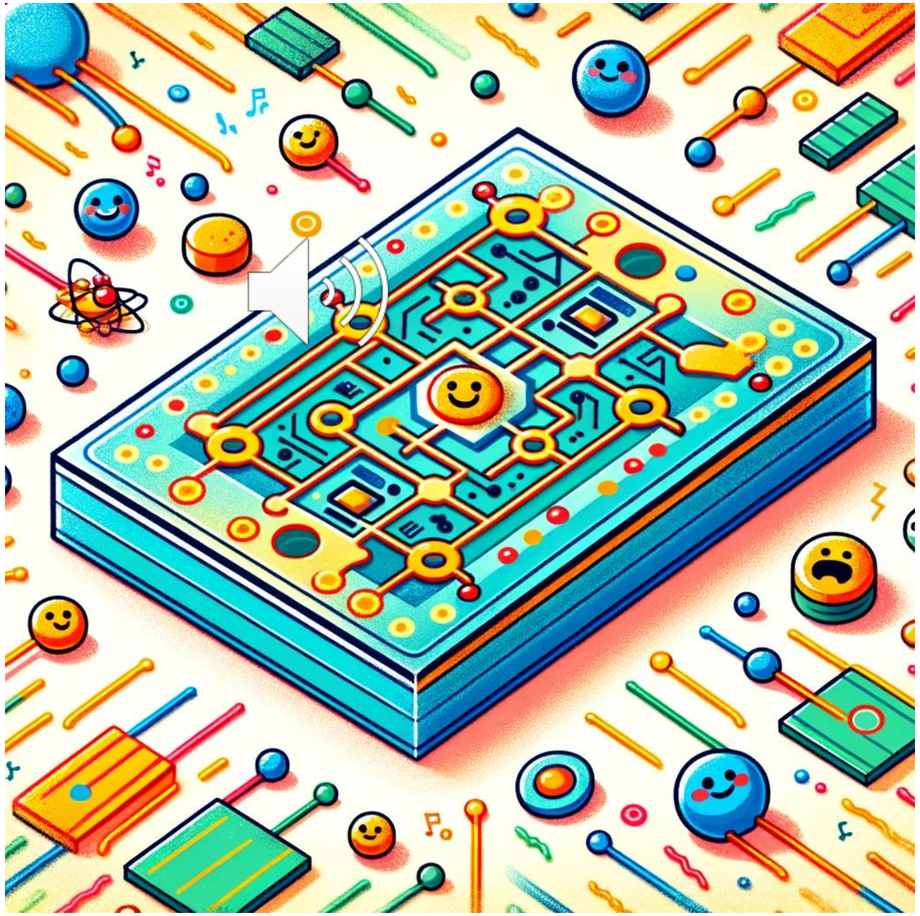
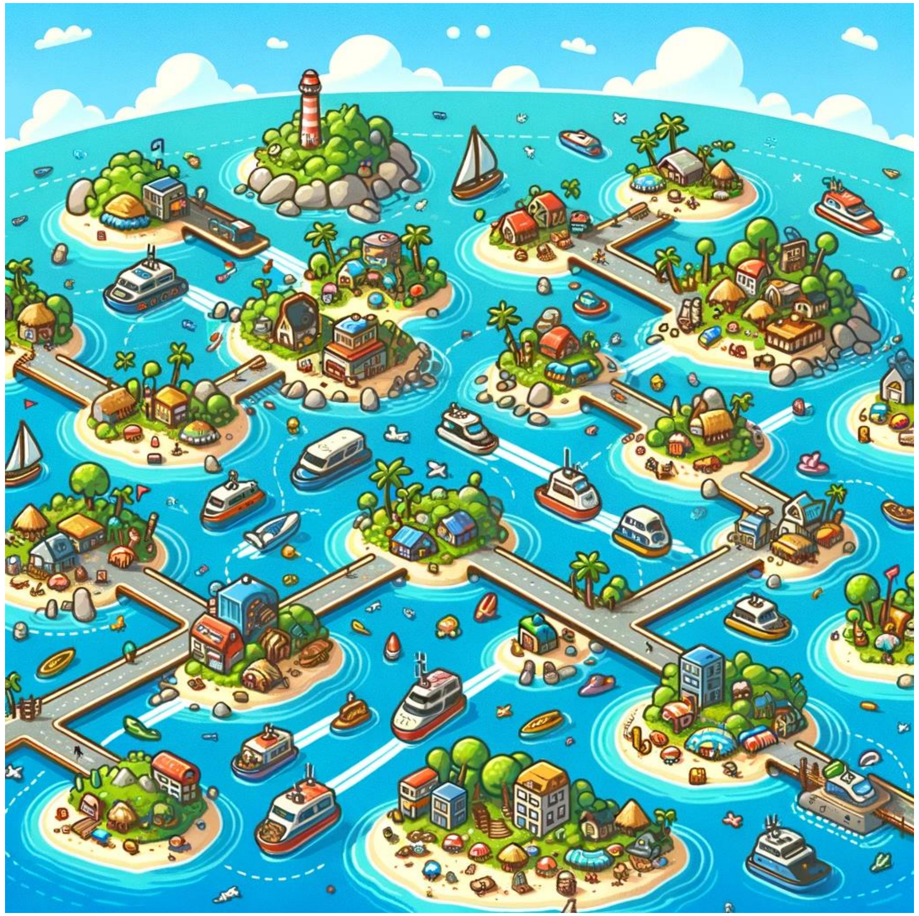
Test beam results of an RSD2 450 um pitch matrix

“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

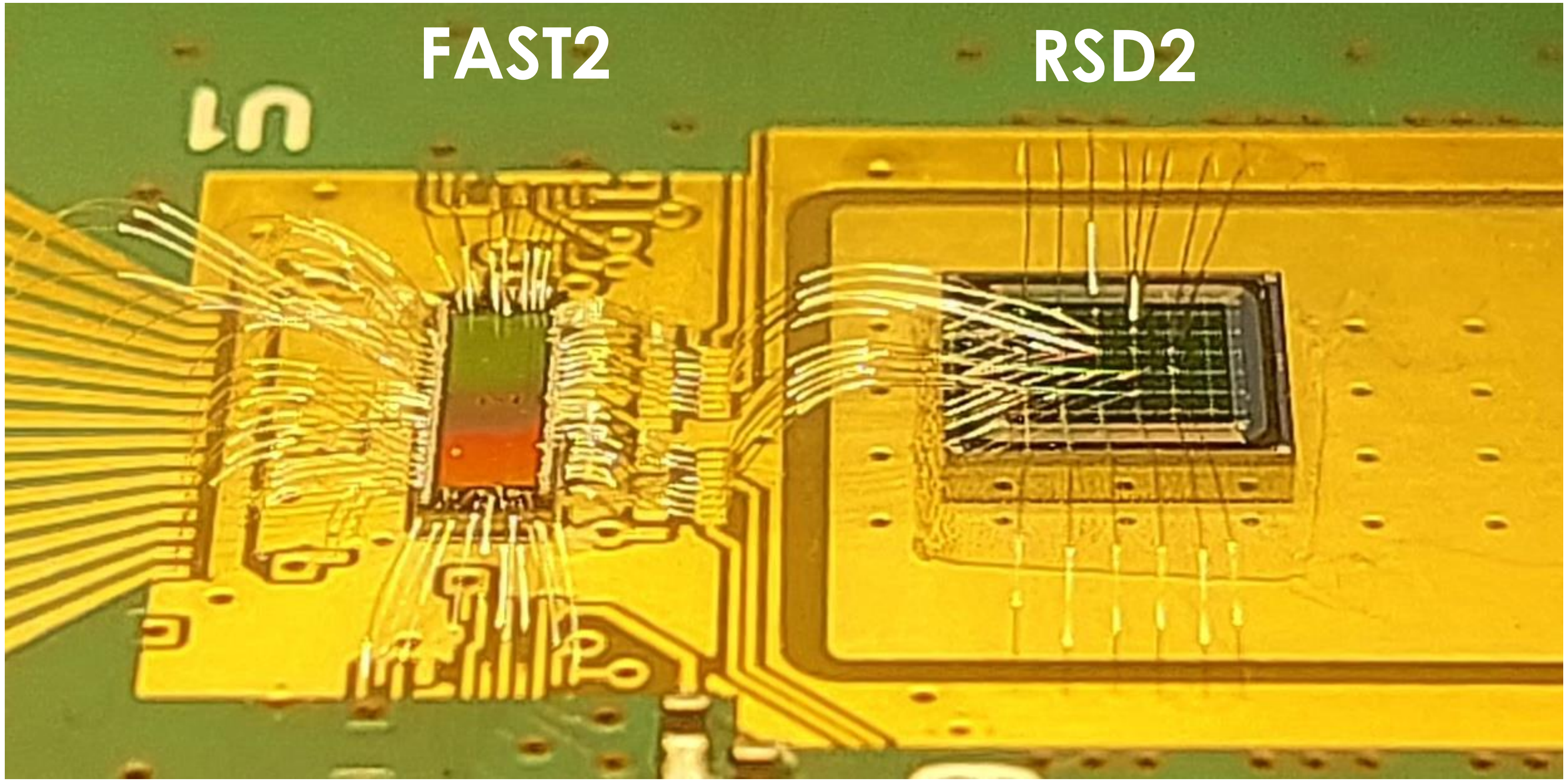
“chatGPT: please make the analysis of the DESY test beam data”

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.

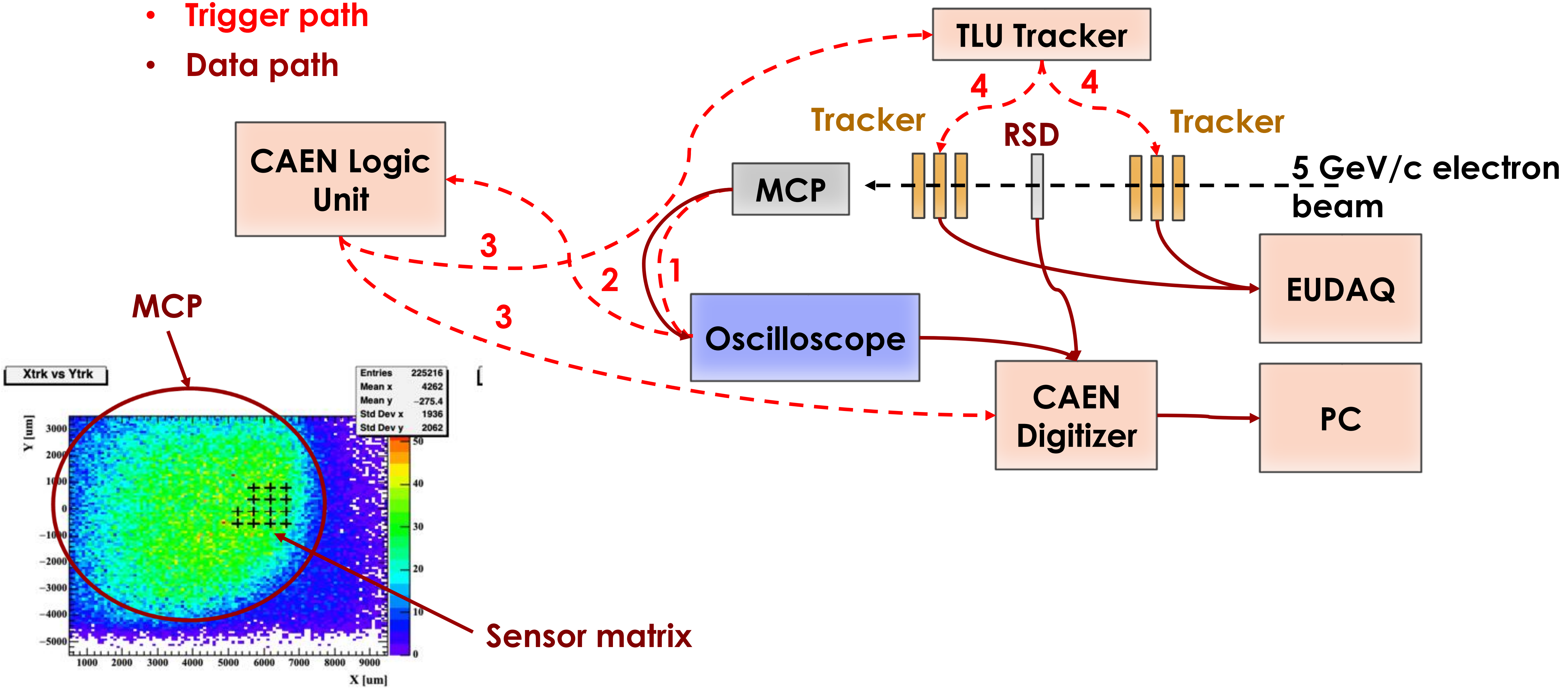


The goal of the study was twofold: test the RSD matrix and test FAST2

Where we did the test: DESY test beam line

Two distinct paths:

- Trigger path
- Data path



TLU Tracker

4

4

Tracker

RSD

Tracker

CAEN Logic Unit

MCP

5 GeV/c electron beam

3

2

1

EUDAQ

3

Oscilloscope

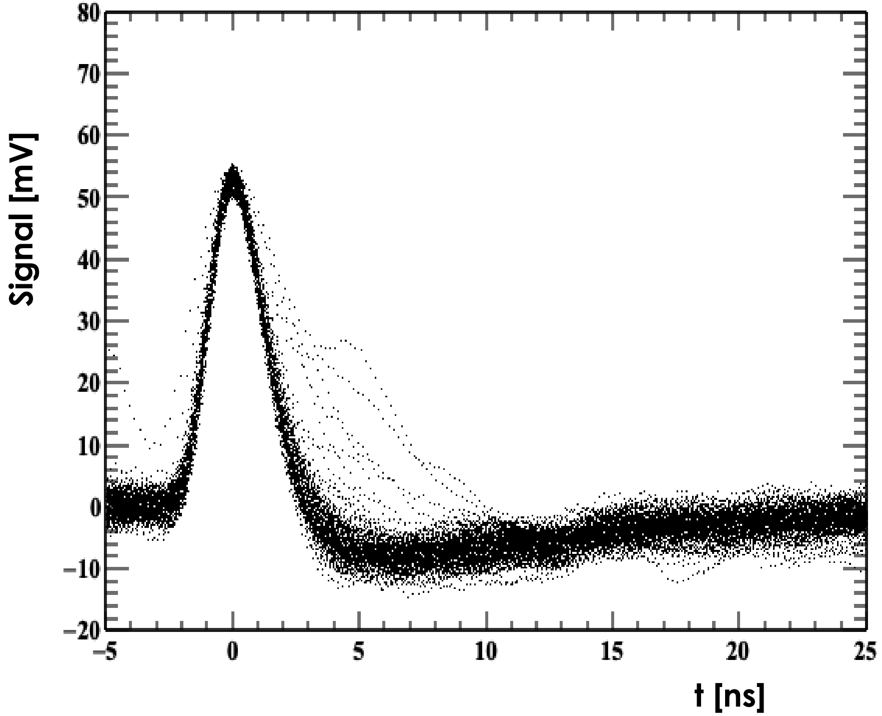
CAEN Digitizer

PC

MCP

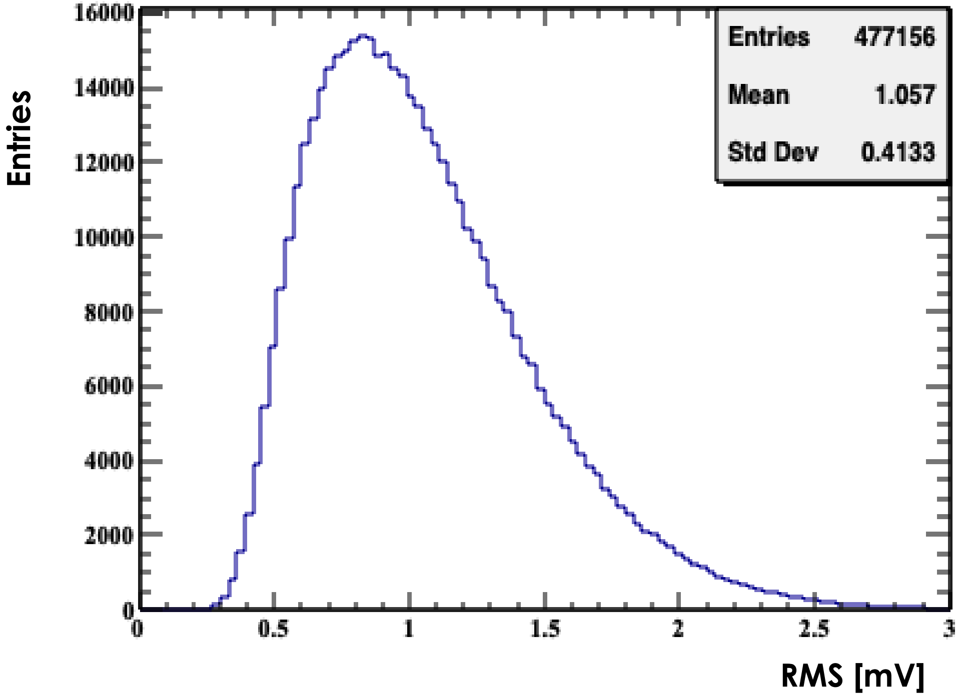
Sensor matrix

FAST2 property



FAST2 signal shape”

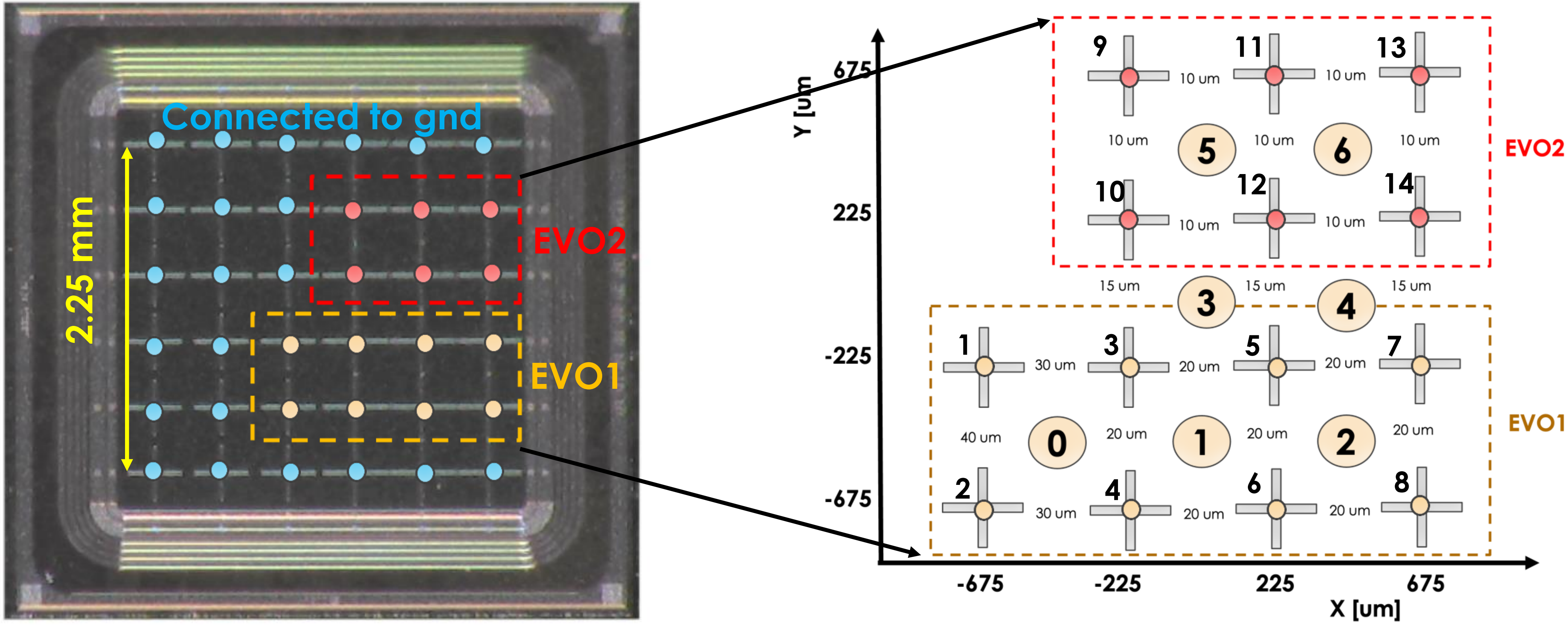
- ~ 1 ns rise time
- ~ 10 mV/fC
- 2 different amplifiers, EVO1 and EVO2.
  Both are trans-impedance amplifiers
  - EVO1 uses regular transistor
  - EVO2 uses RF transistors



FAST2 baseline RMS

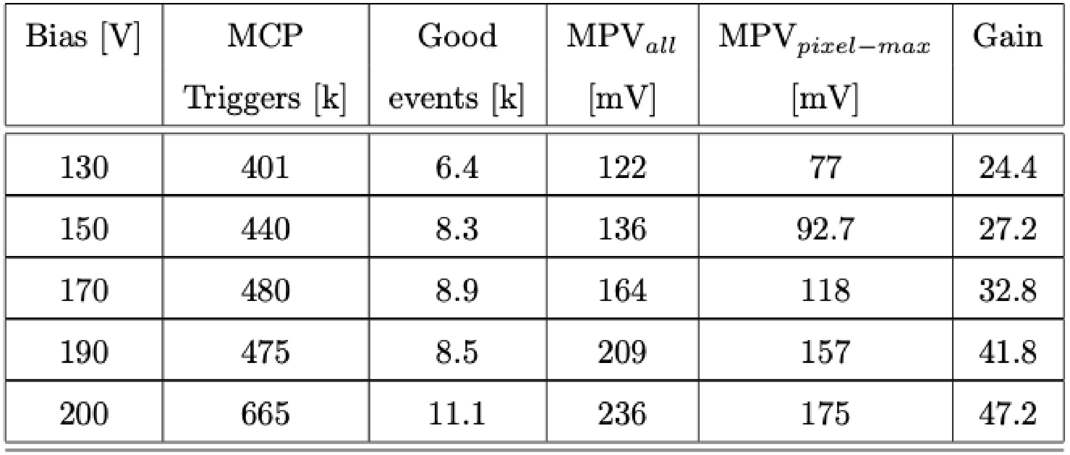
Noise ~ 1.05 mV

RSD matrix

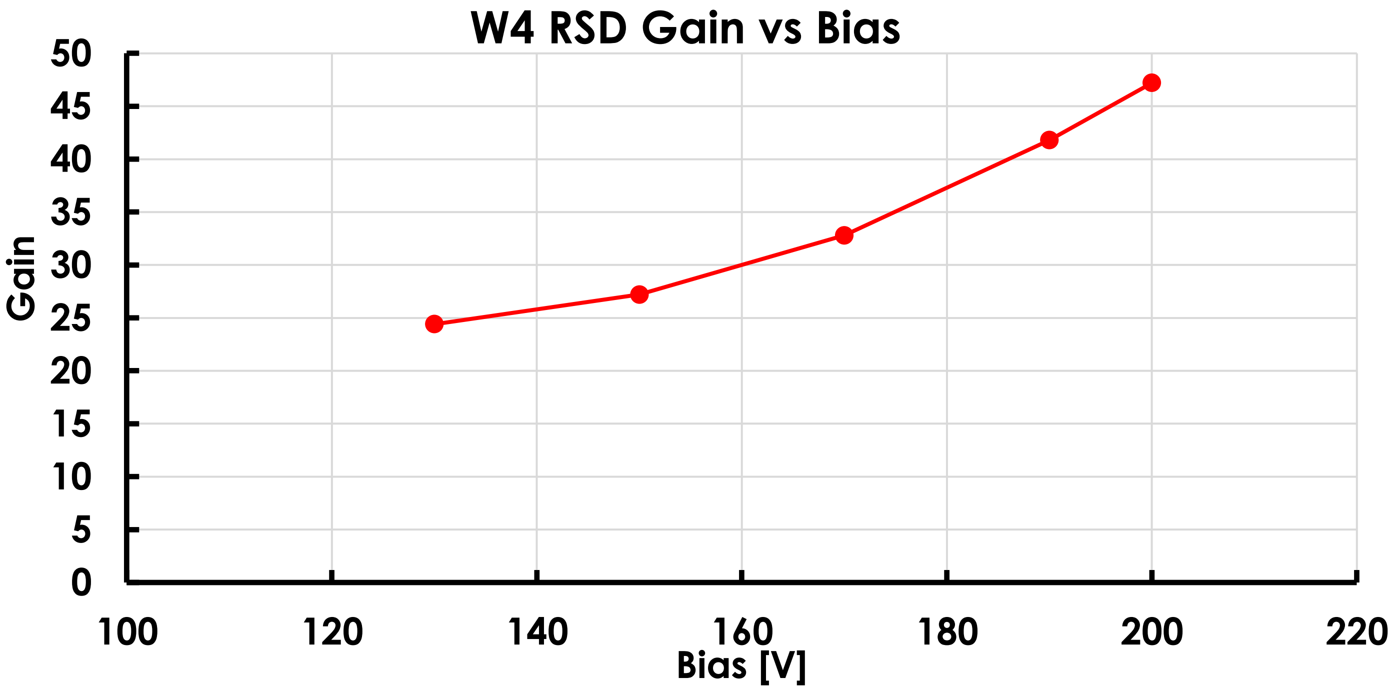


- RSD (aka AC-LGAD) from the RSD2 FBK production
- 6 x 6 cross-shaped electrodes
- 14 active electrodes, the others connected to ground
- 7 full pixels: 3 connected to EVO1, 2 mixed, 2 EVO2

Test beam runs and W4 gain



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

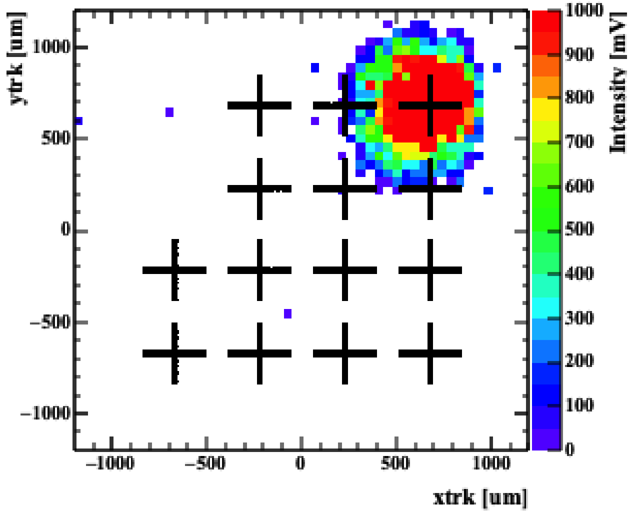


Amplitude vs hit position

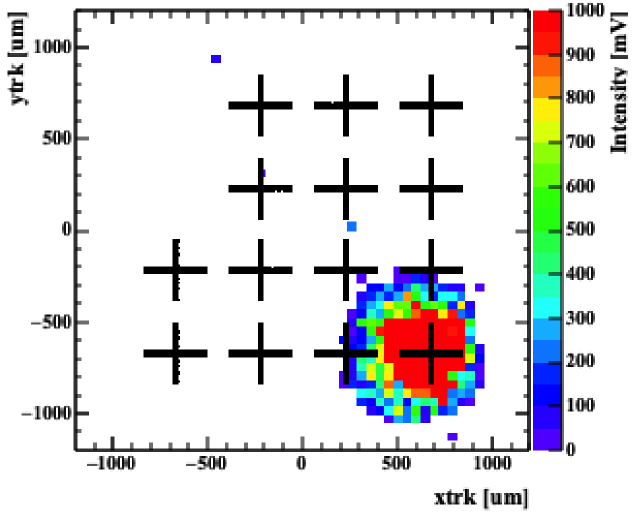
Amplitude seen by an electrode as a function of hit position.

The picture shows that signal sharing is contained within one pixel

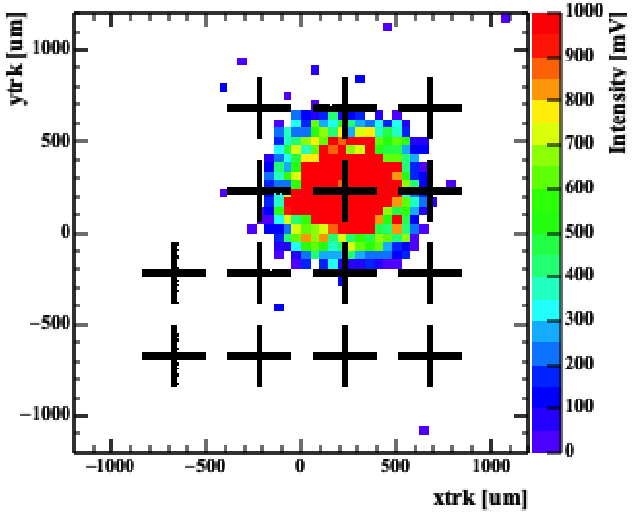
Signal on El 13



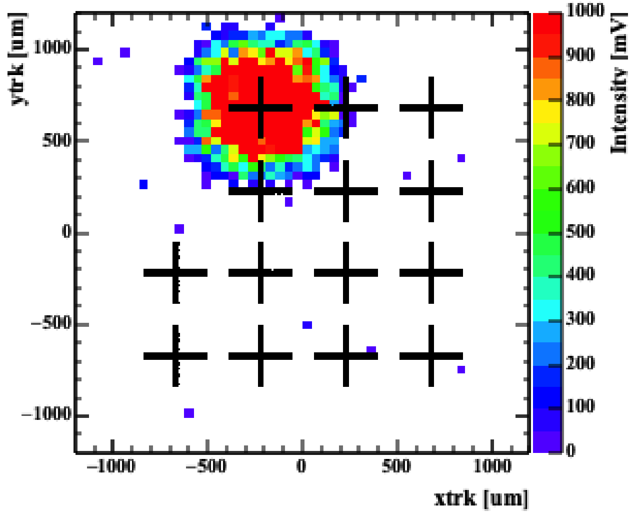
Signal on El 5



Signal on El 11



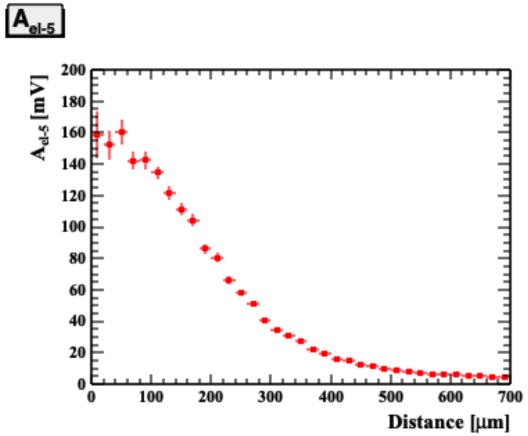
Signal on El 15

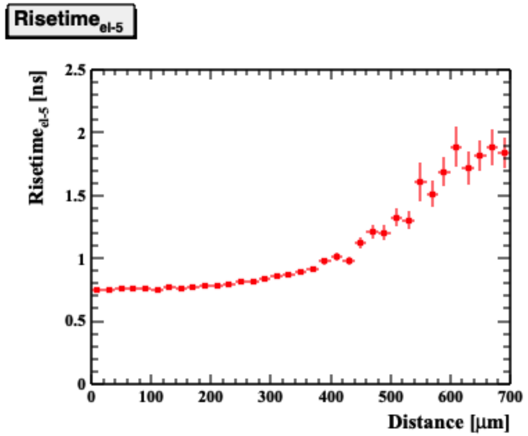


Electrode and pixel signal properties

Electrode signal properties

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

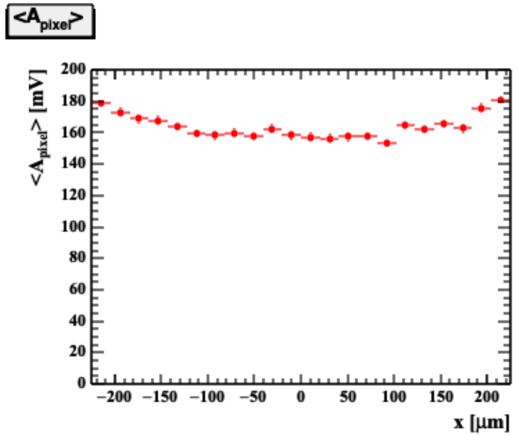


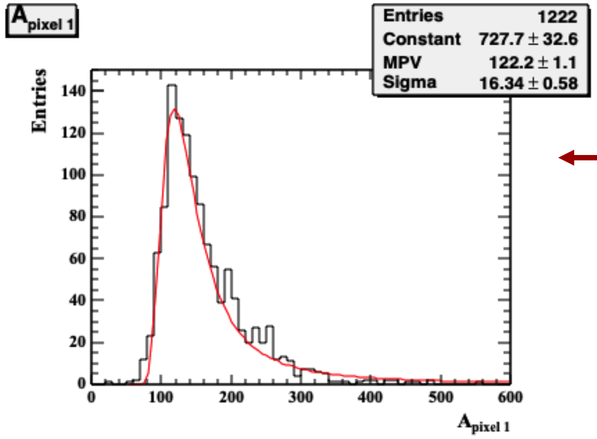


Signal rise time as a function of distance from the electrode

Pixel signal (sum of 4 elec. signals) properties

Sum of the 4 electrode amplitudes in a pixel (projection along the x-projection)





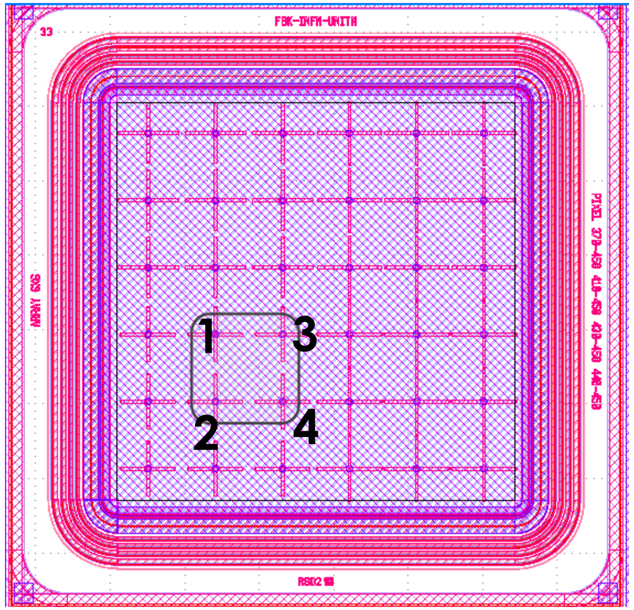
Sum of the 4 electrode amplitudes in a pixel

Reconstruction methods

1) Charge imbalance + migration map

2) Sharing template

Method 1: Charge imbalance (DCP)



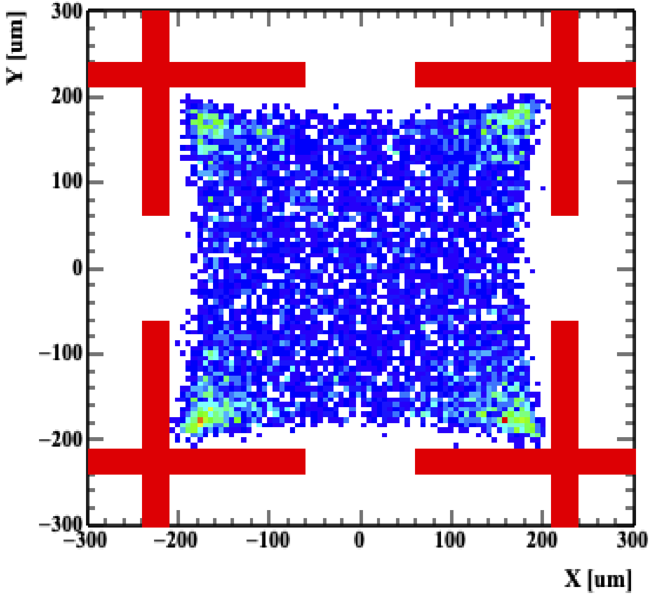
4 pads are readout, all others connected to gnd

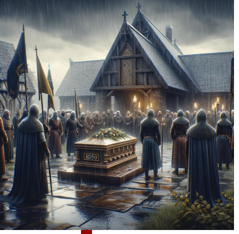
Reconstruction method via charge imbalance (aka charge-weighted position centroid):

$$x_i = x_{center} + \frac{pitch}{2} * \frac{Q_3 + Q_4 - (Q_1+Q_2)}{Q_{tot}}$$

$$y_i = y_{center} + \frac{pitch}{2} * \frac{Q_1 + Q_3 - (Q_2+Q_4)}{Q_{tot}}$$

This is the simplest alghoritms for position reconstruction, however, it suffers from pincushion distortion:

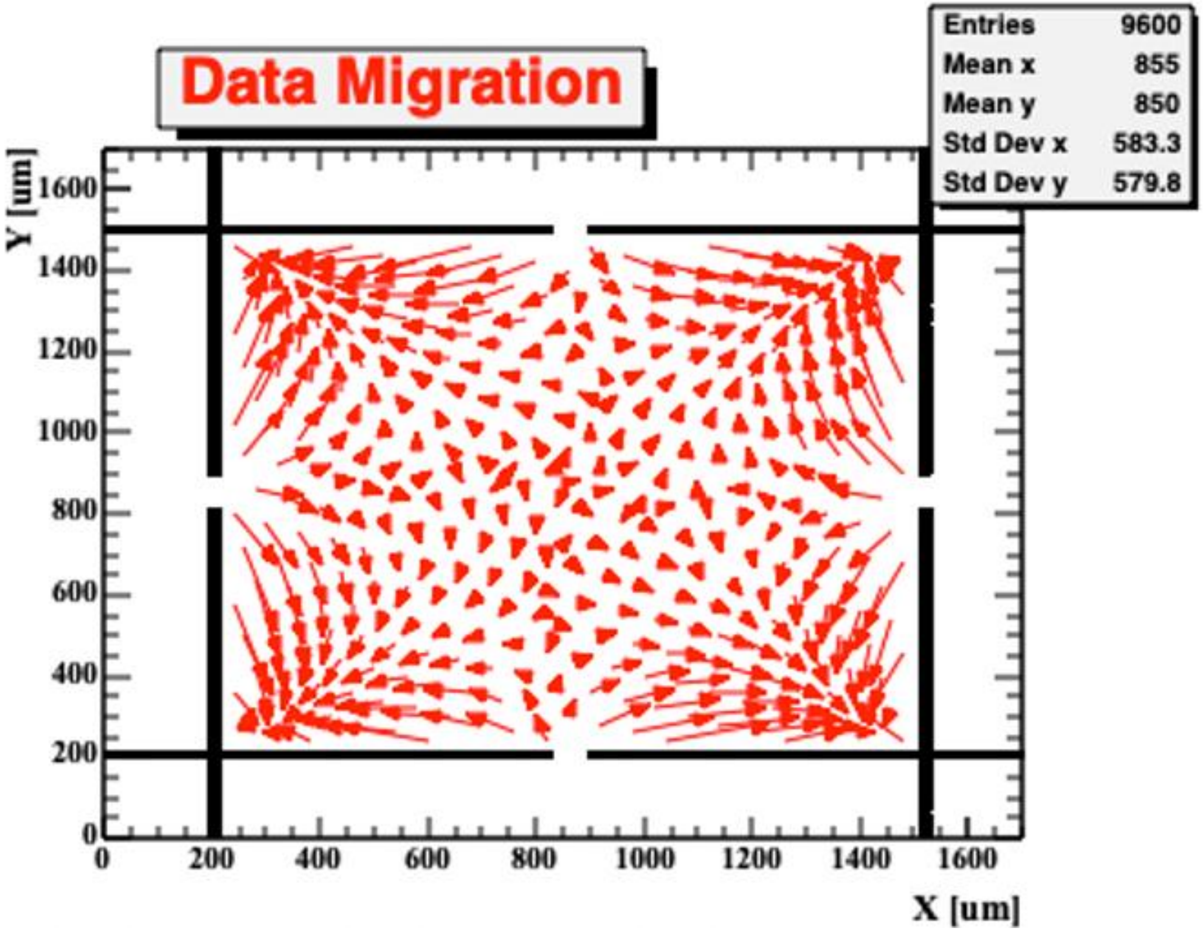


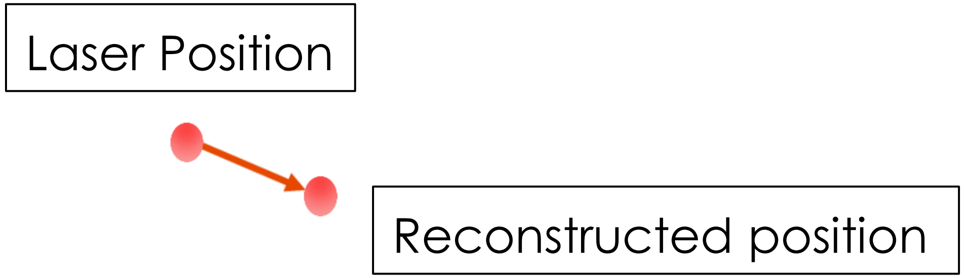


Pincushion correction: migration map

Compute the migration map:

For each laser position, connect the true and reconstructed positions.

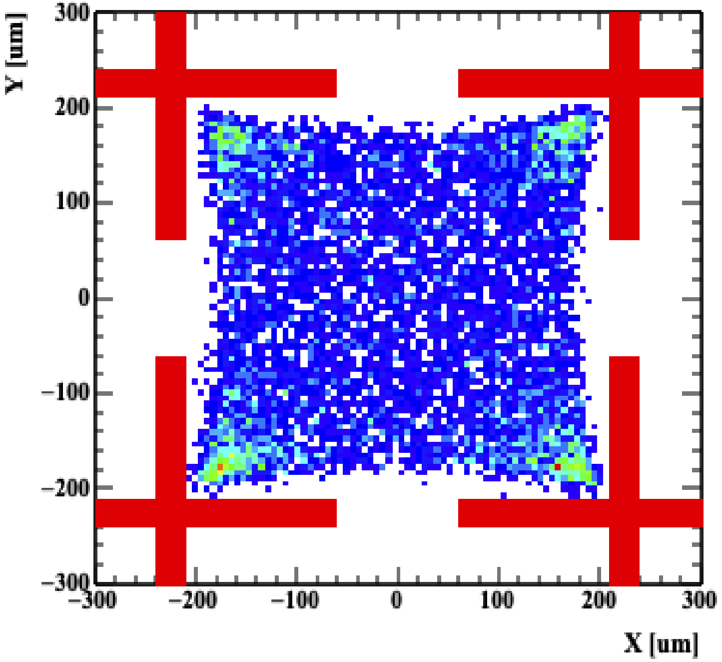




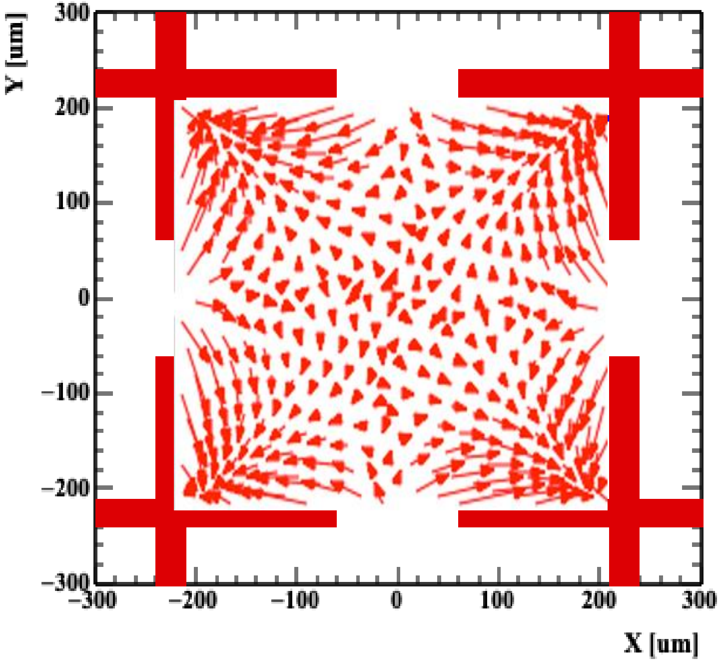
Laser Position

Reconstructed position

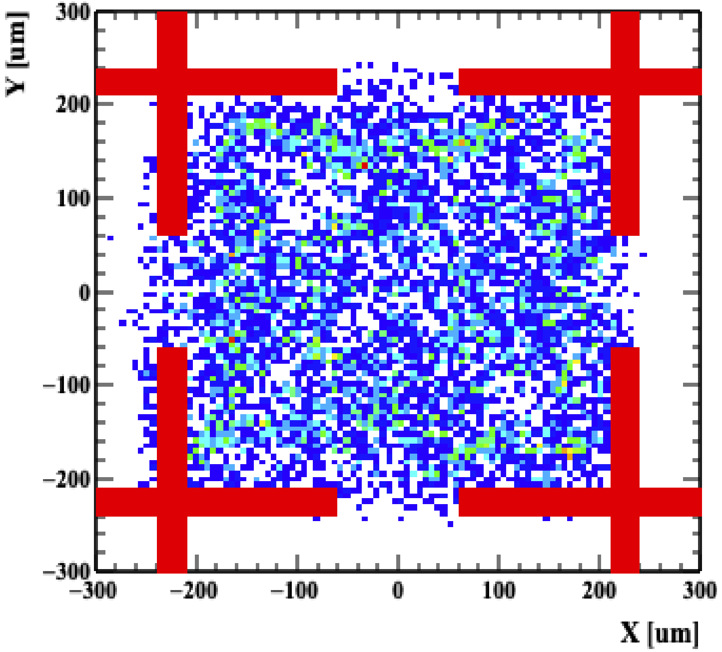
Charge imbalance + migration map



DCP



Migration Map



DCP + Migration Map

$$x_i = x_{center} + \frac{pitch}{2} * \frac{Q_3 + Q_4 - (Q_1+Q_2)}{Q_{tot}}$$

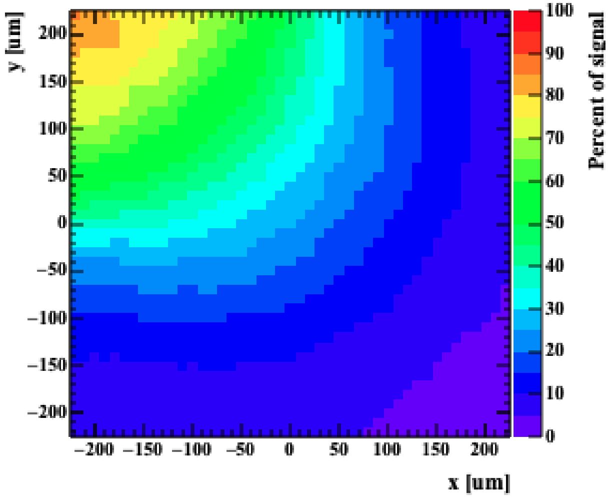
$$y_i = y_{center} + \frac{pitch}{2} * \frac{Q_1 + Q_3 - (Q_2+Q_4)}{Q_{tot}}$$

Method 2: Sharing template (ST)

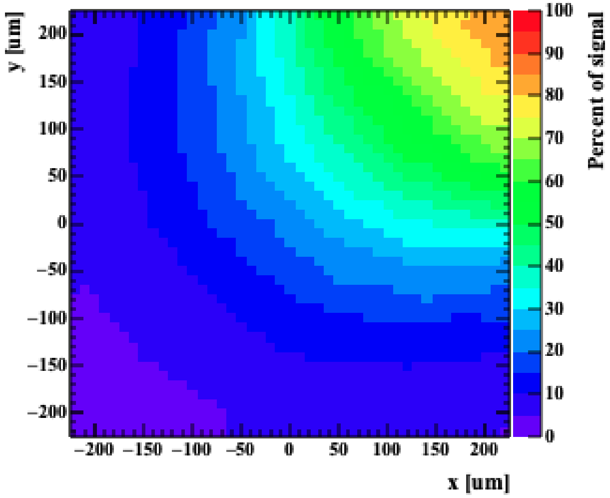
Step 1:
For each position in the pixel, produce look-up tables with the signal-sharing pattern among the 4 electrodes (done with test beam data)

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

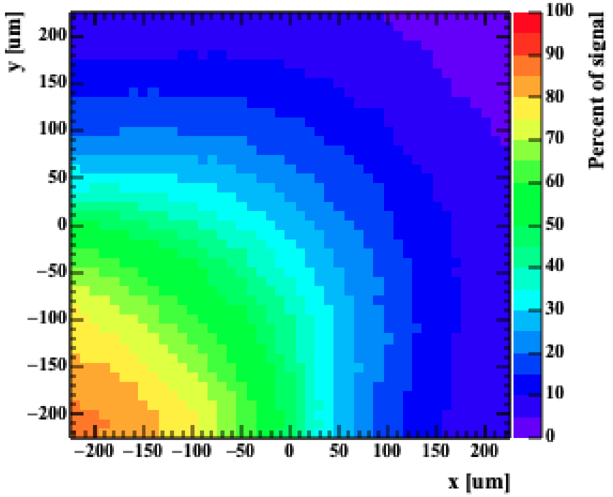
Electrode 1



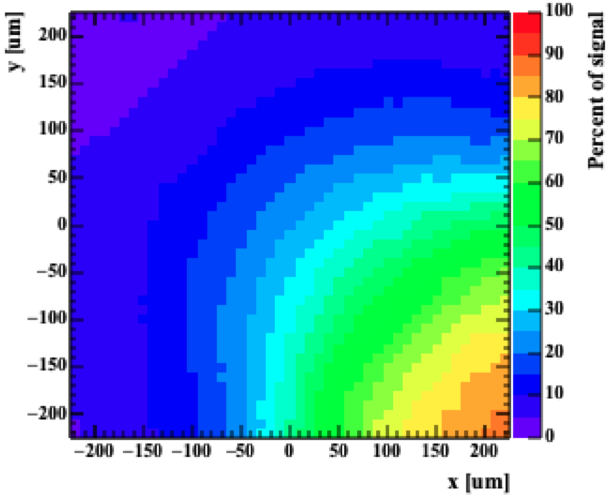
Electrode 3



Electrode 2



Electrode 4



Alignement and tracker resolution

DUT – Tracker alignement

Step 1:

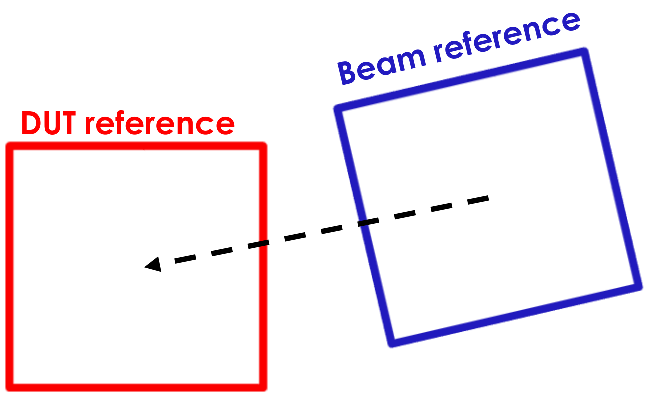
Find the global shift to overlap the telescope reference system to the RSD reference system

==> **Minimize the sum of the differences $\Sigma_1^{14}\Delta x$**

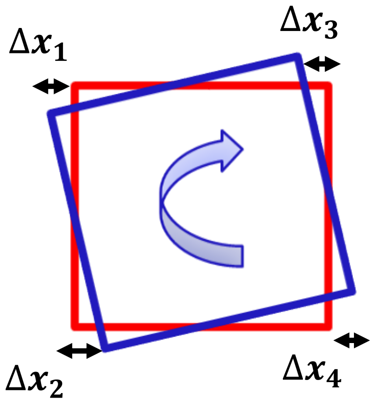
Step 2:

Rotate the reference system

==> Minimize the sum of the absolute values of the differences $\Sigma_1^{14}|\Delta x|$



x,y shift



rotation

Tracker resolution

Step 1:

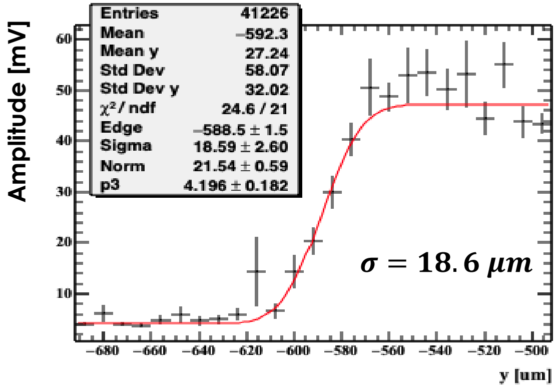
Measure the gain-to-no-gain transition region at the testbeam

Step 2:

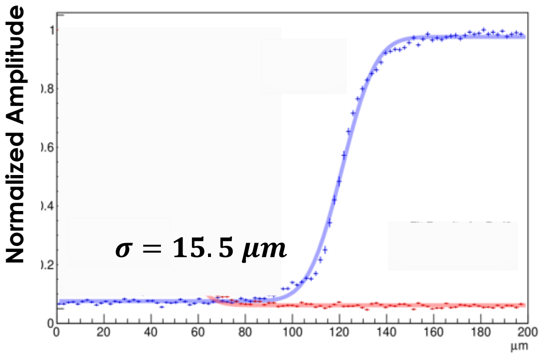
Measure the gain-to-no-gain transition region at the TCT

Step 3:

Knowing the laser width (about 10 micron), the tracker resolution can be evaluated to be $\sigma_{tracker} = 14 \pm 2\ \mu m$

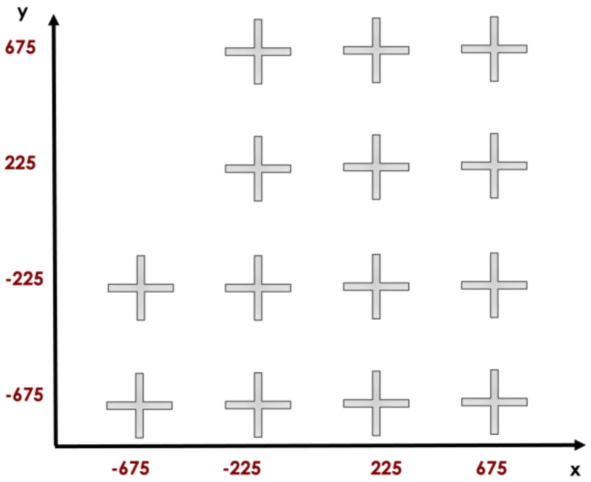


Sensor edge measured at the test beam



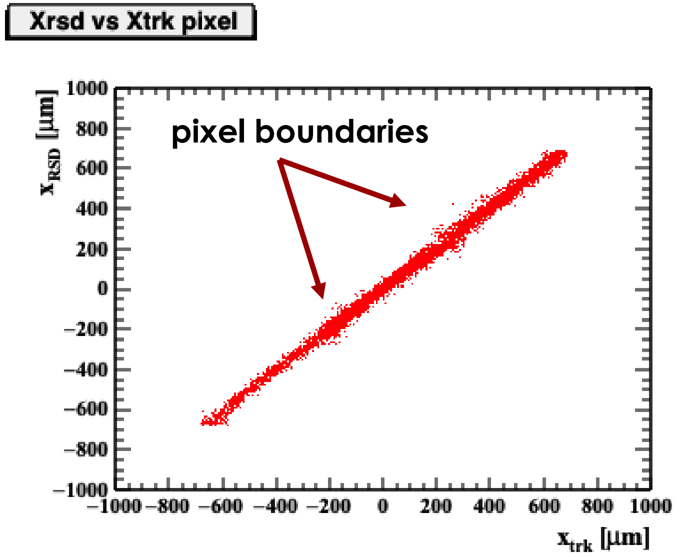
Sensor edge measured in laboratory

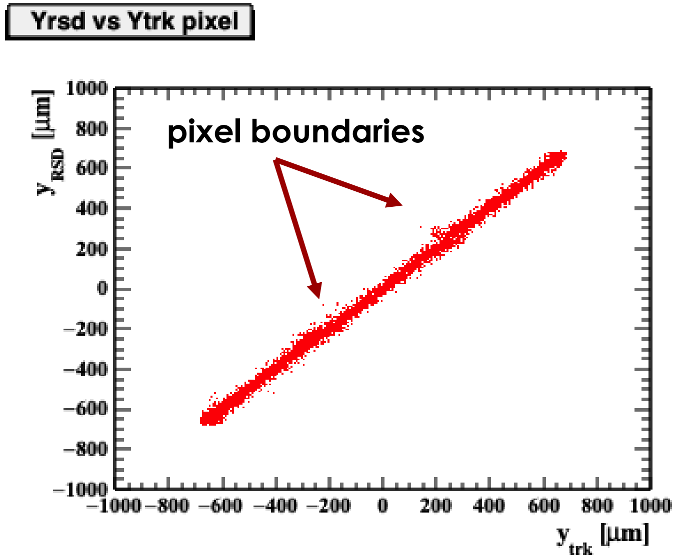
Correlation between tracker and RSD

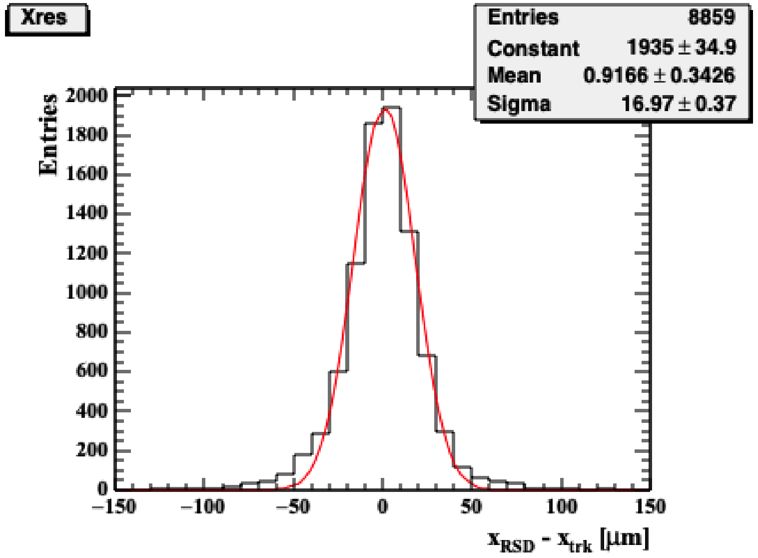


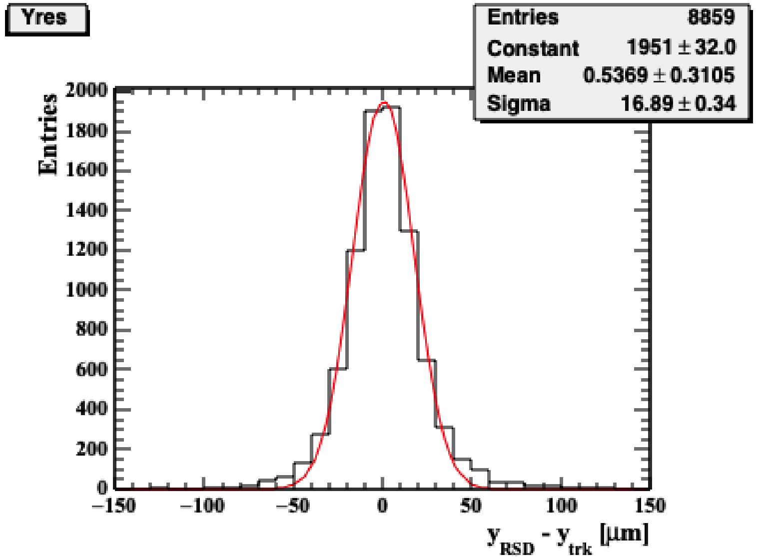
Example of the correlation between tracker and RSD hit positions.

==> Mostly uniform resolution even over pixel boundaries



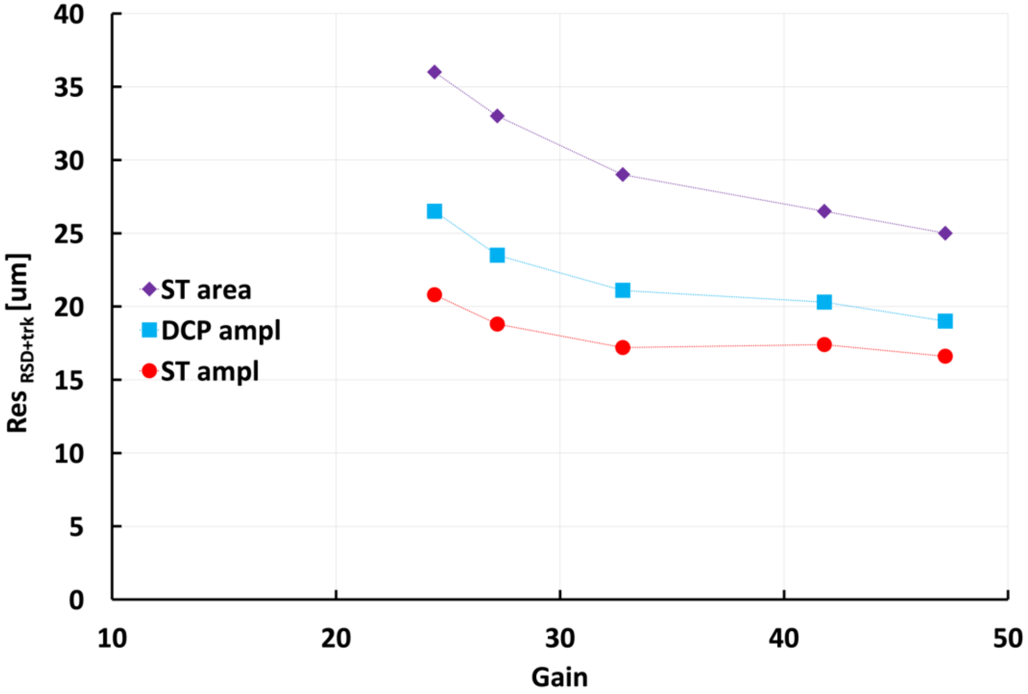




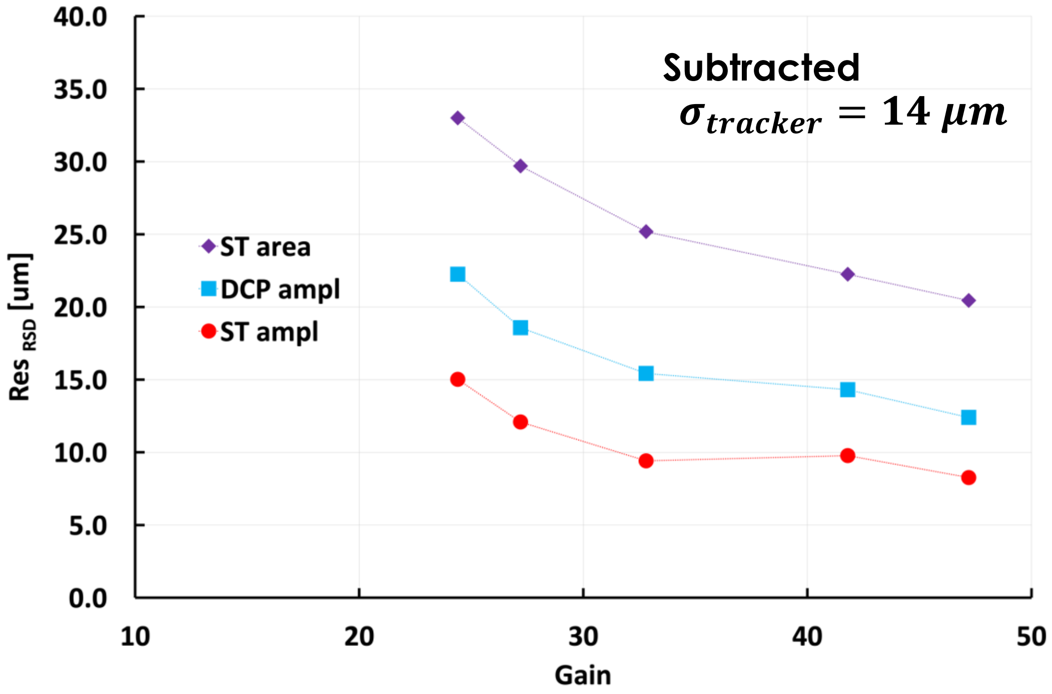


Spatial resolution vs gain

Convolution of the RSD and Telescope spatial resolutions



RSD spatial resolution



Subtracted
$\boldsymbol{\sigma_{tracker} = 14\ \mu m}$

3 methods were used in the reconstruction.

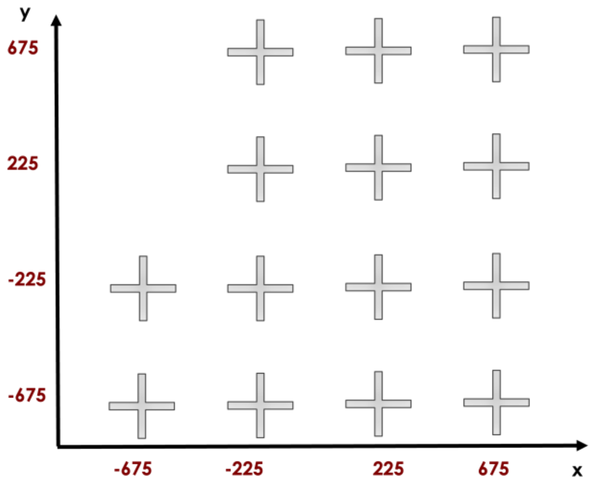
- Using signal amplitude instead of signal area yields better resolution
- Sharing template works better

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

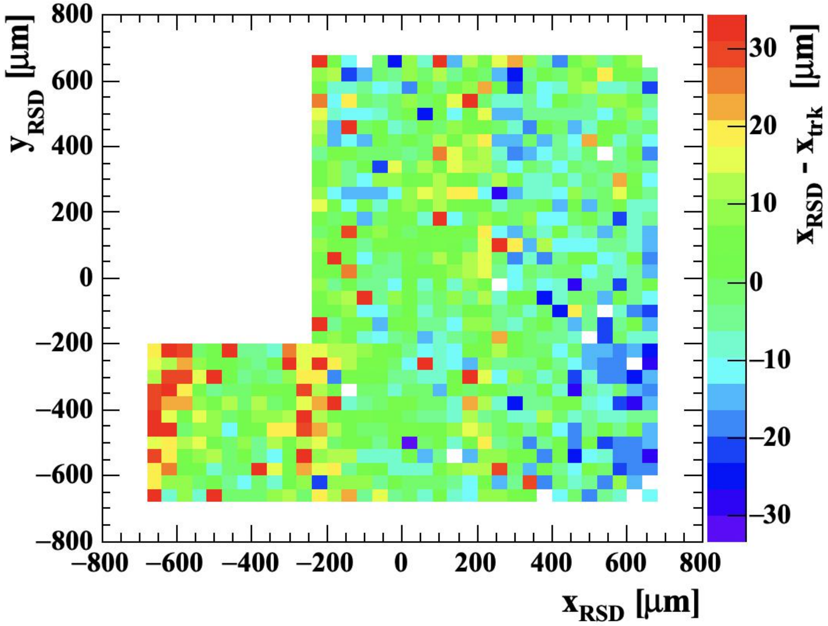
==> With binary readout, this is equivalent to a pitch of ~45 μm

==> A factor of 100 less readout amplifiers

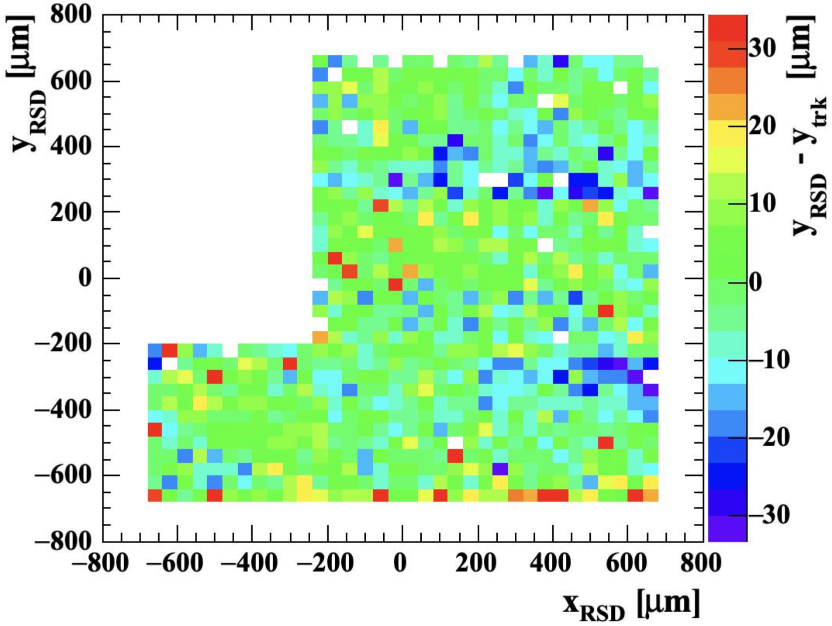
Reconstruction uniformity



RSD – tracker x position



RSD – tracker y position

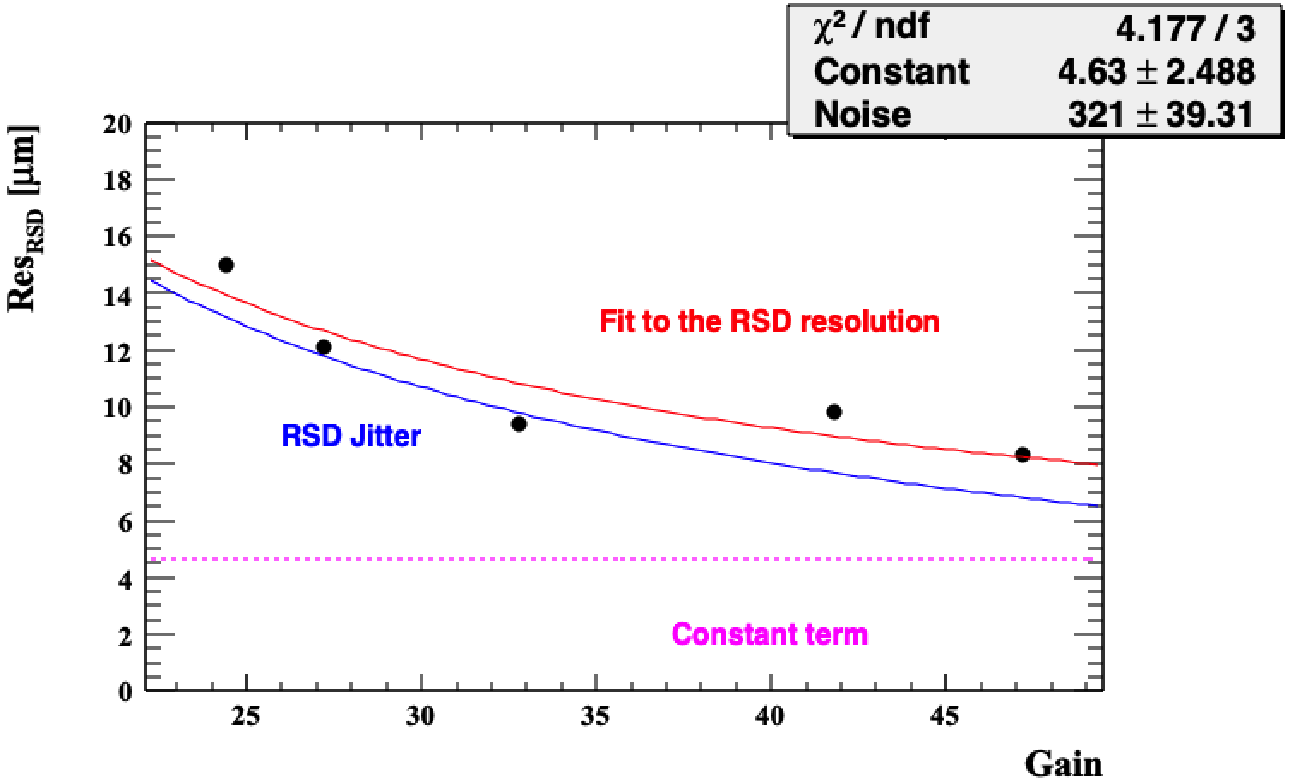


The plots are limited in the z-range to $\pm 2 * \sigma_{res}$ ($\pm 32\ \mu m$) to highlight the areas with the worst resolution

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

Jitter and constant terms

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



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

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 $\boldsymbol{\sigma_{x,y} < 15\ \mu m}$ 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

Acknowledgment

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