Particle Energy Calibration of Timepix Detector

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NASA Active Radiation Sensor Requirements

• Timepix selected to be the main technology used for future exploration missions’ radiation monitoring (NASA dedicated to use technology next 10 – 20 years)

• Accurate, reliable dosimetry of energetic electrons, protons, and higher-Z ions

• Accurate, reliable measurement of energetic particle flux

• Accurate, reliable measurement of LET spectra (dE/dx)
  • Requires accurate measurement of both dE and dx
NASA/JSC Team and Efforts Using Timepix Technology

- REM TEAM
Quite a strong team – 4 HW developers (S. Wheeler), 5 SW developers (N. Townsend), mechanical, thermal engineers
- Development Efforts
  - REM
  - BIRD
  - HERA
  - MPT
- Fast prototyping with off-shell products, following by own development
- Incremental capability
Hybrid Electronic Radiation Assessor (HERA)

- Active dosimetry system built for NASA Multi-Purpose Crew Vehicle, based on semiconductor pixel detector technology (Timepix)
- Modular structure
- Completely stand alone capability, all data processing on board, including alarms, etc.
- Measures dose rates at up to four positions
- Gives estimate of the radiation environment
- dE/dx measurement, directionality measurement

This slide is an example of the latest and greatest...
Energy Calibration

• A calibration laboratory was constructed at JSC
• The task is to calibrate more than 65k of multichannel analyzers
• Threshold set to 5 keV
• Measure spectrum in each pixel while occupancy is low → no pile up
• Measure for at least 3 points on calibration curve
  • 59.54 keV line from $^{241}$Am
  • 25.27 keV fluorescence line from Sn
  • 5.99 keV from $^{55}$Fe
• Note: calibration is using photons and thus not clear what a deposited energy in pixel is during calibration (charge sharing effects) → need of advanced calibration
Energy Calibration

• Due to the detection processes and charge sharing effects the signal from one particle is often detected by several adjacent pixels creating a cluster

• Part of the signal might be lost under threshold

• The complete charge deposited by a particle can then be obtained by summing the signals from all pixels in a given cluster

• Regular calibration shows systematic error caused by difference between incident and measured spectra

Measuring 62 keV for 59.5 keV incident photon
Using data from TDVG, we were able to correct for charge sharing and verify if our estimated energy deposition from calibration was correct (guess method and simulation).

New energies for calibration (Fe – 5.998 keV -> 5.58 keV, Sn – 25.27 keV -> 23.56, 59.54 keV -> 56.71 keV) – 500 µm sensor

Verified by TDVG data where we know exact energy deposited.
dE, (continued)

- Calibration function measured for each pixel
- Calibration curve more complex than thought
- Not defined for energies around 900 keV
“Saturation”

Corrected using data from stopping particles. Results in a new calibration curve applied if the energy in pixel is higher than 850 keV.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Volume</th>
<th>Height</th>
<th>Nominal</th>
<th>Difference</th>
<th>Real height</th>
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<tbody>
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<td>6180.4</td>
<td>2995.3</td>
<td>4997</td>
<td>1183.4</td>
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<td>6079</td>
<td>2816</td>
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<td>4997</td>
<td>0</td>
<td>717.6</td>
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</tbody>
</table>

\[ y = 0.355x + 742.43 \]

**Signal from alpha particle saturation**

Real signal from the comparator corresponding to the analog signal from preamplifier.

Second false signal from the comparator caused by return from undershot of the preamplifier output.

Undershoot of the preamplifier output.

Analog signal from preamplifier with height saturation.

Front-end output [V]
Verification of the Method
# Verification of the Method

Tested on penetrating and stopping particles from protons to neon. Error reduced in some cases by 90%.

<table>
<thead>
<tr>
<th>Primary</th>
<th>True energy (MeV/A)</th>
<th>Uncorrected Fit (MeVA)</th>
<th>Corrected Fit (MeVA)</th>
<th>Uncorrected Cluster Height (keV)</th>
<th>Error uncorrected</th>
<th>Error corrected</th>
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<tbody>
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<td>-0.4</td>
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<td>155.7</td>
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<tr>
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<td>9.1</td>
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</table>
dx

• Using fuzzy logic to calculate polar angle and track length, which corresponds to dx

• Found some issues for parallel tracks – resolved, going to more complex algorithm
Carbon, 400.0 MeVA, at $\phi = 45^\circ$, CLUSTER-LSU 003

$R^2 = 0.9322$
$|\text{nominal - fit}| = 0.5481 \text{ keV/\mu m}$
relative error = 2.68%
Real Utility: Energy Reconstruction

• Want to use dE/dx measurements for particle ID and energy reconstruction

• Ongoing effort; first results will be published soon
Conclusions

• NASA has very well defined application for Timepix, will continue to work with it

• We are interested in the new chip development, improvements on front-end, TOA, low-power mode

• We plan to continue work on energy calibration (volcano effect) and evaluation procedures (thermal studies), simulations (Fluka and Geant4 models), eager to see TPX2

• We publish results of our work and plan to present more on MPX meeting (TPX3 study, advanced calibration, etc.)