The Development of Coplanar CZT Strip Detectors for Gamma-Ray Astronomy

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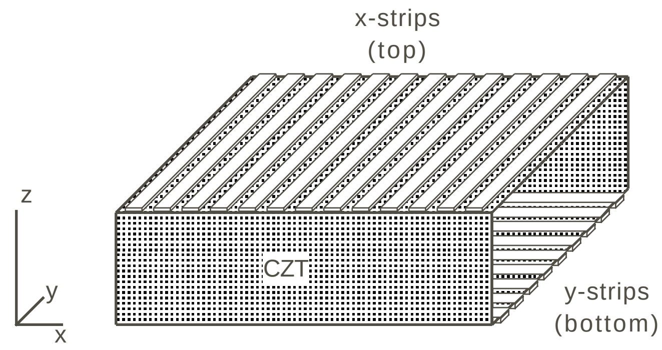
Traditional CZT Strip Detectors



Concept

• Uses orthogonal strips on opposite sides of the detector.

• One set of parallel strips collects holes; the other collects electrons.

Advantages

• Effectively provides N^2 pixels with only 2N electrical channels.

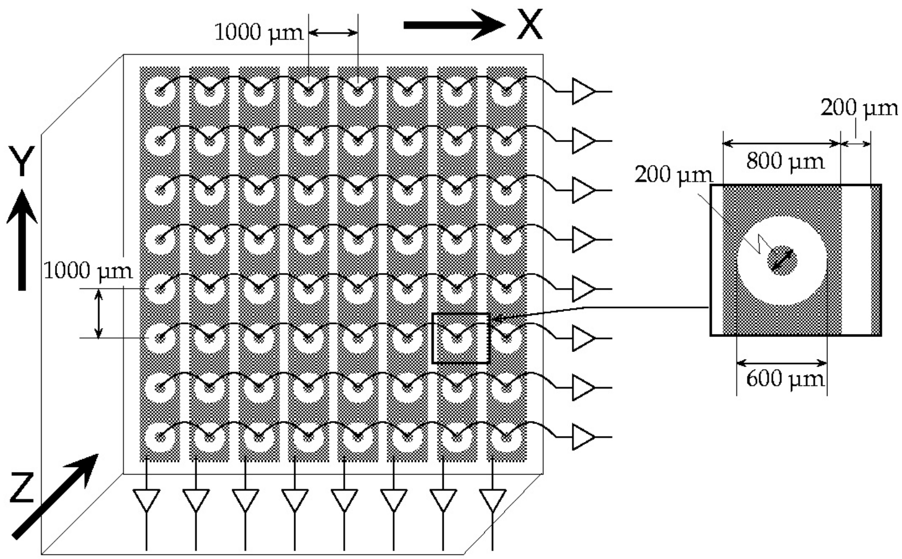
• Considerably reduces complexity and power requirements.

Disadvantages

• Effective detector thickness is limited by hole trapping to a few mm.

• Requires signal connections to both top and bottom surfaces.

Orthogonal Coplanar Anode Design



Concept

• Both sets of orthogonal "strips" on same side of detector.

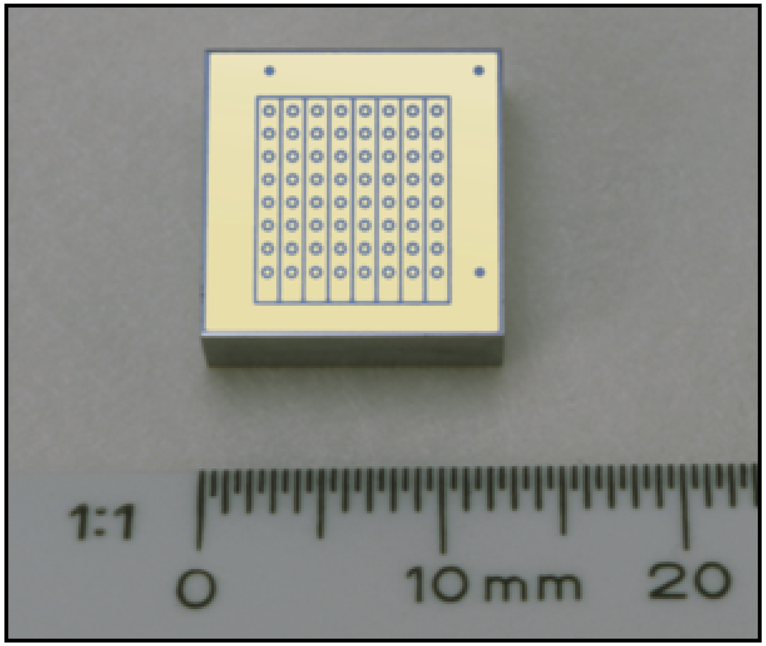
• Rows of interconnected "pixels" collect electrons.

• Orthogonal strips, at slightly different bias, act as steering electrodes and register induced-charge signals.

• Pixel row signals can be interpolated to get sub-pitch Y-coordinate.

• Strip signals can be interpolated to get sub-pitch X-coordinate.

Orthogonal Coplanar Anode Design



CZT substrate with gold anode contact pattern.

Advantages

• Provides N^2 pixels with only 2N electrical channels.

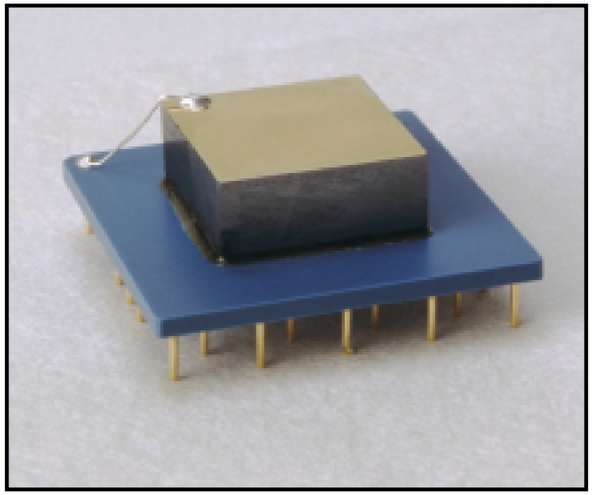
• Considerably reduces complexity and power requirements.

• Electron-only device.

• Permits thicker detectors (> 1 cm). Limited by electron mobility.

• All signal connections on one side $\Rightarrow$ close-packing.

Prototype CZT Detector Modules



Prototype detectors have been fabricated and tested

• 5 mm thick CZT substrate (single-crystal, discriminator grade, eV Products)

• Gold anode contact pattern provides an 8×8 array of 1 mm “pixels”.

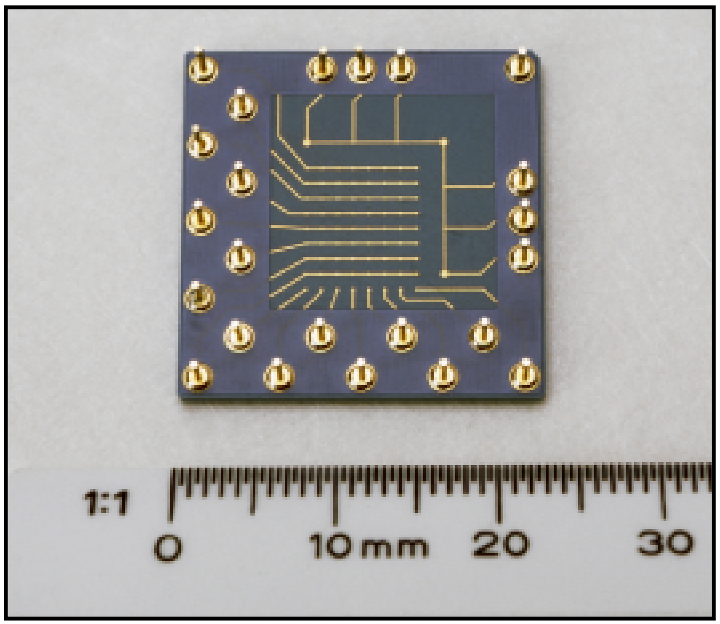
Assembly of prototype detectors involves two key technologies

• Low-Temperature Co-fired Ceramics (LTCC)

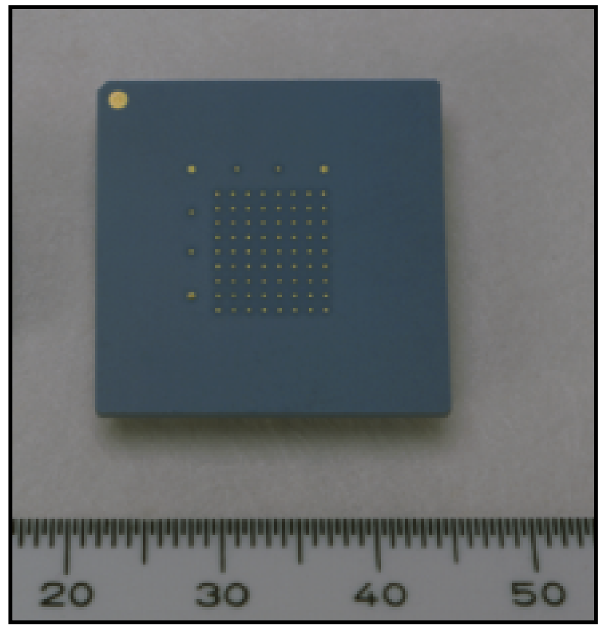
• Polymer Flip-Chip (PFC) Bonding (no wire bonds)

Low-Temperature Co-fired Ceramics

- Substrate fabrication featuring 170 μm filled vias for electrical connections.
- Provides low leakage under HV bias.
- Has thermal expansion coefficient similar to that of CZT.



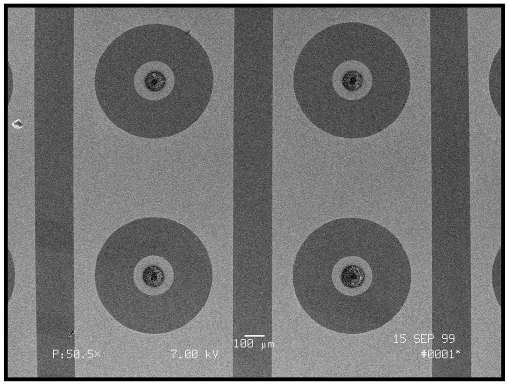
Underside of LTCC carrier showing electrical connections.

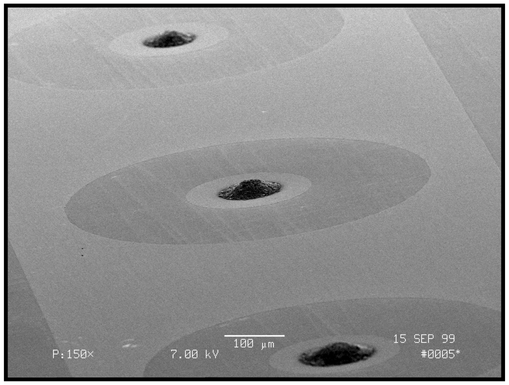


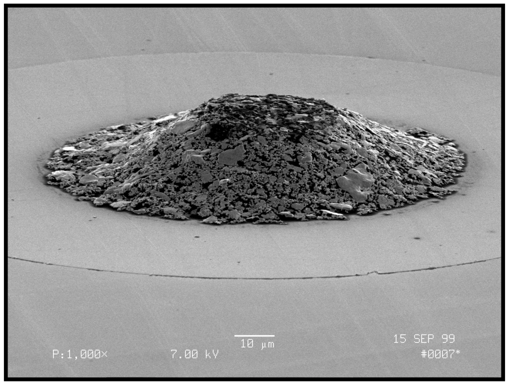
Topside of LTCC carrier that is bonded to CZT.

Polymer Flip-Chip Bonding

- A low-temperature bonding process (T < 80° C).
- Conducting polymer bumps are stencil printed on CZT and the LTCC carrier.
- Bumps are 120 µm diameter and 20 µm high.
- A non-conducting epoxy is used as an underfill between the mating surfaces.
- Underfill provides both a strong mechanical assembly and thermal isolation.



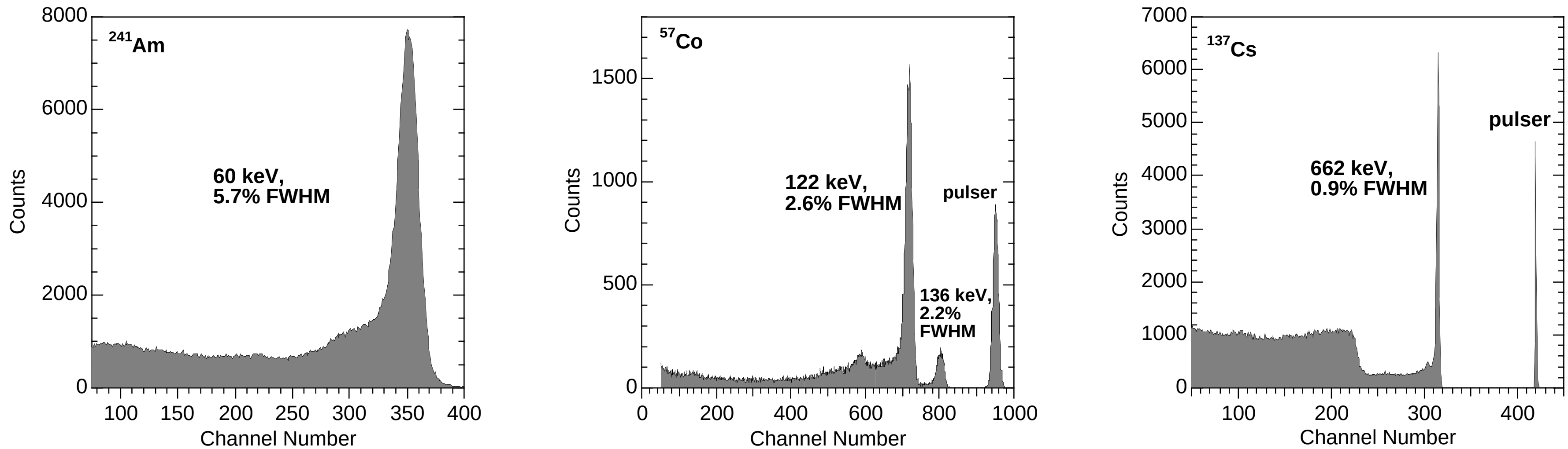




SEM photos showing polymer bumps on the patterned CZT substrate

Single "Pixel" Spectra

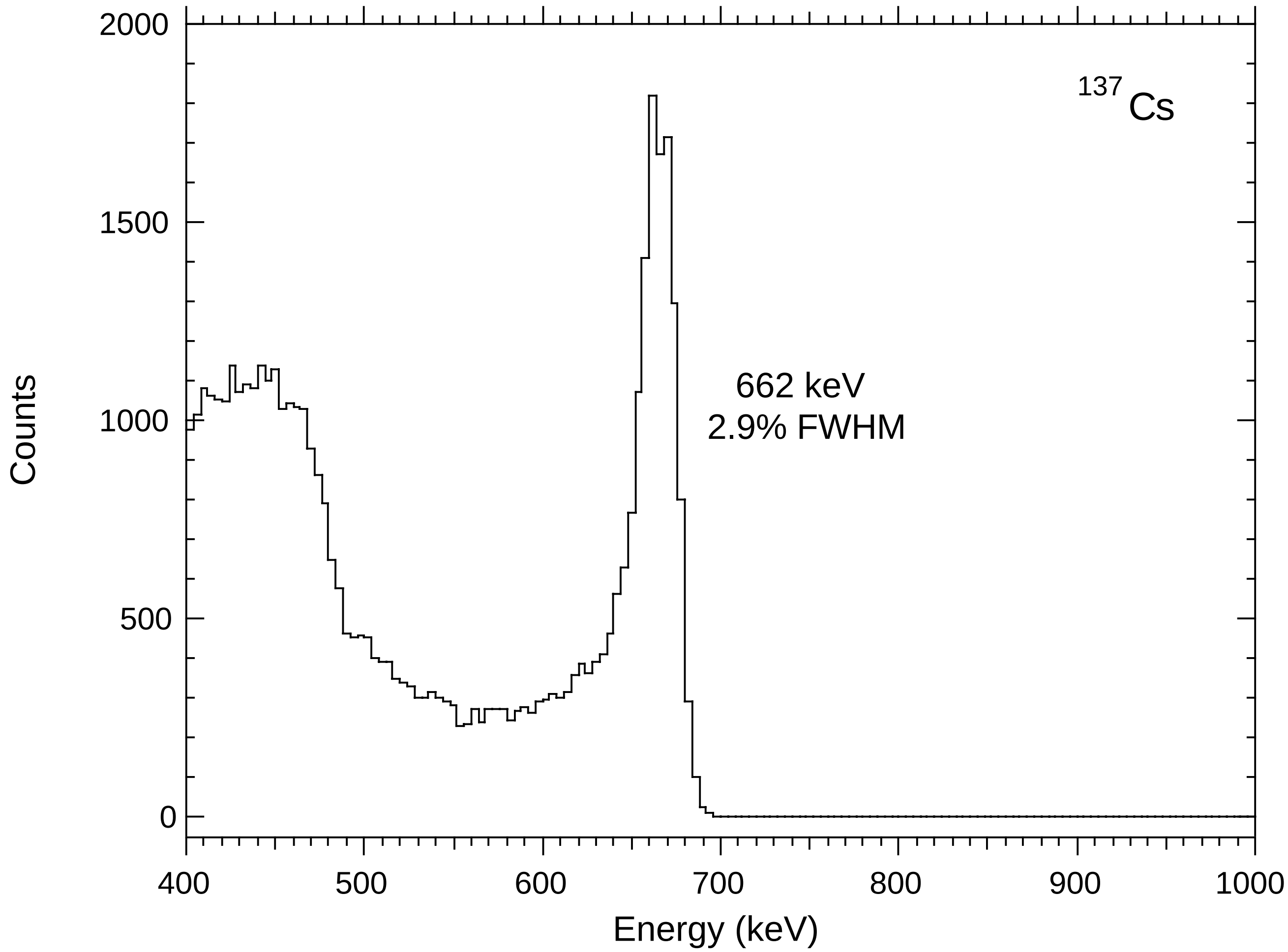
- Required coincidence between one strip and one pixel row.
- Bias levels: cathode = –800 V, anode pixels = 0 V, anode strips = –30 V.
- Measured FWHM resolutions are 3.4 keV (at 60 keV), 3.2 keV (at 122 keV), and 6.0 keV (at 662 keV).



"Bulk" Spectrum

Spectrum generated from the full detector volume.

Bias levels: cathode = –550 V, anode pixels = 15 V, anode strips = 0 V.



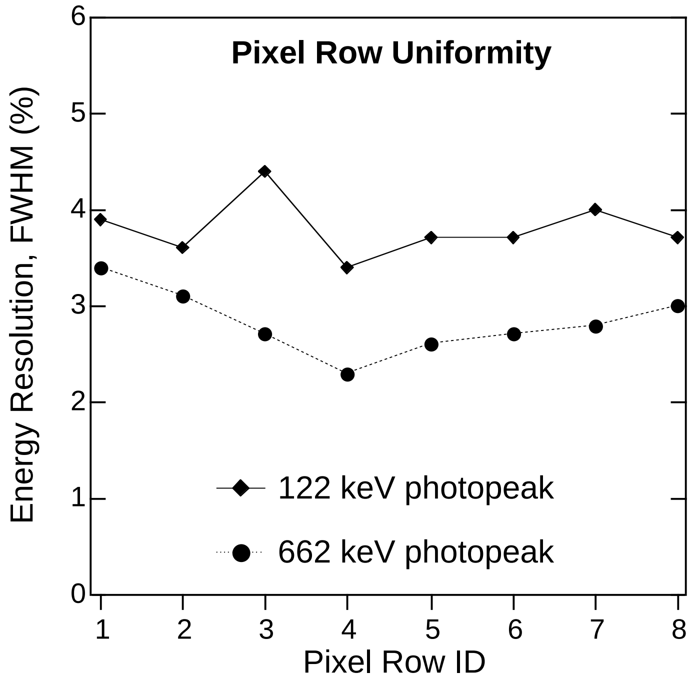
Response Uniformity

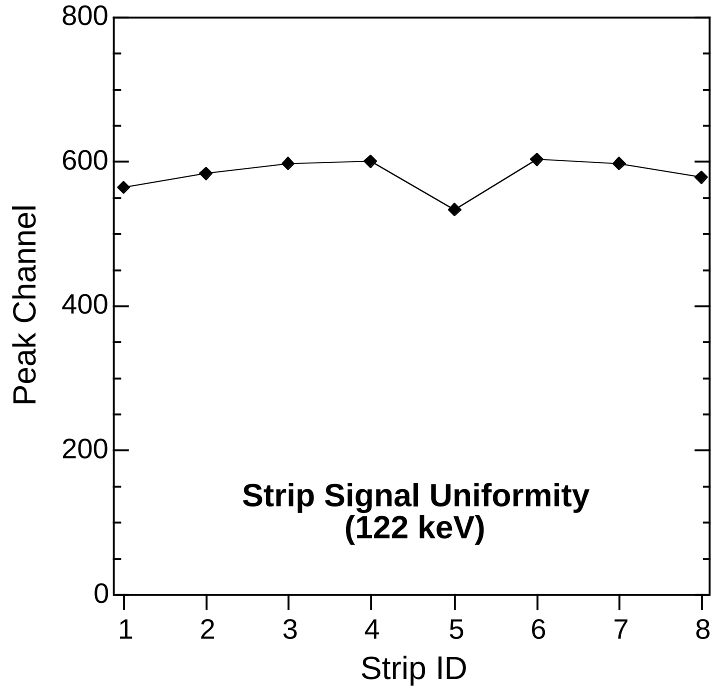
Uniformity measurements :

1) Energy resolution at 122 keV and 662 keV for each pixel row.

2) Signal pulseheight (at 122 keV) for each strip.

These data indicate that the detector fabrication yielded reliable interconnections for all 64 "pixels".

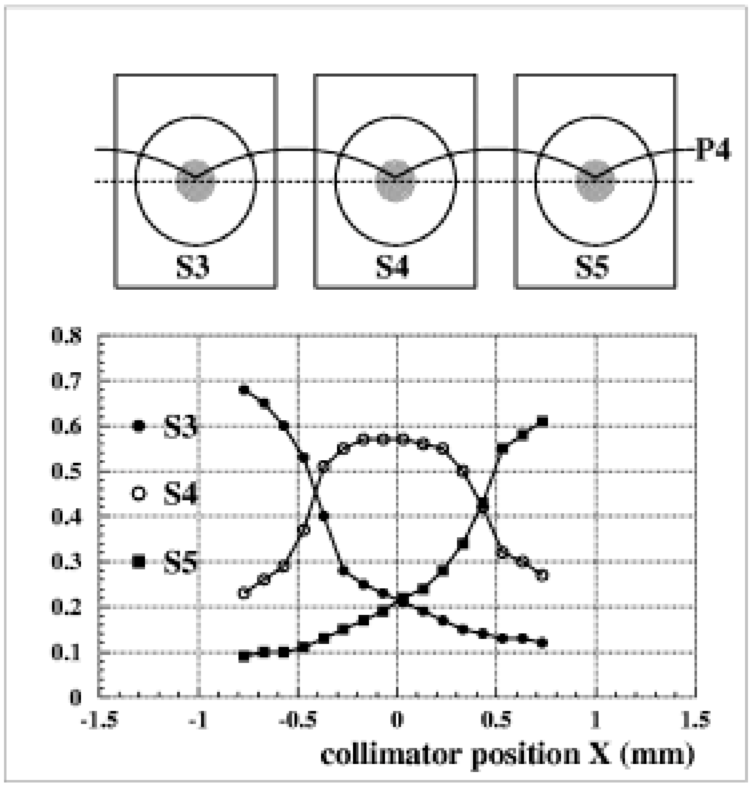


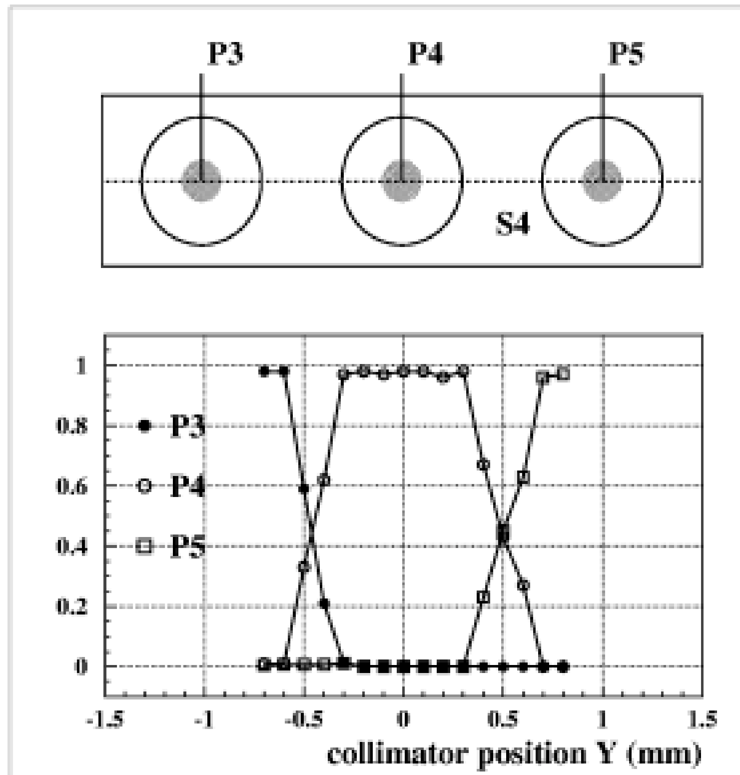


X-Y Spatial Resolution

Charge sharing between adjacent strips permits sub-strip spatial resolution in X.

Limited charge sharing between pixels reduces the ability to interpolate in Y.





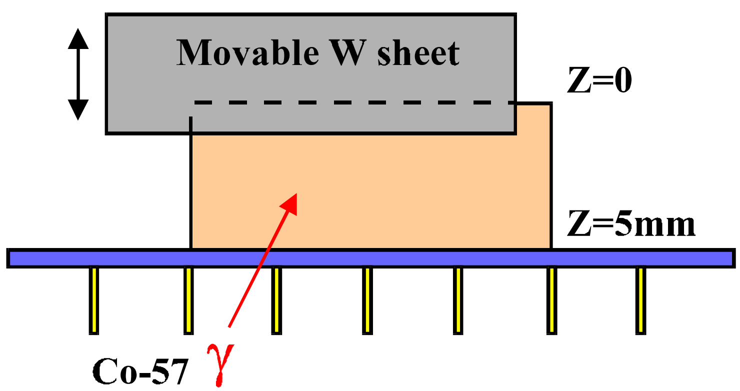
Lab measurements with a collimated alpha source.

Depth Measurement

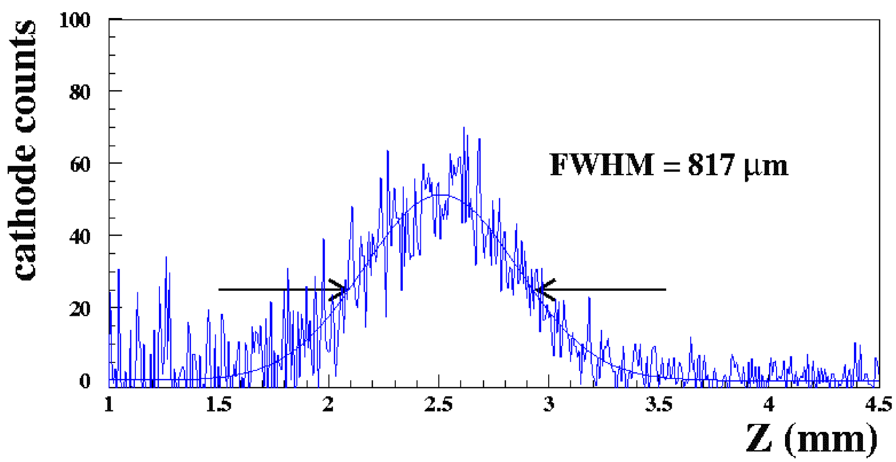
Using both the cathode and anode signals, the interaction depth is given by,

$$z = \left(1 - \frac{cathode\ signal}{pixel\ signal}\right) L$$

where *L* is the detector thickness (= 5 mm in our prototypes).

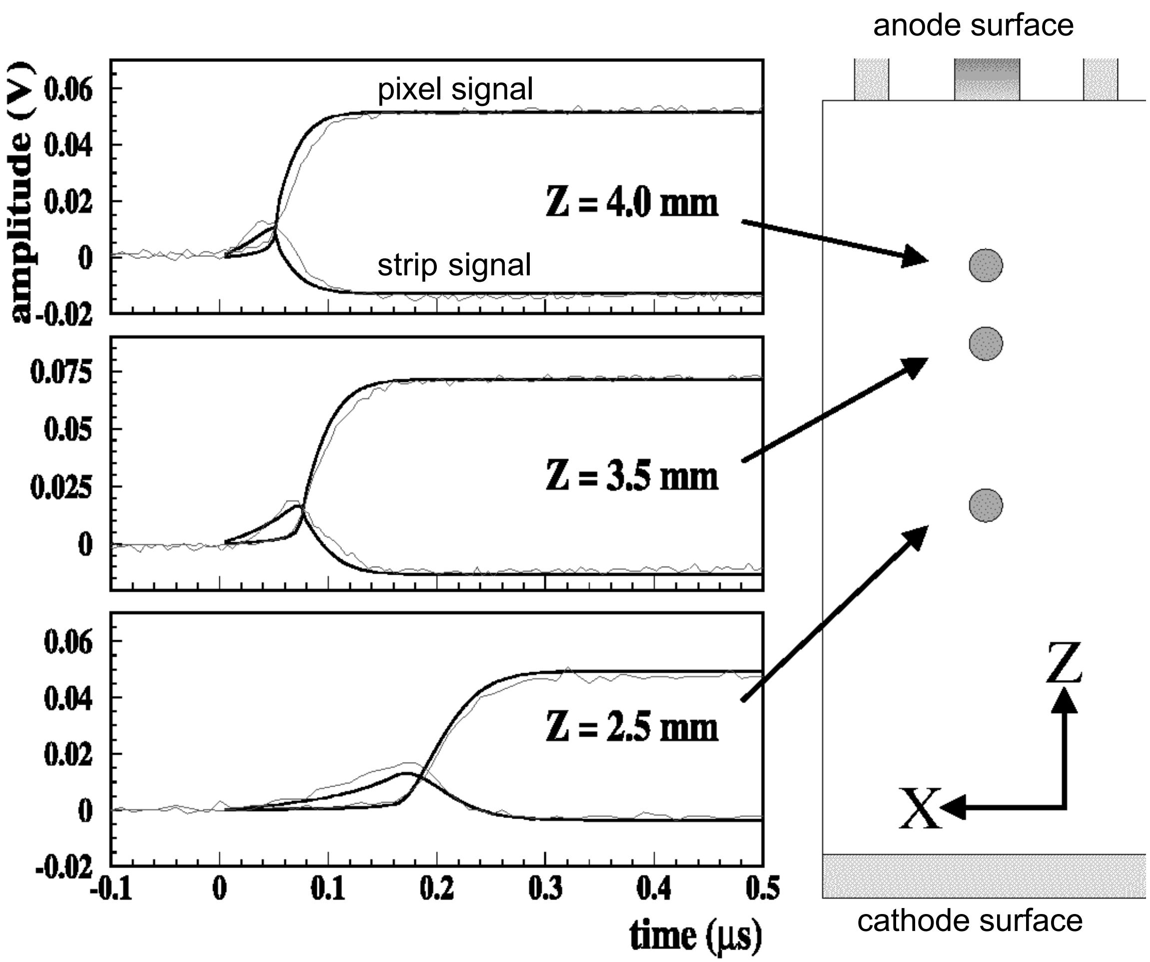


Measurements with a Tungsten sheet at two different *Z*-positions differing by 500 μm.



The difference between the two depth distributions yielded an effective slit measurement.
$\sigma_z \approx 350$ μm.

Measured and Simulated Signals

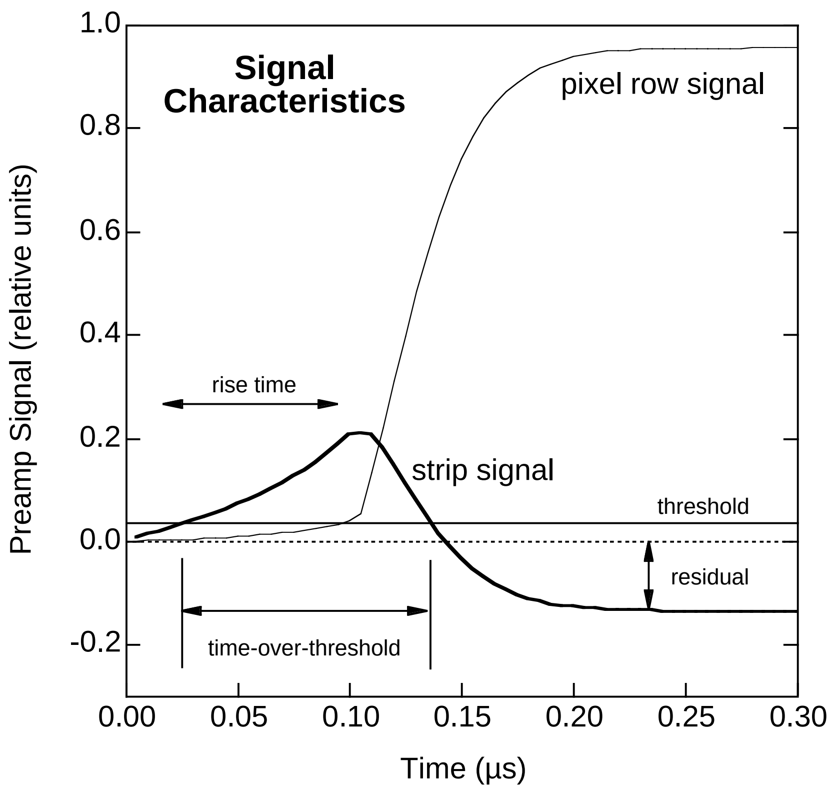


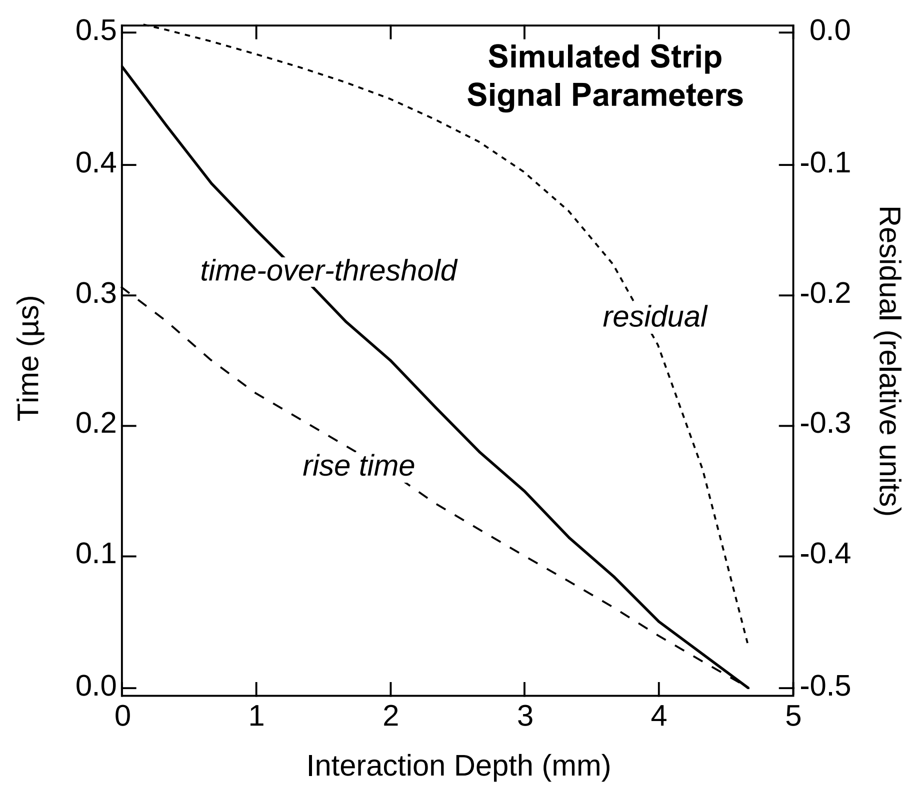
Simulated signals compare well with measured data.

Here are seen comparisons for signals at three different depths within the detector.

Signal Characteristics

The characteristics of the anode strip signals can be used to define a measurement of the interaction depth without the cathode signal.



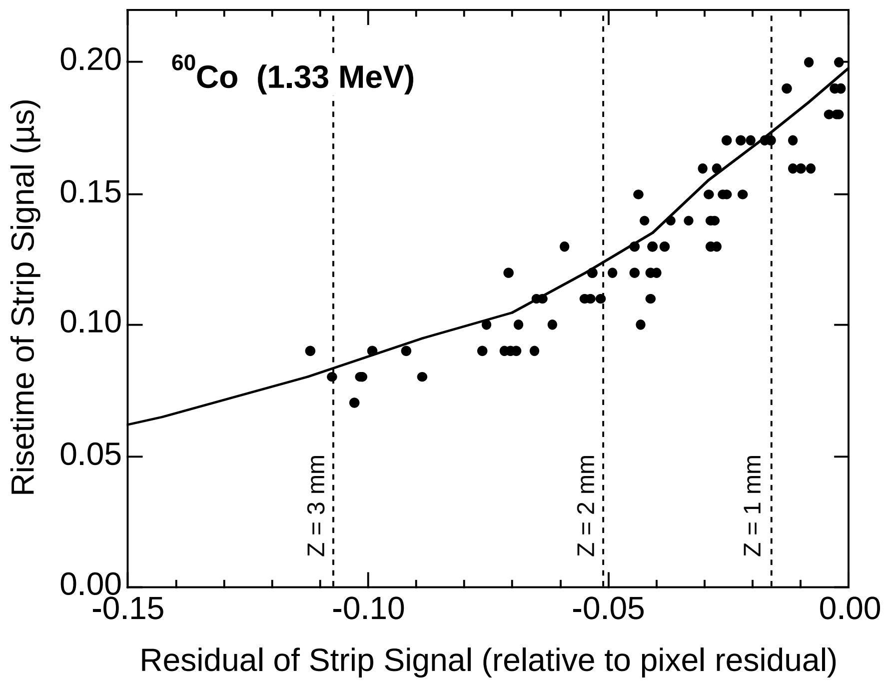


Measurements of Strip Signal Parameters

The plot below shows the measured relationship between the strip signal risetime and the strip signal residual.

The solid line represents the relationship expected based on simulations.

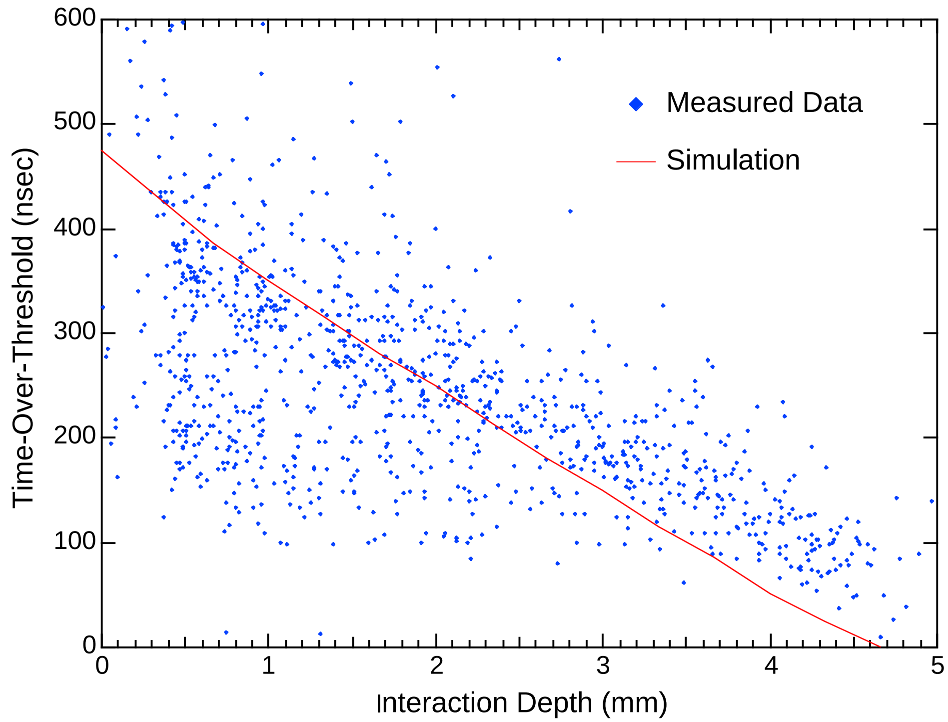
These data support the claim that depth measurements will be possible using just the anode signals.



Time-Over-Threshold vs. Depth

We have chosen to explore the use of the time-over-threshold (TOT) of the strip signal for determining the interaction depth.

An analog circuit design has been developed to measure TOT.



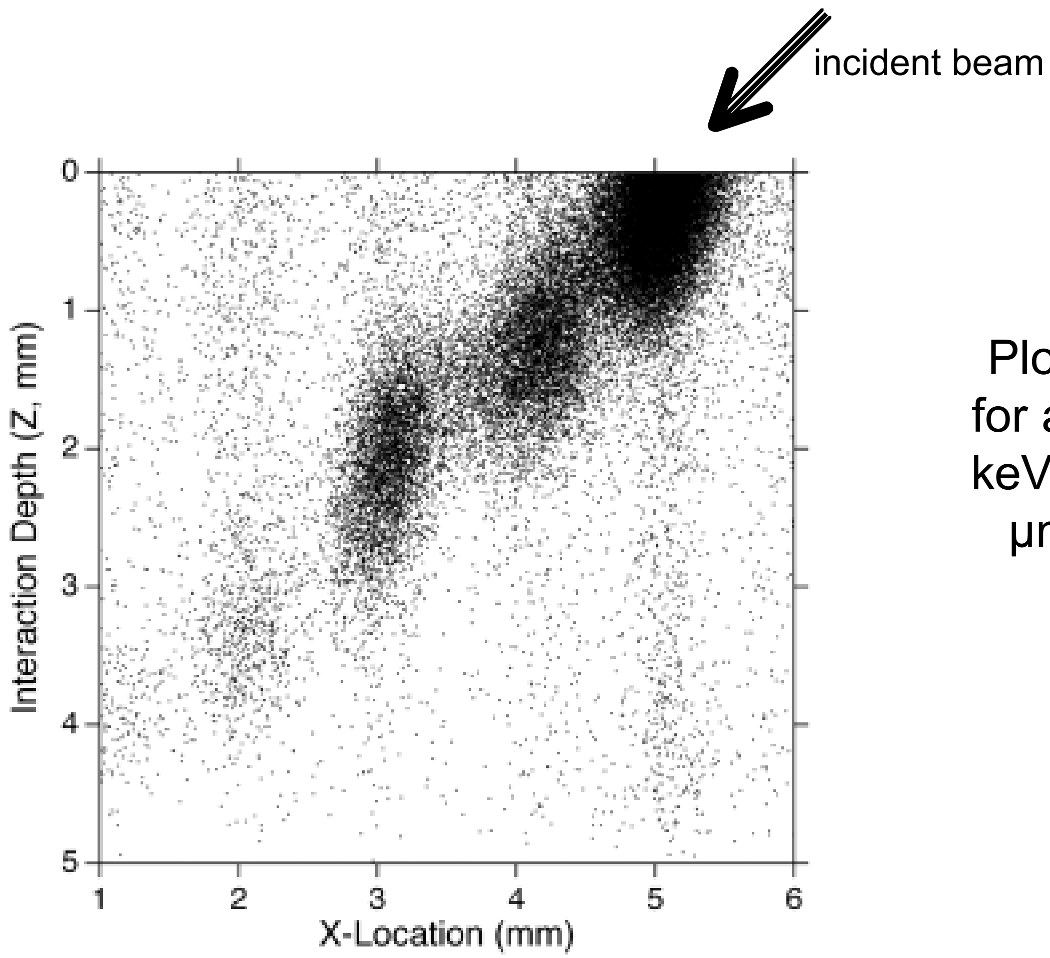
Event trigger came from a single pixel row with no coincident strip requirement.

Lack of a strip coincidence requirement introduces events from adjacent "pixels".

These data were collected using a prototype TOT circuit, measuring a single strip.

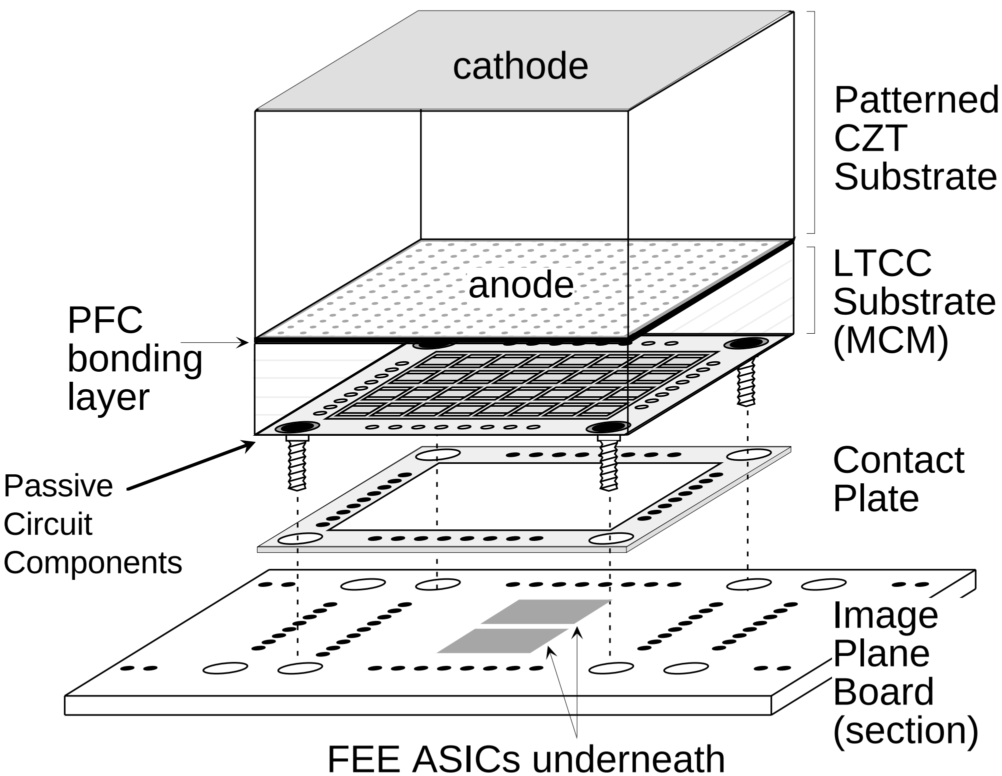
Three-dimensional Imaging

A VME-based DAQ system (developed at the Univ of Montreal) provides readout of all signal channels.



Plot of interaction locations for a collimated beam of 122 keV photons (spot size ~200 μm) obliquely incident on cathode surface.

Conceptual Module Packaging Design



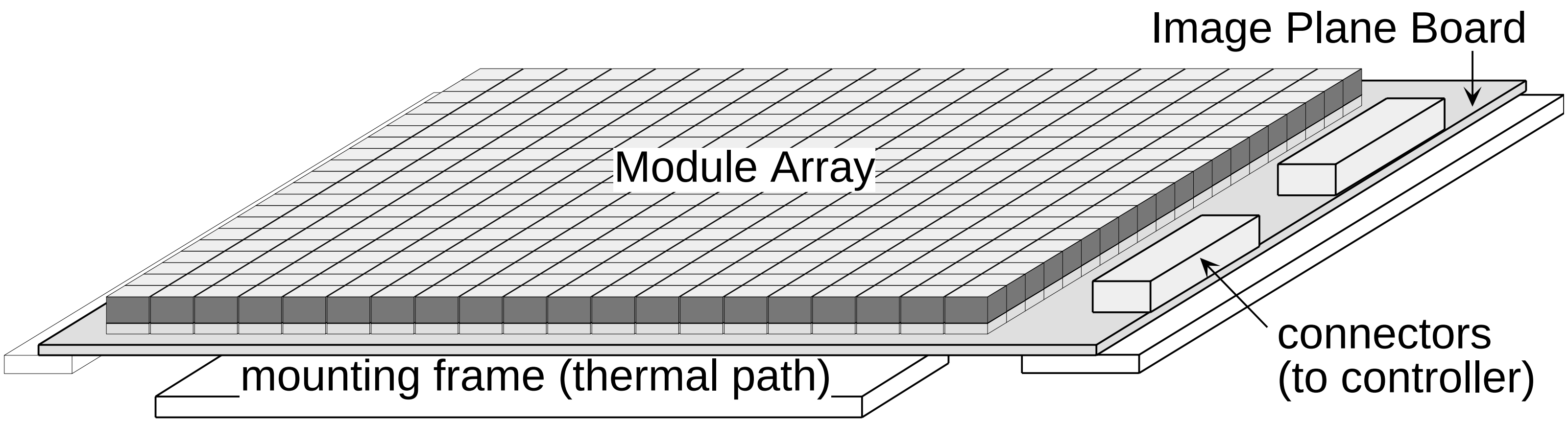
The current concept for the packaging of a single CZT module is based on experience with the prototype.

The concept involves a single module with 16 × 16 (256) logical pixels (32 channels) on a 1 mm pitch (2.56 cm^2 active area).

All front-end electronics will fit within the foot-print of the CZT substrate.

Closely-Packed Array of CZT Modules

The module design will provide a packing fraction of ~90-95%.



An array of 20 $\times$ 20 modules with a total active area of 1024 cm^2.

Total power of 26 W for 12,800 channels, assuming 2 mW/channel
(vs. 205 W for a 102,400 channel pixellated array).

Current Status and Future Efforts

We have successfully demonstrated the viability of a coplanar anode design for CZT strip detectors.

We have developed a compact, reliable packaging concept that will permit the fabrication of large-area closely-packed arrays.

Future efforts will be focused on:

- optimizing the anode design using simulation tools.
- fabrication and testing of thicker (10 mm) prototypes.
- continued development of circuitry to process the bipolar strip signal for the depth measurement.
- ASIC development.
- continued packaging development.
- studying the effects of multiple interaction sites at higher energies.
- evaluating the ability to measure incident photon polarization.