Freiburg status report on 3D-stc detectors

11th RD50 Workshop
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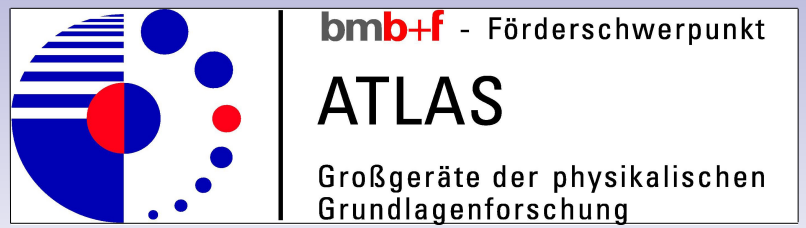


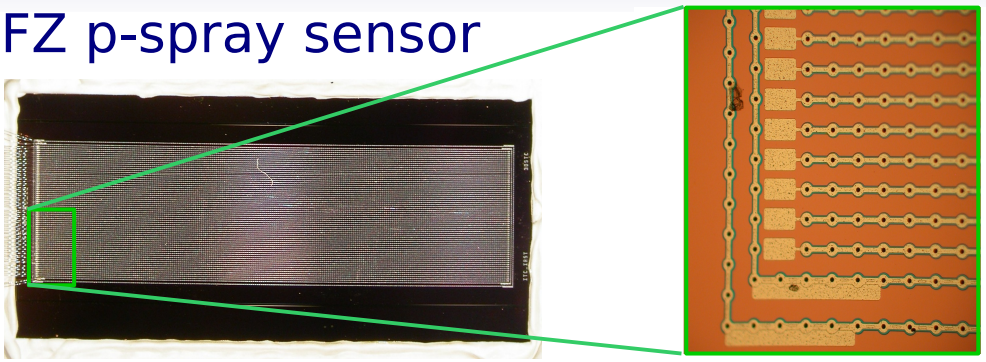
Outline

- The Sensors
- The Modules
- Experimental setups
- Measurements before and after irradiation
  - Noise
  - Charge Collection
  - Position resolved CCE scans
- Test beam @ CERN
- Summary and Outlook

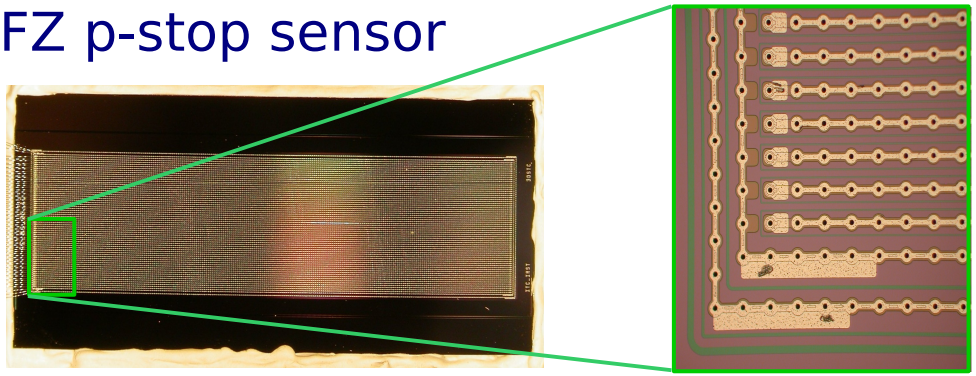
The Sensors

- 3D-stc n^+-on-p microstrip devices from FBK-irst, Trento
- Different materials and isolation schemes
- Thickness
  - FZ 525 µm
  - Cz 300 µm
- 64 strips
  - strip pitch 80 µm
  - length 18.4 mm
- 230 columns per strip
  - column pitch 80 µm
  - depth 150 µm
- AC coupled

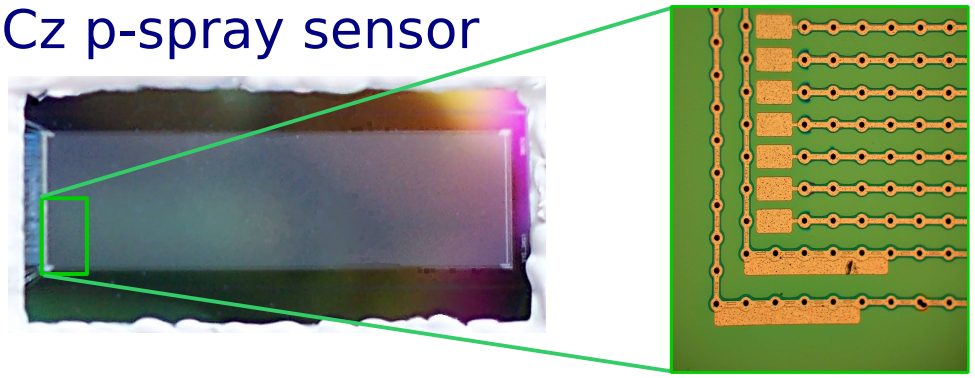
- FZ p-spray sensor



- FZ p-stop sensor

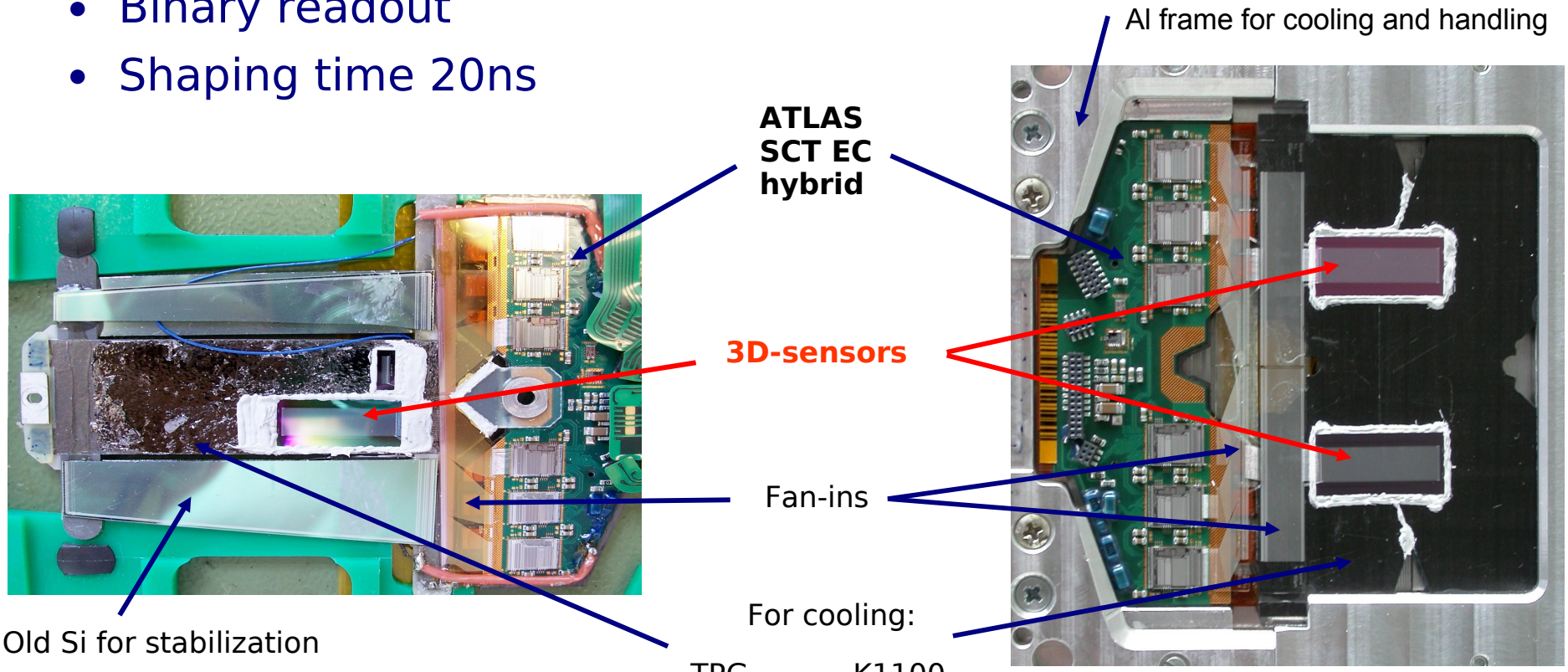


- Cz p-spray sensor



The Modules

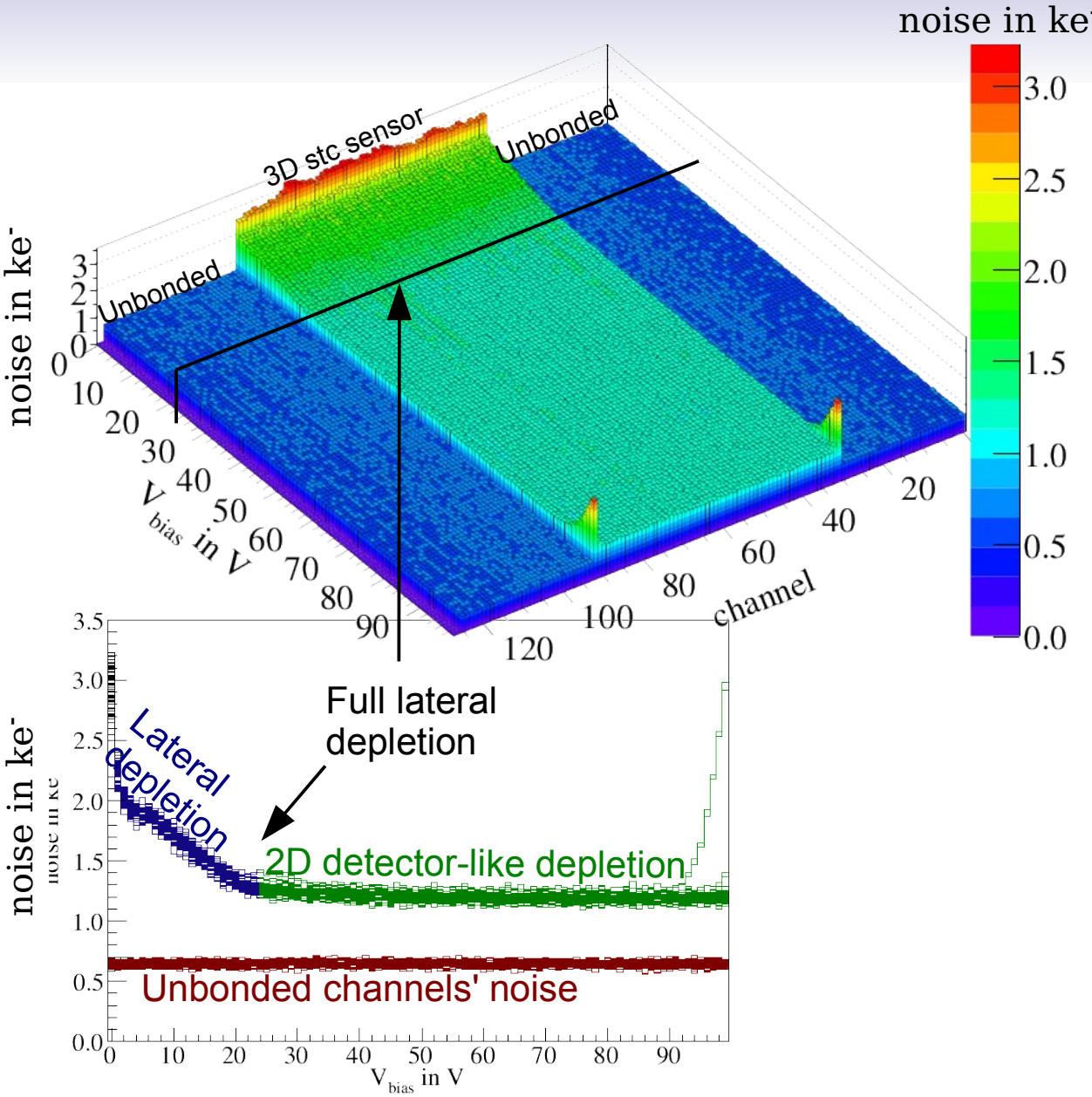
- Readout
  - Based on 40MHz ATLAS SCT EndCap electronics
  - Binary readout
  - Shaping time 20ns



Experimental setups

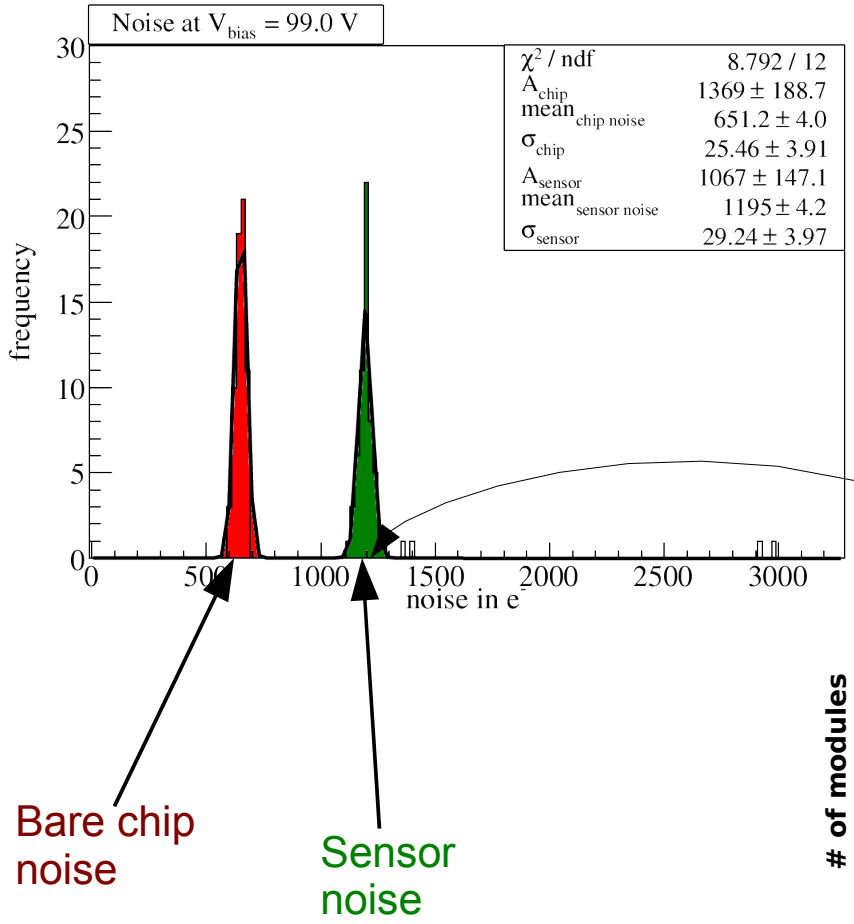
- Beta source
  - based on a Sr^{90} β-source and two thin scintillators
  - triggered from MIP-like electrons
  - cooled setup: sensor temperature -10 °C
- IR Laser
  - Penetration depth @ $\lambda = 982nm \approx 100\mu m$
  - Length of pulse ≈ 1-2ns
  - Microscope to focus optically → laser spot Ø ≈ 4–5µm
  - *x*-*y* stages with µm resolution
  - *z*-axis manual, but also with µm accuracy
  - Nitrogen flushed test box with cooling system
- Irradiation
  - 26 MeV protons up to a fluence of 0.9 x 10^{15} Neq/cm^2
  - measurements without annealing

Noise – CZ p-spray unirradiated

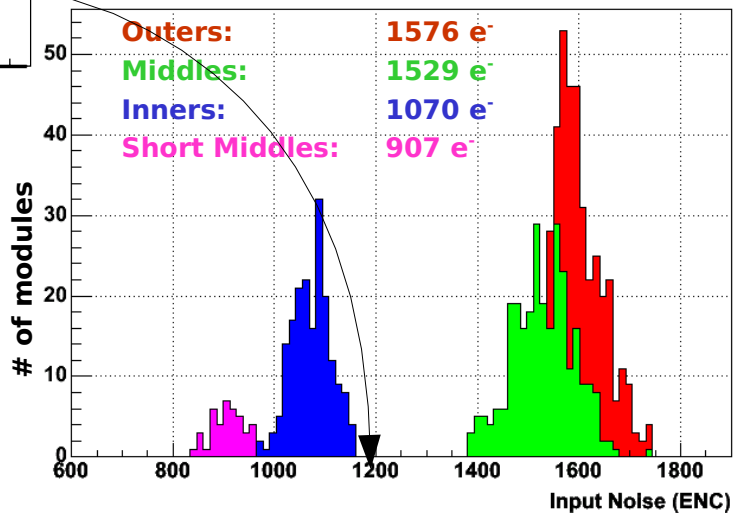


- uniform across sensor
- decreases rapidly with V_{bias} until
- lateral depletion is reached at $V_{Bias} \approx$ 25V
- V_{Bias} > 30V: noise ≈ 1200 electrons
- sensor continues to deplete towards backside → slow decrease

Comparison of 3D-stc detectors and ATLAS SCT Endcap Modules

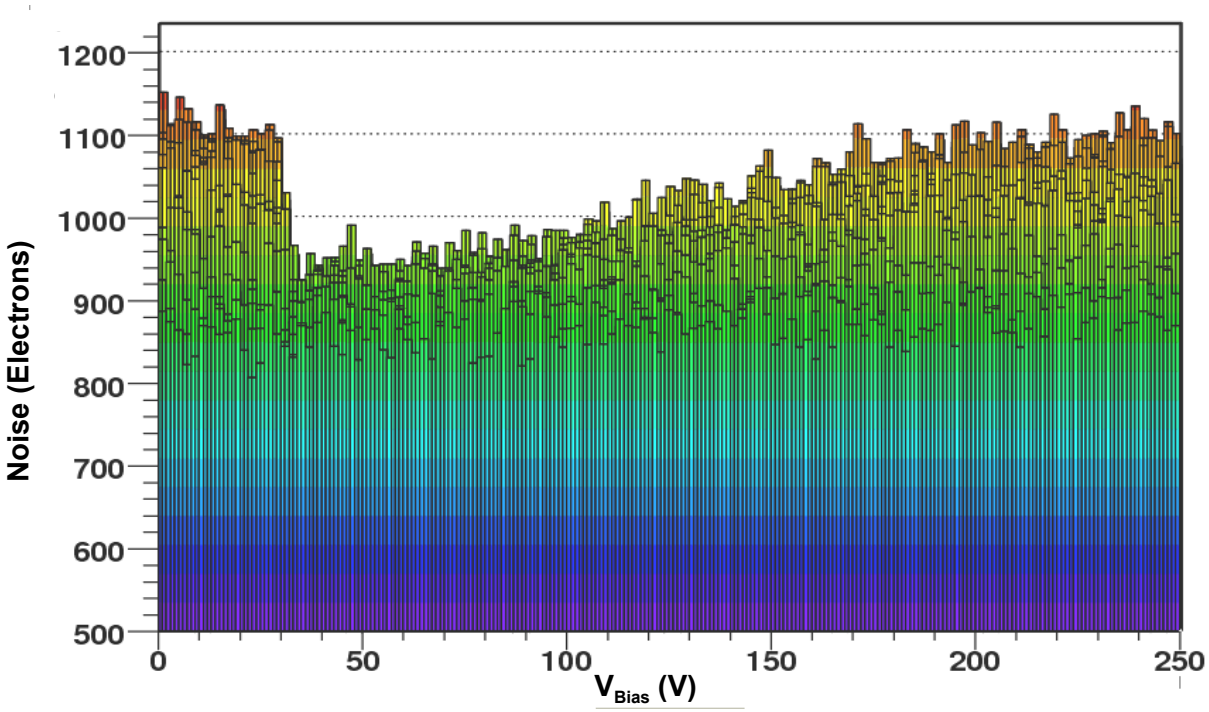


- At bias voltages > 40V noise is comparable to ATLAS SCT modules
- Strip length feasible for "short strip" region



(A. Abdesselam et al. NIMA575 (2007))

Noise – CZ p-spray irradiated

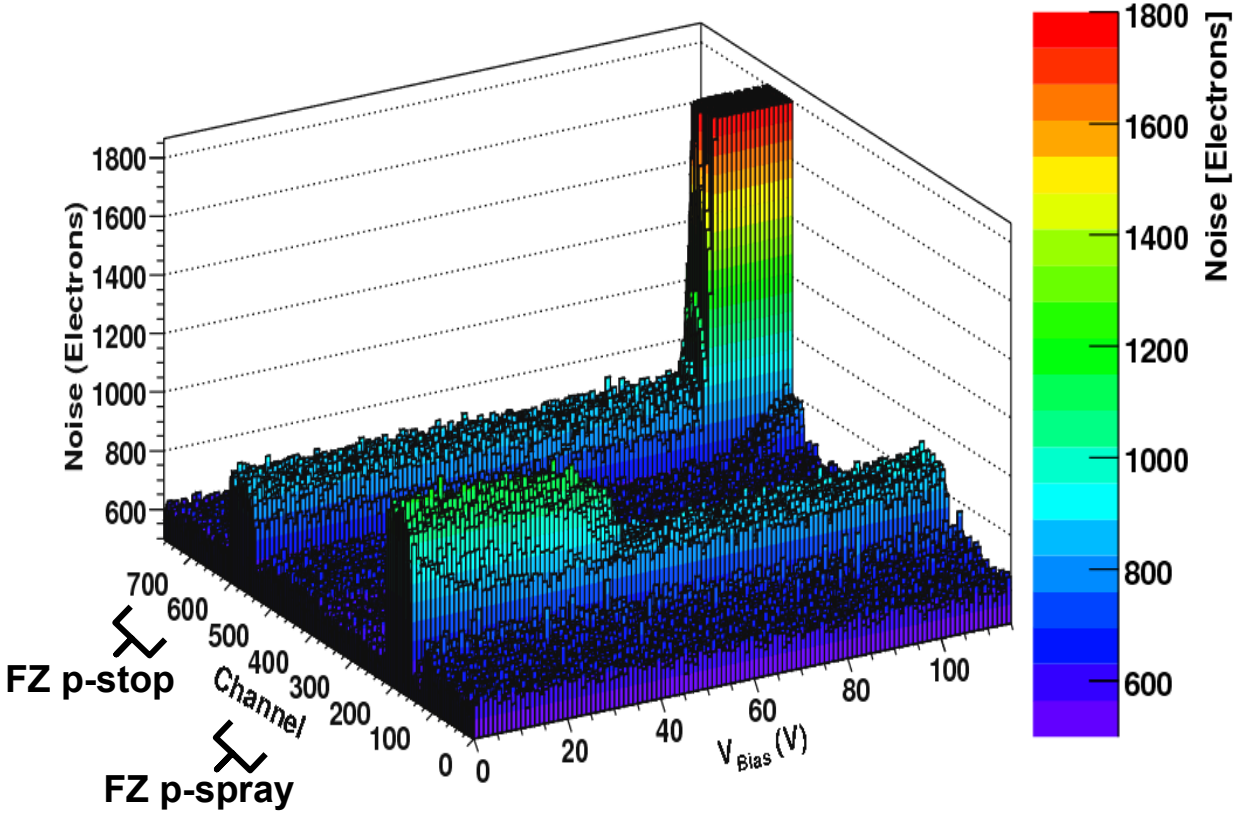


- decrease until lateral depletion at $V_{Bias} \approx 35V$
- $35\ V < V_{Bias} < 100\ V$: noise ≈ 950 electrons
- for higher V_{Bias} rising to ≈ 1100 electrons at 250V

- lower noise on sensor after irradiation, reason not clear
- $I_{leak,max} = 0.017\ A/cm^3$ at $V_{Bias} = 400V$ (corrected to 20 °C), corresponds to expectations

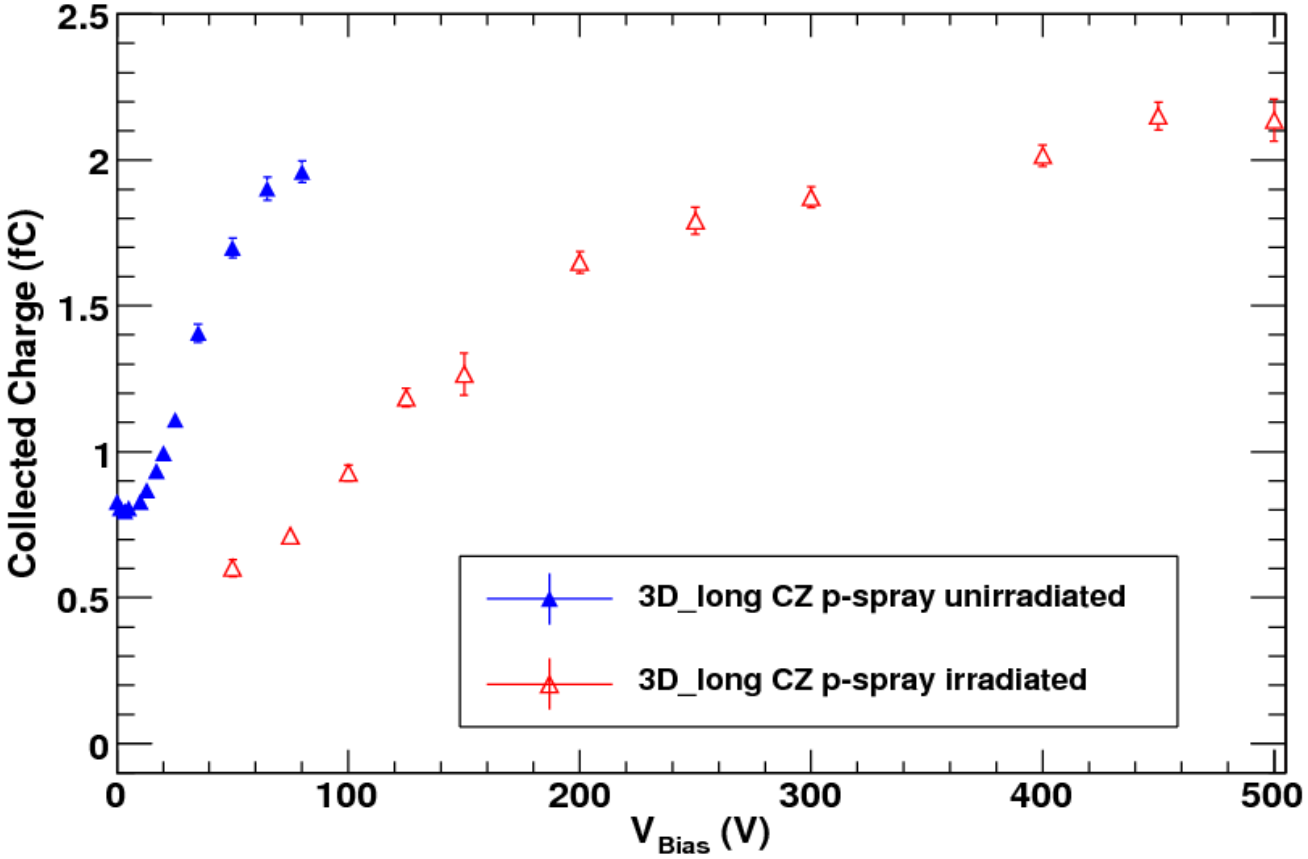
Noise – FZ sensors

- Before irradiation
  - noise comparable to CZ sensor
  - lateral depletion @ V_{Bias} ≈ 7 V (p-stop) / 12 V (p-spray)
- After irradiation



- FZ p-stop:
  - high noise above V_{Bias} = 95 V, low noise of 900 electrons until microdischarge starts
- FZ p-spray:
  - noise drops steeply at ≈ 50 V, microdischarge starts at 250 V
  - shows low noise until high voltages

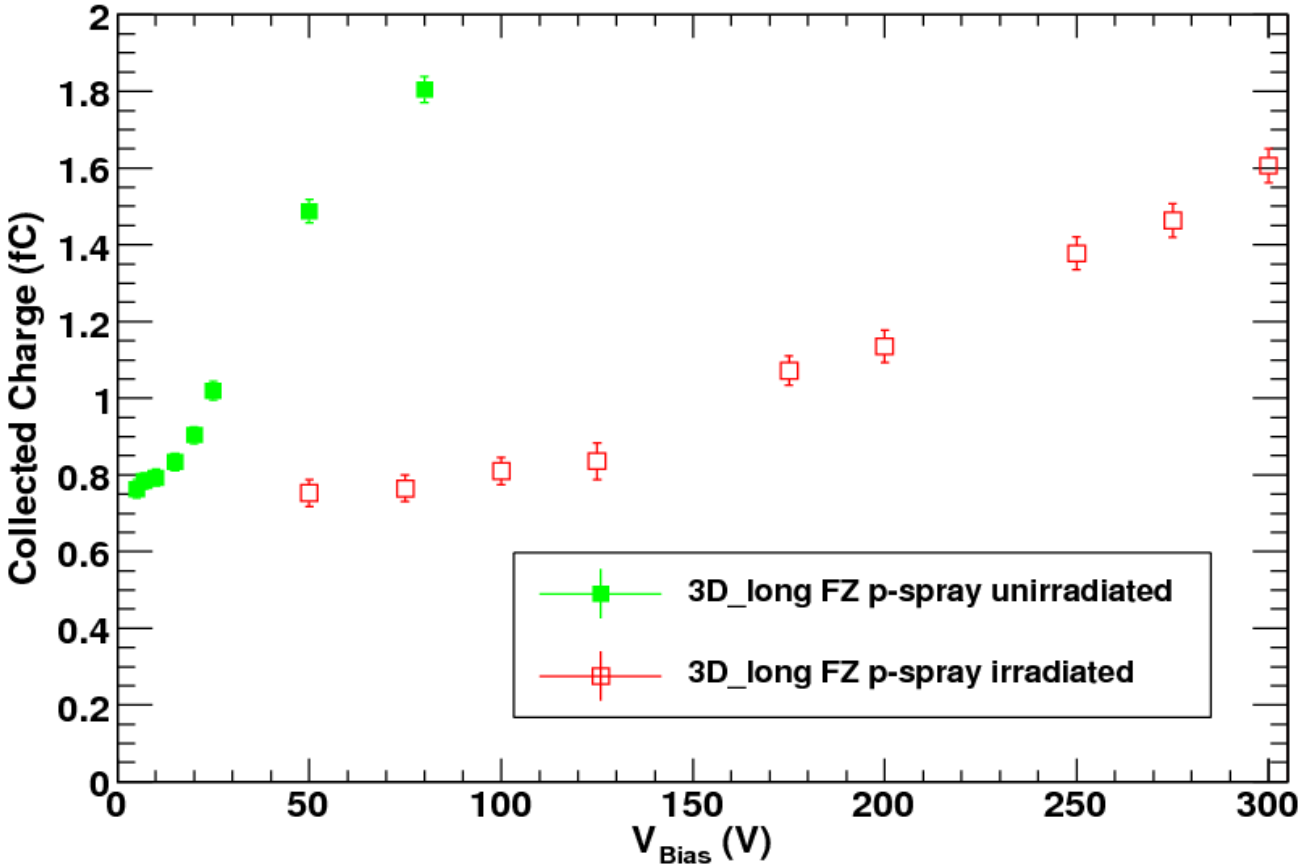
Collected charge – CZ p-spray



- before irradiation
  full depletion at 70V:
  Q = (1.96 ± 0.04) fC
  ≈ 12600 electrons
- after irradiation
  full depletion at 450V:
  Q = (2.14 ± 0.07) fC
  ≈ 13800 electrons
  (T = -7°C)

- Sensor performance not degraded after irradiation if full depletion (overdepletion) can be achieved
- Collected charge not measurably reduced by trapping

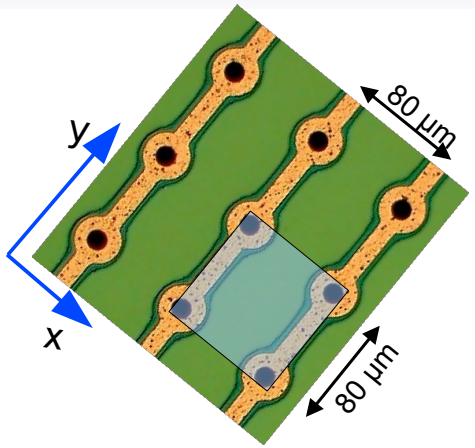
Collected charge – FZ p-spray



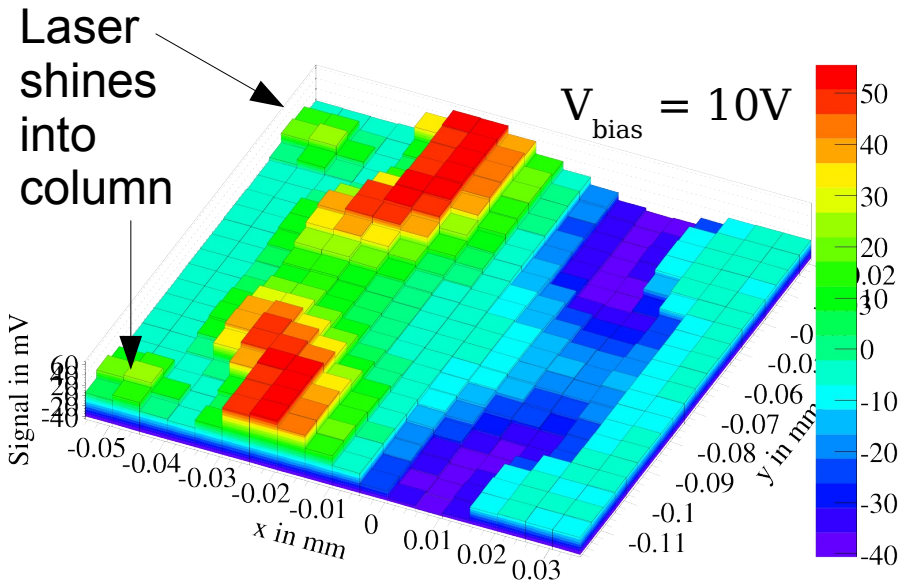
- before irradiation
  at V_{Bias} = 80V:
  Q = (2.31 ± 0.04) fC
  ≈ 14850 electrons
- after irradiation
  at V_{Bias} = 300V:
  Q = (1.61 ± 0.04) fC
  ≈ 10400 electrons
  (T = -7°C)
- no full depletion (microdischarge)

- Collected charge at 300 V for FZ sensor less than for CZ sensor (+ 0.3 fC)

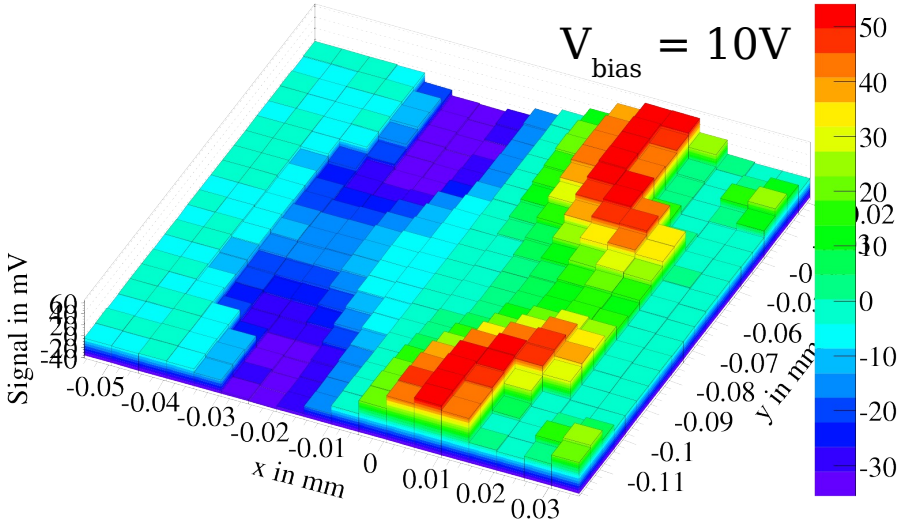
Position resolved Laser scans



- Cz p-spray, unirradiated
- 5µm step size
- 80µm × 80µm area
- *y* axis along the strips
- At variable bias voltage

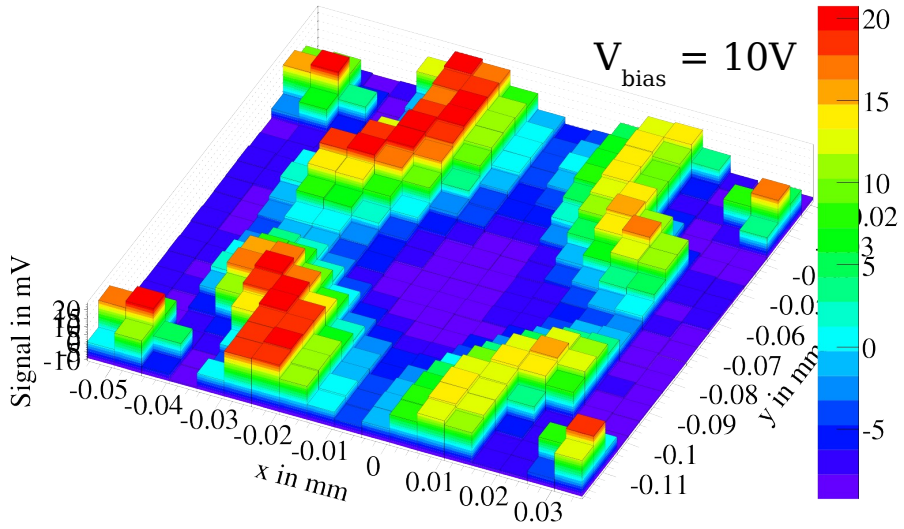


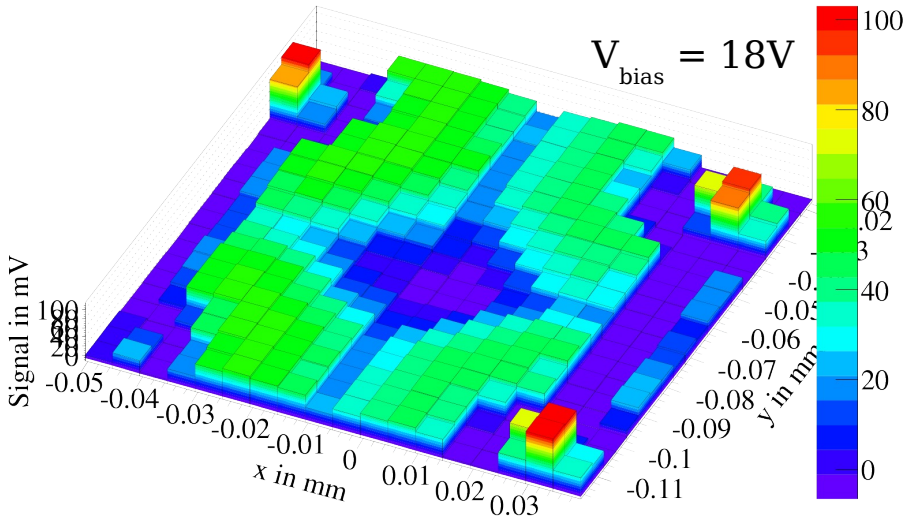
signal on left strip

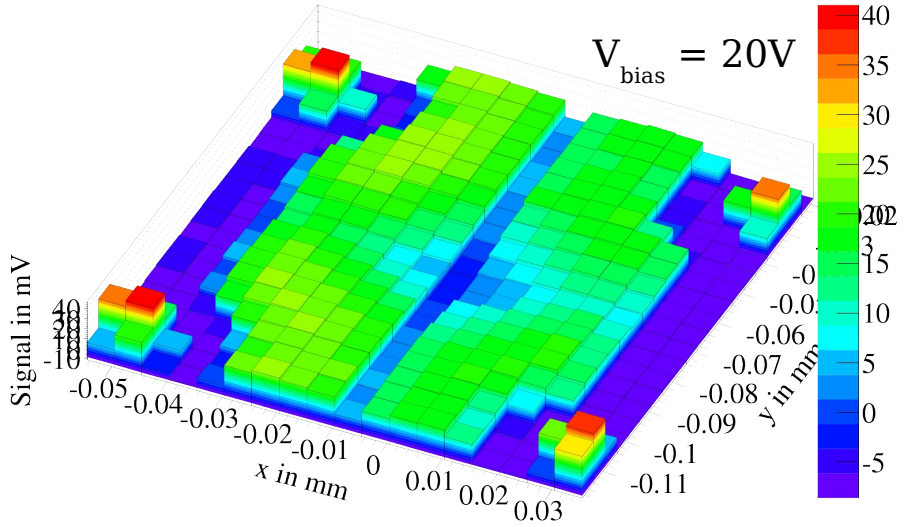


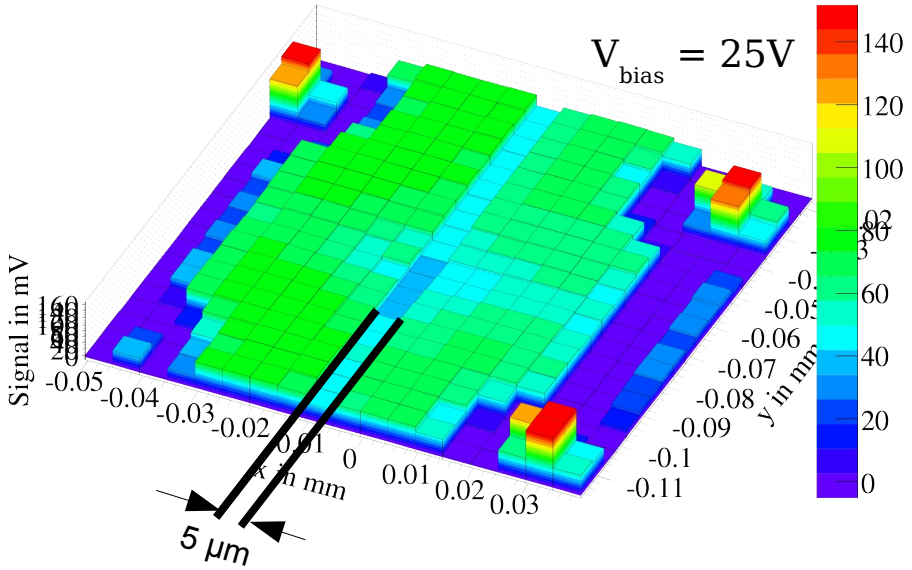
signal on right strip

CCE as a Function of Applied Bias Voltage for CZ p-spray

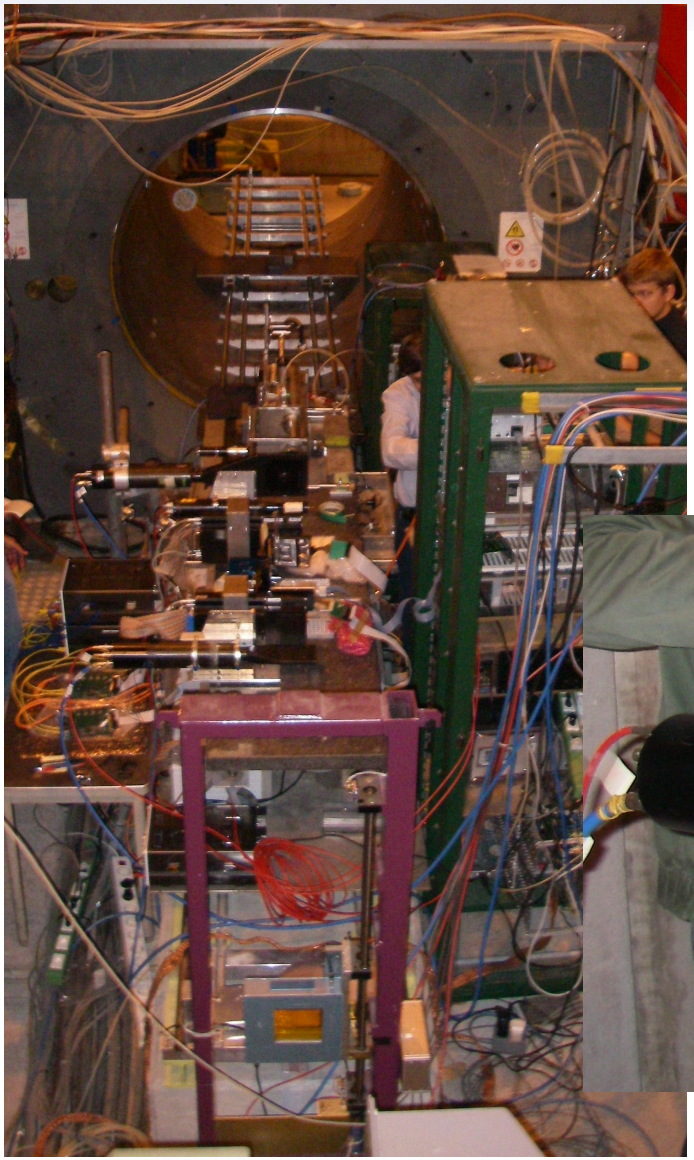




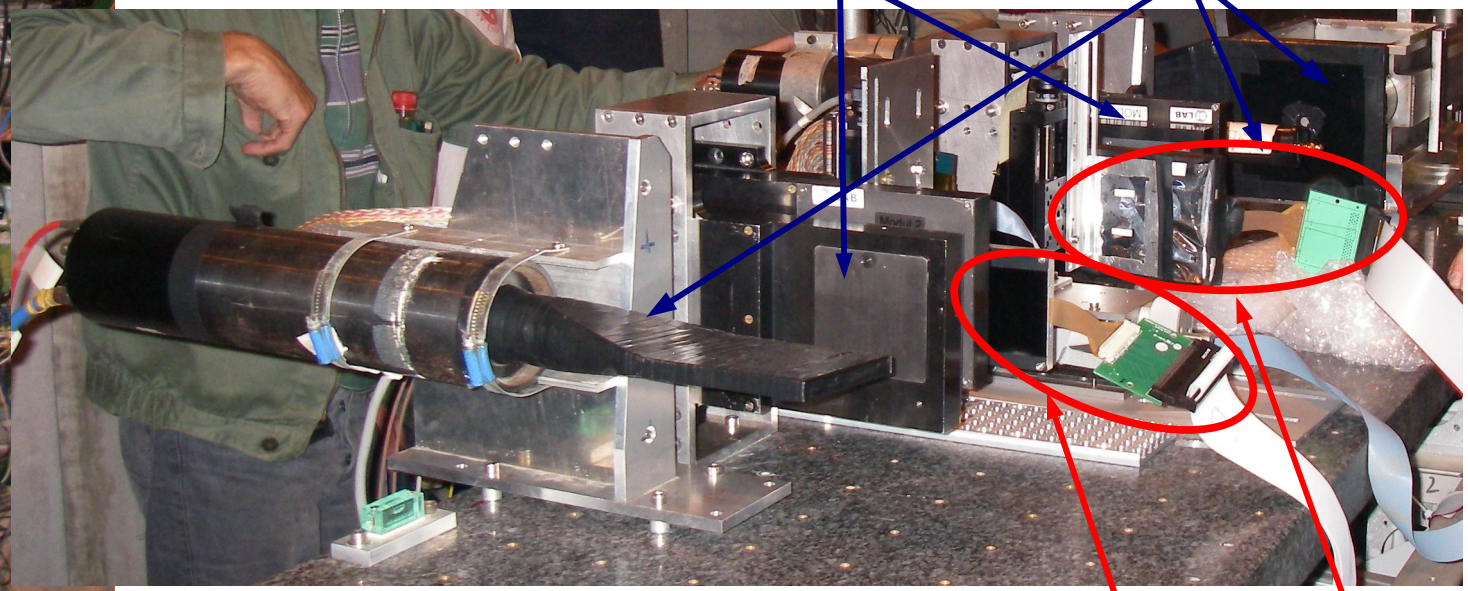




Test beam setup

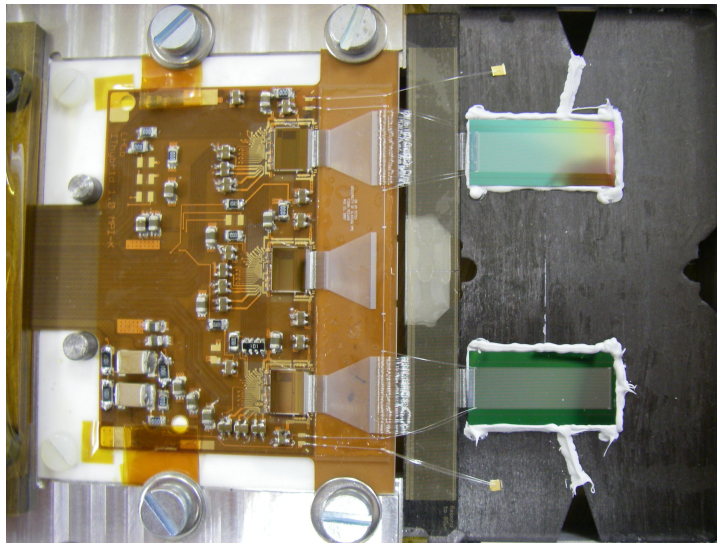


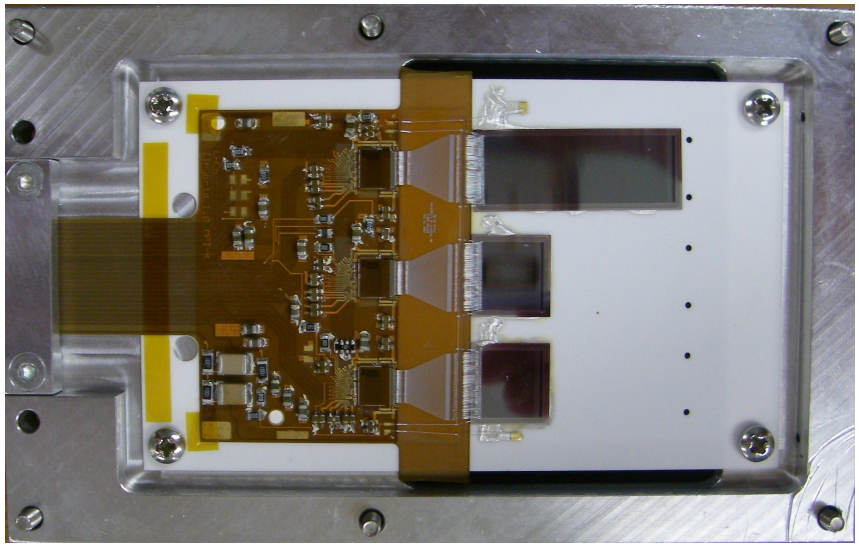
- ATLAS test beam at CERN H8 area with Stanford, FP420
- this work: close collaboration with Glasgow
- 180 GeV π beam
- Bonn ATLAS Telescope (BAT), 5µm resolution



Devices under test

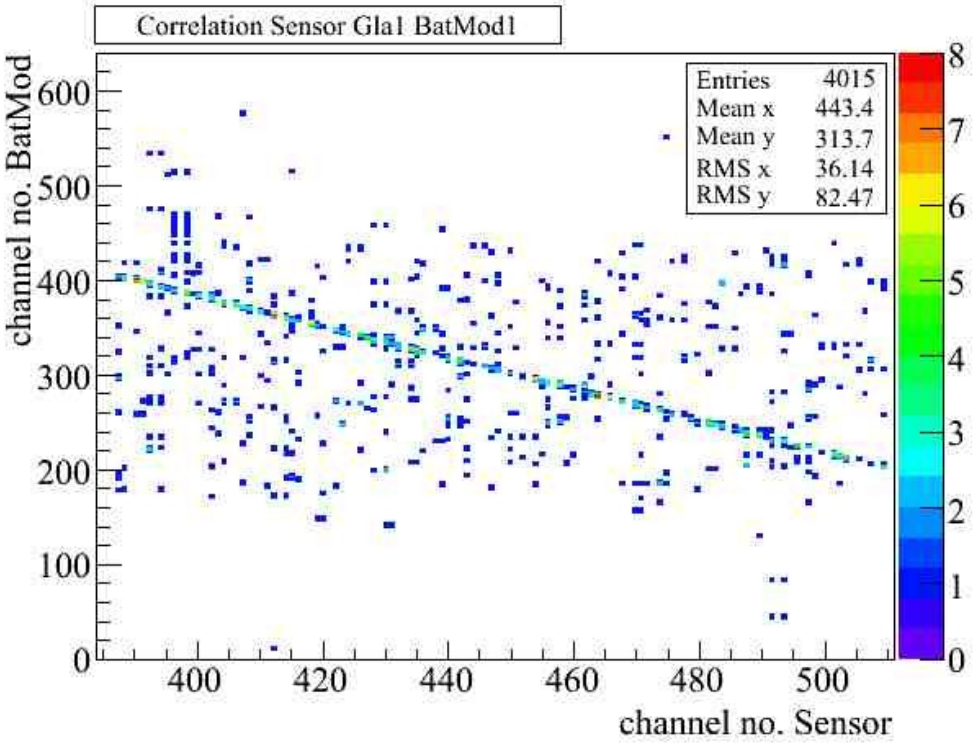
- Freiburg module
  - 3D-stc n^+-on-p Cz microstrip devices from FBK-irst, Trento
  - strip length 18.4mm
  - p-spray / moderated p-spray
- Glasgow module
  - planar n^+-on-p devices by Micron, FZ/Cz
    (3Ds from ICEMos and 3D-dtc not available)
  - strip length 3 / 1 / 1cm

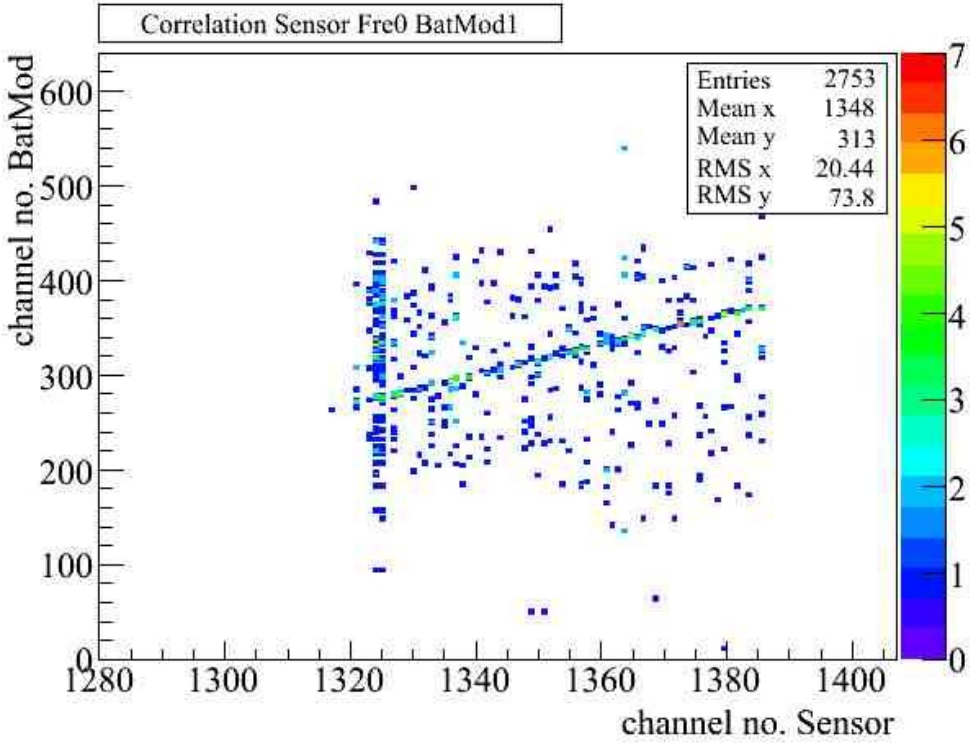




- all sensors were simultaneously read out with analogue 40MHz LHCb readout (Beetle chip and TELL1, see talk by Lars Eklund)
- Shaping time 25ns, 5 consecutive time bins

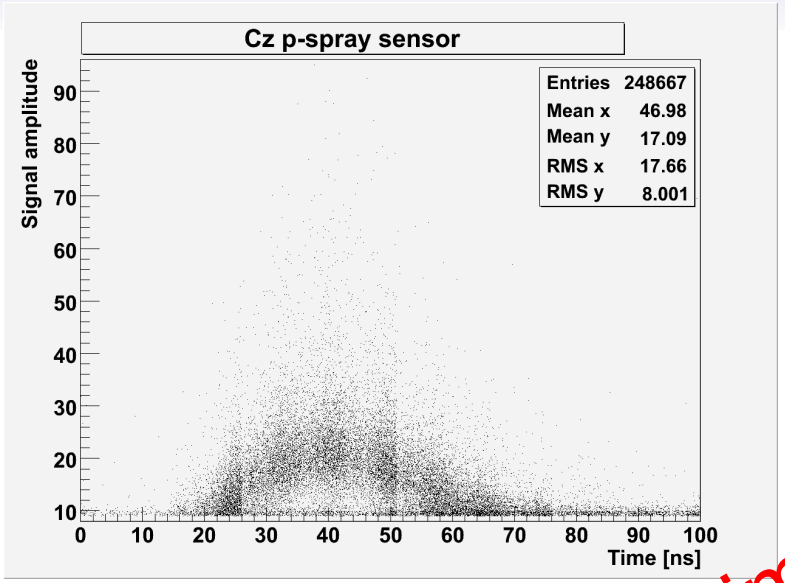
Correlation plots

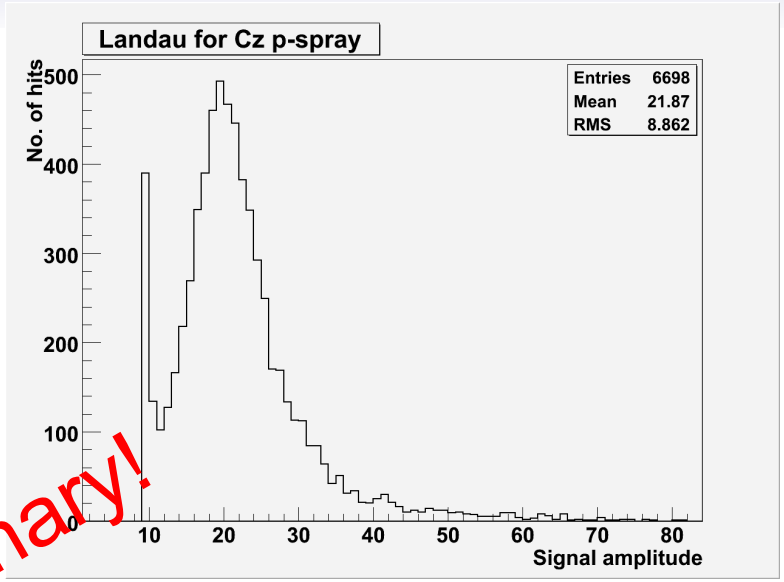


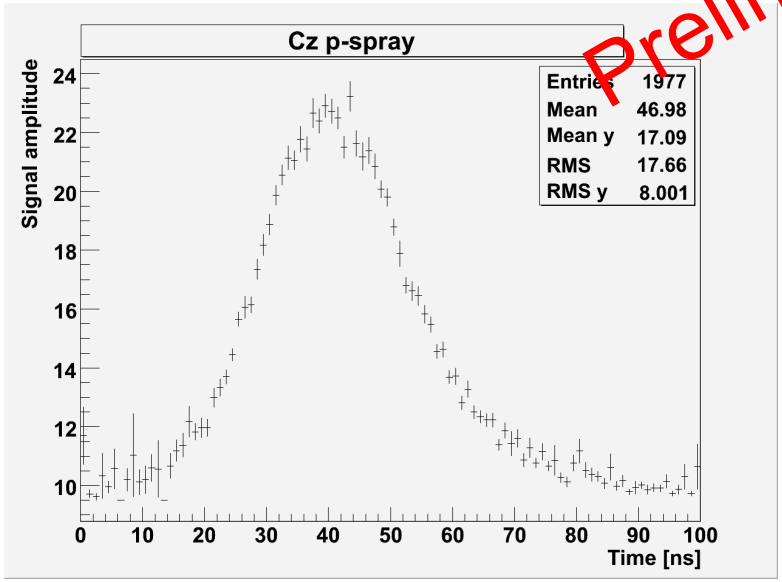


- No SN cut, threshold for noise suppression
- Correlation visible → sensors positioned in beam
- Glasgow module mounted upside-down wrt BAT Module 1z

Pulse shape and Landau for 3D-stc CZ p-spray sensor







Preliminary!

- Landau shape clearly visible
- still contains many fake hits
- no SN cut
- no clustering
- no tracking

Summary and Outlook

- Several 3D-stc prototypes have been tested with different setups (beta source, Laser) and 40MHz ATLAS SCT EC readout before and after irradiation
- Noise for Cz and FZ reasonably low before and after irradiation - comparable to ATLAS SCT
- Charge Collection: little degradation of sensors due to irradiation
- Position resolved scans show good uniformity across sensor and low field region between strips (inefficient CCE)
- Test beam with 180GeV π and 40MHz LHCb readout

- Test beam analysis ongoing – position resolved scans with MIPs possible
- More sensors to be irradiated, also with higher fluences

Thanks to FBK-irst (Trento) for sensors and simulations, to Alex Furgeri (Karlsruhe) for irradiation and to Glasgow for test beam support!

The End

- Backup Slides
  - 3D and 3D-stc
  - Beta source setup
  - IR Laser setup
  - Rebondable Fan-ins
  - CC all sensors unirradiated
  - Signal/Noise
  - 3D-stc depletion simulation
  - Low CCE interstrip region for Cz p-spray
  - Low CCE interstrip region for FZ p-stop

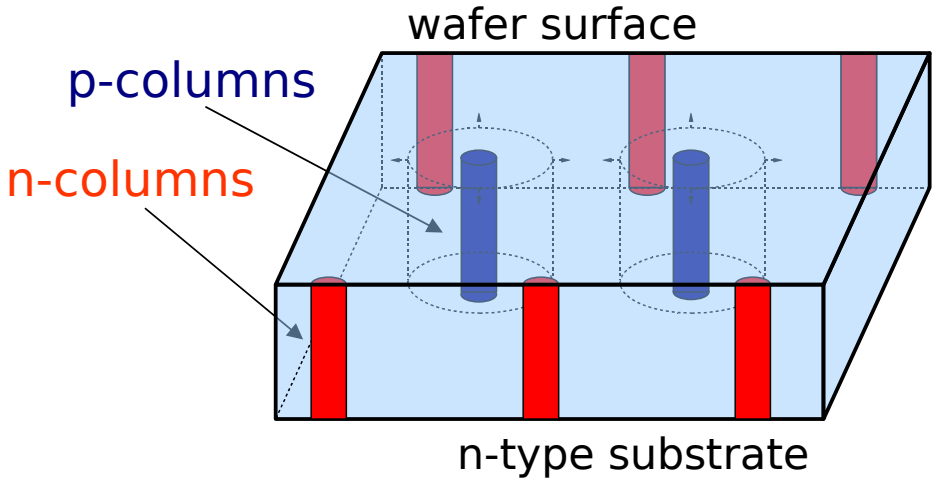
3D and 3D-stc

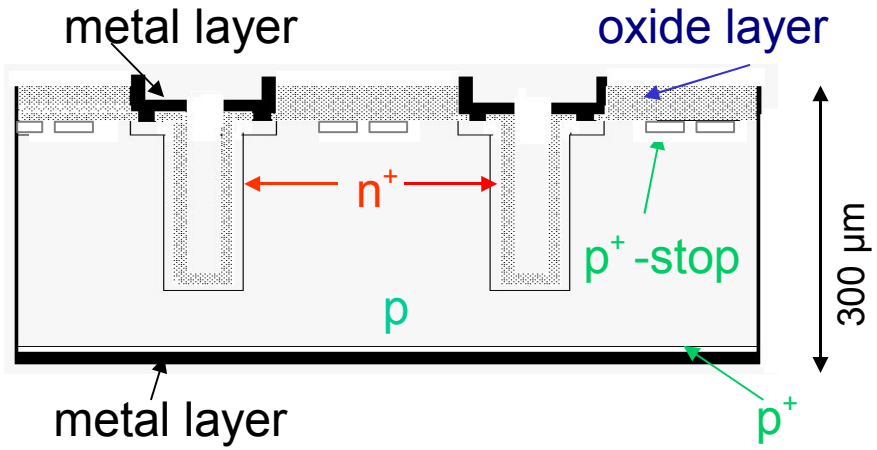
- 3D: decouple depletion and thickness (→Signal) by depleting "sideways" (Parker et al. NIMA395 (1997))
- 3D-stc: single type columns, not completely etched through
- Simplification of processing
  - no support wafer
  - no wafer bonding

  → lower price

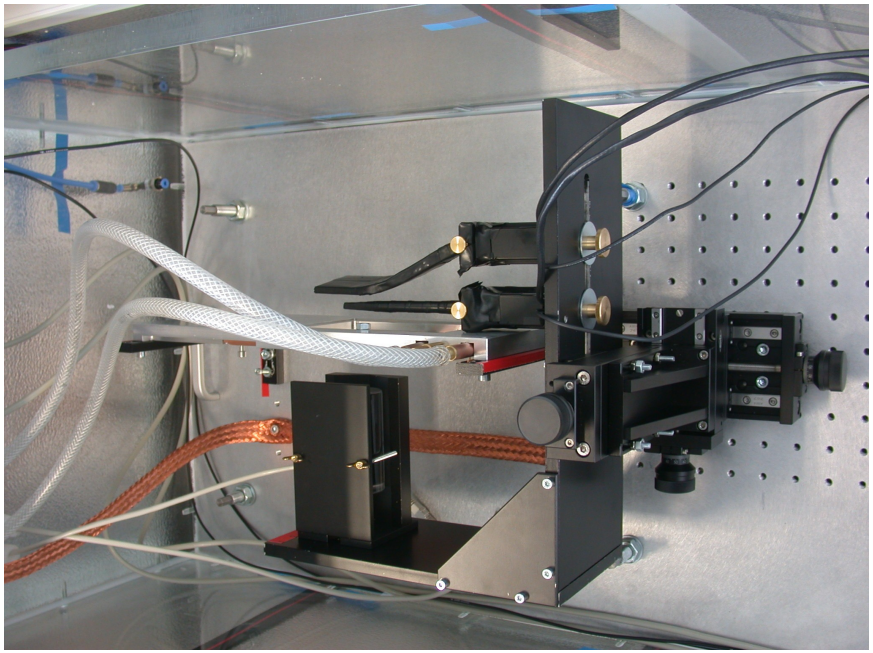
  → ideal to optimize technology and study charge collection mechanism in different field

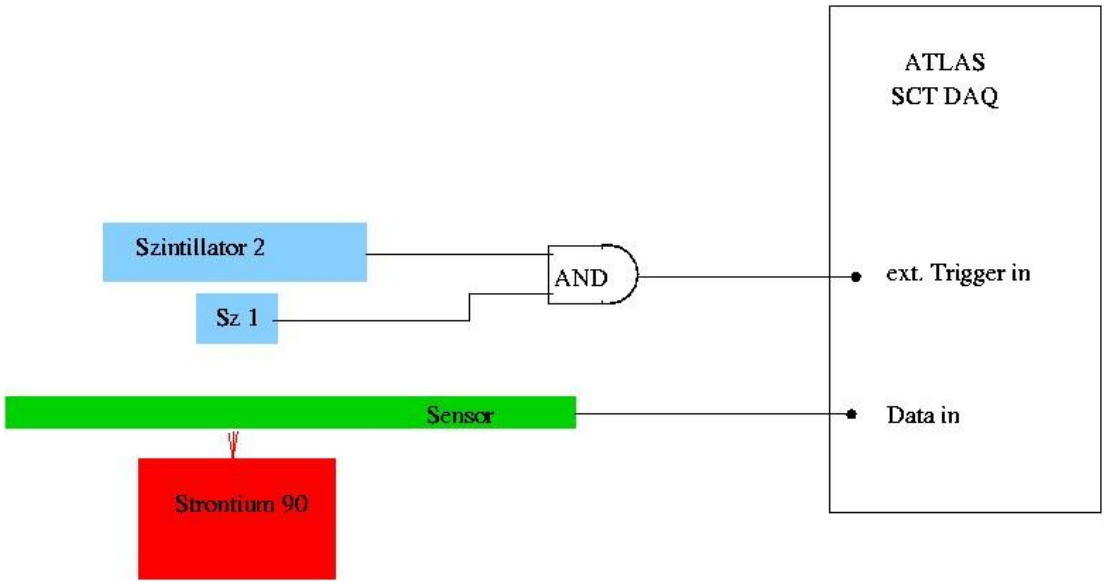
  → important steps towards a full 3D device



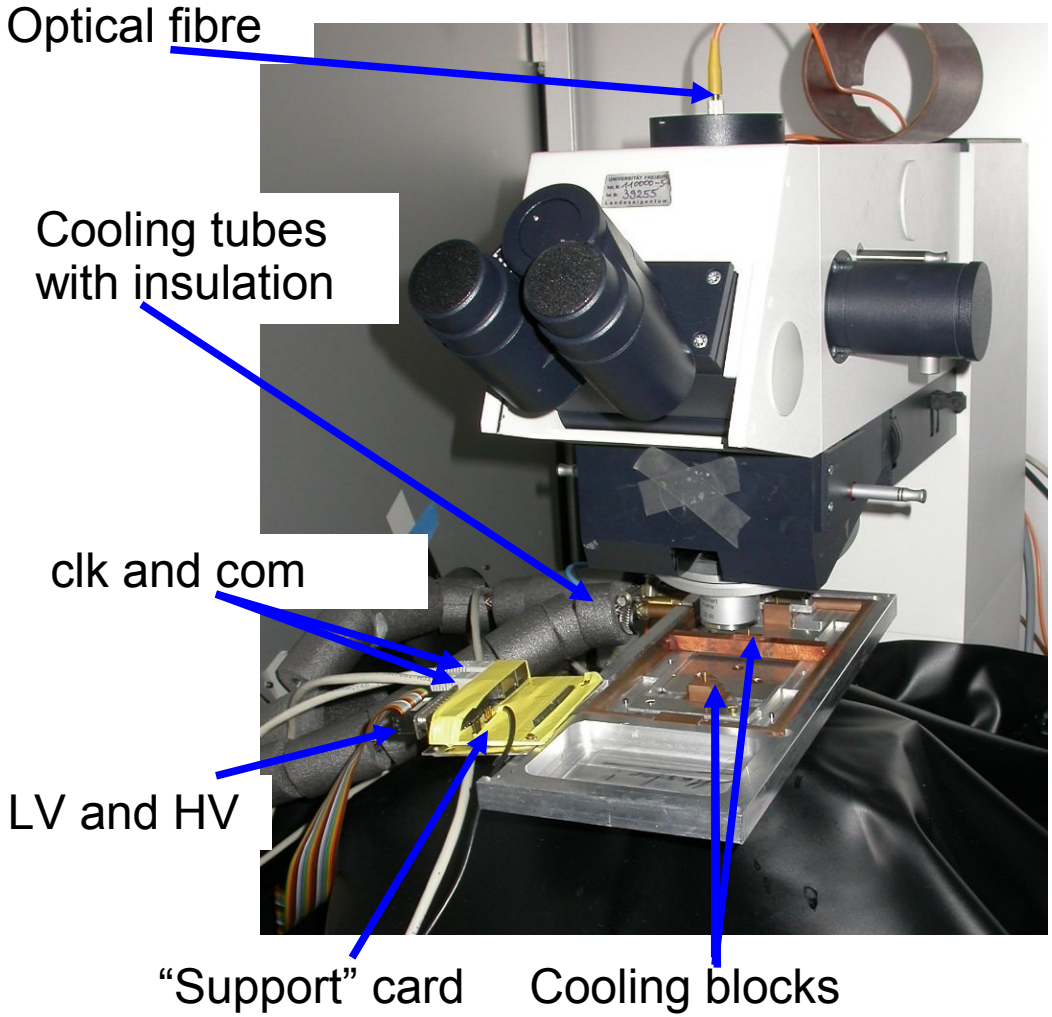


Beta source setup

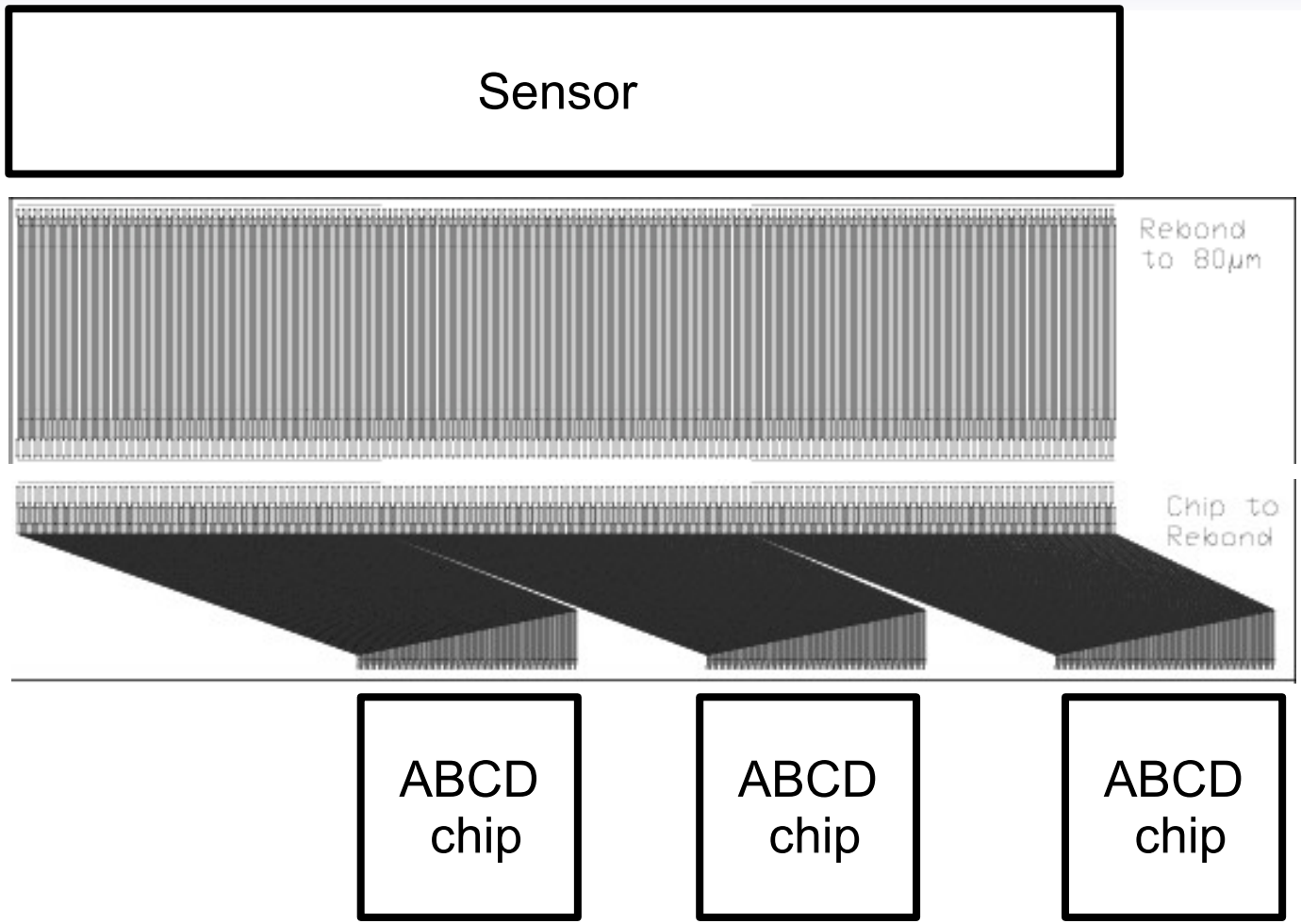




IR Laser setup



Rebondable Fan-ins

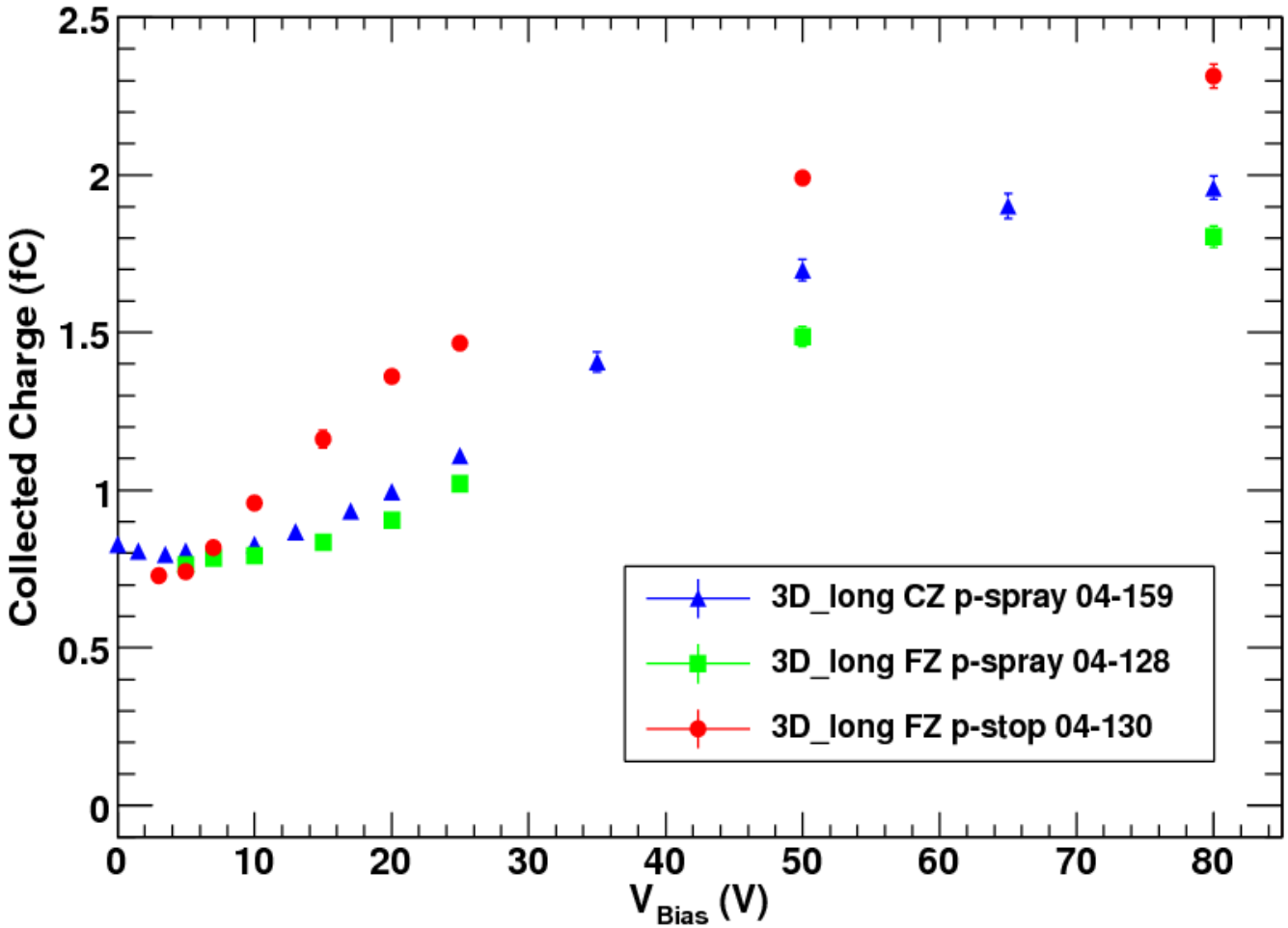


fan-in 1

fan-in 2

- Shape determined by layout of ATLAS-SCT-EC hybrid

Collected charge - unirradiated



- FZ p-stop sensor
  collects at V_{Bias} = 80V:
  Q = (2.31 ± 0.04) fC
  ≈ 14850 electrons
  (T = -10°C)
- CZ p-spray sensor
  collects at V_{Bias} = 80V:
  Q = (1.96 ± 0.04) fC
  ≈ 12600 electrons
  curve saturates at ~ 70 V (full depletion)

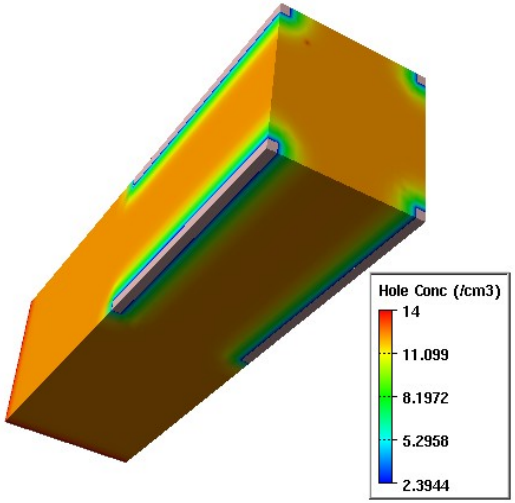
- V_{Bias} is limited by leakage current limit

Signal/Noise

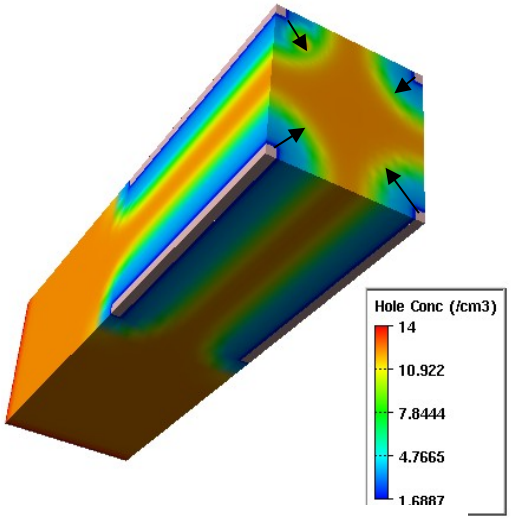
- Before irradiation
  - FZ sensors: Signal/Noise ~ 15 (@ V_{Bias} = 80 V)
  - CZ sensor: Signal/Noise ~ 11 (@ V_{Bias} = 80 V)
- After irradiation
  - FZ p-spray sensor: Signal/Noise ~ 12 (@ V_{Bias} = 300 V)
  - CZ p-spray sensor: Signal/Noise ~ 13 (@ V_{Bias} = 500 V)
- Sensors with p-spray isolation show little degradation caused by irradiation (Fluence 0.9 x 10^{15} Neq/cm2), in case full depletion (overdepletion) can be achieved.

3D-stc Simulations – Depletion

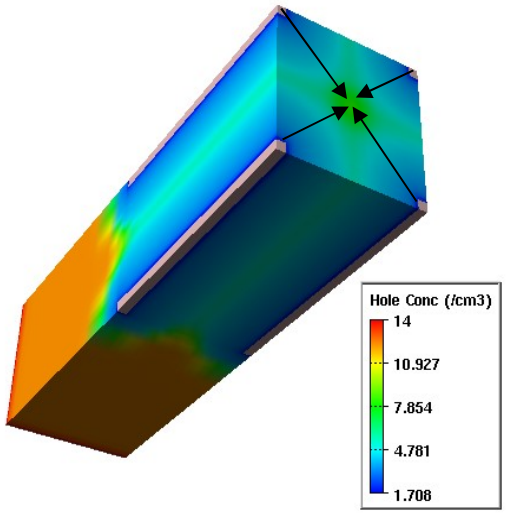
1) V_{bias}=0V



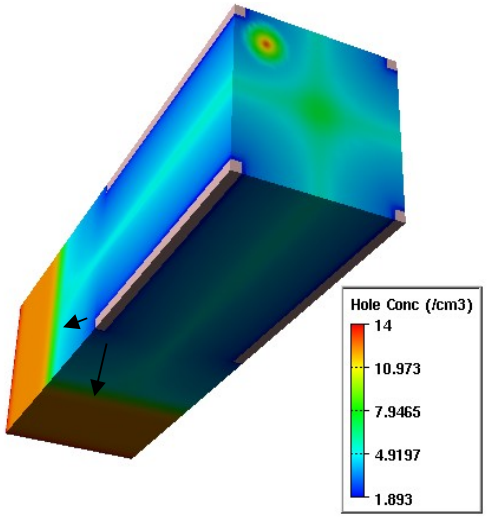
2) V_{bias}=2V



3) V_{bias}=5V

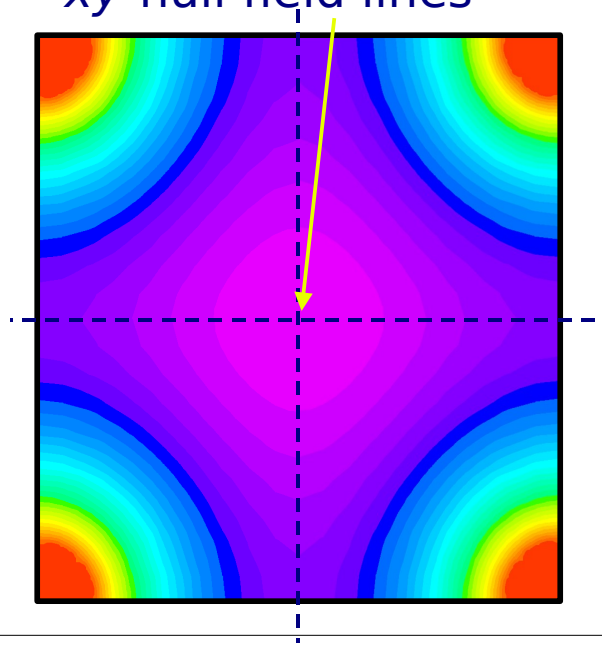


4) V_{bias}=20V

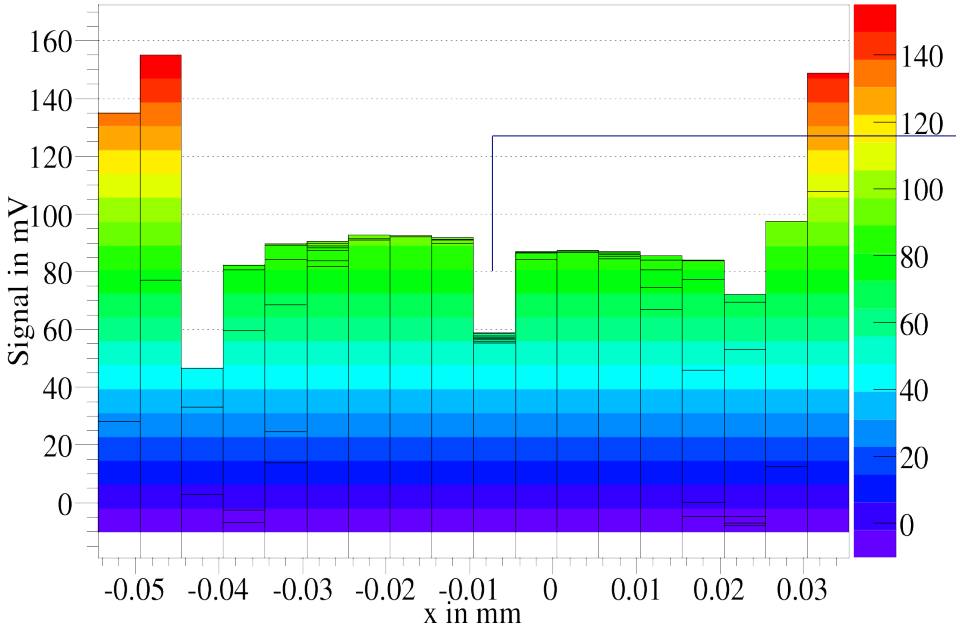


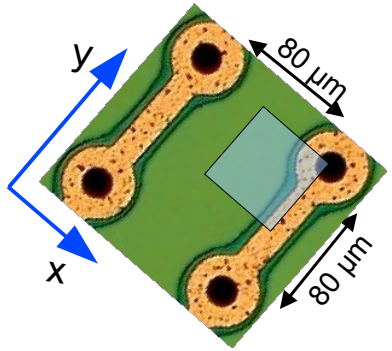
- Rapid lateral depletion at around 5V (FZ Si)
- Then depleting like a planar device
- Low Field in the central region remains

xy-null field lines



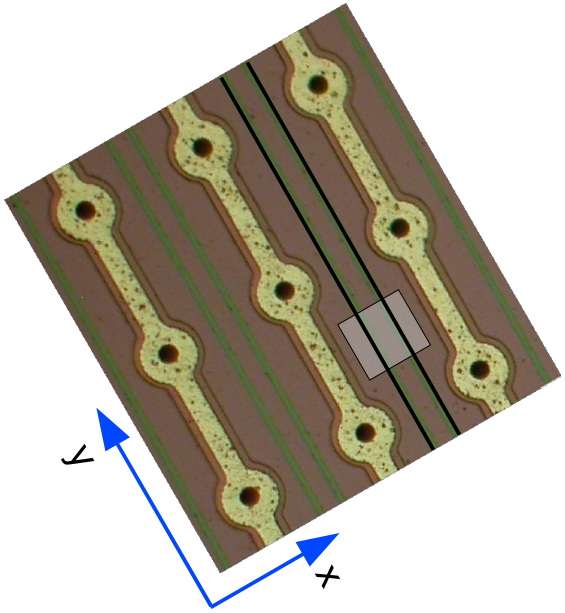
Interstrip region for the Cz p-spray sensor





- Region with lower CCE, but quite narrow ≈ 5µm
- Signal drops by ≈25% - 30%
- High resolution scan:
  - 2µm step size
  - 50µm×50µm area
  - *y*-axis along the strips
  - At variable bias voltage
- Width independent of bias for $V_{bias} > 25V$

CCE as a Function of Applied Bias Voltage for FZ p-stop



- Sensor unirradiated
- Lateral depletion around 12V
- Low CCE region width ≈ 13µm
  → larger than for p-spray (≈ 5µm)
- isolation affects the electric field