



# Carrier lifetime variations in proton irradiated LGAD structures

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# Outline

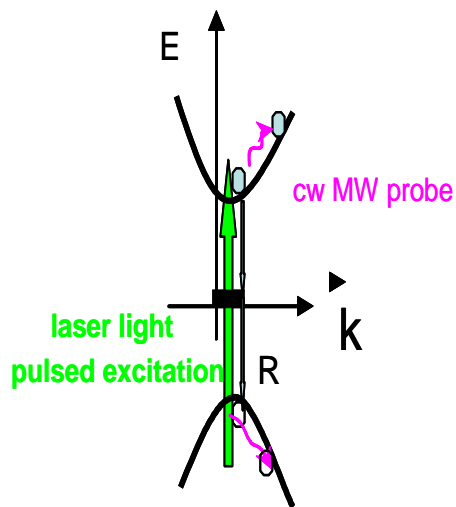
- ❑ Objective of investigation
- ❑ Principles of measurement techniques and instruments
  - ❑ Carrier lifetime profiling by edge scanning of microwave probed photoconductivity transients
  - ❑ Measurement geometries and regimes
- ❑ Samples
- ❑ Carrier lifetime in LGAD structures
  - ❑ Carrier lifetime in non-irradiated LGAD structures
  - ❑ Carrier lifetime variations in 23 GeV proton irradiated LGAD structures
- ❑ Conclusions



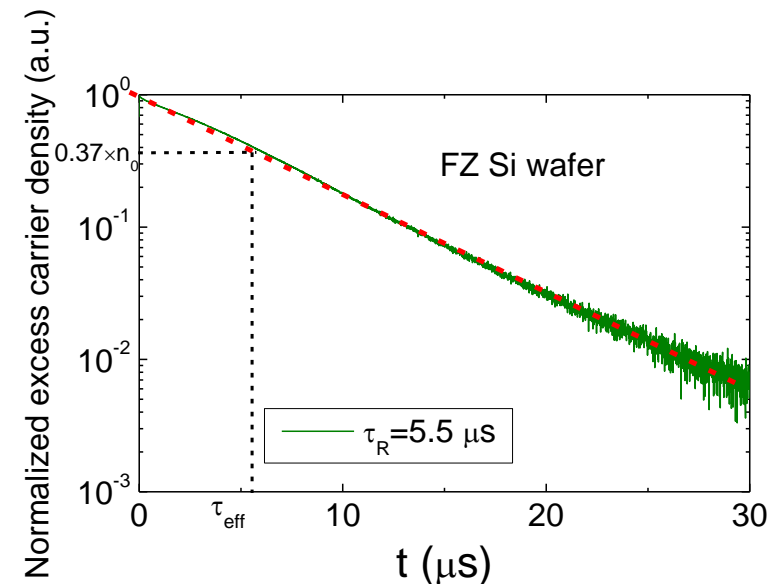
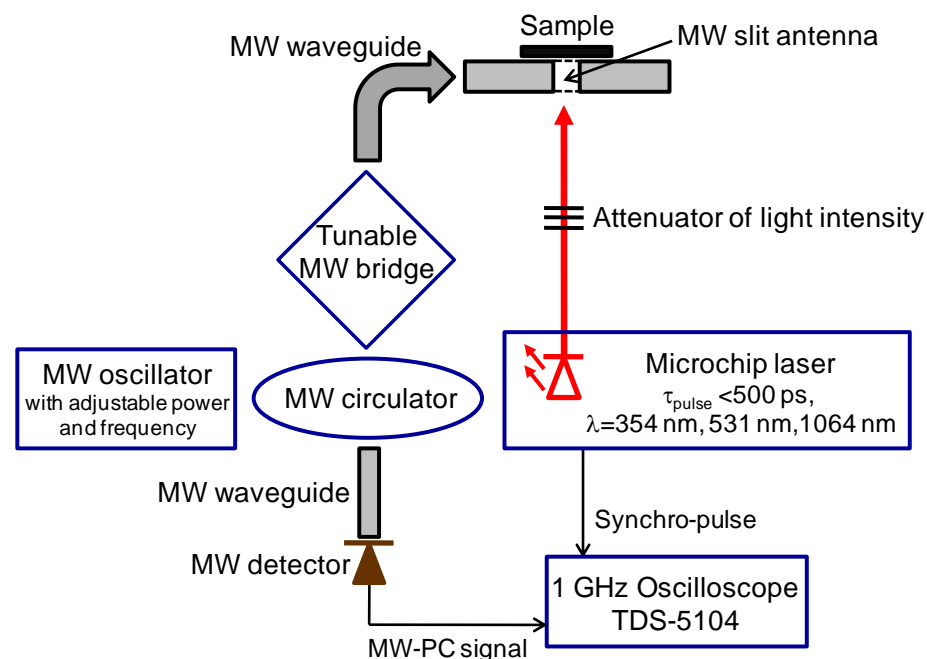
## Objective of investigation

Direct measurements of fluence dependent recombination lifetime in LGAD layered structures.

# Measurement techniques and instruments

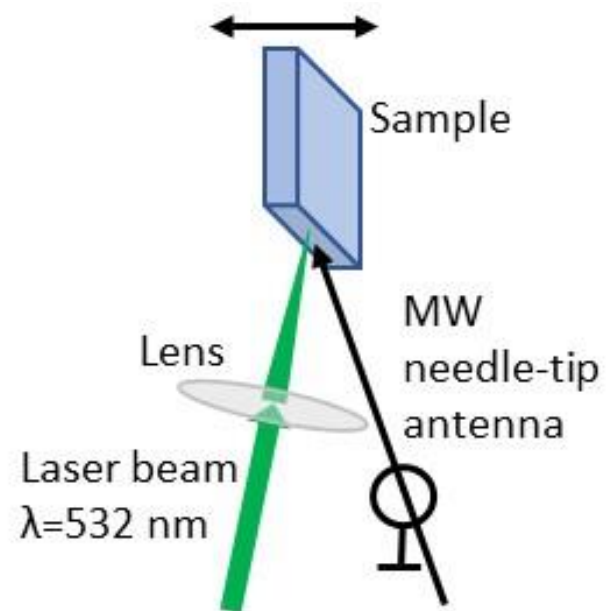
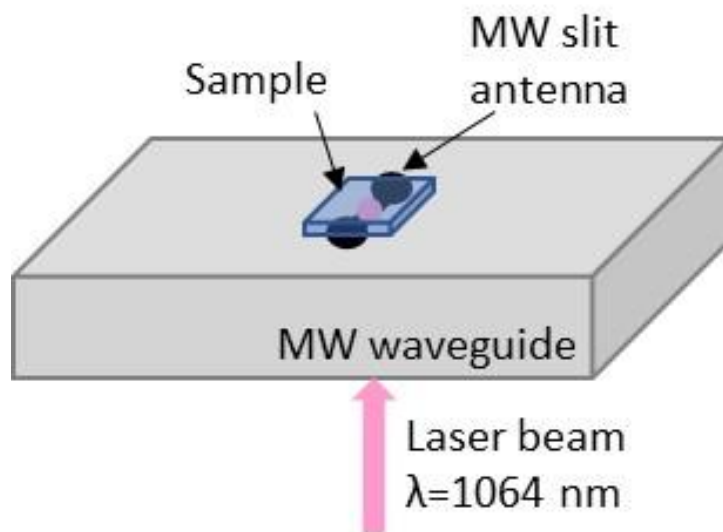


The microwave probed photoconductivity technique is based on the direct measurements of the carrier decay transients by employing MW absorption by excess free carriers.



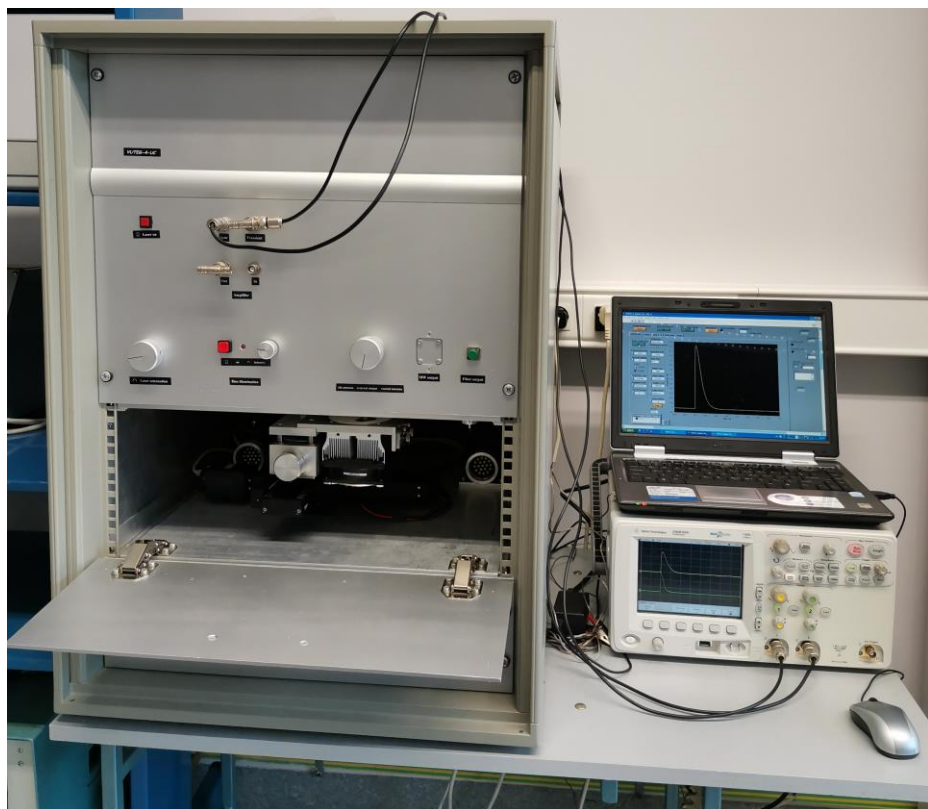
$$\tau_R = n / \left( - \frac{\partial n}{\partial t} \right) \Big|_{\exp(-1)}$$

# Measurement geometries and regimes



Experimental geometries for carrier lifetime measurements using MW slit antenna (left) and for carrier lifetime profiling by edge scanning of microwave probed photoconductivity transients using needle-tip antenna (right).

# Measurement techniques and instruments



Technical capabilities of the instrument VUTEG-4:

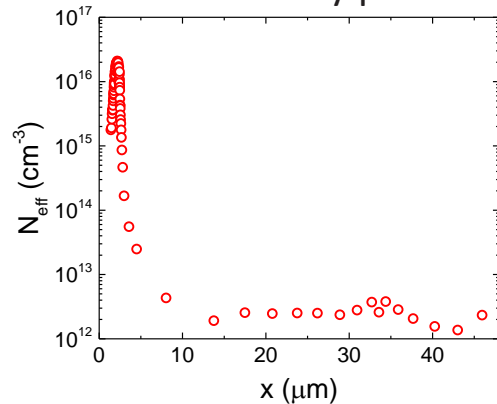
- 2D recombination lifetime scanning of Si wafers of dimensions up to 12 cm in diameter.
- Scan regime of wafer edge is foreseen in this instrument.
- Assurance of the nitrogen gas and temperature stabilized environment during measurements.

Vilnius University proprietary made instrument VUTEG-4.

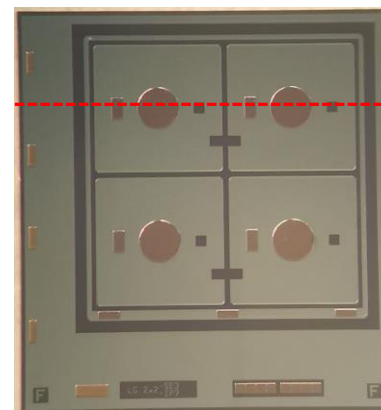
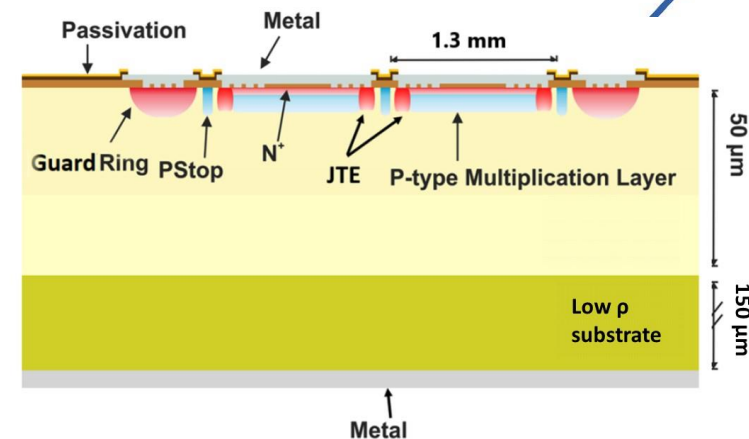
# Samples

LGADs manufactured by Hamamatsu Photonics (HPK) –  
HPK2 run, wafer W31:

- $n^{++}p^{+}pp^{++}$  structure,
- $2 \times 2$  matrix with  $1.3 \times 1.3 \text{ mm}^2$  of area sensors,
- $50 \text{ }\mu\text{m}$  thick active layer,
- $200 \text{ }\mu\text{m}$  total thickness,
- single guard ring,
- irradiated with 23 GeV protons in the range of fluences  $\Phi=10^{12}\text{-}10^{16} \text{ cm}^{-2}$ ,
- cut and boundary polished for profiling of carrier lifetime.

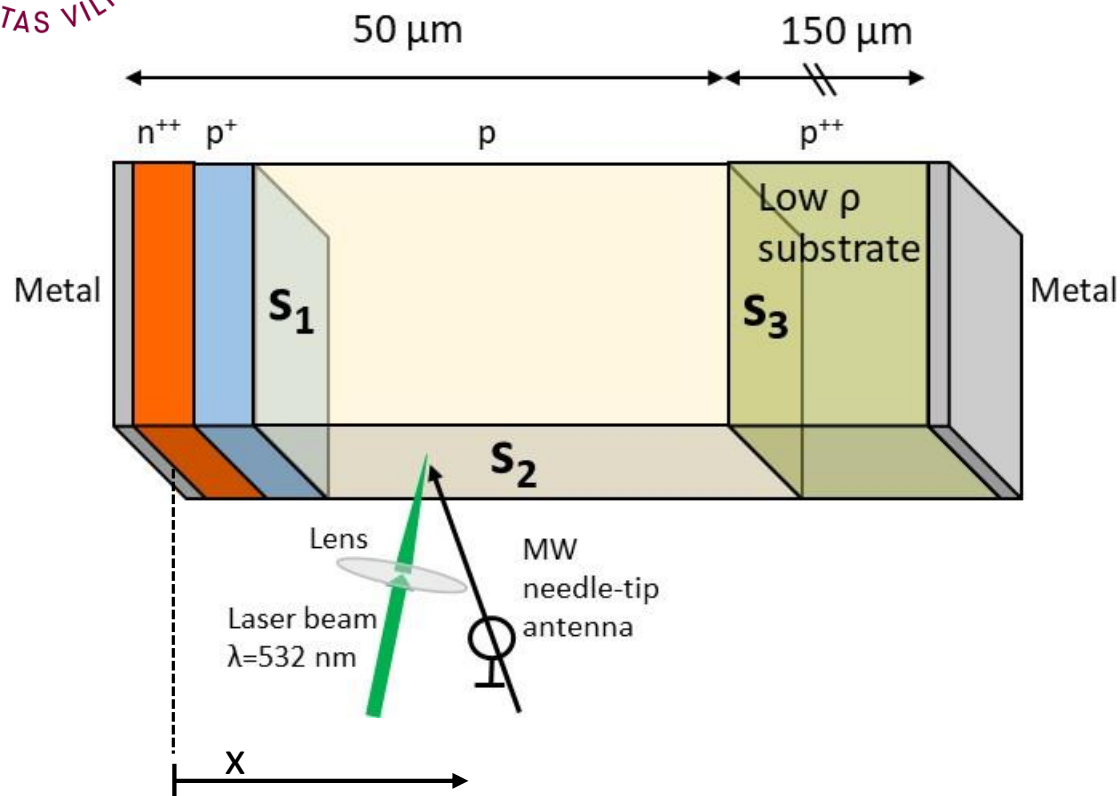


Doping profile of active layer of non-irradiated  
LGAD evaluated from C-V characteristic.



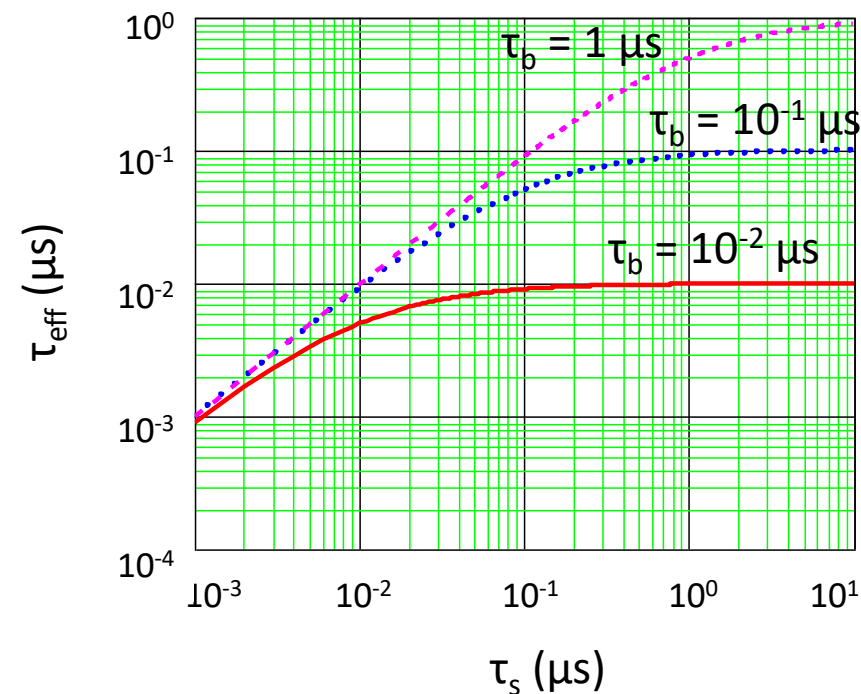
Structure (top figure) and photos of front and backside view (bottom left and right, respectively) of the investigated LGAD structures.

# Influence of surface recombination



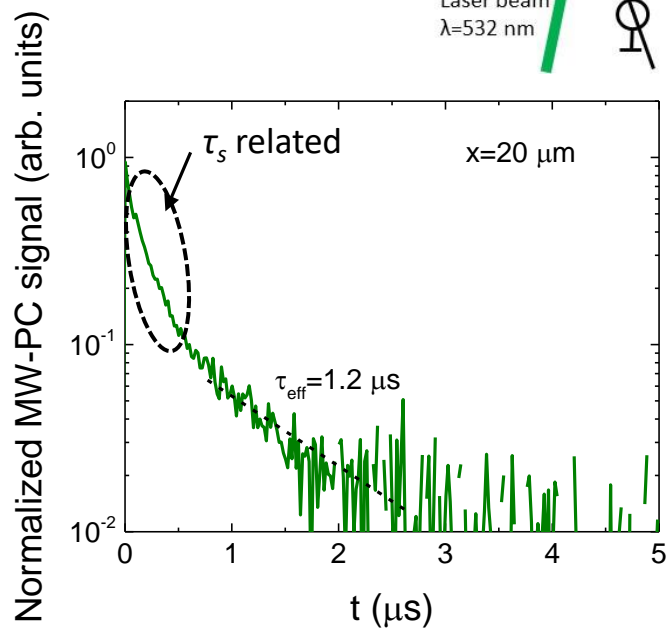
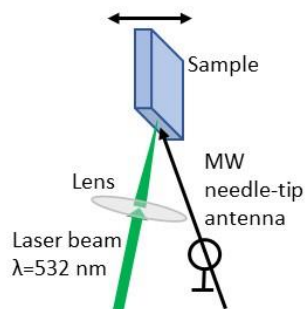
Competition of carrier recombination within bulk and at the sample surfaces  $s$ , affect the shape of recorded MW-PC transients and complicate the extraction of  $\tau_b$ .

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_b} + \frac{1}{\tau_s}$$

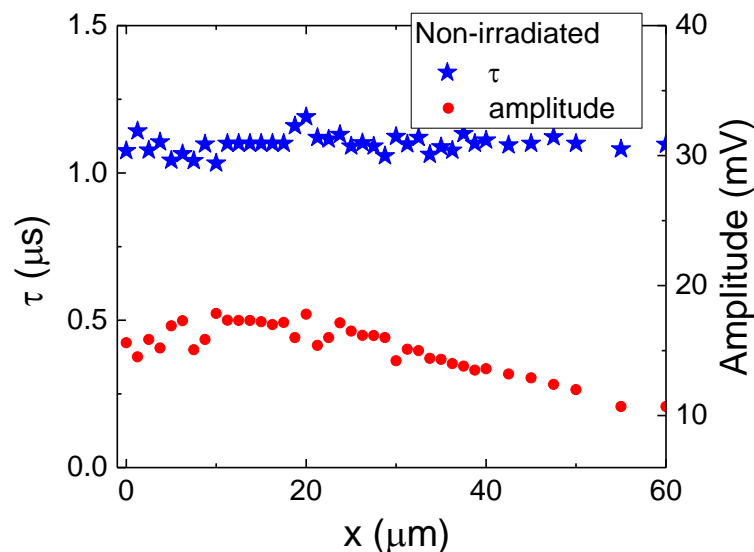




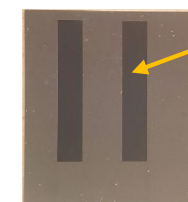
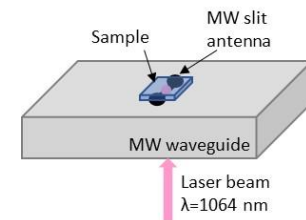
# Profiling of carrier lifetime in non-irradiated LGAD structures



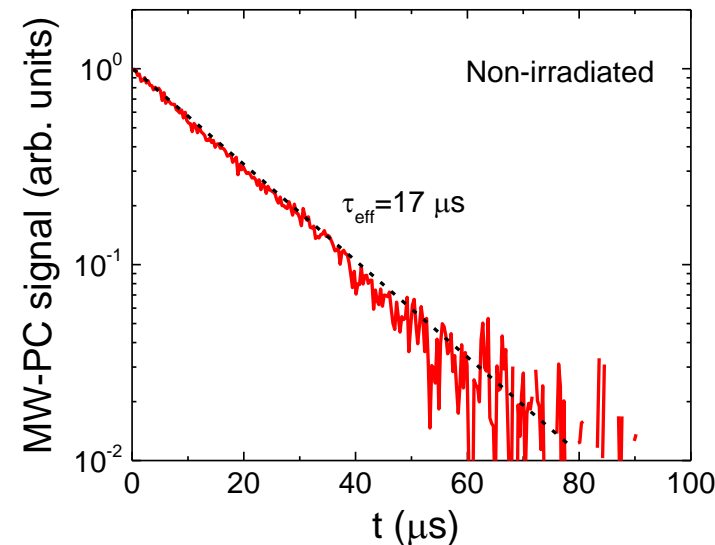
MW-PC transient obtained by edge scanning of boundary of non-irradiated LGAD structure.



Distribution of carrier lifetime and MW-PC signal amplitude obtained during scanning of boundary of non-irradiated LGAD structure.

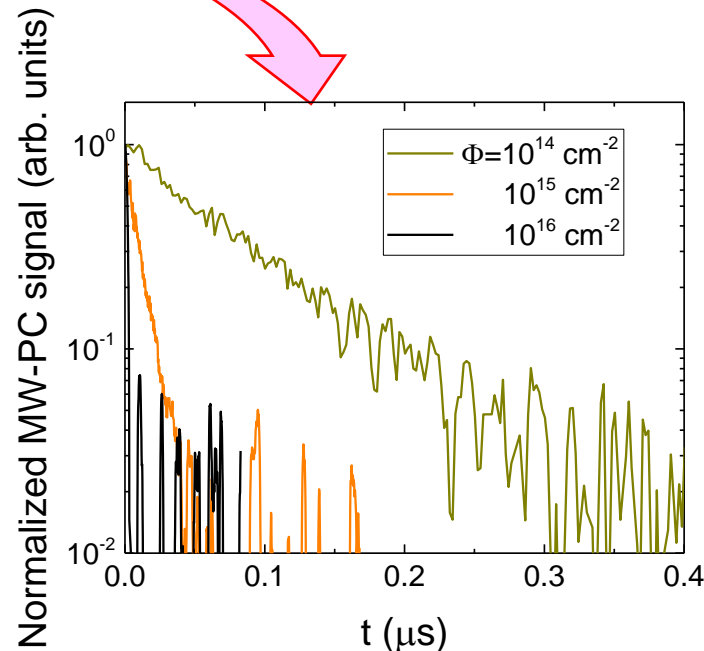
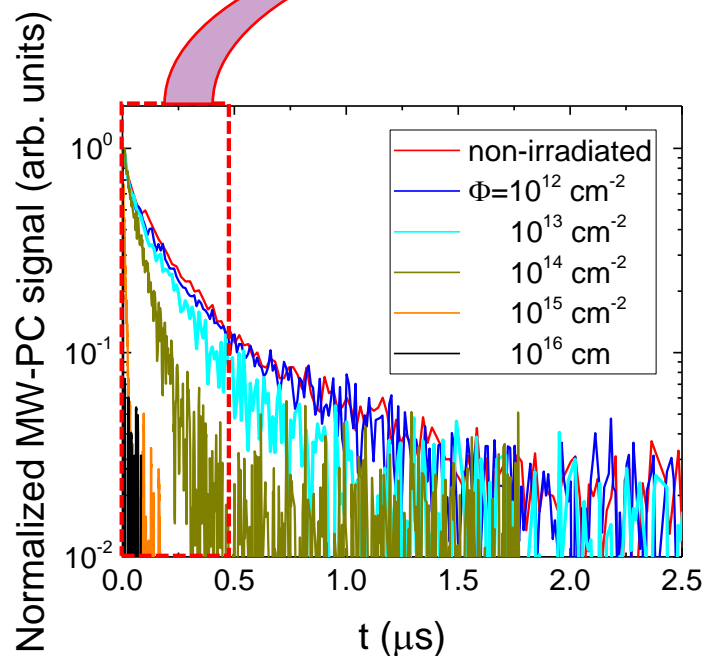


Non-metallized areas used for excess carrier excitation.

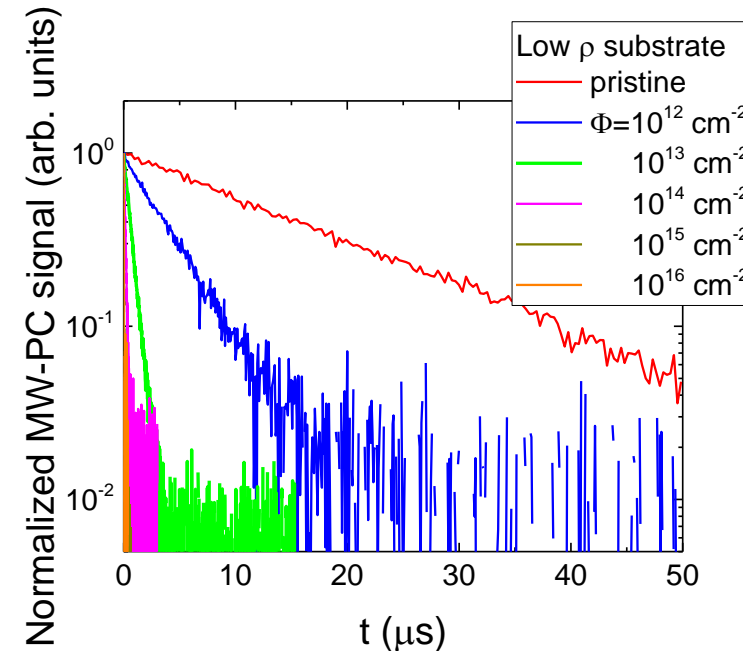


MW-PC transient obtained using bulk excitation of low  $\rho$  substrate.

# Profiling of carrier lifetime in proton irradiated LGAD structures

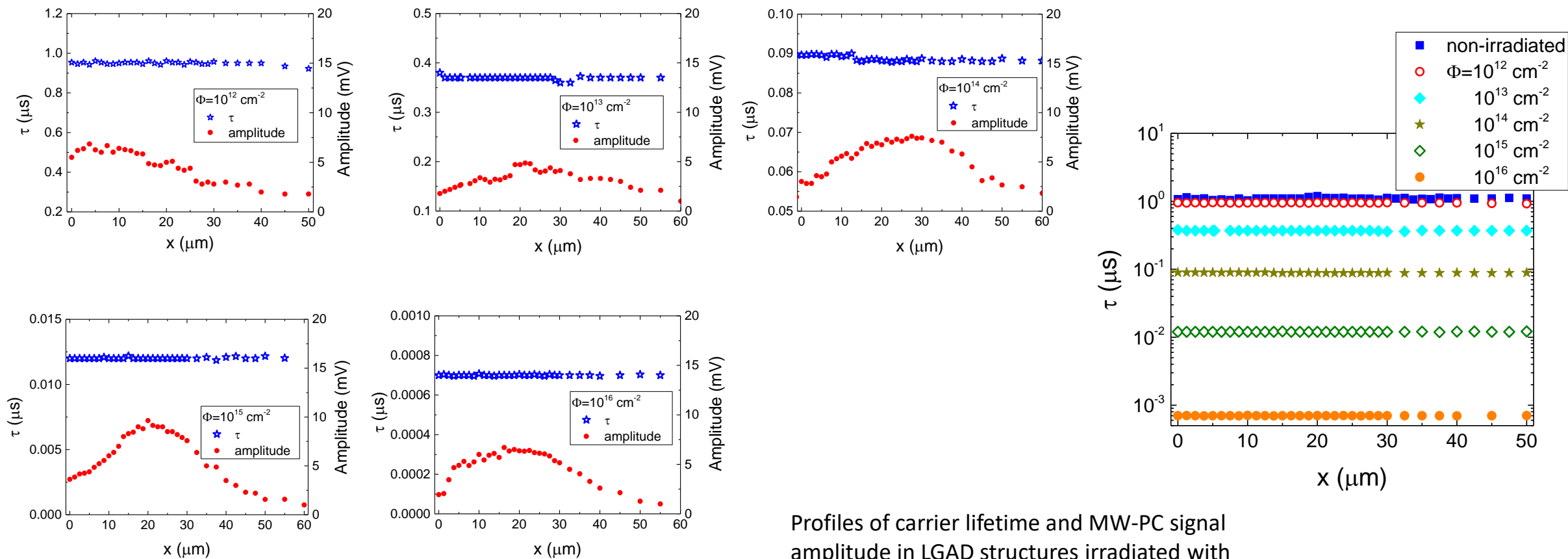


MW-PC transients obtained by edge scanning of the boundary LGAD structures as a function of proton irradiation fluence.



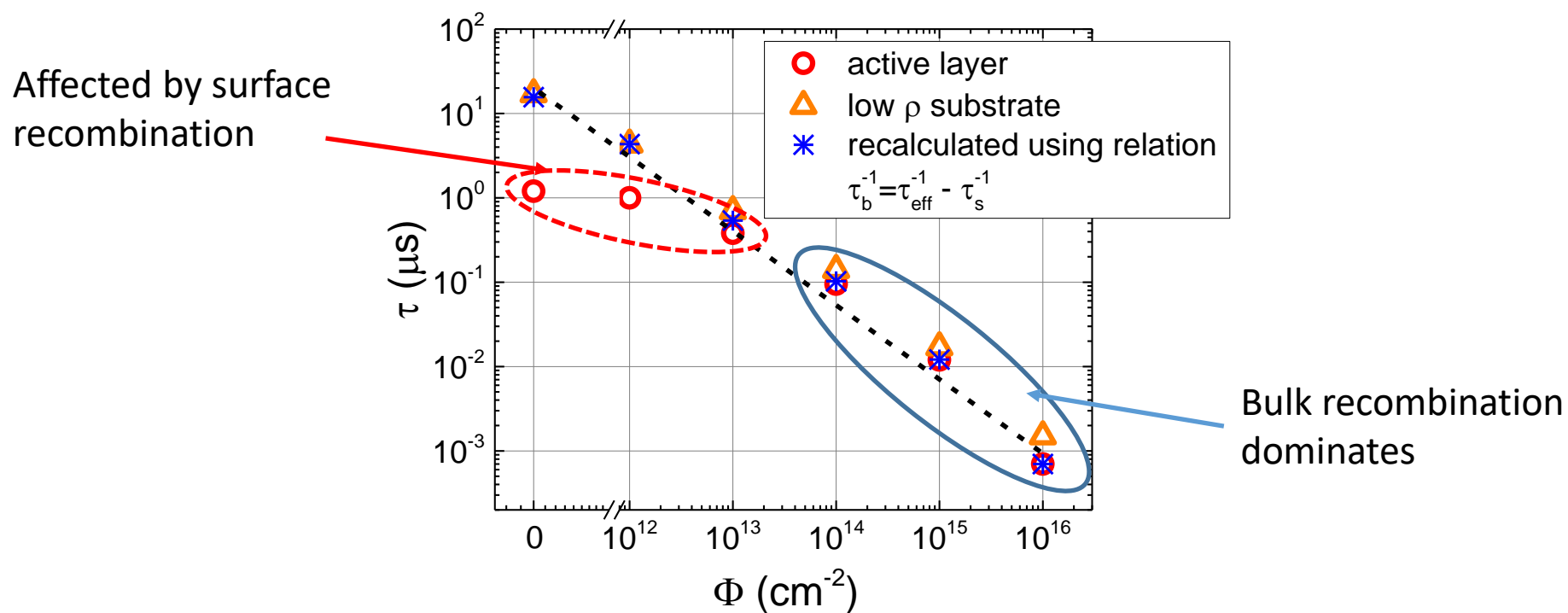
MW-PC transients obtained using bulk excitation of low  $\rho$  substrate as a function of proton irradiation fluence.

# Profiling of carrier lifetime in proton irradiated LGAD structures



Profiles of carrier lifetime and MW-PC signal amplitude in LGAD structures irradiated with protons at different fluences.

# Carrier lifetime variations in proton irradiated LGAD structures



Recombination lifetime as a function of proton irradiation fluence in LGAD structures.

# Conclusions

- ❑ The edge scanning of microwave probed photoconductivity transients can be employed for profiling of carrier lifetime within active region of LGAD structures, although the extraction of carrier lifetime values is complicated due to significant impact of surface recombination at  $\Phi \leq 10^{13} \text{ cm}^{-2}$ . At higher irradiation fluences  $\Phi \geq 10^{14} \text{ cm}^{-2}$  the bulk recombination dominates.
- ❑ Carrier lifetime in low  $\rho$  substrates can be measured using bulk excitation regime and obtaining MW-PC signal by MW slit antenna through non-metallized area within the backside electrode of the LGAD structure.
- ❑ The carrier lifetime profiles, obtained by edge scanning of microwave probed photoconductivity transients, revealed that lifetime values are almost invariable within the depth of LGAD structures due to homogeneous distribution of radiation defects after 23 GeV proton irradiations.
- ❑ Carrier lifetime is inversely proportional to 23 GeV energy protons irradiation fluence in active region and low  $\rho$  substrates of the investigated LGAD structures.

*Thank you for your attention*

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