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A multi channel TCT setup for investigations of silicon sensor properties during high intensity charge injection

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Detector laboratory

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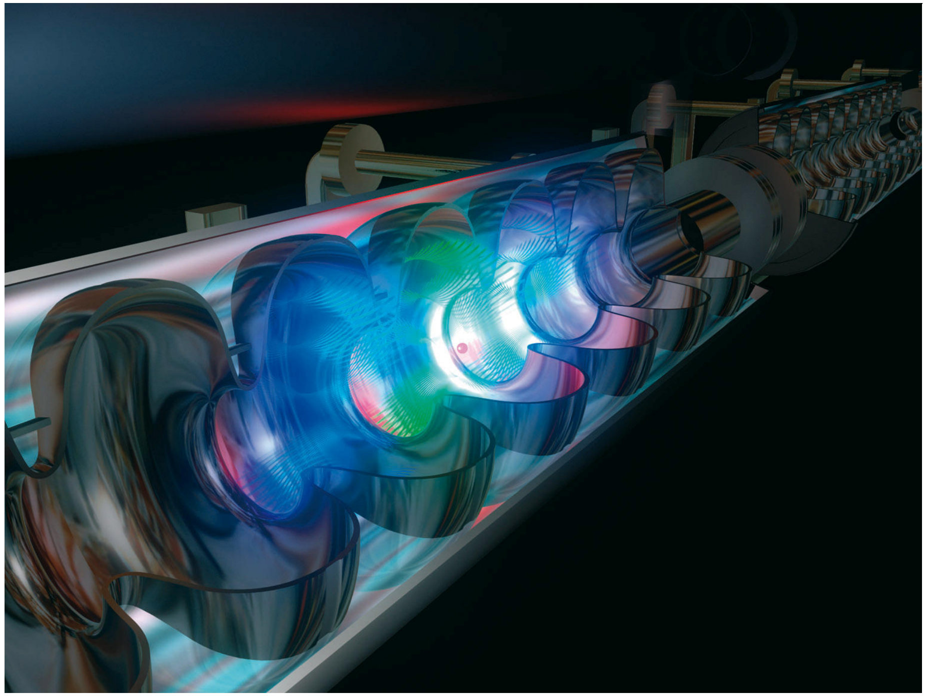
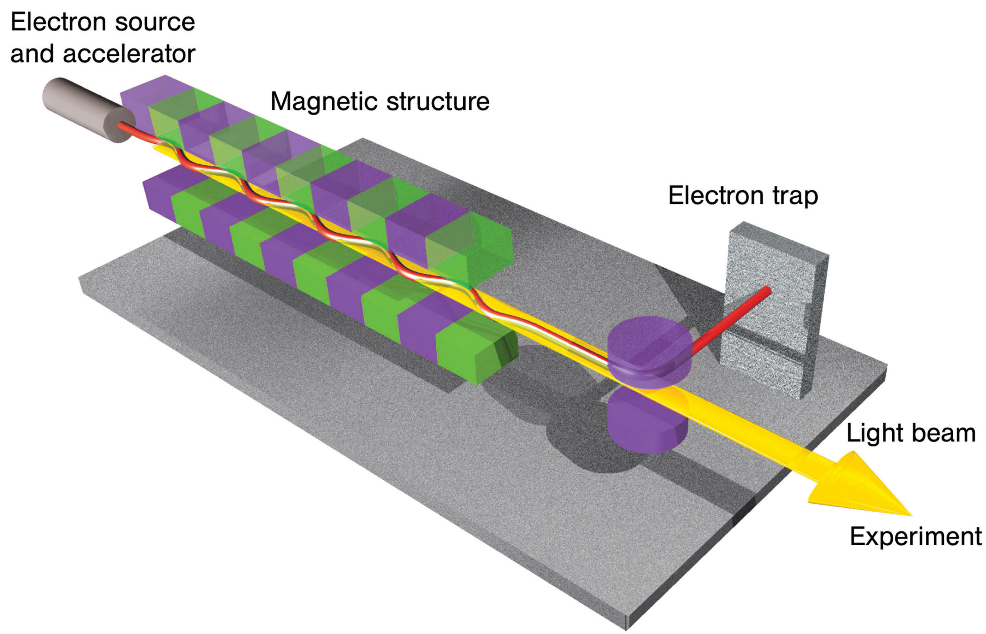
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

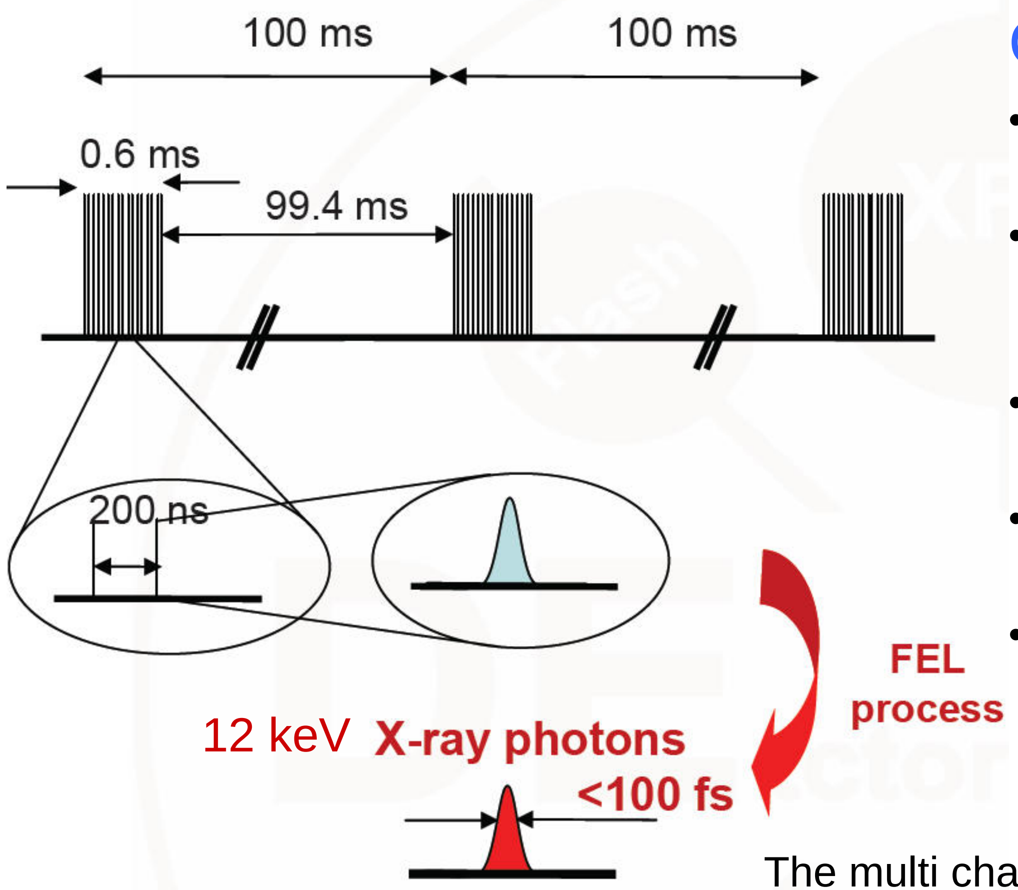
X-Ray Free Electron Laser (XFEL)

- 17.5 GeV linear electron accelerator
- 101 cavities along 1.6 kilometers acceleration length
- producing 0.1 nm light (12.4 keV) through FEL process
- unprecedented peak brilliance

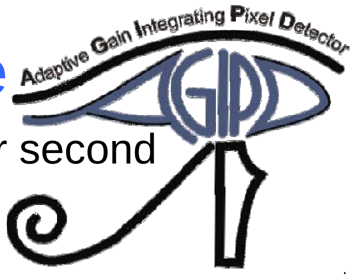




Introduction – AGIPD



Challenges for the AGIPD



- up to 30'000 bunches per second
  -> readout
- very high intensities (up to $10^{12}\gamma$/bunch -> 10^5 γ/pixel)
  -> integrated dose, dynamic range
- instantaneous charge deposition
  -> charge explosion
- very high repetition rates (up to 5 MHz)
  -> very fast internal pixel storage
- large dynamics (10^0 - 10^5 γ/pixel) (pulse pattern and pulse to pulse)
  -> dynamic range switching

The multi channel Transient Current Technique (TCT) setup presented here allows studies of the charge explosion in a controlled laboratory environment

Setup available for measurements

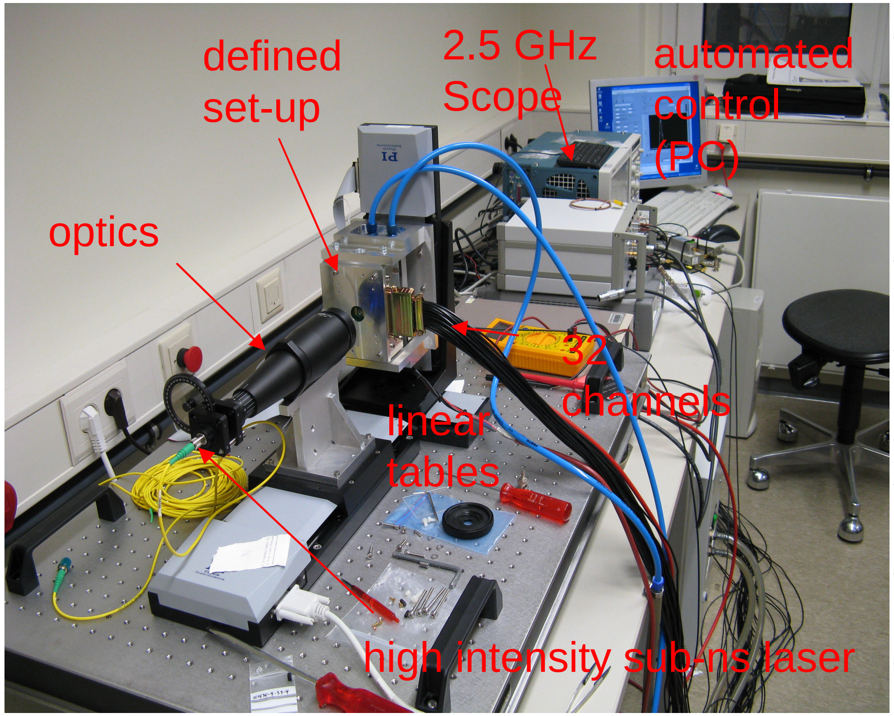
Main goal:

- **Determination of the pulse shape of individual pixels with XFEL type irradiation**
- **Agreement of experimental reference data with simulations (WIAS-Berlin)**

Challenges:

Properties of the injected charge cloud are not well understood for more deposited energy than mips (~25'000 e,h pairs). Observed effects include:

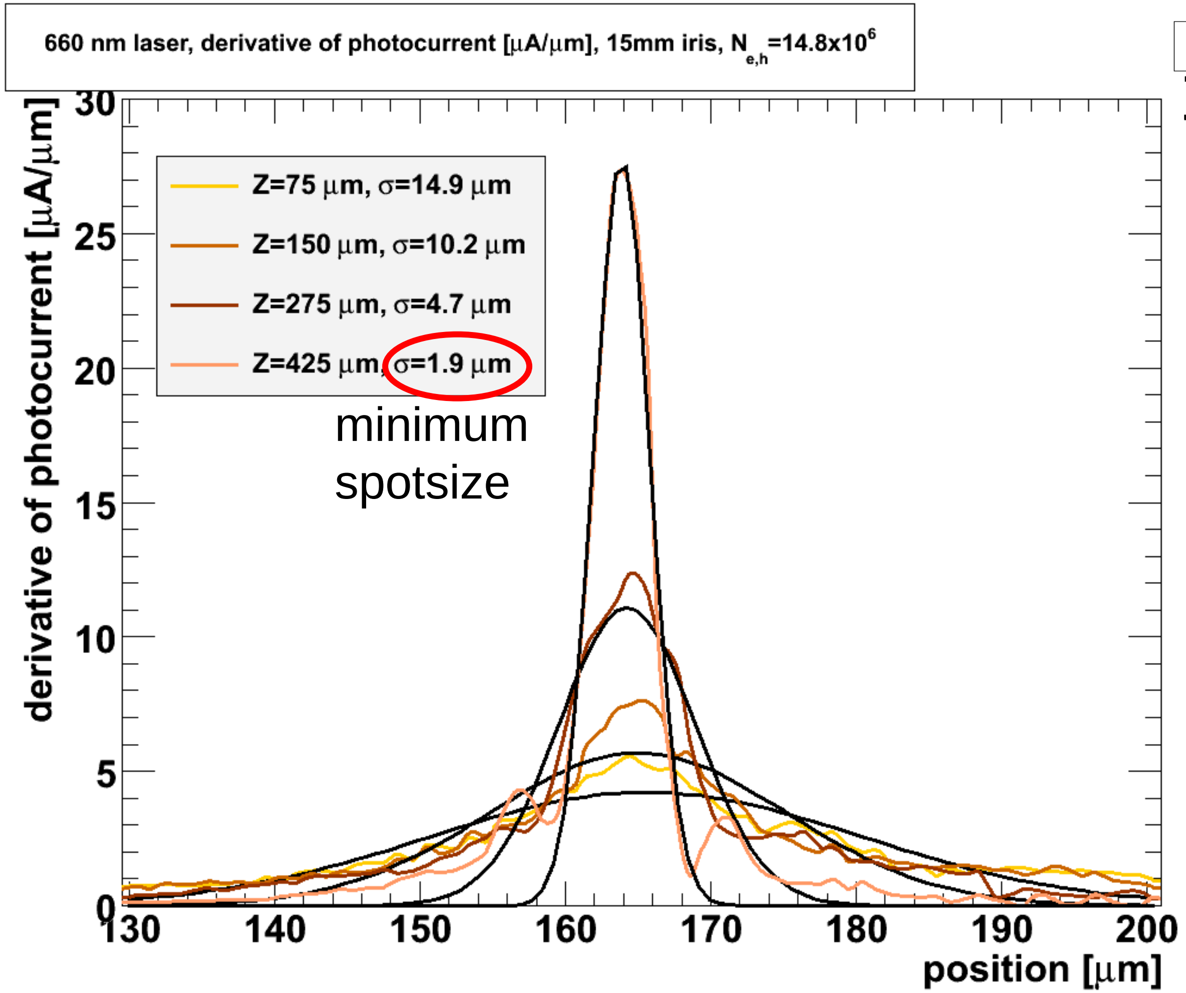
- **Plasma effects:** Distortion of pulses
- **Charge Cloud expansion:** Charge sharing in neighboring pixels due to diffusion and electrostatic repulsion

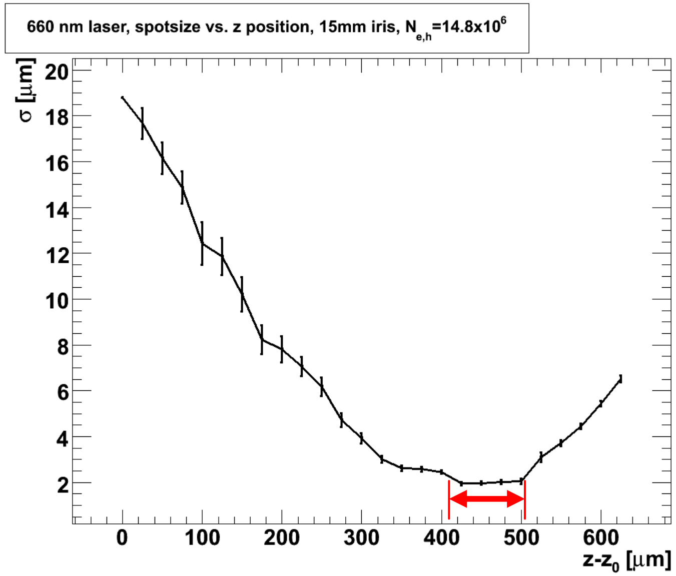


Key features:

- laser pulses
  ~ 100ps duration
  ~ 10^5 12 keV γ equivalent
  ~ $\leq$ 3µm spot size
  ~ 100µm focus depth
- 660nm, 1015nm, 1052nm wavelength
- high bandwidth electronics
- 0.1 µm position control
- 32 channels (4 simultaneously)
- temperature control (-35℃ to 50℃)
- front and backside injection possible

Laser beam characteristics





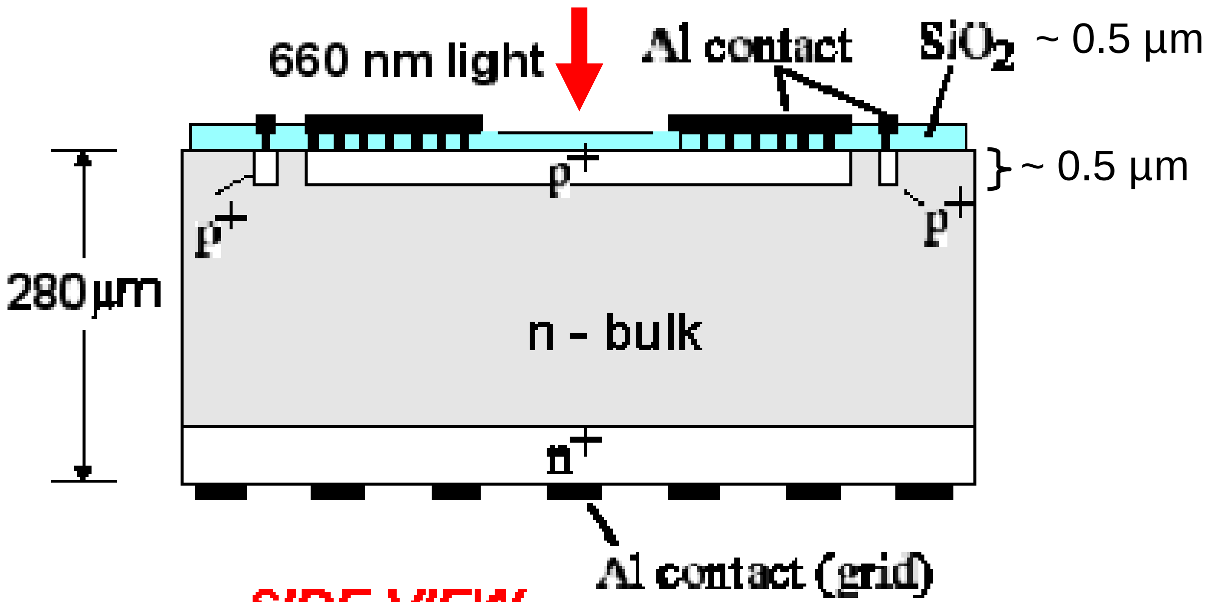
Beam profile

colored lines -> measurement
black lines -> gaussian fit

- gaussian spot with minimum sigma of ~2 μm (for 660nm light)
- depth of focus of ~100 μm due to special optics with 75mm focal length

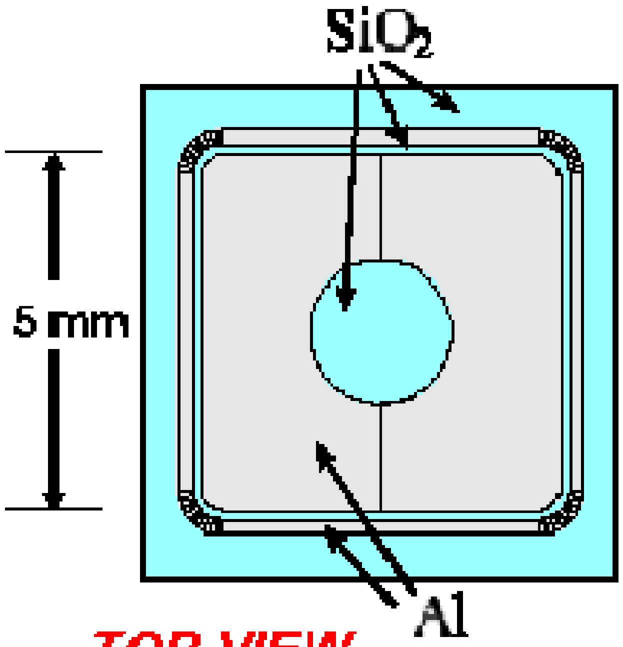
Measurements on pad diodes

FZ-n-Si 280 µm, N_{eff}= 7.6x10^{11} cm^{-3}, U_{dep} = 45 V, C_{dep} = 12 pF, ρ= 5.5 kΩcm



SIDE VIEW

not to scale



TOP VIEW

not to scale

- frontside injection of 660nm light (3 µm absorption length ~ 1 keV γ)
- only electrons drift through diode
- backside bias

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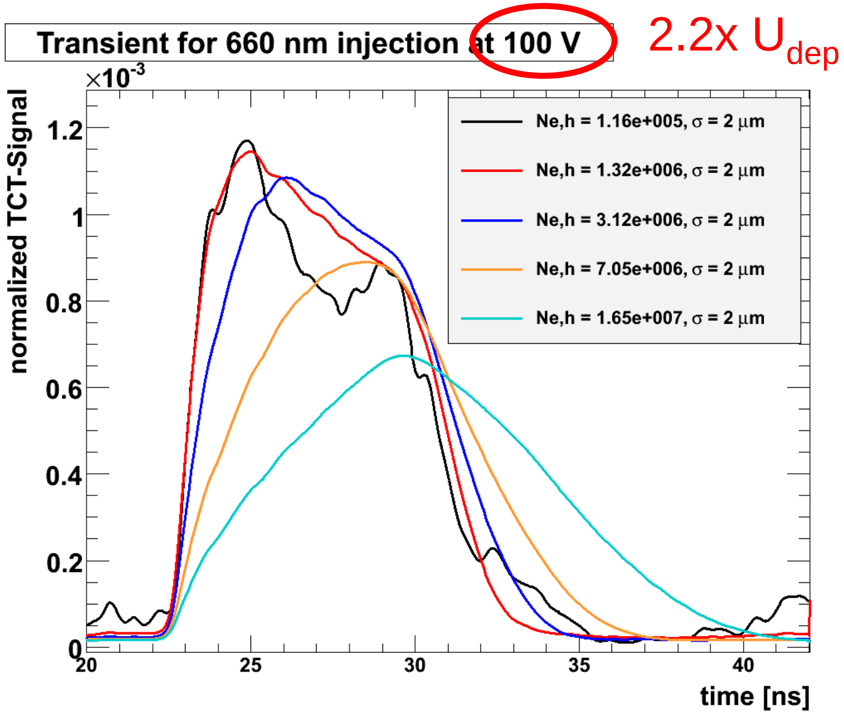
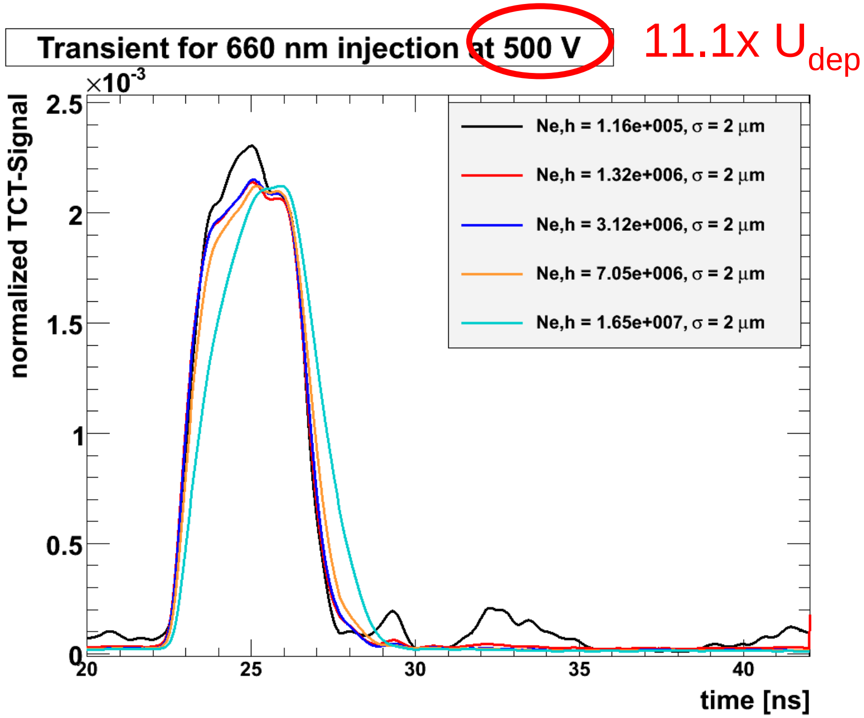
Measurements on pad diodes

frontside injection 0.116 – 16.5 x10^6 e,h Pairs, scaled to same integral



pulse distortion clearly visible



pulse distortion mostly suppressed

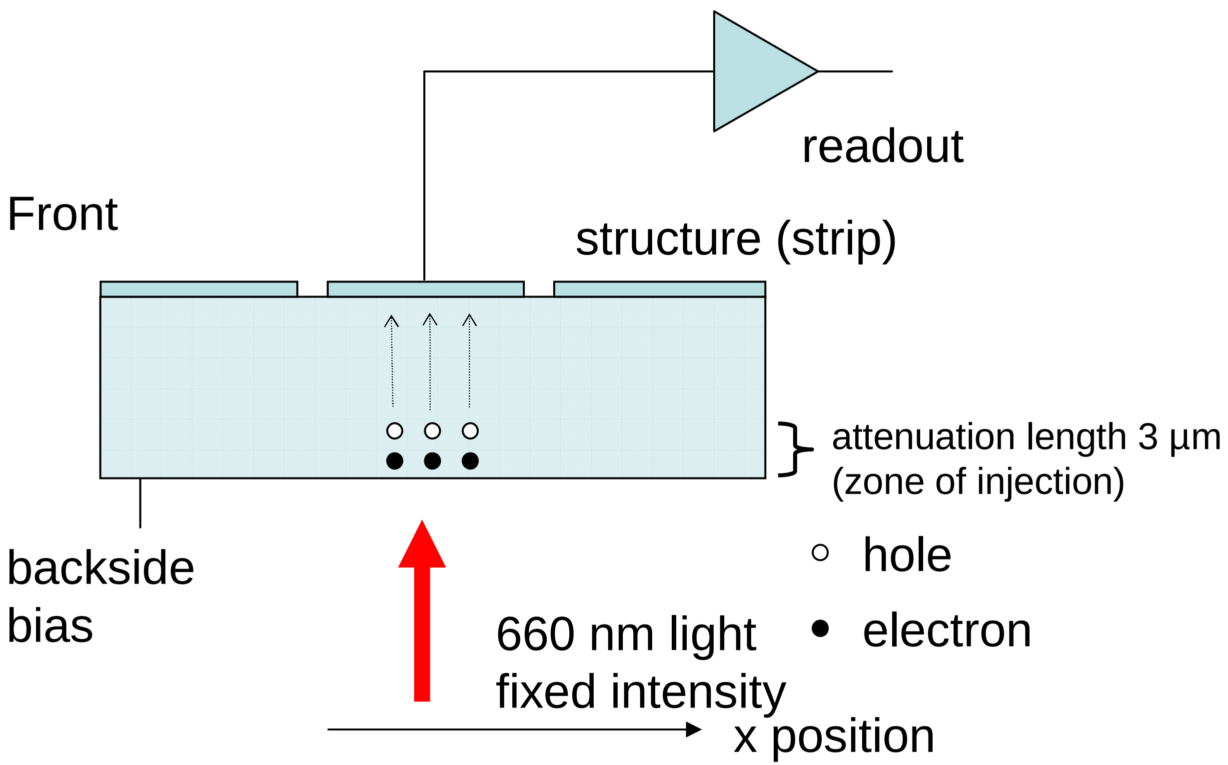
FZ-n-Si 280 µm, N_{eff}= 7.6x10^{11} cm^{-3}, U_{dep} = 45 V, C_{dep} = 12 pF, ρ= 5.5 kΩcm

Measurements on Strip detectors

position scan with spotsize sigma ~2 µm

injection of 660 nm light from backside (holes)

pn junction on front side (low field at injection side)



Strip detector

same wafer as pad diode

FZ n-type Silicon

Thickness 280 µm

U_{dep} ~ 63 V

N_{eff} ~ $1x10^{12}$ cm^{-3}

ρ ~ 3.9 kΩcm

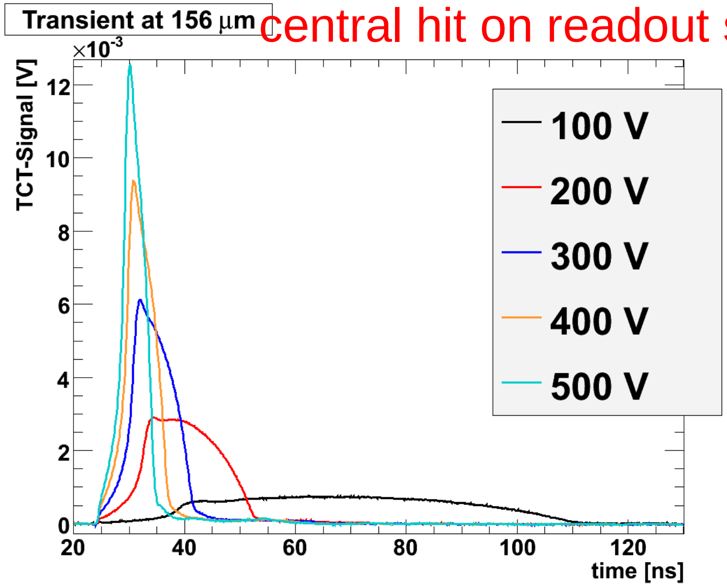
Pitch 80 µm

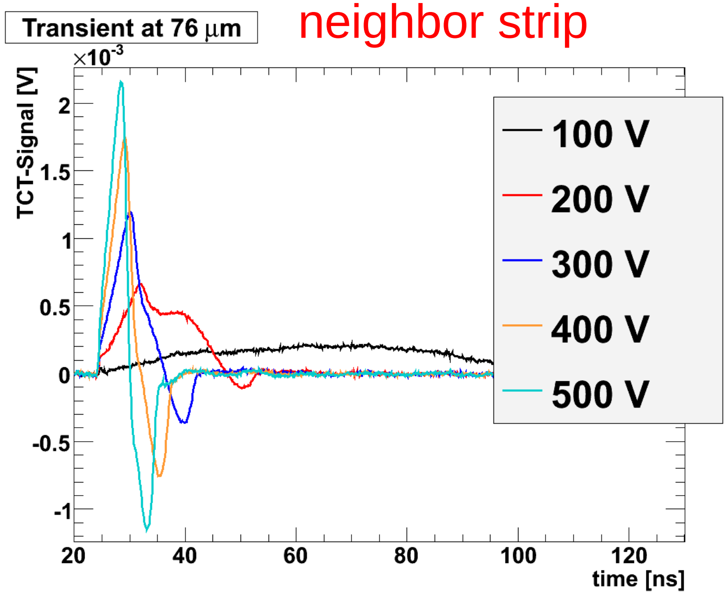
Width 20 µm

Position sensitive transients

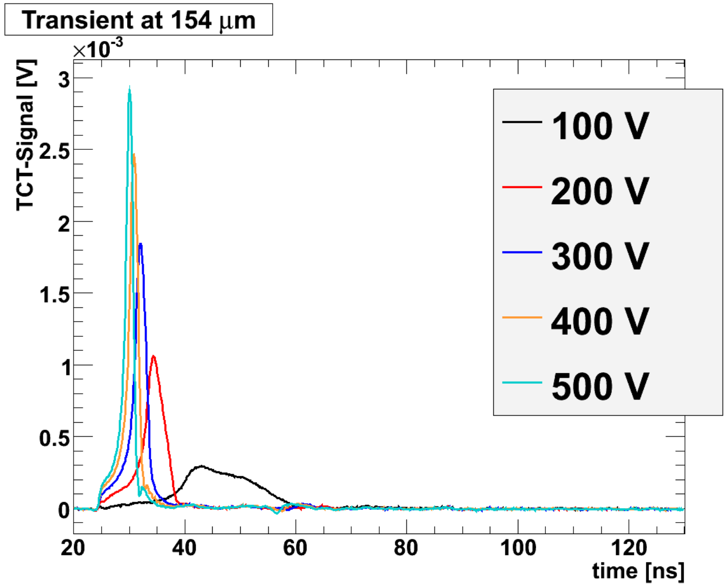
central hit on readout strip

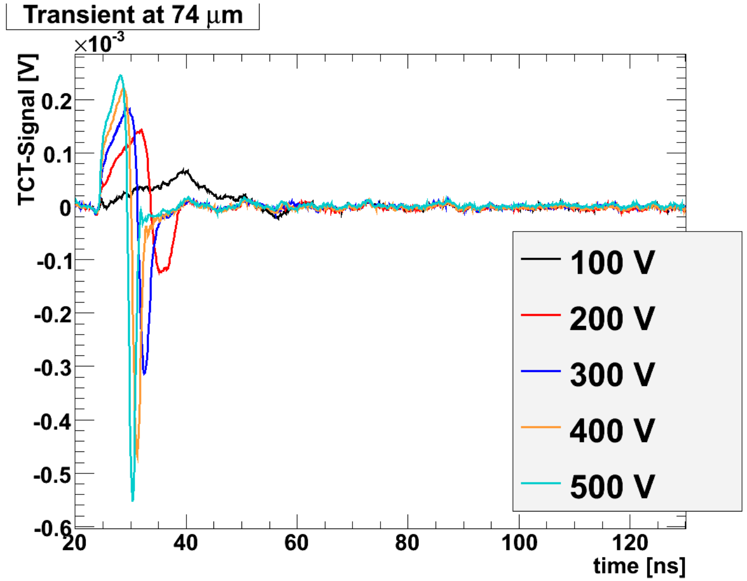
neighbor strip





9.1 x 10^6 e,h pairs -> 32’760 1 keV γ



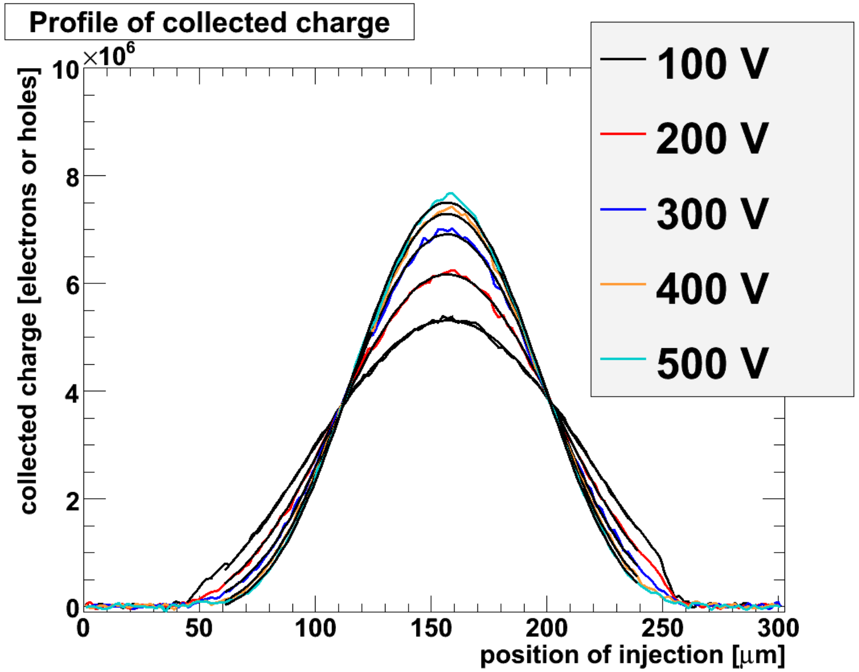


0.8 x 10^6 e,h pairs -> 2’880 1 keV γ

urg

Charge cloud profile

9.1×10^6 e,h pairs
-> 32’760 1 keV γ



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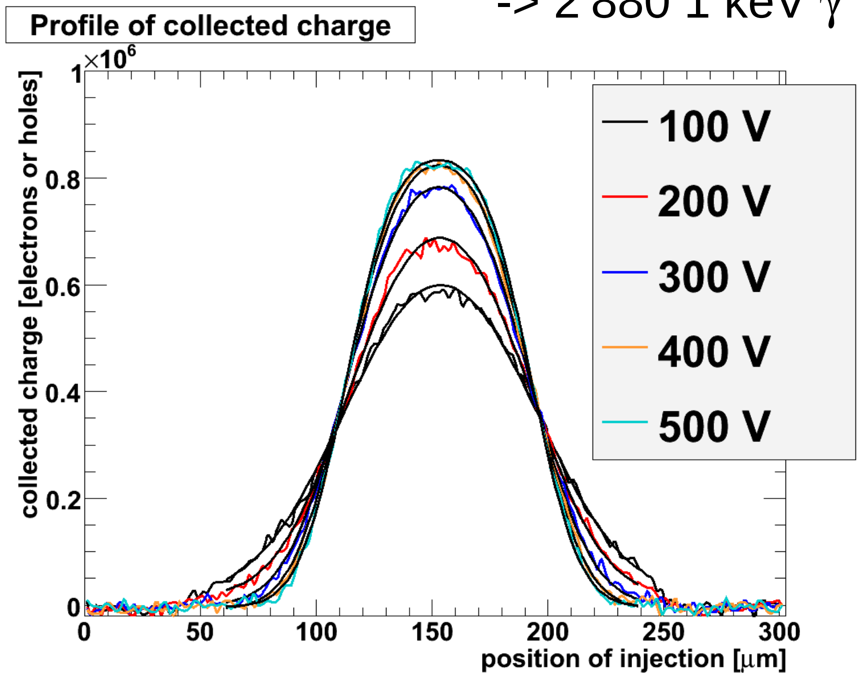
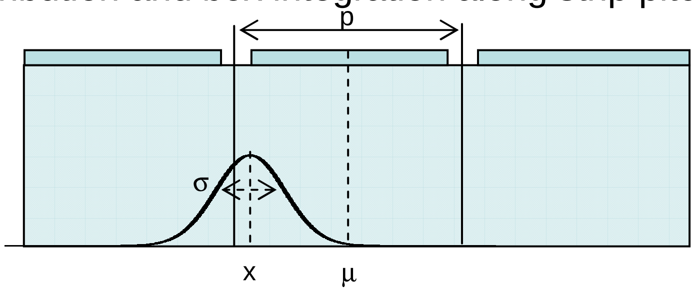


Fitting done with assumption of gaussian charge carrier distribution and box integration along strip pitch



$$C(x) = c_0 + \frac{N_0}{\sigma\sqrt{2\pi}} \int_{\mu-\frac{p}{2}}^{\mu+\frac{p}{2}} \exp\left(-\frac{(y-x)^2}{2\sigma^2}\right) dy$$

C(x) collected charge

x position of injection

c_0 contribution of noise

N_0 total number of injected carriers

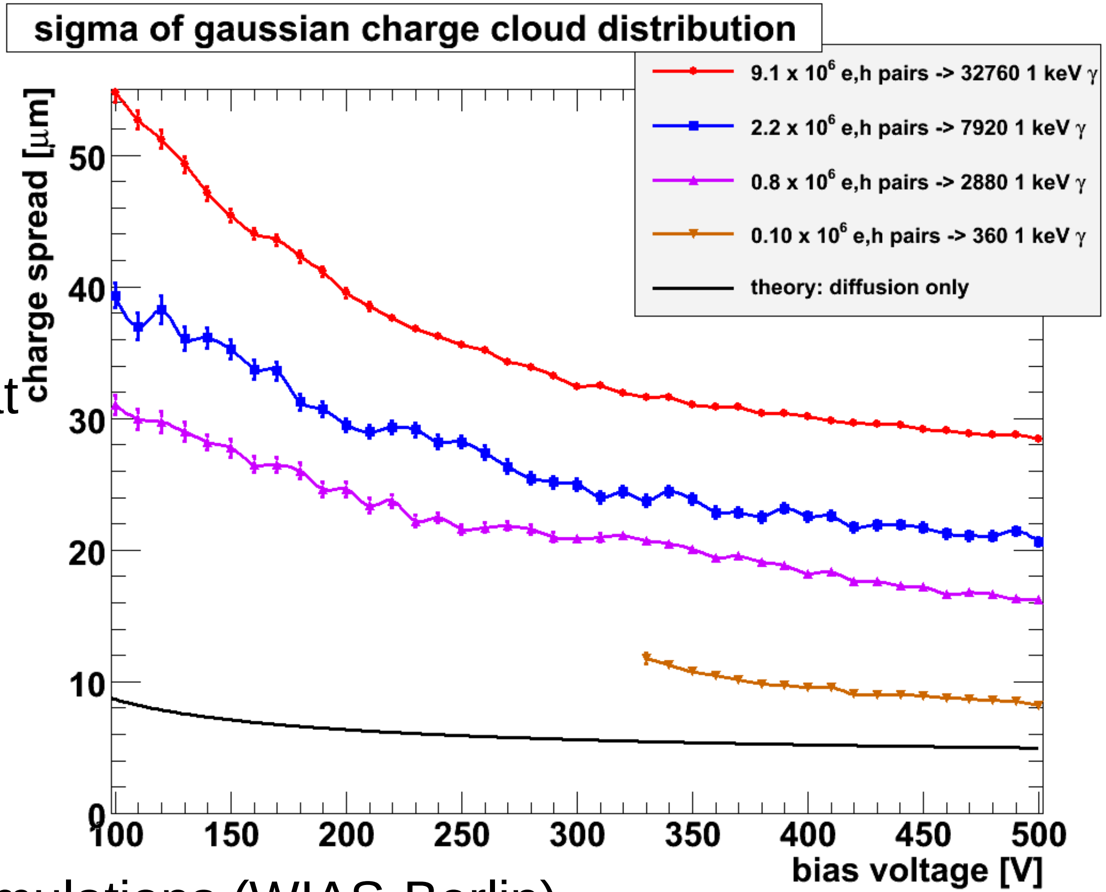
p strip pitch

µ position of strip center

σ spread of charge carrier distribution

Summary

- calibrated multi channel TCT setup available for measurements
- Plasma effects observed at high intensities
- Charge spread measured with 660nm light at strip detector (280µm/80µm)



Outlook

- detailed comparisons to simulations (WIAS-Berlin)
- investigations with 1015 nm laser
  (absorption length ~250 µm ~12 keV photons)
- parameterization of charge spread as function of e,h density, electric field, etc

Backup

Position sensitive transients

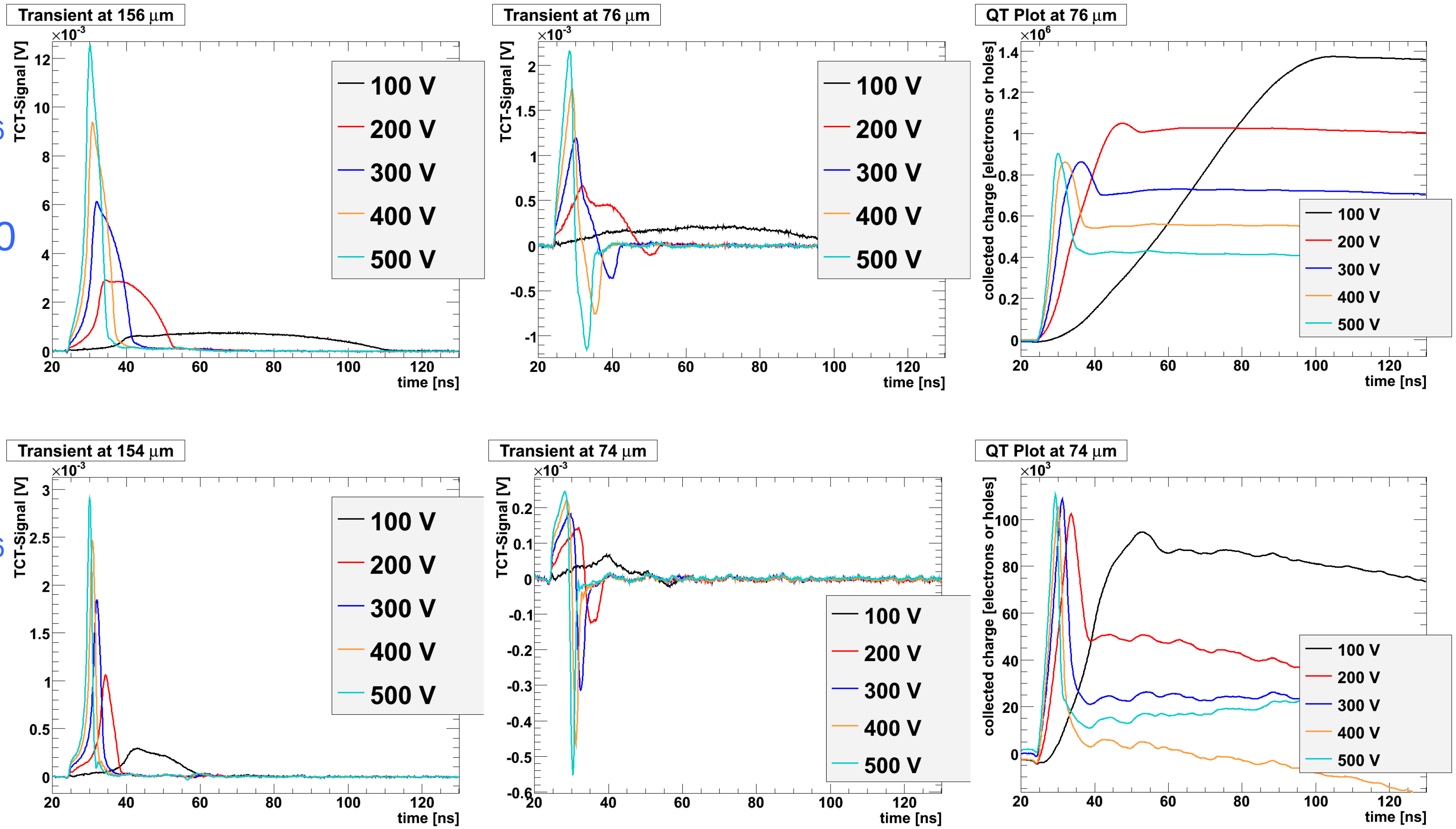
central hit on readout strip

neighbor strip

charge on neighbor

9.1 x 10^6 e,h pairs -> 32'760 1 keV γ

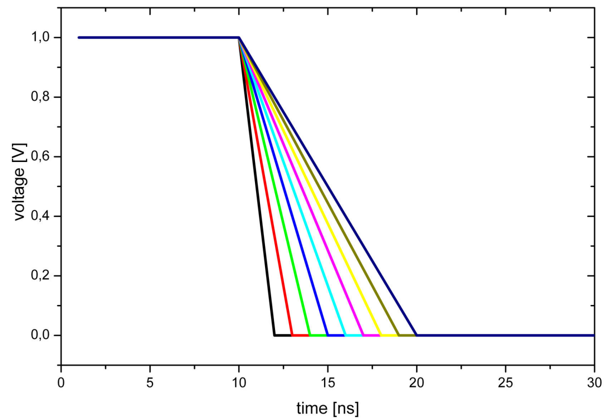
0.8 x 10^6 e,h pairs -> 2'880 1 keV γ

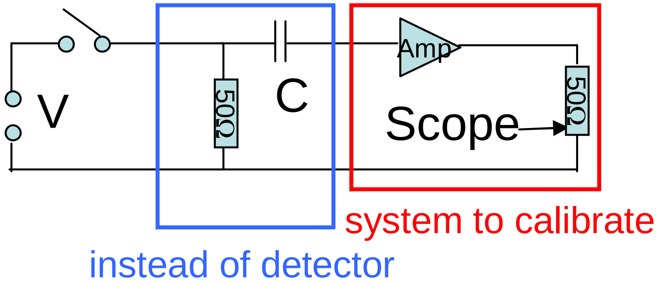


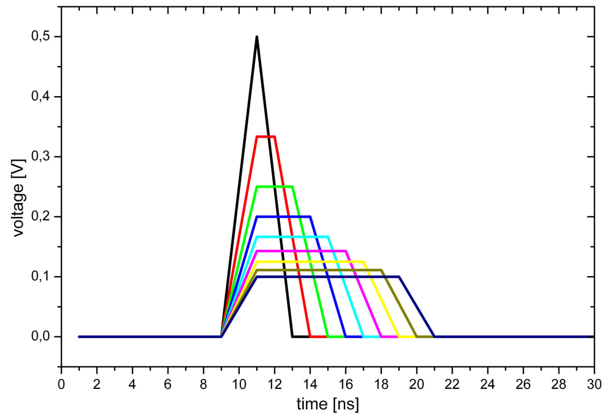
System calibration

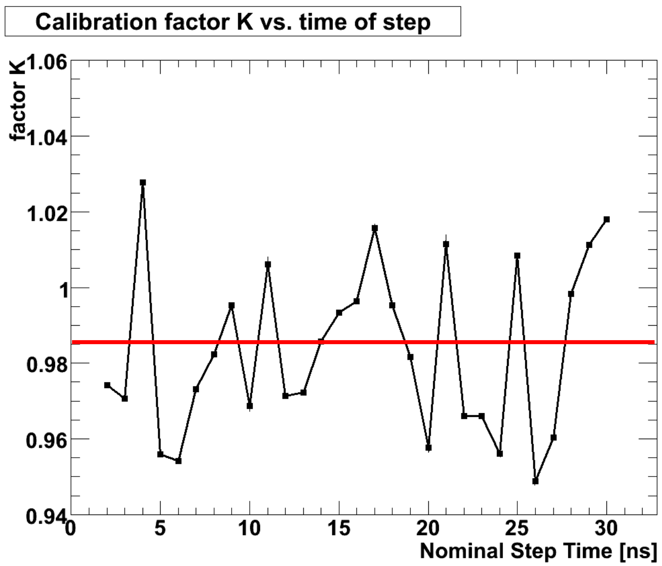
Injection of a step function (V) over a known capacitance (C) into the system instead of detector. When no charge is lost: $C \times V = \int U_{osc}(t) / R_{osc} dt$ is valid

$$Q_{inj} = Q_{meas}$$





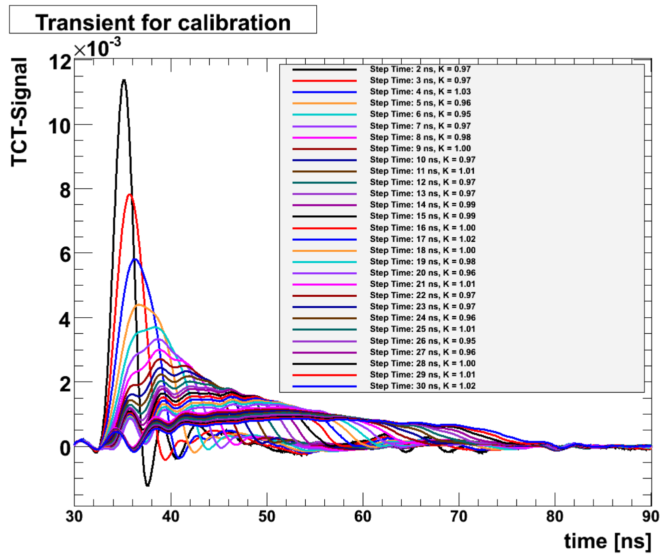




Measurement yields:

$$K = {Q_{meas}}/{Q_{inj}}$$

$$K_{avg} = 0.984$$

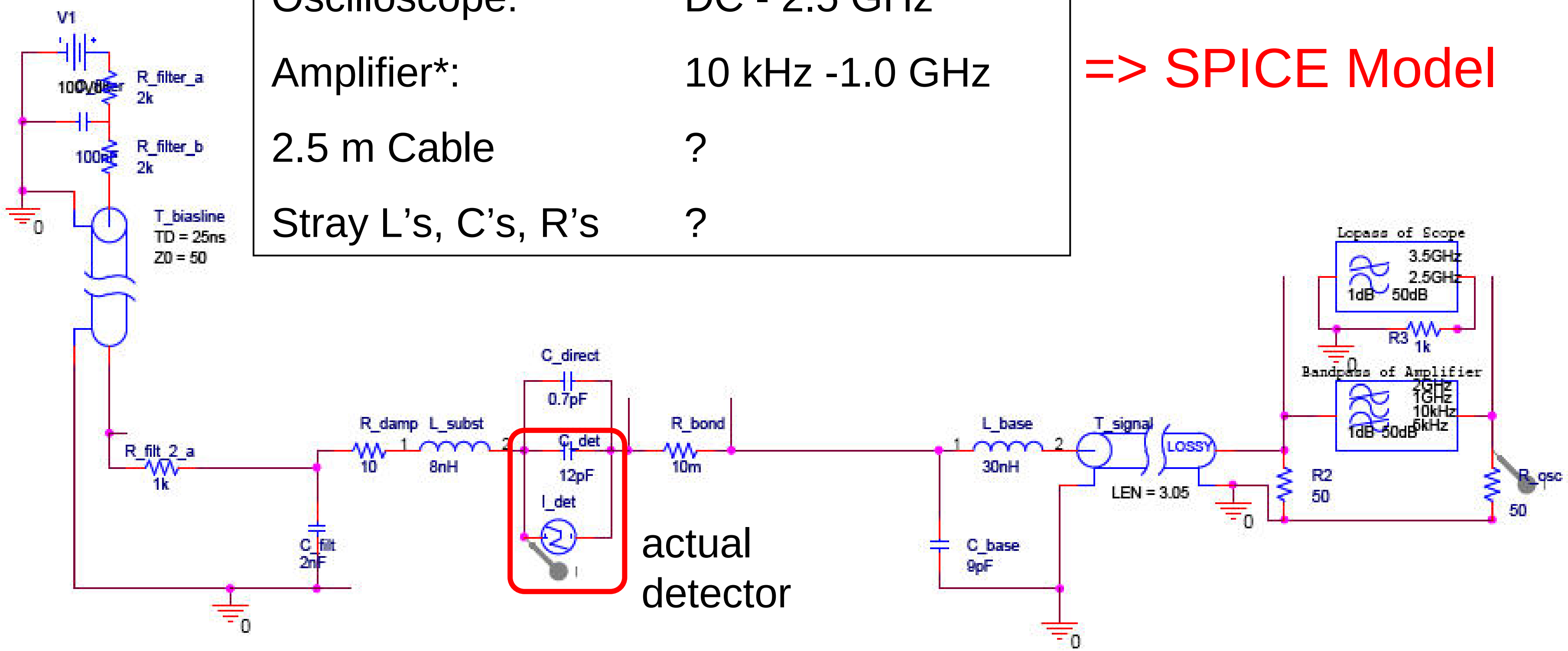


Some words on electronics

Element	*Bandwidth*
Attenuator:	DC - 4 GHz
Oscilloscope:	DC - 2.5 GHz
Amplifier*:	10 kHz -1.0 GHz
2.5 m Cable	?
Stray L's, C's, R's	?

Pulse shape is electronically smeared!

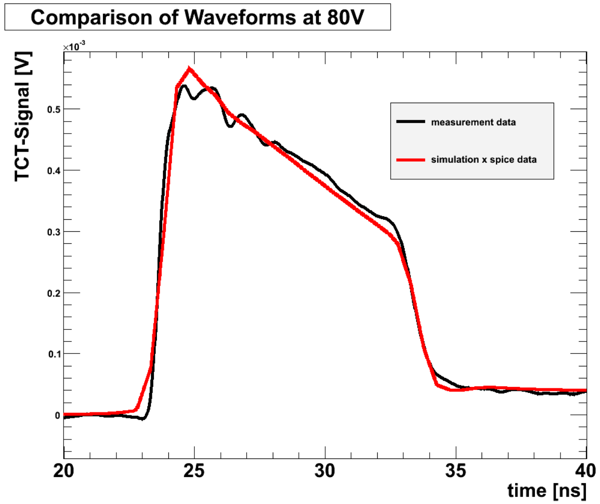
=> SPICE Model

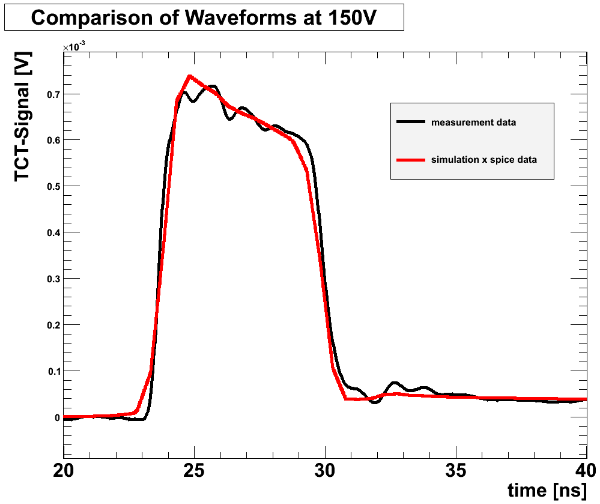


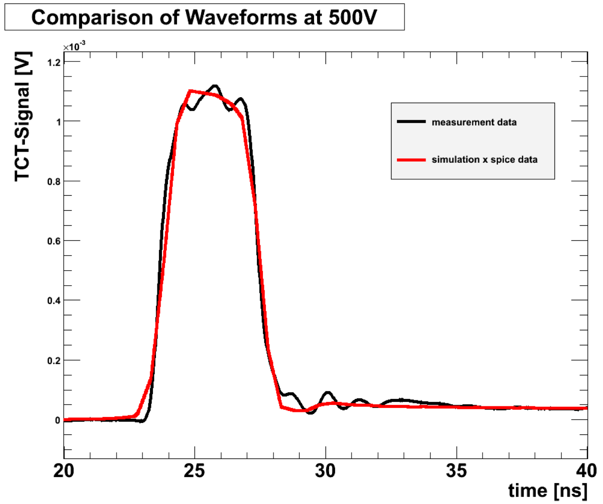
* only necessary with low intensity injection

Comparison to simple Sim. (HH)

frontside (electron) injection







Laser timing structure taken into account

exponential injection decrease taken into account

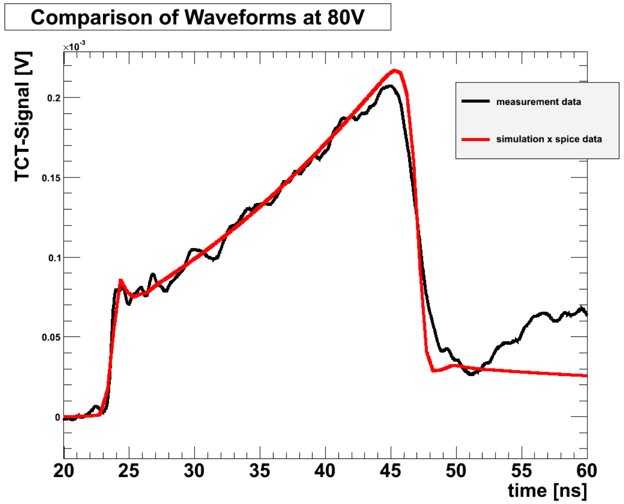
non focused laser beam

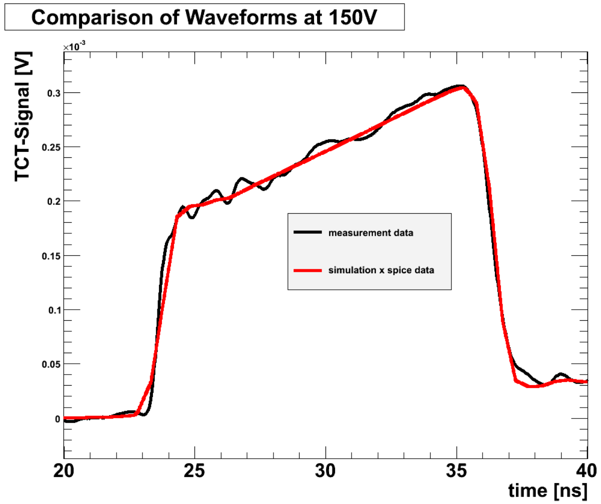
no carrier interactions taken into account

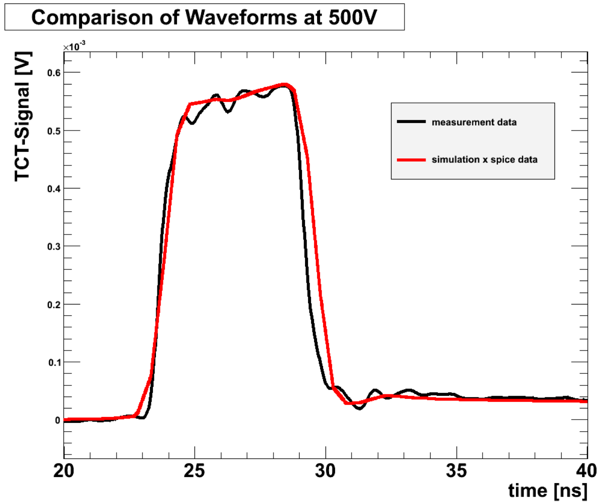
no diffusion taken into account

Comparison to simple Sim. (HH)

backside (hole) injection







Laser timing structure taken into account

exponential injection decrease taken into account

non focused laser beam

no carrier interactions taken into account

no diffusion taken into account

Mobility in simple Sim. (HH)

$$\mu = \frac{\mu_0^*}{\left(1+\left(\frac{\mu_0^* E}{v_{sat}}\right)^{\beta}\right)^{\frac{1}{\beta}}}$$ Jacoboni

$$\mu_0^* = \mu_{\min} + \frac{\mu_0 - \mu_{\min}}{\left(1+\frac{N_{eff}}{C_{ref}}\right)^{\alpha}}$$ Selberherr

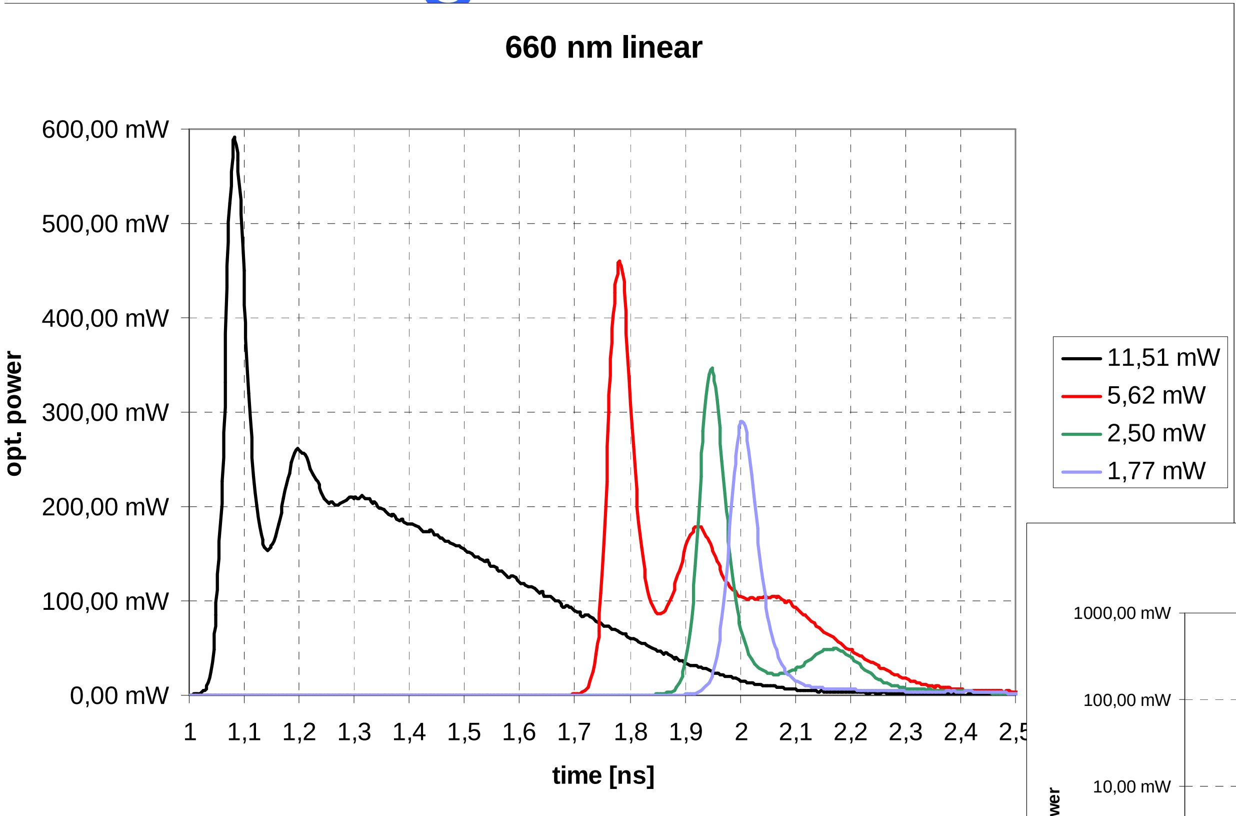
$$\alpha = 0.72\left(\tfrac{T}{300K}\right)^{0.065}$$
$$C_{ref,e} = 1.12\times10^{17}\left(\tfrac{T}{300K}\right)^{3.2}$$
$$C_{ref,h} = 2.23\times10^{17}\left(\tfrac{T}{300K}\right)^{3.2}$$
$$\mu_{0,e} = 1430\,\tfrac{cm^2}{Vs}\left(\tfrac{T}{300K}\right)^{-2.0}$$
$$\mu_{0,h} = 460\,\tfrac{cm^2}{Vs}\left(\tfrac{T}{300K}\right)^{-2.18}$$
$$\mu_{\min,e} = 80\,\tfrac{cm^2}{Vs}\left(\tfrac{T}{300K}\right)^{-0.45}$$
$$\mu_{\min,h} = 45\,\tfrac{cm^2}{Vs}\left(\tfrac{T}{300K}\right)^{-0.45}$$
$$v_{sat,e} = 1.45\times10^{7}\sqrt{\tanh\left(\tfrac{155K}{T}\right)}$$
$$v_{sat,h} = 9.05\times10^{6}\sqrt{\tanh\left(\tfrac{312K}{T}\right)}$$

Jacoboni
$$\beta_e = 2.57\times10^{-2}\left(\tfrac{T}{1K}\right)^{0.66}$$
$$\beta_h = 0.46\left(\tfrac{T}{1K}\right)^{0.17}$$

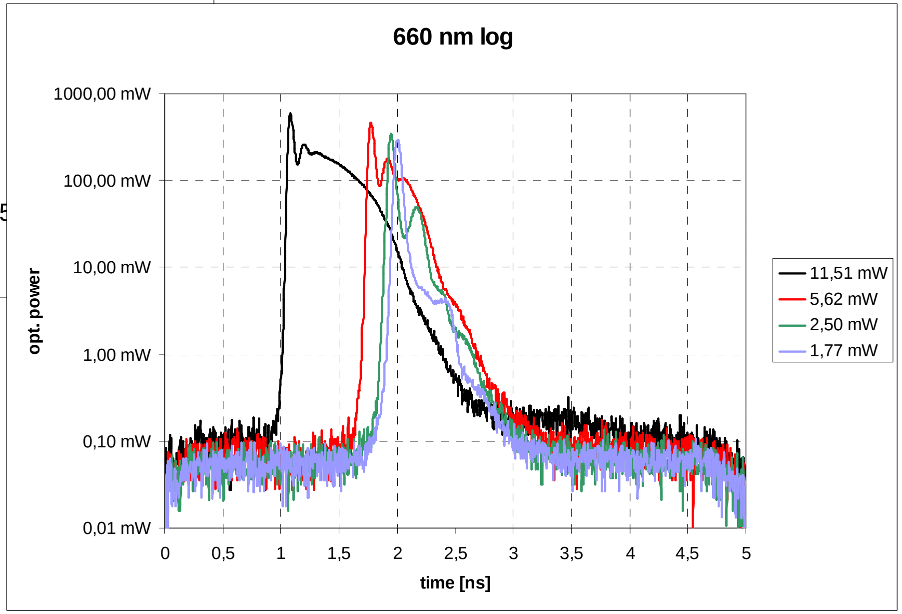
for holes μ_0* was multiplied by 1.075 to produce transients of the right time

electric field was assumed linear and independent of charge carriers

Timing structure of 660 nm laser



provided by manufacturer



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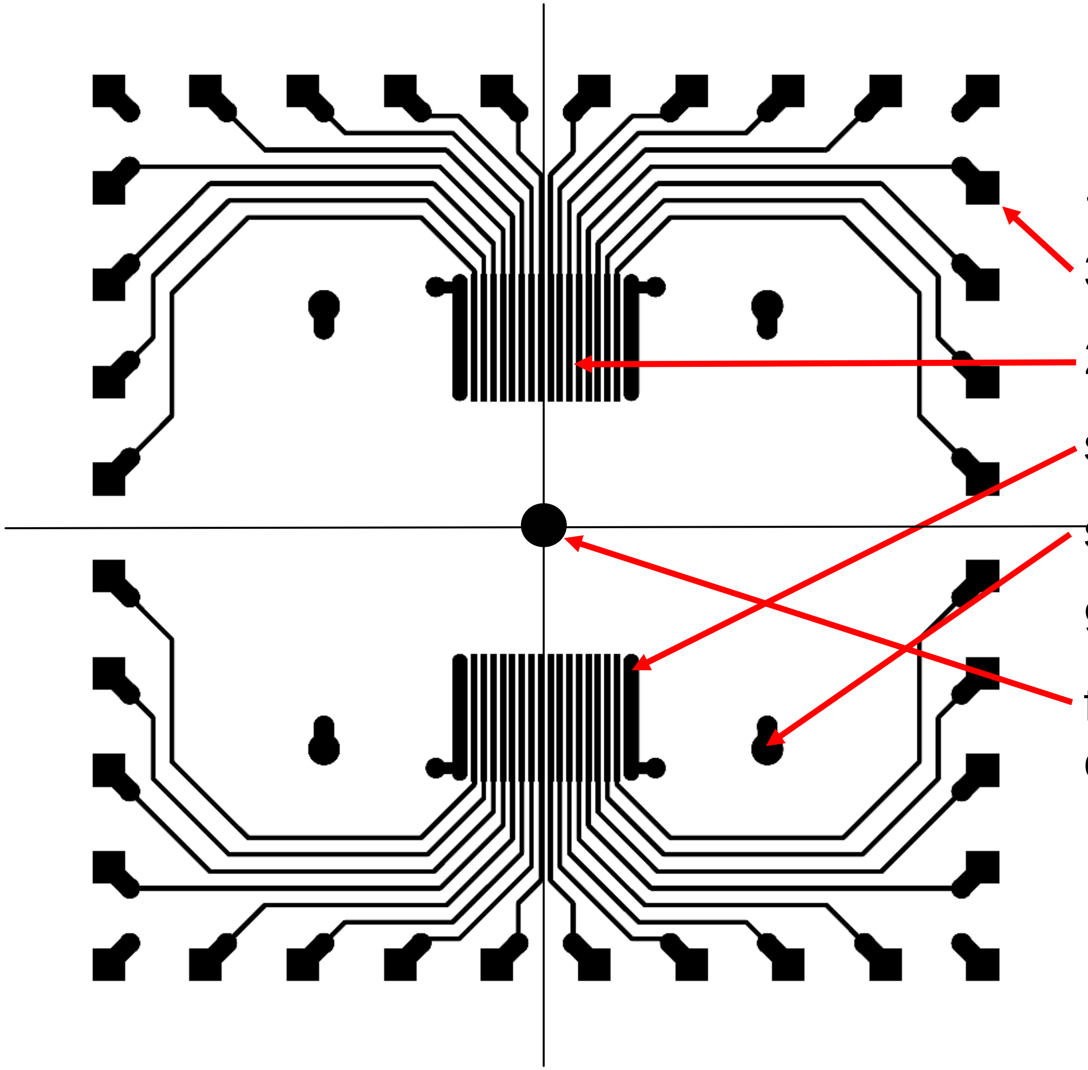
M-TCT ceramics



- 13x26 mm^2 space for d.u.t
- 32 Pads -> individual channels
- 2x 16 landing zones for wire bonds
- separate pads for ground contact
- separate pads for HV contact
- 90° rotation symmetry
- flip symmetry (vias at pads) and central hole for backside injection

Transient little plasma effects