Beam injection and extraction in radial sector FFAG accelerator

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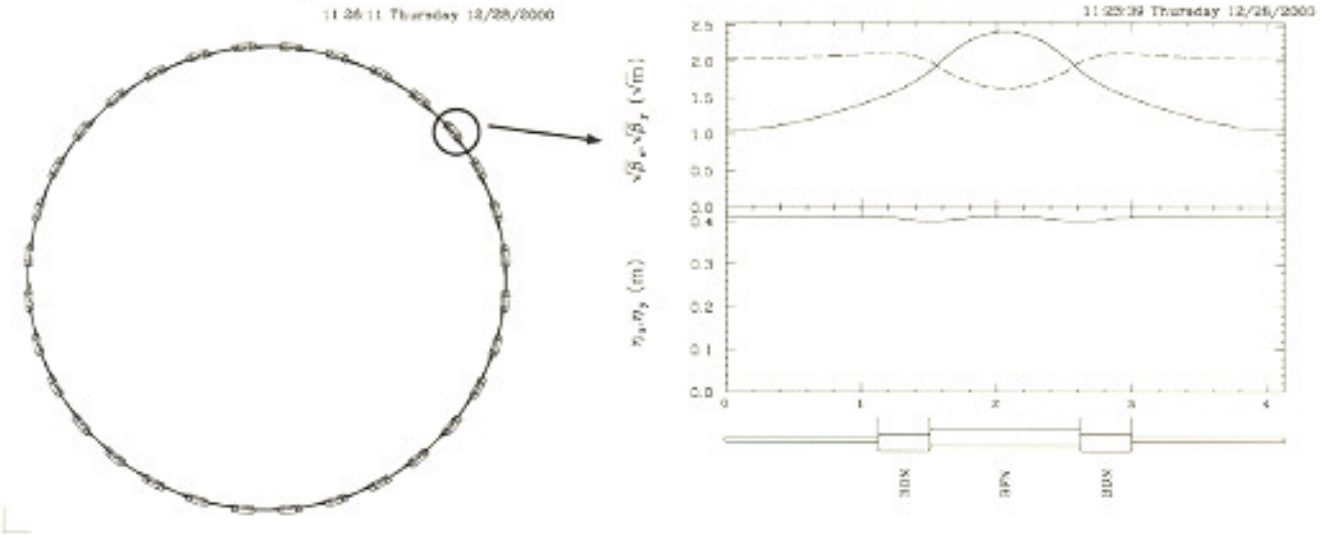
Introduction

radial sector FFAG

(1) Triplet (DFD) ex. PoP FFAG
(2) Triplet (FDF)
(3) Singlet (FODO)

*triplet type FFAG gives
longer straight sections

ex. DFD triplet



From the point of view of injection and extraction, which scheme is more preferable ?

Hardware specification

Kicker

Aperture : 20cm(V)×30cm(H)
Field strength : 1kgauss
rise time : 4μs

Required N·I~16kA·Turn
Available space for kicker ~2m
3kicker is installed in one section
$L_0=\mu_0\, wl/g\cdot N^2 \sim 1.7\times N^2\ \mu H$
$L_{magnet}=L_0+L_{leak} \sim L_0(1+g/w)\sim 1.6L_0$
5turn coil is installed

V=55kV
I =3200A
τ =4μs
1Hz repetition

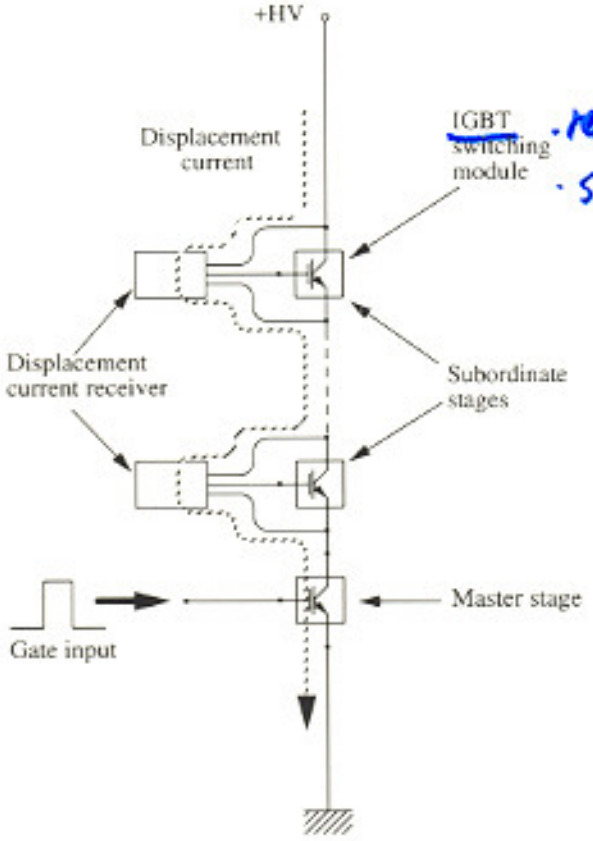
Feasible specifications !!!

Septum

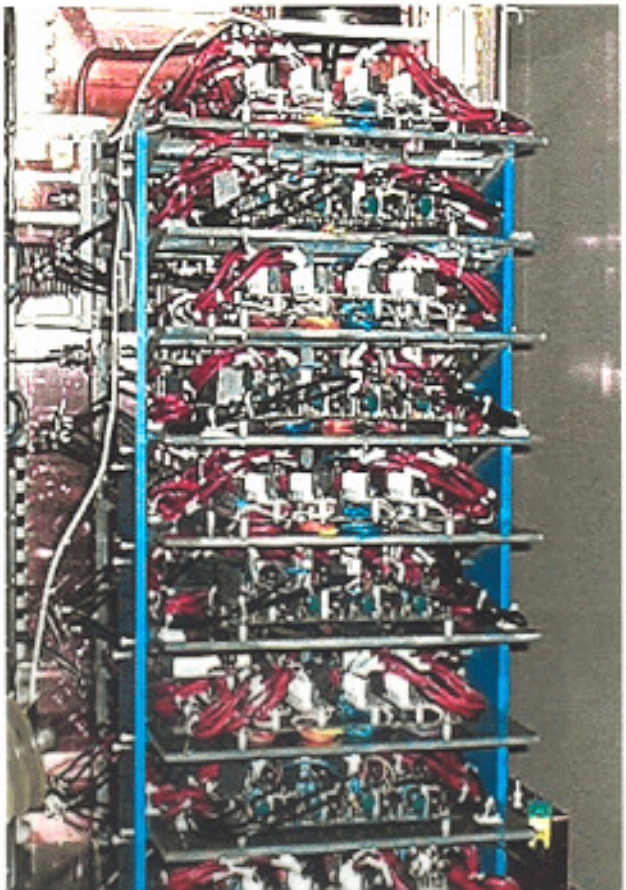
Super conducting septum is available
thickness of coil ~6mm
Field strenght ~2T
(developed by KEK BC group in '80s)

* With present technolgy,
5T field is available.

Trigger scheme of Kicker PS



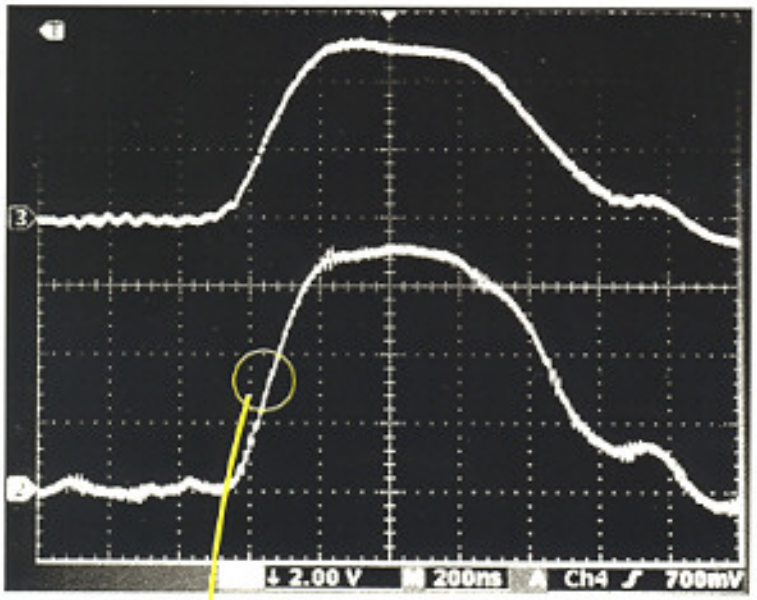
· reliable.
· switching time ~ 100 ns



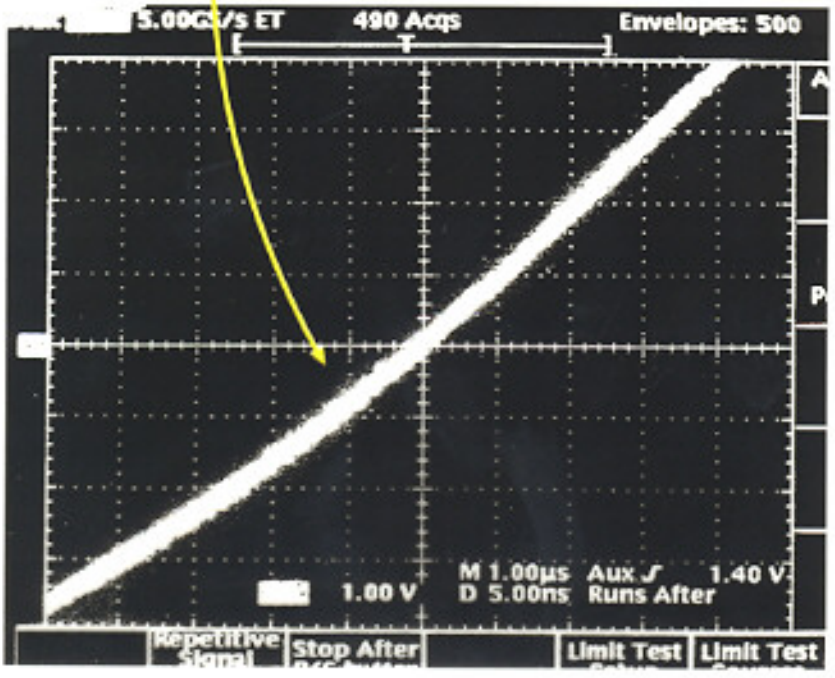
by Y. Shirakabe et. al.

Specificatoins of Kicker PS

Max PFN charging voltage	35kV
Max kicker current	700A
PFN impedance	25Ω
Rise time	300ns
Flat top width	200ns
Flat top accuracy	+-2.5%
Jitter	+-5ns
Max rep. rate	1kHz



Output pulse of Kicker PS



Jitter <+-5ns

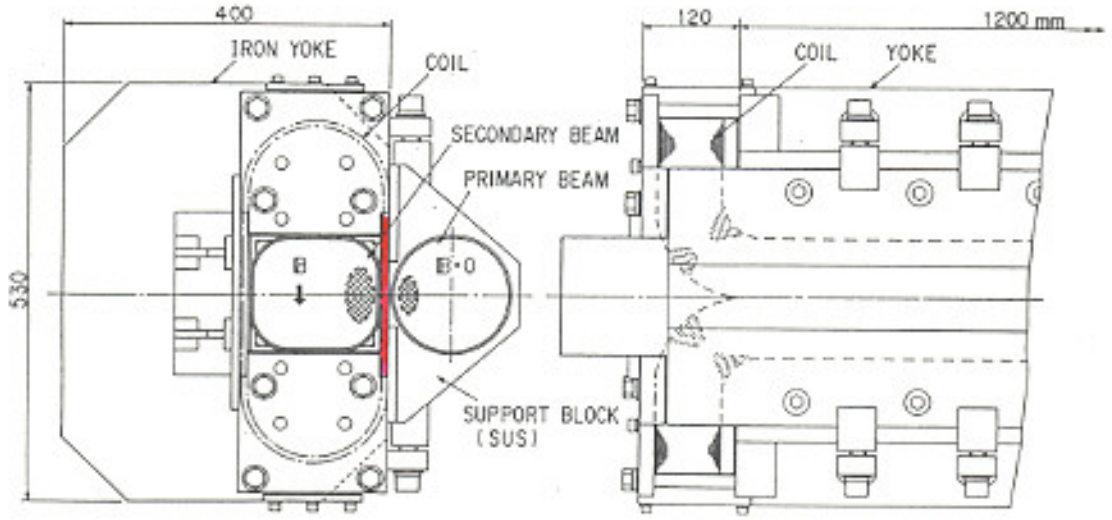


Fig. 5. Cross sections of the superconducting septum magnet.

Table 3
Main parameters of the superconducting septum magnet

Maximum magnetic field	2 T
Magnetic aperture ($h \times w$)	140×160 mm^2
Cold bore aperture	134×154 mm^2
Magnetic length	1.27 m
Septum coil thickness	6.4 mm
Coil current	2220 A
Ampere-turns	2.22×10^5 AT
Current density	280 A/mm^2
Inductance	21 mH
Stored energy	52 kJ
Bursting force	22.7 tonf/m
Cold mass (coil and yoke)	2 ton
Superconductor	
Material	Nb–Ti/Cu
Type	Compacted strand cable
Cable size ($h \times w$)	1.27×6.23 mm^2
Number of wires	19
C/S ratio	1.8/1
Critical current (at 4 T, 4.2 K)	4700 A
Cable insulation	3 layers of Kapton (25 μm)
Total cable length	400 m

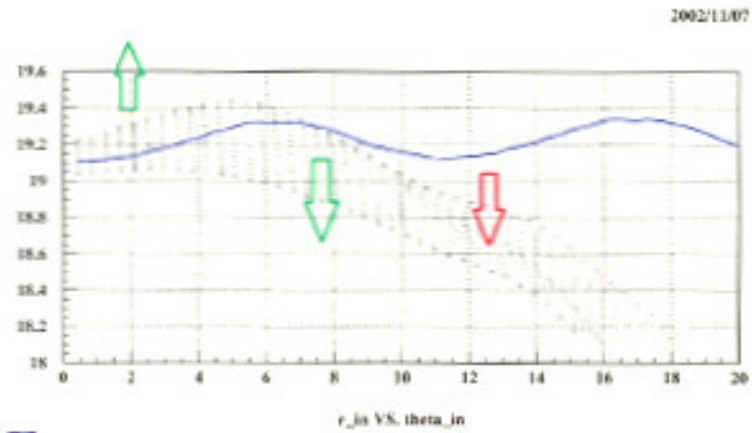
Injection(0.3~1GeV/c ring)

Requirements ....

(1) Orbit separation at septum >50cm

(2) kicker voltage <100kV

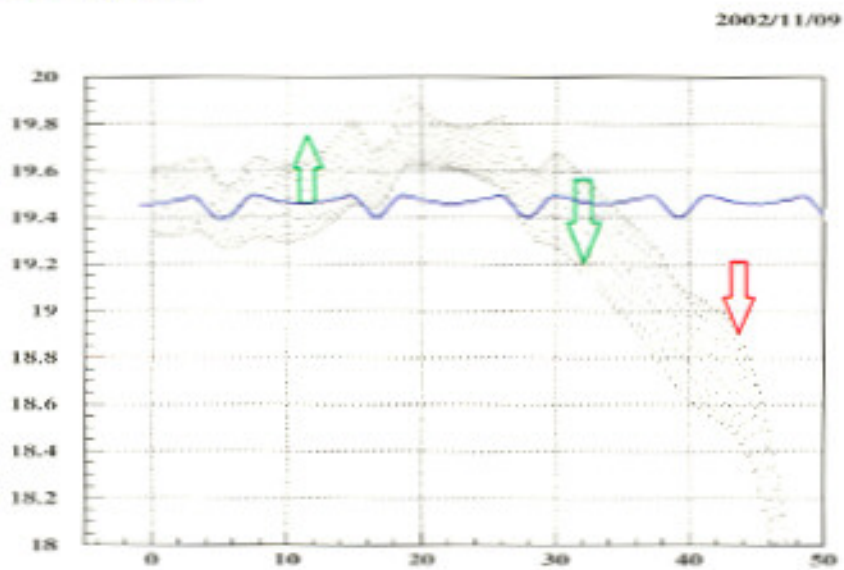
FODO case



kicker 1.5kgauss

septum 0.5kgauss

FDF case



kicker 1.5kgauss

septum 0.5kgauss

Momentum : 0.3GeV/c
Radius : 19.1m
k : 43
L(drift) : 0.9m

Long drift in the peripheral region,
will distort the beam shape and increase the beam loss

For DFD lattice, no solution was found in present lattice
** smaller acceptance than FDF lattice

Summary

Beam injection and extraction in various FFAG lattice were studied.

For triplet lattice, FDF triplet is more preferable.

FoDo lattice is promising. D-magnet works as septum magnet.

Requirements for the elements are modest.

As long as adopting present lattice parameters, injection and extraction from Nufact FFAG rings are feasible.

IGBT module realizes a very high repetition rate Kicker PS(~1kHz)

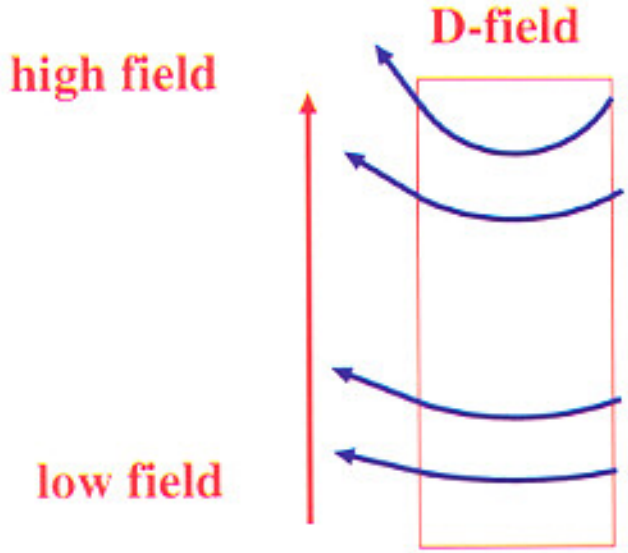
Kicker R&D is now undergoing.

Triplet(DFD or FDF) or FODO ??

Triplet : Longer straight secion
Yoke-free type is desirable
for injection & extraction

FODO : Shorter straight section
Simple structure
easier injection & extraction

**D magnet works as septum



$\Delta B/B = k \cdot \Delta R/R$

ex. 20GeV FODO ring

k=680

B_0=6T ⇨ ΔB~2T

R_0=200m

ΔR=10cm

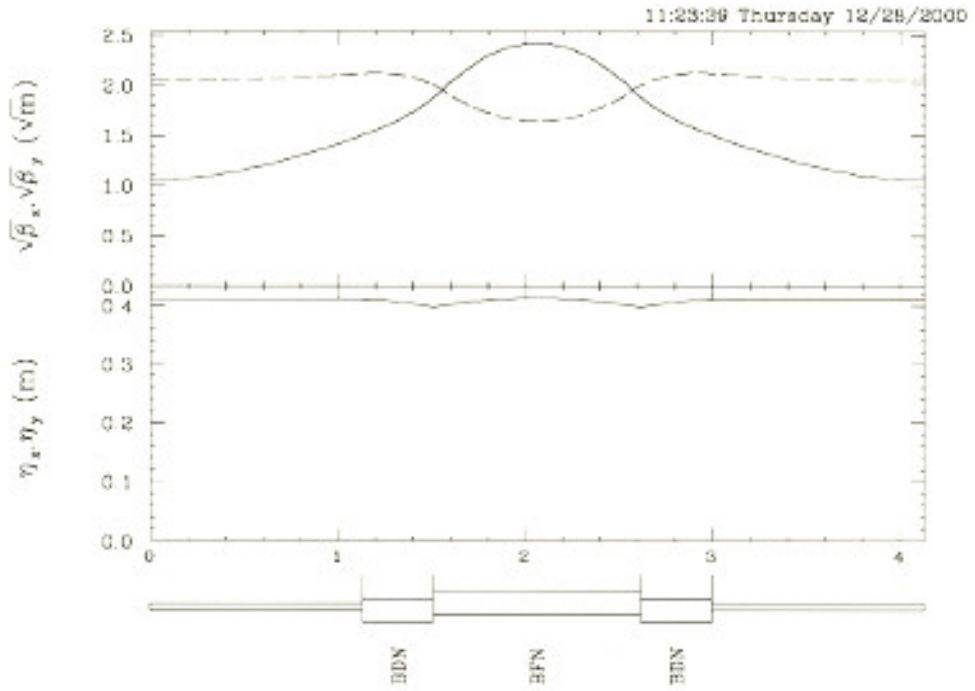
Beam injection and extraction from triplet lattice

DFD or FDF ?

crucial point in fast extraction

⇒ Orbit separation at septum

$$\Delta x = \Delta\theta \sqrt{\beta_1 \beta_2} \sin\phi$$



Center of F : β_h	max β_v	min
Center of D : β_h	min β_v	max

From the point of view of fast extraction(injection)
FDF- triplet is more preferable.

Example of Beam extraction from 20GeV FoDo ring

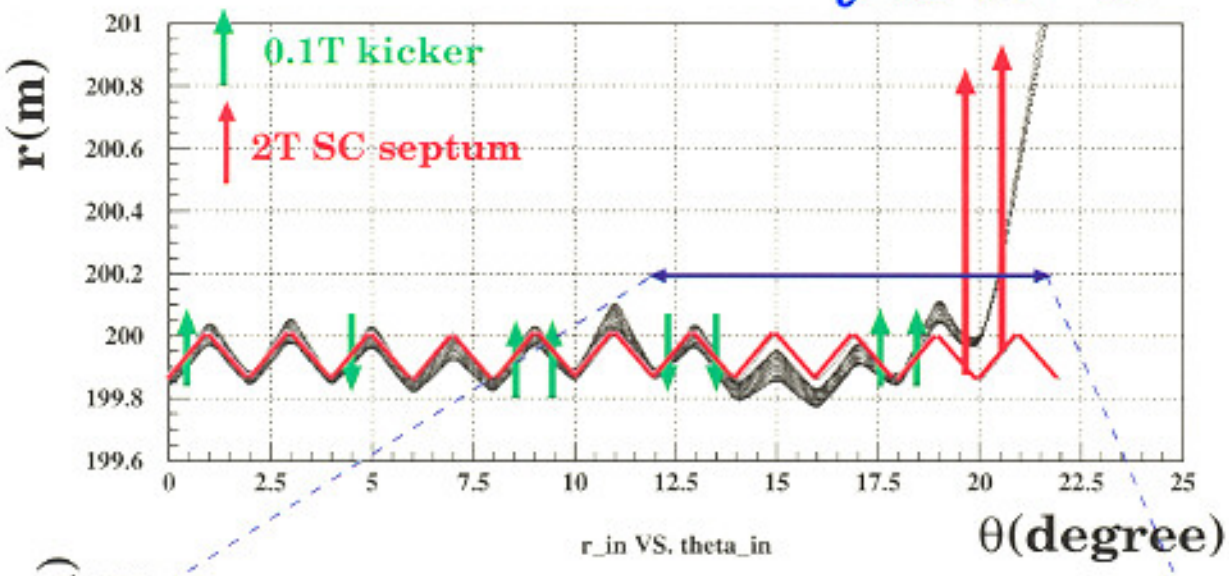
R : 190m

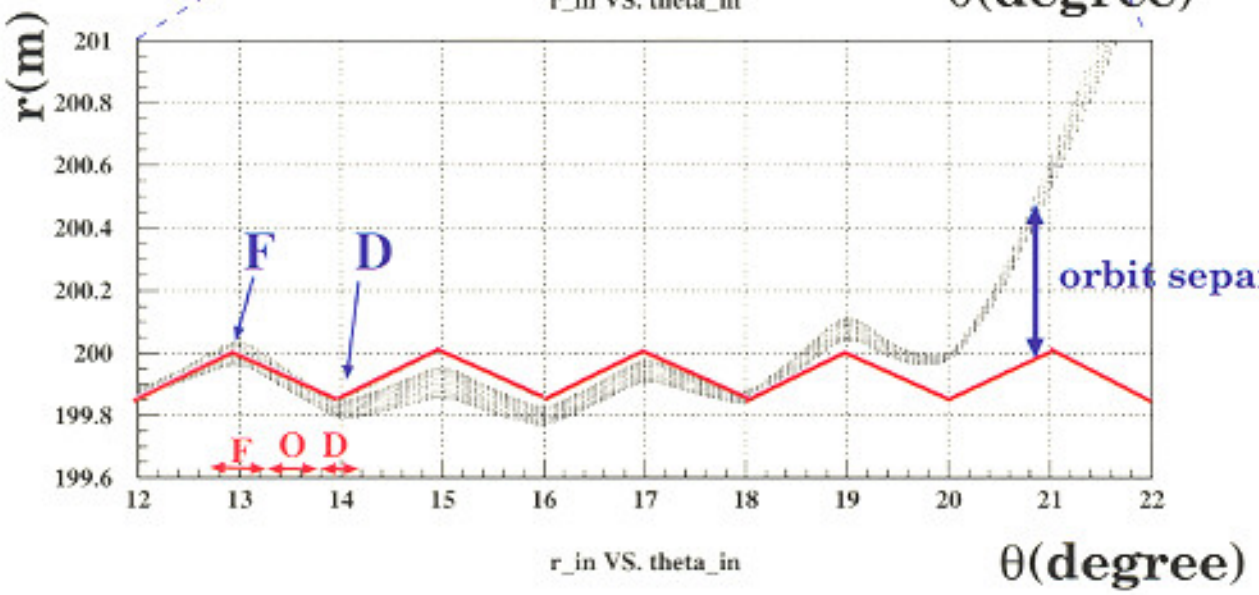
N_{cell} : 180

k : 680

(L_{drift} ~1.4m)

$\varepsilon \sim 300\pi$ mm mrad





Ring size of FFAG neutrino factory ....

ring		R_{ave} (m)	t_{rev} (ns)	L_{mid} (m)
0.3~1GeV ring	(NC)	21	440	2.3
	(SC)	10	210	2.2
1~ 3GeV ring	(NC)	80	1680	4.0
	(SC)	30	630	3.7
3~10GeV ring	(SC)	90	1880	5.0
10~20GeV ring	(SC)	200	4188	5.6

*DFD triplet lattice

cf. (10~20GeV ring(SC) FODO : R 120m
t ~3000ns
L~2m

- Free space for kicker magnet is sufficiently large

- Rise time is modest(~400ns or more)
  * Except SC 0.3~1GeV ring