Mapping the Asymmetry in the SAA Fluxes Using the Medipix Particle-by-Particle Directional Information

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0.5s in South Atlantic Anomaly, Wed Apr 02 2014
12:24:03 Dose Rate = 30 uSv/hr

Pixel (x)

Pixel (y)

Energy (keV)

Slow Proton

Fast Proton

Fast Alpha

Probably…
Calculation of Track Angles in Timepix

• $4\pi$ view of sky, $1\pi$ discrimination (slope cannot tell up from down, projection of a line symmetric around 180 degrees)

• Assumption of sensor penetration for slope, work on corrections for stopping protons in progress.
Slope Calculation for Heavier Tracks

where $TOT$ is the recorded number of Counter-Clock pulses, $E$ is the energy deposited in the detector that resulted in the charge collected by the pixel and $a$, $b$, $c$ & $t$ are the 4 parameters that need to be determined for each pixel. Equation 3 can be inverted to yield the Energy as a function of the $TOT$ value.

3. Incident angle estimation

When an energetic particle penetrates the detector layer, electrons and holes liberated along the particle's track drift in the electric field of the depletion bias voltage, diffusing both laterally and horizontally with respect to the field. The diffused charge will generally spread out over multiple pixels creating a cluster of pixels associated with a single event. This spreading follows an interesting pattern: the shape and energy intensity at pixels provide precise information about the azimuthal direction and the angle of incidence with respect to the normal direction. However, one cannot simply fit the shape with a certain model -- such as an ellipse -- and determine the angle resolution based on the elongation. The existence of energetic $\delta$-rays, the heightened recombination of electrons and holes in regions with very high levels of ionization (the so-called "plasma effect") [6], and the effects of producing variations with different bias-voltage and source of charged particles [2][3], make the incident angle difficult to estimate accurately.

By looking carefully into the structure of clusters, we were able to identify three main components: a core part at the center of each cluster, the region immediately surrounding the core, called "skirt", and an $\delta$-ray part which comes from recoil electrons liberated from the ionization process (Figure 4).

The core contains most of the pixels with high energy, as it is the area where charges are collected from multiple overlapping electrons along the traversed path. The skirt contains low energy pixels, where electron densities are low. The core and the skirt part constitute the primary track or continent, the $\delta$-ray part can be considered in the geographic analogy as peninsulas connecting to the continent.

The $\delta$-ray part also contains low energy levels that provide hints on the velocity or energy of the $\delta$-rays in their length and total energy. The $\delta$-rays begin deep within the core and emerge through the skirt, and they can be distinguished clearly if the energy of incident particle is high enough.

![Figure 4. Cluster’s components](image)

The tails of $\delta$-rays do not play an important role in calculating angle resolution, and were removed using a morphology operator. This operator iteratively removes low energy pixels with few neighbors.

We determined an azimuthal direction of the track by employing a linear regression technique to fit a line over all remaining pixels that belong to the core and skirt parts. We applied this technique several times with different thresholds of energy and obtained an average to determine a slope along the "major direction" of the track. A "minor direction" can be easily obtained by finding a line perpendicular to this major direction. We projected all remaining pixels onto the major and minor axes.

$$\tan (\phi) = \frac{55}{T} \left( \text{major} - \frac{\text{minor} - 1.5}{\text{major} + 1} \cdot \text{minor} \right)$$

“LET Estimation of Heavy Ion Particles based on a Timepix– Based Si Detector”, Hoang et al (2012)
Caveats - Limitations of Angular Discrimination

- Limits of around 15 degrees on $\theta$ for low $\phi$
- Detectors move around
- Detectors change their view of the sky

Angular space wraps in the timepix

Low $\phi$ (perpendicular) tracks (poor $\theta$ discrimination)

High $\phi$ tracks (good $\theta$ discrimination)
SAA Angular Distributions
1st April 2014

Angular distribution of tracks - SAA Frames, April 1 2014, REM J02

Angular distribution of tracks - SAA Frames, April 1 2014, REM D03

Angular distribution of tracks - SAA Frames, April 1 2014, REM J02

Angular distribution of tracks - SAA Frames, April 1 2014, REM G03

500 um unit
One Pass, April 1st 2014

ISS Position 1/4/2014 11:35

Dose Rate Profile

Latitude
Longitude (Deg)

Dose Rate (uSv/hr)
Elapsed Time (s)

Angular Profile of Particles - Sinusoidal (Area Preserving) Projection

Equirectangular Projection

Azimuth (Deg)

Altitude (Deg)
One Pass, April 1st 2014
One Pass, April 1st 2014
One Pass, April 1st 2014
One Pass, April 1st 2014
One Pass, April 1st 2014

ISS Position 1/4/2014 11:41

Latitude
Longitude (Deg)

Dose Rate Profile
Dose Rate (uSv/hr)
Elapsed Time (s)

Angular Profile of Particles - Sinusoidal (Area Preserving) Projection
Azimuth (Deg)
Altitude (Deg)

Equirectangular Projection
Azimuth (Deg)
Altitude (Deg)
One Pass, April 1st 2014

ISS Position 1/4/2014 11:42

Latitude

Longitude (Deg)

Dose Rate Profile

Dose Rate (uSv/hr)

Elapsed Time (s)

Angular Profile of Particles - Sinusoidal (Area Preserving) Projection

Azimuth (Deg)

Altitude (Deg)

Equirectangular Projection

Azimuth (Deg)

Altitude (Deg)
One Pass, April 1st 2014
One Pass, April 1st 2014

- SAA associated with change in average angle
- Average theta for GCR (~5 degrees) - offset
- Average GCR phi 40 degrees) - should be 45
Angle and Dose Rate

- SAA associated with change in average angle
- Average theta for GCR (~5 degrees) - offset
- Average GCR phi 40 degrees) - should be 45
Average (absolute) Theta Angle, Unit J02 (Columbus Module), 1st-5th April 2015
Dose Rate Correlations

Daily Dose Rates (April 2014)

- SAA (uGy/day)
- Total (uGy/day)
- GCR (uGy/day)

Angle (Deg)

DOM (April 2014)

Angle(Deg)

DOM (April 2014)
Mean Chord Lengths
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