FFAG02

Spot Scanning Irradiation with ^{11}C Beams at HIMAC

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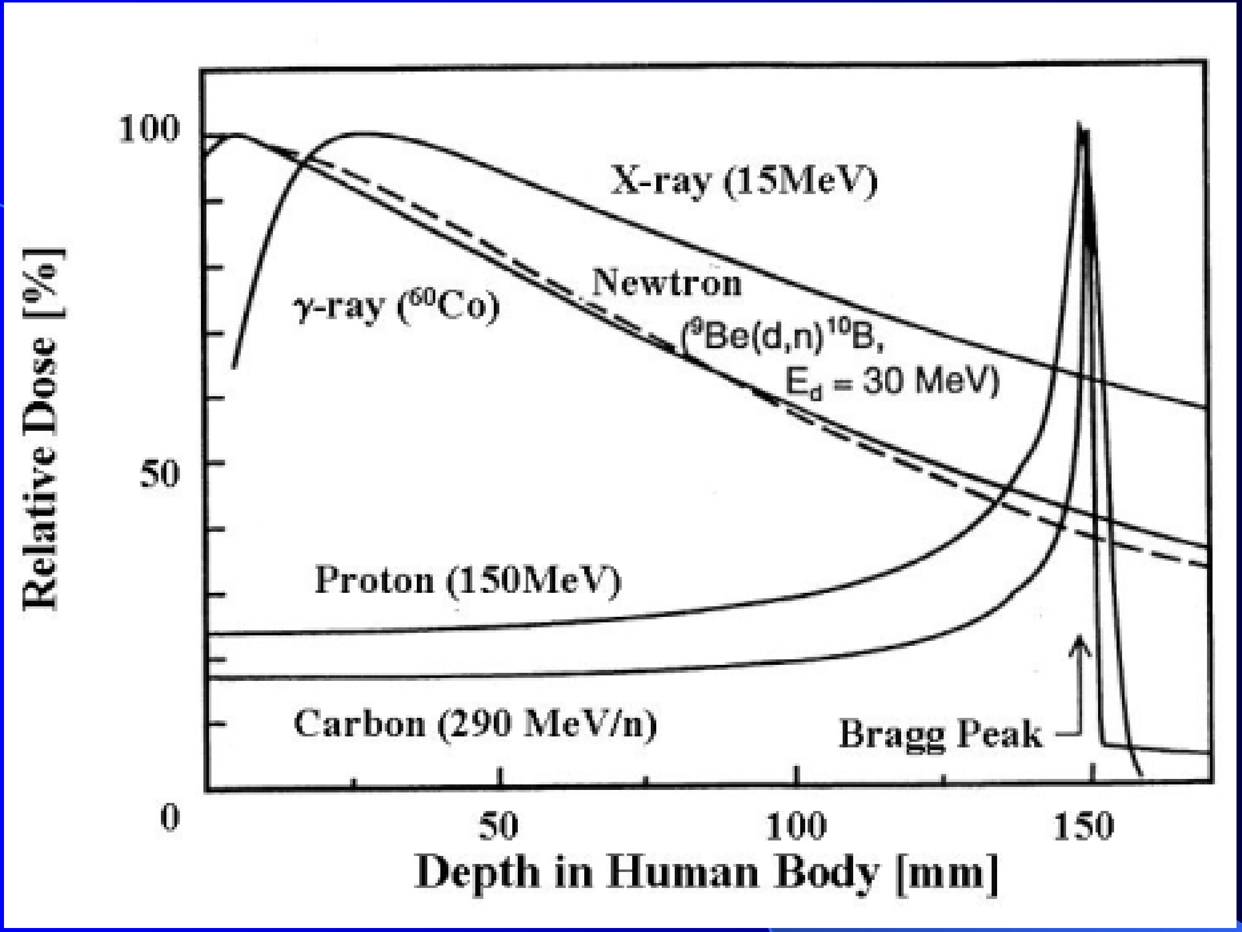
1. Review of Spot Scanning Irradiation for Treatment
2. Spot Scanning with ^{11}C Beams at HIMAC

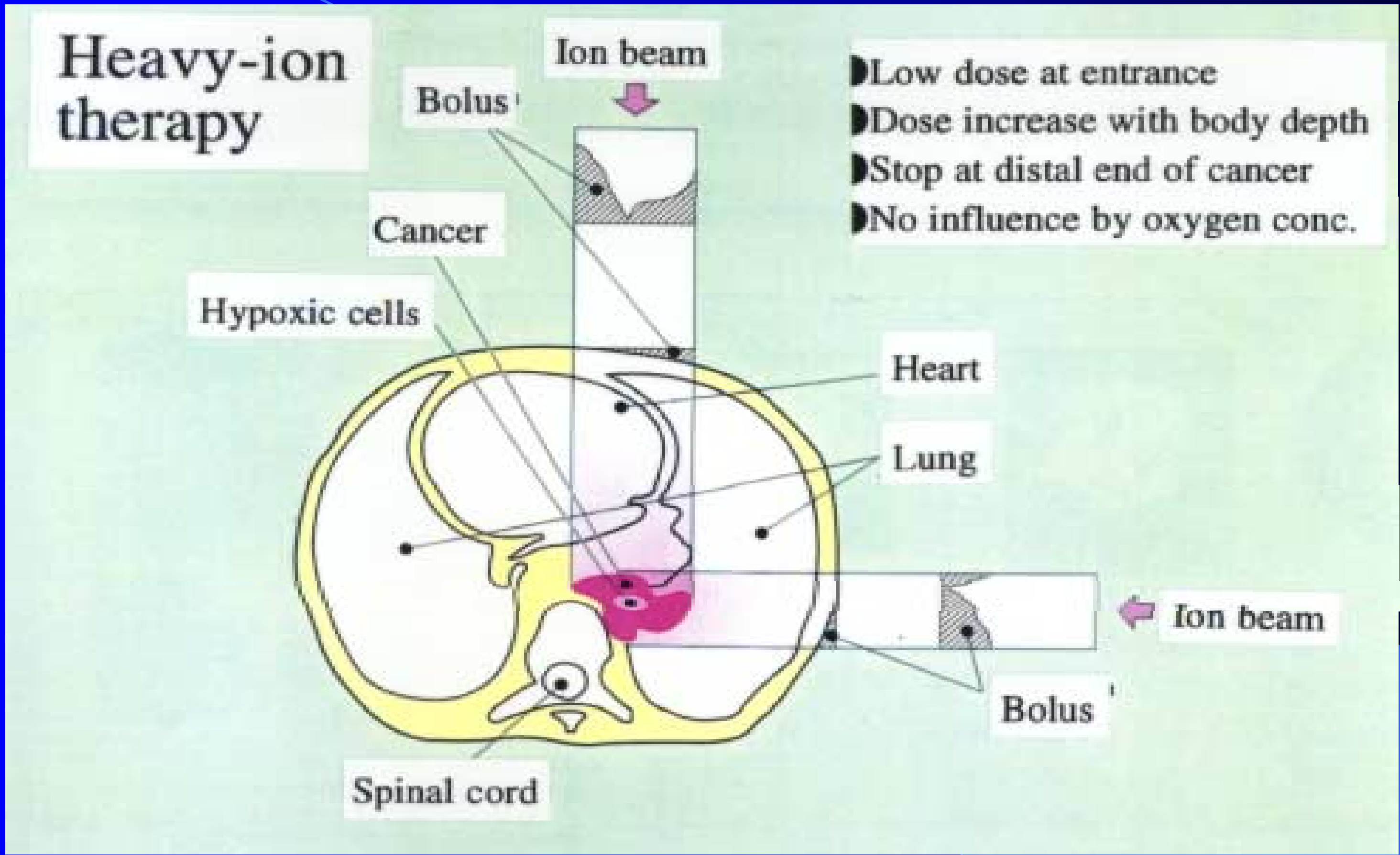
Dose Distribution of Radiation



Using the Bragg-peak characteristics,
dose can be concentrated to the tumor.
Carbon has the biological effectiveness for killing cell.

Request for Medical Irradiation

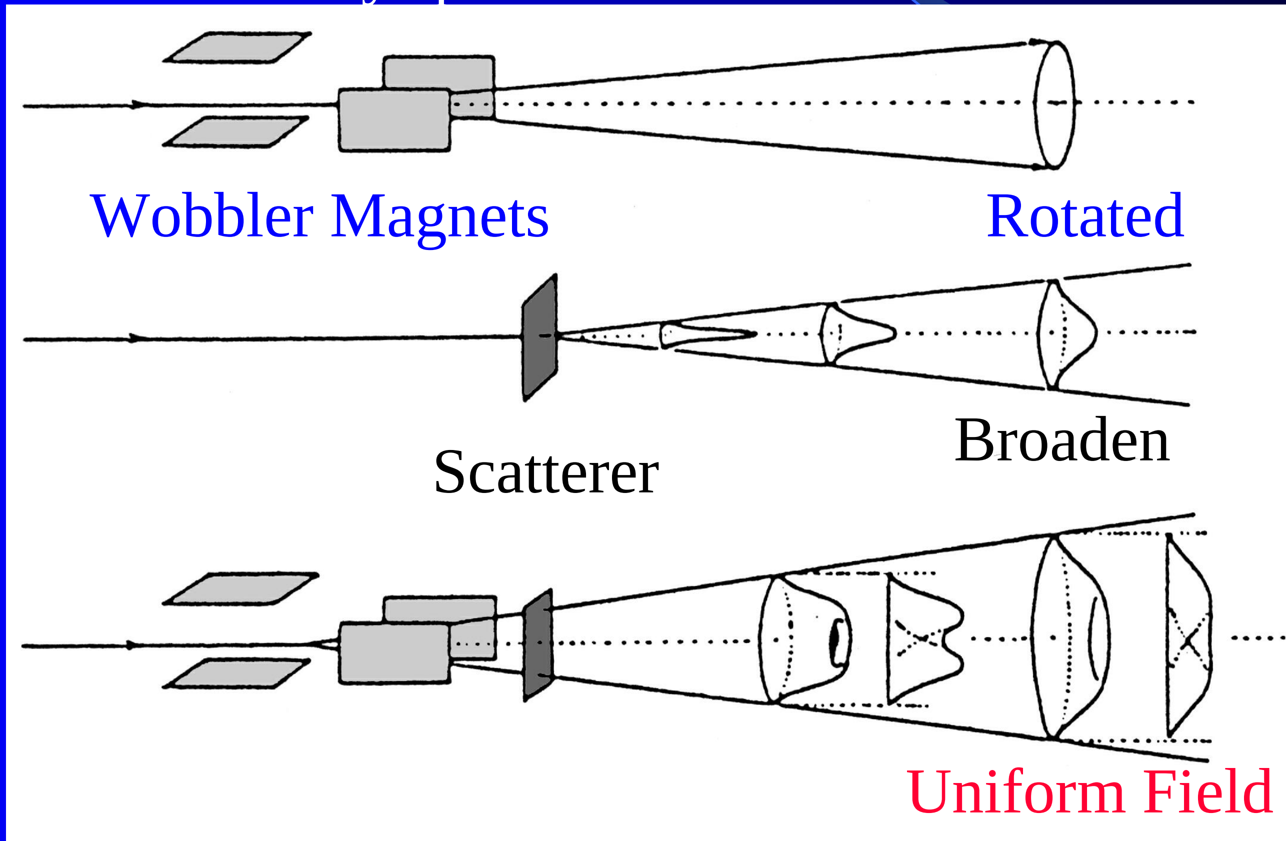
Uniform irradiation Field, which fits the shape and position of the tumor.



Usual Irradiation Method - I

Wobbler Method :

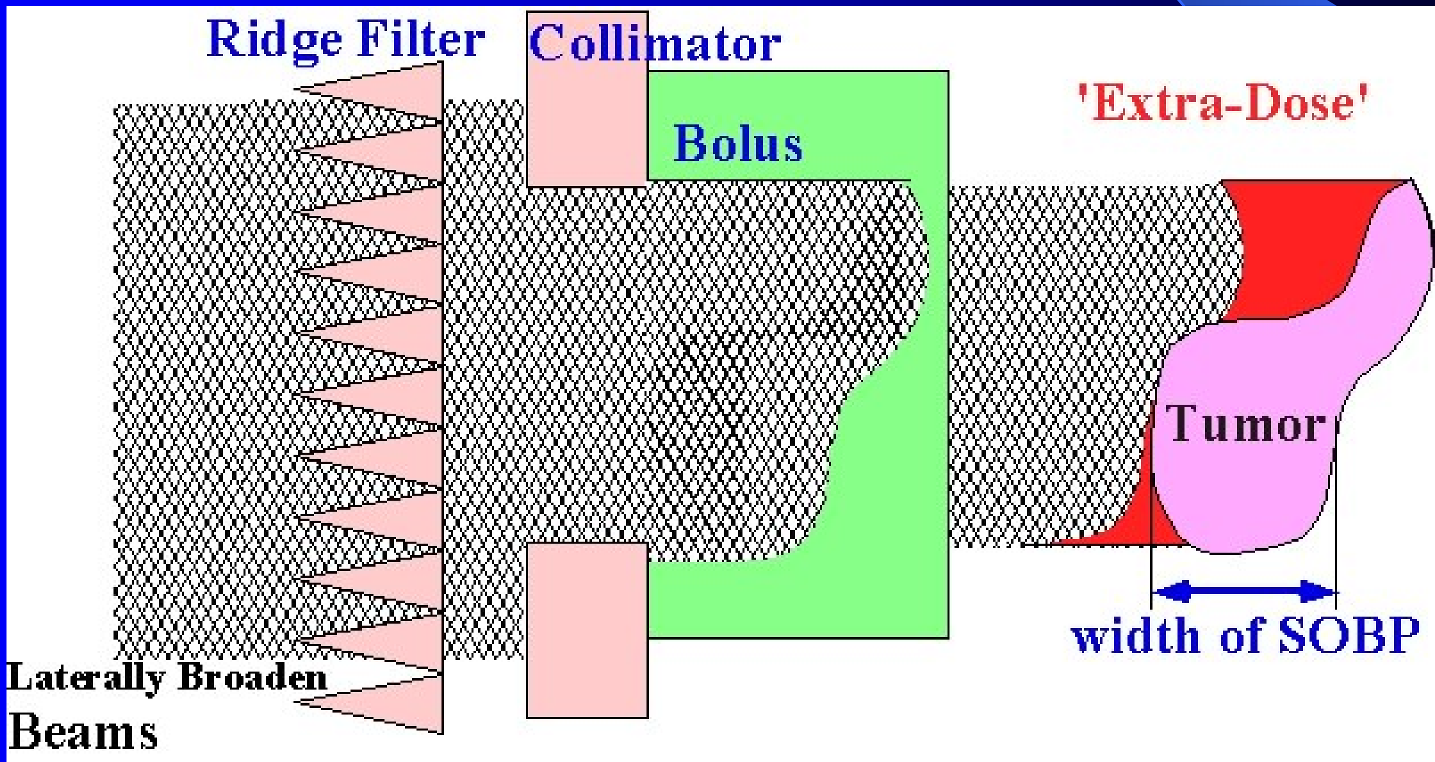
Initial beam is laterally spread to form the uniform irradiation field



Double Scatterer Method

Usual Irradiation Method - II

1) Laterally-broaden beam is vertically spread to the width of tumor. by Ridge filter.
2) The lateral shape of irradiated field is fit that of tumor by Collimator.
3) The distal edge of irradiated field is fit that of tumor by Bolus.



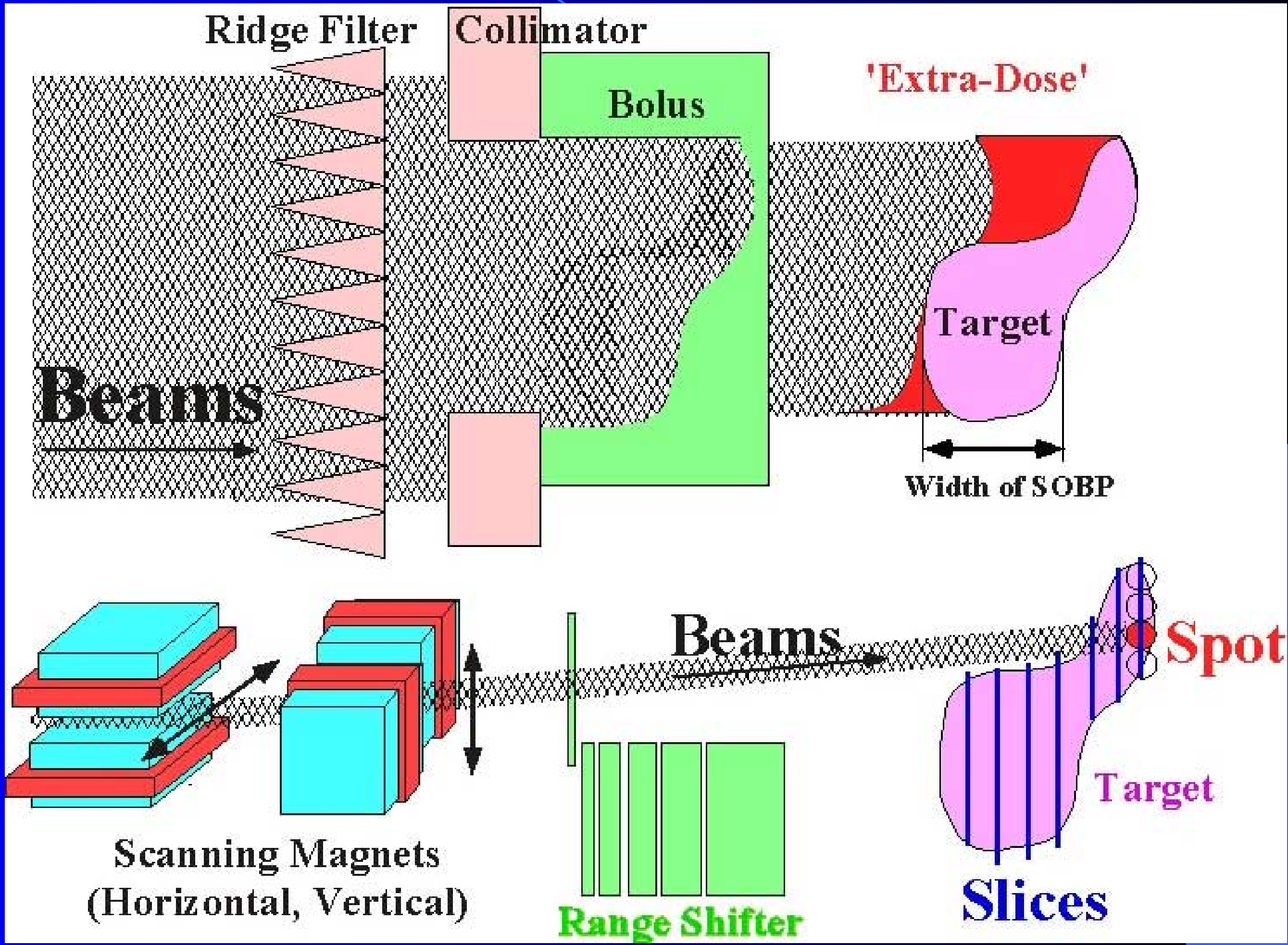
Comparison of Irradiation Method

Wobbler Method

Beam Efficiency
～30%

Spot Scan Method

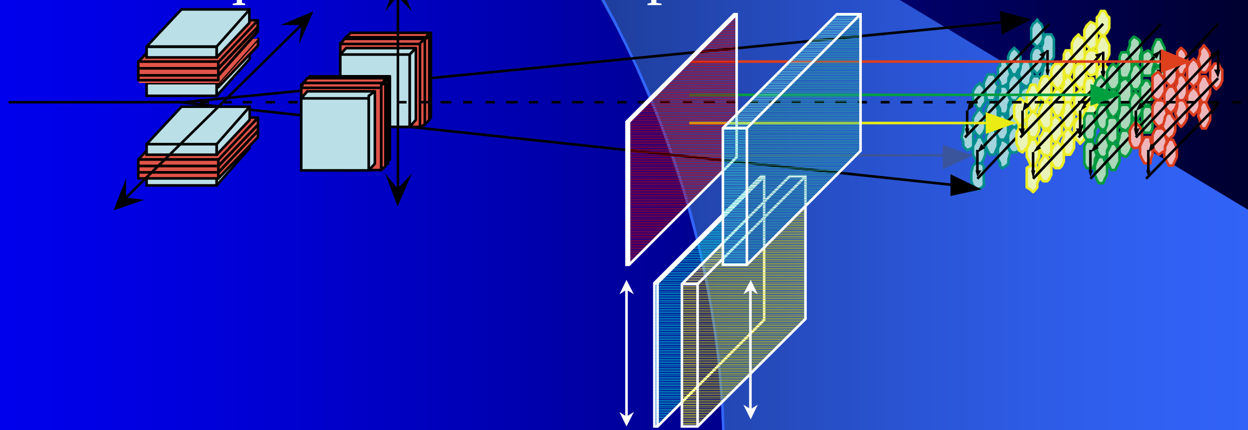
Beam Efficiency
90～100%



Merit/Demerit of Spot Scanning

Merit : ○3D-conformal Irradiation
○Better Utilization of the Beam
○Reduction of the Individual Hardware
○Fully Automated Computer Control

Demerit : ○Technical Complex
○Need Investment costs
○Sensitivity on Errors (from motion of organ etc.)
○Severe request for the Shape and Position of Beam Spot



Scanning for Treatment ~ Accelerator

Institute Accelerator	NIRS NIRS-Cyclotron	PSI PSI-Sector-Cyclotron	GSI SIS-Synchrotron	NIRS HIMAC-Synchrotron
Therapy Period	1979-1988	1994-	1997-	2004??-
Beam	Proton (70MeV)	Proton(85-270MeV)	^{12}C (80-430MeV/n)	^{11}C (-355MeV/n)
Beam Size	10mm-square collimated	5-15mm-FWHM	4-10mm-FWHM	~10mm-FWHM
Intensity	0.1 μ A	5 μ A	10^6-10^9 pps	~10^6 pps
Reference	T. Kanai et al.: Med. Phys. 7(4) (1980) 365	E. Pedoroni et al.: Med. Phys. 22(1) (1995) 37	T. Haberer et al.: NIM A 330 (1993) 296	E. Urakabe et al.: JJAP 40 (2001) 2540

Scanning for Treatment ~ Scanning System

Institute	NIRS	PSI	GSI	NIRS HIMAC
Scanning Method	X,Y: Magnetic Scan,	X: Magnetic scan, Z: Range shifter, Y: Movement of patient table	X,Y: Magnetic Scan, Z: Energy variation by Synchrotron	X,Y: Magnetic Scan, Z: Range Shifter
Beam Stopping	Beam shutter	Electrostatic-splitter & Fast kicker	Slow-Extraction & Tune shift out of resonance	RF-KO Slow-Extraction & its stopping

Scanning for Treatment ~Beam Monitors

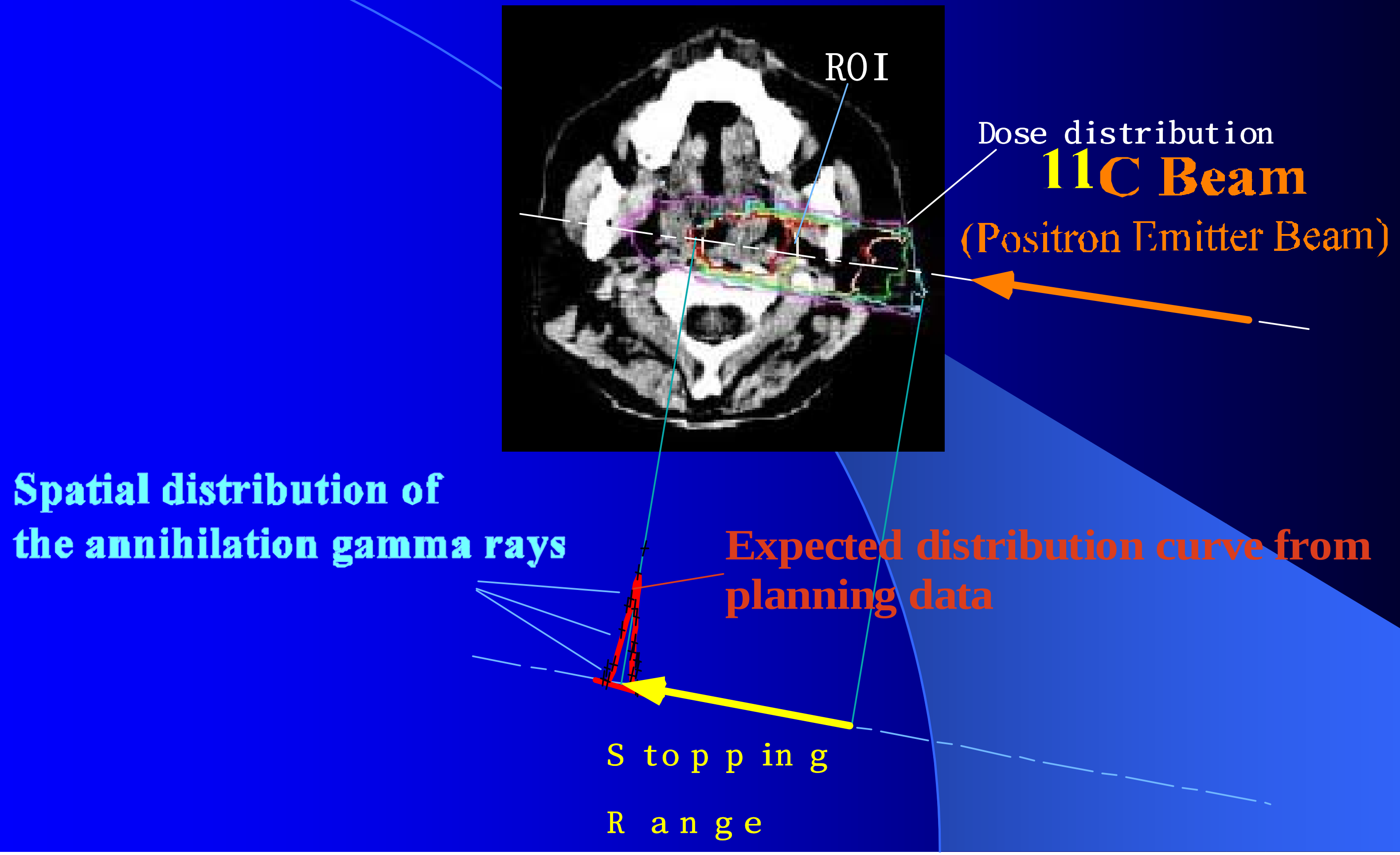
Transmission type

Institute	NIRS	PSI	GSI	NIRS HIMAC
Intensity Monitor (Effective Volume)	PPIC filled with Air. (300-ϕ × 10mm^3)	PPIC filled with Air. (220×30×5/10mm^3)	PPIC filled with N_2. (250×250×10mm^3)	PPIC filled with Air. (150-ϕ × 5mm^3)
Position Monitor	Small PPIC for check the initial beam position	Strip PPIC (4.44mm-width Al strip ×48/8 ch, 1spot-integrated)	MWPC (2mm-wire spacing ×126 ch, 100μs-integrated)	Strip PPIC (1mm-width Al strip ×152/112 ch, 1spot-integrated)

Range Verification using ^{11}C Beams

^{11}C is decay with positron emit at its range.

Direct measurement of beam stopping point, using PET detector.



Utilization of Spot Scanning with ^{11}C

Flow of the treatment:

1) Irradiation for treatment using ^{11}C Beams.
2) Check the irradiated field (The stopping point distribution of ^{11}C is measured by PET).
3) Feedback to the treatment planning.

^{11}C Beams has low intensity.

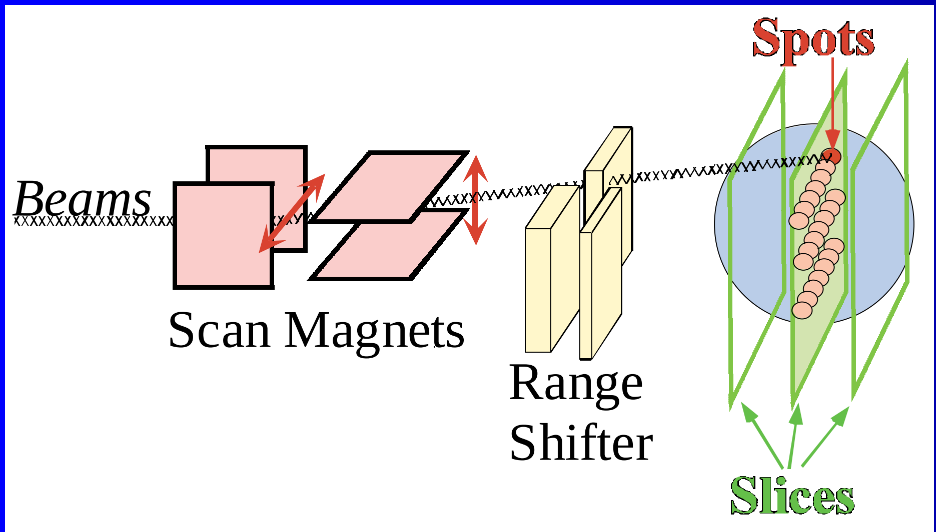
→ In order to use **^{11}C** for treatment irradiation, High Beam Efficiency is necessary.

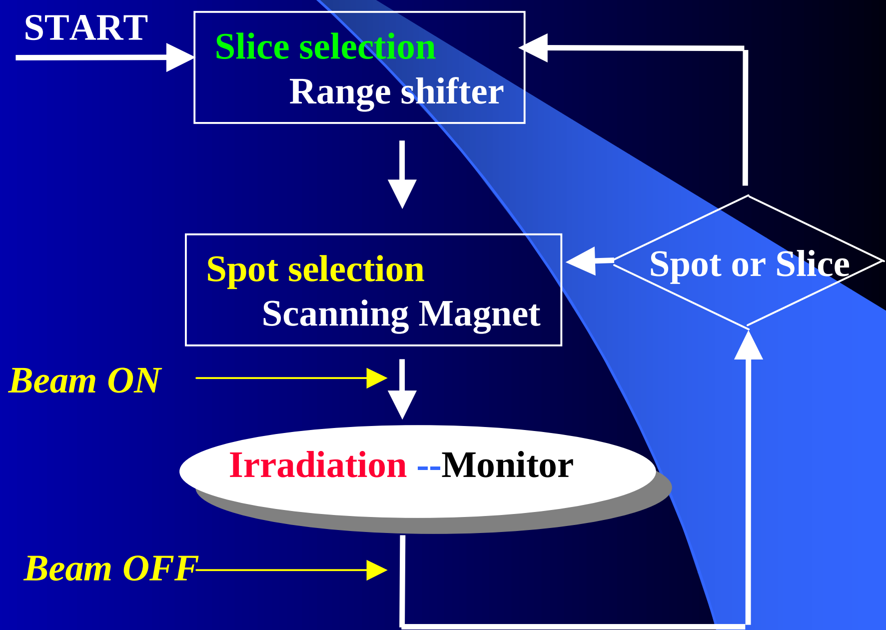
Specification of Spot Scanning@HIMAC

Irradiation Volume:	$100 \times 100 \times 180\text{mm}^3$
Maximum Range:	210mm
Intensity:	$10^6 \sim 10^9$ particle per second
Dose Uniformity:	within ±2%

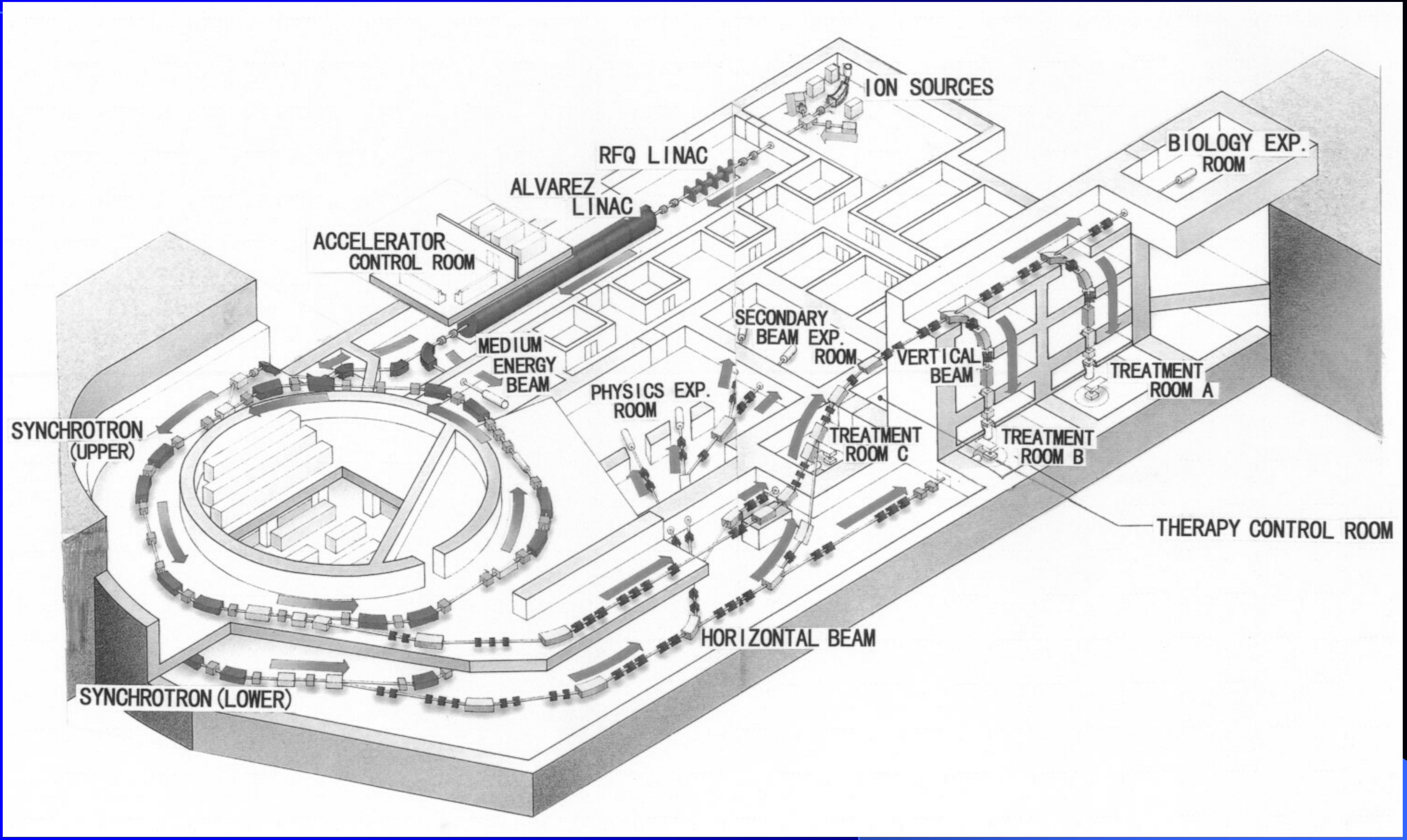
Spot Position Control:	Scanning Magnets, Range Shifter
Check for Each Spot:	Dose、Position and Width of spot beam
Beam Irradiation ON/OFF:	On/Off of the RF-KO Slow Extraction

Scanning Method @ HIMAC

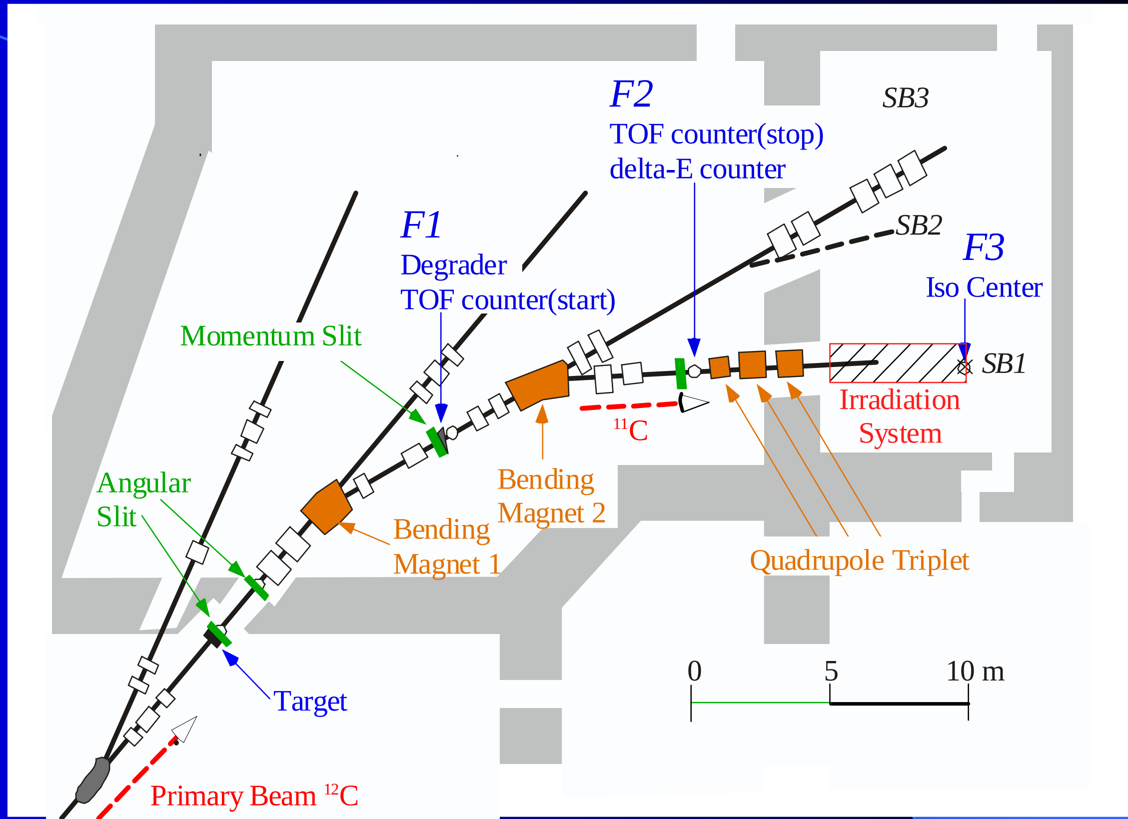




Heavy Ion Medical Accelerator in Chiba (HIMAC)



Secondary Beam Course



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

Production of ^{11}C Beams

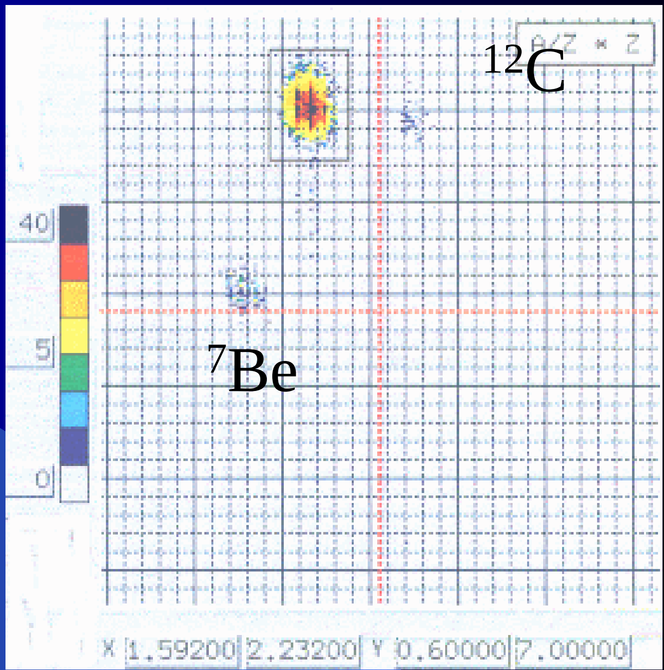
- Typical parameters:

–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)

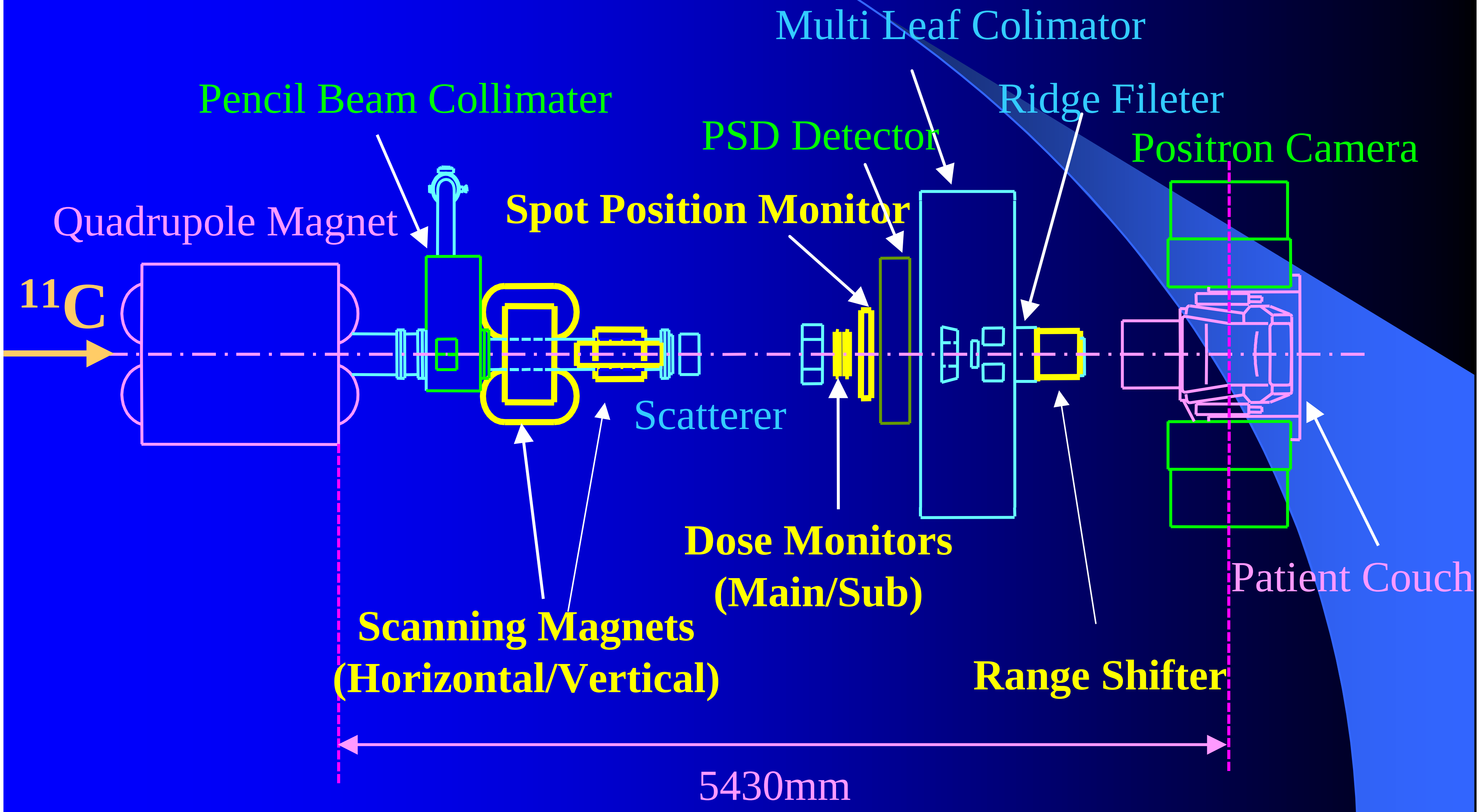
- Results:

–Energy of secondary ^{11}C	355MeV/n
–Range in water	21cm
–Production rate	0.4%
–Purity	93%
–Beam size at patient	9mm (FWHM)

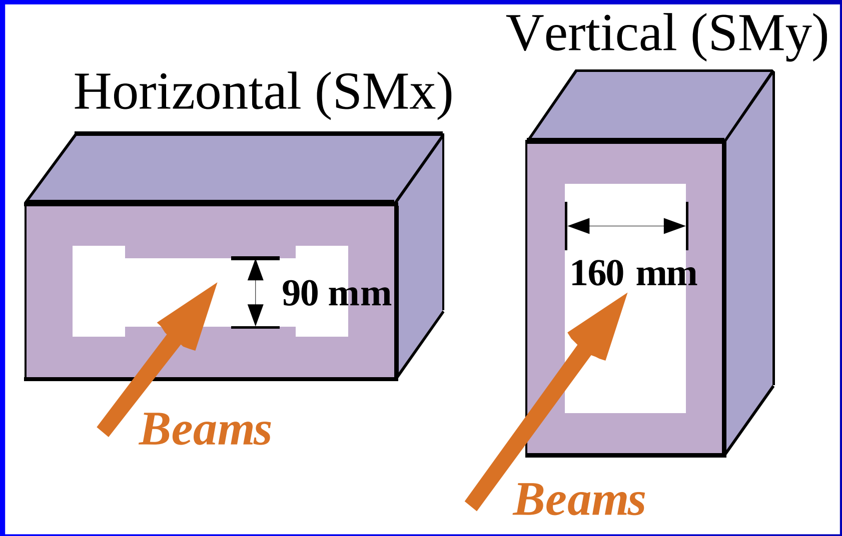
^{11}C

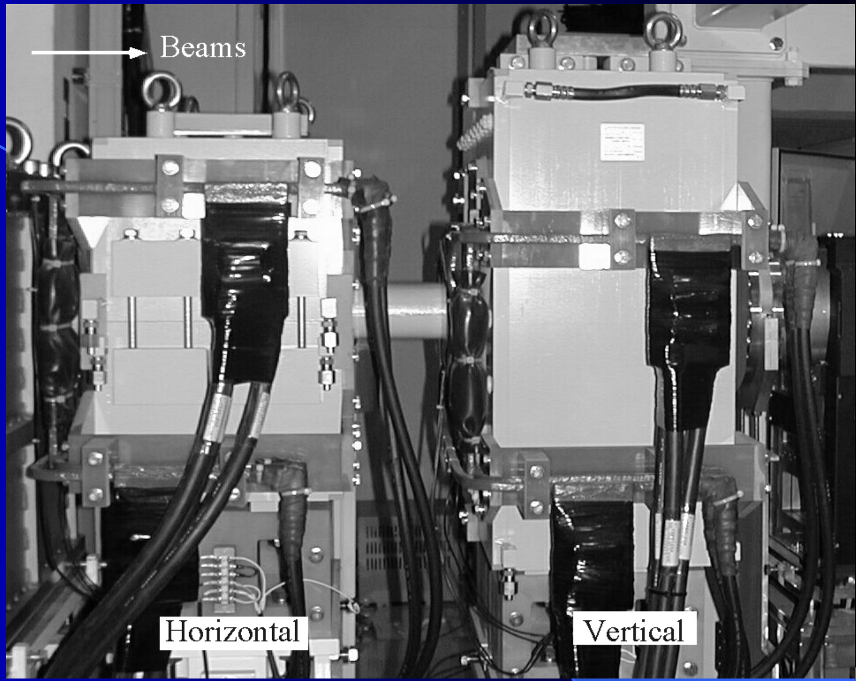


Irradiation System



Scanning Magnets

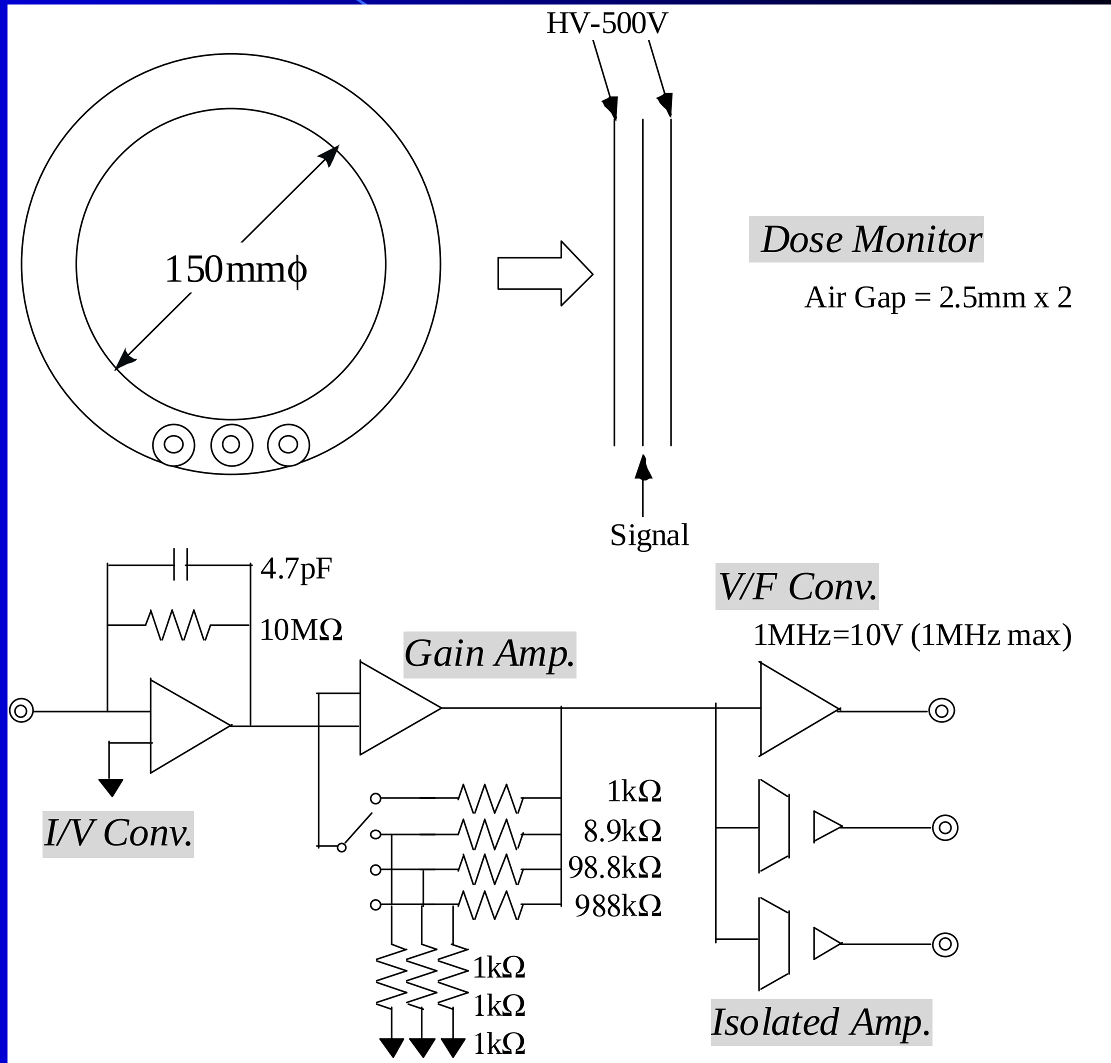




・Irradiation Field of 100×100mm^2 ・Transition between spots（350MeV/u ^{12}C)	14.2mrad 1mm/0.2msec	16.6mrad 1mm/0.5msec

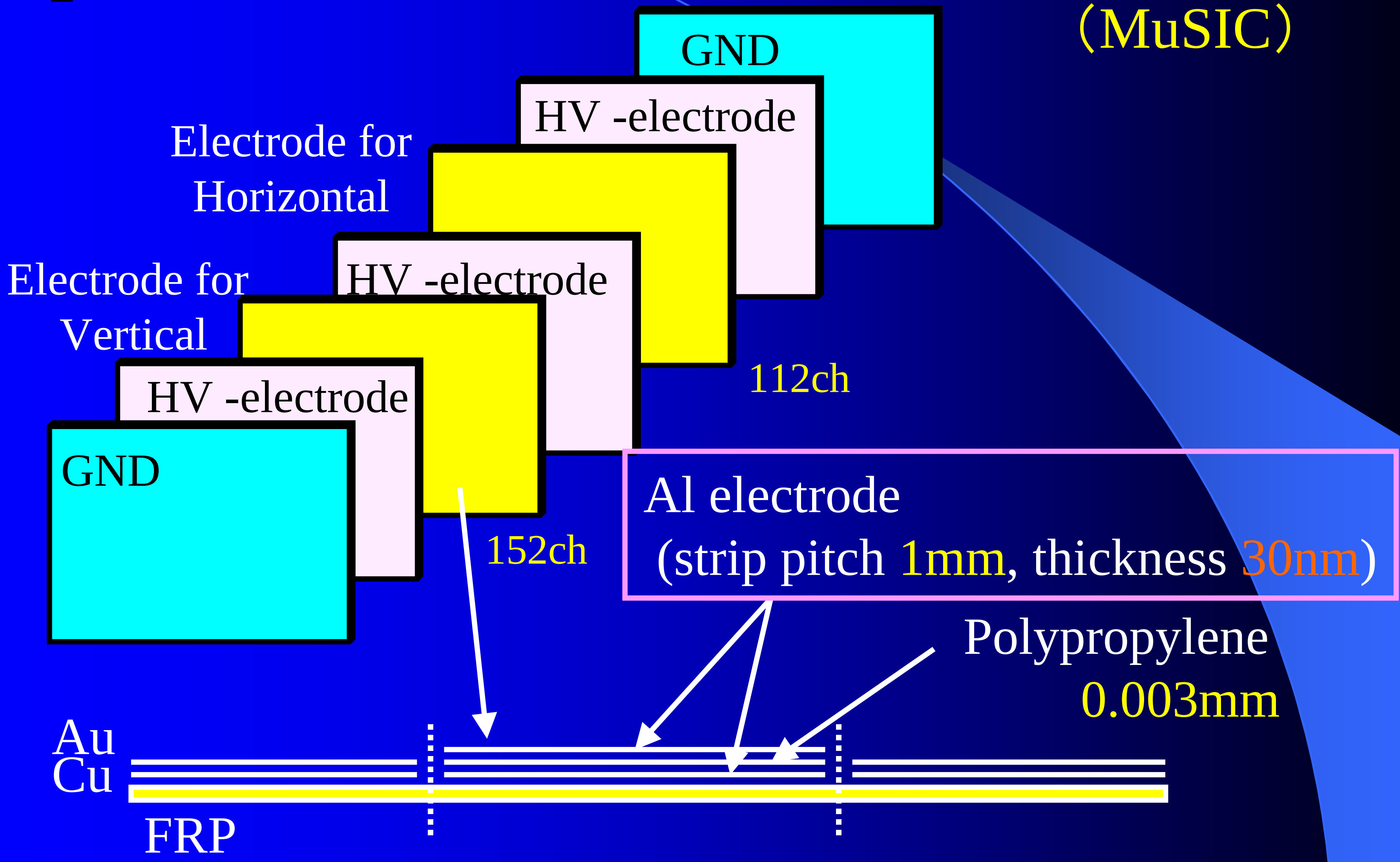
Field of 100×100×50mm^3 irradiated with spot spacing of 5mm：
No. of spot = 20×20×20=8000 →Transition time ≦ 10sec
↓↑
Total Irradiation time = 10-20 min.

Dose Monitor

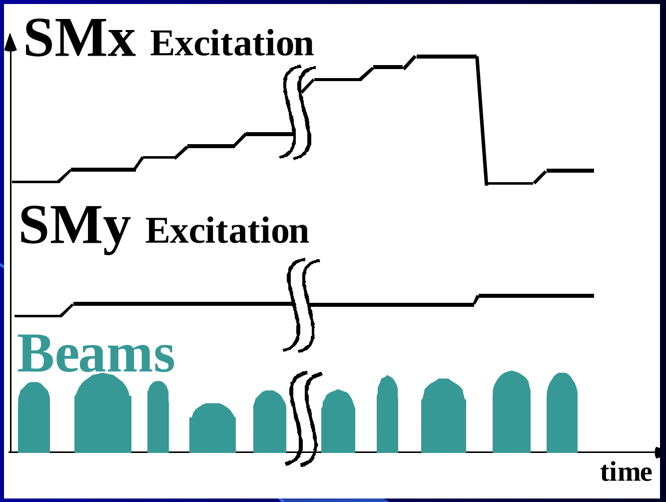


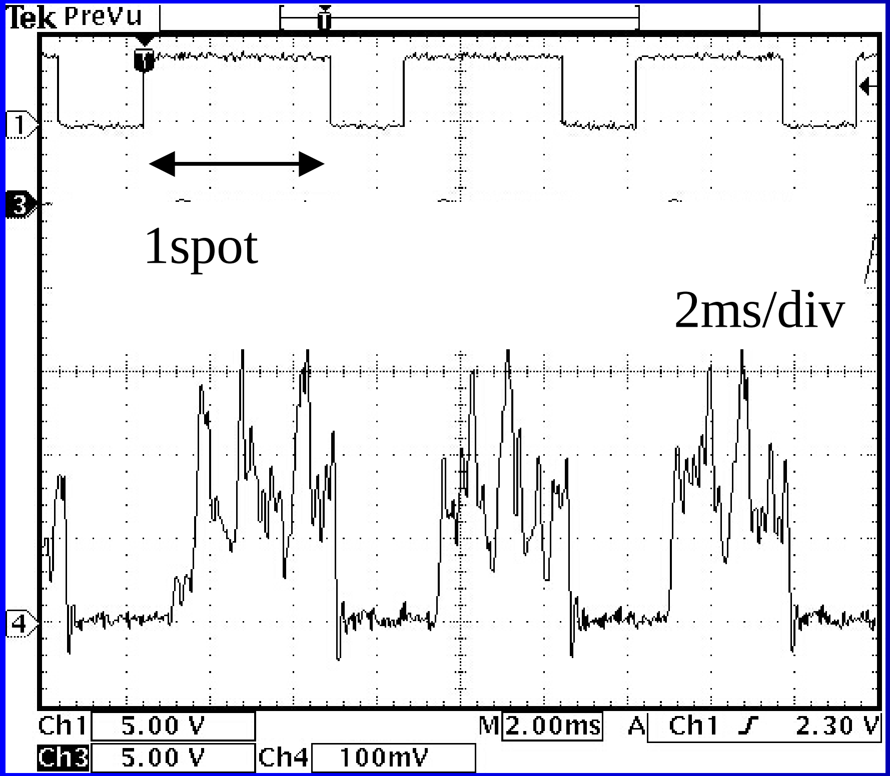
Spot Position Monitor

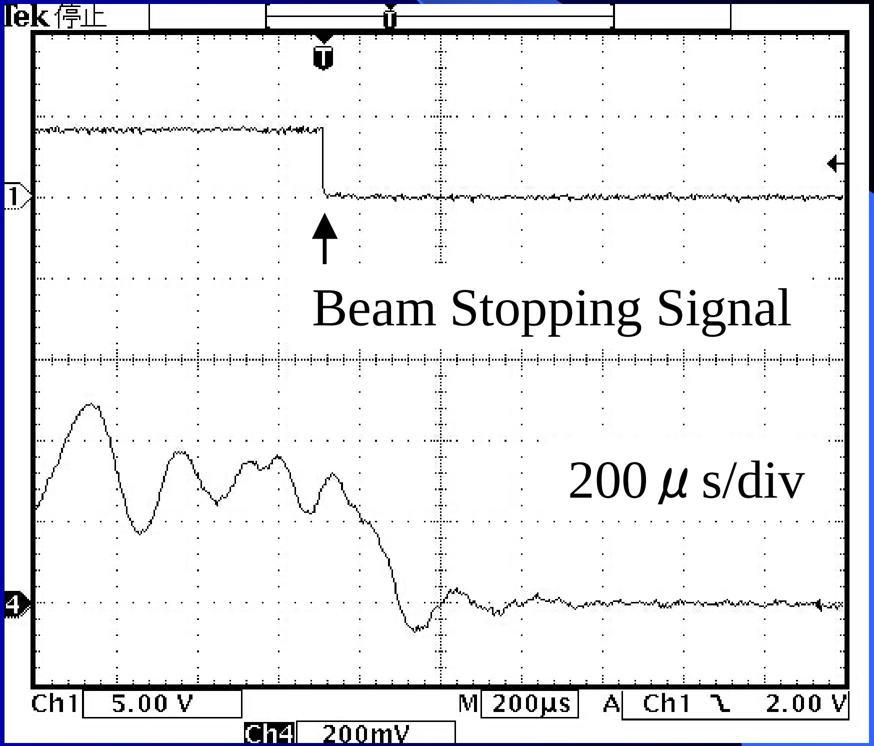
Multi-strip
parallel plate ionization chambe
（MuSIC）



Beam On/Off at Each Spot







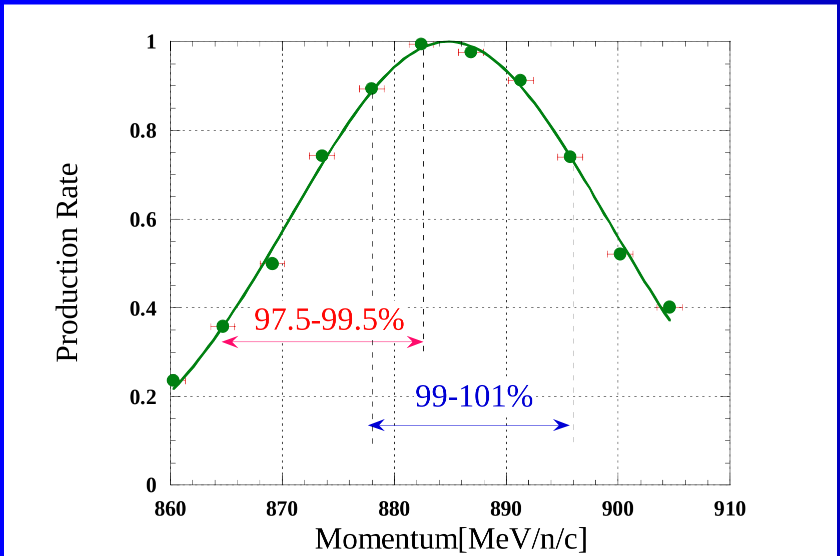
Design the Depth Dose Distribution of Spot

1) Maximize the Beam Efficiency
2) Optimize the Number of Slices
3) Minimize the Distal Falloff

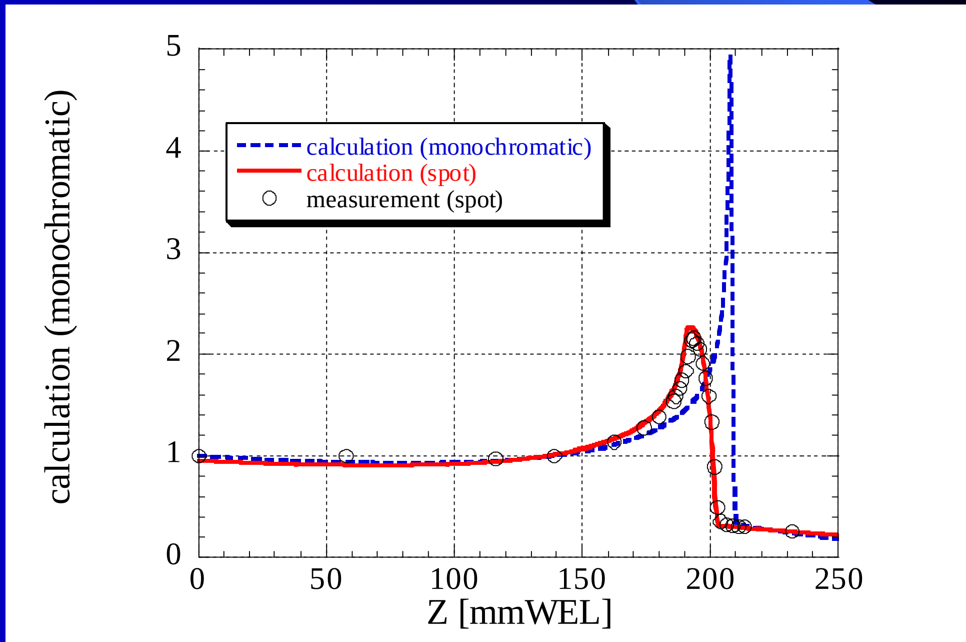
Decided Parameter

Primary Beam : ^{12}C(430MeV/n)
Production Target : Be 51mm-t
Momentum Distribution : 97.5-99.5%

Momentum Distribution of ^{11}C

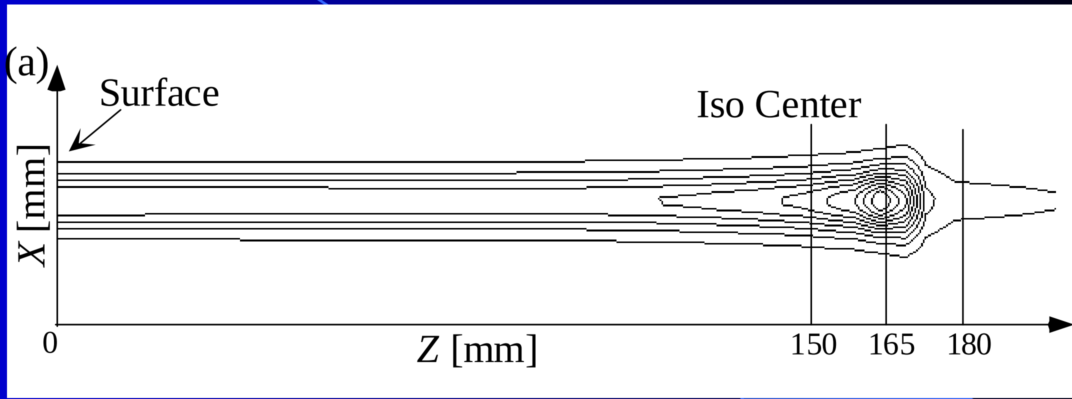


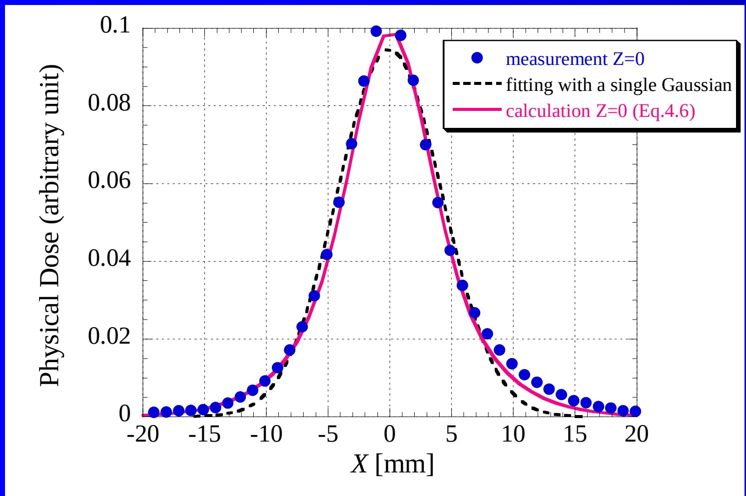
Depth Dose Distribution ^{11}C (355MeV/n)

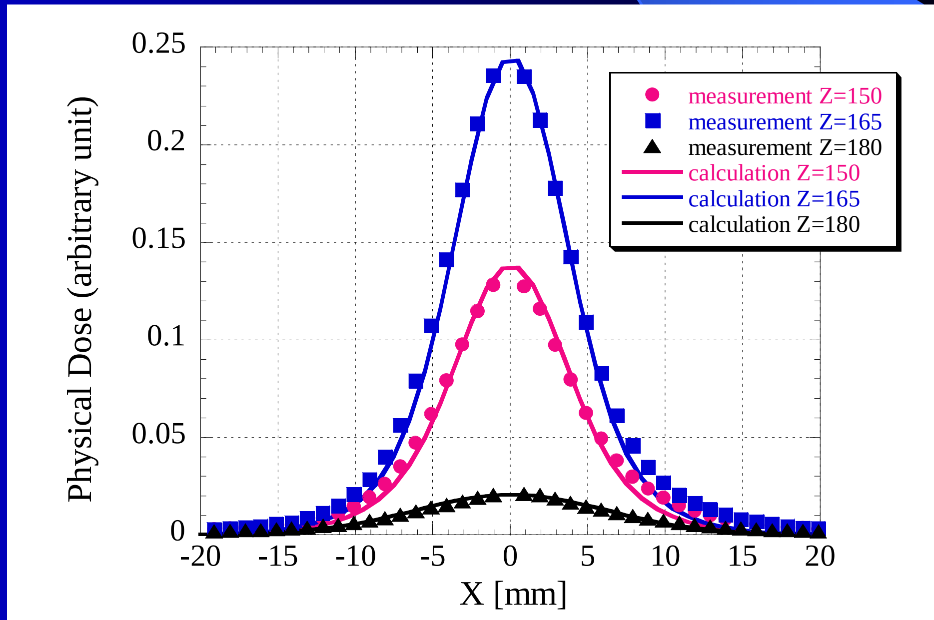


Dose Distribution of Spot Beam

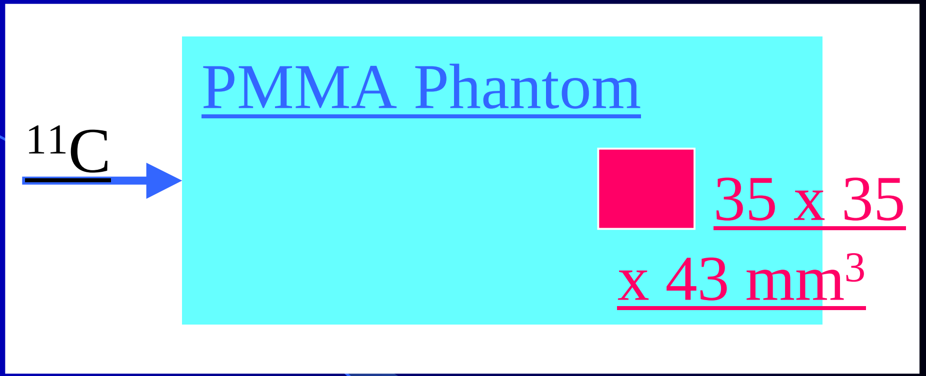
Dose Distribution of ^{11}C(874MeV/c/n,±1%) in PMMA phantom



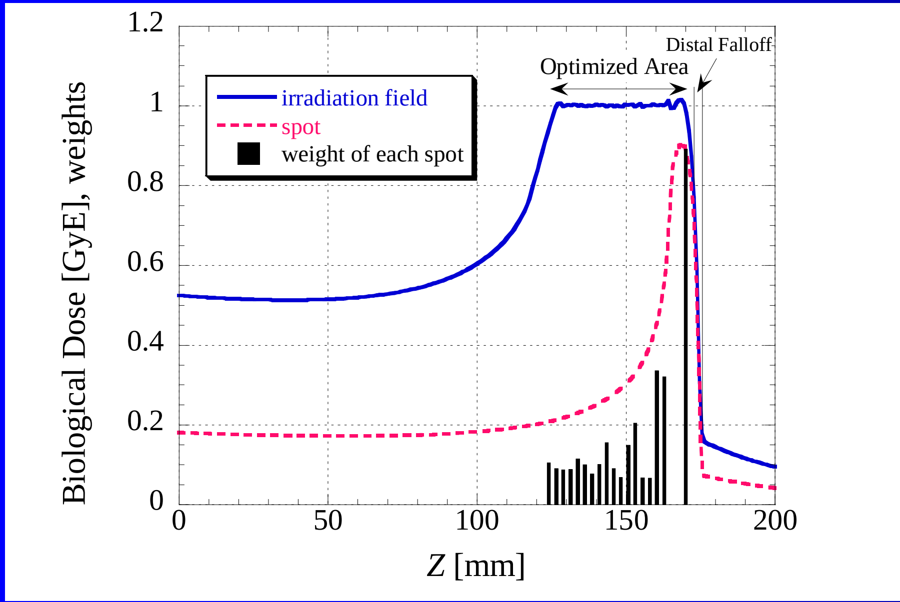




Irradiation Field

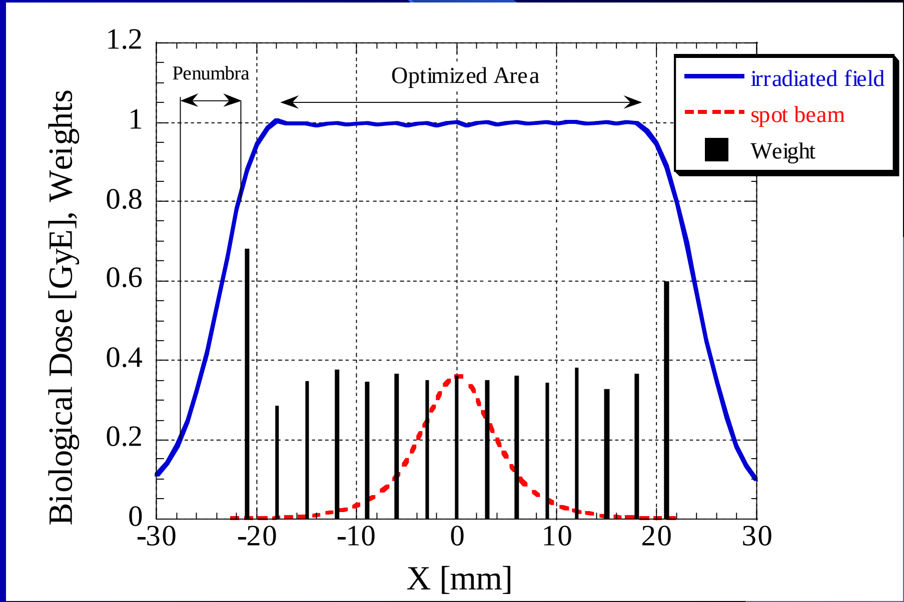


Depth Dose Distribution



Distal Falloff (80-20%)
＝2.7mm

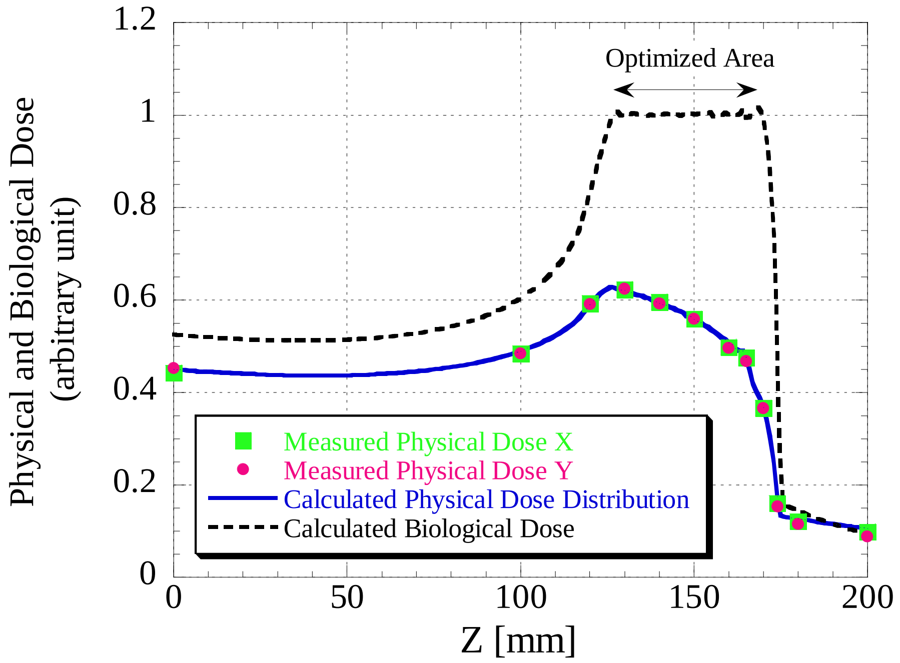
Lateral Dose Distribution



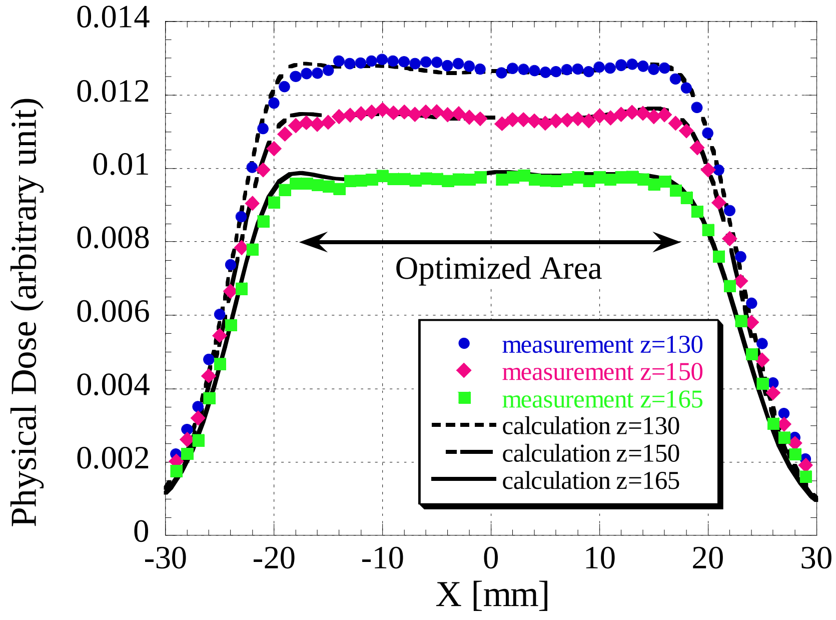
Spot Size（FWHM)＝9mm
Penumbra (80-20%) ＝ 6.1mm

Dose Distribution

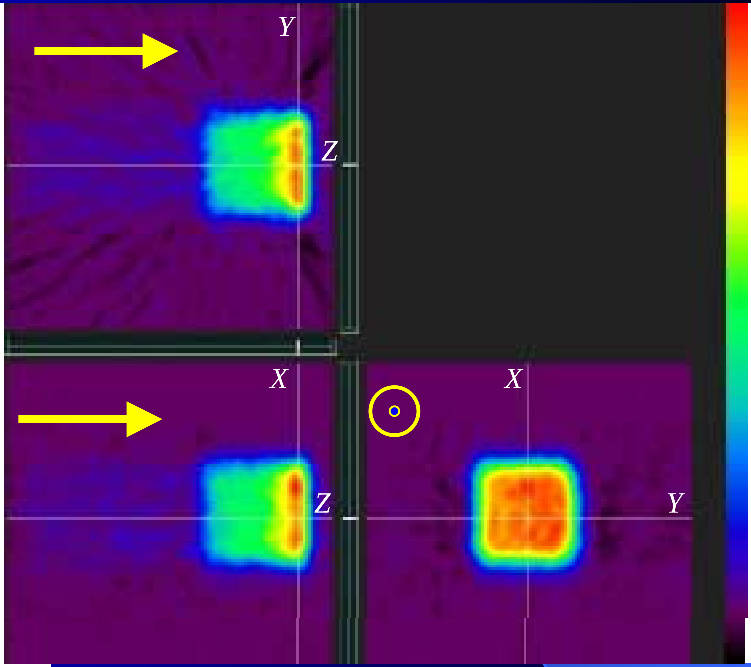
Depth Dose Distribution

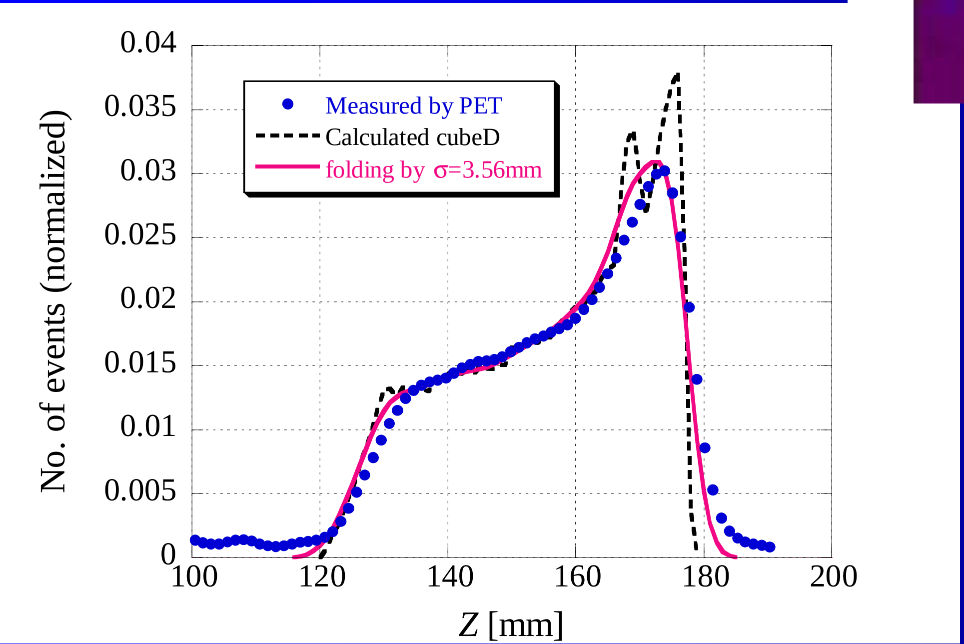


Lateral Dose Distribution



Stopping point measured by PET





Volume of Irradiation Field

$35 \times 35 \times 43 mm^3$

Dose at Center

1.0 Gy

Summary

Present Status:

- ○The parameter for spot beam is investigated.
- ○Spot-scanning irradiation-system is installed.
- ○3-D irradiation field is formed.
  - The dose distribution is measured by ionization chamber.
  - The stopping point distribution is measured by PET.

Future Plan:

- ○Patient positioning system.
- ○The parameter of the spot beam for treatment.
- ○The database for the input of treatment planning.
  - (dose distribution of spot beam in water etc.)
- ○Dose measurement system
- ○Treatment planning
- ○Quality Assurance

・・・

Request from Spot Scanning

- Beam Energy
  - -Maximum Range = 30cm in water (Proton ~ 230MeV)
  - -Energy variation for slices
- Beam ON/OFF
- Intensity Modulation
  - -Provide the beams for each spot in error by less then 1% of the prescribed dose.
- Beam Size and its stability
- Beam Position and its stability