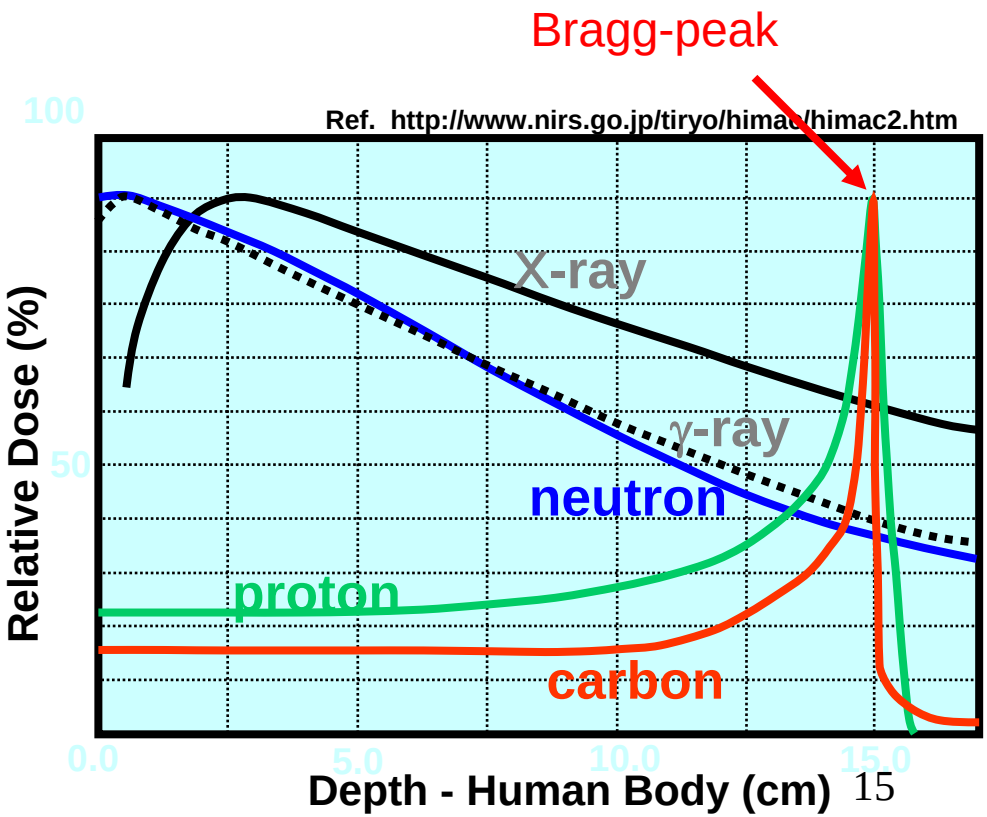
Fragmentation reaction of therapeutic carbon beam

Toshiyuki Toshito (KEK/JST-CREST)

Heavy ion therapy

a few 100MeV/n ^{12}C beam



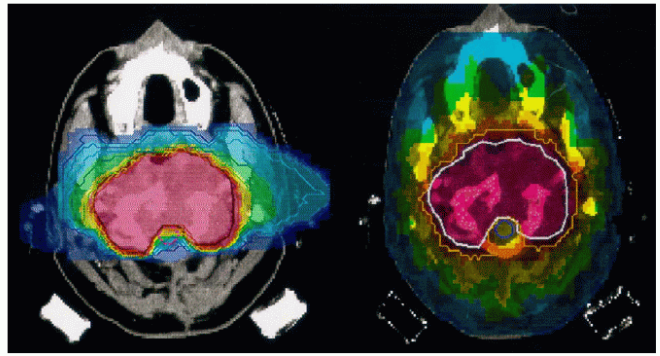
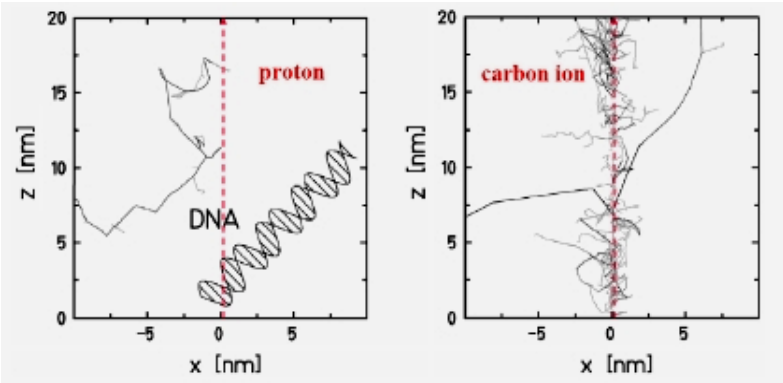


Figure 4. C … arbon ion (IMPT—left panel) and with
9 fields of x … the conformity to the target volume is
good but for … much smaller.

carbon vs. X-ray

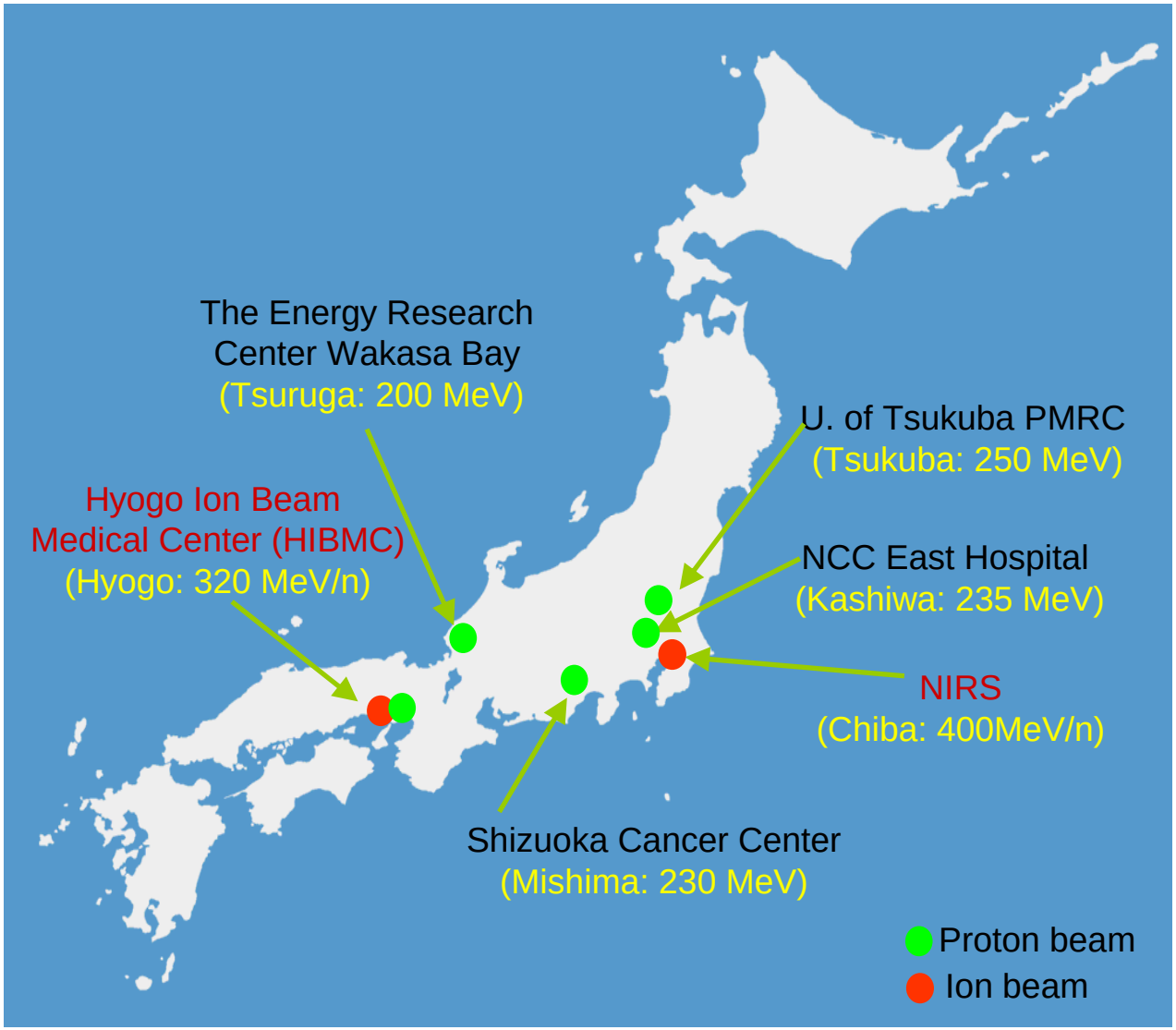


proton vs. Carbon

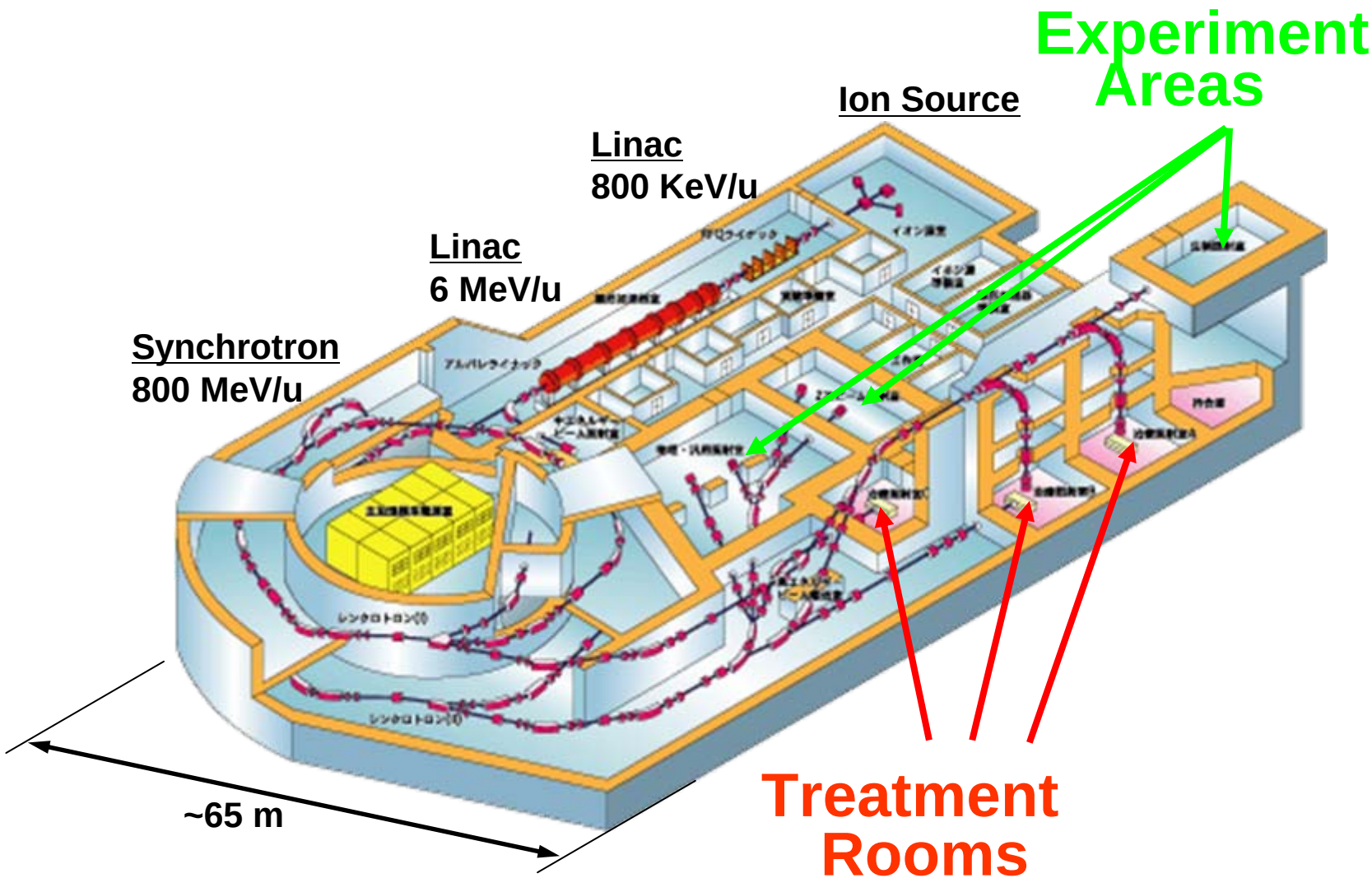
BEVALAC (Berklay-US) 1975 - 1992 Ne, Si ~400
NIRS (Chiba-Japan) 1994 - ^{12}C more than 3000
GSI (German) 1997- ^{12}C
HIBMC (Hyogo-Japan) 2002 - ^{12}C

Amaldi and Kraft
Rep.Prog.Phys.68 1861 (2005)

Particle therapy facilities in Japan

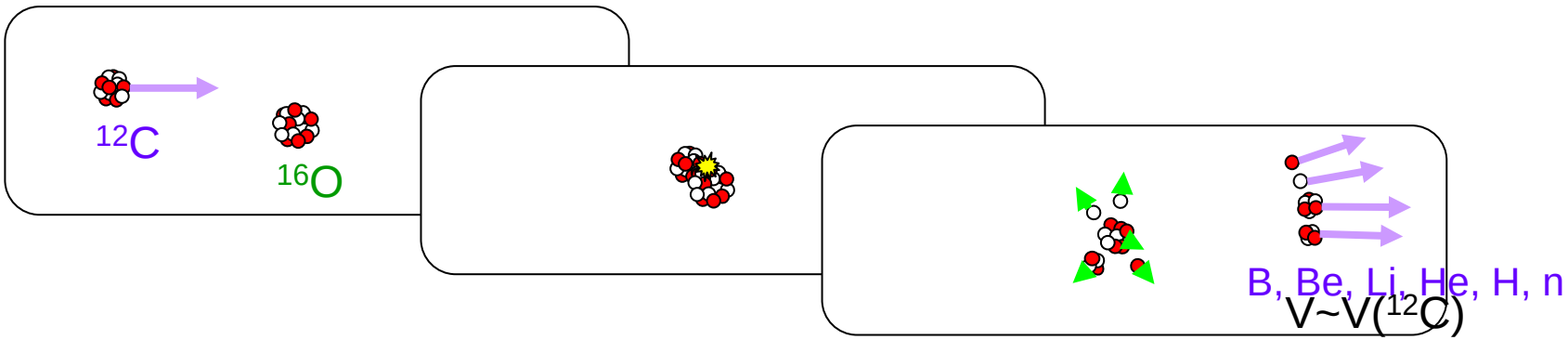


HIMAC at NIRS (National Institute of Radiological Sciences)



Fragmentation reactions

- In the case of 400MeV/n (~30cm in water), only 30% of beams can reach the region of bragg-peak; about 70% of beams are lost by fragmentation.
- Fragments having lower Z than carbon contribute to tail and lateral dose.
- Fragmentation reaction largely modulate dose distribution.
- Knowledge of fragmentation reaction is important to calculate dose distribution.



NIRS-HIMAC P152 experiment

collaboration

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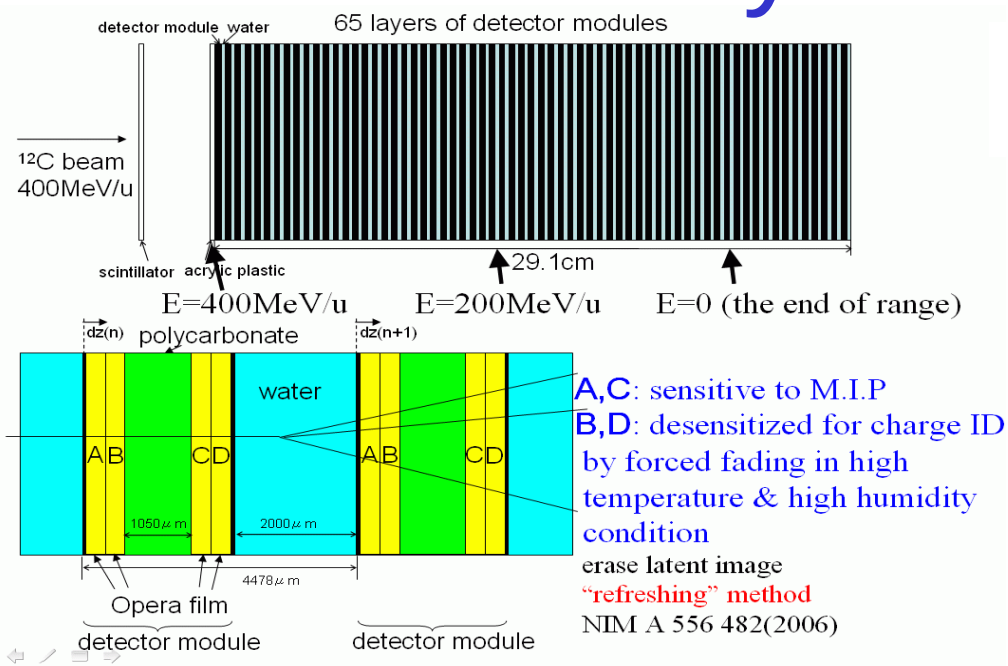
- Organized by institutes from HEP, medical and space domains
- Aimed to provide database of fragment reactions related to carbon ion therapy
- Emulsion is used as a tracking device.
- UTS is used for scanning to obtain large statistics.

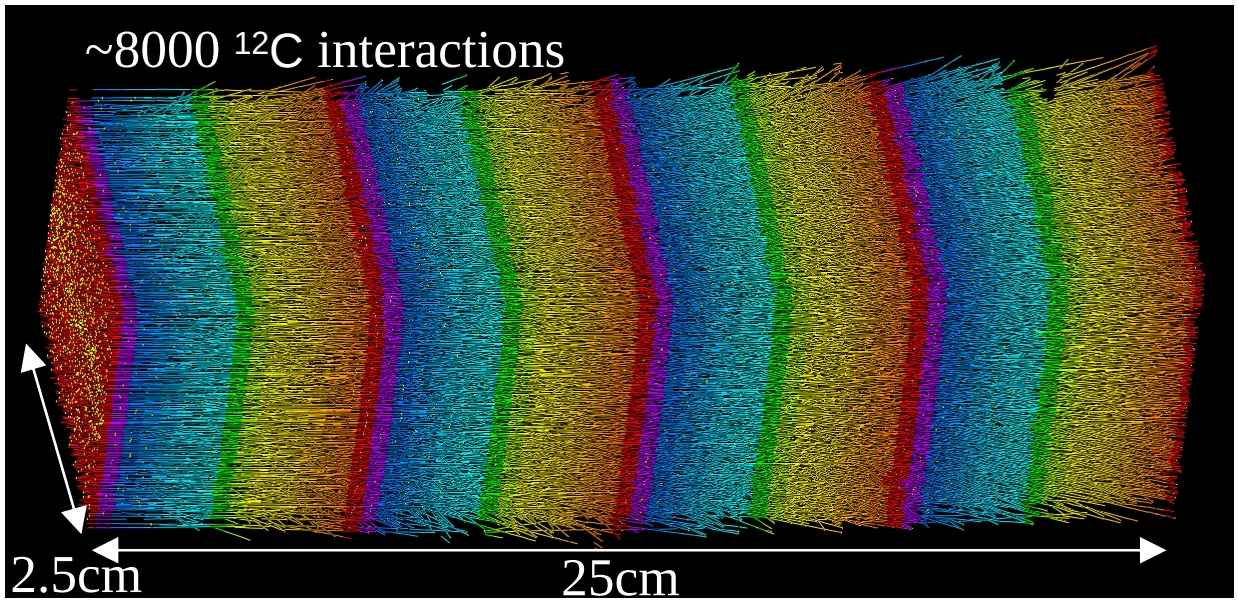
Physics Run

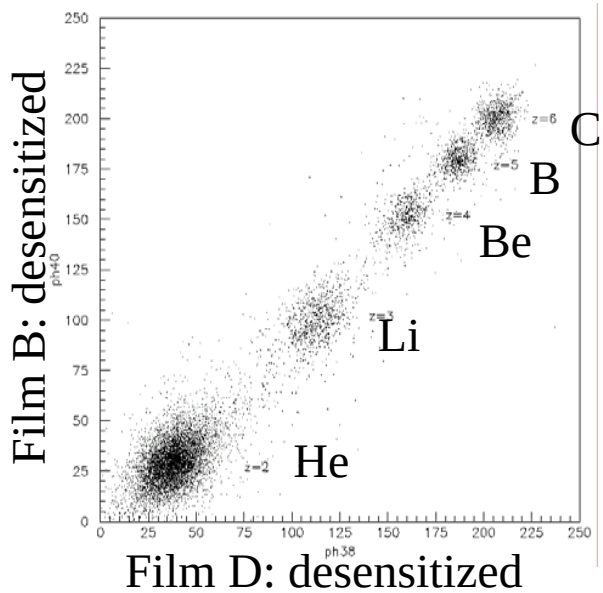


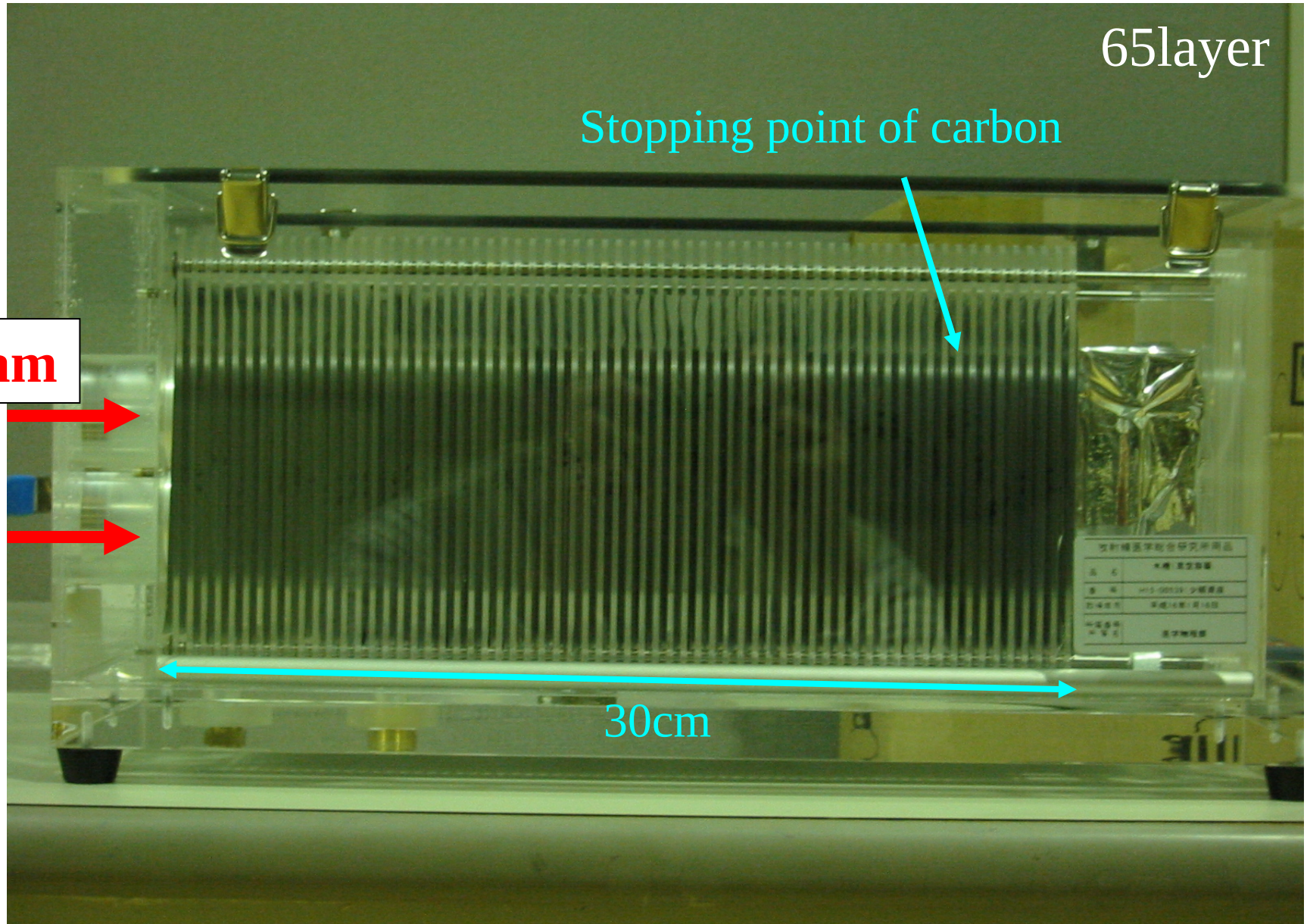
Water:
best tissue equivalent material

- Thanks to its large acceptance, superb position resolution and high efficiency, bias in the analysis are minimized.

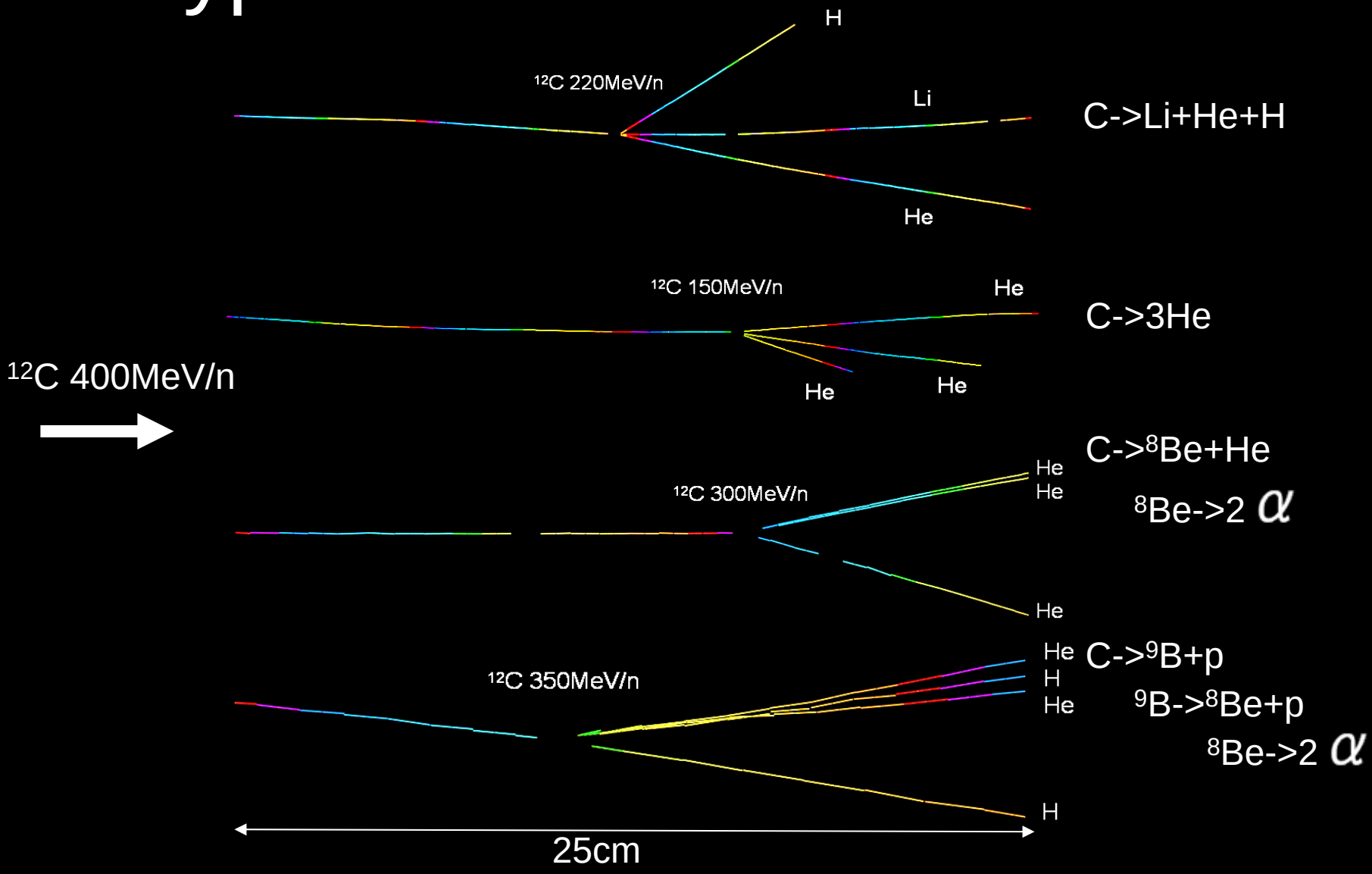
T. Toshito et al., NIM A 556 482 (2006)






65layer
Stopping point of carbon
beam
30cm

Typical reconstructed events

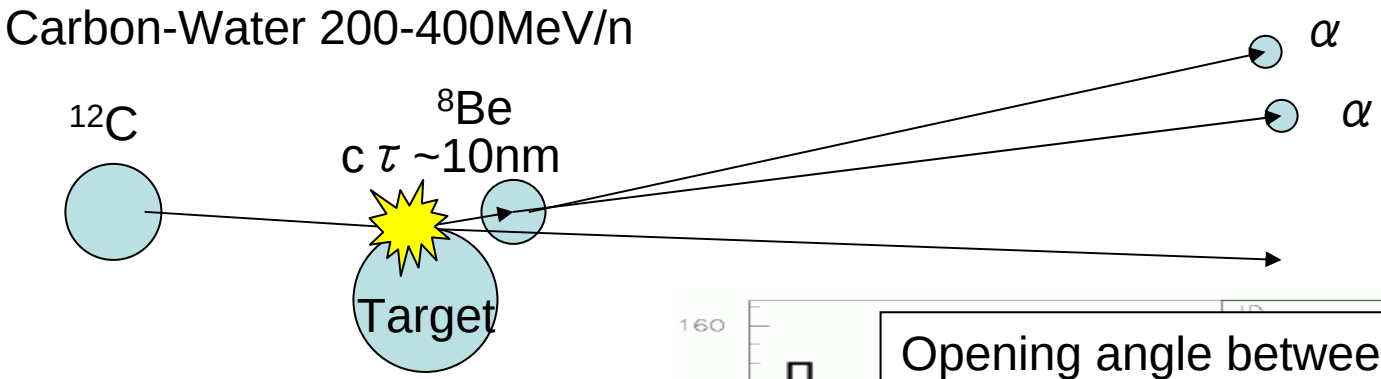


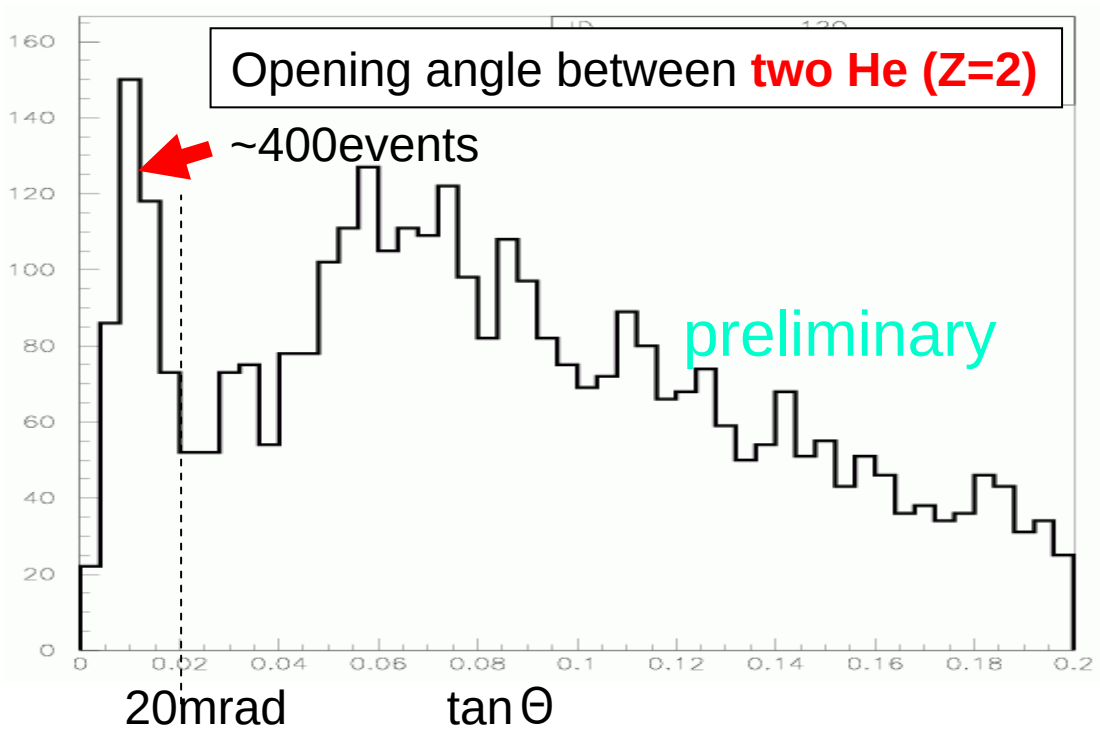
Angle of each individual track is measured with the accuracy of a few mrad.

Detection of $^{8}Be_{ground\ state}$

Small Q-value :~90keV

Opening angle between two α < 20mrad

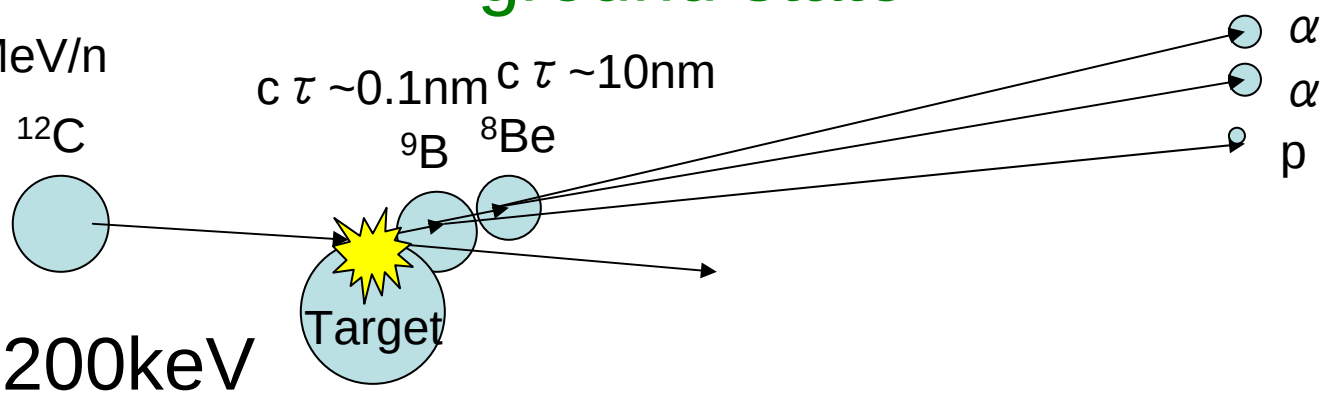




Detection of $^{9}B_{ground\ state}$

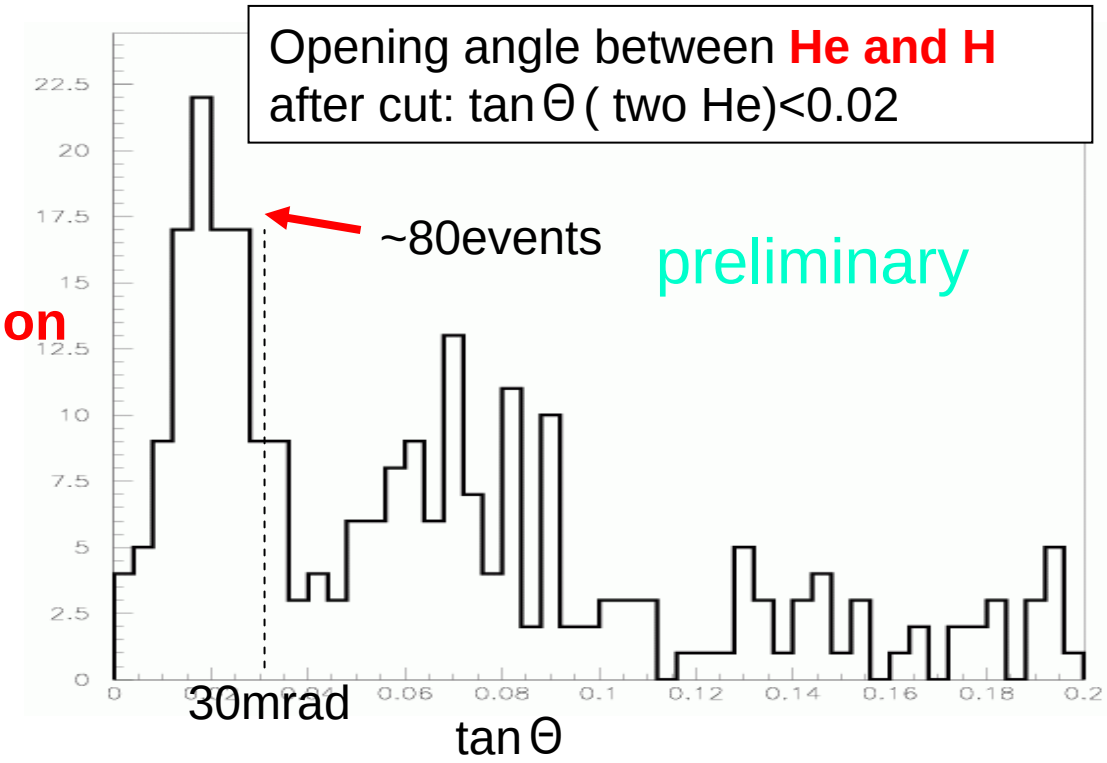
Carbon-Water 200-400MeV/n

$^{9}B \rightarrow {}^{8}Be + p$
$\hookrightarrow 2\alpha$



Small Q-value :~200keV

Opening angle between α and p < 30mrad

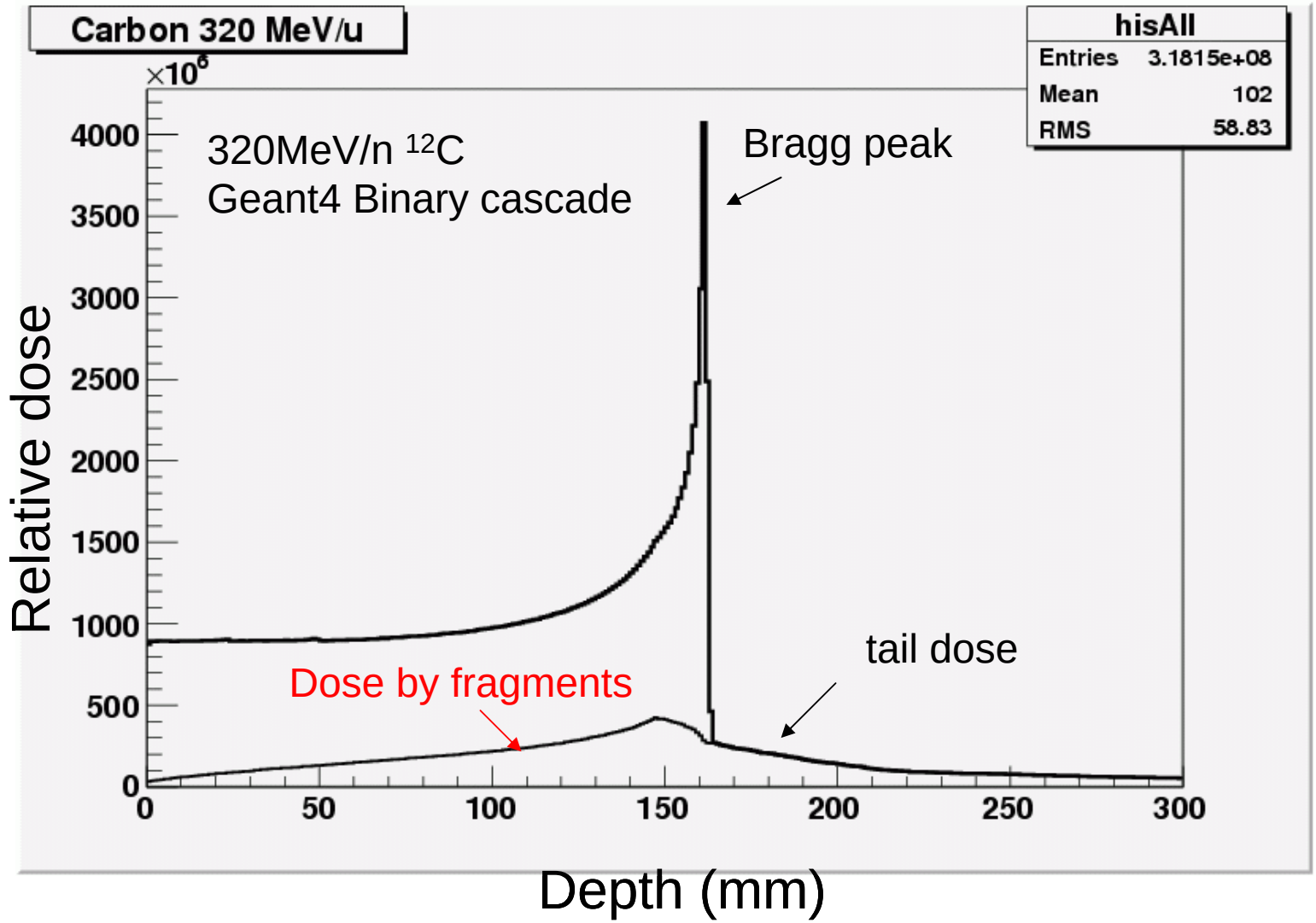


- **First observation in a few 100 MeV/n region**
- **Bumpy structure in tanΘ would be explained by contribution from excited states**

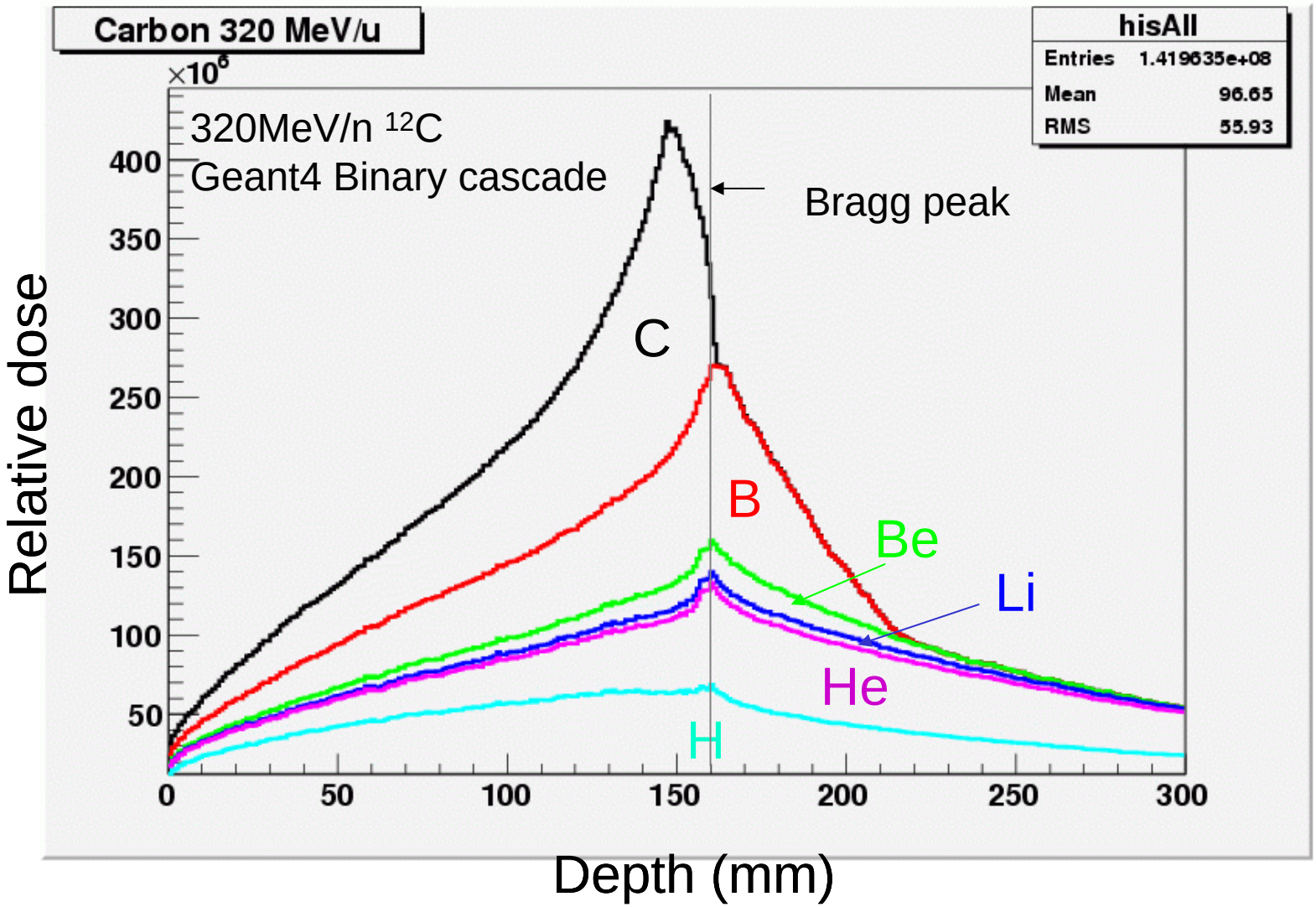
Medical application of Geant4

- Geant4 is a world-standard toolkit for HEP detector simulation
- Geant4 is a large degree of functionality and flexibility
  - Many application fields beyond HEP
  - Recently some codes to simulate Ion-Ion interaction become available
- Geant4 can be applied to simulate dose distribution in patients body in the field of ion therapy.
- This method is expected to provide more enriched and useful information than conventional algorithm.
- Validation is indispensable to establish this method.

Simulated dose in water



Simulated dose by fragments



Models for fragmentations in Geant4

- Binary cascade (G4BinaryLightIonReaction)
- Wilson's abrasion (G4WilsonAbrasionModel)
- JQMD (JQMD2G4InelasticModel)

  K. Niita et al., Phys. Rev. C 52 2620 (1995)

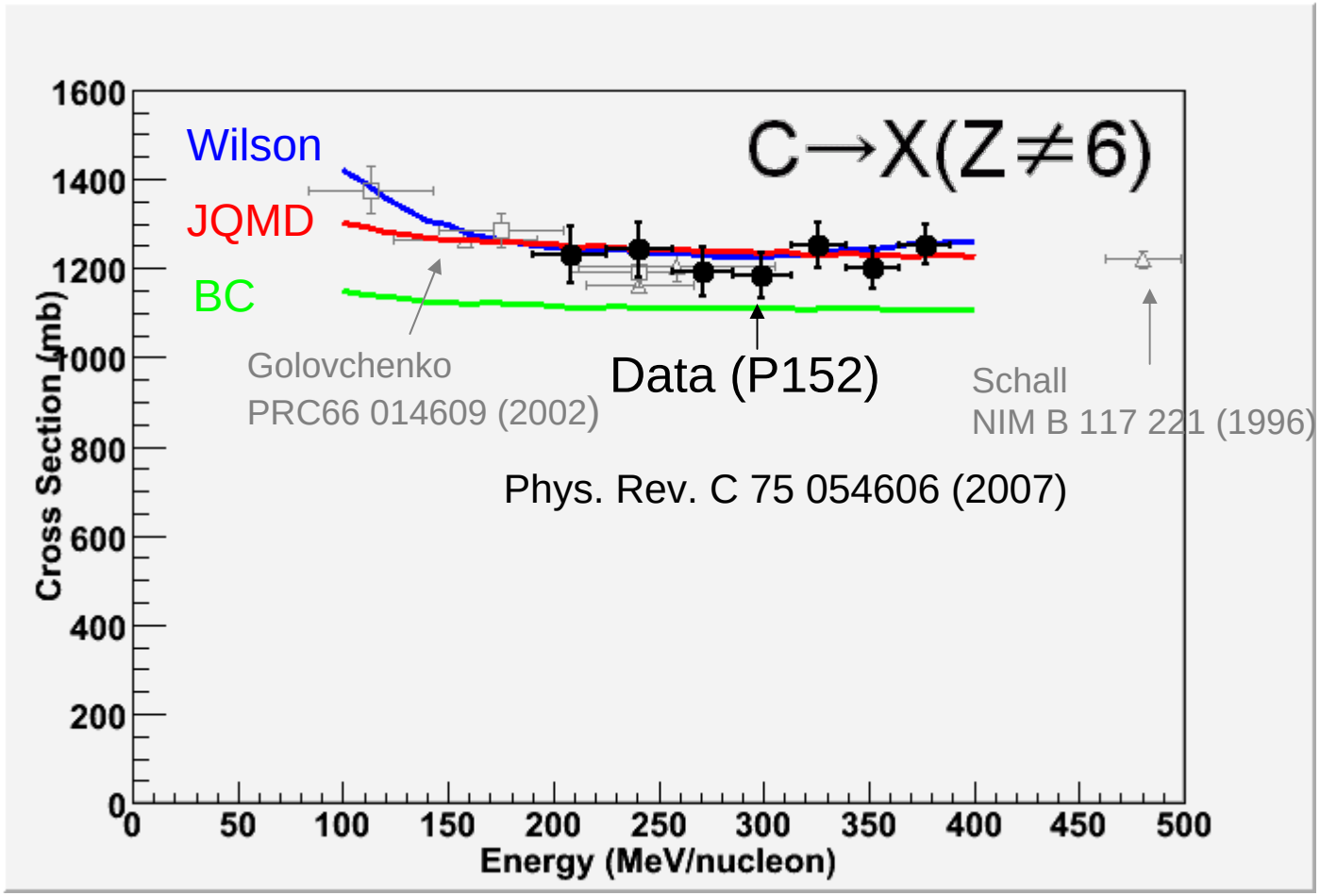
  T. Koi et al., CHEP03 ECONF C0303241 THMT005 (2003)

Cross section: Shen fomula(G4IonsShenCrossSection)

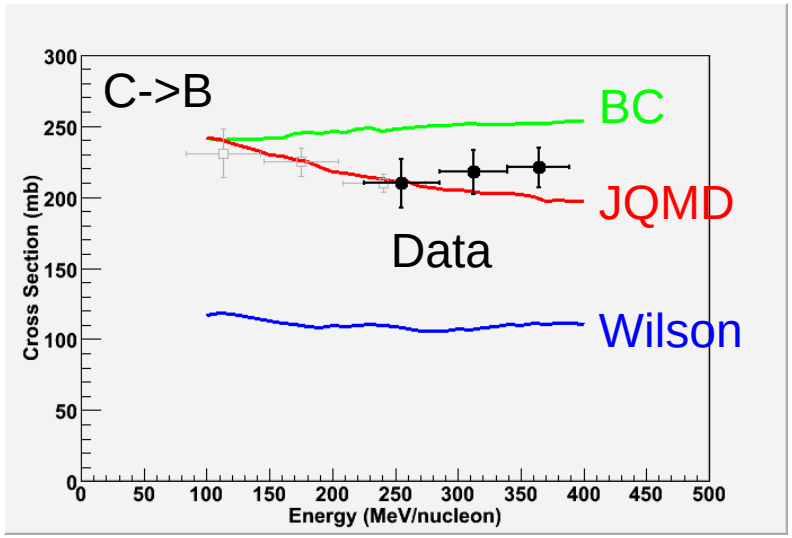
-Nuclear Physics. A 49 1130 (1989)

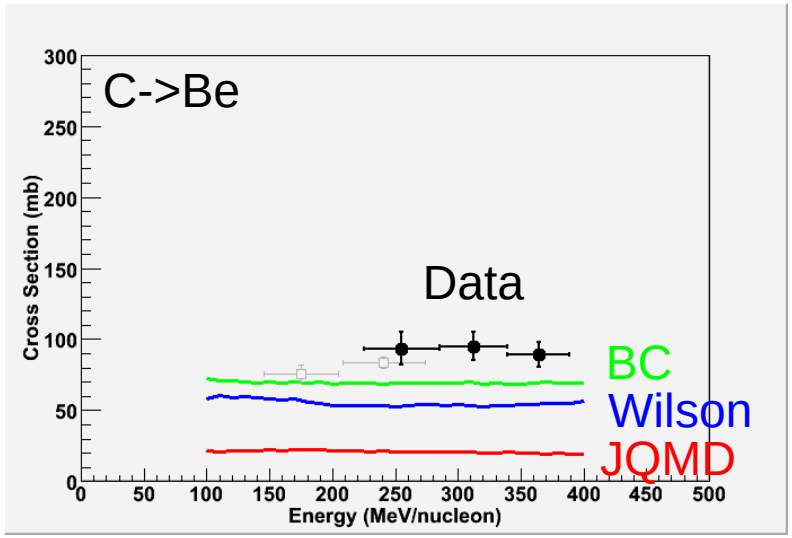
Version 4.9.0

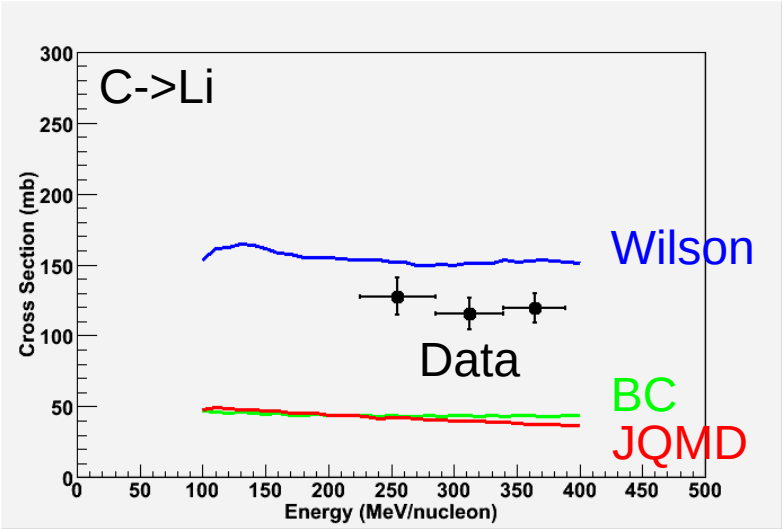
Carbon-Water
total charge-changing cross sections



Carbon-Water
partial charge-changing cross sections

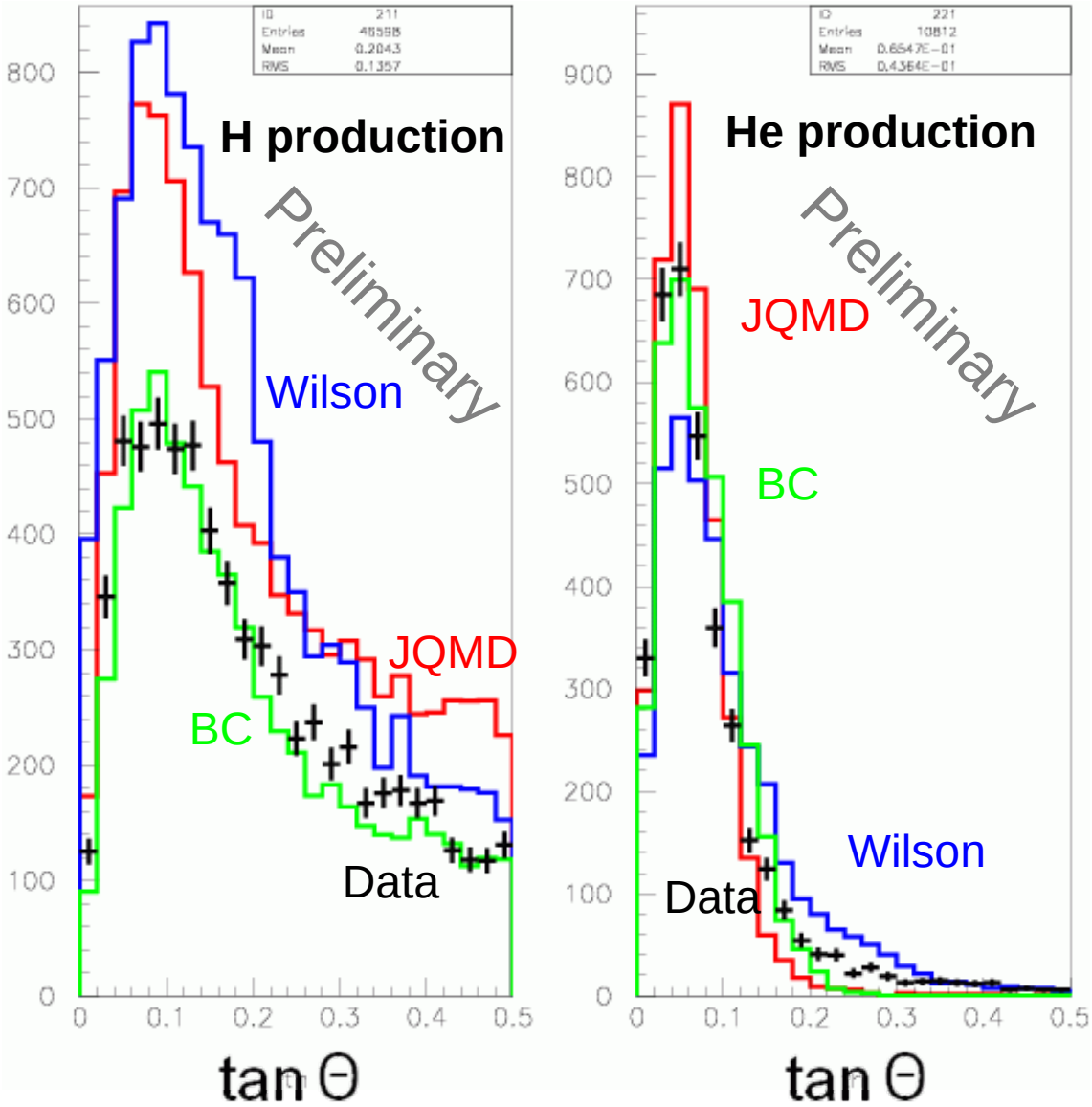






Important for tail dose

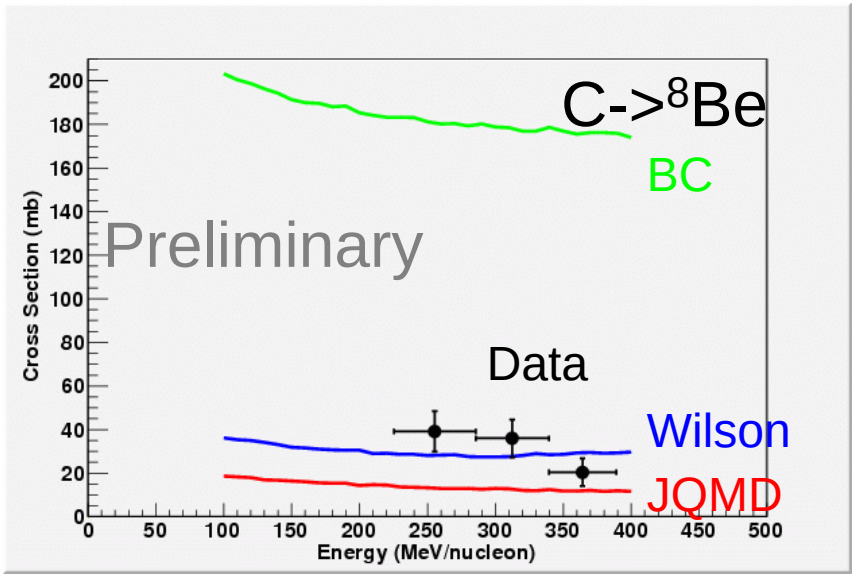
Angular distributions of H and He fragments in Carbon-Water int.

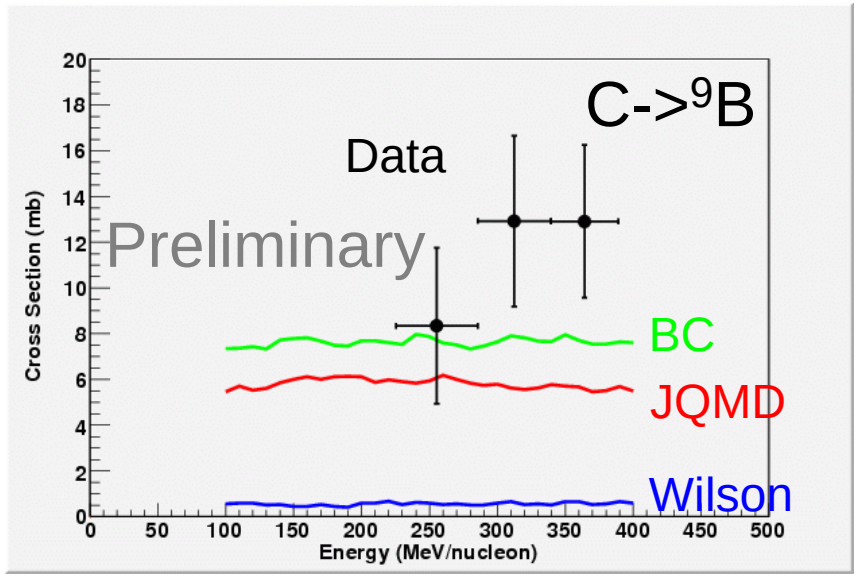


200-400MeV/n

Important for lateral dose

Carbon-Water
^{8}Be and ^{9}B production cross sections





Japanese-French collaboration on fragmentation study

More than 3000 patients have been treated with carbon ion therapy at NIRS in Japan since 1994.

France is joining the club of countries with hadron therapy machines "étoile" project to be realized in Lyon.

Fragmentation study is crucial to limit the damage of safe tissue

The energy range of such machines is of few 100 MeV/n

NIRS-HIMAC facility provides 100-400 MeV/n energy ions beam
GANIL facility provides few to 100 MeV/n energy ions beam

Tools to study the fragmentation are available in both countries. They are complementary.

Mannai Kais from Lyon is in Nagoya to work with us from 21th Jan to 10th Feb.

NIRS-HIMAC P231

- Since 2007, first beam on 10th Jan, next beam on 1st Feb.
- Successor to P152
- Dedicated to medical application
- To study fragmentation for many combinations of beams such as O, B, Be, Li and, He and targets such as C, Al, Ca, P and, Pb.
- To study fragmentation at low energy below 100MeV/n
- Gold development (see Kubota's poster) and hybrid setup with CR-39 are applied to improve charge identification.

Summary

- NITRS-HIMAC P152 experiment has provided physics results useful for dose calculation and also production cross sections of ^{8}Be and ^{9}B.
- Systematic validation and improvement of fragmentation models build in Geant4 is proceeding.
- New experiment of P231 to extend P152 is running.