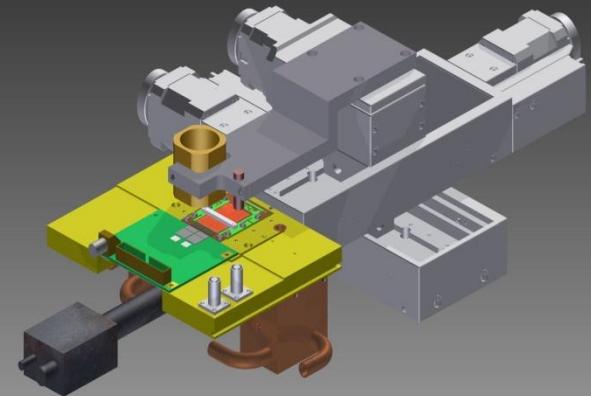
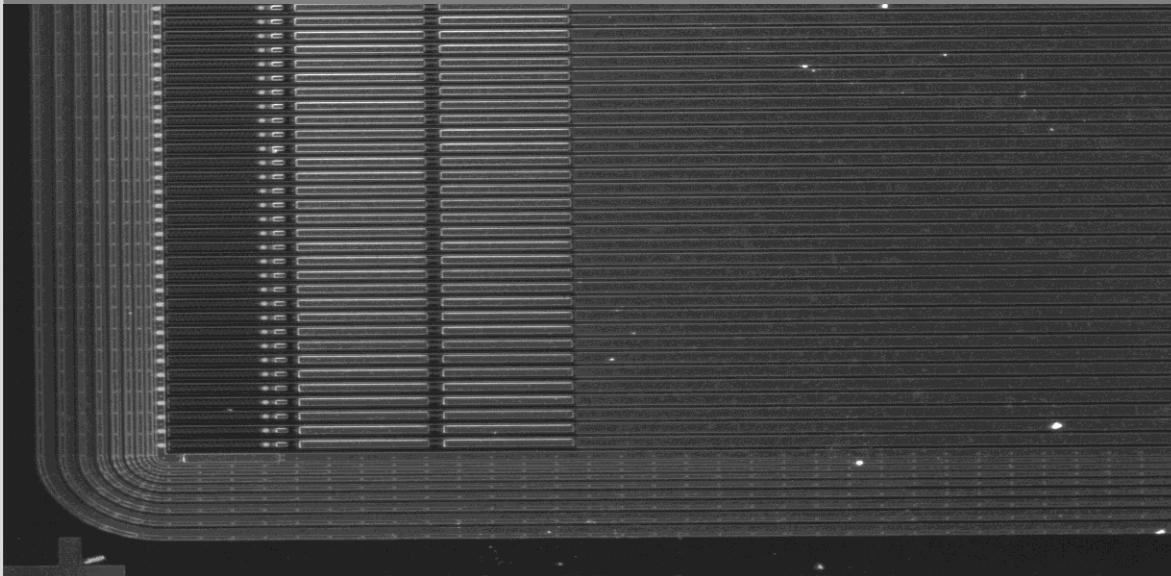


Investigation of Charge Multiplication in Silicon Strip Detectors

20th RD50 Workshop 30.05.- 01.06.2012

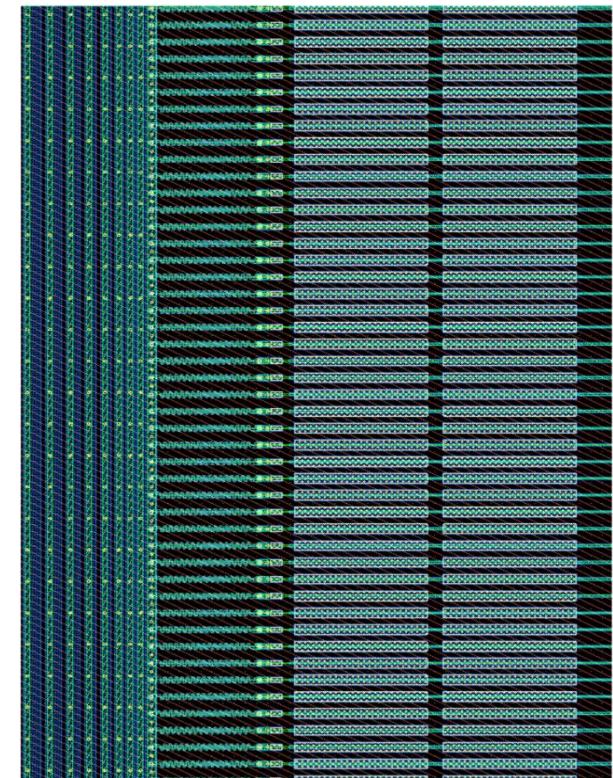
Lokman Altan, T. Barvich, F. Bögelspacher, W. de Boer, A. Dierlamm,
K.-H. Hoffmann, R. Eber, A. Nürnberg, P. Steck

Institut für Experimentelle Kernphysik



Overview

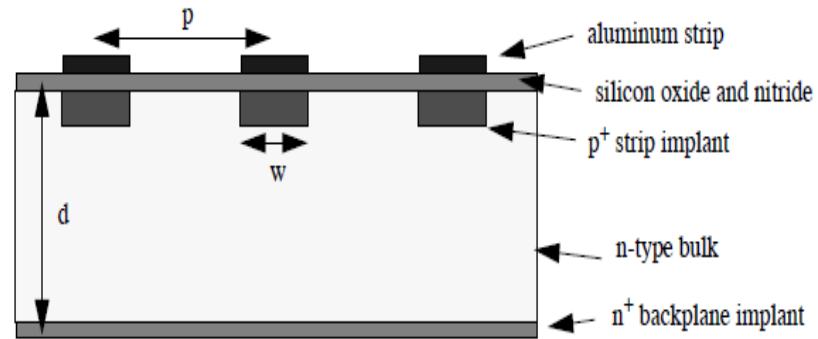
- Introduction
 - Overview of sensor properties
- Qualification before and after irradiation
 - IV/CV measurement
 - Interstrip measurement
 - Bias resistance and coupling capacitance
- Charge collection before and after irradiation
 - CCE
 - Signal to noise ratio
 - Leakage current
- Summary



RD 50: Sensor Properties (p-Type)

■ Geometry

- Depth ($d = 150 \mu\text{m}, 305 \mu\text{m}, 675 \mu\text{m}$)
- Width/pitch ($0.075 < w/p < 0.75$)
- Interstrip
- Active area: $10.18 \text{ mm} \times 11.76 \text{ mm}$



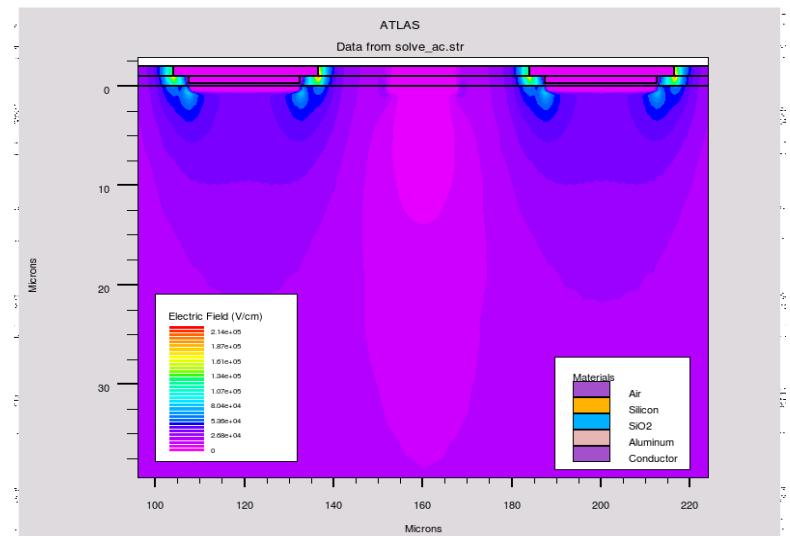
■ Processing

- Diffusion time
- Implantation energy

■ Irradiation

- Irradiation with protons and/or neutrons
- Variation of fluence

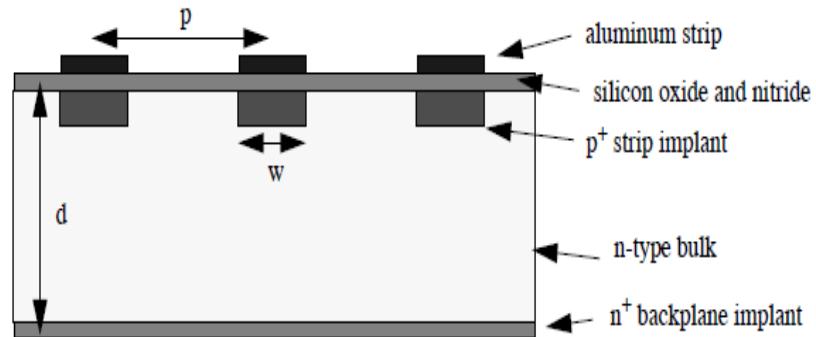
■ Annealing time



RD 50: Selected Sensors (p-Type)

■ Geometry

- Depth ($d = 150 \mu\text{m}$, **305 μm** , $675 \mu\text{m}$)
- **Width/ pitch ($0.075 < w/p < 0.75$)**
- Interstrip
- Active area: $10.18 \text{ mm} \times 11.76 \text{ mm}$



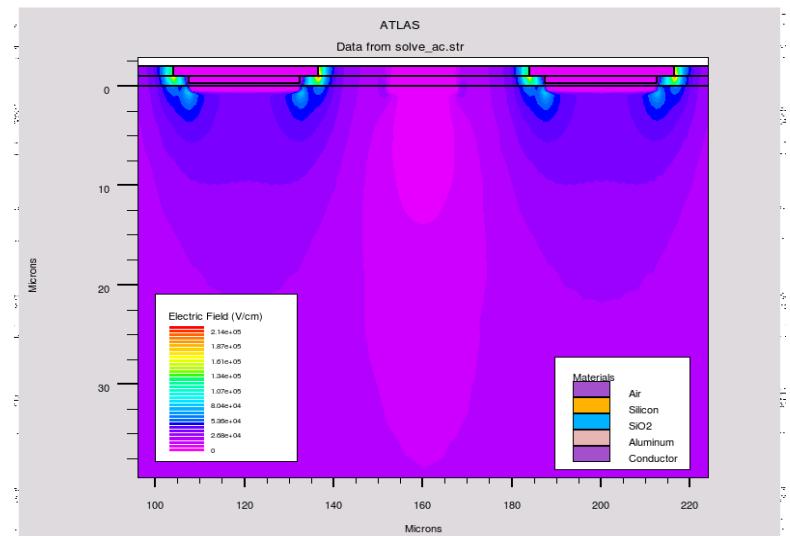
■ Processing

- Diffusion time
- Implantation energy

■ Irradiation

- **Irradiation with protons and/or neutrons**
- **Variation of fluence (1×10^{15} , 5×10^{15} , $1 \times 10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$)**

■ Annealing time



Irradiation with Protons

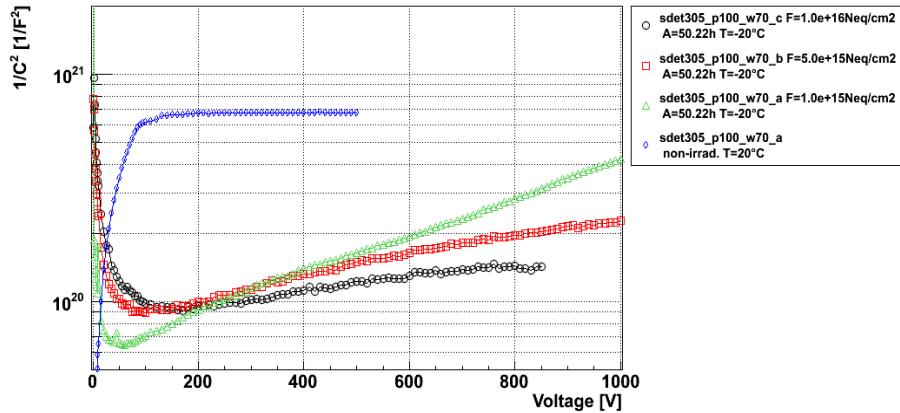
(a) $1*10^{15} n_{eq}/cm^2$	Status	(b) $5*10^{15} n_{eq}/cm^2$	Status	(c) $1*10^{16} n_{eq}/cm^2$	Status
p100_w70_a	completed	p100_w70_b	completed	p100_w70_c	Strip scan
p100_w33_a	completed	p100_w33_b	completed	p100_w33_c	Strip scan
p100_w10_a	completed	p100_w10_b	completed	p100_w10_c	Strip scan
p80_w60_a	completed	p80_w60_b	Strip scan		
p80_w25_a	completed	p80_w25_b	completed		
p80_w6_a	completed	p80_w6_b	Strip scan		

- p100_w70_a: **pitch** 100µm, **width** 70µm, **a**: fluence $F = 1*10^{15} n_{eq}/cm^2$
- Depth: 305µm
- Choose different fluences
- Irradiation with protons in Karlsruhe (23MeV protons)
- Irradiation with neutrons in Ljubljana (finished and ready to measure)
- Standard processing: no change of diffusion time and implantation energy

Qualification before and after irradiation with protons: CV-measurement

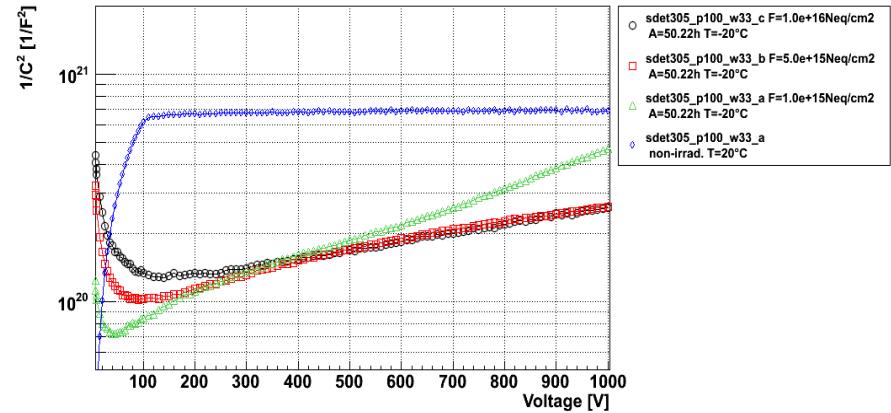
Capacitance - Voltage
f=1000Hz guard=1

w70



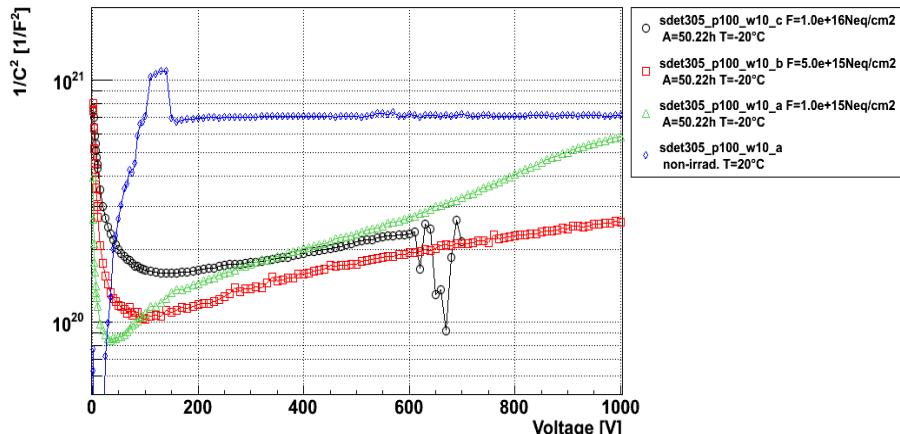
Capacitance - Voltage
f=1000Hz guard=1

w33



Capacitance - Voltage
f=1000Hz guard=1

w10



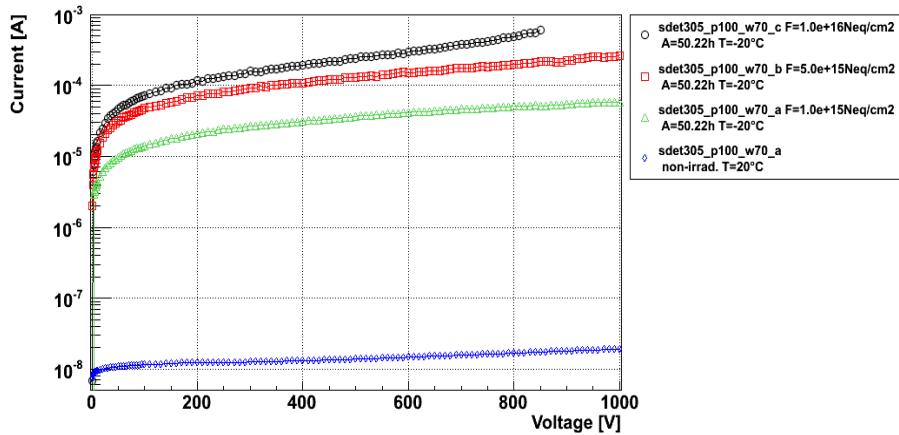
- p100-sensors
- blue: no irradiation
- green: $F = 1 \times 10^{15} n_{eq}/cm^2$
- red: $F = 5 \times 10^{15} n_{eq}/cm^2$
- black: $F = 1 \times 10^{16} n_{eq}/cm^2$

no irradiation: $V_{dep} \sim 100V$
 irradiated : $V_{dep} > 1000V$

Qualification before and after irradiation with protons: IV-measurement

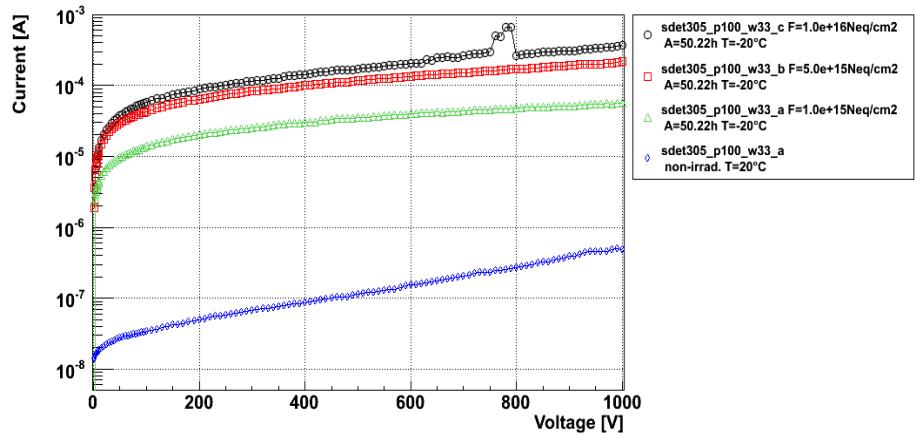
Current - Voltage
guard=1

w70



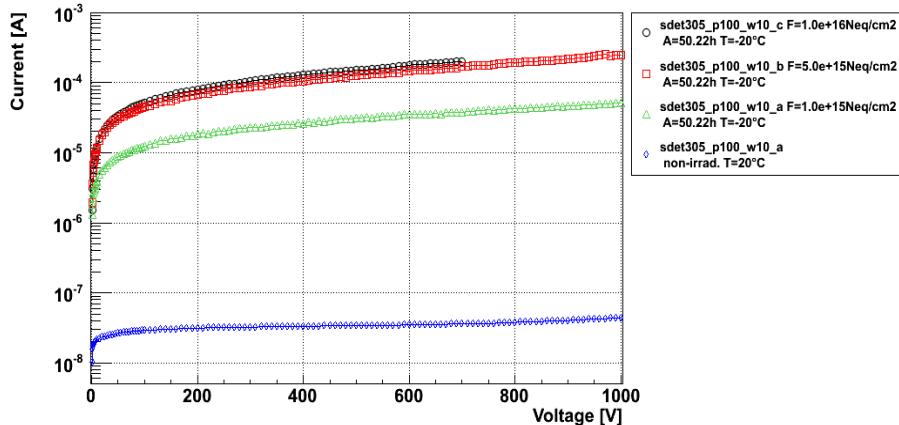
Current - Voltage
guard=1

w33



Current - Voltage
guard=1

w10

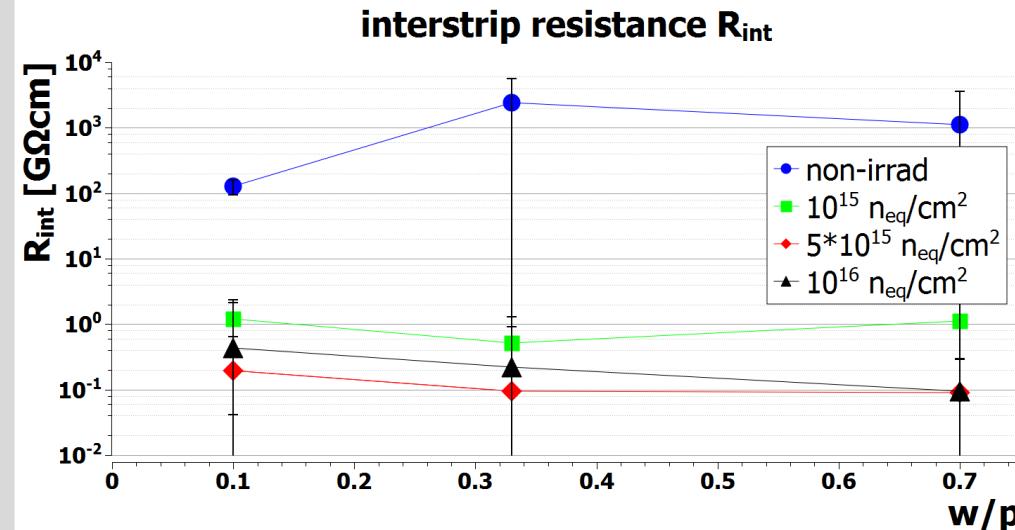


p100-sensors

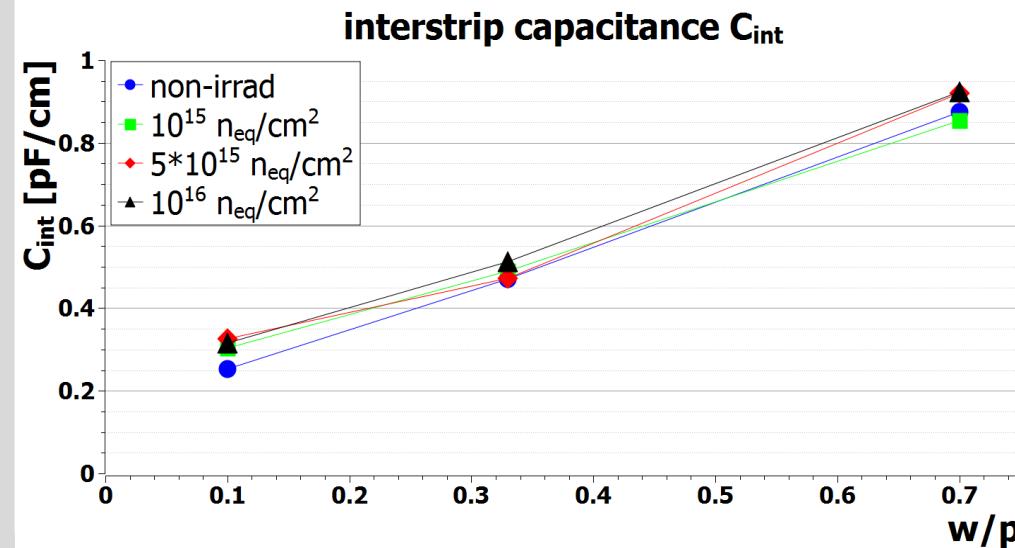
no irradiation, $F= 1*10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$,
 $F= 5*10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, $F= 1*10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$

$\alpha @ T=-20^\circ\text{C}: 1.4*10^{-18} \text{ A/cm}$
 (outlier: p100_w10_c)
 expected parameter (M.Moll):
 $\alpha @ T=-20^\circ\text{C}: 0.9*10^{-18} \text{ A/cm}$

Qualification before and after irradiation with protons: interstrip-measurement



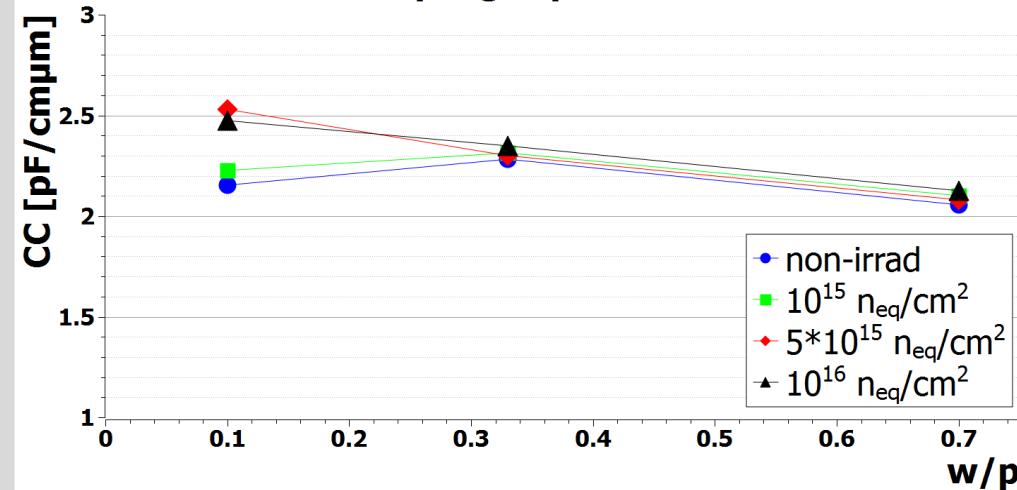
- p100-sensors
- Interstrip resistance R_{int}
- R_{int} decreases with fluence



- Interstrip capacitance C_{int}
- C_{int} increases with w/p-ratio
- C_{int} for two strips (only for one neighbor)

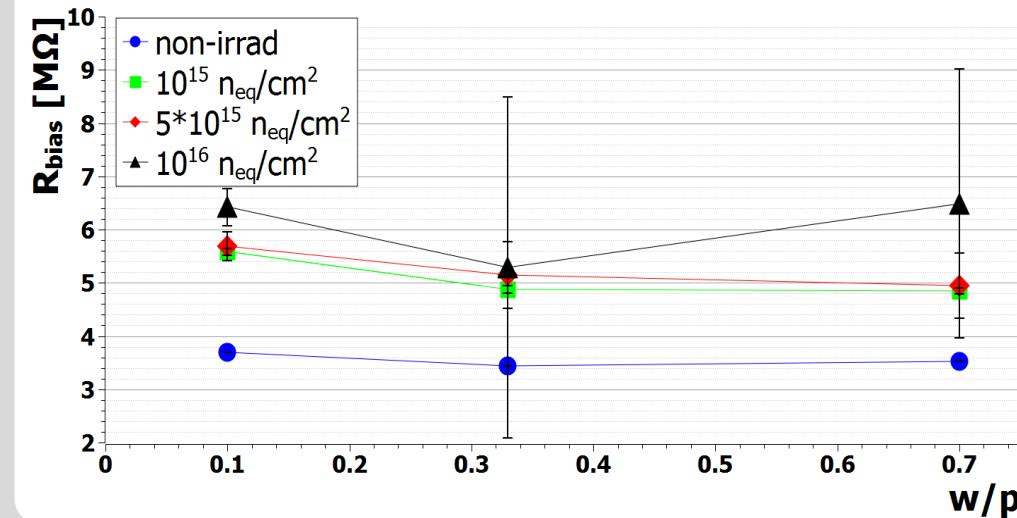
Qualification before and after irradiation with protons: coupling capacitance & bias resistance

coupling capacitance CC



- p100-sensors
- Coupling capacitance CC
- CC: 2-2.5 (pF/cm μ m) before and after irradiation

bias resistance R_{bias}



- Bias resistance R_{Bias}
- After irradiation R_{Bias} increases about 30%
- R_{Bias} higher with increasing fluence

Setup and Annealing

Annealing

temperature (°C)	60	80	80	80	80
time (min)	76	15	30	60	60
sum (days@21°C)	14.7	41.8	119.9	324	528

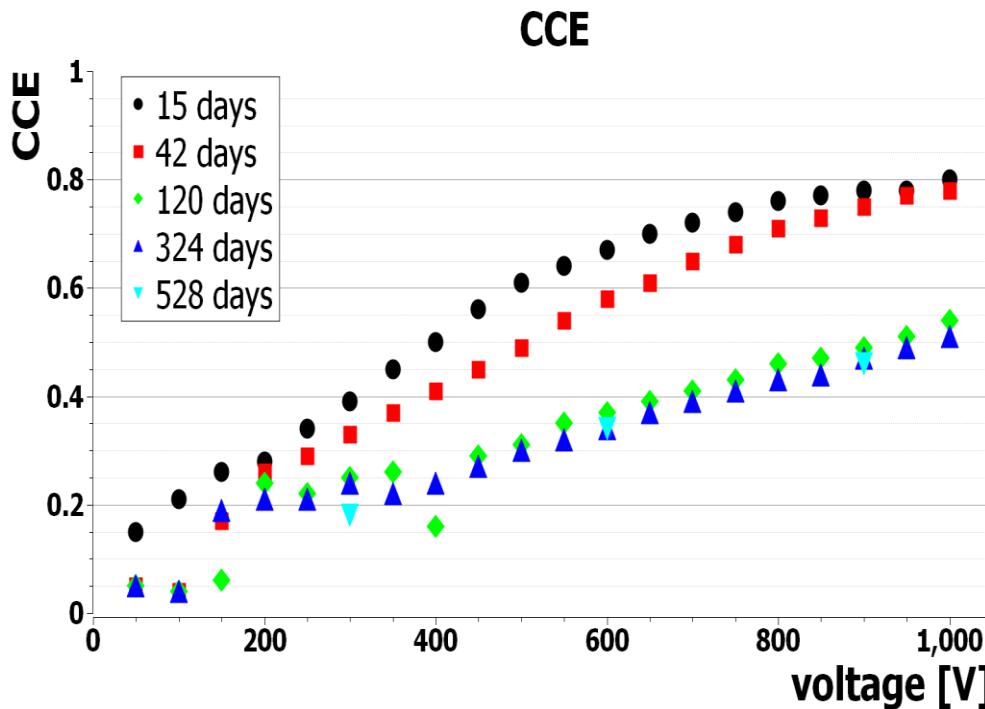
Measurement

- ALiBaVa-Measurement
- ^{90}Sr source
- Cuts
 - Seed: S/N > 5
 - Neighbors: S/N > 2
- Temperature: -20°C
- Voltage: 150V – 1000V in 50V steps
- After each annealing step, a voltage ramp has been measured
- **After last step:** only four voltage values have been measured
- CCE
- Signal to noise ratio
- Leakage current

Measurement Results

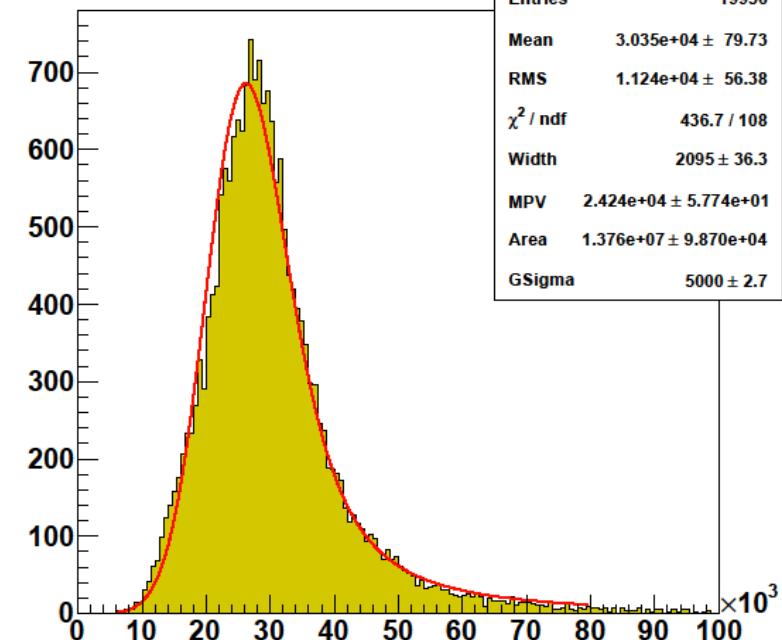
Pitch = 100 µm

p100_w70_a: Complete Measurement



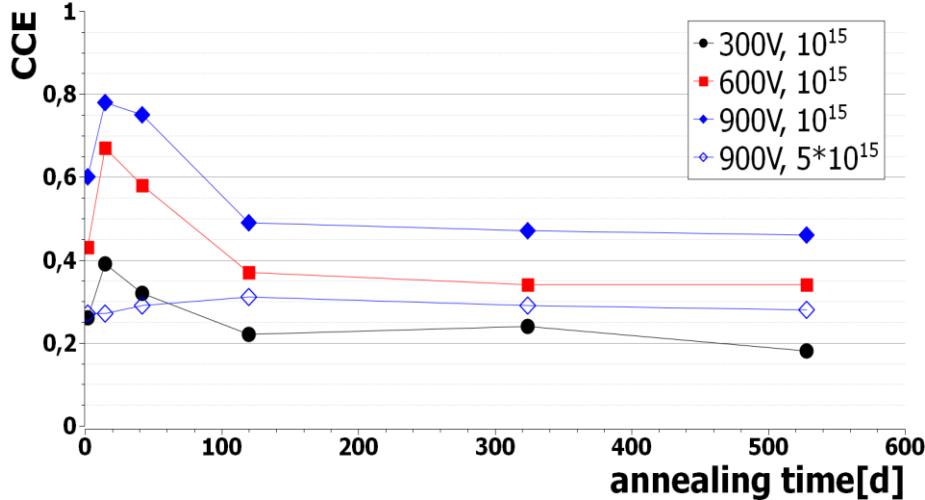
- ALiBaVa measurement
- T= -20°C
- 100'000 Trigger
- Landau-Gauß-Fit

Cluster Signal in e-

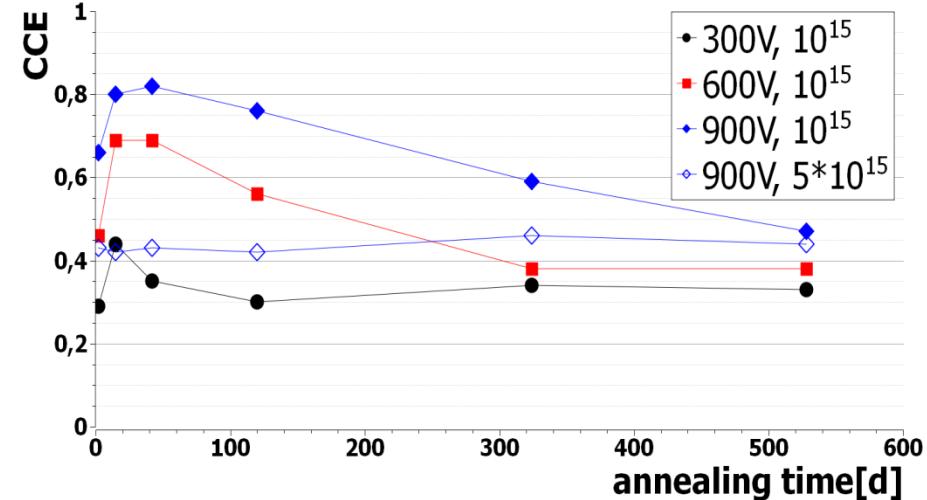


Charge Collection Efficiency (CCE), Pitch=100μm

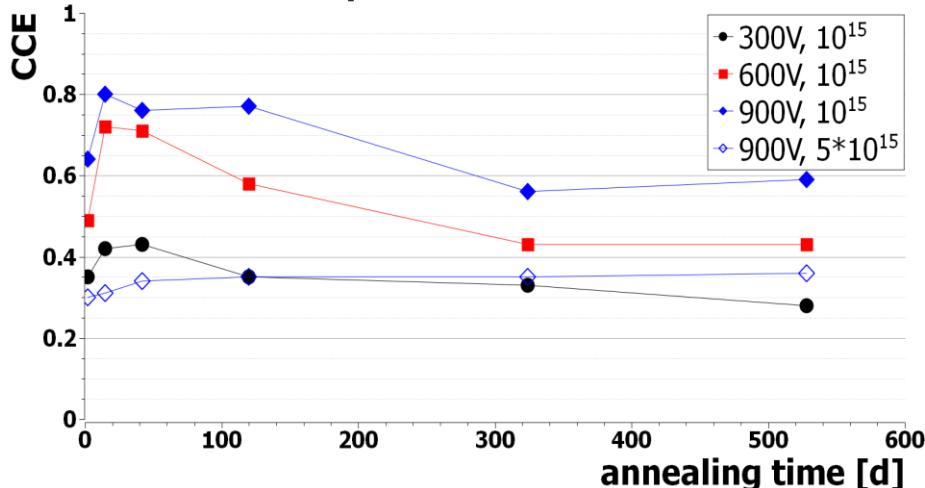
p100_w70 @ -20°C



p100_w33 @ -20°C



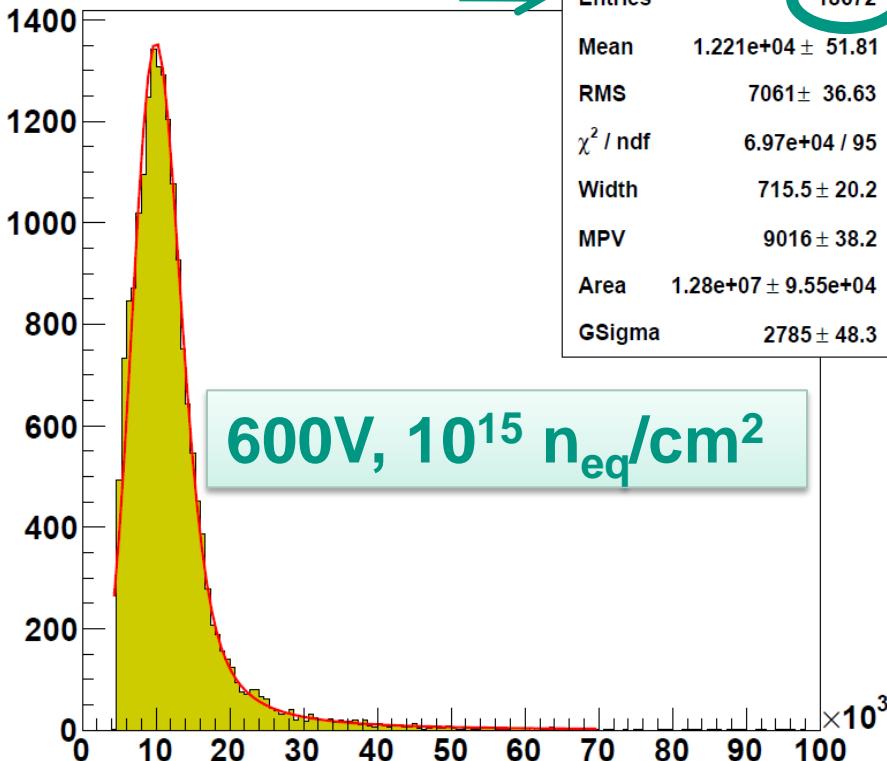
p100_w10 @ -20°C



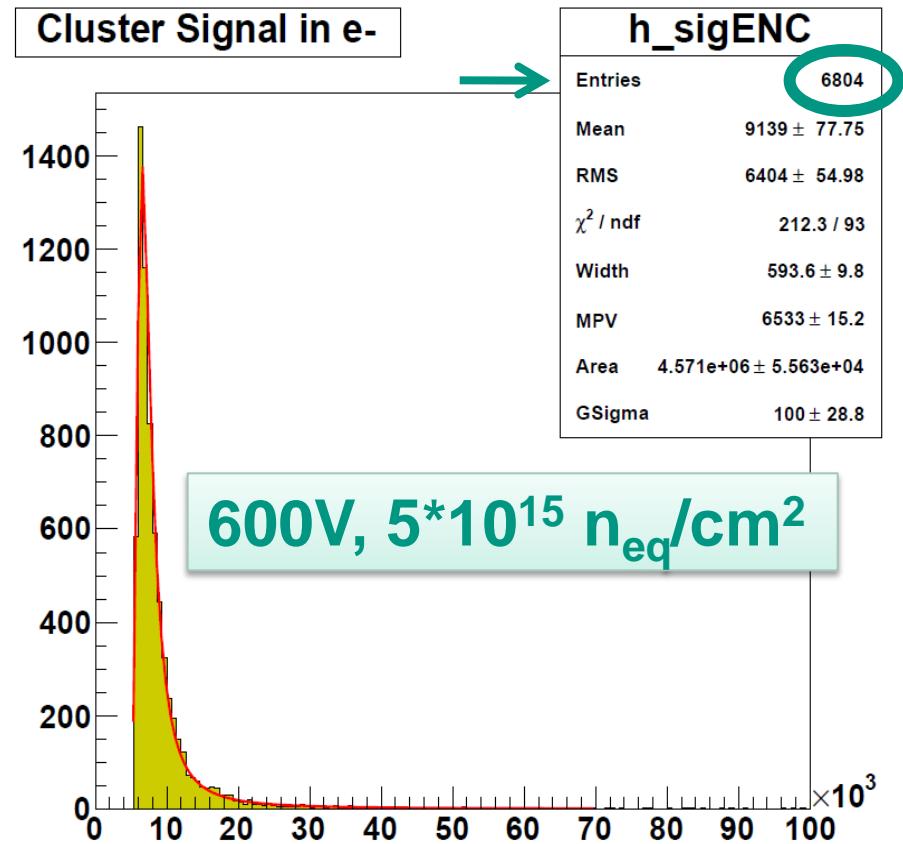
- no Charge Multiplication recognizable
- $10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$: signal increases after short annealing time (*beneficial annealing*) and after long annealing time signal decreases (*reverse annealing*)
- $5*10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$: only small dependence of charge collection on annealing time

Histogram: 1×10^{15} n_{eq}/cm² vs. 5×10^{15} n_{eq}/cm²

Cluster Signal in e-

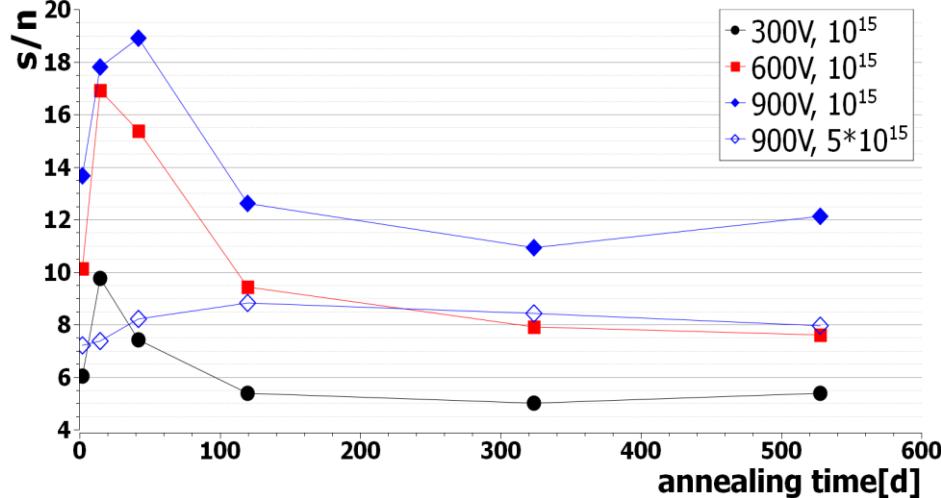


Cluster Signal in e-

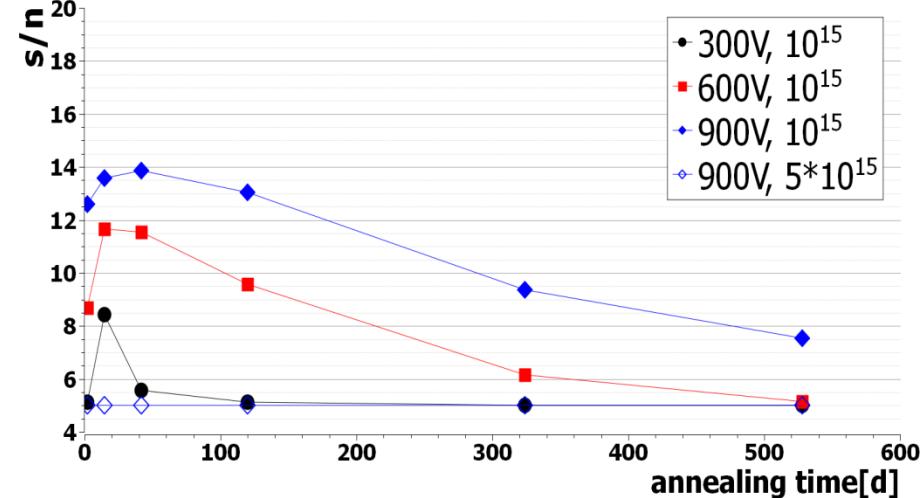


Signal to Noise (s/n)

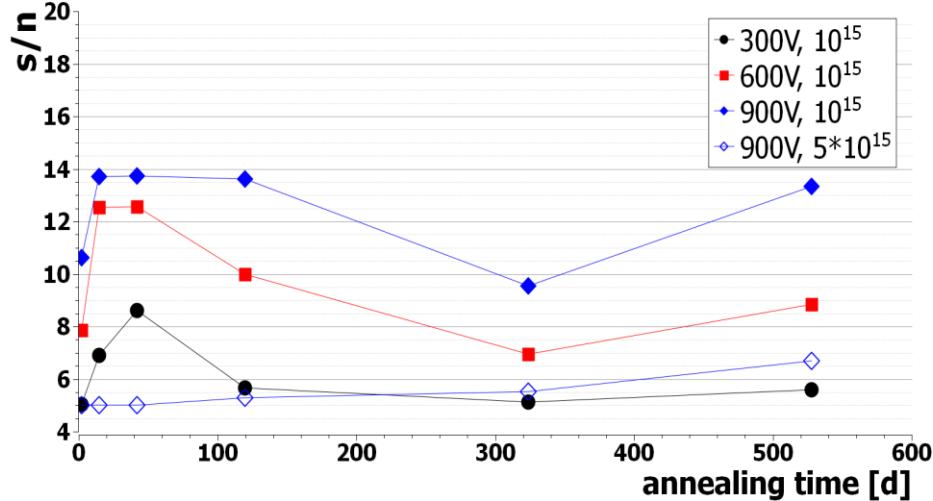
p100_w70 @ -20°C



p100_w33 @ -20°C



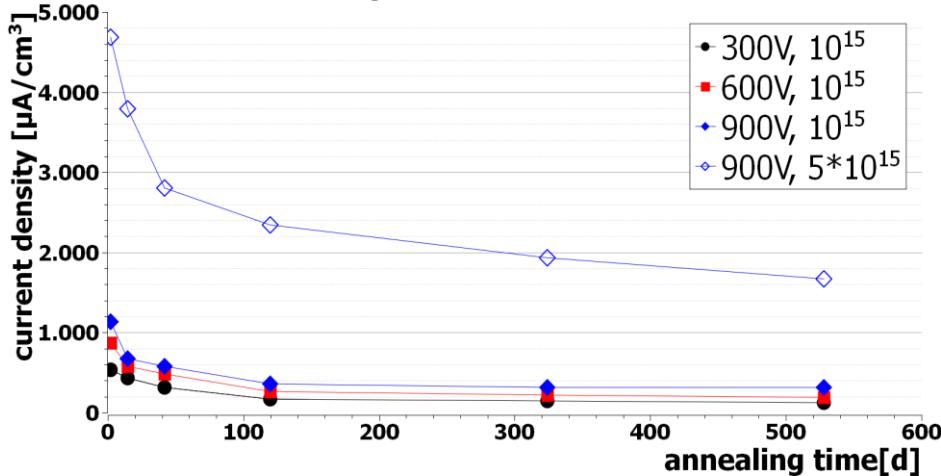
p100_w10 @ -20°C



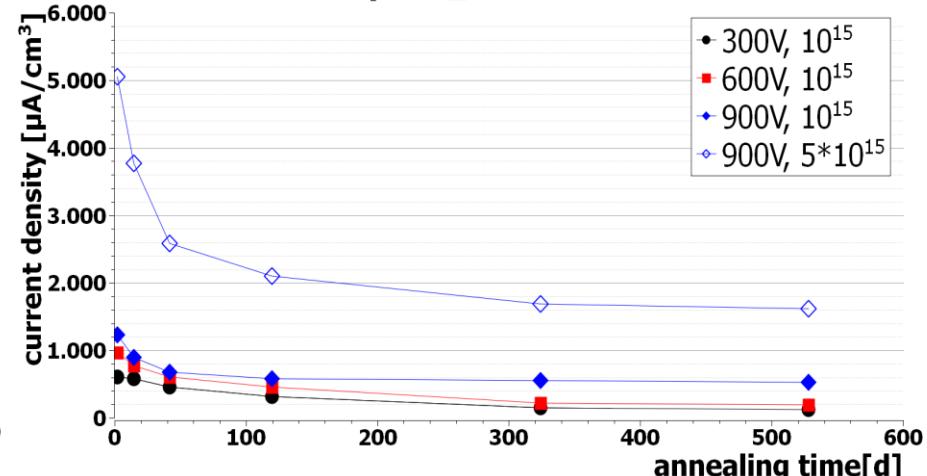
- No difference between course of signal/noise and CCE
- s/n increases with w/p-ratio
- $5 \times 10^{15} n_{eq}/cm^2$: small value, sometimes below limit of s/n = 5

Leakage current

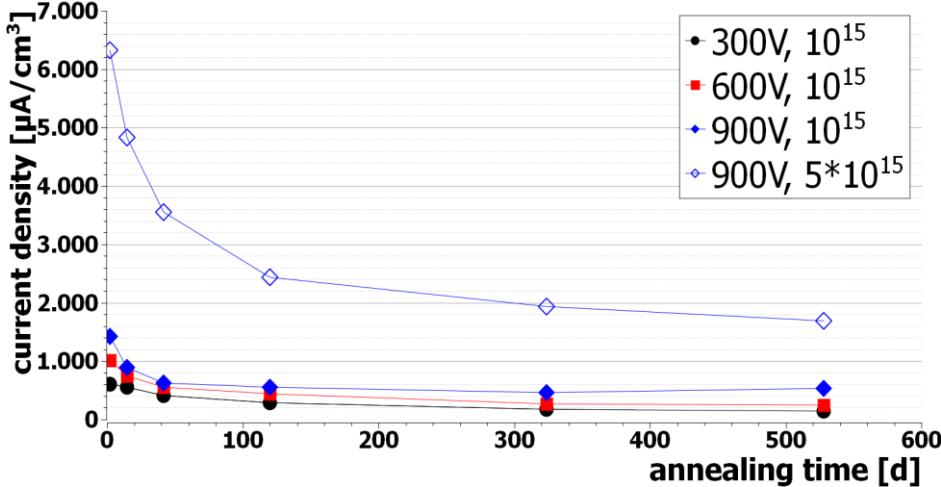
p100_w70 @ -20°C



p100_w33 @ -20°C



p100_w10 @ -20°C



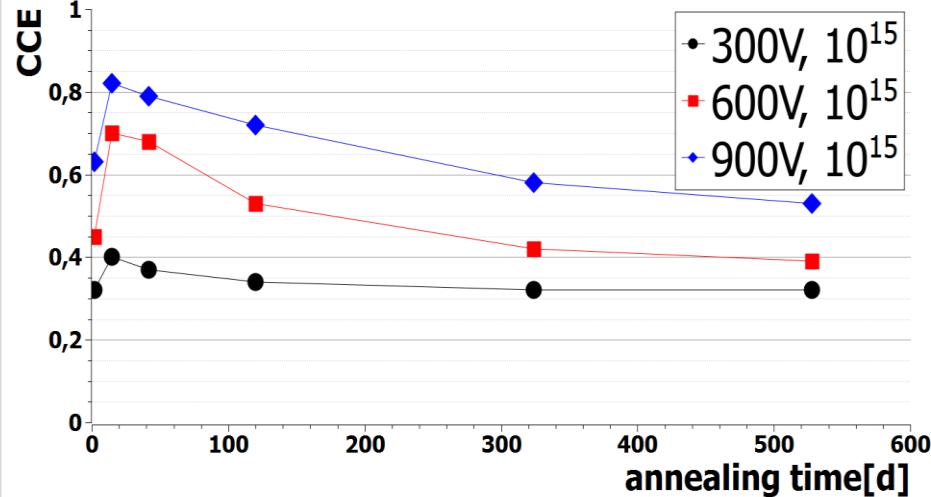
- Leakage current decreases with annealing time (as expected)
- Leakage current increases with higher fluence and smaller w/p value

Measurement Results

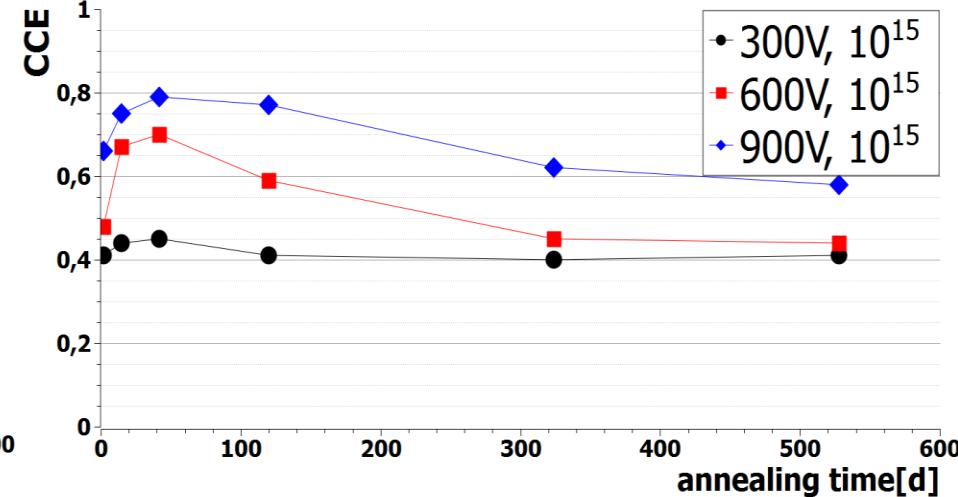
Pitch = 80 µm

Charge Collection Efficiency (CCE), pitch 80 µm

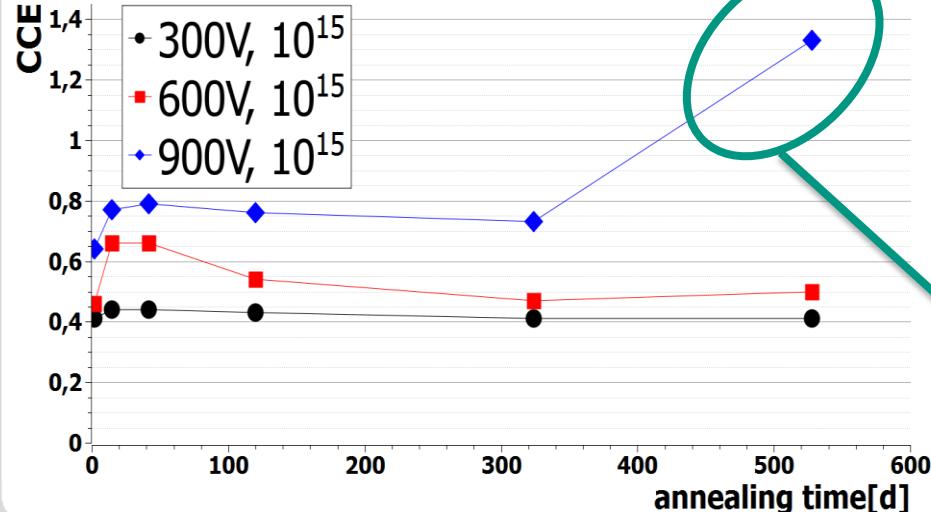
p80_w60 @ -20°C



p80_w25 @ -20°C



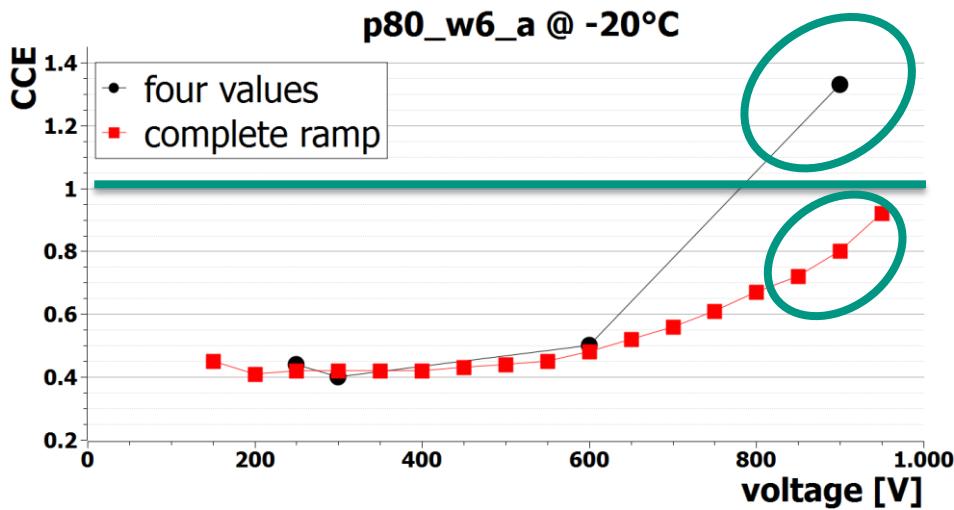
p80_w6 @ -20°C



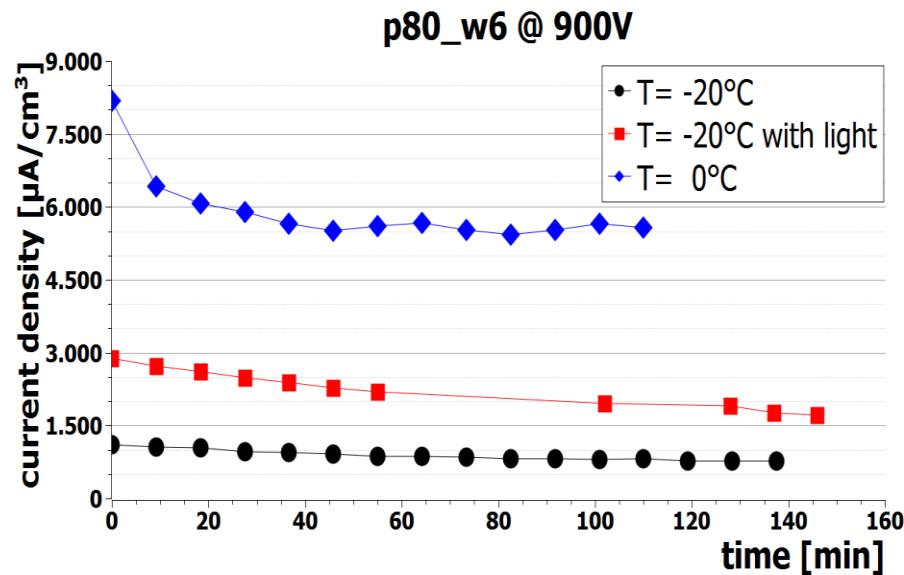
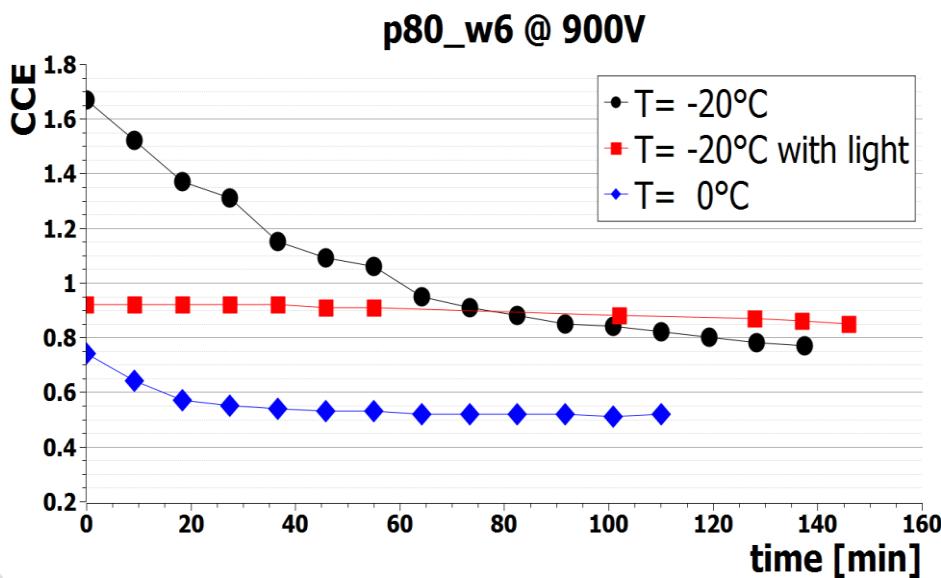
- signal increases after short annealing time (beneficial annealing) and after long annealing time signal decreases (reverse annealing)
- charge multiplication recognizable at smallest w/p ratio (p80_w6)

repeat measurement

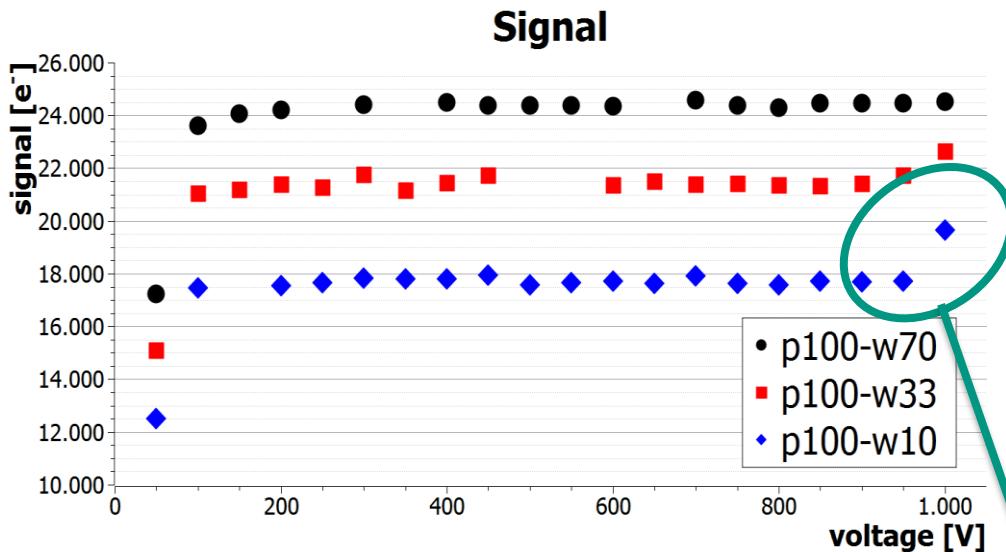
Charge Collection Efficiency (CCE), pitch 80 μm



- CCE decreases with time at a constant voltage
- Measurement was repeated always the next day
- More current \rightarrow “less” CCE

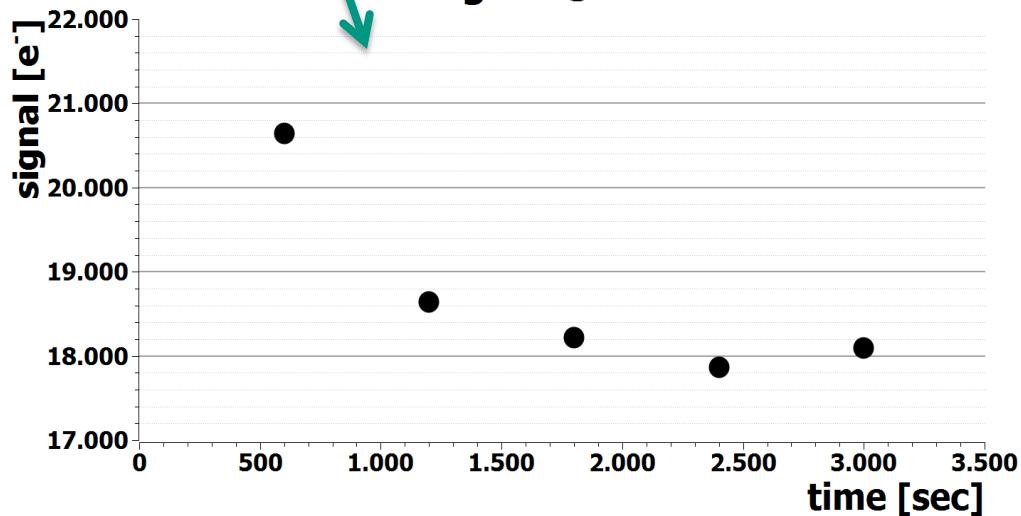


Charge effect

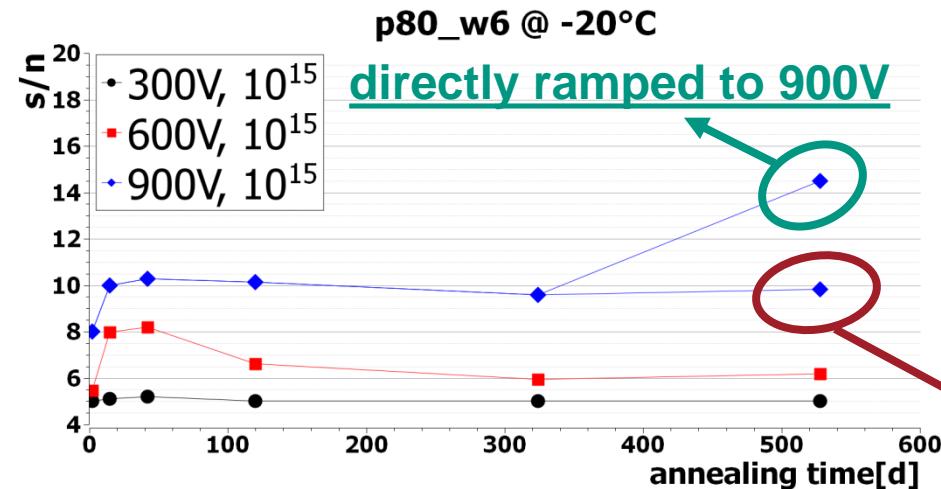
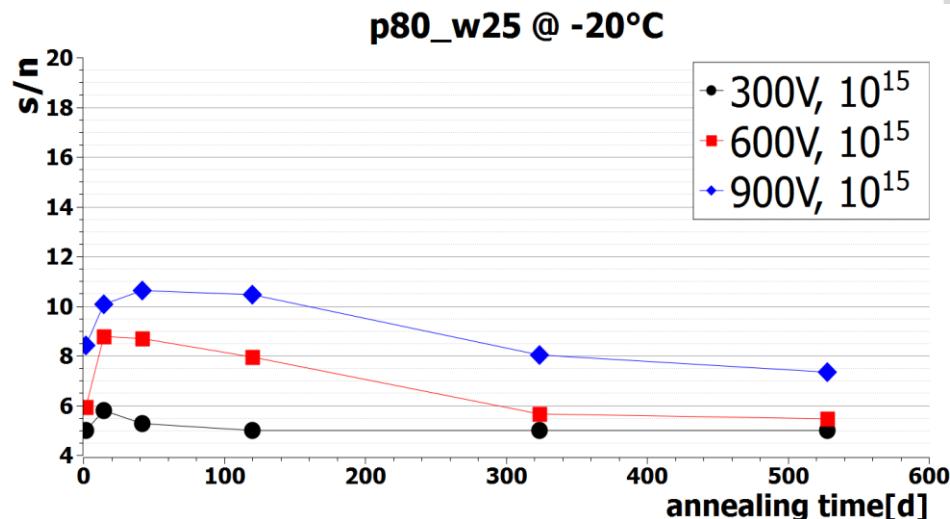
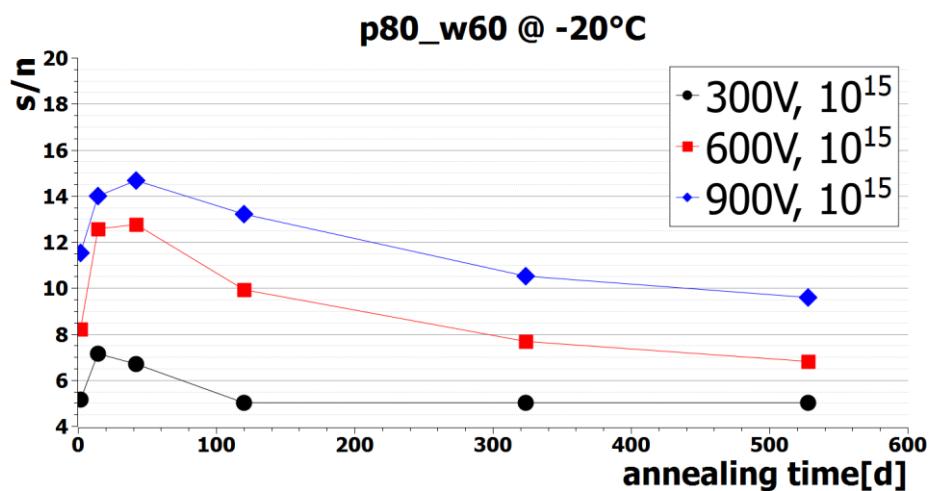


- Effect has also been seen in *non irradiated* condition
- Signal was measured from 1000V to 50V
- Signal decreases with time

Signal @ 1000V

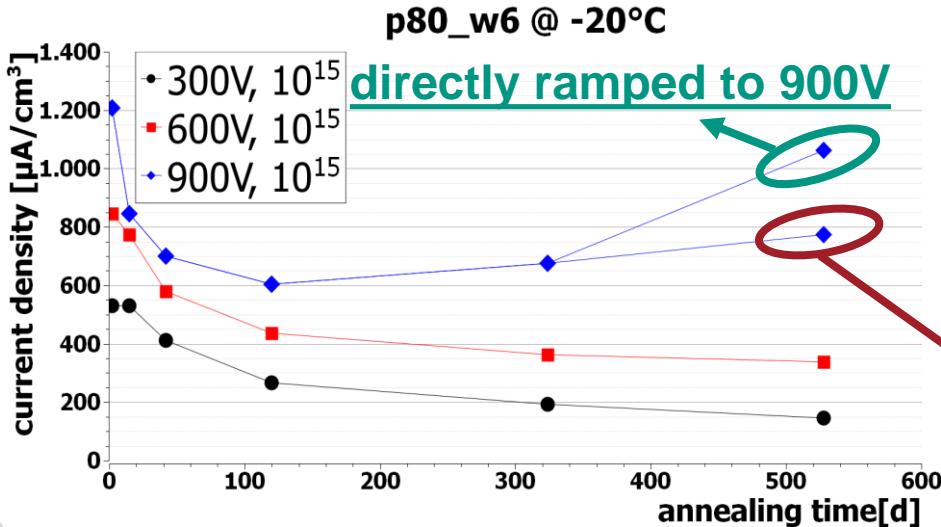
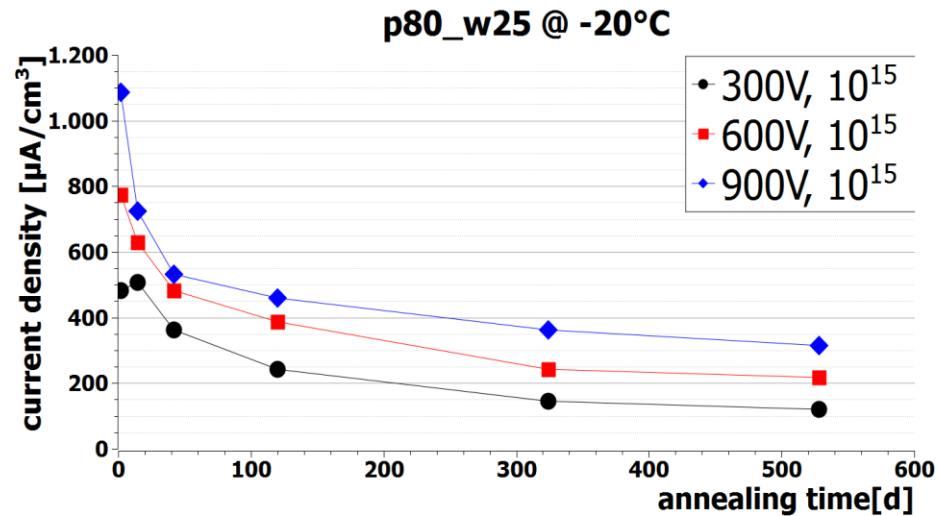
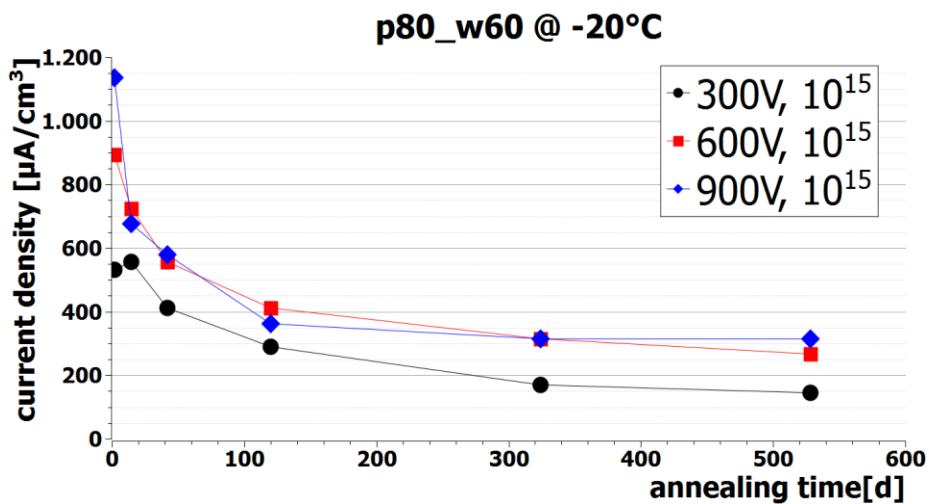


Signal to Noise (s/n)



- No difference between course of signal/noise and CCE
 - s/n increases with w/p ratio
 - Directly ramped to 900V: s/n increases after last annealing step
 - Complete ramp: no increase
- complete voltage ramp**

Leakage current



- Leakage current decreases with annealing time
- Directly ramped to 900V: Current increases after last annealing step
- Complete ramp: no increase

complete voltage ramp

Summary

- Increased charge collection for a short duration at high voltage (900V) and a fluence of $10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$
 - Signal to noise and leakage current also increase for a short time
 - This effect has to be understood (perhaps more measurement with Edge - TCT)
- No Charge Multiplication at a fluence $5*10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ so far
- Next step: measuring samples after neutron irradiation
- Dependence on processing will be investigated
 - Sensors already measured in non irradiated condition

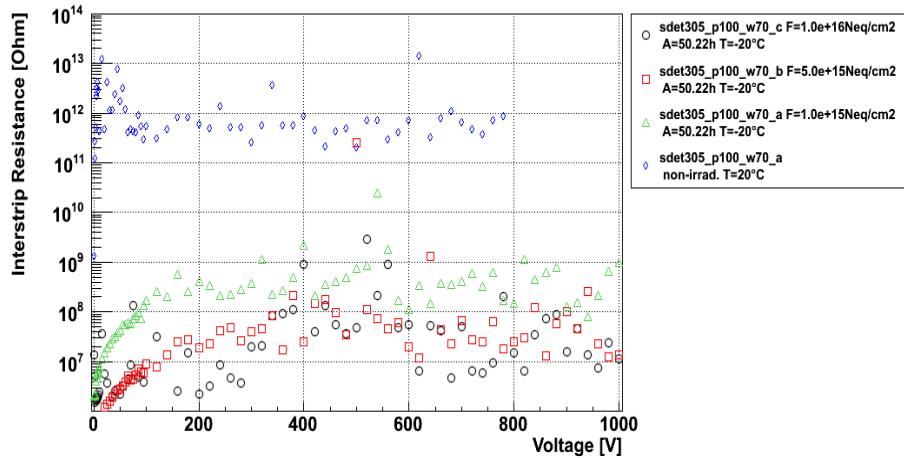
Thanks for your attention

Backup

Qualification before and after irradiation with protons: interstrip resistance R_{int}

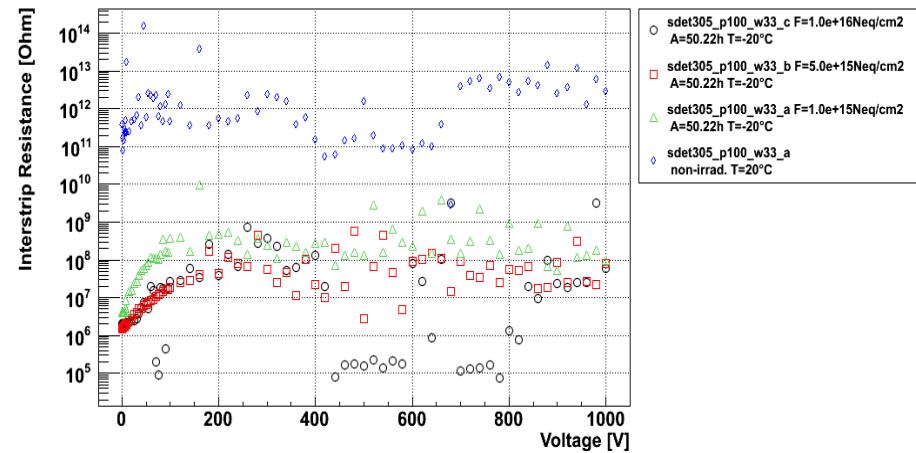
Interstrip resistance ramp

w70



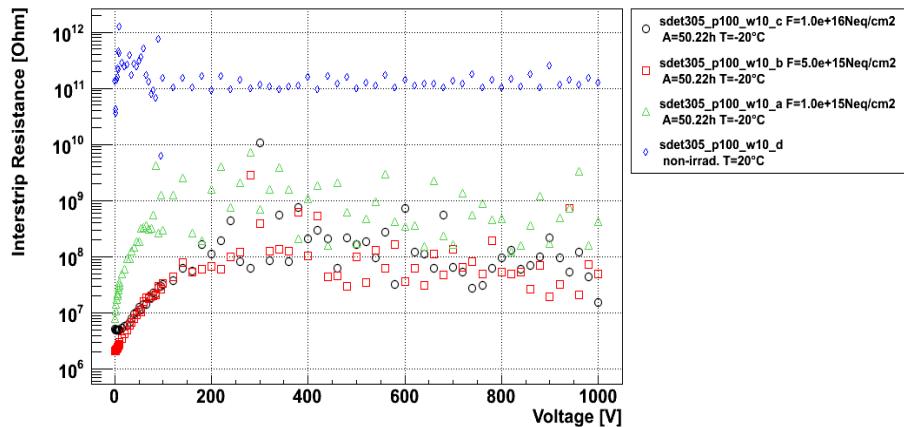
Interstrip resistance ramp

w33



Interstrip resistance ramp

w10



p100- sensors

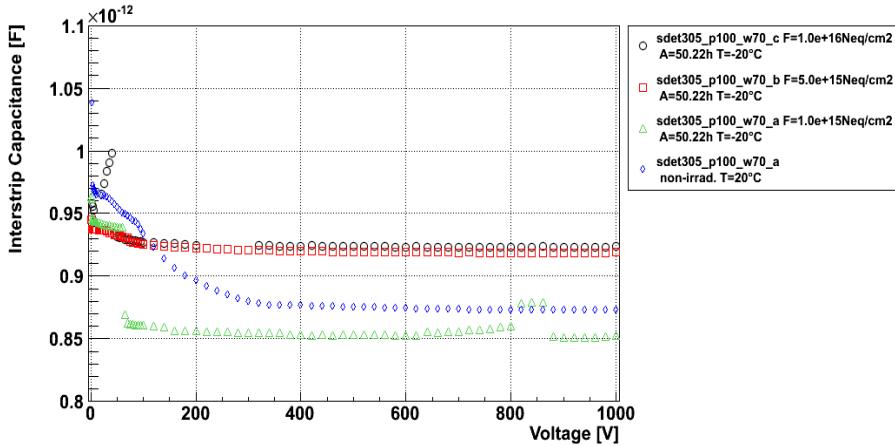
no irradiation, $F= 1*10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$,
 $F= 5*10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, $F= 1*10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$

- R_{int} increases with width/pitch (w/p)-ratio
- R_{int} decreases with fluence
- coefficient ~1000 between irradiated and non- irradiated samples

Qualification before and after irradiation with protons: interstrip capacitance C_{int}

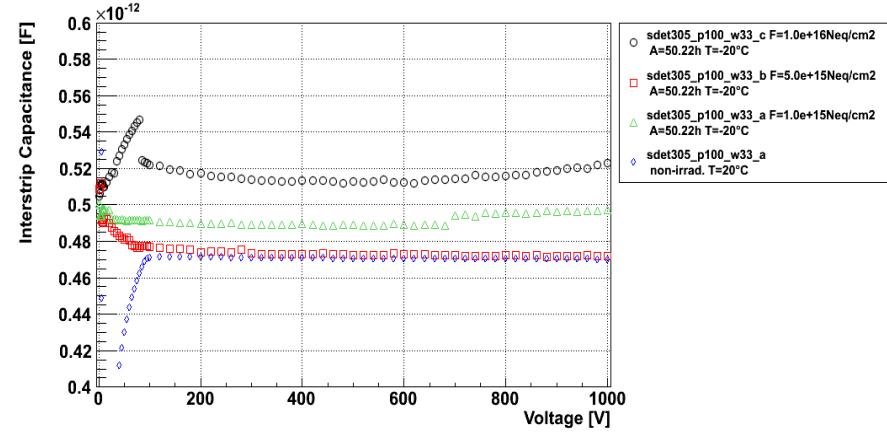
Interstrip capacitance ramp

w70



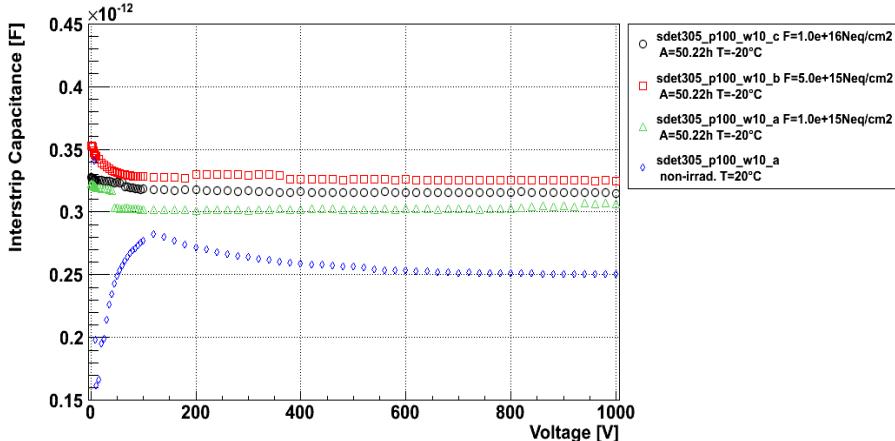
Interstrip capacitance ramp

w33



Interstrip capacitance ramp

w10



p100- sensors

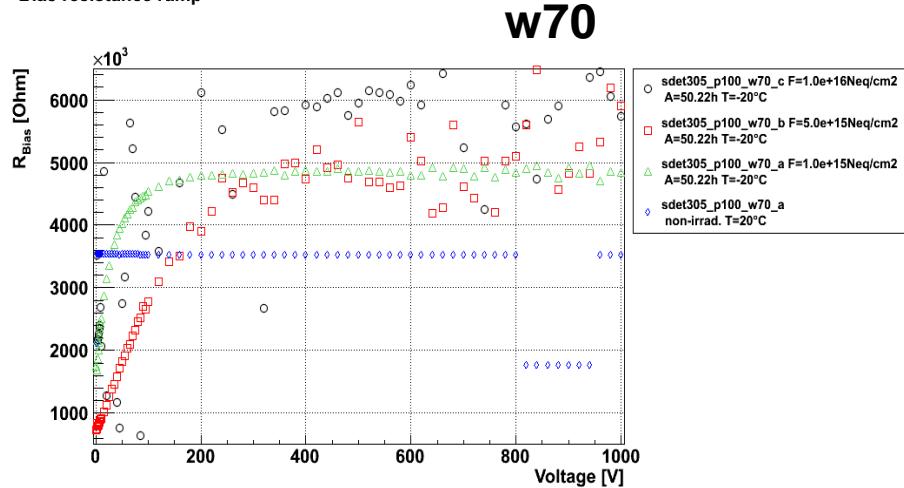
**no irradiation, $F = 1 \times 10^{15} \text{ n}_{eq}/\text{cm}^2$,
 $F = 5 \times 10^{15} \text{ n}_{eq}/\text{cm}^2$, $F = 1 \times 10^{16} \text{ n}_{eq}/\text{cm}^2$**

- C_{int} increases with w/p- ratio
- C_{int} for two strips (only for one neighbor)
- C_{int} increases a little bit after irradiation (except p100_w70_a)
- after irradiation the permittivity changes

Qualification before and after irradiation with protons: bias resistance R_{Bias}

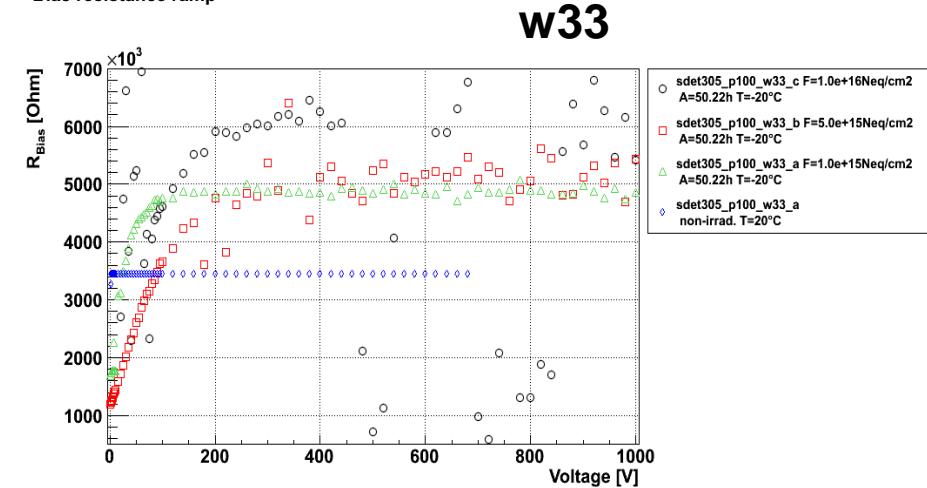
Bias resistance ramp

w70



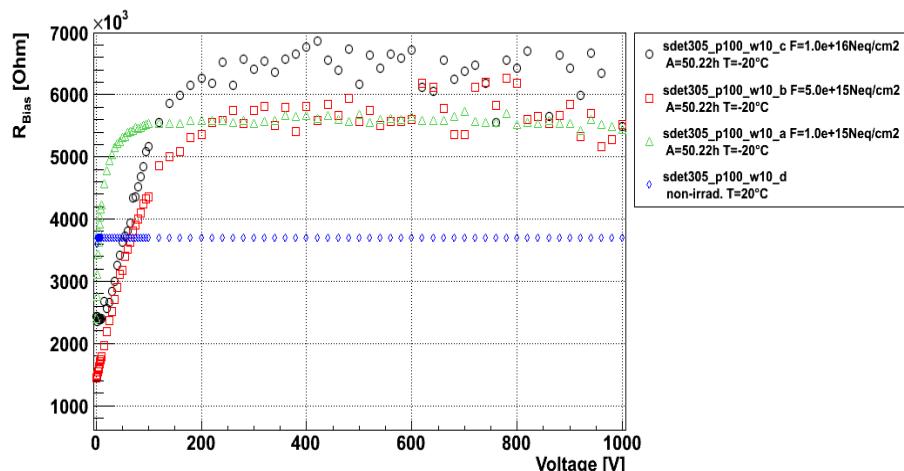
Bias resistance ramp

w33



Bias resistance ramp

w10



p100- sensors

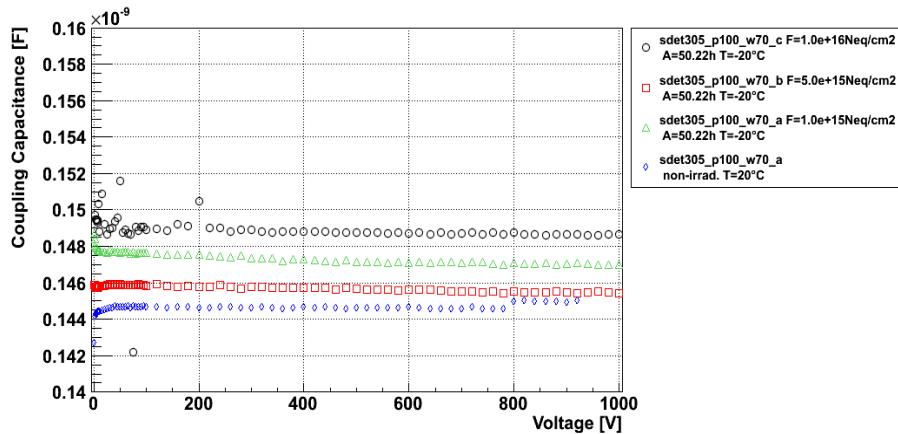
no irradiation, $F = 1 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$,
 $F = 5 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, **$F = 1 \times 10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$**

- after irradiation R_{Bias} increases about 30%
- R_{Bias} higher with increasing fluence
- R_{Bias} scatters after irradiation

Qualification before and after irradiation with protons: coupling capacitance CC

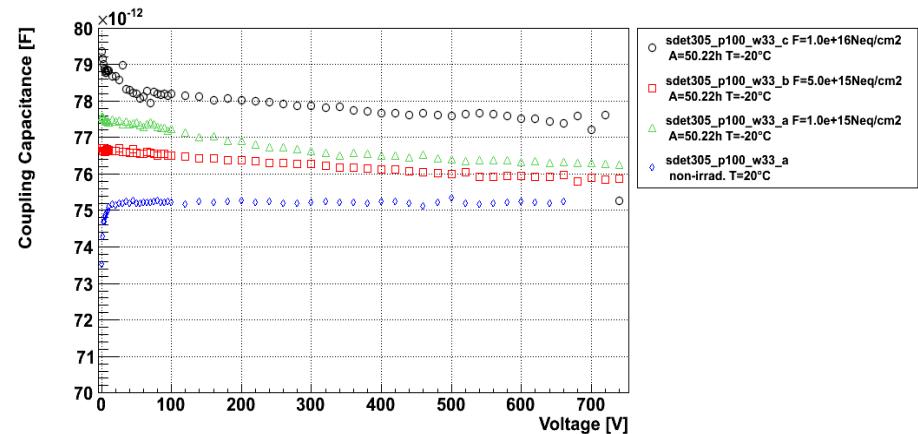
Coupling capacitance ramp

w70



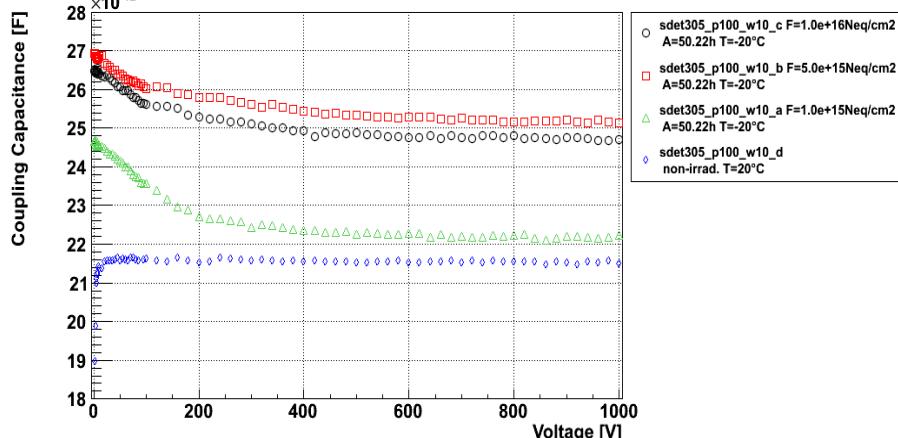
Coupling capacitance ramp

w33



Coupling capacitance ramp

w10



p100- sensors

**no irradiation, $F = 1 \times 10^{15} n_{eq}/cm^2$,
 $F = 5 \times 10^{15} n_{eq}/cm^2$, $F = 1 \times 10^{16} n_{eq}/cm^2$**

CC higher for increasing w/p- ratio

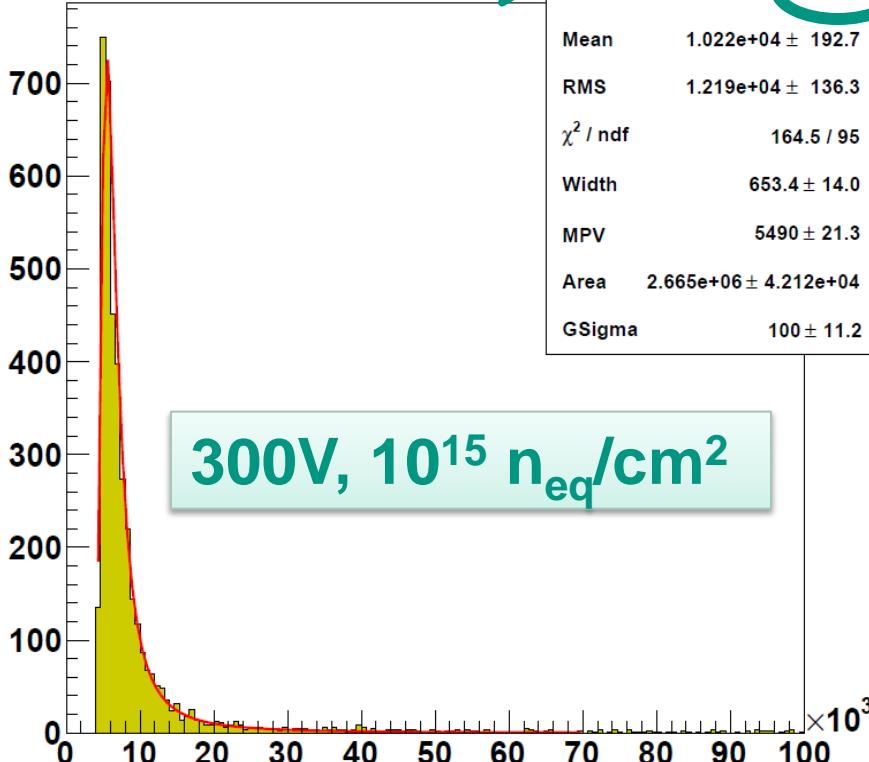
$$\frac{CC}{w}$$

is almost constant in non-irradiated condition

after irradiation CC increases a little

Histogram: $1 \times 10^{15} n_{eq}/cm^2$ vs. $5 \times 10^{15} n_{eq}/cm^2$

Cluster Signal in e-



Cluster Signal in e-

