Phonon-Mediated Distributed Transition-Edge-Sensor X-ray Detectors

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TES 3 at Gainesville

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Overview

- **Goals, applications and detector basics**
- Energy systems, charge traps and neutralization
- 2-d Si
- 2-d Ge
- 2-d Si with deep trenches
- Energy Resolution

Performance Goals

- 2 dimension resolving.
- 1-10 keV band.
- Position resolution $x/\delta x$ and $y/\delta y \sim 100$.
- Energy resolution $E/\delta E \sim 1000$.

- Eventually multiplexed into 30 x 30 arrays.
- Equivalent to a 10 megapixel device.

Applications

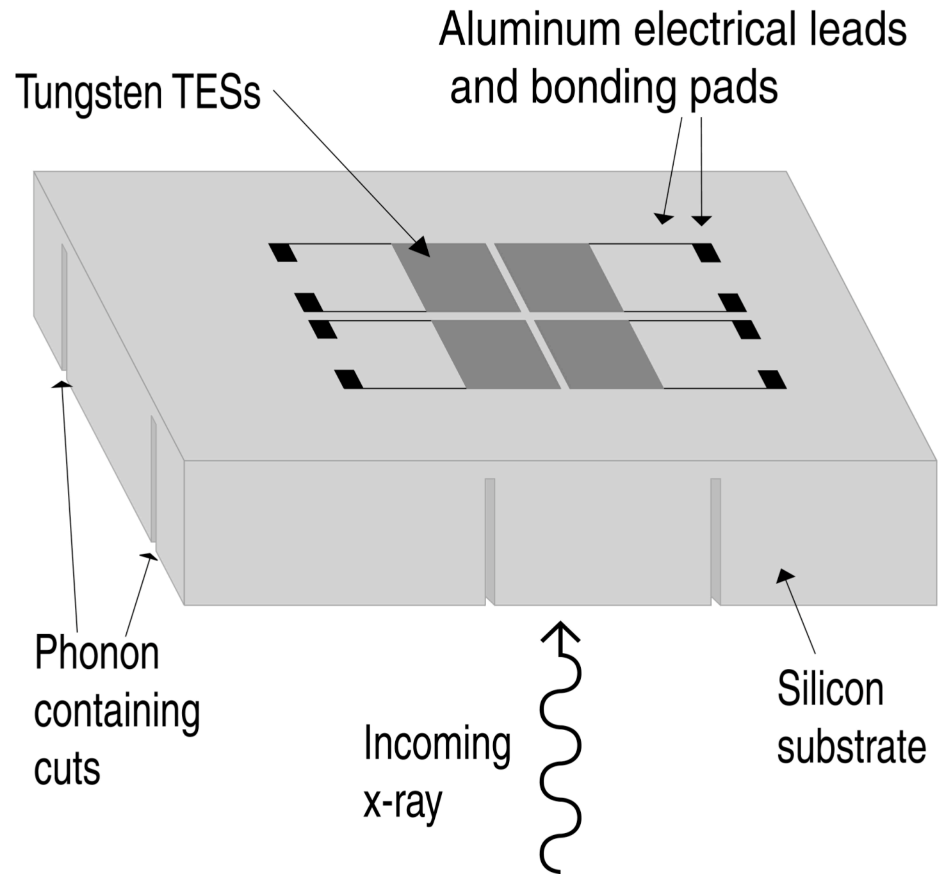
- Large area, time resolution, energy resolution and position resolution, dead time…
- Astrophysical studies such as…

- Magnetic recombination in the solar corona.
- Warm–hot intergalactic medium
- Surveys of clusters and groups of galaxies.

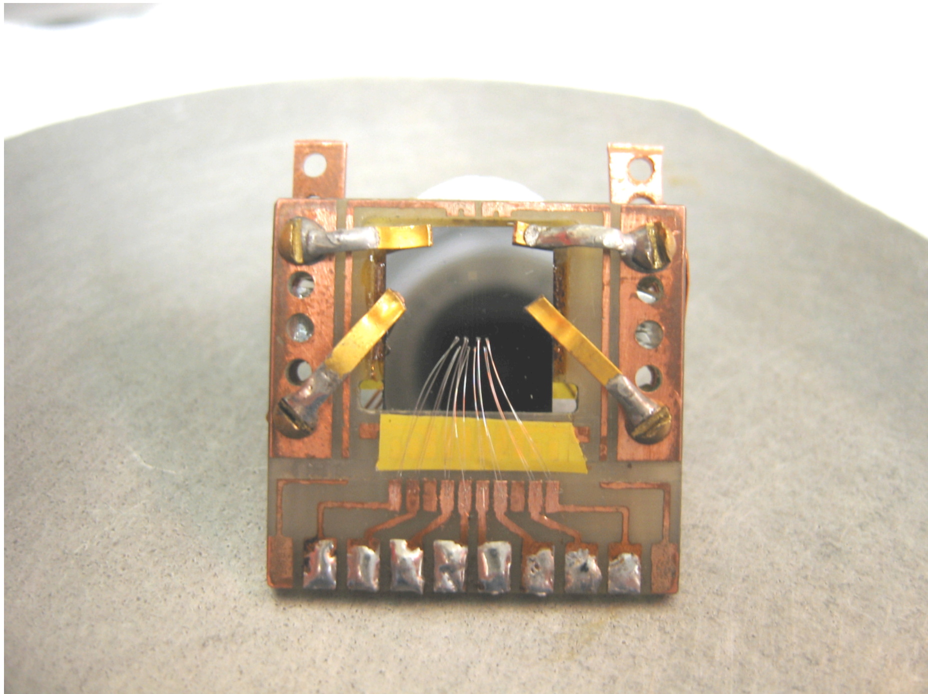
- These have been suggested by Blas Cabrera, Steven Kahn, Bob Stern, Steve Deiker and others.

2x2 Detector

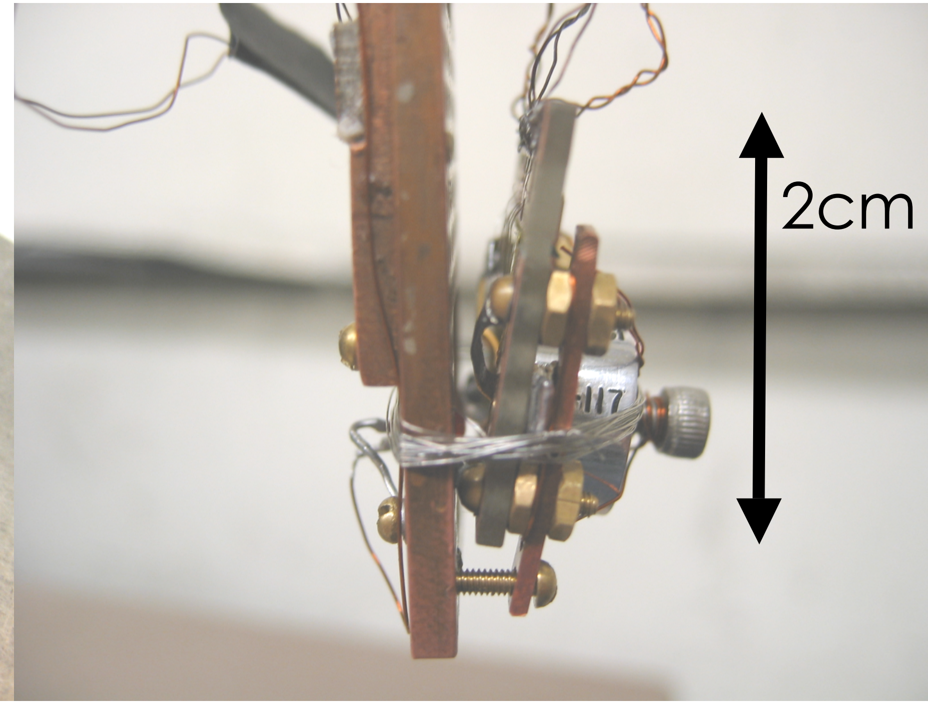
- Position cuts in 2 directions.
- Third dimension not resolvable.
- The four TESs cover a region 500μm x 500μ m.
- The crystal is 350μm thick.
- The trenches are ~220 μm deep.



Detector with Source



1cm



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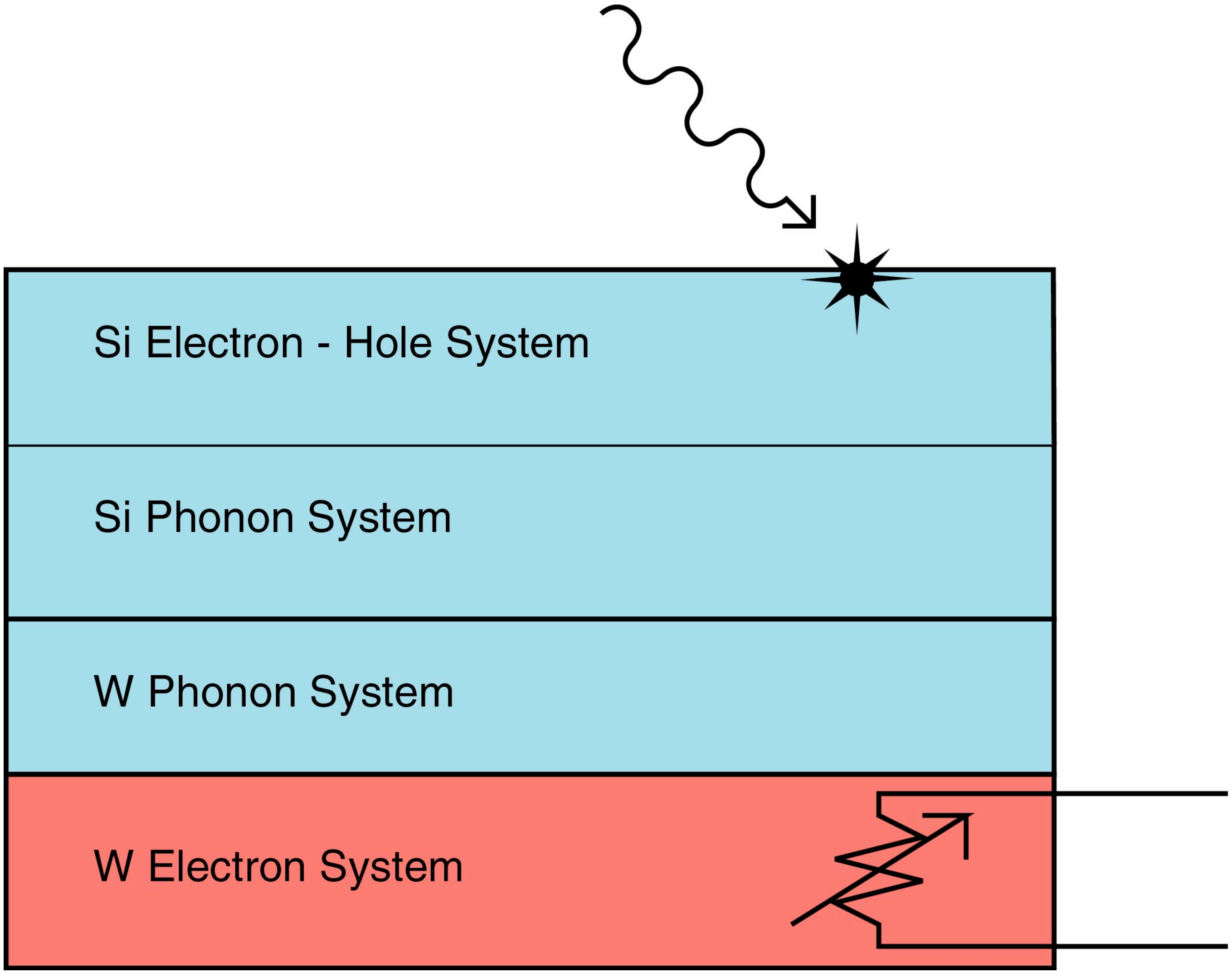
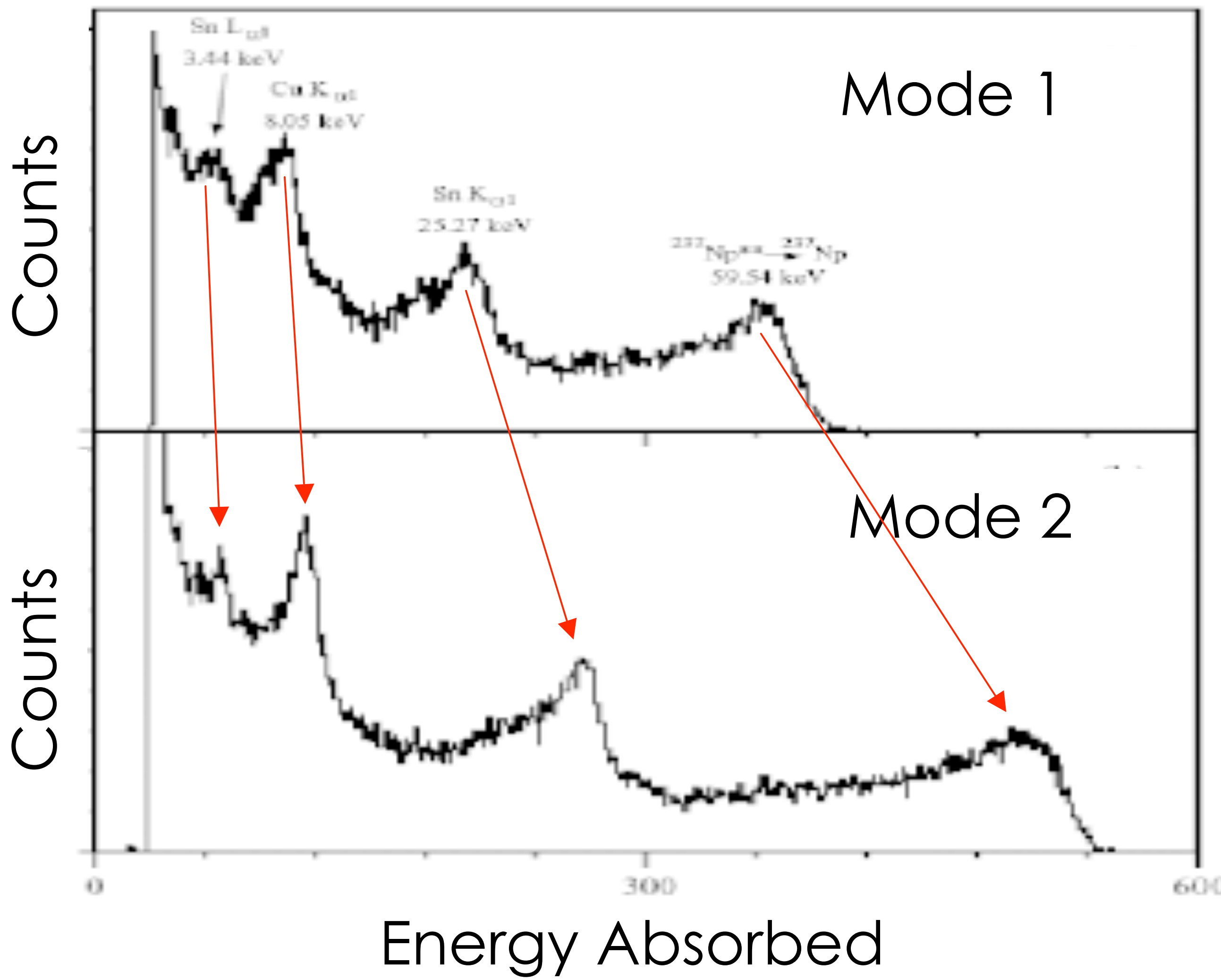
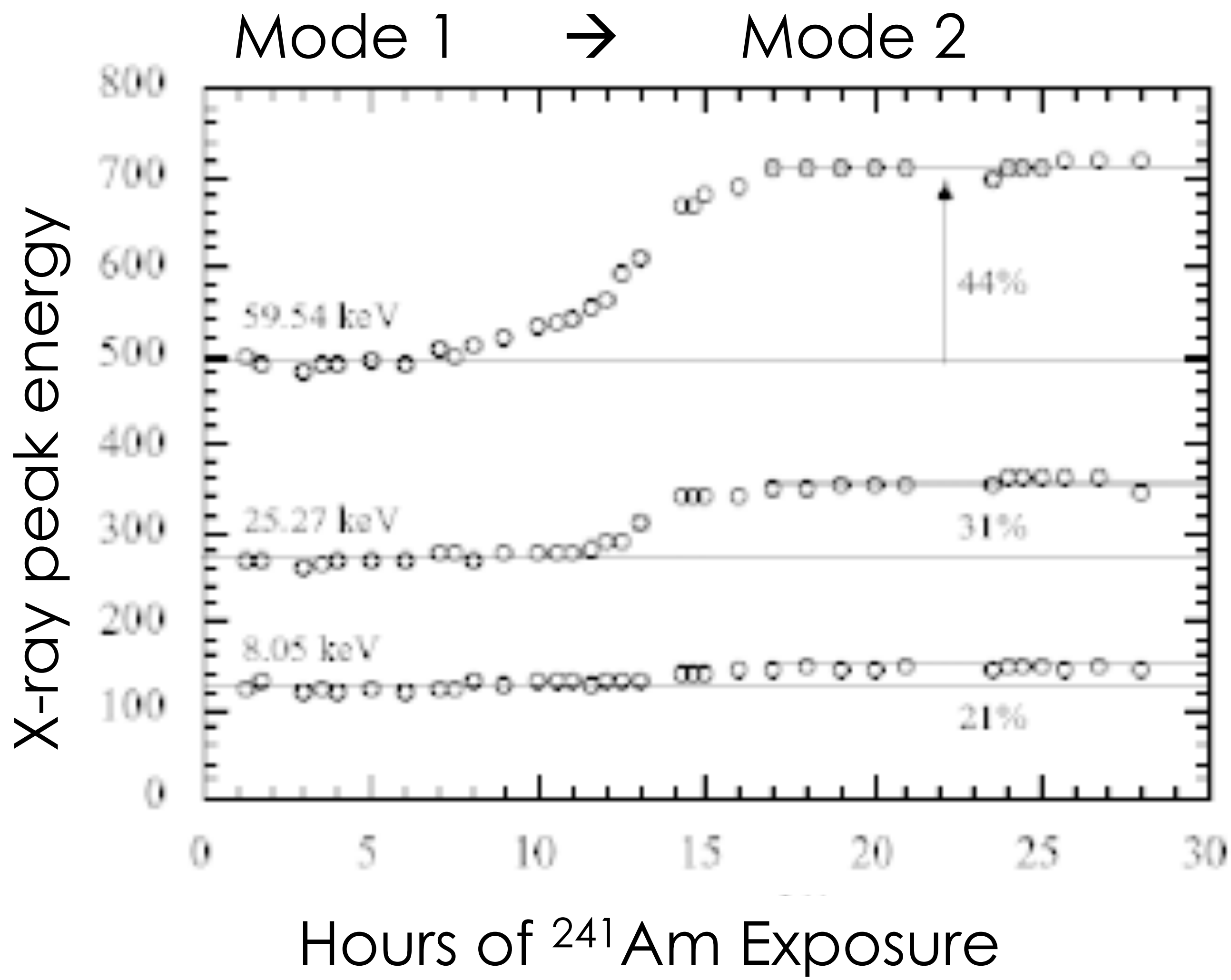
Energy Systems



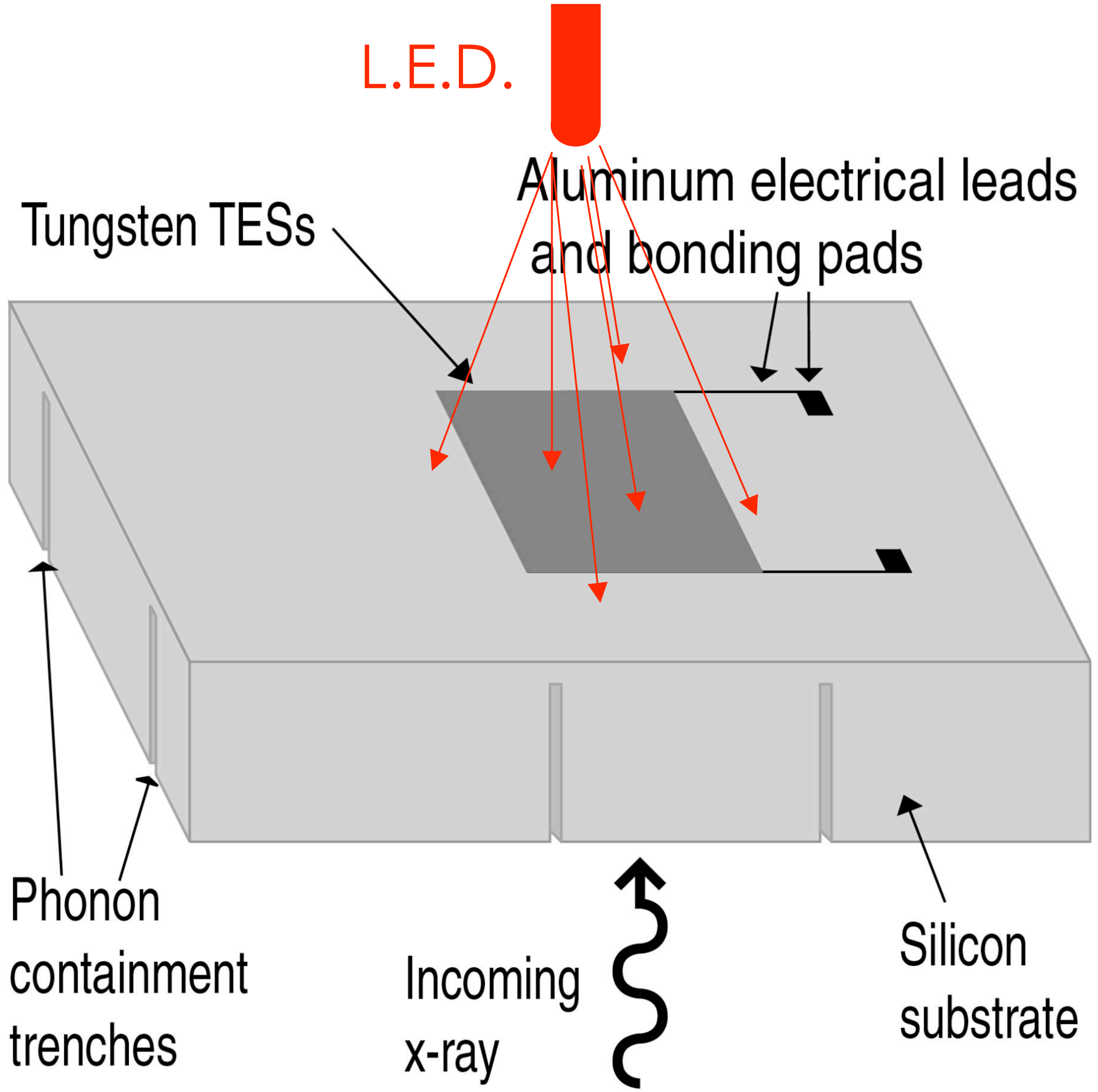
Charge Traps



Neutralization Completion



Crystal Neutralization



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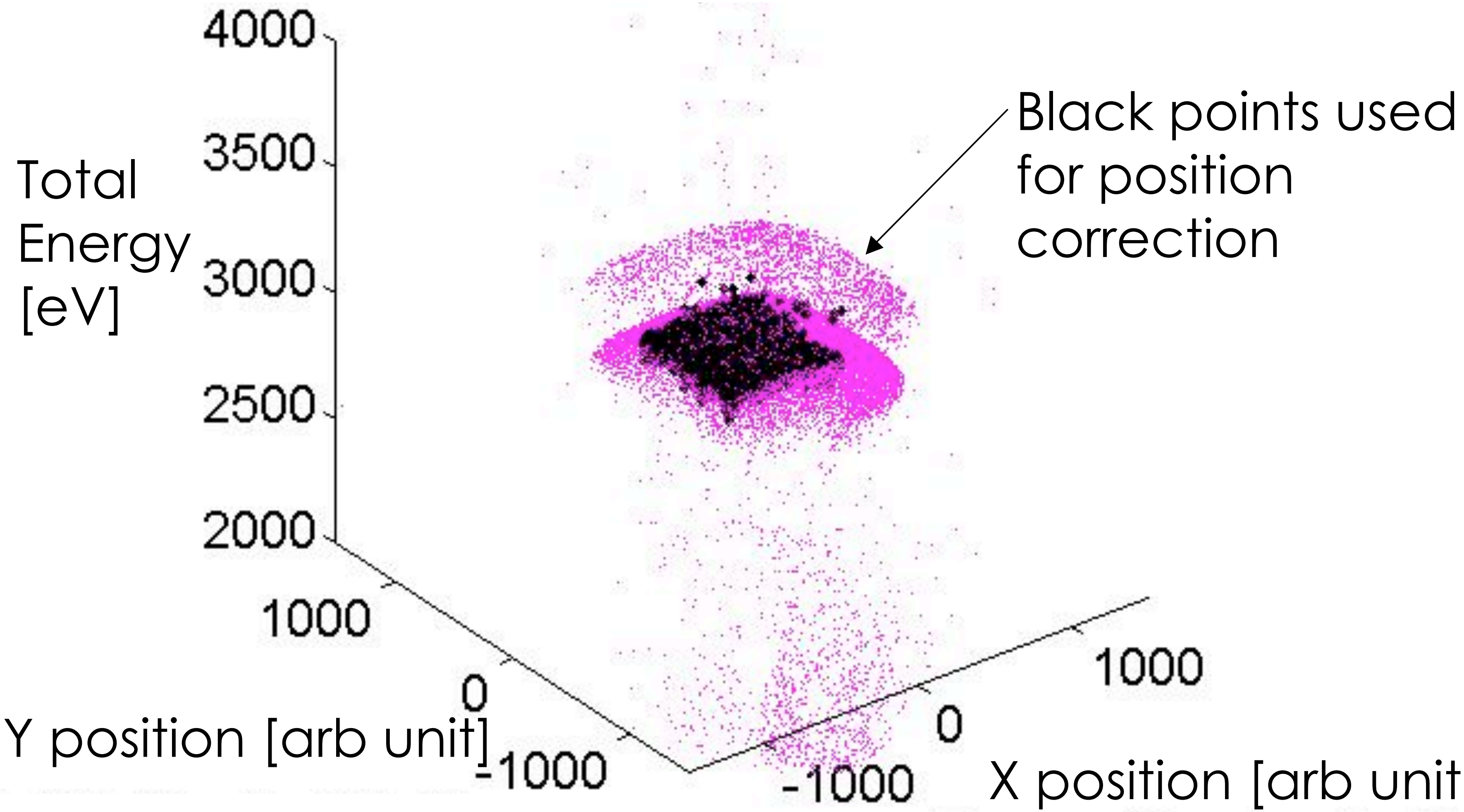
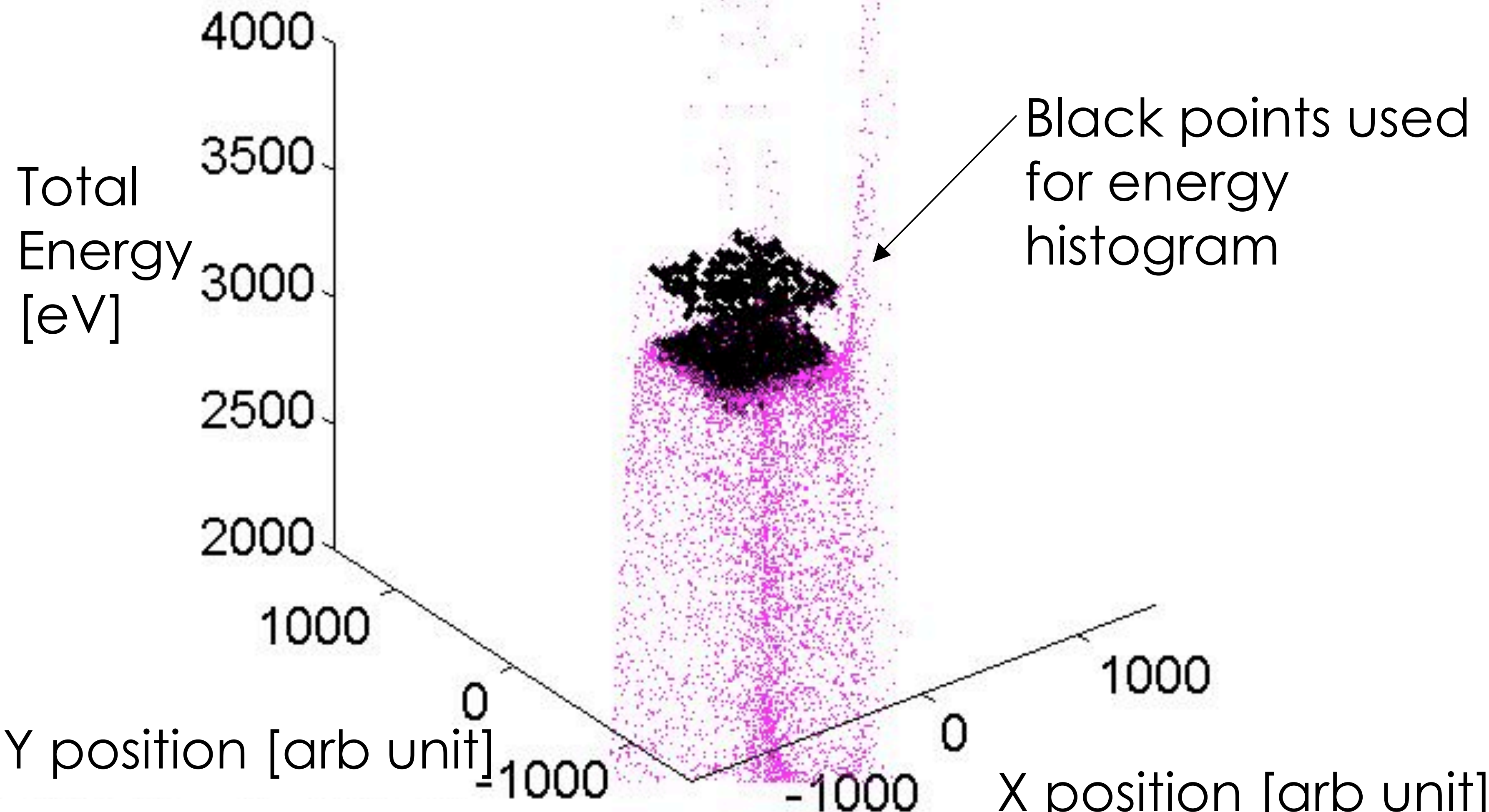
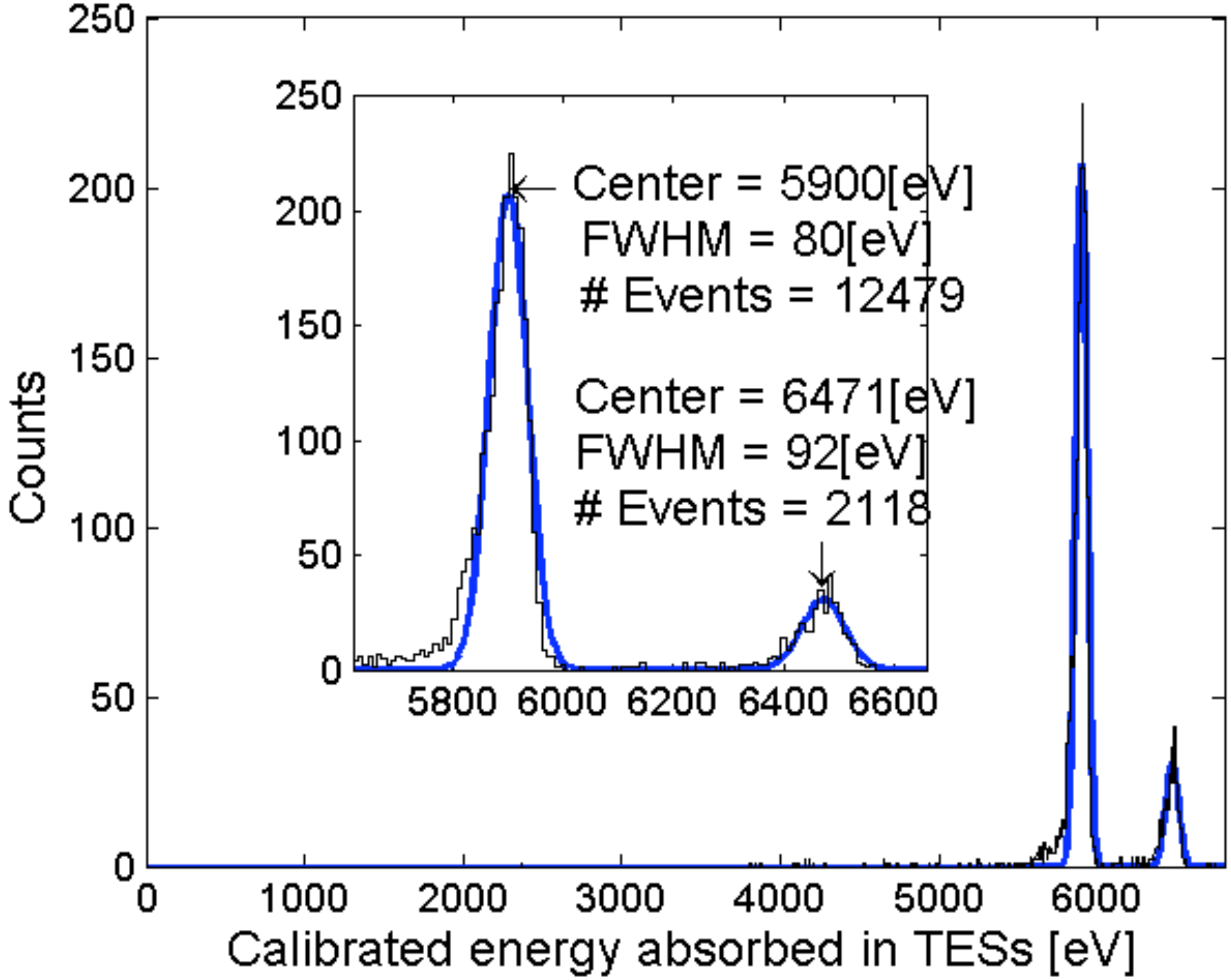
Energy Partitioning



Energy Partitioning



Spectra



Counts
Calibrated energy absorbed in TESs [eV]
0
1000
2000
3000
4000
5000
6000
50
100
150
200
250
Center = 5900[eV]
FWHM = 80[eV]
# Events = 12479
Center = 6471[eV]
FWHM = 92[eV]
# Events = 2118
5800
6000
6200
6400
6600

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Energy Losses

- Energy resolution is degraded due to energy going into nondetectable channels.
  - Electron—hole pairs lost in charge traps.
  - Electron—hole pairs diffuse through bridge and lost to the environment.
  - Phonons escape through bridge and lost to the environment.

Germanium Absorbers

- Want pure Ge absorbers (less charge traps).
- First use cheaper doped Ge absorbers.
- Problems…
  - Xtal thicker.
  - Bridges thicker (Very conservative trenching since Ge is more fragile).
  - Debye frequency ~1/2 of Si's (coupling to W ~frequency).

Germanium Detector

- These problems led to a reduction in the amount of energy absorbed in the TESs (~500eV).
  - Actually, only 3 TESs were working and the 500eV amount is what would be expected in four working TESs.
  - This is consistent with simulation indicating that the simulation's parameters are not far off.
- An actual line width was not determined.

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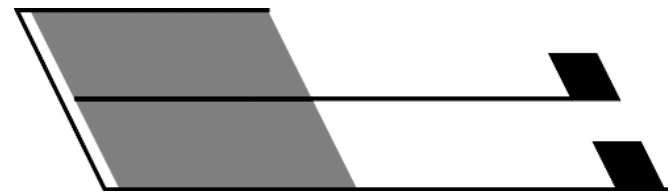
2-d Si Detector with ``split'' TESs and deep trenches

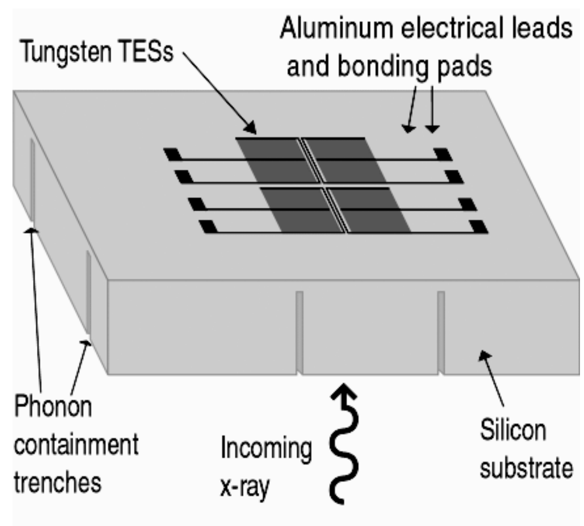
- Deeper trenches to reduce phonon and charge losses through the connecting bridge.
- The trenches are 320μm deep, 90% of crystal thickness.
- ~70% of the initial x-ray energy was read out by the TESs.
- Considering the 220μm deep trenches and 320μ m deep trenches absorption of 49 & 70% respectively, a total of 76% absorbed in completely trenched detector.

Split TESs

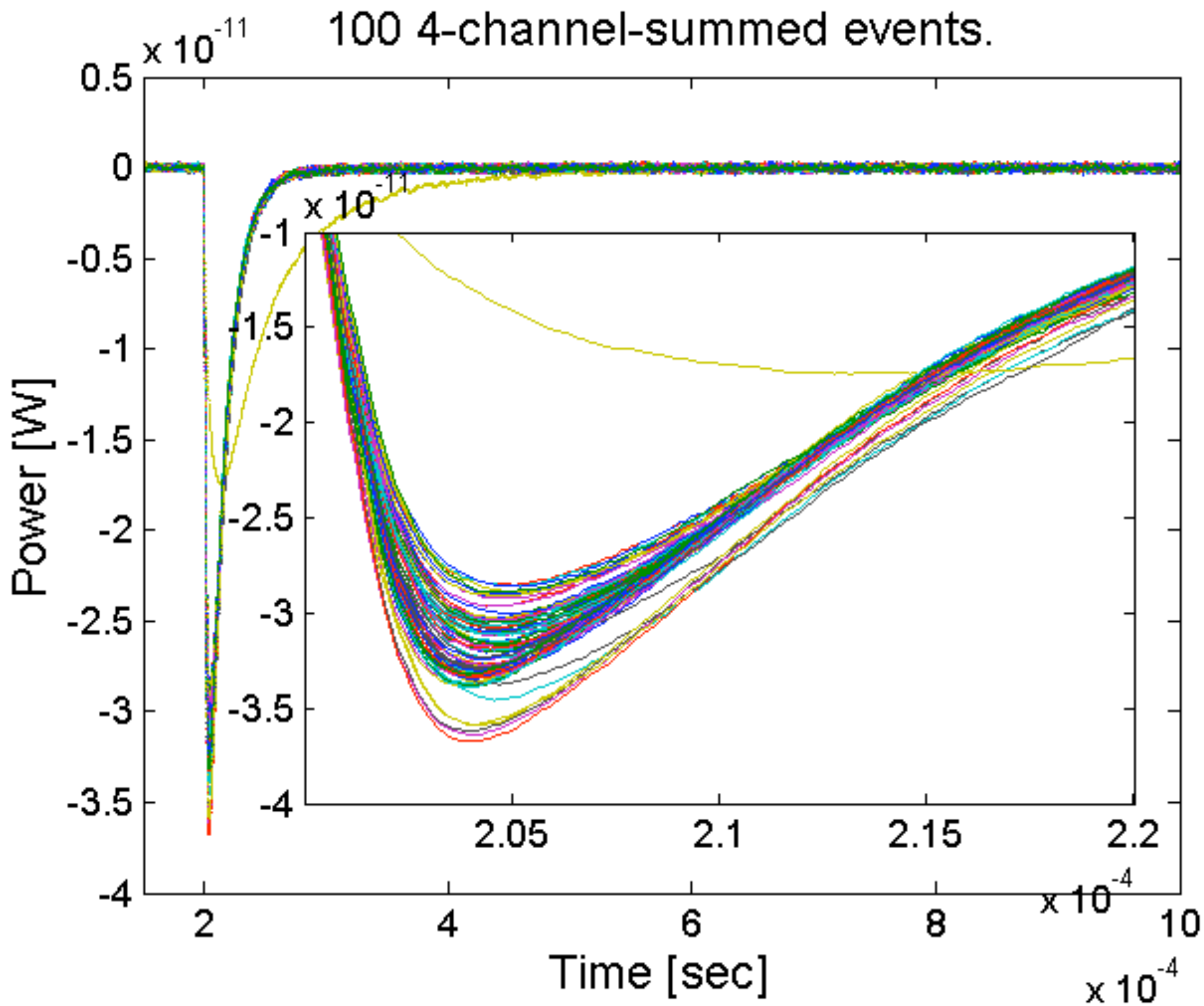
- Split TESs suppress / reduce phase separation in the current flowing direction.

$$l_{\max}^2 = \pi^2 L_{Lor} / \alpha \Sigma T_c^3 \rho_n$$



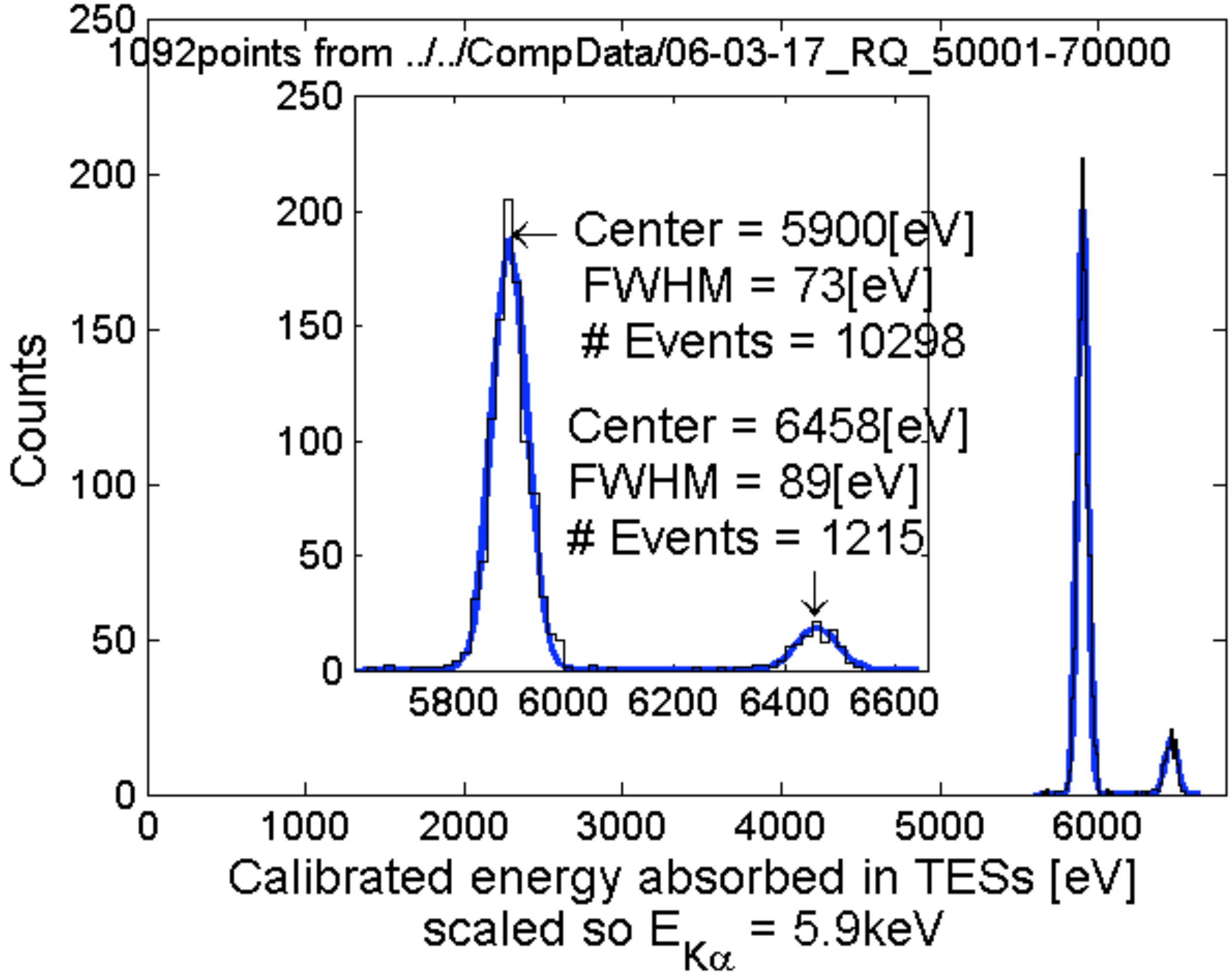


Band Mixing



100 4-channel-summed events.
x 10^-11
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Power [W]
2
4
6
8
10
Time [sec]
x 10^-4
x 10^-11
-1
-1.5
-2
-2.5
-3
-3.5
-4
2.05
2.1
2.15
2.2
x 10^-4

After Cuts



1092points from ../../CompData/06-03-17_RQ_50001-70000
Counts
Calibrated energy absorbed in TESs [eV]
scaled so $E_{K\alpha}$ = 5.9keV
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
Center = 5900[eV]
FWHM = 73[eV]
# Events = 10298
Center = 6458[eV]
FWHM = 89[eV]
# Events = 1215
5800
6000
6200
6400
6600

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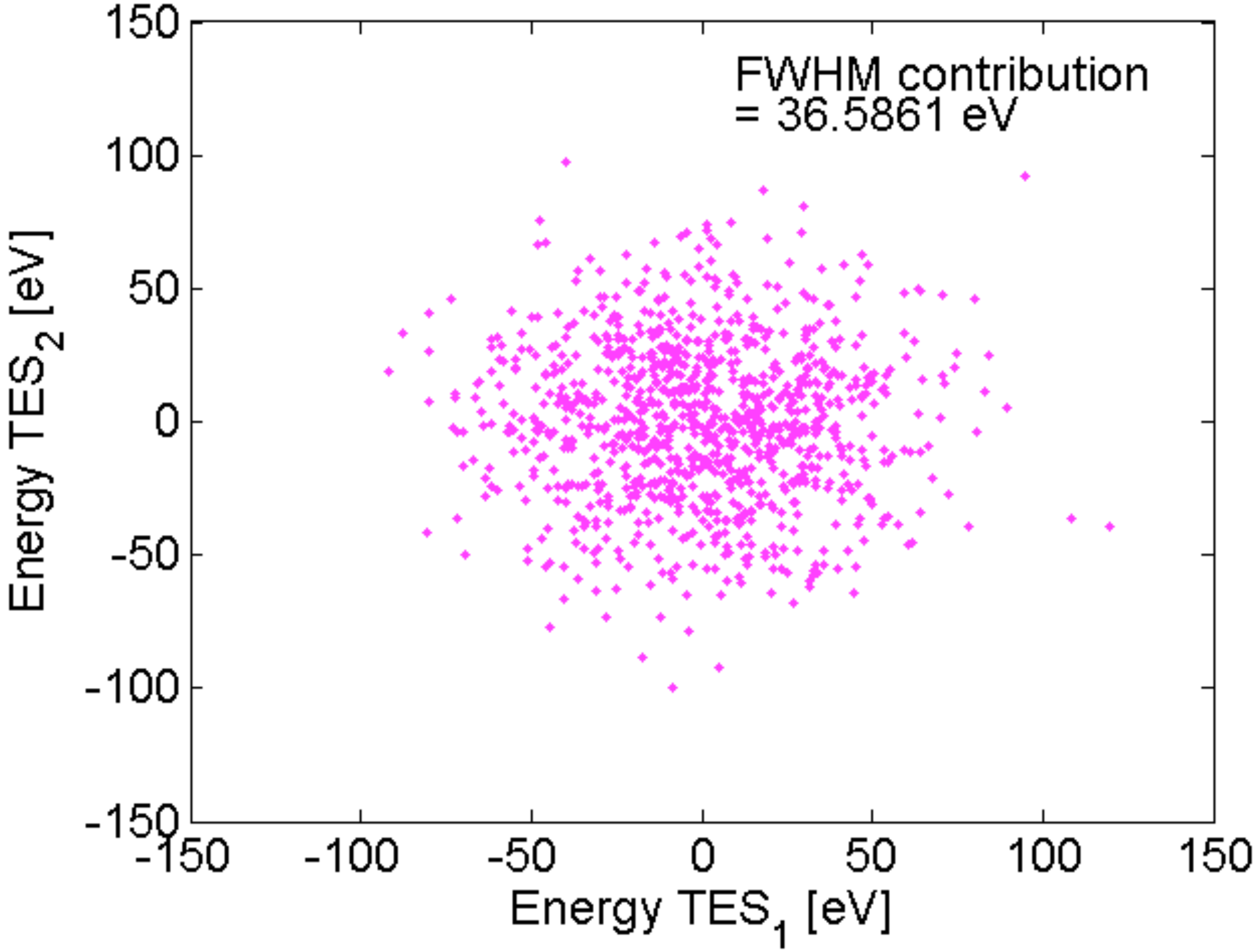
Noise FWHM Effect



Fano Factor

$$\sigma = \sqrt{F \times E / \varepsilon_0}$$

$$\sigma = \sqrt{0.08 \times 5900[\mathrm{eV}] / 3.8[\mathrm{eV}]}$$

- X-rays absorbed → electron—hole pairs produced.
- Average 3.8eV of energy for their production.
- Their fluctuation however is no Poisson, but modified by the Fano factor.

Phonons

$$\sigma = 1.2[\mathrm{eV}] \times \sqrt{0.08 \times 5900[\mathrm{eV}] / 3.8[\mathrm{eV}]}$$

- These electron—hole pairs shed energy until they reach the velocity of sound.
- Their gap energy then dominates ~1.2eV.

Full-Width at Half-Maximum

$$\Delta E_{FWHM} = 2.355 \times 2 \times 1.2[\text{eV}] \times \sqrt{0.08 \times 5900[\text{eV}] / 3.8[\text{eV}]}$$
$$= 63[\text{eV}]$$

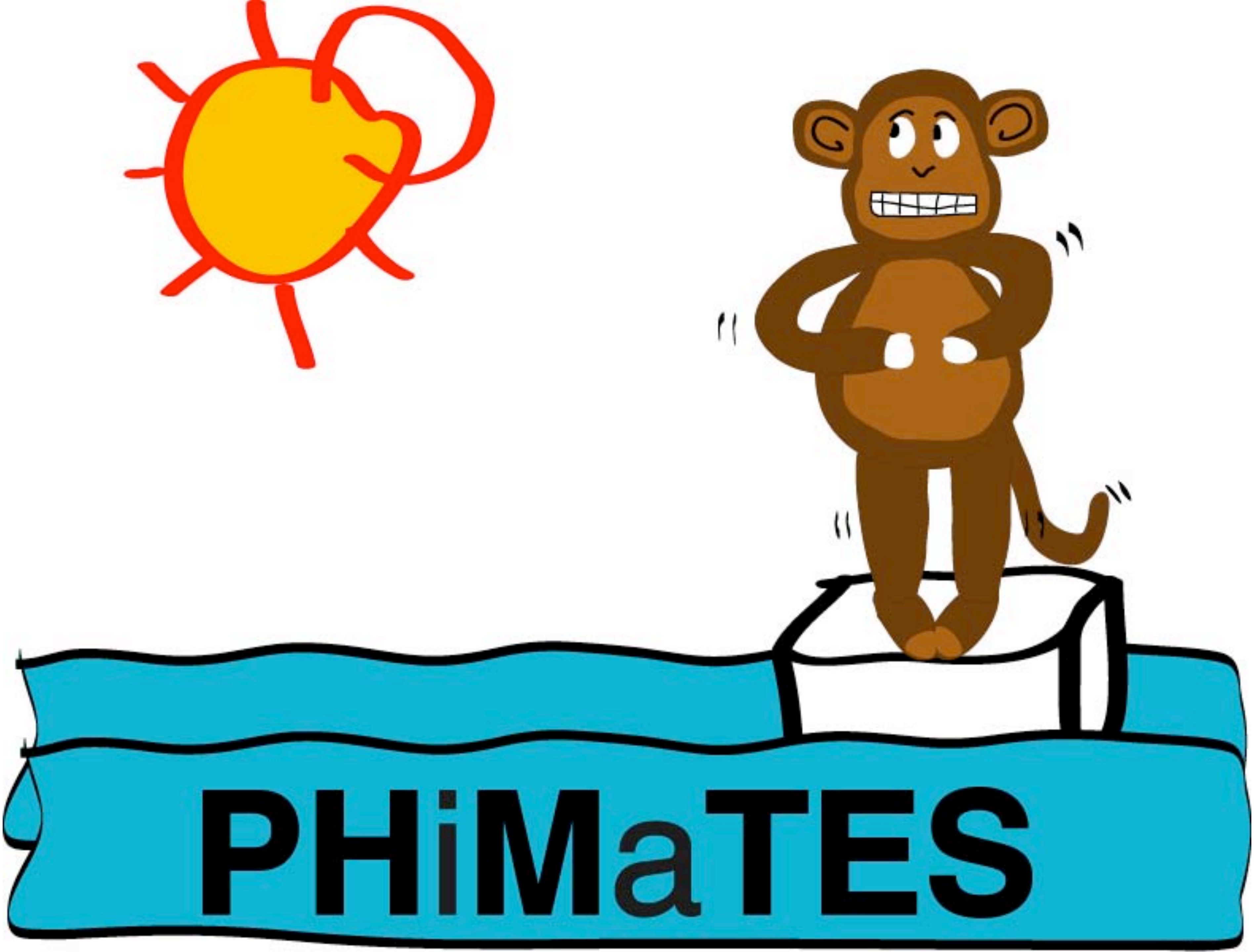
$$\sqrt{63^2 + 37^2} = 73 \approx 80$$

- ~2 calibration factor.
- 2.355 to convert to FWHM.
- 68% of energy initially goes into phonons. 76% could be absorbed in completely trenched TESs.
- Could this suggest the electron—hole pairs are not releasing their energy in the detector?

Trap Concentrations

- Penn / Dougherty
  - 8,000 Ω cm
  - 10^{13} traps / cm^3

- Us
  - 10 Ω cm
  - 10^{16} traps / cm^3


PHiMaTES