Proton Driver with FFAG Accelerator

Research on Accelerator Driven Subcritical Reactor project with FFAG accelerators at Kyoto University

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Proton Driver

- purpose
  - generation of intense secondary particles
- Beam Energy
  - depend on secondary particle species
    - neutron : 2 MeV ~a few 100MeV(spallation)
    - pion : ~500MeV
- Beam Power
  - P> 1MW
  - notice: production efficiency is poor
    - spallation neutron Pn/Pb ~ 1/10-1/100

Research Reactor Institute
Kyoto University

Neutron Factory Project

Problems on Research Reactor

- Requirement for more advanced & diverse utilizations
- Safety concerns
- Fuel problems

Advanced Utilization of Neutrons

Hybrid System

New Nuclear Energy System

KUR

＞500MeV

20~70MeV

KUCA

Particle beam Lab.

Hybrid System

Phase 2

- Upgrading of neutron injector
- Realization of hybrid system
- Higher utilization of particle beam

Phase 1

- Renewal on neutron injector
- Basic research on hybrid system
- Utilization of particle beam including medical irradiation

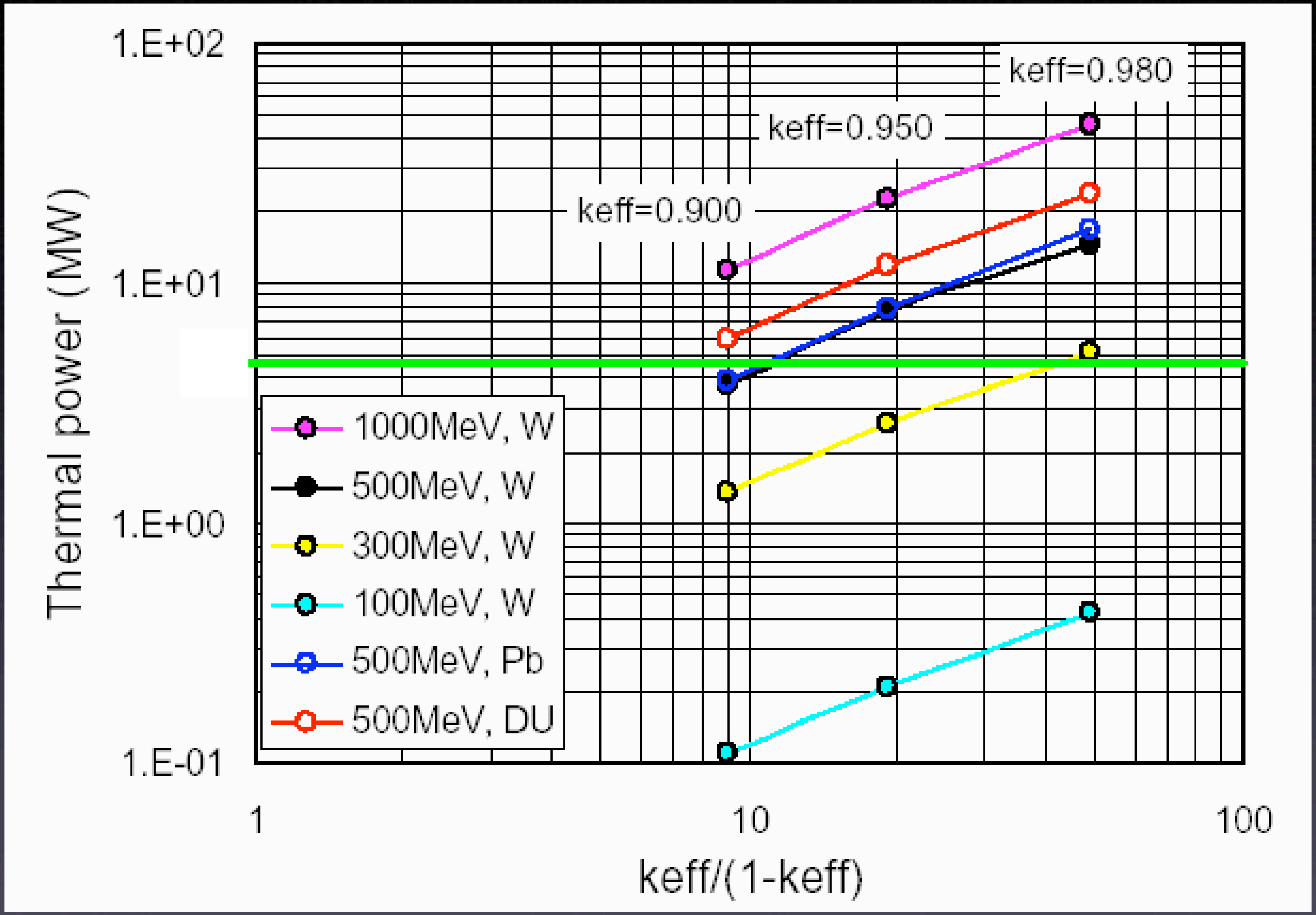
Previous Results of Neutronic Calculations for ADS

- ◆ Characteristics of ASD depends significantly on neutronics in the subcritical core

- ◆ Neutronic design of ADS requires much higher accuracy in calculations
  ∵ neutron multiplication $\mu 1/(1-k_{eff})$

- ◆ Method for analyzing dynamics of ADS should be developed
  - Monte-Carlo calculation taking account of delayed neutrons

Calculated Thermal Power of KUR-type ADSR

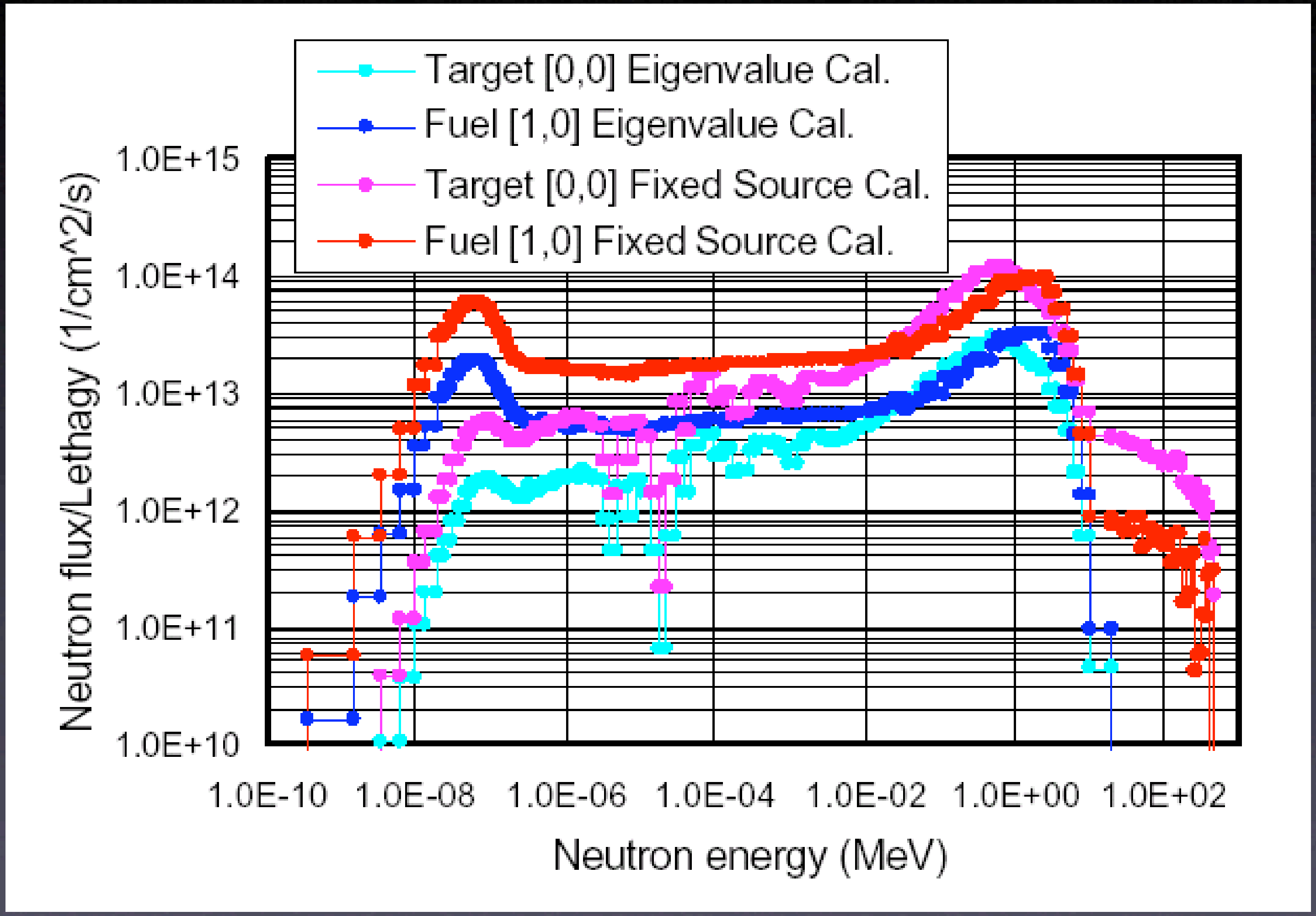


Thermal power of KUR-type ADSR (proton beam current=1mA) as a function of target material and effective multiplication factor

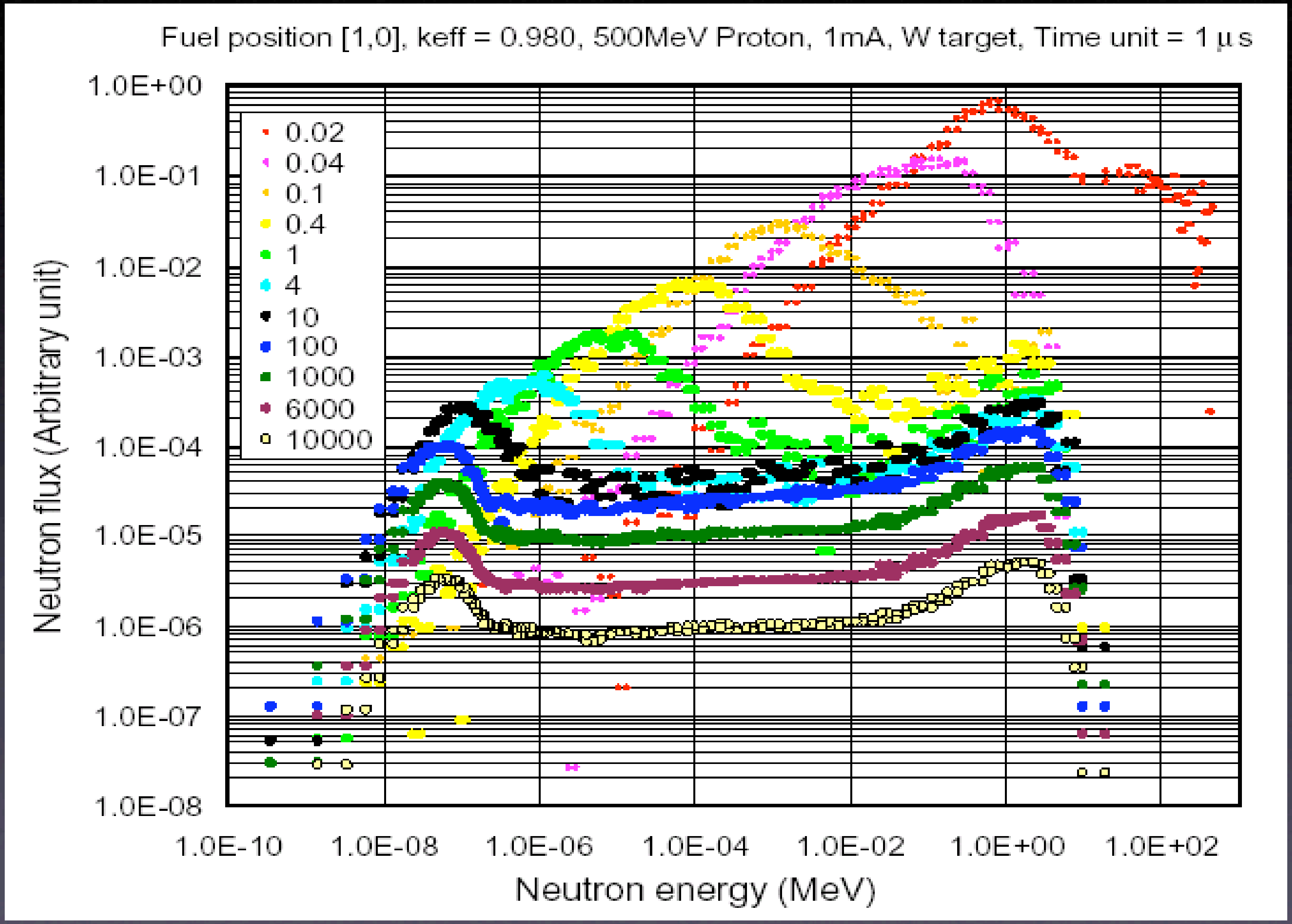
Calculation result of neutron spectrum in KUR-type ADSR

Eigen value calculation (W-target, keff=0.98, power=5MW)

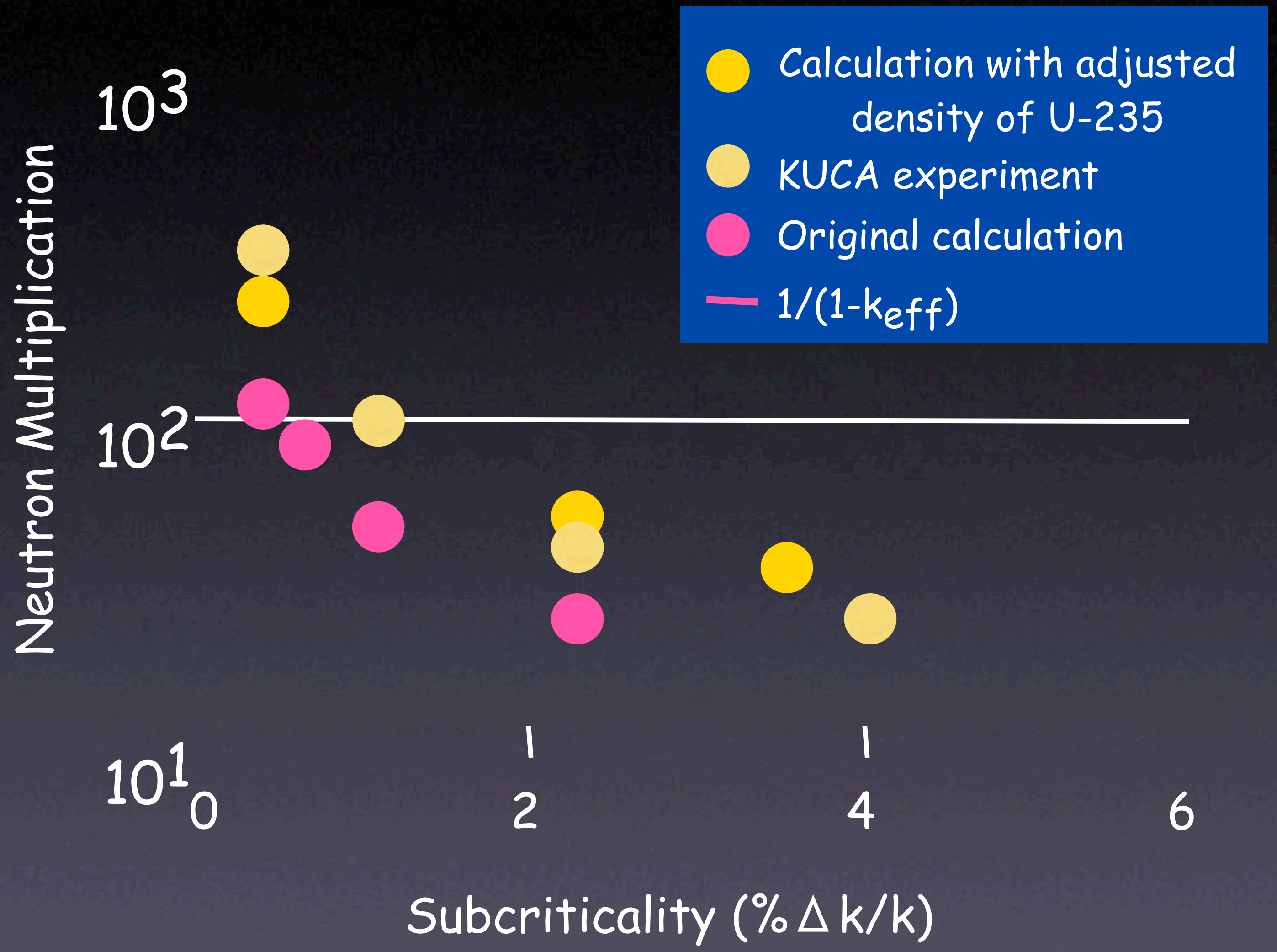
Fixed source calculation (W-target, 500MeV proton(1mA) injection)



Temporal variation of neutron spectrum in ADSR after injection of pulsed proton

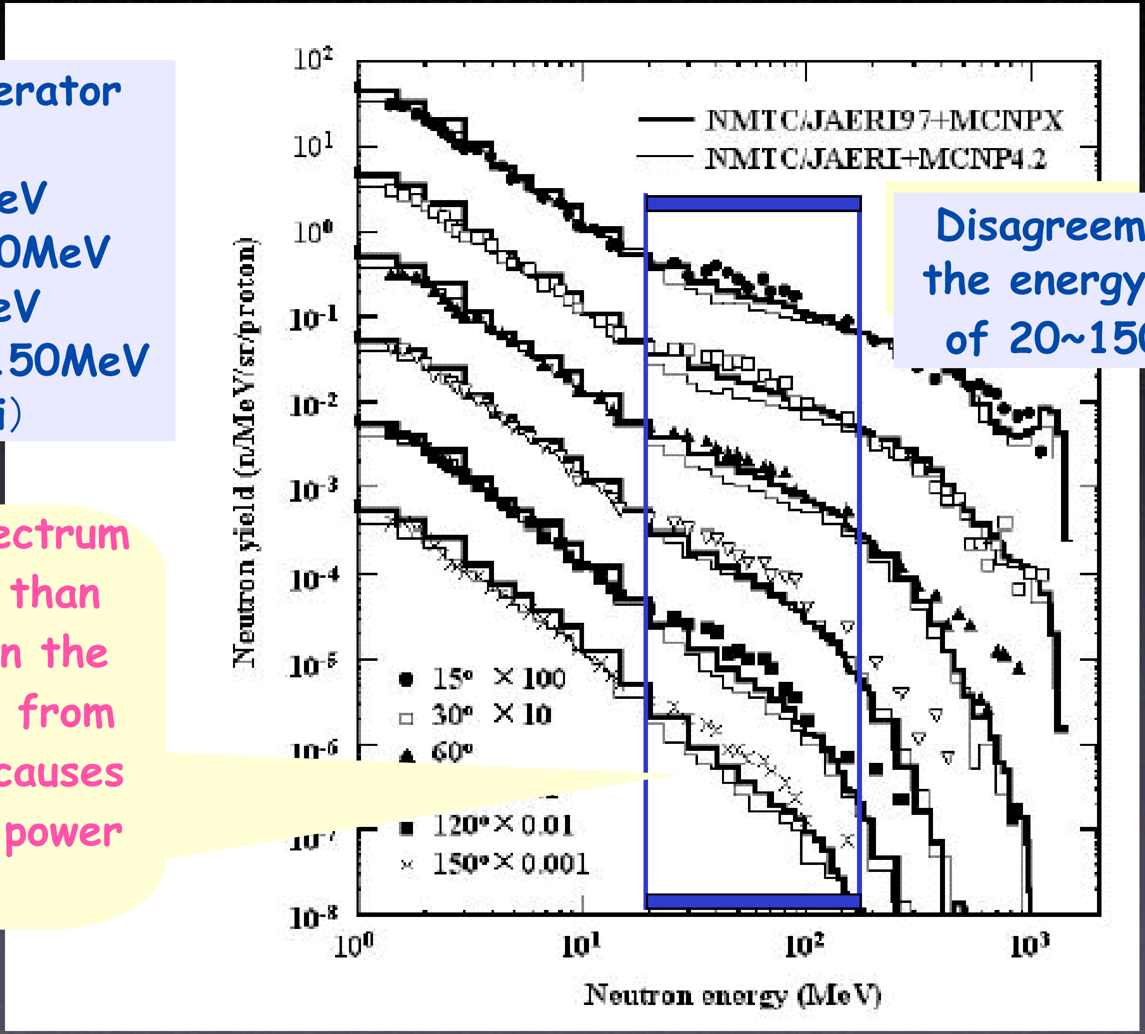


Comparison of Neutron Multiplication between Experiment and Calculation



Experimental and Calculated Neutron Yield for 1.5GeV Proton Incident on Lead Target
(15 by 15 cm in width and 20 cm thick)

Exp.：KEK proton accelerator
Calculations：
① MCNP4.2＜20MeV
NMTC/JAERI＞20MeV
② MCNPX＜150MeV
NMTC/JAERI97＞150MeV
（by Ishibashi）



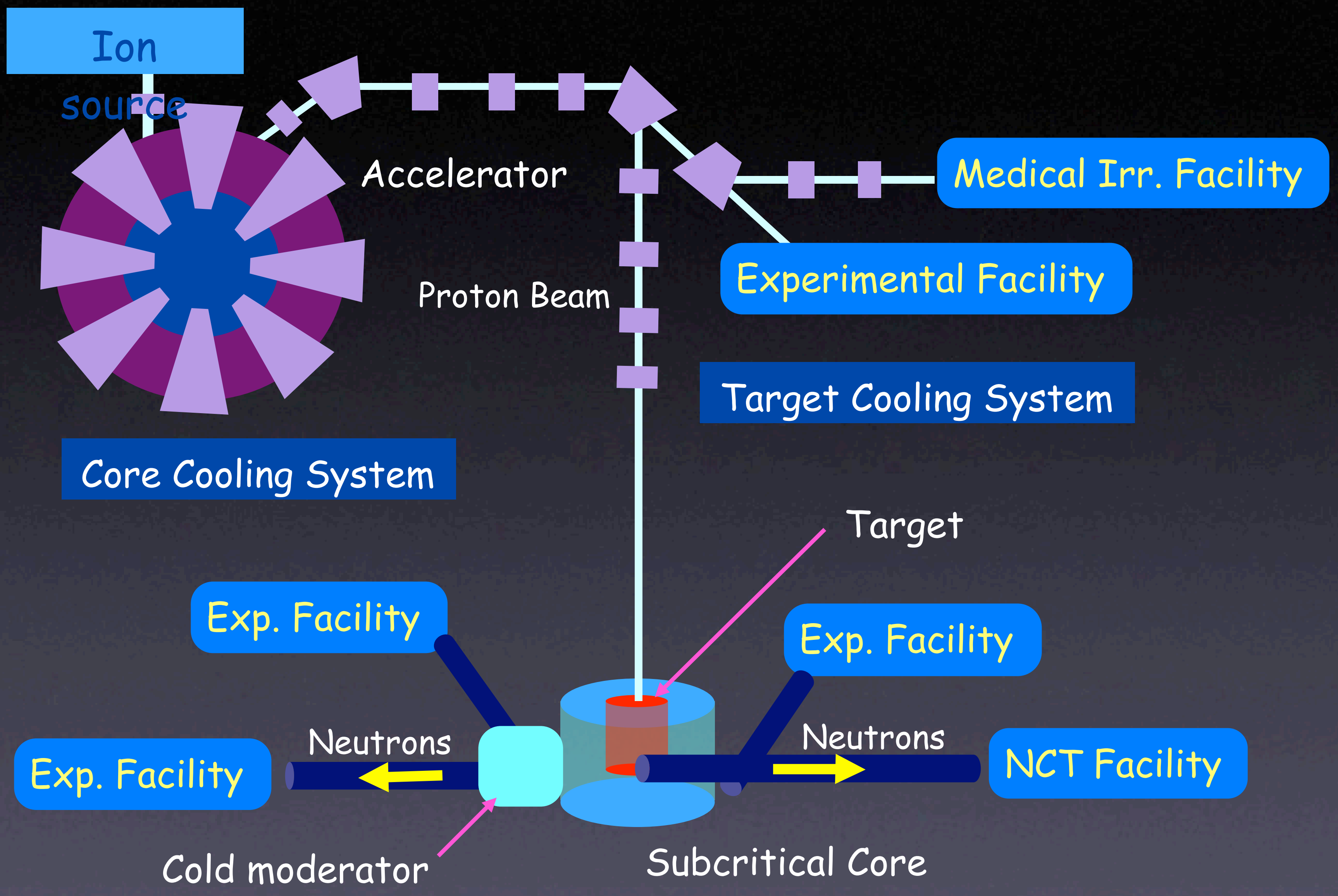
Disagreement in the energy range of 20~150MeV

Calculated neutron spectrum is 2 ~3 times larger than experimental values in the neutron energy range from 20 to 80MeV, which causes 4 % error in thermal power of ADS

Objectives of Present Neutronic Study on ADSR

- KUCA Preliminary Experiment Using 14MeV incident neutrons
  - Measurement of subcriticality and neutron decay constant in subcritical enriched-U and mixed U/Th thermal neutron systems
  - Optimization of neutron beam collimator
- Analysis of preliminary KUCA experiment using continuous energy Monte-Carlo codes MVP, MCNP and MCNP-X
  - Evaluation of criticality of enriched-U and mixed U／Th thermal neutron systems
  - Evaluation of prediction accuracy of criticality and subcriticality by analyzing critical and subcritical KUCA experiments
  - Comparison of prediction accuracy between MVP, MCNP and MCNP-X codes
- ADSR experiment using coupled FFAG accelerator and KUCA
  - Measurement of neutronic characteristics of ADSR

Concept of ADS Research Reactor



Five-year project (US$~10M in total)

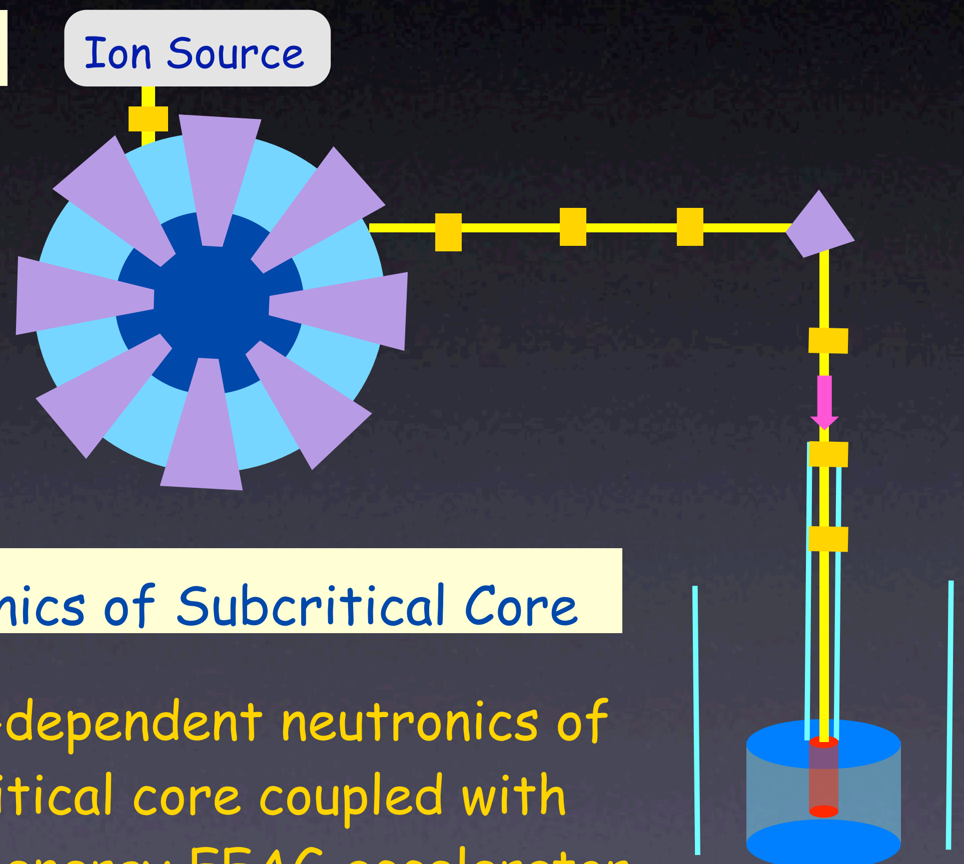
Feasibility Study on ADSR Using FFAG Accelerator

supported by

MEXT Technology Development Project for Innovative Nuclear Energy System

Accelerator Development

Development of variable energy FFAG accelerator with high acceleration efficiency



Neutronics of Subcritical Core

Energy-dependent neutronics of subcritical core coupled with variable energy FFAG accelerator

Main Feature of Proposed ADS

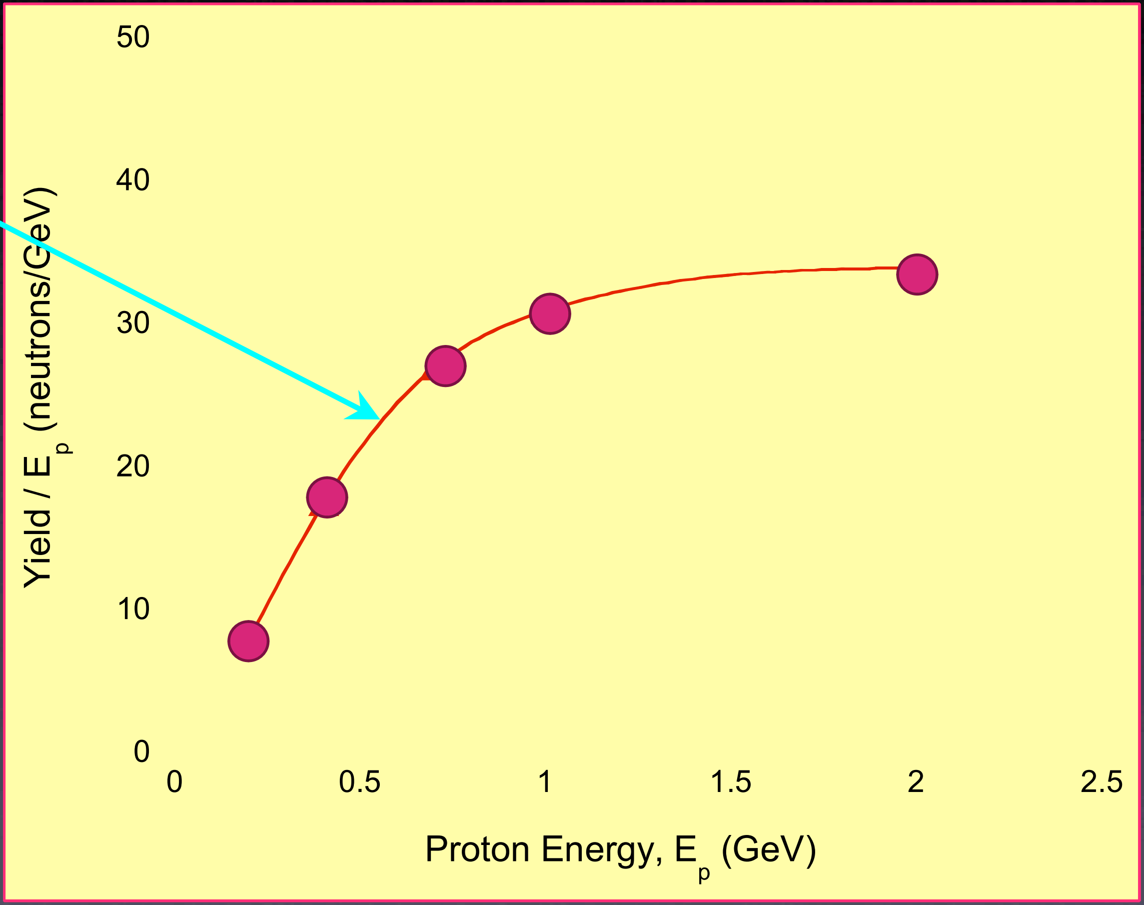
ADS Power $\propto \dfrac{S}{1-k_{eff}}$

Control of S
- Control by beam current
- Control by beam energy

Variable-energy FFAG accelerator
- Control by beam energy & beam current

Spec. of FFAG accelerator
- Energy : 2.5～150 MeV
- Current: ～1 mA

Subcritical core: thermal neutron system
(Not fast neutron system)



History of FFAG Proton Accelerator

- 1953: Basic concept by Ohkawa

  Proton FFAG accelerator was not successful until recent

  →**difficulty in fabricating RF cavity with variable frequency & high gradient field**

- 1998 : Development of RF cavity using Magnetic Alloy

  Grant-in-Aid for Scientific Res. by MEXT : Y. Mori, KEK

- 2000 : Development of Proton FFAG Accelerator

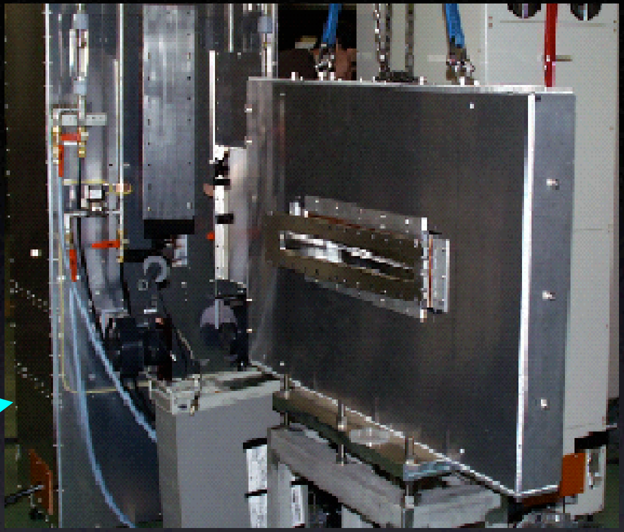
  Grant-in-Aid for Scientific Res. by MEXT: Y. Mori, KEK

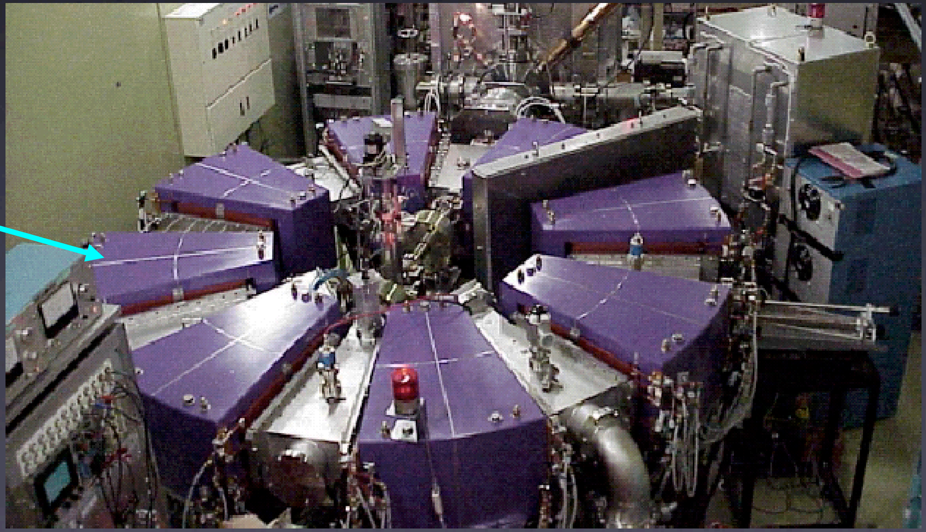
- 2002 : Development of 150MeV multipurpose FFAG accelerator

  100Hz Operation!

  Grant-in-Aid for Creative Basic Res.

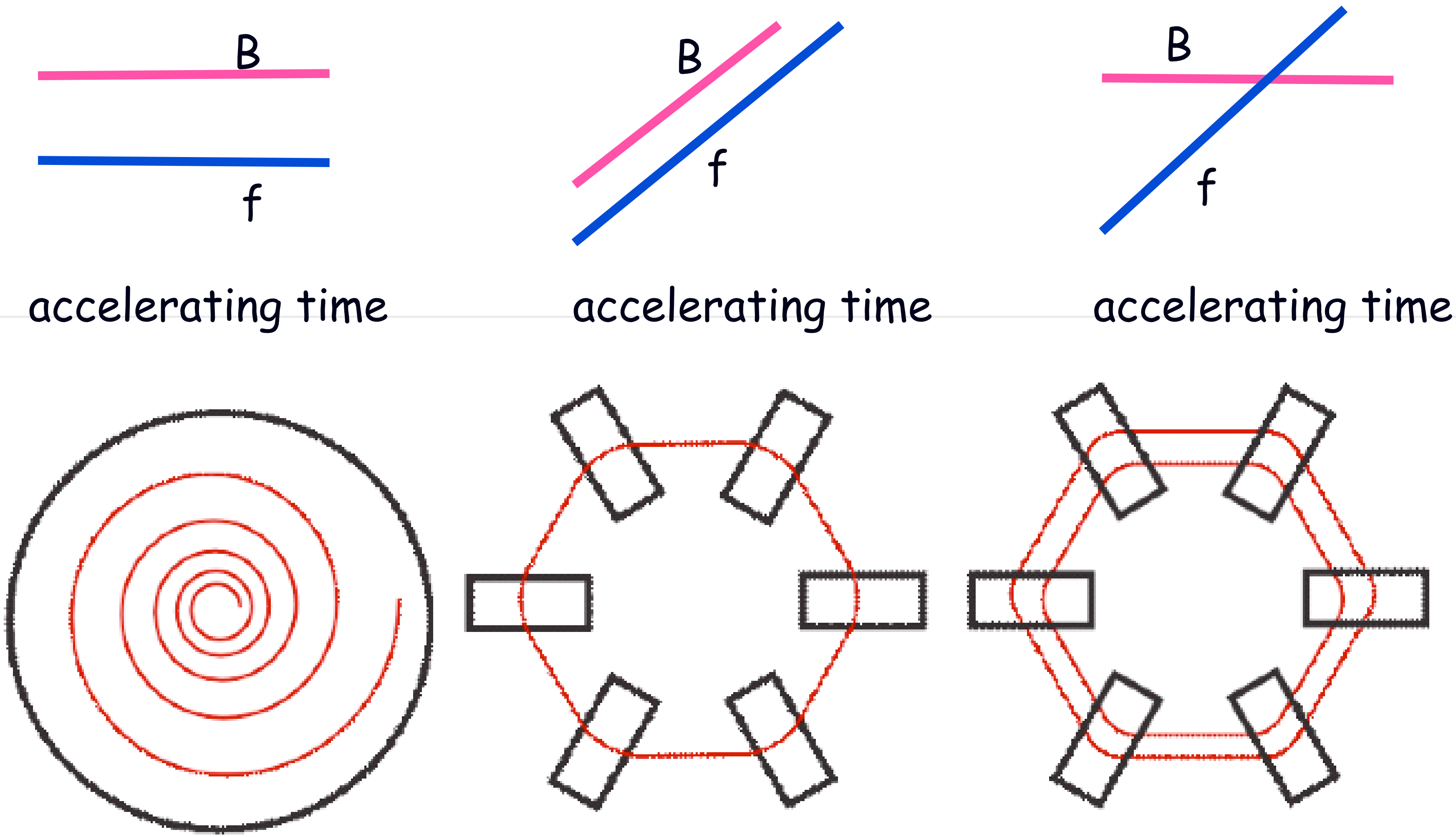
RF Cavity





Proof-of-Principle (PoP)-Proton FFAG Accel.

Comparison among Cyclotron, Synchrotron and FFAG



Cyclotron
isochronous

Synchrotron
*const. closed orbit
(varying magnetic field)

FFAG
*varying closed orbit
(const. magnetic field)

Comparison between Synchrotron and FFAG

	FFAG	Synchrotron
1. Magnetic field	static (fixed)	varying with time
2. Closed orbit	moving	fixed
3. Focusing	strong	strong
4. Duty factor (Repetition cycle)	large～10-50% (max.～1kHz)	small～1% (～50Hz)
5. Space charge instability	not critical	severe

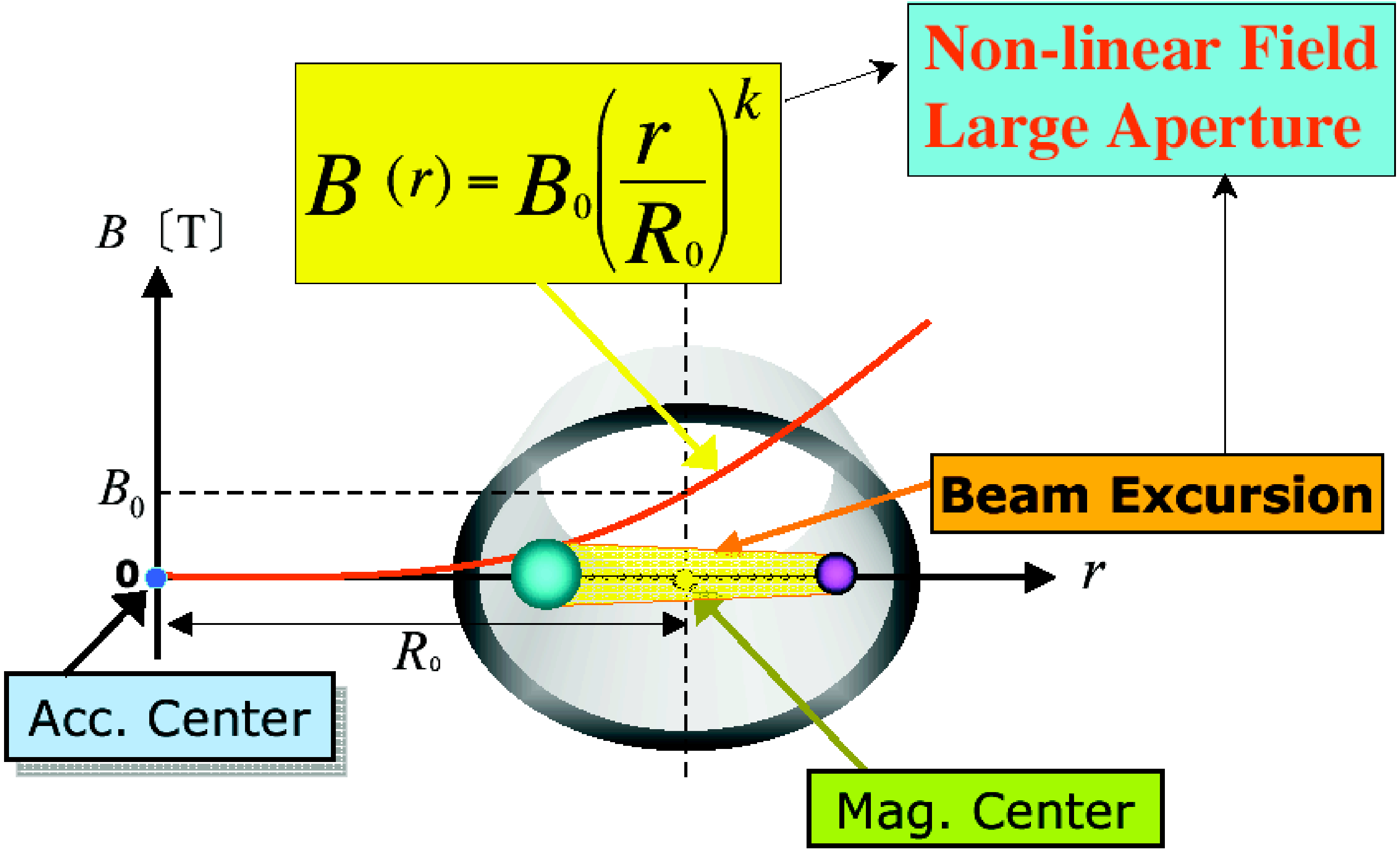
Problems to be solved to develop FFAG accelerator

＊Complicated magnetic field → 3D Codes（TOSCA, etc.）

＊RF system: high acceleration＋rapid tuning

→Development of high gradient & broad band RF cavity

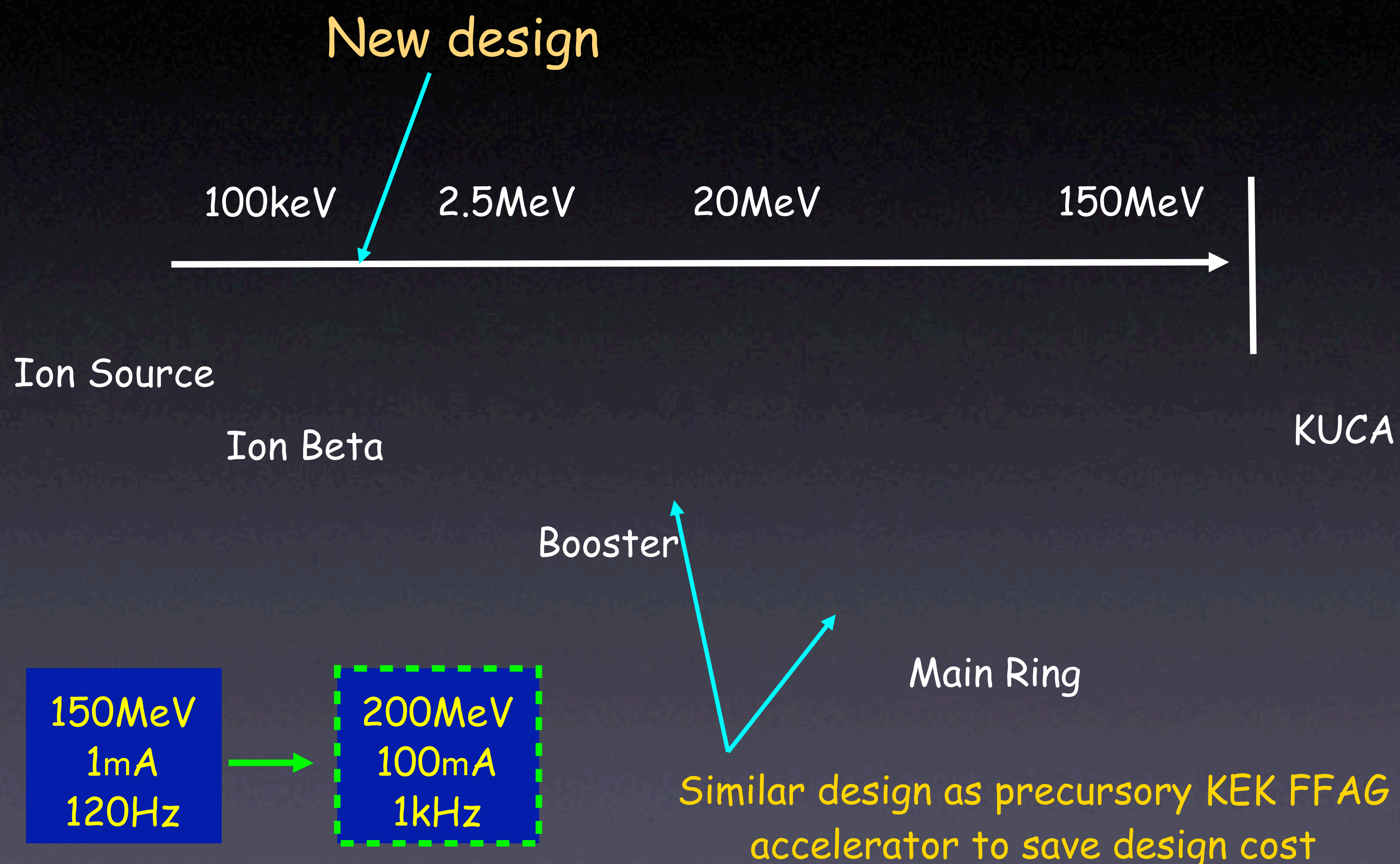
Non-linear Magnetic Field in FFAG accelerator



Beam Specs of FFAG Accelerator

Beam Species	H+
Energy	20 – 150 MeV
Average Beam Current	1I A
Pulse Repetition Rate	120Hz

Configuration of FFAG Accelerator Complex

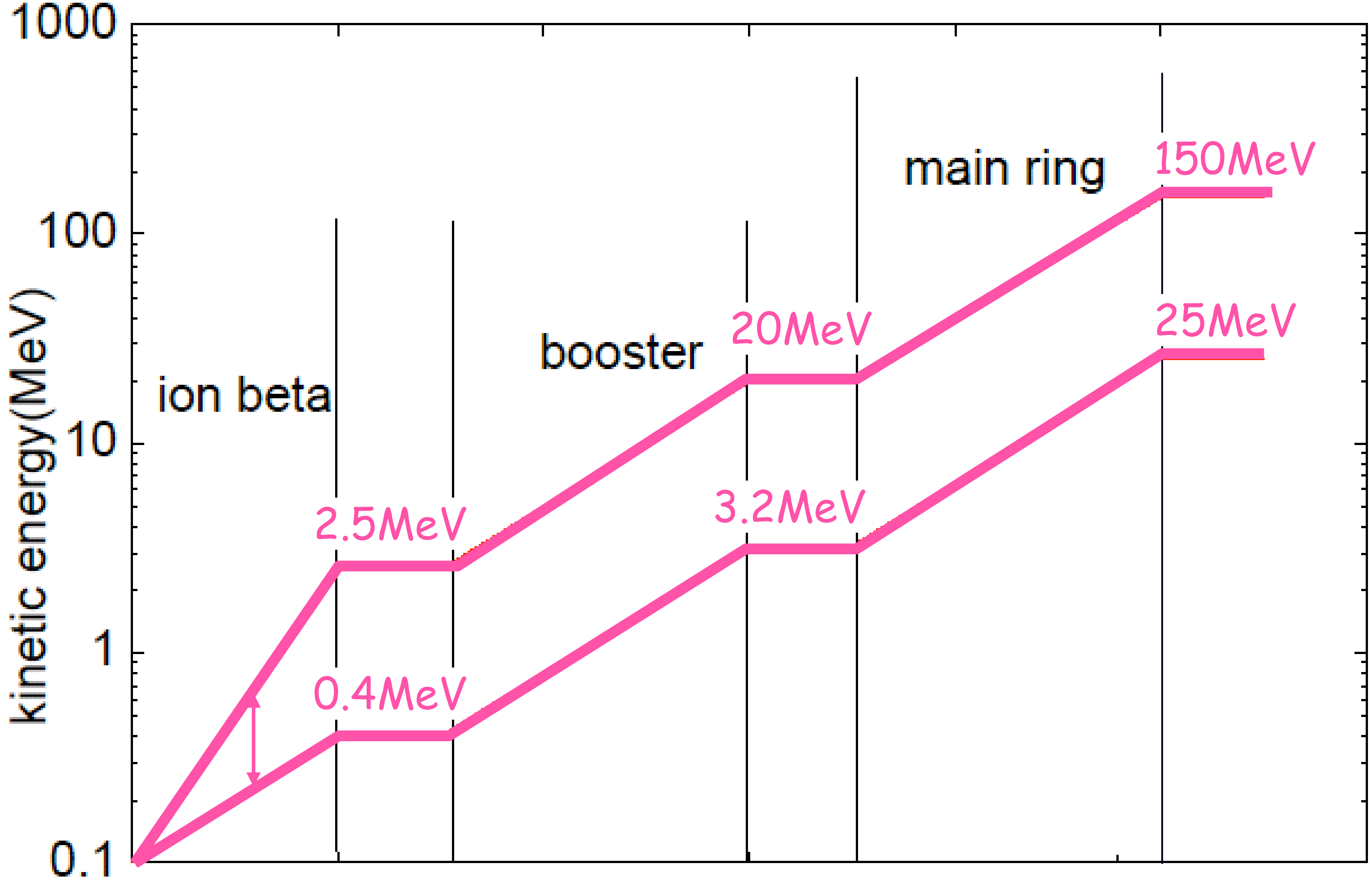


System Parameters of FFAG Accelerator

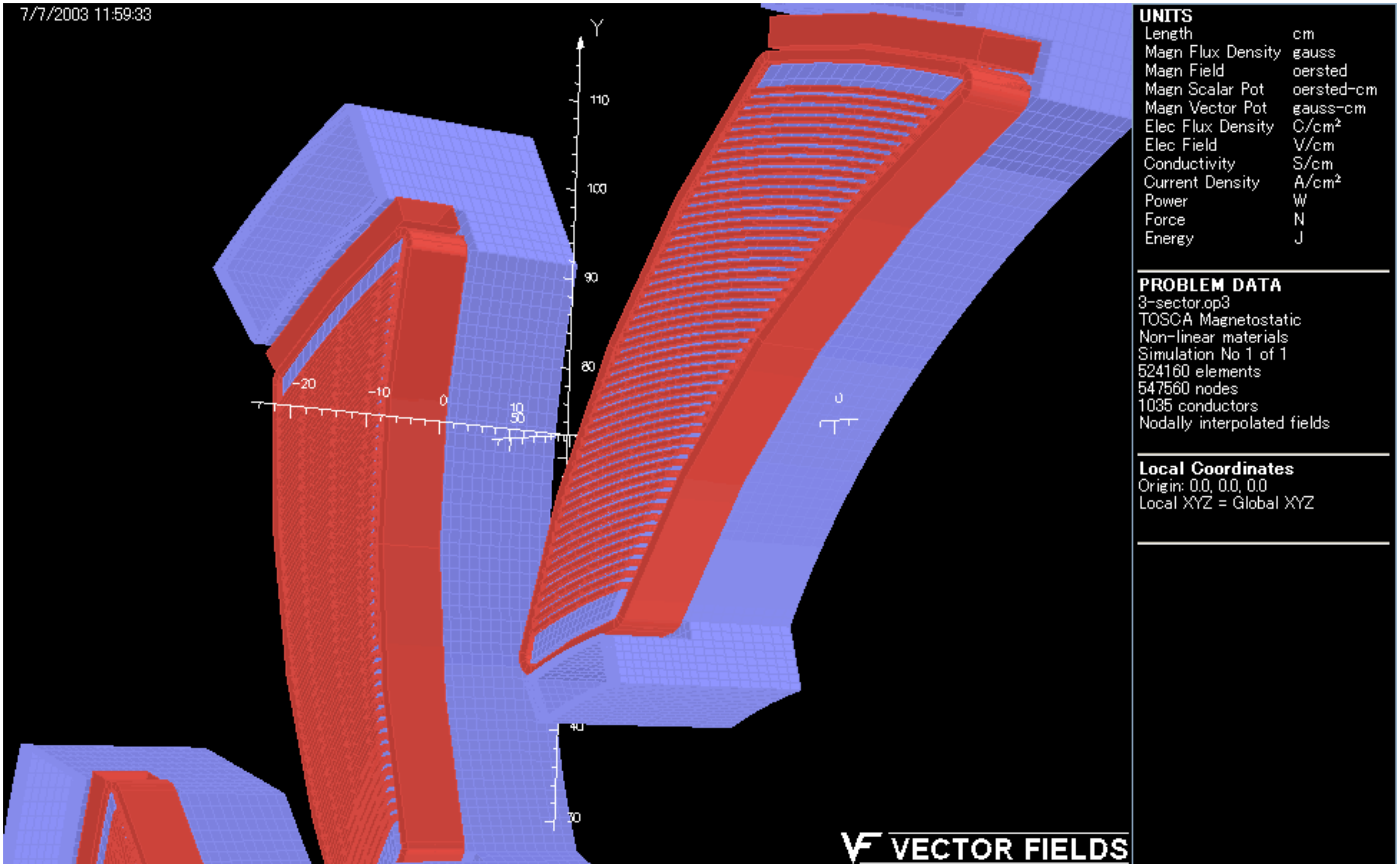
	Ion Beta	Booster	Main Ring
Focusing	Spiral	Radial DFD	Radial DFD
Acceleration	Induction	RF	RF
Number of Cells	8	8	12
k-value	2.5	4.5	7.6
Injection Energy	100keV	2.5MeV	20MeV
Exit Energy	2.5MeV	20MeV	150MeV
Pext/Pinj	5.00	2.84	2.83
Injection Orbit	0.60m	1.42m	4.54m
Exit Orbit	0.99m	1.71m	5.12m

Variable Energy FFAG Accelerator Complex

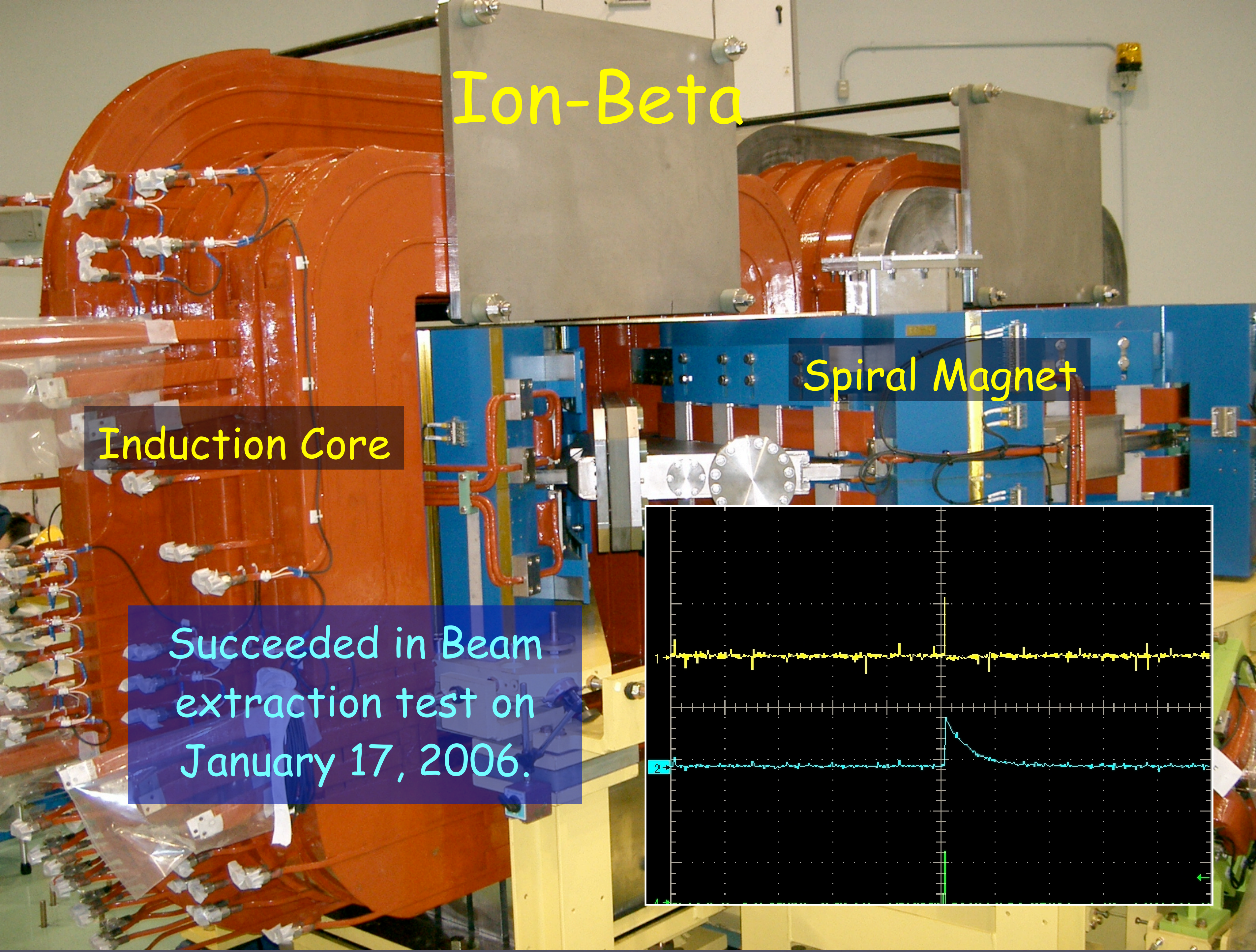
Extraction proton energy can be varied by changing k-value of Ion Beta

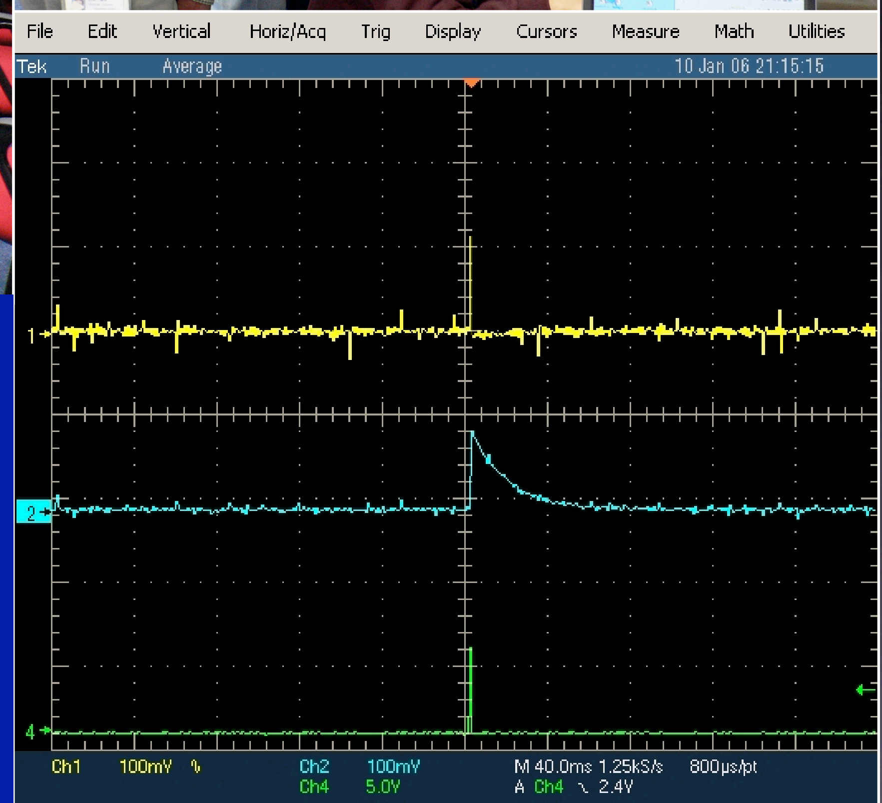


スパイラル磁石形状（モデル1：48分割）



Ion-Beta


Spiral Magnet
Induction Core
Succeeded in Beam extraction test on January 17, 2006.



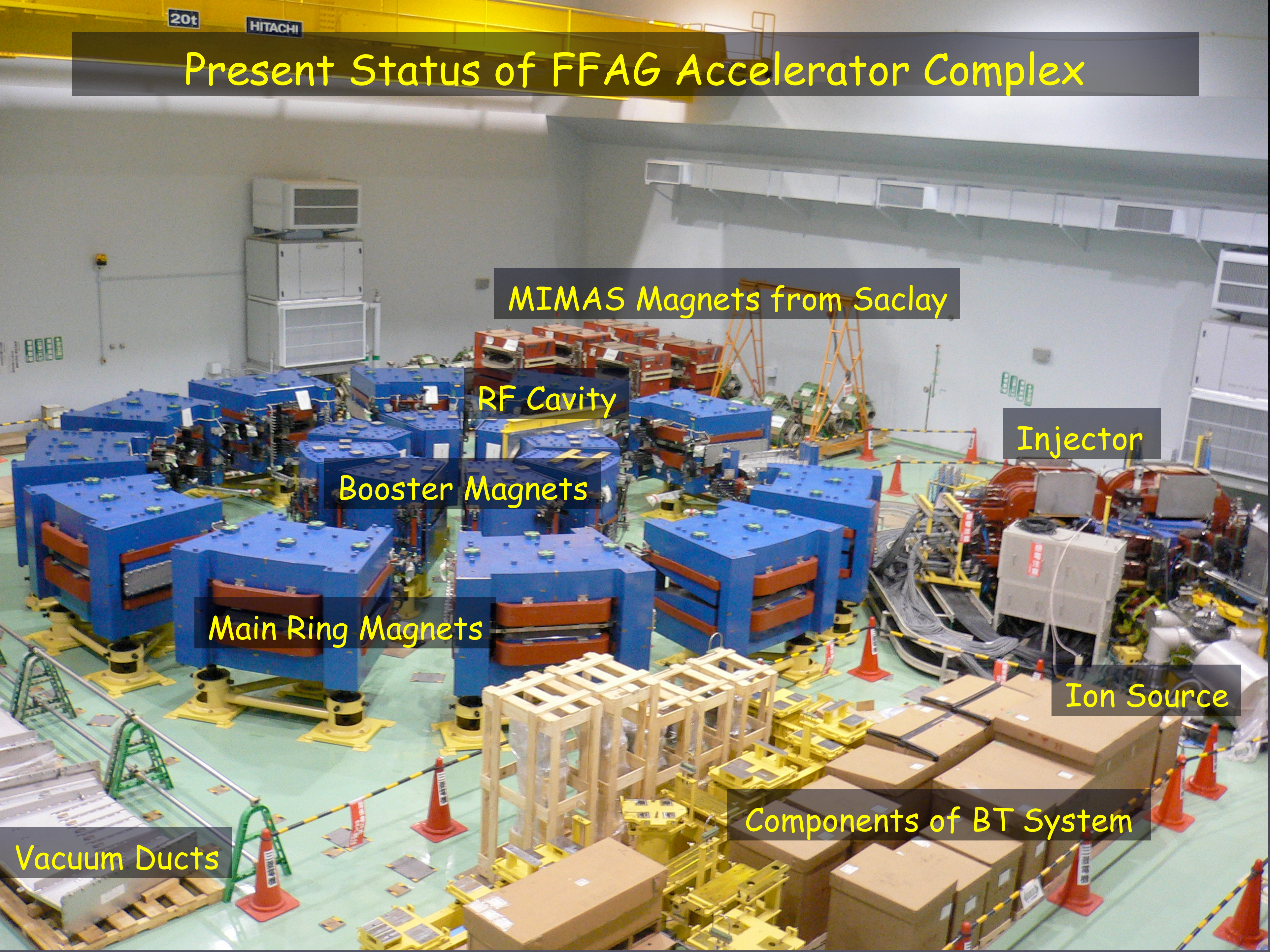
<u>Injector</u>

Acceleration & Extraction

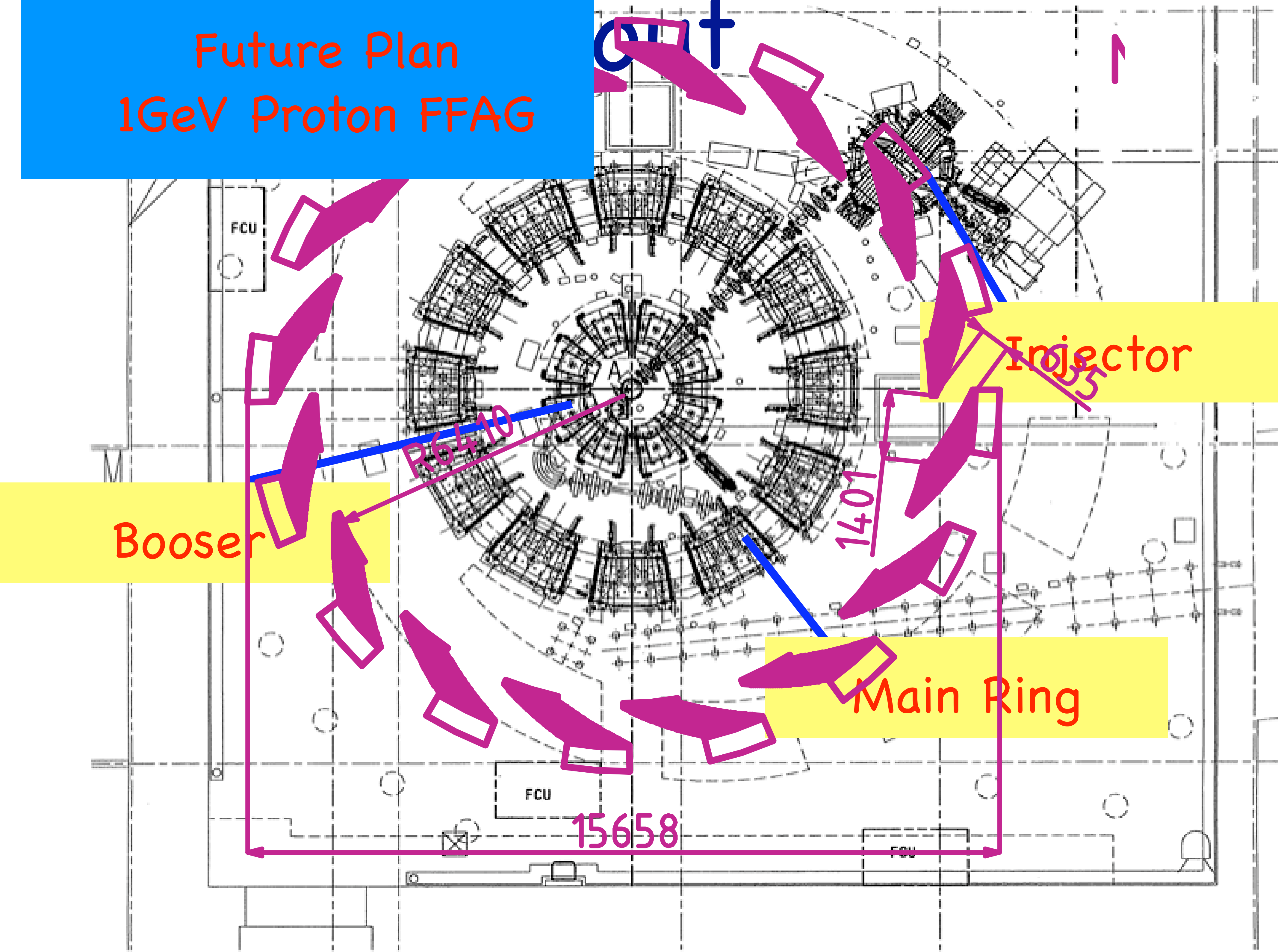
Completed: Jan. 17, 2006

provided by Prof. Mishima

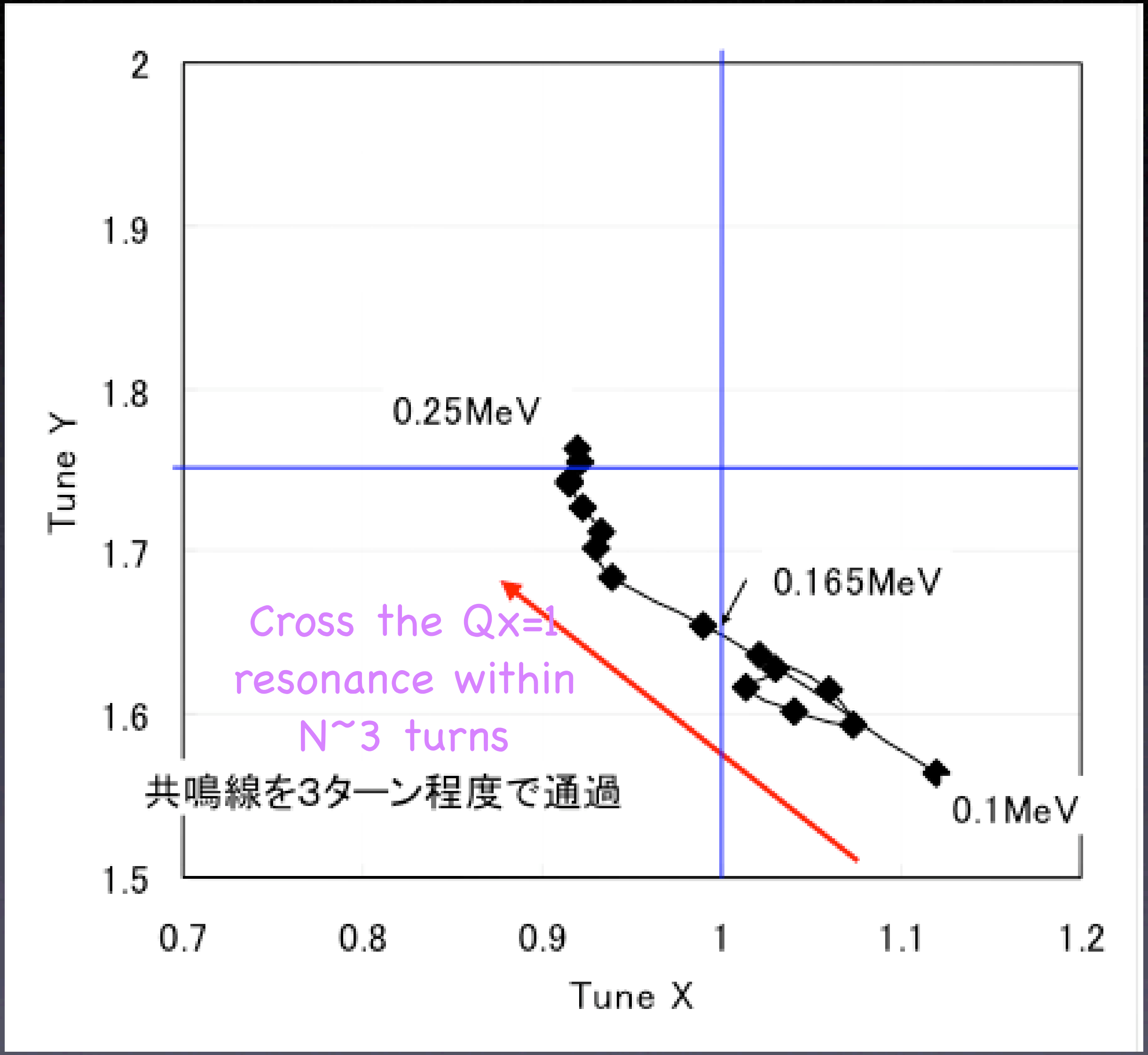
Present Status of FFAG Accelerator Complex



Future Plan
1GeV Proton FFAG



Resonance (integer) crossing experiment with variable k injector



k=0

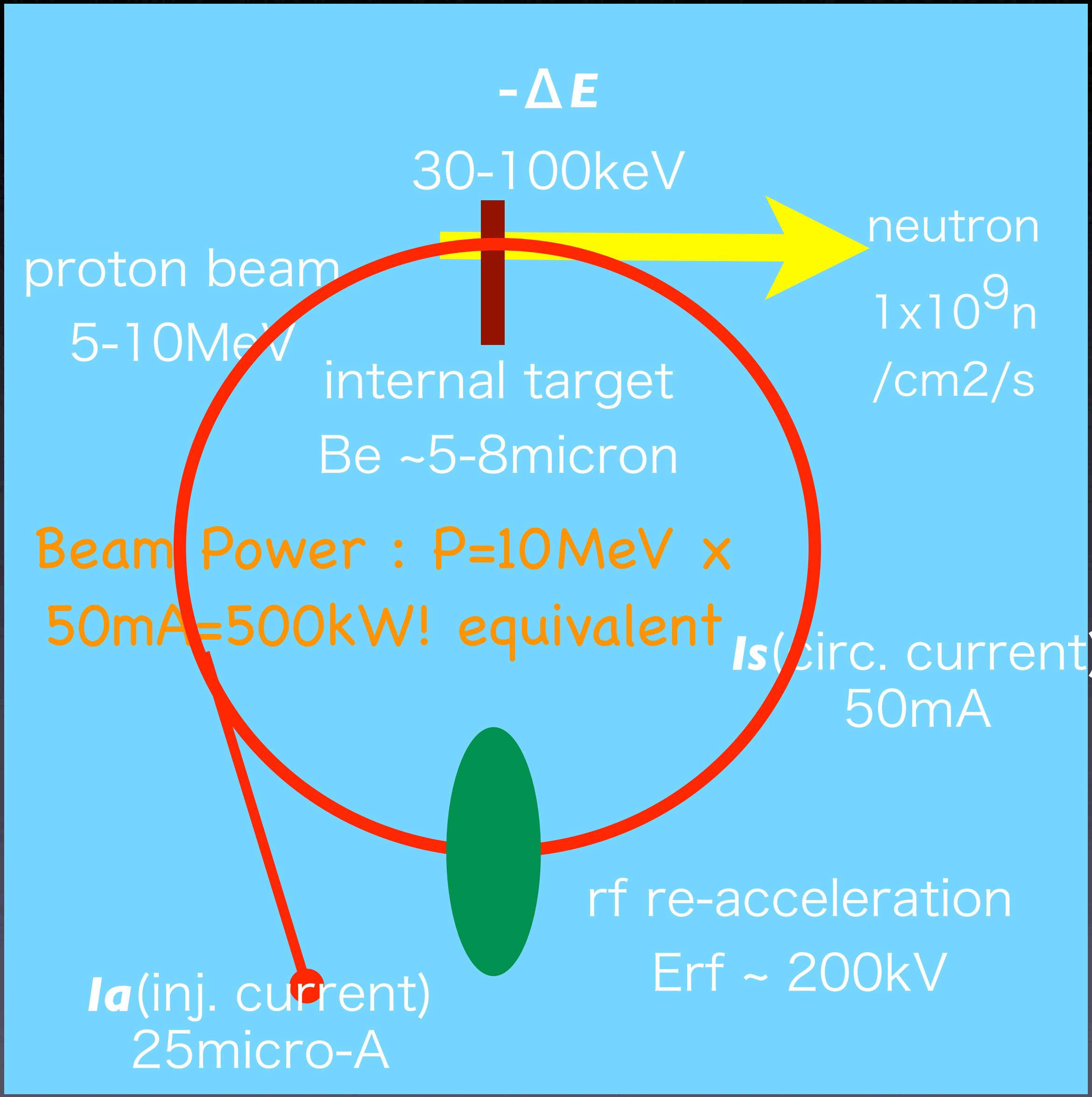
Neutron Source with FFAG-ERIT

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



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

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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

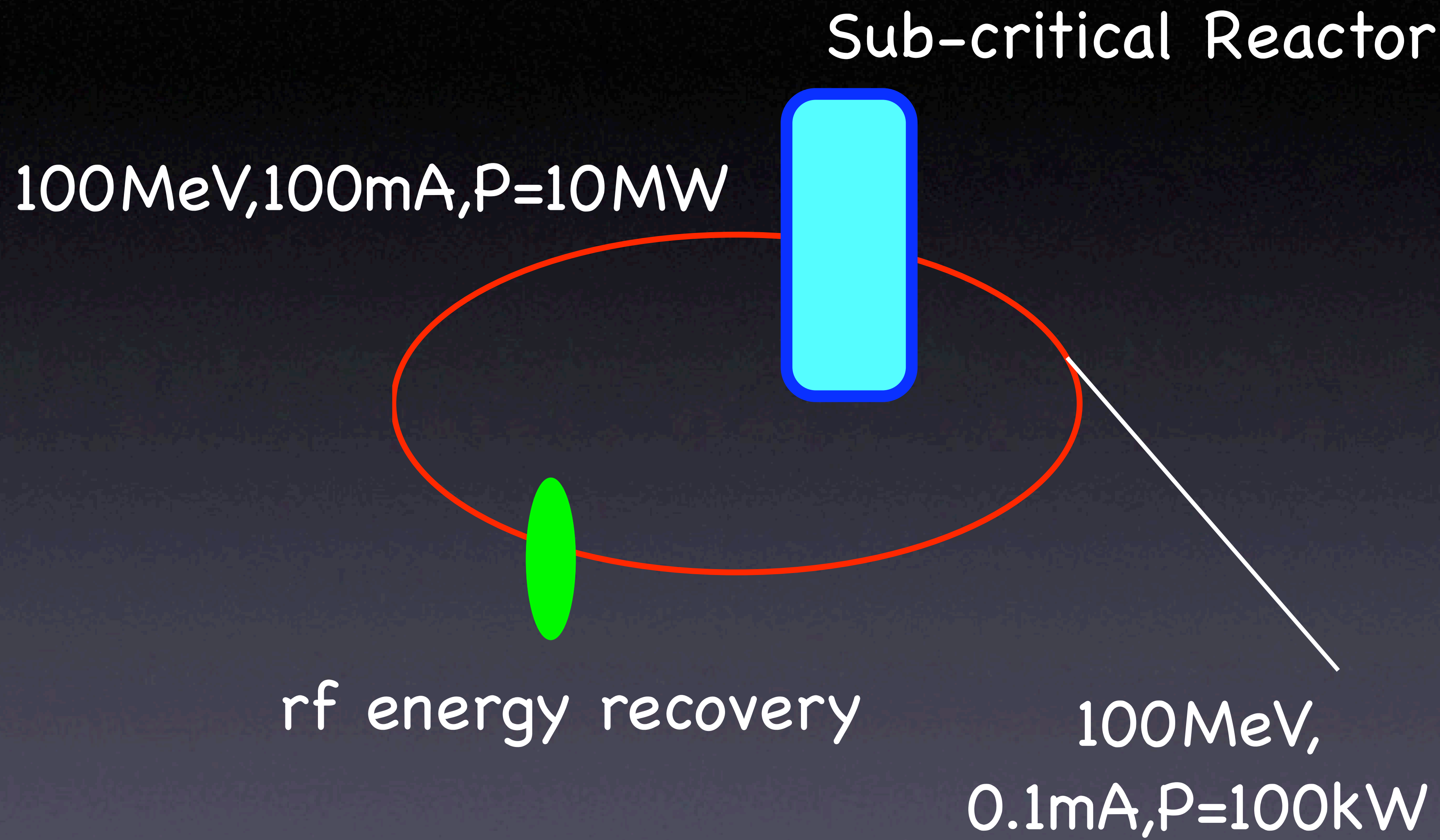
The Fixed Field Alternating Gradient (FFAG) synchrotron has unique features compared with other types of

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

FFAG-ERIT scheme

- Ionization Cooling
- energy range
  - p<300MeV cooling OK
    - electron scattering dominant
    - spallation neutron
  - p>500MeV cooling difficult but....
    - nucleon interaction dominant

ADSR+ERIT



Sub-critical Reactor
100MeV,100mA,P=10MW
rf energy recovery
100MeV,
0.1mA,P=100kW

Summary

- FFAG + ADSR test facillity at Kyoto University
  - Experiment will start from Sept. 2006.
  - Future : 1GeV FFAG, 100microA
- FFAG-ERIT type secondary particle source
  - neutron flux = 10MW nuclear reactor
    - eq. high power proton driver