RI beam projects in NIRS

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Projects

- Secondary beam project
  - Projectile fragmentation
  - Spot scanning irradiation
  - Positron camera for range verification
- ISOL research
  - RI generation
  - RI beam acceleration
- Detector development
  - Open PET

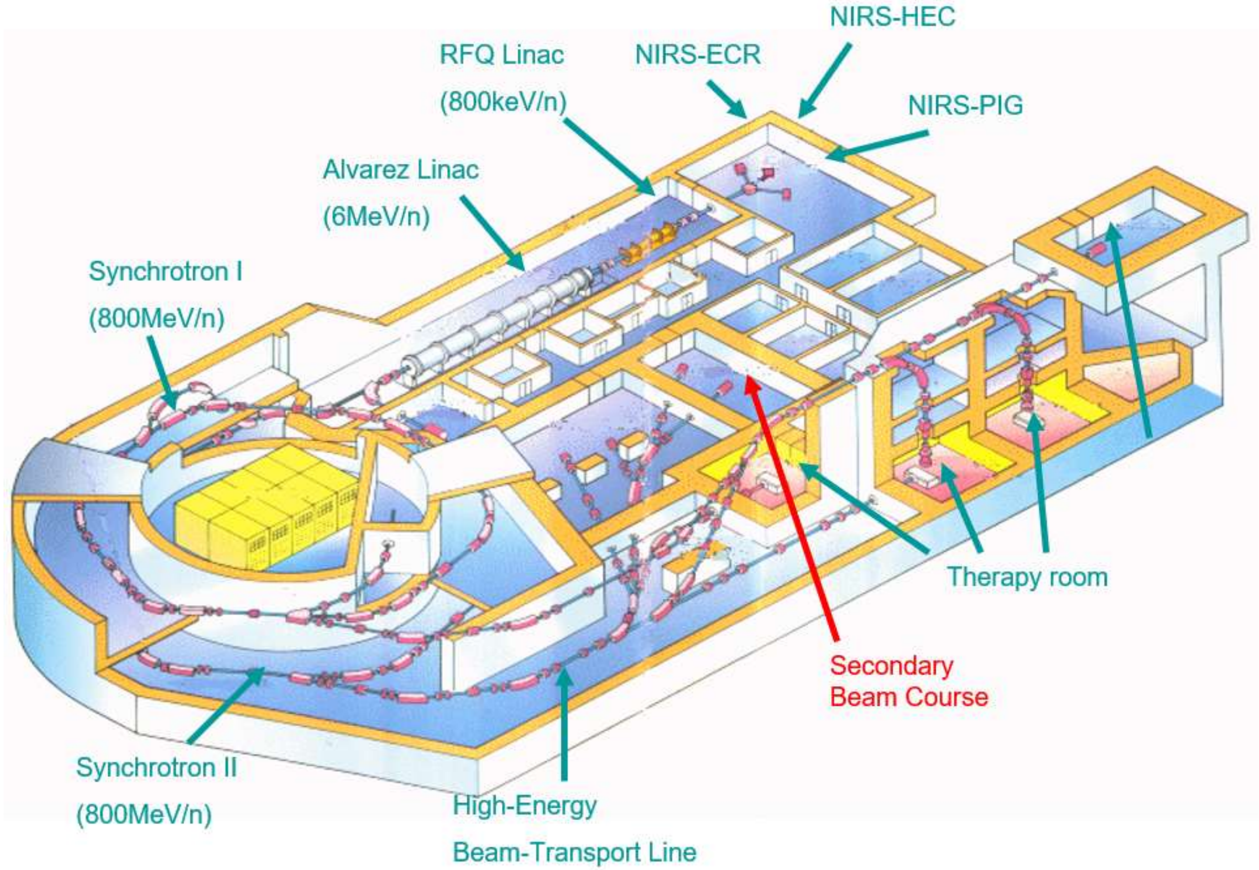
Secondary beam project

1995 ～ 1997 Secondary beam line construction

1998 ～ 1999 Irradiation room preparation

2000 ～ 2002 Beam test using positron camera

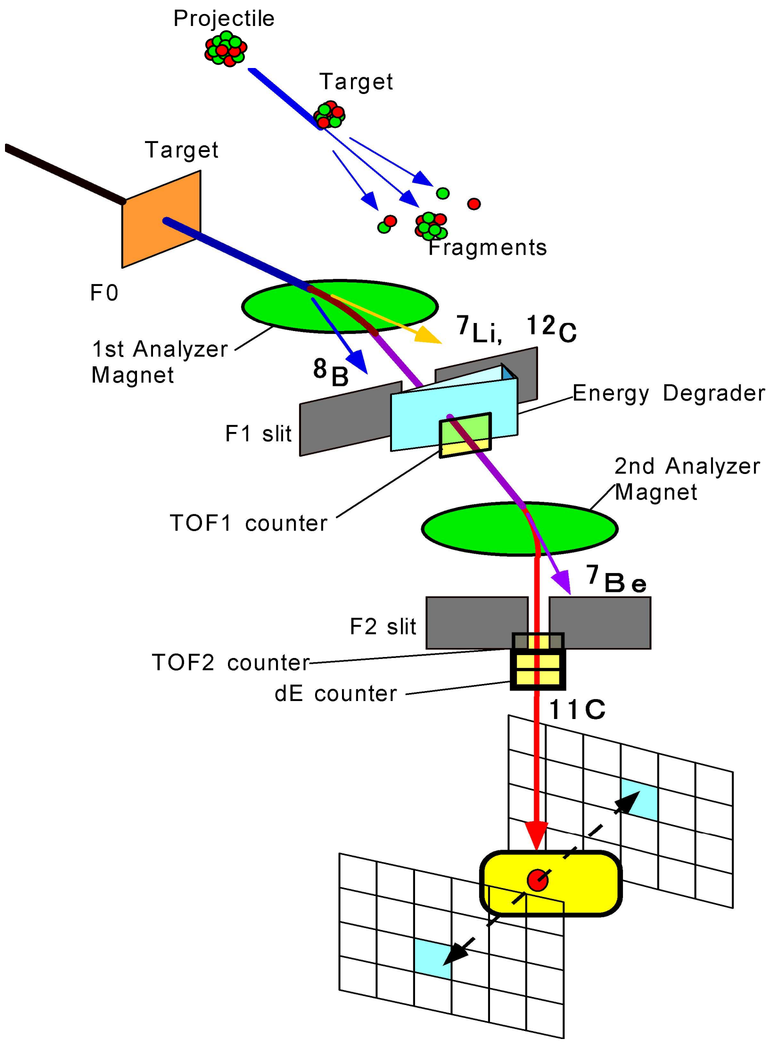
2002 ～ 2003 Washout measurements of RI in the rabbit

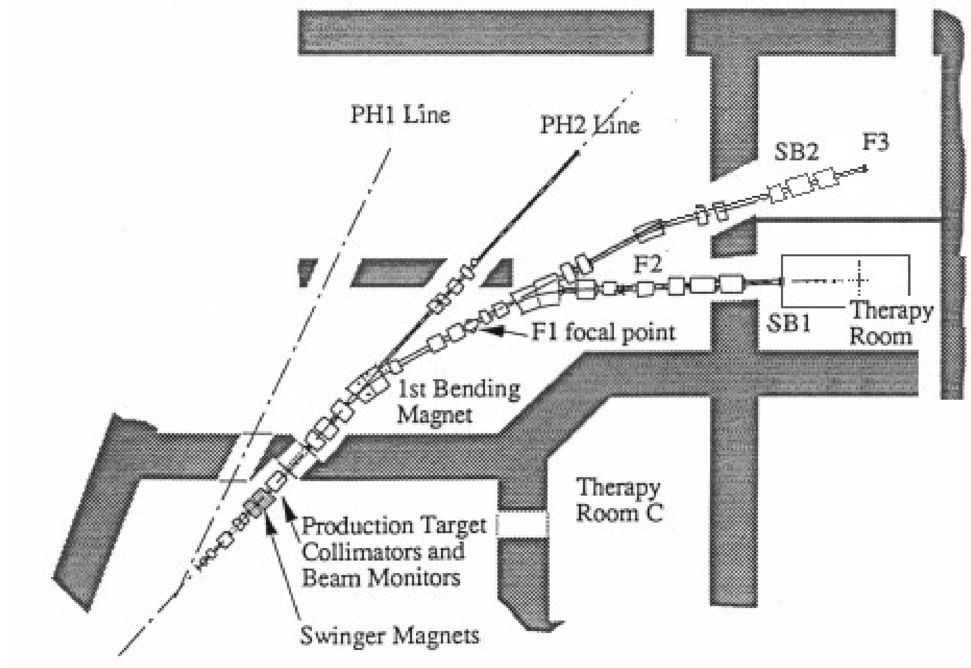


Development of RNB system

- Radioactive nuclear beam (RNB) course
  - Projectile fragmentation of relativistic high energy beam is used to produce various radioactive nuclei.
  - Secondary beam is directly used for the irradiation of cancer treatment.
- Beam irradiation system
  - In order to obtain a desired 3D shape, the spot scanning method is utilized.
- Detectors for the measurement of radioactive nuclei
  - Commercial PET system is available for the ^{11}C beam.
  - Positron camera is developed in order to obtain the 1D range information.

Secondary beam course

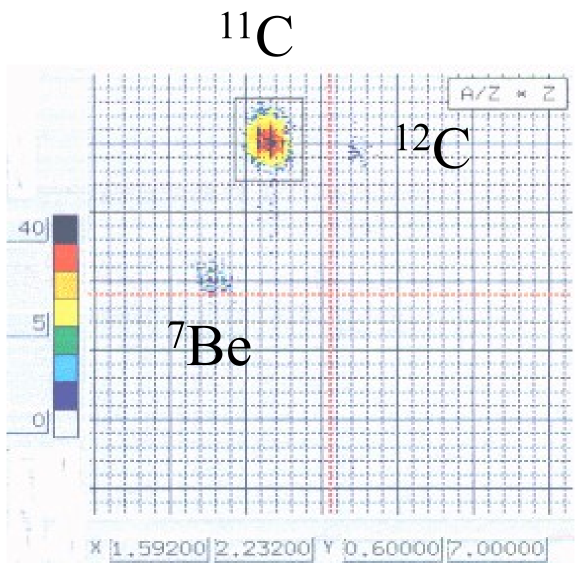


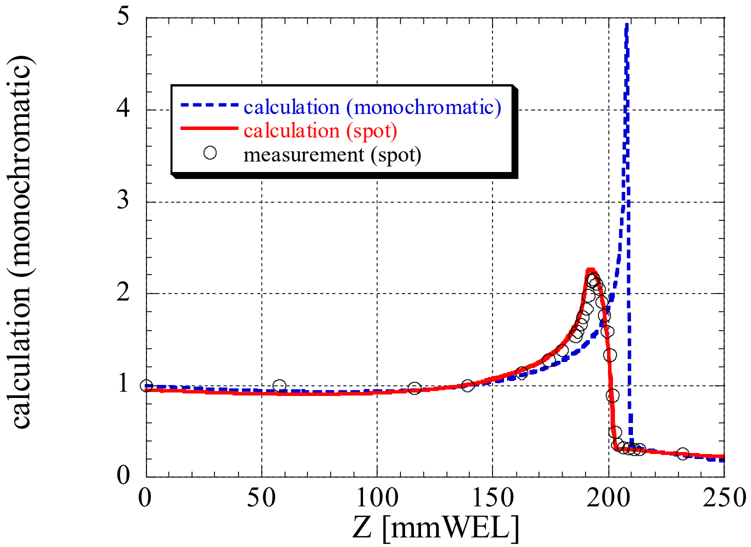


- Maximum magnetic rigidity 8.13Tm
- Radius of bending magnet 5m
- Maximum beam energy (for ^{20}Ne) 600MeV/n
- Momentum acceptance 5%(FW)
- Angular acceptance (h, v) 26mrad(FW)
- Momentum dispersion at F1 2.0m

Production of ^{11}C Beam

Typical parameters	
Energy of primary ^{12}C	430MeV/n
Thickness of Be target	51mm
Thickness of Al degrader	none
Rigidity window	2.0% (FW)
Angular window H.&V.	26mrad (FW)
Results	
Energy of secondary ^{11}C	355MeV/n
Range in water	21cm
Production rate	0.4%
Purity	93%
Momentum spread	3.5% (FWHM)
Beam size at F2	4mm (FWHM)
Beam size at patient	9mm (FWHM)





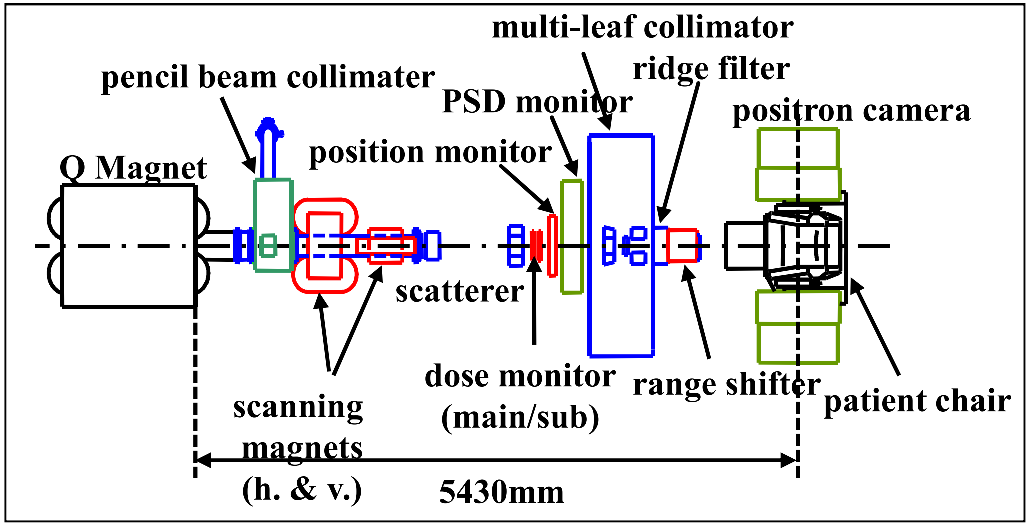
3D irradiation system

Maximum scanning volume

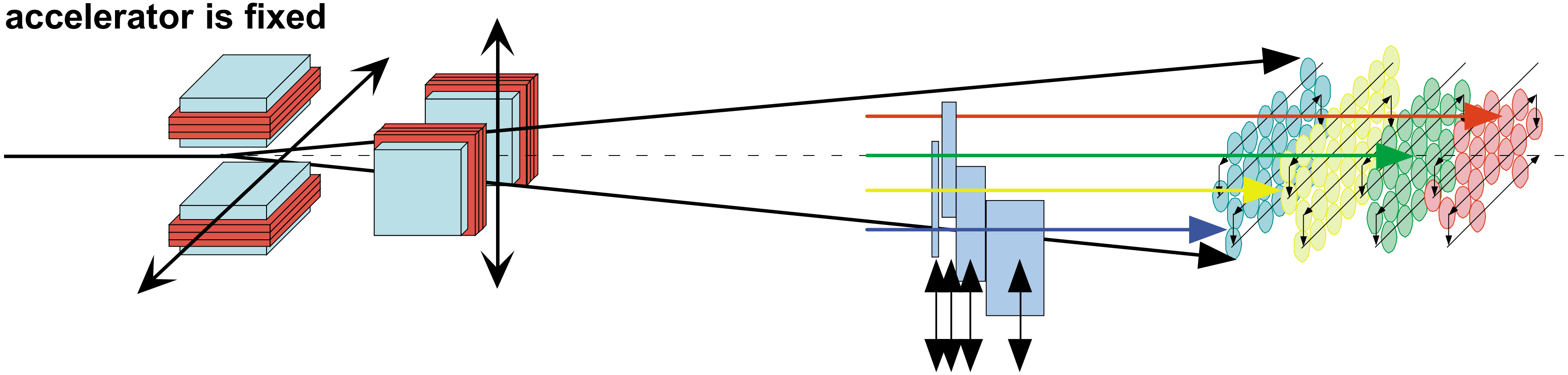
10 x 10 x 18 cm (WE)

Scanning speed (x, y)

2 ms/cm



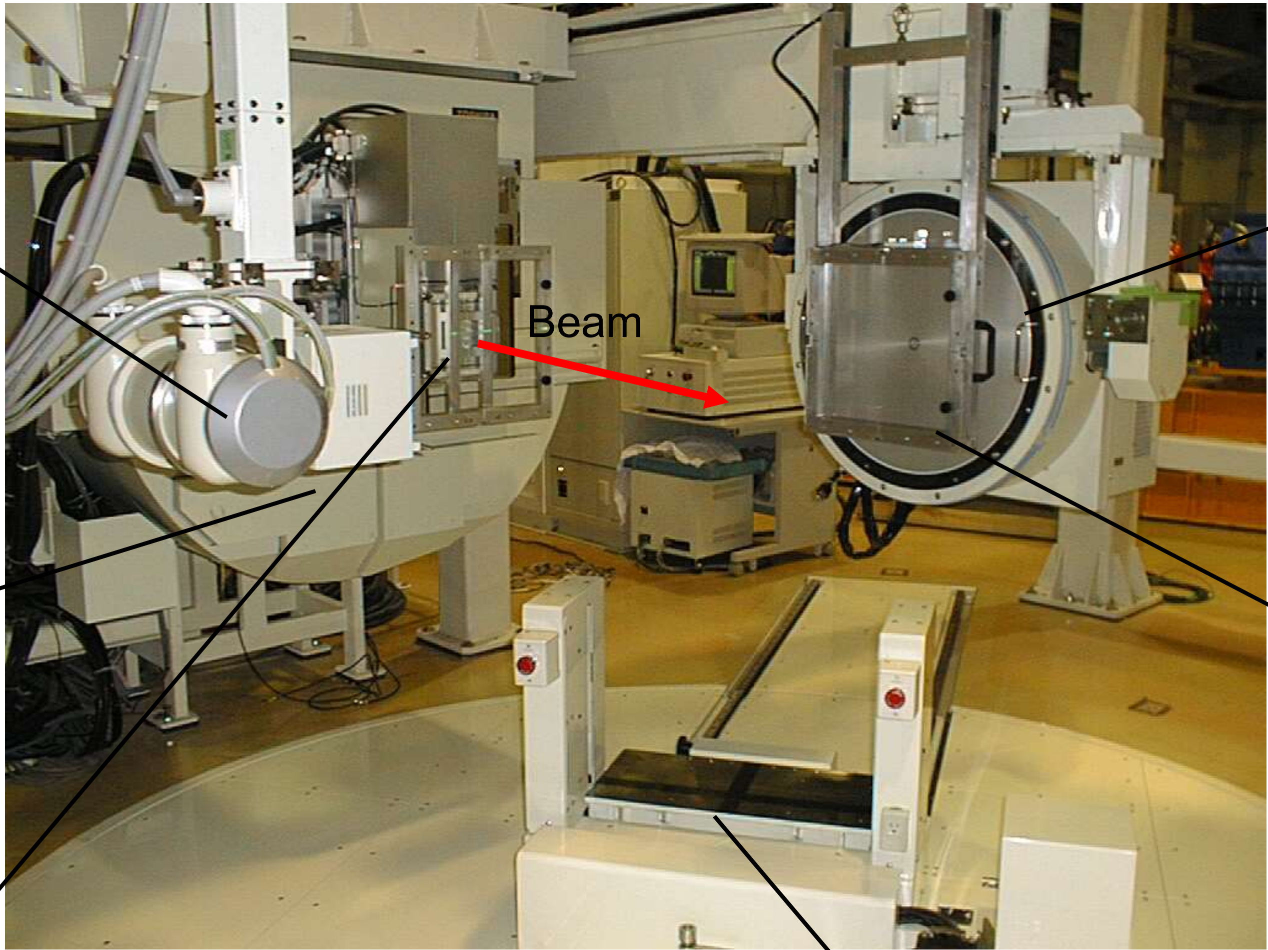
Beam energy from the accelerator is fixed



Position scanning in a slice by the scanning magnets

Range scanning by the range shifter

Patient positioning system and chair



X ray tube

Multi-leaf collimater

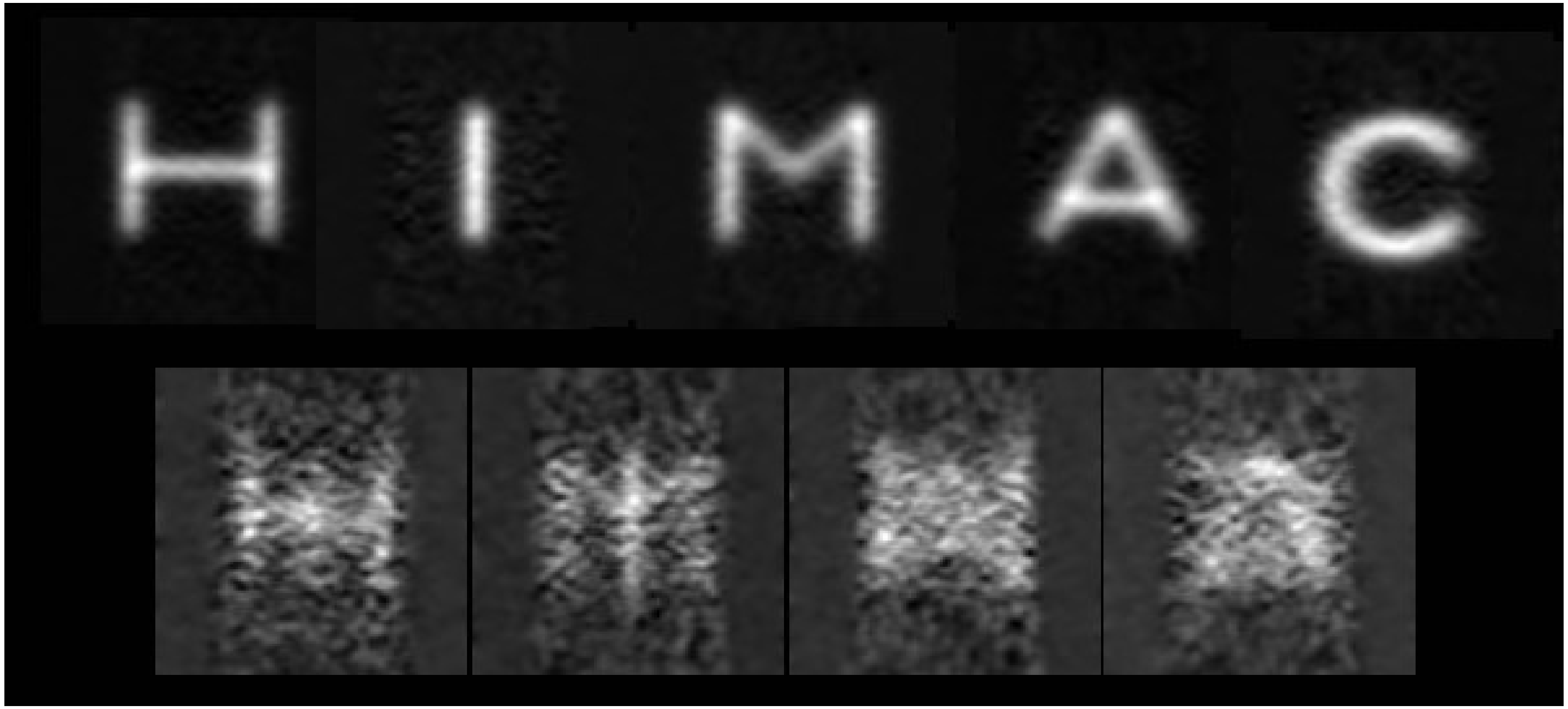
Range shifter

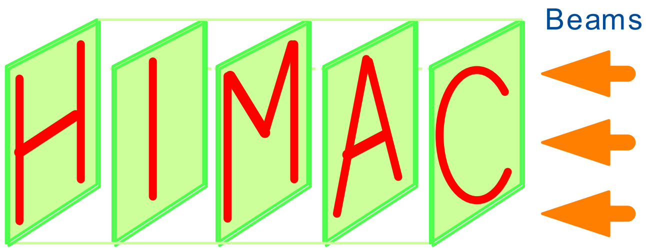
Positron camera

CR

Rotating patient chair

Demonstration of 3D scanning by PET image





Pattern Test

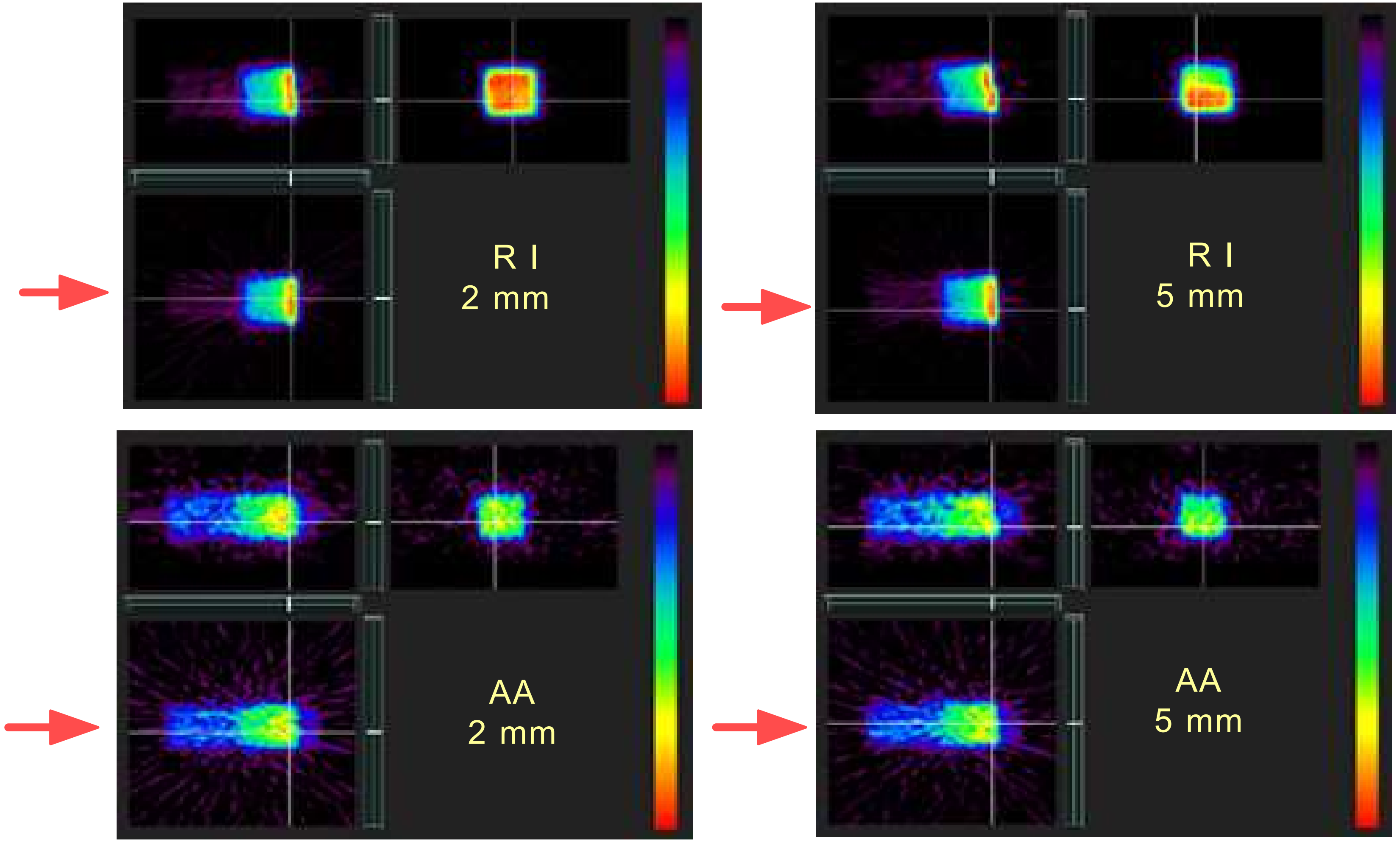
63x63 mm, 20 mm apart,
3 mm step

Development of measurement system

- Positron Emission Tomography (PET)
  - For the check of the irradiation volume after the treatment, a 3D image can be observed by a commercial PET system.
  - ^{11}C beam is used for the treatment instead of ^{12}C beam.
- Positron Camera
  - In order to determine a precise beam range, a pilot pencil beam and positron camera are used.
  - A pilot pencil ^{11}C beam with a few dose is necessary.
  - By using more short-lived ^{10}C (half life is 19s) beam, the range can be measured on line without any biological effects.

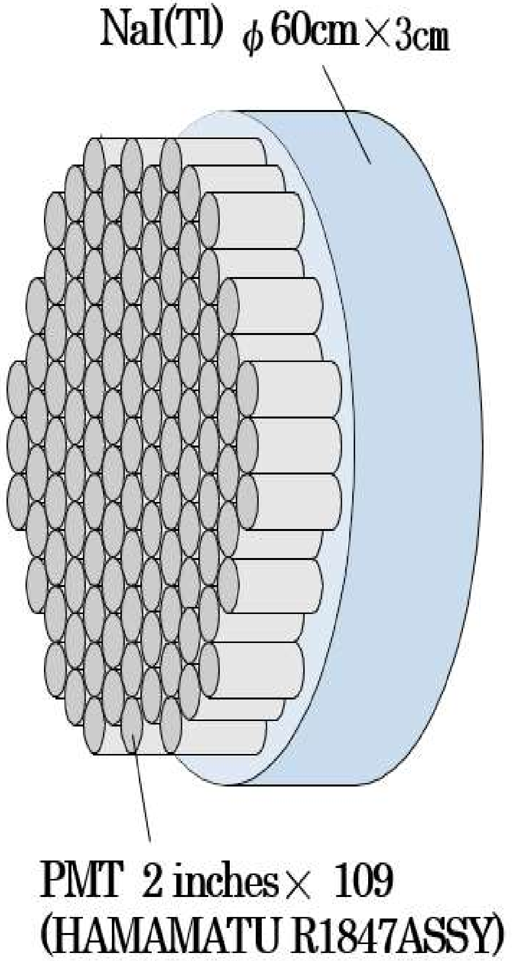
Measurement by commercial PET

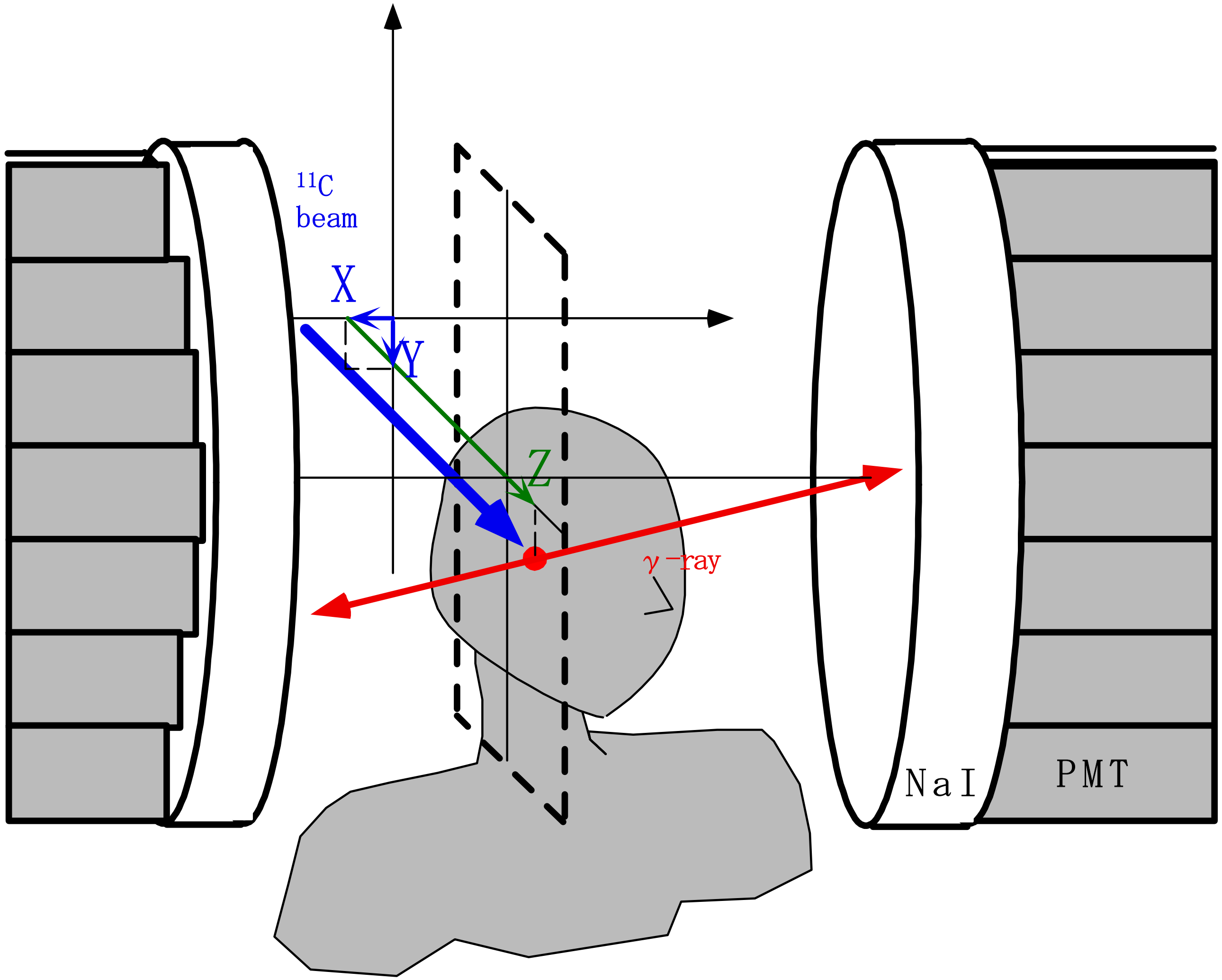
Comparison of ^{11}C Beam (RI) and Autoactivation (AA)



Irradiation Dose: 1 Gy, Irradiation Field: 35x35x50 mm WE

Range verification by positron camera





Feasibility measurements using positron camera

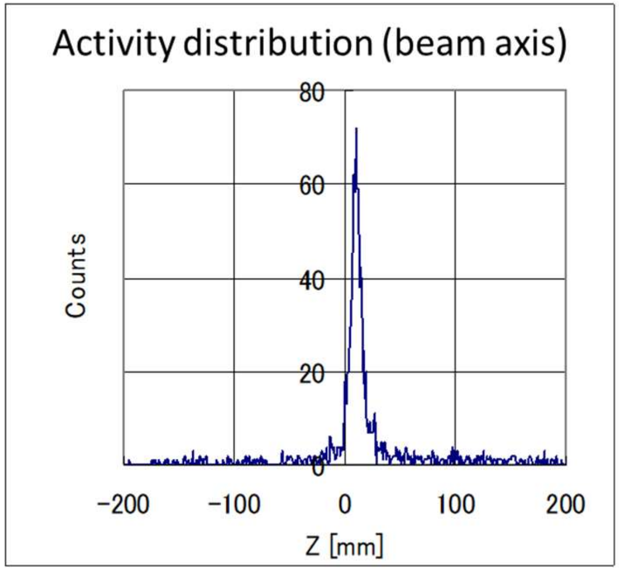
C-11 beam irradiation(3,500k particles)

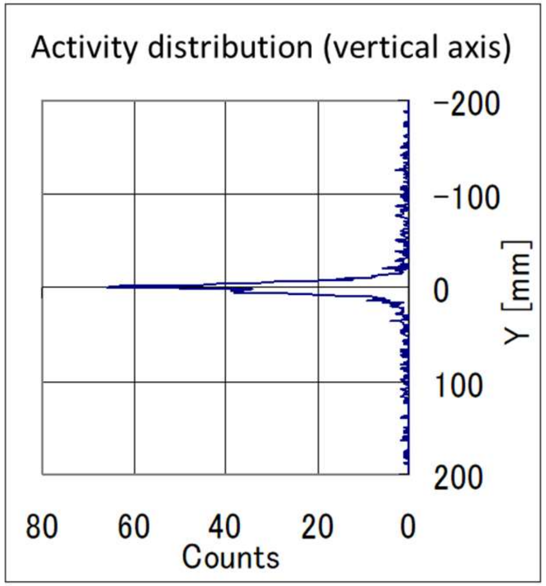
↓

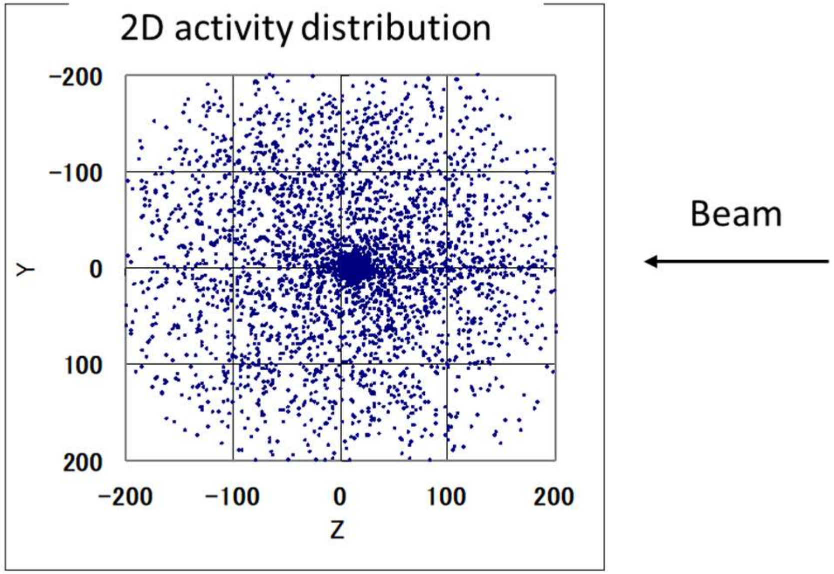
Measurement time 100s

↓

$\sigma_Z \sim 5.7$ mm (gauss fitting)

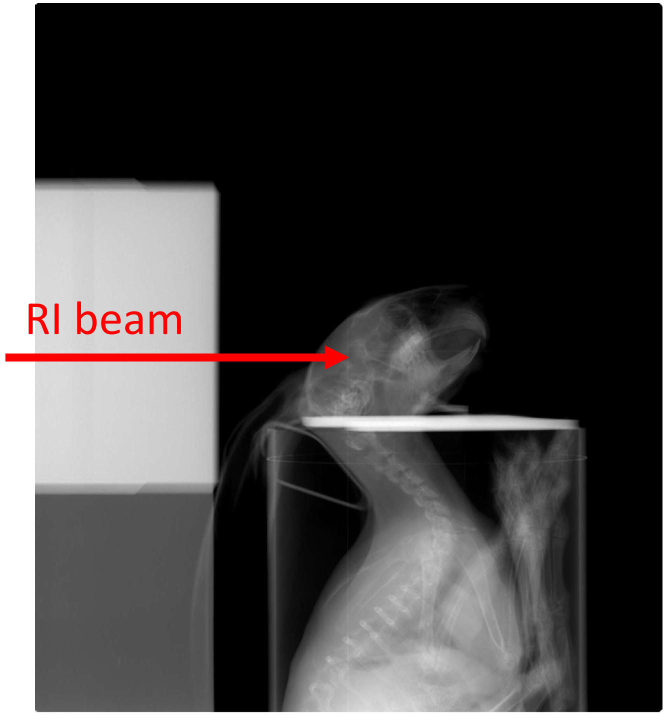






Washout measurements of RI in the rabbit

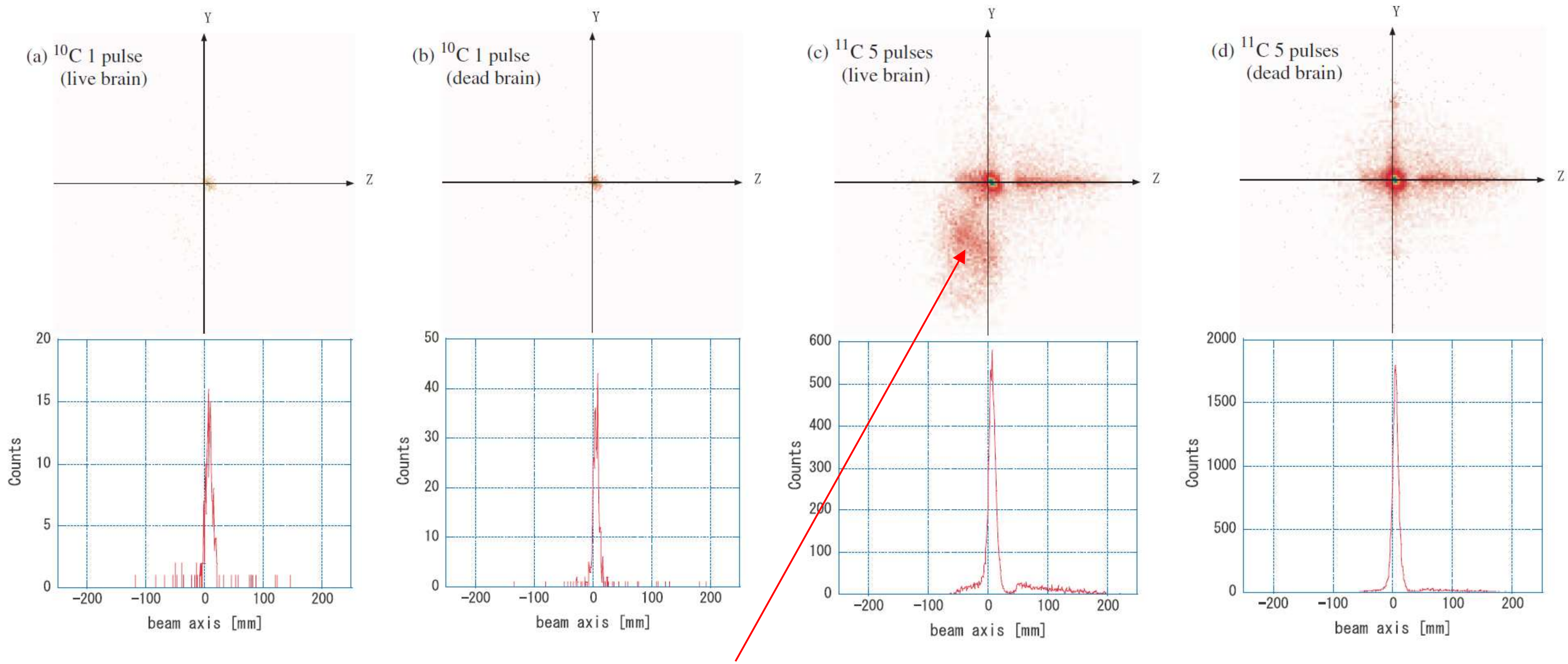
To study the washout effect, rabbit was irradiated by C-10 and C-11 beams.



Brain and thigh muscle were selected as targets.

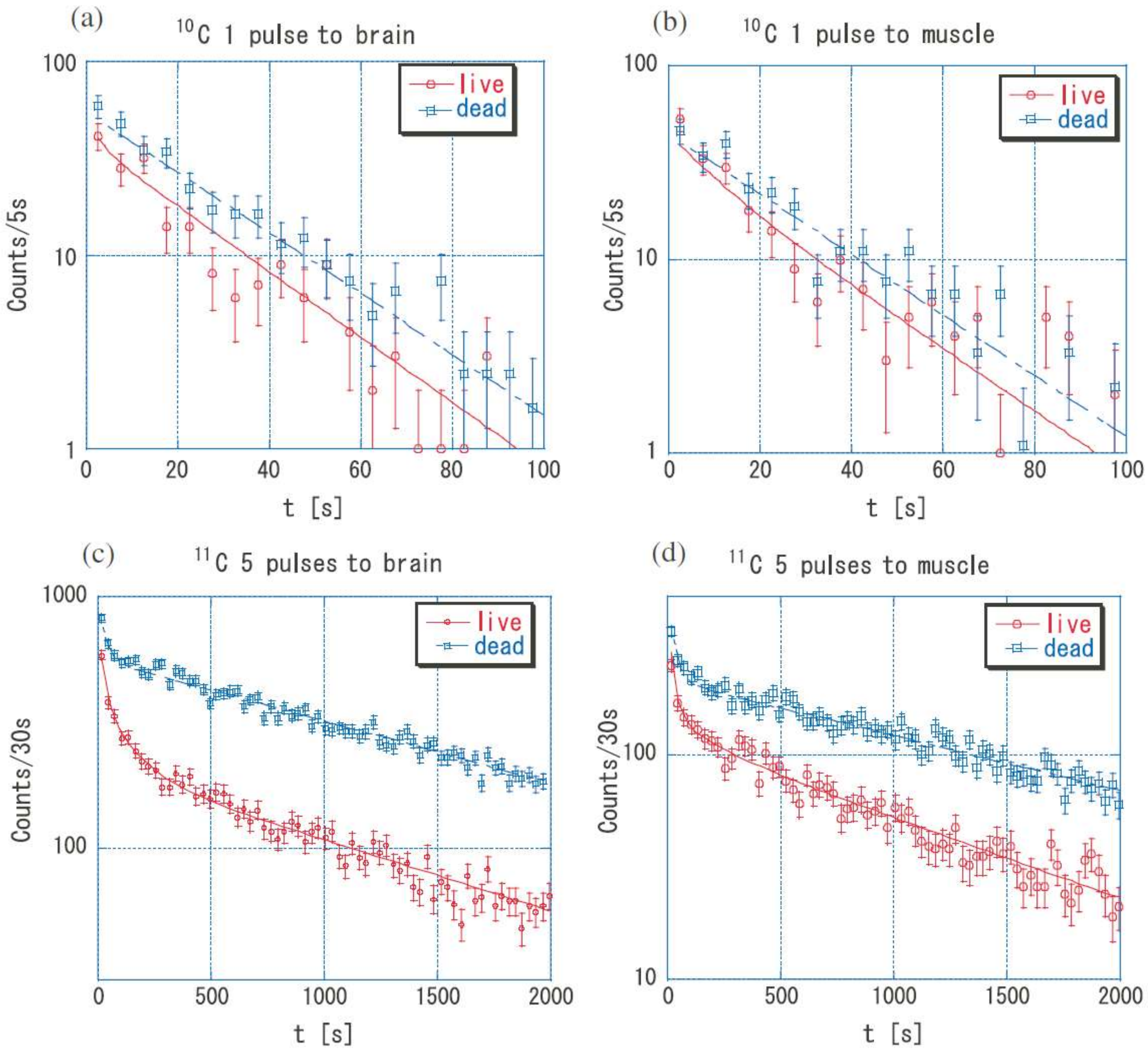
Washout measurements of RI in the rabbit (cont.)

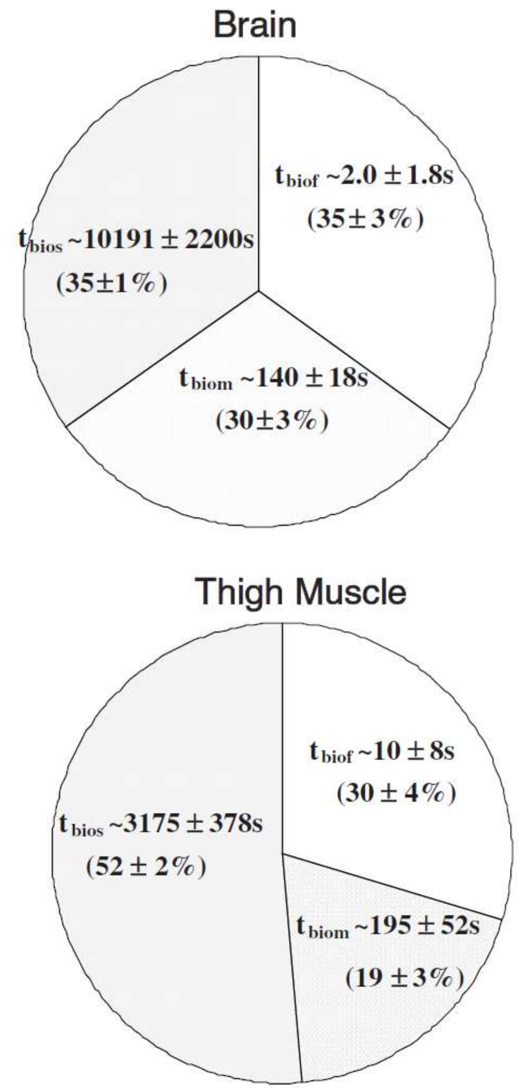
One- and Two-dimensional position distribution of brain irradiation.
(Beam comes from right side.)



Washout effect was clearly seen for C-11 irradiation to live brain.

Washout measurements of RI in the rabbit (cont.)





3 components were exist for the wash out effect.

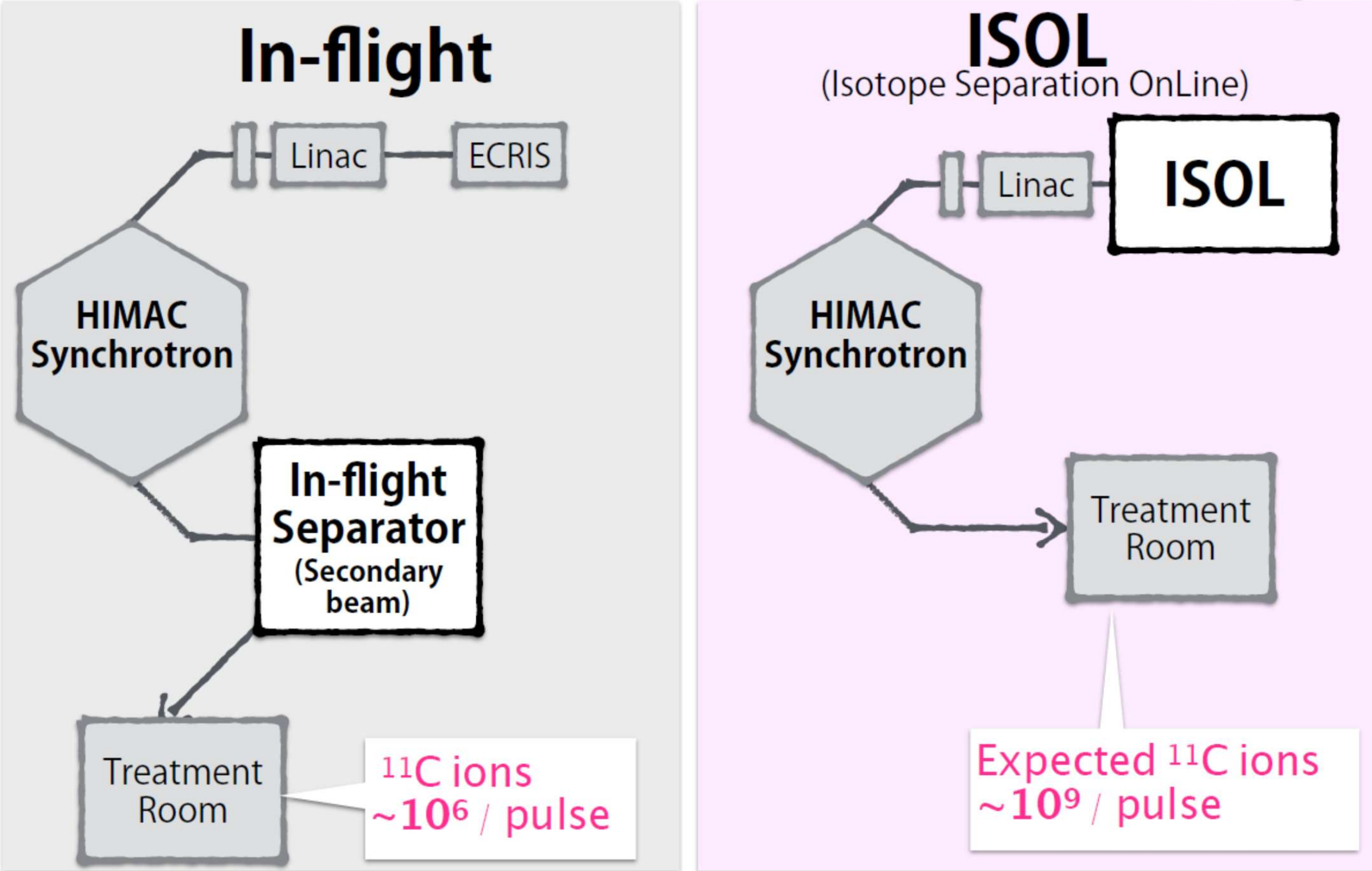
Issues to be solved

To apply these techniques to real clinical situation,

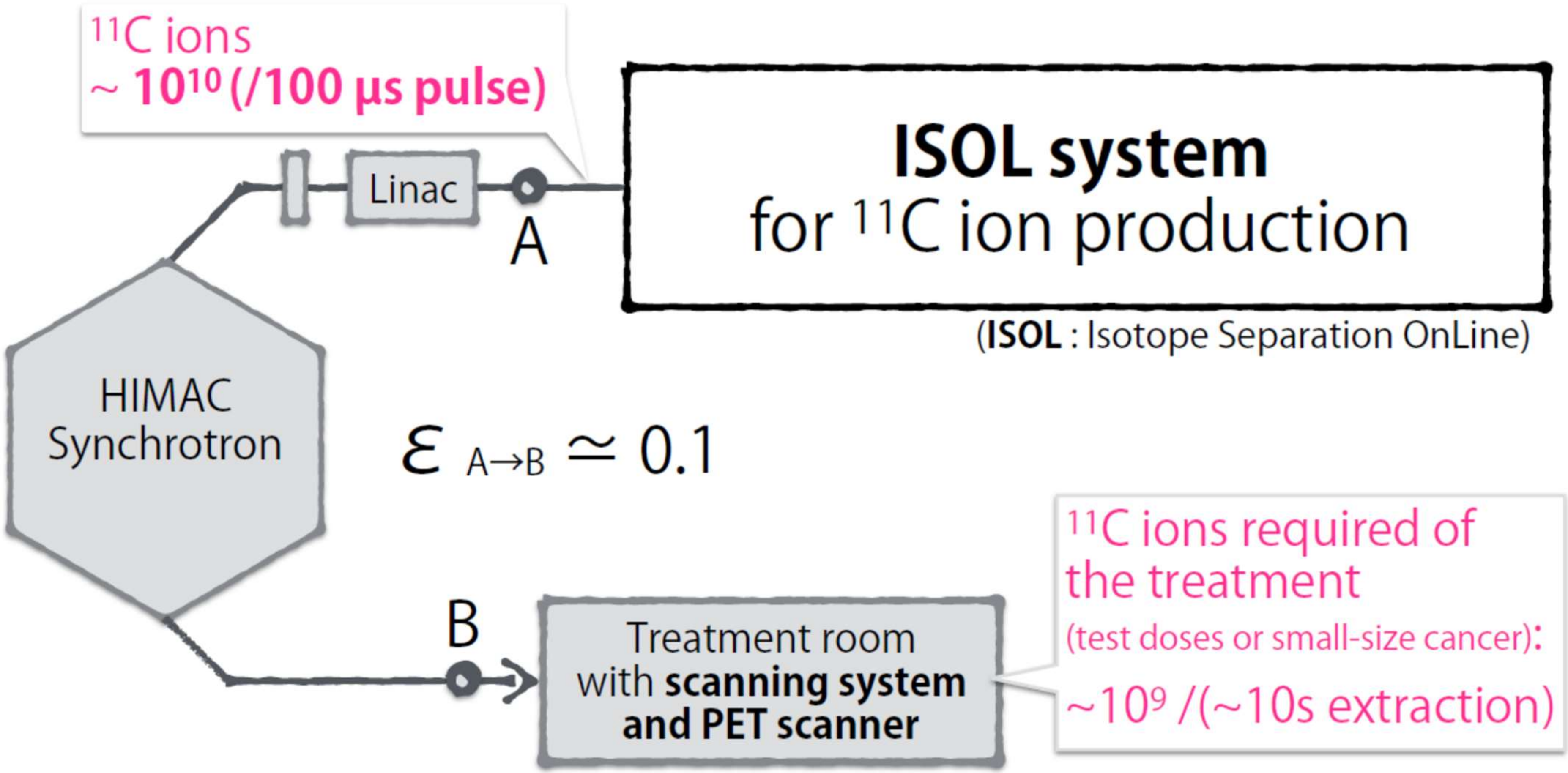
- washout effect should be studied more in detail.

- the intensity of RI beam (^{10}C and ^{11}C) should be increased.

ISOL technique for further amount of ^{11}C



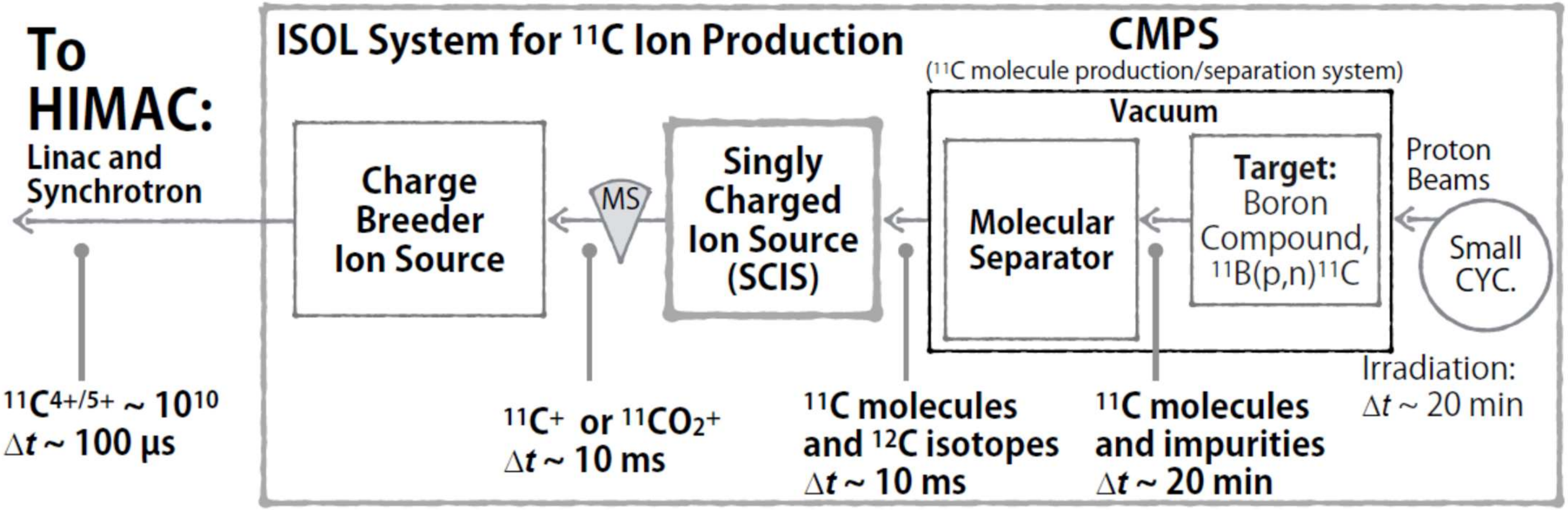
Purpose: development of an ISOL system for ^{11}C ion acceleration



Conditions required of the ISOL system:

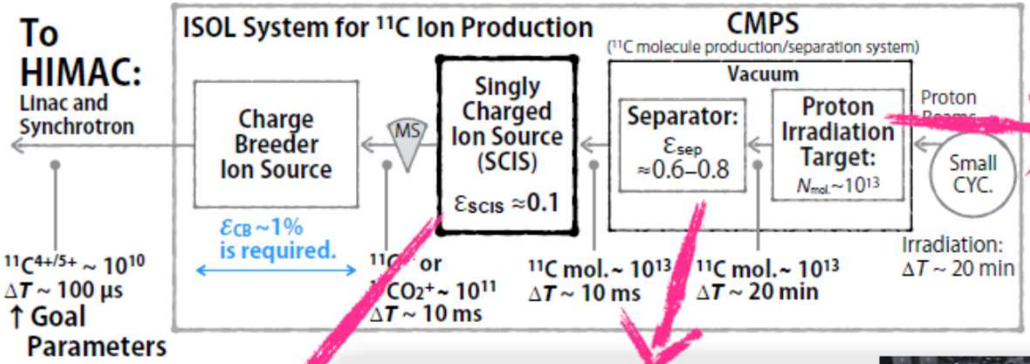
^{11}C ions **~10^{10}**, **ΔT ~ 100 μs**

ISOL system for ^{11}C ion production



- providing **one pulse every 20 min**; production and accumulation of ^{11}C molecules with a commercially available cyclotron (~20 μA).
- pulse compression required of the injection into synchrotron; **20 min → 100 μs**
- **EBIS (Electron-Beam Ion Source)**-charge breeder enables **highly efficient use of ^{11}C** by trapping ions. *cf.* cw-ECRIS

Each module that has been developed so far has good performances: **target, separator and SCIS**



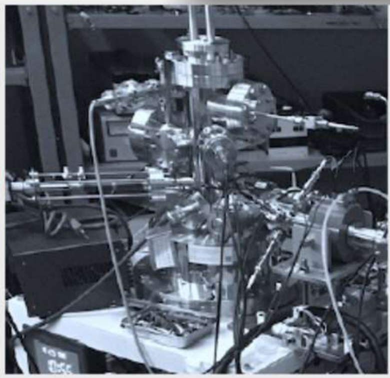
Target	Beam current × Irradiation time (μC)	Produced ^{11}C mol.	Residual in target (%)	Corrected ^{11}C mol. (%)	No. of corrected ^{11}C mol.
$NaBH_4$ [3]	1.94×10^4 (18 μA, 18 min)	$^{11}CH_4$	70.4%	29.3%	5.0×10^{12}
B_2O_3	1.92×10^4 (16 μA, 20 min)	$^{11}CO_2$	21.2%	**76.4%**	**1.4×10^{13}**

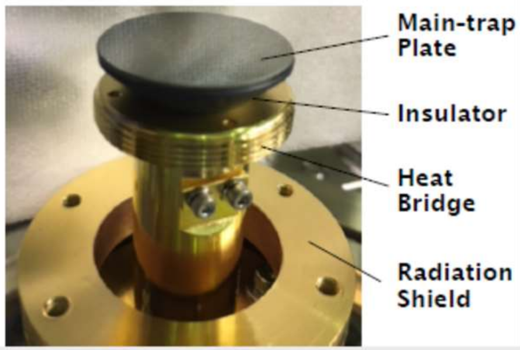
Target: $N \sim 10^{13}$

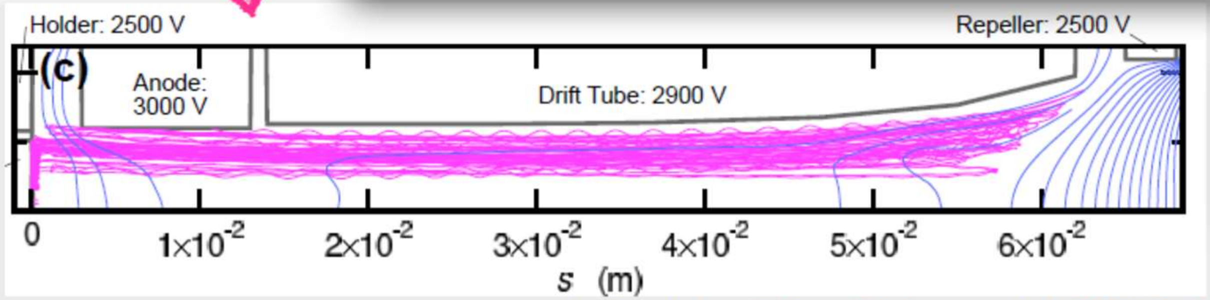
K. Katagiri et al., Rev. Sci. Instrum. 85, 02C305 (2014).

Separator: $\varepsilon \simeq$ 60–80%

K. Katagiri et al., Rev. Sci. Instrum. 86, 123303 (2015).







SCIS: $\varepsilon \simeq$ 10%

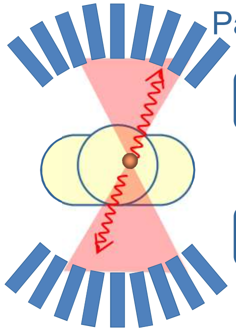
- K. Katagiri et al., Rev. Sci. Instrum. 89, 113302 (2018).
- K. Katagiri et al., Rev. Sci. Instrum. "Ion-production efficiency of a singly charged ion source using low energy electron beam", to be submitted.

OpenPET :
PET-guided particle therapy

"OpenPET"
our idea for 3D in-beam PET

Conventional in-beam PET

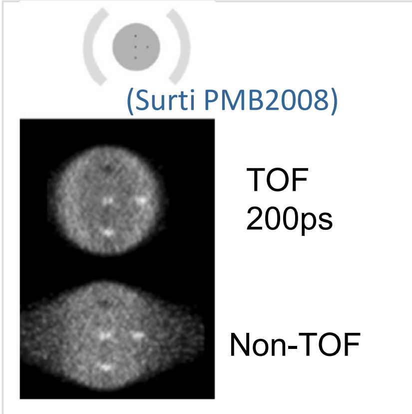
GSI
Pawelke et al, 1996



Partial detectors

2D imaging

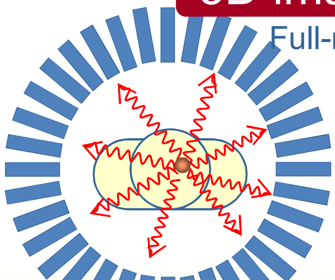
Limited sensitivity



OpenPET

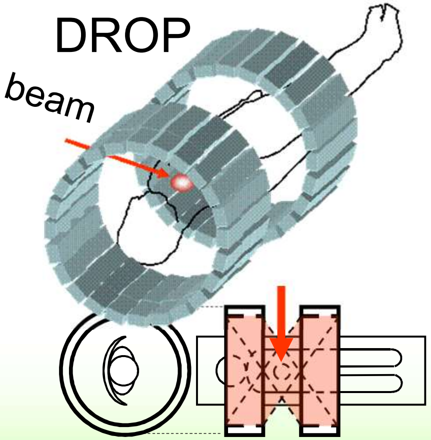
3D imaging

Full-ring detectors

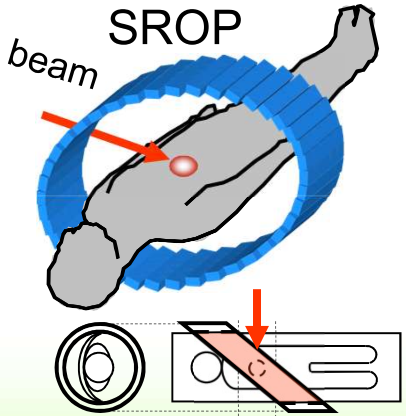


High sensitivity

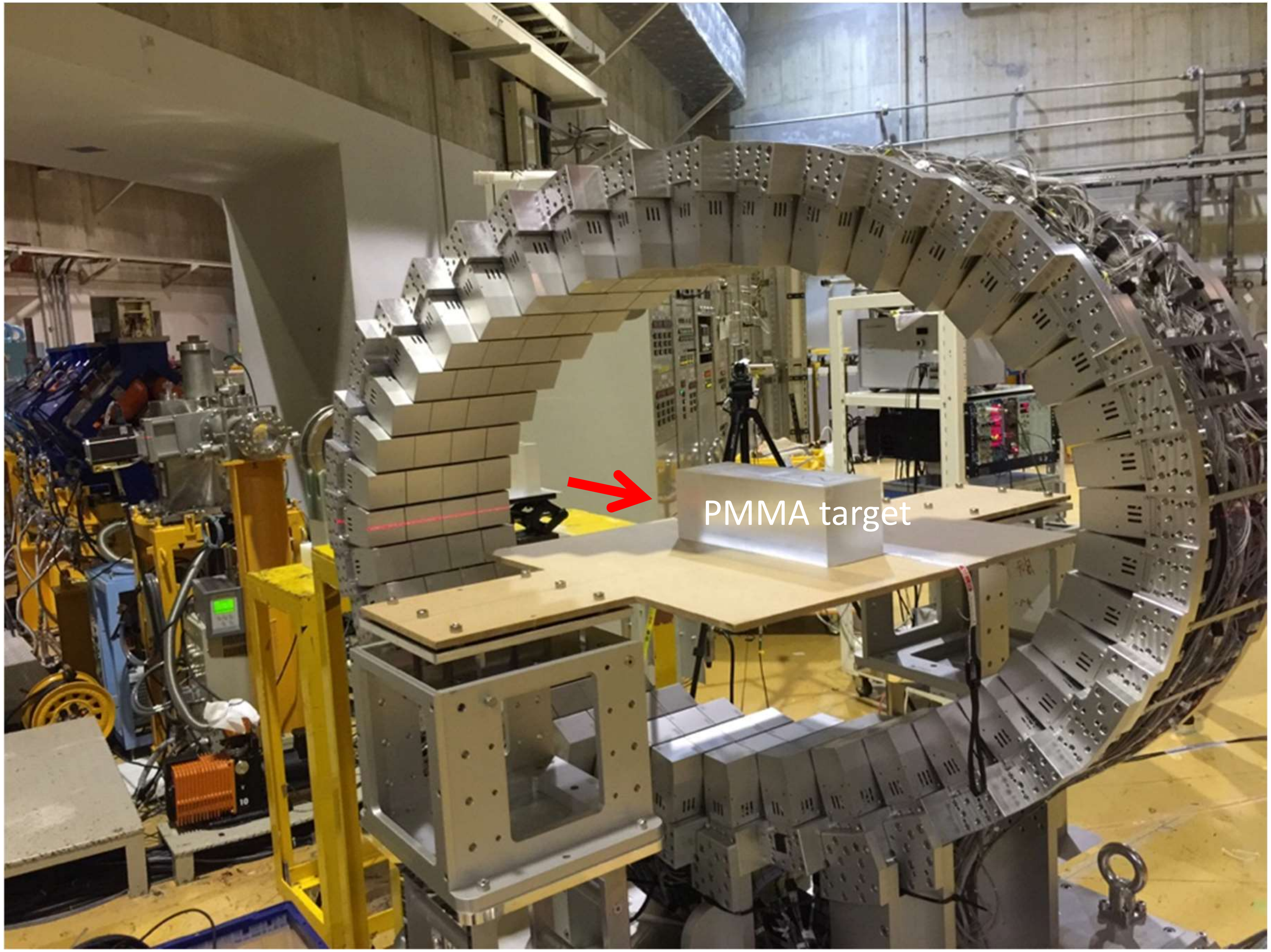
Yamaya PMB 2008



Tashima PMB 2012



SROP type OPEN PET

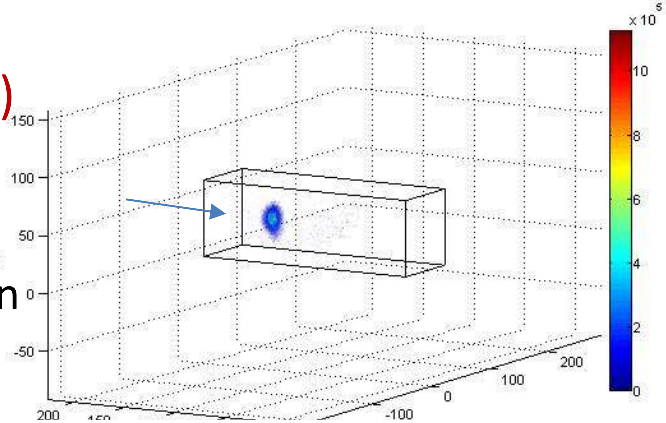


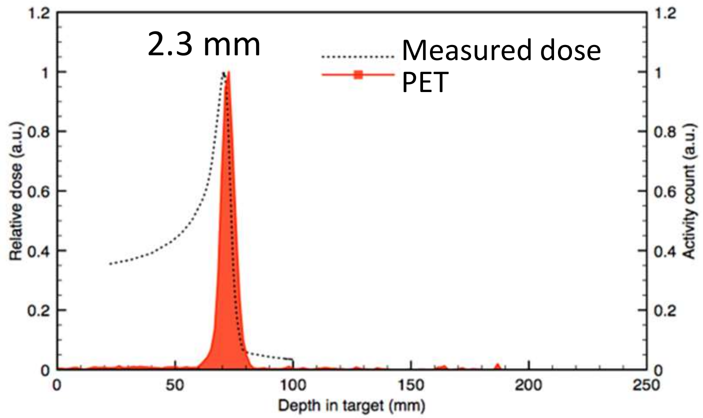
Spill off + beam off
OSEM
1.5 mm^3 voxel

Akram Mohammadi, et al., NIMA 2017 p76

^{11}C ($6x10^6$ pps)

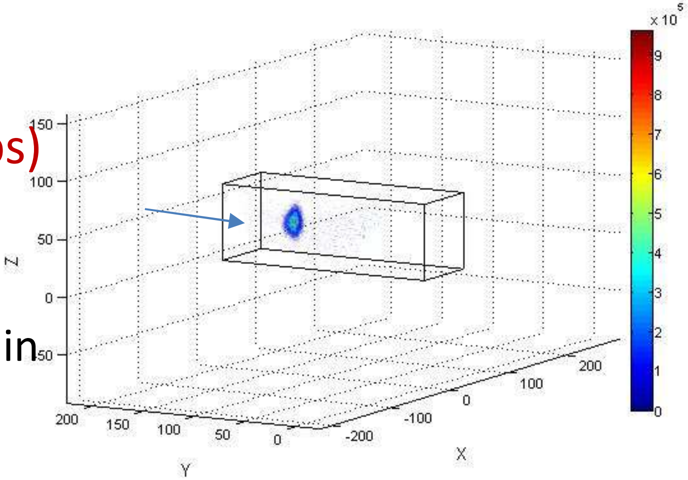
- Half life: ~20 min
- 3 spills
- Scan time: 23 min

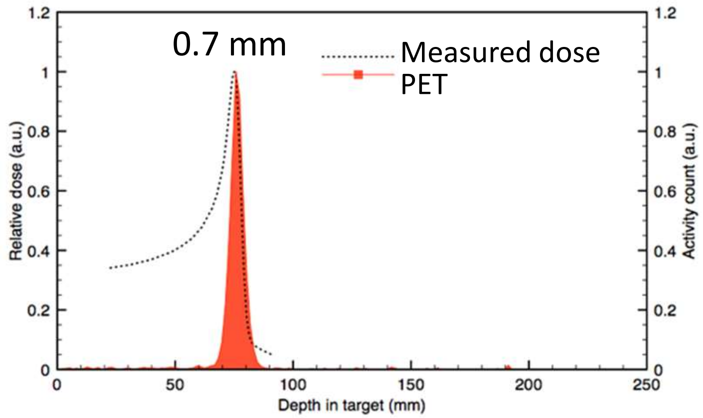




^{15}O ($7x10^6$ pps)

- Half life: ~2 min
- 2 spills
- Scan time: 13 min





Summary

- By secondary beam project, the beam course was developed and studies on biological washout effects were performed.
- To overcome the low intensity RI beam, ISOL research is ongoing.
- OpenPET was developed for efficient use of the limited signal from RI.


Thank you for your attention