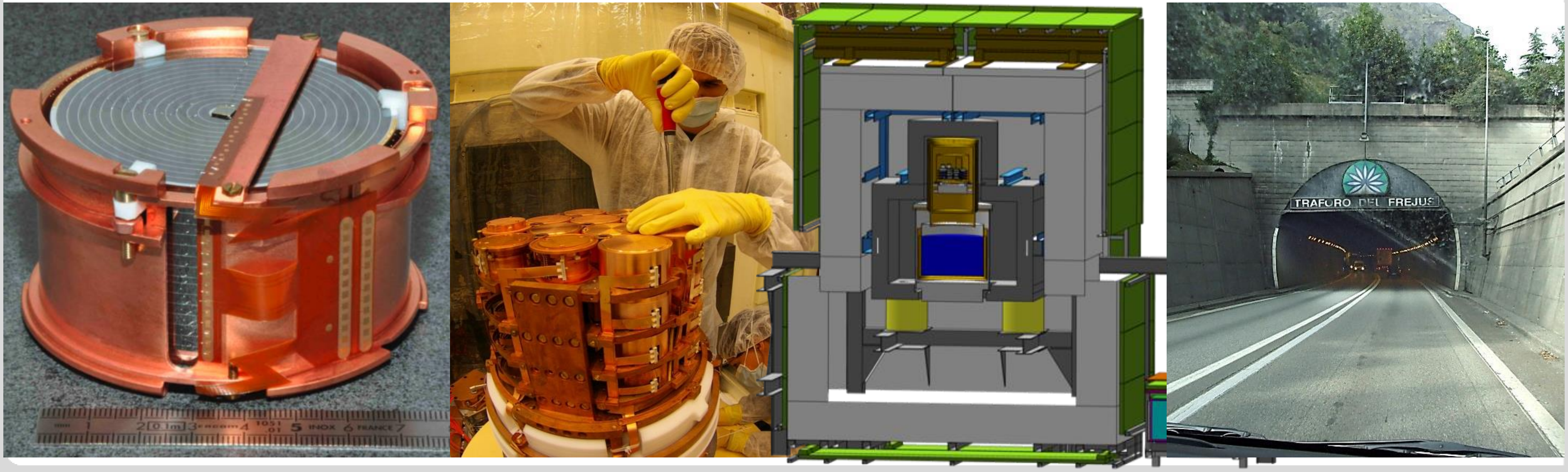
Karlsruhe Institute of Technology

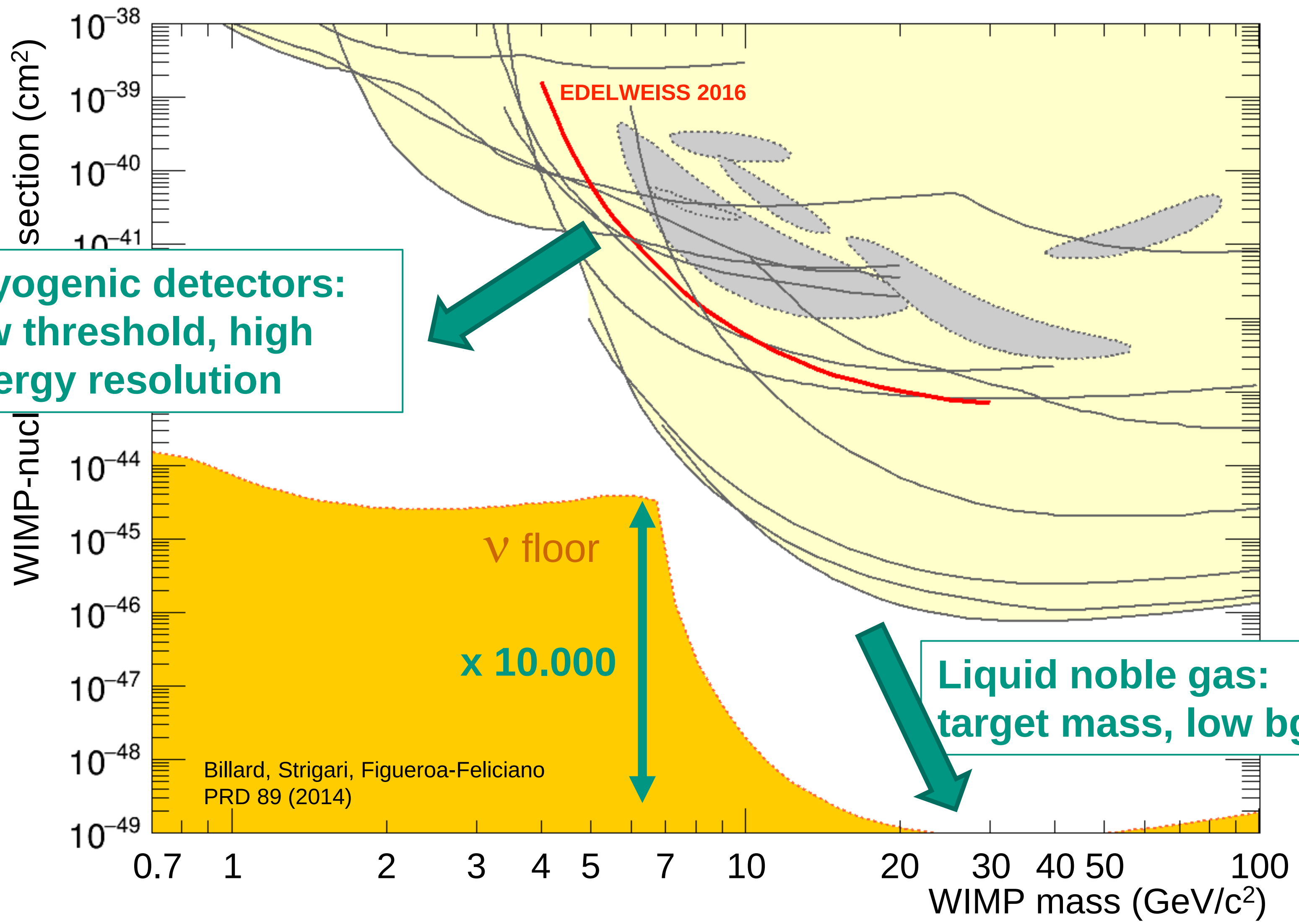
Results from the EDELWEISS-III Dark Matter search, Prospects for EDELWEISS-LT and beyond

UCLA Dark Matter 2018
Los Angeles

Bernhard Siebenborn



WIMP search strategy



Billard, Strigari, Figueroa-Feliciano
PRD 89 (2014)

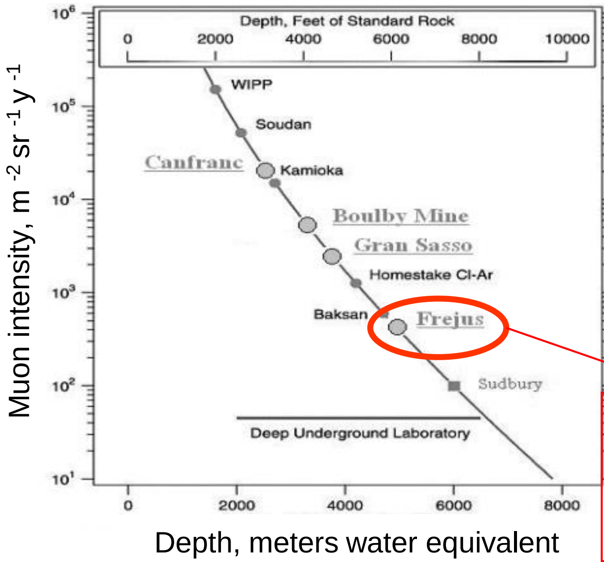
Cryogenic detectors: low threshold, high energy resolution

Liquid noble gas: target mass, low bgd

EDELWEISS collaboration

EDELWEISS 2016 @ KIT

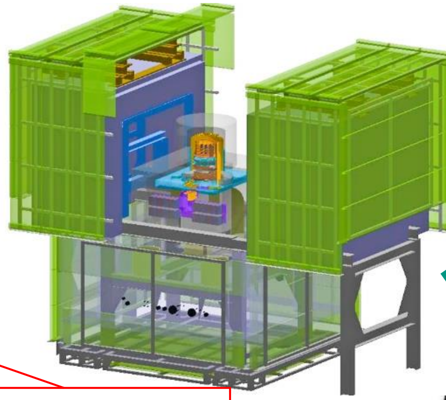
France	CEA Irfu/Iramis (Saclay) CSNSM (Orsay) Institut Néel (Grenoble) IPNL (Lyon) LPN (Marcoussis)
Germany	KIT (Karlsruhe)
Russia	JINR (Dubna)
GB	University of Oxford University of Sheffield

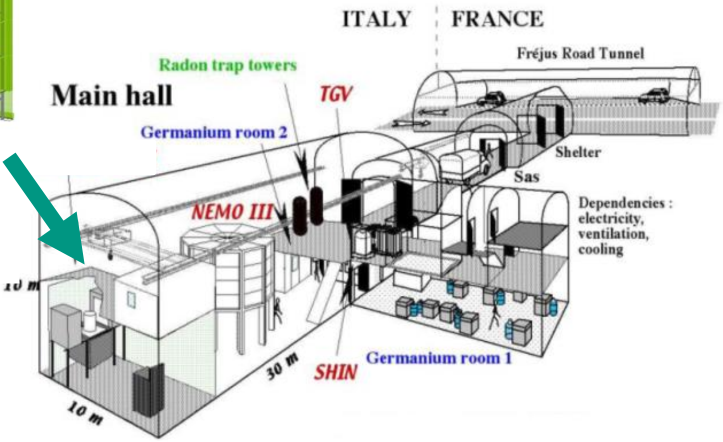


5 $\mu/m^2/day$

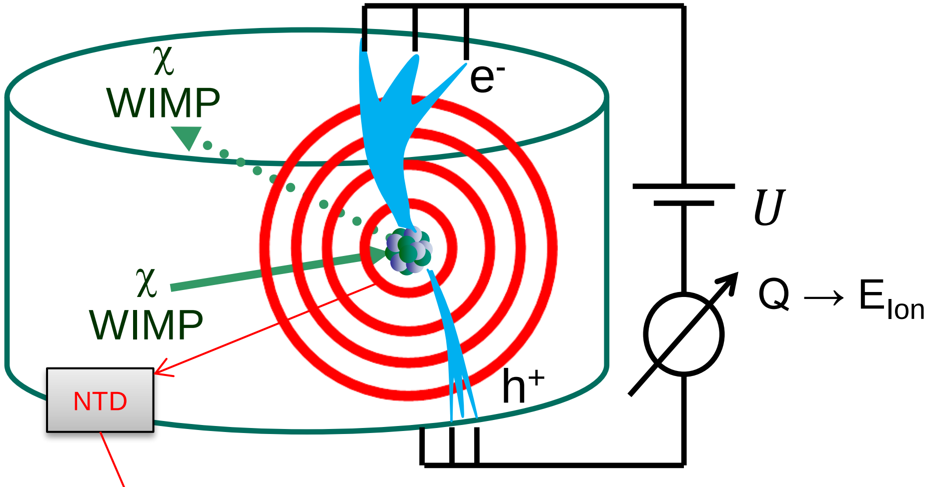
4800 mwe

(deepest in Europe)

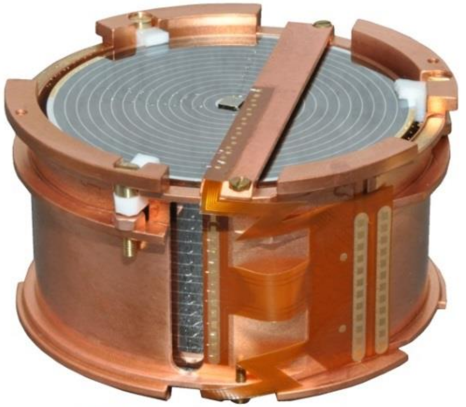




EDELWEISS-III FID800 detectors



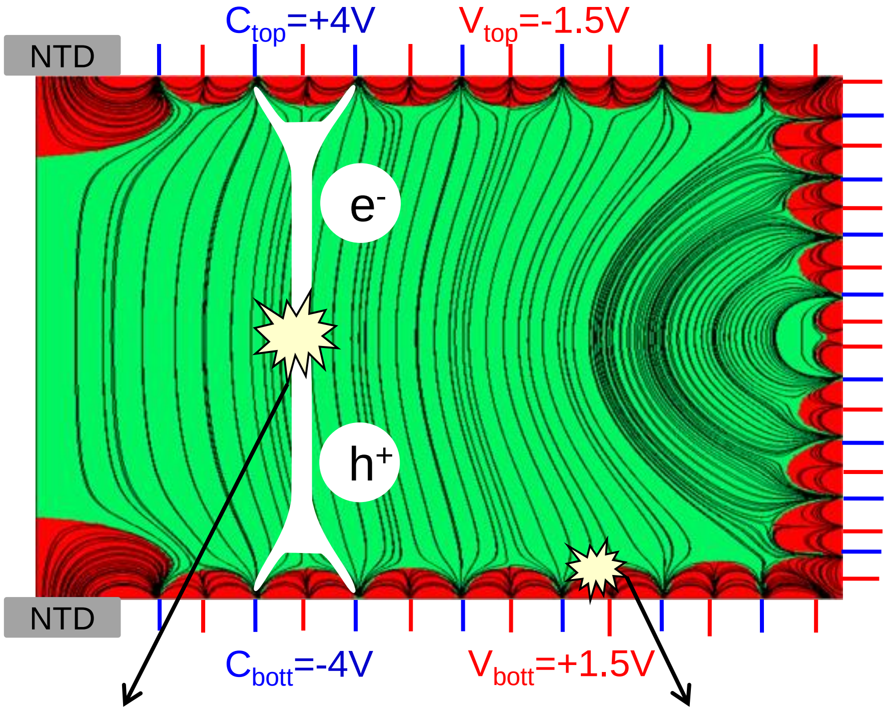
$\Delta T \sim E_{heat} = E_{recoil} + E_{NL}$



T_{op} = 18mK

Fully **I**nter**D**igitized ~870g HPGe detectors

A. Broniatowski et al., Phys Lett B 681 (2009) 305–309



Bulk/Fiducial event:
Signal on C_{top}&C_{bott}

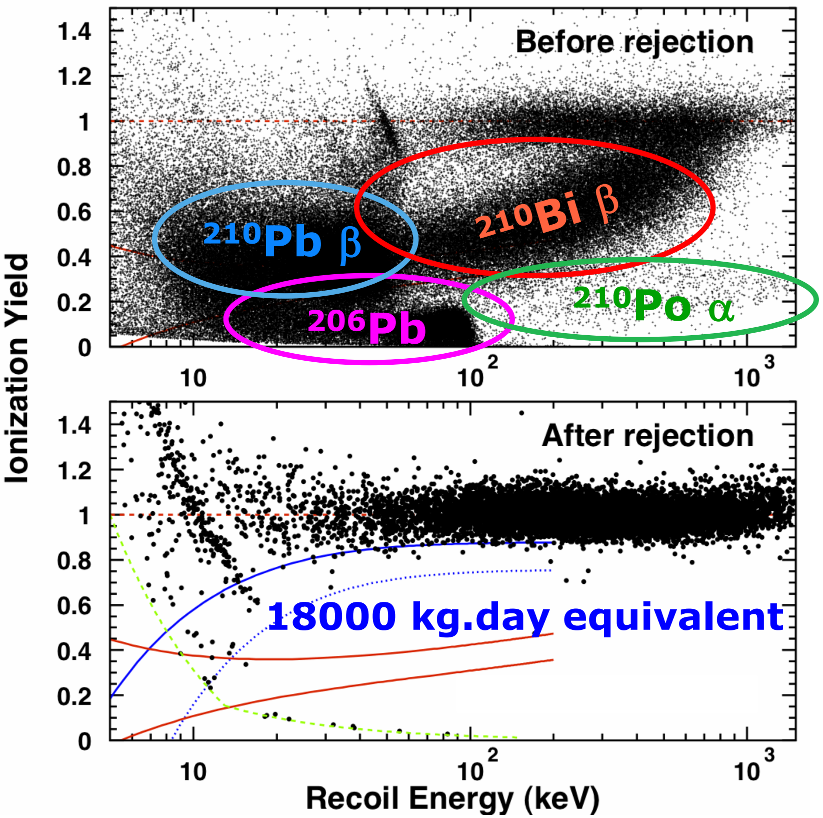
Surface event:
Signal on C_{bott}&V_{bott}

Ø=70mm, h=40mm 2 GeNTDs heat sensors
XeF_2 surface S. Marnieros et al., JLTP(2014)176:182

Surface event rejection and gamma rejection

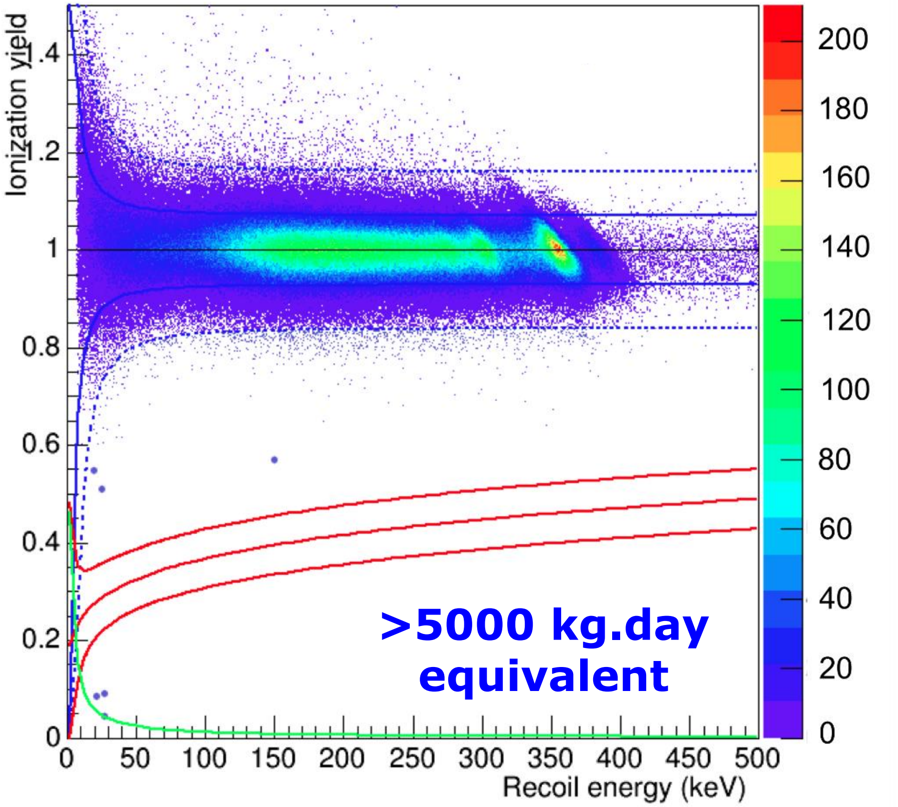
- Surface event rejection (^{210}Pb+^{210}Bi β, ^{210}Po α, ^{206}Pb recoils): < 4 x 10^{-5} JLTP(2014)176:870
- γ rejection factor: < 5.6 x 10^{-6} JLTP(2012)167:1056
- *Improved to < 2.5 x 10^{-6} with additional detectors + statistics* JINST 12 (2017) P08010

^{210}Pb source



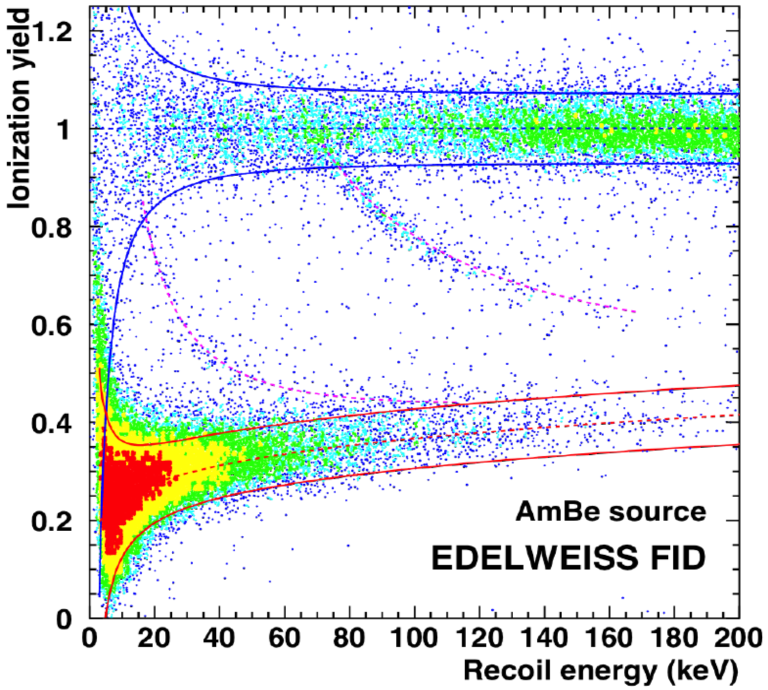
18000 kg.day equivalent

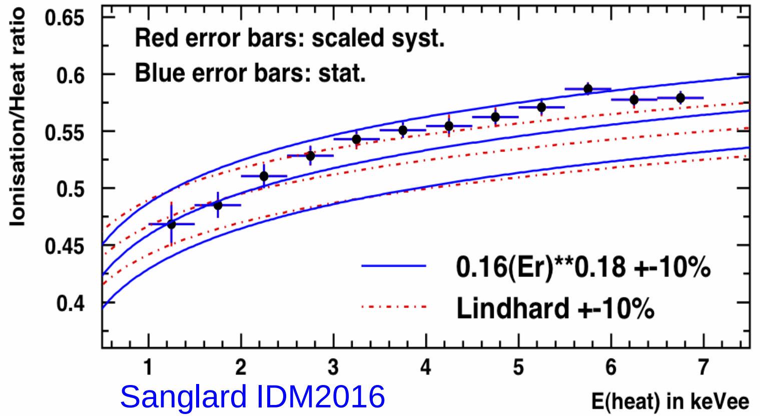
^{133}Ba γ calibration



>5000 kg.day equivalent

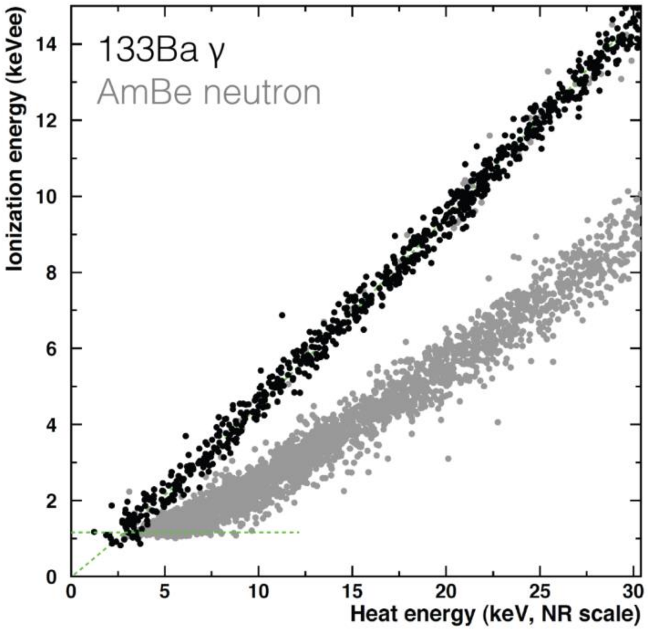
Nuclear recoil calibration - event discrimination





Sanglard IDM2016

- Clear **event-by-event** separation down to 5 keV energy (nuclear recoils)
- Response to nuclear recoils calibrated down to the analysis threshold for low-mass WIMP searches *(1 keV$_{ee}$ heat = 2.5 keV nuclear rec.)*

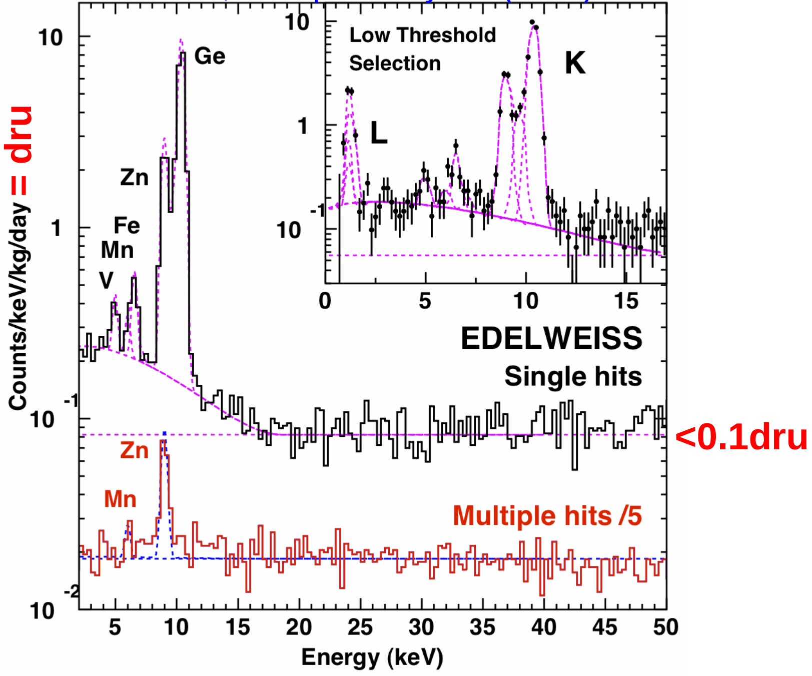


EDELWEISS-III 2014-2015 science run

161 days of physics data with 24 FIDs: >3000 kgd total exposure

Low ER bkg: 19 FIDs used in first measurement of cosmogenic production of ^{3}H in Ge

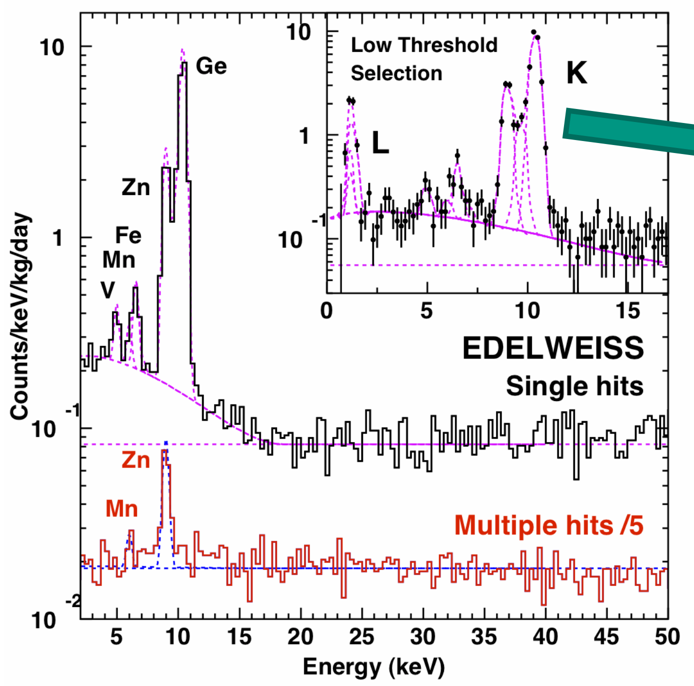
S. Scorza et al., Astropart. Phys.91(2017)51



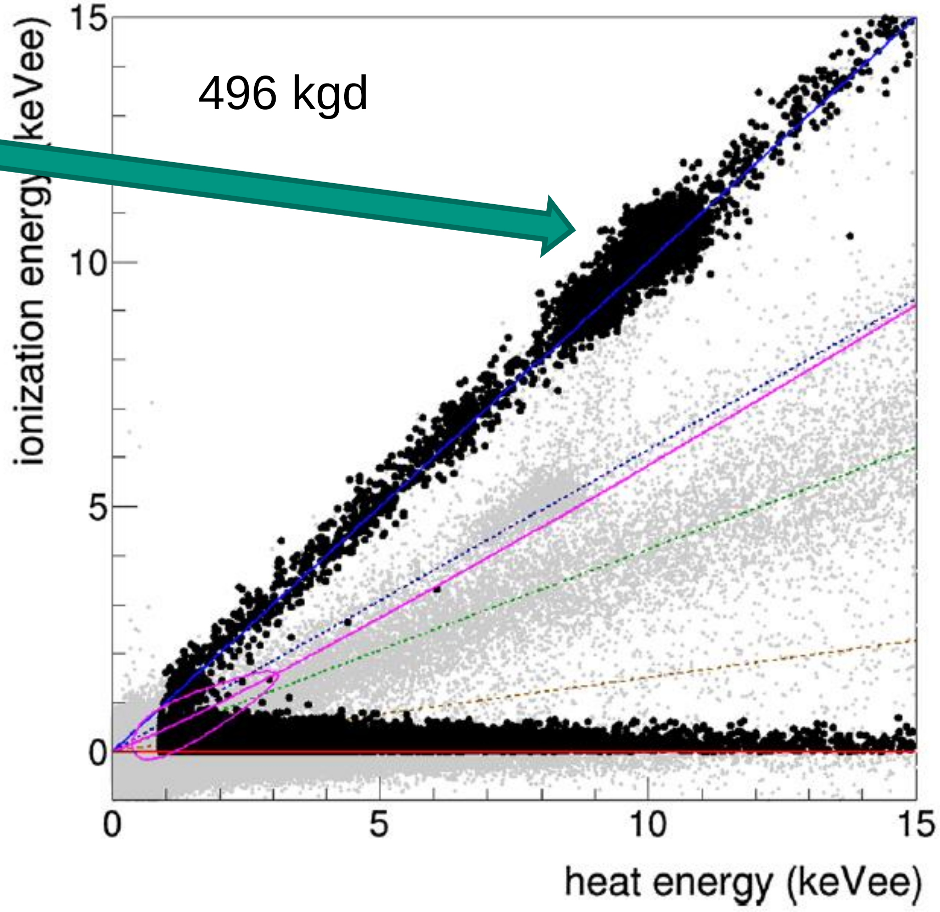
8 lowest threshold FIDs used for low-mass WIMP search

Low mass WIMP search with likelihood analysis

Electron recoils



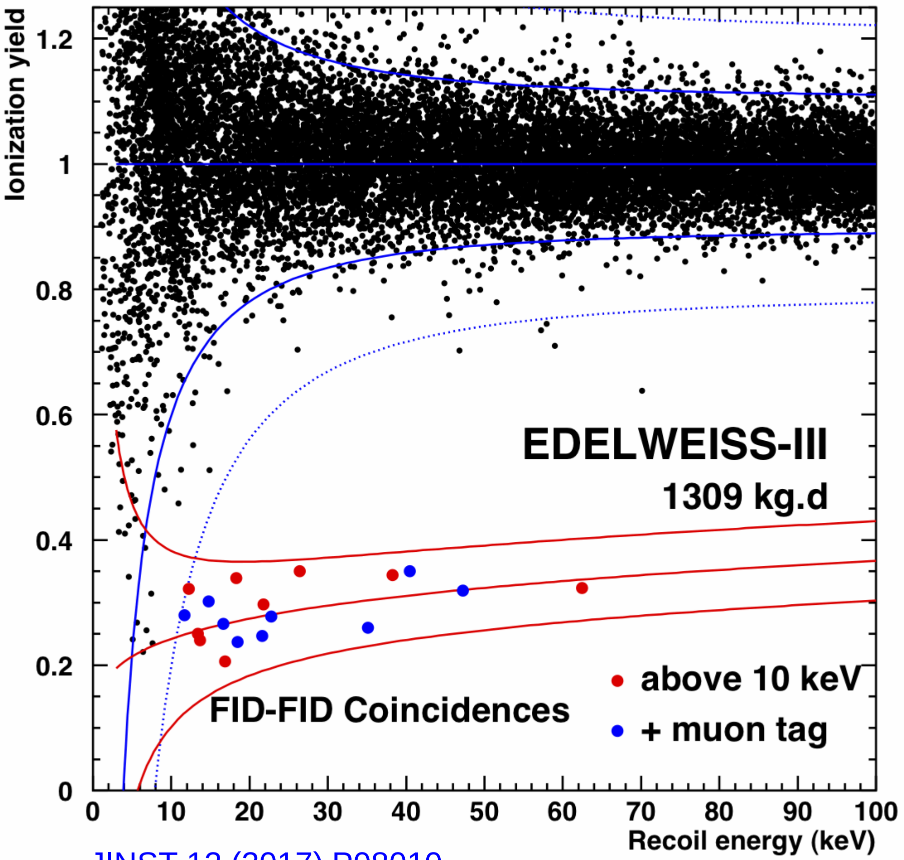
8 lowest threshold detectors



496 kgd

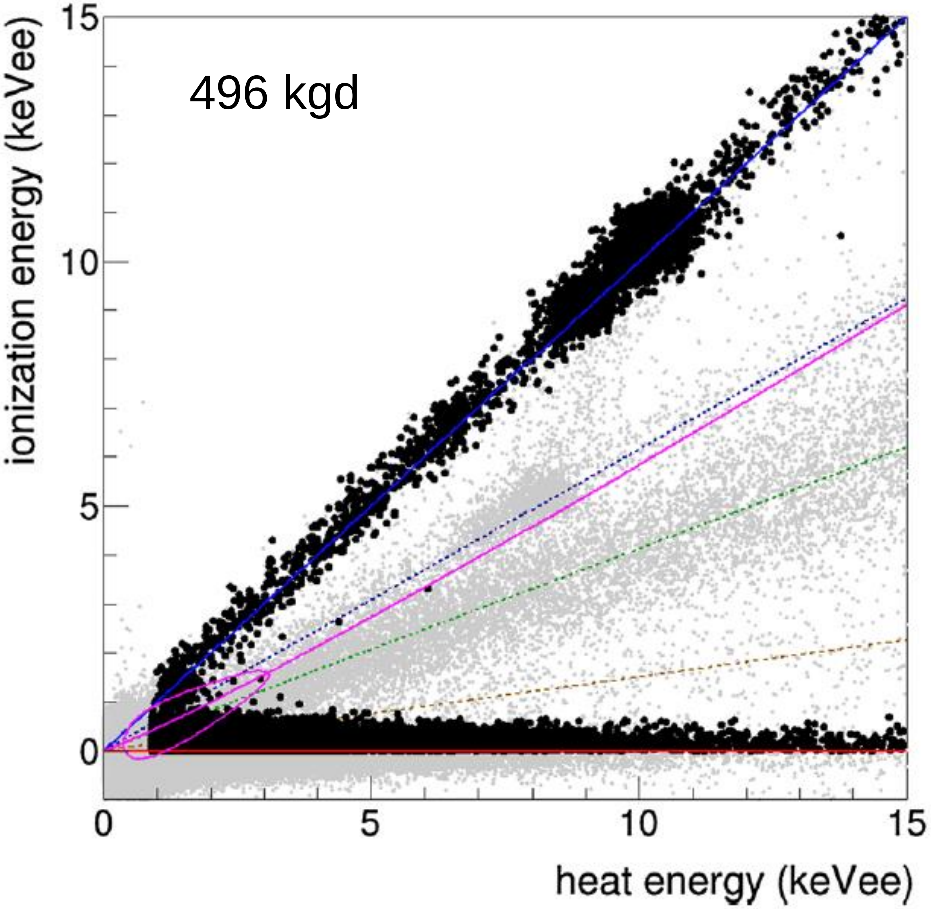
Low mass WIMP search with likelihood analysis

Nuclear recoils; neutrons



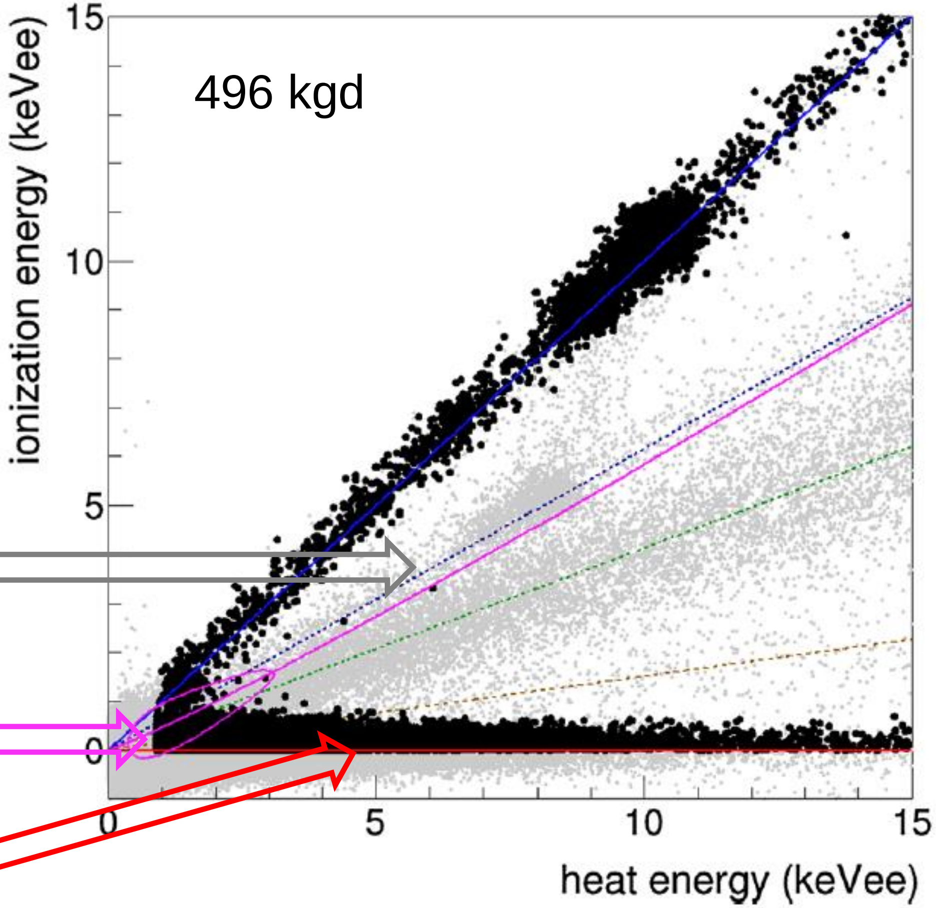
JINST 12 (2017) P08010

8 lowest threshold detectors



Low mass WIMP search with likelihood analysis

8 lowest threshold detectors



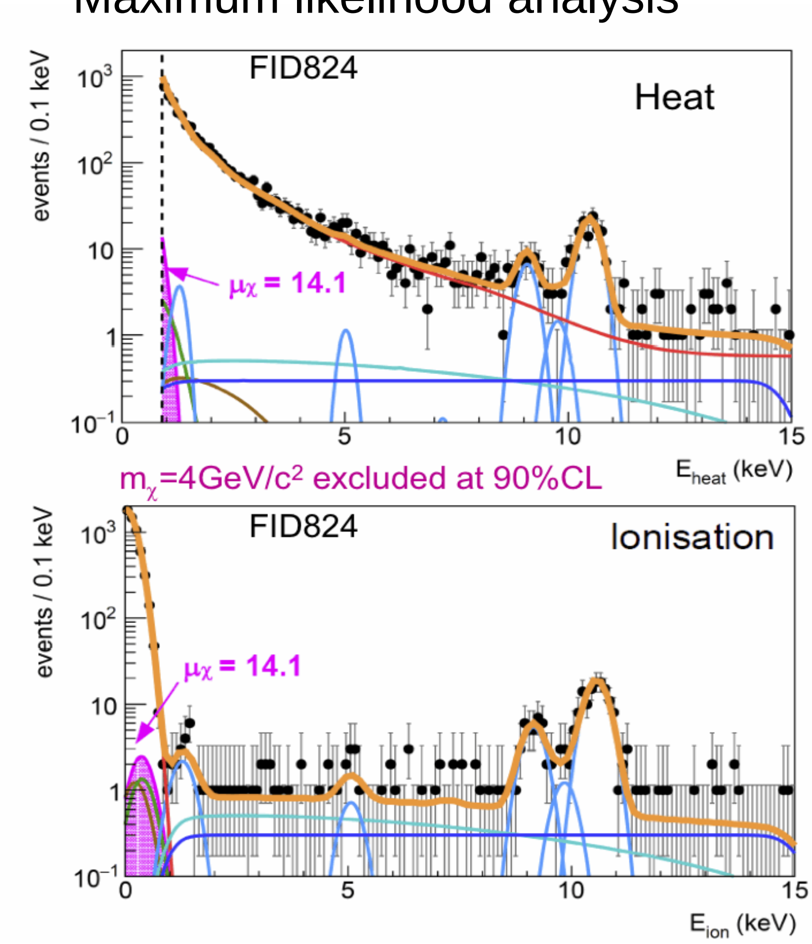
gray: rejected surface events

contour: 10 GeV/c^2 WIMP signal

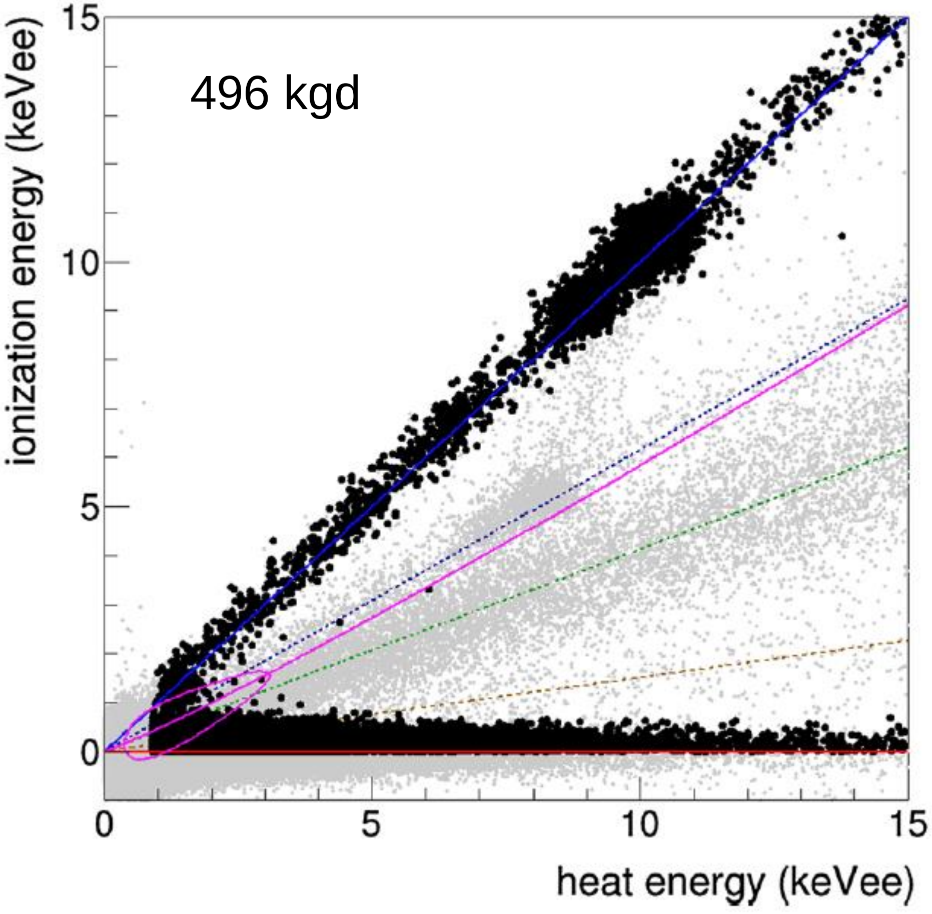
heat-only events

Low mass WIMP search with likelihood analysis

Maximum likelihood analysis



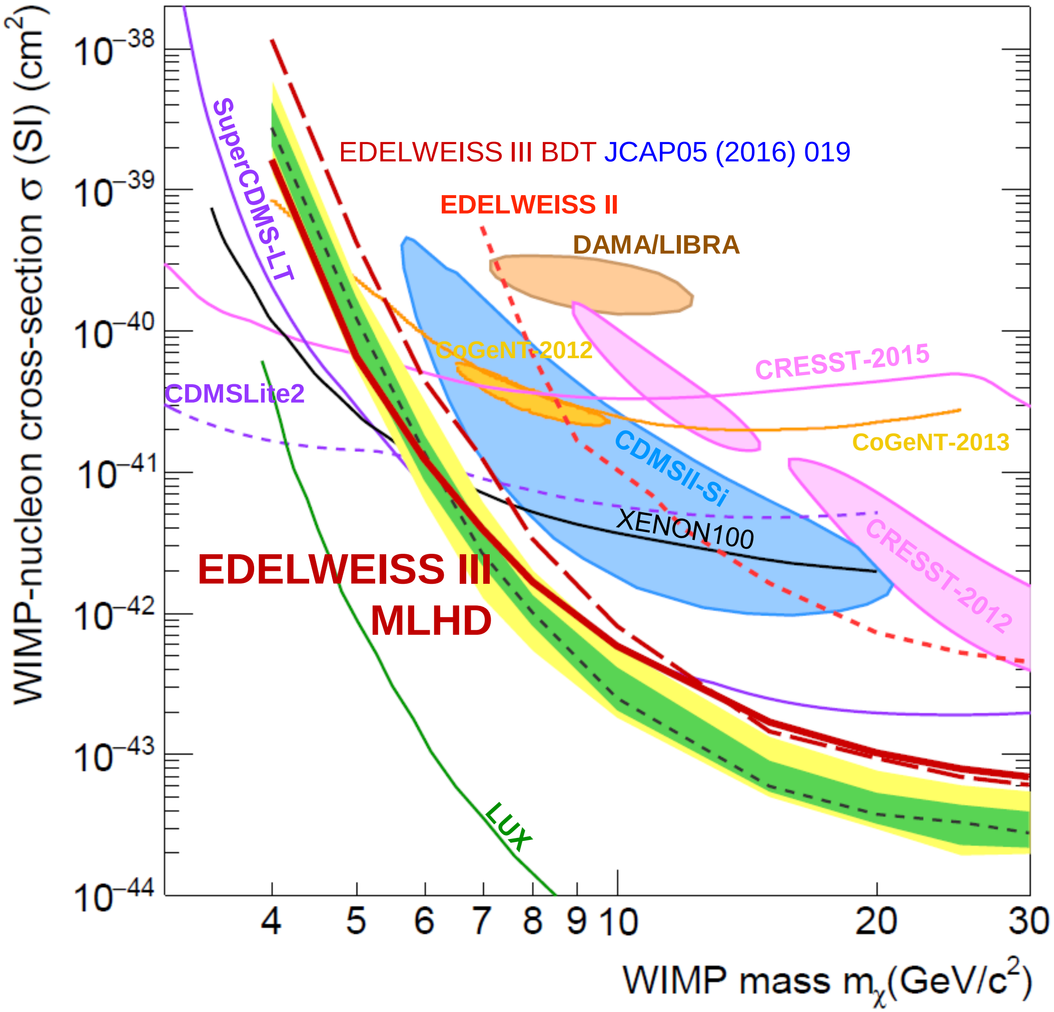
8 lowest threshold detectors



496 kgd

First results of EDELWEISS-III phase

L. Hehn et al., EPJC(2016)76:548

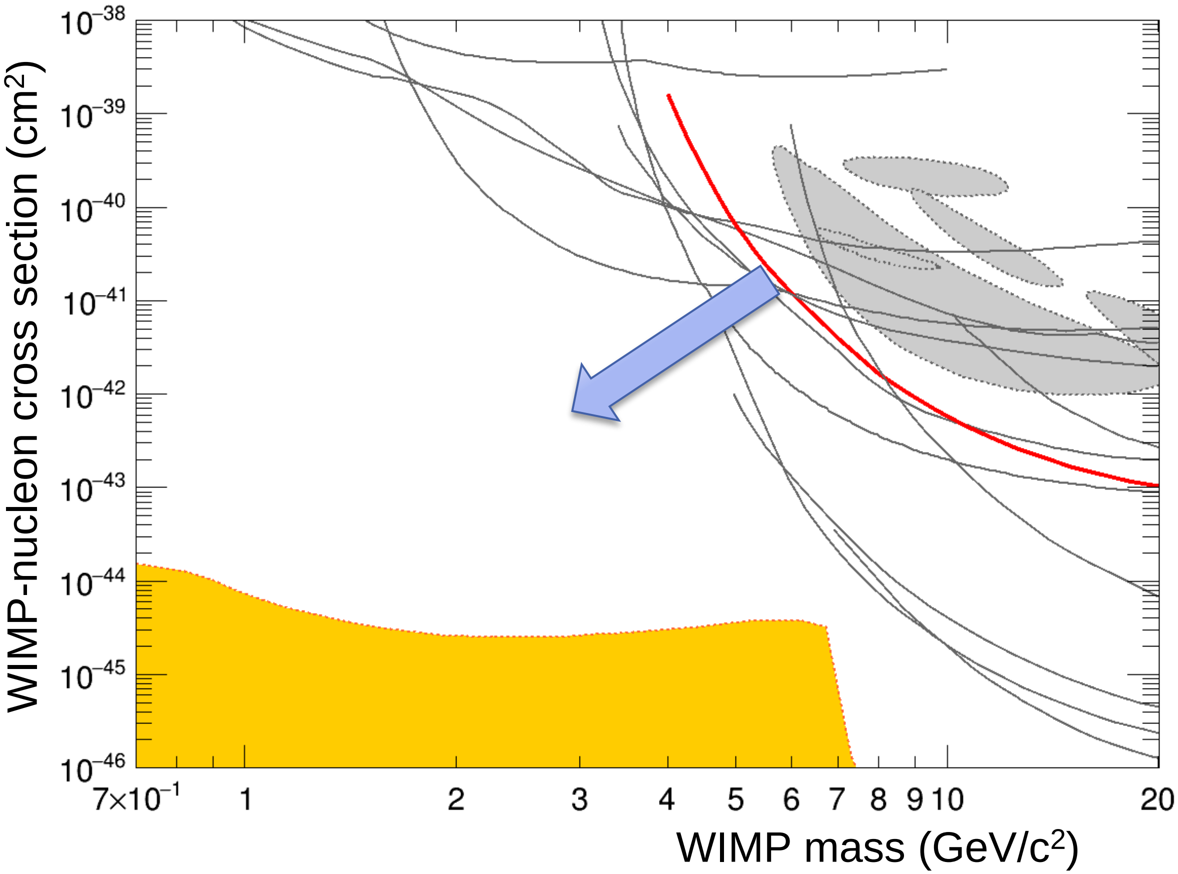


- Improvement by x 20-150 between 7 and 10 GeV wrt EDELWEISS-II

Lessons learned:

- Limited by heat-only bkd: identification and rejection using the σ = 230 eV resolution on ionization
- Ionization resolution is key for rejection
- **Heat resolution is key for low threshold**

EDELWEISS 2018 goals: low mass WIMP search



Challenges:

1. Neganov-Luke operation
   → V_{bias} = 8V → 100V
   achieved

2. Improved heat sensors
   → σ_{heat} = 500eV → 100eV
   achieved with 200g detector

3. HEMT transistor read out
   → σ_{ion} = 200eV → 100eV

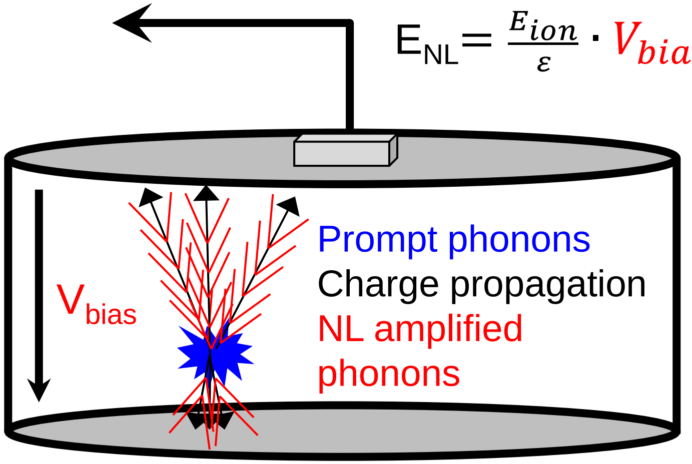
4. "Heat only" events
   → x100 reduction

Lower threshold by increased voltage

Neganov-Luke effect

$\Delta T \sim E_{heat} = E_{recoil} + E_{NL}$

$E_{NL} = \frac{E_{ion}}{\varepsilon} \cdot V_{bias}$



V_{bias}

Prompt phonons

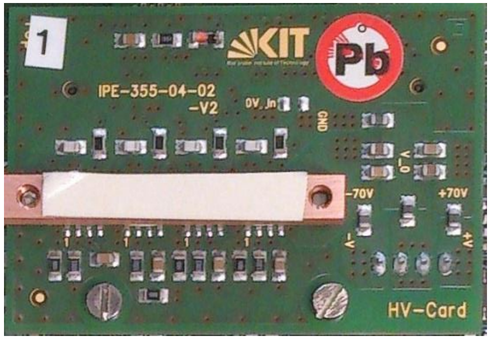
Charge propagation

NL amplified phonons

Detector bias upgrade:

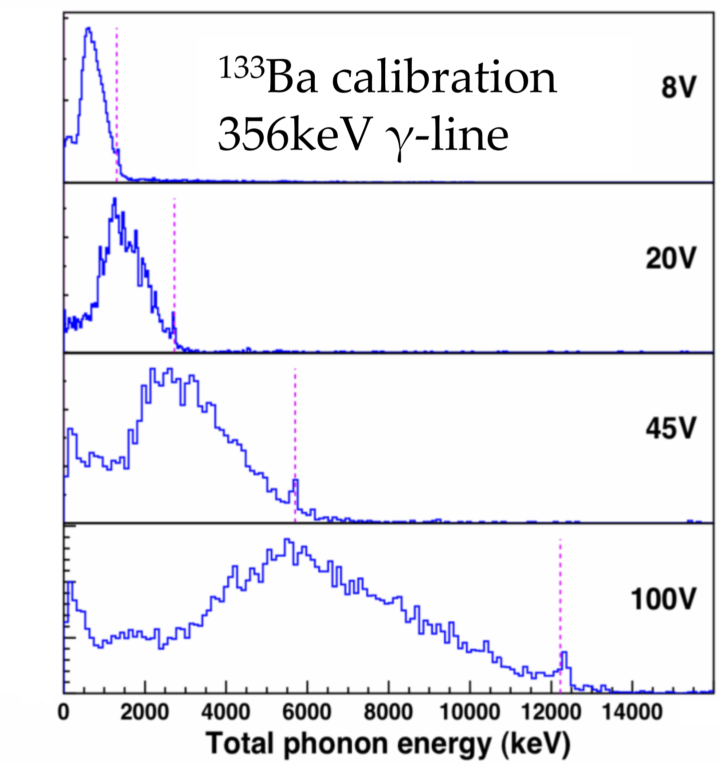
V_{bias} = 8V → 140V

Individual channel control



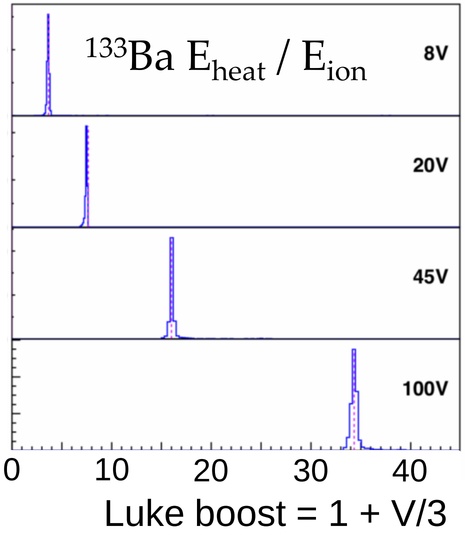
Luke-boost:

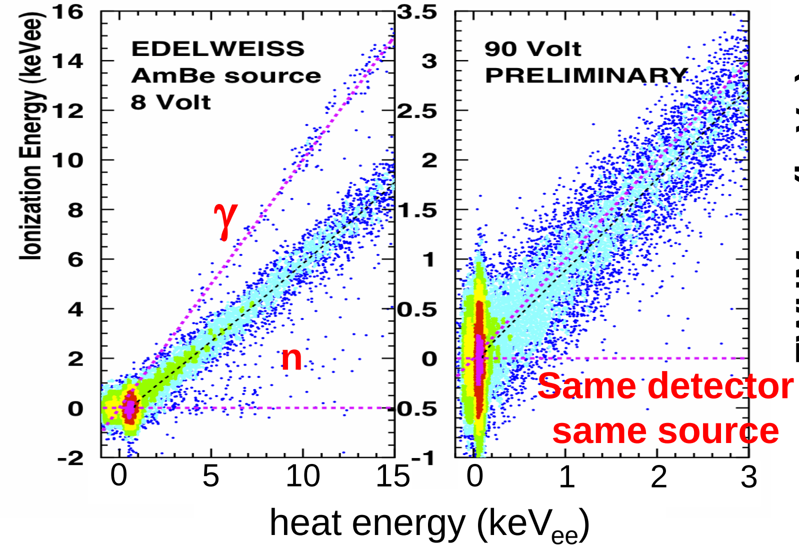
$$E_{heat} = E_{recoil}\left(1+\frac{V_{bias}}{3\ \mathrm{V}}\right)$$

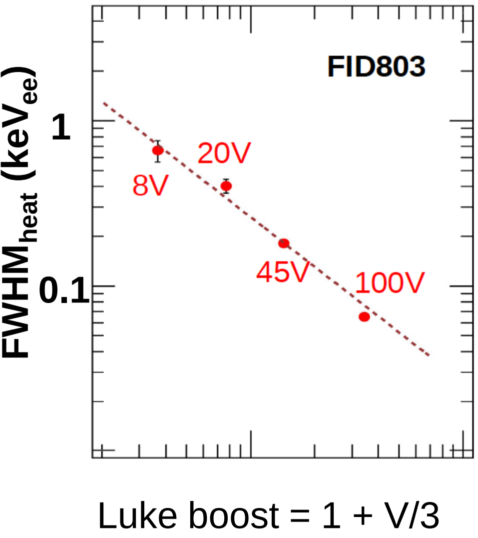


Ionization signal measured via heat channel
→ No particle discrimination at threshold

Confirmation of NL-mode and amplification







Luke boost ✓

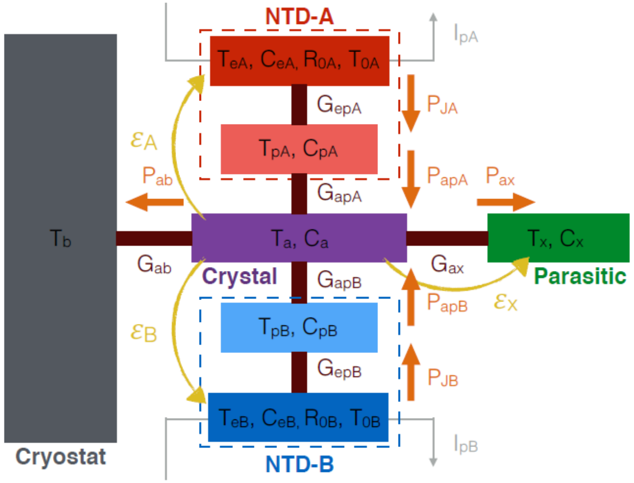
as expected:
loss of event-by-event discrimination

improved threshold ✓

no additional noise ✓

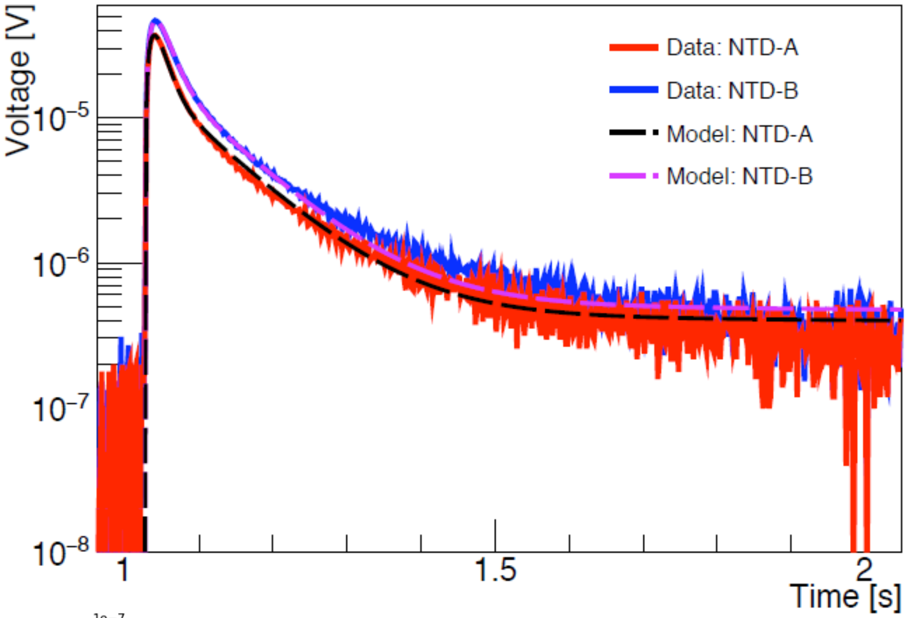
Detector R&D: Thermal model & heat sensor

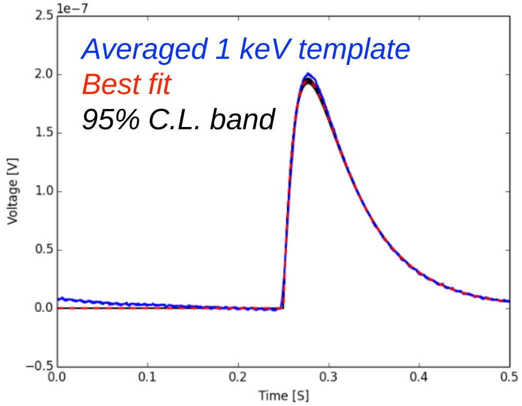
- Better understanding of heat signal
  - Thermal modeling of signal, verified with dedicated R&D
  - Identification of sensitivity to ballistic phonons
  - Identification of parasitic heat capacity



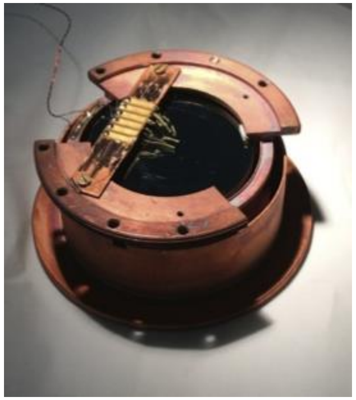
- Sensitivity of 200 nV/keV
  - (x6 wrt present FIDs) achieved on 250 g test detectors

J. Billard et al., JLTP(2016)184:299



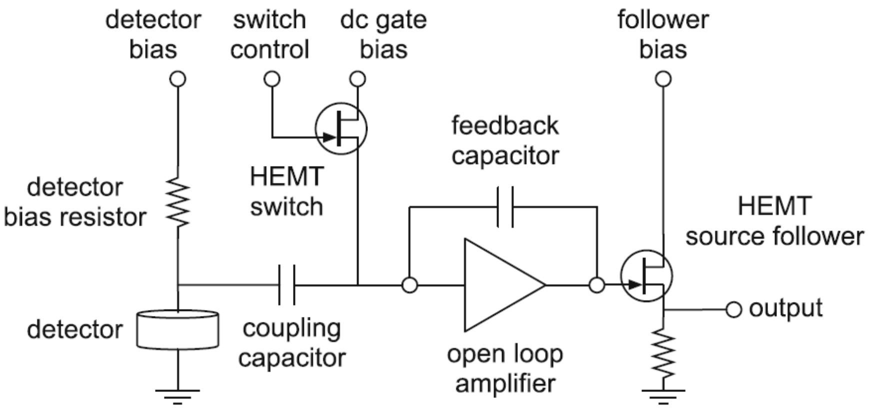


Averaged 1 keV template
Best fit
95% C.L. band



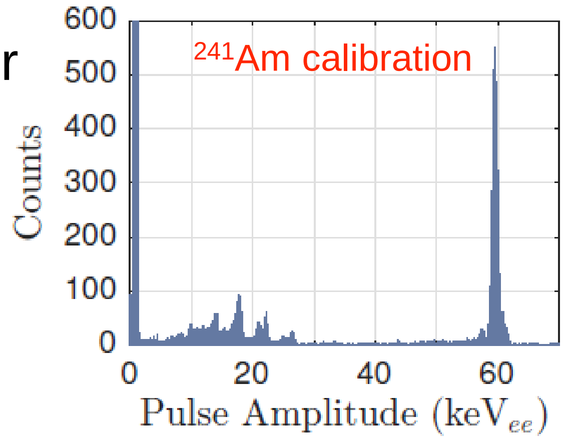
Detector R&D: HEMT read out

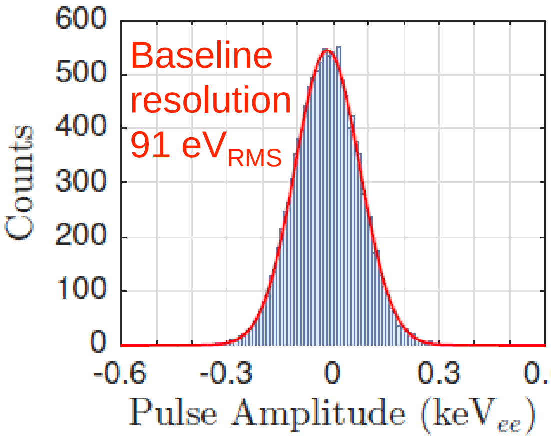
- JFET → HEMT
  - Reduced intrinsic noise
  - Lower heat load
  - Operates at 4K stage
    - →shorter cabling
    - Reduced capacitance
    - Better SNR



- Successful HEMT amplifier with sub-100 eV_{RMS} ionization resolution

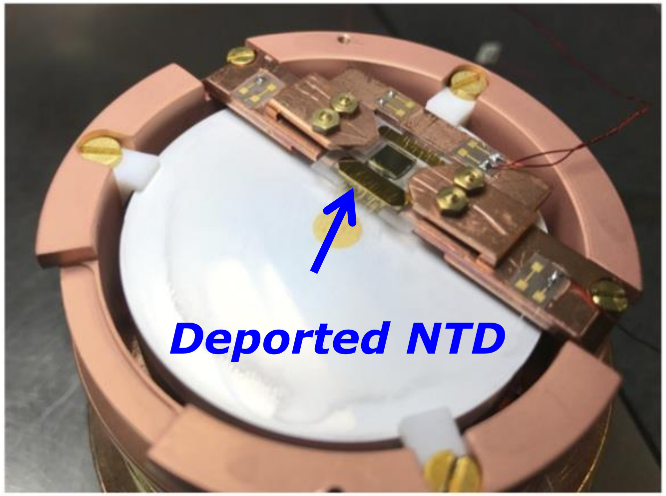
A. Phipps et al., JLTP(2016)184:505
collaboration between SuperCDMS and EDELWEISS

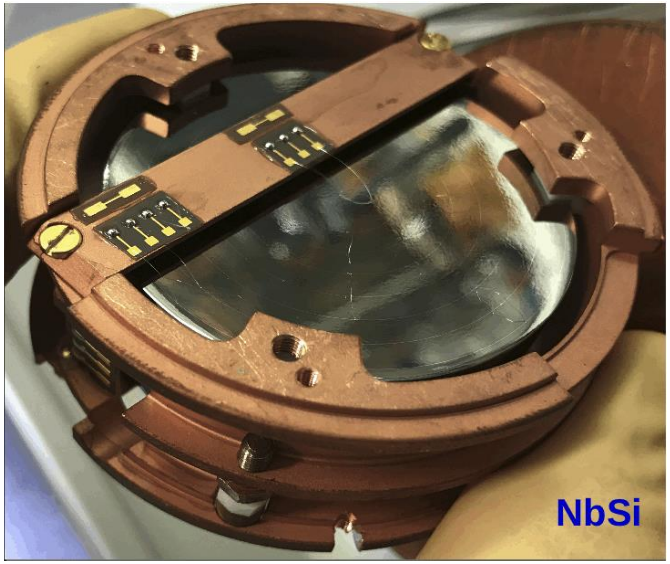




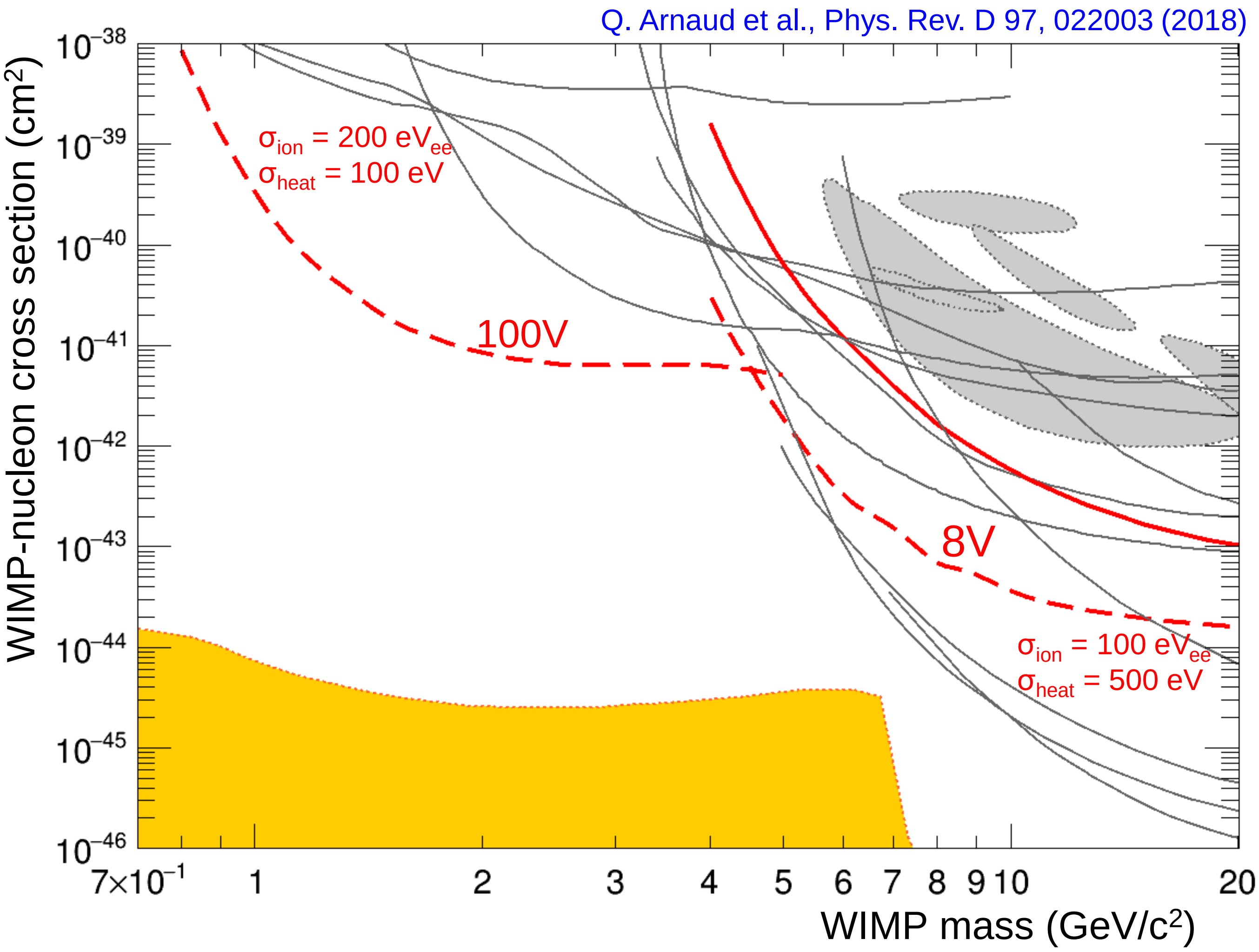
Detector R&D: reducing heat only events

- Signals on both NTDs, but no ionization signal
- Many studied hypotheses, none conclusive so far: noise, cryogenics, stress from detector suspension, gluing, natural radioactivity…
- New detector configuration being tested to study these hypotheses
  - “deported NTD”, glued on separate sapphire wafer
  - Photo-lithographed high-impedance NbSi TES, sensitive to athermal phonons
- **Dominant at low energy, but sufficiently reproducible for analysis of present 100V data**





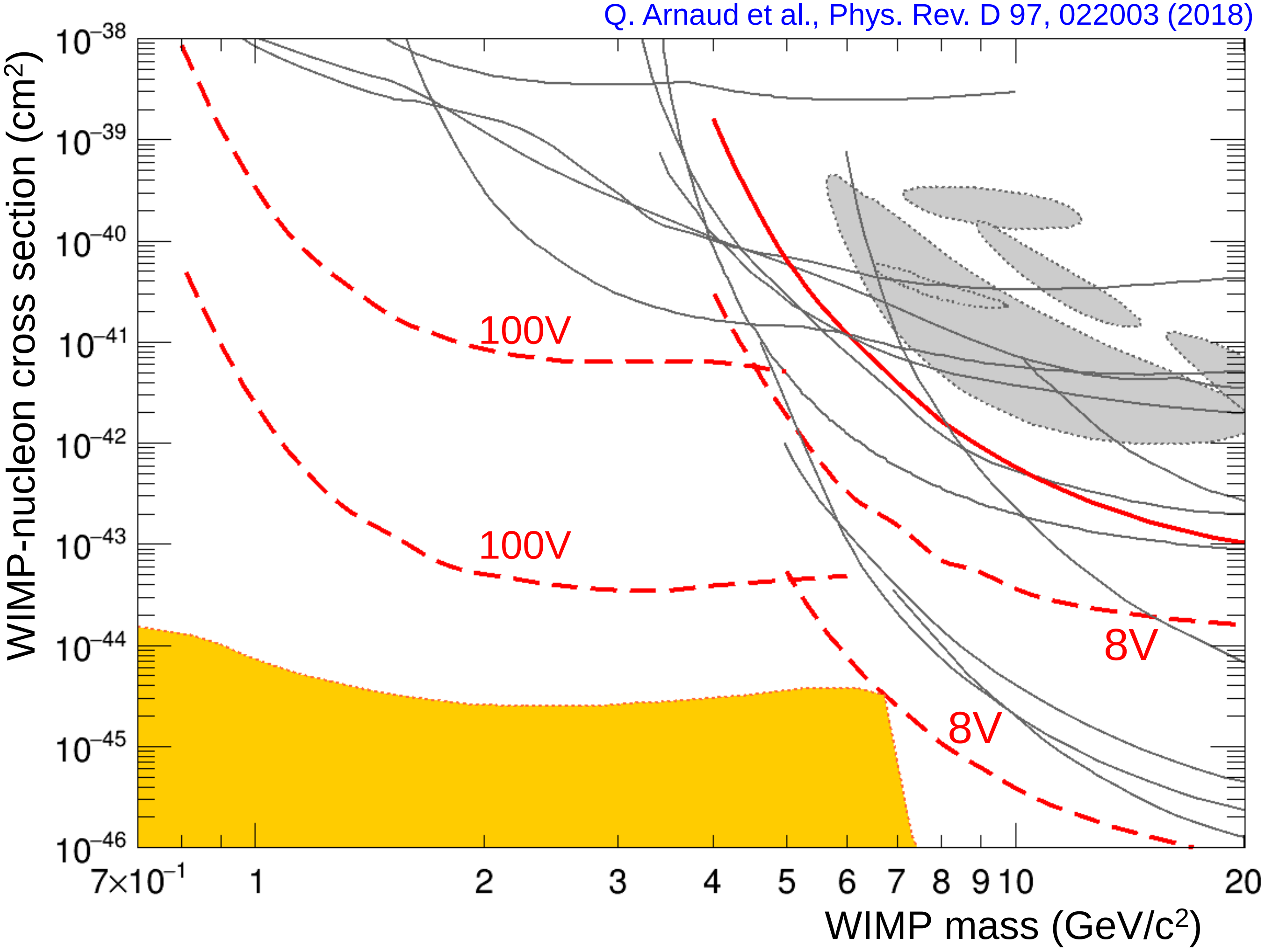
EDELWEISS-LT sensitivity



EDELWEISS-III goals 2018/19
with present bgd
500 kgd

Potential EDELWEISS-LT technology

Q. Arnaud et al., Phys. Rev. D 97, 022003 (2018)

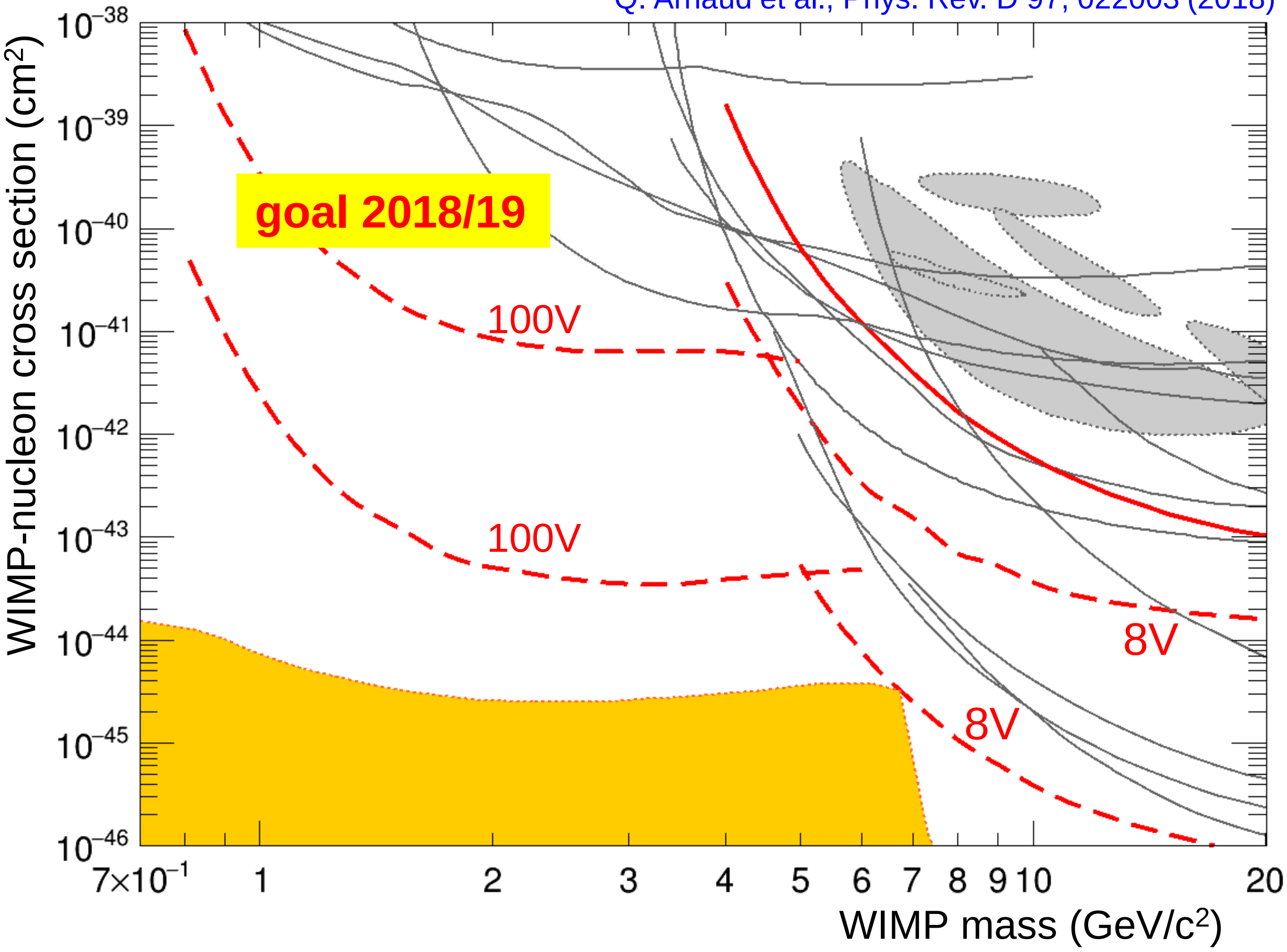


EDELWEISS
technology potential
50.000 kgd
σ_{ion} = 100 eV$_{ee}$
σ_{heat} = 100 eV

but:
no heat-only bgd
no neutrons
compton / 10

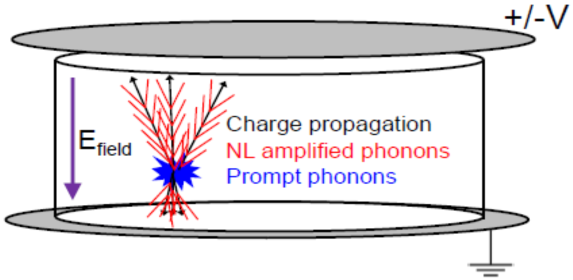
EDELWEISS-LT sensitivity

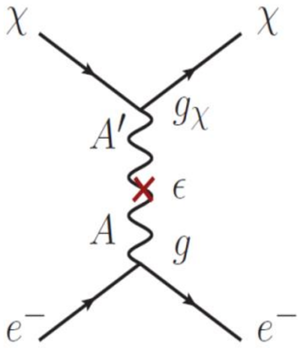
Q. Arnaud et al., Phys. Rev. D 97, 022003 (2018)

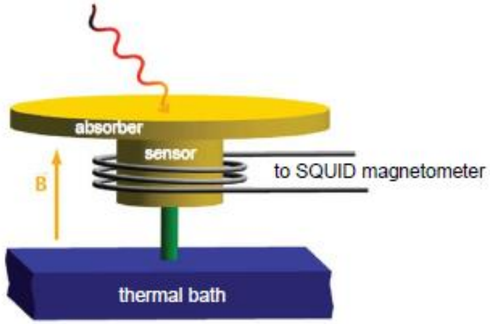


Search for Light Dark Matter with DELight

Cooperation of University of Heidelberg and KIT
Combining HPGe crystal with vacuum electrode and metallic magnetic calorimeter



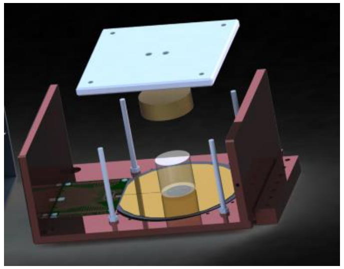


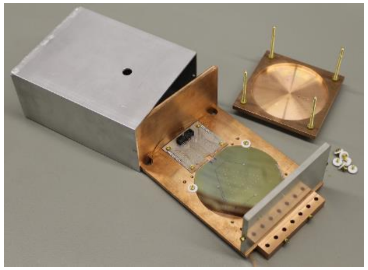


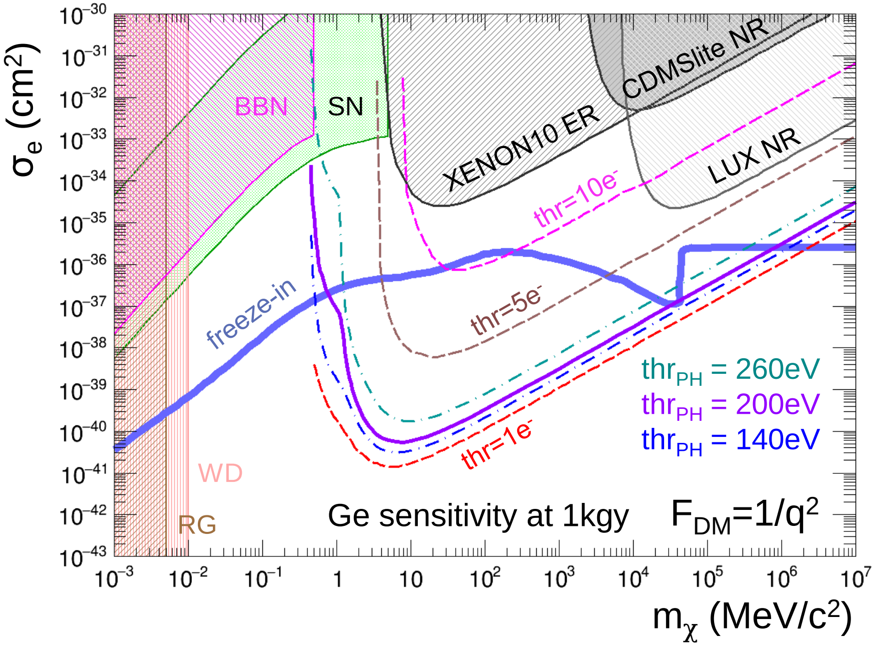
A. Fleischmann, C. Enss, G.M. Seidel,
Metallic Magnetic Calorimeters in
Cryogenic Particle Detection
(Topics Appl. Phys. 99, p151-216,
ed. C. Enss, Springer 2005)

$\Delta E_{FWHM} = 1.6$ eV

A. Fleischmann et al.,
AIP Conference Proceedings,
1185 (2009) 571

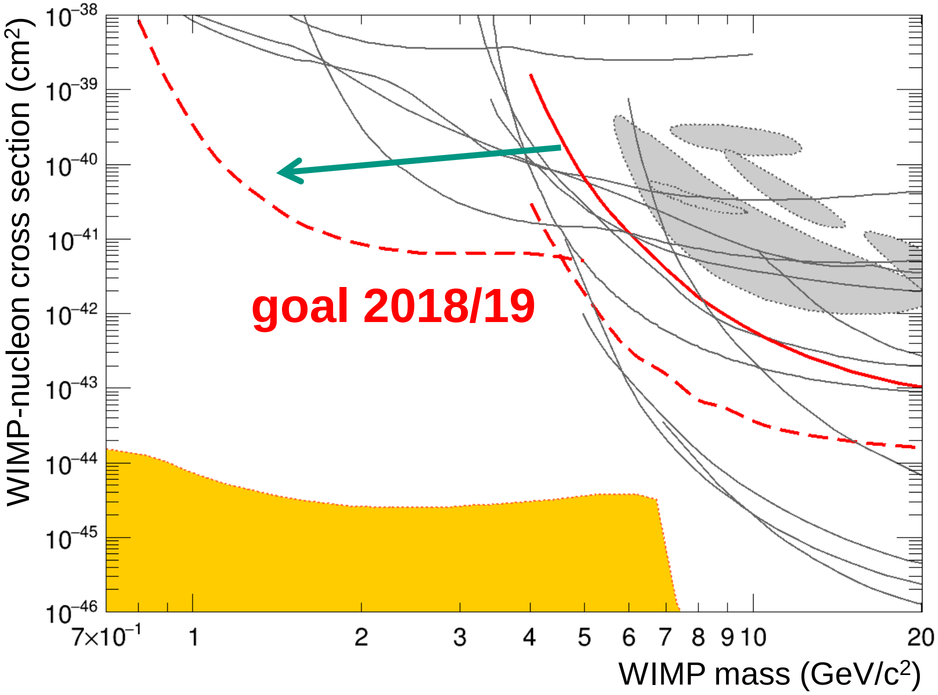






Conclusions

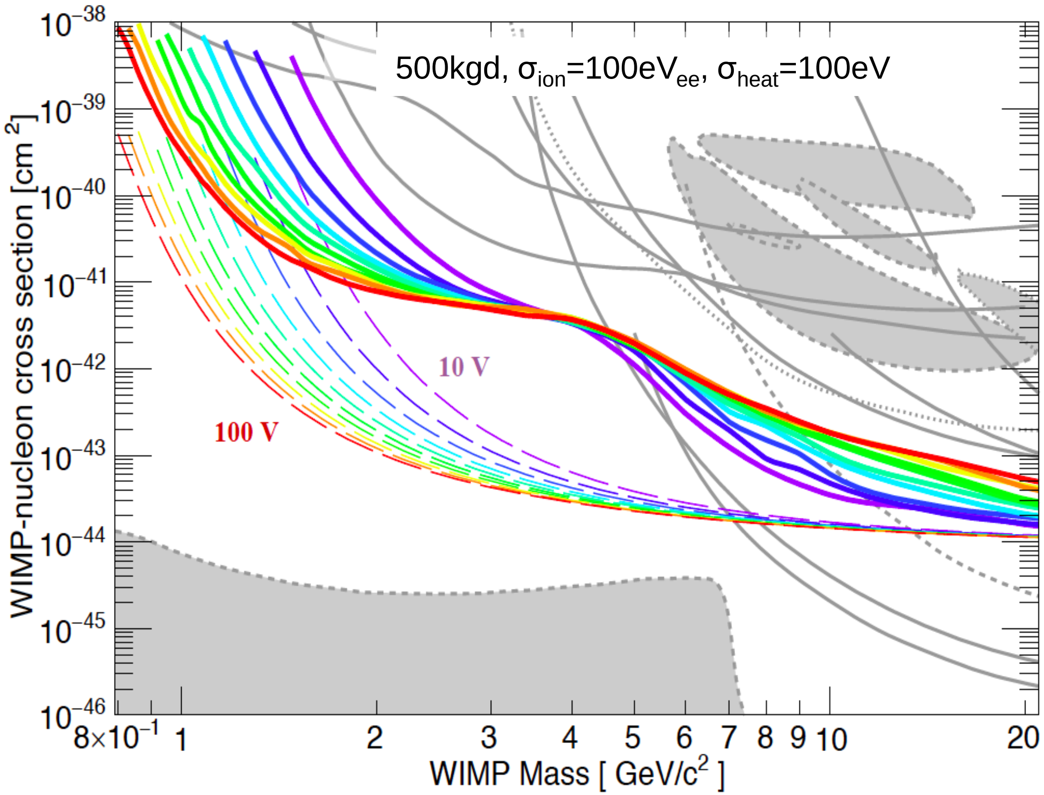
- Factor 20 to 150 improvement wrt EDELWEISS-II phase
- Present threshold $<0.1\mathrm{keV}_{ee}$
- Objective: operate 4 detectors at 100V
  - $10^{-41}\mathrm{cm}^2$ sensitivity at low mass
- Data already recorded at 100V
- Analysis of HV data under way



Backups

- With projections of other experiment…

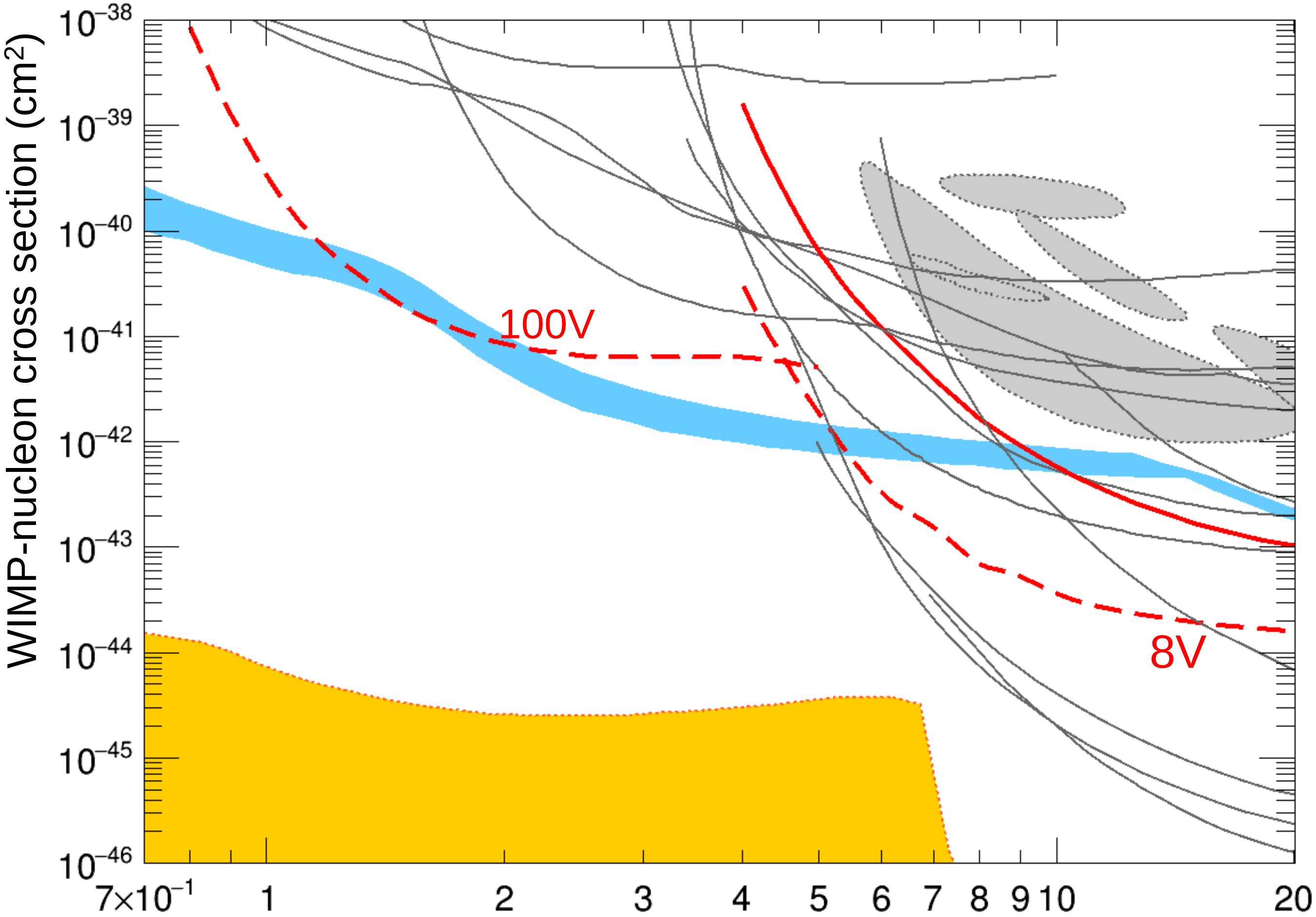
EDELWEISS proj. for different voltages



Phys.Rev.D97,022003(2018)

- Heat signal boosted by Luke effect:
  - ~Joule heating, factor [1+V$_{bias}$/3]
- Loss of ionization-based bkg discrimination:
  - method benefits low-mass searches only
  - 10^{-41} cm^2 with 500 kgd and current bkgs
- 100 V bias already achieved
- Observe nuclear recoils down to ~0.1 keV$_{ee}$

EDELWEISS-LT sensitivity

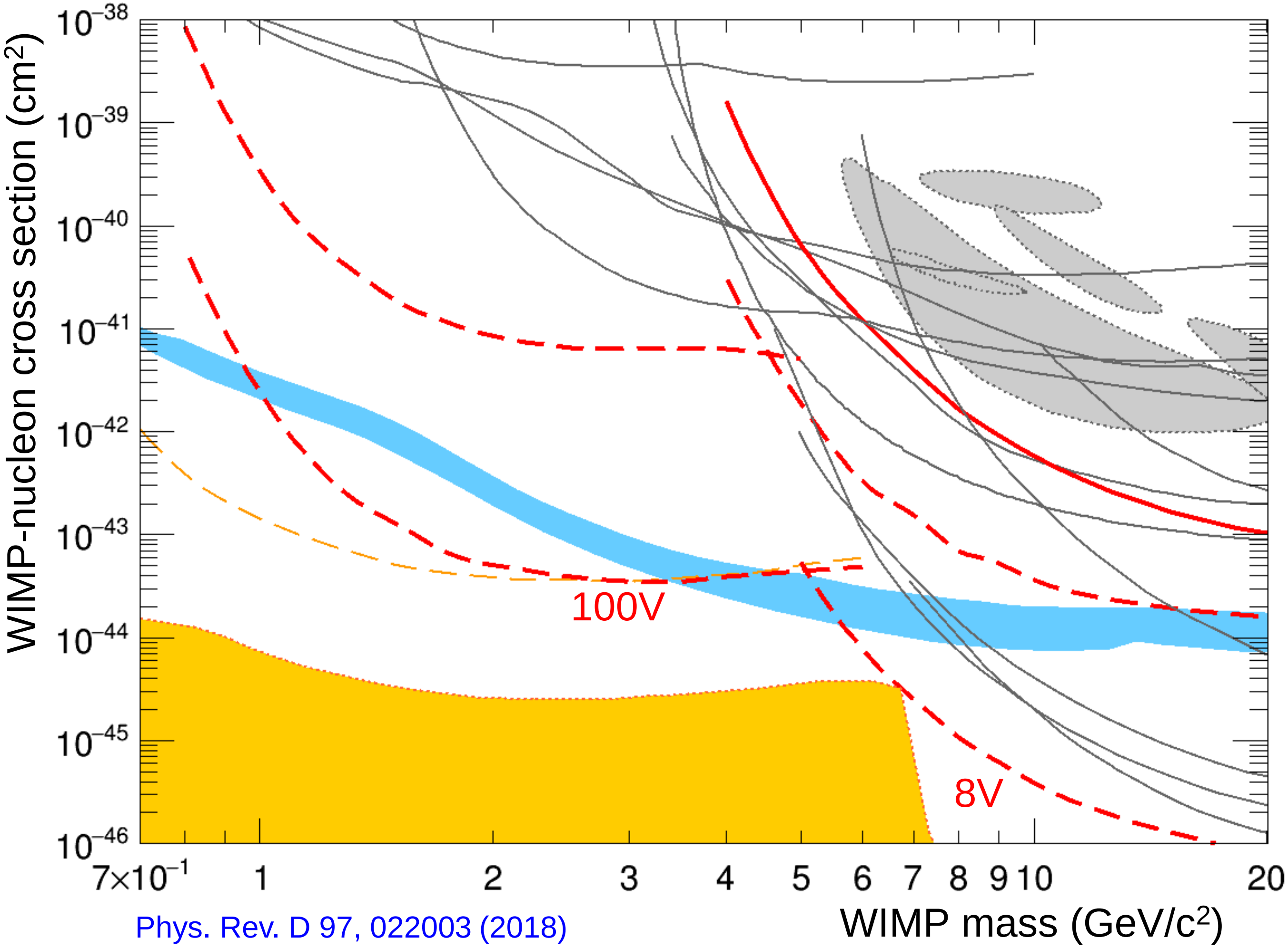


Phys. Rev. D 97, 022003 (2018)

EDELWEISS-III goals
2018
with present bgd
500 kgd
σ_{ion} = 100 eV_{ee}
σ_{heat} = 100 eV

CRESST-III Phase 1
50 kgd

EDELWEISS-LT sensitivity



Phys. Rev. D 97, 022003 (2018)

EDELWEISS
technology potential
50.000 kgd
σ_{ion} = 100 eV_{ee}
σ_{heat} = 100 eV
no heat-only bgd
no neutrons
compton / 10

CRESST-III Phase 2
1000 kgd

SuperCDMS SNOLAB
Ge, 100V
16.060 kgd
σ_{heat} = 10 eV
Phys. Rev. D 95, 082002