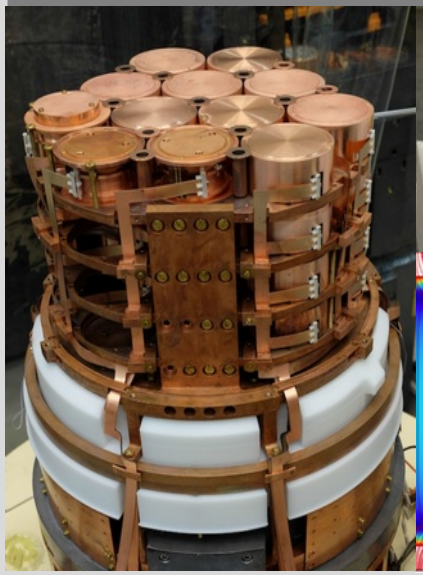
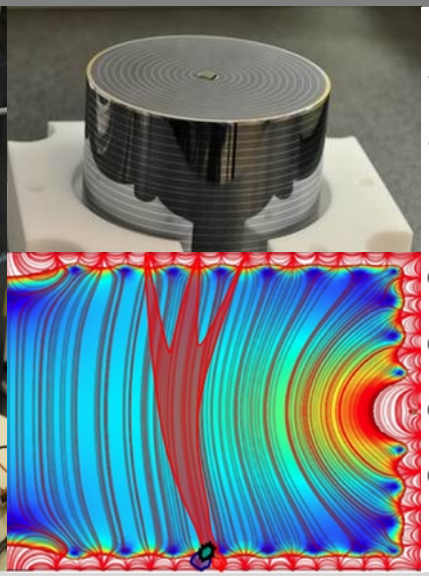
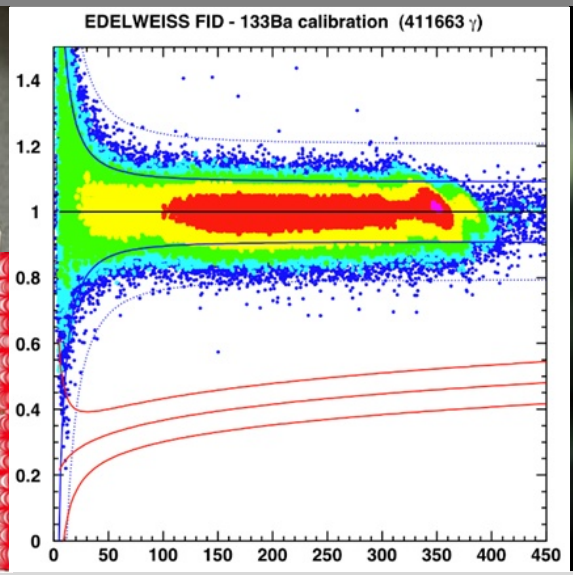
The EDELWEISS-III Search for Low Mass WIMPs

HAP Dark Matter 2015
21-23 September 2015, Karlsruhe

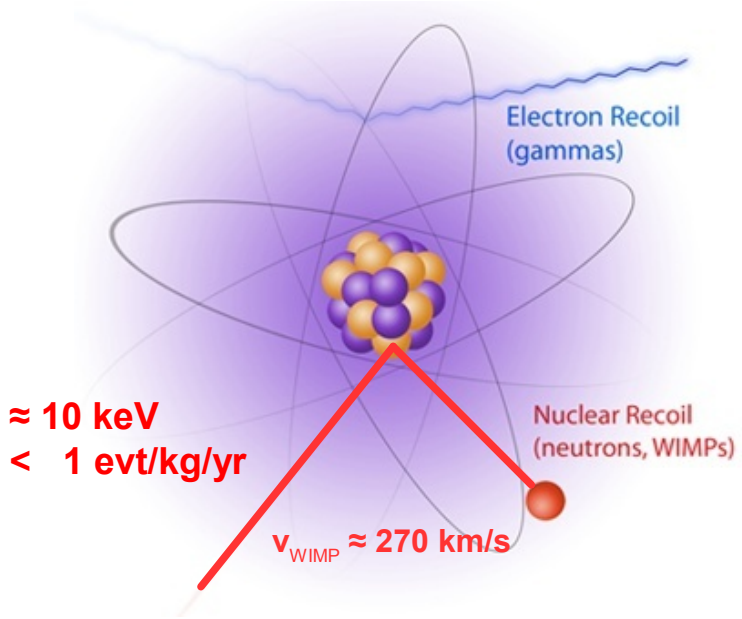
Lukas Hehn, Institut für Kernphysik (IKP)

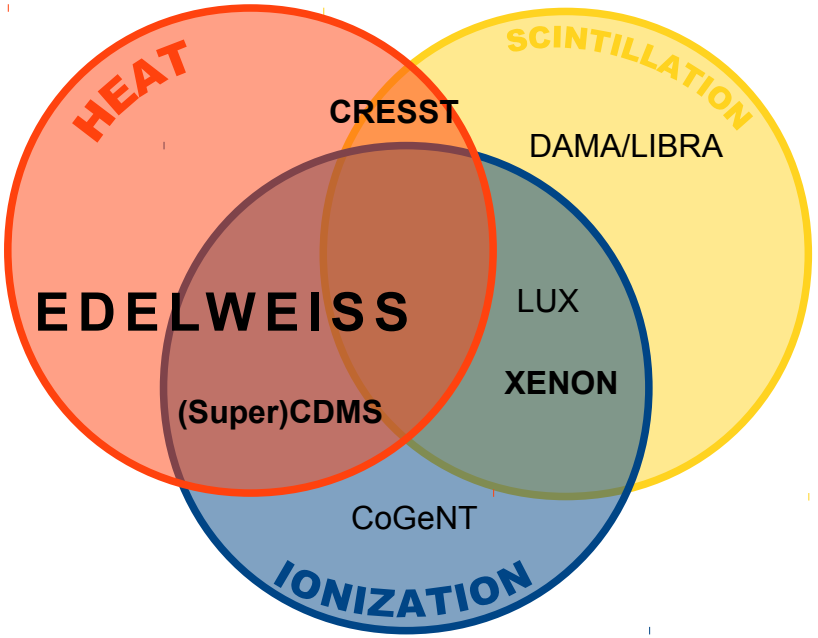




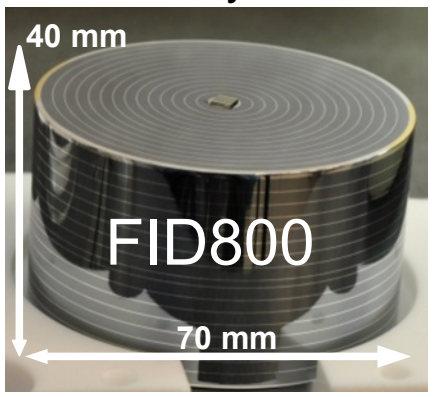


Direct Dark Matter detection with EDELWEISS





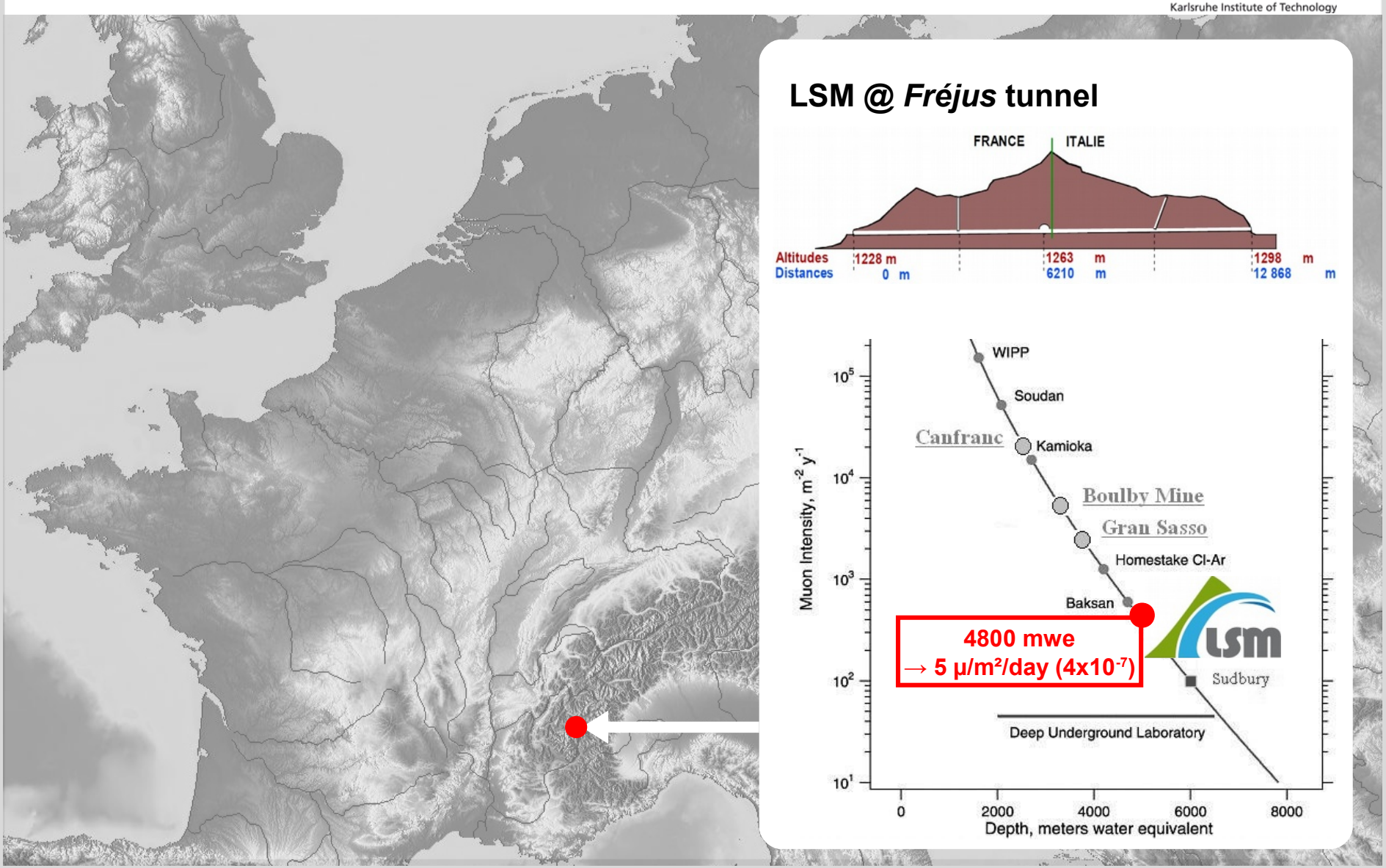
Ge monocrystal bolometer



background discrimination:

- 2 *NTD* phonon sensors:
  → calorimetric measurement of total energy
  @ T=18mK → ΔT≈0.1 μK/keV
- 4 groups of *interleaved* Al ring electrodes:
  → ionization measurement

Location of the EDELWEISS experiment



LSM @ *Fréjus* tunnel

The EDELWEISS collaboration

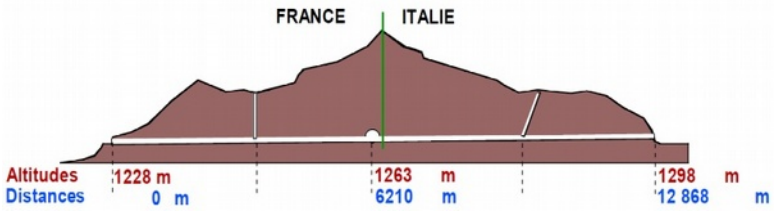
CEA Saclay (IRFU and IRAMIS)
CSNSM Orsay (CNRS/IN2P3, Paris Sud)
IPNLyon (CNRS/IN2P3)
Néel Grenoble (CNRS/INP)

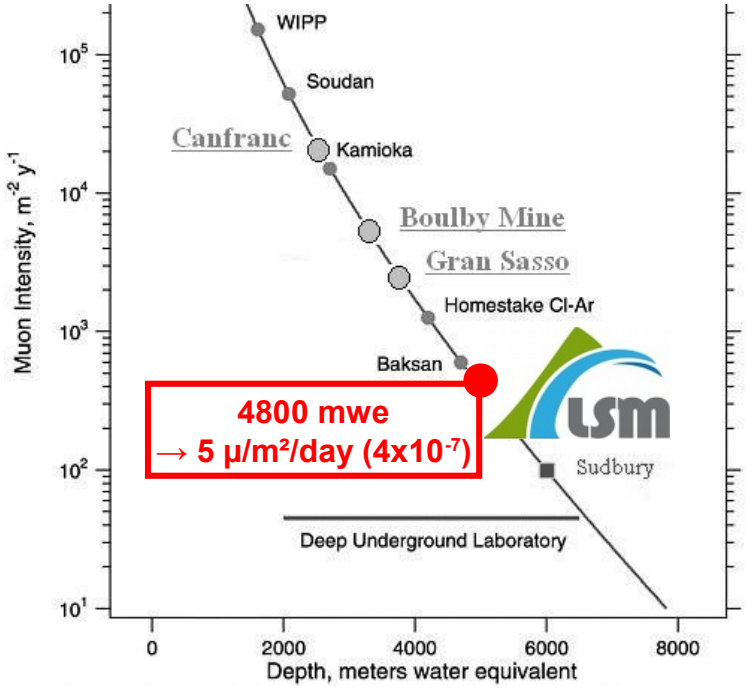
KIT Karlsruhe (IKP, EKP, IPE)

JINR Dubna

Oxford University
University of Sheffield

LSM @ *Fréjus* tunnel





The EDELWEISS Shielding Concept

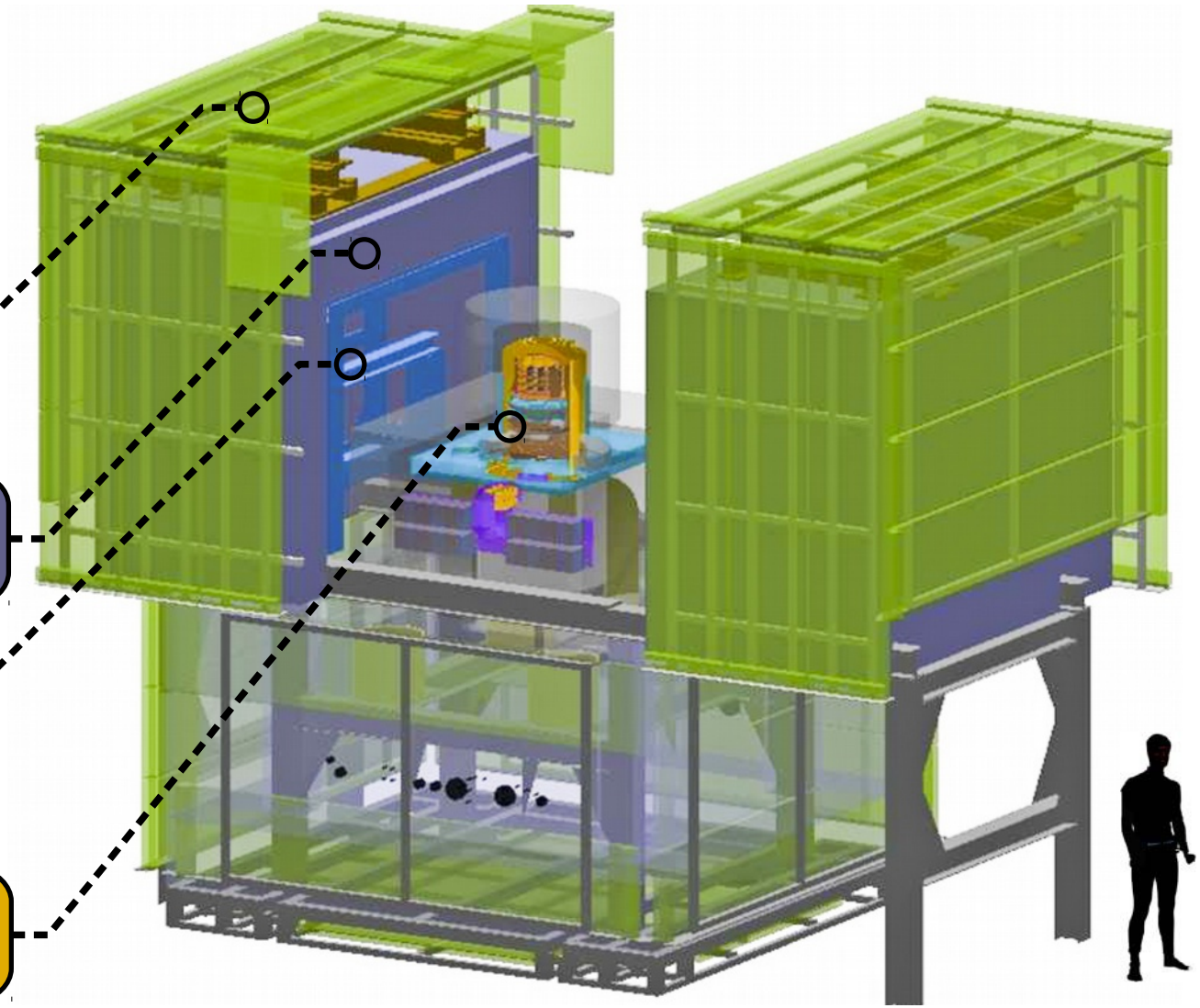
clean room (Rn)
with derodanized air supply
(from 10 Bq/m³ → ≈ 30 mBq/m³)

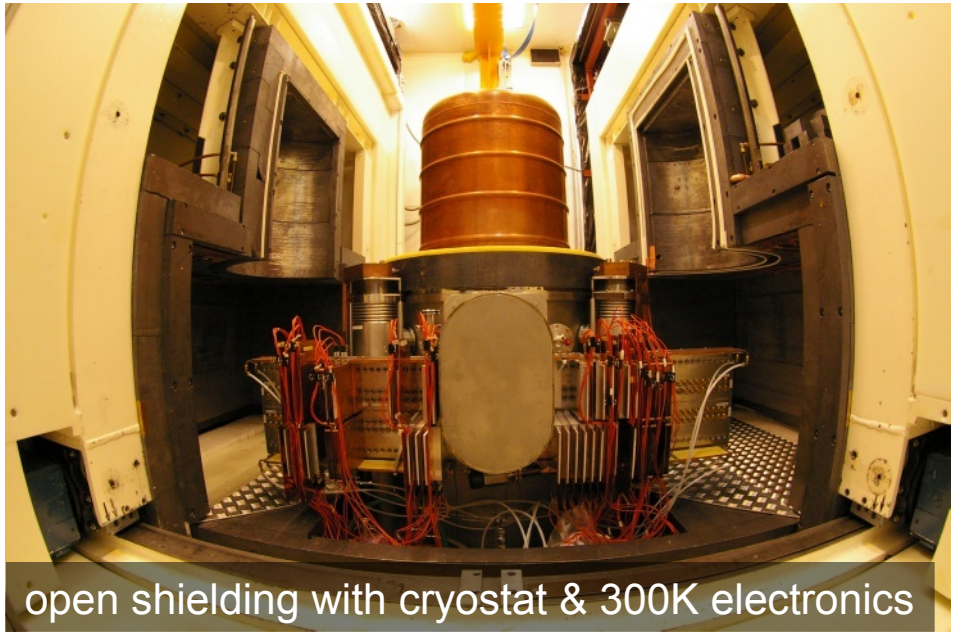
active muon veto (μ)
98% geometric coverage

polyethylene shield (n)
50cm, for moderation

lead shield (β, γ)
18cm + 2cm roman lead

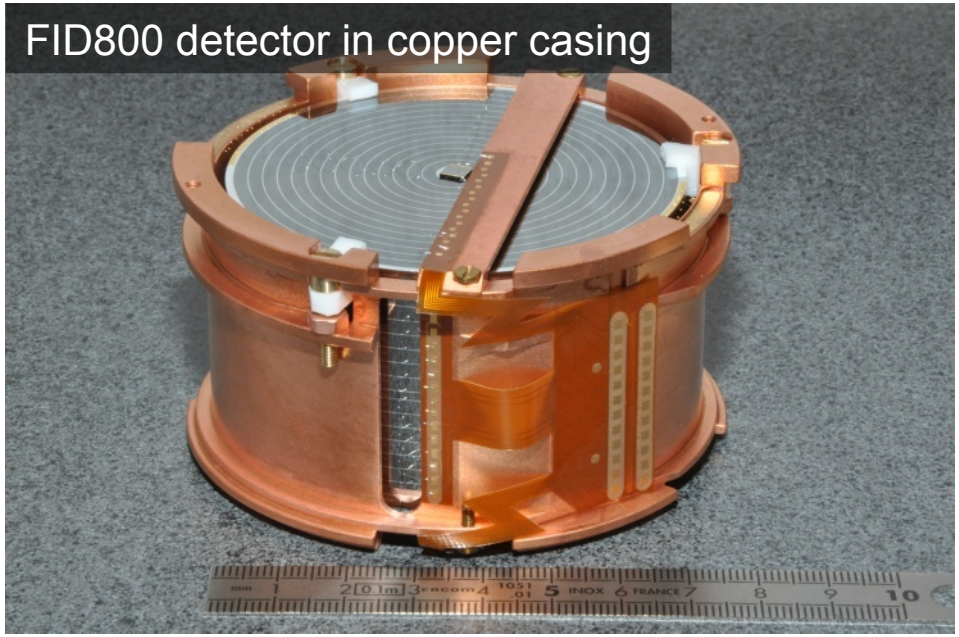
copper cryostat (β, γ)
with additional internal PE and Pb





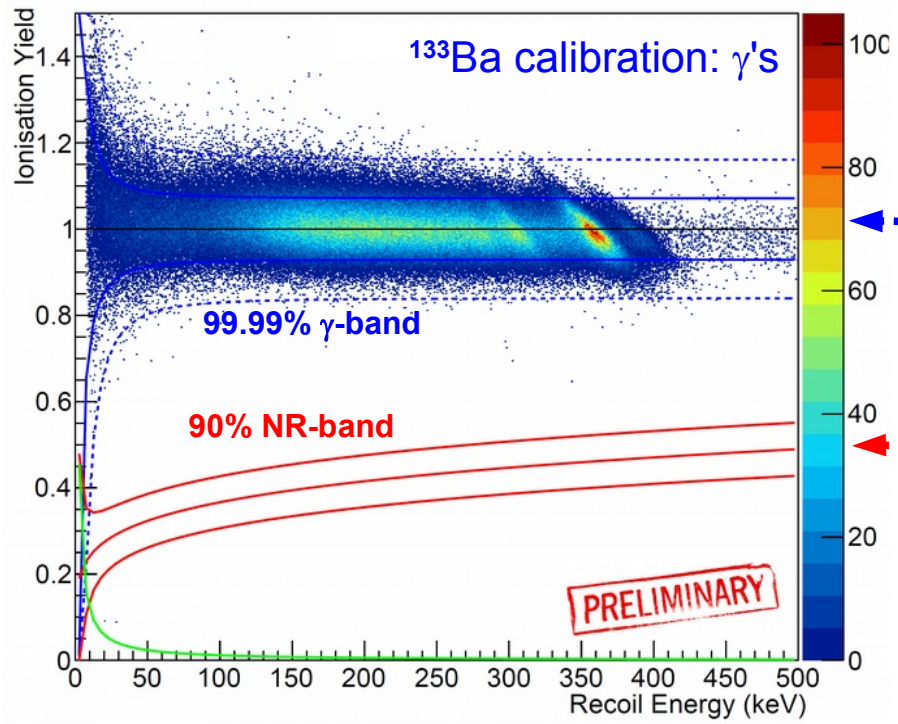
open shielding with cryostat & 300K electronics

open cryostat and bolometer plates



FID800 detector in copper casing

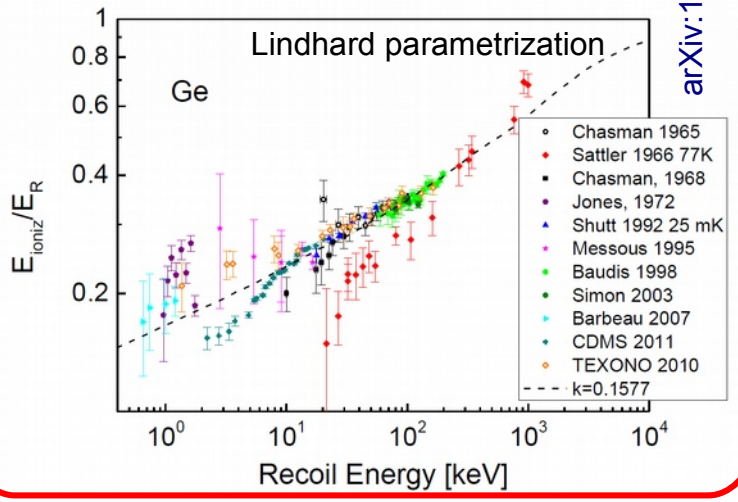
Nuclear recoil discrimination



Ionization yield $Q = E_{ion} / E_{recoil}$

Electron Recoils:
Q = 1
(by normalization)

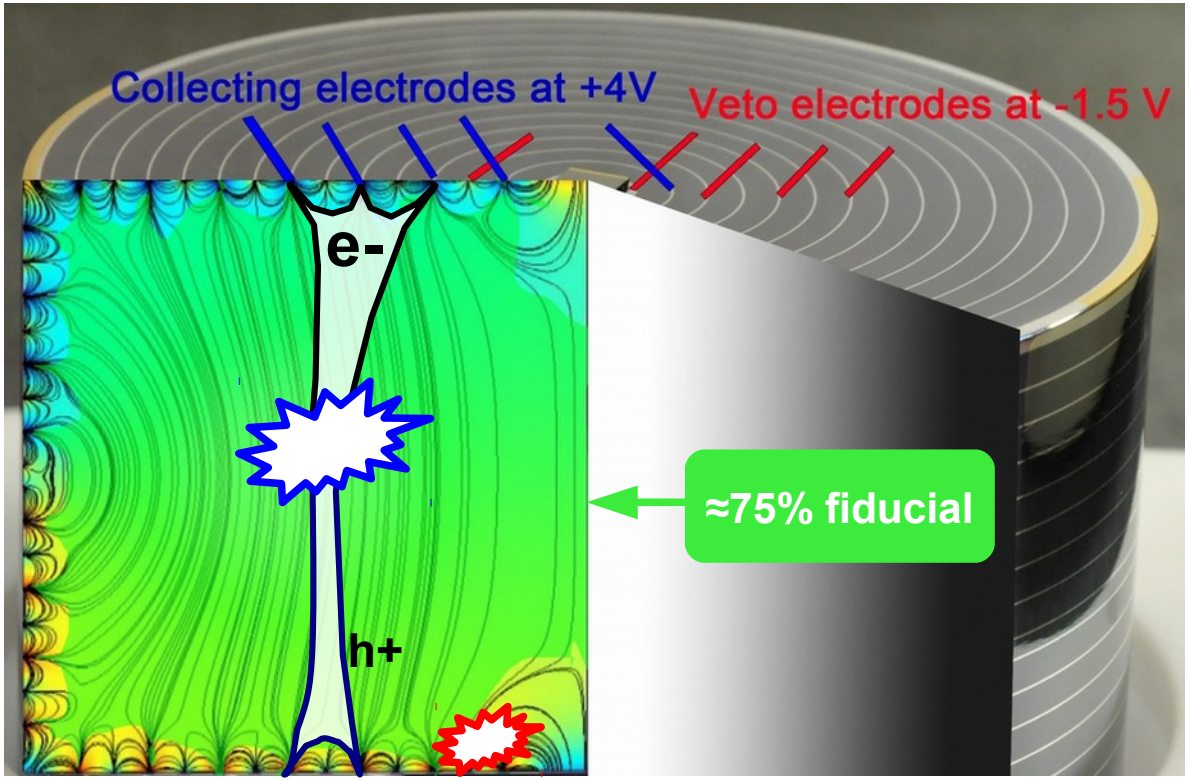
Nuclear Recoils:
Q ≈ 1/3
("quenching")



arXiv:1505.06340

- recoil type determination via ionization yield
- not possible if charge collection incomplete
  → need to reject surface events efficiently

Surface event rejection with the *full inter-digitized* (FID) electrode readout design

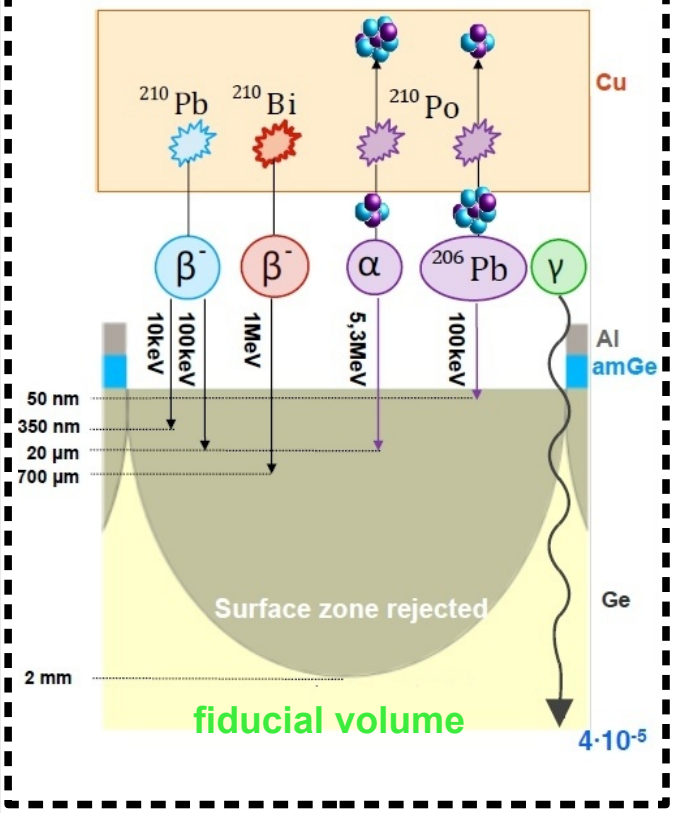


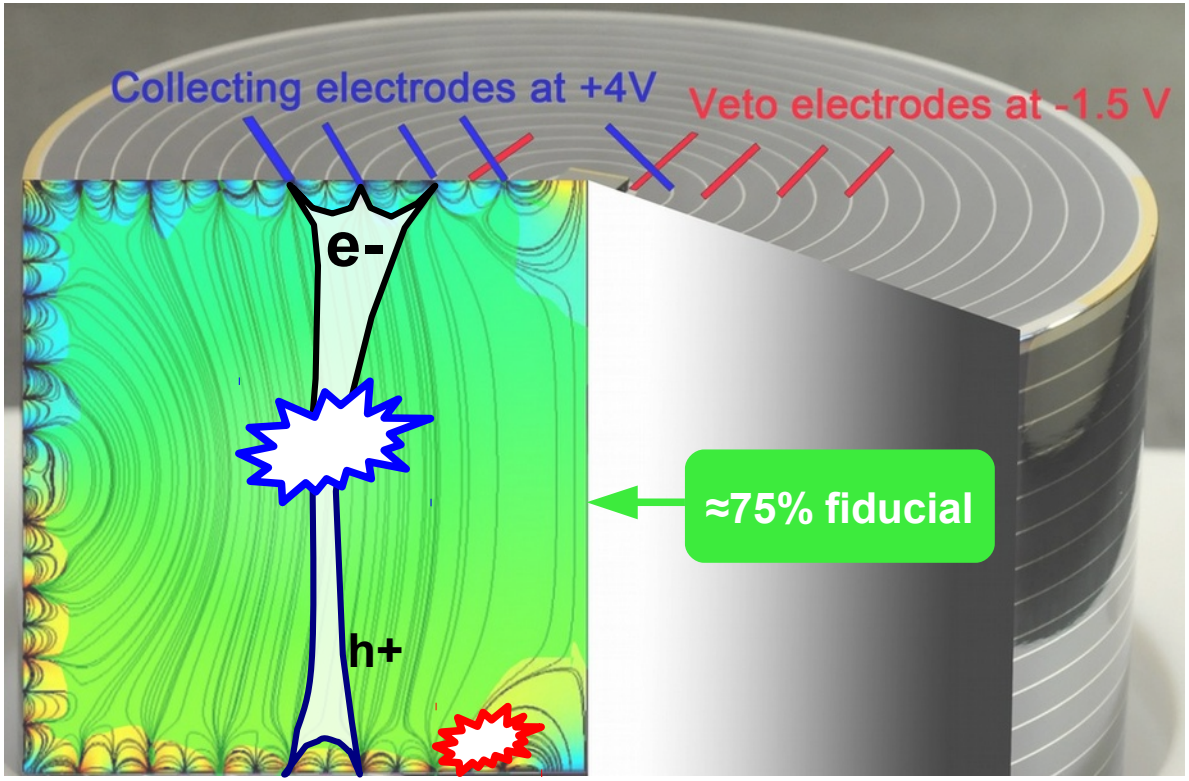
bulk event:
charge collection on
collecting electrodes

surface event:
charge collection on
veto electrodes

Surface event rejection with the *full inter-digitized* (FID) electrode readout design

From calibration measurement with implanted ^{210}Pb source:





bulk event:
charge collection on
collecting electrodes

surface event:
charge collection on
veto electrodes

Data for WIMP search

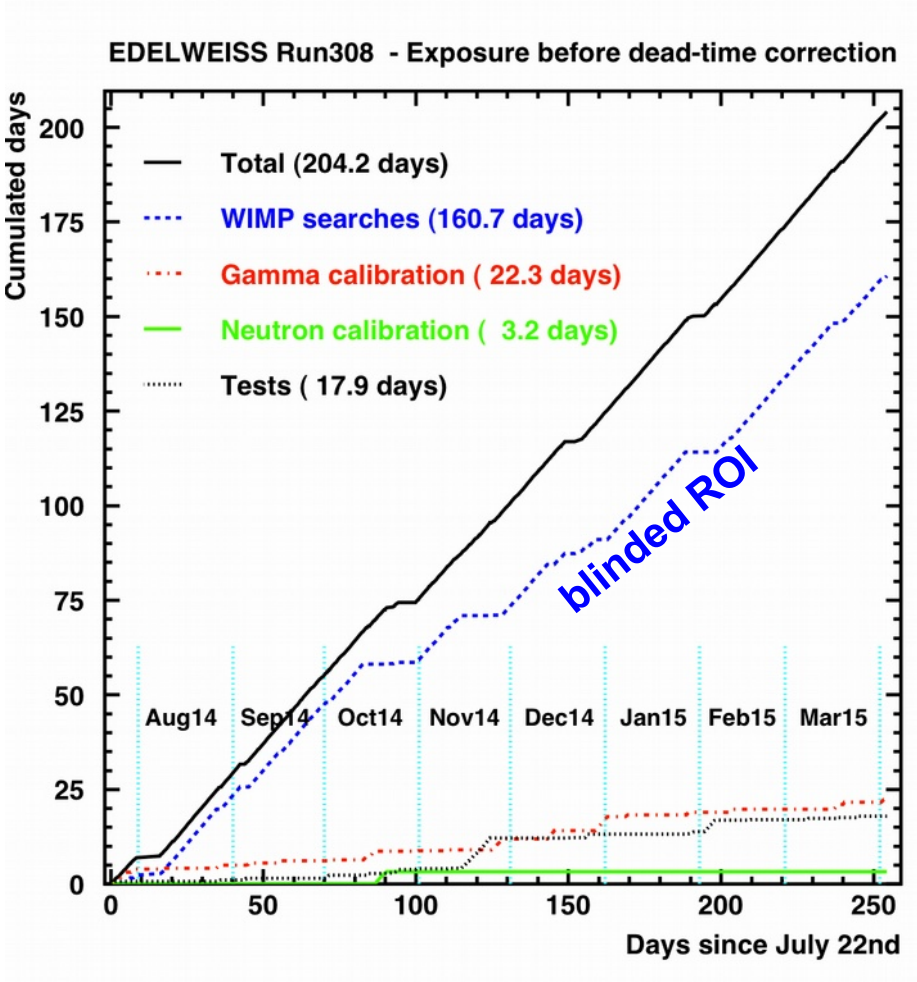
8 months of physics data 2014/2015
with 24 x FID800 detectors

Low mass WIMP search:

- blinded ROI
- **8 detectors** with good baselines and low trigger thresholds
- homogeneous data set
- analysis threshold in heat:
  4x FID800 @ 1.0 keVee
  4x FID800 @ 1.5 keVee*

*1 keVee ≈ 2.4 keVnr

582 kg.days (fiducial)
(EDELWEISS-II: 113 kg.days)
sensitivity for WIMPs in [4, 30] GeV



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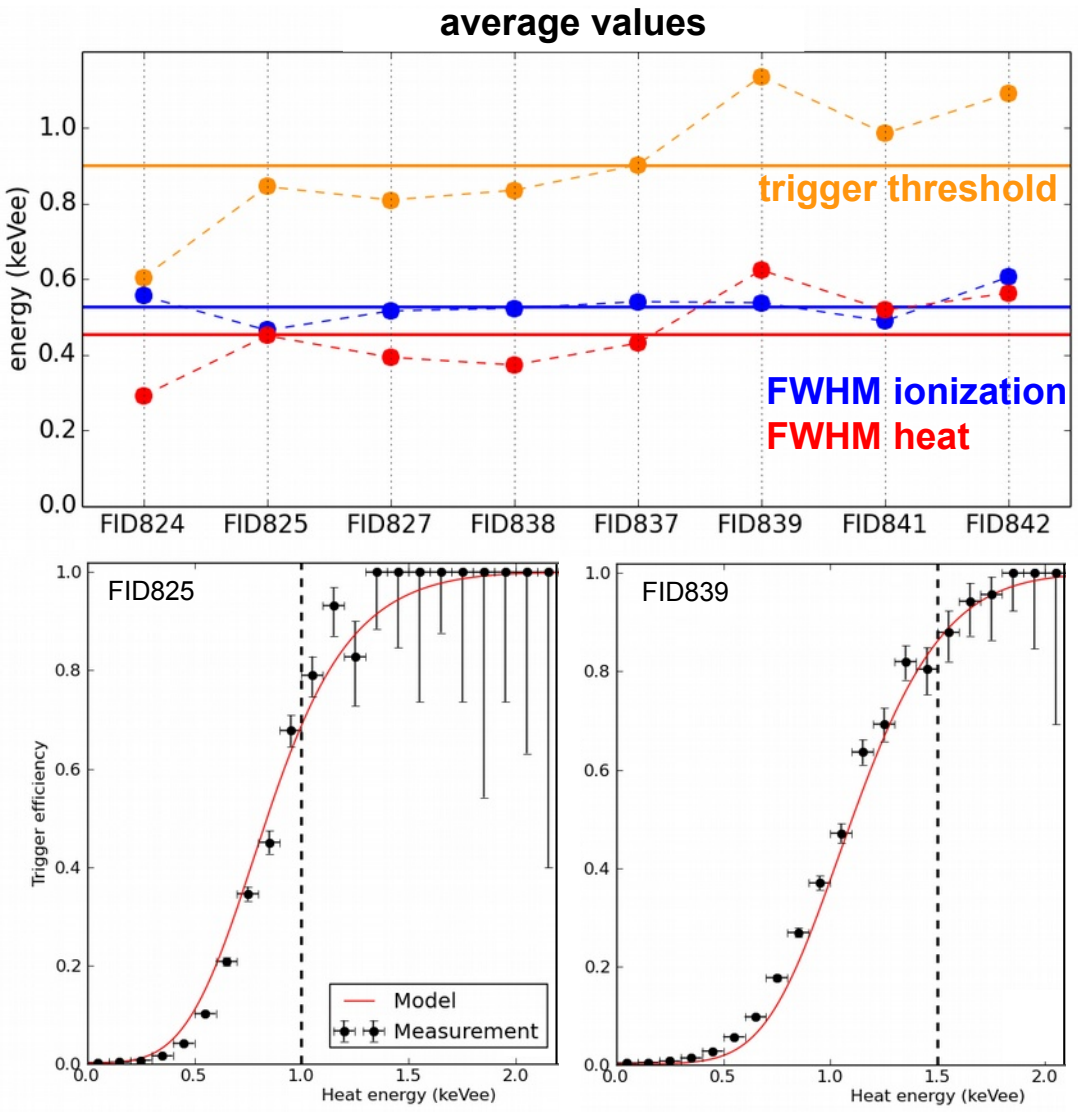
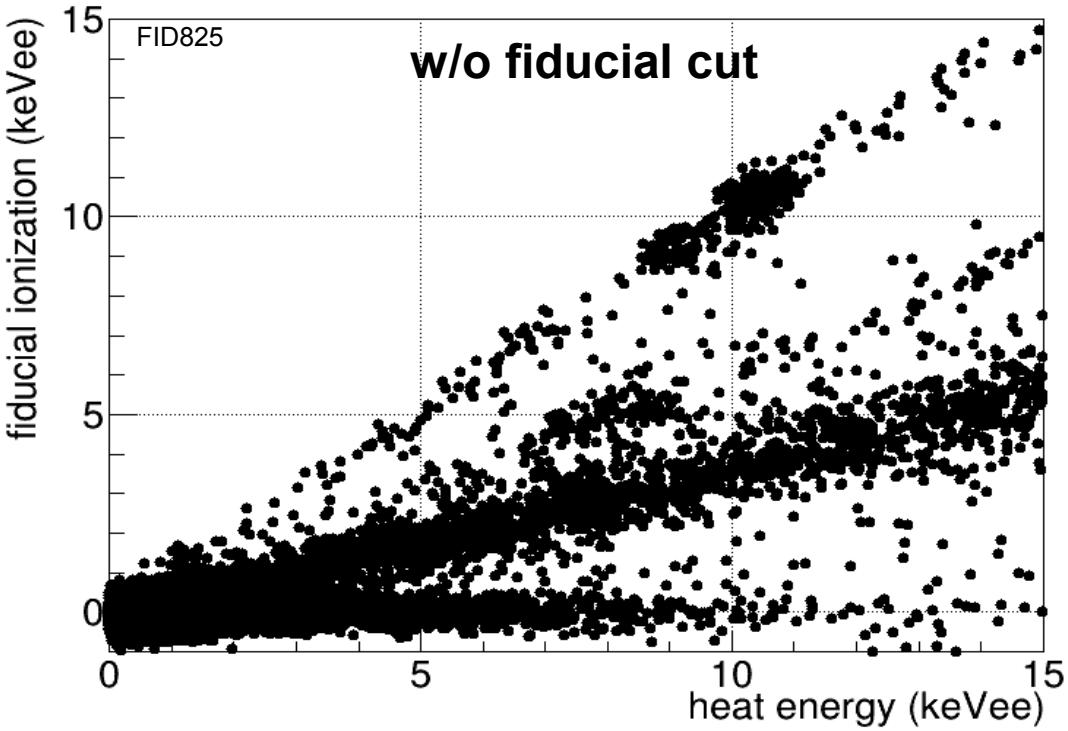
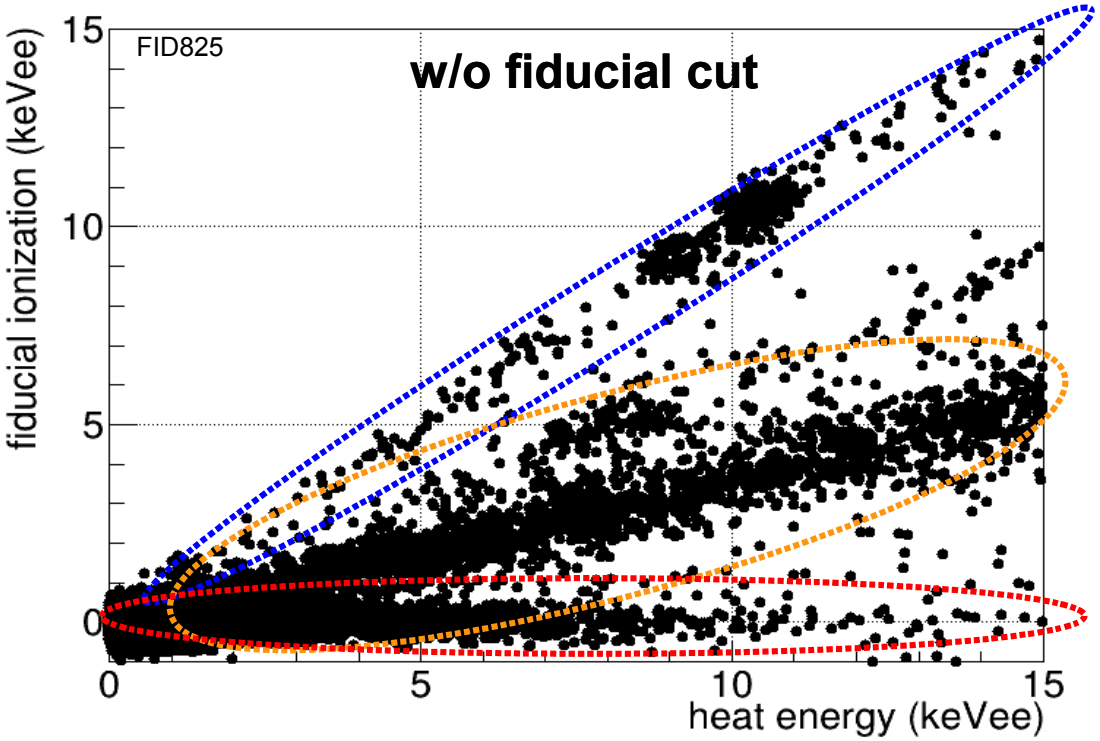


All data - backgrounds



All data - backgrounds



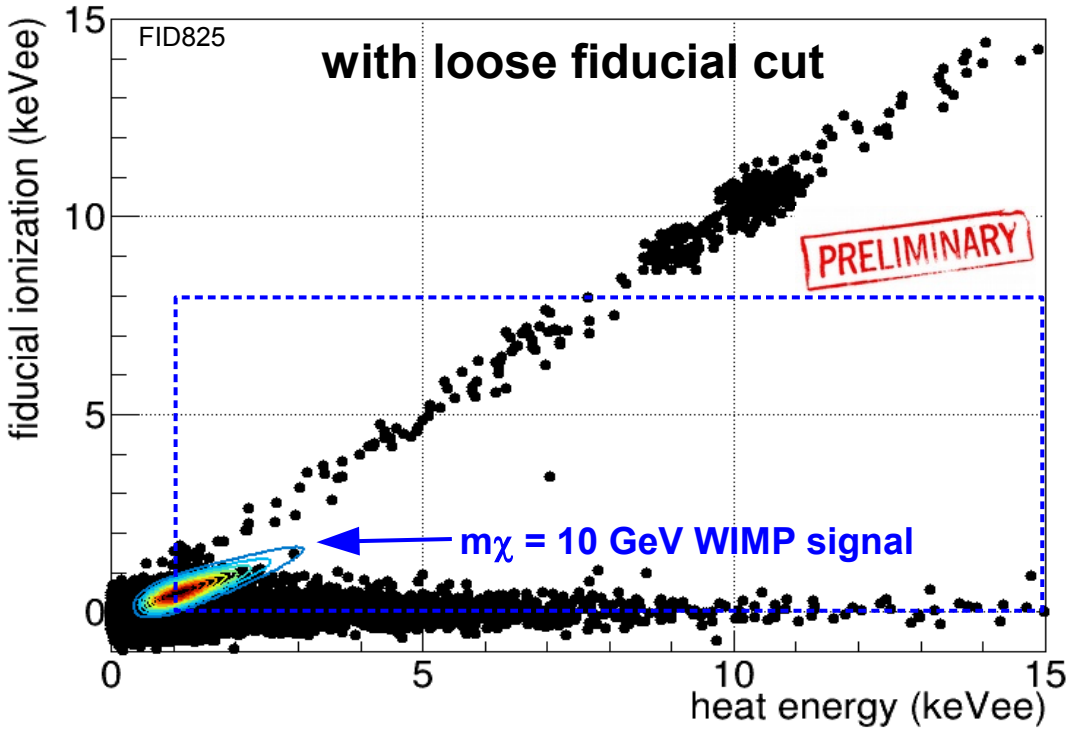
Ionization yield Q:

bulk gammas	Q = 1.0
surfaces:	
gammas	Q ~ 0.9
betas	Q ~ 0.4
lead recoils	Q ~ 0.1
heat only	Q = 0.0

Description of detector backgrounds from WIMP search data:

- energy spectra and quenching modelled from regions without signal (sidebands)
- calibration data is used for cross checks

All data - before BDT analysis



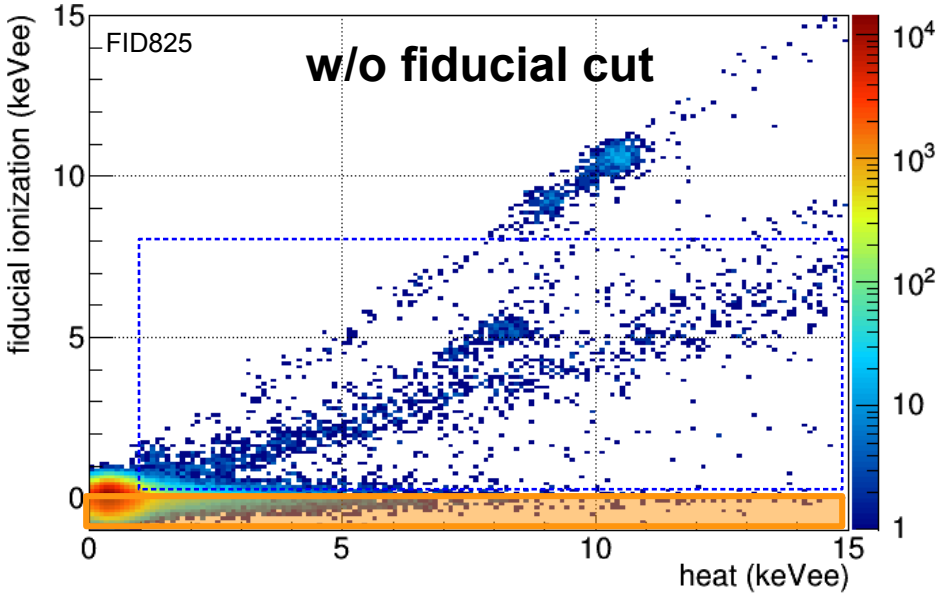
WIMP box:

- loose fiducial cut: $Sig_{veto} < 5\sigma_{baseline}$
- fiducial ionization: [0, 8] keVee
- heat energy: [1(1.5),15] keVee

Boosted Decision Tree (BDT):

- sig/bkg discrimination with **6 variables:**
  4 ionization + 1 (combined) heat + 1 heat-only rate
- individual detector effects: DAQ trigger, noise
- BDT training with high statistics

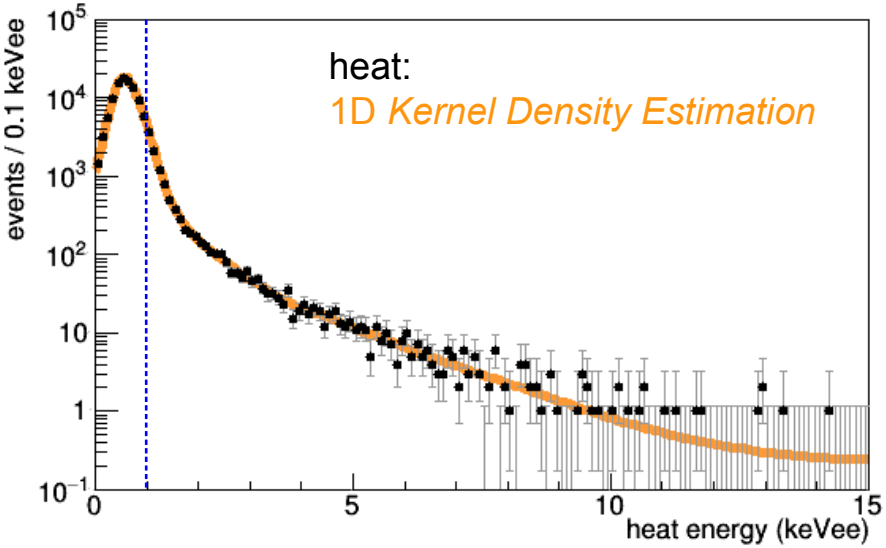
Heat-only events

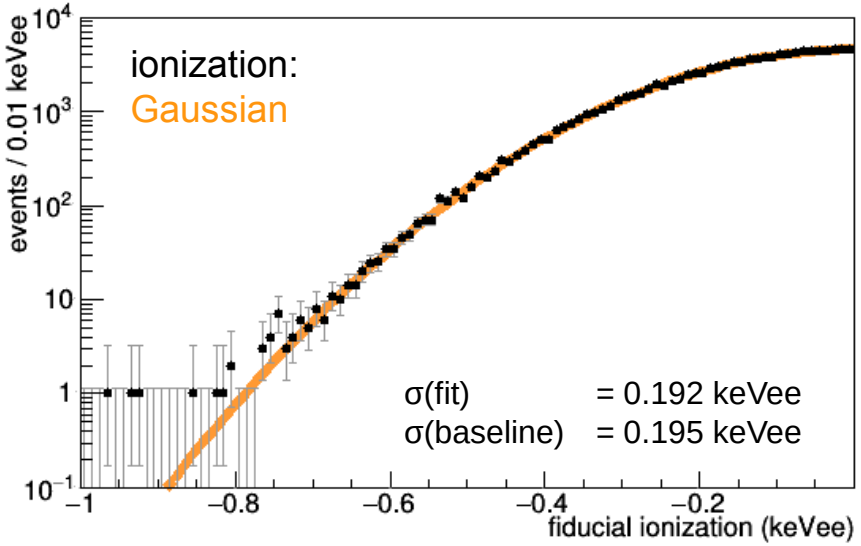


our dominant detector background:

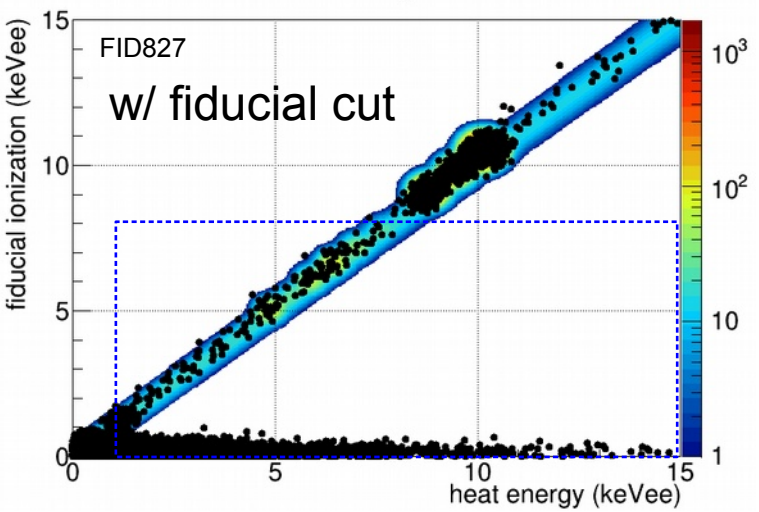
- origin still under investigation (probably mechanical)
- Gaussian ionization spectrum as expected from noise

→ **ionization < 0 keV sideband** is used to model these events





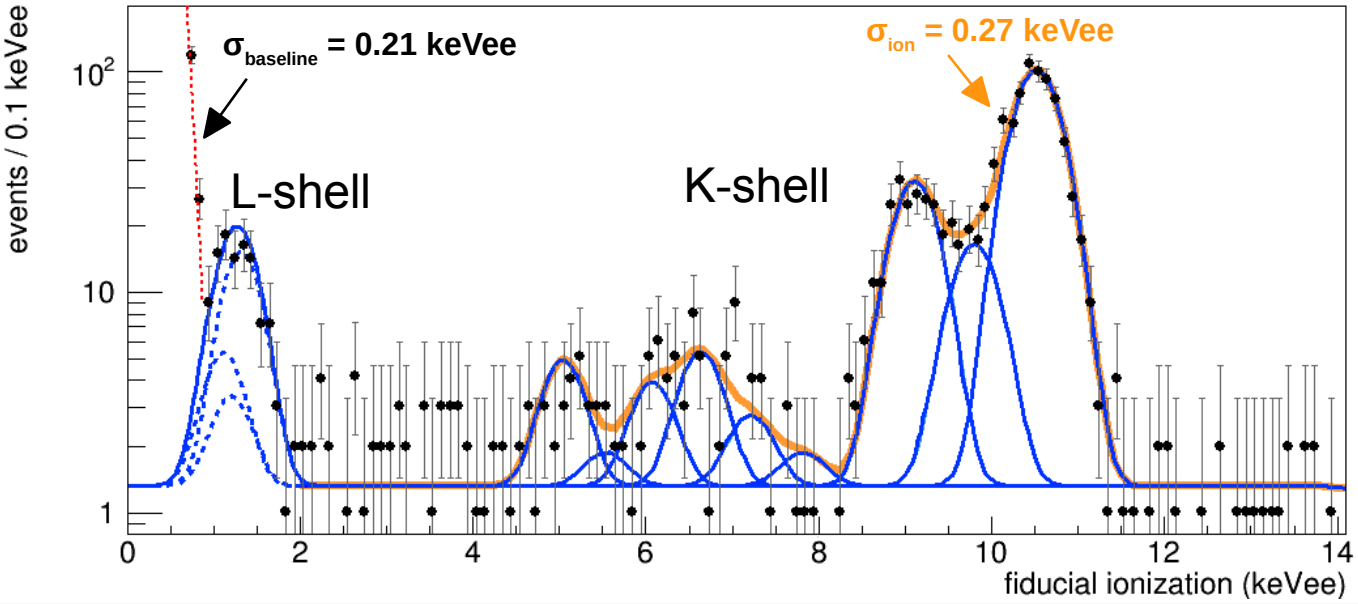
Bulk gammas



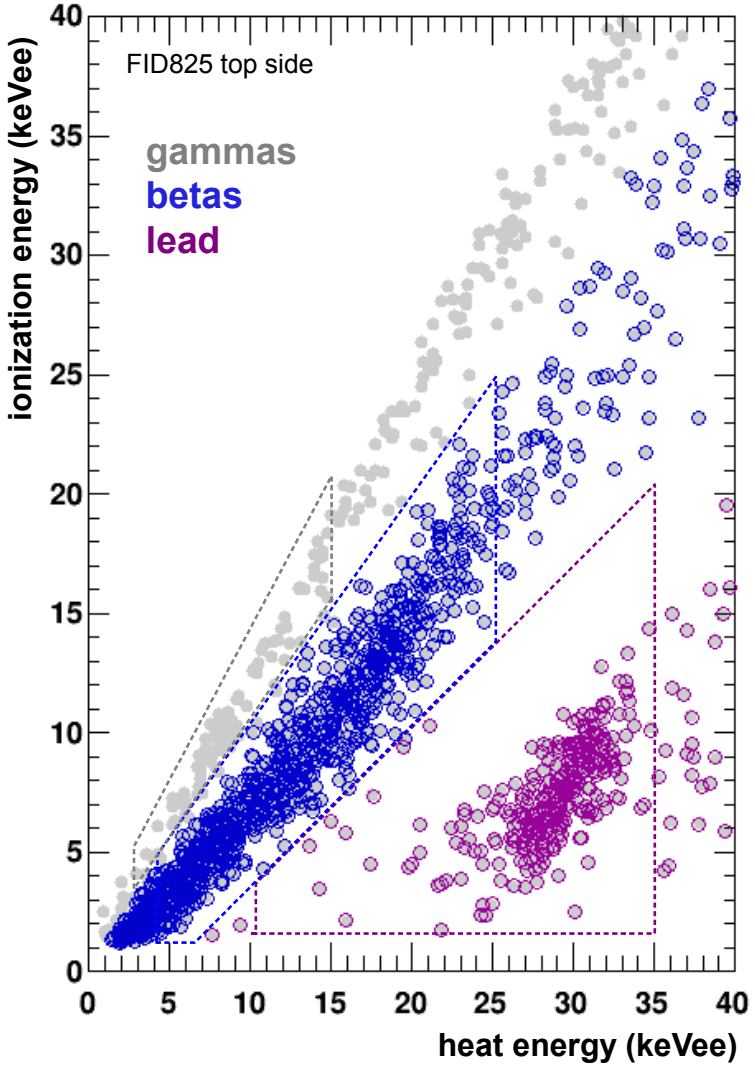
fit of fiducial gammas in [3, 15] keVee heat energy:

- K-shell peaks and flat compton spectrum
- flat component extrapolated down to 0 keV
- L-shell peak intensity derived from K-shell peaks and L/K-ratio ~ 0.11*

*J. Bahcall, Phys. Rev. 132, 362 (1963)



Surface event populations



- individual models for detector sides *top* and *bottom*
- use clear surface events with **Signal$_{veto}$ > 5σ$_{baseline}$**

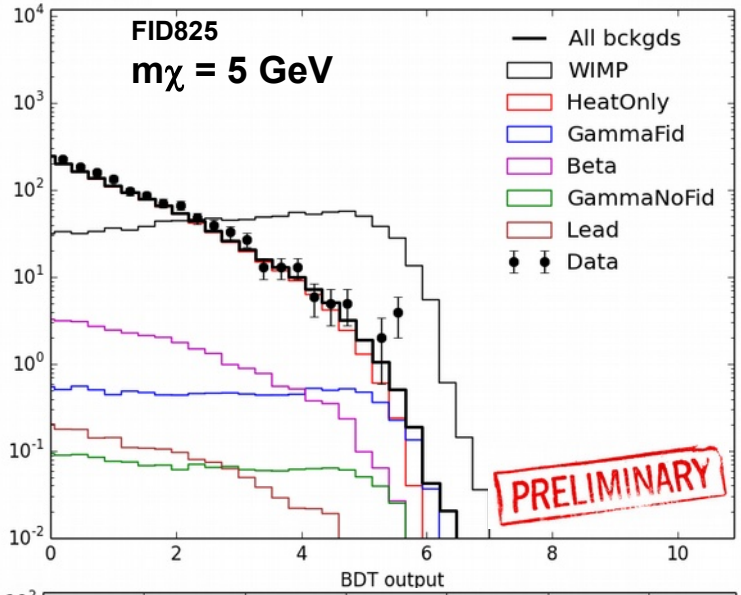
Gammas:
fit of flat compton & cosmogenic lines in [3,15] keVee
line intensity fixed from fiducial gammas and mass fraction

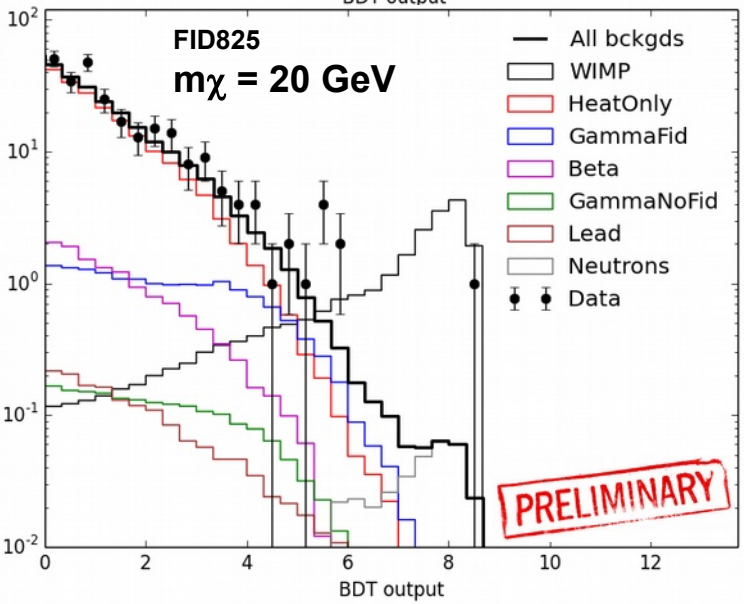
Betas:
fit of spline function in [4,25] keVee
extrapolation down to 0 keVee

Lead:
fit of Gaussian peak & flat component in [10,35*] keVee
extrapolation down to 0 keVee

*^{206}Pb recoil of 103 keV ≈ 33 keVee

BDT analysis and output

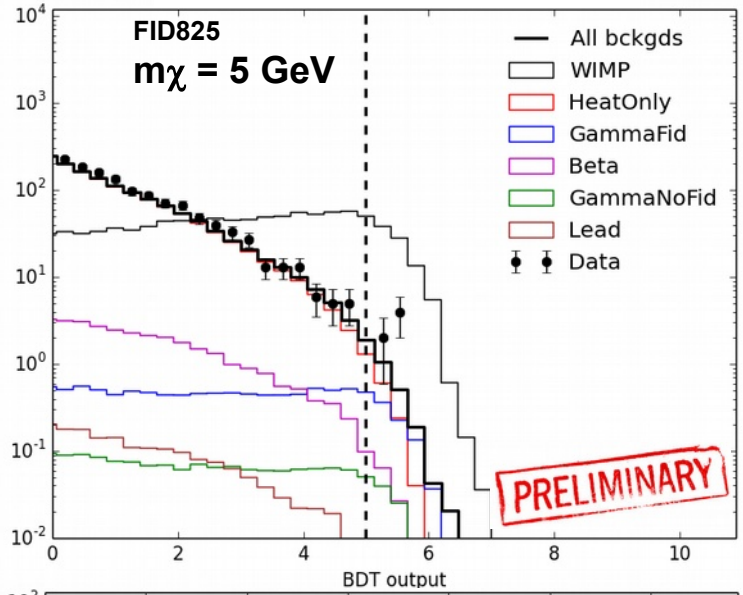


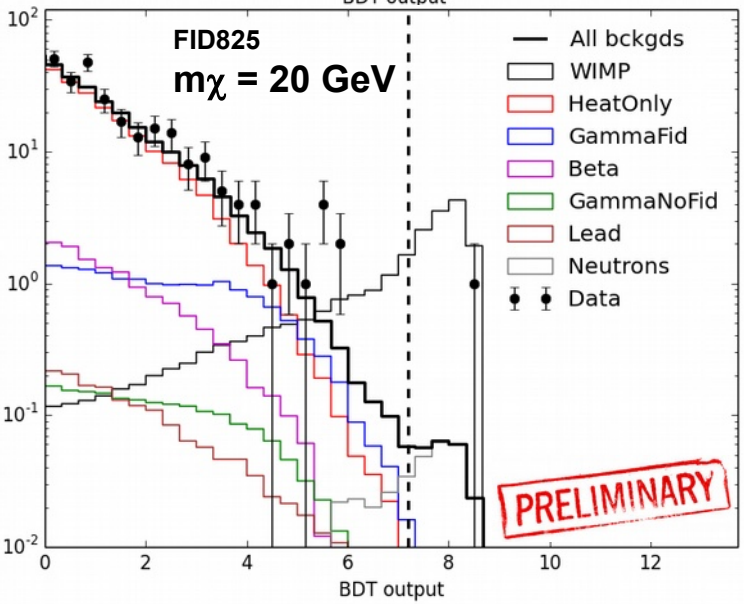


For each detector:

- one BDT distribution for each WIMP mass [4, 5, 6, 7, 10, 15, 20, 30] GeV
- backgrounds normalized to expected # of evts
- BDT cut optimized before unblinding

BDT analysis and output





For each detector:

- one BDT distribution for each WIMP mass [4, 5, 6, 7, 10, 15, 20, 30] GeV
- backgrounds normalized to expected # of evts
- **BDT cut** optimized before unblinding

For all 8 detectors in BDT selected cut window:

mχ	N_bkgd expected	N_bkgd observed	p-value (stat only)
5 GeV	6.14	9	0.17
20 GeV	1.35	4	0.10

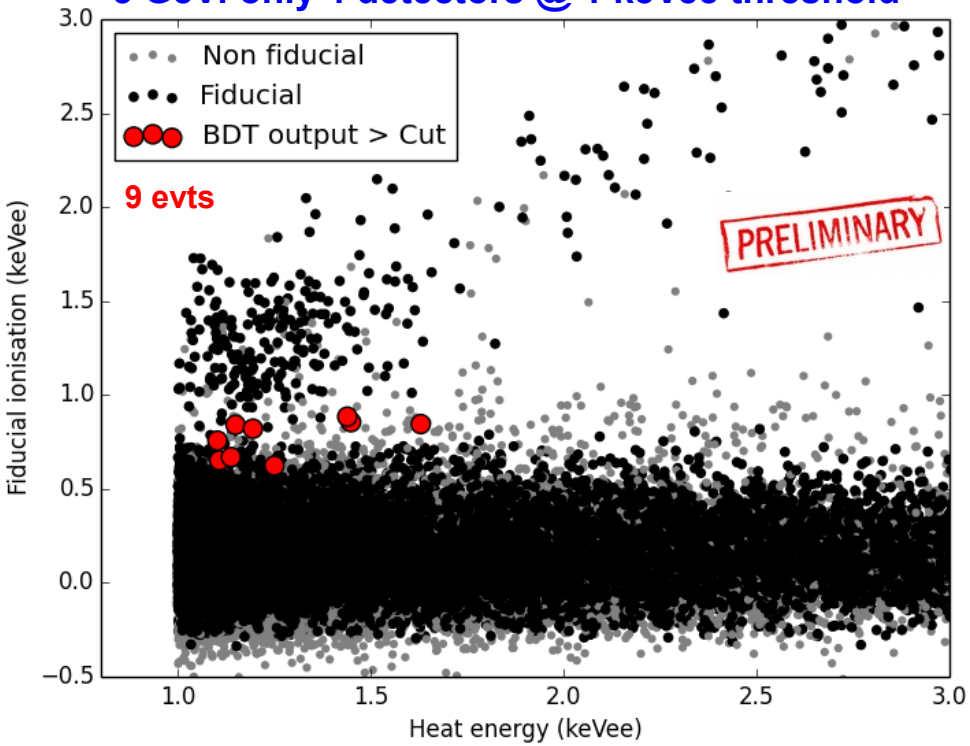
Dominant backgrounds:

- low WIMP mass:
  heat-only events & (cosmogenic) gammas
- high WIMP mass:
  radiogenic neutrons
  (preliminary systematic ~45%)

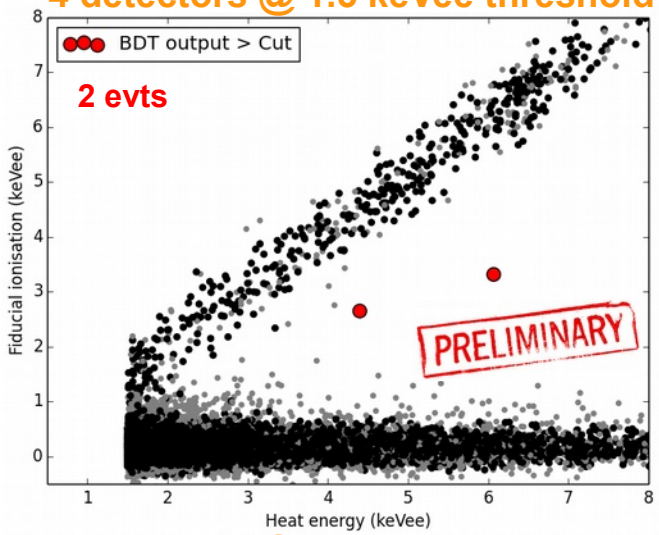
Observed candidate events after BDT cut

$m\chi$	N_bkgd expected	N_bkgd observed	p-value (stat only)
5 GeV	6.14	9	0.17
20 GeV	1.35	4	0.10

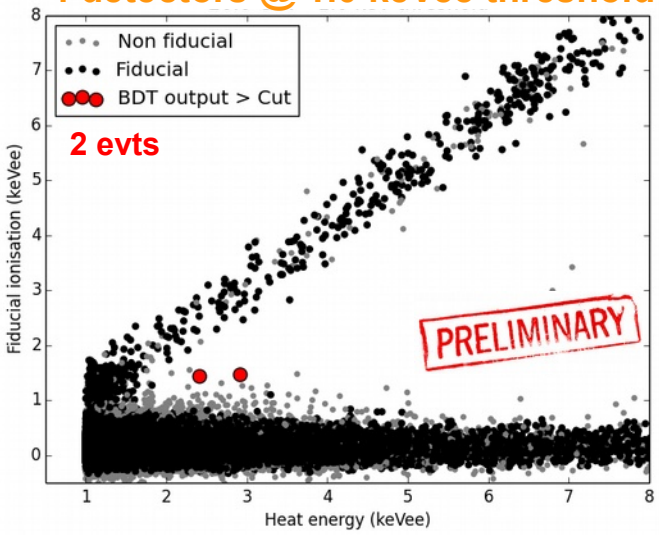
5 GeV: only 4 detectors @ 1 keVee threshold



20 GeV:
4 detectors @ 1.5 keVee threshold

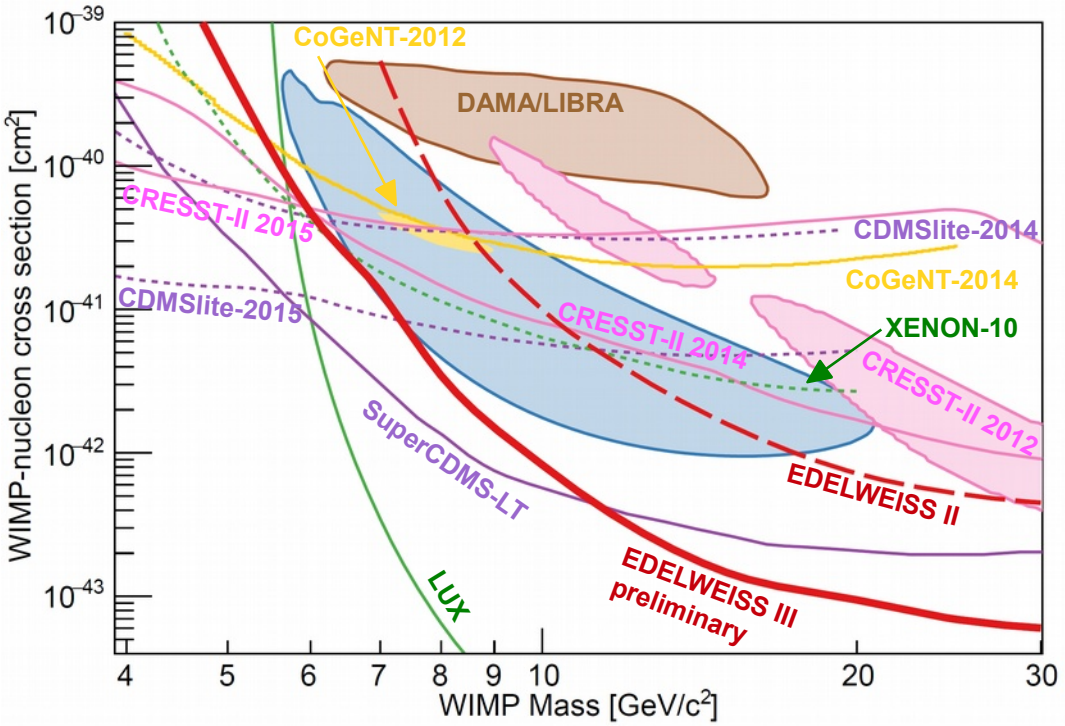


4 detectors @ 1.0 keVee threshold



Low mass WIMP limits and outlook

- Poisson limits **w/o** background subtraction
- *preliminary* 90% C.L. exclusion limit for spin-independent WIMP-nucleon scattering:
  4.6 x 10^{-40} cm² @ 5 GeV
  6.2 x 10^{-44} cm² @ 30 GeV
  → **factor 40 improvement @ 7 GeV & new data down to 4 GeV**
- cross checks with 2d profile likelihood analysis ongoing and in good agreement
- post-unblinding checks ongoing
- *"high energy analysis"* coming soon



Current run:

- DAQ resumed in June 2015
- 23 FID800 installed (12 new)
- 1 FID200 for "High-Voltage" R&D (Neganov-Luke amplification)

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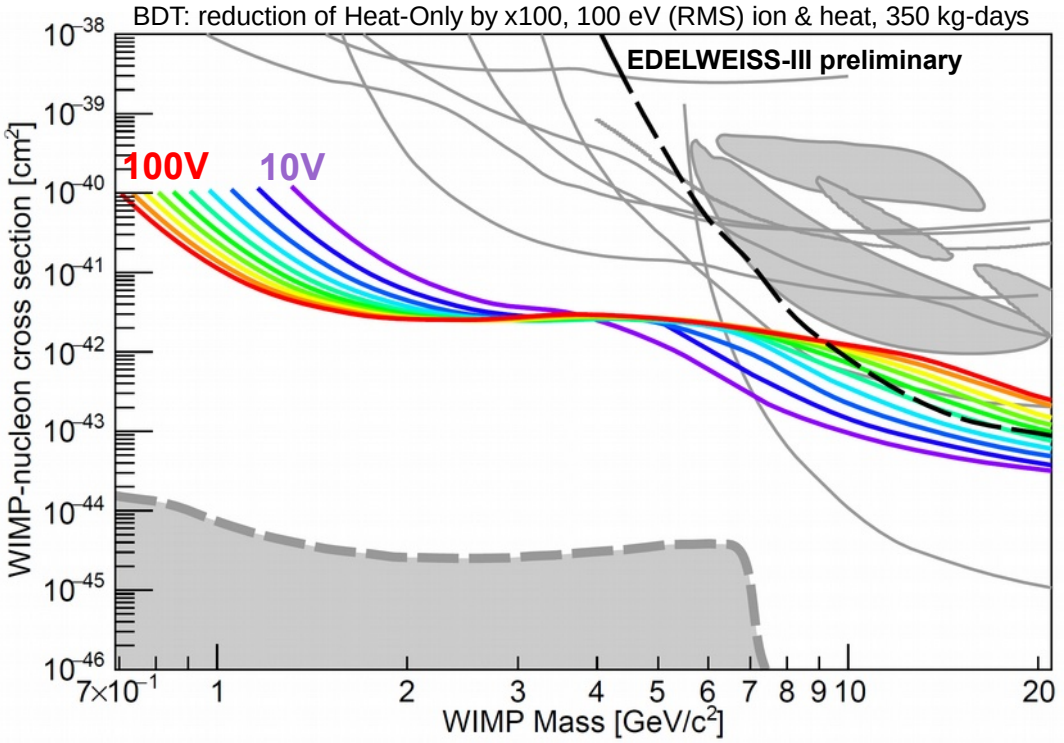

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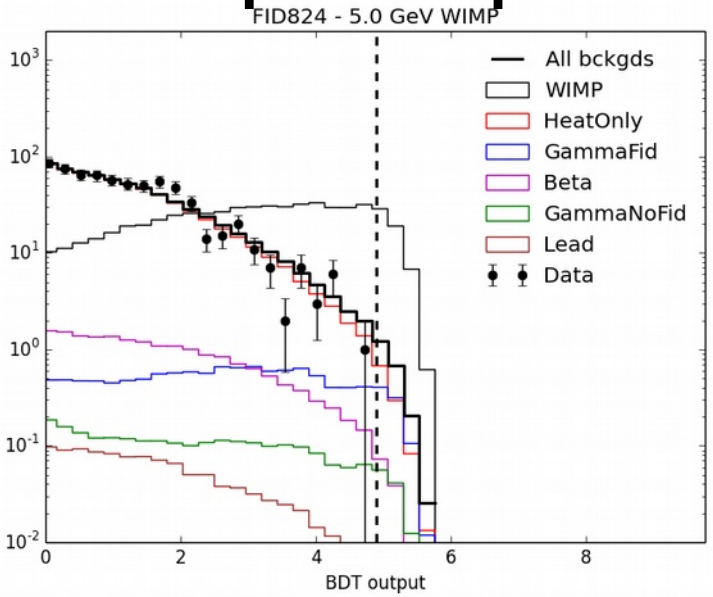
R&D on HEMT
to lower ionization threshold down to σ_{ion} = 100 eV

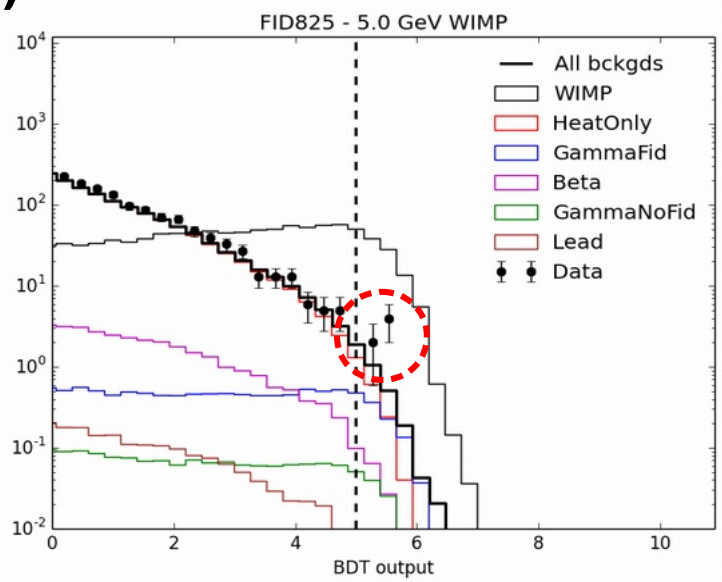
R&D on heat sensors and HV (Luke-Neganov)
goal σ_{heat} = 100 eV and reduce recoil threshold

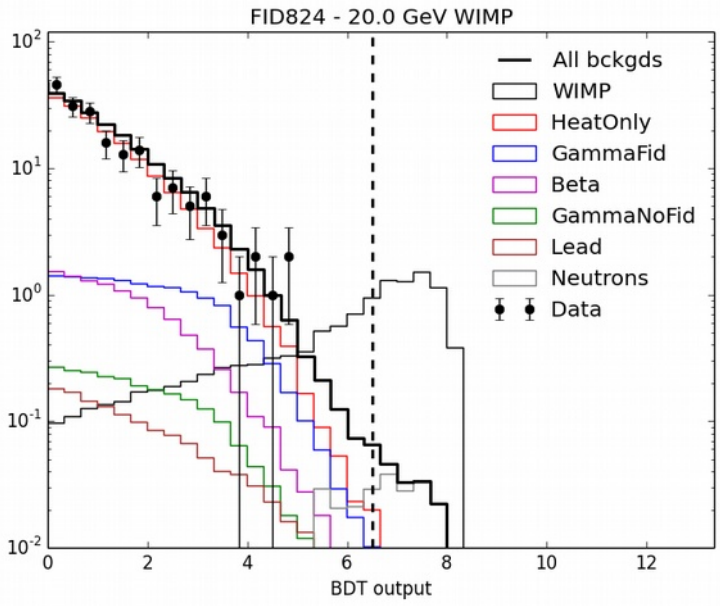
R&D to reduce heat-only events

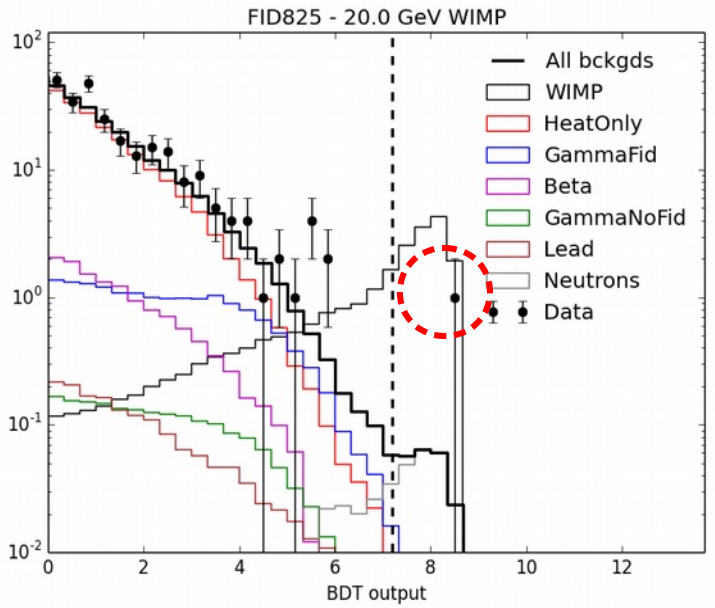
backup slides

BDT output comparison (1)

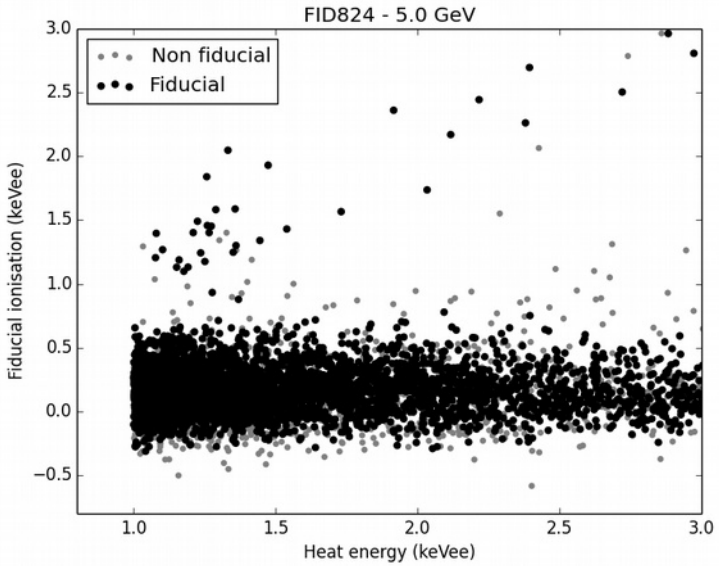


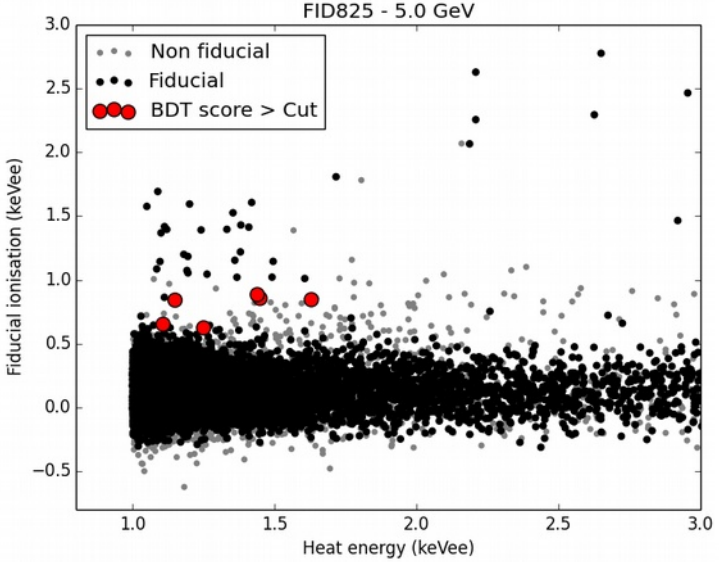


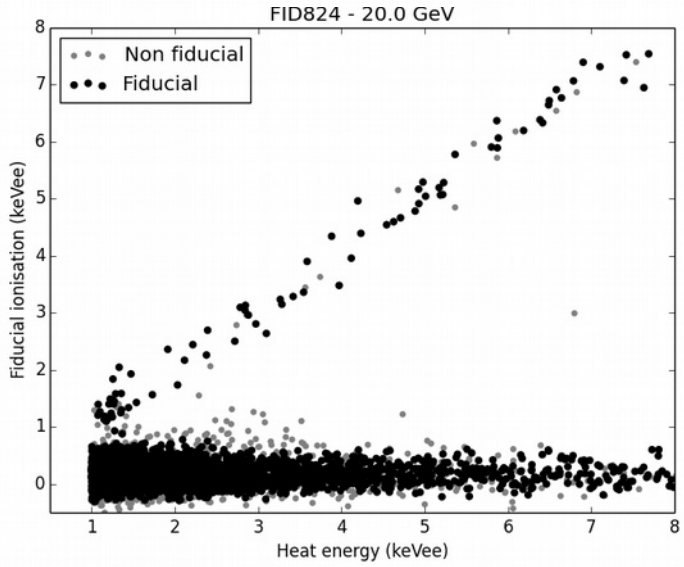


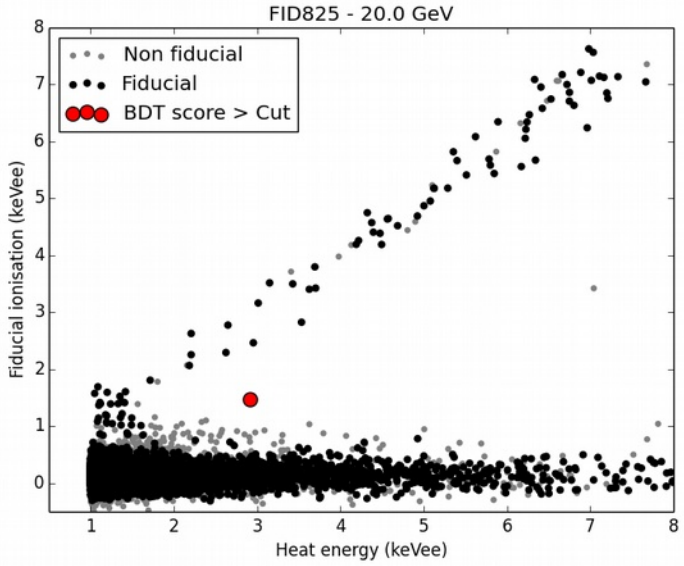


BDT output comparison (2)

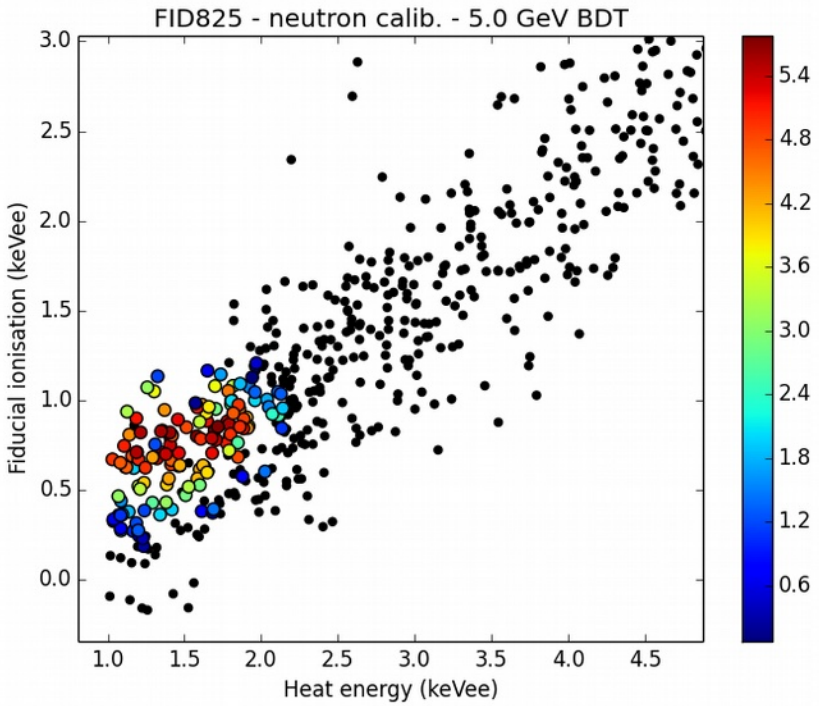


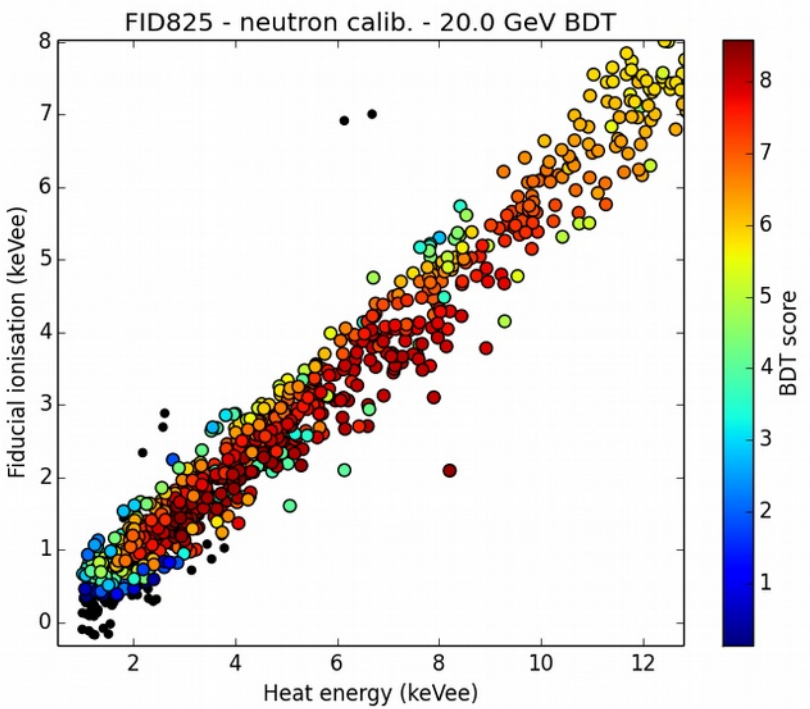






AmBe Neutron calibration and BDT output

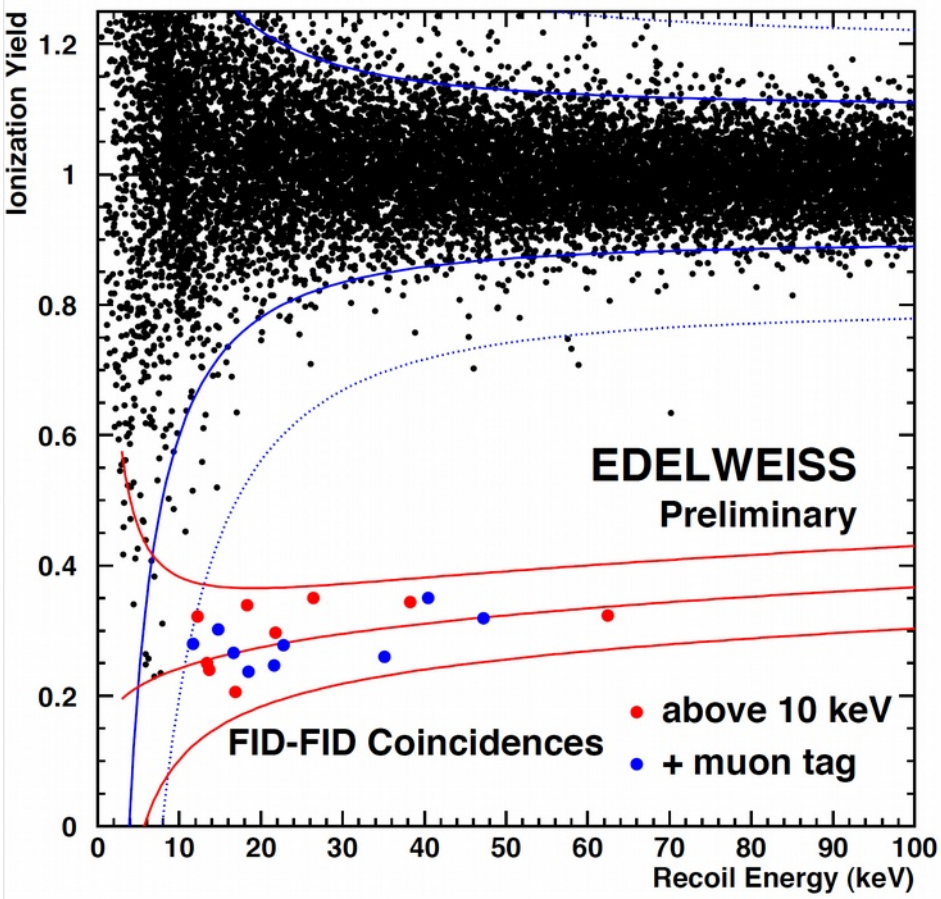




Low WIMP mass:
neutrons are a negligible background. Events passing the BDT cut are below 2keVee heat energy and we would expect radiogenic neutrons at higher energy

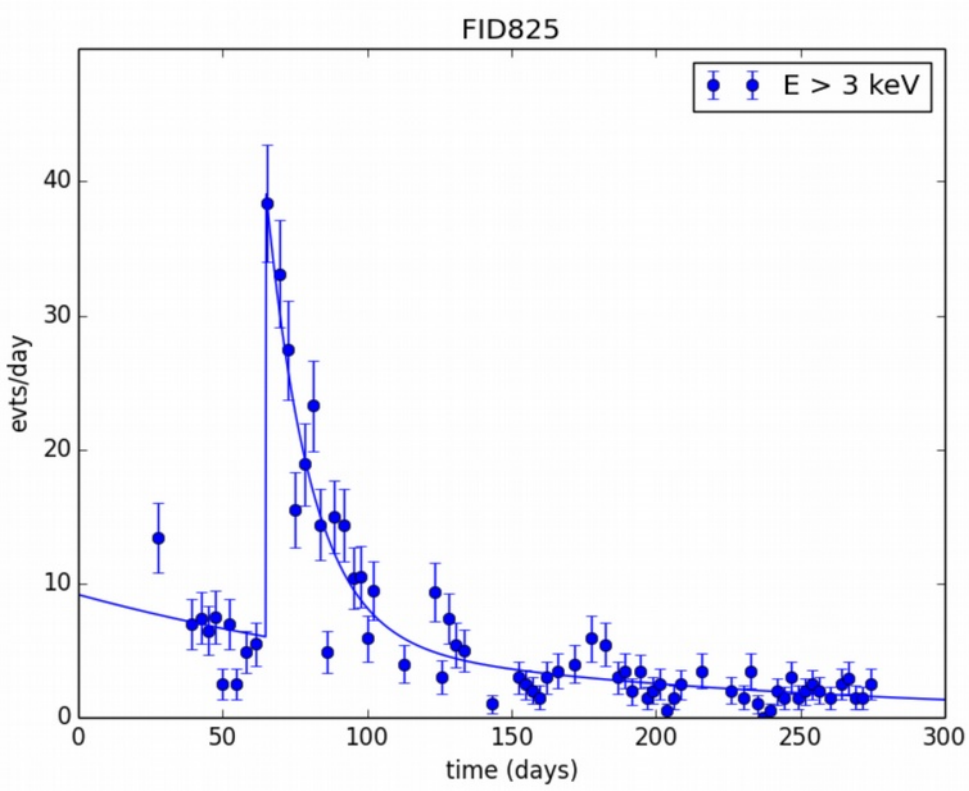
High WIMP mass:
BDT cut at ~7, dark red events are passing the cut.

Neutrons

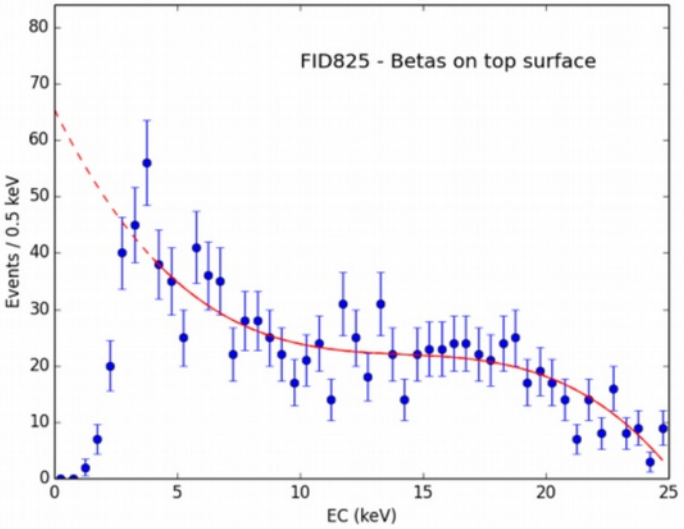


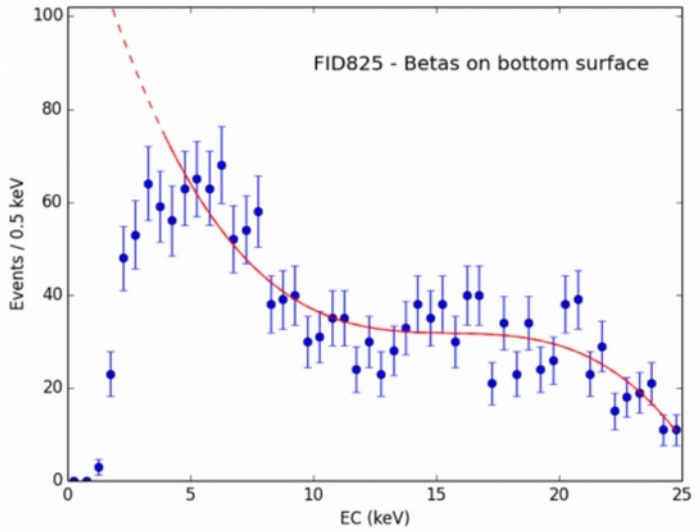
- During the WIMP search, we see 9 multiple nuclear recoil events (excluded from the search data set) after muon cut, in 17 detectors in 1300 kg.days
- This has been used as normalization factor in simulation, BDT training and BDT cut optimization along with the single-to-multiple ratio
- Single-to-multiple ratio from radiogenic neutron simulations varies between FIDs. An average has been considered
- Systematics : sqrt(9) + large variation is single-to-multiple ratio

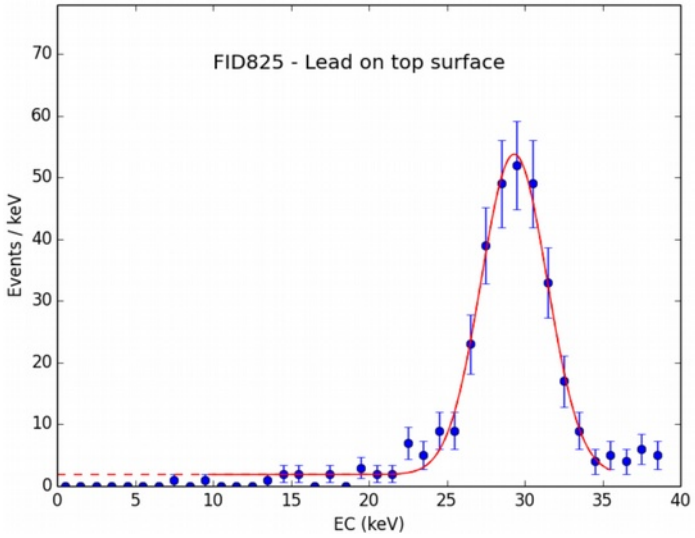
Heat-only time dependance

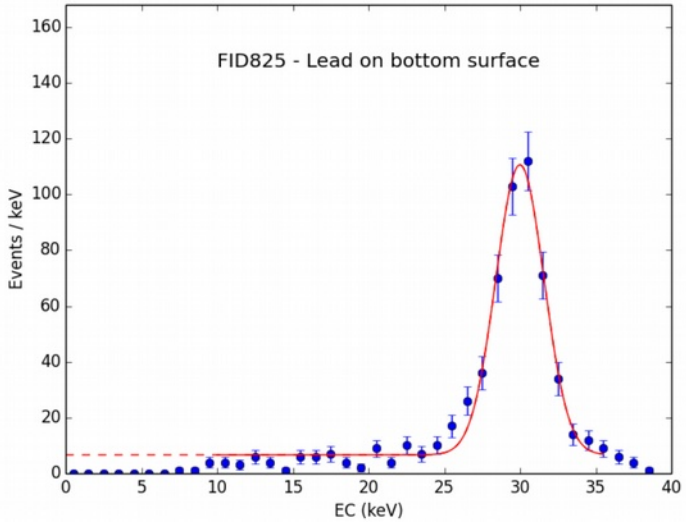


Beta and Lead models



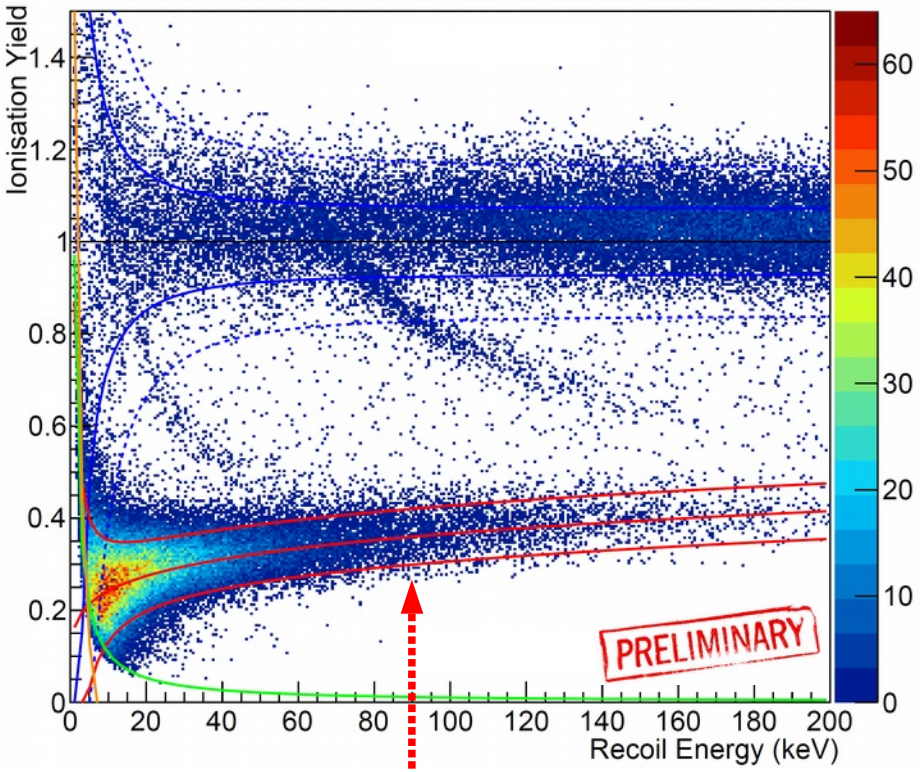




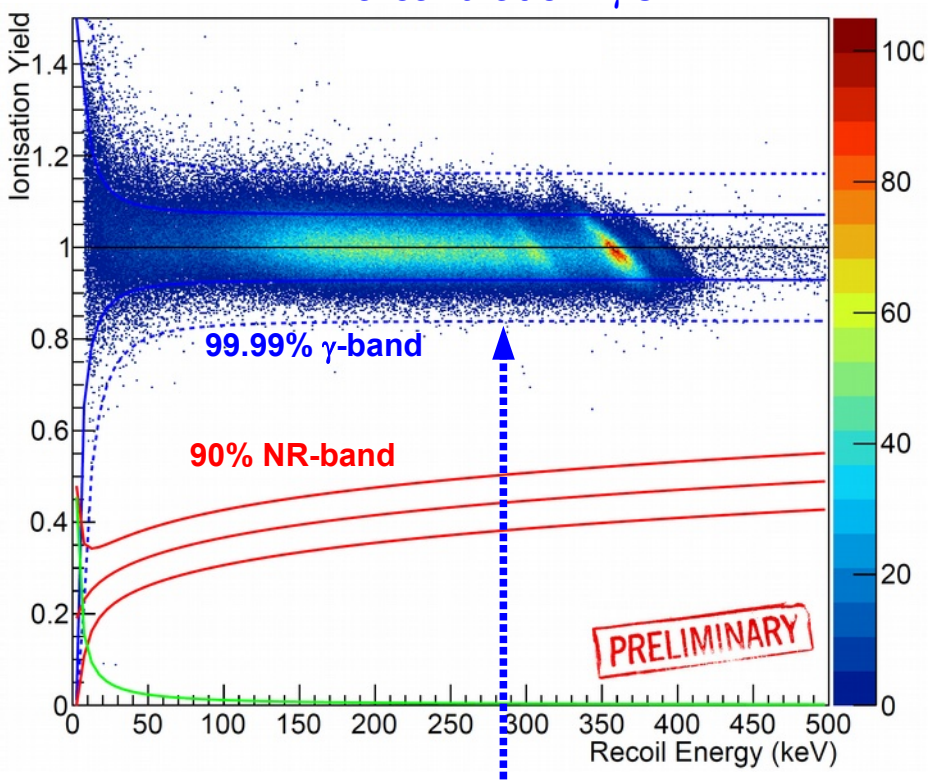


Neutron and γ calibration of FID800 detectors

AmBe calibration: n + 60% γ's



^{133}Ba calibration: γ's



Nuclear Recoils
Q ≈ 1/3
("quenching")

Ionization yield
$Q = E_{ion} / E_{recoil}$

Electron Recoils
Q = 1
(by normalization)