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PHYSICS AT THE TERA SCALE
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Charge collection close to the Si-Si0$_2$ interface of silicon strip sensors

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Sergej Schuwalow, Jörn Schwandt, Jiaguo Zhang

University of Hamburg

19th RD50 Workshop, CERN, Geneva
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Overview

Introduction

Charge collection close to the Si-Si0$_2$ interface

- Weighting potential
- Time resolved signals
- Integrated signals

Results: Charge losses vs. humidity and bias history

Conclusions

Outlook

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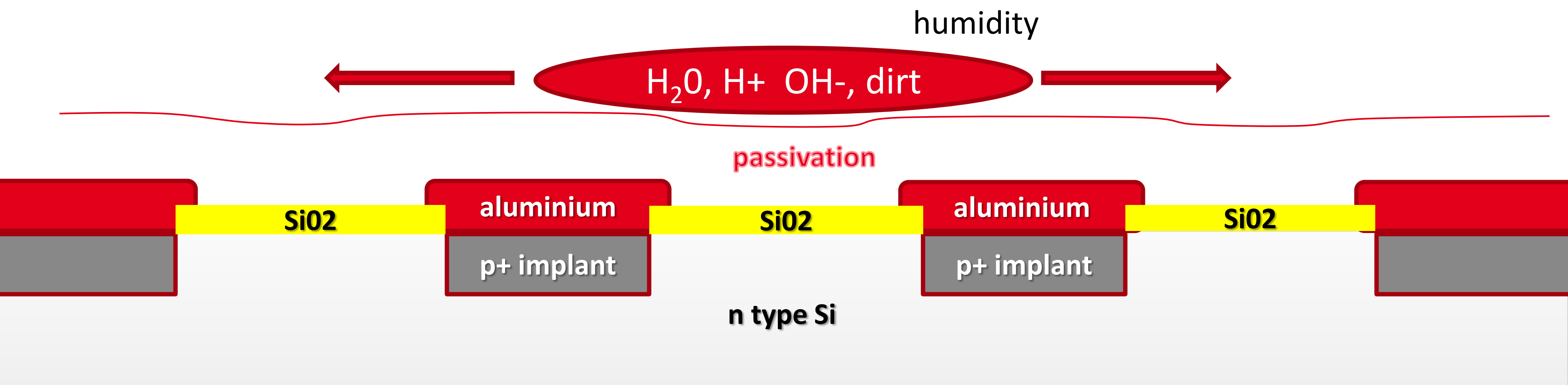
Motivation – why surface studies?

Surface effects:

- Relevant for sensor stability (breakdown, stability of dark current, etc.)
- Charge carrier losses
- Humidity found to influence the electric field in sensor

- Electric field at the interface ?

(surface charges, surface potential, oxide charges, etc. => boundary conditions ?)



Sensors and irradiation

Producer	HPK	CiS
Coupling	DC	AC
Full depletion voltage	155 V	63 V
n-doping	10^{12} cm^{-3}	8 10^{11} cm^{-3}
Pitch	50 µm	80 µm
Implant width	11 µm*	20 µm
Number of strips	128	98
Strip length	8 mm	7.8 mm
Thickness	450 µm	285 µm
Orientation	< 1 1 1 >	< 1 0 0 >
SiO_2 (+Si_3N_4)	334 nm	300+50 nm

* + 2 µm Al overhang

Irradiation:

- Non-irradiated
- Irradiated (1 MGy x-rays, 12 keV)

⇒ surface damage only

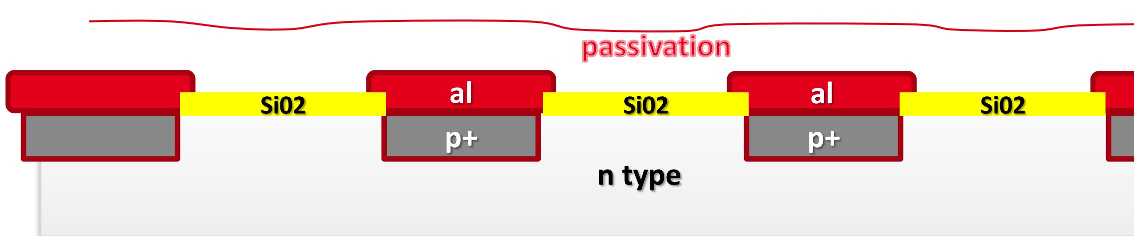
fixed oxide charge: N_{ox} = ~ 2 10^{12} cm^{-2}

surface current: I_{surf} = ~ 6 µA cm^{-2}

Atmosphere during measurement:

- Humid (> 50% humidity)
- Dry (nitrogen, < 5% humidity)

T = ~24 °C (room temperature)

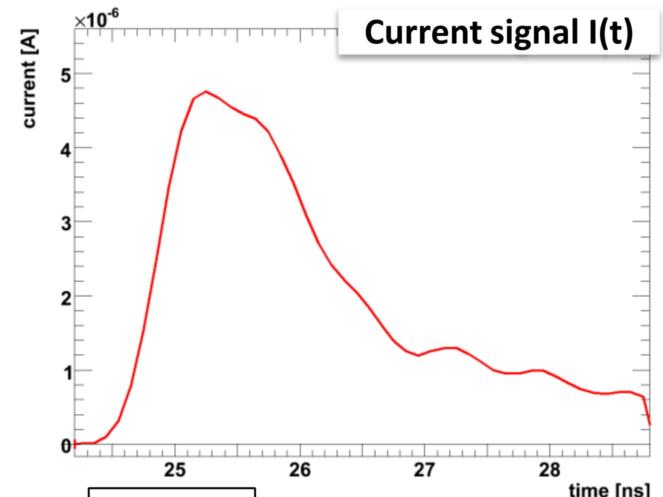


Measurement procedure (red laser TCT)

Red laser light (front illumination, λ = 660 nm, penetration depth ~ 3 µm)

Sub ns-pulses (FWHM 100 ps, 1 kHz, 30 000 to 500 000 eh-pairs)

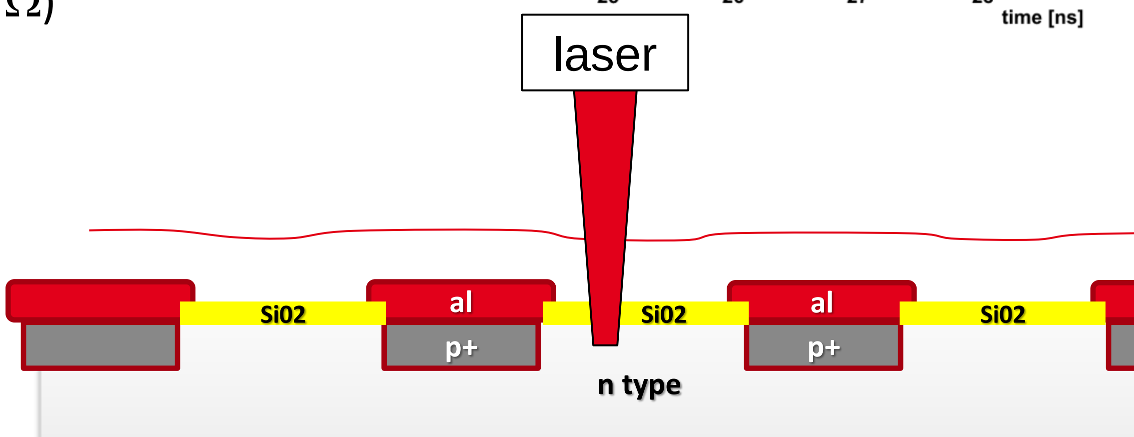
Focus: σ = 3 µm (+ tails)



Readout: 2 strips + 1 rear contact

- Miteq AM-1309 current amplifiers
- Tektronix oscilloscope, 2.5 GHz bandwidth

Neighbour strips on ground (via 50 Ω)

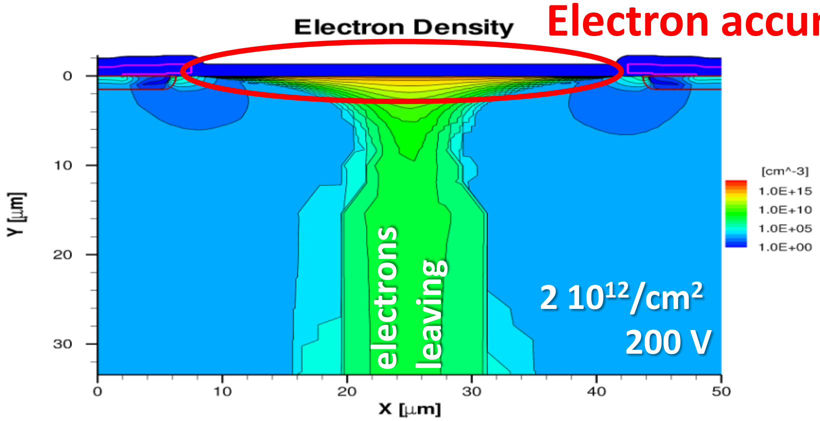


Charge Q calculated offline:

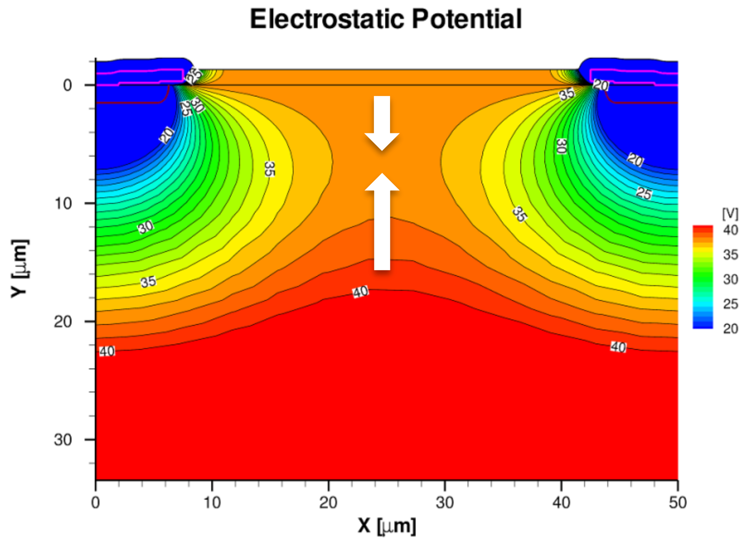
$Q = \int I(t)\, dt$

Accumulation layer and electric field (simulation)

Electron accumulation layer



b.c.: $\vec{\nabla}\phi = 0$



1 MGy irradiation (surface damage)

$\Rightarrow$ N_{ox} = 2 10^{12} cm^{-2} , I_{surf} = 6.4 µA cm^{-2}

$\Rightarrow$ Electron accumulation layer present

$\Rightarrow$ Electron losses !

$\Rightarrow$ Influences the weighting potential $\phi_{w,\,j}$

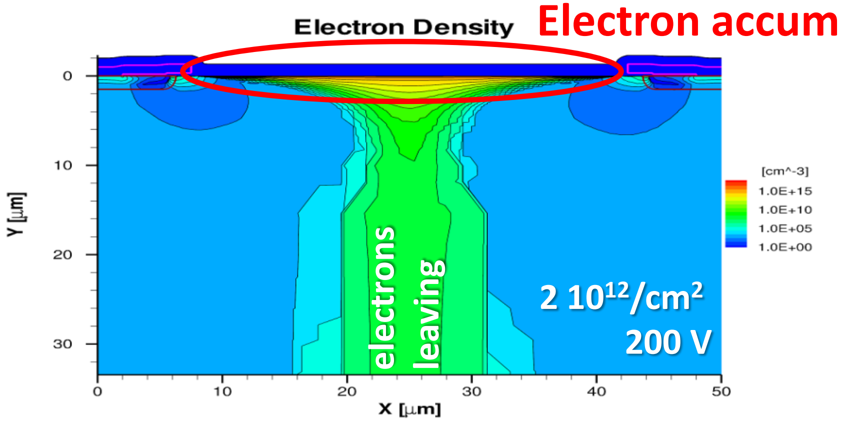
$\Rightarrow$ Calculate $\phi_{w,\,j}$ under bias:

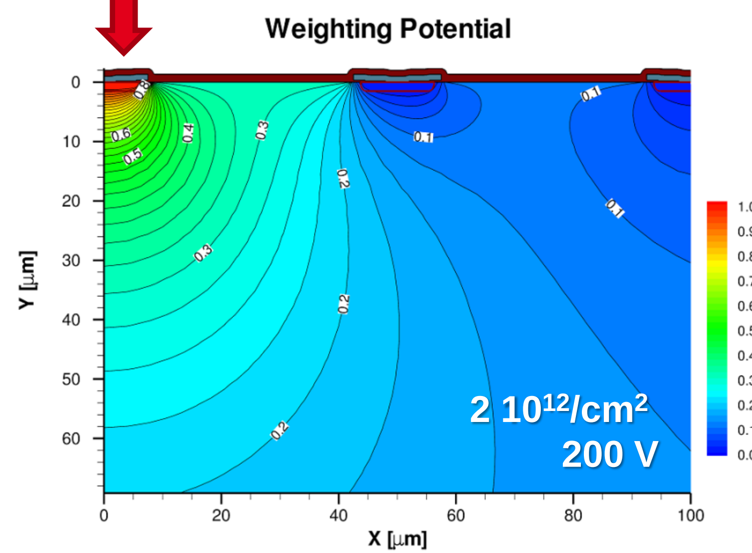
$\phi_{w,j}$ = [read out strip j: 1 V; other strips: 0 V; rear side: 200 V] − [readout strip j: 0 V; other strips: 0 V; rear side: 200 V]

also see Hamel, Julien NIMA 597(2008), 207

Weighting potential (simulation)

readout j





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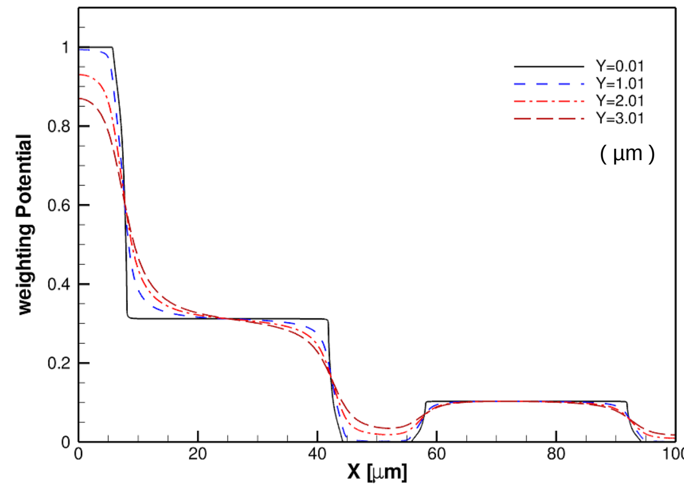

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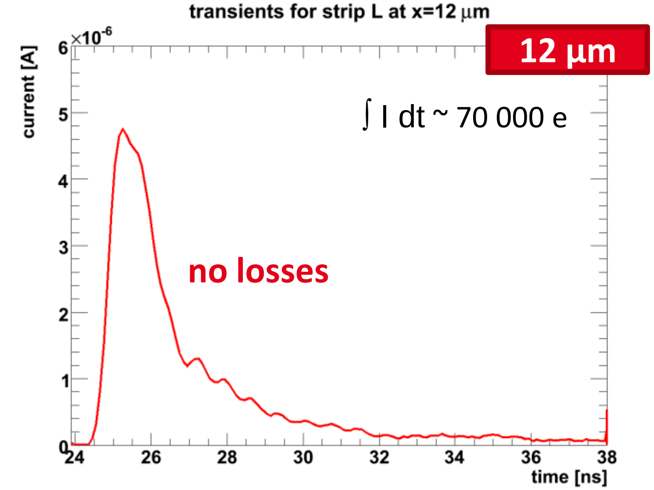
Weighting potential and induced current

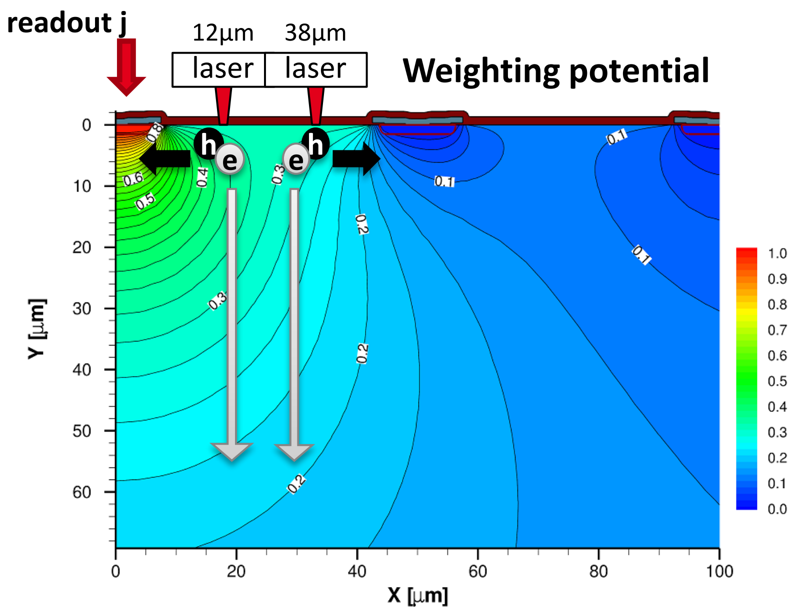
Charge carriers (q)

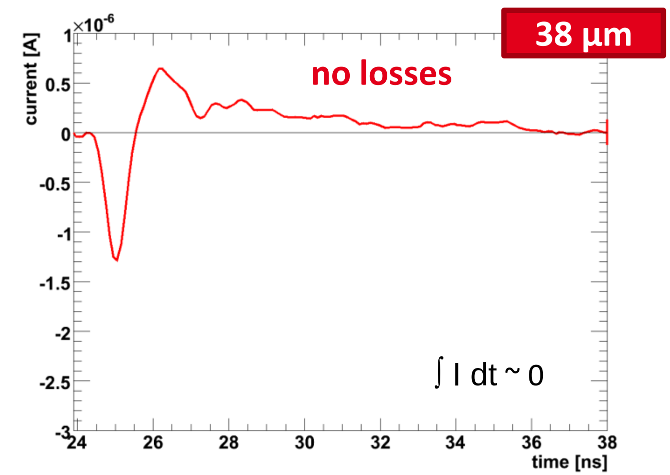
- drift in the electric field : $\vec{v}_{dr} = \mu \vec{E}$

$\Rightarrow$ Induced current: $I_j = q\, \vec{E}_{w,j} \cdot \vec{v}_{dr}$, $\vec{E}_{w,j} = \vec{\nabla}\phi_{w,j}$

Collected charge : $Q_j = \int I_j \, dt$







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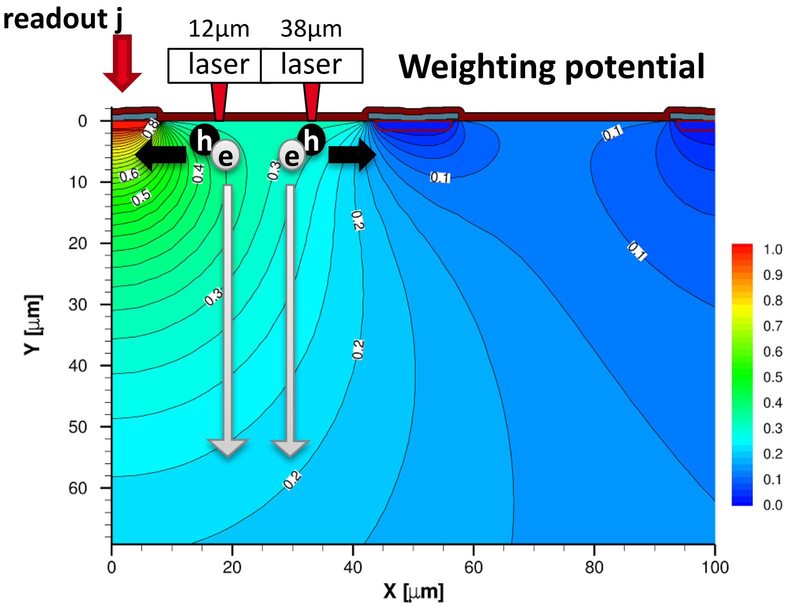

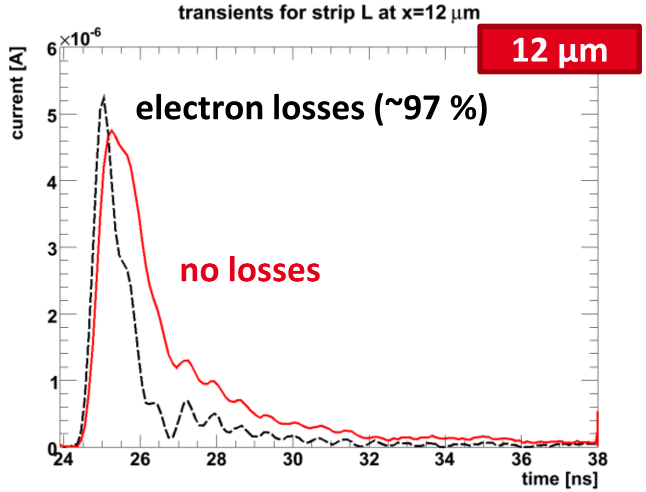

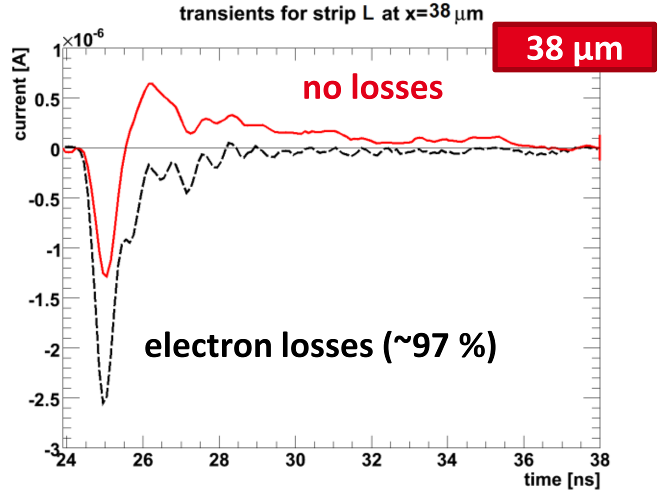

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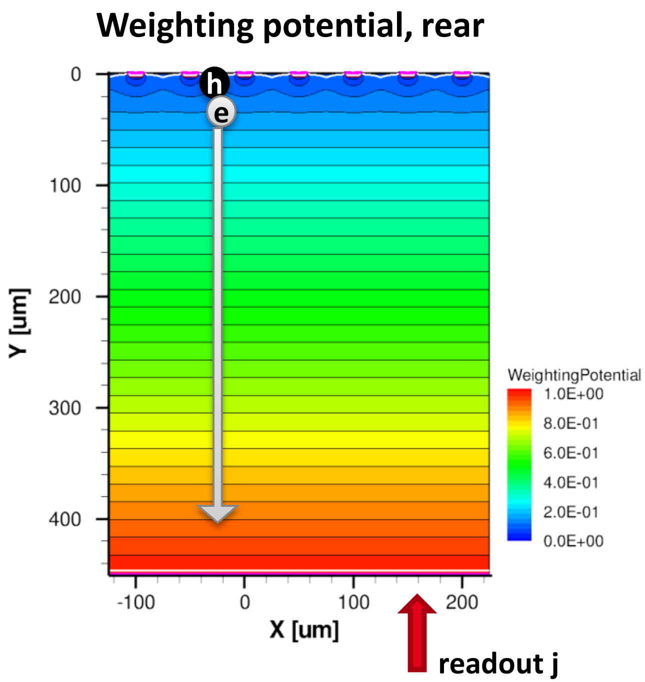
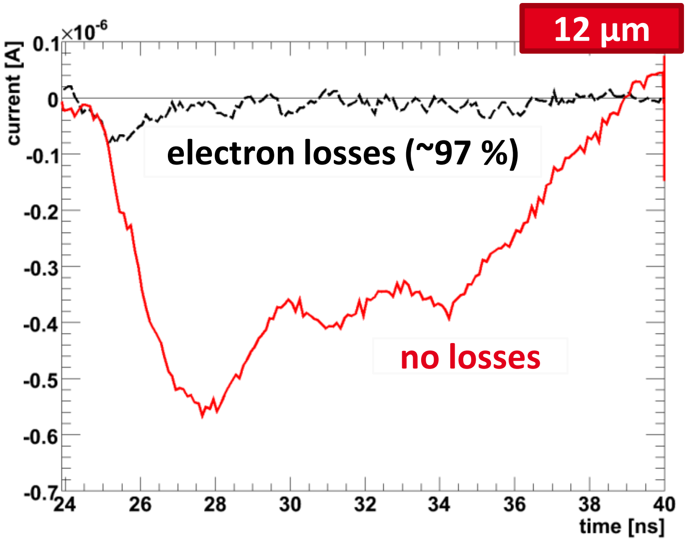
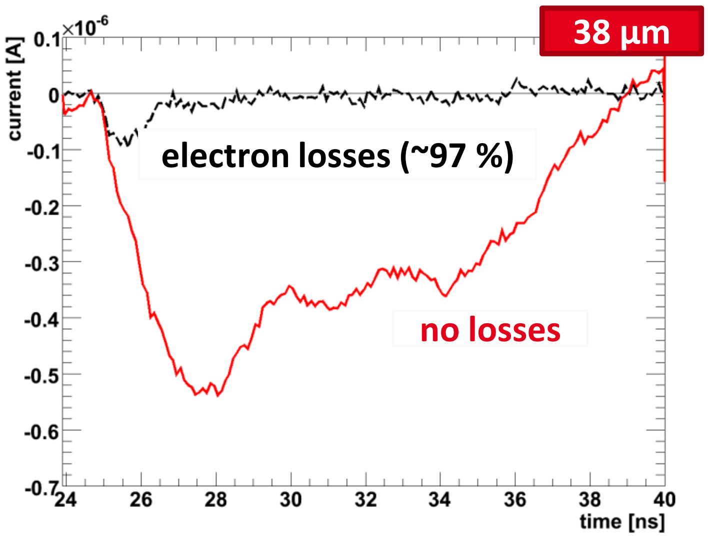
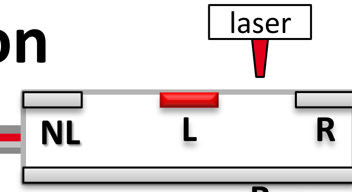
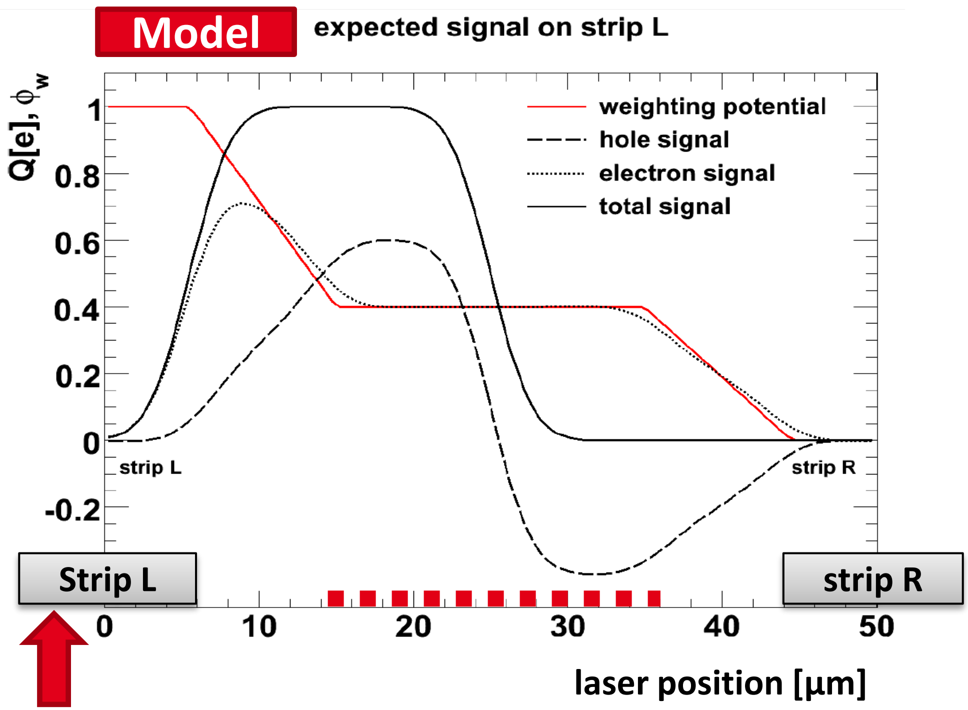


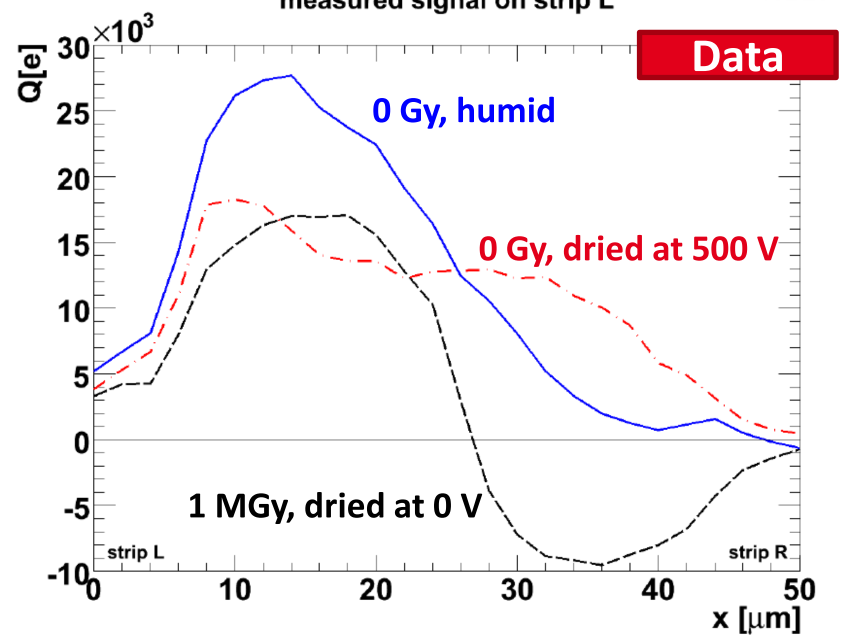




Collected charge vs. laser position







+ hole diffusion

Assumptions:

ϕ_W = const at accumulation layer, linear else

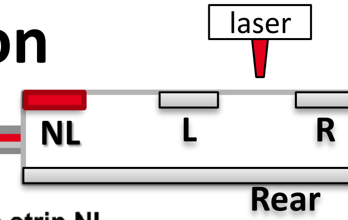
Holes: collected at closest strip

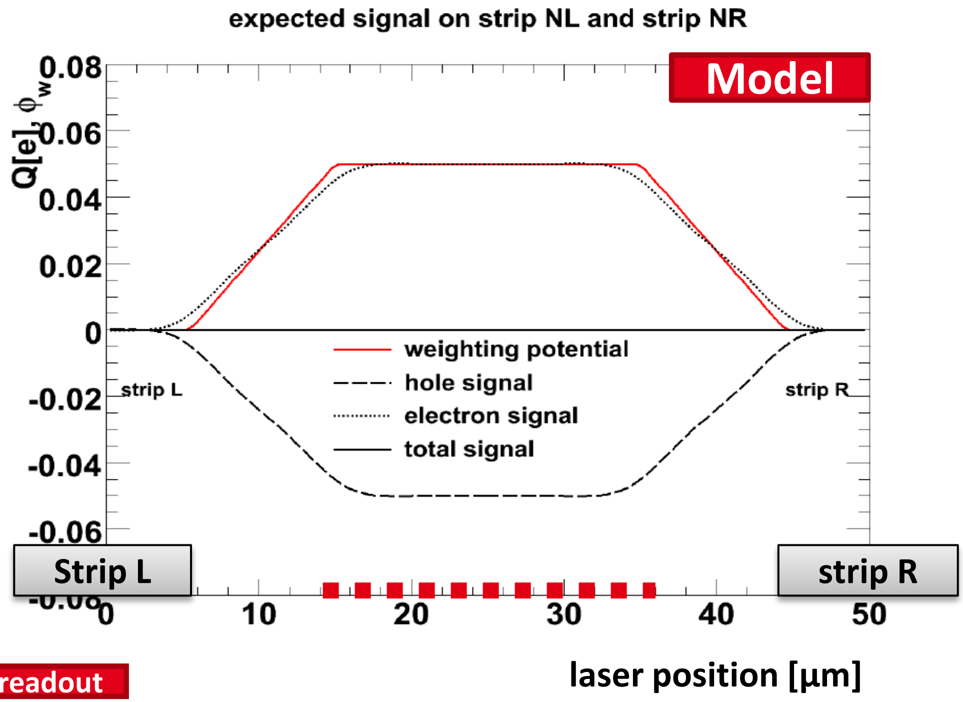
Light profile: gaussian with σ=2 µm

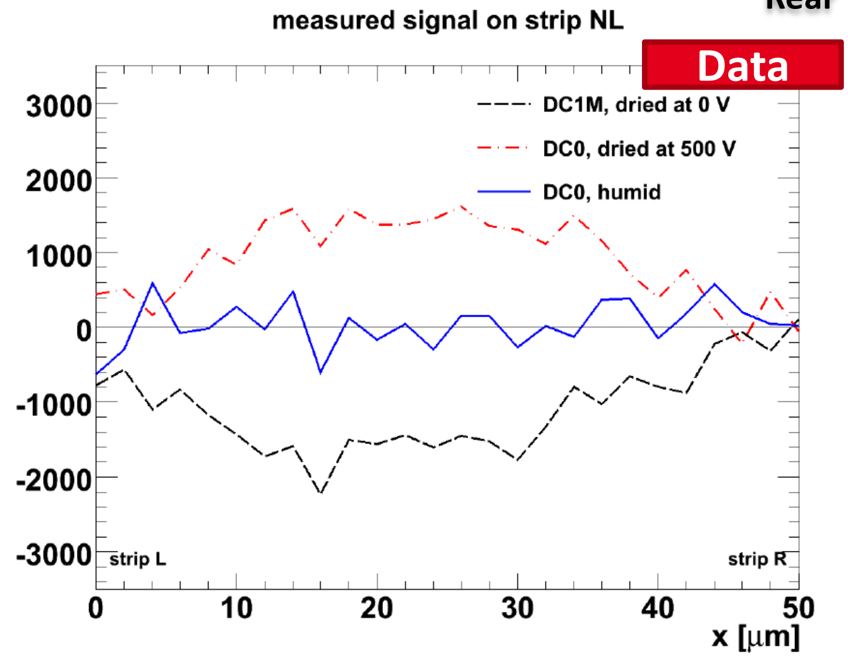
Fit results

	1 MGy	dried at 500V	humid
electr.	1k	35k	33k
holes	29k	7k	31k
acc layer	38 µm	30 µm	-

Collected charge vs. laser position







readout

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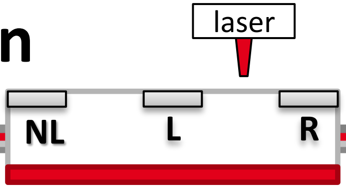
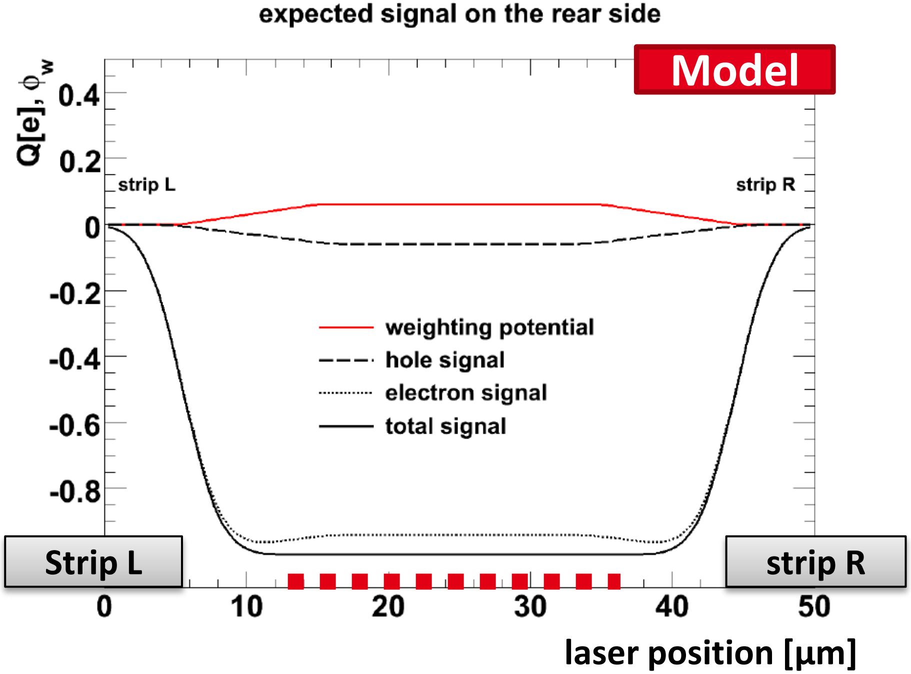
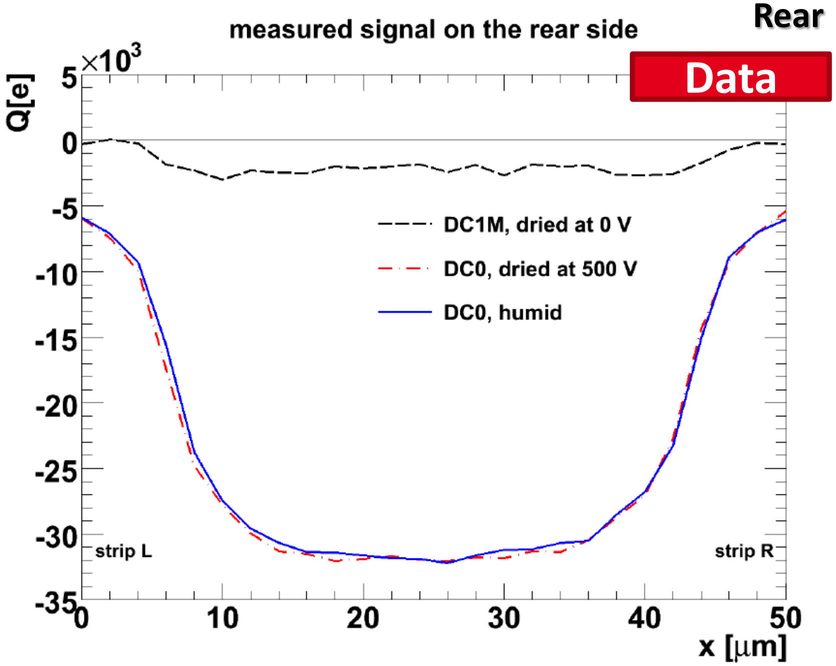




Readout: rear contact



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	1 MGy	dried at 500V	humid
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Results on humidity and bias history

0 V steady state ⇒ 0 V dry	200 V dry		200 V humid	
	e loss	h loss	e loss	h loss
non irradiated	40 %	0 %	0 %	0 %
irradiated (1 MGy)	97 %	15 %	60 %	15 %

500 V steady state ⇒ 500 V dry	200 V dry		200 V humid	
	e loss	h loss	e loss	h loss
non irradiated	0 %	85 %	0 %	0 %
irradiated (1 MGy)	20 %	15 %	60 %	15 %

same steady state for all humidities and bias histories!

humid: steady state* reached after < 5 min

dry: steady state* reached after >> 1 hour (hours or days)

(time constants depend on many parameters)

* steady state in respect to charge loss behavior

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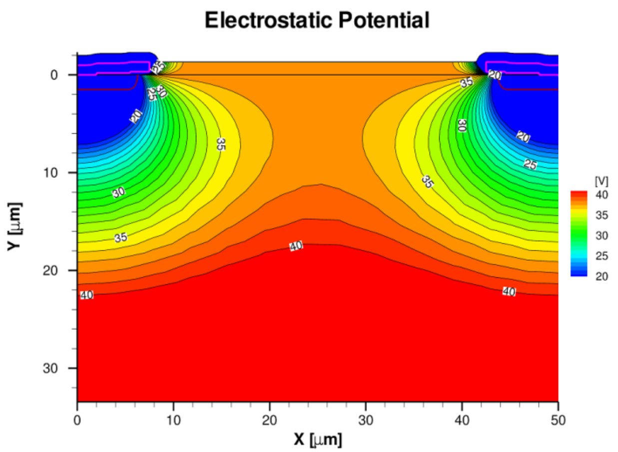
Time dependent surface charges ? Dangling bonds ?



humid: steady state* reached after < 5 min

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(time constants depend on many parameters)

* steady state in respect to charge loss behavior

Summary and conclusions

Charge collection close to the Si-Si0$_2$ interface was investigated in TCT setup and described succesfully by model.

Significant losses of electrons and / or holes observed.

Charge losses depend on **applied voltage, humidity, bias history** and **irradiation.**

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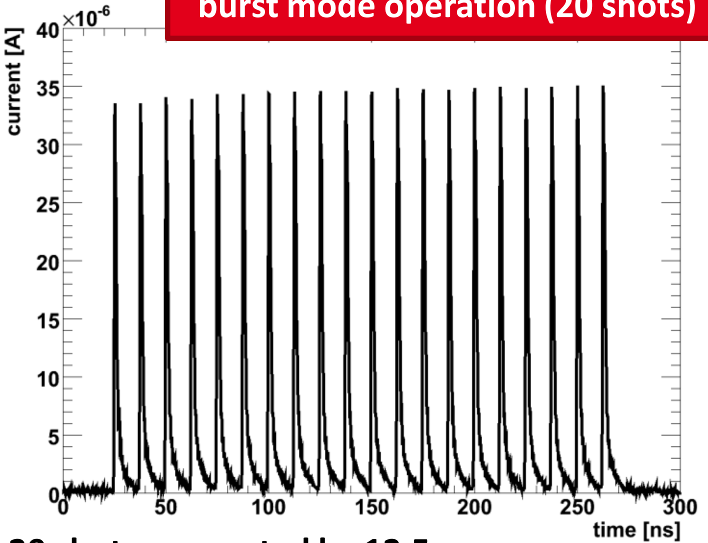
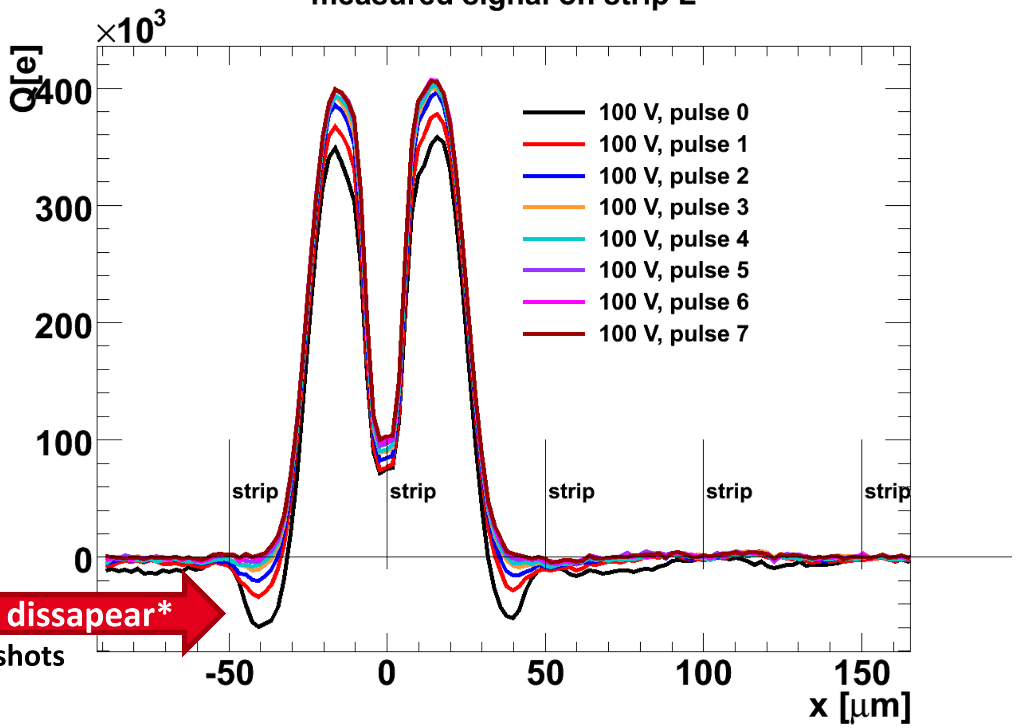
Outlook: Saturation of electron losses

burst mode operation (20 shots)

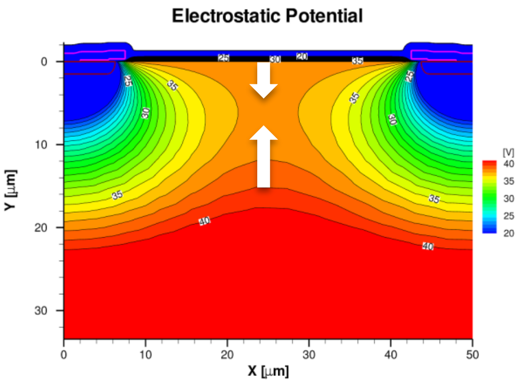


20 shots, seperated by 12.5 ns
1 ms later: next 20 shots



electron losses dissapear*

* for later shots



$\Rightarrow$ method to estimate the maximal amount of electron losses in the gap

and potentially deptrapping time

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Saturation of electron losses

burst mode operation (20 shots)

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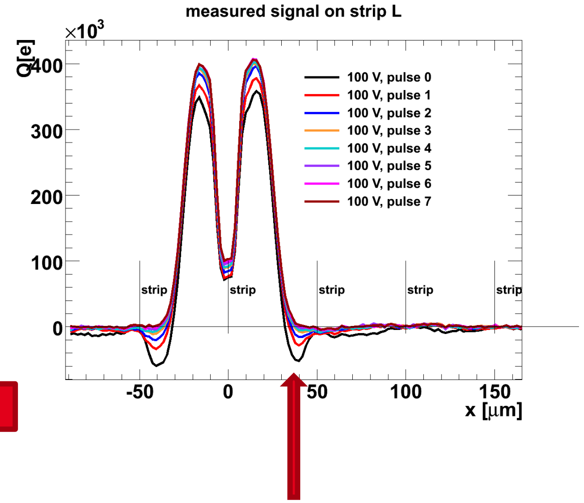
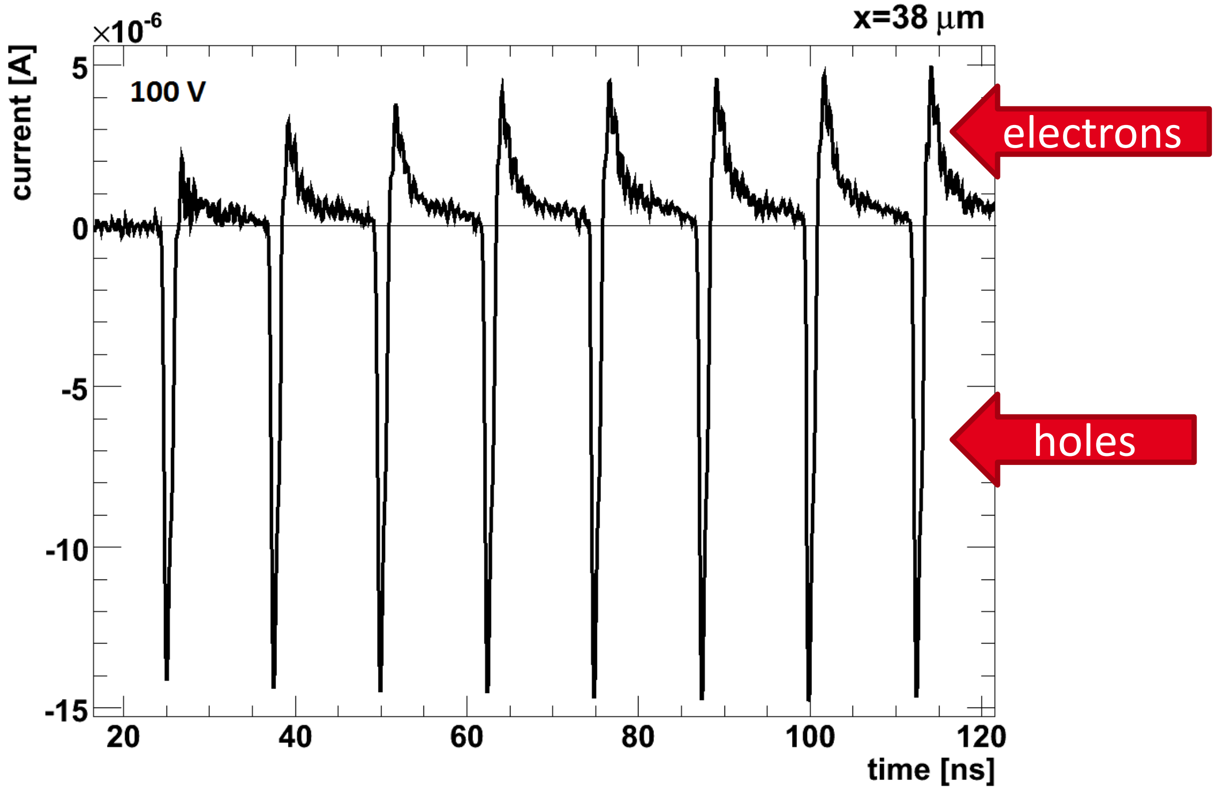




Collected charge for carrier losses

Full charge collection:

Collection: holes at strip L, electrons at rear side

$\Rightarrow Q_L = \# \text{ holes} \cdot q_o = 3\, q_o$

$\Rightarrow Q_{rear} = - 3\, q_o$

$\Rightarrow Q_{R,NL,NR} = 0$

Charge losses (not collected at end of integration time):

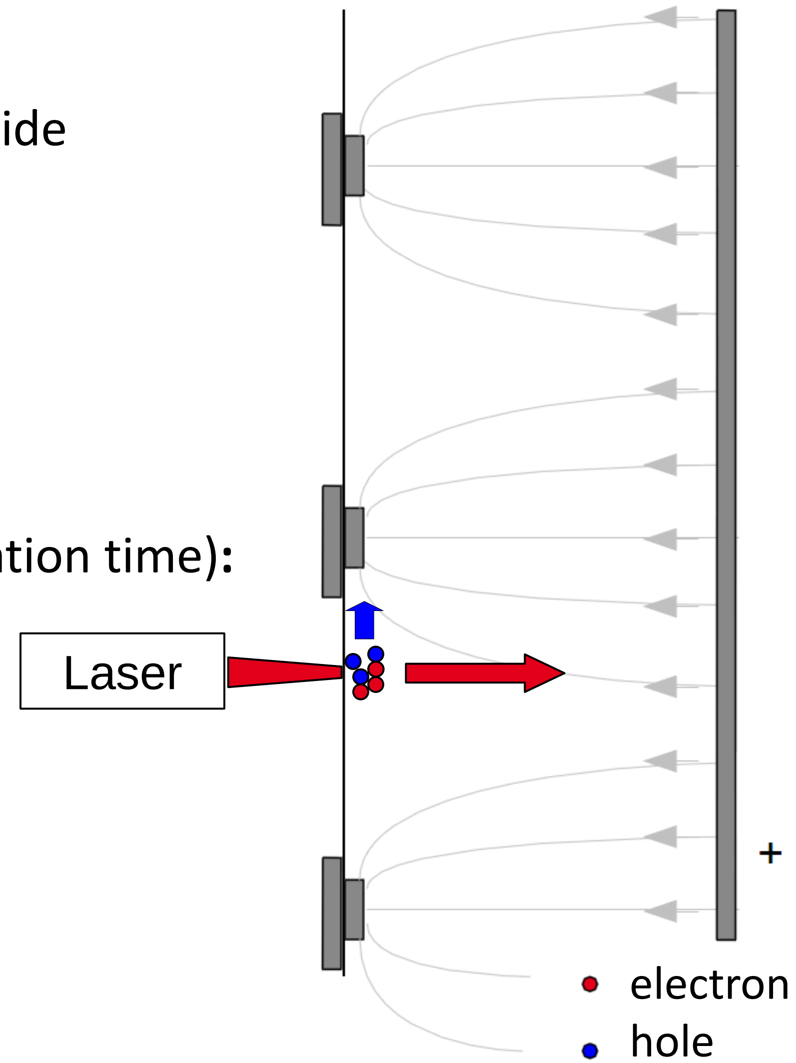
$\Rightarrow Q_{ind,j} = \pm\, q \cdot \phi_{w,\,j}\,(\text{final position})$

$\Rightarrow Q_L < 3$

$\Rightarrow |Q_{rear}| < 3$

$\Rightarrow Q_{R,NL,NR}$ > 0 for hole losses

< 0 for electron losses



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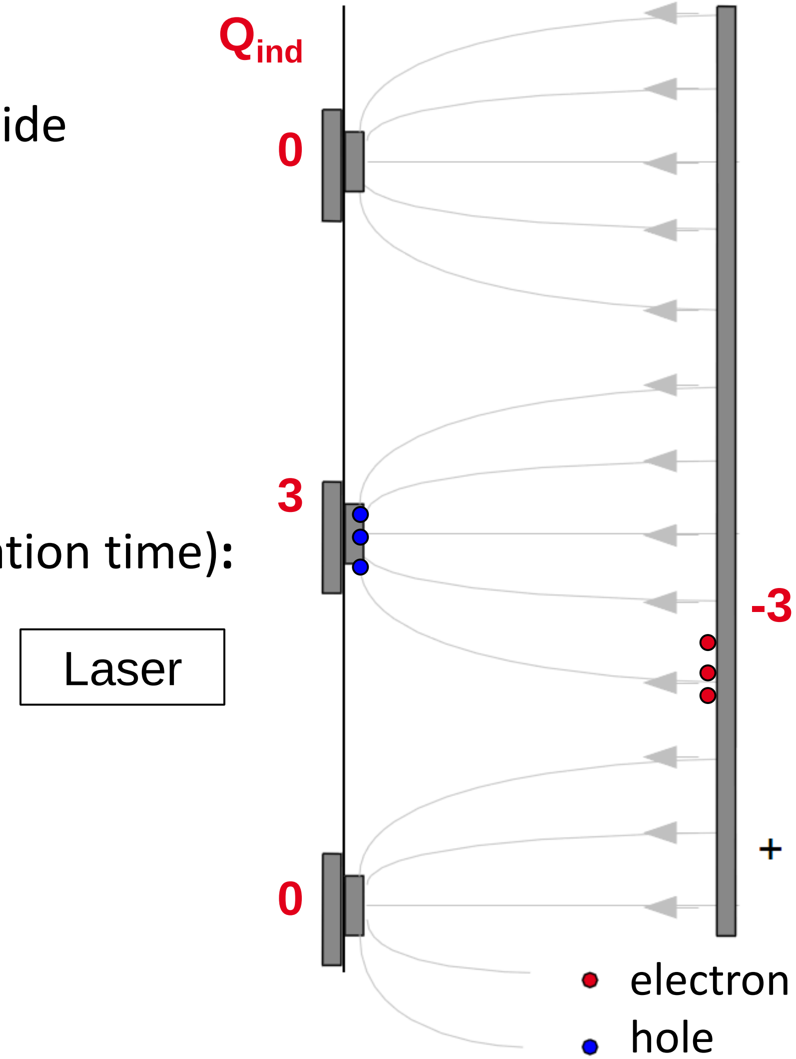

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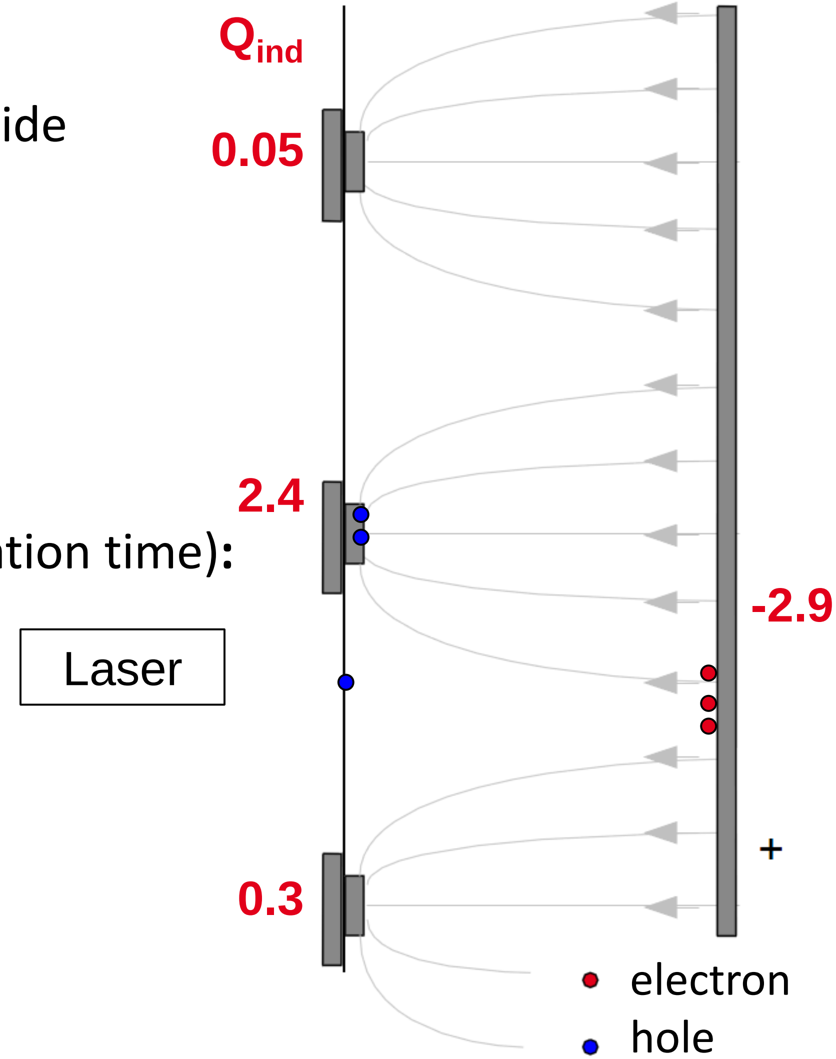

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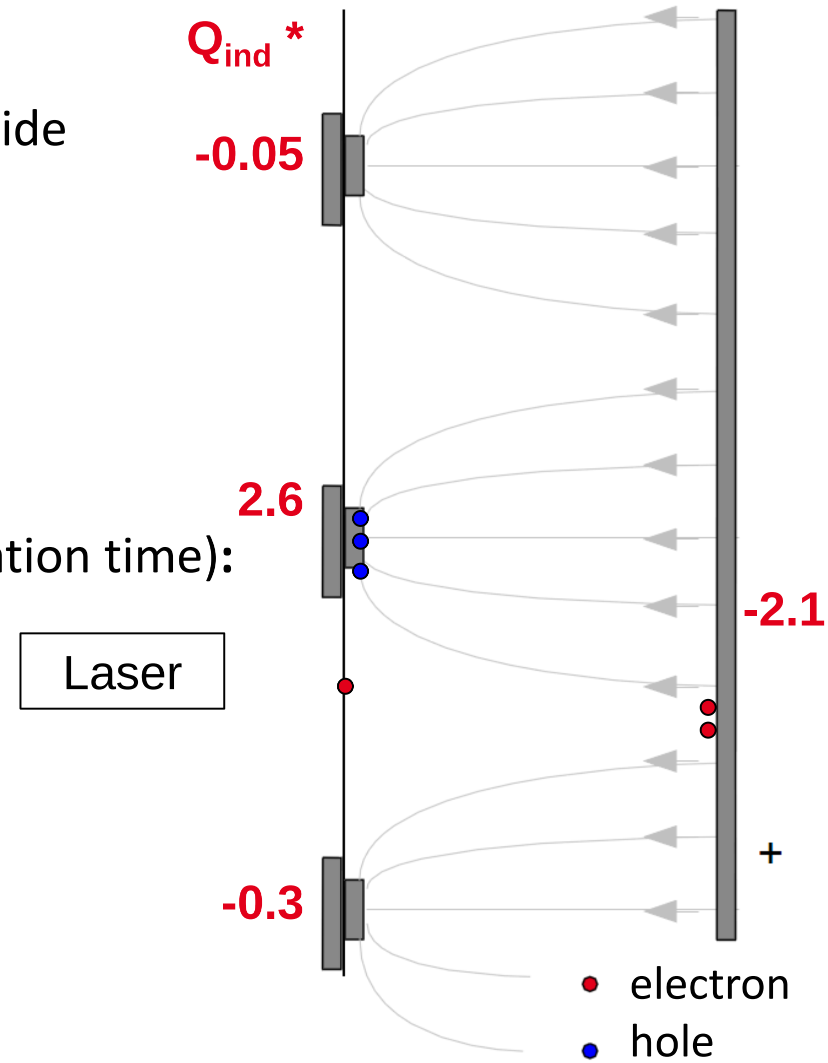
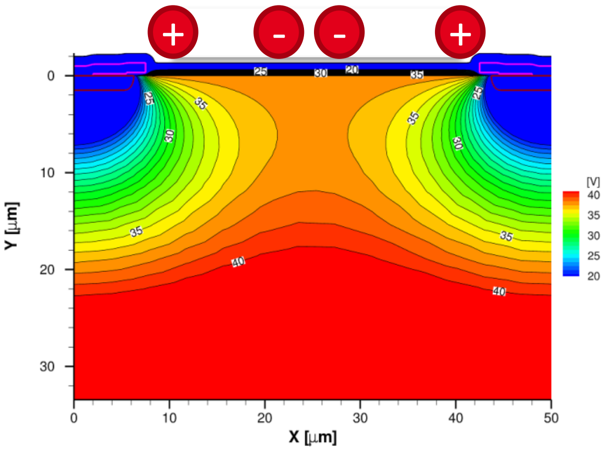


Boundary conditions

boundary conditions:

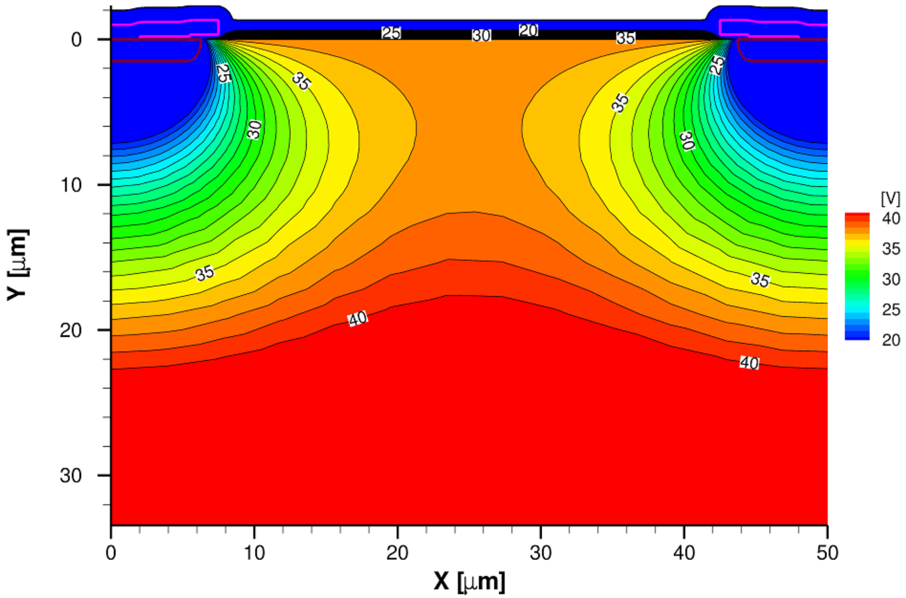
- constant potential: ϕ = 0 V (Dirichlet)
- zero electric field component: E_y = 0 (Neumann)

~ humid ?



~ if dried at 0 V ?

Φ_{el} Dirichlet b.c.



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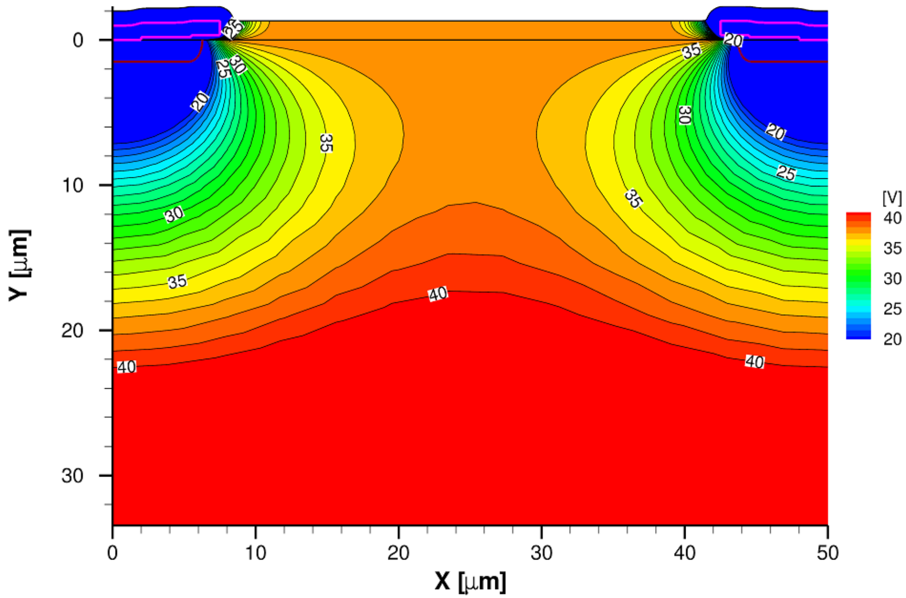

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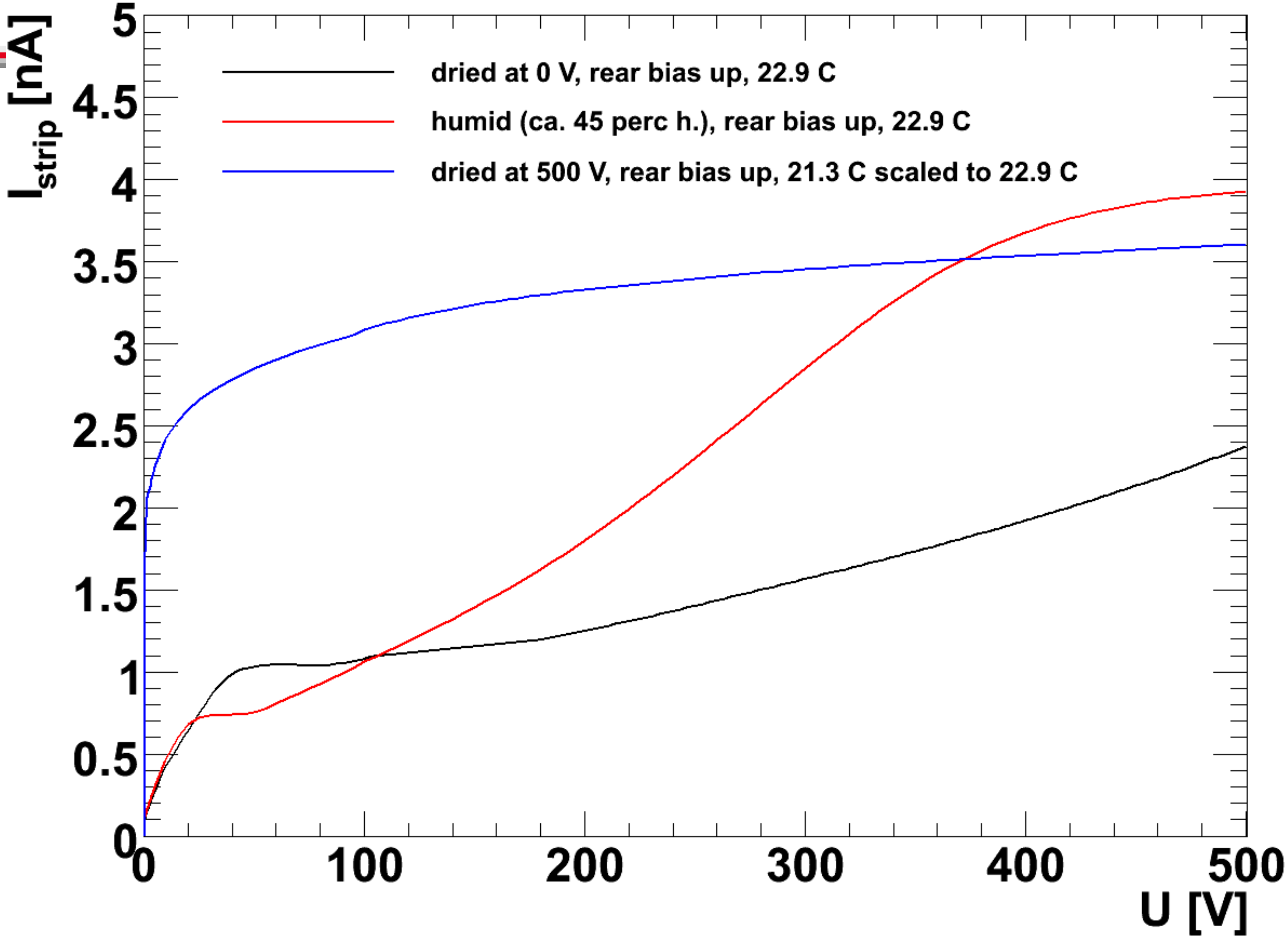
Strip current for 1 MGy



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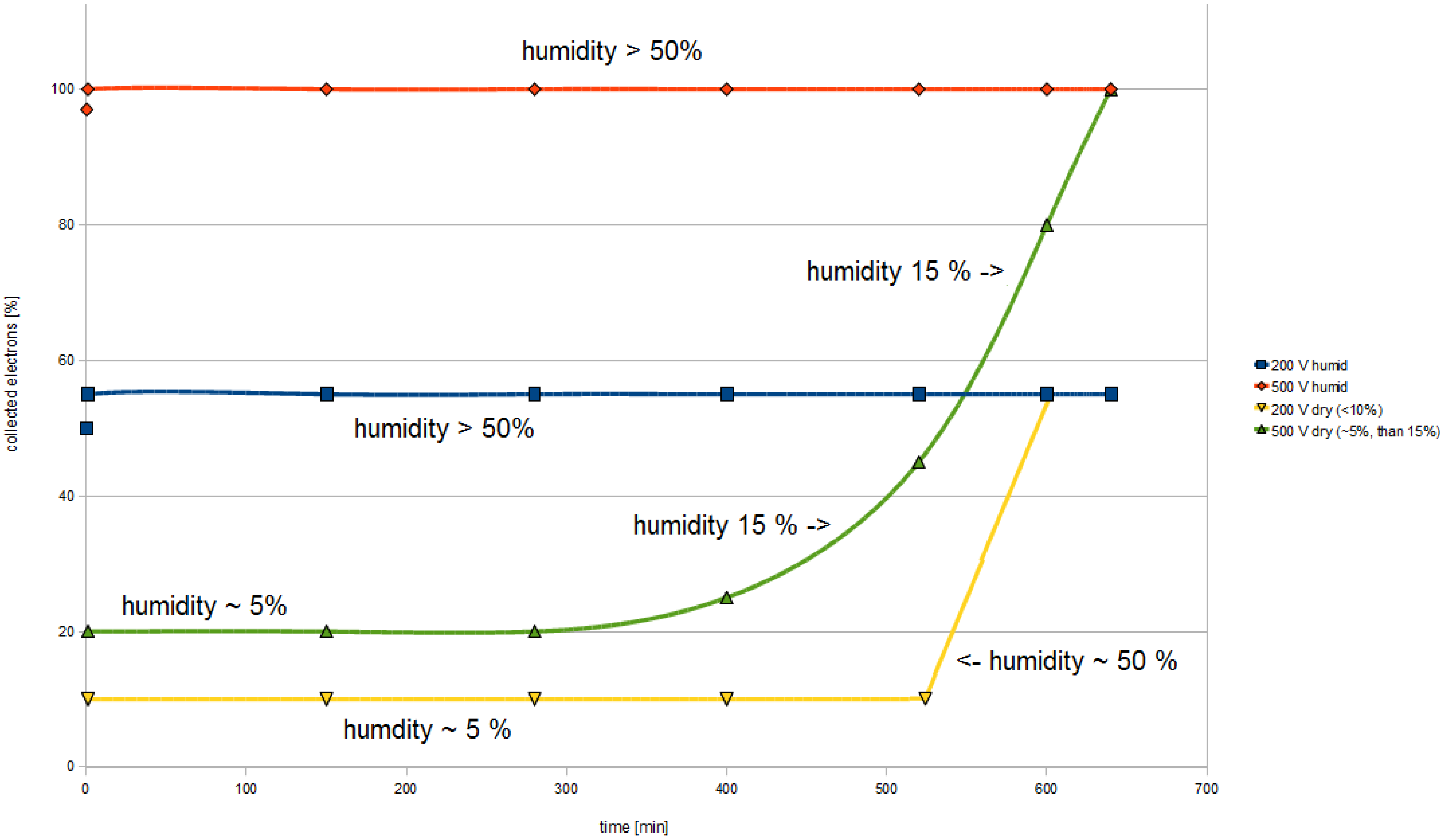
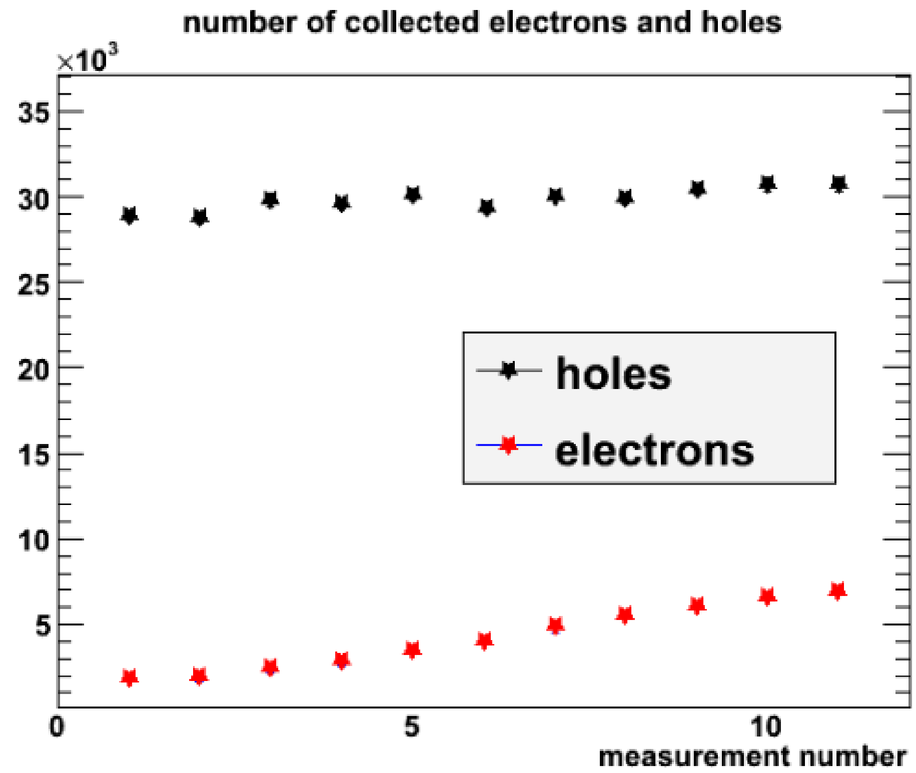
Time dependence after 1 MGy



200 V, 1 MGy, dried at 0 V



Messablauf für Elektronenverluste

Messablauf:

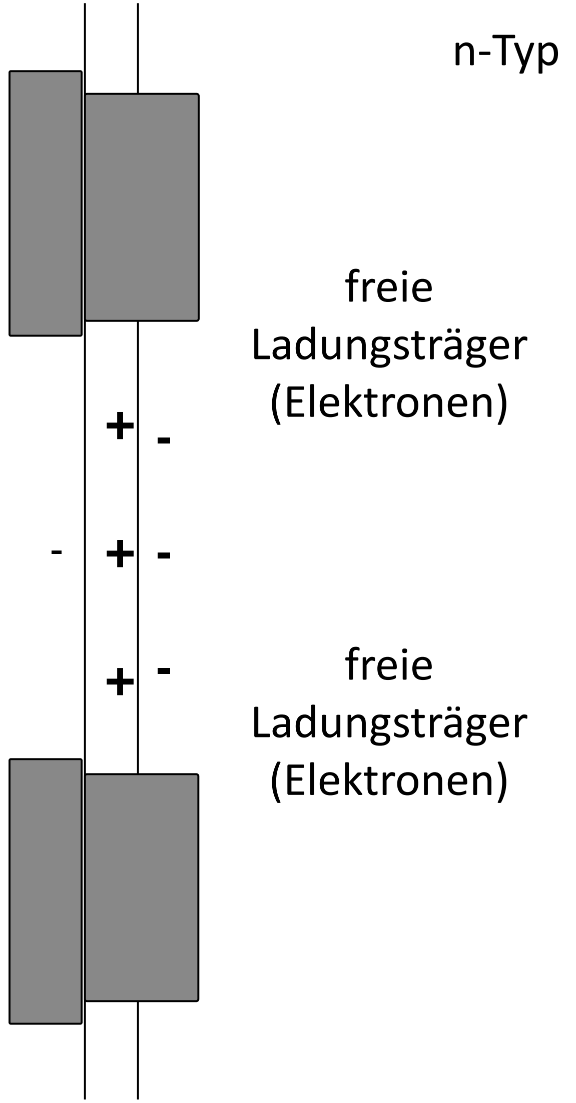
Sensor getrocknet bei 0 V

→ 200 V

Was passiert im Detektor?

0 V : Oxidladungen kompensiert durch freie Ladungsträger

200 V : Oxidladungen unzureichend kompensiert



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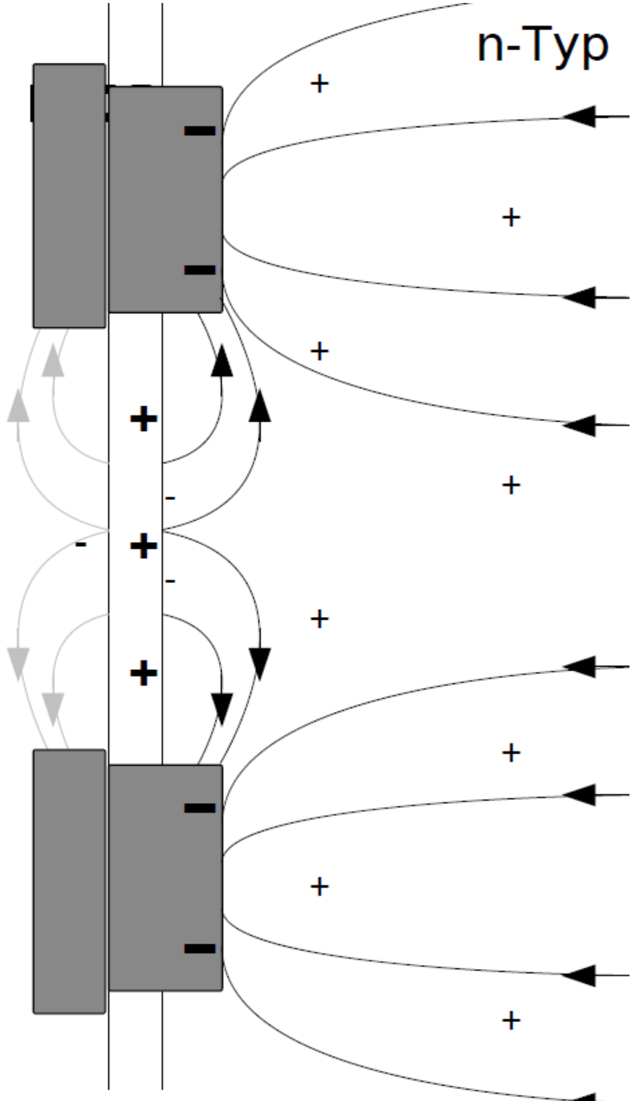
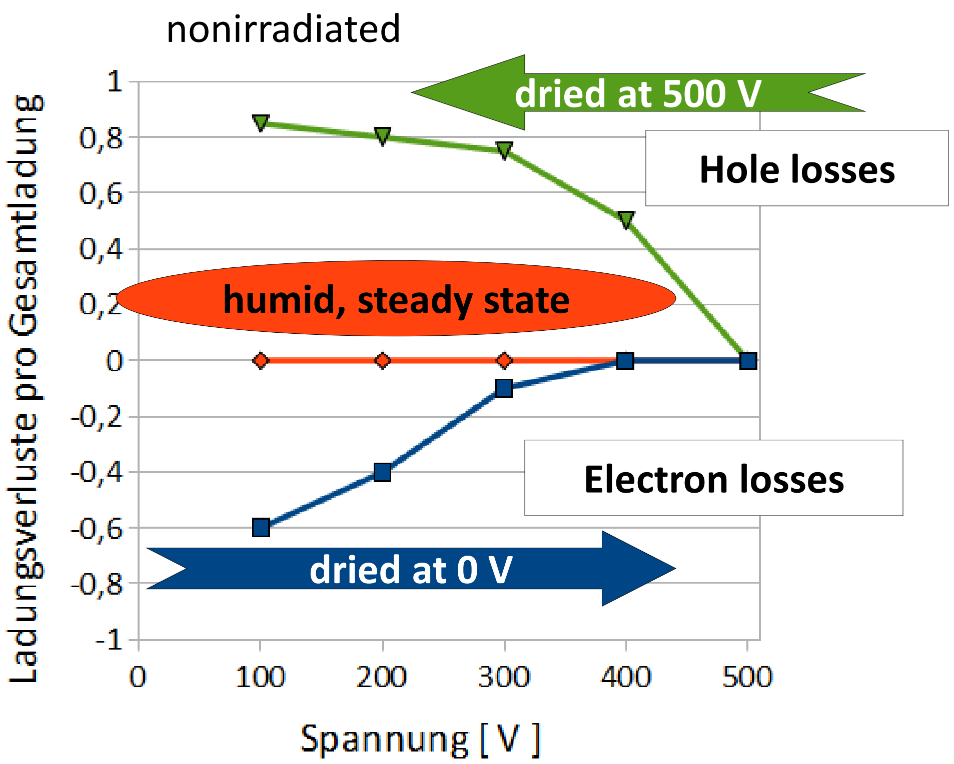
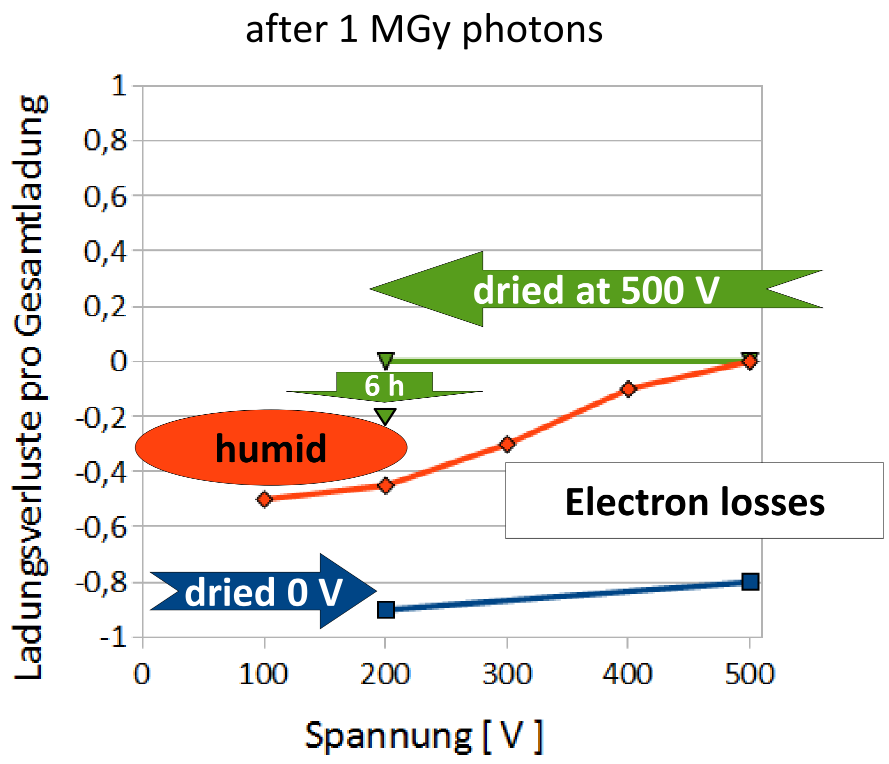
0 V : Oxidladungen kompensiert durch freie Ladungsträger

200 V : Oxidladungen unzureichend kompensiert



Übersicht der Ladungsverluste





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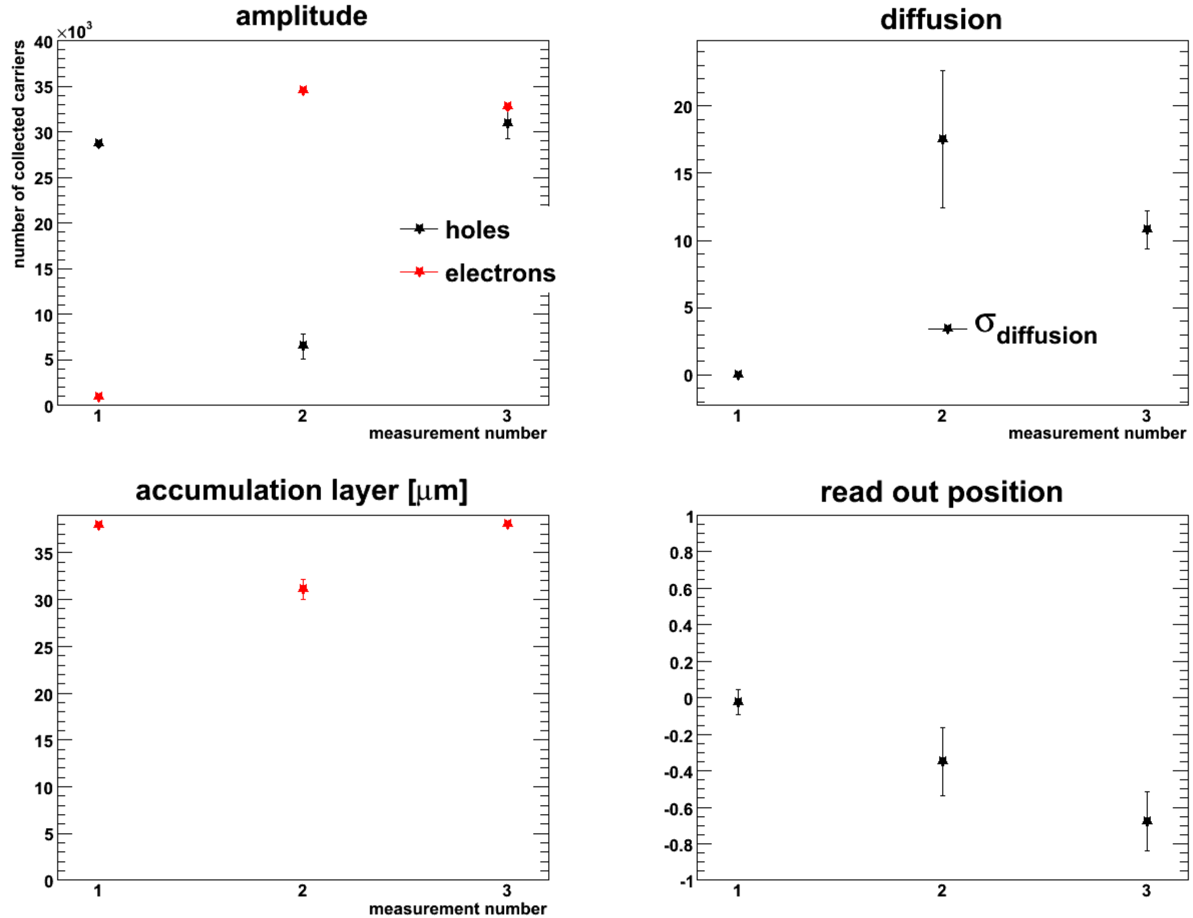
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Free parameters:

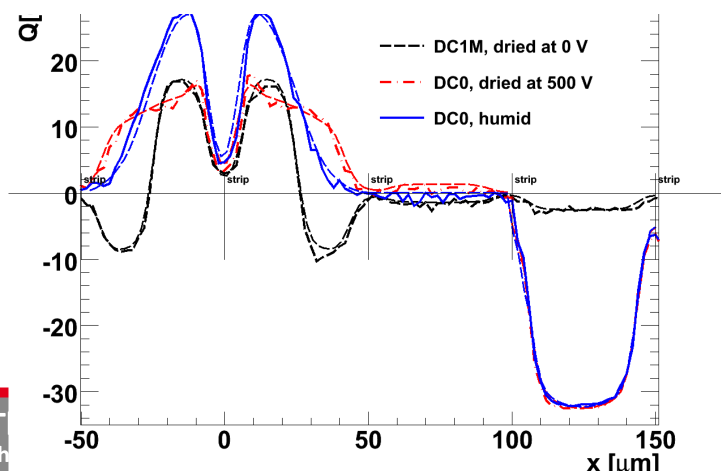
- number of electrons
- number of holes
- diffusion of holes: σ_{dif}
- strip position
- accumulation layer wi



Fixed parameters:

- light profile σ_1=3μm

  + tails σ_2=9μm
- ϕ_N=0.35, ϕ_{NN} =0.05, ϕ_{rear} =0.06
- strip width = 12 μm



Measured signal compared to calculation

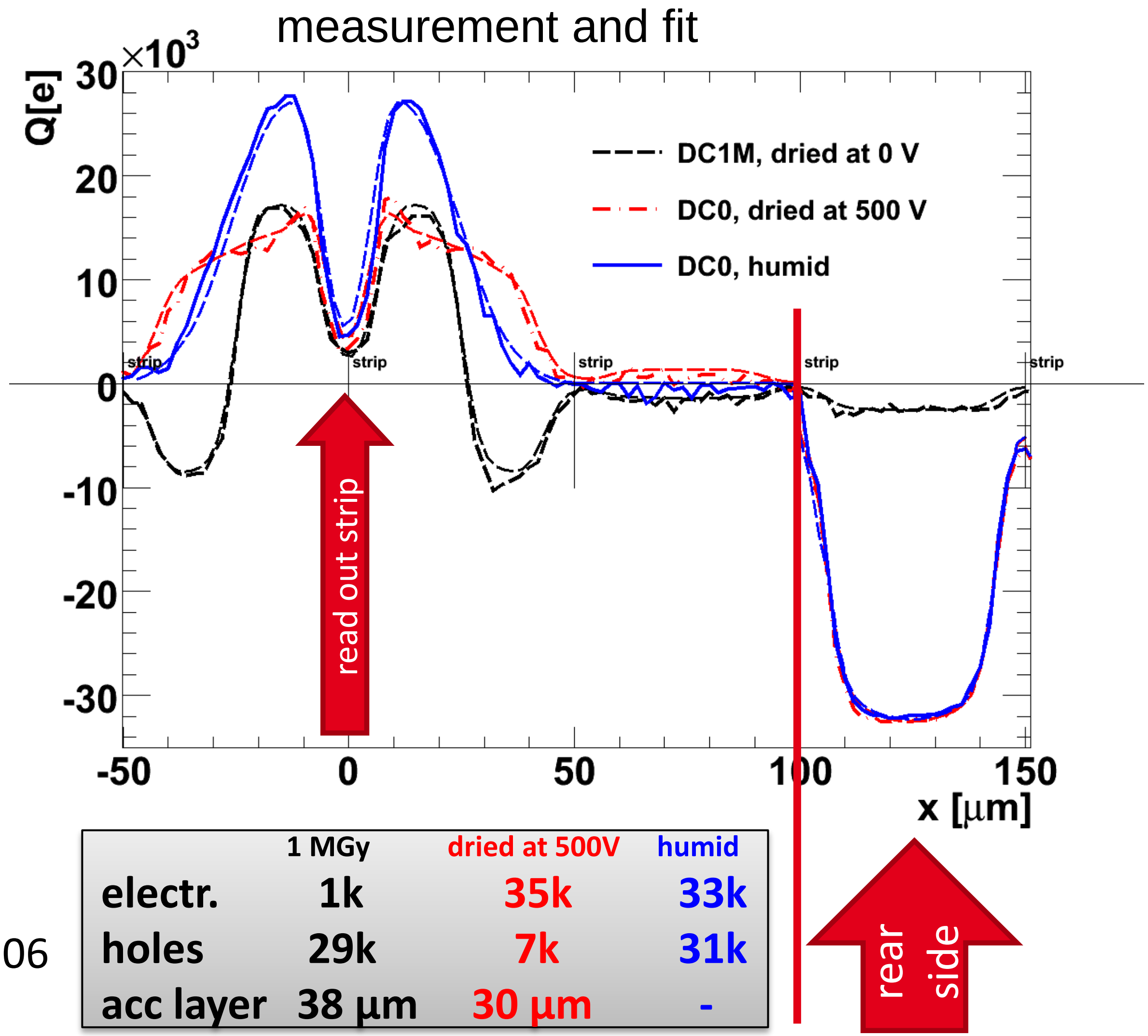
Free parameters:

- number of electrons
- number of holes
- diffusion of holes: σ_{diff}
- strip position
- accumulation layer width

Fixed parameters:

- light profile σ_1=3µm

  + tails σ_2=9µm
- ϕ_N=0.35, ϕ_{NN} =0.05, ϕ_{rear} =0.06
- strip width = 12 µm



	1 MGy	dried at 500V	humid
electr.	1k	35k	33k
holes	29k	7k	31k
acc layer	38 µm	30 µm	-