Medical Applications with FFAG Accelerator in Japan

Yoshiharu Mori
Research Reactor Institute, Kyoto University

Contents

- Introduction
- FFAG(Fixed Field Alternating Gradient) accelerator
  - principle & features
  - development history
- FFAG for hadron beam therapy
- FFAG for BNCT(Boron Neutron Capture Therapy)
- Summary

Introduction

- Accelerator for medical applicatin
  - Diagnosis - PET （Cyclotoron, Linac）
  - Therapy - Xray （Linac） Hadron beam - p,C(Cyclotron,Synchrotron)
- Subects for future advanced therapy
  - Hadron beam low cost, advanced treatment （spot scanning）
  - BNCT(Boron Neutron Capture Therapy) Intense neutron source instead of nuclear reactor
  - Hybrid treatments DDS(Drug Delivery System)
- FFAG(Fixed Field Alternating Gradient)

FFAG: Fixed Field Alternating Gradient

- Strong focusing (AG focusing, phase focusing)

  It is like synchrotron.

- Orbit excursion

  It is like cynclotron, but not much.

- zero-chromaticity

  Constant phase advance/turn (betatron tune): Scaling FFAG

  cf. Non-scaling FFAG

Advantages of FFAG

- Fast acceleration
  - DC magnetic field allows the beam acceleration only by RF pattern. No needs of synchronization between RF and magnets.
- High intensity with large repetition rate and modest number of particles in the ring
  - Space charge and collective effects are below threshold.
- Large acceptance
  - Transverse (hor.)>10,000mm.mrad
  - Longitudinal dp/p>10%

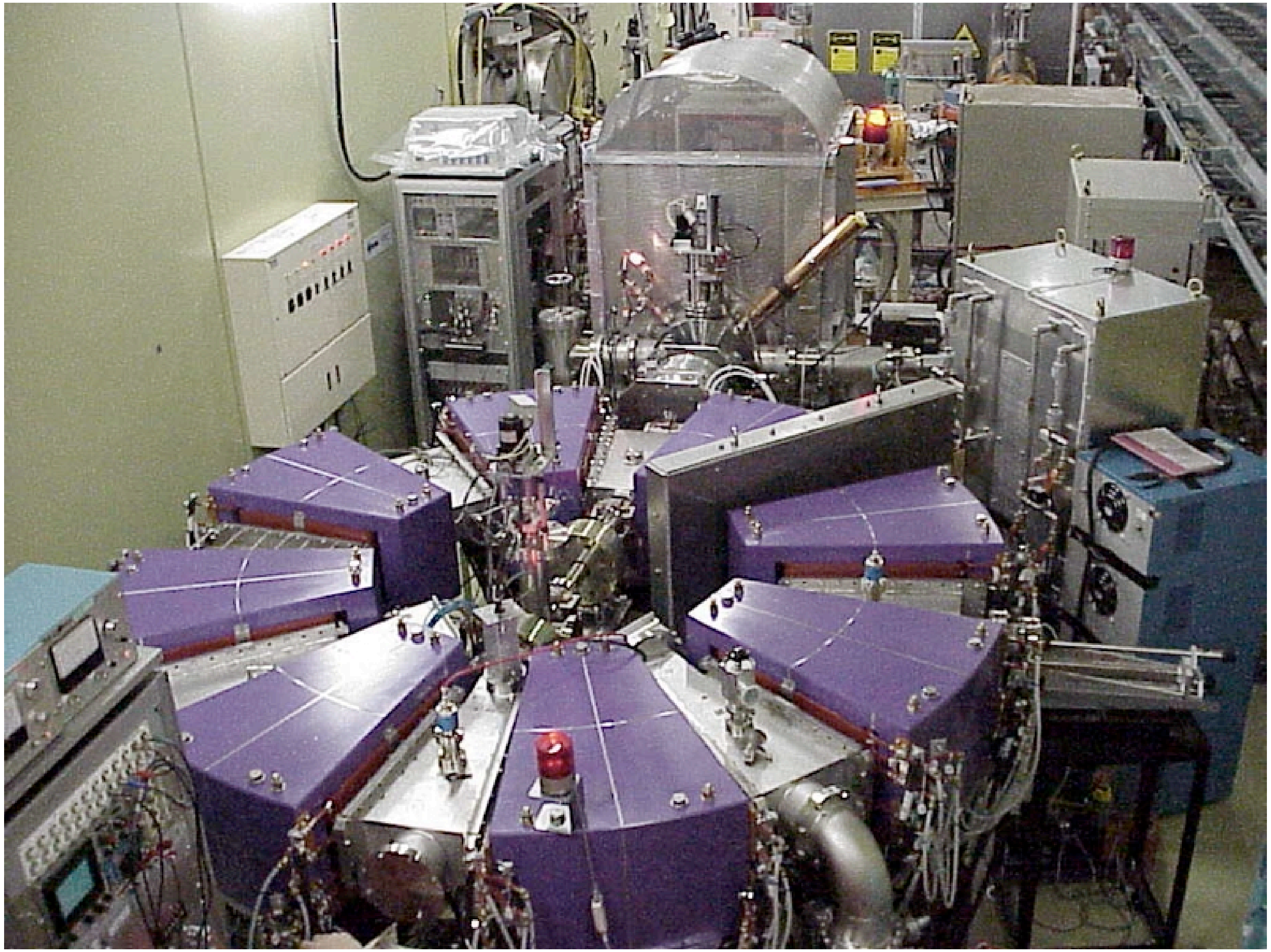
FFAG Accelerators : Hisotry

- *Ohkawa (1953), Kerst & Symon, Kolomenski*
  - *MURA project e-model, induction acceleration ~'60s*
- *No practical machine for 50years!*
  - *Complicated magetic field configuration : 3D design*
  - *RF cavity :Variable Frequency & High Gradient.*

– **Proton FFAG!** (world first)

-----> PoP FFAG @KEK, 1999

PoP proton FFAG !



- World first proton FFAG, 1999 at KEK

International Workshop on FFAG Accelerator

- (history)
  - 1st FFAG99 (Dec. 1999) KEK PoP-FFAG first beam!
  - 2nd FFAG workshop (July 2000) CERN
  - 3rd FFAG00 (Oct. 2000) KEK
  - 4th FFAG02 (Feb. 2002) KEK 150MeV FFAG approved
  - 5th FFAG workshop (Sept. 2002) LBL
  - 6th FFAG03 (July 2003) KEK
  - 7th FFAG workshop (Sept. 2003) BNL
  - 8th FFAG workshop (Mar. 2004) TRIUMF
  - 9th FFAG04 (Oct. 2004) KEK 150MeV FFAG acceleration
  - 10th FFAG workshop(Apr. 2005) FNAL 150MeV FFAG extraction
  - 11th FFAG05 (Dec. 2005) KURRI 150MeV FFAG 100Hz
  - 12th FFAG2006 (May 2006) BNL

Almost twice per year! One the most active fields in accelerator physics and technology.

150-MeV proton FFAG accelerator 2001-2005

- Prototype for various applications:

  @Madical application

  Hadron Beam Cancer Therapy

Media Contact:
Youhei Morita, KEK Public Relations Office, +81 29-879-6047

Press release URL:
http://www.kek.jp/intra-e/press/2006/FFAG.html

Press Release
1 May 2006

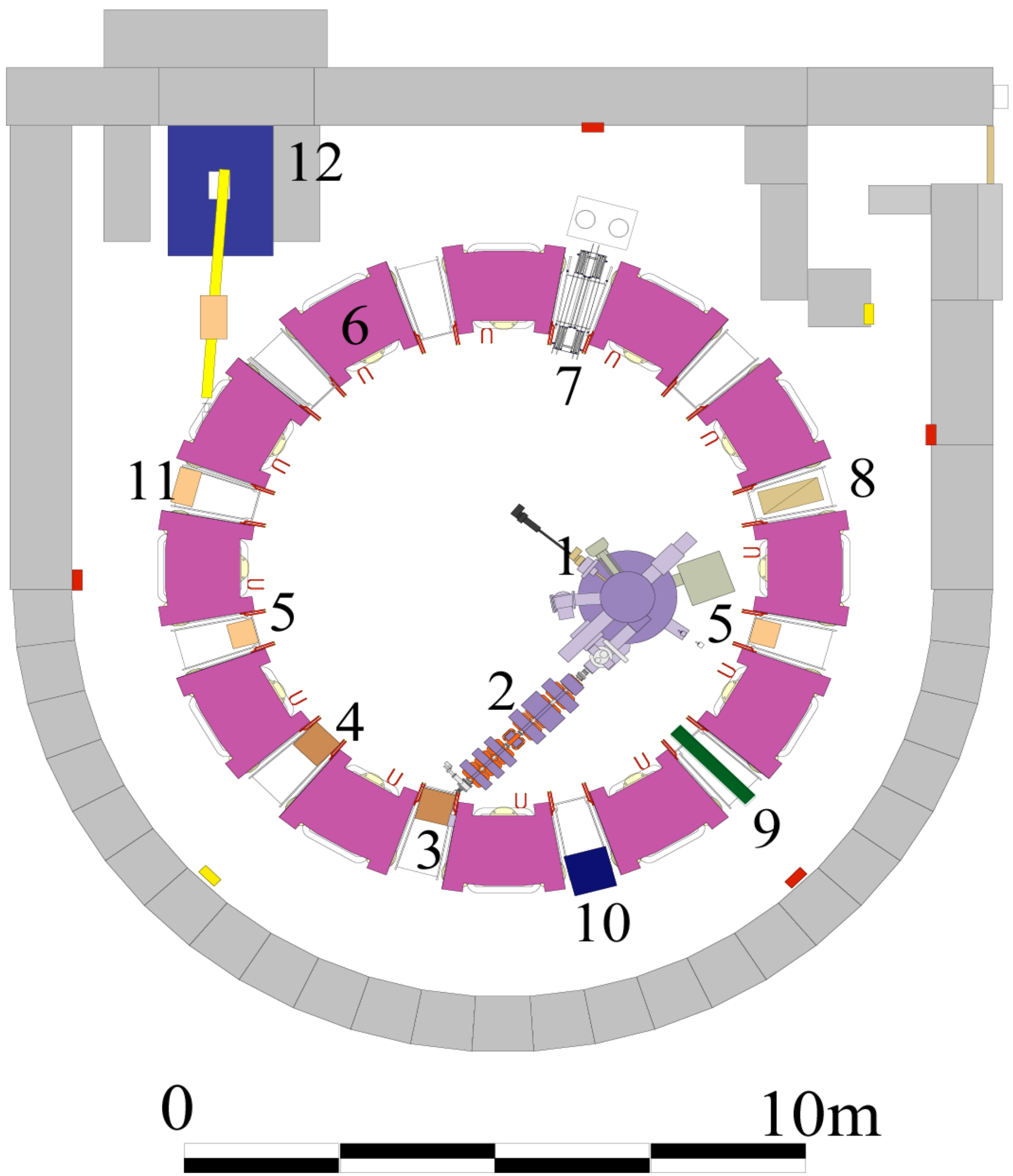
For immediate release

An FFAG synchrotron accelerates protons to 100MeV at a repetition rate of 100Hz.

Tsukuba, Japan - Accelerator physicists and engineers at KEK, High Energy Accelerator Research Organization announced today (May 1, 2006) the successful acceleration of protons up to 100MeV at a repetition rate of 100Hz with a Fixed Field Alternating Gradient (FFAG) Synchrotron. The high repetition rate of acceleration had not been possible in any other type of accelerators before.

"FFAG proton synchrotron opens a door to the new type of research using it's rapid acceleration cycles," Yoshiharu Mori, professor of Kyoto University and of KEK, points out the uniqueness of the accelerator. "It was originally conceived by a Japanese physicist Chihiro Ohkawa in 1953, and has the merits of both traditional synchrotrons and cyclotrons. It enables the acceleration of particles to the desired energy with rapid cycles."

Schematic view
150MeV FFAG



1. Injection cyclotron
2. Injection line
3. Injection septum magnet
4. Injection ES septum
5. Bump magnet
6. Triplet magnet
7. RF cavity
8. Beam position monitor
9. Current monitor
10. Extraction kicker
11 Extraction septum
12 Beam dump

Main parameters
150MeV FFAG

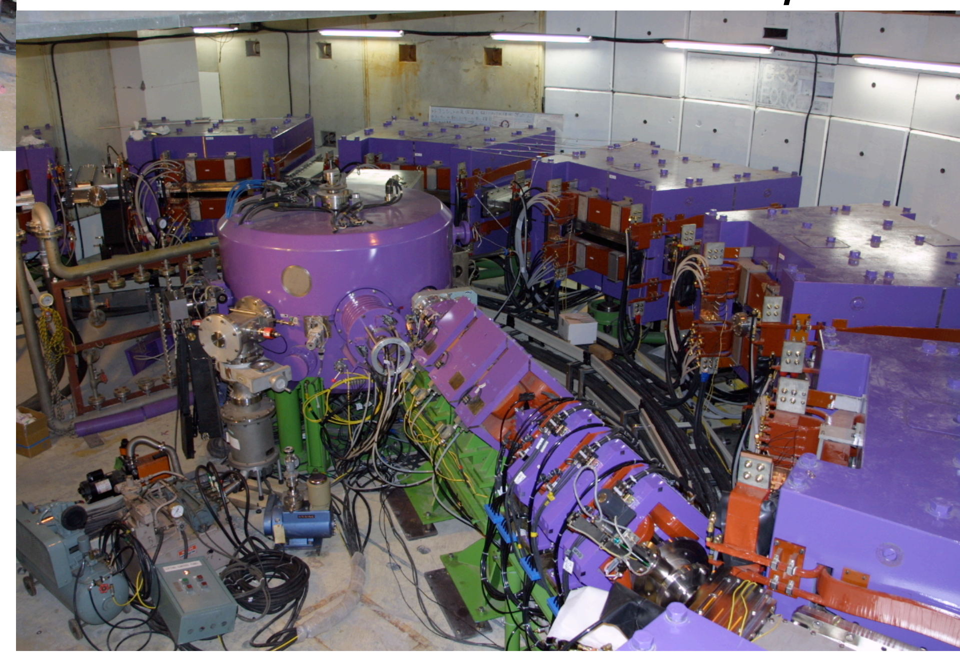
No. of sectors	12
Field index(k -value)	7.5
Energy	12MeV - 150MeV
Repetition rate	250Hz
Max. Magnetic field	
Focus-mag.	1.63 Tesla
Defocus-mag.	0.13 Tesla
Closed orbit radius	4.4m -5.3m
Betatron tune	
Horizontal :	2.7
Vertical :	1.2
rf frequency	1.5 -4.6MHz

150MeV FFAG Proton Accelerator 2003 Apr.

Cyclotron(Injector) and Beam transport

Cyclotron

- 10 MeV proton beam
- 250Hz pulse operation
- Max. extraction current 0.5 μ A

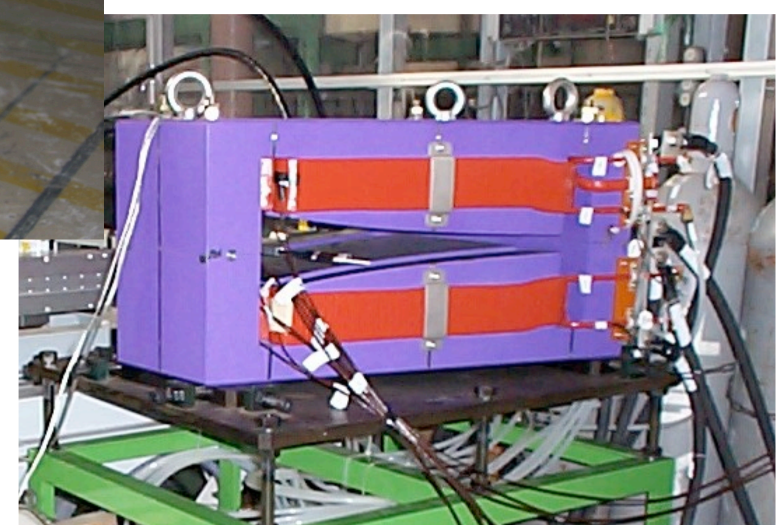


Transport

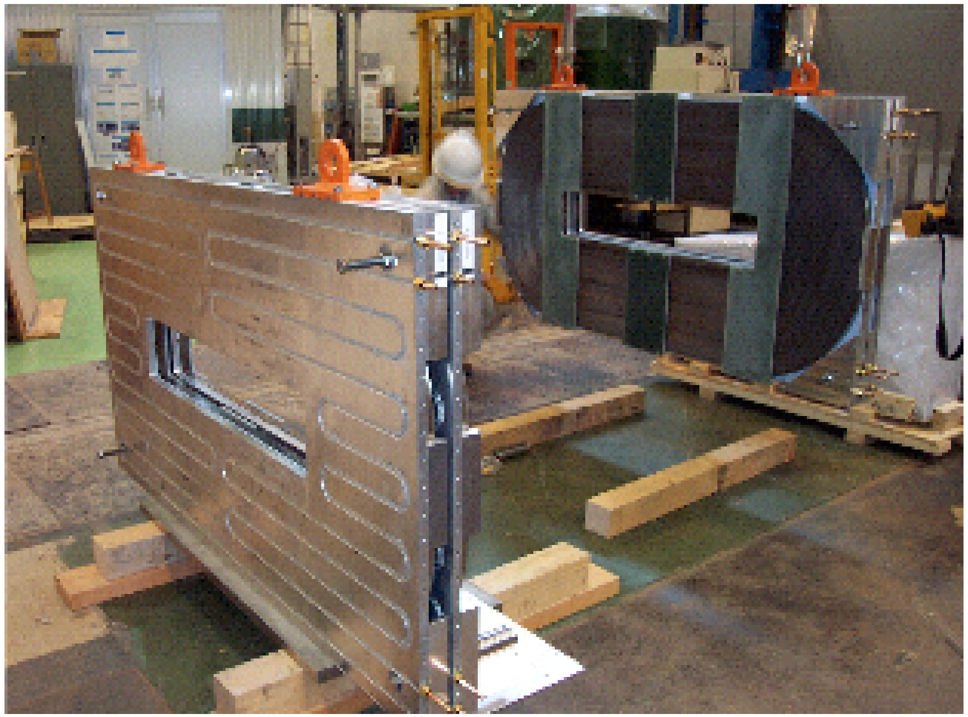
2 sets of steering+triplet Q mag.

150 MeV FFAG - Return Yoke Free Magnet

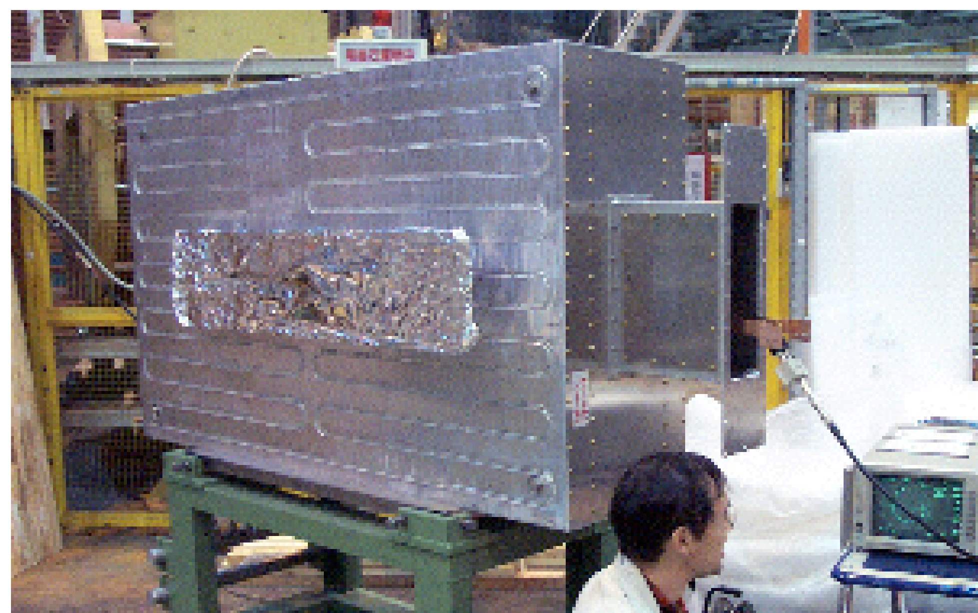
150 MeV FFAG magnet, the view from the center of the ring.



RF Cavity assembly



Number of cores	2~4
Outer size	1.7m x 1m
Inner size	1m x 0.23m
RF frequency	1.5 - 4.6 MHz
RF voltage	9 kV
RF output	55 kW
Power density	1 W/cm^3
Cooling water	70 L/min



150-MeV FFAG beam intensity

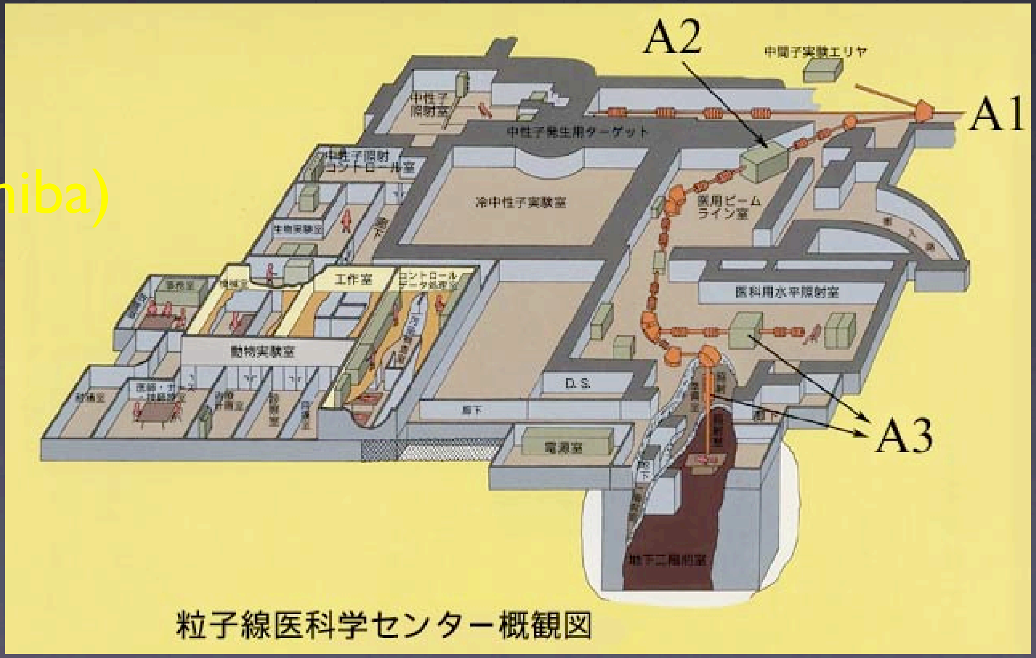
- Injected beam
  - Energy 10 MeV (not 12 MeV)
  - Repetition rate 100Hz
  - Intensity Ip=10 μA at injection septum
  - Turn number ~2turns(ave.) : ΔT=1.7 μsec
  - Np=1.1 x 10^8ppp, Ip=1.7nA
- Extraced beam after acceleration
  - Energy 100MeV
  - Ip=1.5nA after beam extraction, Efficiency: ~85%
  - Adiabatic capture effecitve but not perferct.
  - Looks small beam loss after rf capture.

Hadron Beam Therapy

History of Hadron Therapy in Japan

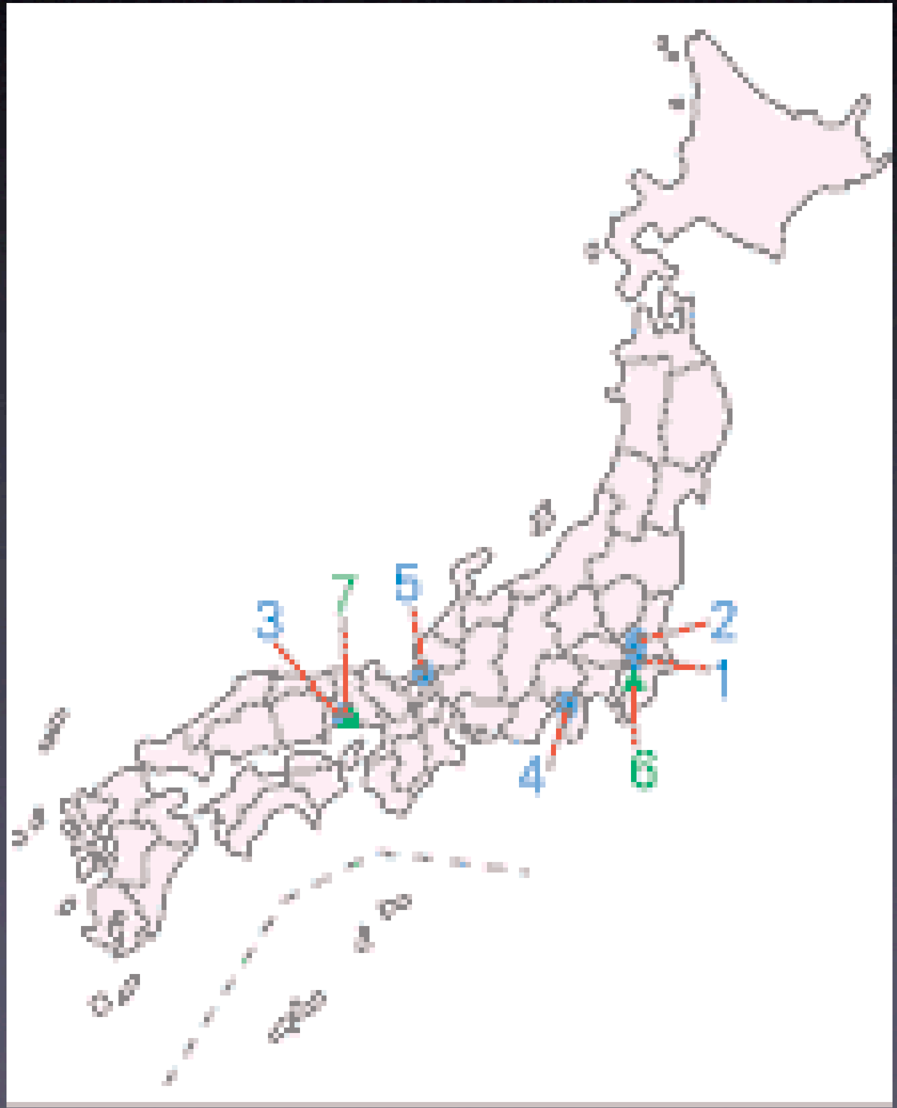
- 1980~2002 Proton therapy with the 500-MeV KEK booster. Profs. Suwa (first DG of KEK),Nishikawa(2nd DG).
  - E=250MeV(degraded from 500MeV)
  - Pulsed beam 20Hz
  - Intensity ~10E11ppp, 5Gy/min
  - Respiration mode (first invented)
  - Number of patients ~900
- 1994~ Carbon therapy at HIMAC(chiba)
  - E=400MeV/u(C)
  - Slow extraction ~0.5Hz
  - Intensity ~5E09ppp
  - Number of patients ~1500

KEK Particle Medical Center
1980-2002



Hadron Therapy Facilities in Japan

- Proton
  1. National Cancer Center 2001~
     Cyclotron(IBM)
  2. Tsukuba Univ. 2002~
     Synchrotron(Hitachi)
  3. Hyogo Pref. 2001~
     Synchrotron(Mitsubishi Ele.)
  4. Shizuoka Pref. 2003~
     Synchrotron(Mitsubishi Ele.)
  5. Wakasa-wan 2003~
     Synchrotron(Hitachi)
- Carbon
  6.HIMAC 1994~
     Synchrotron(misce.)
  7Hyogo Pref. 2001~
     Synchrotron(Mitsubishi Ele.)
- New 3 facilities (2:p, 1:C) approved



Requirements

To extend the use of Proton Therapy widely in (Japanese)society

- Efficient treatment
  - >500pateints/year
- High dose rate
  - >5Gy/min.
- Flexibility (various types of cancer)
  - Respiration mode
  - Spot scanning
- Easy operation
- High maintenance ability
  - Small residual radio activities
- Small cost
  - Construction and operation

Beam Intensity

>5Gy/min. with respiration mode

Proton Therapy

- Biological effect
  - RBE (proton) ~1.0-1.1
- Proton equivalent dose
  - E=250MeV (measured at KEK) ~ 0.1Gy/10^{11}protons
- Respiration mode treatment
  - Duty factor ~0.3
- Beam collimation, range filter,etc.
  - Efficiency ~0.5

Required Beam Intensity

$$N_p = \frac{5[Gy/\min]}{0.1[Gy]} \times \frac{10^{11}[p]}{0.3 \times 0.5} = 3.33 \times 10^{13}[p/\min] \approx 89\,nA$$

ビーム強度

- Synchrotron
  - ~1x10^{11} ppp @Einj=7MeV(Space charge limit)
  - Ip ~ 16nA @1Hz
- Cyclotron
  - Ip ~ 200nA (NCC)
- FFAG
  - Ip ~ 200nA @100Hz, Np=1.3x10^{10} ppp <<SCL

Maintenance

residual radio activity

Need small beam loss of < 1W/m at beam extraction.(beam power, P~20W)

- Synchrotron
  - No problem : Low current & High extraction efficiency
- Cyclotron
  - Problem : Poor extraction efficiency <70% cf. Need a cooling off time of >10days (NCC).
- FFAG
  - No problem : Fast extraction with kicker >95%

Features

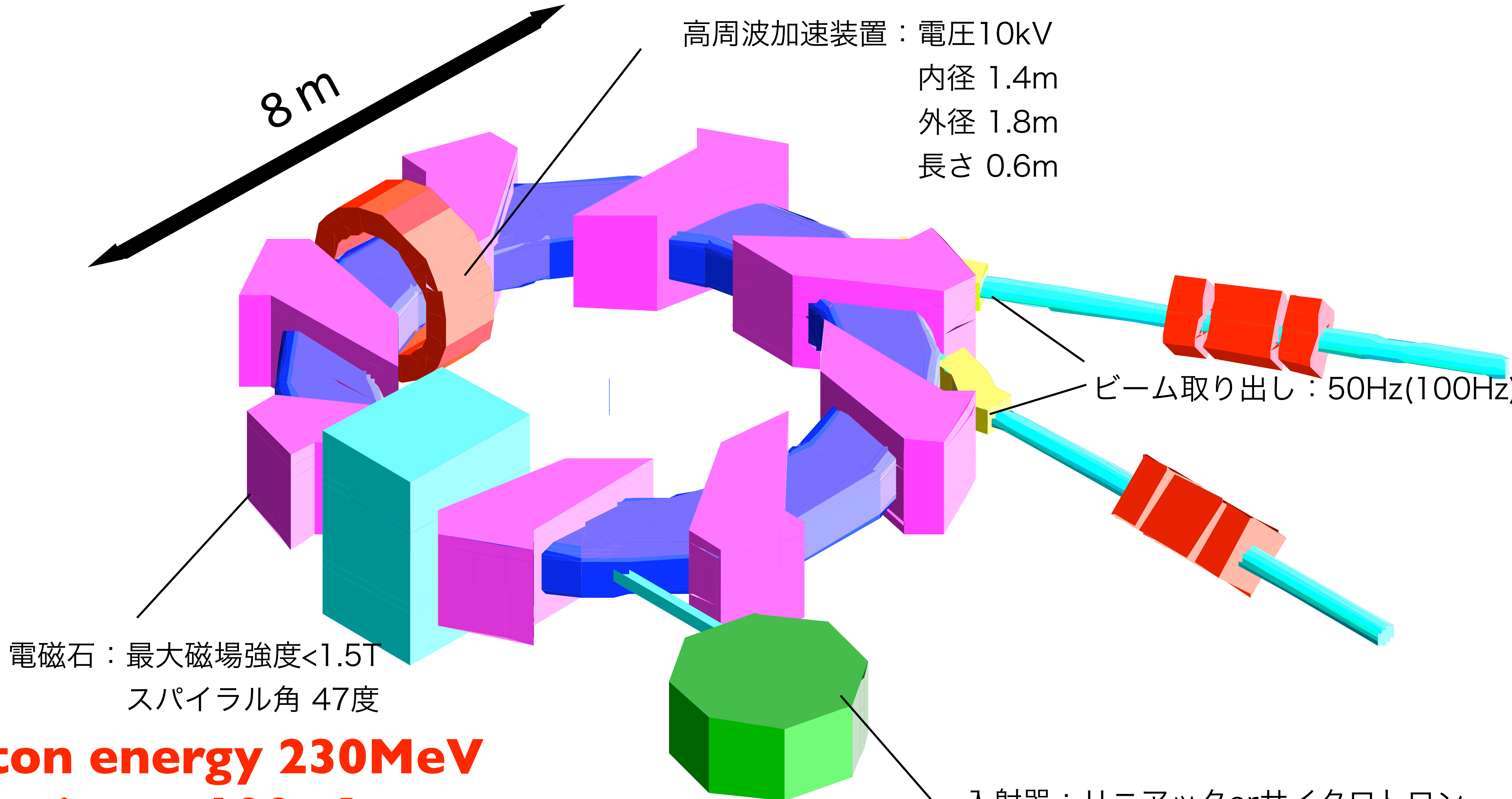
proton therapy accelerator

	Synchrotron	Cyclotron	FFAG
• Intensity	Low	Enough	Enough
• Maintenance	Normal	Hard	Normal
• Operation	Not easy	Easy	Easy
• Multi-extraction	Difficult	No	Yes

Accelerator for Hadron(proton) Therapy

- Requirements
  - Proton energy 250MeV (variable)
  - Intensity >100nA : 5Gy/min
  - Beam extraction efficiency >90%
- Synchrotron 1~16nA, not enough
- Cyclotron Extraction efficiency ~<70%
- FFAG 1 > 100nA (100Hz), Extraction >95%

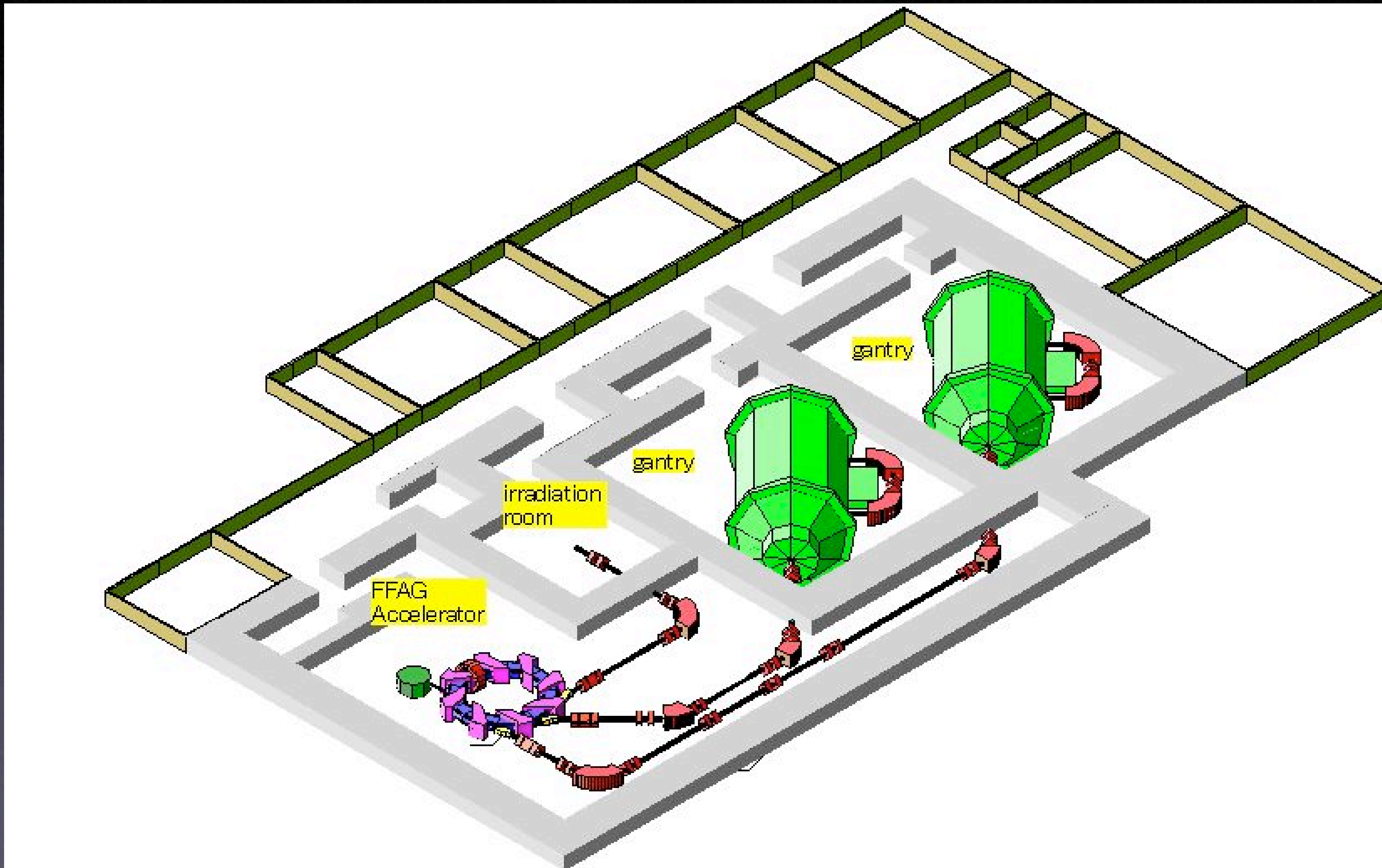
Proton Beam Therapy
FFAG Accelerator



injector 7MeV

Proton energy 230MeV
Intensity > 100nA
Rep. rate 20-100Hz(synchro.respiration)
Diameter ~8m
Extraction multi-port

Hadron therapy (proton)



3D Conformal
Fast Beam Scanning with FFAG

- Fast spot scanning in respiration mode
  - High repetition >100Hz
  - Short pulsed beam <1μsec
  - >100spots/0.5~1sec (for each depth)

Features

・Good synchronization of 3D scannning with respiration mode

・Easy dose control 1pulse=1spot

・High beam current: 4×10^8 proton/pulse

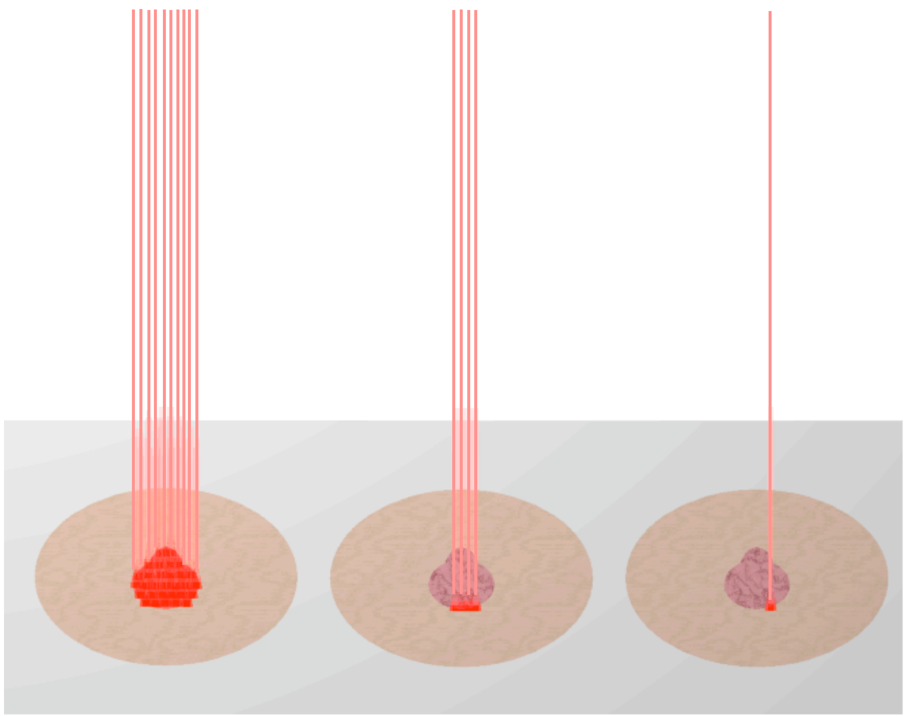
・Fast treatment ~<3minutes

・Need no filter, collimator : conformal irradiation

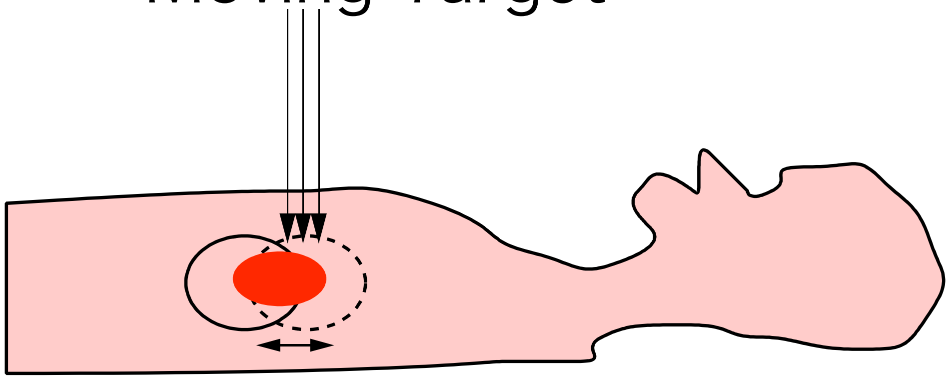
Ordinary Conformal Scanning

Conformal Scanning
with Respiration Mode

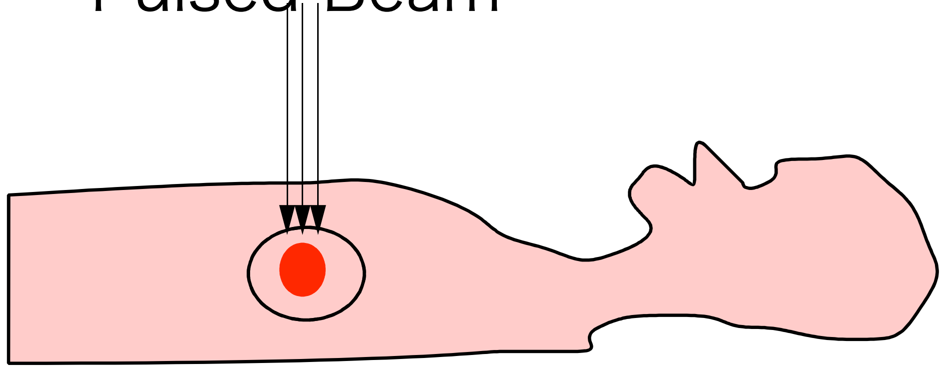
Still Target



Moving Target

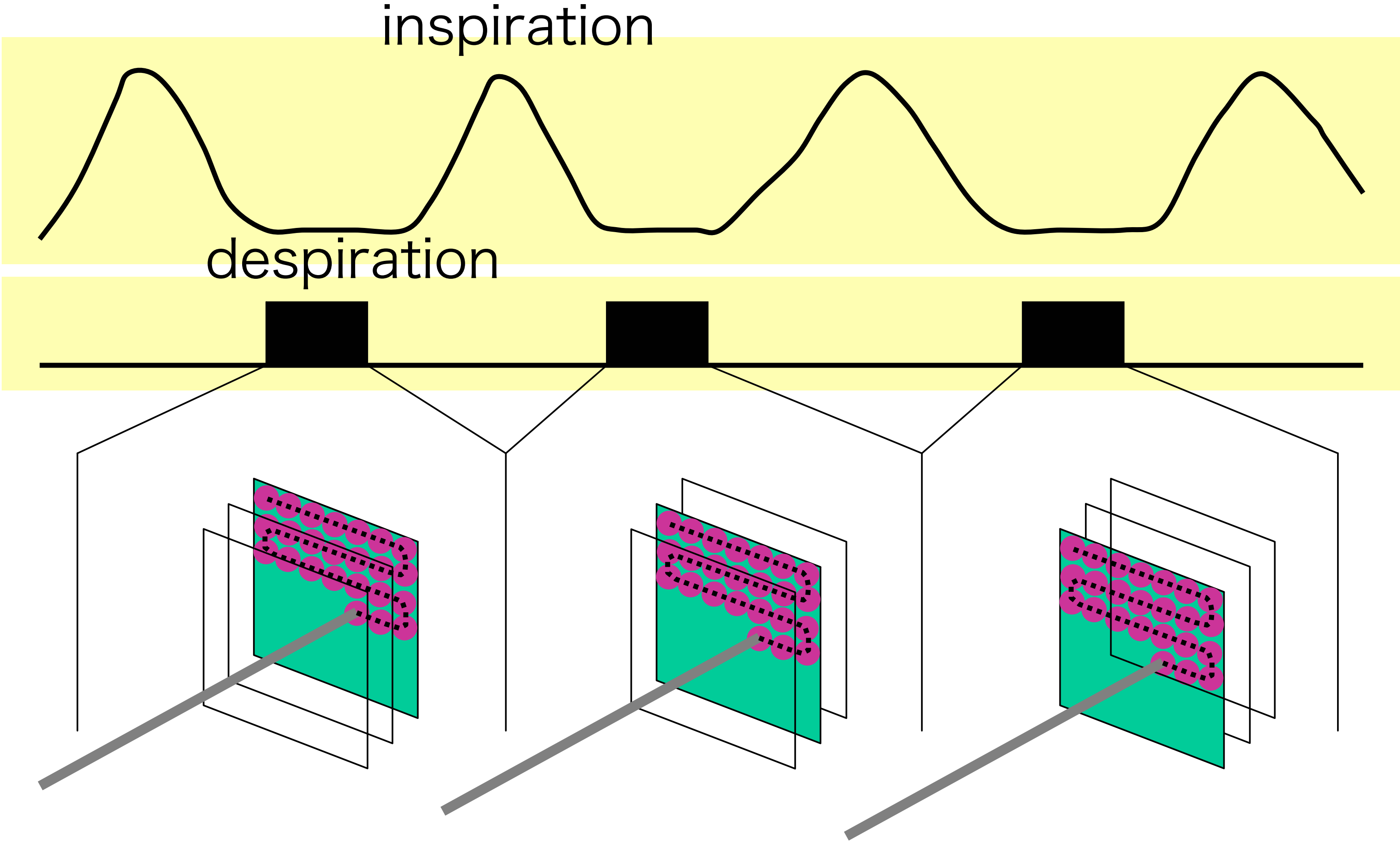


High Repetition
Pulsed Beam

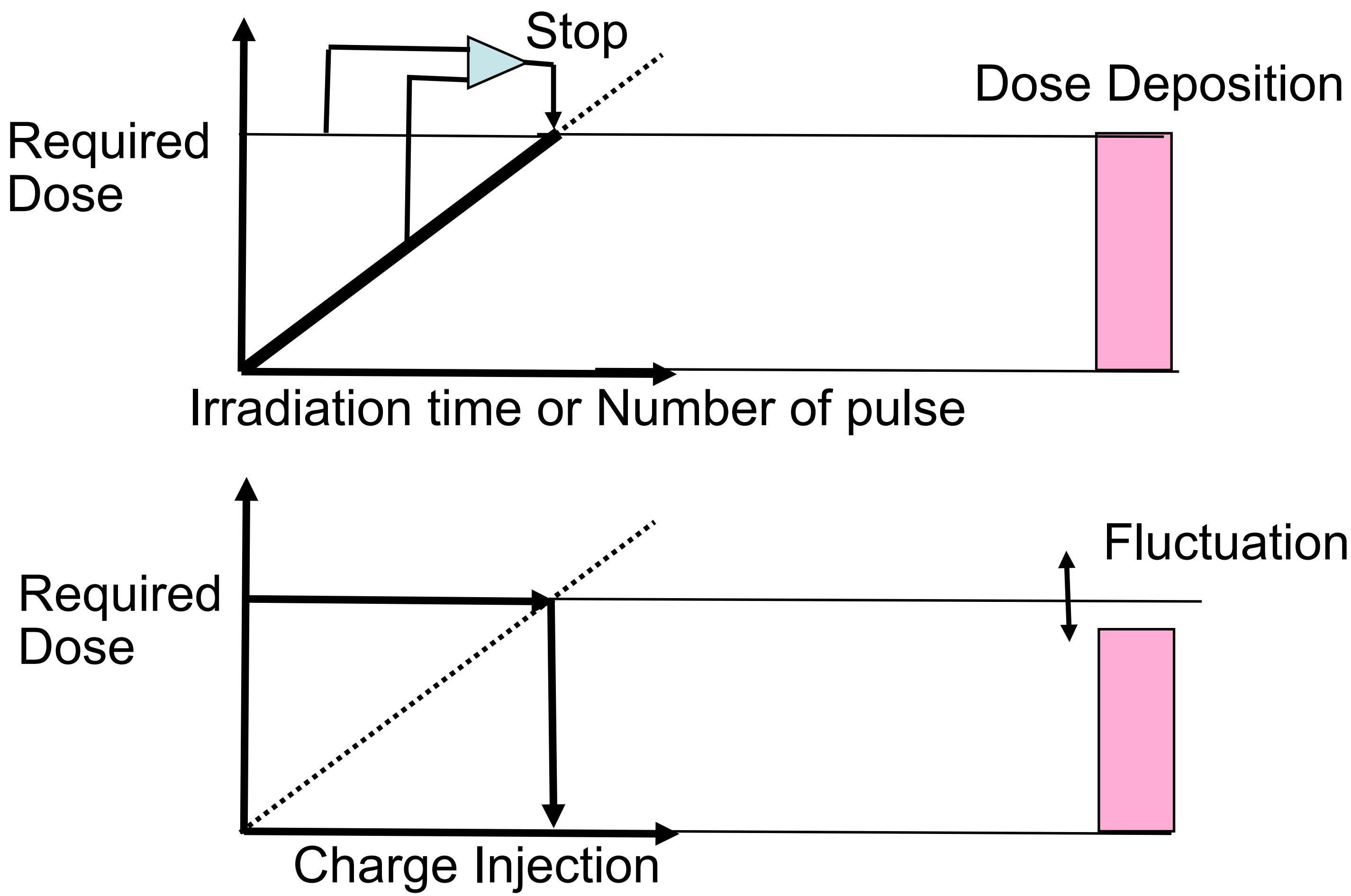


Fast Spot Scanning with Respiration Mod

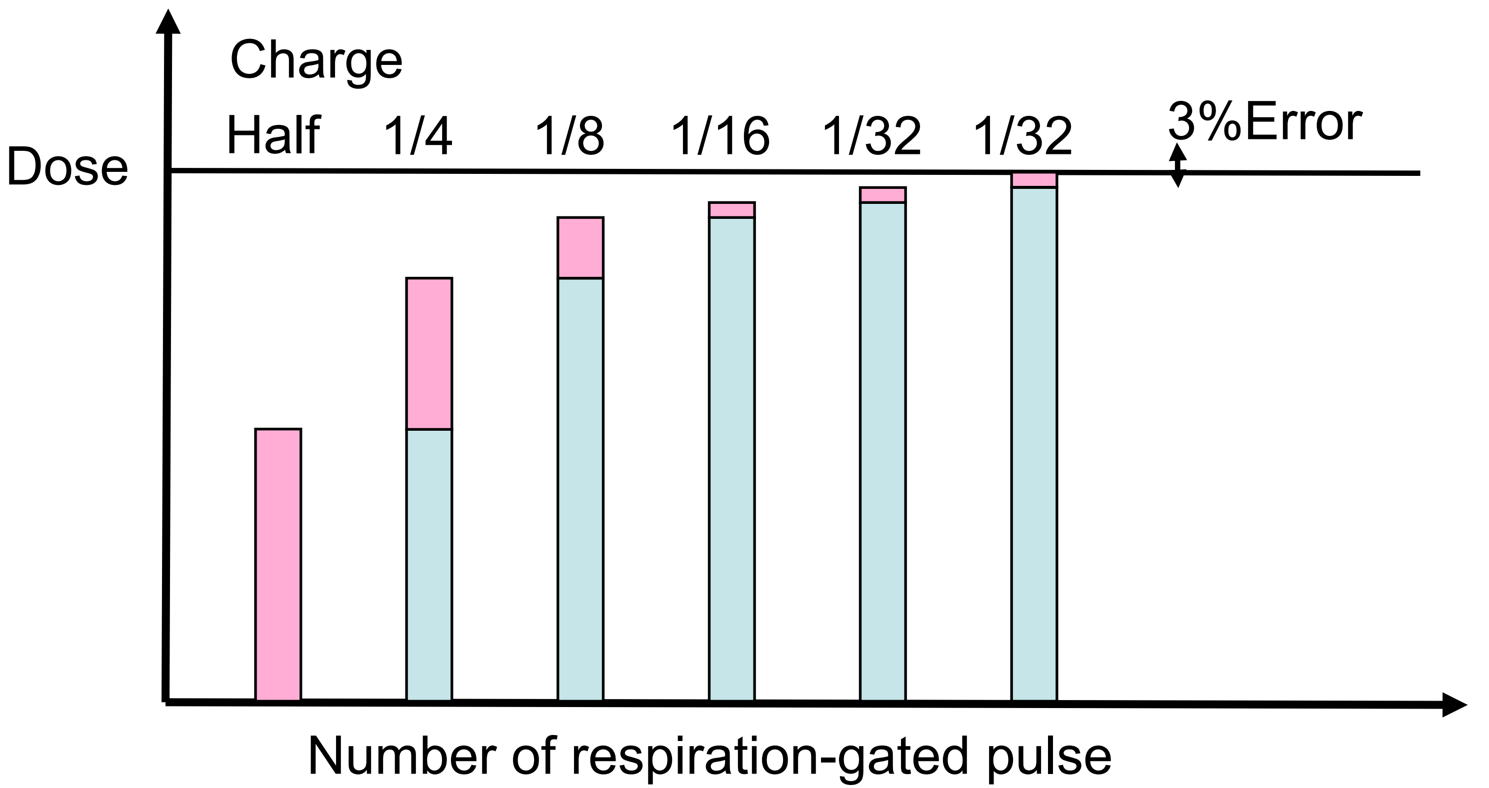
呼吸同期に対応するスキャンニング照射

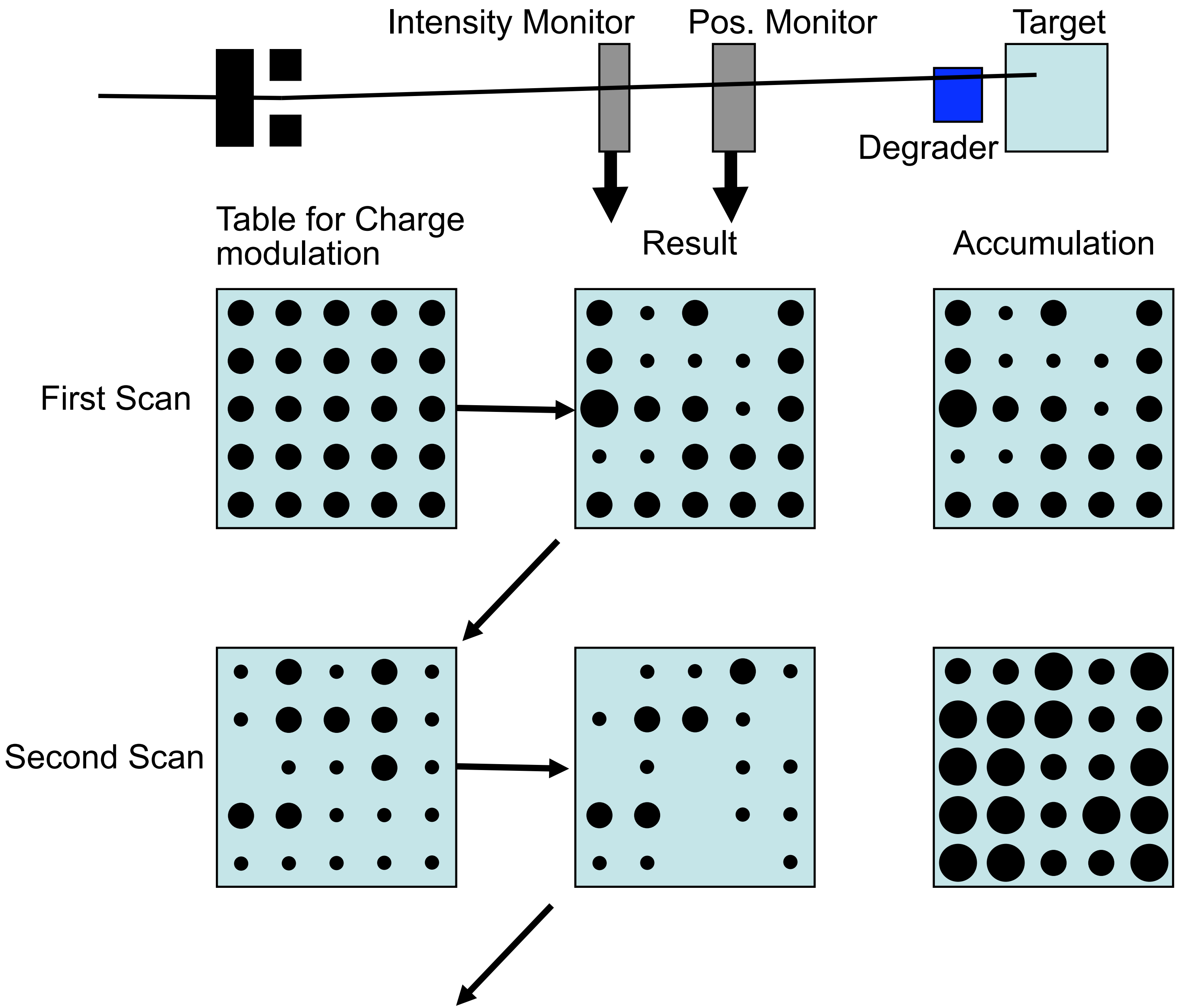


Feedback and non-Feedback Control for Dose Deposition

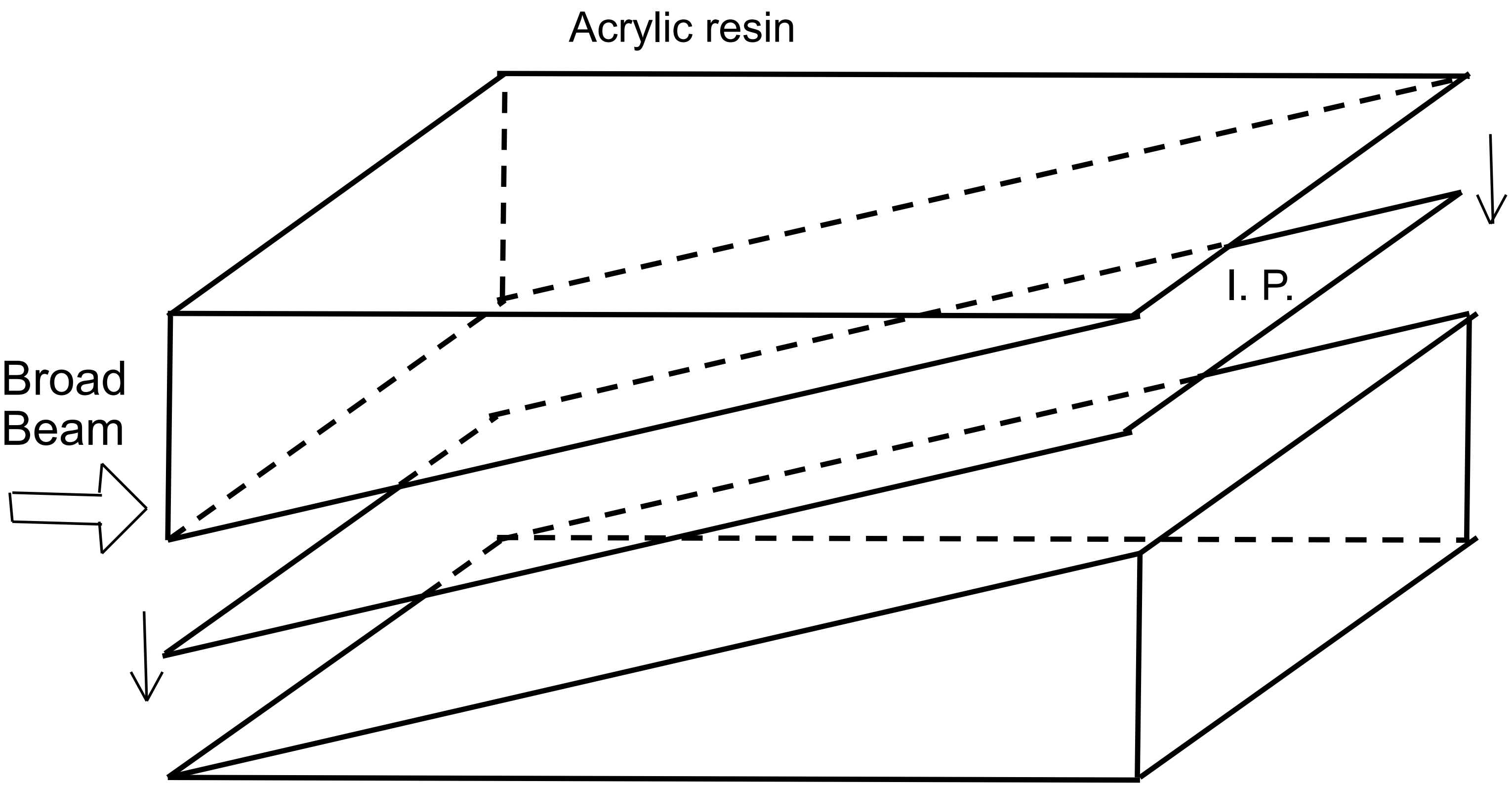


Successive dose accumulation by charge modulation

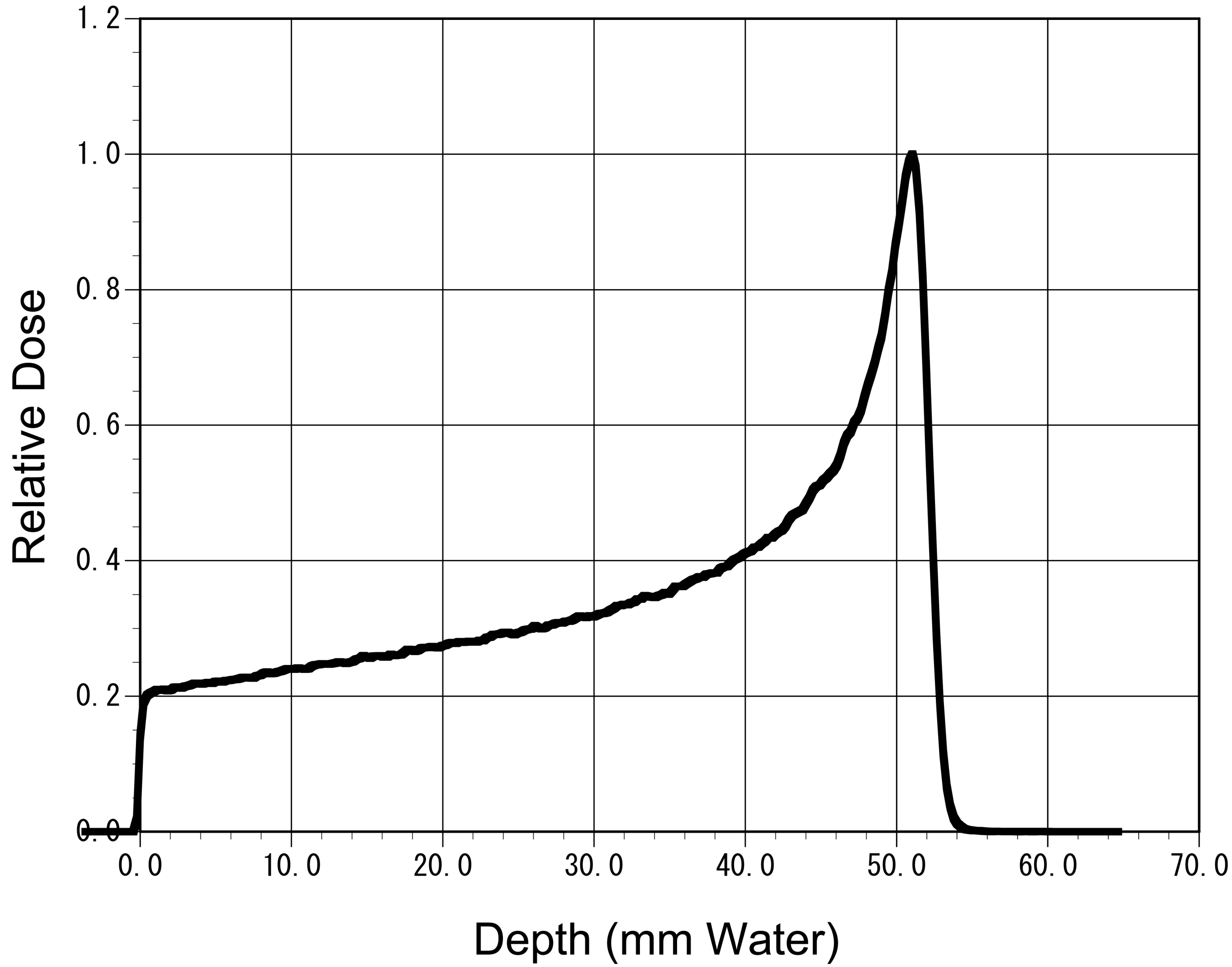



Intensity Monitor
Pos. Monitor
Target
Degrader
Table for Charge modulation
Result
Accumulation
First Scan
Second Scan

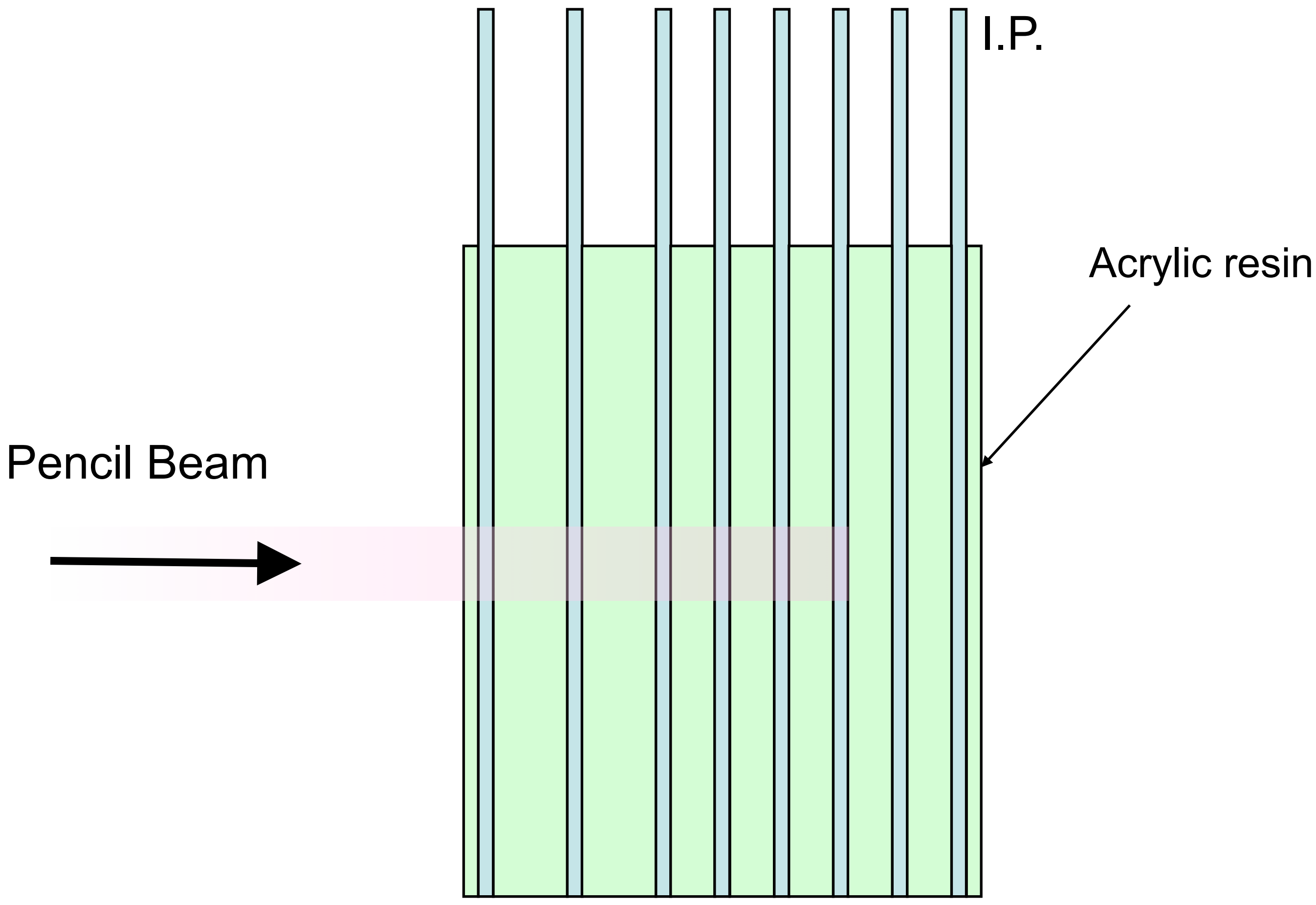
Dose Distribution Measurement for Broad Beam with KEK FFAG



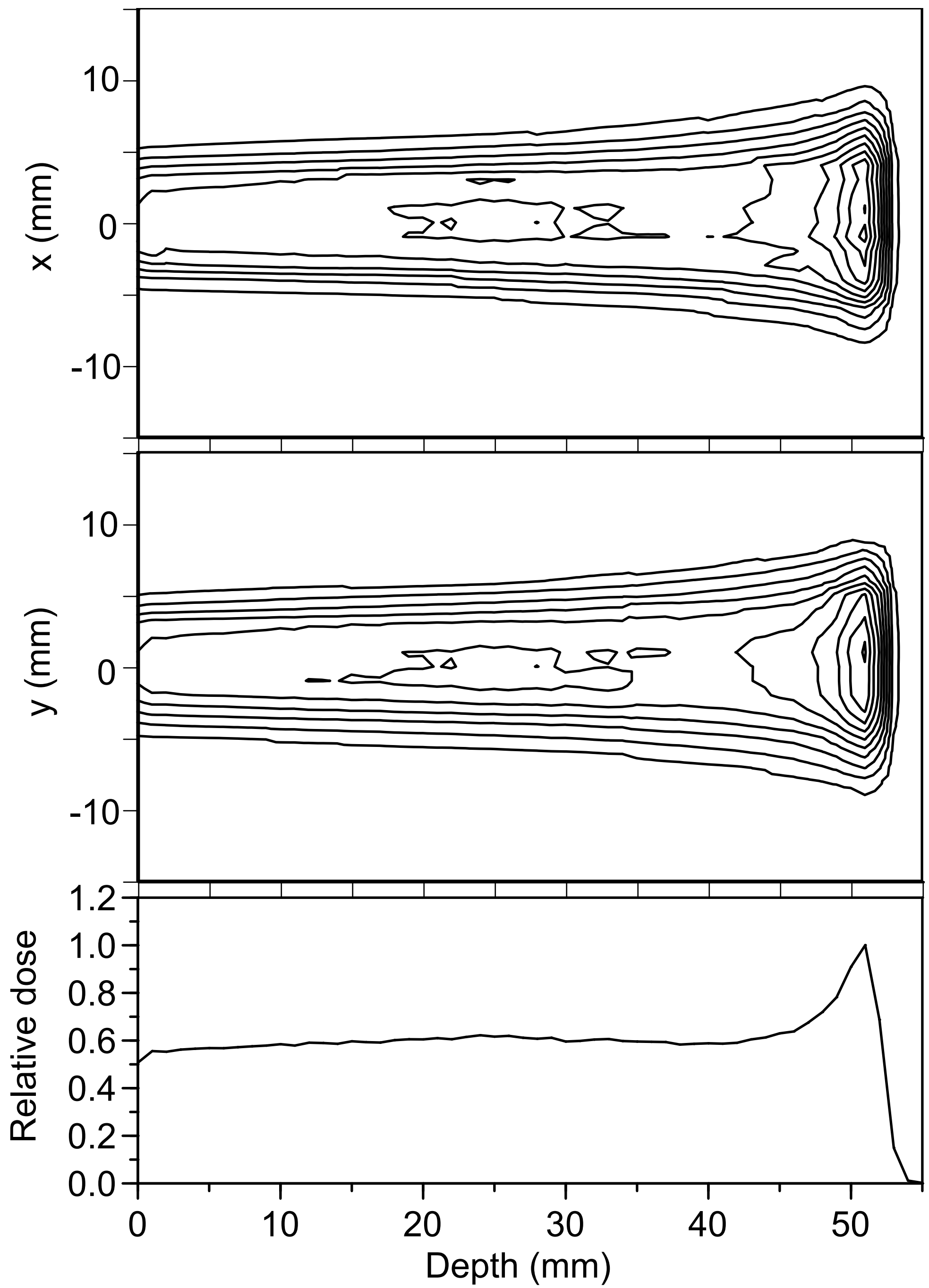
By Y. Hayakawa, A. Nohtomi



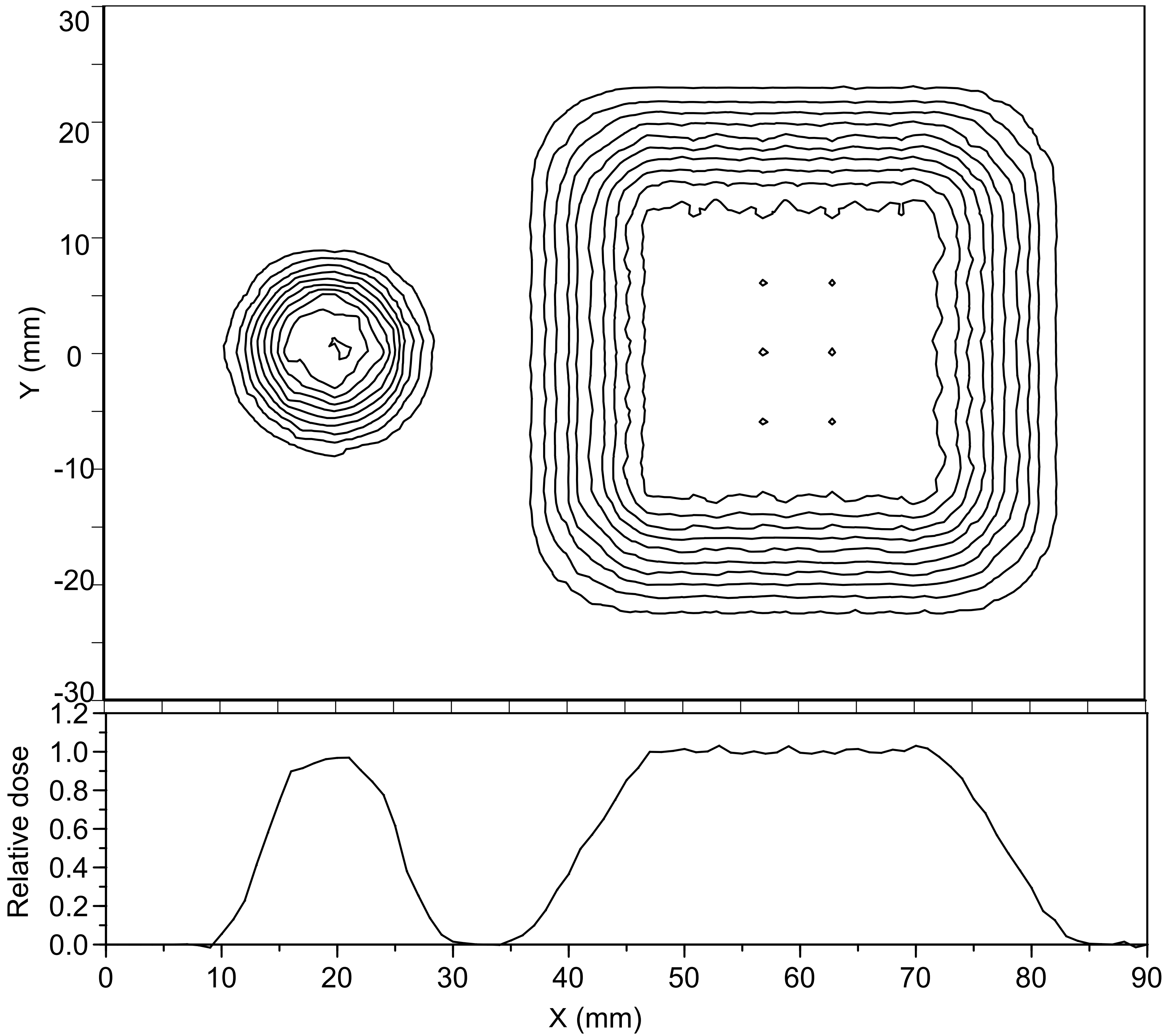
E ~100MeV, 30Hz



Dose distribution measurement for a pencil beam by a stack of IP and plastic with KEK FFAG



10
0
-10
x (mm)
10
0
-10
y (mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Relative dose
0
10
20
30
40
50
Depth (mm)



Spot Scanning Simulation

FFAG for ADS

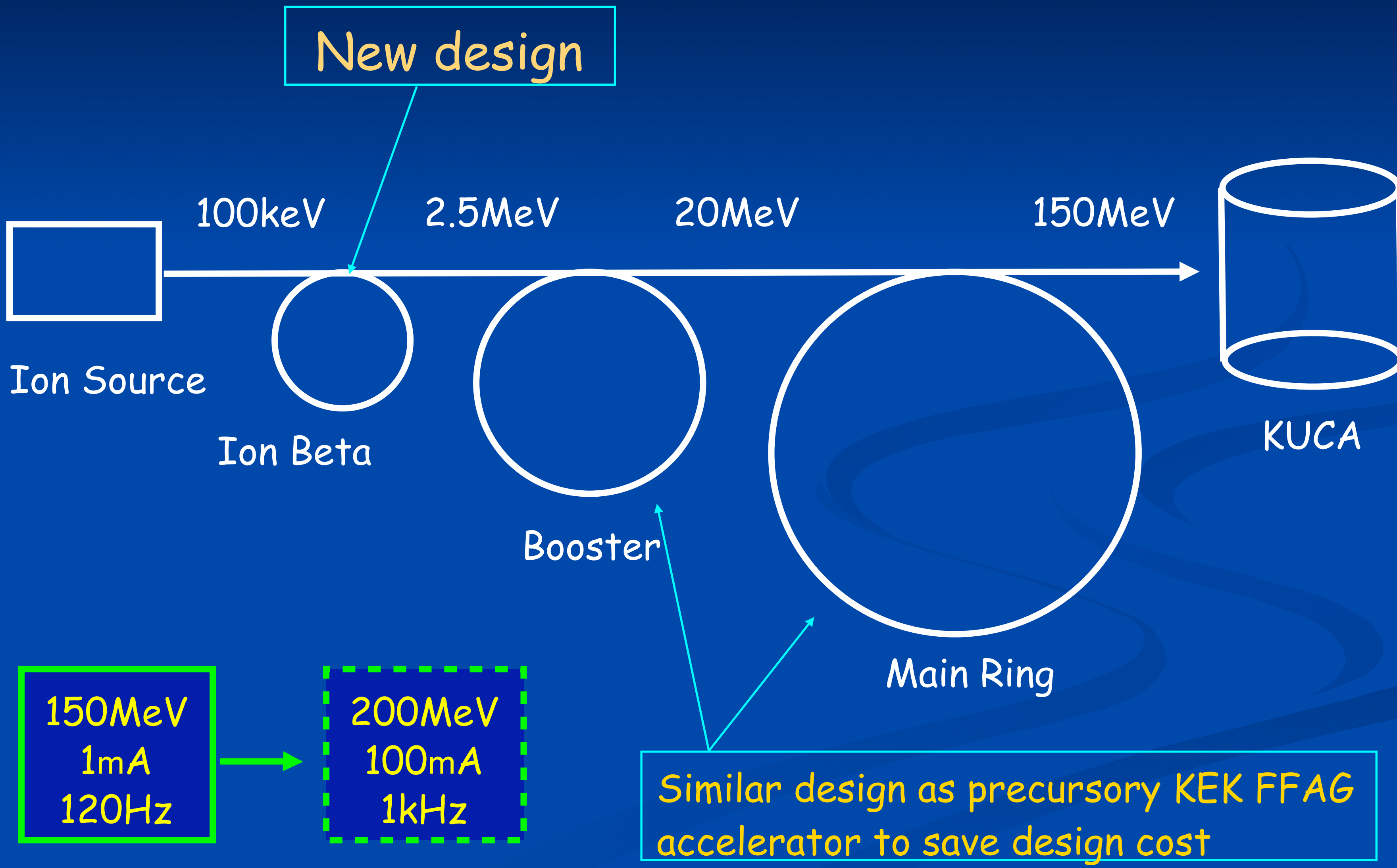
ADSR in Kyoto University Research Reactor Institute (KURRI)

Feasibility study of ADSR
Five-year program 2002 – 2006

Subject
Accelerator technology
-variable energy FFAG
Reactor technology
-basic experiments for energy dependence of the reactor physics
Future Proton Therapy

Research Reactor Institute
Kyoto University

Configuration of FFAG Accelerator Complex



System Parameters of FFAG Accelerator

	Ion Beta	Booster	Main Ring
Focusing	Spiral	Radial DFD	Radial DFD
Acceleration	Induction	RF	RF
Number of Cells	8	8	12
k-value	2.5	4.5	7.6
Injection Energy	100keV	2.5MeV	20MeV
Exit Energy	2.5MeV	20MeV	150MeV
Pext/Pinj	5.00	2.84	2.83
Injection Orbit	0.60m	1.42m	4.54m
Exit Orbit	0.99m	1.71m	5.12m

Present Status of FFAG Accelerator Complex

FFAG for BNCT
intense neutron source

-FFAG-ERIT scheme-

Particle Beam Therapy for Malignant glioma

1. Proton (Tsukuba, Hyogo, Shizuoka, Loma Linda, MGH)

   RBE:1, fine (physically) dose distribution

3. Carbon (HIMAC, GSI)

   RBE:3, high LET,fine (physically) dose distribution

3. BNCT (α particle)

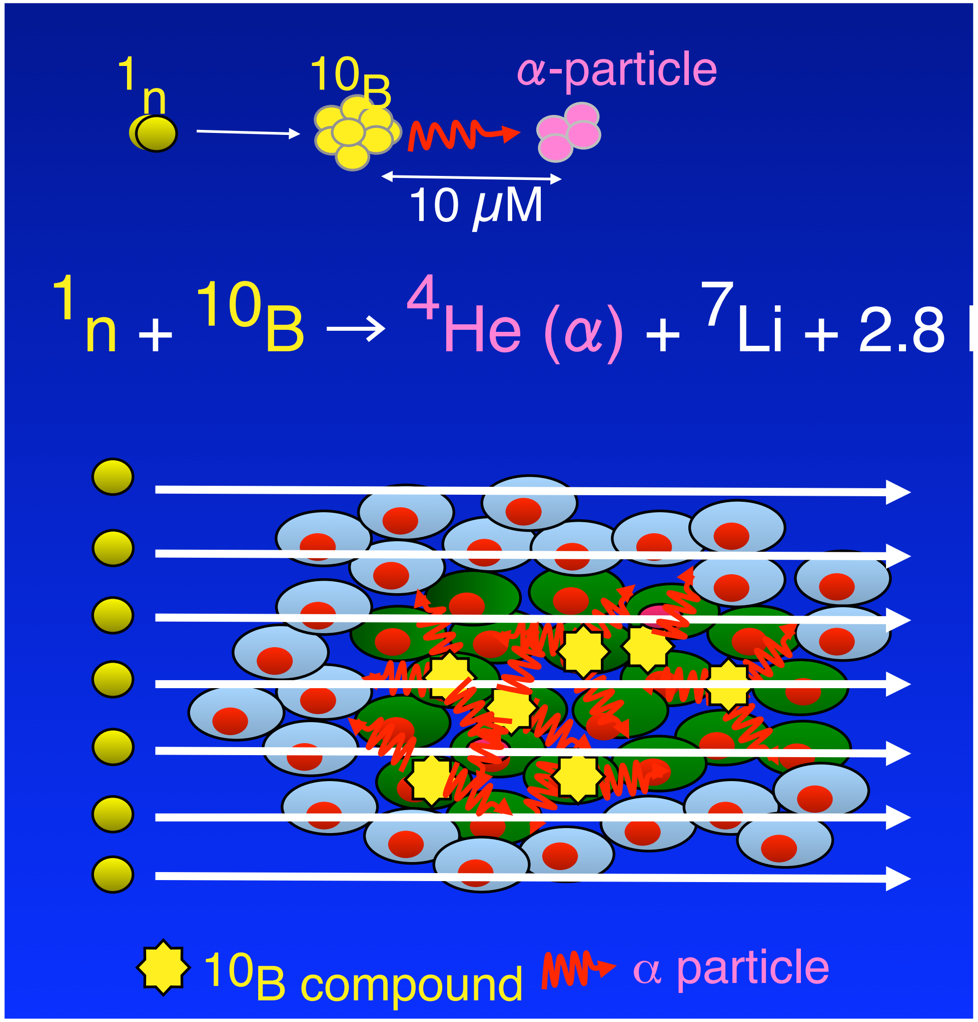
   RBE:3-4, high LET, Range ~ cell size(10micro.m)

   very fine(biologically) dose distribution (cell level selectivity)

   Only the radiation therapy having distinctiveness between normal and malignant tumor cell

Neutron Source for BNCT

- ***Requirements***
  - *Large neutron flux*
    > 1x10^9 n/cm^2/sec at patient
  - *Low energy spectrum*
    thermal/epi-thermal neutron

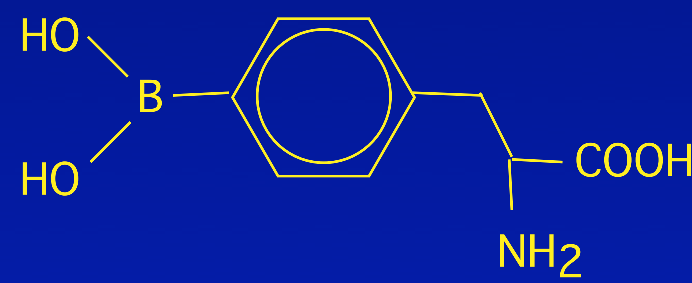


Nuclear reactor only can provide these neutrons.

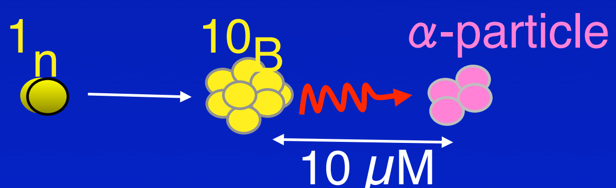
Limited to extend the use of BNCT widely in society.

Boron Neutron Capture Therapy (BNCT)

Borocaptate sodium
(BSH)



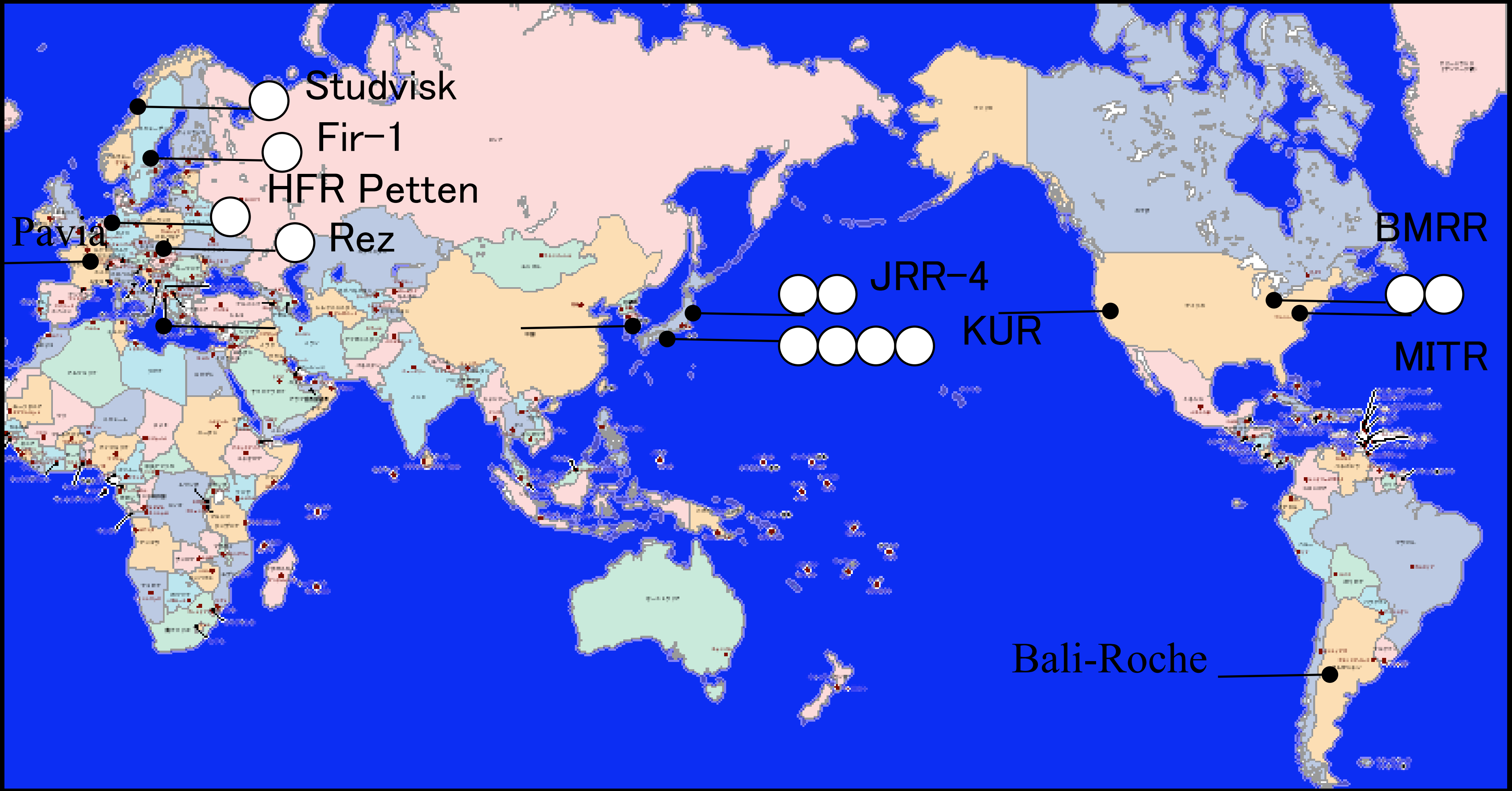
L-p-Boronophenyl alanine
(BPA)



$$^{1}n + {}^{10}B \rightarrow {}^{4}He\ (\alpha) + {}^{7}Li + 2.8\ \text{MeV}$$

Department of Neurosurgery
University of Tsukuba

Facilities for BNCT in the world



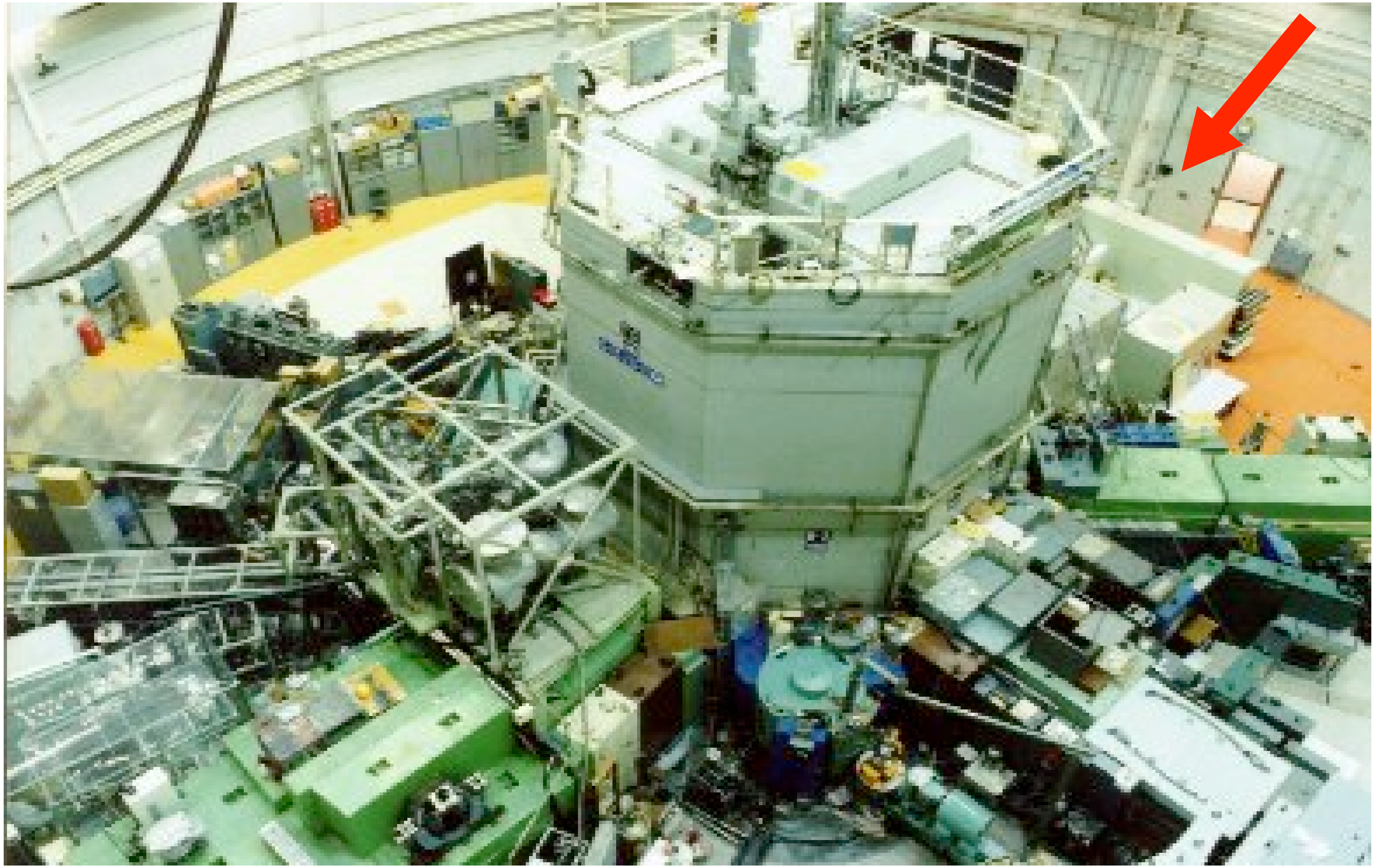
Limited stage : experimental level

Neutron source

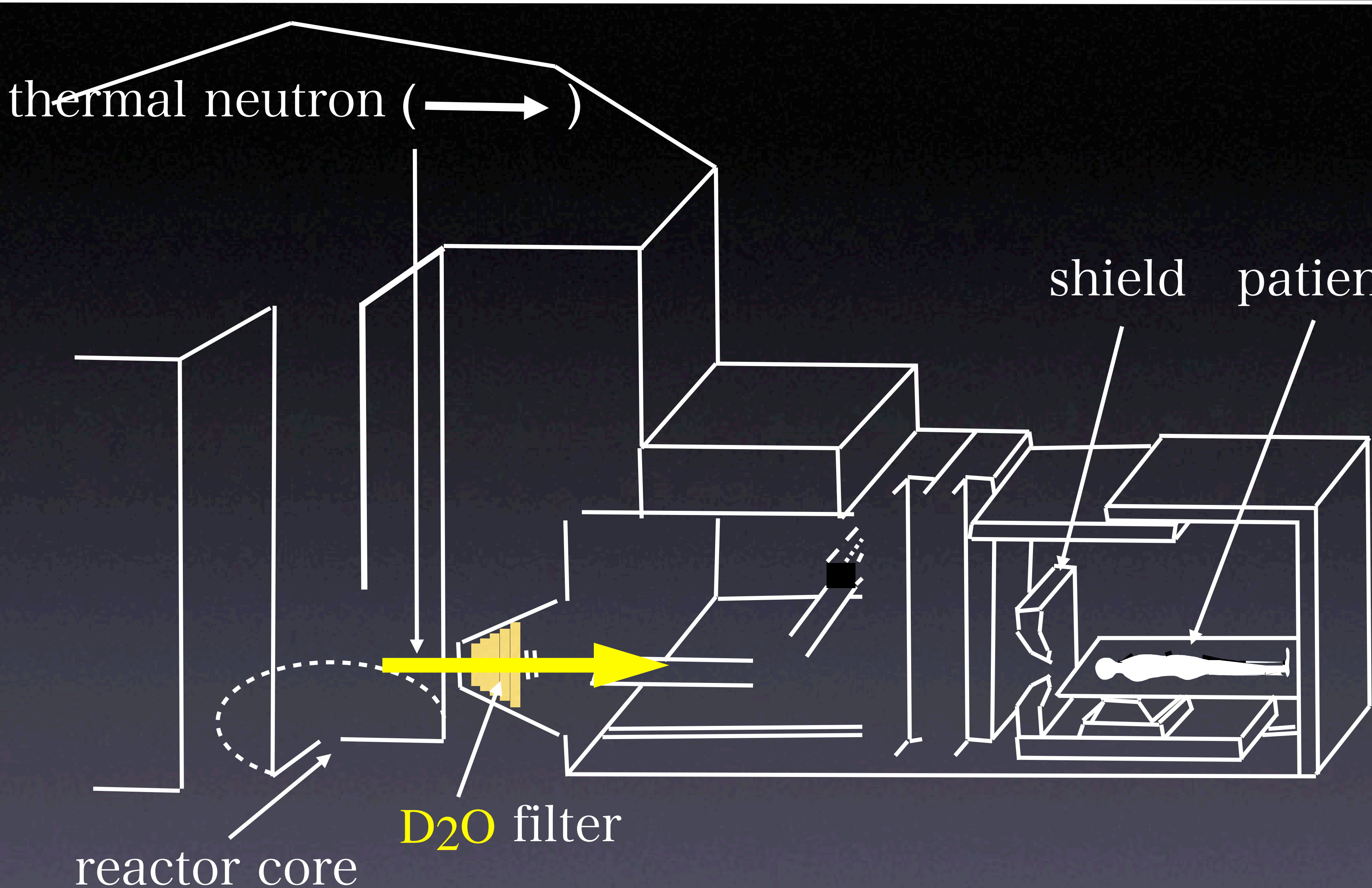
- High neutron flux
  - **> 1x10E09 n/cm2/sec** at patient for 30 min. treatment.
    - Nuclear reactor only can provide.
- Low energy spectrum :thermal/epi-thermal neutron

Limited to extend the use of BNCT widely in society.

Kyoto University Research Reactor (KUR)



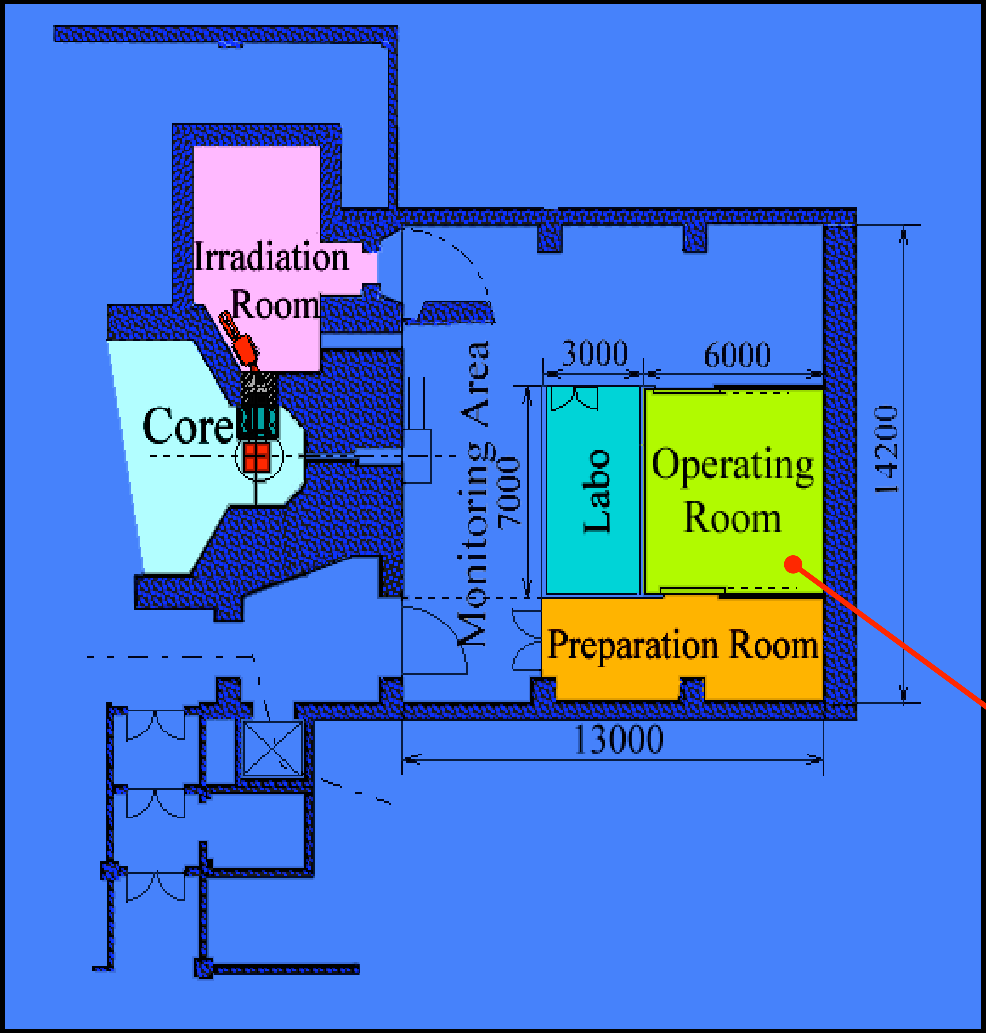
The rough sketch of D_2O-neutron facility in KUR

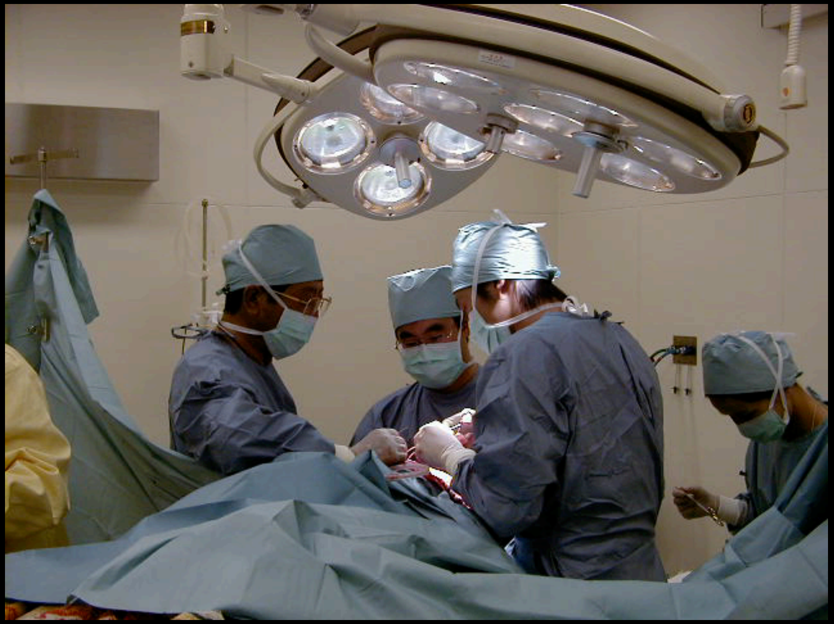


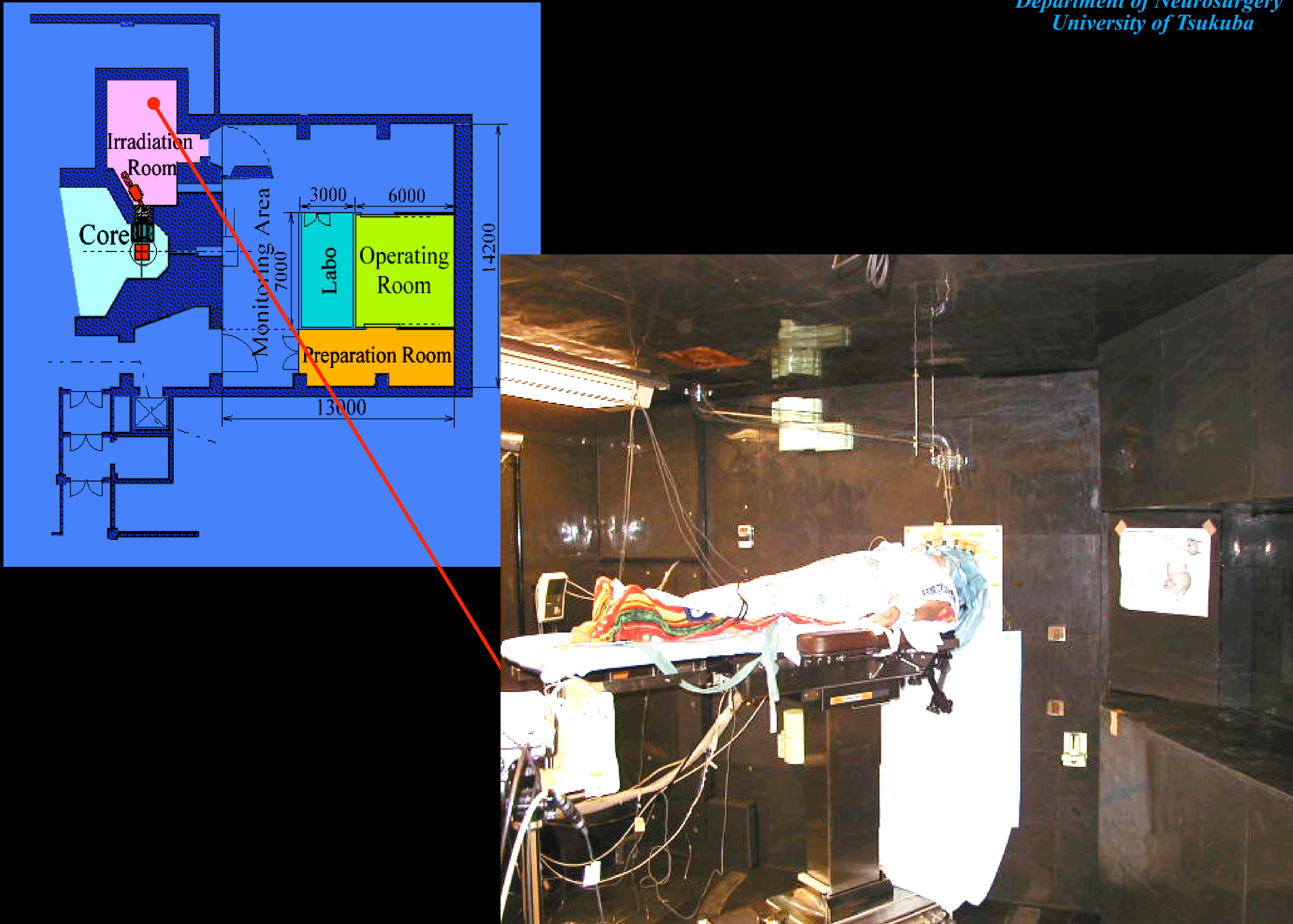
treatment(normal) : 1 session (0.5-1hour)
80-90patients/year, one day/week

JRR4(JAEA)-Tsukuba Univ.

Department of Neurosurgery
University of Tsukuba

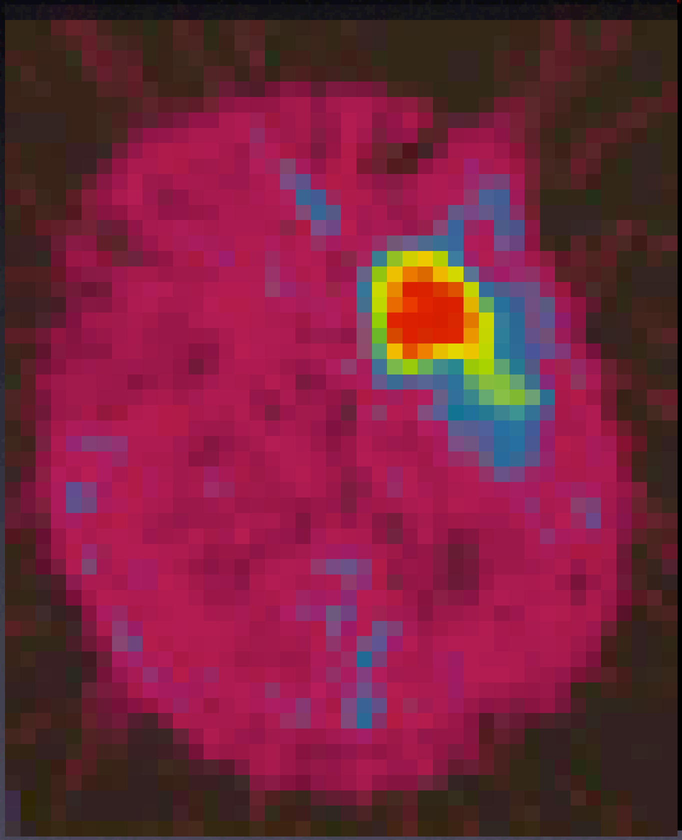




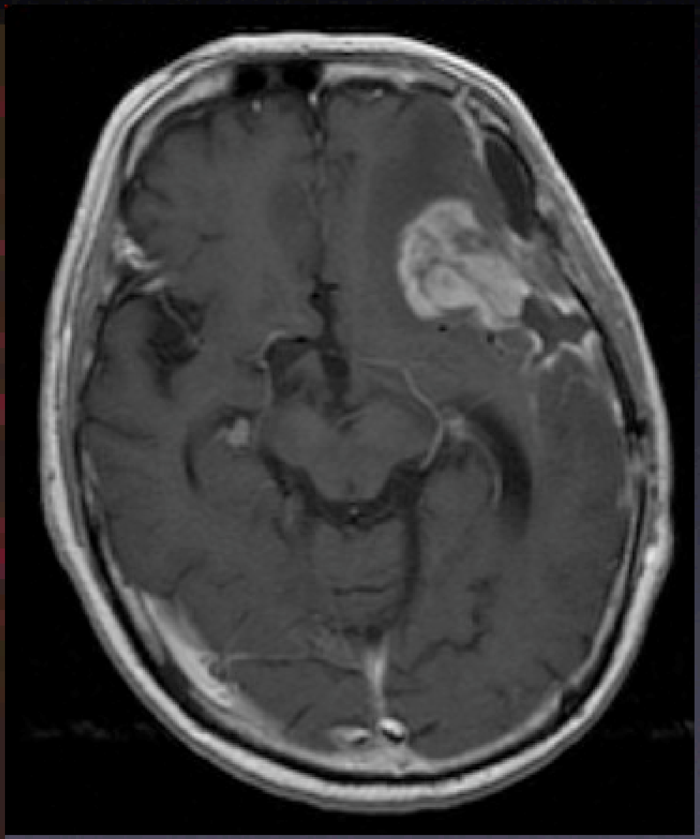

Irradiation Room
Core
Monitoring Area
3000
6000
Labo
Operating Room
7000
14200
Preparation Room
13000

Diagnosis ^{18}F-BPA-PET

BPA-PET (T/N 7.8)



Pre BNCT T1Gd



T/N :T / Normal Brain ratio

Department of Neurosurgery
University of Tsukuba

Cases for BNCT except glioma

Cases applied

Melanoma：Kawasaki MU、Tsukuba Univ.

Parotid gland cancer etc.：Osaka Univ.、
Kawasaki MU、Tsukuba Univ.

Liver cancer：Pavia Univ-INFN、Kyoto Univ.

Lung cancer：Kyoto Univ.

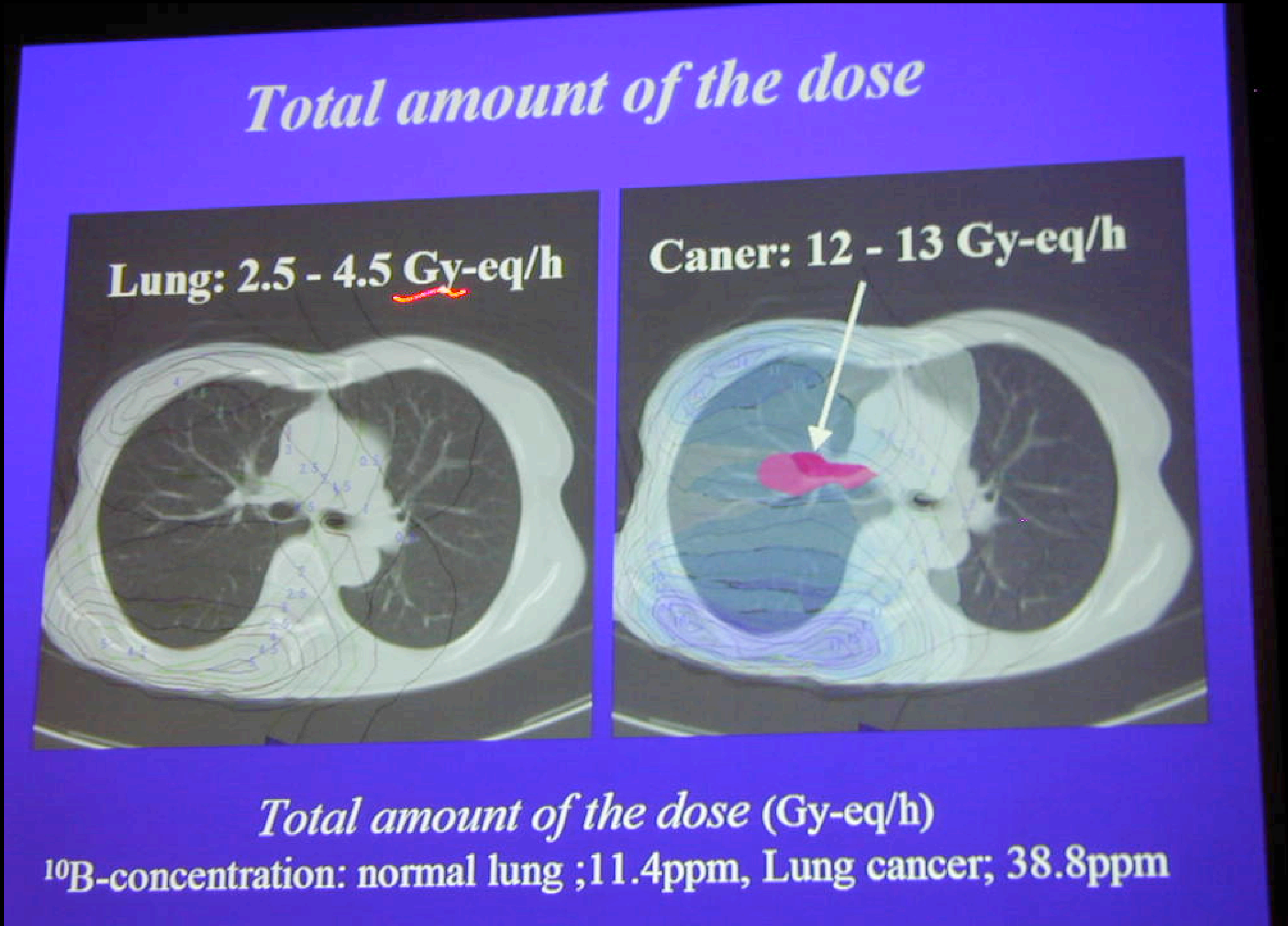
Cases scheduled

Breast cancer(Tokyo Univ.)

Pnacreatic cancer（Tokyo Univ.）

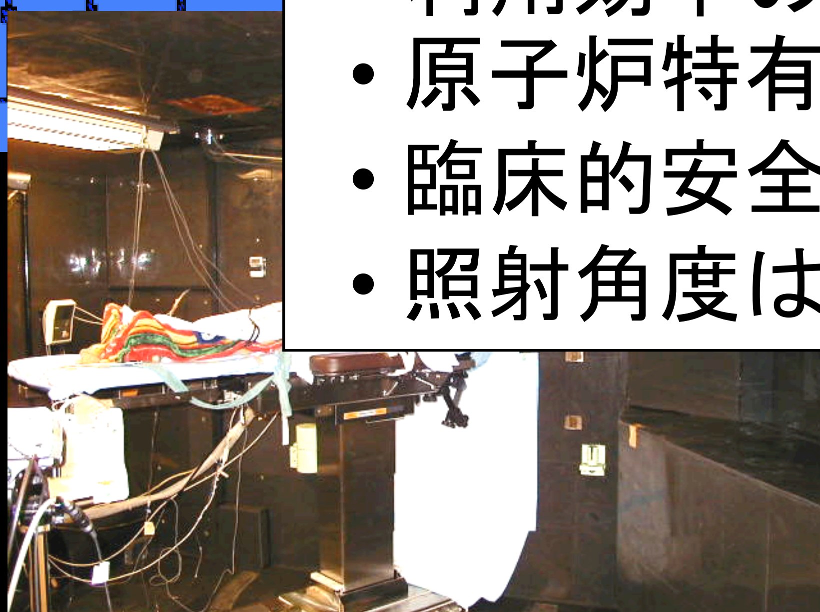
Thyroid cancer(Kyoto Univ.)

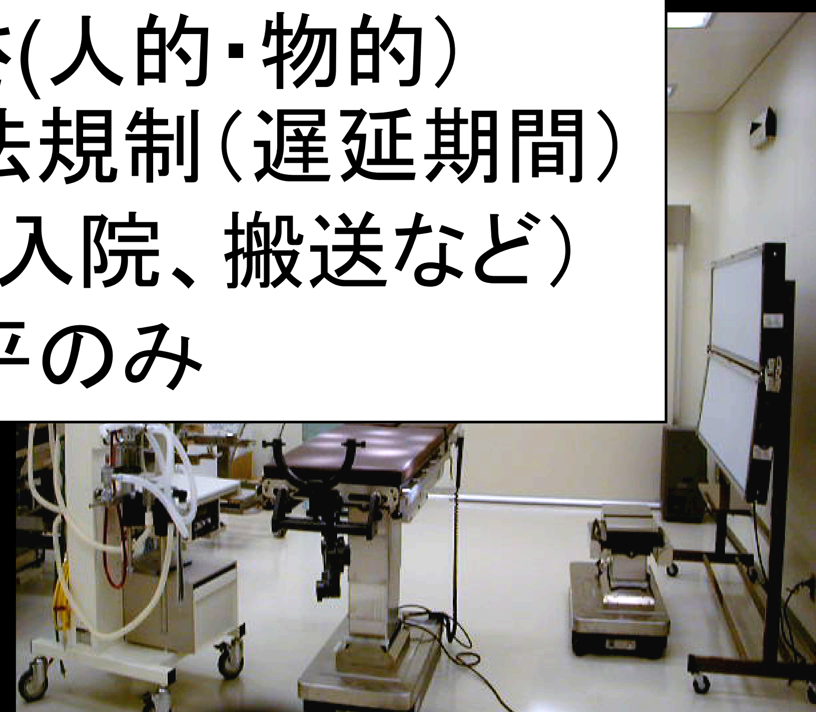
Department of Neurosurgery
University of Tsukuba



Better dose distribution than particle beam therapy

原子炉での中性子捕捉療法
（日本原子力研究所東海研究所）





原子炉の問題点

- 病院から離れた研究施設の制約
- 利用効率の悪さ(人的・物的）
- 原子炉特有の法規制（遅延期間）
- 臨床的安全性（入院、搬送など）
- 照射角度は水平のみ

Problems of BNCT

- Clinical safeness (transport, hospitalization)
  -far away from hospital
- Poor efficiency (man power, machine time)
- Strict regulation for nuclear reactor
- Treatment position only horizontal

Because of Nuclear Reactor

Need ! Accelerator based Neutron Source

Required specifications for ABNS

Required specifications for ABNS

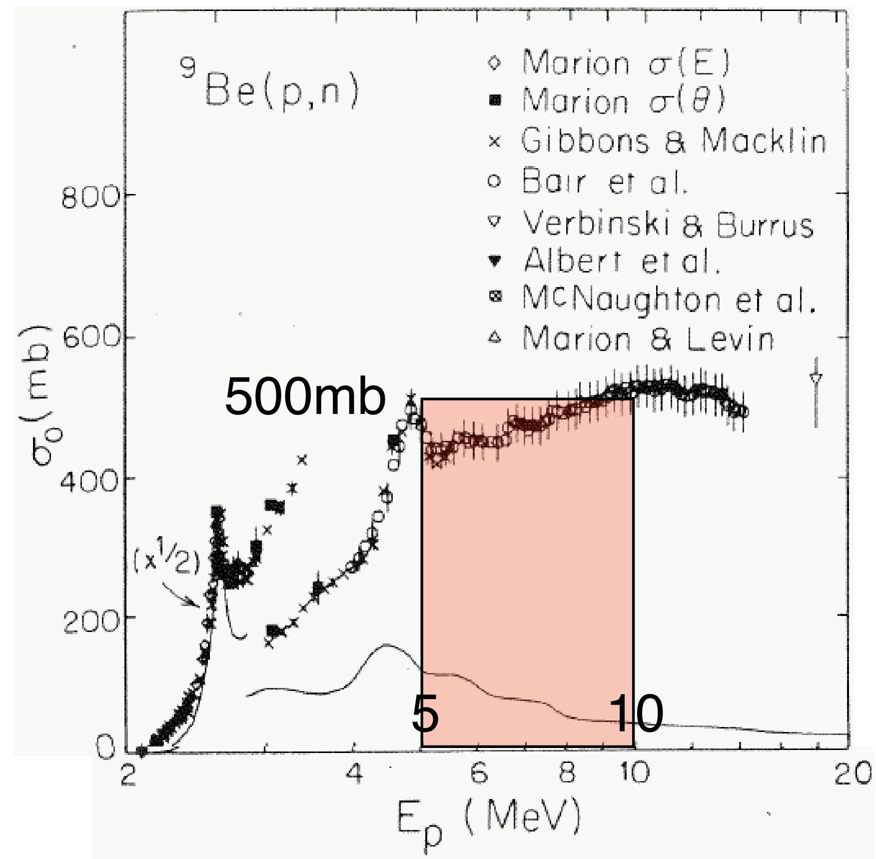
- Intense neutron flux as well as reactor
  - 109 n/cm2/s
- Elimination of fast neutrons
  - E<100keV
- Various positions(horizontal, vertical)

Accelerator based Neutron Source

In order to obatin

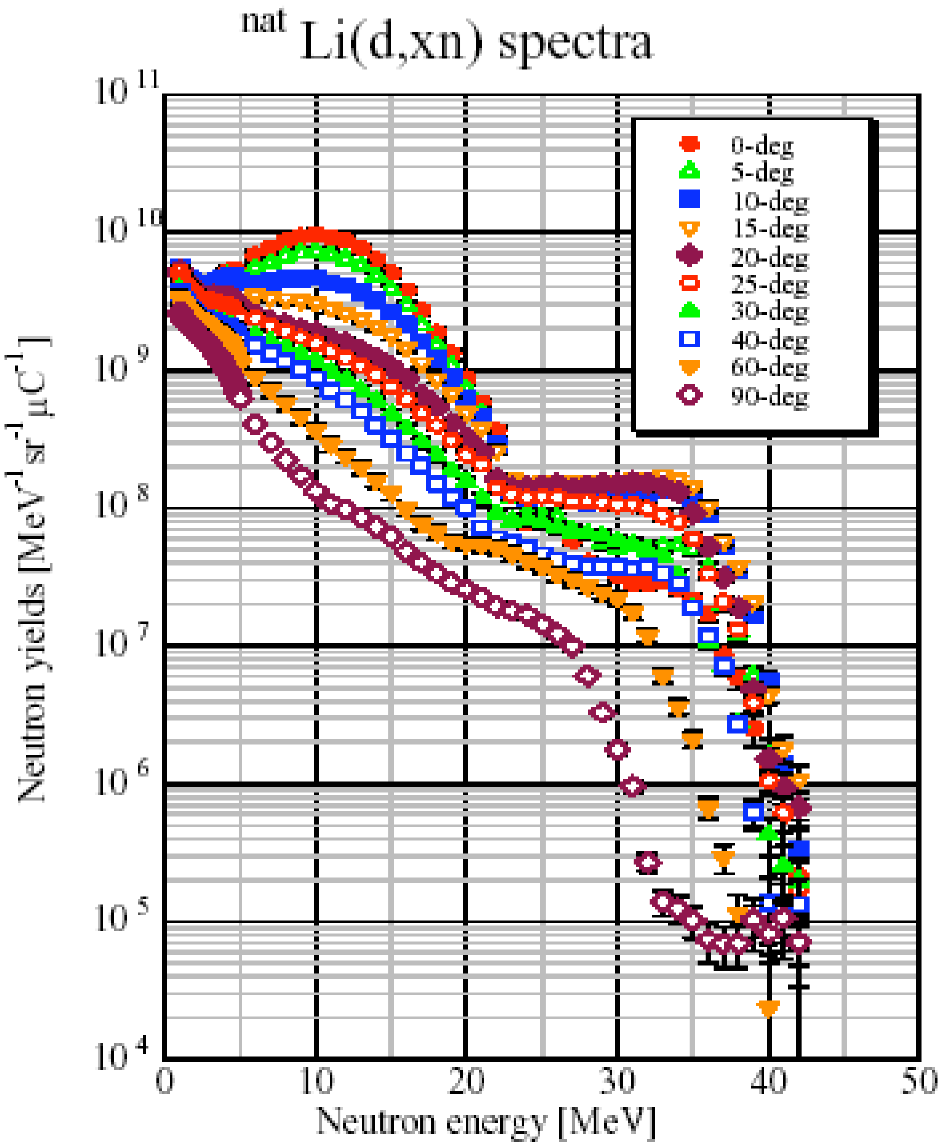
$\varphi > 10^9$ n/cm2/s

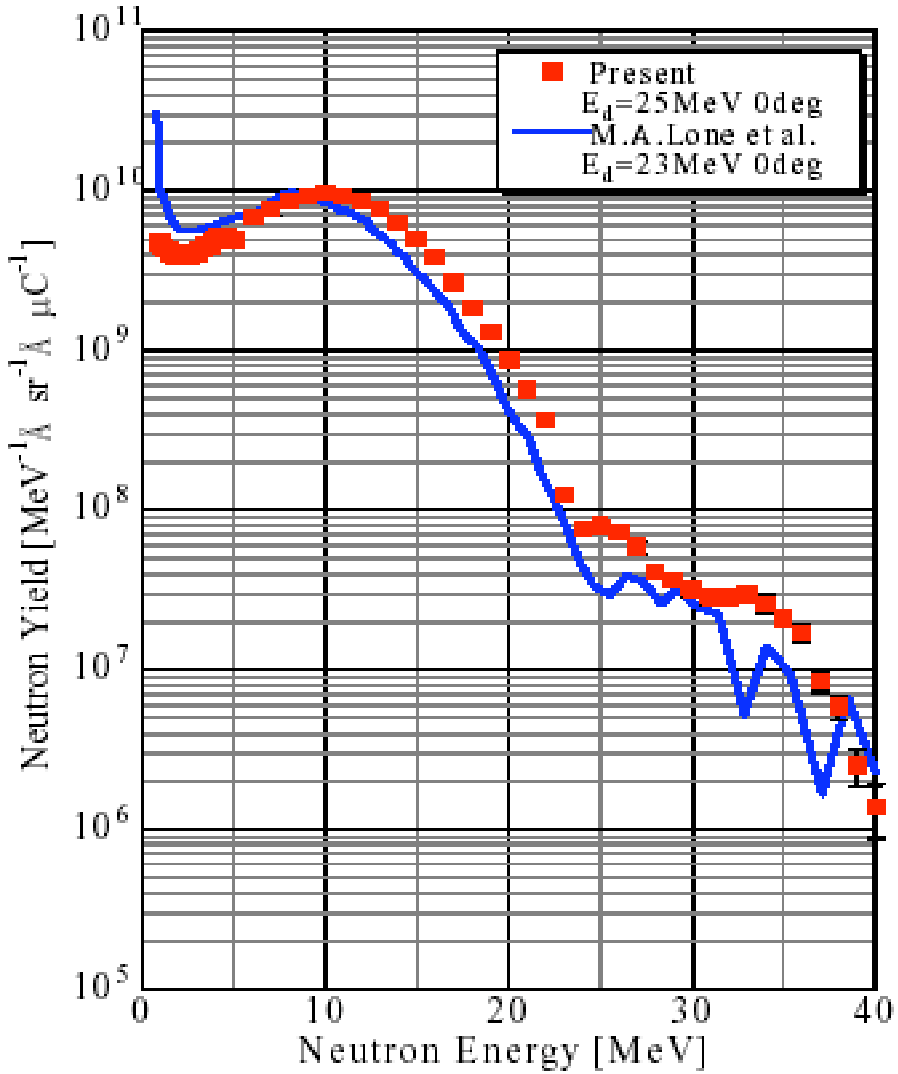
- Neutron production
  - Reaction 9Be(p,n)B, 7Li(p,n)Be
  - energy ~10MeV
  - target thickness ~10micron
  - Neutron yield ~1/10000 n/p
- Proton beam current ~40mA



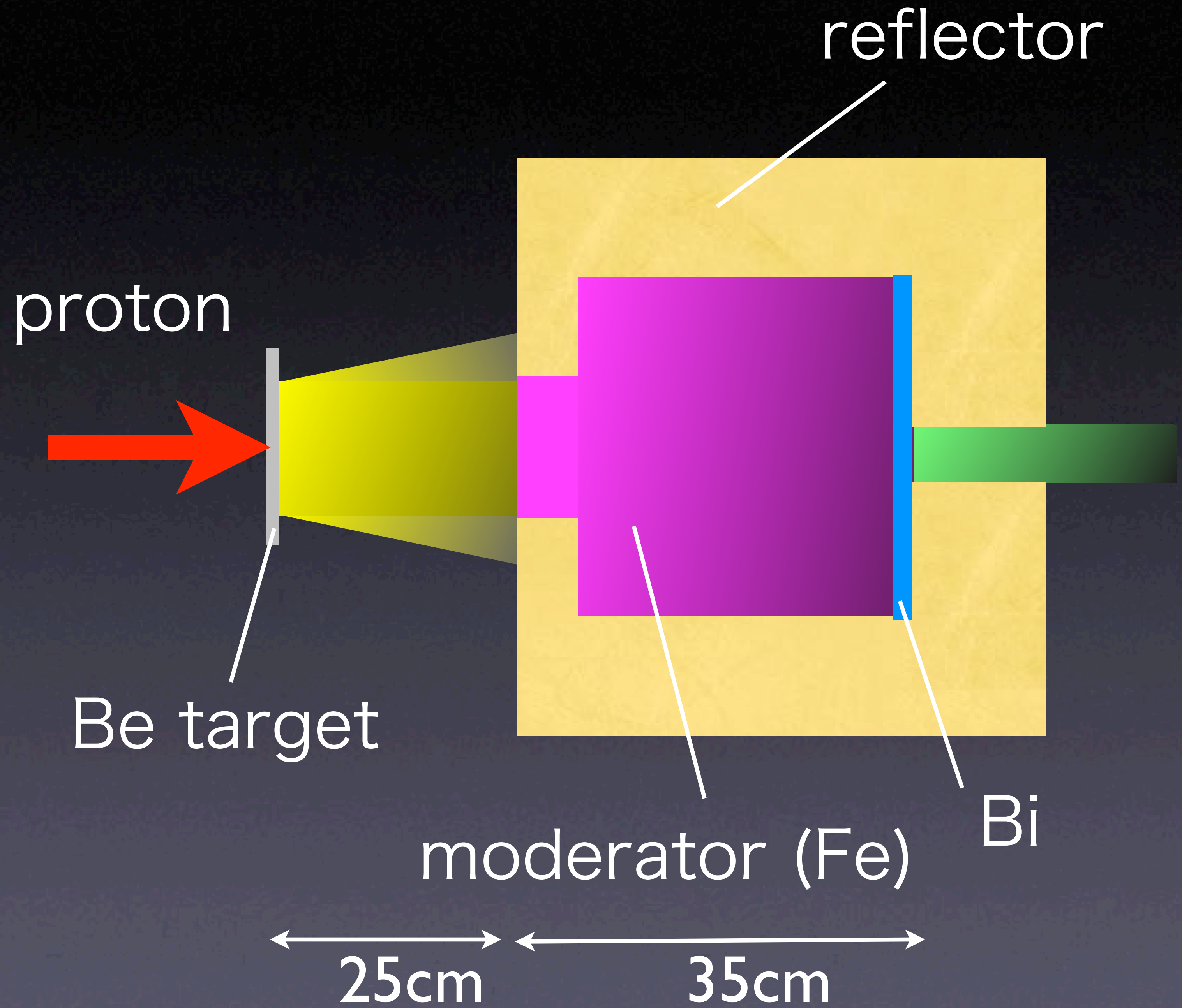
3. 中性子スペクトル結果
3.1 Ed=25 MeV

馬場その他（東北大学）





Target & Moderator



Proton Beam Current

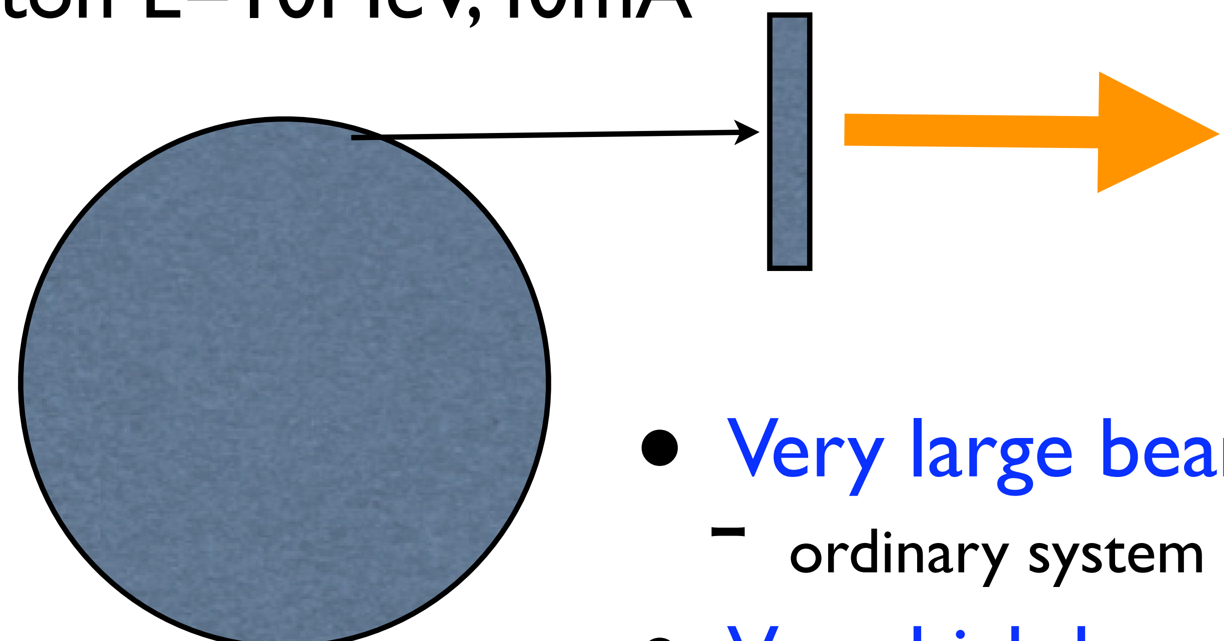
- Fraction
  - target-moderator ~ 0.5
  - moderator solid angle ~1/12000

  *without reflection efficiency
- Proton beam intensity
- $N(p/s)=10^9 x1/0.5x12000x10000=2.4x10^{17}(p/s)$:38mA

Ordinary Accelerator Based Neutron Source

proton E=10MeV,40mA

neutron



Cyclotron, Linac

- Very large beam current
  - ordinary system   Ip~0.1-1mA
- Very high beam power
  - P ~>100kW

Difficluties

- Accelerator
  - energy is low, but beam current is very large
    I > 40mA (CW)
    technically hard and expensive
- Target
  - thin target t<0.1mm ∵dE/dx~50MeV/g/cm2
    beam power is relatively large > 100kW
    difficult cooling and shorter lifetime
- Radiation
  - full beam dumping for 100kW beam
    huge shielding and large gamma-ray contamination

Proton beam power is mostly consumed by ionization in the target, not by neutron production.

- Neutron production/Ionization(energy loss)

Efficiency ~ <1/1000

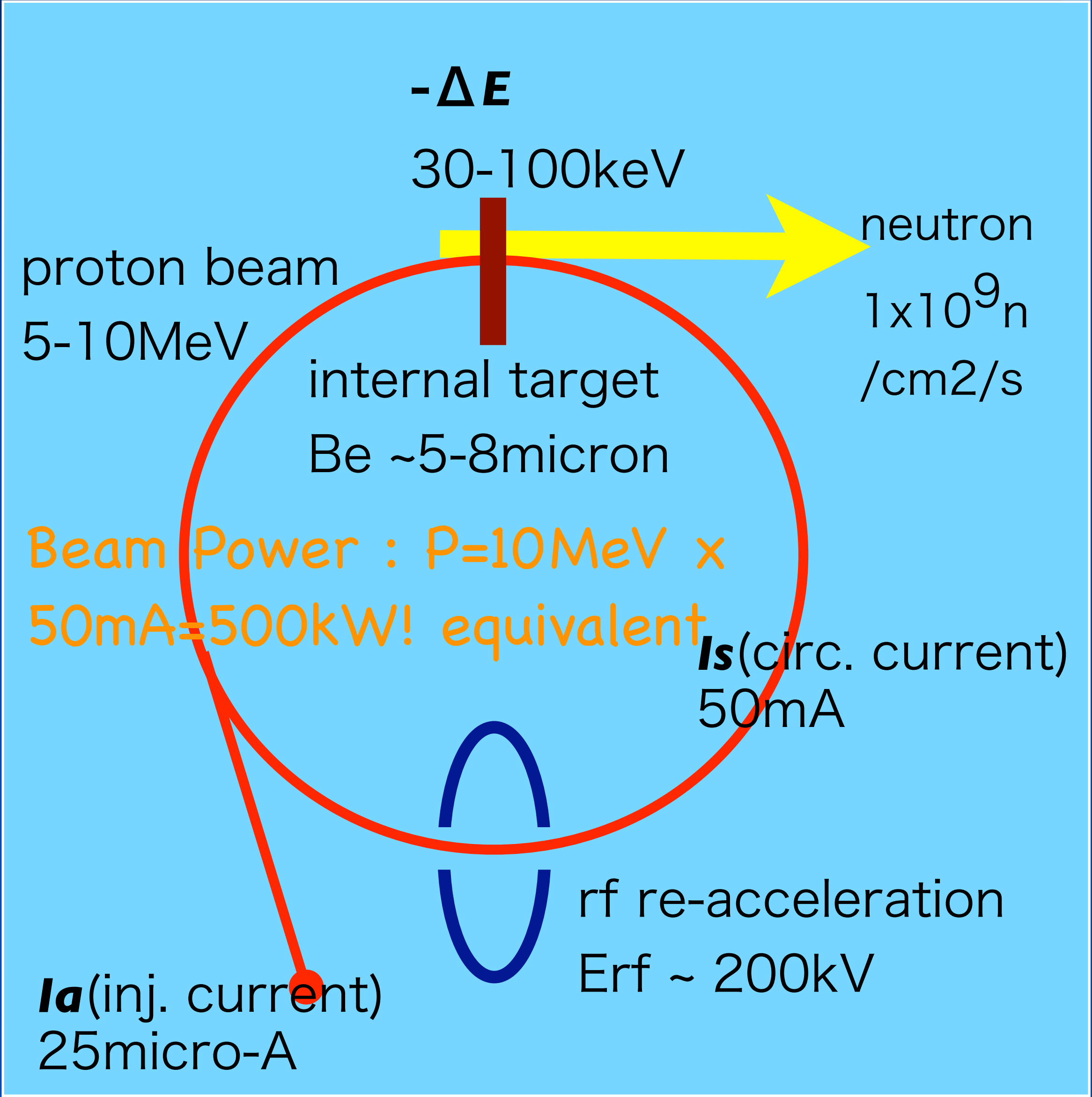
If the beam energy lost in the target is recovered by re-acceleration, the efficiency of neutron production can be improved.

Neutron Source with FFAG-ERIT

Emittance-energy Recovery Internal Target

- Proton driver
  - another concept
- FFAG-ERIT scheme
  - internal target
  - energy loss
    - recovered by rf
  - emittance growth
    - ionization cooling
  - large acceptance
    - FFAG(scaling)
  - target
    - heat loss 1kW

Project approved
2005-2007
Under Construction



3B2v8:06a=w (Dec 5 2003):51c
+ model
NIMA : 44834
Prod:Type:FTP
pp:1–5(col:fig::NIL)
ED:M:S:Usha
PAGN:Uday SCAN:Nil

ARTICLE IN PRESS

ELSEVIER

Available online at www.sciencedirect.com
SCIENCE DIRECT®

Nuclear Instruments and Methods in Physics Research A] (]]]])]]]–]]]

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Development of FFAG accelerators and their applications for intense secondary particle production $

Yoshiharu Mori*

Kyoto University, Research Reactor Institute, Kumatori, Osaka 590-0494, Japan

Abstract

Fixed Field Alternating Gradient (FFAG) synchrotron was revived recently with modern accelerator technologies. Quite a few projects using FFAG synchrotrons have been proposed and some of them are under construction. One of the most interesting applications with FFAG synchrotron is an intense thermal or epithermal neutron source with energy recovery internal target.

PACS: 29.20.Mr

Keywords: FFAG; Internal target; Ionization cooling

1. Introduction

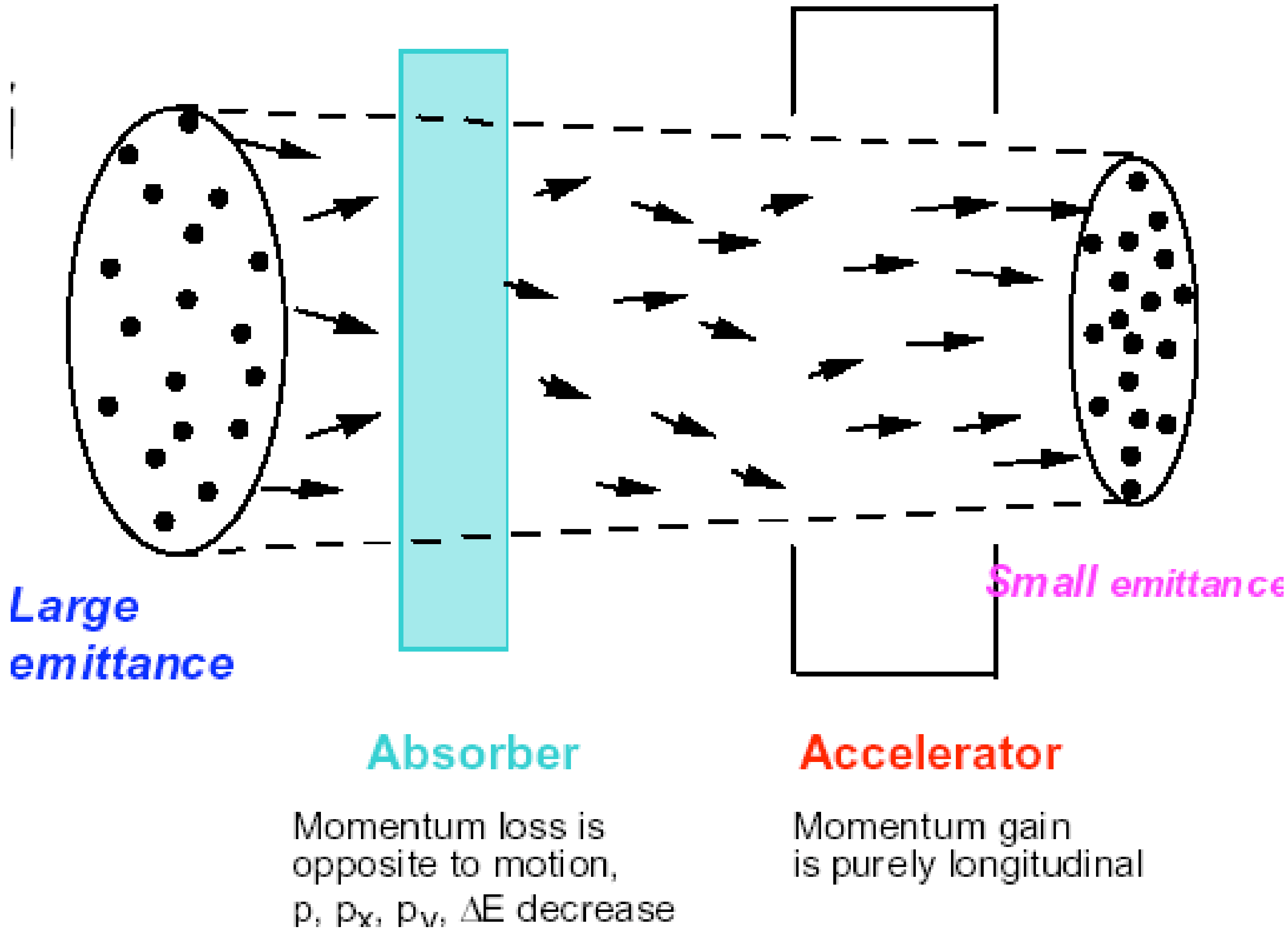
The Fixed Field Alternating Gradient (FFAG) synchrotron has unique features compared with other types of

This results a high repetition rate of beam acceleration with modest number of particles in the ring. High average beam current, therefore, can be available because space charge and collective effects become below threshold. Very large

Emittance growth

- Using an internal target in the ring, the beam emittance can be increased in 3-D directions by Rutherford multiple scattering and stragling
- In ERIT scheme, however, the beam emittance growth can be cured by "Ionization Cooling" effect
- In other word, ERIT is "Ionization Cooling"

Ionization Cooling



Only muon!

How about proton?

$\tau_\mu = 2.2\gamma\ \mu s$ or $L_\mu = 660\beta\gamma$ m

Ionization Cooling

$$\frac{d\varepsilon}{ds} = A\varepsilon + B$$

ε : beam emittance

transverse

$$A = -\frac{1}{\beta^2 E}\left\{\frac{dE}{ds}\right\} \qquad B = \frac{\beta\gamma}{2}\beta_T \frac{(13.6MeV)^2}{(\beta cp)^2 L_s}$$

Ratherford mulitple scattering

longitudinal

$$A = 2\frac{\partial\left(\frac{dE}{ds}\right)}{\partial E} \qquad B = 4\pi\left(r_e m_e c^2\right)^2 n_e \gamma\left[1 - \frac{\beta^2}{2}\right]$$

straggling

cf. proton beam 10MeV
Be target

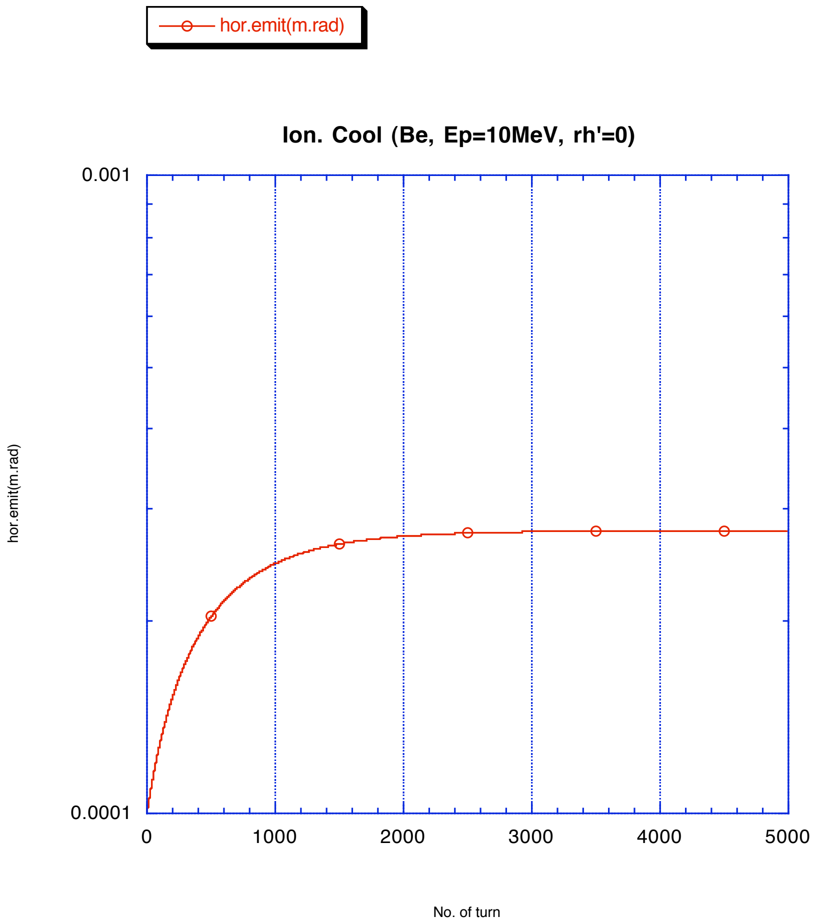
3D beam cooling becomes possible if transverse and longitudinal motions are coupled.

Transverse→Cooling
Longitudinal→Heating

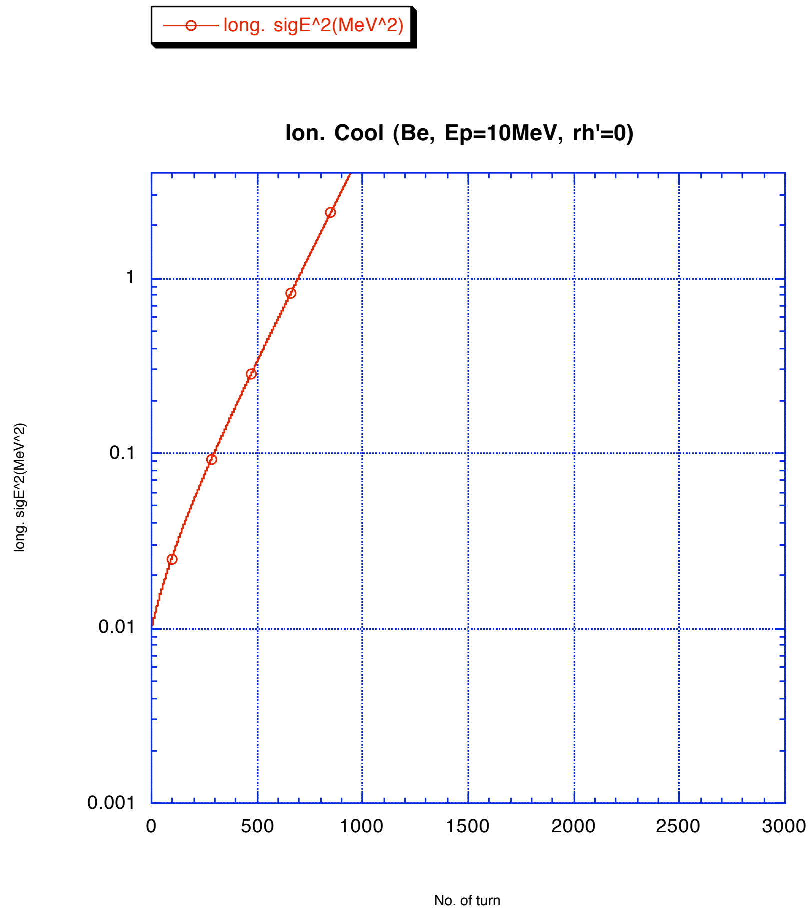
分配関数の和＞0 $\sum_{1}^{3} g_i > 0$

エミッタンス (rate equation)

Transeverse



Longitudinal



Coupling

logitudinal direction

$$\frac{d\langle \sigma_E{}^2 \rangle}{ds} = -2\frac{\partial (dE/ds)}{\partial E}\langle \sigma_E{}^2 \rangle + \frac{d\langle \Delta E^2{}_{rms} \rangle}{ds}$$

heating by straggling

cooling condition $\frac{\partial (dE/ds)}{\partial E} > 0$

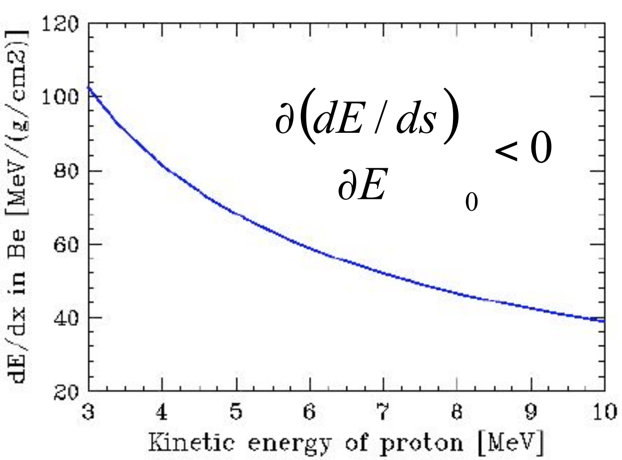
$$\frac{d\langle \Delta E_{rms}{}^2 \rangle}{ds} \cong 4\pi (r_e m_e c^2)^2 n_e \gamma^2 \left(1 - \frac{\beta^2}{2}\right)$$

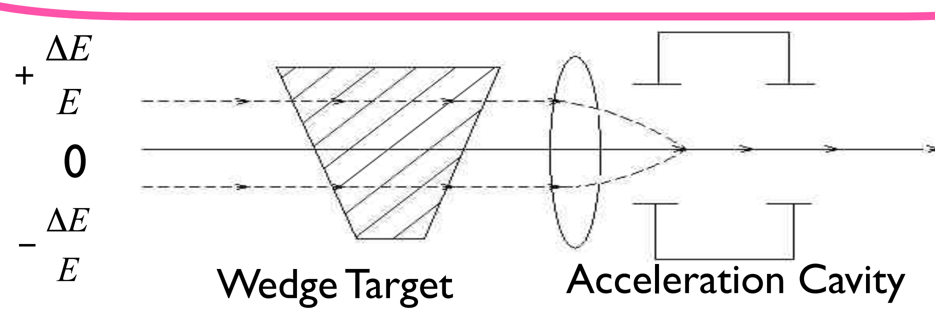
$$\frac{\partial (dE/ds)}{\partial E} \Rightarrow \left.\frac{\partial (dE/ds)}{\partial E}\right|_0 + \frac{dE}{ds}\frac{1}{pc\beta} D \frac{\rho'}{\rho_0}$$

ρ' : variation of thickness

When the wedged target is placed at dispersive point $\frac{\partial (dE/ds)}{\partial E} > 0$ can be possible.

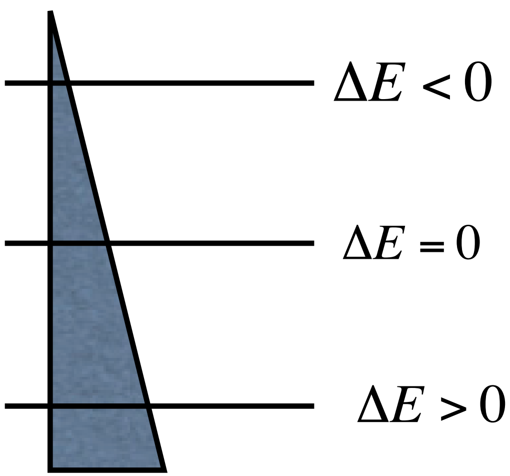
dE/dx



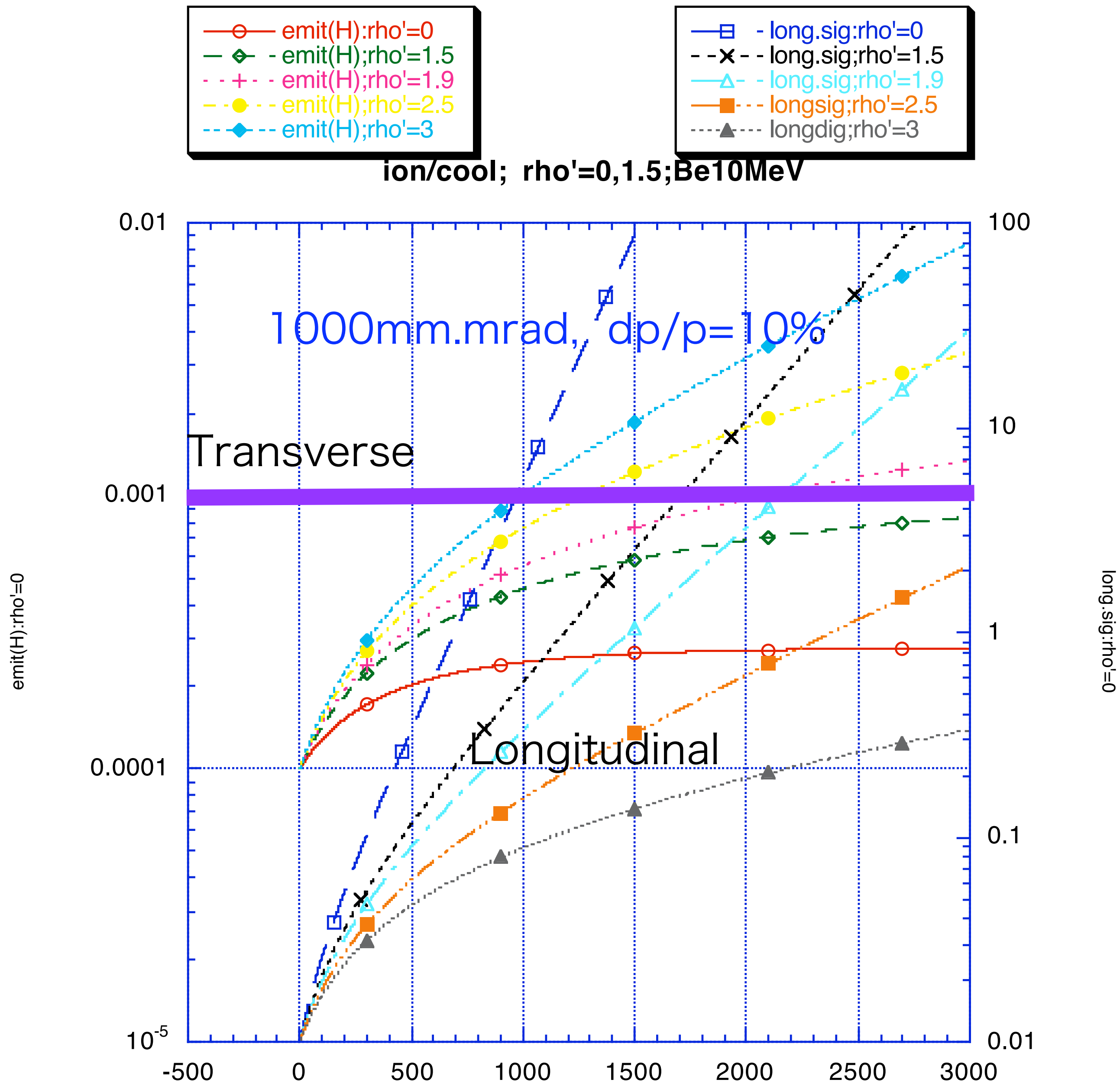


ERIT　ionization cooling

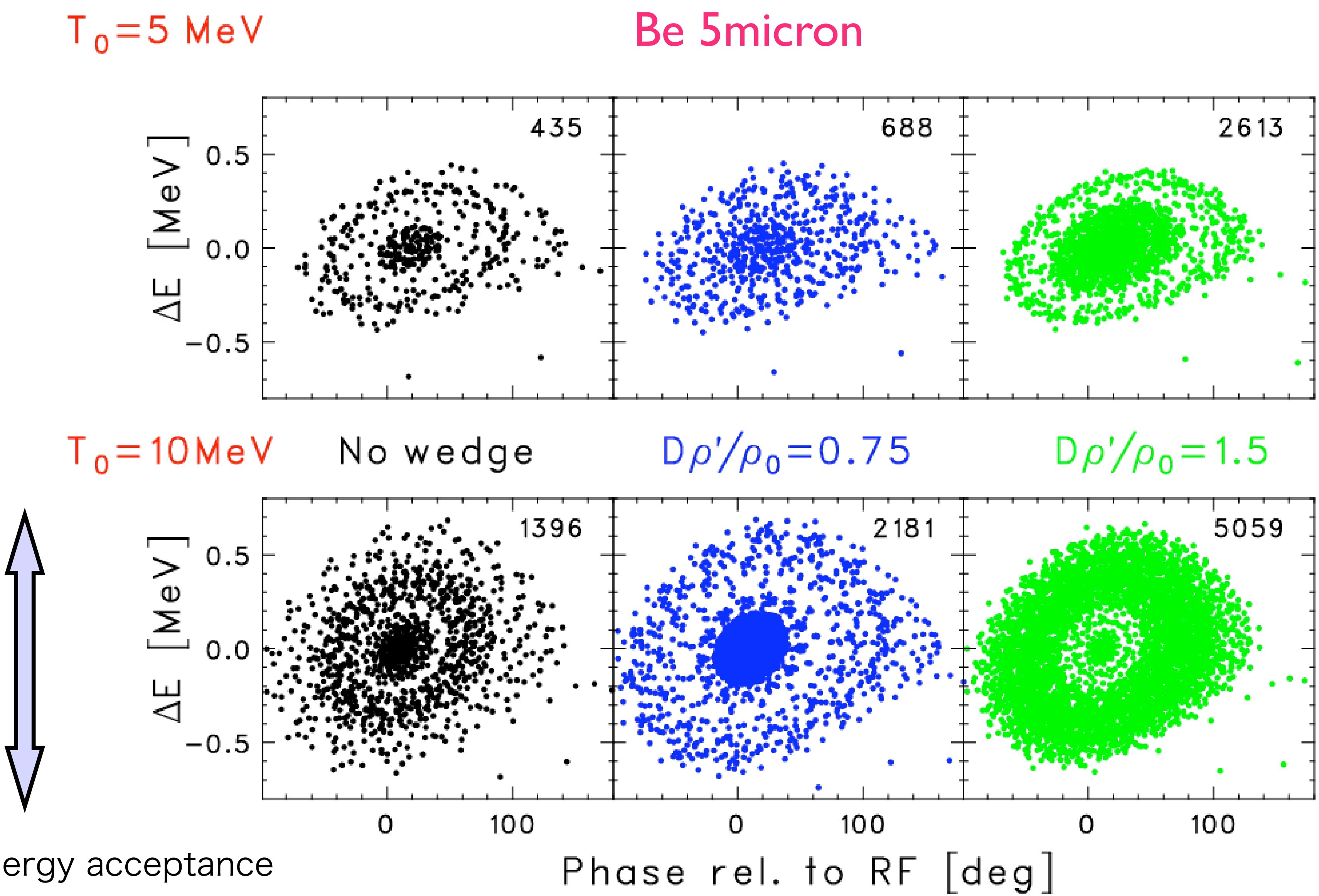
coupling x-z



wedge target



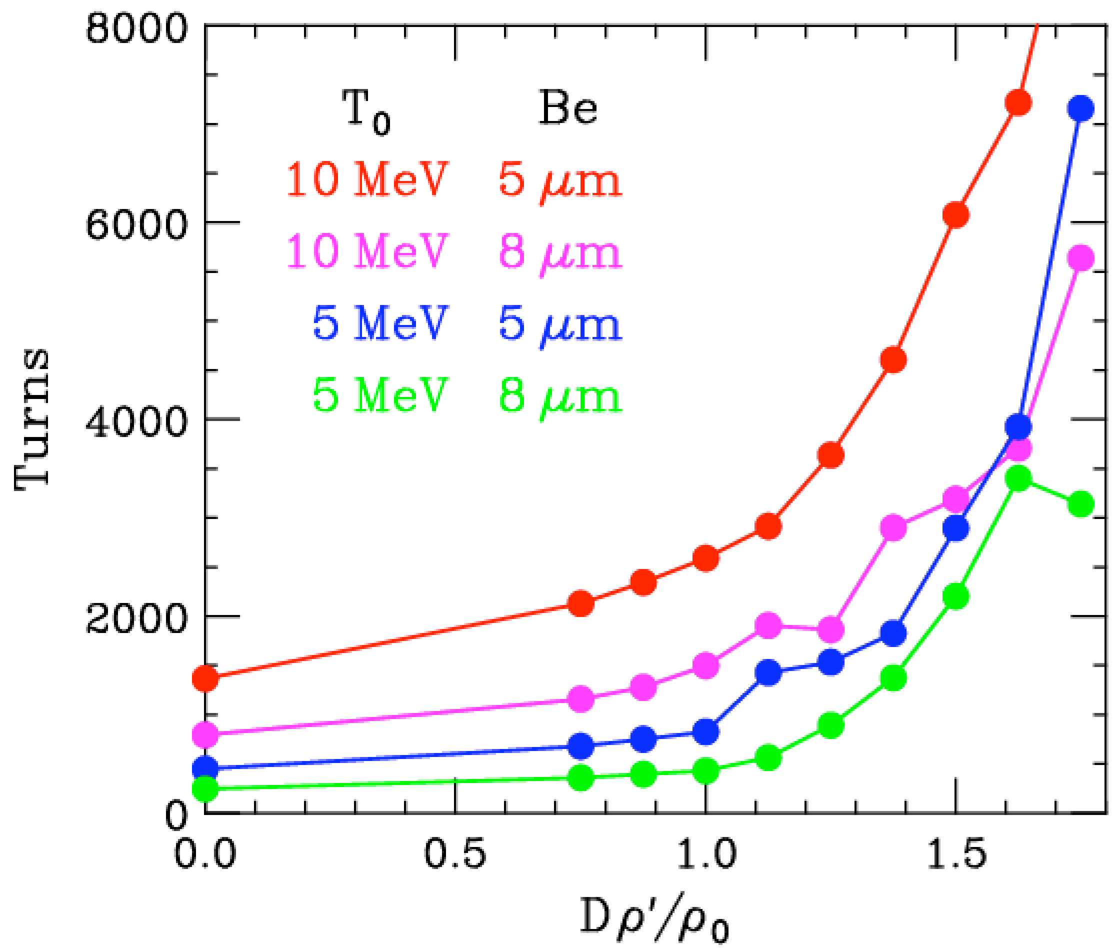
Simulation



energy acceptance

～１０%

summary of long. cooling



Number of turns : 2~3000 turns are possible.

Target : heat load

- dE/dx ~smallest at the maximum beam energy
  - advantage of ERIT
- beam power loss at target $\Delta P = Ic \times \Delta E$

25mA x 30keV=750W only! **cf. Be 5μm**

E=10MeV

Temperature rise of Be target

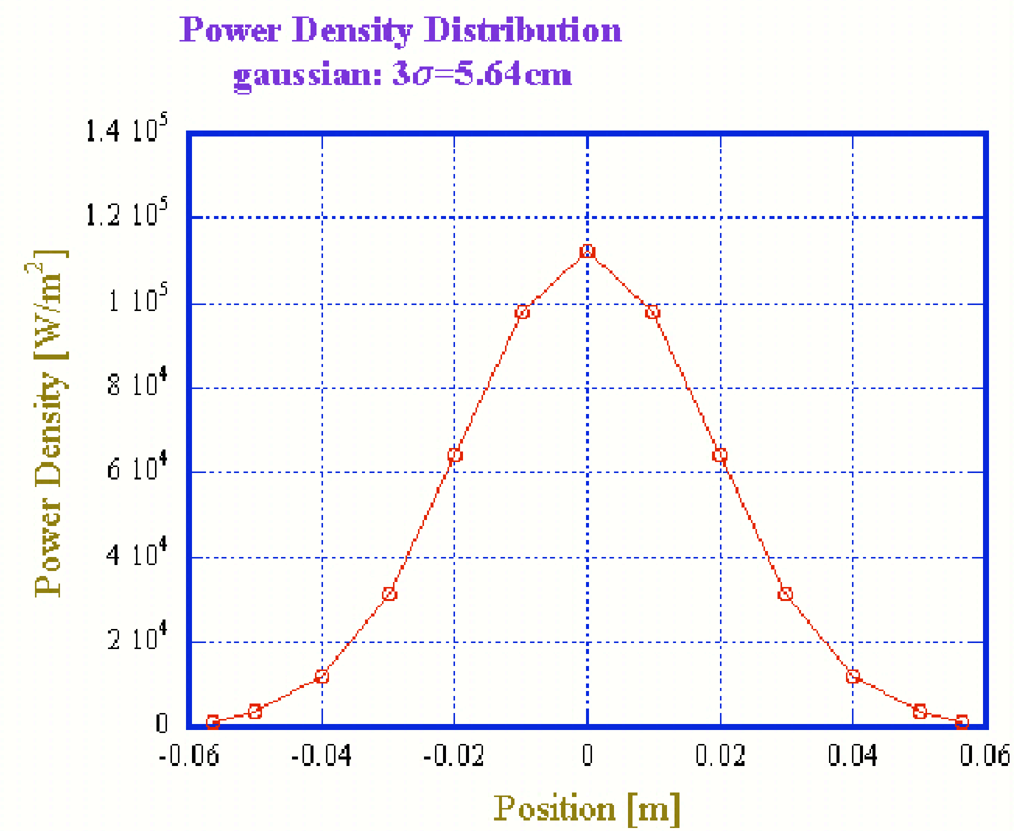
heat load **500W**

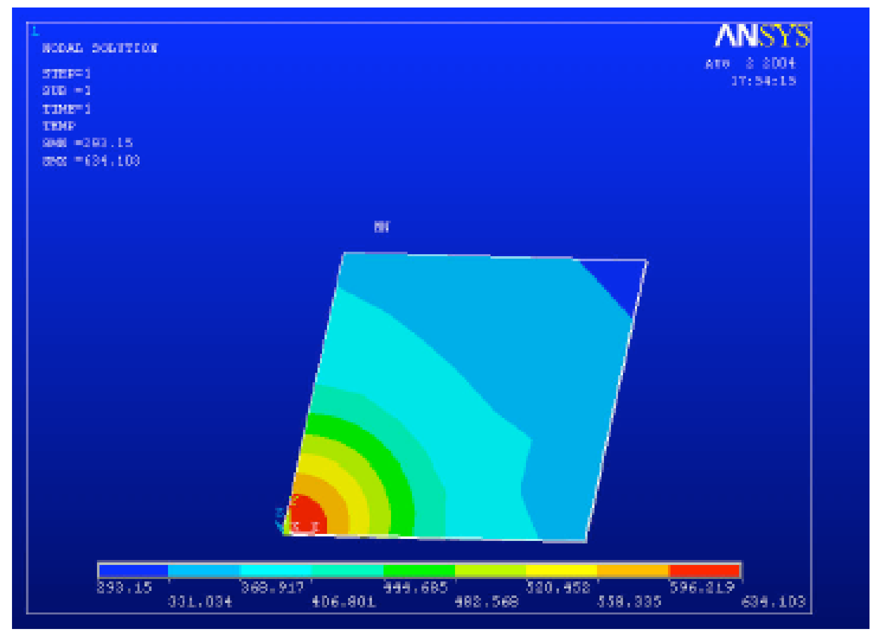
beam distr. **Gauss (3σ: 5.64cm)**

radiation $\propto T^4$

ANSYS

max. temperature ~634°K



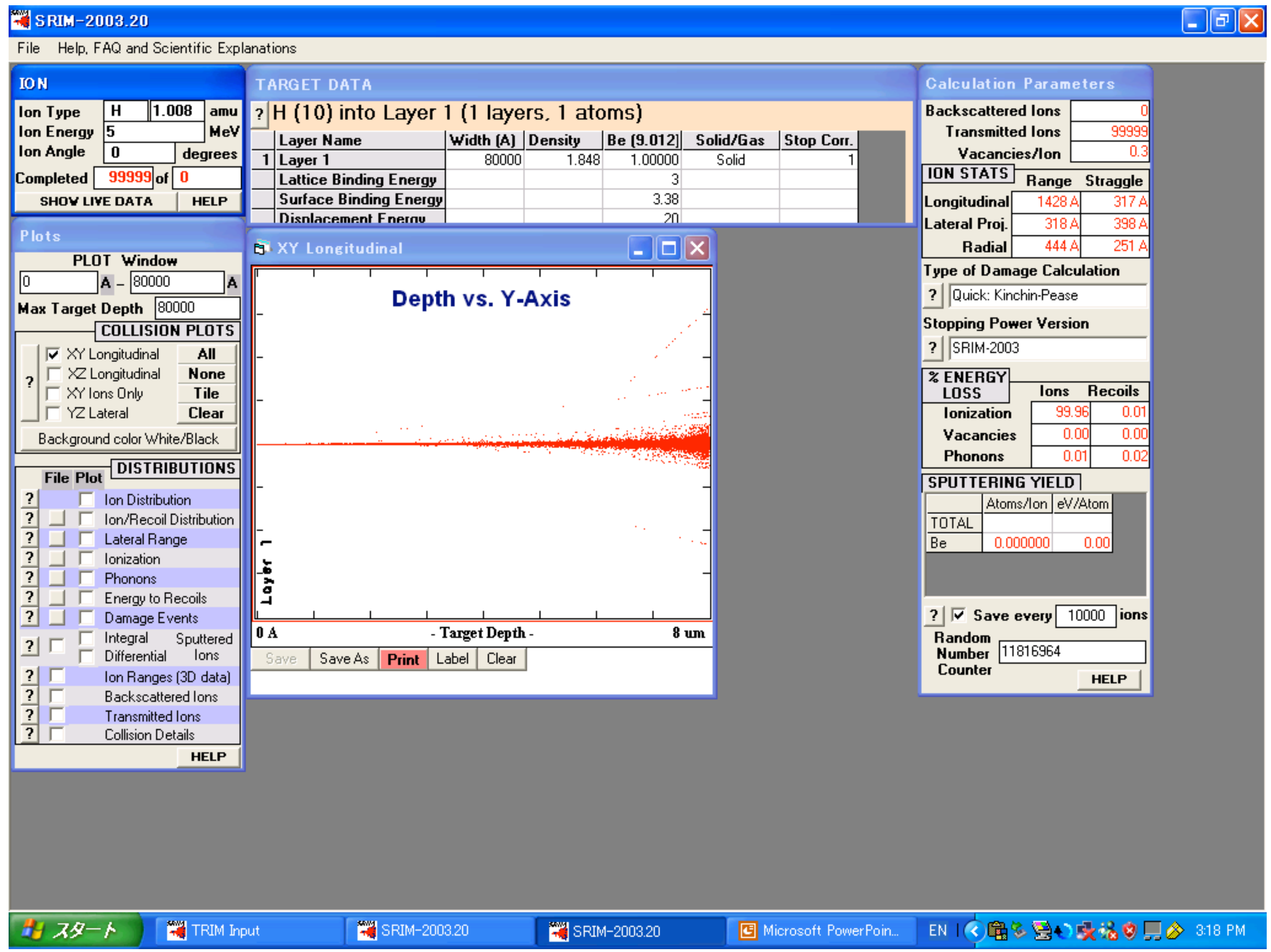


Irradiation damage of Be target

SRIM code

proton beam current 1A
energy 10MeV
Be target 8micro-m

Dislocation
< 0.1dps
small enough



FFAG-ERIT Neutron Source

Injector(RFQ + IHDTL)

Full energy injection

H^- kinetic energy	10 [MeV]
Average beam current	~ 45 [mA]
Repetition	>1 [kHz]

FFAG ring

H^- injection

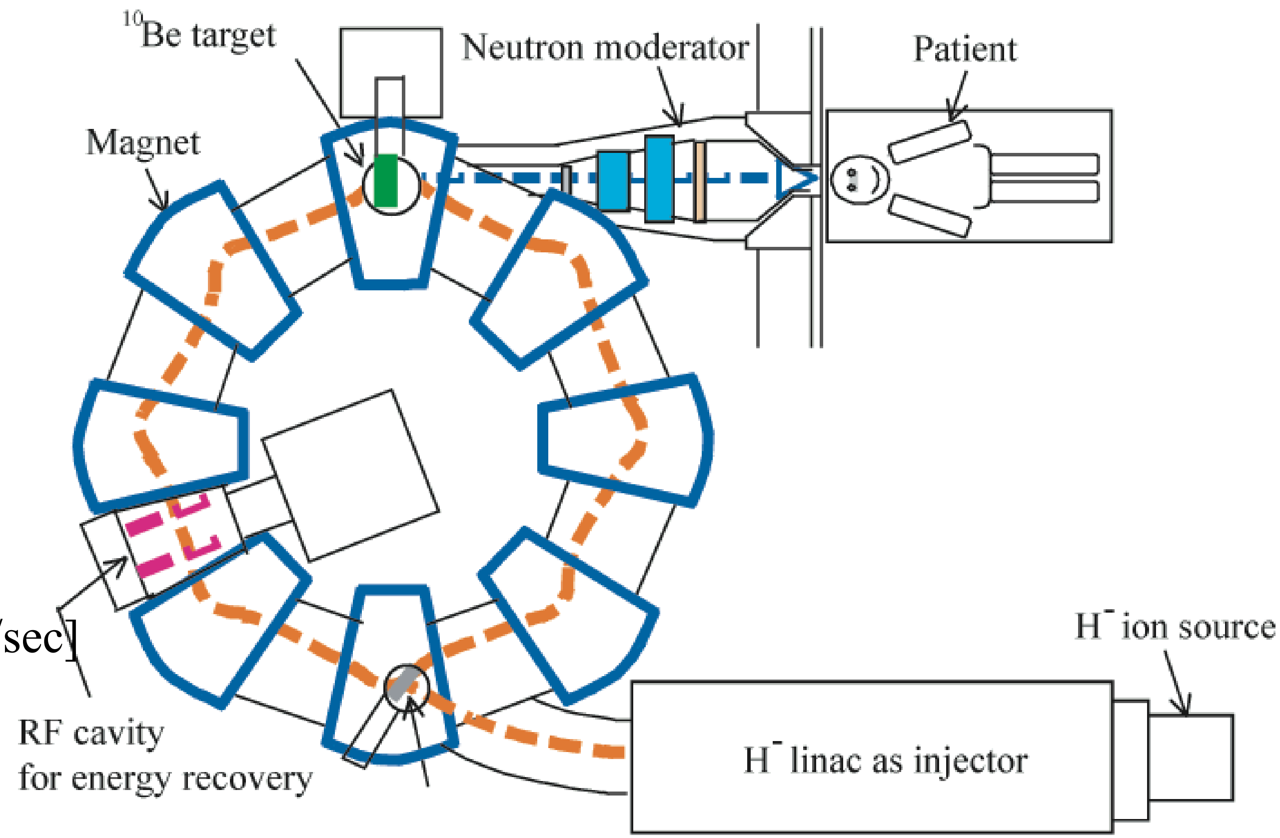
proton kinetic energy	10 [MeV]
Average beam current	~ 45 [mA]

ERIT system

Turn number	> 1000 turn
Internal target thickness	~ 5 [mm]
Neutron beam intensity	> 10^9 [n/cm^2/sec]

RF cavity

RF voltage	> 200 [kV]
Harmonic num.	~ 5



project schedule

- Project has been approved by MITI
  - Development of FFAG-ERIT and Drug Delivery System(DDS)

    FFAG/DDS research organization
  - 3-year project 2005-2007
- Place
  - Research Reactor Institute, Kyoto University

Summary

- Medical applicatins with FFAG accelerators.
  - Hadron beam therapy
    - 150-MeV FFAG accelerator   100Hz operation
    - Spot scanning
  - BNCT
    - Accelerator based neutron source with FFAG-ERIT concept
    - 3-year project has been approved and progressing in Japan
  -

We are in a very active phase!