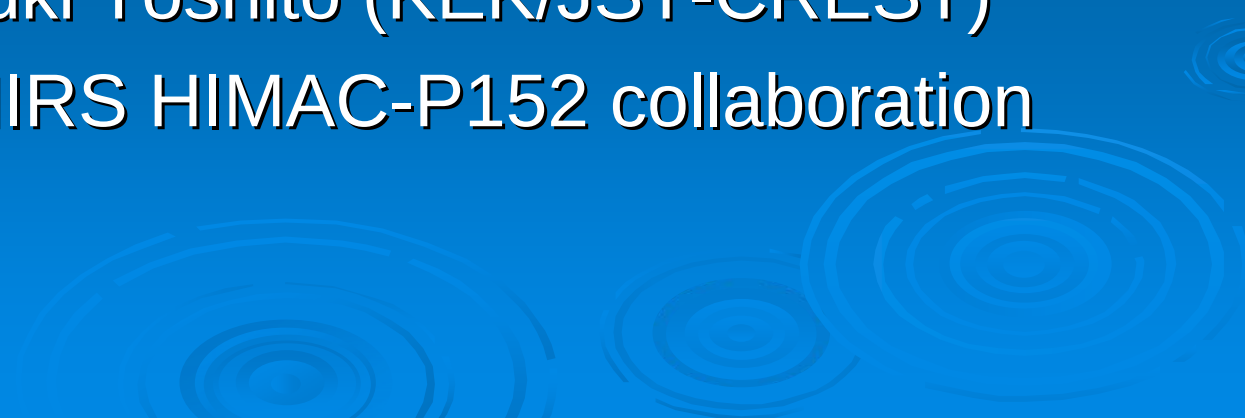


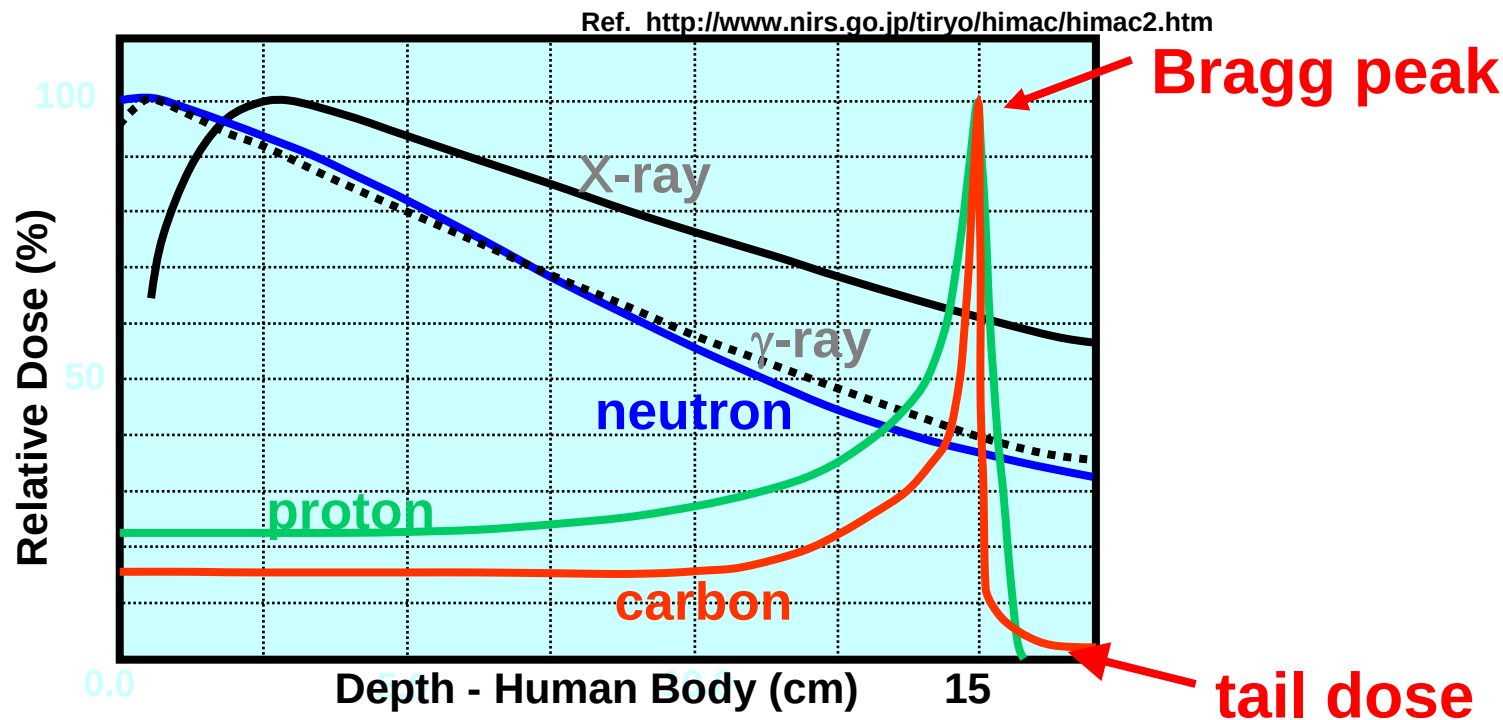
Study of fragmentation of therapeutic carbon beam with emulsion technology

Toshiyuki Toshito (KEK/JST-CREST)
for the NIRS HIMAC-P152 collaboration

A decorative graphic consisting of three concentric circles, resembling ripples in water, is located in the bottom right corner of the slide. The circles are light blue and have a subtle gradient.

Carbon ion therapy

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



- 70% primary carbons (400MeV/n) are lost by fragmentation before stopping region
- Fragmentation significantly modulates depth-dose profile and causes unwanted dose to the healthy tissue in lateral region and beyond the bragg peak (tail dose)

Calculation of dose distribution

- Deterministic method using semi-empirical models
for example Sihver's model
- Monte carlo codes to simulate fragmentation
for example Geant4, PHITS, Fluka
- However experimental data to validate models or MC codes
were scarce.
- So we launched the project to study fragmentation with emulsion
technology using HIMAC at NIRS since 2003.
to establish reaction database
(cross sections, angular distributions etc.)
- The results will be utilized
to validate models at a level of fundamental processes
to improve the accuracy of dose calculation

NIRS HIMAC-P152 experiment

Organization:

- 12 institutes from high energy physics, medical and space domains

Emulsion

- Nagoya Univ.
- Toho Univ.
- Aichi Univ. of Education
- Kobe Univ.

Geant4

- High Energy Accelerator Research Organization (KEK)
- Ritsumeikan Univ.
- Naruto Univ. of Education
- SLAC

Medical

- National Institute of Radiological Science (NIRS)
- Gunma Univ., Faculty of Medicine

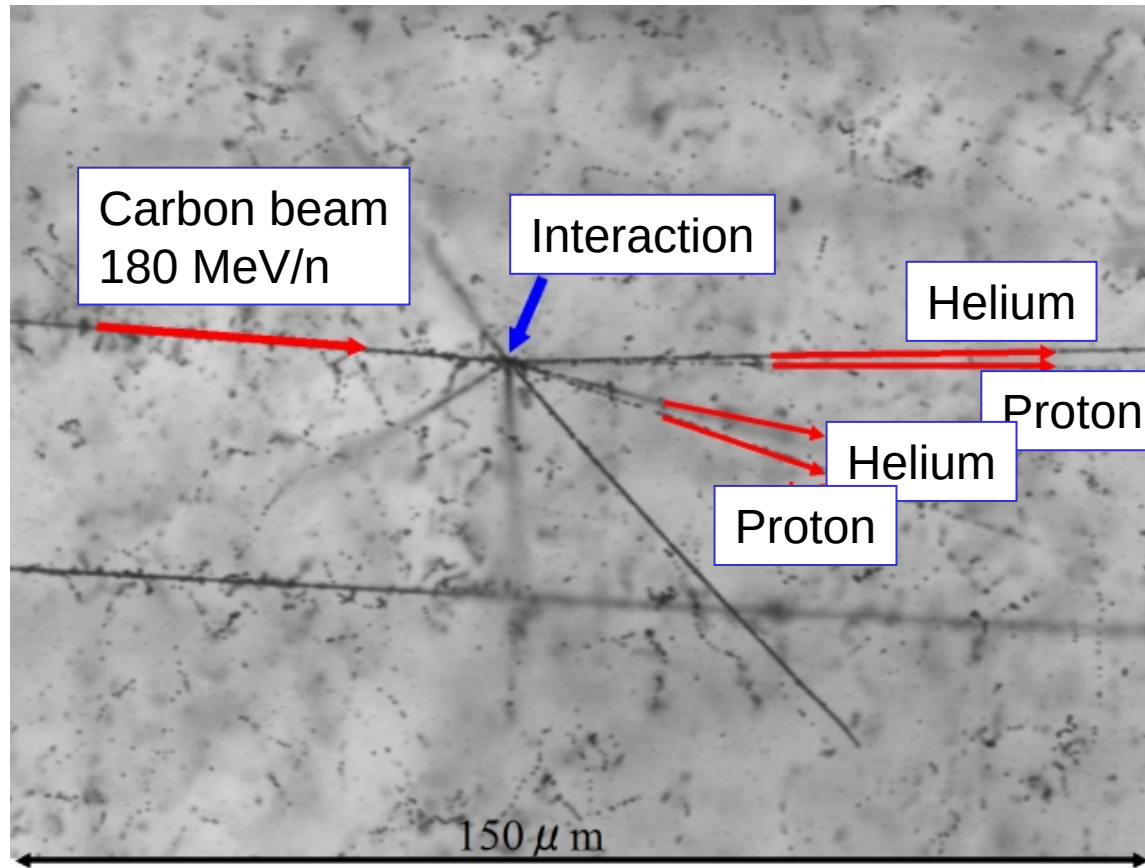
Space

- Japan Aerospace Exploration Agency (JAXA)
- Univ. of Tokyo

2003~ Detector R&D for particle identification

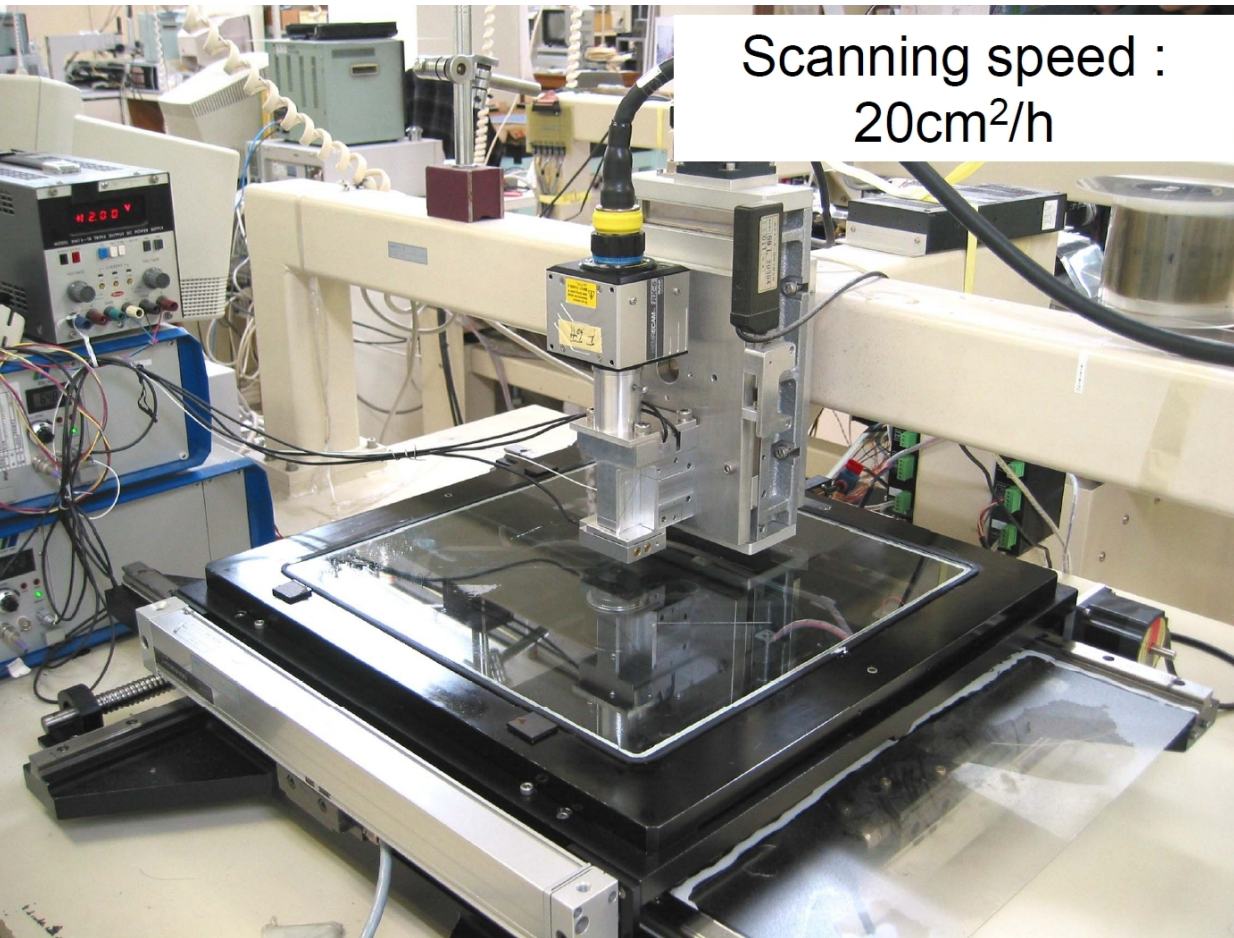
2004~ Physics data taking and analysis

Emulsion as a detector of fragmentation



- 4π tracking device with 3D resolution of $\sim 1\ \mu\text{m}$
- Track by track particle identification
- Event by event full reconstruction
capable of detailed analysis
such as correlation of multiple tracks

High speed emulsion read-out system



Scanning speed :
20cm²/h

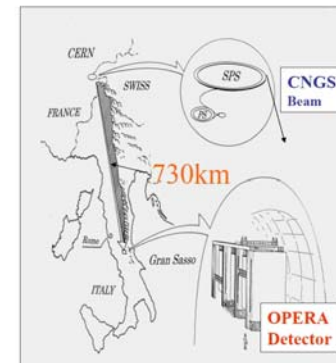
Developed at Nagoya university

DONUT: ν_τ discovery (2000)

OPERA: $\nu_\mu \rightarrow \nu_\tau$ oscillation (since 2006)



OPERA



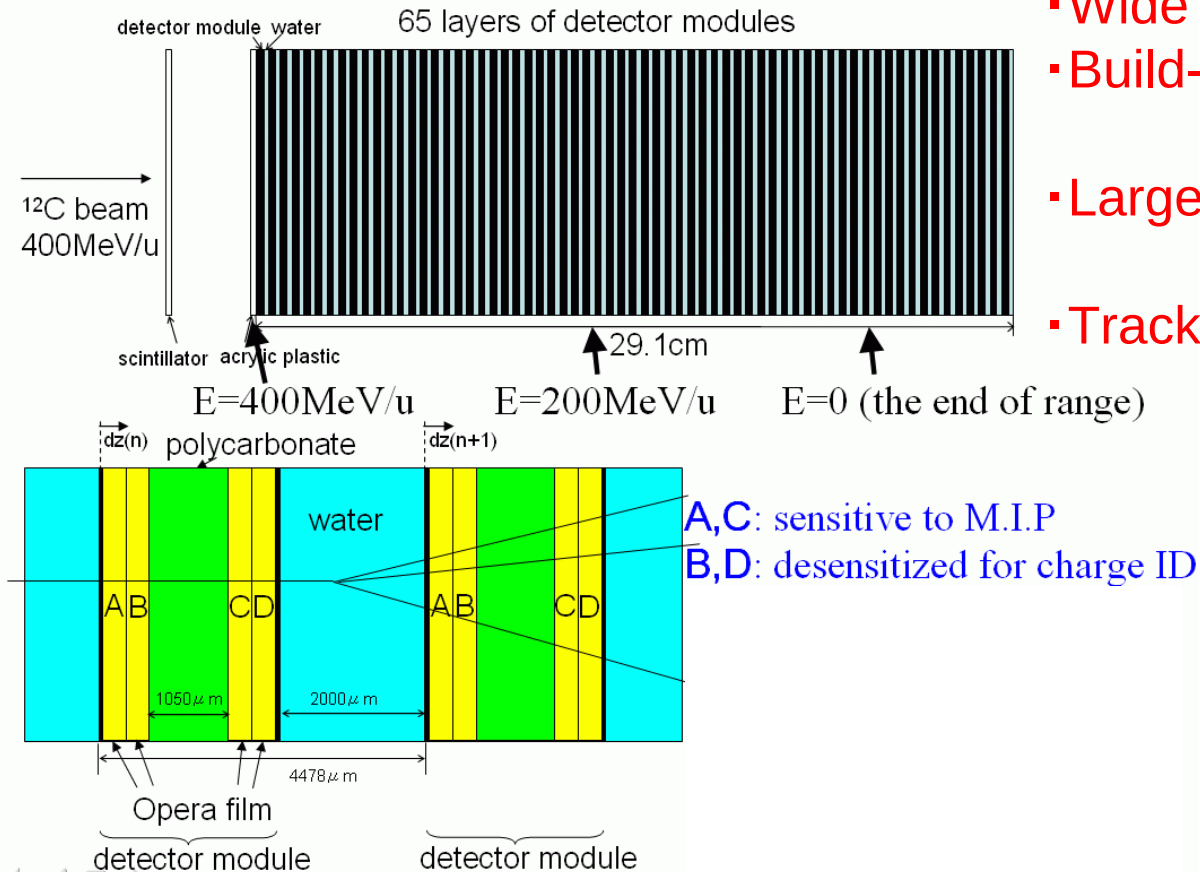
An Emulsion-Counter
Hybrid experiment for
**Tau neutrino
Appearance
Detection.**

Collaboration :
13countries 37 Institutes

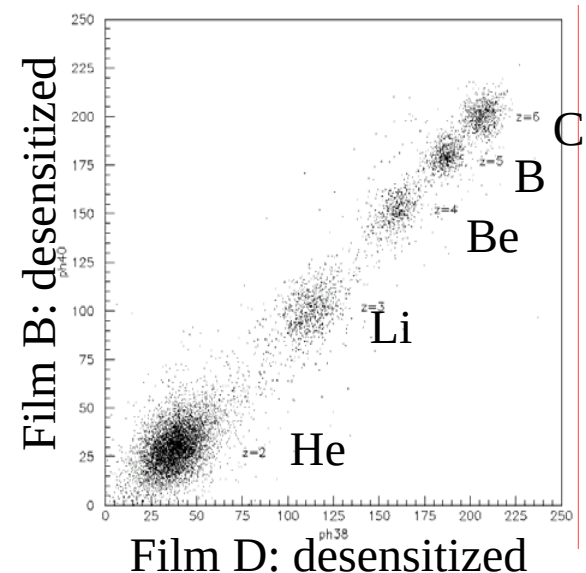
First Neutrino
to Gran Sasso
at 2006 August

Physics run with 400 MeV/n ^{12}C and water target

Water is the best material as a tissue equivalent material

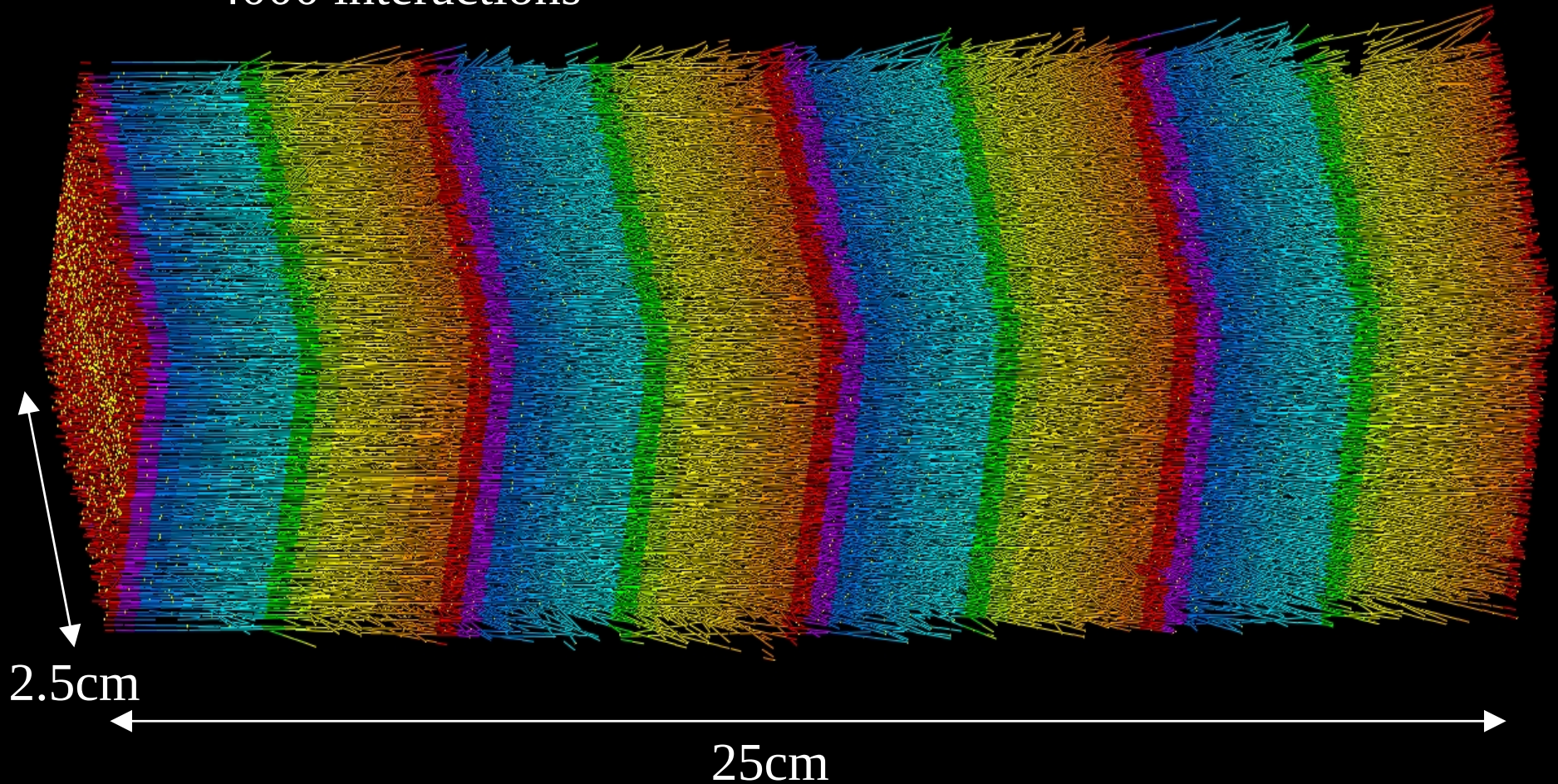


- Wide energy range
- Build-up of thin (2mm : $\sim 0.015 \lambda_{\text{int}}$) water target
- Large angular acceptance : $\tan \theta < 0.5$
- Track by track charge identification



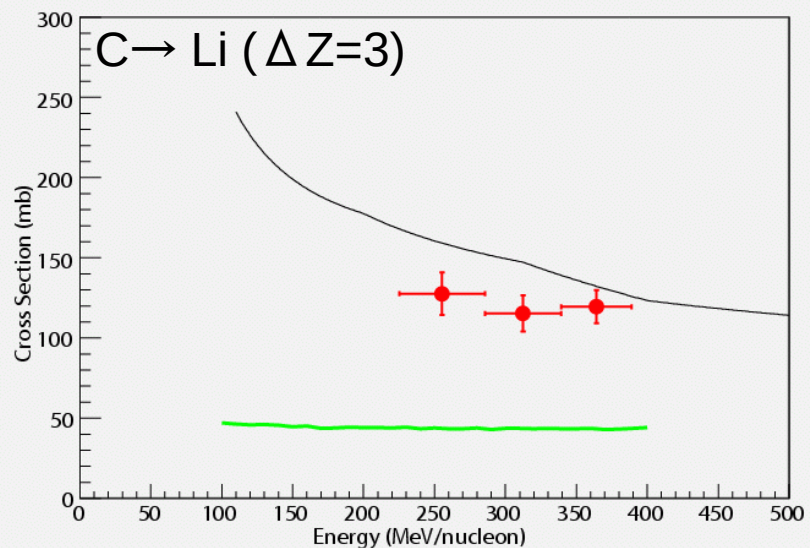
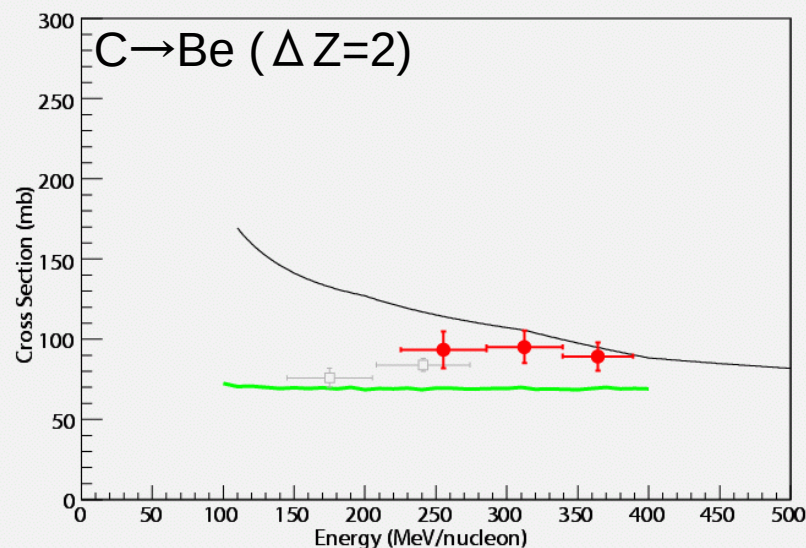
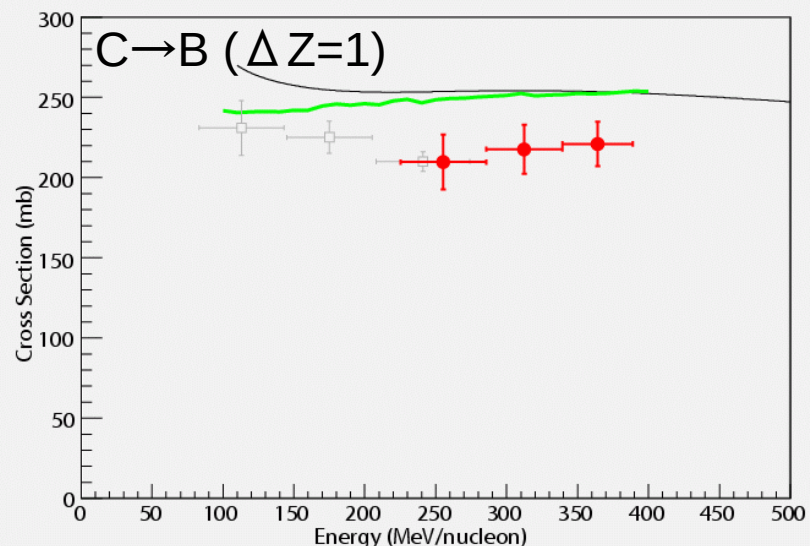
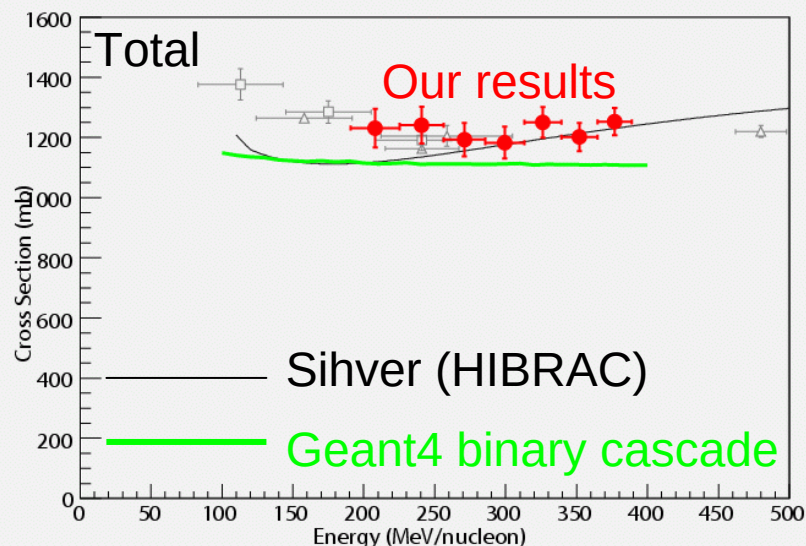
Track and vertex reconstruction after emulsion read-out: NETSCAN

^{12}C Beam ~ 10000 particles
 ~ 4000 interactions

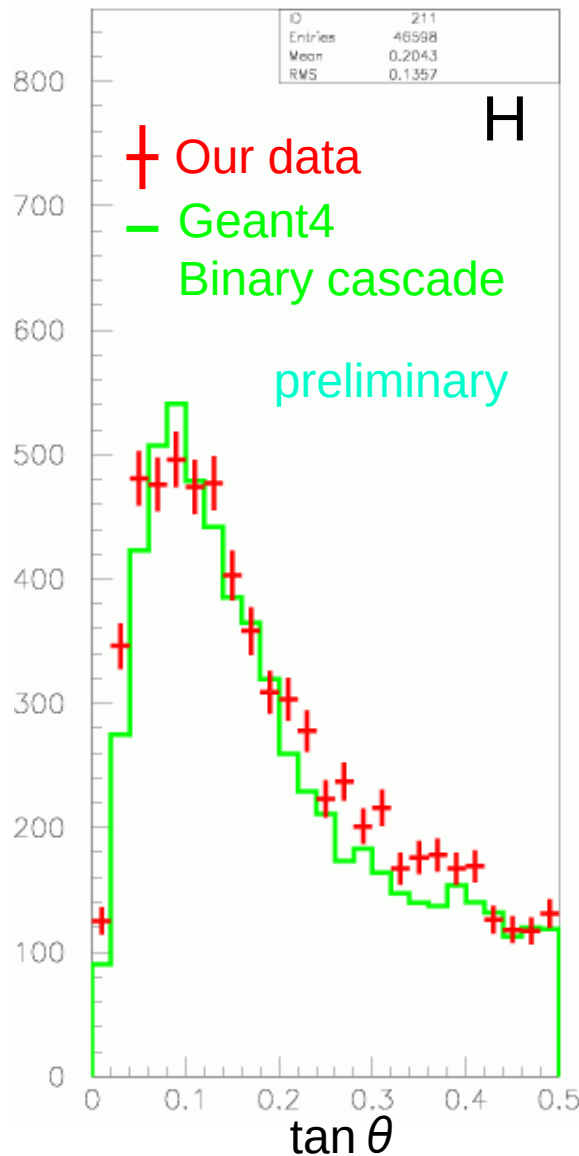


Carbon-Water

charge-changing cross sections 200-400 MeV/n



Angular distributions of H and He fragments in Carbon-Water interactions

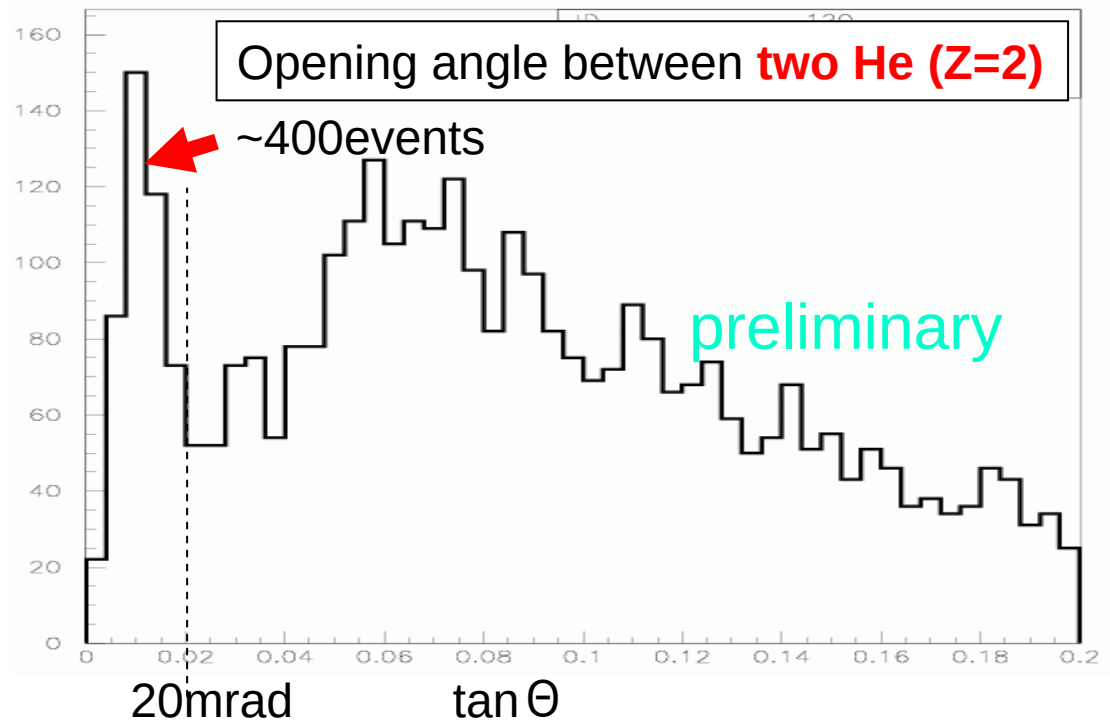
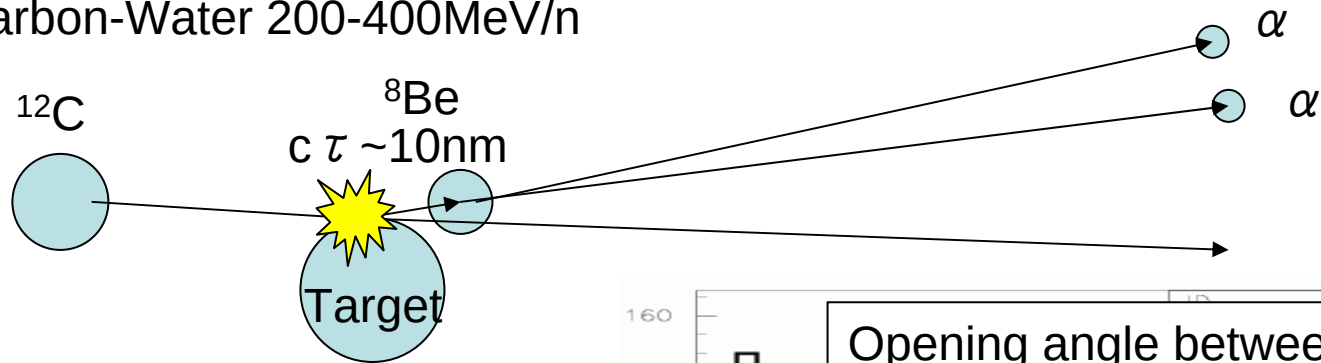


Detection of ^8Be ground state

Small Q-value : $\sim 90\text{keV}$

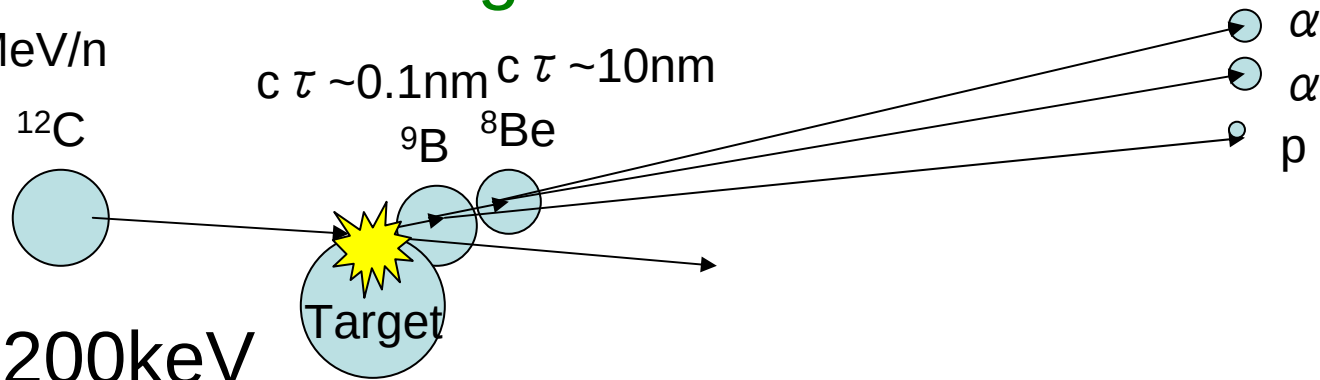
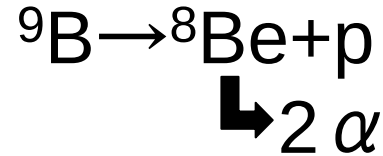
Opening angle between two $\alpha < 20\text{mrad}$

Carbon-Water 200-400MeV/n



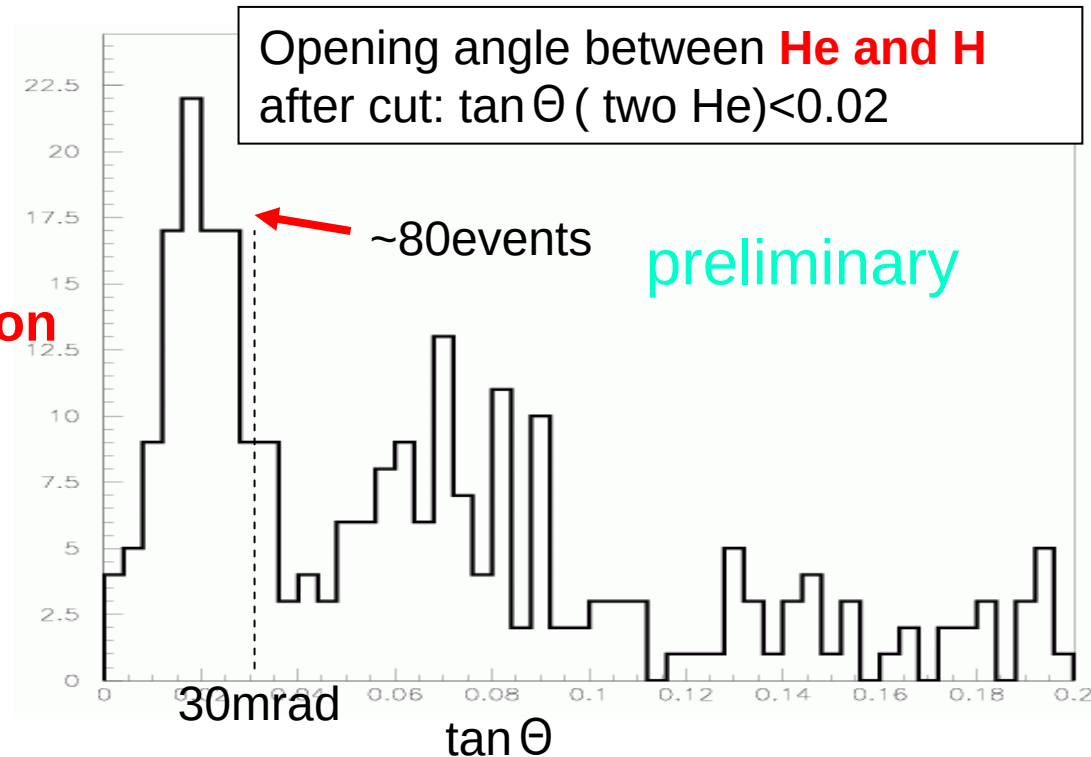
Detection of ${}^9\text{B}$ ground state

Carbon-Water 200-400 MeV/n



Small Q-value : $\sim 200\text{keV}$

Opening angle between α and $p < 30\text{mrad}$



- First observation in a few 100 MeV/n region
- Bumpy structure in $\tan \Theta$ would be explained by contribution from excited states

${}^9\text{B}_{\text{g.s.}}$ candidate

Side-view

${}^{12}\text{C}$ 350MeV/n

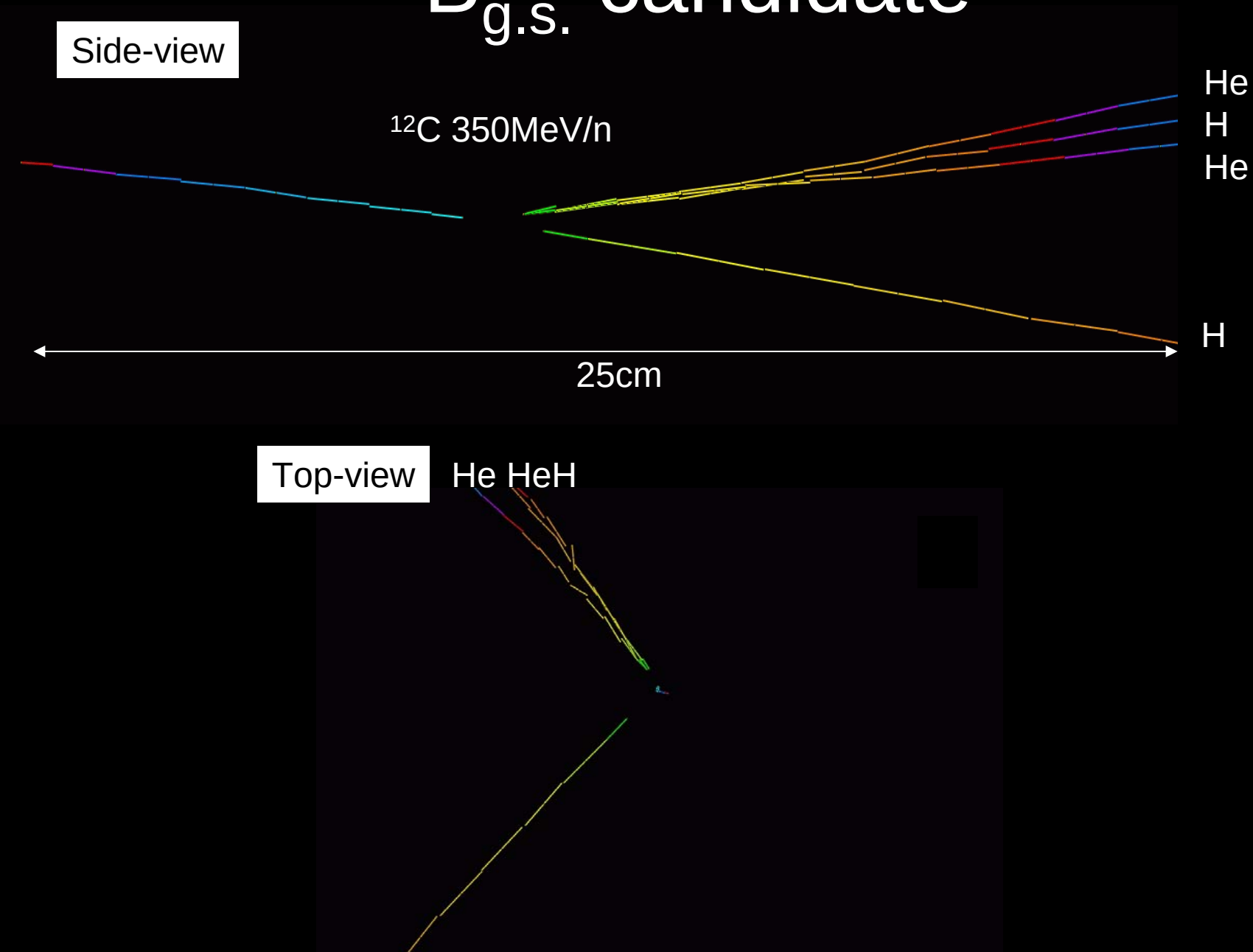
25cm

He
H
He

H

Top-view

He HeH



Summary

- We have measured fragmentation reaction of therapeutic carbon ion with water using emulsion.
charge-changing cross sections 200-400 MeV/n
total, B, Be, Li productions Phys. Rev. C 75 054606 (2007)
angular distributions of H and He
useful to improve dose calculation
 ${}^8\text{Be}_{\text{g.s.}}$ and ${}^9\text{B}_{\text{g.s.}}$ observation
- We made some comparisons between our data and model calculations.

We will extend the measurements to lower energy region and for more beams and targets combinations to establish reaction database for carbon ion therapy in the near future.