Investigation of non-Gaussian noise in irradiated n-bulk sensors

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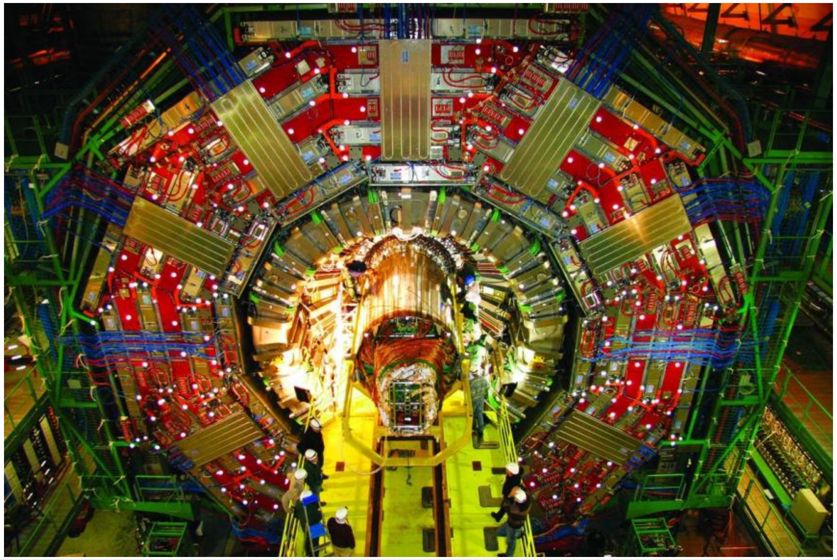
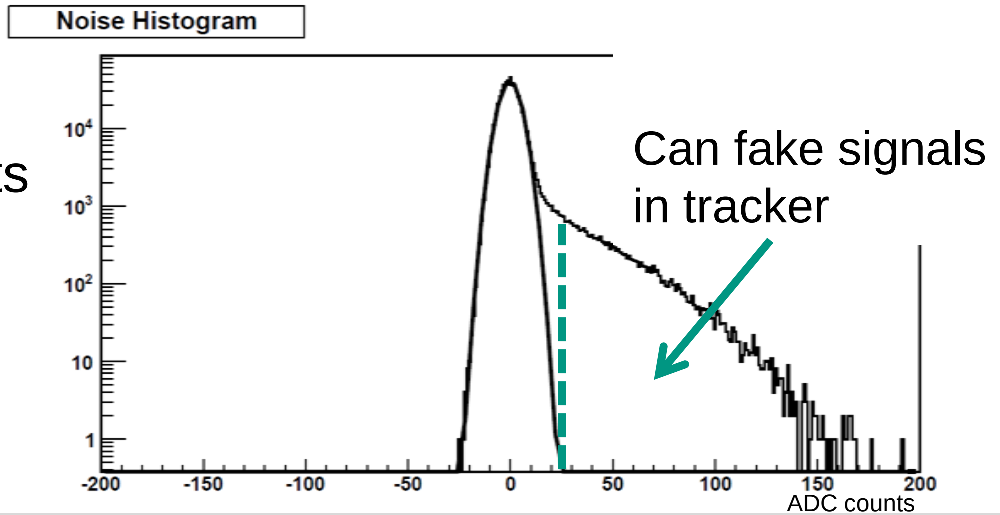


Outline

- What is non-Gaussian noise?
- Non-Gaussian noise after
  - Proton irradiation
  - Neutron irradiation
- Non-Gaussian noise
  - Dependence on strip geometry
  - T-CAD simulation
- Summary

Non-Gaussian noise

- Non gaussian noise (nGn) seen in most irradiated n-type sensors by several groups and using different readout systems throughout CMS HPK campaign
- Intensity depends on fluence, bias voltage and annealing state
- In order to compare the effect, we need a quantity which measures the amount of this noise
  - Take pedestal-run
  - Count entries which are above 5 times the width of the fitted Gaussian
  - Normalize to number of strips and events
  - → Number of ghost hits per strip and per event
- Extreme example plot



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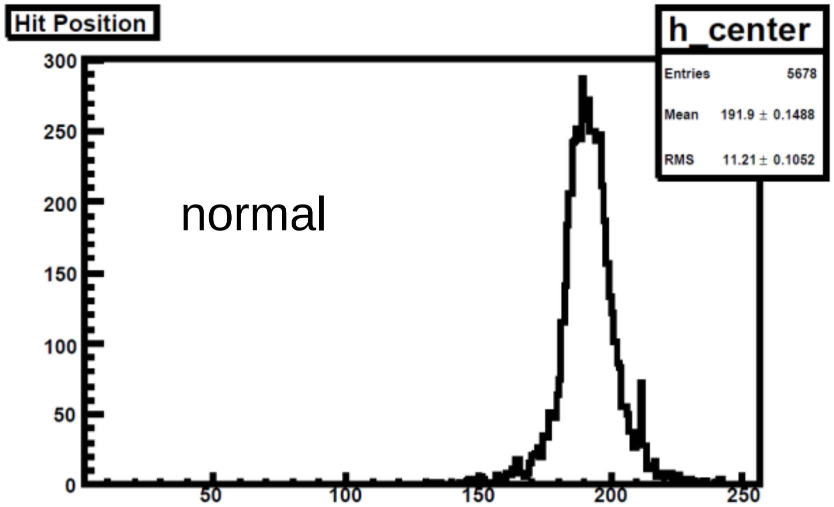
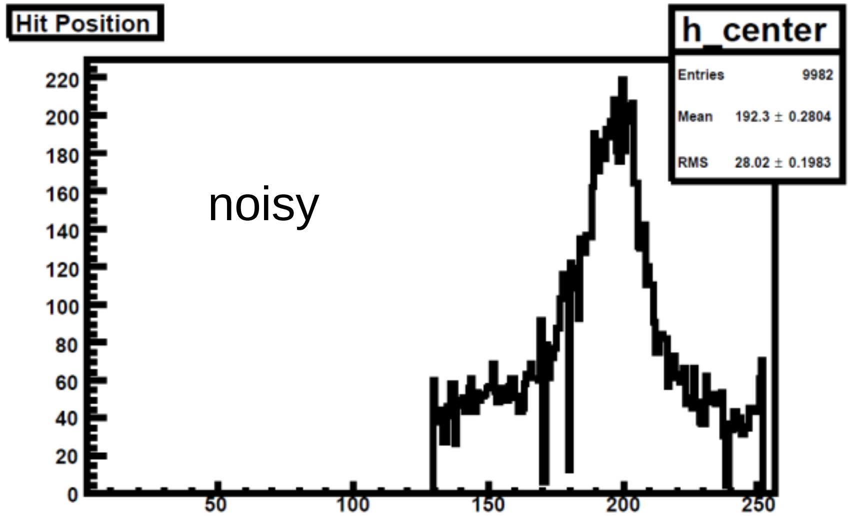
Influence on signal measurement

- Use ALiBaVa setup (Beetle chip) for annealing studies on mixed irradiated sensors
- Sr90 source
- Non-Gaussian noise hits appear randomly distributed on the whole sensor





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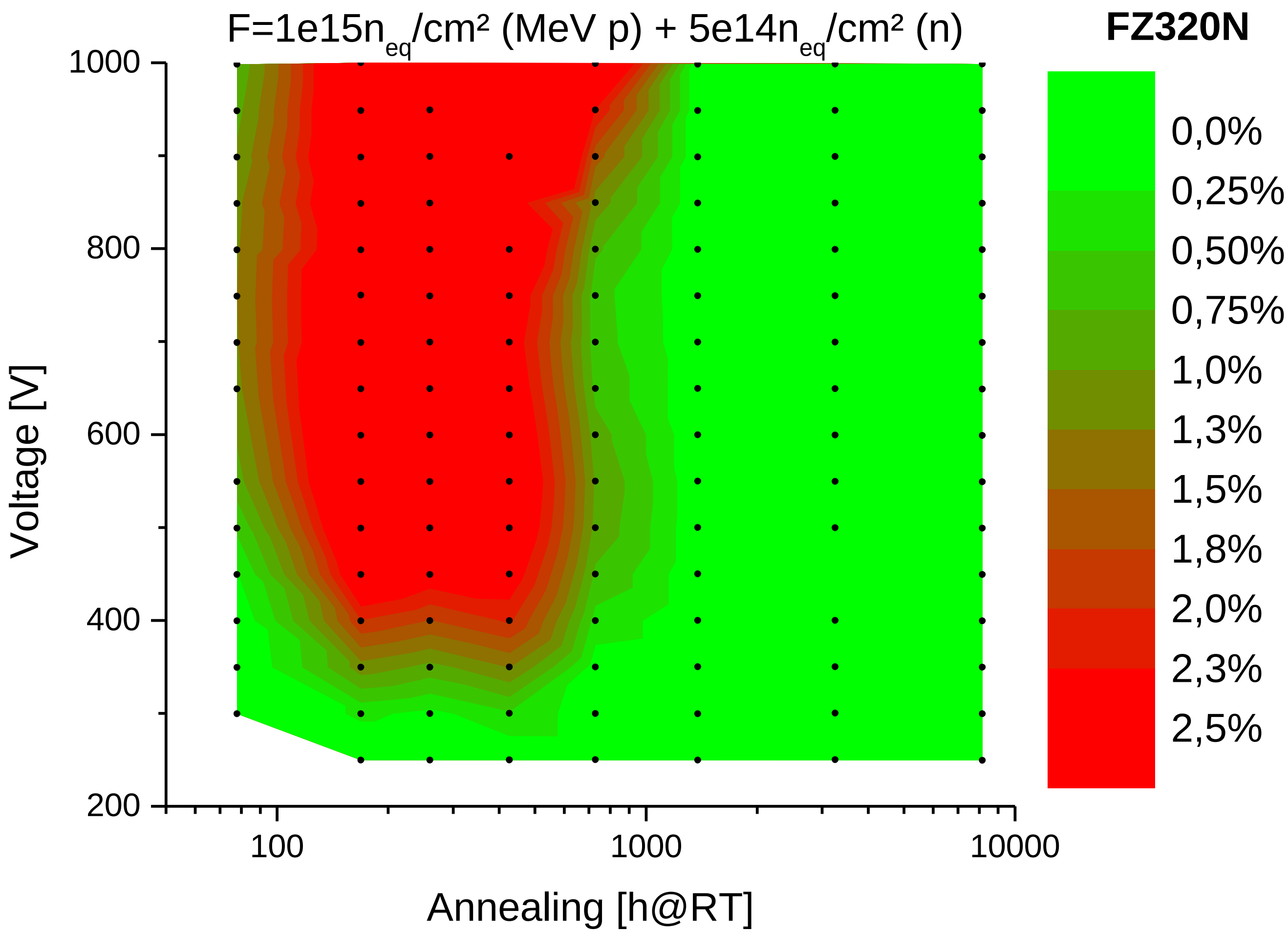
Non gaussian noise as function of bias and annealing



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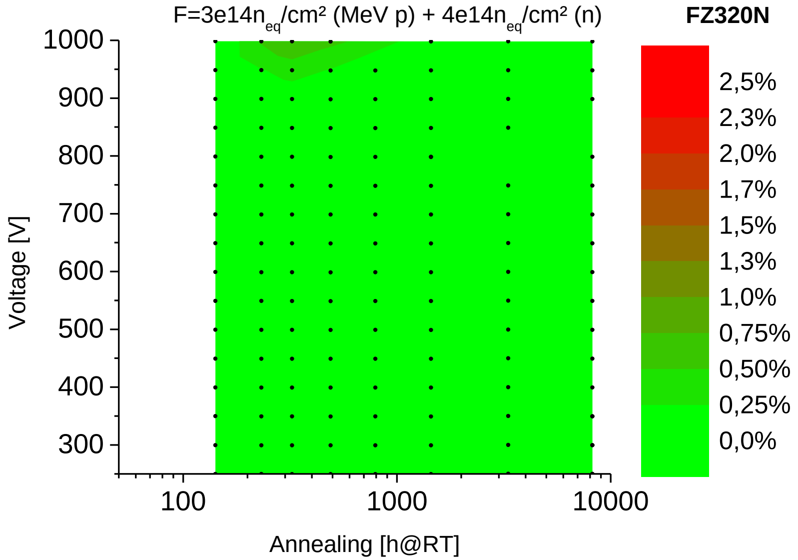
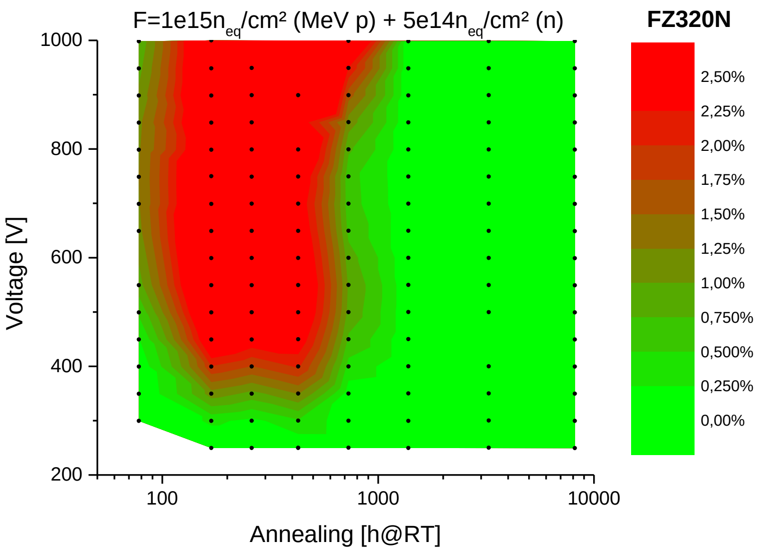
Irradiation with 23 MeV protons

- 320µm thick sensor
- 23 MeV proton (Karlsruhe cyclotron) + Neutron irradiation

7e14



1.5e15



- 320µm thick float zone sensor at 1.5e15 neq/cm^2 already at low bias voltages affected
- Long-term annealing cures the effect
- Noise increases with fluence

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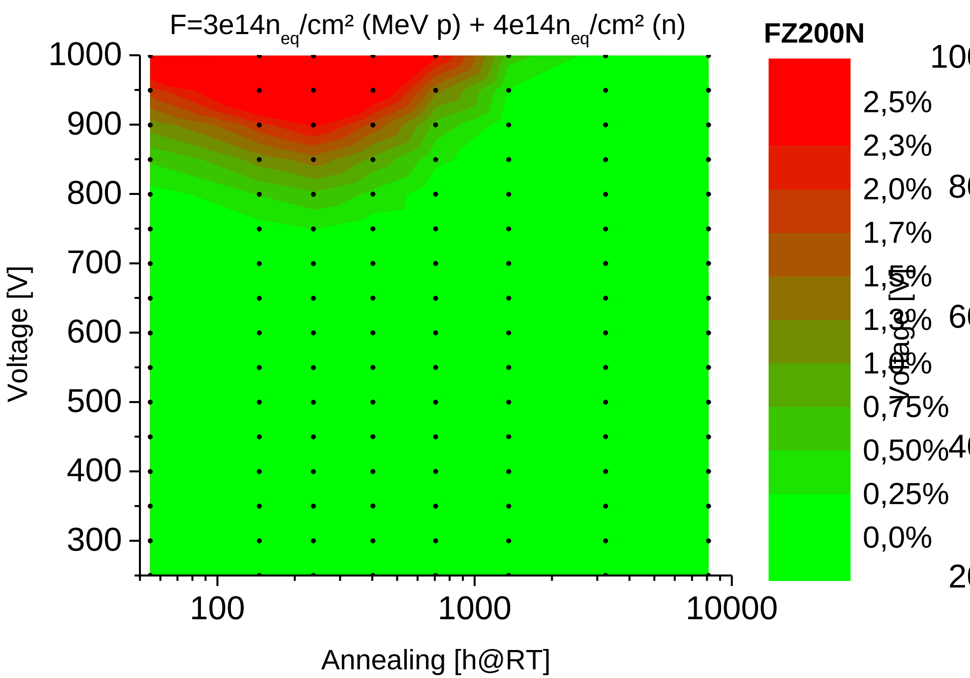
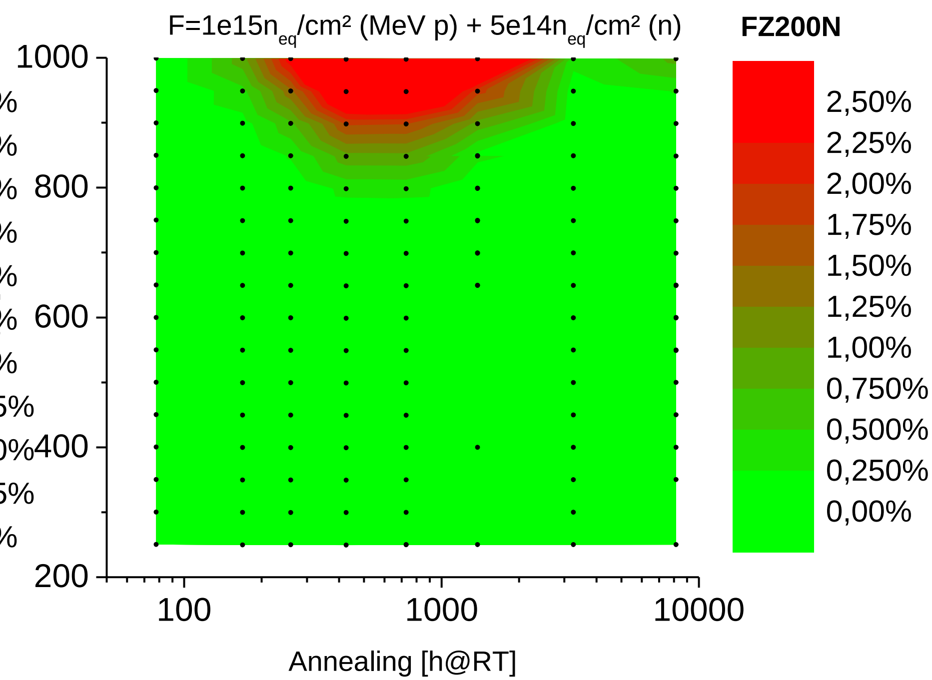
Irradiation with 23 MeV protons

- 200µm sensor

7e14



1.5e15



- 200µm thin sensors (FZ-dd) show nGn only at high bias voltage above 800V

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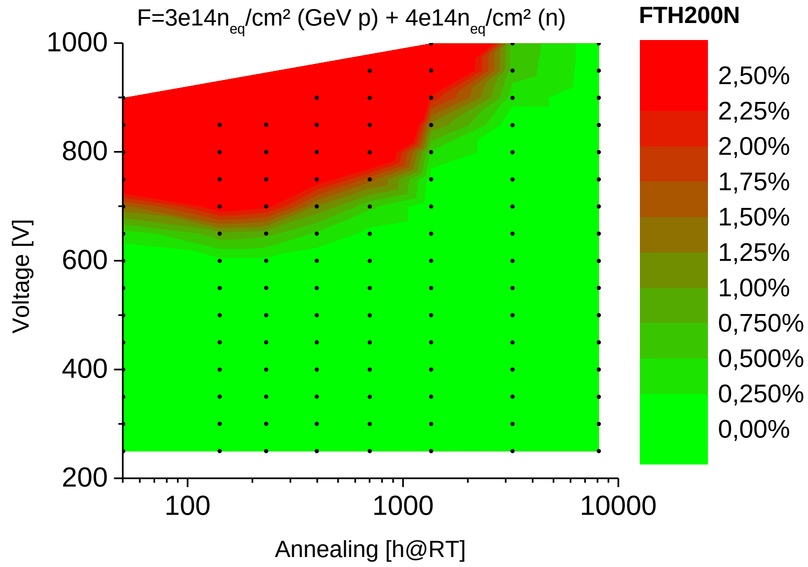
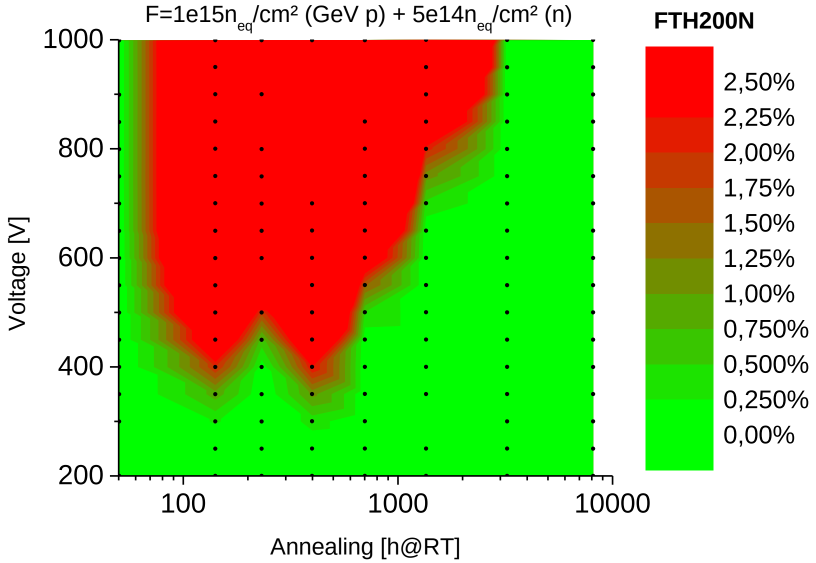
Irradiation with 23 GeV protons

7e14



1.5e15



- 200 µm physical, 23 GeV protons (CERN PS) + neutrons
- Already after first fluence point (7e14 neq/cm^2) 200µm thin sensors show nGn above 600V
- After 1.5e15 neq/cm^2 irradiation, sensor only usable after very long annealing

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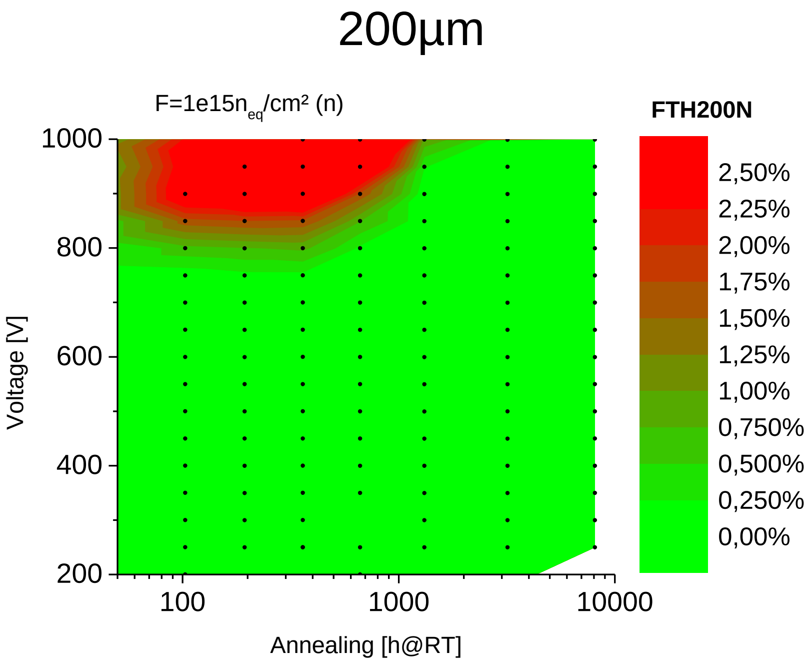
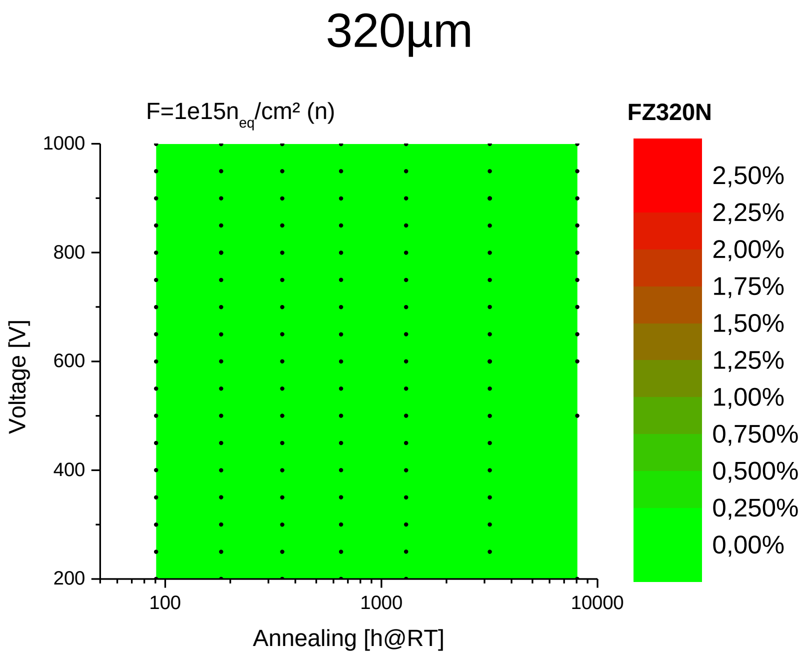
Neutron only irradiation





- Effect is much reduced for neutron only irradiation (1e15 neq/cm^2)
- Dependence on ionizing radiation hints towards a combined effect of bulk damage and surface charge Q_f

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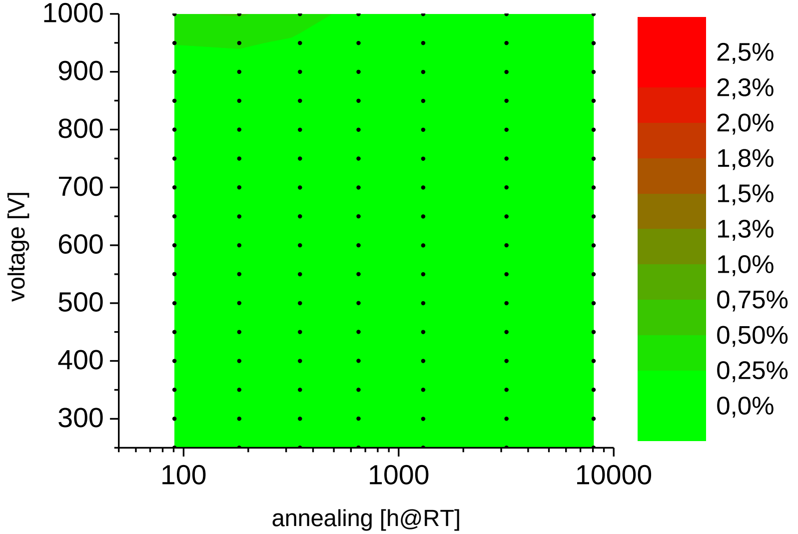
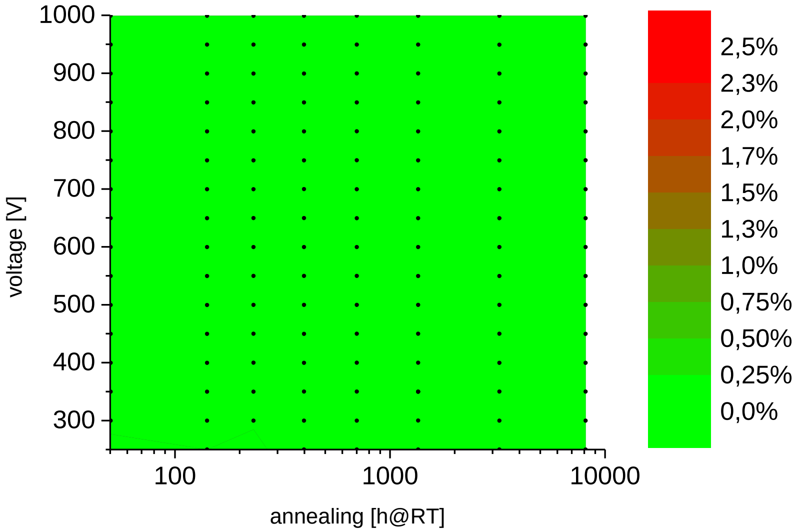
nGn in Infineon & HPK CMS mini sensors

- HPK mini sensor (320µm) cut out of CMS wafer teststructure
- CMS tracker production run
- 6e14 neq/cm^2
  23 MeV proton irradiation

- Infineon mini test sensor (320µm)
- 1e15 neq/cm^2
  23 MeV proton irradiation



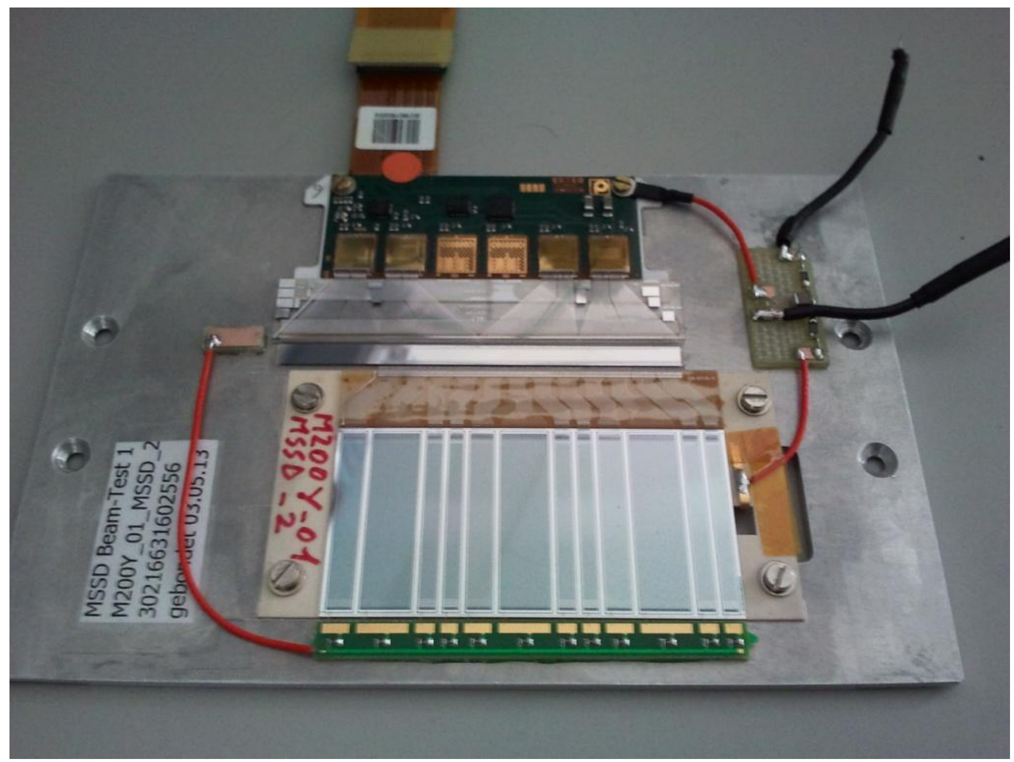


- CMS sensor slightly affected
- Infineon sensor very clean

HPK multi geometry sensor

- Multi-Geometry strip sensor
- APV readout
- regions with different geometry
  - Pitch:
    70 µm
    80 µm
    120 µm
    240 µm
  - w/p
    0.13 ▼
    0.23 ●
    0.33 ▲
- 12 regions in total

Label	Irradiation	Annealing state
FTH200N	15e14 p only	80min@60°C+30min@80°C
MCZ200N	15e14 p only	80min@60°C+30min@80°C
FTH200P	15e14 p only	80min@60°C



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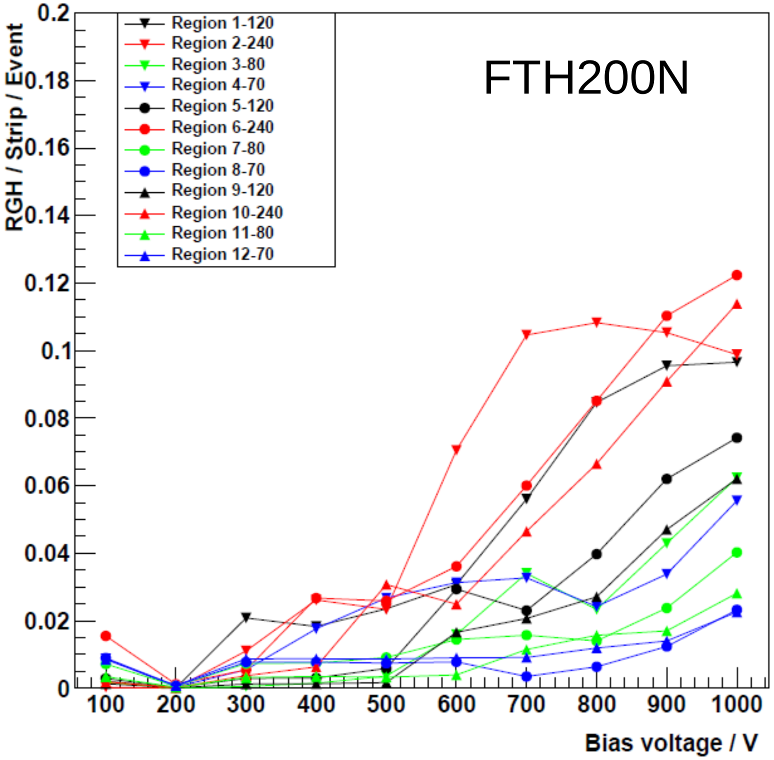
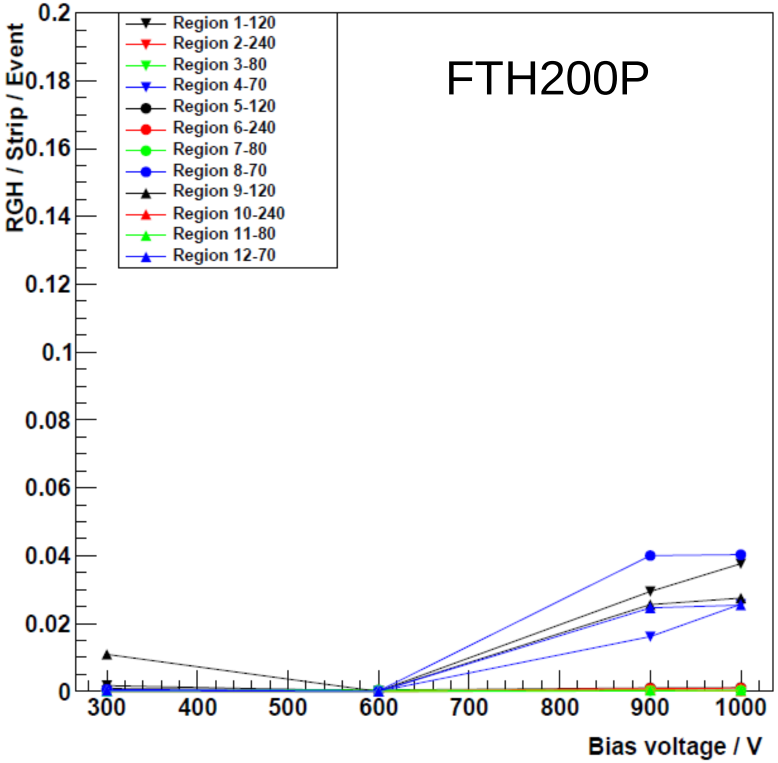
nGn in multi geometry sensor

- The non Gaussian noise contribution increases drastically with bias voltage on n-type sensors, as seen before





- Large pitch and small w/p ratio affected first
- P-type less affected, has to be pushed hard

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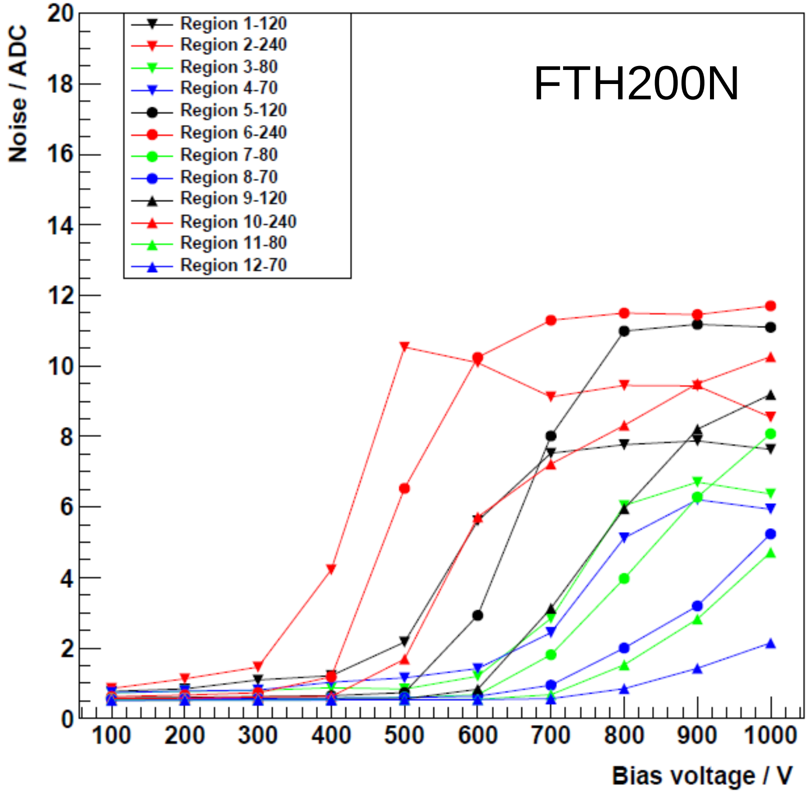
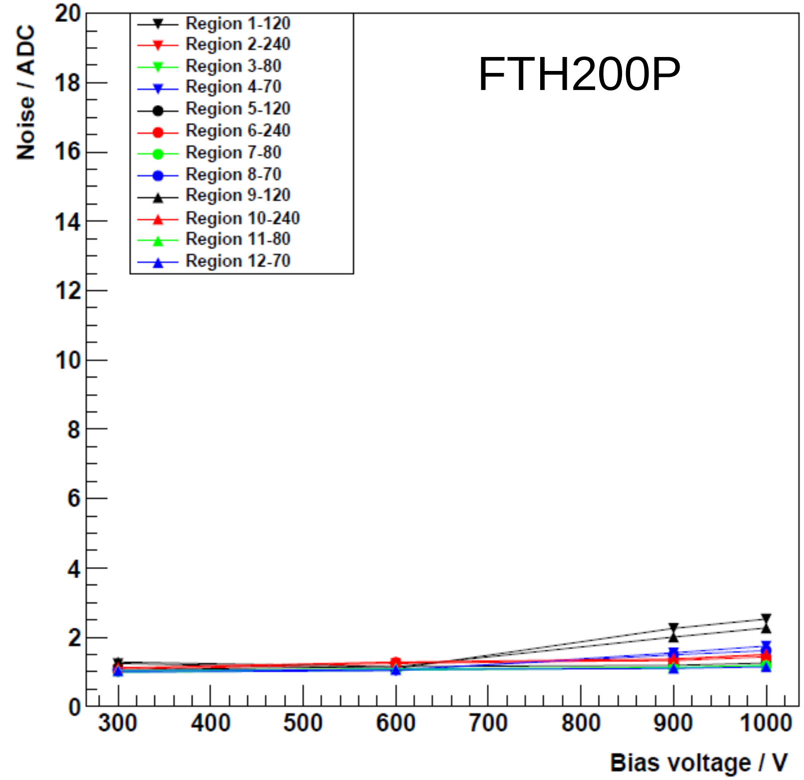
xGn in multi geometry sensor

- Also the symmetric Gaussian kernel of pedestal distribution increases





- Strong increase only for n-type sensors
- High pitch and small w/p ratio affected first

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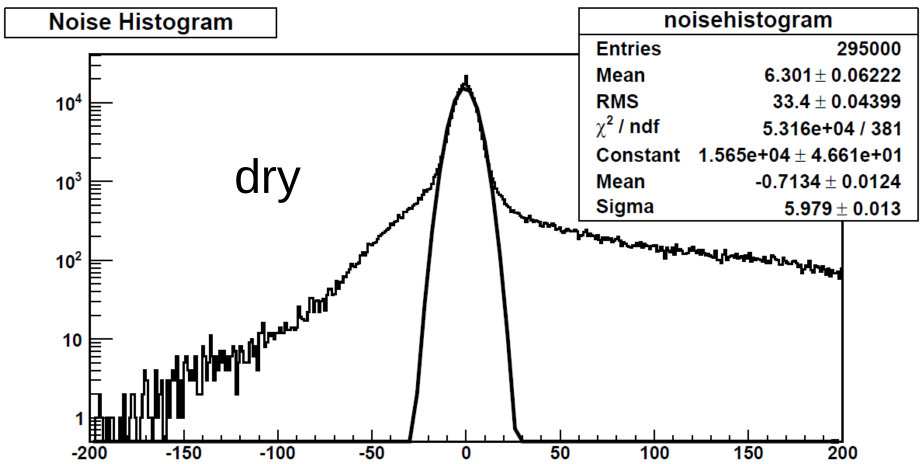
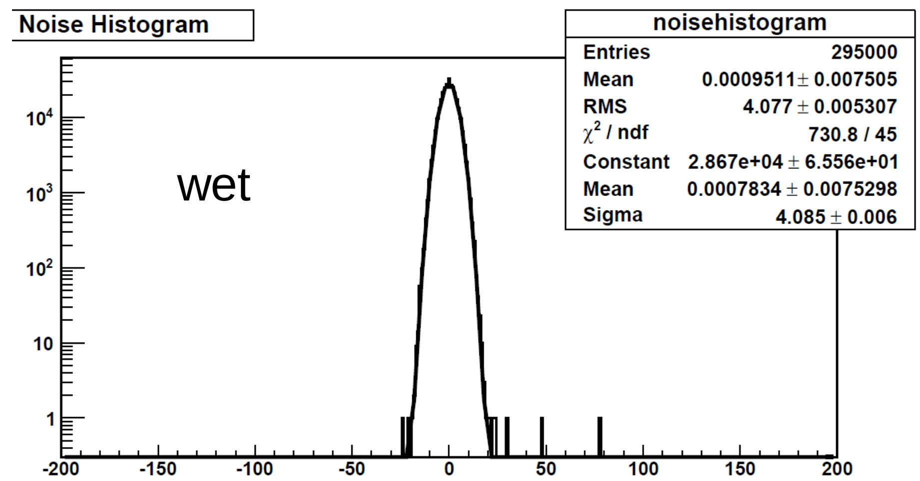
Influence of humidity on nGn

- High relative humidity → condensation on sensor
- Bias sensor for a few minutes with wet surface
- Dry and cool down further





- nGn occupancy < 0.1‰, even at high voltage

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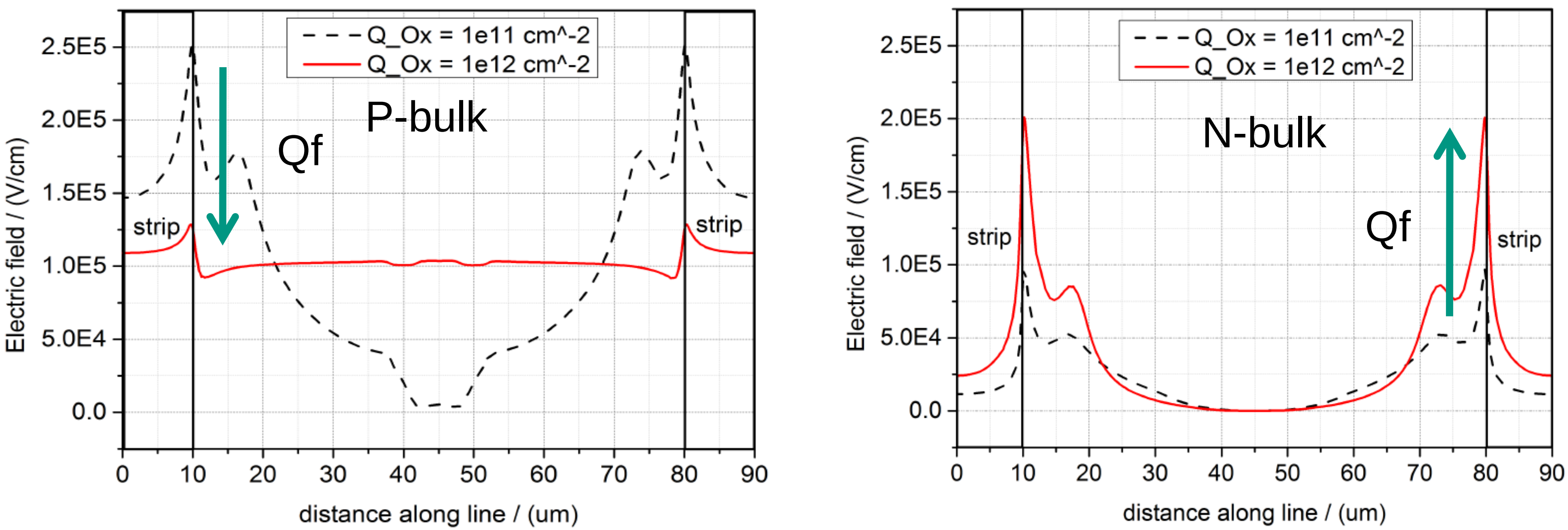
Simulated electric field near strips after irradiation

- Geometry dependence → high electric fields at the front side promote the effect
- Dependence on irradiation type (neutron or proton) → surface damage promote the effect
- T-CAD simulation of n- and p-bulk sensor using effective 2-trap model



- Higher electric field in n-bulk near the sensor surface after irradiation

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Summary

- Strong increase of noise on n-bulk sensors after irradiation
- Besides the Gaussian noise, an additional non Gaussian contribution faking particle hits makes this sensors problematic in a tracking detector
- Noise occupancy may be larger than 10%
- Dependence on type of irradiation particle (charged or neutral hadrons) hints towards an interplay between bulk and surface damage
- Geometry dependence indicates that high electric fields at the strips promote the effect
- Higher field near the strips in irradiated n-bulk sensors confirmed by T-CAD simulation
- Effect can be suppressed by humidity

- nGn not occurring in p-bulk sensors was one reason for CMS to decide on choosing p-bulk sensors for Phase 2 strip tracker upgrade

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BACKUP

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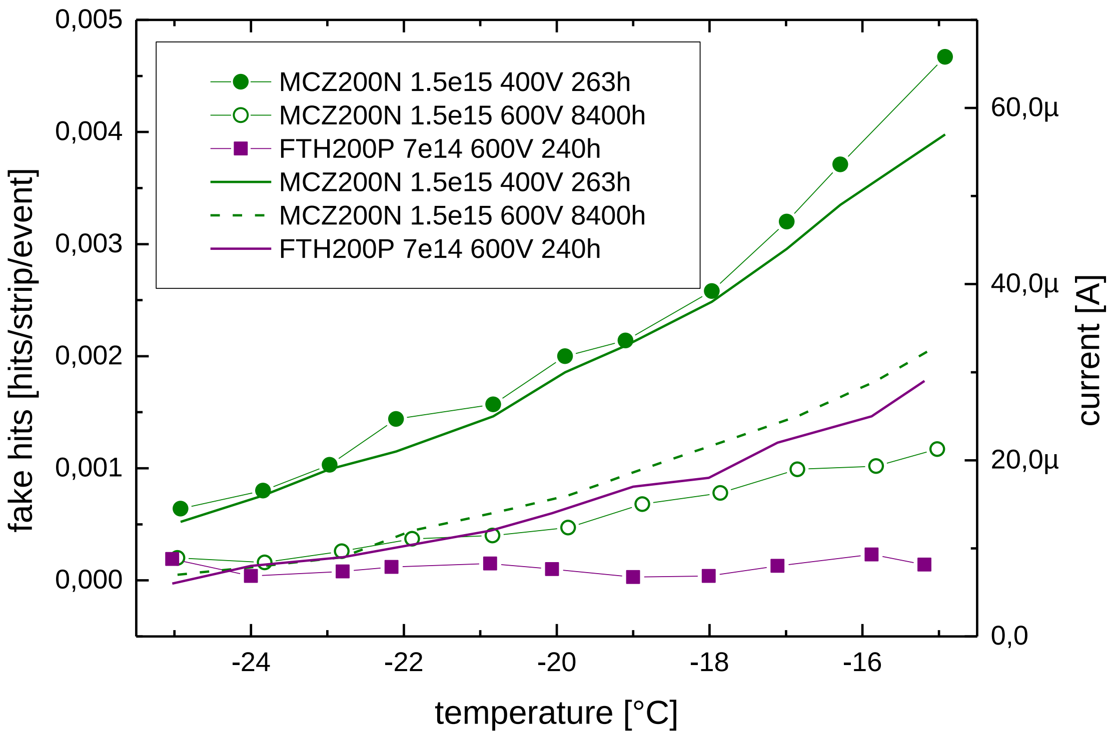
Temperature dependence of nGn



- Fake hit rate increases with temperature following current!
- The increase of fake hit rate is typically linked to an increase in current.
- But an increase in current does not necessarily lead to fake hits.

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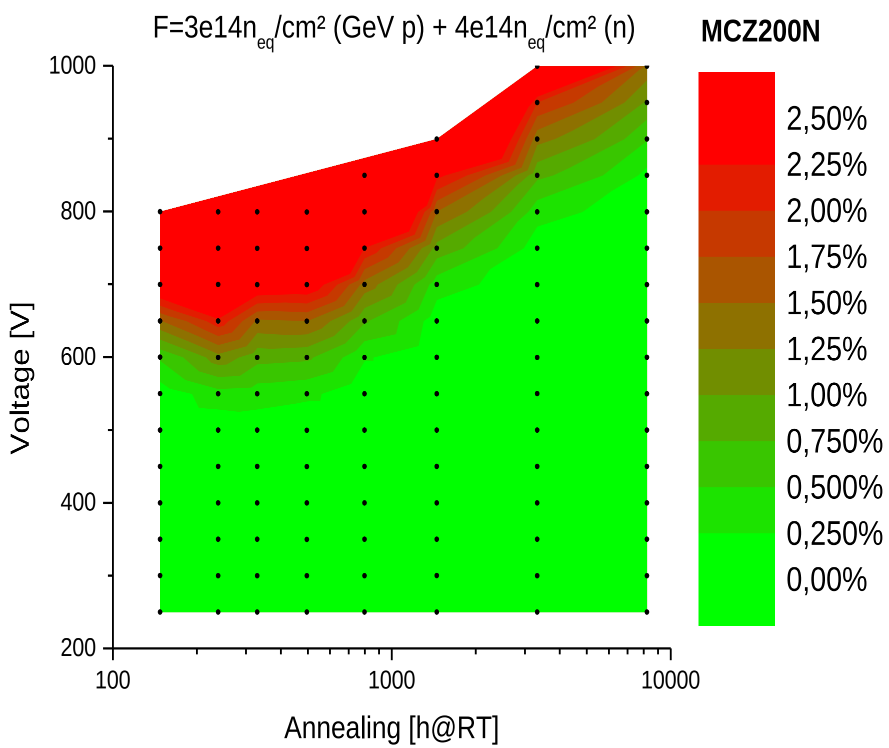
Trap model

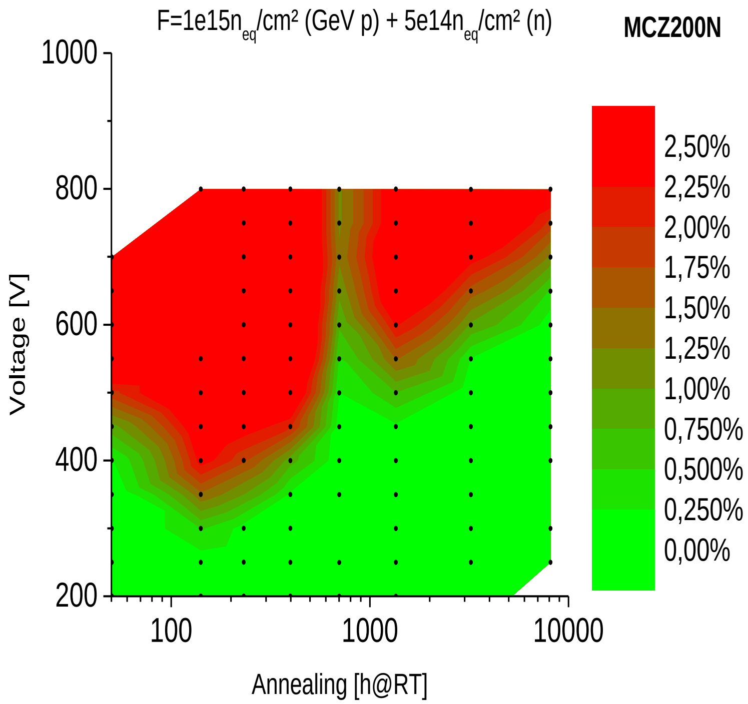
- PhD thesis Robert Eber
- Effective irradiation model (tuned especially for proton irradiation)
- Synopsis T-CAD

- 2 traps
  - 1 donor
  - 1 acceptor

Parameter	Donor	Acceptor
Energy	E_V + 0.48eV	E_C - 0.525eV
Concentration (cm^3)	5.598 * **F** – 0.959e14	1.189 * **F** + 0.645e14
σ(e)	1.0e-14cm^2	1.0e-14cm^2
σ(h)	1.0e-14cm^2	1.0e-14cm^2

- MCz 200µm
- 23 GeV protons





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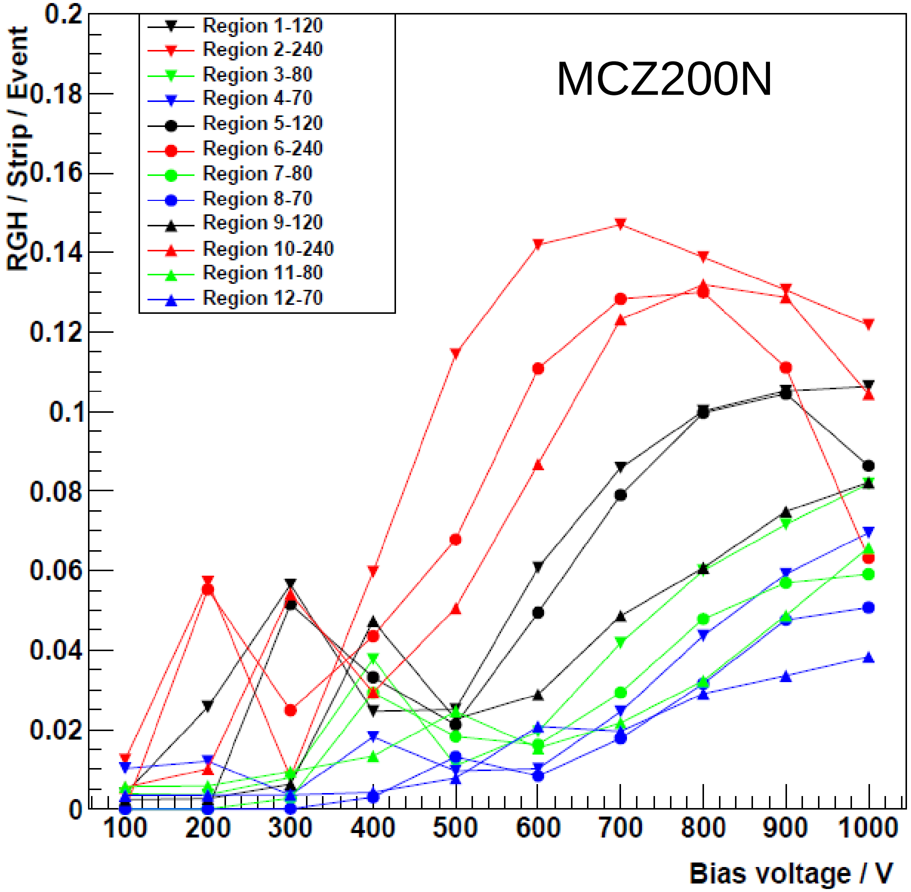
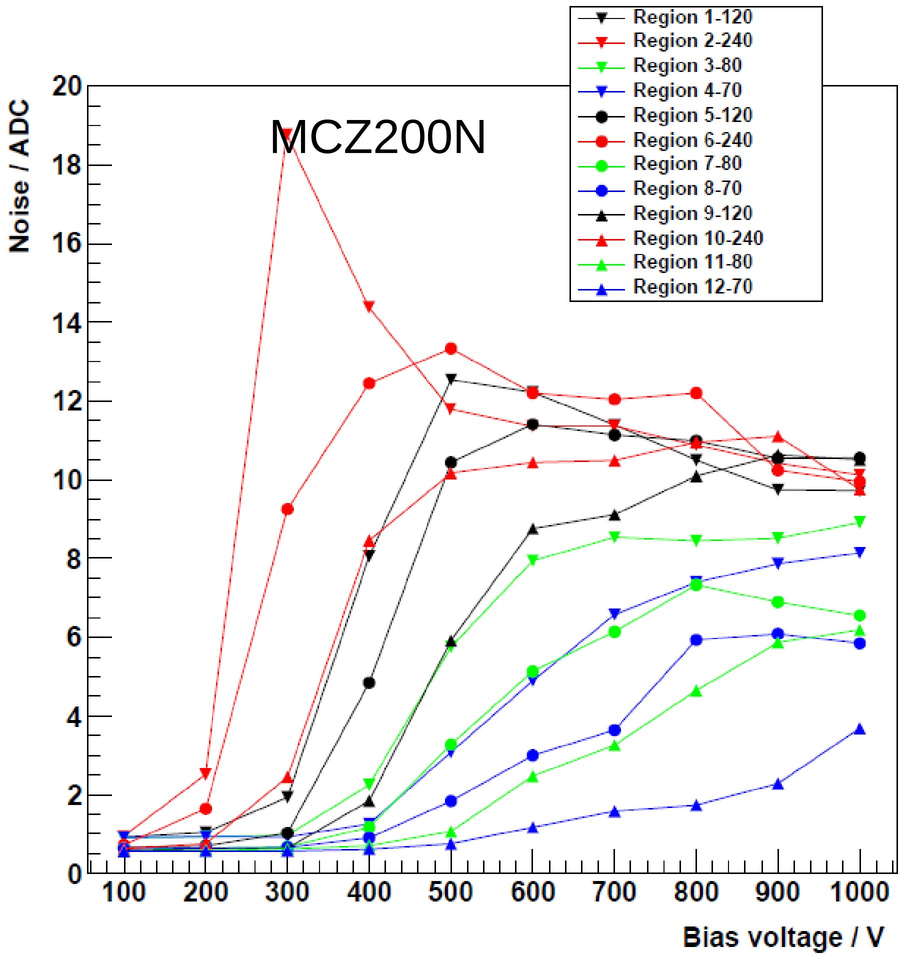
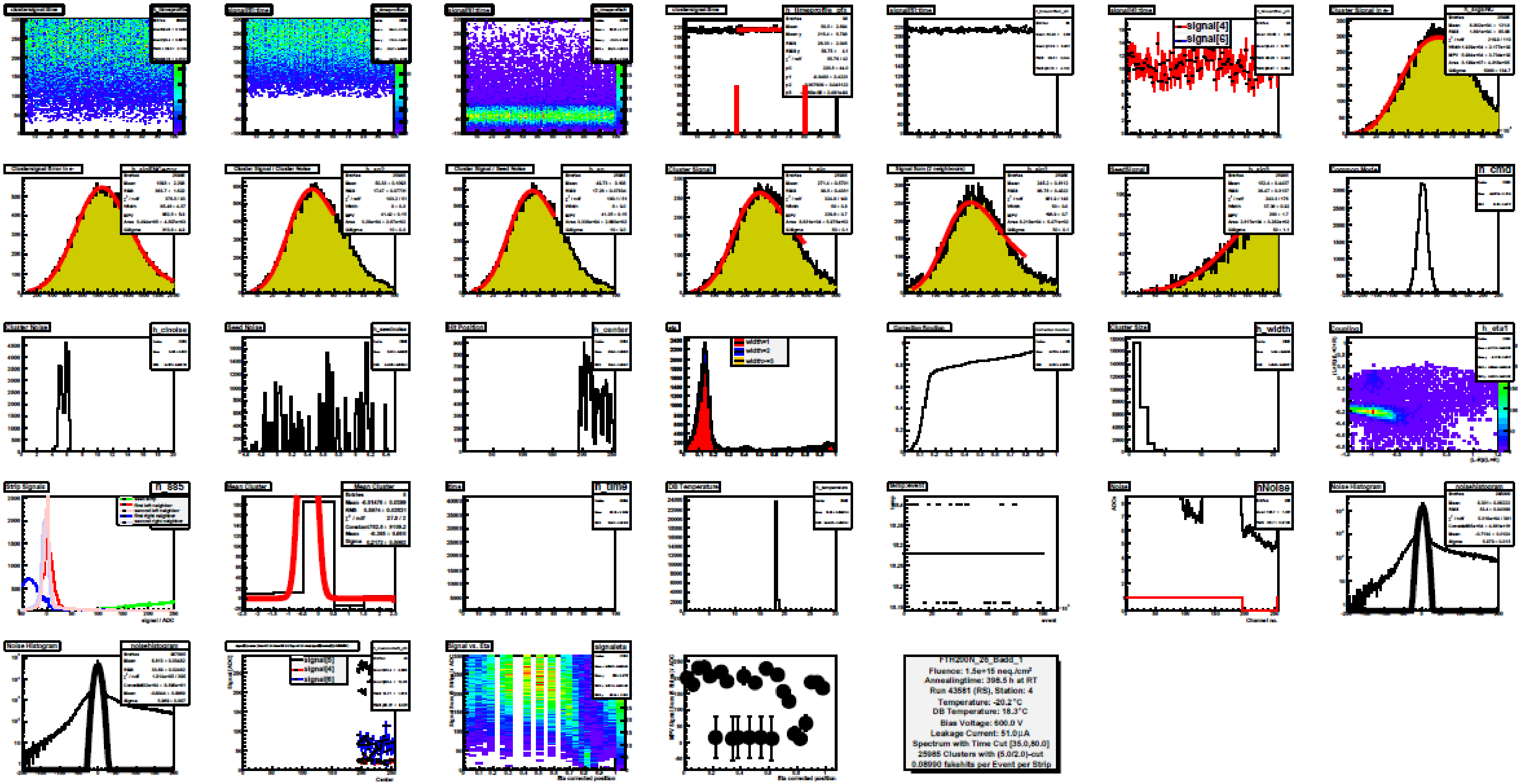

MCZ200N
RGH / Strip / Event
Bias voltage / V
Region 1-120
Region 2-240
Region 3-80
Region 4-70
Region 5-120
Region 6-240
Region 7-80
Region 8-70
Region 9-120
Region 10-240
Region 11-80
Region 12-70
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
100
200
300
400
500
600
700
800
900
1000


MCZ200N
Noise / ADC
Bias voltage / V
Region 1-120
Region 2-240
Region 3-80
Region 4-70
Region 5-120
Region 6-240
Region 7-80
Region 8-70
Region 9-120
Region 10-240
Region 11-80
Region 12-70
0
2
4
6
8
10
12
14
16
18
20
100
200
300
400
500
600
700
800
900
1000

Dry (600V)



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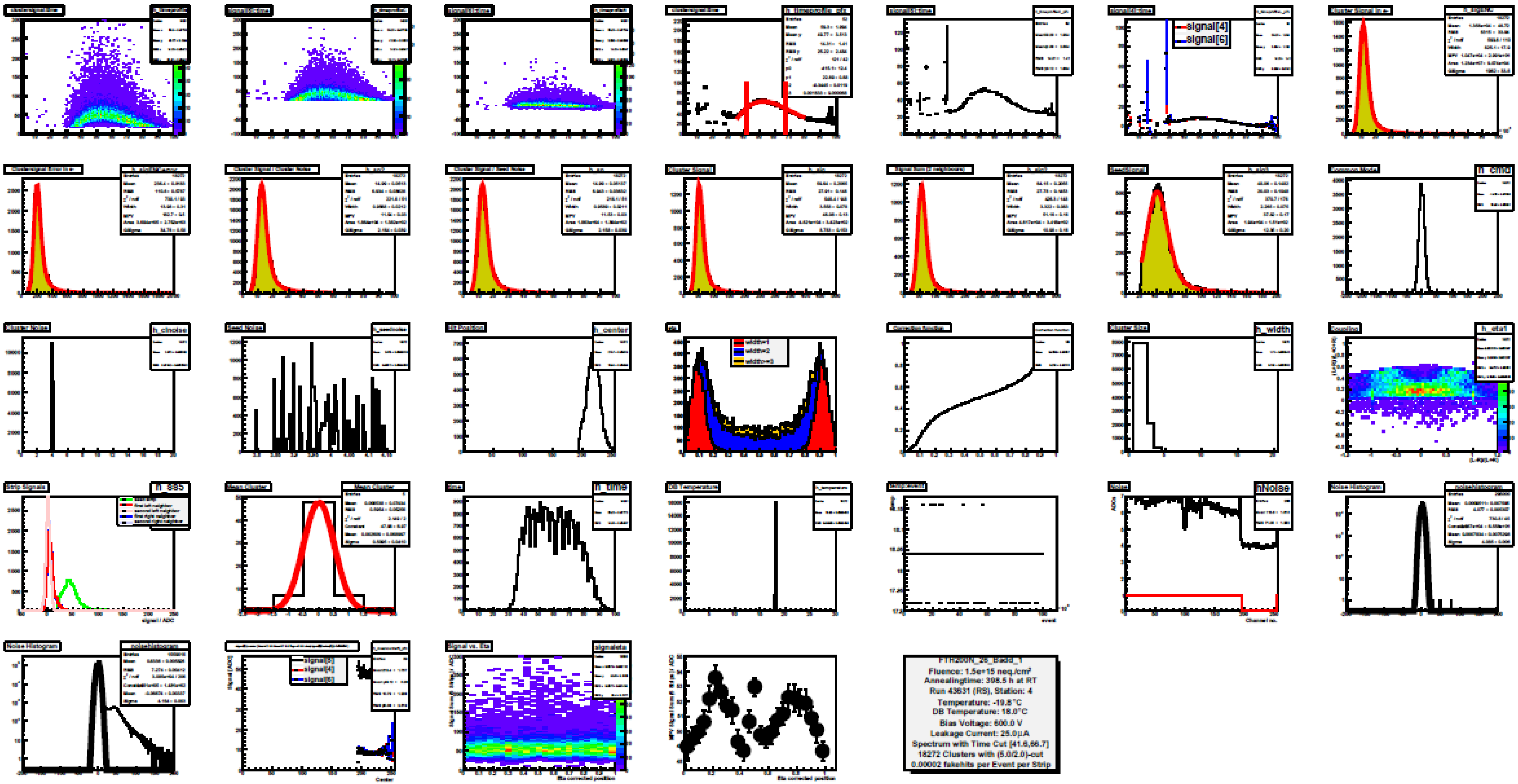
Wet → dry (600V)



signal[4]
signal[6]
width=1
width=2
FTH200N_25_Badd_1
Fluence: 1.5e+15 neq./cm²
Annealingtime: 398.5 h at RT
Run 43831 (RS), Station: 4
Temperature: -19.8°C
DB Temperature: 18.0°C
Bias Voltage: 600.0 V
Leakage Current: 25.0µA
Spectrum with Time Cut [41.6,66.7]
18272 Clusters with (5.0/2.0)-cut
0.00002 fakehits per Event per Strip

Abstract

- In the CMS campaign to find the new baseline material for the next tracker, irradiated p-on-n sensors showed a non-gaussian noise behavior. The effect has been quantified and studied systematically as a function of the applied bias voltage and sensor annealing, as well as irradiation fluence, particle type and energy and sensor geometry. In some operation area, this effect would lead to an noise occupancy of the sensor of over 10%, which makes this p-on-n sensors unuseful as a tracking device. The dependence on the sensor geometry (strip pitch and w/p ratio) indicates, that a high electric field at the strip side promotes the effect. T-CAD simulations of irradiated strip sensors showed an intrinsically higher electric field at the front side of p-on-n sensors compared to n-on-p sensors, thus making the occurrence of the effect more likely in p-on-n sensors.