Longterm performance of silicon strip detectors under high bias voltage: charge collection and laser measurements

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26th RD50 workshop, Santander, 2015.06.22

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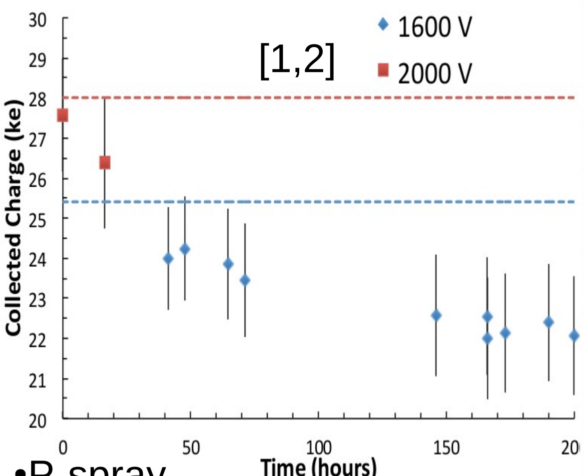
Outline

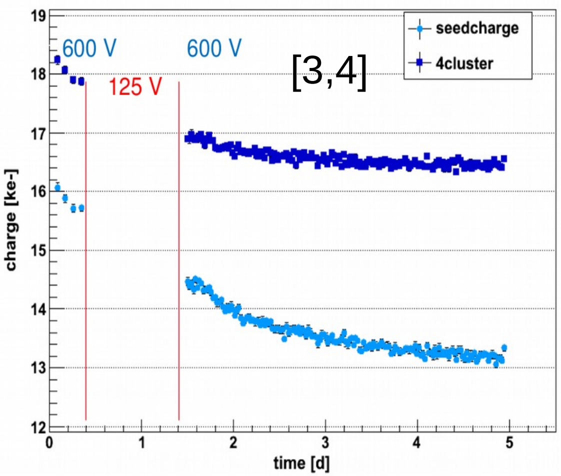
- Introduction:
  - Observations.
  - Causes.
  - Possible explanations.
- Materials:
  - Tested sensors.
  - Set-ups.
- Methods:
  - Experimental procedures.
  - Analysis.
- Experimental results and discussion:
  - Distribution in charge multiplication mode.
  - Longterm charge collection results (beta source).
  - Longterm spatial performance results (laser).
- Summary and outlook.

Introduction: observations

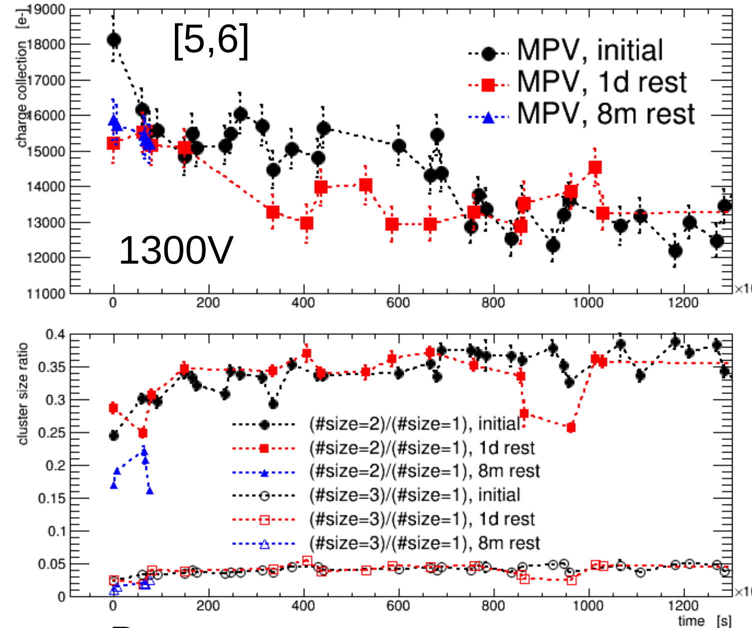
- Observations:
  - Recently it has been observed a performance decrease on silicon strip sensors tested at high voltage (especially showing charge multiplication).
    - It happen with very high voltage (>1kV) and small radioactive source (~MBq) irradiation.
    - It is correlated to a slight increase of the cluster size.



- P-spray.
- $1*10^{15}$ n_{eq}/cm^2 (n).



- P-stops.
- $1*10^{10}$ n_{eq}/cm^2 (e-).



- P-spray.
- $5*10^{15}$ n_{eq}/cm^2 (n).

[1] Sven Wonsak, private communication.
[2] Chris Betancourt, RD50 workshop, talk, 2013.11.
[3] Steinbrück, Outer tracker sensor meeting, talk, 2014.01.
[4] Klanner, TIPP, talk, 2014.06.
[5] Mori et al., NIM A RESMDD proceed., 2015.02.
[6] Kühn, talk RD50 CERN, 2014.11.

Introduction: causes

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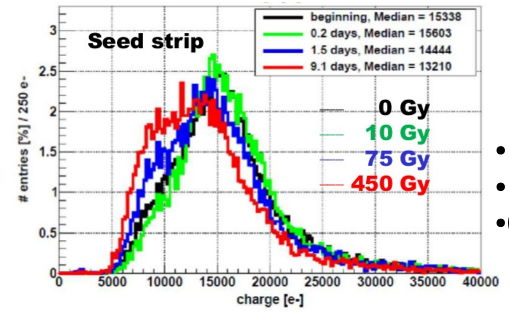
•*What is interacting with the silicon in the longterm?*

- Dose from the small source.
- High voltage stress.

Introduction:possible explanations

Possible explanations:

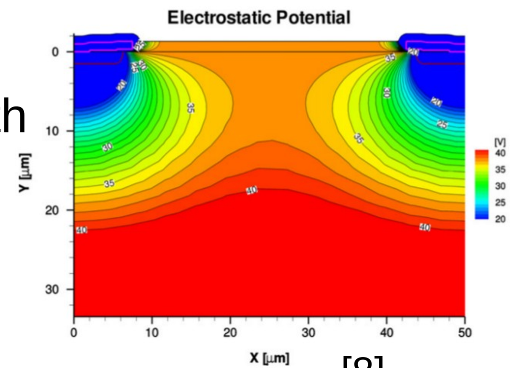
- *Surface effect:*
  - positive charge in the SiO2 increases the charge sharing.
    - *P-stop/P-spray should protect.*
    - *SiO2 expected to be saturated from irradiation.*



[4]

- P-stops.
- Non irradiated.
- 600V.

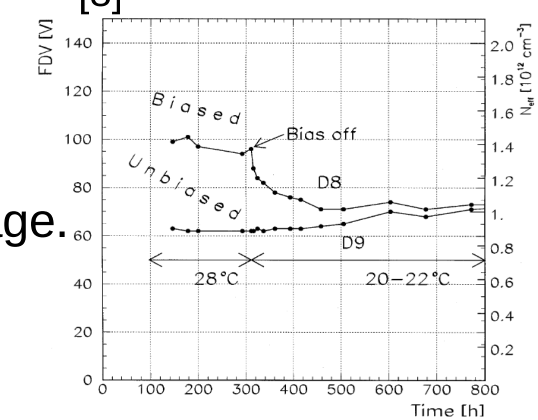
- *Polarization effect:*
  - Defect charge distribution changes slowly with the carrier flow (<u>bulk or interface defects</u>).
    - *Usually much faster than days…*
  - *A bistable defect?*



[7]

- No p-spray/stop.
- P-on.n
- Non irradiated.
- 200V, simulation.

[8]



- *High-field driven "annealing" effect:*
  - Permanent movement of charge defects due to high voltage.
    - *Very slow at low temperatures.*

[4] Klanner, TIPP, talk, 2014.06.
[7] Pöhlsen, NIM A 700, 2013.
[8] Cindro et al., NIMA 498, 1998

Introduction: strategy

•*How to discriminate between those explanation?*

- Monitoring of side properties (current, capacitance,…).
  →To describe the phenomenon observing additional properties.

- Measurements without source/without voltage
  →Which is the main cause?

- Recovery trials
  → Permanent change?

Materials: sensors

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Producer	Isolation	Fluence [neq/cm2]	Voltage [V]	Charge collection [ke-]
Micron	p-spray	0	Only during meas.	22±1
Micron	p-spray	1e15(p)	375	9±1
LGAD		0	300 and 500	15±1
Micron	p-spray	1e15(p)	1000	19±1
Micron	p-spray	1e15(p)	820	16±0.5
Micron	p-spray	1e15(p)	700	13±0.5
HPK ATLAS12A	p-stop	2e15(p)	1100	17±0.5
Micron	p-spray	5e15(n)	1300	18±1 → 14±1
Micron	p-spray	5e15(n)	1300	13±1 → 10±1
Micron	p-spray	1e15(p)	1300	18.5±1 → 17±1
HPK ATLAS07	p-stop	2.1e15(mix), ann4200min@RT	1100	15±1 → 12±1
HPK ATLAS07	p-stop	2.8e15(mix), ann4200min@RT	1100	17.5±1 → 14.5±1
HPK ATLAS07	p-stop	2.8e15(mix), ann720min@RT	1100	15.5±1 → 14±1

Experimental results: distribution analysis

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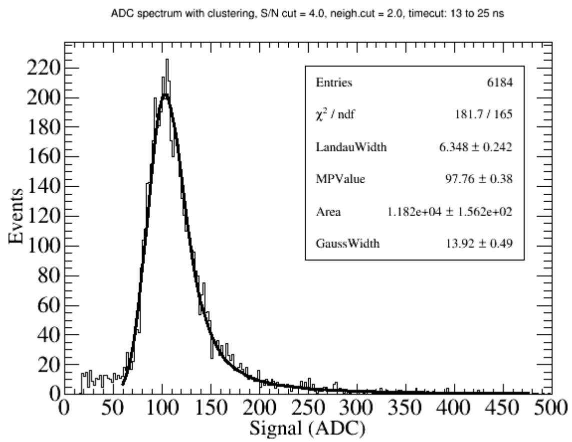
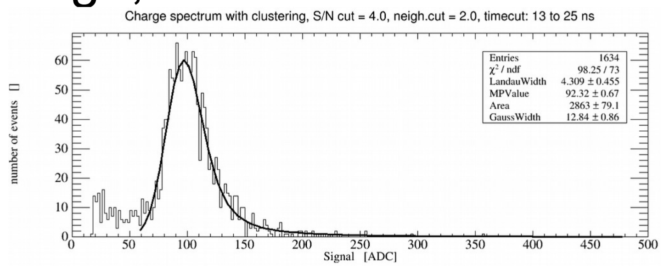
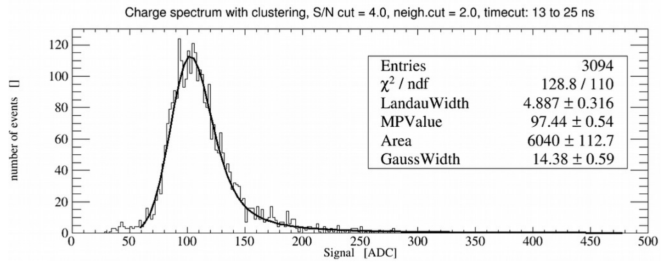
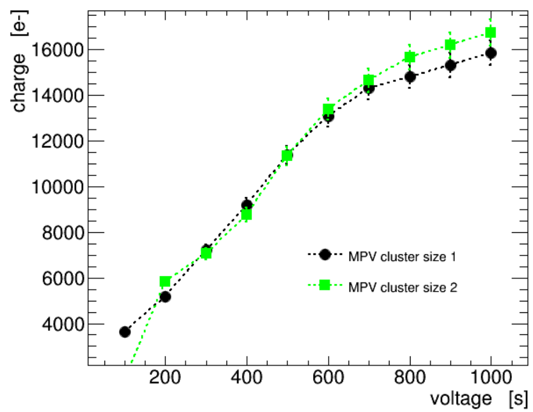
- Discriminating between different cluster size events: case with no drop:
  - Distributions and MPV vs. voltage, time:

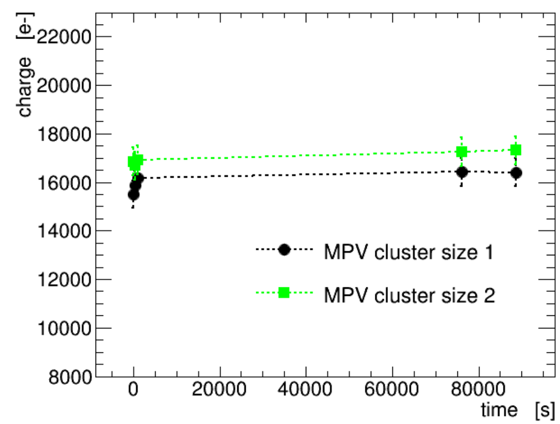






- ATLAS12.
- (Pitch,width)=(74.5,16)um.
- P-stop.
- $2*10^{15}$ n_{eq}/cm^2 (n).

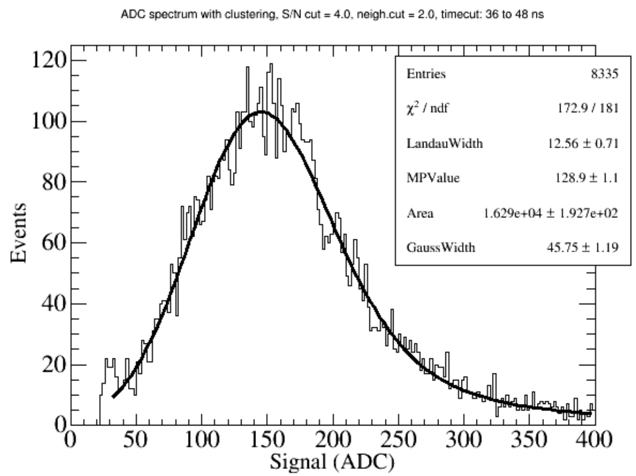


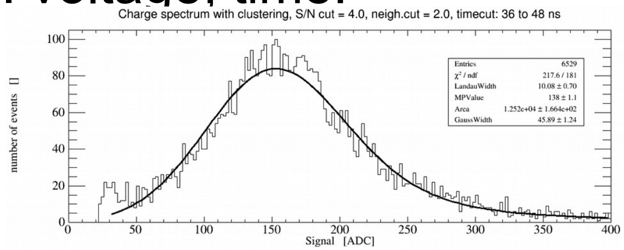


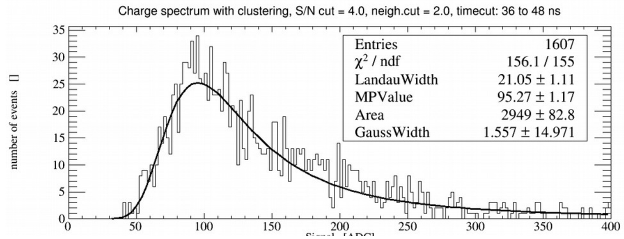
- No drop on ATLAS12.
- Same MPVs for events having cluster size 1 and 2.

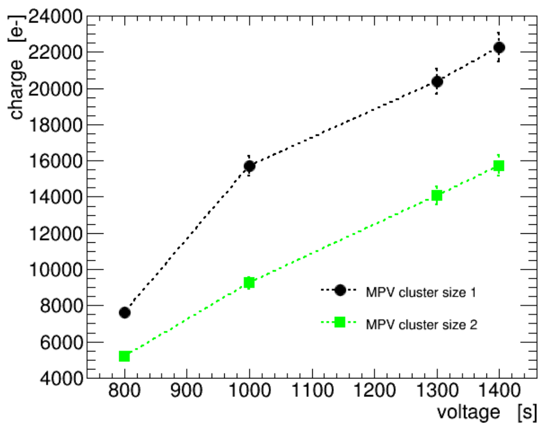
Experimental results: distribution analysis

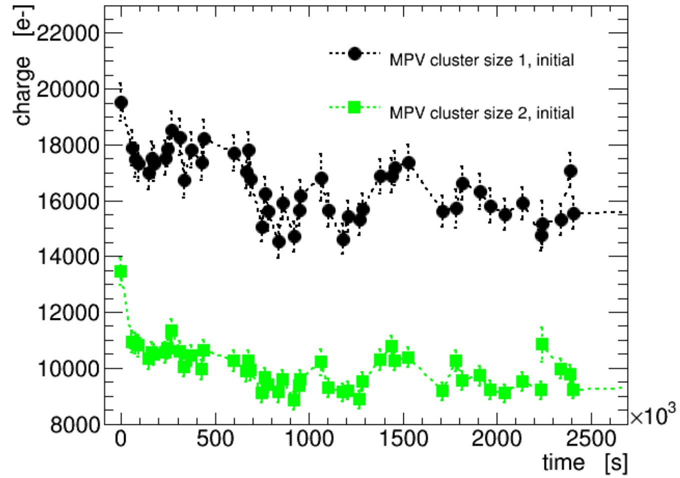
- Discriminating between different cluster size events: case with drop:
  - Distributions and MPV vs. voltage, time:











- Micron.
- (Pitch,width)=(100,10)um.
- P-spray.
- $5*10^{15}$ n_{eq}/cm^2 (n).

- Charge multiplication: multiplication occurs mainly on 1 strip events.
- Drop occurs in events with cluster size 1 and 2.

Experimental results: no source

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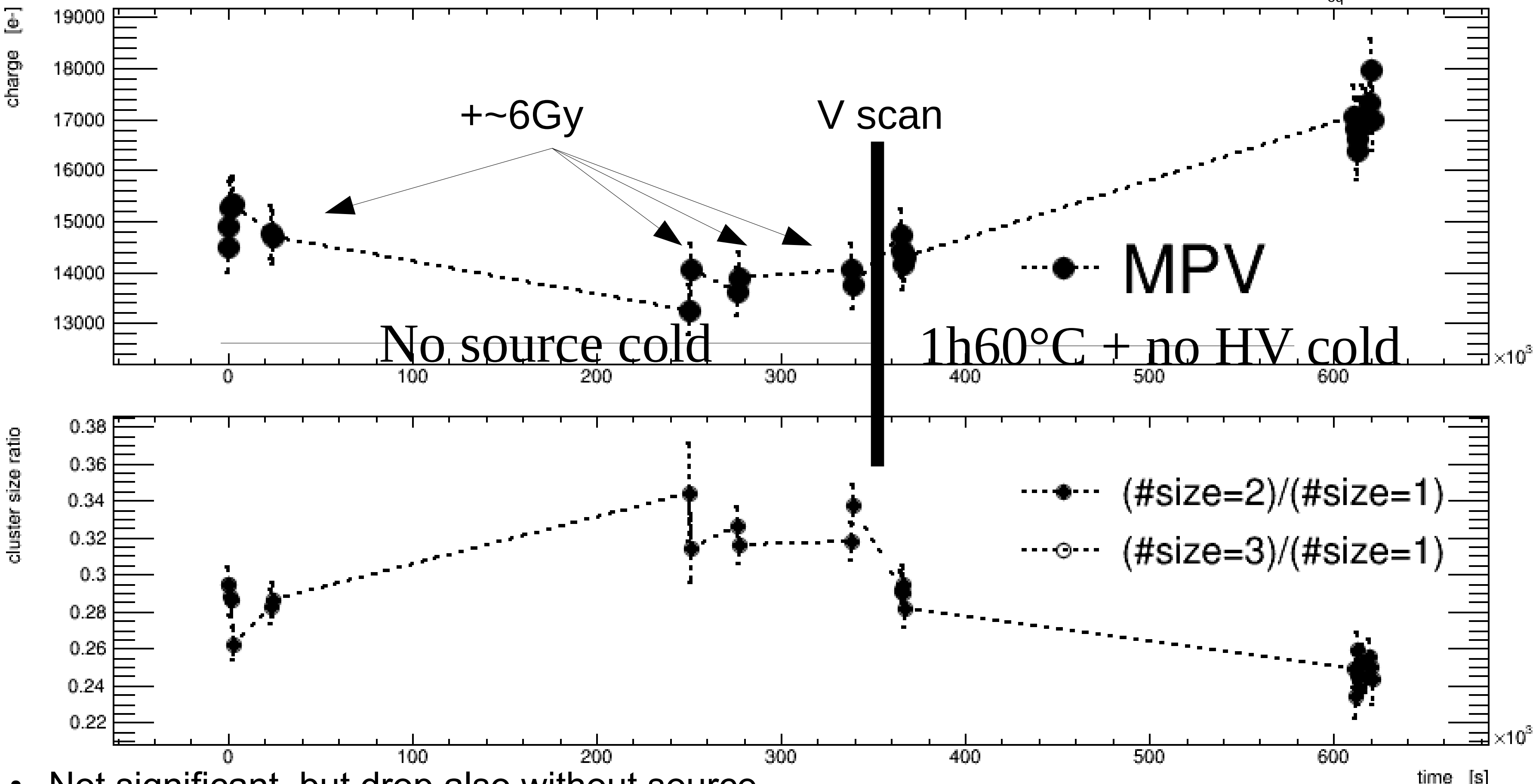
- Removing the source:
  - Charge collection and cluster size vs. time:

- ATLAS07.
- (Pitch,width)=(74.5,16)um.
- P-stop.
- $(1.18+0.26+1.02)*10^{15}$ n_{eq}/cm^2 (mix).

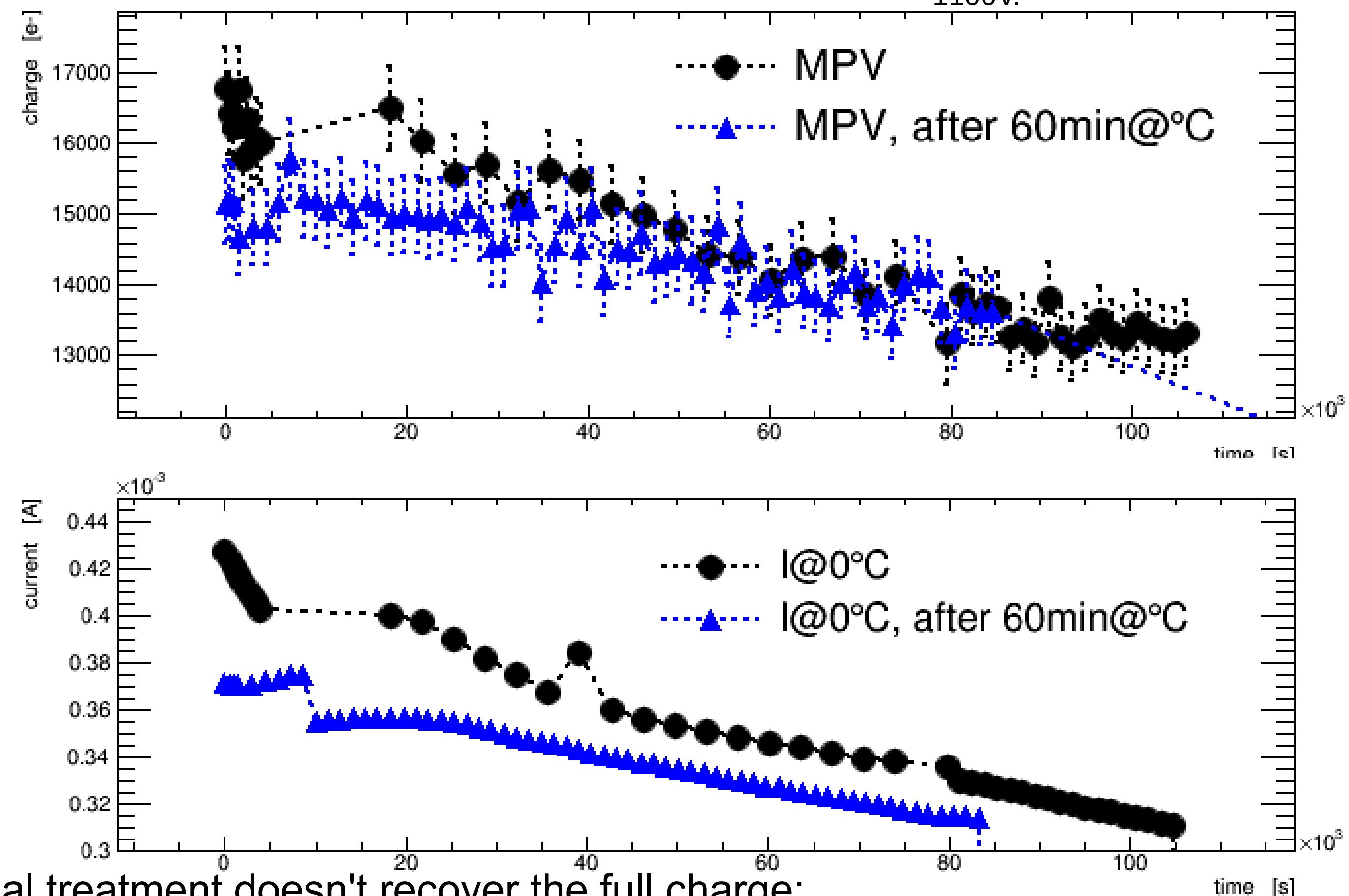


- Not significant, but drop also without source.
  - Effect should come from the high voltage.
- Thermal and no-HV treatments have large effect (the sensor was tested before time=0s).

Experimental results: recovery trials

- Thermal treatment effect:
  - Charge collection and current vs. time:

•ATLAS07.
•(Pitch,width)=(74.5,16)um.
•P-stop.
•(0.932+0.19+0.945)*10^{15} n_{eq}/cm^2 (mix), 4200 min@RT.
•1100V.

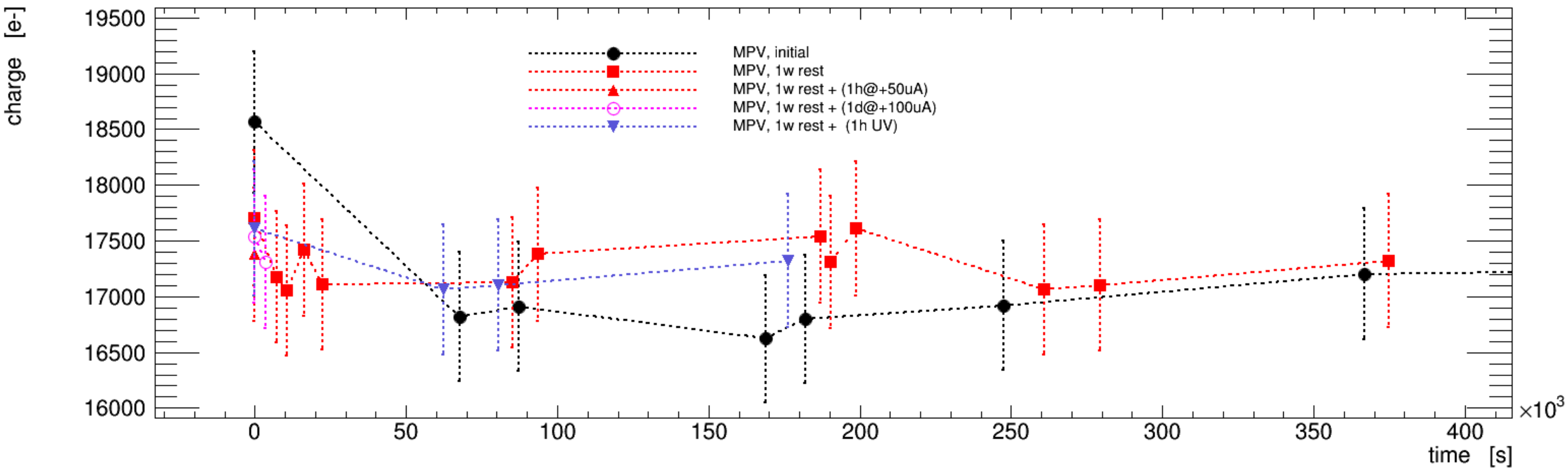


- Thermal treatment doesn't recover the full charge:
  - There is a permanent effect.
- Current reflects the drop in charge collection.

Experimental results: recovery trials

- UV-light and forward bias:
  - MPV vs. time:

•Micron.
•(Pitch,width)=(100,10)um, 2E impl..
•P-spray.
•$1*10^{15}$ n_{eq}/cm^2 (p).
•1300V.

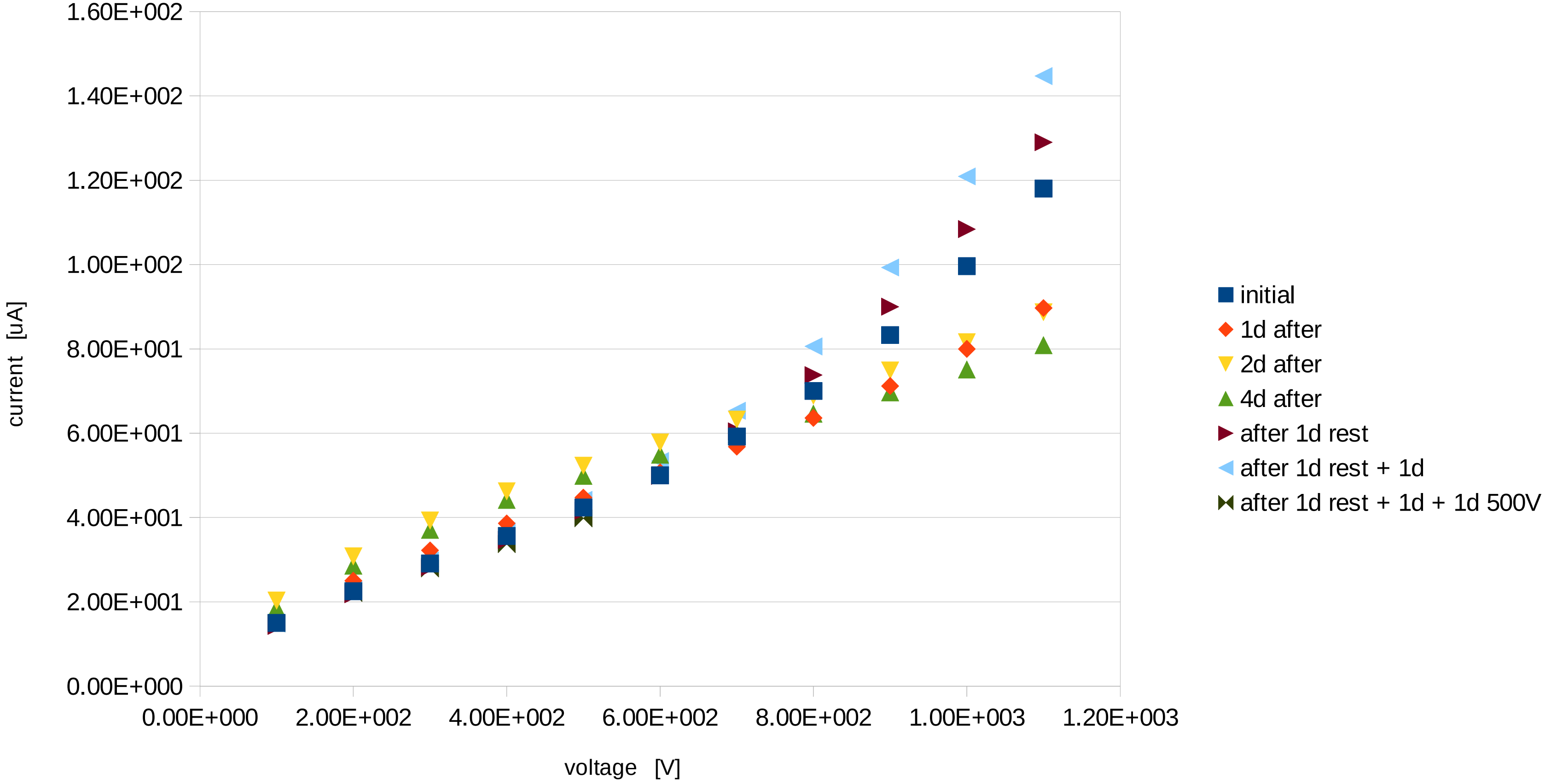


- UV light (1h), forward bias (100uA, 1d), do not have significant effects.

Experimental results: laser

- Current vs. voltage:

•ATLAS07.
•(Pitch,width)=(74.5,16)um.
•P-stop.
•$(0.932+0.19+0.945)*10^{15}$ n_{eq}/cm^2 (mix), 4200min@RT.



- The current decreases with the high voltage stress, loosing the higher order component.
- Resting time without high voltage restores the higher current.
  - It can come from the decreasing of the junction edge field or of the SiO2-Si interface current.

Experimental results: laser

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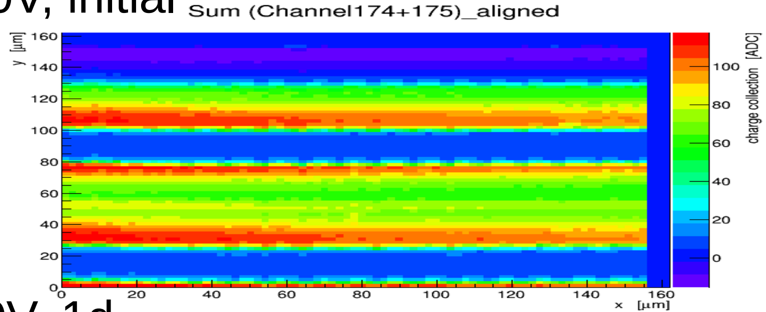
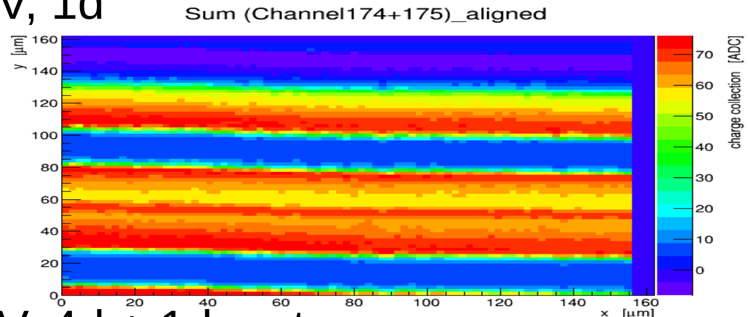
- Maps vs. time:

•ATLAS07.
•(Pitch,width)=(74.5,16)um.
•P-stop.
•$(0.932+0.19+0.945)*10^{15}$ n_{eq}/cm^2 (mix), 4200min@RT.

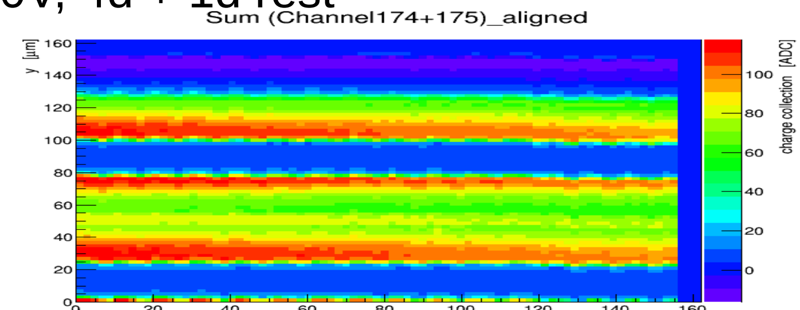
•1100V, initial



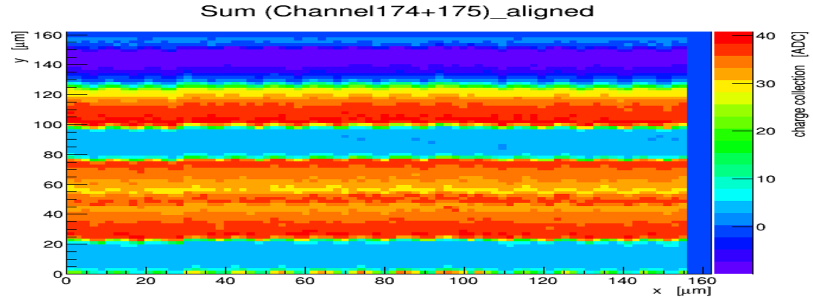
•1100V, 1d



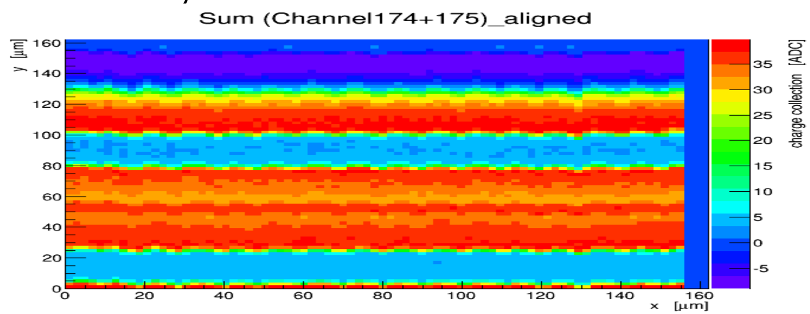
•1100V, 4d + 1d rest



•500V, initial



•500V, 1d



- Large part of the drop occurs close to the implants.
- Drop occurs only at high voltage,
- No bias period recovers works (at least partially, sensor was already tested before).

Experimental results: laser

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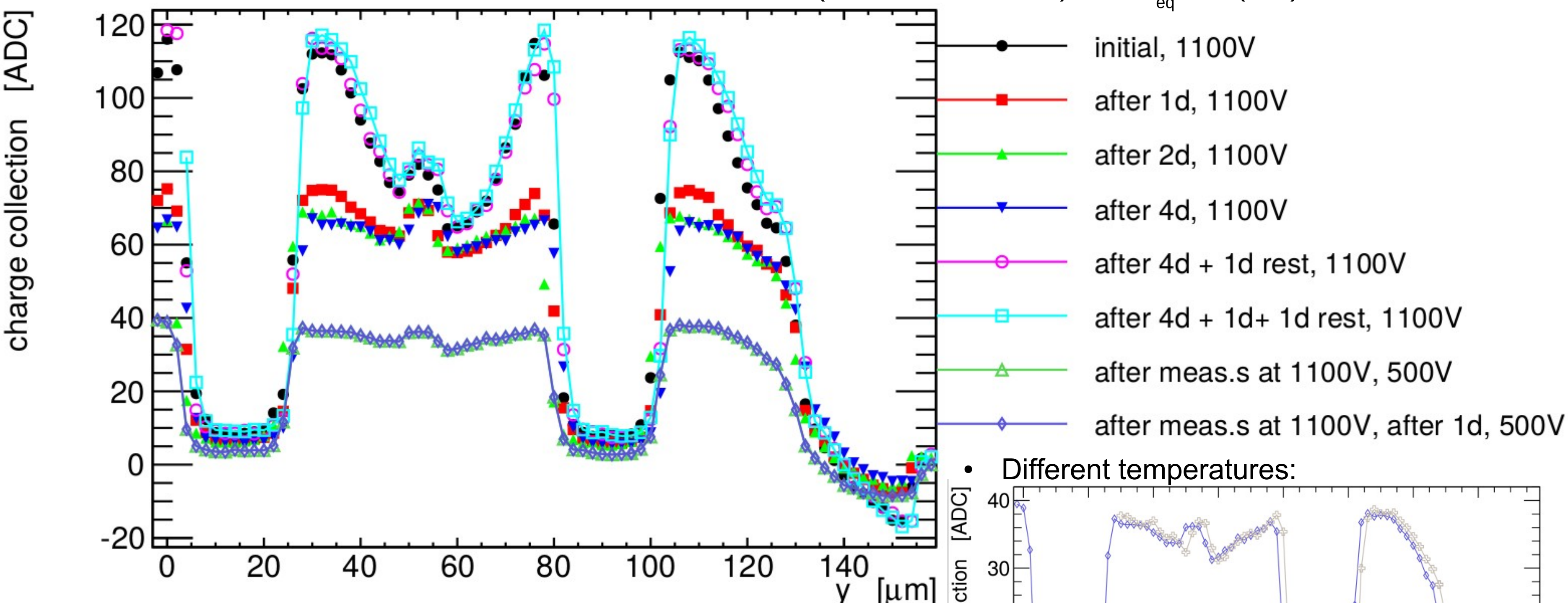
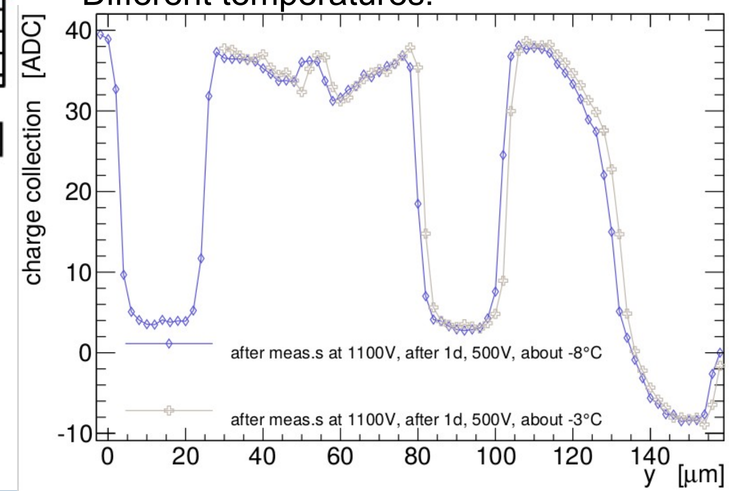
- Profiles:

•ATLAS07.
•(Pitch,width)=(74.5,16)um.
•P-stop.
•(0.932+0.19+0.945)*10^{15} n_{eq}/cm^2 (mix), 4200min@RT.



- Different temperatures:



- Large part of the drop occurs close to the implants.
- Drop occurs only at high voltage,
- No bias period recovers works.
- No significant temperature influence.

Discussion

- Temporary effect:
  - Coming from a bistable defect, slowly changing properties with the high voltage.
  - Coming from a change in the charge distribution on defects:
    - Slow change => large trapping time => small capture cross section or low carrier velocity.
      $T=1/(\sigma^* v^* N_t)$
    - Defects at the SiO2-Si interface can have very small cross[9] section and are in a region with low field (then low carrier velocity).
  - Coming from other effects related to the high current in charge multiplication mode.

- Permanent effect:
  - Still no explanation. We guess that the defect distribution is changed in a sort of annealing due to the very high field or to the very high current (also higher temperature) at the implant corners. (Here even a small change is critical for charge multiplication…)

- Possible further measurements:
  - Localization of the change:
    - Edge-TCT measurements: but we need very high resolution to resolve the implants…
  - Correlation with the defects and eventual (permanent) change:
    - Defect spectroscopy (TSC, DLTS, etc.) longterm measurements: relatively easy to be done.

[9] e.g. Ryan et al., APL 106, 2015.

Summary

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- Work:
  - Several sensors have been tested in a longterm measurements by means of beta source or laser measurements.

- Results:
  - Events having cluster size 1 or 2 have different charge distributions, explaining the broad (double-peaked) Landau.
  - Many sensors drop in charge collection with voltage higher than 1kV on 300um. (Interesting no drop on HPK ATLAS12.)
  - Laser measurements without beta source show also a drop in performance.
  - The change happens close to the implant edges, the region with the highest field.
  - It has been confirmed that there is a permanent and a temporary change, the latter recovered with a resting time without bias or by warming up.

- Conclusions:
  - The main cause of the performance drop is the high voltage.
  - The temporary change can be due to a polarization effect involving particularly slow defects (in the bulk or at the SiO_2-Si interface).
  - The permanent effect has still to be explained.

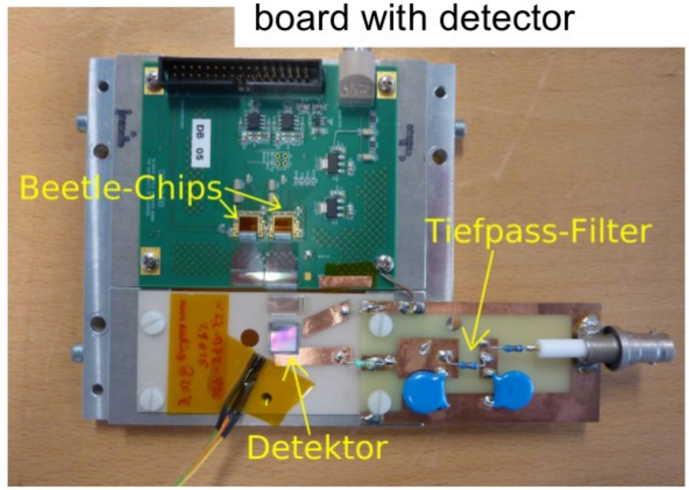
Back-up

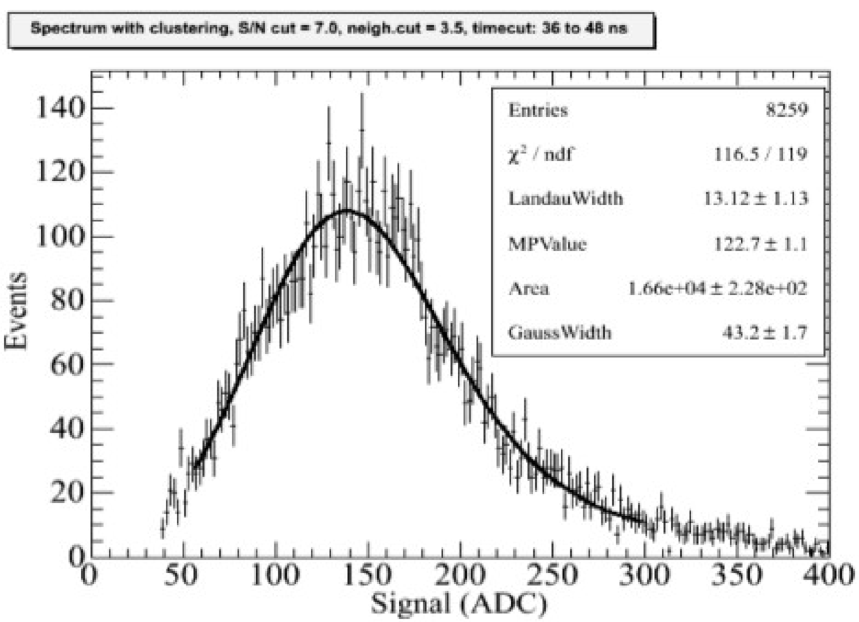
- Materials:
  - AliBaVa.
  - Set-up.
- Methods.
- Results:
  - Distribution: double Landau.
  - Other sensors longterm.
- Discussion:
  - CC ATLAS vs. fluence.
  - Accumulation layer.

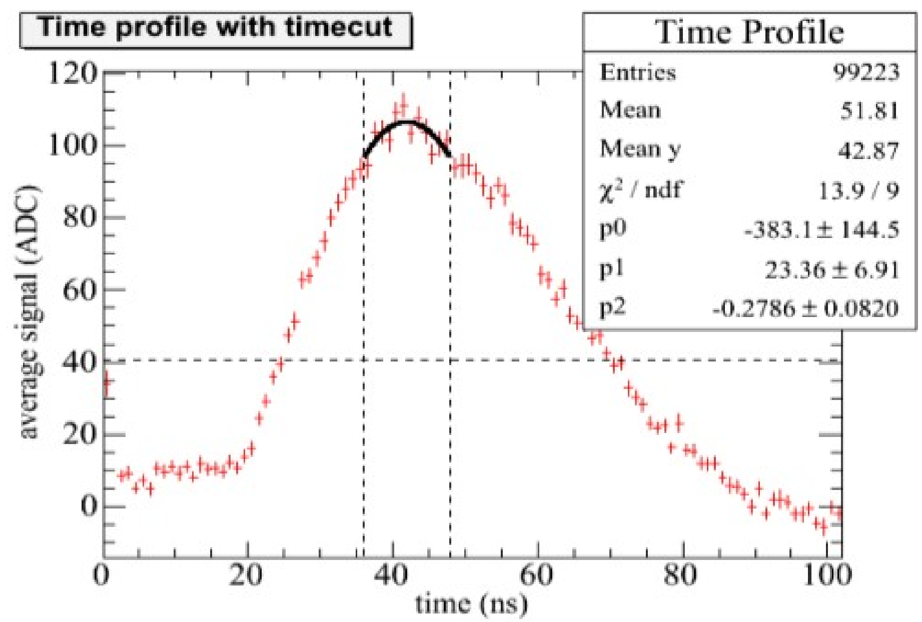
Back-up: materials

- AliBaVa.

ALIBAVA daughter board with detector

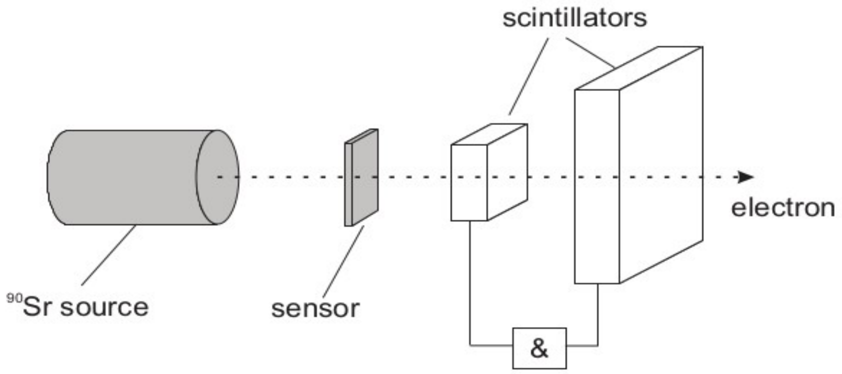




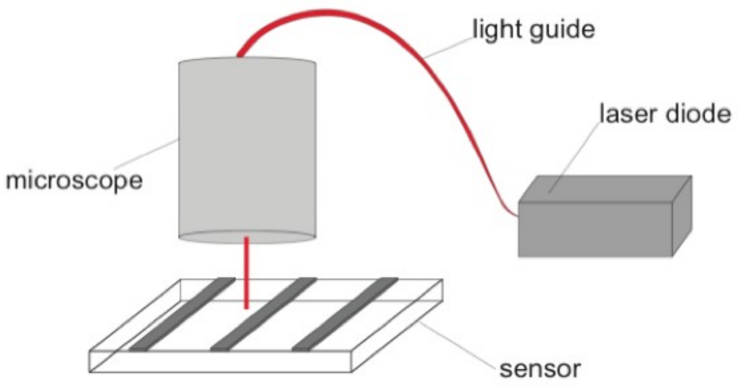


Back-up: materials: set-ups

- Beta:
  - ^{90}Sr source, two scintillators in coincidence.
  - AliBaVa system (Beetle chip) (daughter board calibrated in temperature with a standard 296μm thick sensor).
  - Freezer (down to -20°C).



- Laser:
  - 971nm, ~4μm FHWM.
  - AliBaVa system (Beetle chip).
  - Chiller (down to -8°C).

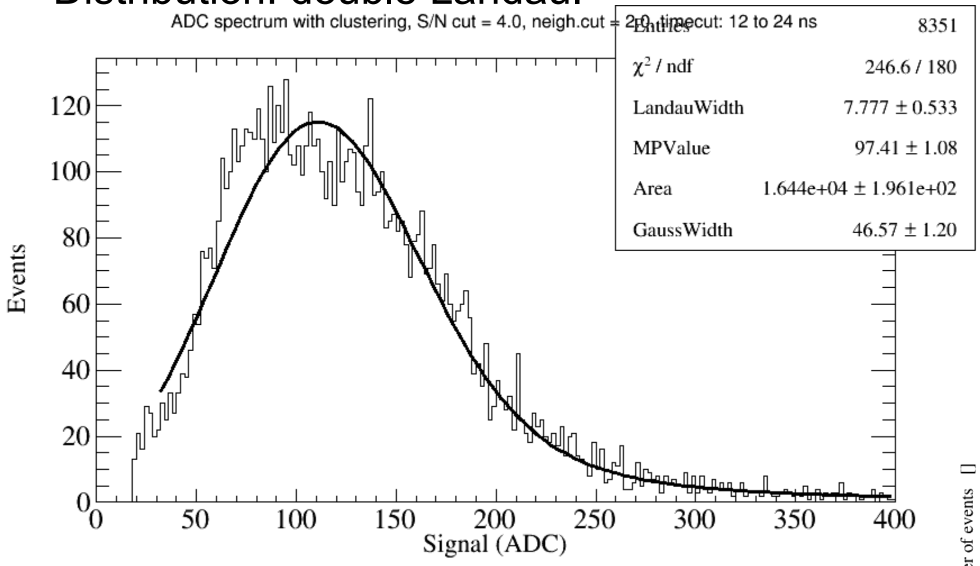


Back-up: methods

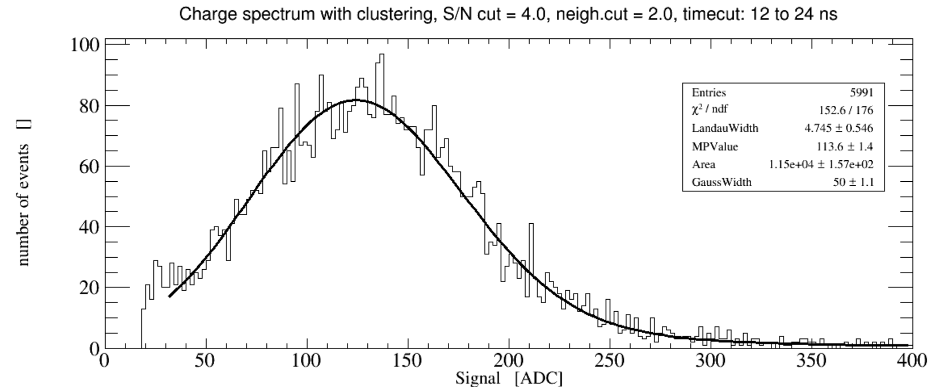
- Experimental:
  - Beta:
    - Longterm with high voltage (HV) and source in front.
    - Longterm with high voltage removing the source.
      - Recovery trials: no bias, UV light, warming.
    - (Capacitance spectrum monitoring.)
  - Laser:
    - Longterm with high voltage, laser scan on a large area (160*160 um2).
      - Recovery trials: no bias.
- Analysis:
  - Beta:
    - Most Probable Value (MPV) (or median) vs. time.
    - Distributions discriminating between cluster size 1 and 2 (to explain the broad distribution and relate it with the drop in charge).
  - Laser:
    - Relative charge collection profiles orthogonal to strips.
    - Different temperatures (to observe dependence on it).

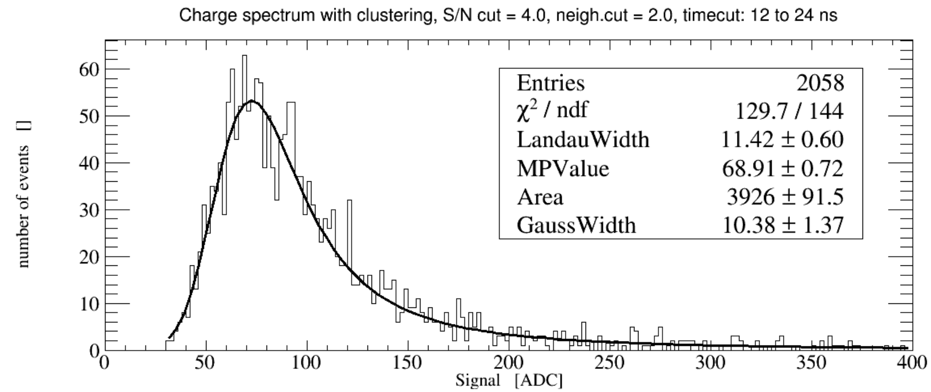
Back-up: results

- Distribution: double Landau.



- Micron.
- P-spray.
- $5*10^{15}\ n_{eq}/cm^2$ (n).





Back-up: results

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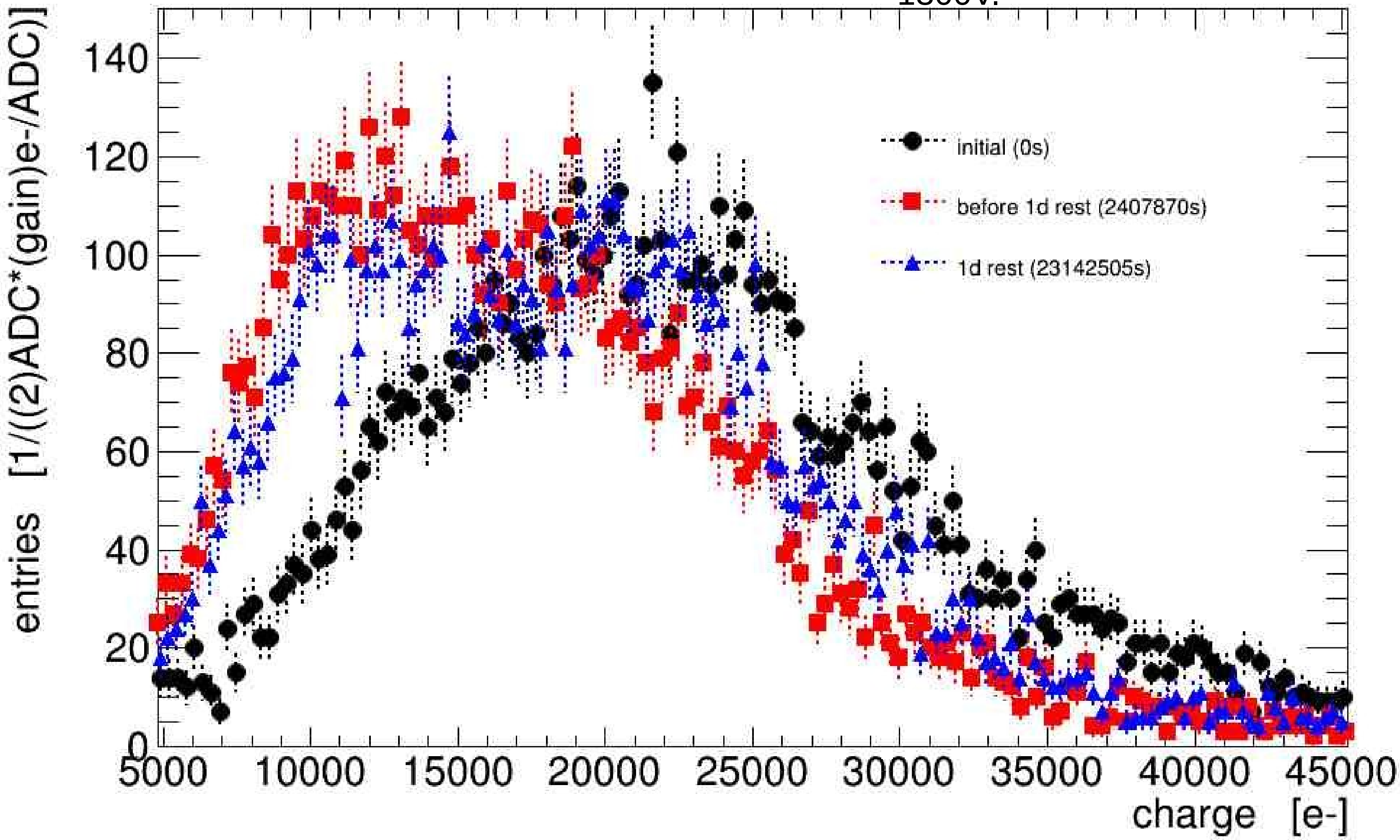
- Distribution: versus time.

- Micron.
- P-spray.
- $5*10^{15}$ n_{eq}/cm^2 (n).
- 1300V.



Back-up: results

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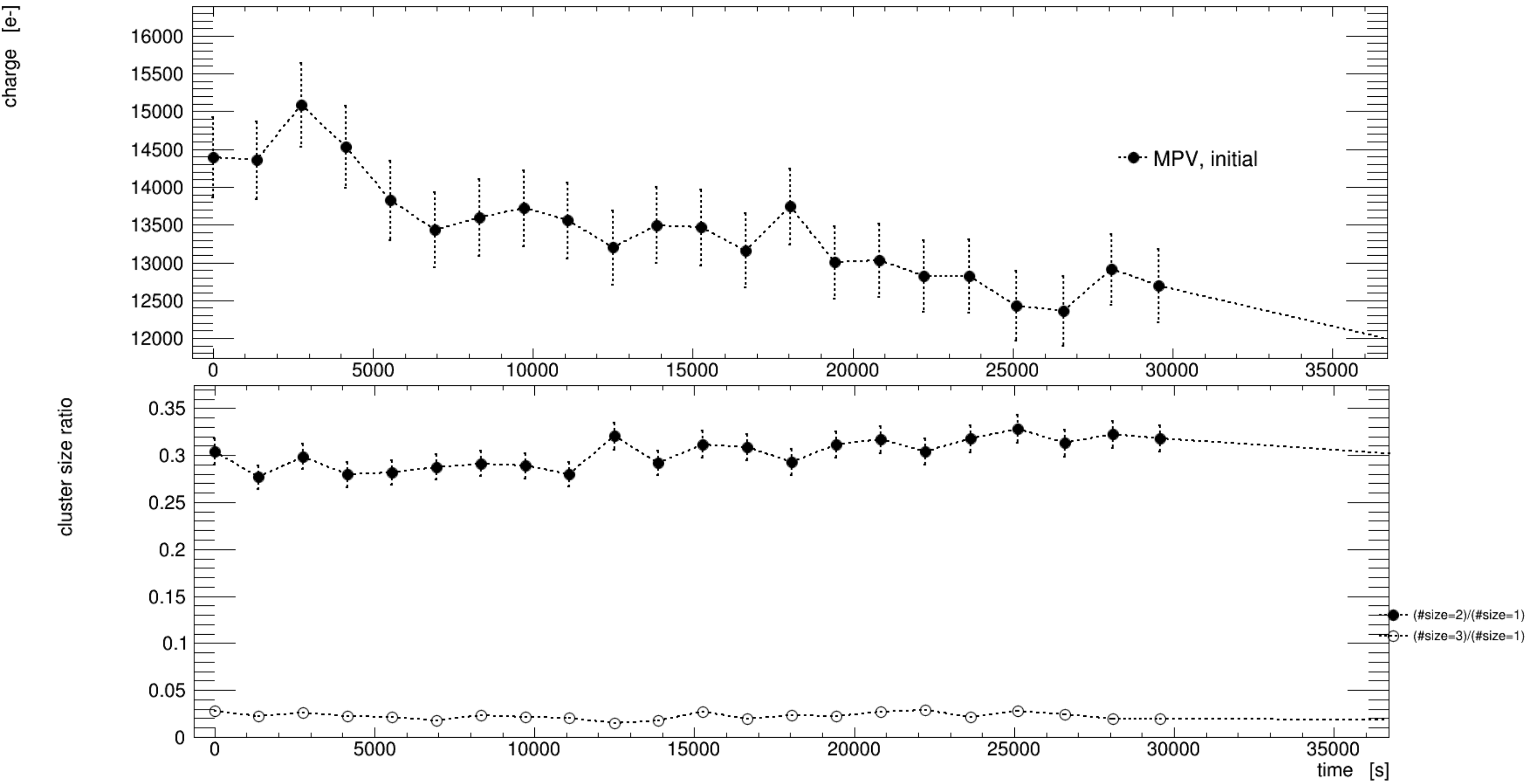
- Longterm results: charge collection drop (sensor tested with laser).
  - ATLAS07.
  - P-stop.
  - $(0.932+0.19+0.945)*10^{15}$ n_{eq}/cm^2 (mix), 4200min@RT.
  - 1100V.



Back-up: results

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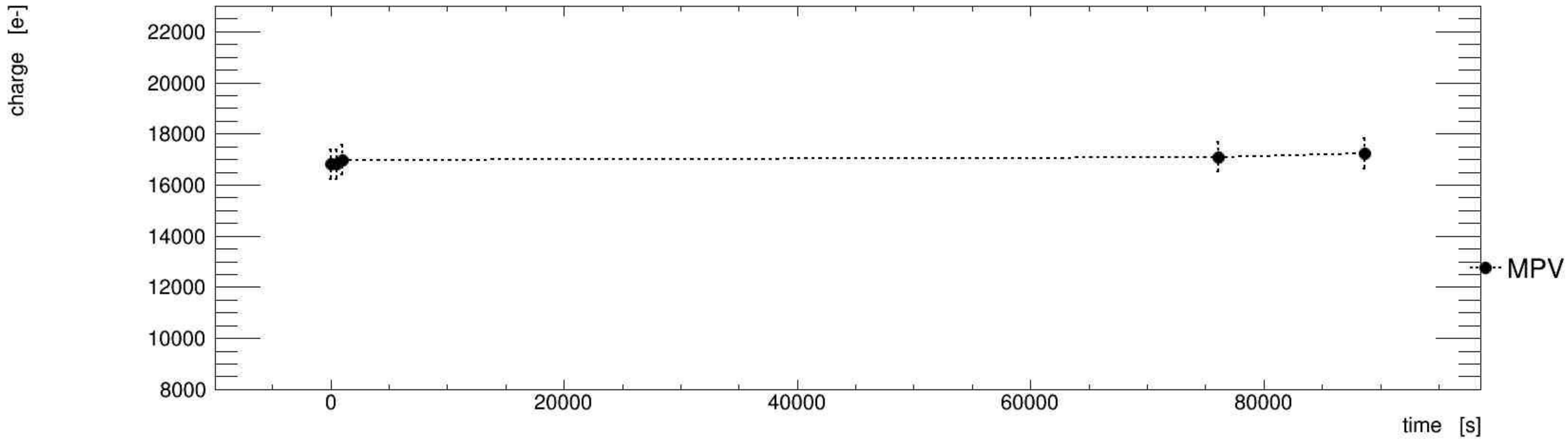
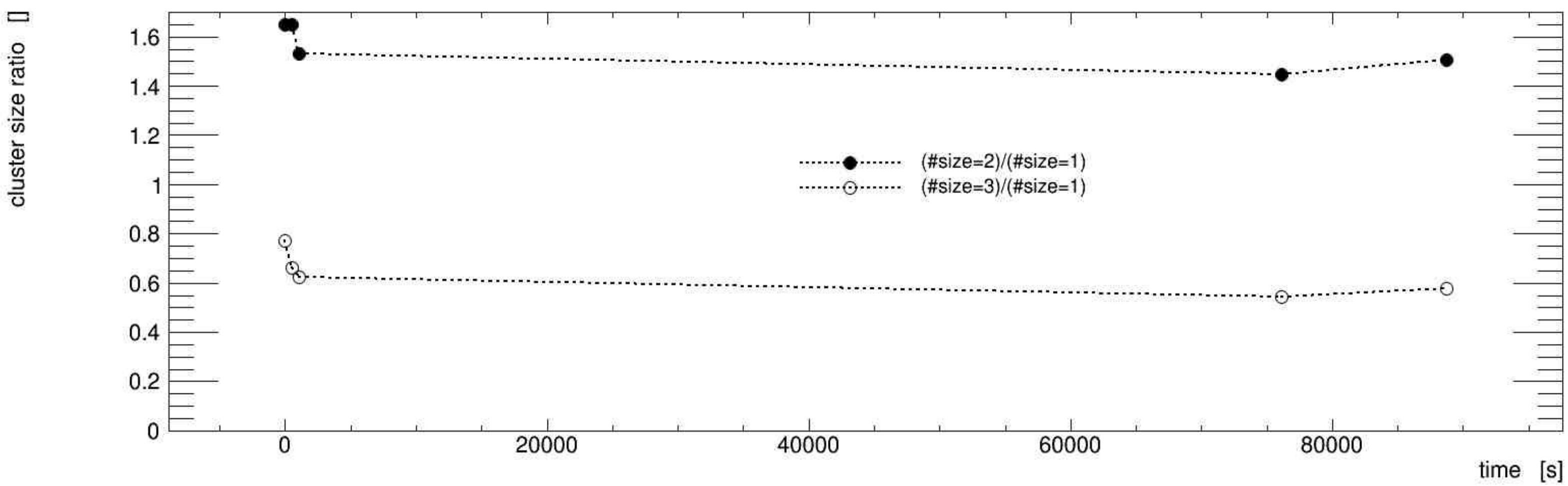
- Longterm results: ATLAS12.

•ATLAS12.
•P-stop.
•$2*10^{15}$ n_{eq}/cm^2 (p), 80min@60°C.
•100V.





Back-up: results

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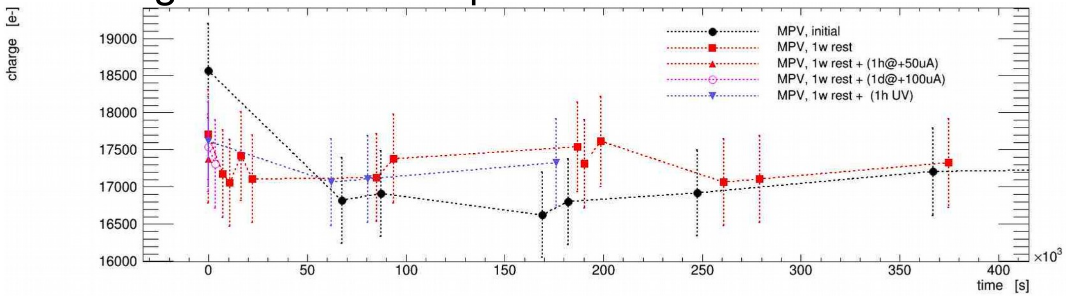
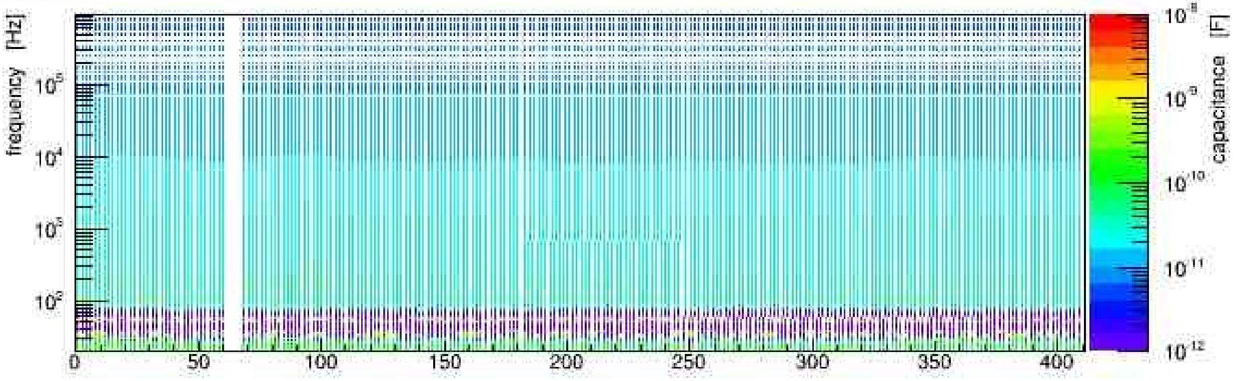
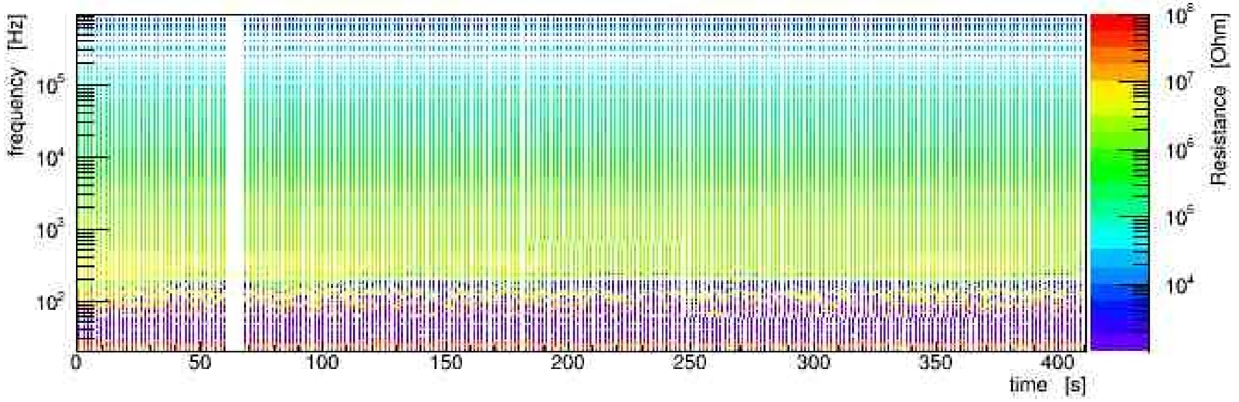
- Longterm results: impedance.



- Micron.
- P-spray.
- $1*10^{15}$ n_{eq}/cm^2 (p).
- 1300V.





Back-up: discussion

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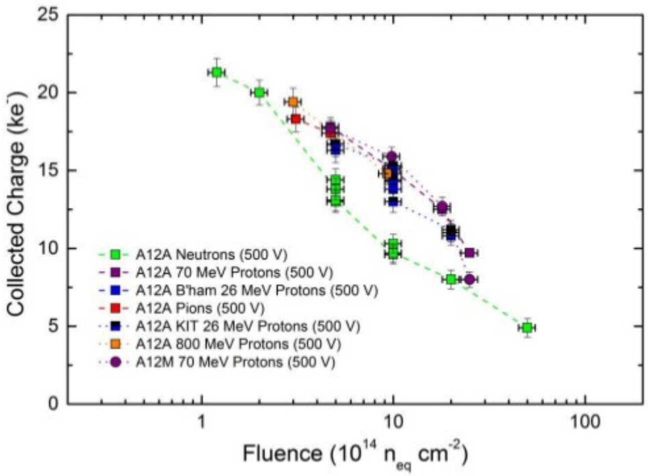
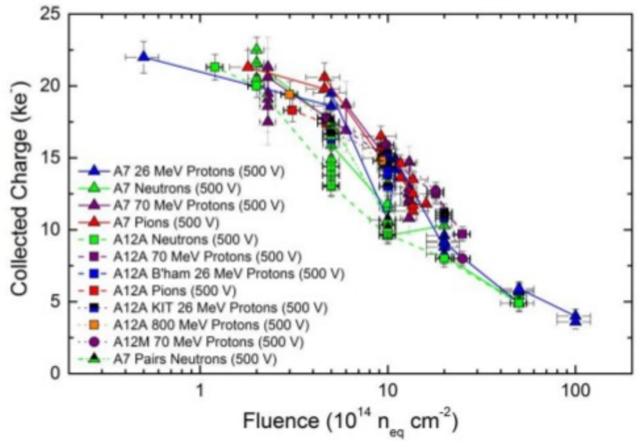
- CC HPK ATLAS12 vs. fluence.

Grand Summaries

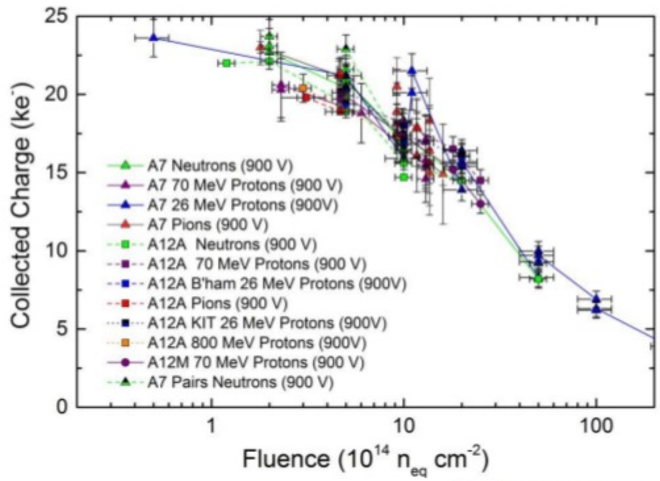
ATLAS

[10]





Measurements match expectations.
For ATLAS12 difference between neutrons and charged irradiations larger.
At 500 V, the neutron irradiated devices are still significantly lower than charged
At 900 V, everything is more similar.



[10] Affolder, talk AUW 2014.

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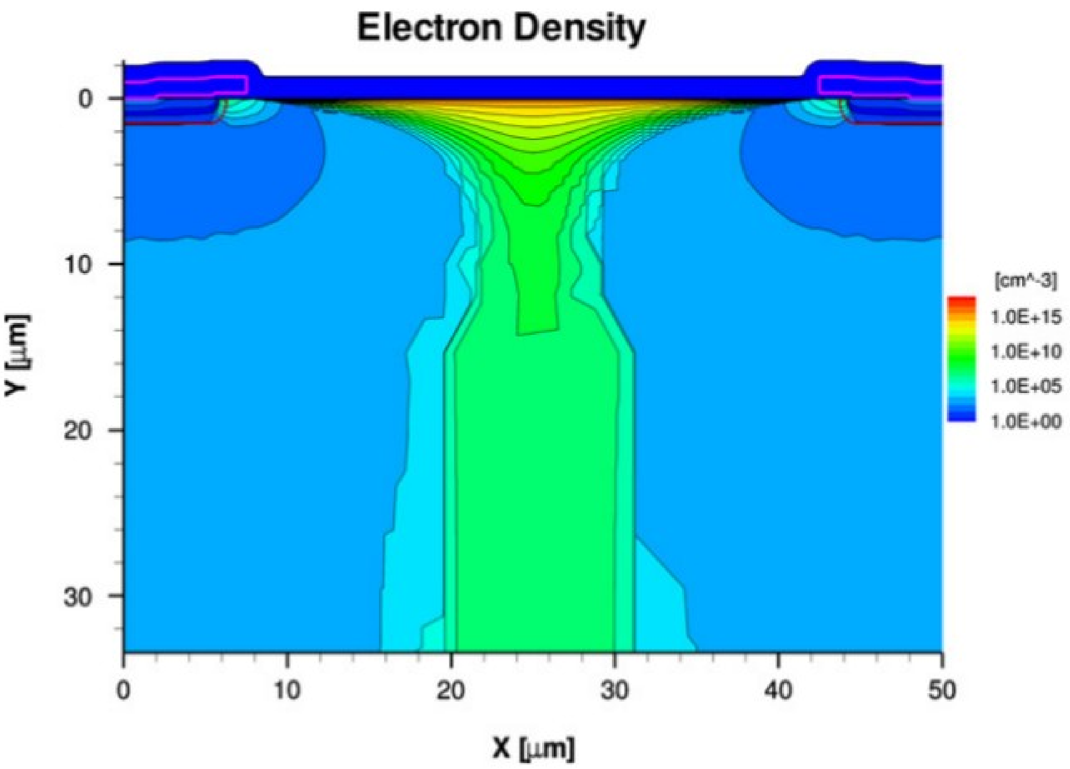
Back-up: discussion

- Electron accumulation layer:

[7]



[7] Pöhlsen, NIM A 700, 2013.