Max-Planck-Institute for extraterrestrial Physics

Development of Silicon Strip Detectors for a Medium Energy Gamma-ray Telescope

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Abstract

We report on the design, production, and testing of advanced double-sided silicon strip detectors under development at MPE as part of the *Medium Energy Gamma-ray Astronomy (MEGA)* project. The detectors are designed to form a stack, the tracker, with the goal of recording the paths and energies of energetic electrons produced by Compton-scatter and pair-production interactions. We show results for a laboratory tracker prototype.

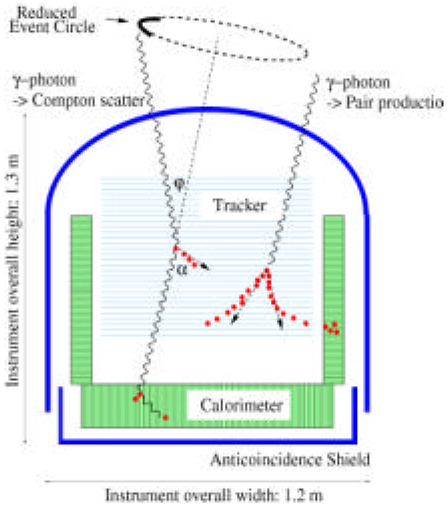
MEGA: Principles of Operation

•Goal of MEGA: To provide sensitive astronomical observations from **0.4-50 MeV**

•MEGA employs a **tracker** and **calorimeter** to image Compton-scatter and pair-production events

•**Compton-scatter** events: Incident photon scatters off an electron in the tracker. The scattered photon is absorbed in the calorimeter. The incident angle φ is determined from the Compton equation. For large scatter angles the recoil electron is tracked in the tracker to constrain the incident direction.

•**Pair-production** events: Incident photon converts into an electron-positron pair in tracker. Both particles are tracked to determine the incident direction. Particles are absorbed in the calorimeter to determine energy.

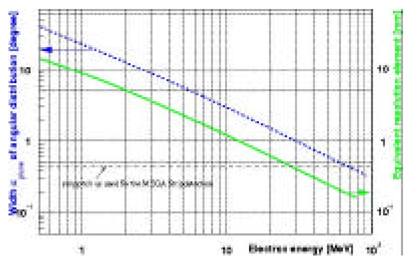


Measurement principles of the MEGA telescope.

Requirements for the Tracker

Position Resolution:

1) The tracker must accurately measure the tracks of electron-positron pairs. The accuracy is ultimately limited by small-angle scattering in the detector material. Thus the position resolution need not be finer than the average scattering in each layer. The graph at right shows the standard deviation of an electron´s path due to Moliere scattering after traversing 250 µm of silicon (blue), and the resolution element that would record the same stdev at a distance of 10 mm (green).



2) The tracker must record the position of Compton-scatter interactions, which are localized. Therefore each layer must measure position in two dimensions.

A resolution of 0.5 mm is sufficient below 30 MeV.

Energy Resolution:

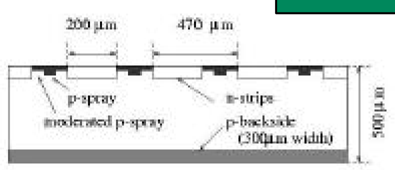
The tracker must record the energy imparted to the recoil electron in Compton-scatter interactions. From the Compton equation, the reconstructed photon incidence angle depends on the tracker energy accuracy. A fundamental limit to the accuracy of the incident direction stems from the unknown momentum of the electron in its atomic shell, which produces a *Doppler broadening* of the reconstructed scatter angle. The table below shows the equivalent energy resolution which would produce the same uncertainty as the Doppler broadening. The tracker energy resolution need not be finer than this. **The energy resolution of large silicon strip detectors, 10-15 keV FWHM, is only slightly worse than this.**

Energy of the primary photon [keV]	140	511	1000	2000	5000
FWHM of the Doppler-broadened Scatter angle distribution **[degree]** For Untracked/Tracked events.	2.1 / -	0.65 / -	0.3 / 0.5	0.15 / 0.25	0.1 / 0.15
Equivalent energy resolution **[keV]** For Untracked/Tracked events.	**1.5 / -**	**2.1 / -**	**2.4 / 4.5**	**3.5 / 6.5**	**3.7 / 9.0**

Time Resolution:

The tracker must provide a fast timing signal for a coincident trigger with the calorimeter. Because no time-of-flight measurement will be attempted, the charge-collection time in thin silicon (50-100 ns) is sufficient.

MEGA Strip Detector Design



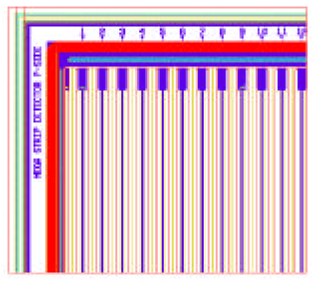
•6cm x 6cm, 500 µm thick, 128 orthogonal p and n strips on opposite sides

•n-side strips separated by p-spray implantation

•AC coupling on wafer via metal strips on an oxide/nitride insulating layer

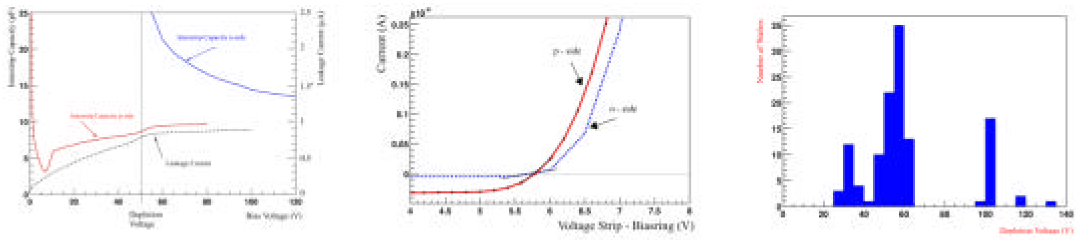
•Punch-through biasing across gap between strips and common bias ring

•Multiple guard rings on p-side



Layout of strip detector, p-side

Individual Wafer Results



Interstrip Capacitance:

The capacitance was measured between adjacent strips as a function of bias voltage. For the p-side the capacitance is independent of bias and in agreement with simulations (9 pF). Simulations also indicated an n-side capacitance of 9 pF, which is not measured. The slow decrease with bias above depletion may indicate a slow depletion of the p-spray region. Simulations predict a capacitance between strips and backside of 5.5 pF.

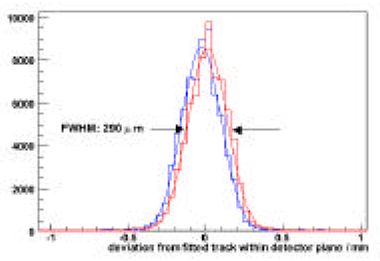
Punch-Through Biasing:

The dynamic resistance of the punch-through contacts was measured to be 11 MΩ on the p-side and 50 MΩ on the n-side. This bias resistance is high enough to be negligible for noise considerations.

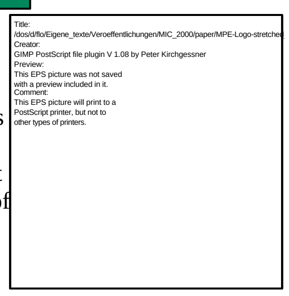
Depletion Voltage:

The wafers were found to have different depletion voltages. The variation of depletion voltages has to be carefully taken into account, as several wafers are mounted within the same layer. Wafers from the same production batch have similar depletion voltages, indicating the differences stem from variations in the starting material´s resistivity.

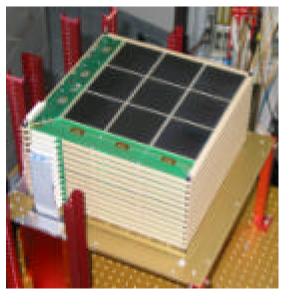
Tracker Layer Results

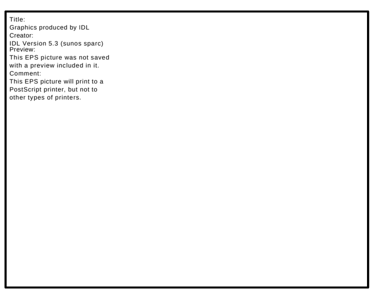


Left: The tracker position resolution was measured using muon tracks (red=p-side, blue=n-side). Interpolating between strips where applicable allows sub-strip pitch resolution. **Right:** Shadow mask image at 122 keV showing the imaging capability of the MEGA strip detectors.



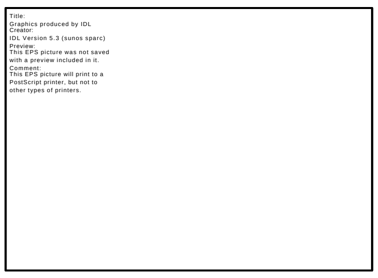
Right: Assembled prototype tracker. Each layer consists of 9 wafers wire-bonded together into a 3x3 array and read out by a 128-channel TA1.1 ASIC. The p-side readout chips are on the left, with the n-side chips on the underside at the front.





Left: Measured noise for 7 layers at 3 temperatures, compared with calculated values. The p-side (open circles) is in good agreement, while the n-side (closed circles) is a factor of 2 high.

Below: Co-57 spectra measured at 2 temperatures with one layer. Photopeak FWHM values are 15.7 keV at 21°C and 10.3 keV at 8°C. No cuts were applied to the data, but signals from neighboring strips were combined.



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