Prospects for light WIMP searches with EDELWEISS

Context

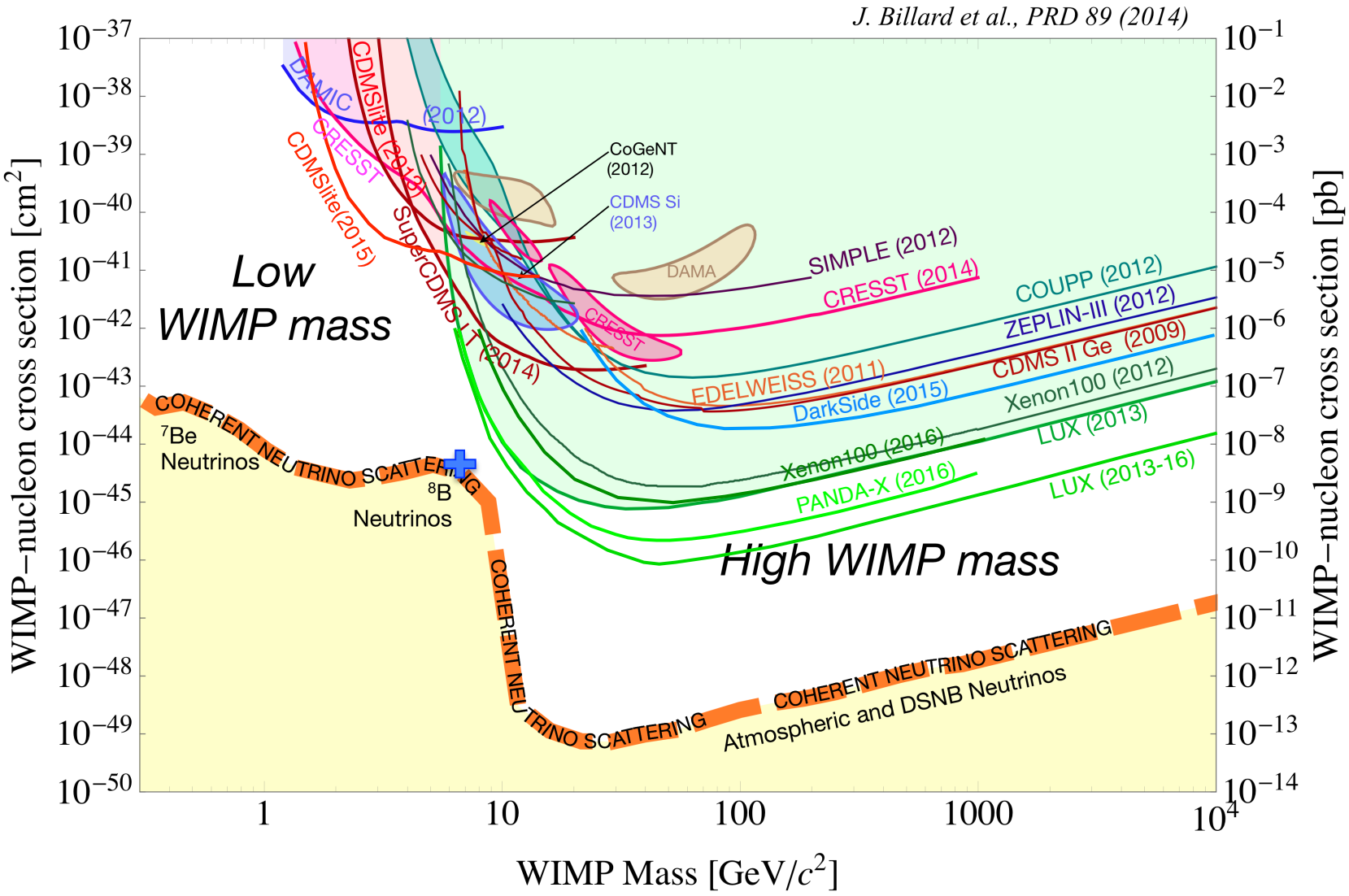
Present status of EDELWEISS-III

Prospects for ~GeV scale masses

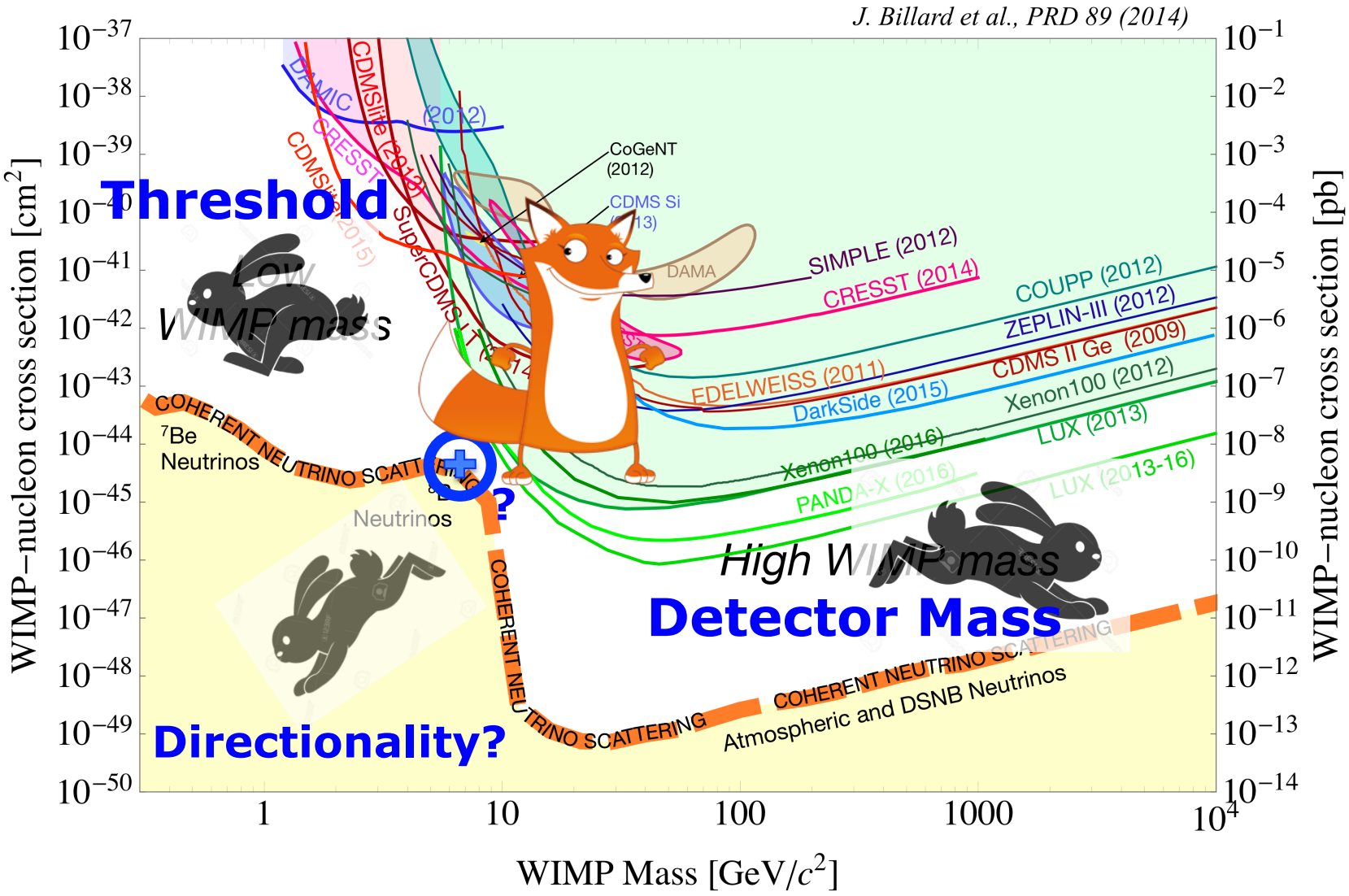
Prospects for the ^{8}B region

Jules Gascon
(IPNLyon, Université Lyon 1 + CNRS/IN2P3)

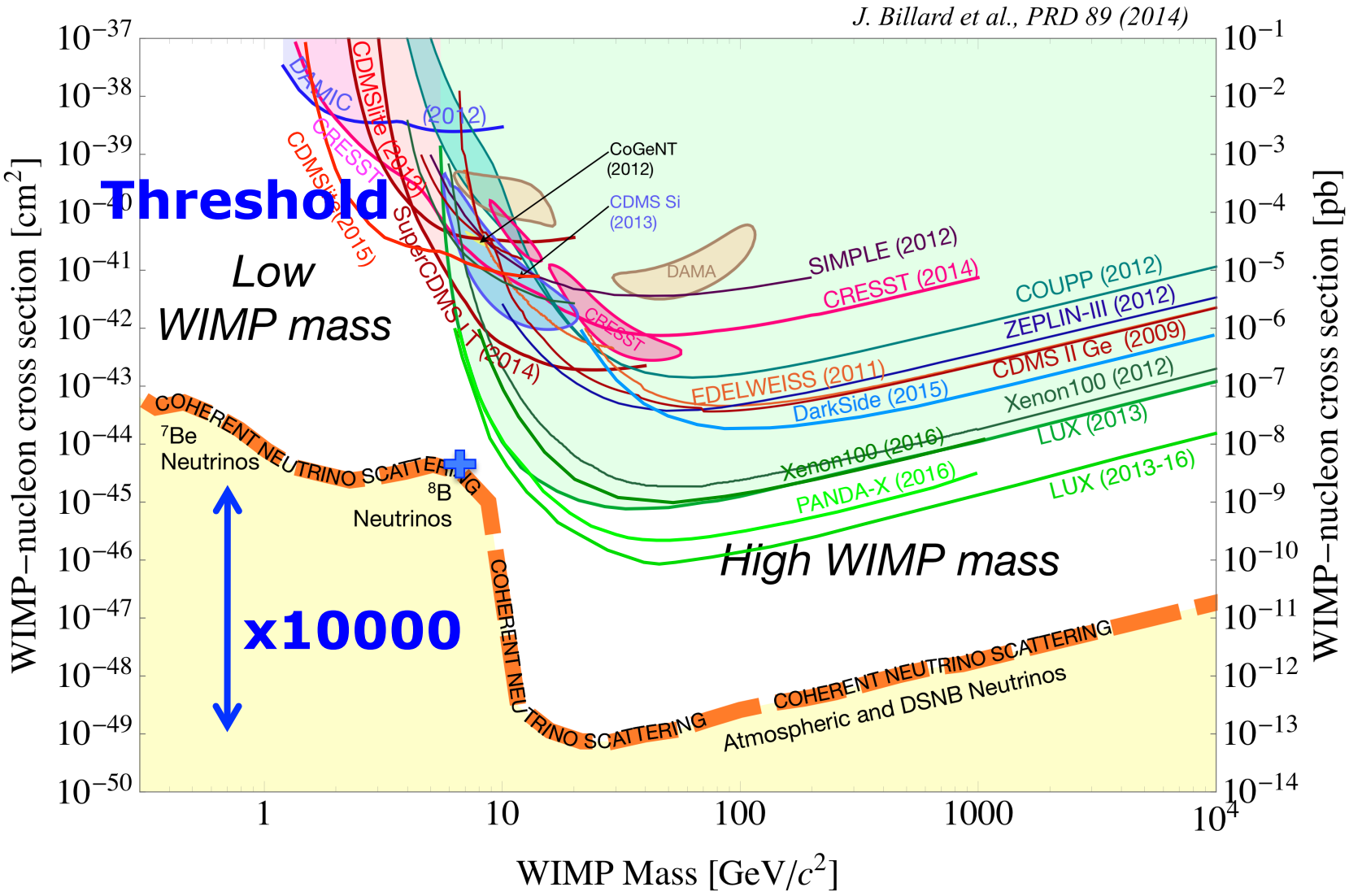
Direct searches at low and high masses



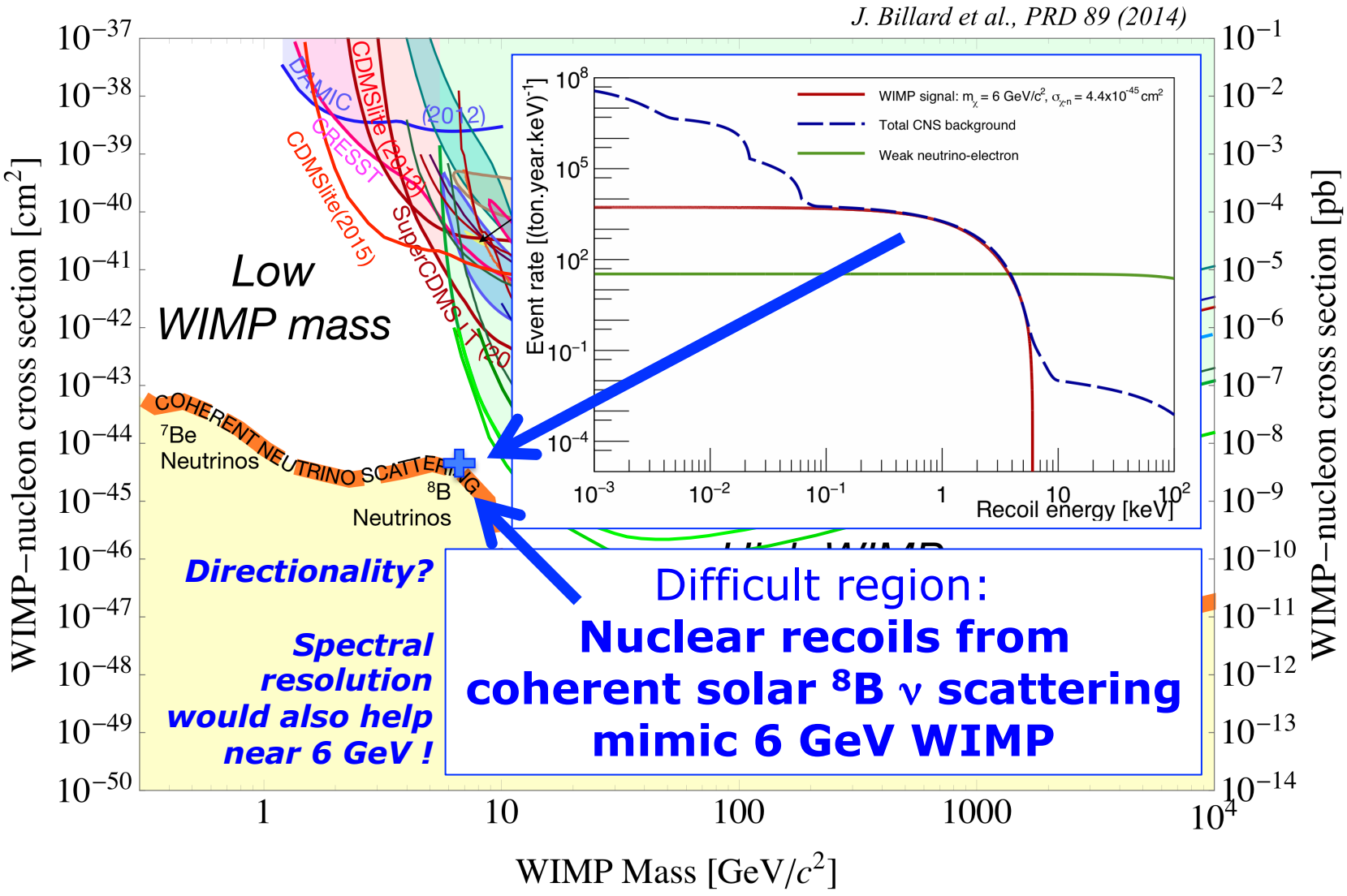
Where to hunt?



The GeV region

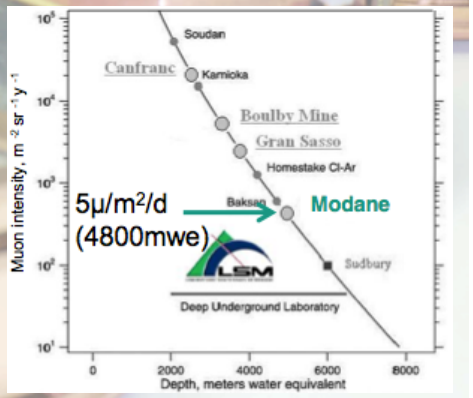


The ^{8}B region



The EDELWEISS Experiment

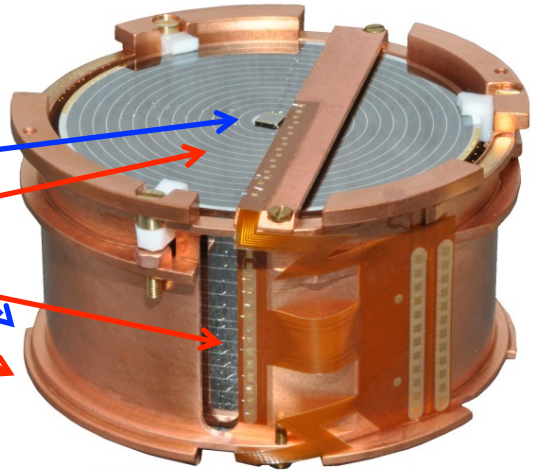
- **Direct detection of WIMPs, germanium target**
- **20 kg Ge total, 870g units**
- **Ionization + Heat**
- **Simple & robust design**
  - **Important for scalability to large arrays**
  - **Initially designed for >20 GeV WIMP search, extended down to 5 GeV given achieved resolutions**
- **Laboratoire Souterrain de Modane**
  - **Deepest in Europe : 5 μ/m²/day**

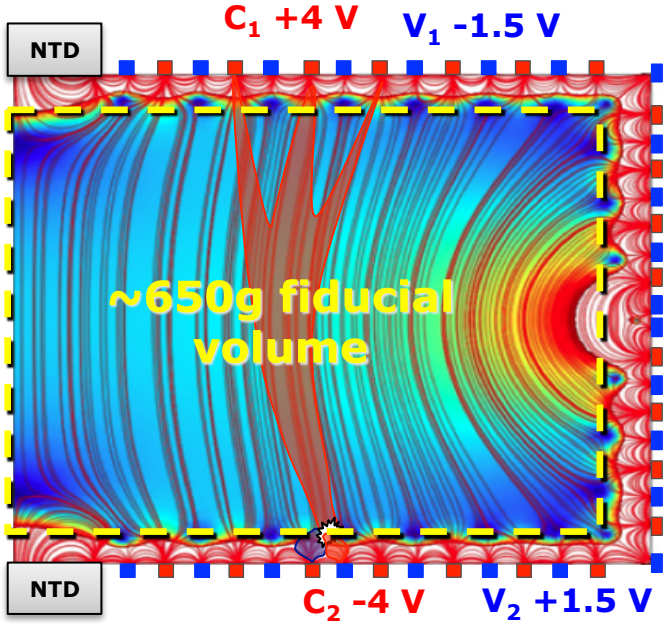


Fully InterDigitized electrode design

- ~870g detectors (ϕ=70 h=40 mm)
- 2 GeNTDs heat sensor per detector
- Electrodes: concentric Al rings (2 mm spacing) covering all faces
- XeF_2 surface treatment to ensure low leakage current (<1 fA) between adjacent electrodes

J Low Temp Phys (2014) 176: 182-187





Surface event rejection

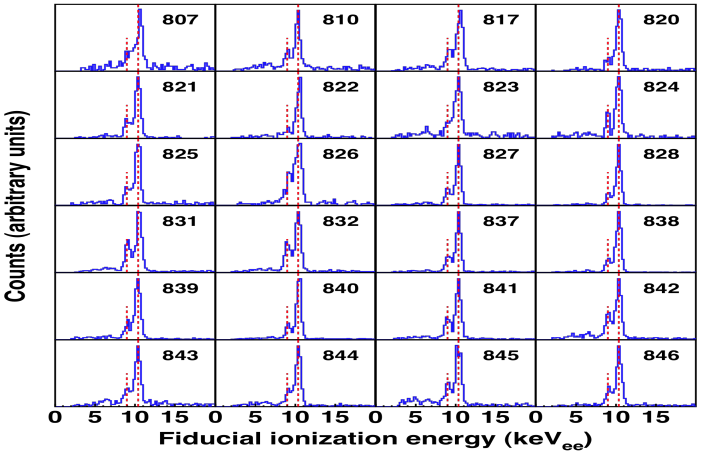
Phys Lett B 681 (2009) 305–309

- Bulk event: charges collected by C_1 and C_2: V_1 and V_2 act as veto
- Surface events: charges collected by either C_1V_1 or C_2V_2

EDELWEISS-III 2014-2015 data taking

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

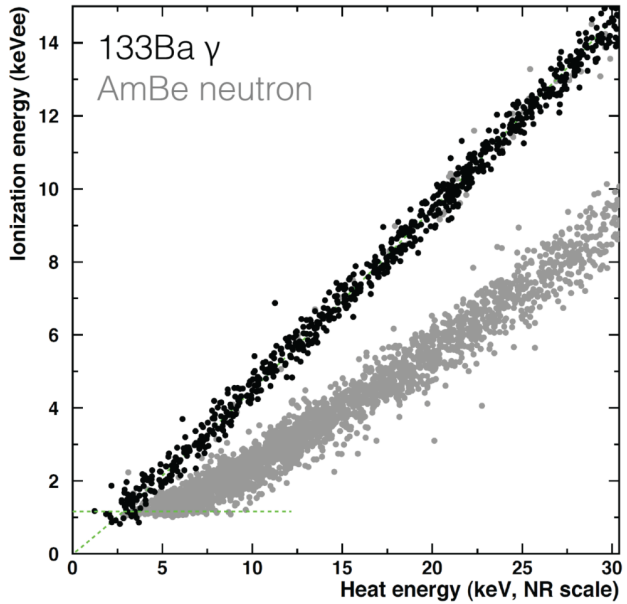
- 24 FID with good resolutions and threshold > 5 keV_{ee} (performance studies, coincidences)

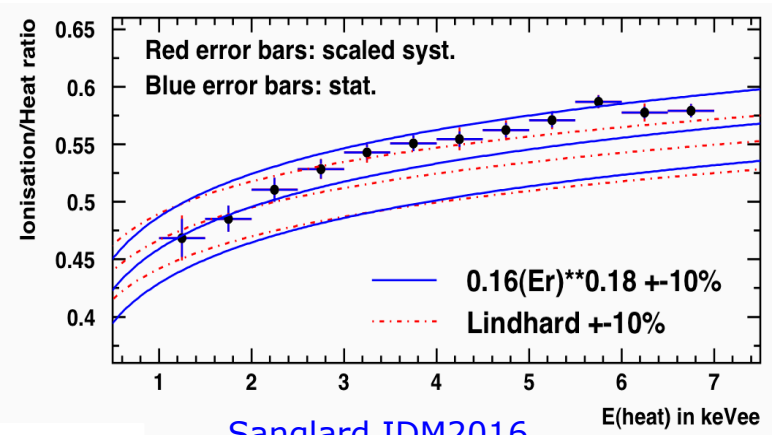


Clear 10 keV peak on all FIDs

- 19 FID with > 2 keV_{ee} (used for study of cosmogenics + ^{3}H, etc.)
- 8 lowest threshold FIDs used for low-mass WIMP search

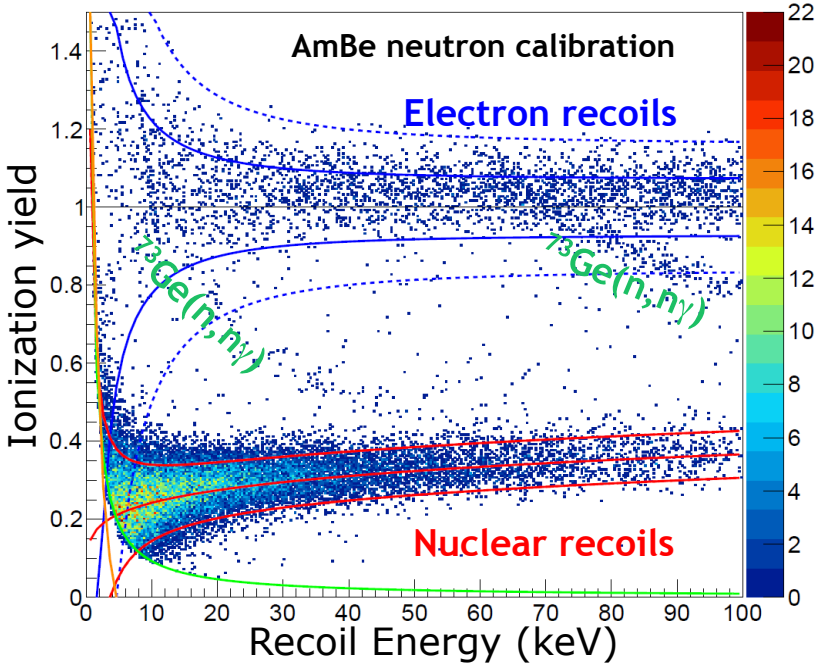
Nuclear recoil calibration + discrimination





Sanglard IDM2016

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



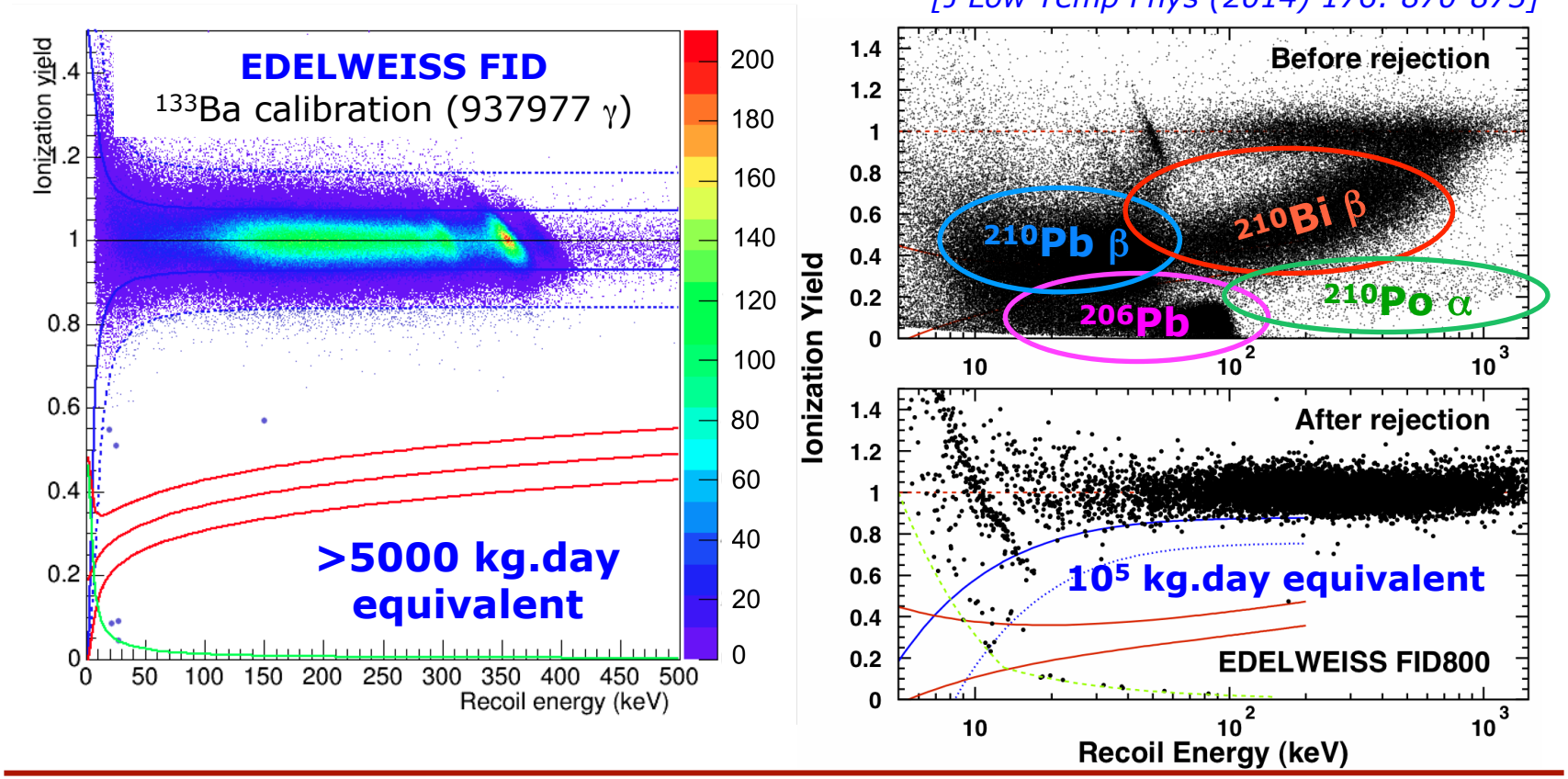
Gamma rejection & Surface rejection

- γ rejection factor: < 5.6 x 10^{-6} *[J Low Temp Phys (2012) 167: 1056-1062]*

  Updated now to < 2.5 x 10^{-6} with additional detectors + statistics

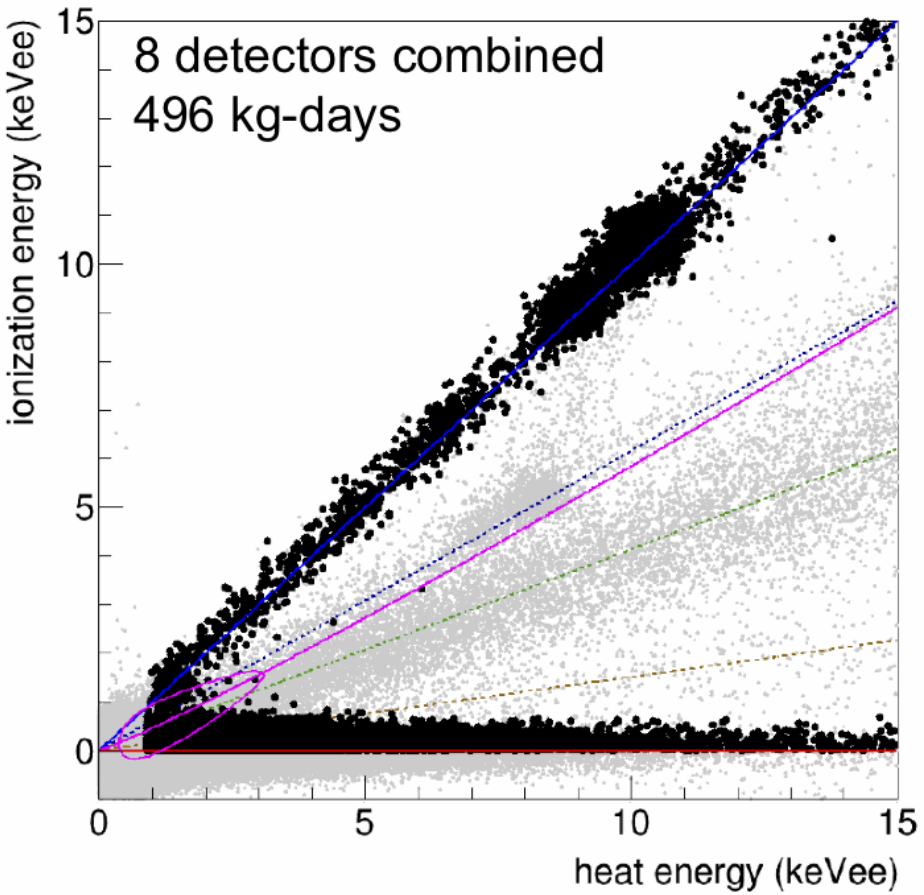
- Surface evts rejection (^{210}Pb+^{210}Bi β, ^{210}Po α, ^{206}Pb recoils): < 4 x 10^{-5}

[J Low Temp Phys (2014) 176: 870-875]



Low-Mass analysis

- Analysis with Boosted Decision Tree [JCAP05 (2016) 019]
- Analysis with Profile Likelihood [EPJC 76 (2016) 548]



Data-driven background models based on sidebands

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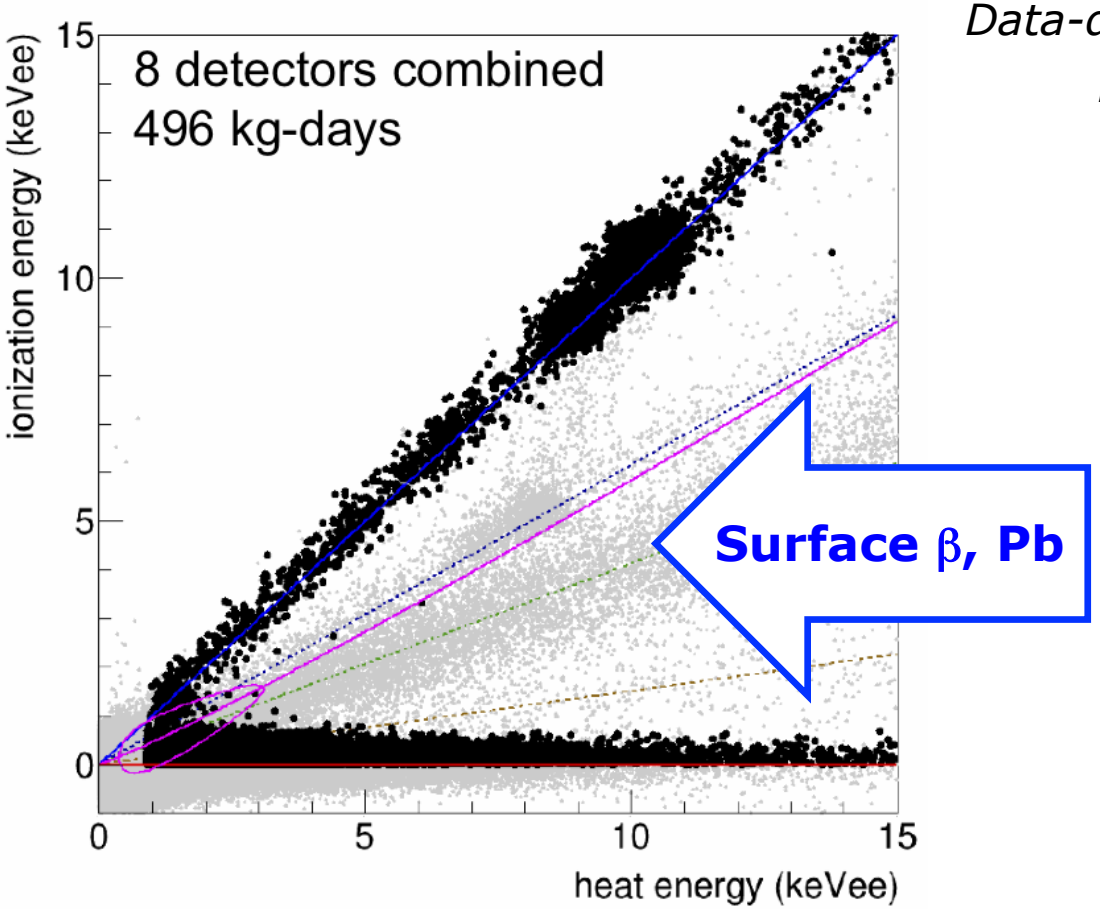

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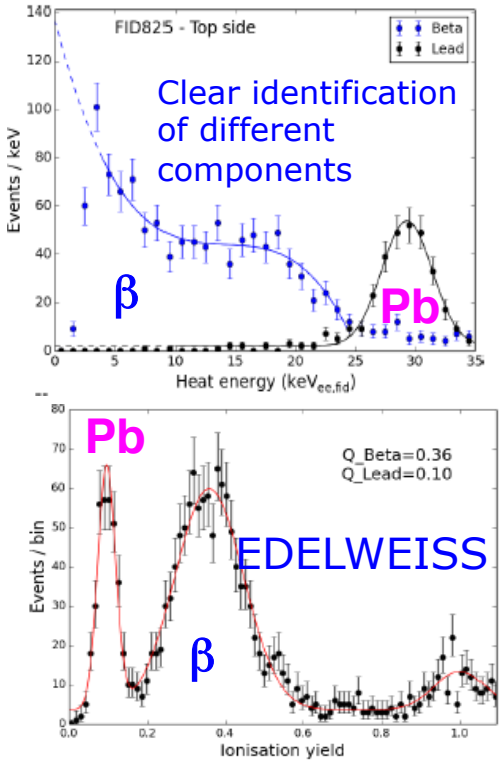

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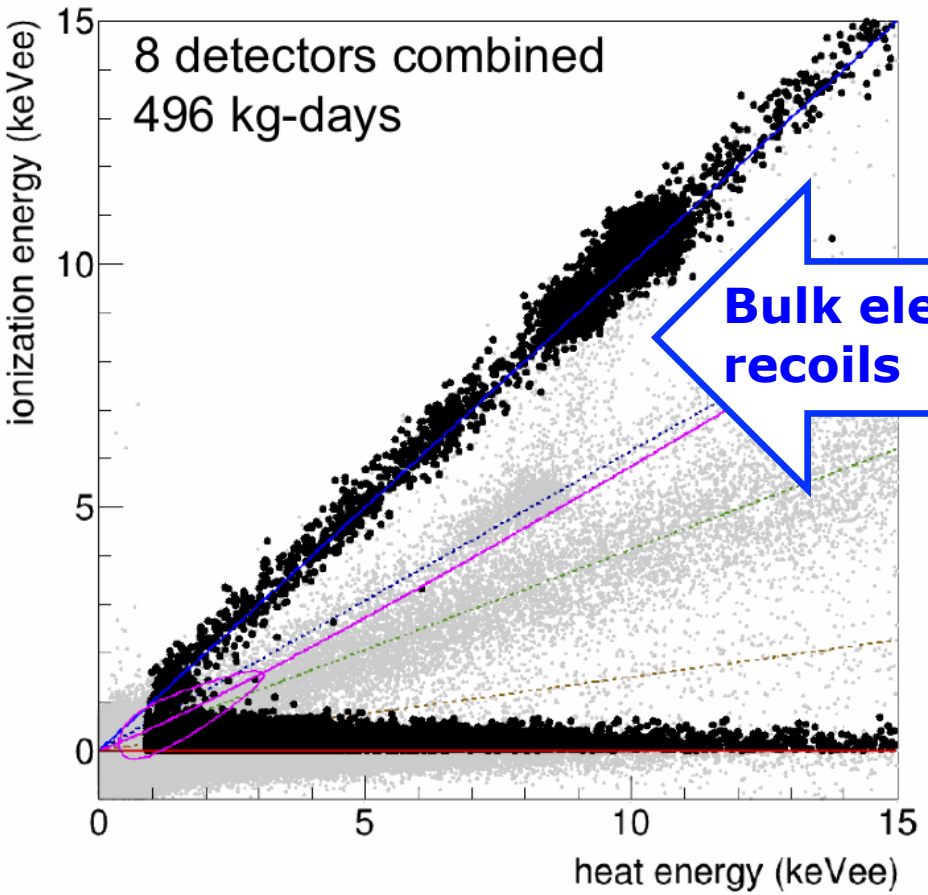

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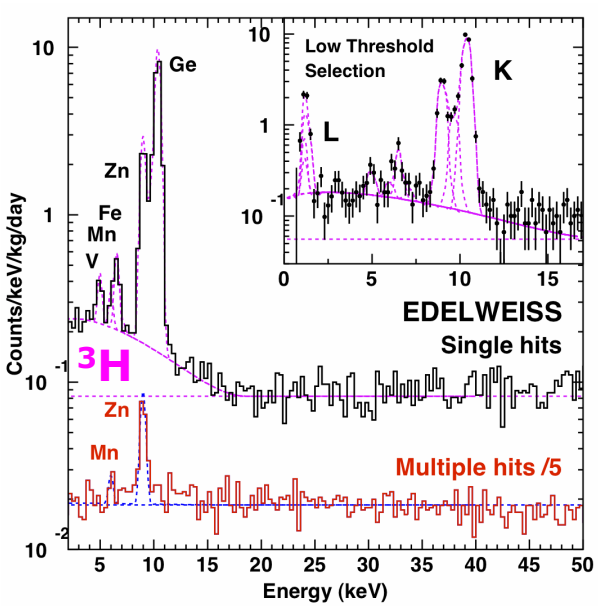

First measurement of cosmogenic production of ^{3}H in Ge [arxiv:1607.04560]

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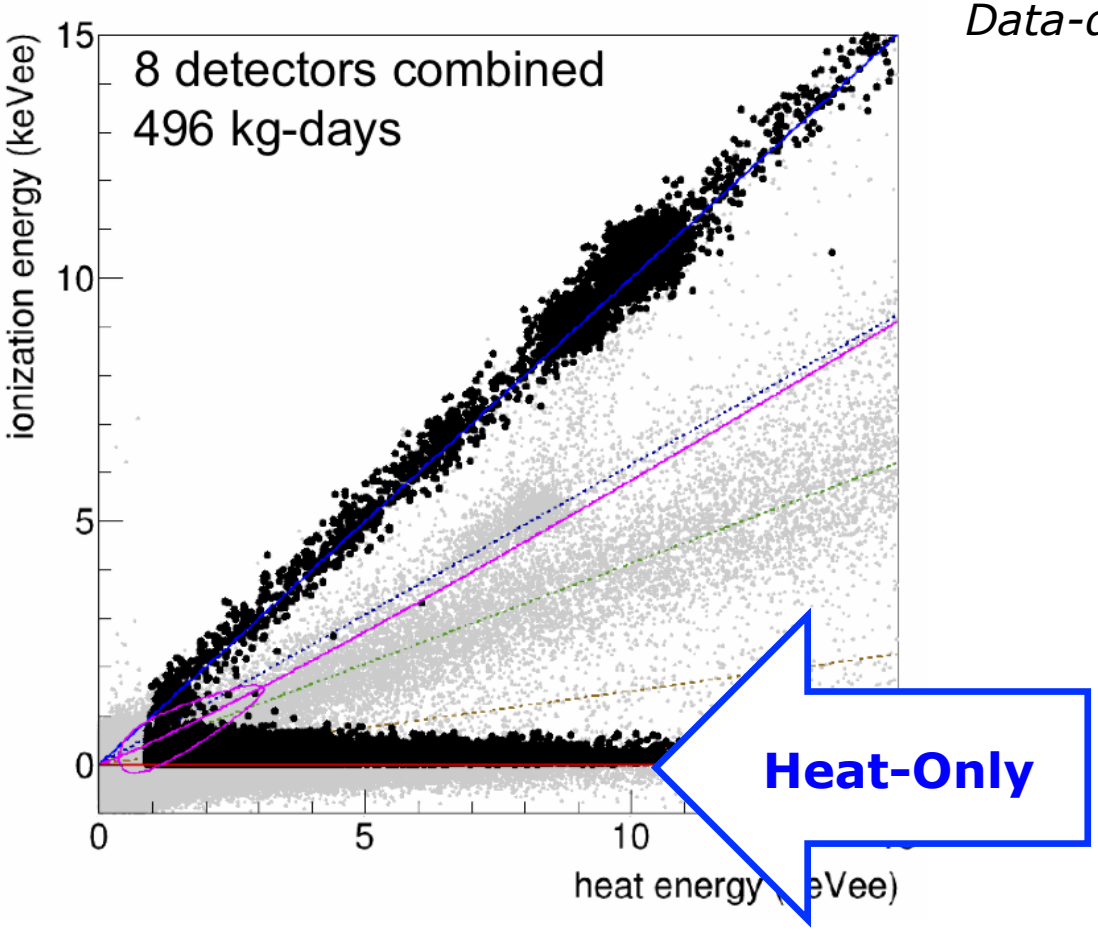
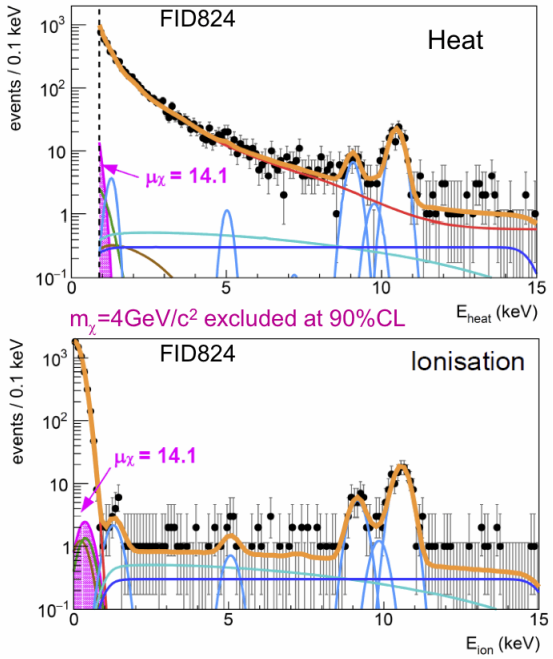


Data-driven background models based on sidebands

Origin under investigation



Low-Mass analysis

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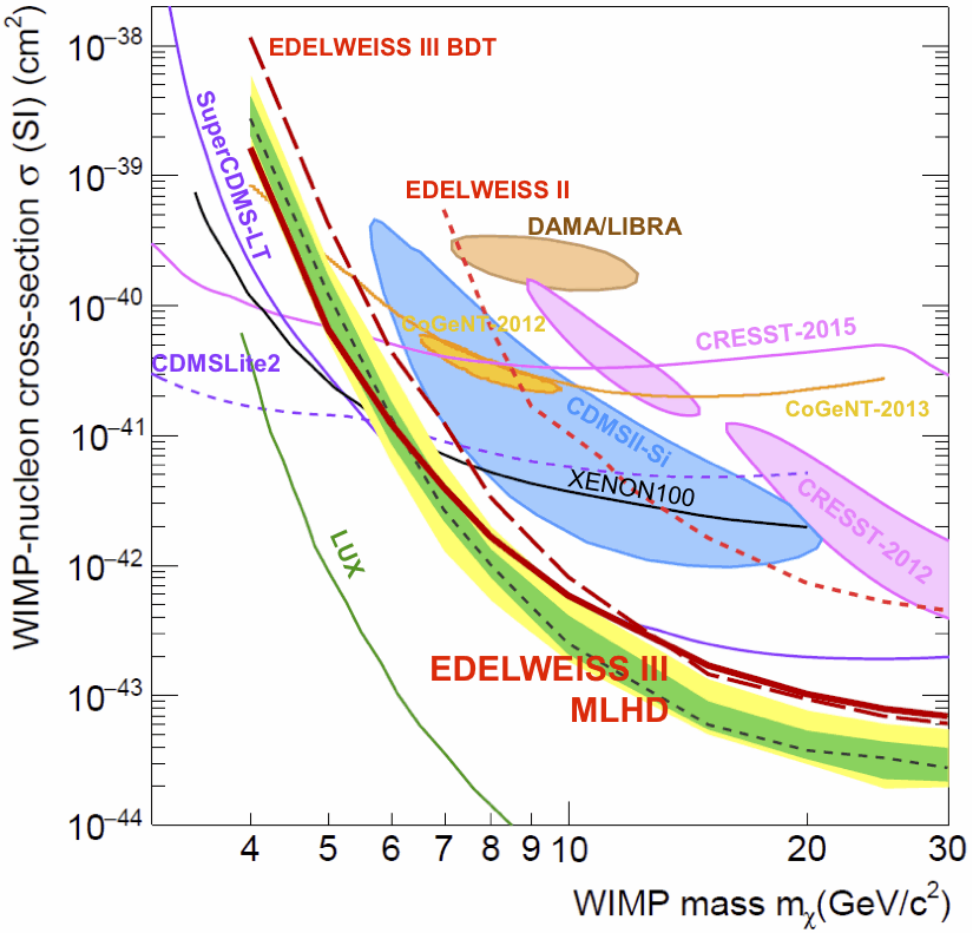


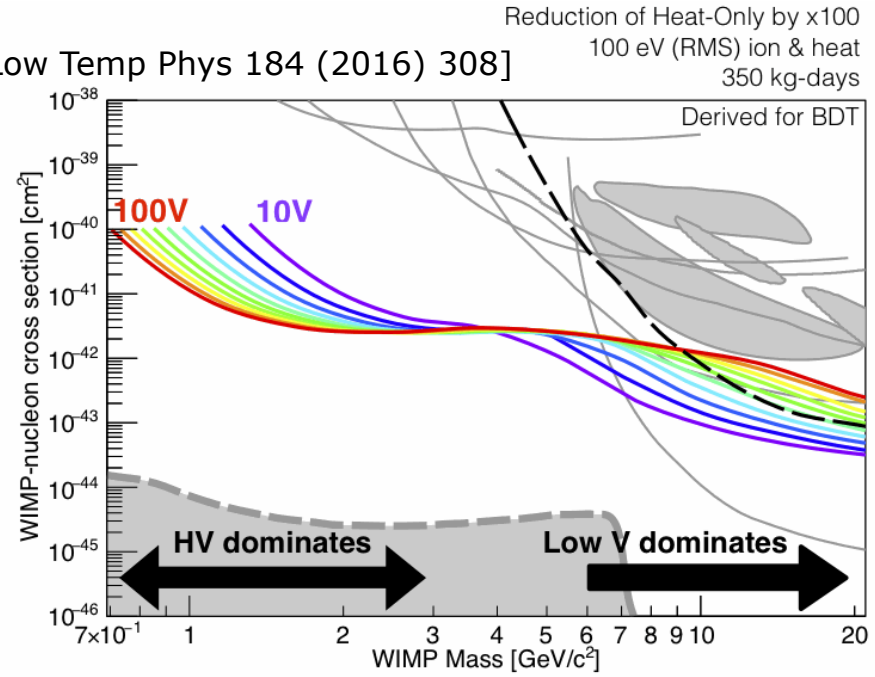
- Improvement by x20 to x150 between 7 and 10 GeV wrt EDELWEISS-II
- Limited by heat-only background: *identification and rejection using the σ=230 eV resolution on ionization*
- Ionization resolution is key for rejection
- Heat resolution is key for low thresholds

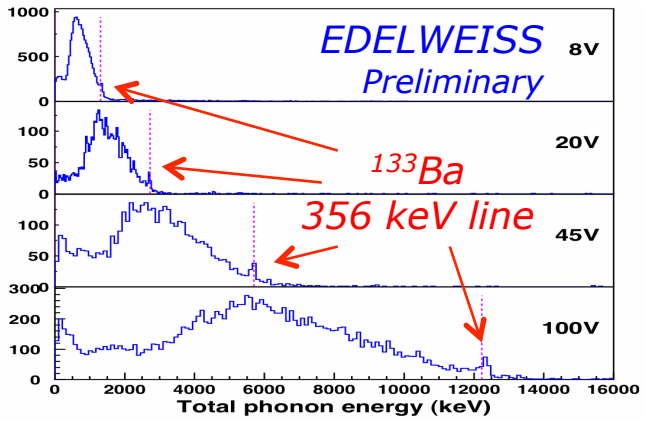
Prospects for GeV-range masses

Heat thresholds can be improved by applying larger bias voltages

- Heat signal boosted by Neganov-Luke effect (~Joule heating, factor $[1+V_{bias}/3]$)
- Loss of ionization-based background discrimination: method benefits low-mass searches only

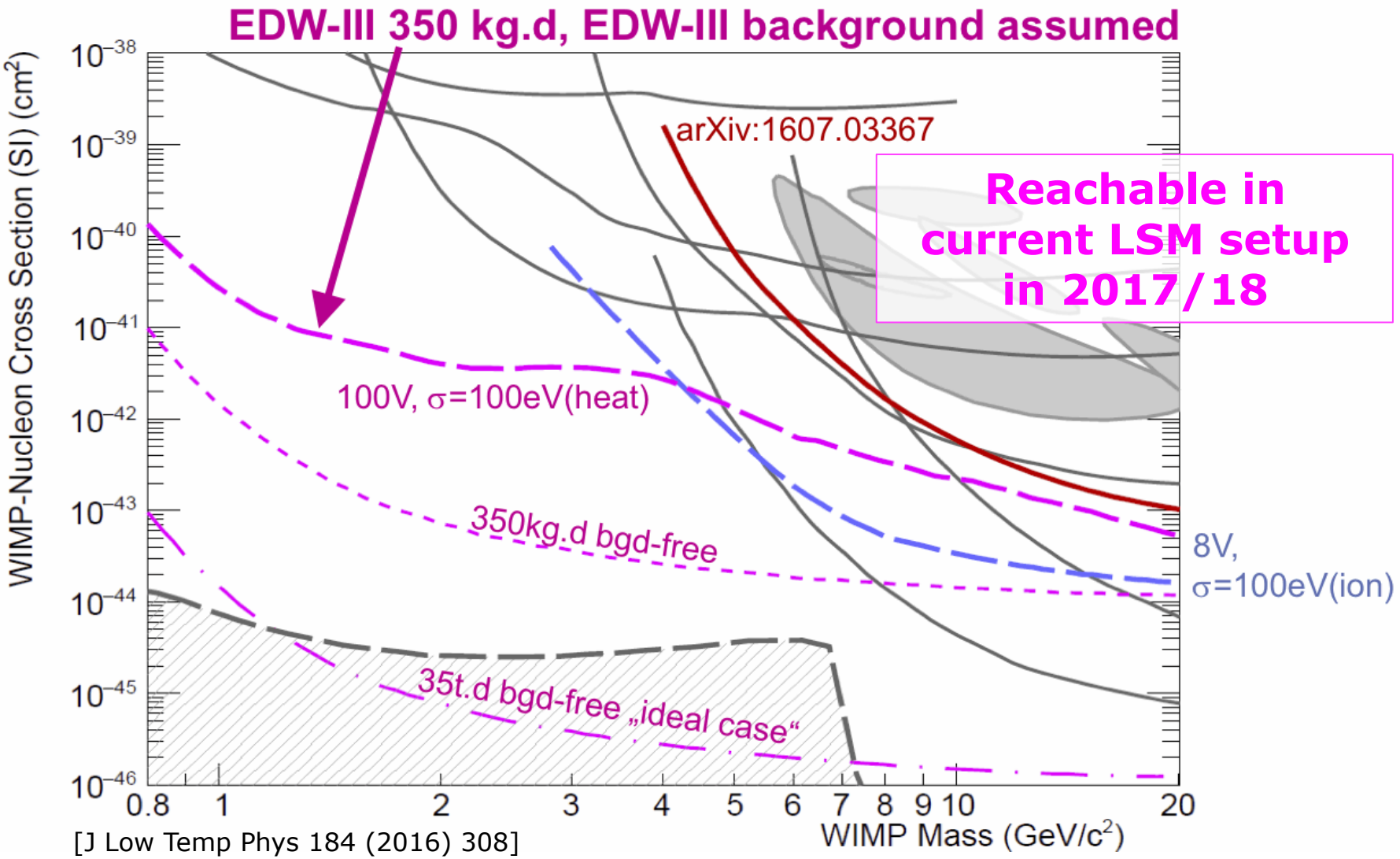
[J Low Temp Phys 184 (2016) 308]





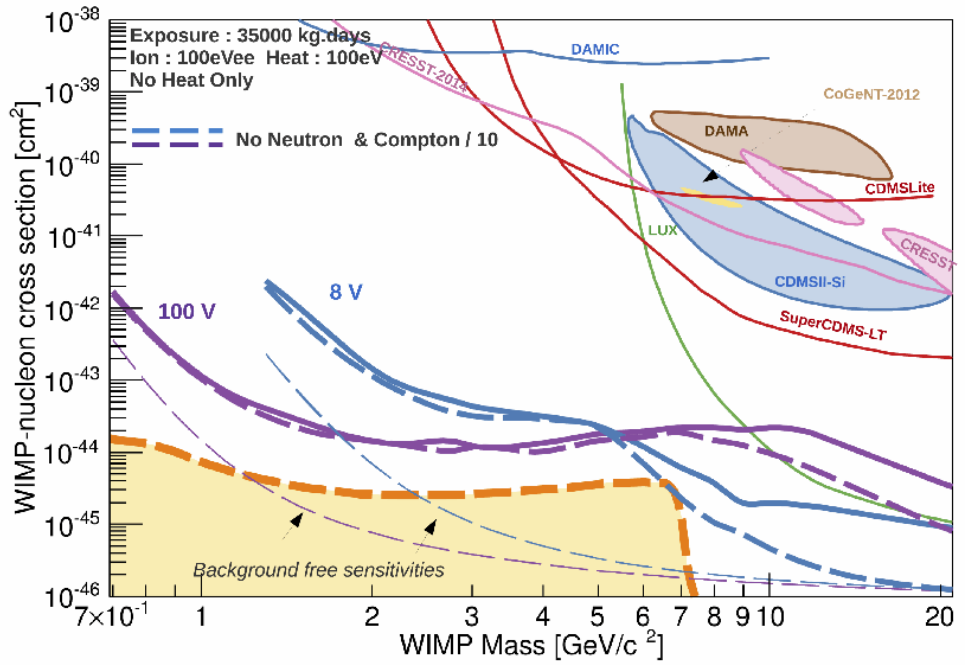
100V bias already achieved

Prospects for GeV-range masses



Future: reduce backgrounds, increase mass

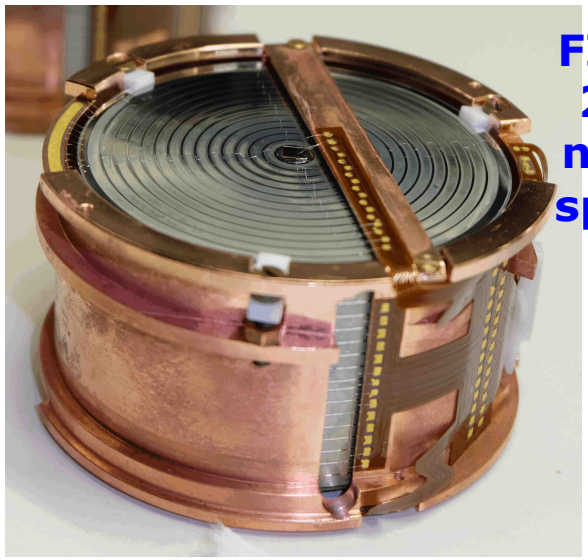
- EDELWEISS sensitivity for 35 ton.day = 100 kg x 1 year *[J Low Temp Phys 184 (2016) 308]*
- Suppression of Heat-Only becomes essential in GeV range
- In 5-20 GeV range, need:
  - Improve ionization resolution (for discrimination) from σ=230 to 100 eV
  - reduction of neutron + bulk electron recoils reduction by /10
    - ➔ *achievable in future in SuperCDMS environment planned @SNOLAB*



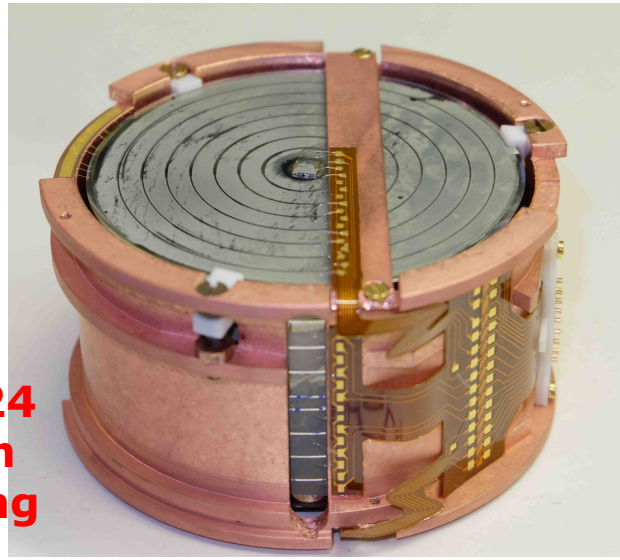
- Study implication of SuperCDMS tower design +HEMT readout on EDELWEISS detectors
- Collaboration on CUTE test facility @SNOLAB
- *Study improvement of charge readout with HEMTs*

HEMT readout

- High Electron Mobility Transistors [JLTP 176 (2014) 466 and 911; XB+AB NIMA 787 (2015) 51]
  - Low noise, low heat load
  - Can work at 4K: shorter cabling length reduces capacitance & improves ion. σ
  - Considered by EDW/HARD (reso.) and SuperCDMS (heat load), with joint R&D
- *σ=50 eV ion. resolution possible with FID + reduced C electrode design*



FID842
2 mm
normal
spacing

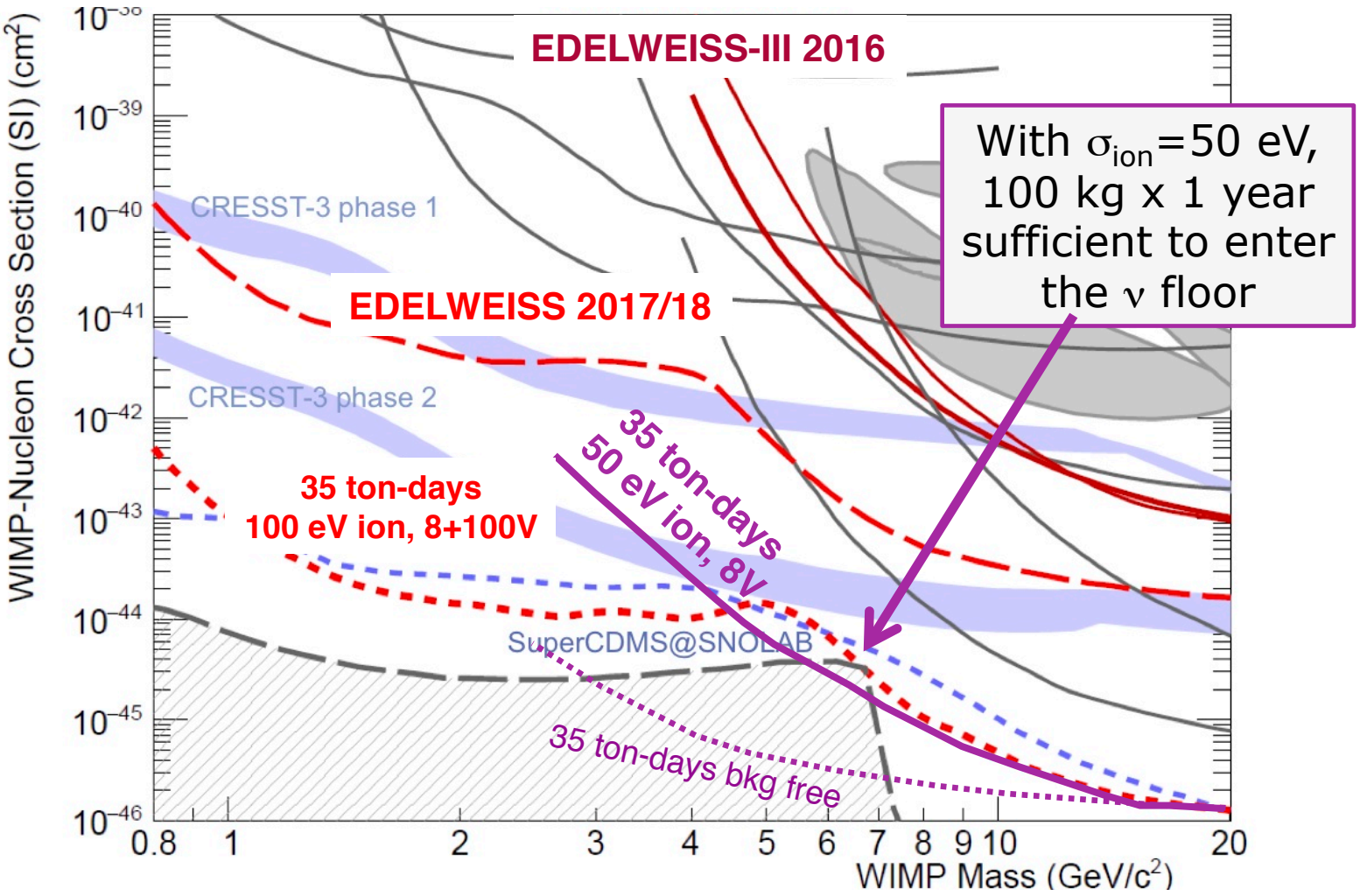


FID824
4 mm
spacing

- Reduction by 2 of number of electrodes on FID already done with success
  (one of the 8 "best" detectors used for WIMP searches!)

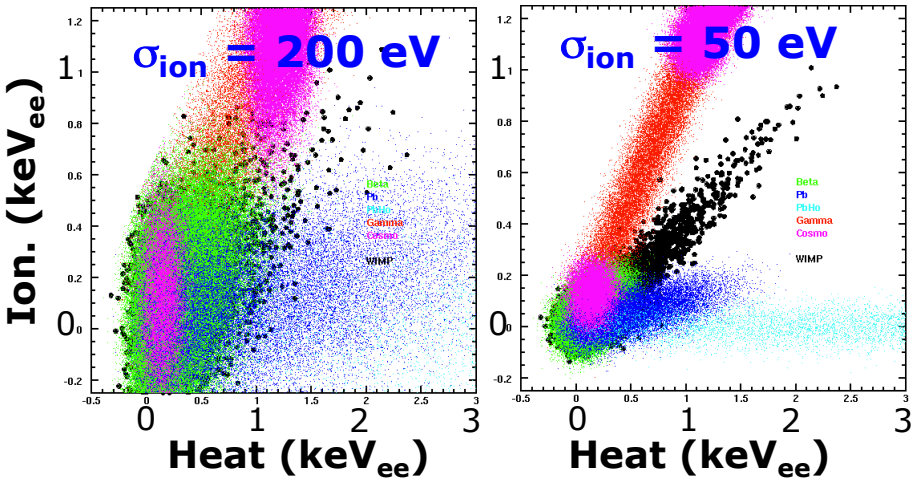
Entering the ^{8}B region

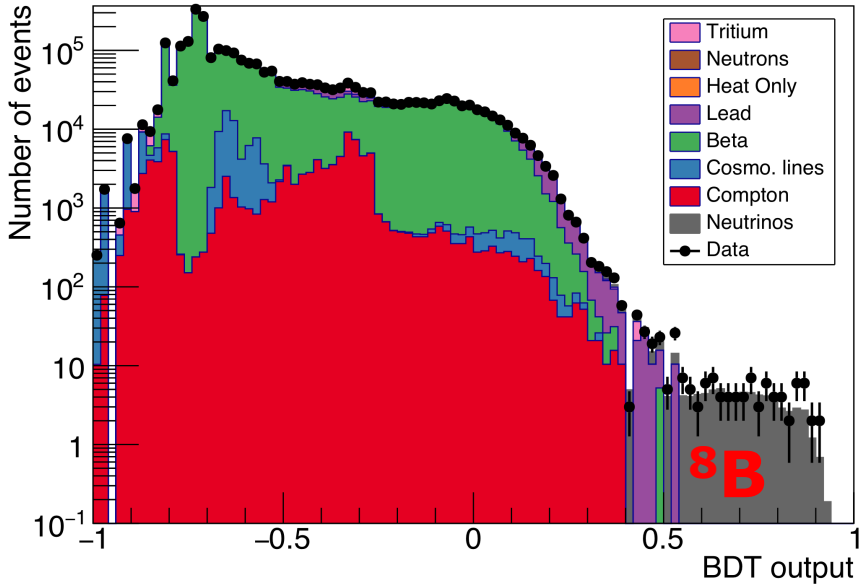
- Projection with σ=100 eV ion. resolution, 100 kg x 1 year



^{8}B region exploration with FID+HEMT

- Separation of ^{8}B signal (=6 GeV WIMP, black) with σ_{ion} = 50 eV (wrt present ~200 eV)
- E resolution: ~10% @ 1 keV$_{ee}$ *spectral separation for WIMP searches close to 6 GeV*
- Simulated BDT analysis: *78 background-free ^{8}B events in 200 kg x 5 years*
- *8 in 100 kg x 1 year (wrt <3 with σ_{ion}=100 eV)*
- Direct measurement of this important + interesting "bkg"





Conclusions

- EDELWEISS-III conclusions
  - Robust design, good reproducibility of performances
  - Improved ionization resolution & thresholds lead to x40 improvement of WIMP sensitivity at ~5-10 GeV wrt EDELWEISS-II.
  - Gamma and Surface rejection performances confirmed
- Prospects in the GeV-WIMP range: 2017/18 goal = 10^{-41} cm^2
  - Improve thresholds x10 using boost from 8 to 100V (achieved)
  - Optimize heat resolution
  - Reduce heat-only background
  - 10^{-41} cm^2 achievable with present levels for other backgrounds
- Prospects for WIMPs in the ^{8}B region
  - 50 eV ionization resolution to obtain pure nuclear recoil sample + 10% resolution on recoil energy: clear spectral identification of ^{8}B ν
  - Use HEMT preamplifier + reduce electrode capacitance (reduction by a factor of 2 of number of electrodes achieved)
  - ~100 kg FIDs at SNOLAB to complement nicely the SuperCDMS-SNOLAB reach

EDELWEISS collaboration

CSNSM CNRS/IN2P3

iPNL CNRS/IN2P3

NÉEL institut CNRS/INP

Laboratoire de Photonique et de Nanostructures CNRS

Irfu CEA/IRFU

IRAMIS CEA/IRAMIS

KIT Karlsruher Institut für Technologie IKP EKP IPE

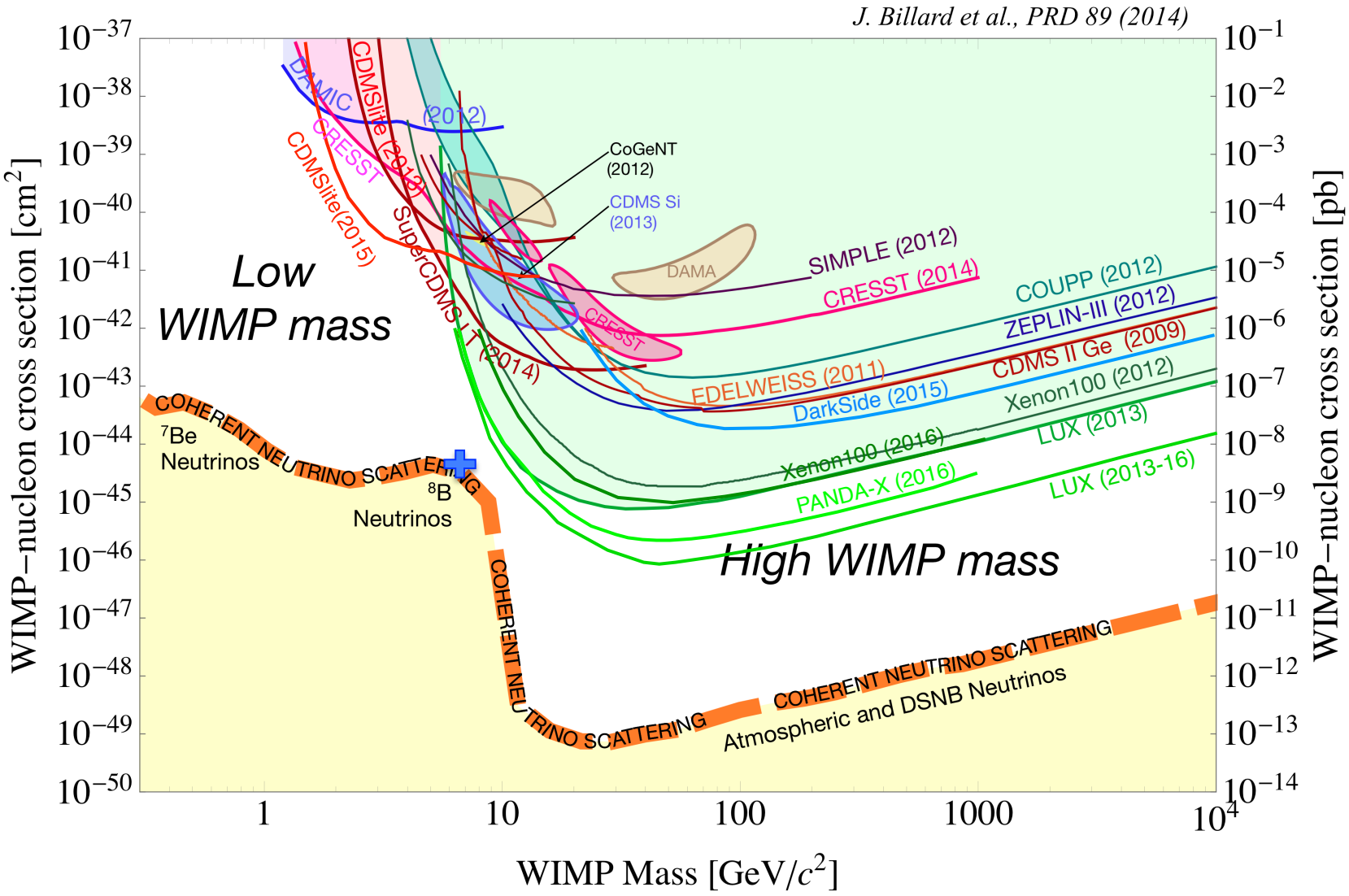
JINR JINR DUBNA

University of Oxford Univ. OXFORD

The University Of Sheffield. Univ. SHEFFIELD

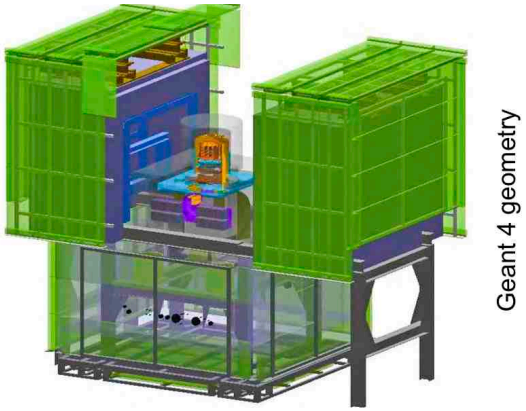
BACKUP

Direct searches at low and high masses



EDELWEISS Setup

Originally dimensioned for ~3000 kgd high-mass WIMP search



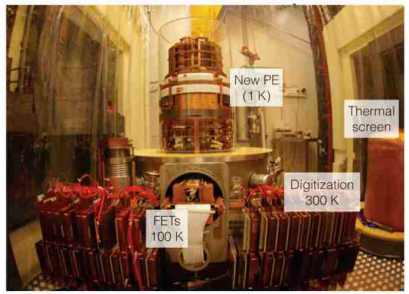
✓ **Clean Room** (Class A: <10000 p/m3) with deradonized air (from 10 Bq/m^3 → ≈ 30 mBq/m^3)

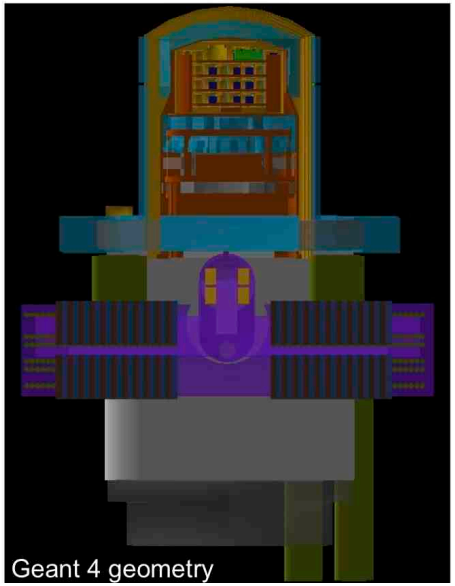
✓ **Active muon veto** : 97.7% geometric coverage

- $N^{\mu\text{-}n} = 0.6\ ^{+0.7}_{-0.6}$ evts (90% CL, 3000kg.d)

✓ **External PolyEthylen Shielding** (n): 50 cm

✓ **External Lead Shielding** (β,γ) : 18 cm + 2cm Roman Lead

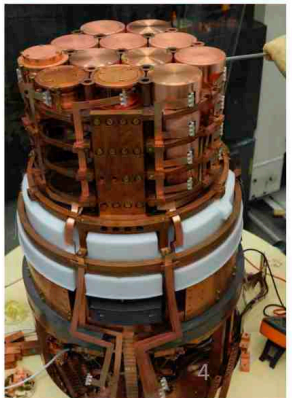




- Extra 15 cm Internal Roman Pb (1K)
- Material selection

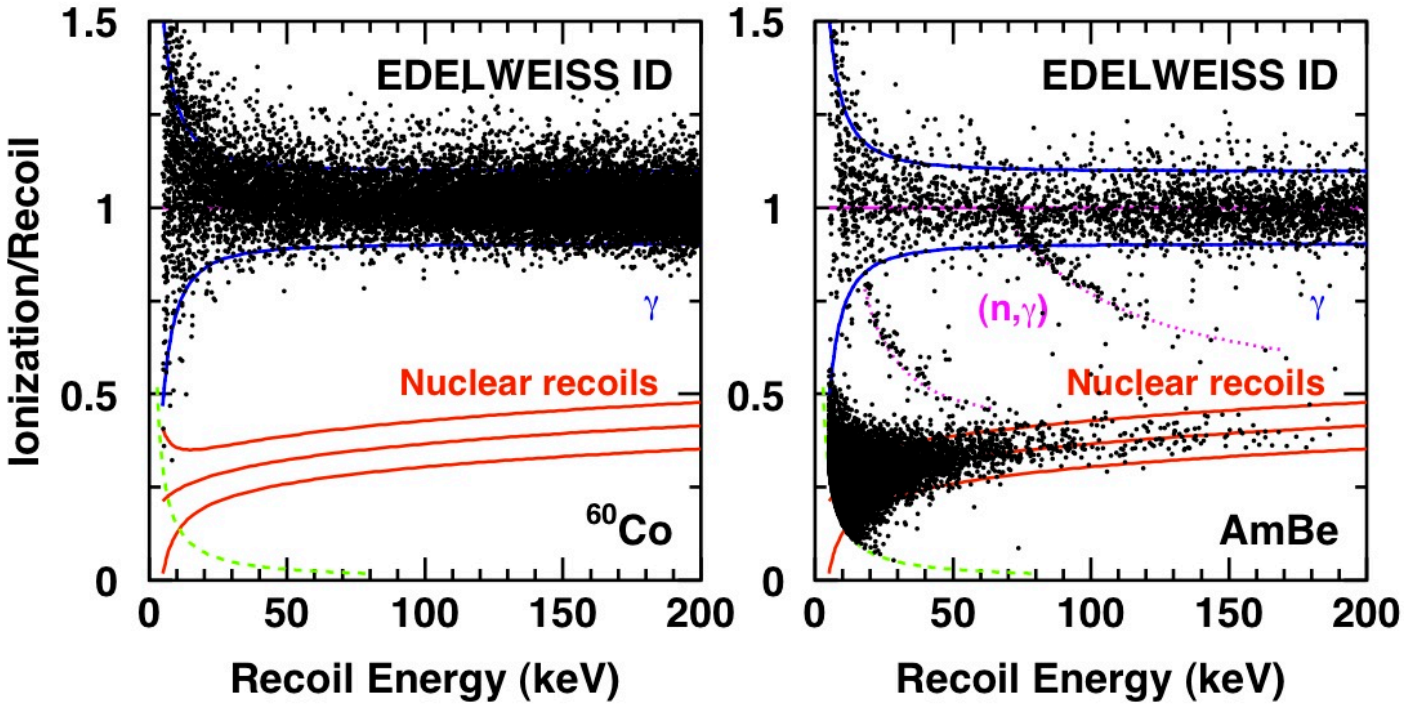
✓ **New w/r to EDW-II :**

- **Extra 10 cm PE** shield below detectors
- **NOSV Copper**
- New Kapton cables and connectors : 1K-10mK (Steel) and 10mK-10mK (Cu)
- **New electronics** (FETs 100K and Digitization 300K)
- **New Cryogenics** to reduce microphonics



Nuclear recoil discrimination

- Heat: GeNTD thermistor (~15mm^3): R ~MΩ at T= 18 mK, ΔT ~1 μK/keV. Fully thermalized: position-independent signal.
- Ionization: evaporated Al electrodes, polarized at a few V/cm
- Ionization yield for nuclear recoils is ~1/3 of value for e^- recoils
- Limitation: poor charge collection for events <<1mm from surface

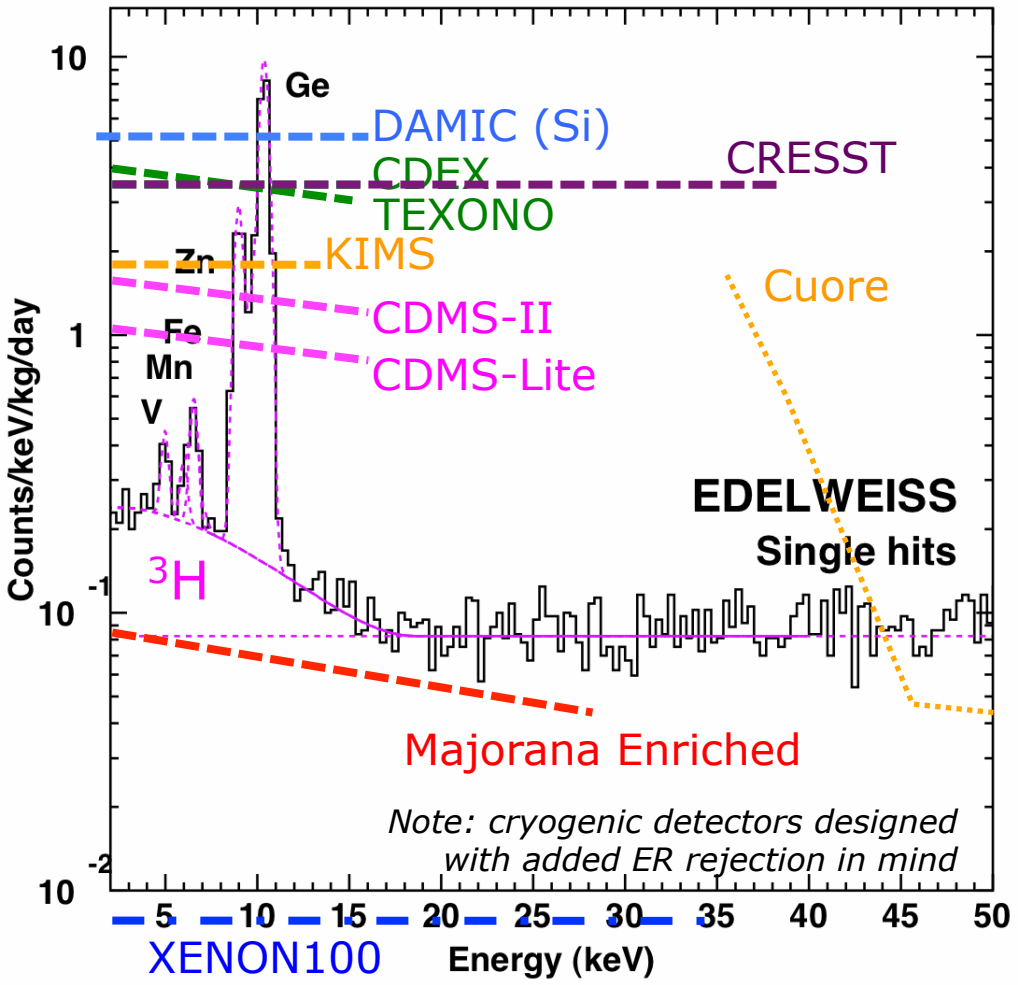


Electron recoil spectra (... an unfair comparison)

Some electron recoil rates presented at IDM2016

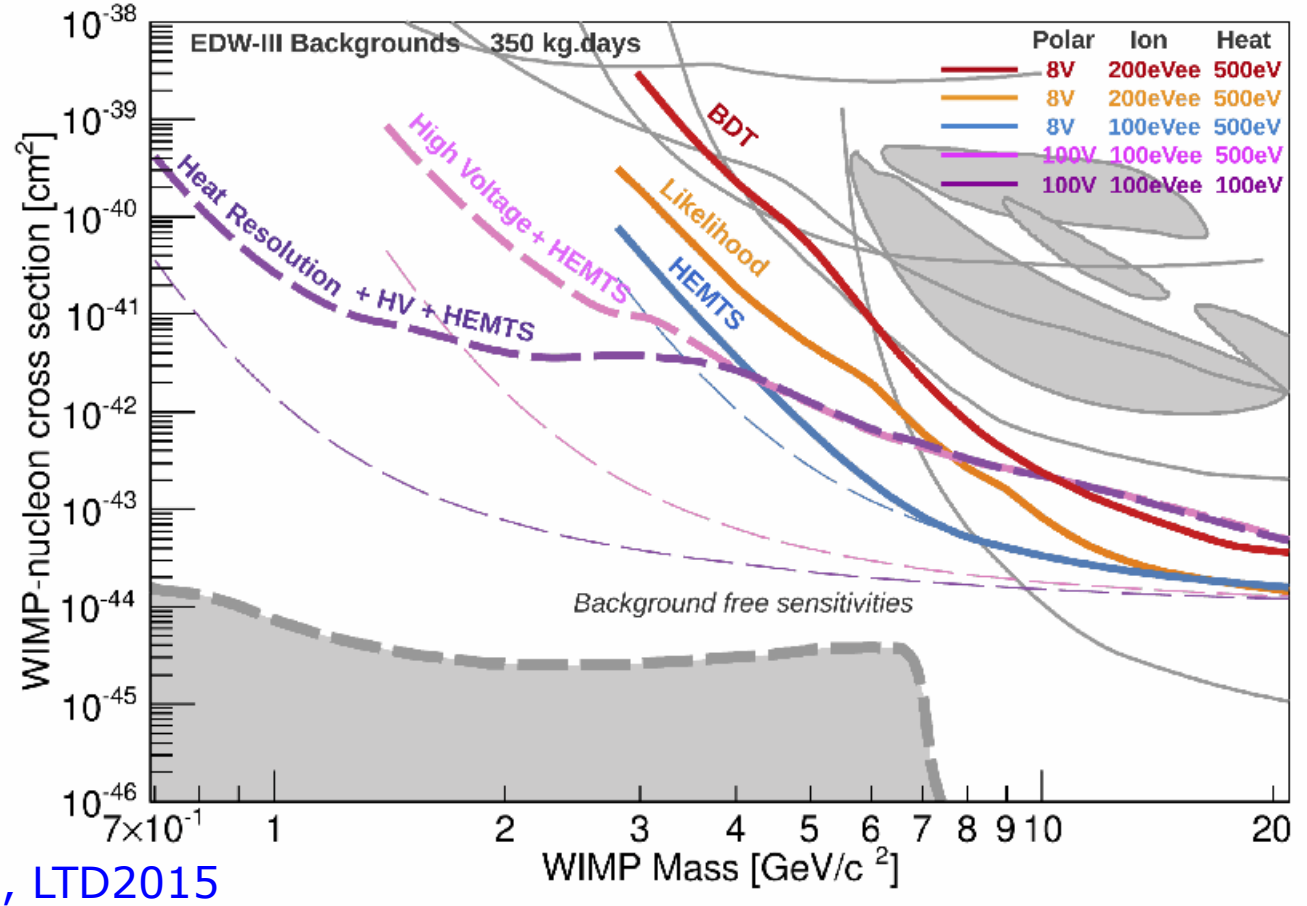
- DAMIC (Liao)
- CDEX (Lin)
- TEXONO (Singh)
- CRESST (Gorla)
- KIMS (Lee)
- CDMS-Lite (Cushman)
- EDELWEISS (Scorza)
- Majorana (Lopez-Asamar)
- Cuore (Piperno)

- XENON, LUX, PandaX: below scale (self-shielding)



What can be done with 1 kgyear

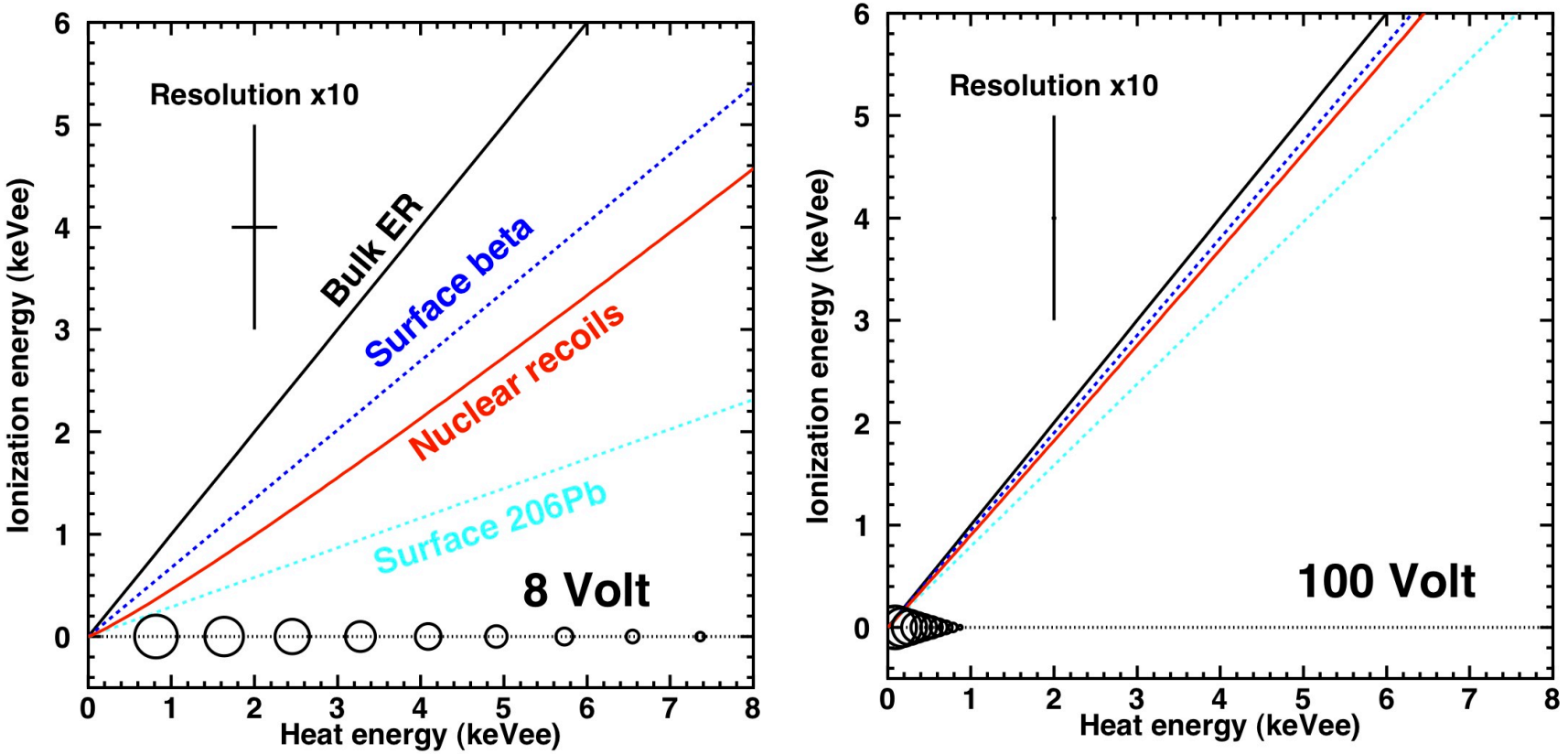
- Calculated assuming present EDELWEISS background (including Heat-only)



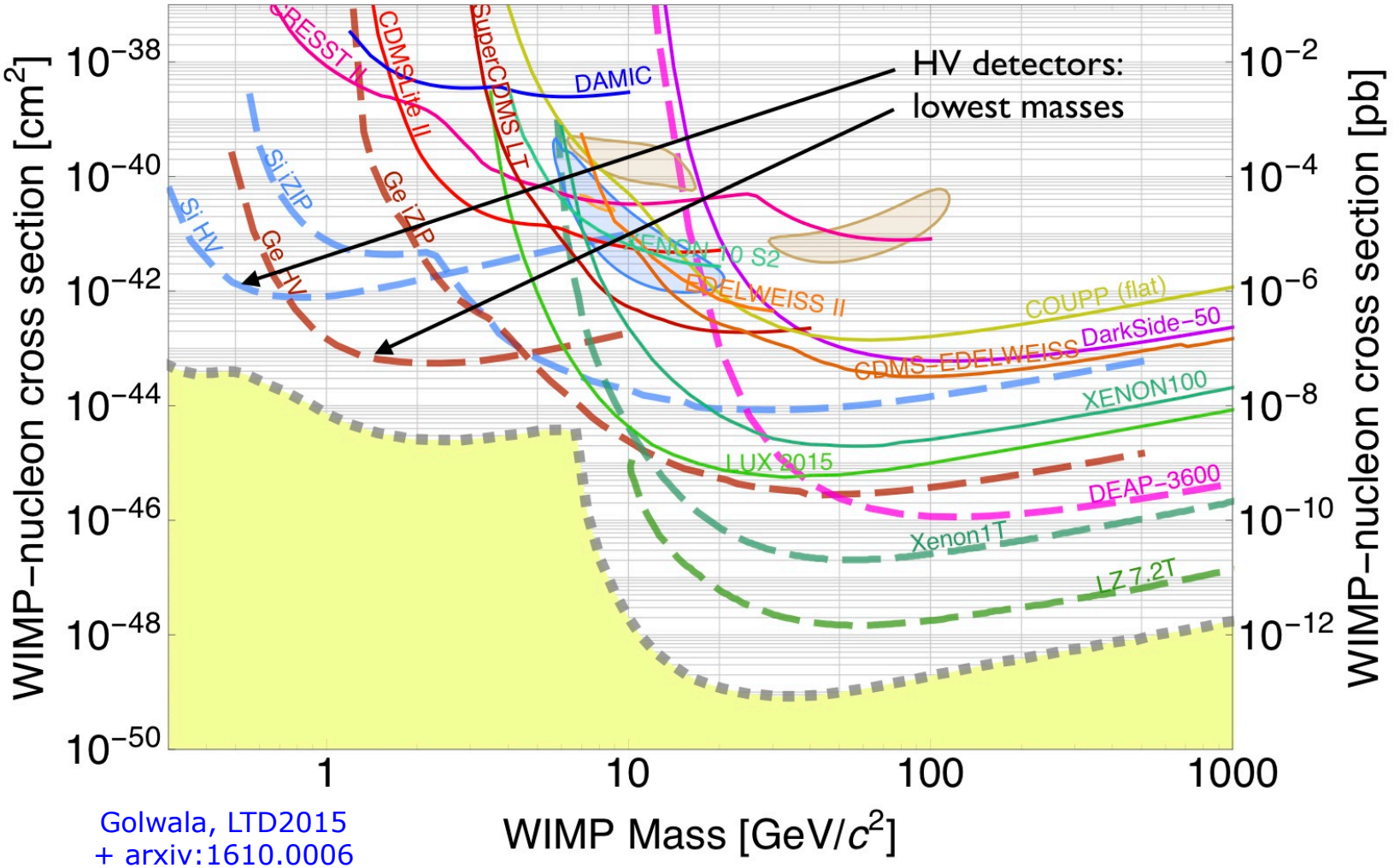
Arnaud, LTD2015

Low- vs High-voltage operations

- Threshold (in keV_{ee}) reduced by factor (1+V/3)
- Loss of discrimination (except for heat-only events)



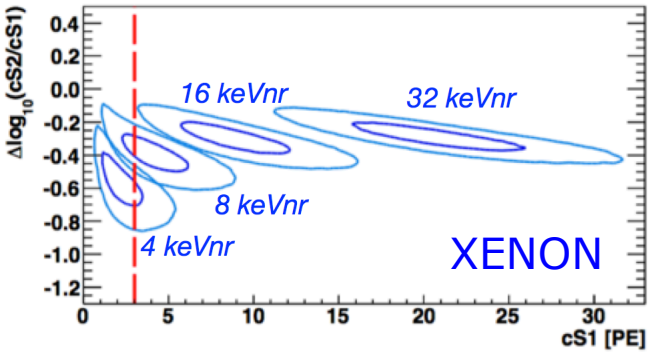
SuperCDMS strategy for low masses

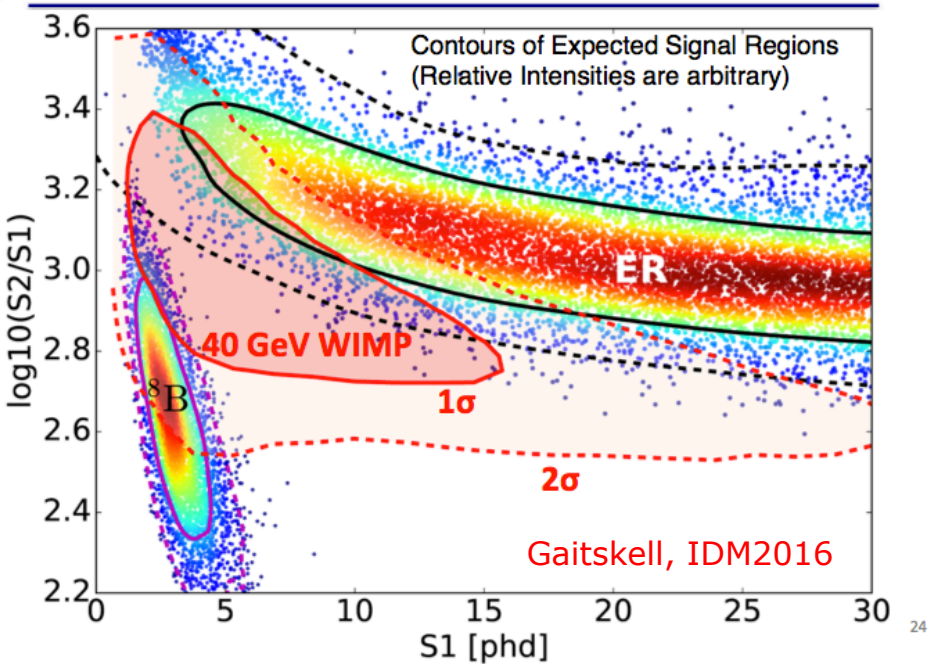


Golwala, LTD2015
+ arxiv:1610.0006

^{8}B region with xenon

- Xenon experiments may reach ^{8}B floor in coming years
  - Very small efficiency limited by photon collection
  - ^{8}B backgrounds difficult to control: very little spectral response





Measurement WITH good energy resolution and background rejection is needed to properly control this background