Cosmogenic Activation of Germanium Detectors in EDELWEISS III

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Background

Rare search event experiment: small expected rate and radioactive background of most of the material gives higher rate

Very low background environment is needed

Background sources:

- Cosmic rays -> deep underground sites and muon veto
- Natural radioactivity (^{238}U, ^{232}Th, ^{40}K) γ, e^-, β, n, α -> passive/active shielding
- Intrinsic sources (^{222}Rn, long and medium-lived cosmogenic products of target material)
- Ultimately: neutrino-nucleus scattering (solar, atmospheric and supernovae neutrinos)

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It can not be removed once detector is contaminated

Activation at Sea-Level

Decay rate of a radioactive isotope depends on the time of material exposure to the source of radiation (t_{exp}) and on the time the isotopes were allowed to decay without being exposed to cosmic rays (t_{dec}).

$$\underbrace{\frac{dN}{dt}}_{\text{decay rate}} = P \times \underbrace{(1 - e^{\frac{-t_{exp}}{\tau}}) \cdot (e^{\frac{-t_{dec}}{\tau}})}_{\text{saturation fraction}}$$

Production rate P of induced isotopes:

$$P_i = \sum_j N_j \int \phi(E)\sigma_{ij}(E)dE$$

E = energy

σ = production cross section

ϕ = cosmic neutron flux

N_j = number of target nuclear isotope j

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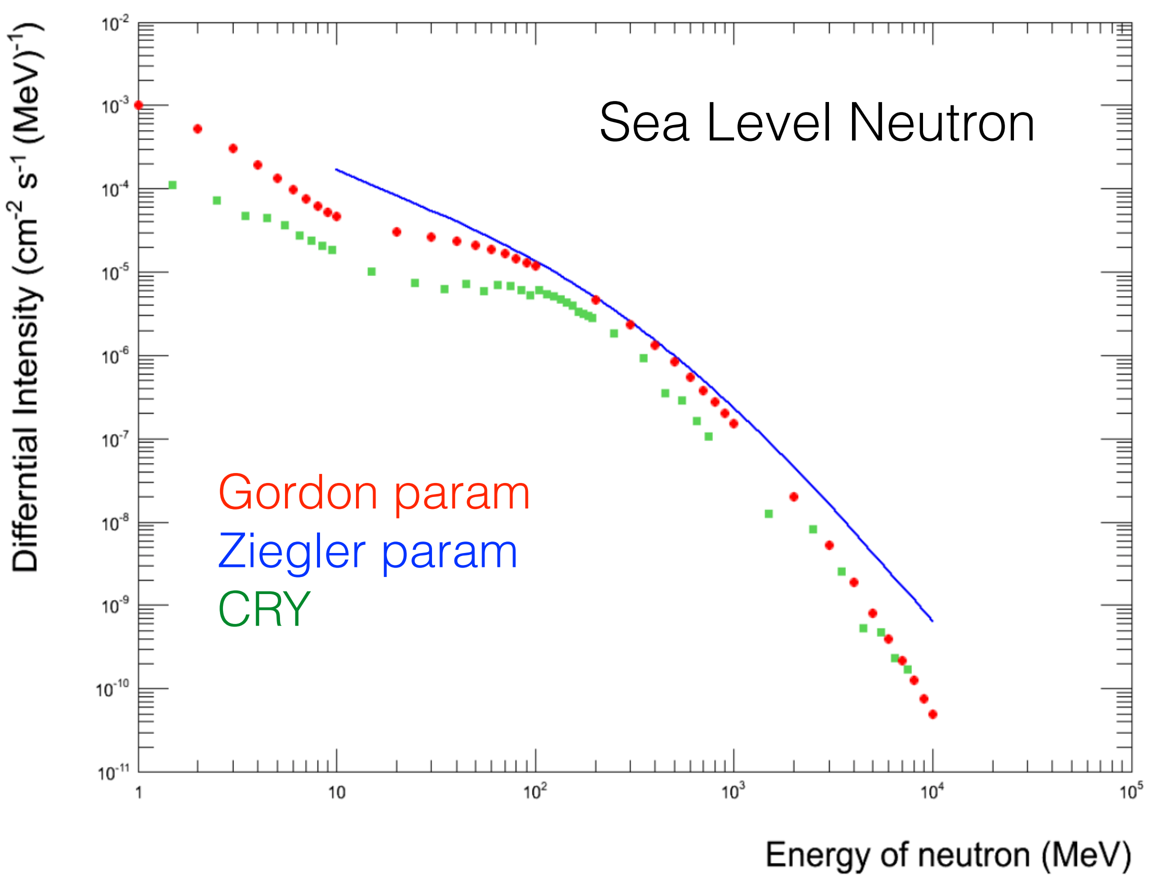

$$P_i = \sum_j N_j \int \phi(E) \sigma_{ij}(E) dE$$

Different input cosmic-ray neutron spectra, can lead to a variation in production rates of about **20-30%**

via Scorza

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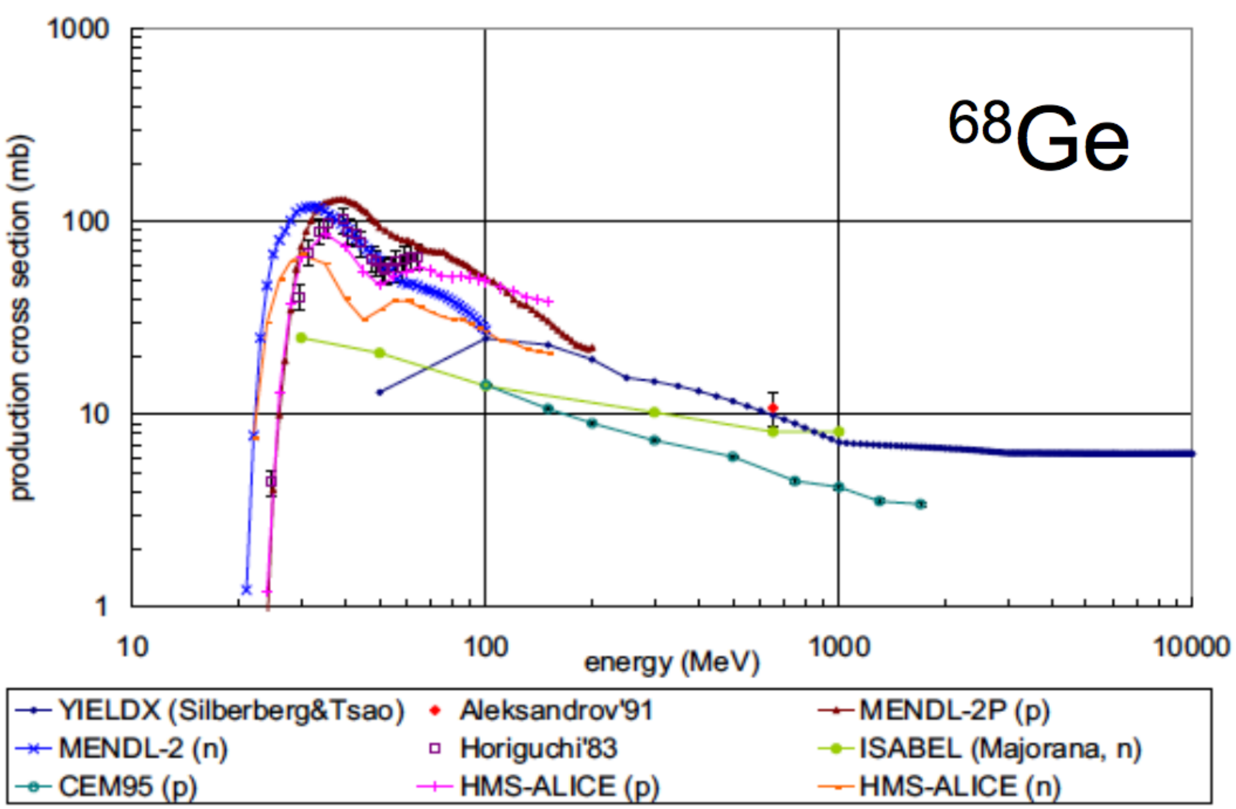

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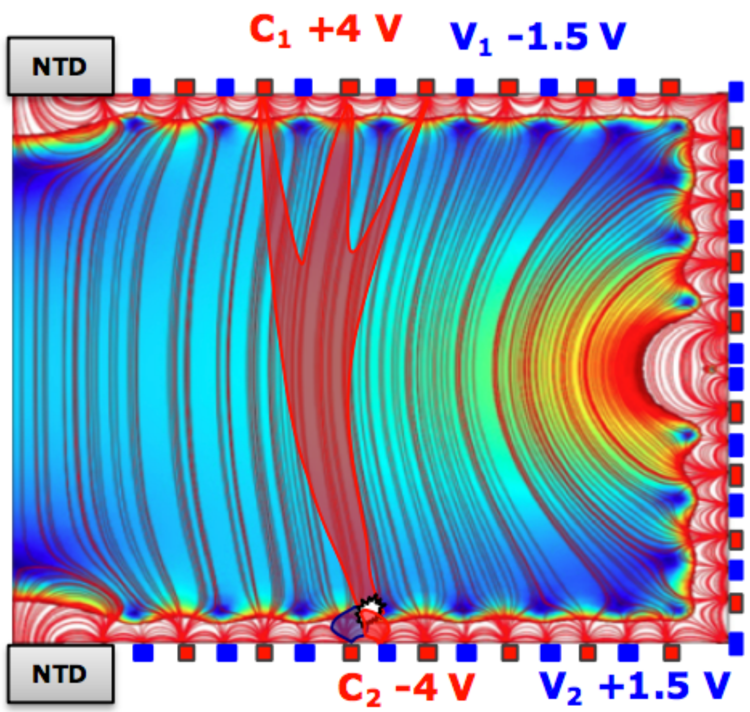
Excitation functions may account for up to a factor of 2 difference in the production rate of ^{68}Ge. The difference increases with the atomic number of the isotope produced.

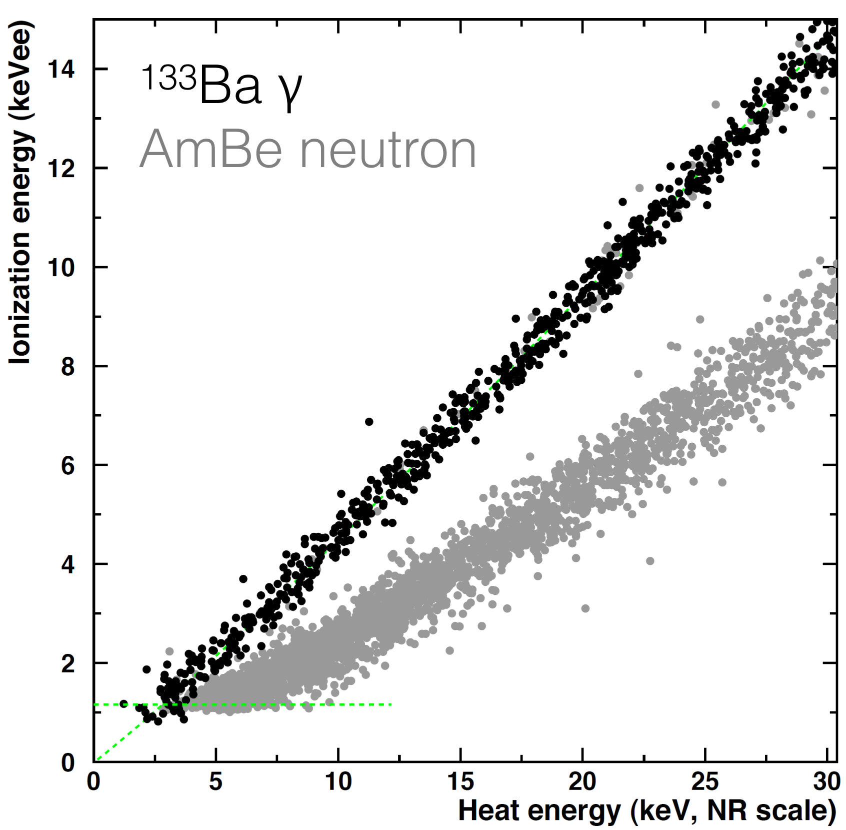
R308 Analysis



FID Ge crystals: event ID from measurements of ionization and phonon energies

- 280 days July14 -April15: 160 days WS data
- 24 FIDs for coincidence study
- 19/24 FIDs selected with > 2 days
  (13 detectors in production rate interpretation)
- Exposure of 1853 det·days
- Hourly online threshold <2 keV
- Ionization resolution <400eV

- Chi-2 selection - pulse template reconstruction
  - Efficiency loss <1%
- Fiducial selection
  - Clean sample, no surface leakage



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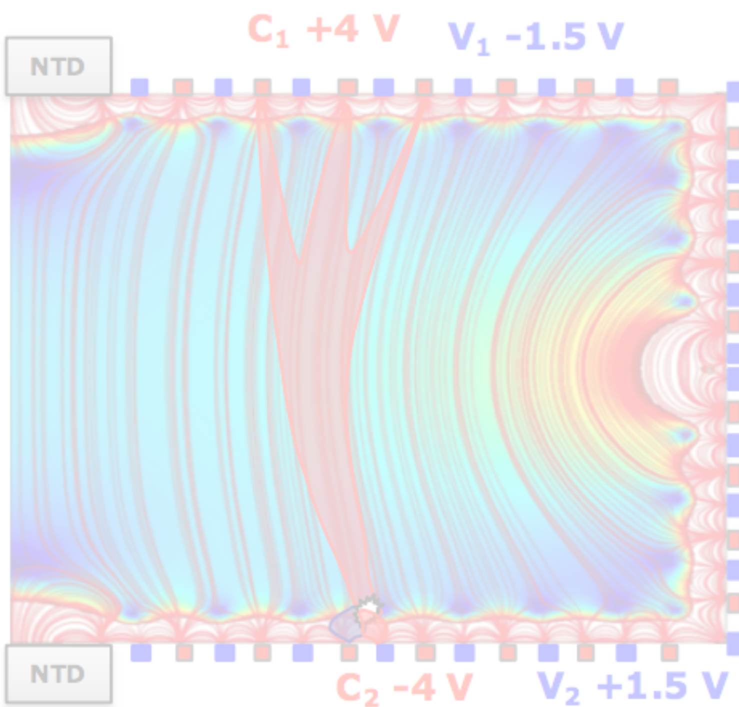

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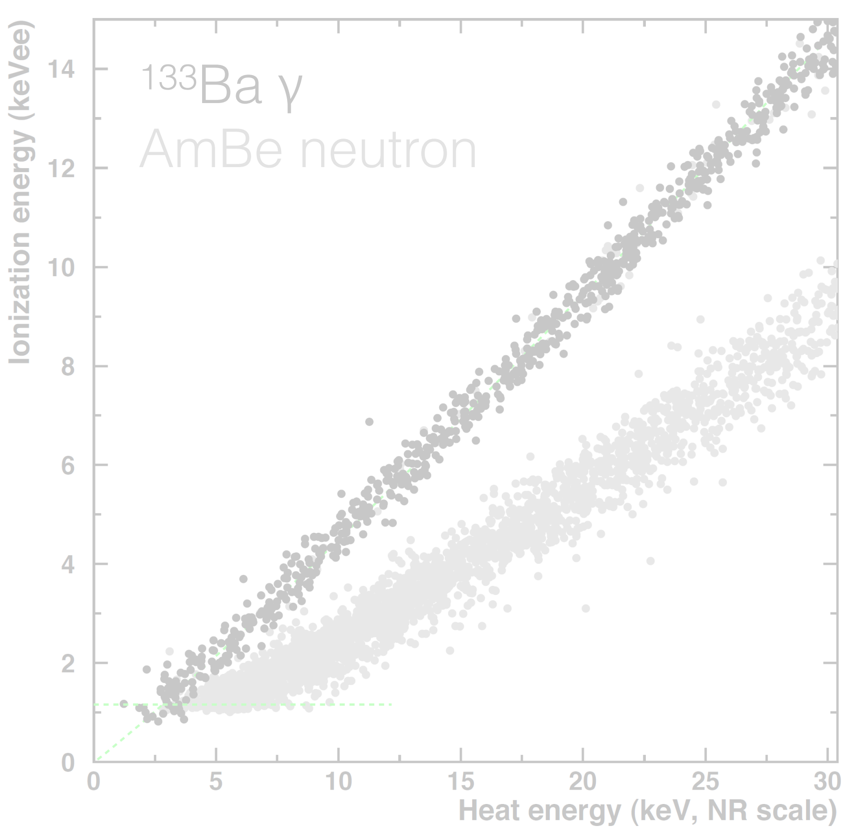

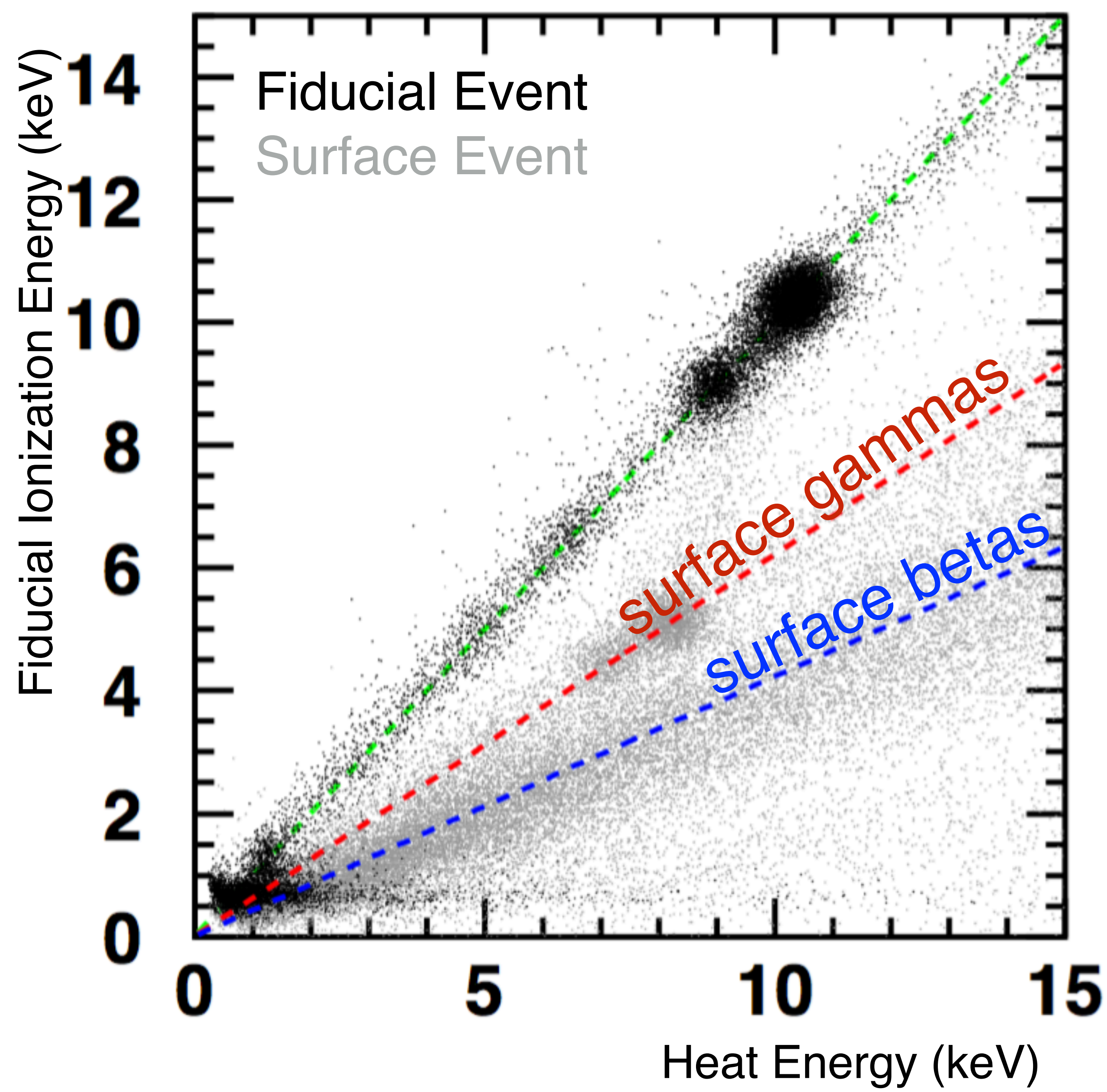

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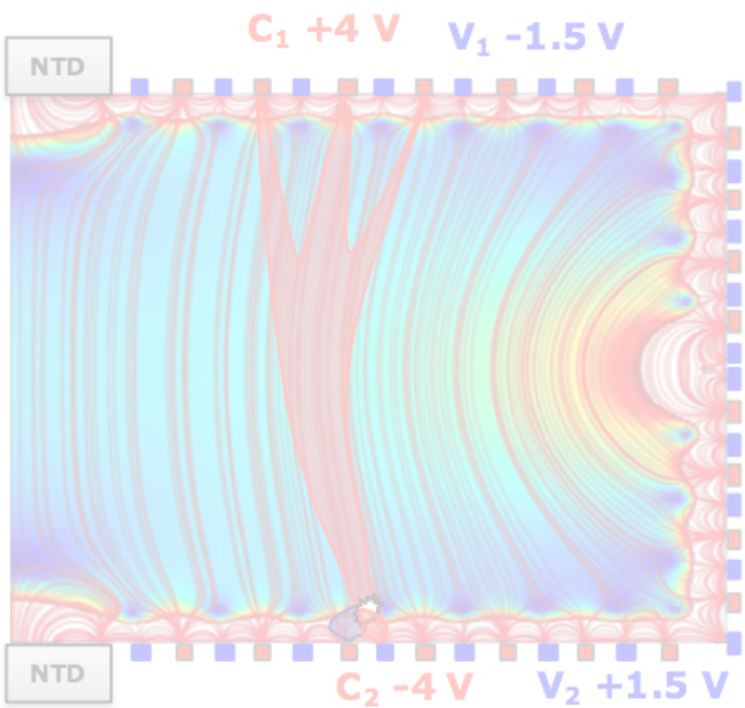

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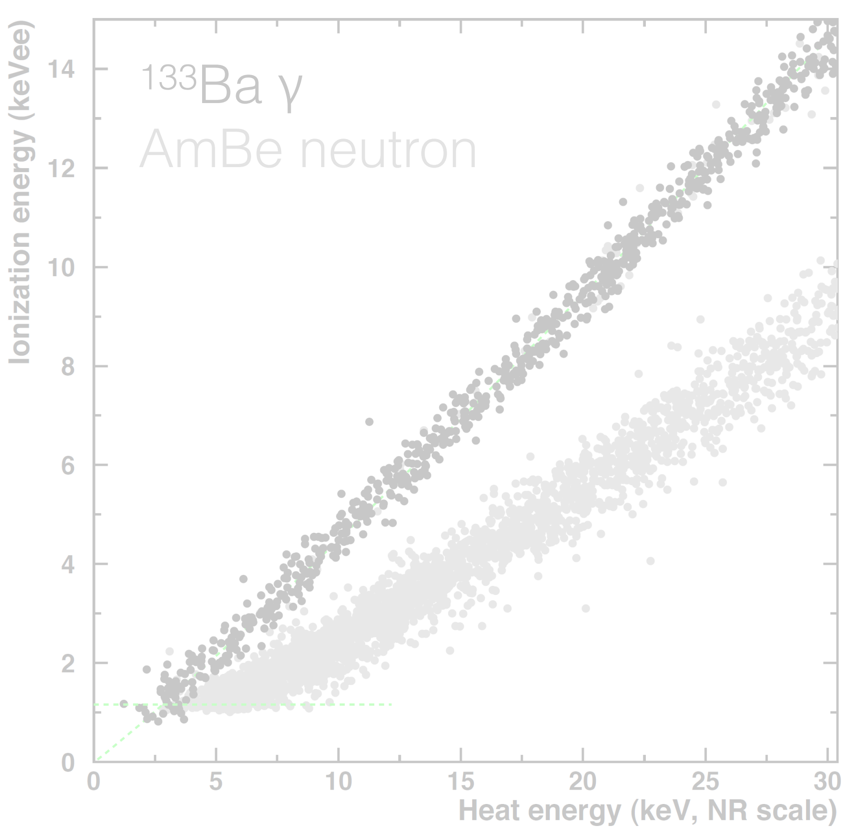
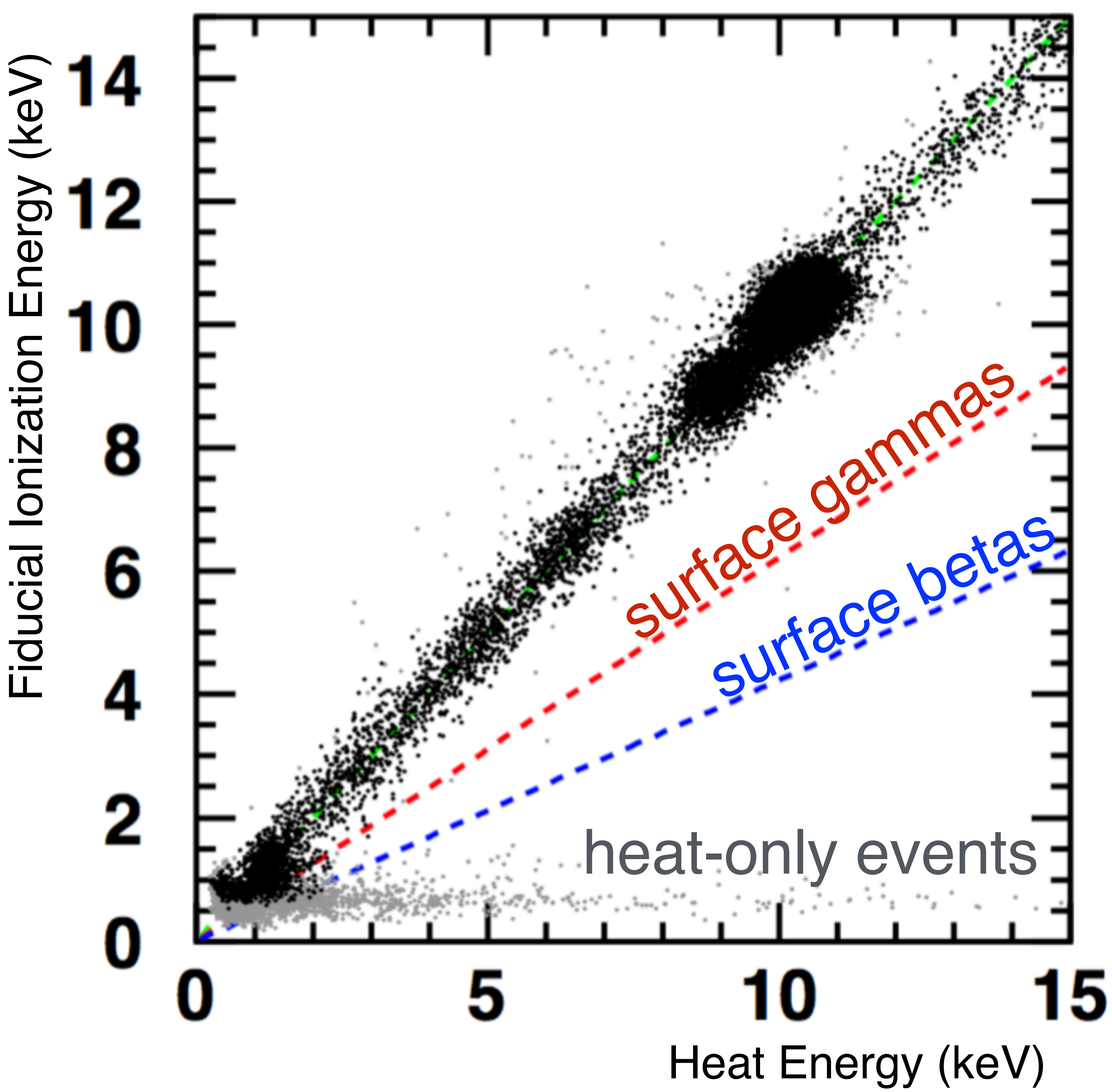
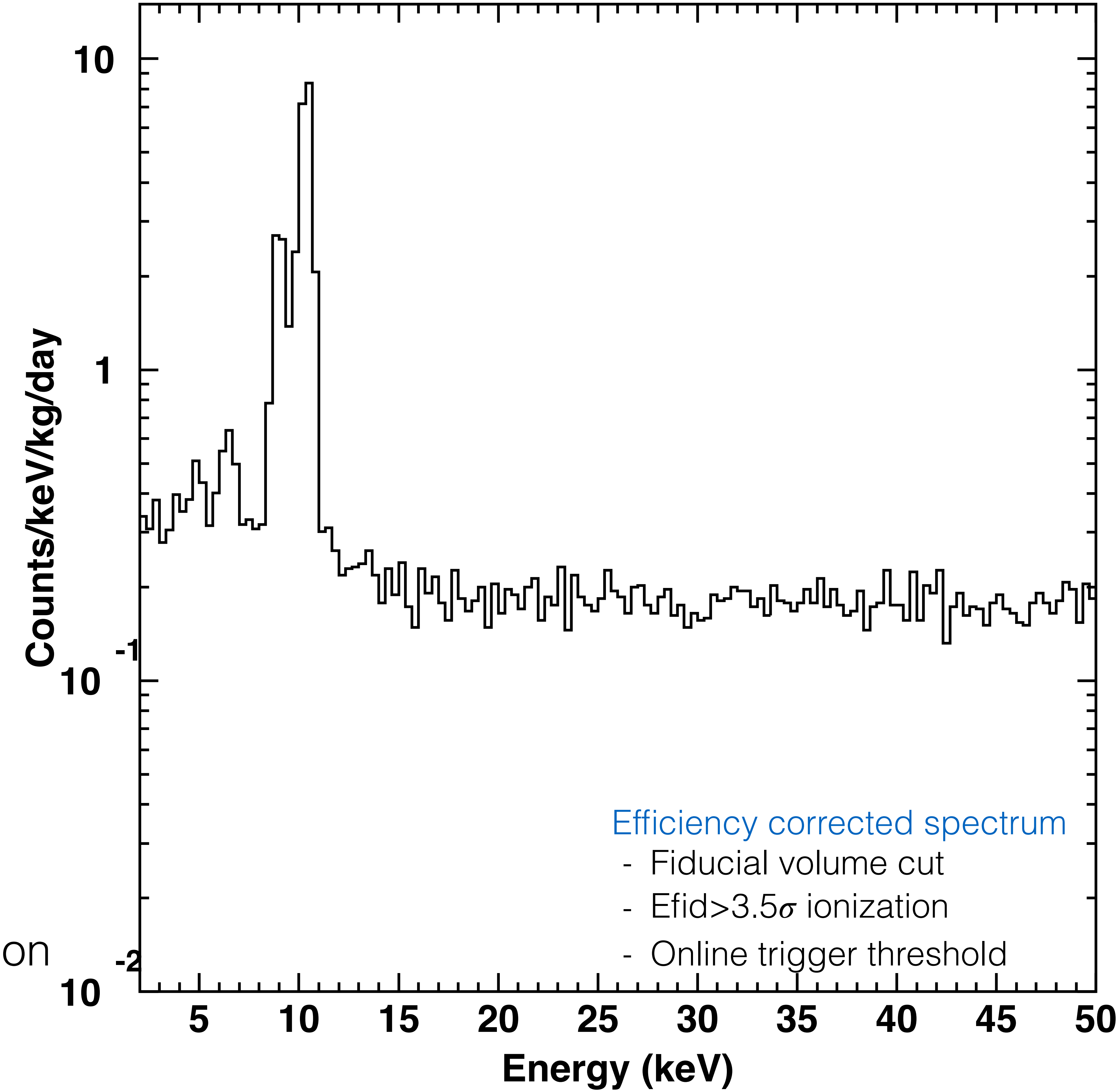


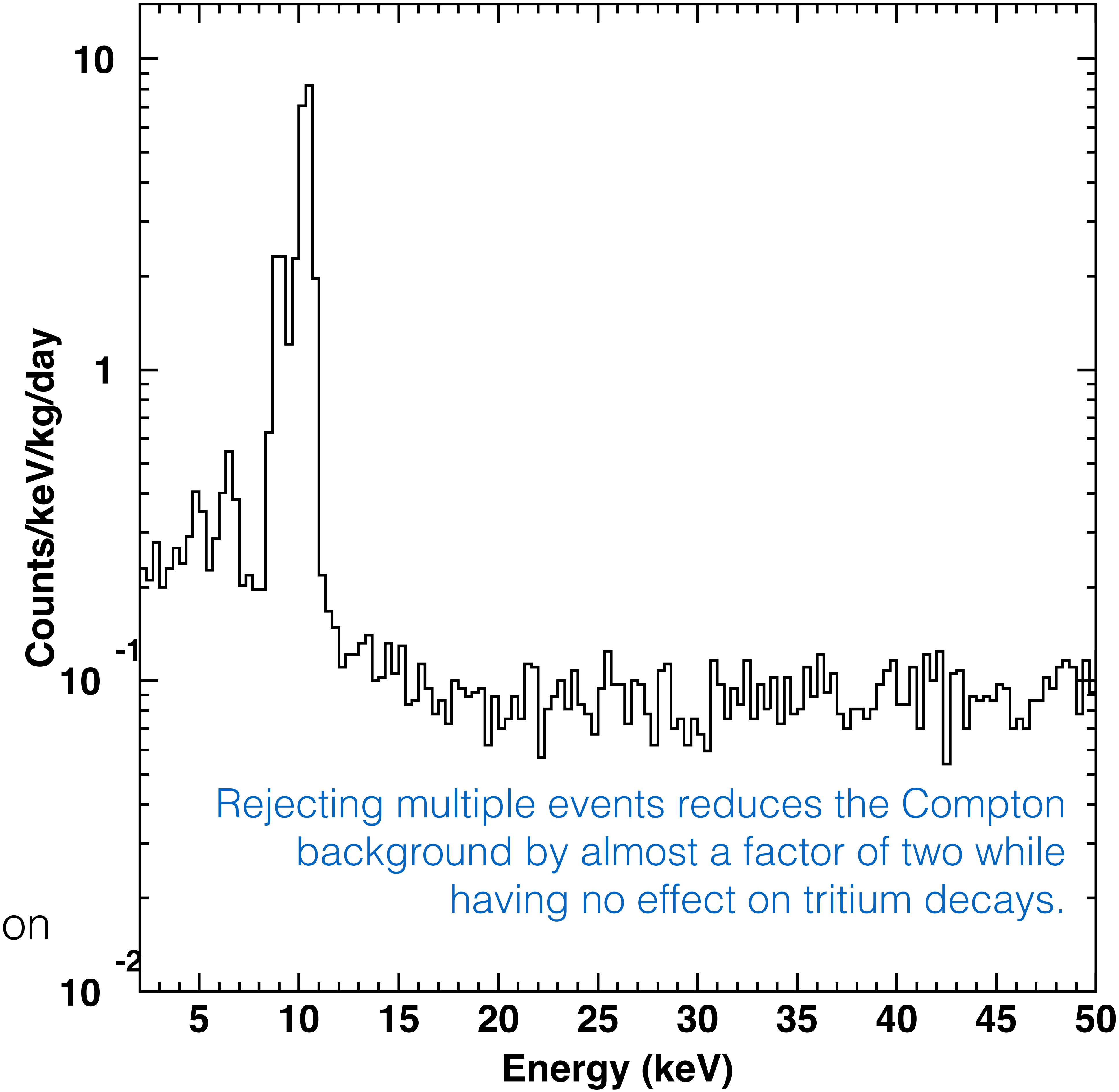




- Best energy estimator
- 19 detectors
- 1853 det.days
- ER fiducial selection

Efficiency corrected spectrum

- Fiducial volume cut
- Efid>3.5σ ionization
- Online trigger threshold



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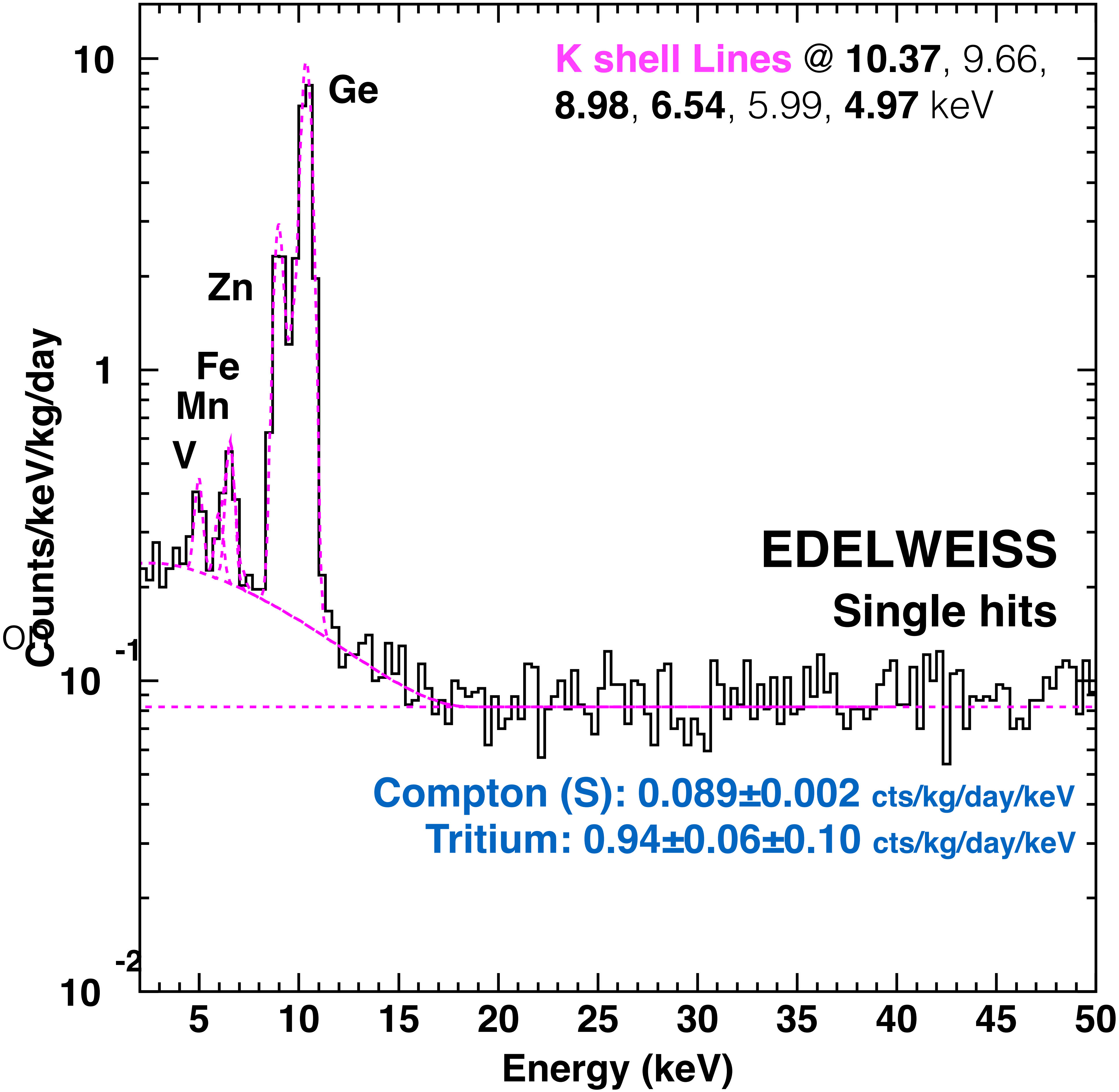
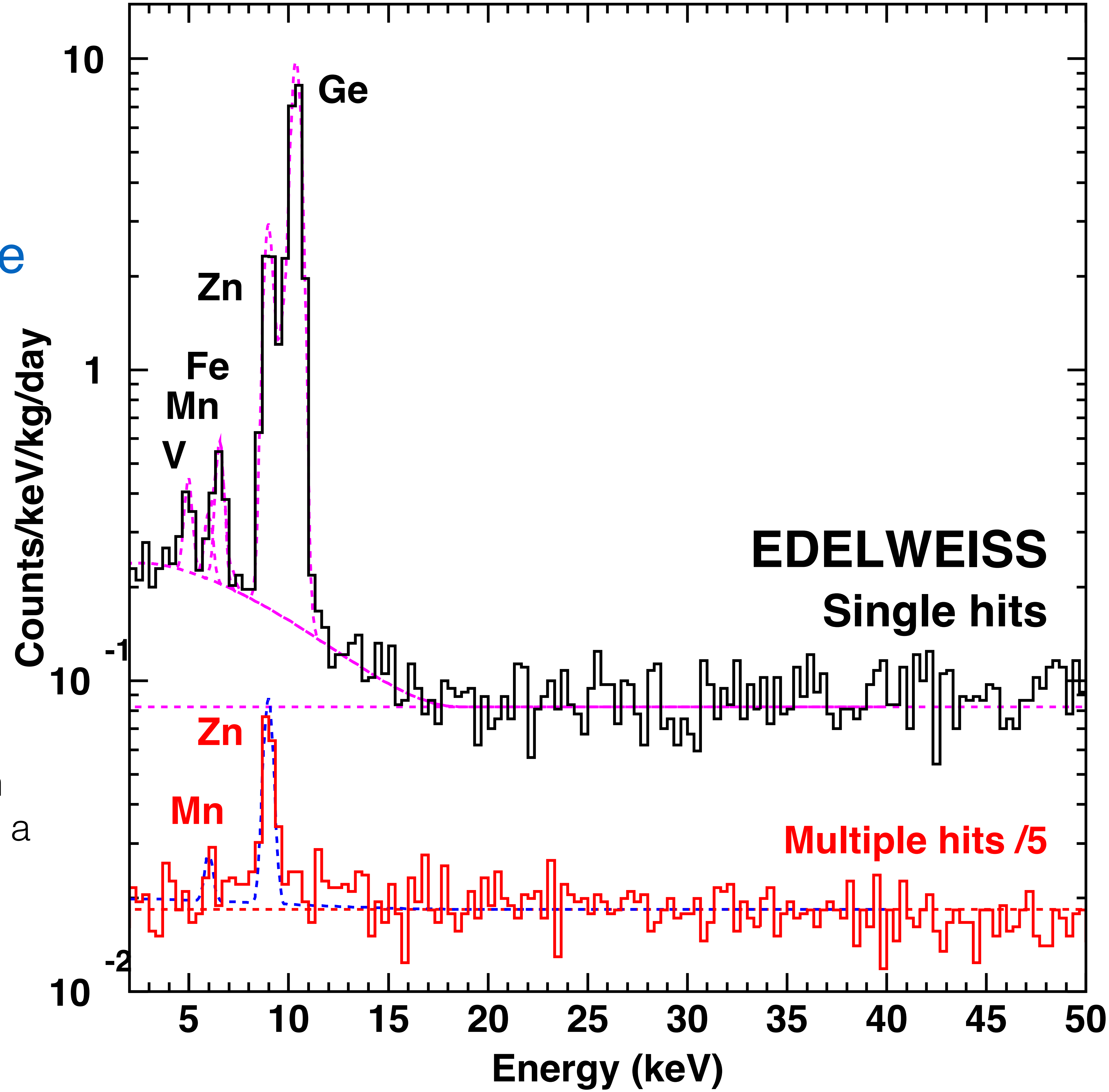
- + Tritium β-decay (Q_β =18.6 keV) + EC decay of isotopes + Compton background



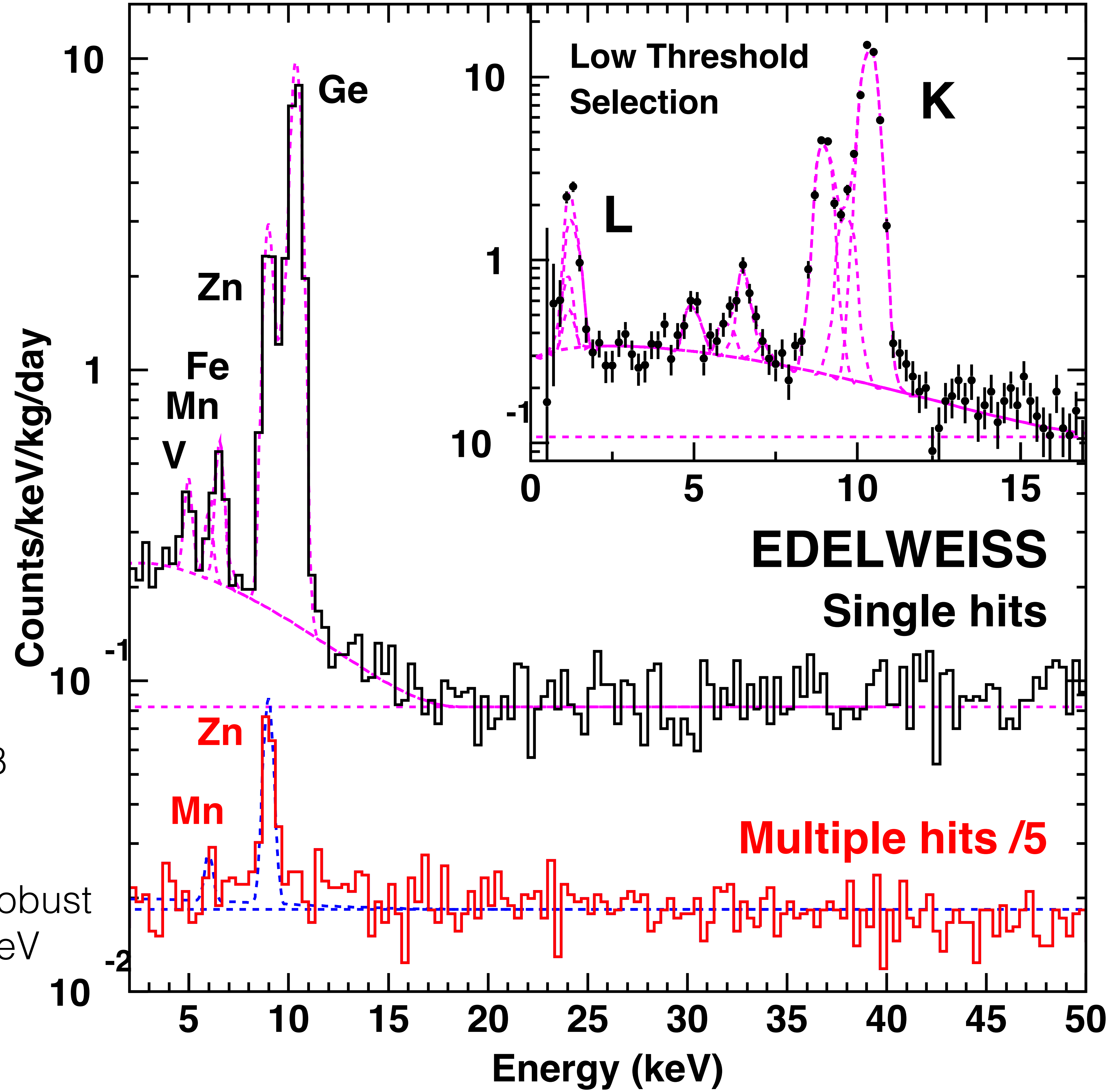
Single/Coincidence @ 2 keV:

Understanding of global Compton behavior

The multiple-hit spectrum is compatible with the expectation that only the ^{65}Zn and, possibly, ^{54}Mn peaks, are contributing to a flat Compton background below 20 keV.



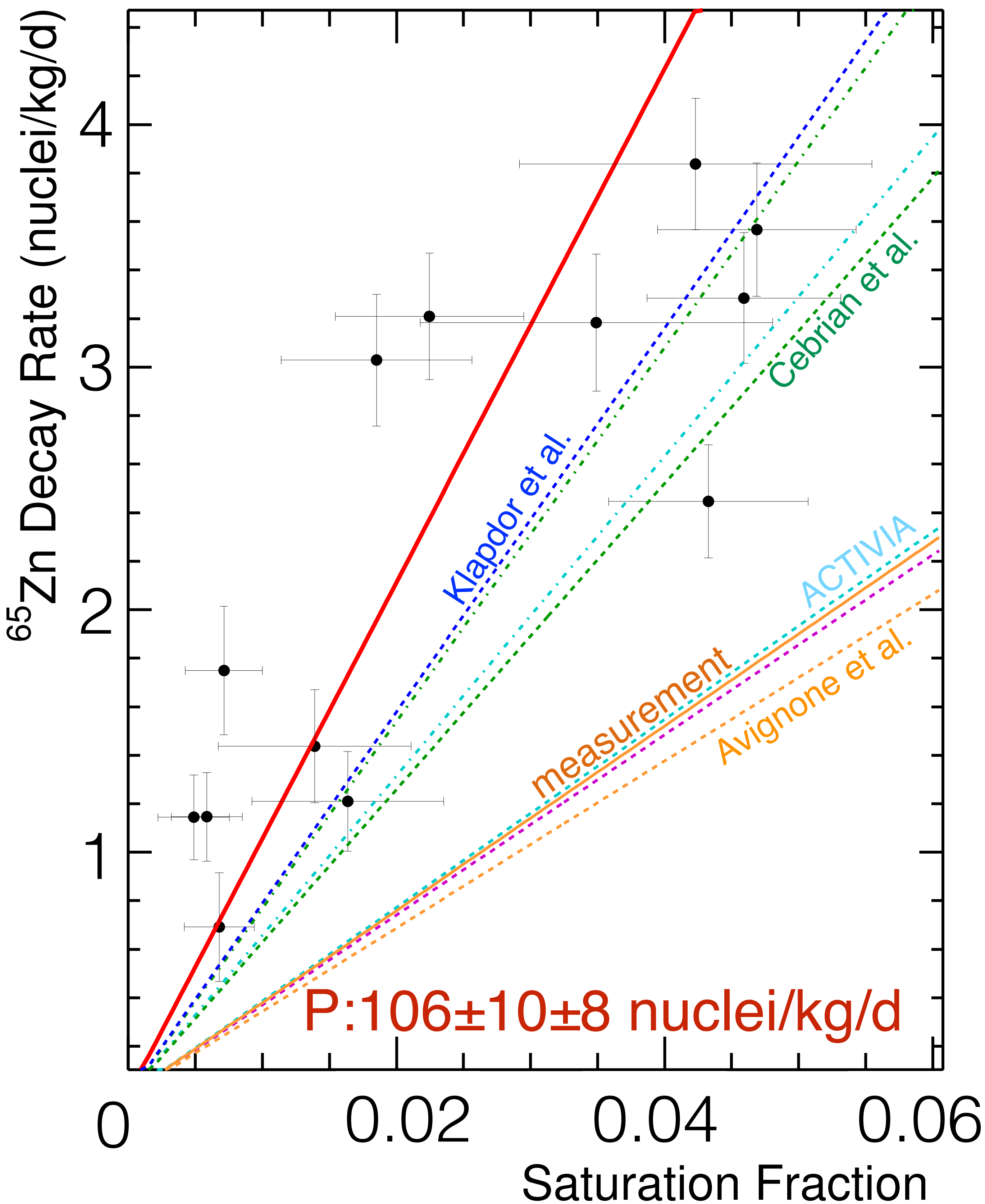
@ 0.8 keV:
Understanding of
- low-energy structure down to 1 keV
- efficiency model



L/K ratio = 0.113 ± 0.008 (statistical error only)

The efficiency model is robust for energies above 2.0 keV

^{65}Zinc

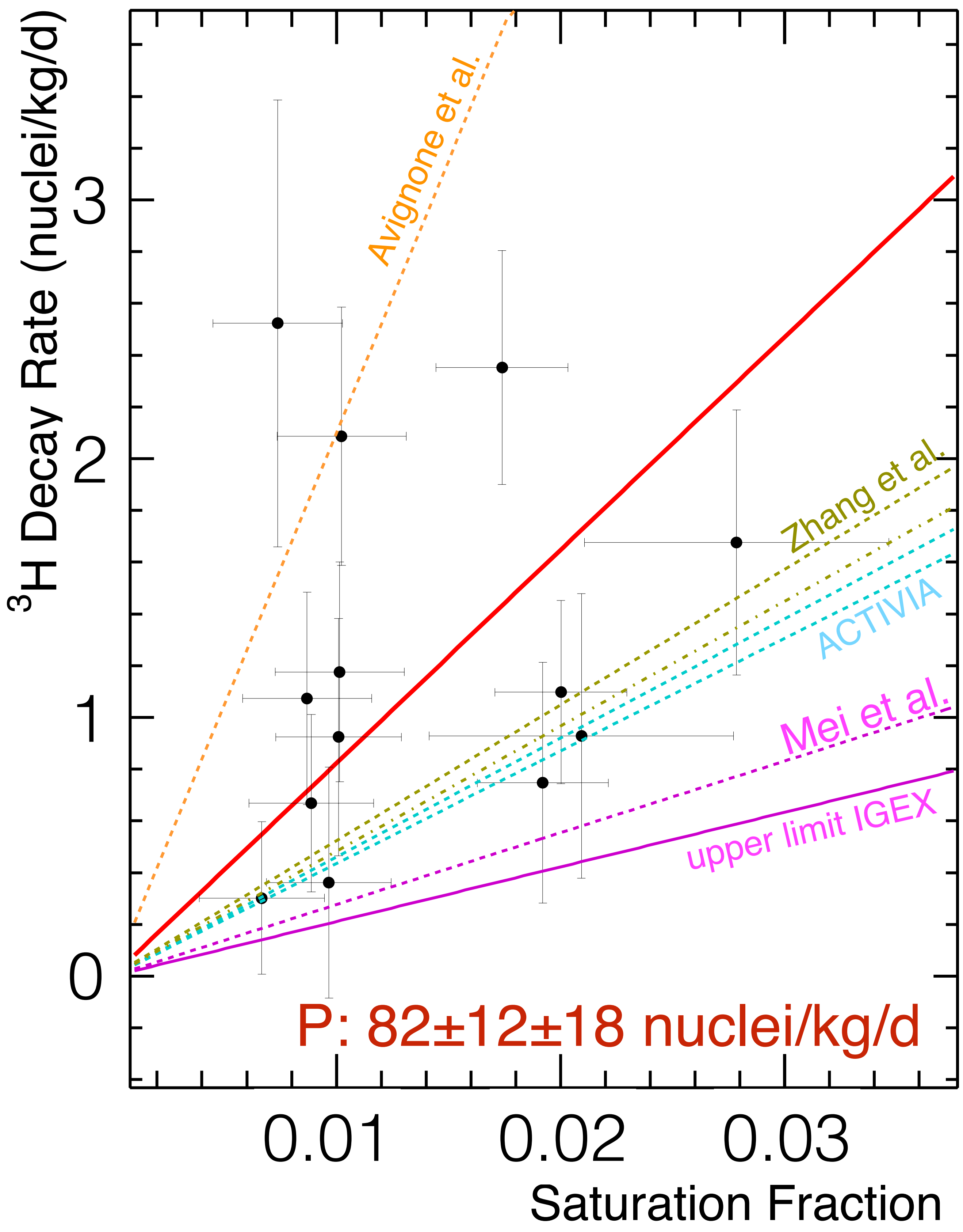


Good correlation history vs decay rate

Strong tension @5.9σ (stat) with previous measurement Avignone et al.
Agreement < 2σ with ACTIVIA calculation

Model estimates from P=34.4 to P=79 nuclei/kg/day

Tritium



Relative error bars of the decay rate are more important

IGEX upper limit in tension with any estimates

Agreement $< 2\sigma$ with ACTIVIA calculations

Model estimates difference up to one order of magnitude

Summary

	This work		Cebrian		Barabanov	Mei	Zhang	Klapdor	Avignone	
	Exp.	Calc.	(Ziegler)	(Gordon)						Exp.
^{3}H	82±21	46 (a) 43.5 (b)				27.7 <21 (E)	48.3 (I) 52.4 (II)		210	
^{49}V	2.8±0.6	1.9 (a,b)								
^{65}Zn	106±13	38.7 (a) 65.8 (b)	77	63		37.1		79	34.4	38±6
^{55}Fe	4.6±0.7	3.5 (a) 4.0 (b)	8.0	6.0		8.6		8.4		
^{68}Ge	>71	23.1 (a) 36.2 (a*) 45.0 (b) 97.6 (b*)	89	60	81.6	41.3		58.4	29.6	30±7

Astropart. Phys. 91 (2017) 51

(a) semi-empirical cross sections
(b) MENDL-2P database cross sections.

(I) GEANT4 calculations
(II) ACTIVIA calculations

(a*) and (b*) ACTIVIA calculations including a potential 10-h flight of Ge powder.

Conclusions

Cosmogenic activation of materials can compromise the sensitivity of ultra-low background experiments via the production of long-lived isotopes at Earth's surface due to nucleons.
Tritium contribution dangerous due to continuum beta decay shape and lifetime of 17.79year

First direct measurements of tritium and ^{49}V. ^{55}Fe and ^{65}Zn in germanium also presented. A lower limit of ^{68}Ge is discussed, too.

Tritium production rate in Ge of 82±21 nuclei/kg/d.
Minimize exposure to cosmic rays, better control of cosmogenic activation.

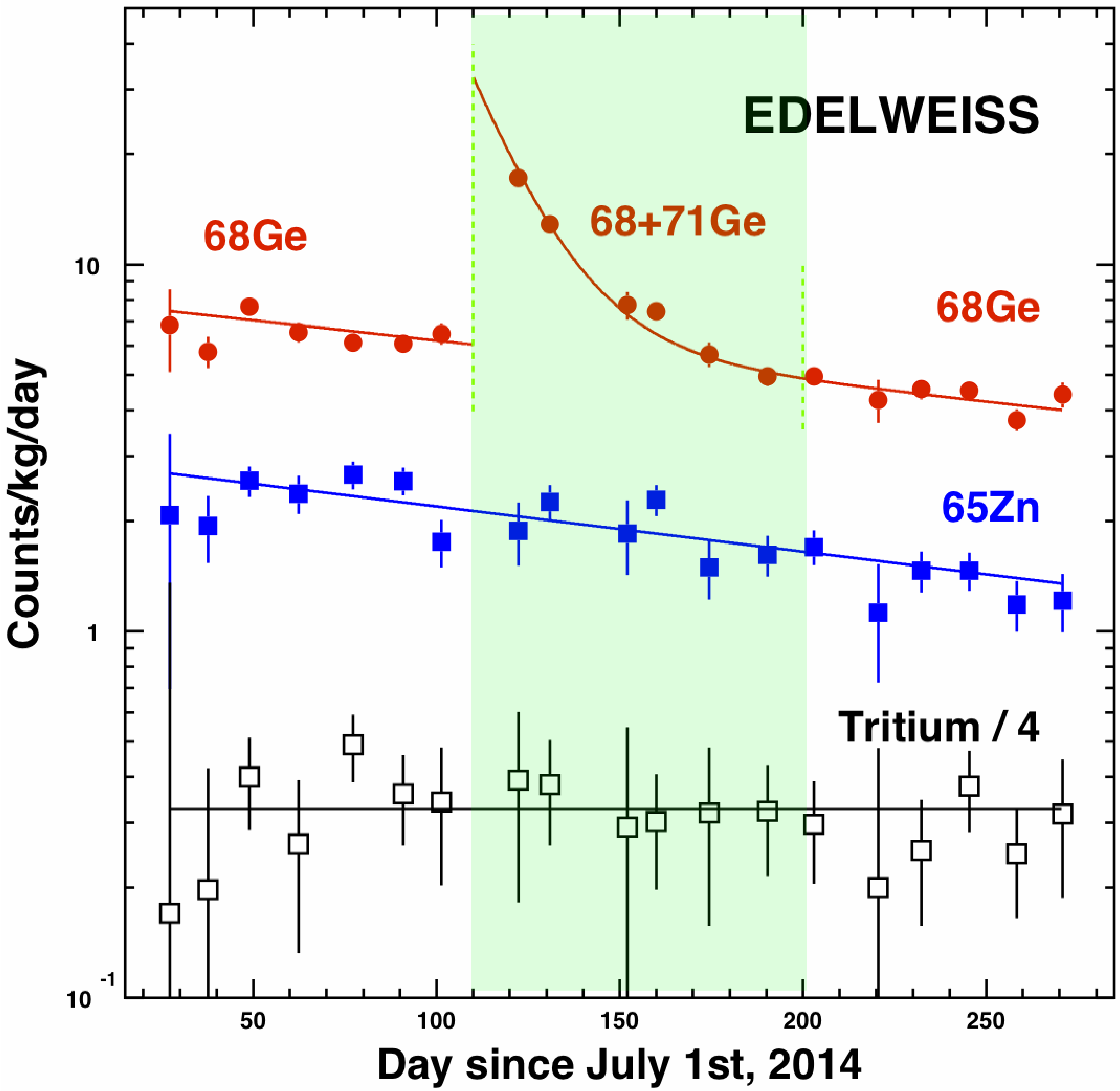
Production rates of ^{3}H, ^{49}V, ^{55}Fe, ^{65}Zn and ^{68}Ge estimates with ACTIVIA code.

The main sources of uncertainty in the calculations come from difficulties on

- precise evaluation of inclusive production cross-sections
- accurate description of cosmic ray spectra

-> More measurements might help constraining the model

Thank you!

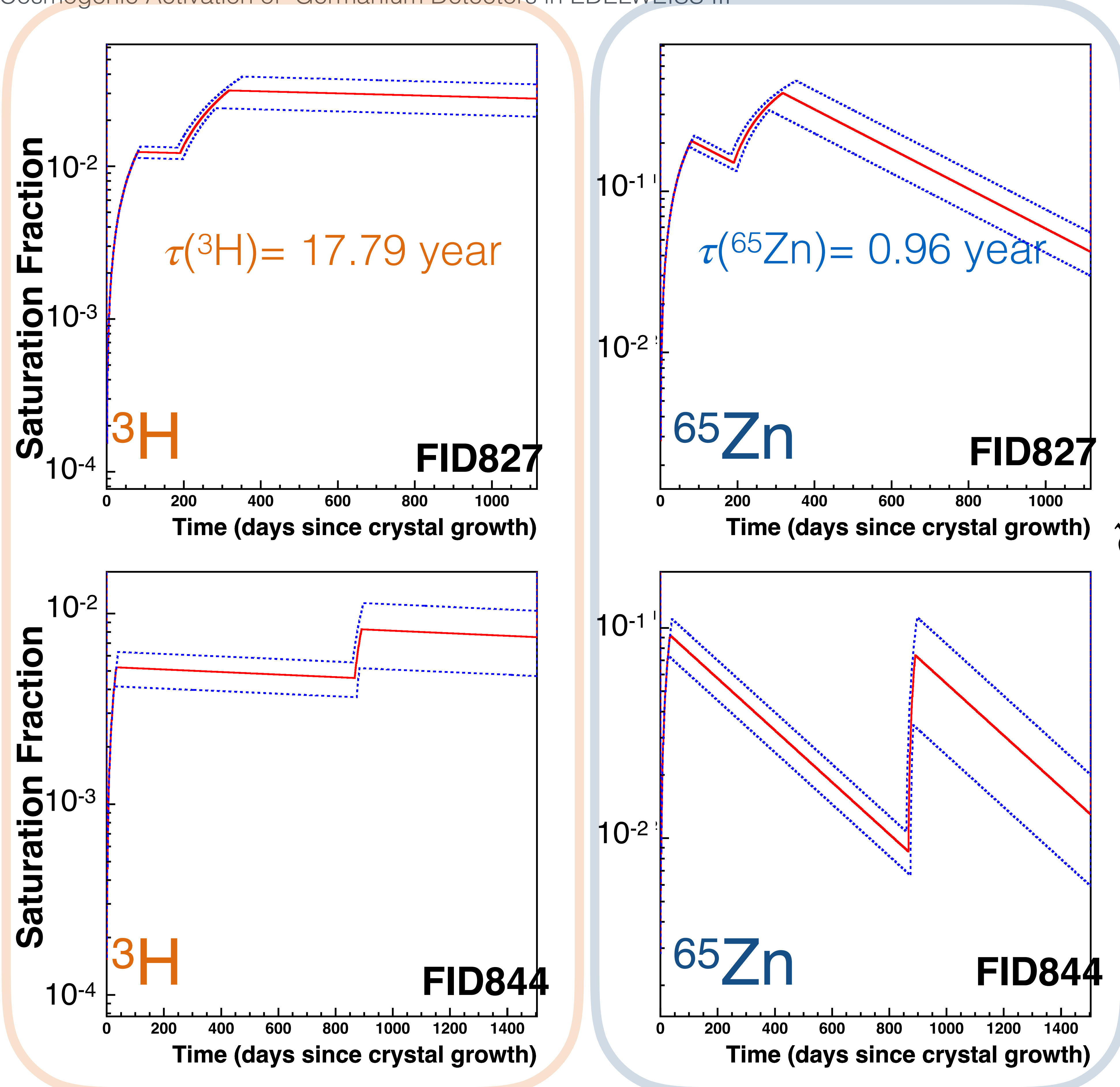


Data taking acquisition ~1 year

^{68}Ge and ^{65}Zn half-lives < 3y
decay rate not constant
-> rate corrected by exp(tau)

Tritium half life of 17.79 y
decay rate constant

In addition for ^{68}Ge, 90 days have been excluded in the analysis to avoid ^{71}Ge contamination due to AmBe neutron calibration



$$\frac{dN}{dT} = P \times (1 - e^{\frac{-t_{exp}}{\tau}}) \cdot (e^{\frac{-t_{dec}}{\tau}})$$

Last value proportional to the rate measured in the detectors

FID844 (standard history)
FID827 (longer texp2)