Direct detection of Dark Matter with the EDELWEISS experiment

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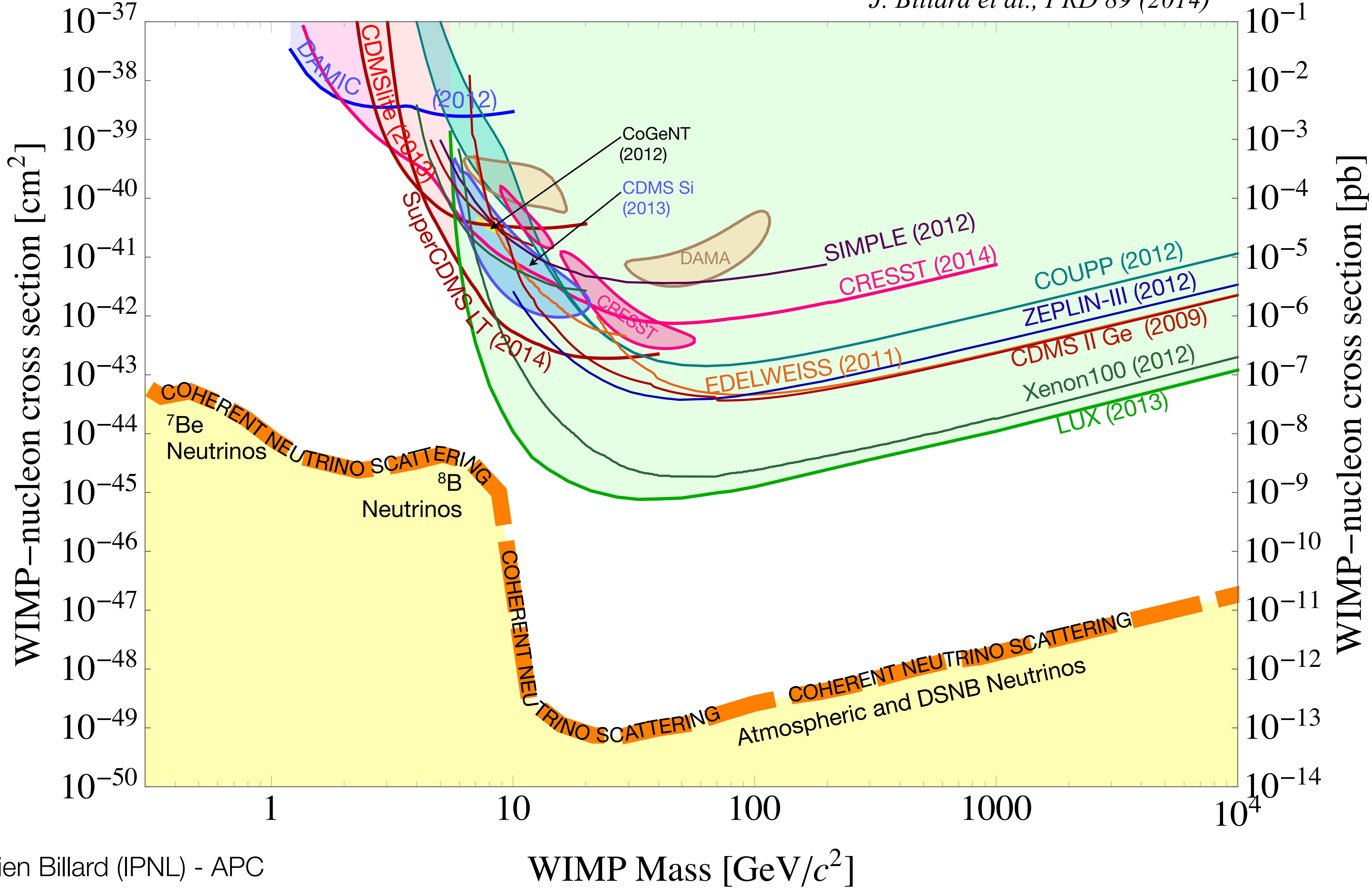
on behalf of the EDELWEISS collaboration
Institut de Physique Nucléaire de Lyon / CNRS / Université Lyon 1

Journée Matière Noire, APC
1er Décembre, 2016

The neutrino background

J. Billard et al., PRD 89 (2014)



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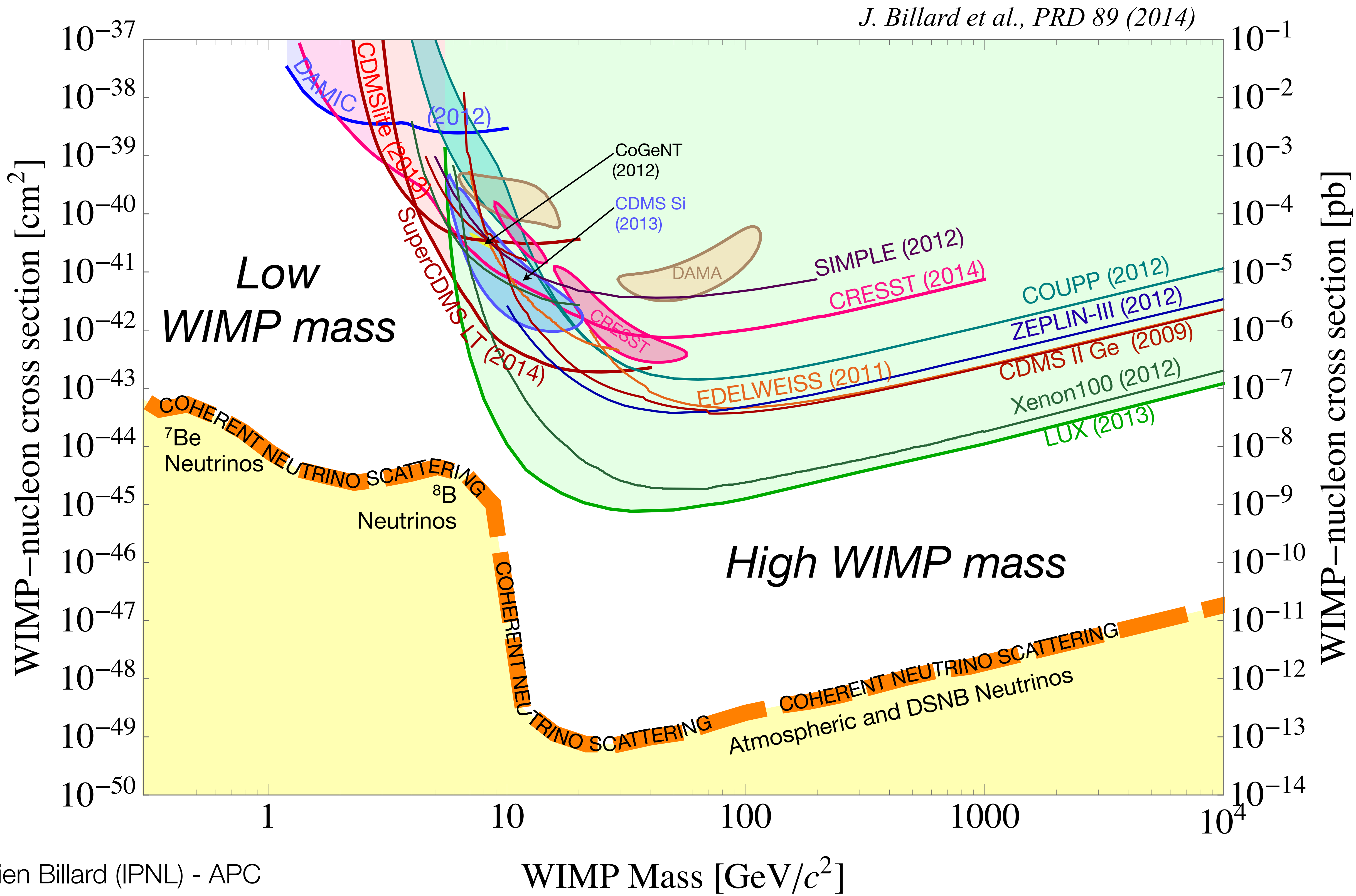

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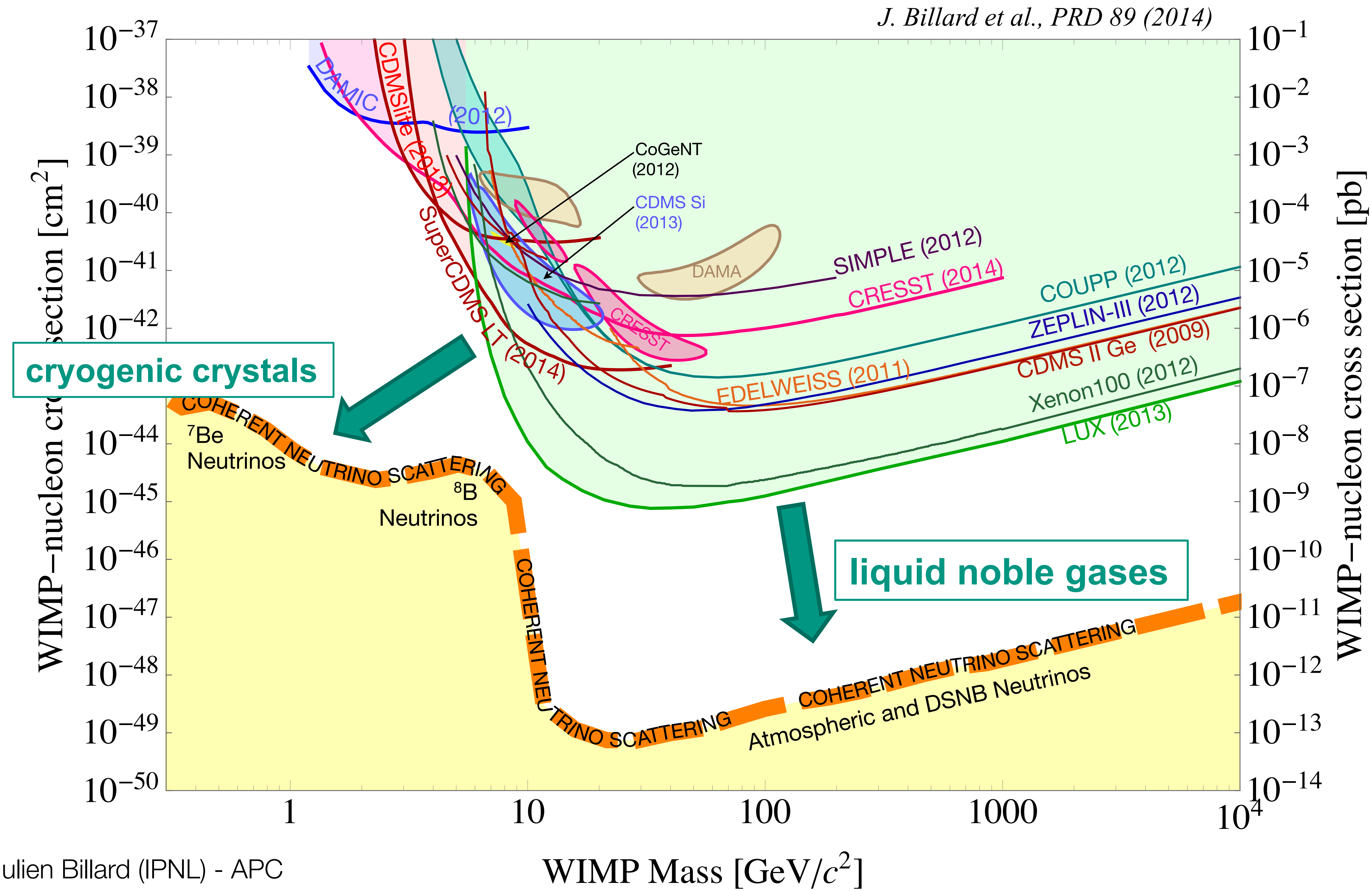


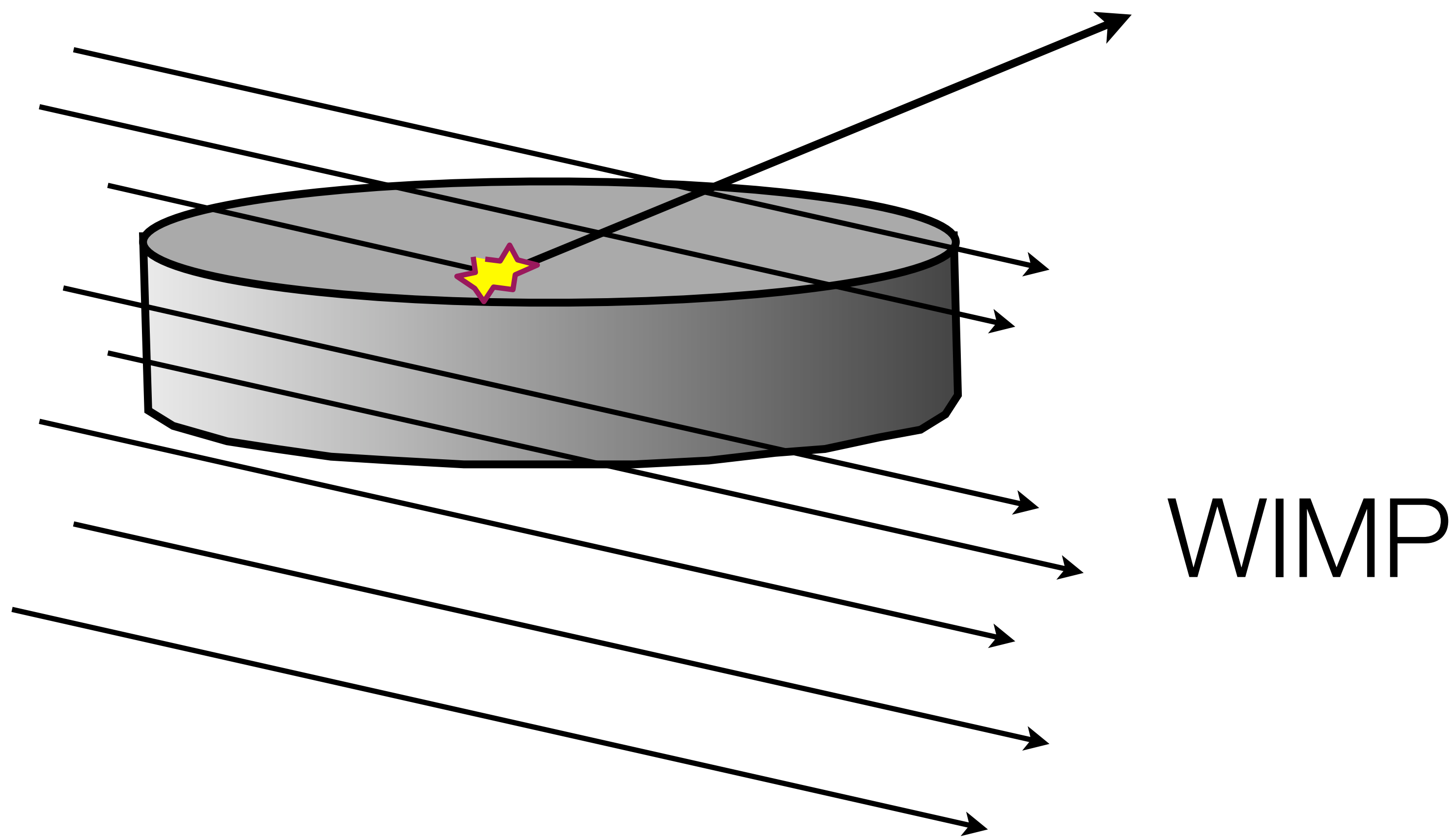
The EDELWEISS-III Experiment

CSNSM CNRS/IN2P3
IPNL CNRS/IN2P3
NÉEL institut CNRS/INP
Laboratoire de Photonique et 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

10 institutions

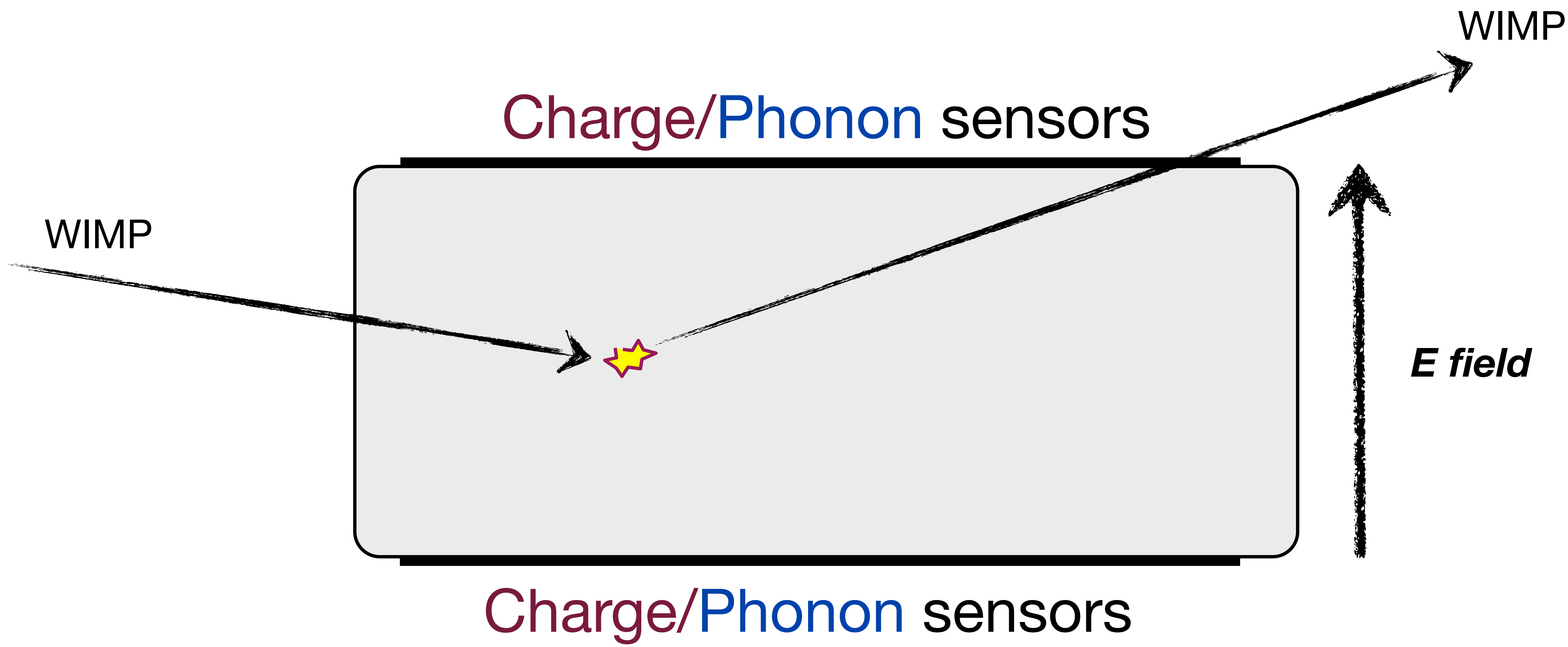
http://edelweiss.in2p3.fr

The EDELWEISS-III Experiment



Cryogenic semiconductor detectors looking for WIMPs

The EDELWEISS-III Experiment



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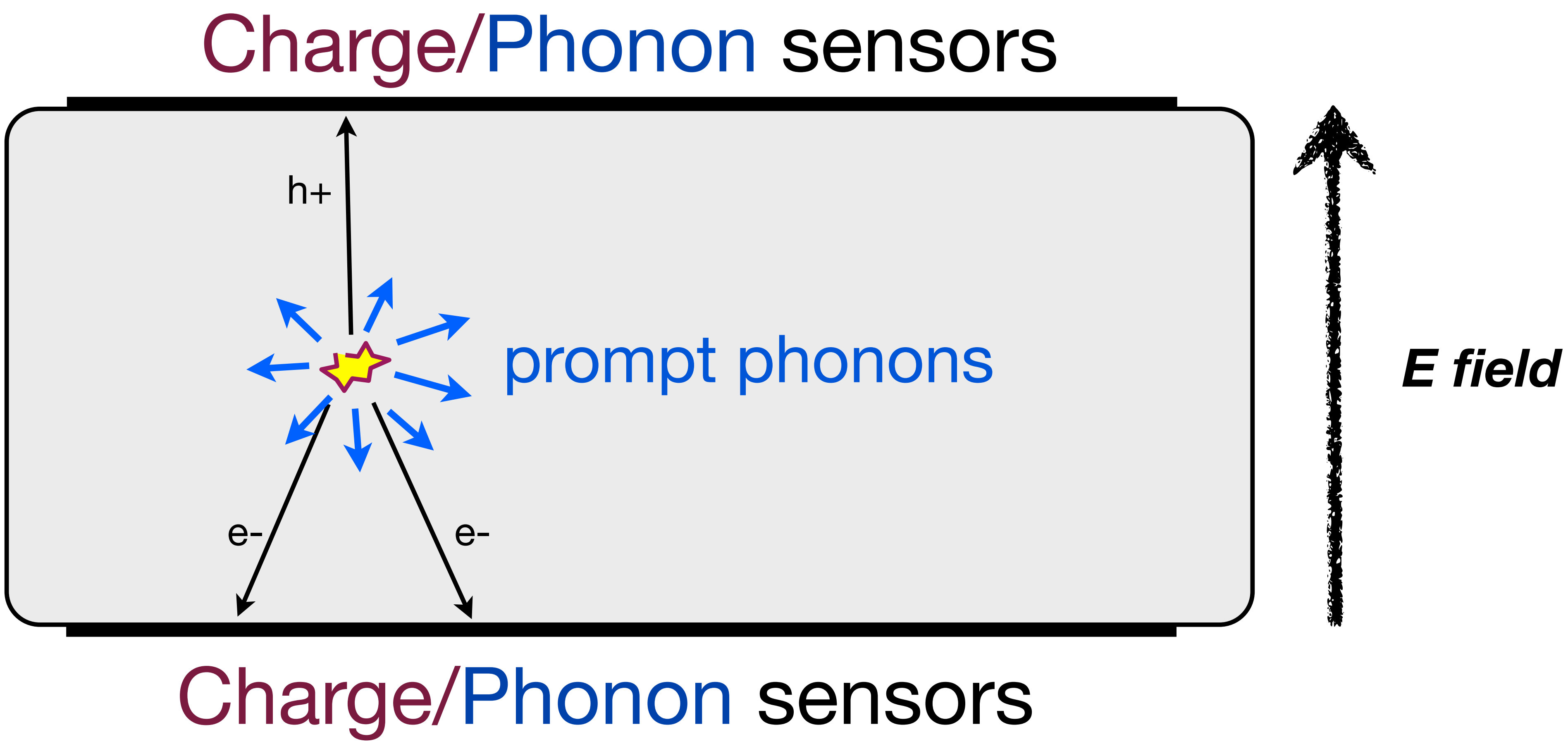

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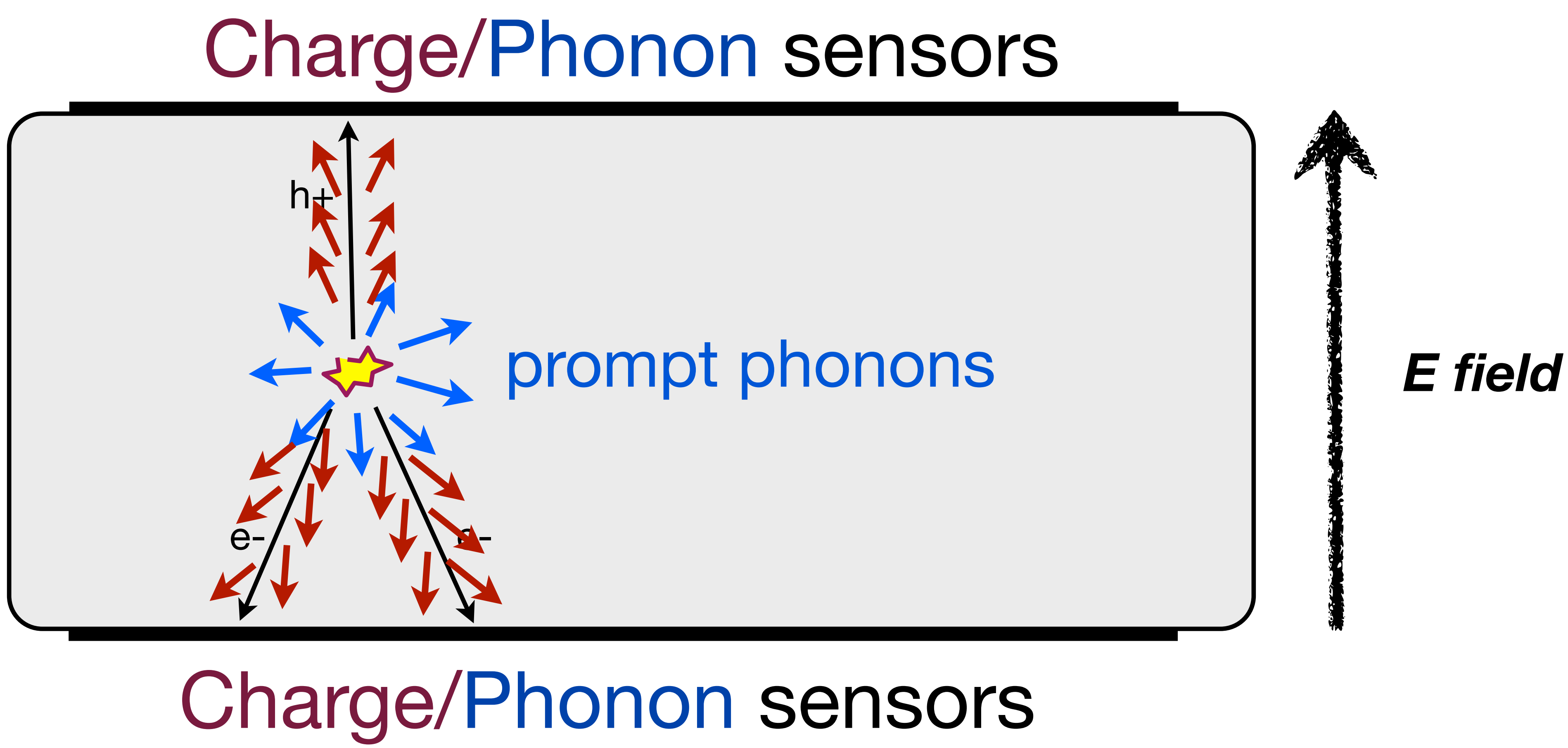

$$E_{total} = E_{recoil} + E_{luke}$$
$$= E_{recoil} + \frac{1}{3\ eV} E_Q \Delta V$$

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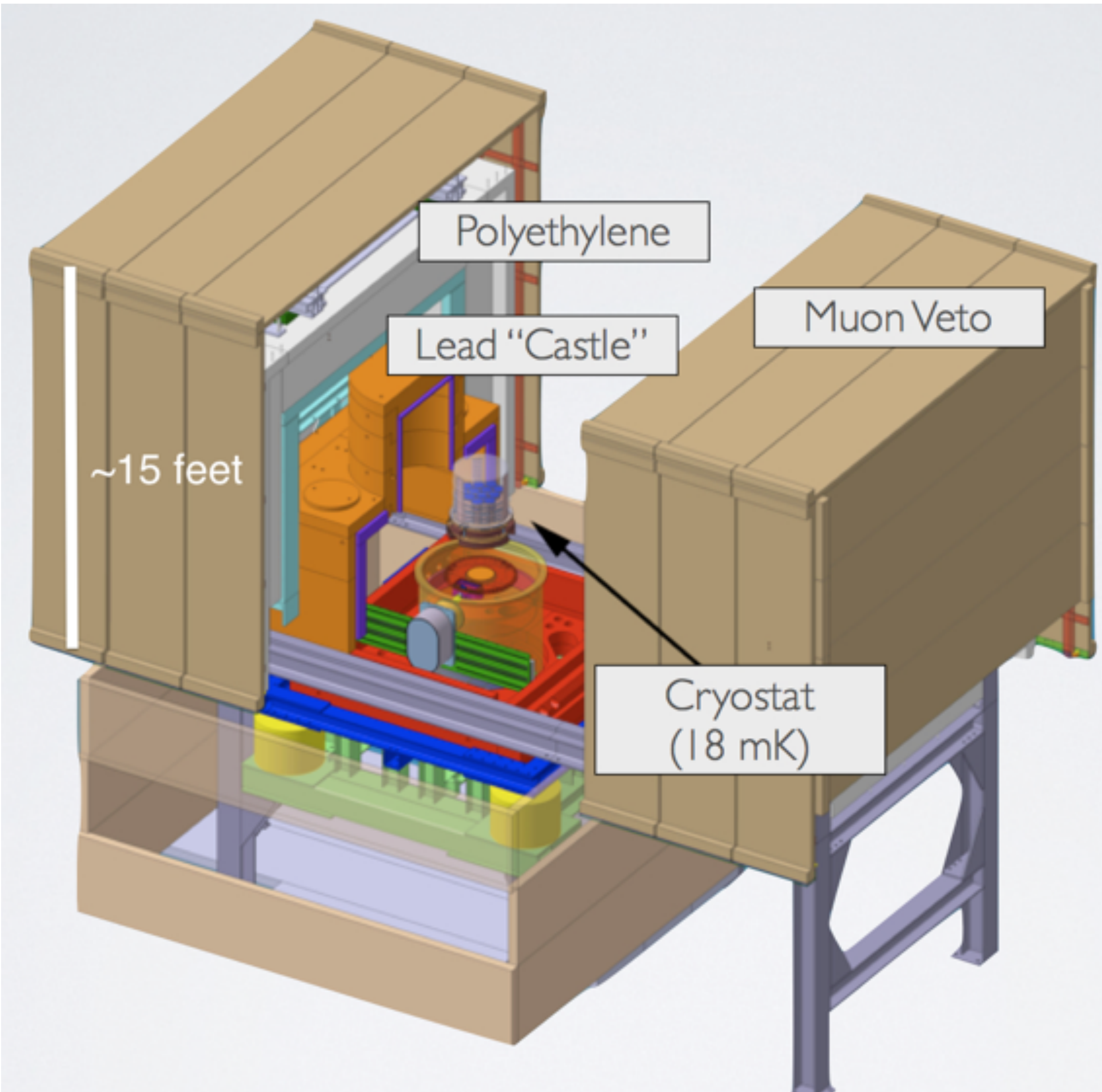
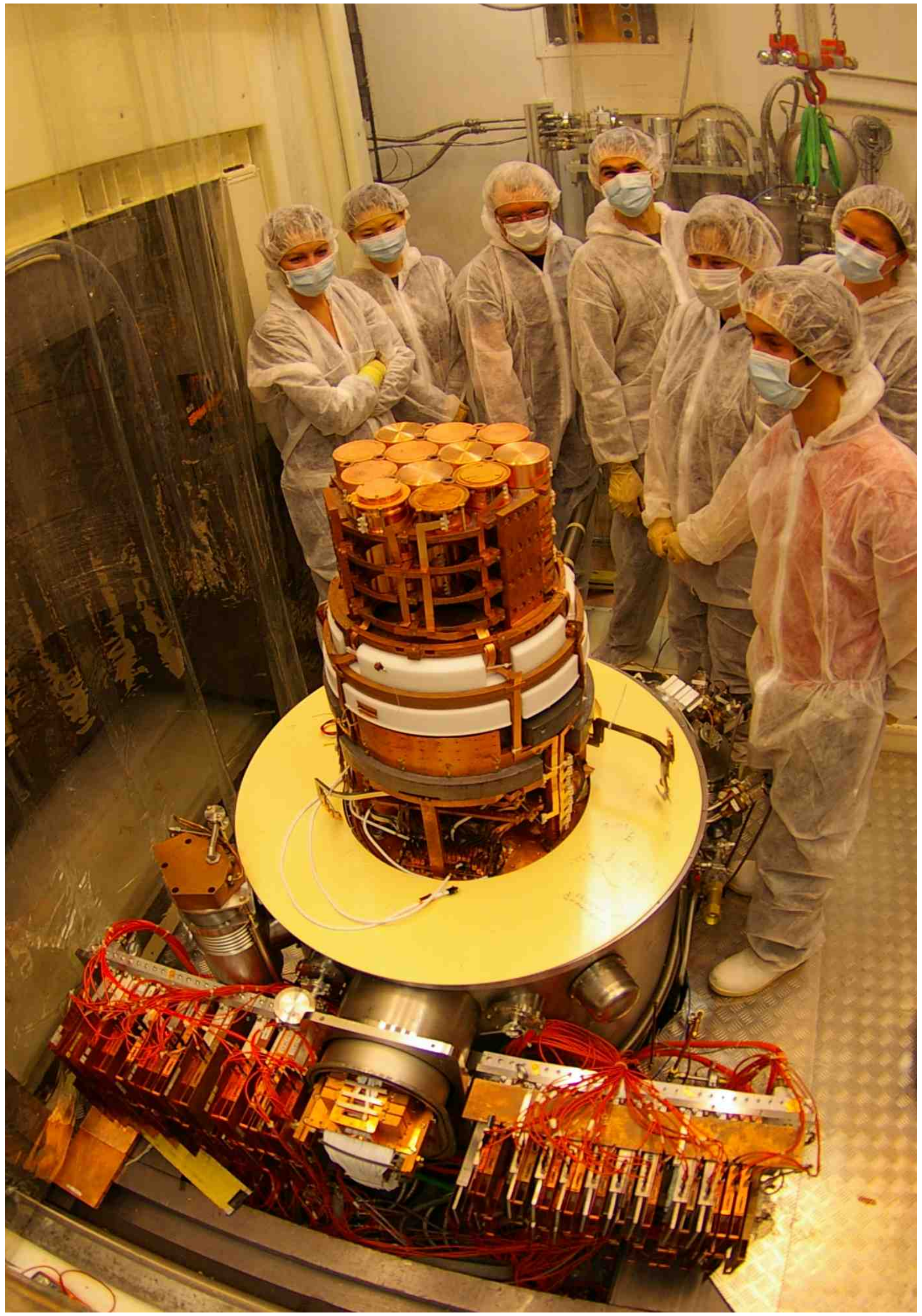


EDELWEISS setup

- Clean room
- Radon-free air around the detectors
  - To reduce surface contamination with radioactive contaminants
- Two layers of lead shield
  - To stop the gammas
    - Standard (far from detectors)
    - Ancient (near the detectors)
- Inner and outer polyethylene shield
  - To stop the neutrons
- Muon veto
  - To suppress muon induced neutrons in surrounding materials

The EDELWEISS-III Experiment

- Upgrade from EDELWEISS-II:
  - Extra 10 cm internal PE shield
  - New electronics
  - Cryogenics (Vibrations)



The EDELWEISS-III Experiment

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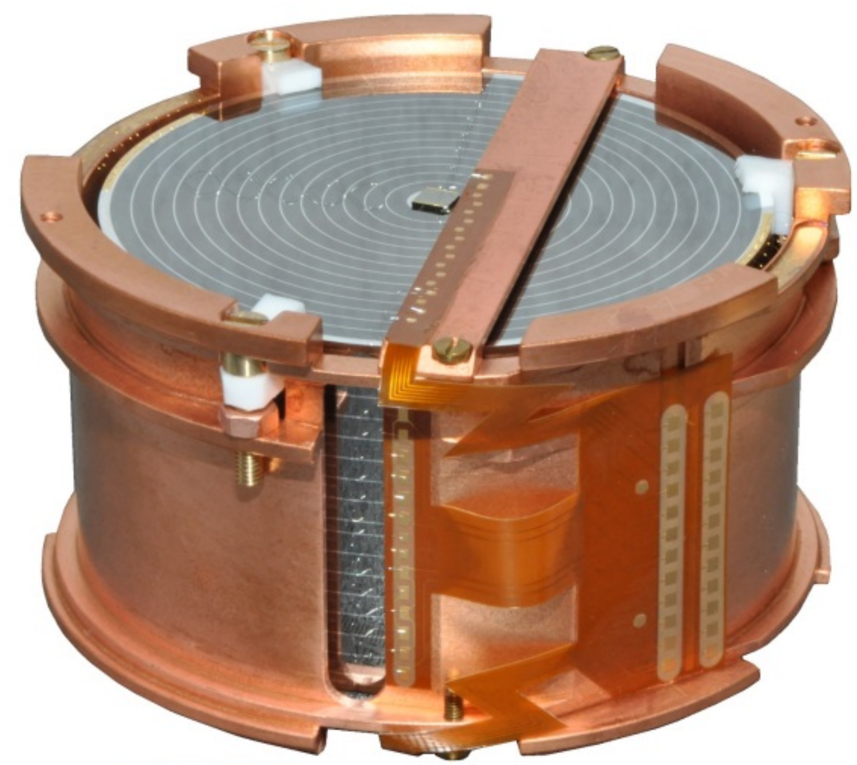
- New FID800 (850g) germanium detectors measure both ionization and heat



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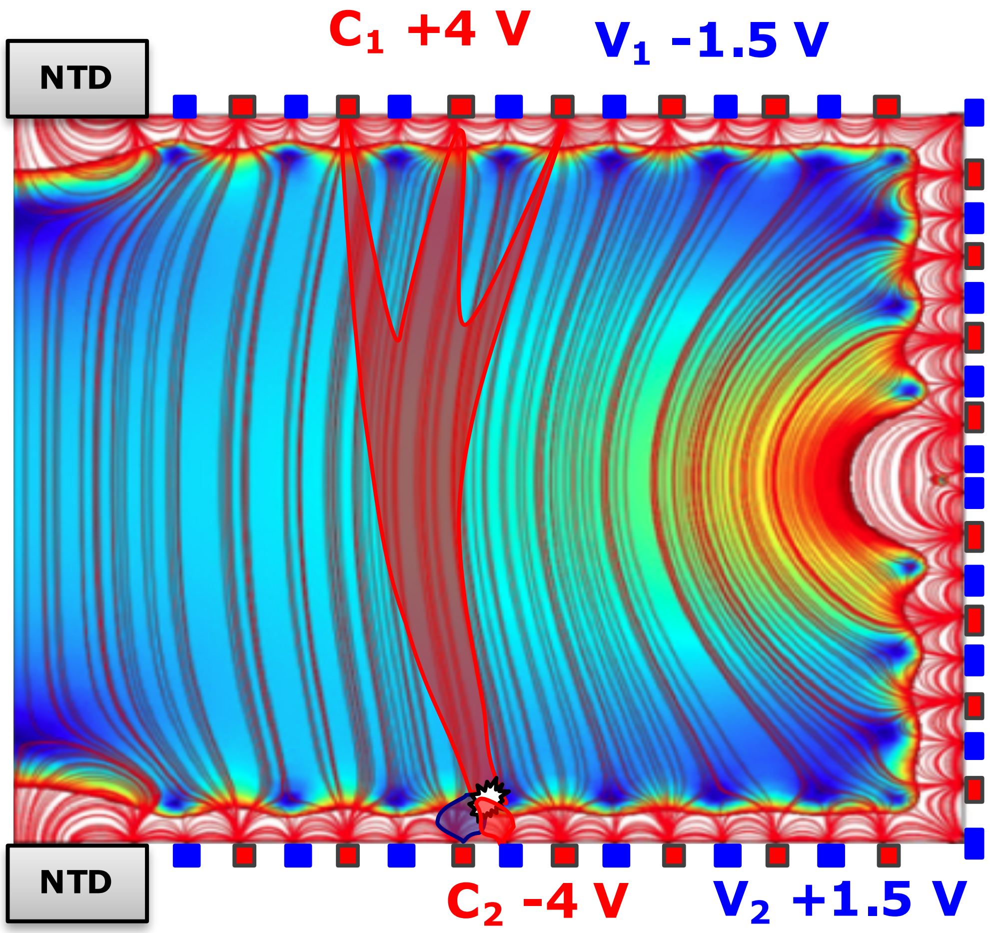

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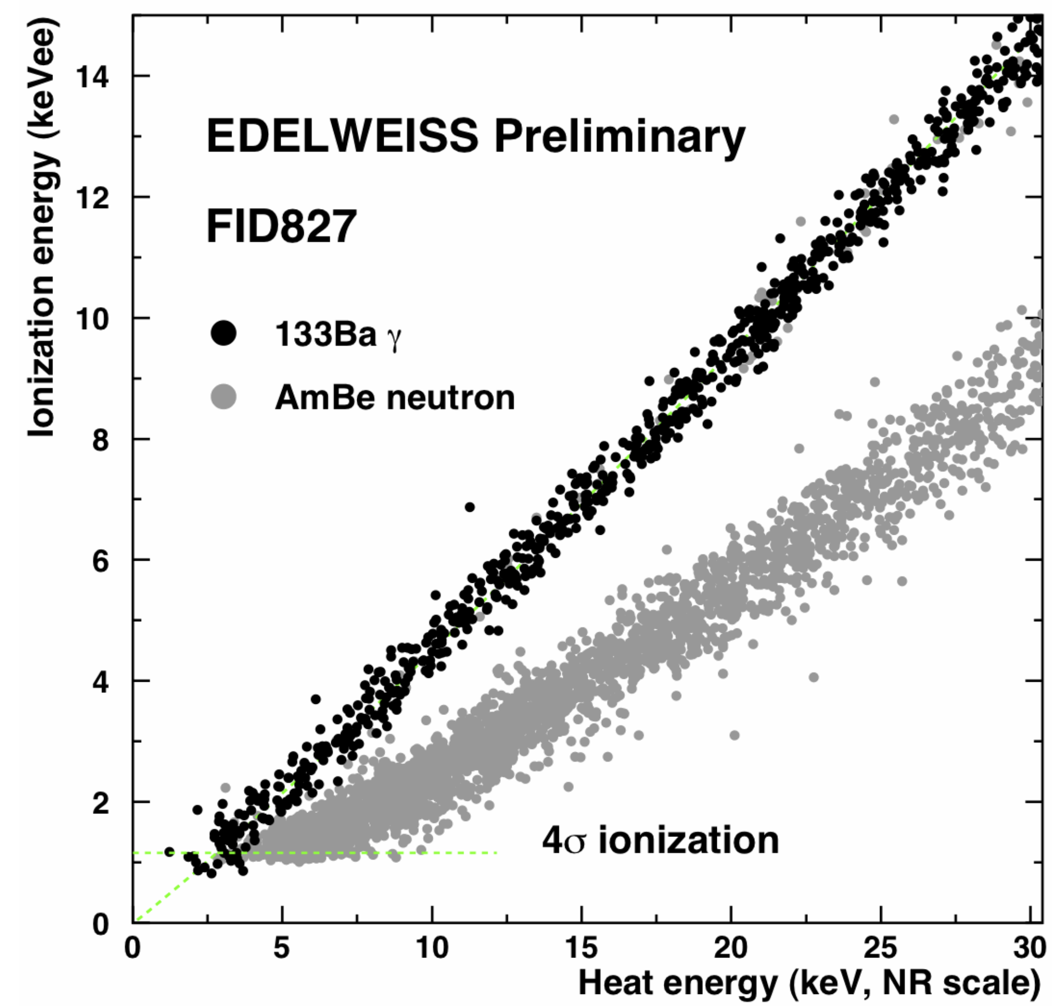

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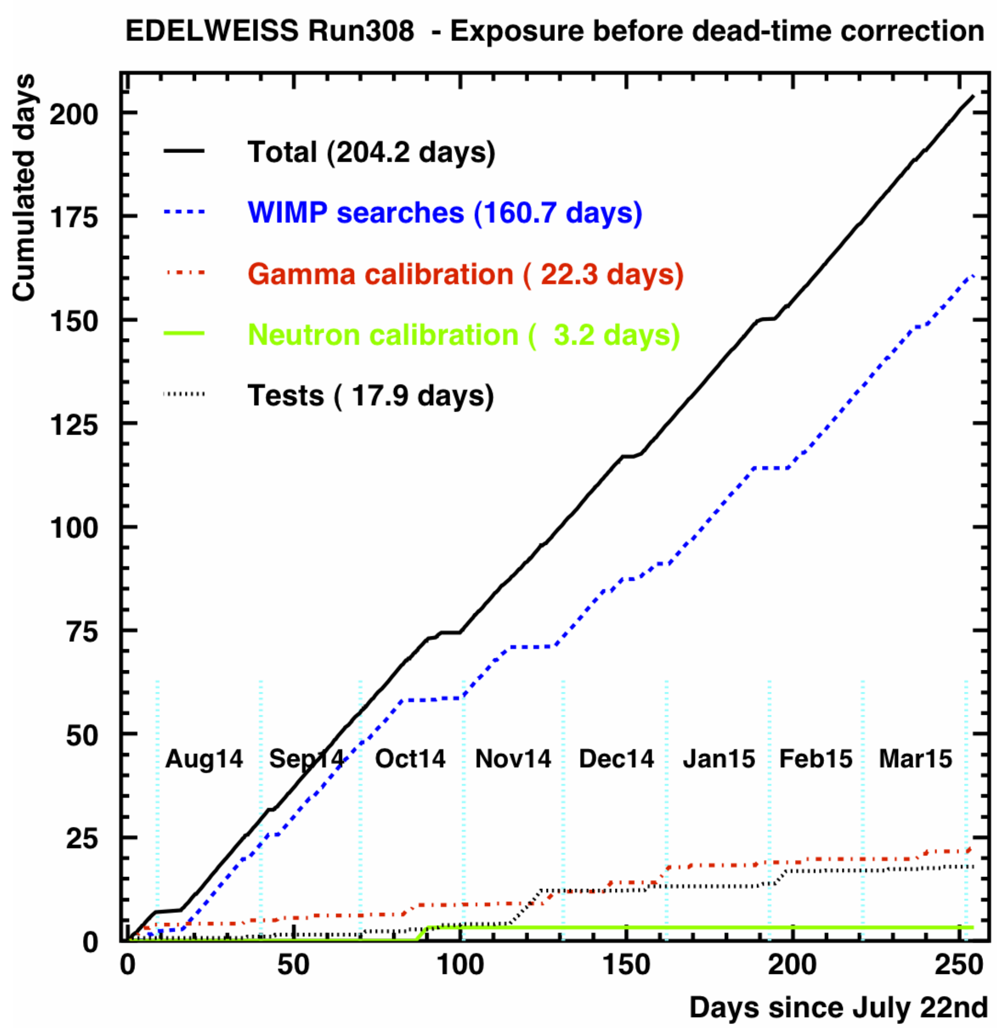
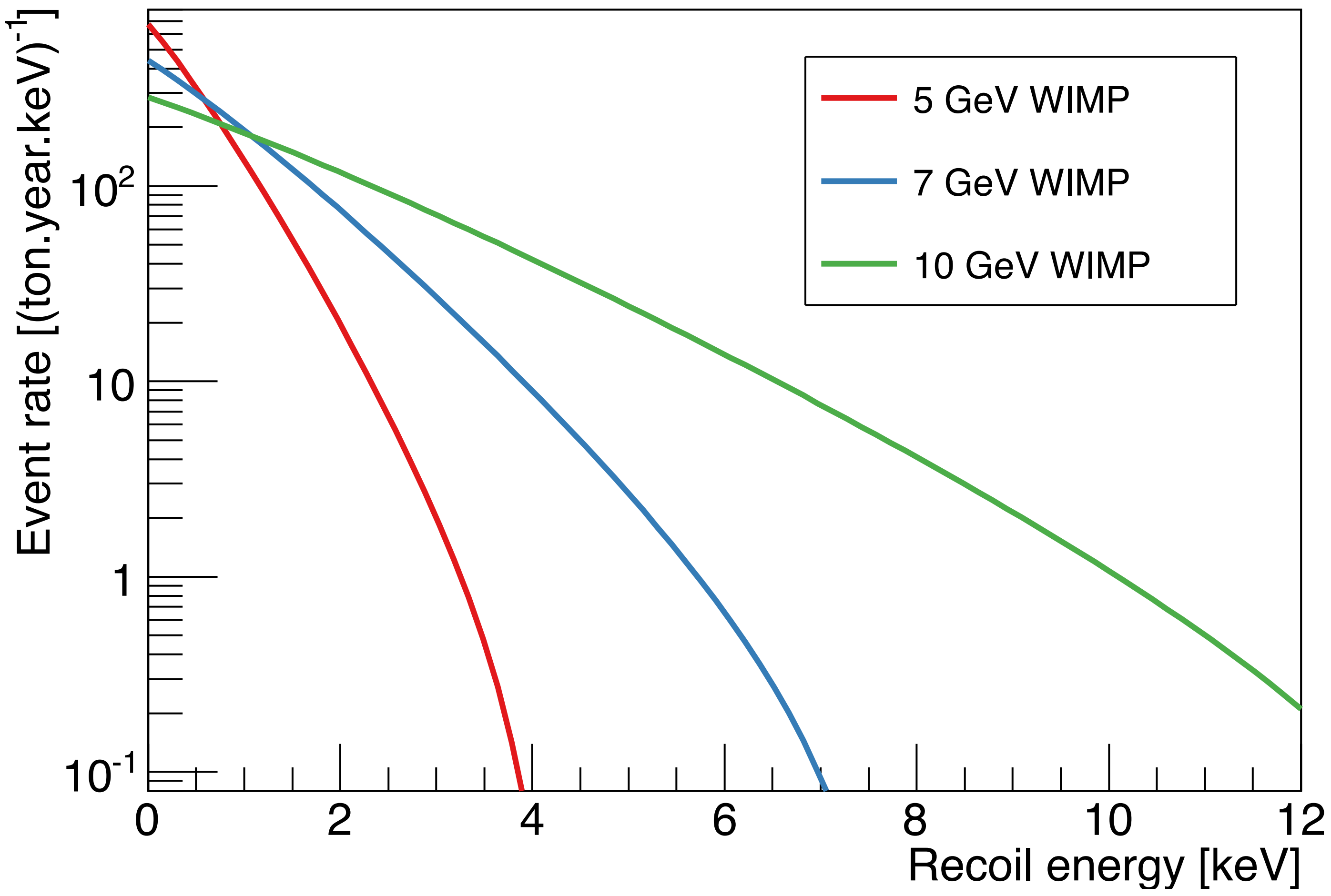


- Original design (ANR FIDSUSY 2010):
  - 20 kg of Ge target, 161 days of DM data
  - Largest bolometer array for direct detection
  - Initial physics goal: WIMP masses > 20 GeV, $\sigma \sim 10^{-9}$ pb, ~3000 kg.day

 Technical paper: EDELWEISS Coll., to be submitted soon

Strategies for Light WIMP Searches

Lowering the energy threshold is the key for light WIMP searches

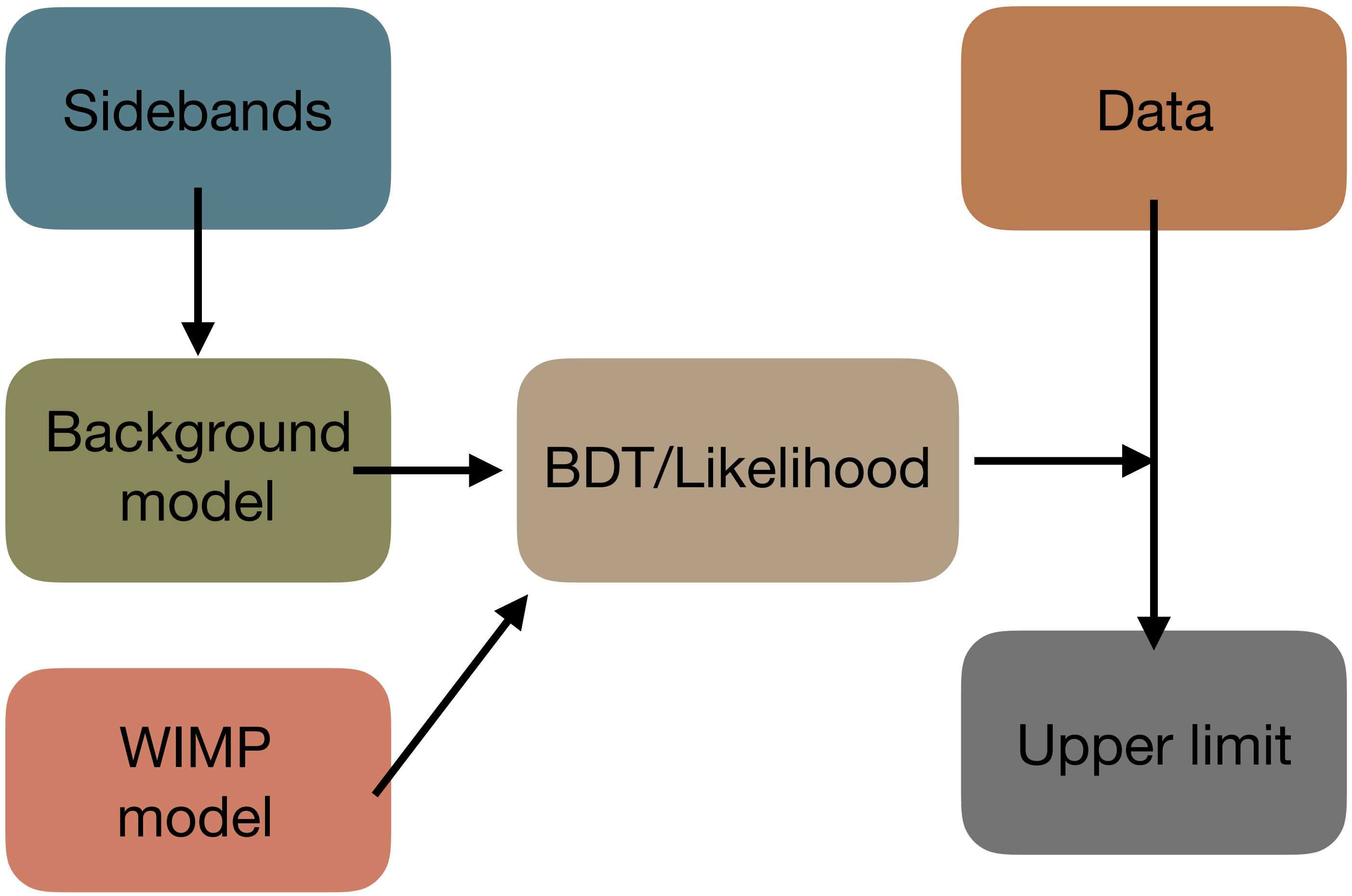


1. Low Threshold analysis: Improve exposure and extend background ID to low energy

Low Threshold analysis

Lowering the analysis thresholds down to the experiment's trigger thresholds

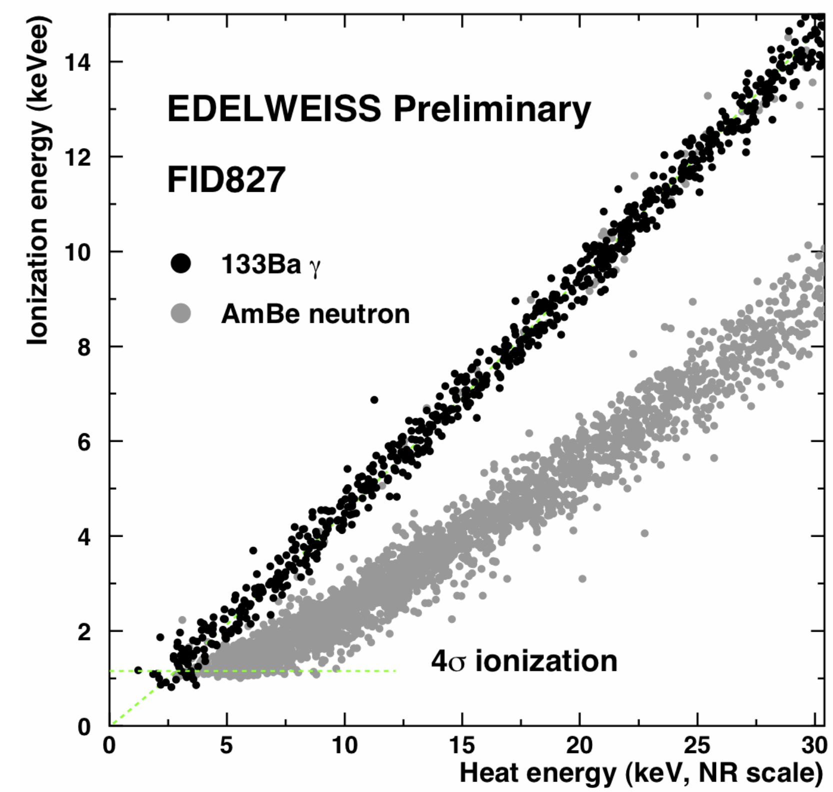
- Use 8 detectors with lowest trigger thresholds (4 @ 2.4 keVnr and 4 @ 3.6 keVnr)
- 582 kg-d of fiducial exposure (August. 2014 - March 2015)
- **2 analyses in parallel optimized for exclusion: BDT and Likelihood**



Low Threshold analysis

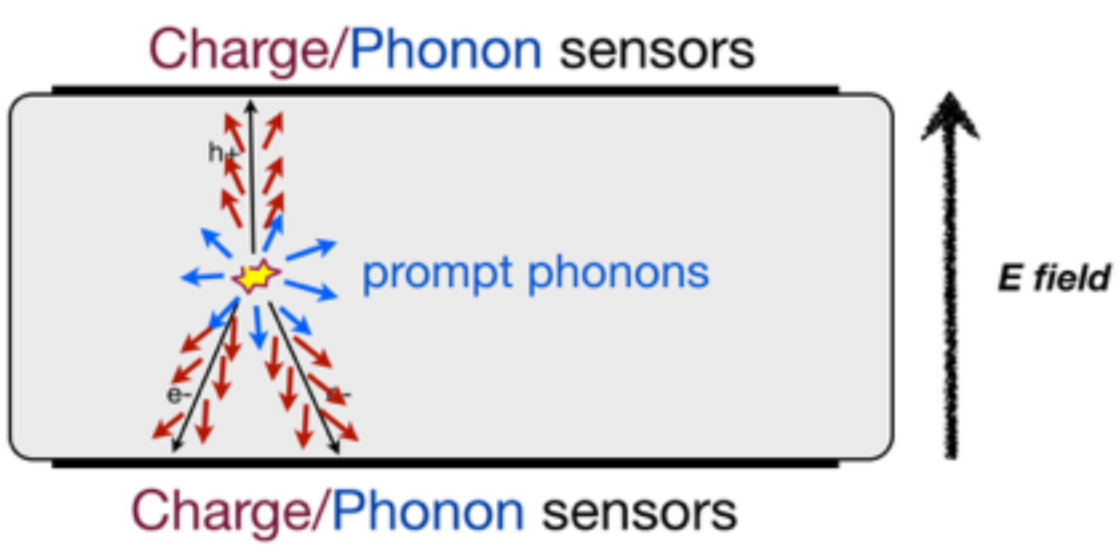
$$E_t = E_r + E_L$$

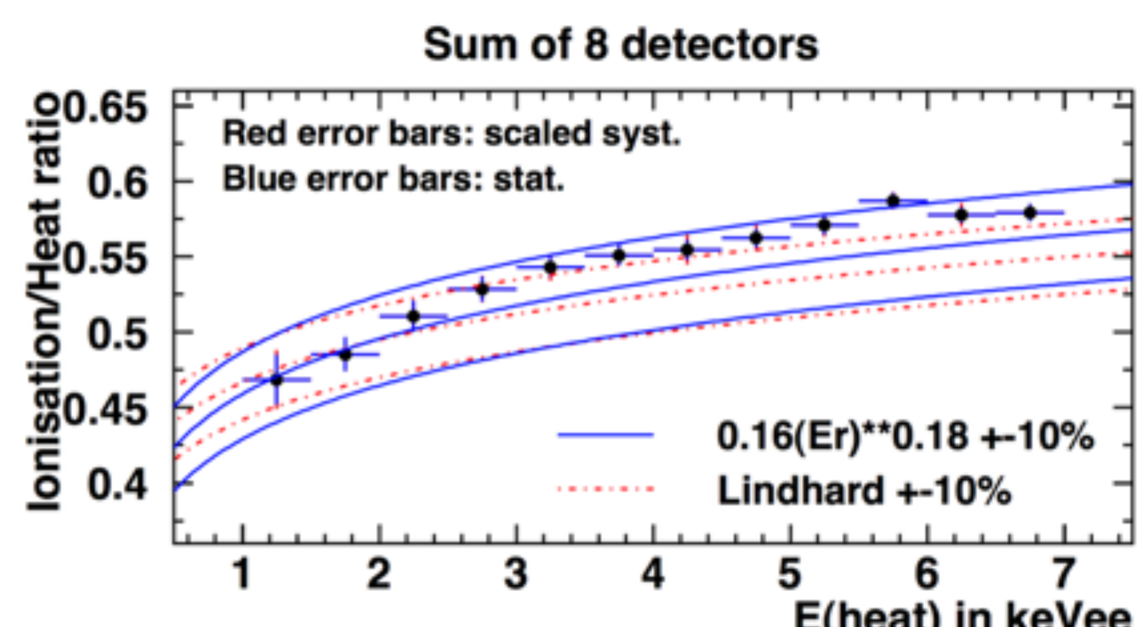
$$E_r = E_t - \frac{1}{3\ eV} E_Q(E_t)\Delta V$$



- Since signal-to-noise is poor, consider mean ionization energy for nuclear recoils
- Nuclear recoil calibration better fitted to a power law
- Consistent with Lindhard's prediction with less ionization at low energy and more at high energy

8V

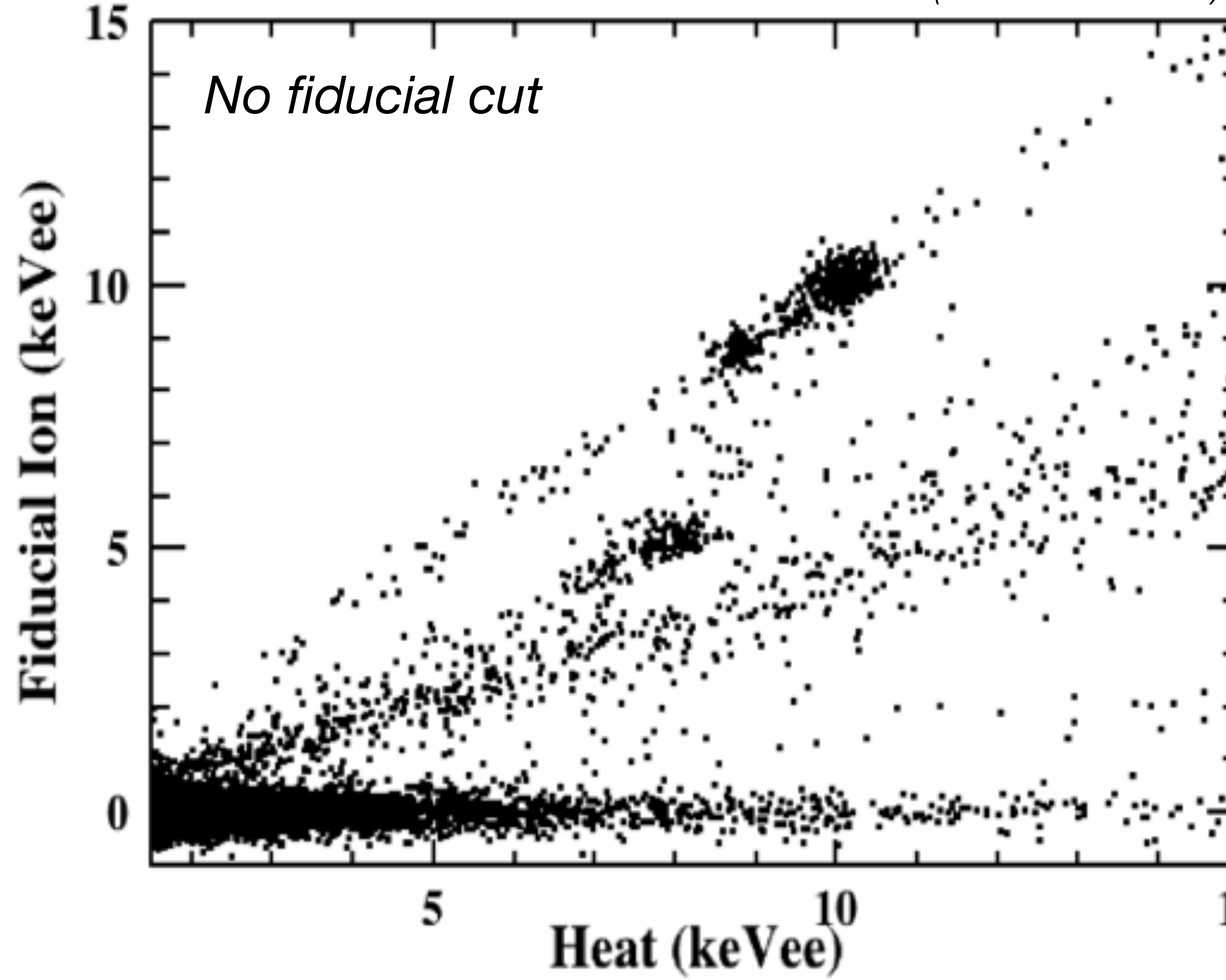




Low Threshold analysis

EDELWEISS-III backgrounds

for illustration (FID837 subset)



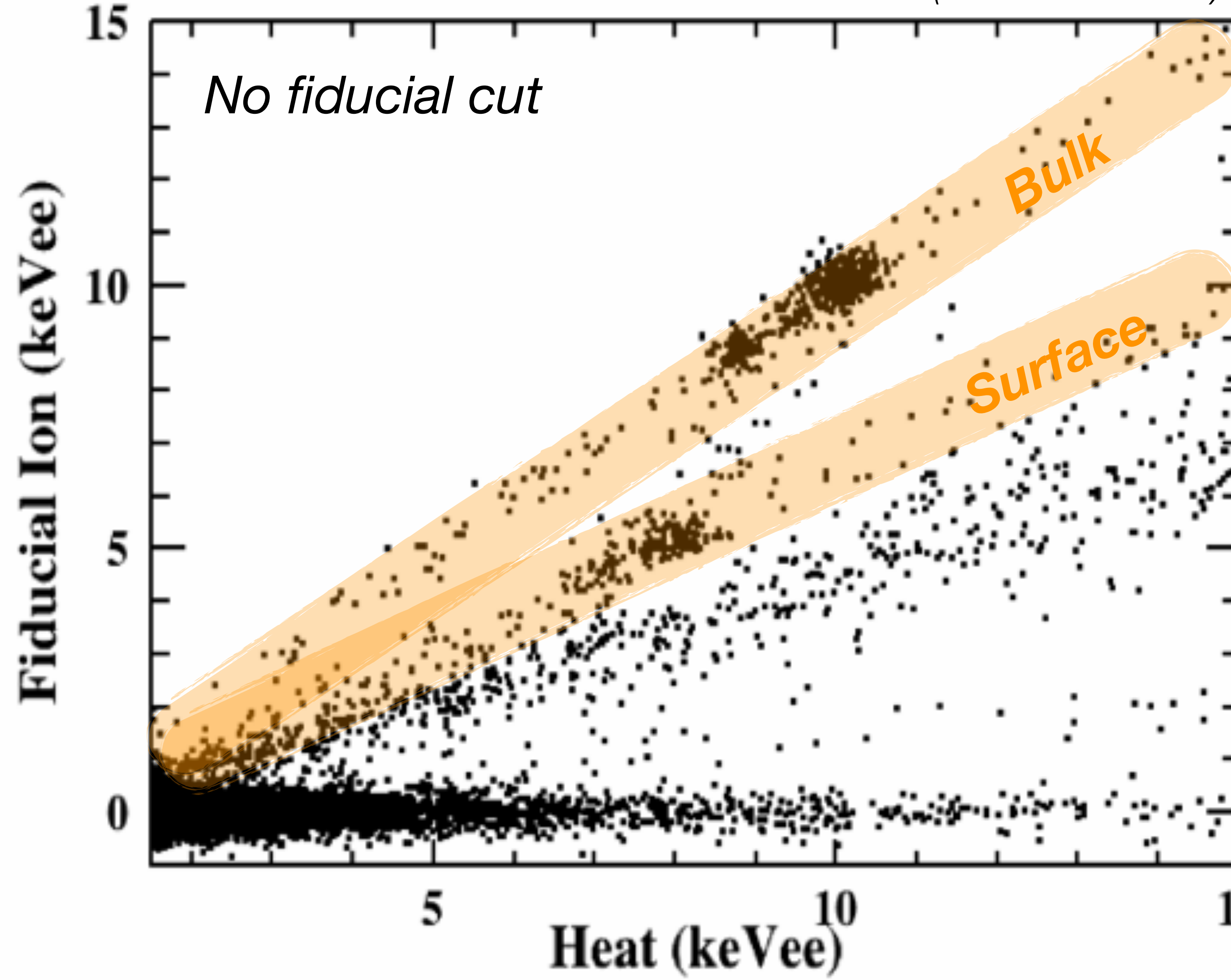
For all backgrounds : data-driven model from sideband data

Low Threshold analysis

Gamma + activation lines

- Internal radioactivity from shielding and cryostat
- Cosmogenic activation lines: K/L-shell capture from $^{68,71}Ge$, ^{65}Zn, ^{68}Ga

for illustration (FID837 subset)

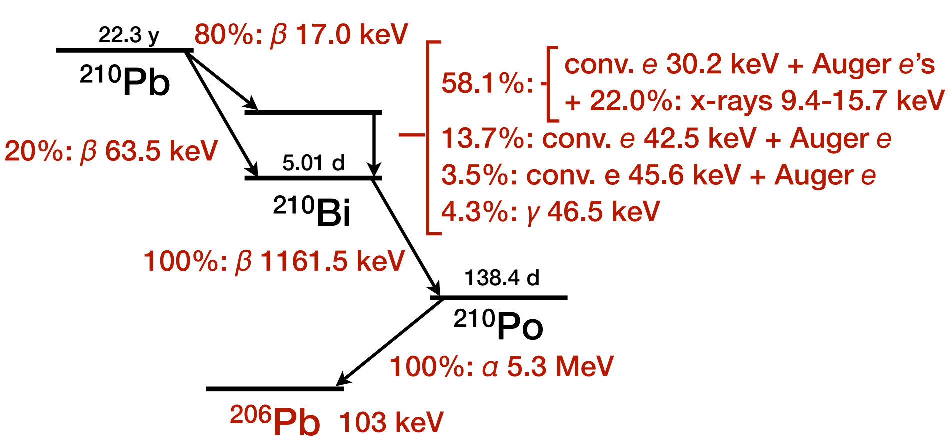


For all backgrounds : data-driven model from sideband data

Low Threshold analysis

^{210}Pb "surface events"

- betas and ^{206}Pb nuclei from ^{210}Pb decay chain
- events are located on detector face and sidewall ***surfaces*** from ^{222}Rn contamination



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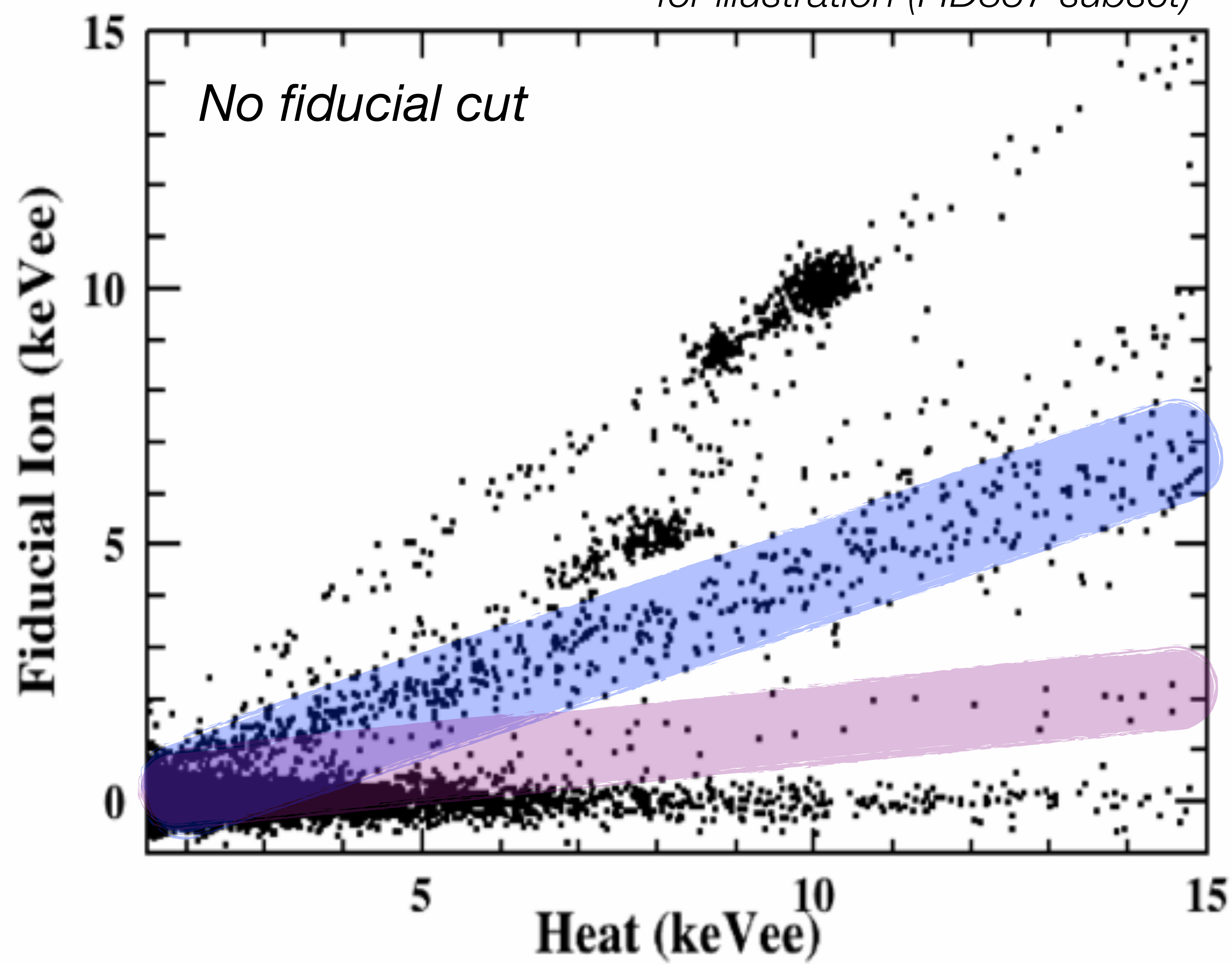


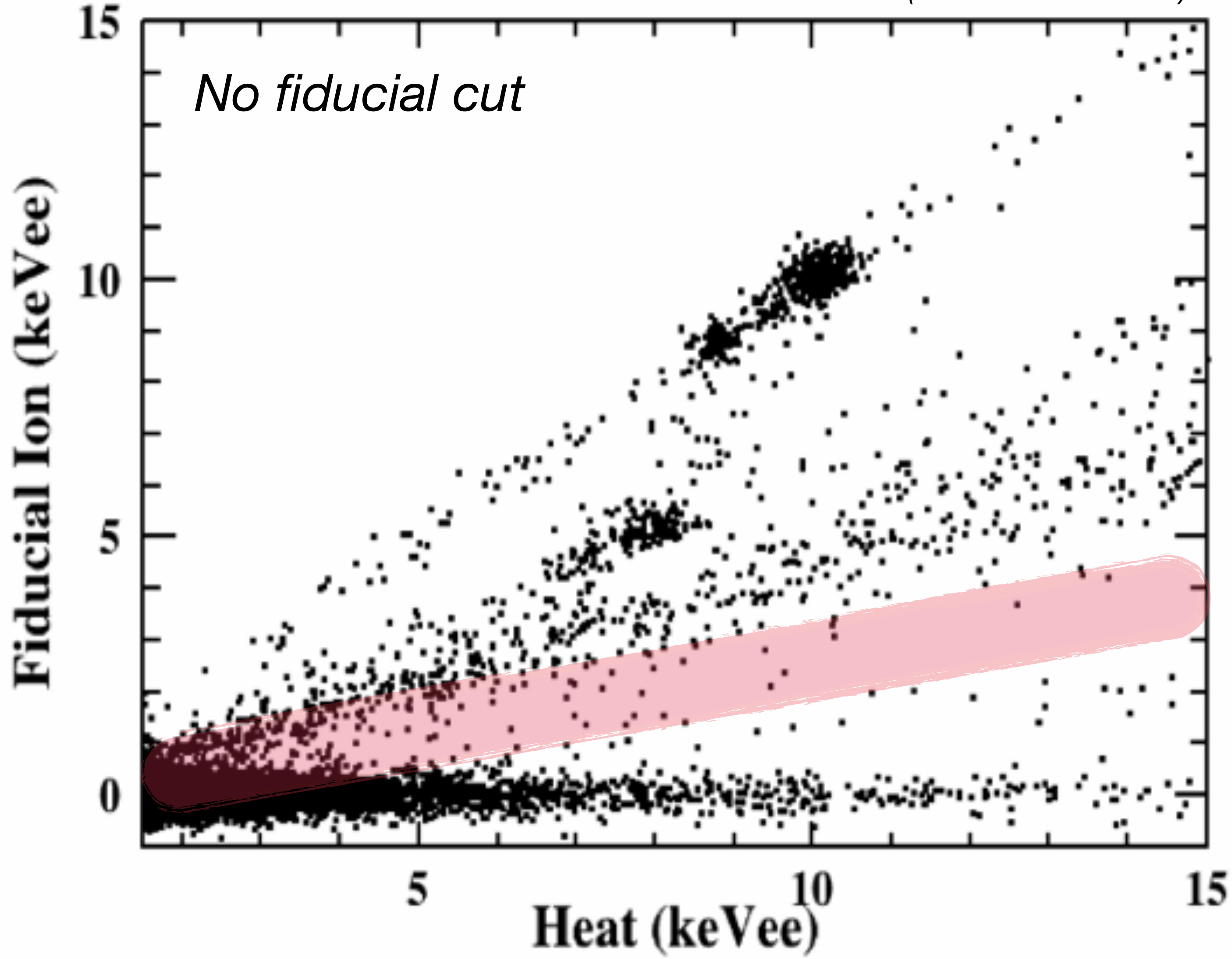
For all backgrounds : data-driven model from sideband data

Low Threshold analysis

Neutron

- Radiogenic origin only for the neutron background
- Estimated from coincident Nuclear Recoils scaled by the single-to-multiple ratio derived from Geant4 simulations

for illustration (FID837 subset)



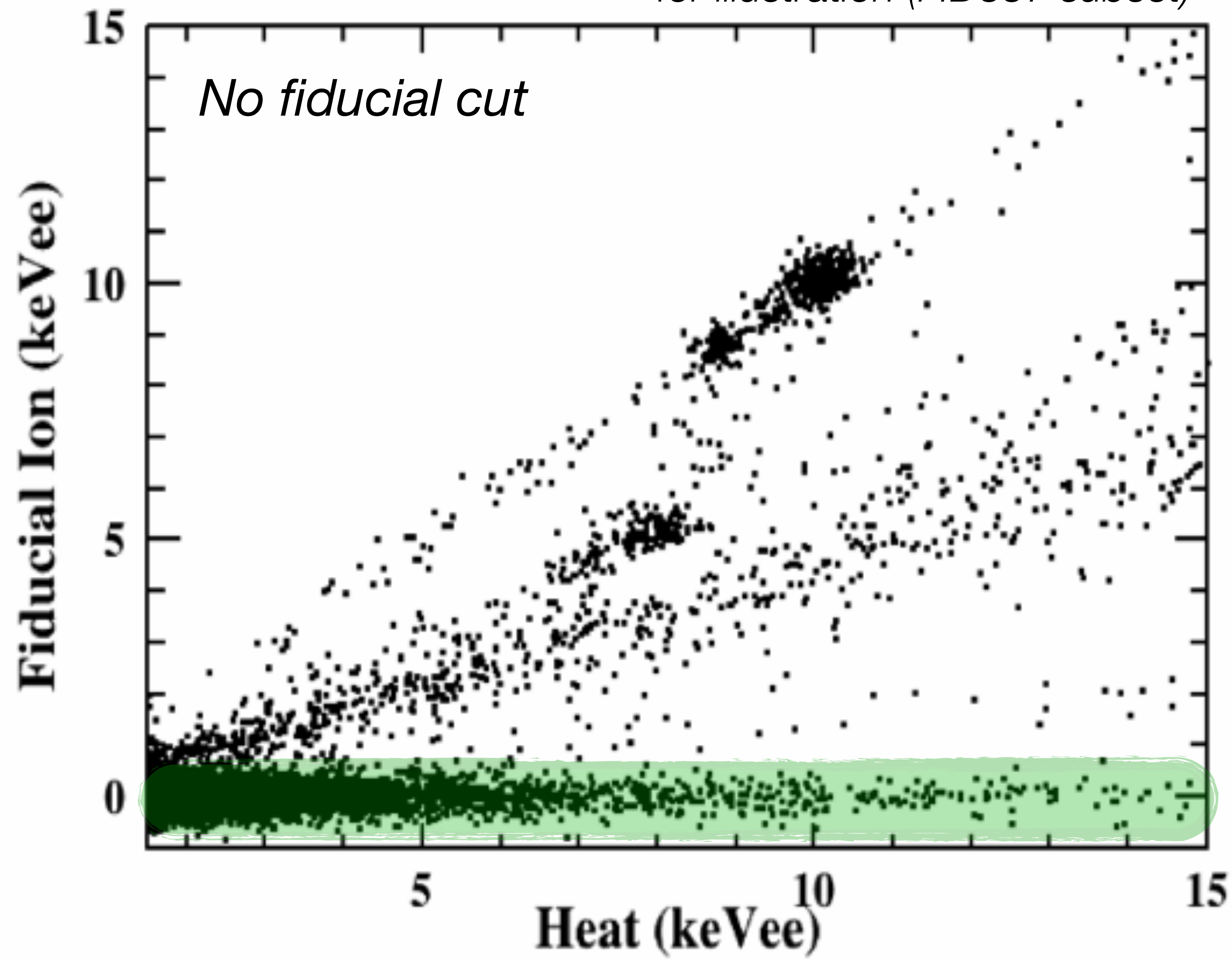
For all backgrounds : data-driven model from sideband data

Low Threshold analysis

Heat only

- Dominating background at low-energy
- Estimated from Eion<0 sideband data (no WIMP expected)
- Origin under investigation highest priority of the EDELWEISS collaboration

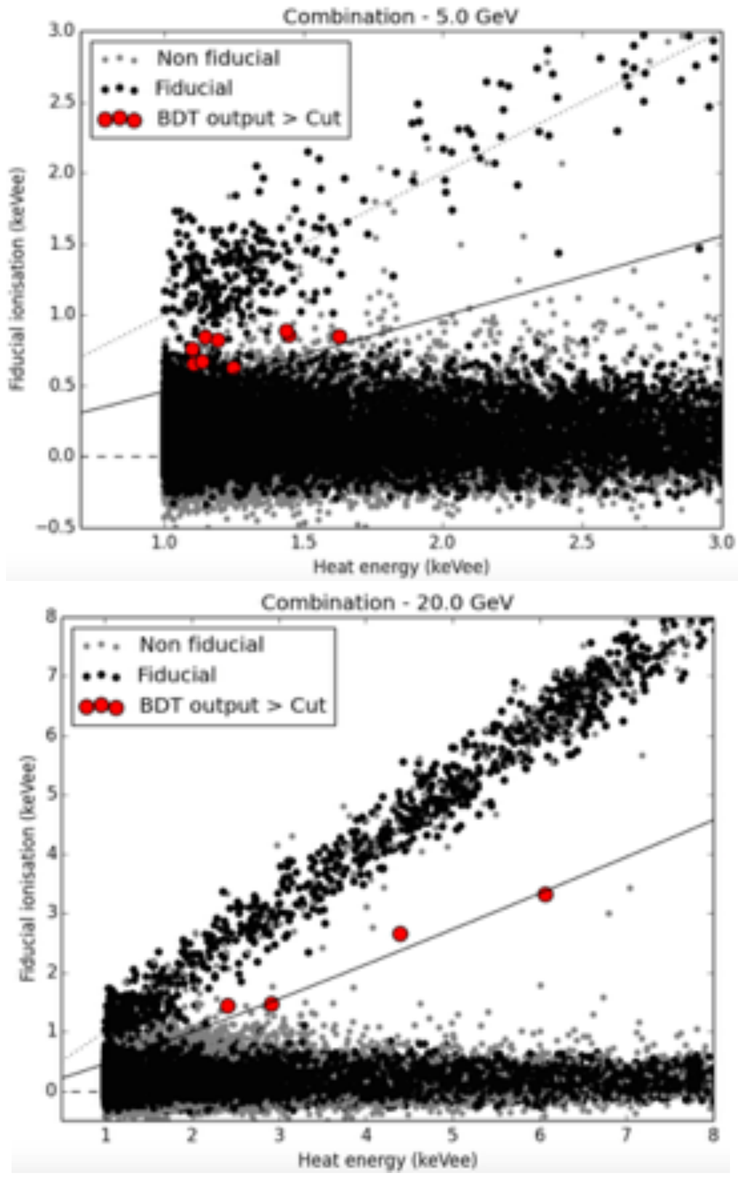
for illustration (FID837 subset)



For all backgrounds : data-driven model from sideband data

Low Threshold analysis

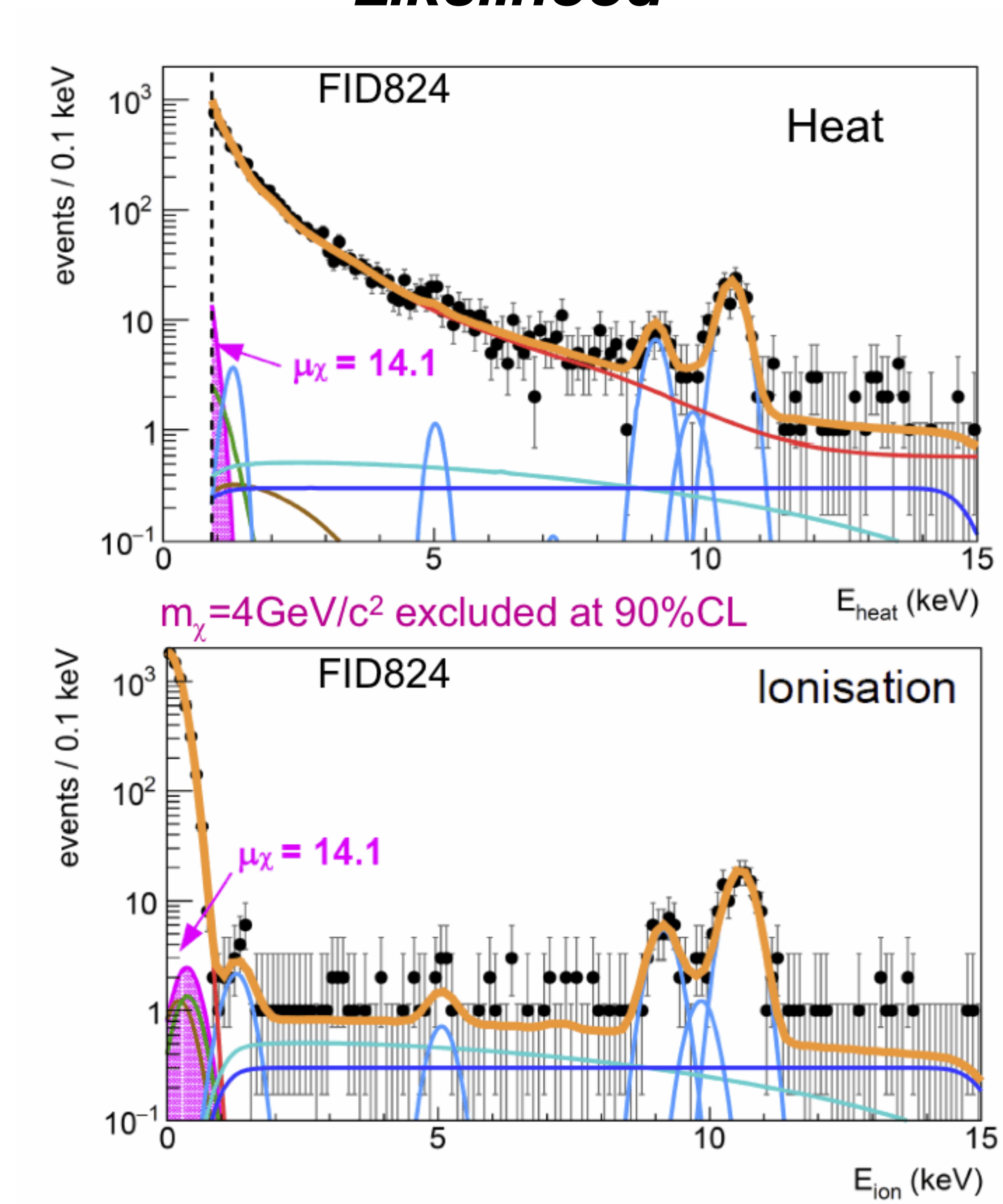
BDT



EDELWEISS Coll., JCAP 05 (2016) 019

- No statistically significant excess
- Dominant backgrounds:
  - **5 GeV: Heat Only**
  - **20 GeV: Radiogenic neutrons**

Likelihood



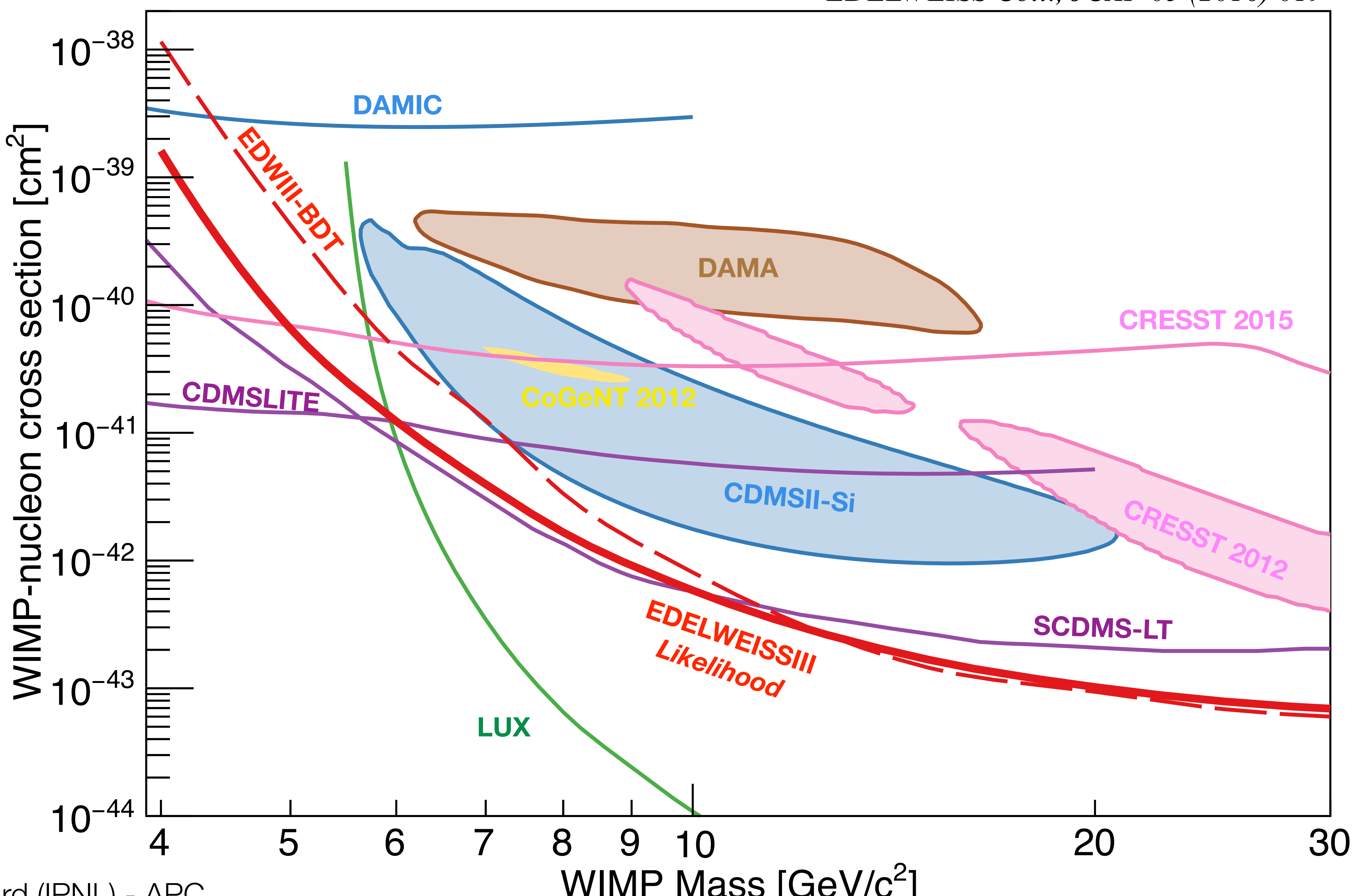
EDELWEISS Coll., EPJ C (2016) 76:548

- 2D fit E_ion Vs E_heat
- Joint fit over the 8 selected detectors
- **x7 better at low mass w.r.t BDT**
- **Method of choice for the future**

Low Threshold analysis

EDELWEISS Coll., EPJ C (2016) 76:548

EDELWEISS Coll., JCAP 05 (2016) 019



Low Threshold analysis

Let's take a closer look at the ER band…

$${}^{3}_{1}T \xrightarrow{\beta-} {}^{3}_{2}He + e^{-} + \bar{\nu}_{e}$$

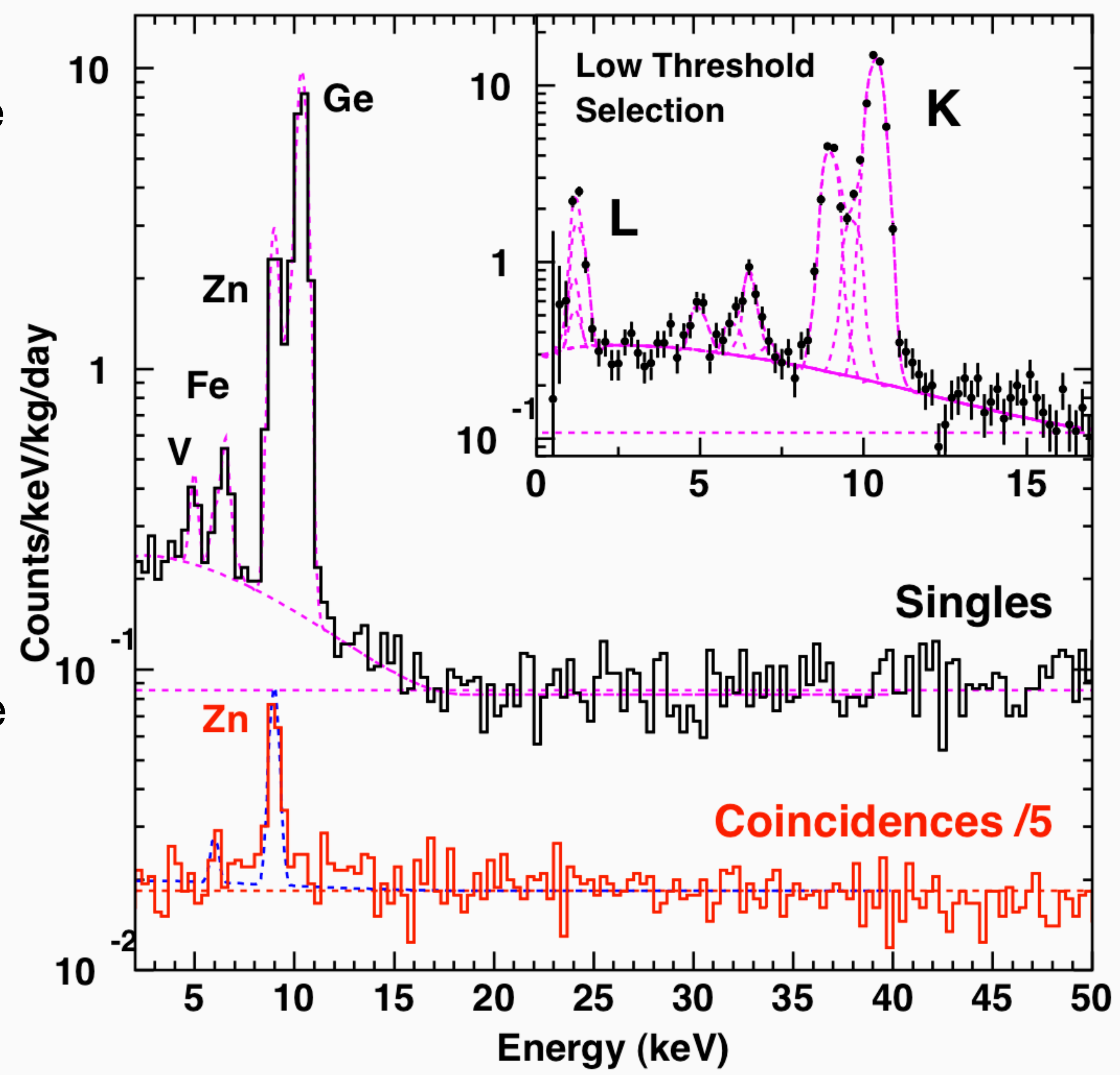
- Cosmogenically produced tritium will become one of the major background component for next generation Ge experiments

- Thanks to its impressively low gamma background (<0.1 DRU) and exquisite ionization energy resolution (200 eV RMS)

- EDELWEISS-III is the first Ge experiment to observe this ultimate background and to have measured its production rate which is of first importance for next generation experiments !

$$82{\pm}21\ \mathrm{nuclei/kg/day}$$

EDELWEISS Coll., arXiv:1607.04560



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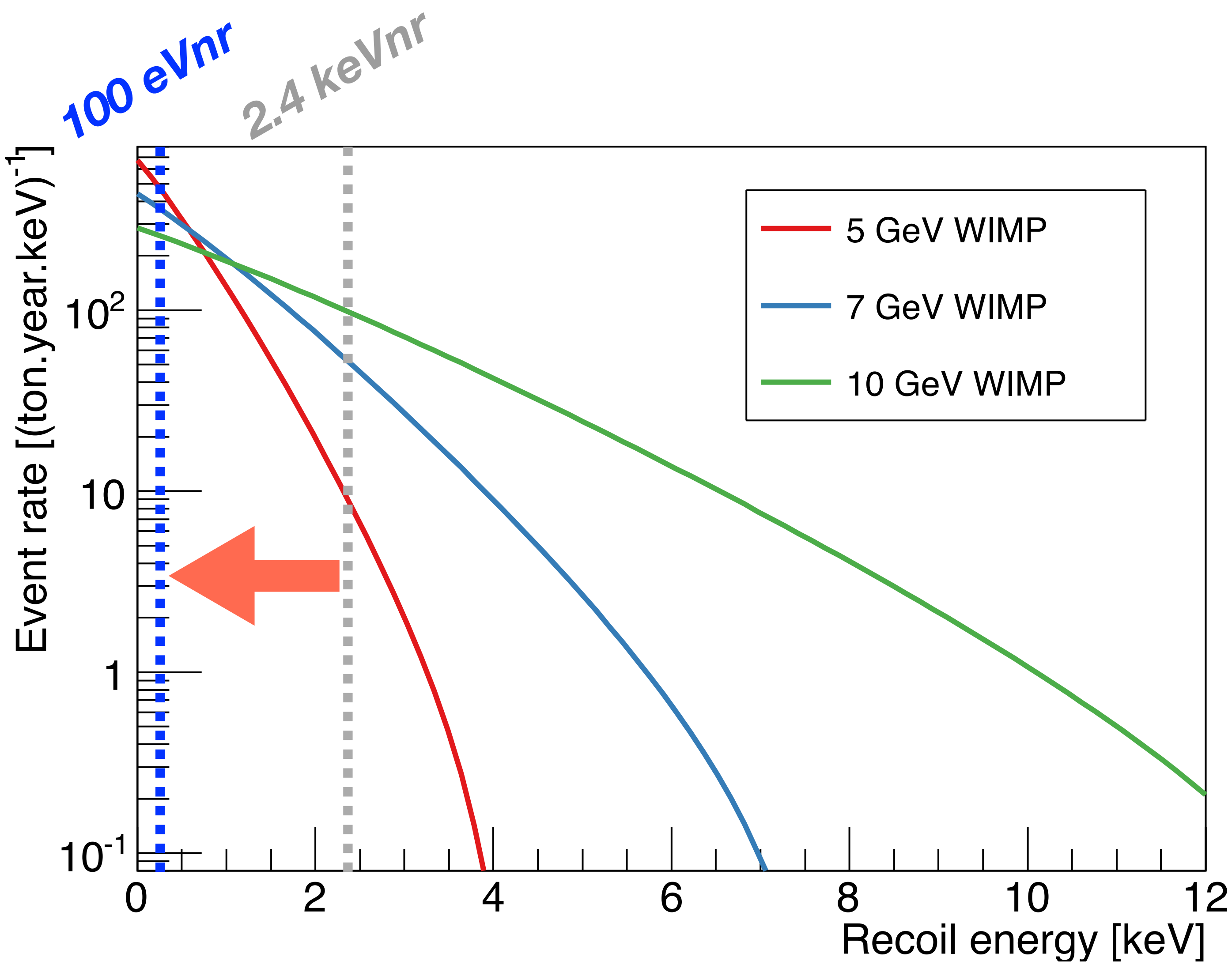


1. **High Voltage**
   Amplify heat signal to reduce threshold
   8 V —> 100 V

2. **Lower the intrinsic heat threshold**
   Improved heat sensors
   500 eV (RMS) —> 100 eV (RMS)

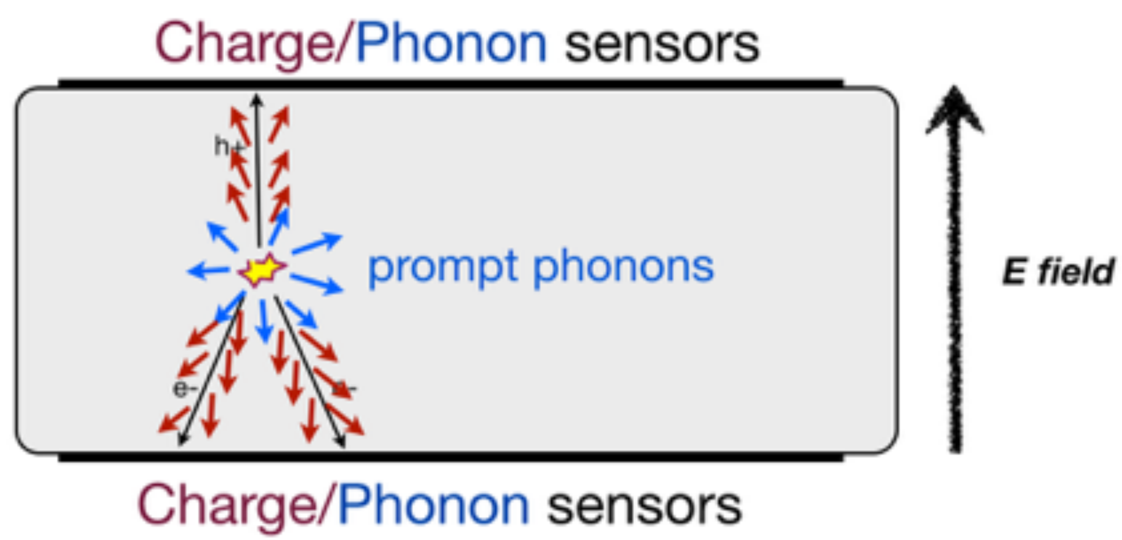
3. **Extended background ID to lower energy**
   Improved ionization sensors
   200 eV (RMS) —> 100/50 eV (RMS)

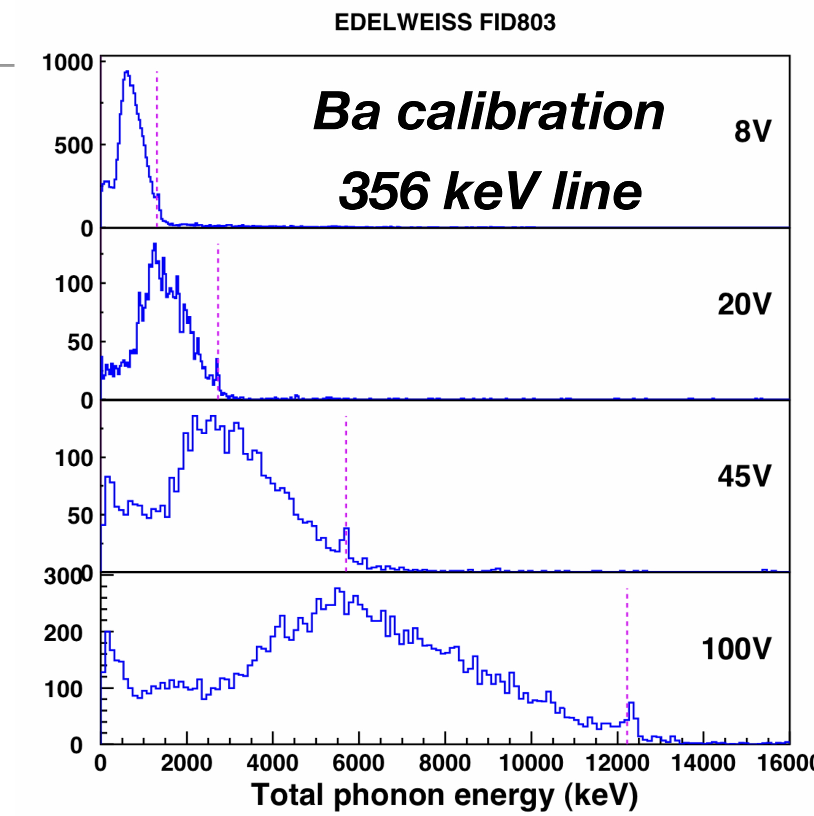
4. **Reduce irreducible backgrounds**
   /100 heat only rate

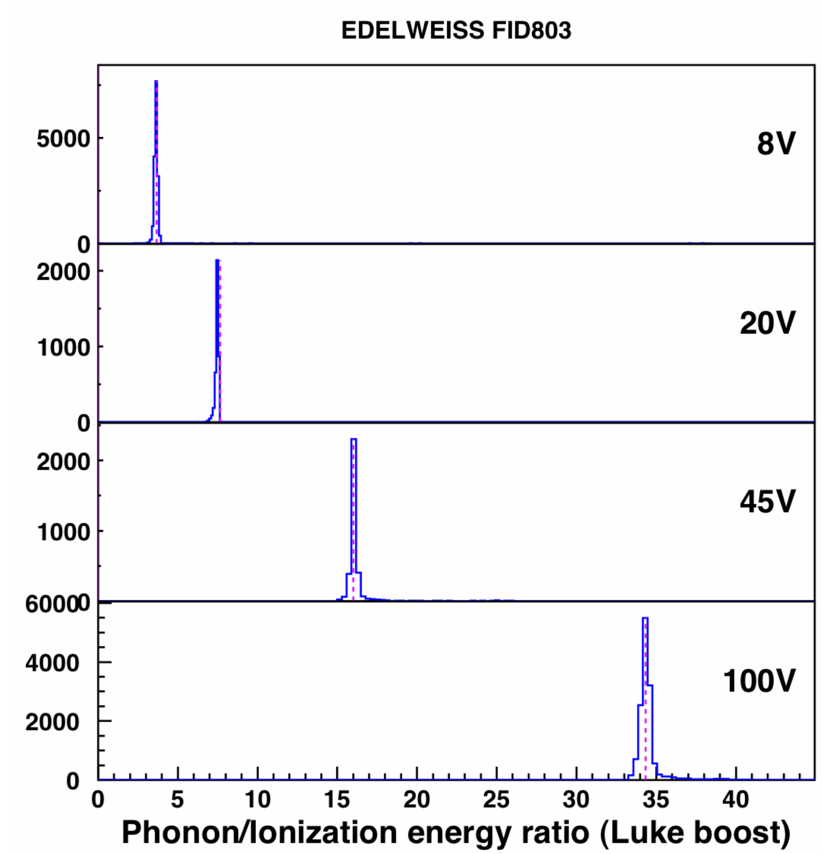
An intense R&D program to lead the low mass WIMP search at the horizon 2017…

Goal #1: High Voltage

$$E_t = E_r + \frac{1}{3\,eV} E_Q \Delta V$$







- First Dark Matter run with HV detectors ongoing
- **Successfully reached 100 V** leading to a boost factor of ~35 with Lowest threshold achieved of **60 eVee**
- Even in HV mode, we can still **readout both ionization and heat signals contrarily to SuperCDMS**
- However, loss of particle ID at high voltage —> **Exclusion strategy dedicated to the lowest WIMP masses reachable**

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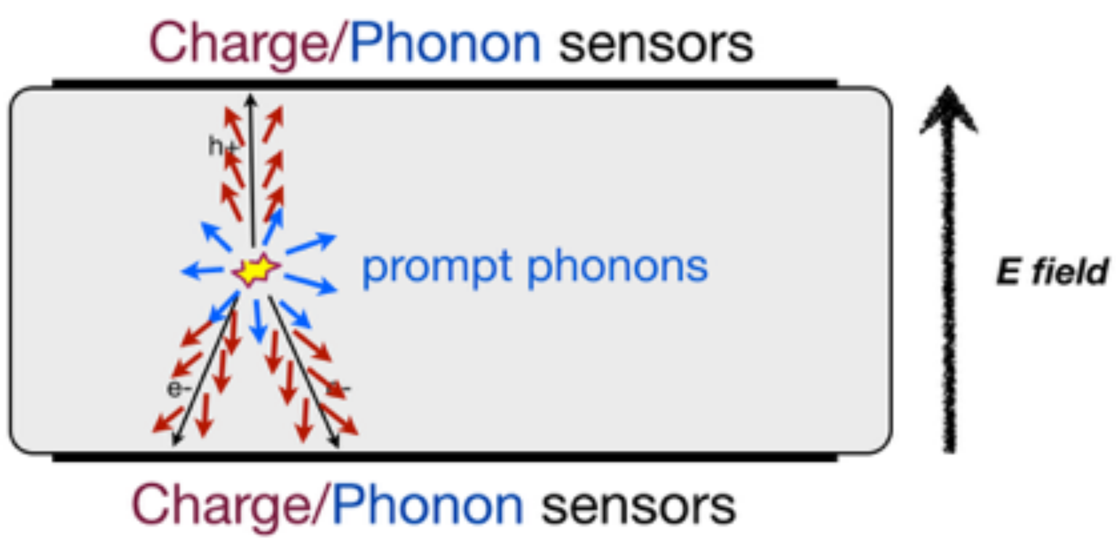

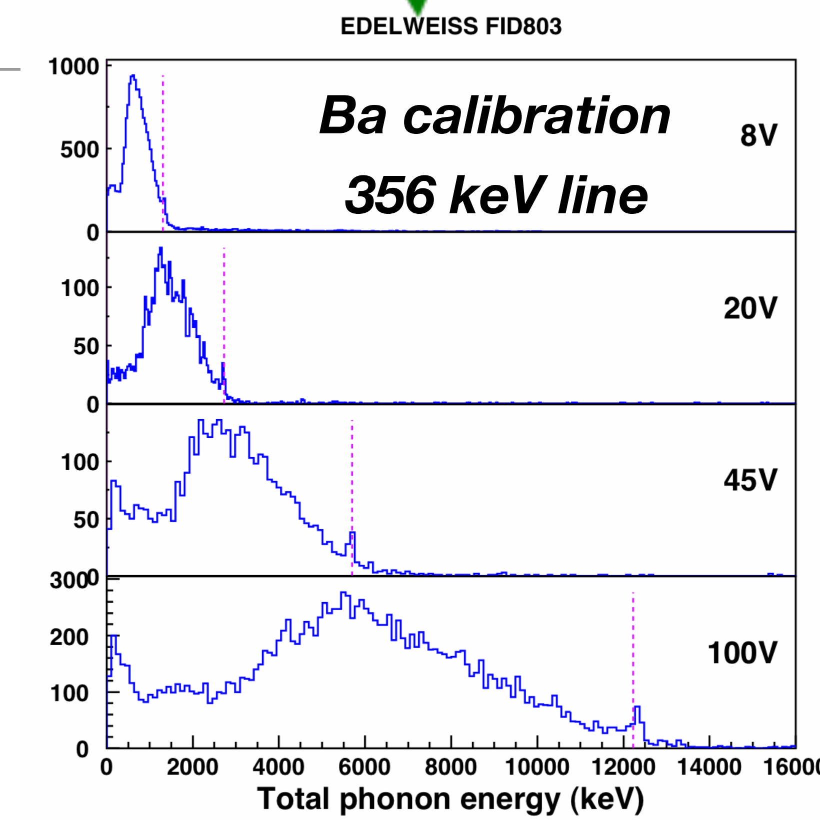

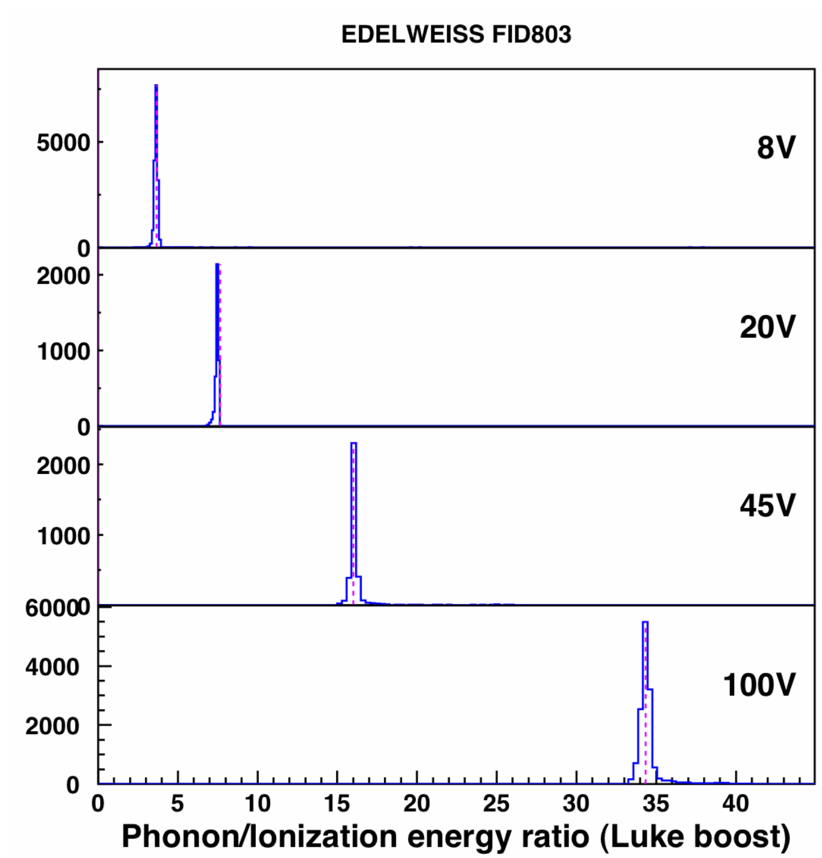

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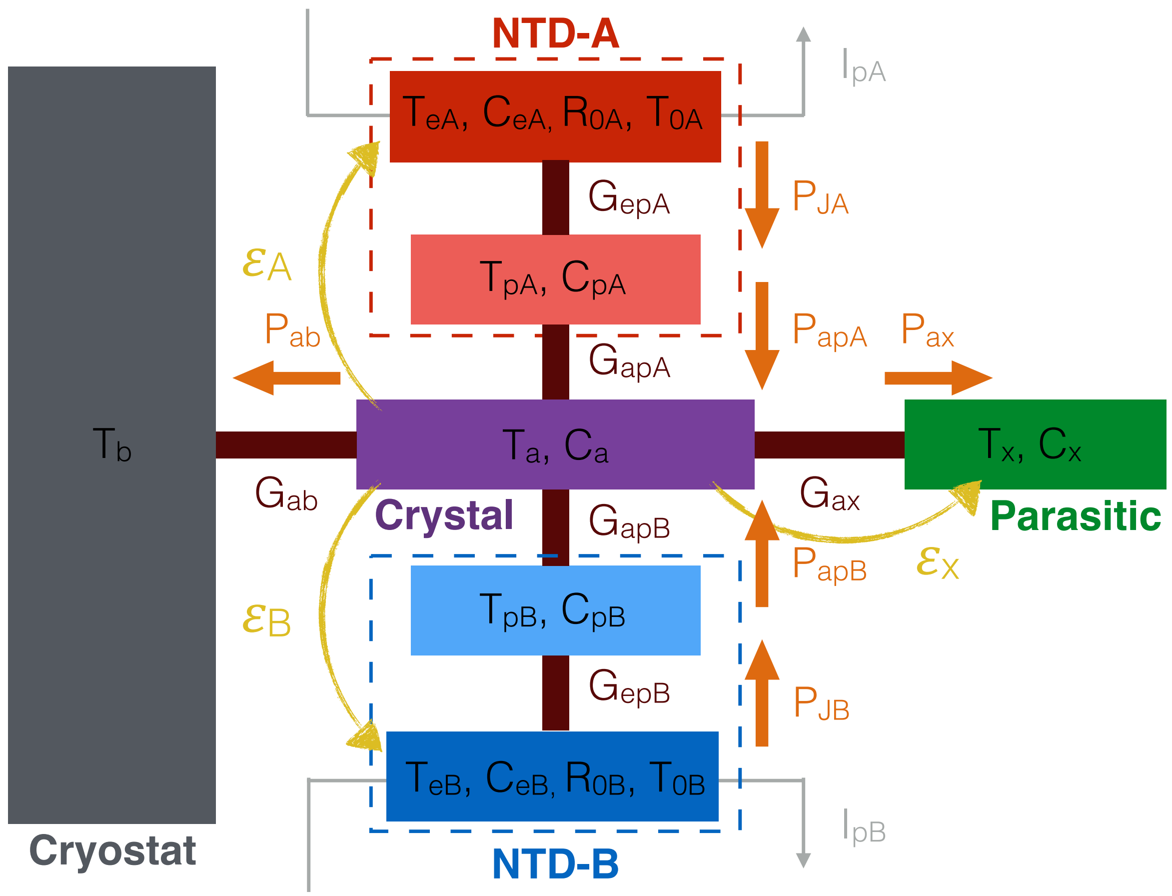
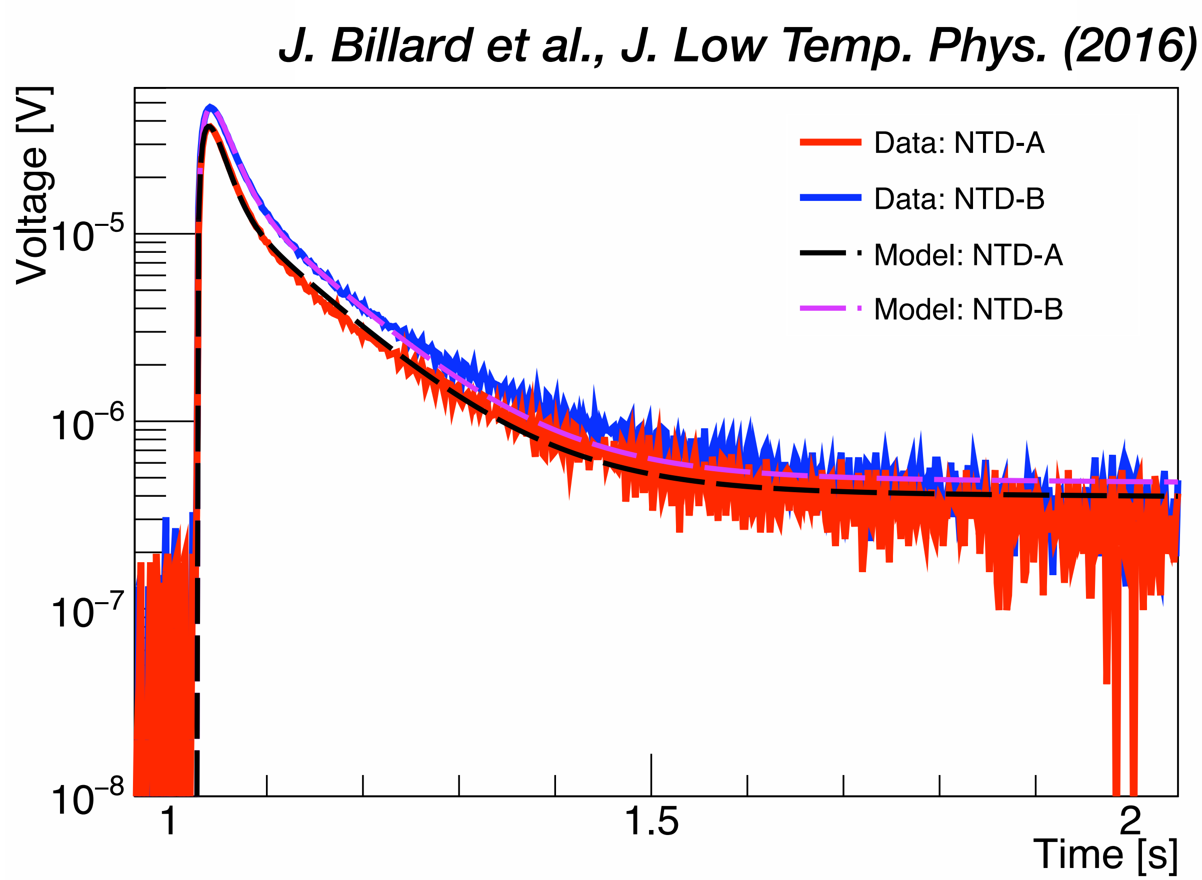
Goal #2: Improved heat sensors





- We developed a detailed model of our heat signals that fits very well observed pulses
  - Sensitivity to ballistic phonons
  - Presence of a parasitic heat capacity
- We should be able to further optimize our heat sensors and gain a factor of 5 is sensitivity

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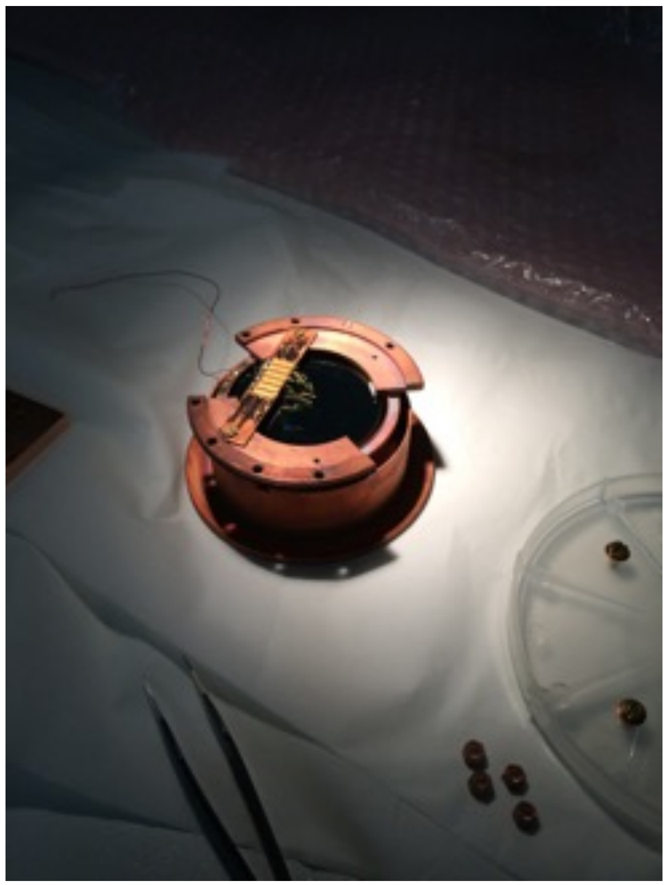

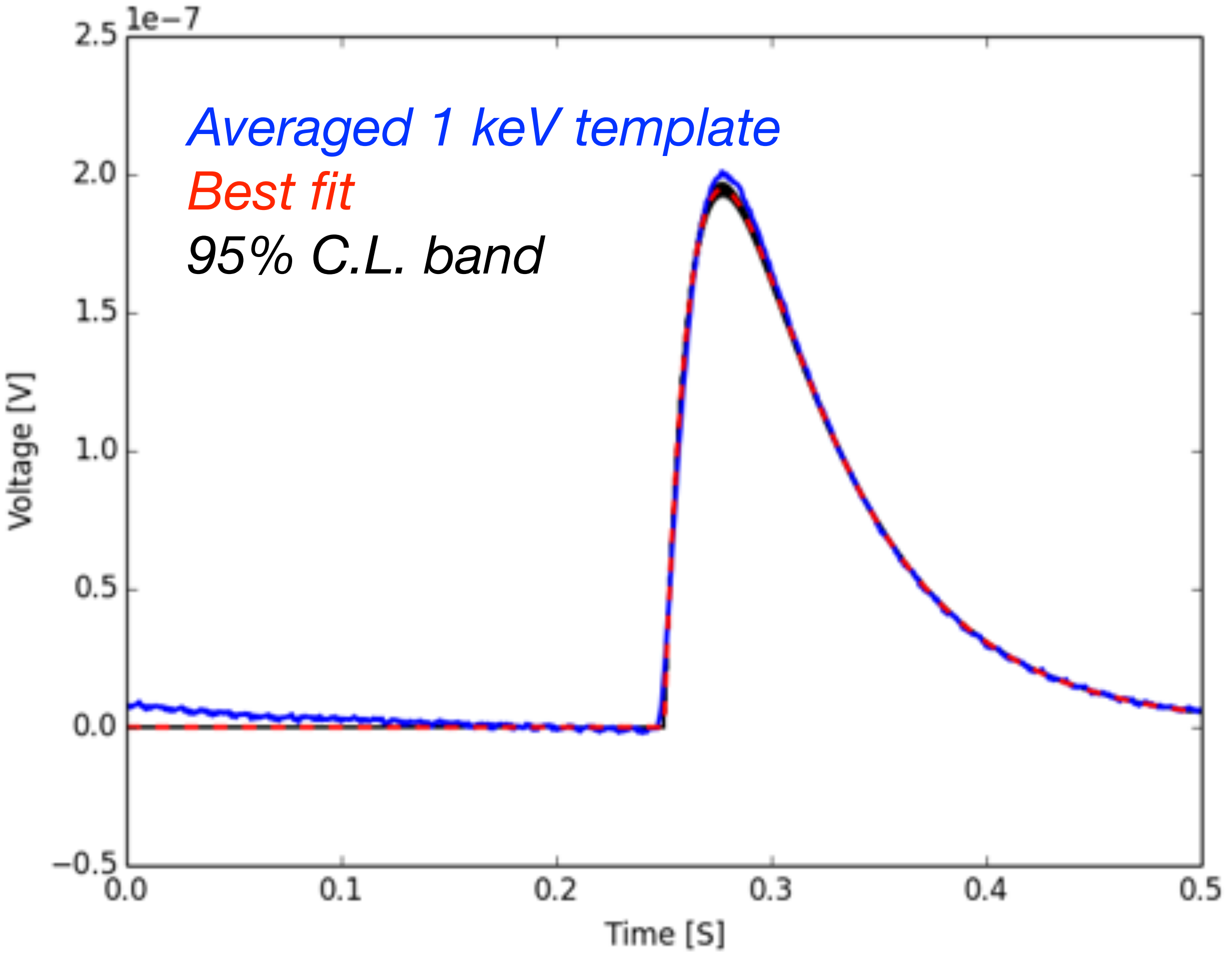

- A dedicated R&D to optimize the heat sensors has started mid-2016:
  - no loss in sensitivity: no evidence of parasitic heat capacity
  - Perfect agreement with thermal model predictions: possibility to optimize via simulations
- We observed a sensitivity of **200 nV/keV** compared to **30 nV/keV** with FID installed in Modane
- Extrapolating to the noise level observed in Modane —> **heat resolution of 50 eV (RMS) !!!**

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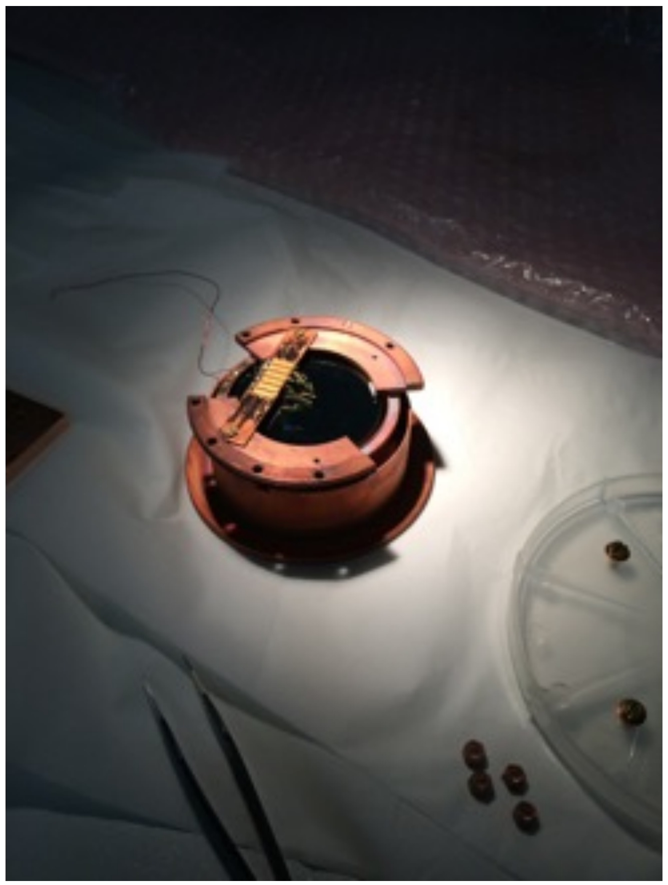

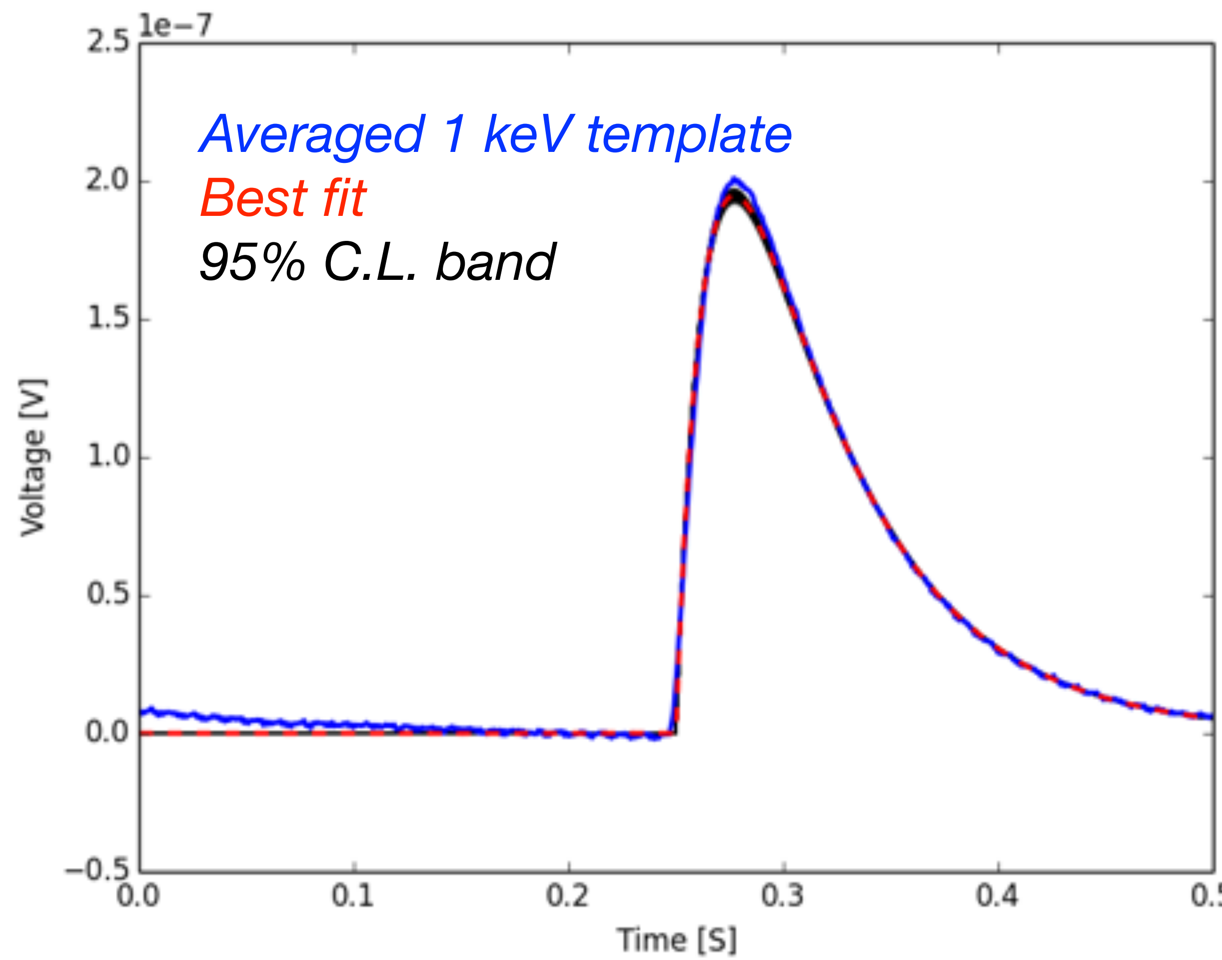

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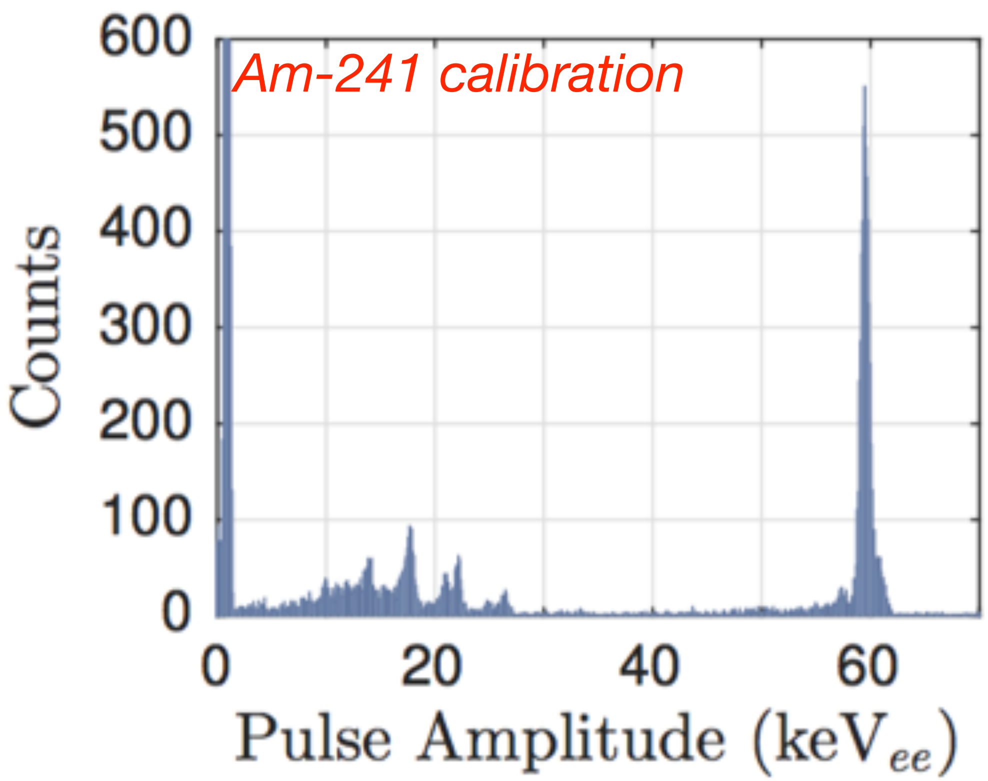
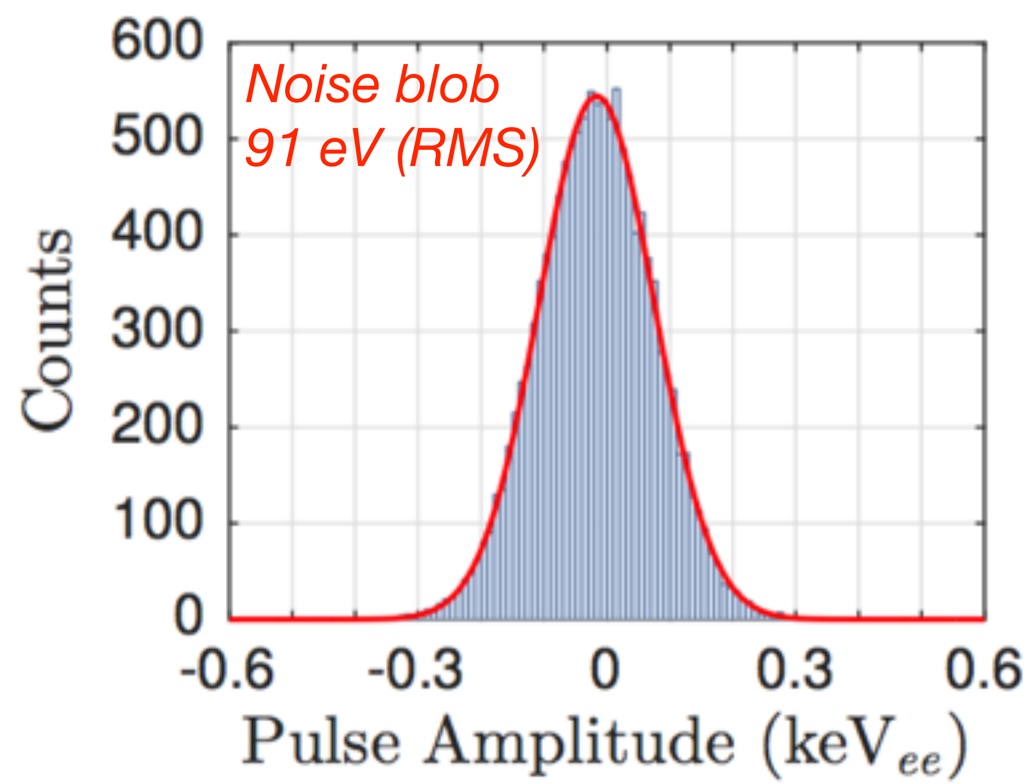
Goal #3: Improved ionization sensors

A. Phipps et al., arXiv:1611.09712

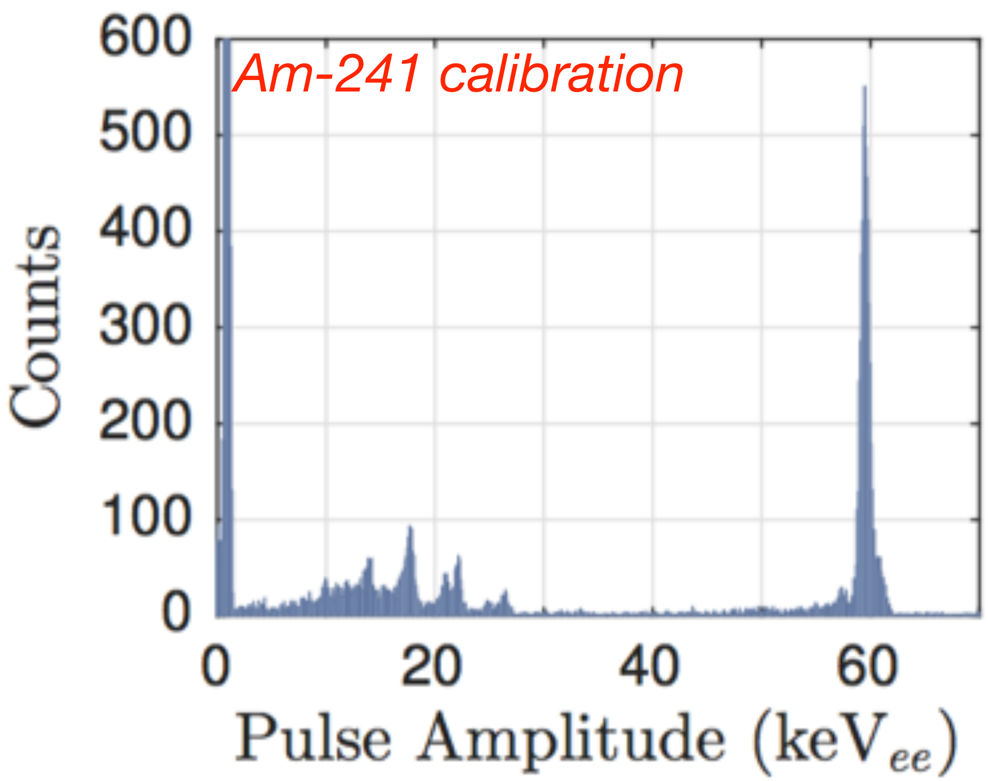


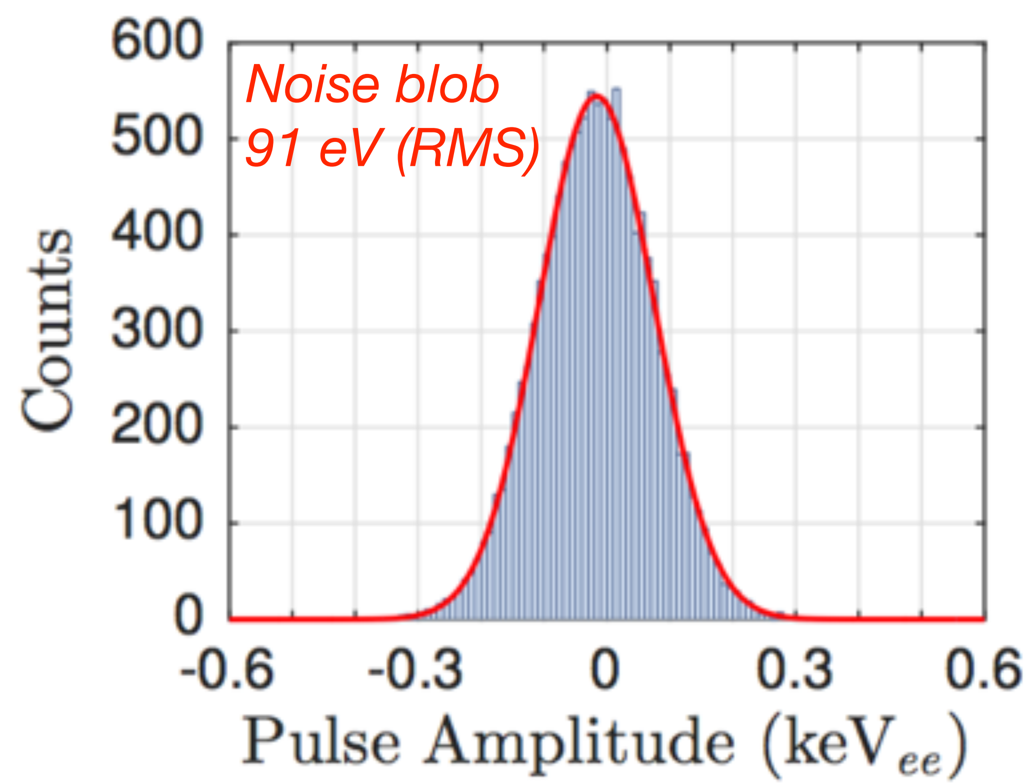


- Transitioning from JFET to HEMT:
  - Lower intrinsic noise, low heat load
  - Can work at 4K: shorter cabling length reduces capacitance and improves resolution
  - Considered by EDW/HARD (resolution) [*XB+AB NIMA 787 (2015) 51*]
  - and SuperCDMS (heat load) [*A. Phipps et al., JLTP 176 (2014) 466 and 911*]
- A successful HEMT amplifier has been designed in collaboration between SuperCDMS and EDELWEISS with **sub-100 eV (RMS) ionization resolution**
- Next step #1: **Upgrade our ionization electronics following this newly designed amplifier**
- Next step #2: **New electrode design *(already successfully tested!)* to reach 50 eV (RMS)**

Goal #3: Improved ionization sensors

A. Phipps et al., arXiv:1611.09712





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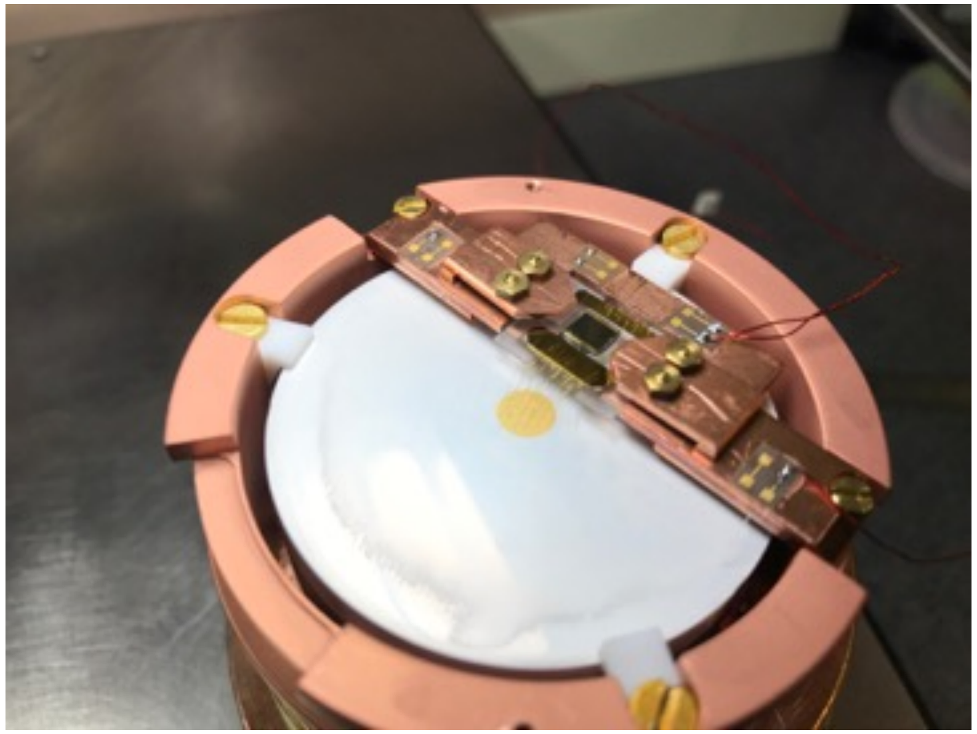
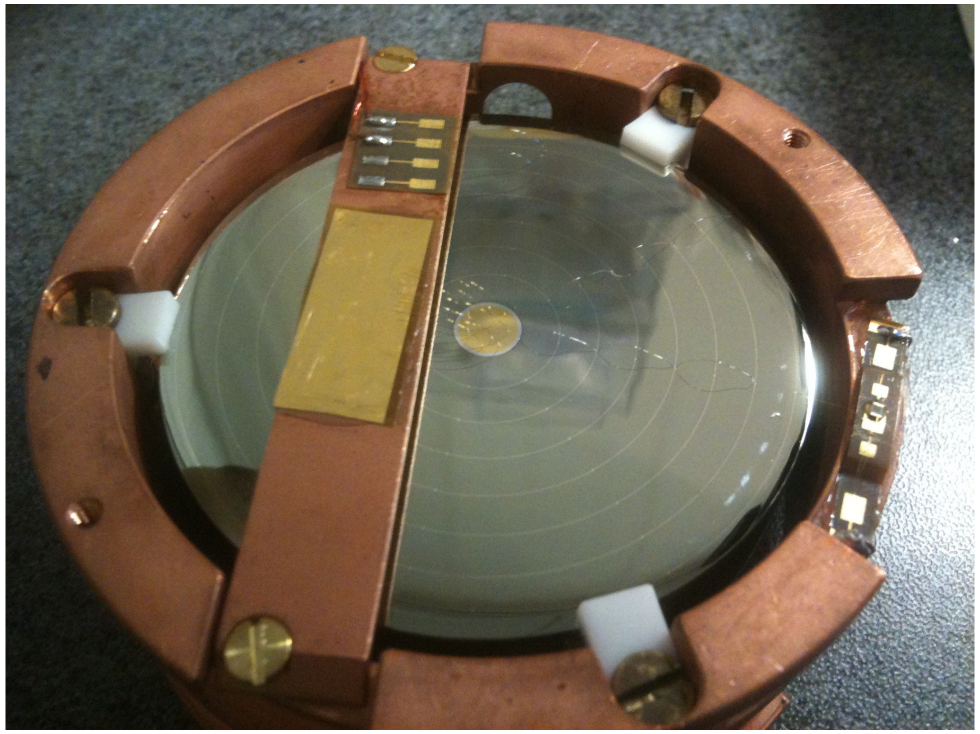
Goal #4: Reduce heat only rate

2 deported NTDs



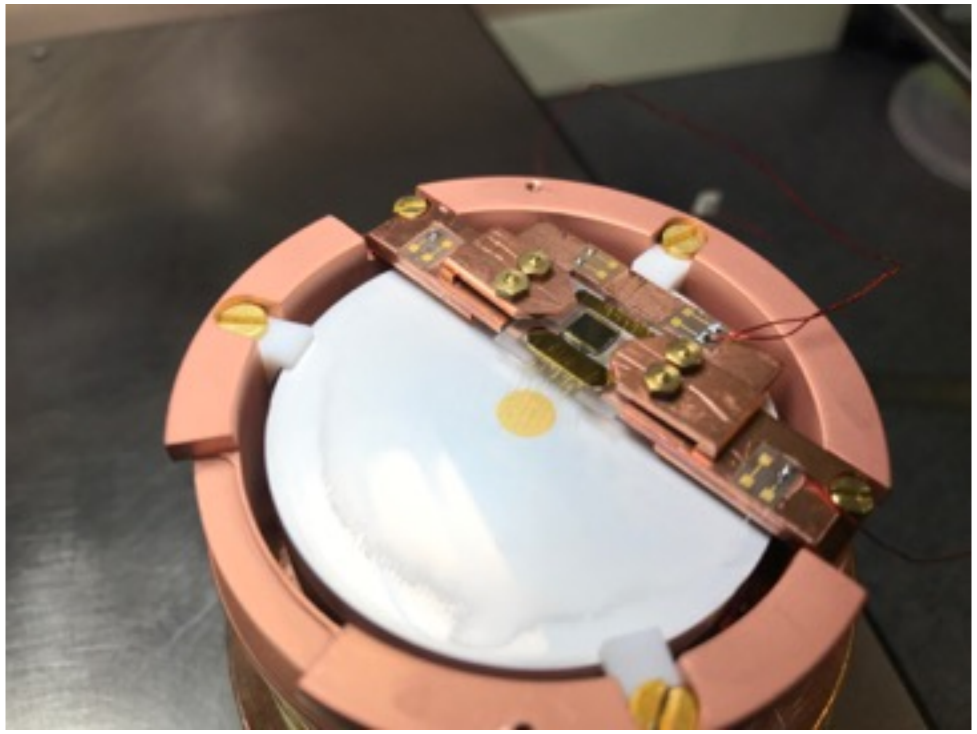
NbSi TES



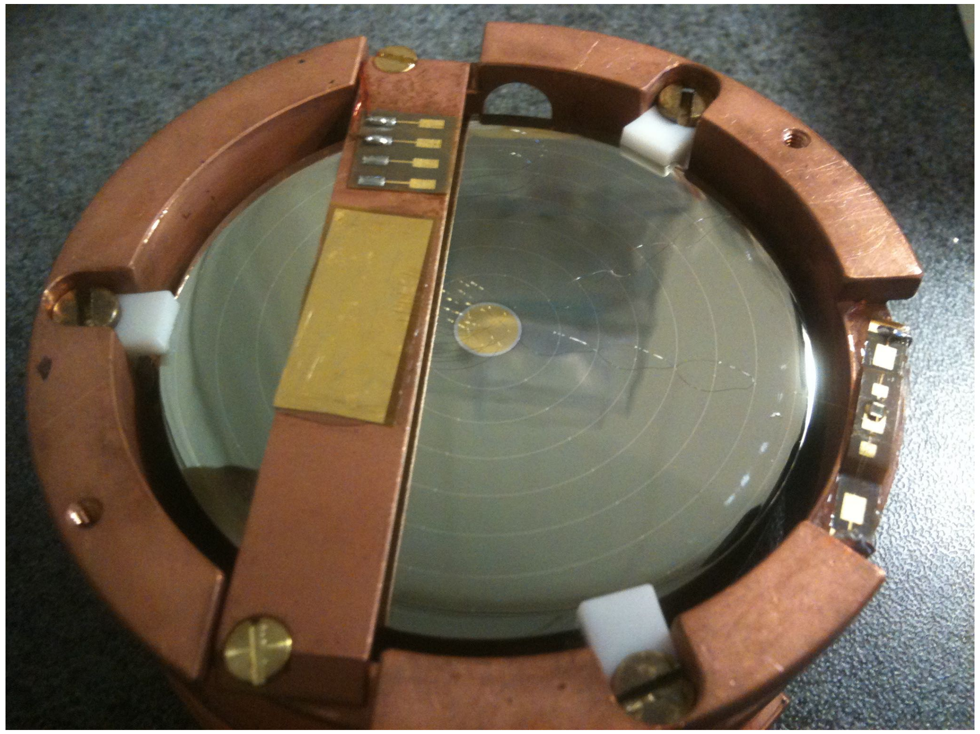
- Heat only events are our dominating background for low-mass WIMP searches
- The idea is to remove any glue from the crystal as it may generates « cracks »
- Two ways out:
  - Using 2 deported NTDs, we have demonstrated the ability to reject « glue events »
  - Using a totally new sensor technology based on high impedance NbSi TES that are photo-lithographied on the Ge surface (no glue) and sensitive to athermal phonons
- ***To be confirmed with our 7 dedicated detectors being cooled down in Modane***

Goal #4: Reduce heat only rate

2 deported NTDs



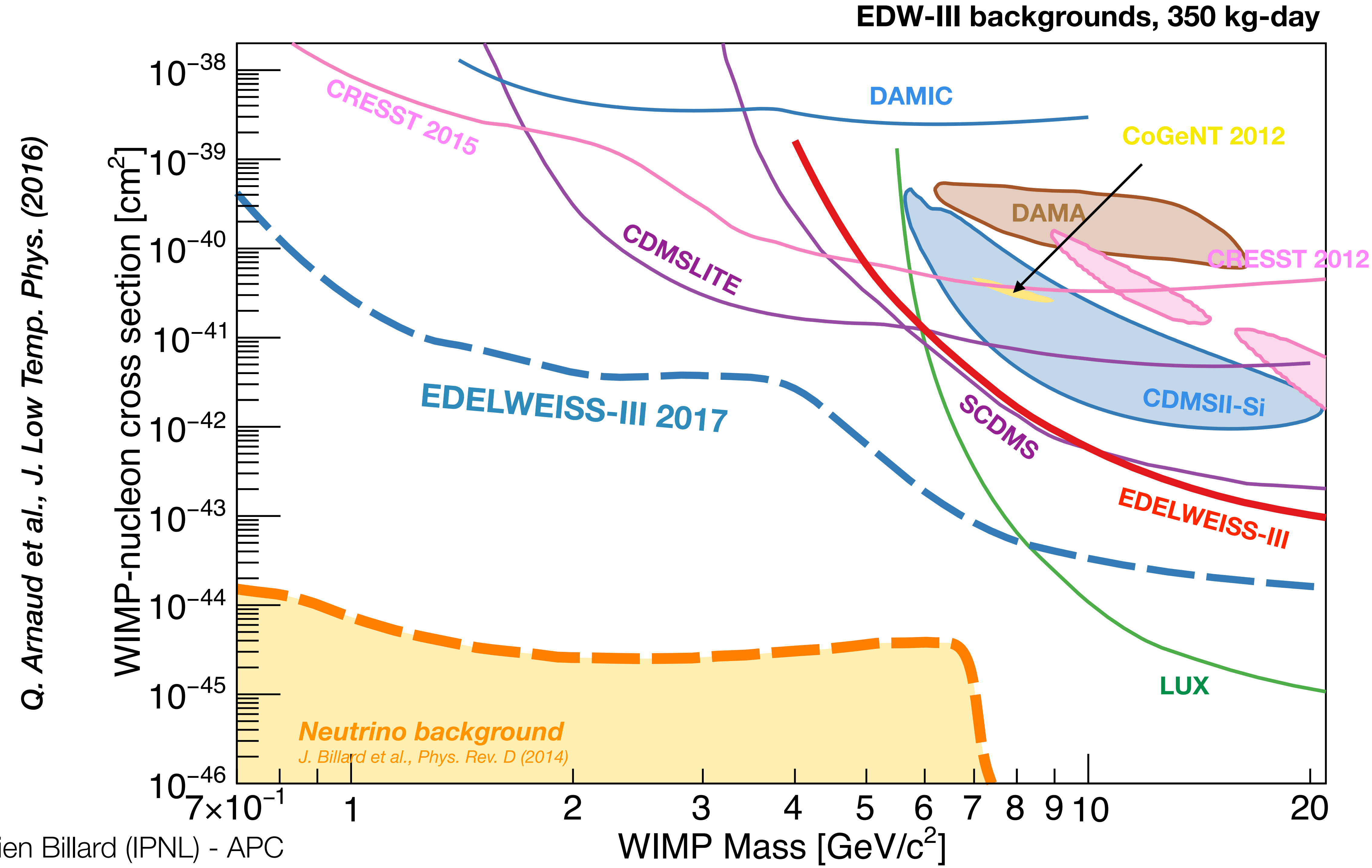
NbSi TES



- Heat only events are our dominating background for low-mass WIMP searches
- The idea is to remove any glue from the crystal as it may generates « cracks »
- Two ways out:
  - Using 2 deported NTDs, we have demonstrated the ability to reject « glue events »
  - Using a totally new sensor technology based on high impedance NbSi TES that are photo-lithographied on the Ge surface (no glue) and sensitive to athermal phonons
- ***To be confirmed with our 7 dedicated detectors being cooled down in Modane***

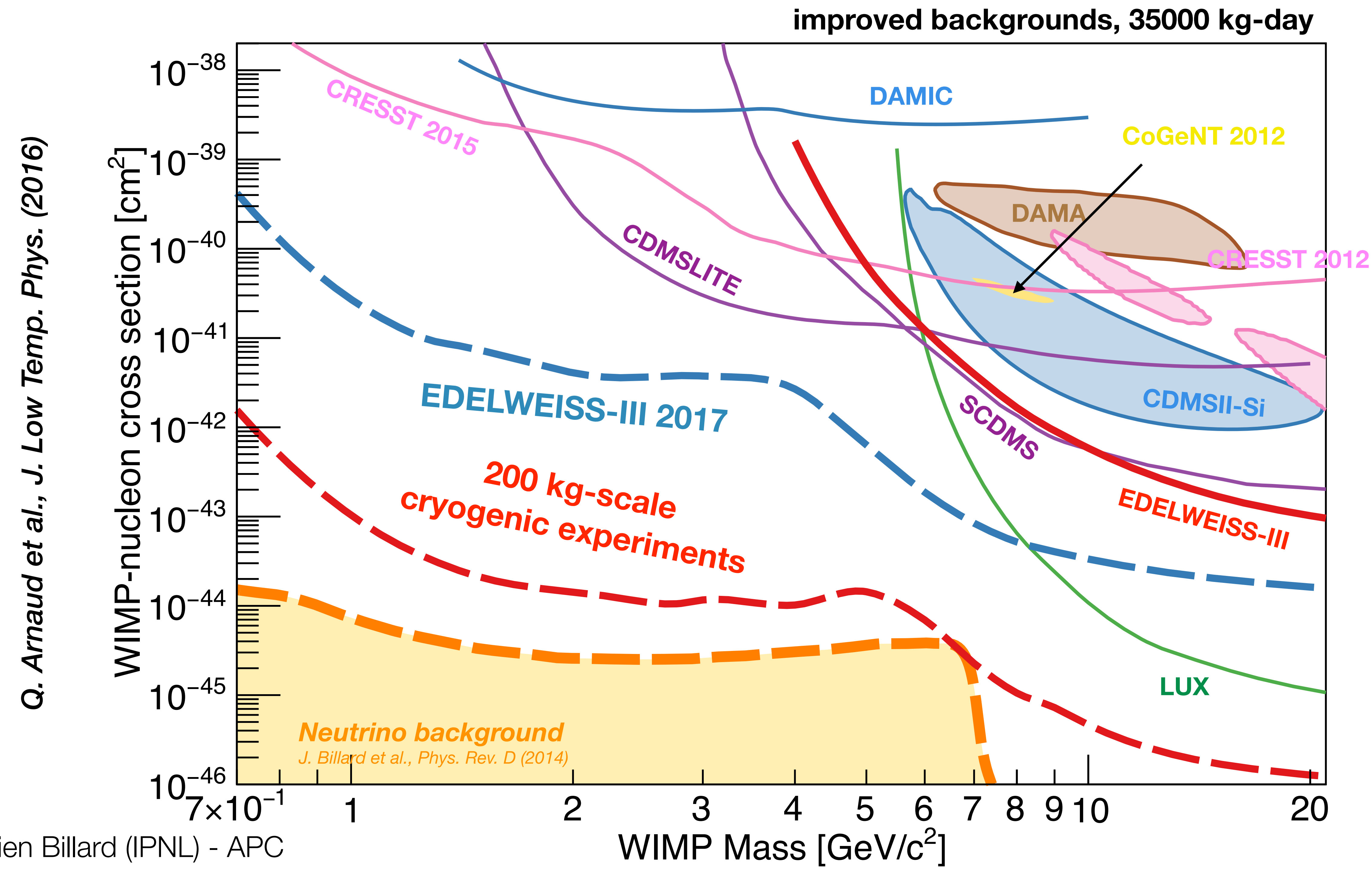
The EDELWEISS-III Physics goals

Goal for 2017 reachable from EDELWEISS-III setup:



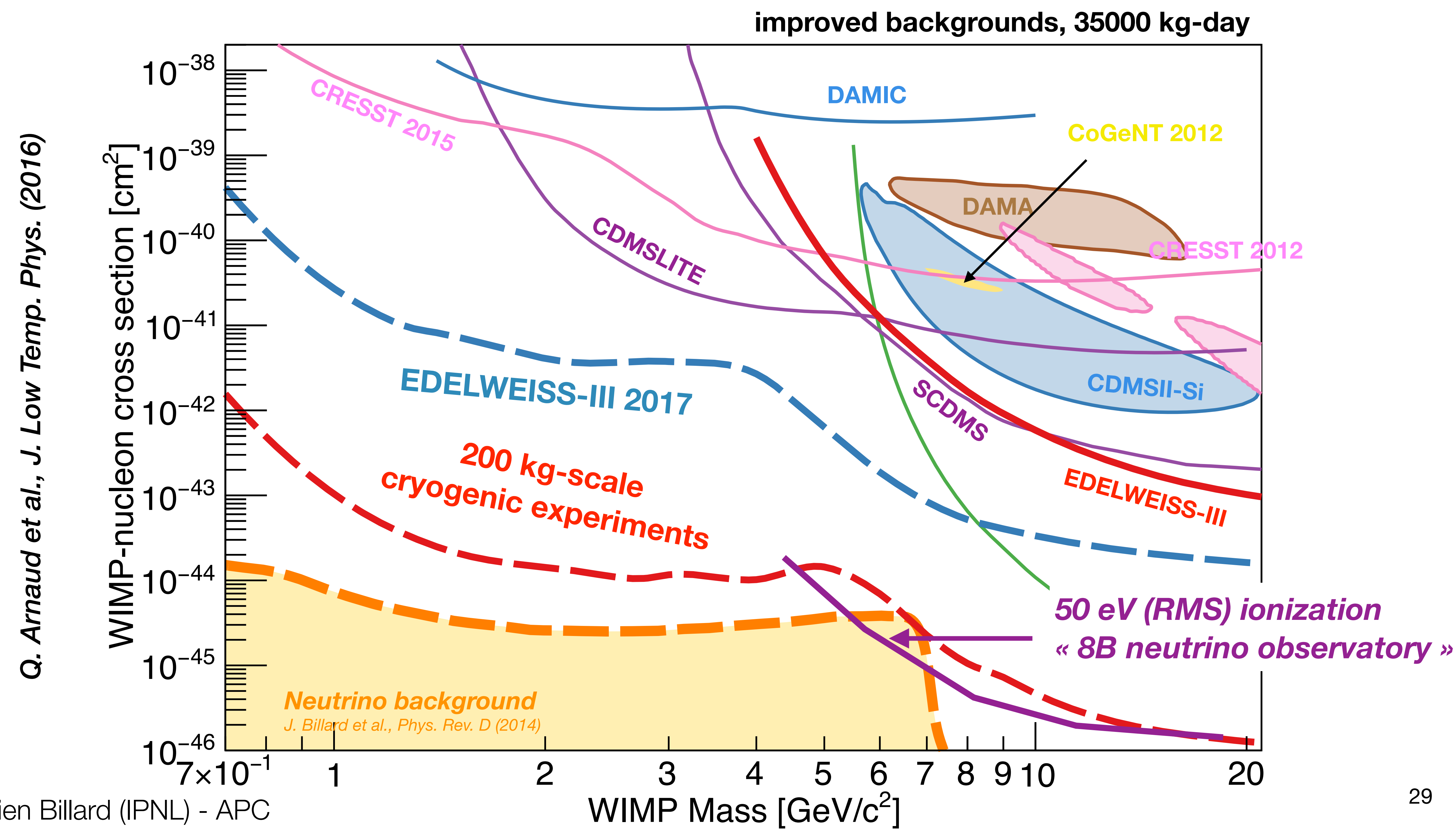
Beyond EDELWEISS-III

Goal beyond 2017 from the SuperCDMS-EDELWEISS collaboration @ SNOLab



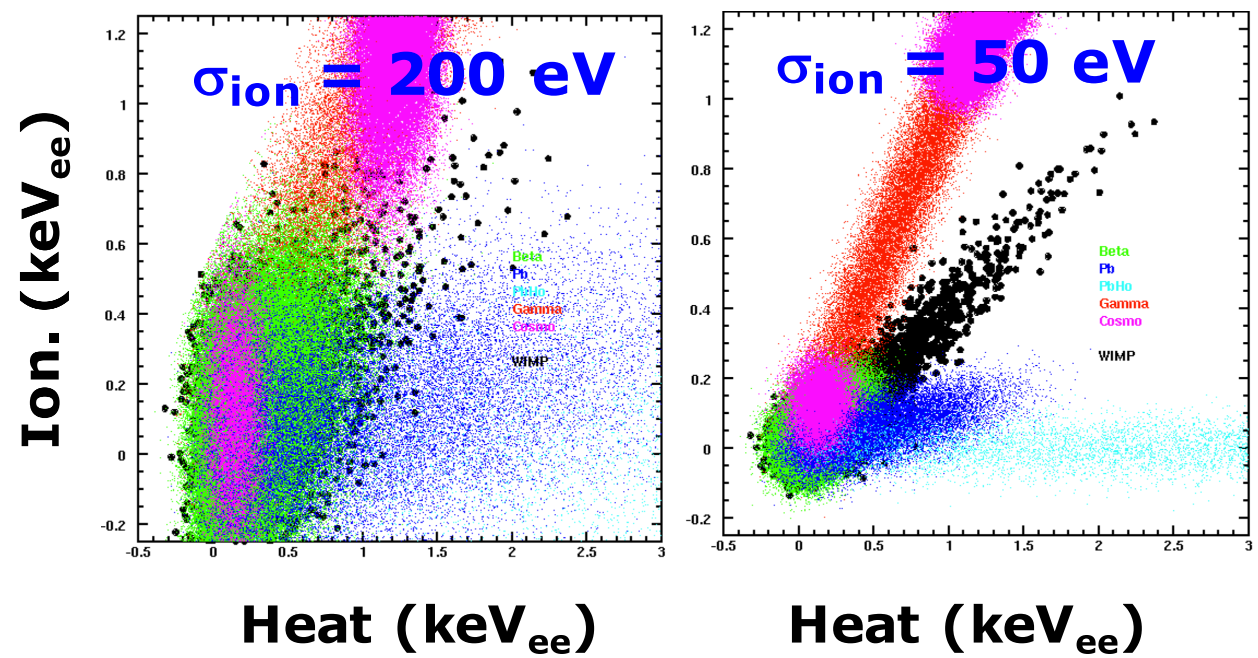
Beyond EDELWEISS-III

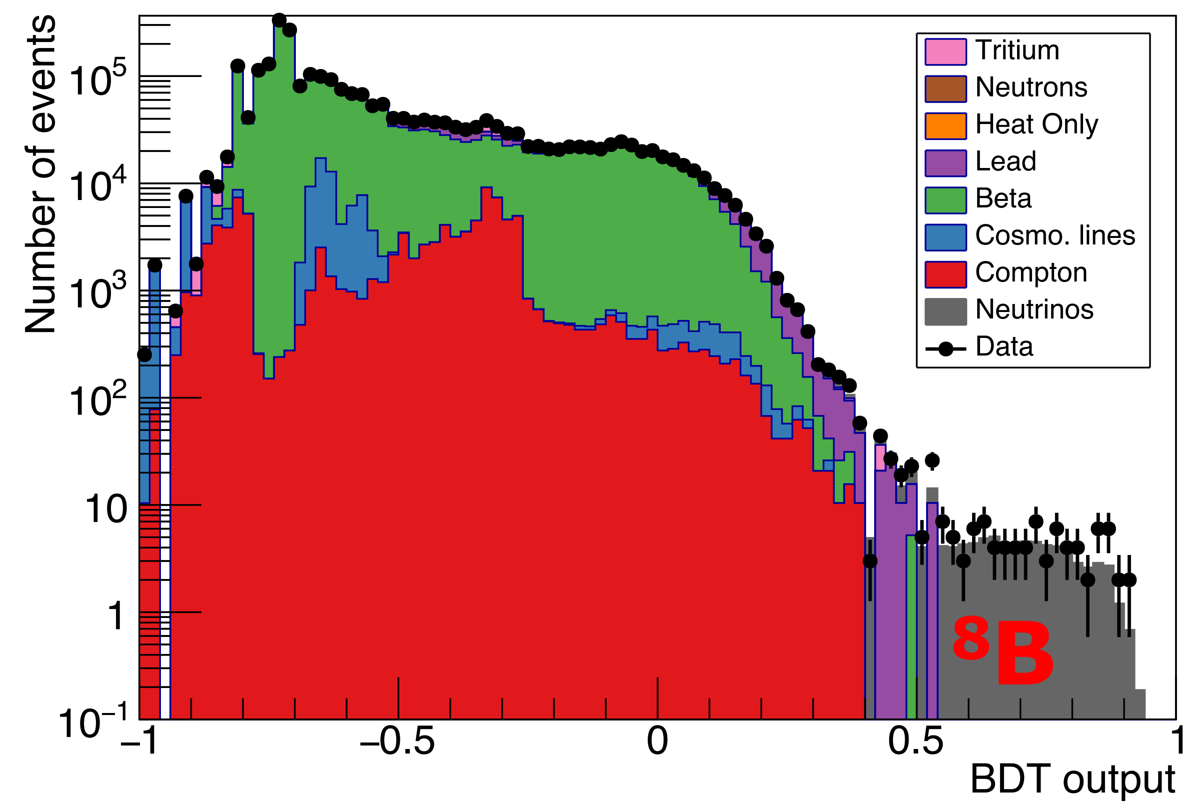
Goal beyond 2017 from the SuperCDMS-EDELWEISS collaboration @ SNOLab



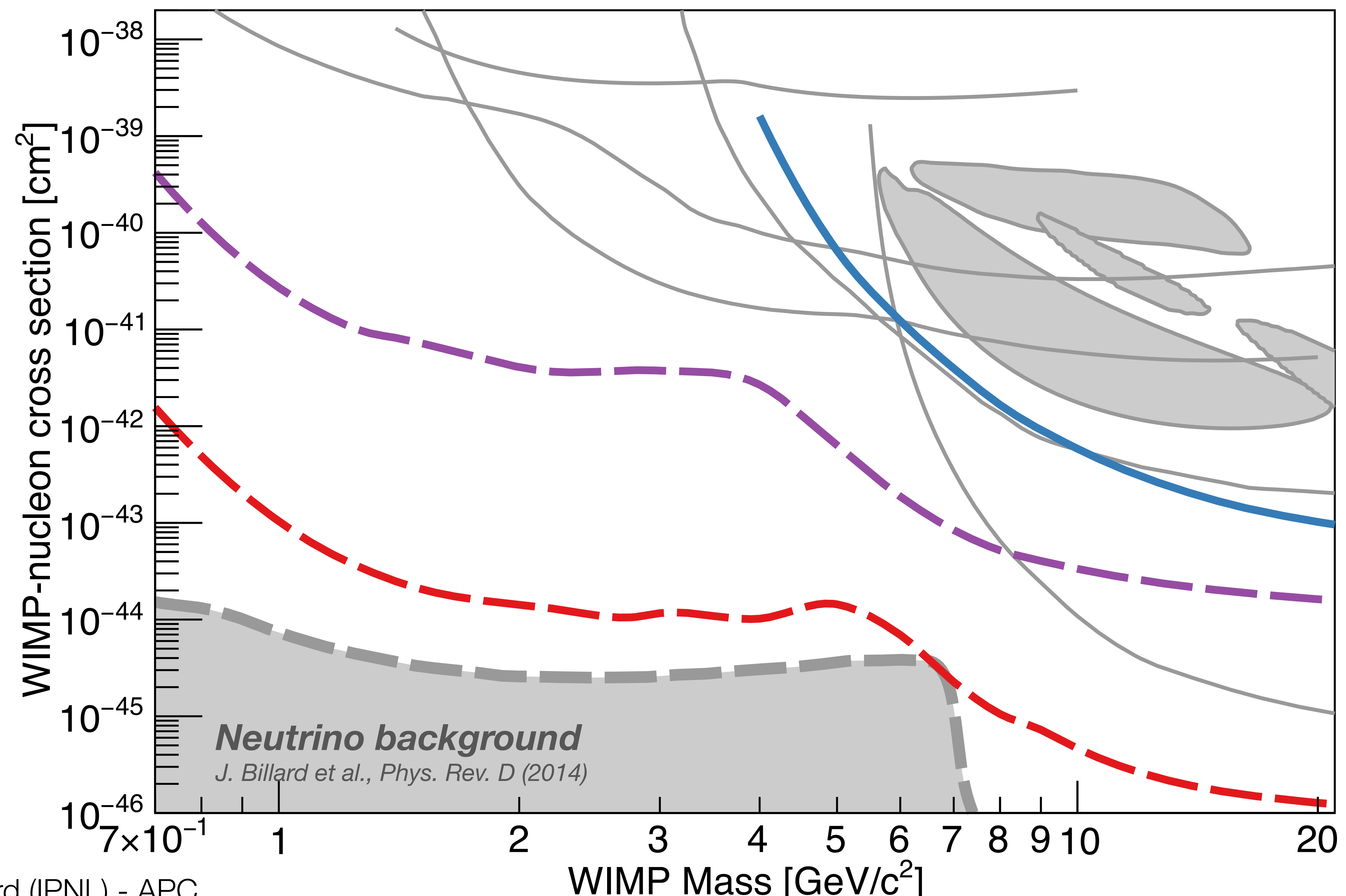
Beyond EDELWEISS-III

- Comparison in separation power between the 8B neutrino signal and the remaining backgrounds for 200 eV and 50 eV ionization resolutions (RMS)
- We expect about 10% nuclear recoil energy resolution @ 1 keVee **leading to great spectral measurement**
- A BDT analysis of 1 ton-year of simulated data show about **78 « background free » neutrino events (out of 300)**
- Unique possibility to study in great detail the still unobserved Coherent Elastic Neutrino-Nucleus Scattering process **offering new probes for physics beyond the SM !!**





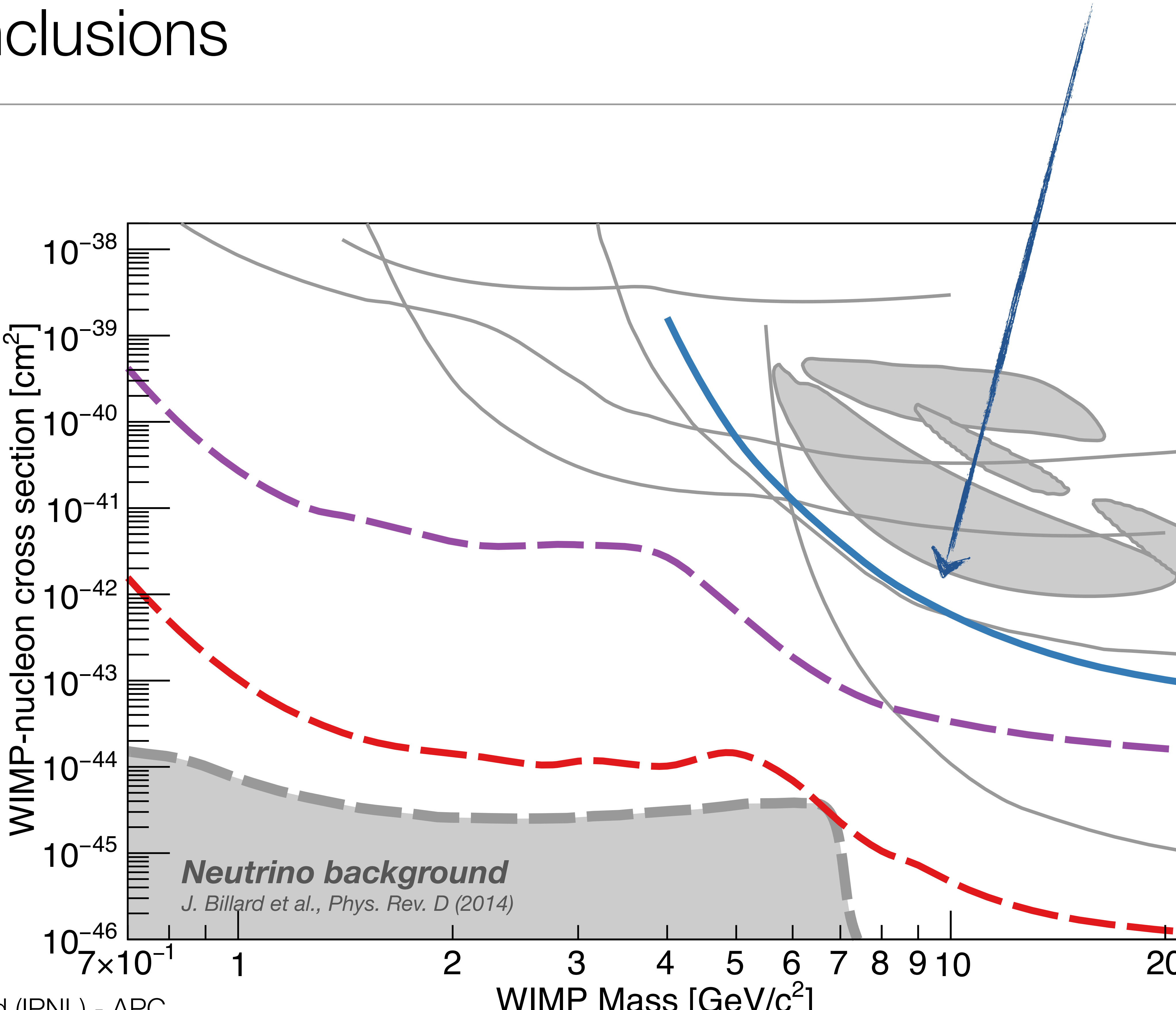
Conclusions



EDELWEISS-III LT analysis

JCAP , EPJC

Conclusions



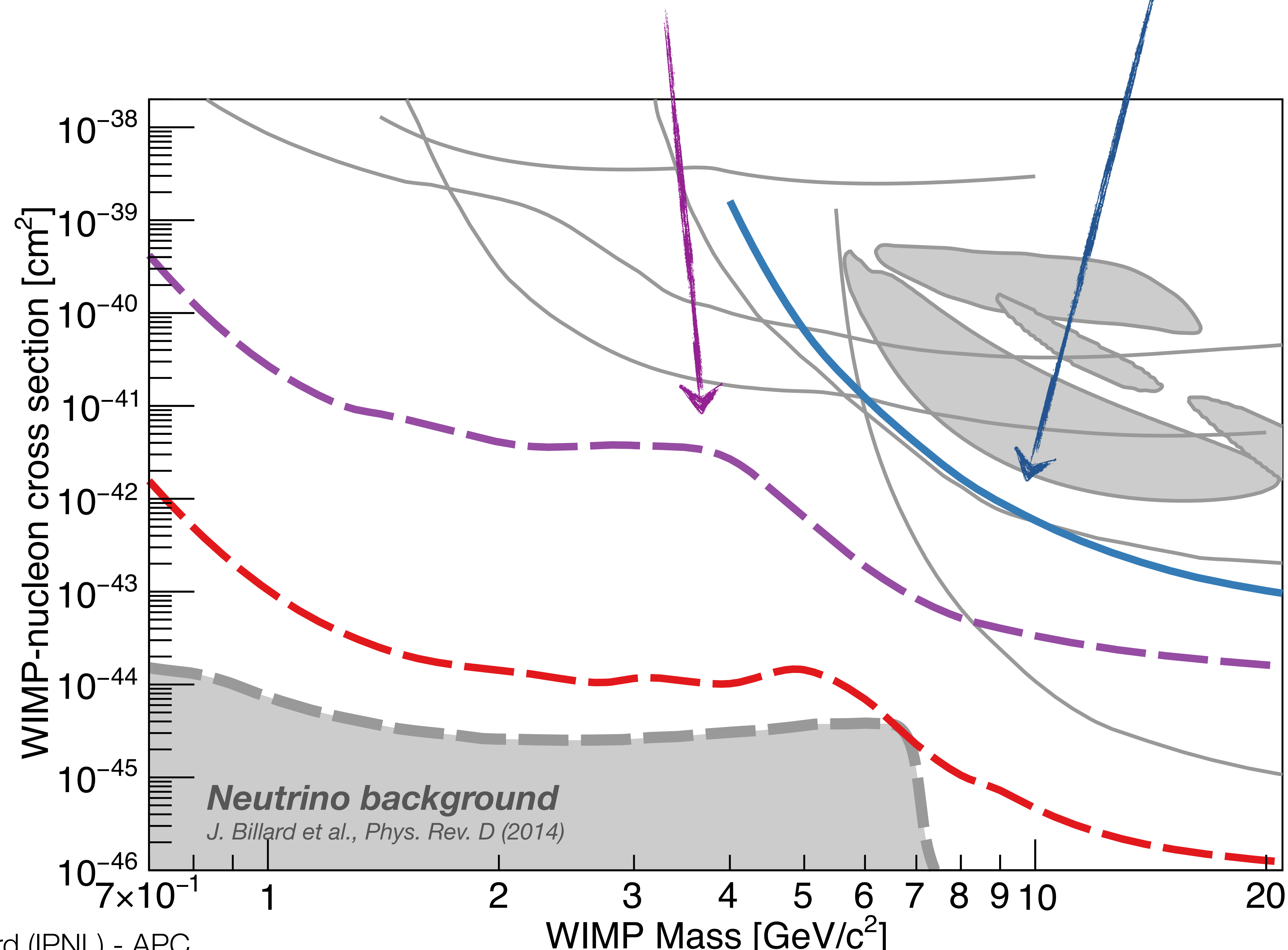
EDELWEISS-III LT analysis

JCAP , EPJC

Conclusions

EDELWEISS-III goals for 2017

intense R&D efforts ongoing



Conclusions

EDELWEISS-III LT analysis

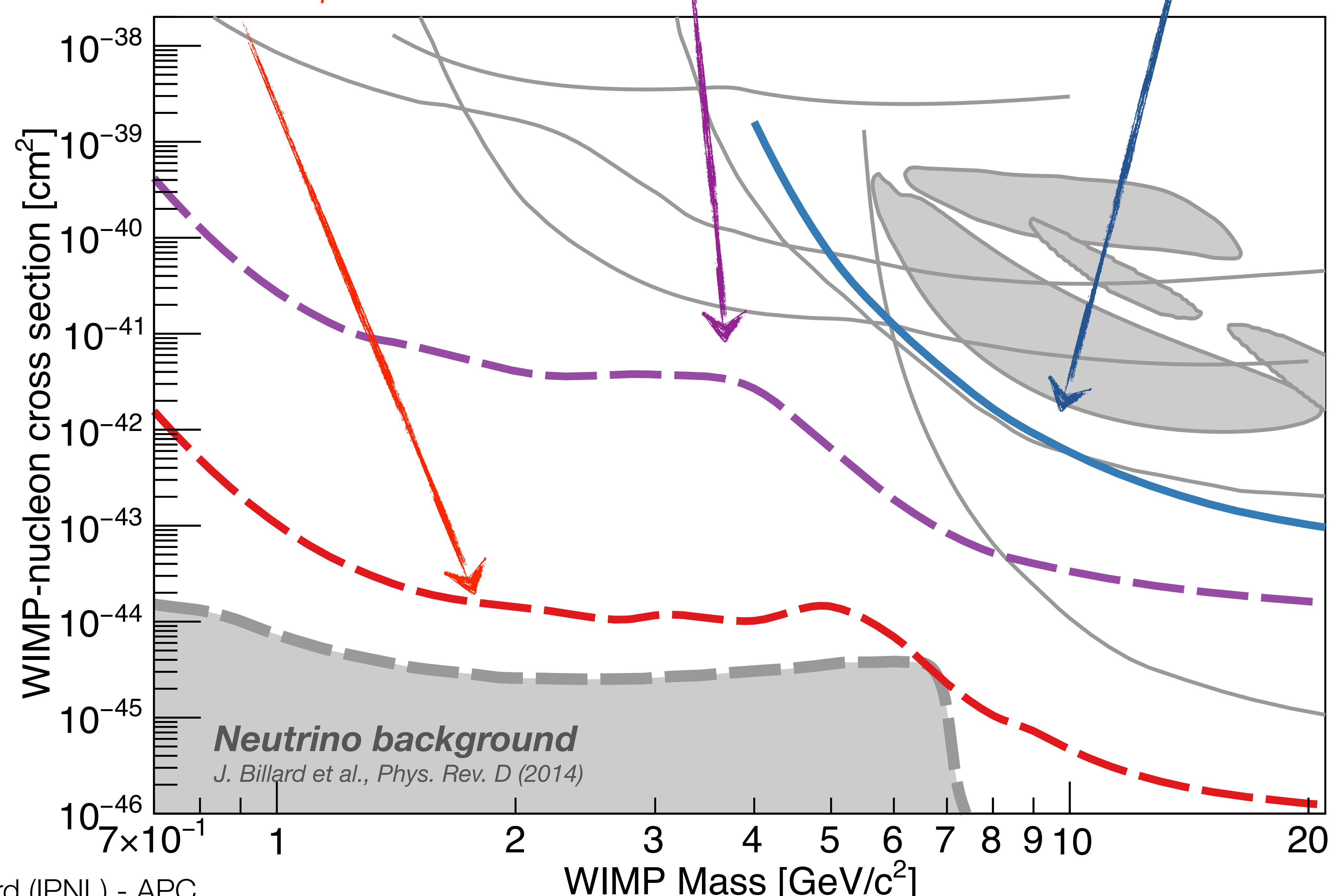
JCAP , EPJC

EDELWEISS-III goals for 2017

intense R&D efforts ongoing

Going beyond (200kg-scale)

EDELWEISS-EURECA-SuperCDMS



Low WIMP mass region (1 GeV - 10 GeV)