Investigations of 3D Silicon Strip Detectors

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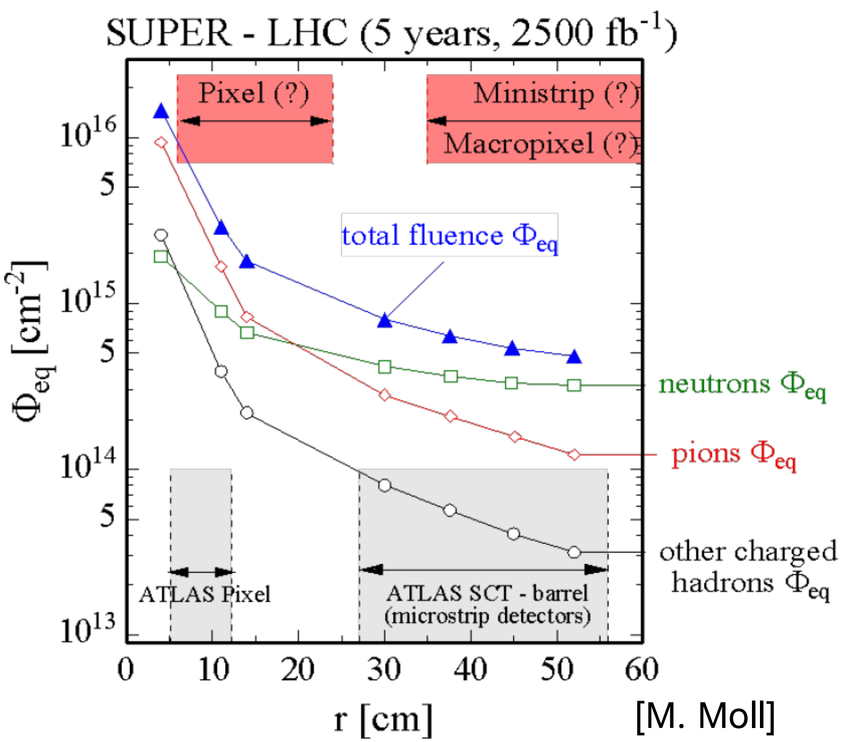
SLHC: More Radiation Hardness Needed

- ~ 2019: luminosity upgrade of the LHC (super LHC)

  → Peak luminosity increased tenfold: $L=10^{35}\ cm^{-2}\ s^{-1}$



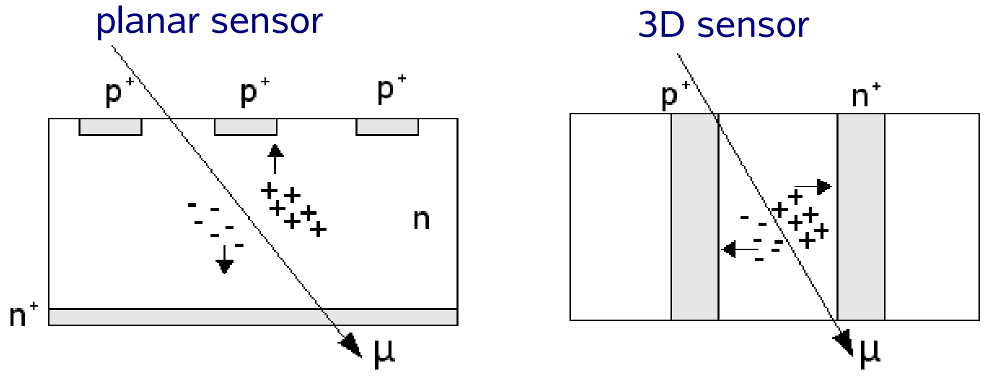
[M. Moll]

- High radiation level causes considerable radiation damage in silicon tracking sensors
- Three main effects of radiation damage in silicon:
  - Higher depletion voltage
  - Higher trapping
  - Higher leakage current

- New technologies needed for the tracking detectors, especially for the inner layers!

3D Detectors

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



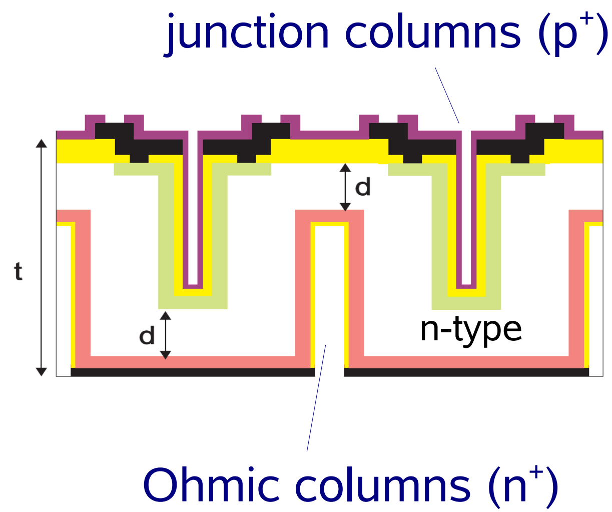
- Dominating problem at very high radiation fluences: trapping – charge carriers are trapped during drift through the silicon and are then lost for the readout

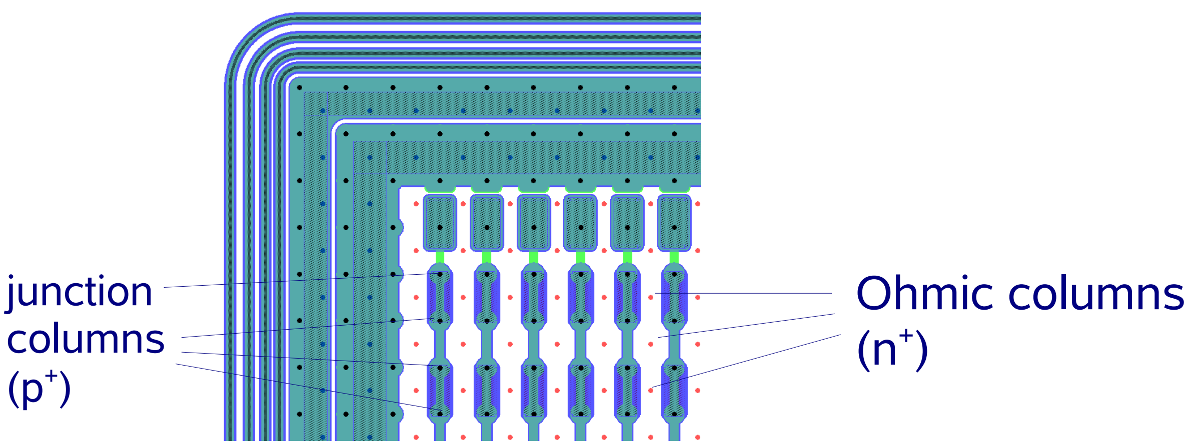
  → Measured signal decreases

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

3D-DDTC

- 3D-DDTC (double-sided, double type column) detectors: Columns etched into the wafer from both sides, but not fully penetrating
  - Here: columns are connected to strips
  - Process much simpler than full 3D detectors
- Questions:
  - Which signal can be measured?
  - Is charge collection uniform?

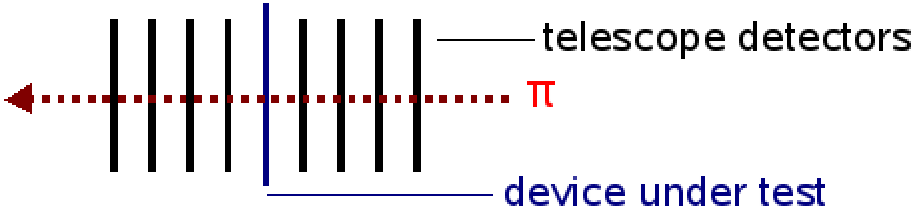




Test Beam July 2008

- Test beam: unique tool to study space-resolved charge collection in a realistic environment
- CERN SPS, H2 beamline, 225 GeV/c pions
- Track positions measured by the Silicon Beam Telescope (SiBT), resolution ≈ 4 µm (or even better)

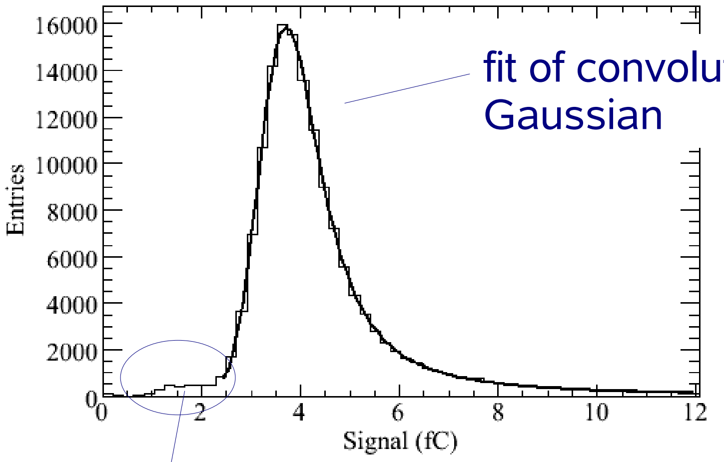
- Readout with CMS prototype hardware, APV25 front-end (50 ns shaping time)



Signal Spectrum at 40V Bias

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

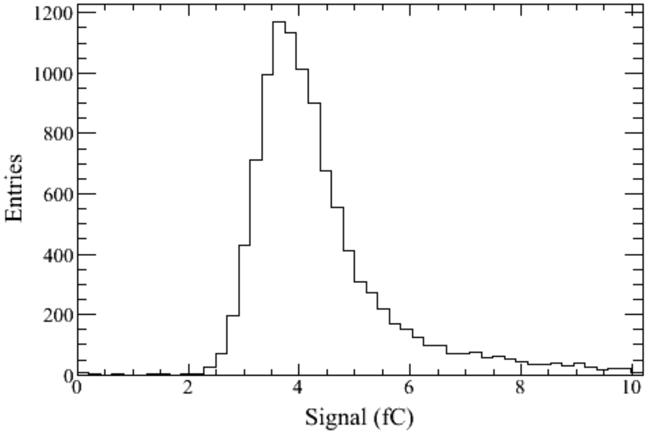
all tracks:



fit of convoluted Landau / Gaussian

contribution from particles going through the columns

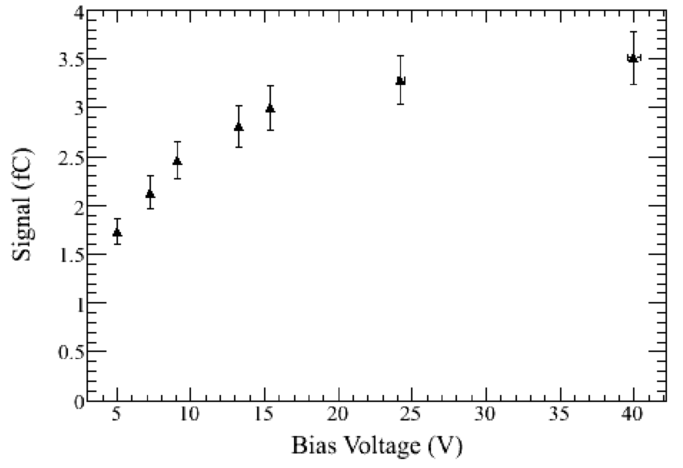
tracks far away from columns:



- Tracks crossing the hollow columns: charge deposition only in silicon below the columns, thus lower signal

Signal Versus Bias

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



- Maximum charge at 40 V: (3.5 ± 0.3) fC, (22 ± 2) ke$^-$
  - Signal to noise ratio: ~ 31
  - Expected signal for 300 µm silicon: 3.7 fC, 23 ke$^-$

  → Measured signal in agreement with expected signal

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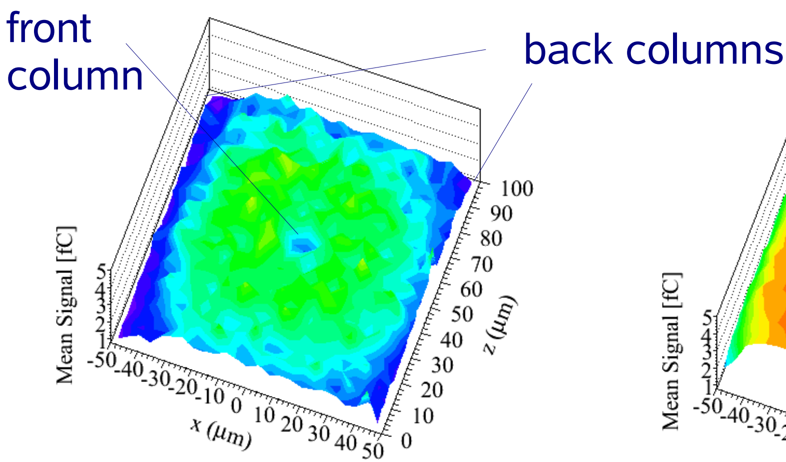
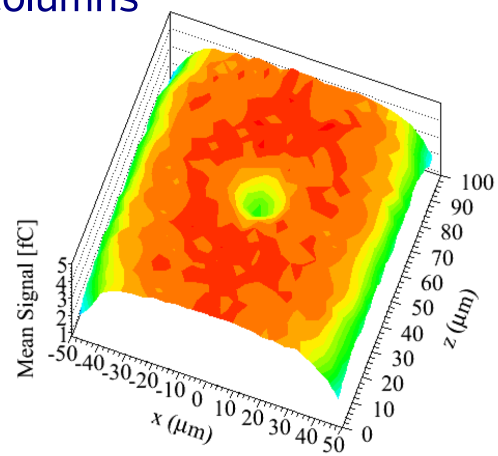
Charge Collection 2D

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



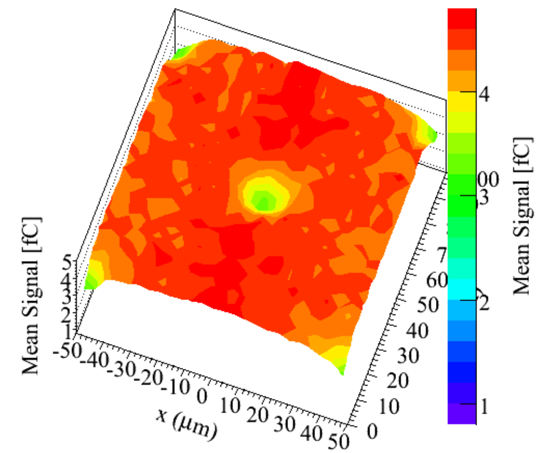
- 5 V bias, signal of single strip

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

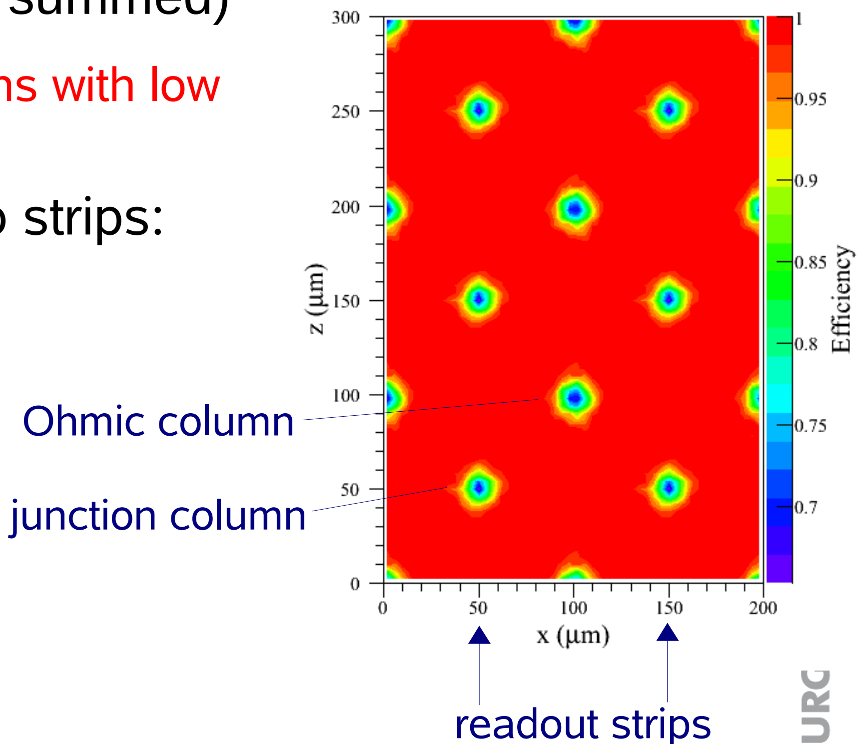
Signal uniform (apart from the column positions)

2D Efficiency in 3D-DDTC

- Efficiency: ratio of hits over certain threshold and total hits
- Sensor area superimposed onto one uni cell and plotted six times next to each other
- Column structure clearly visible for threshold of 2 fC (here: signal of two strips adjacent to track position summed)

  → Apart from column position: no regions with low efficiency visible

- Efficiency for summing signals of two strips:
  - at 2 fC: (98.53±0.03)%
  - at 1 fC: (99.80±0.01)%



Conclusion / Outlook

- Measurements with first batch of 3D-DDTC detectors are promising:
  - Full charge can be collected
  - Apart from column positions: signal and efficiency uniform

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

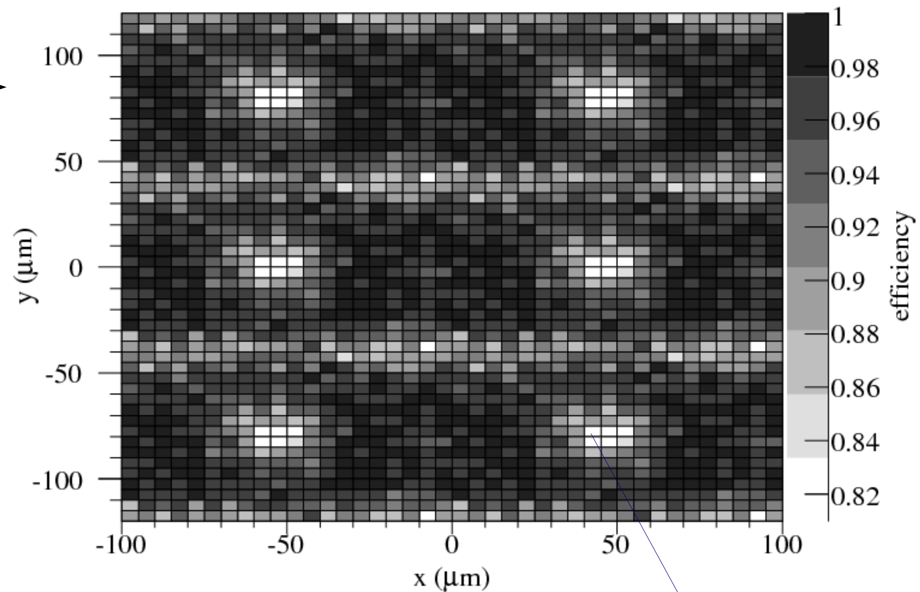
  → Direct comparison of radiation hardness of 3D and planar sensors

Backup Slides

2D Efficiency in 3D-STC

- Testbeam from 2007 with 3D-STC detectors [G. Pahn et al., IEEE TNS]
  - 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

readout strip

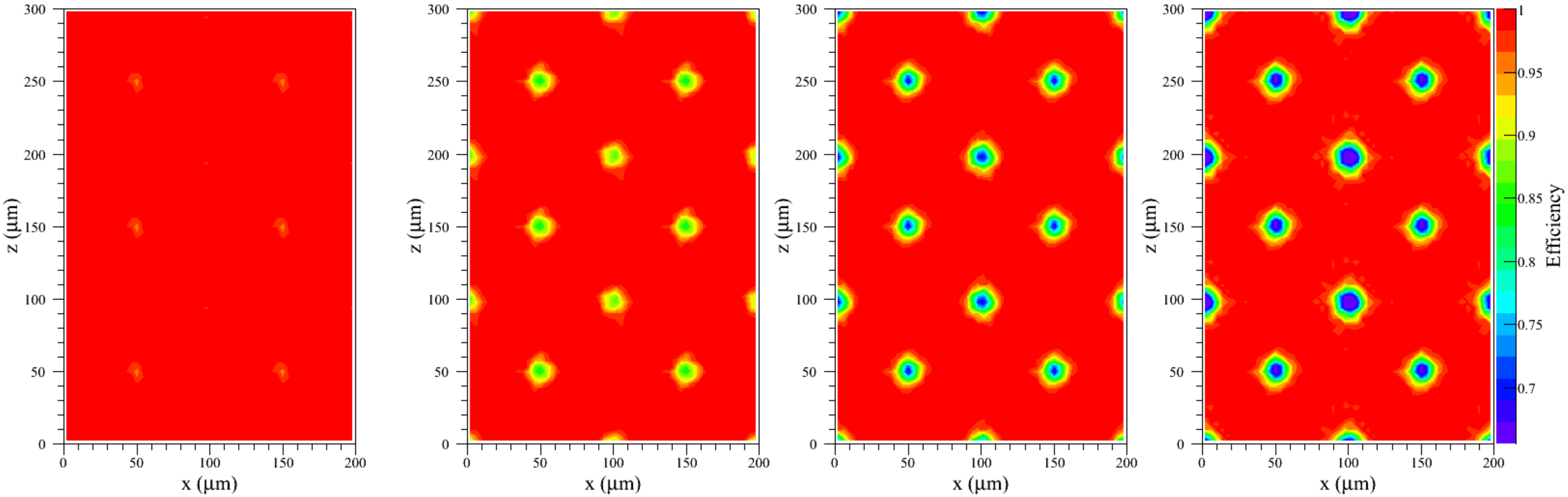


readout column

2D Efficiency, Different Thresholds

- Again: Signal of two strips summed

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)%