Searches for Low-Mass WIMPs with EDELWEISS

The EDELWEISS-III experiments

Low-Mass search results

Future Prospects

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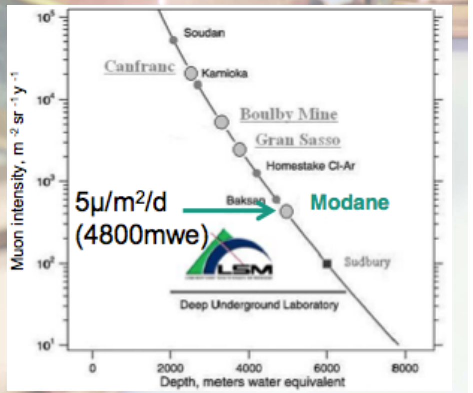
The EDELWEISS Experiment

- **Direct detection of WIMPs, germanium target**
- **20 kg Ge total, 850g units**
- **Ionization + Heat**
- **Simple & robust design**
  - **Important for scalability to large arrays**

- **Laboratoire Souterrain de Modane**
  - **Deepest in Europe : 5 $\mu/m^2/day$**



EDELWEISS Setup

Originally dimensioned for ~3000 kgd high-mass WIMP search

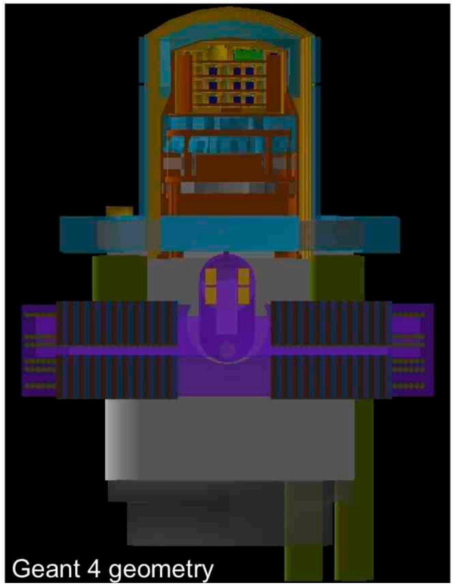
✓ **Clean Room** (Class A: <10000 p/m3) with deradonized air (from 10 Bq/m^3 → ≈ 30 mBq/m^3)

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

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

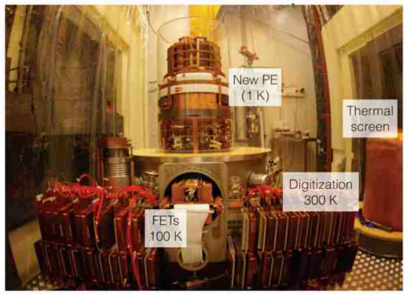
✓ **External PolyEthylen Shielding** (n): 50 cm

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



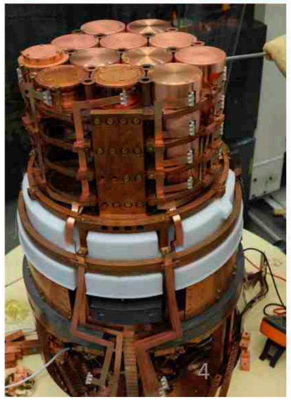
Geant 4 geometry

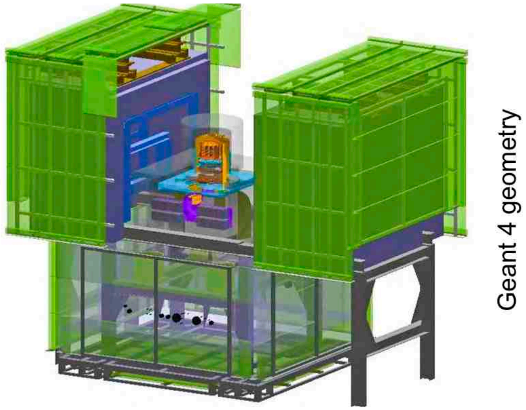
- Extra 15 cm Internal Roman Pb (1K)
- Material selection



✓ **New w/r to EDW-II :**

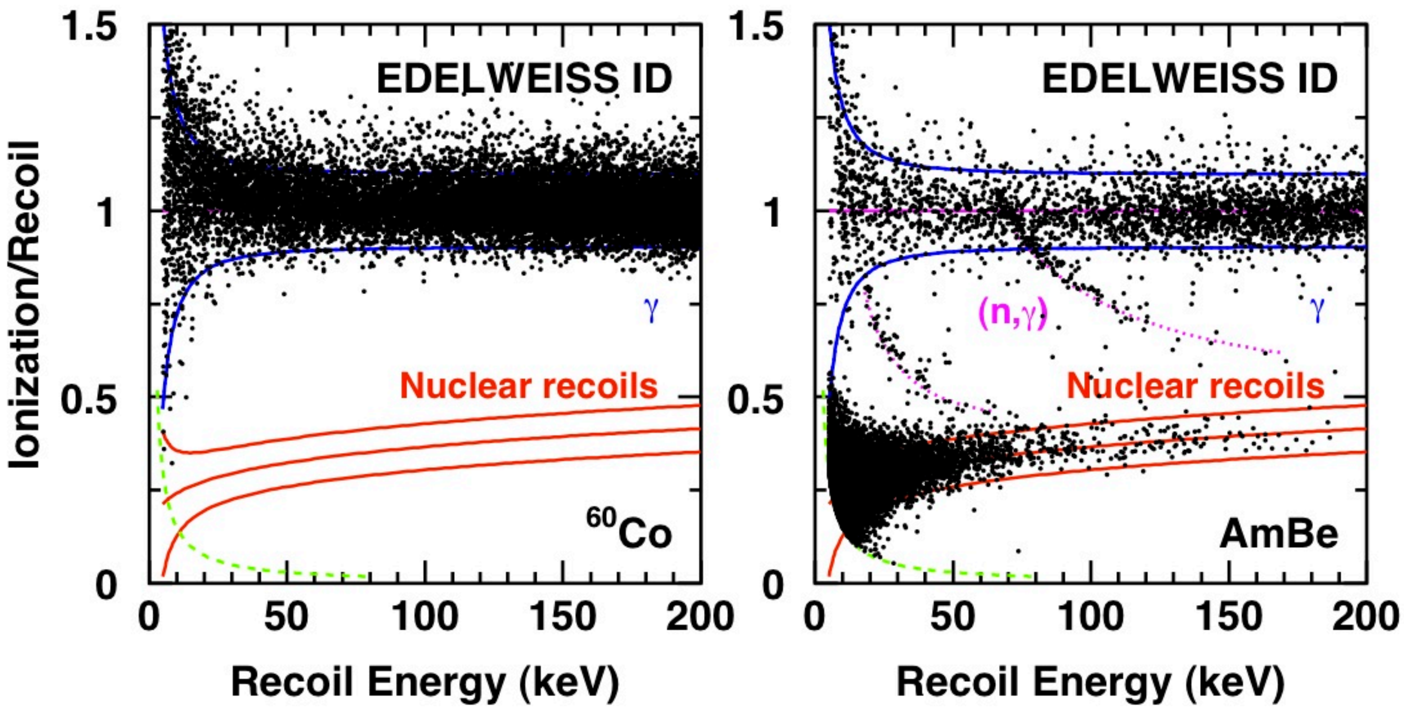
- **Extra 10 cm PE** shield below detectors
- **NOSV Copper**
- New Kapton cables and connectors : 1K-10mK (Steel) and 10mK-10mK (Cu)
- **New electronics** (FETs 100K and Digitization 300K)
- **New Cryogenics** to reduce microphonics





Nuclear recoil discrimination

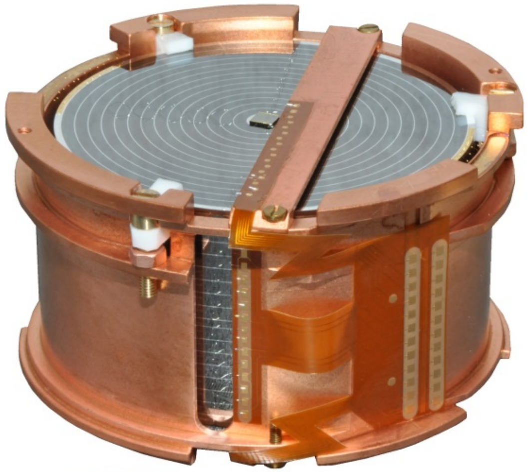
- Heat: GeNTD thermistor (~15mm^3): R ~MΩ at T= 18 mK, ΔT ~1 μK/keV. Fully thermalized: position-independent signal.
- Ionization: evaporated Al electrodes, polarized at a few V/cm
- Ionization yield for nuclear recoils is ~1/3 of value for e$^-$ recoils
- Limitation: poor charge collection for events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

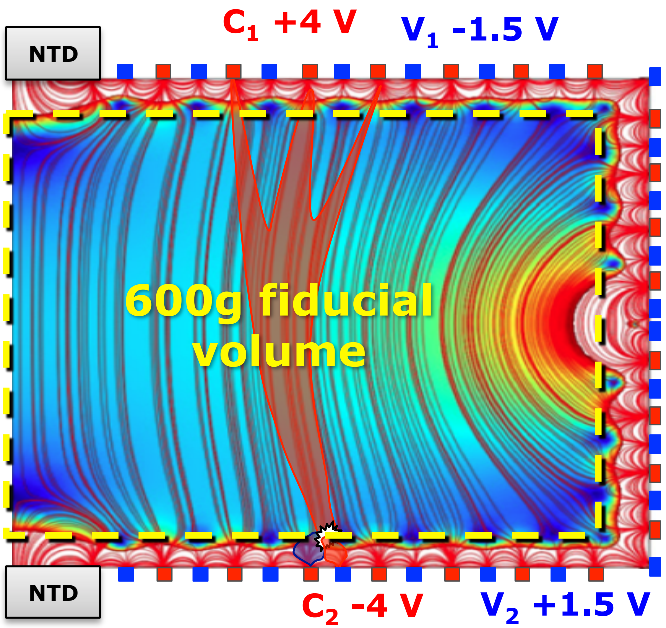


Fully InterDigitized electrode design

- ~820g detectors (ϕ=70 h=40 mm)
- 2 NTD per detector
- Electrodes: concentric Al rings (2mm spacing) covering all faces
- XeF2 surface treatment to ensure low leakage current (<1 fA) between adjacent electrodes

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





Surface event rejection

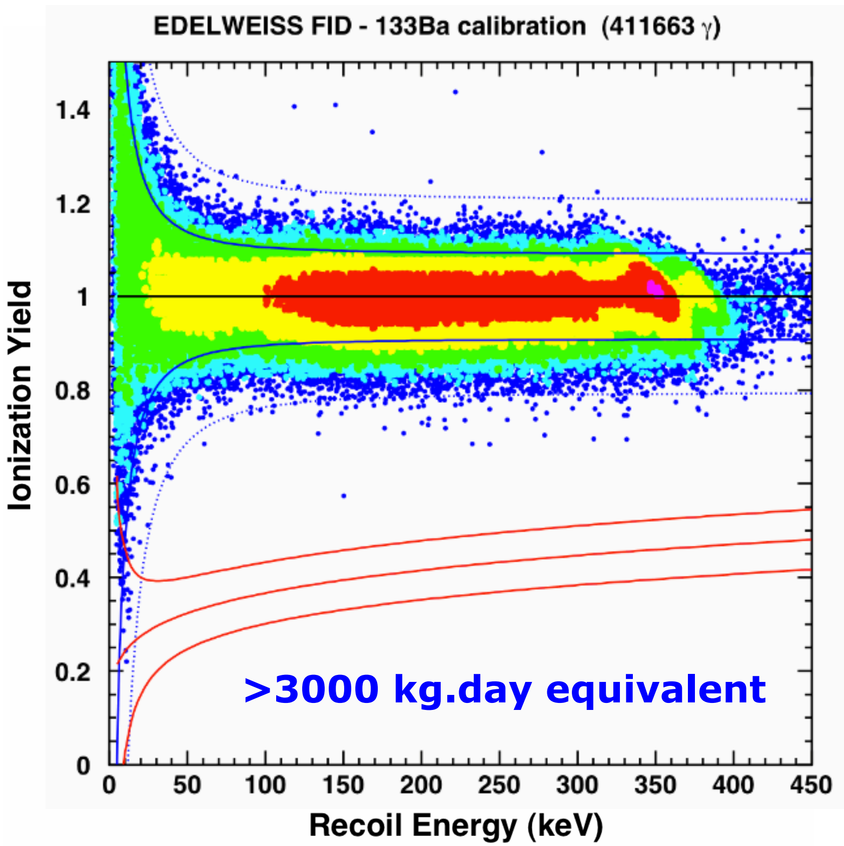
Phys Lett B 681 (2009) 305–309

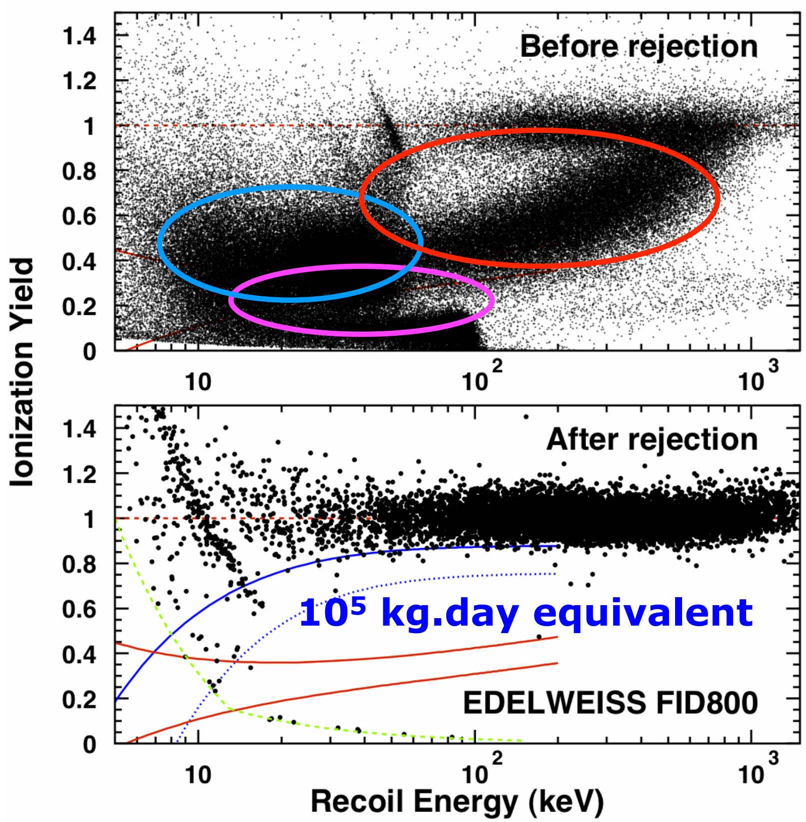
- Bulk event: charges collected by C_1 and C_2: V_1 and V_2 act as veto
- Surface events: charges collected by either C_1V_1 or C_2V_2

Gamma and surface rejection

- γ rejection factor: $< 5.6 \times 10^{-6}$ *[J Low Temp Phys (2012) 167: 1056-1062]*
- Surface evts rejection ($^{210}Pb+^{210}Bi$ β, ^{210}Po α, ^{206}Pb recoils): $< 4 \times 10^{-5}$

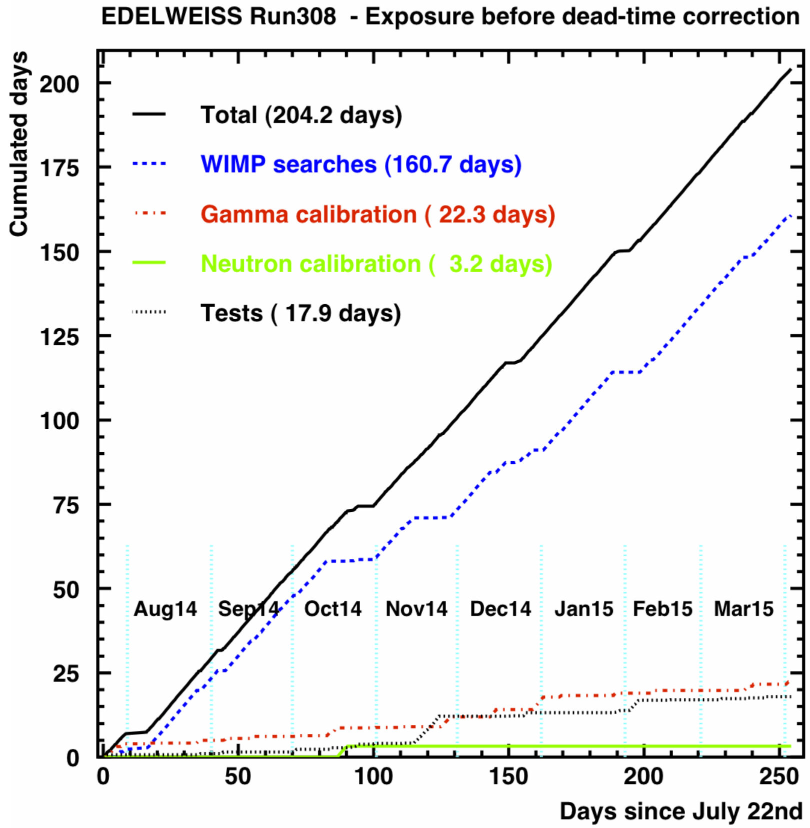
[J Low Temp Phys (2014) 176: 870-875]





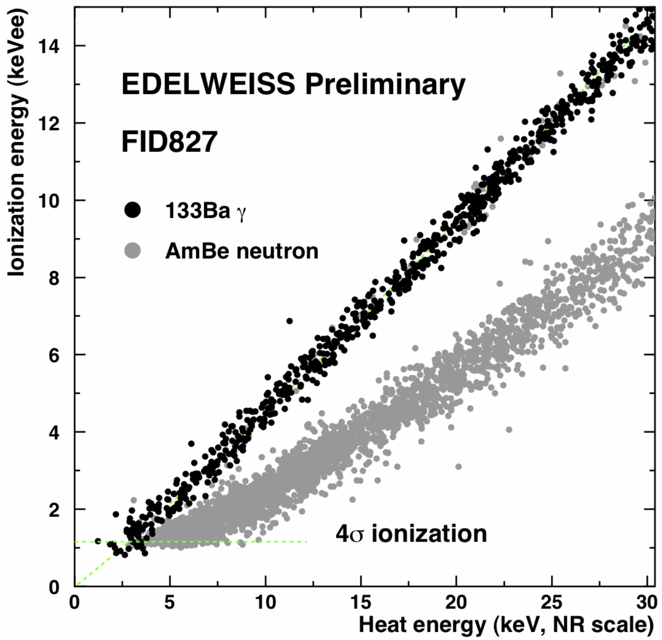
EDELWEISS-III data taking

- 161 days of physics data with 24x800 g



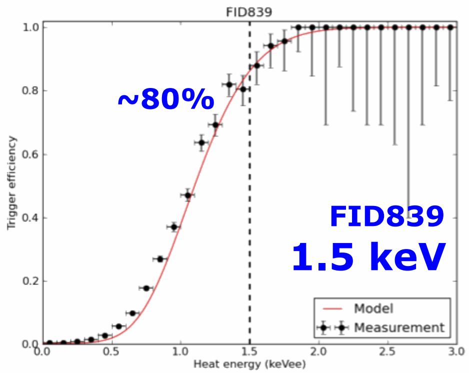
Low-mass search with EDELWEISS-III

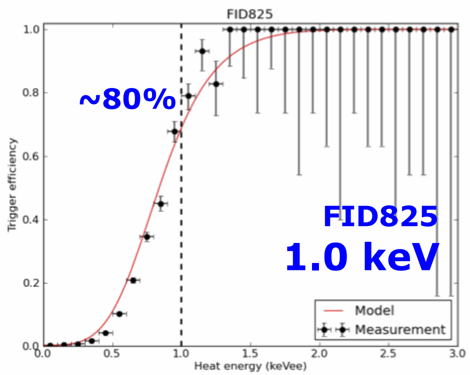
- 8 FIDs selected for their baseline resolutions & low thresholds
- Homogeneous data set:
  - avg. σ(ion): 200 - 230 eV_{ee}
  - avg. σ(heat): 130 - 240 eV_{ee}
  - } ~/2 wrt EDW-II
- Adaptative online heat threshold detector avgs: 0.6 to 1.1 keV_{ee}



- **582 kg.day (fiducial)**
- Analysis heat threshold:
  - 4 FIDs @ 1.0 keV_{ee}
  - 4 FIDs @ 1.5 keV_{ee}

($1keV_{ee}$ = 2.4 keV_{nr})





Boosted Decision Tree (BDT) analysis

- Training with high-statistics *WIMP signal* and *background model* simulations
- Background model based on *sideband* populations (blinding of single fiducial events with ionization/recoil<0.5)
- Six variables (4 ionization + 1 heat channel + 1 heat-only event rate)

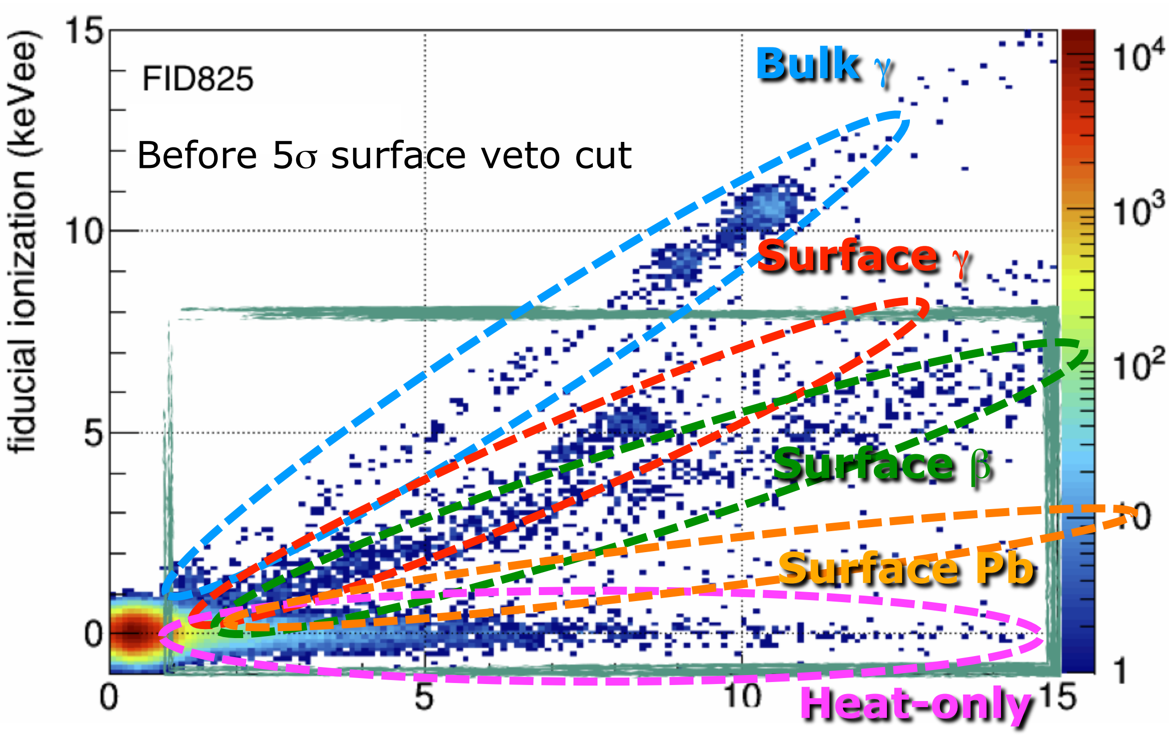
- Modelization of time-dependent noise+trigger of individual detectors

ROI for WIMP search:

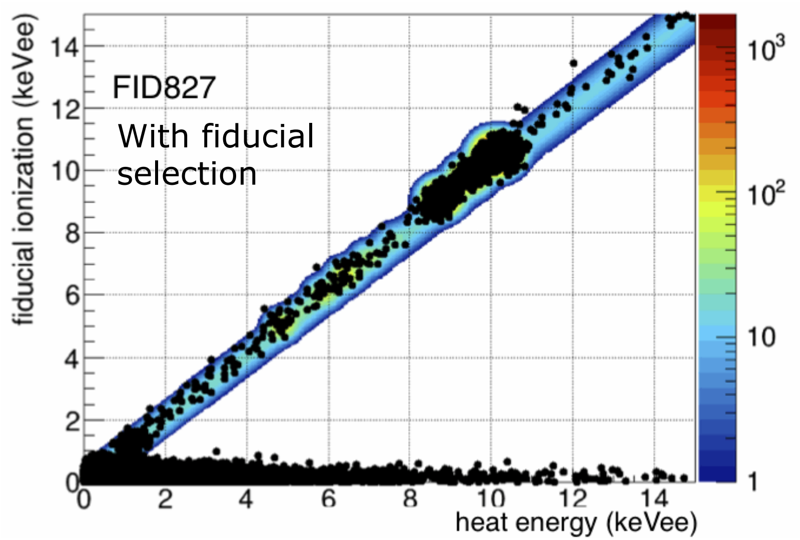
- Fiducial ion. 0 - 8 keVee
- Heat 1/1.5 – 15 keVee
- Veto electrode < 5σ

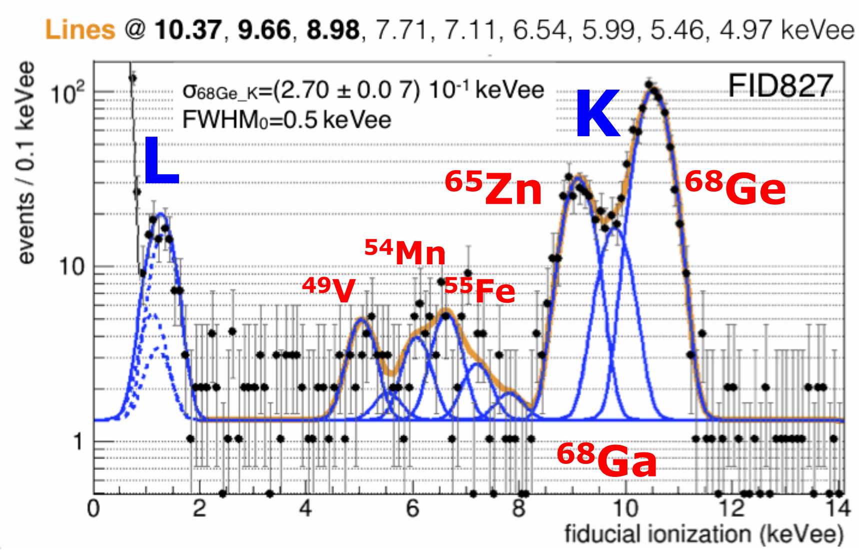
Bkg model components:

- Bulk gamma
- Surface events (γ, β, Pb)
- Heat-only events
- Neutrons (from coinc. data)



Gamma background

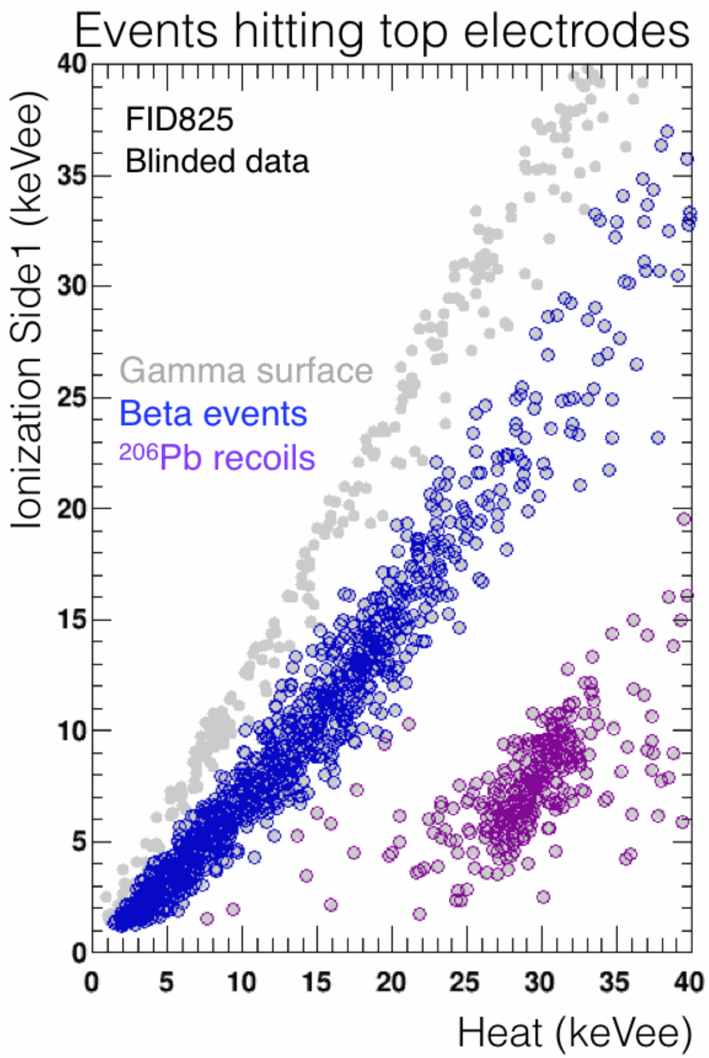




- Cosmogenic activation peaks used to measure bulk/surface ratio
- Fiducial spectrum fit in [3,15] keV interval
- Flat extrapolation to 0 keV
- L/K ratio = 0.11⌘ used to extrapolate intensity of ^{68}Ge, ^{68}Ga and ^{65}Zn L-lines at 1.1-1.3 keV (consistent with observed intensities)

⌘ Bahcall, Phys. Rev. 132, 362 (1963)

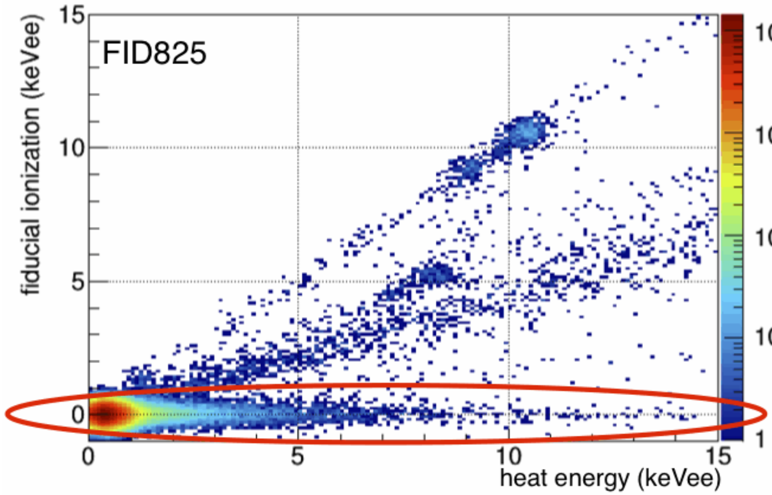
Surface events



Background model for top and bottom sides:

- **Gammas:** fit constant+cosmogenic peaks in [3-15] keVee heat energy range, with same relative intensity as for bulk cosmogenic peaks
- **Betas:** spline fit in the [4,25] keVee heat energy range
- **^{206}Pb recoils:** fit gaussian peak + constant in the [10-35] keVee heat energy range
- Model extrapolated down to 0 keV

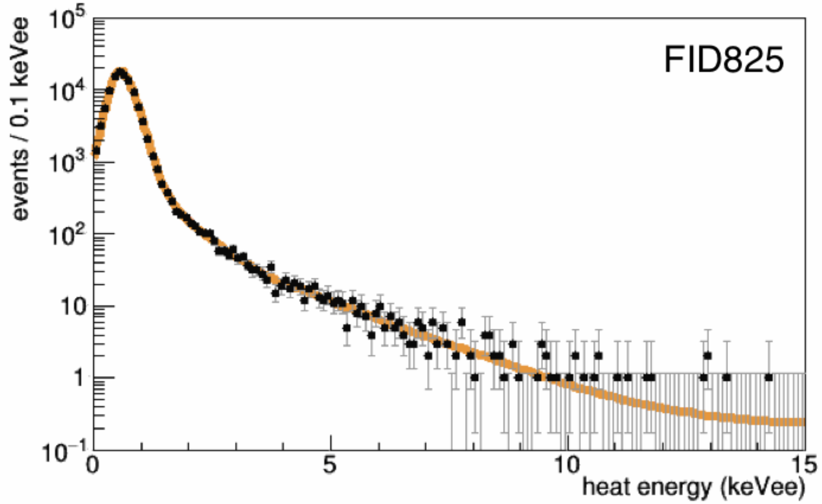
Heat-only event

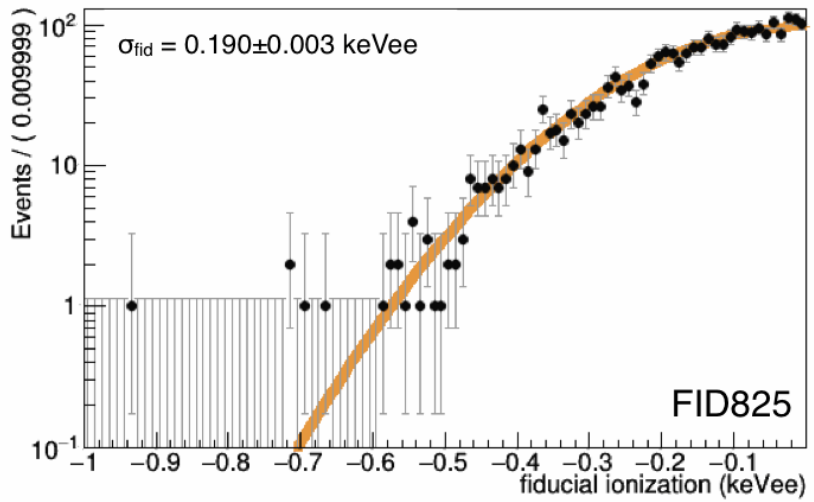


Events without ionization signal at energies well beyond the heat baseline (>1.5 keV ee)

Dominant background at low energy

Symmetric distribution in Eion<0 or >0: use Eion<0 sideband to model Eion>0
(above 1 keVee, no WIMP expected with Eion<0)

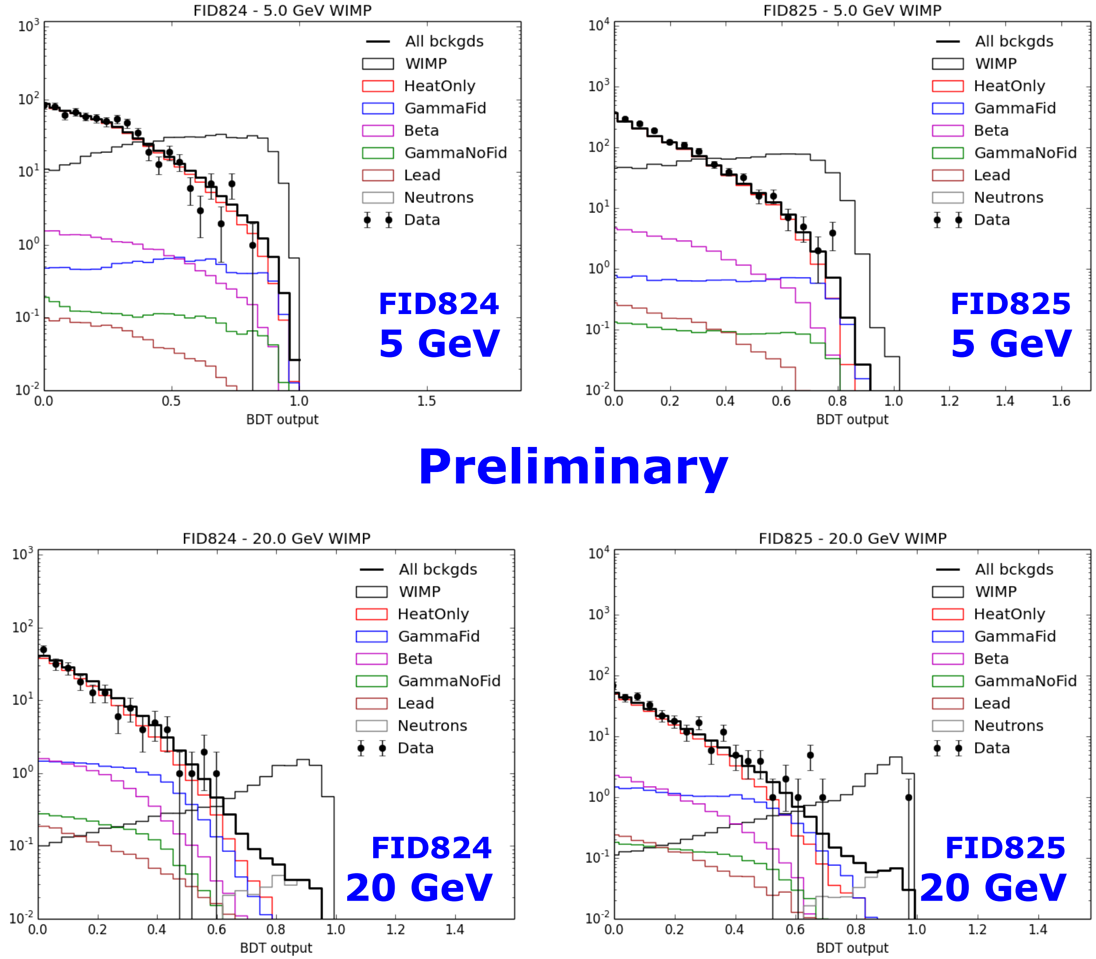




BDT Output

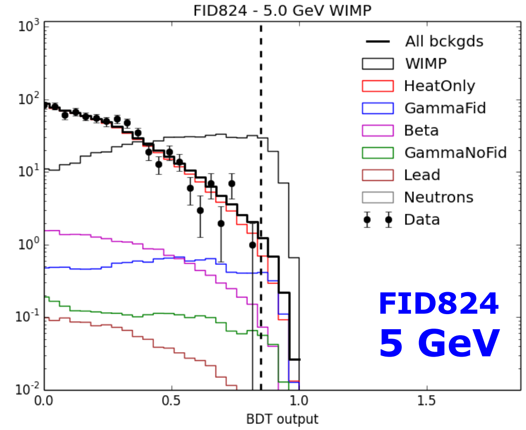
- One BDT distribution per WIMP mass per detector
- 4, 5, 6, 7, 10, 15, 20 and 30 GeV.

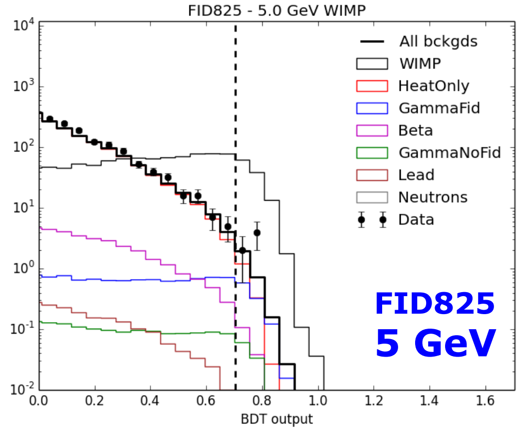
- Backgrounds normalized to the expected rate for that given detector and data selection.
- Neutrons normalized to observed coincident nuclear recoil rate, scaled by single/coincidence ratio from MC



BDT Output

- *Cuts based on model only (from expected sensitivity), before unblinding*

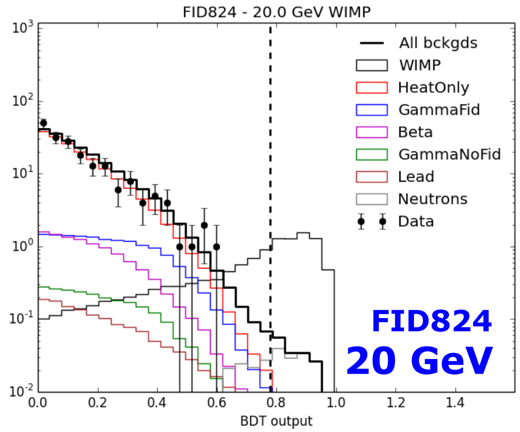


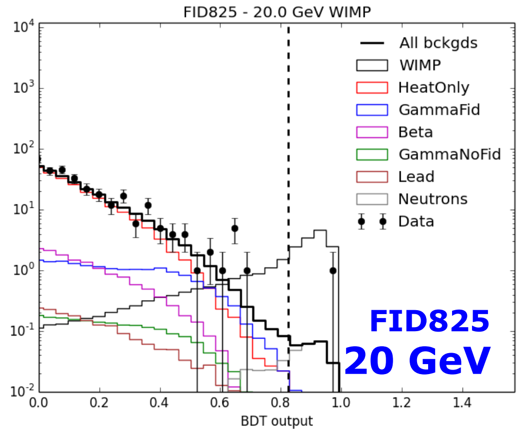


Dominant bkgs:

Preliminary

- 5 GeV: Heat-only and cosmogenics
- 20 GeV: radiogenic neutrons



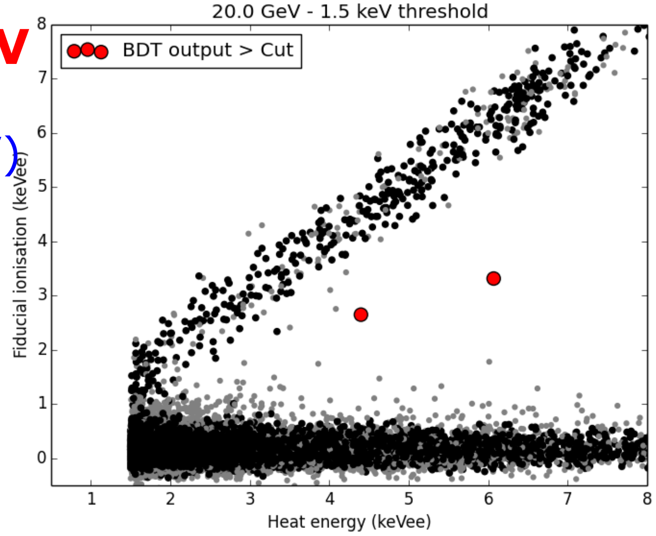


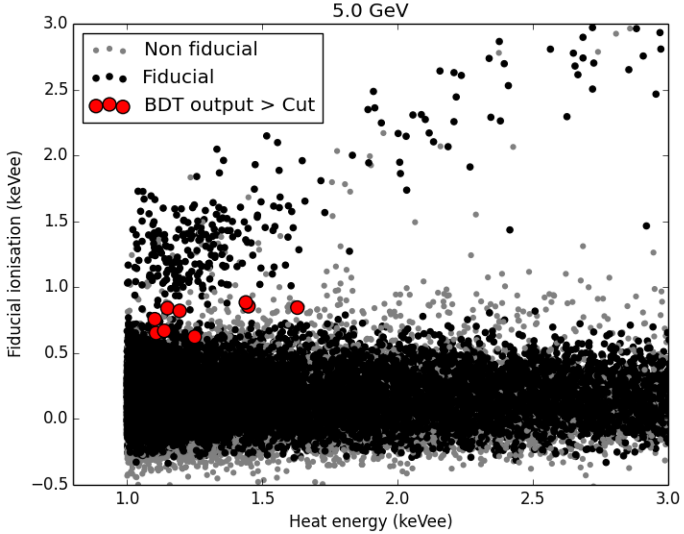
Candidate events

After BDT and WIMP box cut in 8 FIDs

	N_bkg expected	N_bkg observed	p_value (stat only)
5GeV	6.14	9	0.17
20GeV	1.35	4	0.10

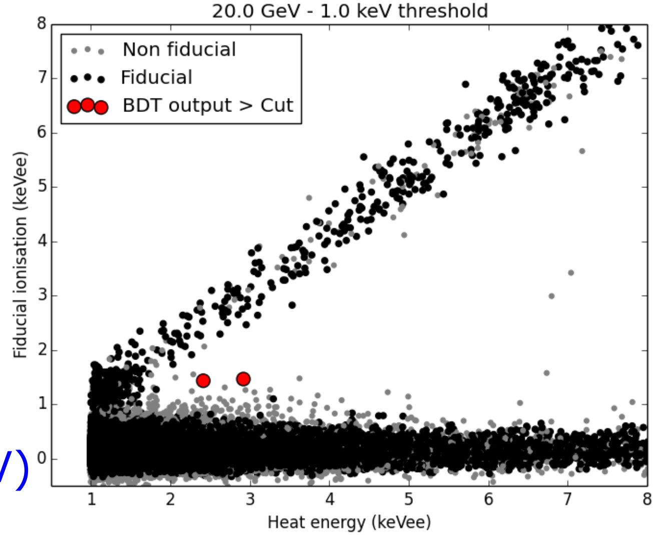
20 GeV (4 FIDs @1 keV)





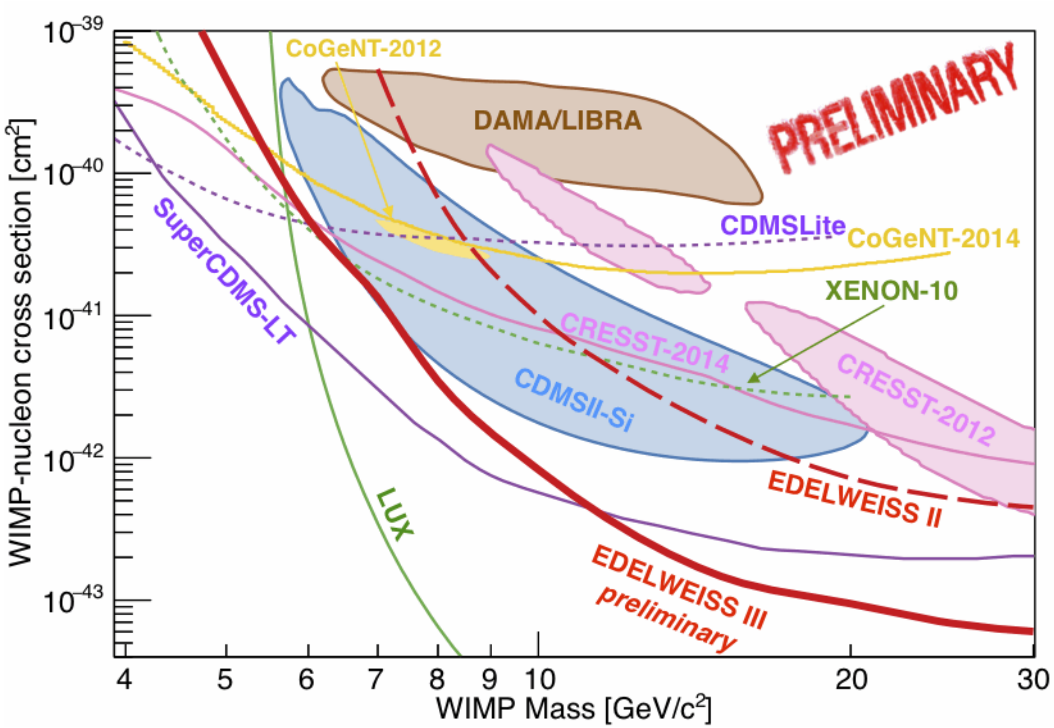
5 GeV (4 FIDs @1 keV)

20 GeV (4 FIDs @1.5 keV)



Low-mass spin-independent limits

- Poisson limit, no background subtraction
- Cross-check with likelihood analysis: good agreement
- 4.6×10^{-40} cm^2 at 5 GeV (x40 better than EDW-II [PRD 86 (2012) 051701R])
- 6.2×10^{-44} cm^2 at 30 GeV (x8 better than EDW-II)



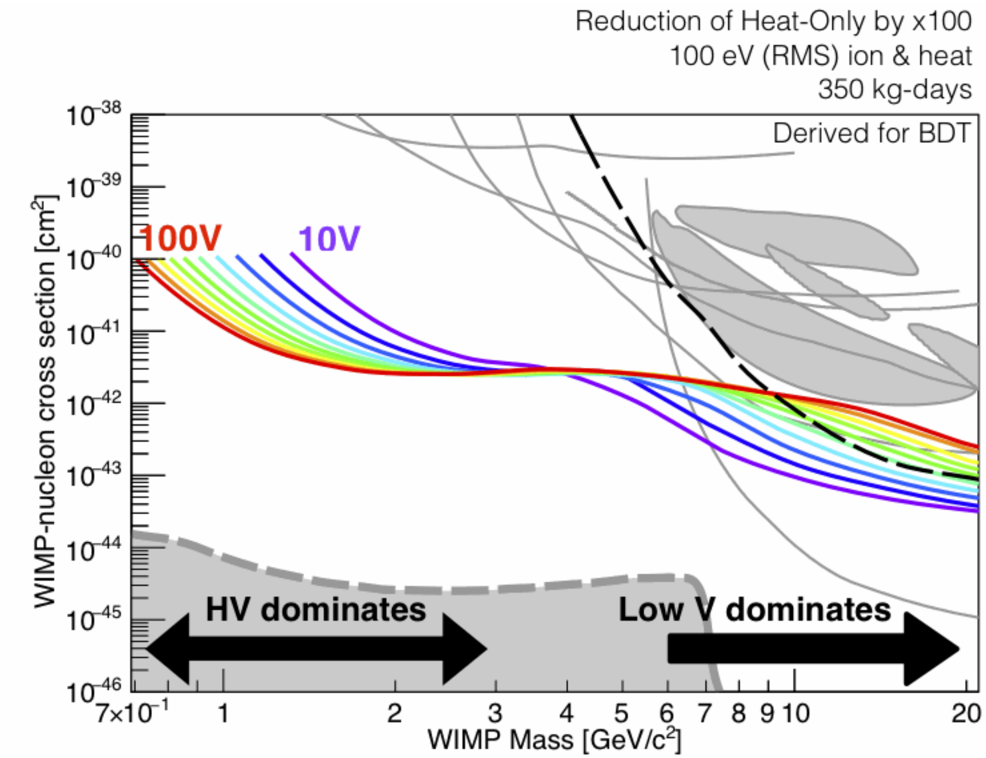
Next steps (ongoing):

- Publication
- Eliminate of heat-only evts (similar noise fixed by CRESST in the past)
- Threshold reduction: heat resolution (σ = 100 eV goal) + gain increase using Luke-Neganov boost

Luke-Neganov boost for low-mass WIMPs

Heat thresholds can be improved by applying larger bias voltages

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

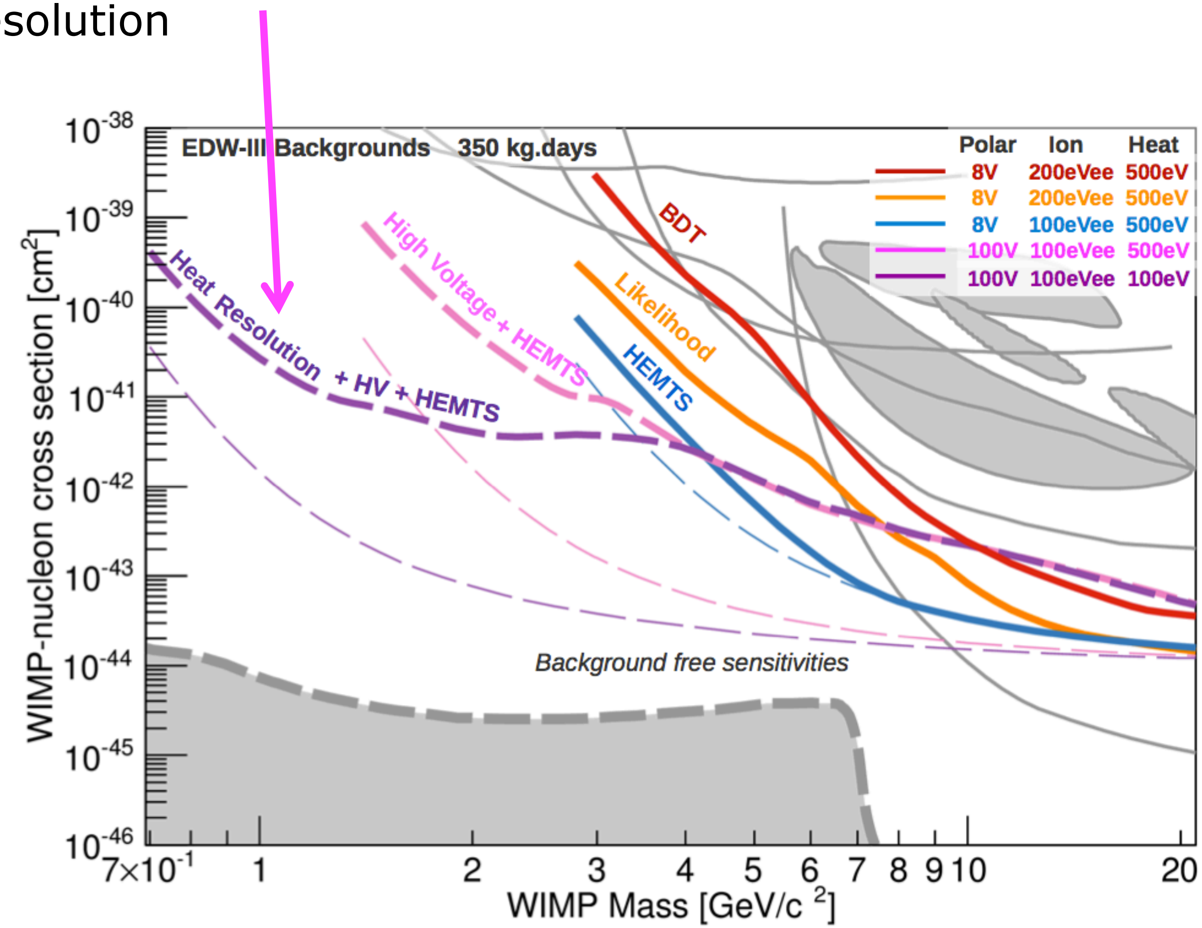


Submitted to JLTP: see LTD16 poster
http://ltd16.grenoble.cnrs.fr/IMG/UserFiles/Images/G2_22_Quentin_Arnaud.compressed.pdf

EDELWEISS projections

2017 goal

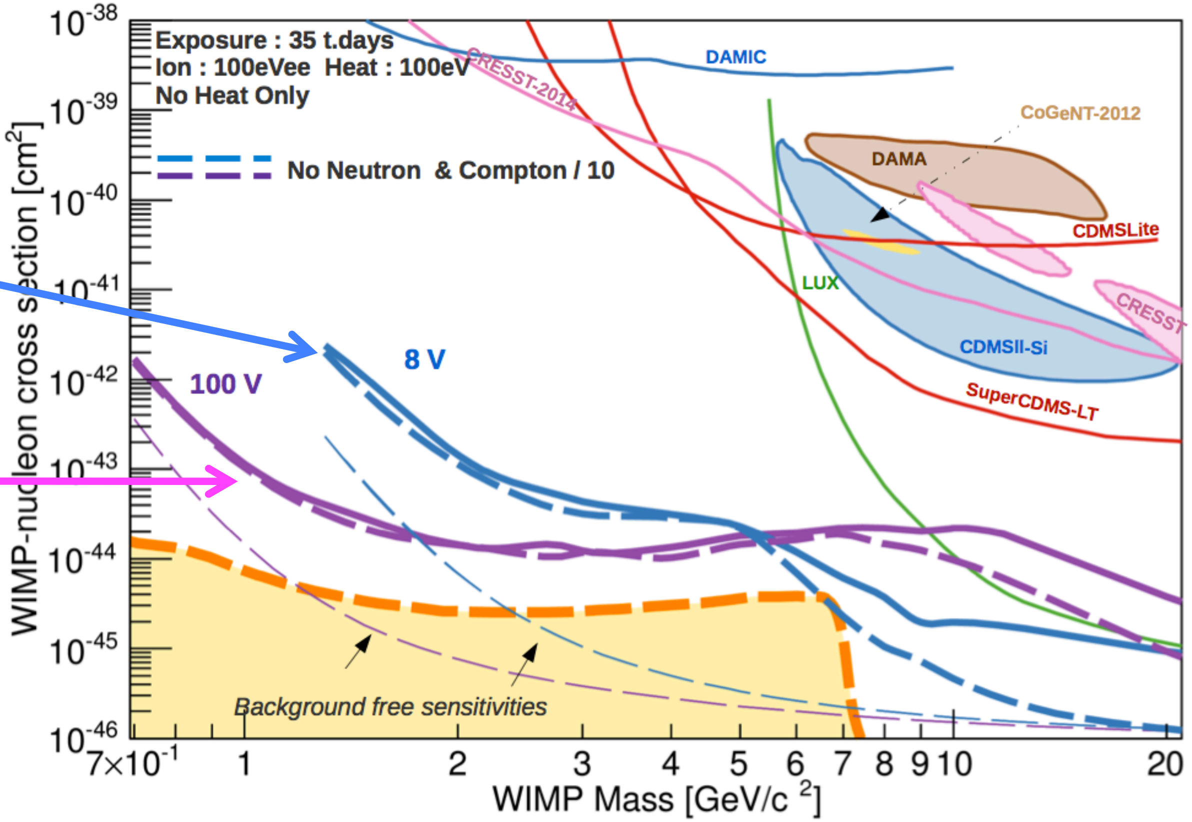
- 350 kgd (few detectors @ LSM) with 100V Luke-Neganov boost + σ =100 eV heat resolution



EDELWEISS projections

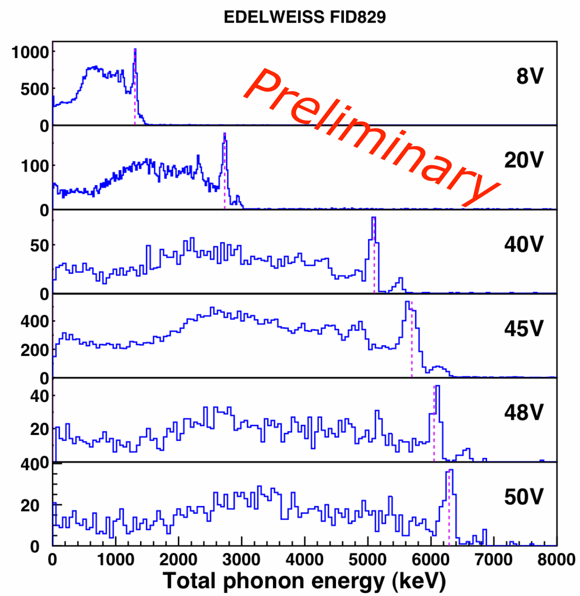
Future

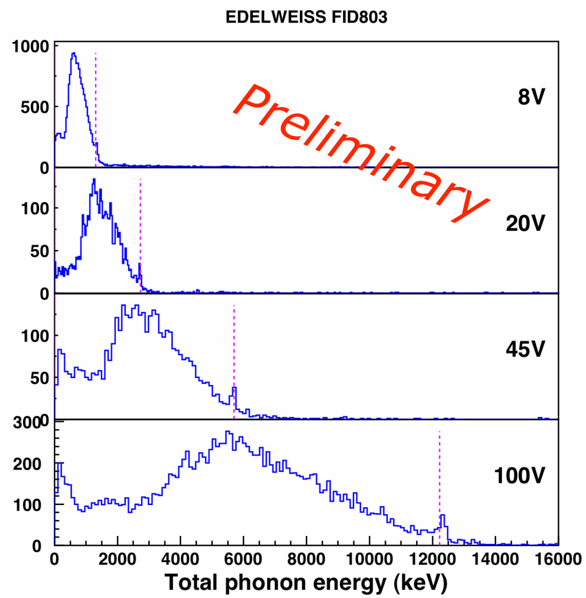
- σ=100 eV ion. resolution with HEMT amplifiers, to gain discrimination (5-20 GeV)
- Background and mass limitations: more ambitious program to be done at SNOLAB within the EDELWEISS-EURECA-SuperCDMS collaboration + CUTE project
- With ionization discrimination (5-10 GeV)
- Luke-boosted (1-5 GeV)



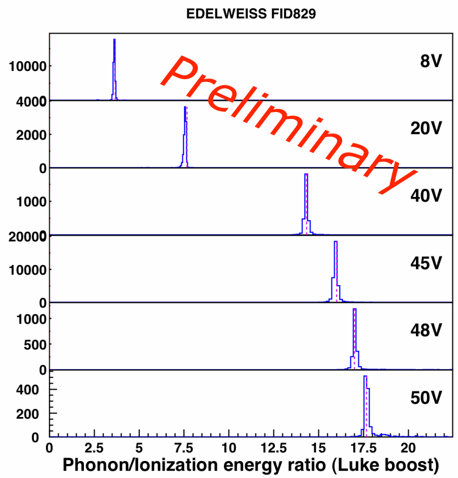
First Luke-boosted data at LSM

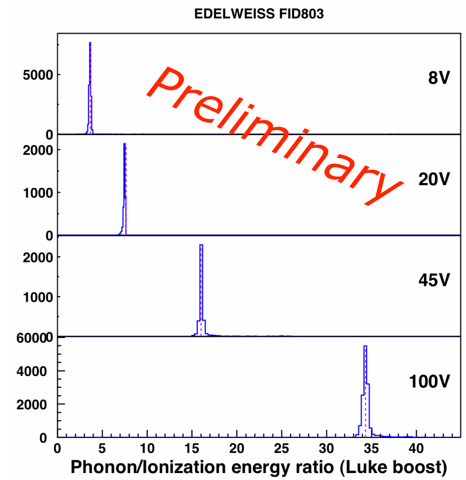
- Bias up to 50 or 100 V achieved on present 800g FIDs





- Observation of expected Luke boosts





Both ionization and photon read out

Conclusions

- EDELWEISS has improved its reach for low-mass WIMPs
  - X8 to X40 improvement relative to EDELWEISS-II
- For 2016-2017, plans to extend search reach down to 1 GeV masses & 10^{-41} cm^2
  - Removal of heat-only events, heat resolution, Luke-Neganov amplification

    First results with Luke amplification at LSM with 800g FID
- Beyond, more ambitious mass+background goals within the EDELWEISS-EURECA-SuperCDMS collaboration

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

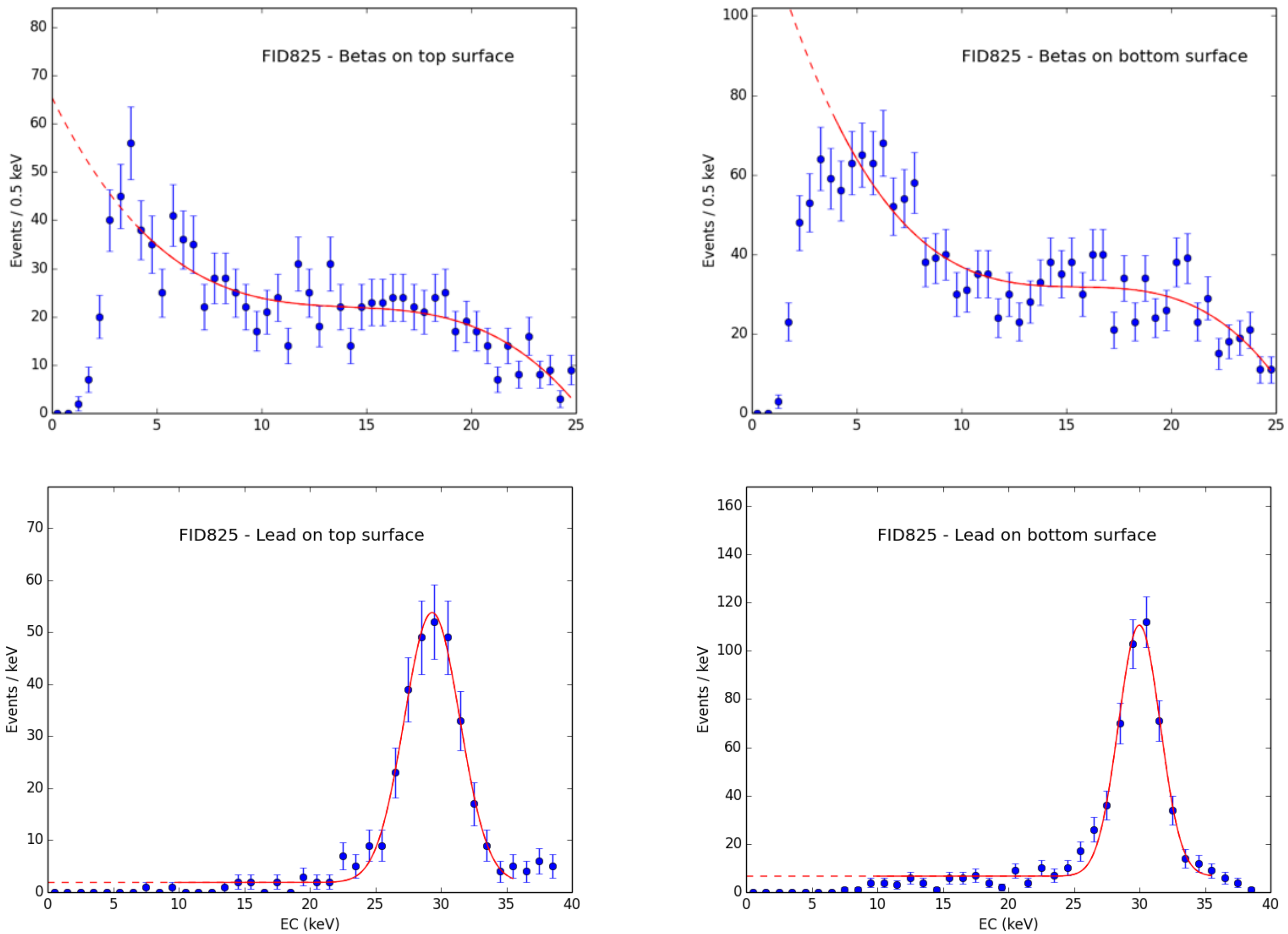
JINR JINR DUBNA

University of Oxford Univ. OXFORD

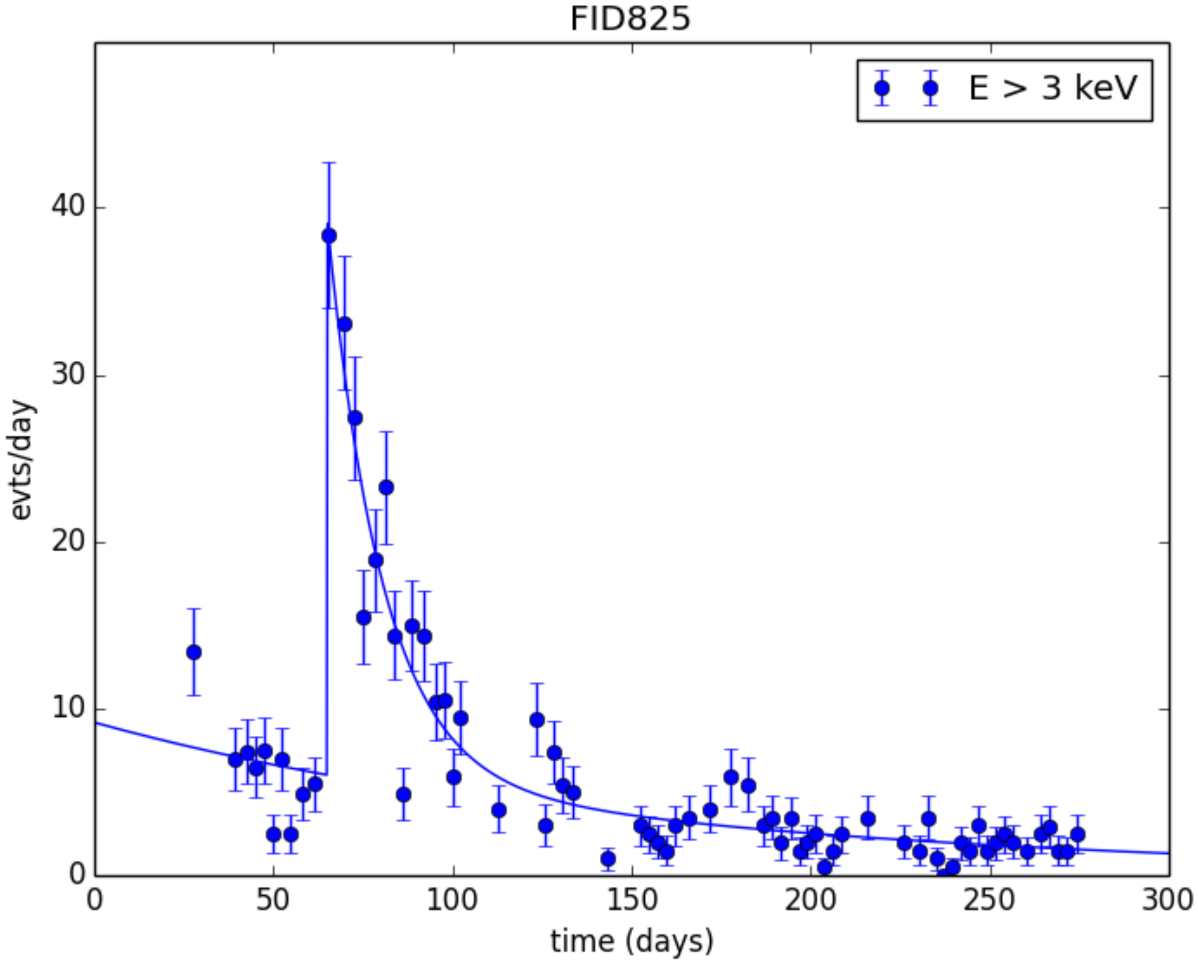
The University Of Sheffield. Univ. SHEFFIELD

BACKUP

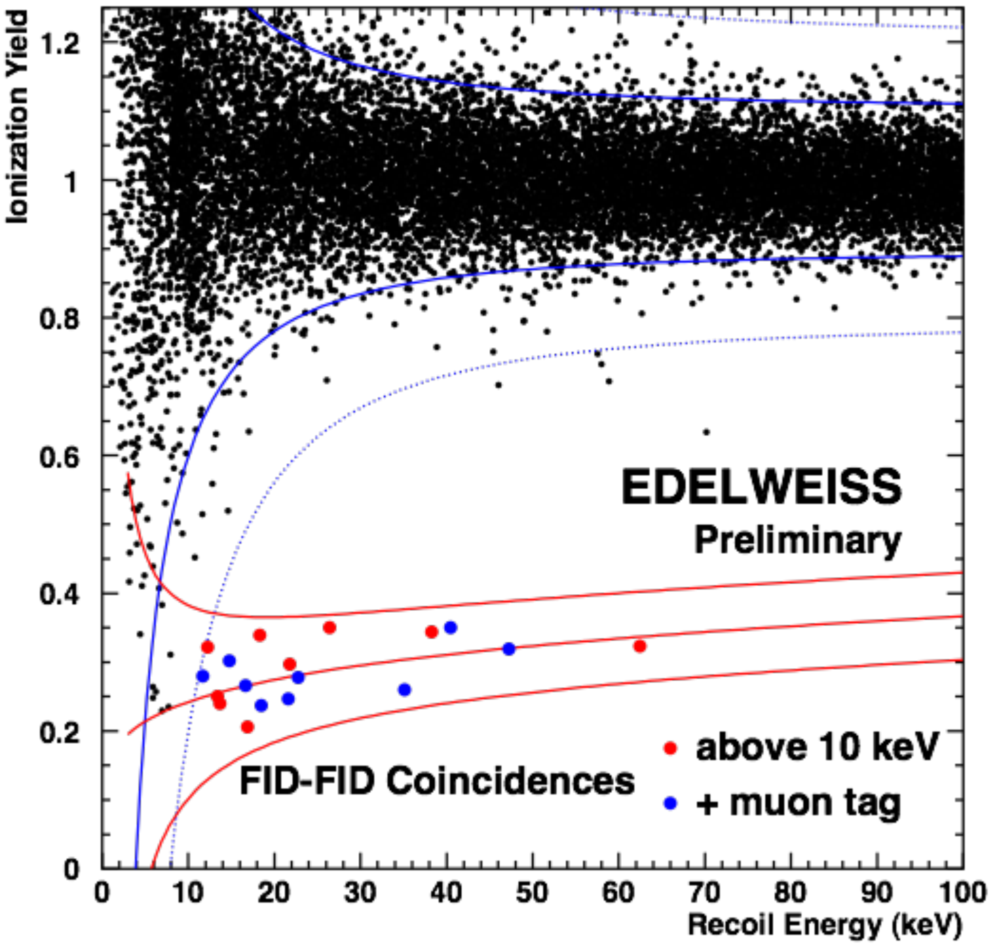
Surface event models



Time dependence of heat-only rates

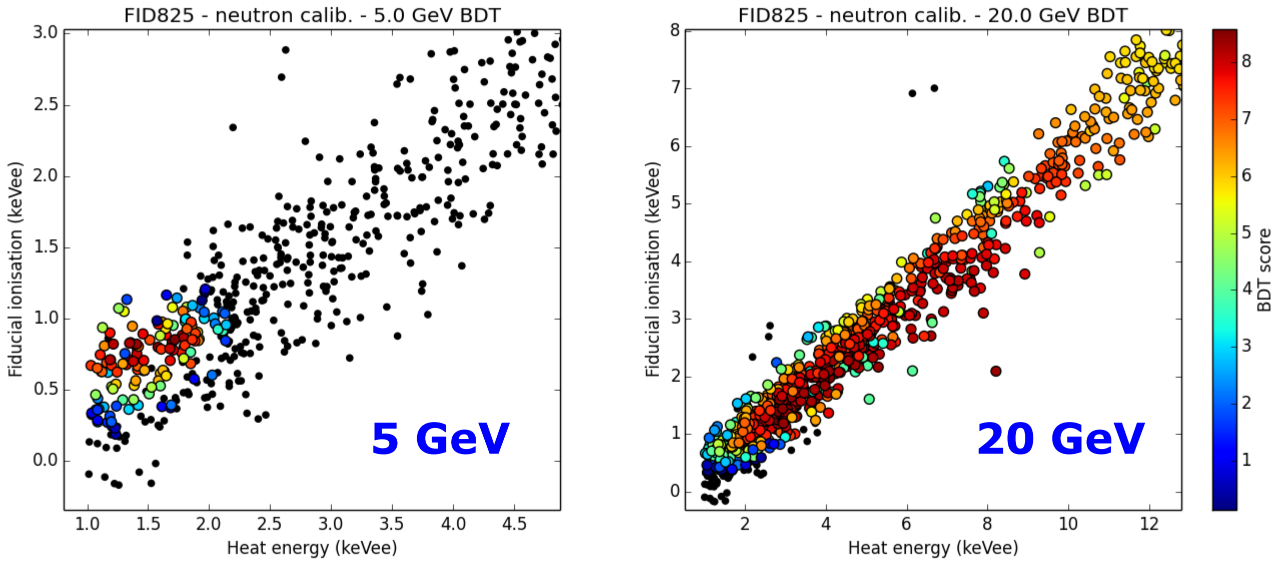


Neutron background model



- FID-FID coincidence data (excluded from WIMP search)
- 17 detectors, 1300 kg.day
- After μ-veto coincidence rejection, observe 9 nuclear recoil coincidences (10-100 keV recoil energy range)
- Radiogenic neutron flux of GEANT4 simulation scaled to reproduce the 9 observed coincidences.
- Neutron model: single spectrum of the scaled simulation

BDT response to neutrons from AmBe



Dark red:
passes the cut

BDT score for events from AmBe calibration
(FID825)

- Low WIMP mass: radiogenic neutron spectrum is too hard, the BDT cuts event above 2 keVee heat energy. Negligible background.
- High WIMP mass: BDT cut keeps neutron events up to ~8 keVee, radiogenic neutrons become the dominant background.

Adaptative heat trigger

- Automatic trigger level adjustment to keep constant trigger rate

- Red line: trigger at 1.9 FWHM