Software Suite for Particle Therapy Simulation

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and
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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)

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

Motivation

- Geant4 is well designed software to simulate interaction between particles and matter
- However, Geant4 is not easy to use in a 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 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
- Even a private hospital !
  - Fukushima (proton 2008)
    - http://www.minamitohoku.or.jp/ryushisen/ryushisen.htm
- Approved in 2006
  - Gunma University (Heavy Ion: 2009)
  - Wakasa
- Plan
  - Ibaraki Pref., Kanagawa Pref., etc,.

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

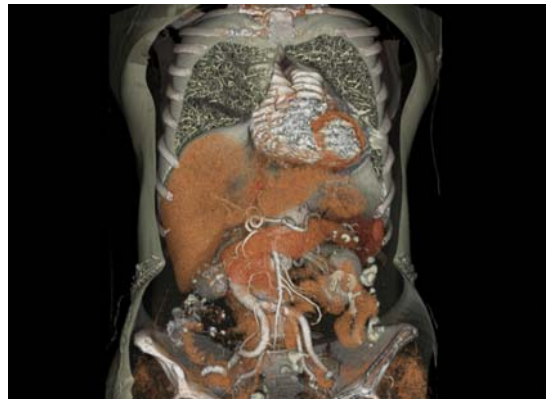
- Carbon
  - GSI, Germany
- Proton (total 17)
  - US 4
  - Russia 2
  - France 2
  - Swiss 2
  - Germany, Canada, Sweden, South Africa, China, Italy, England

Highlights of our project

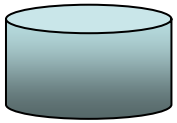
- Common software parts are provided as software toolkit
  - User can adopt for their own target with minimal modification or addition of a class derived from the base class provided
    - In many cases, the same or similar geometry are used
    - Requirements on physics processes looks similar
- Framework 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 experimental data
  - proton beam first then carbon

The system structure



Knowledge DB



GRID Deployment

visualization/interactivity

PTSsim

framework for medical application

DICOM interface

Geant4

Scoring/Tally Package

modeler

Physics List
for Radiotherapy

Dose Calculation Engines

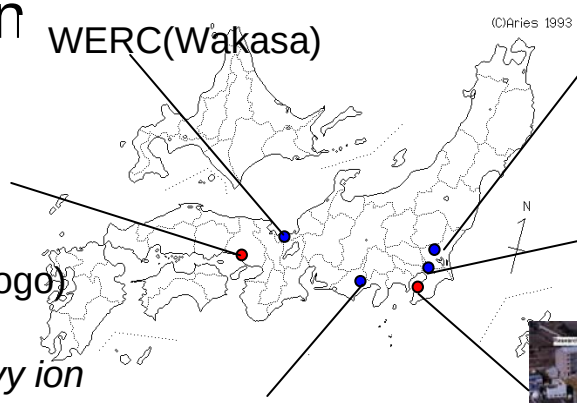
JQMD

EGS4

...

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)

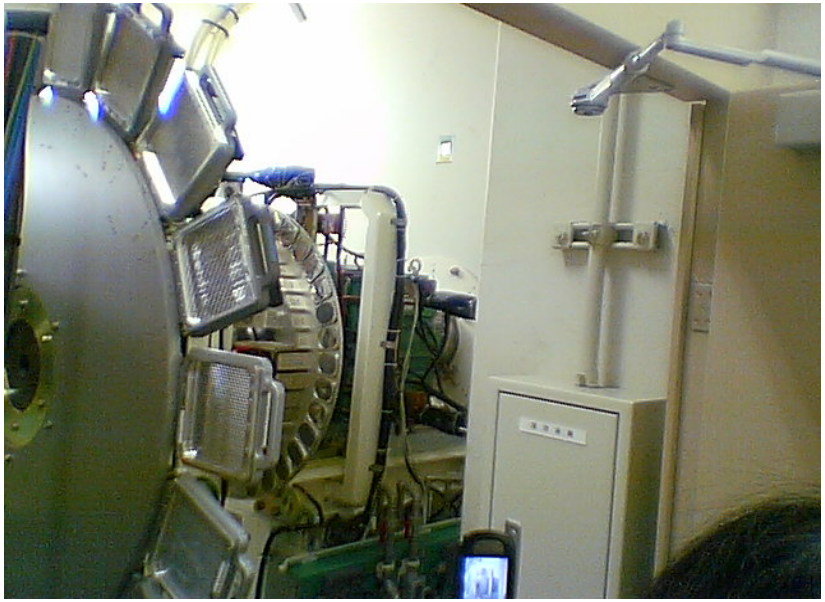
HBMC (Hyogo)

NCC-EAST (Kashiwa

- *proton/heavy ion*
- *proton*

SCC (Shizuoka)

NIRS,HIMAC (Chiba)




-150
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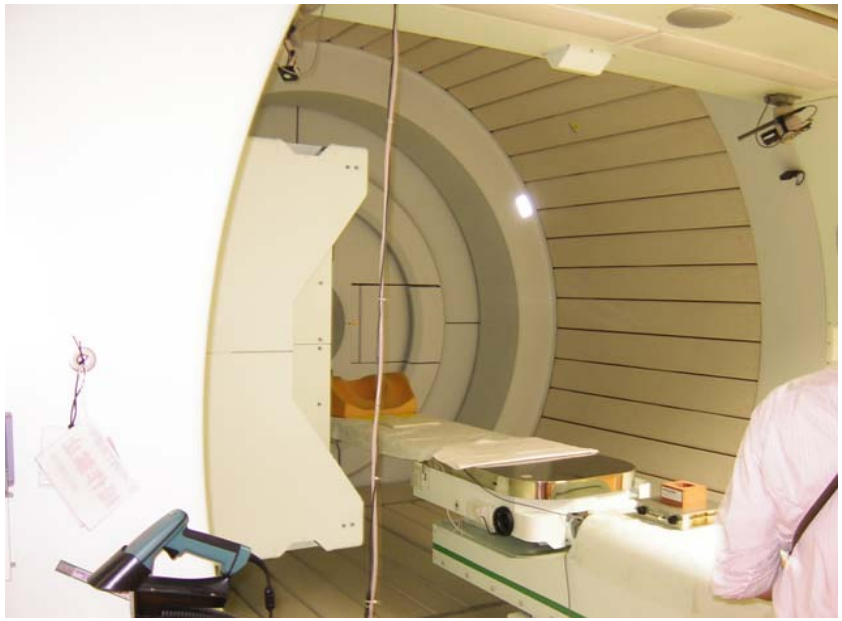
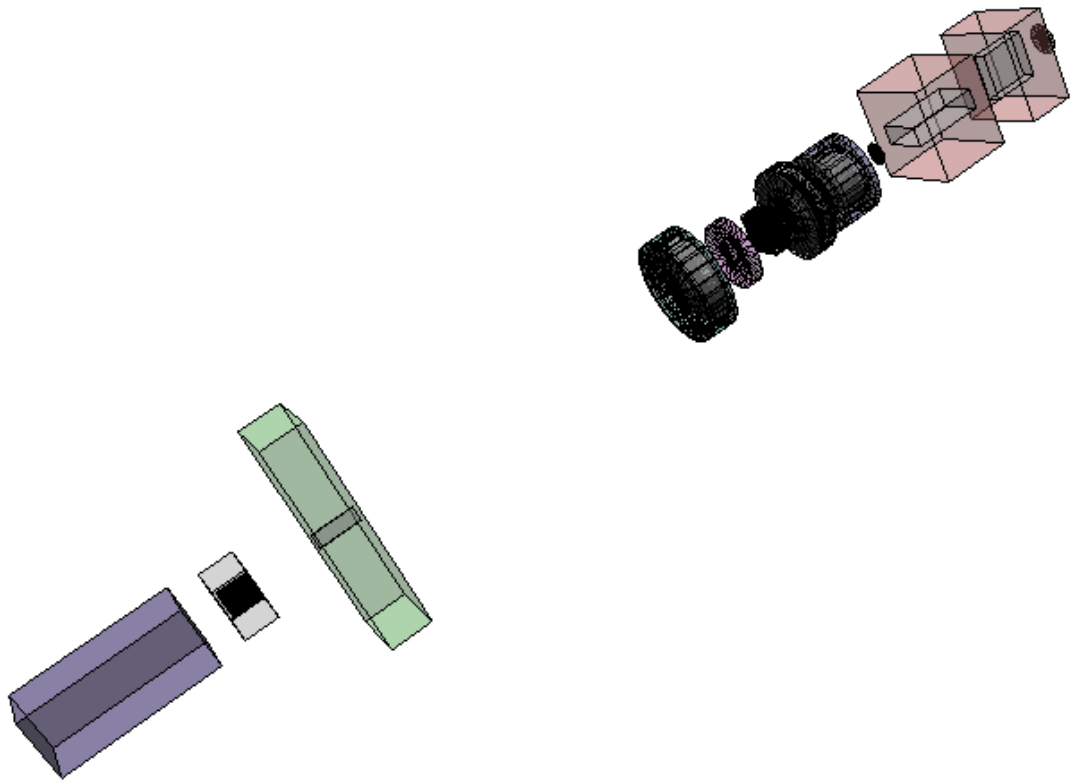


PTSsim

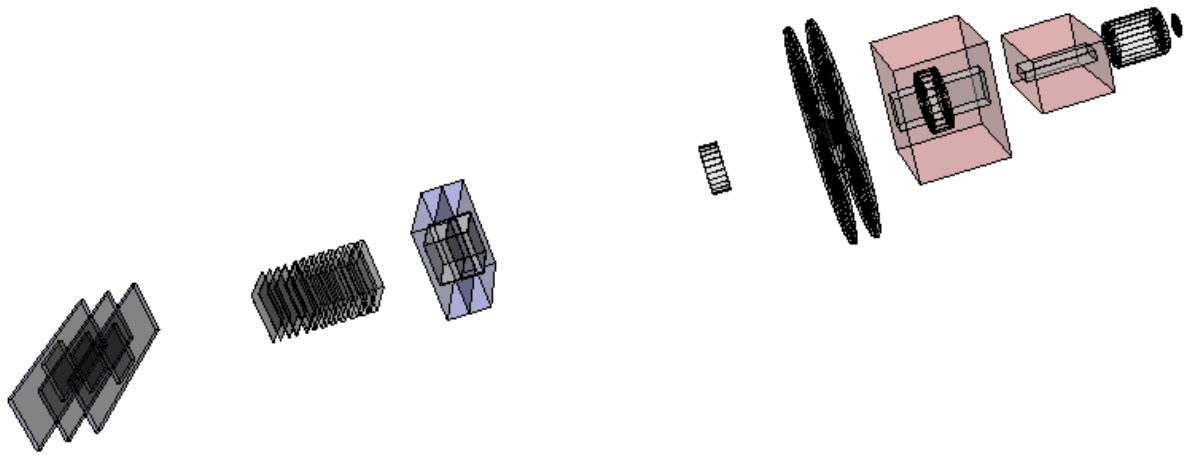
- Software framework for particle therapy
- The class library for implementing a geometry model of hadron therapy facilities are provided
- Beam lines at HIMBC, NCC-East and NIRS are implemented already (for water phantom experiments)
- Physics validation will be done for data taken at those facilities

HIBMC



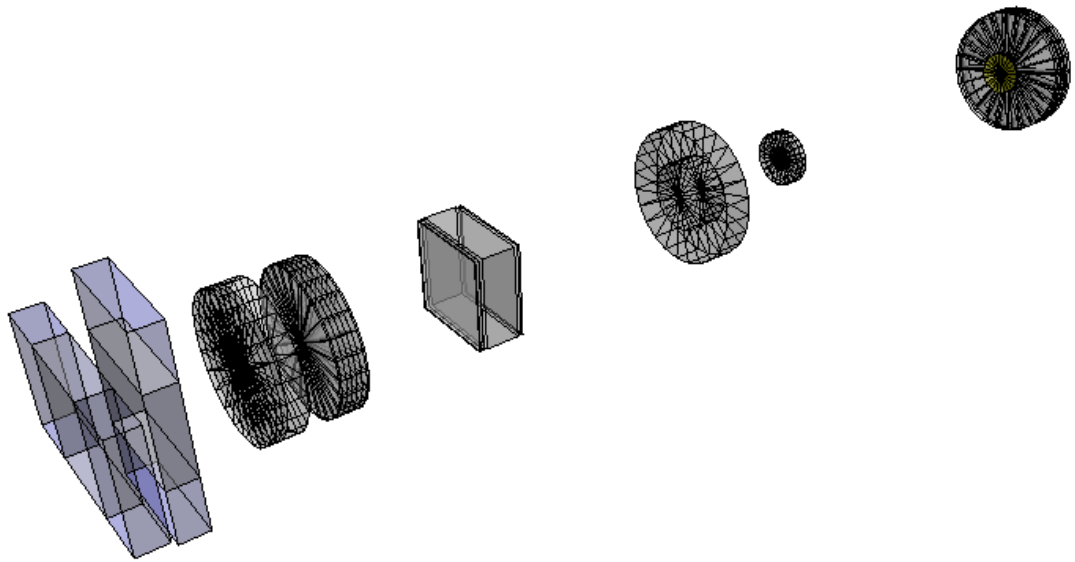
Quads : 9798
Triangles : 1392

New beam line at HIMAC



Quads : 552
Triangles : 768

NCC East



Quads : 1152
Triangles : 2208

Physics validation

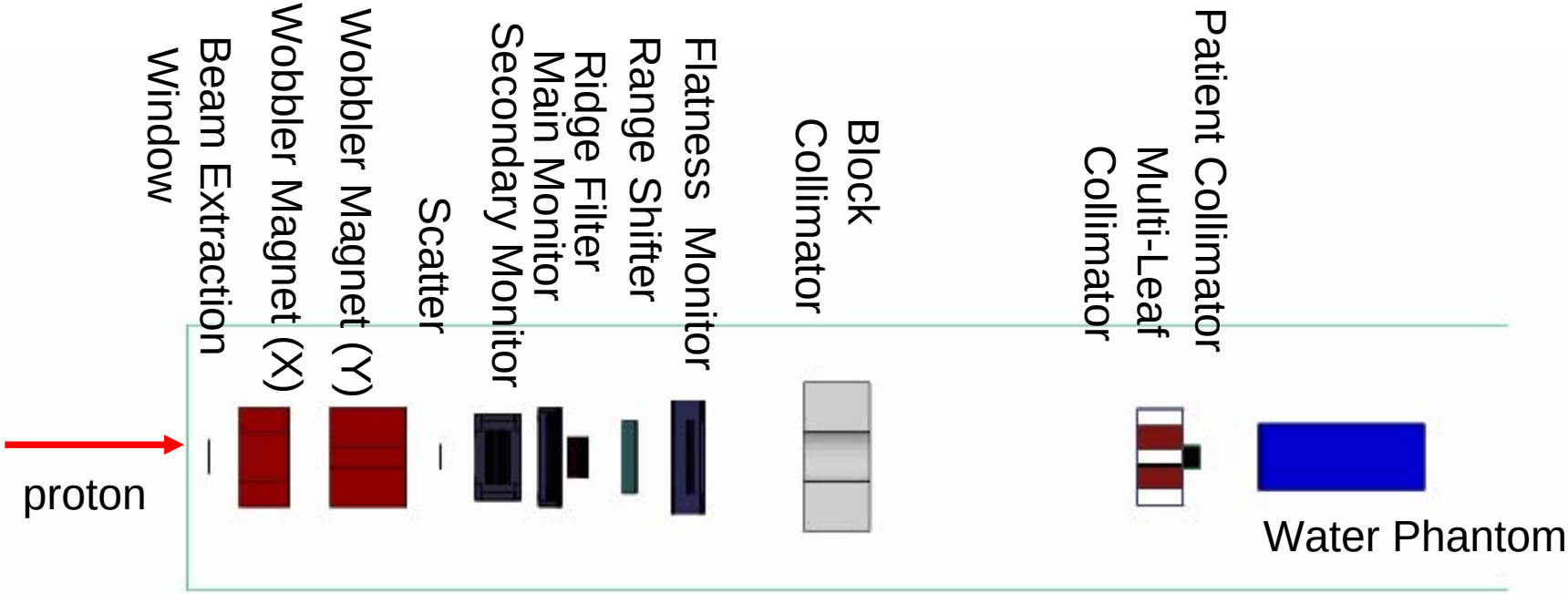
- In most cases, implementing a simulation using Geant4 is not difficult because much information are already available
- Users should consider about the validity of the results
  - Why you can believe the results?
  - If you publish any results using Geant4 without validation, you are silly enough
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

Collaborating Facilities

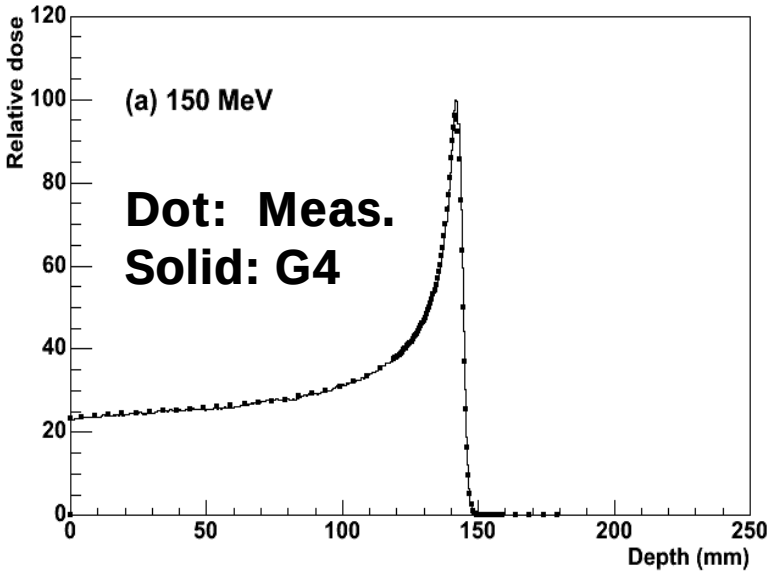
- Protons
  - National Cancer Center
    - Kashiwa, Japan
  - Hyogo Ion Beam Medical Center
    - Hyogo, Japan
  - UCSF
    - San Francisco, US
- Carbons
  - NIRS
    - Chiba, Japan
  - Hyogo Ion Beam Medical Center
    - Hyogo, Japan
  - Under discussion
    - DKFZ, Heidelberg, Germany
    - Etoile,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



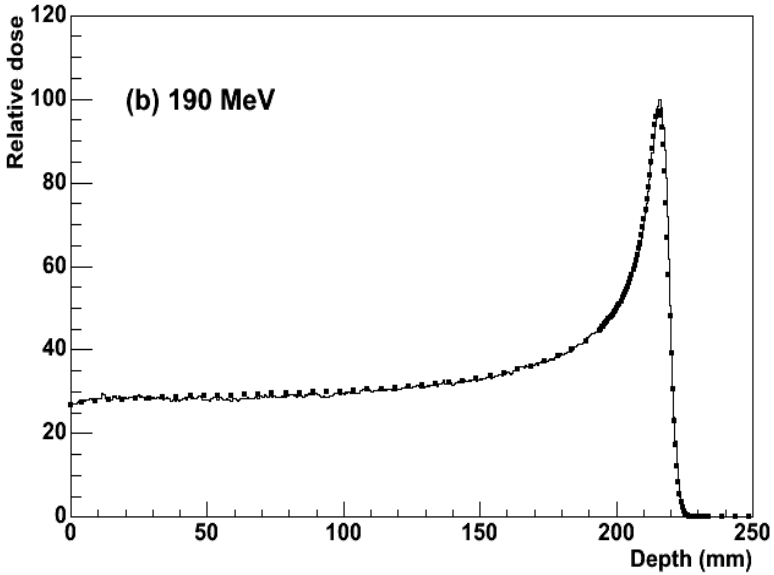
Bragg peak

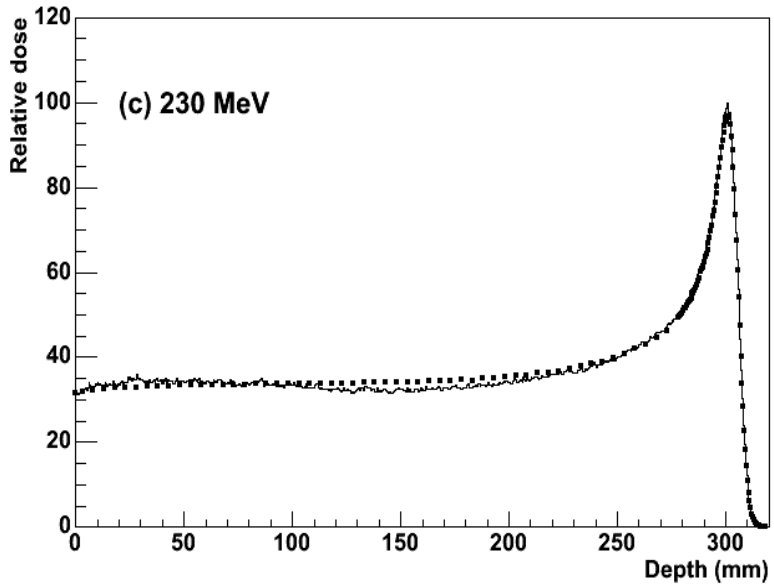


IEEE Transaction on Nuclear Science, Volume 52, Issue 4, Aug.2005, pp.896-901

Comparison between measurement at HIBMC and Geant4 simulation

proton beam with 150, 190 and 230 MeV





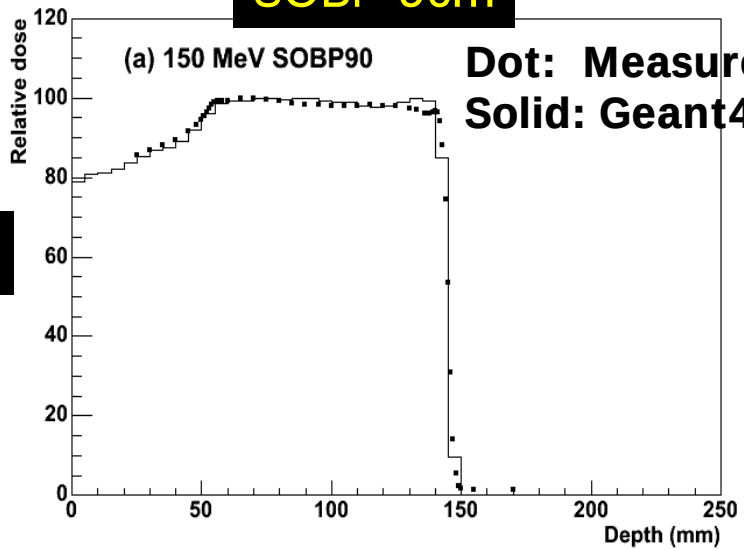
Spread Out Bragg Peak (SOBP)

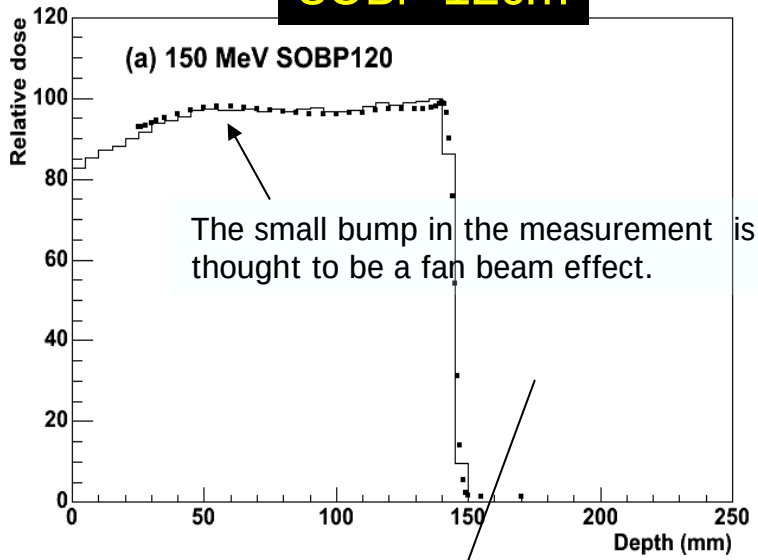
SOBP 9cm

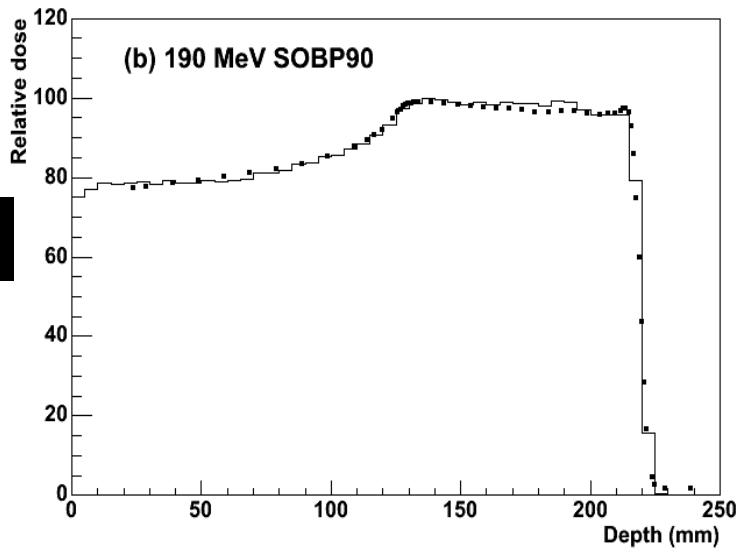
SOBP 12cm

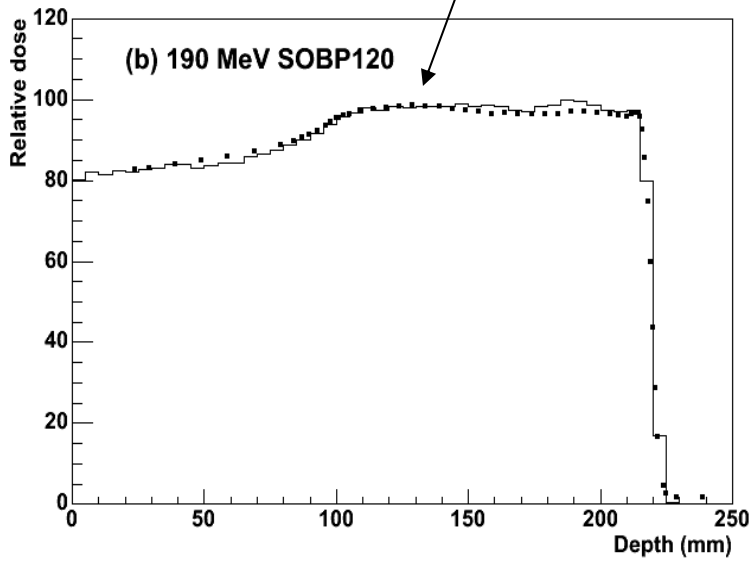
150MeV

190MeV







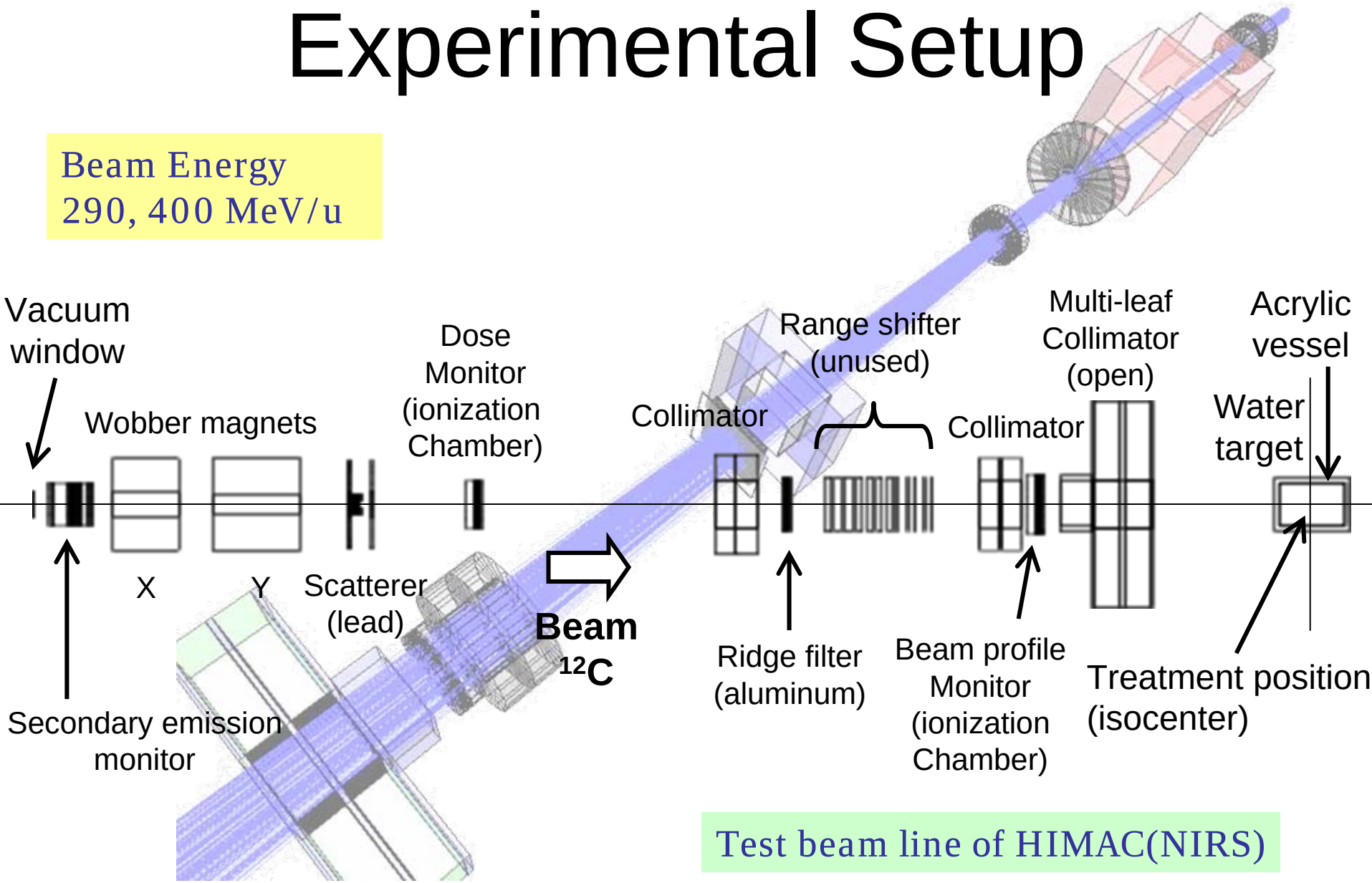


Validation against carbon data

- Data taken at new beam line at the therapy beam line and also new beam line at HIMAC (water phantom)
- 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

Experimental Setup

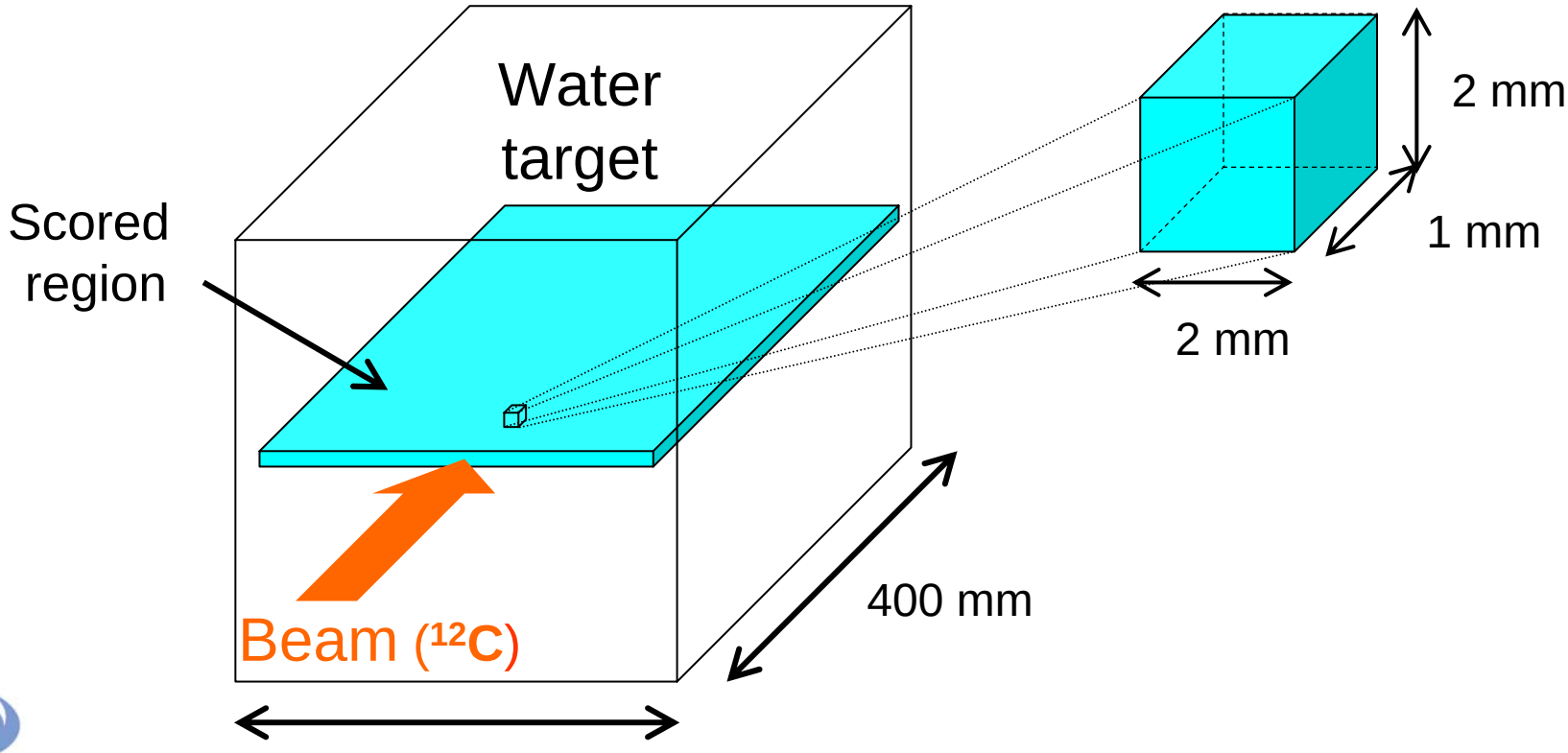
Beam Energy
290, 400 MeV/u



Test beam line of HIMAC(NIRS)

Water target / Scored region

- Dose distribution in a water target was measured using the horizontal arrayed dosimeters
  - voxel size of each element is 2 x 2 x 1 mm.
  - scanning along the depth direction

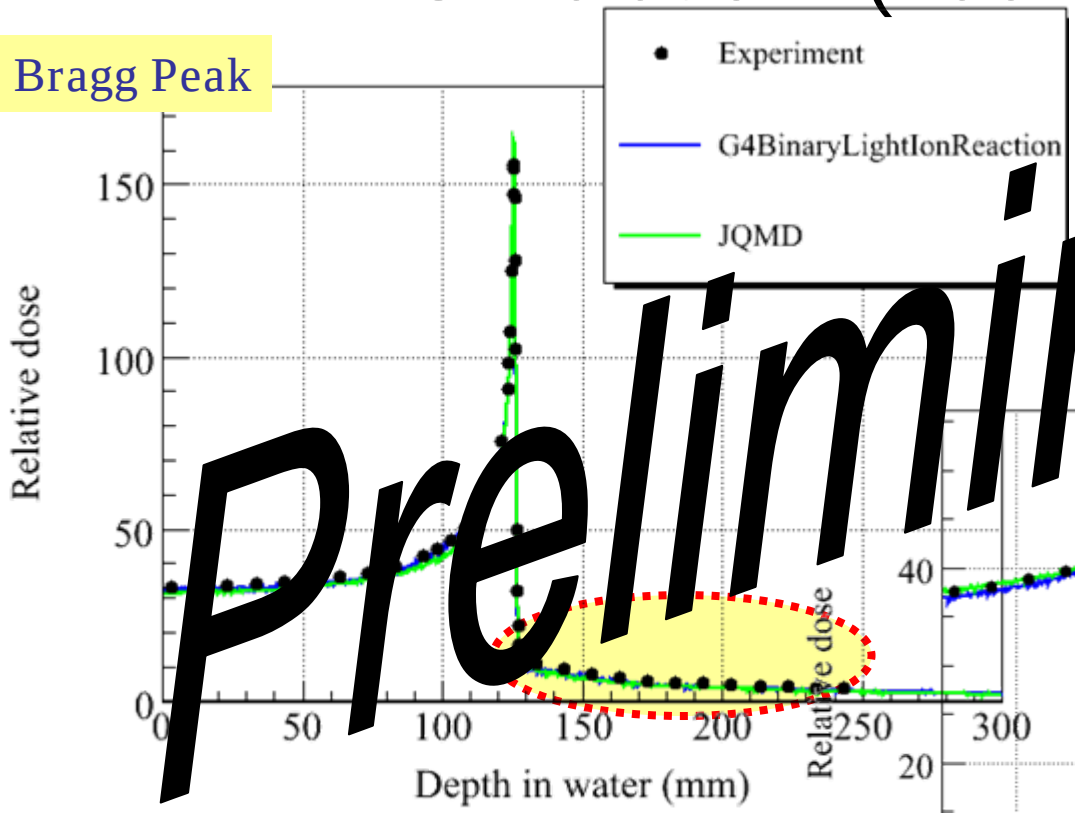


Physics List

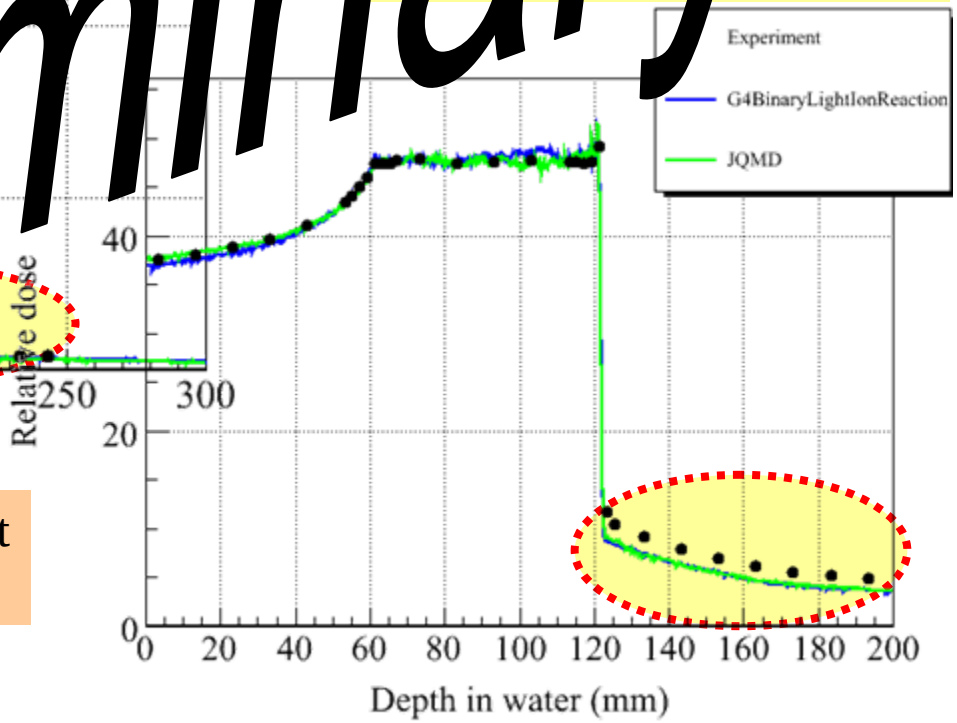
- Generic Ions
  - elastic scattering
  - Binary light ion cascade or JQMD
    - cross section : Tripathi / Shen
  - radioactive decay
  - ionization / multiple scattering
- Hadron
  - elastic scattering
  - L(H)EP+Binary cascade
  - ionization / multiple scattering
- electron/gamma
  - standard EM

Comparison between Experiment and Simulation (290 MeV/u)

Bragg Peak



SOBP
(Spread-Out Bragg Peak)
w/ Ridge Filter

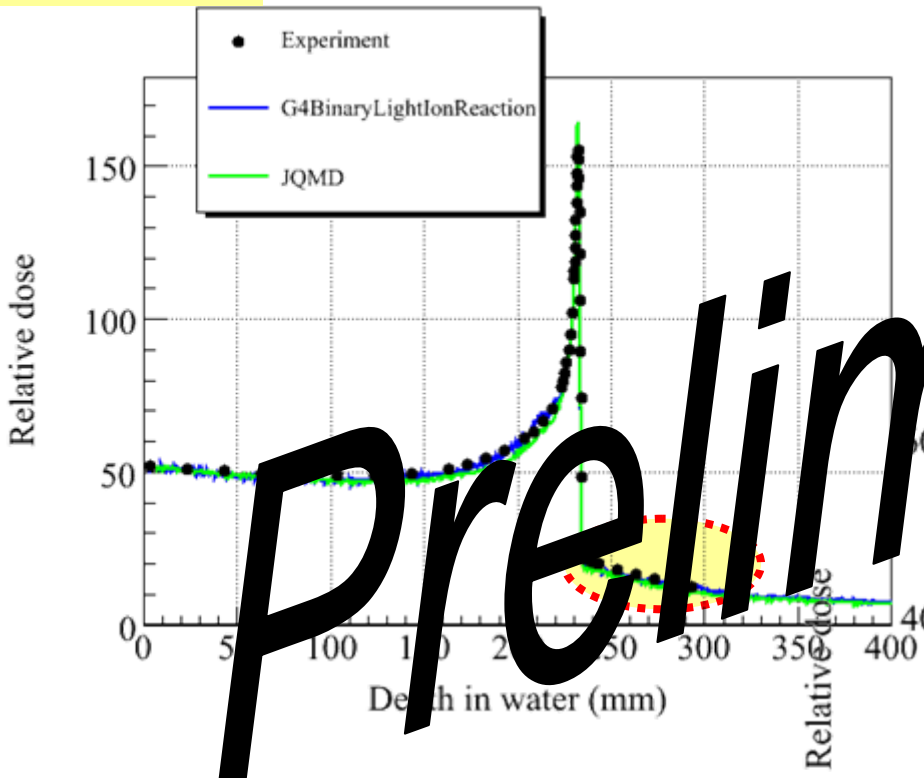


Preliminary

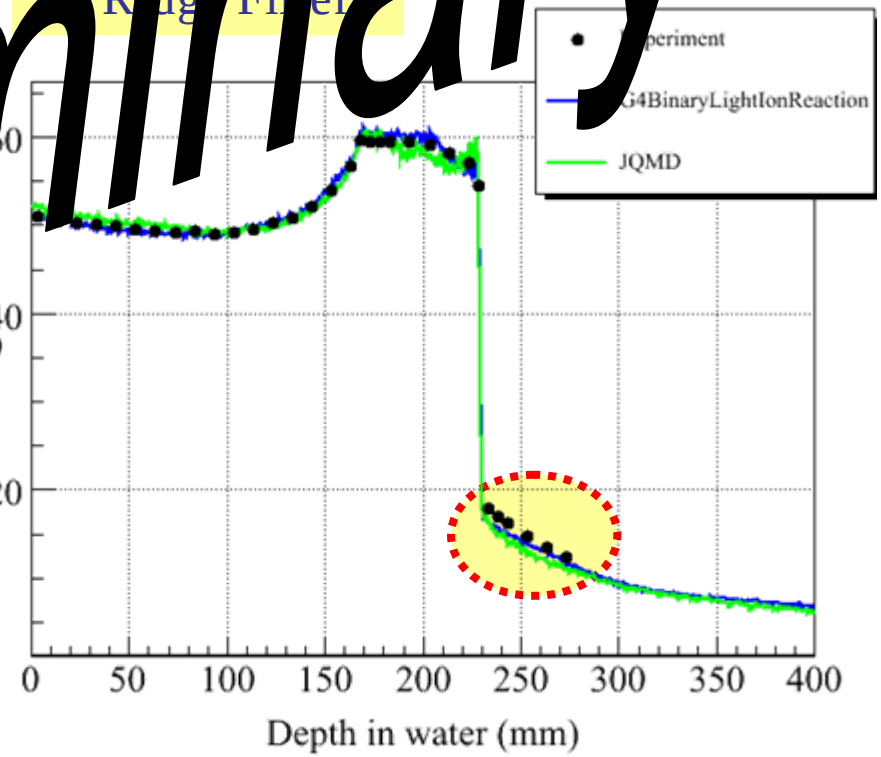
tends to underestimate the tail effect coming from beam fragments

Comparison between Experiment and Simulation (400 MeV/u)

Bragg Peak



SOBP



Preliminary

tends to underestimate the tail effect coming from beam fragments

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

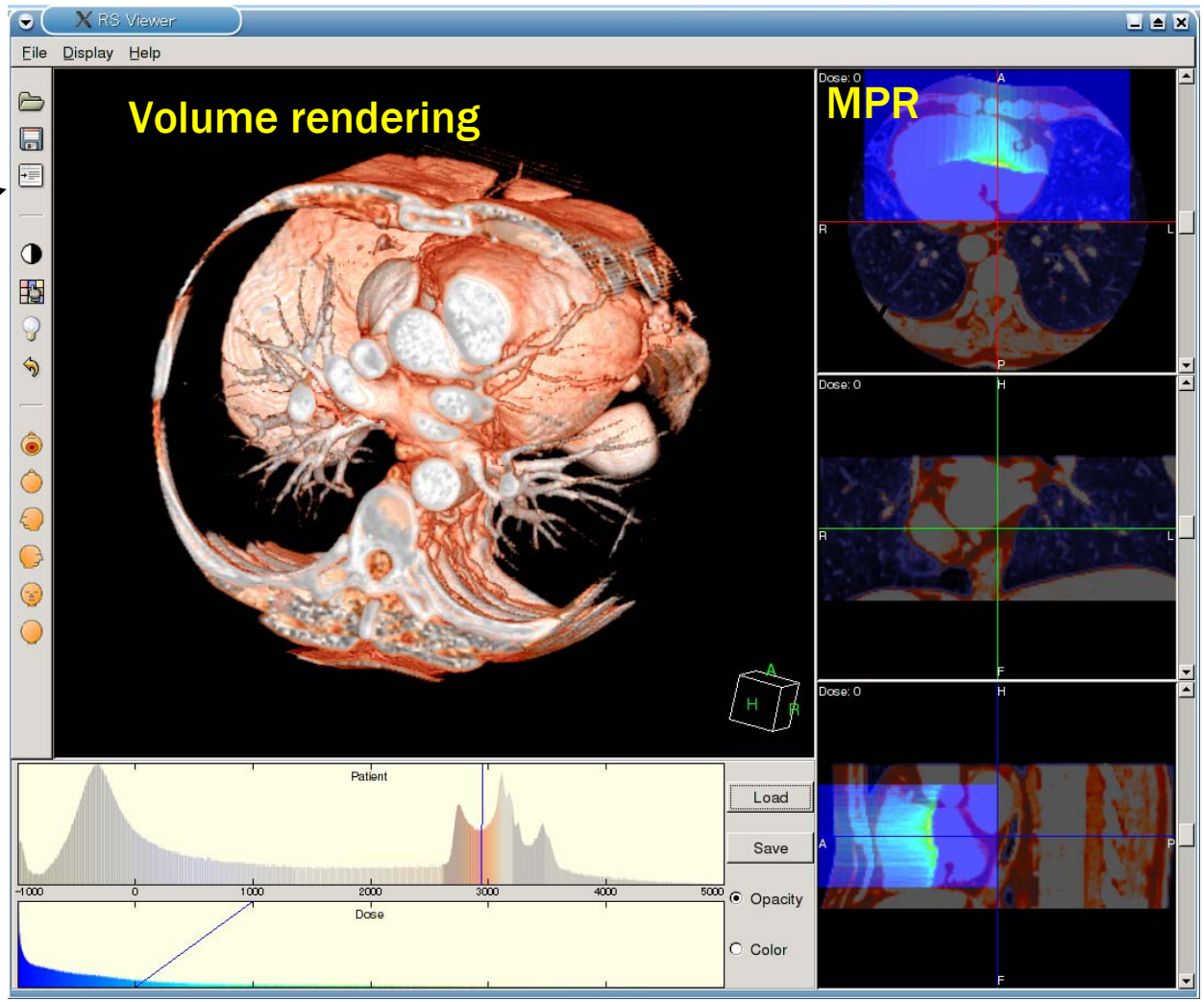
Tool bar

Open file
Save as image
Data information

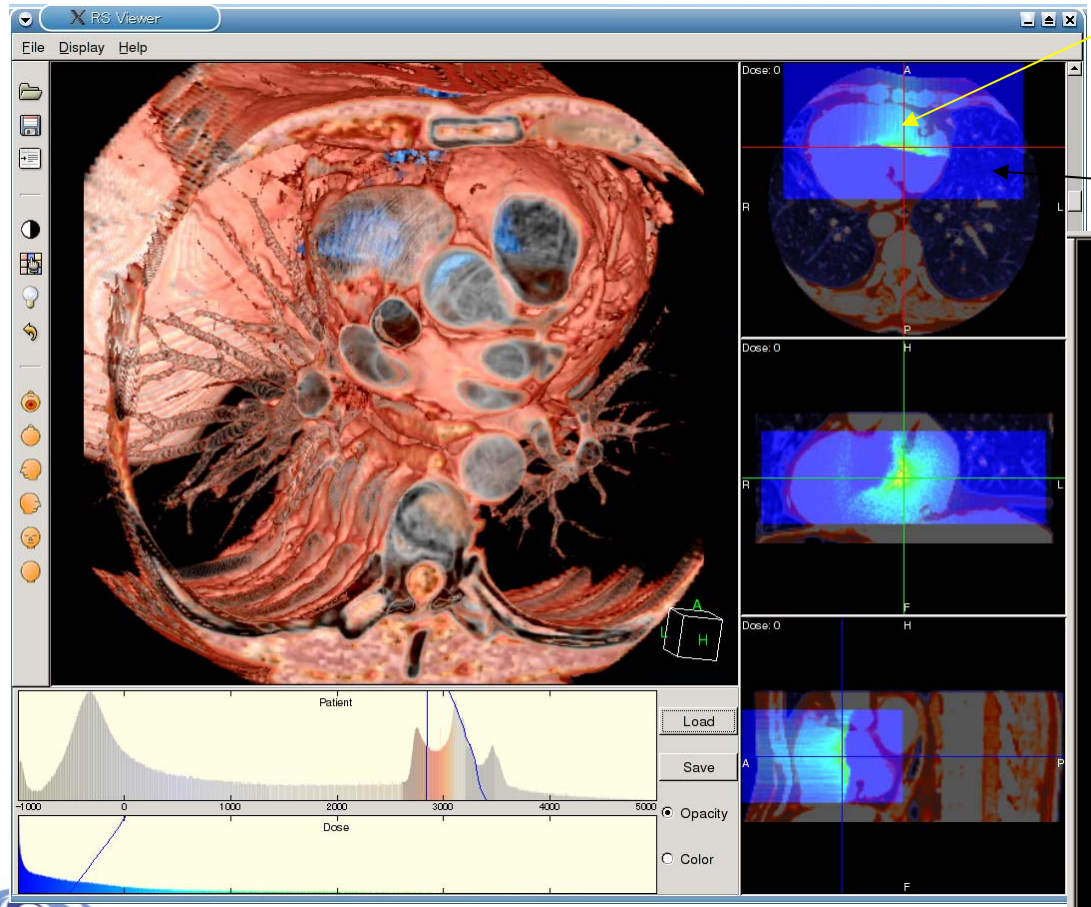
MPR contrast
3D Resolution
3D Light
3D Reset

Directions

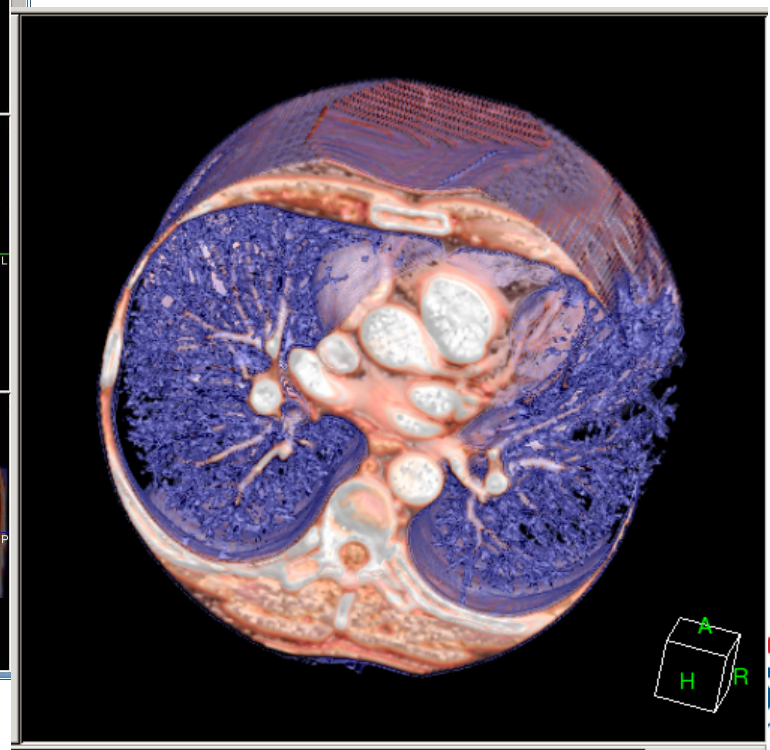
Transfer function & color map setting



Visualization Samples

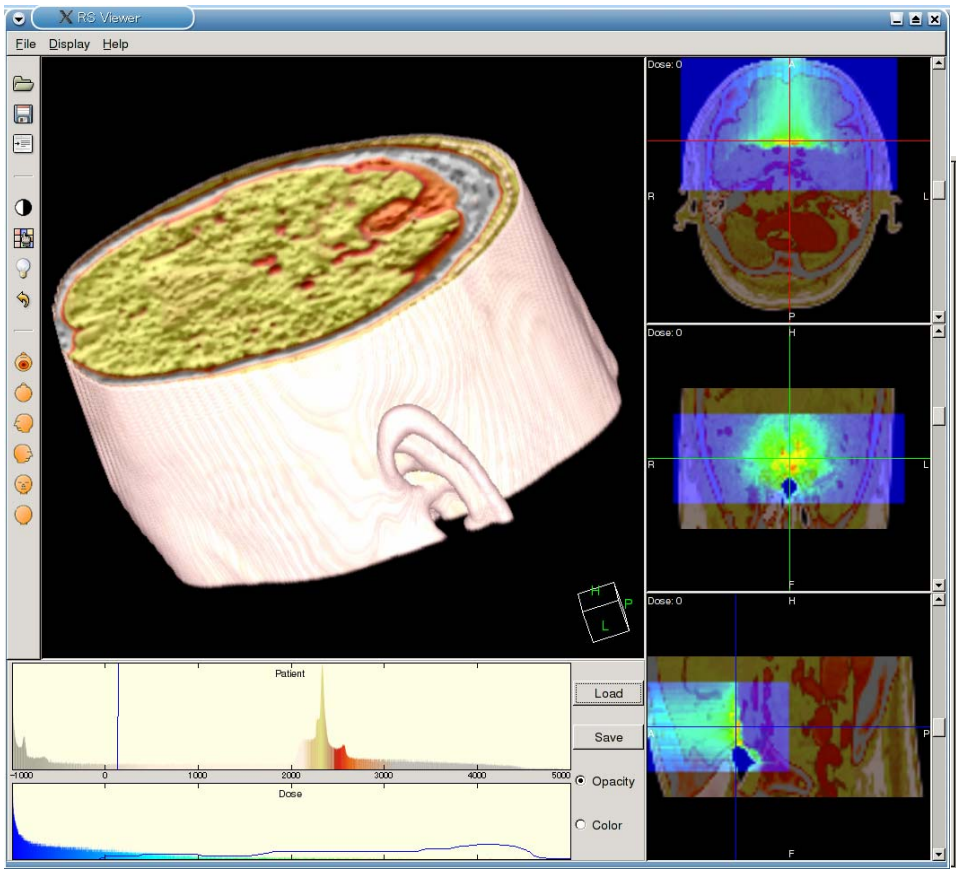


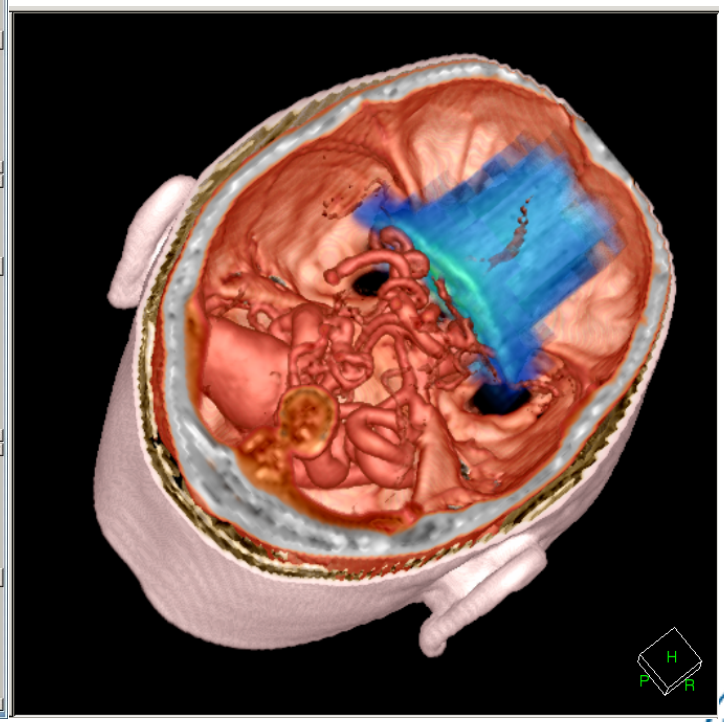
Dose map region



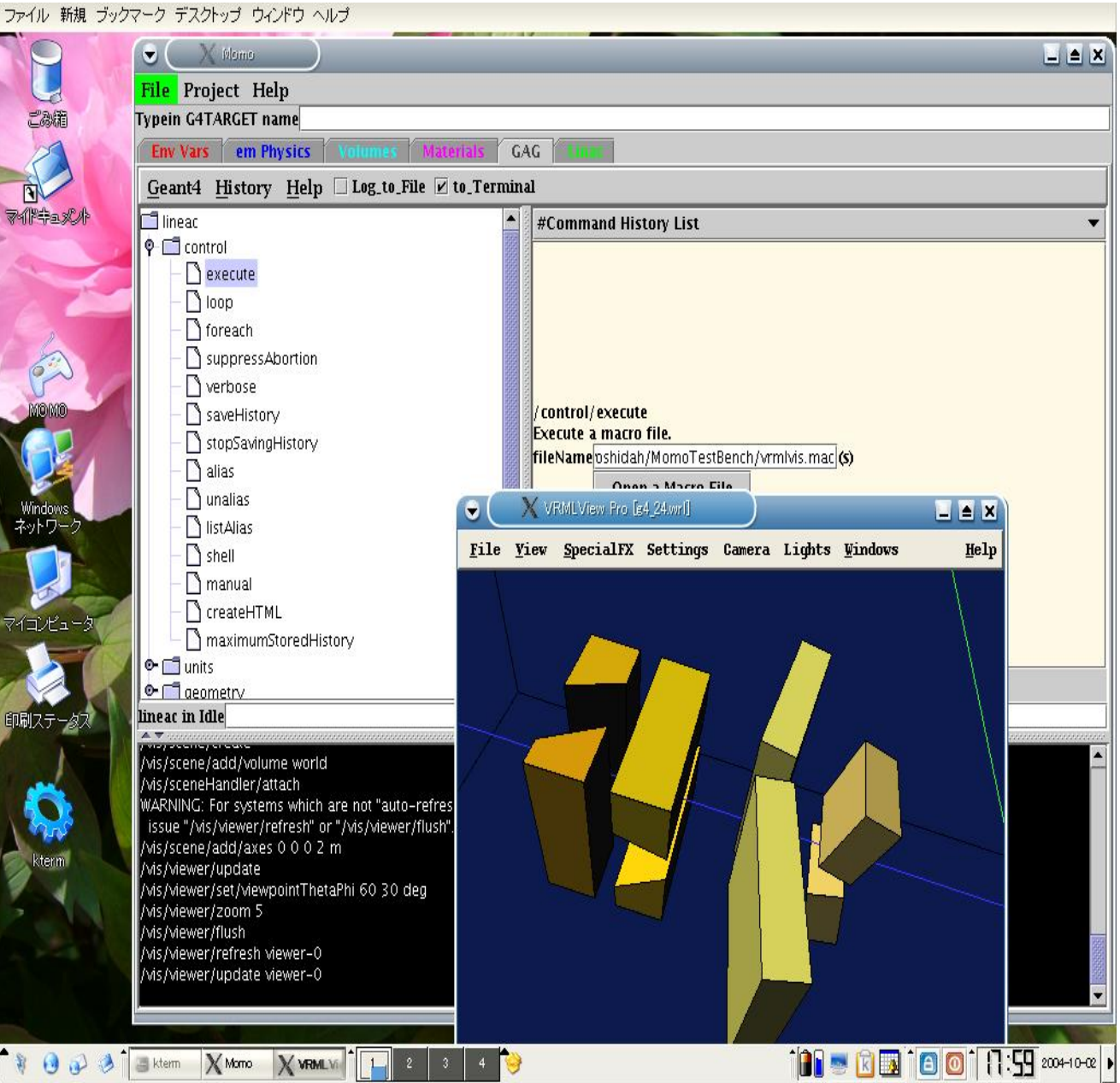
Visualization Samples

- 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.

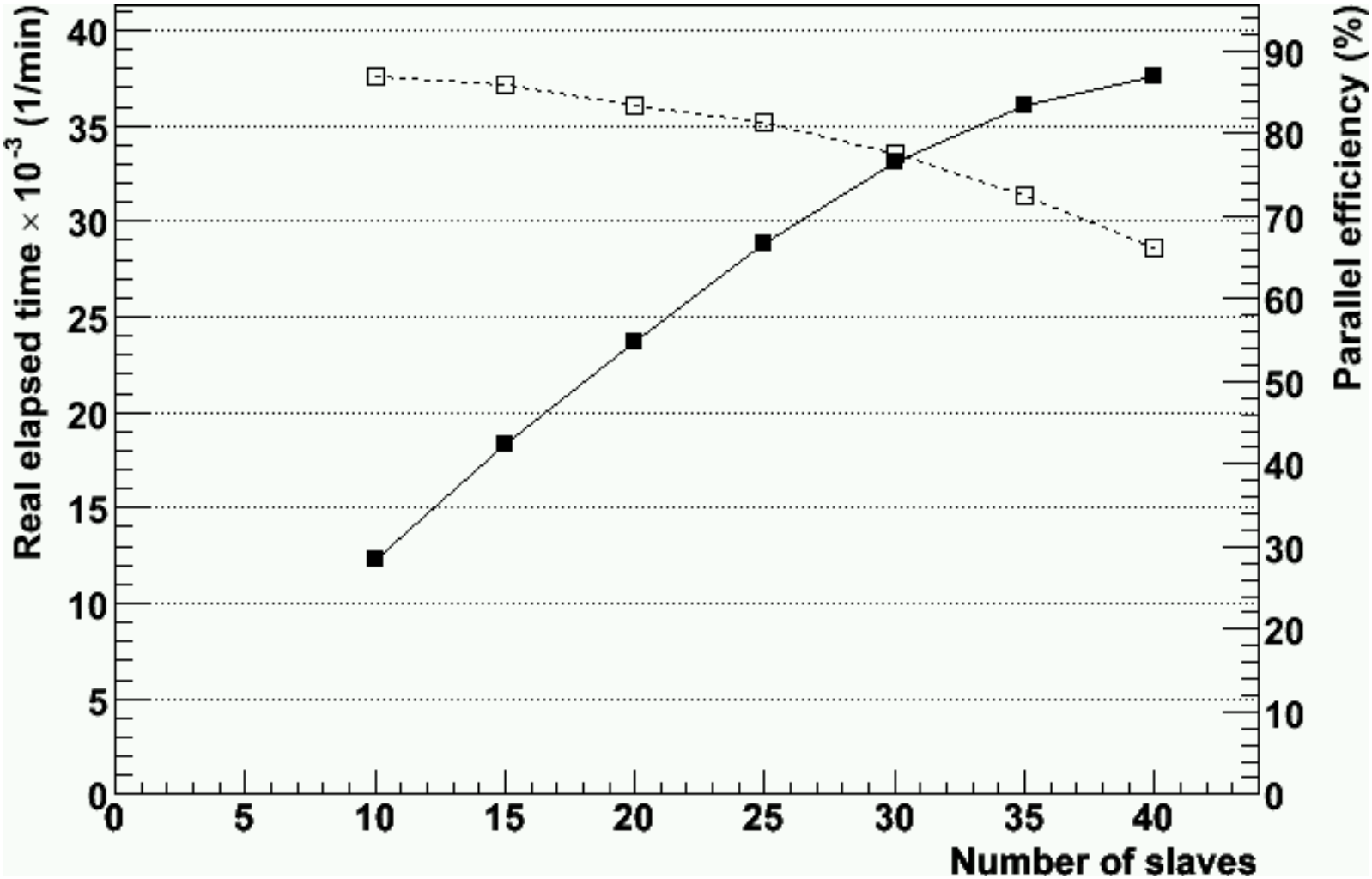
With GUI, design change can be manipulated easily and C++ source code to describe the geometry setup for Geant4 will be produced automatically.

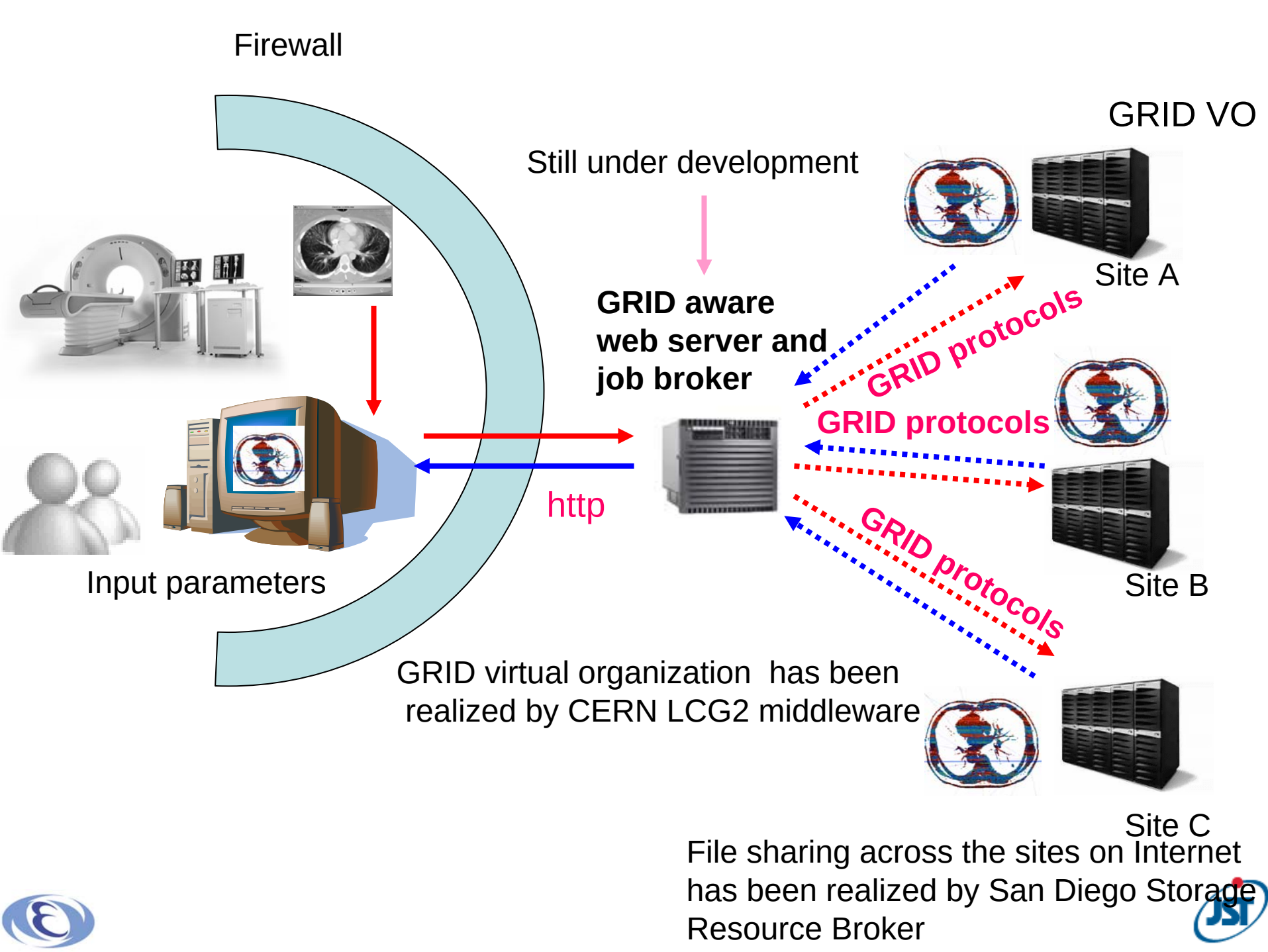
Needs only a web browser and Java!

Parallelism and GRID deployment

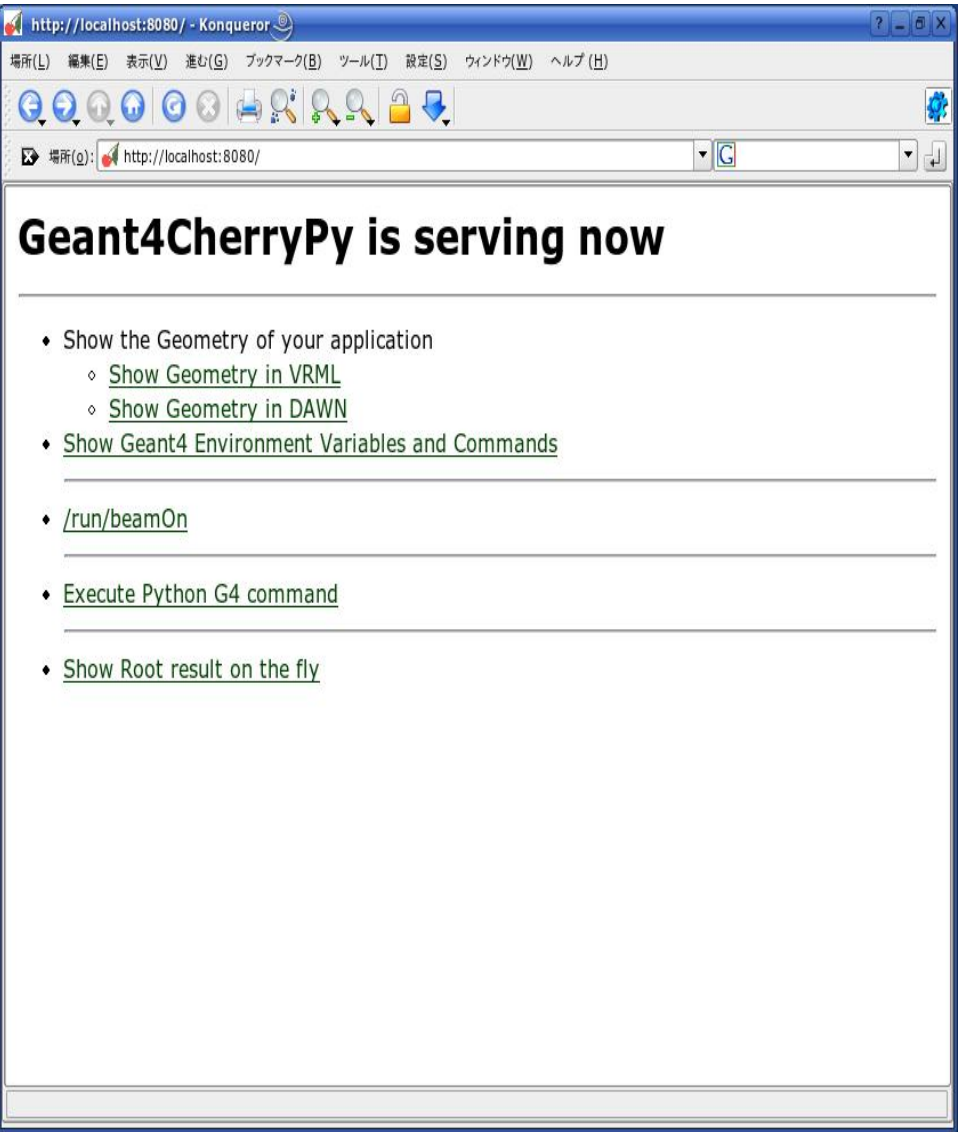
- Event level parallelism has been implemented for general purpose using MPI-C++ interface
  - No other component, but just MPI implementation is necessary, such as MPICH
    - Independent from the TOP-C example in G4 distribution
- Parallel simulation over the Internet is realized by GRID middleware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

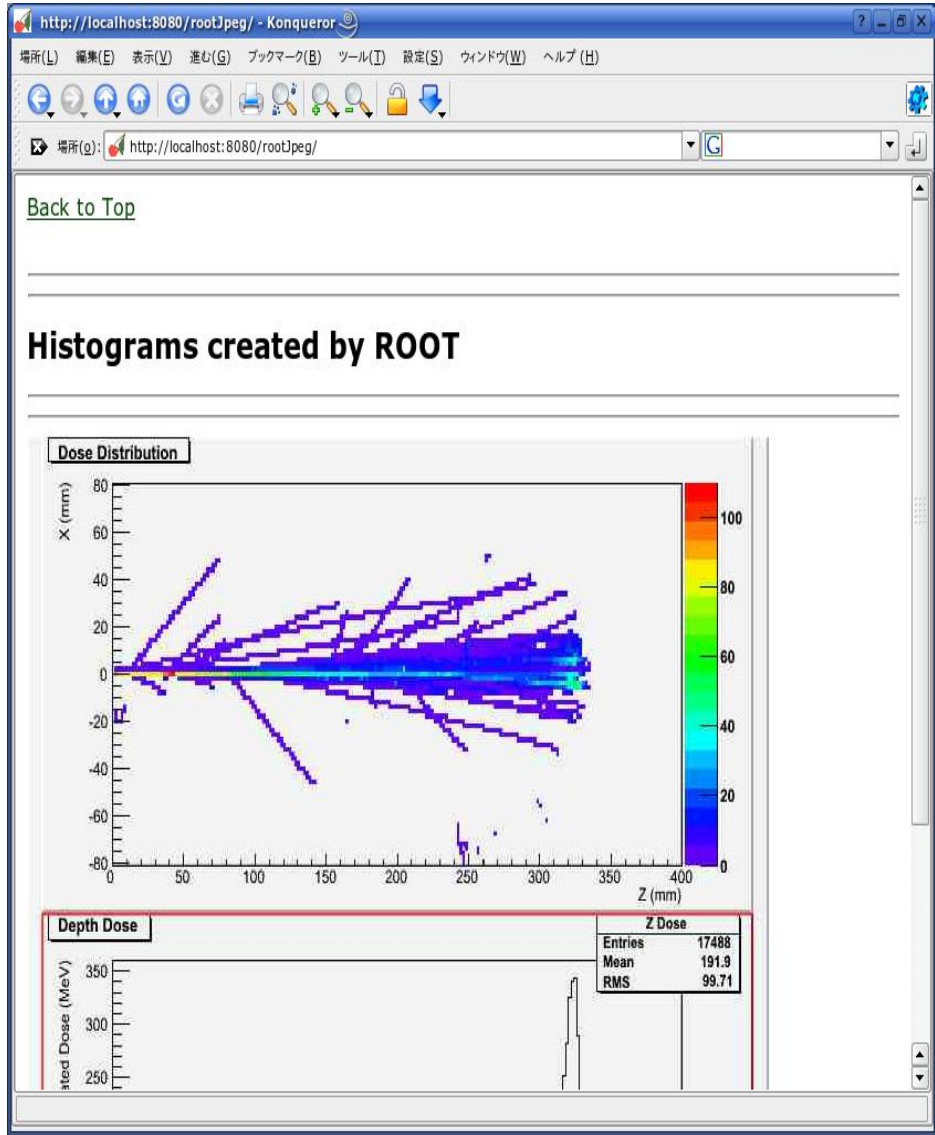
Parallelization efficiency




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 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 in December 2006
  - 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
- Also validation against data are done very seriously
  - Protons
    - HIBMC, NCC-eat
  - Carbons and heavier ions
    - HIMAC
    - Needs more data

Symposium in December

- Japan-Taiwan Symposium on Simulation in Medicine
  - Special event: Geant4 Lecture Course
    - December 12
  - December 13-14 @Tsukuba, 60km in north east from Tokyo
    - EGS, PHITS and Geant4 developers will join
- Welcome to join!
  - Call for papers were distributed recently
  - http://www-conf.kek.jp/geant4

Acknowledgements

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