AstroPix: Investigating the Potential of Silicon Pixel Sensors in the Future of Gamma-ray Astronomy

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CMOS

- **Complementary Metal-Oxide-Semiconductor (CMOS)** is a common fabrication technique used in commercial industry.
  - Mass produced —> low cost!
- Pixelated silicon sensors use High Voltage CMOS manufacturing processes to co-integrate detector and readout electronics.
  - Saves on space, power requirements
  - Less noisy
ATLASPix

- Built and optimized for the CERN experiment ATLAS.
  - Optimized for Minimizing Ionizing Particles (MIPs):
    - Radiation hard, oblong pixels.
    - Fast timing resolution of 25 ns, low digital energy resolution of 6 bits.
- Monolithic silicon pixels, each pixel 50 μm by 140 μm and 100 μm thick.
- Four matrices, each matrix 25 by 100 pixels (x by y).
- We’re using the same hardware to communicate to the device as was used at CERN and collaborators at CERN provided baseline measurements for our tests.

Two ATLASPix detectors side-by-side [2].
## AstroPix Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Resolution</td>
<td>&lt;2% at 60 keV, 10% at 60 keV required</td>
</tr>
<tr>
<td>Power Usage</td>
<td>~3 mW/cm²</td>
</tr>
<tr>
<td>Passive Material</td>
<td>&lt;5% on the active area of the silicon</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>500 um</td>
</tr>
<tr>
<td>Silicon Thickness</td>
<td>500 um</td>
</tr>
<tr>
<td>Time Tag</td>
<td>~ 1us</td>
</tr>
<tr>
<td>Position Resolution</td>
<td>~250 um</td>
</tr>
</tbody>
</table>
Experimental Setup

- Radioactive sources were chosen based on the current dynamic range of the detector (~5 keV to 33 keV)
- Dynamic range limited by the current thickness of Si

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe55</td>
<td>5.89</td>
</tr>
<tr>
<td>Ge</td>
<td>9.89</td>
</tr>
<tr>
<td>Y</td>
<td>14.96</td>
</tr>
<tr>
<td>Mo</td>
<td>17.5</td>
</tr>
<tr>
<td>Cd109</td>
<td>21.99</td>
</tr>
<tr>
<td>Ba133</td>
<td>30.97</td>
</tr>
</tbody>
</table>
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TOT = Time Over Threshold

TOT photopeaks represent TOT hits from individual pixels, with pixels used from across the entire detector.
Analog Energy Calibration

- Calibration relates the found peak position in V at each source and energy and the theoretical energy value in keV.

- The detector response is non-linear, this isn’t surprising

- A three-degree polynomial was found to best represent the detector response
Analog Energy Resolution

E Res for Fe and Ba is ~7%. This exceeds the min requirement of 10% at 60 keV
AstroPix V1

- **Pixel**
  - 165x165 μm active pixel area, 200 μm pitch
  - Read out by connecting to both row and column

- **Matrix**
  - 4.5 x 4.5 mm chip area
  - 18 x 18 pixel matrix

- **Digital Periphery**
  - Time stamp counters for each row and column

- **Other**
  - 36 analog/comparator outputs

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AMEGO-X and Multimessenger Astrophysics

Gamma-ray observations played the critical discovery role in all major multimessenger discoveries in the past half decade.

- **Gravitational Waves + gamma rays:** Identified the first counterpart to a gravitational wave event.
- **High energy neutrinos + gamma rays:** Identified the first source of high energy neutrinos outside the galaxy.

The Science of Extreme Explosions and Extreme Accelerators
Summary and Next Steps

• Analog energy resolution of ATLASPix, a driving parameter for AstroPix, is encouraging

• Digital resolution needs to be redesigned; we can borrow from the functionality currently devoted to timing resolution

• AstroPix V1 has been fabricated and is about to undergo testing

• Promising start to monolithic Si in the future of gamma-ray astrophysics
References

Analog Output of ATLASPix

Histograms of the raw analog data (in volts) from two pixels. The same two sources, Fe55 and Cd109, were used. Left: Pixel (12,50). Right: Pixel (0,50).

- Pixel (12,50):
  - Fe: $0.081 \pm 0.005$ V
  - Cd: $0.288 \pm 0.005$ V

- Pixel (0,50):
  - Fe: $0.084 \pm 0.006$ V
  - Cd: $0.291 \pm 0.005$ V

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Hit Distribution

- Heatmaps of the ATLASPix detector showing the distribution of hits when the detector is exposed to radioactive sources.
- Both axes represent pixel number in the x and y direction respectively. Data was extracted from the digital DAQ file, which records x and y position of each hit.
- Left: Fe55, Right: Cd109