Results of Beam Test Measurements with 3D-DDTC Silicon Strip Detectors

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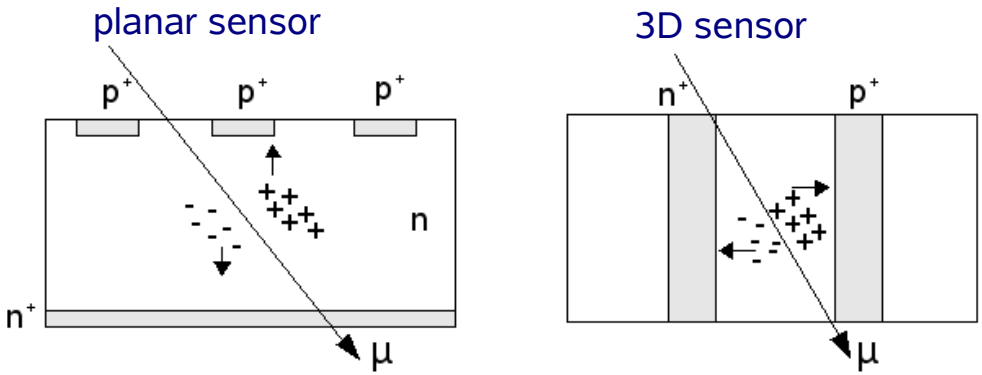
3D Detectors

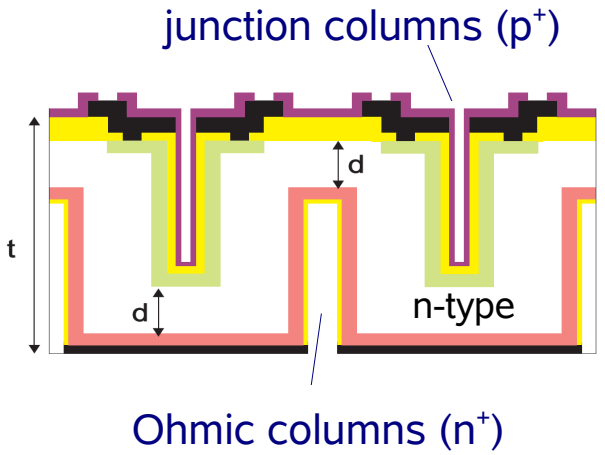
- Decoupling of thickness and distance for charge collection: columnar electrodes are etched into the sensor and doped
  - Lower depletion voltage, lower trapping



- Fabrication of 3D detectors challenging – modified designs under investigation

3D-DDTC

- FBK-IRST (Trento) and CNM (Barcelona): 3D-DDTC (double-sided, double type column)



- Columns etched into the wafer from both sides, but not fully penetrating
  - Process much simpler than full 3D detectors: less production steps, no support wafer required

- General designs of both manufacturers similar, but:

FBK:

- Columns unfilled
- Ohmic columns connected by uniform n^+-doping layer and metallisation
- AC and DC coupled readout pads

CNM:

- Columns partially filled with Poly-Silicon
- Ohmic columns connected by Poly-Silicon and metallisation
- DC coupled readout pads

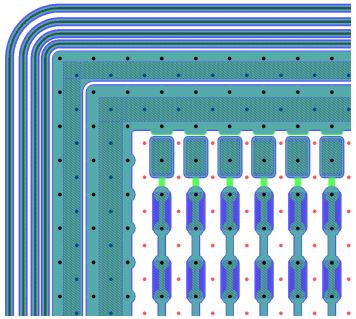
Devices Under Test

- Two devices under test (produced by FBK and CNM)
  - Of both manufacturers: first 3D-DDTC batches ever produced

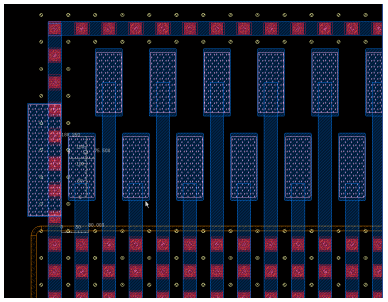
- Columns on “front” side (p^+-doped) are joined to strips
- Detector properties:

Property	FBK	CNM
Substrate Thickness	300 µm	285 µm
Substrate type	n-type (FZ)	n-type (FZ)
Strip pitch, column spacing in strips	100 µm	80 µm
Depth of junction columns (front side)	190 µm	250 µm
Depth of Ohmic columns (back side)	160 µm	250 µm
Strip Length	8.1 mm	4 mm
Number of Strip	81	50

FBK



CNM

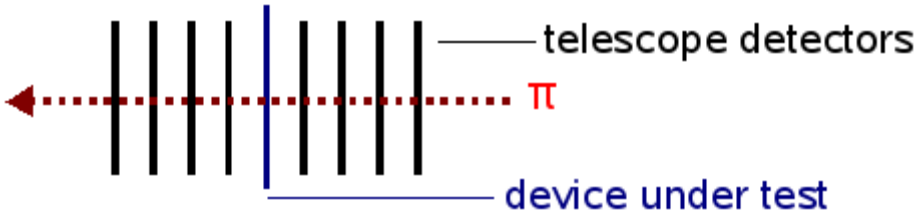


- Although 3D detectors are currently mainly a candidate for the sLHC pixel layers, it is still worth studying 3D detectors with strip design – the readout is much simpler

Test Beam July 2008

- CERN SPS, H2 beamline, 225 GeV/c pions
- Test beam in the framework of RD50 and CMS, organised by the University of Helsinki
- Silicon Beam Telescope (SiBT), resolution ≈ 4 µm

- Readout with CMS hardware, APV25 Chip (50 ns shaping time)



What Is New?

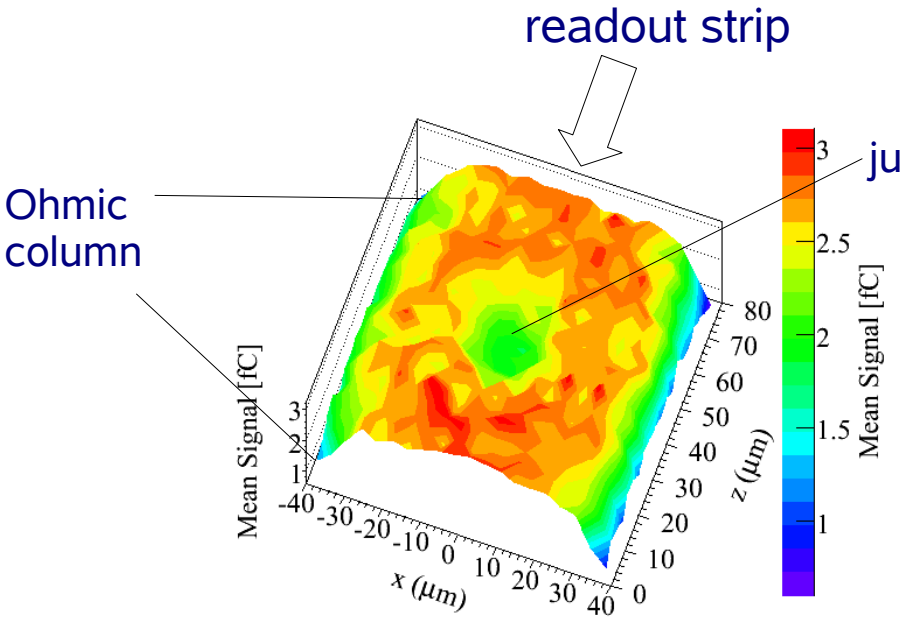
- Talk on test beam results already given during RD50 meeting in June 2009
  - Results limited on FBK sensor

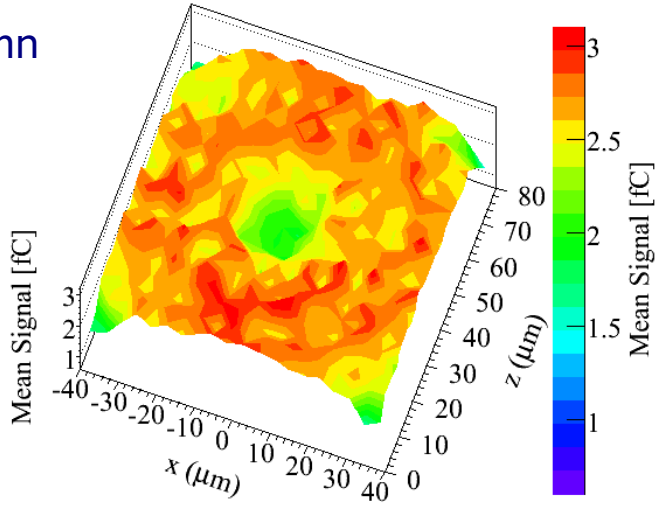
- Progress since June:
  - Recalculation of noise, pedestals and calibration
  - Analysis of the data of the CNM detector

    → This talk presents results of both detectors, but with a focus on the CNM sensor

Charge Collection 2D

- CNM device, 9 V bias
- Mean charge, data superimposed on unit cell



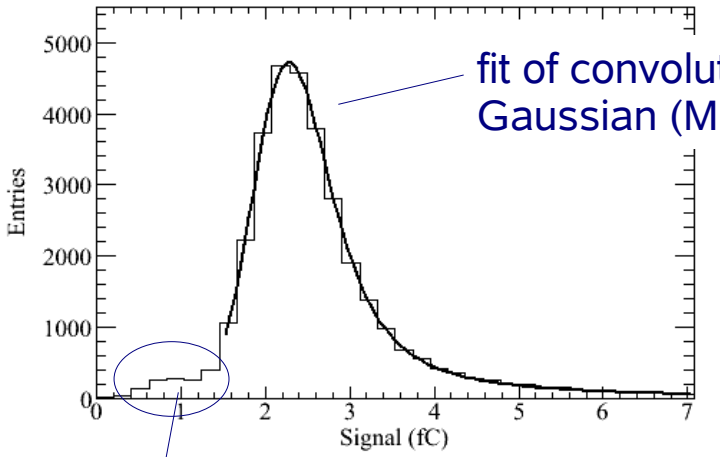


- Signal of single strip: charge sharing visible
- Signal of two neighbours summed up: lower signal only at column positions

Signal Spectrum at 9 V Bias (CNM)

- Sum of signal of the two strips closest to the track point of impact

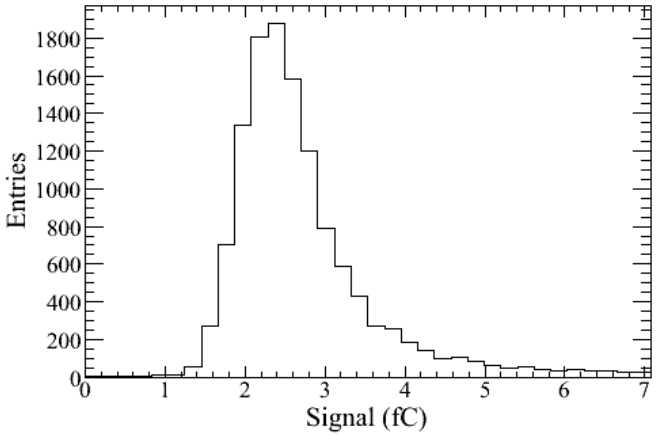
all tracks:



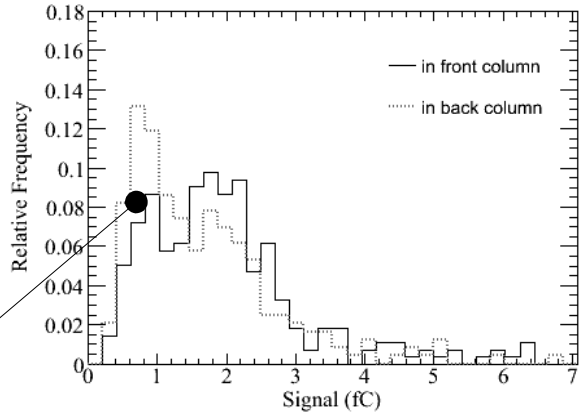
fit of convoluted Landau / Gaussian (MPV=2.1 fC)

contribution from particles going through the columns

tracks far away from columns:



tracks in front and back columns:



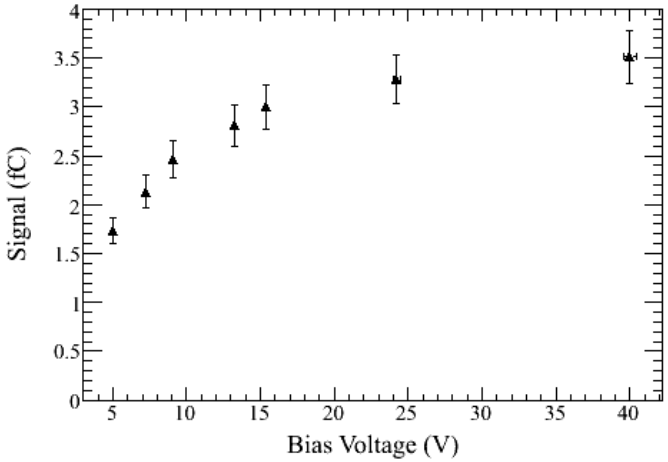
~30 % of full signal

- Tracks crossing the hollow columns: charge deposition only in silicon below the columns

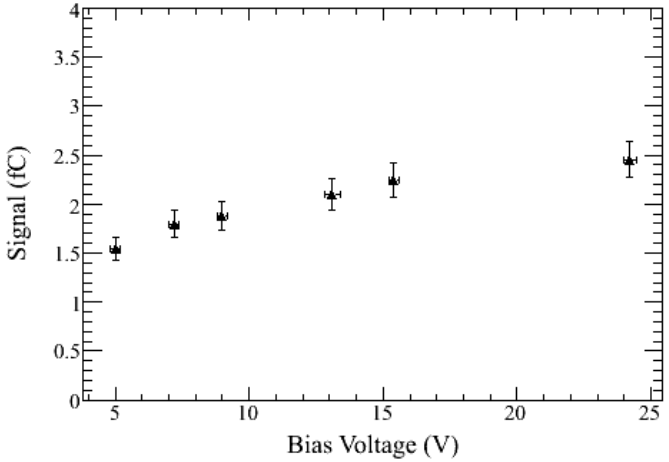
Signal Versus Bias

- Landau MPV vs bias voltage (clusters of both strips closest to track)

FBK



CNM

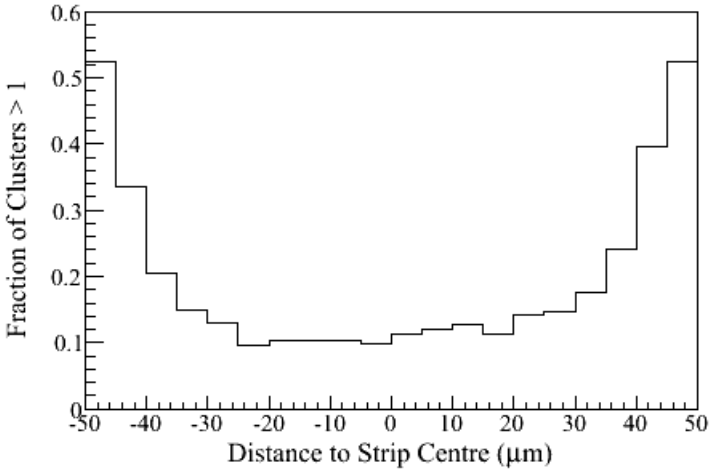


- FBK detector:
  - Max. signal at 40 V: (3.5 ± 0.3) fC, (22 ± 2) ke^-, S/N ~31
  - Expected for 300 µm silicon: 3.7 fC, 23 ke^-
  - → Measured signal in agreement with expected signal
- CNM detector:
  - Max. signal at 24 V: (2.5 ± 0.2) fC, (15.6 ± 1.2) ke^-, S/N ~30
  - Expected for 285 µm silicon: 3.5 fC, 22 ke^-
  - → Max. signal ~30% lower than expected (detectors are from very first batch!)

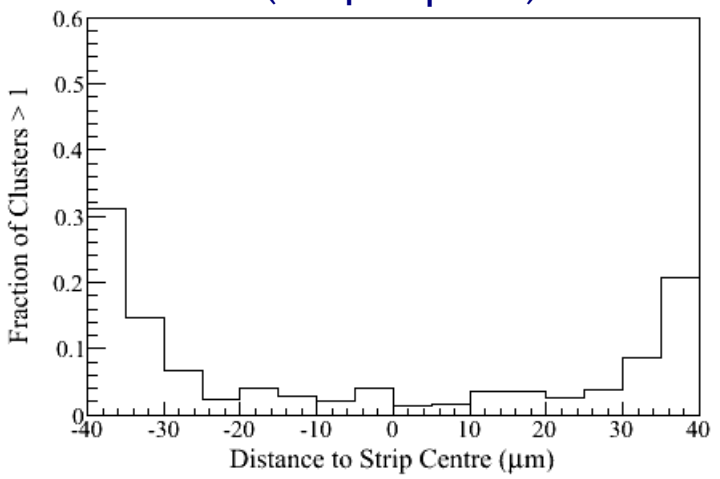
Charge Sharing

- Fraction of Clusters with > 1 strips vs distance to strip centre
  - Seed cut: S/N > 9, neighbour cut: S/N > 4
- Bias Voltage: 24 V

FBK (100 µm pitch)



CNM (80 µm pitch)



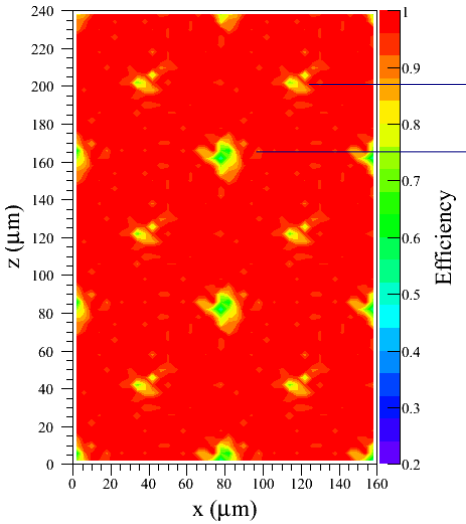
- Deeper columns in CNM detector

  → Lower charge sharing

2D Efficiency (CNM)

- Data superimposed onto unit cell – unit cell plotted six times side by side
- Bias: 24V, signals of two strips adjacent to the track position summed up
  - At 1 fC threshold: Eff. = 97.9 % - column structure visible
  - At 2 fC threshold: Eff. = 92.1 %

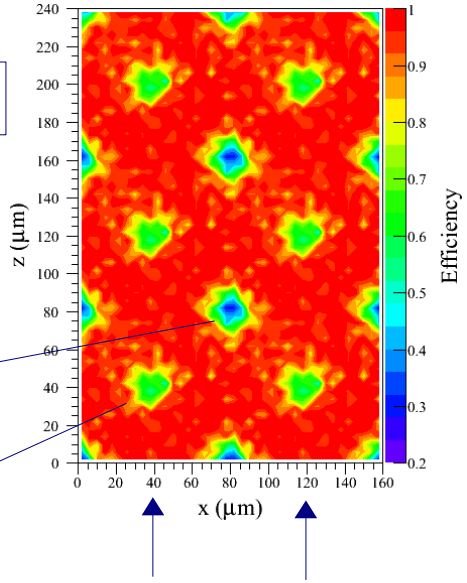
1 fC:



junction column

Ohmic column

2 fC:



Ohmic column

junction column

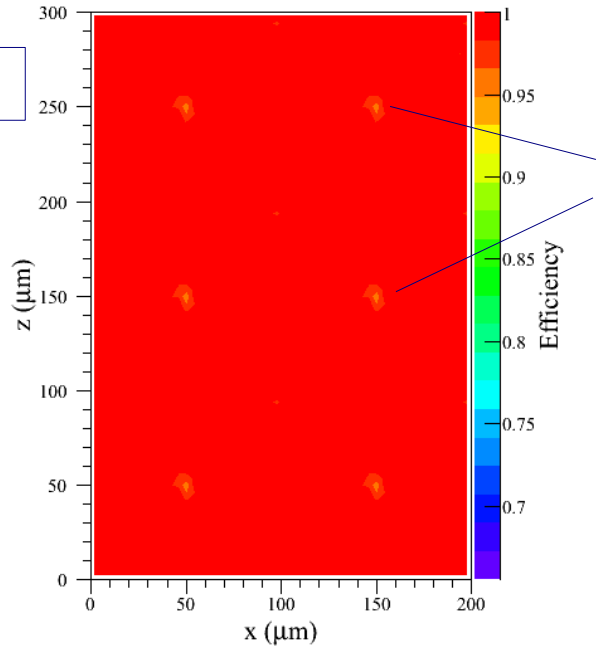
readout strips

- Efficiency, when only signals of single strips are considered:
  - at 1 fC: 97.5 %, at 2 fC: 90.4 %

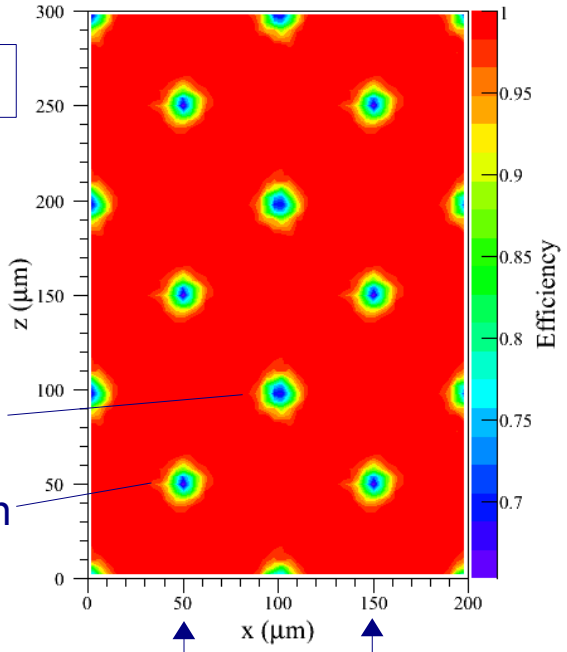
2D Efficiency (FBK)

- More statistics than for CNM detector → less fluctuations
- Bias: 40V, signals of two strips adjacent to the track position summed up
  - At 1 fC threshold: Eff. = 99.8 %
  - At 2 fC threshold: Eff. = 98.5 % - column structure clearly visible

1 fC:



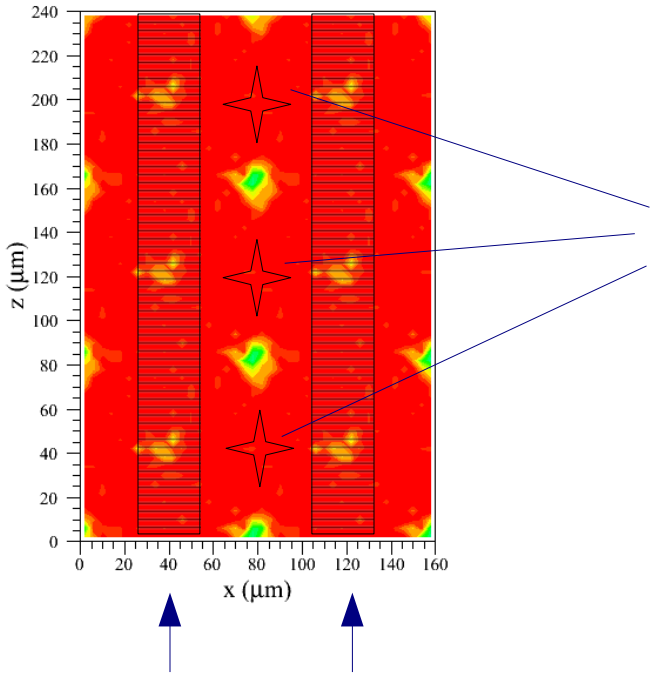
2 fC:



- Efficiency, when only signals of single strips are considered:
  - at 1 fC: 99.5 %, at 2 fC: 97.3 %

Low Field Region

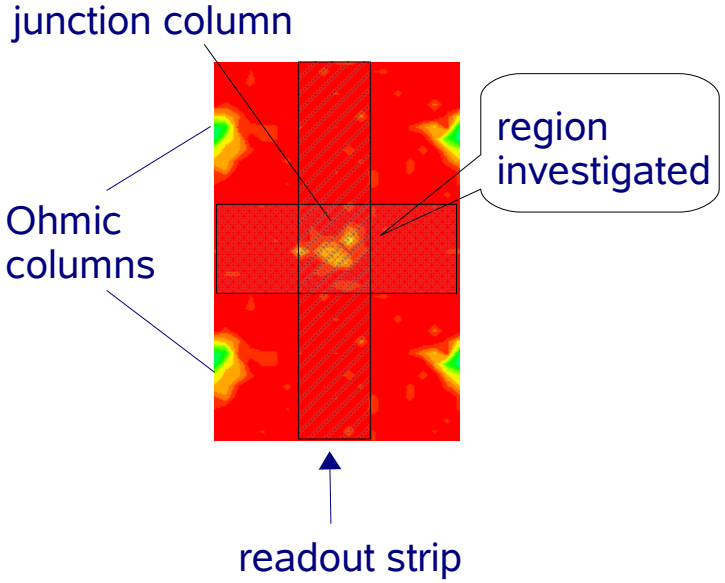
- From symmetry: region with minimum electric field is located in the middle of four columns



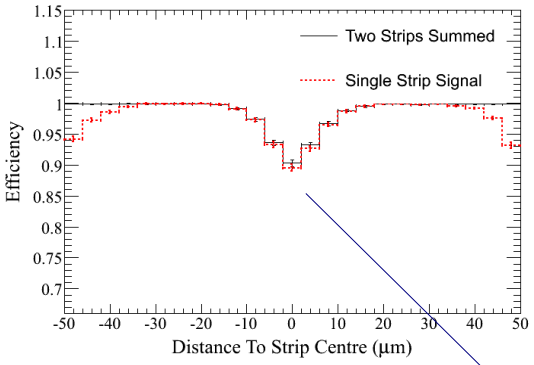
- Further investigation: uniformity of efficiency in low field region

Efficiency in Low Field Region

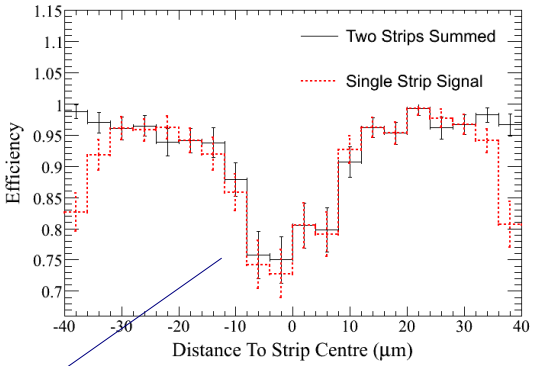
- To get a more quantitative view: consider one-dimensional efficiency in selected region
  - Threshold: 2 fC; exclude region around Ohmic column
  - Low field region located at left and right boarder of investigated region



FBK (40 V bias)



CNM (24 V bias)



junction column position

- In low field region: no efficiency drop observed when summing up signals of two neighbouring strips

  → Single strip signals: lower efficiency due to charge sharing

Conclusion / Outlook

- Measurements with first batch of 3D-DDTC (FBK and CNM) are promising:
  - Full charge collected in FBK sensor
  - Lower charge in CNM device
    - Detectors from 2nd batch: full charge measured (→ talk Richard Bates)
  - Apart from column positions: efficiency uniform

    → Improvement compared to 3D-STC (Single Type Column) detectors with columns of one doping type only

- Outlook: test beam with irradiated 3D and planar detectors performed in summer 2009 – data to be analysed

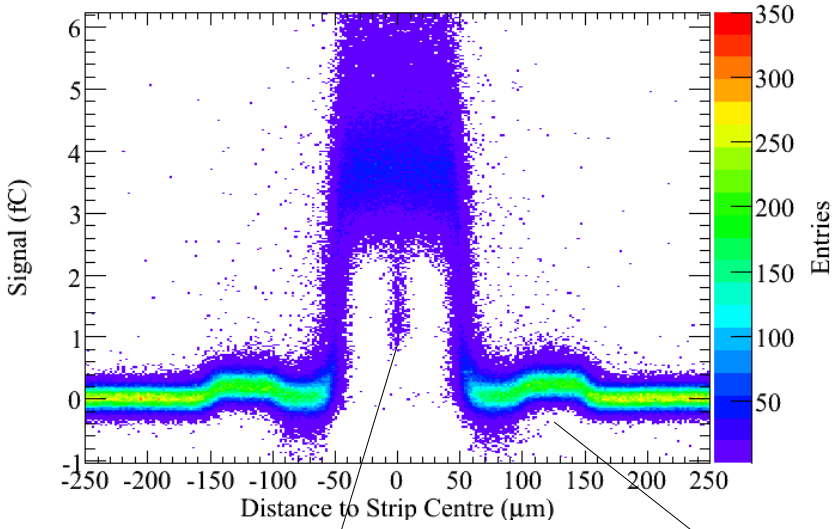
  → Direct comparison of radiation hardness of 3D and planar sensors

Backup Slides

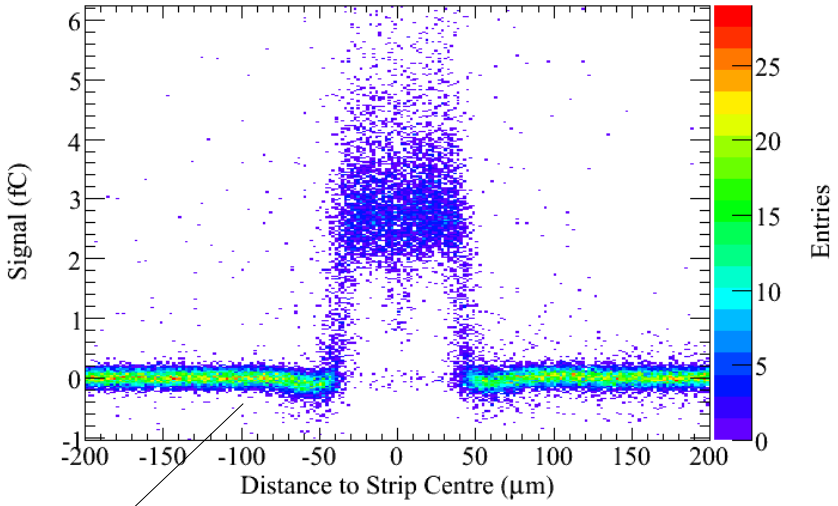
Signal vs X

- Signal vs distance to strip centre
  - FBK: higher signal on neighbour strip (-> charge sharing)

FBK, 40 V



CNM, 24 V



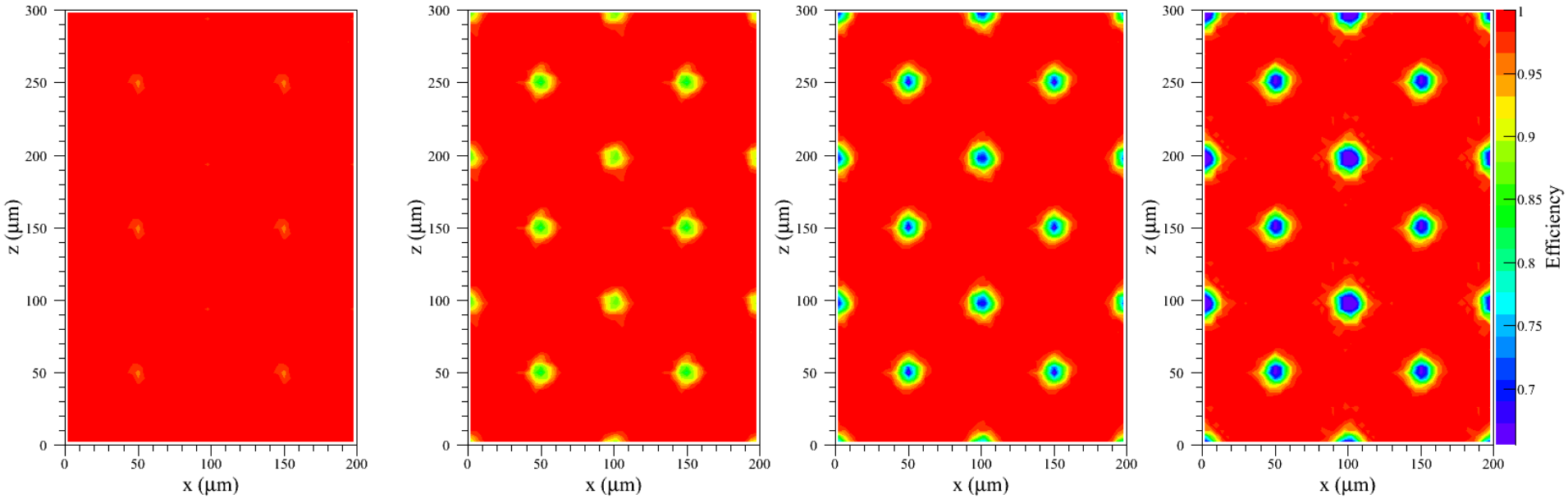
junction column

positive bump on neighbour only visible at FBK sensor

2D Efficiency, Different Thresholds (FBK)

- Again: Signal of two strips summed, 40 V bias

1 fC | 1.5 fC | 2 fC | 2.5 fC



eff.: (99.80±0.01)% | (99.24±0.02)% | (98.53±0.03)% | (97.52±0.04)%