Geant4 medical activities in Japan

Takashi Sasaki
KEK and JST/CREST
• I will introduce the activity in my group mainly, but also other activities which we recognized at Japanese Geant4 workshops
Development of simulation framework for advanced radiotherapy

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The project

- 5 years project since October 2003 to September 2008 were accepted by Japan Science and Technology Agency (JST) in Core Research for Evolutional Science and Technology (CREST) program
- Research director appointed by JST
  - Takashi Sasaki (myself)
- [http://g4med.kek.jp](http://g4med.kek.jp)
  - Japanese only currently
  - English version will be prepared
Members

• Medical physicists
  – National Institute of Radiological Science (NIRS)
    • T.Kanai, N Kanematsu, M Komori, Matsufuji
  – National Cancer Center, Kashiwa
    • T Nishio
  – Gunma University Faculty of Medicine
    • K Yusa
  – Hyogo Ion Beam Medical Center (HIBMC)
    • T Akagi
  – Kitasato University
    • Maruyama, Hasegawa, Muraishi

• Astrophysics
  – Japan Aerospace Exploration Agency (JAXA)
    • Ozaki, Watanabe, Maeda, Nakazawa

• Geant4 Developers
  – All Japanese Geant4 developers are involving
  – Katsuya Amako, Hajime Yoshida, Hiasaya Kurashige, Koichi Murakami, Tsukasa Aso, Akinori Kimura and Takashi Sasaki
Main goals

• Provide a software framework for simulating radio therapies, mainly, particle therapies and validation results
  – Rich functionalities are to be provided also
    • Visualization
    • Parallelism
    • GRID….
Sub-projects

• Simulation engine (core)
  – Framework design and implementation
  – Improvements on Geant4 kernels

• Validation
  – Validation of physics in Geant4
  – Comparison against measurement

• Visualization
  – Dose distribution on DICOM image (GRAPE)

• Parallelism and GRID
Simulation Engine (CORE)

• Geant4 is the engine
  – Kernel improvements
    • Scorer has been donated to Geant4
  – Module implementation
• Geometry framework for particle therapy
• Pythonized framework
  – Without GNUmake, g++ nor Linux, just Python
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
The system structure

Knowledge DB

Geant4

Dose Calculation Engines

JQMD  EGS4  ...

Scoring/Tally Package

Physics List for Radiotherapy

GRID Deployment

visualization/interactivity

DICOM interface

modeler

framework for medical application
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
Requirements

- 1% accuracy in dose distributions
- DICOM/DICOM-RT handling
- Interface to existing treatment planning systems
- Easy to use
  - Medical physicists are not computer nurds
- And so on...
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
HIBMC
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 HIBMC 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.

Dot: Measured
Solid: Geant4

SOBP 9cm

SOBP 12cm

(a) 150 MeV SOBP90

(a) 150 MeV SOBP120

(b) 190 MeV SOBP90

(b) 190 MeV SOBP120

150MeV

190MeV
Validation against carbon data

• Data taken 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)
  – NIM A Volume 556, Issue 2, 15 January 2006, Pages 482-489
Does distributions of carbons in the water tank at 290 MeV/u and 400 MeV/u

The new beam line at HIMAC, NIRS

Carbon 290 MeV/u

Further investigation will be done

Carbon 400 MeV/u

Major contributor: Satoru Kameoka
Comparison among different physics models in Geant4

Data taken at the therapy line

C12 400MeV/u
DICOM and visualization

• Geant4-DICOM and DICOM-RT (still HIBMC 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

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Visualization Samples

Dose map region
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 parallelization efficiency](image)
File sharing across the sites on Internet has been realized by San Diego Storage Resource Broker.

GRID virtual organization has been realized by CERN LCG2 middleware.

Still under development.

GRID aware web server and job broker.

Firewall.
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
Plan

• Releasing beta version of software parts and tools first, e.g. G4-DICOM viewer, then complete system
  – The details will be announced
  – DICOM-G4 viewer
    http://geant4.kek.jp/GRAPE/
Future collaboration

• We are very happy to collaborate with people who have interests in this field
  – 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
• We still need to learn from medical physicists
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
• We need more data from different facilities for further validation
  – We give you the simulation software to implement your geometry if you give us your data in trace
Acknowledgements

• Some slides are prepared by members of the project, Tsukasa Aso, Go Iwai, Satoru Kameoka, Akinori Kimura, Koichi Murakami and Ken Yusa
Other projects in Japan
Geant4 Japan workshop

• 2005
  – http://www-geant4.kek.jp/g4users/g4ws05/
    • “Evaluation of Charged Particle Multiplicity in Fragmentation Reactions Induced by Therapeutic 12C Beams”, T. Magara, Kitasato Univ.
    • A novel method of verifying the field irradiated by therapeutic X-ray beam, F. Matsubayashi, Kitasato
    • Using TOP-C for Proton Beam Dose Volume Simulations, Kenneth Sutherland, JST-CREST
Other activities recognized in Japan

• PET simulation with GATE
• Carbon CT simulation