Impact of high photon densities on AGIPD requirements

Julian Becker
University of Hamburg
Detector Laboratory

1. Heating estimations
2. Confined breakdown
3. Range switching in adjacent pixels
4. Measurements on charge collection time
5. Measurements of the PSF
6. Baseline sensor specification
7. Summary

new data (items 4–5)

Universität Hamburg

AGIPD

European XFEL

Instantaneous local heating

Basic estimation of local temperature increase due to photon absorption, neglecting heat conductance

$$\Delta T = \frac{N_\gamma E_\gamma}{V \rho c_{Si}} = \frac{2.5mK}{10^6\ 12\ keV\ \gamma}$$

$$E_\gamma = 12\ keV$$

$$V = 40x40x300\ \mu m^3$$

$$\rho = 2.33\ {}^{g}/_{cm^3}$$

$$c_{Si} = 0.7\ {}^{J}/_{gK}$$

To reach melting temperature
> $5*10^{11}$ photons are needed

Total heat load

Heat sources:

photon absorption, photocurrent, leakage current

$$P_{\gamma abs,bunchtrain} = N_\gamma E_\gamma f = \frac{9.6W}{10^9\ 12\ keV\ \gamma} N_\gamma$$

$$P_{photo,bunchtrain} = UI = U\frac{dQ}{dt} = U\frac{eN_\gamma E_\gamma f}{3.6eV}\frac{t_{drift}}{T_{rep}}$$

$$= U\frac{eN_\gamma E_\gamma f^2 d}{3.6eV\ v_{drift}} = U\frac{67mW}{10^9\ 12\ keV\ \gamma} N_\gamma$$

$$P_{leak} = UI_{leak} \quad \Rightarrow \quad \overline{P}_{total} < \frac{1W}{10^9\ 12\ keV\ \gamma} N_\gamma + UI_{leak}$$

$$f = 5\ Mhz$$

$$v_{drift,sat} = 1x10^5\ m/s$$

$$\overline{P} = P_{bunchtrain} t_{bunchtrain} f_{XFEL}$$

$$\overline{P} = 6x10^{-3} P_{bunchtrain}$$

→ $\Delta T_{bunchtrain}(1Mpix,1000V,10^9\gamma)=2mK$

Local temperature increase

Estimation of local temperature increase during bunch train assuming 10^6 photons in a single pixel for all 3000 frames and neighboring pixels at constant temperature (heat conductance only, no additional cooling)

$$P_{10^6 \gamma, total} \leq 80 mW$$

$$\dot{Q}_{total} = (4 \frac{200x500}{200}) \mu m * \lambda \Delta T$$

$$P_{\gamma, bunchtrain} = \dot{Q}$$

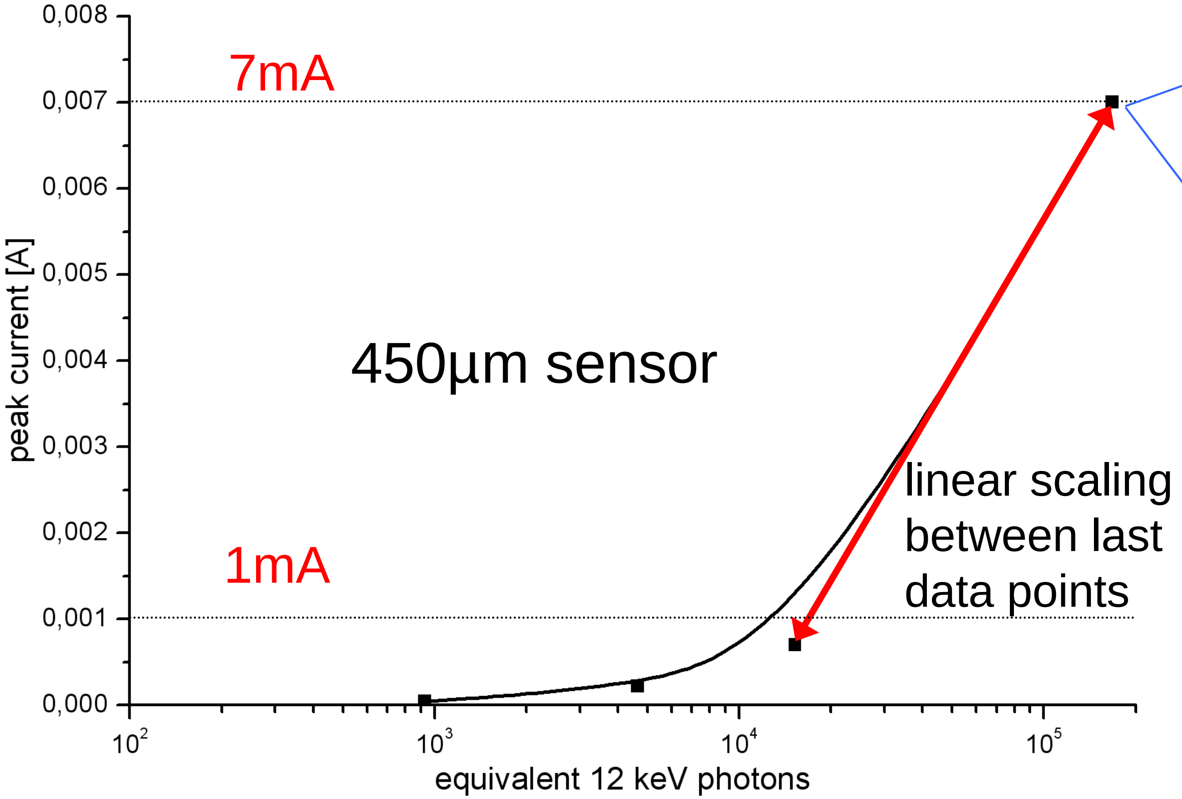
$$\Rightarrow \Delta T \leq \frac{0.27 K}{10^6 \, 12\, keV \;\gamma} N_\gamma$$

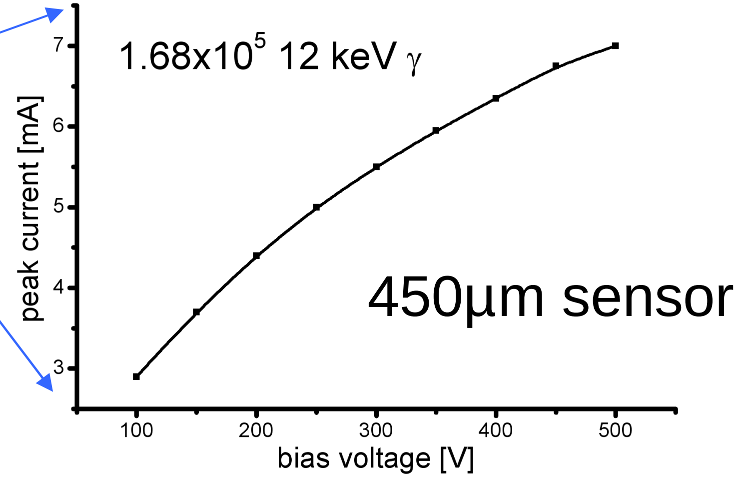
$$\lambda_{Si} = 148 \, W / m*K$$

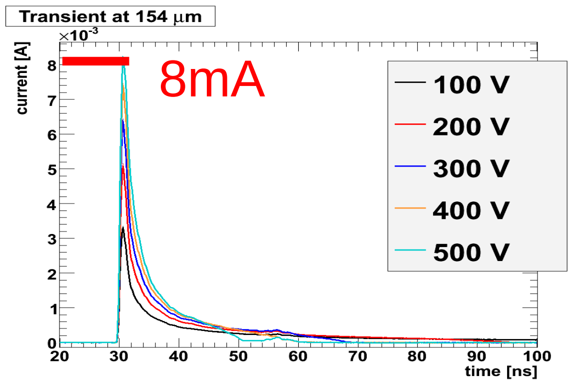
$$\dot{Q}_{neighbor} = \lambda \frac{A}{l} \Delta T$$

$$\dot{Q}_{total} = 4 \dot{Q}_{neighbor}$$

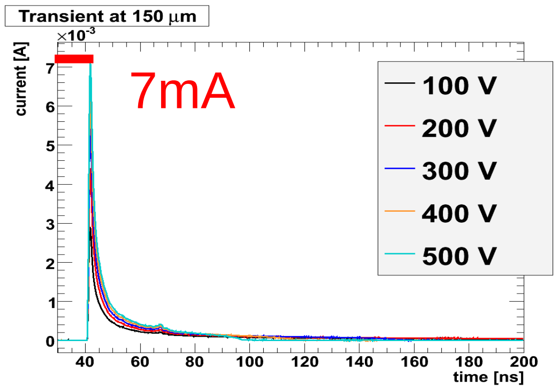
Confined breakdown







280µm sensor



450µm sensor

Current peaks of up to 8mA have been observed in measurements so far, assuming linear scaling to 10^6 and 50 Ω impedance of the preamplifier

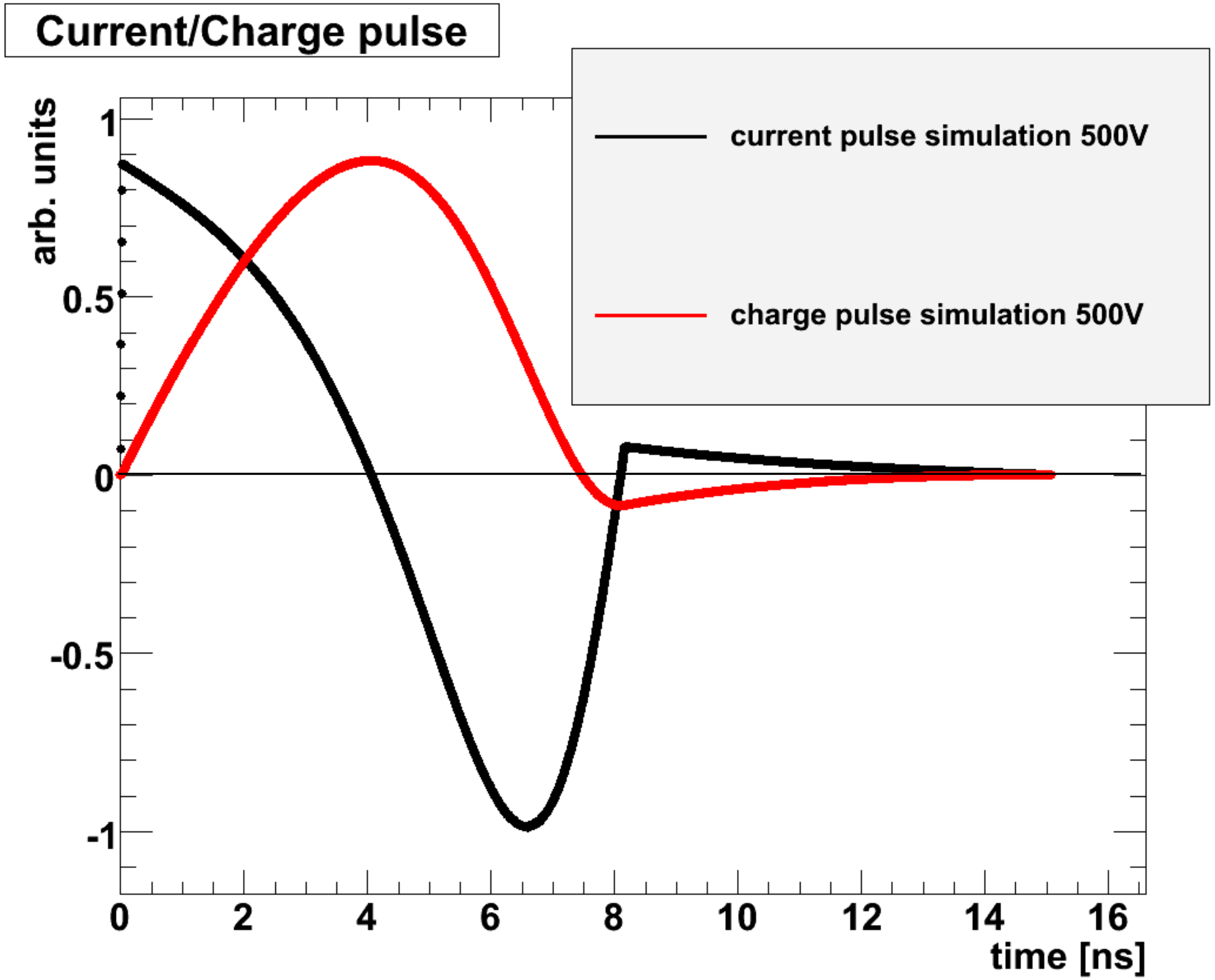
⇒4V across the input of preamp

⇒"killing" threshold will probably be in the region 10^7-10^8 photons/pixel

Input protection will add noise to the measurements

Discussion of trade off between noise and dead pixel count should be encouraged

Range switching in adjacent pixels



Current/charge pulse on adjacent pixel assuming continuous photon absorption, n-in-n pixels, no plasma effects and 500V bias.

Range switching will be triggered if peak of red curve > 85 photons.

⇒Nγ > 2600 in primary pixel will trigger switching to second gain stage in adjacent pixels

⇒Nγ > 6.8×10^4 in primary pixel will trigger switching to third gain stage in adjacent pixels

Having a primary pixel in third gain stage will result in switching in adjacent pixels even if less than 85 photons are absorbed

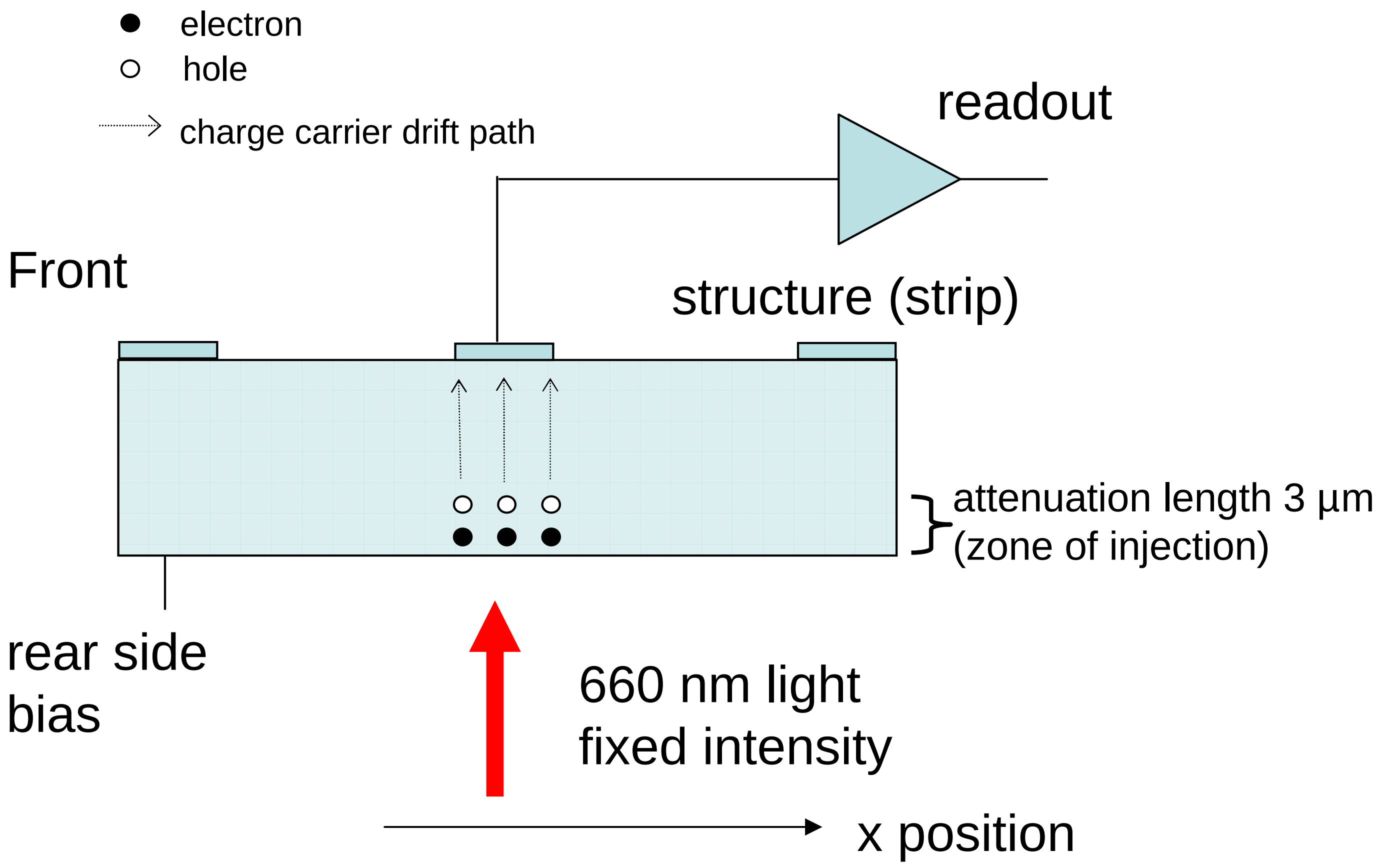
Range switching in adjacent pixels

sensor thickness	voltage	$N\gamma$ in primary pixel to switch to 2nd stage	$N\gamma$ in primary pixel to switch to 3rd stage
500µm	500V	2615	6.77×10^4
500µm	1000V	2880	7.45×10^4
1000µm	500V	2225	5.76×10^4
1000µm	1000V	2414	6.25×10^4

Having a primary pixel in third gain stage will result in switching in adjacent pixels even if less than 85 photons are absorbed

Measurements on PSI strip sensor

- injection of 660 nm and 1015 nm light from rear side
- pn junction on front side (low field at injection side)
- position scan with spotsize ~3 µm



PSI strip sensor

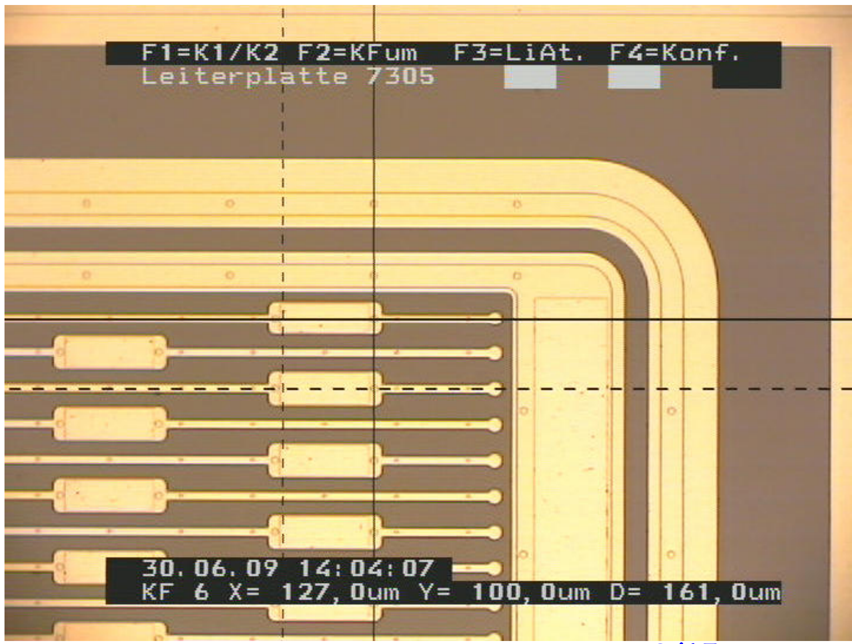
<111> orientation

thickness 450 µm

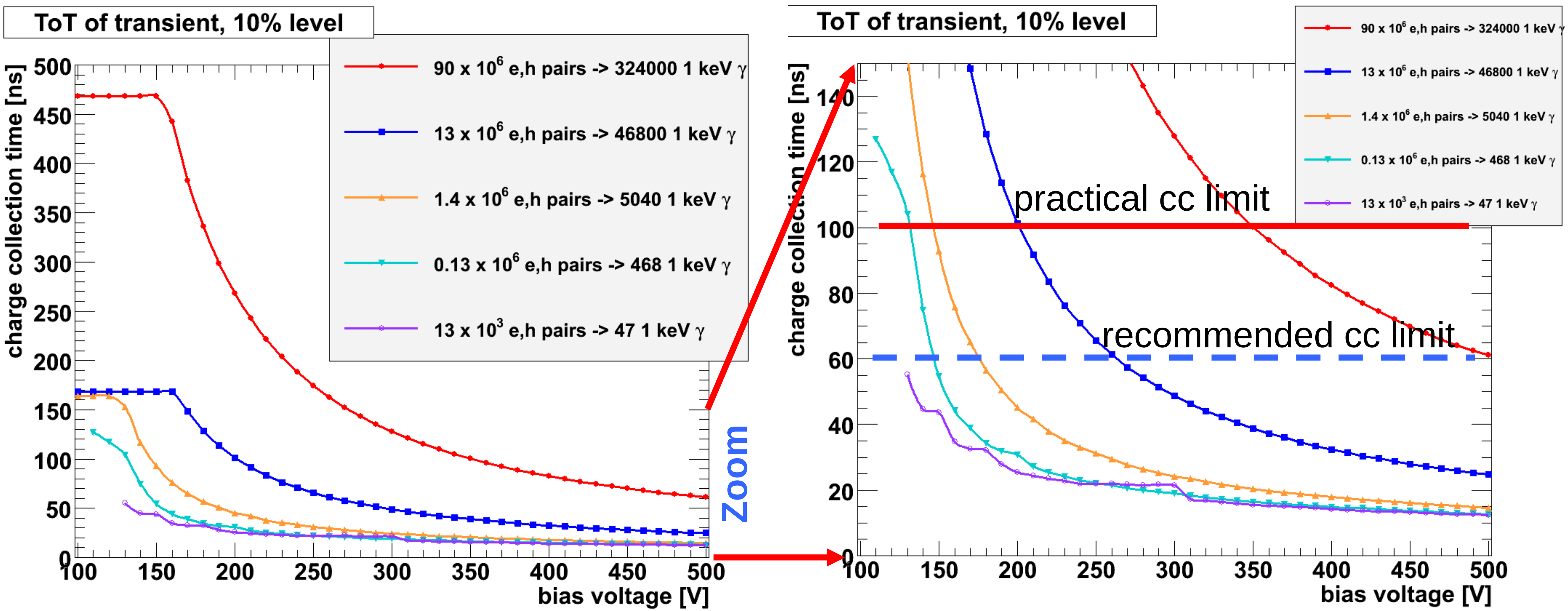
U_{dep} ~ 150 V

pitch 50 µm

width 11 µm



Measurements on charge collection time

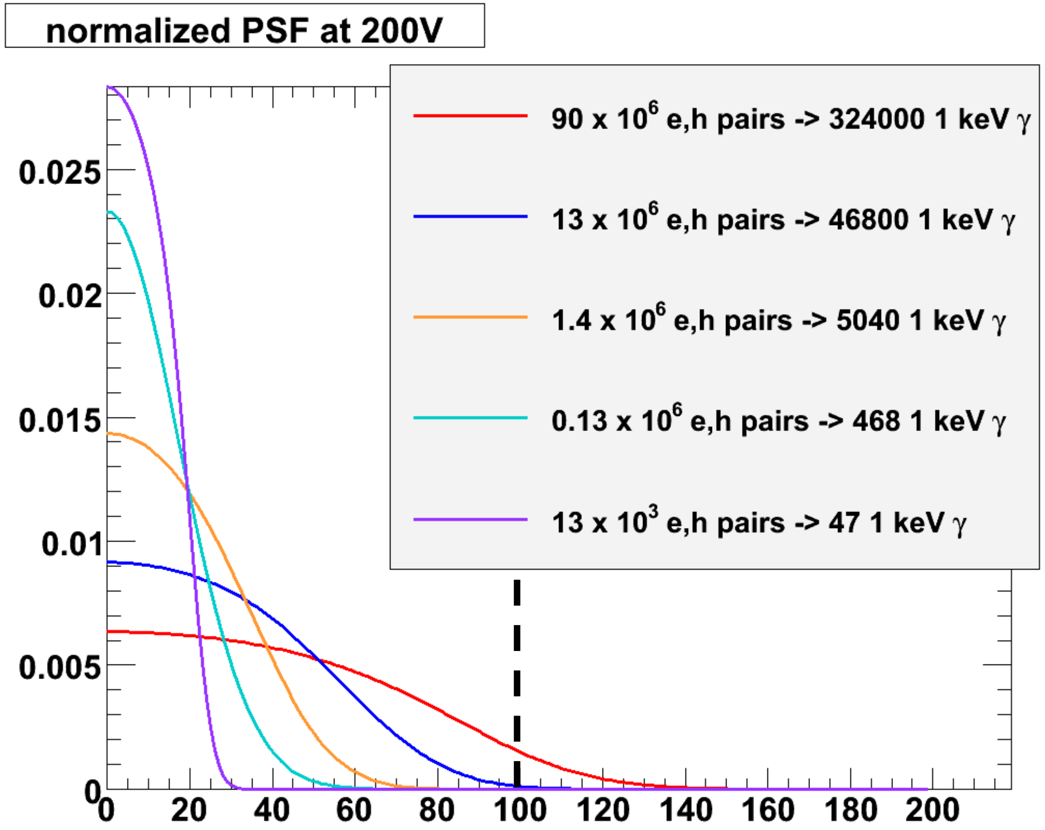


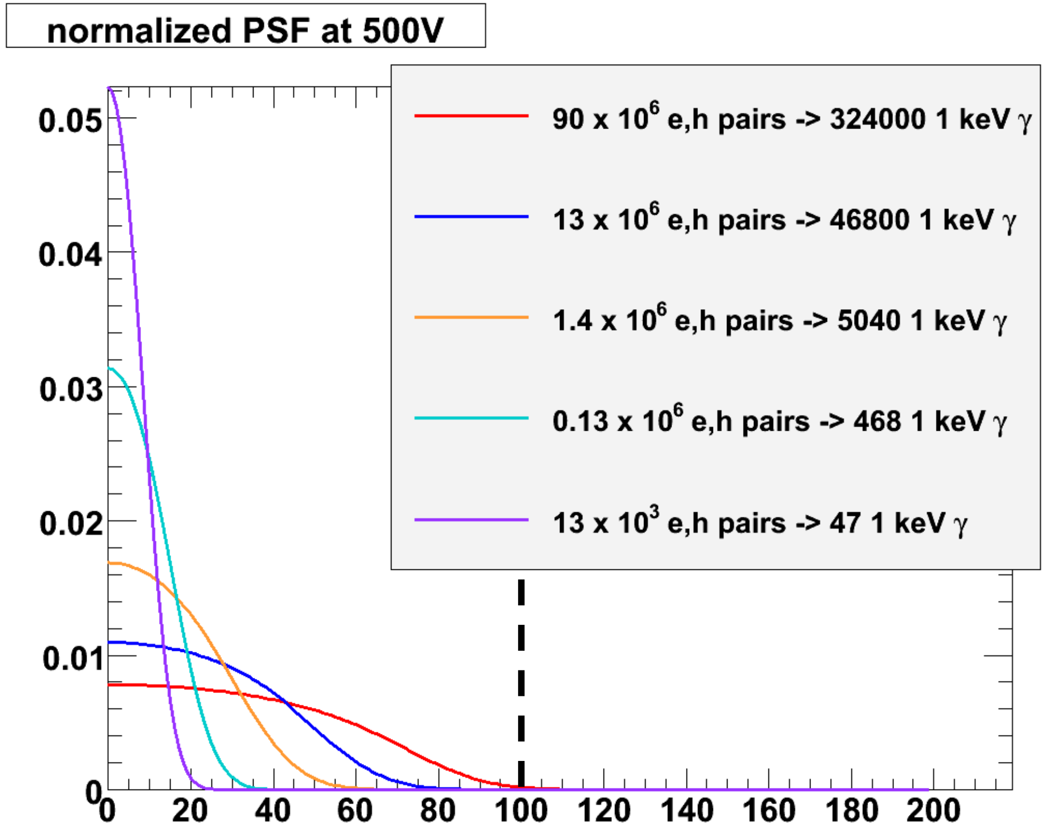
tightly focused (3 µm) soft x-rays (~1 keV) on 450 µm p-in-n strip sensor

plasma delays for low bias voltages included

=> charge collection time stays below 60 ns even for very high Nγ if sufficient voltage is applied

Measurements of the PSF



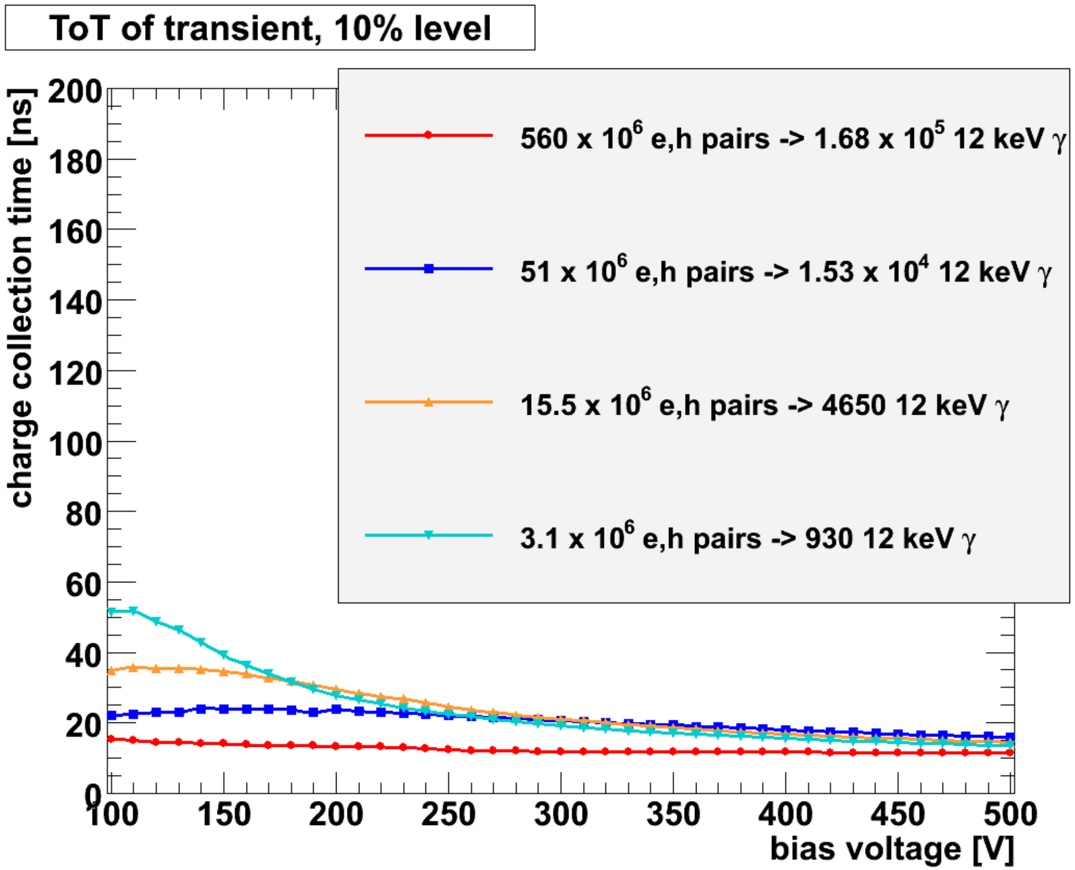


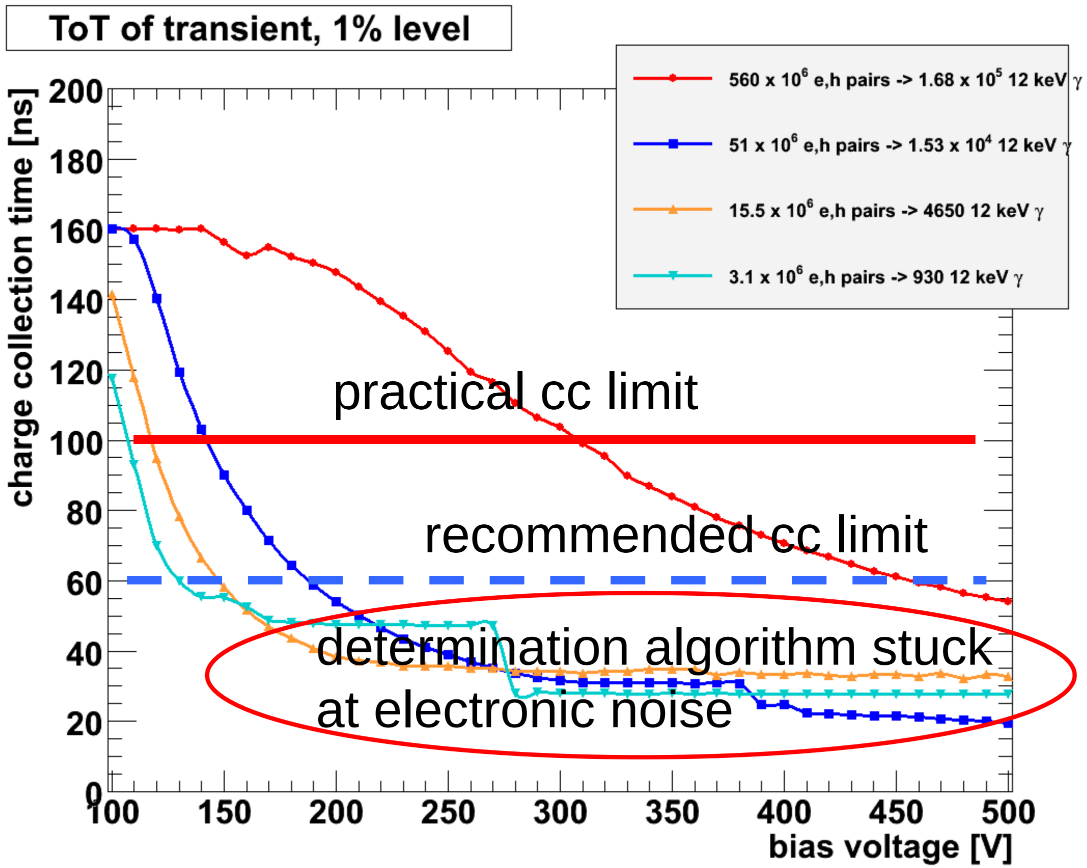
tightly focused (3 µm) soft x-rays (~1 keV)

new parameterization:
Gaussian (diffusion) ⊗ circle (plasma)

=> only of minor influence on imaging performance as plasma effects stay mostly confined in the pixels

Measurements on charge collection time





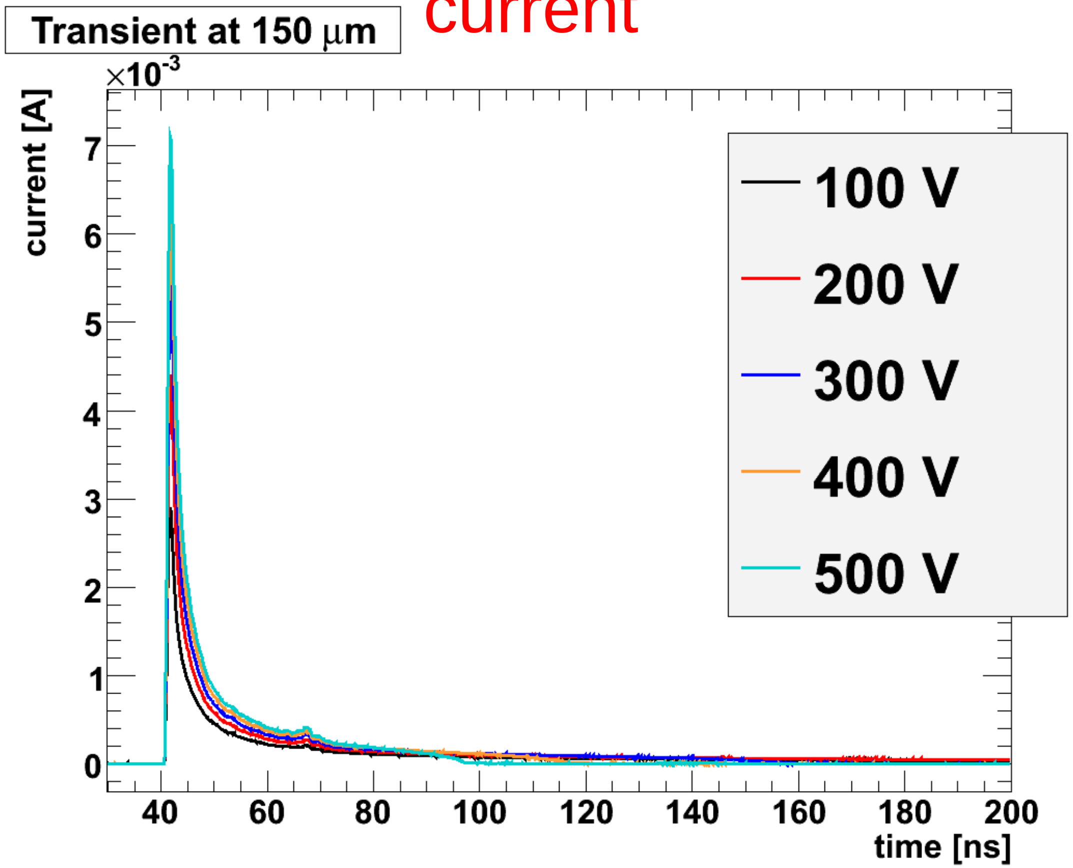
tightly focused (3 µm), hard x-rays (~12 keV) on 450 µm p-in-n sensor

strongly dependent on threshold level (exponential pulse shape!)

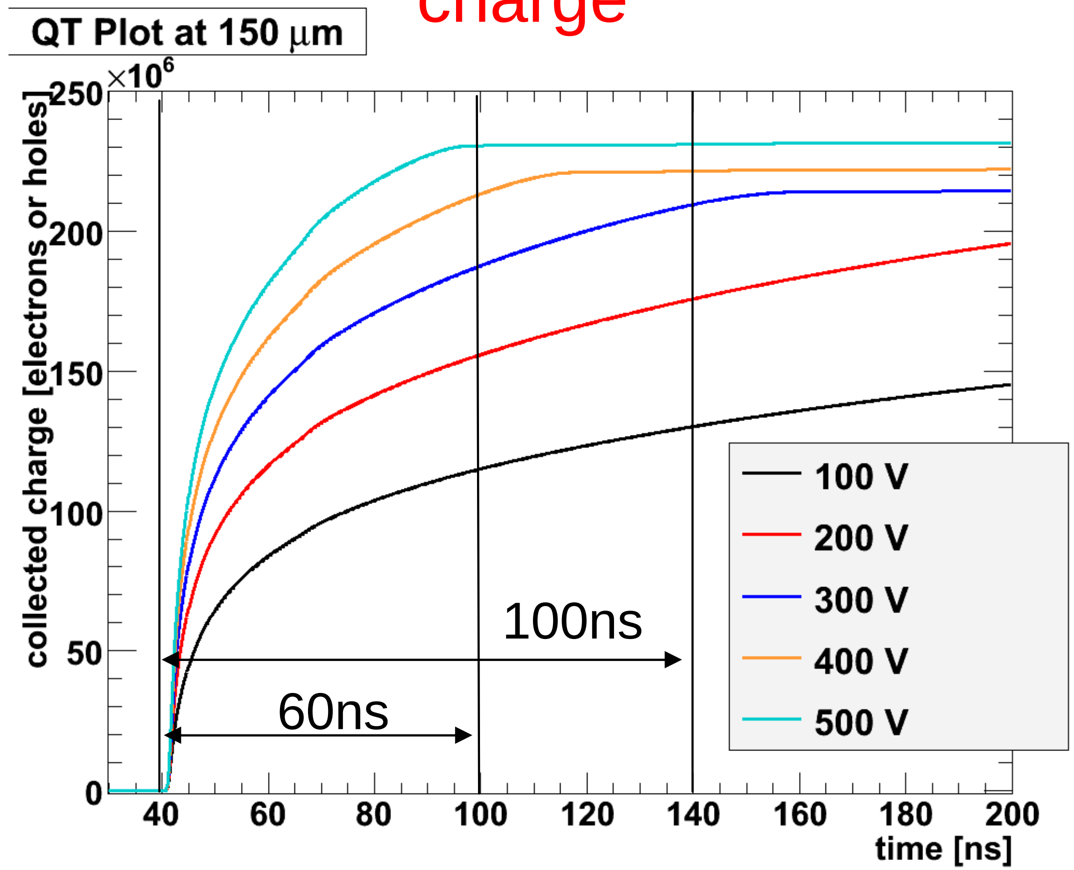
Measurements on charge collection time

1.68 x 10^5 12 keV photons

current



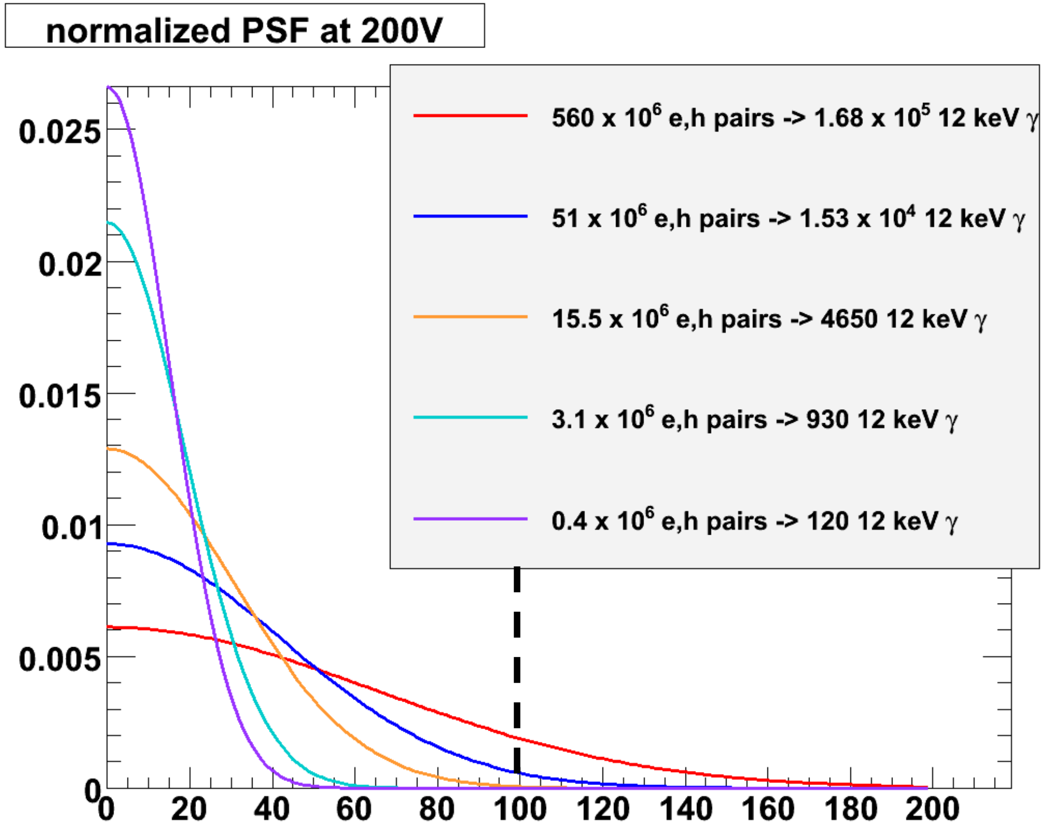
charge

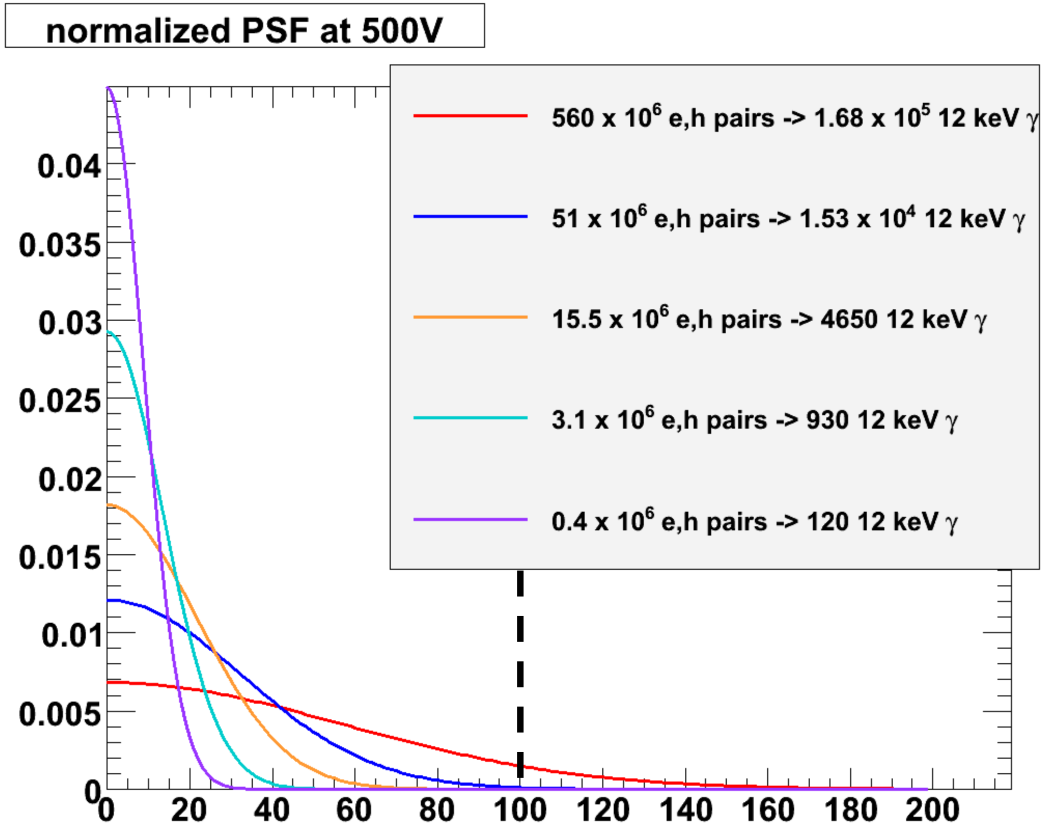


long tails may be an issue, peak increasing with voltage

- no significant effects on current frame
- tail may spill over to next frame (0.1% of 10^5 photons is still 100 photons!)

Measurements of the PSF





tightly focused (3 µm) hard x-rays (~12 keV)

new parameterization:
Gaussian (diffusion) ⊗ circle (plasma)

=> only of minor influence on imaging performance up to 1x10^4 photons as plasma effects stay mostly confined in the pixels

Baseline sensor specification

Choice of technology

- n-in-n
  - superior performance in high density case
  - edges on ground

Choice of bias voltage

- reasonably high (500 V? depends on resistivity, i.e, U_{dep})
  - less cumbersome than 1000 V (wire bonds etc.)
  - charge collection time can be “tuned” to ASIC needs
  - less peak voltage for the ASIC to stand

input from mechanical design welcome

Choice of temperature

- low (-20℃?)
  - faster charge collection time (-13% for 20℃ to -2 0℃)
  - about 5% increase in spread for high voltages (20°C to -20℃)

input from ASIC designers welcome

Summary

- Heating (local, global) not a problem if leakage current is low
- Pixel “killing” threshold probably around 10^7-10^8 photons/pixel
  - Additional input protection needed?
- Range switching will occur in adjacent pixels if primary pixel is in third gain stage
- Bright pixels have long tails (no problem for soft x-rays)
  - Memory effects
  - Effective non-linearity

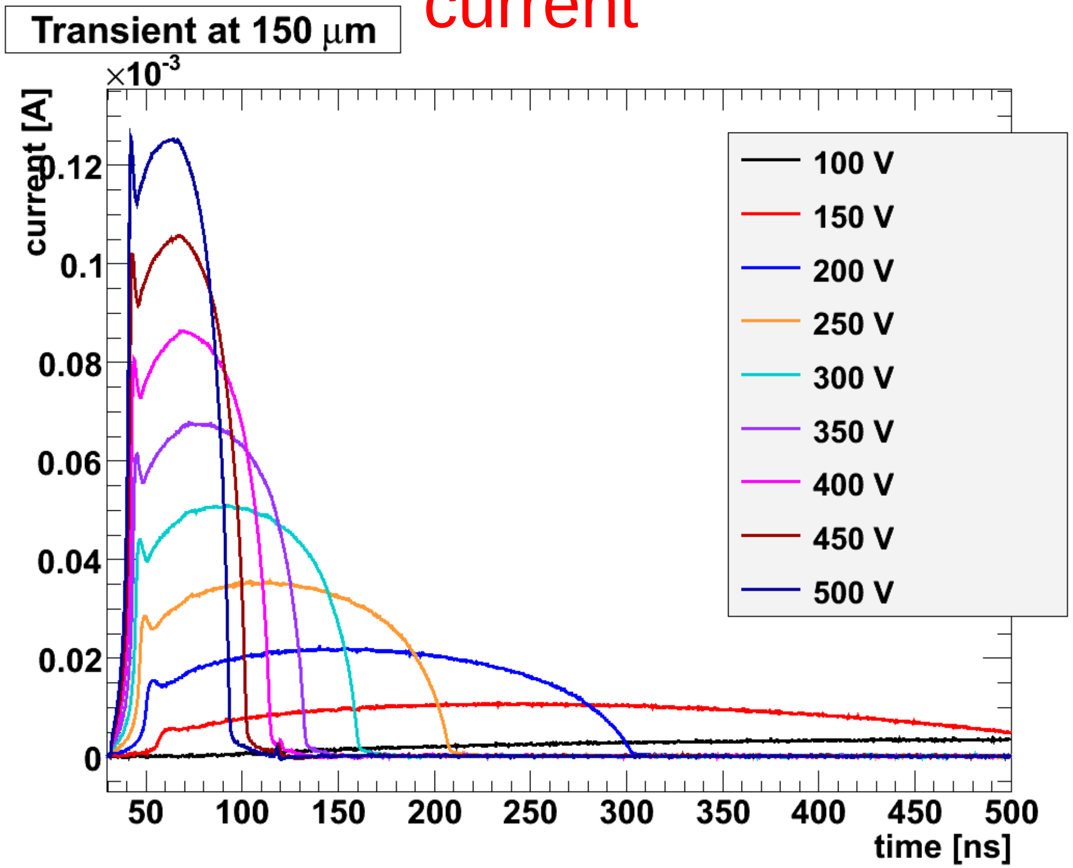
  } under investigation next
- 500 V seems sufficient bias (even in p-in-n!) to prohibit plasma effects from deterioration the imaging performance

Backup

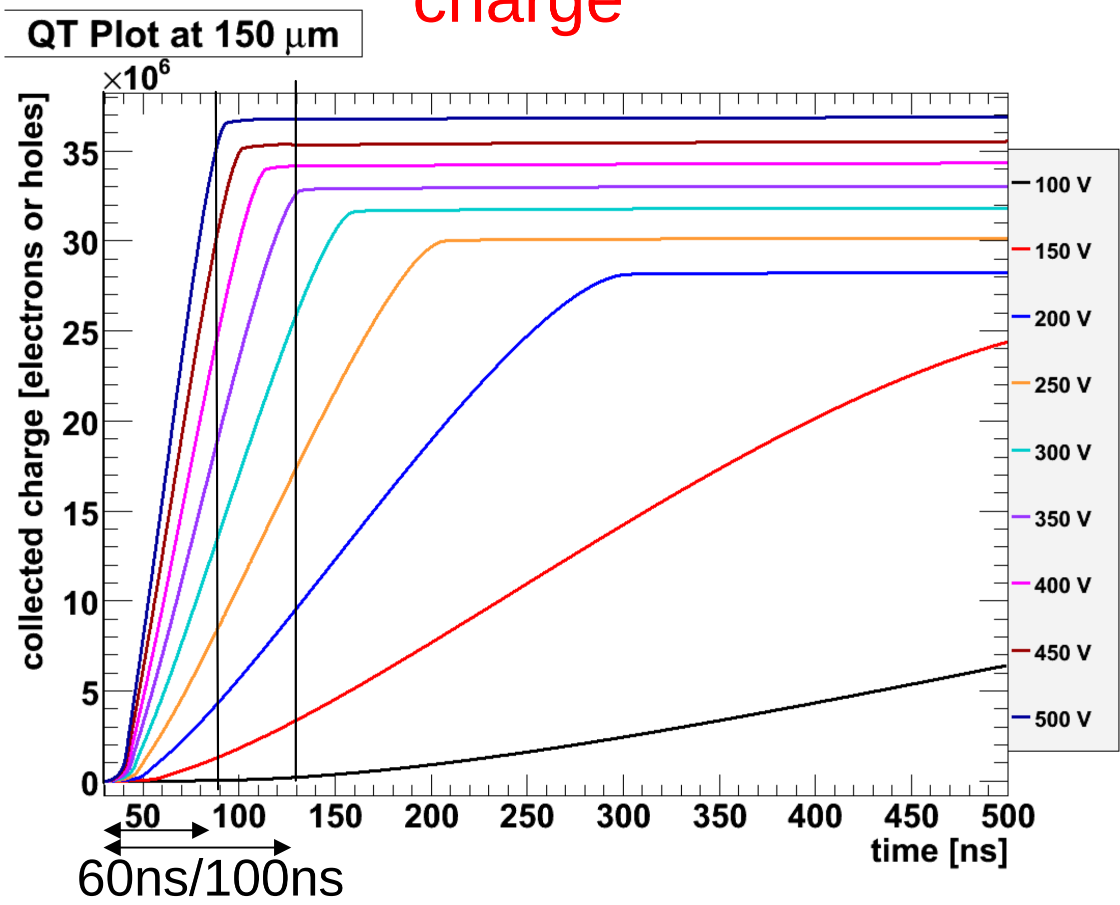
Measurements on charge collection time

90x10^6 e,h pairs -> 3.24x10^5 1 keV photons

current



charge



no exponential shape!