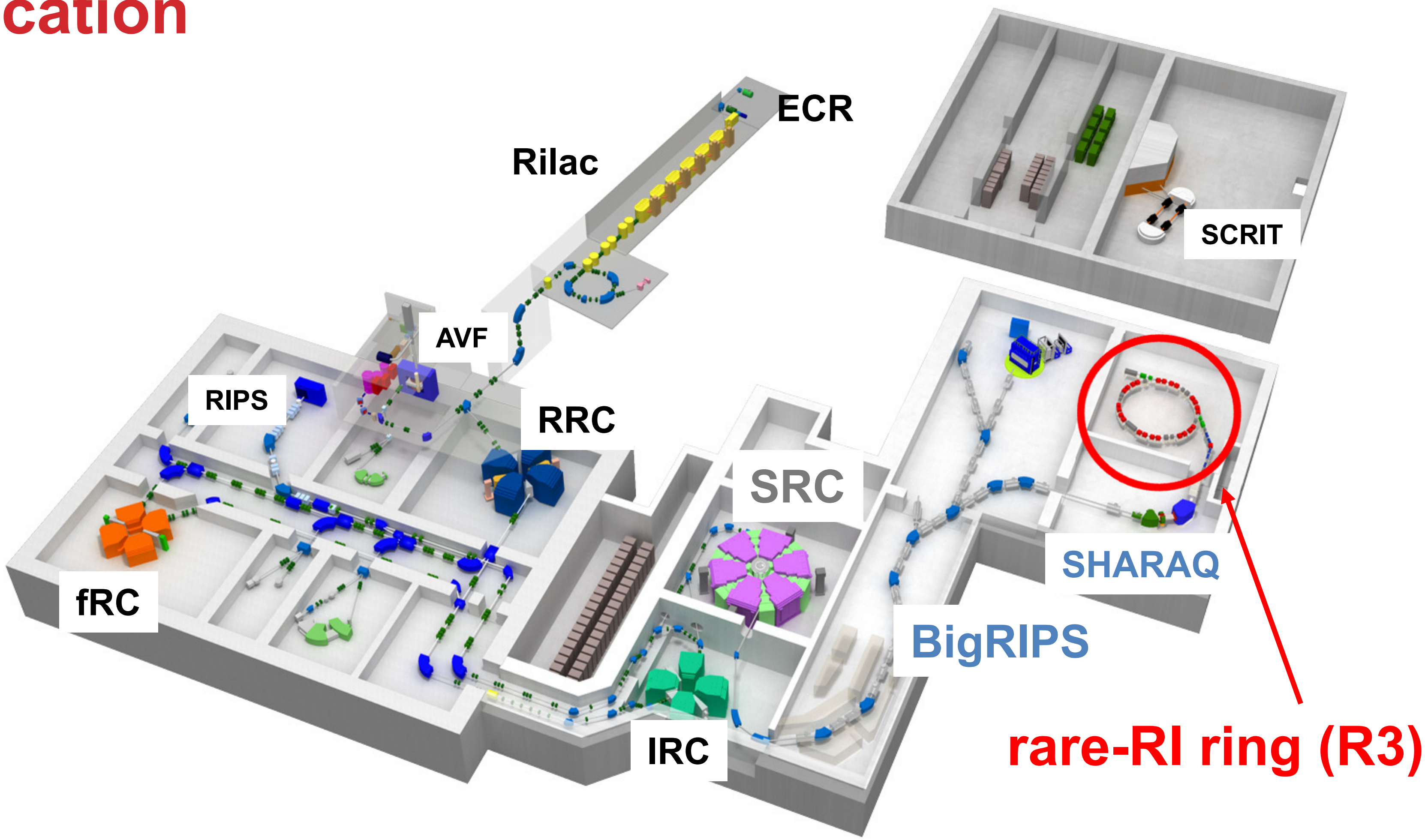
# The Rare-RI Ring at RIKEN RI Beam Factory

**Y. Yamaguchi** for rare-RI ring collaboration

**HIAT2015 September 8, 2015**

# Location




A storage ring dedicated to mass measurements of exotic nuclei based on Isochronous Mass Spectrometry (IMS)

- Measurement time is as short as 1 ms
- Expected mass resolution is in an order of ppm
- Self-trigger mechanism with a fast-kicker system is adopted

# Progress of construction and machine study


2012 - 2013

- Installation of all magnets were completed at the end of fiscal year 2012.

- We prepared the related equipment and carried out the excitation tests of the magnets in 2013.

2014 - 2015

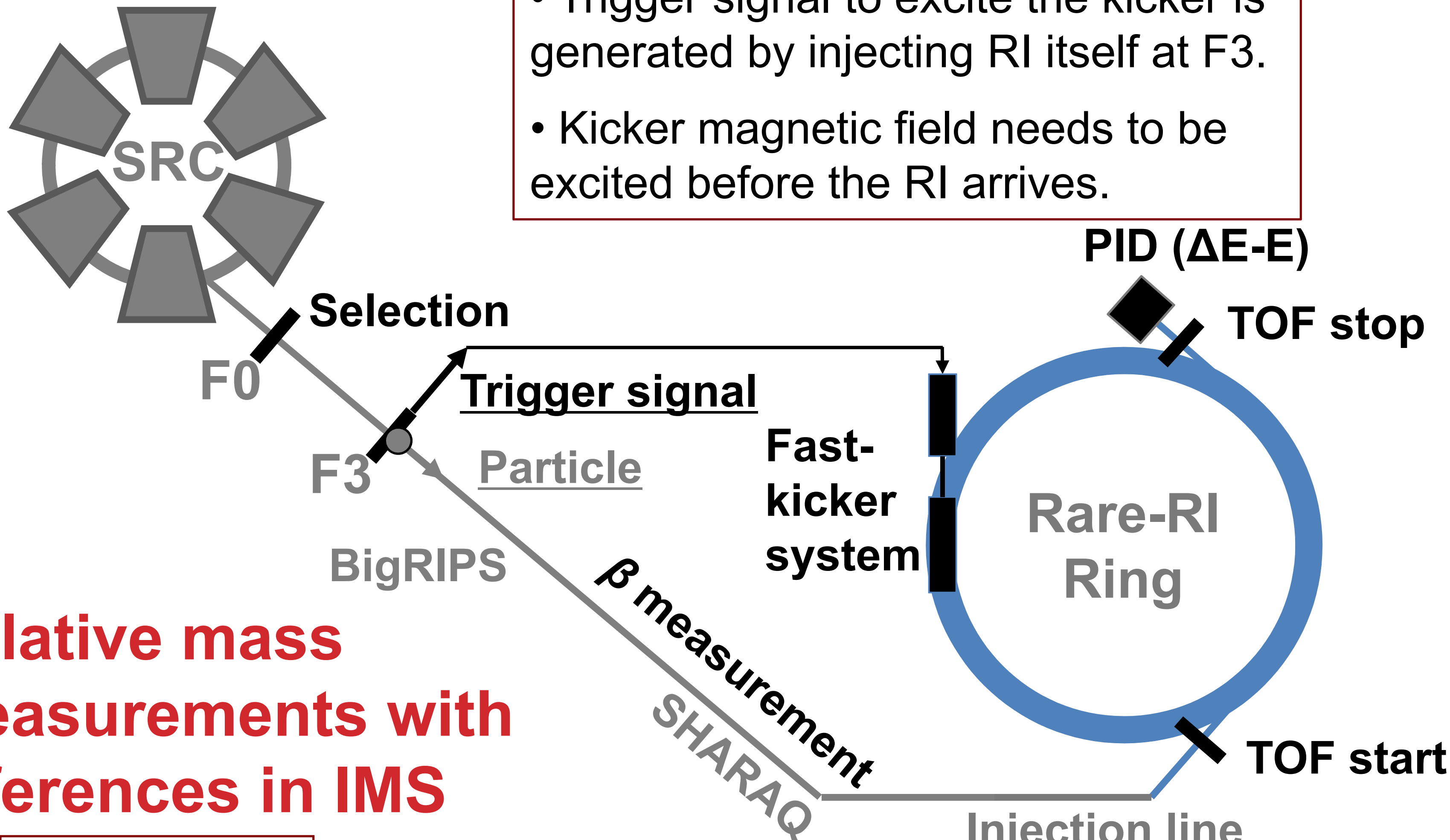
- Basic performance test of R3 using the α-source in 2014.
  - → <u>Trim-coils can adjust the isochronism.</u>
  - → <u>Successful in the individual injection and extraction.</u>

- We developed a fast-kicker system (fast-response, fast-recharging) and the beam diagnostic devices. (Resonant Schottky pick-up, C-foil + MCP)

- First commissioning of R3 using $^{78}$Kr beam was performed in June 2015 and off-line analysis is in progress.

# Self-trigger mechanism

- Trigger signal to excite the kicker is generated by injecting RI itself at F3.
- Kicker magnetic field needs to be excited before the RI arrives.




# Relative mass measurements with references in IMS

$$\frac{m_1}{q}\gamma_1\beta_1 = \frac{m_0}{q}\gamma_0\beta_0$$
$$\beta_1 T_1 = \beta_0 T_0$$

$$\frac{m_1}{q} = \left(\frac{m_0}{q}\right)\frac{1}{T_0}T_1\sqrt{\frac{1-\beta_1^2}{1-\left(\left(T_1/T_0\right)\beta_1\right)^2}} = \left(\frac{m_0}{q}\right)\frac{1}{T_0}T_{1\mathrm{corr}}$$

# Expected mass resolution

$$\frac{\delta(m_1/q)}{m_1/q} = \frac{\delta(m_0/q)}{m_0/q} + \frac{\delta(T_1/T_0)}{T_1/T_0} + k\frac{\delta\beta_1}{\beta_1}$$

$$k = -\frac{\beta_1^2}{1-\beta_1^2} + \left(\frac{T_1}{T_0}\right)^2 \frac{\beta_1^2}{1-(T_1/T_0)^2\beta_1^2}$$

↓ ppm order

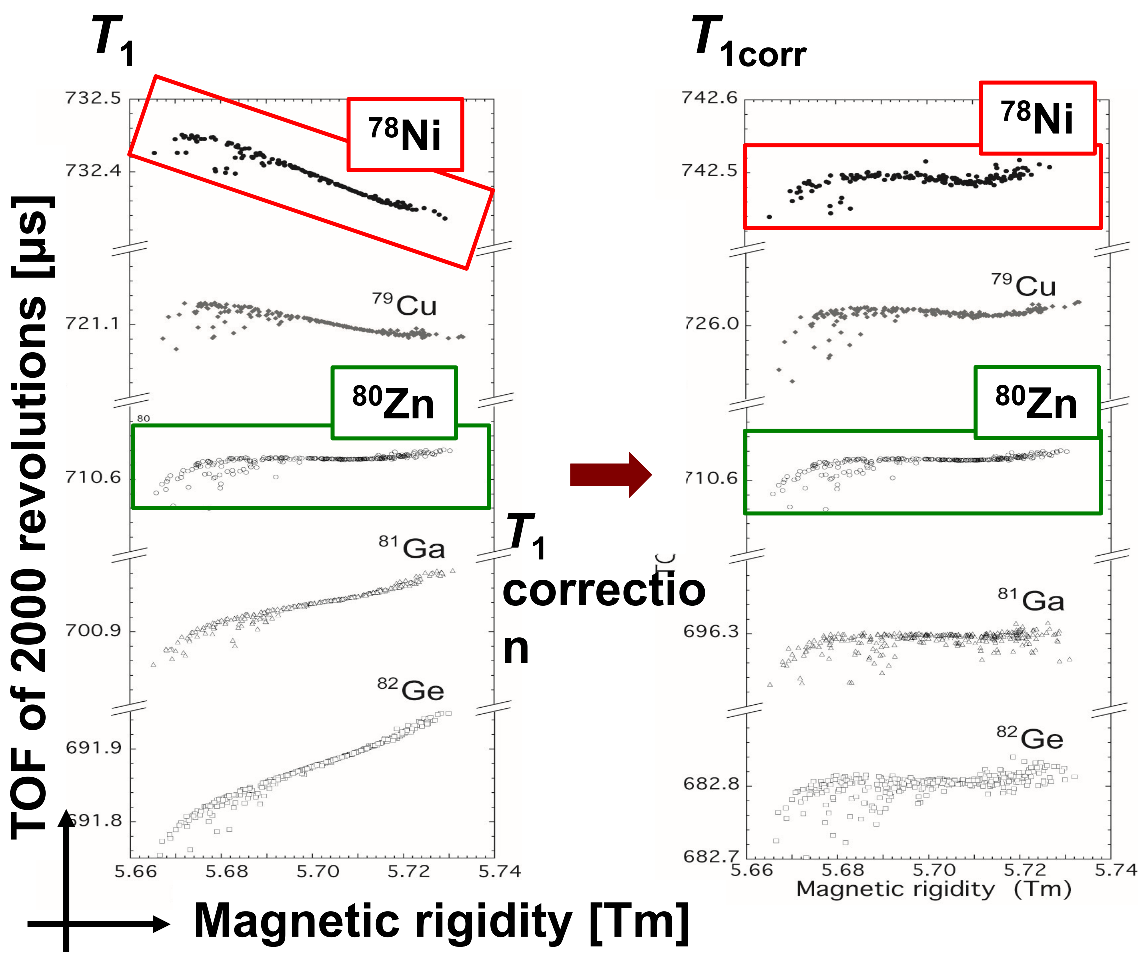
$< 10^{-6}$

$\sim 10^{-6}$

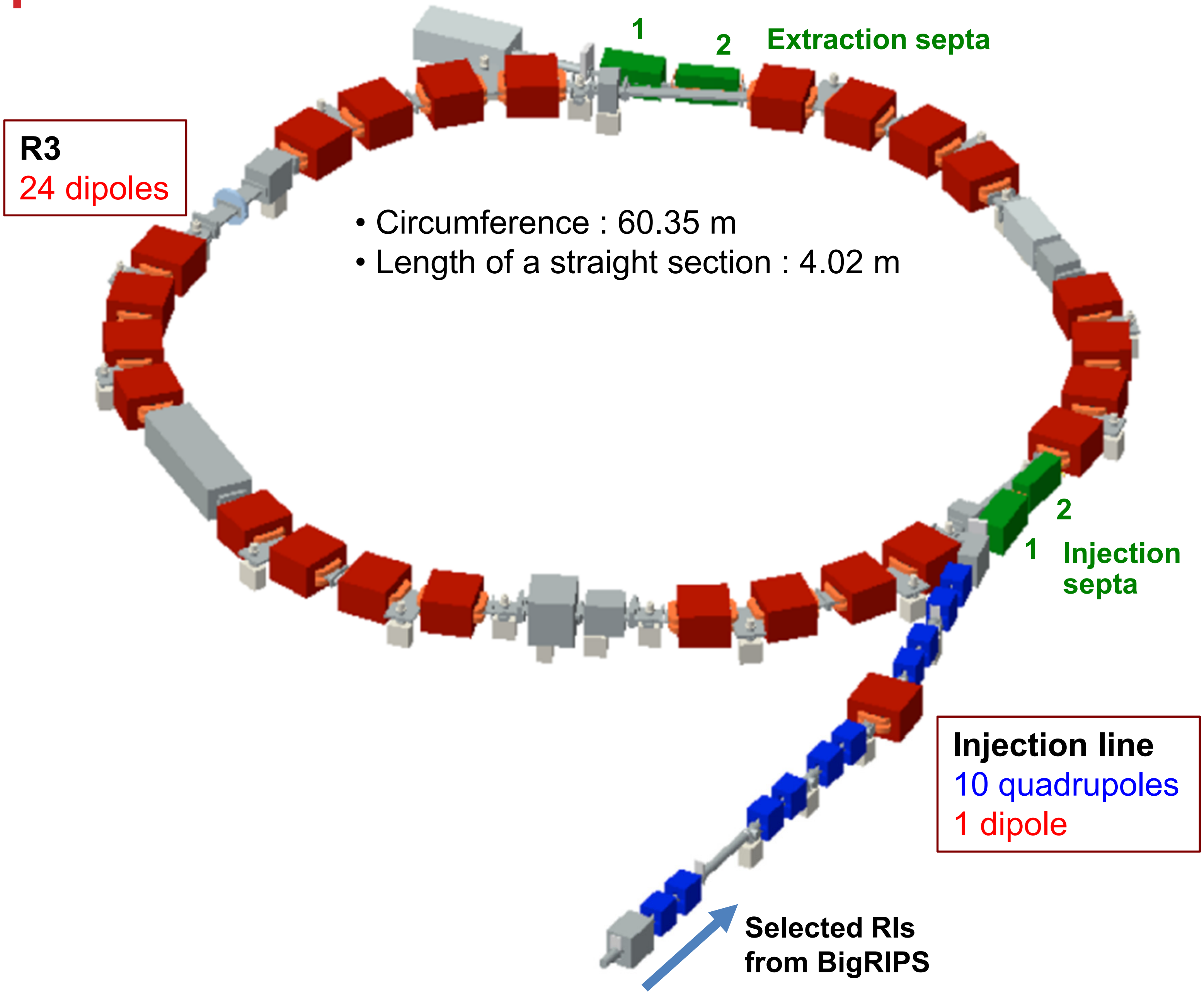
$\beta_1 \sim 10^{-4}$ ($k \sim 10^{-2}$)

# Simulation for $^{78}$Ni

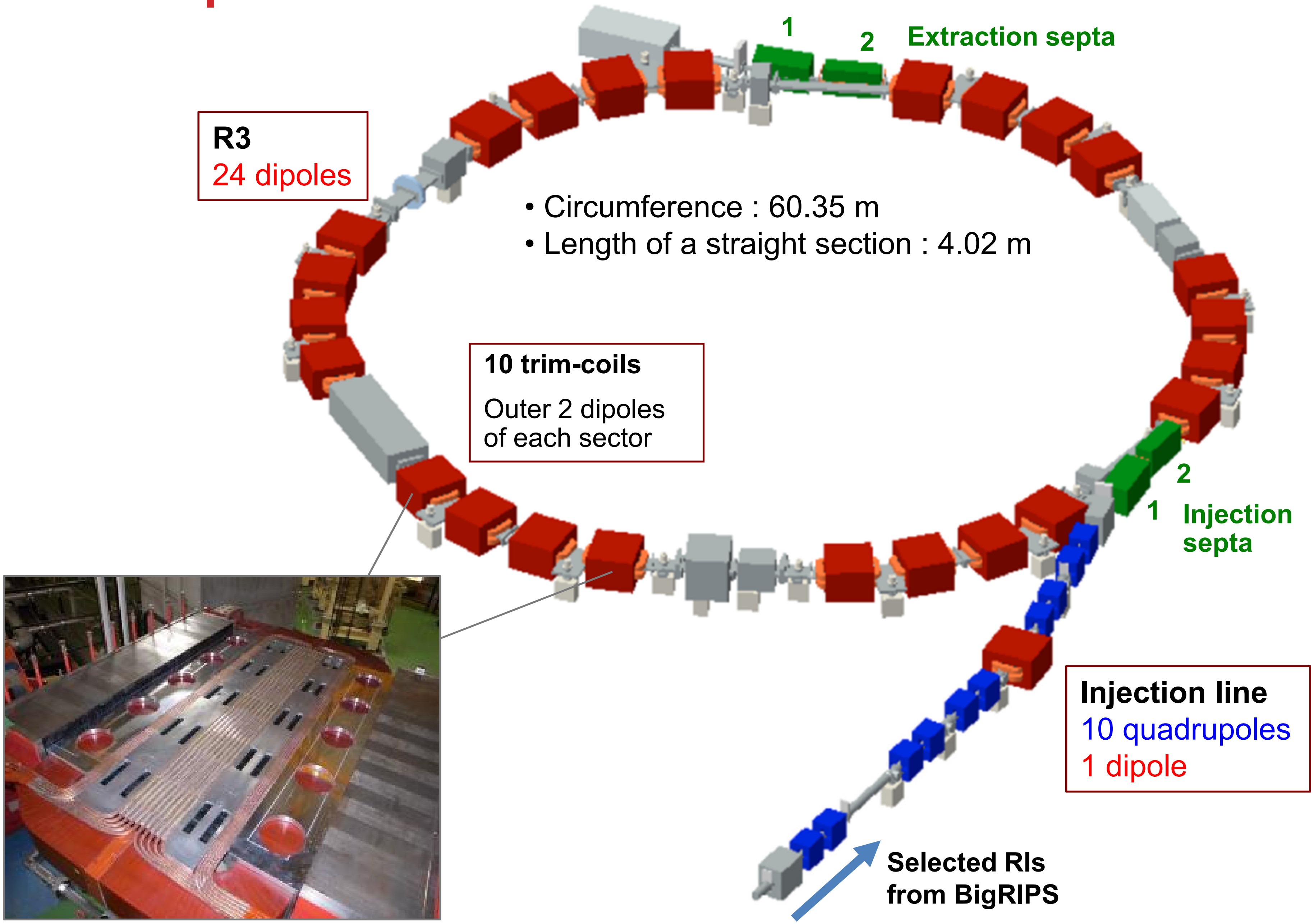
- Several particles are accepted in a given machine condition.
- Isochronism in R3 is tuned for $^{80}$Zn.
- Some of them are references for mass determination.



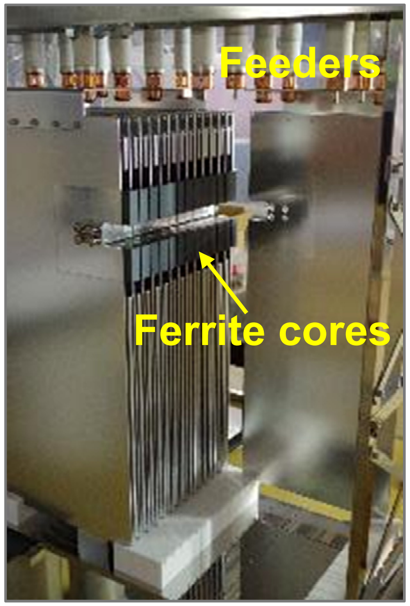
# R3 components



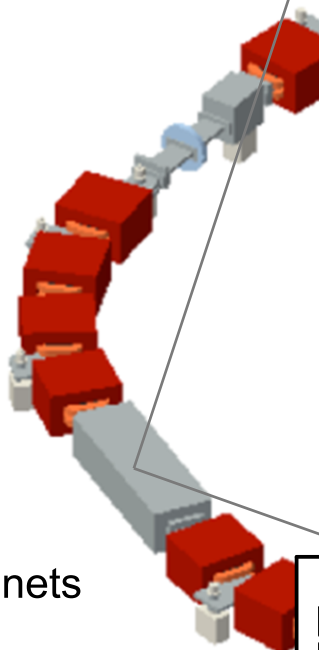
# R3 components

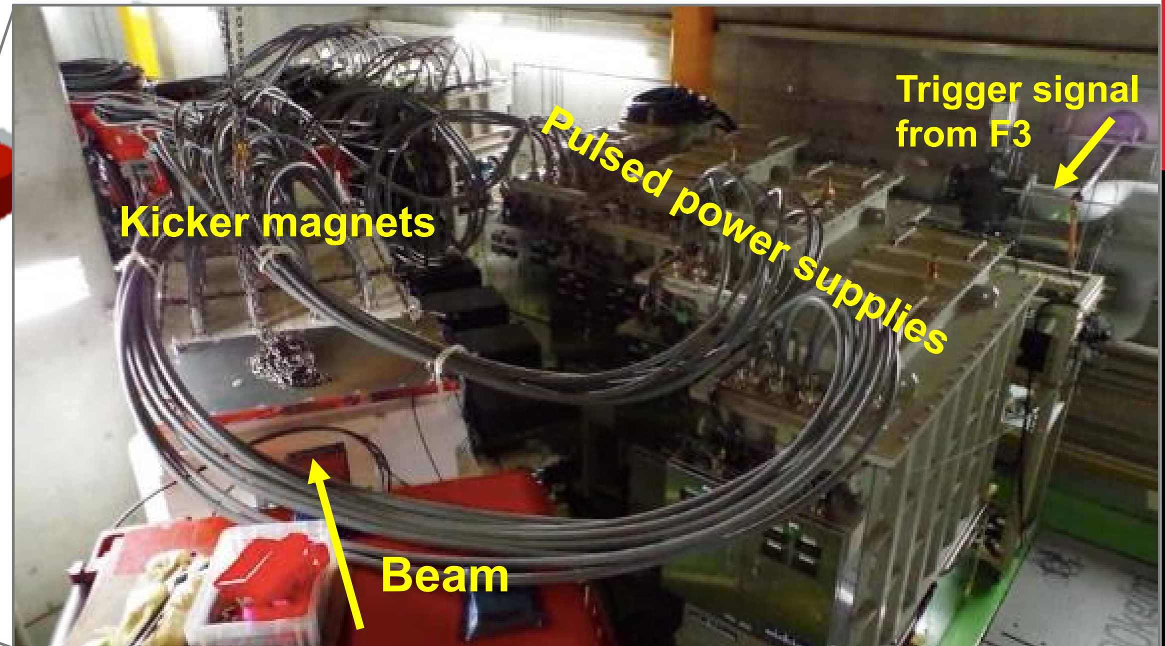


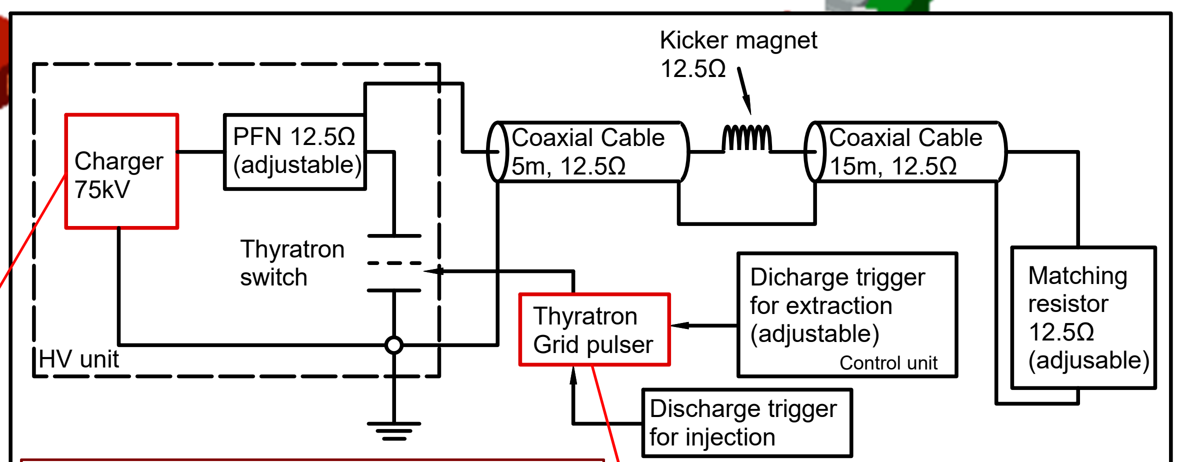
# Fast-kicker system




Twin-type kicker magnets
13 cells for one side
350 pF / cell, 100 nH / cell





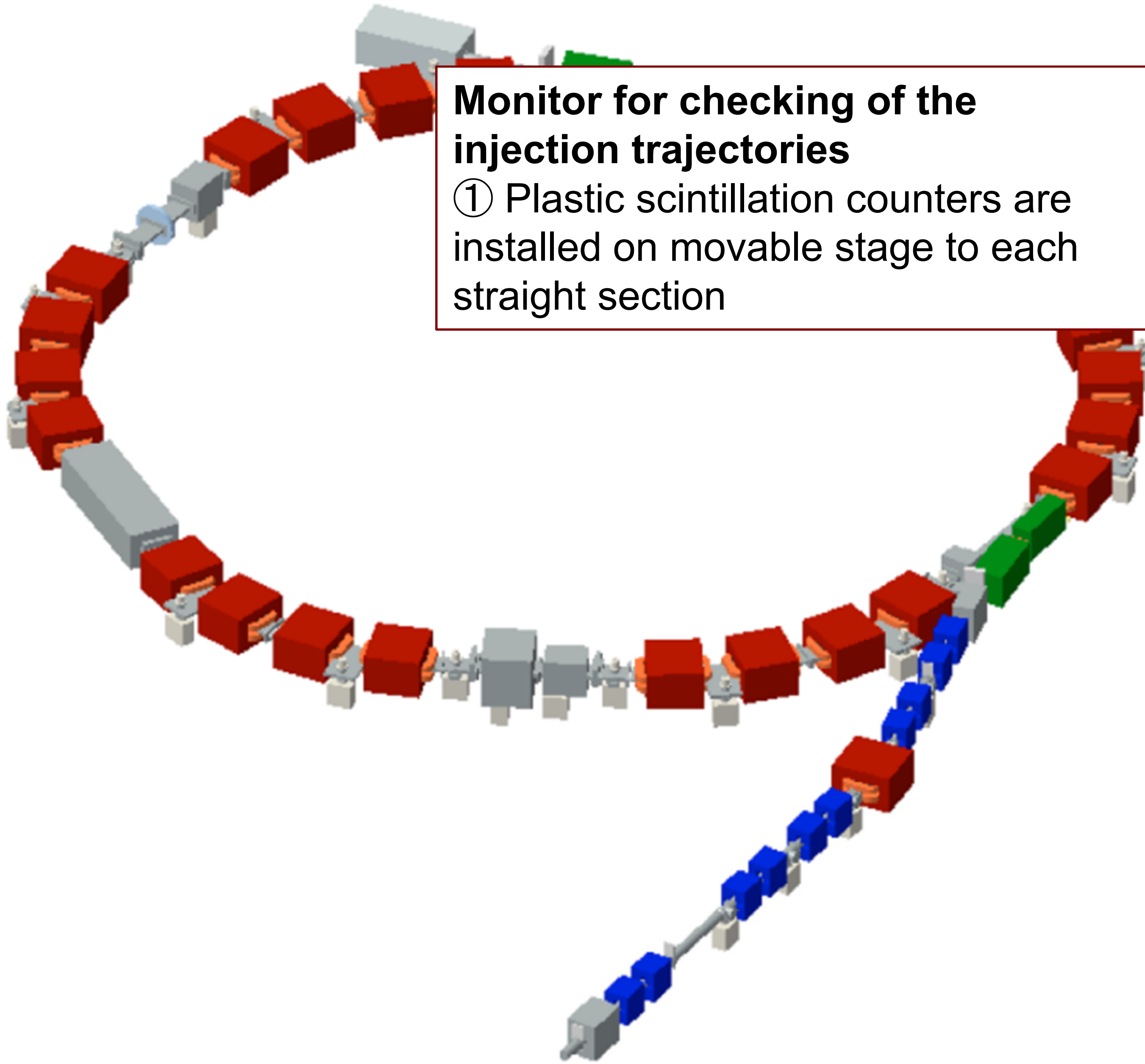

**Fast-recharging mechanism**

new hybrid charging system
to extract as soon as possible
using same kicker magnet
of injection.

**Fast-response mechanism**

new gate board for Thyratron
to excite a kicker magnet as fast as possible.

# Beam diagnostic devices

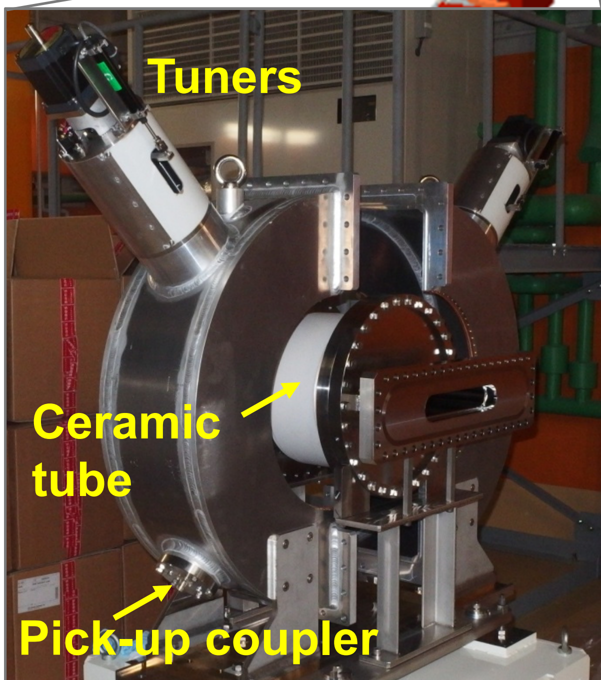


**Monitor for checking of the injection trajectories**

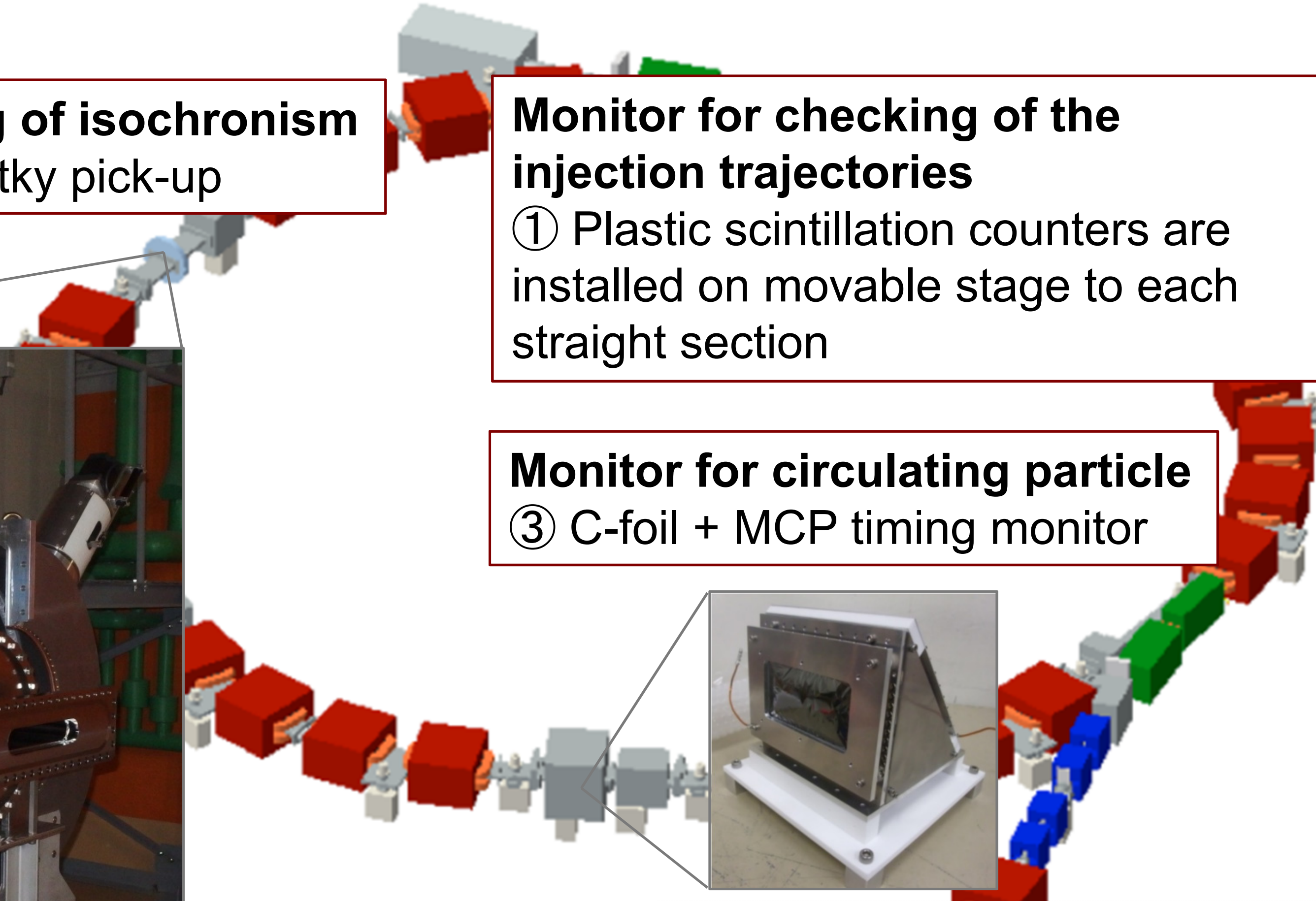
① Plastic scintillation counters are installed on movable stage to each straight section

# Beam diagnostic devices

**Monitor for tuning of isochronism**
② Resonant Schottky pick-up




| | |
|---|---|
| Resonance frequency : | 173MHz ($TM_{010}$) |
| Tuning range : | ±1.5MHz |
| Shunt Impedance $R_{sh}$ : | 161kΩ |
| Quality factor $Q_0$ : | 1880 |
| Ceramic tube size : 290mmΦ, 15mm thickness | |



**Monitor for checking of the injection trajectories**
① Plastic scintillation counters are installed on movable stage to each straight section

**Monitor for circulating particle**
③ C-foil + MCP timing monitor

C-foil (60μg/$cm^2$)
MCP secondary electron detector
- Window size : 100×50 $mm^2$
- Position sensitivity : less than 10mm
- Efficiency : 75 %
- Time resolution : 340ps with $^{84}Kr$ 200MeV/u

# Commissioning of R3 using $^{78}$Kr beam

**Items**

① Establishment of individual injection using self-trigger mechanism
② Confirmation of circulating particles using C-foil + MCP
③ Confirmation of extraction the circulating particles from the ring
④ Check the ring conditions using the information of TOF vs. F6x
⑤ Check the signal of resonant Schottky pick-up with single $^{78}$Kr ion

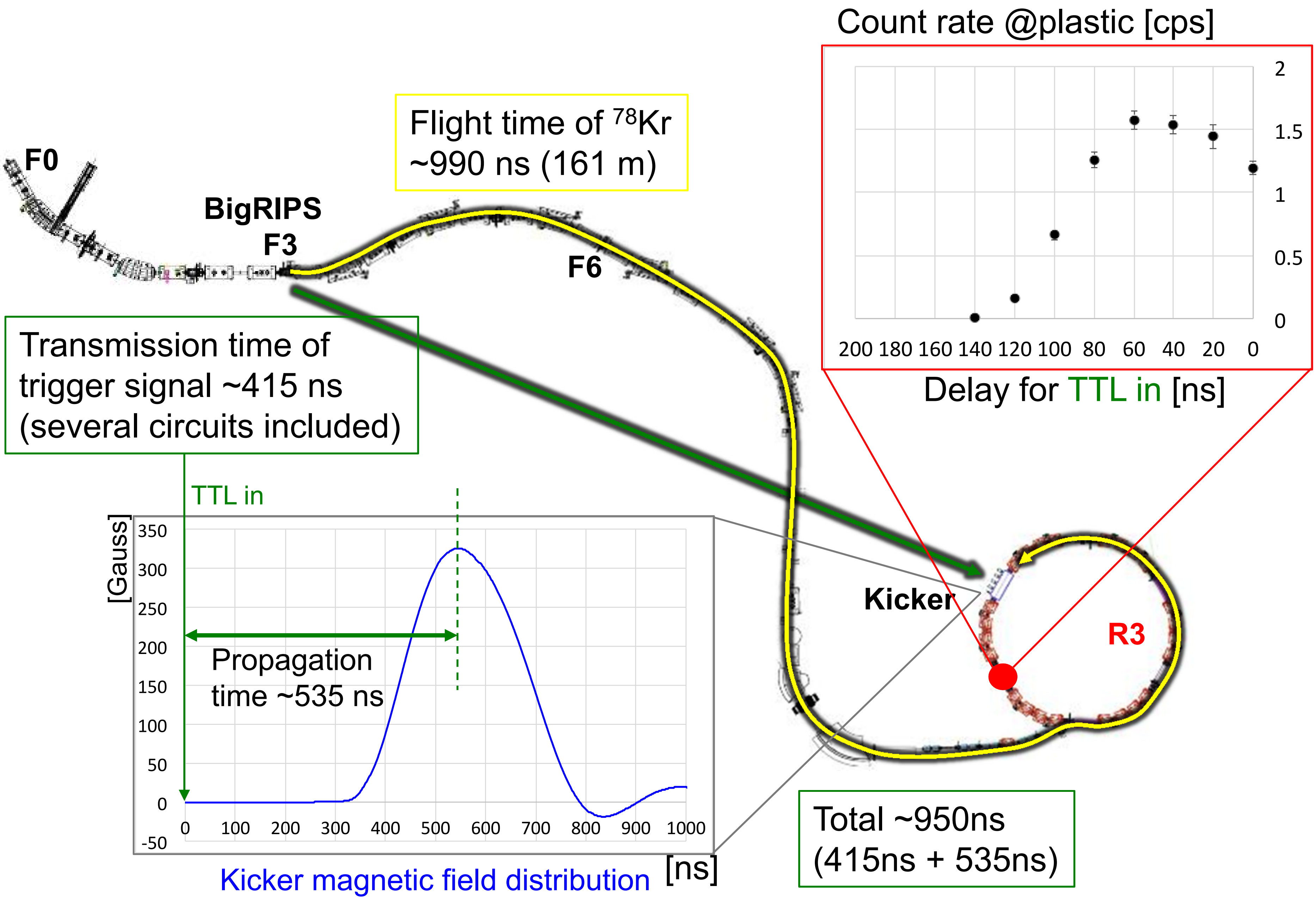
**Beam conditions**

- Energy : 345 MeV/u → 168 MeV/u @R3
- Intensity : ~1 kcps @BigRIPS-F3
- Injection repetition rate : 90 Hz (@F3 circuit)

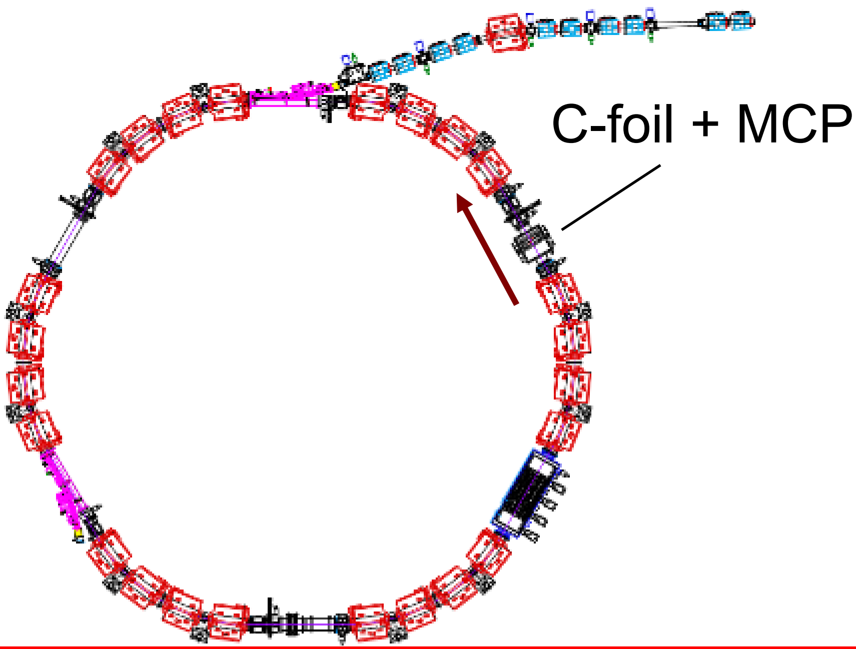
**Ring conditions**

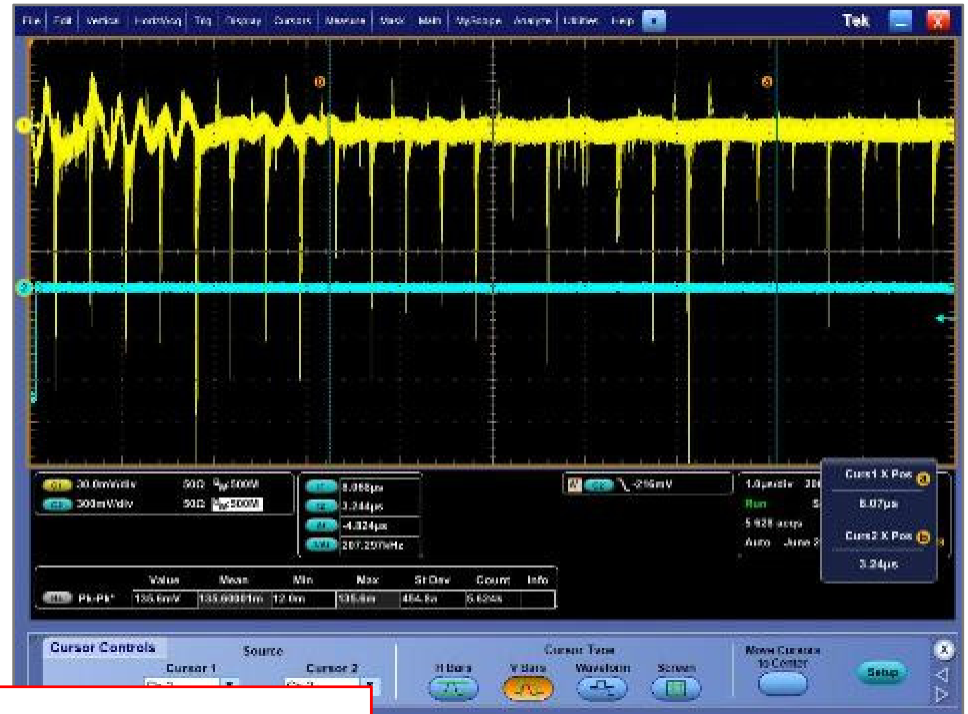
- Transition $\gamma_{tr}$ : 1.18
- Betatron tune : $Q_x = 1.18$, $Q_y = 0.93$
- $\beta$ function : $\beta_x = 8.4$ m, $\beta_y = 11.9$ m
- Dispersion : 7.0 m
- Kick angle : ~11 mrad

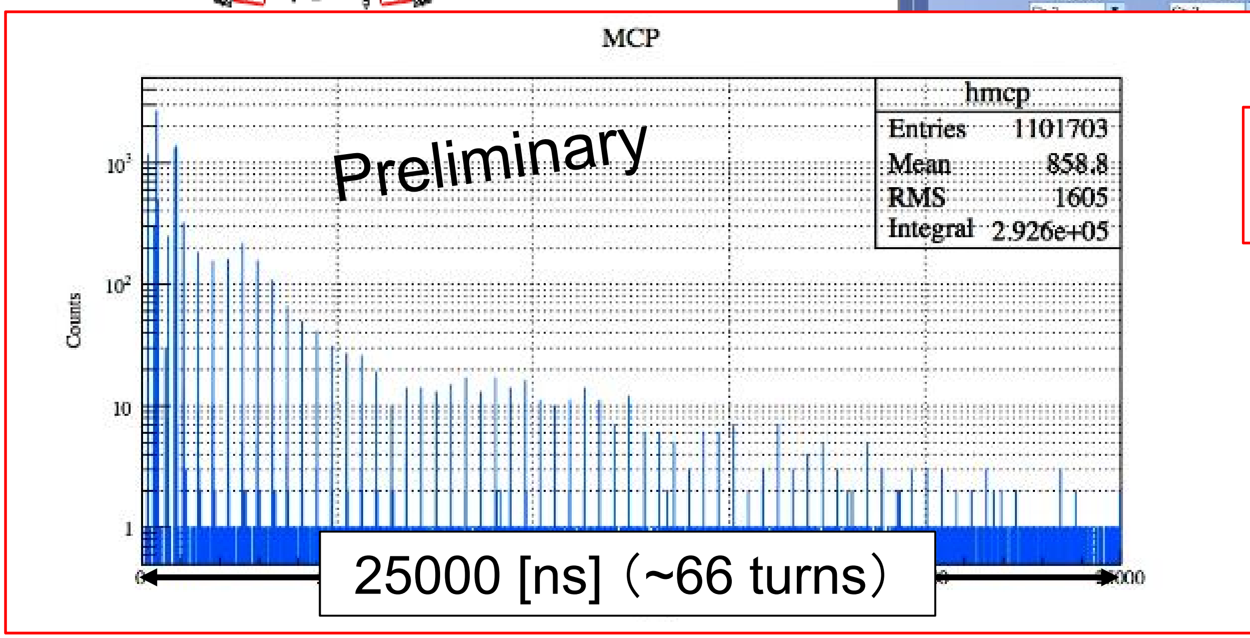
# 1. Individual injection



# 2. C-foil + MCP can detect the circulating particles



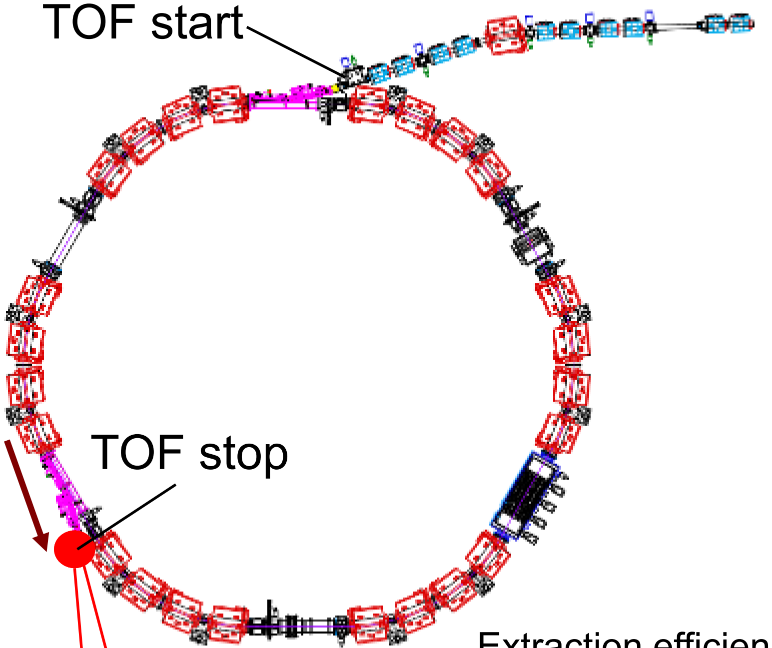




TDC（Aquiris TC890）
→ 379.65 ns / turn

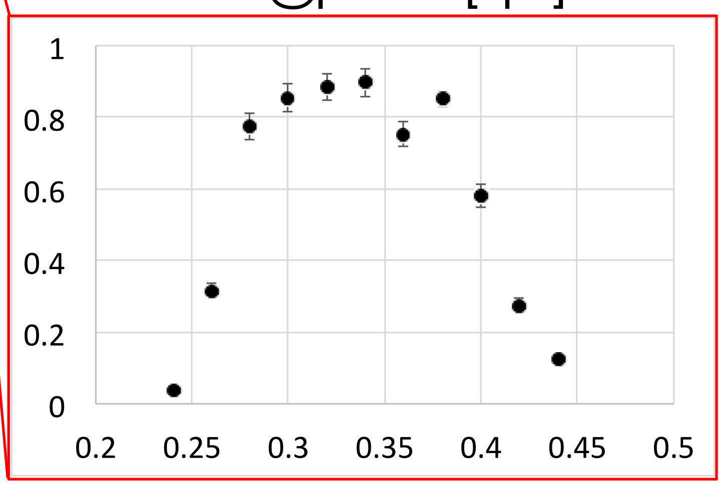
Useful information
for determining
the resonance frequency
of Schottky pick-up.

# 3. Extraction



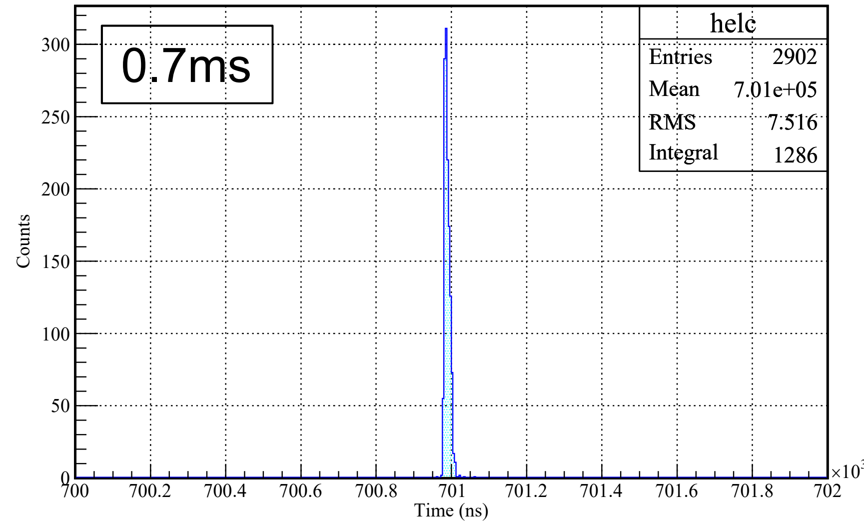

Extraction efficiency ~1%

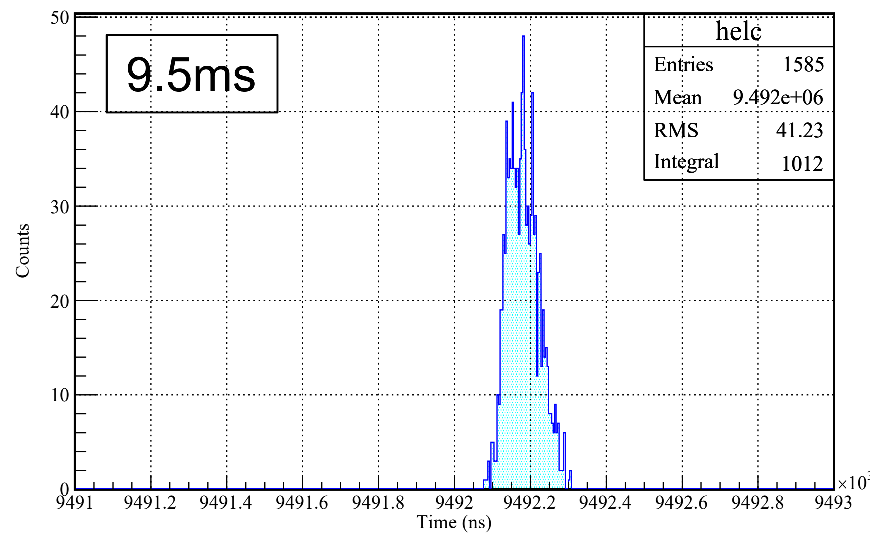
Count rate @plastic [cps]




700μs + delay time [μs]

TOF spectra
for the difference extraction timing



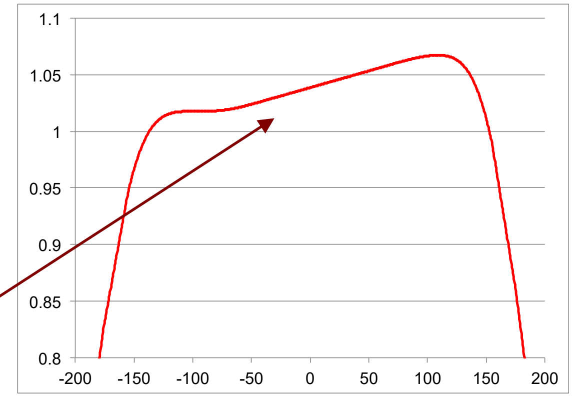



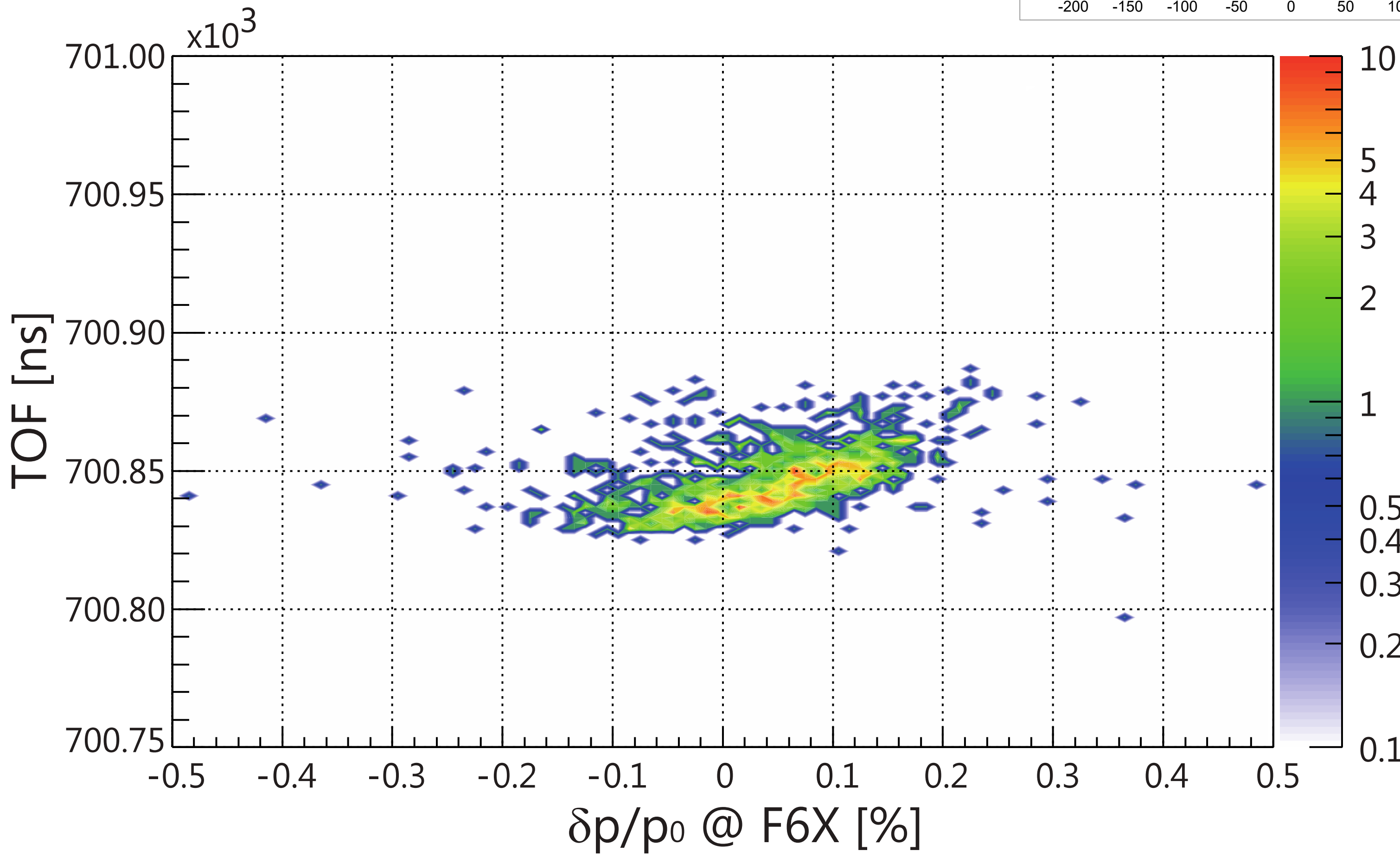
# 4. Information of TOF vs. F6x

Tested on the effect of trim-coils
for adjusting the isochronism

First-order trim field $(dB/dr)/B_0$=0.277

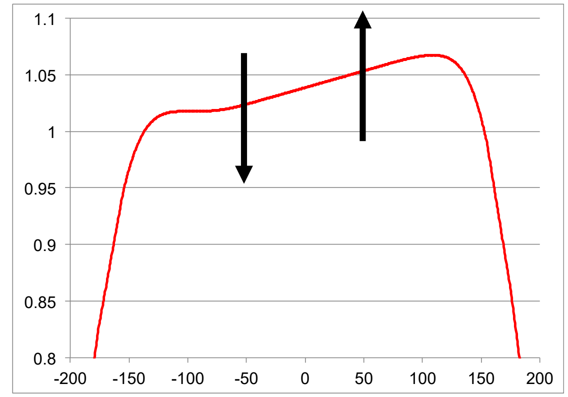
Magnetic field distribution



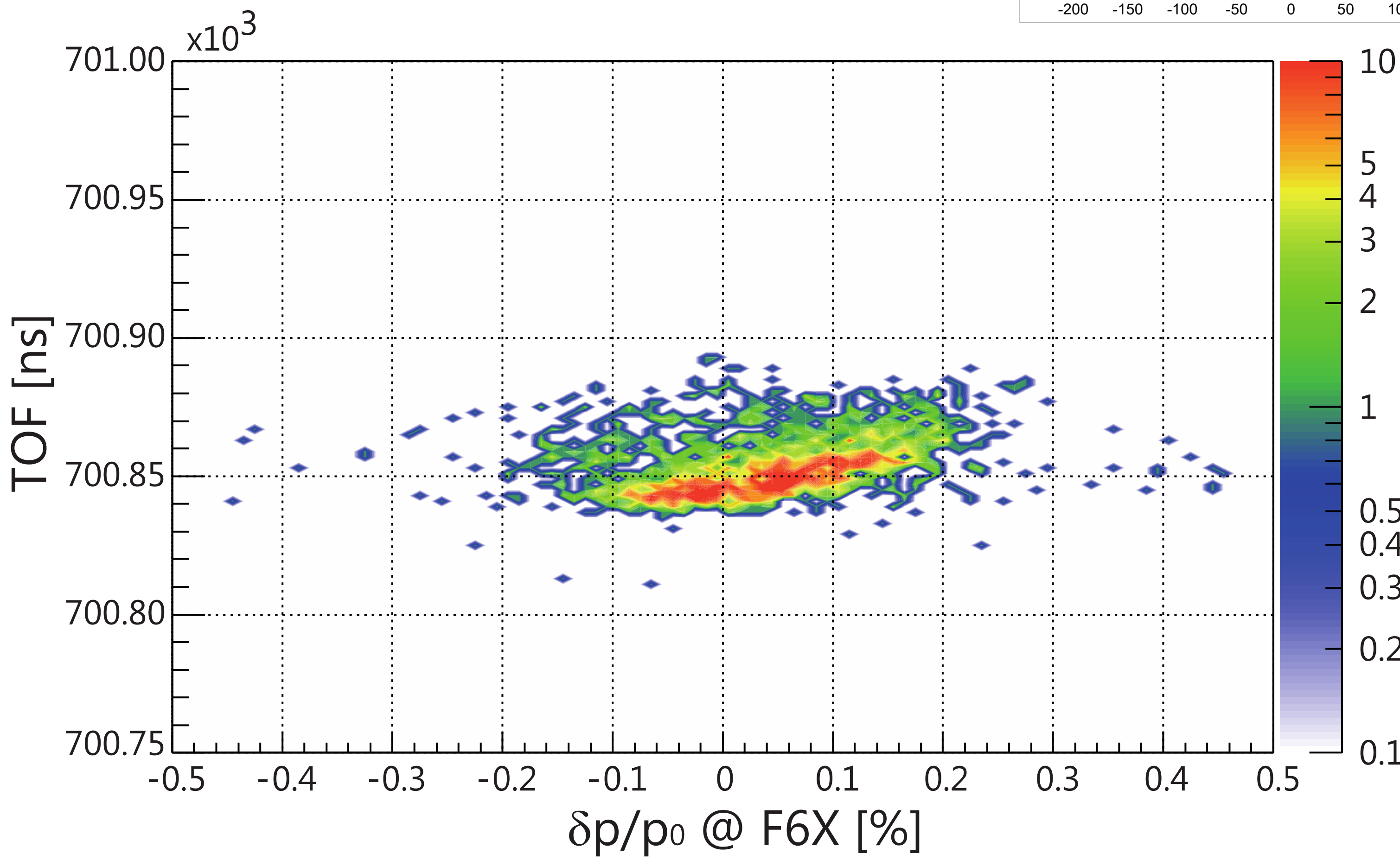



# 4. Information of TOF vs. F6x

Magnetic field distribution




First-order trim field
$(dB/dr)/B_0$=0.277 → 0.279

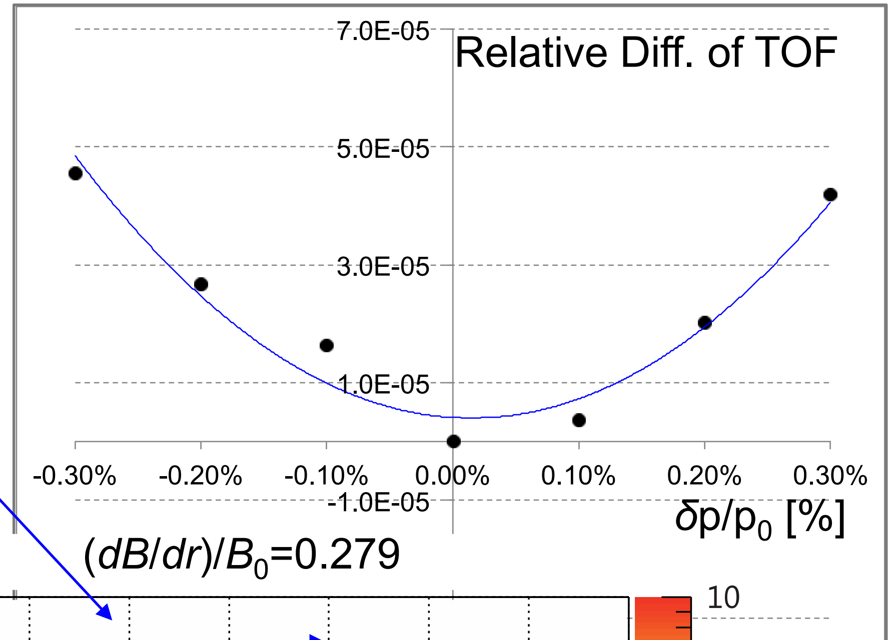


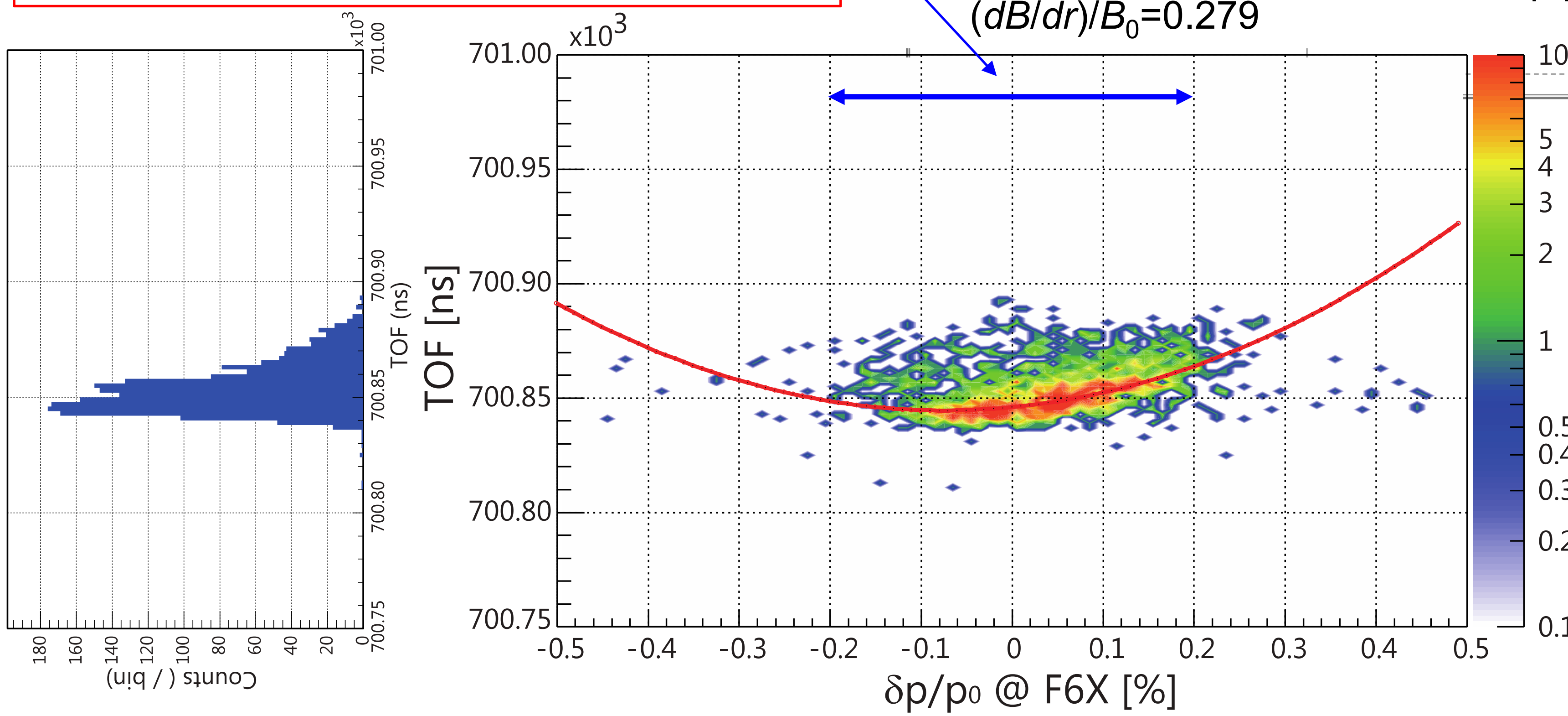
# 4. Information of TOF vs. F6x

- Extractable momentum width : ±0.2%
- TOF width : ~25ns (FWHM)

→ Degree of isochronism : ~$3.5\times10^{-5}$
(10-ppm order including the tail)

Result of numerical analysis

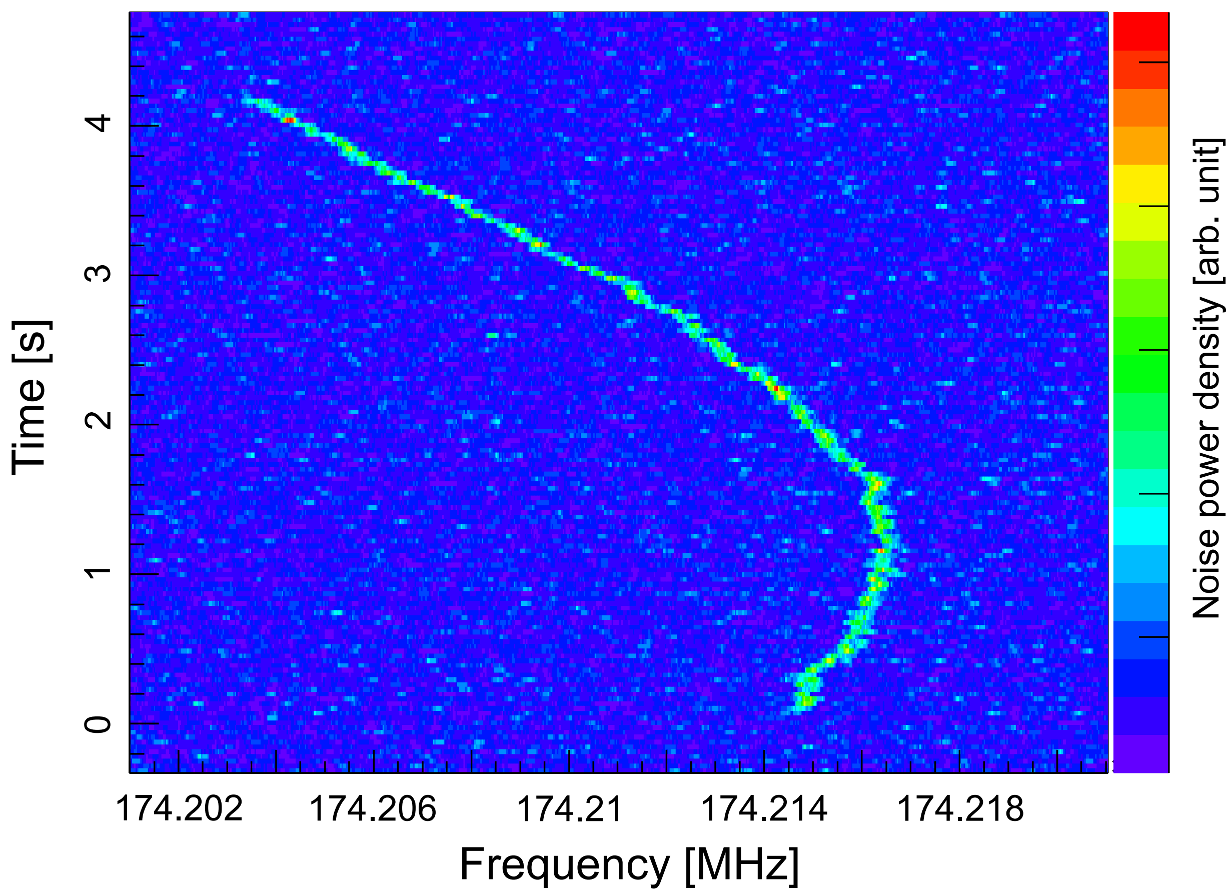


# 5. Resonant Schottky pick-up

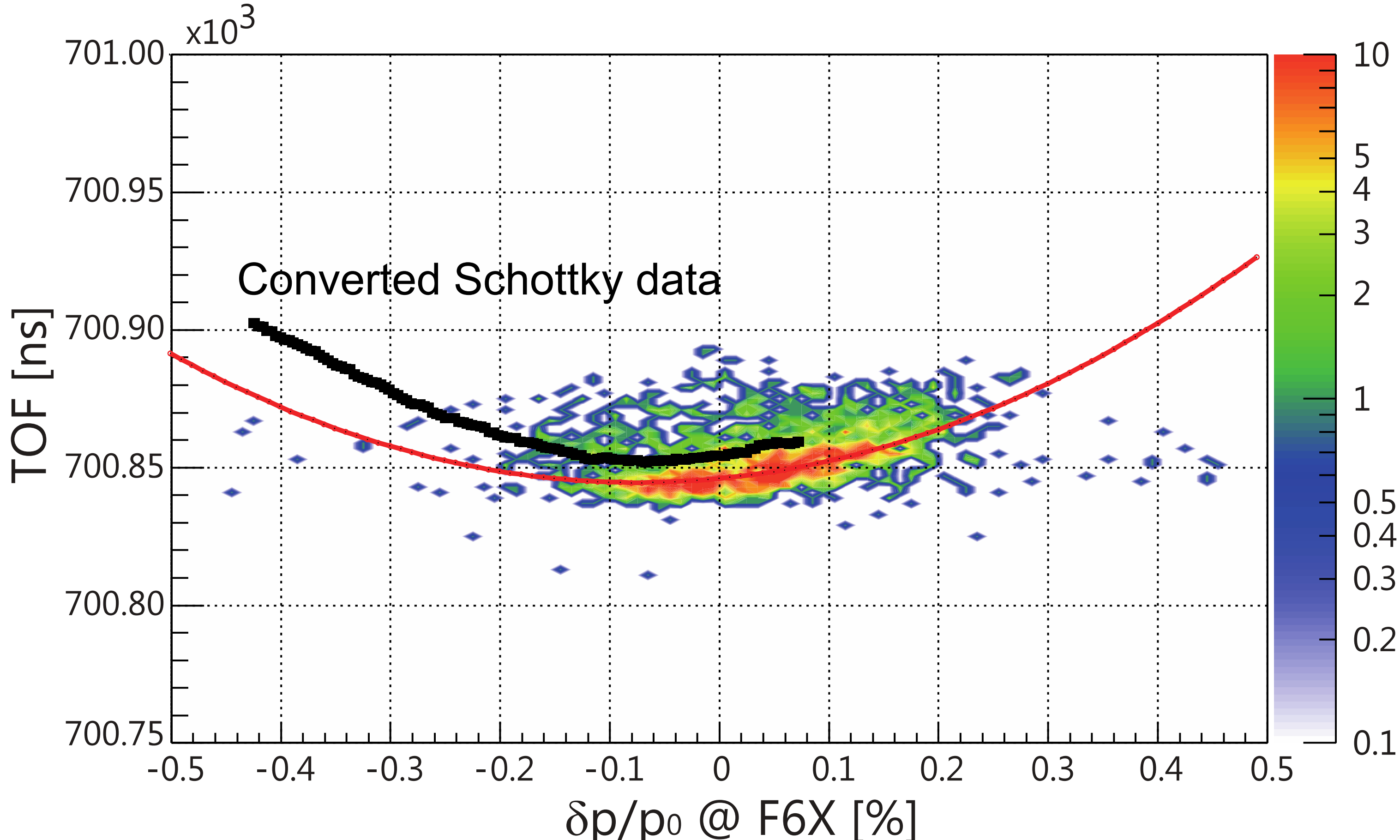
- Succeeded in detecting the single $^{78}Kr^{36+}$ ion → high sensitivity
- Frequency resolution : ~$1.3 \times 10^{-6}$ (FWHM) → enough resolution

- Stored in the ring about 4 seconds while changing its frequency due to the poor degree of vacuum in the ring.
- The shape of curve indicates the isochronous condition.




42 events in total !

# Under consideration




Harmonics : 66
Turn number : 1850
Main residual gas : $H_2O$ vapors (assumption)
Pressure : ~4 x $10^{-5}$ Pa (fixed the worst case)

# Conclusion and Prospect

• First commissioning using $^{78}$Kr beam was finished successfully.

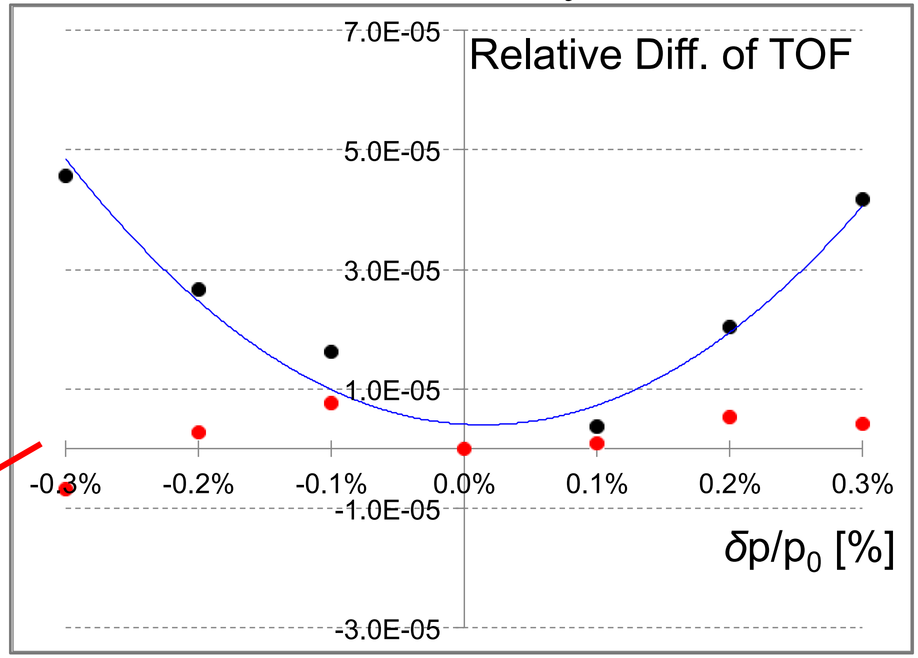
• First-order trim field can adjust the isochronism in an order of 10-ppm.

• Second-order trim field should be taken into account for adjusting the isochronism in an order of ppm.

↓

Resonant Schottky pick-up can be used for checking it.

Result of numerical analysis




Next beam commissioning is scheduled in Dec. 2015.

• We'd like to verify the principle of relative mass measurements by using several secondary particles

Primary beam : $^{48}$Ca 345 MeV/u

Secondary particles : $^{38}$K, $^{40}$Ca, $^{36}$Ar, $^{39}$Ca, $^{37}$Ar, etc...

# Thank you for your attention