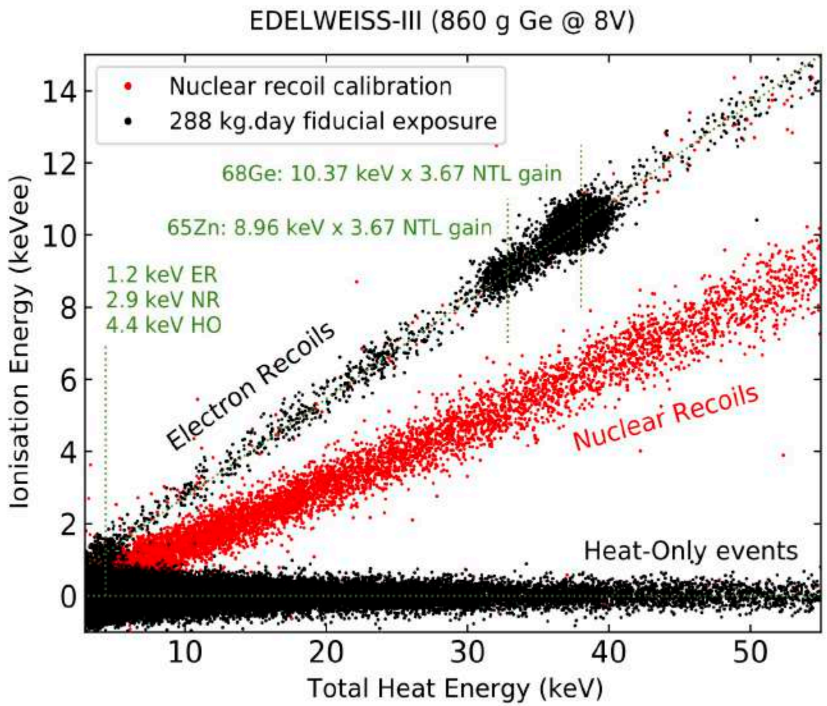
Neganov-Trofimov-Luke (NTL) heating

$$E_{heat} = E_{recoil} + N_{pairs} V$$

- Reduced ionis. yield for Nuclear Recoils

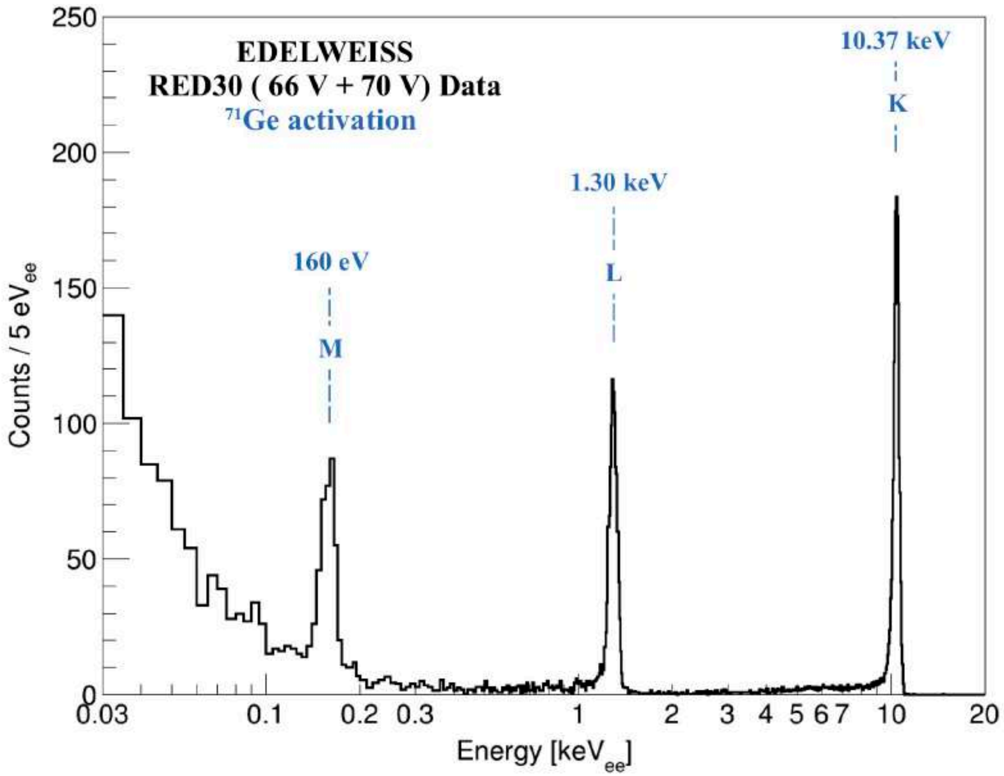
  $N_{pairs} = Q * E_{recoil} / 3$ eV

  with Q ~ 0.2 for 5 keV NR
- 3rd category: "Heat-only events" (HO)



Energy scale uncertainties

- Absolute scale from ^{71}Ge triplet (160 eV, 1.3 keV, 10.37 keV)
- Heat channel non-linearity correction:
  - Scaling ^{71}Ge spectrum up/down using NLT boost (from 8V to 78V)
  - Heat/ionisation ratio of Compton plateau used in 10-2000 keV range
  - ~5% correction between 3 and 300 keV, controlled to <1%

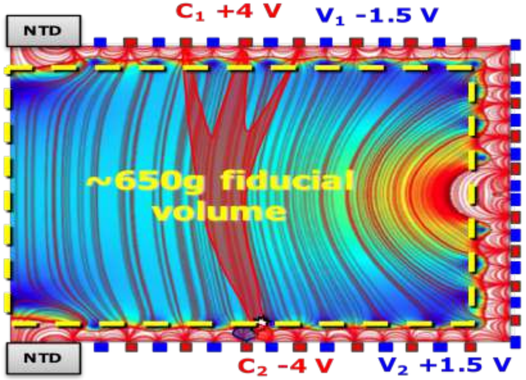


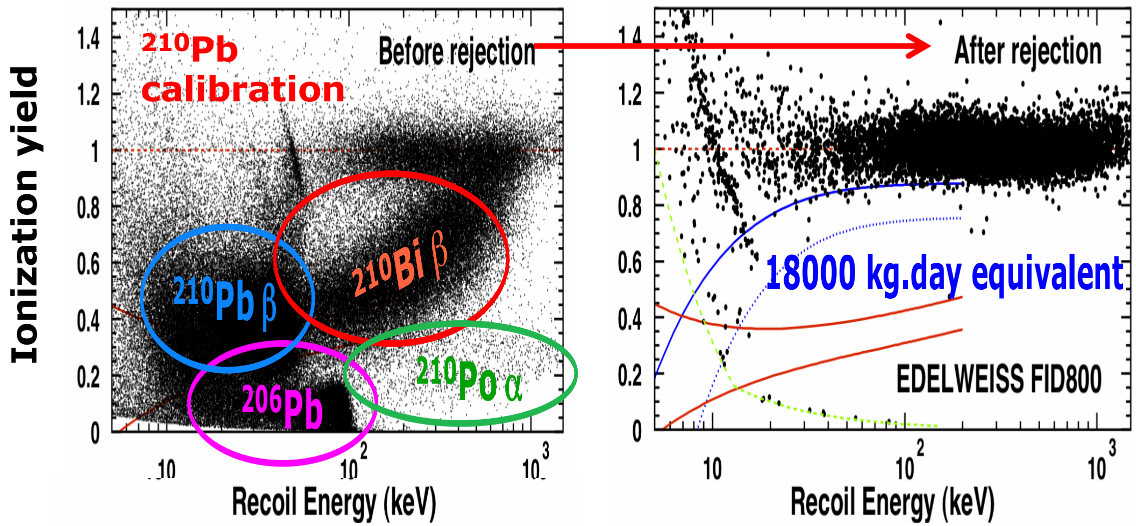
Uniform activation of entire Ge volume

In long runs with newly produced 800g detector, also use ^{65}Zn/^{68}Ge cosmic activation + ^{232}Th background

Surface Event Identification

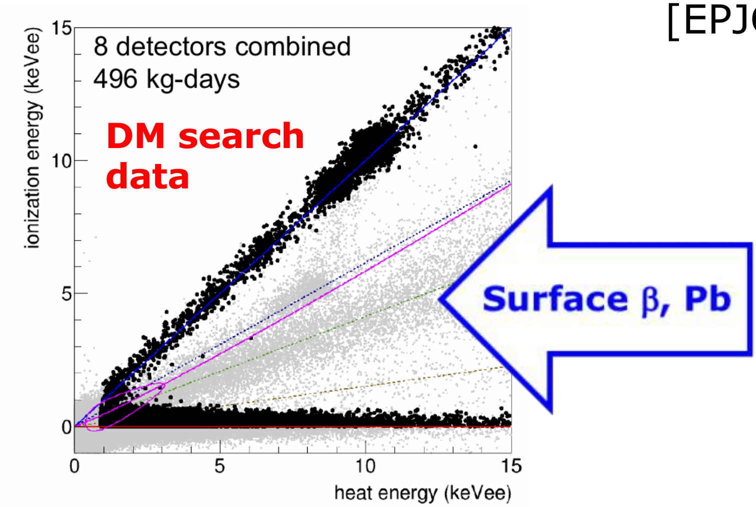
Full interleaved electrodes readout:
<4x10^{-5} **surface event rejection**.

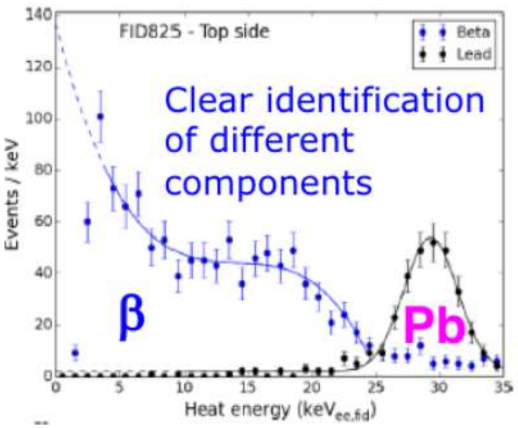


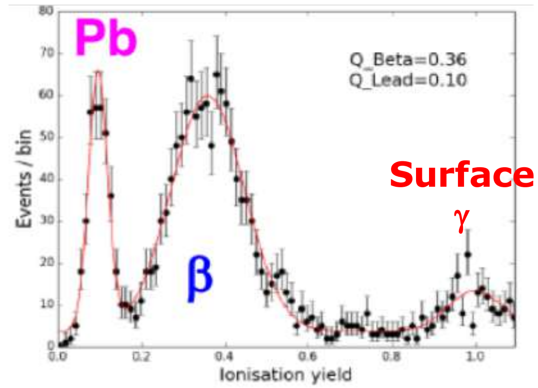


- Used in determination of background model for all surface events

[EPJC 76 (2016) 548]





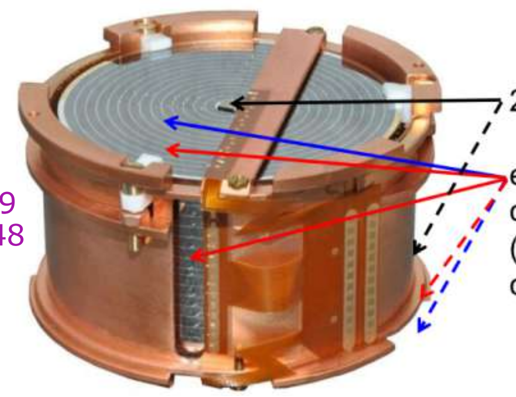


Edelweiss-Ricochet Ge detectors

EDELWEISS-III (2011-2017)

- 24x860g FID detectors with >500 eV heat resolution (230 eV_{ee} ionisation)
- **Complete data-driven background model > 1-5 keV**

JCAP05 (2016) 019
EPJC 76 (2016) 548



870 g Ge

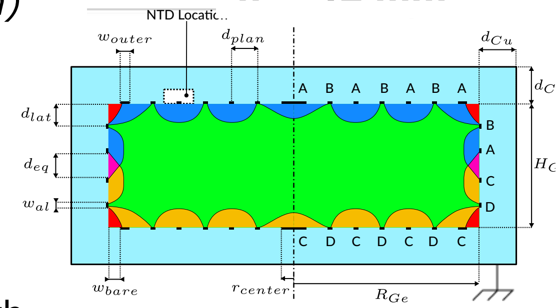
2 GeNTD heat sensors

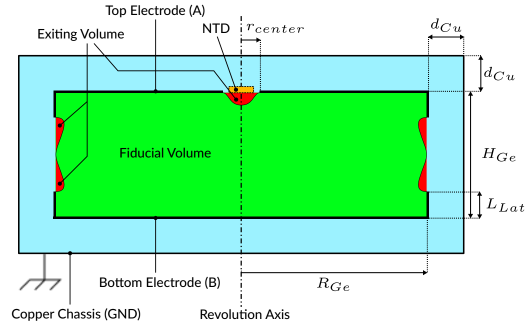
electrodes:
concentric Al rings
(2mm spacing)
covering all faces

Operated at T = 18 mK

ø = 70 mm
h = 42 mm

[JINST 12 (2017) P08010]





Ricochet-Ge (2022...)

- Goal: 27x38 g Ge detectors, σ=10 eV heat
- HEMT: 20 eV_{ee} ionisation *(HO mitigation)*
- Planar electrode option (if surface backgrounds are confirmed to be sub-leading in CENNS studies)

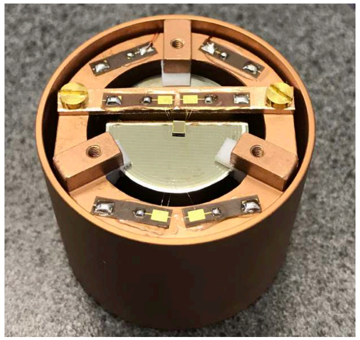
RED20/30 (2018-2020)

- EDELWEISS DM searches performed with 33.4 g prototypes from common Ricochet/EDELWEISS R&D
- **First look at bkgs below 1 keV**

PRD 99 082013 (2019)
PRL 125, 141401 (2020)

RED20

RED30



EDELWEISS-SubGeV first steps

Also: development of HO mitigation using HEMT readout, and SSED / NbSi TES sensors

Edelweiss-Ricochet Ge detectors

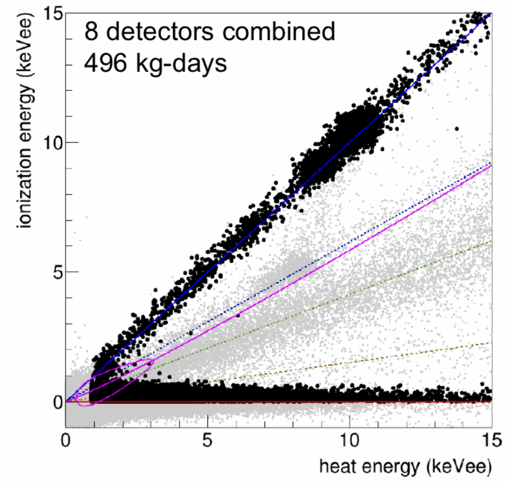
Name	Mass (g)	Heat sensor	Electrode	Site	σ_{heat} eV (eV_{ee})
FID800	820 870	2 x NTD	Full Interleaved	LSM	500 (140 @8V) 1500 (400 @8V)
NbSi	200	2 x NbSi TES	Planar	LSM	115 (5 @66V)
RED30	33	1 x NTD	Planar	IP2I LSM	43 (1.6 @78V)
RED20	33	1 x NTD	None	IP2I	17.7 (17.7)
FID38	38	1 x NTD	Full Interleaved	IP2I *ILL*	*Test ongoing*
PL38	38	1 x NTD	Planar	IP2I *ILL*	*Test ongoing*

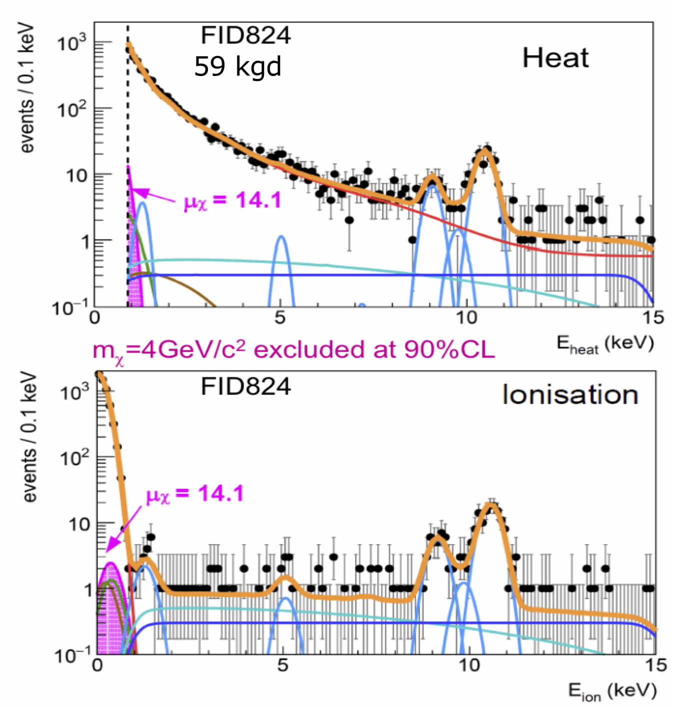
Edelweiss *DM searches* (FID800, NbSi, RED30, RED20)
Common R&D (RED30, RED20, FID38)
Ricochet *CENNS* (FID38, PL38)

LSM: 4800 m.w.e. overburden IP2I: above-ground facility, 6 m.w.e.

Heat-Only background

- Dominates the spectrum at low energy
- Average of ~40 DRU @ 5 keV in search data.
  (140 DRU @ 1.3 keV_{ee}): 4 times less by end of run
- Extensive study in E. Queguiner's thesis, Oct. 2018
  (https://tel.archives-ouvertes.fr/tel-02025002)
- No ionisation ($<E_{ion}>=0$, $\sigma_{HO} = \sigma_{ion\_baseline}$)

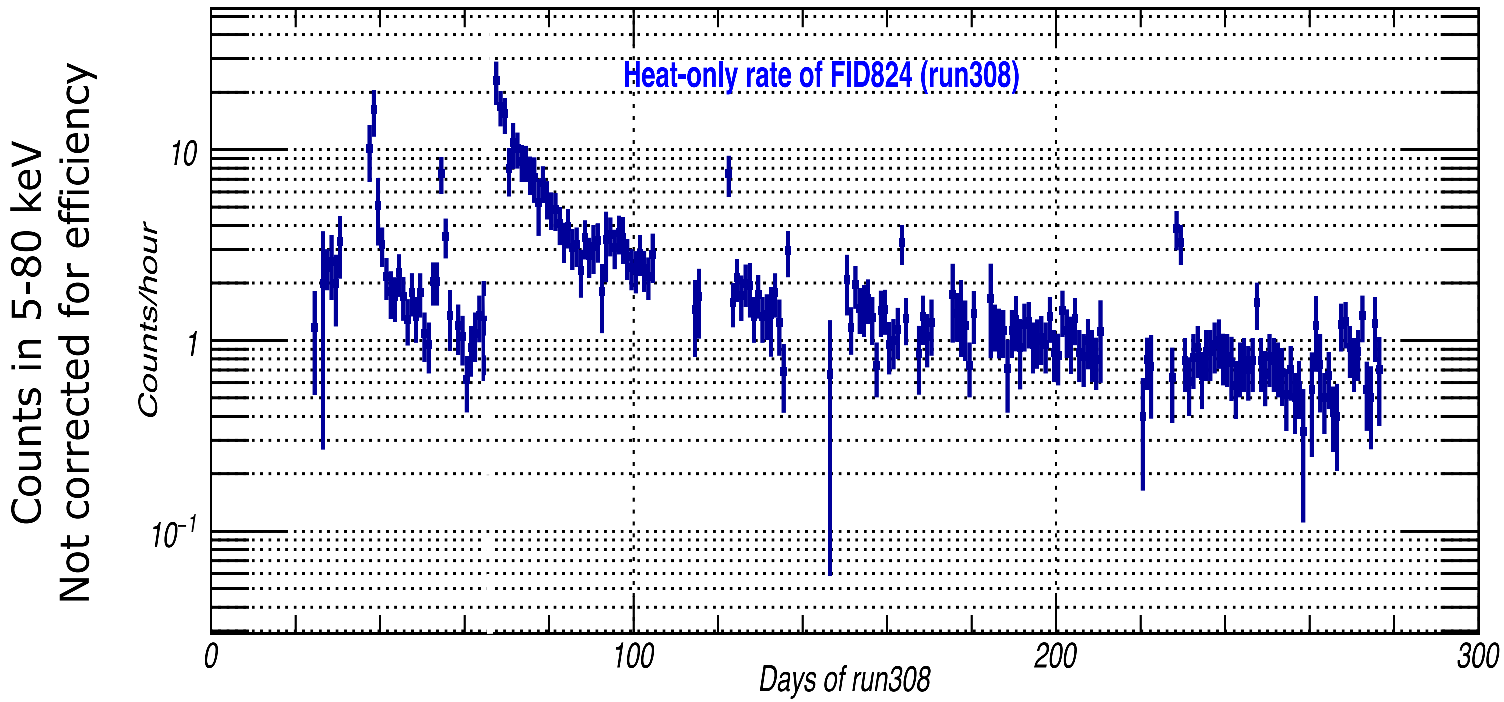




- Pulse shape of signal consistent with standard pulse on both GeNTD sensor, same amplitude
- Time between events follows Poisson distribution
- ~triple-exponential energy distribution
- No coincidence with other detectors or muon veto
- Incompatible with ^{206}Pb recoil rate (~0.1 DRU @ 5 keV) expected from observed α rate
- Comparable rates in all detectors within factor 3
- Rates in detectors vary in a correlated way

Time evolution of HO rate

- Global trend: decrease of rate with a 250±100 day time constant
- Sudden increase (following cryostat warm up) by factor 14±4 observed in all detectors, decaying with a time constant of 12±2 days: inconsistent with known sources of radioactivity
- Similar trends observed over a period of 3 years



Efficiency-corrected spectra (before rejection)

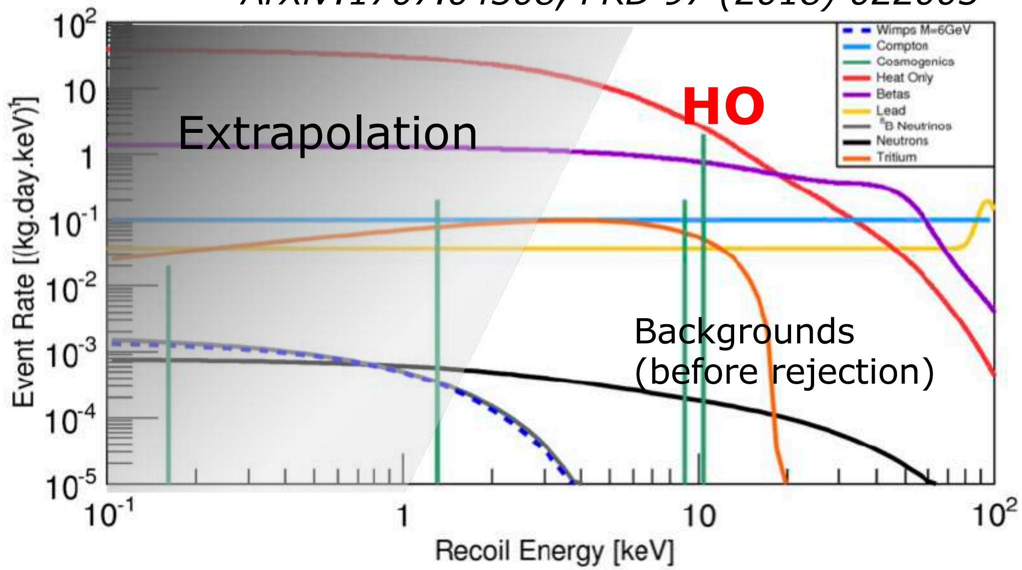
860 g detectors

- Data-driven likelihood for individual contributions
- Extrapolations below 1 keV (gamma) - 5 keV (HO)

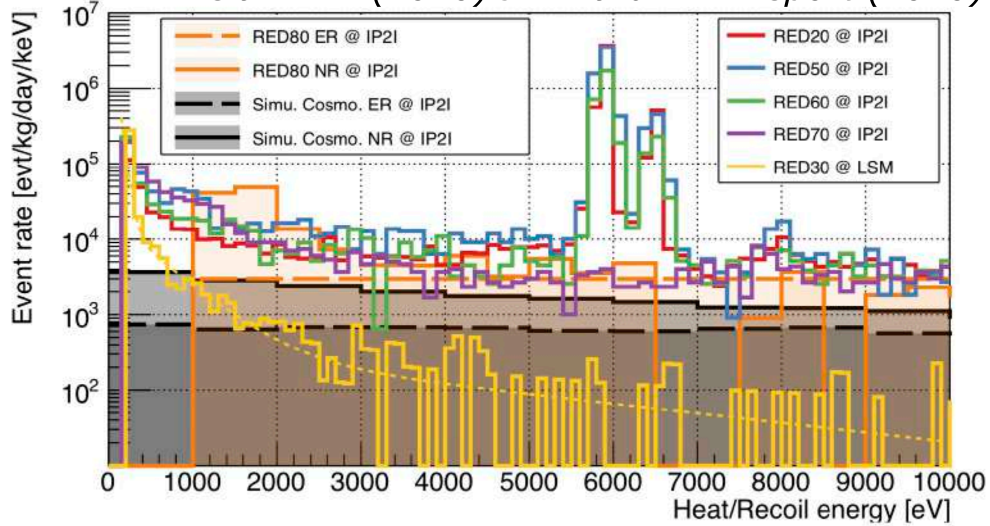
33 g detectors

- *First look at 0.1 – 5.0 keV*
- Above ground (except for RED30)
- No separation of components (except RED80 above 1 keV)
- **Wrt 860g, increase by one order of magnitude in RED30 @ 5 keV: 860 g/33 g**
- **No excess wrt expected above-ground bkg above 1 keV**
- **10^5 DRU at 200 eV**

ArXiv:1707.04308, PRD 97 (2018) 022003



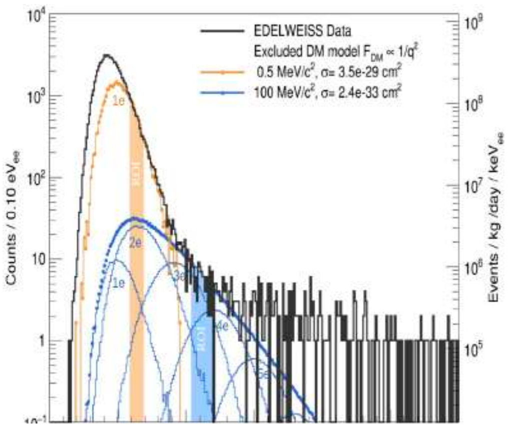
D. Misiak PhD (2020) J. Billard HDR report (2020)



Search for NTL boost in 0.1 - 5 keV range

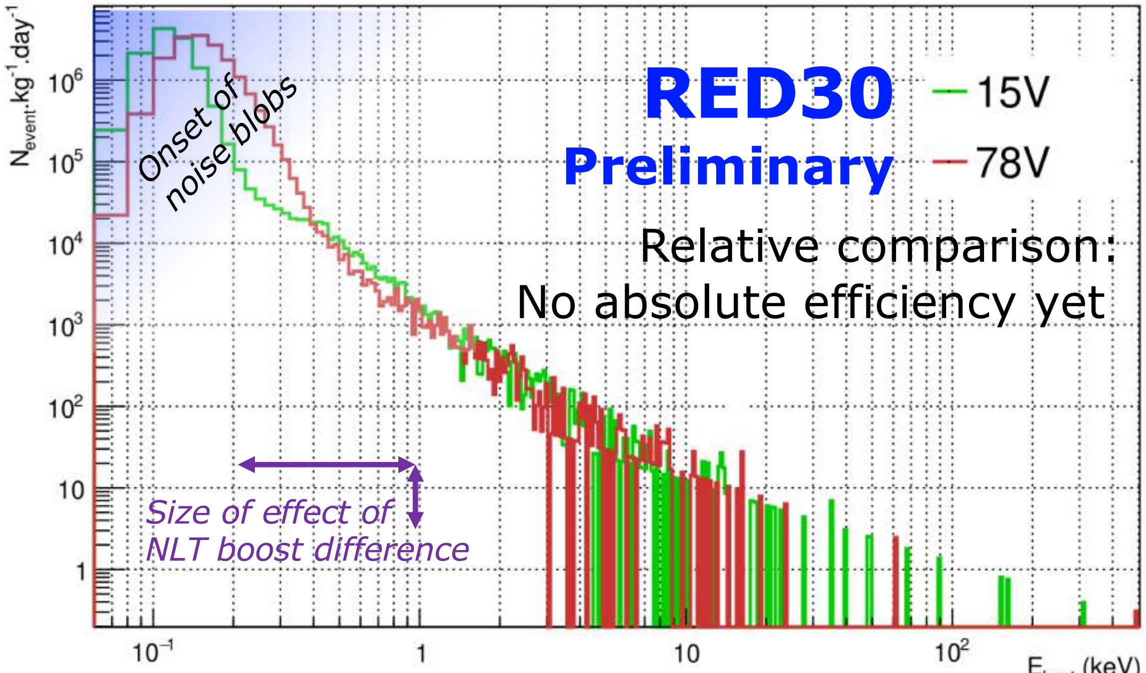
- No reliable ionization tag in 0.1– 5 keV range
- Use NTL boost instead to test for charge
- Compare detector rates over similar time range (reduce HO rate fluctuations)
- Measurement limited by possible fluctuations of heat resolution over the period
- **Electron recoil contribution negligible above 400 eV**
- <400 eV: worse resolution (35 vs 42 eV) and leakage currents at 78V?

RED30 78V data interpreted as Electron Recoils



0 10 20 30

Electron-equivalent energy (eV_{ee})



Total heat Energy (keV)

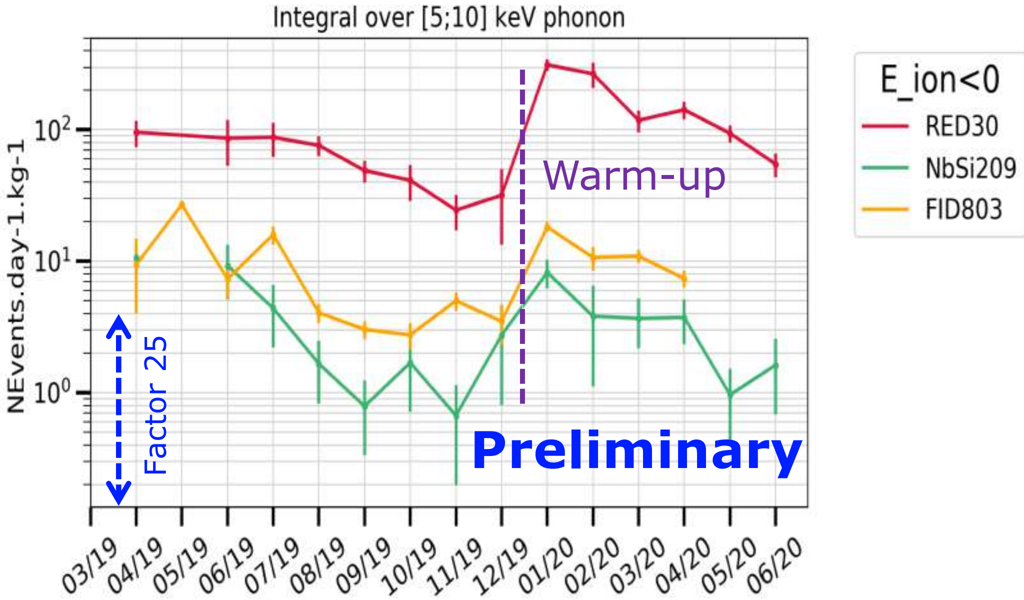
Detector size & sensor

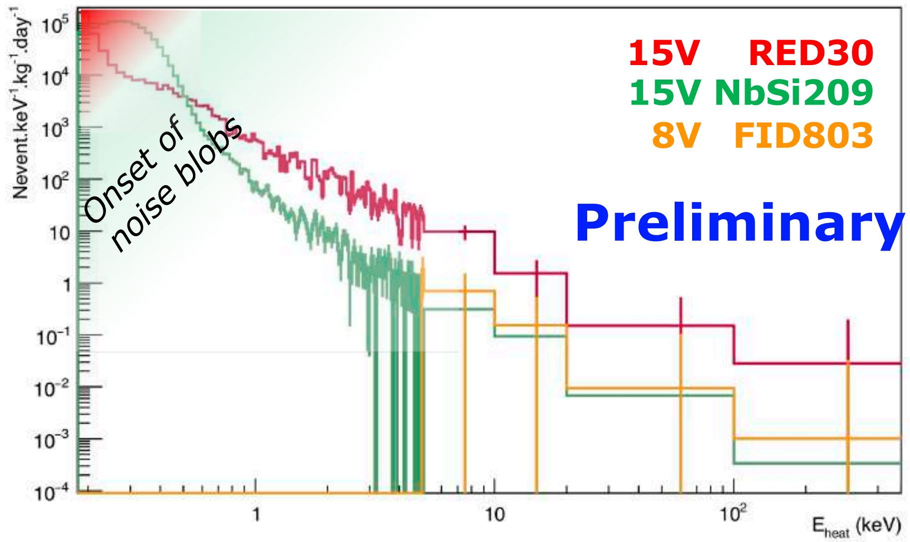
Relative comparison:
No absolute efficiency yet

- **RED30:** 33.4g
- **NbSi209:** 196 g (mass x6 RED30)
- **FID803:** 820 g (mass x25 RED30)

- Rates per day in RED30 and FID803 comparable (factor ~25 in rates per kg.d)

- Some reduction of rate in detector with NbSi sensor: Sensitivity to athermal phonons? Absence of glue?





Possible explanations explored so far

[E. Queguiner, PhD thesis, Oct. 2018]
https://tel.archives-ouvertes.fr/tel-02025002

Hypothetic source	induced by	Tests	Period
Stress in Ge	vibration	GM ON/OFF + FID211	run309, run310
	pressure from holder	Removed Cu holder	run310
	gluing **Some effect ?**	NbSi + DEP detectors	run311
^{4}He	condensation/evaporation	^{3}He as exchange gas	run309
^{206}Pb, α, β	in Al	Study of surface event rate and ratio	all runs
	in αGe	Study of surface event rate and ratio	all runs
Glue	radioactivity	HPGe measurements + NbSi + DEP detectors	run311
NTD	radioactivity	Event shape + NbSi TES	run311
Gold pad	radioactivity	HPGe measurements	run310
Thermal link (Kapton®)	radioactivity → injection of a heat pulse via the thermal link	Thermal link directly on NTD FID840 and FID844	run311
Teflon®	radioactivity and stress	Replaced by VESPEL® (FID837) + Cu holders (FID841)	run310
XeF_2 etching	chemical treatment of detector surface	Difference between detectors	all runs
Radiogenic source	^{222}Rn, ...	Study of heat-only event rate	all runs

Table 4.2 – Summary of the different tested hypotheses concerning the origin of heat-only events. Expected characteristics and tests realized to remove them are presented.

+ size of detector, + thermal/athermal phonons

Take-away messages

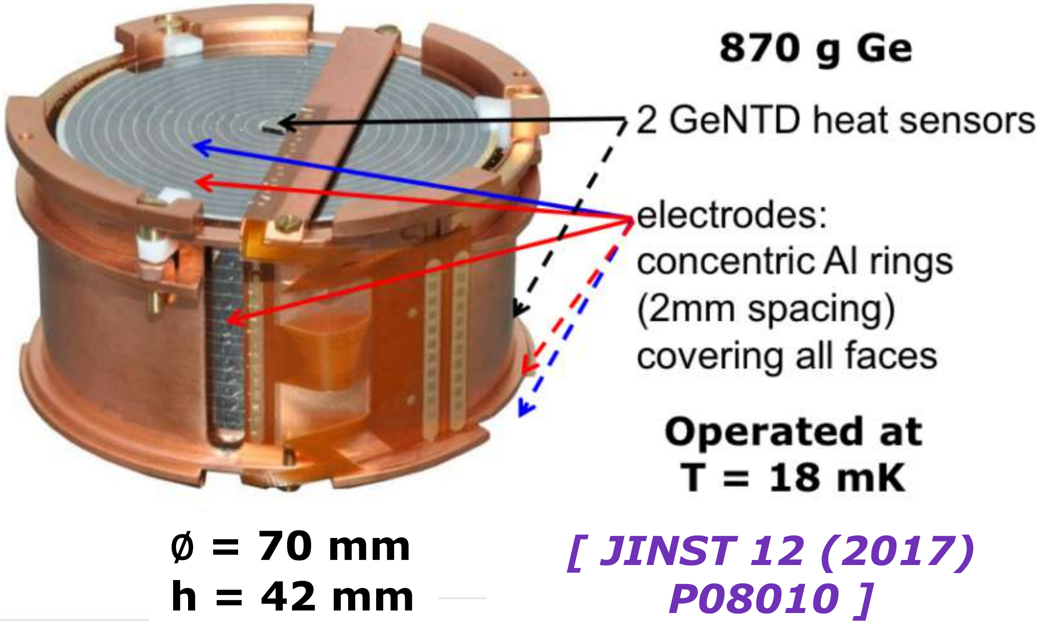
- EDELWEISS spectrum between 200 eV and 10 keV dominated by heat-only events
  - Single events with standard pulse shape, in both NTDs, Poisson distributed in time.
  - 100's to 1000's DRU at 1 keV
  - Rates decrease slowly with time (month – year), but may increase suddenly following a warm up. Correlation of rates between the detectors.
  - Comparable rates in all the 800 g detectors
  - Smaller detectors: similar number of event/day; increase of the rates in DRUs.
- Steep rise at low energy observed in 33g detectors
  - 10^5 DRU at 200 eV
  - not affected by NTL boost (ER rate at 100 eV_{ee} < 6×10^3 DRU)
- No single source could be isolated (multiple sources?)
  - Strong case against: ^{206}Pb recoils and other source of radioactivity; ^4He desorption; radioactivity in NTD or in thermal link; stress release in Ge crystal.
  - Weaker case (inconclusive yet): stress release in support or in glue.
  - Best lead: significant reduction (as low as few ten's of DRU at 1 keV) when NTD sensor is replaced by NbSi TES: effect of total absence of glue? Effect of sensitivity to athermal vs thermal phonons?

Work on HO mitigation (HEMT readout, charge tag with NbSi SSED/TES sensors)

BACKUP

Detectors: EDELWEISS-III

- Complete coverage of interleaved electrodes (incl. side of cylinder): maximal surface rejection
- 24 x 820-870g Ge
- 2 x GeNTD (4x4x0.45 mm^3) glued on Al electrode
- Supported by 3x2 Teflon clamps inside Cu casing (4pi coverage)
- Heat link to Cu casing via gold pad + gold wire + kapton

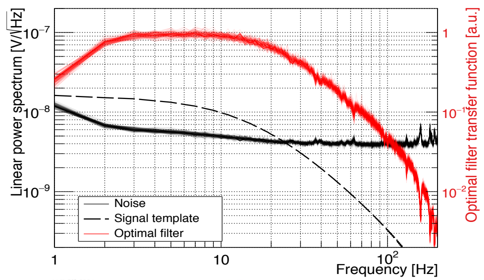


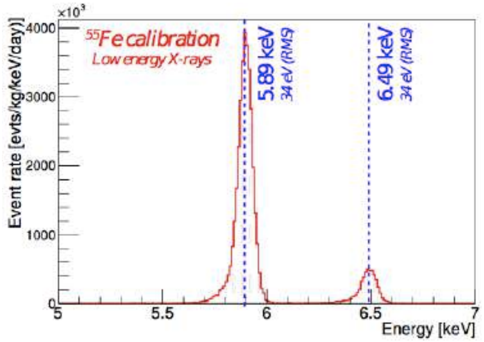
[JINST 12 (2017) P08010]

- Site: LSM (5 μ/m^2/day, 10^{-6} n/cm^2/s)
- Shielding: active muon veto + 50 cm PE + 20 cm Pb + 10cm internal PE
- >99.996% tag of surface events (depth ~2mm) using ionisation
- Heat resolution: 500 to 1500 eV (with 8V NLT boost: 150 to 500 eV_{ee})
- Average ionisation channel resolution = 230 eV_{ee}.
- Exposure: 3000 kgd (250 day cool-down, 2014-2015) followed by tests cumulating ~350 day exposure (2015-2017)

Detector RED20

- Ricochet and Edelweiss R&D to improve thresholds
- Reduction of mass from 800 to 33.4 g (h20 phi20)
  - Reduced size of GeNTD: 2x2x0.5 mm^3
- Remove thermal link via gold pad, go through NTD
  - Improves NTD sensitivity
  - Heat pulse from environment have a different pulse shape
- No electrode; one GeNTD, glued directly on Ge
- Above-ground lab (IP2I), 17 mK
- 10 cm Pb, with 50^o opening above the detector
- 17.7 eV resolution; 60 eV analysis threshold
- Not NTL boost : no quenching uncertainties
- ***2018: Above-ground search for SIMP***
- Continuous data stream saved on disk, offline trigger
  - Accurate measure of trigger and analysis efficiency (as well as pulse reconstruction bias) by injection of simulated pulses
- Also with similar size/geometry : RED50-60-70

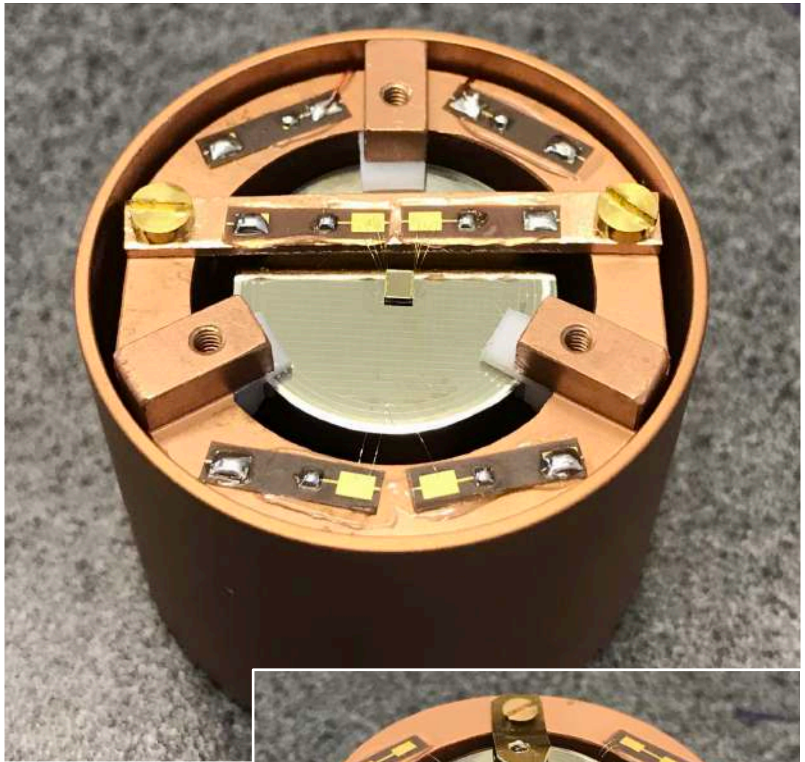
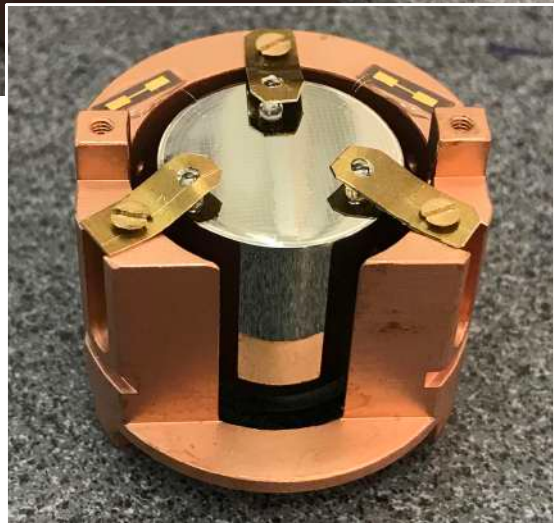




Detector RED30

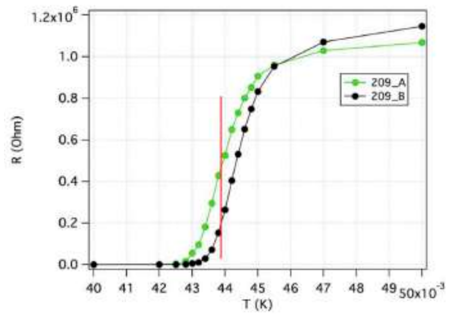
- Same geometry as RED20: 33.4g Ge, h= 20 mm, ∅= 20 mm, 2x2x0.45mm^3 NTD
- Al electrodes on top/bottom surfaces for NLT boost and ionisation readout = lithographed Al grid (500 mm pitch, 4% coverage to reduce phonon trapping)
- **EDELWEISS-III cryostat (20.7 – 22 mK)**
- 43 eV resolution at 78V : **1.58 eVee**
- Analysis range: 3 – 30 eV_{ee} (80 – 800 eV total energy)
- Lowest reconstructed energy used in **DM-electron interaction and Dark Photon searches**: 6 eV_{ee} (162 eV)

- Also with similar geometry (h10 ∅30, 38g) RED80: detector for above-ground R&D at low bias (2V) to fully exploit ER/NR discrimination (Ricochet goal)

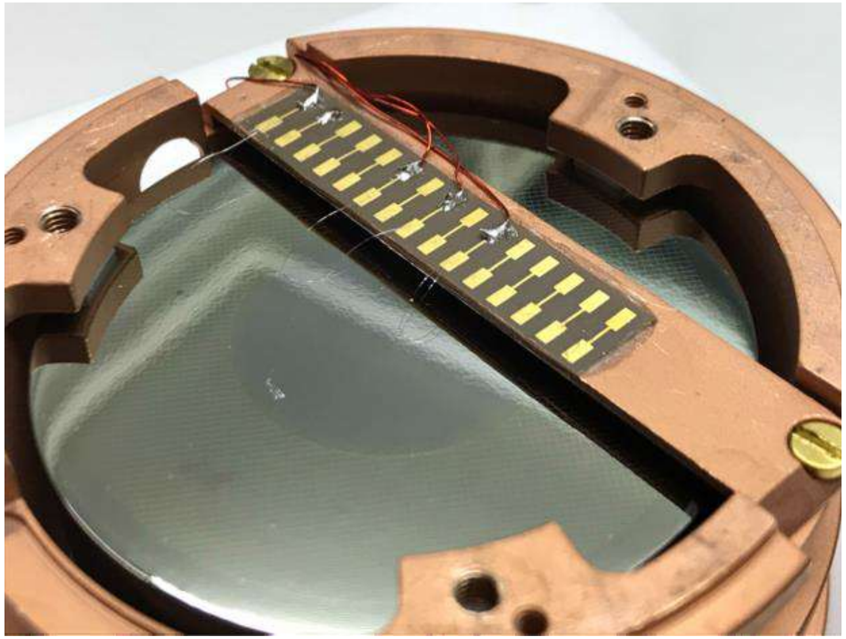



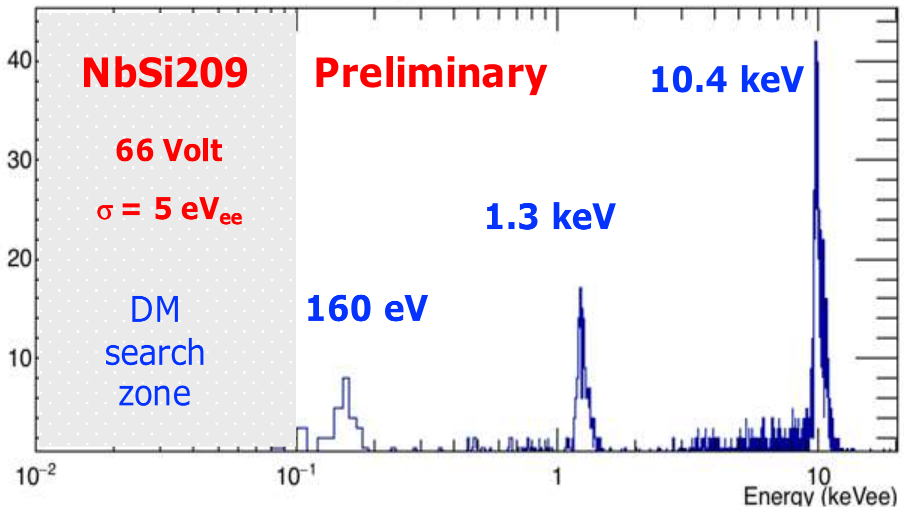
Detector with NbSi phonon sensor

- Ge crystal h20 mm phi 48 mm (196 g Ge)
- NbSi Transition Edge Sensor: sensitivity to athermal phonons
- 100 nm thick, 20mm diam. spiral NbSi sensor lithographed on top surface
- Electrode on top/bottom surfaces: Al grid with 4% coverage
- Transition between 0 -> 1 kOhm at 44 mK
- **σ<110 eV, 5 eV_{ee} at 66V bias**

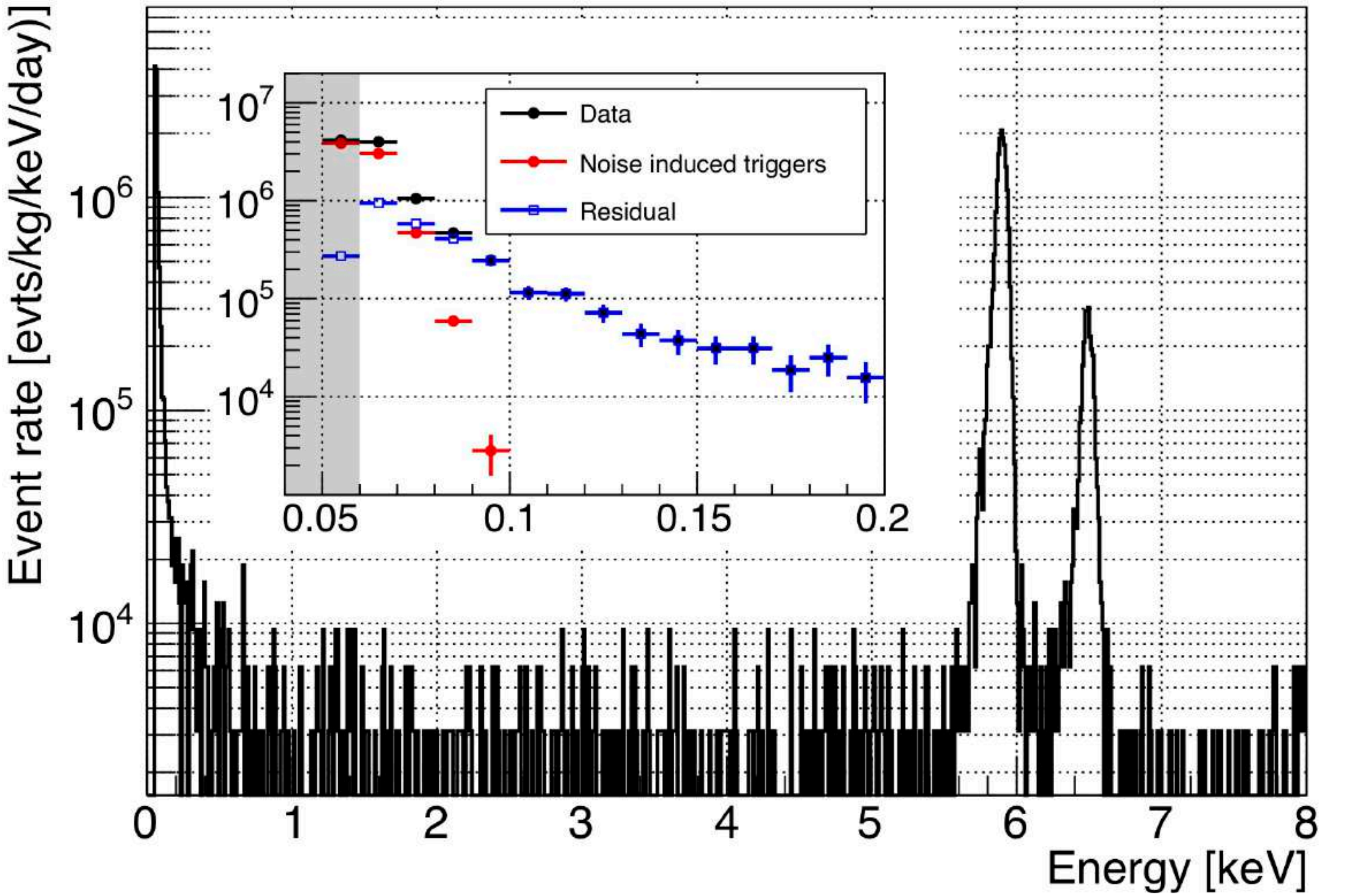


Physics data analysis ongoing





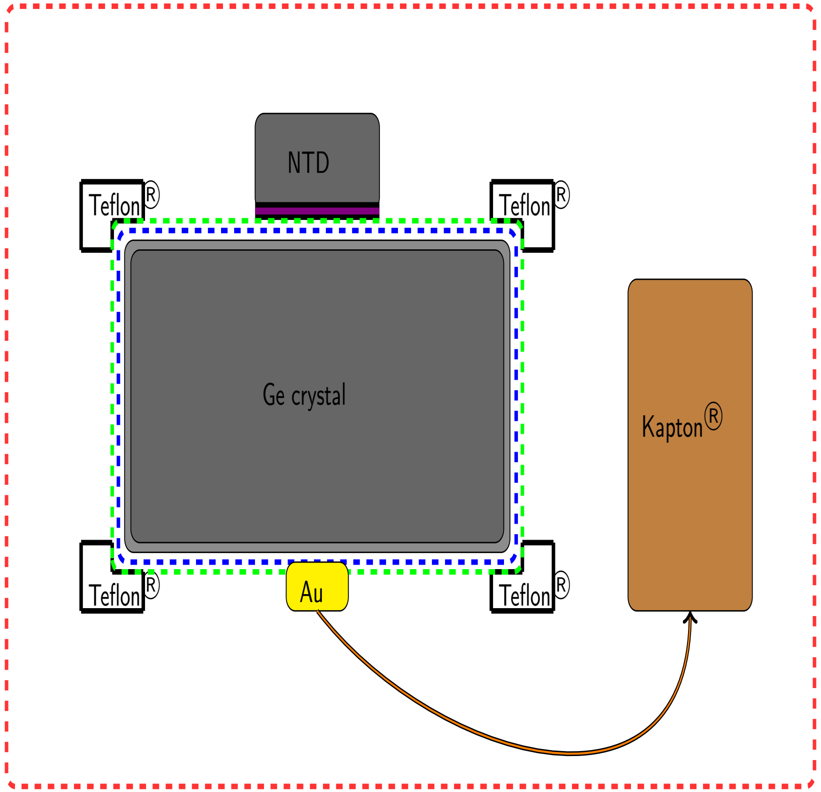
RED20: contribution of noise-induced triggers



Heat-Only events: studied hypotheses

Hypotheses about HO origins

E. Queguiner, PhD thesis, Oct. 2018



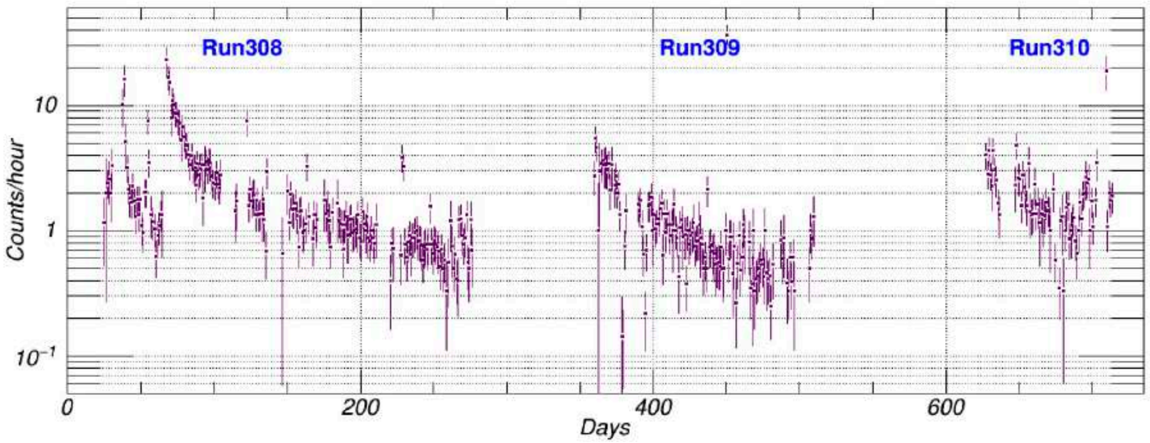
- Radiogenic source → ^{222}Rn
- ^{4}He → condensation/evaporation
- Gold pad → radioactivity
- Thermal link → entry point
- Teflon → radioactivity, stress
- Kapton → radioactivity, stress
- Surface events → ^{206}Pb, α, β
- NTD → radioactivity, stress
- Glue → radioactivity, stress
- Stress in Ge crystal → vibration, pressure, gluing
- Surface treatment → chemical treatment

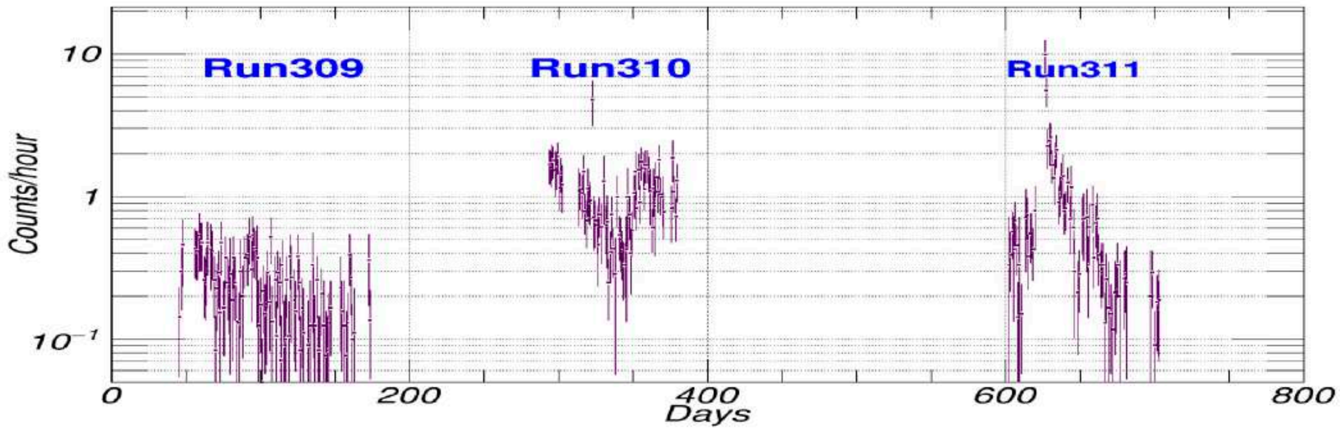
Each hypothesis:

→ has been studied
→ can not fully explain by itself the heat-only rates.

Time dependency and other correlations

- Counts/hour in range 5-80 keV in FID824 (860g)





- Counts/hour in range 15-80 keV in FID803 (820g)

Electron rates per gram.day

Efficiency-corrected **RED30 upper limit** on rate of 1, 2, 3, 4... e- evts **per gram.day** compared with CDMS (arXiv:2005.14067) & SENSEI (arXiv:2004.11378)

Note: SENSI/RED30 ratio in Mass = ~16, ratio in surface ~1/4 -> factor 64

	Mass (g)	1 e^-	2 e^-	3 e^-	4 e^-
RED30	33	<11000	<210	<18	<6
CDMS 140V	0.93	157000	1300	171	58
CDMS 100V	0.93	149000	1100	207	53
CDMS 60V	0.93	165000	1200	245	77
SENSEI	2	450 (<525)	2.4 (<4.4)	<0.25	<0.25