Charge multiplication in irradiated sensors after long annealing times

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Introduction

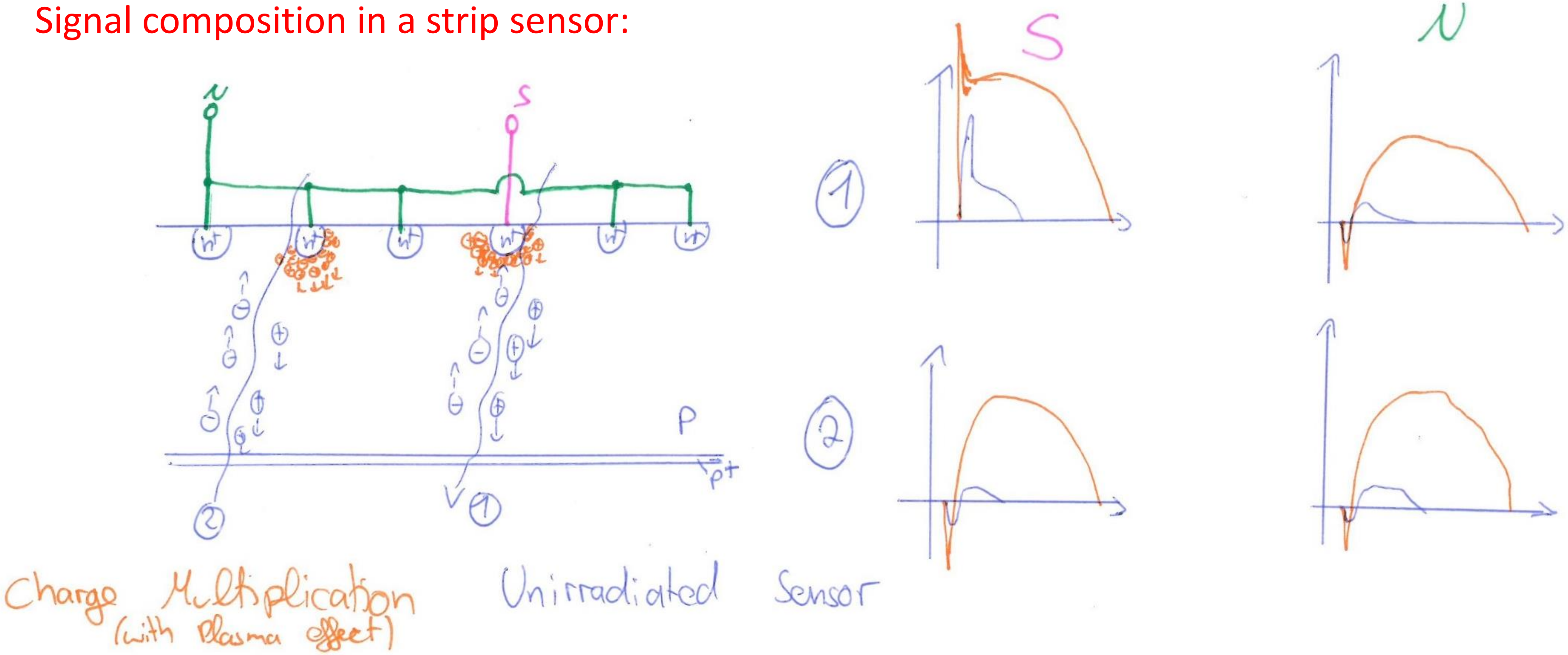
- Aims:
    - In previous studies charge multiplication was observed after long annealing times.
    - In this study we investigates deeper the CM, its dependencies and its stability.

- Materials:
    - P-type detectors, irradiated up to a fluence of 2e15 $\frac{n_{eq}}{cm^2}$, annealed at 60°C or at 70°C.

- Methods:
    - Charge Collection measurements with a beta-source using the ALIBAVA readout system for each annealing step.
    - Direct recording of the signal pulse with an oszilloscope (work in progress).

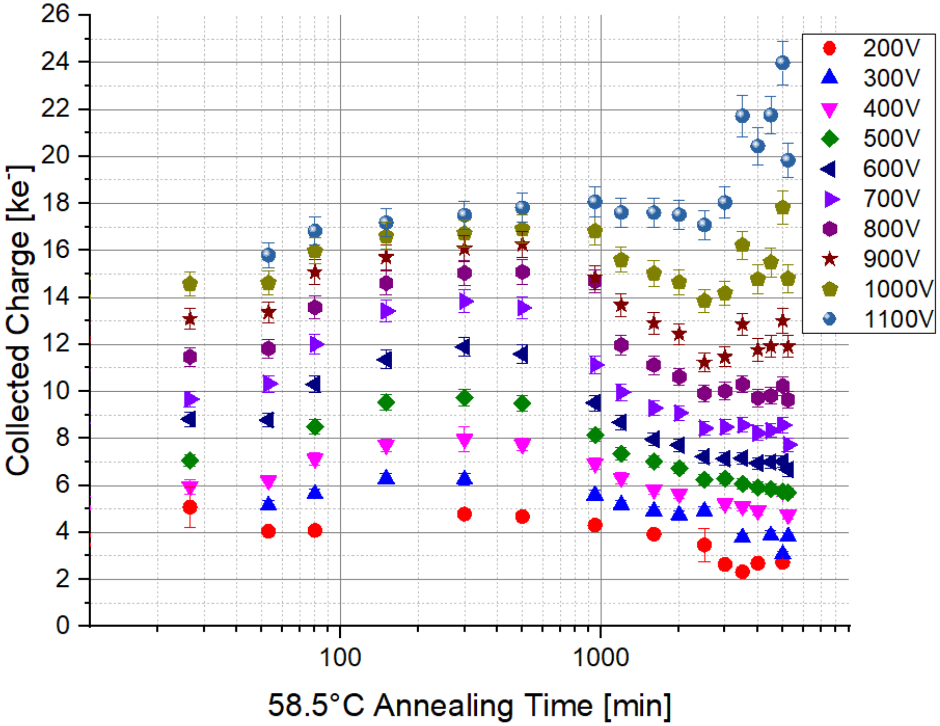
Theory

- Plasma effect
  - Free carriers are not negligible and determine the electric field distribution.
  - Increases charge collection time by so-called plasma time.
  - Carriers drift apart due to diffusion and electrostatic repulsion -> lateral spread.
  - Screening effect -> charge „clouds“ travel slower.
- Signal composition in a strip sensor:

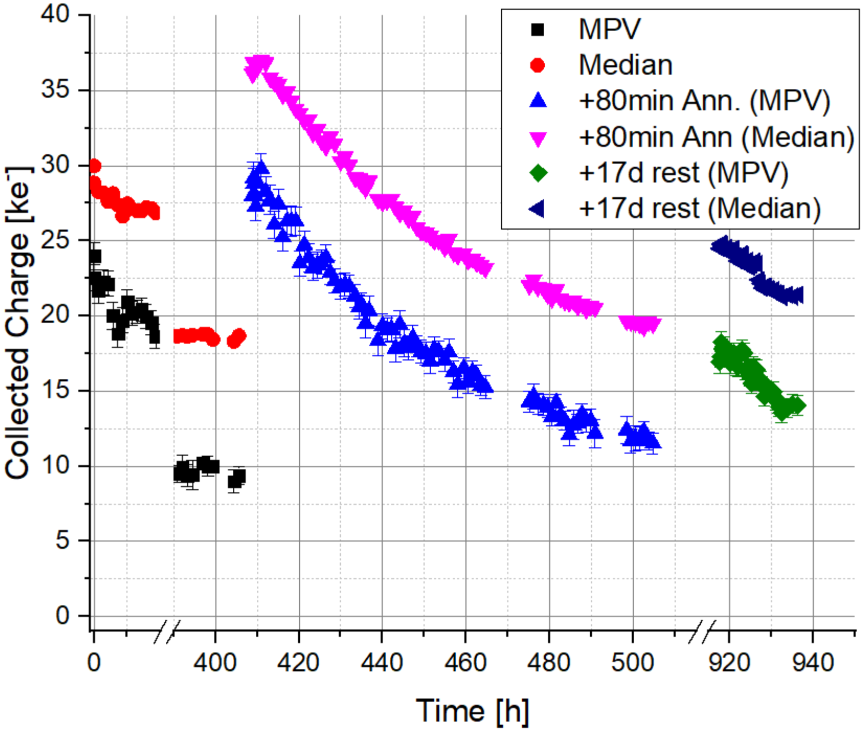


Charge multiplication measurements

Sensor irradiated with 2e15 $\frac{n_{eq}}{cm^2}$, annealed at 58.5°C :



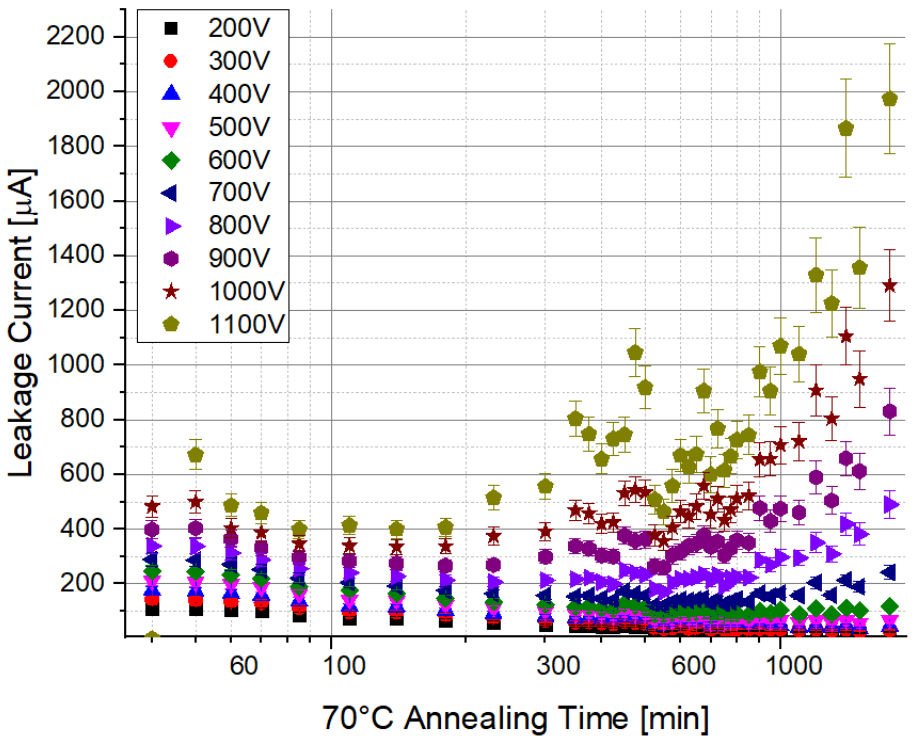
5000min annealed (58.5°C)

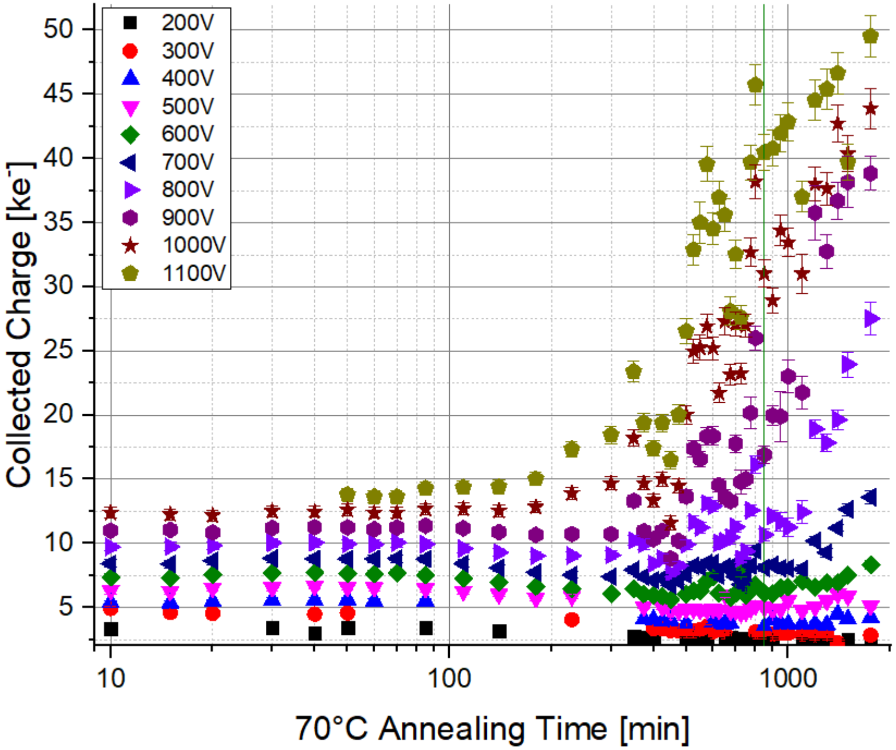


- Clear charge multiplication for the highest voltages.
  ->Caused by a very strong electric field at the readout strips.
- Long term stress (permanent biasing) decreases the CM effects.
- Additional annealing [resting] completely [partially] restored the CM.

Charge multiplication measurements

Sensor irradiated with 2e15 $\frac{n_{eq}}{cm^2}$, annealed at 70°C :

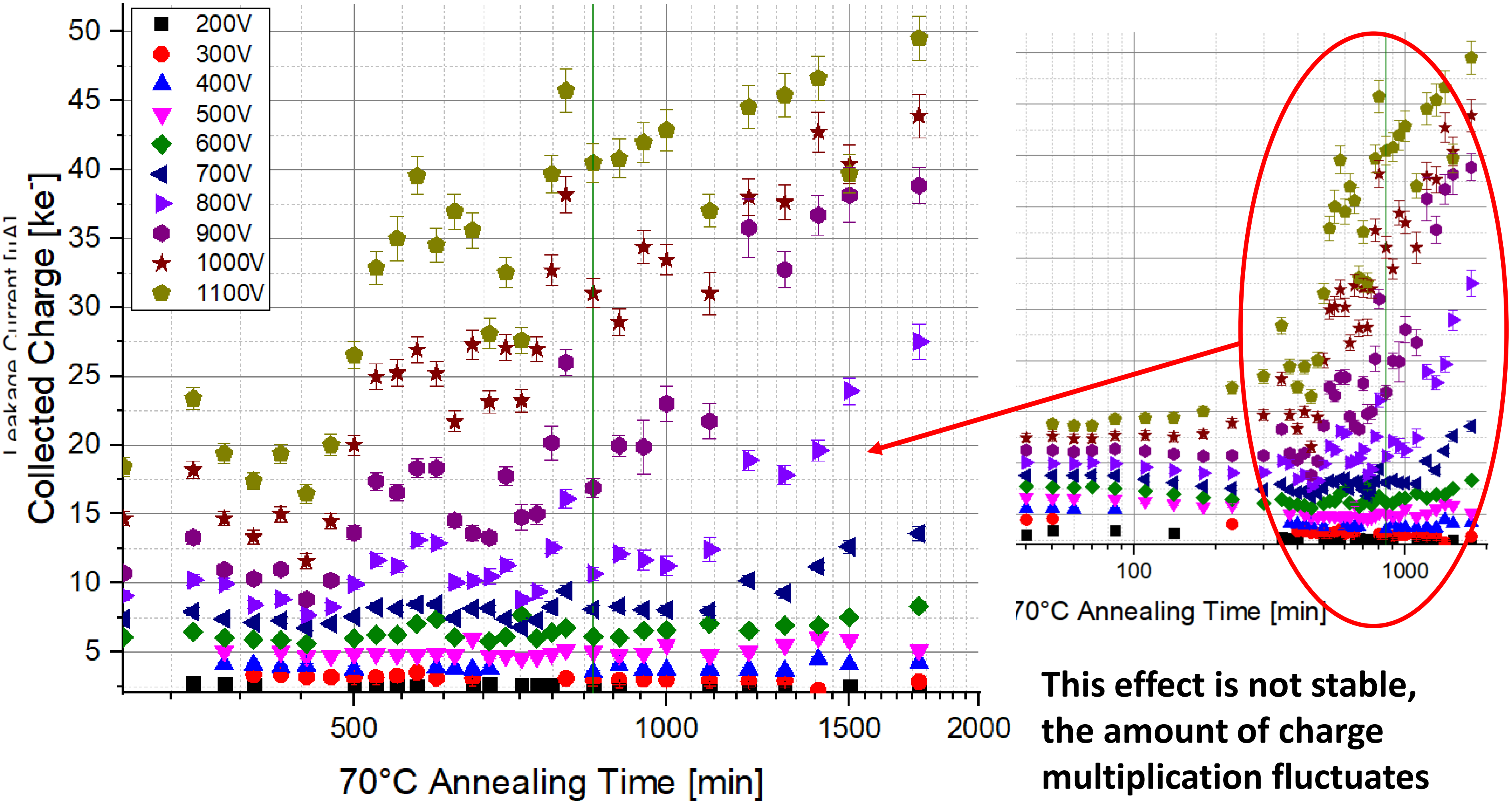




- Clear charge multiplication already at lower fluences.
  -> starts at 800V.
- Maximum value reached (MPV): $47{,}7\ \pm 1{,}7\ ke^{-}$.
- Charge multiplication visible also in the leakage current (strong increase).

Charge multiplication measurements

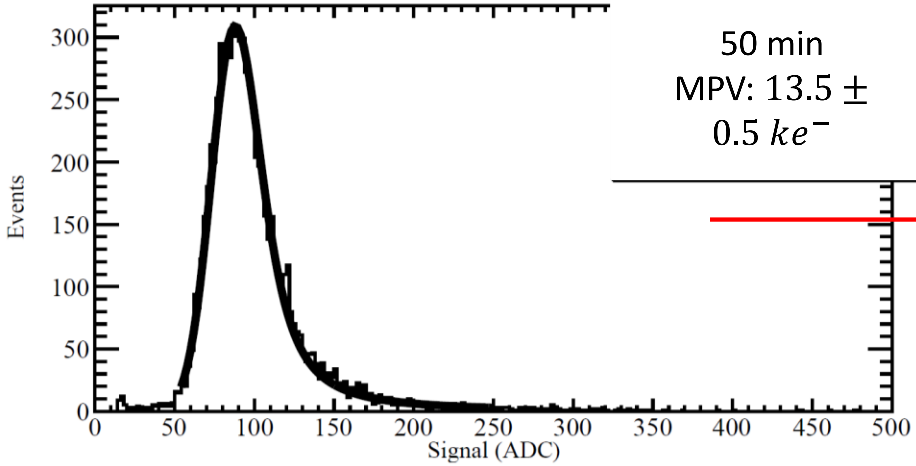
Sensor irradiated with 2e15 $\frac{n_{eq}}{cm^2}$, annealed at 70°C :



This effect is not stable, the amount of charge multiplication fluctuates with annealing time.

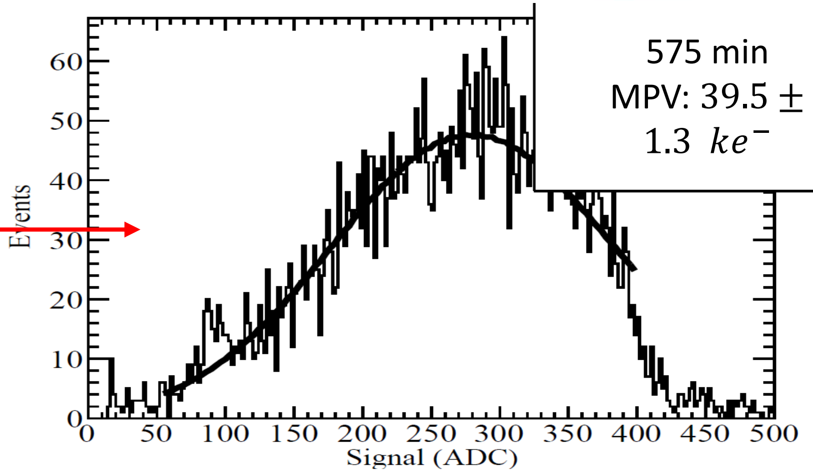
Charge multiplication measurements

Sensor irradiated with 2e15 $\frac{n_{eq}}{cm^2}$, annealed at 70°C :



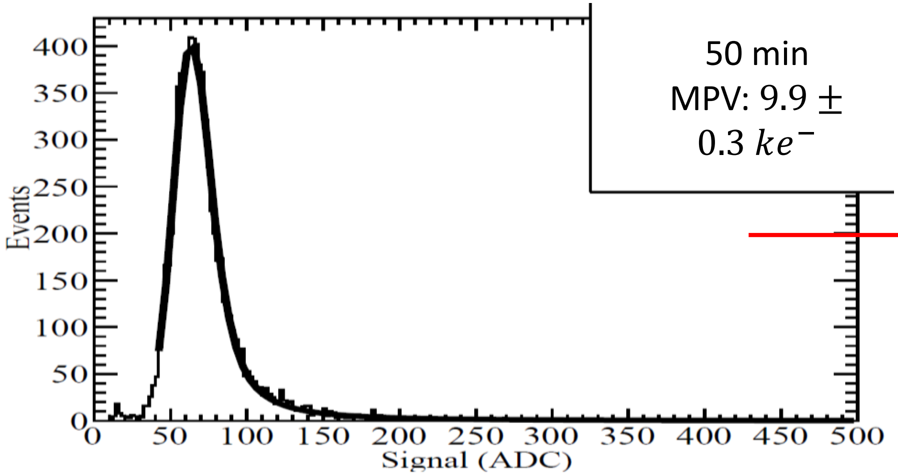
50 min
MPV: 13.5 ± 0.5 ke^-

1100V



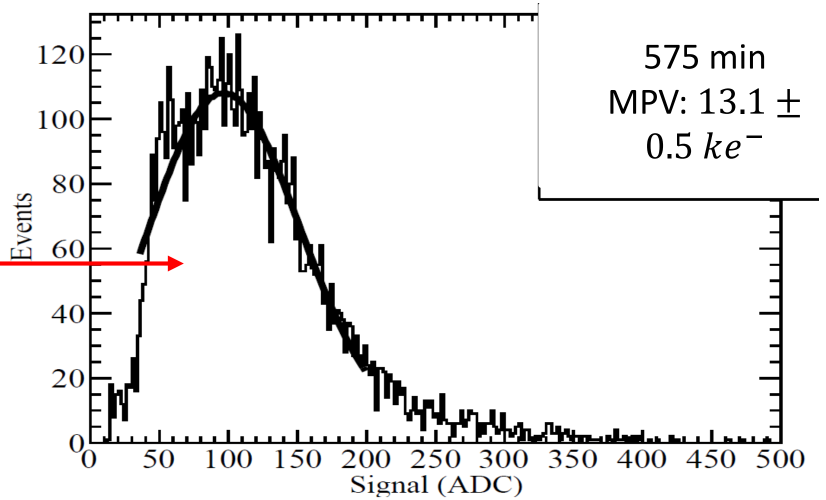
575 min
MPV: 39.5 ± 1.3 ke^-

Difficult to evaluate the full charge (MPV looses meaning), distribution is very broad -> even saturates the readout.



50 min
MPV: 9.9 ± 0.3 ke^-

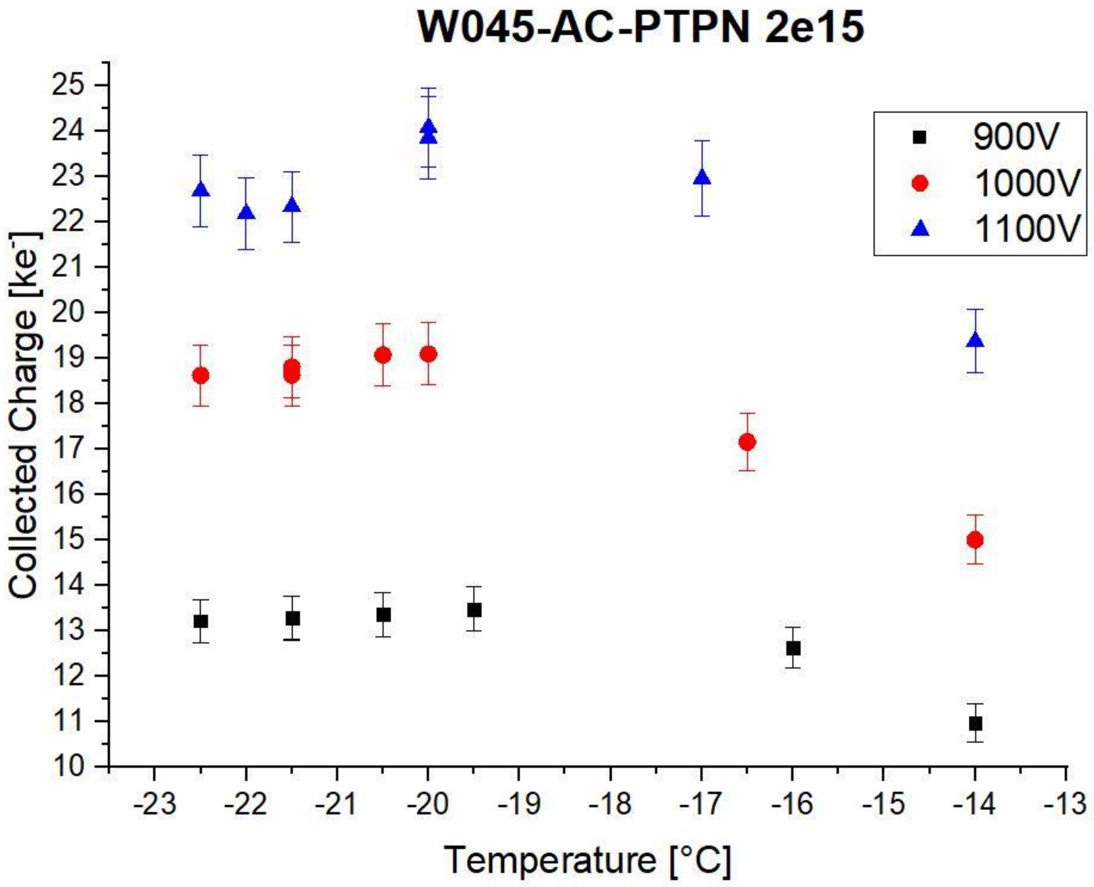
800V:



575 min
MPV: 13.1 ± 0.5 ke^-

Charge multiplication measurements

Charge multiplication: Temperature dependency

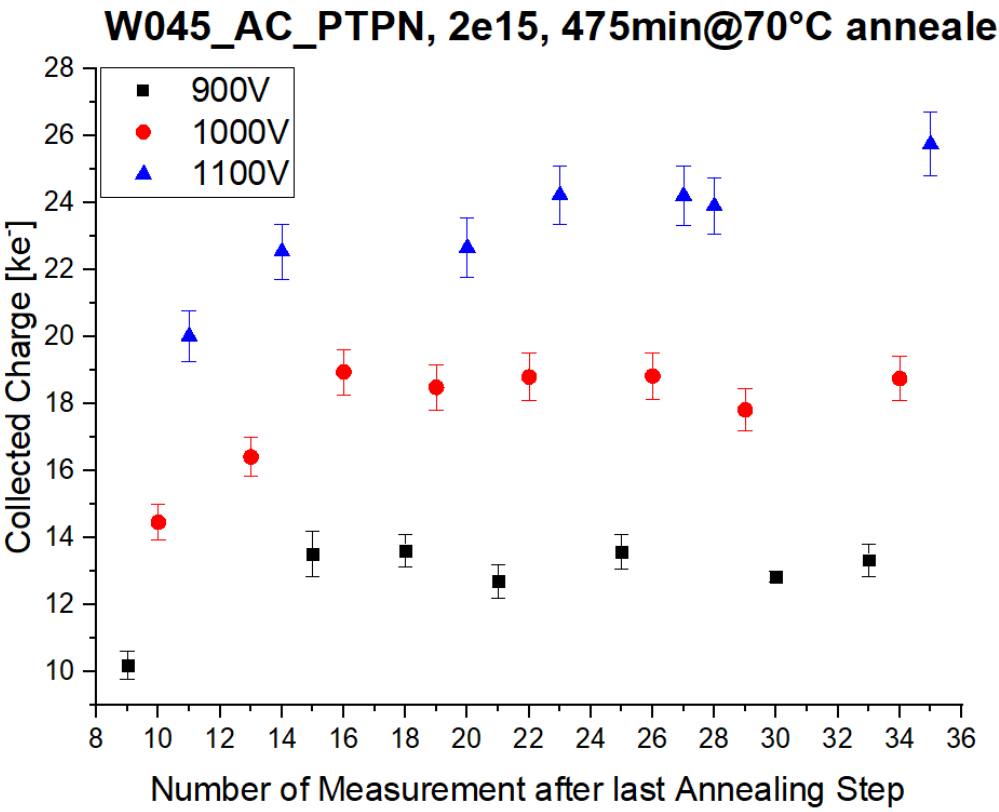


- No clear temperature dependence.
- Temperature gets important: Thermal Runaway due to avalanche.
- Measuring below -20°C prevents runaway of current.

-> Avalanche phenomena are not so strongly depending on temperature.

Charge multiplication measurements

Charge multiplication: Bias voltage cycling



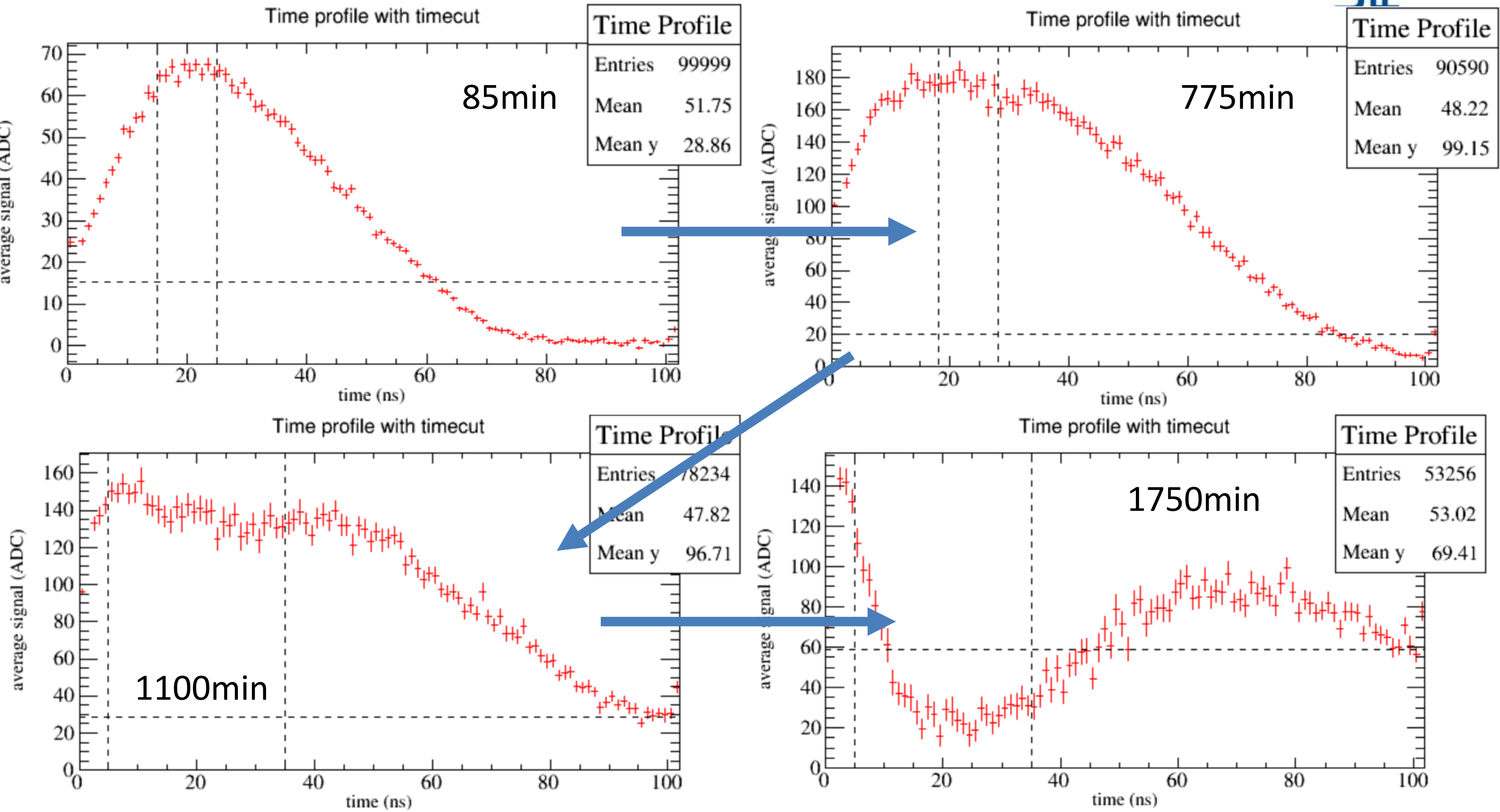
- Ramping the voltage down and up again increases the charge multiplication.
- Especially for the first cycles.
  -> Effect saturates for lower voltages.
- This effect could be seen after each annealing step (for one cycle).

Probably due to different charging of deep enough defects which remain in a metastable state after ramping up/down the voltage.

-> Deep enough=at SiO2-Si interface… (where actually there is high field CM zones)

Charge multiplication measurements

Signal pulse change

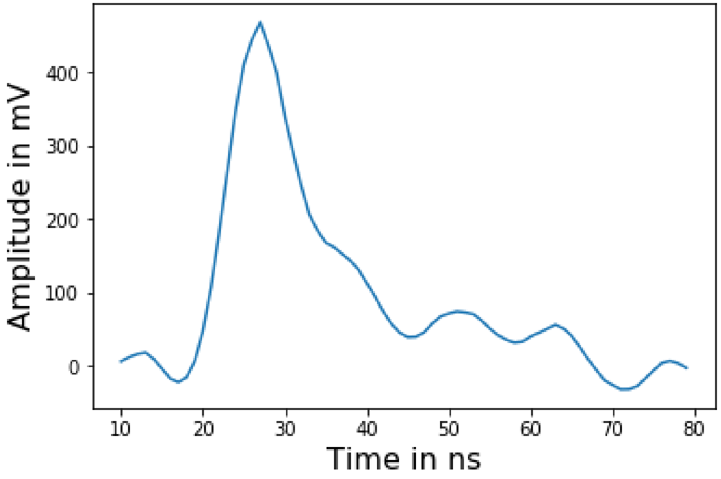


- The number of entries also decreases significantly -> Pulse exceeds the integration time!!!
- Electronics saturate and oscillations occur…

Charge multiplication measurements

Oszilloscope/ Edge TCT measurements

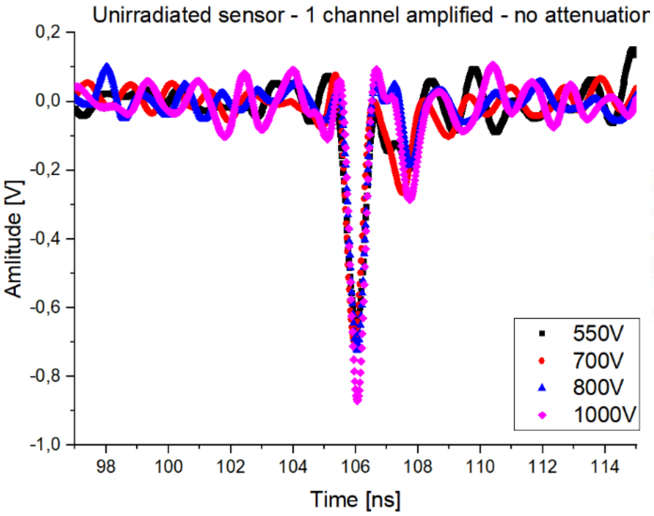
Unirradiated Sensor:



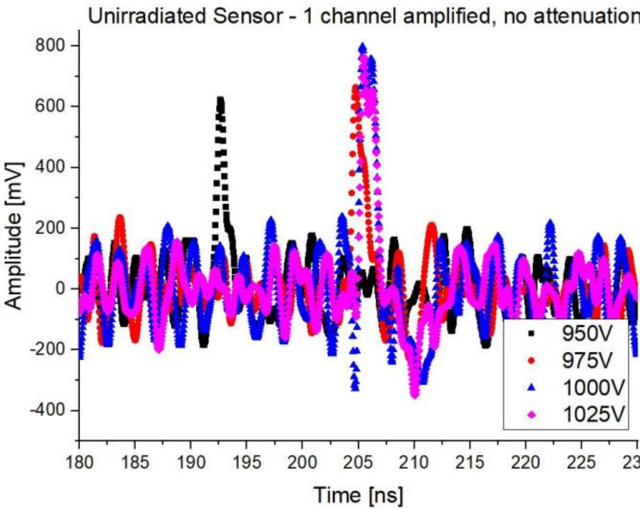
- Measured with Edge-TCT-technique -> laser pulse, not a beta source.
- Fast, big electron peak, small hole contribution.

- Measured with oscilloscope with beta source.
- Left: Rare signal.
- Right: Stable signal, but only visible in a sensor with high current (seldom CM in some strips?).
- We have limited bandwidth, are we collecting all electron signals?

NEIGHBOUR BEHAVIOUR



HIT STRIP BEHAVIOUR



Charge multiplication measurements

Oszilloscope/ Edge TCT measurements

Charge multiplication Sensor:

- Measured with oszilloscope with Beta source.

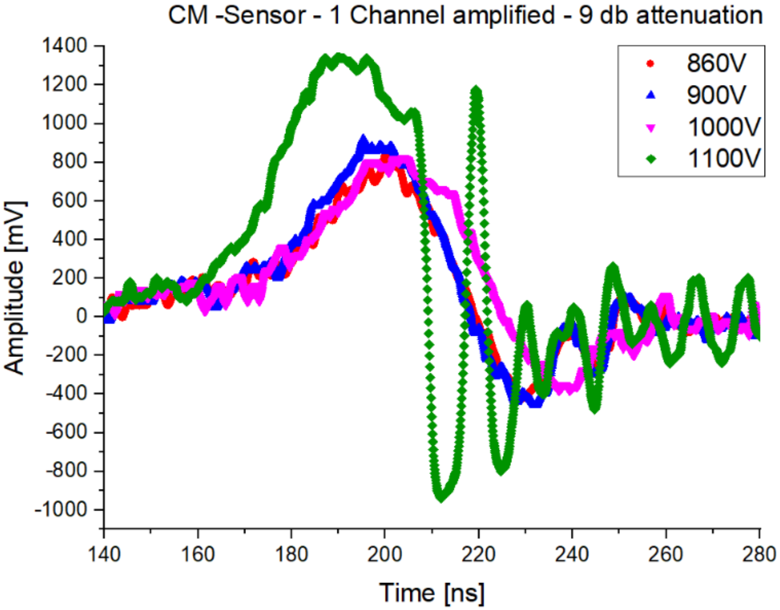
Single channel:

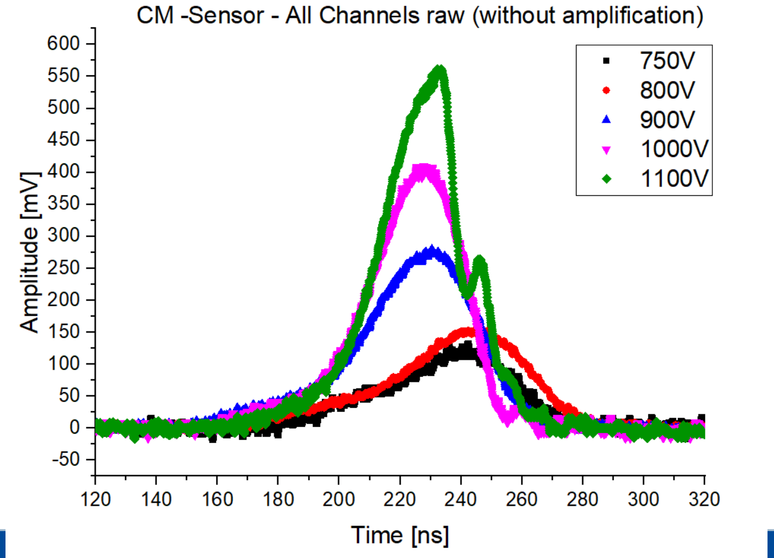
- No electron contribution visible.
- Broad, large peak from the hole contribution.

All neighbouring channels:

- Broad, high peak -> holes.
- No electron contribution visible.

- Positive Signal: Coming from plasma effect?



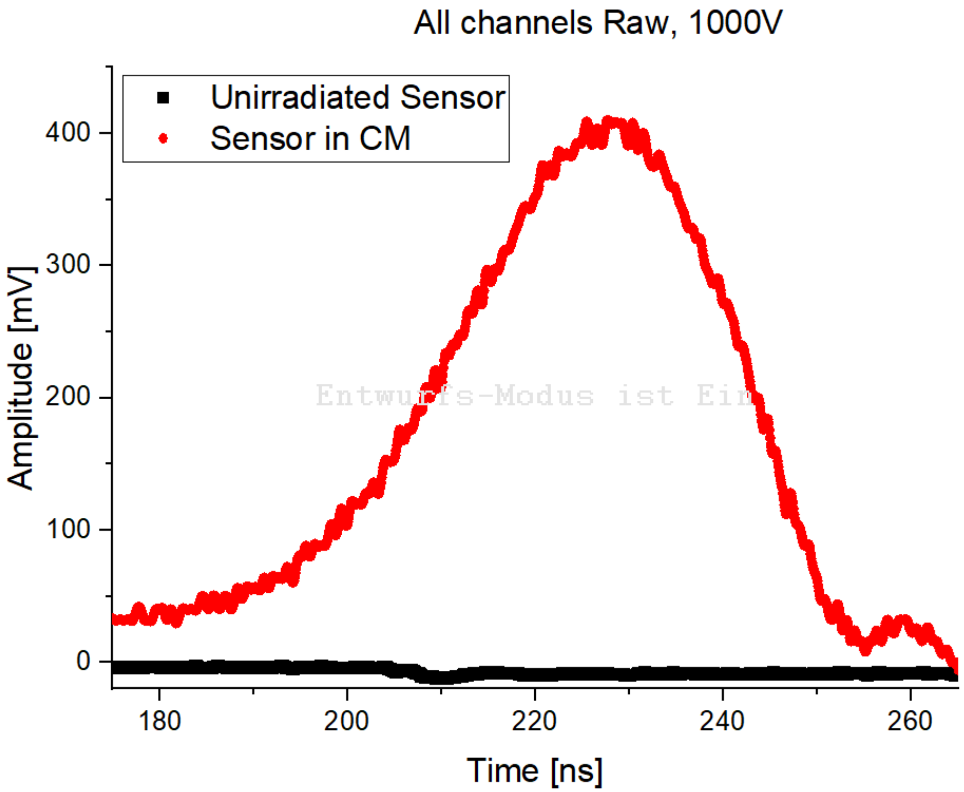


Charge multiplication measurements

Oszilloscope measurements

Neighbouring Channels:

- Unirradiated sensor: short, very small signal.
- Charge multiplication sensor: long, large signal due to the holes.



-> Plasma Effect?

- The amount of holes created due to the avalanche is not neglible any more.
- Holes are created near the strips .
  -> they have to travel through the sensor.
  -> „Cloud“ of holes -> Screening effects.
- Lateral spread: Lots of channels see the holes.

Conclusion & Outlook

Conclusion:

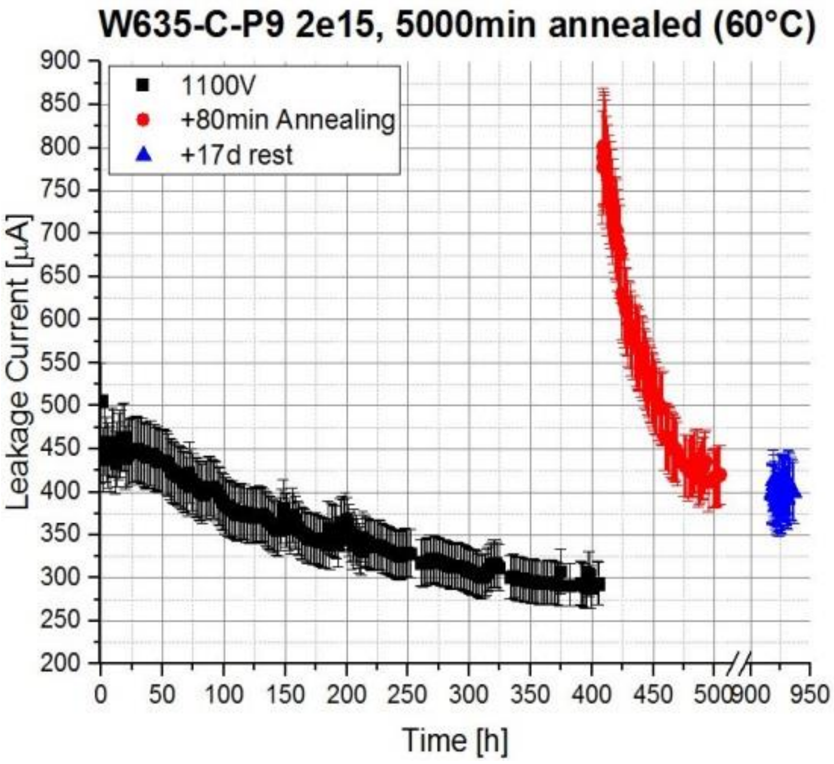
- Charge multiplication in long annealed, highly irradiated samples already at lower voltages.
- Phenomenon is not much depending on temperature.
- It is unstable, „Cycling“ the voltage has positive effect => metastable charge of interface defects.
- Change in signal pulse in time -> Plasma effect for the holes created in charge multiplication.

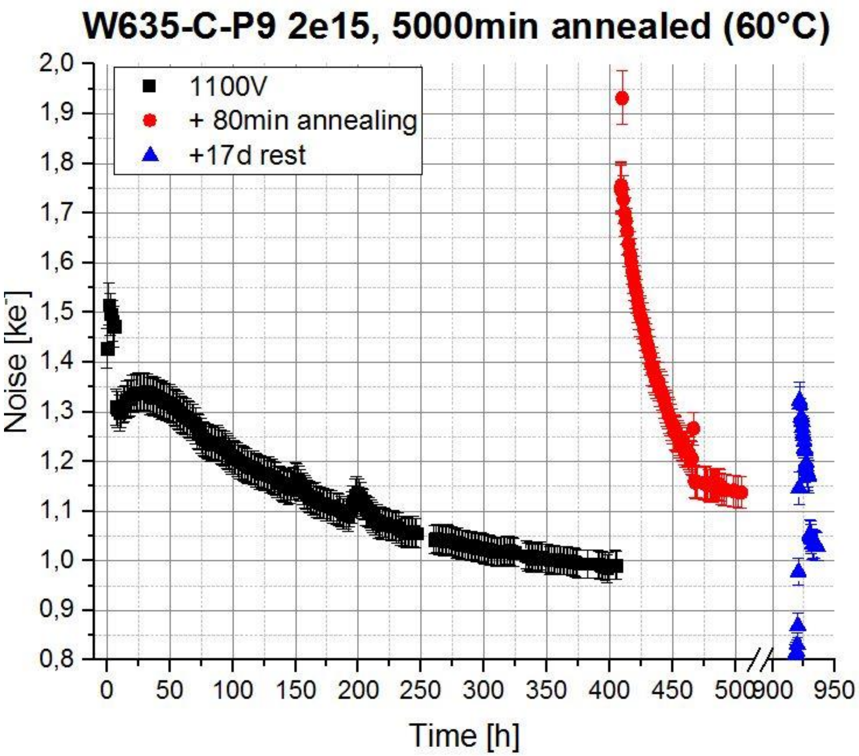
Outlook:

- Optimize the measurements with oscilloscope to find more signals.
- Measurements of the electric field during annealing and in CM with an edge TCT.
  -> learn about origin and dependences of charge multiplication.
  -> more about the change in signal.
- Comparison of it for different fluences -> Investigation of the dependence on fluence: Is Neff saturating before CM for low fluences?

Back Up: Long Term stress (permanent biasing)

Sensor irradiated with 2e15 $\frac{n_{eq}}{cm^2}$, 5000min annealed at 60°C before

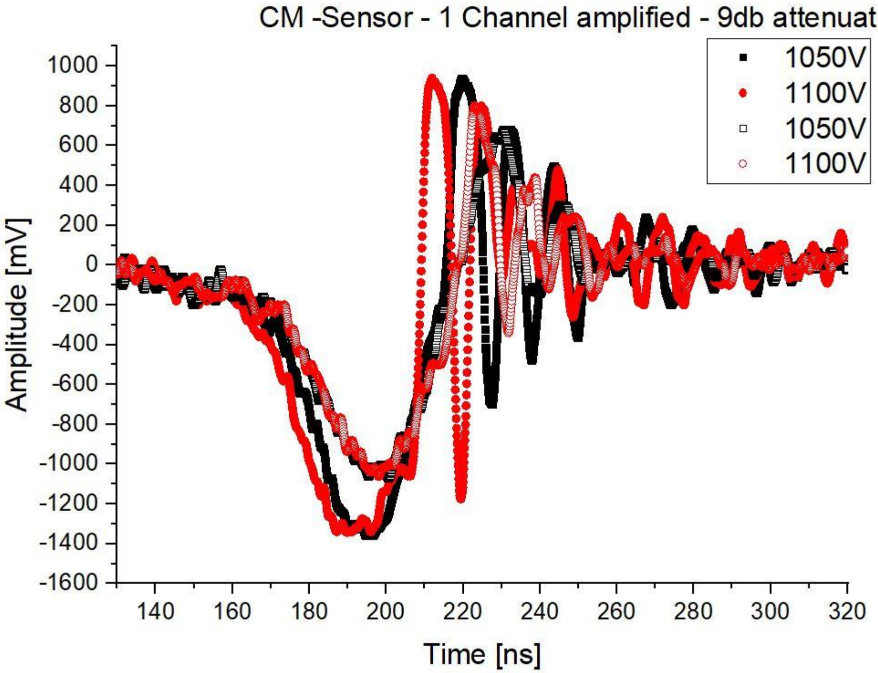


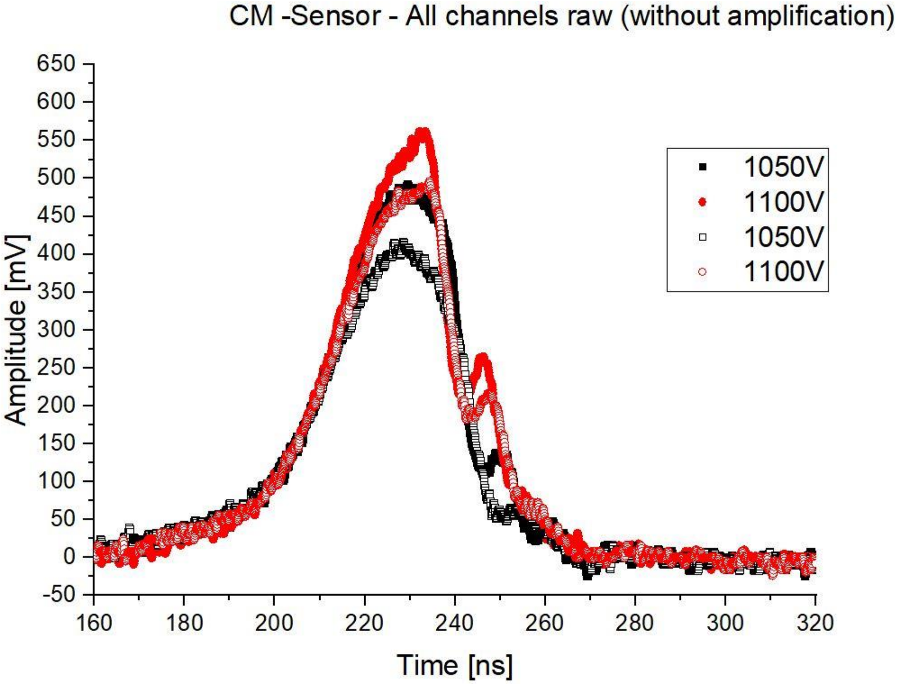


- Leakage current also decreasing due to loss of CM, big increase with the next annealing step, but no increase caused by resting.
- Noise behaviour completely dominated by leakage current dependence

Charge multiplication measurements

Oszilloscope measurements

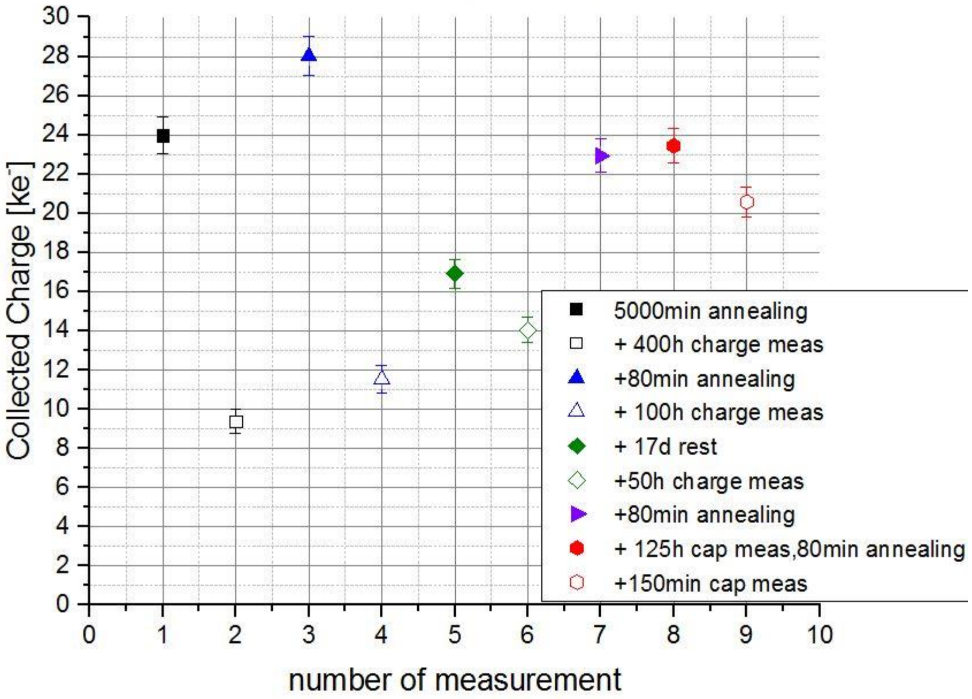




- The amount of charge multiplication is fluctuating
  -> might be depending on which where the particle hit and the avalanche is created

Backup: Long Term stress (permanent biasing)

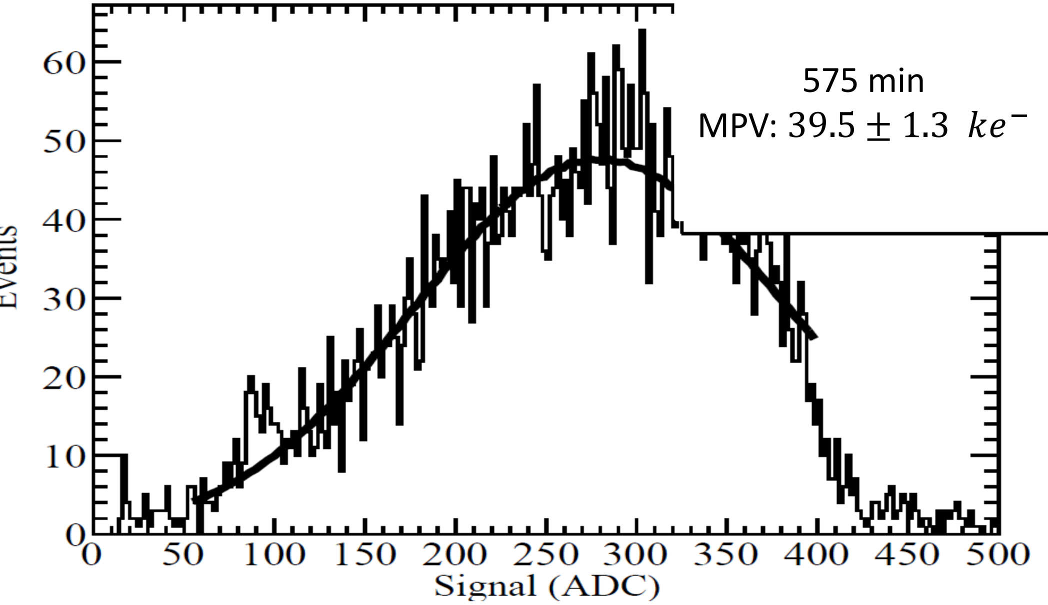
Sensor irradiated with 2e15 $\frac{n_{eq}}{cm^2}$, 5000min annealed at 60°C before



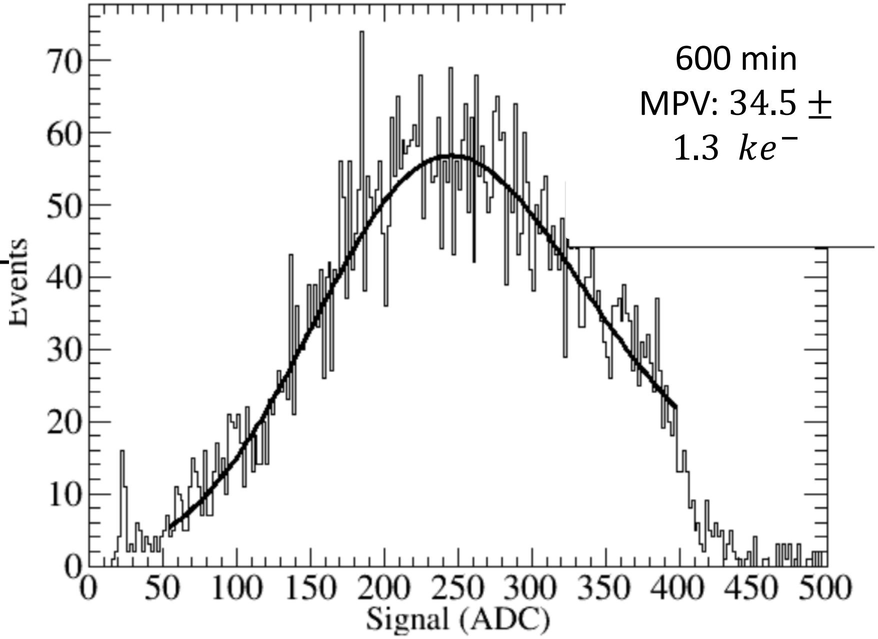
- Measurements always at 1100V constant biasing
- Summary of the behaviour at different stress levels & annealing steps
  -> Timeline of Charge measurement stress, Annealing steps & capacitance measurement stress

Back-Up

Landaus 1100V



575 min
MPV: $39.5 \pm 1.3 \;\; ke^{-}$



600 min
MPV: $34.5 \pm$
$1.3 \;\; ke^{-}$

Charge multiplication measurements

Charge multiplication doesn‘t depend on temperature:

Avalanche phenomena is not so strongly depending on temperature [1]:

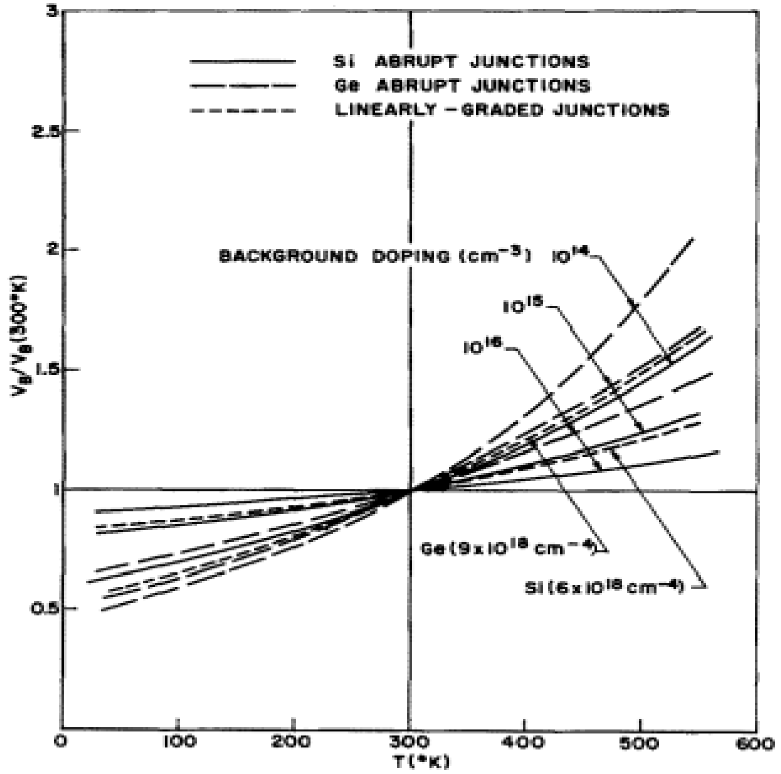


Fig. 4. Breakdown voltage vs temperature for Si and Ge *p-n* junctions. V_B(300°K) is 2000, 330, and 60 V for Si and 950, 150, and 25 V for Ge for dopings of 10^{14}, 10^{15}, and 10^{16} cm^{-3} respectively. The linear-graded junctions have V_B(300°K) the same as those for doping of 10^{15} cm^{-3}.

[1] Crowell and Sze, TEMPERATURE DEPENDENCE OF AVALANCHE MULTIPLICATION IN SEMICONDUCTORS, APL (1966)

Charge multiplication measurements