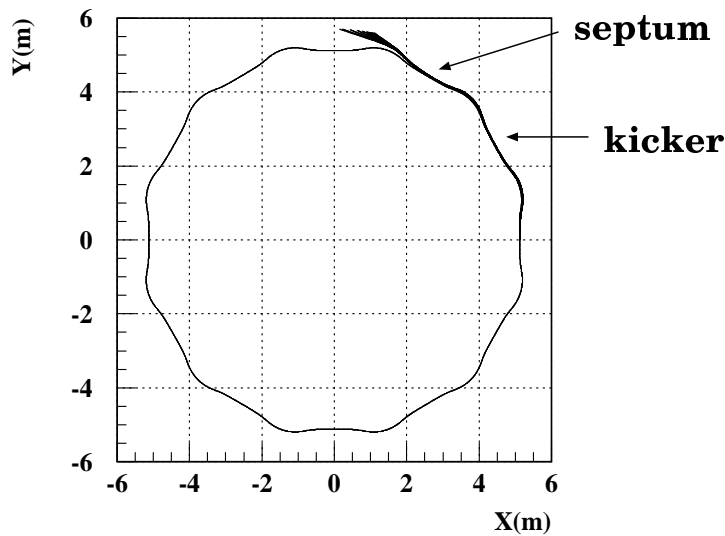


Beam injection and extraction in FFAG accelerators

Takeichiro Yokoi (KEK Acc. Lab.)

Basic Scheme Fast extraction (kicker + septum)



Problems

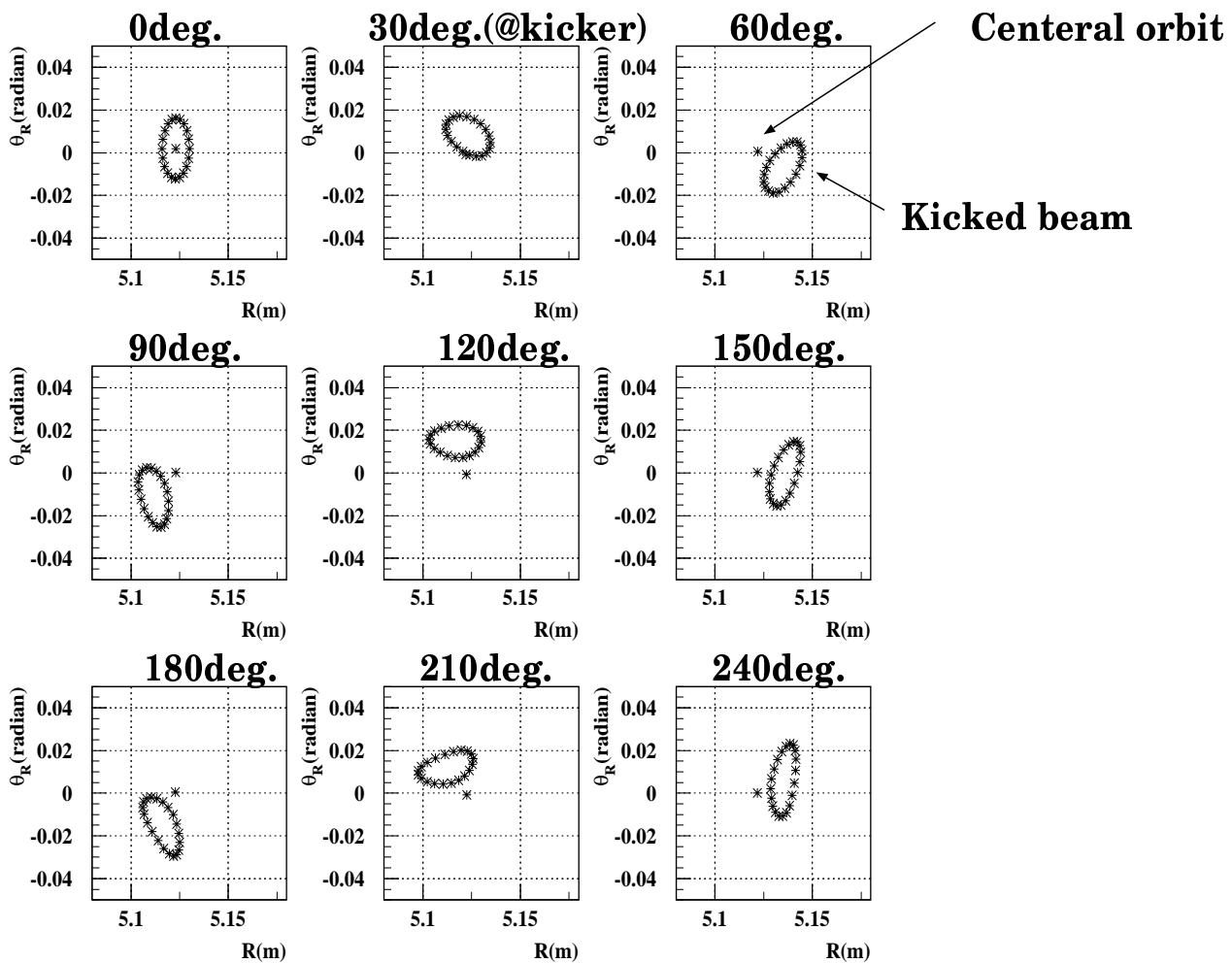
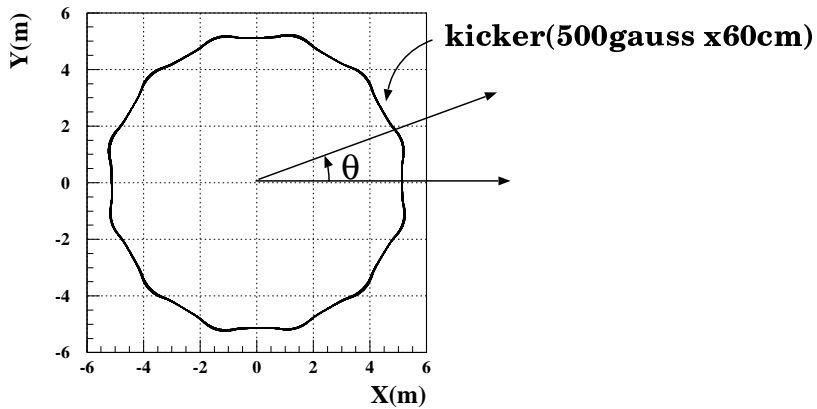
- **Orbit separation @ septum**
(Phase advance
between septum and kicker)

$$\mathbf{x}_{\text{obt}} = \sqrt{\beta_1 \beta_2} \theta_{\text{kick}} \sin \phi$$

Parameters....

- **Momentum**
.... 550/137 MeV/c (Ext./Inj.)
- **Phase advance**
.... ~3.7 (~110°/1cell)
- **Revolution period**
.... ~220 ns
- **Available space/1cell**
.... ~60 cm

Optimum phase advance $\dots(1/2+n)\pi$



Optimum location $\dots 240\text{deg.}(150\text{deg.})$

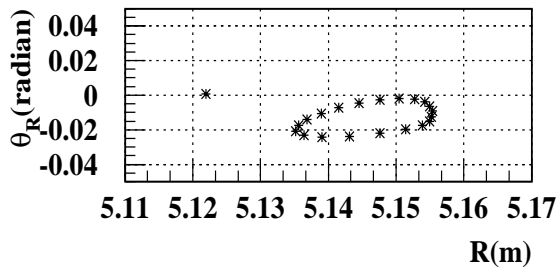
* Stability of Horizoltan tune <0.02
(by M. Aiba)

Beam separation at septum

For the kicker PS,

the maximum field with 3cm gap ... ~930gauss

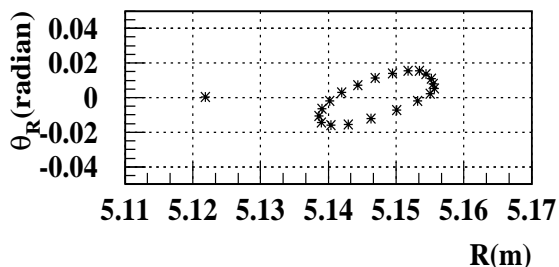
60deg



separation

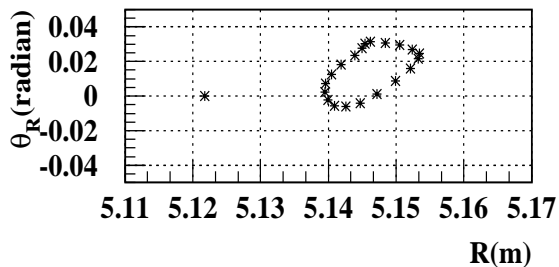
~6mm

150deg.



~11mm

240deg.



~12mm

(beam emittance: 100π mm·mrad)

max currnt density ~ 60A/mm²

gap high 3cm



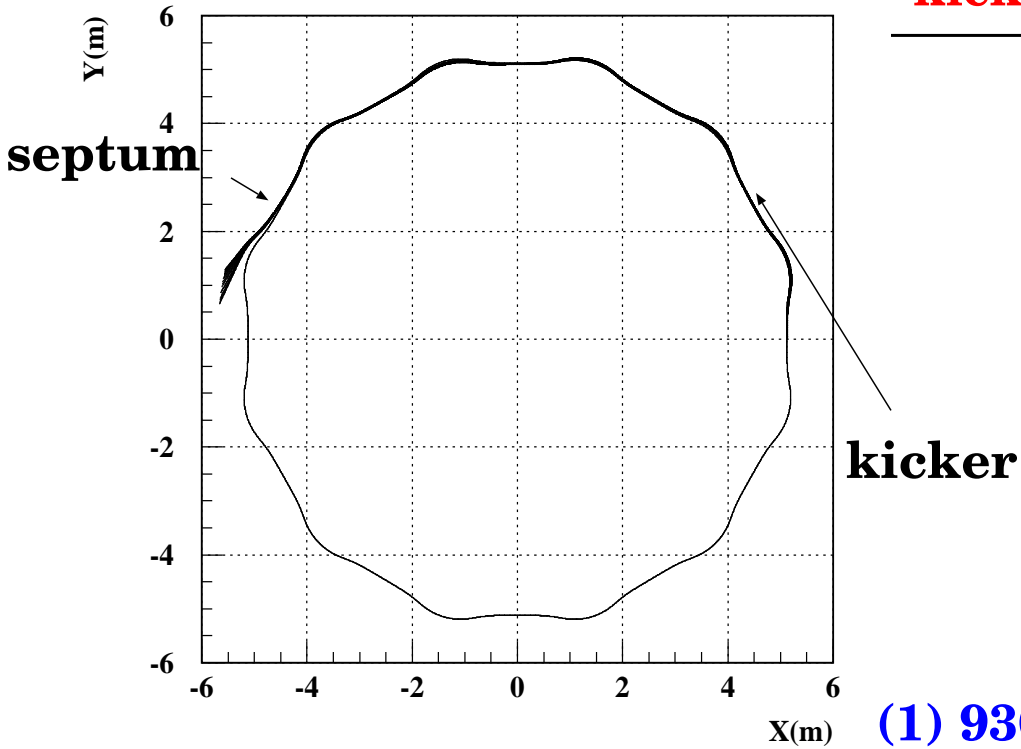
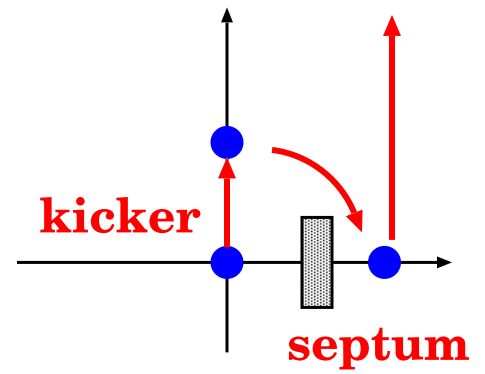
with 6mm thck septum,

available septum field(3cm gap)~2.8kgauss

*temperature rise ~30⁰

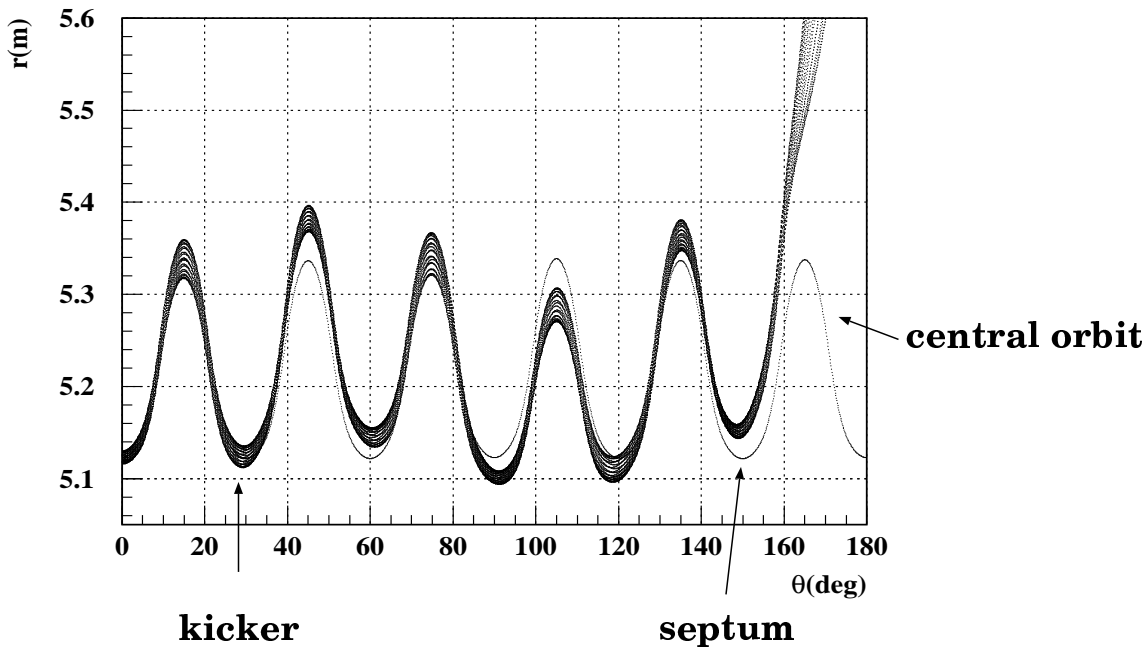
Beam Extraction(example)

Scheme : fast extraction
(kicker + bump)

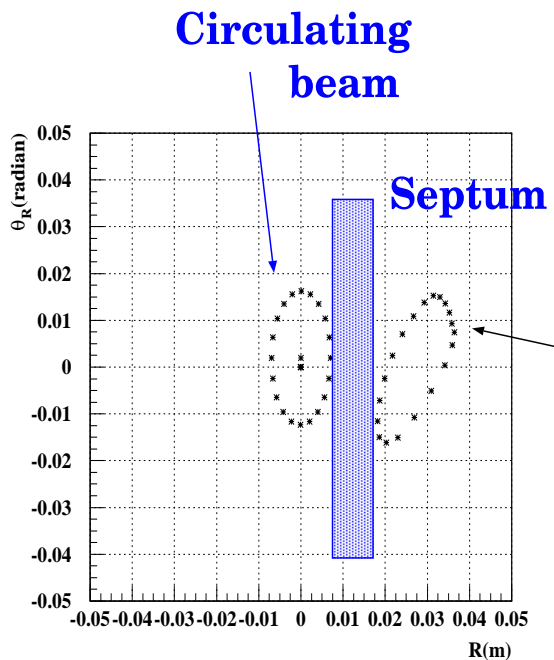


(1) 930gauss kicker

(2) 3kgauss septum



**Emittance of extraction beam
~100 pi mm · mrad(H)**



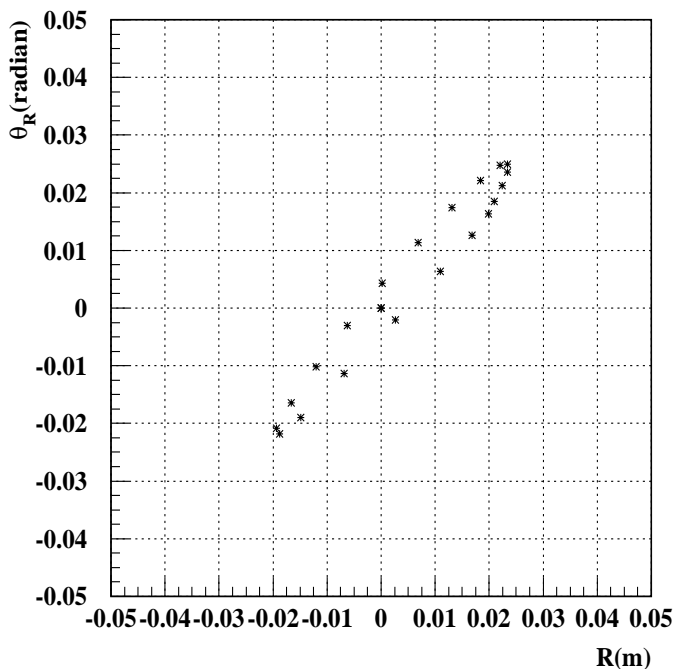
Extraction Beam

~max. 1.3cm thick septum can be inserted.

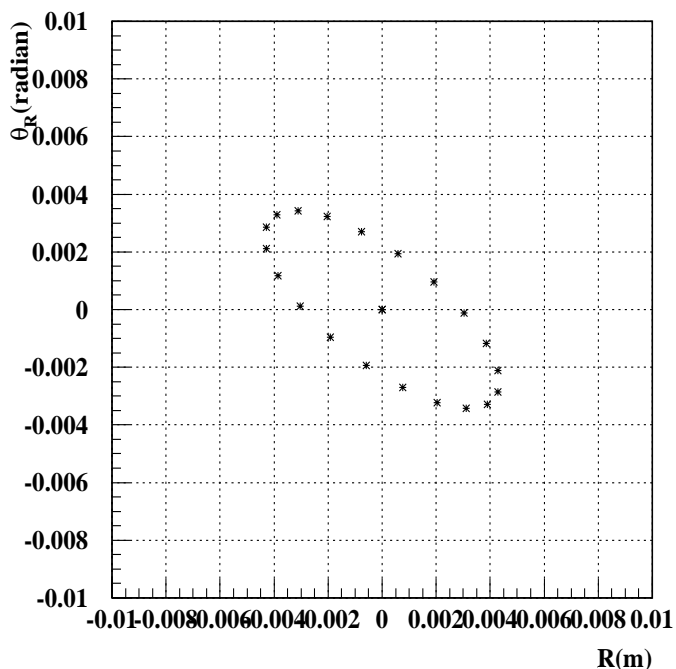
(~4kgauss field is available)

Beam shape of extracted beam

Horizontal phase space

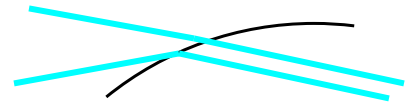


Vertical phase space

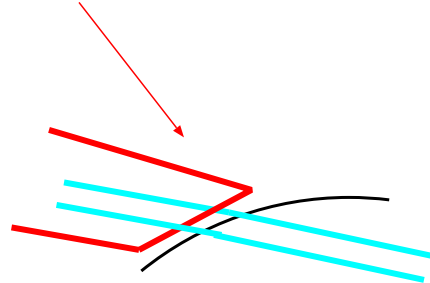
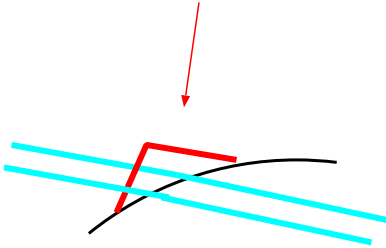


**(1) In triplet magnet(D-F-D type),
beam goes out from the edge of F-Pole.
---> Yoke-free type magnet is desirable.**

(2) Strong edge defocusing at the edge of F-pole



Additional pole or correction magnet is needed.



*** Additional pole might help.**

**However, it changes the field distribution
of the main field**

---> Careful and further study is needed.

**At present, applying strong field in the septum
is the only realistic choice.**

Summary of beam extraction of 150MeV FFAG

**With 930gauss kicker +6m thick 2.8 septum,
100 pi mm·mrad beam can be extracted.**

Optimum septum position 240deg(150deg.)

**Stability of horizontal tune should be
carefully studied.**

Dispersion should be taken into account.

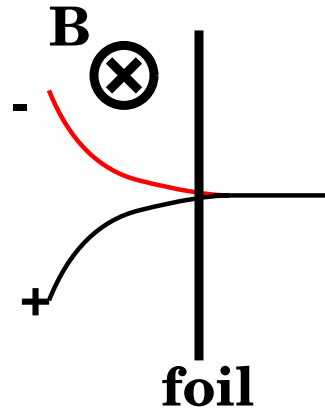
2 schemes

(1) H^- charge exchange

Small beam size

H^- source is a problem

Limited application(charge, energy)



(2) H^+ phase space painting

large beam size

High cost

Wide application

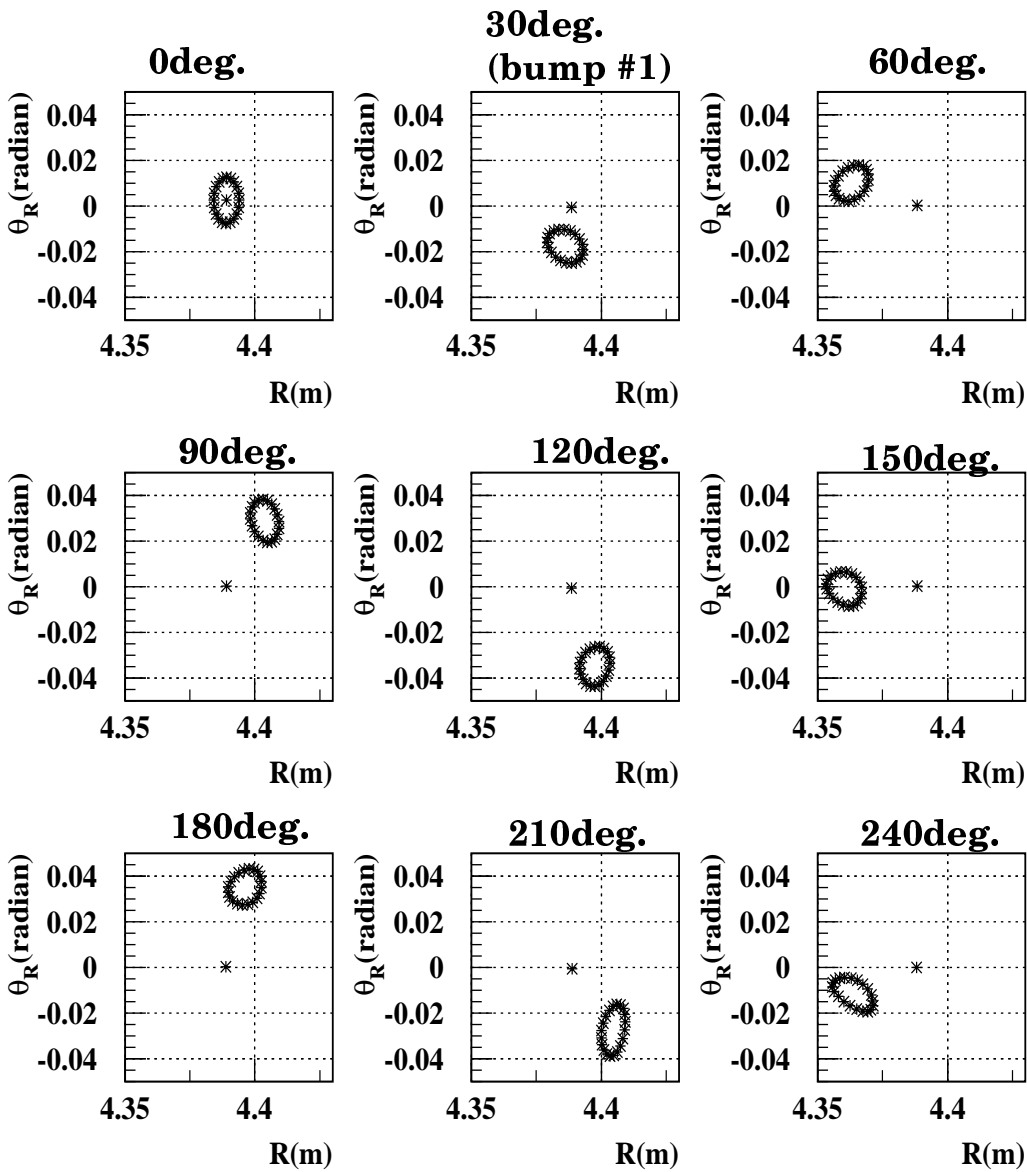
H^+ injection is at present
adopted as the injection scheme.

** injection beam emittance

$50 \pi \text{ mm} \cdot \text{mrad(H)}$

$10 \pi \text{ mm} \cdot \text{mrad(V)}$

Injection bump orbit



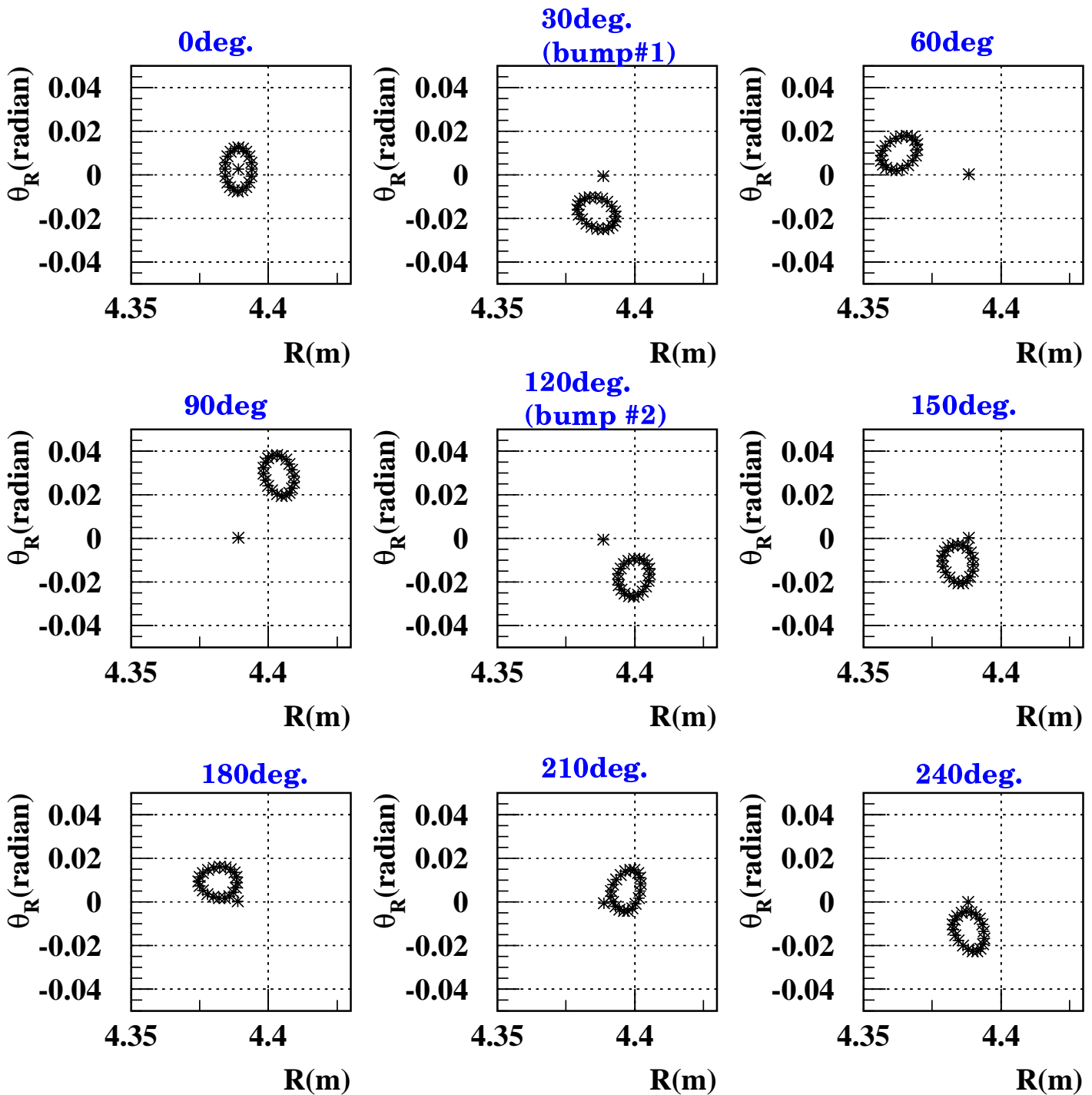
(kick :300gauss x60cm)

2 options

(1) 2π bump(30deg. +120deg.)

(2) π bump(30deg. +180deg.)

Bump orbit study



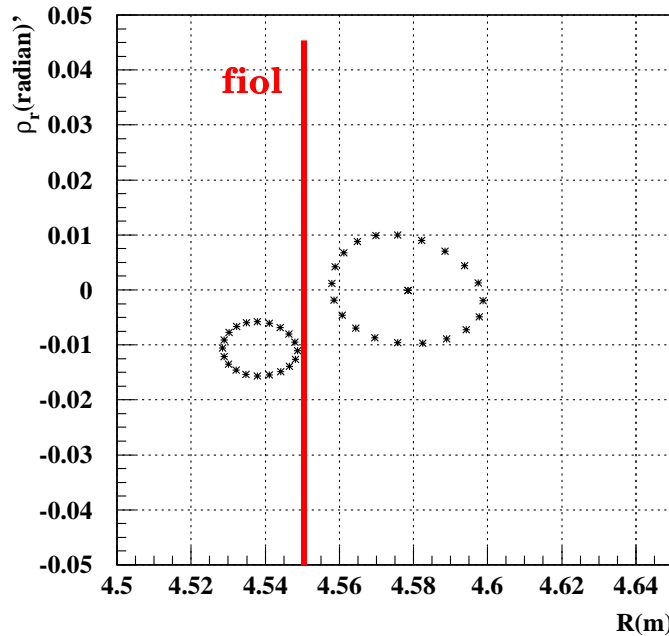
Bump orbit is not closed.

---> additional correction bump might be needed.

Orbit separation at bump orbit

(1) Charge exchange injection

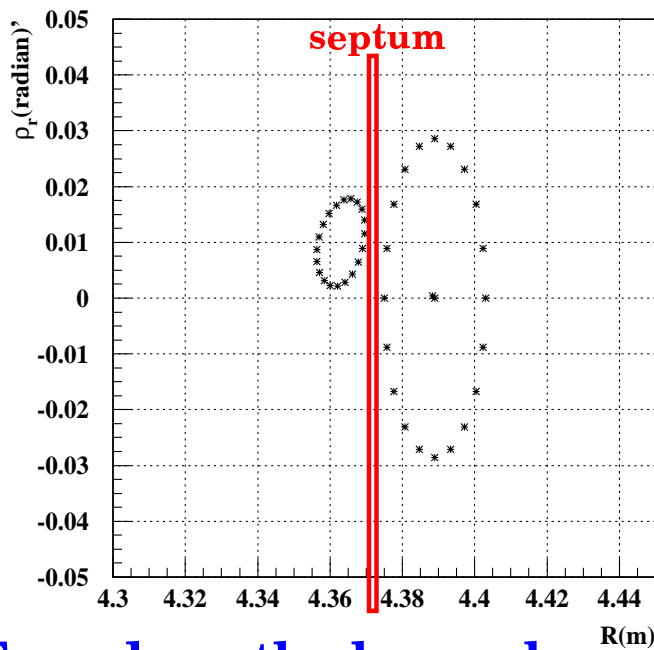
(max emittance : 200 pi mm·mrad)



bump: 300gauss x 60cm

(2) phase space painting

(max. emittance: 400pi mm·mrad)



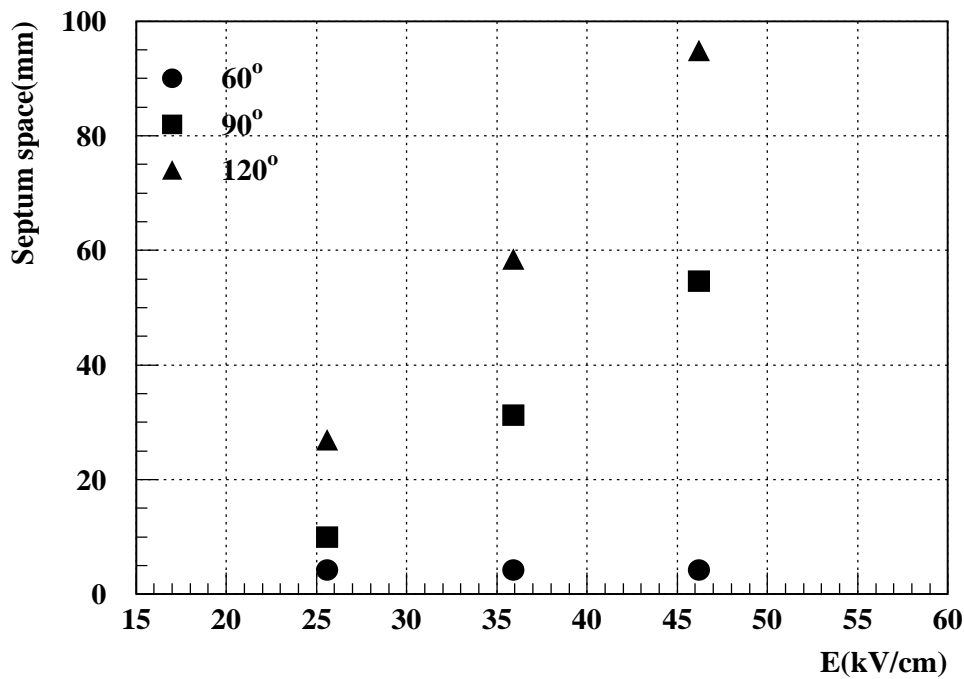
bump: 300gauss x 60cm

To reduce the beam loss,
two septum should be adopted (ES + magnet)

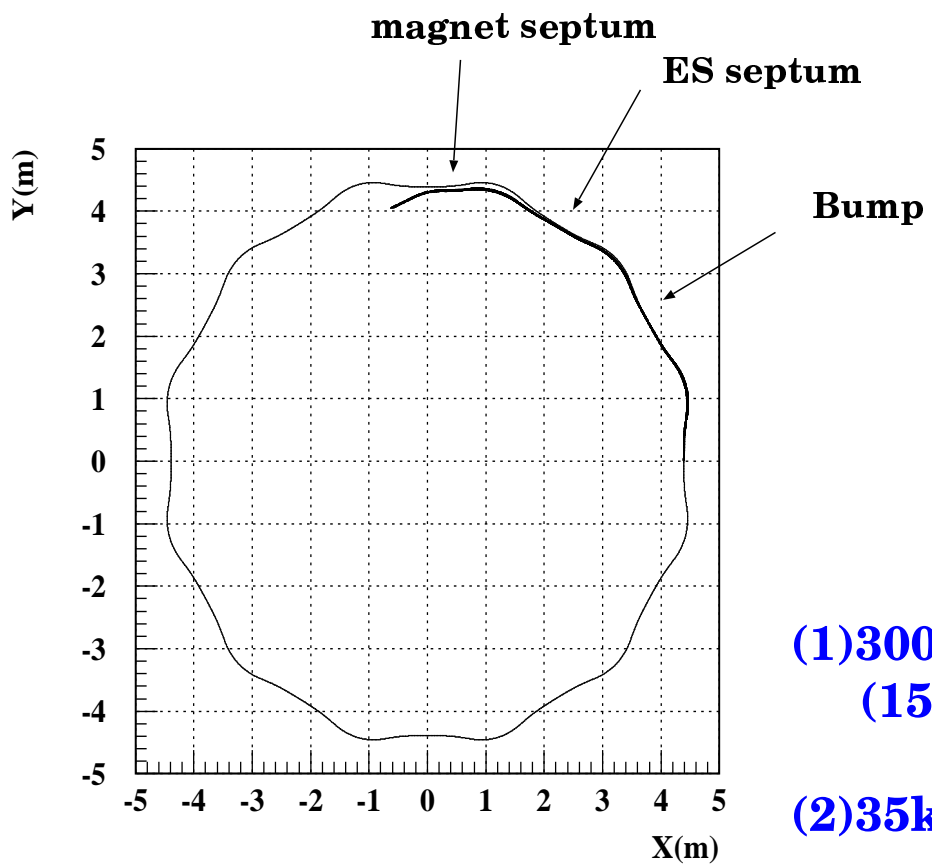
ES septum + magnet septum

Field gradient of ES septum
: 50kV/cm(max)

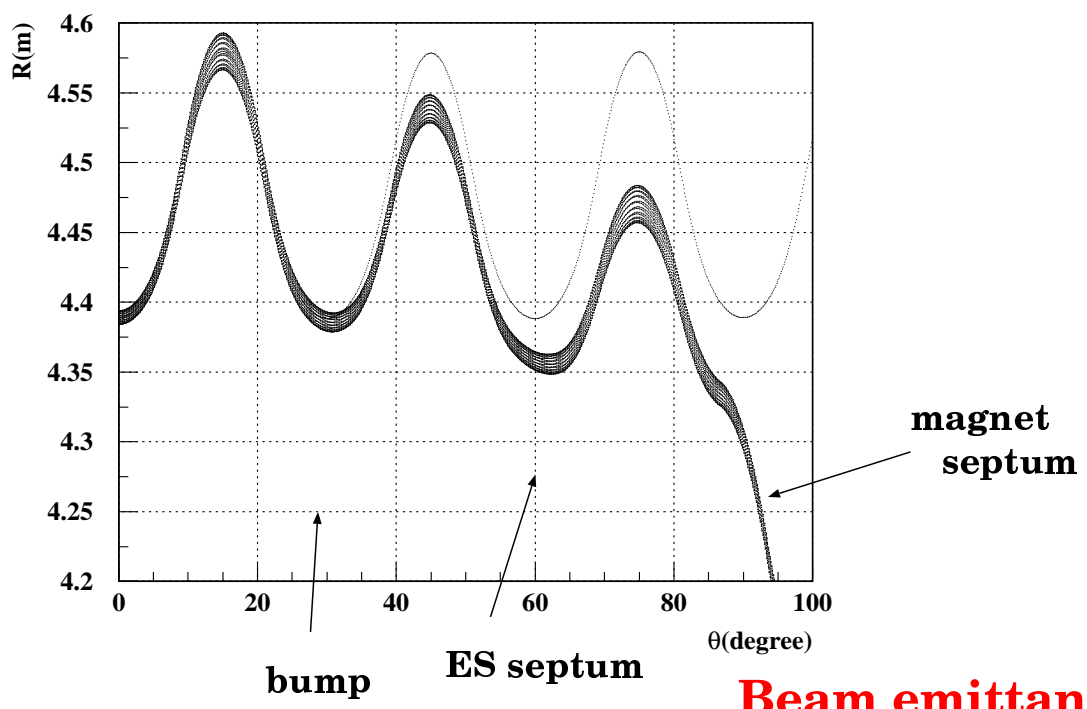
$$\tan \theta = \frac{E \cdot L}{p\beta}$$



More than 30 mm of space can be obtained
at the 1st septum

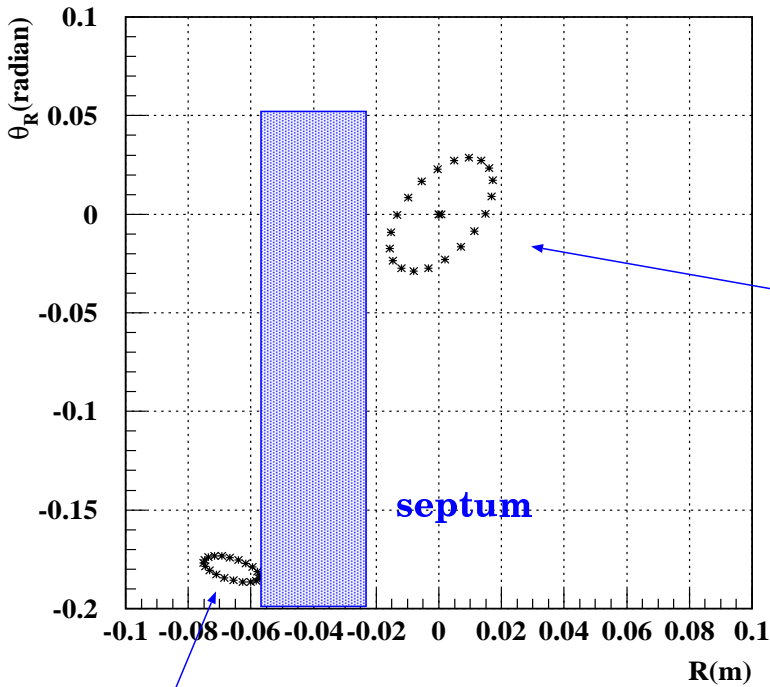


- (1) 300 gauss bump
(15kV/cm ES bump)
(@30deg)
- (2) 35kV/cm ES septum
(@60deg)
- (3) 1T magnet septum
(@90deg)



**Beam emittance(H)
@ injection
~ 400 pi mm·mrad**

Horizontal phase space @ septum magnet



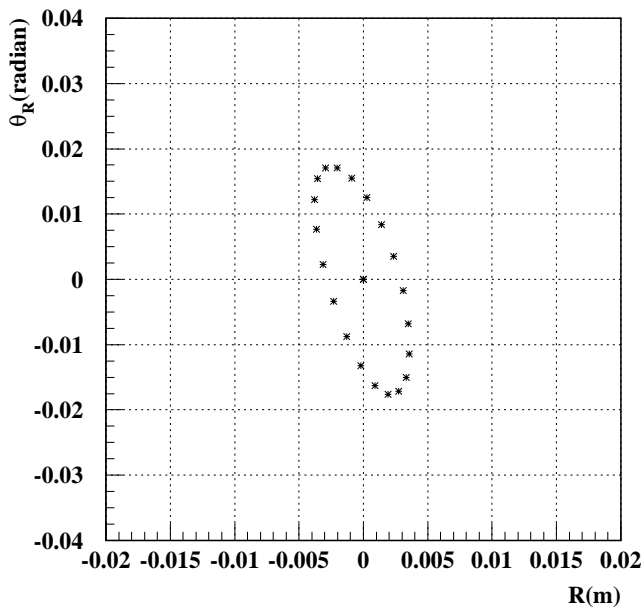
Circulating
beam(400pi mm·mrad)

max. 4cm thick
septum can be inserted

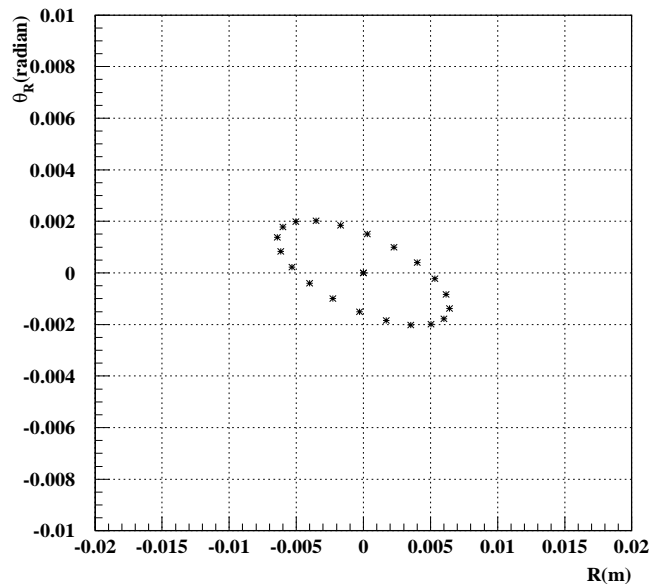
Injection beam
(50pi mm·mrad)

Phase space at the entrance of septum magnet

Horizontal



Vertical



Injection

H⁺ injection

10MeV

**cyclotron (H: 50 π , V:10 π mm·mrad)
after painting(400 π mm·mrad)**

Bump : $\tau = 2 \sim 5 \mu$ sec.

Field : 300gauss(15kV/cm)

beam size(max: H:2 \times V: 1.5cm)

ES septum

Field 35kV/cm

Orbit separation : 5mm

EM septum

Field 1T

Orbit separation : 3.8cm

Extraction

Fast extraction

129MeV(H:100 π , V: 10 π mm·mrad)

Circulating time : ~220ns

Kicker

Rise time : 150ns

Flat top : 80ns

Max field : 1kgauss(70kV 2000A)

Gap : 2cm

Repetition : >250Hz

Septum

Field : 3.5kgauss

Gap : 2cm