Geant4 studies of the CNAO facility system for hadrontherapy treatment of uveal melanomas

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fondazione



Università degli Studi di Pavia



"precision exposures of well defined small volumes within the body"
Robert R.Wilson, 1946





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Hadrons penetrating matter lose energy at the same depth originating the "Bragg peak"





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Hadrons penetrating matter lose energy at the same depth originating the "Bragg peak" High dose can be delivered on tumor also at high depth Undesired dose is reduced w.r.t. conventional therapy



The Uveal Melanoma

Clinically the most common intra-ocular tumour in the adulthood Low incidence Difficult diagnosis and high tendency to metastasise





Hadrontherapy is the most valid and conservative alternative to radical surgery eye enucleation allowing the patient to maintain a visual residual function and a good quality of life

The CNAO:

Centro Nazionale di Adroterapia Oncologica Pavia - Italy

> First patient treatment in 2011 of big seated tumours with light ion beams





- Target volume sliced along its depth
- Irradiation of each slice by means of two orthogonal scanning magnets
- Energy changed by the synchrotron to irradiate each slice



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Because of the efficacy of the protontherapy in uveal melanoma treatment a dedicated eye beam line has been planned at CNAO

For both logistic and budgetary reasons no dramatic changes to the beam line or to the dose delivery system are possible at CNAO

The aim of this work is the building of a MC simulation of the CNAO transport beam line in order to test the feasibility of ocular melanoma treatments and to study the necessary changes to build a dedicated beam line at CNAO

Contents

- Introduction
- Geant4 application:
 - Transport beam line simulation
 - Detectors implementation
- Validation of the simulation
- Conformation of a uniform irradiation
- Simulation of an eye treatment

Simulation features

- Geant4 Release 9.6, patch 01
- Physics Lists
 - G4EmStandardPhysics_option3
 - G4HadronElasticPhysics
 - G4HadronInelasticQBBC
 - G4RadioactiveDecayPhysics

Electromagnetic model

- # Hadronic elastic model
- # Hadronic inelastic model
- # Radioactive decay
- Simulations performed on a desktop computer:
 2.4 GHz Intel Core 2 Duo CPU
 2GB 667 MHz SDRAM
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Simulation features

Settable options:

- Beam parameters: energy, momentum, dimension, particles species etc.
- scanning mode: point-like, bi-dimensional, or bi-dimensional and energy scan (active beam scan)
- detector type (water box, air or water layer, eye-detector, DICOM-detector)
- Detector and passive elements positioning along the beam line
- Sensitive detector or parallel geometry readout
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Simulation of the CNAO transport beam line



Simulation of the CNAO transport beam line



The eye-detector

- Eye anatomy deeply studied and a geometric schematization realized
- Accurate reproduction of all eye-components in the G4 simulation
- Very realistic eye components material implementation



The eye-detector

- Dimensions parameterised as a function of the sclera radius
- Rotation possible to misalign tumour and sensitive sub-components



The DICOM detector



Original CT scan images stored in DICOM files: 512 pixel/slice Slice thick: 2mm

Pixel dimension: 0.9765x0.9765 mm²

<u>10 slices</u> chosen containing the eyes

Cropped image : 86x86 pixel containing the right eye



Validation of the simulation



Beam line optimization









Spread Out Bragg Peak -8.9 mm 9.2 mm

14

12

10

- Water detector 2.5×2.5×2.5 cm²
- Range shifter
 43 mm thick
- I0 different weighted energies
- Peak/entrance: ~80%
- Uniformity 1.5%



WIDTH: 18.1 mm

Energy (MeV)

-100.51

99.03

97.54

96.04

94.51

92.97

91.41

15

mm



Eye treatment simulation



Dose Volume Histograms

Active scanning on a 4×4 cm²

Range shifter 43 mm thick

Brass collimator aperture 20 mm ×22

6 energies SOBP (width 9 mm)

High statistics ~10⁶ primaries



DICOM detector irradiation

mm thick

events





Conclusions & perspectives

- Simulation validated against experimental data
- The introduction in the standard CNAO beam of a range shifter and a collimator is needed
- The beam line has to be slightly modified (isocentre shifting)
- The irradiation on eye-modeled detector results uniform in the 3 dimensions
- Further development of the DICOM detector
- Check on the dose due to secondaries produced by the passive elements introduced

Back up slides





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Issues to be overcome

Issues to be overcome Eye **CNAO** protontherapy 63 - 250 MeV ~60 MeV

Used Energies

(>100 MeV in practice)

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	CNAO	Eye protontherapy		
Used Energies	63 - 250 MeV (>100 MeV in practice)	~60 MeV		
Types of tumour	Big sized deep seated	Small sized at a depth of ~cm		

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TPS	Siemens TPS starting from CT images	Eyeplan TPS starting from US scan and fundus view ³¹		



















Secondaries depth-dose

Configuration B

Point like beam 100.51 MeV Water detector





-Total depth dose

-Secondary particles

-Neutron depth dose

-C12 depth dose

-O15 depth dose

-O16 depth dose

Alpha depth dose

- Deuteron depth dose

-Gamma depth dose

-Proton depth dose

40

Depth (mm)

50

FLUKA comparison



Agreement within ~5%

Spread Out Bragg Peak

Extension in dose deposition in depth achieved by delivering many OSe Bragg peaks, with a successively slightly different range, not equally weighted



Secondary particles production



Secondary particles production



Eye detector materials

Chemicals	Composition	
Proline	$H_9C_5O_2N$	
Idrossiproline	H ₉ C ₅ O ₃ N	
Collagen	Proline (86%) + Idrossiproline (14%)	
Lipids	$H_{48}C_{24}O_6PN_2$	
Lactate	$H_5C_3O_2$	
Sugar	H ₂ CO	
N-AcetilAspartate (NAA)	$H_9C_6O_5N$	
Choline	H ₁₄ C ₅ ON	
Creatine	$H_9C_4O_2N_3$	
Proteins	H(50%) + C(28%) + O(13%) + N(8%) + S(1%)	

Eye detector materials

Eye component	Material	Density (g/cm ³)
Aqueous Humour	H ₂ O (98.5%) + NaCl (1.5%)	1.008
Vitreous Humour	H ₂ O (98.5%) + Protein (1.5%)	1.005
Sclera, Cornea, Ciliary Body	Collagen (50%) + Protein (25%) + Sugar (25%)	1.071
Crystalline Lens	H ₂ O (60%) + Protein (40%)	1.067
Retina	H ₂ O(80%) + NAA (10%) + Choline (5%) + Creatine (5%)	1.0174
H ₂ O (80%) + NAA (3%) + Choline (12%) Tumour + Creatine (3%) + Lipids (1%) + Lactate (1%)		1.0174





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Counts

1.8

1.6

1.4



