Test Beam Measurements with 3D Silicon Strip Detectors
(Fabricated by FBK-IRST and CNM-IMB)

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SLHC: More Radiation Hardness Needed

- ~ 2019: luminosity upgrade of the LHC (super LHC)
  - → Peak luminosity increased tenfold: $L=10^{35}$ cm^{-2} s^{-1}

SUPER - LHC (5 years, 2500 fb^{-1})

[M. Moll]
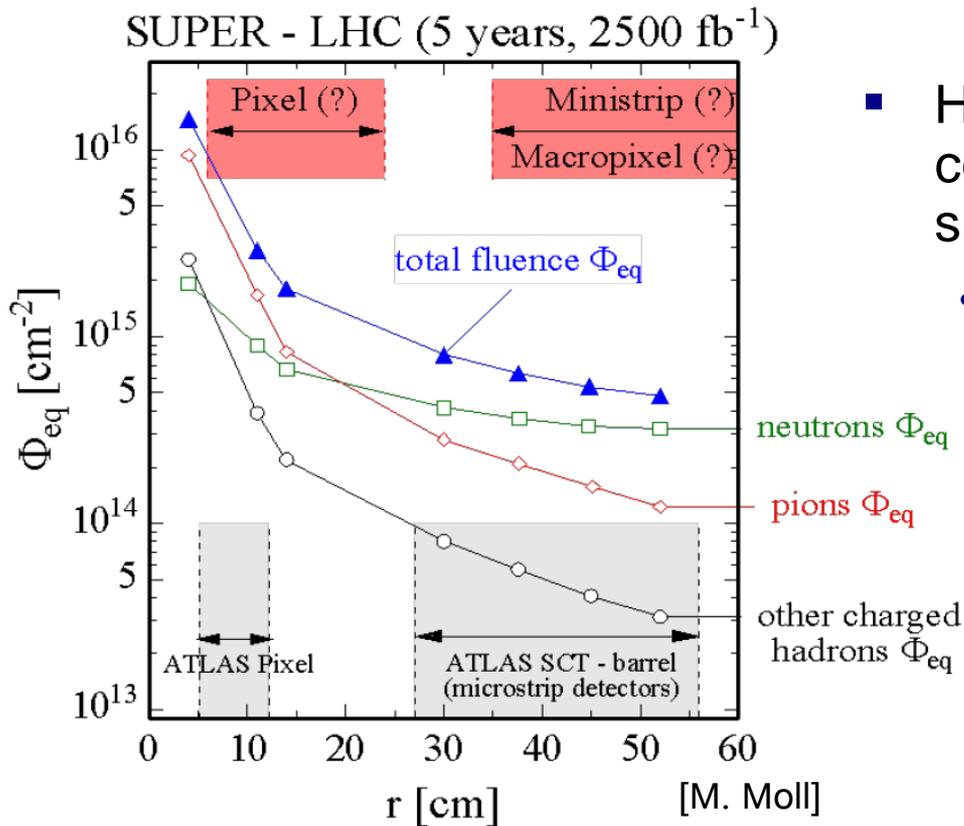
- High radiation level causes considerable radiation damage in silicon tracking detectors
  - New technologies needed for the tracking detectors, especially for the inner layers!

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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

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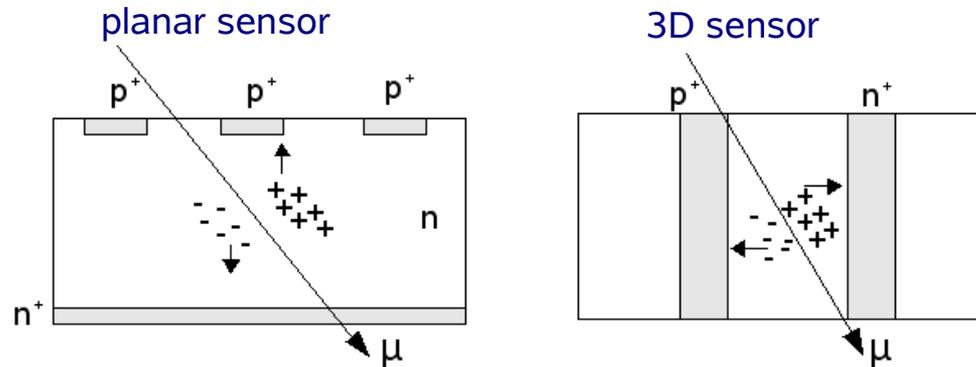
- Fabrication of 3D detectors challenging – modified designs under investigation

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3D-DDTC

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

junction columns (p^+)

n-type

Ohmic columns (n^+)

- 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
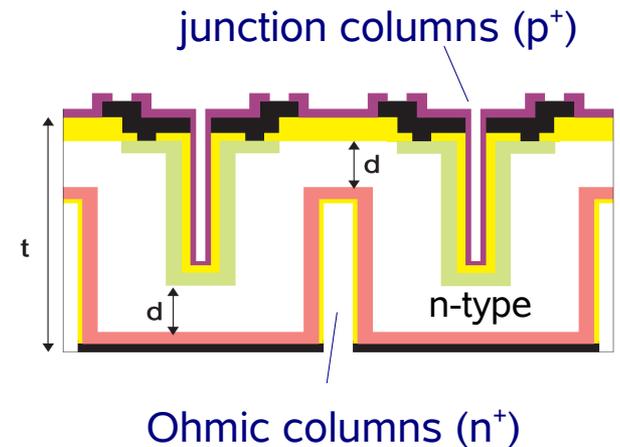
- General designs of both manufacturers similar, but:

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

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Devices Under Test

- Two devices under test (produced by FBK and CNM)

  - Of both manufacturers: first 3D-DDTC batches ever produced

    $\rightarrow$ Perfect performance not expected!

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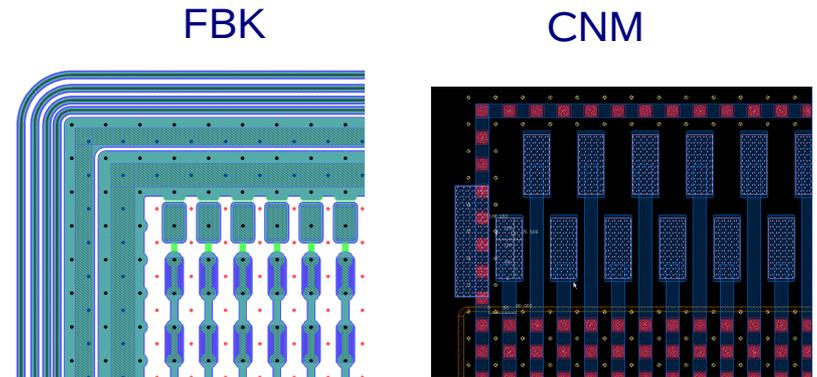
- Although 3D detectors are currently mainly a candidate for the sLHC pixel layers, it is still worth studying 3D detectors with strip design – the readout is much simpler

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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

- Sensor positioned perpendicular to the beam

- Readout with CMS hardware

- Front-end chip: APV25 (50 ns shaping time)

telescope detectors

π

device under test

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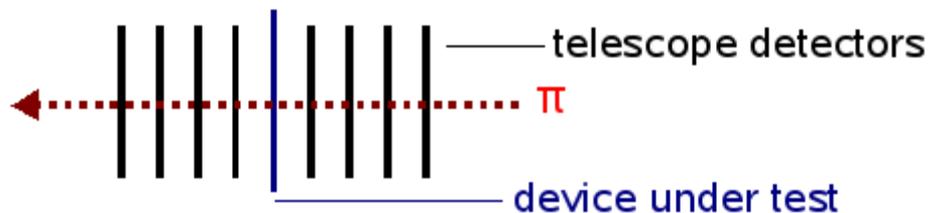
Signal Spectrum at 40 V Bias (FBK)

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

all tracks:

fit of convoluted Landau / Gaussian
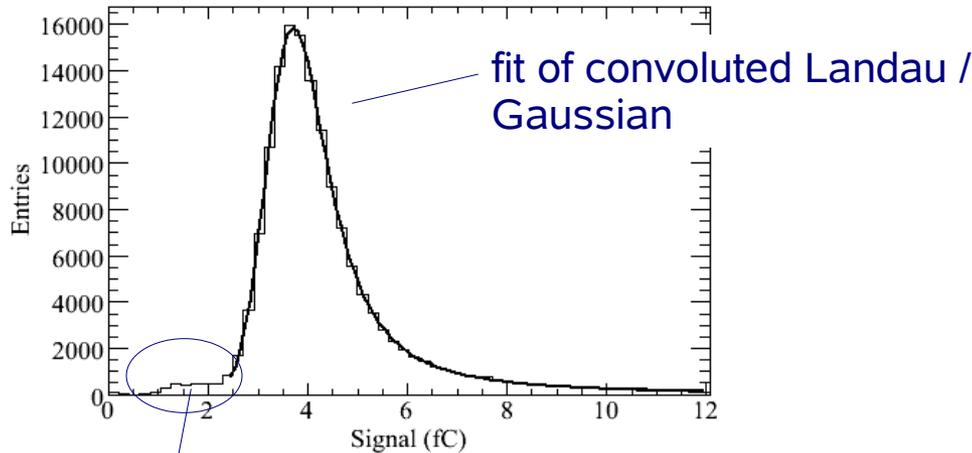
contribution from particles going through the columns

tracks in front and back columns:
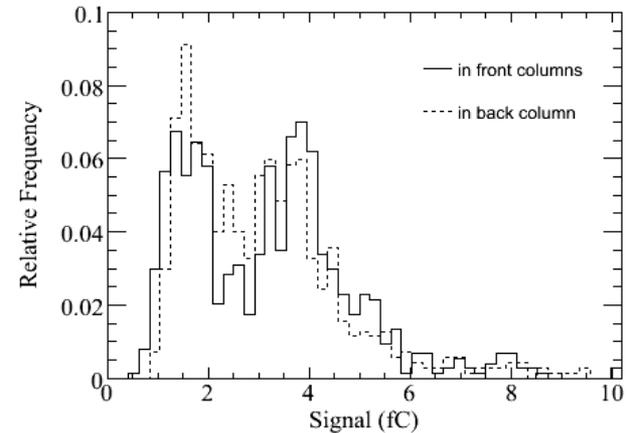
tracks far away from columns:
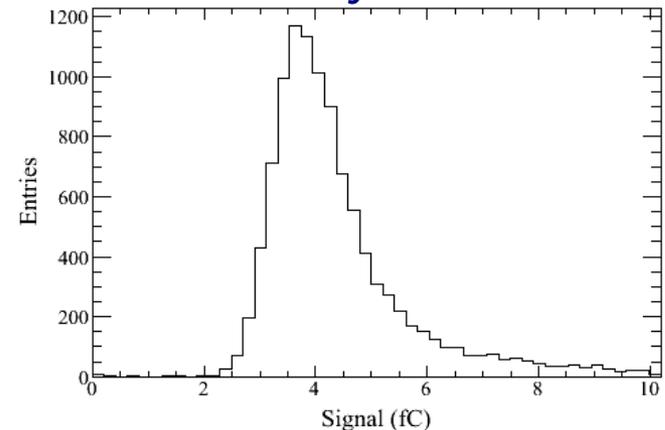
- Tracks crossing the hollow columns: charge deposition only in silicon below the columns

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Signal Versus Bias

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

FBK

CNM
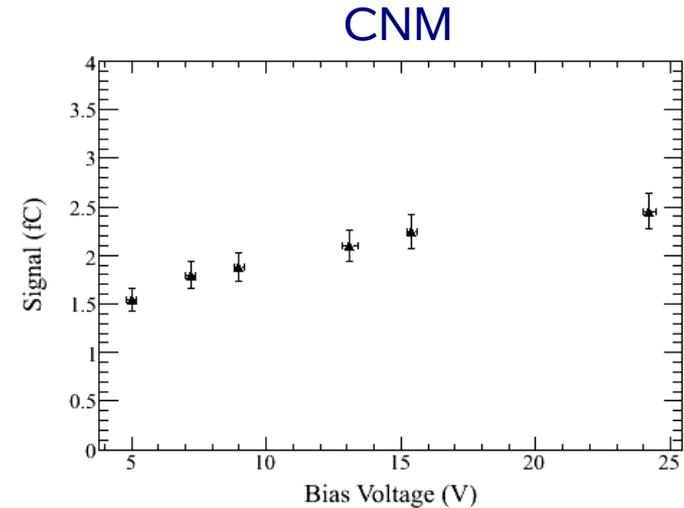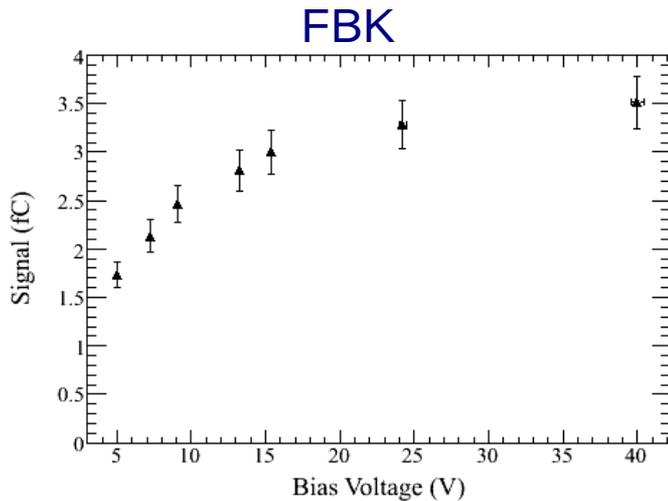
- **FBK detector:**
  - Max. signal at 40 V: (3.5 ± 0.3) fC, (22 ± 2) ke⁻, S/N ~31
  - Expected for 300 μm silicon: 3.7 fC, 23 ke⁻
  - → Measured signal in agreement with expected signal

- **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!)

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2D Efficiency (FBK)

- Data superimposed onto unit cell – unit cell plotted six times side by side

- Bias: 40V, signals of two strips adjacent to the track position summed up

  - At 1 fC threshold: Eff. = (99.80±0.01)%

  - At 2 fC threshold: Eff. = (98.53±0.03)% - column structure clearly visible

1 fC:

junction columns

2 fC:

Ohmic column

junction column

readout strips
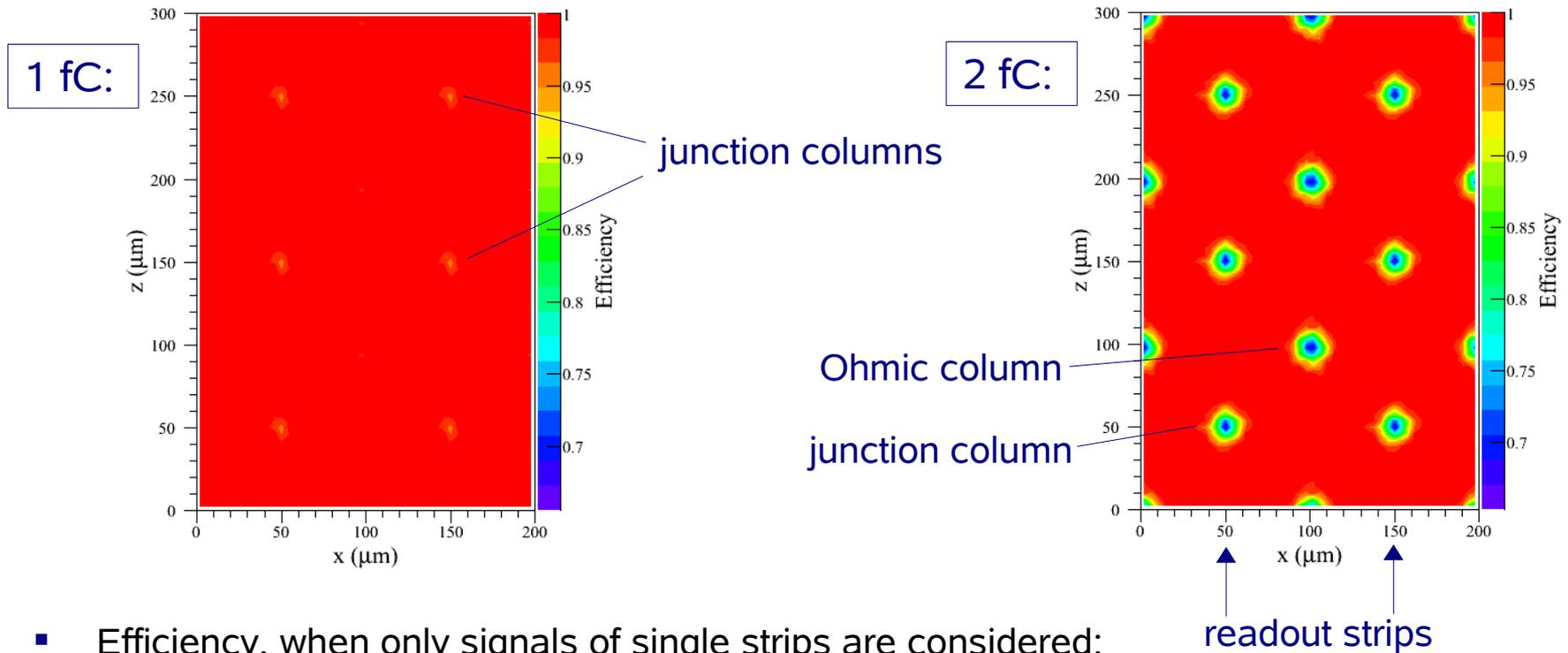
- Efficiency, when only signals of single strips are considered:

  - at 1 fC: (99.46±0.02)%, at 2 fC: (97.29±0.04)%

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2D Efficiency (CNM)

- More fluctuations than in plots for FBK sensor due to lower statistics
- Bias: 24V, signals of two strips adjacent to the track position summed up
  - At 1 fC threshold: Eff. = (97.9±0.2)% - column structure visible
  - At 2 fC threshold: Eff. = (92.1±0.3)%

1 fC:

junction column

Ohmic column

2 fC:

Ohmic column

junction column

readout strips
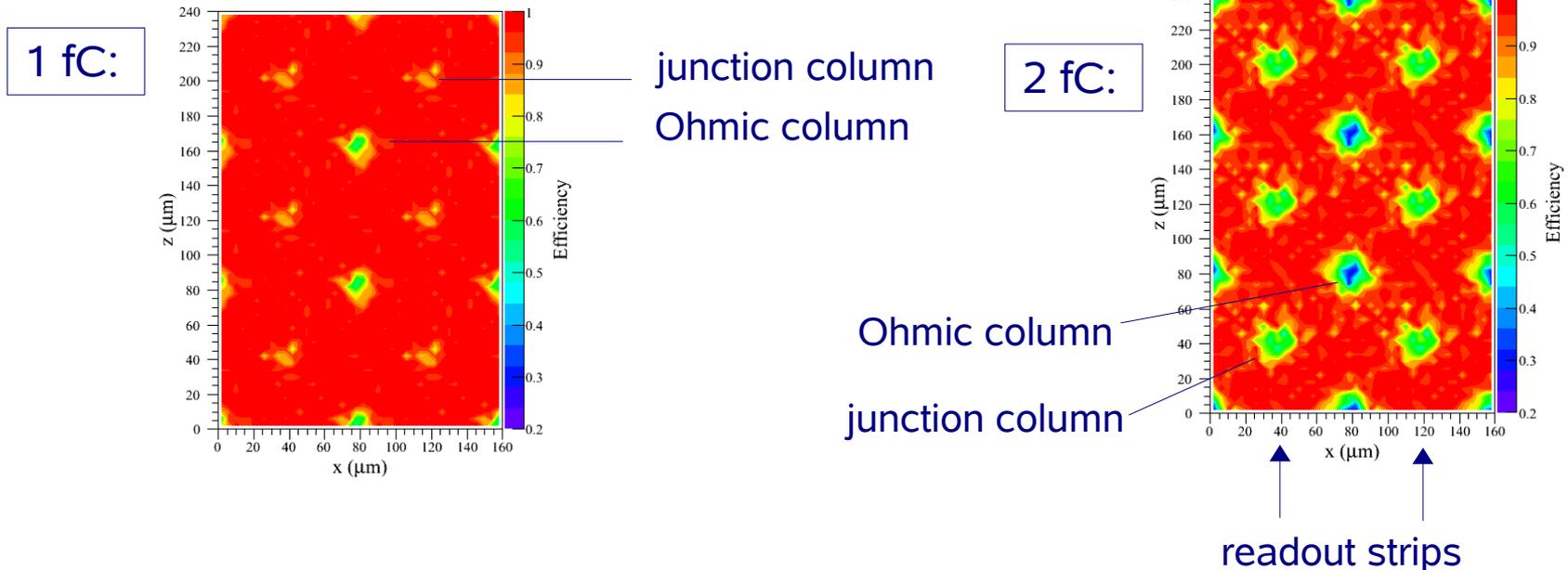
- Efficiency, when only signals of single strips are considered:
  - at 1 fC: (97.5±0.2)%, at 2 fC: (90.4±0.3)%

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Low Field Region

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

minimum electric field

readout strips
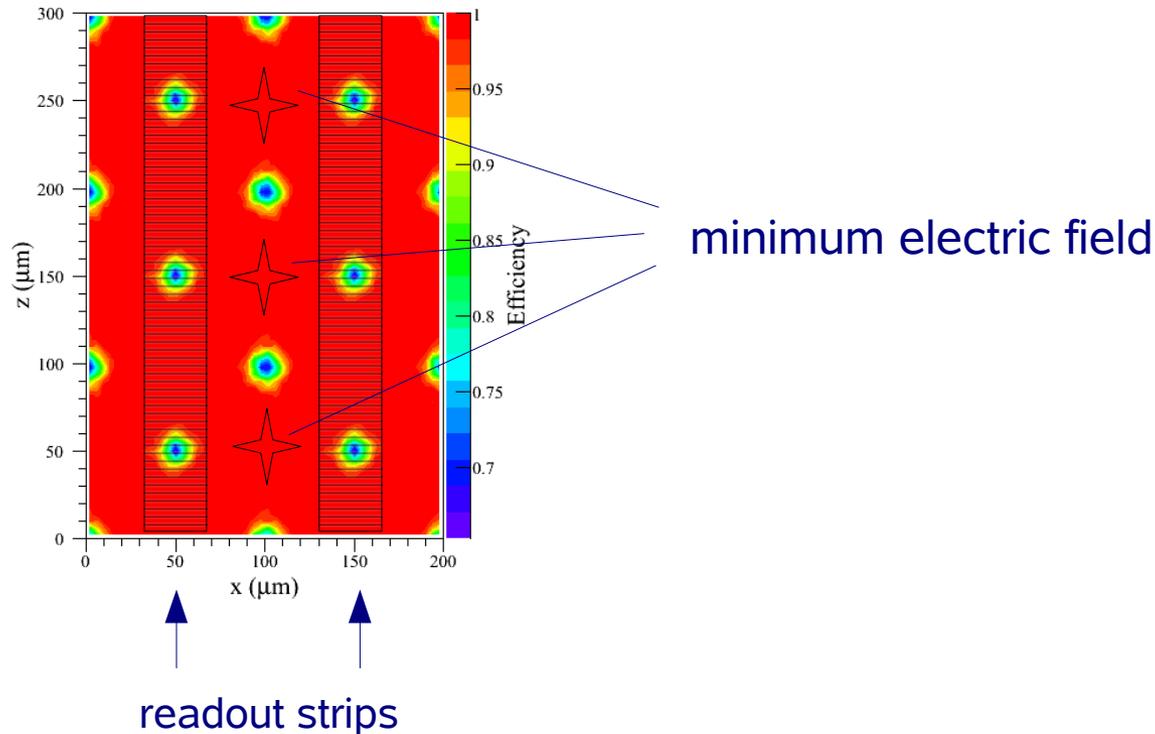
- Further investigation: uniformity of efficiency in low field region

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

junction column

investigated region

Ohmic columns

readout strip
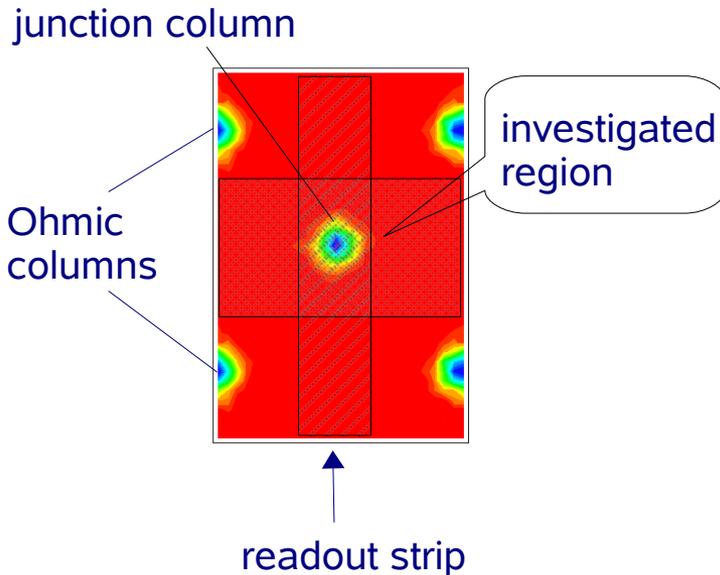
FBK (40 V bias)
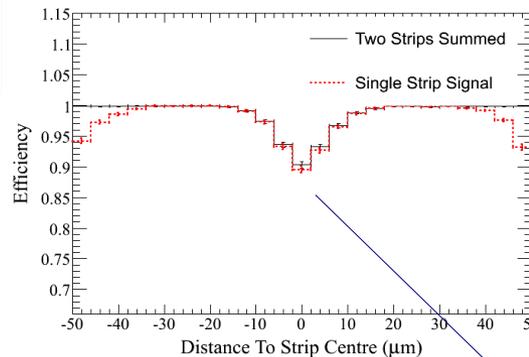
CNM (24 V bias)
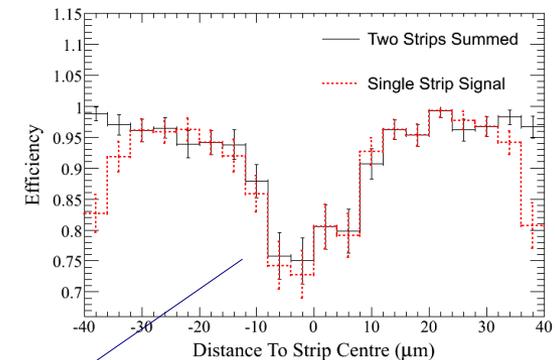
junction column position

- 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

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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 (preliminary laboratory measurements with devices of second batch indicate full carge collection)

  - Apart from column positions: efficiency uniform

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

- Measurements performed with 50 ns shaping time – lower signal expected for shorter shaping time (especially for the FBK sensor geometry due to small column overlap)

  - New batches of DDTC detectors (p-type, FBK: also deeper columns): full charge should be collected within 25 ns

- 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

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Backup Slides

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Charge Collection 2D (FBK)

- Bias: 40 V

- Sensor divided into bins, mean of measured signal (not Landau MPV!) superimposed onto a unit cell

  - Signal of two strips closest to the track position summed up

readout strip

juntion column

Ohmic columns
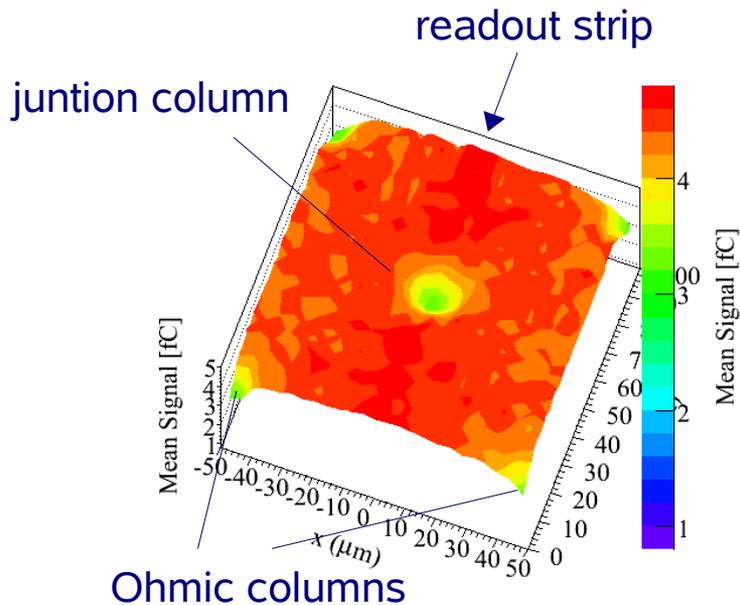
- In column positions: lower signal

Charge Collection 2D

- Sensor divided into bins, mean of measured signal (not Landau MPV!) superimposed onto a unit cell

  - Growth of the depletion visible
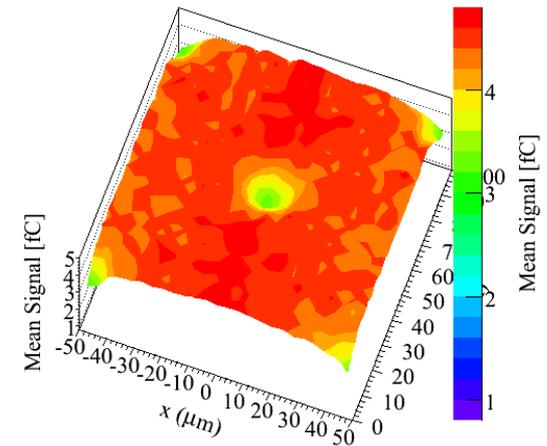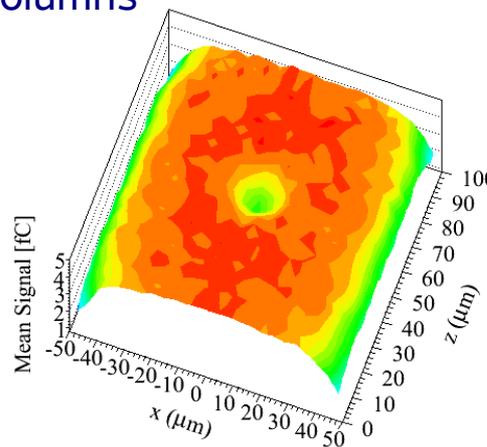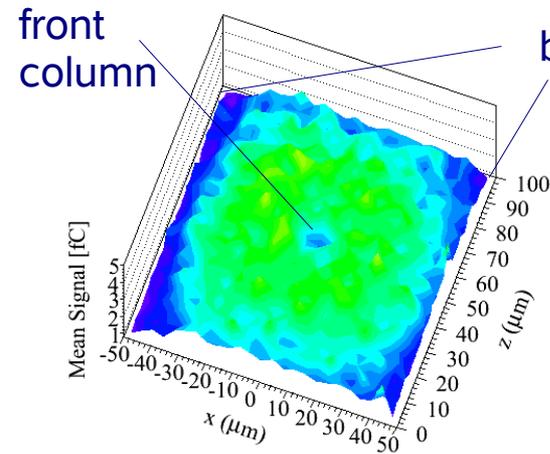
- **5 V bias, signal of single strip**

  Signal still low, confined to region around readout electrode (not yet fully depleted)

- **40 V bias, signal of single strip**

  Charge sharing between readout strips

- **40 V bias, signal sum of two neighbouring strips**

  Signal uniform (apart from the column positions)

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2D Efficiency in 3D-STC

- Testbeam from 2007 with 3D-STC detectors [G. Pahn et al., IEEE TNS]
  - Efficiency: ratio of hits abive threshold and total hits
  - 2D efficiency map (40 V bias) with everything superimposed onto one unit cell and then plotted six times next to each other
  - Cut: deposied charge ≥ 1 fC
- Expressed low field region in the middle between strips visible

readout strip

readout column

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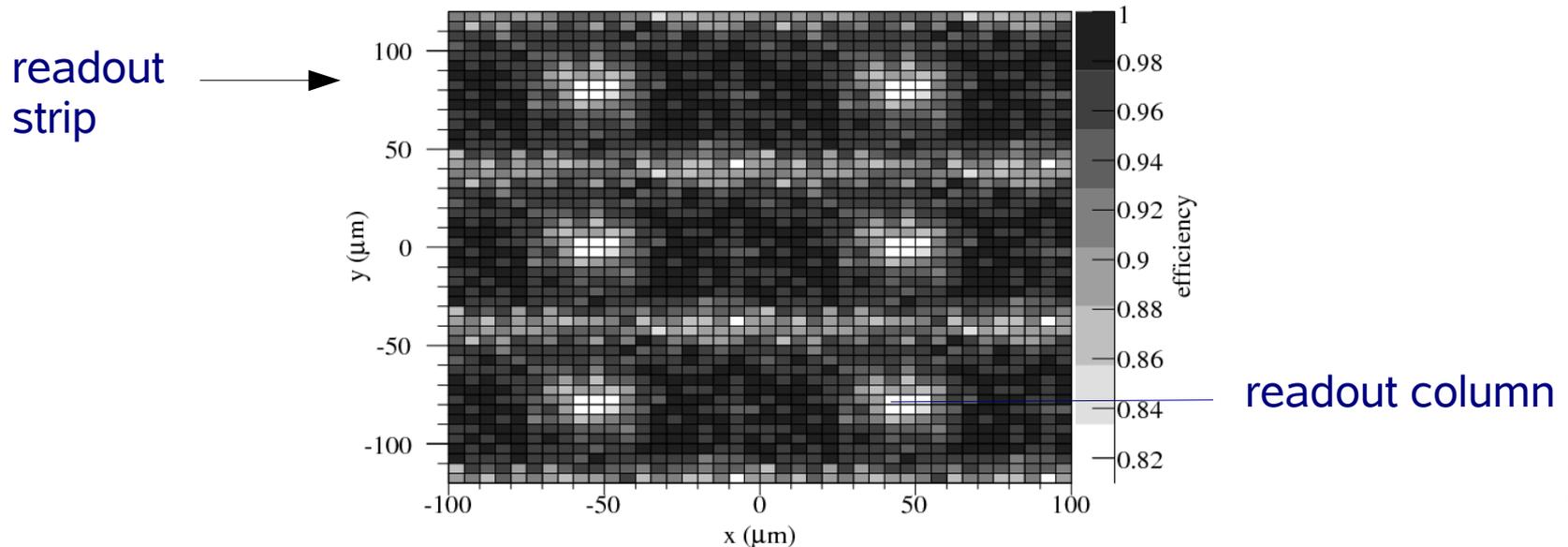
2D Efficiency, Different Thresholds

- Again: Signal of two strips summed, 40 V bias
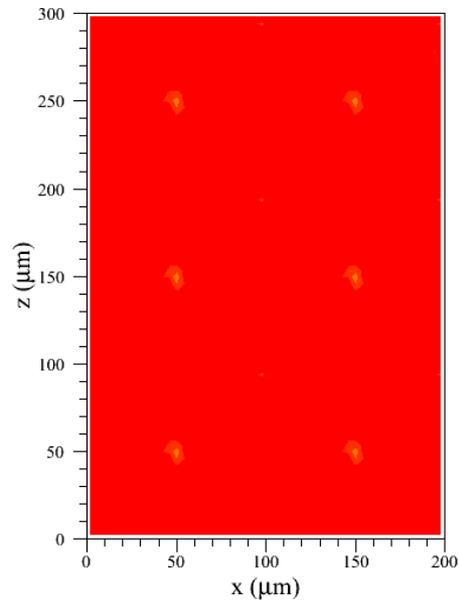
1 fC — eff.: (99.80±0.01)%
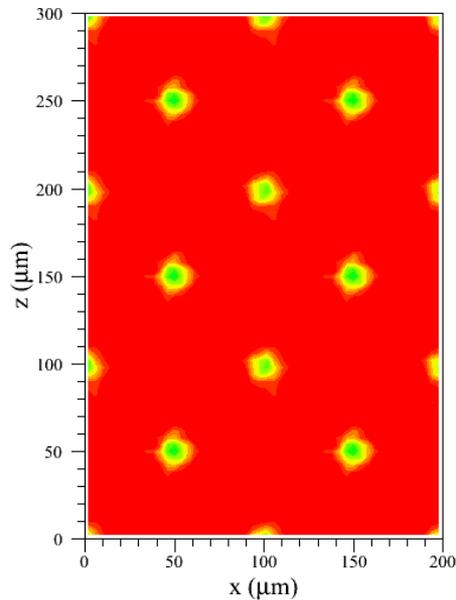
1.5 fC — (99.24±0.02)%

2 fC — (98.53±0.03)%

2.5 fC — (97.52±0.04)%

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