Development of MERIT

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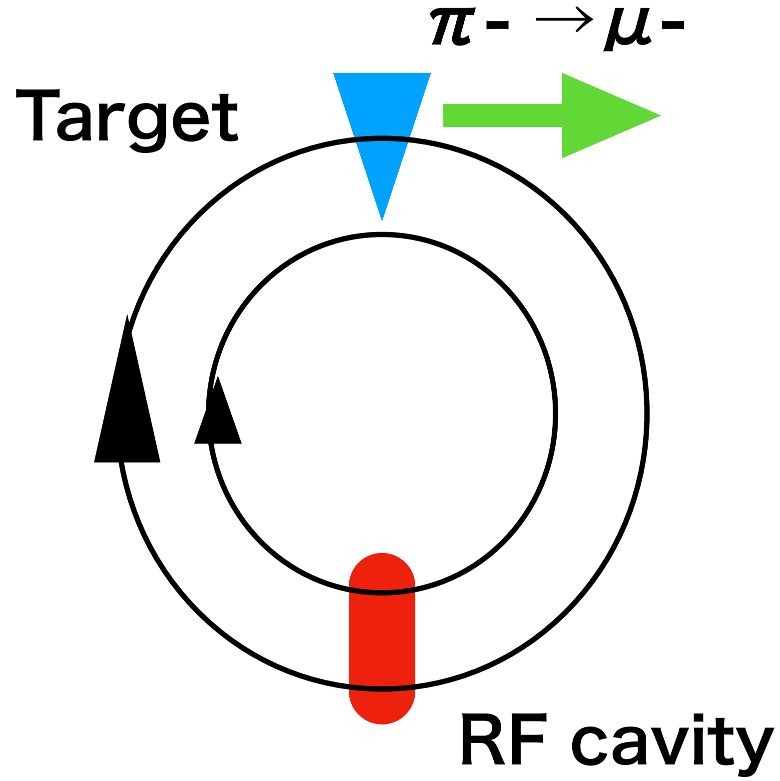
Background



□One of the scheme to mitigate LLFP of nuclear reactor is nuclear transformation using intense negative muon.

□MERIT(Multiplex Energy Recovery Internal Target) scheme with FFAG can be useful to generate muon effectively.

□Proof of principle of MERIT scheme by modified present ERIT ring is curried out. (PoP MERIT ring)

Purpose of PoP experiment

Acceleration & Storage
simultaneously

<u>□Subjects to clarify the MERIT scheme</u>

○Fixed RF frequency Acceleration

- Serpentine or stationary bucket acceleration

○Storage

- Large acceptance

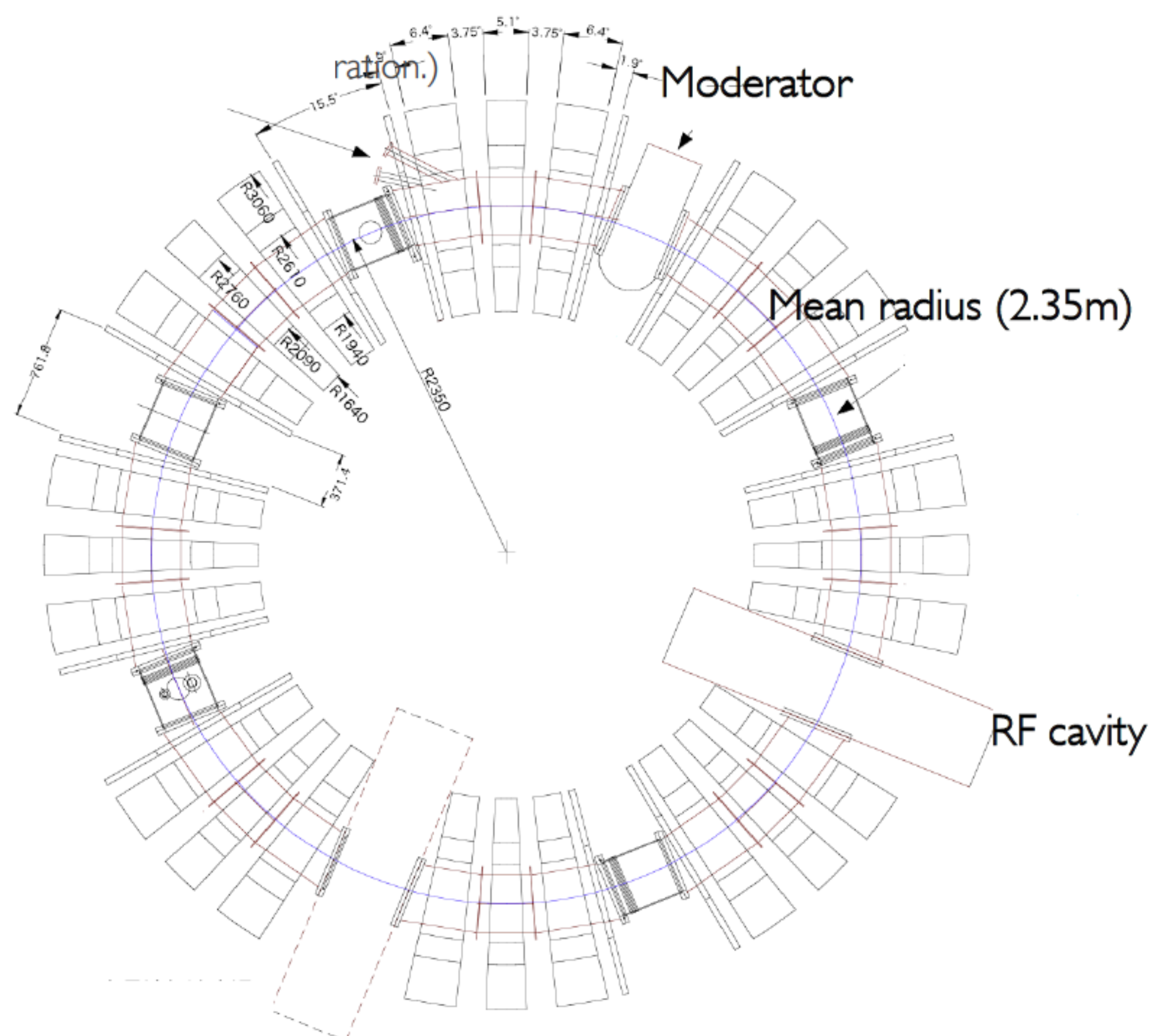
○Injection

- Adjustment of injection beam line
- Generation of short bunch beam

In this presentation, evaluation and current status about these subjects are introduced.

Basic parameters of PoP MERIT ring

Particle	Proton
Energy range	10.0 [MeV] ~ 12.0 [MeV]
Radius	2.2[m] ~ 2.5[m]
Lattice	FDF-triplet
Number of Cell	8
Field Index k	0.03
RF Voltage	~200 [kV]
RF Frequency	18.12 [MHz]



K. Okabe "Design process of FFAG-ERIT ring", FFAG09

Fixed RF Acceleration
~Modification of the field index k~

□Condition of serpentine acceleration

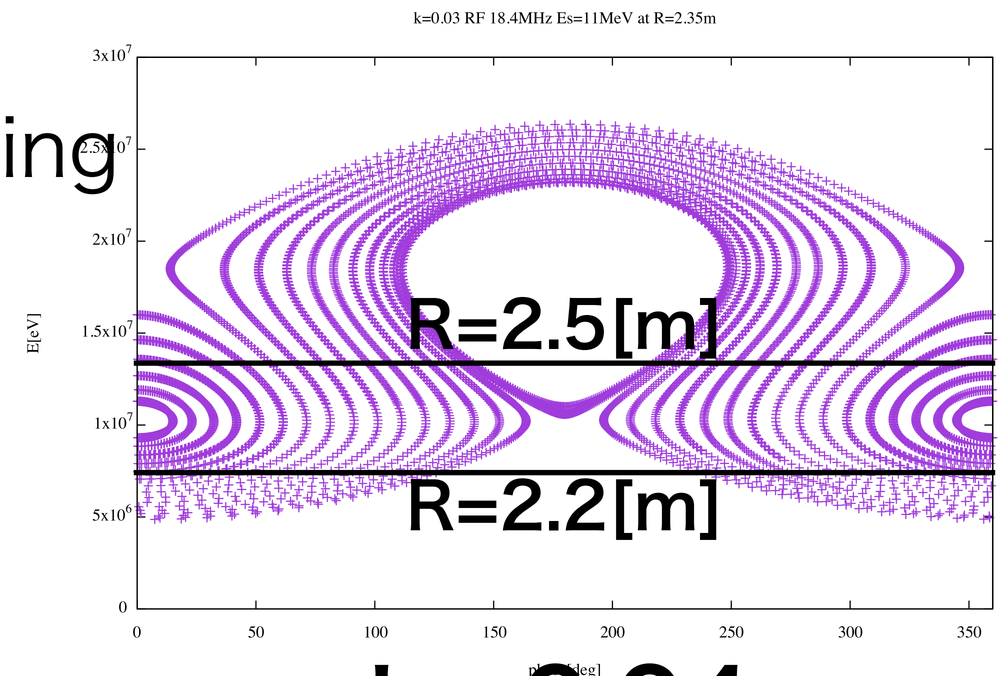
→Close to transition energy

→Modification of field index k from ERIT ring

ERIT k = 1.92 → PoP MERIT ring k = 0.03

(transition E ~ 14 [MeV] @k = 0.03)

k : 0.03

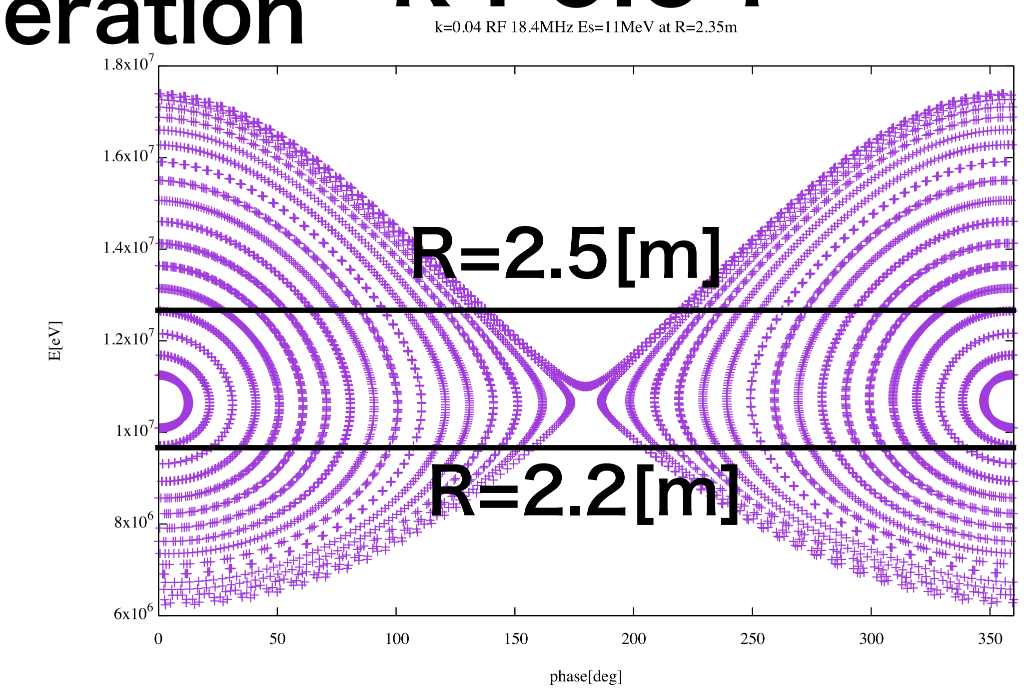


□Another Condition of Fixed RF Acceleration

→Stationary bucket acceleration

ex. k = 0.04

k : 0.04



Fixed RF Acceleration
~Scheme to modify the field index k~

☐**Change the pole face shape.**

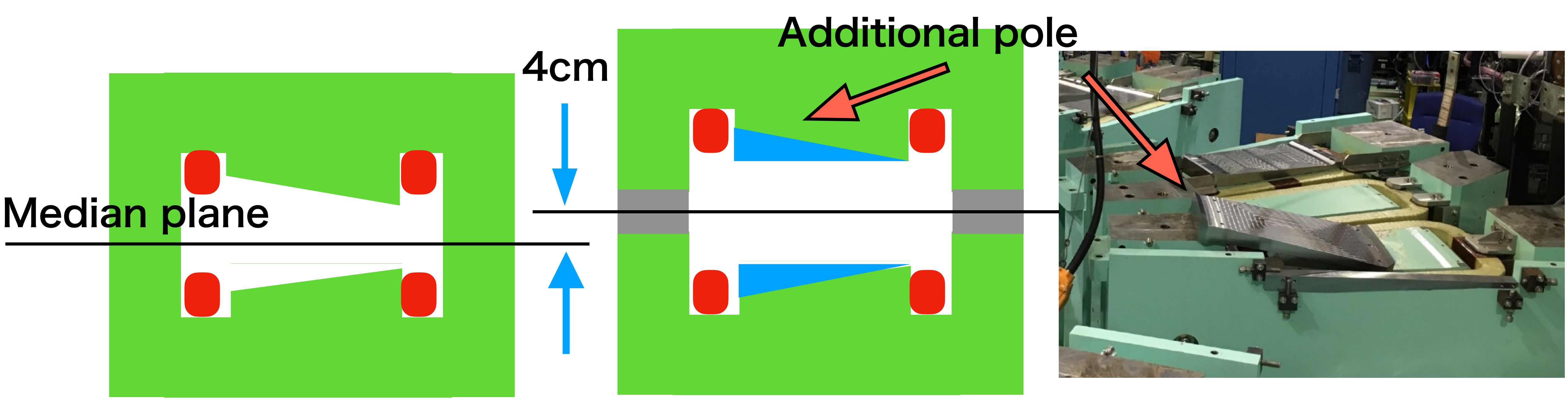
→Set additional pole on the conventional one.

(pole shape : k+1 ~ 1.03)

☐**Height of median plane shift vertically.**

→Shift the position of magnets and devices vertically.

(ex.RF cavity, Magnet and Field Clamp etc.)

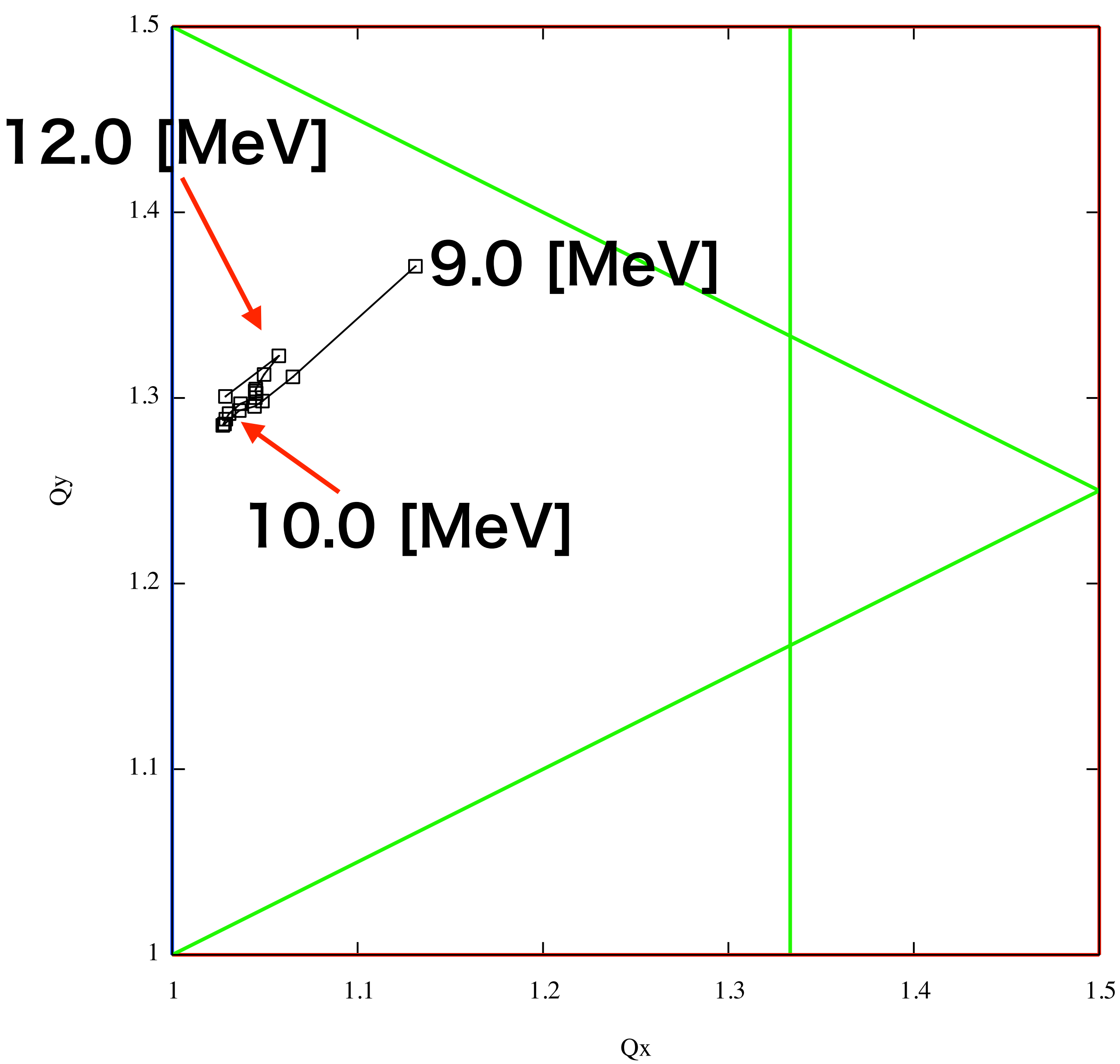


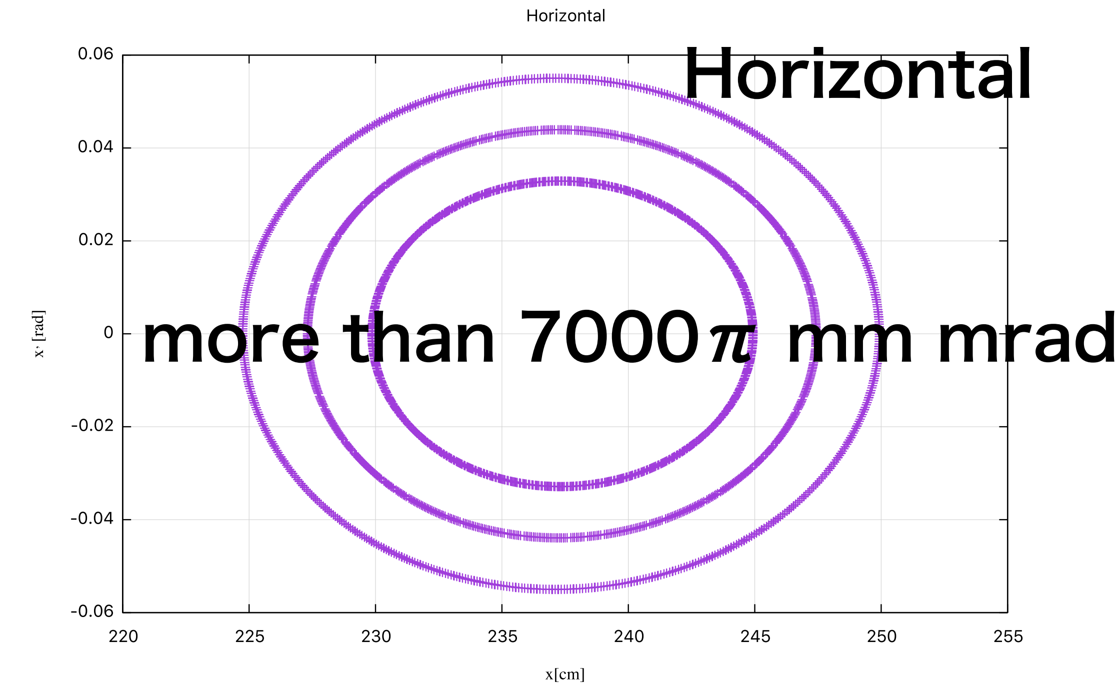
Tune variation & Acceptance~

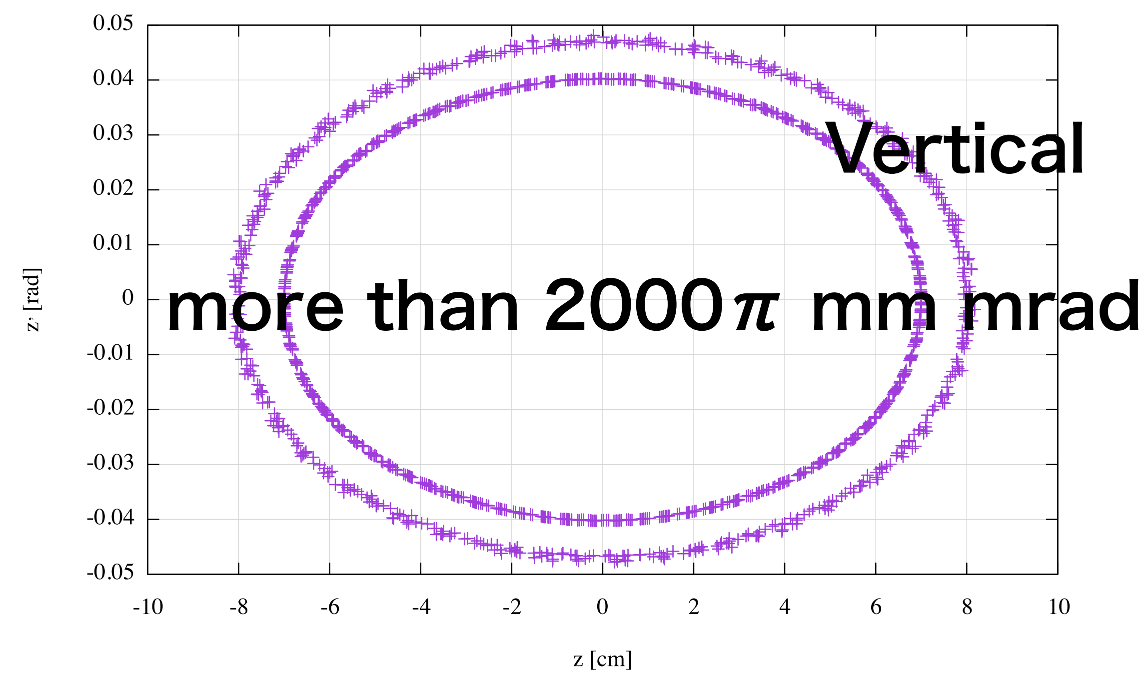
□Results of beam tracking simulation with 3D field map of TOSCA

○Acceptance @ E = 11.0 [MeV]

○Tune diagram







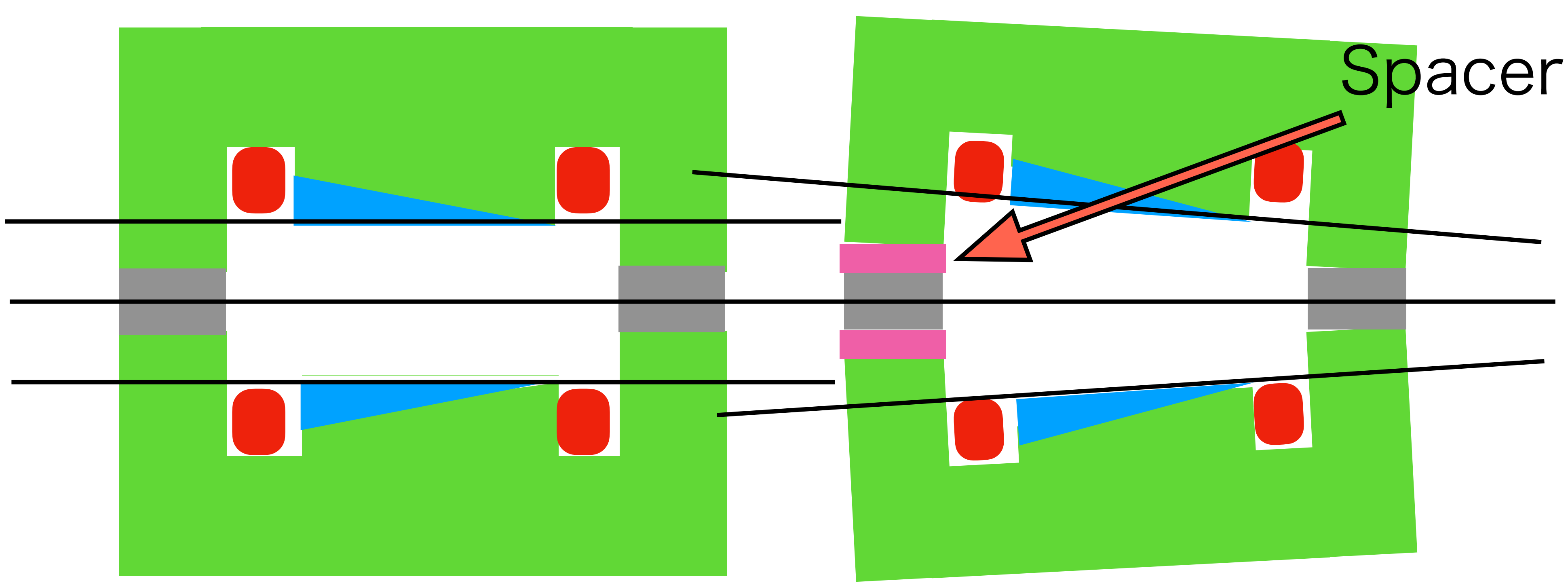
Enough acceptance

Scheme for tuning the field index k

☐**Modify the tilt of pole face.**

→Insert the additional spacer at yoke.

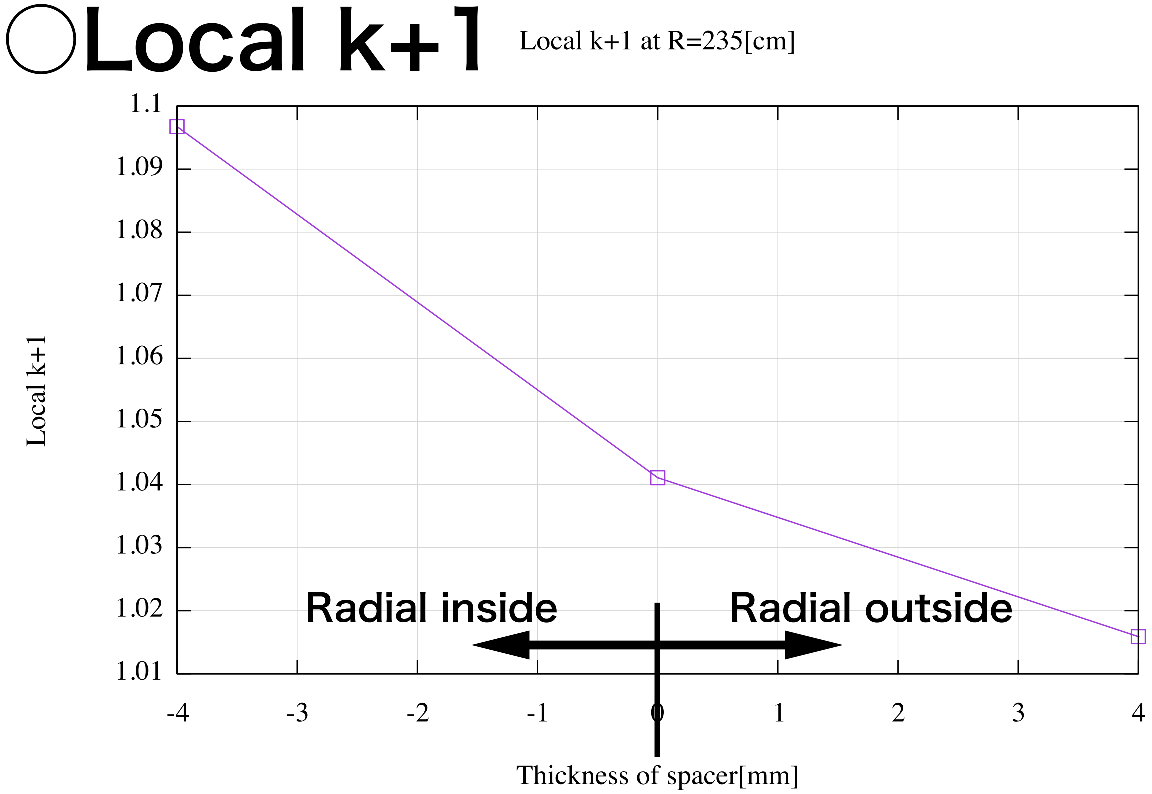
- Radial **<u>inside</u>** yoke → Field index k up⬆️
- Radial **<u>outside</u>** yoke → Field index k down⬇️



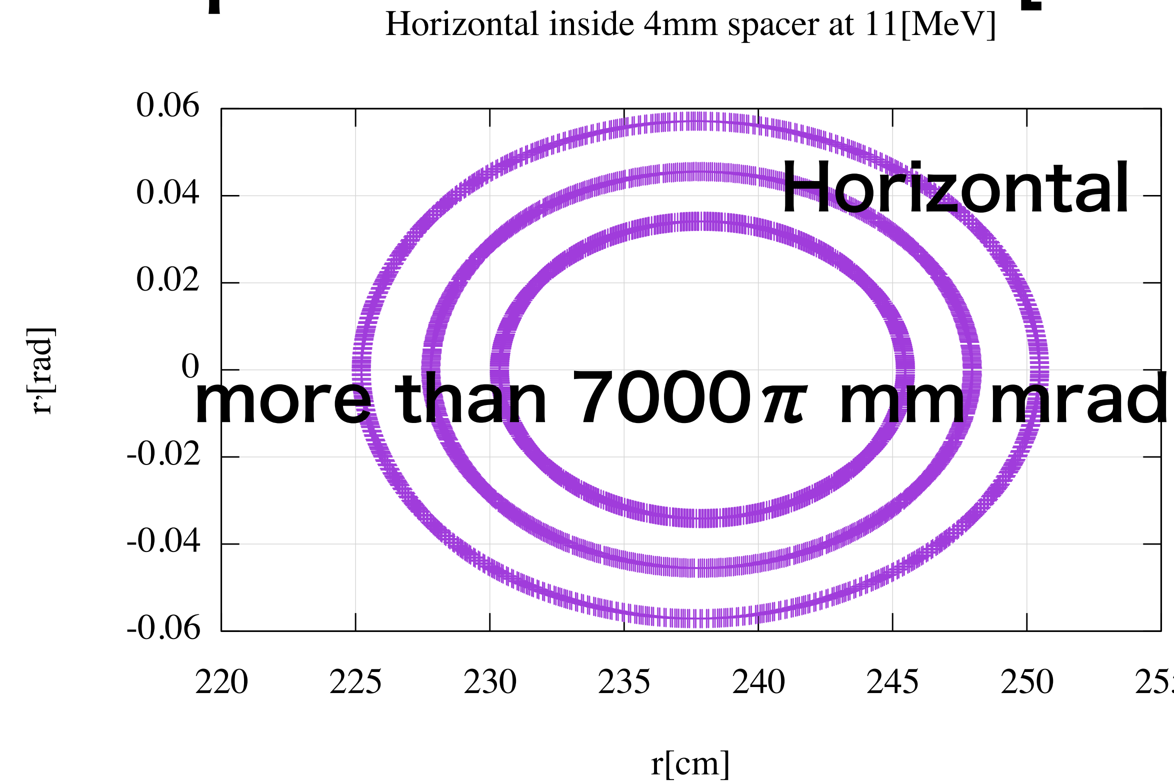
Local k+1 & Tune variation & Acceptance

□Results of beam tracking simulation with 3D field map of TOSCA

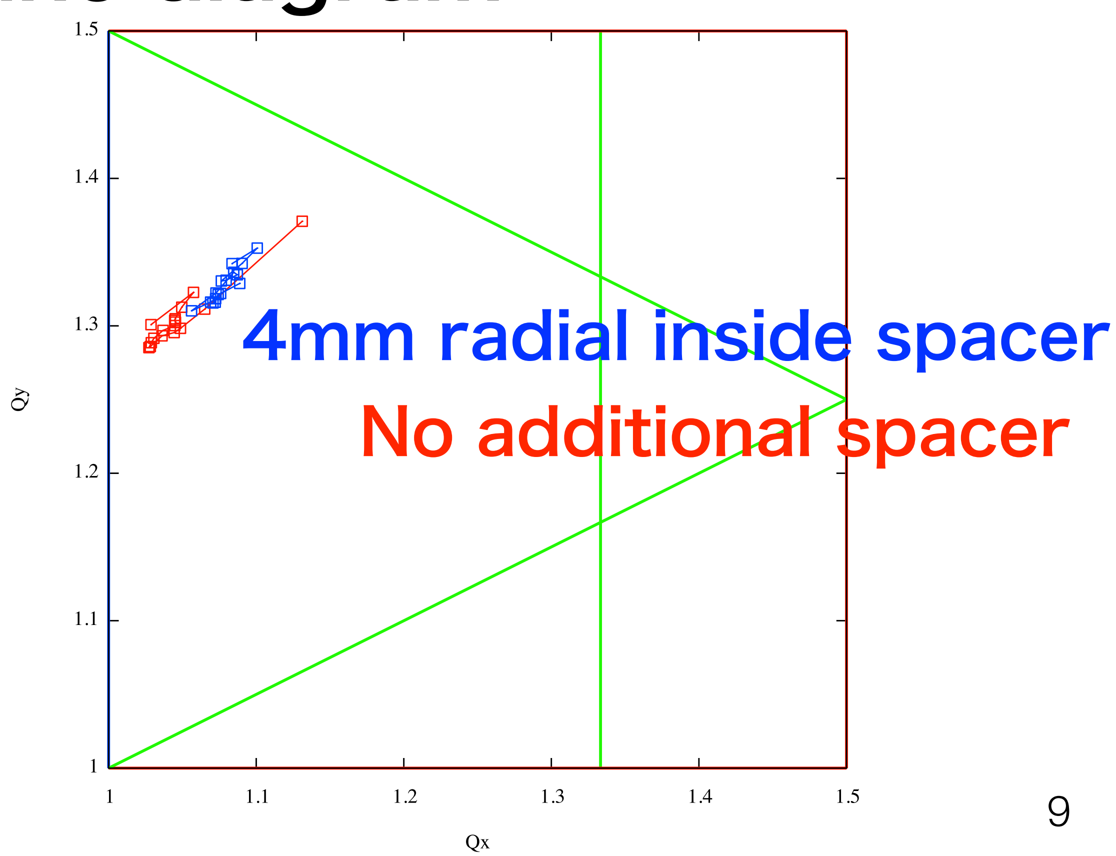
○Local k+1

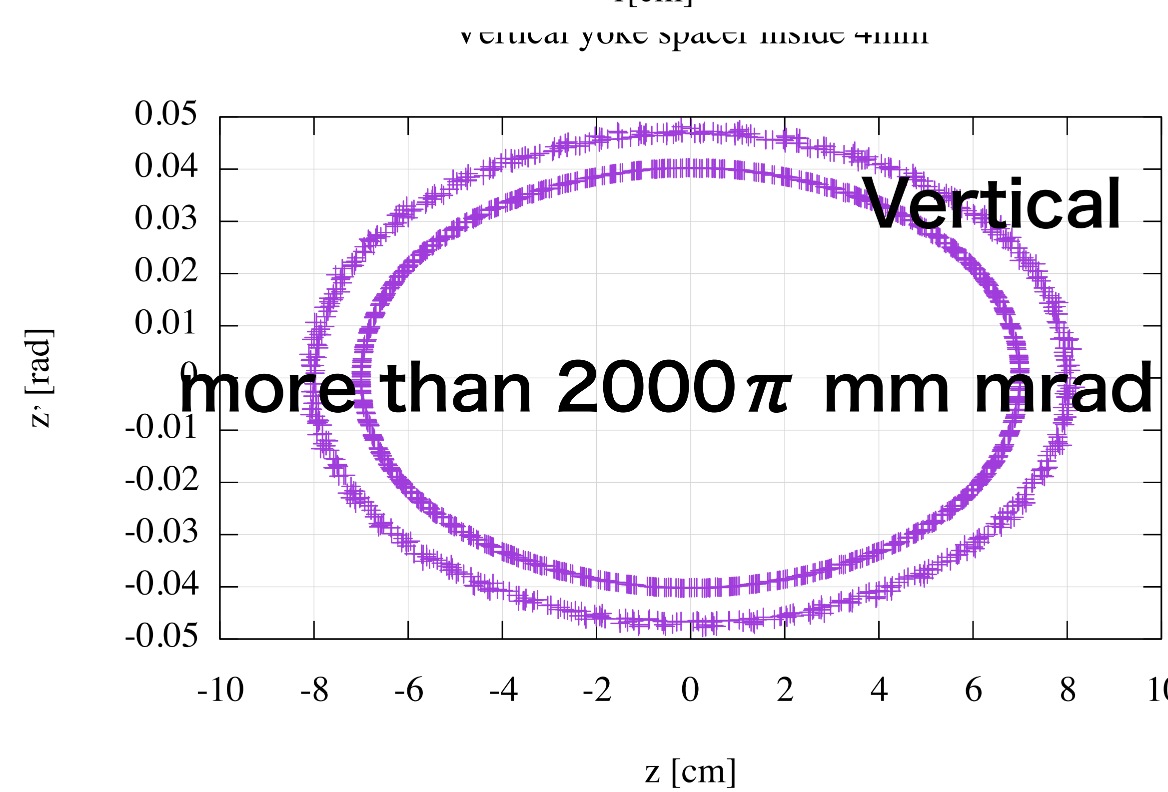


○Acceptance @ E = 11.0 [MeV]



○Tune diagram





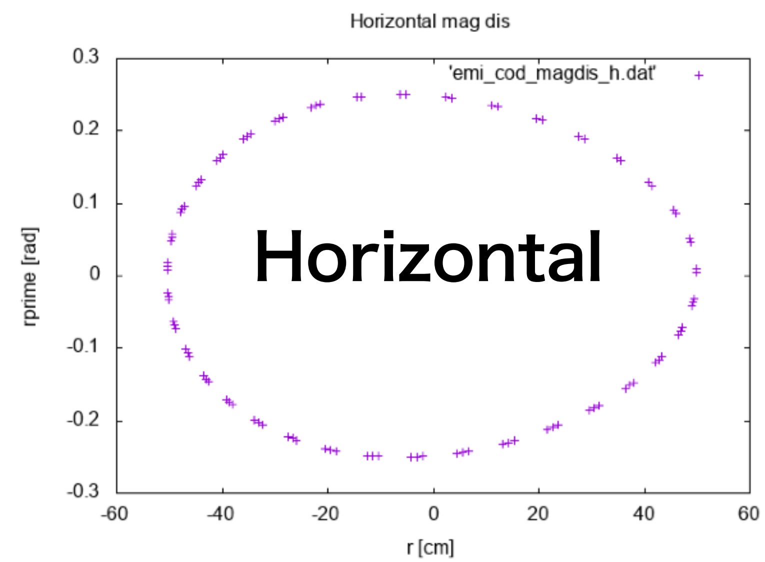
Enough acceptance

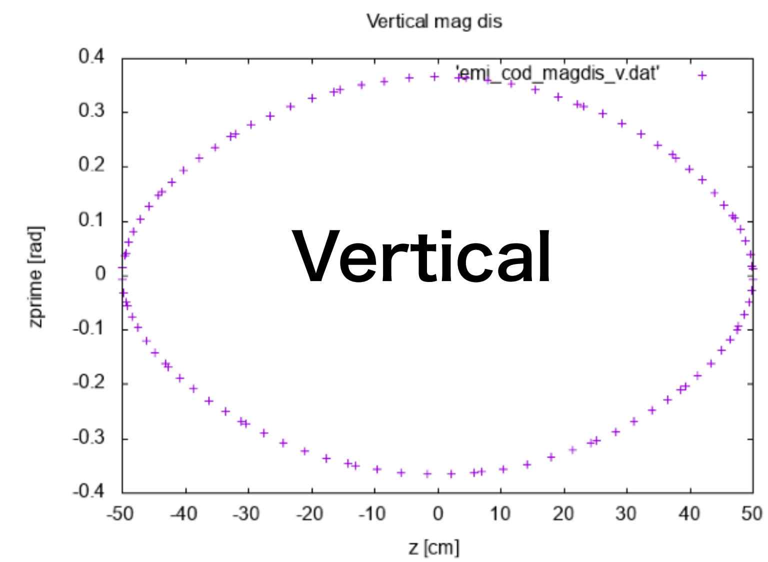
Acceptance ~Error field~

□Horizontal Tune ~1.03 ← Close to Integer resonance (Qx = 1.0)
→Evaluation of acceptance with error field

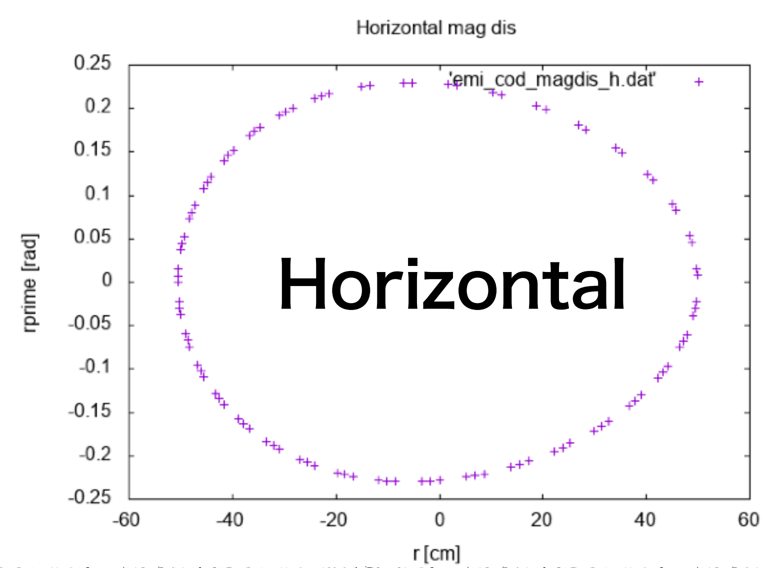
□Results of beam tracking with error field (Linear edge field)

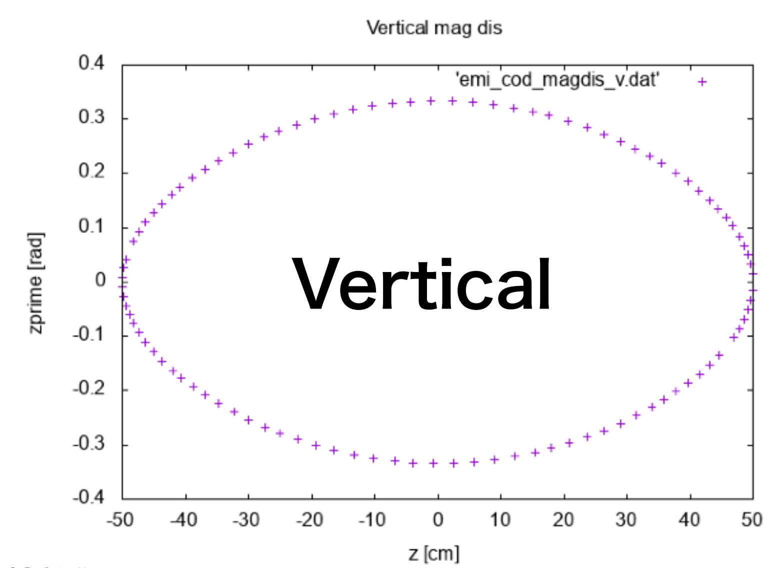
○Misalignment : R direction
dr = -1.0 [mm]





○Misalignment : Z direction
dz = -1.0 [mm]





Enough acceptance too

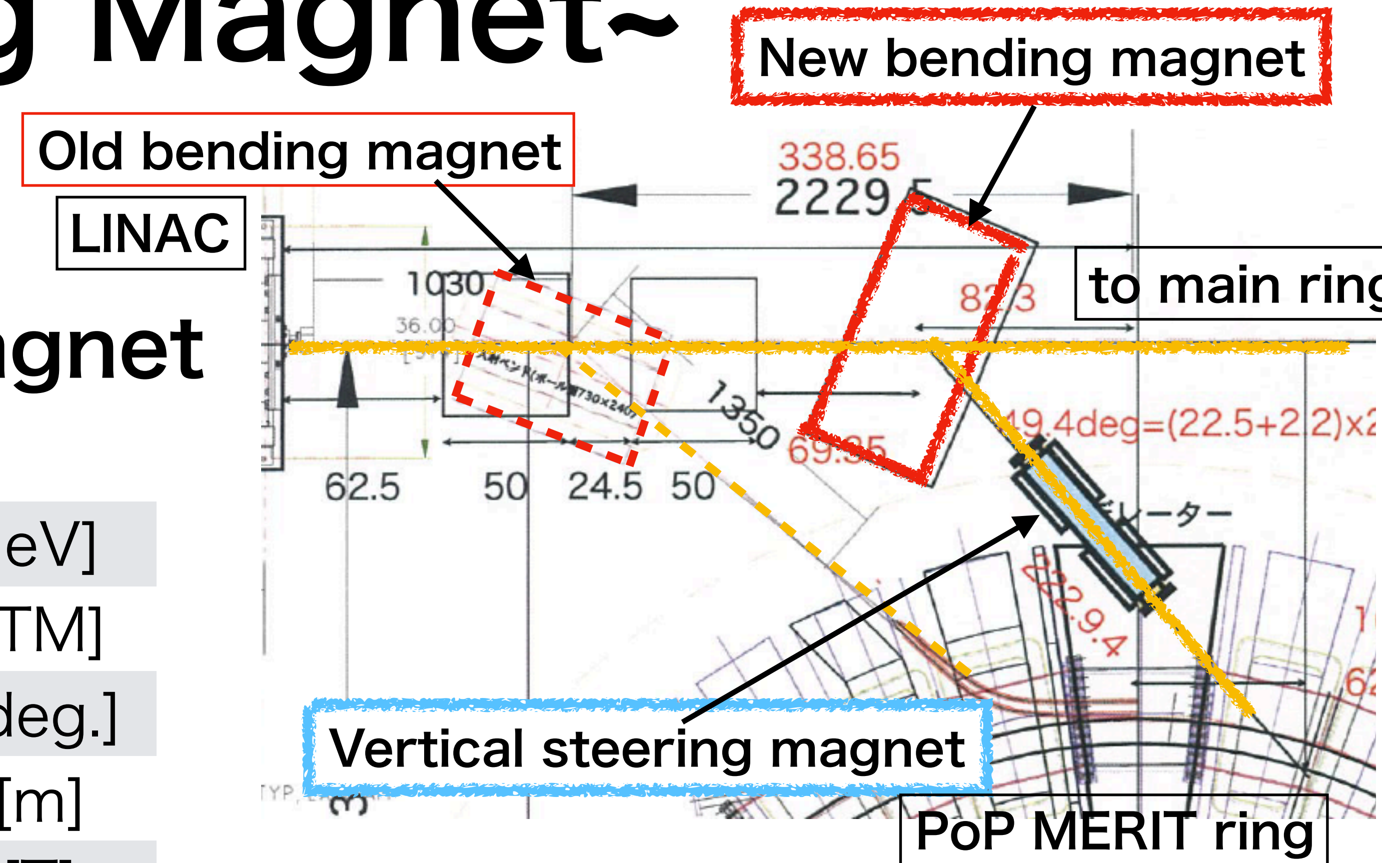
Injection

□Injection beam line from LINAC to PoP MERIT ring is changed.

○Separation of injection orbit and target orbit
→New bending magnet was built and installed.

○Adjustment of height shift of median plane (4cm)
→New vertical steering magnet was built and installed.

Injection
~Bending Magnet~



□Requirements of bending magnet

Particle	H-
Kinetic Energy	11 [MeV]
Magnetic Rigirity : $B\rho$	0.48 [TM]
Bending angle	49.4 [deg.]
Curvature Radius : ρ	1.29 [m]
Magnetic Field : B	0.37 [T]

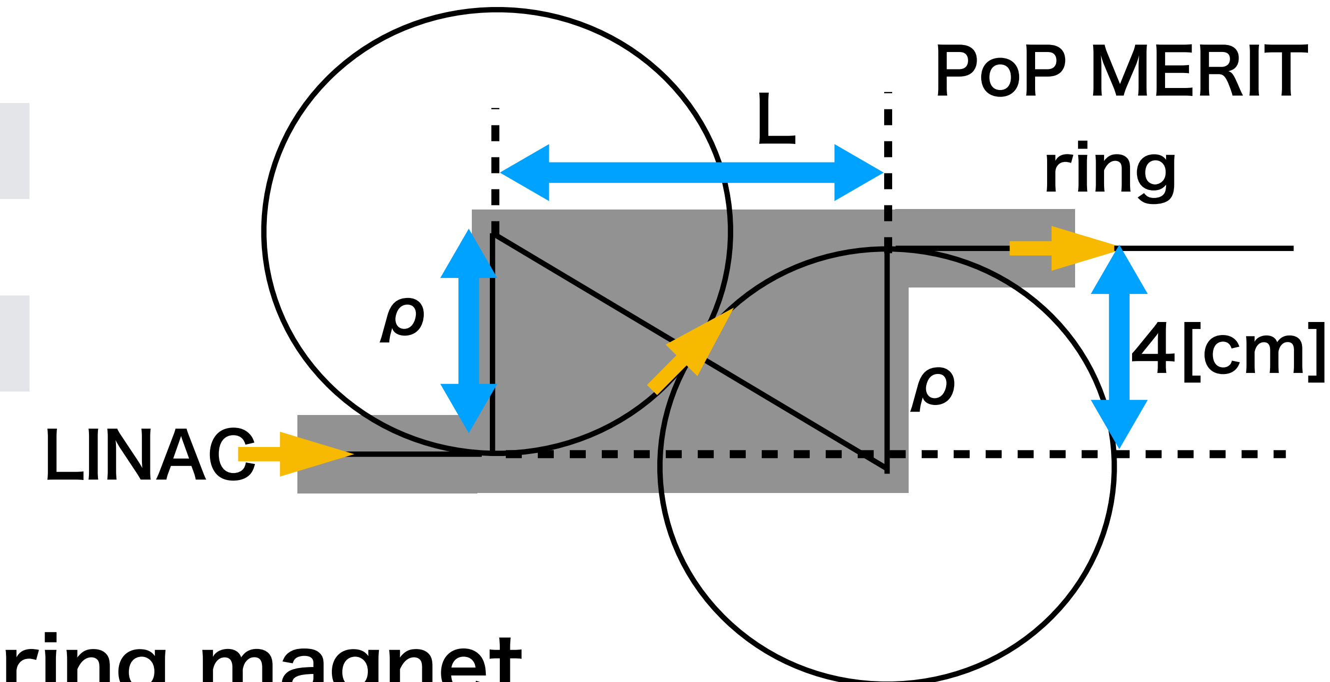
□Specifications of bending magnet

Gap	10 [cm]
Total Current	~30000 [AT]
Number of Coil turn	60[turn]×2
Current	~250 [A]

Injection
~Vertical steering magnet ~

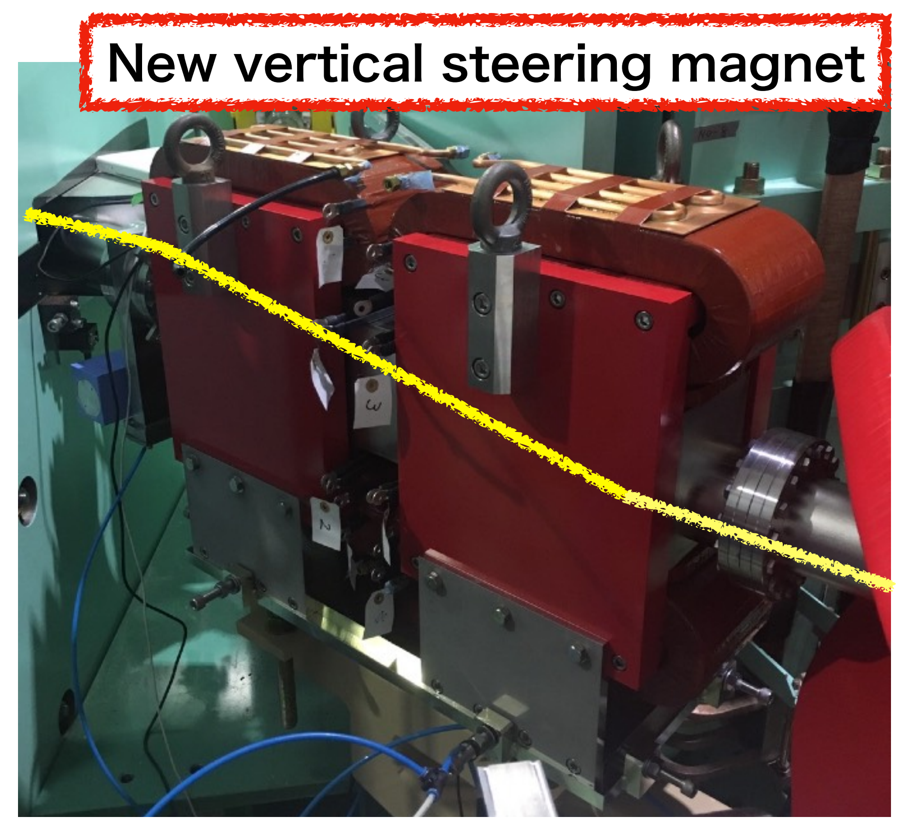
□Requirements of vertical steering magnet

Vertical shift of beam line	4.0 [cm]
Particle	H-
Kinetic Energy	11 [MeV]
Max length of Magnet : L	<= 60 [cm]
Min length of Gap	>=10 [cm]



□Specifications of vertical steering magnet

L	60 [cm]
ρ	2.26 [m]
Magnetic Rigility	0.48 [Tm]
Magnetic Field	0.212 [T]
Gap	15 [cm]
Total Current	~25000 [AT]
Number of Coil turn	325[turn]×2
Current	~40 [A]



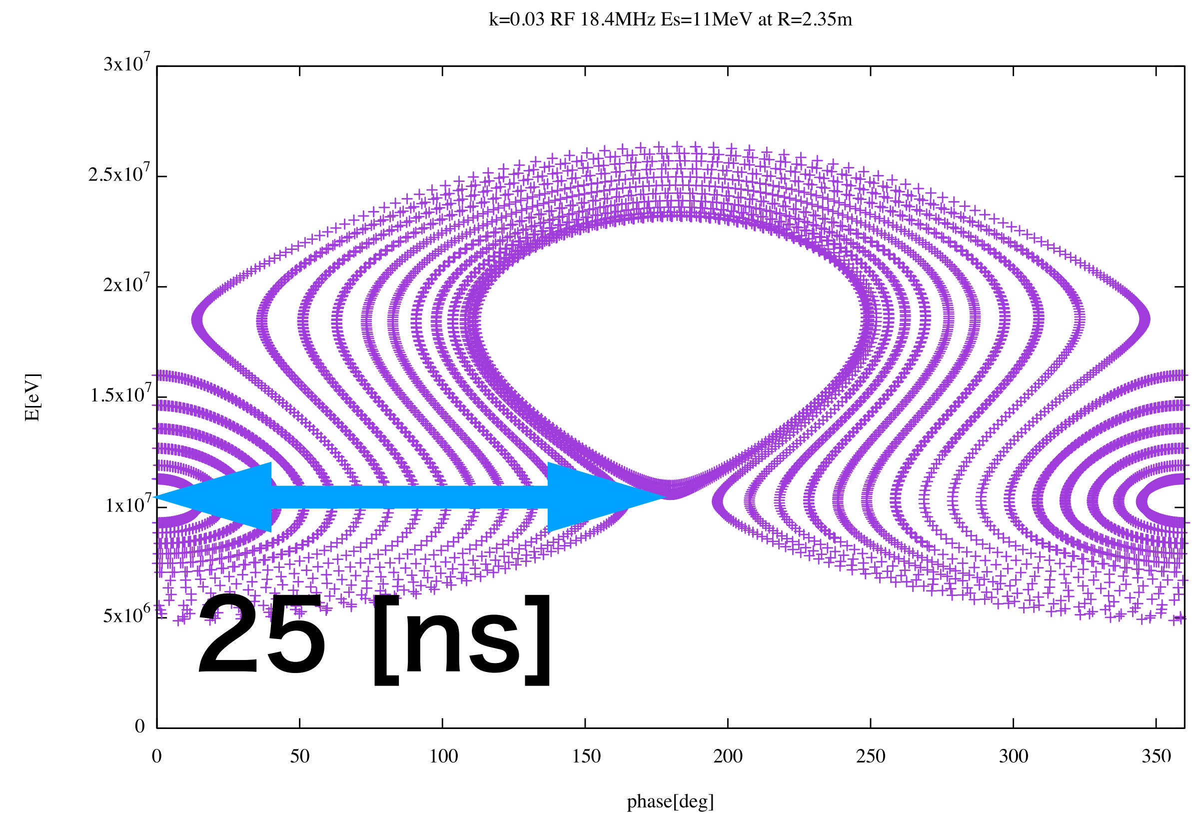
Development of delay line chopper

□Purpose of development

<u>Measure beam position during acceleration accurately.</u>

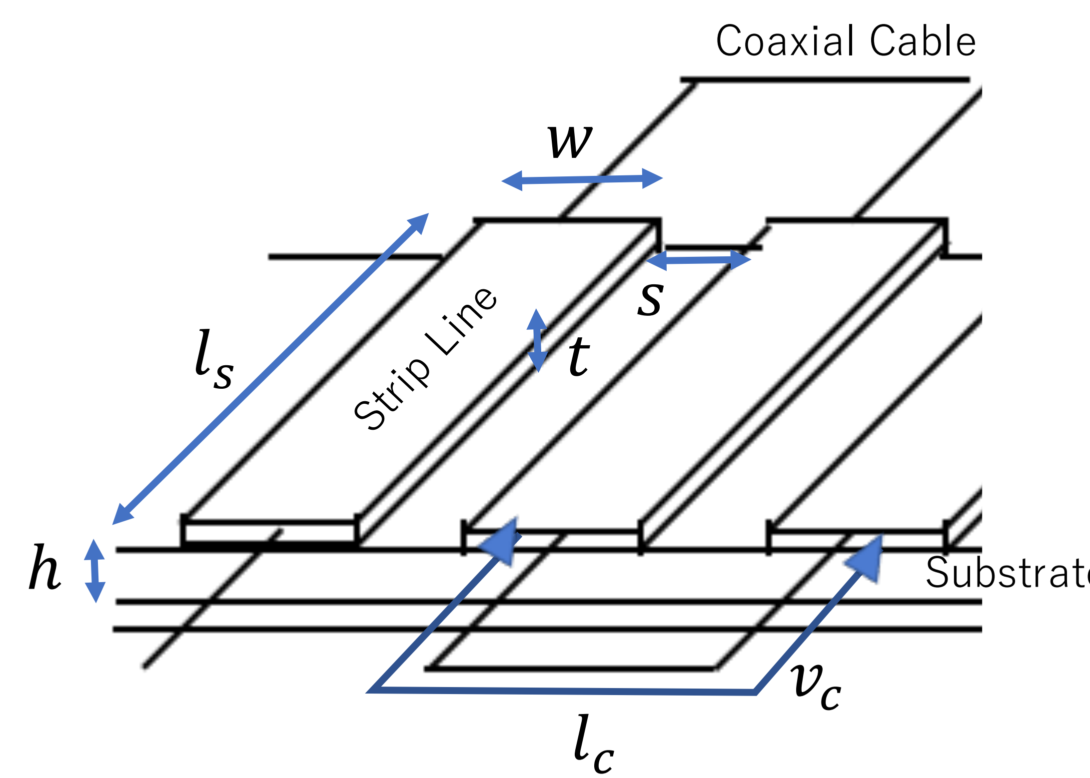
→Beam width : ~10 [ns]

→Delay line chopper



□Delay line chopper

- Generate a short bunch beam at low energy.
- Composed of microstripline & coaxial cable.



Development of delay line chopper ~Parameters~

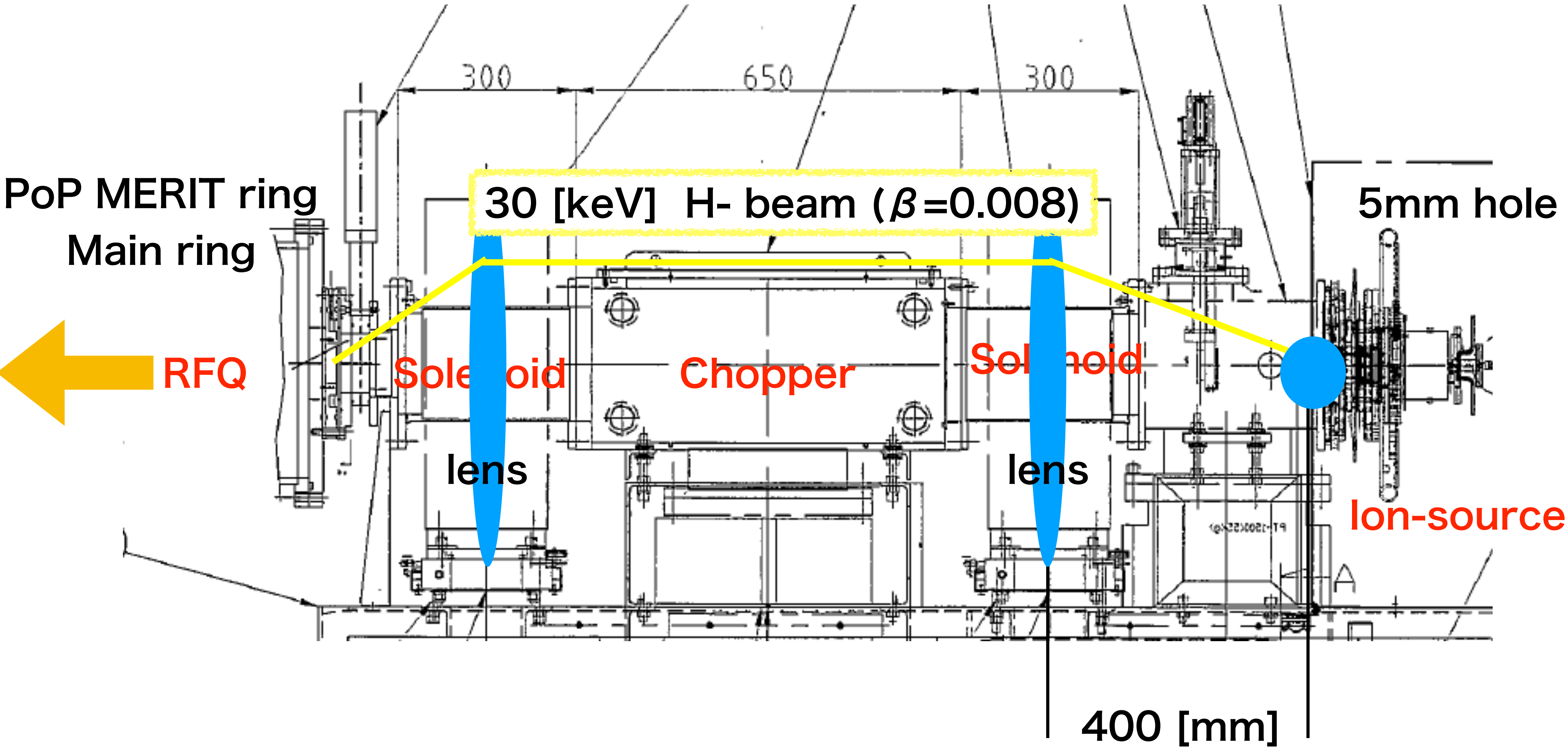
□Requirements

Maximum size of chopper(W×L×H)	400×520×250 [mm]
Beam energy (H-)	30 [keV]
Chop width	10 [ns]
Repetition frequency	20 [Hz]

□Specifications of basic parameters

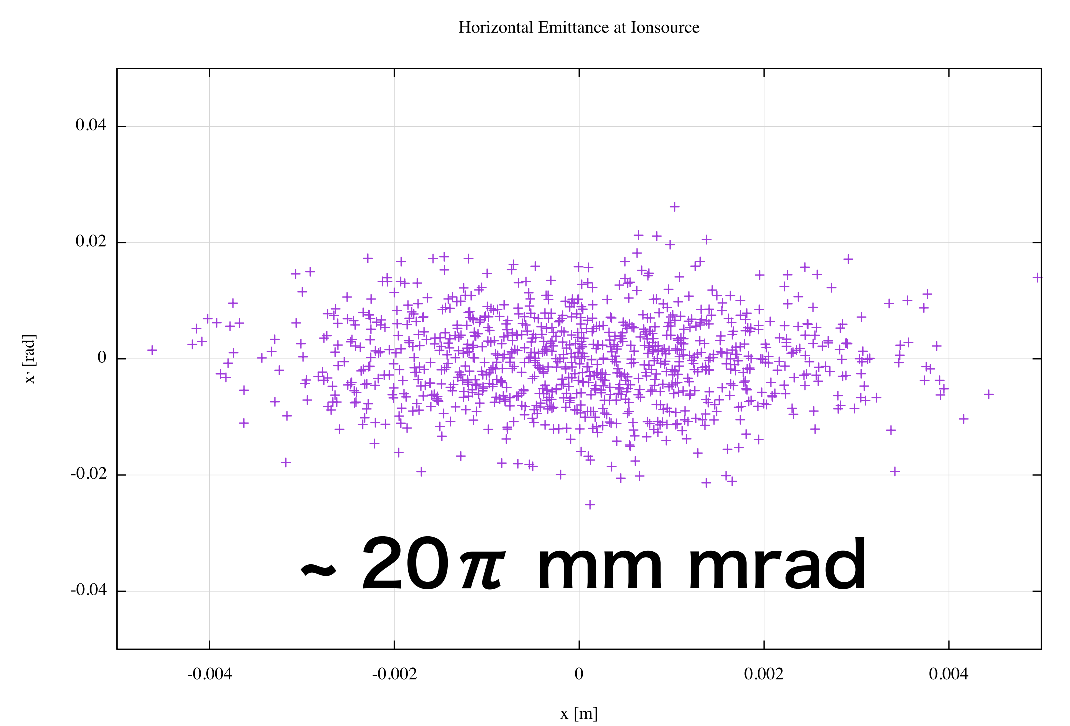
Length of chopper (Beam direction)	500 [mm]
Voltage	100 [V]
Full Gap of chopper	15 [mm]
Characteristic impedance	50 [Ω]

Development of delay line chopper
~Beam line elements~



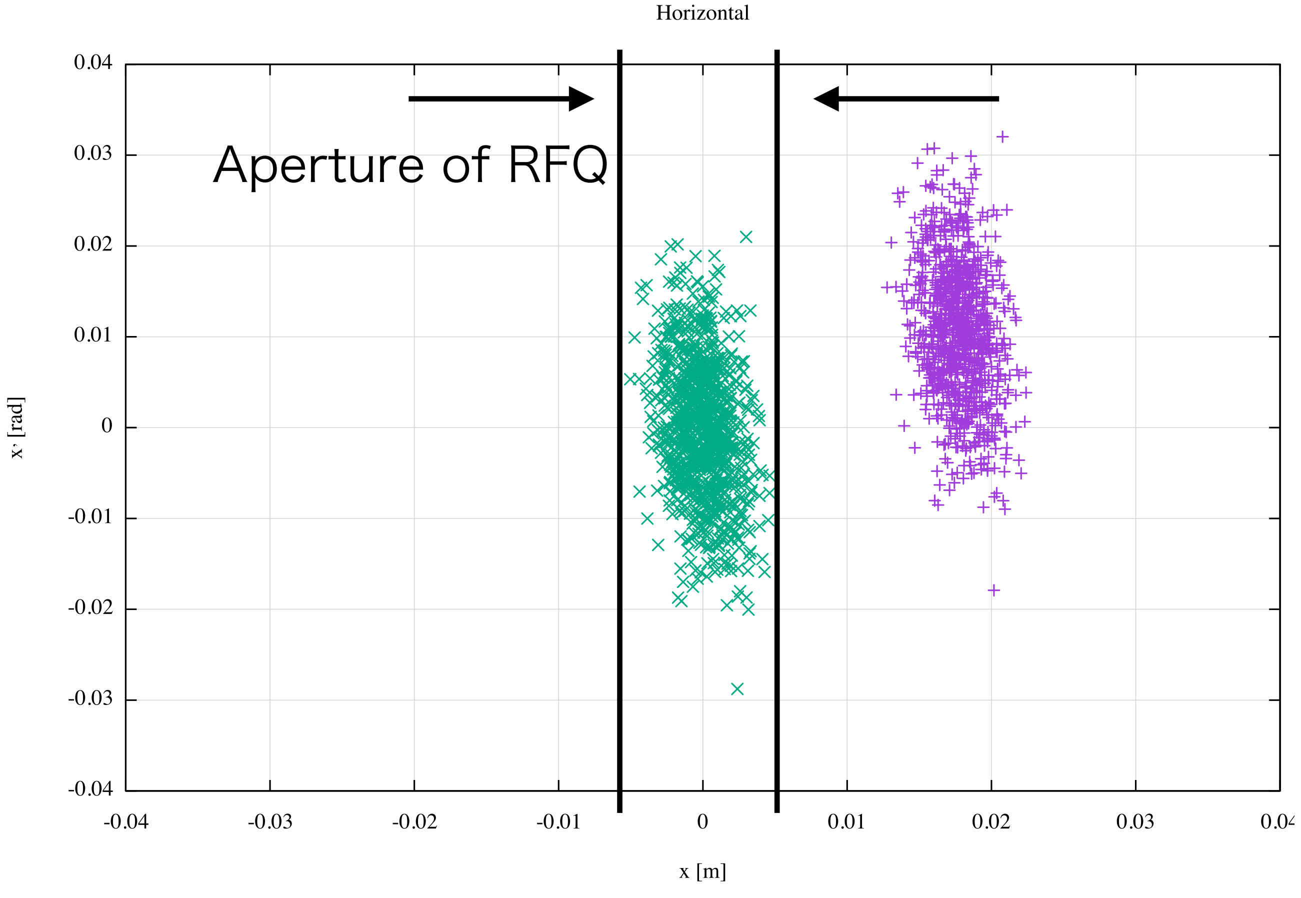
Development of delay line chopper ~Parameters of beam tracking~

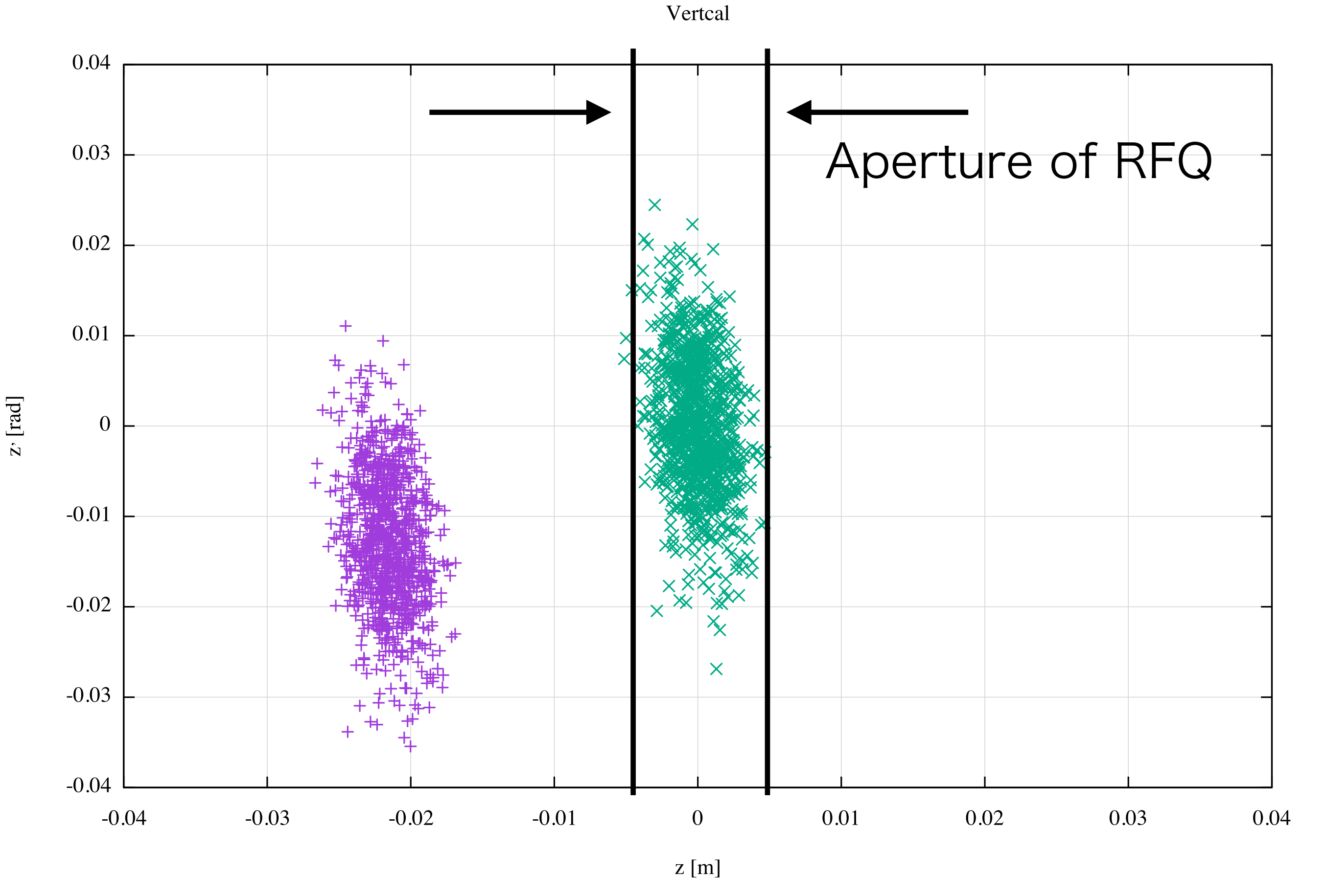
Particle / kinetic energy	H- / 30 [keV] (β=0.008)
Ion temperature of Ion source	5.0 [eV]
Max beam size at exit of Ion source	ϕ10 [mm]
Length of the chopper	500 [mm]
Voltage	100 [V] / 15 [mm]Gap
Magnetic field of solenoid (Ion source side)	1101 [Gauss] g:2.2
Magnetic field of solenoid (RFQ side)	1151 [Gauss] g:2.0
Aperture of RFQ	ϕ10 [mm]



Development of delay line chopper ~Results of beam tracking~

□Results of beam tracking at the entrance of the RFQ





Beam can be separated
at the entrance of the RFQ.

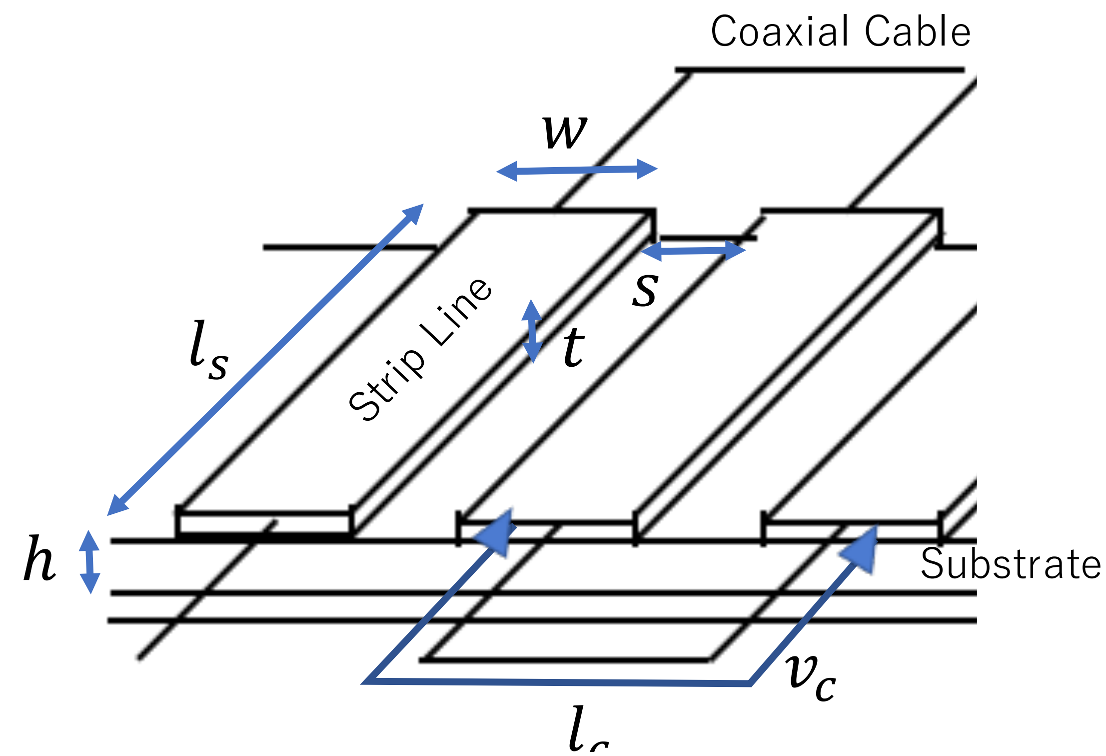
Development of delay line chopper ~Design scheme~

□Size of microstripline is related to the characteristic impedance.

$$Z = 2Z_0\left(1 - 0.48e^{-\frac{0.96s}{h}}\right)$$

$$Z_0 = \frac{60}{\sqrt{0.475\varepsilon_r + 0.067}}\ln\left(\frac{4h}{0.67(0.8w + t)}\right)$$

Characteristic impedance of Single Micro Strip Line



□Length of microstripline and coaxial cable depend on beam energy

$$\frac{l_s}{v_s} + \frac{l_c}{v_c} = \frac{w + s}{\beta c}$$

$v_s = \frac{c}{\sqrt{\varepsilon_{eff}}}$ **:Velocity in microstripline**

v_c **:Velocity in coaxial cable**

β **:Lorentz factor**

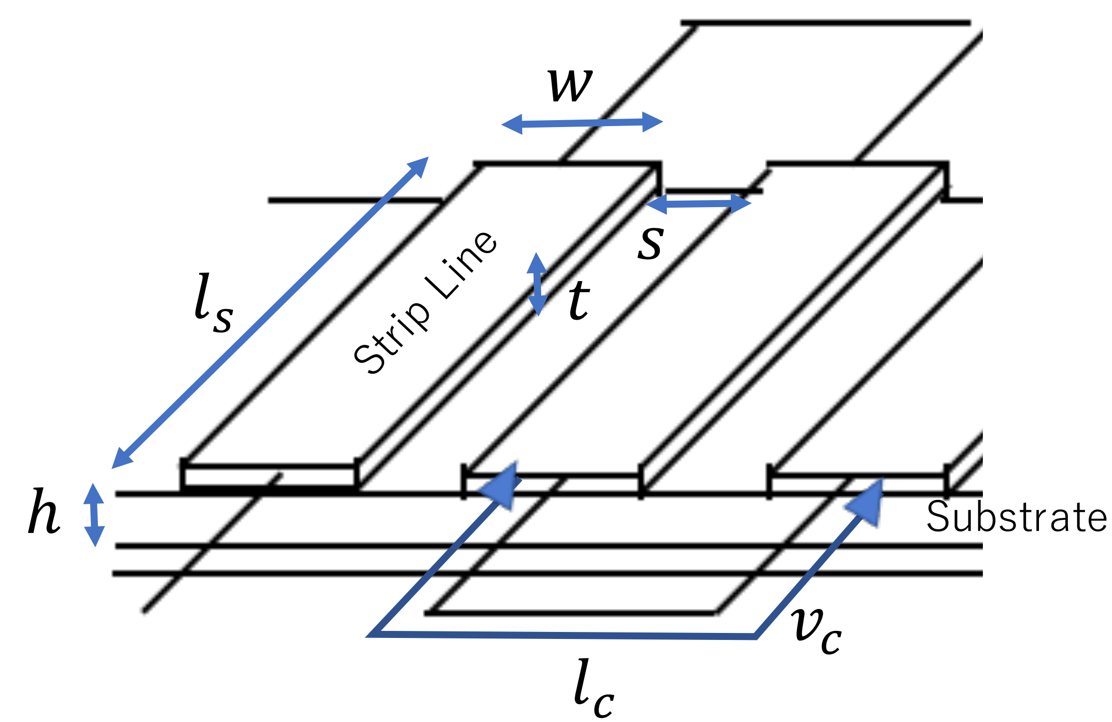
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\frac{h}{w}}}\right)$$ **:Effective dielectric constant**

○ Texas Instruments, "Application Note 905 Transmission Line RAPIDESIGNER Operation andApplications Guide"
○ E. O. Hammerstad, "Equations for microstrip circuitdesign," Proc. 5th Euro. Microw. Conf., 1975, pp.268–272

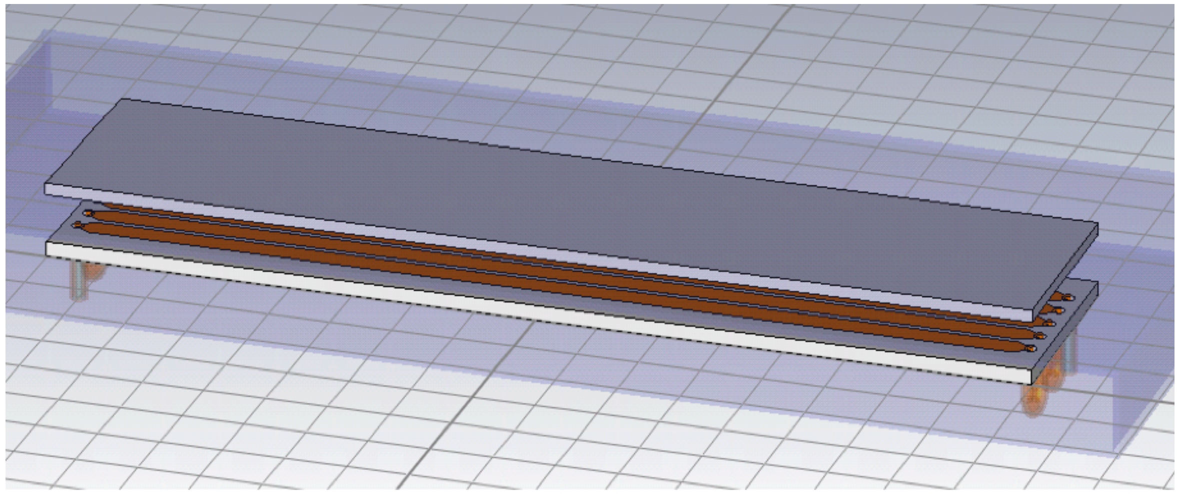
Development of delay line chopper ~Design~

◯Design parameters of delay line chopper

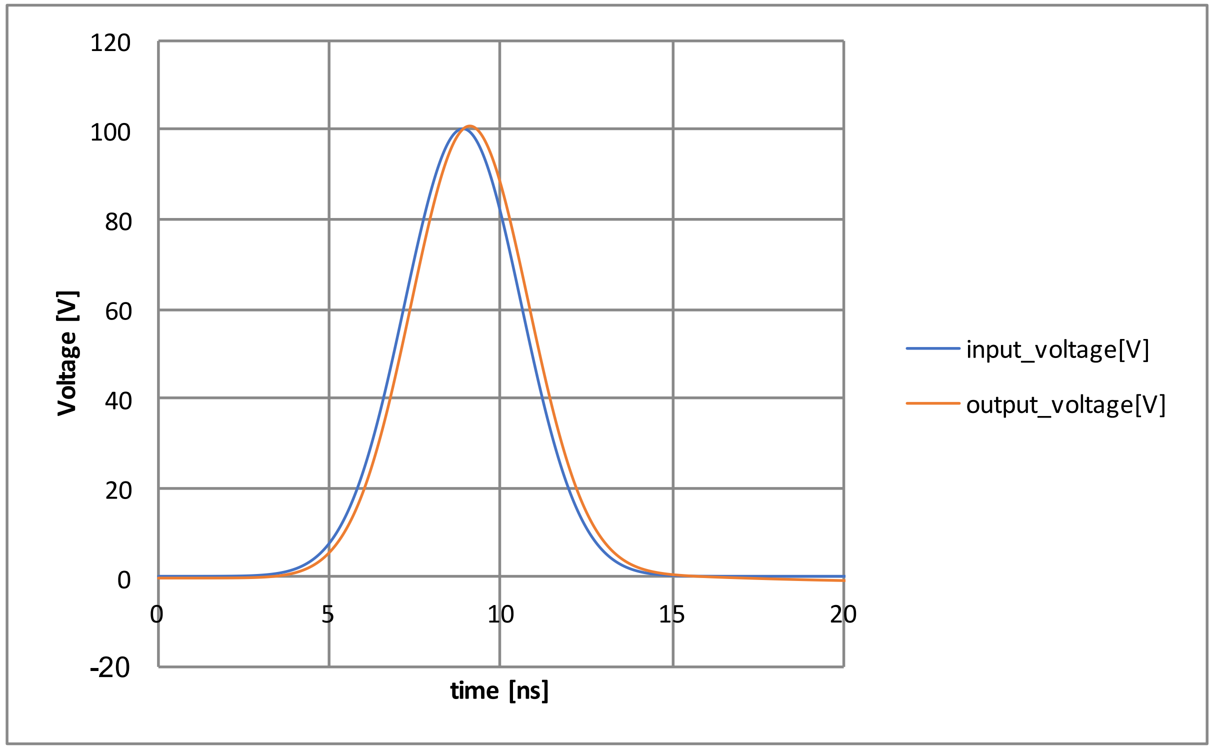
εr (substrate : alumina ceramic)	9.0
w	8.0 [mm]
s	2.0 [mm]
h	5.0 [mm]
t	1.0 [μm]
l_s	30.0 [cm]
l_c	33.0 [cm]
Length of chopper (Beam direction)	50.0 [cm]
Full gap of chopper	15.0 [mm]
Number of microstripline	50
Characteristic impedance of Microstripline	51[Ω]



◯Model of 3D calculation



◯Results of 3D calculation

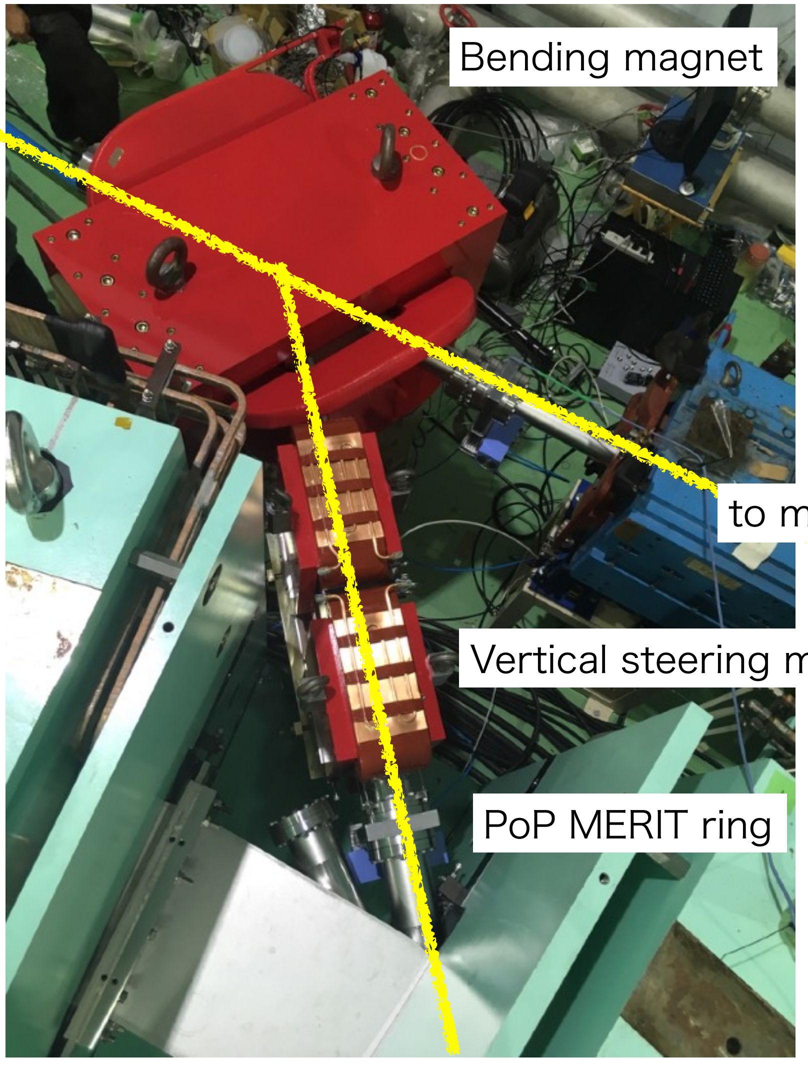


Current Status
~Injection~

□Completion

・Construction work of new beam line
(Bending magnet and Vertical steering magnet)

・Vacuum test (10^-5[Pa])



□Future

・Beam injection to PoP MERIT ring
at the end of September

Current Status
~PoP MERIT ring~

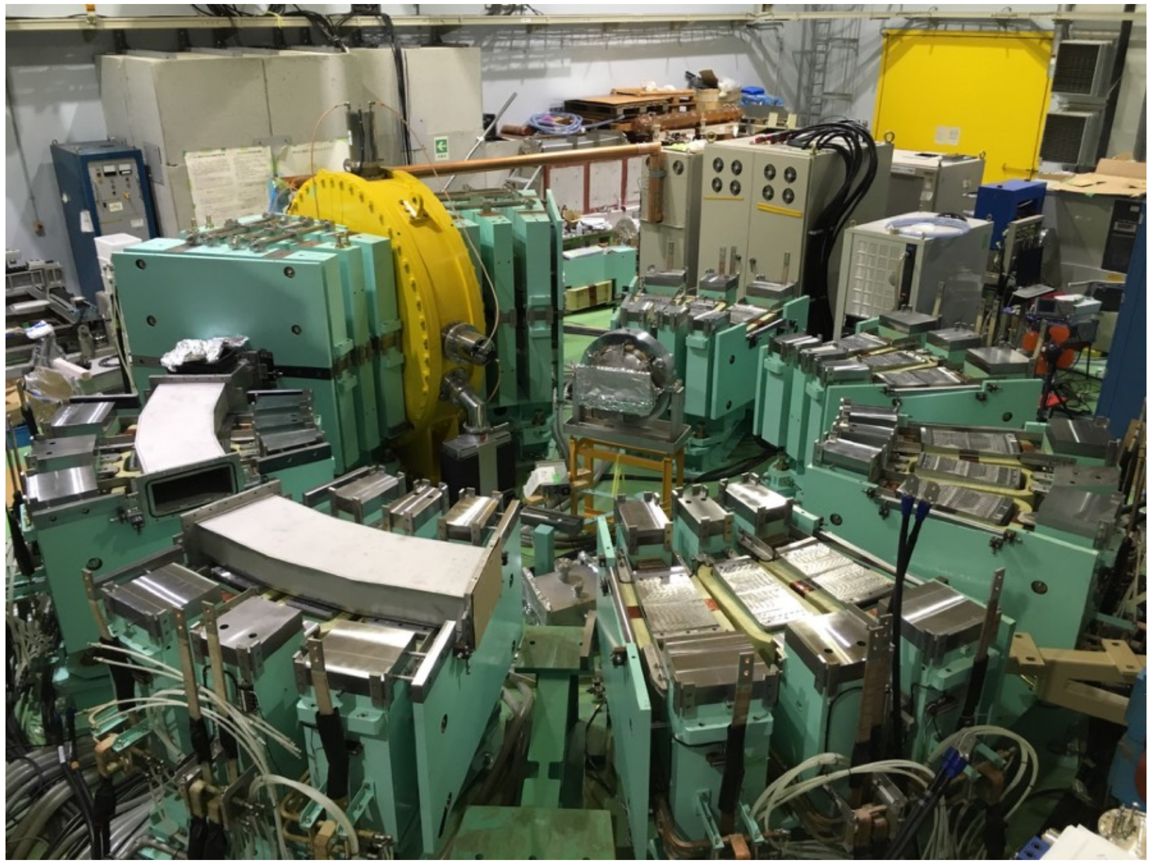
□Completion

・Construction work of PoP MERIT ring

・Vacuum test (10^-5[Pa])

・Excitation test at operation condition

・RF power test
(220 [kV] at 18.0952 [MHz])



□Future

・Beam injection to PoP MERIT ring
at the end of September

Summery

□Purpose

Proof of principle of MERIT Scheme

□Evaluation

○Modification and tuning of field index k for Fixed RF acceleration

○Tune variation and acceptance for storage

○Adjustment of injection beam line

○Development of delay line chopper

□Current Status

○Construction work is almost all finished.

○Preparing to beam injection to pop MERIT ring.

□Future plan

○Beam injection to PoP MERIT ring at the end of September

○Beam circulation test (Charged Stripping Foil etc…)

Thank you for your attention