Measurement of the beam response to quadrupole kick by using stripline pickup monitor at J-PARC Main Ring

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What is J-PARC?

J-PARC :Japan Proton Accelerator Research Complex

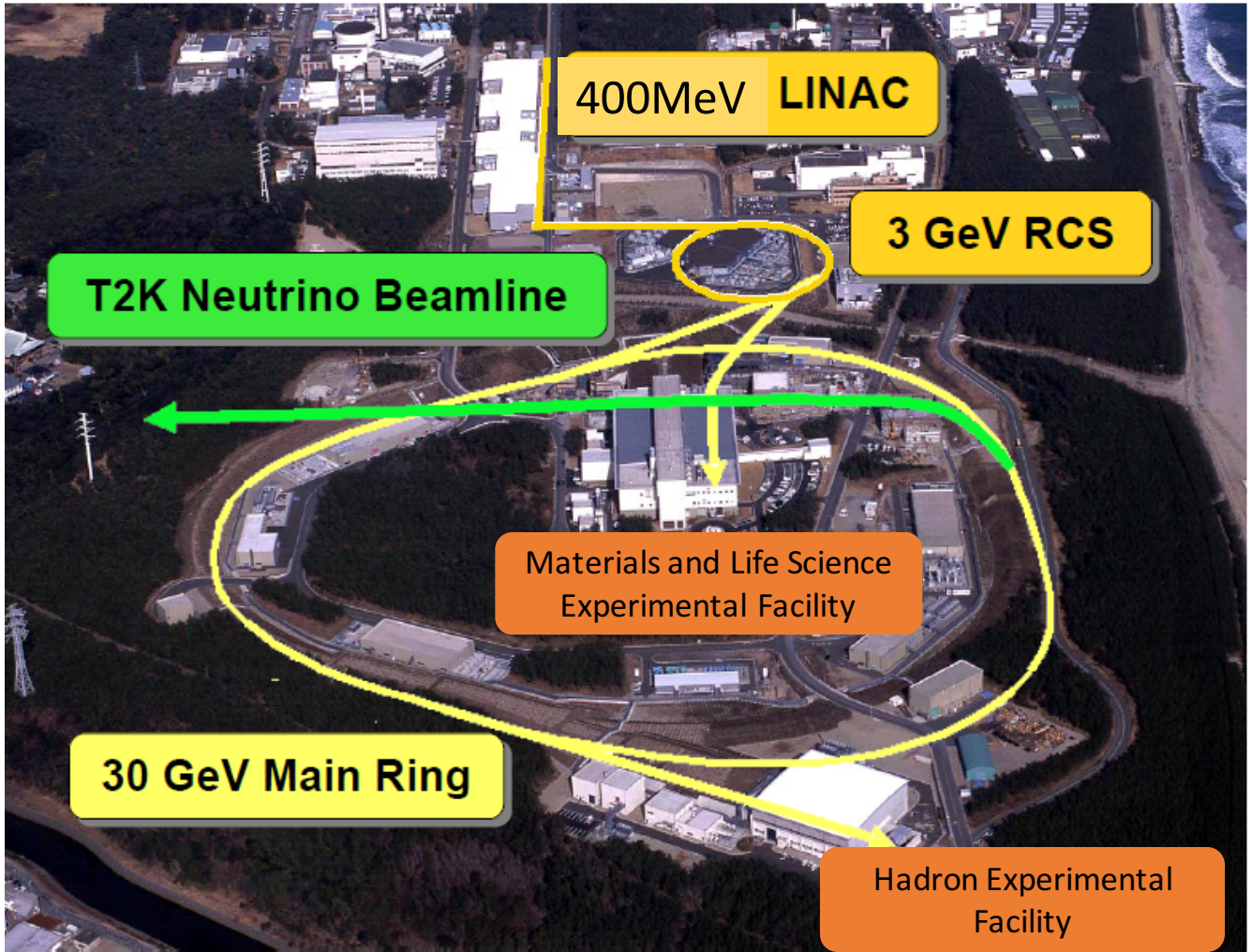
Consists of LINAC, RCS, MR

MR

- 30GeV proton synchrotron
- High intensity proton beam
- Achieved: 415kW, 12,Feb.,2016

----> Aiming : 750kW

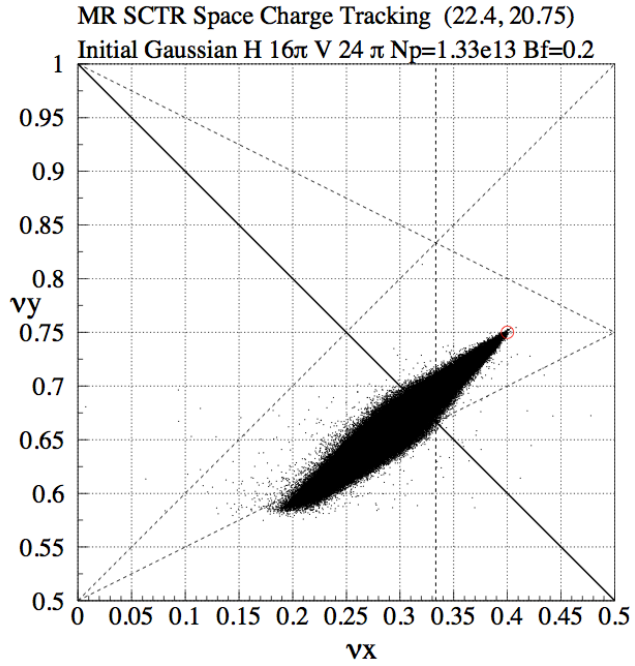
Repetition :2.48s →1.3s



Motivation and outline of this measurement

- J-PARC MR is a high intensity proton synchrotron. (415kW ,12,Feb.,2016)
- To make the beam loss smaller in MR, less than 0.1%, we are trying to measure the tune spread.
- The response to a normal quadrupole kicker was measured by using a four-electrode BPM.

・・・The amplitude of the quadrupole oscillation induced by the quadrupole kicker is mainly contributed by the oscillation of particular tune particles.



Why quardupole??

- Dipole kicker induce a dipole moment(average position) resonance.

$$x'' + K_x x = \mathrm{K_{sc}}(\mathrm{x} - \bar{x}) + \mathrm{f_{kick}}\delta(s - s_k)$$

$$\rightarrow \bar{x}'' + K_x \bar{x} = \mathrm{f_{kick}}\,\delta(s - s_k)$$

・・・Space charge effect cannot be detected.

$\mathrm{K_{sc}}$: Space charge force
K_x : External force
a,b : Envelop in x,y direction
s_k : Location of kicker

- Quadrupole kicker induce a quadrupole moment resonance.

$$x'' + K_x x = \frac{2\mathrm{K_{sc}}}{\mathrm{a(a+b)}}(\mathrm{x} - \bar{x}) + f_{kick}\, x\, \delta(s - s_k)$$

→Envelop eq. is $\ddot{a} + (K_x - f_{kick}\delta(s - s_k))a - \frac{2K_{sc}}{a+b} = \frac{\varepsilon_x^2}{a^3}$

（under the assumption of K-V distribution）

Quadrupole kicker

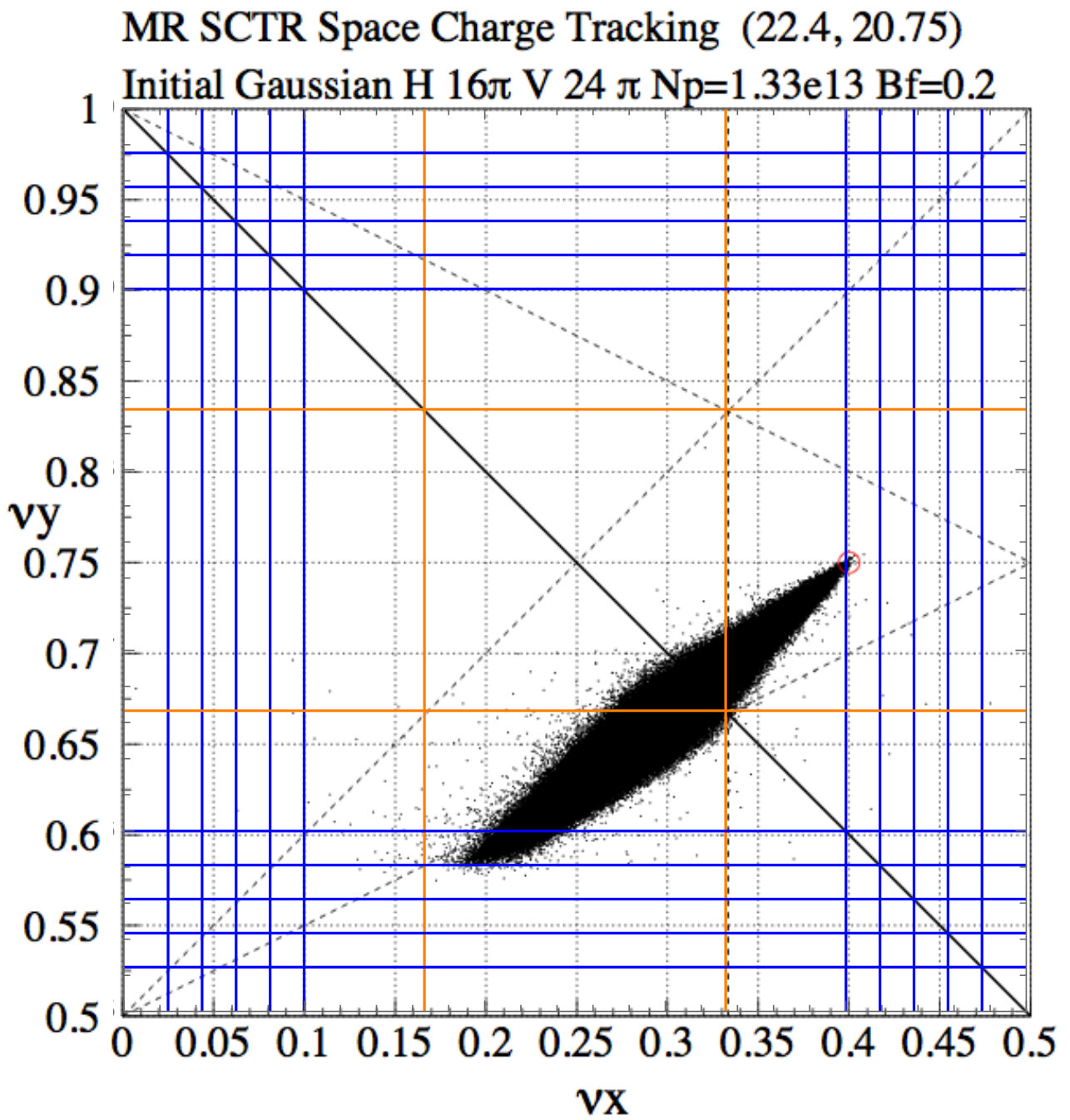
Monochromatic RF signal make normal quadrupole force.

The force induce the resonance line on tune diagram.

$$2\nu_x = n_x \pm f_{RF}/f_{rev}$$
$$2\nu_y = n_y \pm f_{RF}/f_{rev}$$

Particular tune particles will be oscillate larger.

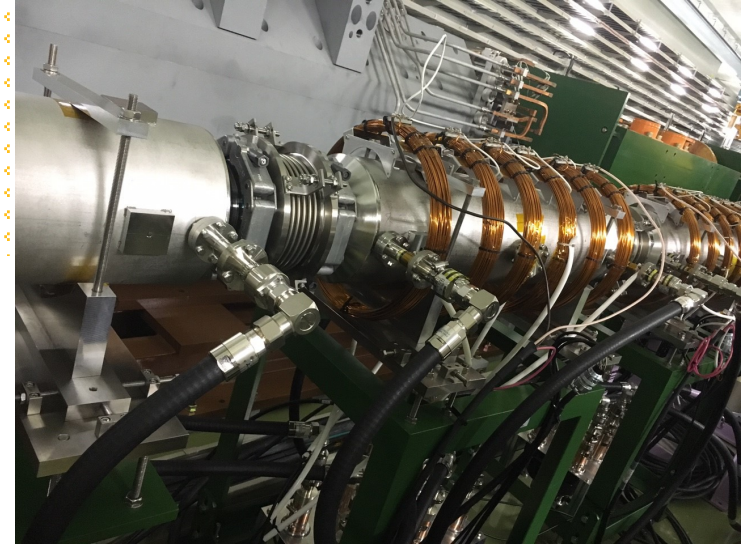
-> Quadrupole moment of the beam will be resonant on the RF kicker frequency.

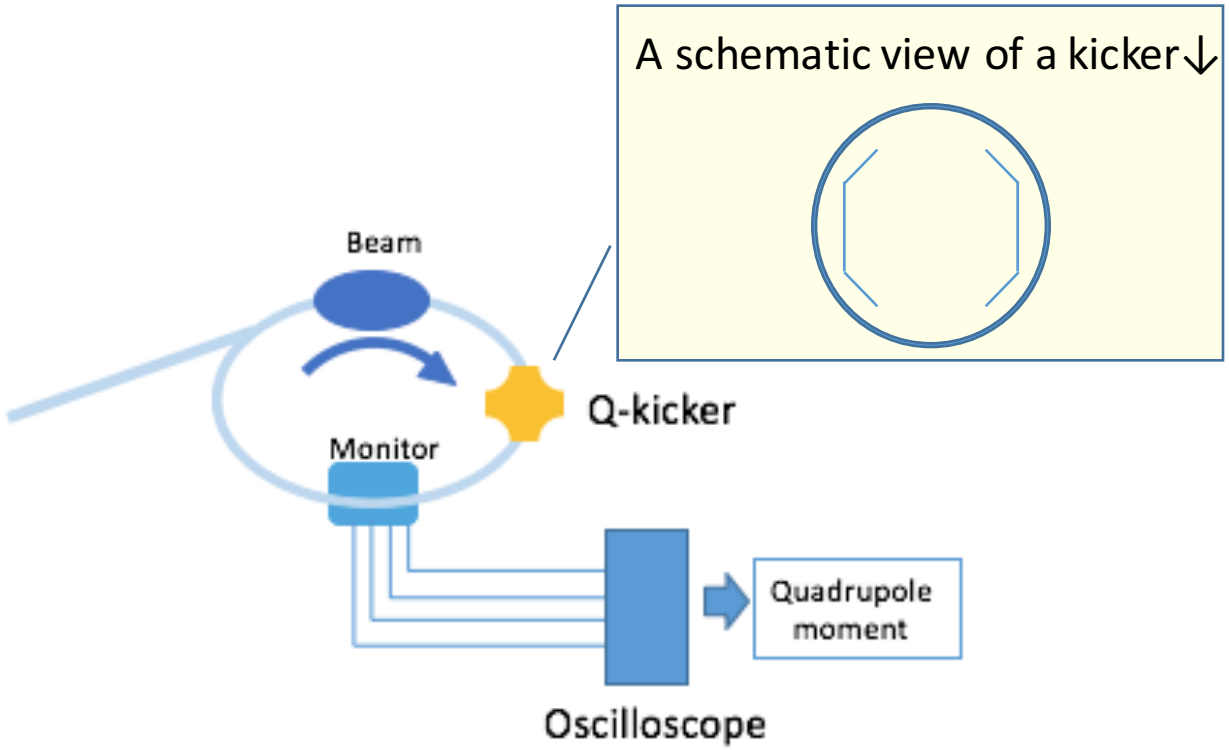


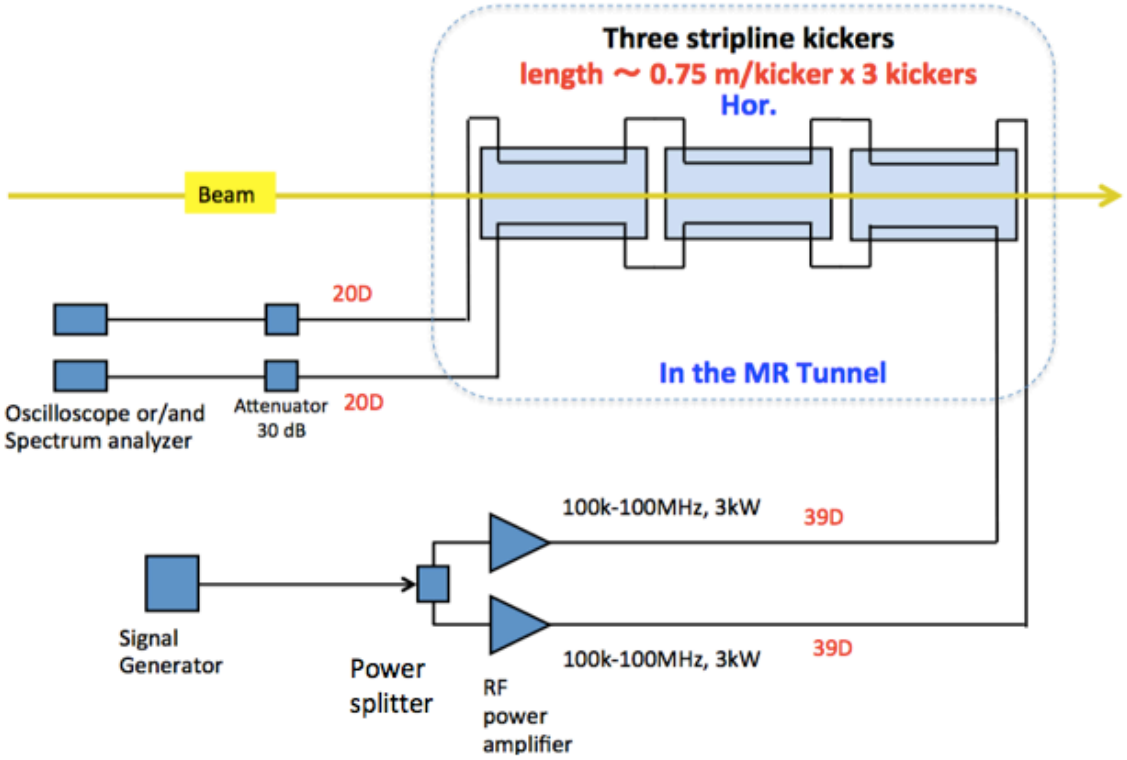
S. Igarashi, The Accelerator Technical Advisory Committee (ATAC) for the J-PARC Project, March 6 – 8, 2014.

Set up of the measurement

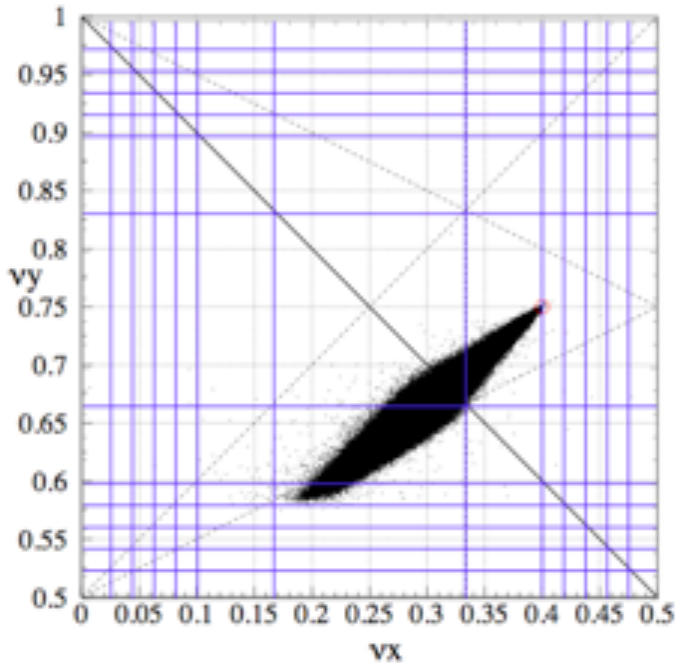
- Three stripline kickers equipped with two electrodes
- Four-electrode tapered coupler BPM
- Oscilloscope







Condition of measurement



- Kicker frequency:

247615 Hz, 222854 Hz, 215854 Hz, 208854 Hz, 201854 Hz,194854 Hz

- Kicker Power : 3kW × 2
- Kick angle : 102 μrad / m / turn (calculated),

$$\rightarrow \Delta\nu_x = 1.06\times10^{-4}, \Delta\nu_y = 1.87\times10^{-4}$$

- Number of particles [protons/bunch]:

$0.99(\pm0.01)\times10^{13}$,$1.28(\pm0.01)\times10^{13}$, $1.39\ (\pm0.02)\times10^{13}$

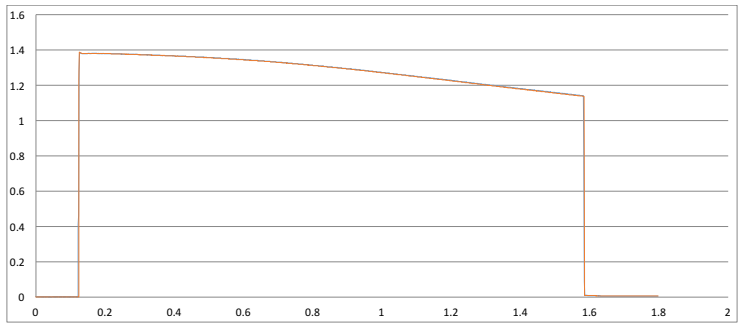
(-> loss by 0.02×10^{13} , 0.05×10^{13} , 0.08×10^{13} during the data taking)

- beam:

Horizontal tune	22.40
Vertical tune	20.75
revolution frequency	185743.5Hz

Beam intensity

[Protons]



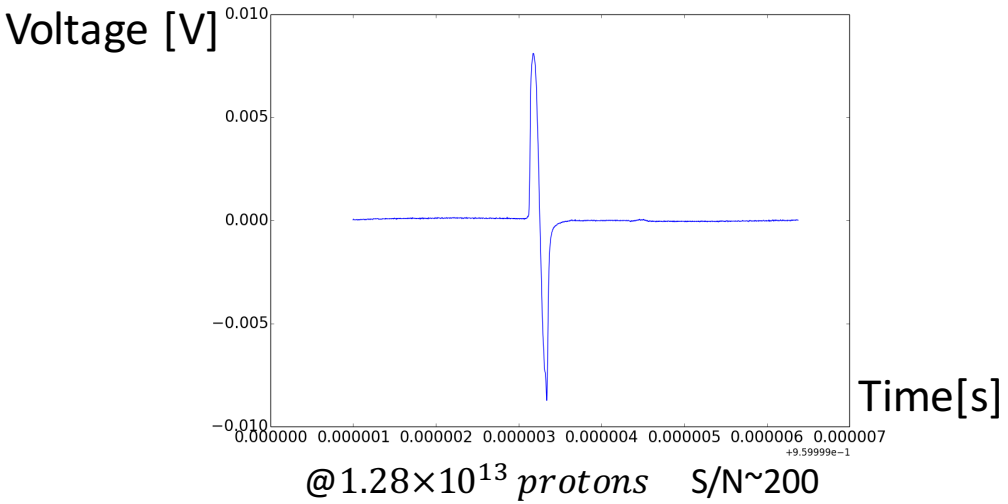
Time[s]

- BPM: $K_Q = 237.4\left[\frac{1}{m^2}\right]$,where $Q = K_Q\times(< x^2 > - < y^2 >)$
- measured three times in the same condition;

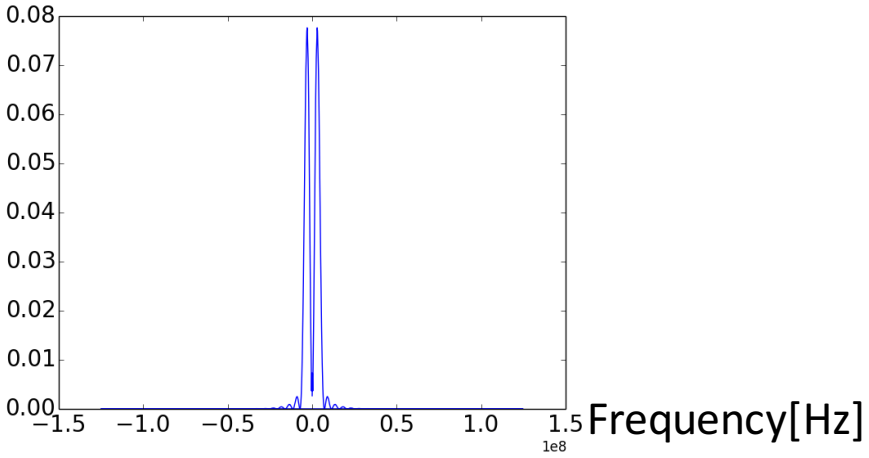
the same beam intensity and the same kicker RF frequency.

Data processing

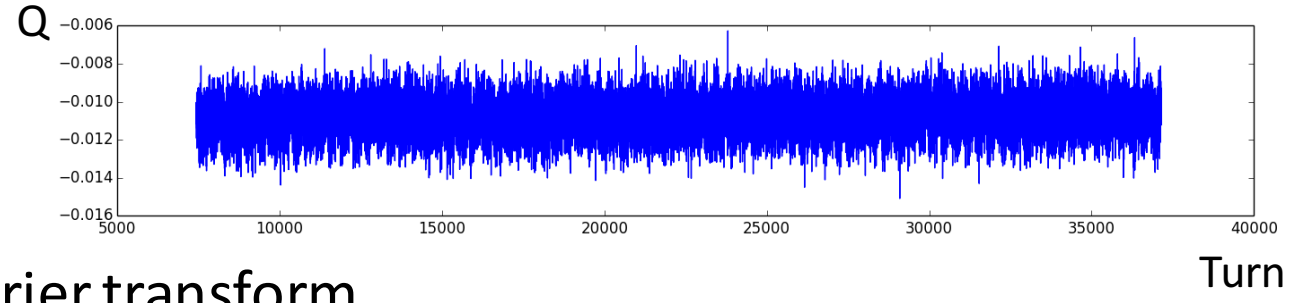
- Cut the data turn by turn -> Fourier transform



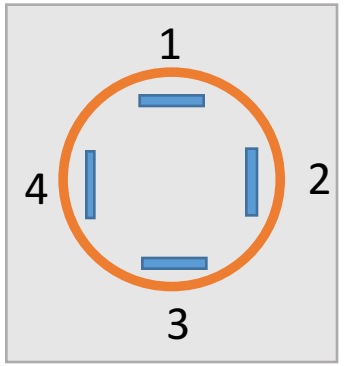
$@1.28\times10^{13}\ protons$ S/N~200



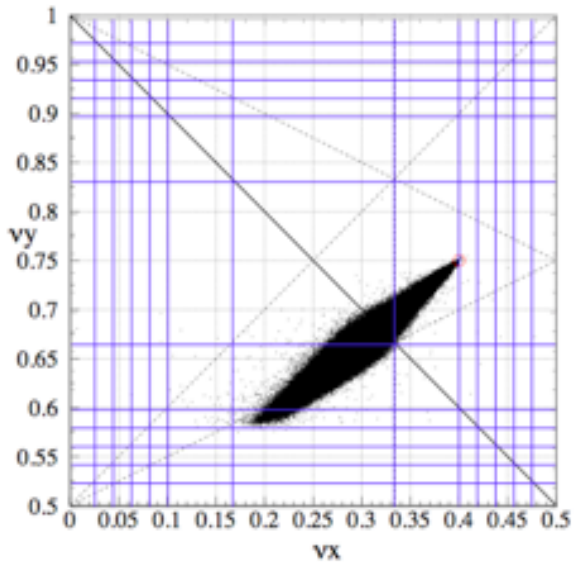
- Q is calculated by $\mathrm{Q} = (V_1 + V_3 - V_2 - V_4)/(V_1 + V_3 + V_2 + V_4)$.



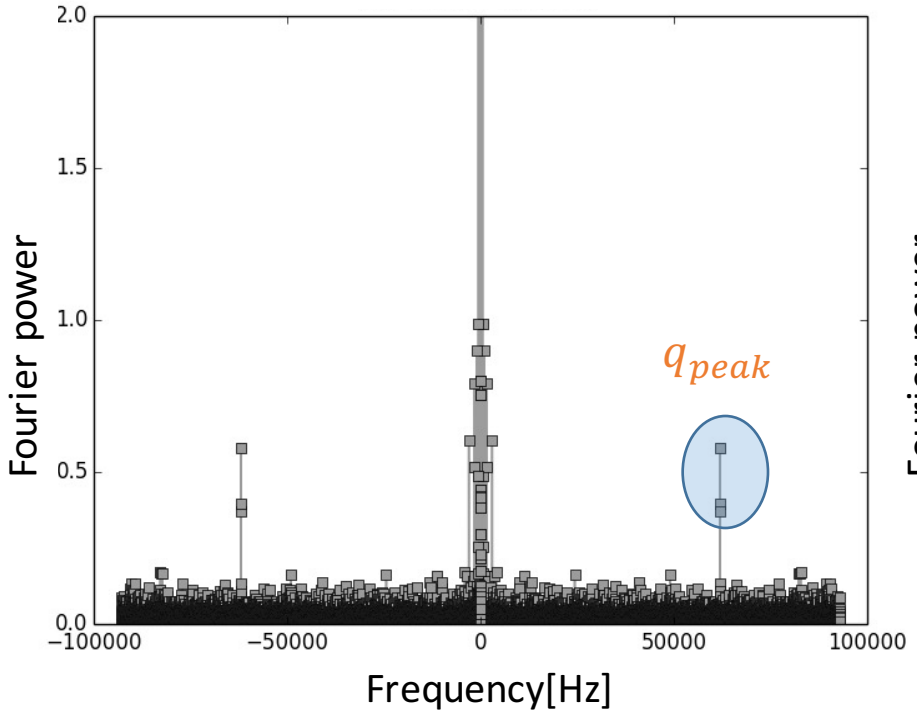
-> Fourier transform

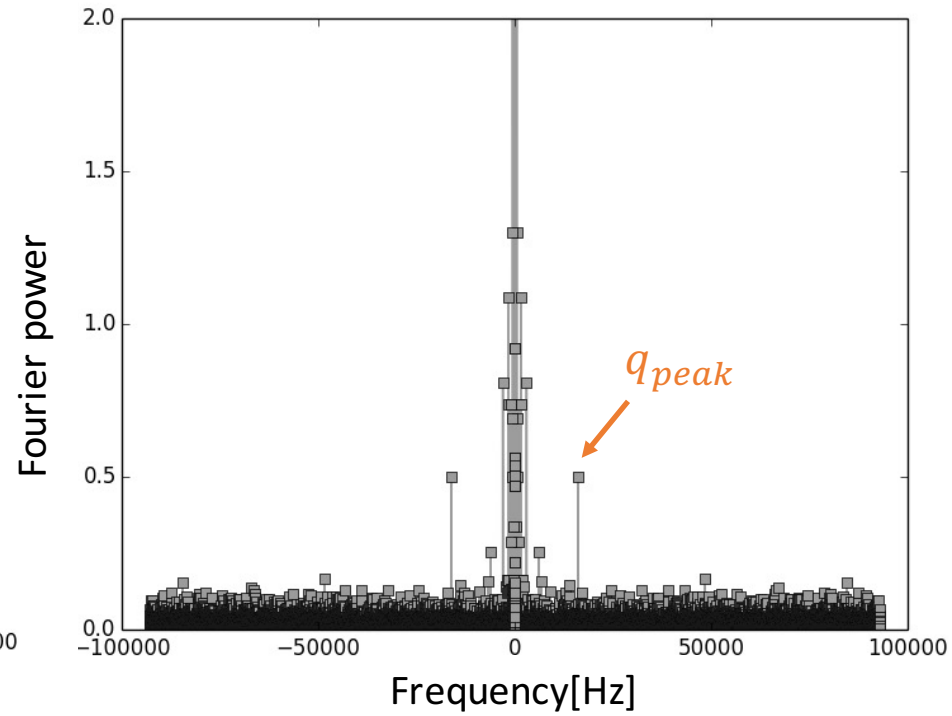


Result



Power spectrum of quadrupole moment.



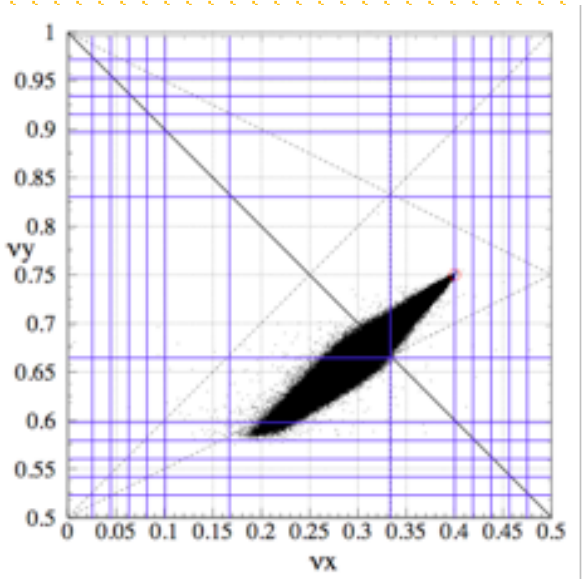


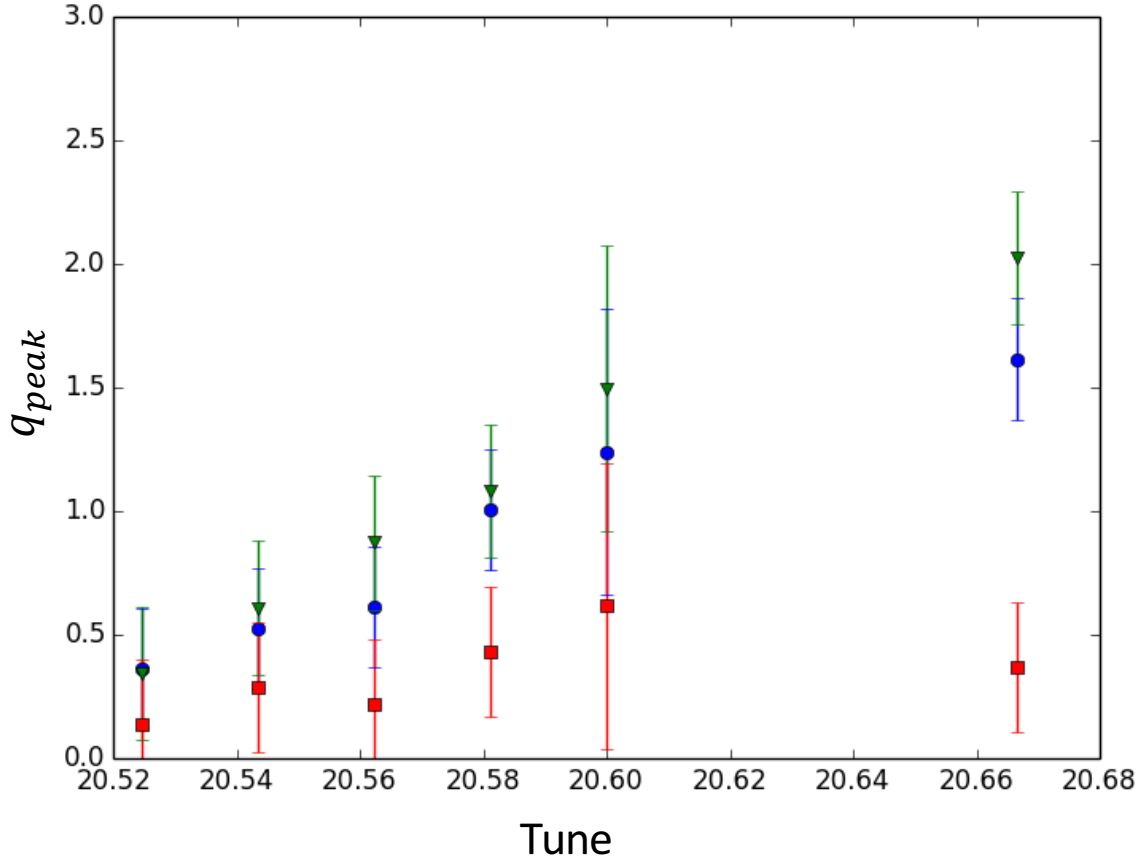
The observed peak indicate existing the resonance oscillation induced by the quadrupole kicker.

↑ The kicker RF frequency : 247615Hz
・・・The width of the peak is wide.
q_{peak} is sum of four Fourier power.

↑ The kicker RF frequency : 201854Hz
・・・The width of the peak is narrow.

Result





Green (triangle)	1.39 (±0.02) × 10^{13} [ppb]
Blue (circle)	1.28(±0.01) × 10^{13} [ppb]
Red (square)	0.99(±0.01) × 10^{13} [ppb]

f : the frequency of the kicker RF

→ ν : tune

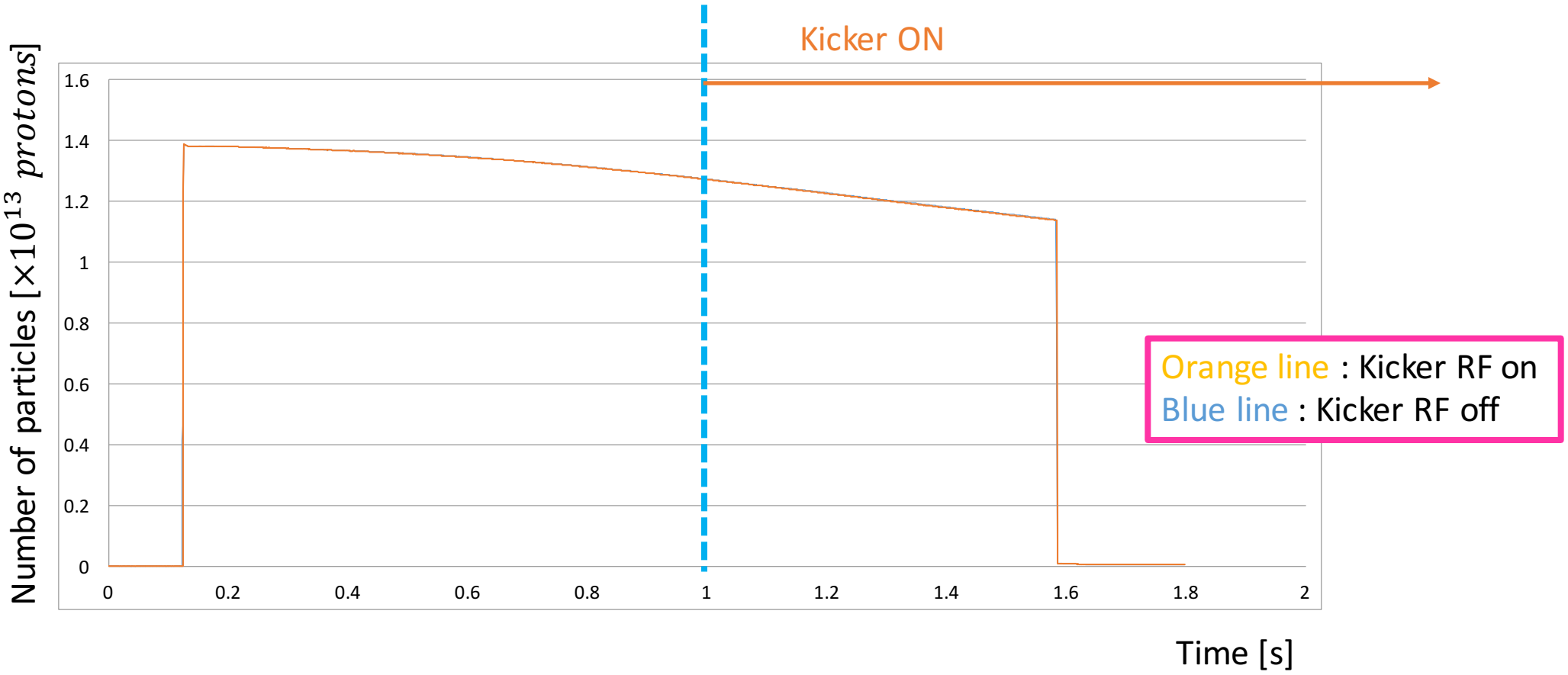
$$\left(\frac{f}{f_{rev}} - 1\right) \cdot \frac{1}{2} + 20.5 = \nu$$

q_{peak} depends on the kicker RF frequency.

q_{peak} depends on the number of particles.

-> Betatron tune spread may be changed.

Beam intensity



Compared the beam intensity between RF OFF & ON
→Not large difference
→The beam loss was not induced by Q-kicker.

Conclusion

- The quadrupole oscillation induced by the quadrupole kicker was measured.
- The resonance arose from the kicker was observed.
- The amplitude(q_{peak}) of the resonance oscillation depends on the kicker RF frequency. (the q_{peak} spectrum)
- The q_{peak} spectrum depends on the number of particles per bunch.

-> This may suggest the change of the betatron tune spread.

<u>Future prospects</u>

- Further experiments.
- Now calculating the amplitude of the quadrupole oscillation from Vlasov-Maxwell eq. including the external quadrupole RF kick.
- The simulation with frozen space charge : transfer matrix approach.