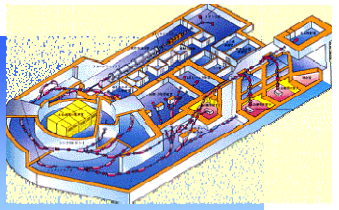
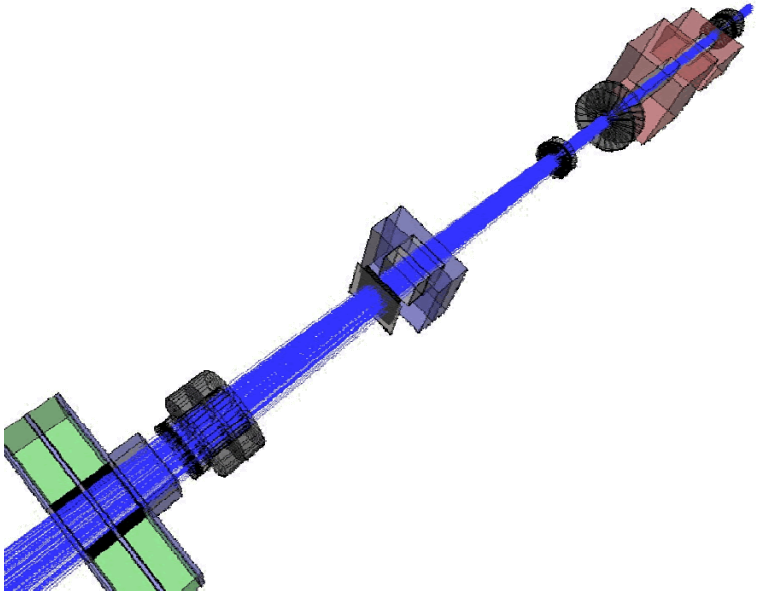


Results from the recent carbon test beam at HIMAC



Koichi Murakami

Statoru Kameoka

KEK CRC

supported by

Introduction

- A joint project among Geant4 developers, astro-physicists and medical physicists in Japan
  - ✓ *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
- The project goal
  - ✓ provides a set of software components for simulation in radiotherapy (especially hadrontherapy),
    - » well designed general purpose software framework
    - » DICOM/DICOM-RT interface
    - » application of GRID computing technology
    - » visualization tools
  - ✓ In addition, physics validation is one of key issues.

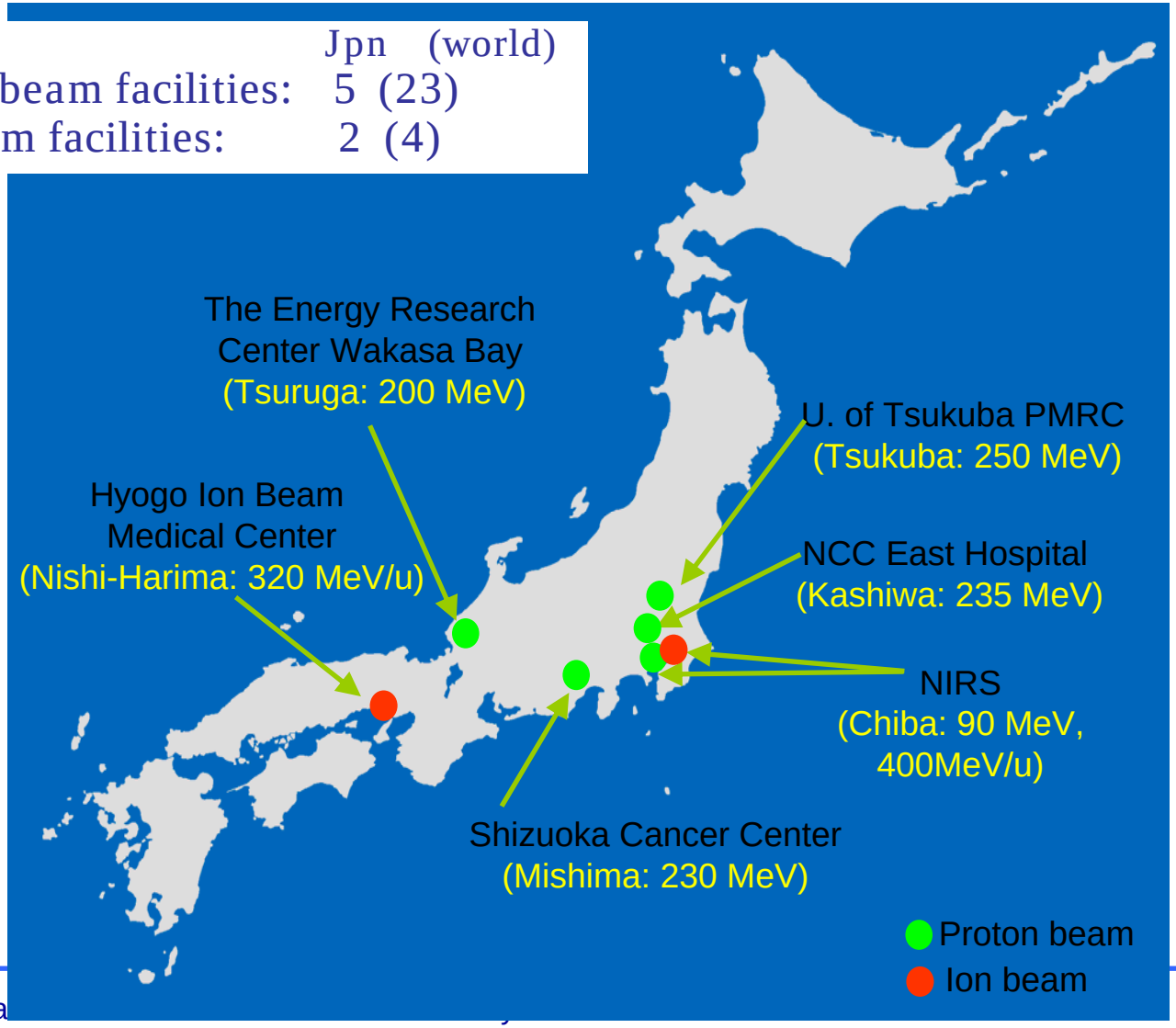
Physics Validation in Radiotherapy

- Geant4 has to reproduce precise dose distributions in human body.
  - ✓ which requires correct simulation for the interactions between various types of beams (X-ray, proton, heavy ions) and materials along beam line
  - ✓ reliable descriptions of
    - ≫ electromagnetic processes
    - ≫ hadronic/nuclear processes
    - ≫ nuclear decay processes

    in the relevant energy regions and particle types.
  - ✓ These are non-trivial issues!
- Physics validation is one of the most critical aspects in the project.

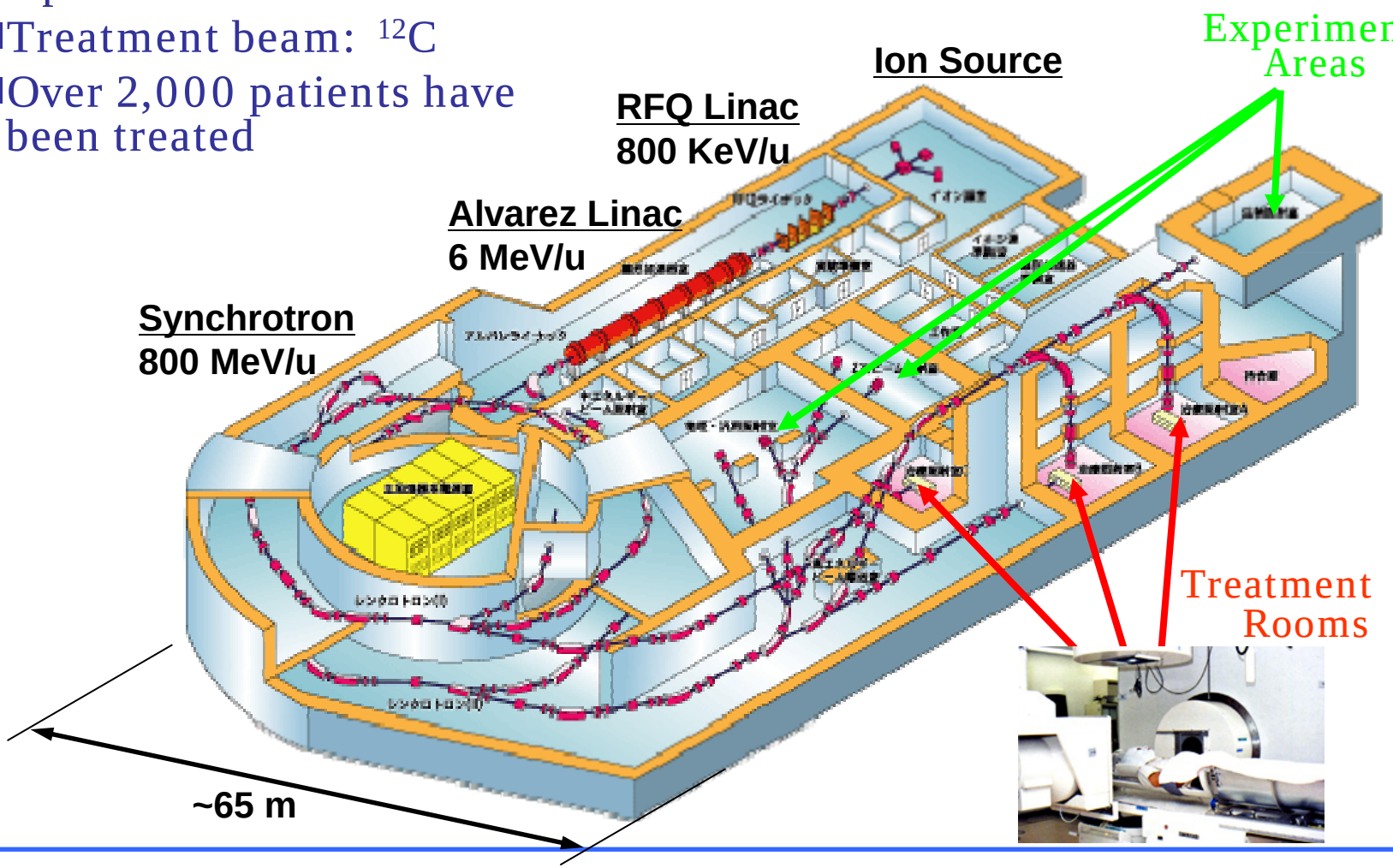
Hadrontherapy Facilities in Japan

	Jpn	(world)
# Proton beam facilities:	5	(23)
# Ion beam facilities:	2	(4)



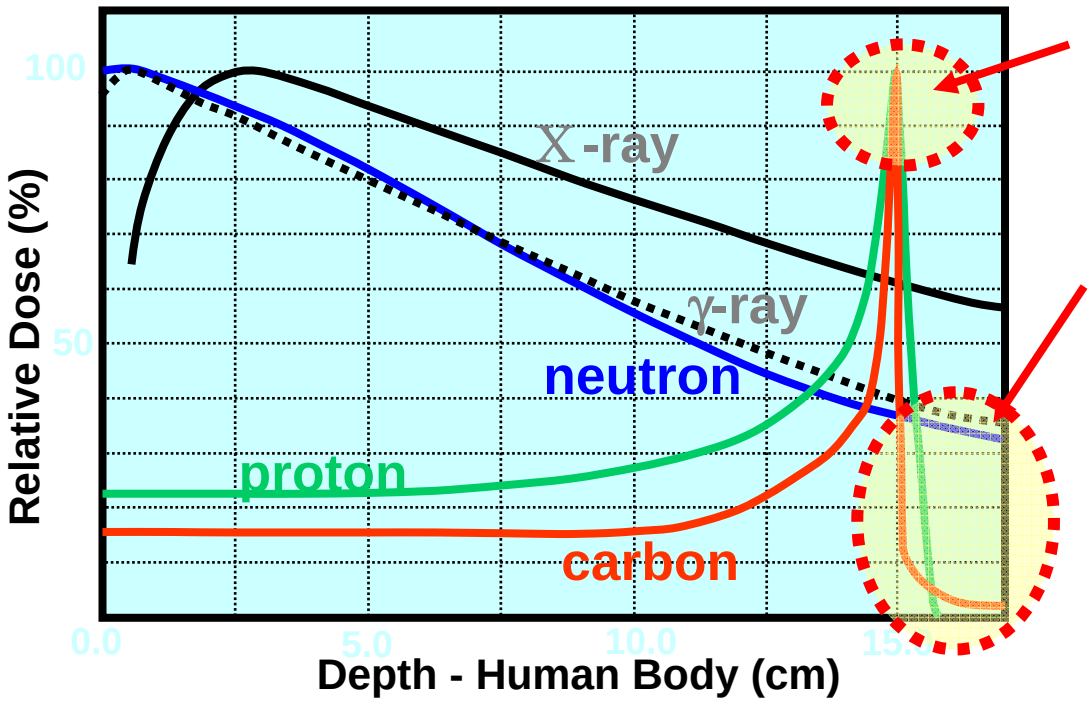
HIMAC at NIRS

- Operation since 1994
- Treatment beam: ^{12}C
- Over 2,000 patients have been treated



Hadron (proton/carbon) Beam

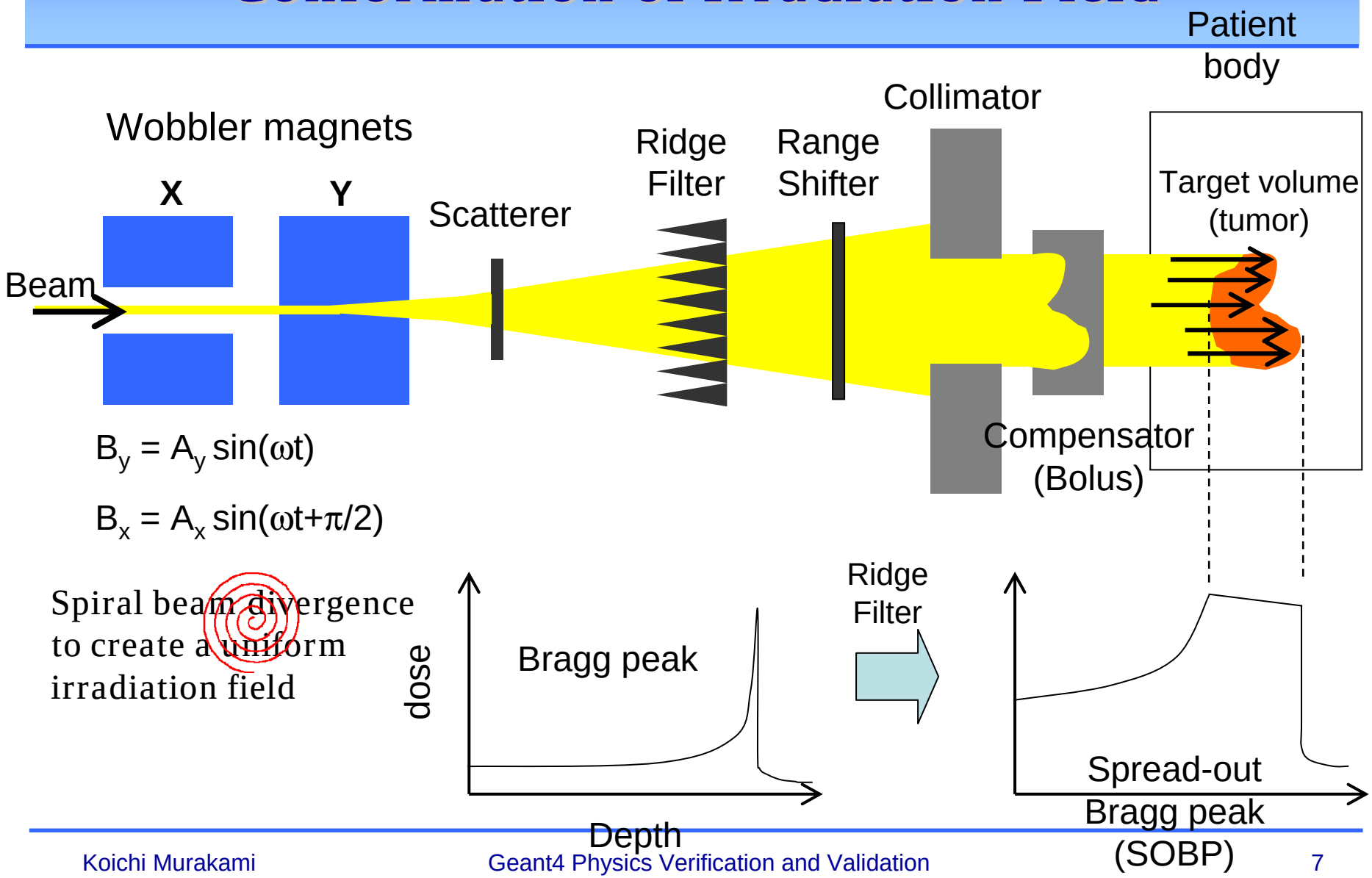
Ref. http://www.nirs.go.jp/tiryo/himac/himac2.htm



- A sharp peak of energy deposition at the end of the range (*Bragg peak*)
- The sharp fall-off of the Bragg peak for carbon beam
  - ✓ A small range straggling
- Carbon produces a longer tail after the Bragg peak.

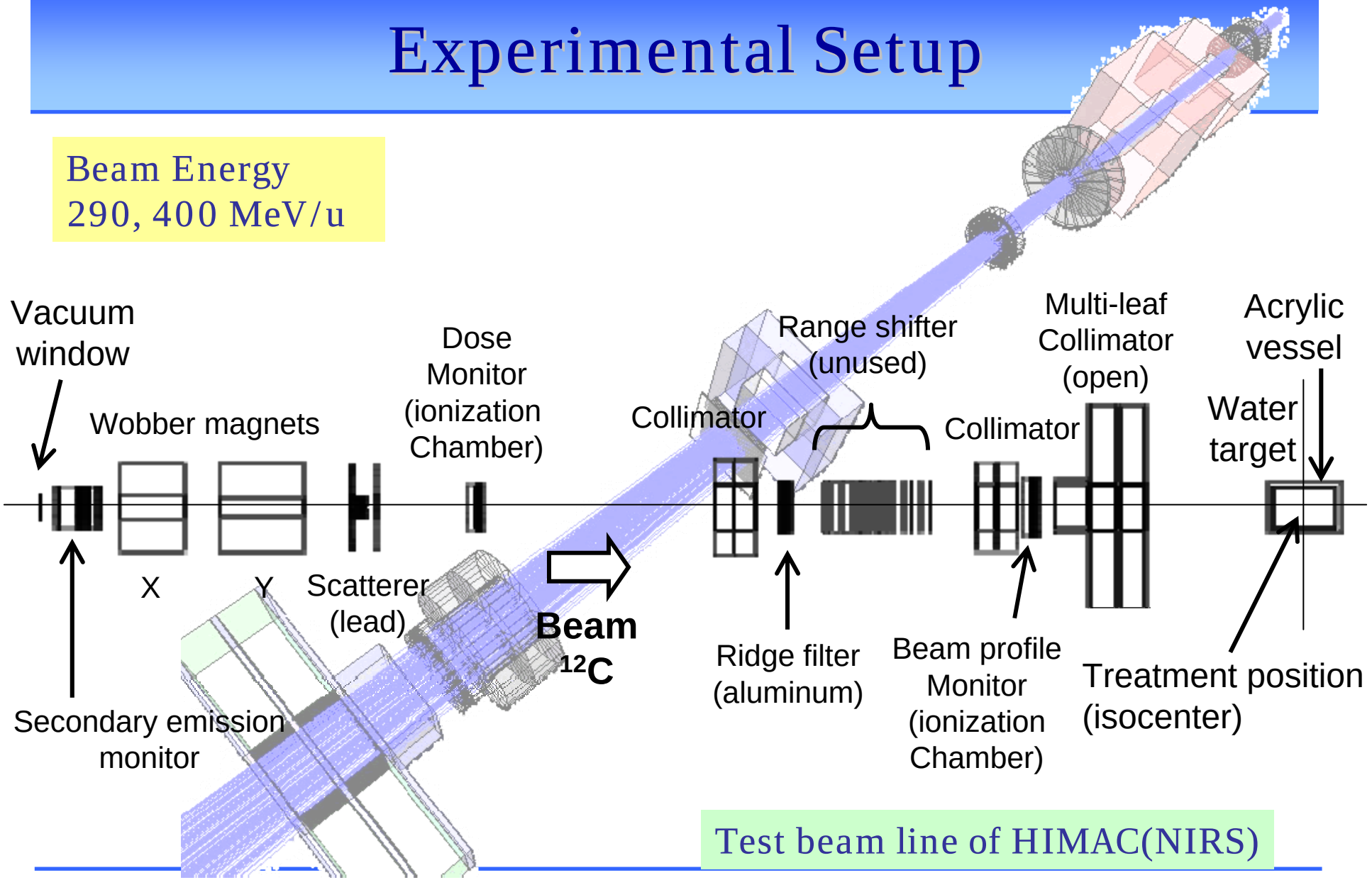
Hadron beams allow conformation of dose distribution better than photons and electrons;

Conformation of Irradiation Field



Experimental Setup

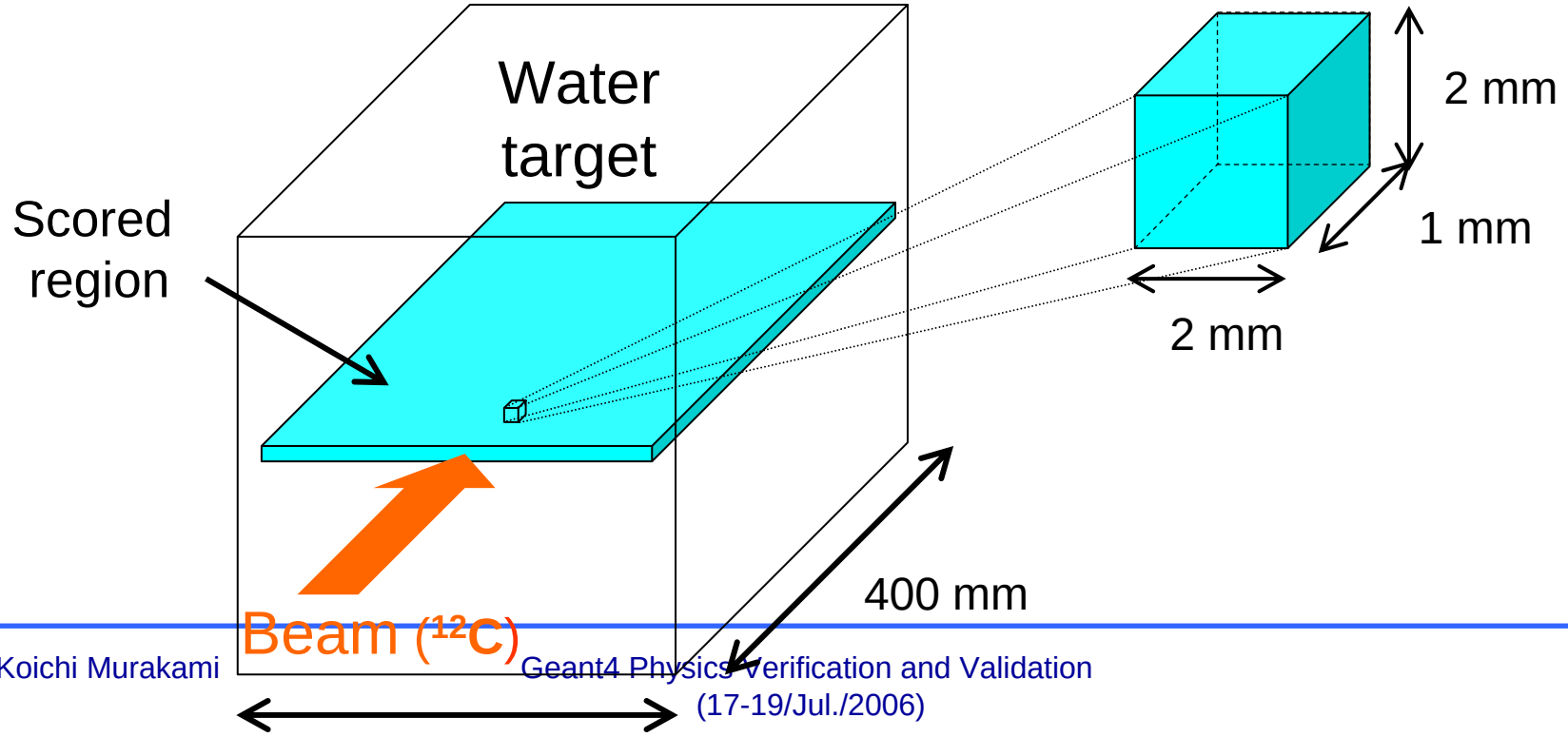
Beam Energy
290, 400 MeV/u



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

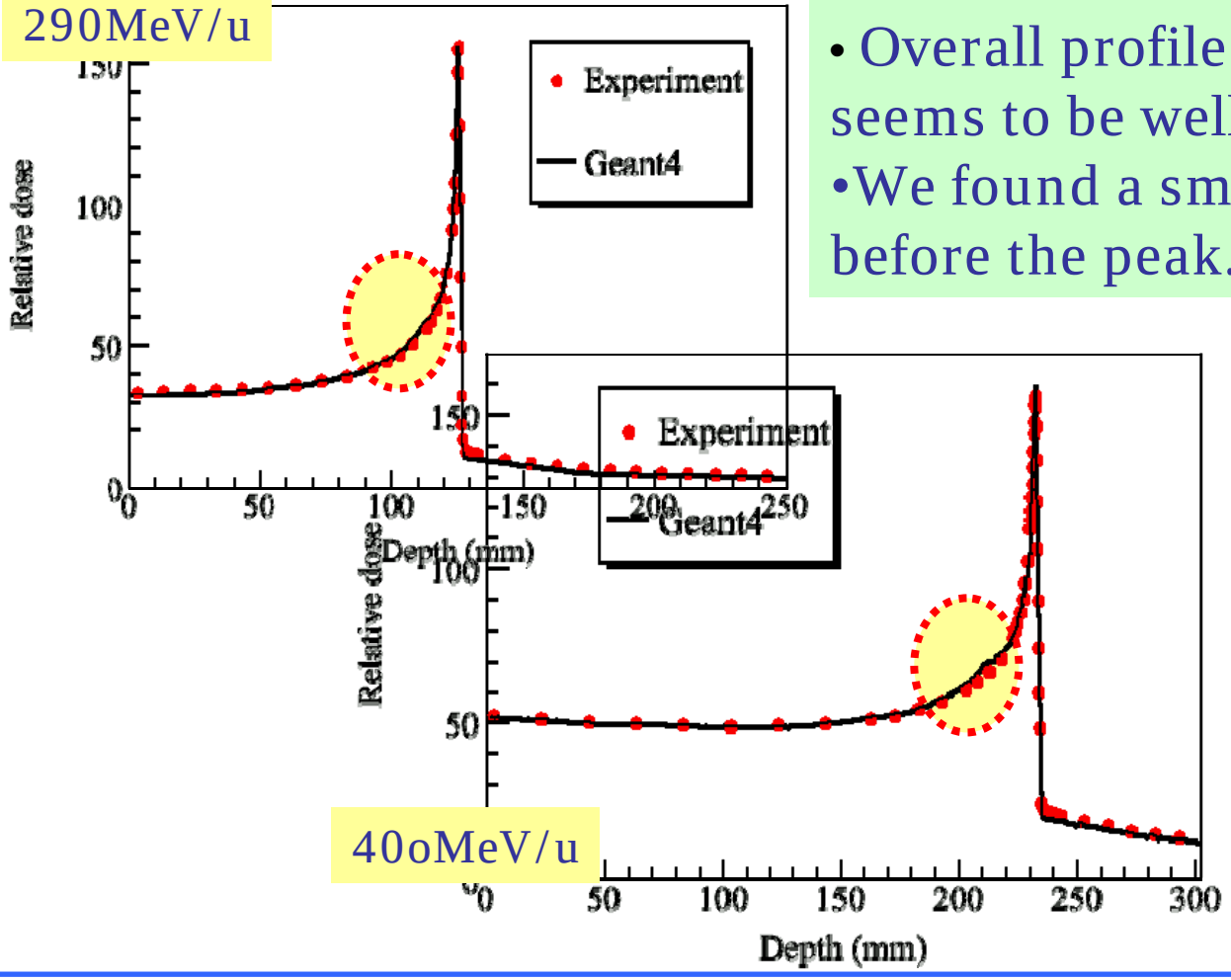


Physics List

- 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

Bragg Peak Simulation (Binary Cascade)

290MeV/u

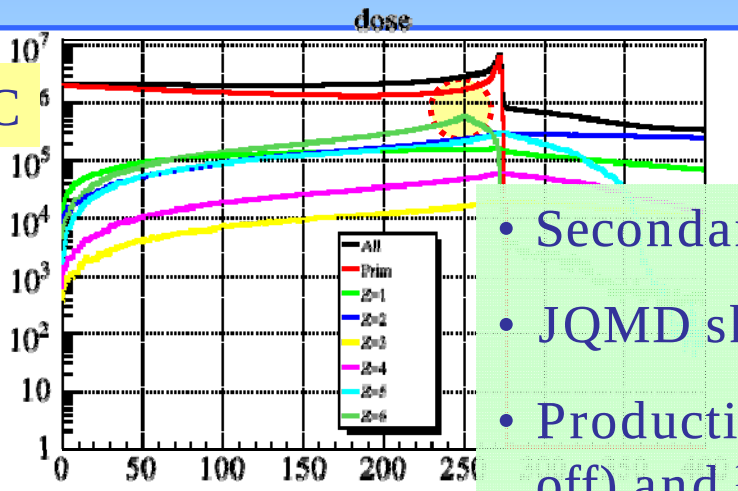


400MeV/u

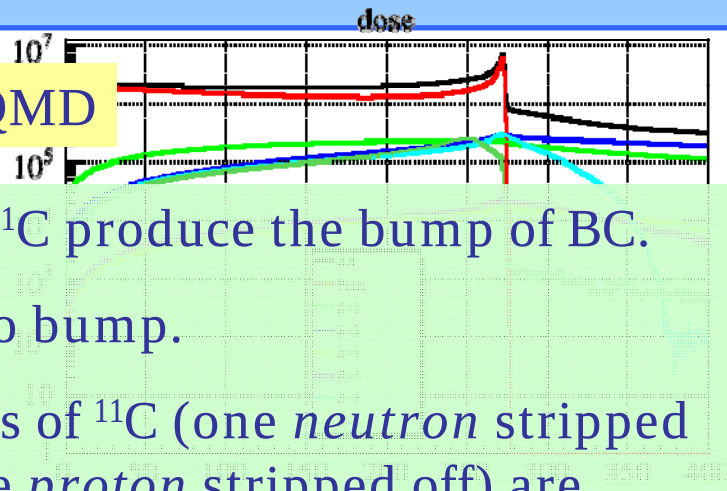
- Overall profile of Bragg peak seems to be well reproduced, but...
- We found a small bump just before the peak... What is this!?

Bragg Peak – more in detail

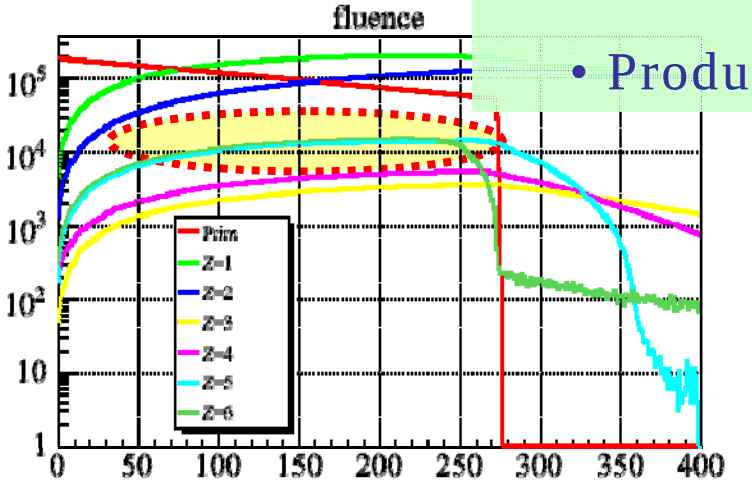
BC

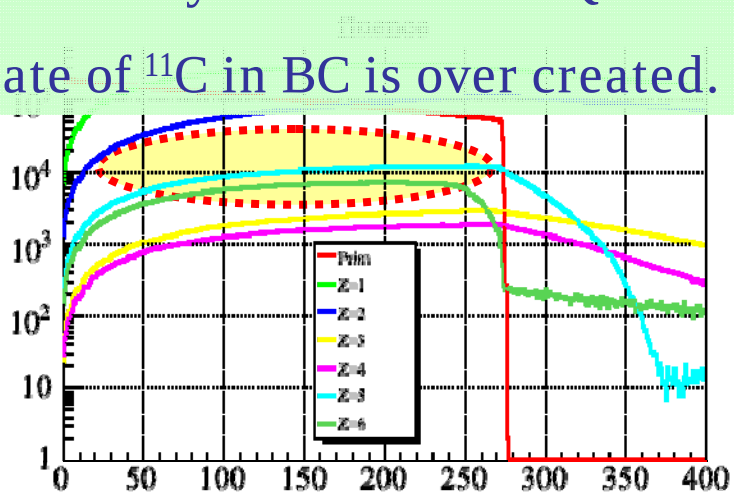


JQMD



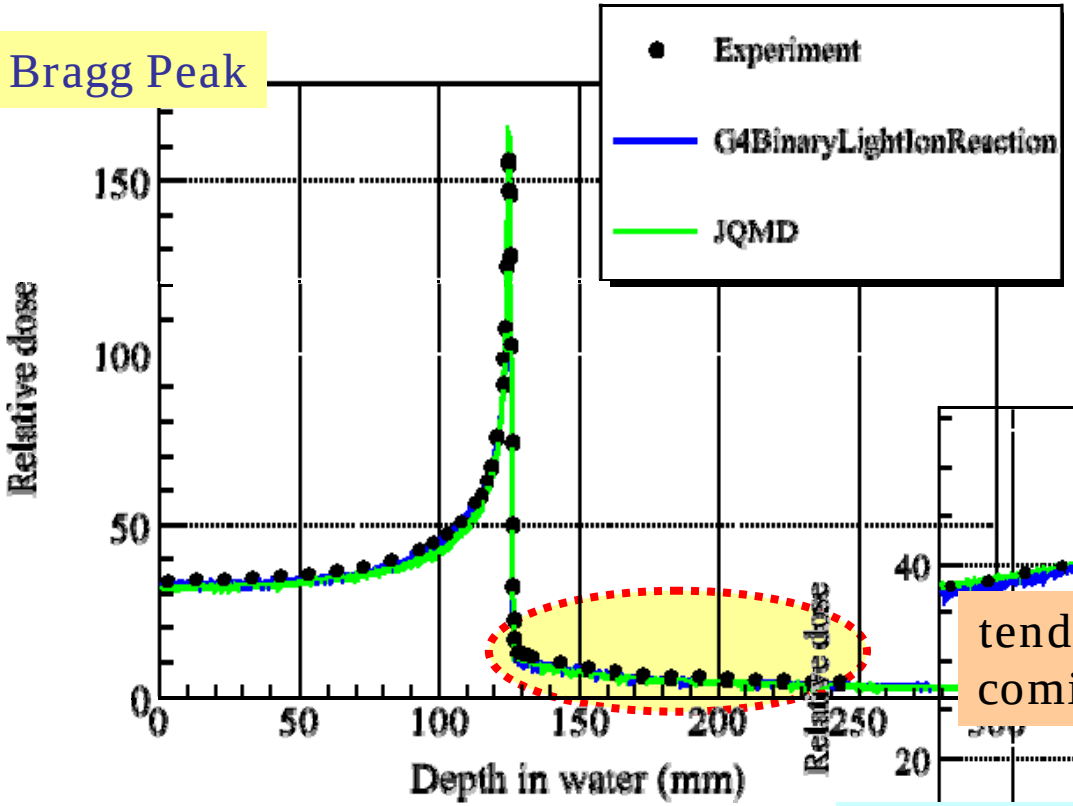
- Secondaries of ^{11}C produce the bump of BC.
- JQMD shows no bump.
- Production rates of ^{11}C (one *neutron* stripped off) and ^{11}B (one *proton* stripped off) are different between Binary Cascade and JQMD.
  - Production rate of ^{11}C in BC is over created.





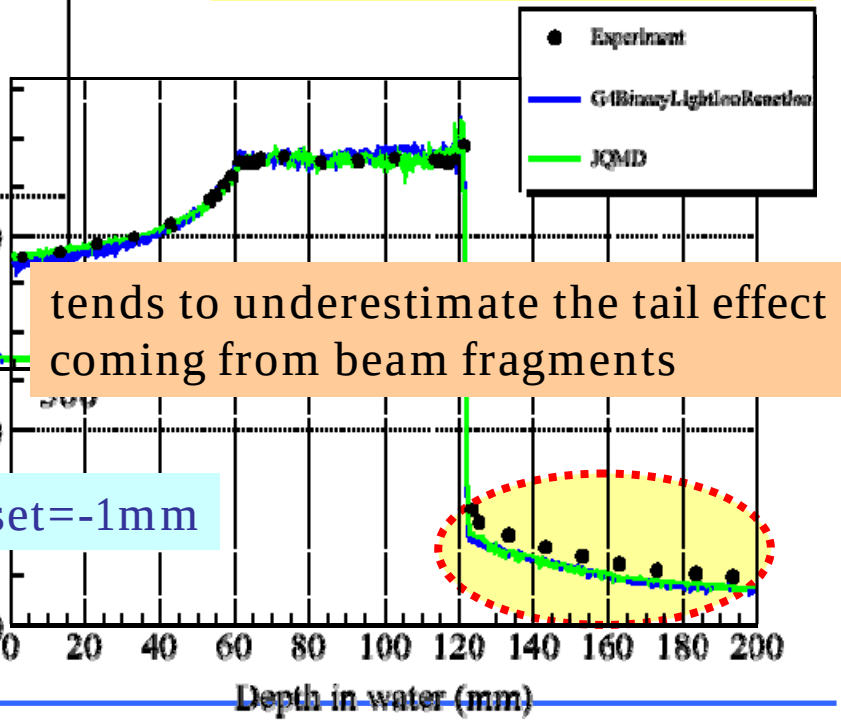
Comparison between Experiment and Simulation (290 MeV/u)

Bragg Peak



offset=-0.8mm

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

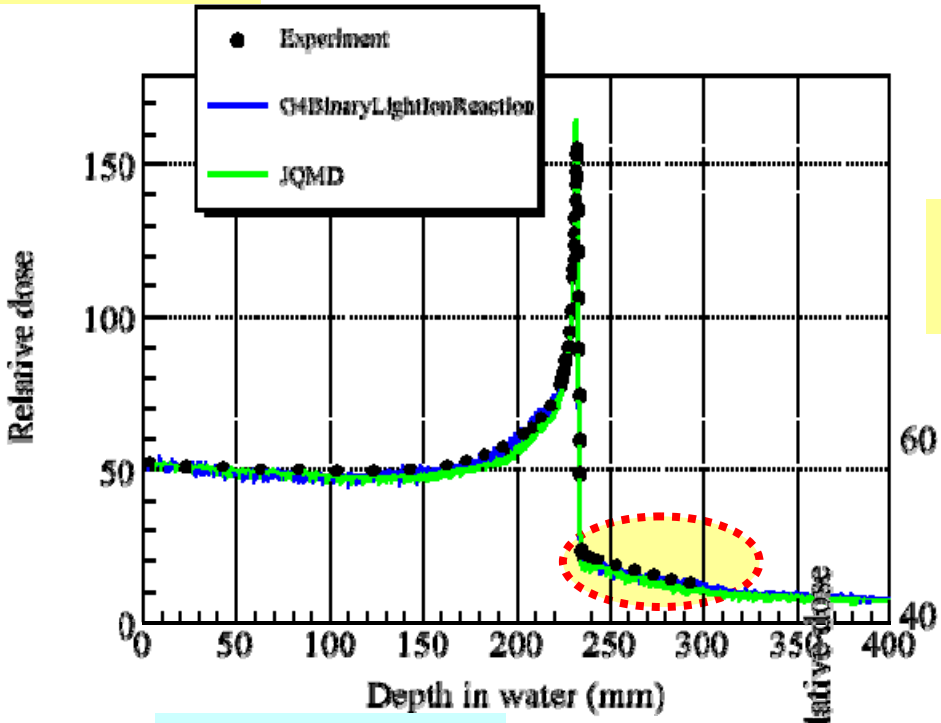


tends to underestimate the tail effect coming from beam fragments

offset=-1mm

Comparison between Experiment and Simulation (400 MeV/u)

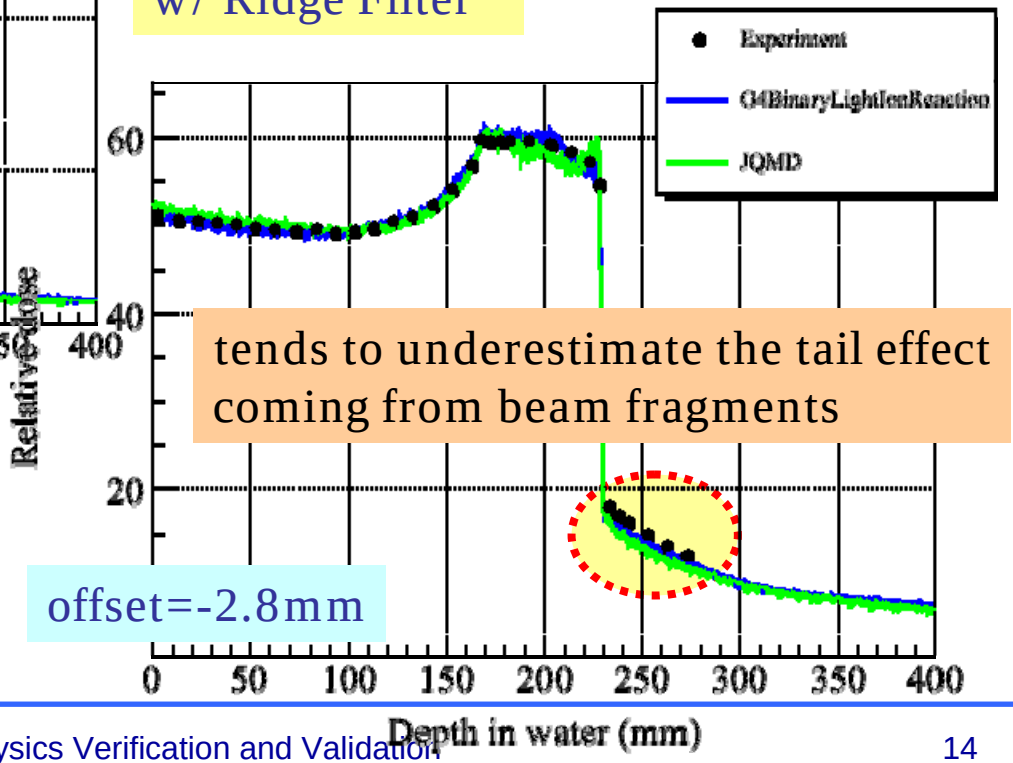
Bragg Peak



offset=-1.2mm

slight inconsistency in offset values?

SOBP
w/ Ridge Filter



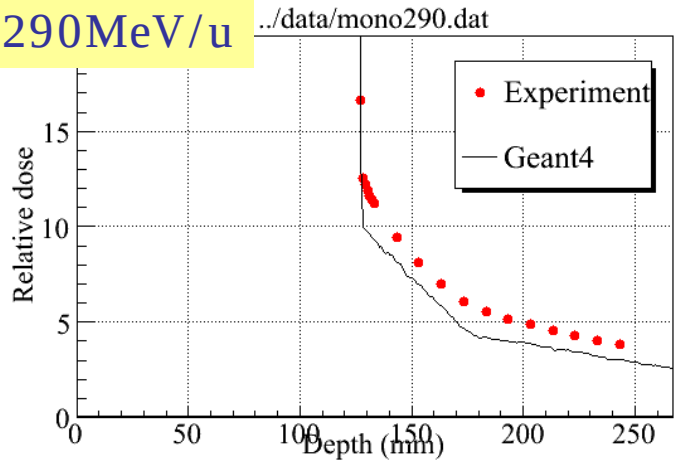
tends to underestimate the tail effect coming from beam fragments

offset=-2.8mm

Tail Effect – more in detail

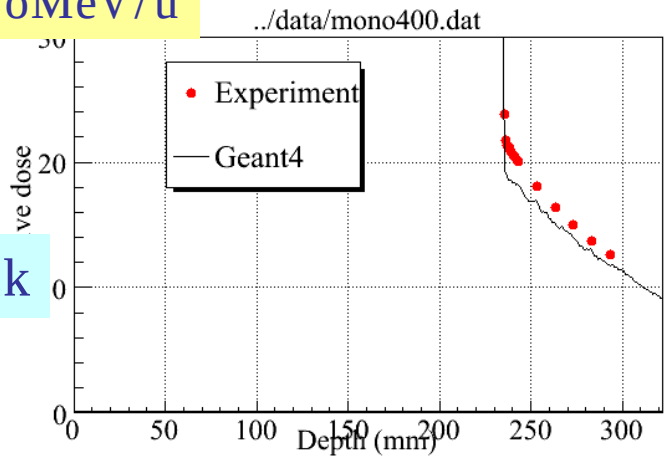
Binary Cascade

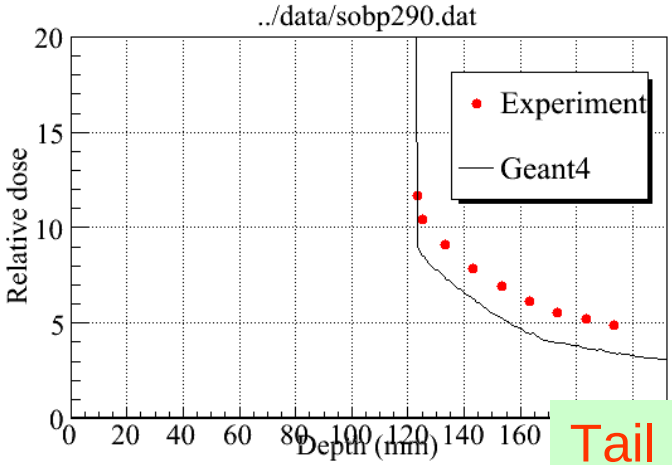
290MeV/u



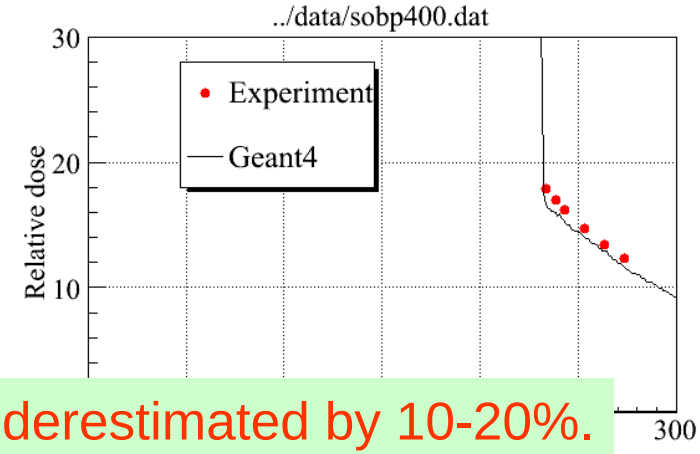
Bragg Peak

400MeV/u





SOBP



Tail effect is underestimated by 10-20%.

Summary

- A joint project among Geant4 developers and medical physicists in Japan is on-going.
  - ✓ Physics validation in medical application (particle therapy) is a critical issue.
- A new test beam line in HIMAC was constructed, and experimental data was obtained. It is a good chance to validate Geant4 ion physics.
  - ✓ Geometry of the test beam line was implemented in Geant4, and comparisons with simulation were carried out.
  - ✓ We tried the Binary Cascade model and the JQMD model for describing ion interactions.
  - ✓ Overall profile of the Bragg peaks are well reproduced by Geant4 simulation.
  - ✓ ... but, we found a problem with the Binary Cascade model in our problem domain. We hope that it will be improved.
  - ✓ The tail effect coming from ion fragments is not fully reproduced. Geant4 tends to underestimate the effect. There are some space to be improved.

Acknowledgements

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