Test beam results of an RSD2 450 um pitch matrix

“chatGPT, please draw a medieval funeral for my dear friend RD50”
Test beam results of an RSD2 450 um pitch matrix

“chatGPT: please make a happy drawing of resistive silicon detectors”
Test beam results of an RSD2 450 um pitch matrix

“chatGPT: please make the analysis of the DESY test beam data”

Just kidding…
What did we test: FBK RSD + FAST2 ASIC

In this test beam, we used:
- an FBK RSD (from the RSD2 production) matrix, 450-micron pitch pixel
- the FAST2 ASIC, a 16-ch amplifier ASIC.

The goal of the study was twofold: test the RSD matrix and test FAST2
Where we did the test: DESY test beam line

Two distinct paths:
- Trigger path
- Data path

Sensor matrix

5 GeV/c electron beam

TLU Tracker

Tracker

RSD

Tracker

EUDAQ

PC

CAEN Digitizer

MCP

Oscilloscope

CAEN Logic Unit

Two distinct paths:
- Trigger path
- Data path
FAST2 property

**FAST2 signal shape**
- ~ 1 ns rise time
- ~ 10 mV/fC
- 2 different amplifiers, EVO1 and EVO2.
  Both are trans-impedance amplifiers
  - EVO1 uses regular transistor
  - EVO2 uses RF transistors

**FAST2 baseline RMS**
Noise ~ 1.05 mV
• RSD (aka AC-LGAD) from the RSD2 FBK production
• 6 x 6 cross-shaped electrodes
• 14 active electrodes, the others connected to ground
• 7 full pixels: 3 connected to EVO1, 2 mixed, 2 EVO2
Test beam runs and W4 gain

<table>
<thead>
<tr>
<th>Bias [V]</th>
<th>MCP Triggers [k]</th>
<th>Good events [k]</th>
<th>MPV$_{all}$ [mV]</th>
<th>MPV$_{pixel-max}$ [mV]</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>401</td>
<td>6.4</td>
<td>122</td>
<td>77</td>
<td>24.4</td>
</tr>
<tr>
<td>150</td>
<td>440</td>
<td>8.3</td>
<td>136</td>
<td>92.7</td>
<td>27.2</td>
</tr>
<tr>
<td>170</td>
<td>480</td>
<td>8.9</td>
<td>164</td>
<td>118</td>
<td>32.8</td>
</tr>
<tr>
<td>190</td>
<td>475</td>
<td>8.5</td>
<td>209</td>
<td>157</td>
<td>41.8</td>
</tr>
<tr>
<td>200</td>
<td>665</td>
<td>11.1</td>
<td>236</td>
<td>175</td>
<td>47.2</td>
</tr>
</tbody>
</table>

W4 RSD Gain vs Bias
Amplitude vs hit position

Amplitude seen by an electrode as a function of hit position.

The picture shows that signal sharing is contained within one pixel.
Electrode and pixel signal properties

Electrode signal properties

- Signal amplitude on a single electrode as a function of distance from the electrode

Pixel signal (sum of 4 elec. signals) properties

- Sum of the 4 electrode amplitudes in a pixel (projection along the x-projection)
- Sum of the 4 electrode amplitudes in a pixel
- Signal rise time as a function of distance from the electrode
Reconstruction methods

1) Charge imbalance + migration map

2) Sharing template
Method 1: Charge imbalance (DCP)

4 pads are readout, all others connected to gnd. Reconstruction method via charge imbalance (aka charge-weighted position centroid):

\[
\begin{align*}
    x_i &= x_{center} + \frac{\text{pitch}}{2} \times \frac{Q_3 + Q_4 - (Q_1 + Q_2)}{Q_{tot}} \\
    y_i &= y_{center} + \frac{\text{pitch}}{2} \times \frac{Q_1 + Q_3 - (Q_2 + Q_4)}{Q_{tot}}
\end{align*}
\]

This is the simplest algorithm for position reconstruction, however, it suffers from pincushion distortion:
Pincushion correction: migration map

Compute the migration map:
For each laser position, connect the true and reconstructed positions.
Charge imbalance + migration map

\[ x_i = x_{center} + \frac{\text{pitch}}{2} \times \frac{Q_3 + Q_4 - (Q_1 + Q_2)}{Q_{\text{tot}}} \]

\[ y_i = y_{center} + \frac{\text{pitch}}{2} \times \frac{Q_1 + Q_3 - (Q_2 + Q_4)}{Q_{\text{tot}}} \]
Method 2: Sharing template (ST)

**Step 1:**
For each position in the pixel, produce look-up tables with the signal-sharing pattern among the 4 electrodes (done with test beam data)

**Step 2:**
For each event, compare the measured signal sharing with the look-up table to find the location that best reproduces the measured sharing
**Alignement and tracker resolution**

**DUT – Tracker alignement**

**Step 1:**
Find the global shift to overlap the telescope reference system to the RSD reference system

\[ \text{Minimize the sum of the differences } \sum_{i=1}^{14} \Delta x \]

**Step 2:**
Rotate the reference system

\[ \text{Minimize the sum of the absolute values of the differences } \sum_{i=1}^{14} |\Delta x| \]

**Tracker resolution**

**Step 1:**
Measure the gain-to-no-gain transition region at the testbeam

**Step 2:**
Measure the gain-to-no-gain transition region at the TCT

**Step 3:**
Knowing the laser width (about 10 micron), the tracker resolution can be evaluated to be

\[ \sigma_{\text{tracker}} = 14 \pm 2 \mu m \]
Example of the correlation between tracker and RSD hit positions.

==> Mostly uniform resolution even over pixel boundaries
3 methods were used in the reconstruction.

• Using signal amplitude instead of signal area yields better resolution
• Sharing template works better

=> Achieved a resolution $\sigma_{x,y} < 15 \mu m$ with a 450 $\mu m$ pitch sensor

=> With binary readout, this is equivalent to a pitch of $\sim 45 \mu m$

=> A factor of 100 less readout amplifiers
Reconstruction uniformity

The plots are limited in the z-range to $\pm 2 \times \sigma_{res}$ ($\pm 32 \mu m$) to highlight the areas with the worst resolution

- Very good overall uniformity
- The less precise reconstruction is clustered around the metal electrodes
**Jitter and constant terms**

\[
\sigma_{RSD}^2 = \sqrt{\text{constant}^2 + \left(\frac{\text{Noise}}{\text{Gain}}\right)^2}
\]

- The jitter term dominates the resolution
- The constant term is \(\sigma_{\text{constant}} \sim 4.6 \, \mu m\)
  - This is smallest resolution possible with this setup

\[
\chi^2 / \text{ndf} = 4.177 / 3
\]

<table>
<thead>
<tr>
<th>Term</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.63 ± 2.488</td>
</tr>
<tr>
<td>Noise</td>
<td>321 ± 39.31</td>
</tr>
</tbody>
</table>
Conclusions

At the DESY test beam, we tested the combination RDS2 + FAST2

The FBK RSD2 sensor tested was a matrix of 7 450 μm pitch pixels

A spatial resolution $\sigma_{x,y} < 15 \mu m$ was achieved, with uniform response over the pixel boundaries. This resolution is about ~ 3% pitch.

Two reconstruction methods, DCP and ST, were used, with similar results.

RSD allows for extremely good spatial resolution with a very limited number of pixels.

The next round of tests will include new RSD designs and the FAST3 ASIC
The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

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Bonus slides