

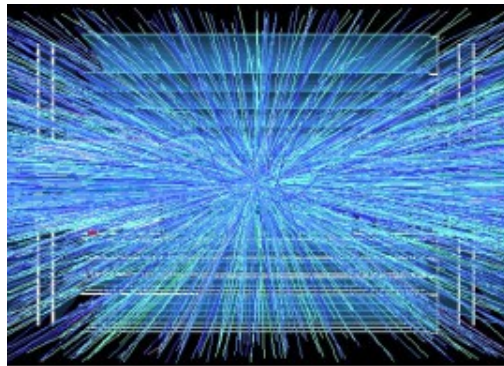
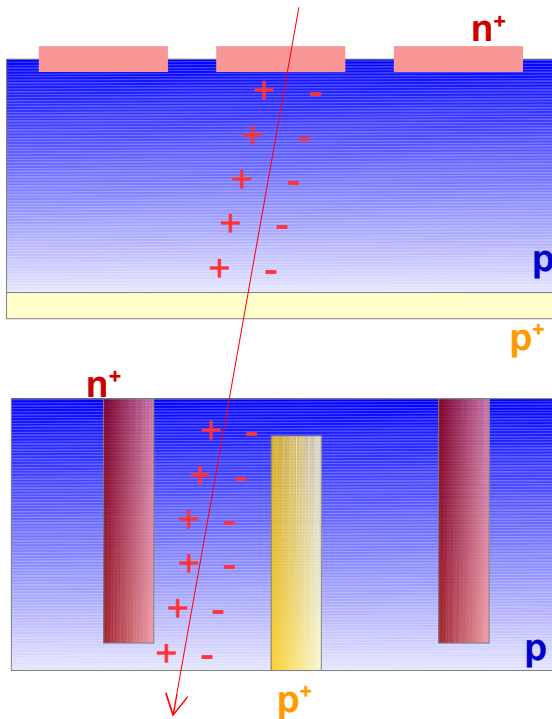
TCT Measurements on 3D Small Pitch Strip Detectors

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Introduction – 3D detectors in ATLAS



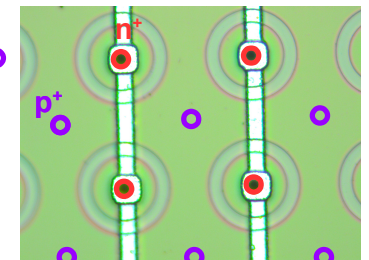
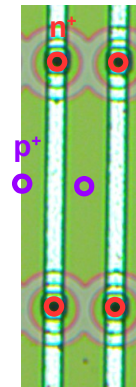
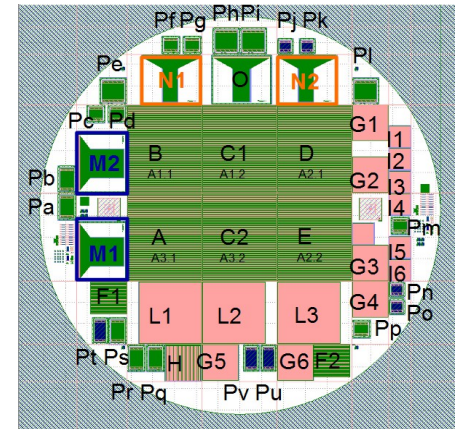
HL-LHC event at ATLAS

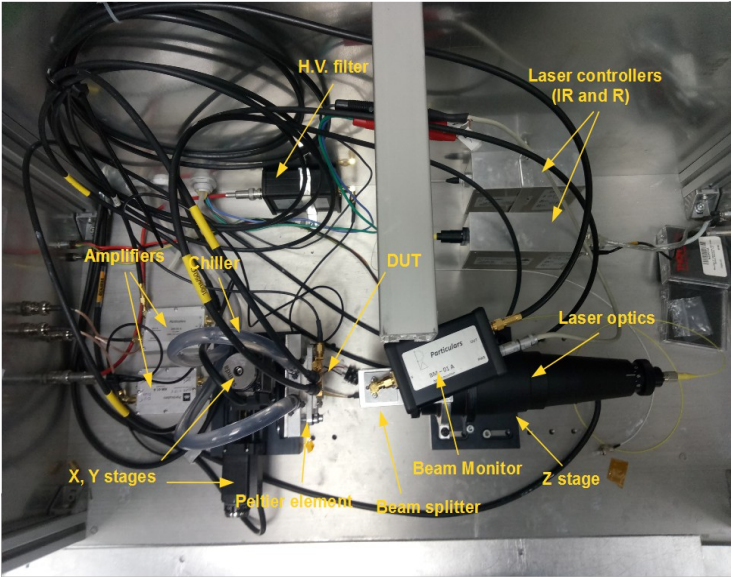
- **3D devices** have penetrating n^+ and p^+ columns acting as electrodes, in contrast to the planar technology
 - Allows lower electrode distance while keeping large thickness
 - Smaller region to deplete allows **low operation voltage** i.e. **low power dissipation**
 - The smaller drift distance reduces the probability of trapping and, hence, **radiation hardness** is improved
- The future **HL-LHC** upgrade of the ATLAS detector is scheduled for 2023
 - The 3D technology is a promising candidate for the innermost pixel layers
 - **Radiation hardness** is needed up to $2 \cdot 10^{16} n_{eq}/cm^2$
 - Also **small pixel sizes** are critical to cope with the high particle occupancy
 - IBL/AFP pixel size: $50 \times 250 \mu m^2$. HL-LHC size: **$50 \times 50 \mu m^2$** or **$25 \times 100 \mu m^2$**
- The first production of 3D devices with small pitch (or pixel size) fabricated in CNM were studied with TCT before and after irradiation

TCT measurements – List of measured samples

- Two geometries studied: **25x100 μm^2** and **50x50 μm^2**
 - CNM run 7781 – RD50 project
 - Wafer thickness: **230 μm**
 - Al contact width: **8 μm**
 - Non-fully passing-through 3D columns ($\phi = 8 \mu\text{m}$)
- 3 samples for each geometry:
 - 1 unirradiated
 - 1 irradiated at $5 \cdot 10^{15} n_{\text{eq}}/\text{cm}^2$
 - 1 irradiated at $1 \cdot 10^{16} n_{\text{eq}}/\text{cm}^2$

} Irradiated with **neutrons** at **Ljubljana!**
- PCB designed by DESY & Hamburg university
 - 2 readout strips, neighboring strips grounded
- Charge collection studies with TCT presented
- CCE calculated comparing the performance of irradiated samples with its unirradiated version (assuming same absorption coefficient in all samples)



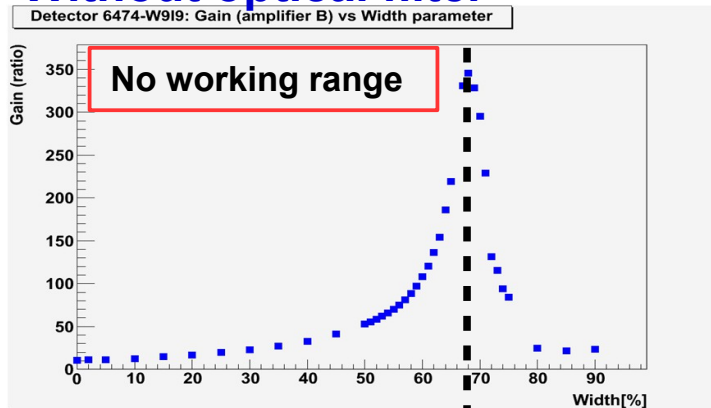


- IR laser
- Beam splitter based BM system (BM-02A)
- Particular's amplifier (AM-01)
- Cooling through peltier
 - T set to -10°C
- Readout through DRS4 board:
 - **Channel 1/2:** readout
 - **Channel 3:** beam monitor
 - **Channel 4:** trigger

TCT setup challenges - Amplifier

- AM-01 amplifier characterized using a planar diode:
 - Compared TCT measurements with and without using amplifier at different amplitudes – Gain calculated from amplitude ratio
 - Full saturation at 900 mV
 - But gain affected already starting at 250 mV

Without optical filter



250 mV

High intensity

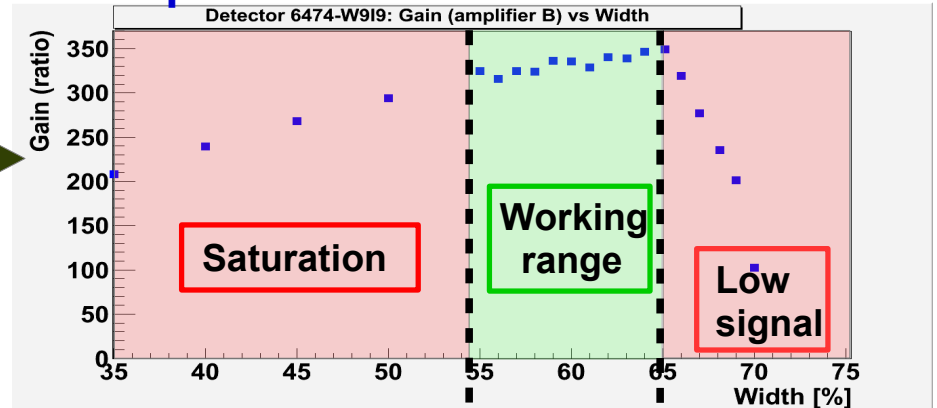
Low intensity

Solution

Reduce laser intensity to keep signals below 250mV (use filter if needed) or, if signals are large enough, not use amplifier

However, no space for beam splitter and optical filter!

With optical filter

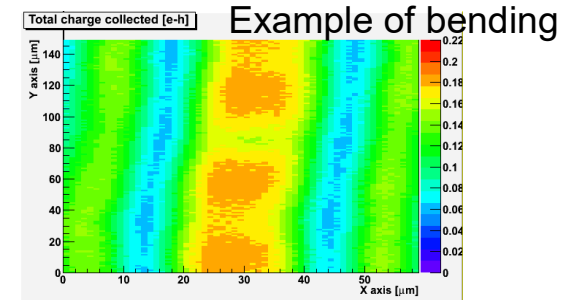
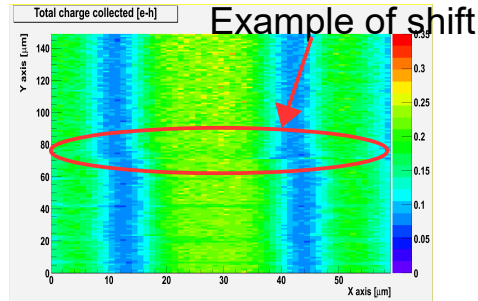


250 mV

100 mV

TCT setup challenges – Stages

- Shifts and random bending observed in some of the 2D maps

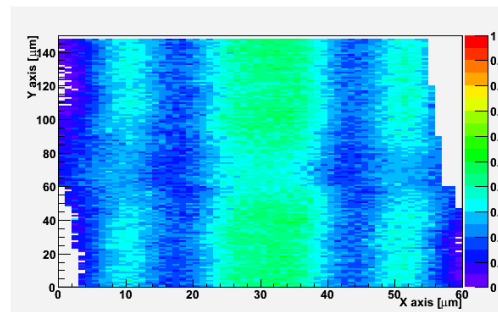
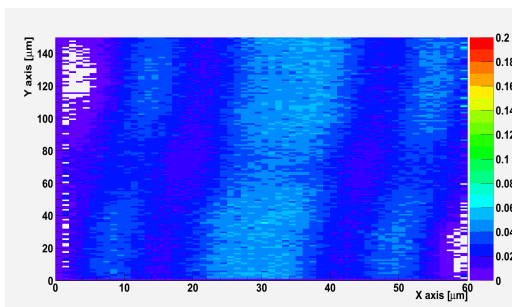


- Several tests performed to disentangle mechanical and stage controller issues
 - Scanning **same line/row** several times using **different stage controllers**
- Conclusion: Shifts due to stage controllers and bending due to a mechanical problem of the Y stage

Solution

Offline correction: $\text{Offset} = (a * y * y + b * y)$

offset obtained fitting a 2nd degree polynomial through 3 points in the Y direction

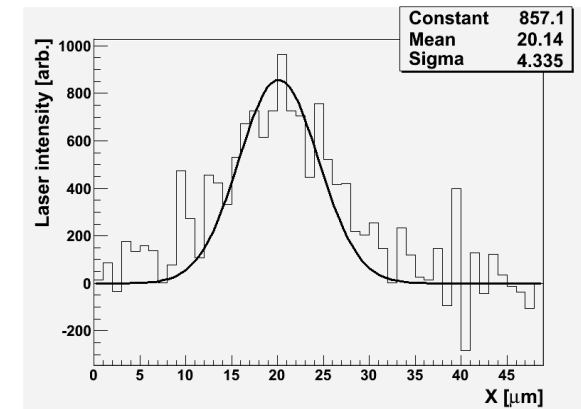
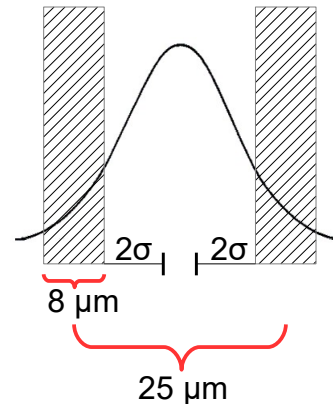


TCT setup challenges – 3D small pitch strip sensors

- Laser spot: gaussian width $\sigma > 4 \mu\text{m}$



Same order than strip distance
in $25 \times 100 \mu\text{m}^2$ sensors



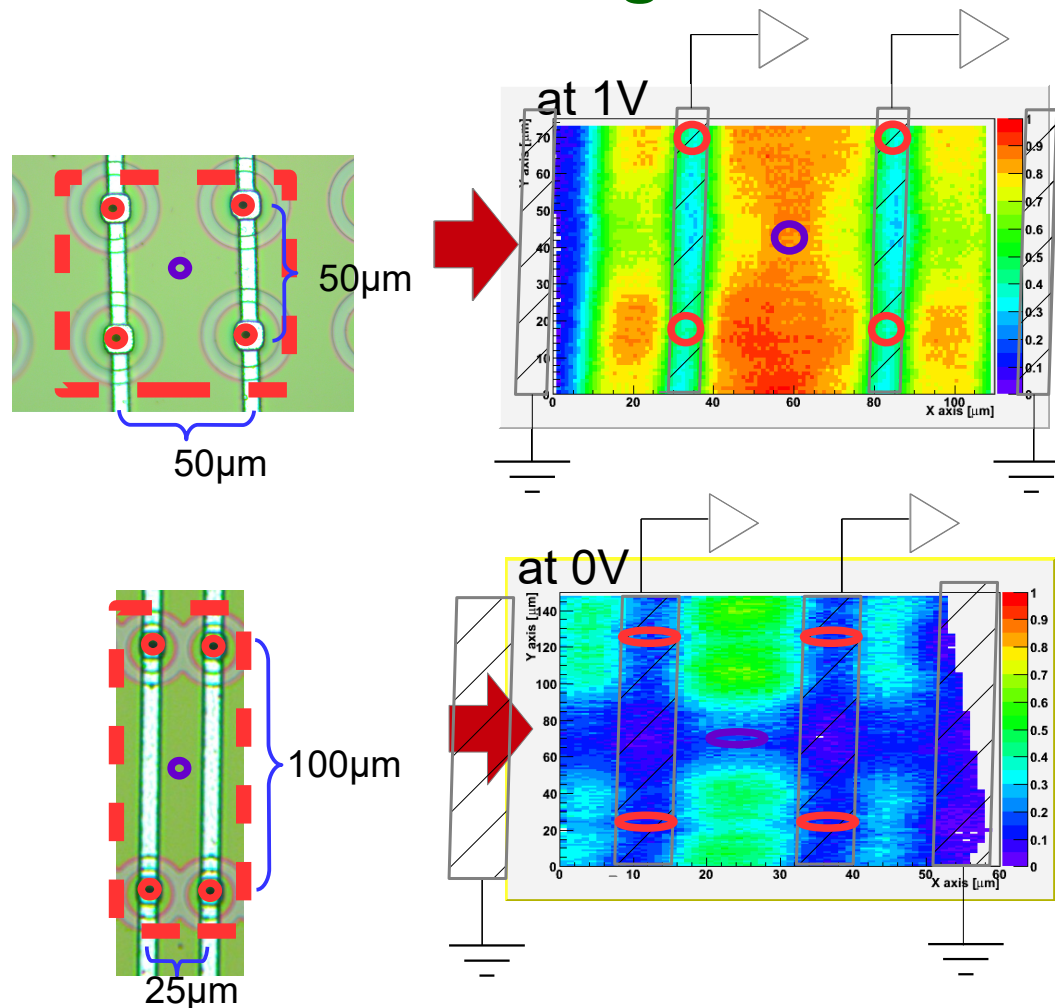
There is only a region of $1 \mu\text{m}$ such that 95% of the light is contained within the two strips (assuming $\sigma = 4 \mu\text{m}$)

- Changing the position/orientation of the optical fiber may uncorrelate the DUT and BM signals (see Emanuele's talk) – Laser position had to be kept fixed during all the measurements



Laser beam may be slightly unfocused in some measurements

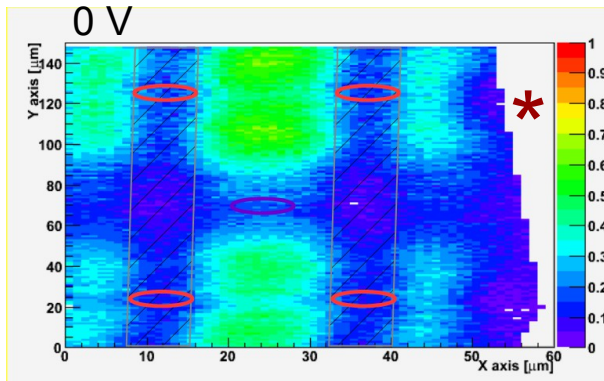
TCT measurements – Charge collection studies



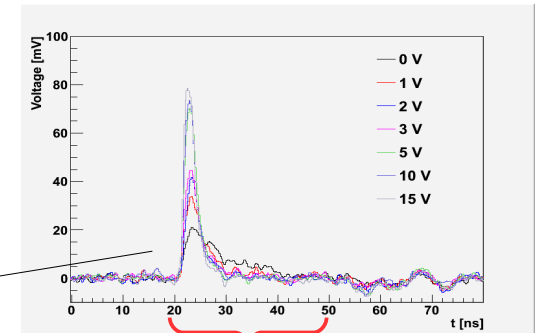
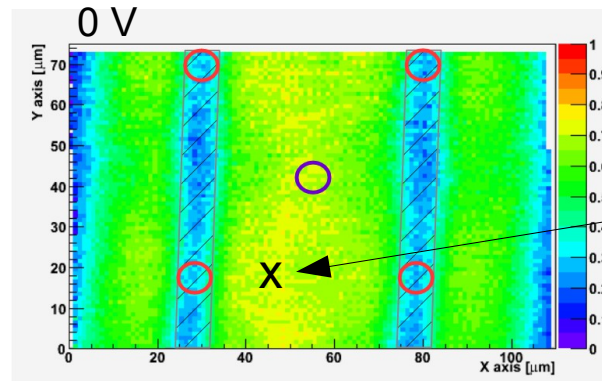
- 2D scans of **systematic regions** ($1.5 \cdot y_{\text{pitch}} \times 2 \cdot x_{\text{pitch}} + 10 \mu\text{m}$) at **different bias voltages**
- Position of **n⁺ columns** assumed on the region where **more charge** is collected **at 0V**
- Charge collected from **both readouts added** and **normalized to BM integral**

TCT measurements – Unirradiated samples

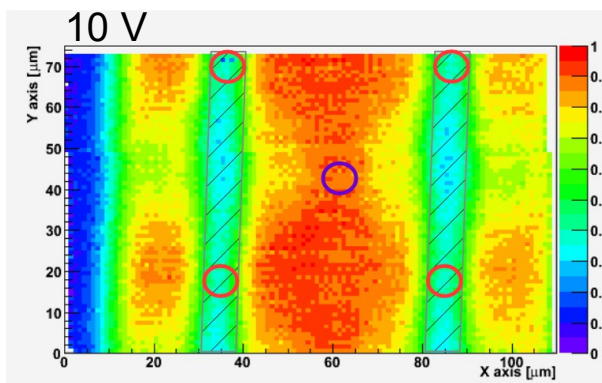
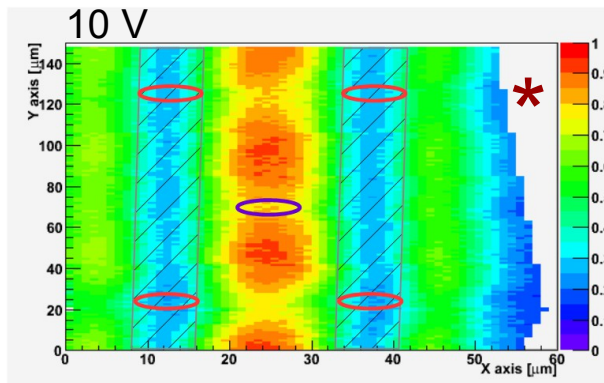
25x100 μm^2 :



50x50 μm^2 :



Integration window

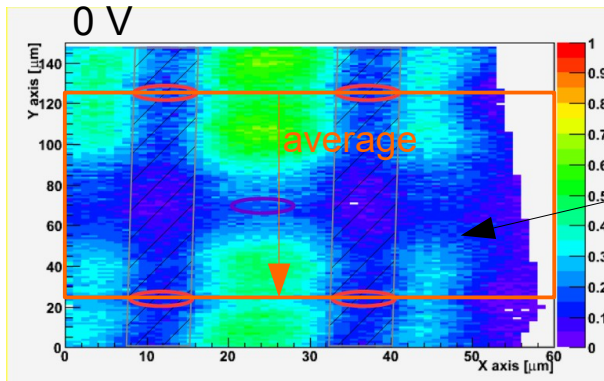


* White bin region due to offline correction of artificial bending caused by stage controller issue

- 2D maps normalized at different scales! → maximum charge in each geometry (0.126 in 25x100 μm^2 and 0.196 in 50x50 μm^2)
- Even at 0 V, charge collected near the n^+ columns
- As the voltage is increased, the depletion region (charge collection) around the n^+ columns increases

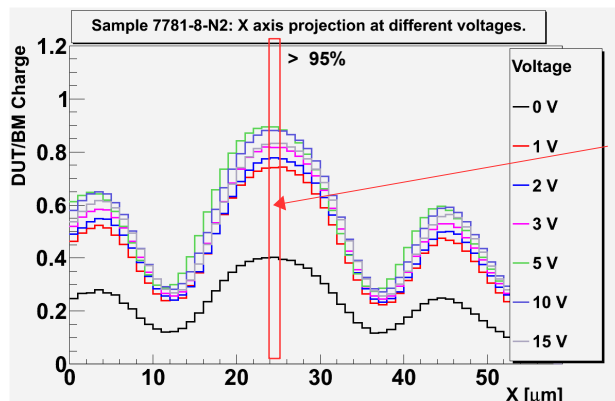
TCT measurements – Unirradiated samples

- Some information is extracted from 1D projections

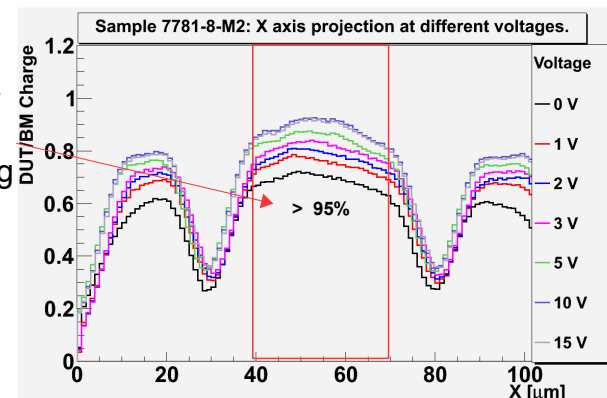


Analogous region for 50x50

Comparison of both geometries through the point that has less impact of the strips in 25x100 μm^2 geometry



Theoretical laser intensity plateau regions assuming $\sigma = 4 \mu\text{m}$



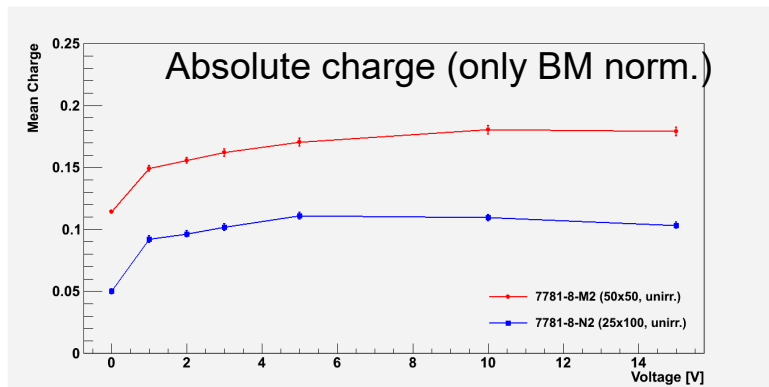
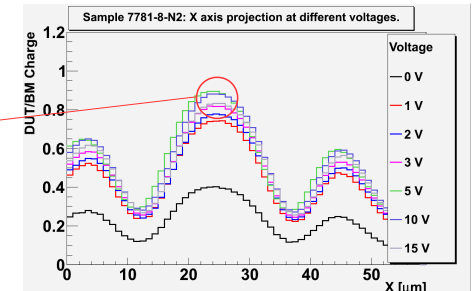
- Due to width of the laser beam ($\sigma \geq 4 \mu\text{m}$) there is a region with less charge collected near the strips **→ Dramatic in 25x100 μm^2 geometry!**
- In 25x100 μm^2 , plateau region is highly focus dependent – With best focus achieved, only 1 μm is illuminated with 95% of the laser spot in the region within strips
- In 50x50 μm^2 this effect is less relevant

TCT measurements – Unirradiated samples

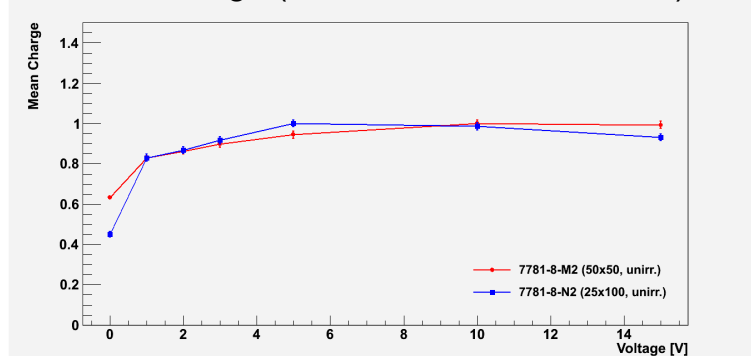
- Comparison of geometries is difficult due to the different impact of the laser width on both geometries



Use point less affected by strips and laser width



Relative charge (50x50/0.18, 25x100/ 0.11)



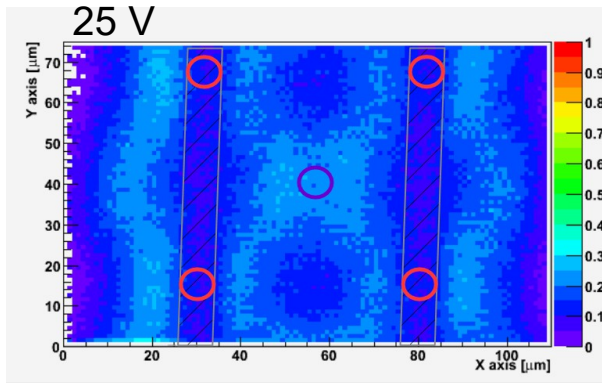
- 40% difference in absolute charge collected!
- Very small depletion voltage (~ 5 V) in both samples
- Large charge collected at 0V ($\sim 40\%$ in $25 \times 100 \mu\text{m}^2$ and $\sim 60\%$ in $50 \times 50 \mu\text{m}^2$)
- Included uncertainty due to BM fluctuations



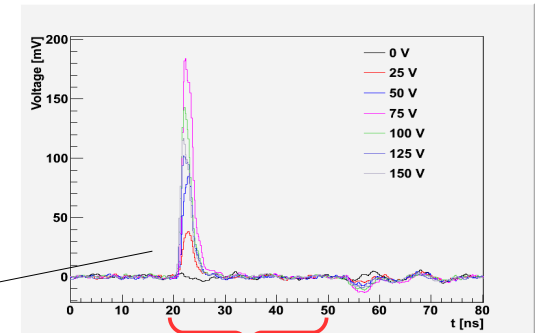
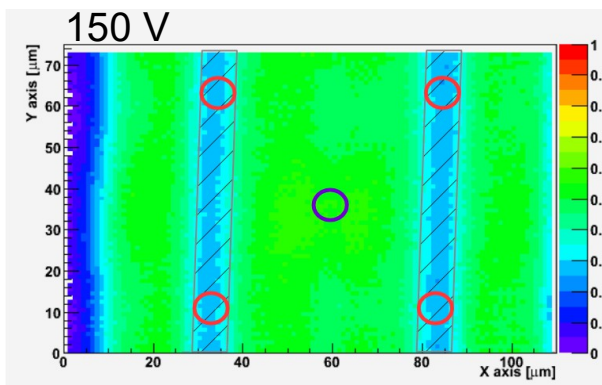
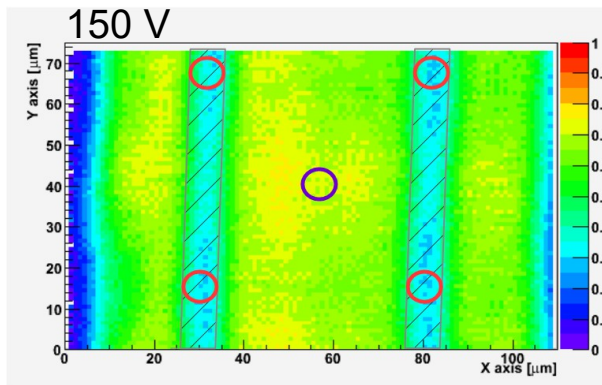
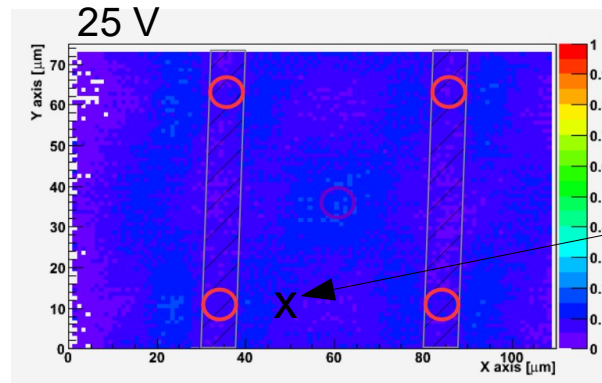
Needs cross-check with radioactive sources

TCT measurements – 50x50 Irradiated samples

$5 \cdot 10^{15}$:



$1 \cdot 10^{16}$:



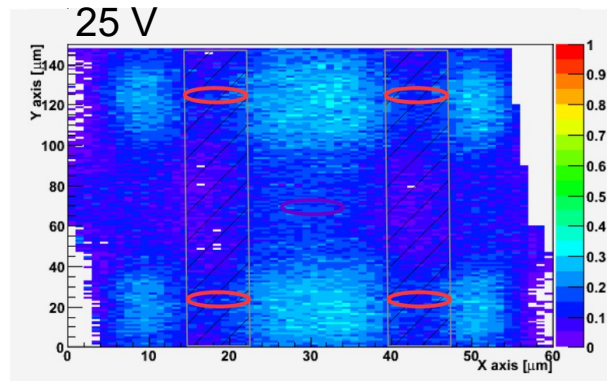
Integration window

Scaled to maximum charge in unirradiated device (0.196)

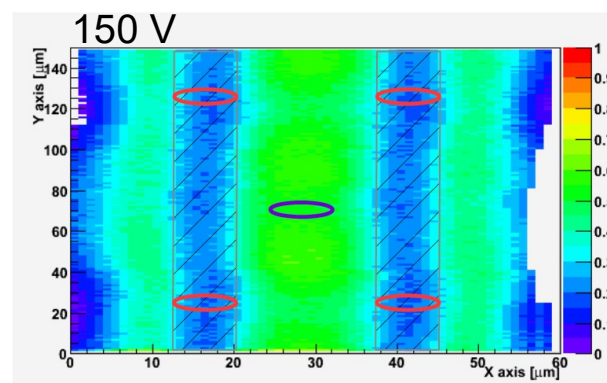
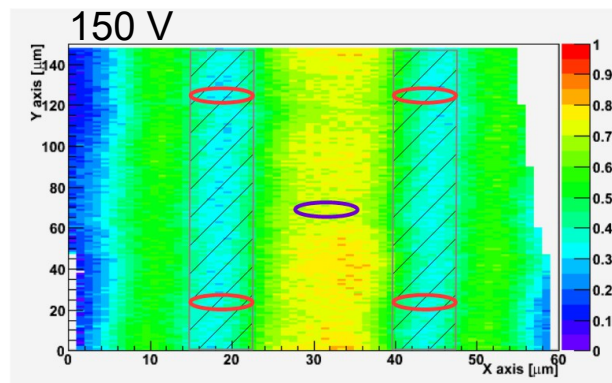
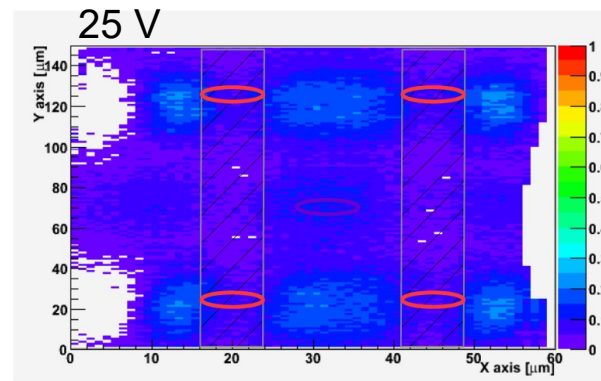
- Similar regions than in unirradiated device
- At 0V no charge collected in both irradiation fluences – Trapping effects are dominant
- At 25 V charge is collected in the stronger field regions
- At 150 V a mostly uniform charge collection region is observed
- The effect of the radiation fluence is evident (less charge in $1E16 n_{eq}/cm^2$ device)

TCT measurements – 25x100 Irradiated samples

$5 \cdot 10^{15}$:



$1 \cdot 10^{16}$:



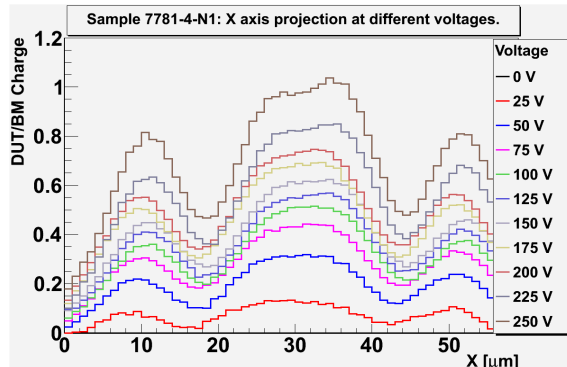
Scaled to maximum charge
in unirradiated device (0.126)

- Similar behavior than in 50x50 μm^2 case

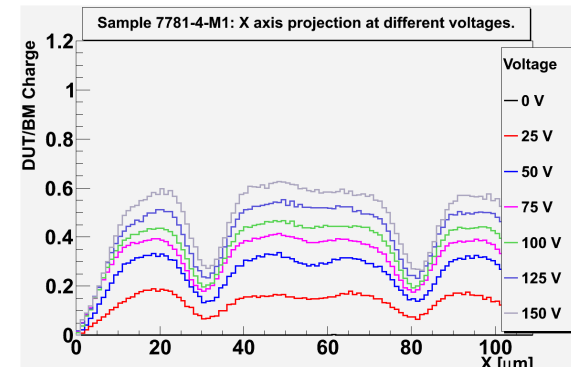
TCT measurements – 1D Projections of Irradiated samples

25x100

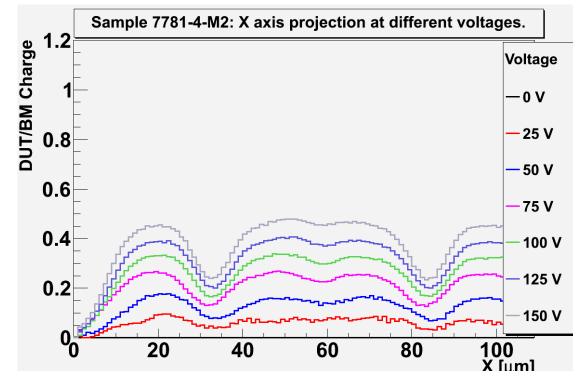
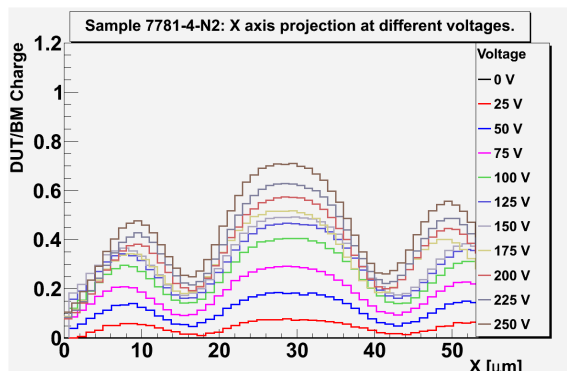
$5 \cdot 10^{15}$:



50x50



$1 \cdot 10^{16}$:

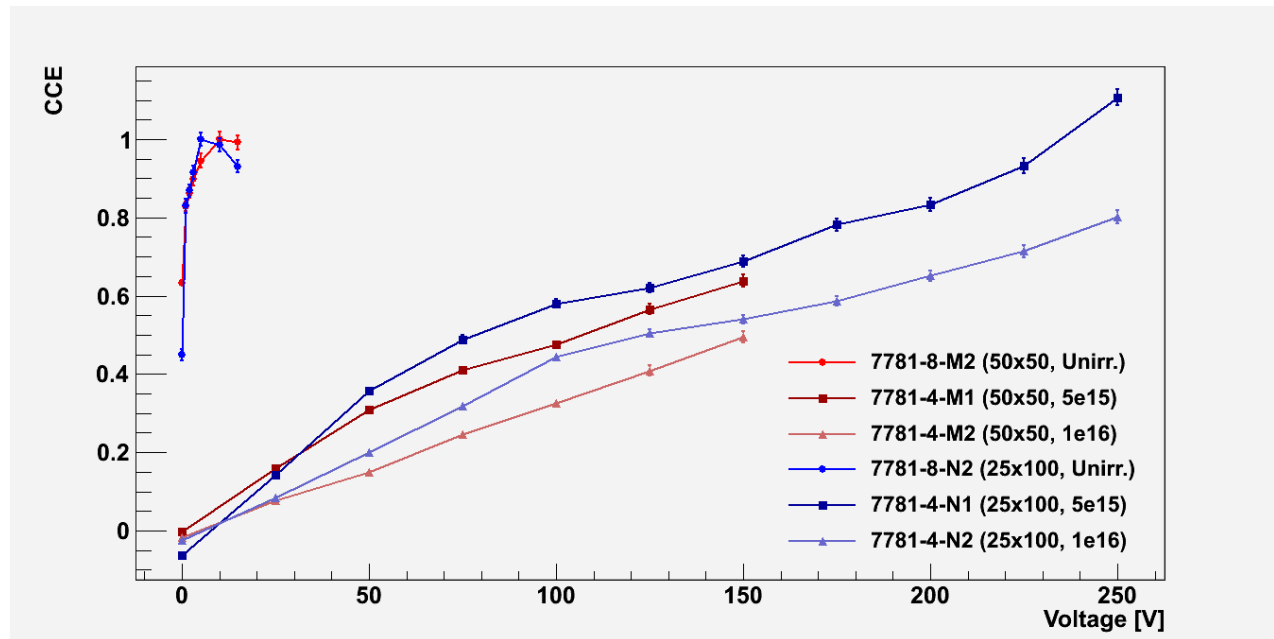


- 25x100 μm² devices seem to have a wider plateau than in the unirradiated sample – laser beam might have been better focused in these measurements



Large systematic uncertainties in CCE on 25x100 μm²

TCT measurements – Charge collection efficiency



- **Good CCE** at relatively low voltages
 - 50x50 up to 60% measured for irradiated fluences of $5 \cdot 10^{15} n_{eq}/cm^2$ and 40% for irradiated at $1 \cdot 10^{16} n_{eq}/cm^2$
 - 25x100 slightly more at the same voltage – **Would expect less CCE if electrode distance is larger!**
 - It can be explained if the **laser beam is better focused in irradiated 25x100 μm^2** measurements than in the unirradiated one
 - 25x100 irradiated at $5 \cdot 10^{15} n_{eq}/cm^2$ effects of charge multiplication starts at 250V?
- **Further studies needed to be done to cross-check these results. However:**
 - **Good performance at high irradiation doses** (40% charge retained in highest irradiated samples at 150V)
 - **Operation voltage relatively low** as compared to planar technology ($\sim 1000V$)

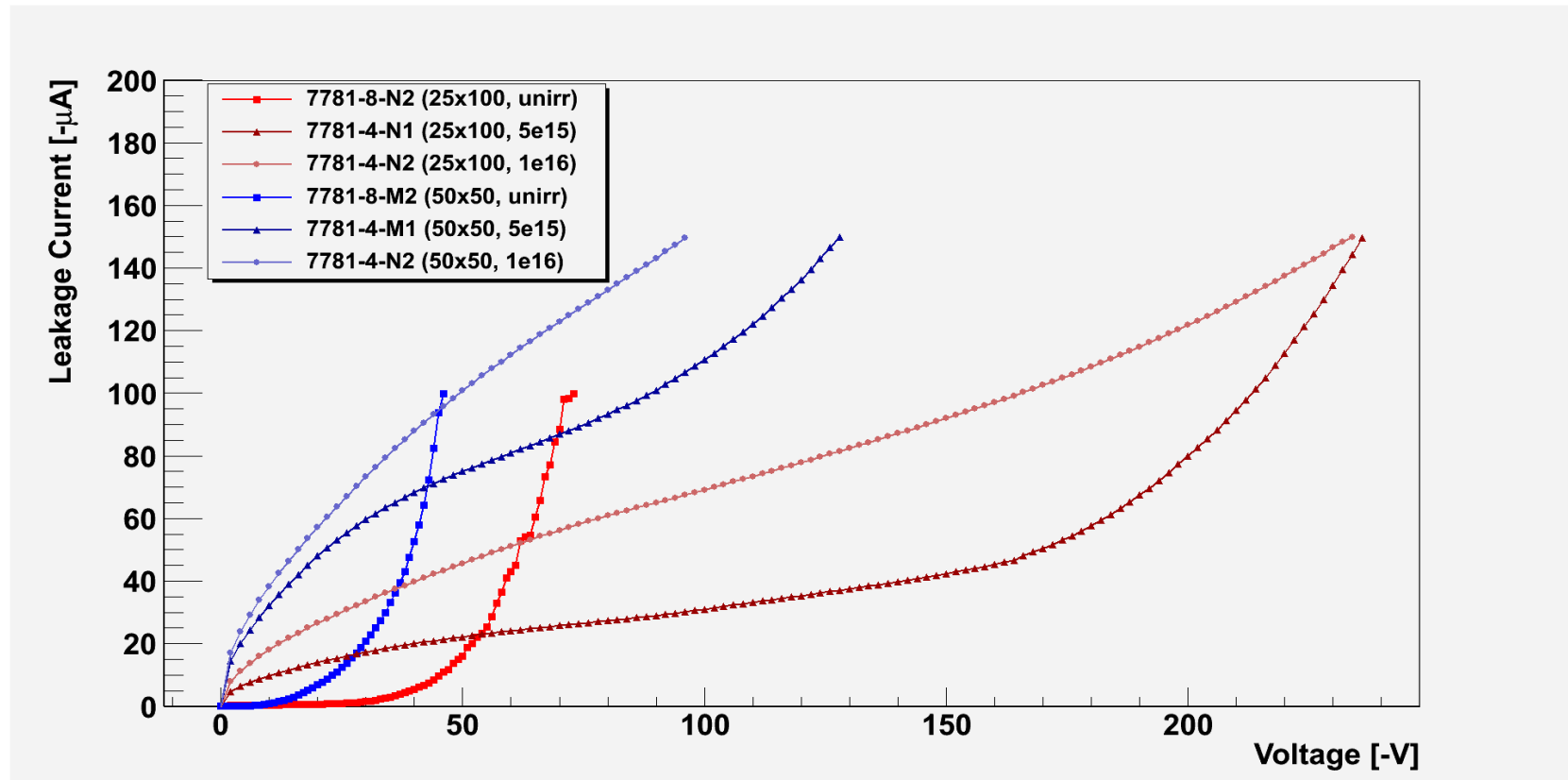
Conclusions

- **50x50 μm^2** and **25x100 μm^2** strips sensors were studied **before** and **after irradiation**
- The unirradiated **50x50 μm^2** device collects about **40% more charge** than the **25x100 μm^2** geometry
 - Laser reflected in Al strips do not clearly explain this huge difference \Rightarrow Needs cross-check with **radioactive sources!**
 - The **laser injection method** seems to be **limited** in the **25x100 μm^2** geometry
- After irradiation, **good performance** was observed in **both geometries**: $\sim 40\%$ of the charge was recovered at 150V after $1 \cdot 10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$
 - The fact that **25x100 μm^2** geometry shows **higher CCE** than the **50x50 μm^2** after irradiation points to a **biased measurement** – Also needs further investigation
- However, first **small pitch 3D strip devices** fabricated at **CNM** show **promising results** in terms of charge collection **before** and **after irradiation**

Thank you

Backup

IV curves for 50x50 and 25x100 devices

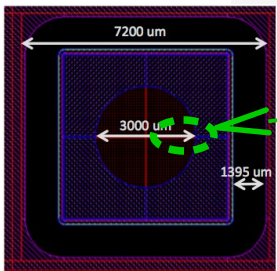
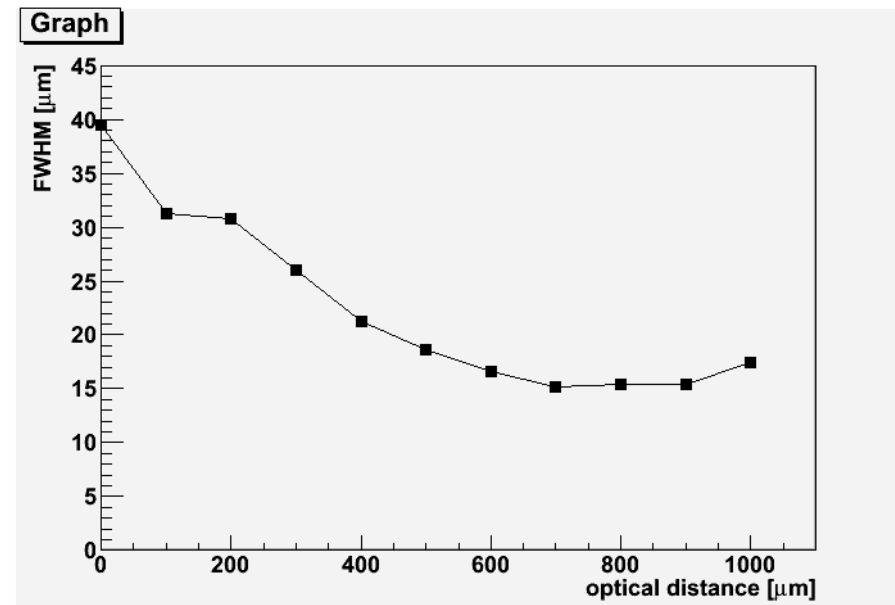
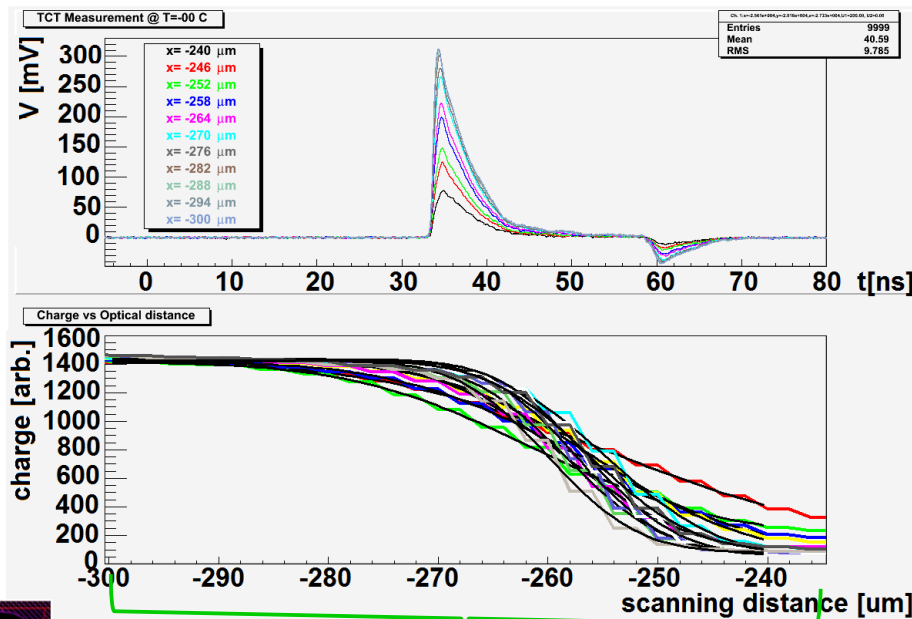


- At 15V still low leakage current on the unirradiated devices
- Large leakage currents at:
 - ~ 150V on 50x50 irradiated devices
 - ~ 250V on 25x100 irradiated devices

TCT setup – Laser focus

Focus scan procedure: obtain the charge collection profile of a detector's edge at different laser positions

- Fit with error function, then focus position → Minimum FWHM



Laser spot 15 μm (better fits show beam spot at 9 μm)