Future Plans and Prospects of TES Microcalorimeter for 14.4 keV Solar Axion Search

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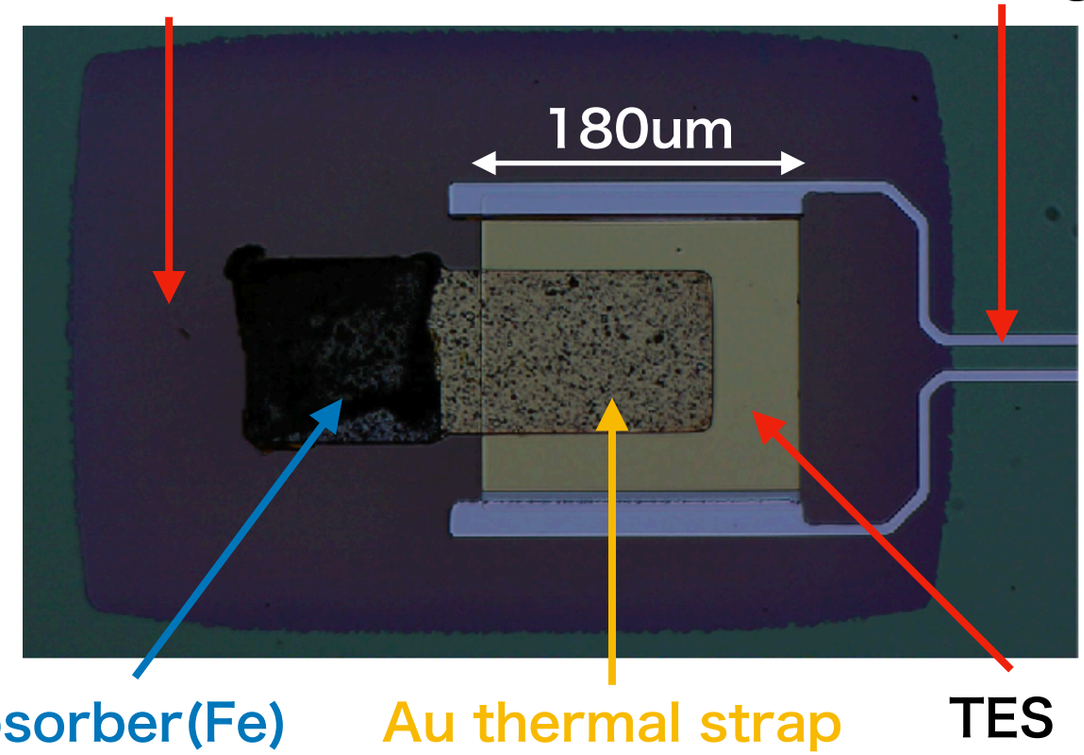
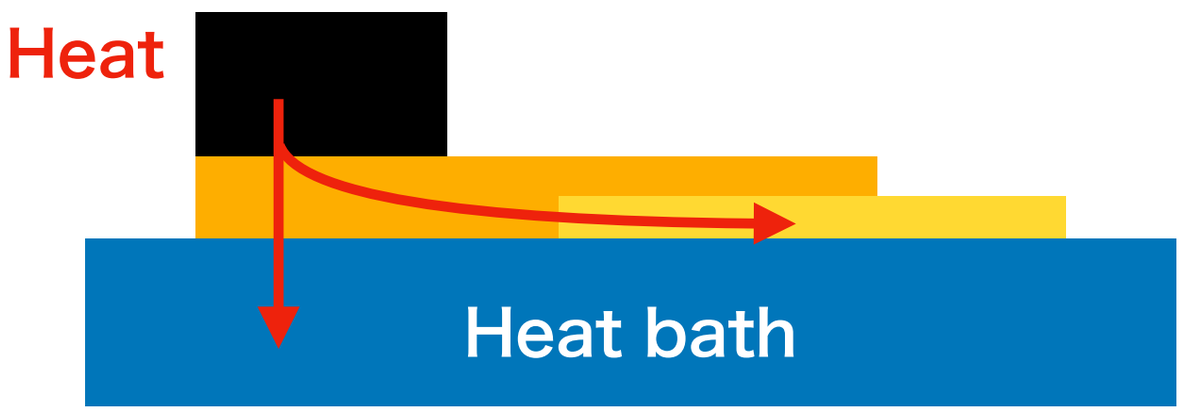
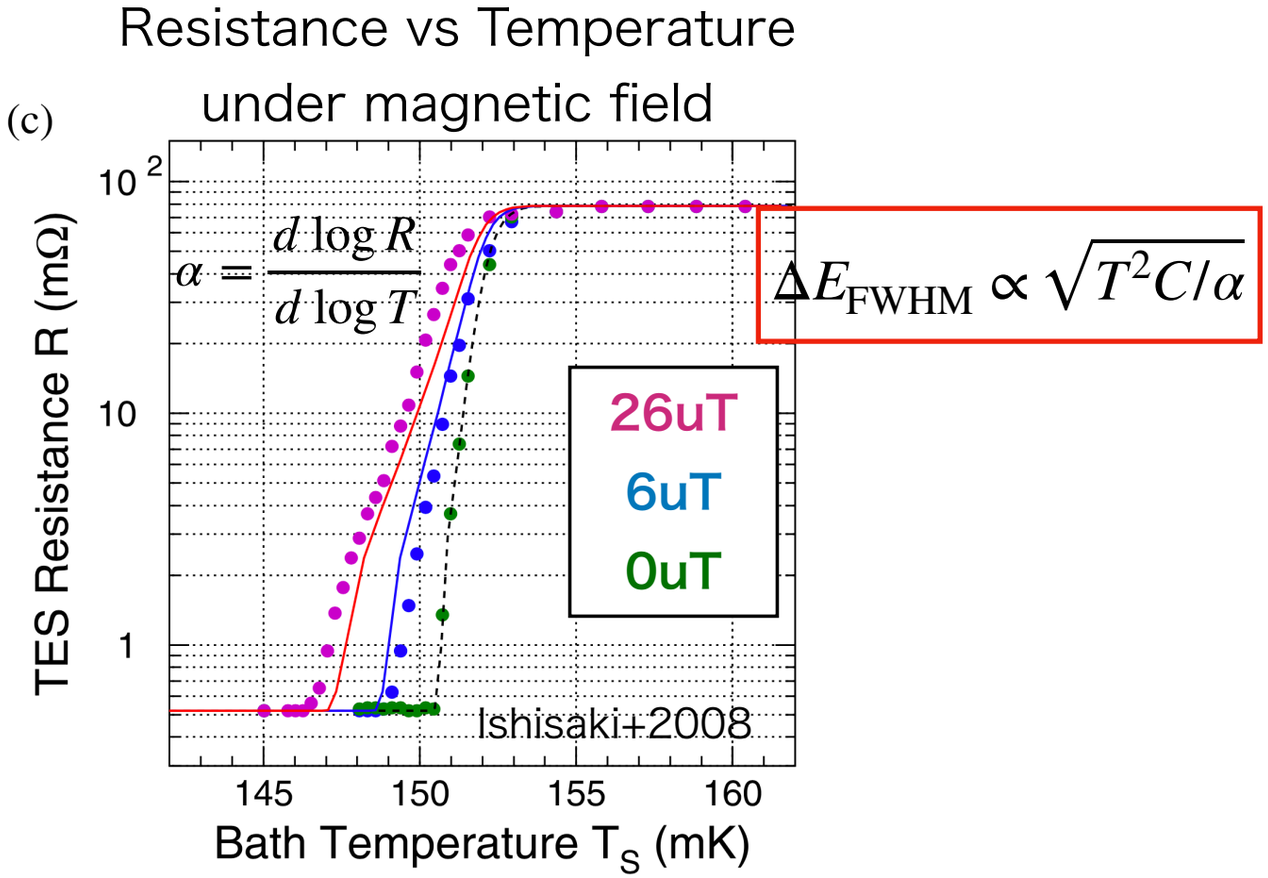
Current Design of TES Microcalorimeter

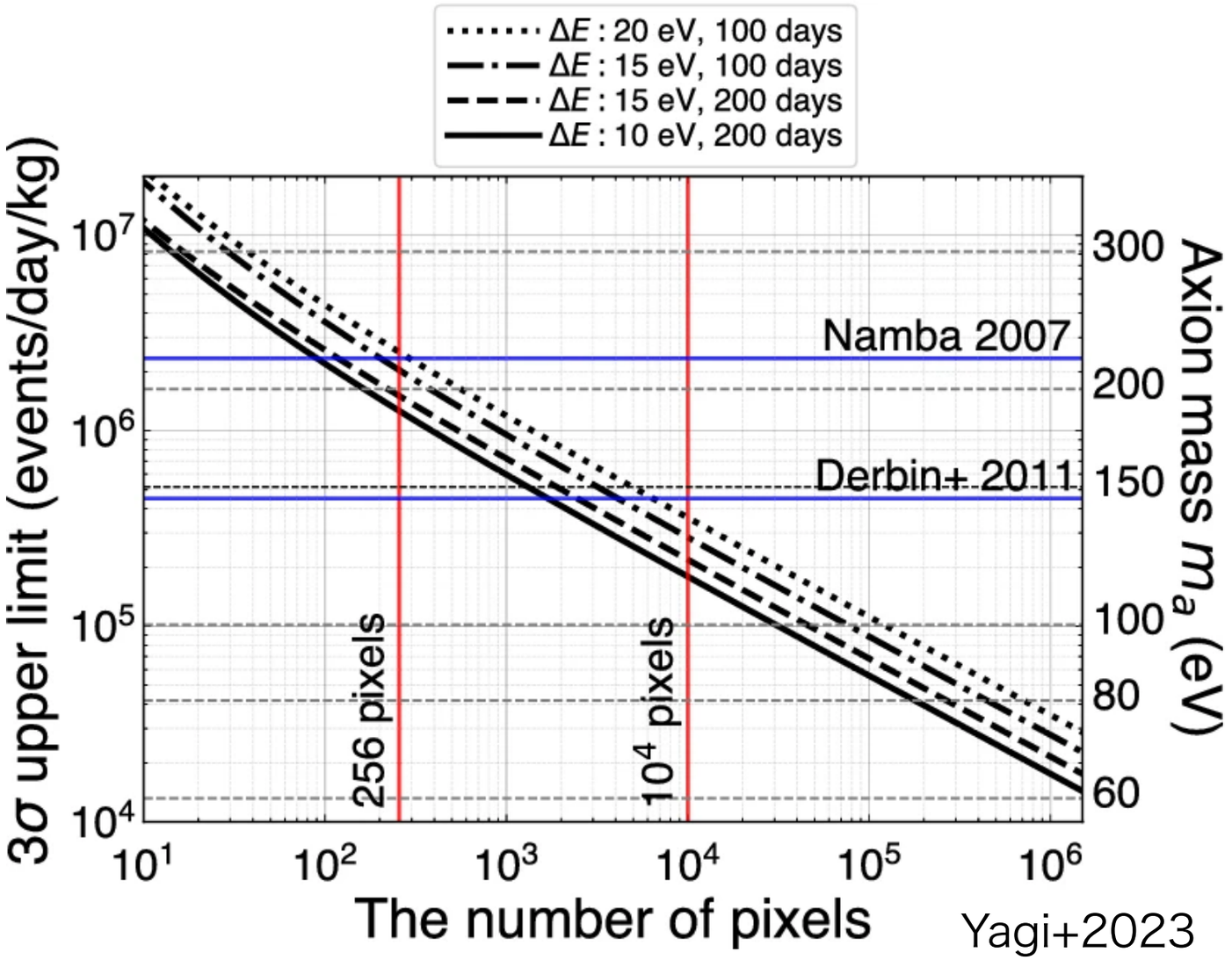






- TES and Fe absorber connected by the Au strap to avoid the Fe magnetic field
- Good thermal conductivity of Fe and Au is needed to improve energy resolution
- We deposit Fe and Au by electroplating to improve thermal conductivity

Sensitivity of Solar Axion by TES Microcalorimeter



Yagi+2023

$$R = \frac{\sqrt{9bN\eta T\Delta E + (9/2)^2} + 9/2}{TMNa}$$

M : Iron mass(single pixel)

ΔE : Energy resolution

b : Background rate

T : Observation time

a : Absorption efficiency

N : The number of pixels

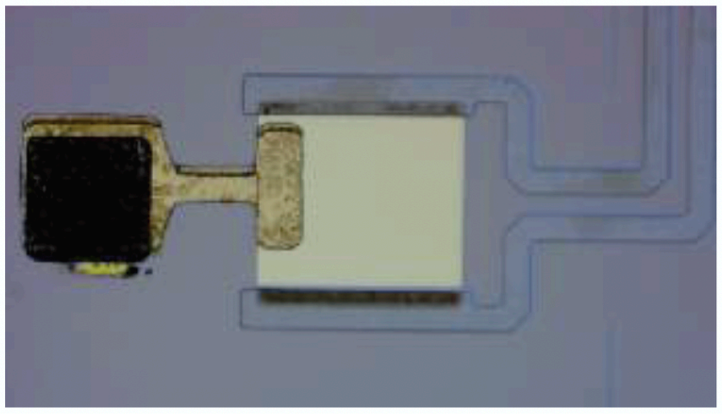
η : Fudge factor

- TES can achieve both high energy resolution (～10 eV) and high absorption efficiency (70%)
- We are improving the detector structure and measurement method to achieve higher energy resolution, higher Fe mass, and lower BGD(Background) rate

Proposal of improvement methods

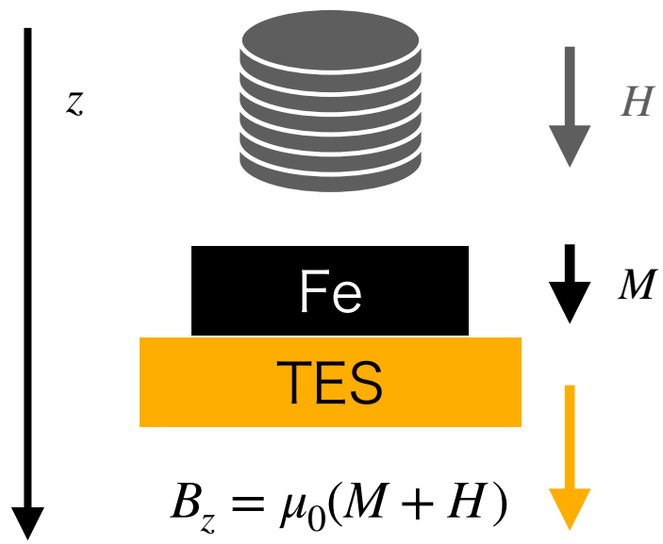
We consider the following three methods to improve energy resolution, Fe mass, and BGD rate

- Modification of the Au strap structure



✓ **Decrease BGD rate**

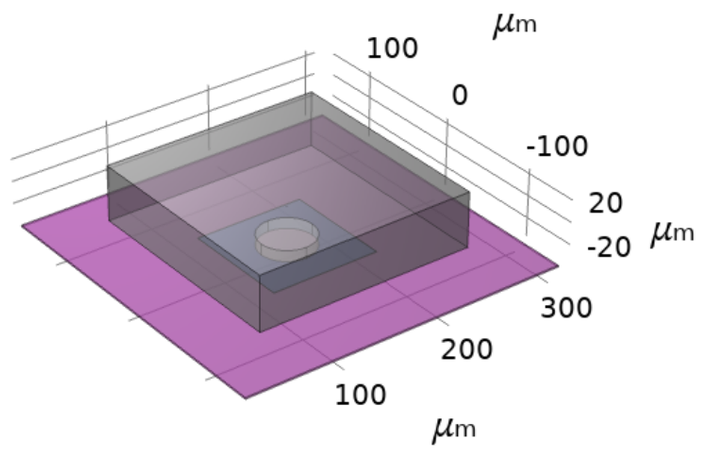
- Measurement method to cancel Fe magnetic field



✓ **Improve ΔE**

✓ **Decrease BGD rate**

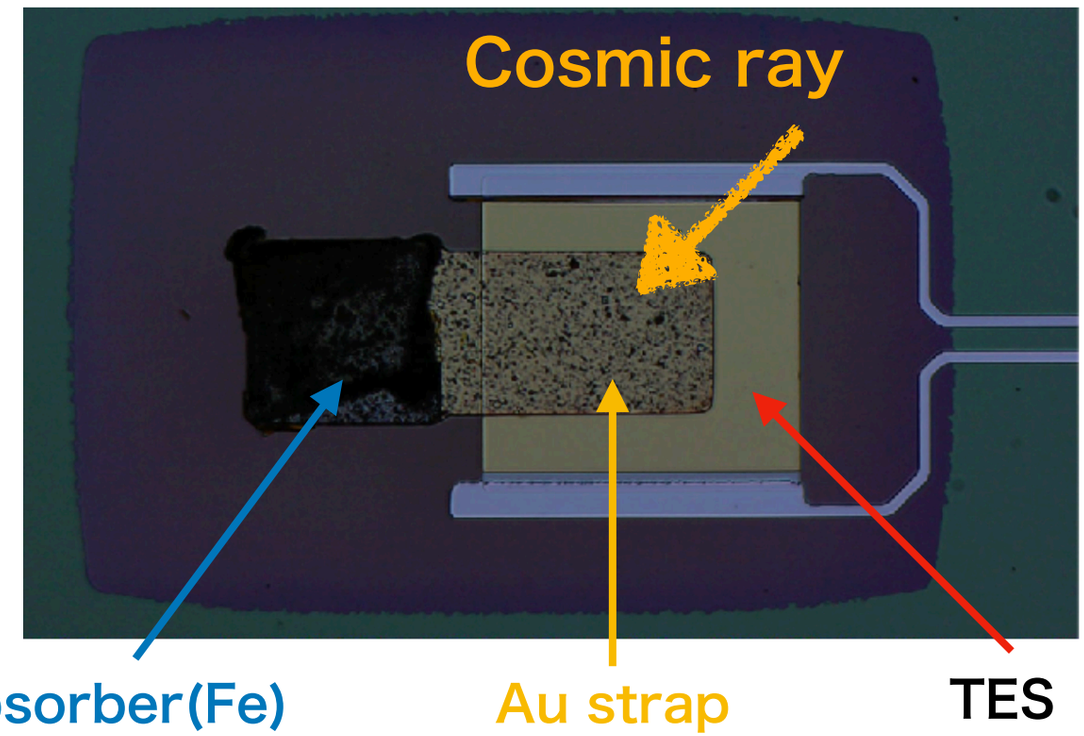
- Fabrication of detectors using Fe foil

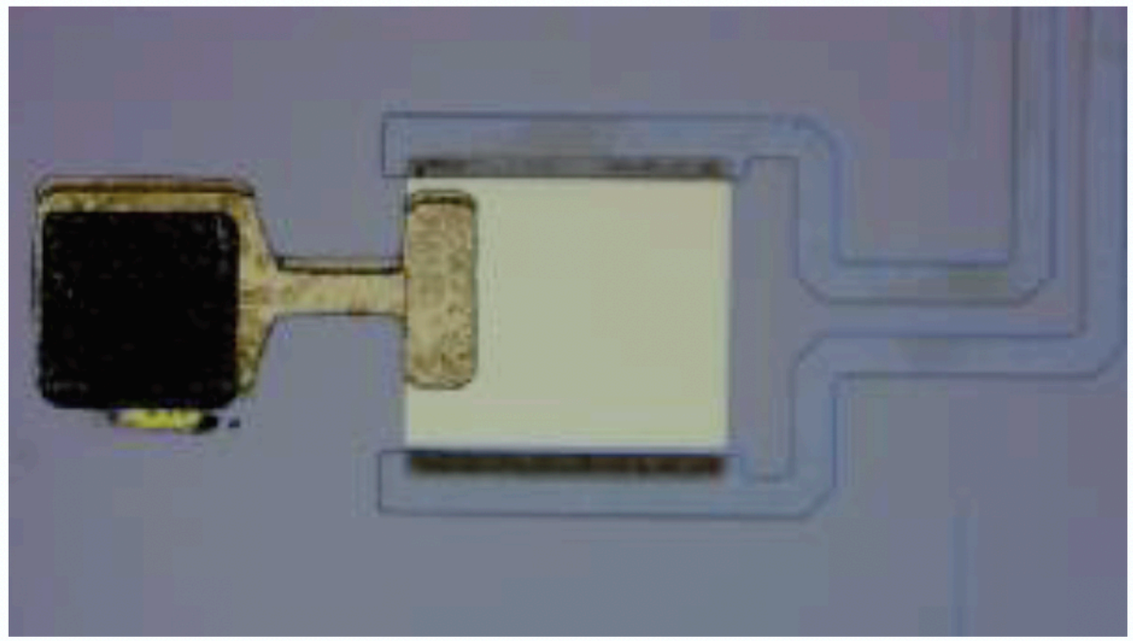


✓ **Increase Fe mass**

For each case, estimate the sensitivity of 14.4 keV solar axion

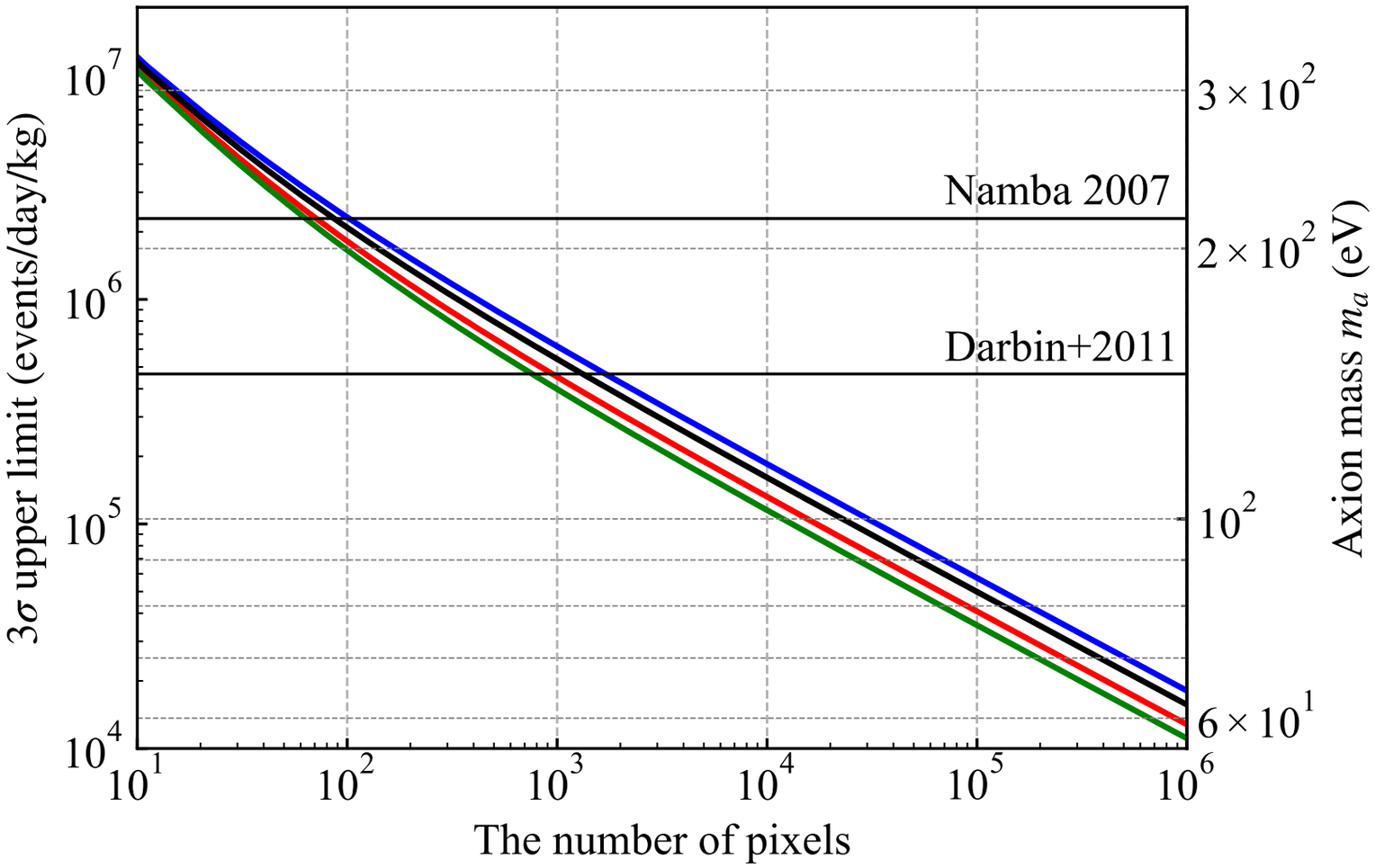
Au Strap Structure





- We fabricated a Au strap structure with a narrow width and a small contact area with the TES.
- The area of Au is reduced by about 50%, which reduces the cosmic ray incidence.
- However, energy resolution may degrade by worsening the thermal conductivity of the gold strap.

Sensitivity : Au Strap Structure

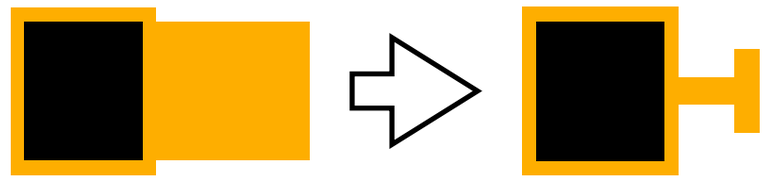


$\Delta E = 40$ eV, $b = 50$ %
$\Delta E = 30$ eV, $b = 50$ %
$\Delta E = 15$ eV, $b = 50$ %
$\Delta E = 15$ eV, $b = 100$ %, Current design

Fe Absorber = 100 μm × 100 μm × 30μm

Observation time = 100 days

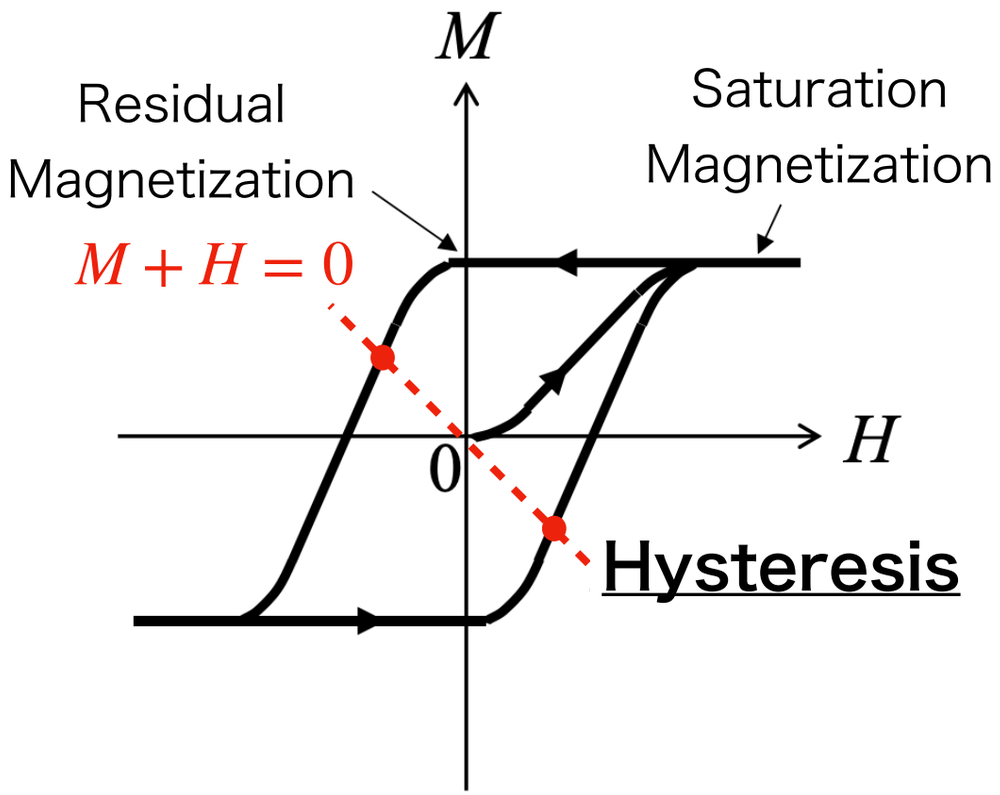
b(100%) = 1.6×10^{-6} count/s/keV/pixels

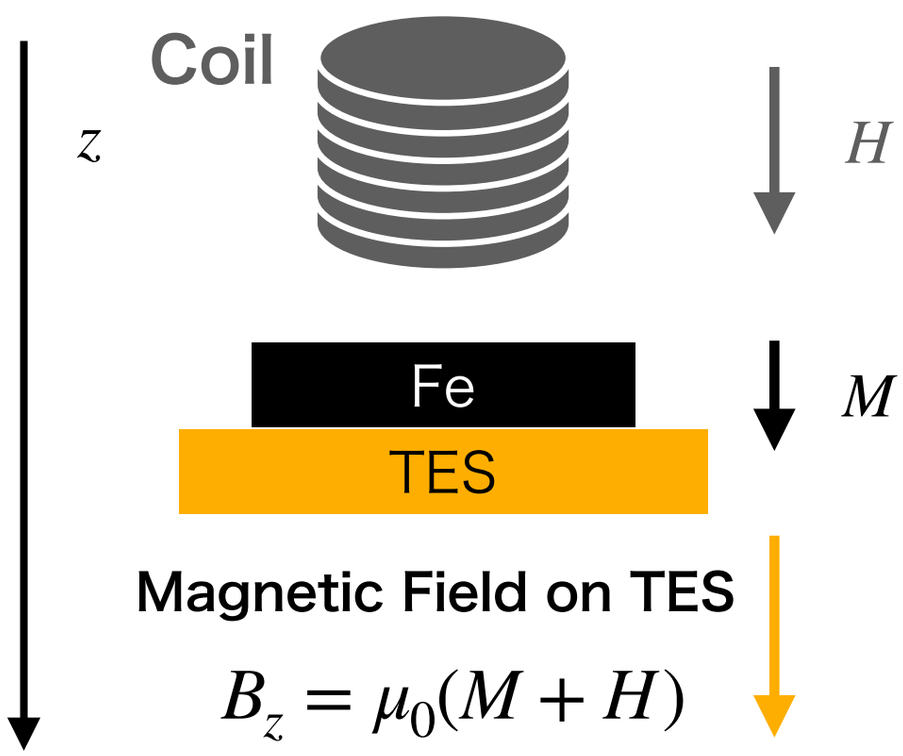


detection area decreased ~ 50%

- Assuming BGD rate decreases by 50%
- If degradation in energy resolution is little (< 30 eV), it will be a stronger limitation than before
- We will measure the energy resolution and BGD rate of a new device.

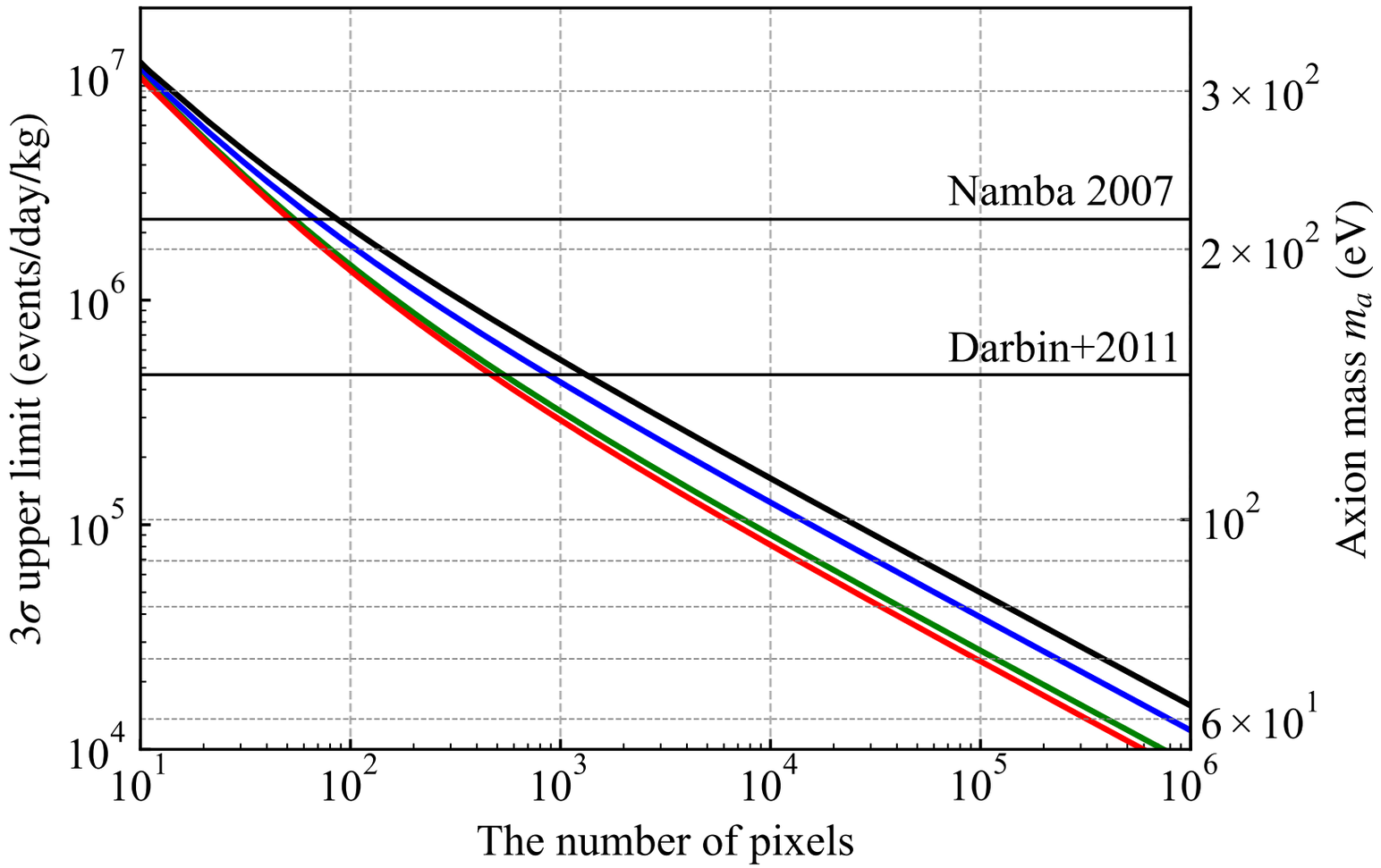
Canceling of Fe magnetic field

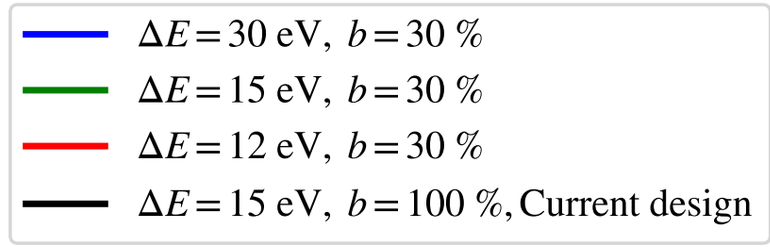




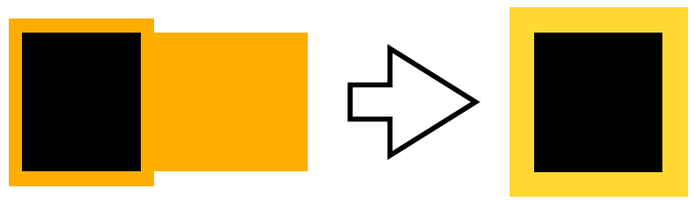
- Fe, a ferromagnetic material, has hysteresis for external magnetic field
- The energy resolution of the TES degrades by a Fe magnetic field
- An external magnetic field can cancel the magnetic field in TES
- The detector area is reduced by 30%
- This setup can achieve good energy resolution and a low BGD rate.

Sensitivity : Canceling of Fe magnetic field

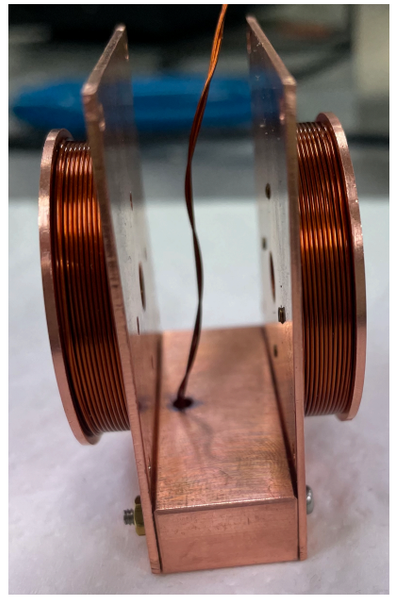




$$\Delta E_{\mathrm{FWHM}} \propto \sqrt{T^2 C/\alpha}$$

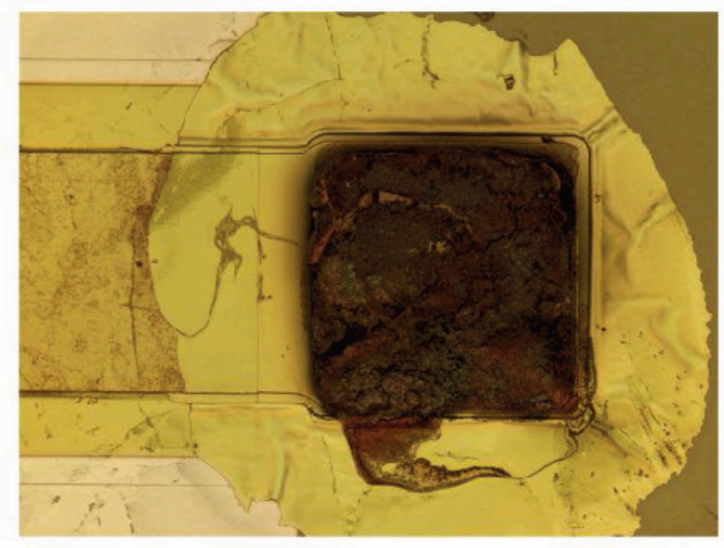


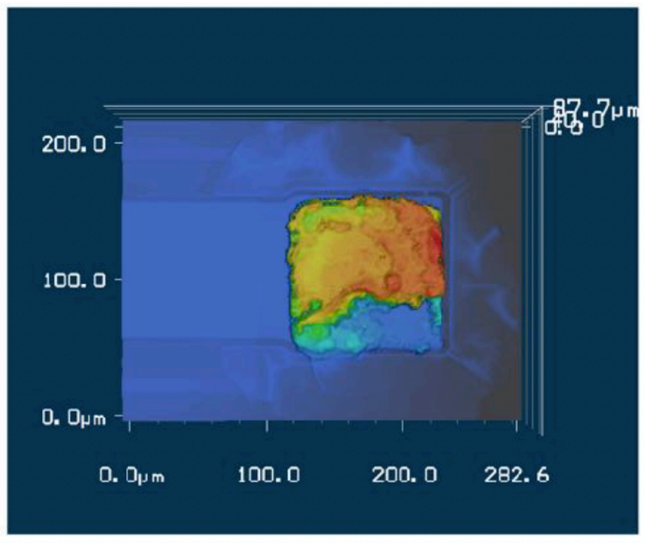
detection area decreased ~ 30%

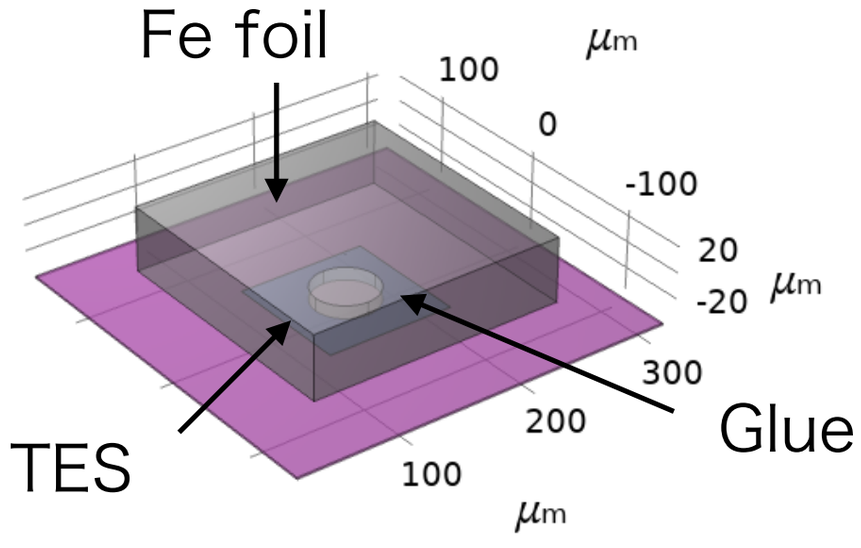


- Assuming BGD rate reduced by 30%
- Without a Au strap, BGD rate decreases significantly
- We are preparing to evaluate the magnetization properties of Fe

Absorber using Fe foil

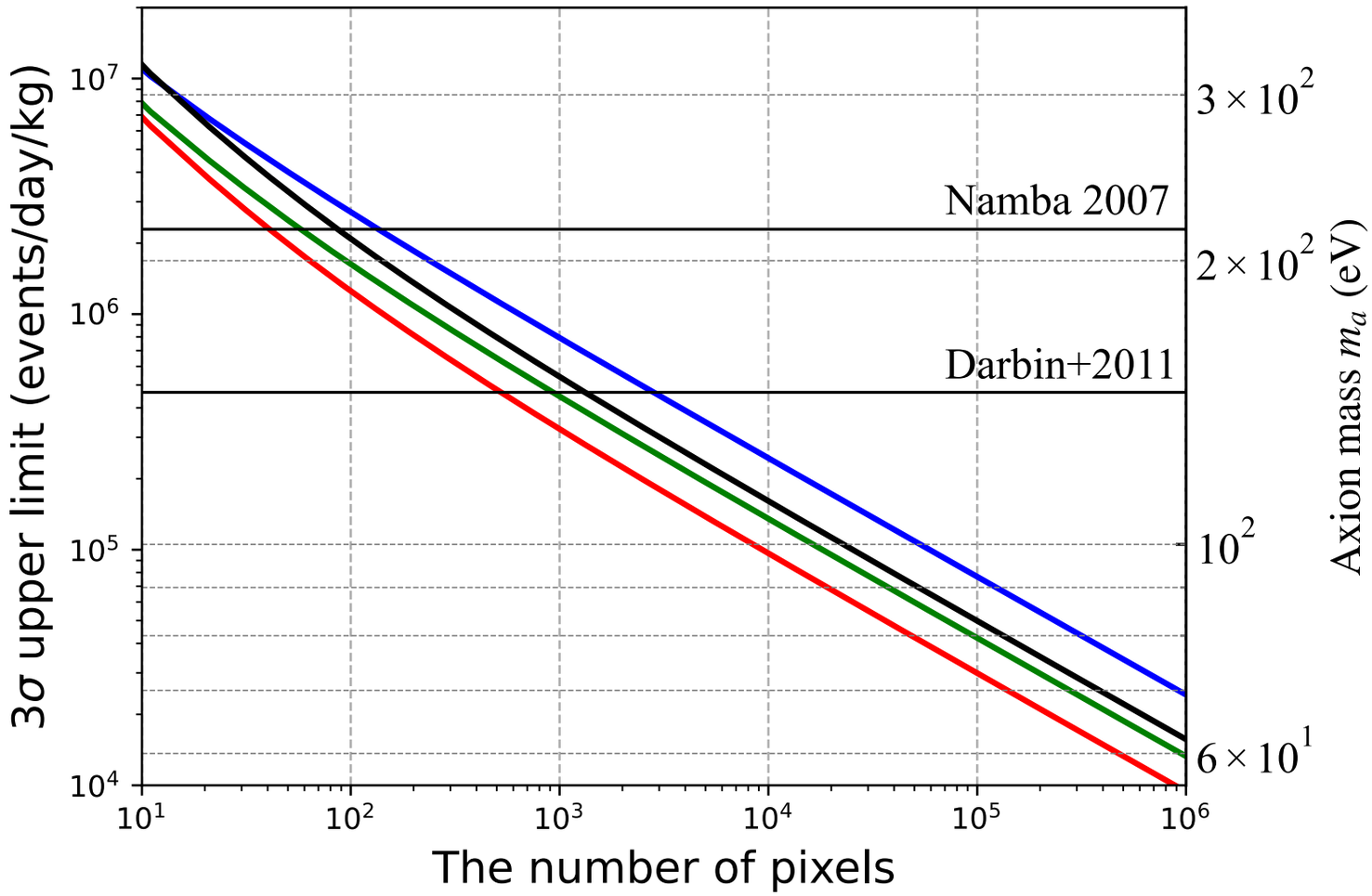


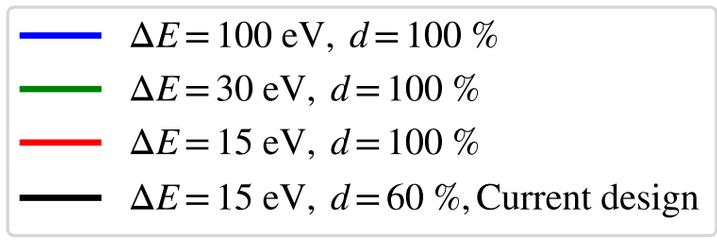




- In the case of the electroplating, the density > 60% of the bulk
- Making a homogeneous and thick film has not been established
- With Fe foil, a homogeneous film with a high Fe density (100%) can be used
- But the thermal conductivity of the Fe foil is worse than electroplated Fe
- Additionally, the glue between Fe and TES may degrade energy resolution

Sensitivity : Absorber using Fe foil





Fe Absorber = 100 μm × 100 μm × 30μm

Observation time = 100 days

b = 1.6×10^{-6} count/s/keV/pixels

- The black line shows electroplated iron and the red line shows iron foil.
- If energy resolution is degraded by the thermal conductivity of Fe foil and magnetic field, sensitivity decreases from the red line to the blue line.
- The magnetic field of Fe may be canceled by an external magnetic field.
- We plan to measure the degradation of the energy resolution.

Summary

- We are fabricating TES microcalorimeters to detect a 14.4 keV solar axion.
- We consider three methods to improve energy resolution, Fe mass, and BGD rate
  - Au strap structure
  - Cancelling of Fe magnetic field
  - Using Fe foil as an absorber
- In each case, roughly calculate the detection sensitivity of an axion.
- The effectiveness of these methods needs to be measured.