Feb. 12 2008@University of Tokyo
5th Geant4 Space User's Workshop

Geant4 Medical Applications and Ion Physics

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Medical application

- Radiology
  - Diagnosis
    - PET
    - Gamma camera

    } for example, GATE
  - Treatment for cancer
    - Radiotherapy

Radiotherapy

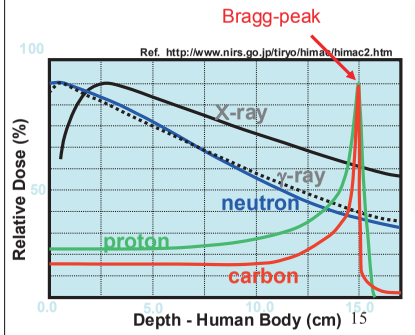
- How to focus the dose?
  - IMRT :intensity modulated radiation therapy
    - X-ray
  - Brachytherapy
    - Encapsulated radio isotope (β -ray, γ -ray)
  - Particle therapy
    - Proton, Ion

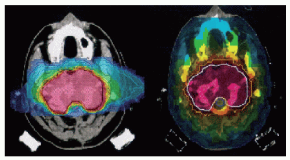
Cancer

- Cancer is the most common cause of death since 1981 in Japan.　31% in 2004
- About 40% of patients have a surgical operation.（National cancer center 2004）
  - Less than 10% of patients have a radiotherapy.
- New treatment techniques which improve treatment results and quality of life are desired.
  - radiotherapy, chemotherapy

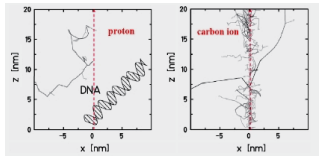
Particle therapy

a few 100MeV/n ^{12}C beam



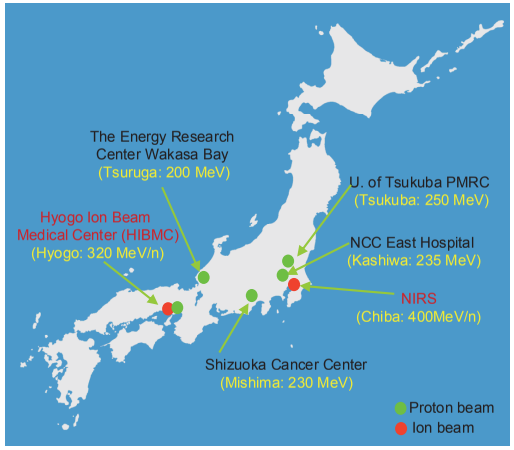


carbon vs. X-ray



BEVALAC (Berklay-US)	1975 - 1992 Ne, Si ~400	proton vs. Carbon
NIRS (Chiba-Japan)	1994 - ^{12}C more than 3000	Amaldi and Kraft
GSI (German)	1997- ^{12}C	Rep.Prog.Phys.68 1861 (2005)
HIBMC (Hyogo-Japan)	2002 - ^{12}C	

Particle therapy facilities in Japan



HIMAC at NIRS (National Institute of Radiological Sciences)

HIBMC in Hyogo

Accelerator complex

Accelerator
Synchrotron
proton(70-230MeV)
Carbon-ions(70-320MeV/n)

Beam lines
4 fixed-angle beam lines (proton & carbon)
2 gantries for proton

The Project

- "The Development of Software Framework for Simulation in Radiotherapy"
  - funded by the Core Research for Evolutional Science and Technology (CREST) program organized by Japan Science and Technology Agency (JST) from 2003 to 2008
- Joint project among medical physicists, astro-physicists and Geant4 developers 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

Geant4

- Japan Aerospace Exploration Agency (JAXA)

Space

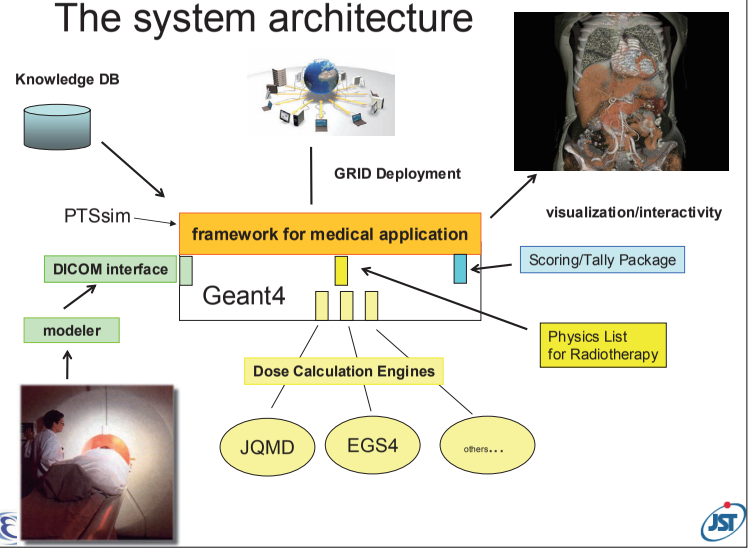
- National Institute of Radiological Science (NIRS)
- National Cancer Center, Kashiwa
- Gunma University Faculty of Medicine
- Hyogo Ion Beam Medical Center (HIBMC)
- Kitasato University

Medical

Goal of The Project

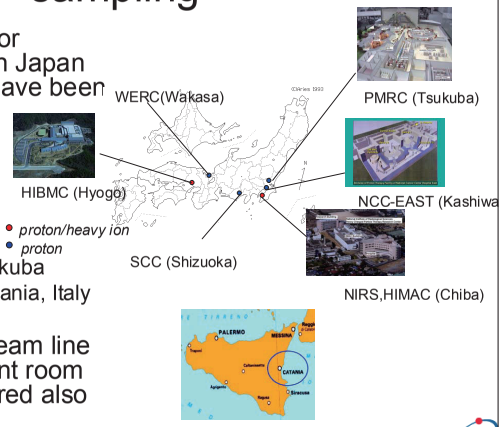
- Provide the software suit for simulation in radiotherapy, especially, particle therapy
  - Software framework and tools
    - Implementation of geometry of facilities
    - DICOM interface
    - Visualization
    - GRID
  - Tuned physics models
- Validation of simulation results
  - Collaboration with facilities

The system architecture



Use case and requirement sampling

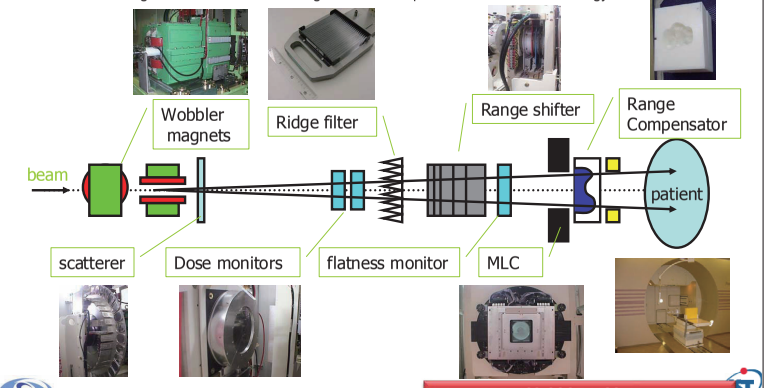
- All of 6 facilities for particle therapy in Japan and one in Italy have been interviewed
  - NIRS
  - NCC-EAST
  - HIBMC
  - WERC
  - SCC
  - University of Tsukuba
  - INFN LNS at Catania, Italy
- Information on components in beam line and also treatment room have been gathered also



Software framework for facility implementation

Basic design of Beam irradiation system

Purpose:
Widen the beam size to fit the tumor size with keeping lateral flatness of beam flux
Adjust the depth of Bragg peak in a patient volume with the tumor position
Other technology:
Double scattering, Spiral wobbling system for shortening the irradiation system
Beam scanning in three dimensions using small beam spot and variable beam energy



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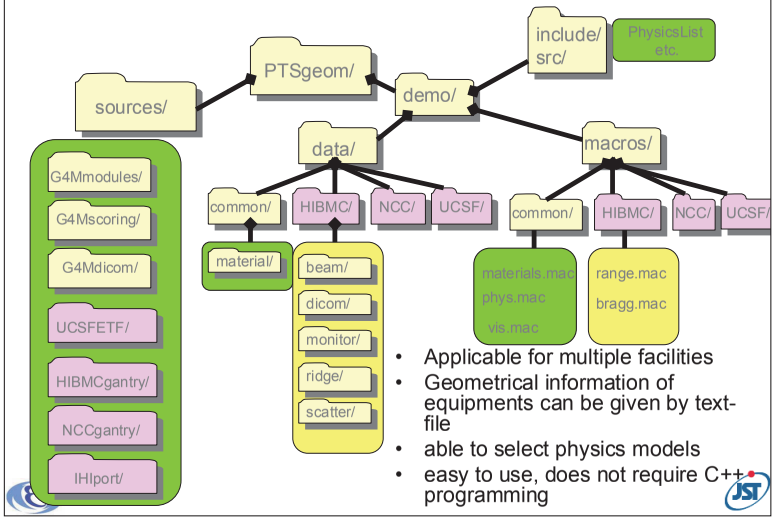
Directory structure of PTS simulator



- Applicable for multiple facilities
- Geometrical information of equipments can be given by text-file
- able to select physics models
- easy to use, does not require C++ programming

Implemented irradiation systems using PTSsim

Facility	Accelerator	Beam Energy (MeV)	Lateral Spreading System	Range Modulator
HIBMC Gantry	Synchrotron	Proton 150,190,230	Wobbler magnets and scatter  	Ridge filter 
NCC Gantry	Cyclotron	Proton 150,190,235	Scatter and double scatter 	Ridge filter 
UCSF	Cyclotron	Proton 67.5	N/A 	Propeller blades 
HIMAC	Synchrotron	Carbon 400 MeV/u	Wobbler magnets and scatter	Ridge filter
HIBMC	Synchrotron	Carbon 320 MeV/u	Wobbler magnets and scatter	Ridge filter
GSI	Synchrotron	Carbon ~400 MeV/u	Beam scanning	Fine Ridge filter 

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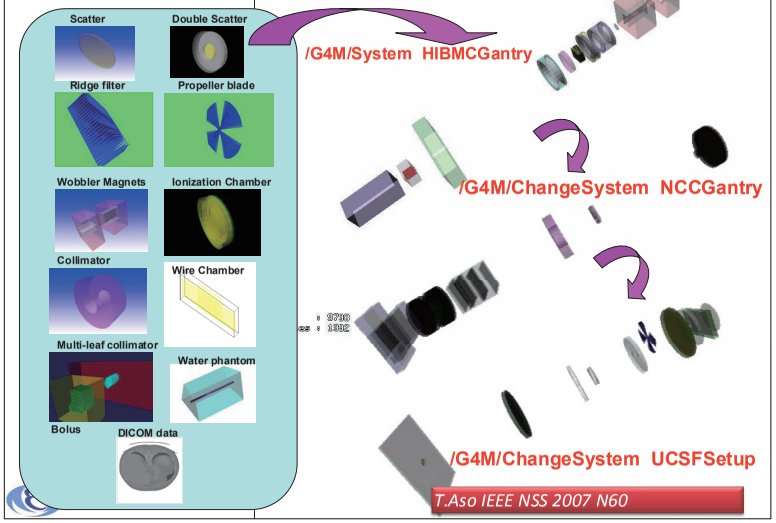
Example of irradiation systems



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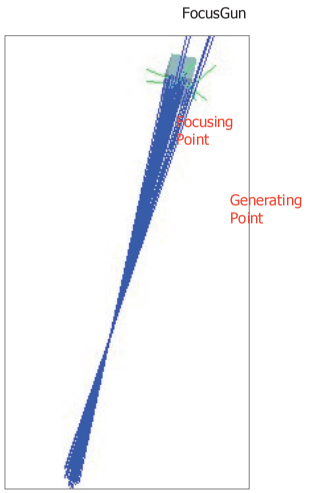
Others

- Primary generator
  - G4MBeamGun - HIBMC
    - Parallel beam with respect to z-axis
      - Spot size
  - G4MFocusGun - NCC
    - Cone beam with focusing points
      - focusing points and emittances of x and y direction
  - G4GeneralParticleSource (GEANT4) - IHIport at NIRS



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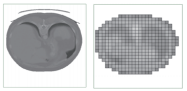
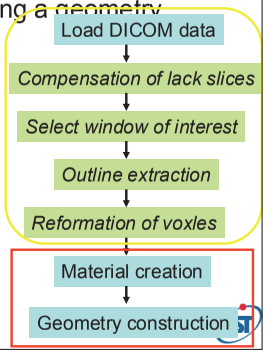
DICOM handling, visualization and UI

DICOM (Digital Imaging and COmmunication in Medicine) interface

- DICOM handler had been developed independently
  - TOSHIBA, SIEMENS, and GE DICOM data had been tested.
  - Filter modules are plugged in for converting original CT data into a suitable format for making a geometry
    - Extraction of patient geometry
    - Reformation of voxels
    - Density conversion



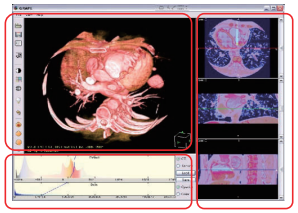
  - DICOM-RT (Radiation Therapy)
    - HIBMC-Mitsubishi is tested



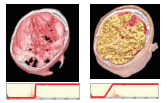
gMocren : DICOM visualizer

http://geant4.kek.jp/gMocren/

3D (ray casting) 2D (MPR)



Opacity curve and color map editor



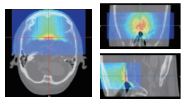
Opacity curve and color map editor

gMocren and utility softwares are freely available.

Supported system :
- Windows 2k/XP or PC Linux OS
- Pentium 4 or faster
- more than 1 GB (recommend)
- no special hardware is necessary

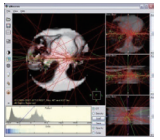
free hand or templates with WW&WL editing

Calculated dose distribution



color mapping

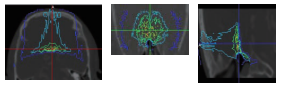
Particle trajectories



Trajectory information in the simulation is available.

***Functionality Requirements* :**

- To visualize
  - the modality image used by the simulation,
  - the calculated dose distribution and
  - the particle trajectories
  - in an agreeable speed
- Transfer function editor
- Multi-platform (Windows, Linux)



contour plot

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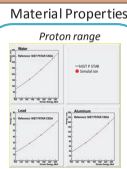
Physics validation

Validation Activities

for Protons

Material Properties

Proton range

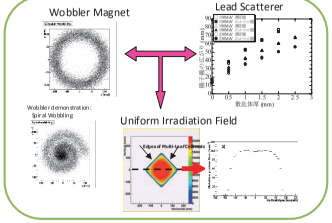


Stopping Power/Range, checked with NIST data

Beam Delivery system validation

Wobbler Magnet

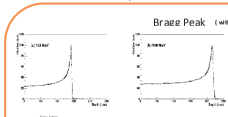
Lead Scatterer



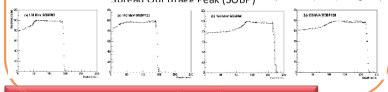
Uniform Irradiation Field

Depth-Dose distribution

Bragg Peak (with Wobbler and Scatter)

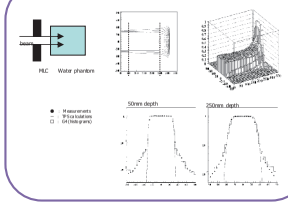


Spread Out Bragg Peak (SOBP) (with Wobbler, Scatter, and Ridge filter)



Nuclear Interaction Effect

by T.Akagi (HIBMC)



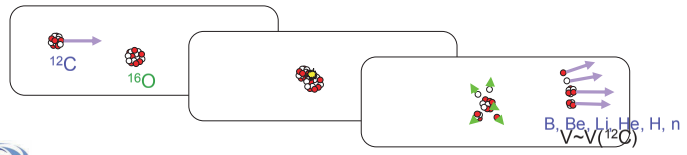
IEEE TNS V52,Issue4, (2005) 896pp

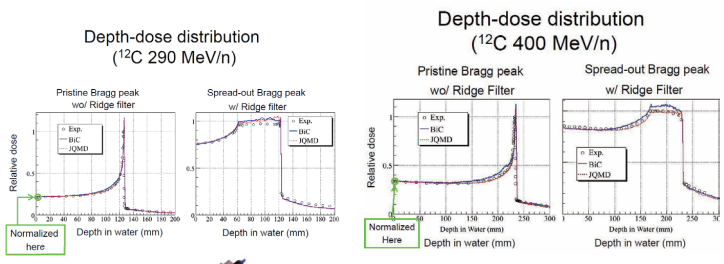
Validation Activities

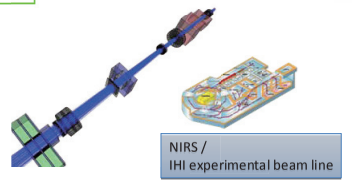
for Carbons

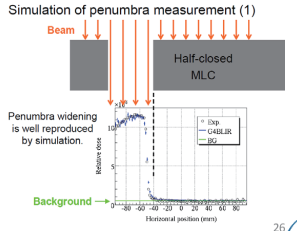
Fragmentation reactions

- In the case of 400MeV/n (~30cm in water), only 30% of beams can reach the region of bragg-peak; about 70% of beams are lost by fragmentation.
- Fragments having lower Z than carbon contribute to tail and lateral dose.
- Fragmentation reaction largely modulate dose distribution.
- Knowledge of fragmentation reaction is important to calculate dose distribution.









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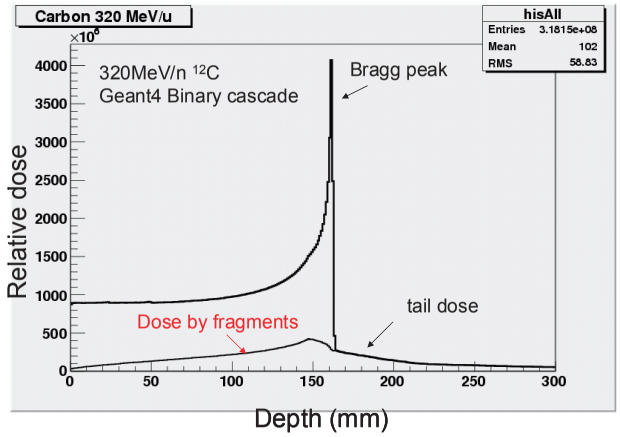
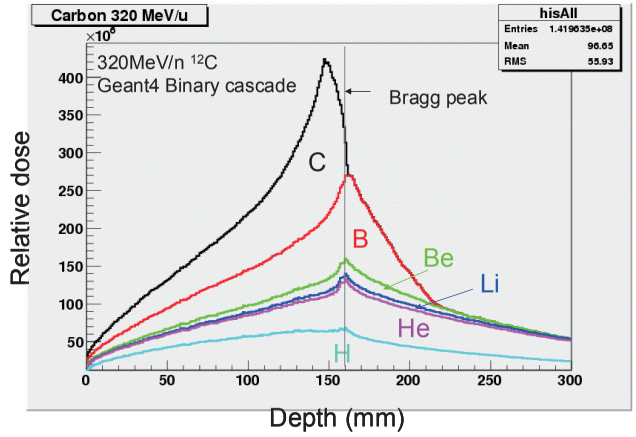
Depth-dose in water



Dose by fragments



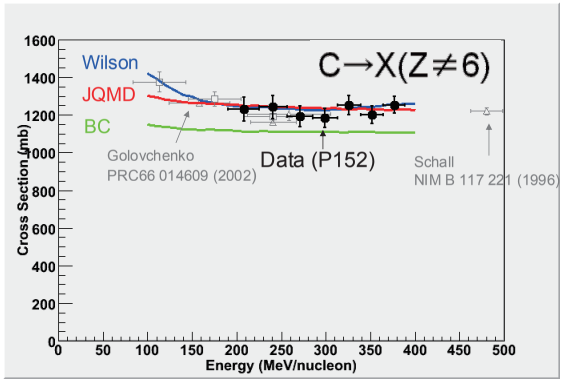
Models for fragmentations in Geant4

- Binary cascade (G4BinaryLightIonReaction)
- Wilson's abrasion (G4WilsonAbrasionModel)
- JQMD (JQMD2G4InelasticModel)
  - K. Niita et al., Phys. Rev. C 52 2620 (1995)
  - T. Koi et al., CHEP03 ECONF C0303241 THMT005 (2003)

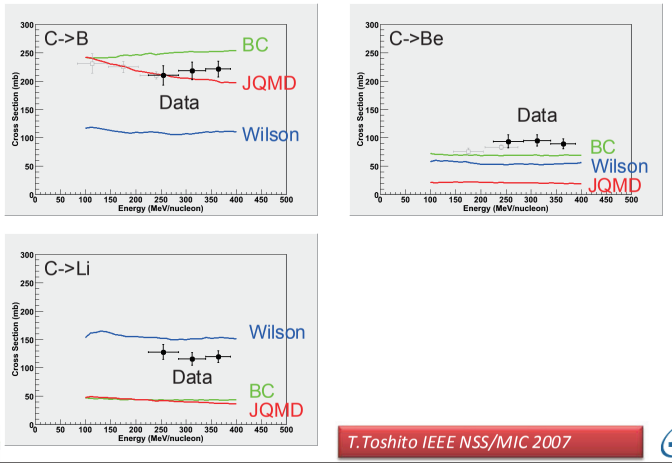
Cross section: Shen fomula(G4IonsShenCrossSection)
-Nuclear Physics. A 49 1130 (1989)

Version 4.9.0

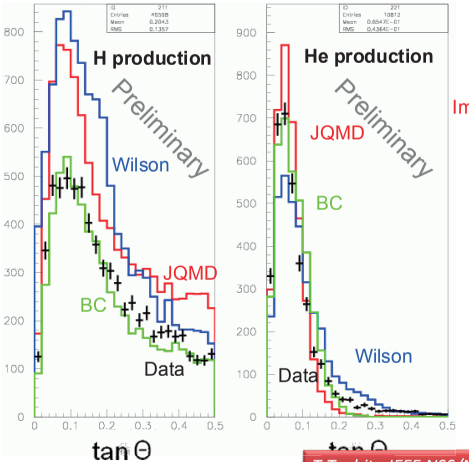
Carbon-Water
total charge-changing cross sections



Carbon-Water
partial charge-changing cross sections



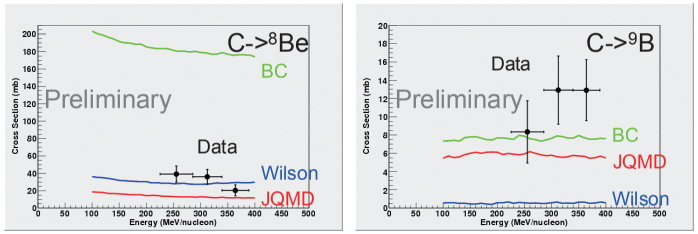
Angular distributions of H and He fragments in Carbon-Water int.



200-400MeV/n

Important for lateral dose

Carbon-Water
^{8}Be and ^{9}B production cross sections

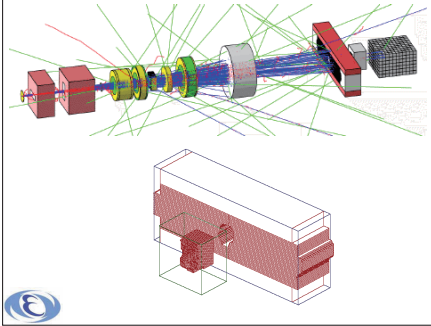


T.Toshito IEEE NSS/MIC 2007

Application at HIBMC

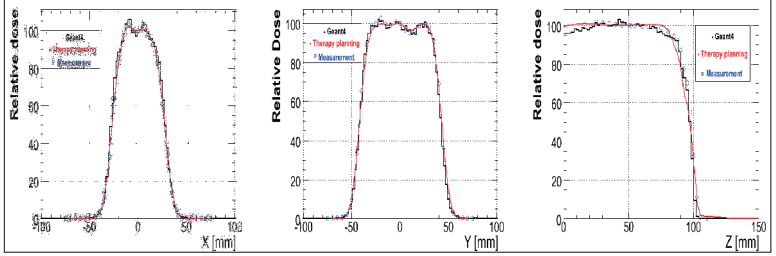
Beam profile

- Comparison of beam profile
  - Geant4.8.2.p01 and pencil beam algorithm used in therapy planning system at HIBMC
  - 150 MeV proton, 2 cm range shifter, 0.16 cm scatterer, bolus, ridge filter designed for 10 cm SOBP and collimator



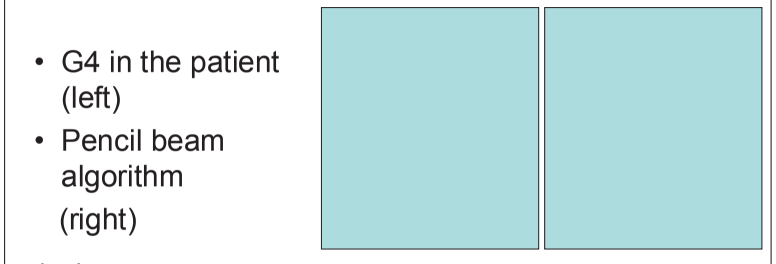
Comparison of dose profiles in water

- Geant4.8.2.p01
- Pencil beam algorithm
- Measurements in water

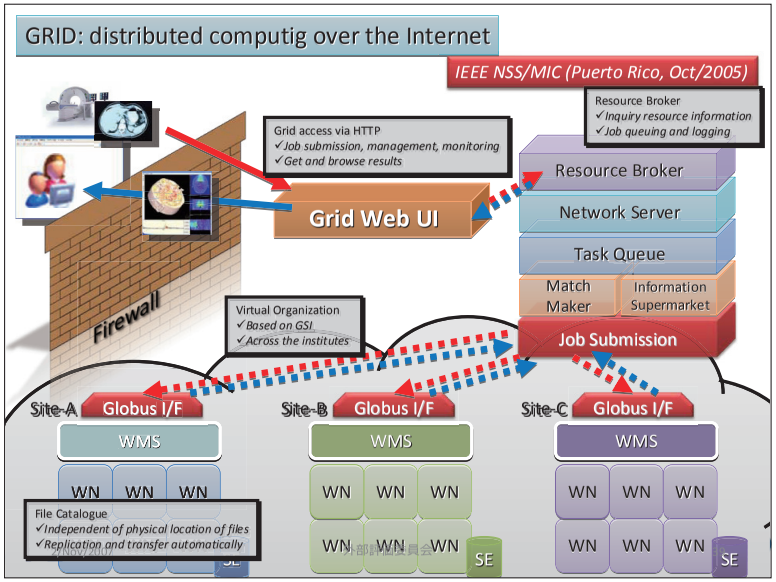


Beam profiles in the patient

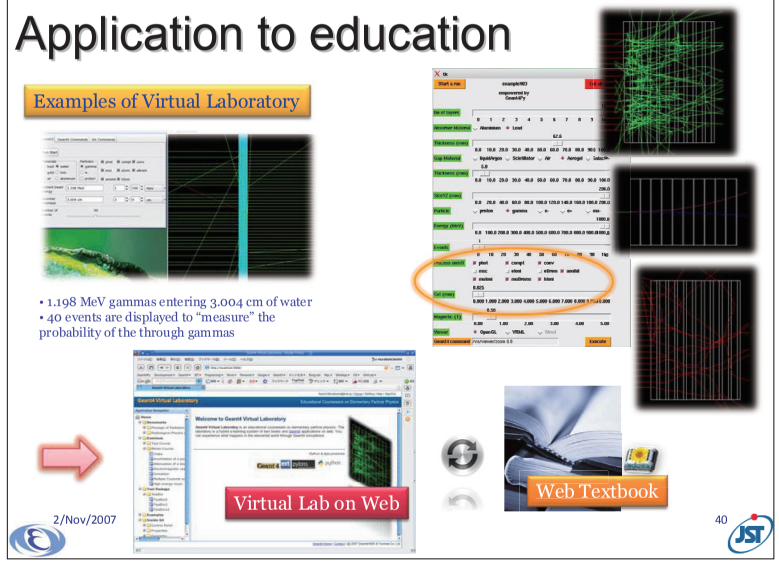
- G4 in the patient (left)
- Pencil beam algorithm (right)



Functionality under development



Application to education



Summary

- Geant4 is extensively applied to radiology because of its capability to handle all particles including ions, complex geometry and electromagnetic fields and flexibility.
- The software suit for simulating radiotherapy has been developed in the CREST project “The Development of Software Framework for Simulation in Radiotherapy”.