Particle beam profilers based on fluence dependent variations of carrier lifetime and scintillation intensity in Si and GaN materials

T. Ceponis, L. Deveikis, V. Rumbauskas, and E. Gaubas
Institute of Photonics and Nanotechnology, Vilnius University

M. Moll
CERN

Outline

- Motivation

- Principles of measurement techniques and instruments
  - Scanning of carrier lifetime distribution within irradiated Si wafers
  - Fluence scans using scintillation intensity variations in GaN wafer fragments

- Samples

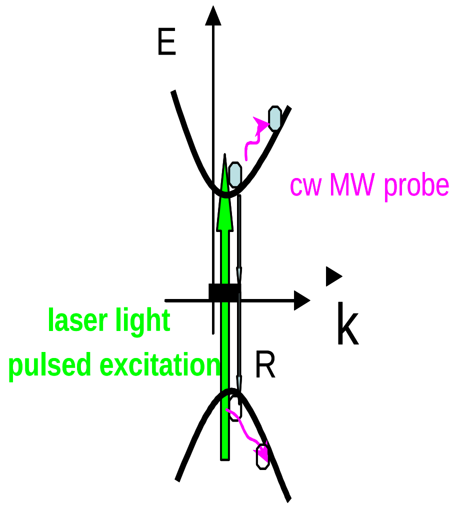
- Recorded profiles of hadron beams
  - Profile of 26 GeV/c proton beam
  - Profile of 8 MeV proton beam
  - Profile of 1.6 MeV proton beam

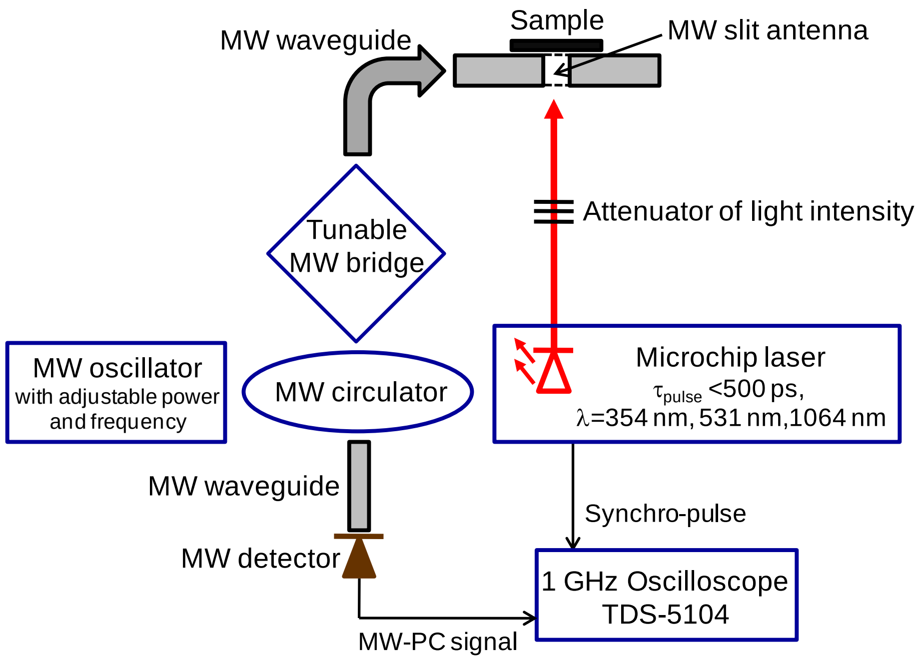
- Conclusions

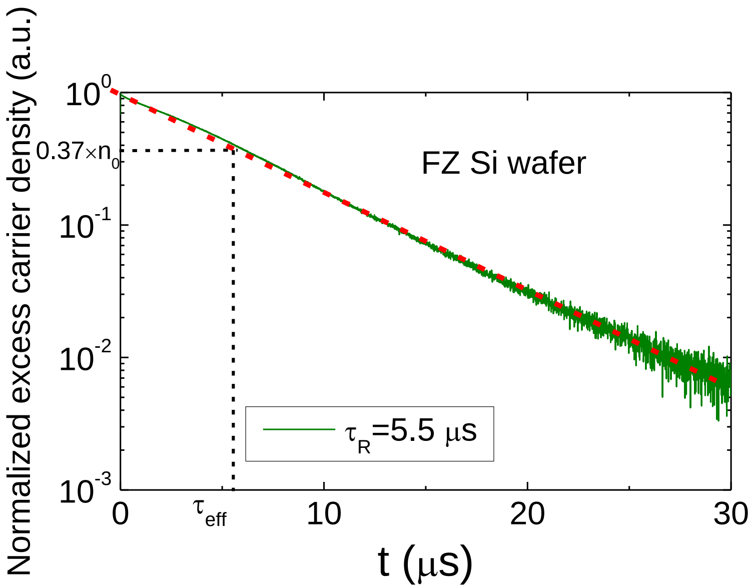
Motivation

- ☐ To develop the particle beam profilers, based on fluence measurements
- ☐ To characterize the proton beams of different energies

Measurement techniques and instruments



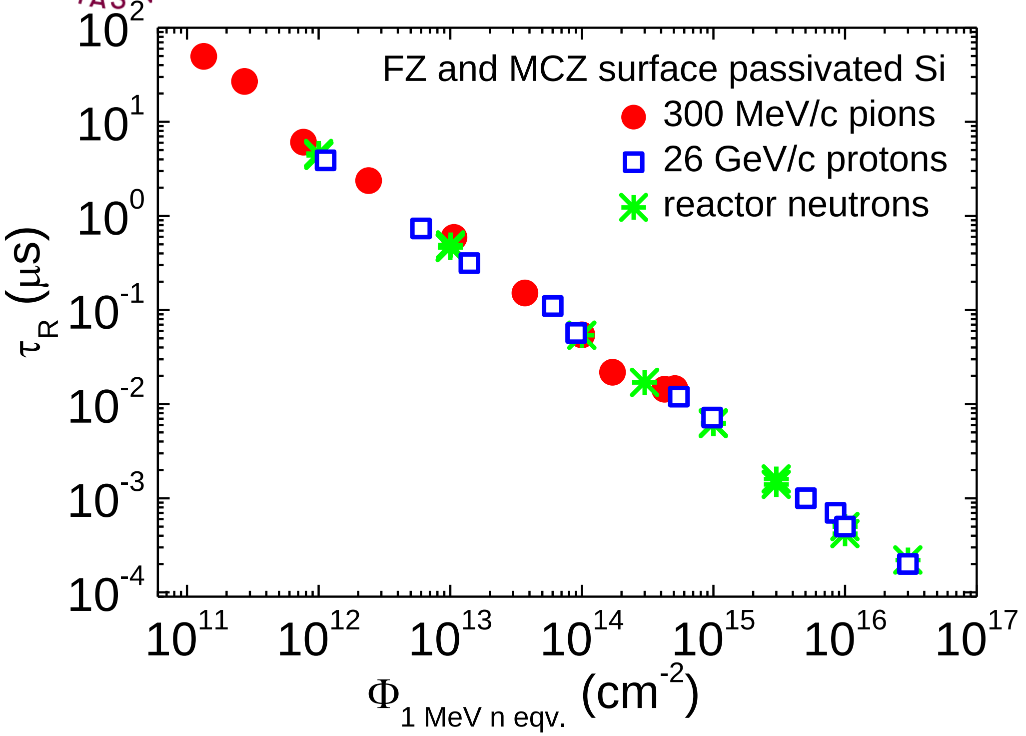




The microwave probed photoconductivity technique is based on the direct measurements of the carrier decay transients by employing MW absorption by excess free carriers.

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

Measurement techniques and instruments



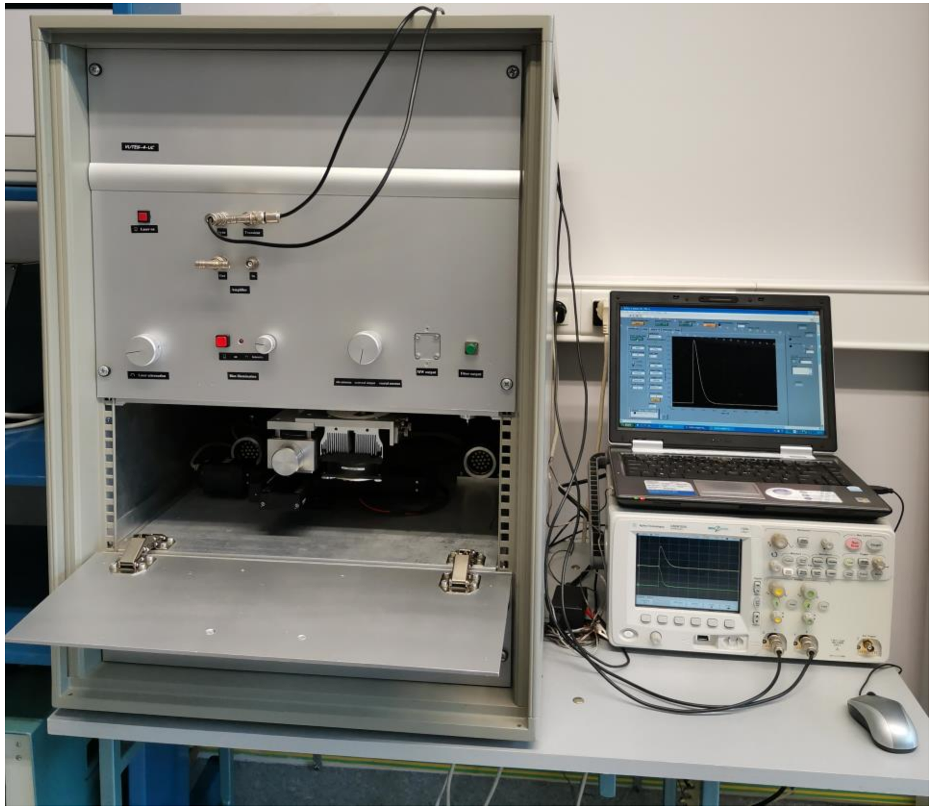
Typical dependence of the recombination lifetime as a function of the penetrative hadron irradiation fluence obtained on high purity (FZ and MCZ) and surface passivated Si wafer fragments irradiated with different particles.

- The reciprocal characteristic of τ_R–Φ is obtained within a double logarithmic scale.

- The linear log τ_R–log Φ characteristic covers about 6 orders of magnitude.

E. Gaubas et al, ECS J. Solid State Sci. Technol. **5**, P3108–P3137 (2016).

Measurement techniques and instruments



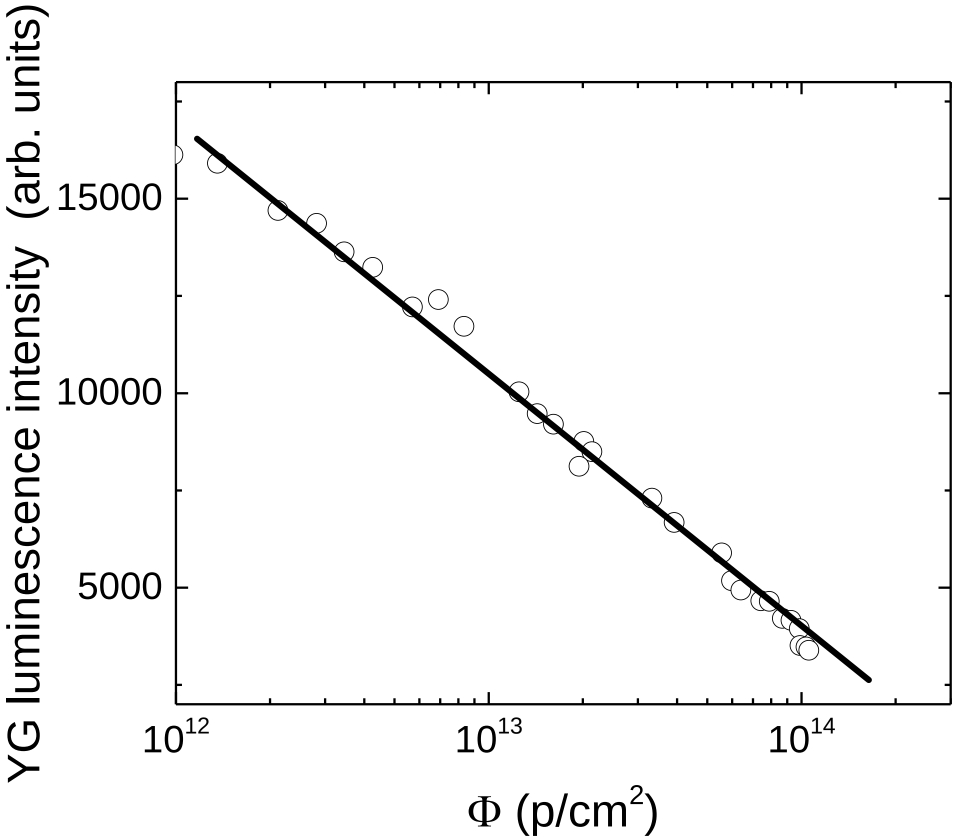
Vilnius University proprietary made instrument VUTEG-4.

Technical capabilities of the instrument VUTEG-4:

- 2D recombination lifetime scanning of Si wafers of dimensions up to 12 cm in diameter.
- The scan regime of wafer edge is foreseen in this instrument, which is implemented using a needle-tip MW antenna probe intersecting with a single mode fibre tip.
- Assurance of the nitrogen gas and temperature stabilized environment during measurements.

- Rather thick (d~300 μm) Si wafers or wafer fragments are usually employed to integrate a response from the relevant density of recombination centres.
- For rather low energy particles with short ranging, the depth inhomogeneity of radiation defect distribution complicates the reliable extraction of local fluence values.

Measurement techniques and instruments

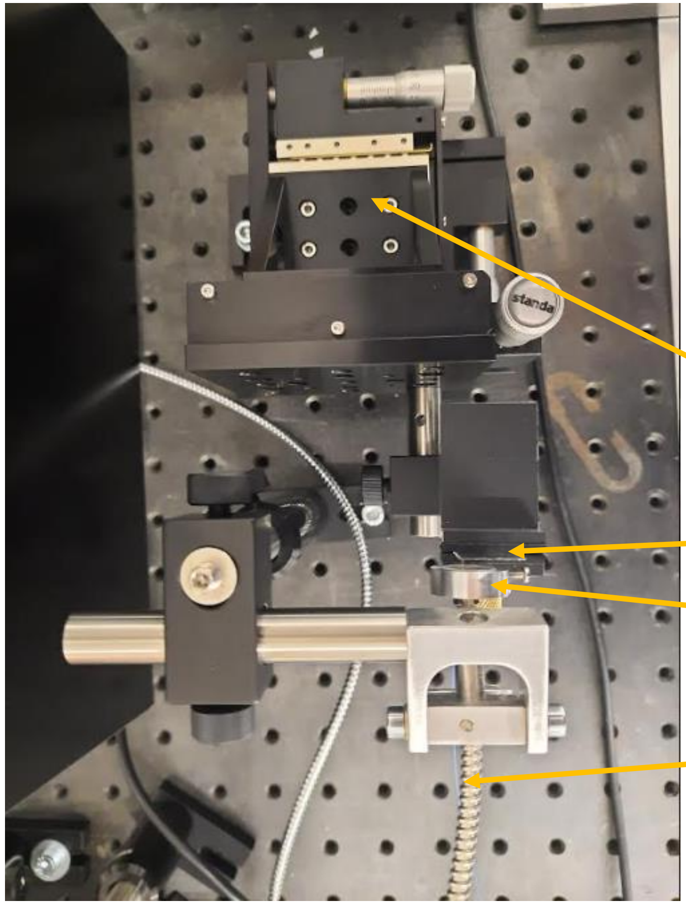


- Scanning of the scintillation signals in rather thin GaN layers, where the depth homogeneous distribution of radiation defects can be obtained, is a good alternative for profiling of the low energy particle beams.

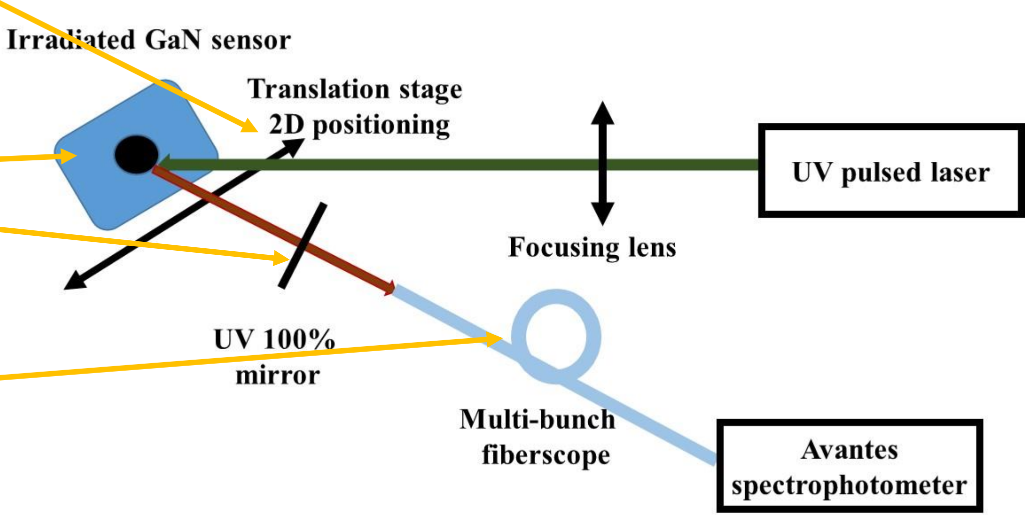
- The calibration characteristic for the short-range (low energy) particle beam profiling is based on YG luminescence intensity variations dependent on 1.6 MeV proton fluence.

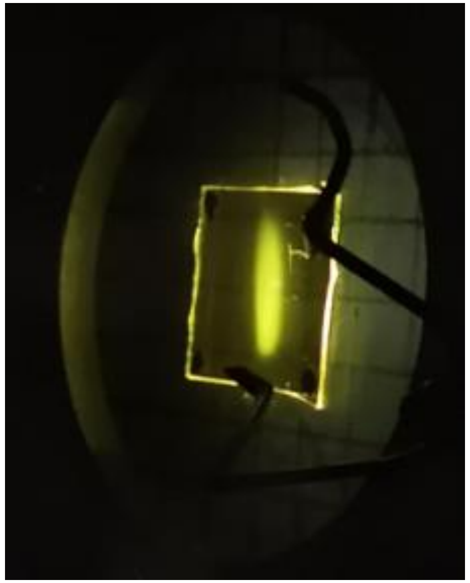
- The measurements of the calibration curve are performed in situ by recording of the GaN luminescence intensity variations under successive accumulation of fluence within a laterally homogeneous irradiation spot.

Measurement techniques and instruments



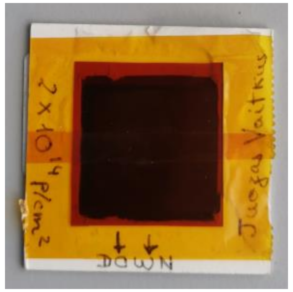
The beam profile is characterized *ex situ* by using UV short pulse (400 ps) laser excitation and monitoring of YG luminescence intensity lateral variations within the GaN sensor.





Samples

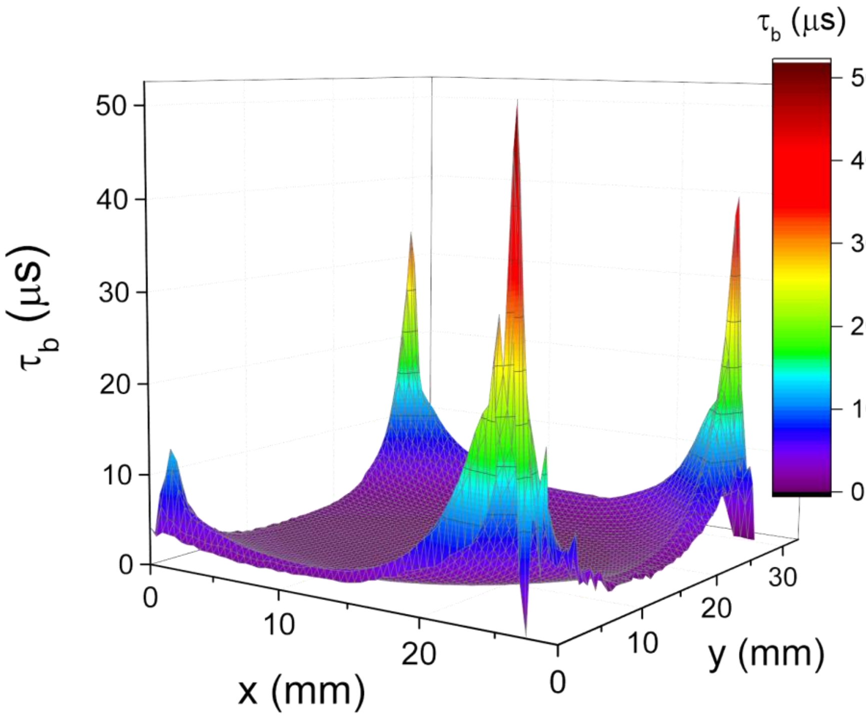
The FZ Si wafer fragments
- surface passivated
- 300 µm thick wafers of dimensions 30 × 30 mm^2
- irradiated with 26 GeV/c protons

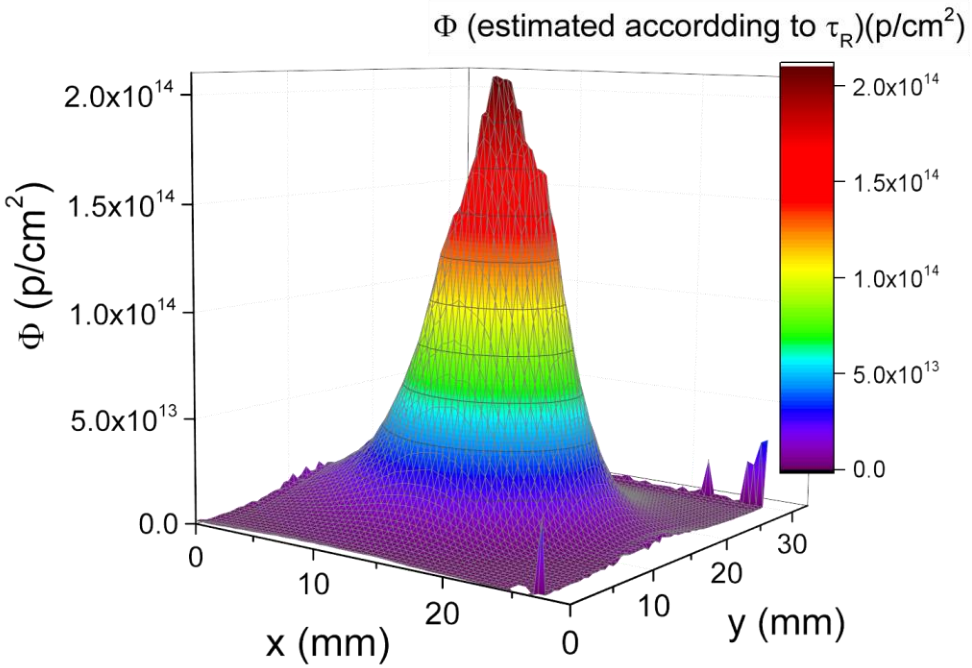


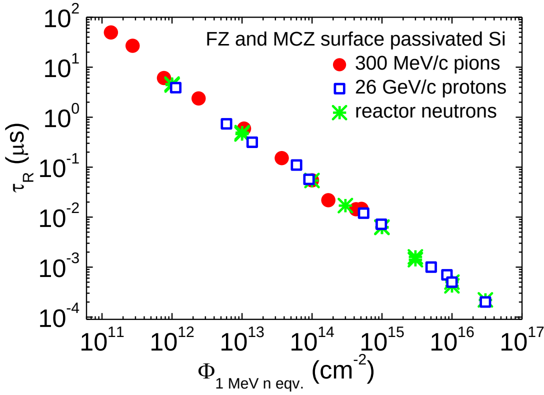
MCZ Si wafer fragment
- surface passivated
- 300 µm thick wafers of dimensions 20 × 10 mm^2
- irradiated with 8 MeV protons

MOCVD grown GaN layers
- ~3 μm thick layers of dimensions 20 × 20 mm^2 grown on sapphire substrates
- irradiated with 1.6 MeV protons

Recorded profiles of 26 GeV/c proton beam

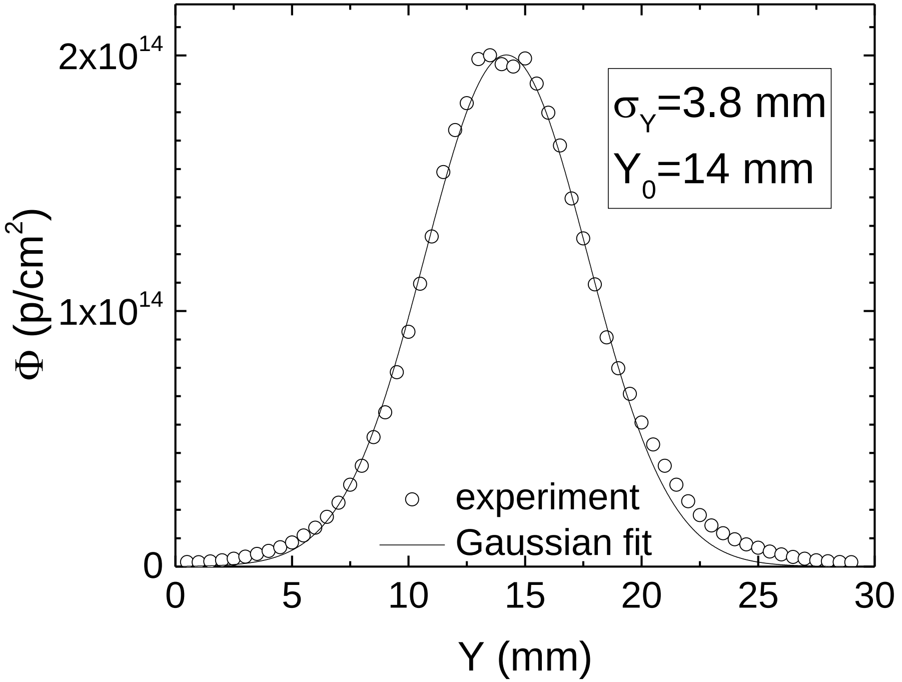






Recorded profiles of 26 GeV/c proton beam

1D fluence distribution profile within 26 GeV/c protons irradiated Si



The profiles of fluence variations crossing the beam centroid are fitted using 1D Gauss function:

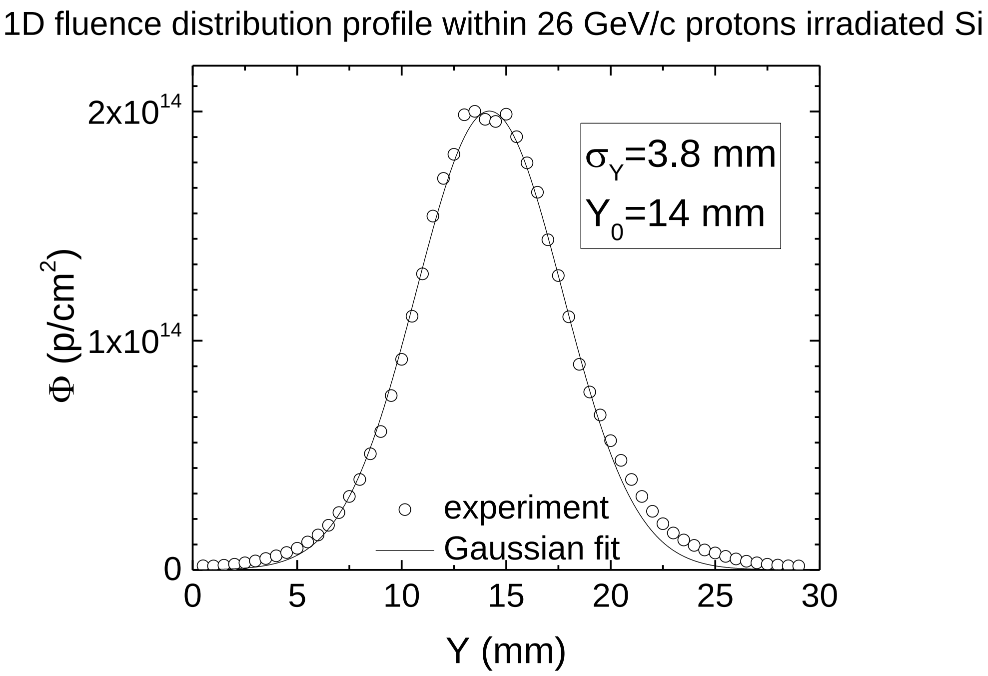
$$\Phi(Y) = \frac{N}{\sigma_Y\sqrt{2\pi}}\exp\left[-\frac{(Y-Y_0)^2}{2\sigma_Y^2}\right]$$

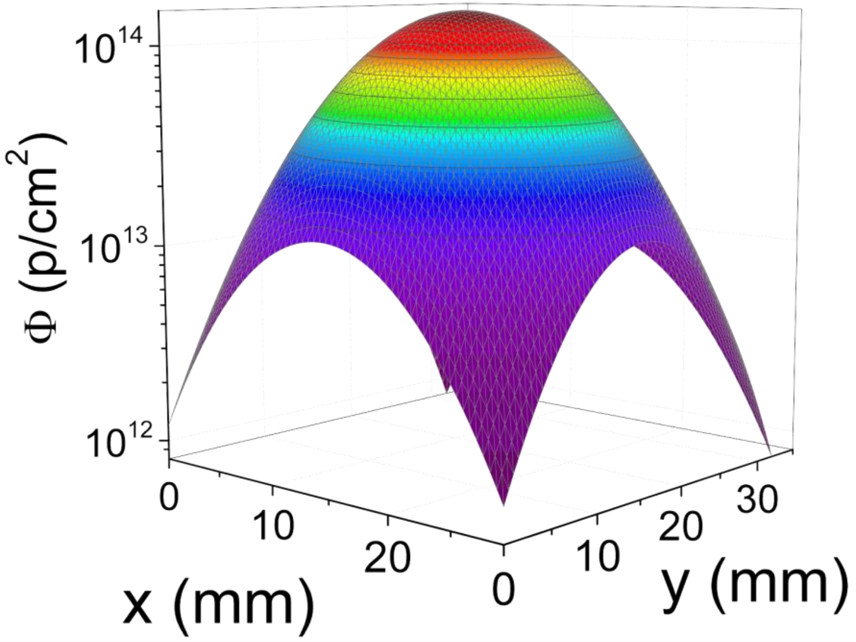
$$FWHM_{X,Y} = 2.35\cdot\sigma_{X,Y}$$

Recorded profiles of 26 GeV/c proton beam

VUTEG-4 scanner

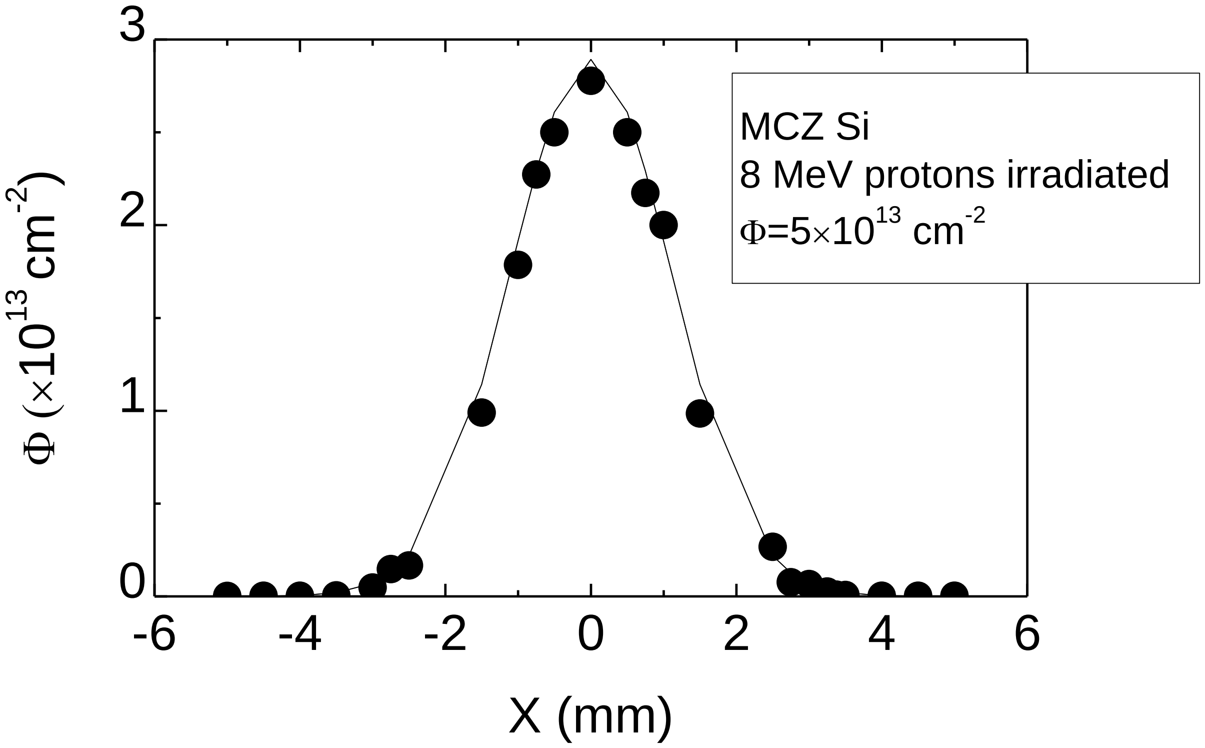
Standard beam profiler





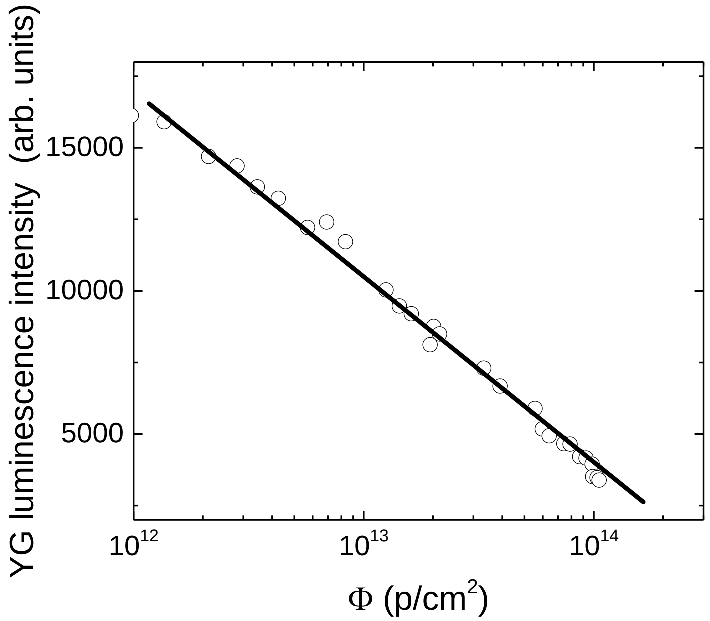
- Values of 2 × 10^{14} cm^{-2} fluence in the beam centre were obtained using both instruments, the VUTEG-4 and standard beam profile monitor.
- Close values of beam profile fitting parameters were obtained by both techniques.

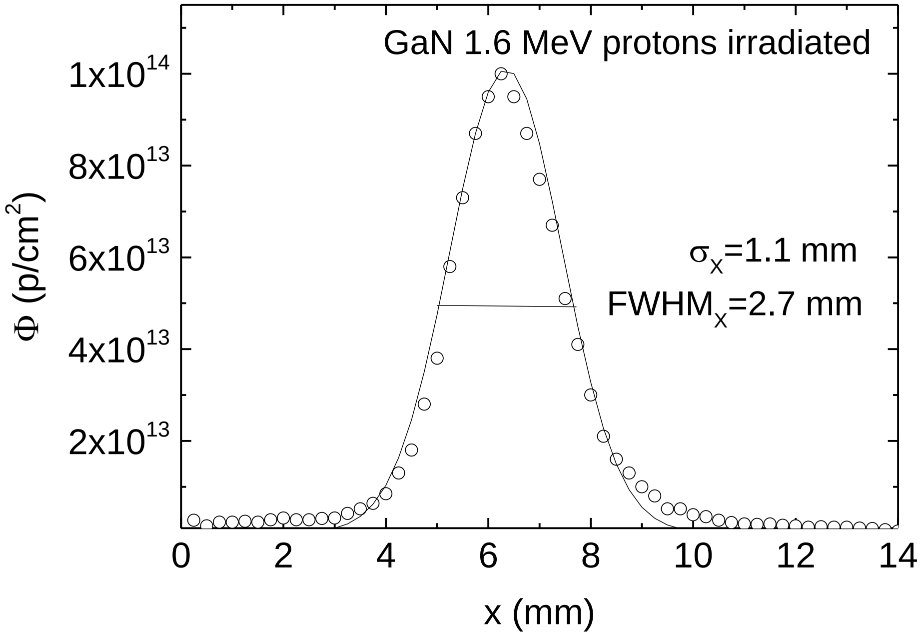
Recorded profile of 8 MeV proton beam

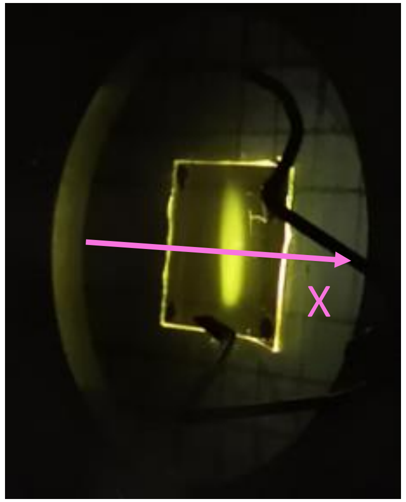


- Penetrative particles for Si wafer of 300 µm thickness - depth-homogeneous introduction of radiation defects.
- The beam is close to the Gaussian shape.

Recorded profile of 1.6 MeV proton beam







- Penetrative particles for GaN wafer fragments of 3 µm thickness - depth-homogeneous introduction of radiation defects.
- The rather symmetric X-directional cross-section has been revealed.

Conclusions

- ☐ The beam profiling techniques based on dosimetry of the hadron irradiated Si and GaN sensors have been demonstrated.

- ☐ Penetrative particle regime should be employed to record fluence distribution profiles.

- ☐ For beams of rather low energy particles, sensors with thin active layers are preferable. Then, the scintillation techniques are eligible to have recordable responses from thin sensor layers.

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Thank you for your attention