

# Serpentine Acceleration in Zero-chromatic FFAG with Long Straight Section

FFAG '10  
30th October

E. Yamakawa  
Graduate School in Kyoto University



# Outline

- Motivation of this study
- Longitudinal hamiltonian in Zero-chromatic FFAG
- Serpentine acceleration in Zero-chromatic FFAG
- Design idea of accelerator scheme with long straight section in non-Zero chromatic FFAG
- Summary

# Motivation of this study

- ADJR → High intensity proton beam with high repetition rate is needed.

Kinetic energy : ~ 1 GeV

## Features of Zero-chromatic FFAG

- A fixed magnetic field
- Zero chromaticity
- Based on strong focusing

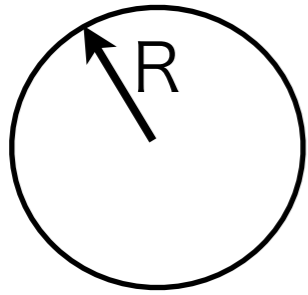
High repetition rate cycle

→ Limited by capabilities of RF system.

★ Constant RF frequency : serpentine acceleration

# Outline

- Motivation of this study
- Longitudinal hamiltonian in Zero-chromatic FFAG
- Serpentine acceleration in Zero-chromatic FFAG
- Design idea of accelerator scheme with long straight section in Zero-chromatic FFAG
- Summary



$$\alpha = \frac{1}{k + 1}$$

$\alpha$  is constant in Zero-chromatic FFAG

- $R_s$  : Radius of synchronous particle
- $T_{revs}$  : Revolution time of stationary particle
- $T_{rev}$  : Revolution time of non-synchronous particle
- $\Delta\phi$  : Discrepancy of phase
- $E_s$  : Stationary energy
- $C$  : circumference

$$\begin{aligned} \frac{T_{rev}}{T_{revs}} &= 1 + \frac{\Delta\phi}{2\pi h} = \left( \frac{C}{C_s} \right) / \frac{P/E}{P_s/E_s} \\ &= \left( \frac{R}{R_s} \right) / \frac{P/E}{P_s/E_s} \\ &= P_s^{1-\alpha} \frac{E}{E_s} P^{\alpha-1} \end{aligned}$$

## Equations of motion

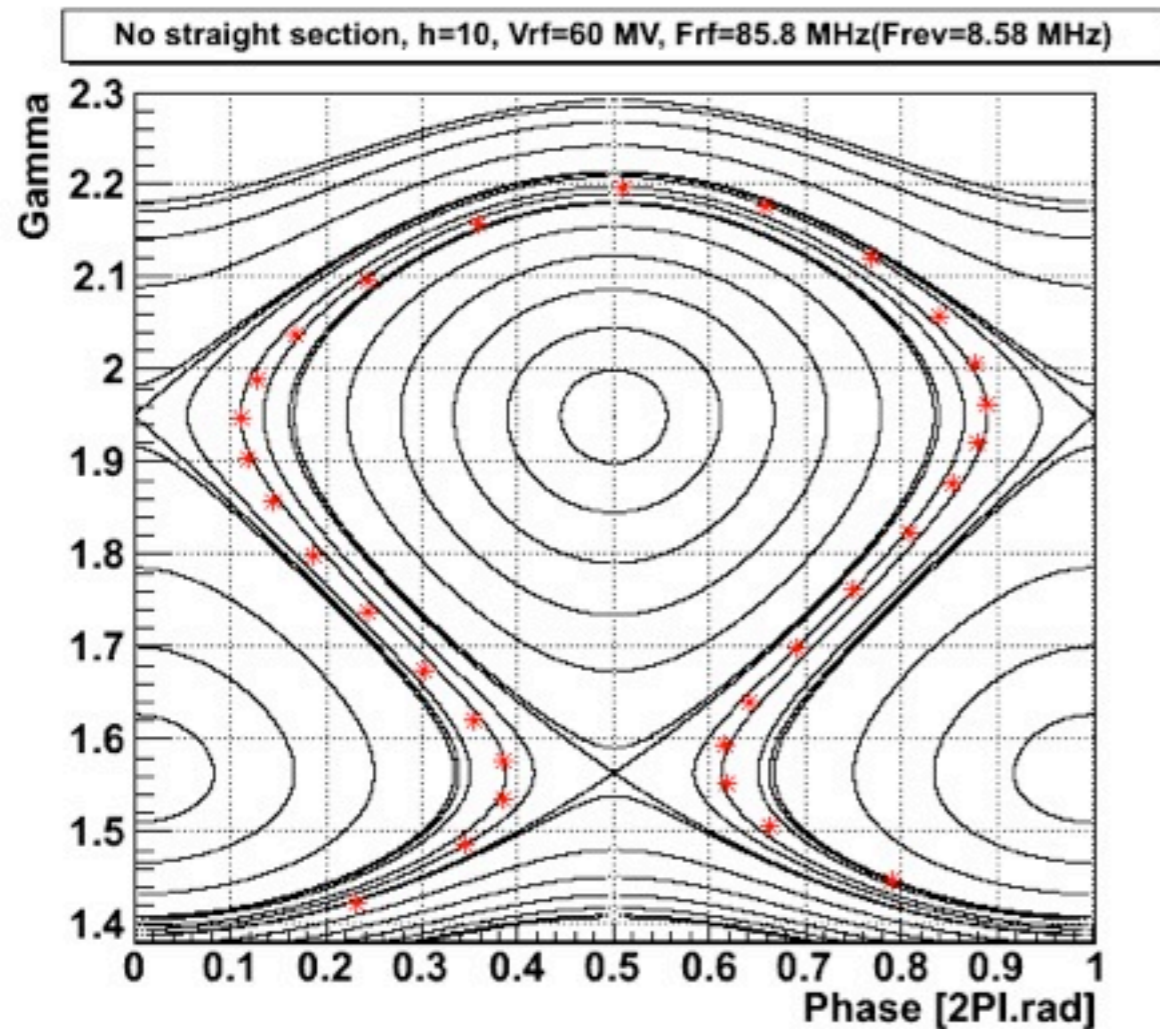
$$\begin{aligned} \frac{d\phi}{d\theta} &= h \left( \frac{P_s^{1-\alpha}}{E_s} E P^{\alpha-1} - 1 \right) \\ \frac{dE}{d\theta} &= \frac{eV_{rf}}{2\pi} \sin \phi, \end{aligned}$$

$$H(E, \phi; \theta) = h \left( \frac{1}{\alpha + 1} \frac{P^{\alpha+1}}{E_s P_s^{\alpha-1}} - E \right) + \frac{eV_{rf}}{2\pi} \cos \phi.$$

# Outline

- Motivation of this study
- Longitudinal hamiltonian in Zero-chromatic FFAG
- **Serpentine acceleration in Zero-chromatic FFAG**
- Design idea of accelerator scheme with long straight section in Zero-chromatic FFAG
- Summary

# Serpentine acceleration in Zero-chromatic FFAG



Stationary kinetic energy : $E_s (> E_t)$	891 MeV ( $r_s = 1.95$ )
Radius of Arc : $r_s$	4.77 m
Harmonic number : $h$	10
RF frequency : $F_{rf}$	85.8 MHz ( $h=10$ )
RF voltage/turn : $V_{rf}$	60 MV ( $h=10$ )

Injection kinetic energy : 380 MeV  
 Final kinetic energy : 1.1 GeV

The relation between RF voltage and frequency is

$$V_{rf} \propto \sqrt{F_{rf}}$$

Ref ) 200 MHz  $\rightarrow$  25 MV/m

$$V_{rf} = 25[MV/m] \times \sqrt{85.8/200} = 16.4[MV/m]$$

Length of RF cavity is needed about 9 [m] per turn.

# Motivation of this study

- ADJR → High intensity proton beam with high repetition rate is needed.

Kinetic energy : ~ 1 GeV

High repetition rate cycle

→ Limited by capabilities of RF system.

★ Constant RF frequency : serpentine acceleration

# Motivation of this study

- ADJR → High intensity proton beam with high repetition rate is needed.

Kinetic energy : ~ 1 GeV

High repetition rate cycle

→ Limited by capabilities of RF system.

★ Constant RF frequency : serpentine acceleration



High RF voltage is needed to obtain big stationary bucket height.

# Motivation of this study

- ADJR → High intensity proton beam with high repetition rate is needed.

Kinetic energy : ~ 1 GeV

High repetition rate cycle

→ Limited by capabilities of RF system.

★ Constant RF frequency : serpentine acceleration



High RF voltage is needed to obtain big stationary bucket height.



Using many RF cavities

# Motivation of this study

- ADSR → High intensity proton beam is needed.

★ High repetition rate cycle

→ Limited by capabilities of rf system.

★ Constant RF frequency : serpentine acceleration



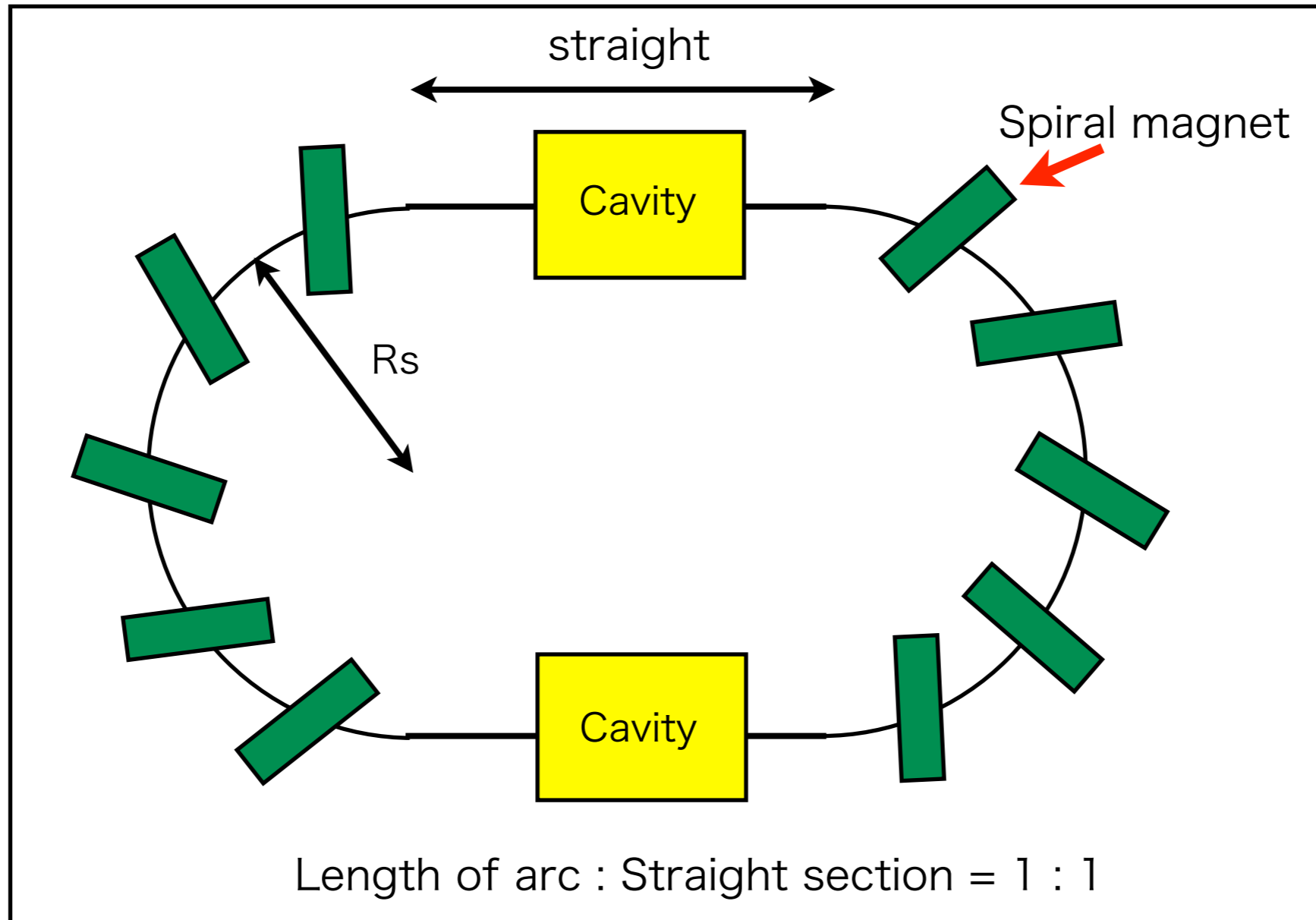
High RF voltage is needed to obtain big stationary bucket height.

Serpentine acceleration with long straight section in  
Zero-chromatic FFAG for proton driver

# Outline

- Motivation of this study
- Longitudinal hamiltonian in Zero-chromatic FFAG
- Serpentine acceleration in Zero-chromatic FFAG
- Design idea of accelerator scheme with long straight section in Zero-chromatic FFAG
- Summary

# One candidate of design



To make a small ring...

Large magnetic field is needed  $B\rho = 5.4[Tm]@\gamma = 2$

↓  
Using SC spiral FFAG magnet in the arc part

# Outline

- Motivation of this study
- Longitudinal hamiltonian in scaling FFAG
- Serpentine acceleration in scaling FFAG
- Design idea of accelerator scheme with long straight section in Zero-chromatic FFAG
- **Summary**

# Summary

- So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.

# Summary

- 📌 So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.
- ◆ RF cavity : to obtain high voltage

# Summary




So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.

◆ RF cavity : to obtain high voltage

Many RF cavity are needed.

# Summary

 So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.

◆ RF cavity : to obtain high voltage

Many RF cavity are needed.  Long straight section is considered.

# Summary



So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.

◆ RF cavity : to obtain high voltage

Many RF cavity are needed. → Long straight section is considered.

◆ Magnet : to obtain large magnetic field

# Summary



So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.


◆ RF cavity : to obtain high voltage

Many RF cavity are needed. → Long straight section is considered.

◆ Magnet : to obtain large magnetic field

Spiral FFAG magnet is considered.

# Summary

 So far, serpentine acceleration in Zero-chromatic FFAG has been considered only in longitudinal.

◆ RF cavity : to obtain high voltage

Many RF cavity are needed.  Long straight section is considered.

◆ Magnet : to obtain large magnetic field

Spiral FFAG magnet is considered.

Consideration of design idea for  
**Zero-chromatic FFAG with long straight section**  
has just started !!

