Preliminary test beam results of SOI monolithic pixel detector

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Monolithic pixel detectors in SOI

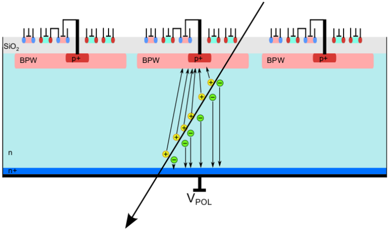
Properties

- Minimum pitch $< 10\ \mu m$
- Small sensor capacitance (good SNR)
- Double SOI $\rightarrow$ radiation hardness
- Wide temperature range $(4 - 400K)$
- Thinner and cheaper then hybrid solutions

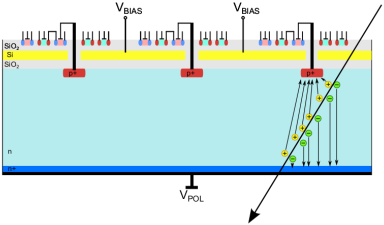
Double Silicon-On-Insulator

- voltage applied on Mid-Si layer allows to correct the potential changes caused by positive charges induced by irradiation,
- Mid-Si shields electronic from negative influence of high voltage needed for fully depletion.

SOI STRUCTURE



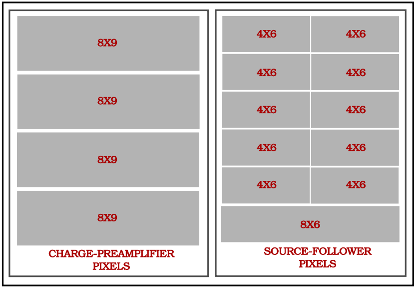
DOUBLE SOI STRUCTURE

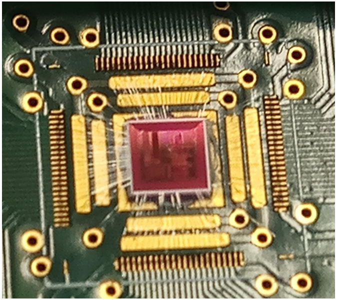


Lapis 200 nm Fully-Depleted Low-Leakage SOI CMOS with four wafer types: FZ(n), CZ(n), FZ(p) and Double SOI(p)

Architecture of SOI prototype chip

- submatrixes with different source-followers and charge pre-amplifiers, various layouts and transistor sizes,
- in total 16×36 pixels,
- $30\mu m \times 30\mu m$ pixel size $\rightarrow \sim 0.52\ mm^2$ matrix area,
- rolling shutter readout (integration time for one frame: $150\mu s$),
- different wafer types **(FZ(n),CZ(n), FZ(p) Double SOI)** with different substrate thickness (300-500 μm) and resistivity ($2k\Omega, 700\Omega, 8k\Omega$),
- technology allows to fabricate thin wafer - down to 50 μm.





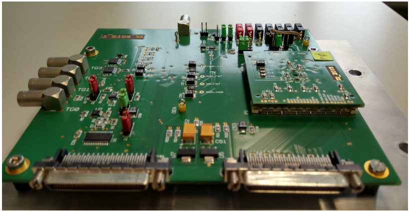
For this study only source-follower pixels were used on FZ(n) wafer.

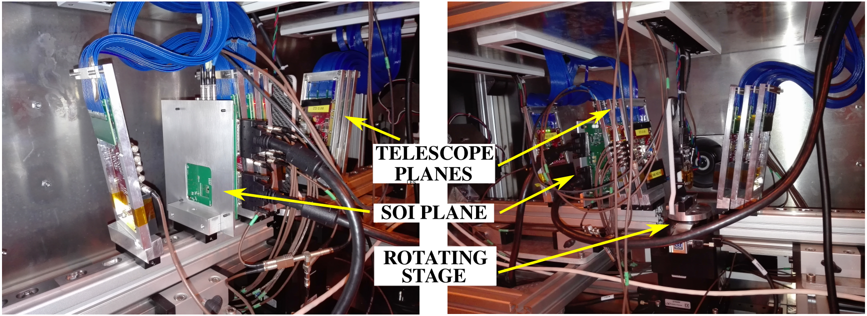
Very small size of submatrixes (different gain, noise) worsens achievable position resolution.

Testbeam setup

DAQ setup:

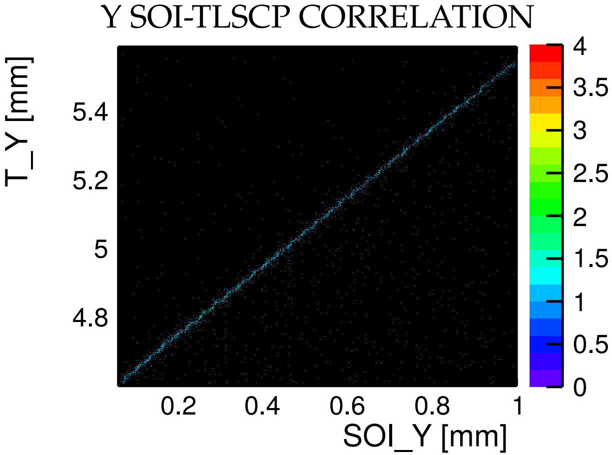
- main readout PCB + mezzanine boards with different SOI chips
- FPGA - PC → Ethernet
- DAQ Software - ROOT 6
- possibility of automatic parameters scans
- TESTBEAM: in the CLICdp Timepix3 telescope in the SPS-H6 beamline





More details about SOI-telescope integration see **Andreas Nurnberg Wednesday talk "Data-taking experience with the CLICdp Timepix3 telescope"**

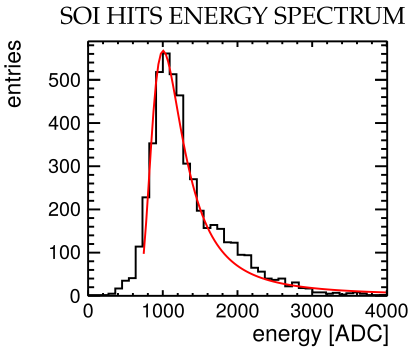
Correlation with telescope

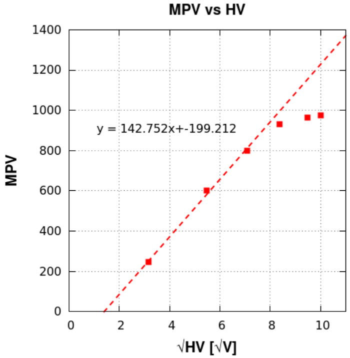


- good correlation with telescope
- large background due to long integration time of SOI pixel

Energy spectrum

- Landau energy spectra of SOI hits after clusterization. Plot shows all hits (before track association).
- The low energy tail most probably comes from readout issues.
- MPV signal saturates above 80V (default biasing was 90V).

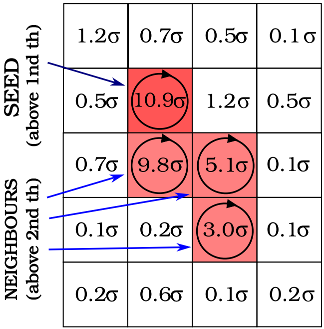




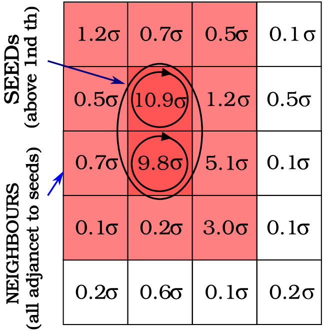
Clusterization methods

Different methods of clusterization in order to improve position calculation:

TWO-SEED METHOD



ALL-ADJANECT METHOD



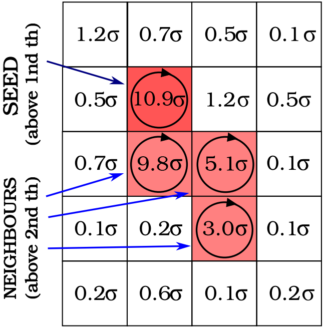
- Find pixels with signal above first threshold (signal $> 9\sigma = 9 \times$ pixel noise)
- Find all adjacent pixels above second threshold (signal $> 2\sigma$)
- When any pixel found, repeat algorithm for each new one.
- 4-pixel cluster is found.

- Find pixel with signal above threshold (signal $> 9\sigma$)
- When seed found, found all next adjacent seeds and repeat for each new one.
- Add to cluster all seeds neighbours
- 12-pixel cluster found.

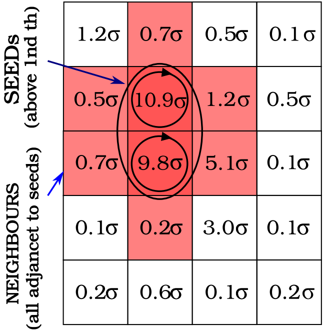
Clusterization methods

Different methods of clusterization in order to improve position calculation:

TWO-SEED METHOD



CROSS METHOD



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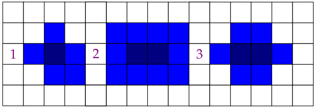
- Find all adjacent pixels above second threshold (signal $> 2\sigma$)
- When any pixel found, repeat algorithm for each new one.
- 4-pixel cluster is found.

- Find pixel with signal above threshold (signal $> 9\sigma$)
- When seed found, found all next adjacent seeds and repeat for each new one.
- Add to cluster all seeds neighbours in "cross" pattern
- 8-pixel cluster found.

Clusterization methods comparison



Two-seed method

- mean cluster size: 3.7 pixels
- asymmetry in resolution in x and in y direction

All-adjacent method

- mainly 2-seed clusters (50%), 1-seed cluster (36%)
- about 80% less reconstructed clusters then in two-seed methods
- resolution in x and in y consistent
- threshold condition used: $30 \times$ *pixel noise* (around 500 ADC) $\rightarrow$ high, but it is still 30% of most energetic pixel in cluster

Cross method

- similar to all-adjacent, but does not take neighbours on diagonal to seed.
- gives the same results as all-adjacent method

Conclusion

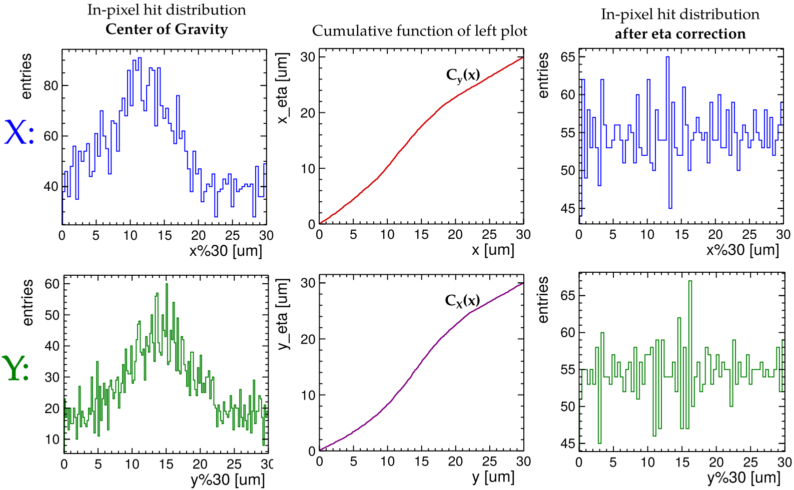
Two-seed method gives the best results in case of energy resolution, but the worse for spatial resolution. All-adjacent and cross methods are the best for position reconstruction, but give pure energy resolution.

Position reconstruction

For position reconstruction two methods were tested:

1. Center of Gravity
2. **Eta correction**

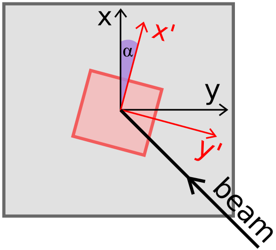
The in-pixel distribution is plotted → the cumulative function of this distribution is calculated: $C_X(x)$ → the corrected position x_{ETA} is given by: $x_{ETA} = C_X(x_{COG})$, where x_{COG} is the hit position obtained from center of gravity method.



Alignment of SOI pixel chip

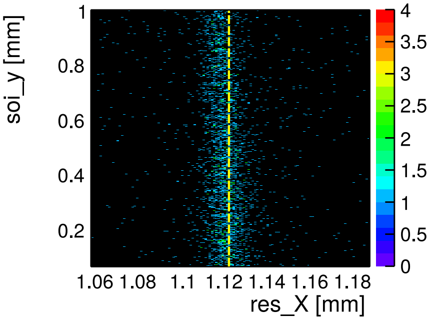
Two alignment methods were applied:

1. slope of soi y hit position versus residuum x,
2. minimum residuum versus rotation angle.

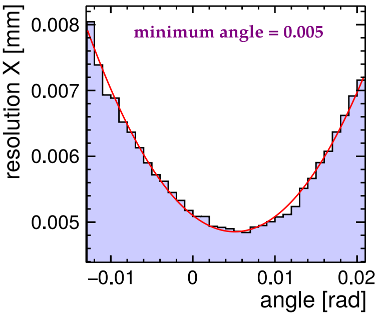


- both methods gave the same angle
- rotation angle is: $\alpha_{rot} = 0.005\ [rad] = 0.285\ [deg]$

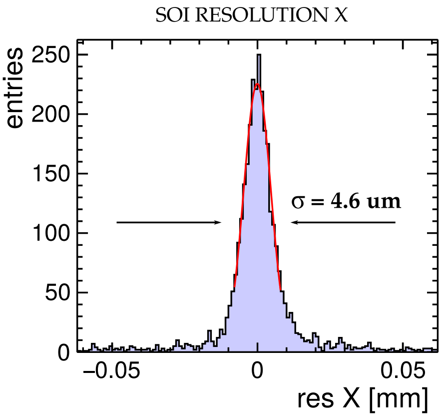
1 METHOD:

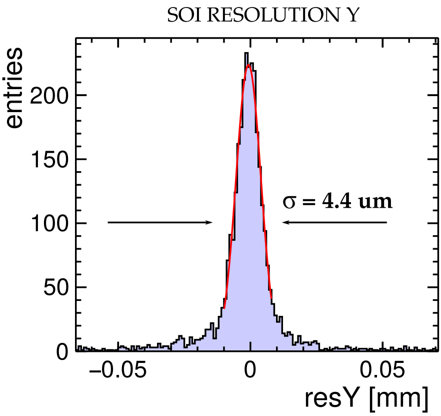


2 METHOD:



Spatial resolution of SOI detector - 90V FZ(n)





all-adjacent, rotation, eta - X

$X_{res} = 4.6\ \mu m$

all-adjacent, rotation, eta - Y

$Y_{res} = 4.4\ \mu m$

Taking into account the telescope resolution ($\sigma_T = \sim 2\mu m$) the SOI resolution is around $\sigma_{SOI} =\sim 4\mu m$.

Summary

1. The SOI pixel detector was tested successfully **for the first time in CLICdp testbeam.**
2. Data analysis including clustering, eta correction and alignment was performed in order to calculate the spatial resolution.
3. **Spatial resolution for** 30 μm **SOI pixels of around** 4 μm **was obtained.**
4. Ongoing studies: resolution vs bias voltage, analysis for different wafers.

Close future plans:

- New SOI prototype with larger and more uniform matrix has been fabricated and will be tested in the next testbeam.
- Next chip with timing information is being developed.

THANK YOU FOR ATTENTION !