12th Geant4 collaboration workshop

Ebden Bridge, UK, 13 – 19 September 2007

The Italian activity of the LNS – INFN group

Francesco Romano
on behalf of Geant4 group at LNS-INFN, Catania

Summary

- Geant4 group at LNS – INFN in Catania
- National and international collaborations
- Our interest in Monte Carlo simulations
- Geant4 activity and some examples:
  - Hadrontherapy advanced example
  - Stereotactic Radiosurgery with Gamma Knife
  - Proton Computed Tomography (pCT)
  - Fragmentation studies for carbon ion beams
- Conclusions

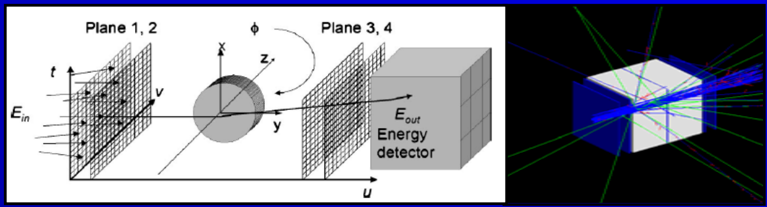
Geant4 group at LNS – INFN in Catania

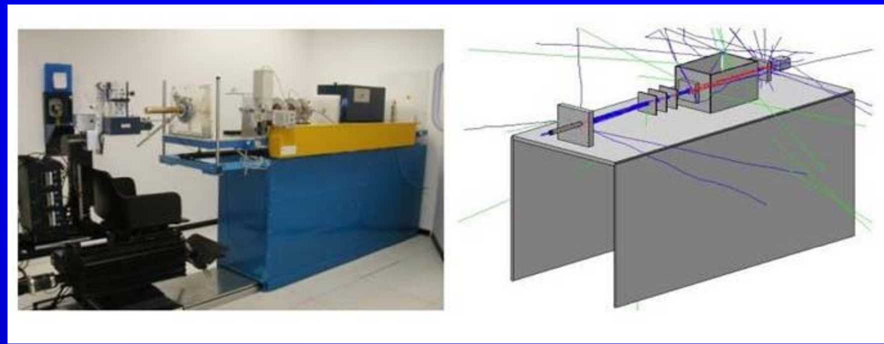
LNS: Laboratori Nazionali del Sud

Giacomo Cuttone: Research Chief at Laboratori Nazionali del Sud
G. A. P. Cirrone: Researcher at Laboratori Nazionali del Sud
Giuliana Candiano: Student at the Medical Physics School
Francesco Di Rosa: Qualified Medical Physicist
Piero Lojacono: PhD student at the Catania University
Francesco Romano: PhD student at the Catania University
Giorgio Russo: Qualified Medical Physicist

Geant4 group at LNS – INFN in Catania

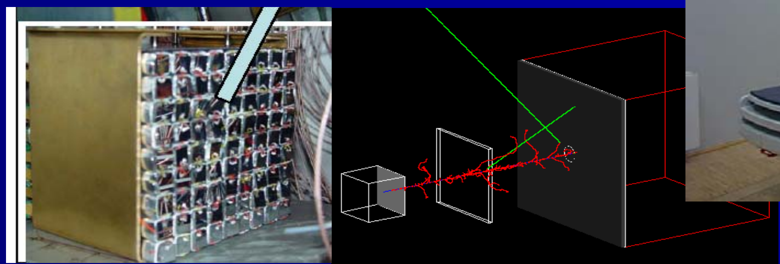
Research activities of the group:

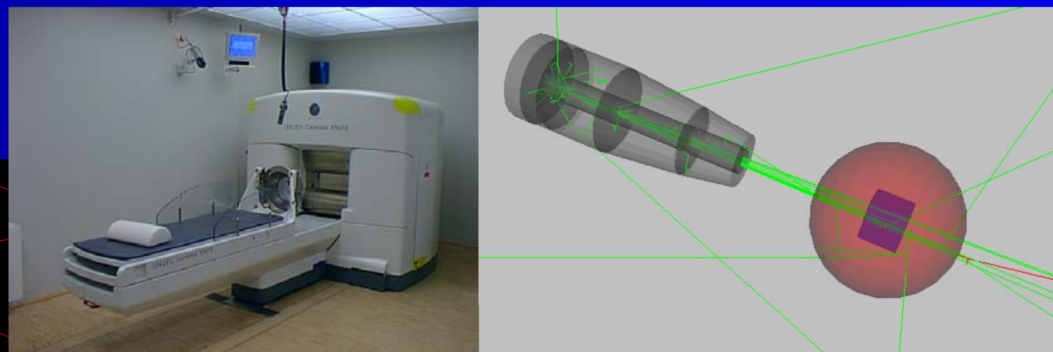




- Hadrontherapy
- Dosimetry for proton and ion beams
- Proton-therapy treatment of ocular melanomas (CATANA project)
- Detector characterisation for dosimetry in proton, electron and photon beams
- Monte Carlo simulations for radiotherapy and diagnostic applications (photons, protons and ions)
- Measurements of nuclear fragments production for carbon ions

For much informatio, visit our wikipage !
http://geant4lns.wikispaces.com





 Francesco Romano, LNS – INFN, Catania, Italy

Geant4 group at LNS and collaborations

External collaborations with national and international institutes:

- **University and INFN section of Florence**
- **INFN section of Pisa**
- **Italian National Health Institute, Rome**
- **University and INFN section of Turin**
- **University and INFN section of Rome "Tor Vergata"**

- **Loma Linda Medical Center, U.S.A.**
- **Vinca Institute of Nuclear Science, Belgrade, Serbia**

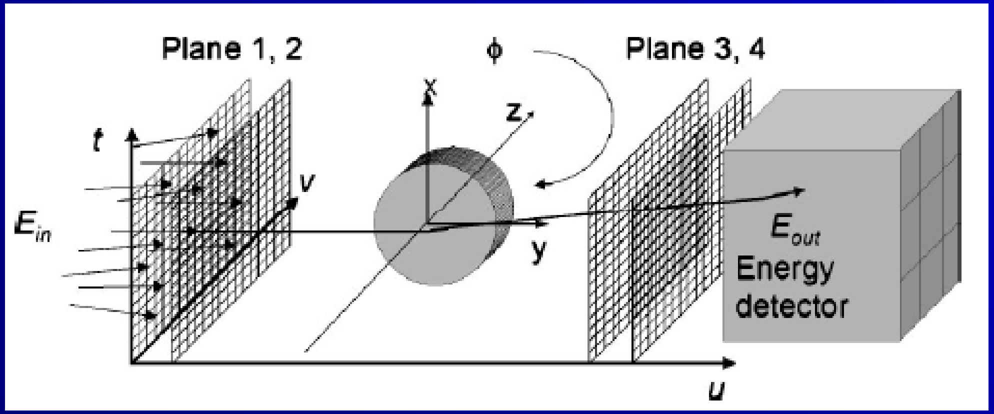
Geant4 group at LNS and collaborations

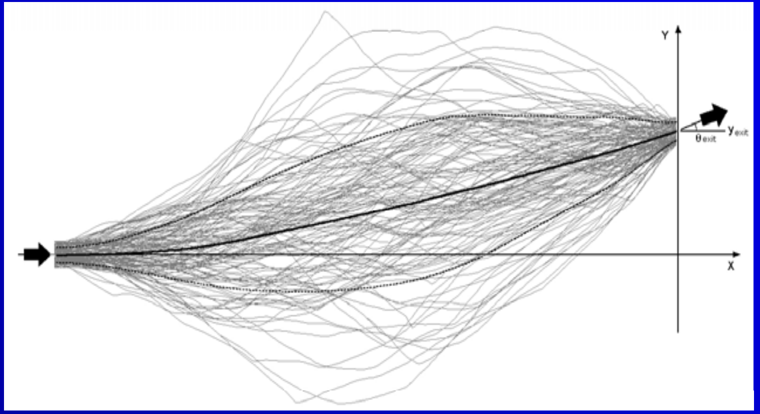
• **University of Florence and INFN section of Florence** (M. Bruzzi, D. Menichelli, M. Scaringella, S. Miglio, M. Bucciolini, C. Talamonti and S. Pallotta)

Development of a new imaging technique based on use of high energy protons

***Proton Computed Tomography* (*pCT*)**

- geant4 Monte Carlo simulations of the protons's paths.
- experimental measures and prototype for a proton radiography device
- the Italian PRIMA (PRoton IMAging) project



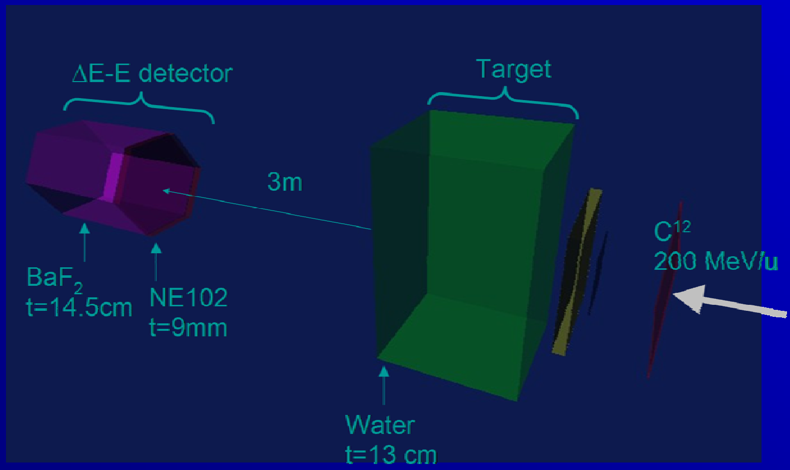


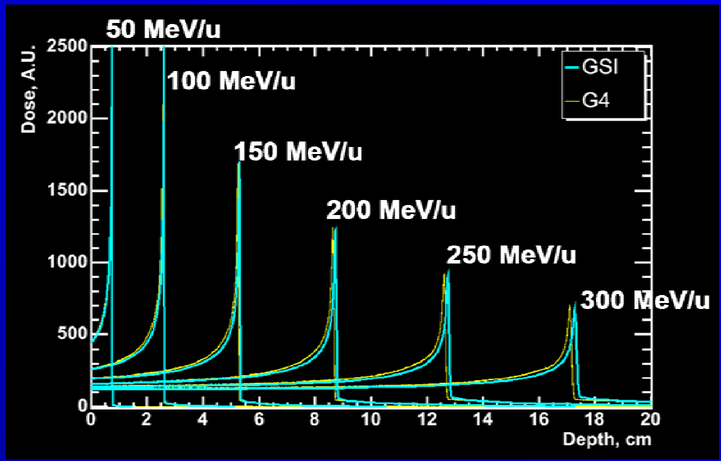
Geant4 group at LNS and collaborations

• **INFN section of Turin** (F Bourhaleb. A. Attili, F. Marchetto, I. Cornelius, I. Rinaldi, V. Monaco)

Simulation of proton and Carbon ion beams interactions with water phantoms

- study of fragmentation products
- simulation of on line devices for measures of delivered dose to the patient
- study of radiobiological effects for carbon ion beams



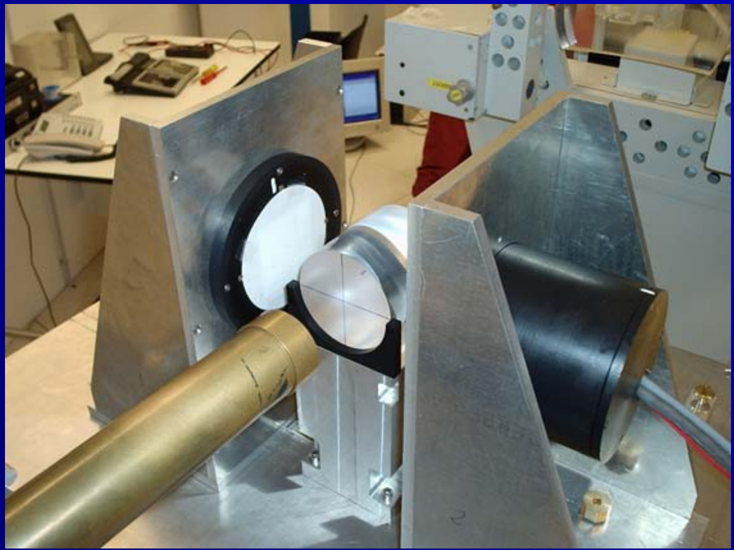


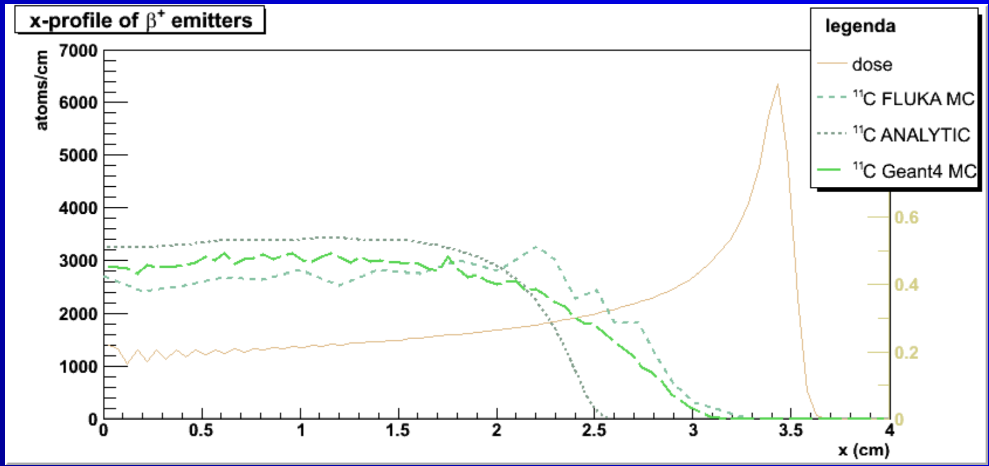
Geant4 group at LNS and collaborations

• **INFB section of Pisa (**F. Attanasi, N. Belcari, M. Camarda, A. Del Guerra, N. Lanconelli, V. Rosso , S. Vecchio**)**

DOPET project: proton therapy monitoring device

- geant4 Monte Carlo simulation of the prototype, composed by two planar active heads
- comparisons with experimental data from CATANA beam line at LNS – INFN, Catania (70 MeV proton beam on PMMA phantom)





Geant4 group at LNS and collaborations

• **Italian National Health Institute** (B. Caccia, M. Mattia, C. Andenna, L. Strigari, A. D'Angelo, G. Iaccarino, G. Frustagli, S. Valentini)

Simulation of proton and Carbon ion beams interactions with water phantoms

- geant4 Monte Carlo simulation for radiometabolic therapy
- simulation of IMRT (Intensity Modulated Radiation Therapy)
- employing of DICOM

• **Vinca Institute of Nuclear Science, Belgrade, Serbia** (A. M. Ristic-Fira, I. M. Petrovic, L. B. Koricanac, J. Pozega)

Irradiation of cells and calculation of LET (Linear Energy Transfer) at different depths and with different materials for:

- proton beams (implemented in Hadrontherapy advanced example)
- carbon ion beams (in progress: study about the LET calculation from the fragmentation spectra of the secondary particles produced)

Our interest in Monte Carlo simulations

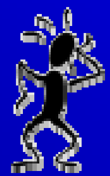
Nowadays Monte Carlo method can be considered one of the most precise technique employed to investigate some open issues in different fields of medical physics

In particular, we think that it can be a powerful instrument for:

- imaging and diagnostic devices
- accurate evaluation of delivered dose especially in particular configurations (heterogenity)
- validation of Treatment Planning Systems (TPS) and knowledge of their limits
- design and improvement of treatment facilities (ex.: CATANA project, Catania)
- direct employment in radiotherapy instead of analitical TPS

We hope in the constitution of an international group devoted to the Geant4 applications in Medical Physics

This isn't just an idea, but it's already reality !!!



G4EMU (*Geant4 European Medical User Organization*) is a "meeting place" in which people of Geant4 medical user community can share issues and practical advices, in order to increase collaborations between the European Institutes.

Visit the web site http://g4emu.wikispaces.com **!!!**

Geant4 activity

Many aspects of the Geant4 toolkit have been investigated since we start using Monte Carlo method.
Particular interest is devoted to medical applications:

- advanced imaging techniques (proton Computer Tomography)
- new radiation therapy techniques (proton and ion therapy)
- stereotactic radiosurgery (GammaKnife)

CATANA project

Our Geant4 activity started with the simulation of a proton therapy beam line

↓

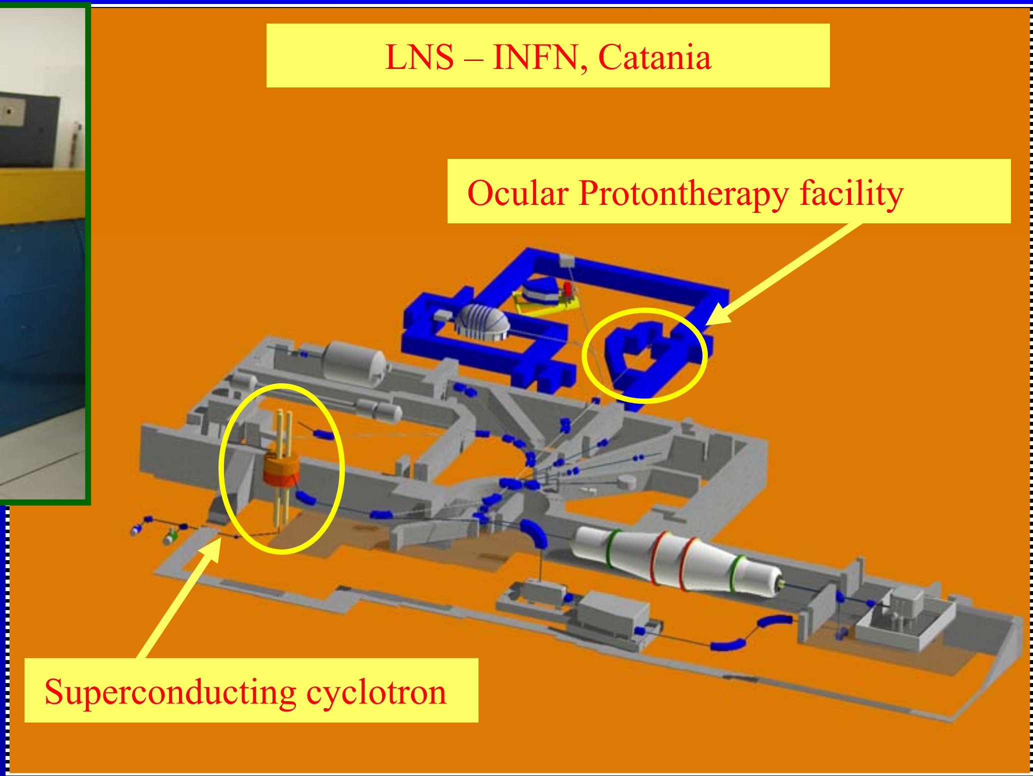
Since 2001 a dedicated irradiation facility is operant inside our laboratory:

CATANA (Centro di AdroTerapia e Applicazioni Nucleari Avanzate) is the first Italian facility for the treatment of ocular tumours

About 150 patients treated → local control of tumour of 95%

CATANA project

Proton beams are accelerated by a superconducting cyclotron until 62 AMev

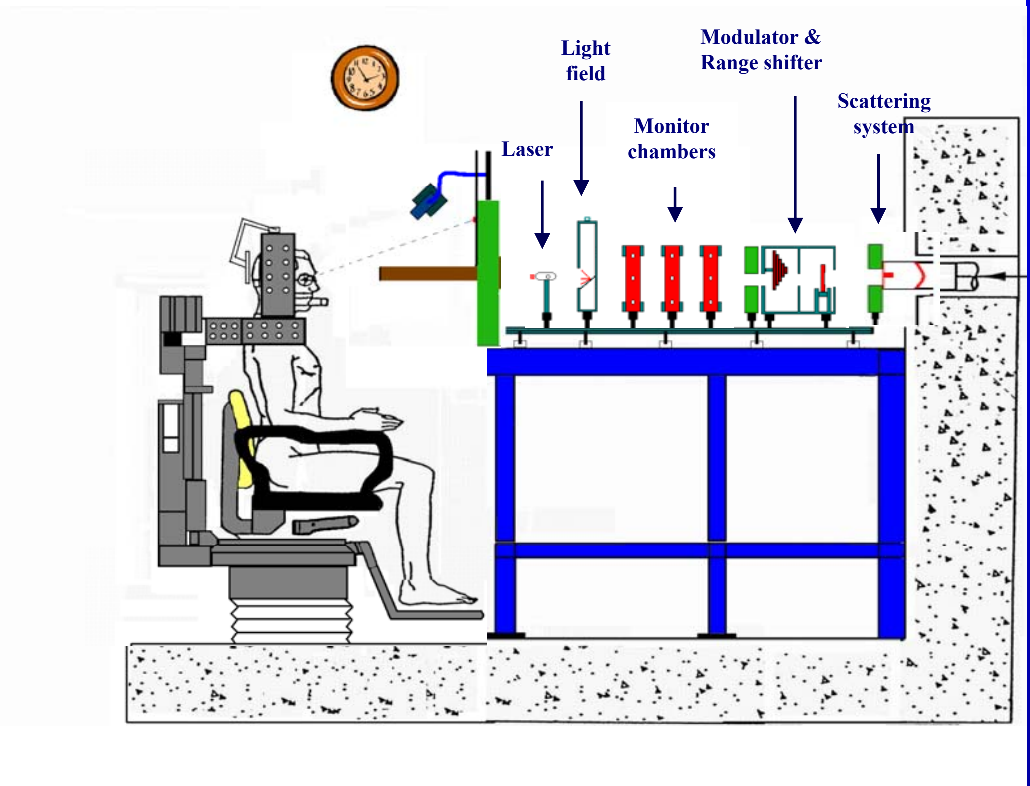


Web site:
http://www.lns.infn.it/CATANA/CATANA/

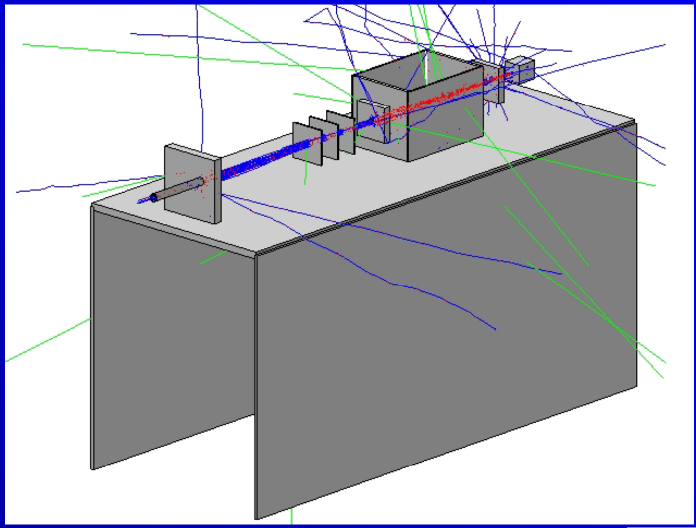
Hadrontherapy advanced example

Why the Monte Carlo Simulation is important for a proton therapy facility?

- to optimize each element of the beam line and improve it
- to calculate the dose distribution inside the tumour volume
- to verify and validate the Treatment Planning System



All the elements of our beam line have been simulated



Hadrontherapy advanced example

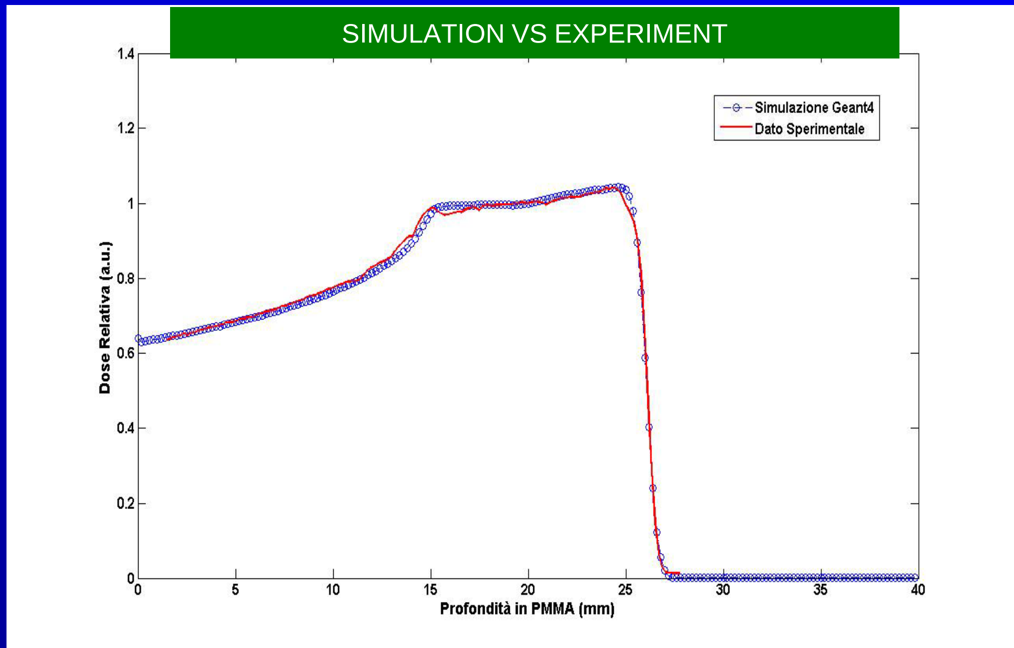
Simulation of the proton beam line → advanced example **Hadrontherapy**

geant4_installDir/examples/advanced/hadrontherapy

- General geometric proton beam line configuration
- 3D dose distribution calculation using a sensitive detector with cubic voxels in different materials

Validation of the application by experimental data:

- depth dose distribution
- lateral dose distribution



*G.A.P. Cirrone, G. Cuttone et al., Implementation of a New Monte Carlo - GEANT4 Simulation Tool for the Development of a Proton Therapy Beam Line, IEEE Trans. Nucl. Sci., vol. 52, no. 1, pp. 262-265, Feb. 2005.

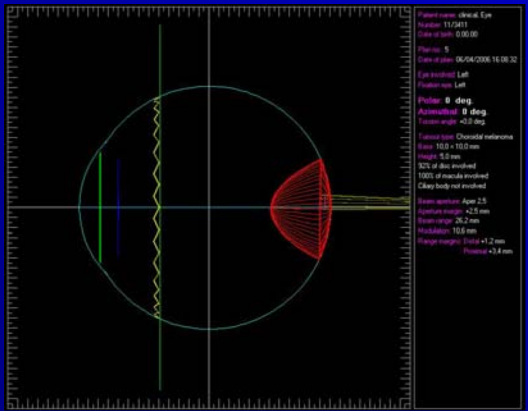
Validation of Eyeplan

Eyeplan is the TPS used inside our proton therapy facility to plan the treatment before the irradiation of the patient

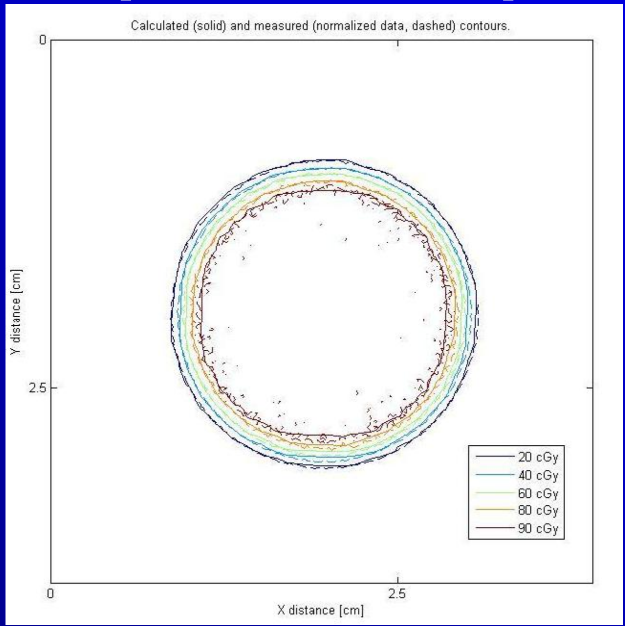
Comparison between Eyeplan and Monte Carlo for a clinical case

the eye geometry for default dimensions has been reproduced in both the two cases

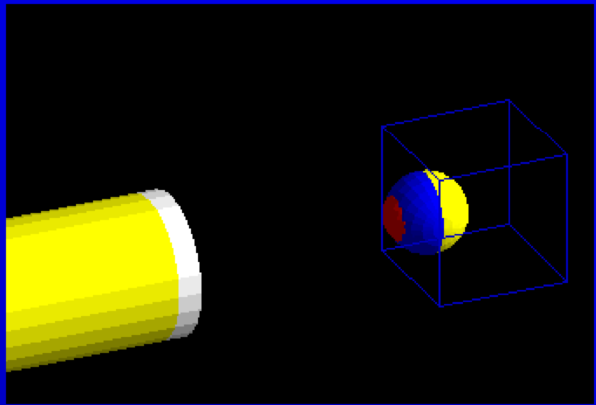
Eyeplan



Comparison in the coronal plane



Geant4



Monte Carlo simulation reproduces correctly the TPS output within the statistical errors

Francesco Romano, LNS – INFN, Catania, Italy

Monte Carlo simulation of the Leksell Gamma Knife®

Stereotactic Radiosurgery with ***Gamma Knife***® is a technique for treating lesions, typically intracranial, with a single high dose of ionizing radiations.

Leksell Gamma Knife® C (Elekta)

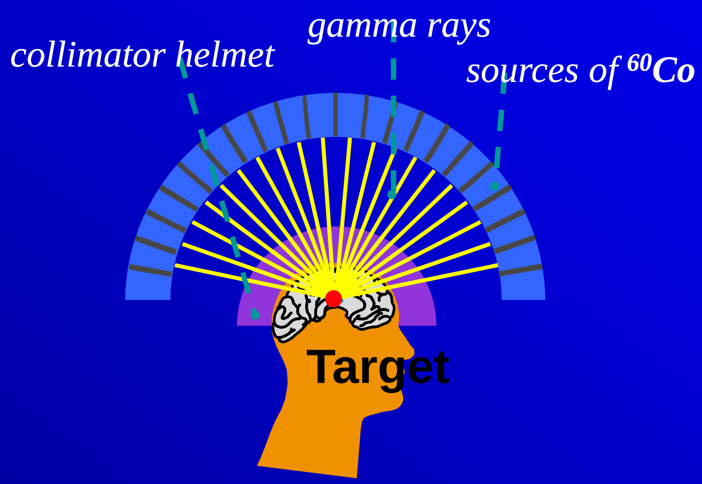
Installed at the "Cannizzaro Hospital"
and already in function for about 2 years

Basic idea:

201 gamma ray beams focalize at the isocentre, delivering high amount of dose to the target and minimum to the sorrounded tissues

irradiation of the target

preservation of the healthy tissues



Monte Carlo simulation of the Leksell Gamma Knife®

Treatment Planning System (TPS) Leksell *GammaPlan*®

Calculation of the delivered dose according to the image data
semi-empirical algorithm → computation in a reasonable time

It assumes that:

- human head is just composed by ***water***

⇩

This approximation can achieve some uncertainties in the dose computation

Monte Carlo simulation is necessary to better understand how these assumptions can affect the dose distribution calculated.

Francesco Romano, LNS – INFN, Catania, Italy

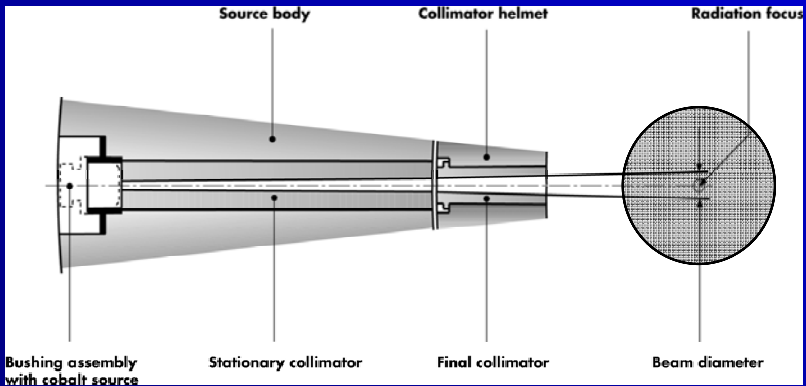
Monte Carlo simulation of the Leksell Gamma Knife®

Monte Carlo simulation of the apparatus with Geant4

The apparatus is composed by 201 identical "elementary unit"

Firstly we simulated one of these (^{60}Co source, stationary collimator and helmet) a spherical water phantom (human head) and a cubic detector (voxels)

simple scheme



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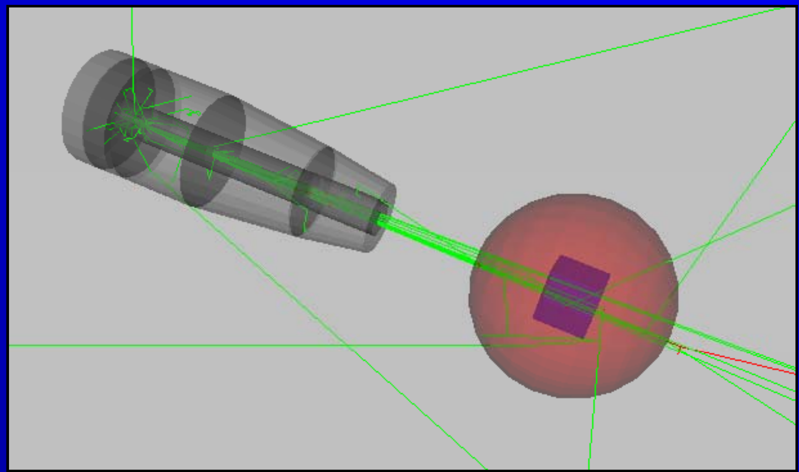
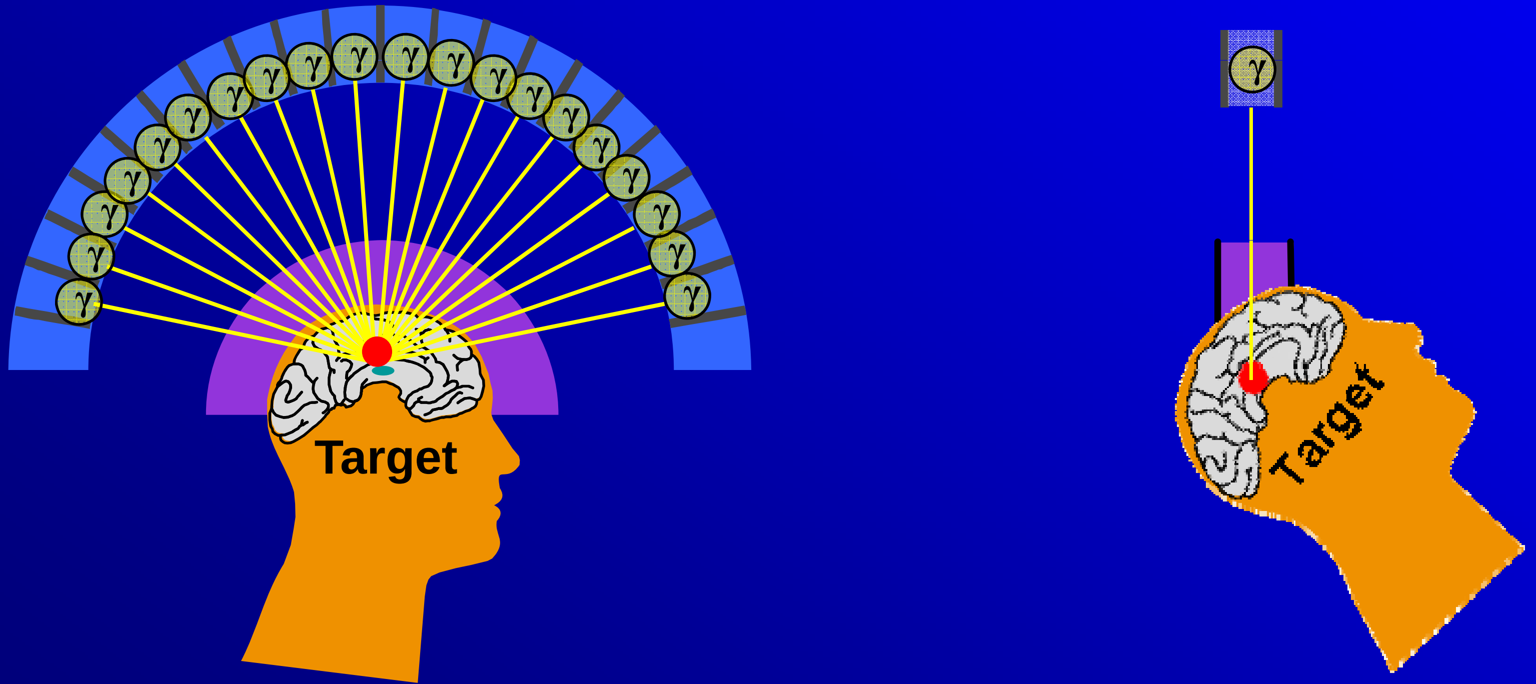


Monte Carlo simulation of the Leksell Gamma Knife®

Monte Carlo simulation of the apparatus with Geant4

Instead of 201 elementary units only one source was simulated
The phantom was rotated at the same angular positions

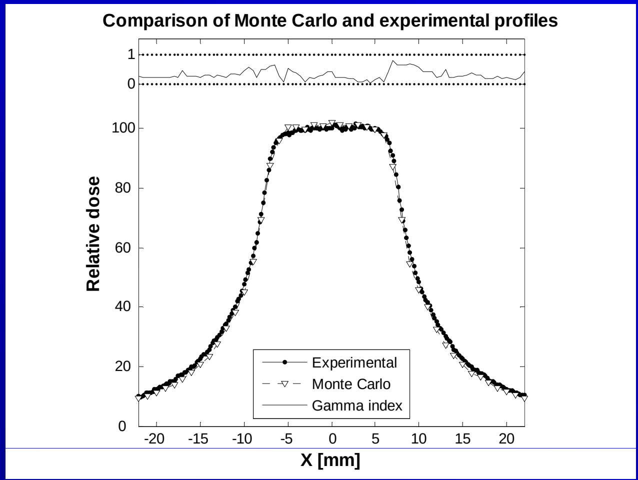
Code is simpler and more easily comprehensible or changeable !!!

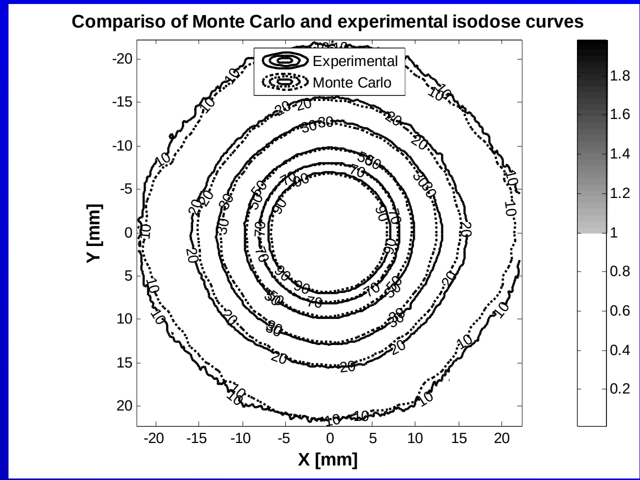


Francesco Romano, LNS – INFN, Catania, Italy

Monte Carlo simulation of the Leksell Gamma Knife®

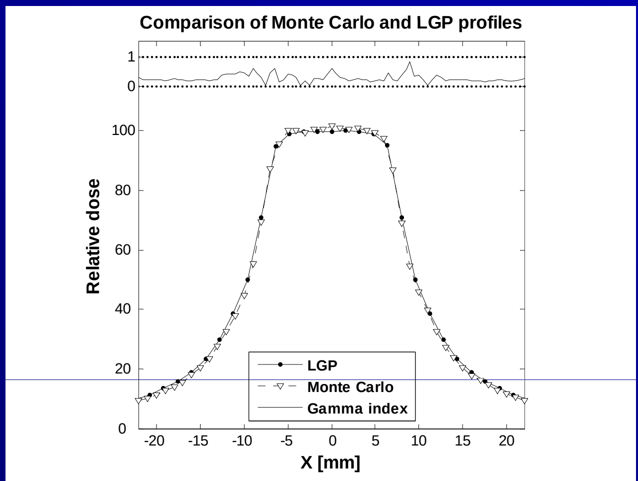
Validation of the simulation by experimental data

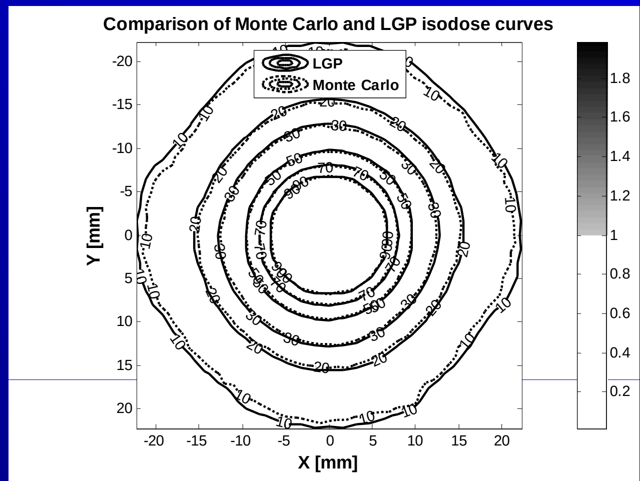




Geant4 simulation validated!

Comparison with the TPS GammaPlan, in standard configuration

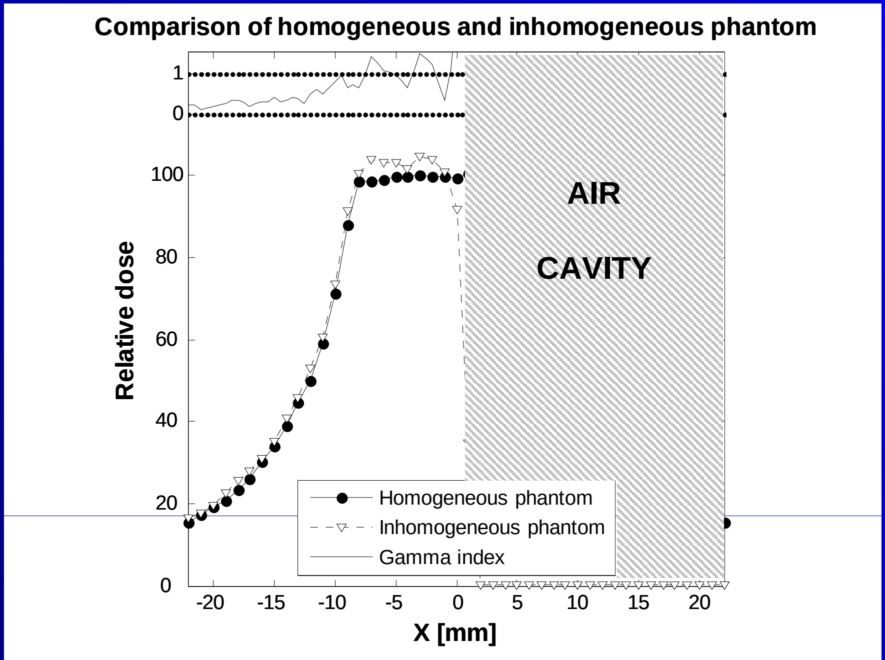


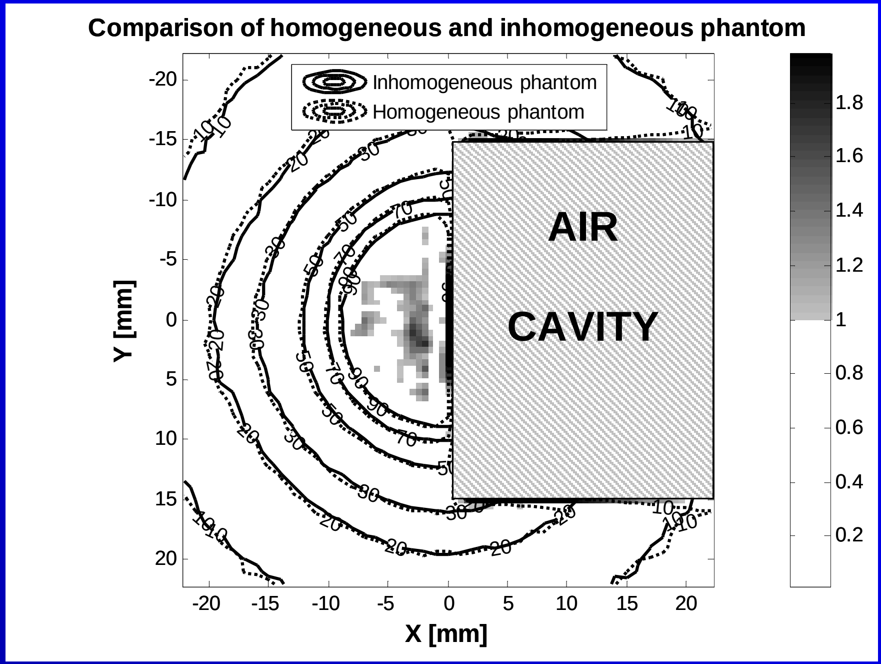


Good agreement for homogeneous phantom

Monte Carlo simulation of the Leksell Gamma Knife®

Comparison with the TPS GammaPlan, for inhomogeneou phantom





<u>TPS GammaPlan undervalues dose deposited of about 4%</u>

Development of a proton Computed Tomography device

pCT and the PRIMA project

The proton Computed Tomography (pCT) is a new imaging technique based on the use of high energy proton beams (about 250 MeV).

PRIMA *(Proton IMAging)* is the Italian project for a pCT device, born by the collaboration of different institutes

The pCT will improve the quality of a proton radiation treatment as it permits the direct measurements of the patients stopping powers

⬇

Monte Carlo simulation!

Development of a proton Computed Tomography device

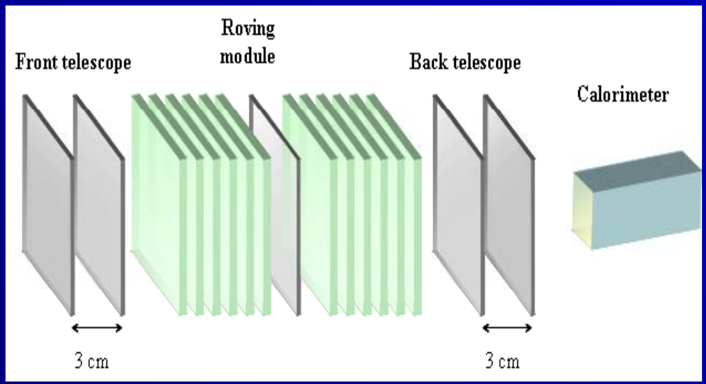
The role of Monte Carlo is also:

- test the estimation of the proton path
- evaluate of image quality
- evaluate the released dose (as function of image quality!)
- evaluate the different reconstruction algorithms

Geant4 Monte Carlo simulation of a pCT prototype has been developed

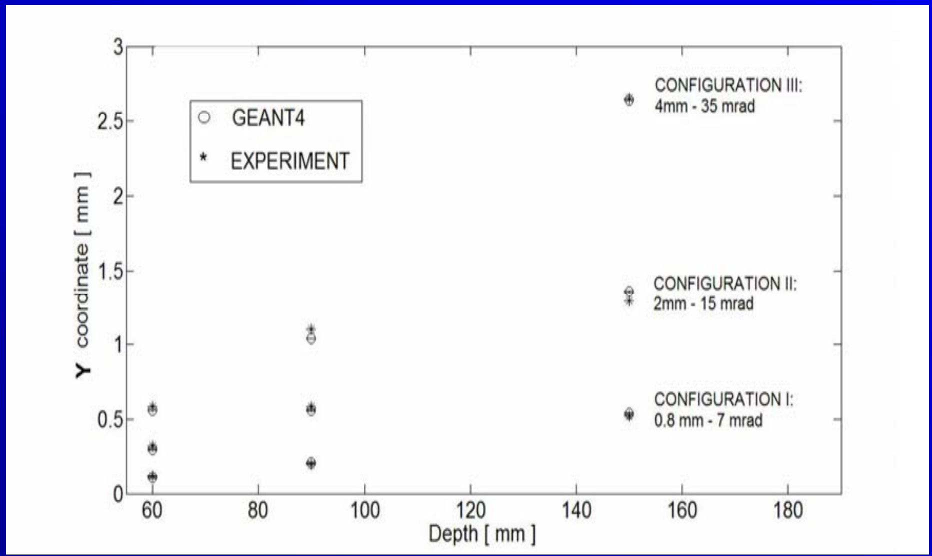
The final part of a proton beam line at Loma Linda Medical Centre was reproduced in order to compare simulation outputs with experimental data

Simulation of the apparatus

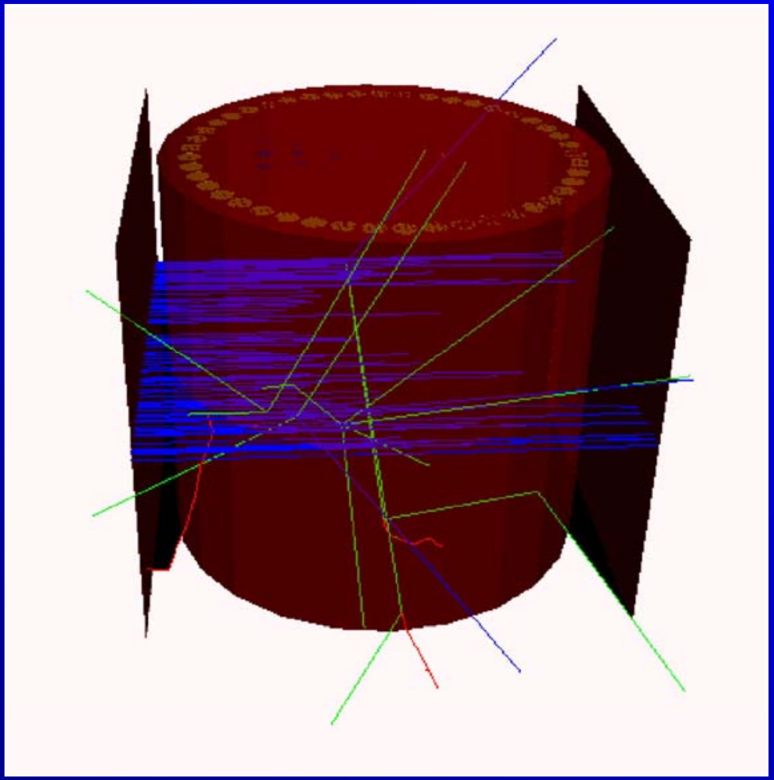


<u>Monte Carlo is a good method to predict the correct mean path</u>

Comparison with the experimental data

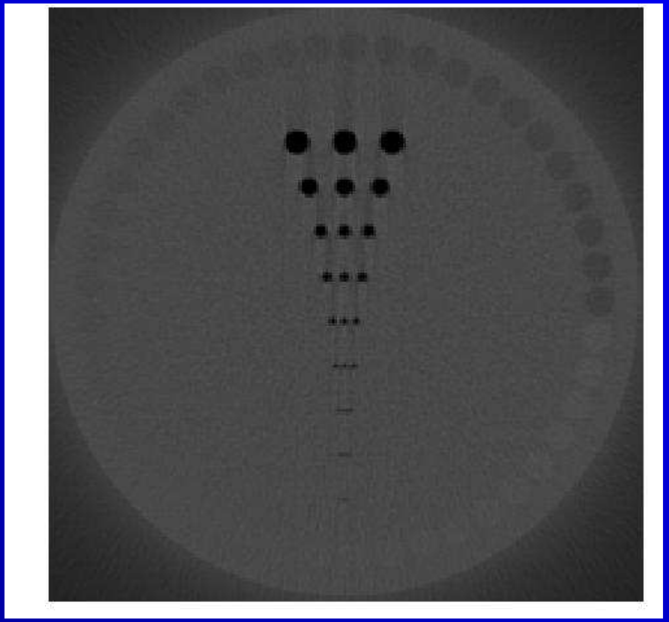


Development of a proton Computed Tomography device



Geant4 visualization of simulated phantom for image reconstruction

Image reconstructed with a suitable algorithm



Fragmentation studies for carbon ion beams

Carbon ion therapy represents one of the most promising frontiers in the struggle against cancer:

- low lateral spread
- high Linear Energy Transfer (LET), in example respect to the proton one.

Study of dose distribution in tissue-like materials by carbon ion beams also for a possible Treatment Planning System (TPS) for carbon ion therapy

Dose released to the patient → uncertainties:

- the fragments production on different angles and depths
- the radiobiological efficiency (RBE) of ions in biological matters

All the secondary particles produced by the fragmentation of carbon ions have to be known:

- Fragmentation along the transport beam line
- Fragmentation into the patient

^{12}C

^{11}C ^{11}B ^{10}B ^{9}Be ^{7}Be ^{7}Li

^{6}Li ^{6}He α ^{3}He t d p

… all physics reactions at the base of hadronic processes !!!

Francesco Romano, LNS – INFN, Catania, Italy

Fragmentation studies for carbon ion beams

It's important to know the cross section of secondary particles production at different angles and for different target materials.
In literature there is not a complete data set in the energy range of interest for carbon ion therapy (0-370 AMeV)

Experimental data
INFN – LNS, Catania

Up to now we have performed two experimental runs with 62 and 35 AMeV carbon ion beams on graphite and gold targets (analysis in progress)

Geant4 Monte Carlo simulations and understanding of the hadronic models

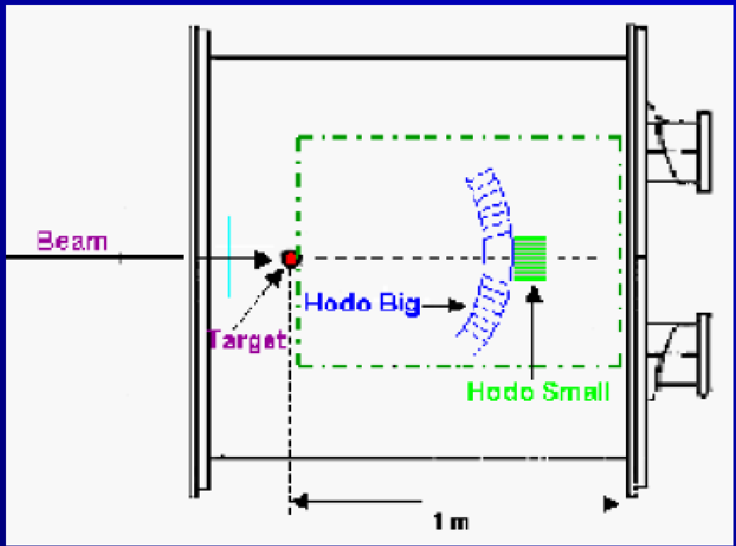
Collaboration with Geant4 hadronic working group

Fragmentation studies for carbon ion beams

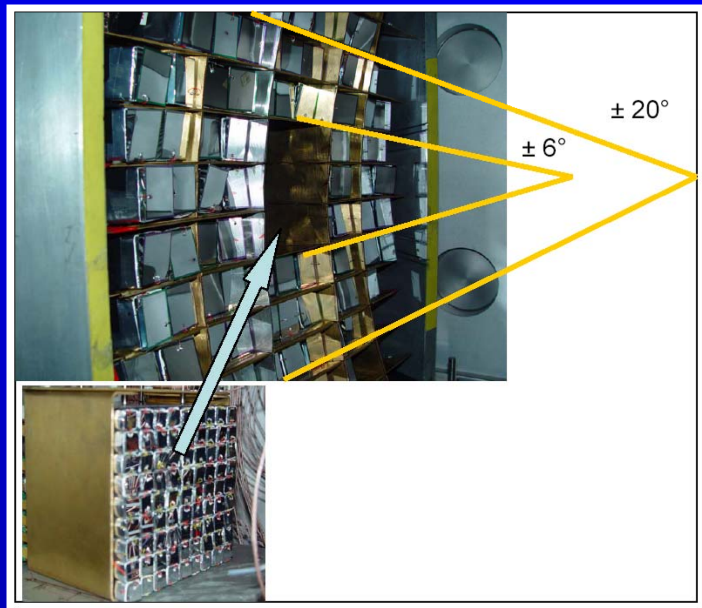
Experimental at LNS – INFN

The experimental apparatus is composed by 88 ΔE-E detectors arranged in a spherical section shape, with the target in the centre of it (r = 60 cm).

It is composed by a smaller detectors apparatus *(hodo small)* and a bigger one (*hodo big*)



Schematic view of the scattering chamber with the beam entrance, target and experimental apparatus

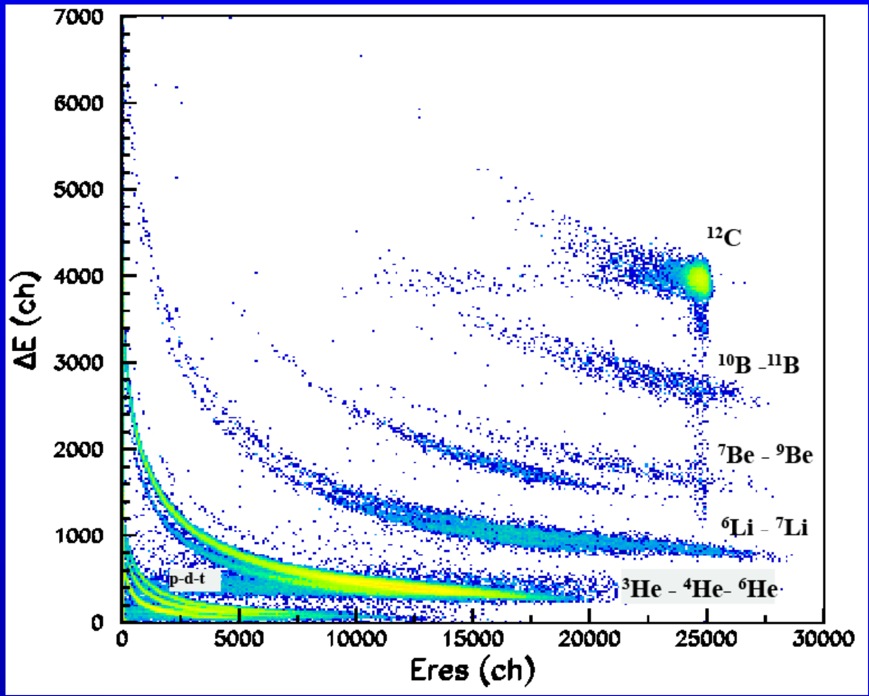


Fragmentation studies for carbon ion beams

First raw results

We can distinguish:

- p, d, t
- ^{3}He, ^{4}He, ^{6}He
- ^{6}Li, ^{7}Li
- ^{7}Be, ^{9}Be
- ^{10}B, ^{11}B
- elastic peak of ^{12}C



Future developments:

- simulation of the experimental apparatus and comparison of results
- comparison with different hadronic physics models in Geant4
- measurements of fragmentation processes at higher energies
- design of a smaller detector for fragments production and on line beam monitoring

Conclusions

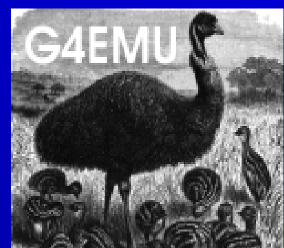
Our group works since 2001 inside geant4 collaboration

Involvement in the hadronic and advanced examples WGs

- thirty researchers
- seven institutions
- two external collaborations

We are working for the constitution of a user group composed by people with common interest to Geant4 in medical physics

Everyone interested can join the G4EMU and give his own contribution for sharing many things as possible.




… thank you!