Trento Institute for
Fundamental Physics
and Applications

UNIVERSITY OF TRENTO - Italy
Department of Industrial Engineering

Quantum dots imaging tests on SPAD for nanodosimetric applications

L. Pancheri, A. Ficorella, M. Dalla Palma, A. Quaranta,
G.F. Dalla Betta, M. Durante

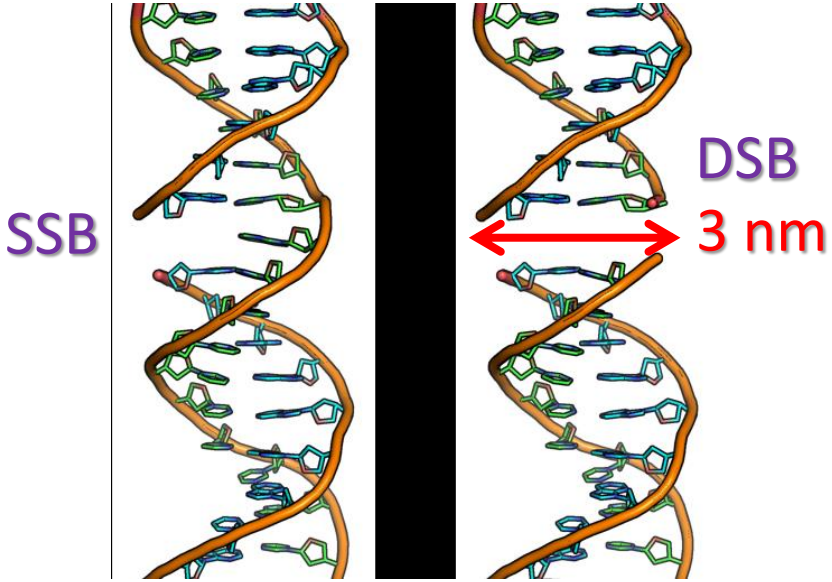
INFN, Trento Institute for Fundamental Physics and Applications (TIFPA)
University of Trento, Department of Industrial Engineering

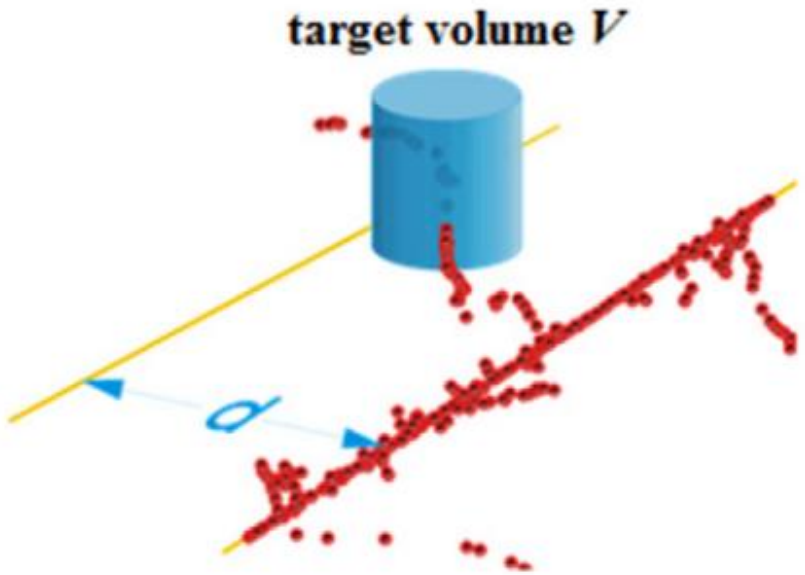
NADIR Collaboration

Biologically relevant
NA*no****D****osimetry for* ***I****onizing* ***R****adiation*

- Principal Investigator: Valeria Conte (INFN-LNL).
- TIFPA Investigator: Alberto Quaranta.
- INFN-LNS Investigator: Pablo Cirrone.
- INFN-Mi Investigator: Stefano Agosteo.

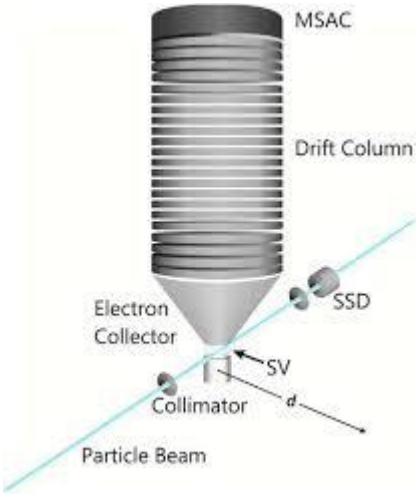
Nanodosimetry

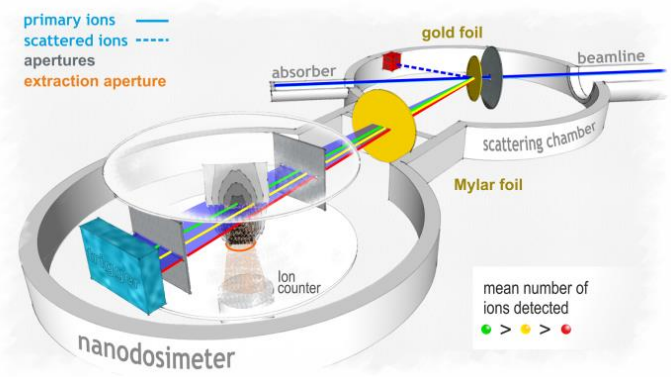


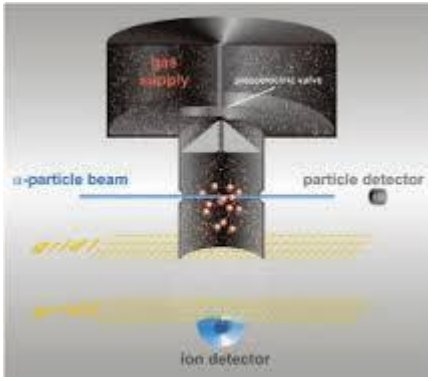


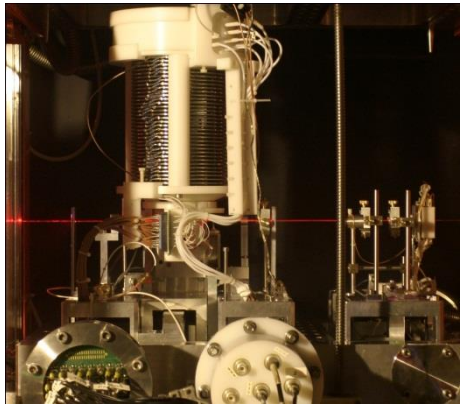
- In hadron therapy the radiobiological effectiveness is determined by the number of ionizations occurring within few nm.
- Ionizations are produced by stochastic interactions and secondary electrons defining the track structure.
- The aim of nanodosimetry is to measure the number of ionizations produced in DNA (equivalent) volumes.

Track ionizations measurements









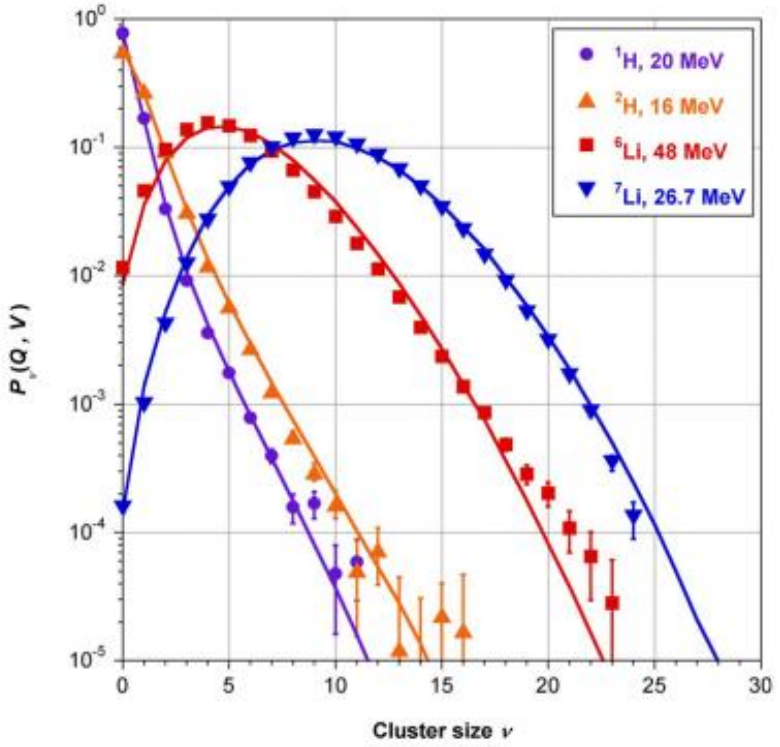
ION COUNTER

JET COUNTER

STARTRACK

Track ionizations measurements

- The ionization cluster size can be accurately measured for different ions.
- The aim is to find a parameter describing the radiobiological effectiveness.

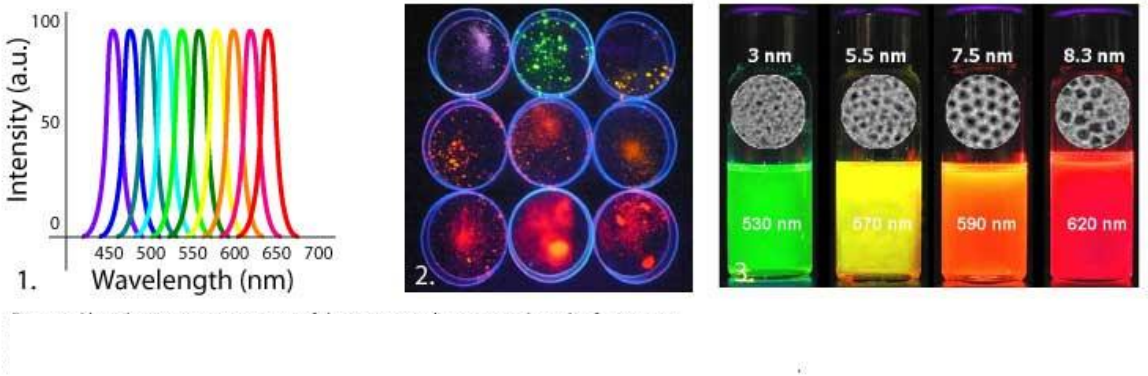


$$F_n = \sum_{\nu=n}^{\infty} P_\nu$$

Cumulative Probability

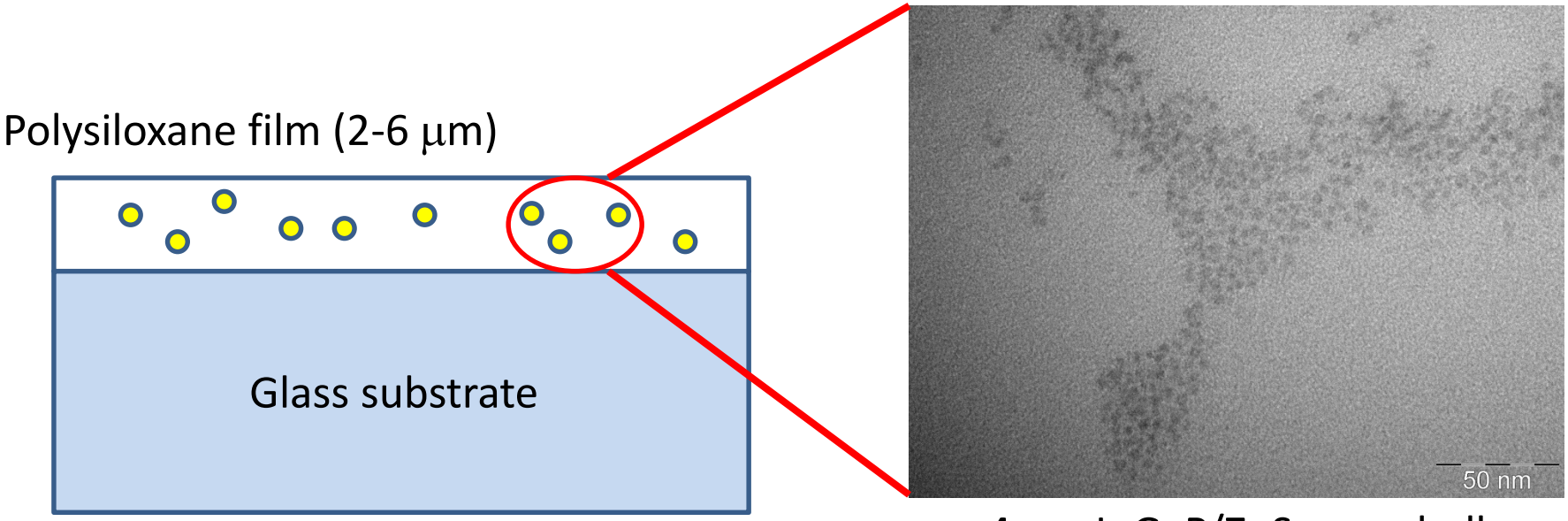
- There are indications that F_2 and F_3 could be used as radiobiological effectiveness parameters.

Portable nanodosimeter



- Need of a portable system for practical nano-dose evauation.
- Luminescent QD are good candidates as nanometric targets.
- Tests with low LET (gamma, electrons) are available.
- Test with swift heavy ions are available (QD demolition).
- Medium LET tests are needed with radiotherapy ion beams.
- Proof of concept for the realization of a QD based nanodosimeter.

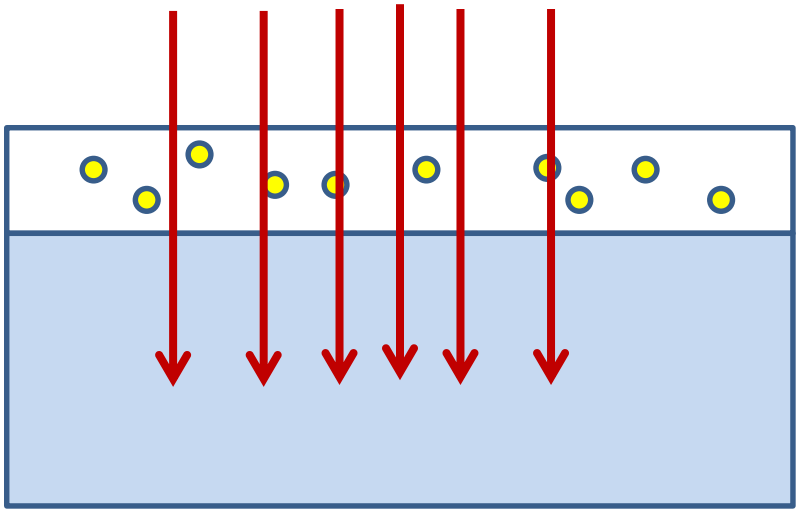
QD sample



4 nm InGaP/ZnS core shell
Evident Technologies

- $n \sim 3 \times 10^{17} \ \ QD/cm^3$
- $N \sim 10^{14} \ \ QD/cm^2$
- $r = 2\ nm \ \rightarrow \sigma \sim 5 \times 10^{-13}\ cm^2$

Ion Irradiation

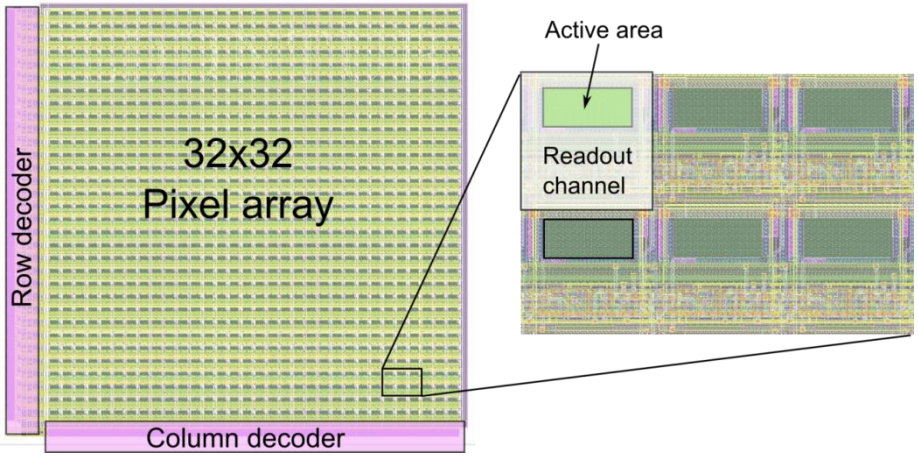


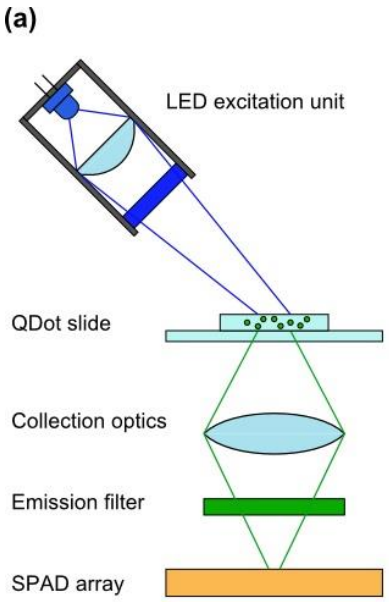
- H^+ 2 MeV – 0.5 μA/cm^2
- dE/dx = 15 eV/nm
- Φ = 5x10^{13}, 10^{14}, 10^{15}, 5x10^{15} H^+/cm^2

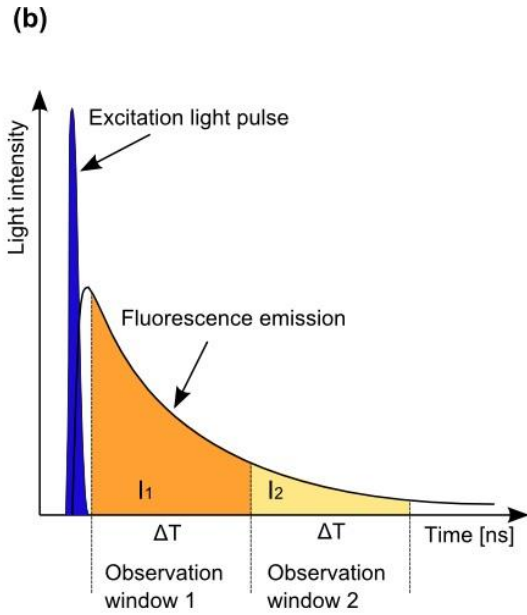
Preliminary Imaging Tests

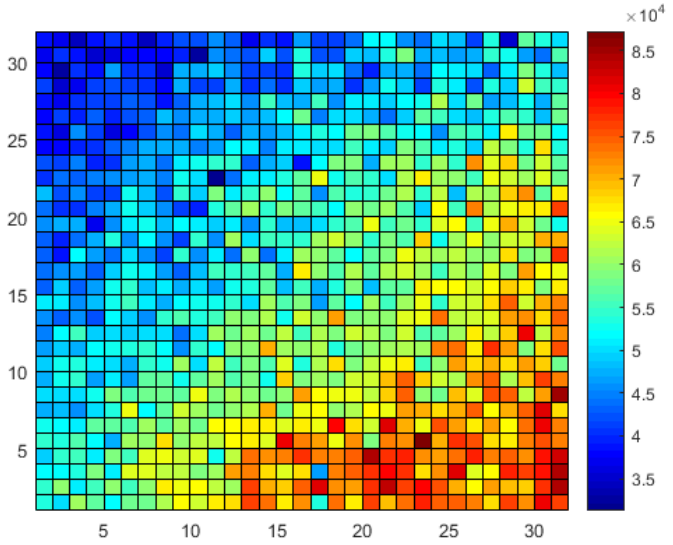
Array size: 0.8 x 0.8 mm

Pixel pitch: 25um
Fill factor: 20.8%









- Single Photon Avalance Diode (SPAD) allows imaging, intensity and lifetime measurements.
- Portable systems can be realized.

Optical Measurements

Fluorescence Spectroscopy

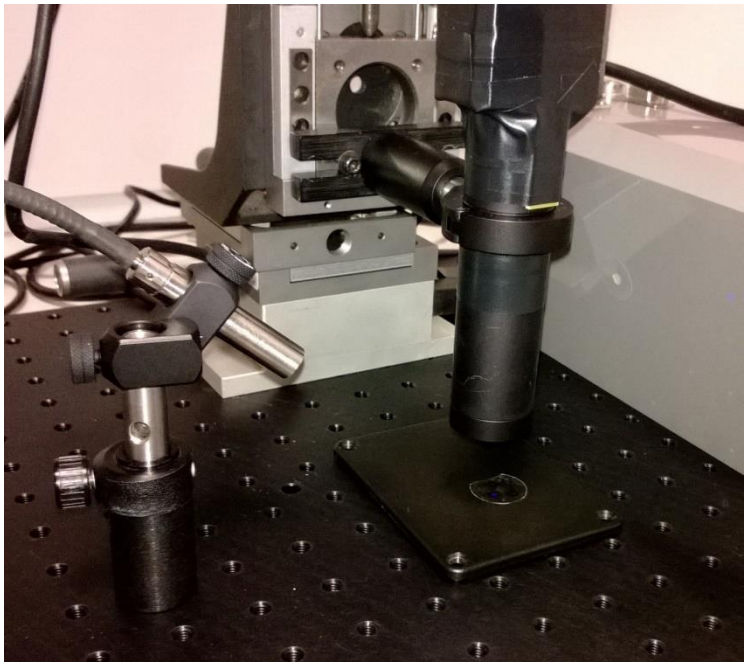
Spectrofluorimeter Jasco FP6300

λ_{ex} = 470 nm

Xe Lamp 150 W

$\Delta\lambda$ = 5 nm

Time Correlated Single Photon Counting



Laser
λ 470 nm
Width 30 ps
Freq. 2.5 MHz

TCSPC Counter
Windows 16 ps
Int. Time 10 s

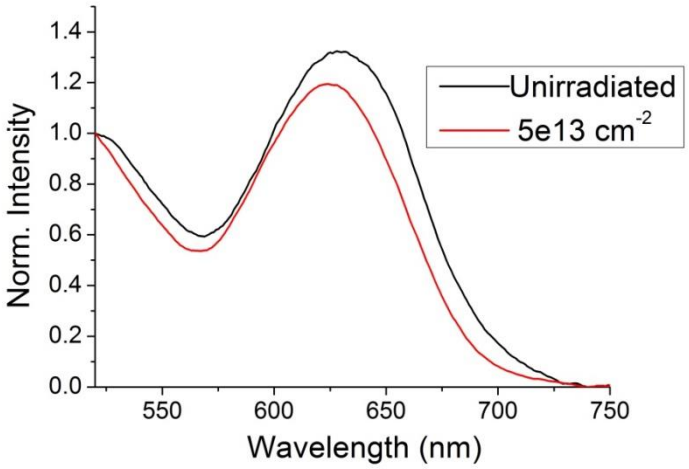
3D Stage

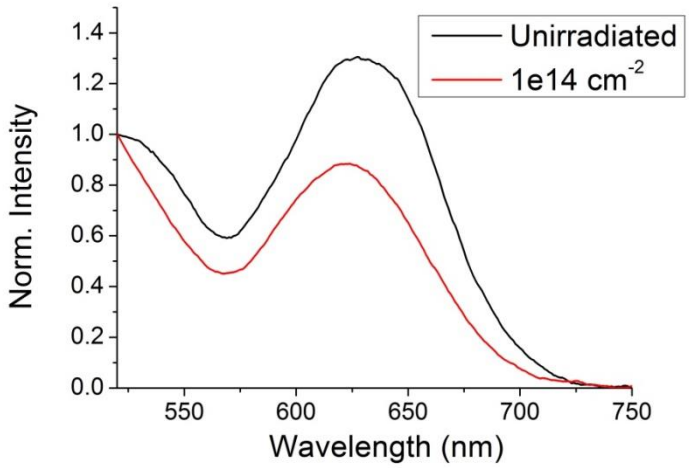
Filter
HP 500 nm

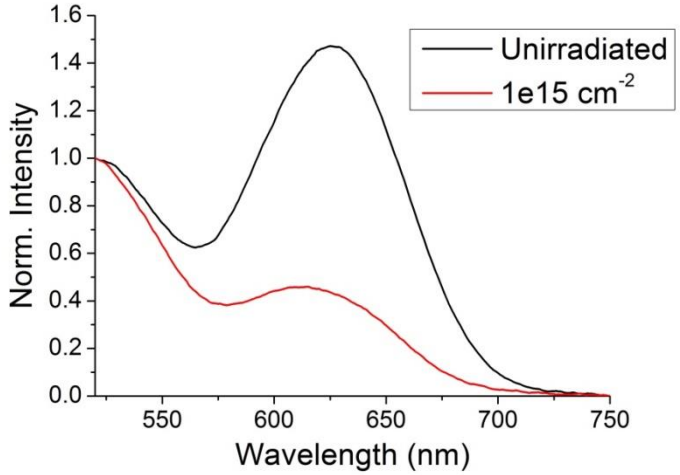
PMT

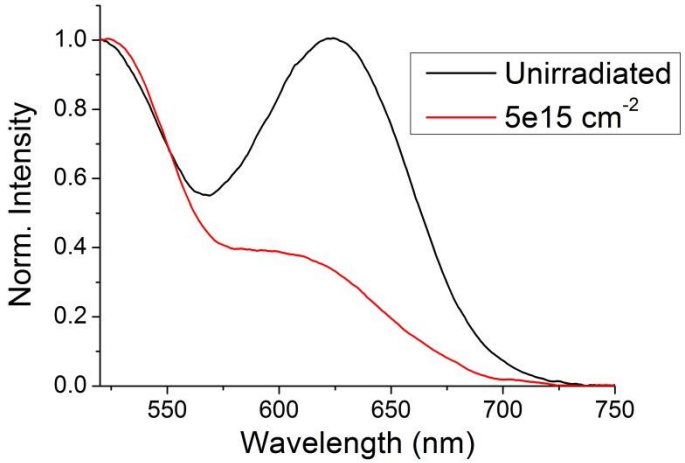
Pulse inverter

Luminescence Spectra



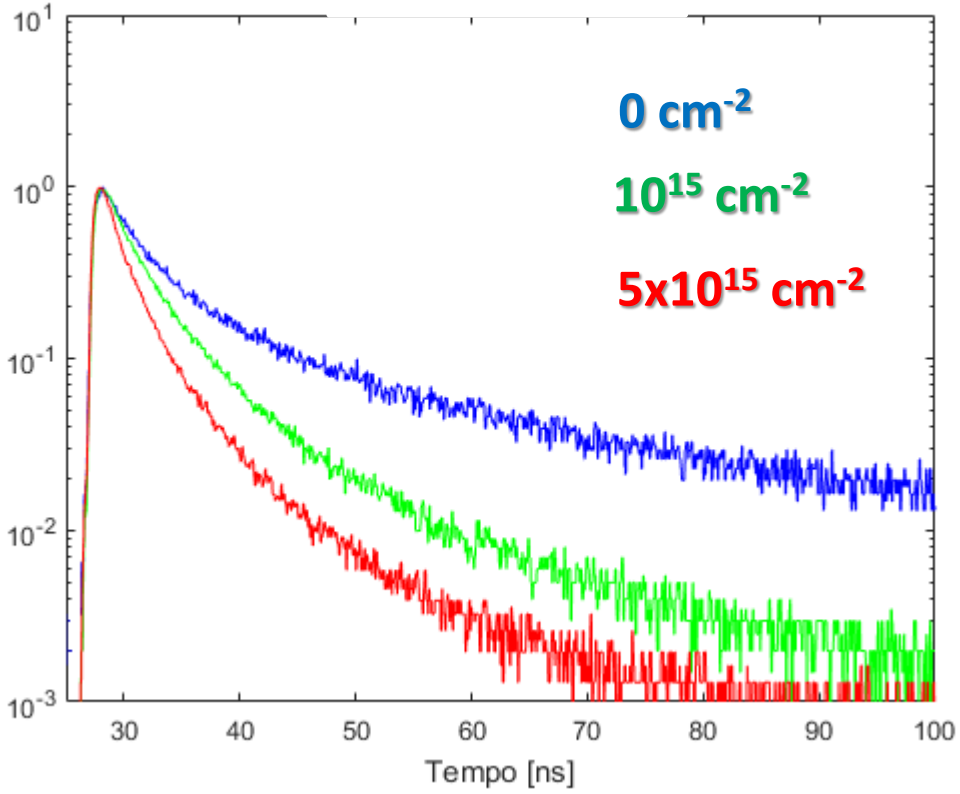






Shift of peak maximum to lower λ (surface effects on QDs).
Lowering of peak intensity (surface quenching centres).

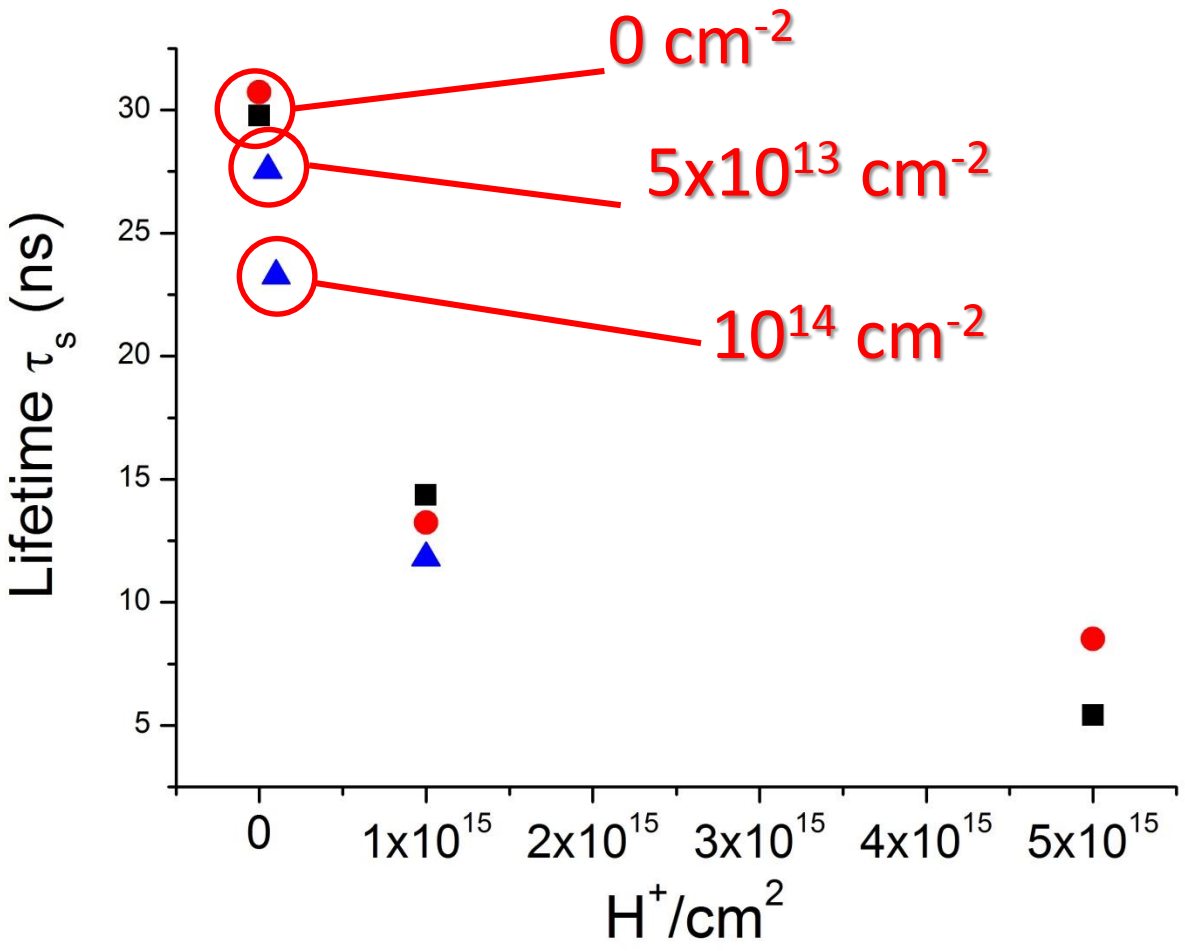
Lifetime Measurements



$$I(t) = A_f exp\left(-t/\tau_f\right) + A_s exp(-t/\tau_s)$$

Fast component τ_f from the glass background.
Slow component τ_s from QDs

Lifetime Measurements



Exponential lowering of the QD component with the fluence.
Increasing of quenching centres concentration.

Conclusions

- SPAD detectors can be used for the realization of portable nano-dosimetric systems.
- Luminescent QDs can be used as probes for the evaluation of the dose within nanometric volumes
- Both luminescence yield and lifetime can be used as parameters for measuring the nanodose.

Work in Progress

- Different QD compositions, substrates, embedding media.
- Parameter to take into account: luminescence yield, radiation hardness.
- The defect formation mechanisms in QD at medium LETs are still unknown.
- Monte Carlo codes for analyzing the interactions with QDs.
- Calibration protocols have to been established with the aim of systems for the ion track characterization.

Thank you for your attention