3D Detector Modules irradiated to sLHC fluences read out with LHC-electronics

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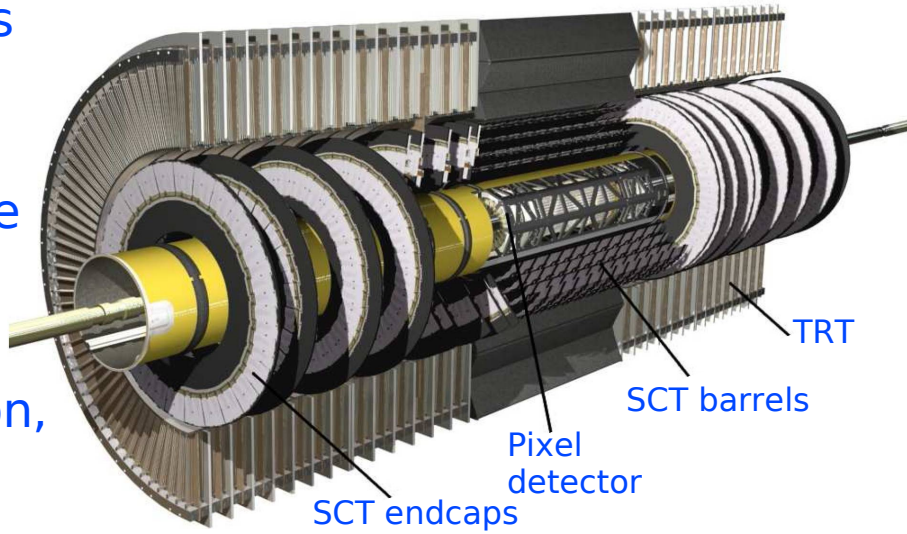
Outline

- sLHC: ATLAS Tracker Upgrade
- 3D Detectors
  - The 3D idea
  - Single-type-column 3D detectors
- 3D prototype module
- Results before & after irradiation
- Forthcoming
- Summary and outlook

sLHC and ATLAS Si-Tracking

- LHC luminosity upgrade foreseen for 2015
  - Overview talks today by Paula Collins (Silicon) and Richard Bates (RD50).
  - Step up luminosity by factor ≤10
  - Massive increase in radiation dose
  - Present SCT can not cope (designed for $2 \cdot 10^{14}$ N_{eq}/cm^2)
  - TRT likely to be replaced by Silicon, too
  - Fluences of several 10^{15} N_{eq}/cm^2 challenging for Silicon pixels and strips

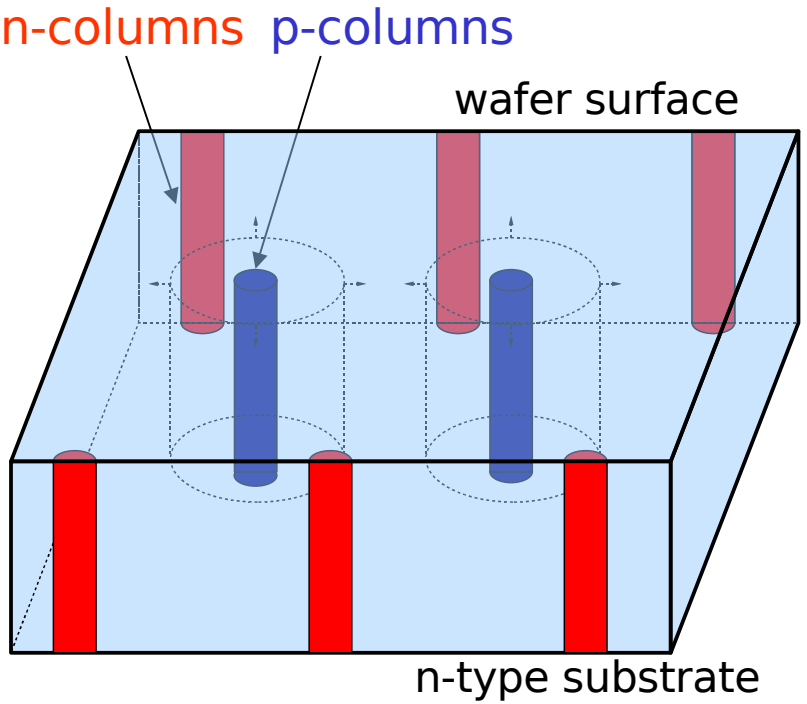


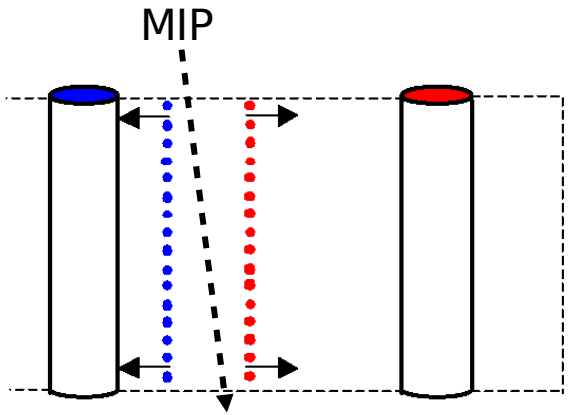
The 3D Idea

- Limitations of planar design in terms of radiation damage
  - Depletion voltage rises
  - Trapping limits signal (thickness does not help)

- 3D: decouple depletion and thickness (->Signal) by depleting “sideways”

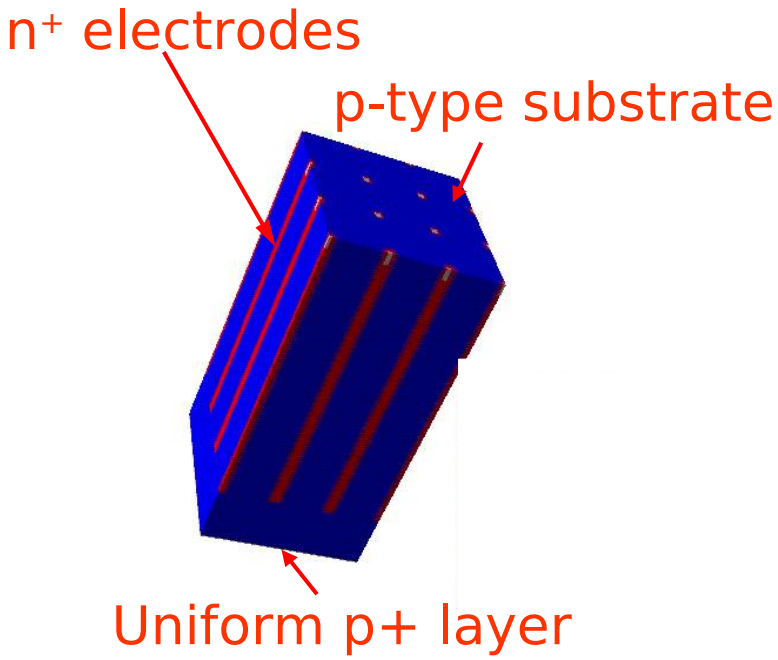
  (Parker et al. NIMA395 (1997))

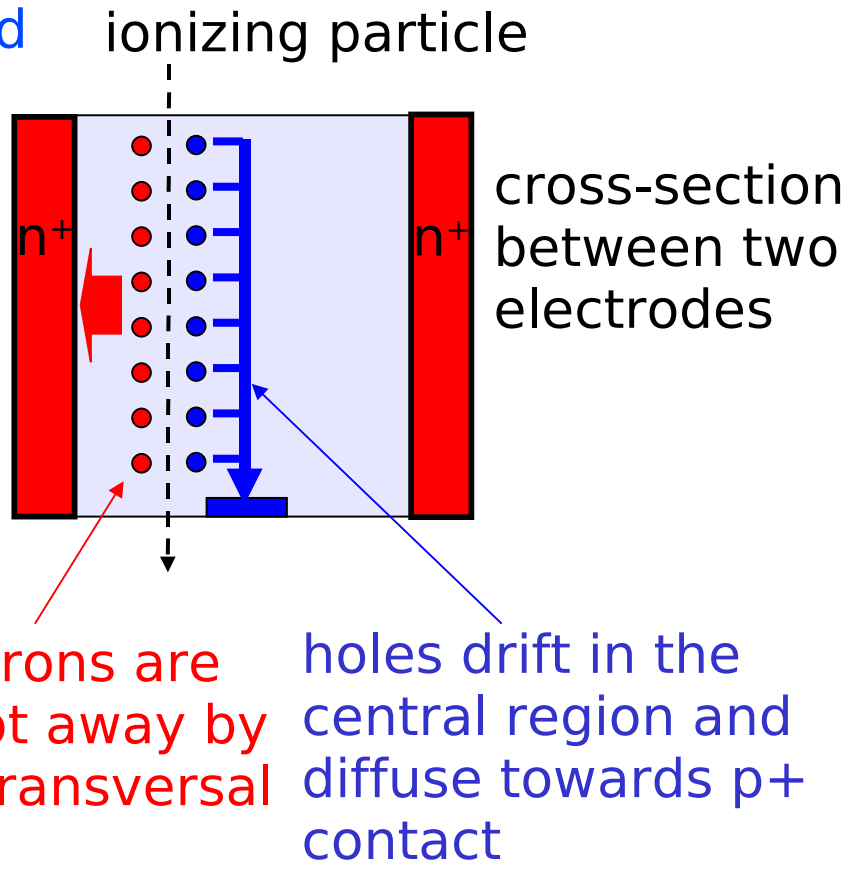




3D STC Design

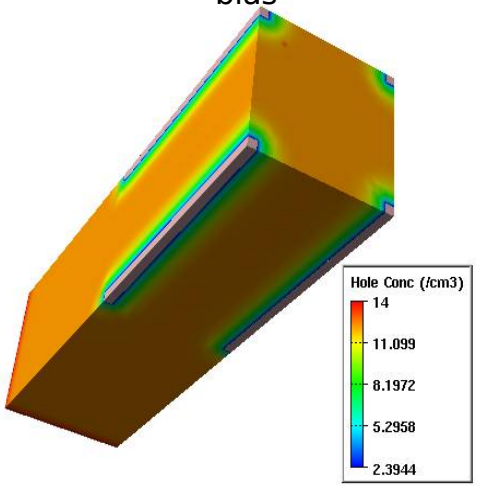
- Single-Type Column (STC) design is a simplification
- Reduction in processing steps and price by roughly a factor of 2



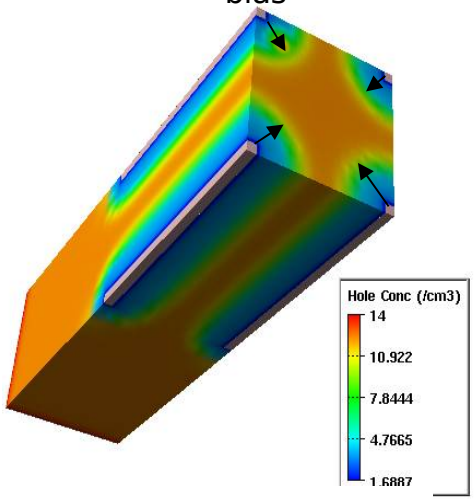


3D Simulations – depletion

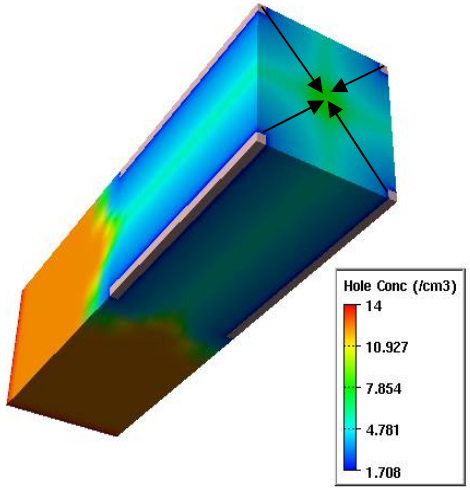
1) V_{bias}=0V



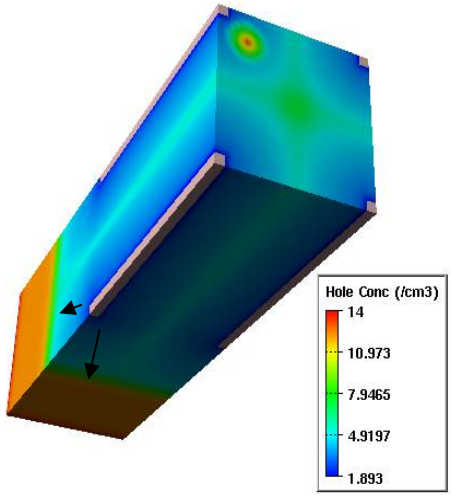
2) V_{bias}=2V



3) V_{bias}=5V

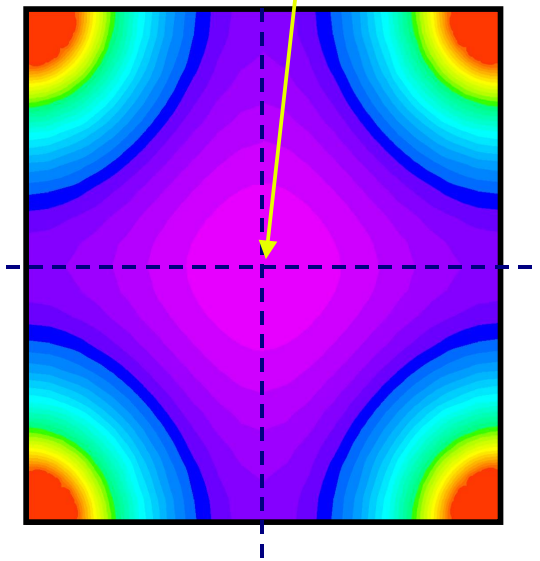


4) V_{bias}=20V



- Rapid lateral depletion at around 5V
- Then depleting like a planar device
- Low Field in the central region remains

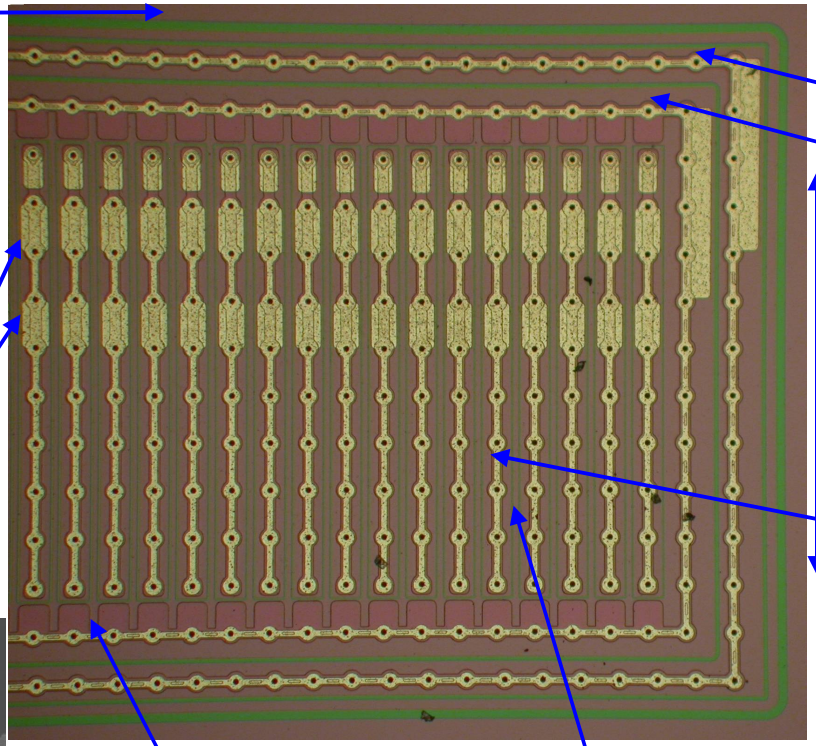
xy-null field lines

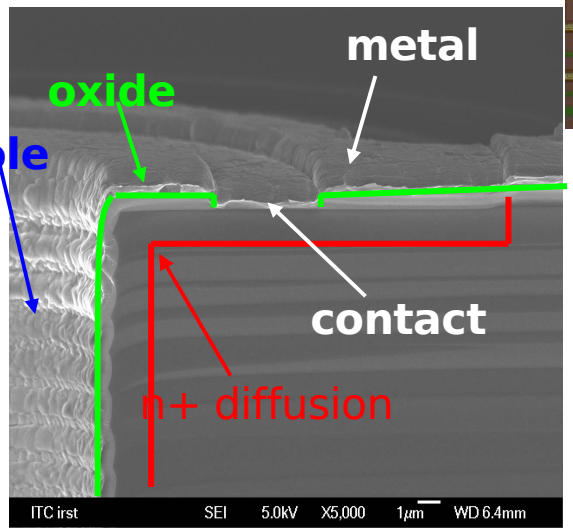


3D STC strip detector

p-type substrate

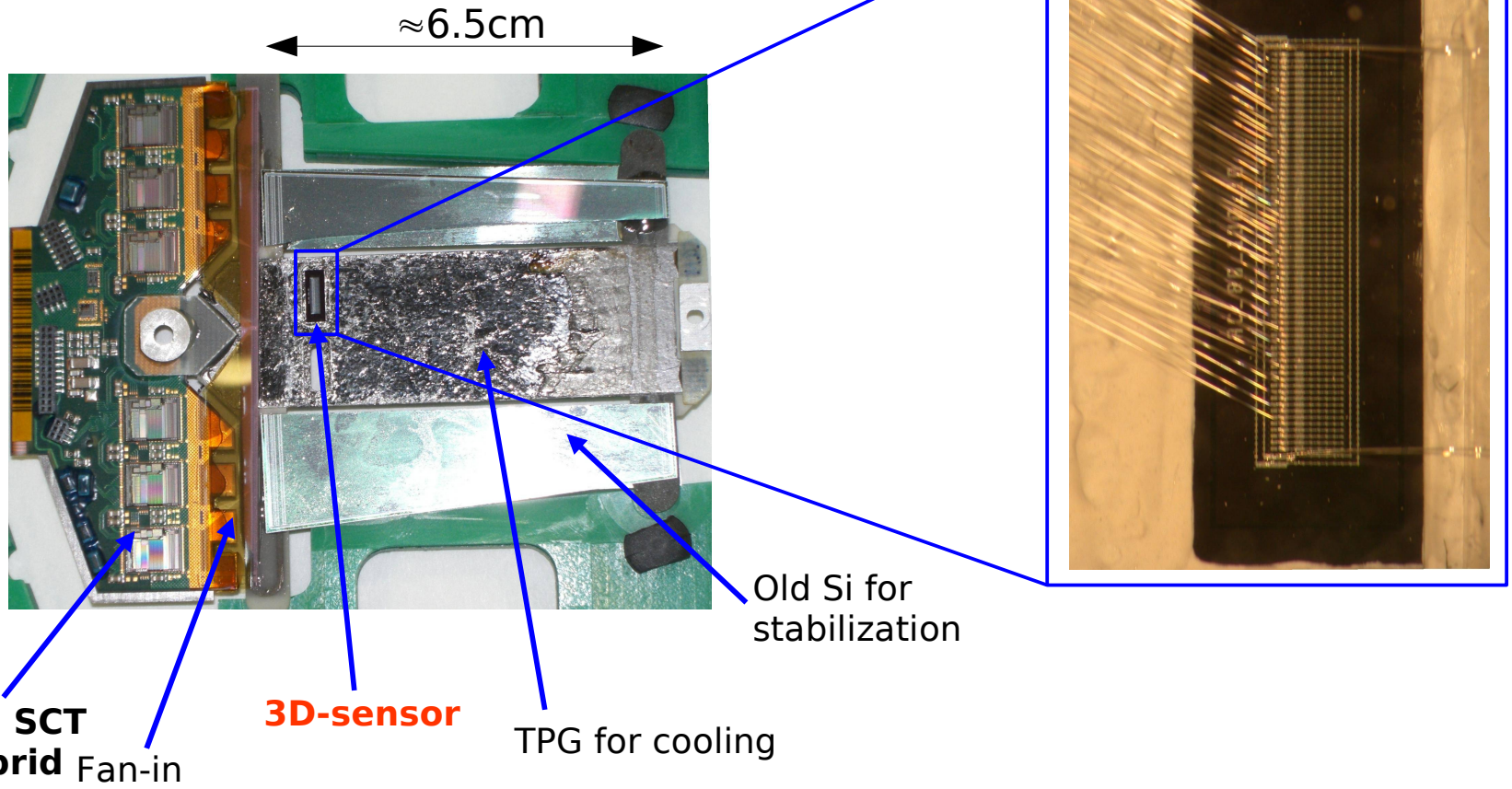
- Collection of e^- instead of holes
  - Faster signal
  - Less trapping
- Non type-inverting even for very high fluences





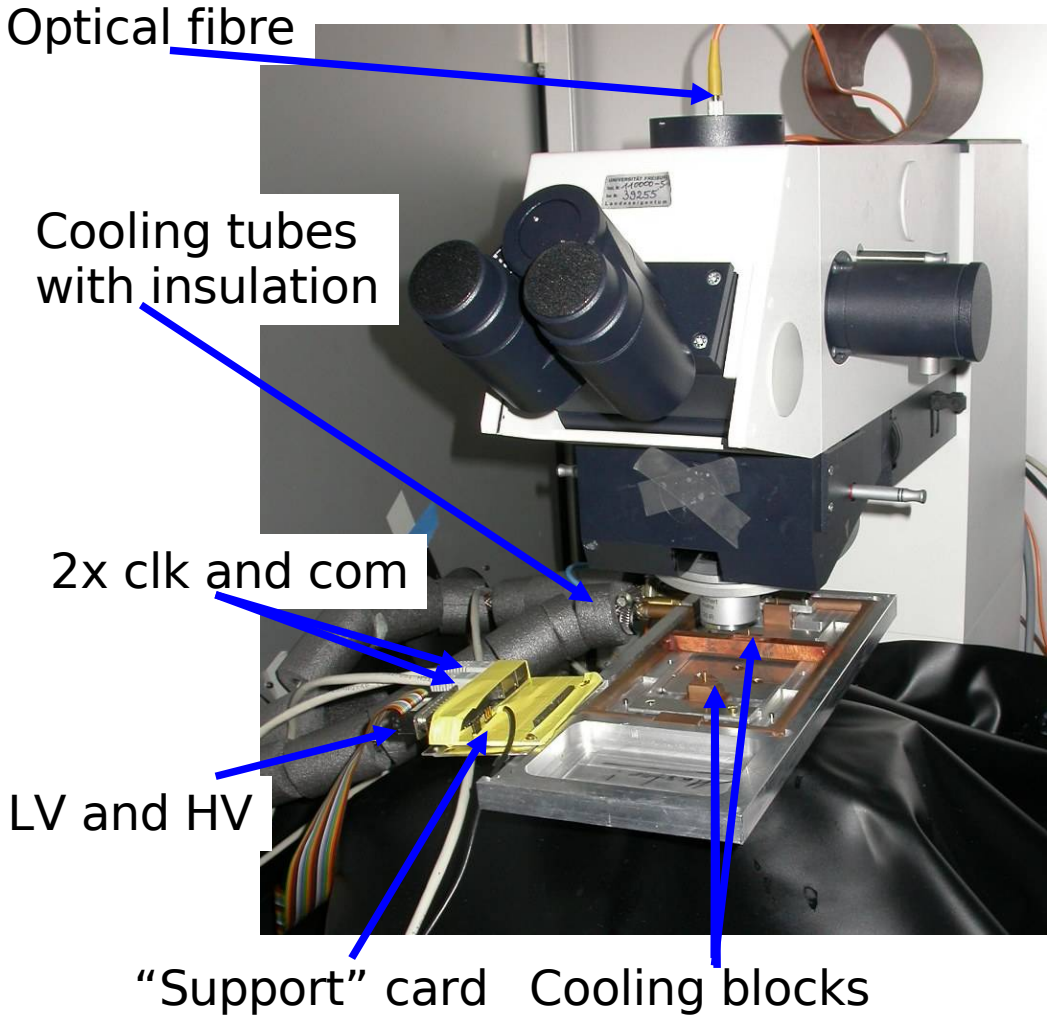
3D module prototype

- AC coupled sensor
- Based on 40Mhz ATLAS SCT electronics – shaping time 20ns



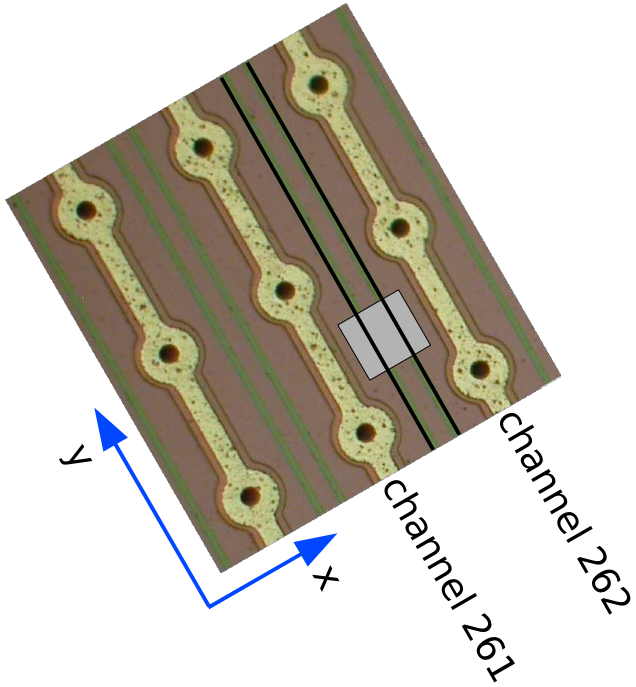
Laser Set-up

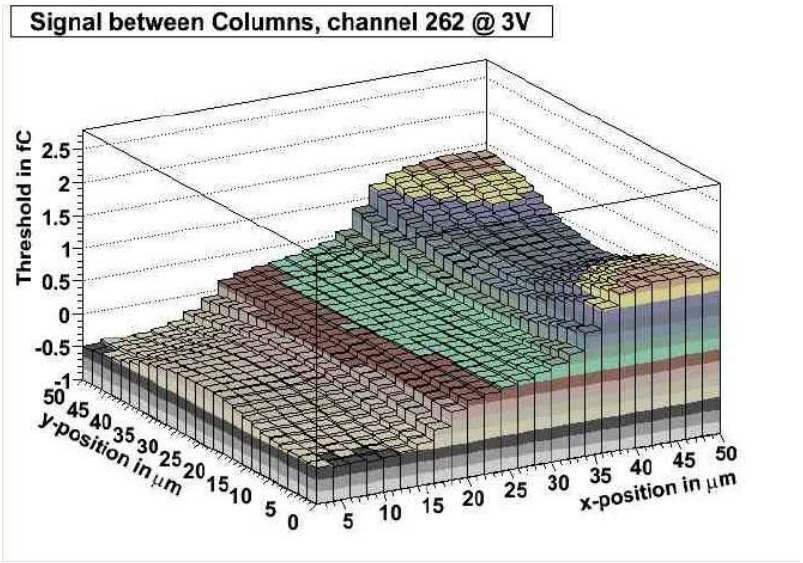
- Penetration depth @ λ = 982nm ≈ 100µm
- Length of pulse ≈ 1-2ns
- Microscope to focus optically → laser spot Ø ≈ 4–5µm
- *x*-*y* stages with µm resolution
- *z*-axis manual, but also with µm accuracy
- Nitrogen flushed test box with cooling system

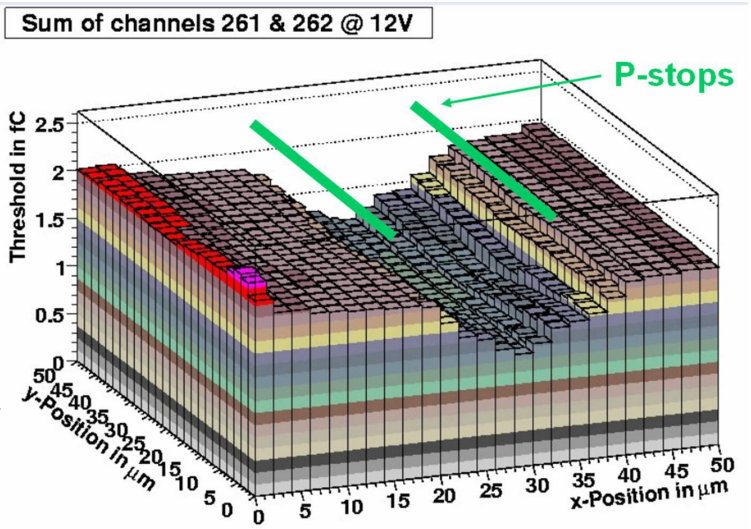


Laser Results

- unirradiated





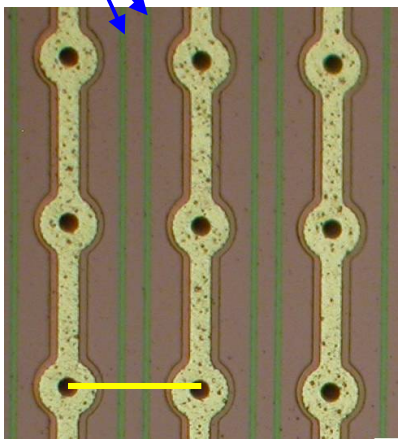


Lateral depletion around 12V

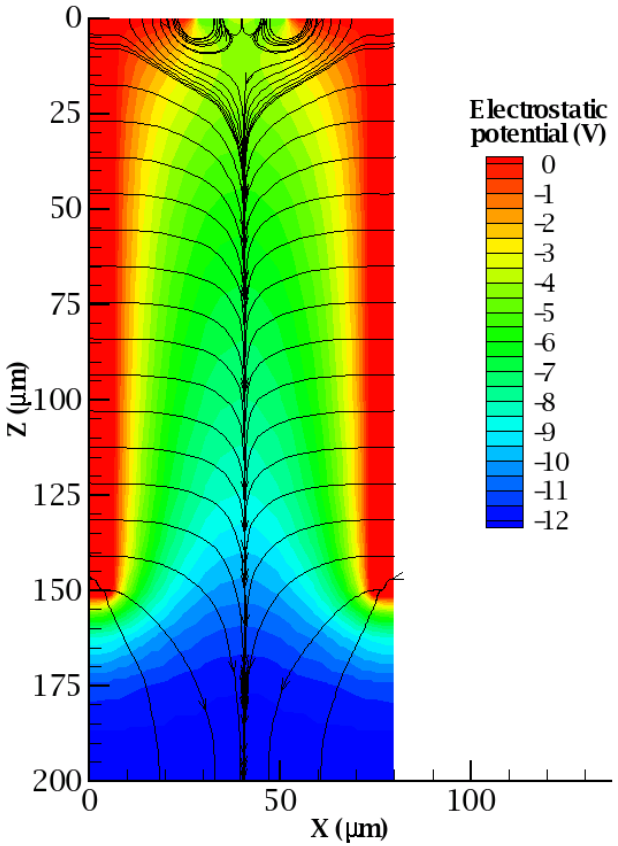
P-stops affect the electric field

- Electrostatic potential between the columns

p-stops



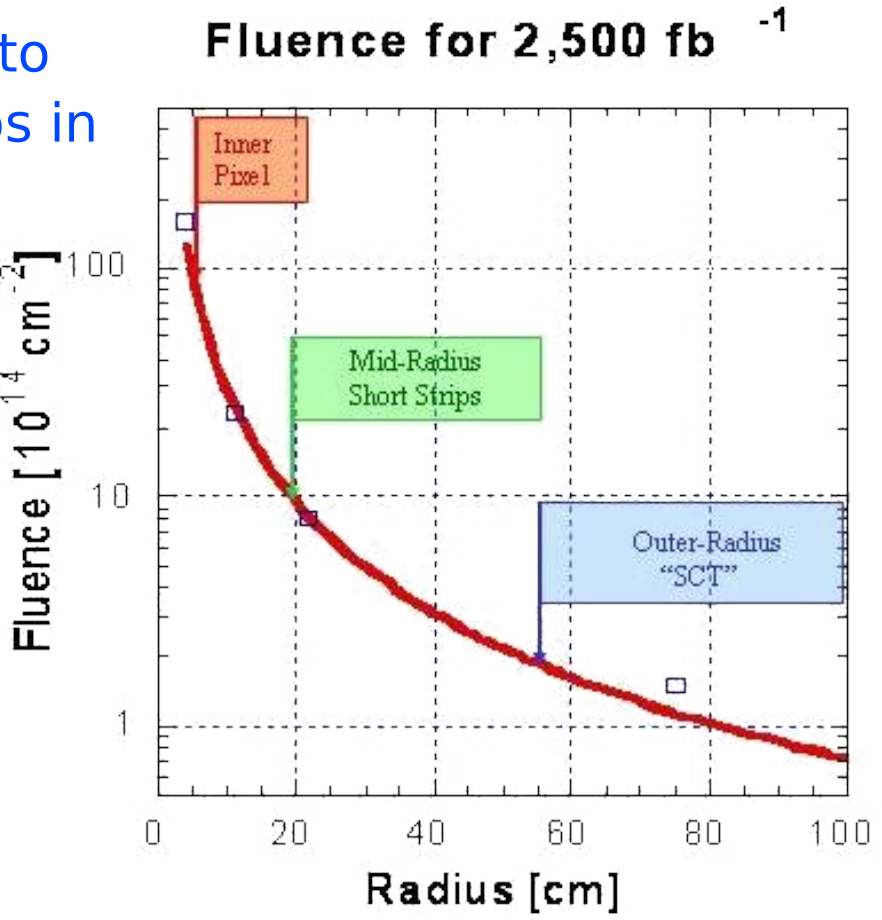
With p-stops



Irradiation

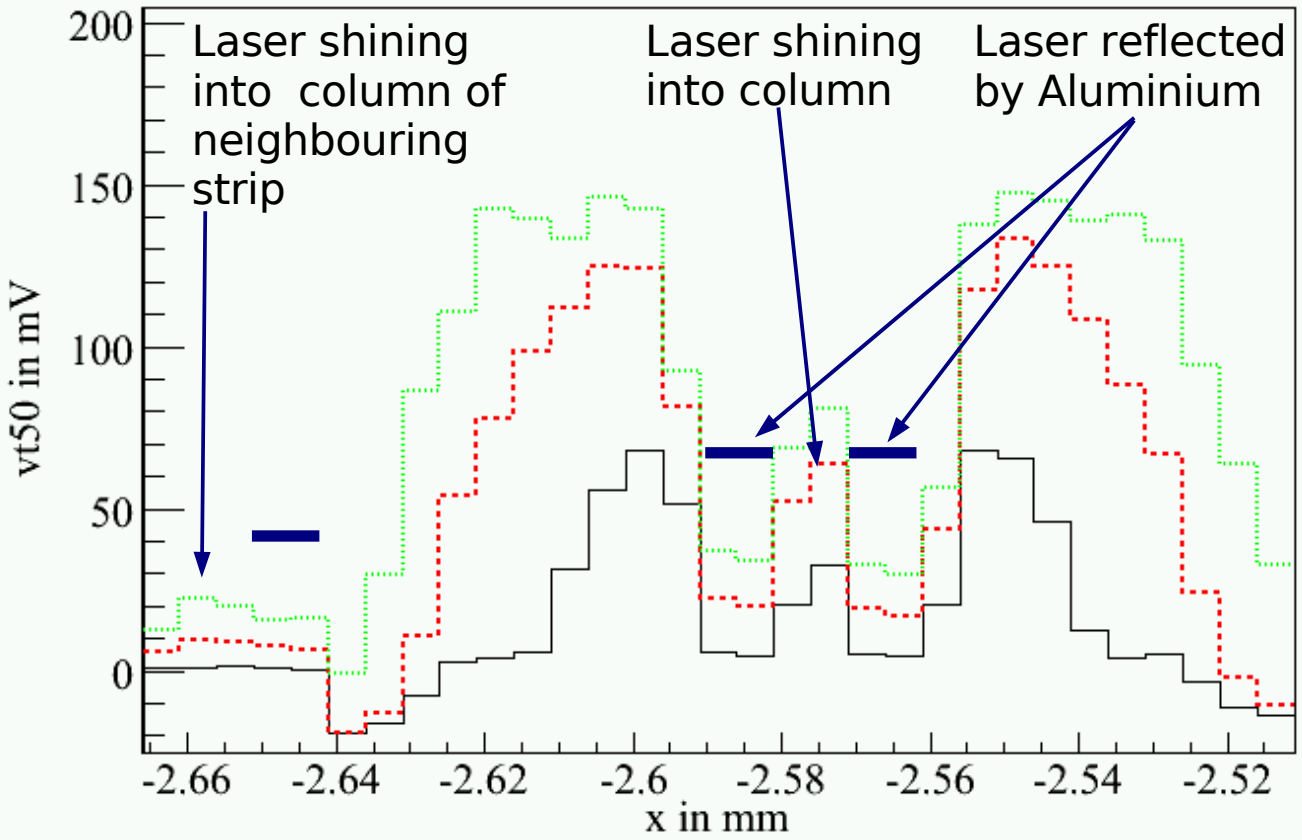
- Irradiated with 26MeV protons
- Dose $10^{15} N_{eq}/cm^2$ corresponds to maximal fluence for short strips in sLHC

- Initial measurements without annealing (module in freezer)
- Annealed 80min at 60˚C
  (→ minimum of N_{eff} and V_{fd}).

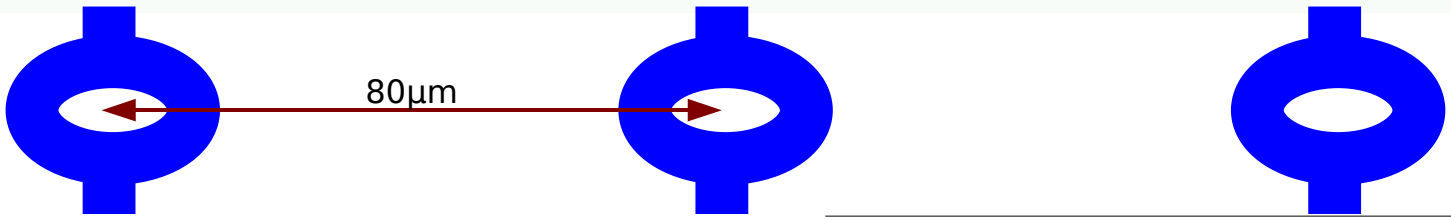


Post-Irradiation: Depletion characteristics

- From scan over 1 column for different bias voltages



- Rapid lateral depletion between the columns
- Diode-like depletion inside column



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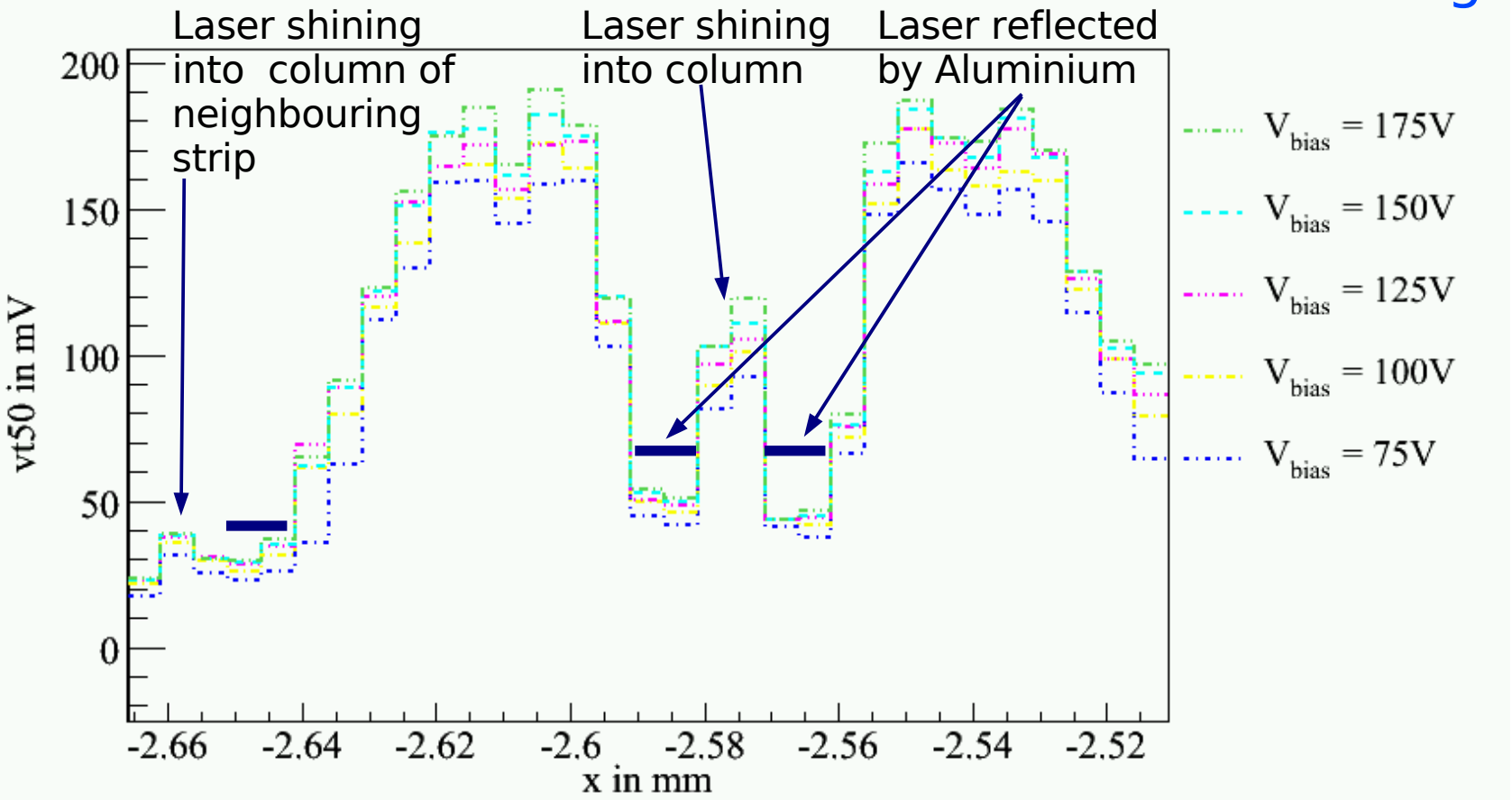

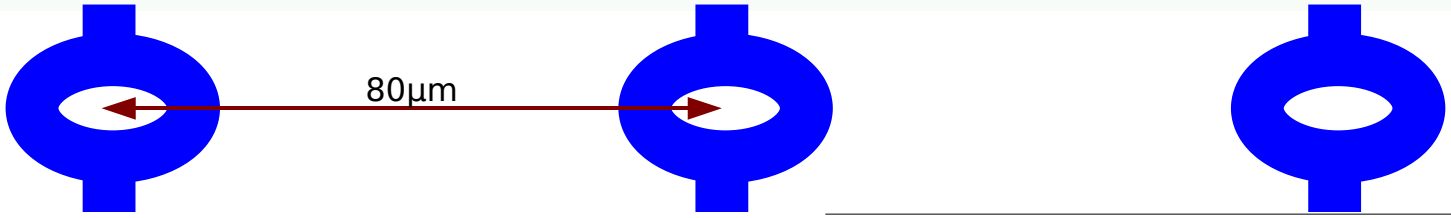

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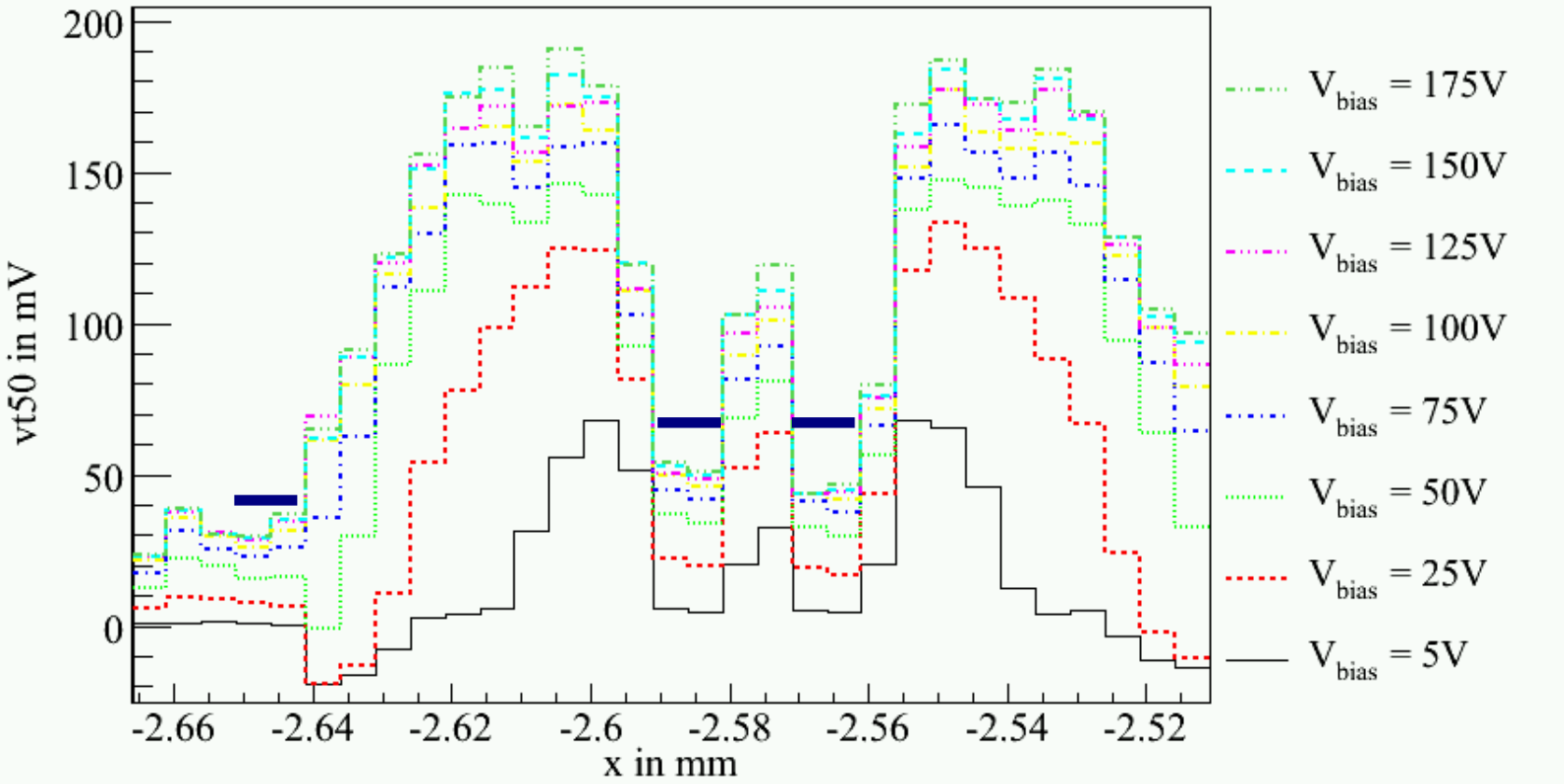
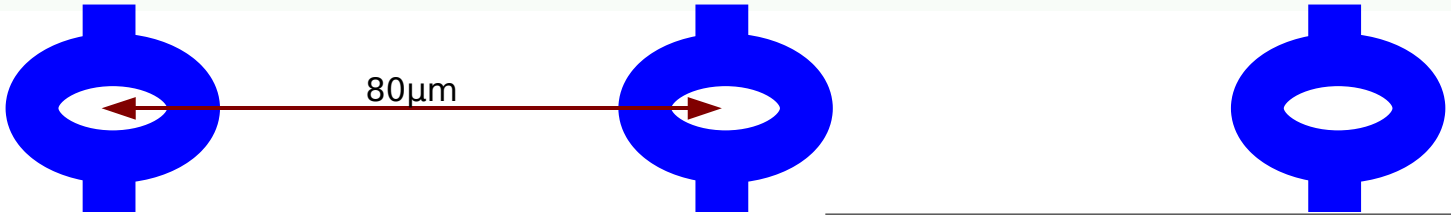
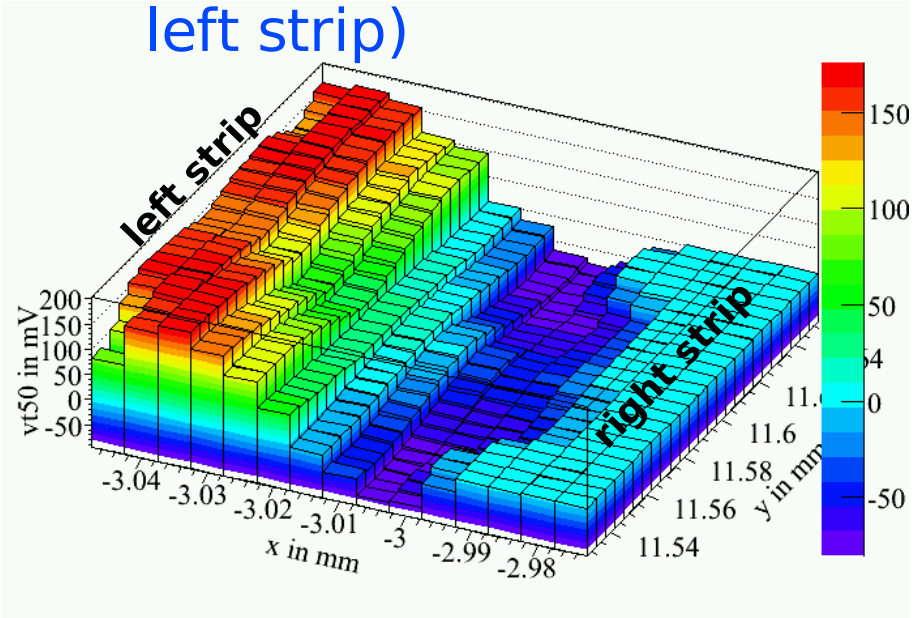




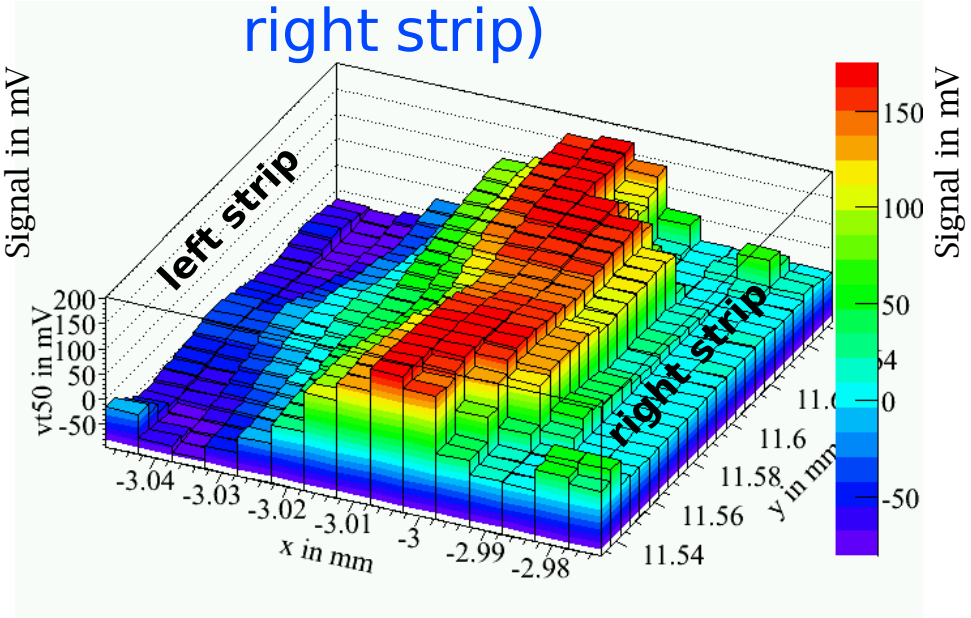
Post-Irradiation: CCE @ 130V

- Good Uniformity within 10% of CCE around columns, low CCE under p-stops – as before irradiation
- Response from left and right channel of a single scan shown separately

- Response from left strip (readout strip: left strip)

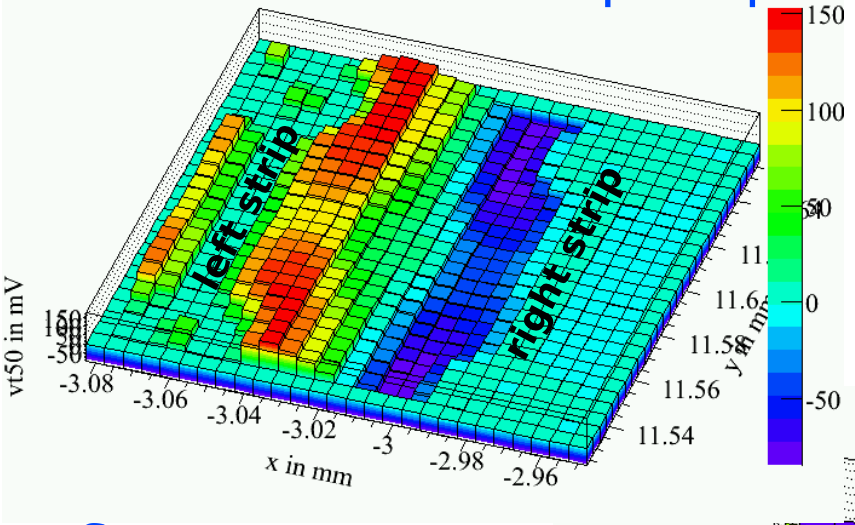


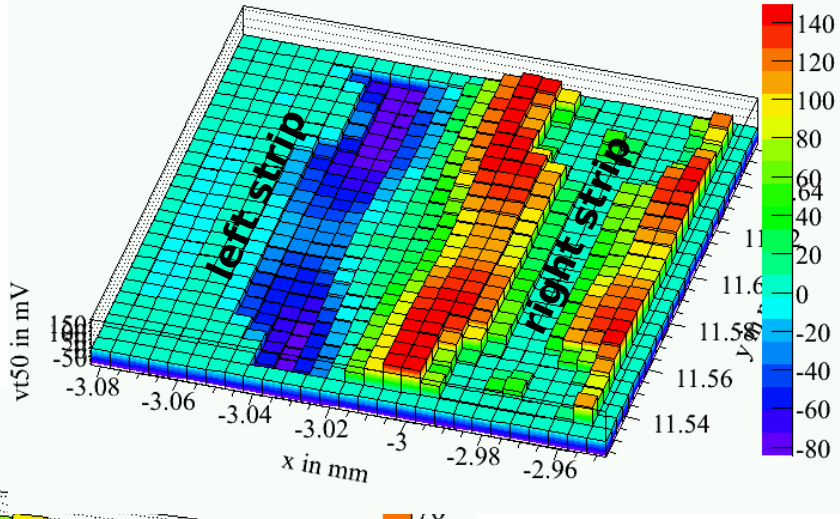
- Response from right strip (readout strip: right strip)



Post-Irradiation: CCE @ 110V

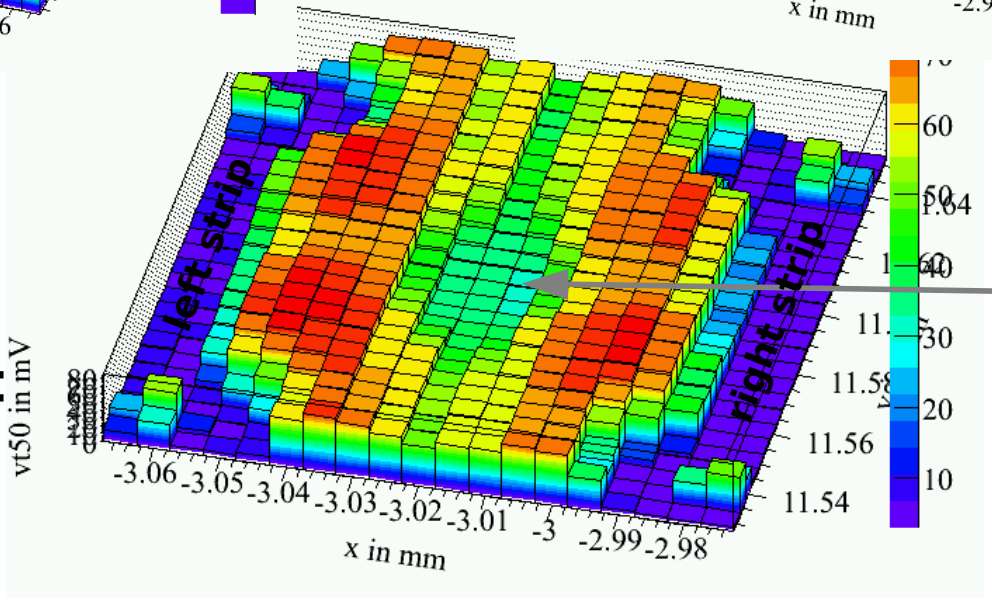
- Good Uniformity within 20% of CCE around columns, low CCE under p-stops – as before irradiation





- Same scan as on the slide before, but at V_{bias} = 110V

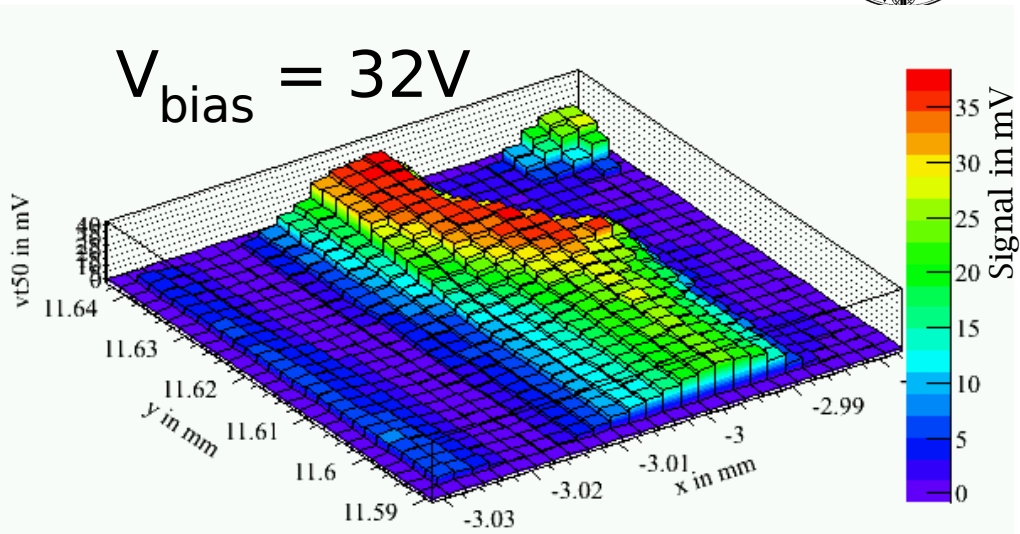
Sum of both strips:

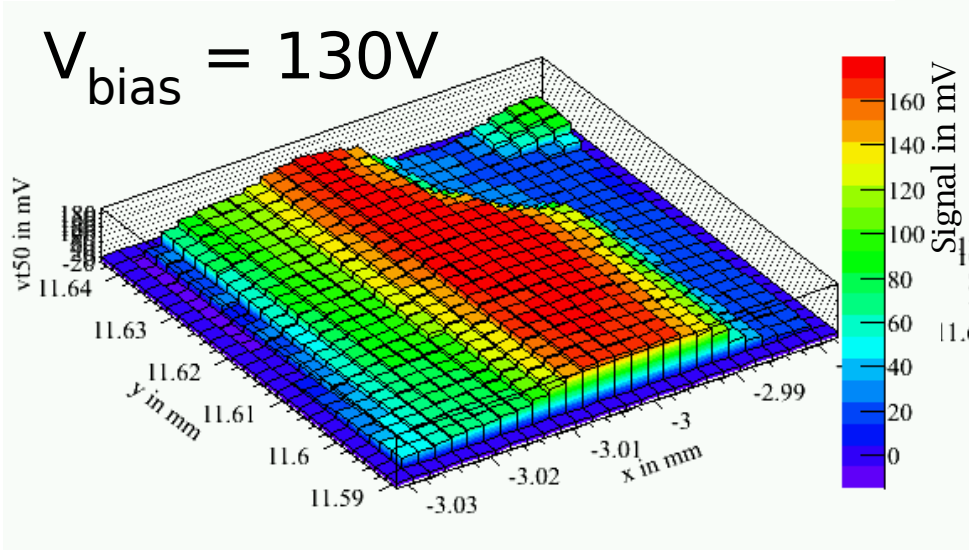


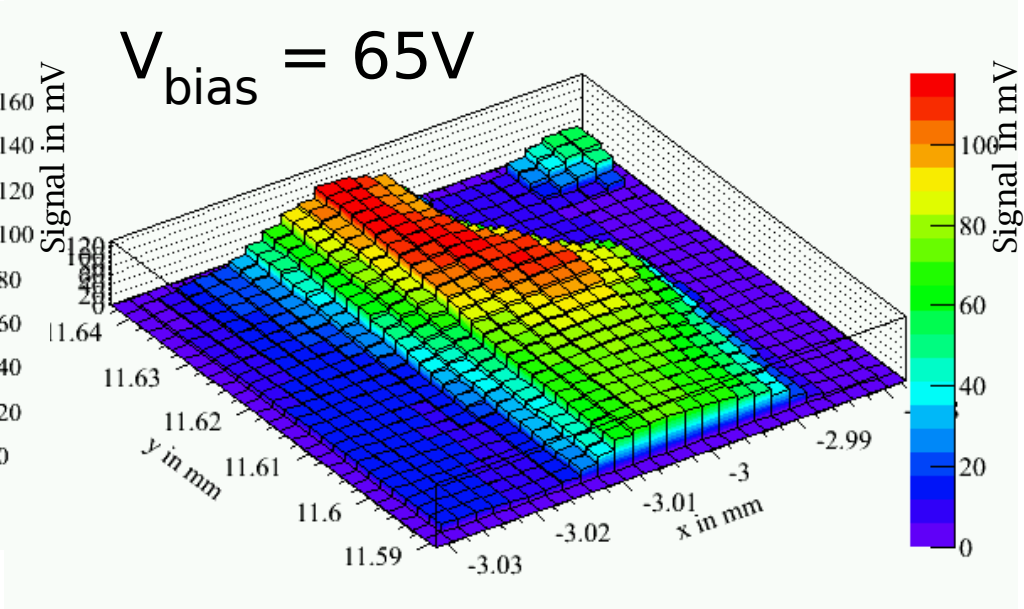
Low field region – or trapping?

Post-Irradiation

- Using a smaller step-size you can nicely see how the depleted region is growing with increasing bias voltage

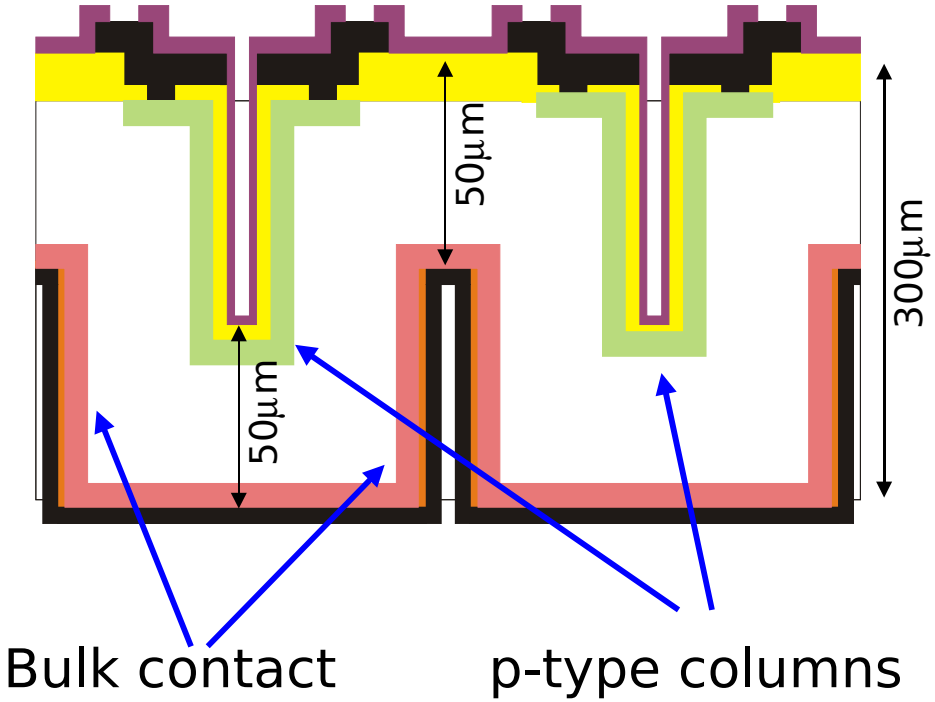






Forthcoming...

- Double-sided
- Double-Type-Column
- front side identical to 3D-STC
- Double type columns to reduce the low field region



Summary & Outlook

- Prototype module built from 3D STC p-type micro-strip detector and ATLAS SCT electronics
- Pre-Irradiation: lateral depletion around 12V, low field region under p-stop
- Irradiated to 10^{15} N_{eq}/cm^2, annealed to min. N_{eff} and V_{FD}
- Depletes laterally between around 75V, uniform CCE along strips, low CCE under p-stops and in the central part of a unit cell

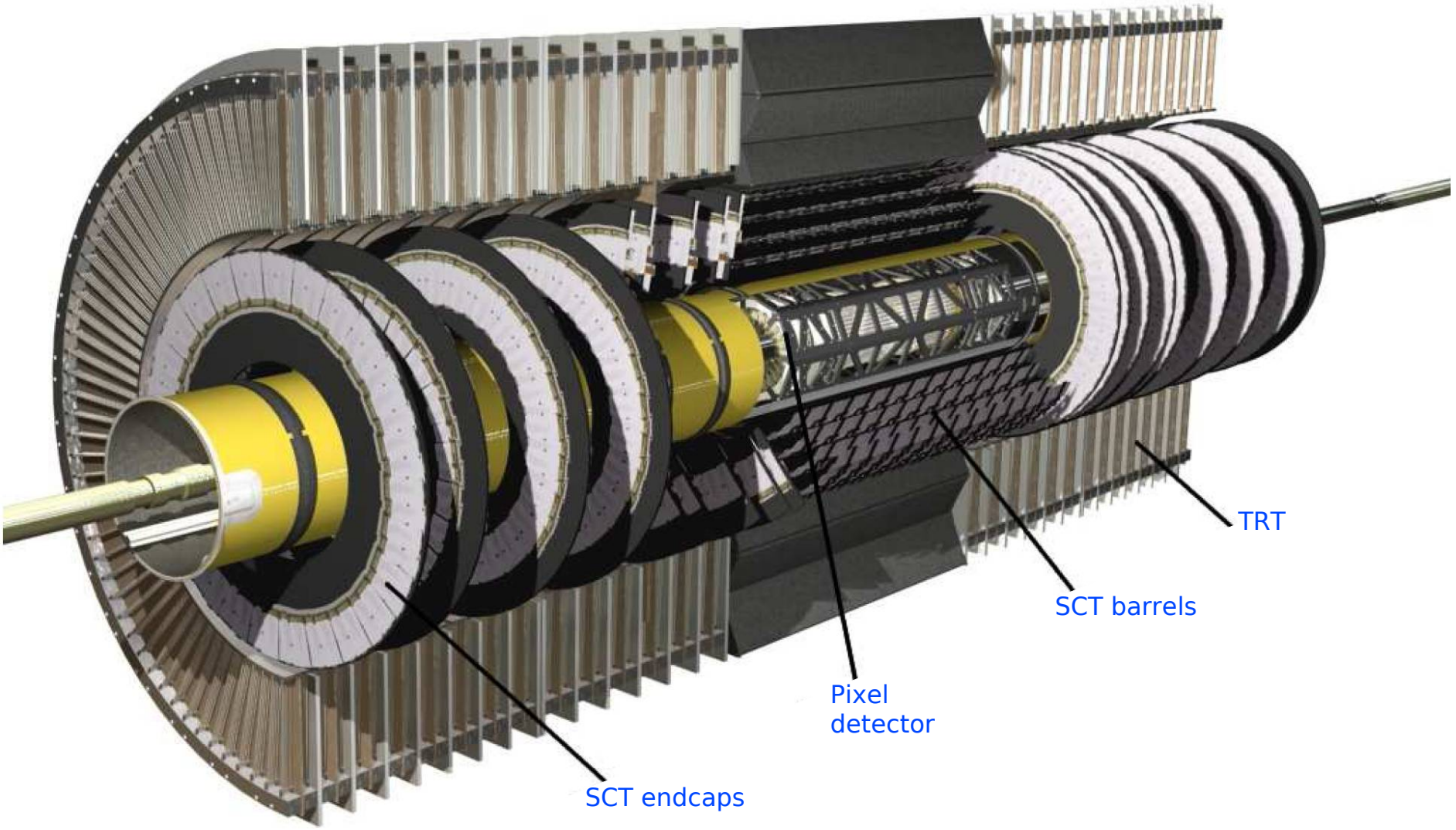
- 3D detectors are a promising candidate for tracking detectors in very harsh radiation environments like the sLHC experiments

- Larger 3D STC detectors available → deeper columns, longer strips (2cm)
  → interesting to investigate noise performance before and after irradiation

- Thanks to Alex Furgeri (Karlsruhe) for the irradiation, David Pennicard (Glasgow) for the simulations and ITC irst (Trento) for the sensors!

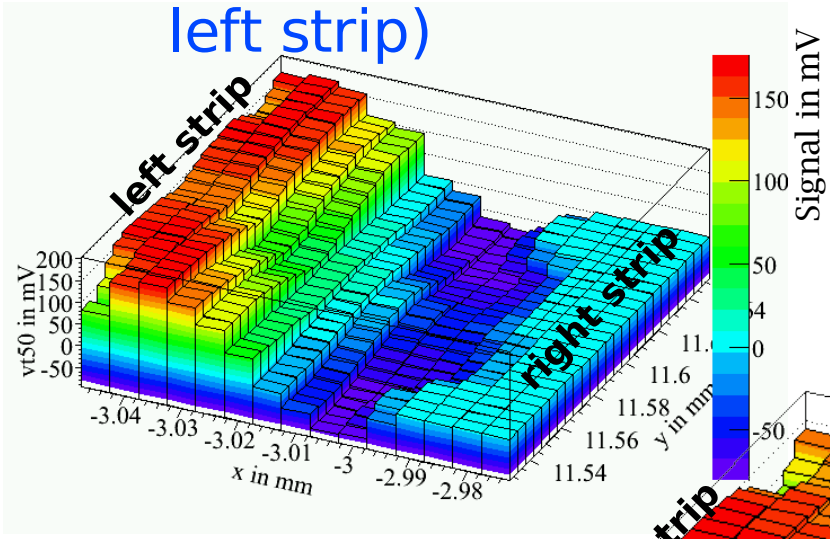
THE END

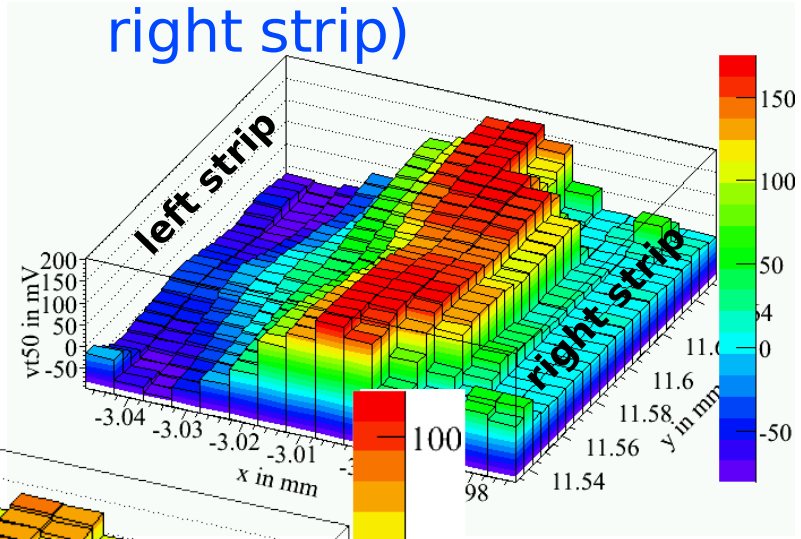
The ATLAS Inner Detector



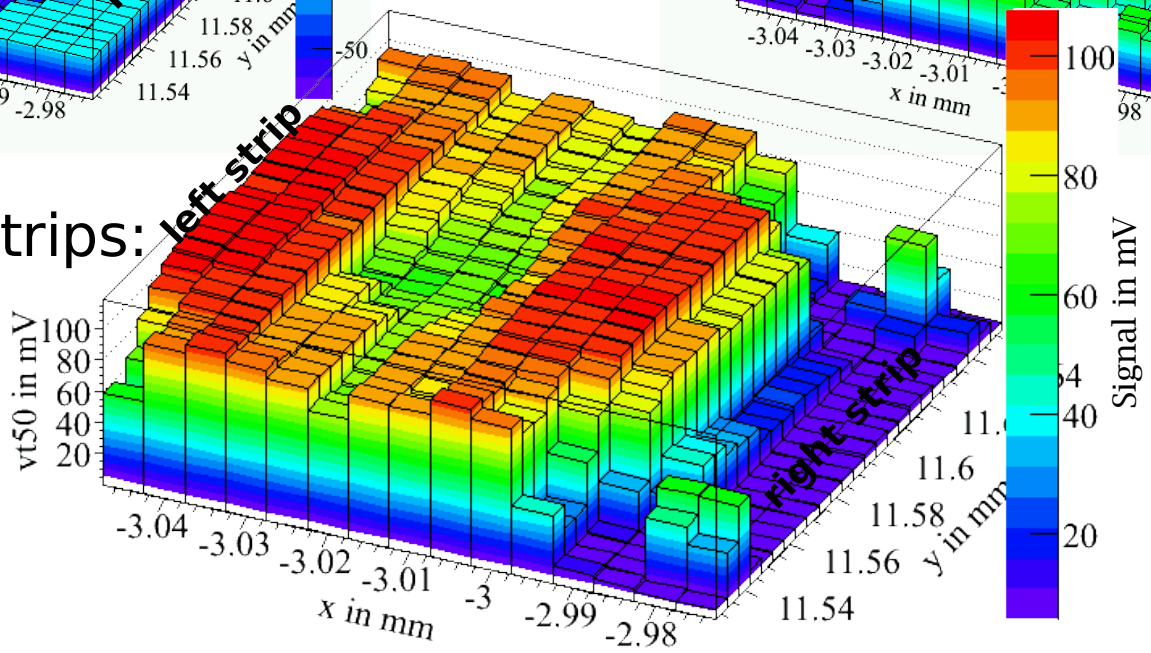
Post-Irradiation: CCE @ 130V

- Response from left strip (readout strip: left strip)
- Response from right strip (readout strip: right strip)



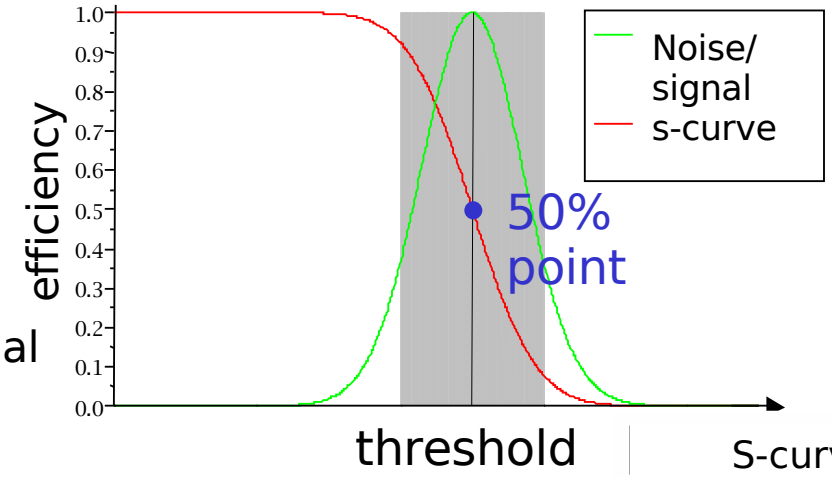


Sum of both strips:

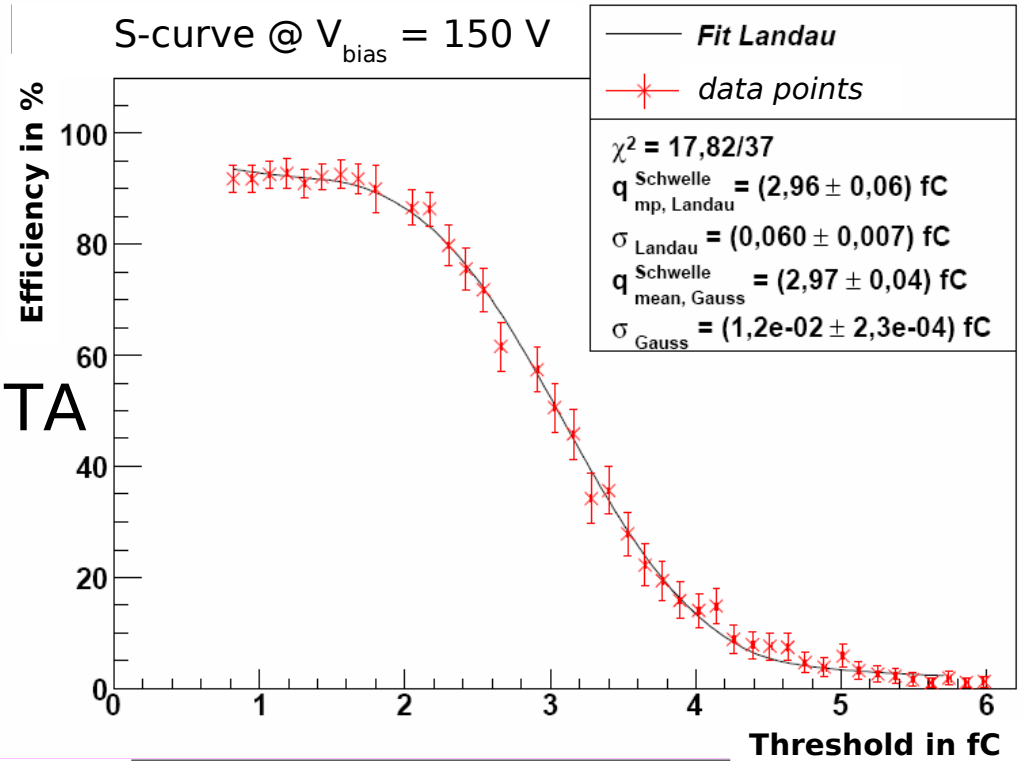


Charge extraction: β set-up

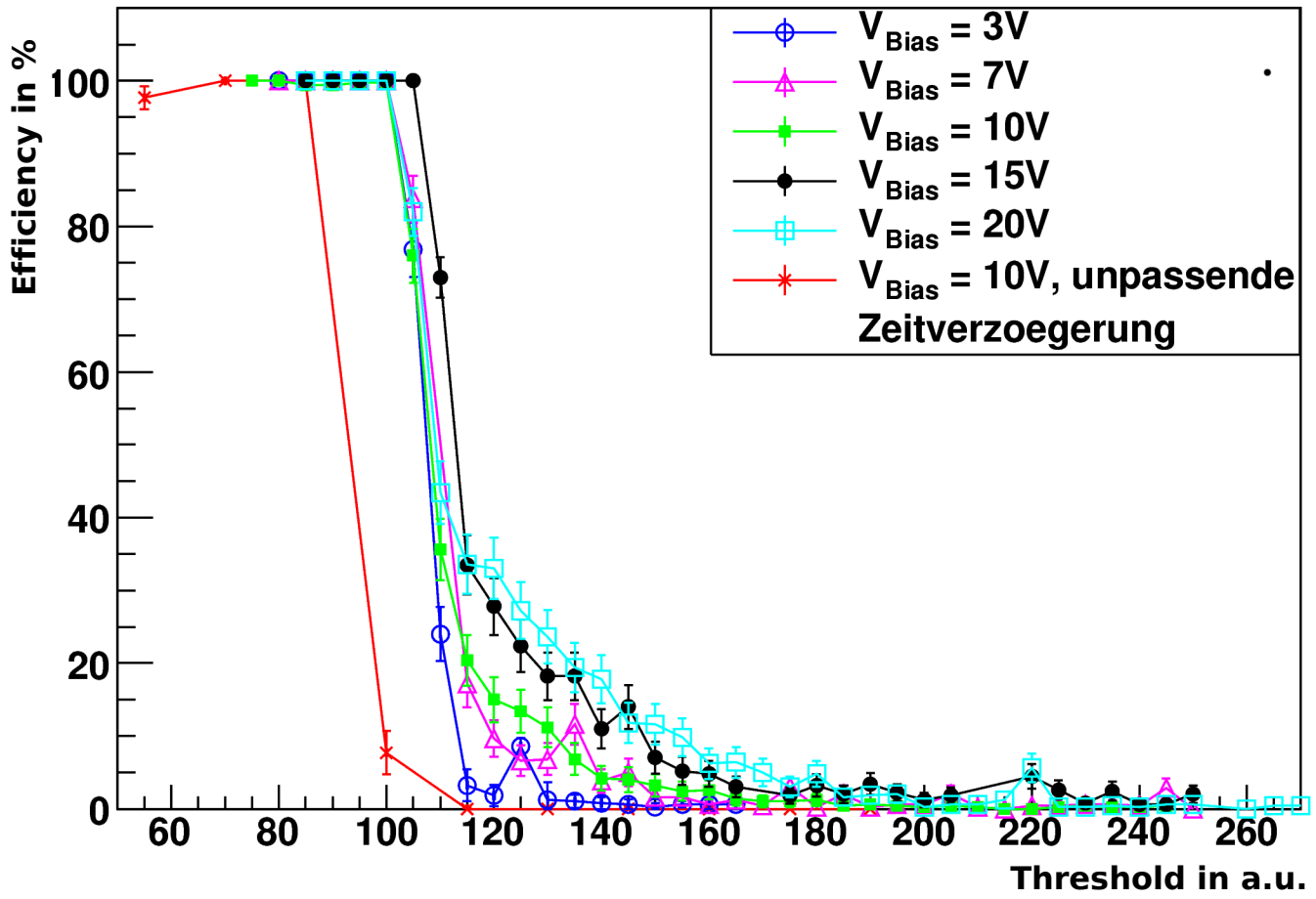
System with Gaussian noise/signal



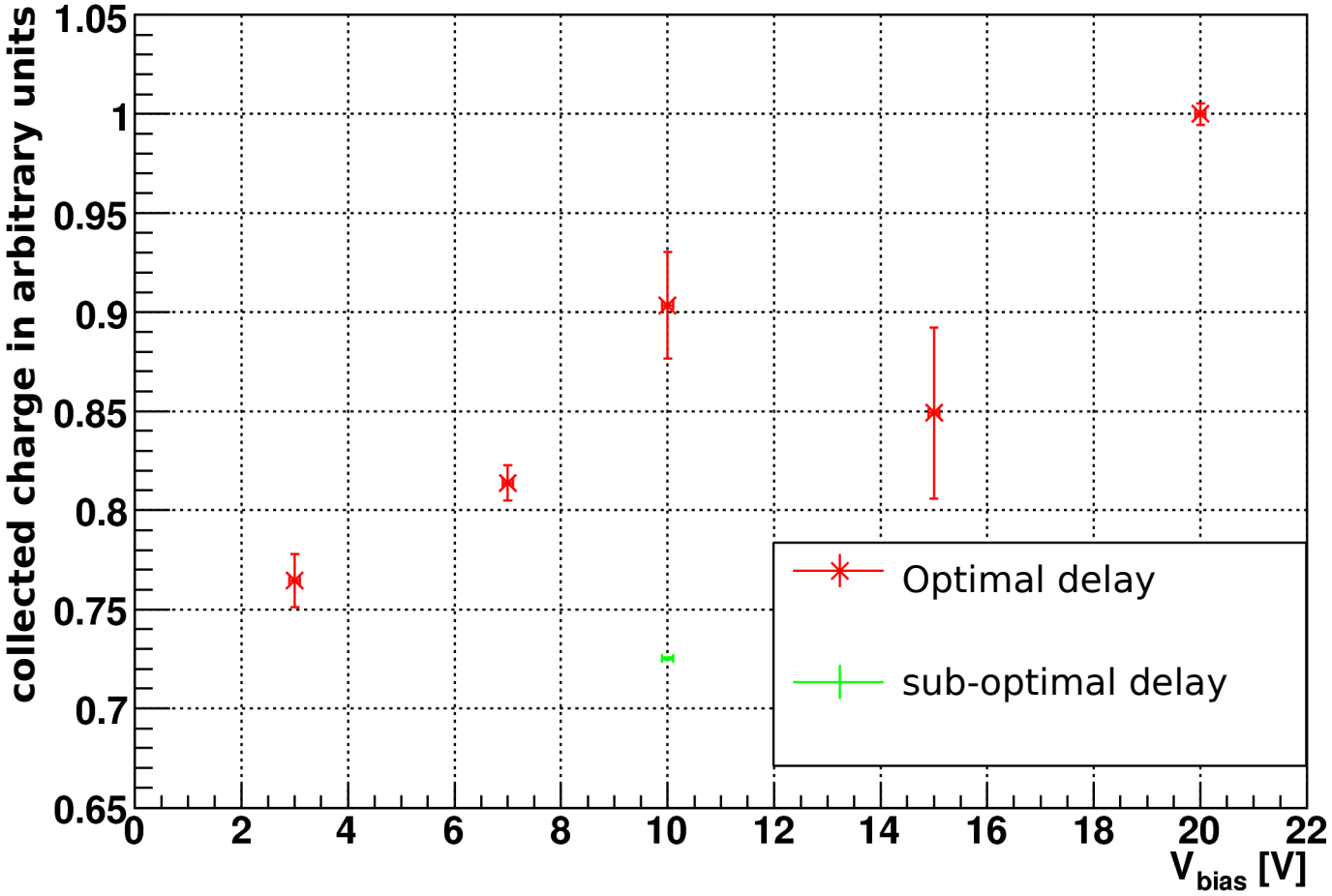
Binary readout system: based on the ATLAS SCT front-end ASIC: the ABCD3TA

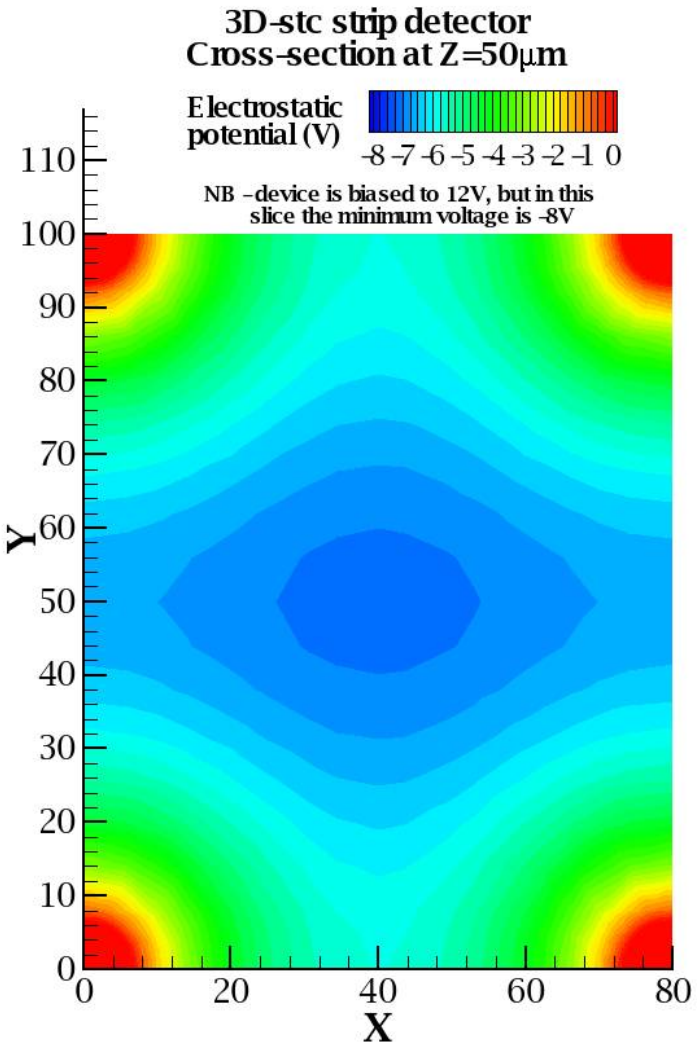


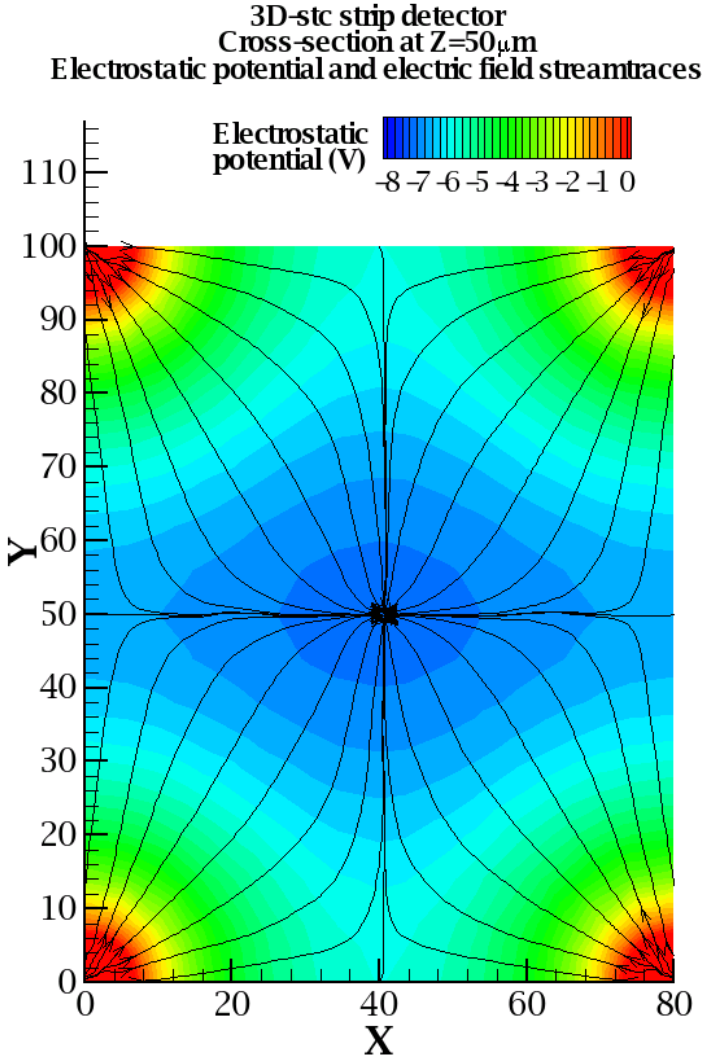
3D STC threshold scan



Collected charge vs. Bias voltage




3D-stc strip detector
Cross-section at Z=50μm
Electrostatic potential (V)
-8 -7 -6 -5 -4 -3 -2 -1 0
NB –device is biased to 12V, but in this slice the minimum voltage is -8V
Y
X
0 10 20 30 40 50 60 70 80 90 100 110
0 20 40 60 80


3D-stc strip detector
Cross-section at Z=50μm
Electrostatic potential and electric field streamtraces
Electrostatic potential (V)
-8 -7 -6 -5 -4 -3 -2 -1 0
Y
X
0 10 20 30 40 50 60 70 80 90 100 110
0 20 40 60 80

P stops affect the electric field