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Stability of Charge Multiplication in Silicon Strip Sensors

PETTL Workshop
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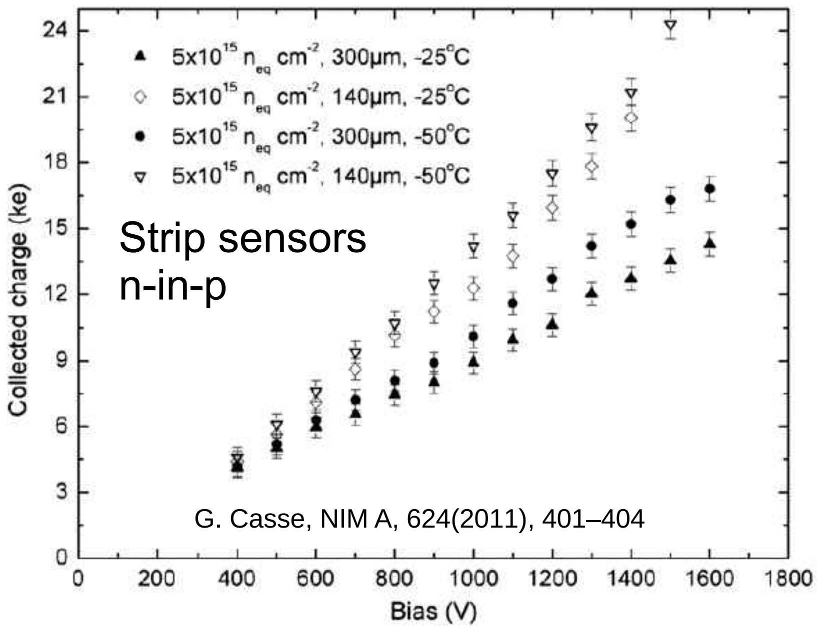
Outline

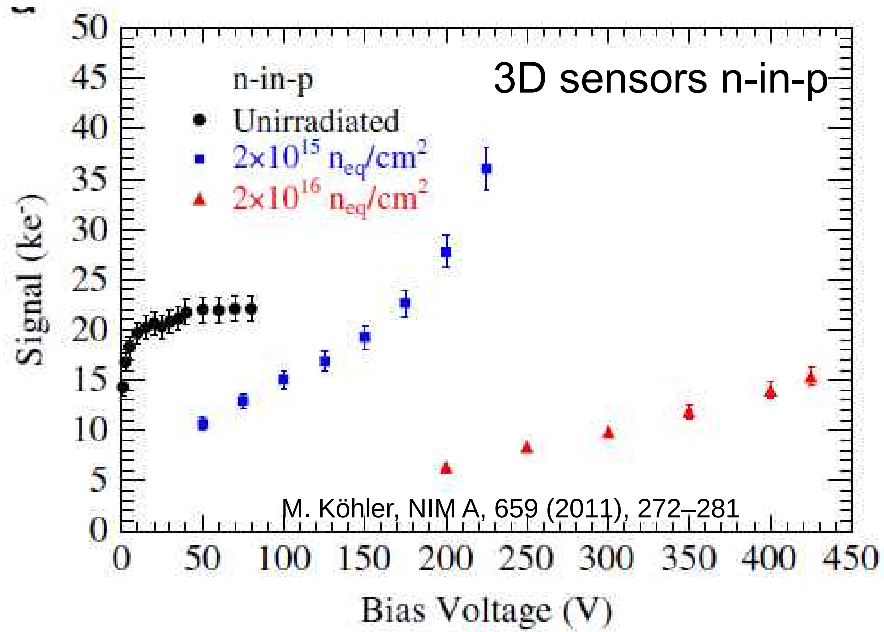
- Introduction
    - Charge multiplication in silicon strip sensors
- Results from simulation
- Results of dedicated charge multiplication sensors
- Results of long-term measurements
- Summary

Most results from recent talk at 9th Trento Workshop 2014 in Genova by Riccardo Mori

Charge Multiplication in silicon sensors

More than 100% collected charge seen after irradiation to 2-5*10^{15} n_{eq}/cm^2:
charge multiplication observed in pad, strip and 3D silicon sensors

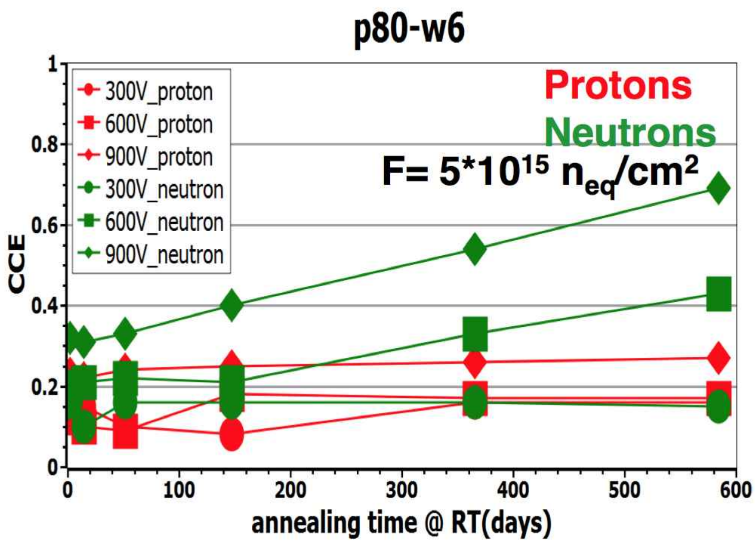




Charge Collection (Beta source, Alibava readout)

Charge Multiplication ctd'

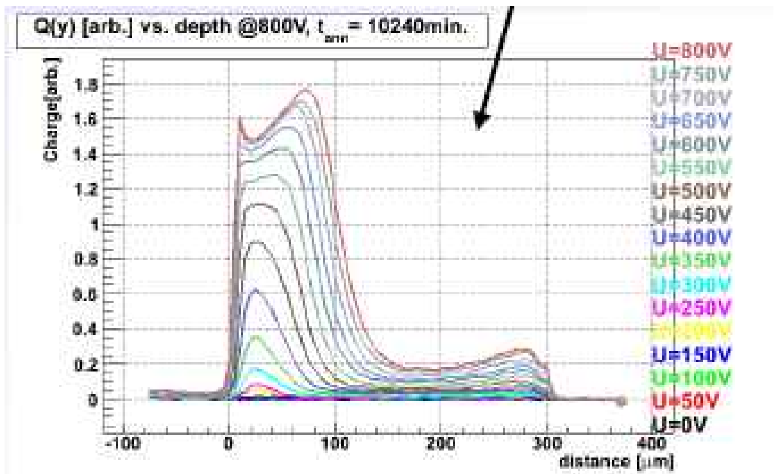
CM observed after long annealing times



[L.Altan, RD50 WS, June 2013]

Edge-TCT measurements indicate where charge is generated and multiplied G. Casse M. Moll, LHCC Report, 2012

[M. Milovanović, 19th RD50 Workshop, Nov.2011]



- CM observed for high neutron irradiation and increasing annealing time depending on sensor geometry
  - F= $5*10^{15}$ n_{eq}/cm^2
  - w/p= 0.075, p=80 μm
  - Depth= 305 μm

- Increase of the electric field close to the strips causing impact ionization/carrier injection when high concentrations of effective acceptors are introduced at very high fluences

Open questions: simulation of effect, long-term stability, behaviour of signal-to-noise

Problems: high leakage currents, noise multiplication

Approach: Simulation studies

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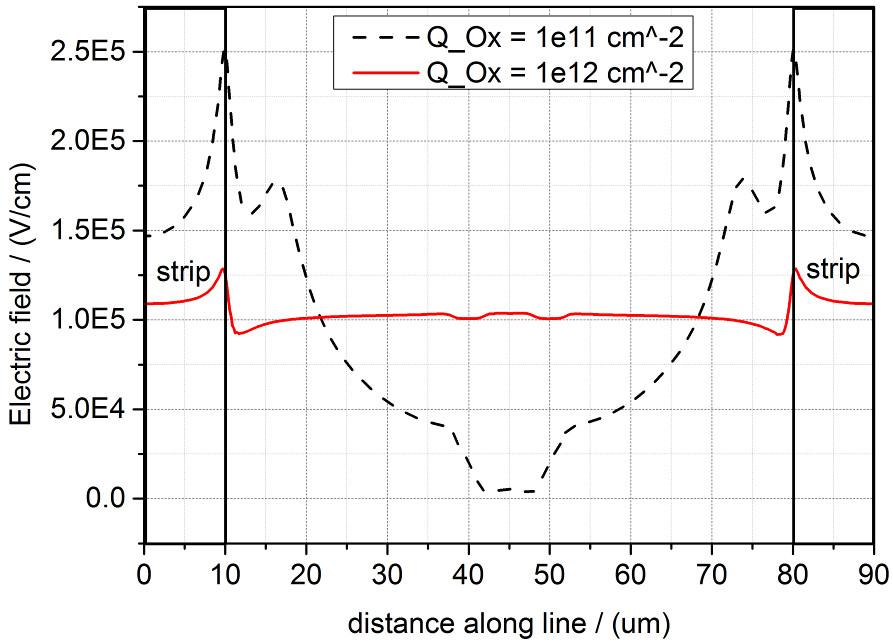
- Simulations show high electric field close to strips

- CM effect of interface oxide charge?
- approach: simulation studies
  - high electric fields at pn-junction decrease with increasing oxide charge Q_Ox
  - charged hadrons introduce oxide damage
  - Q_Ox increases
- CM suppressed in CMS due to significant part of ionising dose by charged hadrons



[M.Printz, CMS-CR-2013-267]

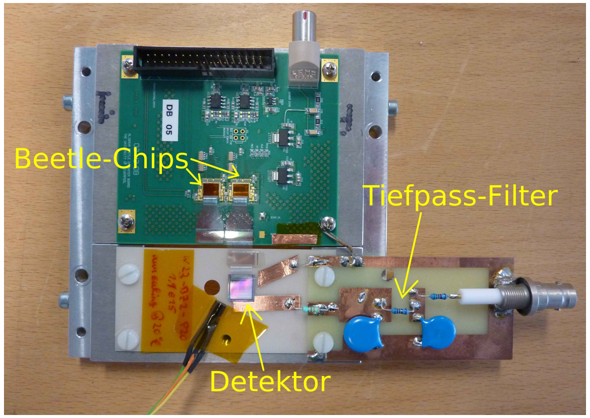
Approach: Tests of sensor with geometries to enhance charge multipl.

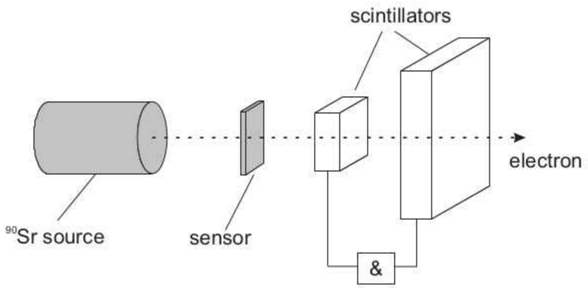
Production of sensors within RD50 Collaboration
Geometry variations:
- Deeper junctions
- Altered doping gradient
- Ratio of strip implant and pitch

Measurements to determine collected charge, noise, signal-to-noise by using beta source set-up

- Samples:
  - Micron, p-type, strip with different pitches and widths, standard and double implantation energy
  - Irradiation: neutrons to [1,5]*10^{15} n_{eq}/cm^2
- Set-up:
  - Sr90 source, two scintillator in coincidence
  - AliBaVa system (Beetle chip, 40 MHz) (daughter board calibrated in temperature with a standard 296 µm thick sensor)
  - Freezer + cold nitrogen vapour flow (~ - 40°C)

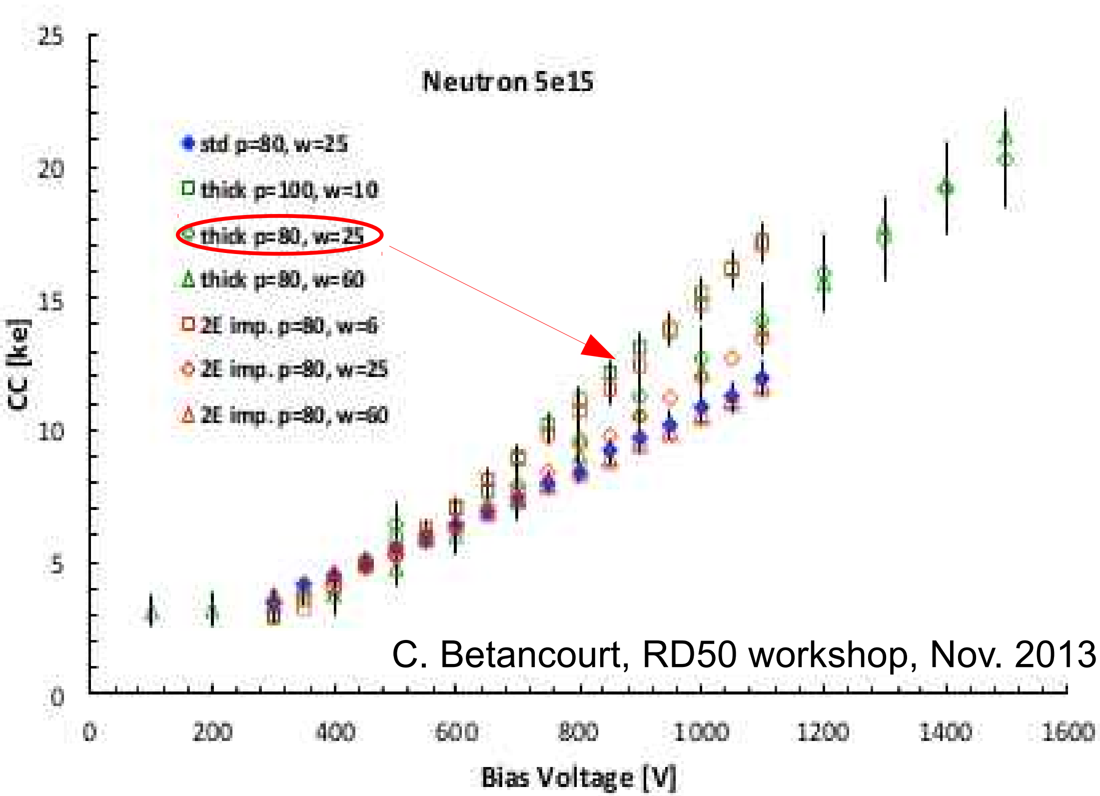
ALIBAVA daughter board with detector

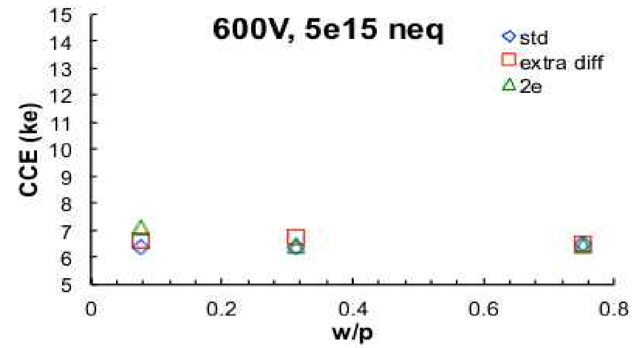


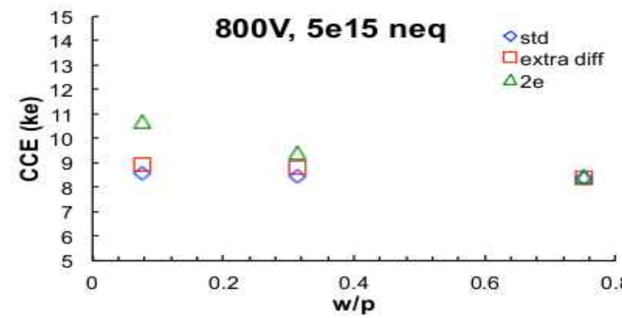


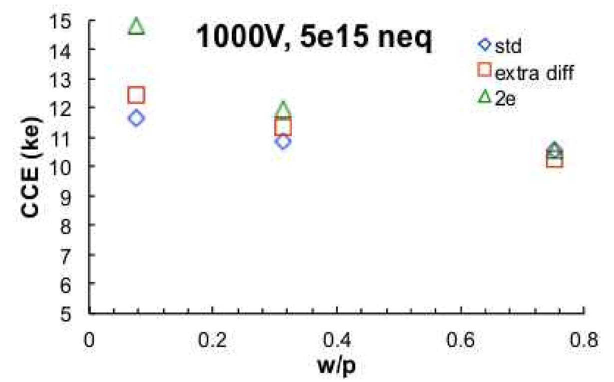
Results after irradiation

- Charge collection dependending on geometry









- Beneficial effect from decreasing width/pitch
- High bias voltage needed

Test of long-term stability of charge multiplication

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Sensors: p-type sensors with (pitches, widths)=(100,10),(80, 25) µm

Measurements:
- Measure charge collection at three bias voltages
- Bias detector maximally: before breakdown, short term stable current
- Keep the detector biased for several days and measure charge collection twice per day
- Monitored operative conditions:
  - temperature around -42 °C, deviations during N refilling;
  - relative humidity <5%;
  - compliance sometimes reduces the bias for ~1h/day during N refilling.

Monitoring of the results and resulting actions
- Significant drop in charge collection?
  - Yes: remove the voltage for 1 h, then 24 h
    - Recovered charge?
      - Yes: continue
      - No: warm up for 24 h
        - Recovered charge?...
- I-V at every break

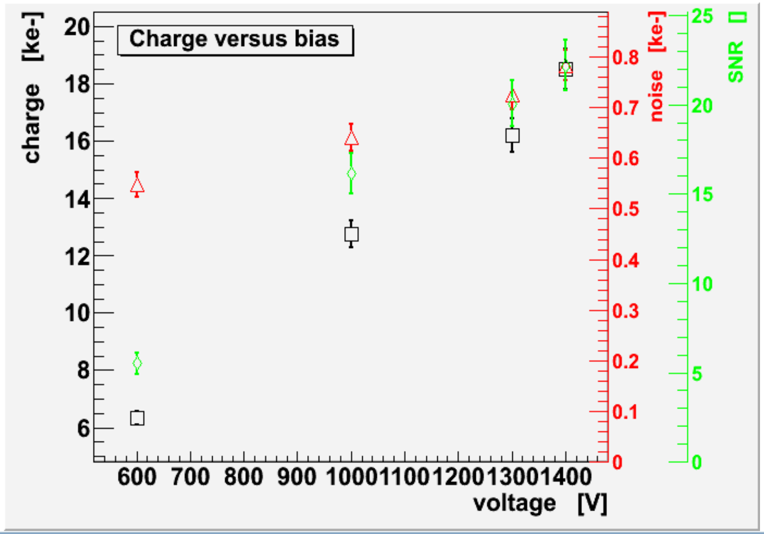
Results long-term tests I

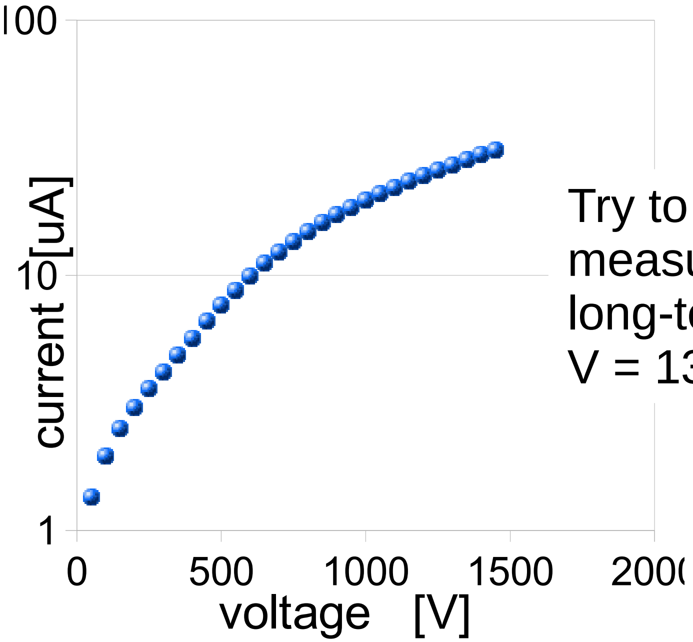
Long-term biasing behaviour

- Standard, $1*10^{15}$ n_{eq}/cm^2: broke in less than a day at 1000 V
- Standard, $1*10^{15}$ n_{eq}/cm^2: broke after 3 stable days at 1100 V
- Standard, $1*10^{15}$ n_{eq}/cm^2: immediate breakdown, irreversible damage
- Standard, $5*10^{15}$ n_{eq}/cm^2: stable for 3 days at 1500 V; breakdown, permanent damage, moving to 1600 V

→ All failed: a relatively short-term stability, does not imply long-term stability

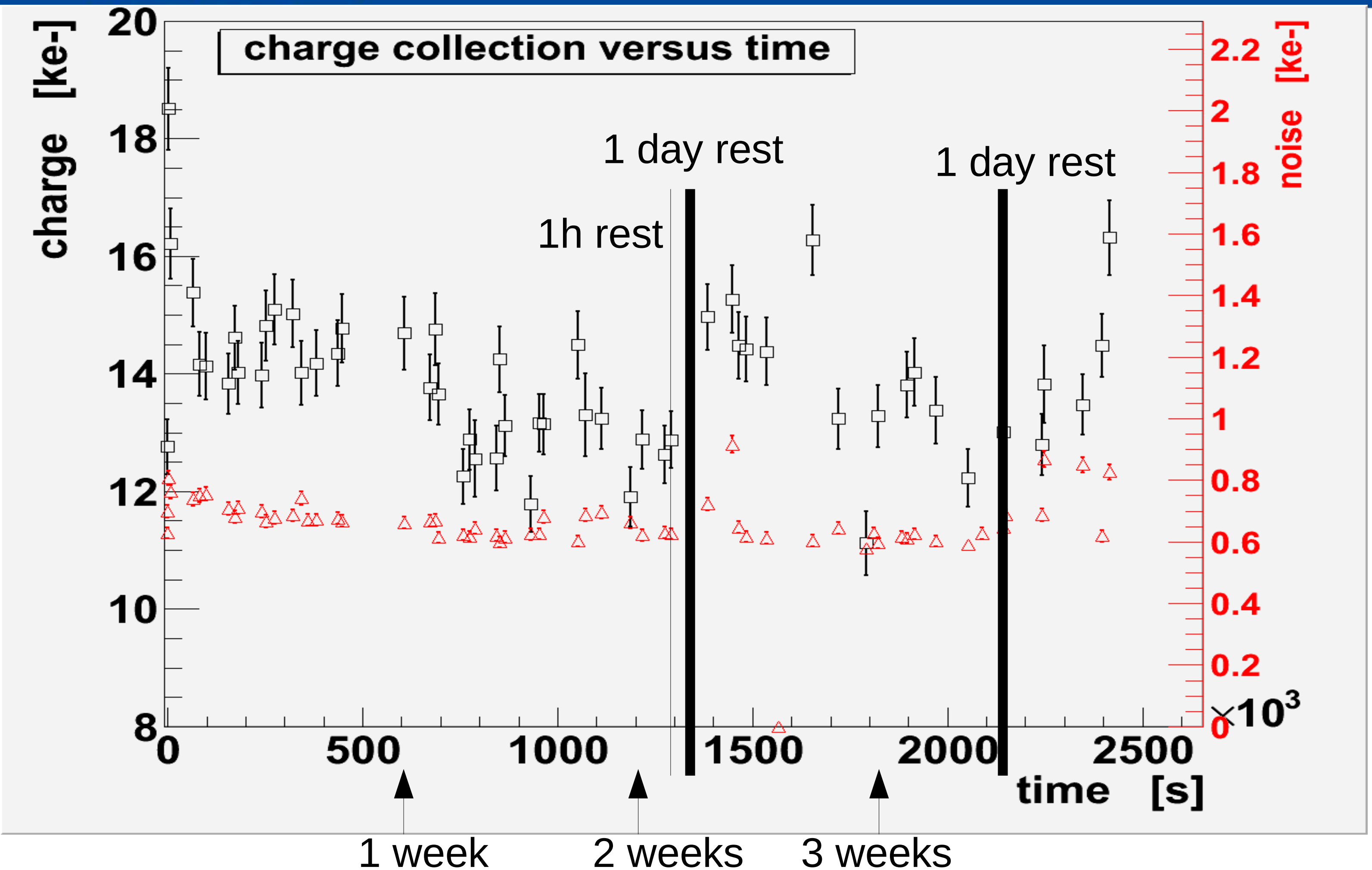
- Standard (p,w)=(100,10) μm, $5*10^{15}$ n_{eq}/cm^2





Try to measure long-term at V = 1300 V

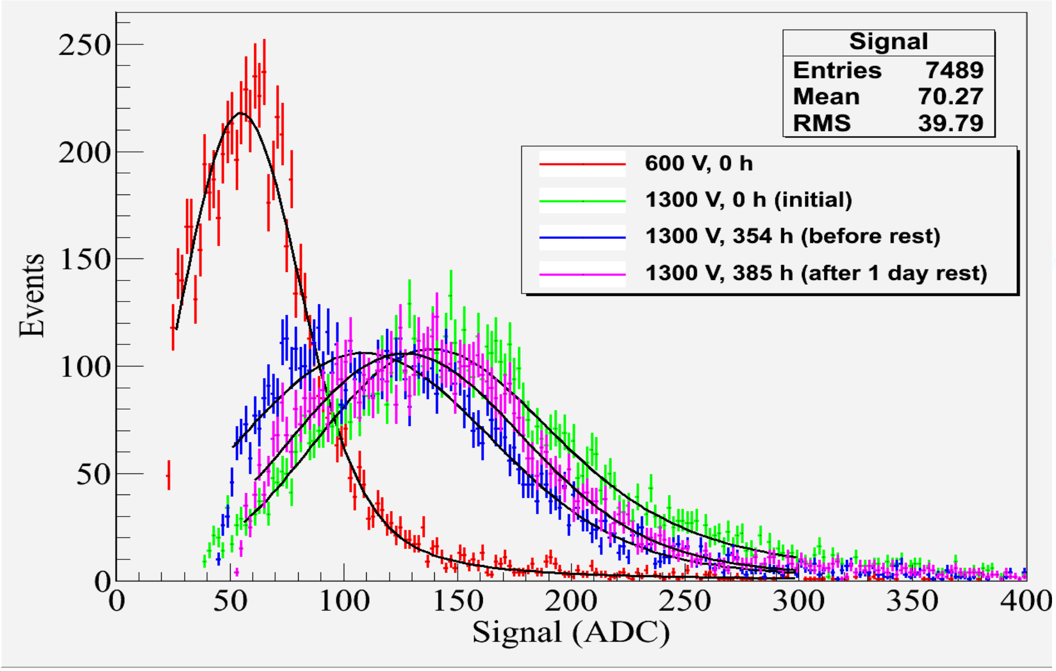
Results long-term tests II: Collected charge

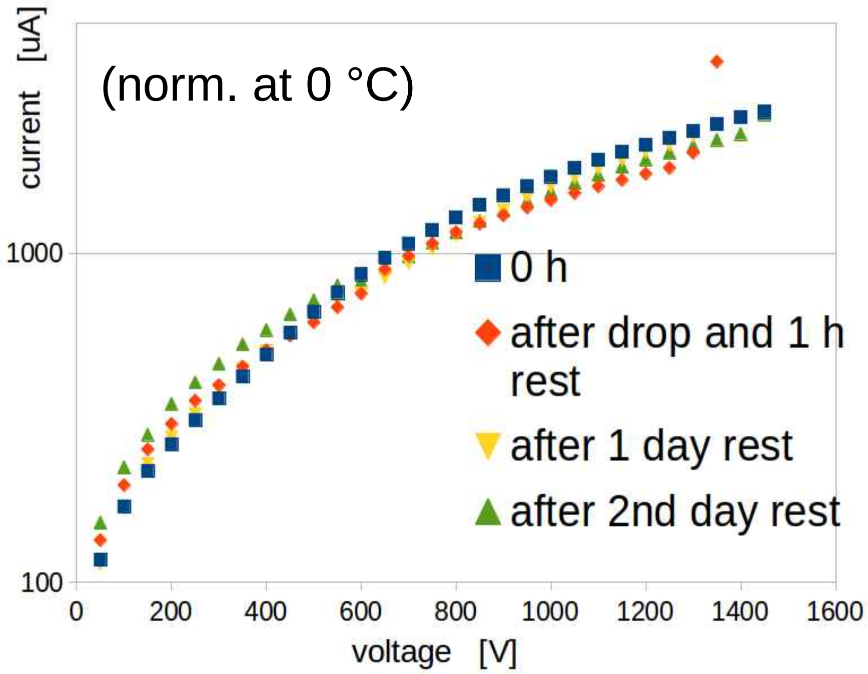


NOTE: outliers also due to much different (lower) temperatures

- Decrease of collected charge after few days
- Removing the voltage seem to (partially) recover the charge collection, but then drop again

Results long-term tests III: spectra and current



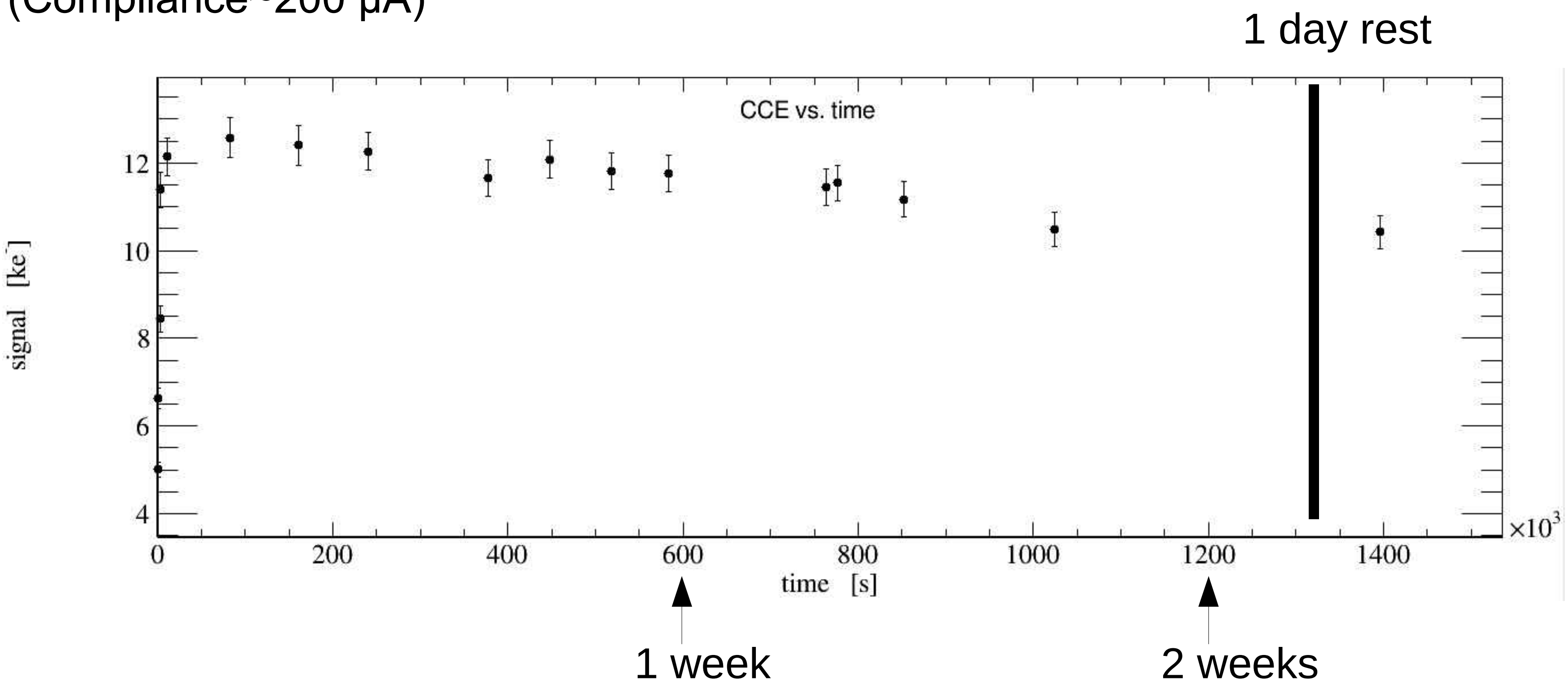


- Charge distribution change from 600 V and 1300 V (broader): statistical fluctuation and broader shot noise *(e.g. Lange et al., NIMA 622, 2010)*
  → charge multiplication take place
- Drop in most probable charge reflect the change in the distribution: broad and lower

- Observed a lower current immediately after resting periods but still persistent higher current in long-term

Results long-term tests IV: ongoing

- Second sensor under test: standard, (p,w)=(80,25) µm, dose $5*10^{15}$ n_{eq}/cm^2 (Compliance~200 µA)

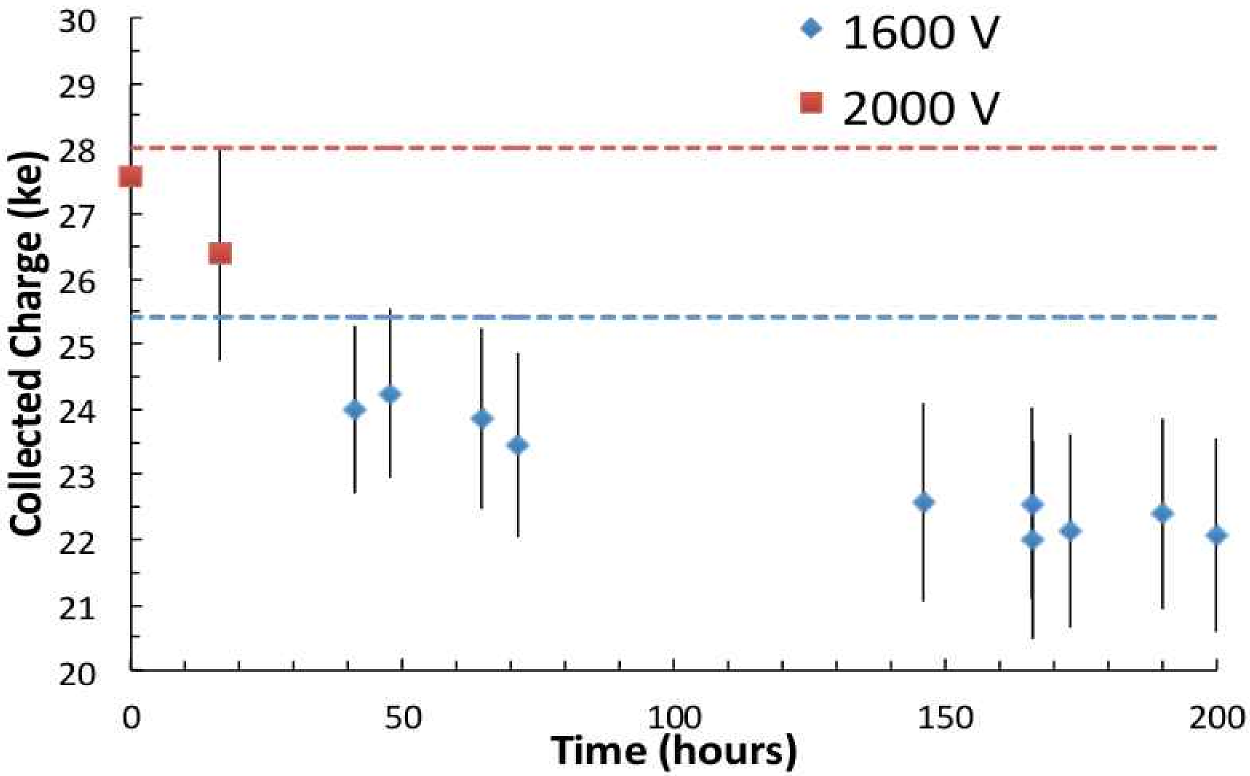


- Again unstable behaviour at 1400 V => down to 1300 V (first 3 points at 600 V, 800 V, 1000 V)
- Lower charge than the previous sensor
- Test ongoing

Comparison to other results (first observation!)

Charge collection over time

- Standard
- (p,w)=(80,60) µm
- $1*10^{15}$ n_{eq}/cm^2



Caused by?

Is an increase of oxide charge happening?
Other effects?

- An indication of a possible drop after several (~6) days.

From:
Sven Wonsak, private communication
Chris Betancourt, RD50 workshop Nov. 2013

Summary

- Charge multiplication is observed by relatively short-term measurements
- Multiplication due to high electric field close to strips, which causes impact ionization

- Simulations show reduction of electric field with increasing oxide charge

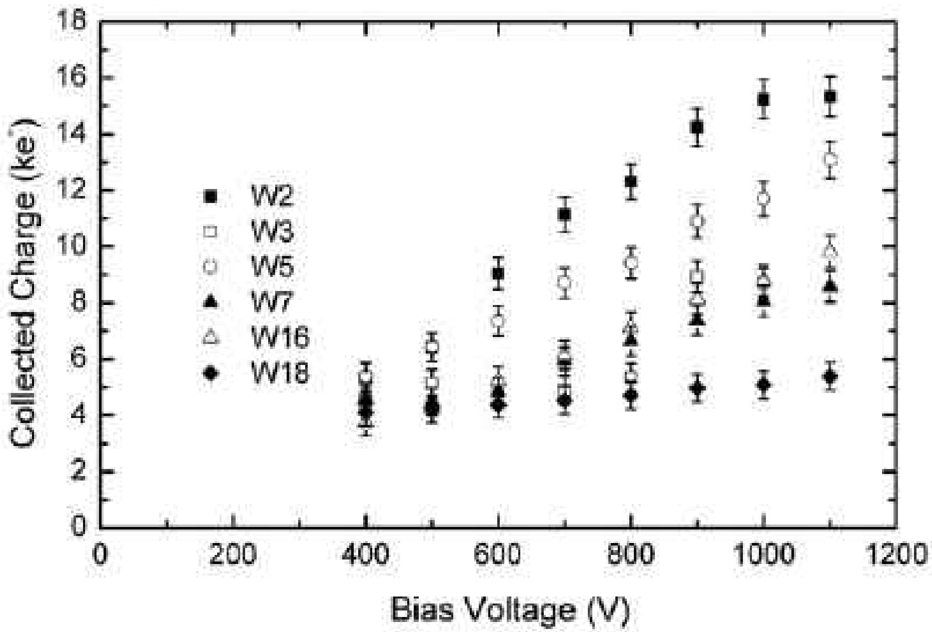
- Long-term tests show
    - Several sensor broken after significant time (several days): stress is long-term related
    - Collected charge reduces after few days: long-term change of sensor properties (electric field distribution)
    - Partial recover after a resting day
- Ideas for explanations:
    - Does the beta source increase the oxide charge? (Reduction of charge in long-term measurements of unirradiated sensors seen in CMS)
    - Is there some other effect changing the electric field?
    - Are trapping effects changing with time?

- More long-term measurements ongoing
    - More samples also unirradiated ones and with different fluences
    - Resting at higher temperature
    - Place source only for measurement of charge
    - UV stimulation at low temperature for some time (see effect of the oxide charge)

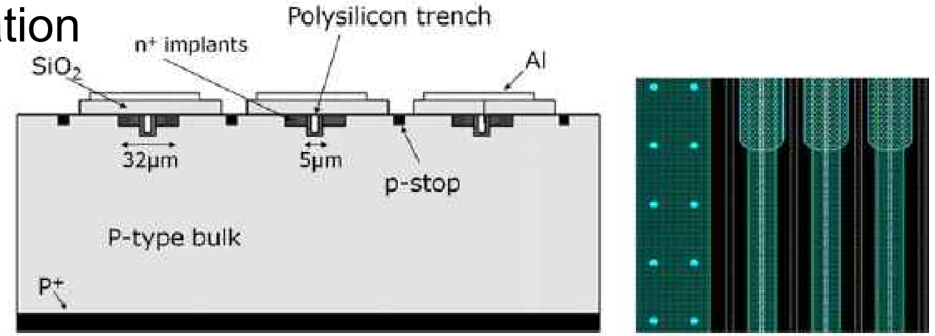
Spares

Sensors with geometries to enhance charge multiplication

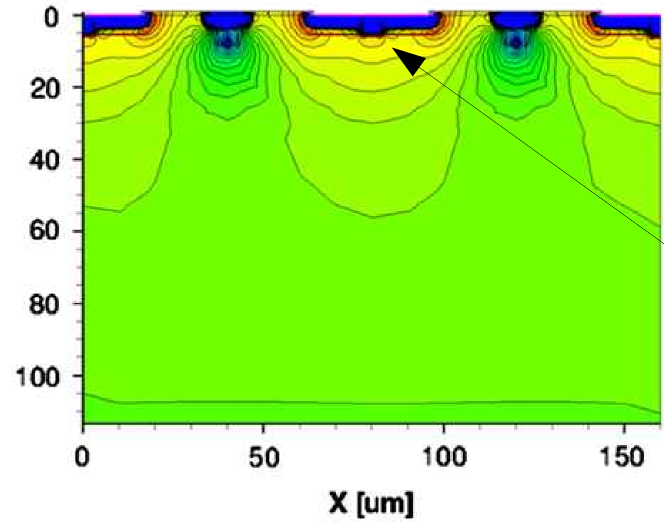
Production of sensors within RD50 Collaboration
Geometry variations:
- Deeper junctions
- Altered doping gradient
- Ratio of strip implant and pitch



Standard n-in-p sensor 300 μm thick, Trenches with 5 (W2), 10 (W7 std), 50 (W5) μm width, Deep diffusion 5 μm (W16), as implant (W18) after $5*10^{15}$ neq/cm^2



G. Casse, NIM A (2012), http://dx.doi.org/10.1016/j.nima.2012.04.033



High electric field (reduced trapping)

P. Fernández-Martínez, NIM A 658 (2011) 98-102

→ Higher collected charge for 5 and 50 μm trenches but higher noise to be avoided

Spares: materials: calibration

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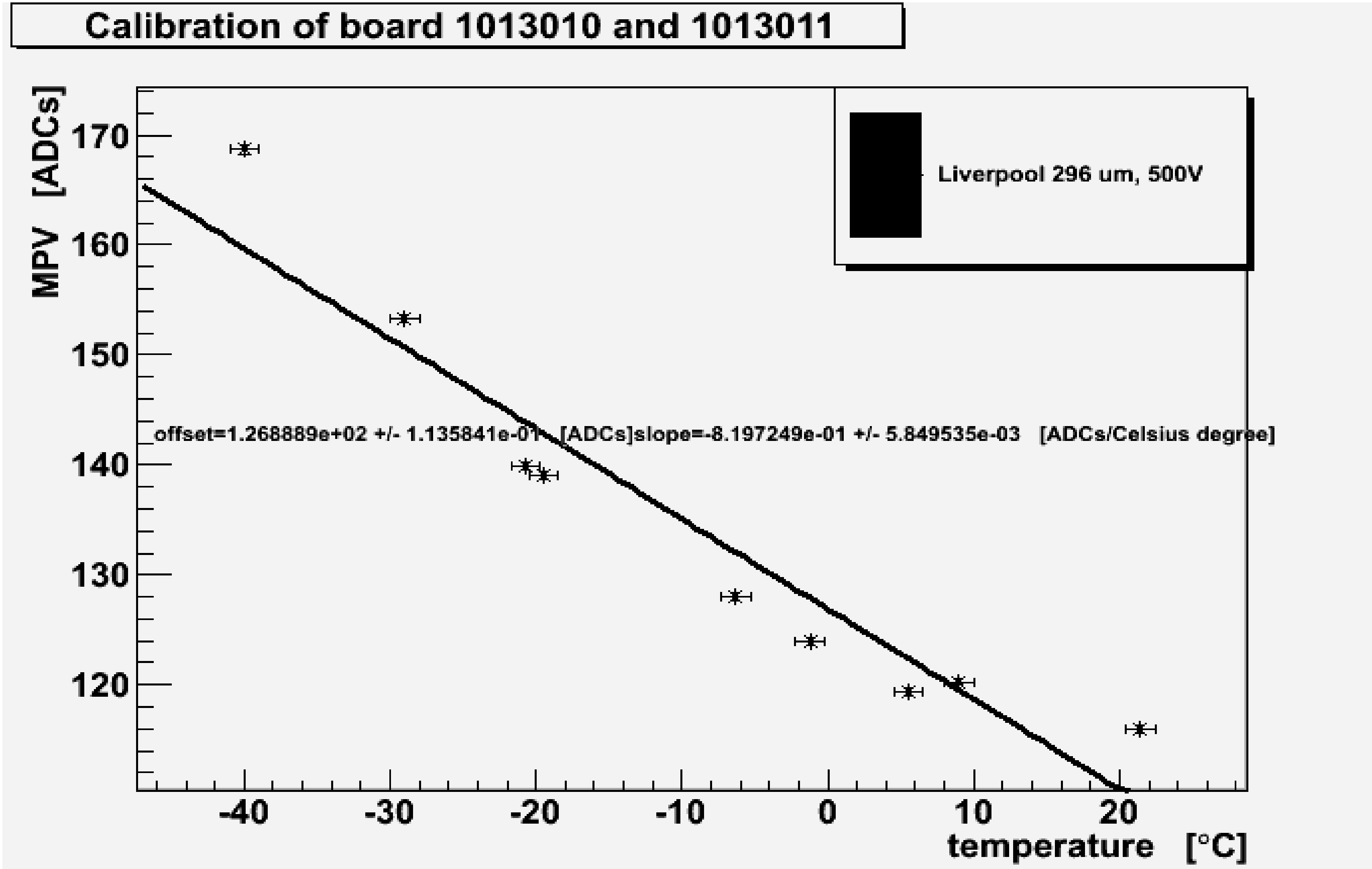
•Spectrum and calibration results:

•Micron, standard, p-type, 296 um.



Spares: results: long term, first (failed) tests

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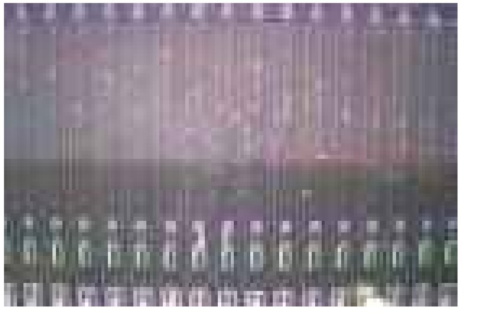
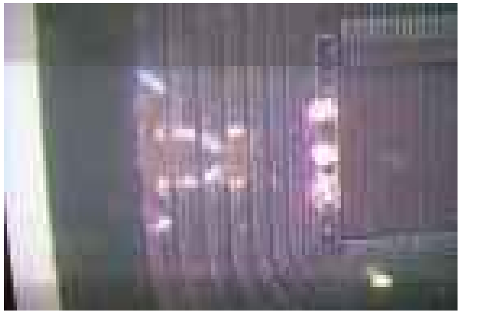
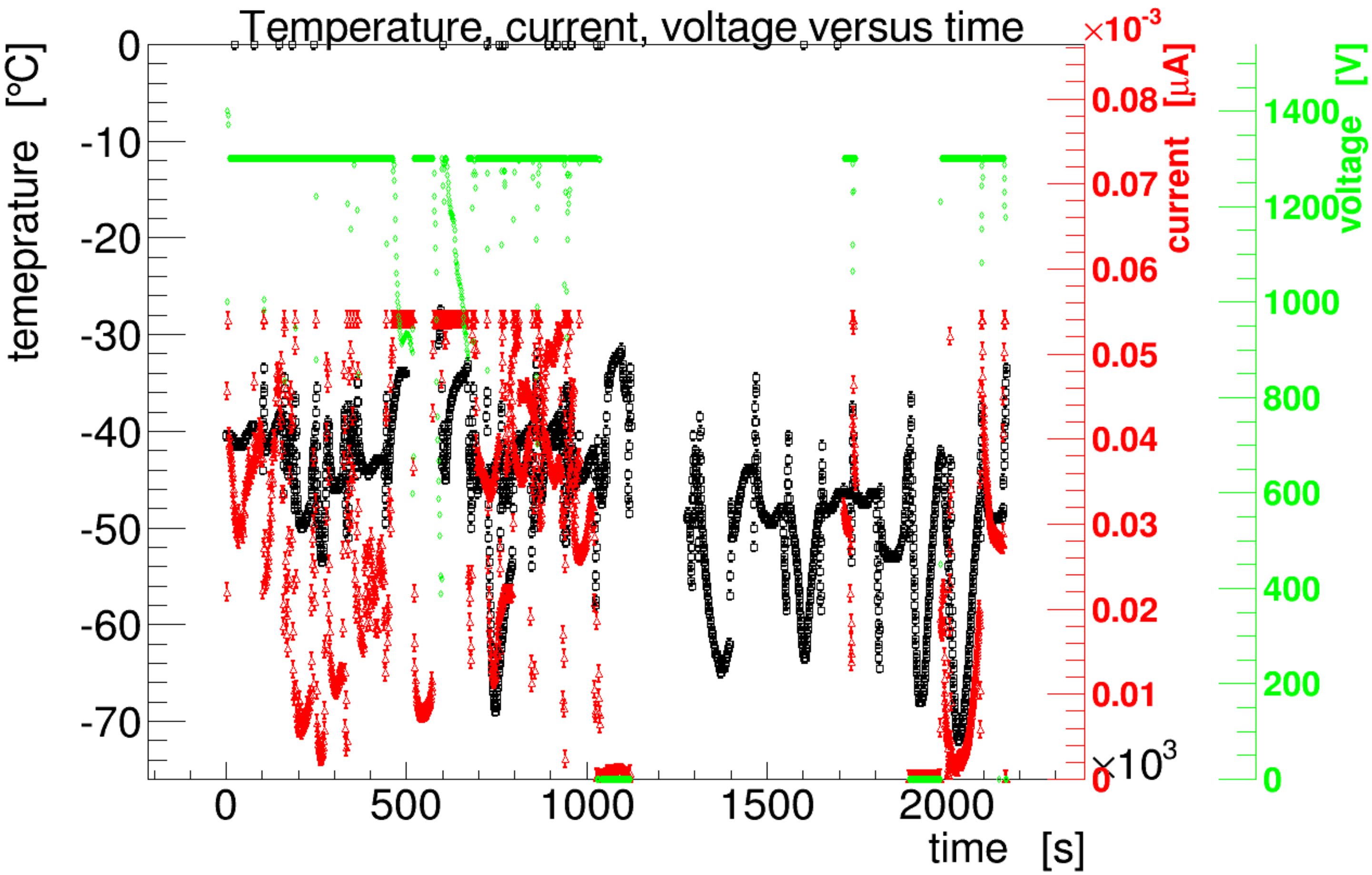
- 2935-8-1-14L: standard, (p,w)=(XXX,XXX), 1*10^{15} n_{eq}/cm^2:
  - ~-18 °C, 1000 V: ~124 uA.
    - Broke over night.
- 2935-8-1-13L: standard, (p,w)=(XXX,XXX), 1*10^{15} n_{eq}/cm^2:
  - ~-15.5 °C, 1100 V.
    - Broke after 3 stable days.
  - ~-40 °C.
    - Permanent high current (100 uA at 700 V).
- 2935-8-3-4L: standard, (p,w)=(XXX,XXX), 1*10^{15} n_{eq}/cm^2:
  - ~-17.5 °C.
    - Immediate breakdown at 1100 V.
  - ~-40 °C.
    - Persistent high current.
- XXXXXXXXX: standard, (p,w)=(XXX,XXX), 5*10^{15} n_{eq}/cm^2:
  - ~-40 °C, 1500 V.
    - Low charge collection over 3 days=> decided to increase the voltage.
  - 1600 V.
    - Breakdown, permanent damage.





Spares: results: long term, succesful test, monitoring

- Temperature, current and voltage over time:



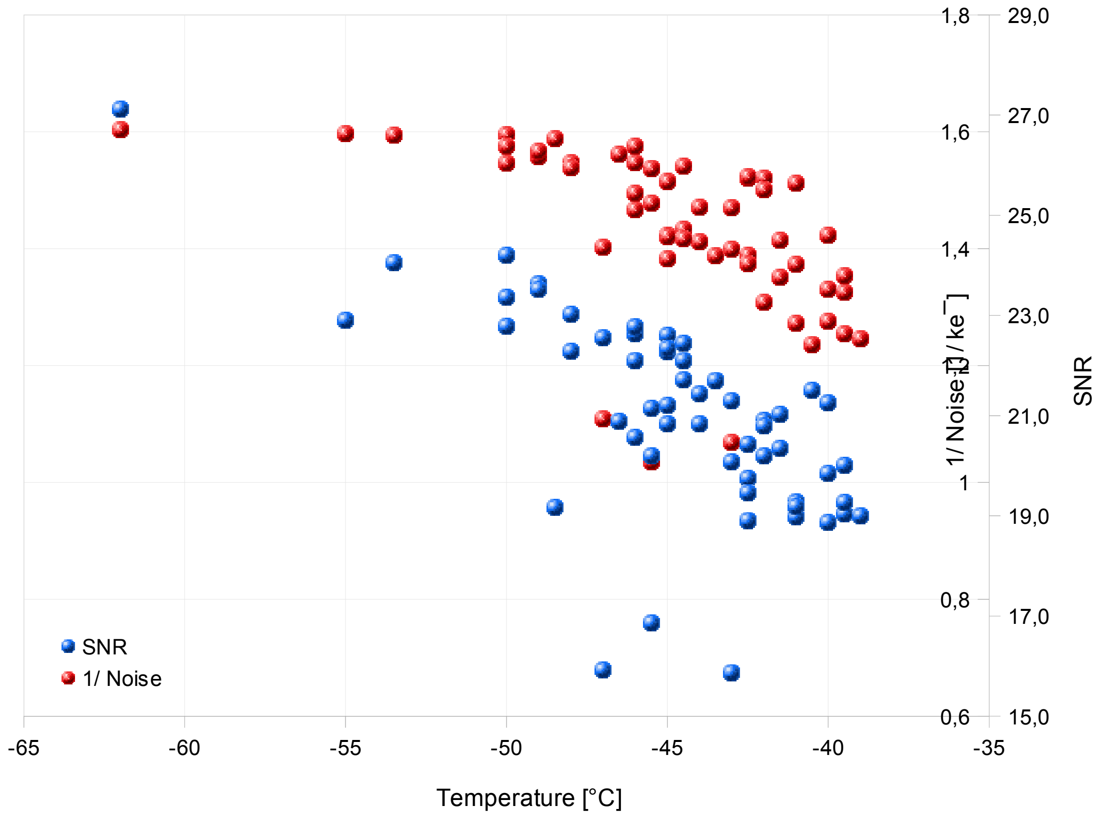
- Standard.
- (p,w)=(100,10) um.
- $5*10^{15}$ n_{eq}/cm^2.
- Compliance=54 uA (too safe).

- Voltage decreased during N refilling (~<1 h/day).

Spares: results: long term, succesful test

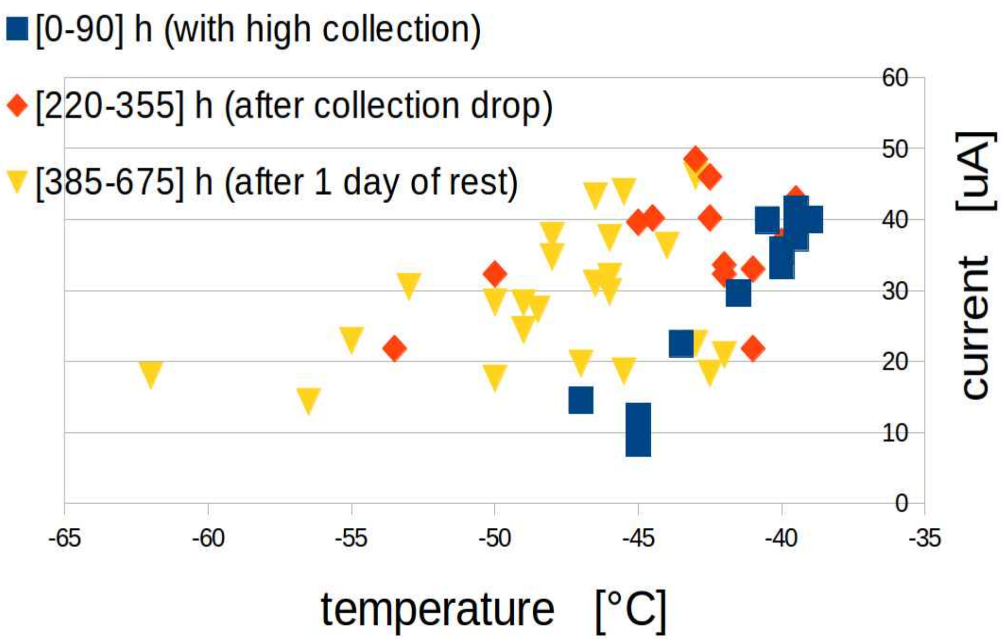
- Various: signal-to-noise ratio versus temperature

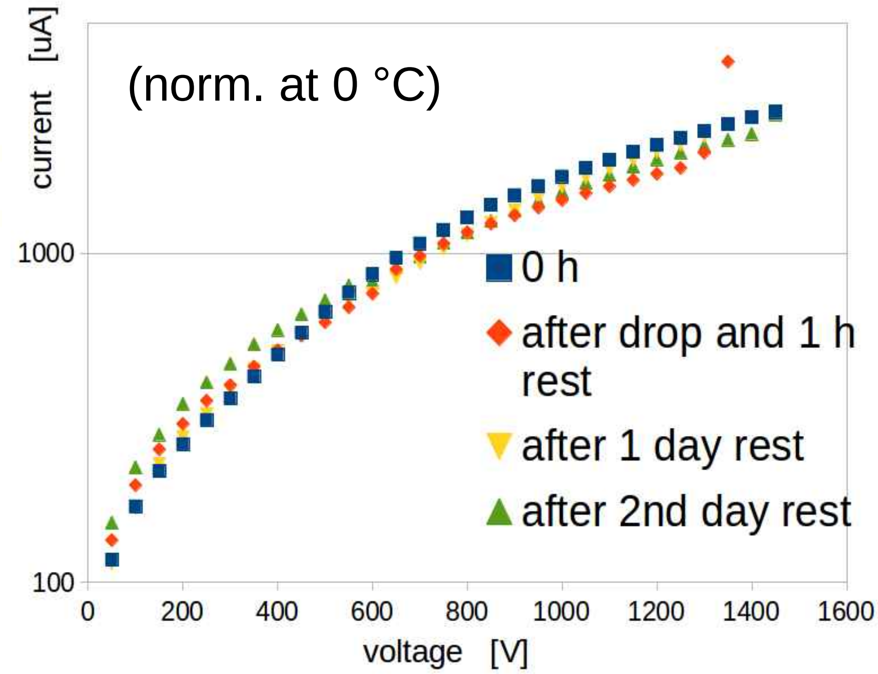
- Standard.
- (p,w)=(100,10) um.
- $5*10^{15}$ n_{eq}/cm^2.



- The signal to noise ratio, scaling as 1/noise, increases for lower temperatures.

Results long-term tests: Current





- Increase of the current after long-term stress and with temperature stress (during N refilling).
- Observed a lower current immediately after resting periods but still persistent higher current in long-term

Spares: results: various

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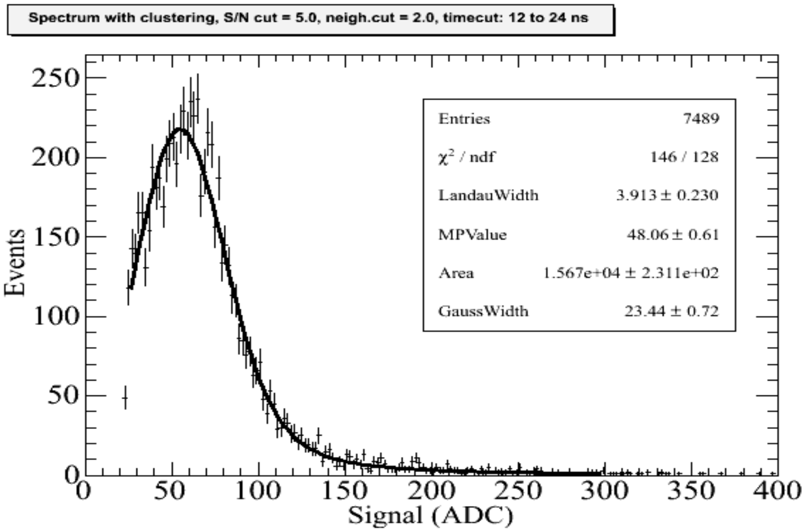
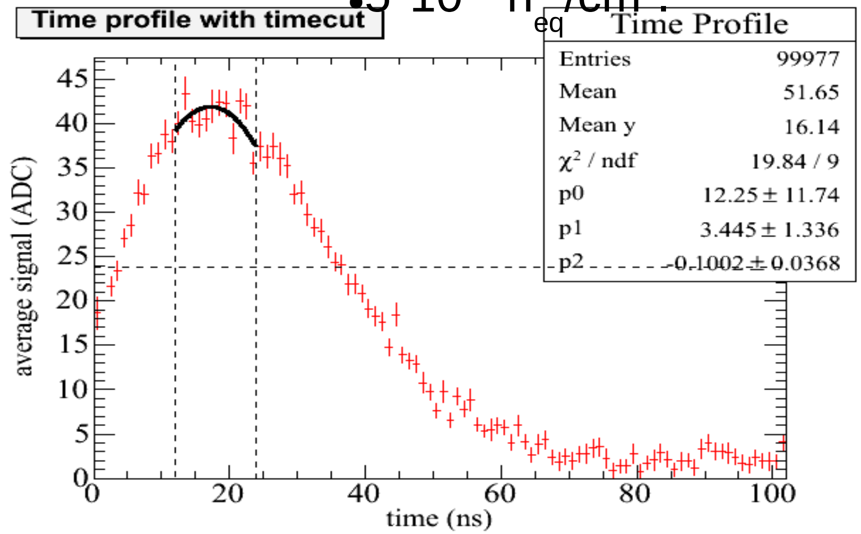
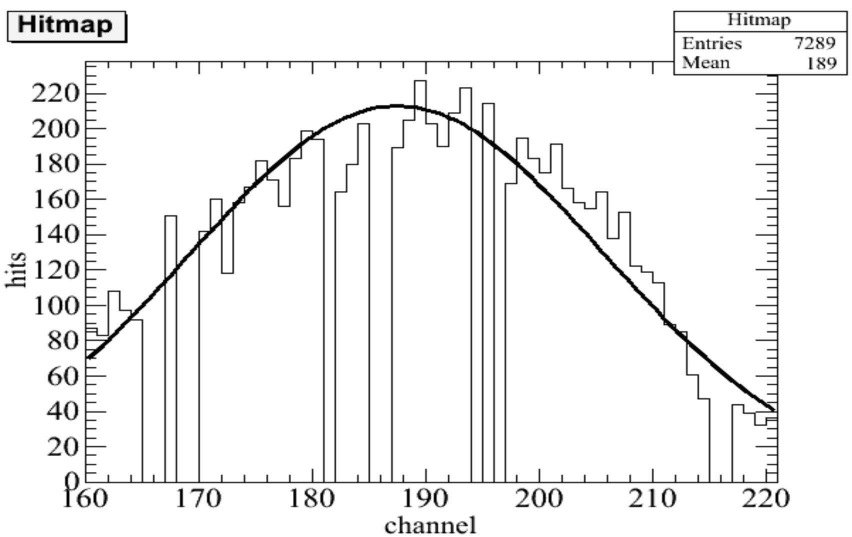
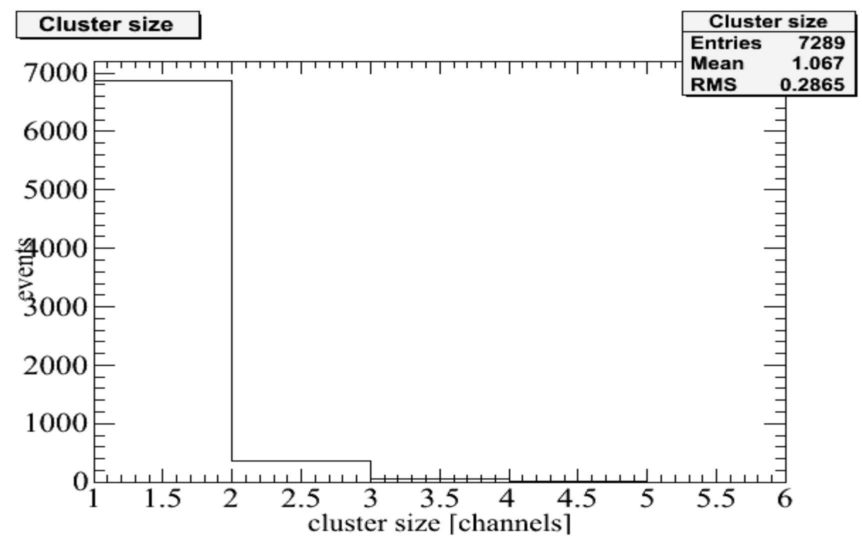
- Various: spectrum 600 V, 0 h

- Standard.
- (p,w)=(100,10) um.
- $5*10^{15}$ n_{eq}/cm^2.









Spares: results: various

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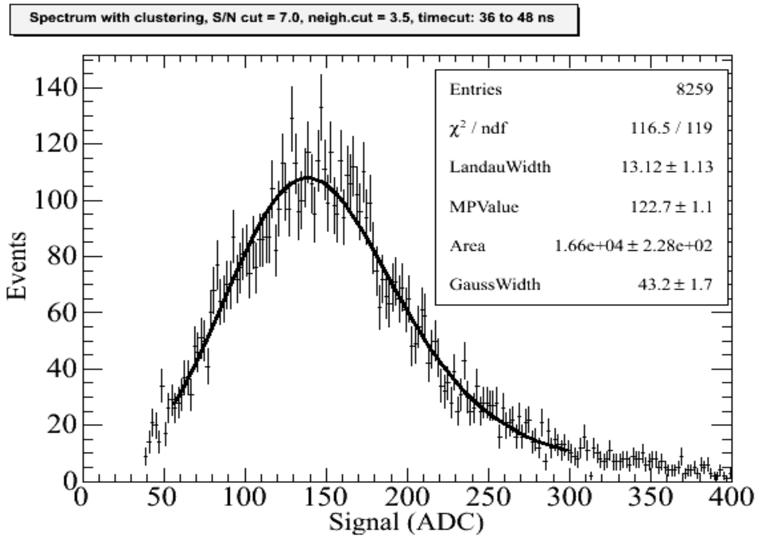
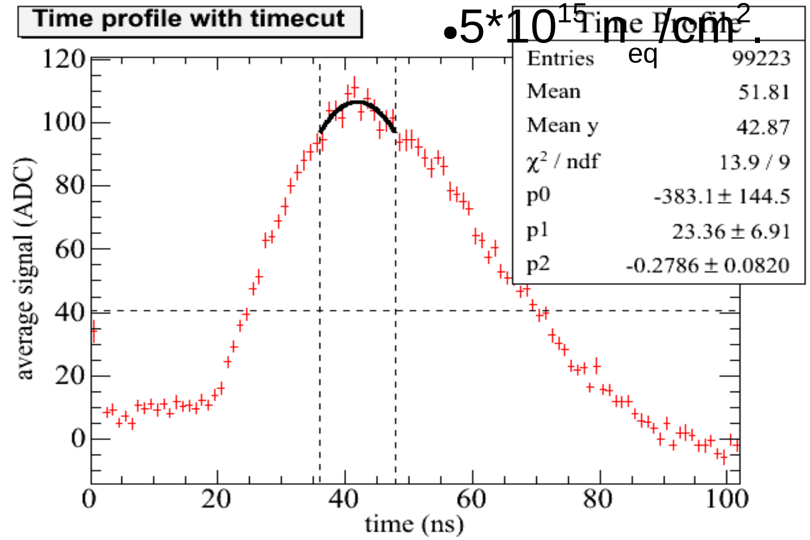
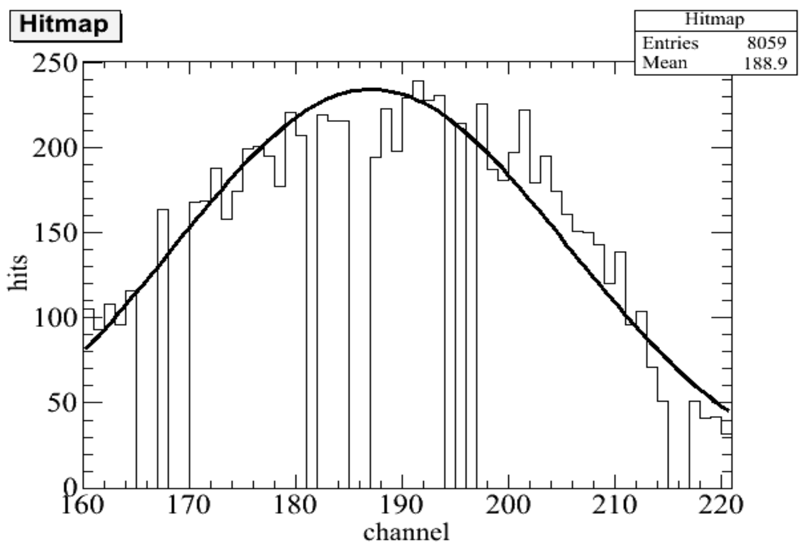
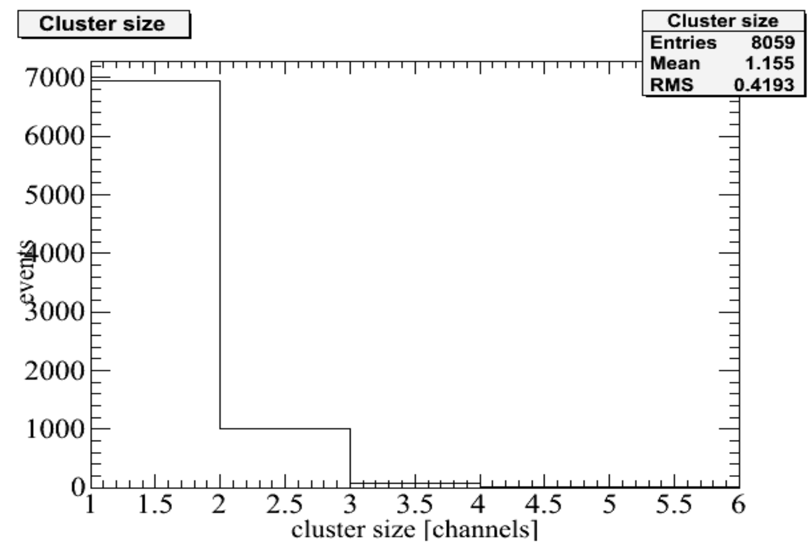
- Various: spectrum 1300 V, 0 h

- Standard.
- (p,w)=(100,10) um.
- $5*10^{15} n_{eq}/cm^2$.









Spares: results: various

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- Various: spectrum 1300 V, 354 h (after drop)

- Standard.
- (p,w)=(100,10) um.
- $5*10^{15}$ n_{eq}/cm^2.