Test Beam and Laser Measurements With Irradiated 3D Silicon Strip Detectors

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Outline

- Test Beam Measurements
- Laser Measurements
- Noise Studies

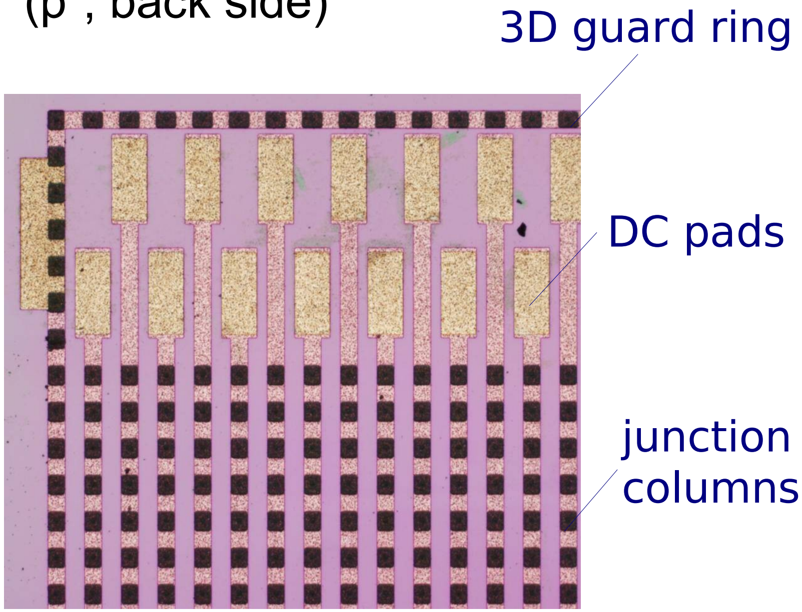
Double-Sided 3D Detectors

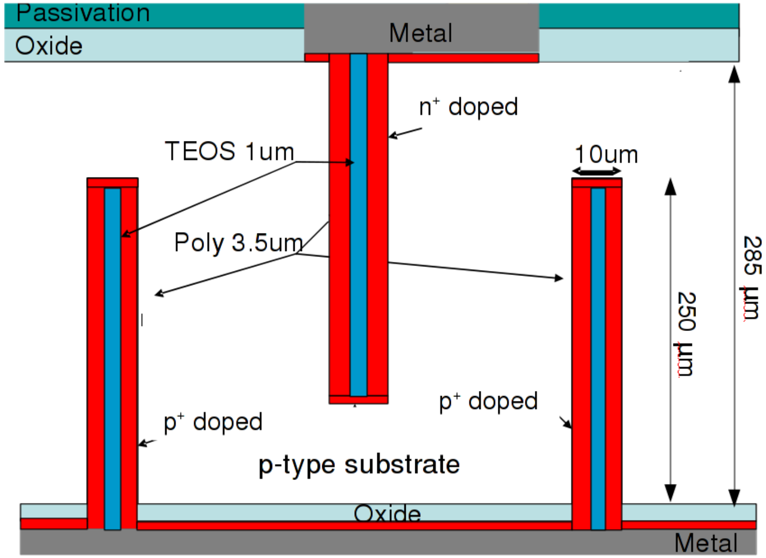
- CNM design:

  285 μm thick p-type or n-type FZ silicon

  250 μm deep junction columns (n^+, front side)

  250 μm deep Ohmic columns (p^+, back side)

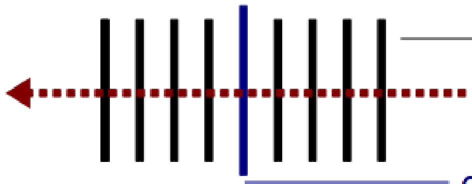




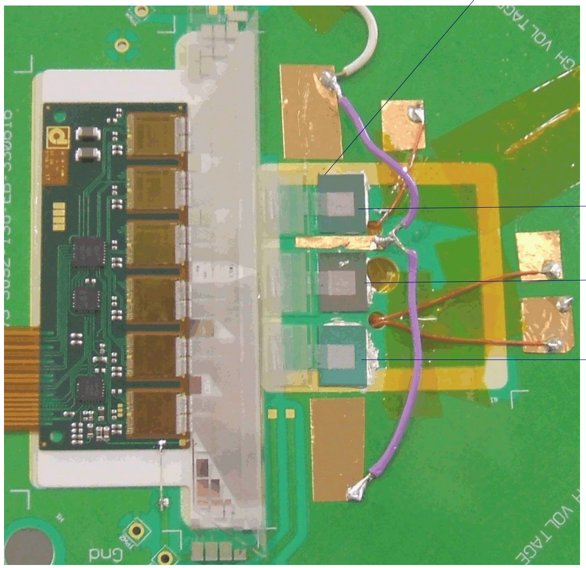
- Detectors irradiated at the proton cyclotron Karlsruhe with 25 MeV protons

Beam Test Setup

- CERN SPS, H2 beamline (225 GeV pions)
- Tracking provided by Silicon Beam Telescope (SiBT), Resolution ~4 µm

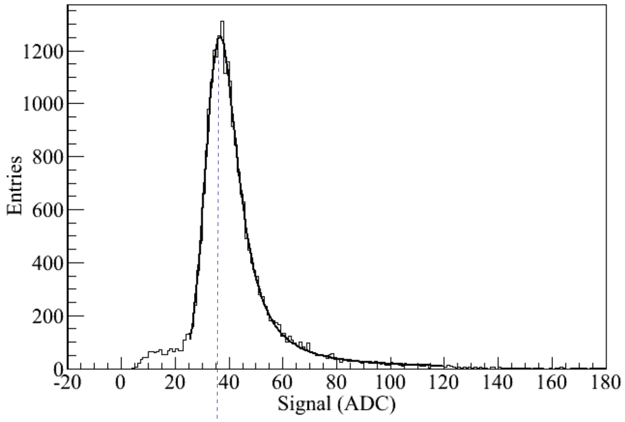


- DAQ: CMS hardware, APV25 front-end (analogue readout)



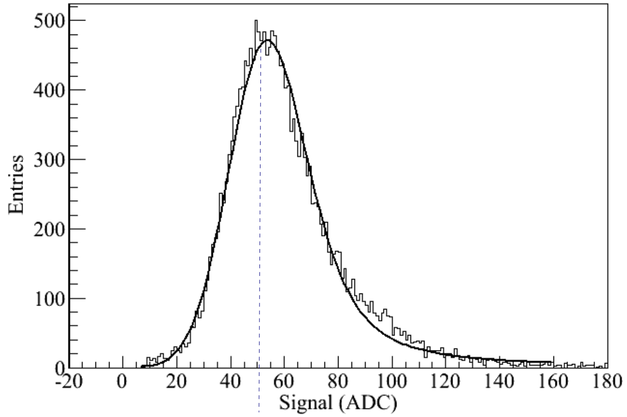
Signal Distribution

unirradiated, 70 V



Landau MPV: 35 ADC

irradiated ($1x10^{15}$ N_{eq}/cm^2), 200 V

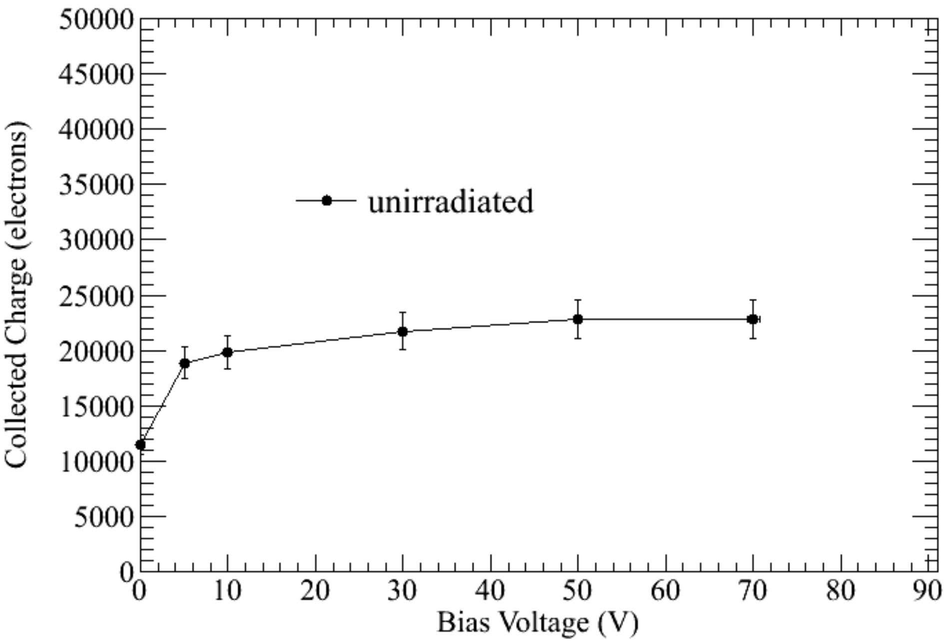


Landau MPV: 49 ADC

- Irradiated detector: higher signal, broader spectrum (also broadened by common mode noise, which could not be completely removed)
  - → Charge multiplication
- Entries at low signal values: tracks going straight through columns

Charge Collection Efficiency

- Landau Most Probable Value as a function of bias voltage



Charge Collection Efficiency

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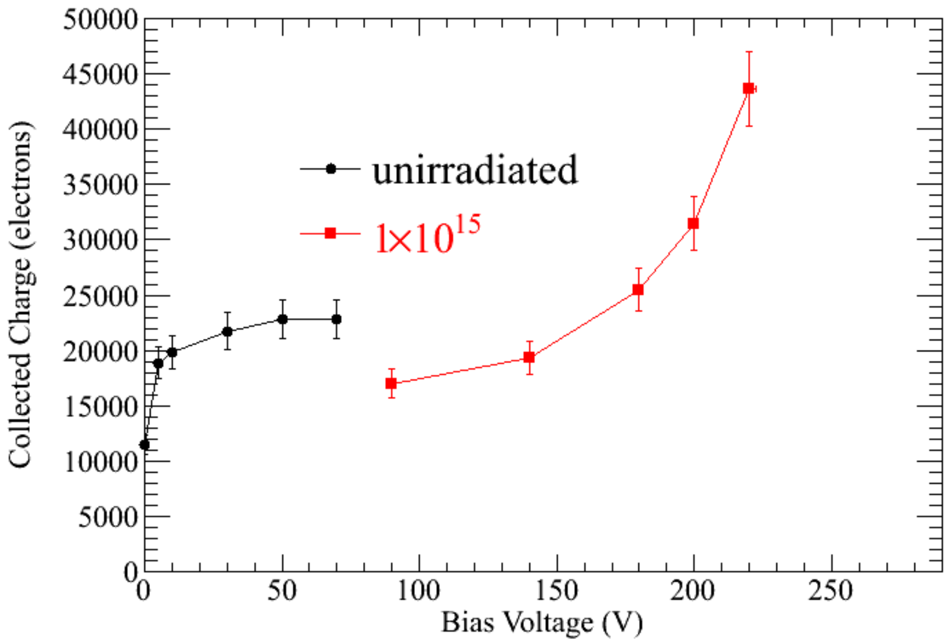
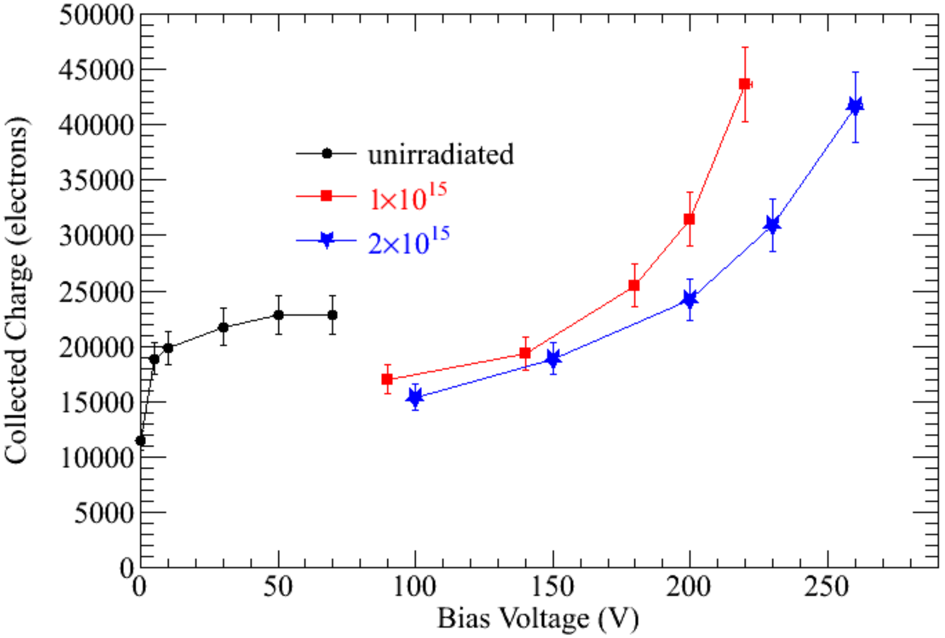


- Irradiated device: increasing signal above ~150 V
  → Charge Multiplication

Charge Collection Efficiency

- Landau Most Probable Value as a function of bias voltage



- Irradiated devices: increasing signal above ~150 V
  → Charge Multiplication

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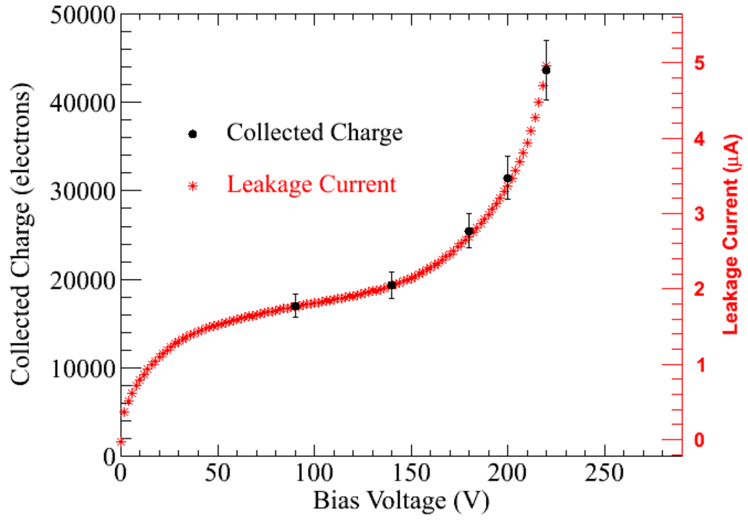
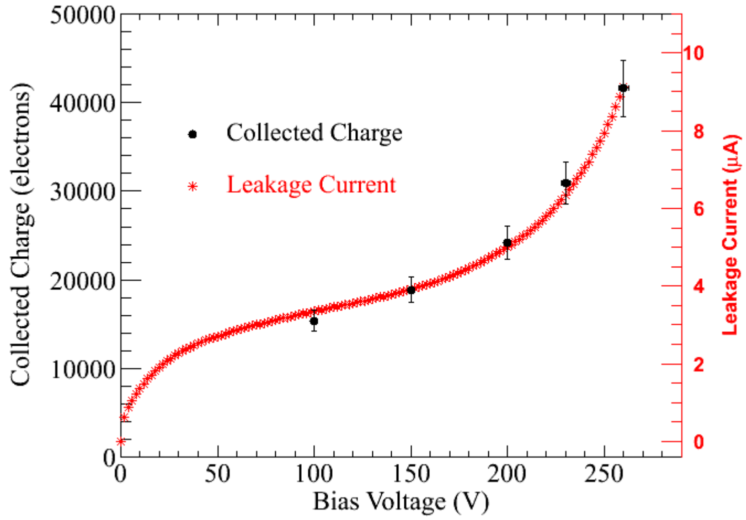
Signal and Leakage Current

- Superposition of collected charge and leakage current
  - Leakage current: guard ring current subtracted, measured at ~-20°C

$1x10^{15}\ N_{eq}/cm^2$



$2x10^{15}\ N_{eq}/cm^2$



- Multiplication also of charge carriers generated thermally

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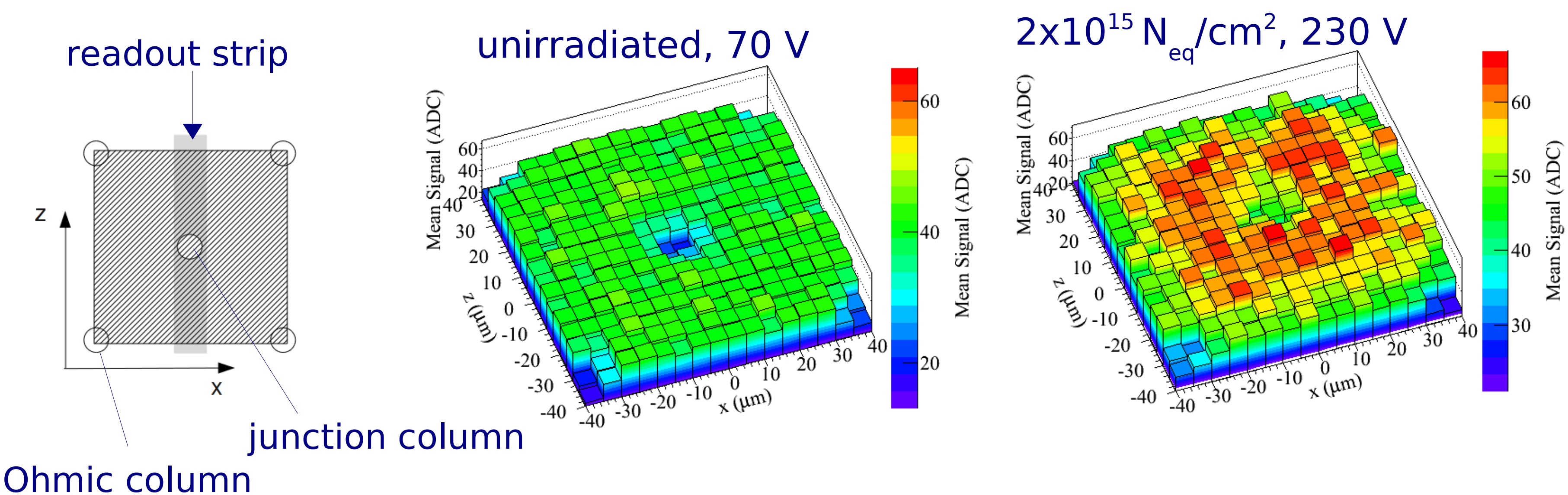
Mean Charge 2D

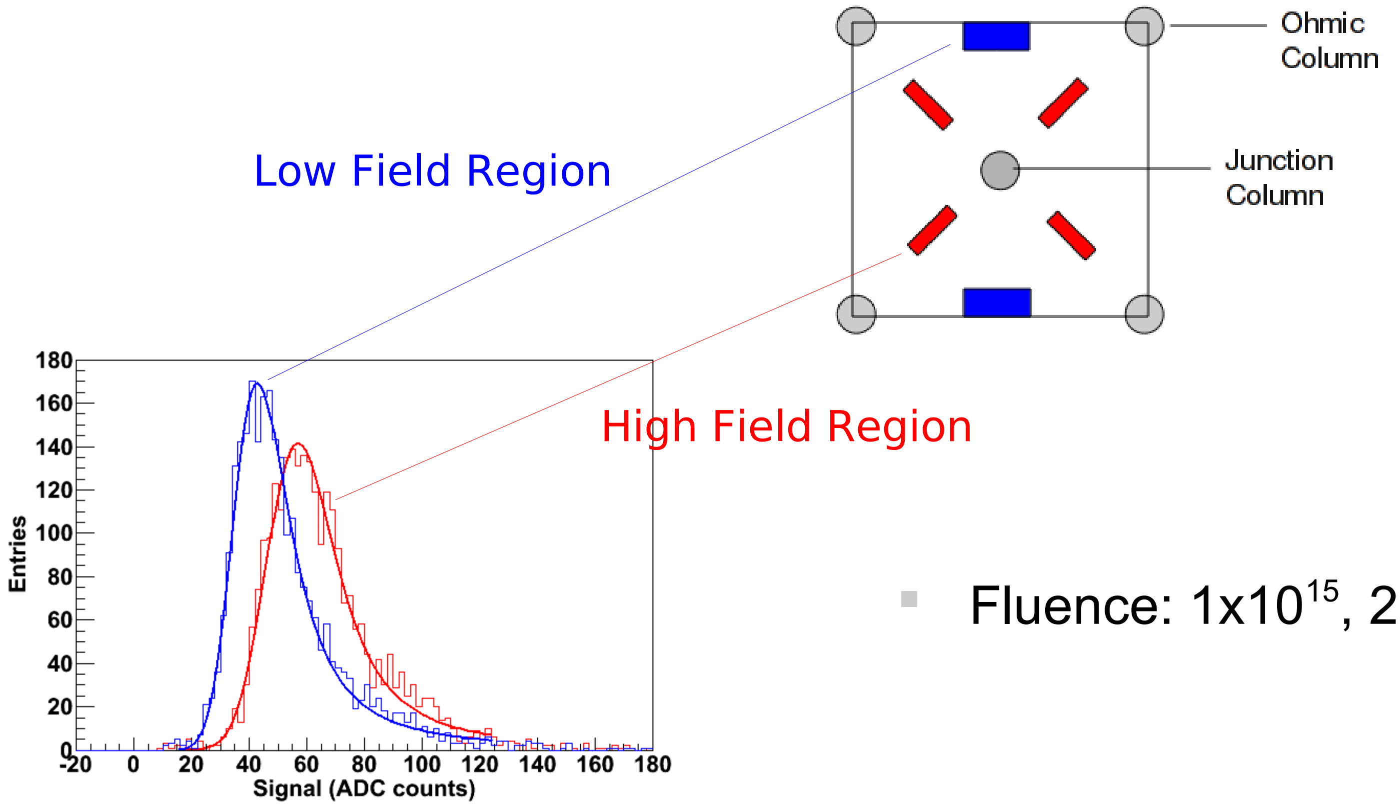
- Mean Signal (not Landau MPV!) superimposed onto unit cell
- Signals of strips around track impact point summed up



- Before irradiation: signal uniform (apart from column positions)
- After irradiation: higher charge multiplication for tracks close to junction column

High Field vs. Low Field

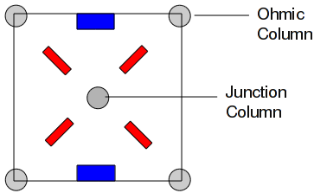
- Signal non-uniformity influenced by electric field variations
  - High field region: along line connecting junction column and Ohmic column
  - Low field region: between columns

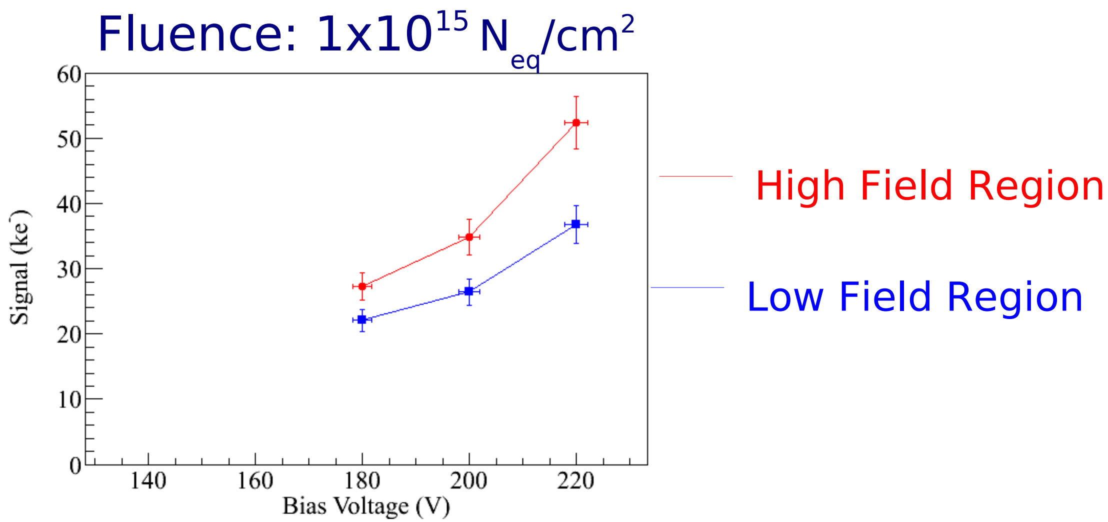


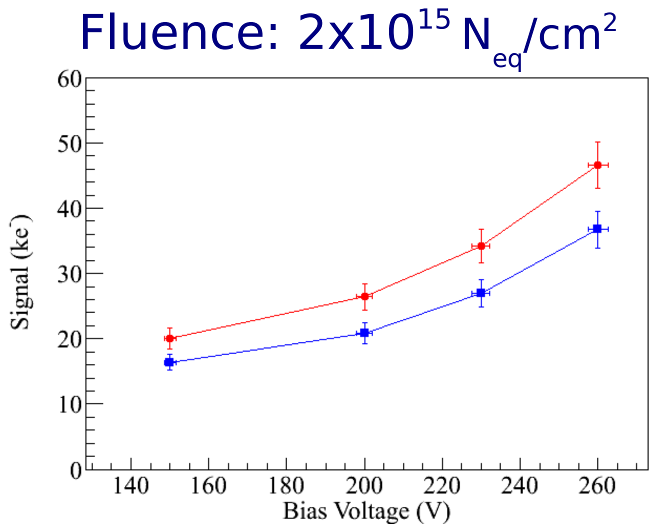
- Fluence: $1x10^{15}$, 200 V

High Field vs Low Field

- Landau MPV versus voltage for tracks in high field region and low field region



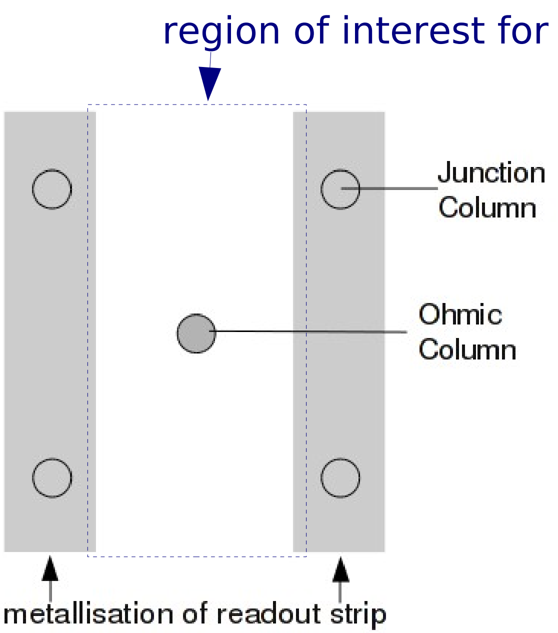


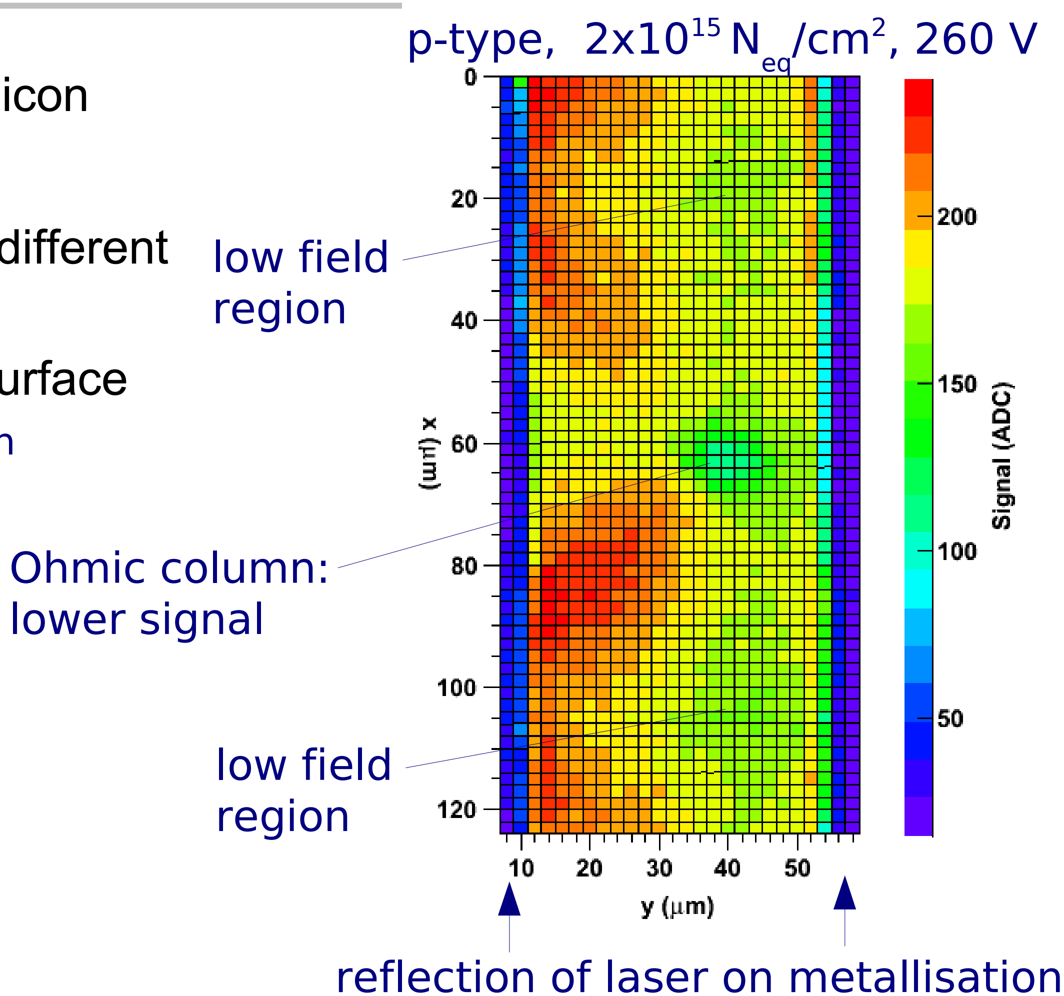


- Multiplication only in thin region around junction column
- Substantially higher signal in region with higher electric field
  - Influenced by different multiplication factors, trapping ...
  - Simulations needed to understand this behaviour quantitatively

Laser Measurements

- Infrared laser, 970 nm wavelength
  → Absorption length: 100 µm in silicon
- Readout: ALIBAVA system
- Relative signal measurements for different laser impact positions
  - Fine step scan of the sensor surface

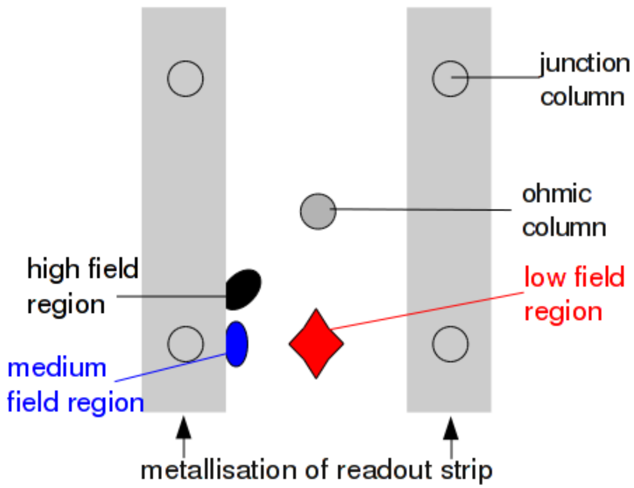


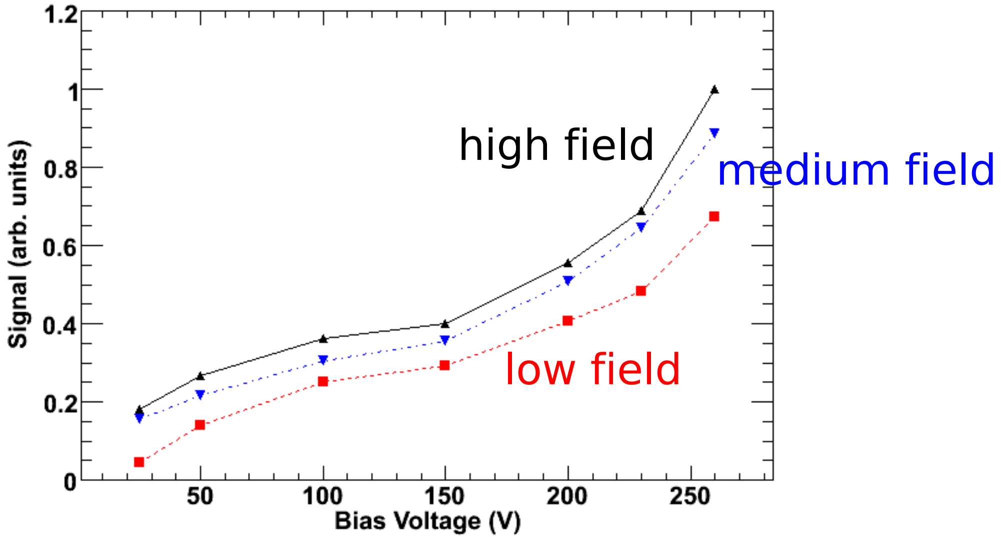


- Position of ohmic columns somewhat shifted from middle between strips

Laser: High Field vs. Low Field, p-type

- Investigate signal generated by laser impinging in different regions:
  high field, medium field, low field
- Here: p-type, $2\times10^{15}\ N_{eq}/cm^2$

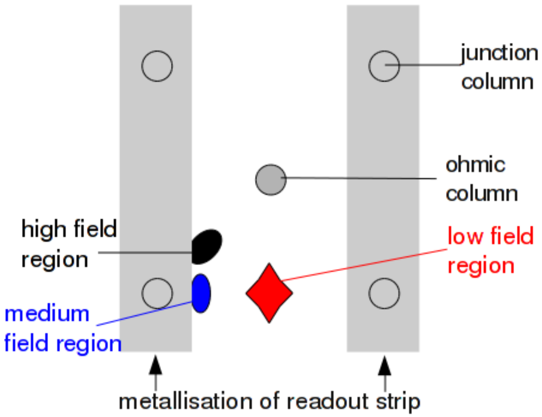




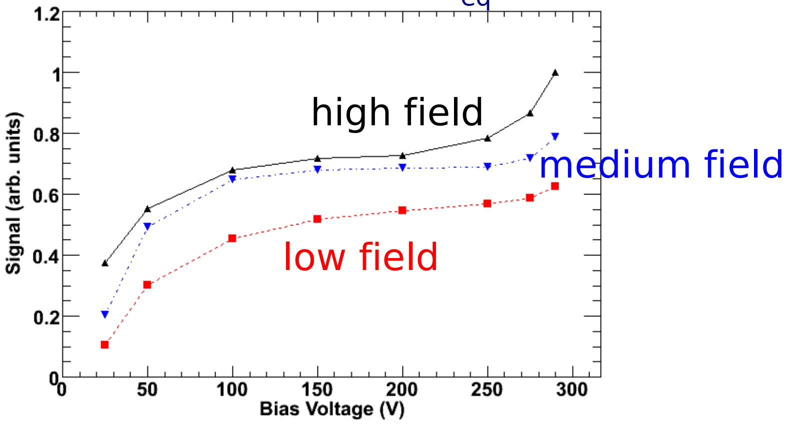
- Confirmation of test beam results: ~30% difference between high field and low field regions
- NB: only relative signal measured with laser, not absolute signal!

Laser: High Field vs. Low Field, n-type

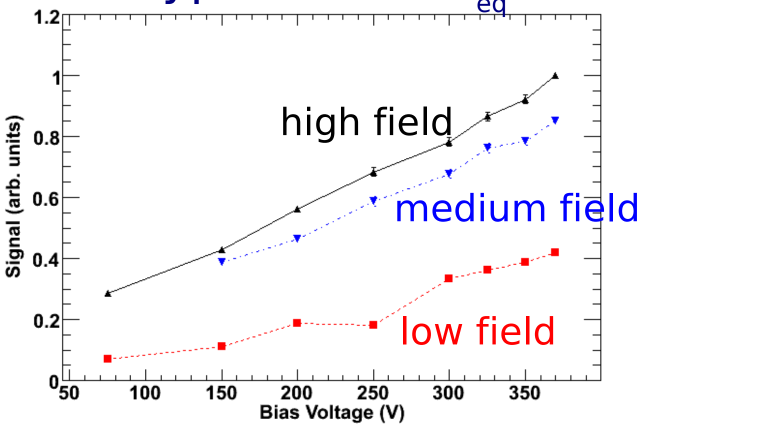
- Laser Signal in different regions, n-type detectors



n-type, 2×10^{15} N_{eq}/cm^2



n-type, 2×10^{16} N_{eq}/cm^2

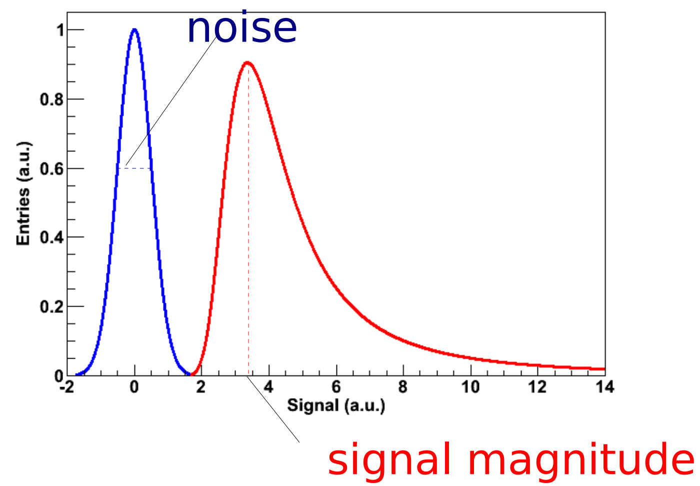


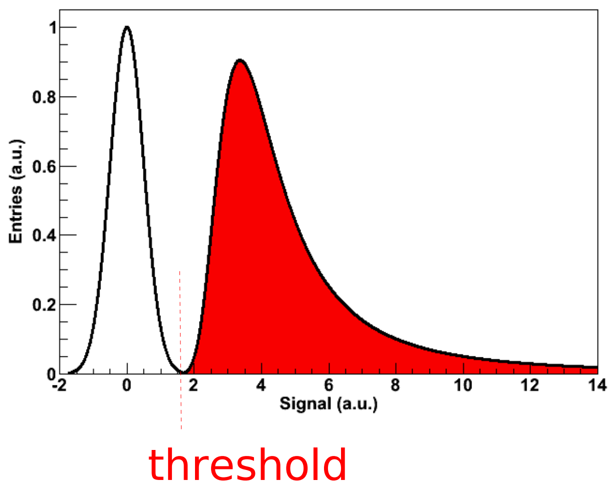
- At 2×10^{15} N_{eq}/cm^2: Charge Multiplication starting at ~250 V (p-type: 150-200 V)
- Signal non-uniformity increasing with fluence (trapping)

Noise

- Ideally: high signal, low noise

  → Signal-to-noise ratio is of importance





In binary systems (as used in ATLAS tracking detectors): signals above a certain threshold are registered

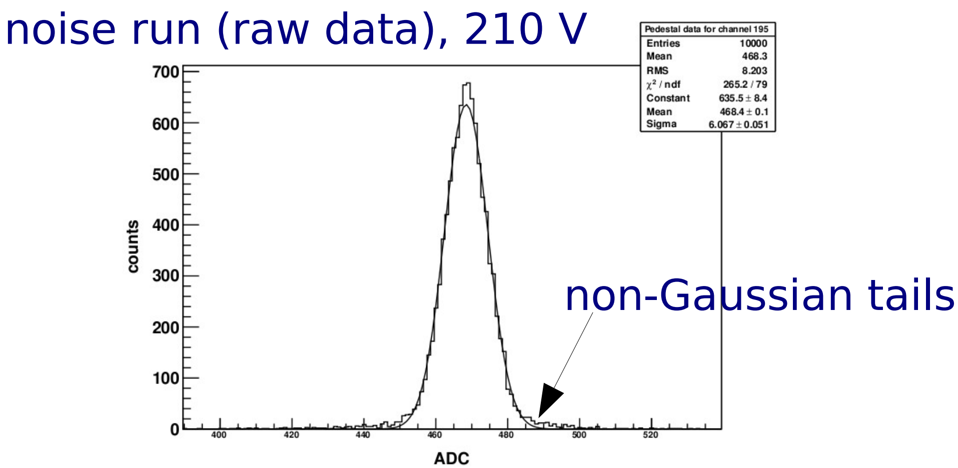
- Threshold must be high enough to suppress noise events: noise occupancy must be limited

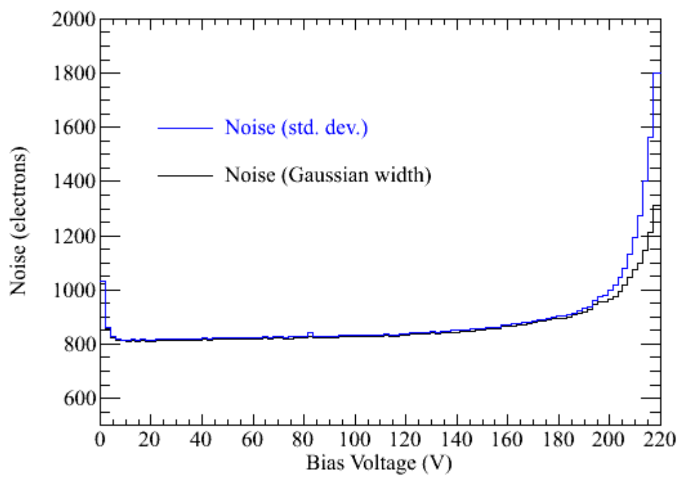
→ Signal-to-threshold ratio might be a better criterion

How does charge multiplication influence the noise?

Noise Measurements

- Noise Measurements:
  - p-type, 1x10^{15} Neq/cm^2 (charge multiplication starting at ~ 150 V)
  - Measured with ALIBAVA readout system





- Charge multiplication: noise is non-Gaussian, pointing to micro-discharge
- Steep noise increase with charge multiplication
- Definition of noise is important - at high bias voltages: noise determined from standard deviation is much higher than Gaussian noise

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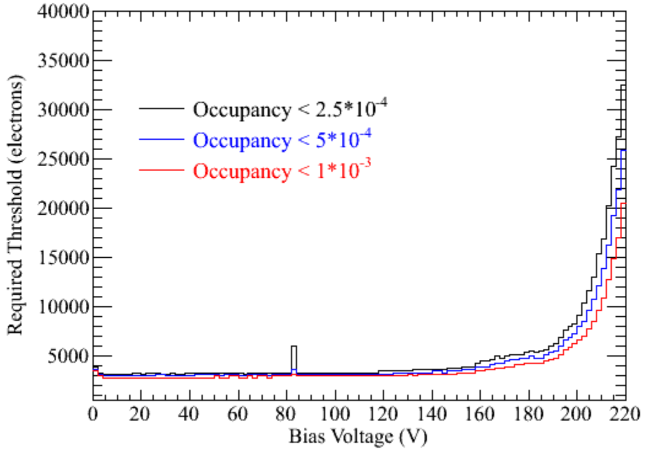
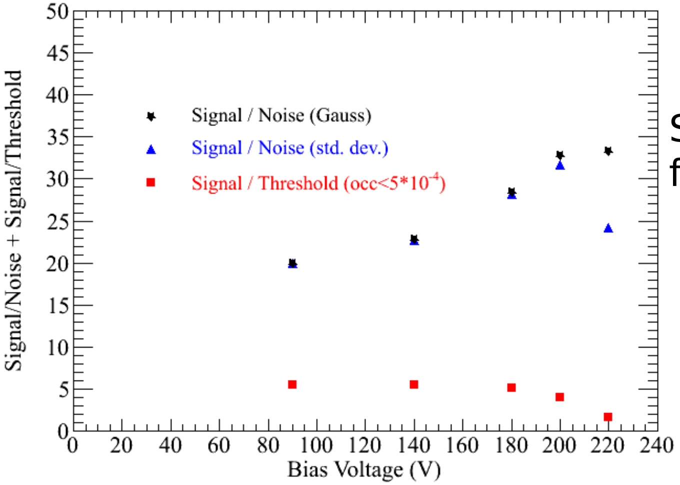
Signal-to-Noise, Signal-to-Threshold ($1x10^{15}$)

- p-type, $1x10^{15}$ N_{eq}/cm^2, T=-20°C
- Threshold (required to keep the noise occupancy below a certain limit) must be increased strongly when charge multiplication is present

threshold required to keep noise occupancy below a certain limit



signal-to-noise ratio, signal-to-threshold ratio



Signal taken from test beam

- Here: charge multiplication is
  - Beneficial, if signal / noise is figure of merit
  - Not beneficial, if signal / threshold is figure of merit

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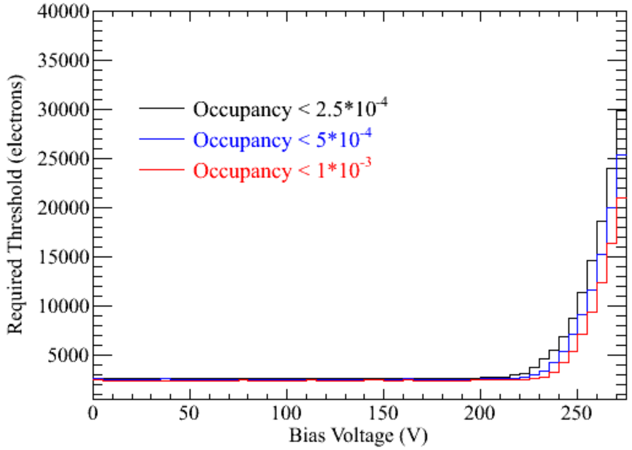
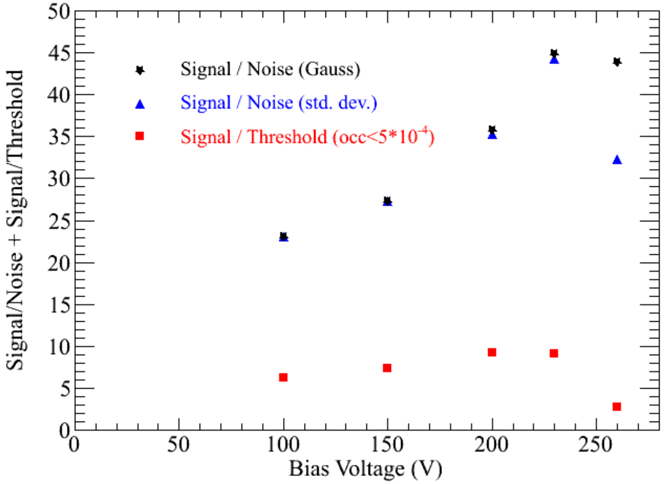
Signal-to-Noise, Signal-to-Threshold ($2x10^{15}$)

- p-type, $2x10^{15}$ Neq/cm^2, T=-26°C

threshold required to keep noise occupancy below a certain limit



signal-to-noise ratio, signal-to-threshold ratio



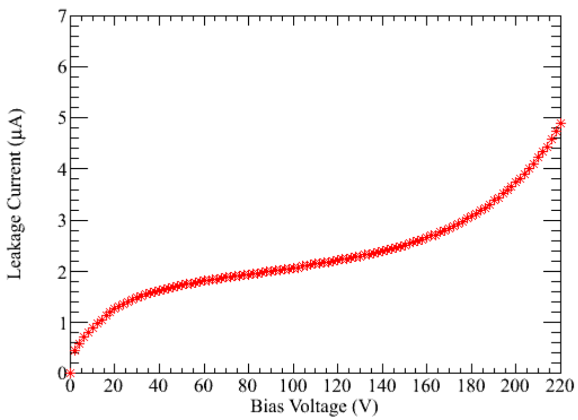
Signal taken from test beam

- Noise increase starting at higher voltages than for detector irradiated to $1x10^{15}$ Neq/cm^2
  - Charge multiplication beneficial for Signal / Threshold and Signal / Noise up to certain point
  - Variations from sensor to sensor? Influence from different temperature?

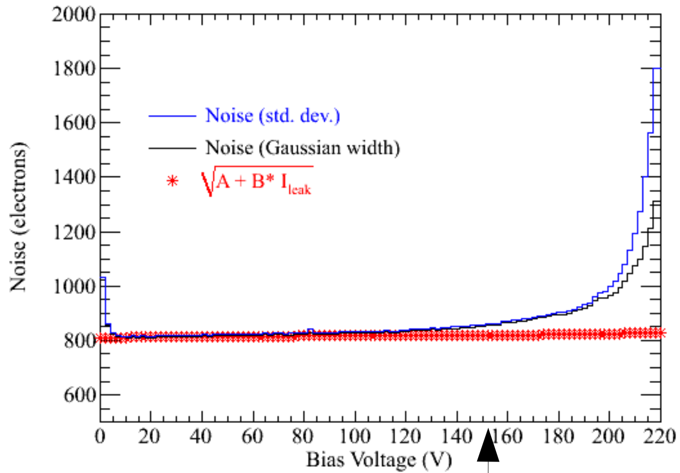
Noise Modelling

- Fluence: $1x10^{15}$ Neq/cm^2
- Steep noise increase is not caused by shot noise

leakage current (all strips)



noise measured and noise calculated using shot noise parameterisation



$A=(807\ e^-)^2$

$B=107^2*t_S/N_{Strips}$

~150 V: beginning of charge multiplication

- Contribution of shot noise is marginal

  → Additional excess noise at presence of charge multiplication (influence of varying multiplication)

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Conclusion

- Charge multiplication measured with double-sided 3D strip detectors

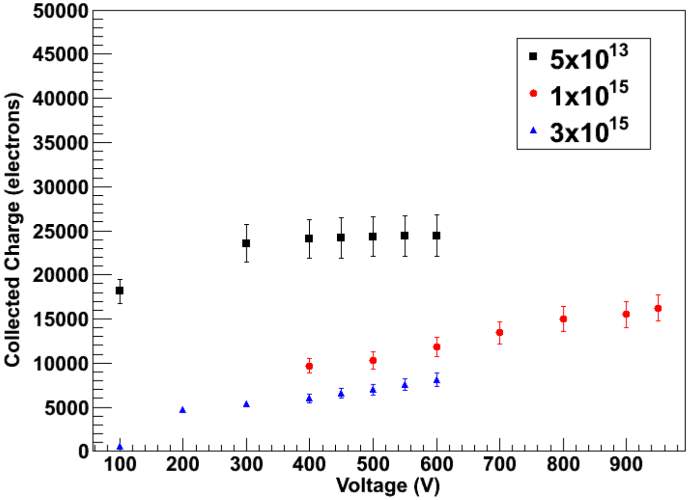
- Space-resolved studies: charge multiplication in thin region around junction column, signal non-uniform
  - Simulations needed to model the behaviour

- Strong noise increase at presence of high charge multiplication
  - Signal-to-noise ratio and signal-to-threshold ratio can be increased, but are decreased at very strong charge multiplication

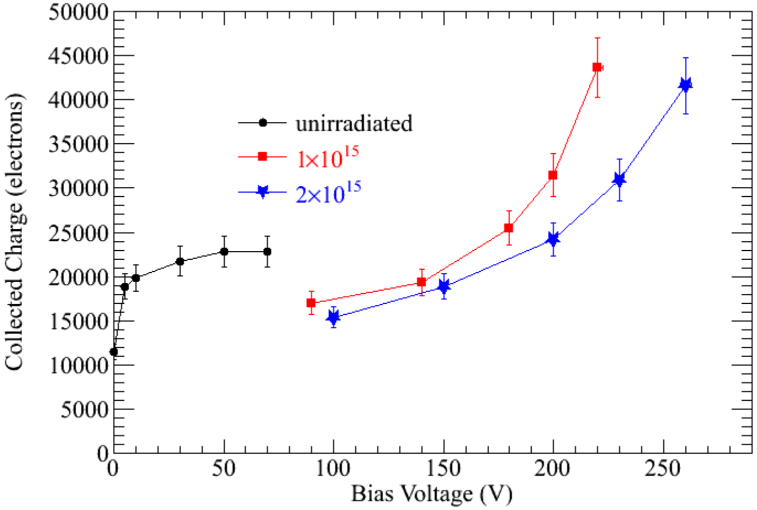
Planar vs. 3D Detectors

- Planar p-type silicon strip detectors were measured in the same test beam

planar detectors (320 µm thick)



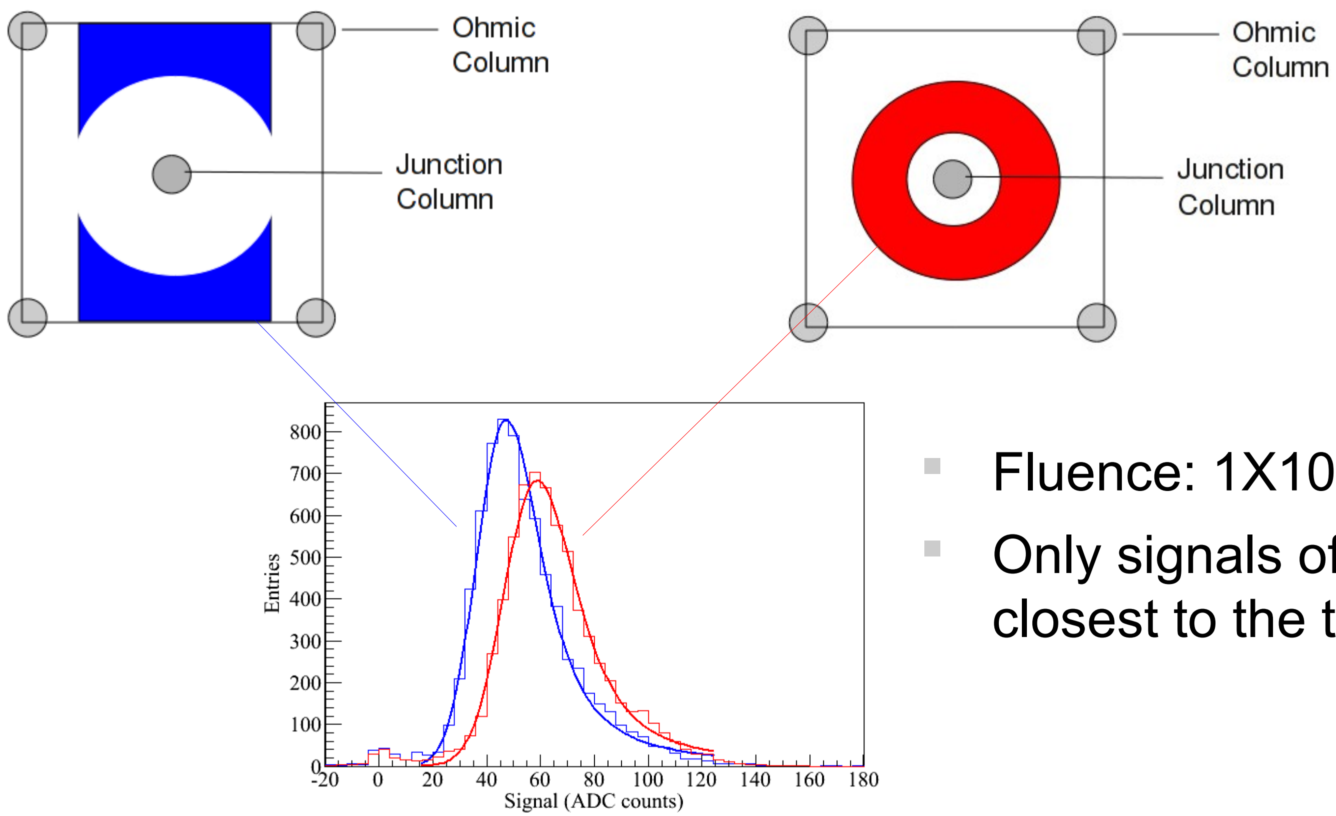
3D detectors (285 µm thick)



- Higher signal measured with irradiated 3D detectors due to early onset of charge multiplication
- NB: This only refers to signal, noise must be considered separately!

High Radius vs Low Radius

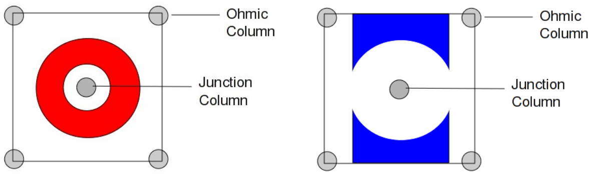
- Signal from tracks impinging on different regions within the unit cell:
- High radius
- Low radius



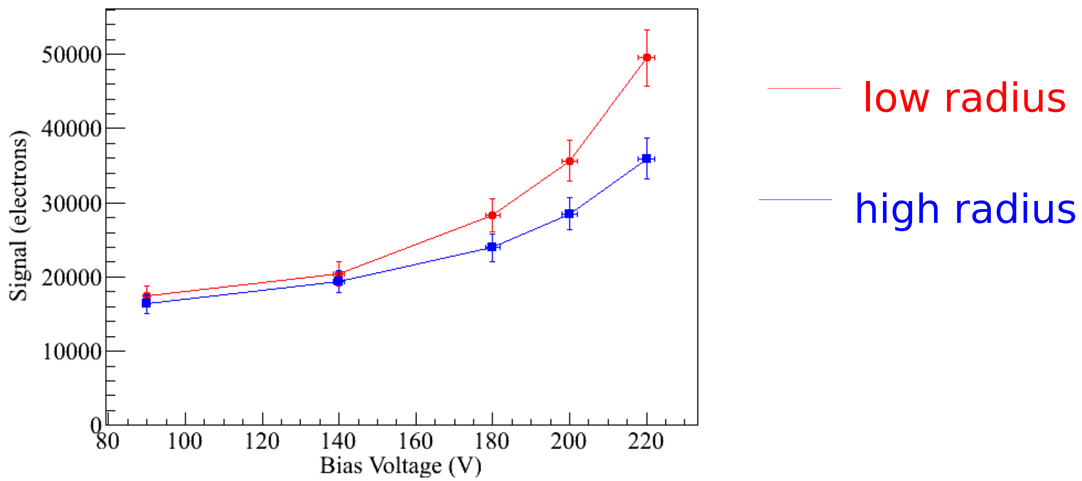
- Fluence: 1X10^{15}, 200 V
- Only signals of the strip closest to the track used

High Radius vs Low Radius

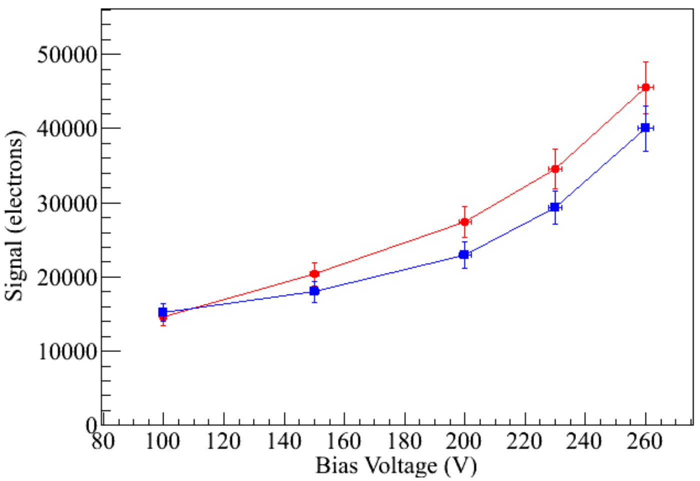
- Landau MPV versus voltage for tracks near junction column and far from junction column



Fluence: $1X10^{15}$



Fluence: $2X10^{15}$



- Lower signal from tracks impinging far from junction column
- To what extend caused by trapping? Simulations needed!
- Apparently: charge multiplication, when charge carriers drift through thin region around junction column