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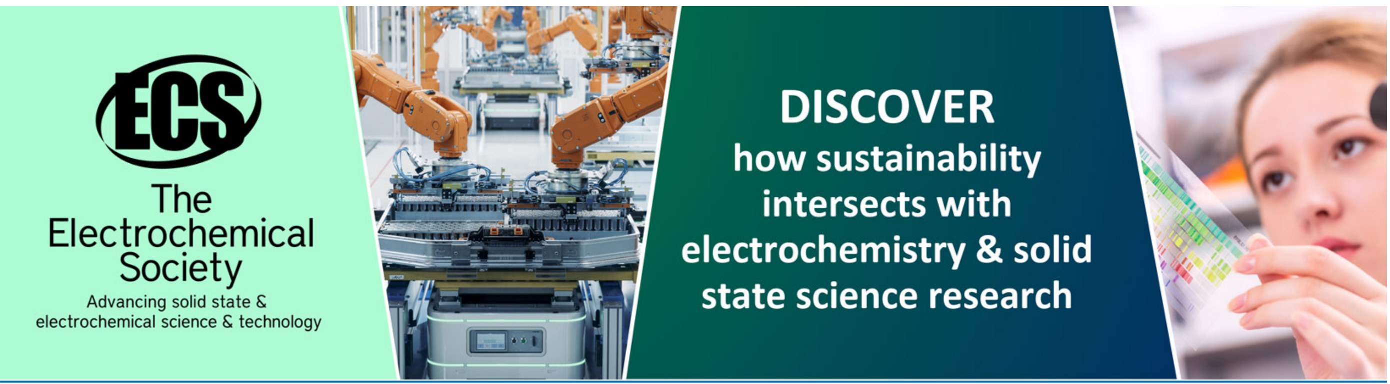

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An Avalanche confinement TEPC as connecting bridge from micro to nanodosimetry

D. Mazzucconi[1,2], D. Bortot[1,2], A. Pola[1,2], S. Agosteo[1,2], A.Selva[3], P.Colautti[3], V. Conte[3]
[1]Istituto Nazionale di Fisica Nucleare INFN, Sezione di Milano, via Celoria 16, Milano, Italy
[2]Politecnico di Milano, Dipartimento di Energia, via La Masa 34, Milano, Italy
[3]Istituto Nazionale di Fisica Nucleare INFN, Laboratori Nazionali di Legnaro, viale dell'Università 2, Legnaro (Padova), Italy

E-mail: valeria.conte@lnl.infn.it

Abstract. It is recognized today that the observable radiobiological effects of ionizing radiations are strongly correlated to the clustering of damages in micrometer- and nanometer-sized subcellular structures, hence to the particle track structure. The characteristic properties of track structure are directly measurable nowadays with bulky experimental apparatuses, which cannot be easily operated in a clinical environment. It is therefore interesting to investigate the feasibility of new portable detectors able to characterize the real therapeutic beams. With this in mind, a novel avalanche-confinement Tissue Equivalent Proportional Counter (TEPC) was constructed for simulating nanometric sites down to 25 nm. Experimental cluster size distributions measured with this TEPC were compared with Monte Carlo simulations of the same experiment and with cluster size distributions measured with the Startrack nanodosimeter.

1. Introduction

The observable radiobiological effects of ionizing radiations are strongly correlated to the clustering of damages in micrometer- and nanometer-sized subcellular structures, hence to the particle track structure [1, 2]. The characteristic properties of track structure are directly measurable nowadays with bulky experimental apparatuses [3], which are not easily transportable and are not suited for the clinical environment. It is therefore the aim of the present work to investigate the feasibility of new portable detectors able to characterize real therapeutic beams. With this in mind, a novel avalanche-confinement Tissue Equivalent Proportional Counter (TEPC) was constructed to simulate biological target sites of size down to 25 nm. Being a proportional counter, the stochastic of the output signal is the product in convolution of the stochastics of the interaction with the stochastics of the gas gain, which increases the variance of the detected signals. The shape of the pulse height distribution measured at 25 nm simulated site-size was studied, in order to understand if the information on relevant stochastic quantities describing the interaction of ionizing radiation with matter is preserved.

2. Material and methods

An avalanche confinement TEPC (AC-TEPC) has been developed and constructed at the Legnaro National Laboratories of the Italian Institute of Nuclear Physics (LNL-INFN), which can simulate site sizes from 0.5 μm to 25 nm [4]. The sensitive volume is a cylinder with equal diameter and height of

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13 mm. A gold-plated tungsten helix 6 mm in diameter wraps 19 coils around the anode, made of a 1 mm graphite rod. When set at the proper potential, the helix forces the electronic avalanche inside the inner volume, thus reducing the variance of the gas gain in dependence of the position of the primary particle interaction. Figure 1 shows a picture of some parts of the detector, during the assembling procedure. In order to analyse the response of the AC-TEPC and the influence of the gas-gain variance, pairwise measurements were performed in the Startrack apparatus of LNL, with the Startrack nanodosimeter [5] and with the AC- TEPC. Figure 2 shows a picture of the experimental setup, with the Startrack counter and the new AC-TEPC aligned on the Tandem accelerator beam line, for first inter-comparison of cluster size distributions measured simultaneously with the two detectors.

In this experimental work both detectors were fluxed with pure propane gas, at pressures of 300 Pa for the nanodosimeter and 105 Pa for the AC-TEPC, corresponding to masses per area of approximately 2.0 and 2.5 μg/cm^2 respectively, that is 20 and 25 nm when scaled at unit density. Measurements were performed with alpha particles from a ^{244}Cm-alpha source. The experimental data were analysed in terms of ionisation cluster size distributions $P(\nu)$, representing the probability of measuring a number ν of ionizations in the sensitive volume. Distributions measured with the AC-TEPC were also compared with Monte Carlo track-structure simulations. The Monte Carlo code has been developed by B. Grosswendt to simulate the ionization component of the tracks of light ions penetrating thin propane layers of small mass per area [6, 7]; here, the simulation was performed modelling the detector and the irradiation geometry.

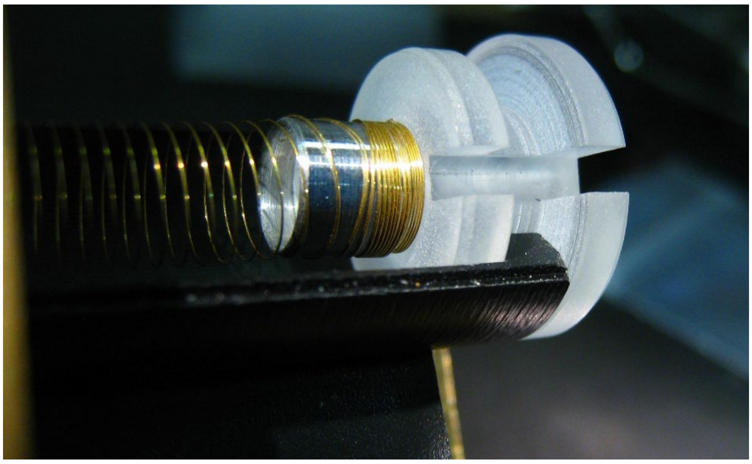

Figure 1. - A detail of the avalanche confinement TEPC. The gold-plated tungsten helix, 6 mm in diameter, and the Rexolite cap with the 1 mm slit for the passage of accelerated light ions or alpha particles from an external source.

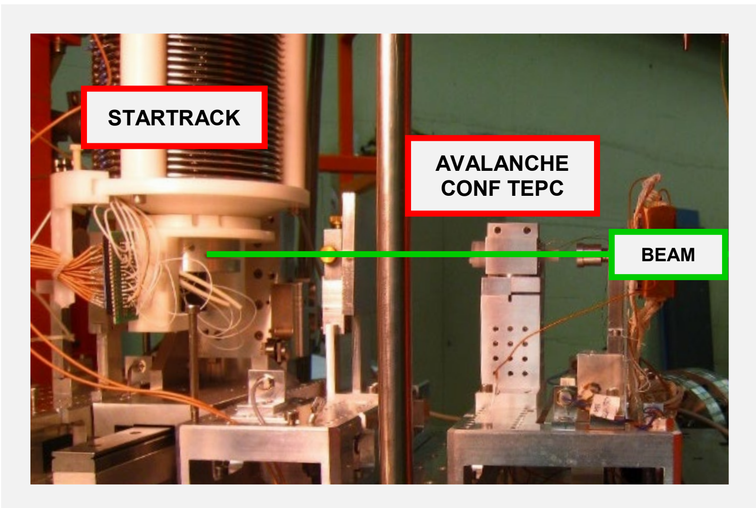

Figure 2. - A picture of the measuring set-up: the primary particle impinges on both detectors, the Startrack counter and the avalanche-confinement TEPC, for first systematic microdosimetry and nanodosimetry comparison.

3. Results

Figure 3 shows the comparison of measured and simulated cluster size distributions *P(ν)*, and it highlights a very good agreement. The mean value M_1 and the variance of the measured and simulated distributions were also derived, obtaining $(M_1)_{exp} = 70$ and $(M_1)_{sim} = 71$, $(VAR)_{exp} = 210$ and $(VAR)_{sim} = 209$.

Considered that simulations were performed in a cylindrical sensitive volume of uniform efficiency 100%, whereas in the experimental case the pulse height results as the product of the initial number of ionizations and the gas gain multiplying factor, the good agreement between measurements and simulations suggests a minor influence of the gas gain variance on the measured cluster size distributions.

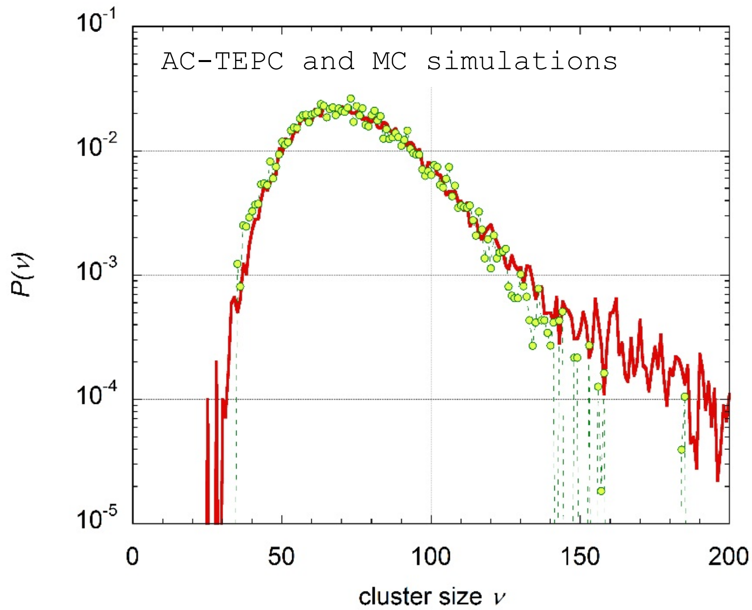

Figure 3. - The cluster size probability *P(ν)* measured with the avalanche-confinement TEPC at 25 nm (symbols connected by a slash line), and the corresponding results of Monte Carlo simulations (continuous line).

In order to study the possibility to use the AC-TEPC measurements to derive relevant information on the particle track structure at the nanometer level, the cluster size probability measured with the AC-TEPC and shown in Figure 3 was compared with the corresponding cluster size distribution (central passage of ^{244}Cm alpha particles) measured with the Startrack nanodosimeter, which is shown as symbols in Figure 4. Whilst the site sizes of the two detectors differ only by about 20 %, it can be observed that the distribution measured with Startrack shifts to much lower cluster size values, resulting in a mean cluster size $M_1 = 8.1$. In order to analyse correctly the shape of the two measured distributions, it must be taken into account that the Startrack nanodosimeter is characterized by a reduced detection efficiency, which decreases moving from the centre of the sensitive volume toward its border, with an average value $\bar{\boldsymbol{\varepsilon}} \approx \mathbf{0.16}$. The distributions measured with the AC-TEPC (25 nm, $\bar{\boldsymbol{\varepsilon}} \approx 1$) can be compared with those measured with Startrack (20 nm, $\bar{\boldsymbol{\varepsilon}} \approx \mathbf{0.16}$), if the different site sizes and efficiencies are taken into account. If $\bar{\boldsymbol{\varepsilon}}$ is the average efficiency of Startrack with respect to the AC-TEPC, The "reduced" distributions $\boldsymbol{P}^*_{\mathrm{TEPC}}(\boldsymbol{\nu})$, to be compared with Startrack, can be related to the original measured ionization distributions, $\boldsymbol{P}_{\mathrm{TEPC}}(\boldsymbol{\nu})$ through the binomial relationship:

$$\boldsymbol{P}^*_{\mathrm{TEPC}}(\boldsymbol{\nu}) = \sum_{\boldsymbol{k}=\boldsymbol{\nu}}^{\infty} \binom{\boldsymbol{k}}{\boldsymbol{\nu}} \boldsymbol{P}_{\mathrm{TEPC}}(\boldsymbol{\nu}) \boldsymbol{P}_{\mathrm{TEPC}}(\boldsymbol{\nu}) \bar{\boldsymbol{\varepsilon}}^{\boldsymbol{\nu}} (\mathbf{1} - \bar{\boldsymbol{\varepsilon}})^{\boldsymbol{k}-\boldsymbol{\nu}} \quad (1)$$

The $\boldsymbol{P}^*_{\mathrm{TEPC}}(\boldsymbol{\nu})$ distributions obtained from the experimental distribution $\boldsymbol{P}_{\mathrm{TEPC}}(\boldsymbol{\nu})$ of Figure 3, applying equation (1) with $\bar{\boldsymbol{\varepsilon}} = \mathbf{0.127}$, and taking into account the dead-time correction as described in [5],are also shown in Figure 4 as a step line. The efficiency $\bar{\boldsymbol{\varepsilon}} = \mathbf{0.127}$ has been derived as the product:

$$\bar{\boldsymbol{\varepsilon}} = \bar{\boldsymbol{\varepsilon}}_{\text{Startrack}} \times \frac{\mathbf{20}\ \text{nm}}{\mathbf{25}\ \text{nm}} \tag{2}$$

The agreement between the two distributions is very good, within statistical uncertainties, and encourages the use of the avalanche confinement TEPC as a portable detector for nanodosimetric characterization of particle tracks. So far, the agreement was tested and verified only for ^{244}Cm alpha particles, and it needs to be confirmed for other radiation qualities (particle types and velocities).

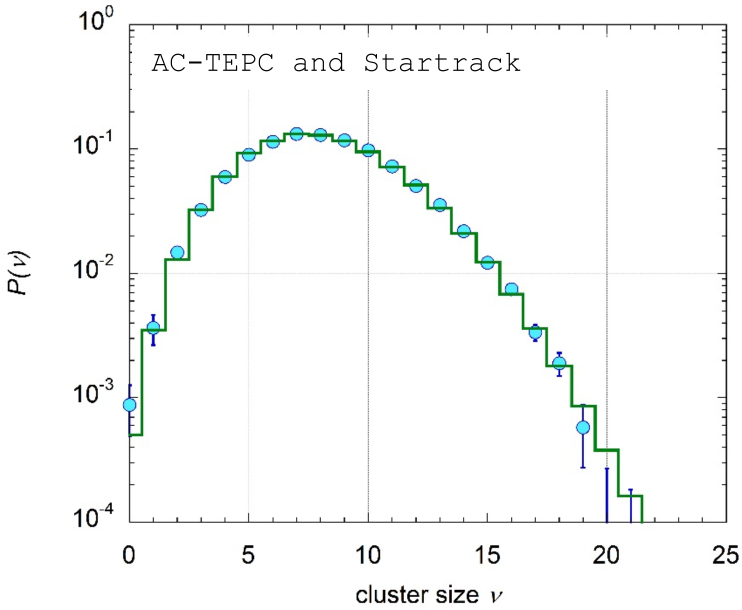

Figure 4. - A picture of the measuring set-up: the primary particle impinges on both detectors, the Startrack counter and the avalanche-confinement TEPC, for first systematic microdosimetry and nanodosimetry comparison.

4. Conclusions

Cluster size distributions produced by ^{244}Cm alpha particles were simultaneously measured with the Startrack counter and with an avalanche confinement TEPC. The comparison of pairwise measurements shows an excellent agreement, when the signals from the TEPC are processed offline in order to include the reduced detection efficiency and the dead time of the Startrack detector. This result suggests a minor influence of the gas-avalanche stochastics on the measured distributions and encourages the use of proportional counters for the experimental characterization of therapeutic hadron beams at the nanometer level. Further measurements with different light ions are ongoing to confirm this finding. A direct and systematic comparison between nanometric-domain microdosimetric distributions and track-nanodosimetric measurements will allow investigating the feasibility of using the nano-microdosimetric spectrum to derive track-structure quantities at the nanometer level (for instance the mean cluster size M_1 and the cumulative distributions F_1, F_2 and F_3) which have been observed to correlate strongly with the radiation damage [8].

5. Acknowledgments

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Journal of Physics: Conference Series **1662** (2020) 012023 doi:10.1088/1742-6596/1662/1/012023

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