Development of Software Framework for Simulation in Radiotherapy

Status and Plan in 2005

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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
- 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

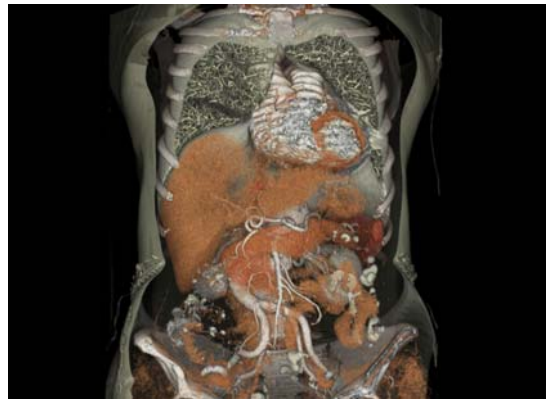
Motivation

- Geant4 is not simple software and not easy to use in some 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, heavy ion therapy is one of such cases and very challenging for Geant4 developers' too
  - Heavy ion physics also applicable to astro-phys

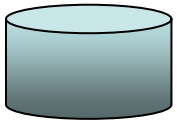
Project Goal

- Provide the framework and software toolkit for simulation in radiotherapy, especially, particle therapy
  - Well designed general purpose software
  - DICOM/DICOM-RT interface
  - Visualization/Interactivity
  - GRID computing
  - etc
- Physics validation is also the important subject

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

...

What is Geant4?

Introduction

The project web page:

http://cern.ch/geant4

- *"GEANT4: A Simulation Toolkit", by the Geant4 Collaboration published in **Nuclear Instruments and Methods in Physics Research A 506 (2003), 250-303**.*
  - *Geant4 is a toolkit for the simulation of the passage of particles through matter. Its application areas include high energy physics and nuclear experiments, medical, accelerator and space physics studies. It includes a complete range of functionality including tracking, geometry, physics models and hits. The physics processes offered cover a comprehensive range, including electromagnetic, hadronic and optical processes, a large set of long-lived particles, materials and elements, over a wide energy range starting, in some cases, from 250 eV and extending in others to the TeV energy range. It has been designed and constructed to expose the physics models utilised, to handle complex geometries, and to enable its easy adaptation for optimal use in different sets of applications. The toolkit is the result of a worldwide collaboration of physicists and software engineers.*

What is Geant4?

- Geant4 is the software toolkit to simulate interaction between particles and matter
- Geant4 is the successor of GEANT3, but designed and implemented from the scratch using C++
- Geant4 is designed to answer a variety of requirements came from HENP, heavy ion physics, cosmic ray physics, astrophysics, space science and medical applications using an Object-Oriented techniques to take into account of maintainceabilty and extendability.
- In order to meet such requirements, a high degree of functionality and flexibility are provided.

Advantages in Geant4

- Detailed geometry description
- Precise magnetic/electric field description
- Easier material composition
- Variety of physics process
  - Electro-magnetic
    - Down to 250 eV up to TeV
    - Optical photons
  - Hadronic
  - Heavy ion
  - User defined processes
- Fast or precise visualization
- Analysis tools and interactivity
- Extendablity as software toolkit
- Open source

Disadvantage of Geant4

- Learning curve
  - Learning C++ and UNIX oriented development environment if you are new for these
  - If you are not a FORTRAN programmer, say a C or C++ programmer , this would be an advantage
- Complex
  - As other Monte Carlo codes
- Toolkit nature
  - Geant4 is not a black box to give correct results
    - Simulation without validation has no meaning

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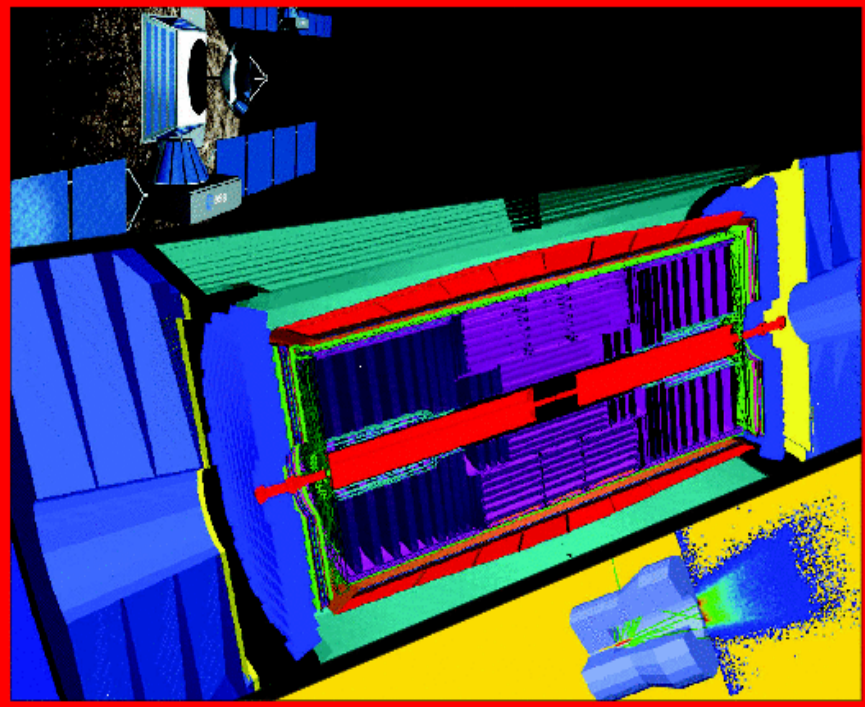


Simulation for physics, space and medicine

http://cern.ch/geant4

Geant 4

Geant4 is a toolkit for the simulation of the passage of particles through matter.
It has been developed and maintained by a world-wide Collaboration of approximately 100 scientists.

Its application areas include high energy physics, astrophysics and nuclear physics experiments, medical, accelerator and space science studies.

GLAST *Gamma-ray Large Area Space Telescope*

ATLAS *at LHC, CERN*

Borexino *at Gran Sasso Laboratory*

ESA XMM *X-ray telescope*

CMS *at LHC, CERN*

BaBar *at SLAC*

High energy μ *Courtesy of L3*

Photon attenuation
Low energy photons
Courtesy of the Italian Nat. Inst. for Cancer Research

An abundant set of Physics Processes handle the diverse interactions of particles with matter across a wide energy range.

Neutrons *Courtesy of CMS*

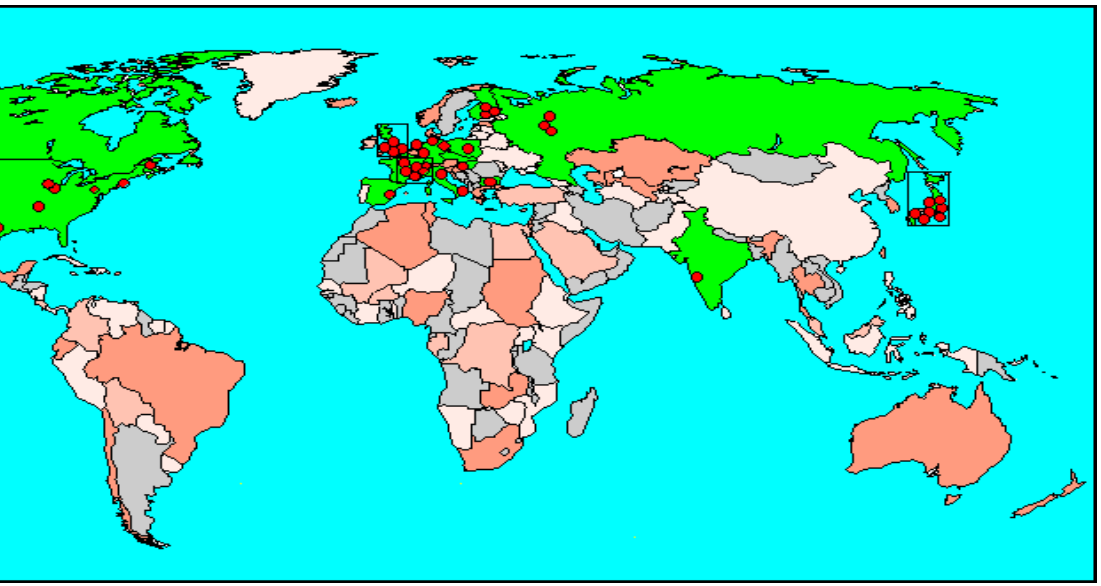
Stopping π
absorption
nuclear deexcitation
Geant4
Exp. data
Energy MeV

Geant4 exploits advanced Software Engineering techniques and Object Oriented technology to achieve transparency of physics implementation.

Budker Inst. of Physics IHEP Protvino MEPHI Moscow Pittsburg University

Geant4 Collaboration

HARP



Lebedev

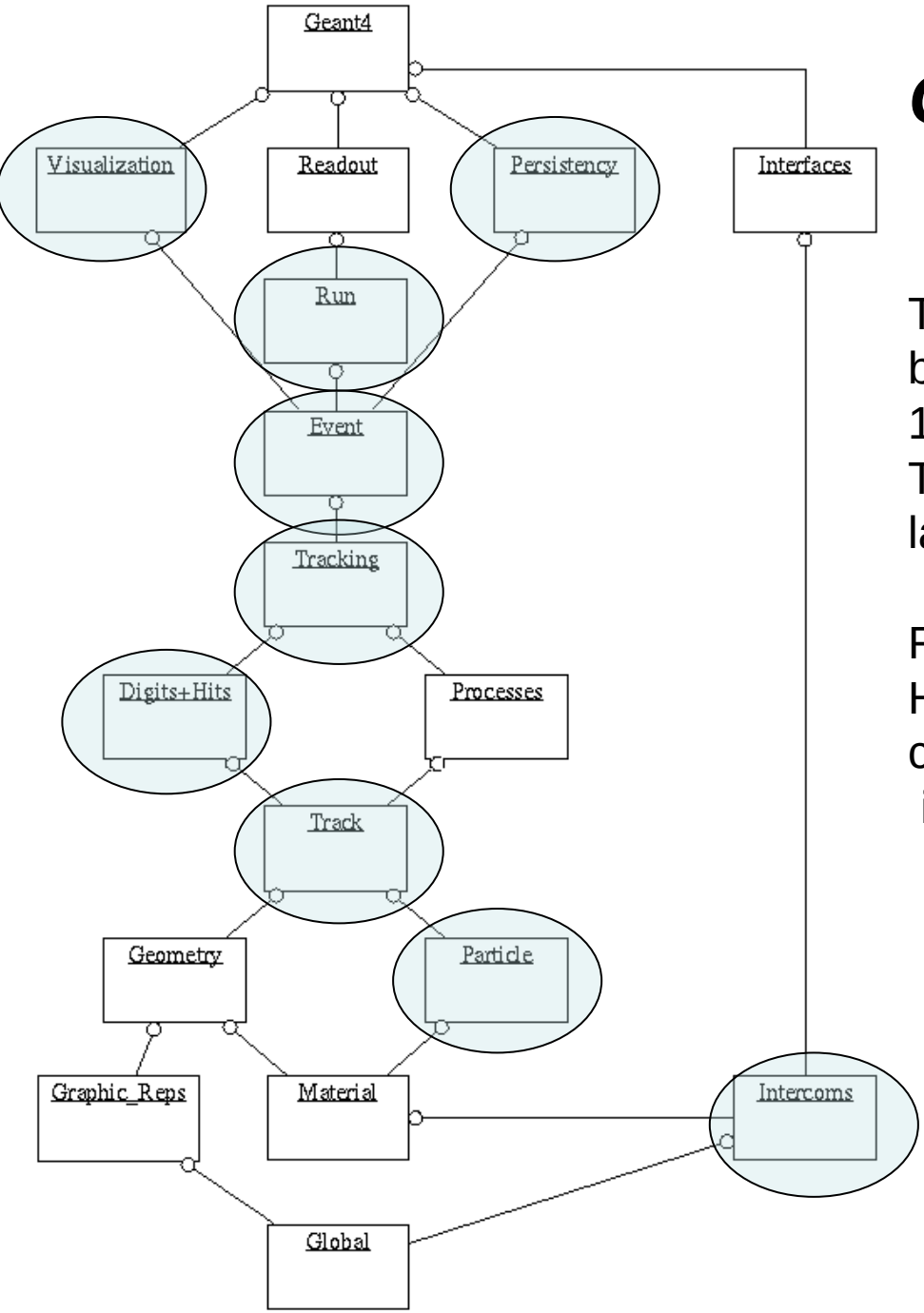
Univ. Barcelona

PPARC

Helsinki Inst. Ph.

Collaborators also from non-member institutions, including
Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

http://cern.ch/geant4



Geant4 global architecture

The global design of Geant4 was done by CERN and Japanese members in 1994 based on Object-Oriented methodology
The implementation is done in ANSI C++ language

From the beginning, application in multi area, HENP, space, medical and so on was considered for the design. Always the design is updated according to new requirements.

A class category maintained by an independent working group

Japanese contribution is more than 90% 9/17

History of Geant4

- Dec ’94 - Project start
- Apr ’97 - First alpha release
- Jul ’98 - First beta release
- Dec ’98 - First Geant4 public release
- ...
- Dec ’03 - Geant4 6.0 release
- Mar ’04 - Geant4 6.1 release
- Jun ’04 - Geant4 6.2 release
- Dec 17th, ’04 - Geant4 7.0 release
  - Feb 26th, ’05 - Geant4 7.0-patch01 release
- two to three public releases every year and bimonthly beta releases in between public releases

Achievement in our project

2003-2004

Concept of design and Strategy

- 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

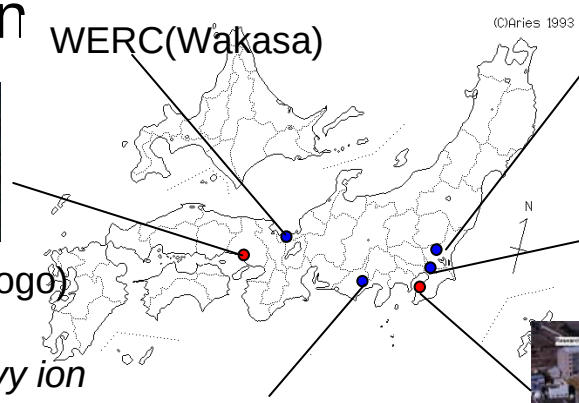
- Parallelization of simulation and GRID computing
- Independent DICOM-G4 interface
  - DICOM-RT is also taken into account
    - Standardization is not yet ready and need adoption for different extension at each facility, anyway
  - DICOM example in the Geant4 distribution has problems and should be 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

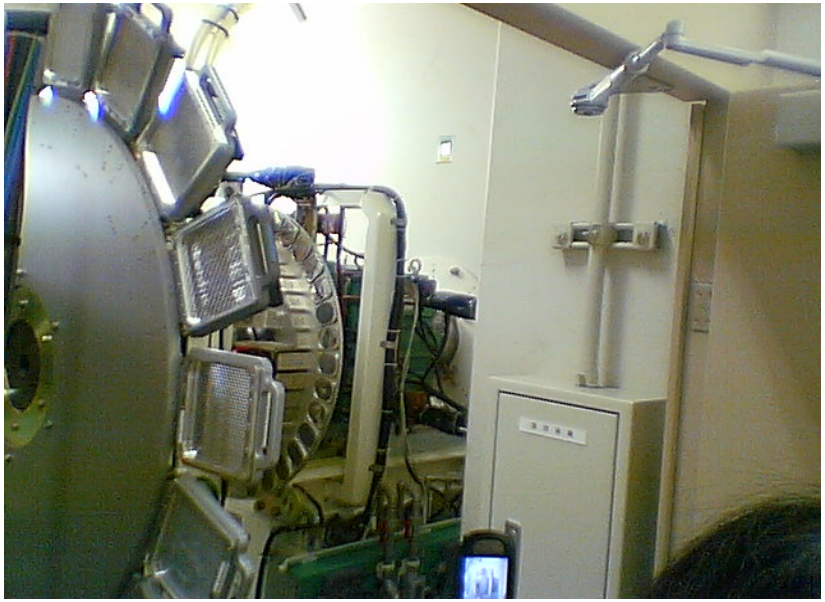
PMRC (Tsukuba)

HBMC (Hyogo)



NCC-EAST (Kashiwa

NIRS,HIMAC (Chiba)

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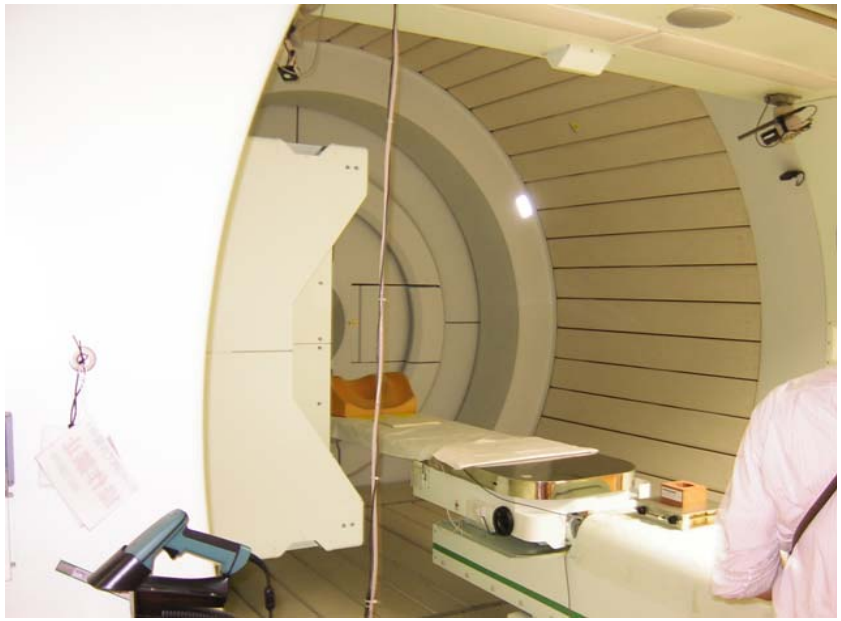
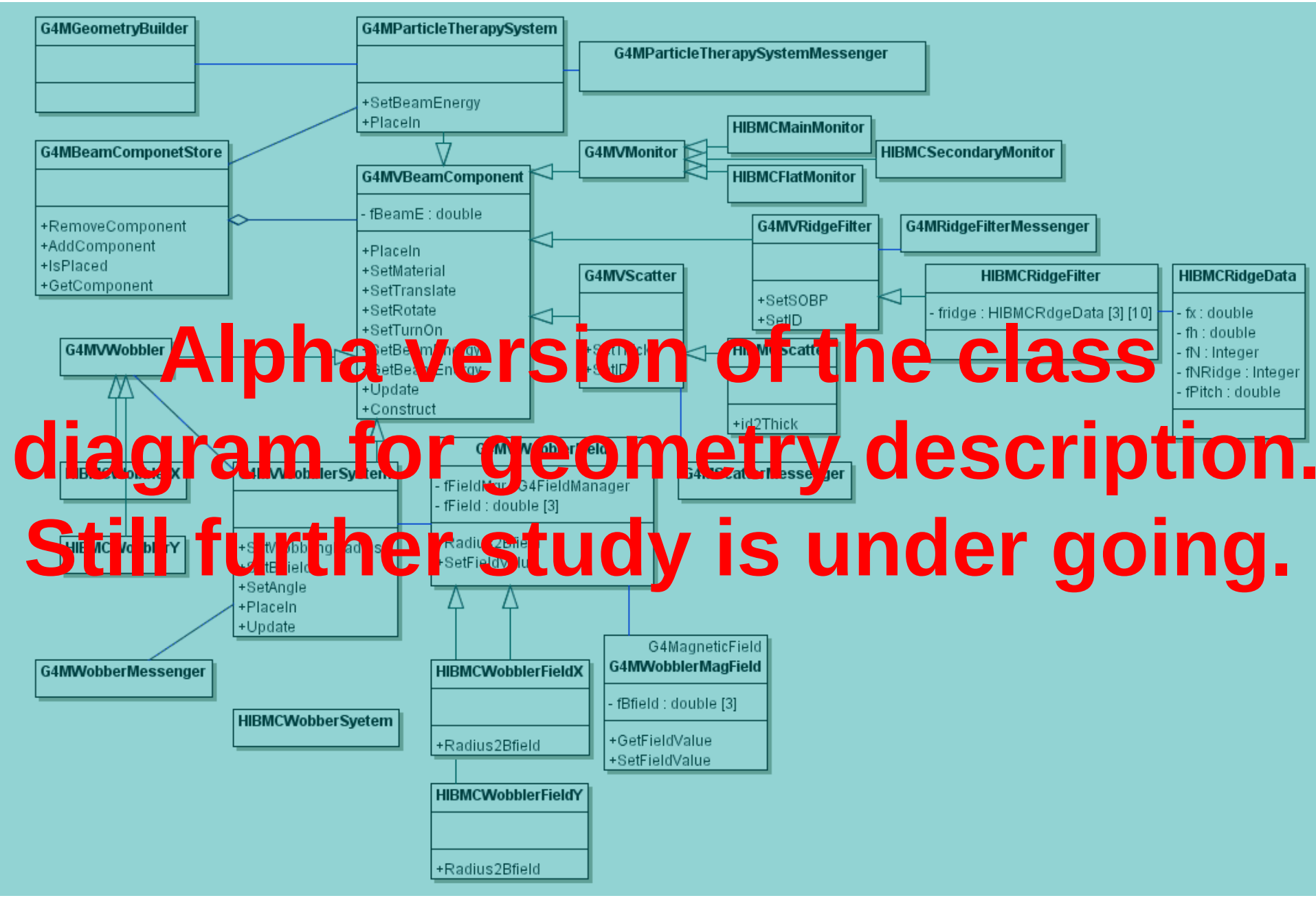
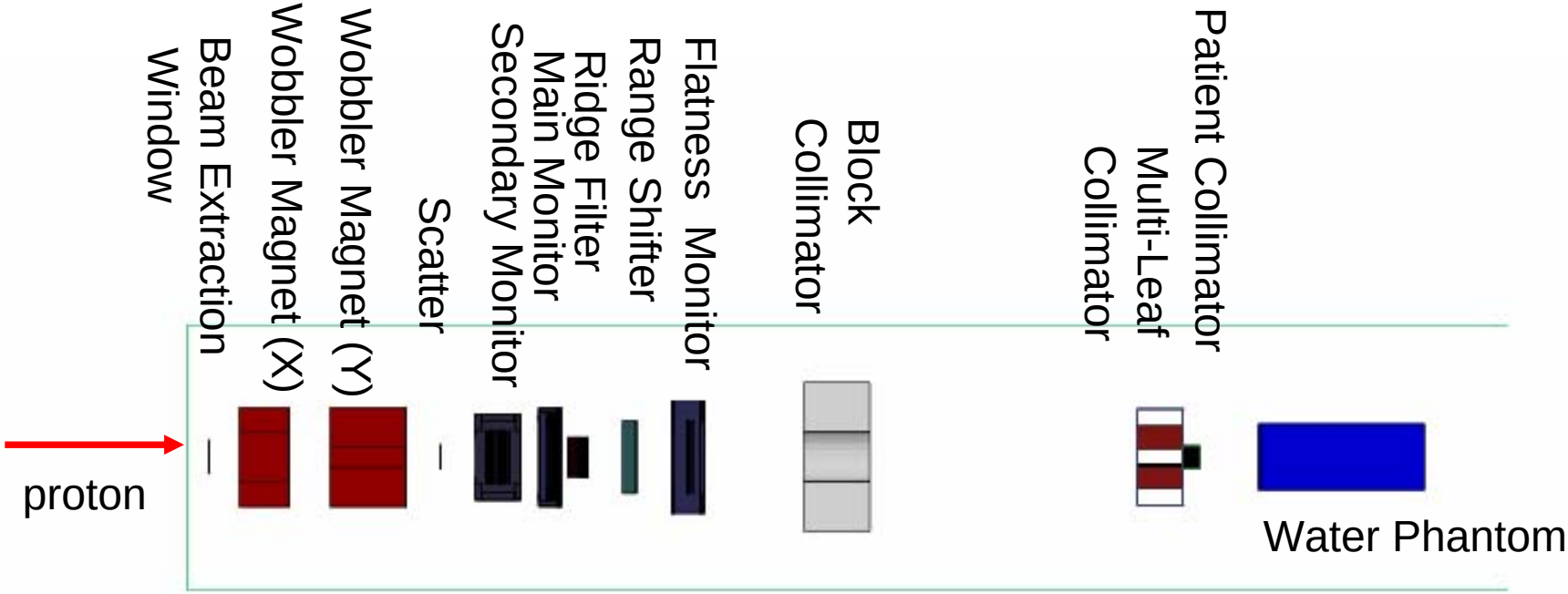




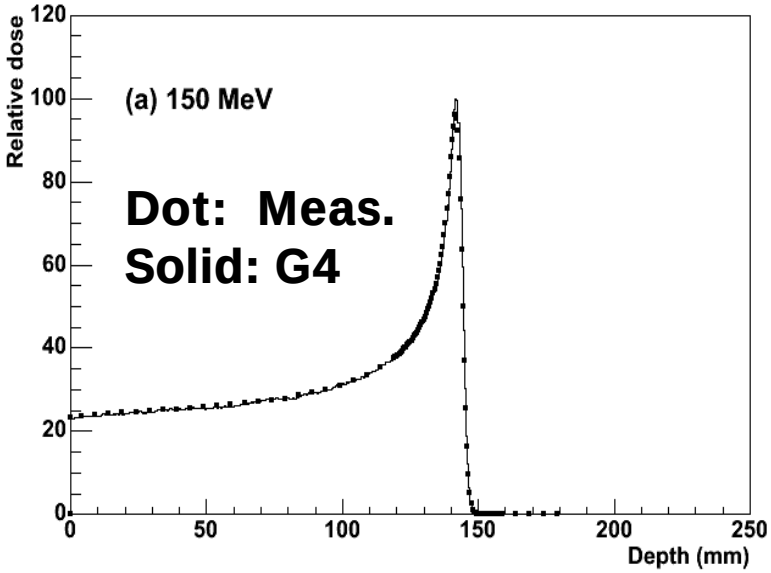
Alpha version of the class diagram for geometry description. Still further study is under going.

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

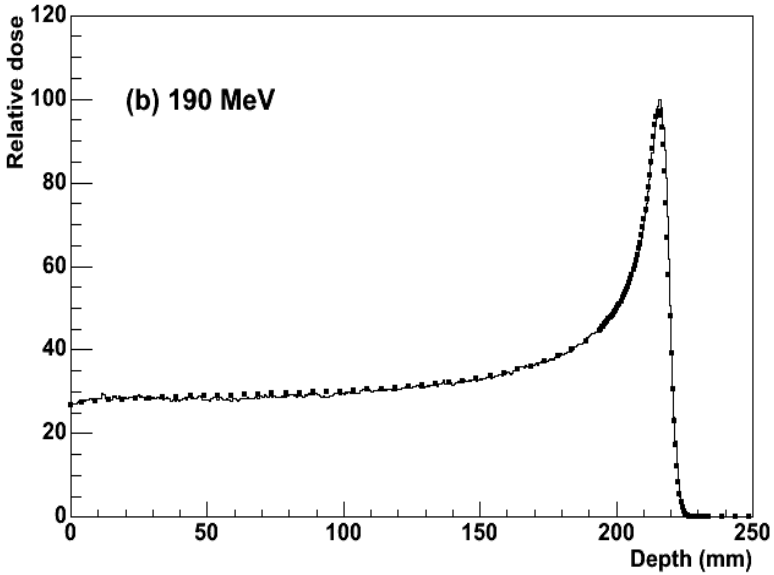


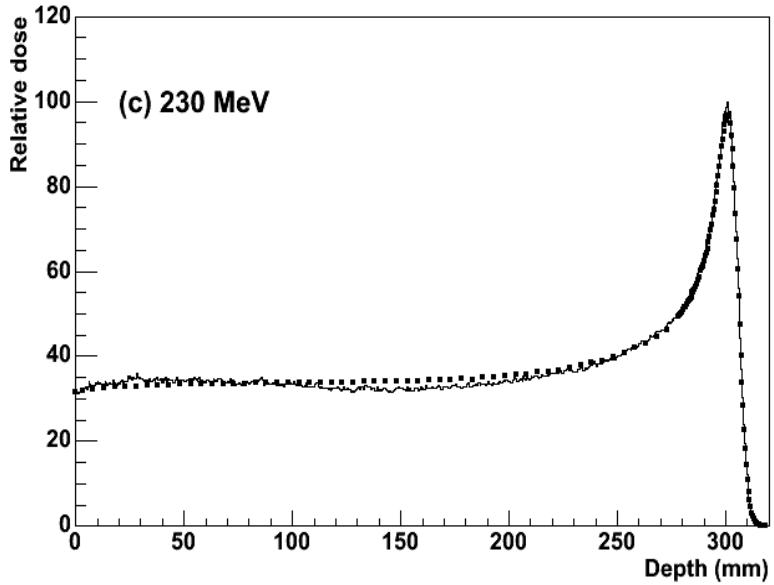
Bragg peak



Comparison between measurement at HIBMC and Geant4 simulation

proton beam with 150, 190 and 230 MeV





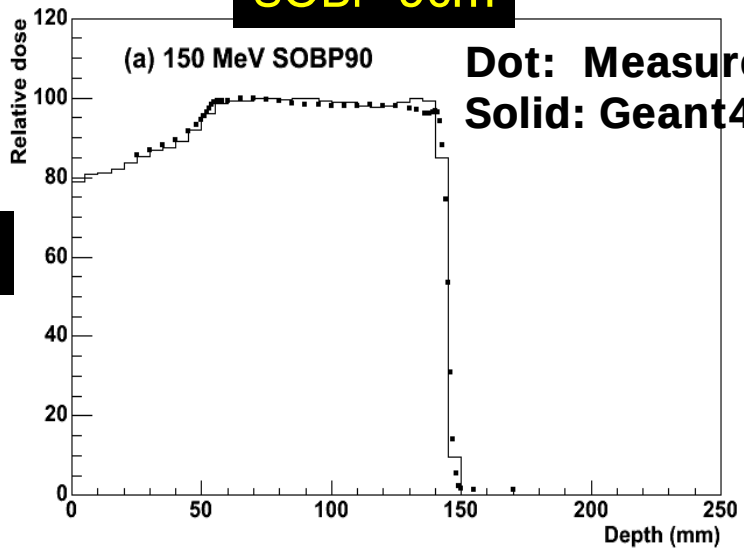
Spread Out Bragg Peak (SOBP)

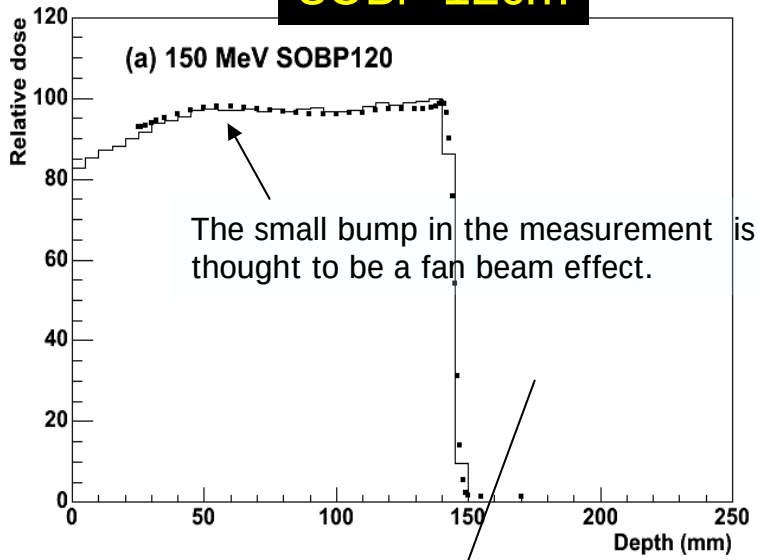
SOBP 9cm

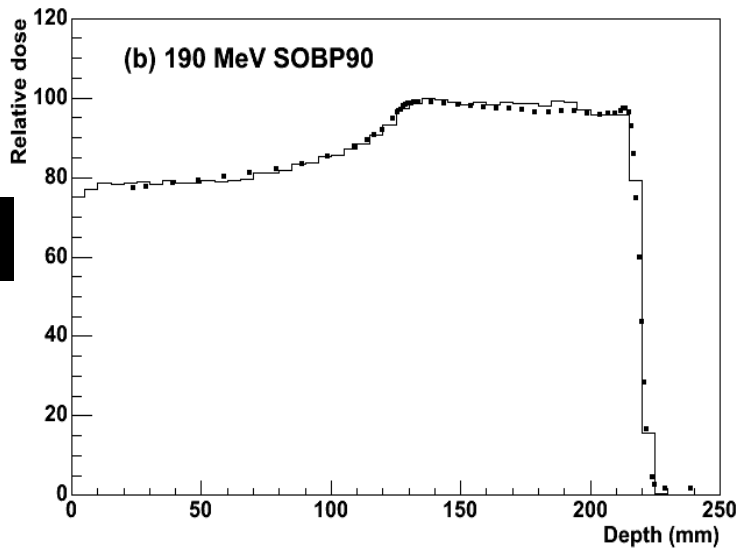
SOBP 12cm

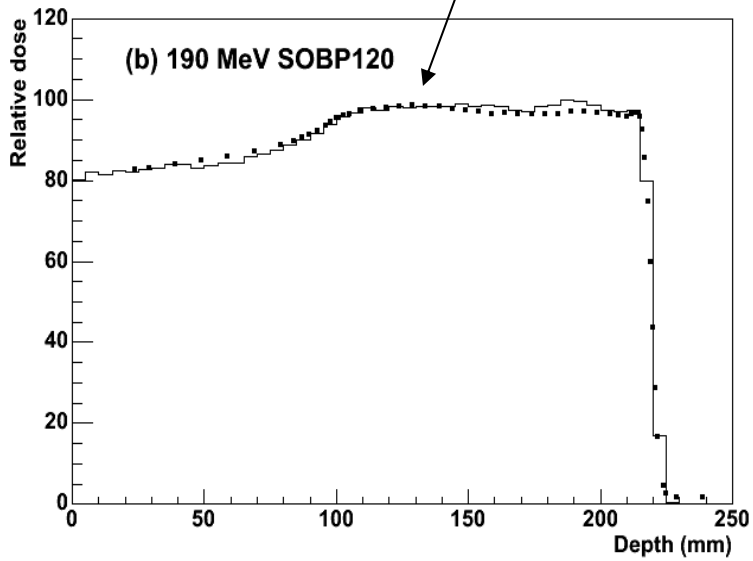
150MeV

190MeV



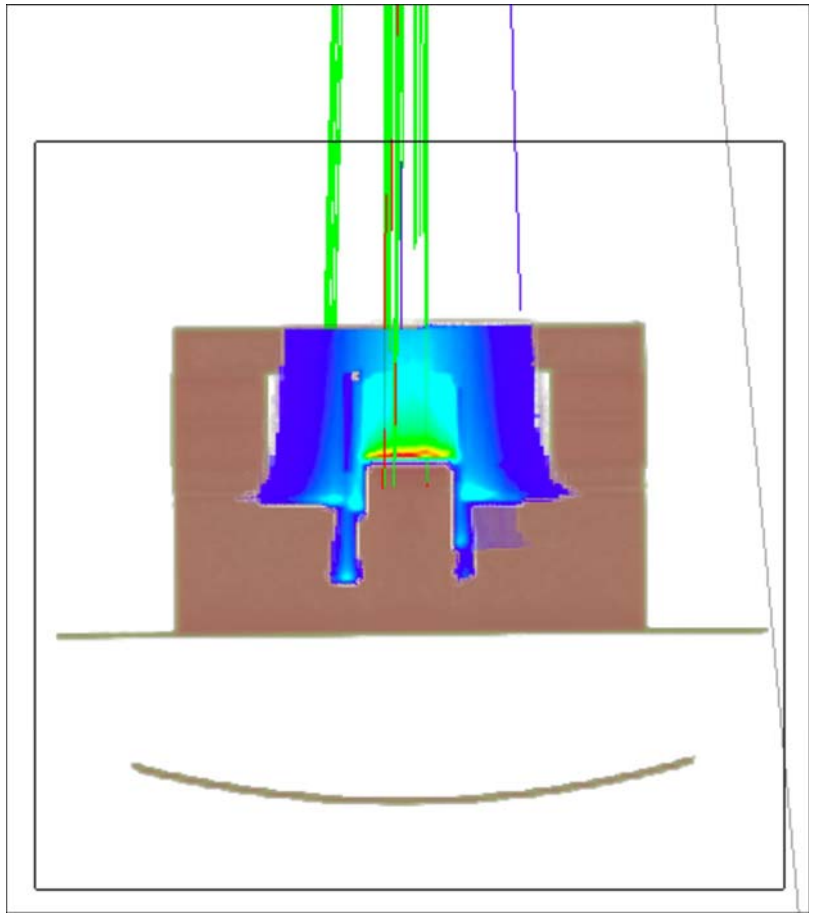






DICOM and visualization

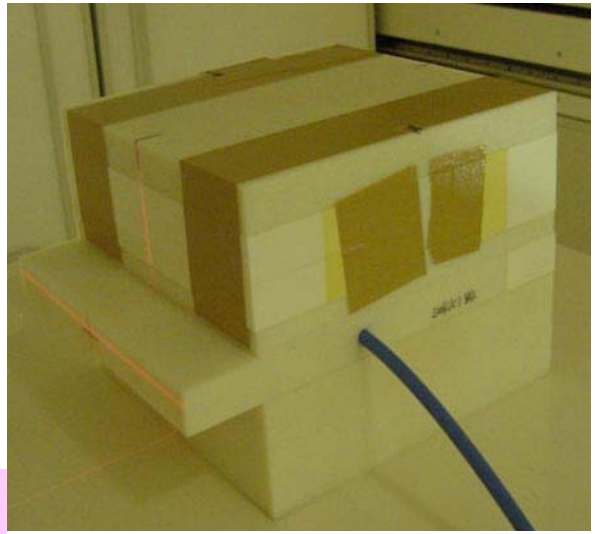
- Please look at the detail on the poster (Number 10) by Dr. Akinori Kimura at this conference
- Geant4-DICOM and DICOM-RT(still HIBMC only) interface
- Visualizer for DICOM image + dose distribution + analysis results



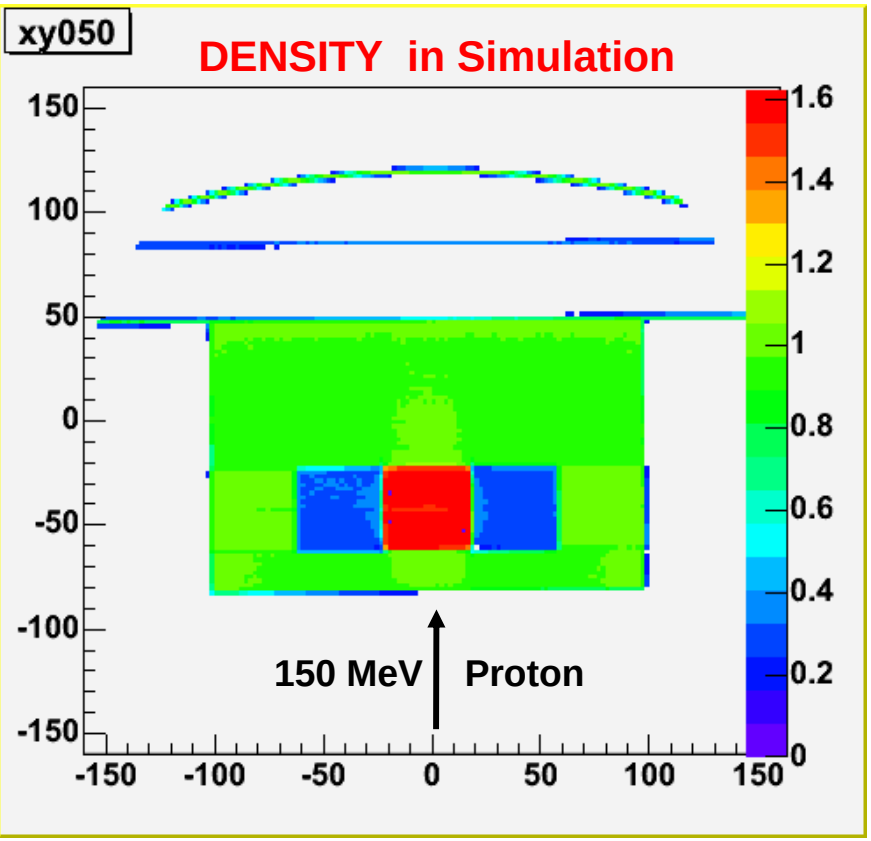
Visualizer prototype

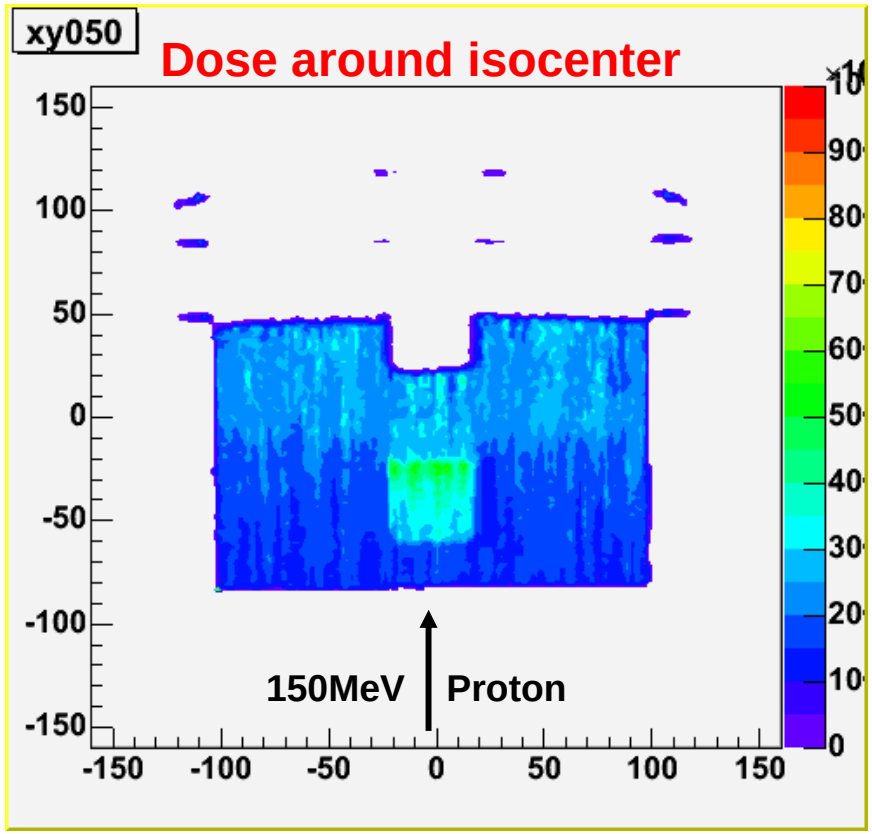
DICOM interface

Dose distribution in the plastic phantom visualized by Geant4 Open-GL package.

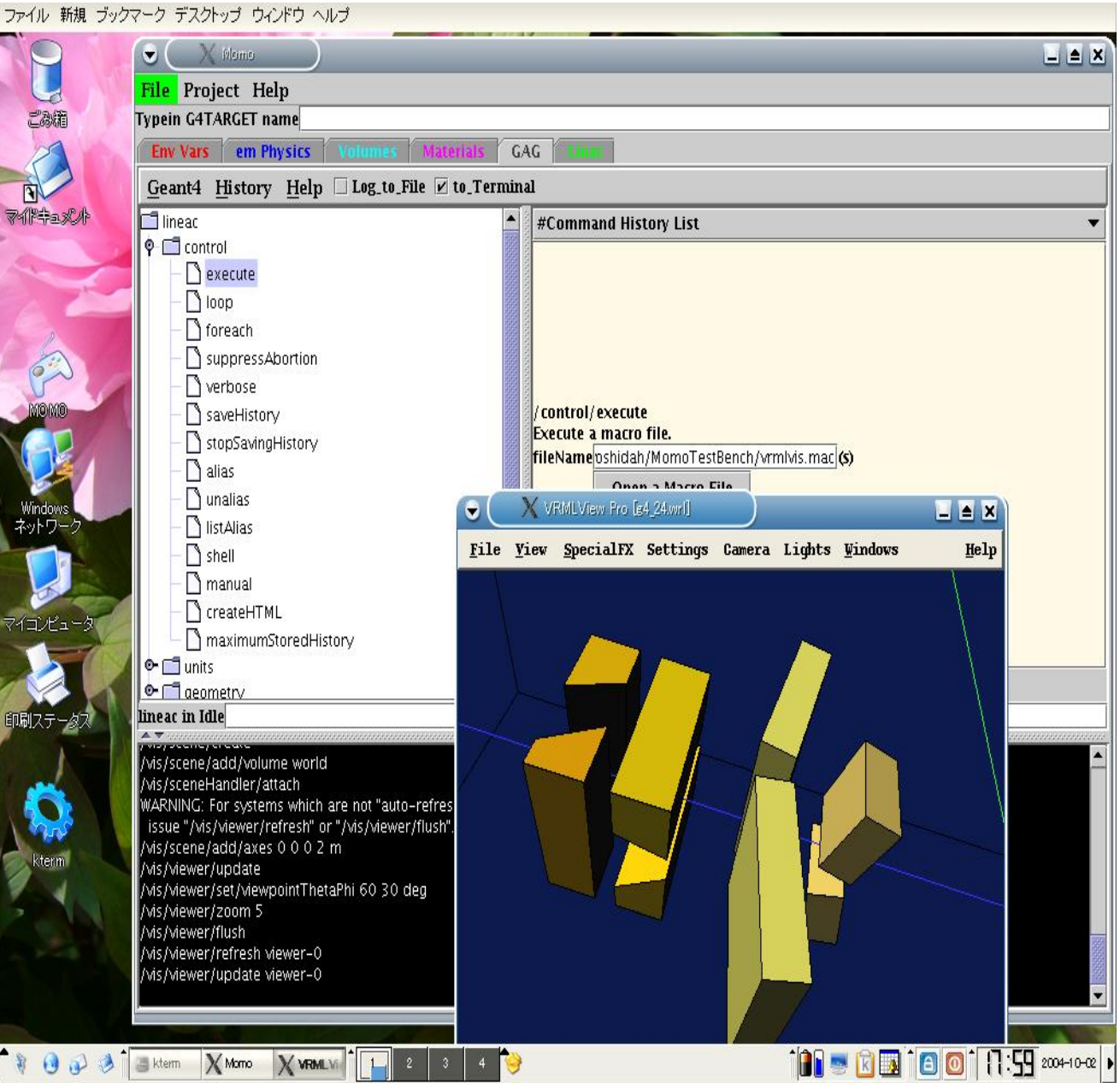


Proton 150MeV





Computer aided geometry design



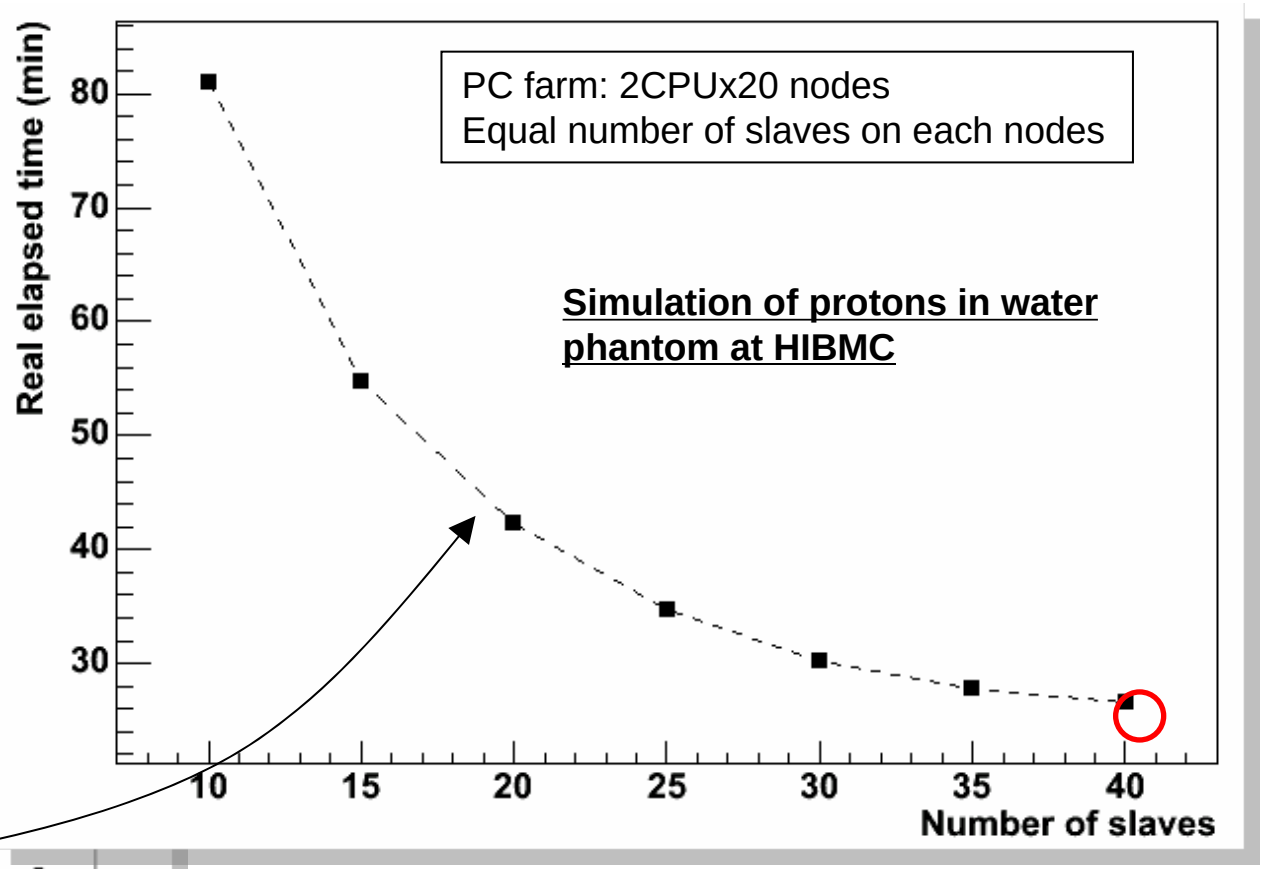
For a first example, electron accelerator head design tool has been designed and implemented.

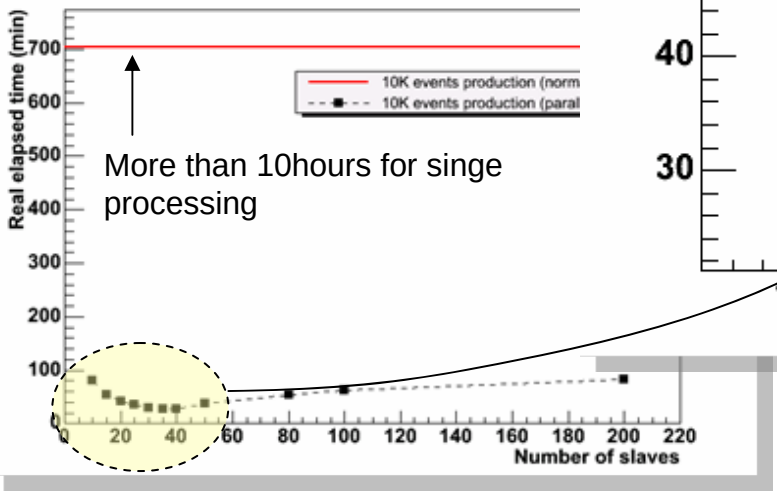
With GUI, design change can be manipulated easily and C++ source code to describe the geometry setup for Geant4 will be produced automatically.

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
- Web interface to access GRID from behind the hospital firewall is under development

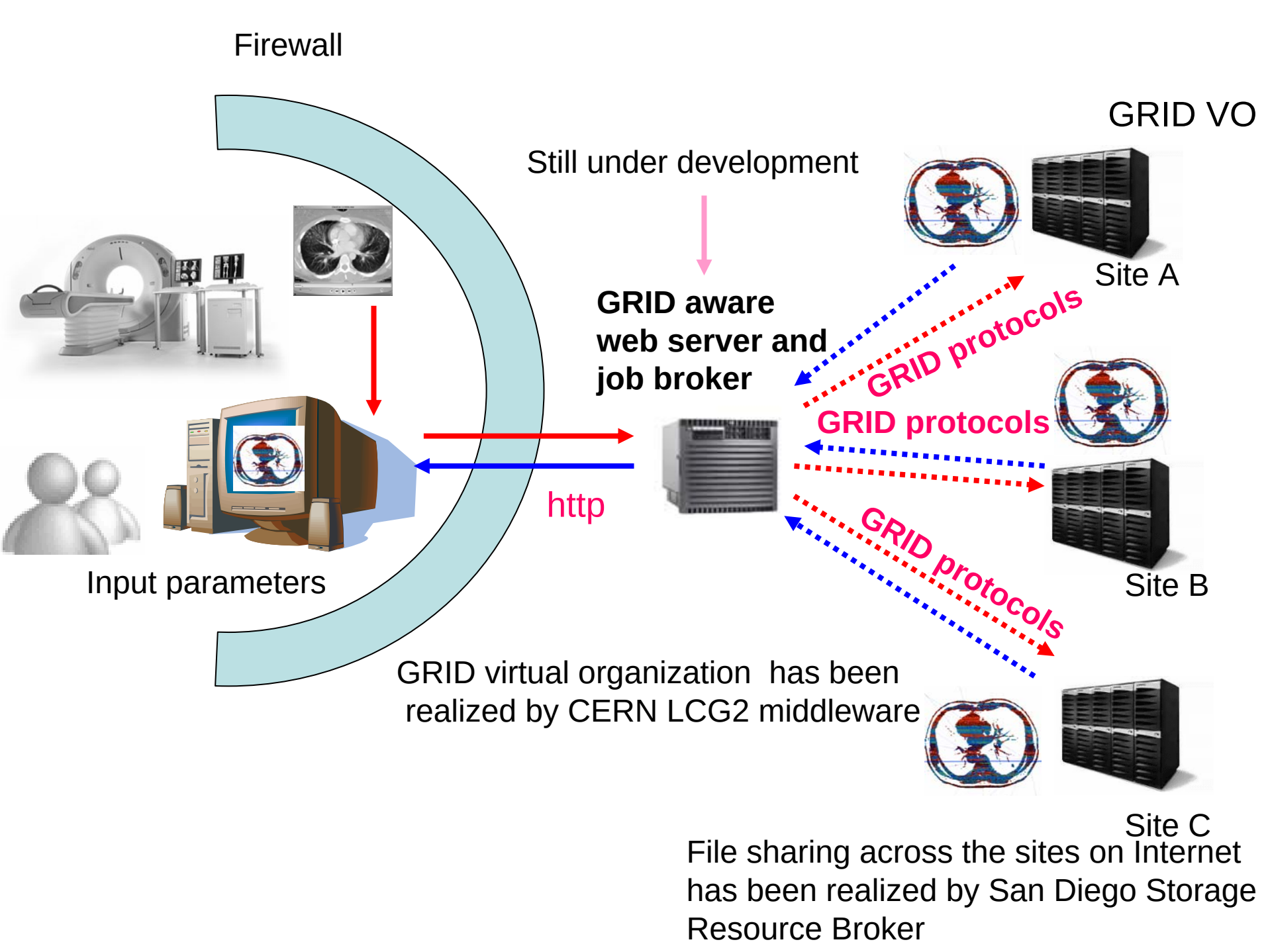
Event parallelism using MPI w/o TOP-C





More than 10hours for singe processing

Master	Slave	# of events	Time (min)	efficiency (%)	Master	Slave	# of events	Time (min)	efficiency (%)
1	10	1000000	80	88	1	40	1000000	26	67
1	15	1000000	54	86	1	50	1000000	38	37
1	20	1000000	42	83	1	80	1000000	54	16
1	25	1000000	34	82	1	100	1000000	62	11
1	30	1000000	30	78	1	200	1000000	81	4
1	35	1000000	27	74	Single process		1000000	704	


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

Summary

- Geant4 is well established software toolkit for simulating interaction between particles and matter
  - Already applied in many fields and well reproduced measurements
- Our project is developing the software framework and toolkit for particle therapy
- Also validation against data are done very seriously
- We welcome very much the contact from any other facility who have an interest to use our product for their simulation
- We would like to visit and interview facilities in other countries, too for sampling use cases and requirements