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”
  - 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 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

Geant4

- 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

Medical

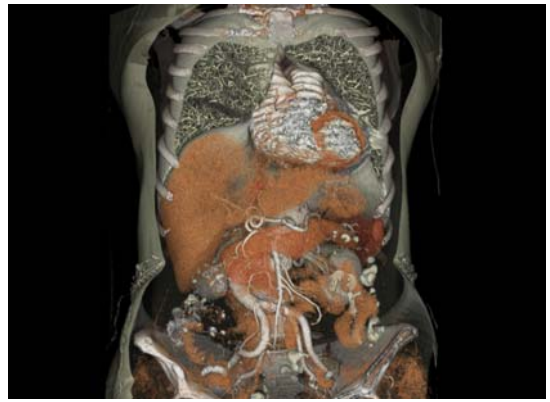
Motivation

- Geant4 is well designed and complete software to simulate interaction between particles and matter
- However, Geant4 is not easy to use in a few case, if
  - geometry is very complex, and
  - physics related is not trivial
    - most of physics process are covered already, but still setting for selection or combination is difficult sometime
    - in very few case, new physics process is 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

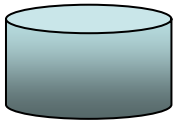
Goal of Our Project

- 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



GRID Deployment

visualization/interactivity

framework for medical application

DICOM interface

Geant4

Scoring/Tally Package

modeler

Physics List
for Radiotherapy

Dose Calculation Engines

JQMD

EGS4

...

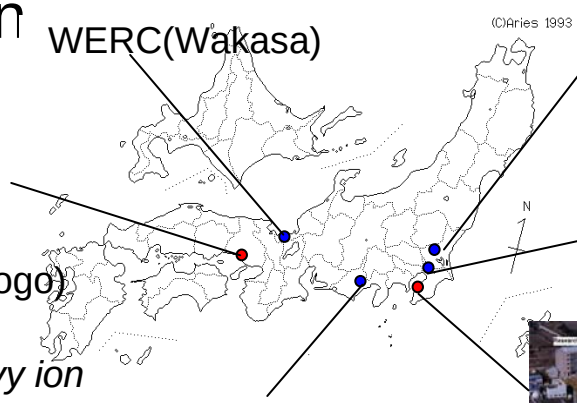
Highlights

- 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



WERC(Wakasa)

PMRC (Tsukuba)

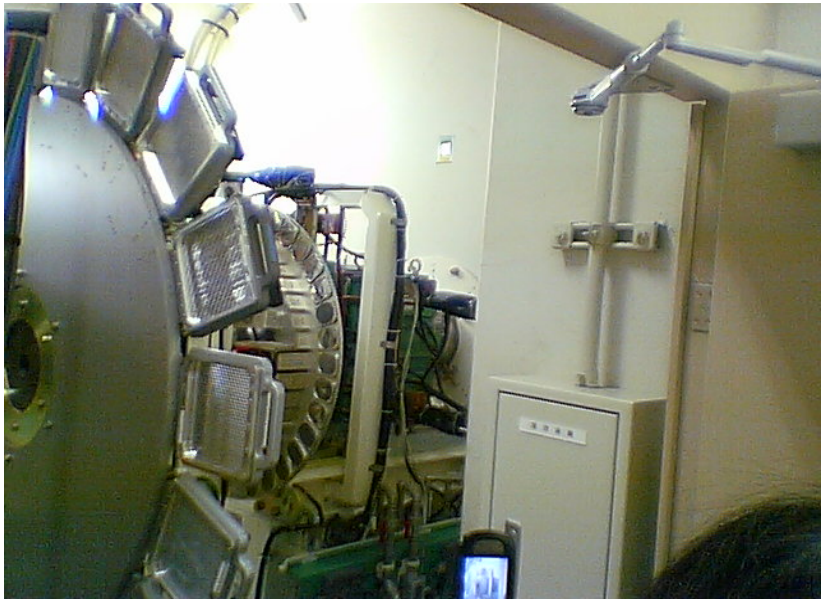
HBMC (Hyogo)

NCC-EAST (Kashiwa

- *proton/heavy ion*
- *proton*

SCC (Shizuoka)

NIRS,HIMAC (Chiba)

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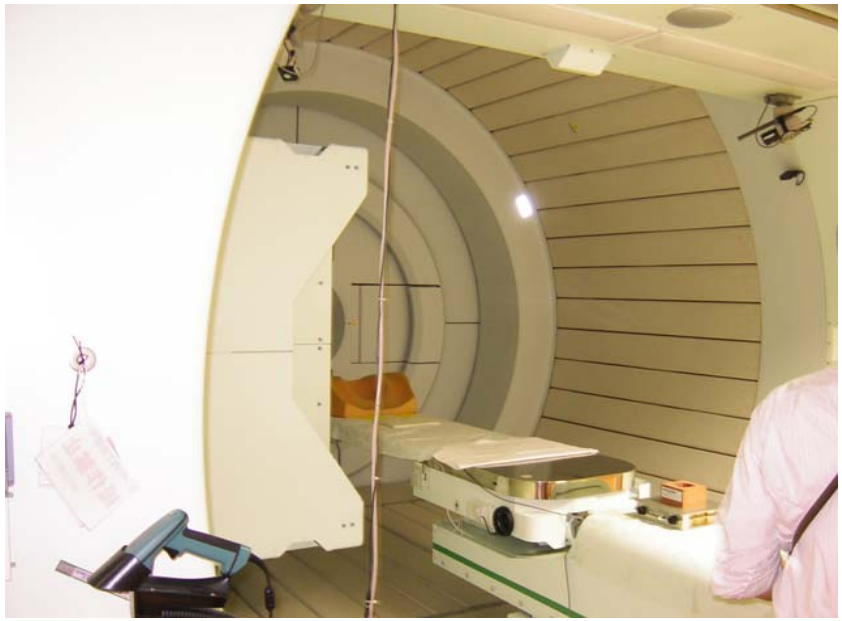
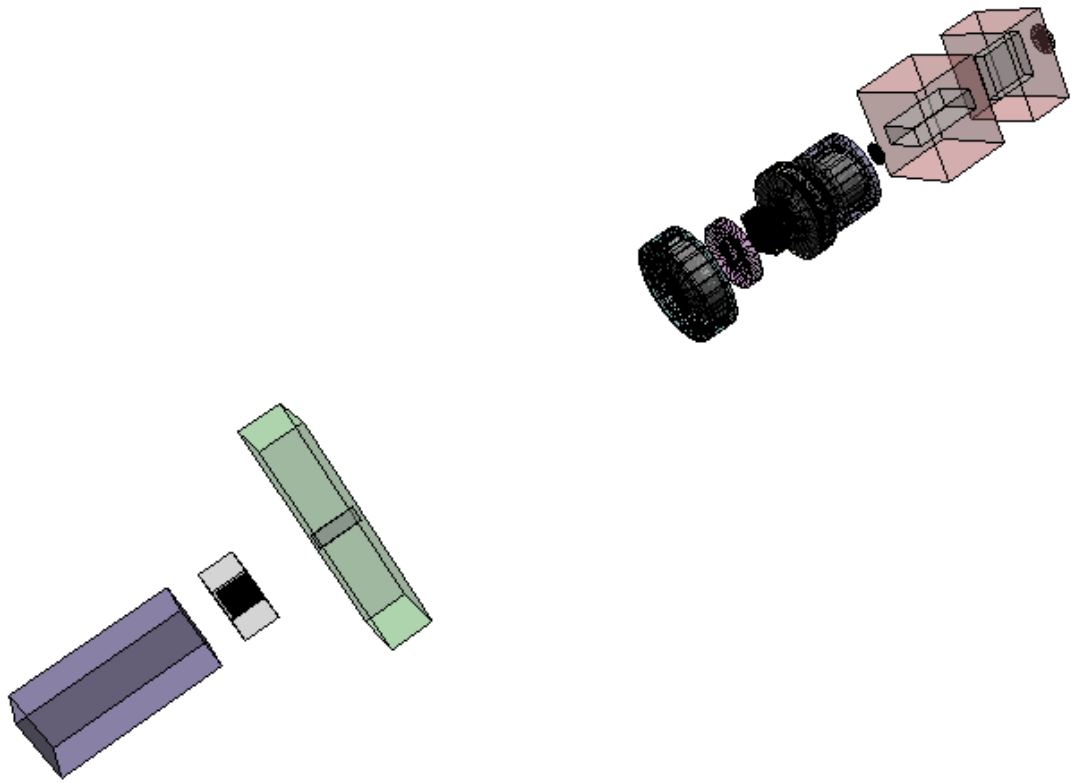


Framework for geometry modeling

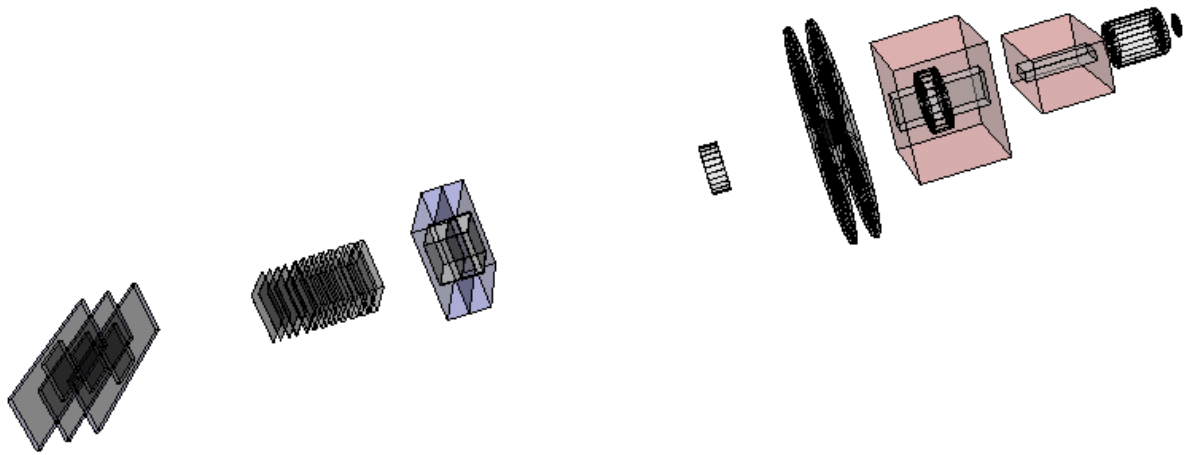
- Class library for implementing a geometry model of hadron therapy facilities are designed and built
- Beam lines at HIMBC, NCC-East and NIRS are implemented already (for water phantom experiments)
- Physics validation will be done for data taken at those facilities

HIBMC



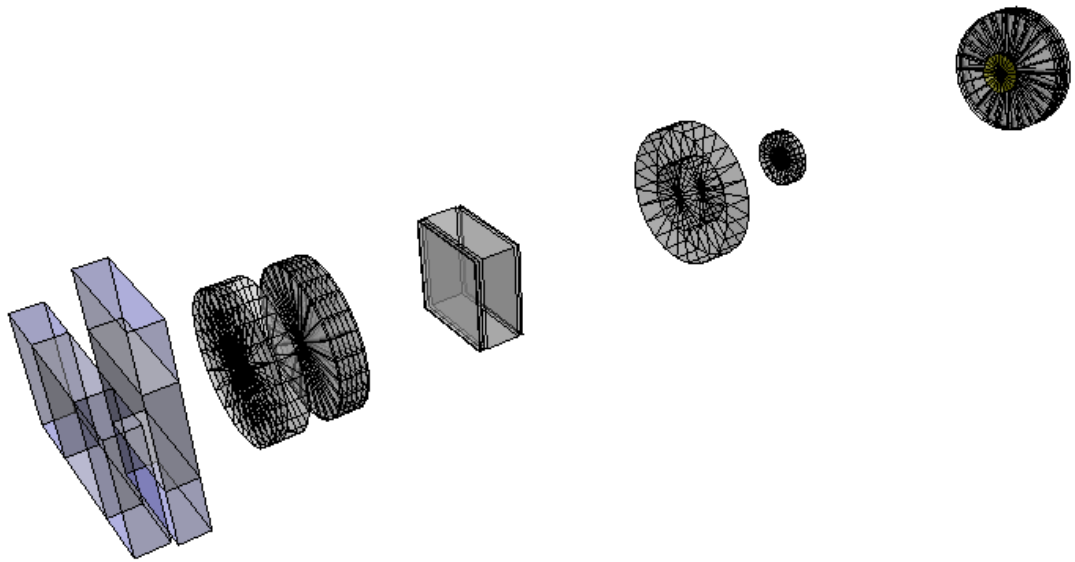
Quads : 9798
Triangles : 1392

New beam line at HIMAC



Quads : 552
Triangles : 768

NCC East



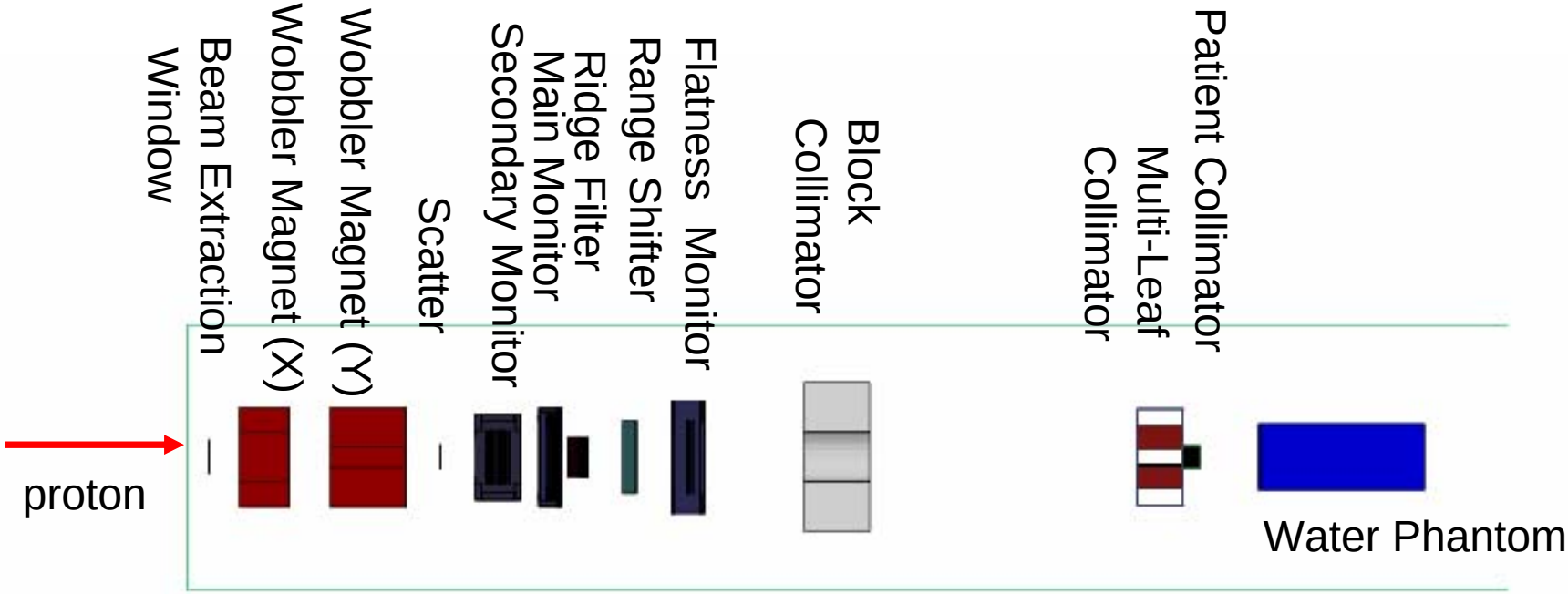
Quads : 1152
Triangles : 2208

Physics validation

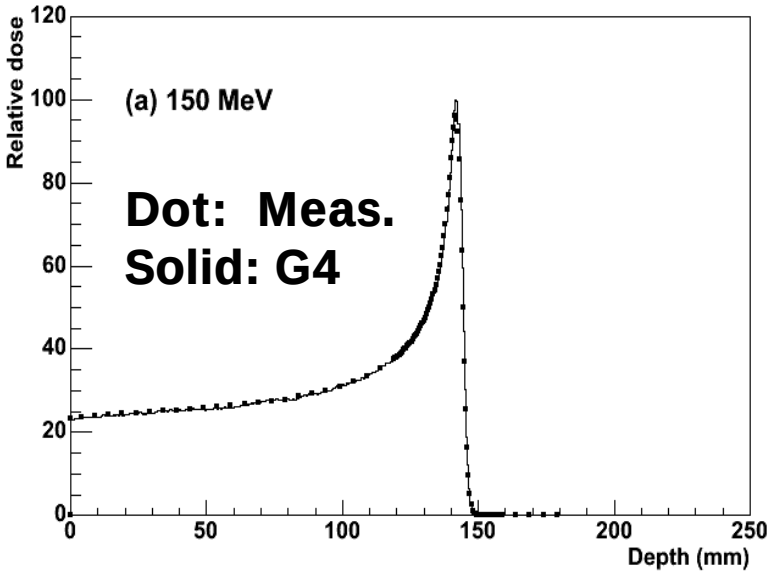
- In most cases, implementing a simulation using Geant4 is not difficult because much information are already available
- Users should consider about the validity of the results
  - Why you can believe the results?
  - If you publish any results using Geant4 without validation, you are silly enough
    - 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



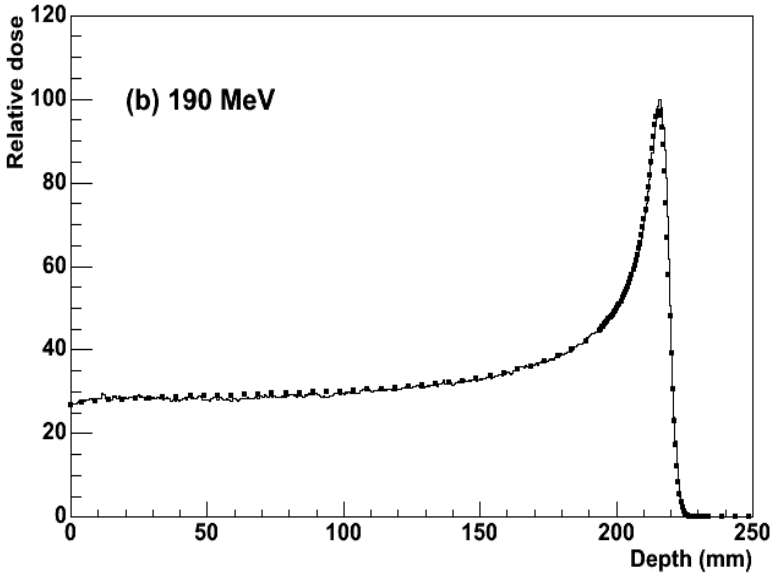
Bragg peak

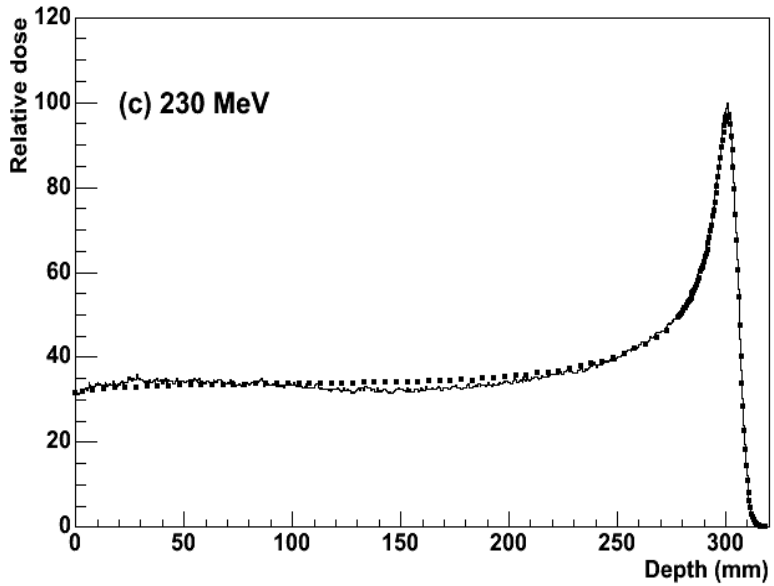


IEEE Transaction on Nuclear Science, Volume 52, Issue 4, Aug.2005, pp.896-901

Comparison between measurement at HIBMC and Geant4 simulation

proton beam with 150, 190 and 230 MeV





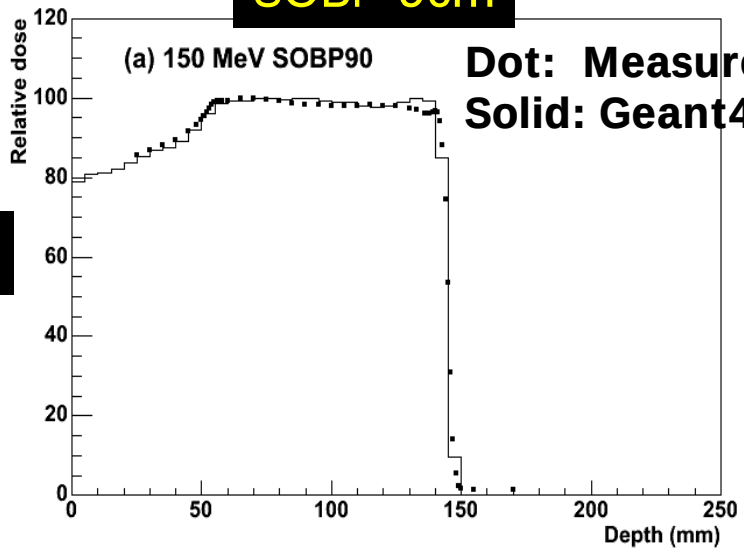
Spread Out Bragg Peak (SOBP)

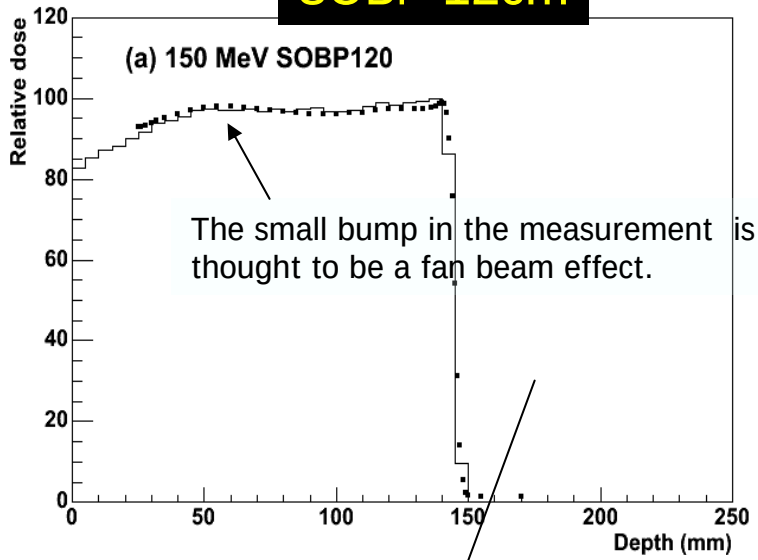
SOBP 9cm

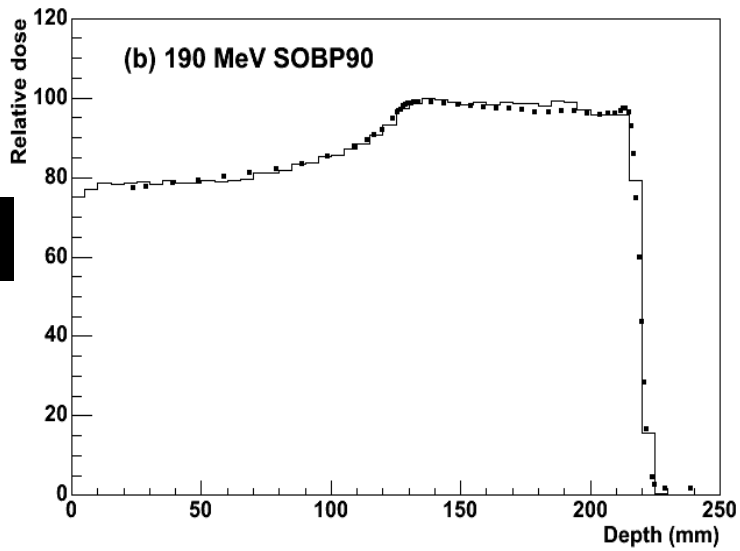
SOBP 12cm

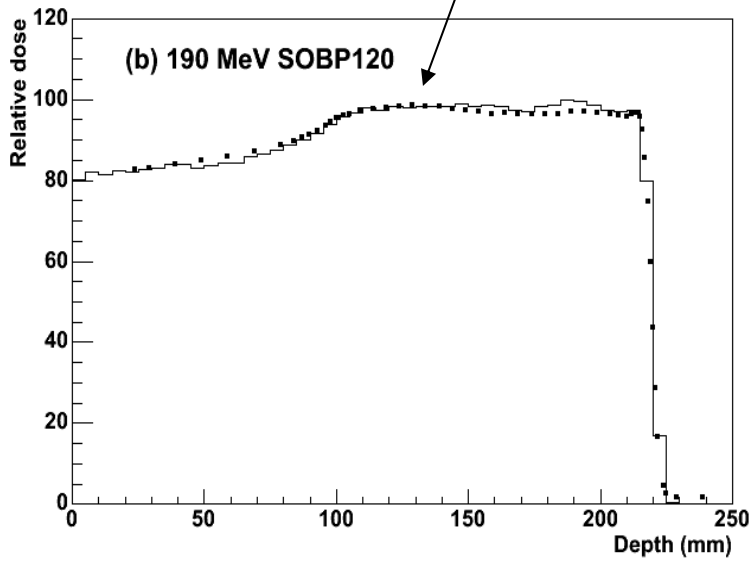
150MeV

190MeV



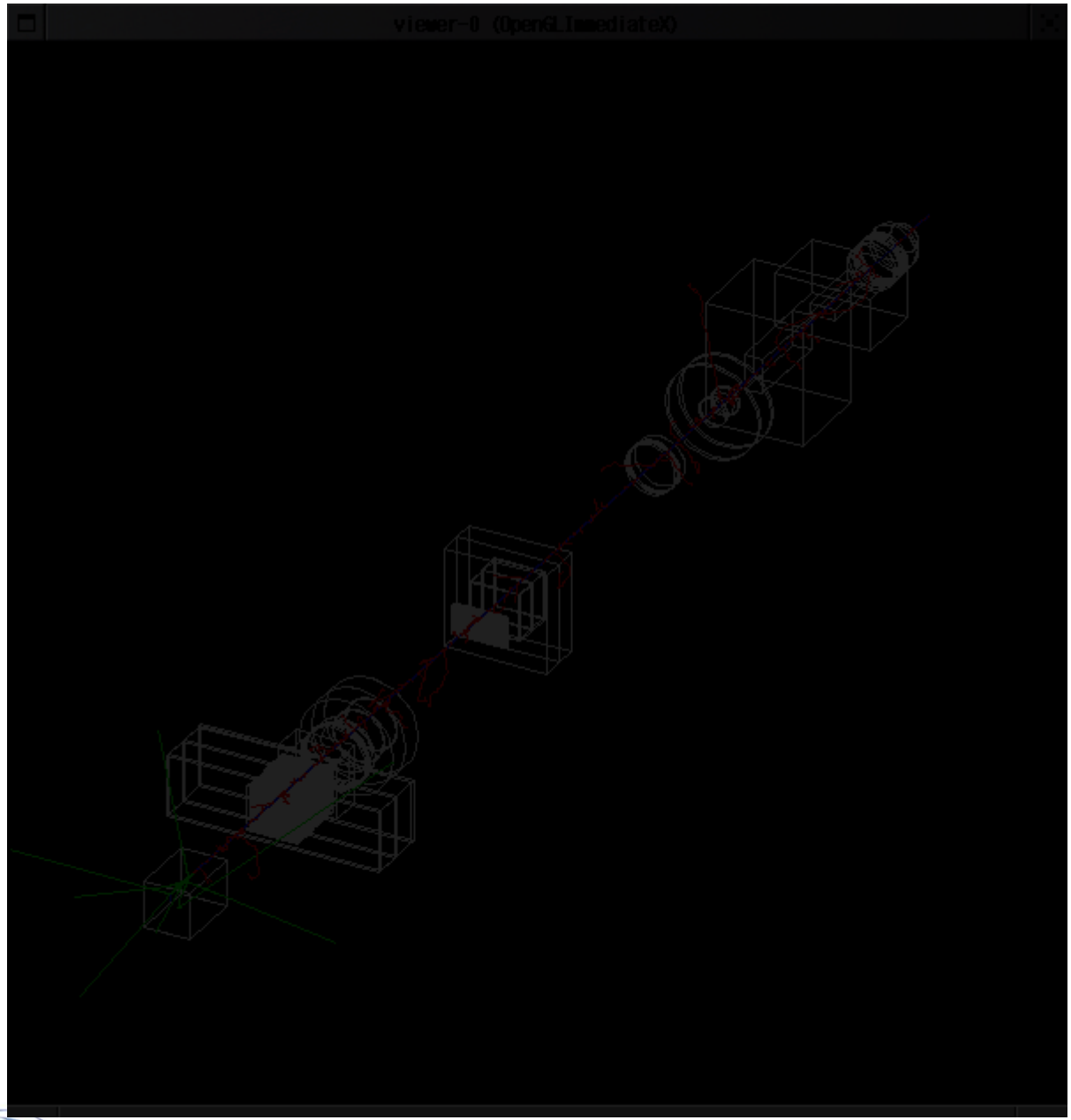






Validation against carbon data

- 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

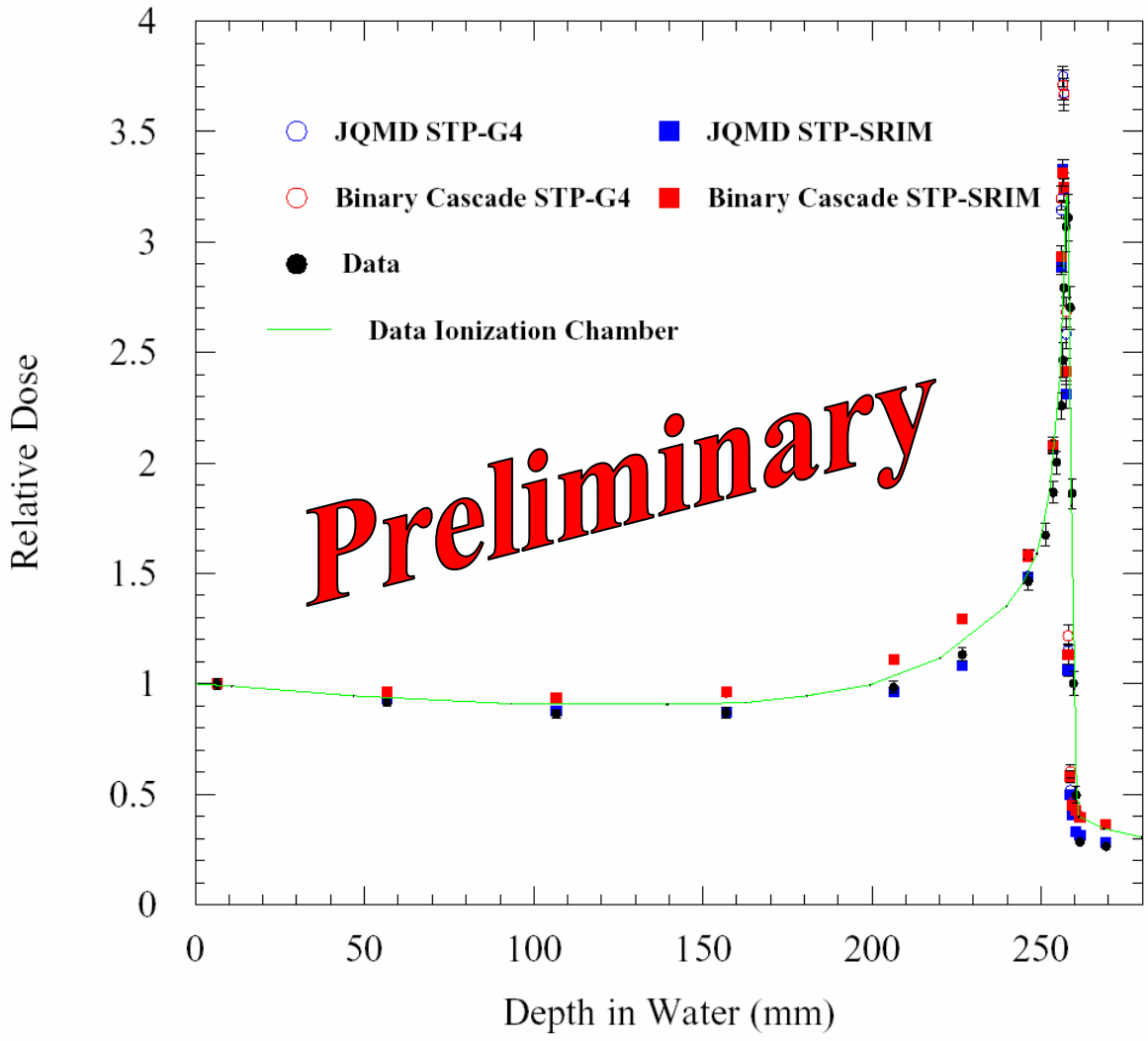
Very Preliminary results

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

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

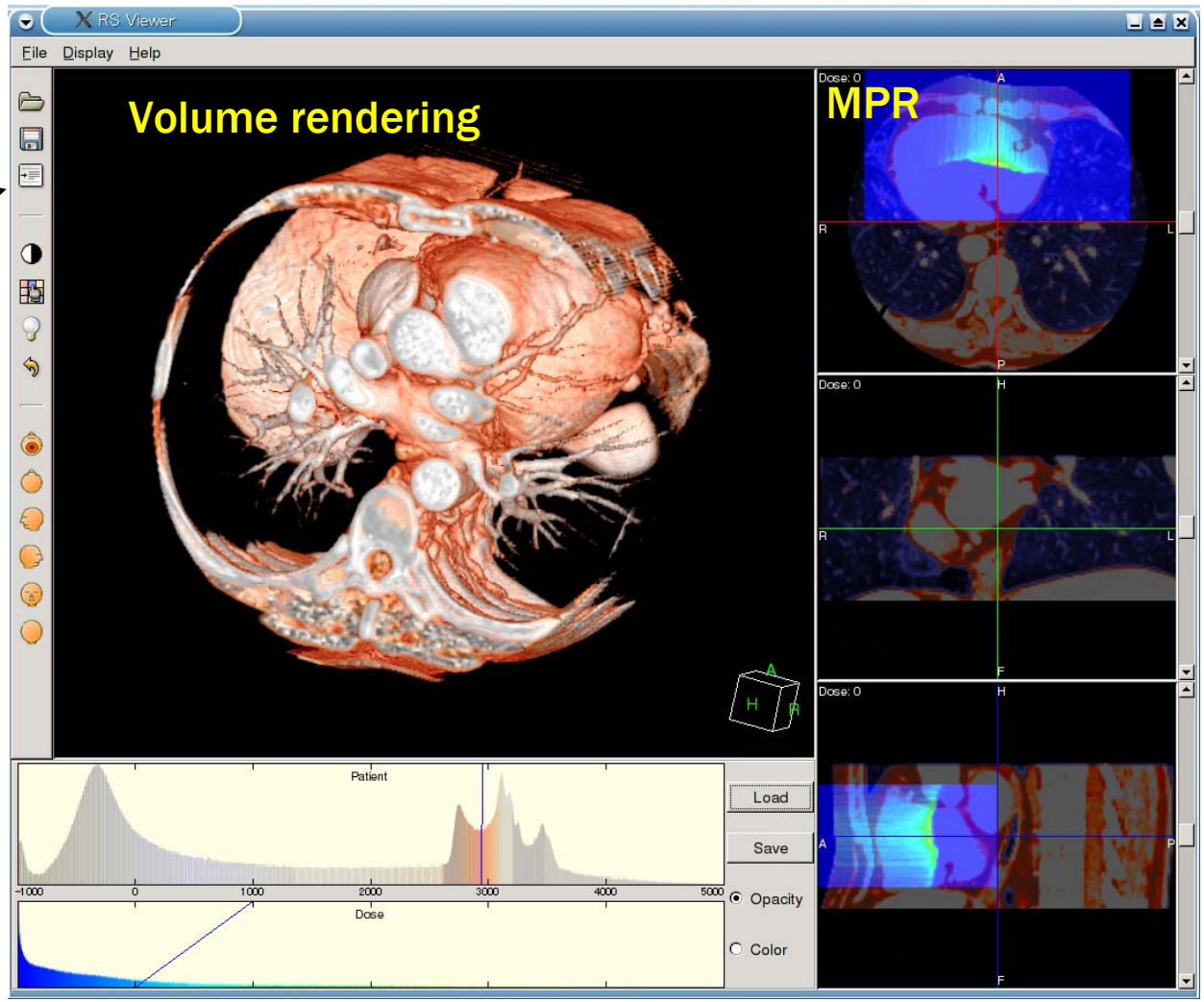
Tool bar

Open file
Save as image
Data information

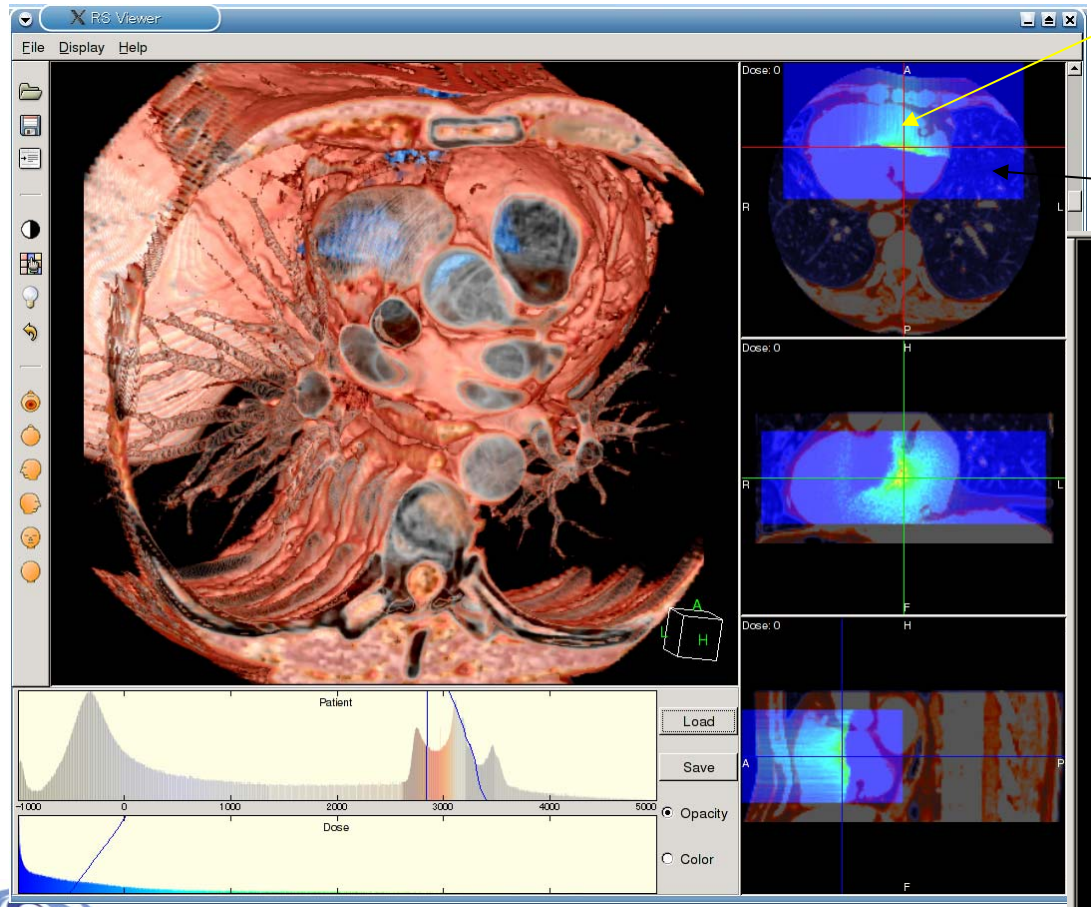
MPR contrast
3D Resolution
3D Light
3D Reset

Directions

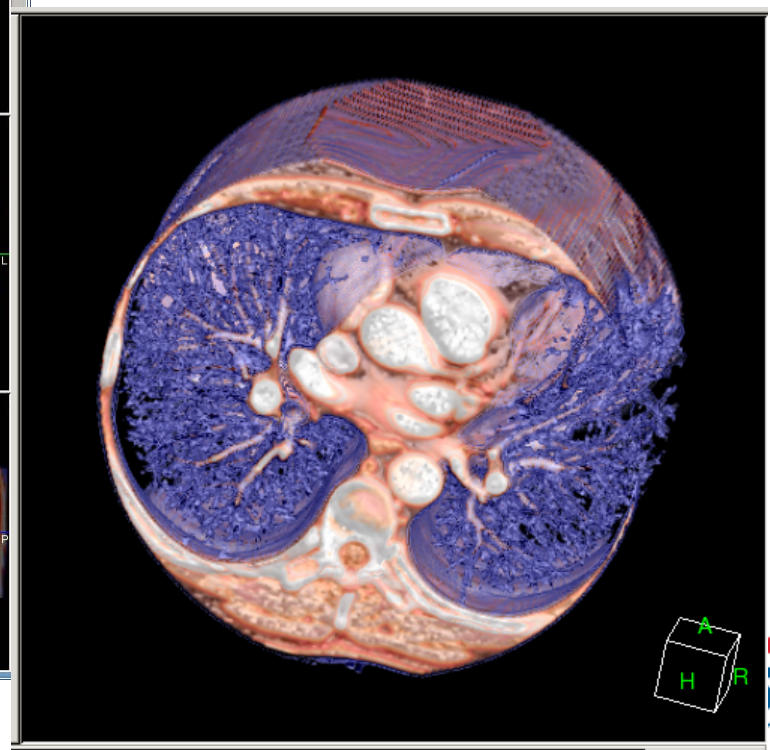
Transfer function & color map setting



Visualization Samples

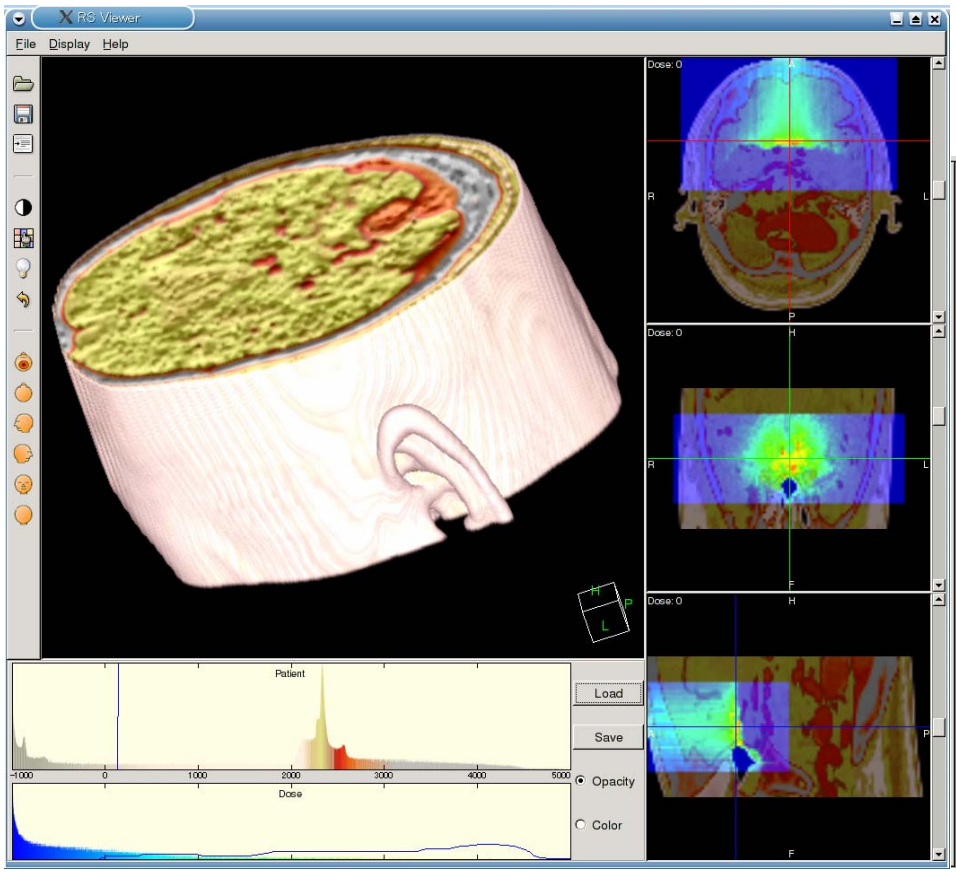


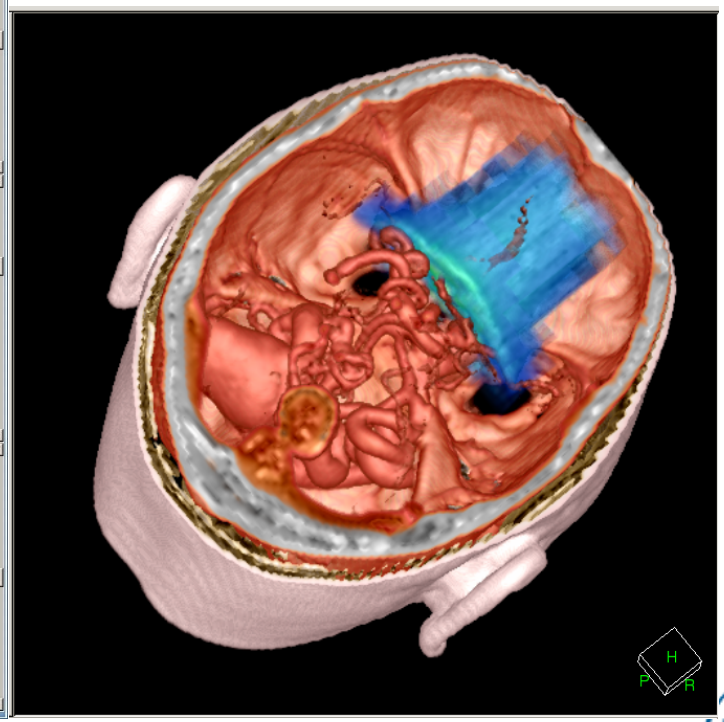
Dose map region



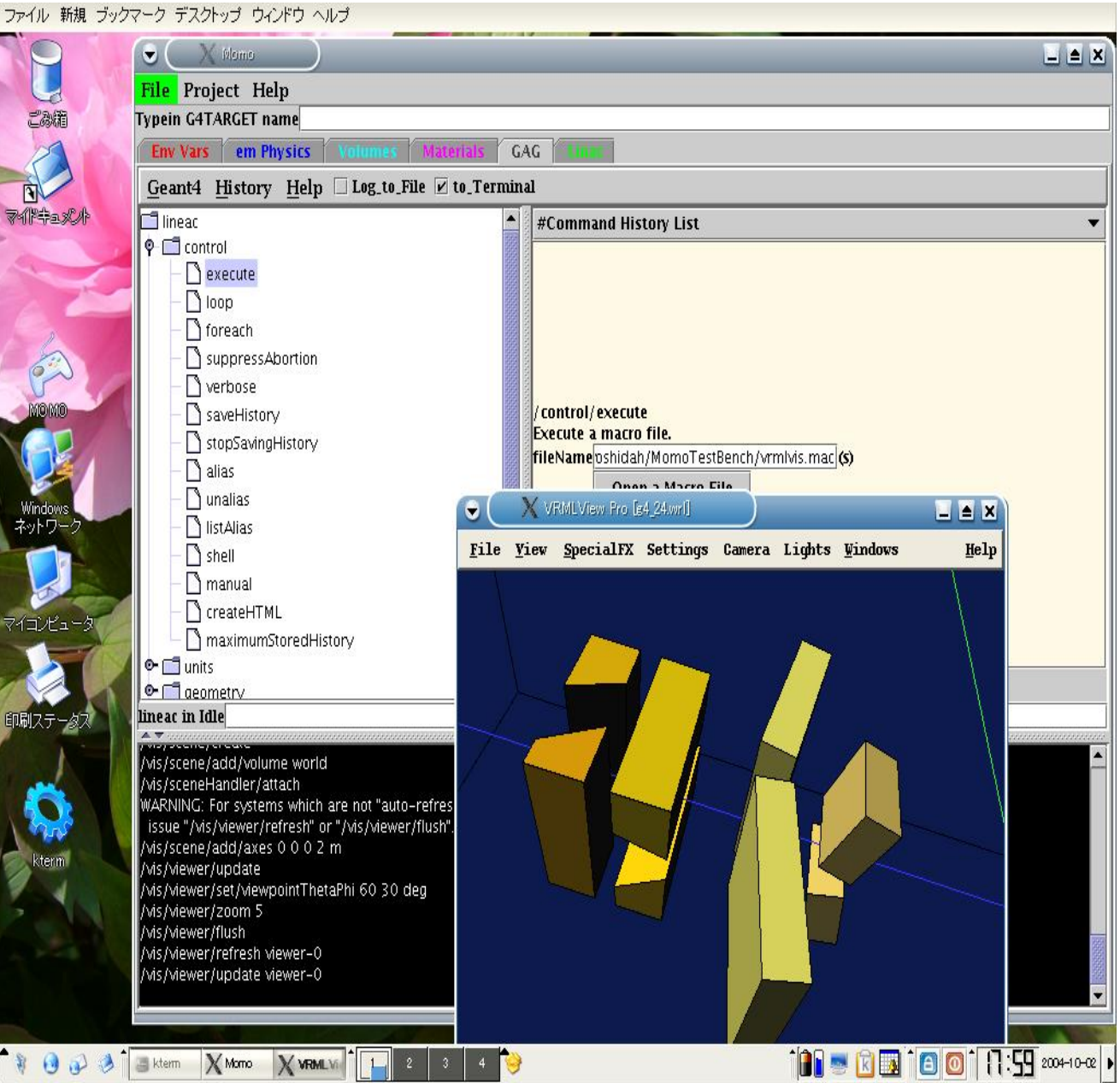
Visualization Samples

- 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.

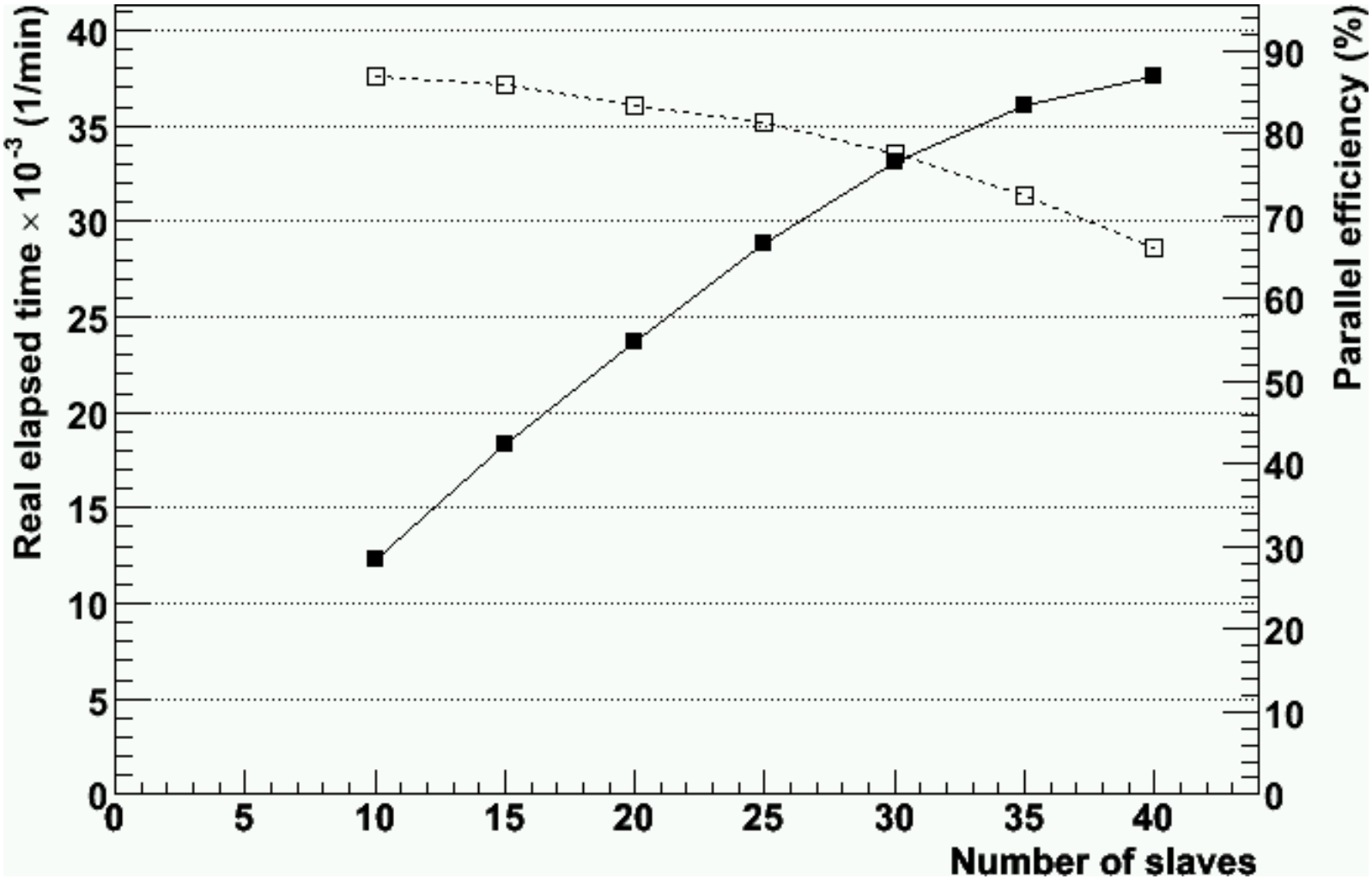
With GUI, design change can be manipulated easily and C++ source code to describe the geometry setup for Geant4 will be produced automatically.

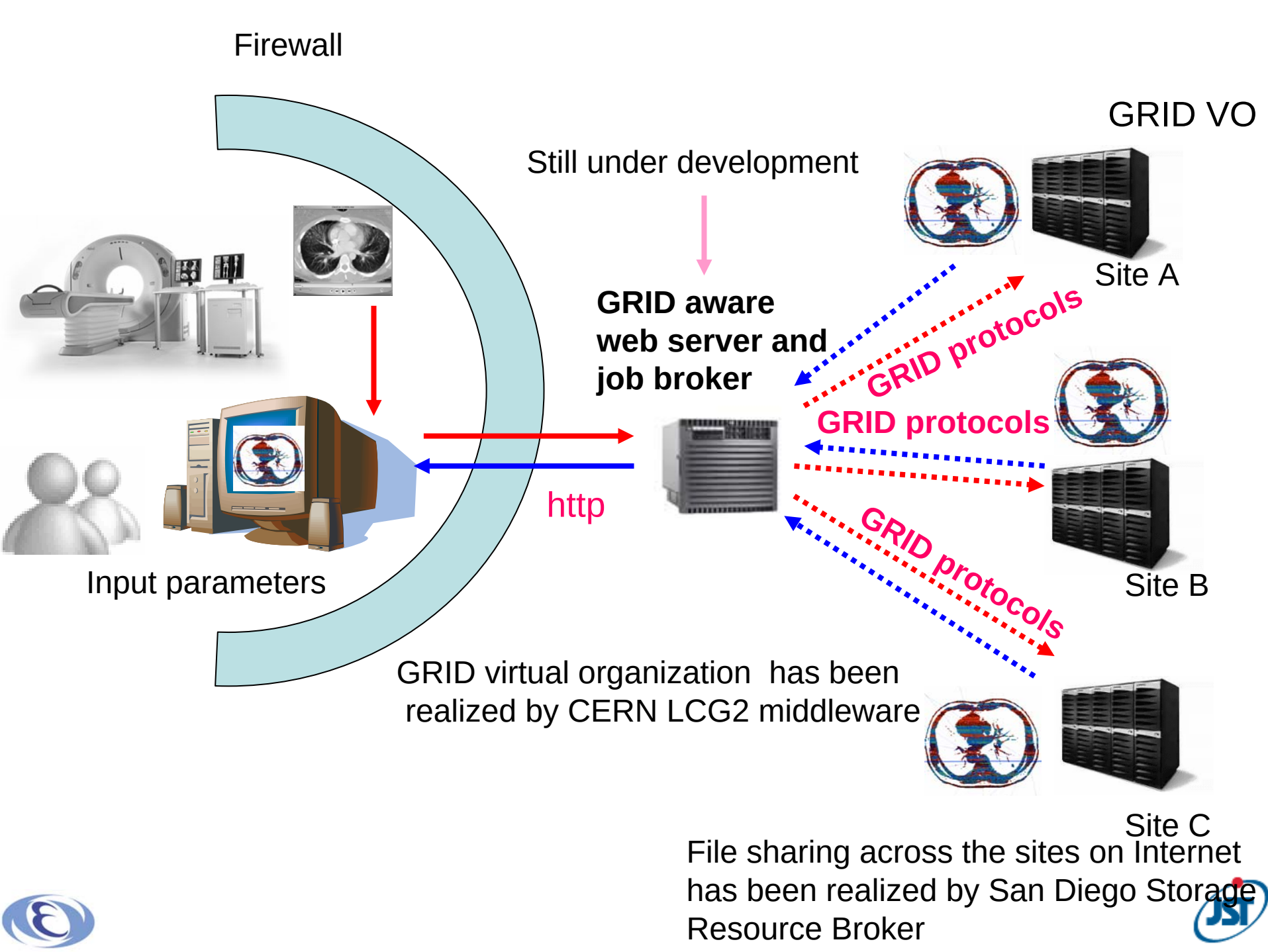
Needs only a web browser and Java!

Parallelism and GRID deployment

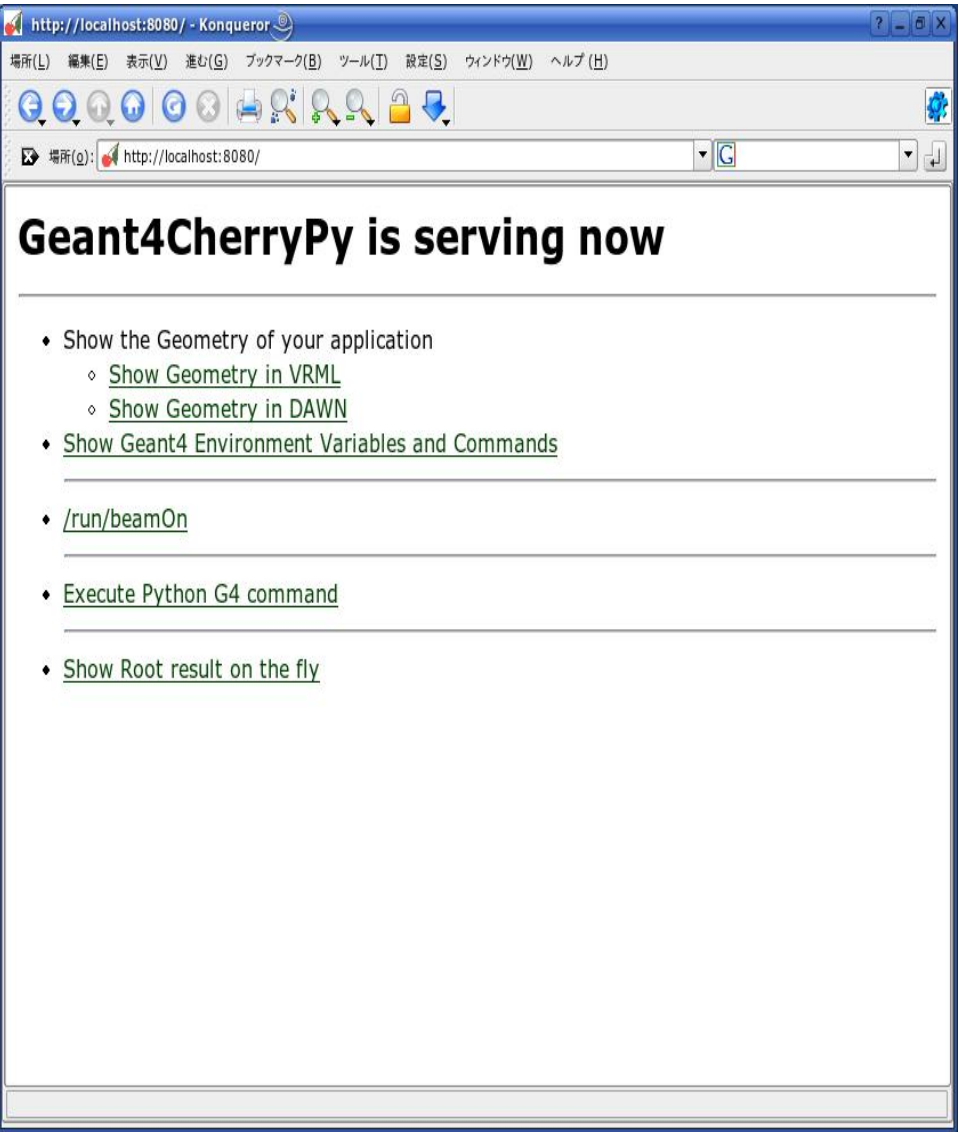
- Event level parallelism has been implemented for general purpose using MPI-C++ interface
  - No other component, but just MPI implementation is necessary, such as MPICH
    - Independent from the TOP-C example in G4 distribution
- Parallel simulation over the Internet is realized by GRID middleware 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

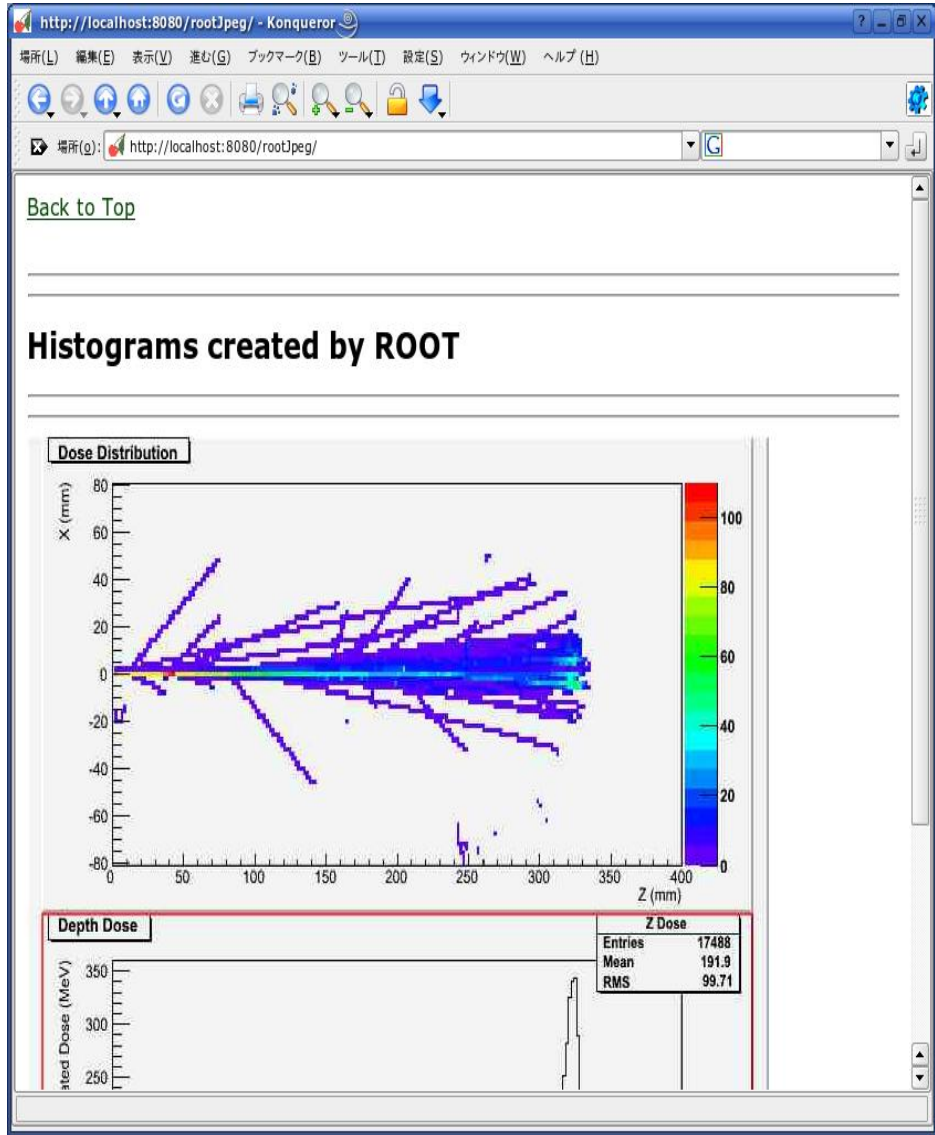
Parallelization efficiency




Firewall
GRID VO
Still under development
GRID aware
web server and
job broker
GRID protocols
GRID protocols
GRID protocols
http
Site A
Site B
Site C
Input parameters
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

Web interface





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

Acknowledgements

- Some slides are prepared by members of the project, Tsukasa Aso, Go Iwai, Satoru Kameoka, Akinori Kimura, Koichi Murakami and Ken Yusa