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GEANT4 simulation and study of a possible use of carbon ions pencil beam for the treatment of ocular melanomas at CNAO Center

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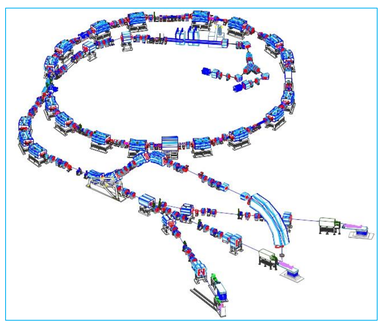
Purpose

The aim of this work is a study of a possible use of carbon ion pencil beams (delivered with **active scanning modality**) for the treatment of ocular melanomas at the National Centre for Oncological Hadrontherapy (CNAO). The Monte Carlo Geant4 toolkit is used to simulate the complete CNAO extraction beam-line, with the active and passive components along it.

A human eye modeled detector, including a realistic target tumor volume, is used as target. Cross check with previous studies at CNAO using protons allows comparisons on possible benefits on using such a technique with respect to proton beams.



The CNAO Center Synchrotron

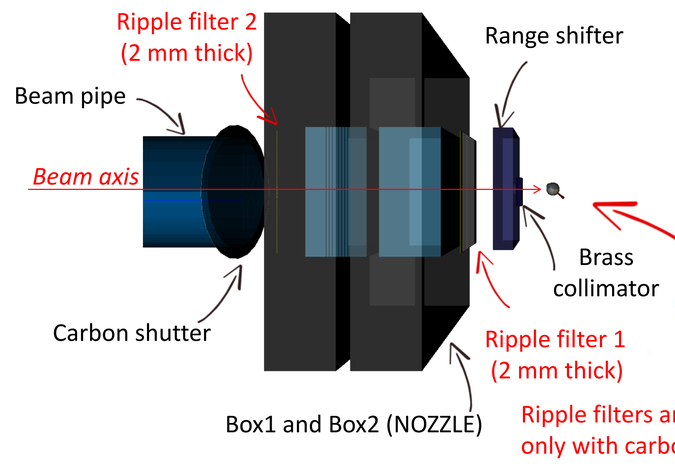
Simulation settings

Release version: **Geant4 vs. 10.0**

Physics Lists: standard_opt4, G4DecayPhysics (only protons), G4RadioactiveDecayPhysics, G4IonBinaryCascadePhysics, G4EmExtraPhysics, G4HadronElasticPhysicsHP, G4StoppingPhysics, G4EmPenelopePhysics, G4NeutronTrackingCut, G4HadronPhysicsQGSP_BERT_HP (only protons), G4HadronPhysicsQGSP_BIC_HP (only carbon ions)

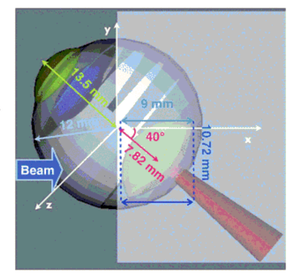
Parallel geometries for scoring purposes and sensitive detectors.

CNAO beam-line [1], eye detector and EBT3 radiochromic films implementation

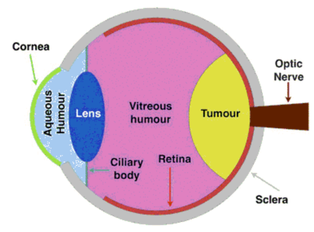


Ripple filters are added to the beam line only with carbon ions

G4 Eye detector
Eye anatomy deeply studied and a geometric schematization realized. Accurate and realistic reproduction of all eye components in the G4 simulation.

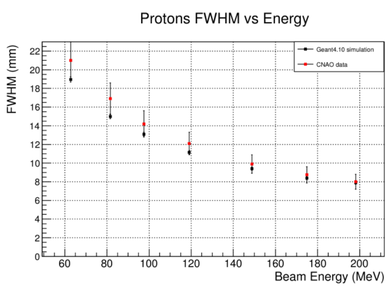


The eye is placed 11 cm downstream the nozzle and rotated by an angle of 40° in the vertical direction

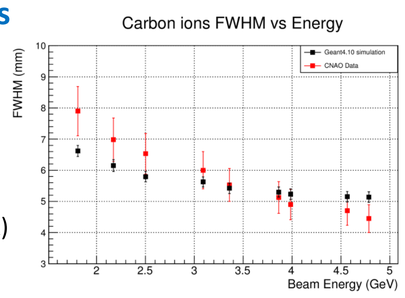


Simulation validation of beam-lines parameters

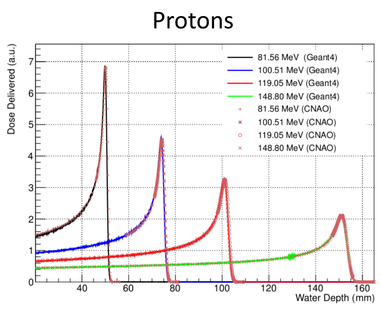
Beam spot profiles



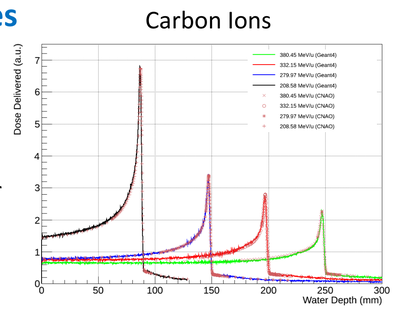
FWHM of protons and carbon ions, in air, at isocenter detected by a EBT3 film (228 um thick)



Depth dose curves



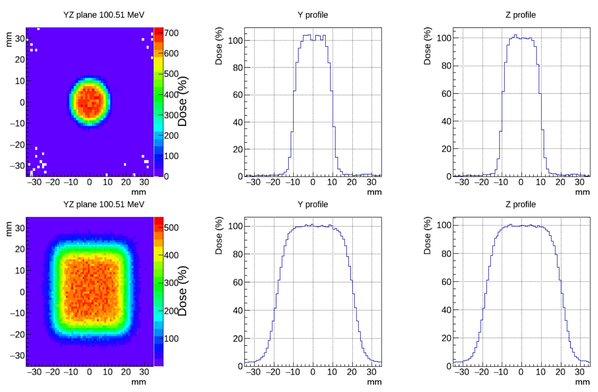
Energy deposited in a 500 x 500 x 500 mm^3 water cube at isocenter for different energies



CNAO data courtesy of A. Mairani

Curves are normalized at the dose deposited by the beam with lower energy (81.56 MeV for protons and 115 MeV/u for carbon ions). For carbon ions 2 ripple filters (each 2 mm thick) were added.

Radiation scanned fields

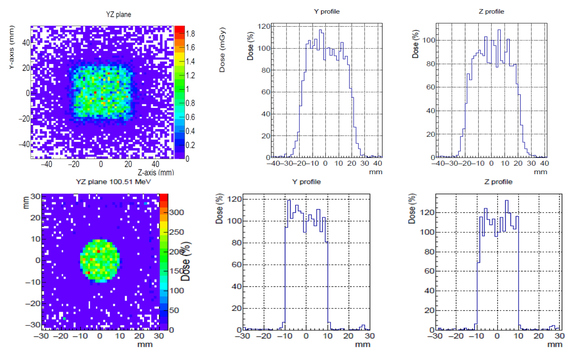


Protons

No collimator	Y profile	Z profile
Field size 50%	40 mm	40 mm
Homogeneity 70%	5.70%	5.20%
Fall-off 80%-20%	7.00 mm	7.00 mm
Collimator		
Field size 50%	20 mm	20 mm
Homogeneity 70%	5.01%	4.30%
Fall-off 80%-20%	2.50 mm	2.50 mm

Carbon Ions

No collimator	Y profile	Z profile
Field size 50%	40 mm	40 mm
Fall-off 80%-20%	5.00 mm	5.25
Collimator		
Field size 50%	20 mm	20 mm
Fall-off 80%-20%	2.5 mm	2.00 mm



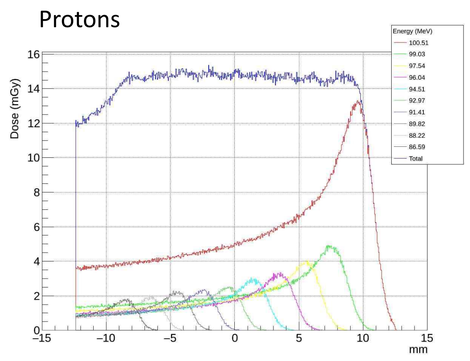
PRELIMINARY RESULTS -> HIGH STATISTICS required to calculate homogeneity

Data analysis for eye treatments with active scanning

The eye-detector is irradiated through a two dimensional transverse beam scan at different depths.

High statistics to minimize statistical errors.

Protons

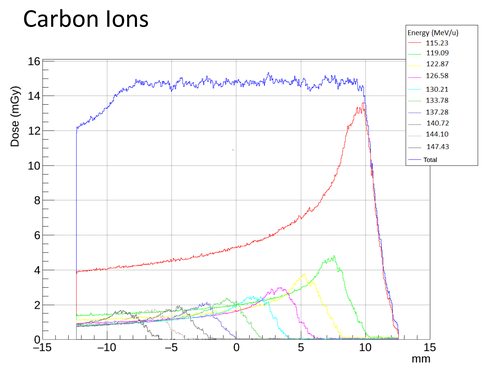


Water detector 2.5x2.5x2.5 cm^3

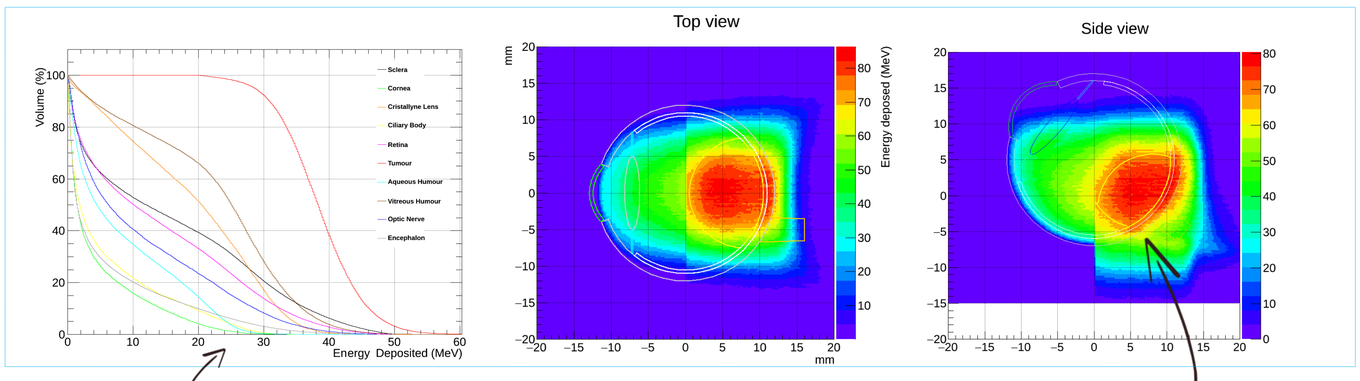
10 different weighted energies

	Protons	Carbon ions
Range shifter	43 mm	20 mm
SOBP width	18.0 mm	18.6 mm
Distal fall-off	1.25 mm	1.45 mm
Homogeneity (field 80%)	4.13 %	3.7 %

Carbon Ions



Protons: Dose Volume Histogram and eye's views



Dose Volume Histograms for a quantitative description of the deposited dose in the eye-detector and for the evaluation of the ratio between the dose deposited in the tumor and the eye components

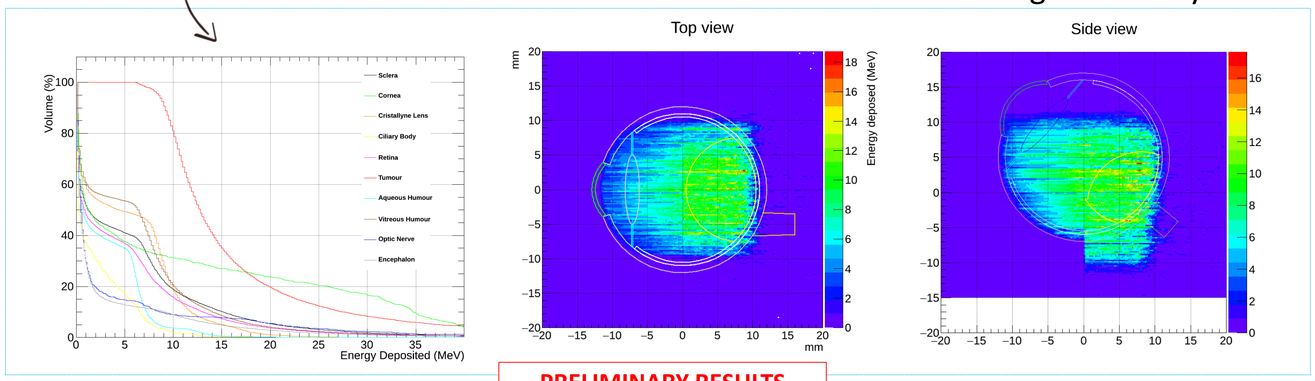
Active scanning on a 40 x 40 mm^2

Range shifter 43 mm for protons and 20 mm for carbon ions.

Brass collimator aperture 20 mm x 22 mm

6 energies SOBP (width 9 mm)

Carbon ions: Dose Volume Histogram and eye's views



PRELIMINARY RESULTS

Summary

The simulation was validated against experimental data and optimization of beam setup for ocular treatment. The uniform 3D dose distribution in the tumor volume has been studied both for protons and for carbon ions. Carbon ions show less lateral penumbra due to a more collimated beam.

Even further validations must be done, in particular the development of the DICOM detector and RT-plan import, the good results so far obtained by this work points out and confirms the possibility of using carbon ions delivered with active scanning beams to treat the ocular melanoma.

References : [1] P. Piersimoni et al., *Optimization of a general-purpose, actively scanned proton beam line for ocular treatments: Geant4 simulations.* Journal of Applied Clinical Medical Physics, Vol 16, No 2 (2015)