Status and plan for the hadron therapy simulation project in Japan

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The Project

• “The Development of Software Framework for Simulation in Radiotherapy”
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• Joint project among Geant4 developers, astro-physicists and medical physicists in Japan
Member Institutes

• High Energy Accelerator Research Organization (KEK)
• Ritsumeikan University (RITS)
• Kobe University
• Naruto University of Education
• Toyama National College of Maritime Technology
• Japan Aerospace Exploration Agency (JAXA)
  • National Institute of Radiological Science (NIRS)
  • National Cancer Center, Kashiwa
  • Gunma University Faculty of Medicine
  • Hyogo Ion Beam Medical Center (HIBMC)
  • Kitasato University
Motivation

- Geant4 is well designed and complete software to simulate interaction between particles and matter.
- However, Geant4 is not easy to use in a few cases, if
  - geometry is very complex, and
  - physics related is not trivial
    • most of physics processes are covered already, but still setting for selection or combination is difficult sometimes
    • in very few cases, new physics processes need to be implemented
- Simulation in particle therapy, especially, in heavy ion therapy is one of such cases and very challenging for Geant4 developers’ too
  - *N.B.* Heavy ion physics also applicable to astro-phys
- Validation of results are very important in any case
  - Geant4 is not a mighty magic box
Goal of Our Project

• Provide the framework and software toolkit for simulation in radiotherapy, especially, particle therapy
  – Well designed general purpose software framework
  – DICOM/DICOM-RT interface
  – Visualization/Interactivity
  – Web interface
  – GRID computing
  – etc

• Validation of results
The system structure

Knowledge DB

DICOM interface

modeler

GRID Deployment

Geant4

framework for medical application

Dose Calculation Engines

JQMD

EGS4

...
Highlights

• Common software parts are provided as software toolkit
  – User can adopt for their own target with minimal modification or addition of a class derived from the base class provided
    • In many cases, the same or similar geometry are used
    • Requirements on physics processes looks similar
• Framework based on PYTHON for more functionality and usability
• visualization and computer aided user assistance tool will be provided as independent software
• Parallelization of simulation and GRID computing
  – Not depends on TOP-C

• New DICOM-G4 interface
  – DICOM-RT is also taken into account
    • Standardization is not yet ready and need adoption for different extension at each facility, anyway
  – DICOM example in the Geant4 distribution has problems and should be fixed
    • Quick fixes are already in the new release

• Validation against experiments
  – proton beam first then carbon
Use case and requirement sampling

- All of 6 facilities for particle therapy in Japan and one in Italy have been interviewed
  - NIRS
  - NCC-EAST
  - HIBMC
  - WERC
  - SCC
  - University of Tsukuba
  - INFN LNS at Catania, Italy

- Information on components in beam line and also treatment room have been gathered also
Framework for geometry modeling

- Class library for implementing a geometry model of hadron therapy facilities are designed and built
- Beam lines at HIMBC, NCC-East and NIRS are implemented already (for water phantom experiments)
- Physics validation will be done for data taken at those facilities
New beam line at HIMAC
NCC East
Physics validation

• In most cases, implementing a simulation using Geant4 is not difficult because much information are already available

• Users should consider about the validity of the results
  – Why you can believe the results?
  – If you publish any results using Geant4 without validation, you are silly enough
    • Geant4 is not a mighty magic box
Validation against proton data

- Comparison between data taken at HIBMC and it’s simulation based on Geant4 has been performed using rapid prototyping.
- Geant4 well reproduced the measurements.
Bragg peak


Comparison between measurement at HIBM C and Geant4 simulation

proton beam with 150, 190 and 230 MeV
Spread Out Bragg Peak (SOBP)

The small bump in the measurement is thought to be a fan beam effect.

(a) 150 MeV SOBP90
(b) 190 MeV SOBP90

(a) 150 MeV SOBP120
(b) 190 MeV SOBP120
Validation against carbon data

- Data taken at new beam line at the therapy beam line and also new beam line at HIMAC
- P152 experiment at HIMAC
  - Full reconstruction of tracks in carbon interaction using ECC (Emulsion Cloud Chamber)
  - The first paper has been accepted by Nuclear Instruments and Method in Physics Research A and to be published soon
HIMAC new beam line

C12 290MeV/u
Comparison between data and MC

Very Preliminary results

Geant4: Binary cascade model

Intentionally removed

C12 290MeV/u
Comparison among different physics models in Geant4

Data taken at the therapy line

C12 400MeV/u

Data Ionization Chamber
DICOM and visualization

• Geant4-DICOM and DICOM-RT (still HIBM only) interface
  – Read DICOM image and model the geometry for Geant4 and interface to therapy planning systems
  – DICOM-RT provides the information on apparatus on the beam line, but not well standardized yet
  – New DICOM interface was developed
    • Bug fixes for the existing example in G4 have been done
      – Byte order problem and other glitches

• Visualizer for DICOM image + dose distribution + analysis results
Visualization Samples

Tool bar
- Open file
- Save as image
- Data information
- MPR contrast
- 3D Resolution
- 3D Light
- 3D Reset
- Directions
- Transfer function & color map setting
Visualization Samples

• A head region data.
Computer aided geometry design

For a first example, electron accelerator head design tool has been designed and implemented, as like BEAM.

With GUI, design change can be manipulated easily and C++ source code to describe the geometry setup for Geant4 will be produced automatically.

Needs only a web browser and Java!
Parallelism and GRID deployment

• Event level parallelism has been implemented for general purpose using MPI-C++ interface
  – No other component, but just MPI implementation is necessary, such as MPICH
    • Independent from the TOP-C example in G4 distribution
• Parallel simulation over the Internet is realized by GRID middleware in our case Globus and also LCG2
  – Our LCG2 system is not a part of CERN VO
• Web interface to access GRID from behind the hospital firewall is under development
Parallelization efficiency

Graph showing the relationship between the number of slaves and the real elapsed time in 1/minute, as well as the parallel efficiency percentage.
GRID virtual organization has been realized by CERN LCG2 middleware. File sharing across the sites on Internet has been realized by San Diego Storage Resource Broker. GRID protocols have been realized by Site A, Site B, and Site C. Firewall is still under development. GRID aware web server and job broker use http for communication.
Web interface

Geant4CherryPy is serving now

- Show the Geometry of your application
  - Show Geometry in VRML
  - Show Geometry in DAWN
- Show Geant4 Environment Variables and Commands
- /run/beamOn
- Execute Python G4 command
- Show Root result on the fly

Histograms created by ROOT
Geant4 kernel improvements

• Tracking in parallel geometry
  – Scoring in a different geometry
    • Improvements on Read-Out geometries
    • Smaller step size for accuracy of physics, but scoring in combined steps for better performance

• Tallying/scoring
  – Relating with the above issue and the idea is borrowed from MCNP
  – Give physical quantities extracted from fundamental values such as energy deposit, timing or other variables in Geant4
    • Dose, temperature and so on
  – Treatment of flux based quantities also will be considered
Plan

• Releasing beta version of software parts and tools first, e.g. G4-DICOM viewer, then complete system
  – For contributors only
  – The details will be announced
Future collaboration

• We welcome very much the contact from any other facility who have an interest to use our software for their simulation
  – We will implement and provide simulation software if you provide us necessary information and data for validation in trade
    • All of required information to simulate experiments are not necessary on the papers
    • Needs direct collaboration with people who took data
Summary

- Our project is developing the software framework and toolkit for particle therapy.
- Also validation against data are done very seriously.
  - Protons
    - HIBMC, NCC-east and others
  - Carbons and heavier ions
    - HIMAC
    - Needs more data
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