Design study on medium energy FFA-ERIT storage ring

Kyushu University: K. Takamatsu

Kyushu University, Japan : N. Ikeda, H. Arima,
Y. Yonemura, A. Kyosuke, T. Domoto, I. Ishibashi

Kyoto University, Japan : Y. Mori

Outline

- Introduction
- Information of 11 MeV FFA-ERIT system
- Status of this study
- Summary

Background

Lately, the demand of accelerator neutron source have been increasing.

- Boron Neutron Capture Therapy
- Nuclear physics (e.g. nuclear data)
- Neutron imaging, Neutron structural analysis

↓

In a traditional method that beam interact with the target once,
a few beam particles contribute to neutron production.

↓

Low efficiency of neutron production

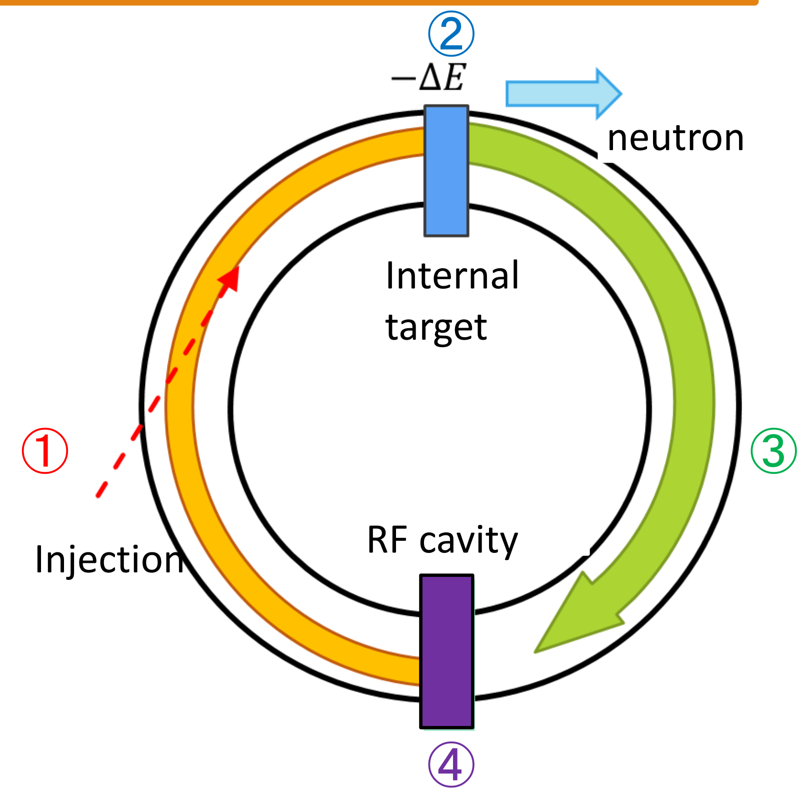
(1): Y. Mori, Nucl. Instrum. Methods Phys. Res. A.,562(2006), 591-595.

ERIT system

Energy Recovery Internal Target system [1] was proposed.
Decreased beam energy is recovered and emittance growth is suppressed.
In the result, beam will interact with the target many times

FFA accelerator that has larger acceptance made ERIT system possible.

① Beam injection
② Beam-target interaction
③ Decreasing beam energy, Emittance growth
④ Recovering beam energy, Suppressing the emittance growth



Status of ERIT system

Low energy ERIT（11 MeV）

2：K. Okabe, et al., Proceedings of EPAC08 (2008), 3512-3514.

Principle verification of beam storage and neutron production with high efficiency have been carried out[2].

Higher beam energy leads two events.

- Increased neutron production
- Wider range of neutron energy

Thus, less neutron irradiation time and more applications are expected.

Medium energy ERIT

Basic study for practical applications

Advantages of ERIT system over the conventional method

<u>efficiency of neutron production of the conventional method η</u>

$$\eta = 1 - \exp(-\varepsilon)$$
$$\varepsilon = \frac{\rho N_A}{A} \int_{E_0}^{E_{th}} \frac{\sigma(E)}{S(E)} dE$$

E_{th} : threshold energy E_0 : beam energy

- $\eta = 6.09 \times 10^{-5}$ with 10 MeV proton beam

<u>ERIT system</u>

In principle, η becomes 1 because all beam particles contribute to the production.
In fact, η is less than 1 because of the beam scattering, etc.

✓ ERIT system is more efficient than the conventional method.

Advantage of medium energy ERIT system

- Neutron production when 6.25×10^{12} proton particles are injected to W-184 target
- This was calculated with PHITS[3]

3 : T. Sato et al., J. Nucl. Sci. Technol. 55, (2018), 684-690

Beam energy [MeV]	Neutron flux with the conventional method [1/㎠/s]
10.0	3.93×10^{6}
100	5.95×10^{9}

Higher beam energy seems to lead more neutron production with ERIT system.

Considering η and number of neutron production

- The medium energy ERIT system has advantages over the conventional method.
- η and number of neutron production of the ERIT system need to be evaluated with involving the beam interaction with the target.

Evaluation of performance of medium energy FFA-ERIT system

There are two important factors about FFA-ERIT system.

- Number of neutron production
- Energy spectrum of neutron

To evaluate these, a simulation that calculates the following two things is essential.

- Interaction with the beam and the target
- Position and momentum of the beam in the storage ring

Objective

To evaluate the performance, a simulation code that combine

- A beam particles tracking code
- particle transport simulation code PHITS

is being developed.

About a beam particle tracking code

- a magnetic field design of the storage ring is necessary.
- the design criteria of the storage ring are obtained by using transfer matrix.

In this study

- Evaluation of proton beam energy that can be stored.
- Evaluation of the stability of the closed orbit using transfer matrix

Outline

- Introduction
- Information of 11 MeV FFA-ERIT system
- Status of this study
- Summary

Utilizations of 11 MeV FFA–ERIT storage ring

- The storage ring of 11 MeV FFA-ERIT proof-of-principle machine is relocated to Kyushu University from Kyoto University.

- In Kyushu University, various utilizations of 11 MeV FFA-ERIT storage ring are considered.

Utilizations of 11 MeV FFA-ERIT storage ring

In this study

- Designing of medium energy FFA-ERIT storage ring is based on modifying 11 MeV FFA-ERIT storage ring.

- At Kyushu University, 80 MeV proton beam is usually available.
- the storage ring that can store beam up to 80 MeV is expected.

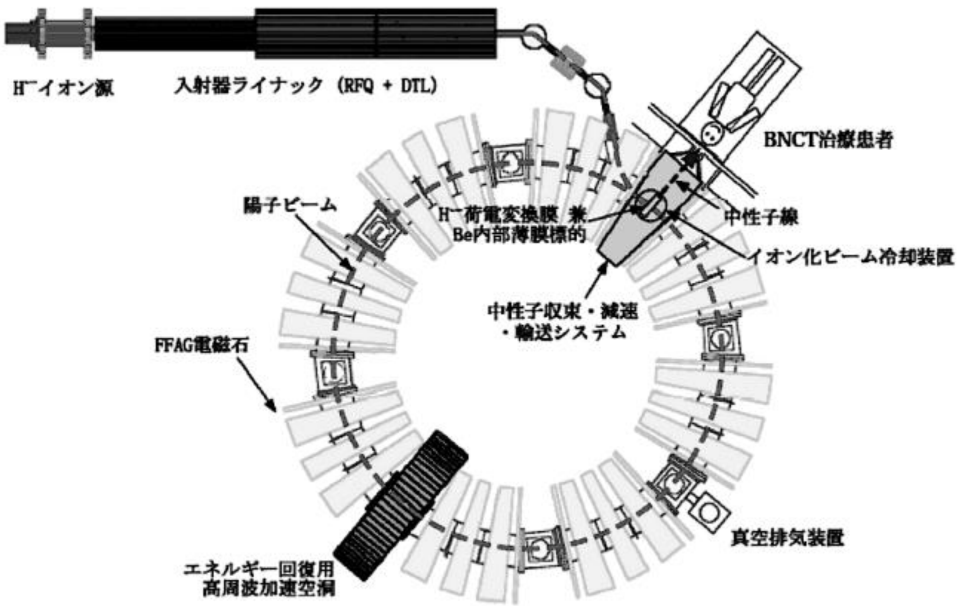
11 MeV FFA-ERIT proof-of-principle machine

11 MeV FFA-ERIT proof-of-principle machine：

- Storages 11 MeV proton beam
- Lattice of the storage ring is radial-sector FDF-triplet.

Parameters of 11 MeV FFA−ERIT[4]	
Beam energy	11 MeV
mean radius	2.35 m
number of cells	8
k	1.92
FD ratio	~ 3

Components of 11 MeV FFA-ERIT[5]



4：K .Okabe, 18th International Conference on Cyclotrons and Their Applications, (2007), 210-212
5：Y. Mori, J. Part. Acc. Soc. Jpn, Vol.5, 2008, 27-35.

Outline

- Introduction
- Information of 11 MeV FFA-ERIT system
- Status of this study
- Summary

Content of the evaluation

To obtain the parameter criteria of a medium energy FFA-ERIT storage ring

- Evaluation of proton beam energy that can be stored
- Evaluation of the stability of the closed orbit using transfer matrix

have been conducted on 2 types of lattice.

Evaluation of proton beam energy

- At the maximum magnetic flux density, the maximum energy that the closed orbit can pass through the mean radius was calculated.

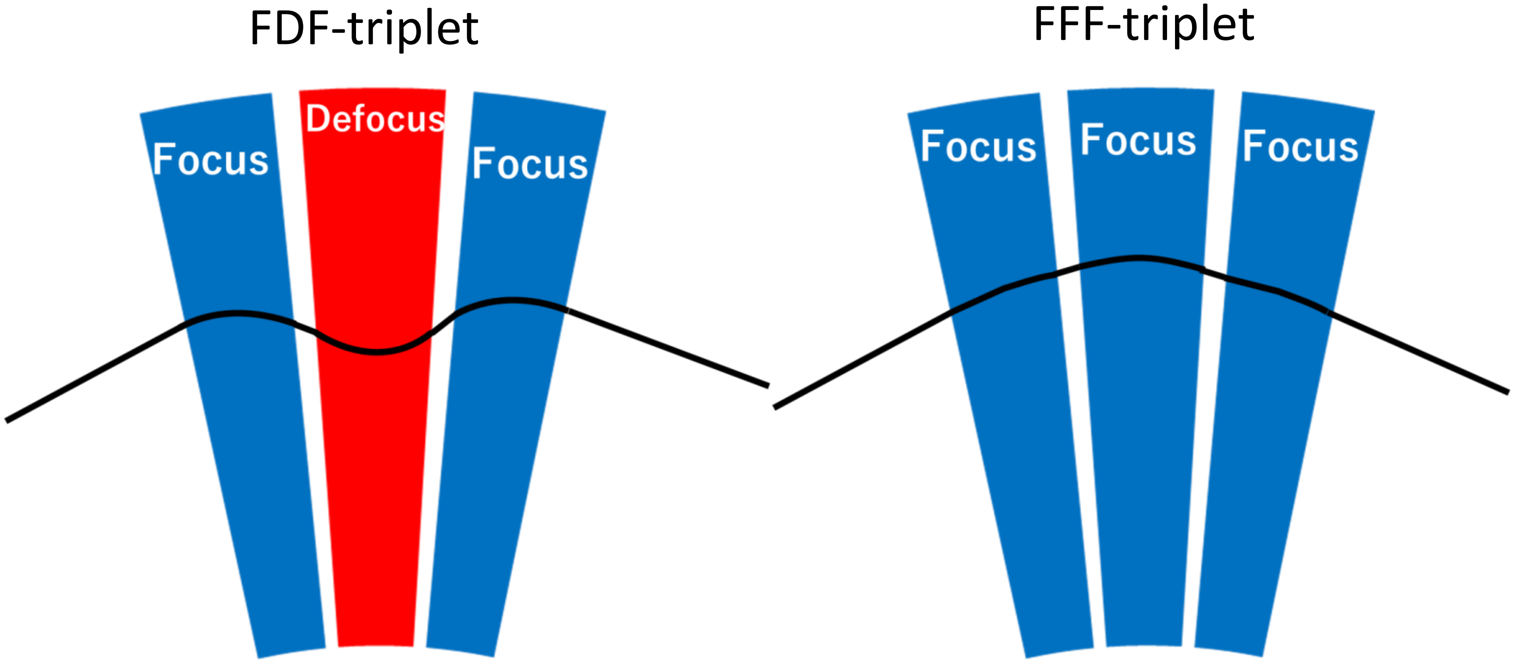
Evaluation of the stability of the closed orbit

- The calculation was conducted
  by not changing the accelerator radius or the position of the magnets,
  but **intensity of the magnetic field and gradient of magnetic field**

Types of Lattice

- Radial sector FDF-triplet or FFF-triplet

- <u>FFF-triplet</u>
  Defocusing magnet of FDF-triplet is replaced to a focusing magnet.
  It can storage higher beam energy than FDF-triplet.



Parameters of the storage ring to be modified

Intensity of magnetic field

- The maximum magnetic flux density is set to 1.7 T

- About the ratio of intensity of magnetic field
  FDF-triplet
  FD ratio : The ratio of the focusing and the defocusing magnetic field
  FFF-triplet
  F_1F_2 ratio : The ratio of the both ends and the center magnetic field

Magnetic field gradient

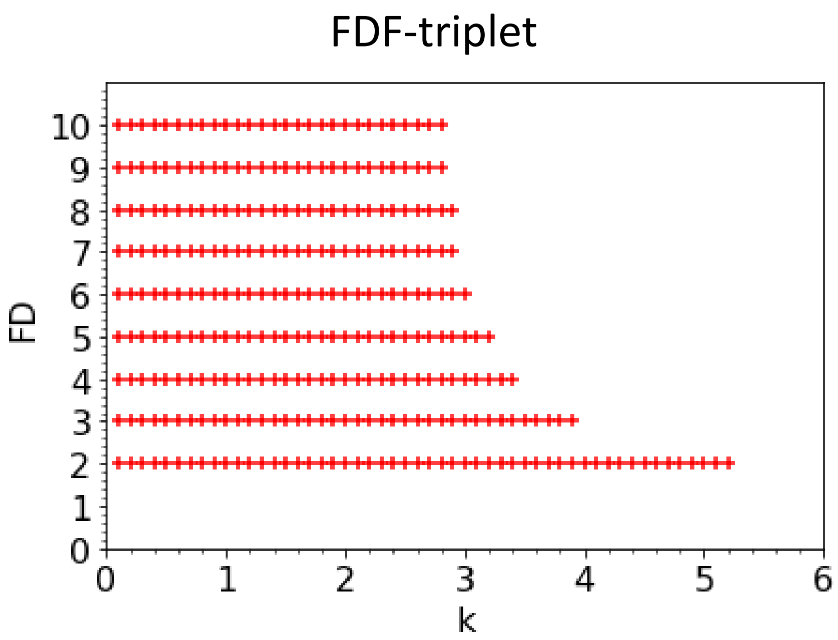
- The value of k is defined as below.

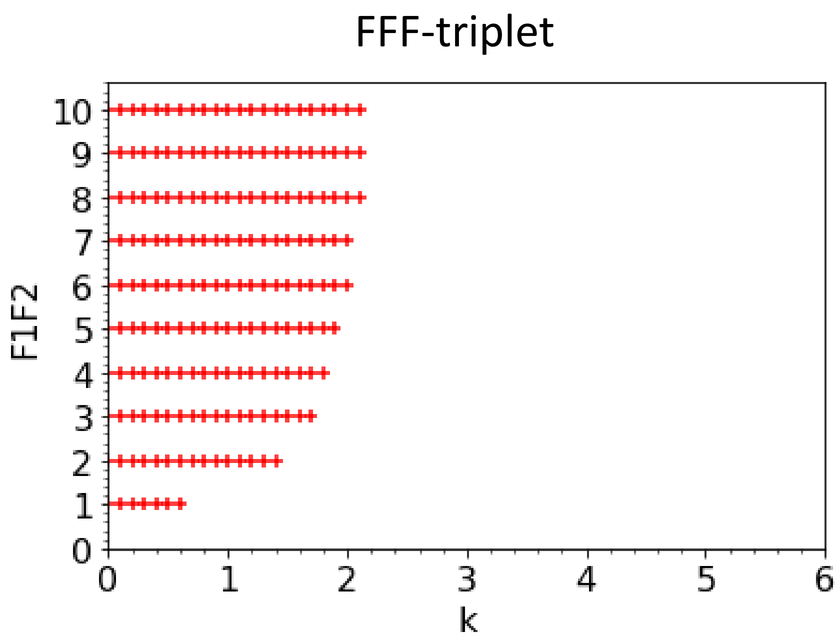
$$k \propto \frac{r}{B}\left(\frac{\partial B}{\partial r}\right)_{\Theta}$$

- The value of k is 0 to 10.

Analysis results

- In the results of mean radius calculations, the beam energy is up to about 30 MeV on FDF-triplet and 57 MeV on FFF-triplet.





- The requirements of beam to pass through the mean radius is FD ratio ≦ 8, F_1F_2ratio ≦ 5.
- k ≦ 2.8 on FDF-triplet, k ≦ 1.9 on FFF-triplet is preferable.

Outline

- Introduction
- Information of 11 MeV FFA-ERIT system
- Status of this study
- Summary

Summary

To obtain the parameter criteria of a medium energy FFA-ERIT storage ring

- Evaluation of proton beam energy that can be stored
- Evaluation of the stability of the closed orbit using transfer matrix

are conducted.

- The beam energy is up to about 30 MeV on FDF-triplet and 57 MeV on FFF-triplet.

- $k \leqq 2.8$ on FDF-triplet, $k \leqq 1.9$ on FFF-triplet is preferable.

Plans

This study
- Evaluation of beam storage performance
- Evaluation of number of neutron production, neutron energy spectrum

Future Prospects
- Experiment of neutron production
  with medium energy FFA-ERIT system
- Utilization of medium FFA-ERIT system