Measurement of betatron tunes in KURRI FFAG Main ring

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Outline

Purpose

Introduction of FFAG at KURRI

Experiment

Result

Summary

Future

Purpose

Beam loss exists at main ring

Beam loss at main ring ➡ Longitudinal instability？

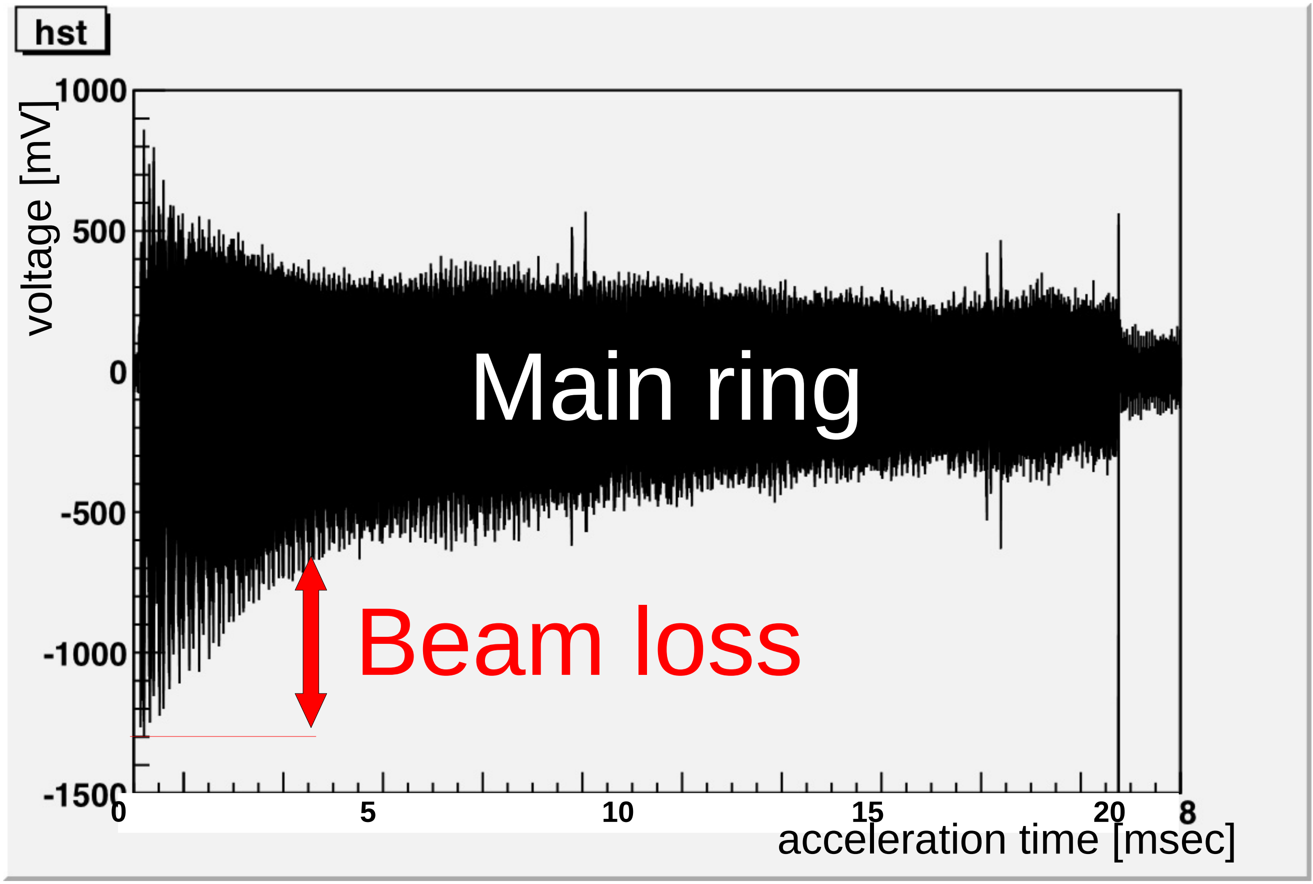
⬇

Transverse instability？

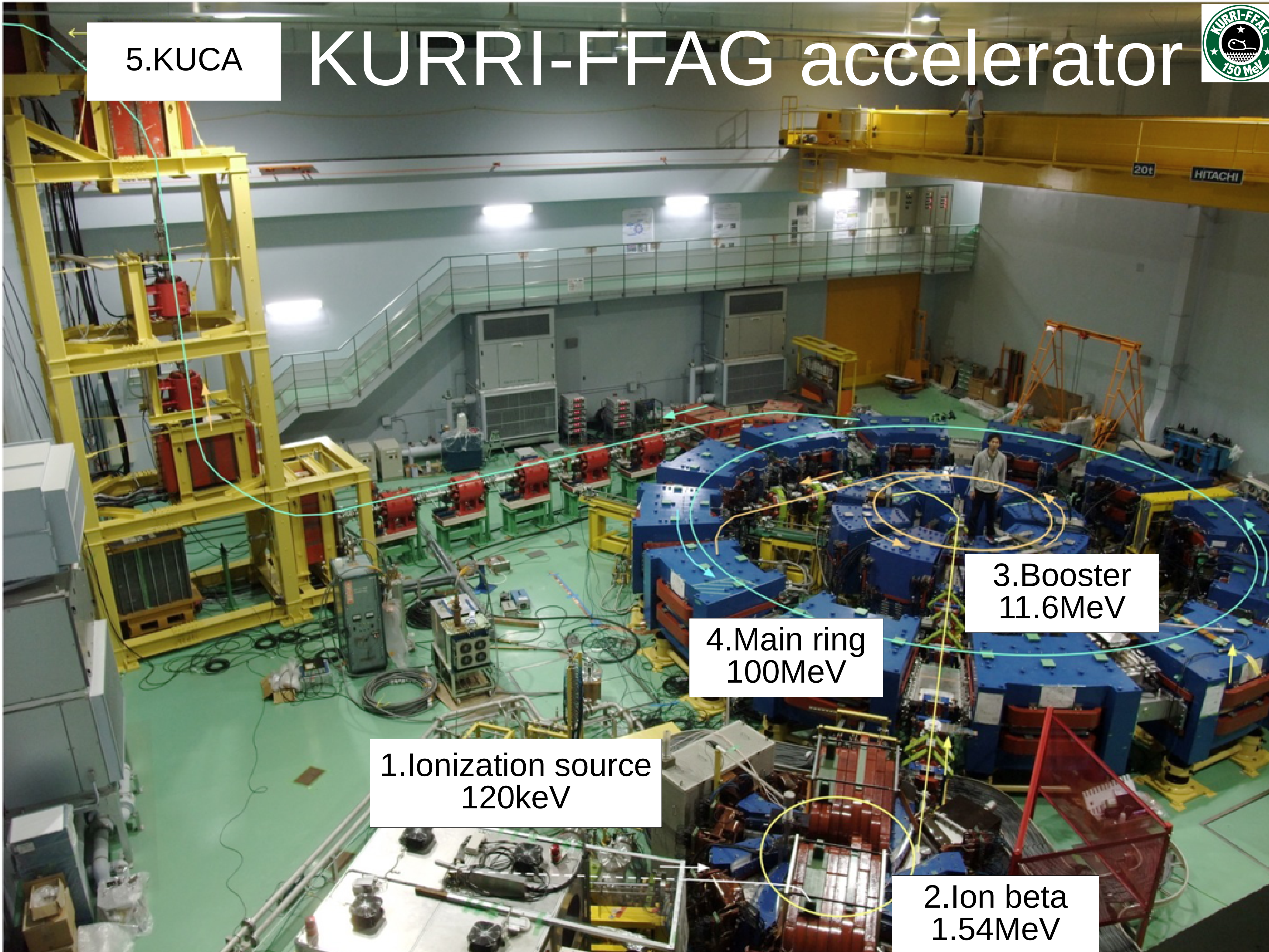
⬇

Measurement of betatron tunes

at Main ring



KURRI-FFAG accelerator



Experimental set up

Main ring

Beam monitor

Amplif er

Signal

Spectrum analyzer (FFT)

Horizontal

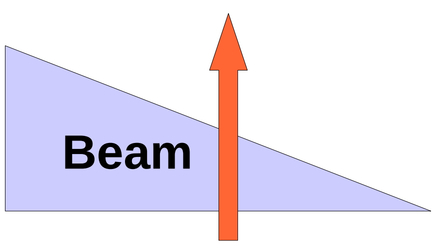
Horizontal perturbator

Being induced betatron horizontal oscillation.

The perturbation component is mixed into the RF pattern for cavity.

Triangular board beam monitor

Beam position detection



Triangular board beam monitor

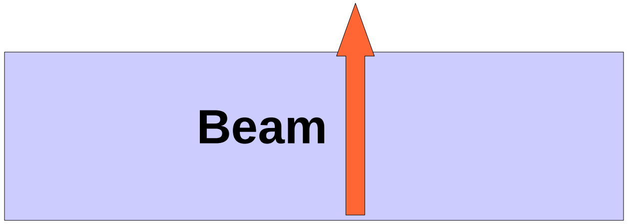
Vertical

Vertical perturbator

Being induced betatron oscillation vertical.
Voltage is applied to the electrodes.

Bunch monitor

beam position detection

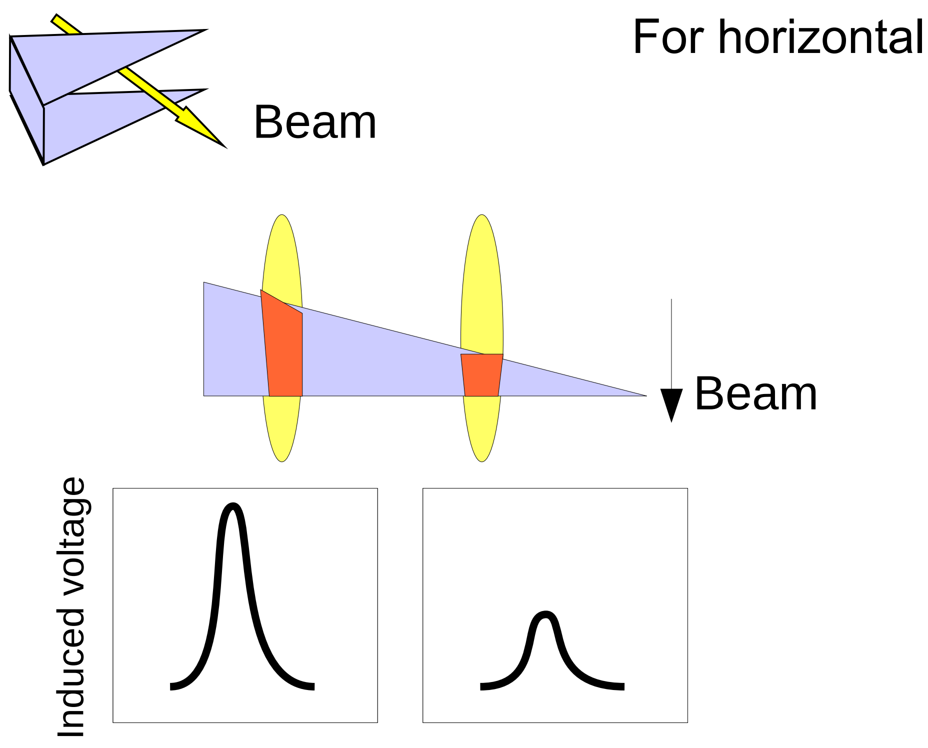


Bunch monitor

Structure of the beam position monitor

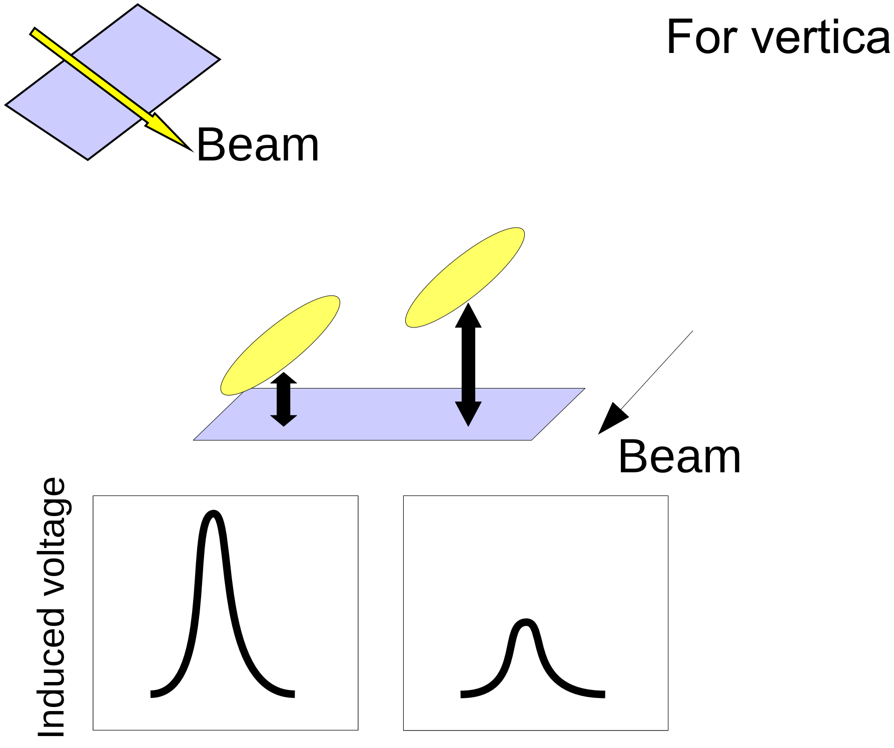
The electrostatic picking up monitors are set up in the vacuum chamber.

Triangular board beam monitor



Deviation of horizontal beam position
= Difference of induced voltage

Bunch monitor



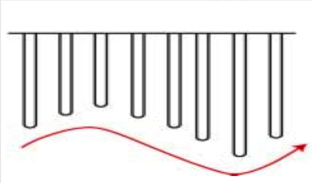
Deviation of vertical beam position
= Difference of induced voltage

We can know the beam position according to the induced voltage

Measurement of betatron oscillation

The betatron oscillation around the close orbit is observed as an amplitude modulation of the output signals.

$$V = A(1+\Delta A)\cos(2\pi f_{rev} t)$$
$$\Delta A = A_{side}\cos(2\pi f_{side} t + \theta)$$



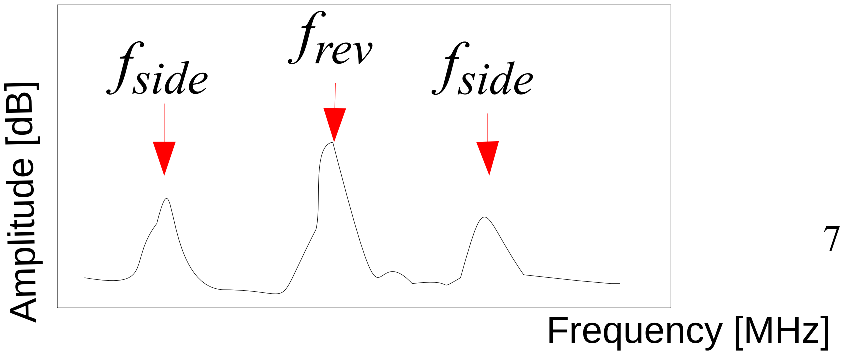
$$V = A\cos(2\pi f_{rev} t) + \frac{A_{side}}{2}\cos\{(2\pi f_{rev} + 2\pi f_{side})t + \theta\} + \frac{A_{side}}{2}\cos\{(2\pi f_{rev} - 2\pi f_{side})t - \theta\}$$

Fourier transform

Revolution frequency (f_{rev}) and sideband (f_{side}) is observed.

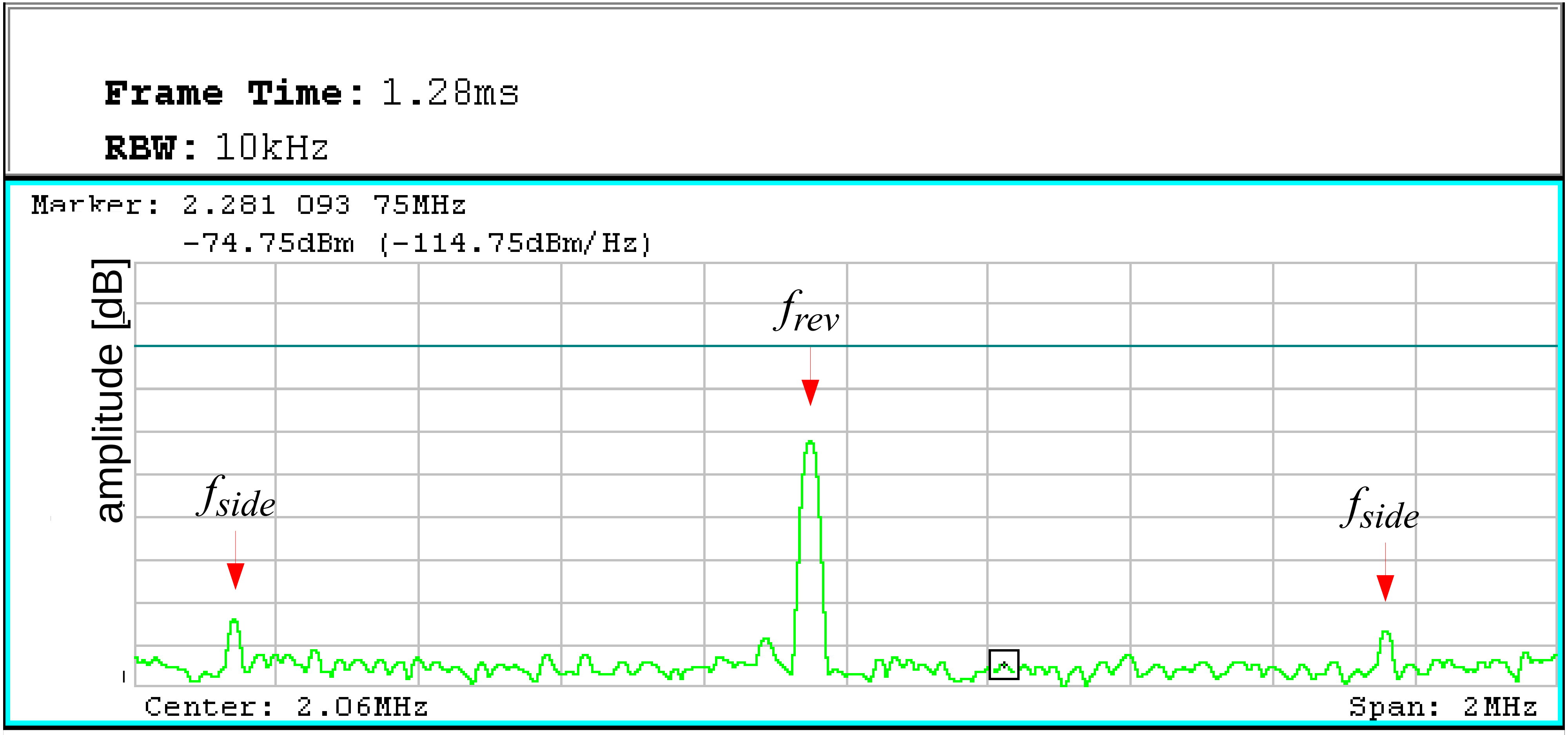
Fraction c of betatron tune is obtained from two peaks .

$$c = \frac{|f_{side} - m f_{rev}|}{f_{rev}}$$



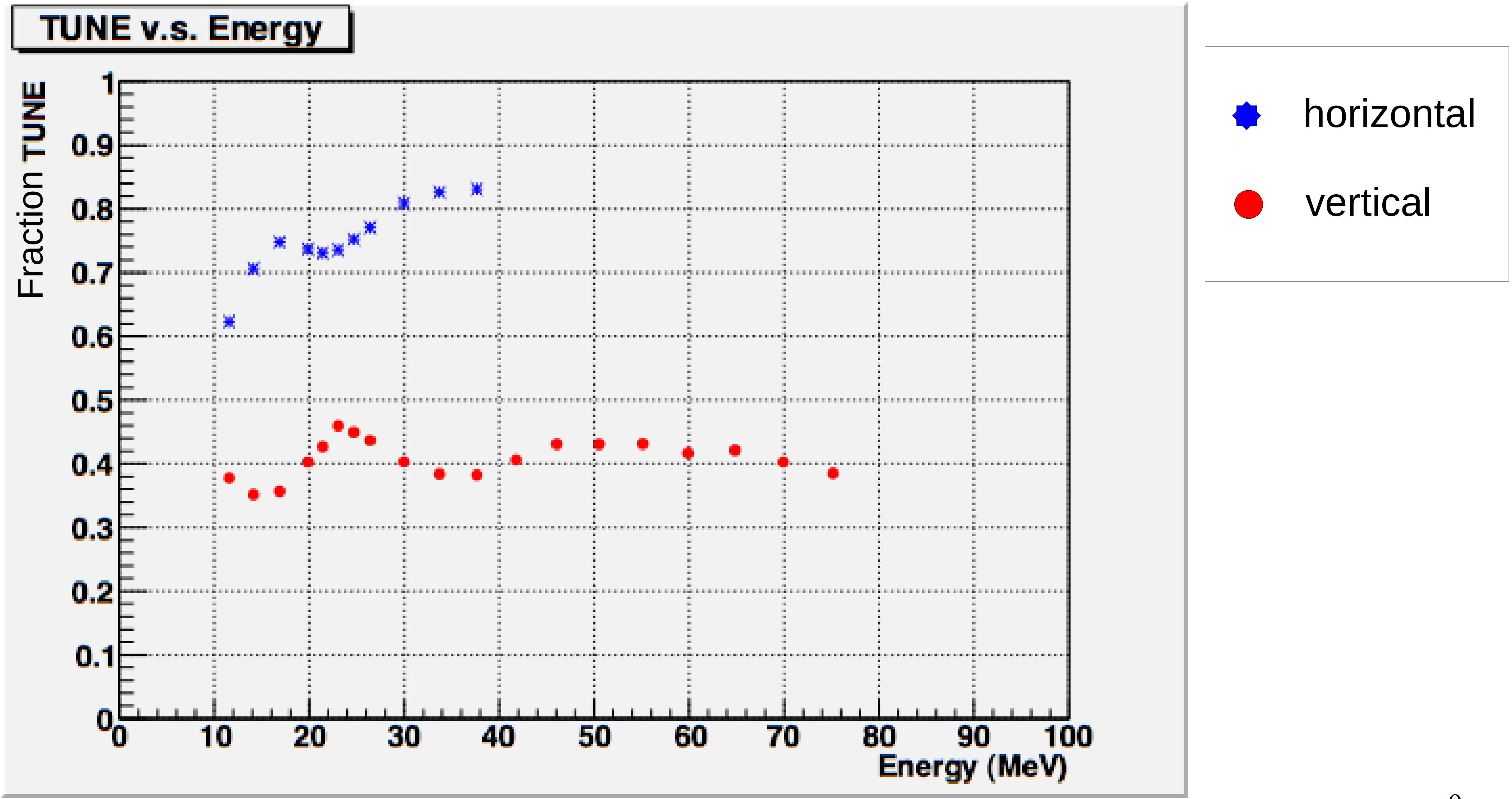
Result of a measurement

Output of spectrum analyzer

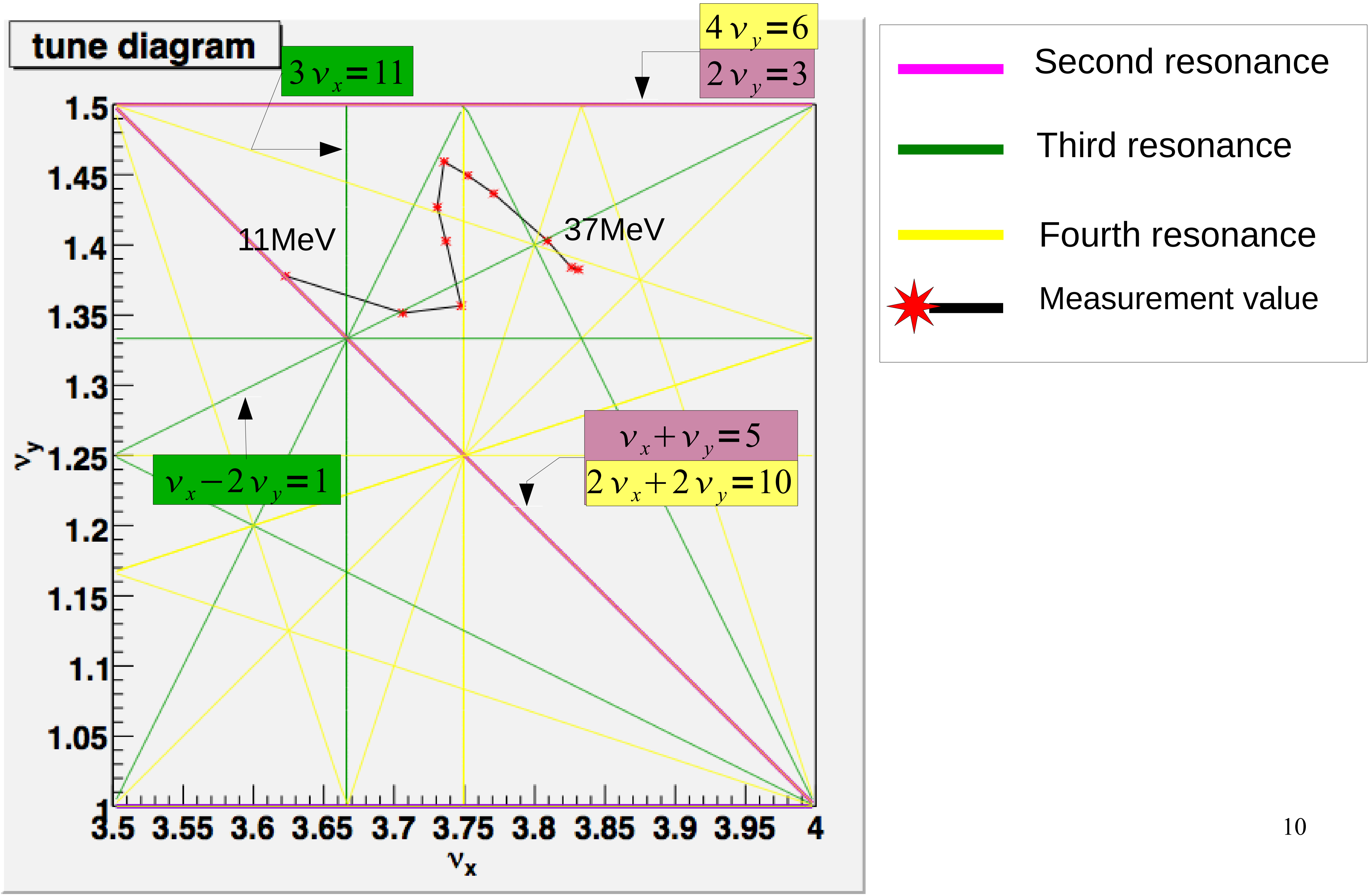


frequency [MHz]

Tune v.s. Energy



Tune diagram



Summary

Tune was able to be measured at main ring

The measuring method of betatron tunes was able to be confirmed

Future

Further measurement of vertical and horizontal tunes

Optimization of betatron tunes

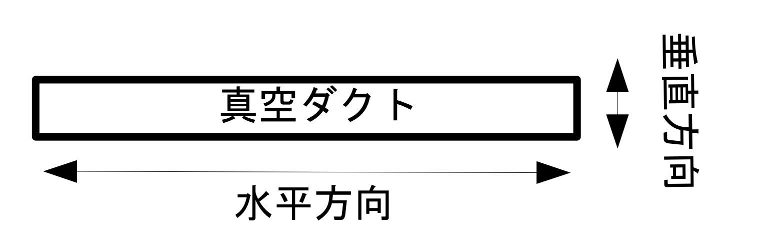
Modification of magnetic pole tip
Change the F/D ratio

Suppress the beam loss through the accelerating process

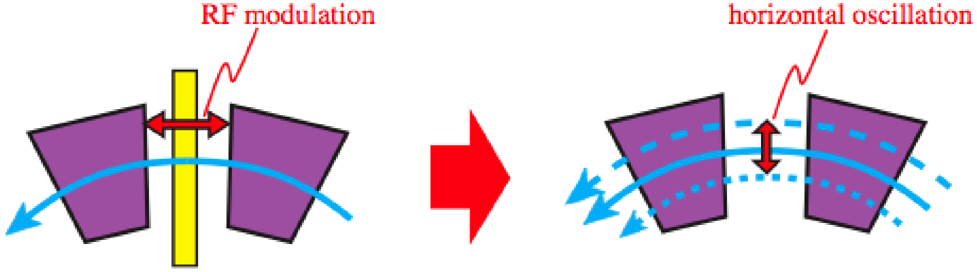
付録

ベータトロン振動の誘起方法

真空ダクトの構造上ベータトロン振動の誘起方法は水平方向と垂直方向で異なる



加速空洞使用（水平方向）

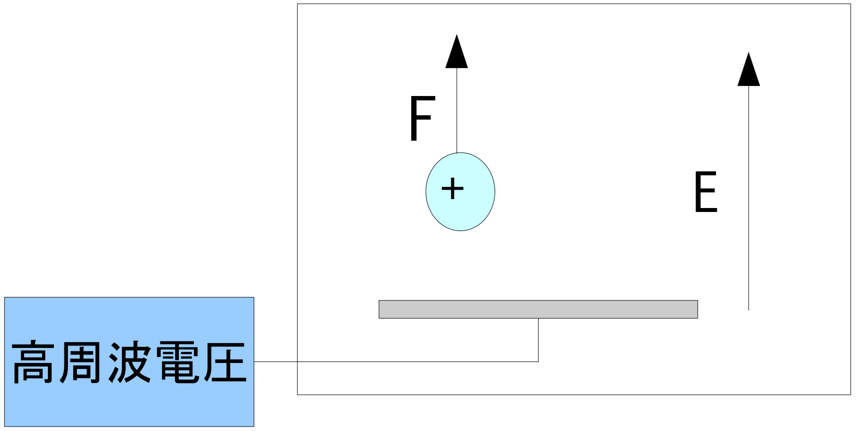


中心軌道の粒子の運動量が変化

↓

軌道半径が変化する

平板電極使用（垂直方向）



高周波電場を発生させる

↓

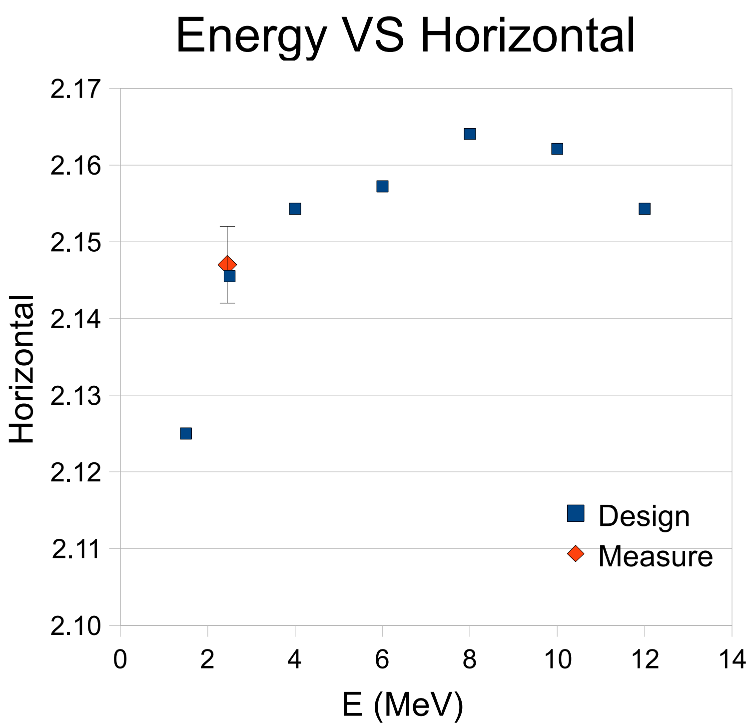
ビームに垂直方向の外力を与える

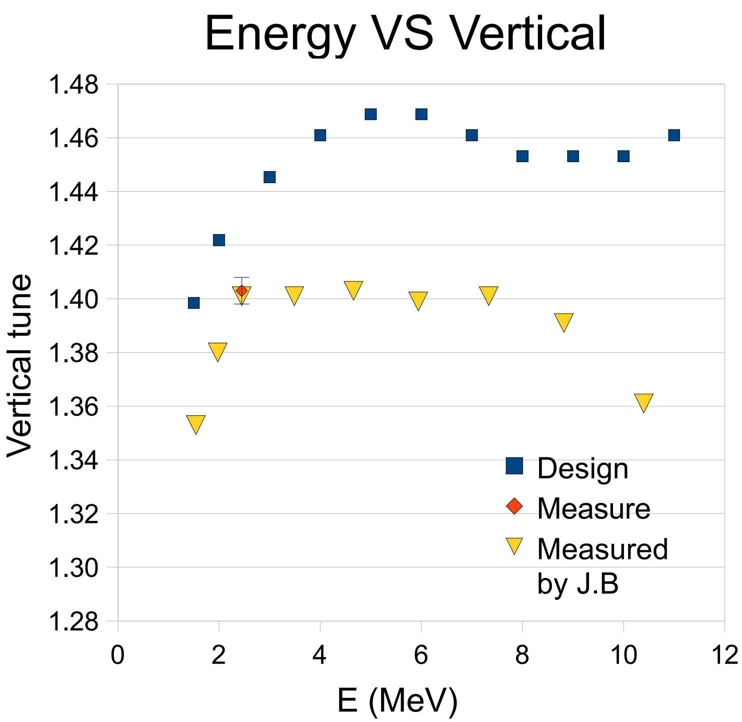
結果ベータトロン振動を誘起できる

設計値との比較

加速時間・エネルギー・周回周波数の表

accelerate time (s)	0	0.5	1	2	3	4	5	6	7	8
E (MeV)	1.5400	1.9740	2.4480	3.4887	4.6581	5.9416	7.3308	8.8200	10.4023	12.0742
F (Hz)	1.9594	2.1438	2.3125	2.6250	2.9063	3.1656				





Design値 :TOSCAでトラッキングシュミレーションしたもの

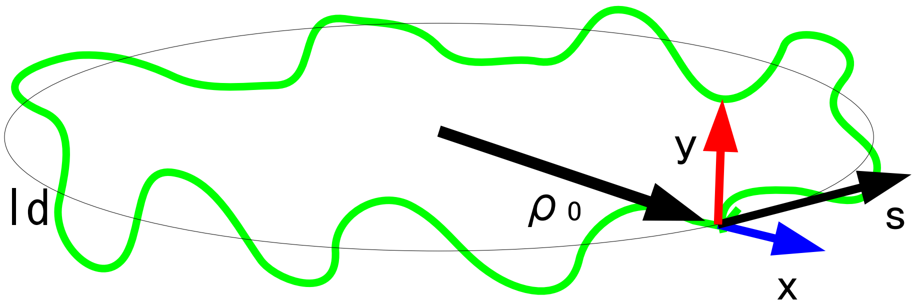
Measured by J.B: 過去に測定した結果
(http://hadron.kek.jp/FFAG/FFAG08J_HP/index.htm)

加速器駆動型未臨界原子炉（ADSR）

KUCA-FFAG結合実験のイメージ図

2009年3月4日
世界初の
加速器駆動型未臨界原子炉実験開始

Behavior of electron in accelerator



◆Motion equation in focusing magnetic field

$$\begin{cases} \dfrac{d^2 x}{ds^2} + \dfrac{(1-k(s))}{\rho^2} \cdot x = 0 & \text{Horizontal} \\ \dfrac{d^2 y}{ds^2} + \dfrac{k(s)}{\rho^2} \cdot y = 0 & \text{Vertical} \end{cases}$$

ρ_0 : Curvature radius

k : Inclination of magnetic field

$$k(s) \equiv -\frac{\rho(s)}{B_0} \frac{\partial B_y}{\partial \rho_0}$$

Betatron vibration

$$x(s) = \sqrt{\varepsilon \beta(s)} \cos(\psi(s) + \delta)$$

The vibration frequency of the small oscillation near a round is callec

$$2\pi\nu = \psi(c) = \oint \frac{ds}{\beta}$$

c : Ring surroundings length

ν : Betatoron tune

ν : An odd value is taken usually

Resonance and tune diagram

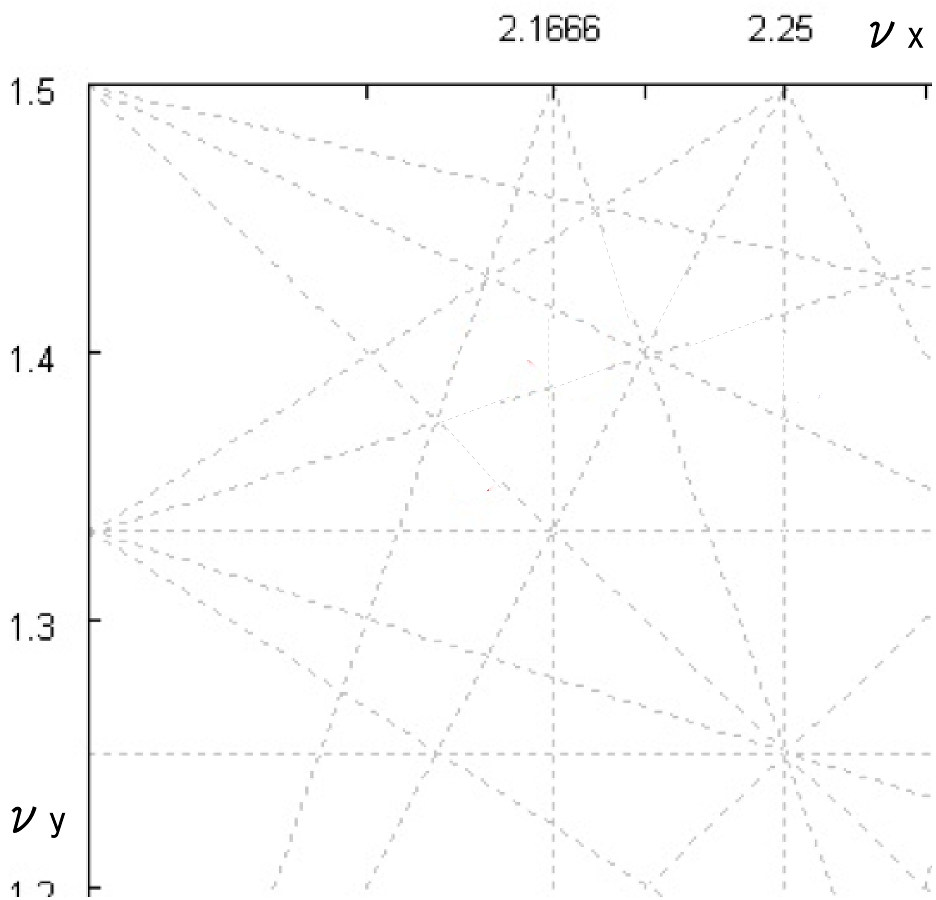
○Periodic power is received by the magnetic field error etc
○It is impossible to adjust the magnetic field error to zero

Resonance condition $m\nu_x + n\nu_y \simeq l$ m, n, l : Integer that is positive or negative

◆Tune diagram

ν_xとν_yを座標軸とする図の上に
共鳴の線（resonance line）を書いたもの

共鳴の線を避ける
運転上好ましいチューンを選ぶ



Integration time

Span [MHz]	Integration time [s]
10	80
5	160
2	320
1	640