Test Beam Measurements with 3D-DDTC Silicon Strip Detectors

Michael Köhler[1], Richard Bates[2], Gian-Franco Dalla Betta[5], Maurizio Boscardin[3], Simon Eckert[1], Jaakko Härkönen[4], Sarah Houston[2], Karl Jakobs[1], Susanne Kühn[1], Panja-Riina Luukka[4], Teppo Mäenpää[4], Henri Moilanen[4], Gregor Pahn[1], Chris Parkes[2], Ulrich Parzefall[1], Sabina Ronchin[3], Andrea Zoboli[5], Nicola Zorzi[3]

[1]University of Freiburg

[2]University of Glasgow

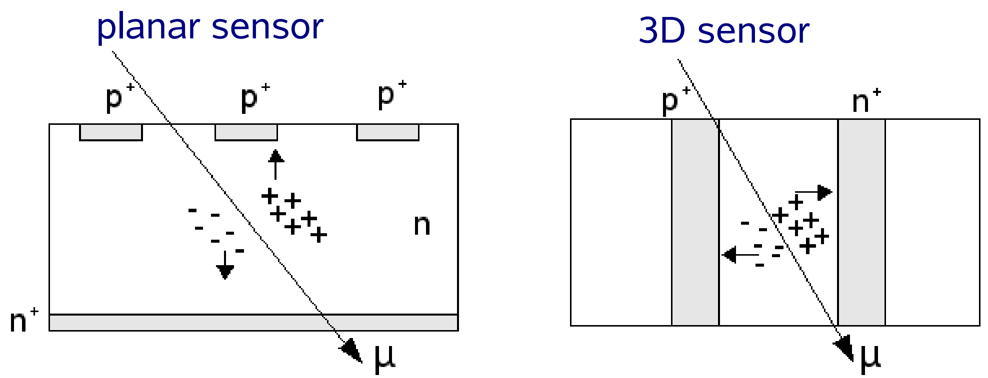
[3]FBK-IRST, Trento

[4]University of Helsinki

[5]INFN and University of Trento

3D Detectors

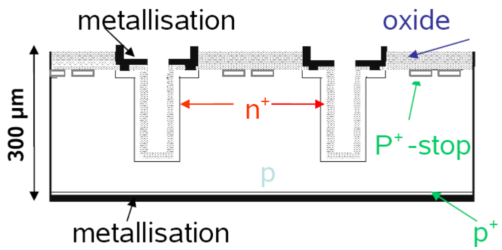
- Decoupling of detector thickness and distance for charge collection: columnar electrodes are etched into the sensor and doped
  - Shorter distance between electrodes: lower depletion voltage, lower trapping



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

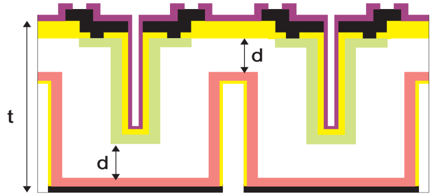
From 3D-STC to 3D-DDTC

- FBK-IRST (Trento) and CNM (Barcelona): First step was production of 3D-STC (single type column) detectors
  - Columns only from one side and one doping type, not completely penetrating



- Problem: low field region between two columns – charge collection not perfect!

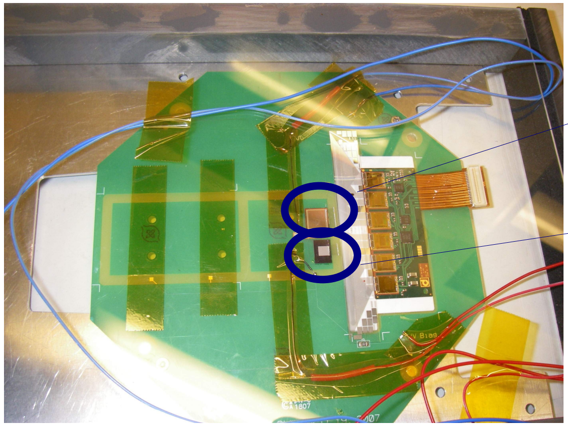
- Next step: columns from both sides, but still not fully penetrating
  - 3D-DDTC (double-sided, double type column)



- Column overlap determines the performance
- Low field regions (as in STC design) expected to be reduced

Test Beam July 2008

- CERN SPS, H2 beamline, 225 GeV/c muons
- In the framework of RD50 and CMS, organised by the University of Helsinki
- Silicon Beam Telescope (SiBT), resolution ≈ 4 µm (or even better)
- Teppo Mäenpää: providing tracking data



FBK sensor

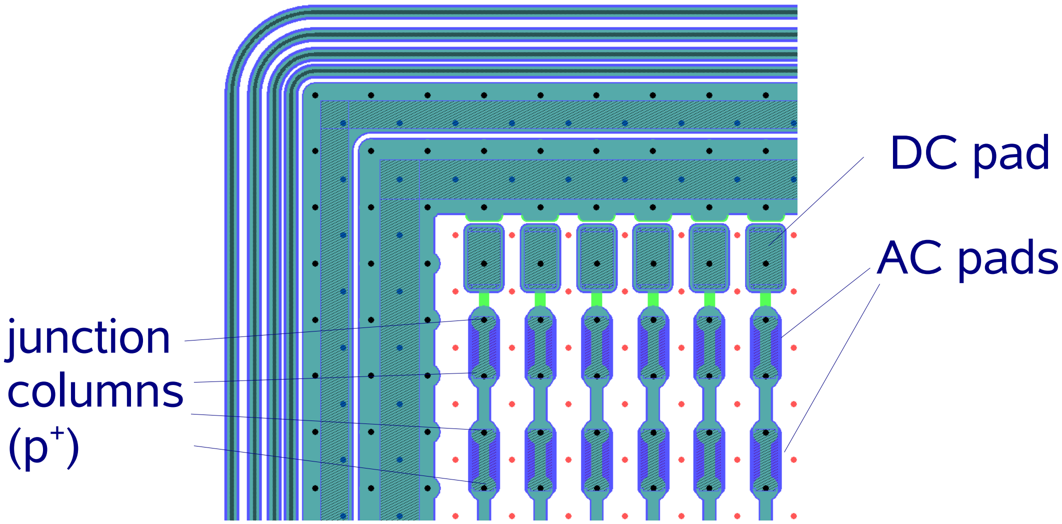
CNM sensor

- Readout: CMS APV25 chip (analogue)
- Peak mode applied (50 ns shaping time)

Device Under Test

- Two microstrip 3D-DDTC detectors tested in the test beam
  - One sensor produced by CNM (Barcelona)
  - One sensor produced by FBK-IRST (Trento)
  - This talk focuses on the detector provided by FBK-IRST

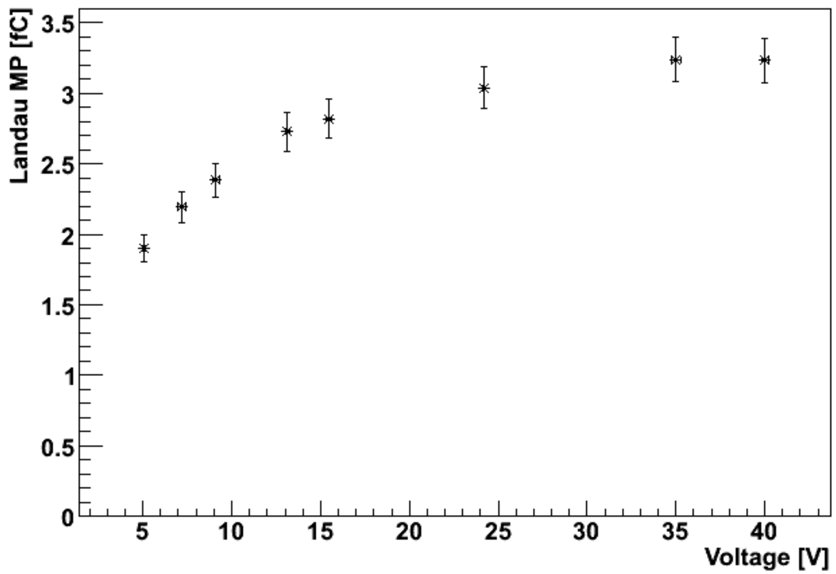
- Columns on “front” side (p-doped) are joined to strips



Substrate Thickness	300 µm
Substrate Type	n-type (FZ)
Resistivity	> 6 kΩ cm
Strip Pitch	100 µm
Depth of Junction Columns (Front Side)	190 µm
Depth of Ohmic Columns (Back Side)	160 µm
Strip Length	8.1 mm
Number of Strips	81
Column Spacing in Strips	100 µm

Collected Charge

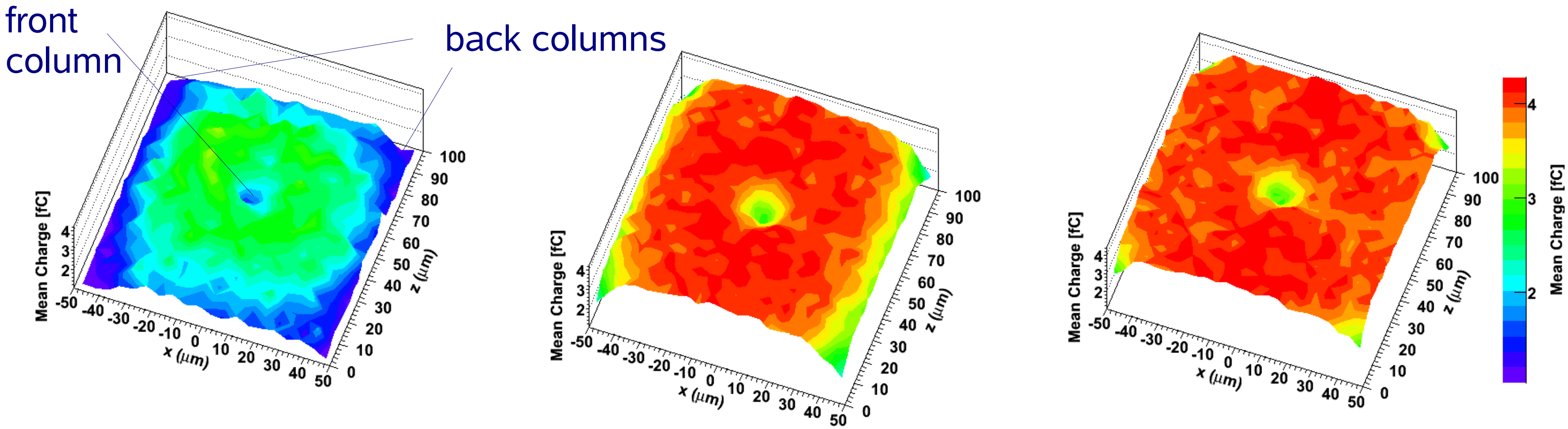
- Landau MPV vs bias voltage



- Maximum charge ≈ 20±1 ke^- (3.2±0.2 fC)
  - expected for 300 µm silicon: 22000 e^- (3.5 fC)
- Charge collection time according to simulations ≈ 45 ns (for n-type, depends also on column depth)
  - No significant ballistic deficit (shaping time 50ns)

Charge Collection 2D

- Sensor divided into bins, mean collected charge (not Landau MPV!) superimposed onto a unit cell
  - Growth of the depletion and electric field visible



- U=5 V, no clustering

Signal still low, confined to region around readout electrode

- U=40 V, no clustering

Signal uniform, only charge sharing between readout strips

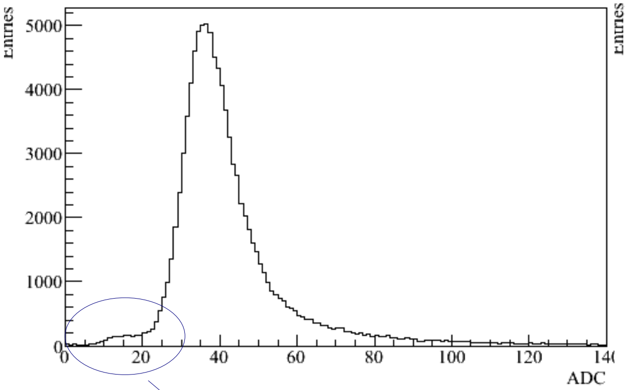
- U=40 V, 3-strip clusters

Signal uniform (apart from the column positions)

Charge Deposition – Different Regions

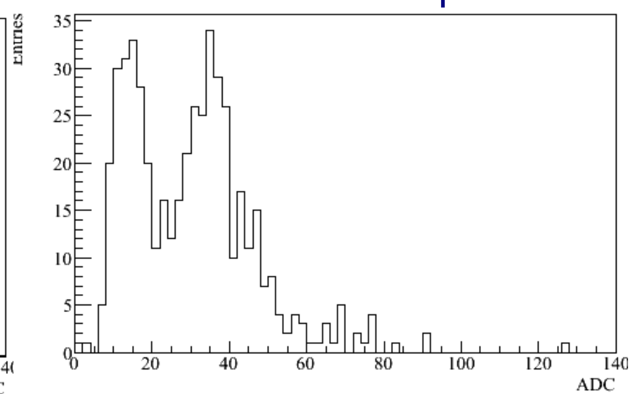
- ADC spectra in different regions of the sensor (sum of highest and second highest ADC):

entire area

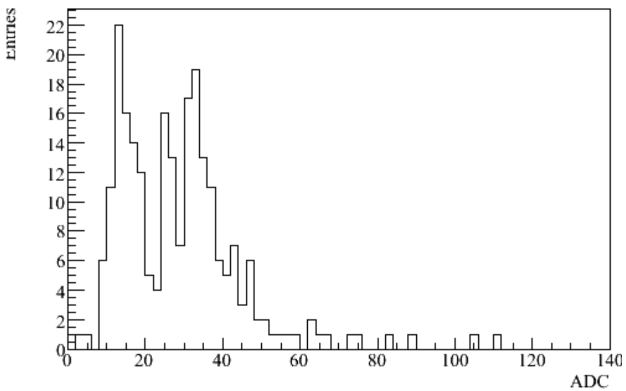


contribution from particles going through the columns

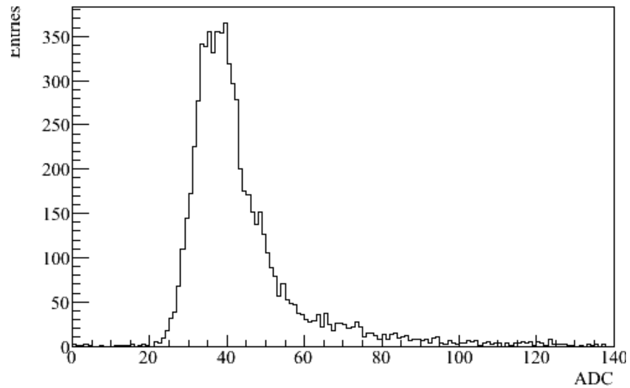
distance to center of front columns < 4 µm



distance to center of back columns < 4 µm



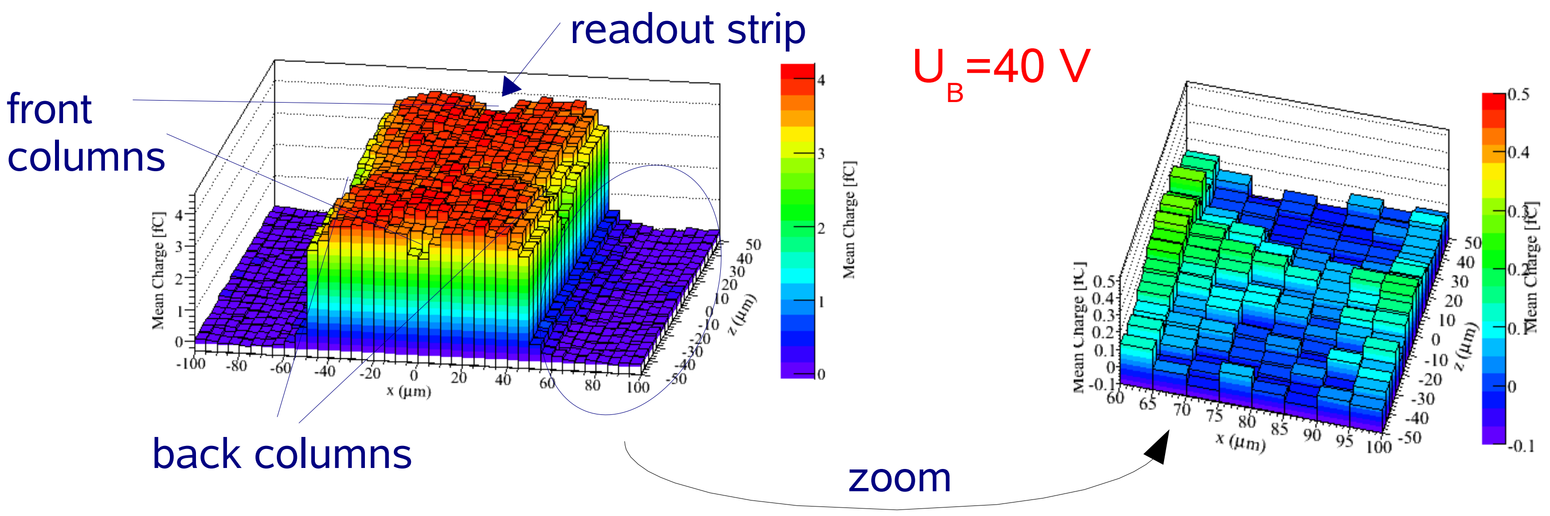
distance to center of front columns: 26 µm - 30 µm



- ADC spectrum in columns: two peaks visible
  - Lower peak believed to come from the particles which deposit charge in the silicon only below the columns
  - Higher peak: telescope smearing, inclined tracks

Induced Signal on Adjacent Strips

- Signal of particles hiting a readout strip directly or one of its neighbours

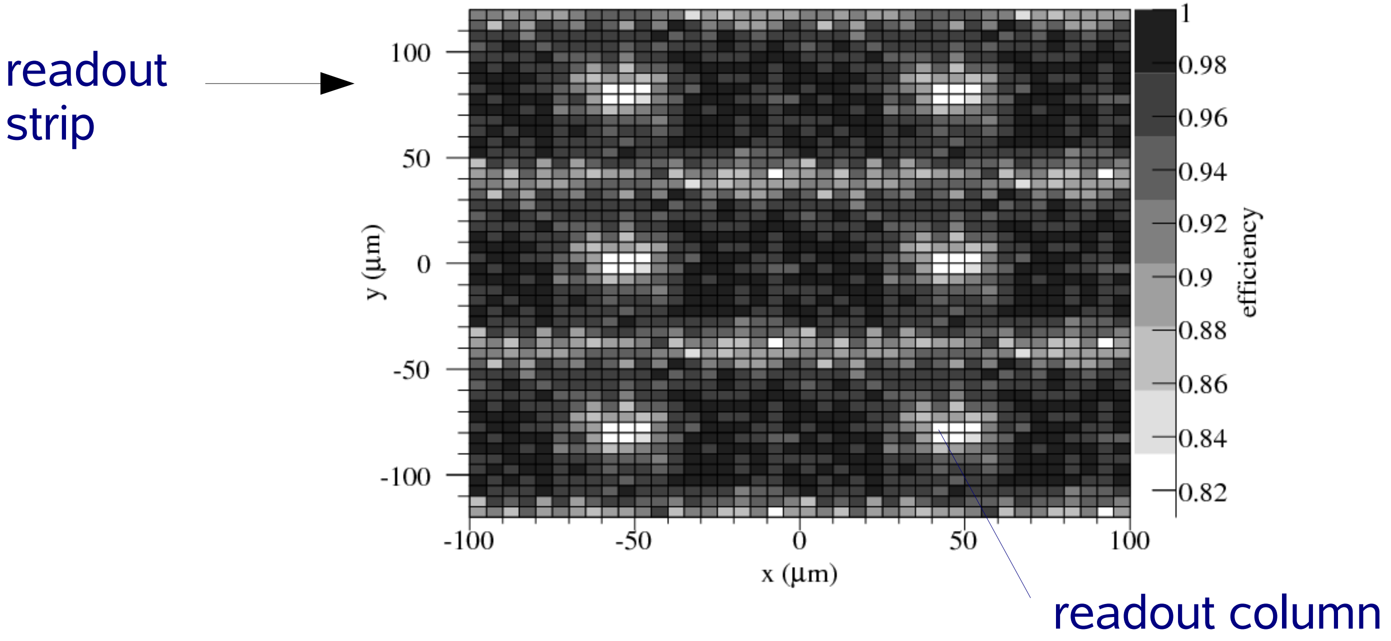


- On the boundary between strips: charge is shared
- Induced signal not uniform
  - In some regions: this signal is slightly negative, but less pronounced than in 3D-STC detectors

→ Qualitative confirmation of laser measurements

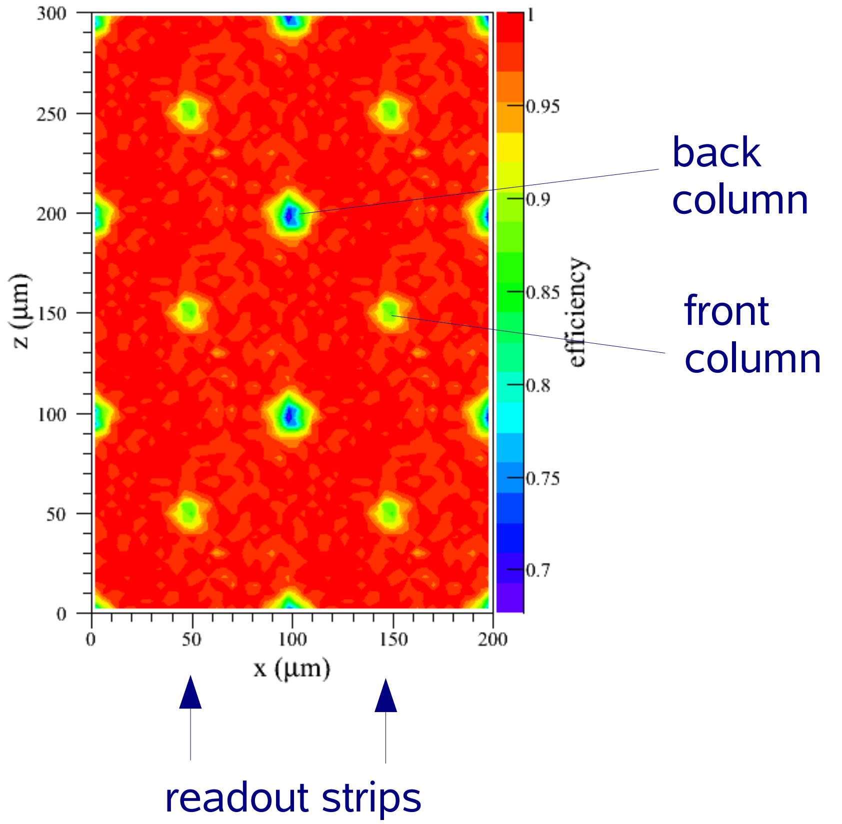
2D Efficiency in 3D-STC

- Testbeam from 2007 with 3D-STC detectors (→ diploma thesis Gregor Pahn)
  - 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 centre between strips visible



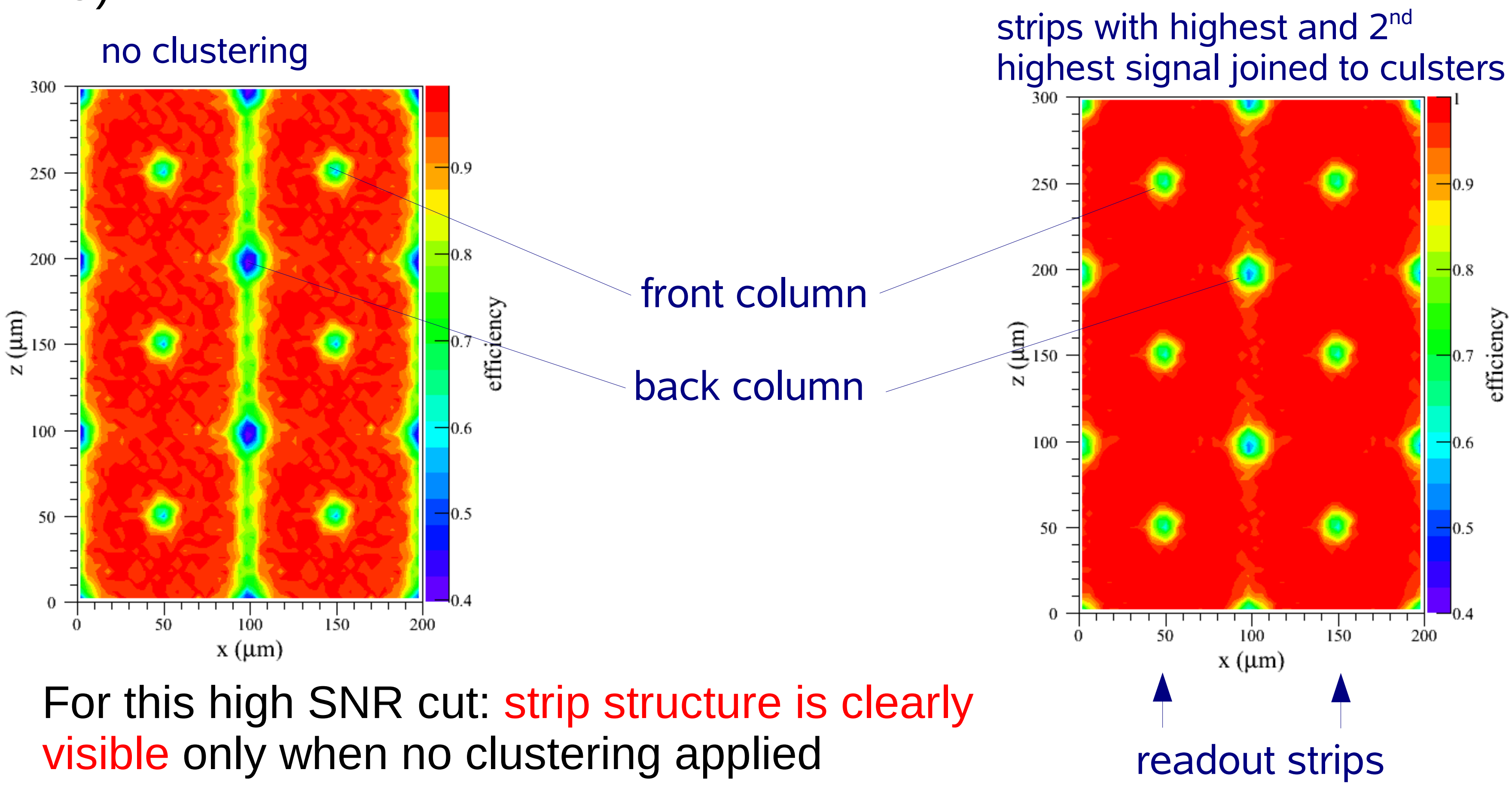
2D Efficiency in 3D-DDTC (1)

- 40 V bias: 2D efficiency for SNR ≥ 5 (corresponds to ≈ 6000 e^-, 1 fC)
  - Again: everything superimposed onto one unit cell and plotted six times next to each other
  - No clustering applied
- Efficiency (of course) lower in columns, but no expressed low field regions visible
- Overall efficiency: 98 %
  - exceeds 99 % with clustering of neighbouring strips



2D Efficiency in 3D-DDTC (2)

- 40 V bias: 2D efficiency for SNR ≥10 (corresponds to ≈ 12000 e^-, 2 fC)

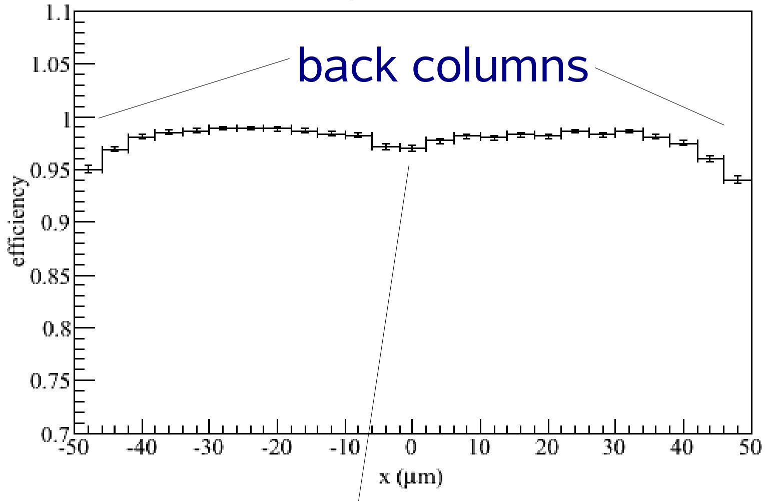


- For this high SNR cut: strip structure is clearly visible only when no clustering applied
- Overall efficiency: without clustering 92 %, with clustering 97 %

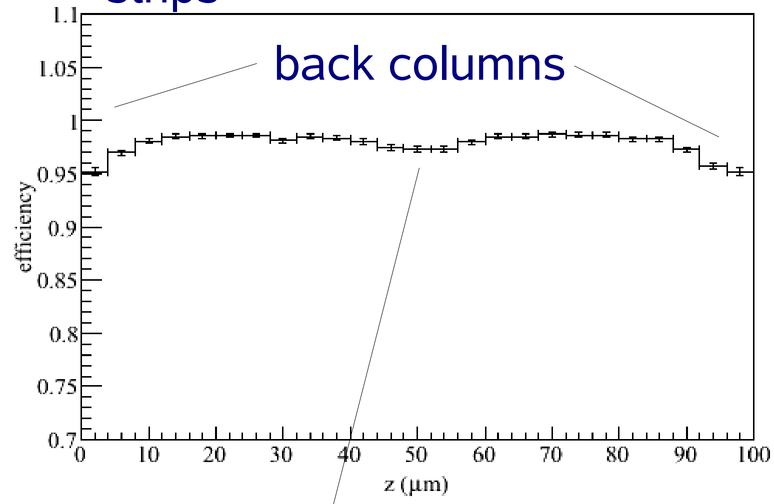
1D Efficiency in 3D-DDTC

- 1D efficiency for SNR ≥ 5 (corresponds to ≈ 6000 e^-, 1 fC), 40 V bias, no clustering

projection perpendicular to readout strips



projection parallel to readout strips



Conclusion / Outlook

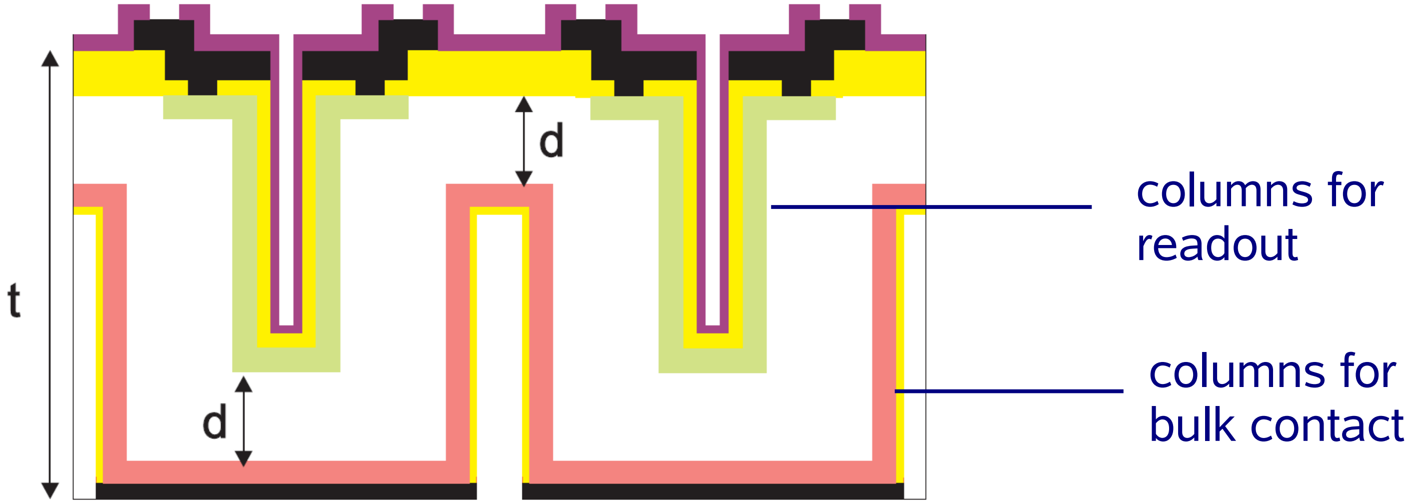
- All results are preliminary!
- Measured charge close to expected value
- Charge collection uniform
- Measurements with 50 ns shaping time – lower signal expected for shorter shaping time (for this special sensor geometry)
  - New batches of DDTC detectors (deeper columns, p-type): Full charge should be collected within 25 ns
- Next Steps: Recalculation of noise and pedestal data (values currently used are an approximation) ...
- Plan: Another test beam in June / July 2009 with 3D detectors and a planar detector (also irradiated)

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

Backup Slides

3D-DDTC Detectors

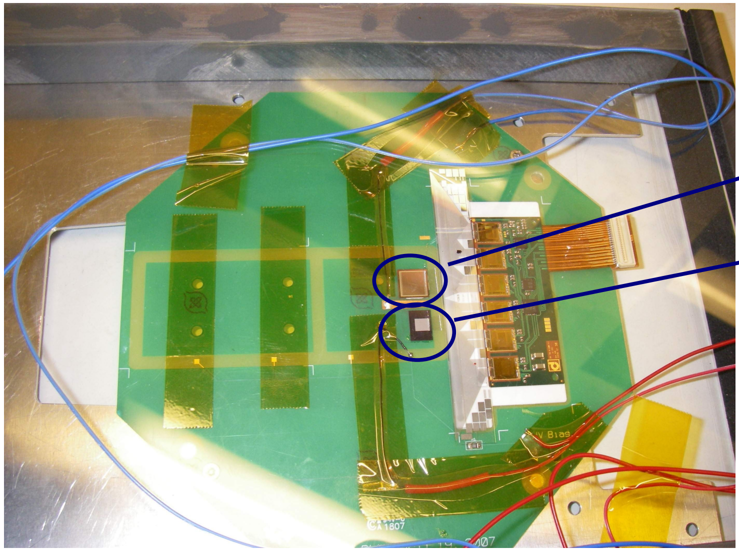
- DDTC: "Double-sided Double Type Columns"
- Columnar electrodes of both doping types are etched into the detector from both wafer sides
- Columns are not etched through the entire detector
  - Charge collection expected to be similar to "full 3D" detectors, but the fabrication process is much simpler



Module

- Readout: APV25, as used in CMS tracker
  - “Peak mode” applied, 50 ns shaping time, analogue readout
  - Trigger accepted during the entire 25 ns clock window (no TDC), but sampling of the signal always at the same time

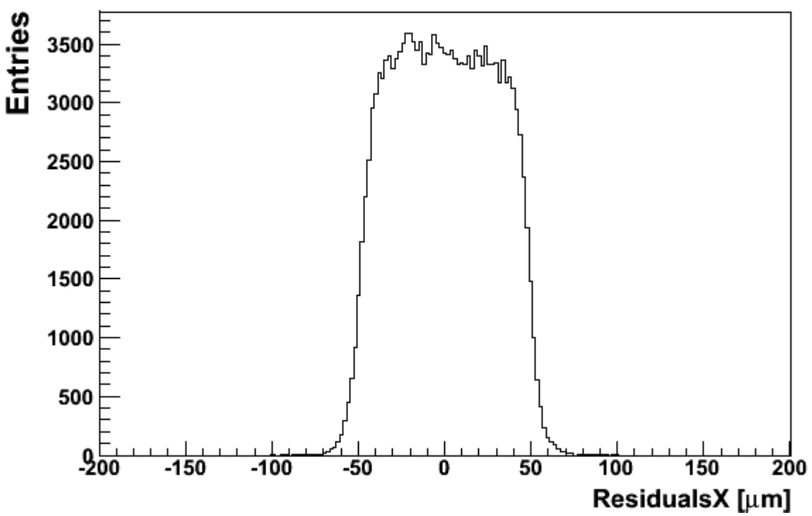
    → Average detected signal expected to be ≈ 10% lower



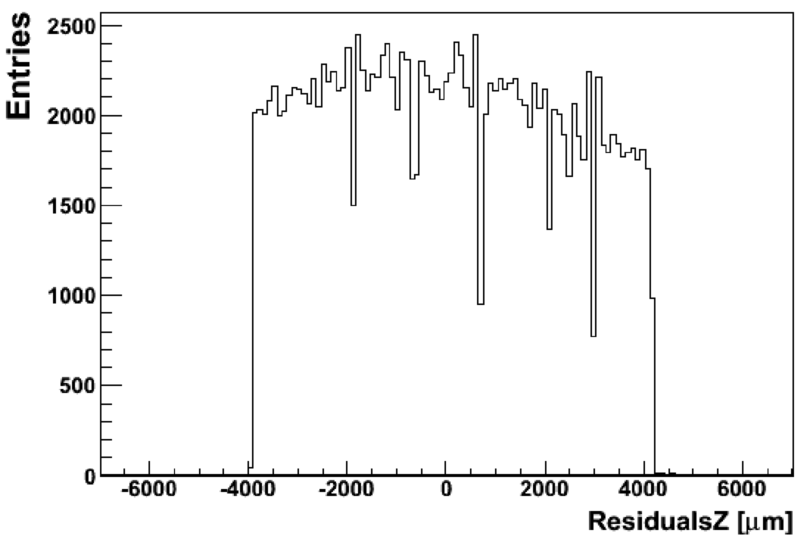
Alignment

- Position of the sensor and rotation w.r.t. the beam is determined by a χ^2-minimisation of the residuals
- Sensor positioned perpendicularly in the beam
- Final Residuals:

Perpendicular to strips: RMS=28.8 µm



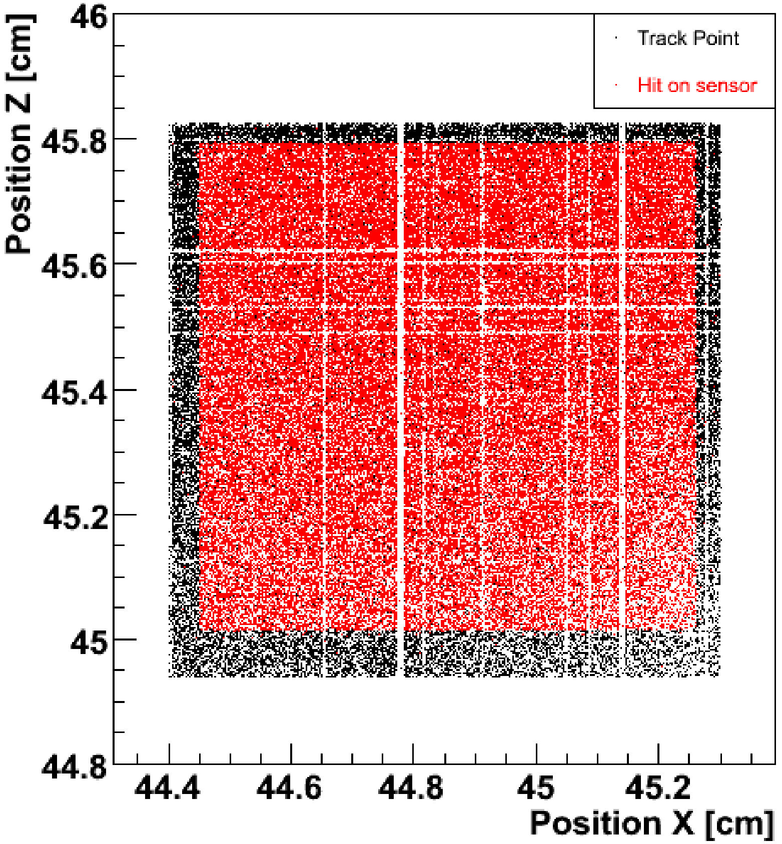
Parallel to strips: RMS=2295 µm



Beam Coverage

- The sensor area was covered by the beam entirely
- Black dots: tracks in region of interest – subset of entire beam shape

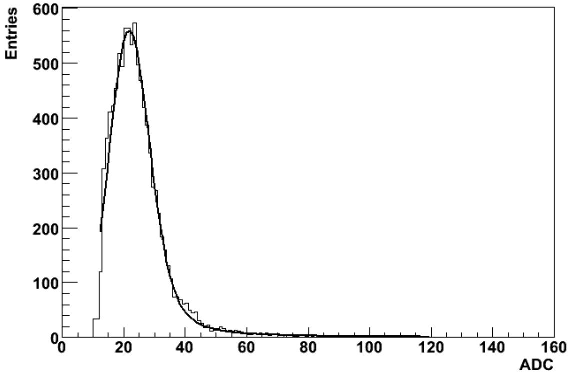
- Cuts applied to define a "hit":
  - SNR ≥ 10
  - Take only events with one hit passing the cut



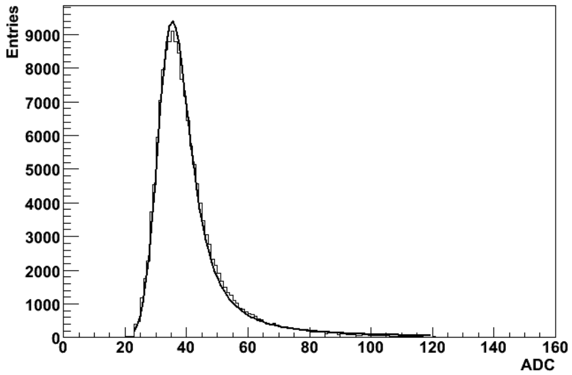
Landau Distribution

- ADC distribution with fit of a convoluted Landau and Gaussian
- Cut: SNR ≥ 10

U_B=5 V
MPV=(20.0±0.1) ADC counts



U_B=40 V
MPV=(34.02±0.02) ADC counts



- Conversion from ADC counts into charge using the spectrum of the well known planar telescope sensors
  - 1 ADC count ≈ 590 e^- (0.095 fC) - still very rough!