Dose distribution characterization in the halo of proton pencil beams with emulsion film detectors

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1 Nuclear emulsion films for medical applications

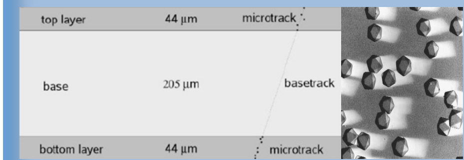
The possibility of employing nuclear emulsion detectors for medical applications is presently investigated at the Laboratory for High Energy Physics (LHEP) of the University of Bern.

These developments include:

- Proton radiography [1]
- Clinical ion beam characterization
- Neutron detection for radiation protection

[1] S. Braccini et al., *First results on proton radiography with nuclear emulsion detectors*, Journal of Instrumentation 2010 JINST 54 P09001.

The scanning laboratory at LHEP in Bern

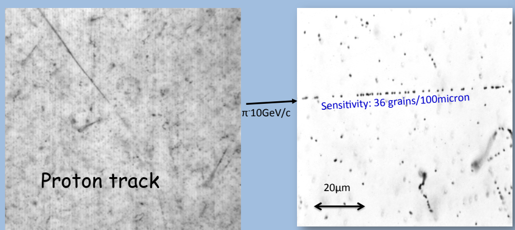


Typical double layer emulsion film (left); AgBr crystals at electron miscroscope (right).

Nuclear emulsion film:

- AgBr crystals embedded in gel
- 10^{13} crystals in a film
- Crystal = Basic detector
- Sensitive area 10 x 12 cm^2

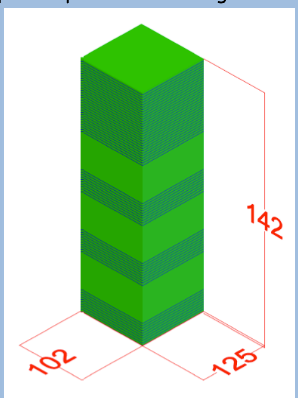
- Single charged particle detection
- Track position resolution < 1 µm
- Track angular resolution of a few mrads



Particle tracks after chemical development.

2 Study of beam halo in a proton therapy beam

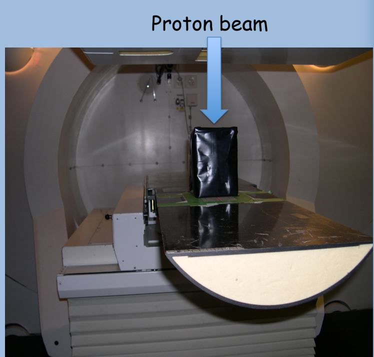
The goal of this study was to assess the dose in the halo region of a clinical proton pencil beam using a method based on nuclear emulsion detectors.



3D model of the emulsion based detector: emulsions (blue), PMMA (green). The dimensions are given in mm.

A 14 cm long detector composed by 60 emulsion films interleaved with PMMA plastic sheets was constructed and irradiated with a 138 MeV proton pencil beam using the Gantry1 at PSI.

A pencil beam was directed at the centre of the detector with a dose corresponding to 6 Gy at the centre of the spot.

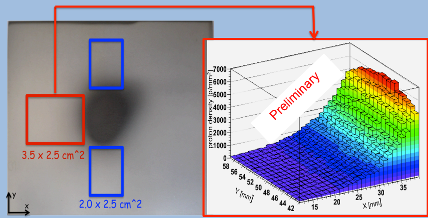


Emulsion based detector irradiated at the Gantry1 at PSI.

While the track density was too high to be measured in correspondence of the centre of the beam, this method allows for counting single proton tracks in the halo along the depth of the detector. This region is particularly interesting since the corresponding dose can be delivered outside the target volume and could potentially lead to undesired secondary cancer induction.

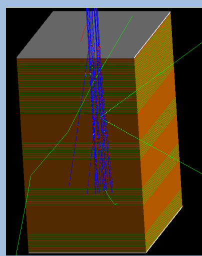
3 Experimental method

The number of protons in the halo region was precisely determined in the emulsions.



An emulsion film after development: the pencil beam is visible (black saturated area) together with the halo. Three areas were selected for the analysis. The number of reconstructed proton tracks as a function of the position is reported in the inset.

After the chemical development, each emulsion was automatically analized with optical microscopes to select proton tracks at different depths. After the microscopic scanning, proton tracks were counted as a function of their position. The irradiated emulsions showed a dark spot in correspondence of the beam profile with a blurry boundary (the halo). Areas at a given distance from the dark spot were chosen for the analysis. Scanning and track reconstruction were performed on the selected areas at several depths.



GEANT4 simulated brick: emulsions (brown), absorbers (orange).

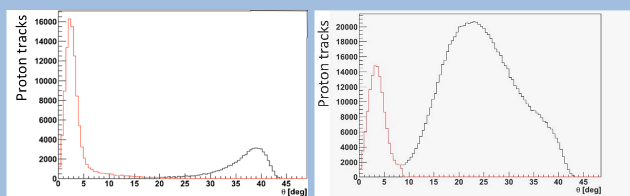
Since a direct assessment of the energy released by each proton was not possible with our system, the dose delivered by each particle was evaluated by means of a GEANT4 Monte Carlo simulation.

4 Results

The angular distributions showed that the protons in the halo region could be subdivided into two components. The former is dominating at small depths and is almost parallel with respect to the beam axis. It is generated up-stream with respect to the detector, in the gantry and in the nozzle. The latter is characterized by large angles and is due to the multiple scattering of the protons inside the tissue equivalent material of the detector. This second component dominates at larger depths.

At small depths, the former component can be quantitatively evaluated while the latter, being at very large angles, is strongly suppressed by the detector efficiency.

At large depths, both components were identified with negligible inefficiencies and allow for a quantitative assessment of the dose.



Angular distribution of the proton tracks at the depth of 3.9 cm (left) and 7.3 cm (right). The almost parallel component is indicated in red while the one due to multiple scattering in black.

In this way, the identification of the proton tracks, together with the corresponding dose estimated by Monte Carlo, allowed assessing an upper limit of the dose in the beam halo region. It was found to be less than **3 x 10^{-4} Gy** for a delivery of 2 Gy in the spot region.