Software Suite for Particle Therapy Simulation

Takashi Sasaki
KEK Computing Research Center
and
CREST/JST

Takashi.Sasaki@kek.jp

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 framework and software toolkit for simulation in radiotherapy, especially, particle therapy to be used for
  - validation of treatment planning systems
  - does distribution calculation for each treatment
  - planning new facilities and new treatment methods
- Validation of simulation results

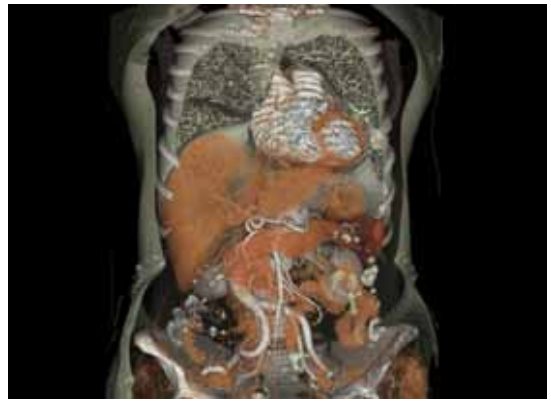
Particle Therapy in Japan

- Facilities under operation in Japan (6 among 24)
  - NIRS (carbon: NIRS and GSI only)
  - NCC-EAST
  - HIBMC
  - WERC
  - SCC
  - University of Tsukuba
- Approved in 2006
  - Gunma University (Heavy Ion: 2009)
  - Wakasa
- Even a private hospital !
  - Fukushima (proton 2008)
    - http://www.minamitohoku.or.jp/ryushisen/ryushisen.htm
  - Kawasaki (carbon 2010)
    - Funded by Mizuho Bank
    - Fujitsu, IHI, JGC and others

Particle Therapy outside of Japan (from the 2005 PTCOG list)

- Carbon
  - GSI, Germany
- Proton (total 17)
  - US 4
  - Russia 2
  - France 2
  - Swiss 2
  - Germany, Canada, Sweden, South Africa, China, Italy, England

The system architecture



Knowledge DB

GRID Deployment

PTSsim

framework for medical application

visualization/interactivity

DICOM interface

Scoring/Tally Package

Geant4

modeler

Physics List
for Radiotherapy

Dose Calculation Engines

JQMD

EGS4

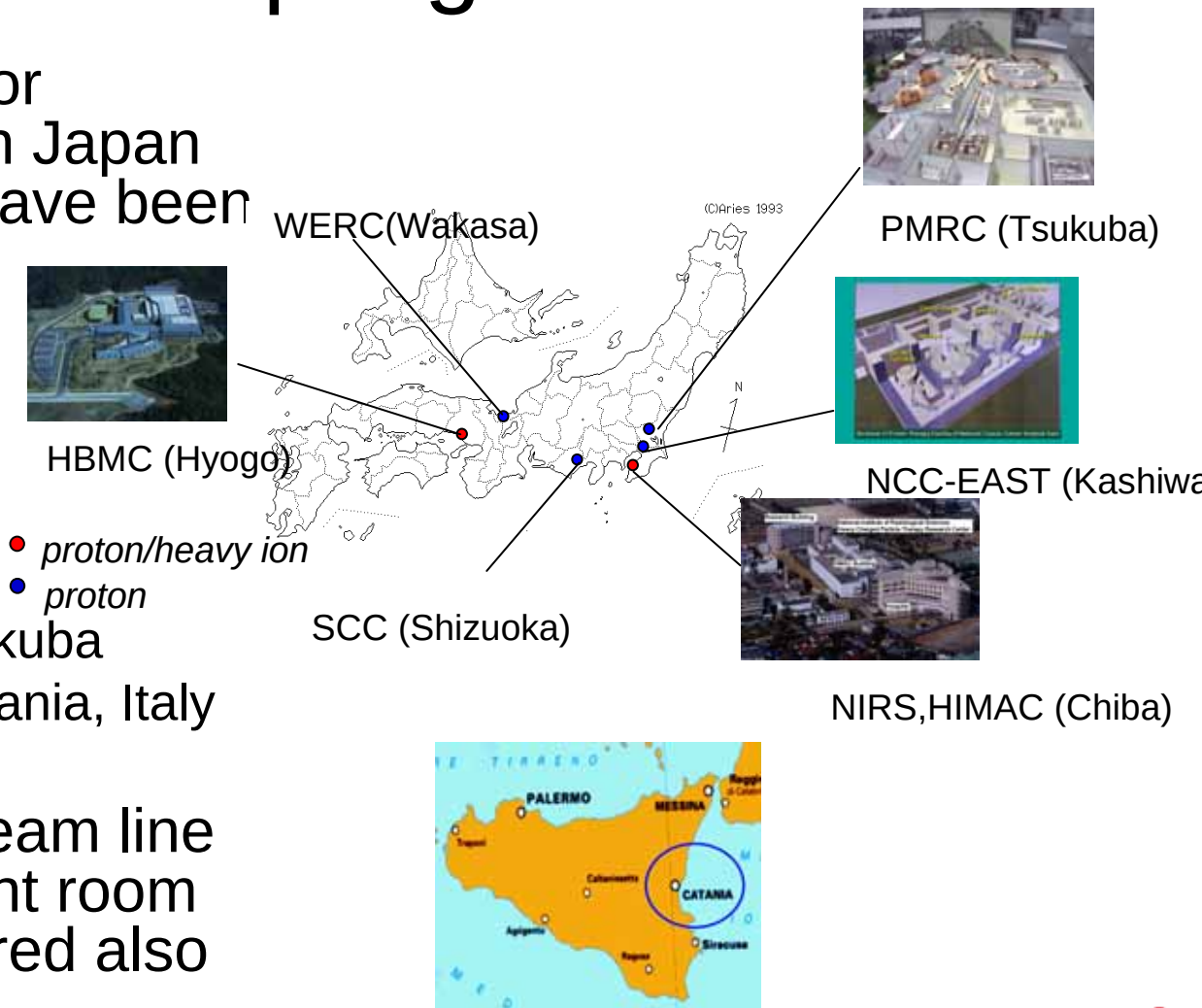
others…

Number of published papers in PMB and Med. Phys. during Jan. 2003 to Dec. 2006

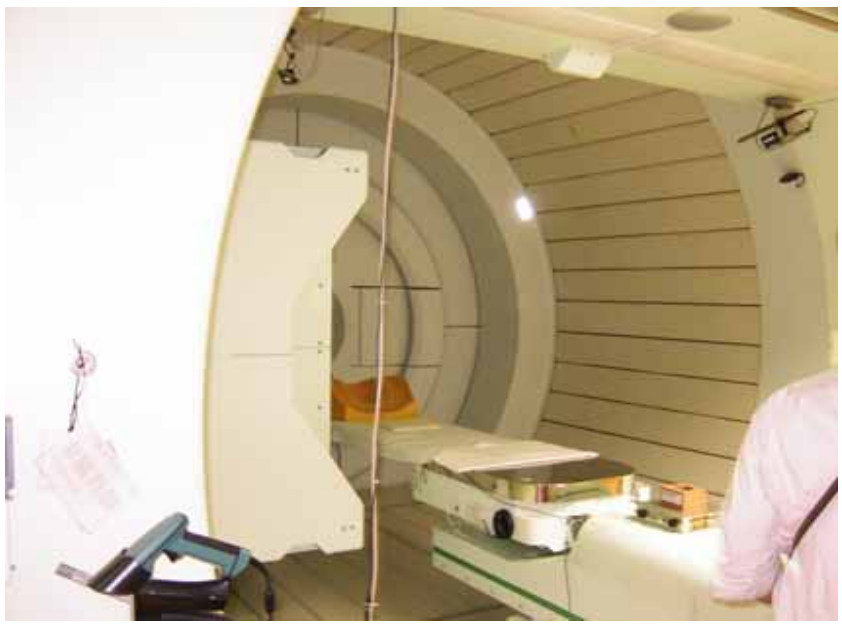
Searched word in title, abstract or keywords	Physics in Medicine and Biology	Medical Physics	total
Geant4	29	62	91
GEANT3	4	2	6
GEANT	6	4	10
FLUKA	5	8	13
EGS	4	13	17
EGS4	22	23	45
MCNP	27	37	64
PENELOPE	13	17	30
PHITS	0	0	0

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



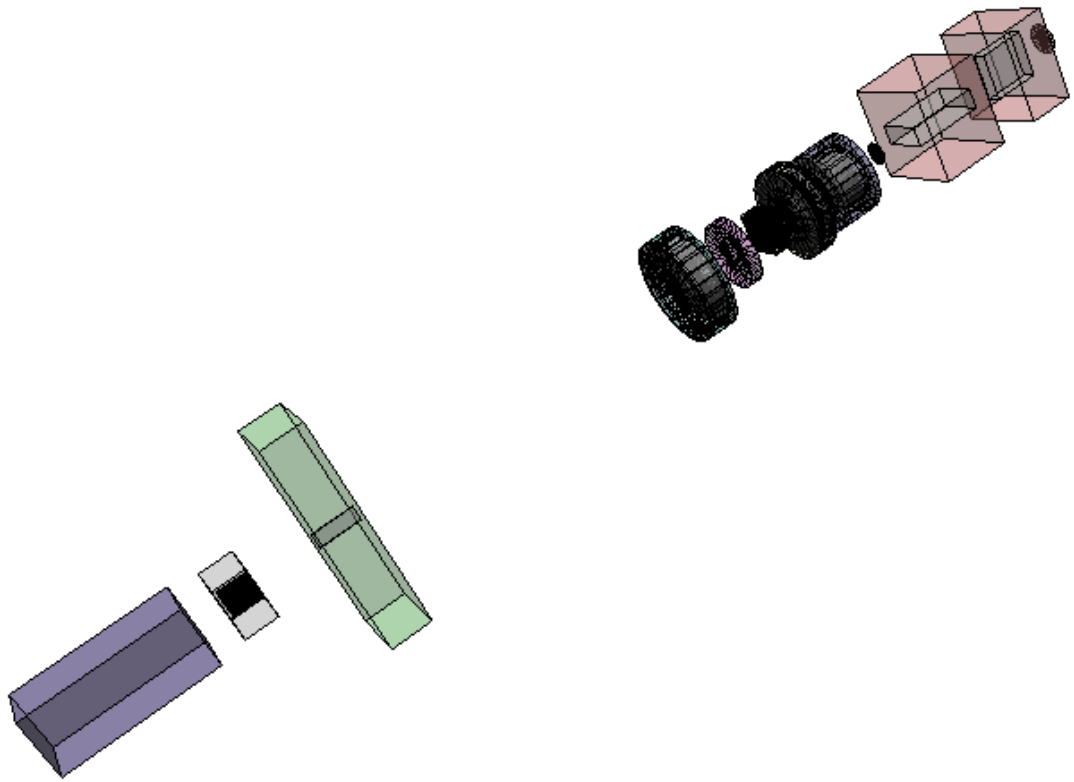

-150
06-2498-2



PTSsim

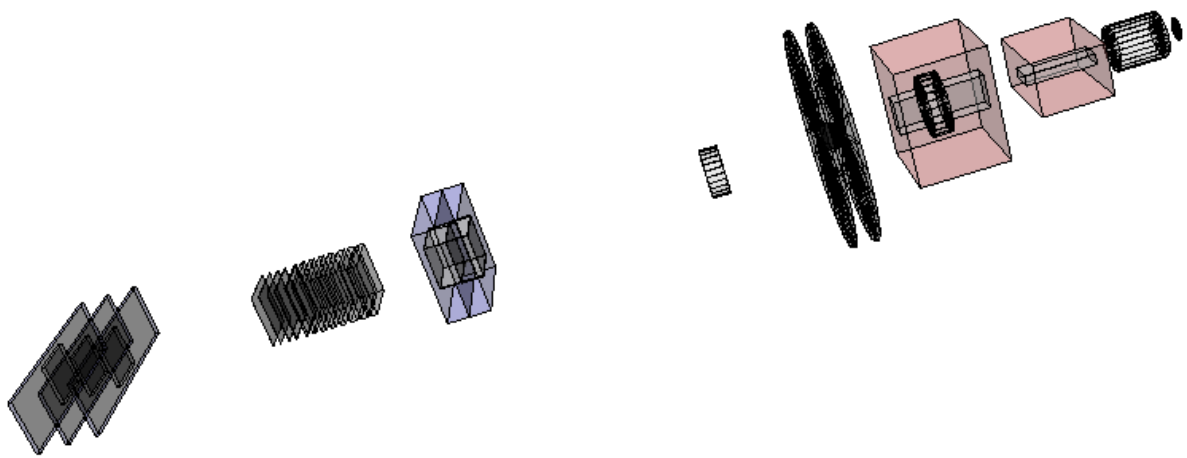
- Core of our product
  - Software framework for particle therapy facility
- The class library for implementing a geometry model of hadron therapy facilities are provided
- Beam lines at HIMBC, NCC-East and NIRS are implemented already
- Physics validation will be done for data taken at those facilities

HIBMC



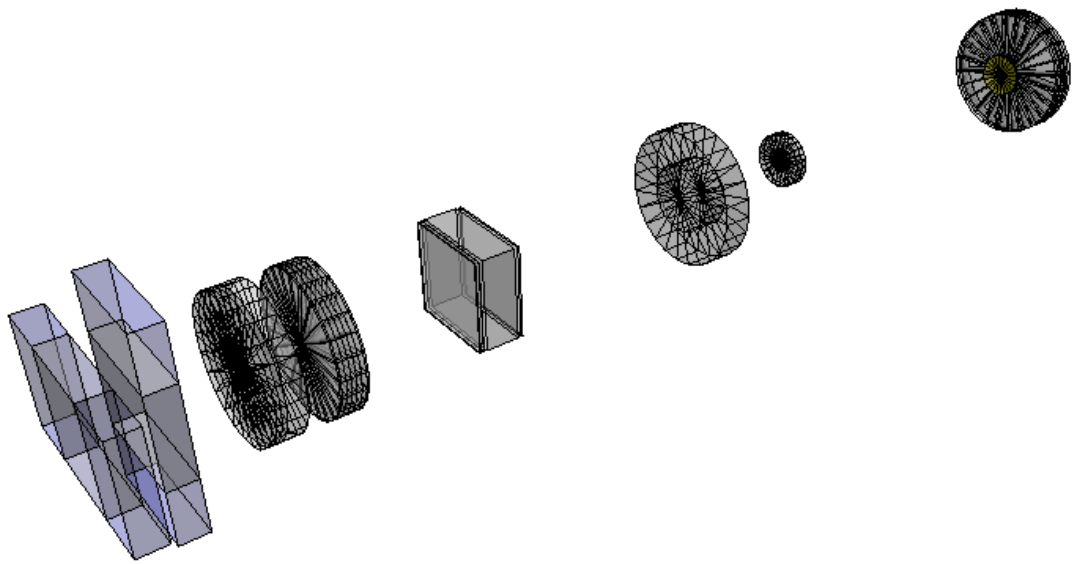
Quads : 9798
Triangles : 1392

New beam line at HIMAC



Quads : 552
Triangles : 768

NCC East



Quads : 1152
Triangles : 2208

Physics validation

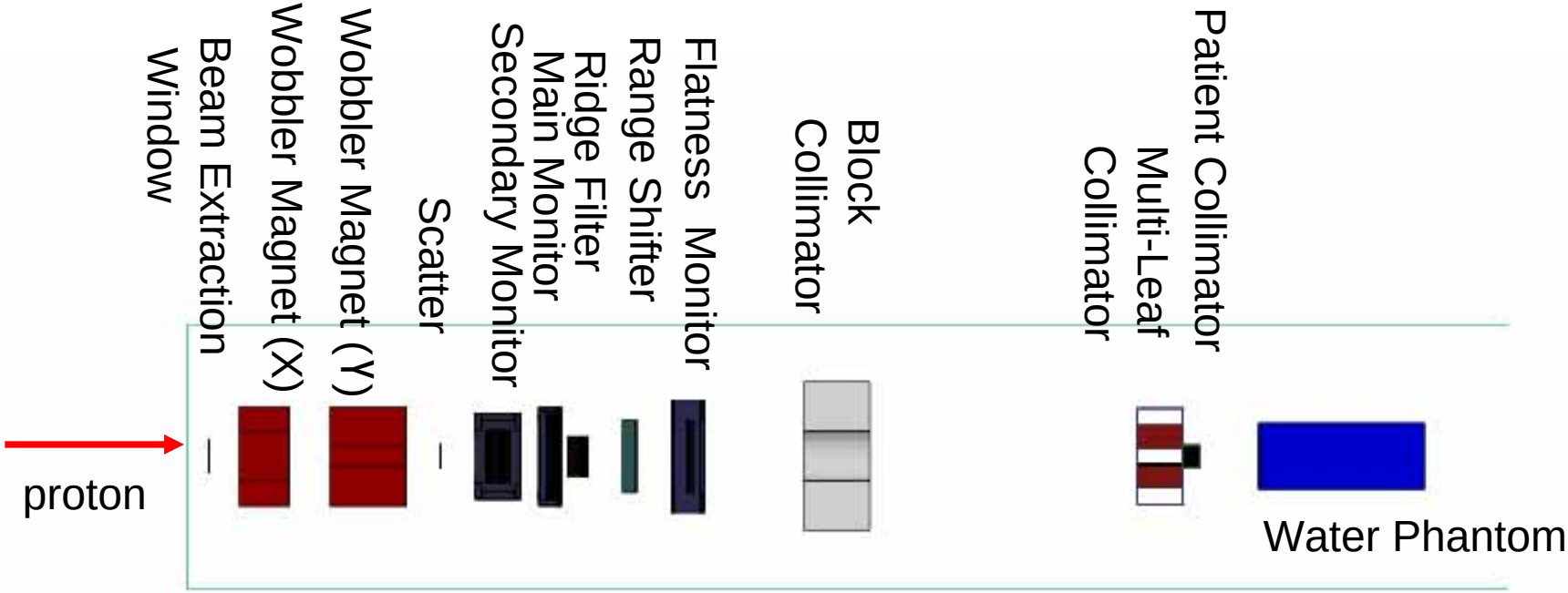
- In most cases, implementing a simulation using Geant4 is not difficult because much information are already available
- Users should consider about the validity of the results
  - Why you can believe the results?
  - If you publish any results using Geant4 without validation, you are silly enough
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

Collaborating Facilities

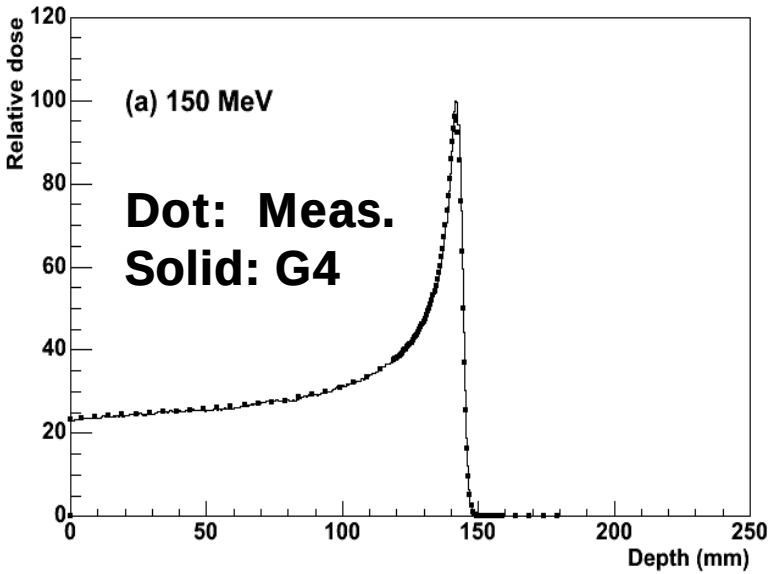
- Protons
  - National Cancer Center
    - Kashiwa, Japan
  - Hyogo Ion Beam Medical Center
    - Hyogo, Japan
  - UCSF
    - San Francisco, US
- Carbons
  - NIRS
    - Chiba, Japan
  - Hyogo Ion Beam Medical Center
    - Hyogo, Japan
  - Under discussion
    - DKFZ, Heidelberg, Germany
    - Etoile, Lyon, France

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



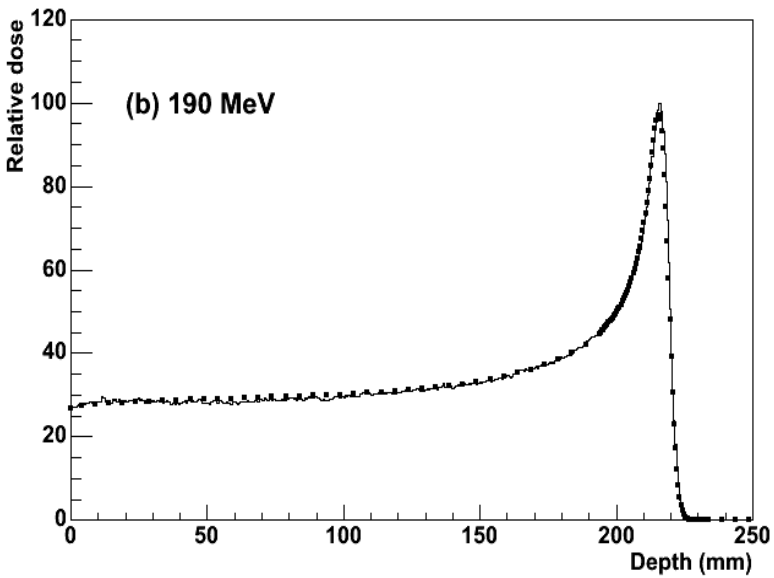
Bragg peak

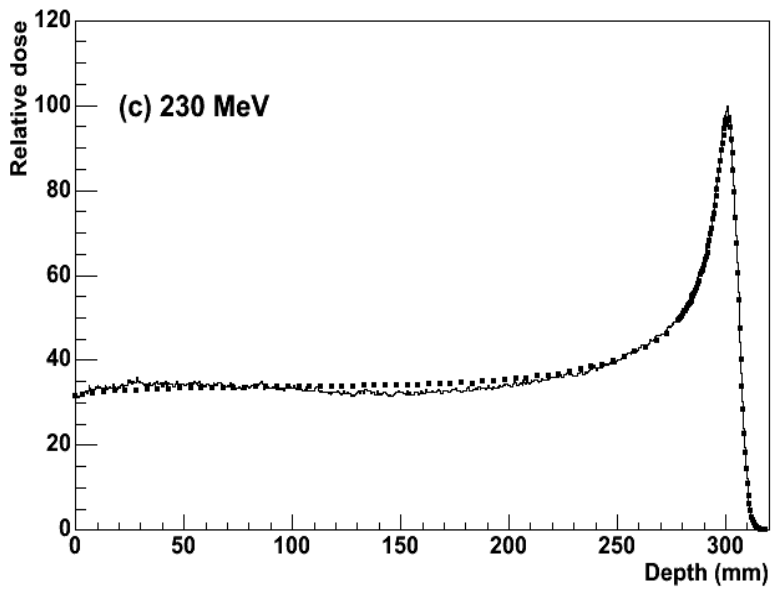


IEEE Transaction on Nuclear Science, Volume 52, Issue 4, Aug.2005, pp.896-901

Comparison between measurement at HIBMC and Geant4 simulation

proton beam with 150, 190 and 230 MeV





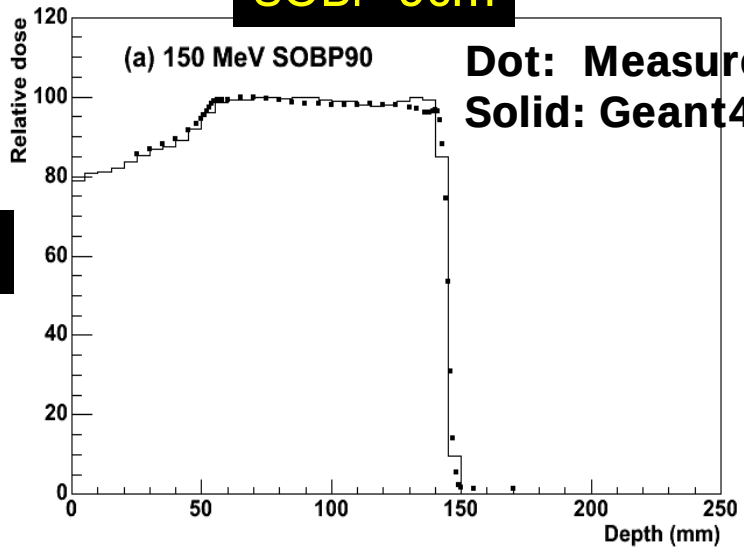
Spread Out Bragg Peak (SOBP)

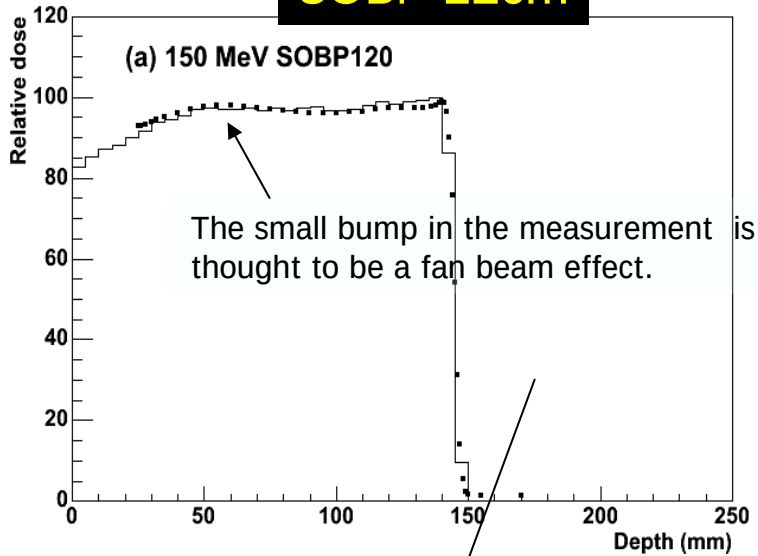
SOBP 9cm

SOBP 12cm

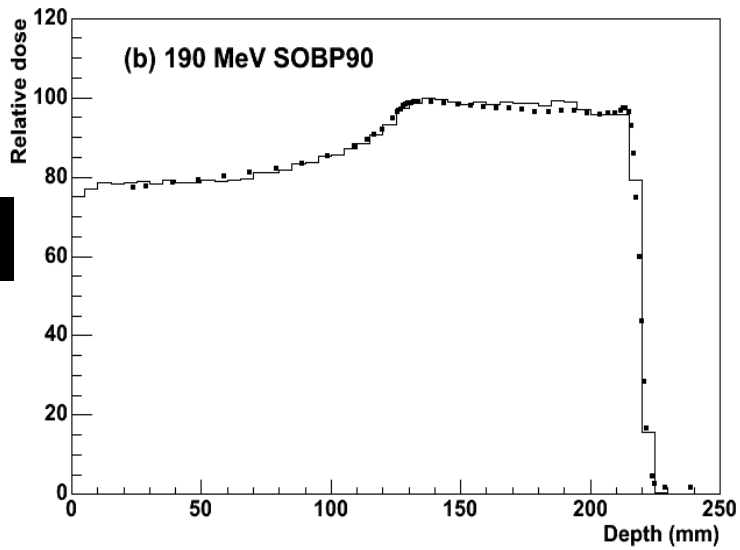
150MeV

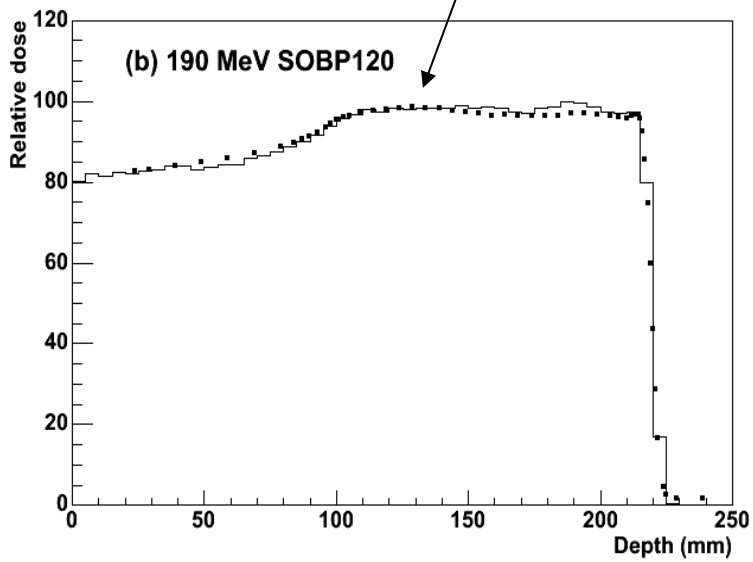
190MeV





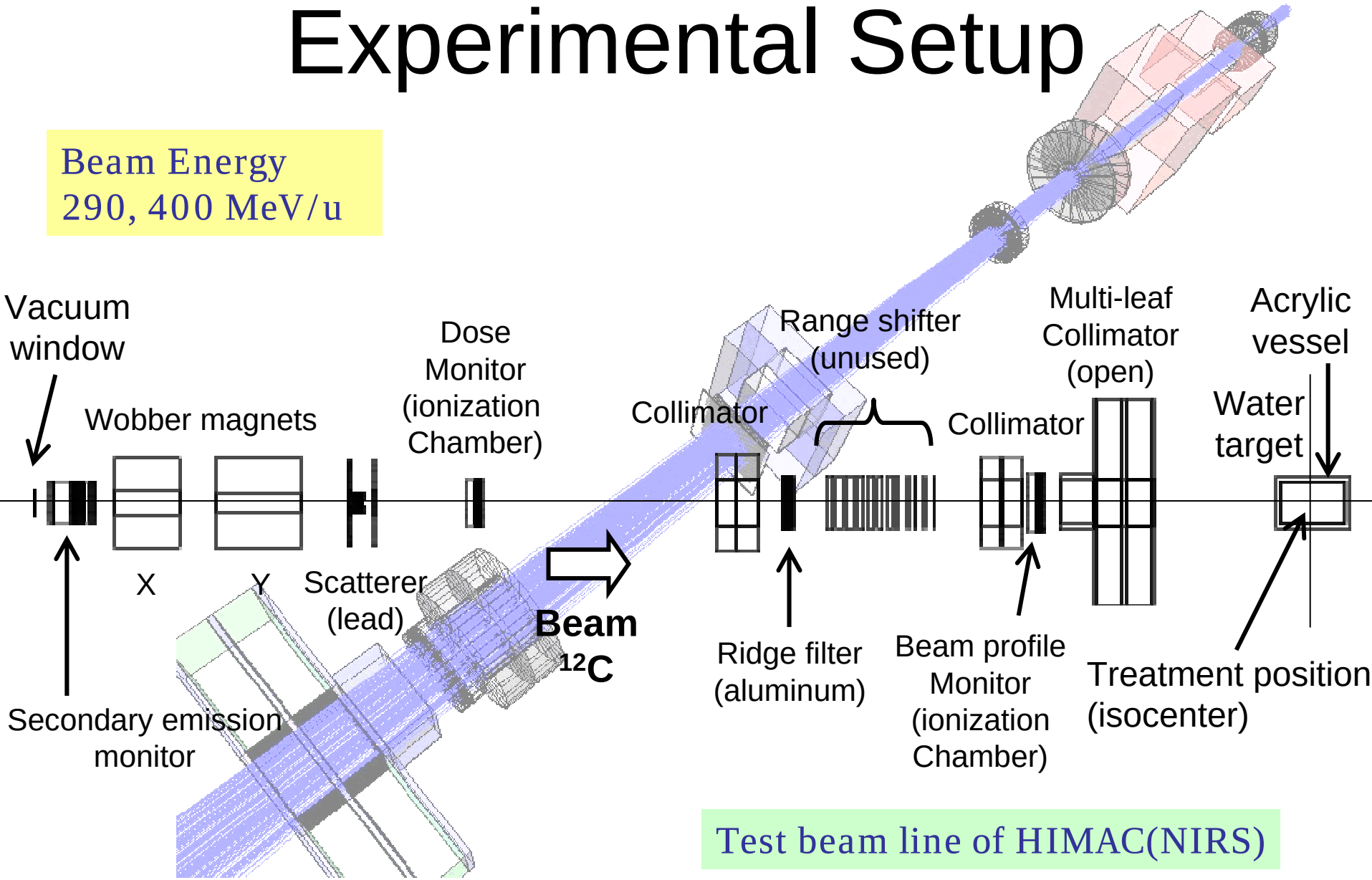
The small bump in the measurement is thought to be a fan beam effect.





Experimental Setup

Beam Energy
290, 400 MeV/u

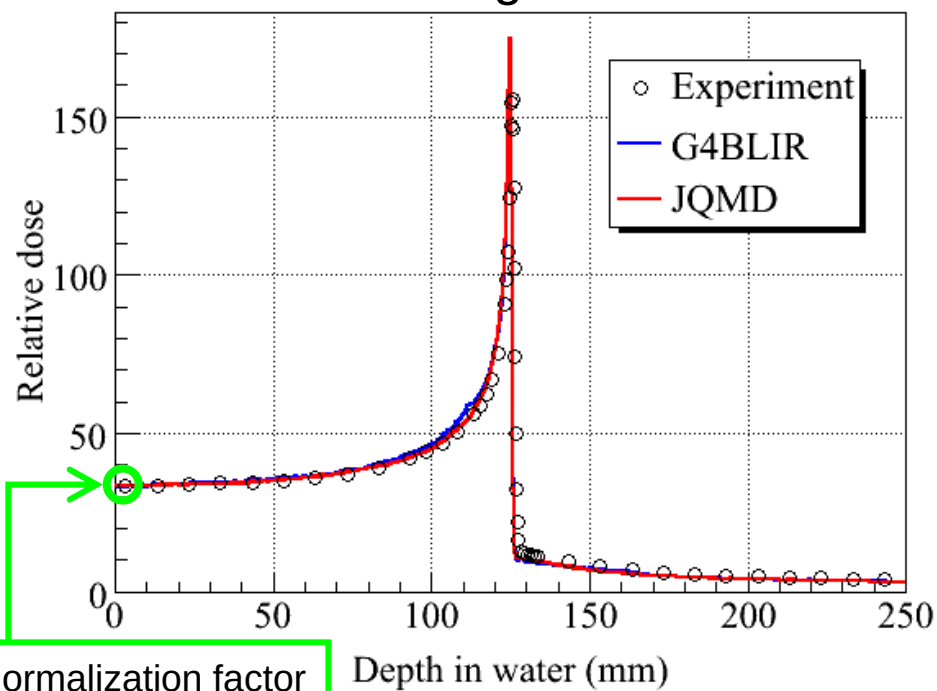


Test beam line of HIMAC(NIRS)

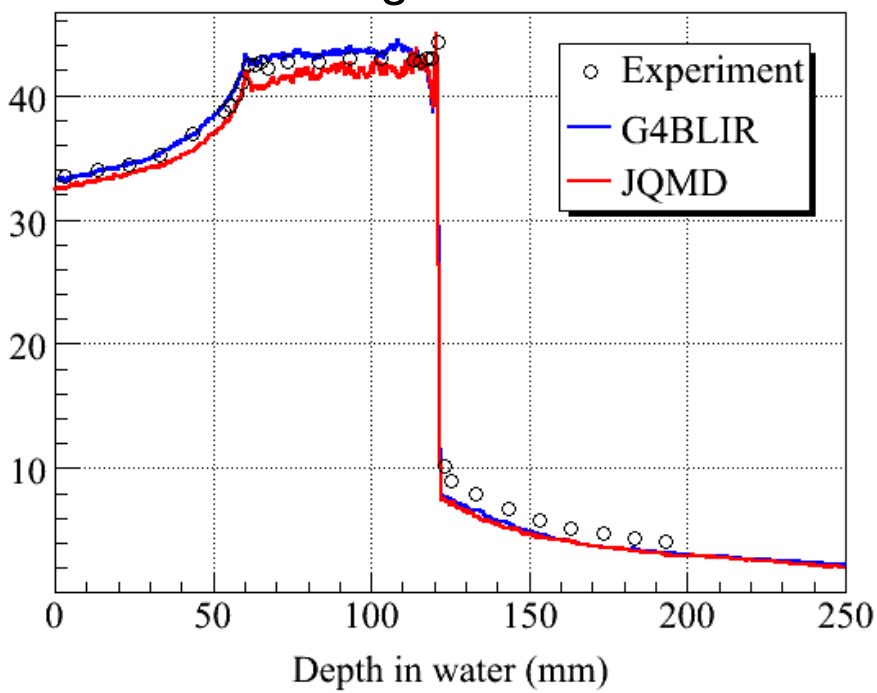
Depth-dose distribution (^{12}C 290 MeV/n)

Simulated dose is normalized to agree with the experimental data of pristine Bragg peak at the surface of the water target, and the same normalization factor is applied to SOBP.

Pristine Bragg peak
wo/ Ridge filter



Spread-out Bragg peak
w/ Ridge filter

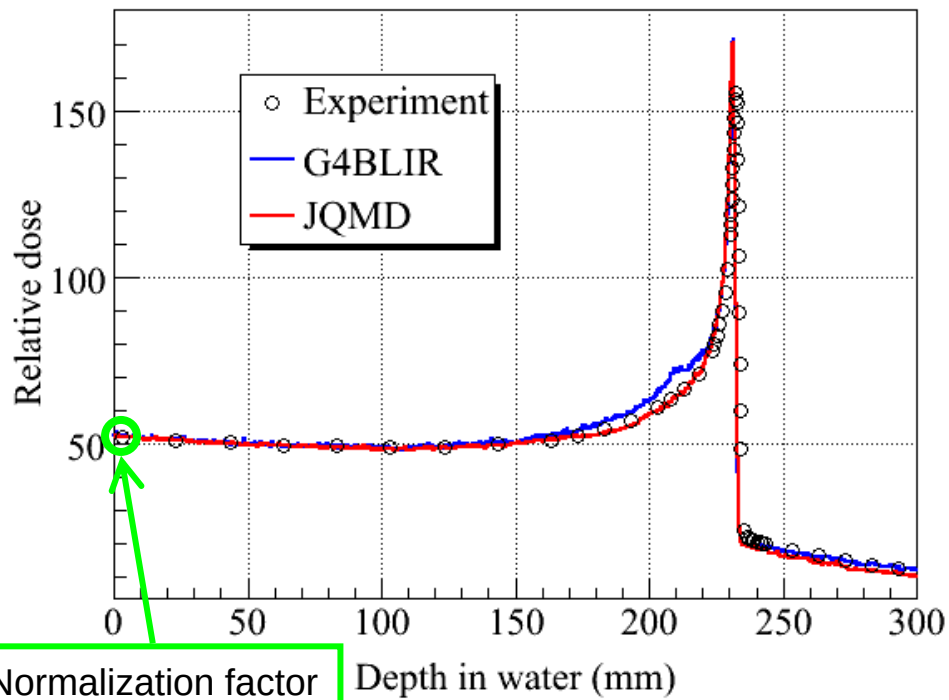


Normalization factor determined here

Depth-dose distribution (^{12}C 400 MeV/n)

Pristine Bragg peak

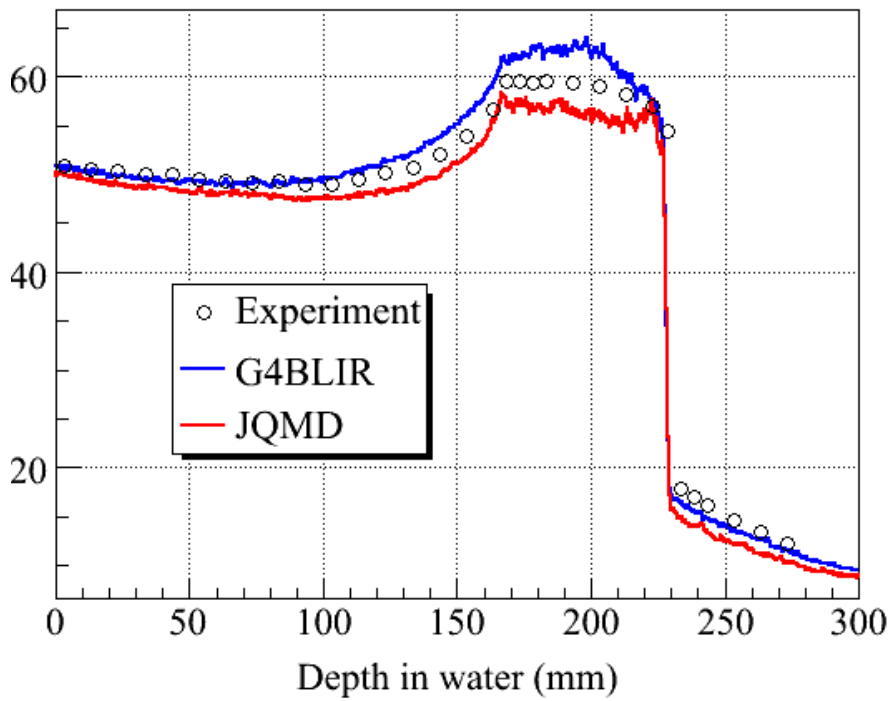
wo/ Ridge Filter



Normalization factor determined here

Spread-out Bragg peak

w/ Ridge Filter



Normalization

- Why?
  a. Number of beam particles injected into the dose meter is unknown (amplitude)
  b. Ambiguity in experimental setup *e.g.* missing material (position shift)
- How?
  1. Using the first bin to adjust the amplitude
  2. Adjust at the peak positions
  3. Fitting over all of the range
     - aF(x+b)
- We have to be careful
  – Incompleteness of physics in simulation (cross section or process) is hidden in the process

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

gMocren

- http://geant4.kek.jp/gMocren/
  - Beta version has been released
  - Free of charge
  - Licensed for Geant4 users only
  - DICOM+dose overlap display

Visualization Samples

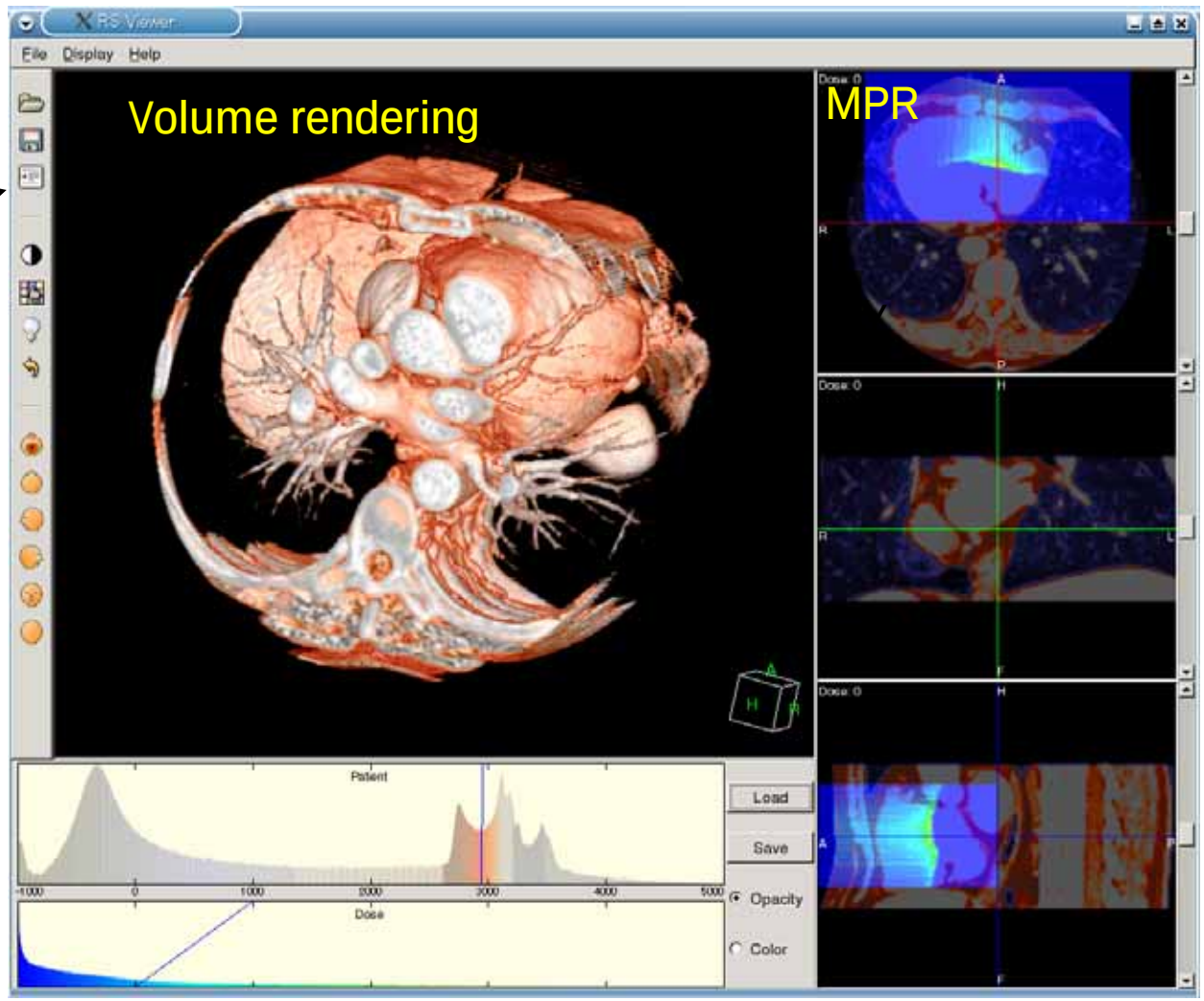
Tool bar

Open file
Save as image
Data information

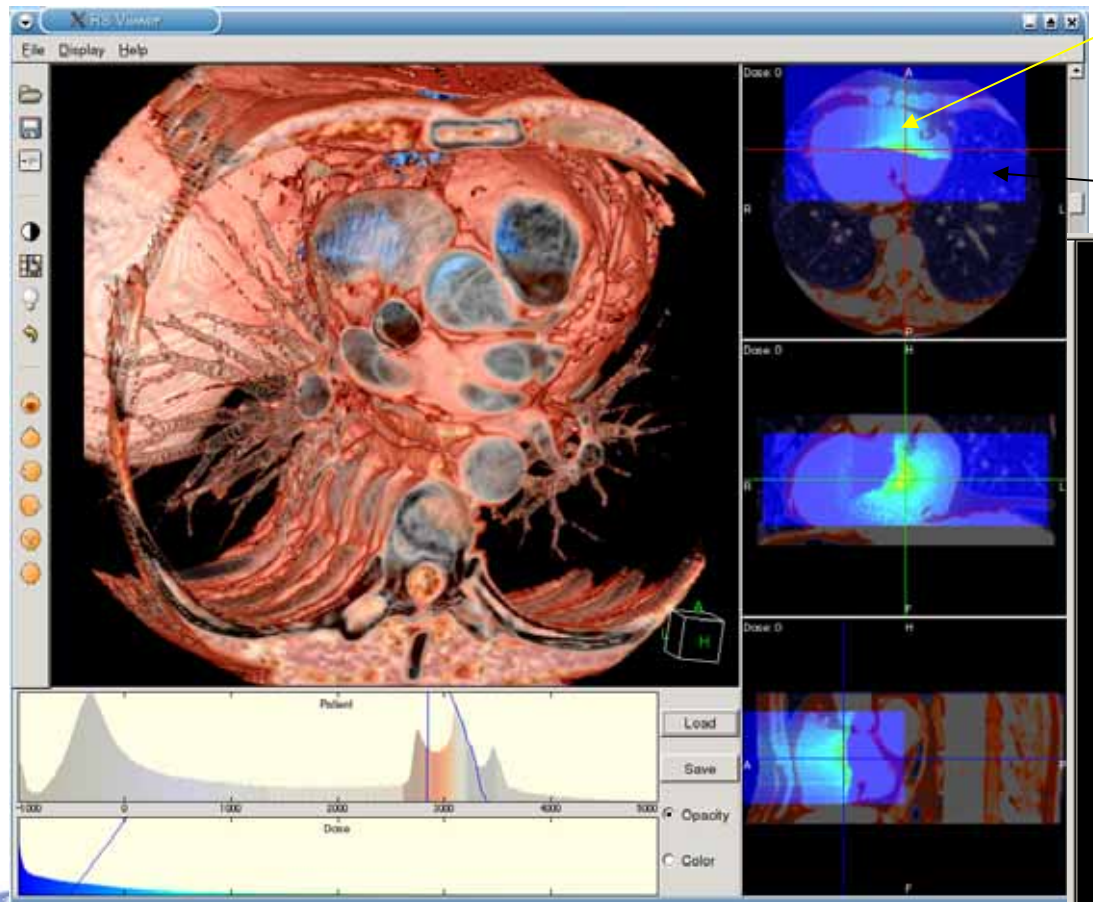
MPR contrast
3D Resolution
3D Light
3D Reset

Directions

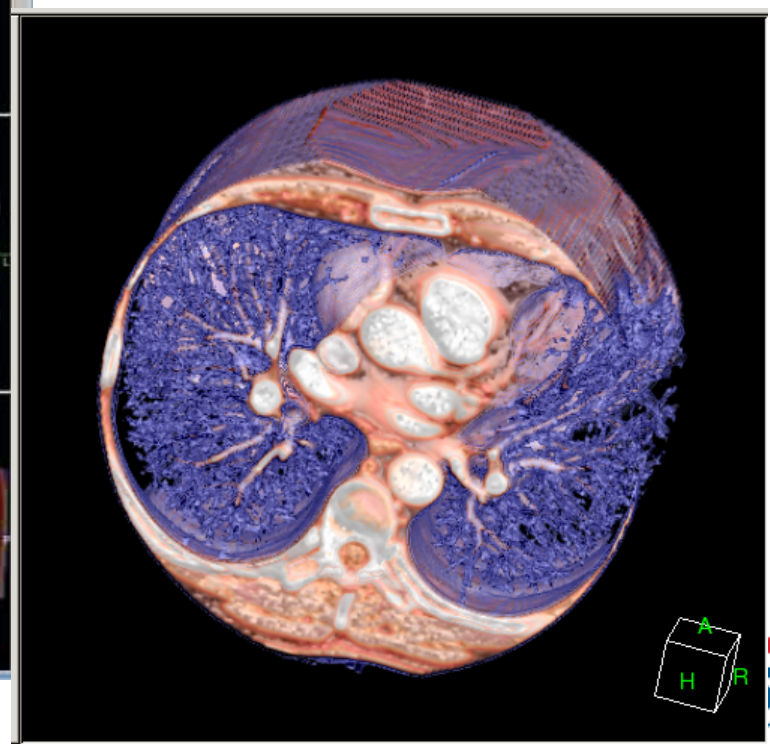
Transfer function &
color map setting



Visualization Samples

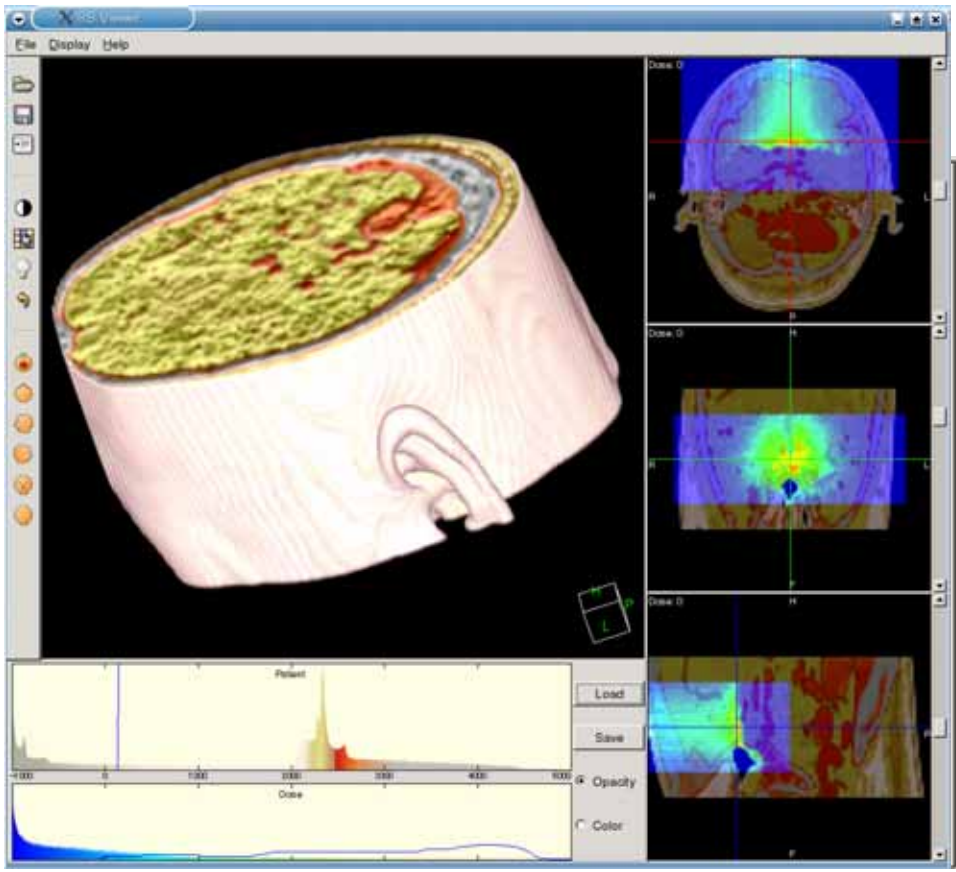


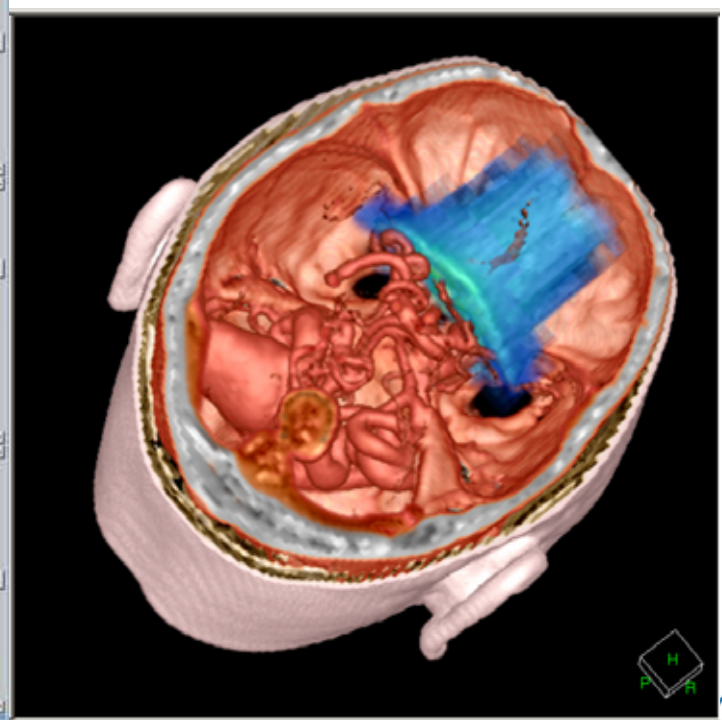
Dose map region



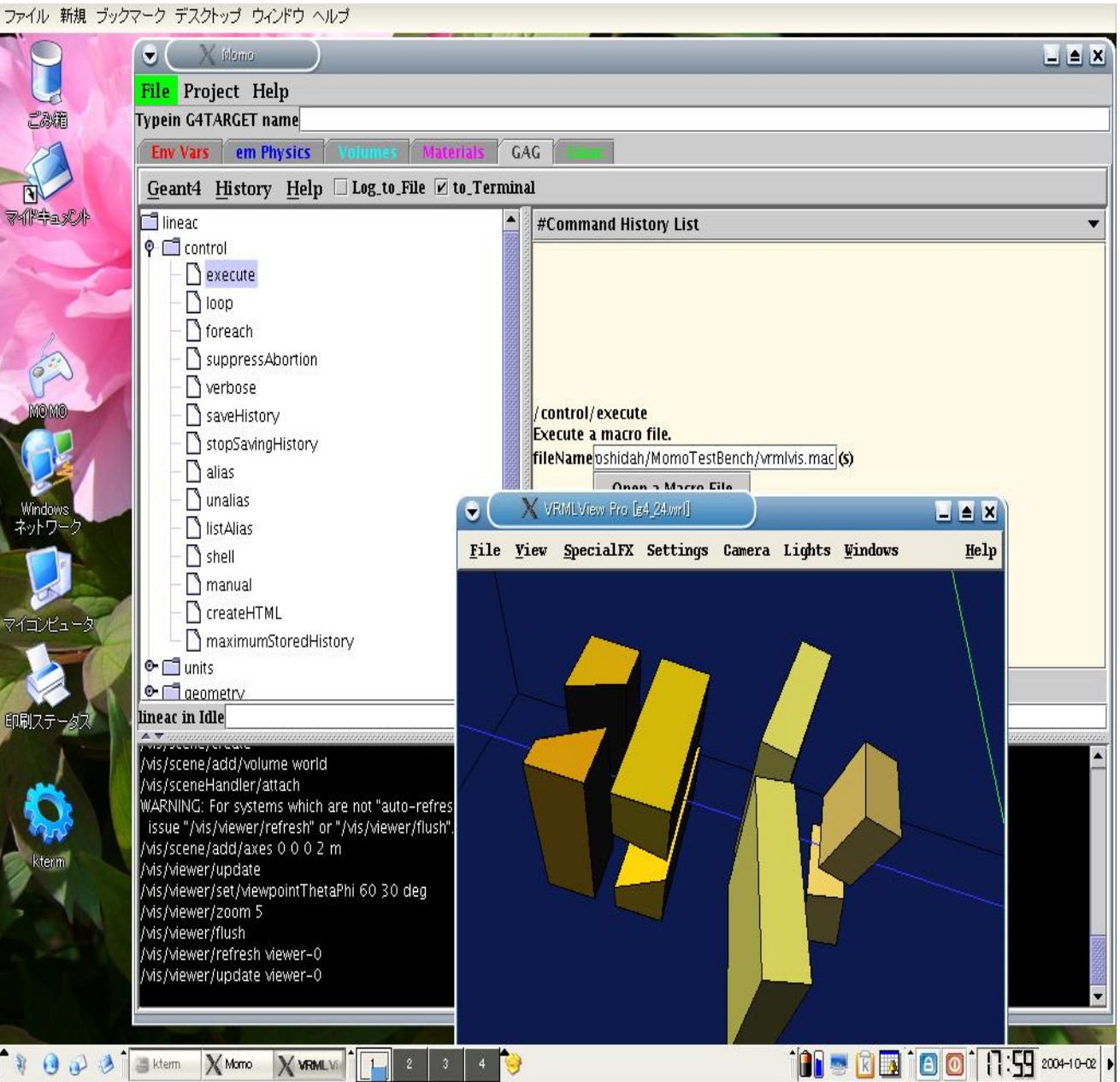
Visualization Samples

- A head region data.





Computer aided geometry design



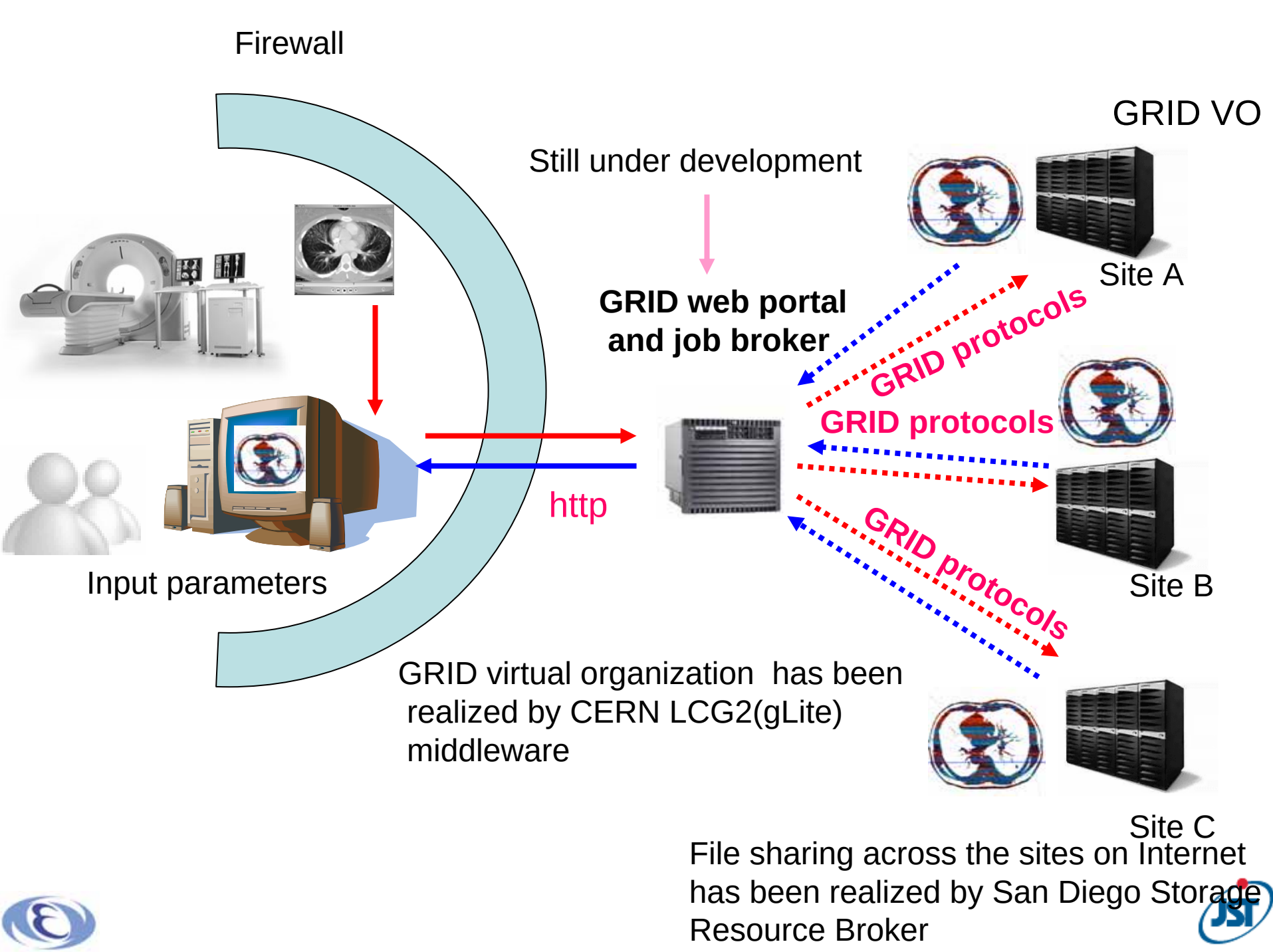
For a first example, electron accelerator head design tool has been designed and implemented, as like BEAM.

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

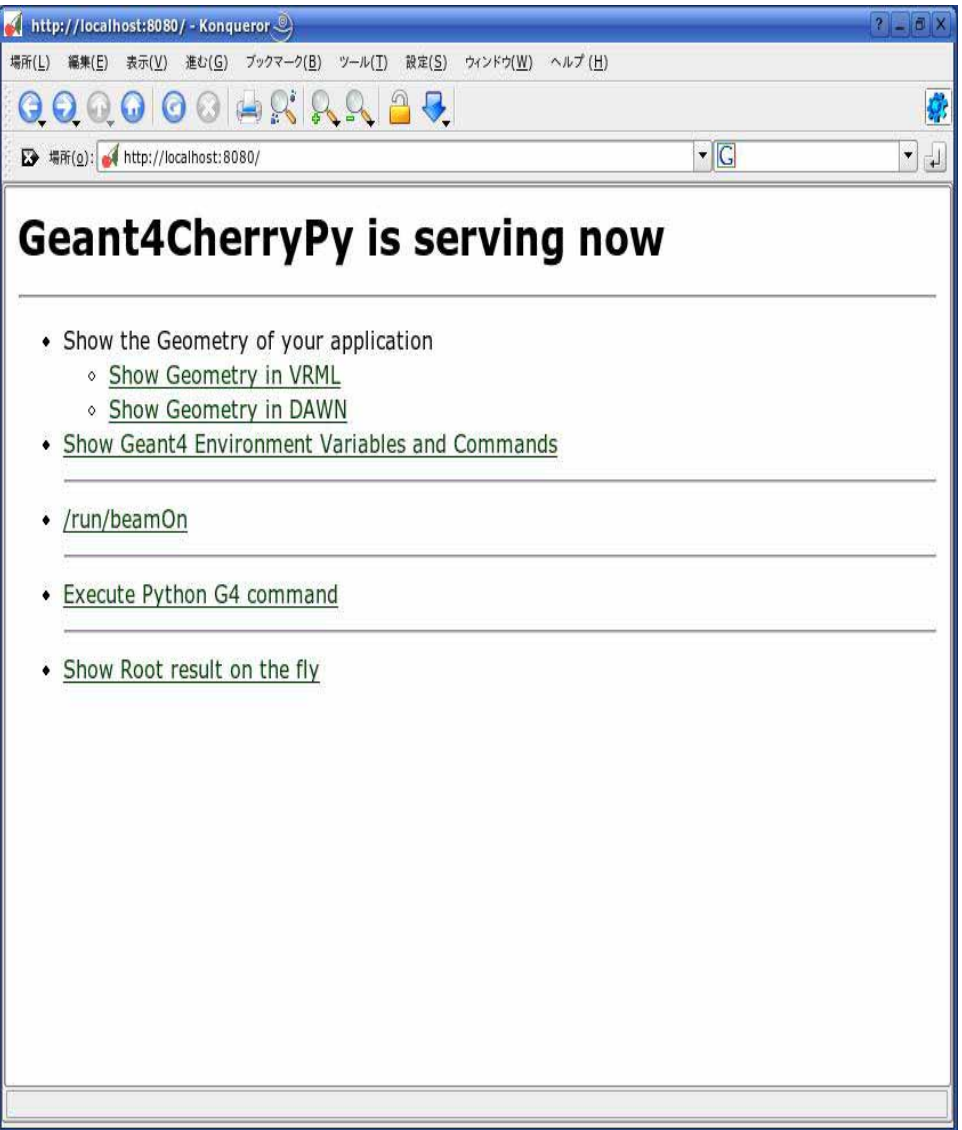
Needs only a web browser and Java!

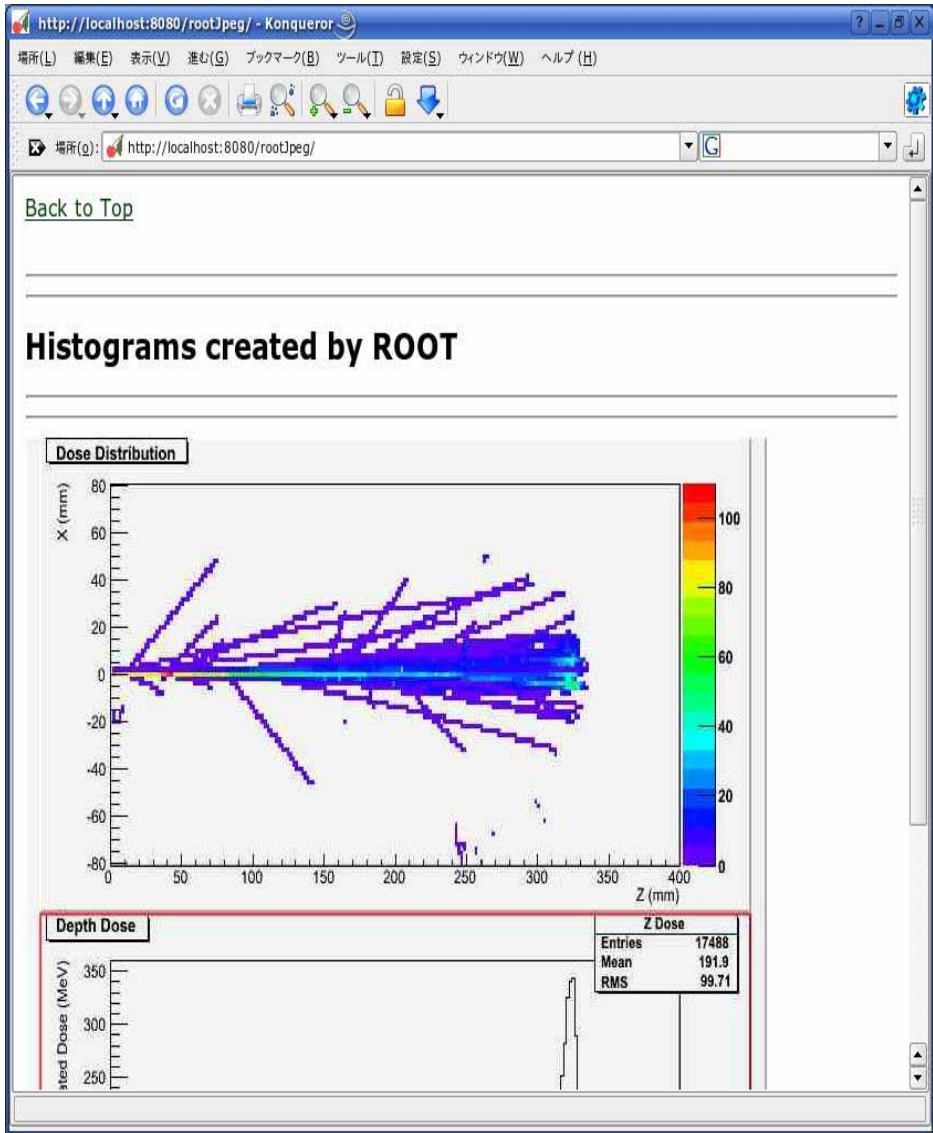
Parallelism and GRID deployment

- Simple parallelism
  - Dispatch many jobs automatically with different random number seeds
  - The results are written on the disk and gathered up after all of jobs finished
  - No MPI and No communication
    - GRID friendly
- Parallel simulation over the Internet is realized by GRID middleware
- Web interface to access GRID from behind the hospital firewall is under development


Firewall
GRID VO
Still under development
GRID web portal
and job broker
GRID protocols
GRID protocols
GRID protocols
Site A
Site B
Site C
http
Input parameters
GRID virtual organization has been realized by CERN LCG2(gLite) middleware
File sharing across the sites on Internet has been realized by San Diego Storage Resource Broker

Web interface prototype





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 the beta version of the software suit soon
  - First for protons, carbons comes later
    - No big difference, but no validation results for carbons

Summary

- Our project is developing the software framework and toolkit for particle therapy
  - DICOM/DICOM-RT interface
  - Does calculation engine
  - Visualization
  - GRID
  - web interface
  - etc
- Also validation against data are done very seriously
  - Protons
    - HIBMC, NCC-eat
  - 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