Review of Geant4 applications in radiation therapy

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MCMA, Naples October 15th – 18th, 2017

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Pietro Pisciotta
Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud

Francesco Romano
NPL, London (UK

Giorgio Russo
Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud
CNR

on behalf of Geant4 Collaboration

Outline

Geant4

Geant4 for Medical Physics

- Electromagnetic Physics
- Hadronic Physics
- Official Examples

Ongoing activities around world: a selection

MC-INFN project

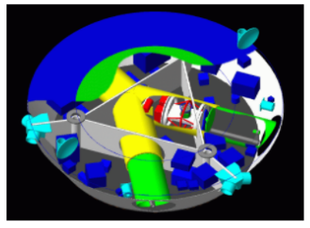
Geant 4

Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The three main reference papers for Geant4 are: *Nuclear Instruments and Methods in Physics Research* A **506** (2003) 250-303, *IEEE Transactions on Nuclear Science* **53** No. 1 (2006) 270-278, *Nuclear Instruments and Methods in Physics Research* A **835** (2016) 186-225.

Applications

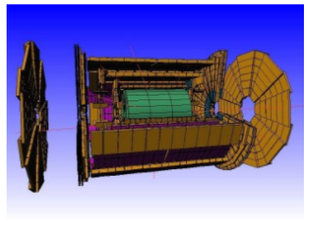
A sampling of applications, technology transfer and other uses of Geant4

User Support



Getting started, guides and information for users and developers

Publications



Validation of Geant4, results from experiments and publications

Collaboration

Who we are: collaborating institutions, members, organization and legal information

Geant4

http://geant4.web.cern.ch/geant4/

What is Geant4?

Open Source toolkit for the Monte Carlo simulation of the interaction of particles with matter

- physics processes (EM, hadronic, optical)
- comprehensive set of particles and materials
- complete set of support functionalities (tracking, geometry)

Distributed software production and management: developed by an international Collaboration

- First release in 1998 (one per year)
- Approximately 100 members, from Europe, America, Australia, Asia, …
- Written in C++ language
- Takes advantage from the Object Oriented software technology

Geant4 for Medical Physics
latest developments

Key points on Medical Physics

Radiation field modelling

Geometry

Physics and its validation by independent teams

User-friendly scoring

Analysis tools

Biasing

GUI and Visualisation

Medical Physics examples

Tools and discussion forums dedicated to the medical physics

G4MED (in Japanese)
Geant4 Medical Physics in Japan

G4NAMU
Geant4 North American Medical Users

GAMOS
Geant4-based Architecture for Medicine-Oriented Simulations

GATE
Geant4 Applications for Tomographic Emission

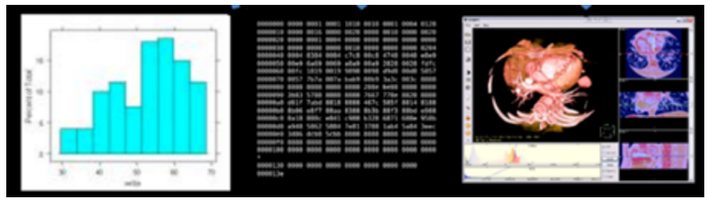
TOPAS
TOols for PArticle Simulations

Tools dedicated to the medical physics

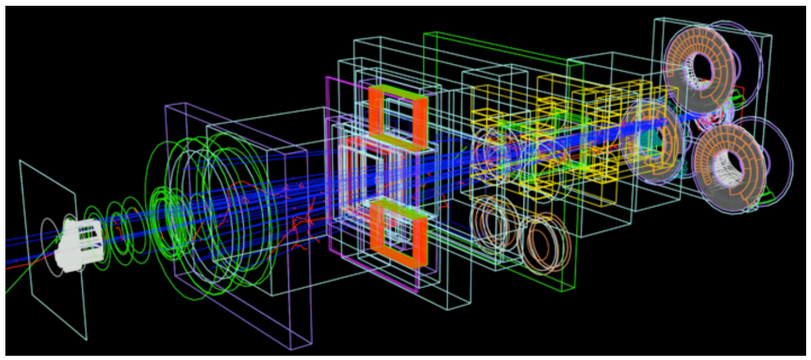
TOPAS

Human phantom

Treatment Planning System Validation



Beam line simulations



SLAC NATIONAL ACCELERATOR LABORATORY

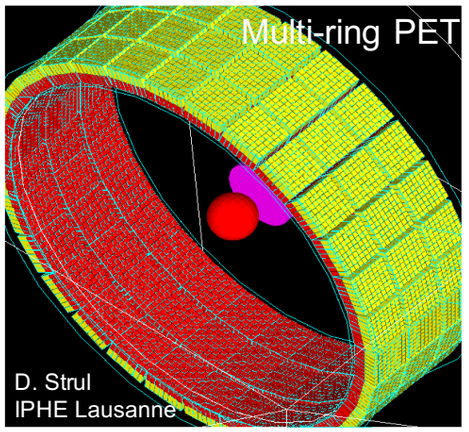
MGH 1811

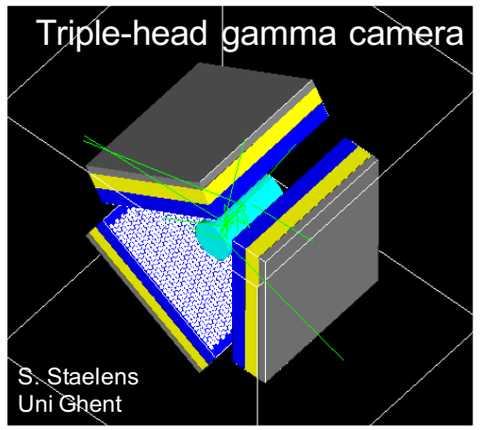
UCSF University of California San Francisco

Members of the OpenGATE Collaboration

- Laboratoire de Physique Corpusculaire - Pôle Physique pour la Santé et l'Environnement (PPSE), UMR6533 CNRS-Université Clermont Auvergne, Clermont-Ferrand
- Laboratoire d'Imagerie et de Modelisation en Neurobiologie et en Cancerologie (IMNC), Orsay
- Centre de Recherche Et d'Applications en Traitement de l'Image et du Signal (CREATIS), Lyon
- Service Hospitalier Frédéric Joliot (SHFJ), CEA-Orsay
- Centre de Recherche en Cancerologie Nantes-Angers (UMR 892 INSERM/CNRS)
- Sogang University (Department of Electronic Engineering), Seoul
- Institut Pluridisciplinaire Hubert Curien (IPHC, Departement Recherches Subatomiques), Strasbourg
- Forschungszentrum-Juelich (IME), Juelich
- Laboratoire de Traitement de l'Information Medicale (LaTIM), Brest
- Memorial Sloan-Kettering Cancer Center (Department of Medical Physics), New York
- Delft University of Technology (IRI)
- Technological Educational Institute of Athens (Department of Medical Instruments Technology), Athens
- Centre de Physique des Particules de Marseille (CPPM), Marseille
- Laboratoire de Physique Subatomique et des technologies associees (SUBATECH), Nantes
- UMR 1037 INSERM/UPS, Toulouse
- UC Davis, California
- Medical University Vienna, Wien
- MedAustron, Wiener Neustadt

- PET Systems
- SPECT Systems
- Radiation Therapy
- Prototypes





Geant4 Physics

Electromagnetic physics

"Standard processes" valid from 1 keV to 100 TeV

"Low Energy" from 10 eV to 100 TeV (changeable via UI commands)

Down to eV for Geant4-DNA in liquid water

Optical photons

Weak interaction physics

Decay of subatomic particles

Radioactive decay of nuclei

Hadronic physics

Pure strong interaction physics valid from 0 to 100 TeV

electro- and gamma-nuclear

Parameterised or "Fast simulation physics"

Electromagnetic physics

- Processes and models
- Physics Lists

Electromagnetic models and processes

Standard package - Condensed history approach

EmStandard_option3

EmStandard_option4 (also for high energy)

Low-Energy package - Condensed history approach

Penelope physics models (down to 100 eV)

Livermore data library (down to 10 eV)

Geant4-DNA (discrete simulations) see talk from S. Incerti

G4-DNA Physics list

Stopping powers, ranges, gamma cross sections

Comparison of

Attenuation coefficients

Stopping powers and ranges of e-, p, alpha as respect to NIST

Project to have systematic regression tests

2005

910 IEEE TRANSACTIONS ON NU... VOL. 52, NO. 4, AUGUST 2005

Comparison of Geant4 Electromagnetic Physics Models Against the NIST Reference Data

Katsuya Amako, Susanna Guatelli, Vladimir N. Ivanchenko, Michel Maire, Barbara Mascialino, Koichi Murakami, Petteri Nieminen, Luciano Pandola, Sandra Parlati, Maria Grazia Pia, Michela Piergentili, Takashi Sasaki, and Laszlo Urban

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

2010

Validation of the Geant4 electromagnetic photon cross-sections for elements and compounds

G.A.P. Cirrone [a], G. Cuttone [a], F. Di Rosa [a], L. Pandola [b,*], F. Romano [a], Q. Zhang [a,c,**]

[a] INFN, Laboratori Nazionali del Sud, Via Santa Sofia 62, I-95125 Catania, Italy
[b] INFN, Laboratori Nazionali del Gran Sasso, S.S. 17 bis km 18+910, I-67100 Assergi (AQ), Italy
[c] Department of Nuclear Physics, China Institute of Atomic Energy, Beijing 102413, China

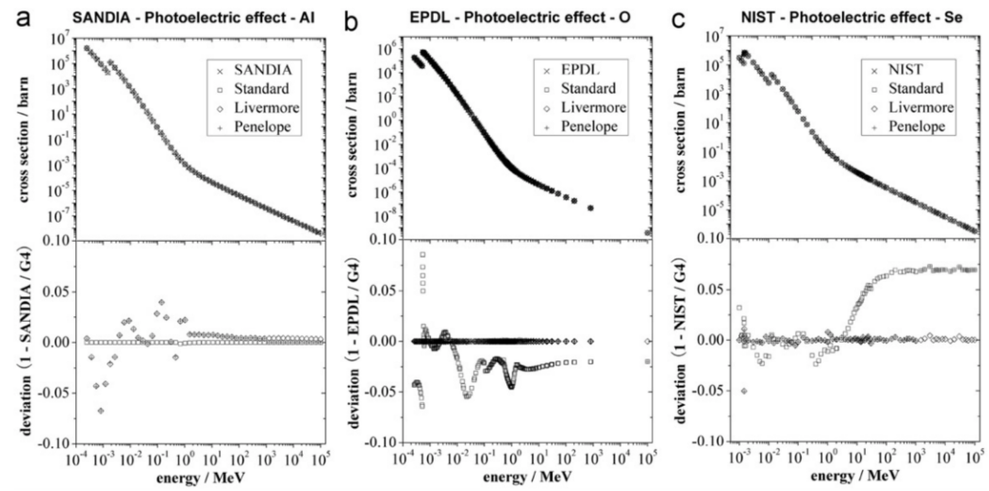


Fig. 4. Photoelectric effect cross-sections for the three EM models compared to data libraries. (a) SANDIA for Al; (b) EPDL97 for O; (c) NIST for Se.

Bremsstrahlung spectra for low energy and thick targets

2015

Comparison of

different physics models

for low energy
(70 keV-3MeV)

Results of potential interest for medical physics applications, where knowledge of the energy spectra and angular distributions of photons is needed for accurate dose calculations with MC and other fluence-based methods.

Nuclear Instruments and Methods in Physics Research B 350 (2015) 41–48

Contents lists available at ScienceDirect

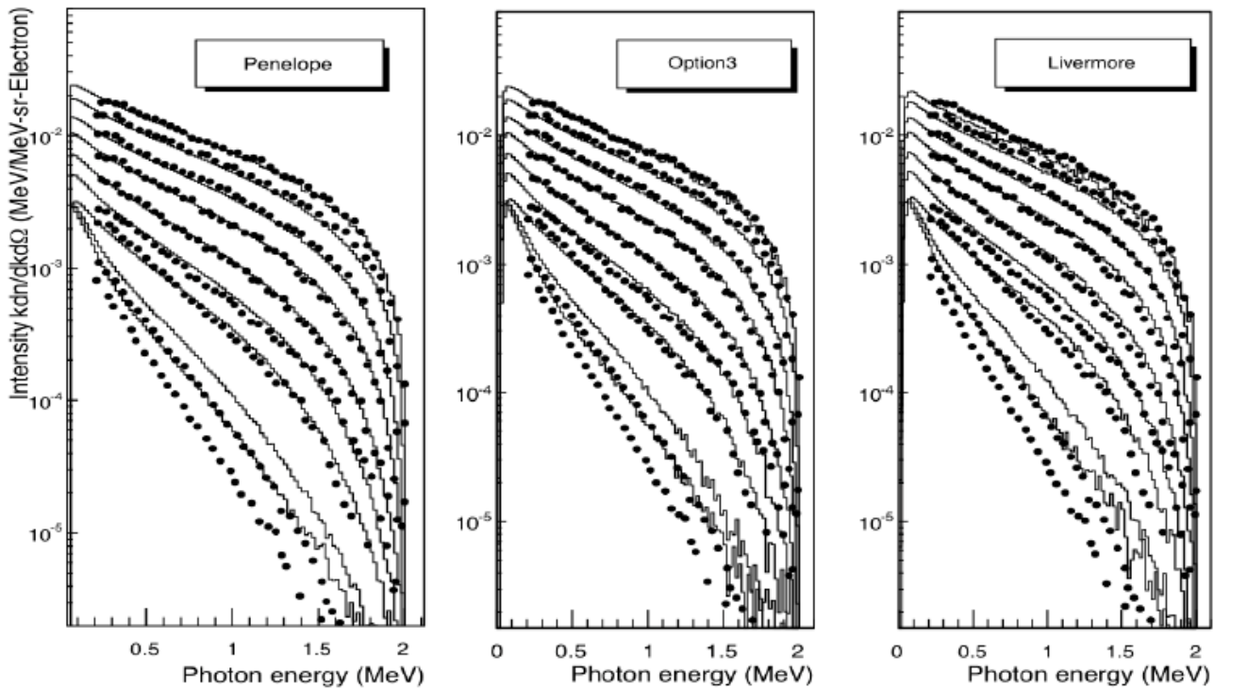
Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Validation of the GEANT4 simulation of bremsstrahlung from thick targets below 3 MeV

L. Pandola[a,b,*], C. Andenna[c], B. Caccia[d]

[a] INFN, Laboratori Nazionali del Sud, Via Santa Sofia 62, I-95125 Catania, Italy
[b] INFN, Gran Sasso Science Institute, Viale Francesco Crispi 7, I-67100 L'Aquila, Italy
[c] INAIL, Dipartimento Innovazioni Tecnologiche e Sicurezza degli Impianti, Prodotti ed Insediamenti Antropici, Via Alessandria 220, I-00198 Roma, Italy
[d] Dipartimento Tecnologie e Salute, Istituto Superiore di Sanità and INFN, Gruppo Collegato dell'Istituto Superiore di Sanità, Viale Regina Elena 299, I-00161 Roma, Italy

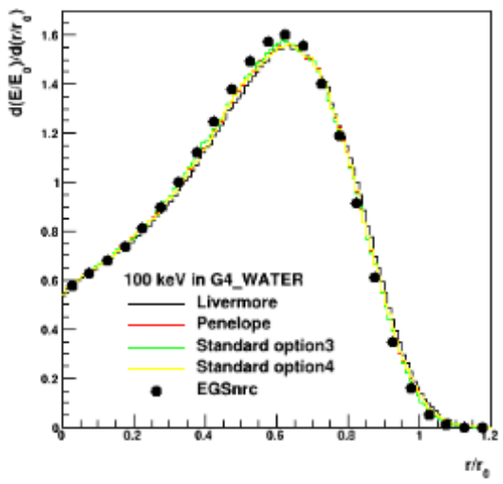


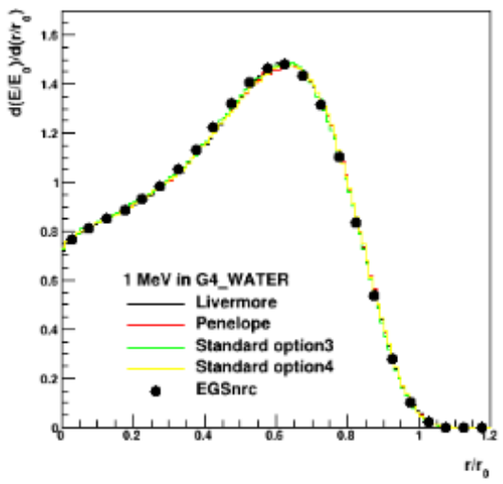
Example of ongoing regular regression tests

Dose point kernel test

Author: S. Incerti

- Dose distribution around a point source of electrons
- Good agreement between Geant4 and EGSnrc, especially at higher energy
- Similar performance of the G4 physics lists
- Note: this is not comparison to experimental measurements



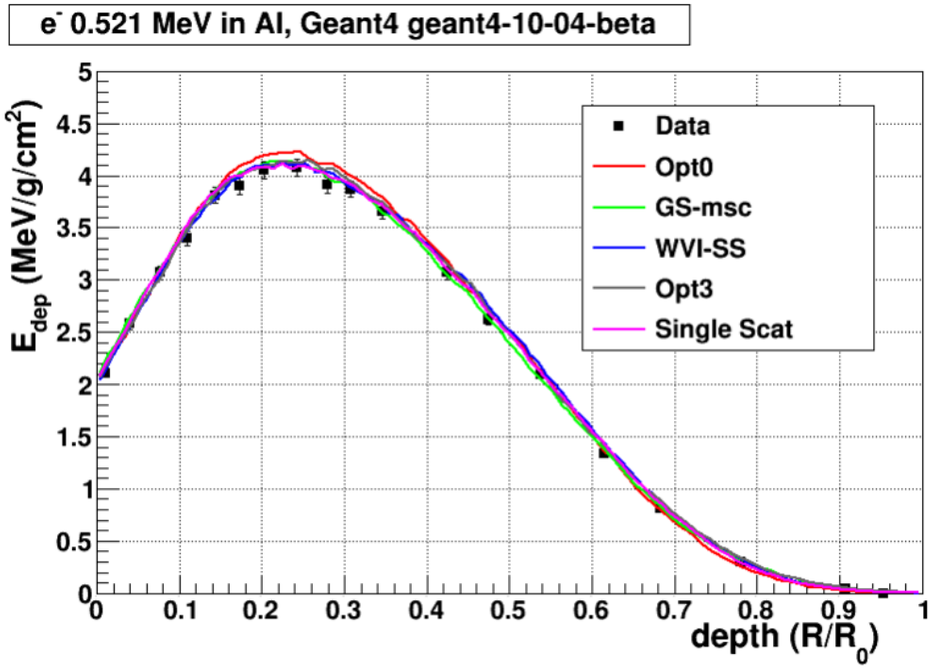


Energy deposition of e⁻

2017

Author: V. Ivantchenko

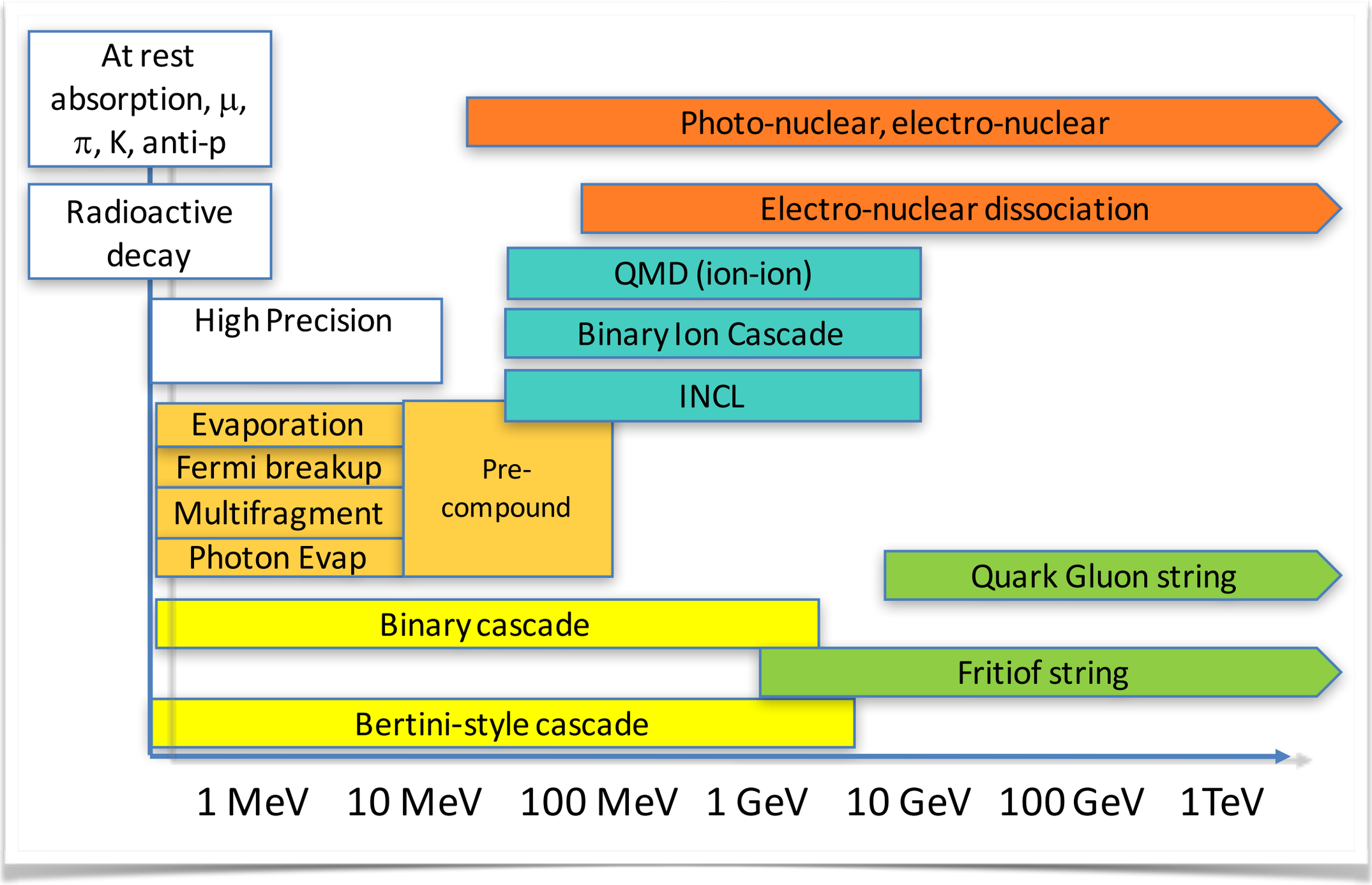
- Comparison against the Sandia reference data
- The agreement with the reference data is better with a strong step limitation (SS, GS, Opt3)
- GS and Opt3 with strong step limits are equivalent to SS



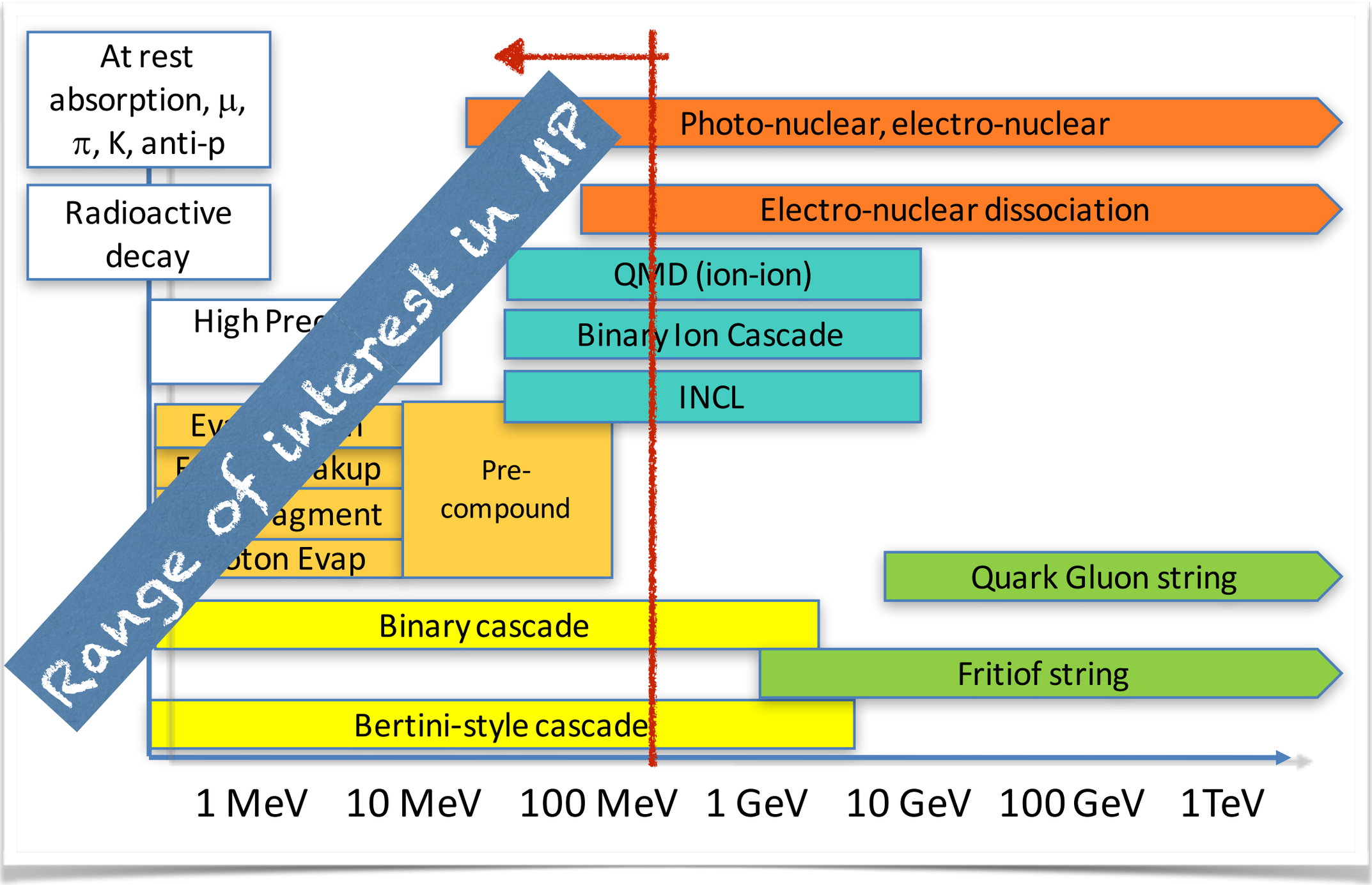
Hadronic physics

- Benchmarck & Validation
- New development

Partial hadronic model inventory



Partial hadronic model inventory



Medical Physics benchmark

1. To identify **benchmarks of medical simulation** that are based on **high quality experimental** or **theoretical data** for simple source and geometry set-ups

2. To prepare these benchmarks for **routine regression testing**

3. To determine when **action needs to be taken** and work with the developers to determine what that action should be.

Bragg peak validation

2010

Nuclear Instruments and Methods in Physics Research B 268 (2010) 2343–2354

Contents lists available at ScienceDirect

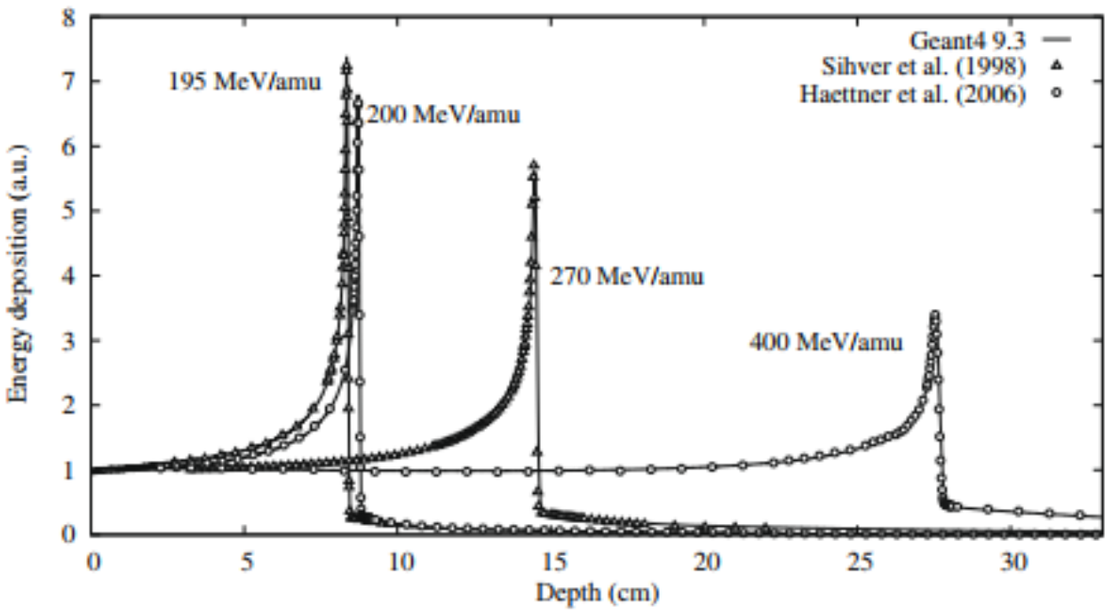
Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Validation of recent Geant4 physics models for application in carbon ion therapy

A. Lechner [a,b,*], V.N. Ivanchenko [b,c], J. Knobloch [b]

[a] Atomic Institute of the Austrian Universities, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria
[b] European Organization for Nuclear Research (CERN), Geneva 23, Switzerland
[c] Ecoanalytica, Moscow State University, 119899 Moscow, Russia



The revised ICRU 73 tables for water are based on model oscillator strength spectra implying a mean excitation energy of 78 eV, compared to 67.2 eV in the original ICRU 73 tables (see P. Sigmund, A. Schinner and H. Paul, "Errata and Addenda for ICRU Report 73", 2009).

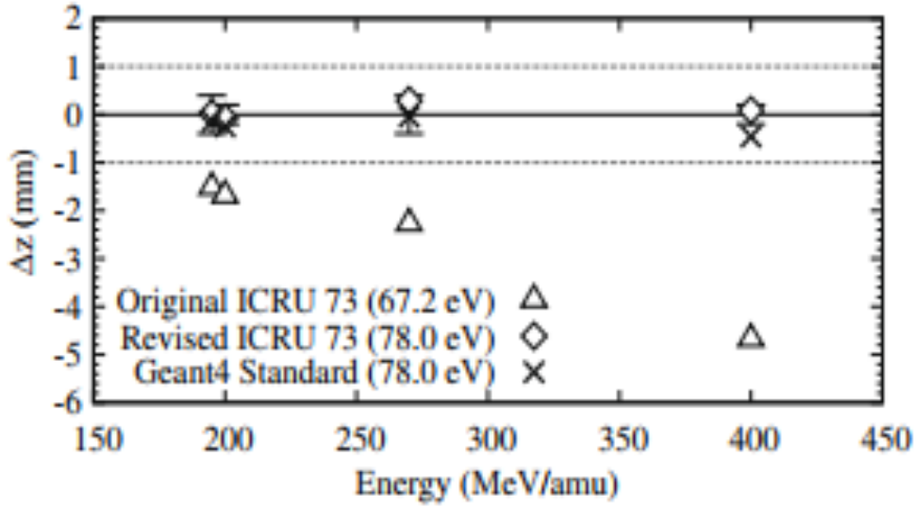


Fig. 2. Comparison of simulated and measured ^{12}C depth-dose profiles in water (0.997 g/cm^3). Simulations were performed with Geant4 9.3, using revised ICRU 73 stopping power tables [22] and the QMD nuclear reaction model [33]. Experimental data derive from Sihver et al. [31] (triangles) and Haettner et al. [32] (circles), where profiles of Haettner et al. [32] were shifted to match more precise measurements of the peak position by D. Schardt et al. [61]. All experimental data by courtesy of D. Schardt.

Validation of fragmentation for ion incident beams

Validation of Geant4 fragmentation for Heavy Ion Therapy

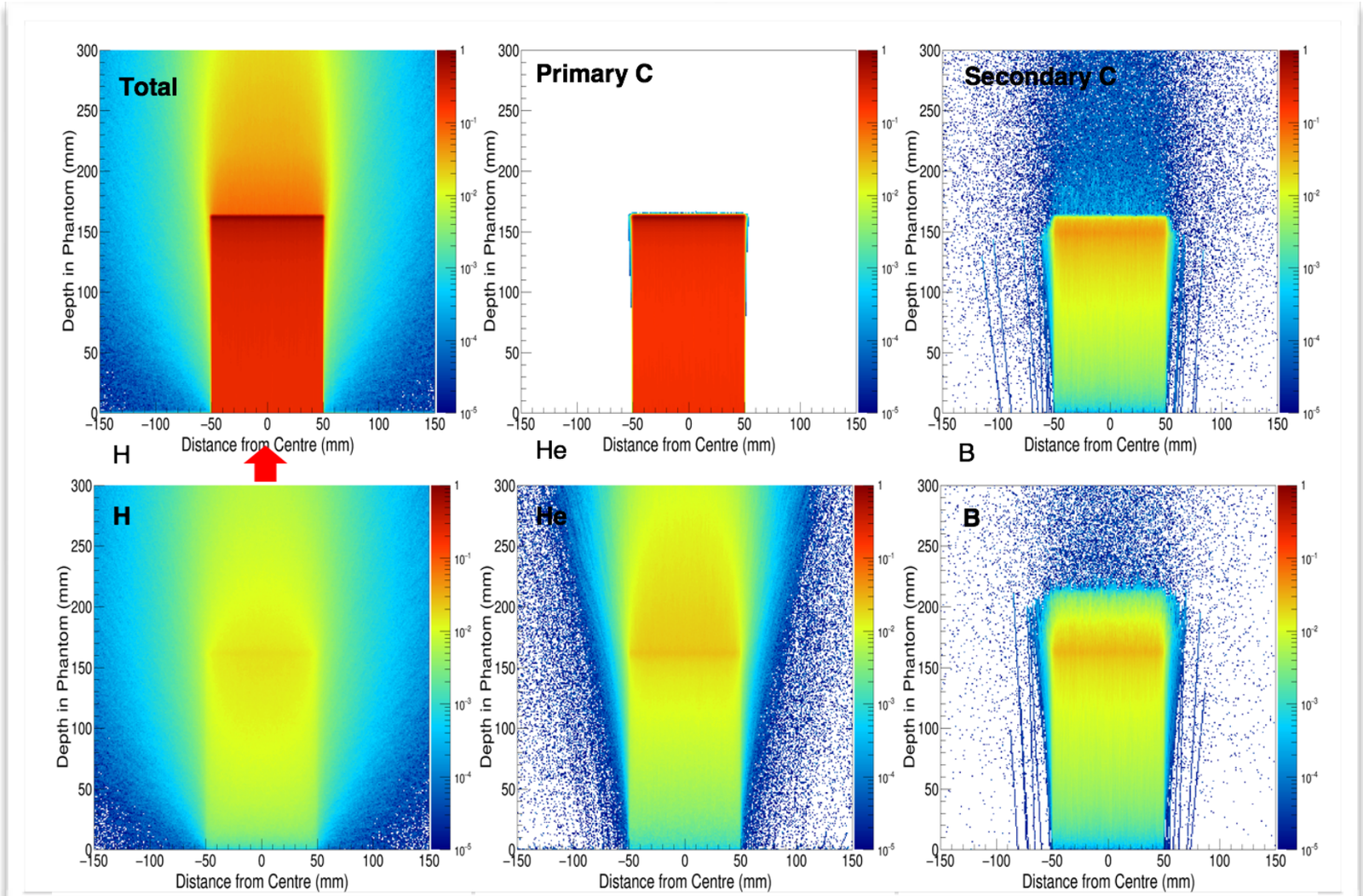
D. Bolst[1], G.A.P. Cirrone[2], G. Cuttone[2], G. Folger[3], S. Incerti[4,5], V. Ivanchenko[3,6], T. Koi[7], D. Mancusi[8], L. Pandola[2], F. Romano[2,9], A. B. Rosenfeld[1] and S. Guatelli[1]

UNIVERSITY OF WOLLONGONG

CENTRE FOR MEDICAL RADIATION PHYSICS

Next talk by S Guatelli

2017



Medical Physics benchmark: fragmentation processes

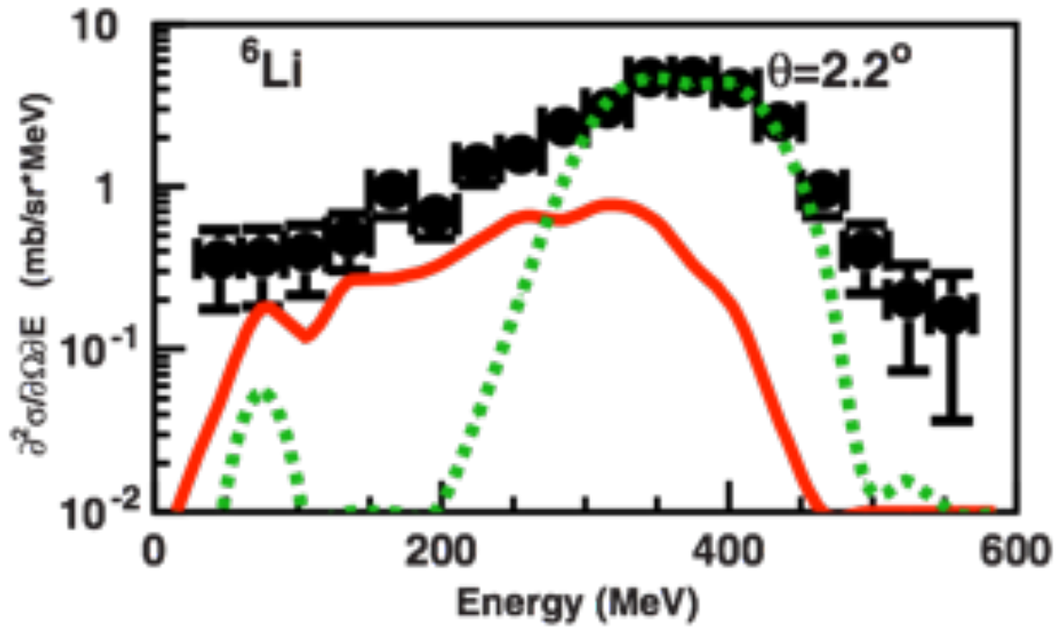
Despite the numerous and relevant applications there is no dedicated model to nuclear interaction below 100 MeV/A in Geant4

Many papers showed the difficulties of Geant4 in this energy domain:

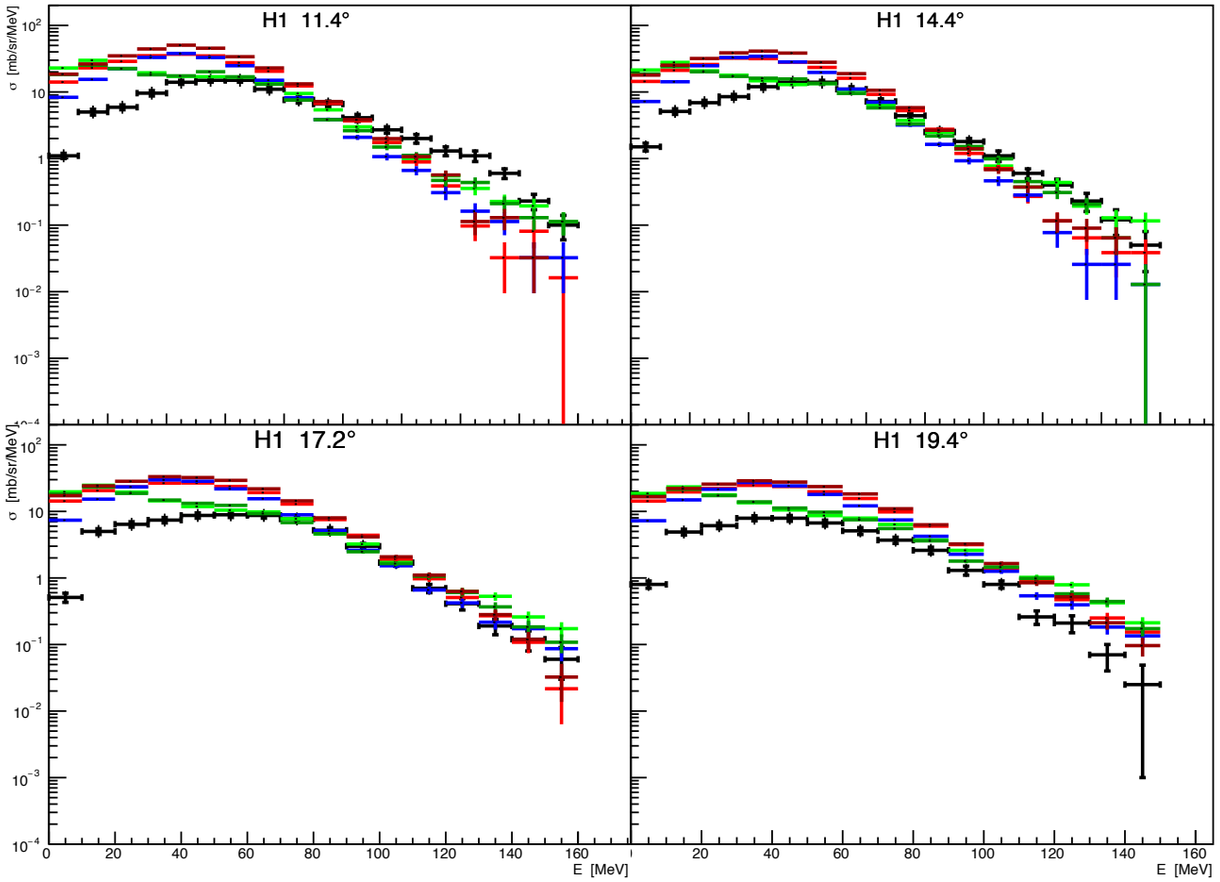
* Braunn et al. have shown discrepancies up to one order of magnitude in ^{12}C fragmentation at 95 MeV/A on thick PMMA target
* De Napoli et al. showed discrepancy specially on angular distribution of the secondaries emitted in the interaction of 62 MeV/A ^{12}C on thin carbon target
* Dudouet et al. found similar results with a 95 MeV/A ^{12}C beam on H, C, O, Al and Ti targets

- **Exp. data**
- **BIC**
- **G4QMD**

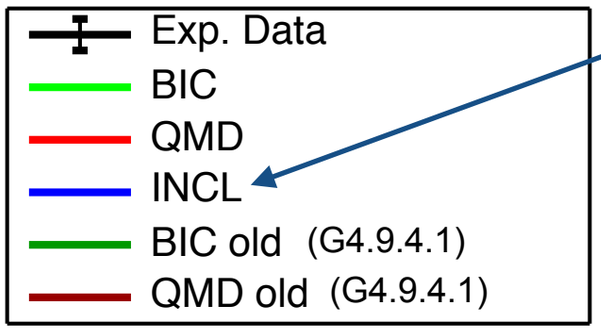
[Plot from De Napoli et al. Phys. Med. Biol., vol. 57, no. 22, pp. 7651–7671, Nov. 2012]



Cross section of the ^{6}Li production at 2.2 degree in a ^{12}C on ^{nat}C reaction at 62 MeV/A.



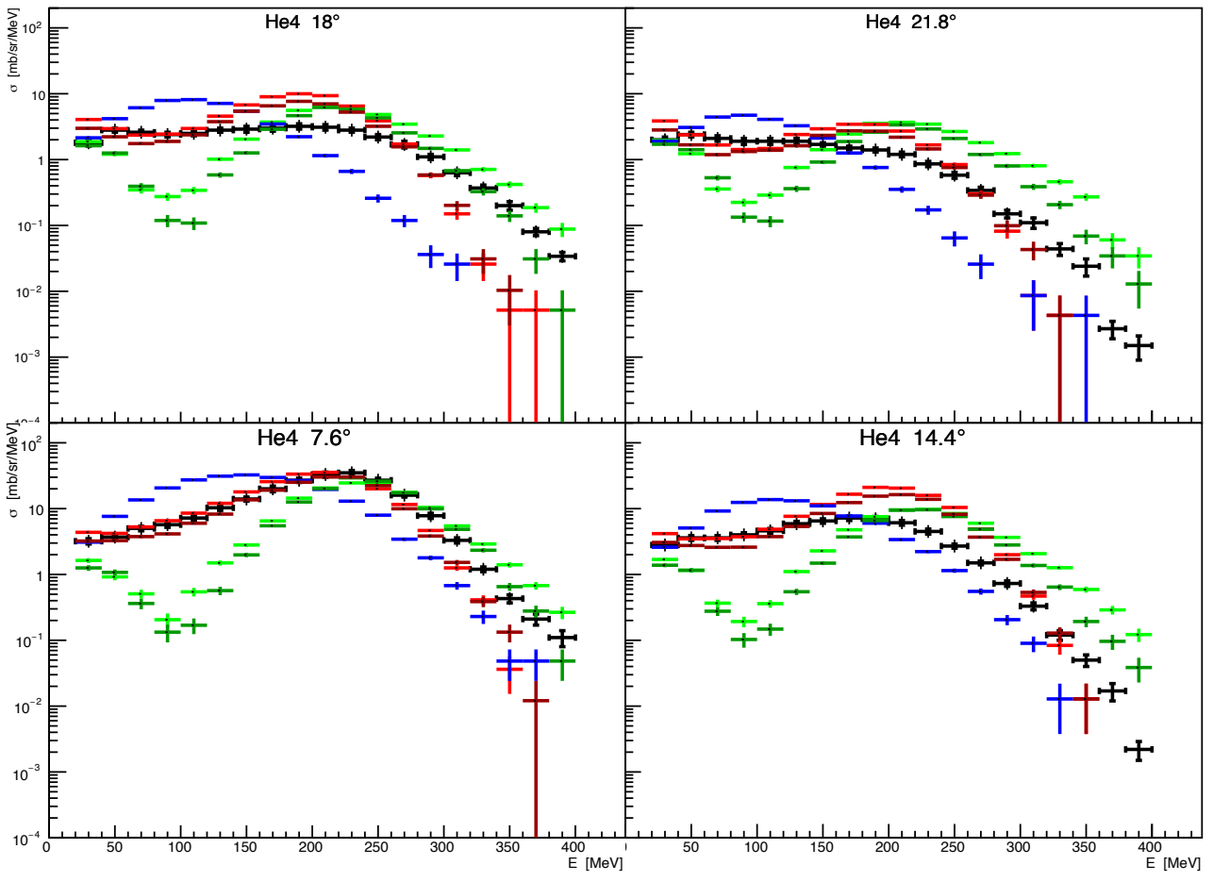
Exp Data from: De Napoli et al. Phys. Med. Biol., vol. 57, no. 22, pp. 7651–7671, Nov. 2012



updated benchmark with the new INCL model

2012 - 2017

protons and alphas at different angles

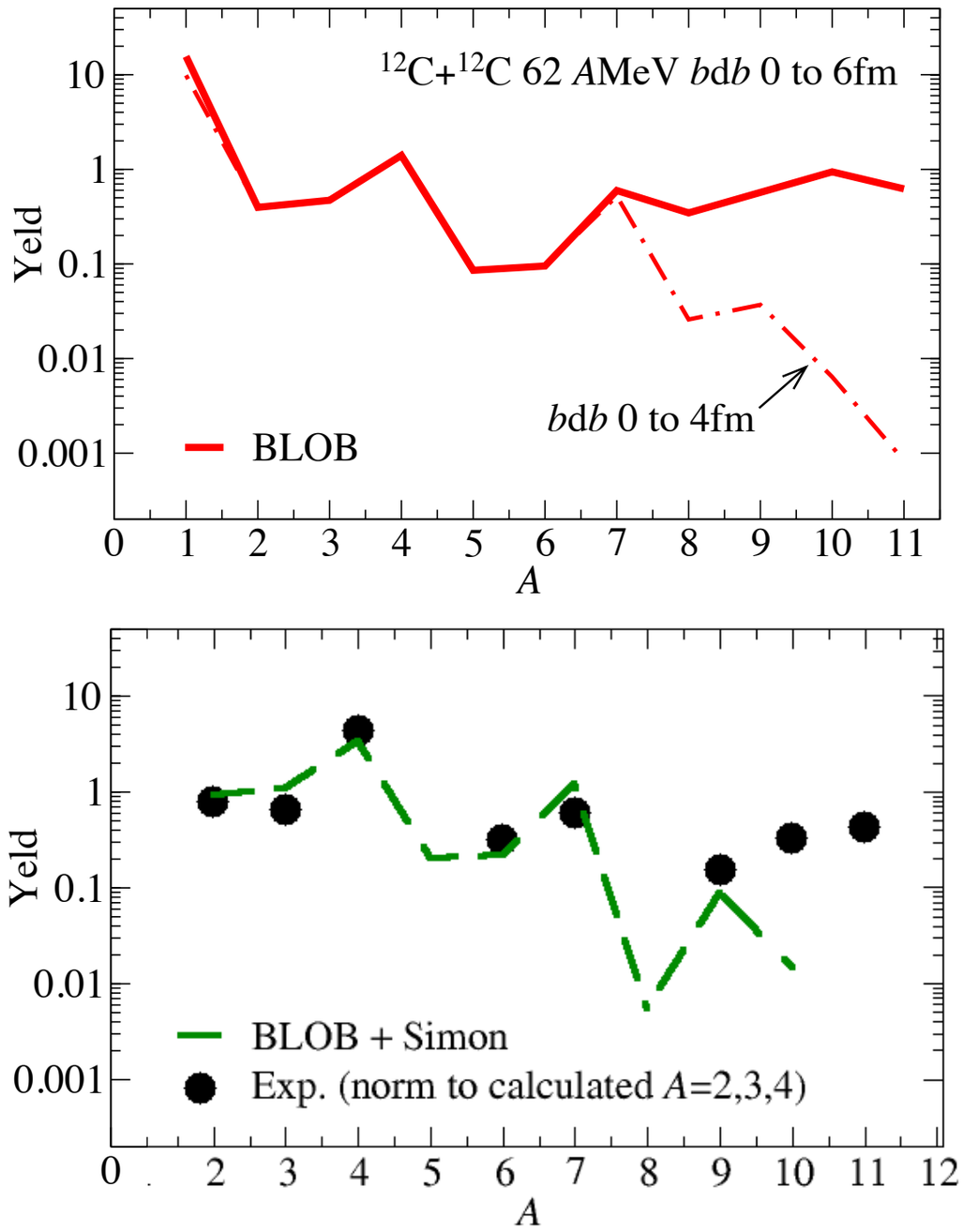


New developments: GENIALE project

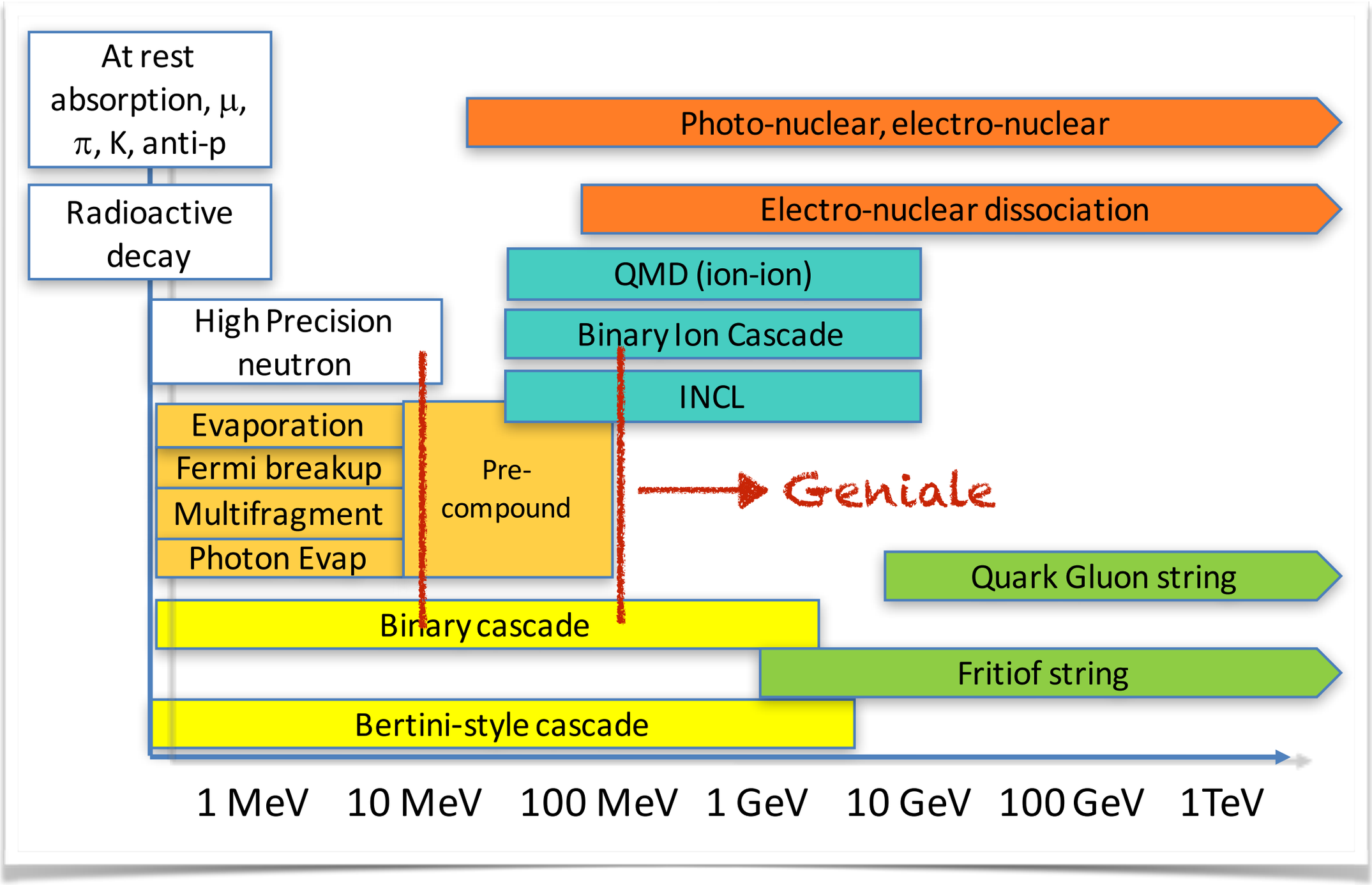
GEant **N**uclear **I**nteraction **A**t **L**ow **E**nergy

- Granted by the INFN National Scientific Committee 5 (CSN5)
- GeNIALE aims at improving the Geant4 performances in nuclear fragmentation below 100 MeV/A
- It will implemented a dedicated model in collaboration with the theoreticians of LNS (Catania) and IPN (Orsay)
  - **SMF** (Stochastic Mean Field) is a BUU model: Developed by **Maria Colonna** (LNS, Catania)
  - **Blob** is a BL model: Developed by **Paolo Napolitani** (IPN, Orsay)
- An update of the benchmark with ^{12}C on C thin target at 62 MeV/A has been done

See poster by C Mancini (Id. 61)



Partial hadronic model inventory



Official examples

Geant4 medical examples

- Advanced examples
  - Brachytherapy
  - Cell_irradiation
  - Human_phantom
  - Medical_linac
  - IORTtherapy
  - Hadrontherapy
- Extended examples
  - Medical
    - DICOM
    - dna
    - FanoCavity
    - ElectronScattering
    - GammaTherapy

Geant4 medical examples

- Advanced examples
  - **Brachytherapy**
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    - FanoCavity
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Brachytherapy

Current authors: S Guatelli and D Cutajar (CMRP, UOW)

Calculation of the energy deposition in water phantom of:

Bebig Isoseed I-125

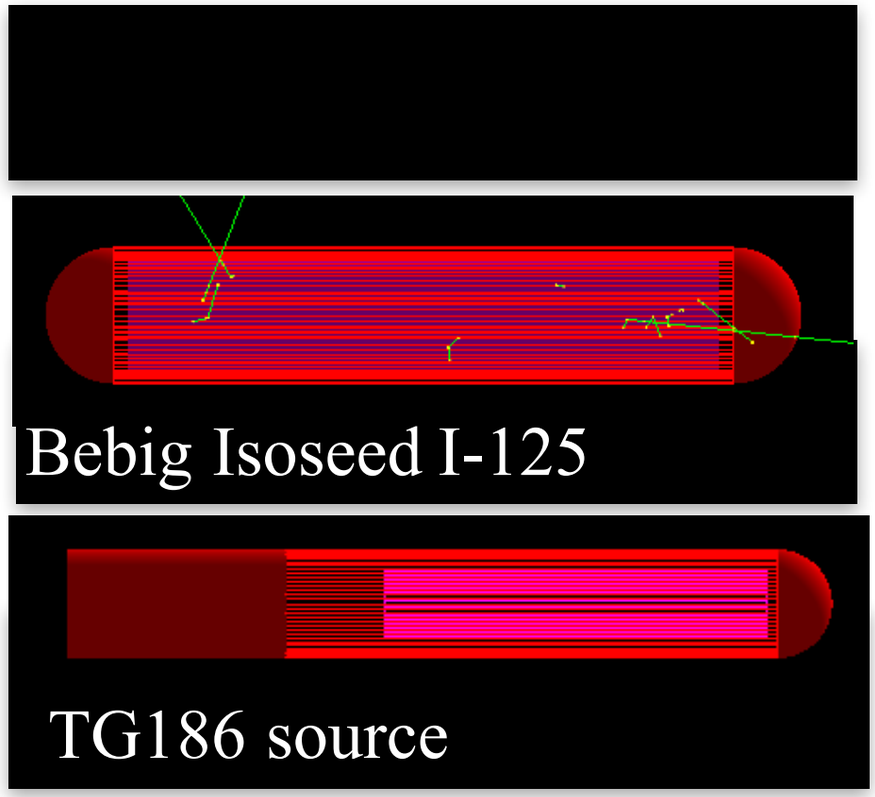
Flexisource Ir-192 (Med Phys 3(12) 2006, 4578-4582)

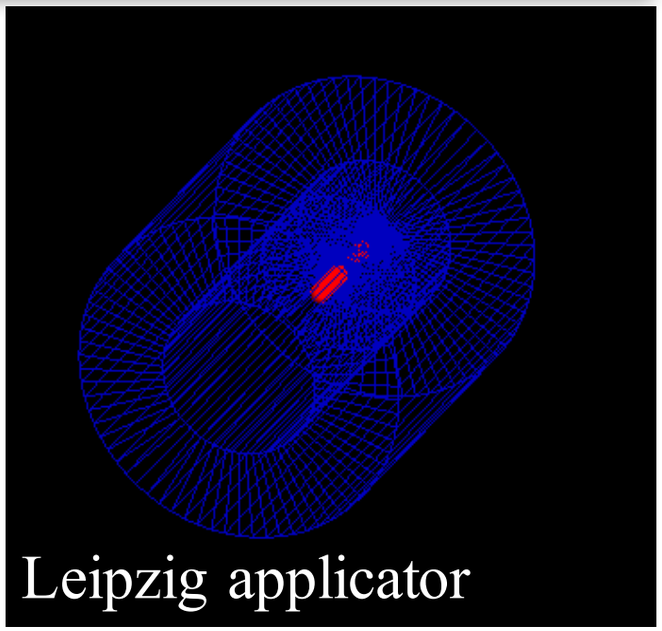
Ir-192 TG186 reference source (Med Phys 42(2015), 3048-3062

Leipzig applicator

How to define a source

How calculate dose distributions



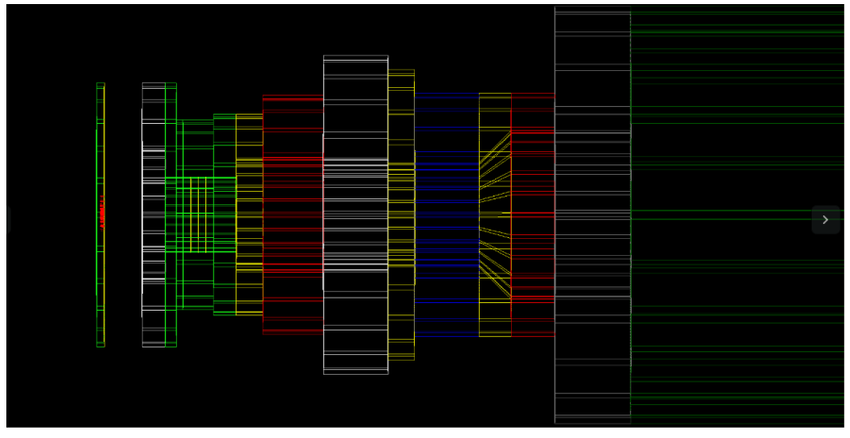


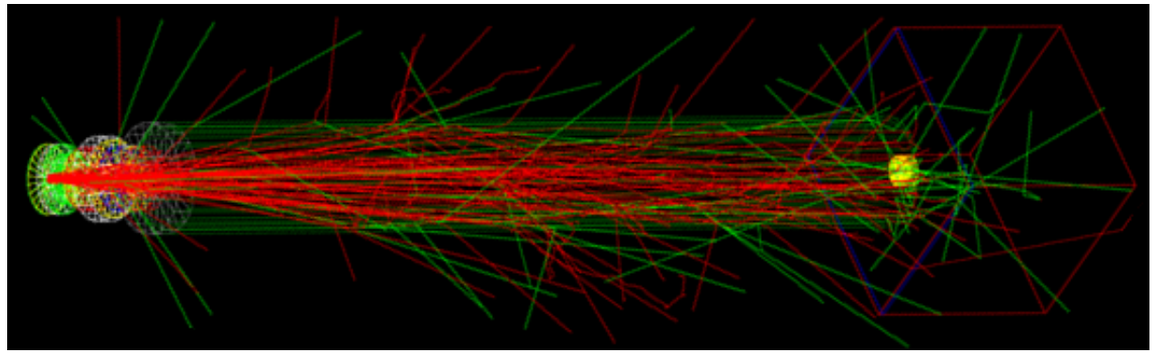
Curtesy of Susanna Guatelli

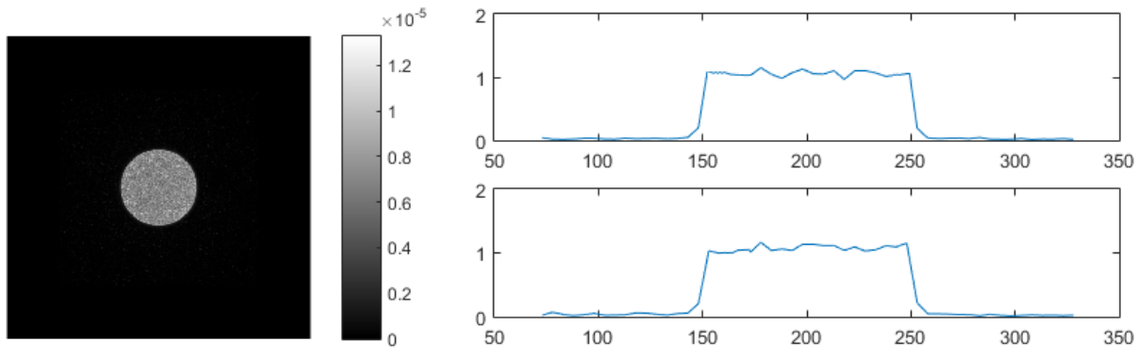
IORT Therapy

Current authors: D. Lamia, P. Pisciotta, G Russo (INFN and CNR) giorgio.russo@ibfm.cnr.it

- **State of the art**
  - Implementation of the geometry of clinical iort devices like NOVAC7 and LIAC10;
  - Experimental validation
- **Future aims:**
  - Goodness evaluation of Geant4 results (PDD, lateral profile @R100);
  - Output factor calculation;
  - Radioprotection assessment







DICOM

Current Unique for its anatomical details and high spatial resolution (0.18 x 0.18 mm^2 pixel size).

Slice thickness: 1.25 mm

Homogeneous brain, Spinal disks, ear canals, sinus cavities, deciduous and descending teeth with enamel and dentin.

To be released in Geant4 10.4 within the DICOM interface

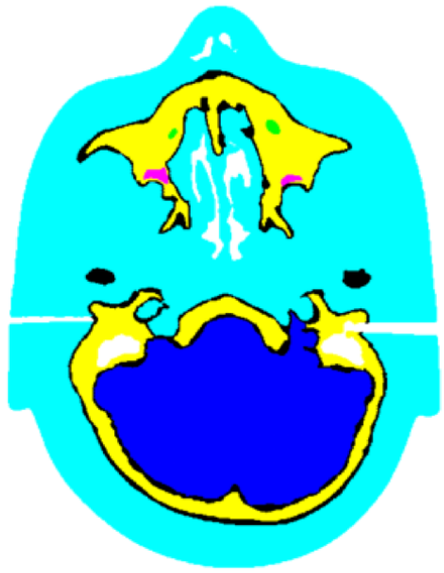
CENTRE FOR MEDICAL RADIATION PHYSICS

UNIVERSITY OF WOLLONGONG AUSTRALIA

Giacometti, V., Guatelli, S., Bazalova-Carter, M., Rosenfeld, A.B., Schulte, R.W. (2017) Physica Medica, 33, pp. 182-188

Collaboration between the University of Wollongong, Australia, and Loma Linda University, US.

HN715,CIRS



Geant4 model

Curtesy of Susanna Guatelli

Hadrontherapy

Current authors: GAP Cirrone, G Cuttone, L Pandola, G Petringa, P. Pisciotta, F Romano

Three beamlines simulated:

Protontherapy facility eye melanoma treatment:

CATANA (LNS-INFN)

Multidisciplinary beamline for ion and proton beams:

Zero degree hall (LNS-INFN)

Multidisciplinary beamline for high energy proton beams:

TIFPA beam line (INFN) **—> Next release**

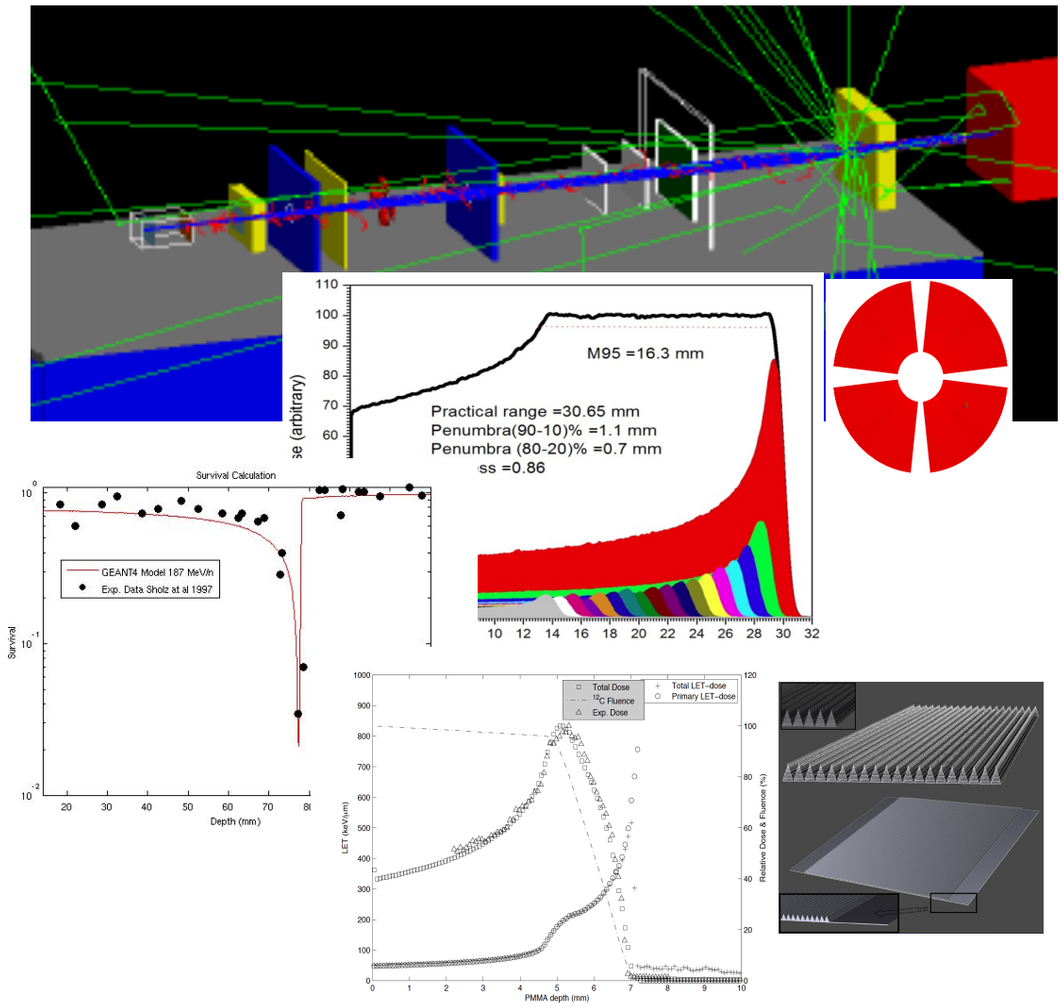
Phase Space **—> Next release**

Dose averaged and track averaged LET

Bragg peak validation

RBE calculations **—> Next release**

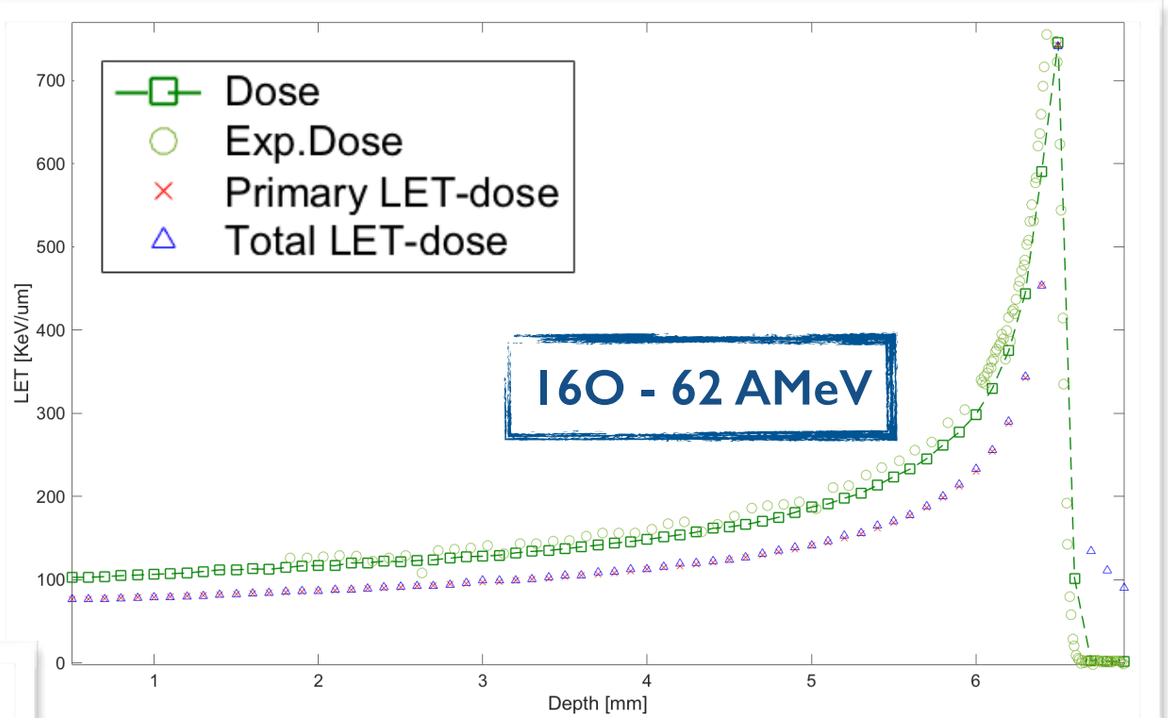
DICOM interface

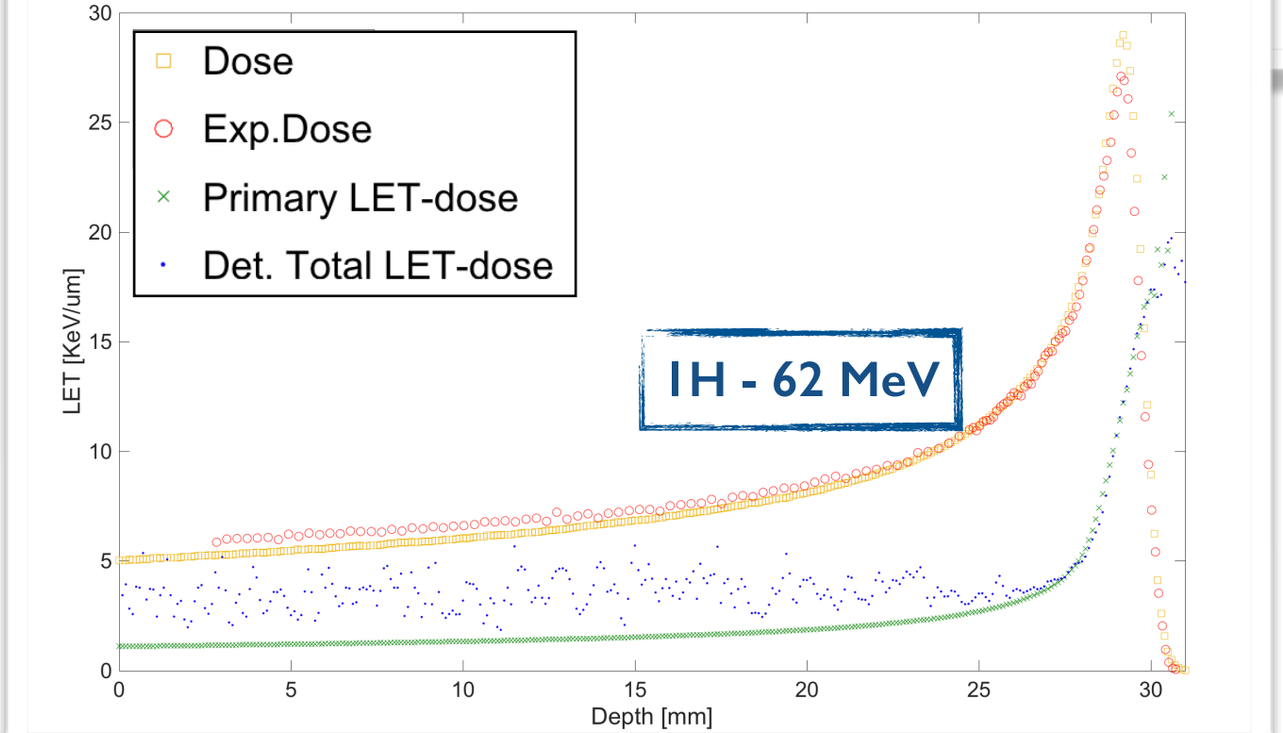


Curtesy of Giada Petringa

Hadrontherapy: LET calculation

- ☑ Development of a **new alghoritm** for total dose-average and track-average LET calculation independent from transport parameters
- ☑ **Validation** of alghoritms for dose-average and track-average LET calculation





Study on averaged LET comparison of 1H, 4He, 6Li, 9Be, 11B, 12C, 14N and 16O

Curtesy of Giada Petringa

Hadrontherapy: RBE calculation

LEM

pre-calculated output

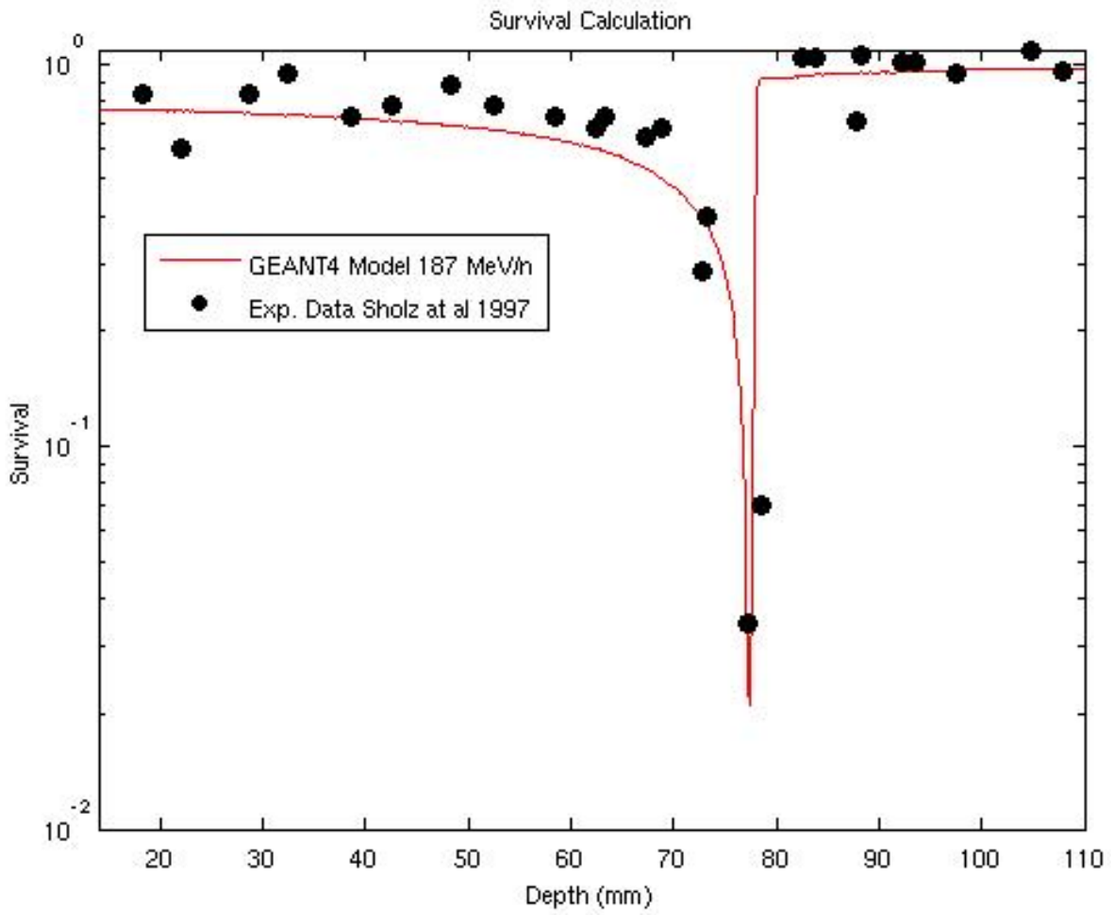
In collaboration with the INFN section of Turin

INTERFACE CLASS

Geant 4

***Hadrontherapy* example**

New dedicated module implemented in the example



Collaboration with

esa

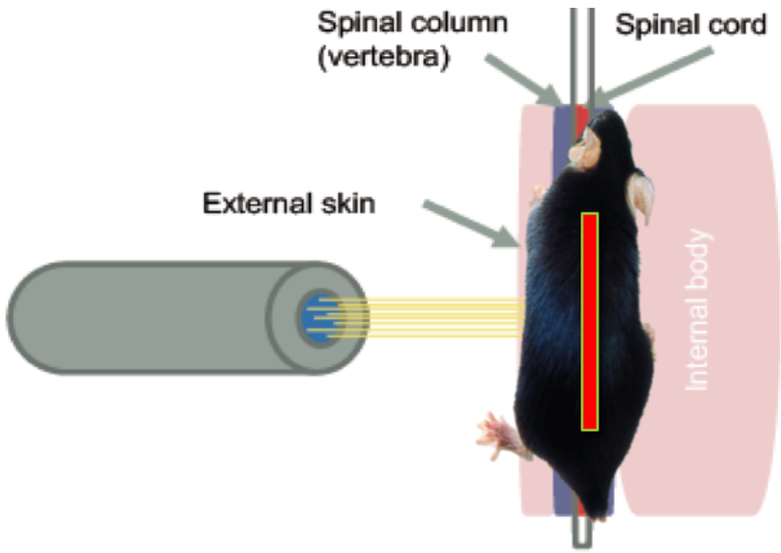
CENBG

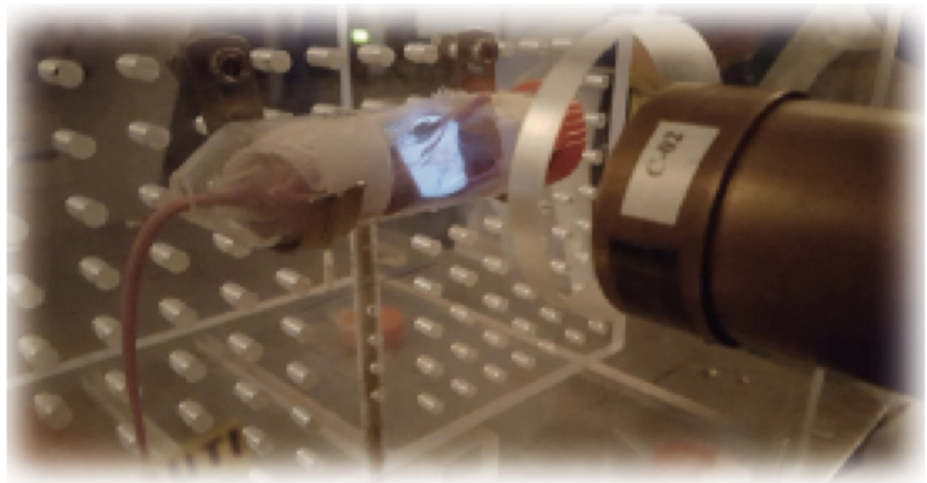
INFN
Istituto Nazionale di Fisica Nucleare

Nuclear Physics Institute, ASCR
Department of Neutron Physics

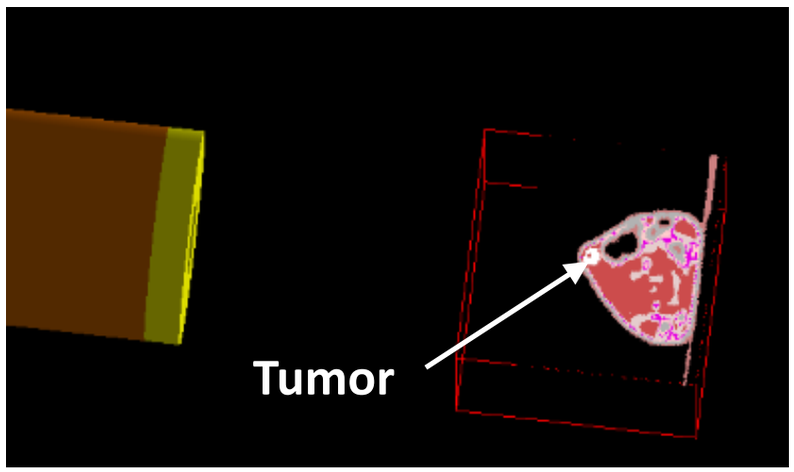
Curtesy of Francesco Romano

Hadrontherapy: DICOM interface

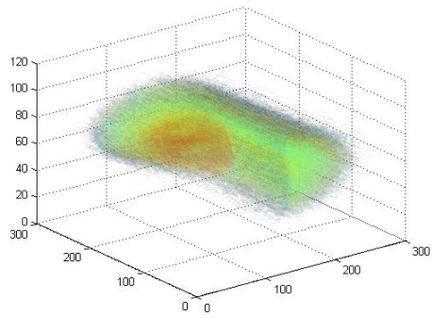




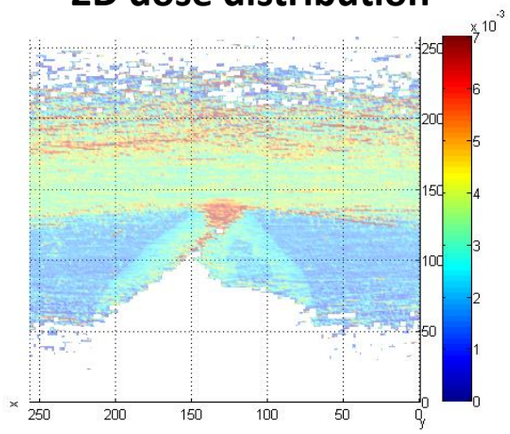
DICOM Interface



3D dose distribution (only one field)



2D dose distribution



See talk by P. Pisciotta

Ongoing activities around world

a selection

2017 Geant4 User Workshop and collaboration meeting

Geant4 User Workshop
19-22 September

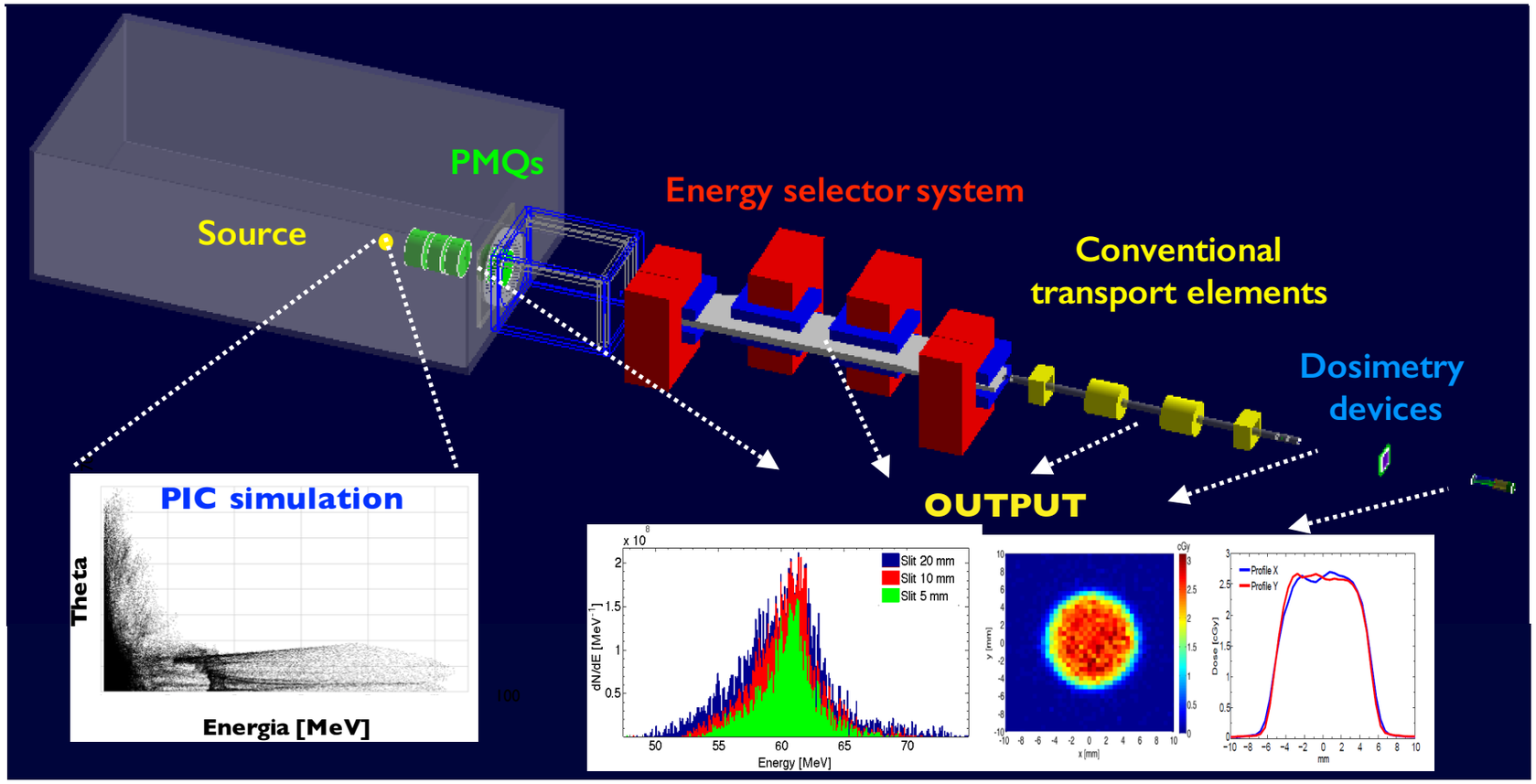
- About 50 attendees
- 75% of talks on the medical physics field
- New developments in medical imaging, radiotherapy, radiobiology

Geant4 Collaboration meeting
25-29 September

- Collaboration members annual meeting
- Discussing new developments of the code
- Fixing the future roadmap

The ELIMED application for laser-driven beams

Current authors: GAP Cirrone, G Cuttone, G Milluzzo, J Pipek, F Romano

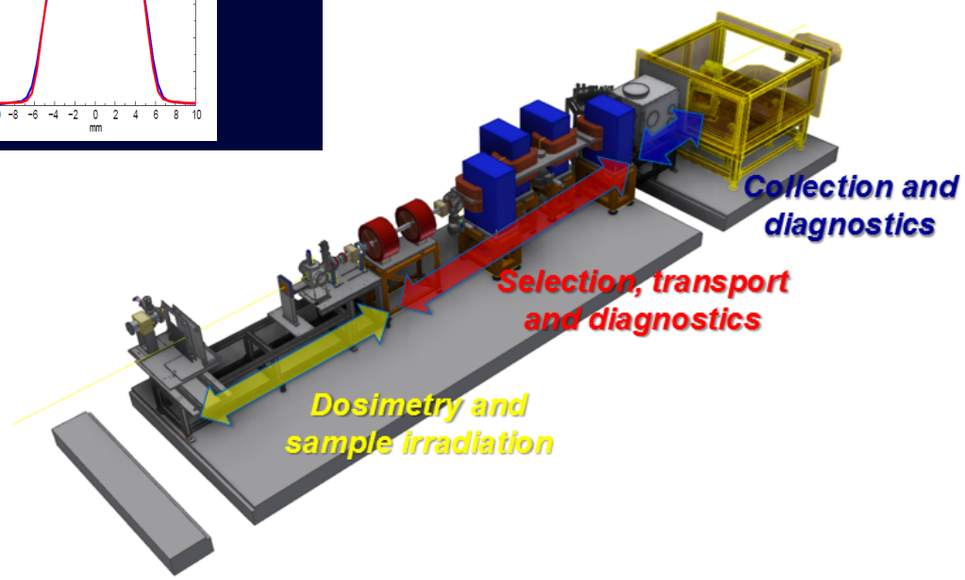


Requirements from ELI

- Easily modify geometrical configurations
- Accurate transport in magnetic fields
- User friendly

Application structure

- Component realistic model
- Magnetic and electric field implementation
- Realistic laser-driven particle source
- Information scoring along the beamline

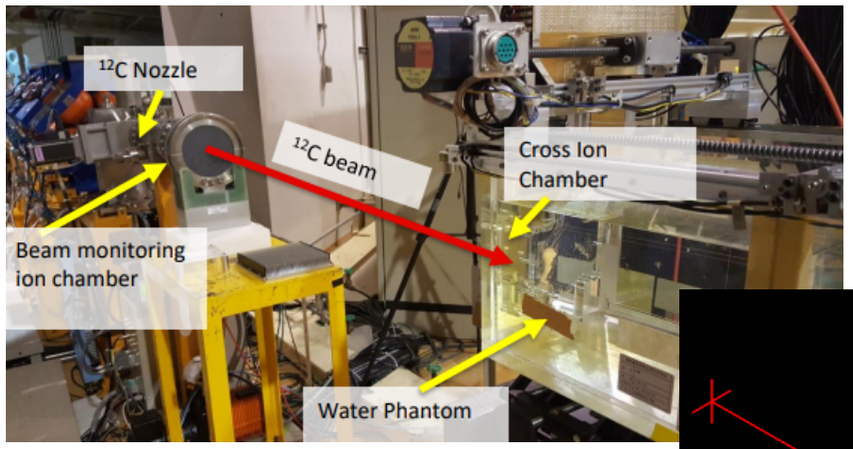


See talk by F. Romano

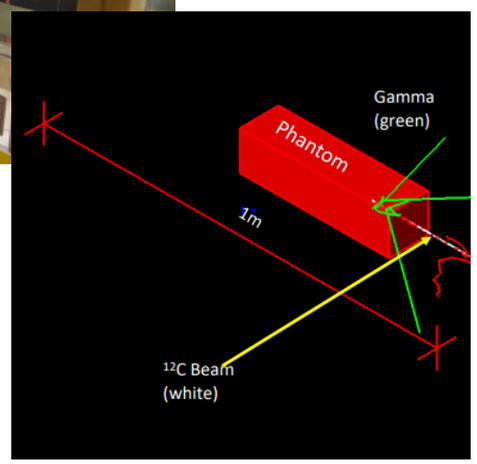
Evaluation of Geant4 for in-vivo range verification in Heavy ion therapy

Current authors: D. Bolst, S. Guatelli et al.

Experiment at Chiba



Geant4 simulation



CENTRE FOR MEDICAL RADIATION PHYSICS

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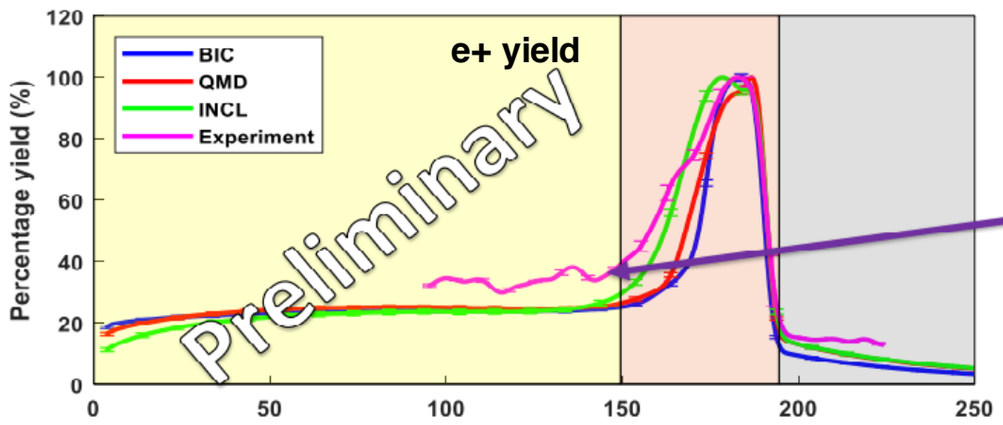
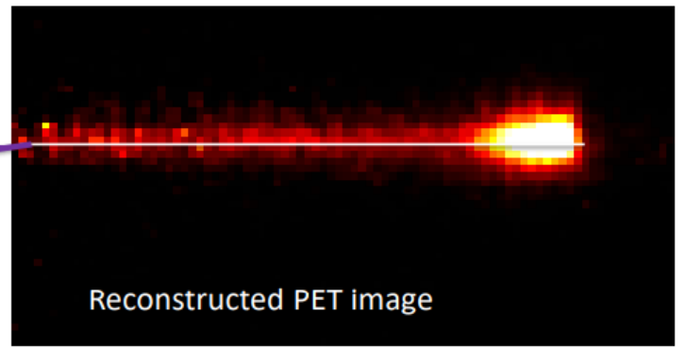
- Distal edges are the same (for e+ and 11C) and **all models are suitable for PET** range verification
- Proximal and relative yield (10C, 15O) discrepancies with the physics lists can cause over or under estimations depending on :
  - Inelastic Model
  - phantom
  - Primary Beam energy
  - InterSpill or Post Irradiation Imaging
  - In room or out of room



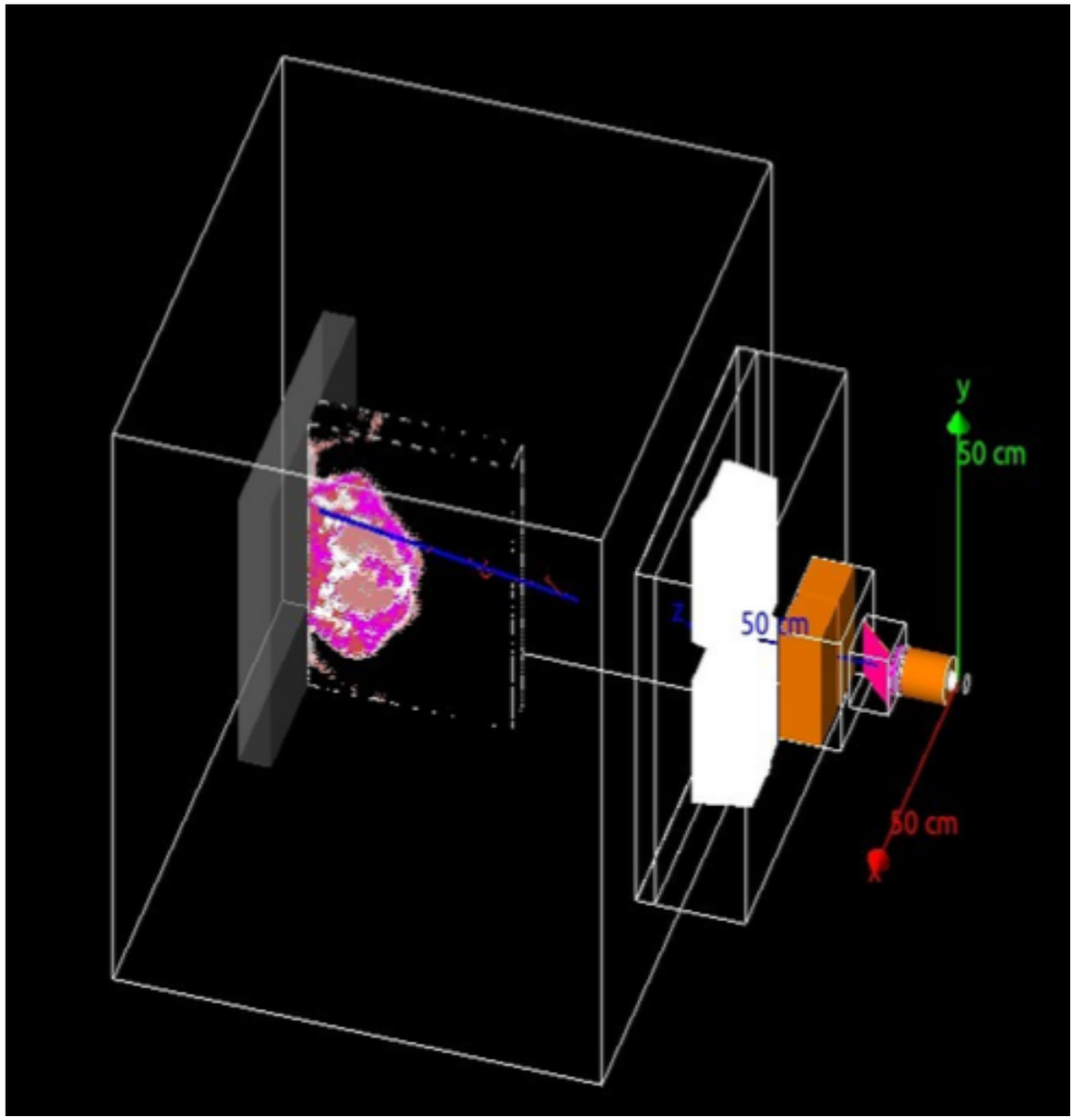
C12 @ 350 MeV/n on PMMA



Dose calculation algorithm

Current authors: A. Perales, M.A. Cortes-Giraldo, M.I. Gallardo

- SIEMENS ONCOR APPLICATION
  - Developed for the simulation of the Siemens Oncor linac treatment head for 6 MV photons.
  - Validation through a comparison with experimental measurements in water.
  - Deviations ≤ 2% at most significant regions.
  - Dosimetric validation of the geometry model of its MLC (160-MLC).
  - Contains a class (DPatientConstruction) which generates the patient geometry, using its DICOM image files, through a parameterization process.



The Italian MC-INFN project

Geant4 - INFN

TWiki > Geant4 Web > WebHome (2015-07-24, AndreaDotti)

Welcome to the Geant4 web

Main topics

- Geant4PerformanceTips: Tips for creating faster simulations with Geant4
- Physics Lists: References to physics lists covering all energy domains
- XeonPhiSupport: Instructions to run Geant4 application on Intel Xeon Phi co-processors

Working groups

- ElectromagneticPhysics: General resources for all electromagnetic physics models of Geant4
- AdvancedExamples: Main webpage for the Geant4 advanced examples
- Geant4MedicalPhysics: Resources for medical physics applications
- NoviceExtendedExamples: Shared documents for N&E Examples working group
- HadronicsMTNotes: Some material for Had WG developers related to Geant4 multi-threading

MC-INFN PROJECT

Monte Carlo activities @ INFN

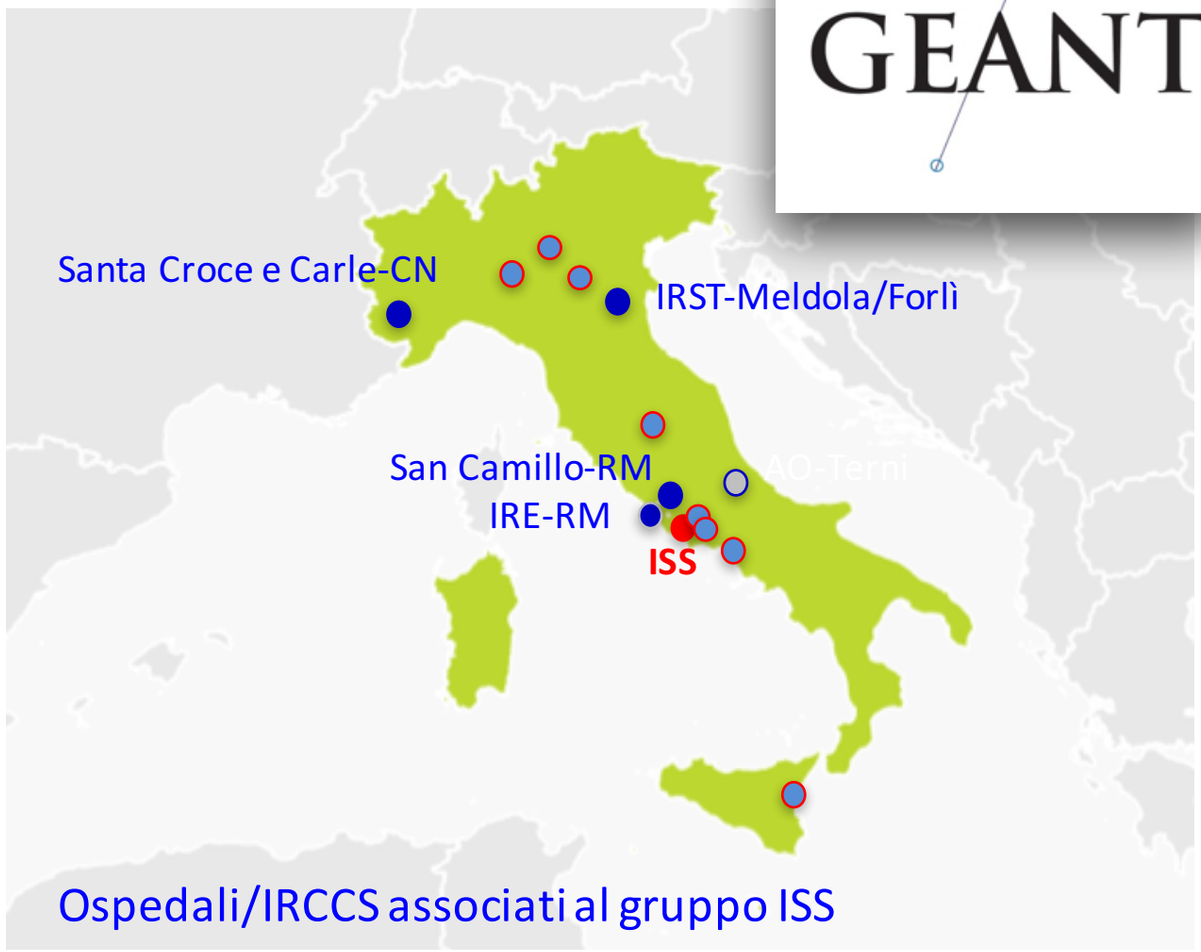
Many INFN Sections and connected hospitals

Activities inside the Geant4 collaboration (developments of algorithms and examples)

Users activity and benchmark

Connection with the FLUKA developers

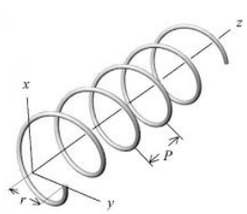
Dissemination

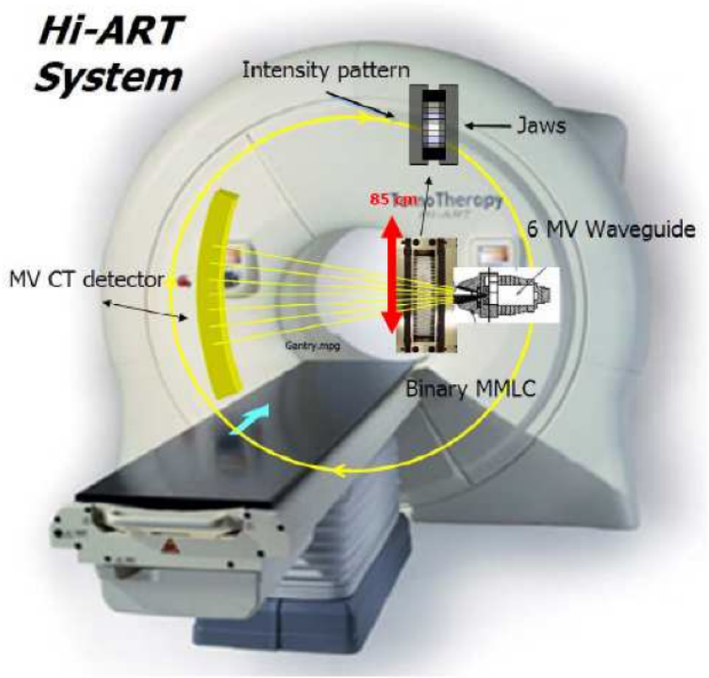


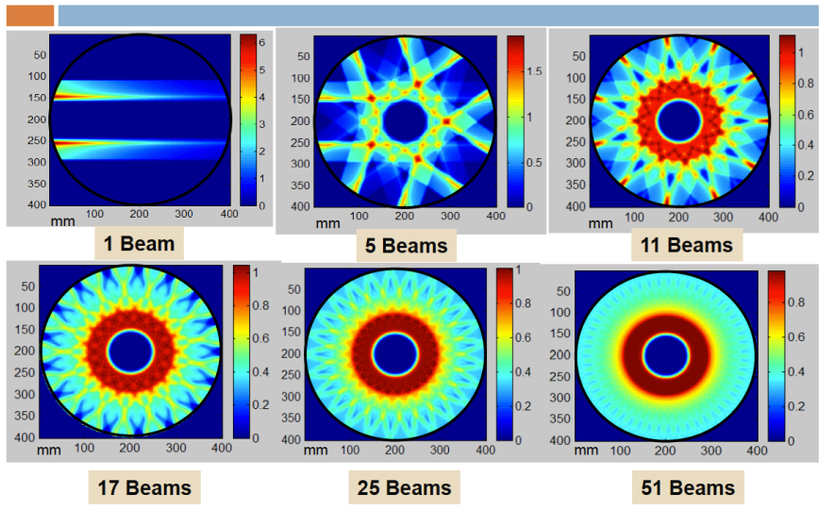
Geant4 - INFN: Tomotherapy

Helical Tomotherapy: a Geant4 computational model as a tool for 3D dose distribution evaluation.

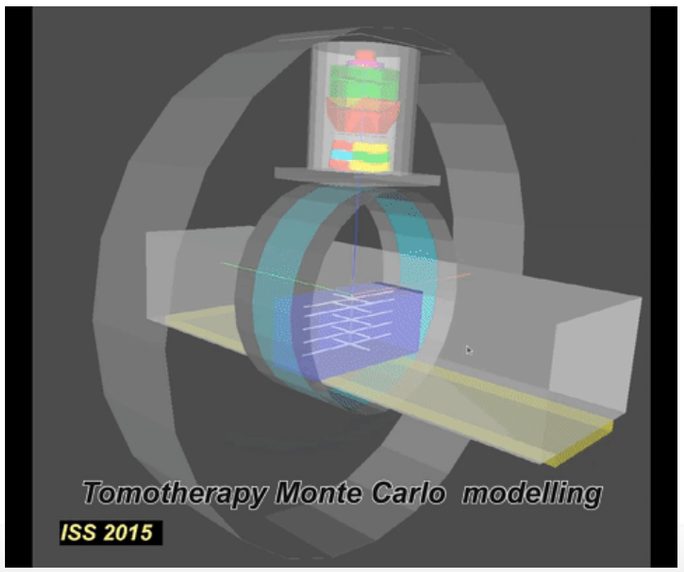
Collaboration: ISS + some Italian oncological hospitals for MC_INFN







Contacts: barbara.caccia@iss.it



See poster by A.Esposito (Id. 62)

Geant4 - INFN: Tomotherapy

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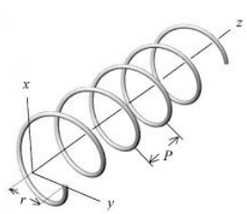

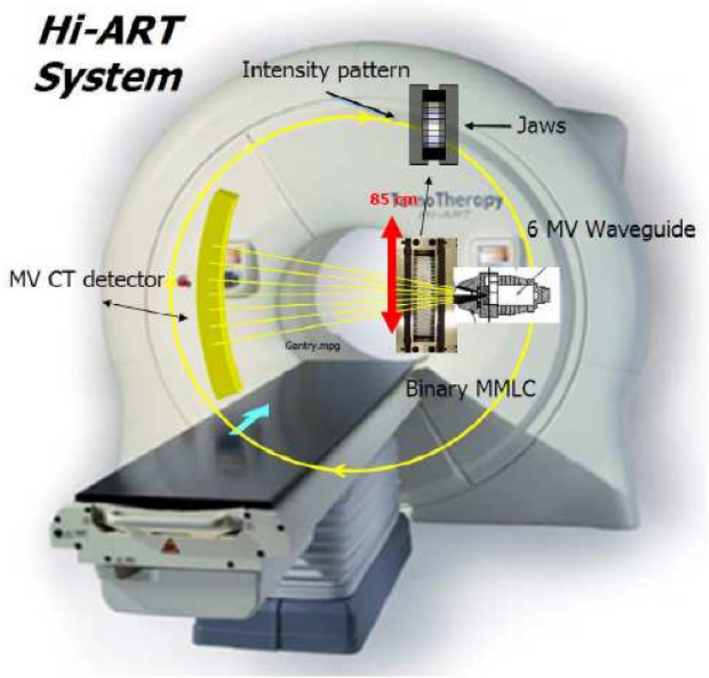

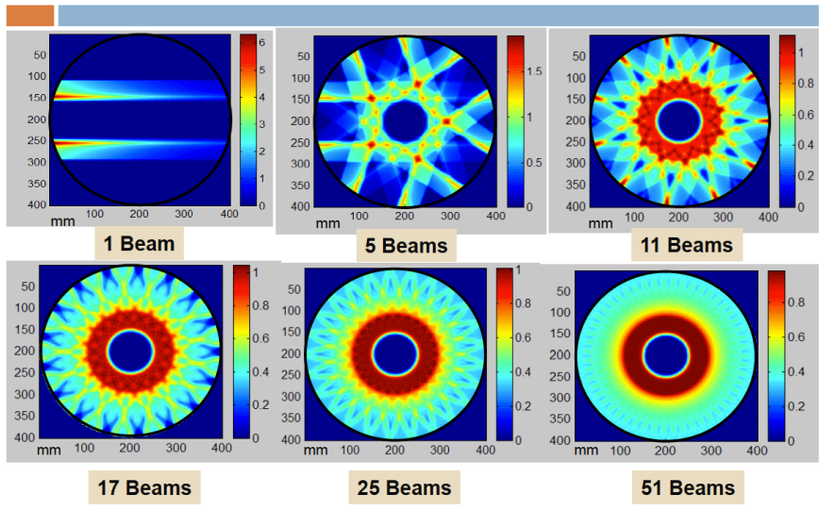

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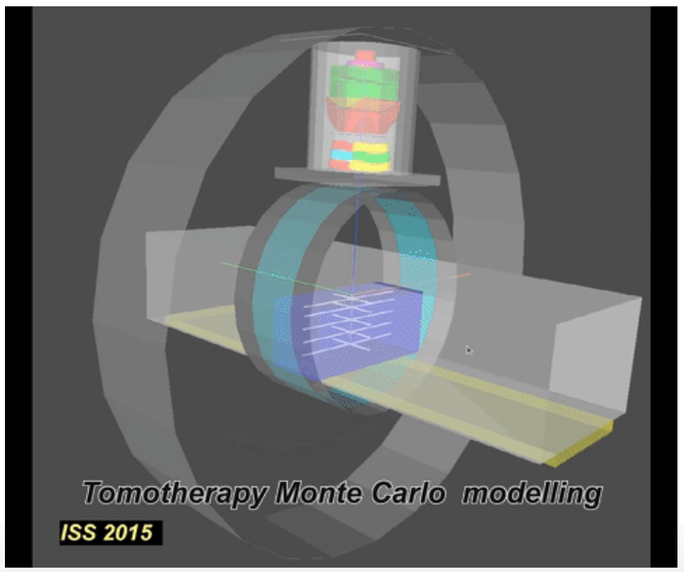
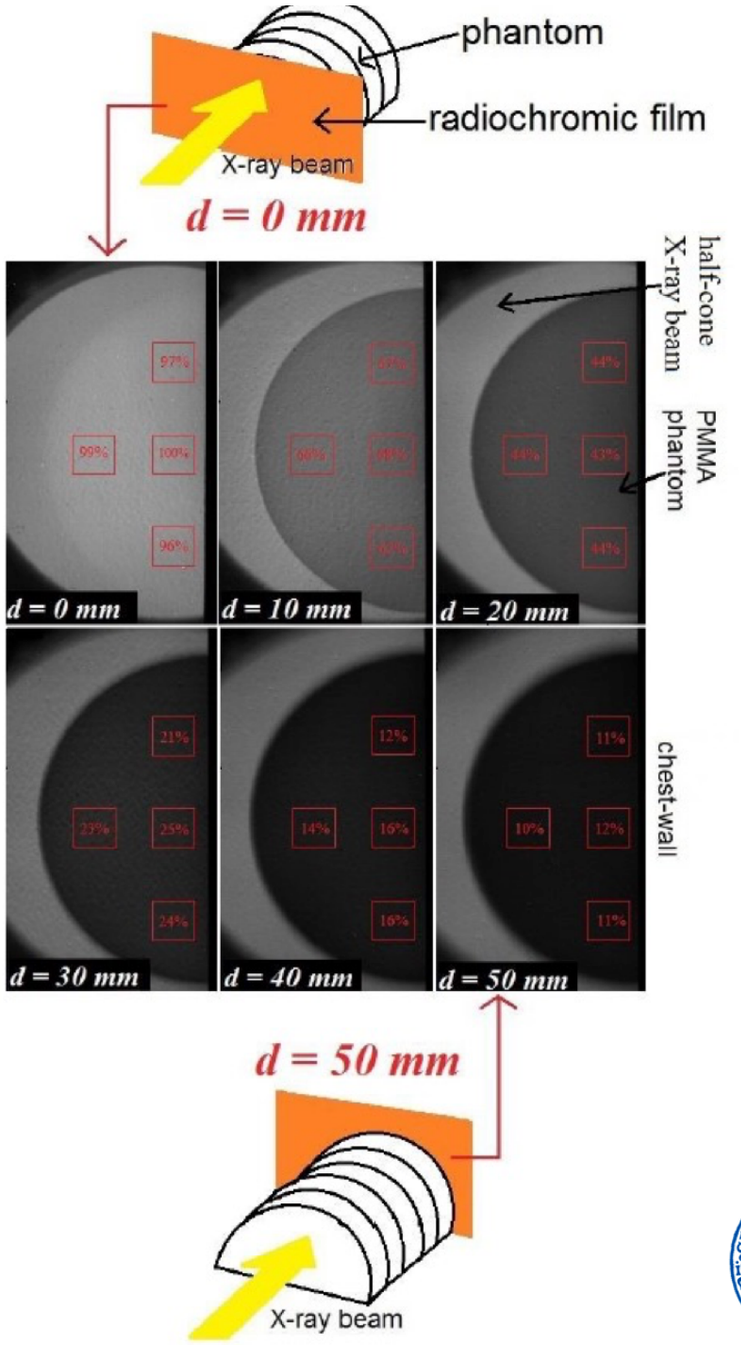
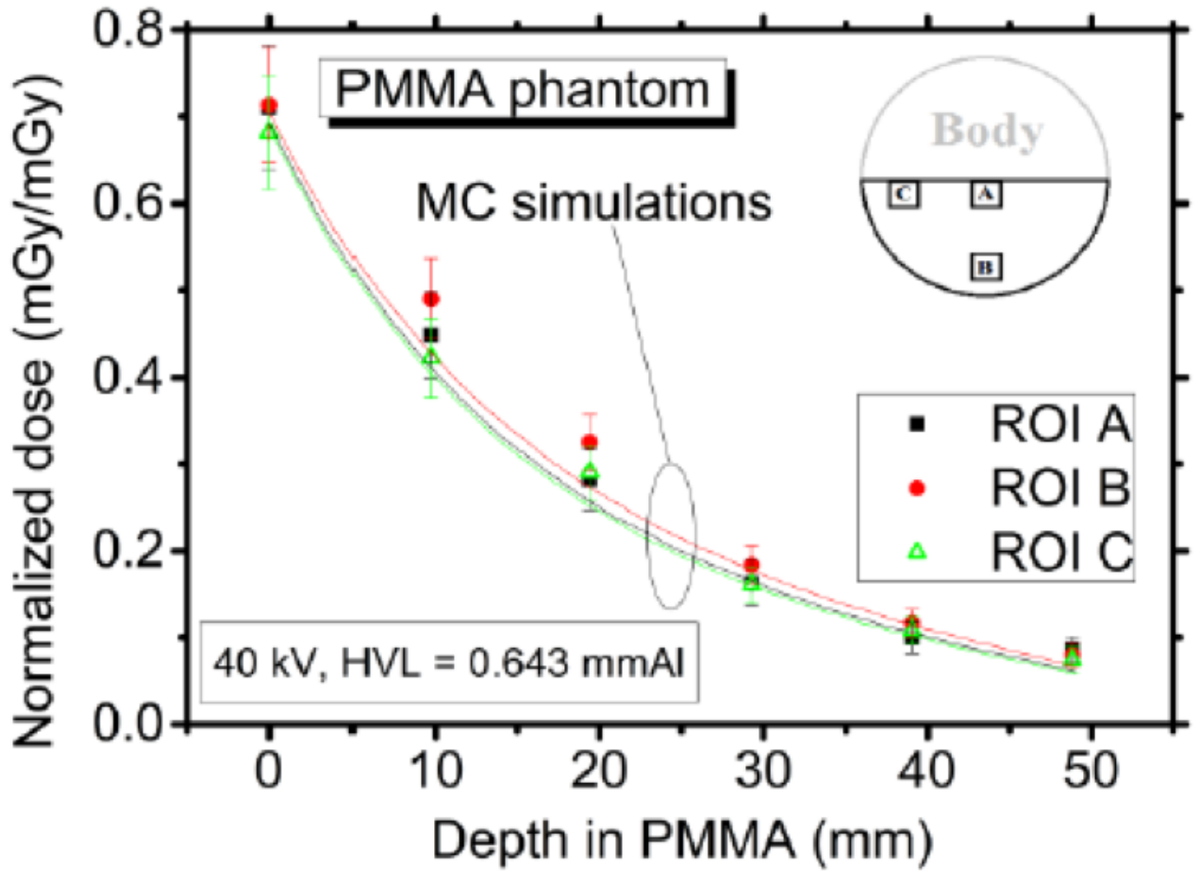


See poster by A.Esposito (Id. 62)

Geant4 - INFN: Breast Dosimetry



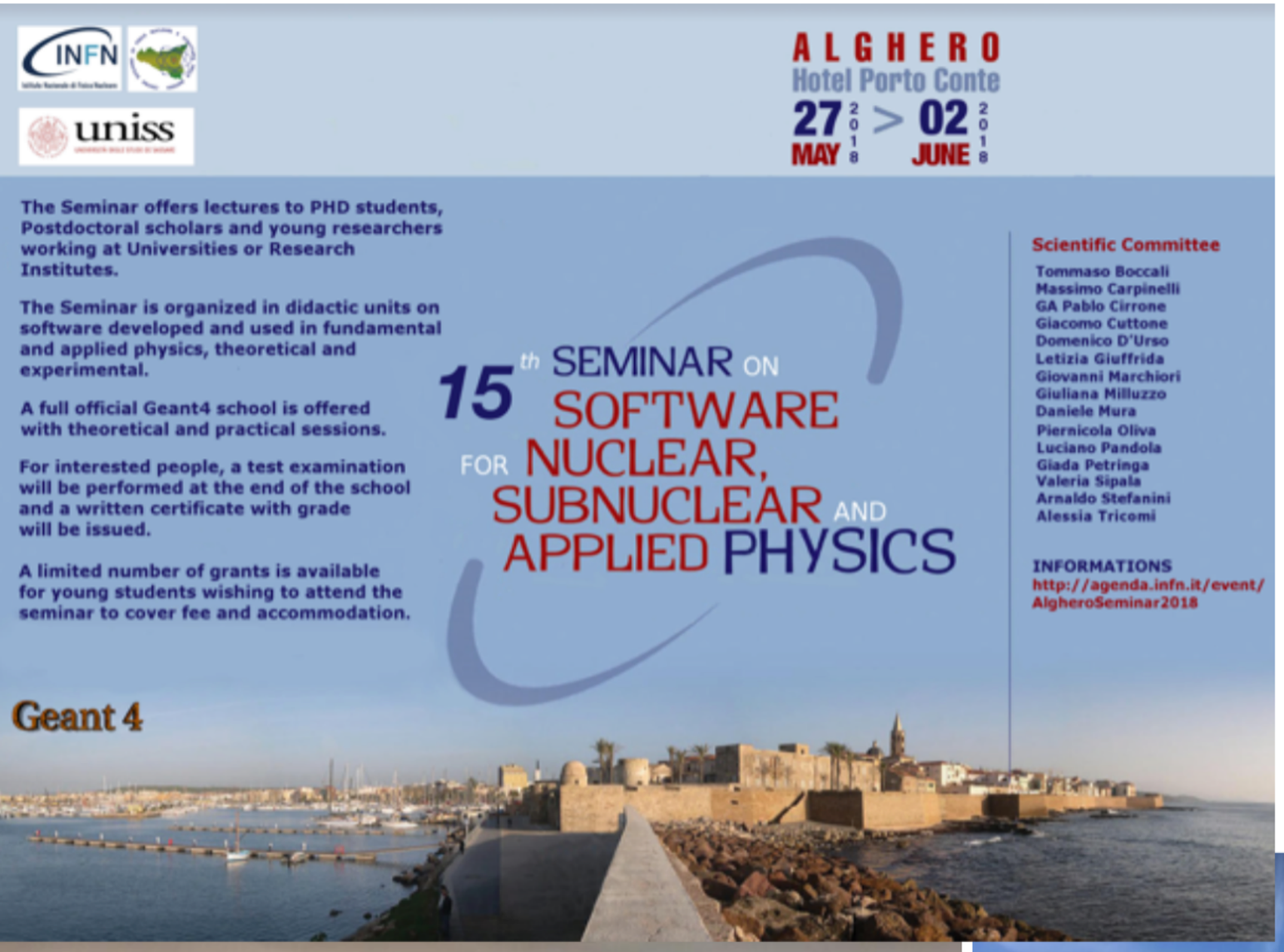
Digital Breast Tomosynthesis



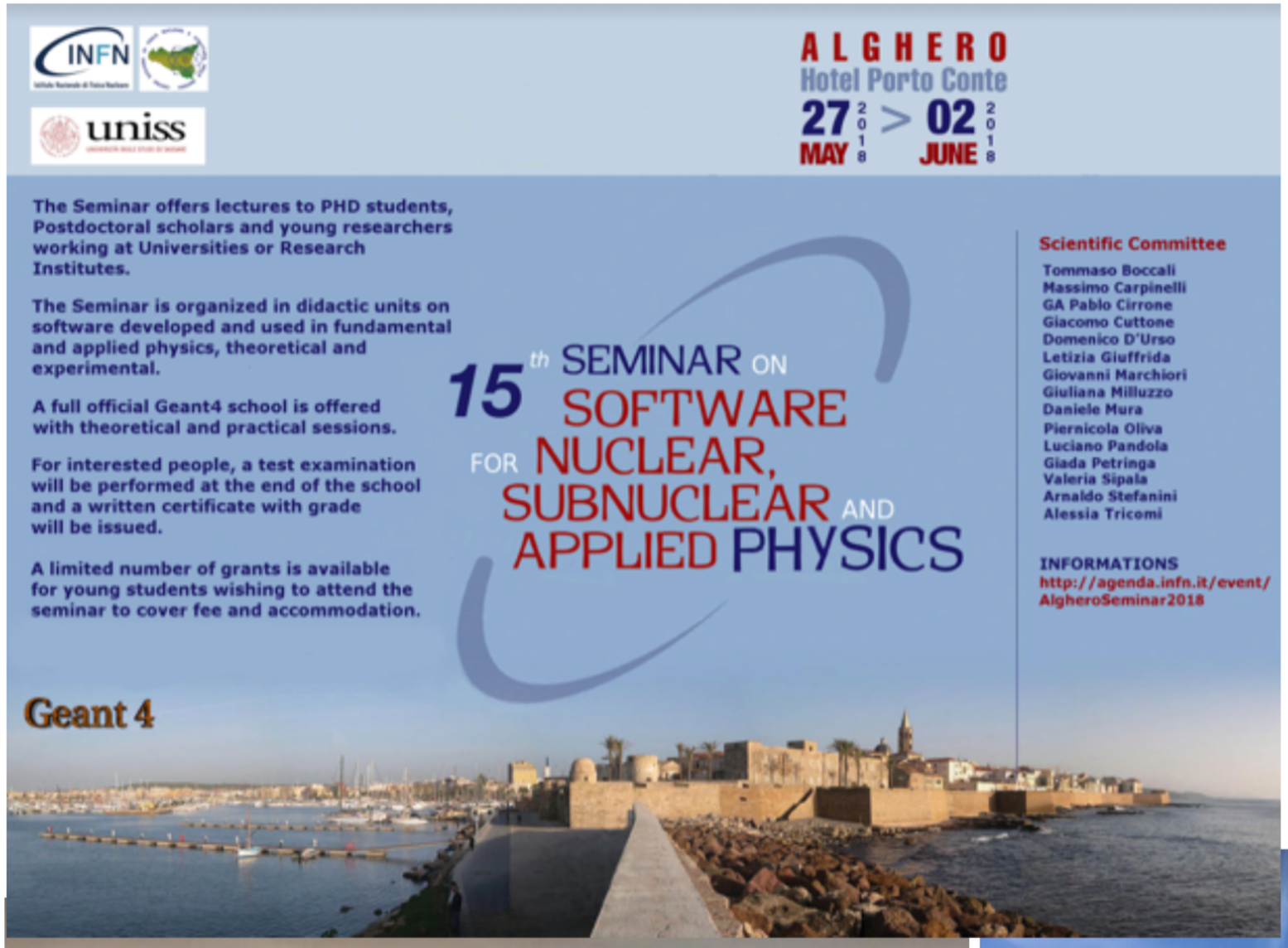
Curtesy of G Mettivier

Next Official Geant4 Schools

-> Alghero (I) 27 May - 2 June 2018
-> Havana, Cuba, November 2017
-> Trento (I), December 2018



https://www.facebook.com/SoftwareandGeant4School/



Next schools:

— Alghero 27 May - 2 June 2018
— Havana, Cuba, Nov 2017
— Trento, Dec 2018

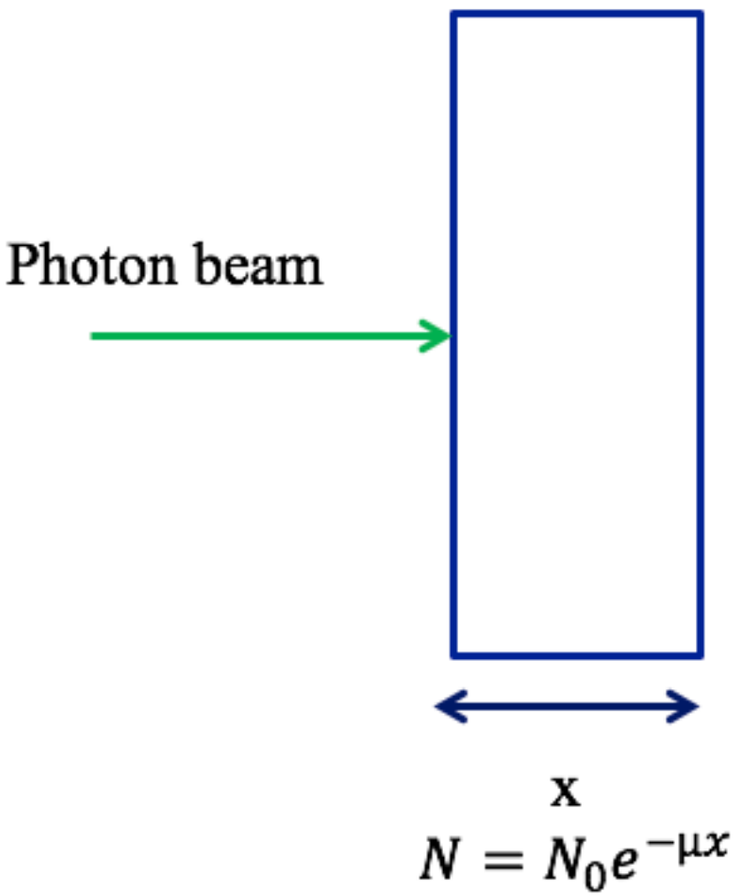
Thank you

https://www.facebook.com/SoftwareandGeant4School/

Backup

Example of ongoing regular regression tests

Simulation set-up



S Guatelli, S Incerti, V Ivantchenko, L Pandola

Physics lists

emstandard_opt0
emstandard_opt3
emstandard_opt4
Livermore
Penelope

Attenuation coefficient calculation

Total
rayleigh scattering
Photoelectric effect
Compton scattering
Gamma conversion

Regression testing

G4 10.0, 10.1, 10.2.p02

New PIXE cross sections

Current authors: S. Bakr[a], D. D. Cohen[b], R. Siegele[b], S. Incerti[c,d], V. Ivanchenko[e,f], A. Mantero[g], A. Rozenfeld[a], S. Guatelli[a]

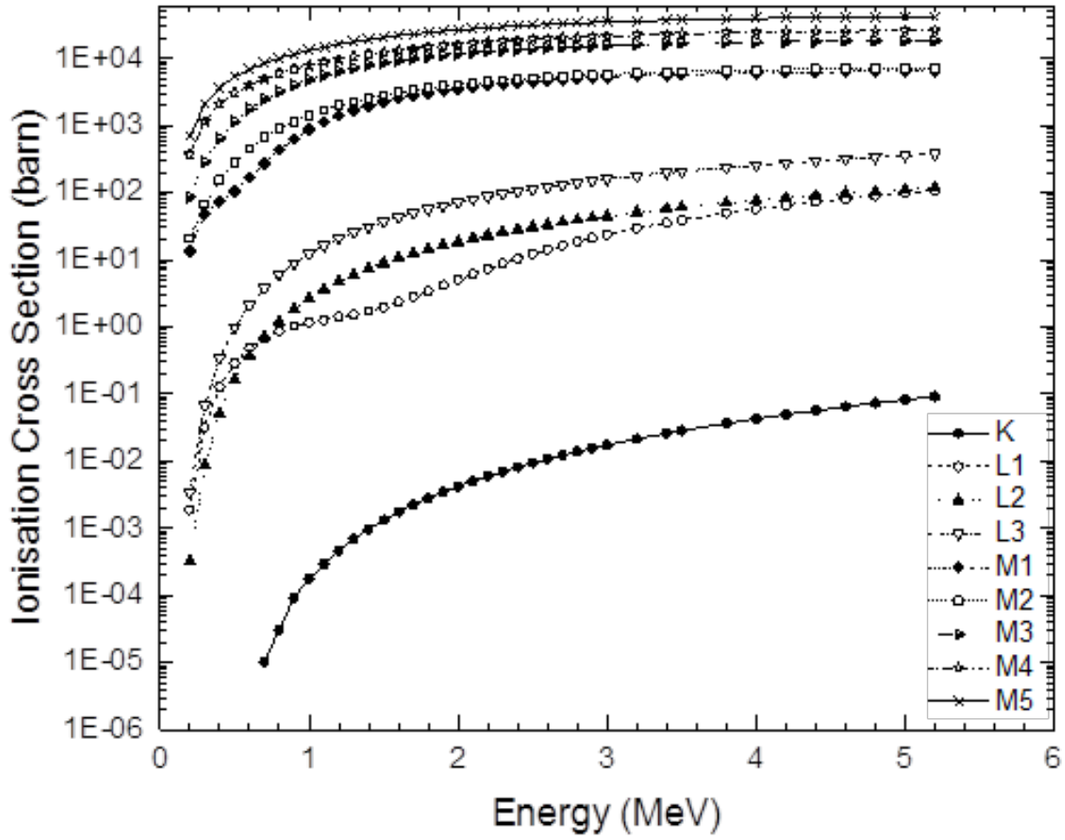
[a] CMRP, University of Wollongong,
[b] Centre for accelerator Science, ANSTO,
[c] CNRS/IN2P3, Centre d'Etudes Nucléaires de Bordeaux-Gradignan,
[d] Université de Bordeaux, Centre d'Etudes Nucléaires de Bordeaux-Gradignan,
[e] Geant4 Associates International Ltd,
[f] Tomsk State University,
[g] SWHARD s.r.l

Based on recommended cross sections developed by D. Cohen at ANSTO

Systematically validated against experimental measurements

Cross sections for protons, alpha particles and carbon ions

To be released as soon as possible



ANSTO proton ionization cross sections for K, L and M subshells for gold

Example of ongoing regular regression tests

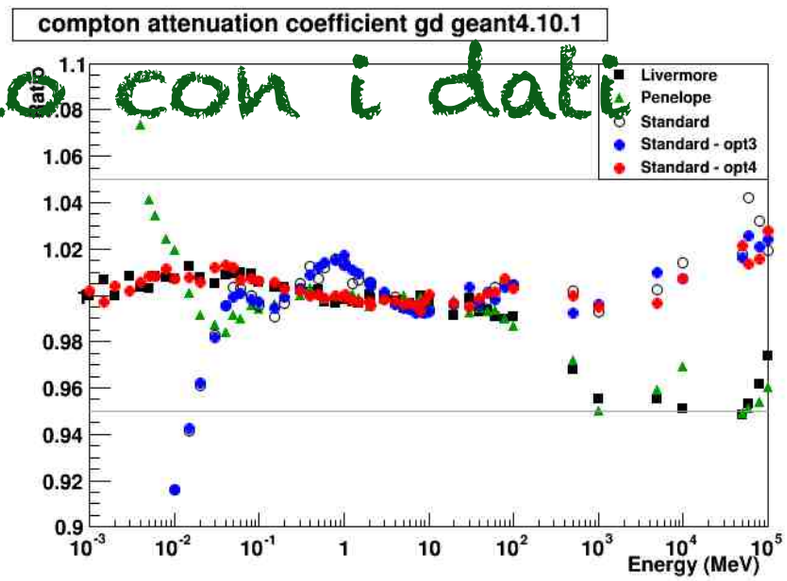
Overall good agreement (< 5%)

Rayleigh cross sections are different from NIST

Compton scattering

Penelope, Standard opt0 and 3 have differences below few keV

Regression test between Geant4 10.0 and 10.1: no differences



meglio fare vedere ul plot del nostro lavoro dicendo che i coeeficienti di attenuazioni sono abbastanza in accordo con i dati

Validation of fragmentation for ion incident beams

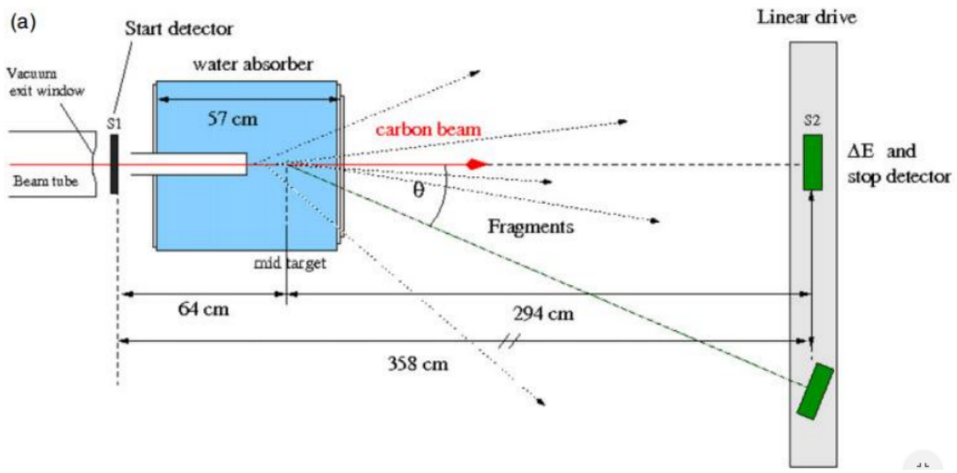
- The accuracy of different fragmentation models in Geant4 was benchmarked for a 400MeV/u ^{12}C beam
  - **BIC, QMD, INCL**

IOP PUBLISHING — PHYSICS IN MEDICINE AND BIOLOGY
Phys. Med. Biol. **58** (2013) 8265–8279 — doi:10.1088/0031-9155/58/23/8265

Experimental study of nuclear fragmentation of 200 and 400 MeV/*u* ^{12}C ions in water for applications in particle therapy

E Haettner, H Iwase[1], M Krämer, G Kraft and D Schardt

GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany



See talk by S. Guatelli

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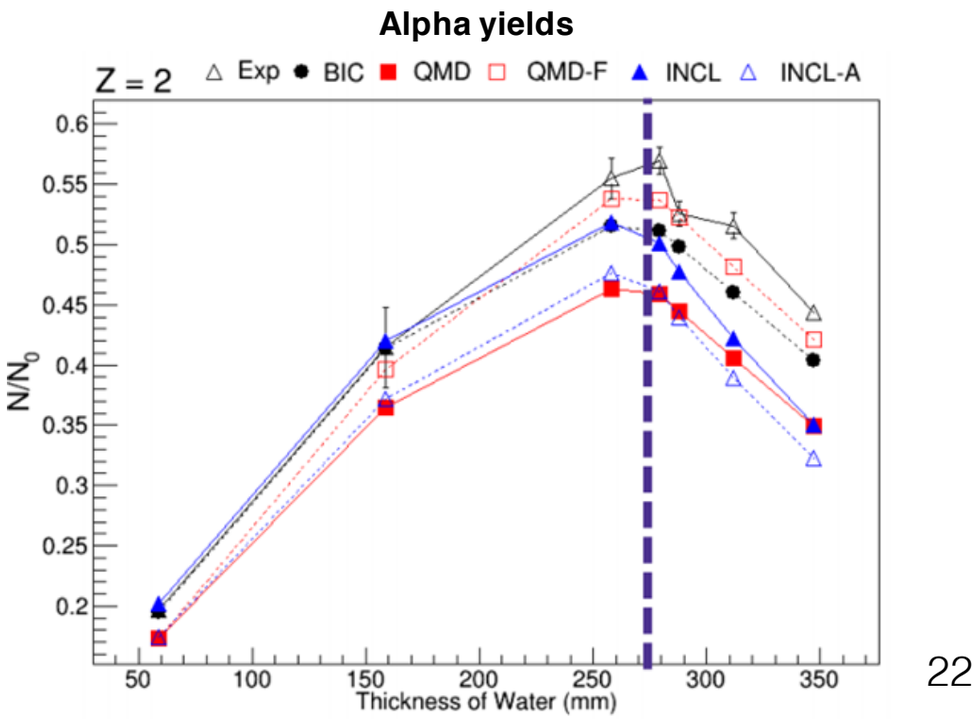
Validation with statistical analysiS
Regression testing



22

The Geniale project

- **The entrance channel model characteristics have a larger effect** on particles and fragments production as compared to the choice of the exit channel

- The core of GeNIALE is the implementation in Geant4 of a new model for the **first stage of the interaction** between a hadron -or a nucleus- and a target nucleus

- Such a model will be coupled with the models already implemented in Geant4 for the second stage, and with the Geant4 framework in general

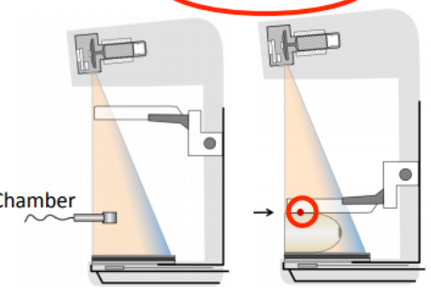
Simulations for breast dosimetry

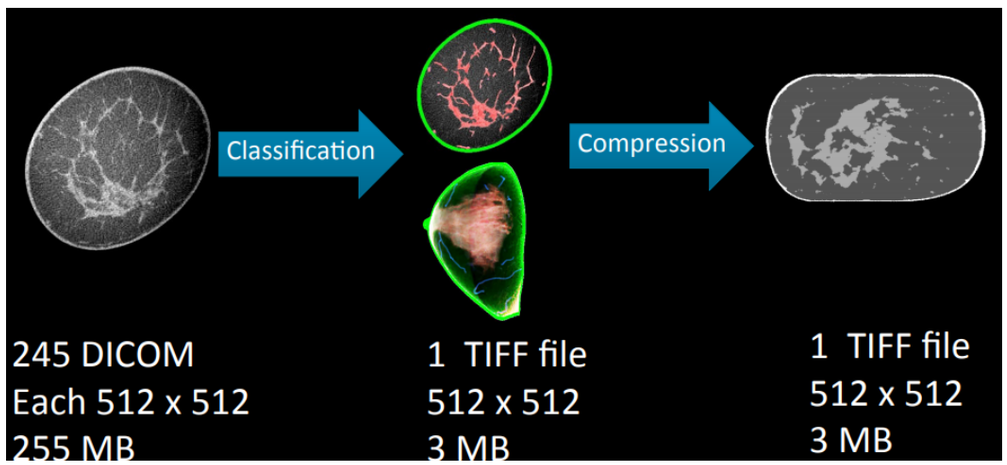
Purpose:
to develop a new model and corresponding methodology to estimate the breast average glandular dose (AGD)

Mean Glandular dose = **Measurable Quantity** **X** **Conversion Factor**

Measurable Quantity → **Air kerma**

Conversion Factor → **Monte Carlo**



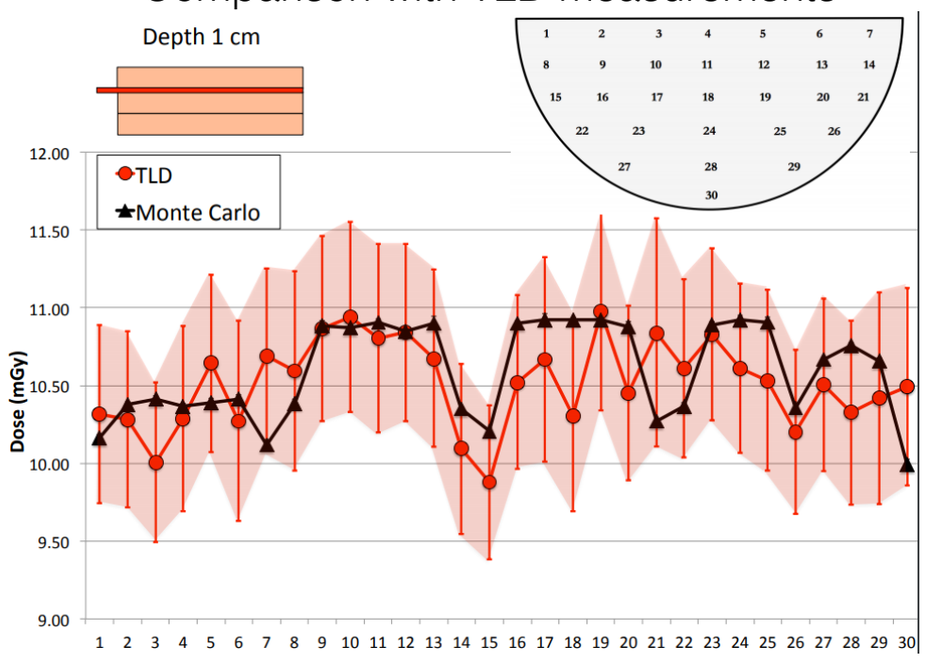


C. Fedon et al.et al.

advanced x-ray tomographic imaging

Radboudumc university medical center

Comparison with TLD measurements



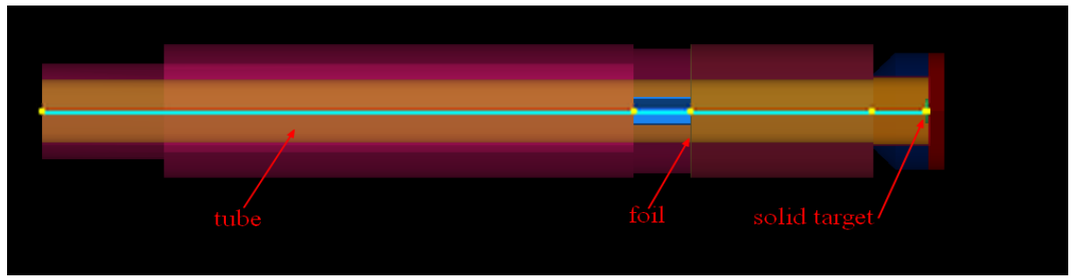
Radio-isotope production simulation

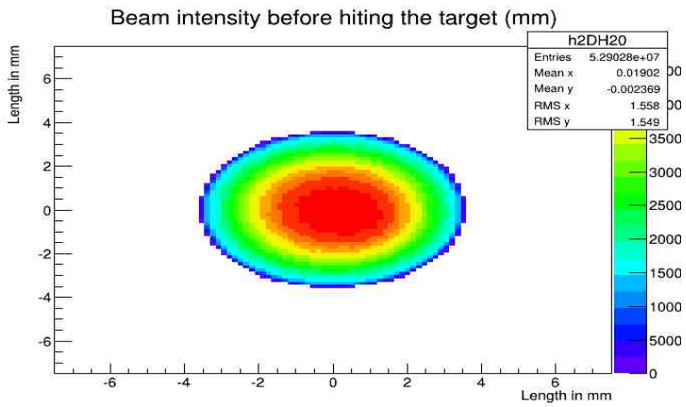
Current authors: F. Poignant et al.

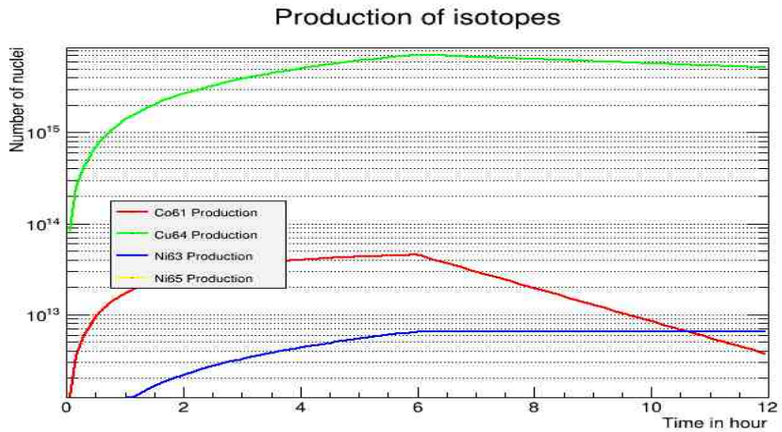
- **Objective** :
  - Predict the production of medical radio-isotopes and undesired by-products yields
- **Features :**
  - Modelling of a solid target system based on the GE PETtrace cyclotron from the South Australian Health and Research Institute

THE UNIVERSITY of ADELAIDE

- **Geant4 GUI user-friendly** interface to select parameters
- **AllParticlesHP** physics list : TENDL based cross sections for low energy [MeV] nuclear interaction high precision
- Analysis tool available







[1] : F. Poignant, S. Penfold, J. Asp, P. Takhar, P. Jackson, GEANT4 simulation of cyclotron radioisotope production in a solid target, Physica Medica, Volume 32, Issue 5, 2016, Pages 728-734, ISSN 1120-1797,

Applications

Dosimetry

Imaging

Treatment Planning System

Radiation protection (also in aviation and space)

Improvement/Optimisation of QA Instrumentation