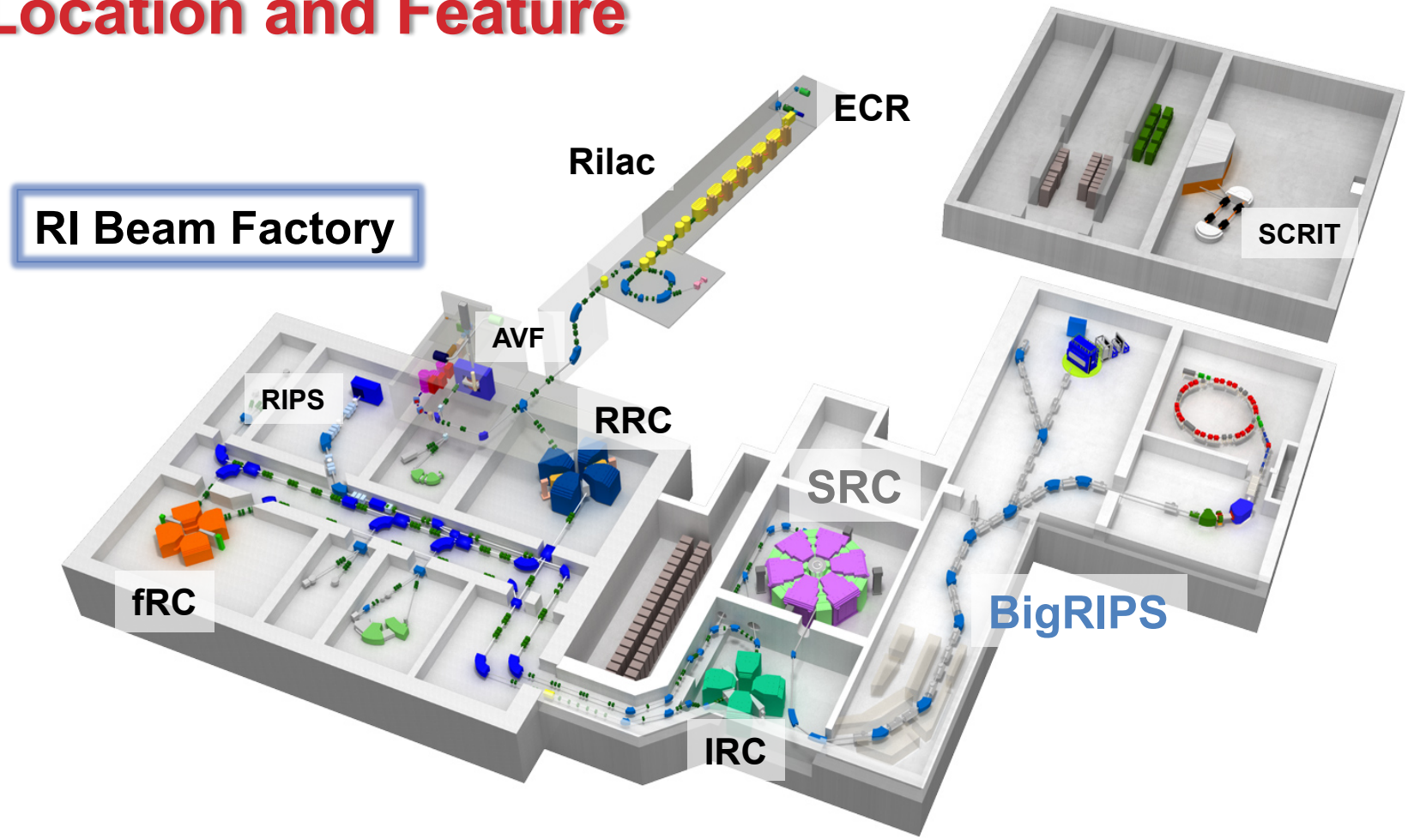
# Commissioning of the Rare-RI Ring at the RIKEN RI Beam Factory

**Yoshitaka Yamaguchi** on behalf of rare-RI ring collaboration

COOL'15 workshop : October 2, 2015

# Location and Feature



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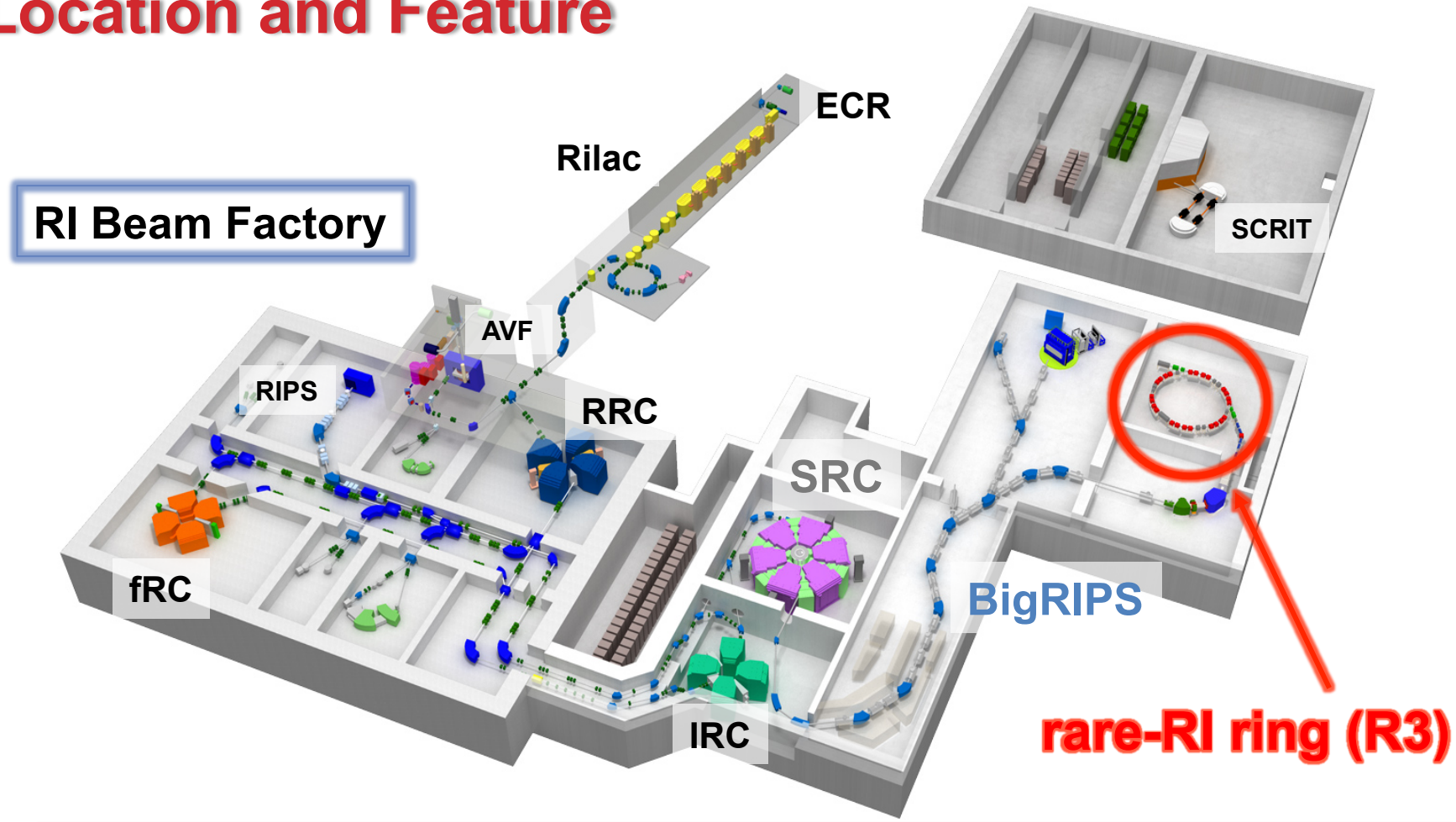
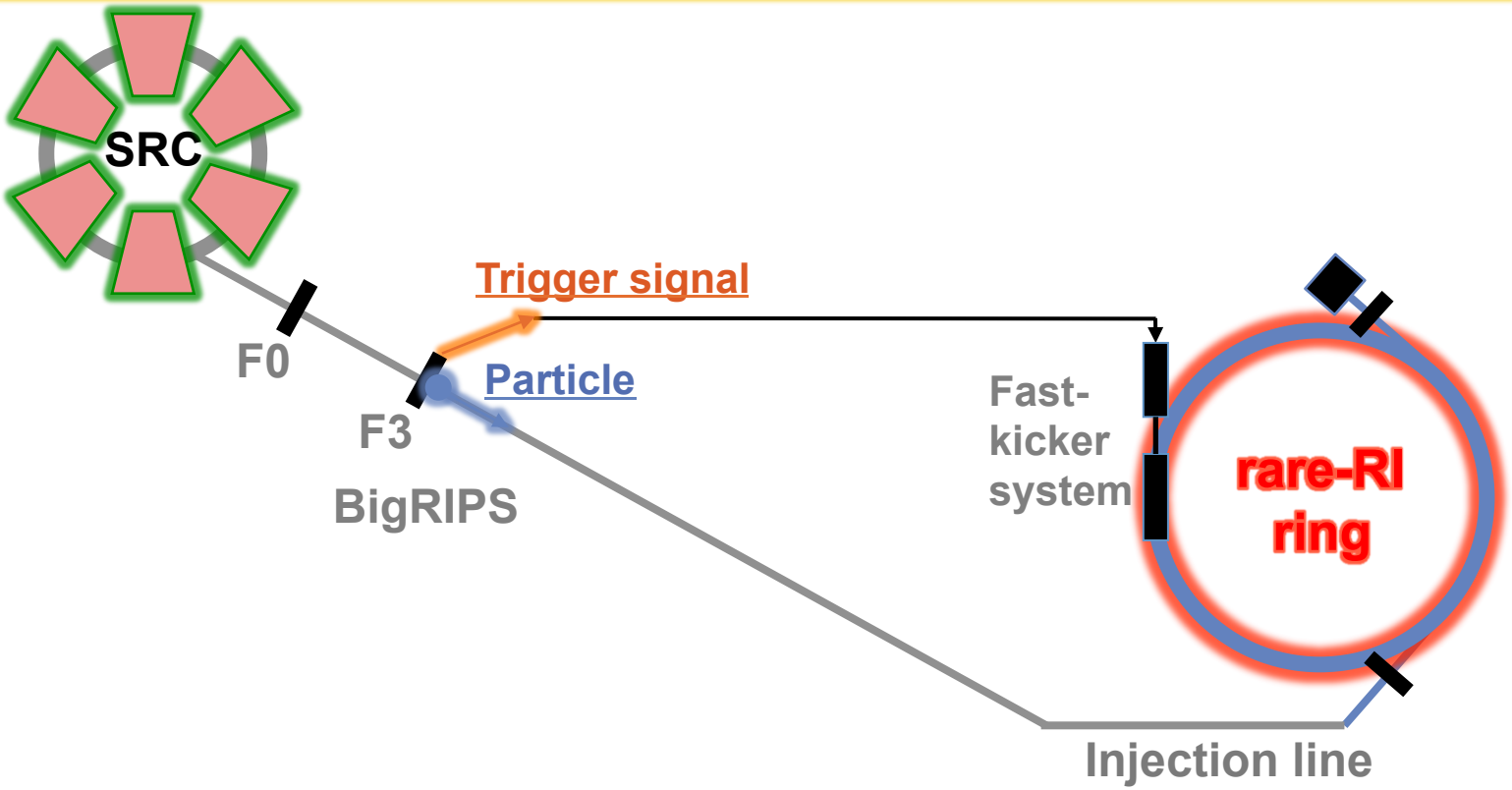



**A storage ring dedicated to mass measurements of exotic nuclei based on Isochronous Mass Spectrometry (IMS)**

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

# 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.



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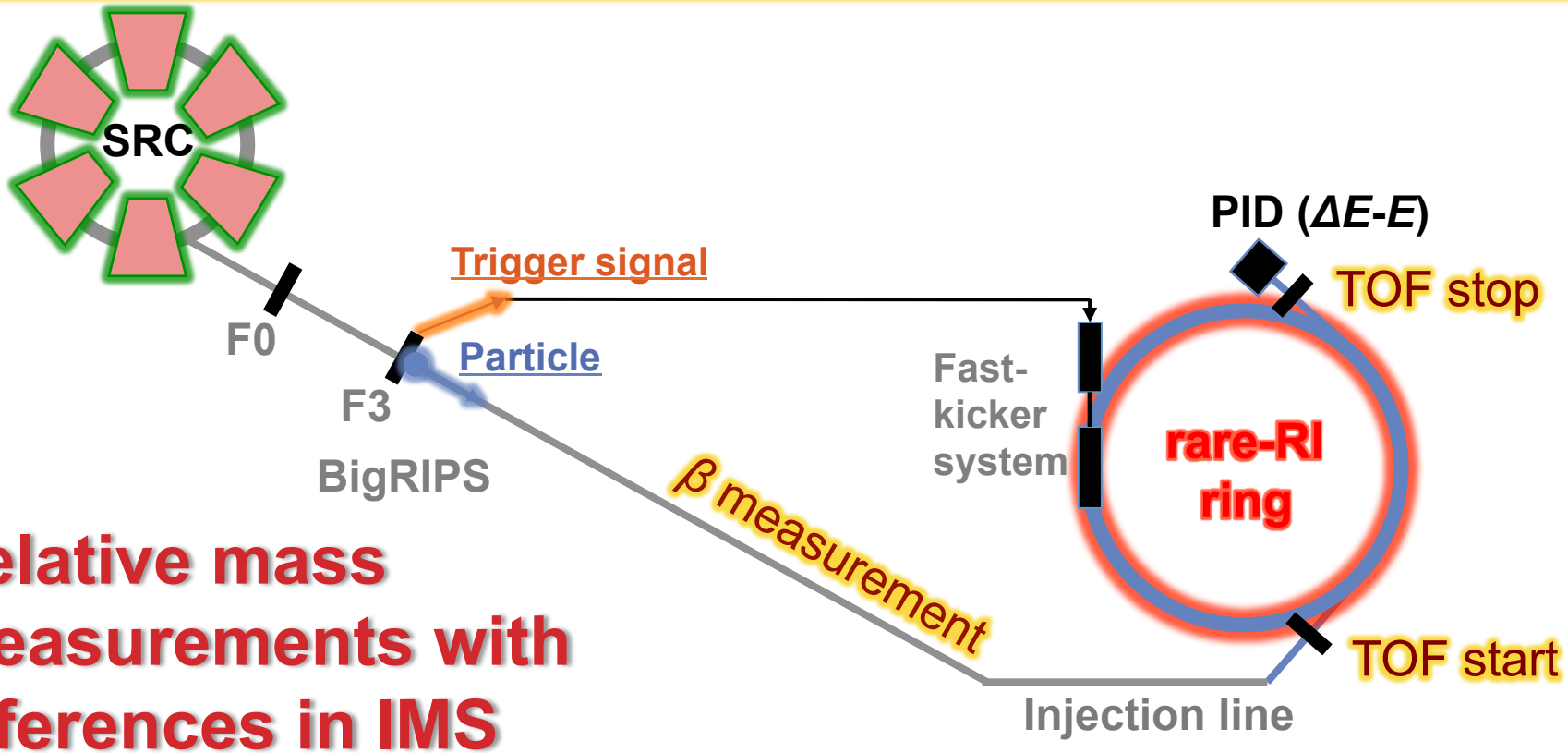
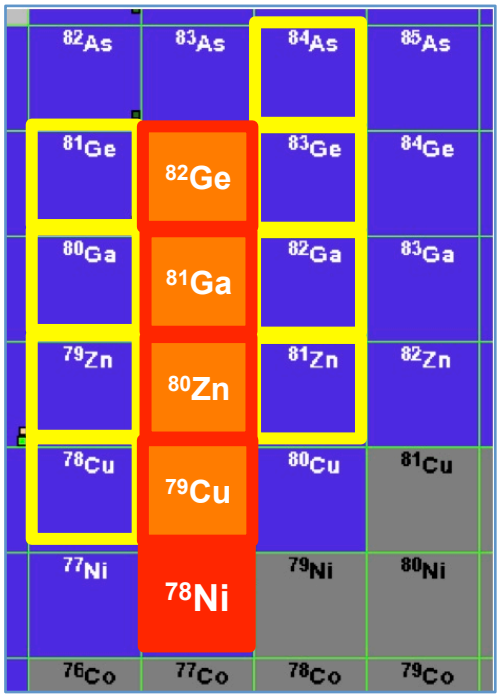
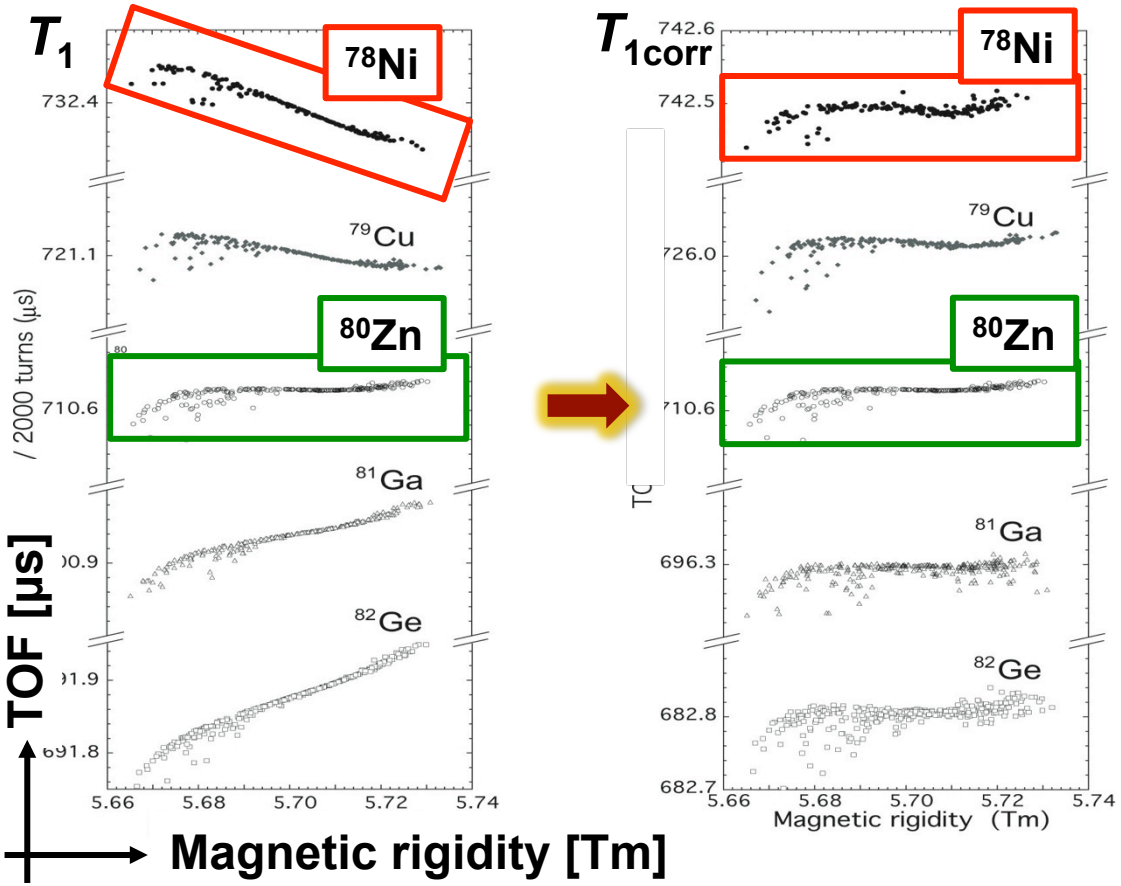



# Relative mass measurements with references in IMS

$$\left.\begin{array}{l} \dfrac{m_1}{q}\gamma_1\beta_1 = \dfrac{m_0}{q}\gamma_0\beta_0 \\ \beta_1 T_1 = \beta_0 T_0 \end{array}\right\} \rightarrow \frac{m_1}{q} = \left(\frac{m_0}{q}\right)\frac{1}{T_0}T_1\sqrt{\frac{1-\beta_1^2}{1-\left((T_1/T_0)\beta_1\right)^2}} = \left(\frac{m_0}{q}\right)\frac{1}{T_0}T_{1\mathrm{corr}}$$

# Simulation for $^{78}$Ni



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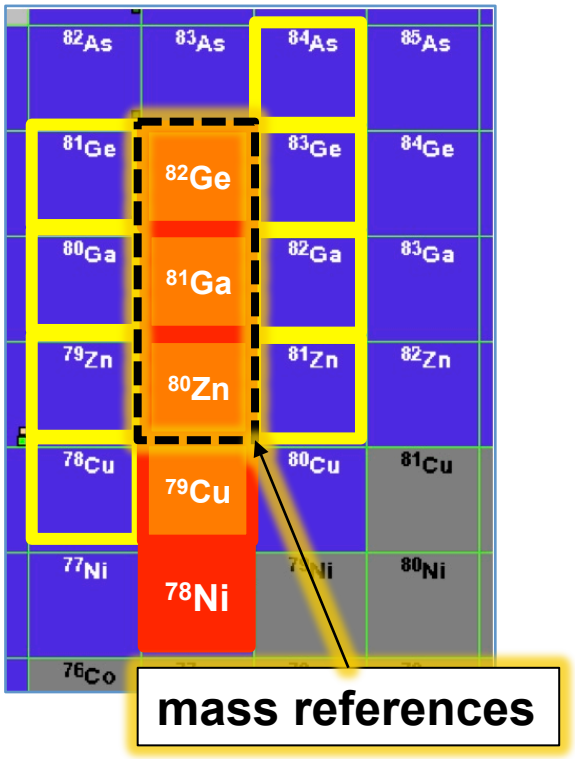


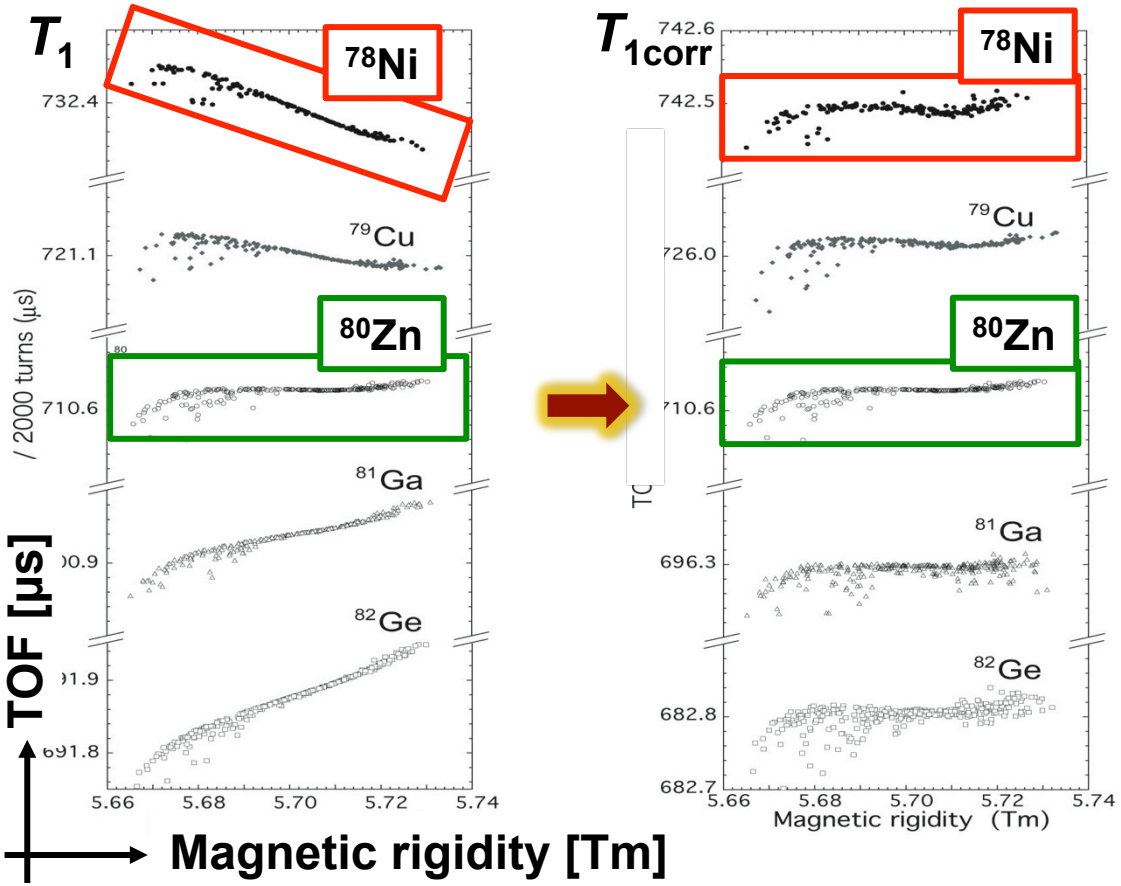

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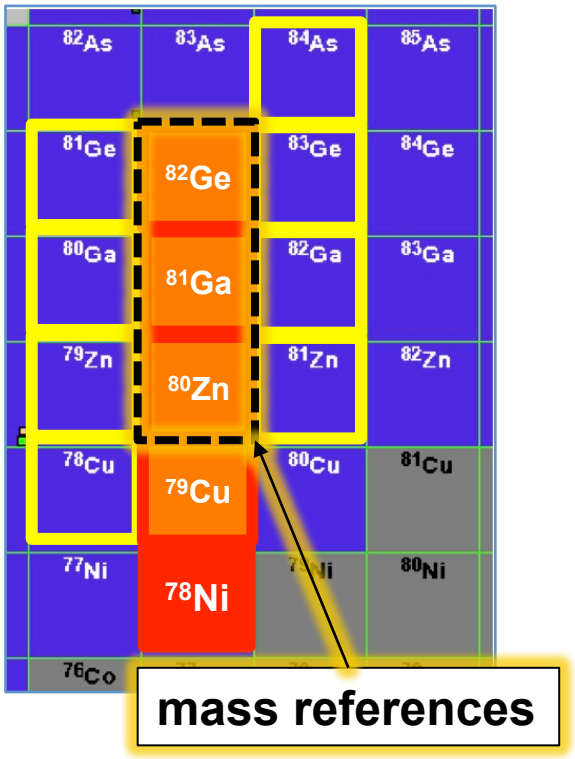


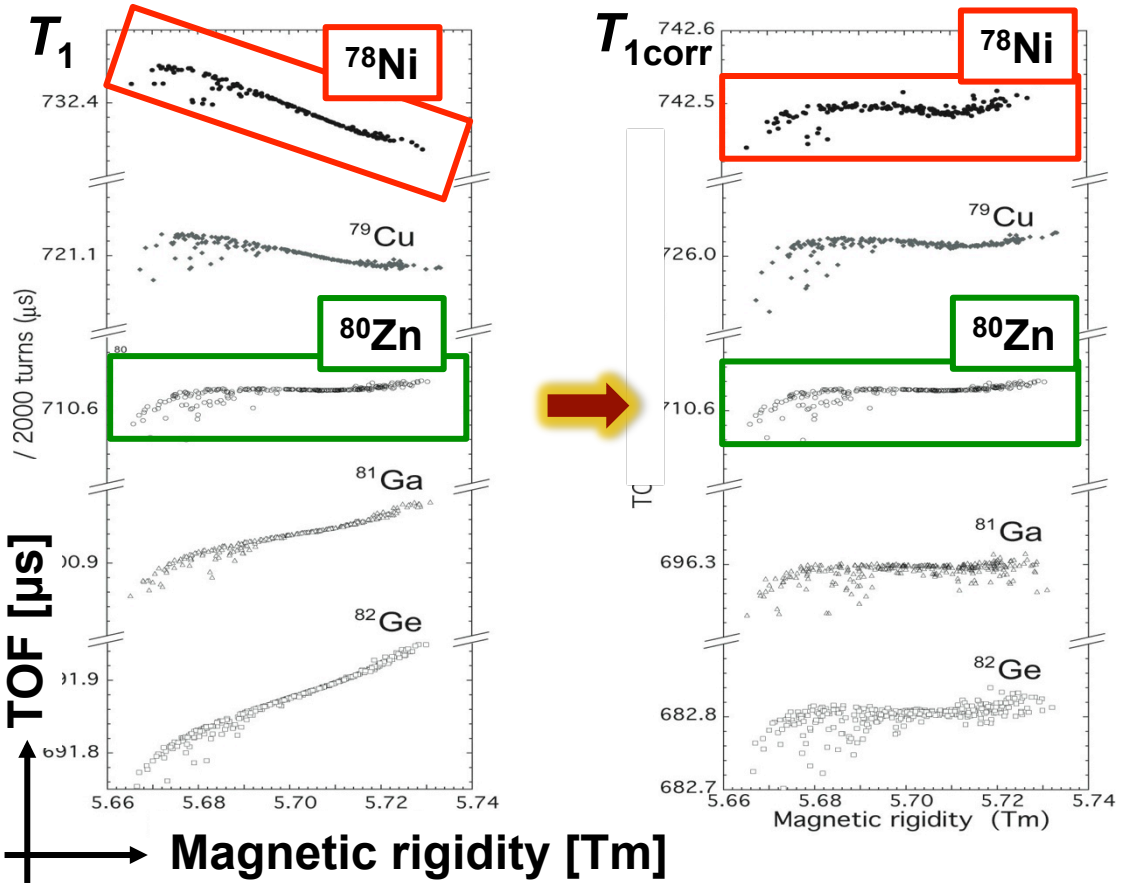


# Expected mass resolution

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

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

**ppm order** $< 10^{-6}$ $\sim 10^{-6}$ $\beta_1 \sim 10^{-4}$ ($k \sim 10^{-2}$)

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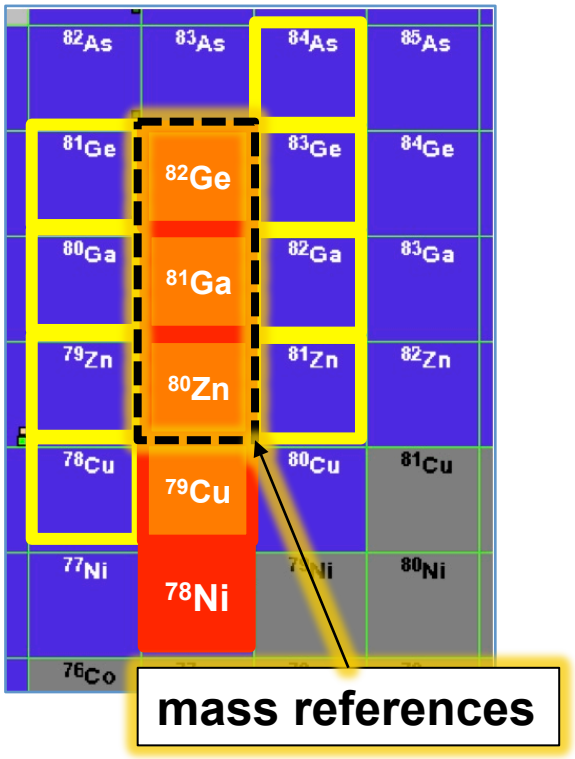


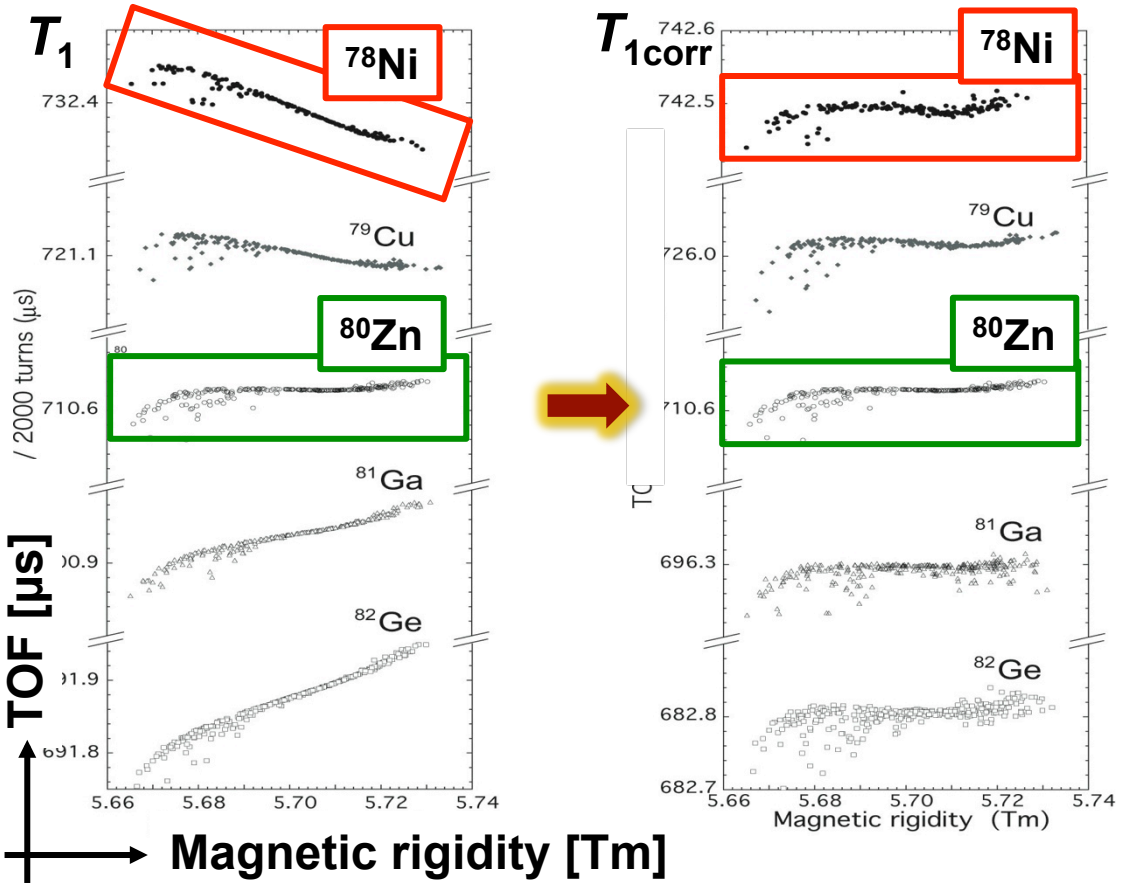


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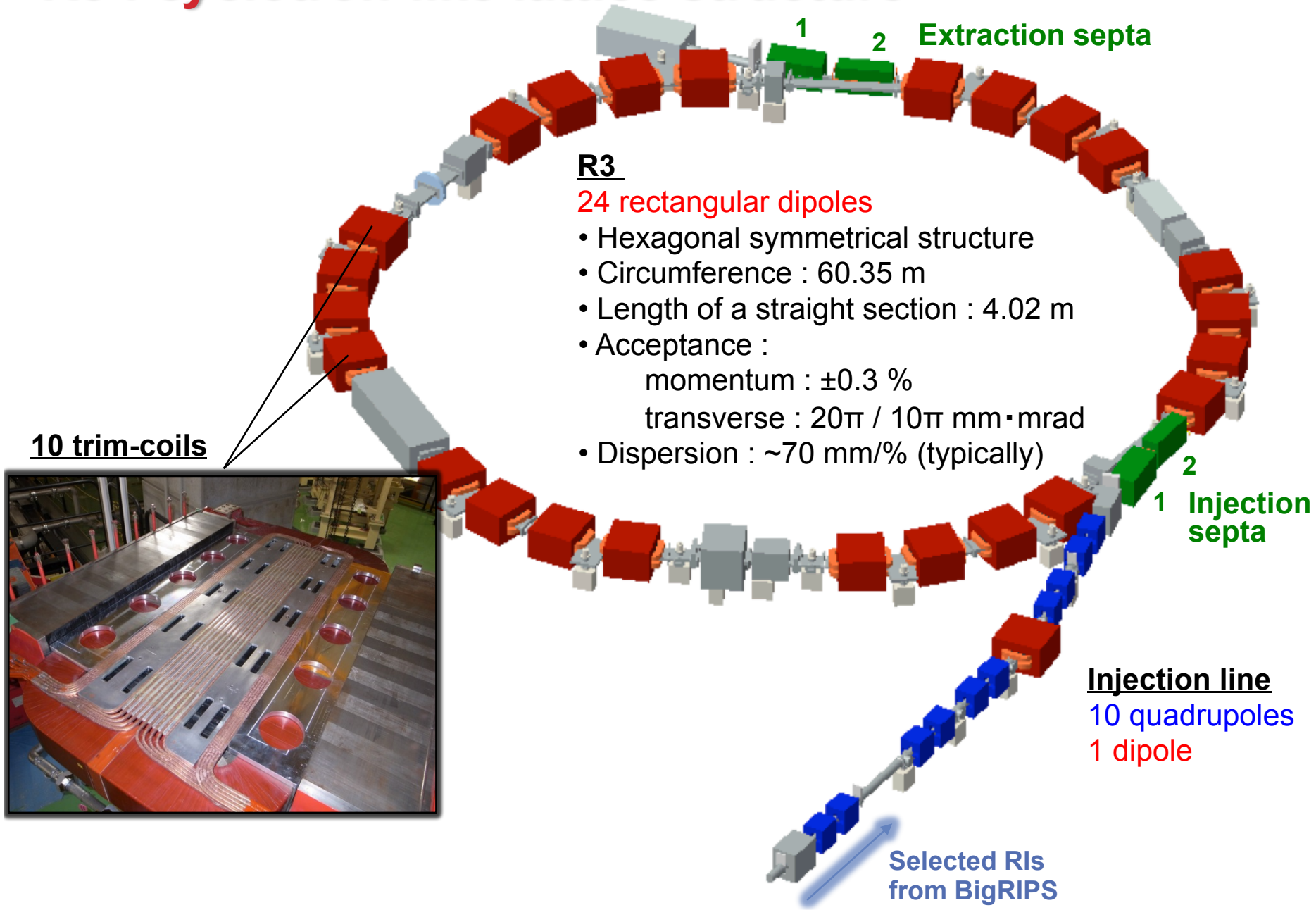
**ppm order** $< 10^{-6}$ $\sim 10^{-6}$ $\beta_1 \sim 10^{-4}$ ($k \sim 10^{-2}$)

**under the isochronous condition of ppm order**

# R3 : cyclotron-like lattice structure



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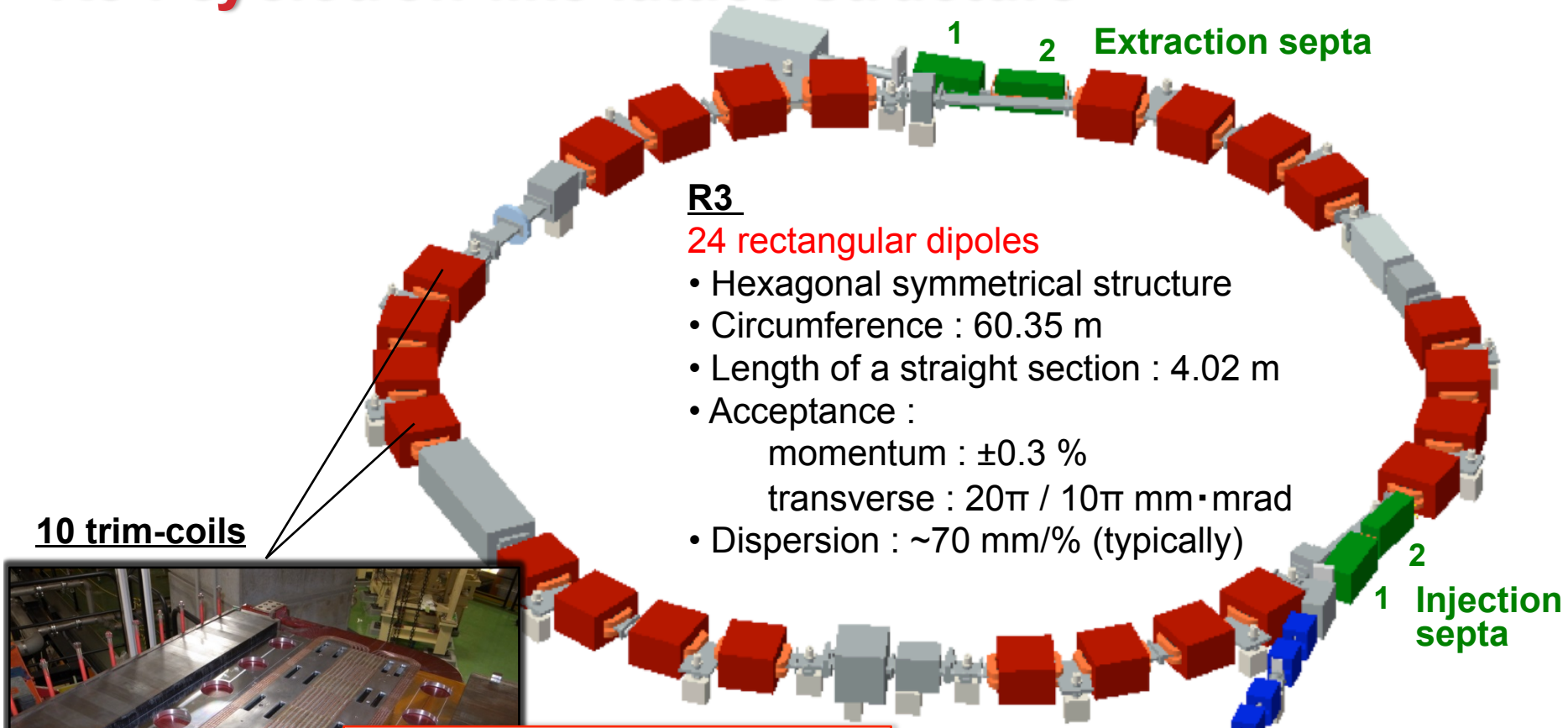
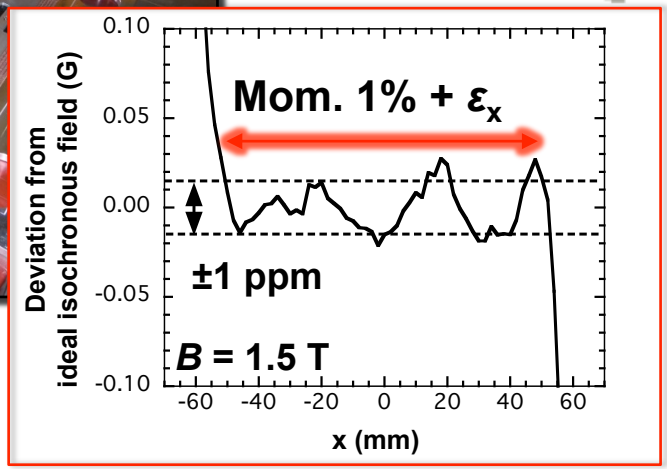


# Construction and Machine study

**2012 - 2013**


**2014 - 2015**

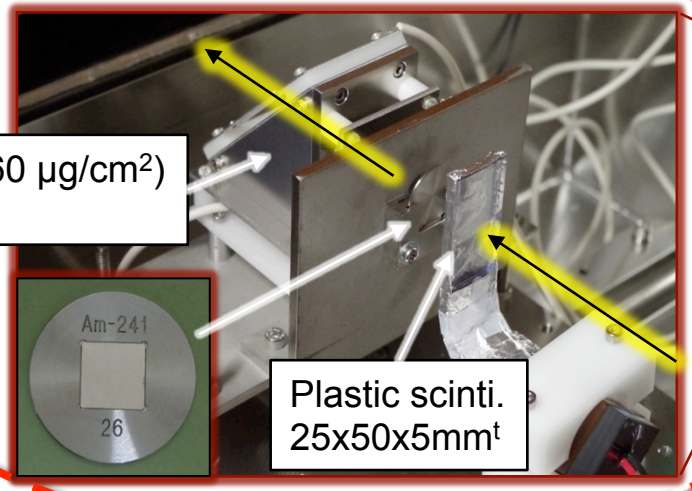
- Basic performance test of R3 using $\alpha$-source.
- Development of fast-kicker system (fast-response, fast-recharging) and beam diagnostic devices. (Resonant Schottky pick-up, C-foil + MCP)
- First commissioning of R3 using $^{78}$Kr beam was conducted on June 2015 and off-line analysis is in progress.

# Performance test of R3 using α-particles I

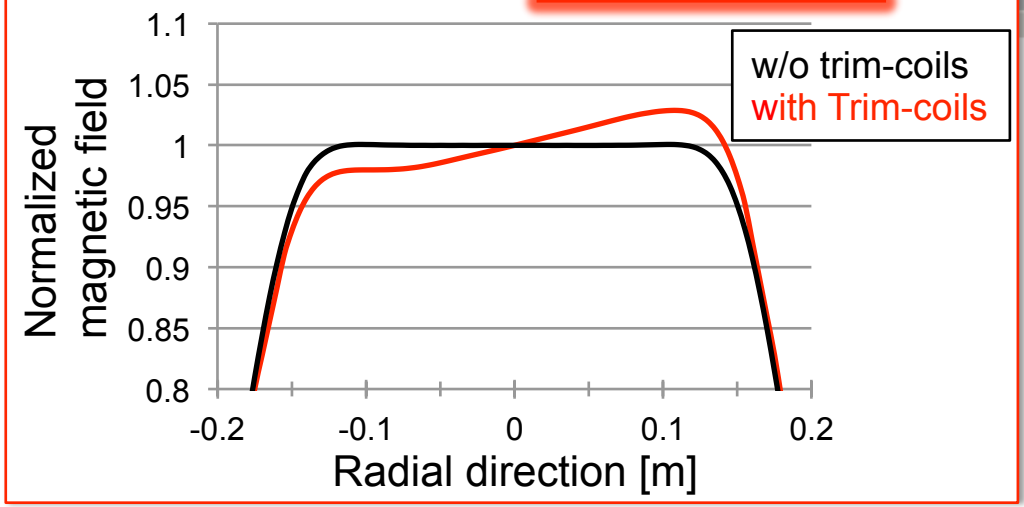
**R3 for α-particle**
Betatron tune : 1.003
Dispersion : 98 mm/%

**Momentum slit**
*dp/p* = ±0.5%

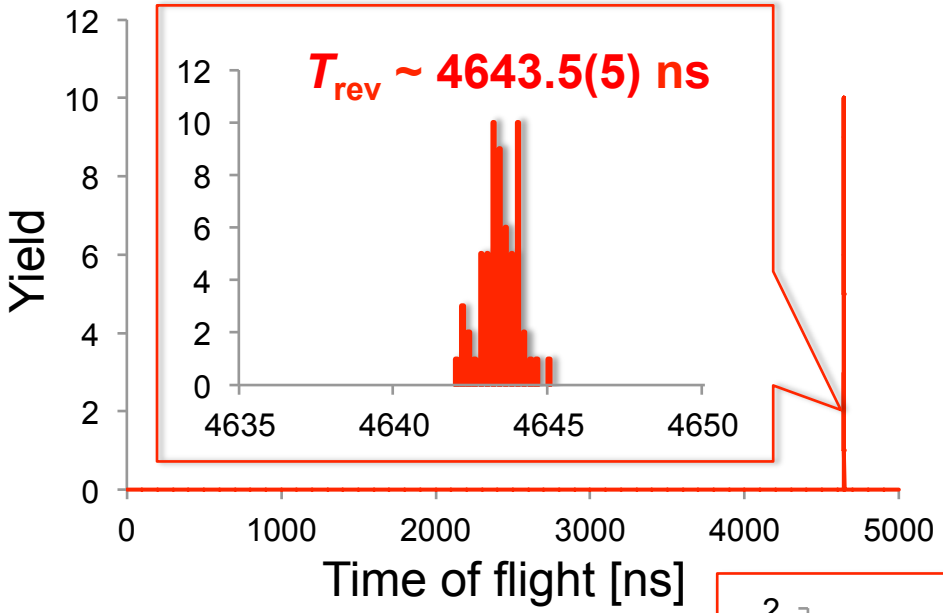
$p_0 + \delta p$ $p_0$ $p_0 - \delta p$

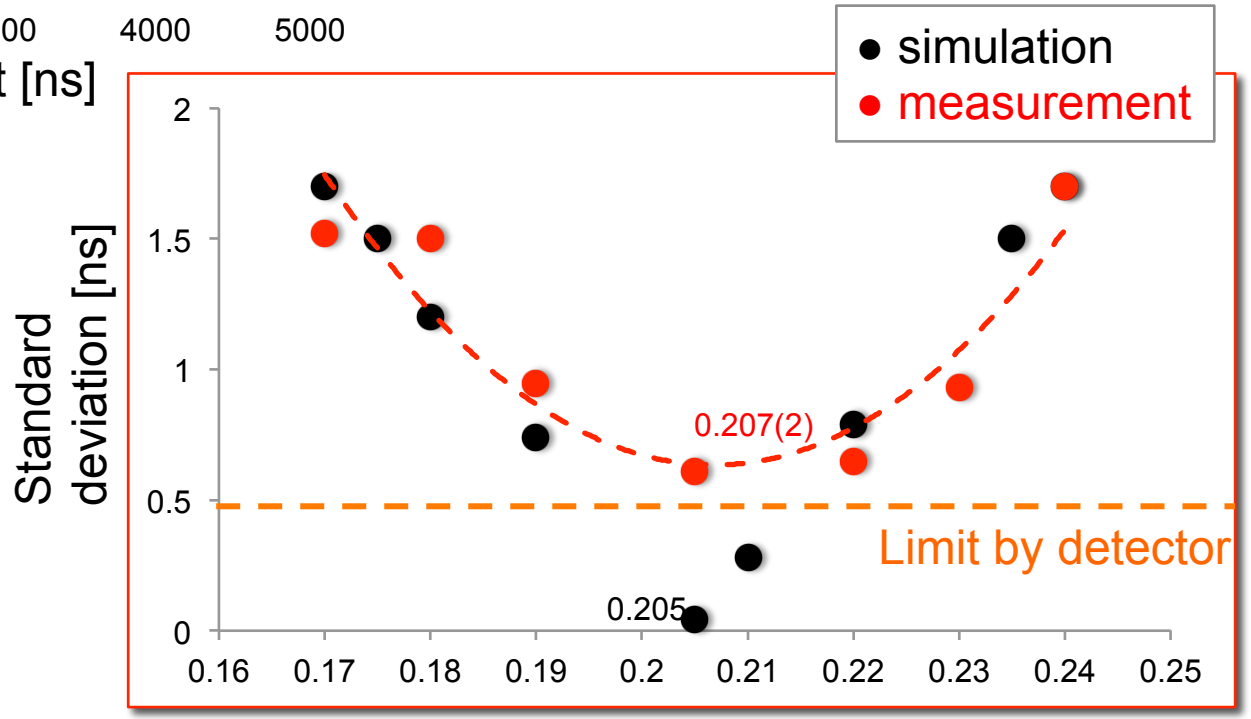



**First-order trim field : $(dB/dr)/B_0$ [1/m]**



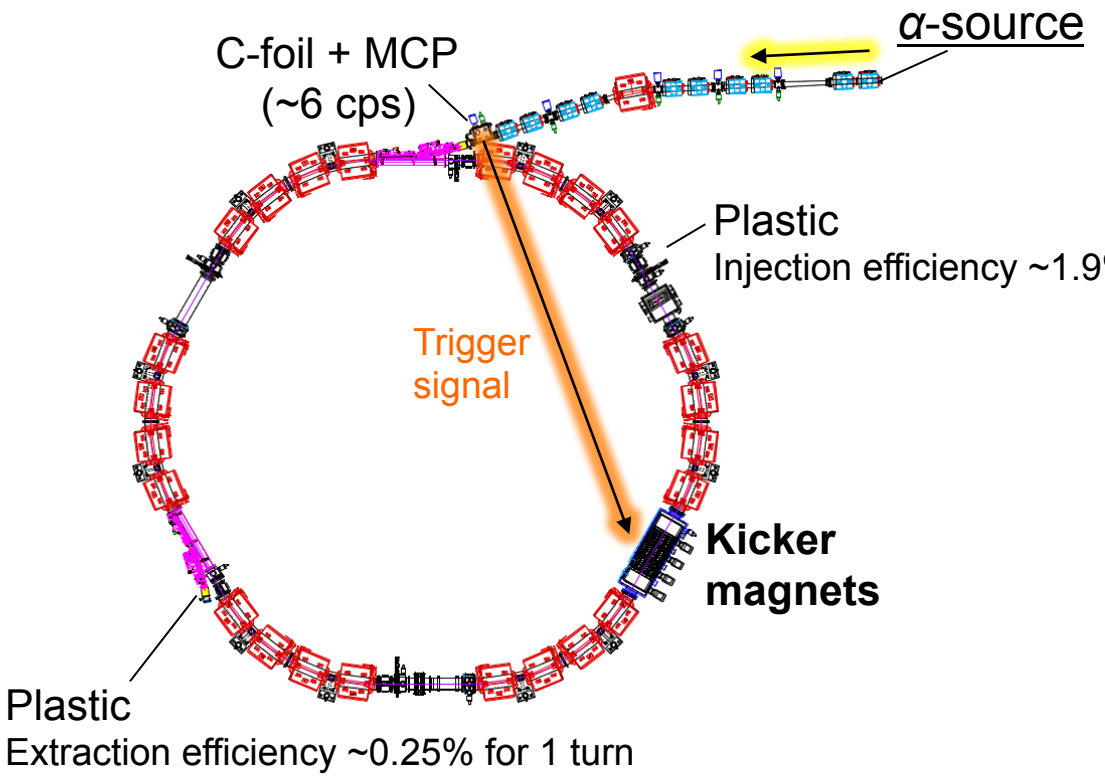
# Performance test of R3 using α-particles II



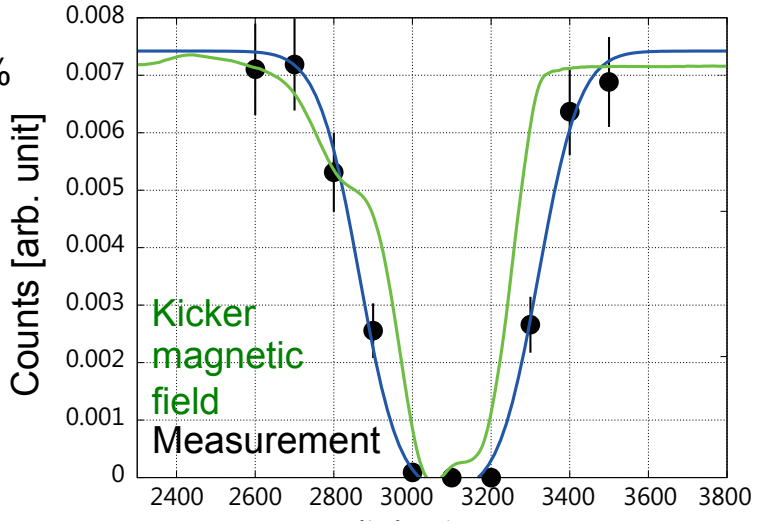




※ Time resolution of this detection system ~460ps

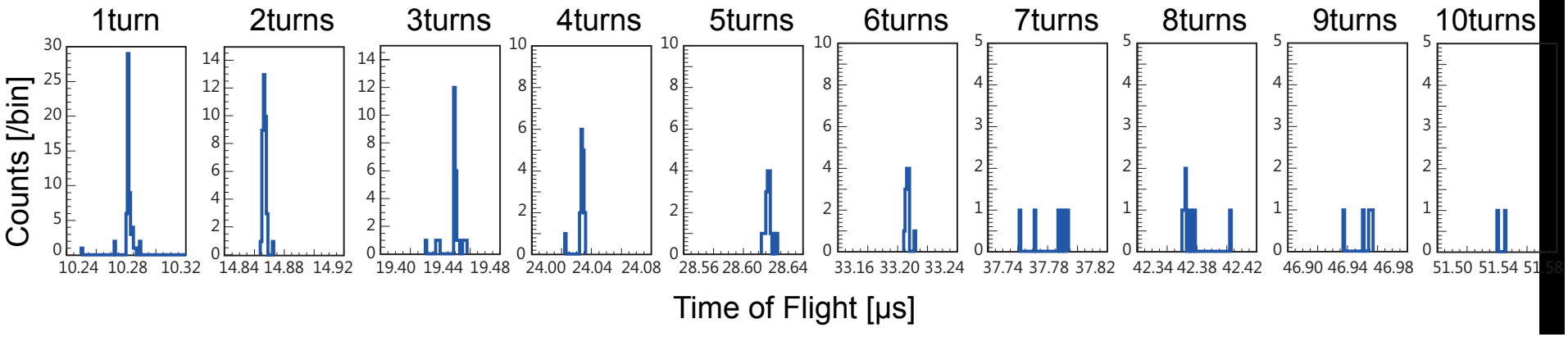
# Performance test of R3 using α-particles III



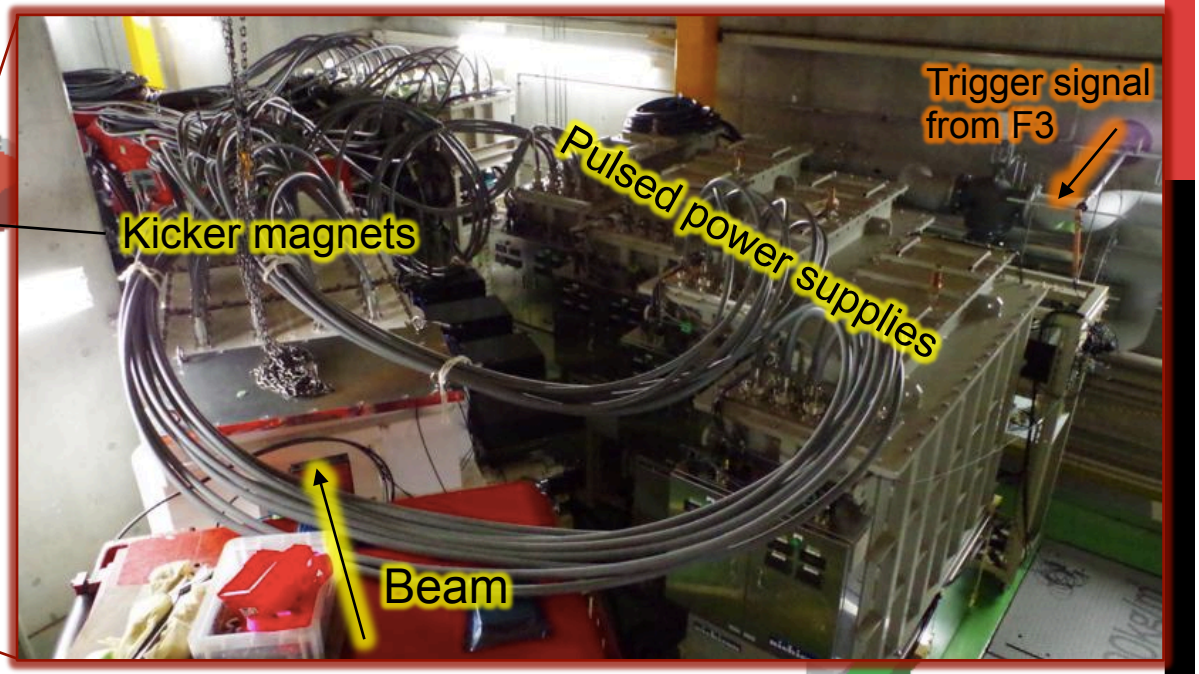

## Injection




## Extraction (4.585 μs/turn)



# Fast-kicker system




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

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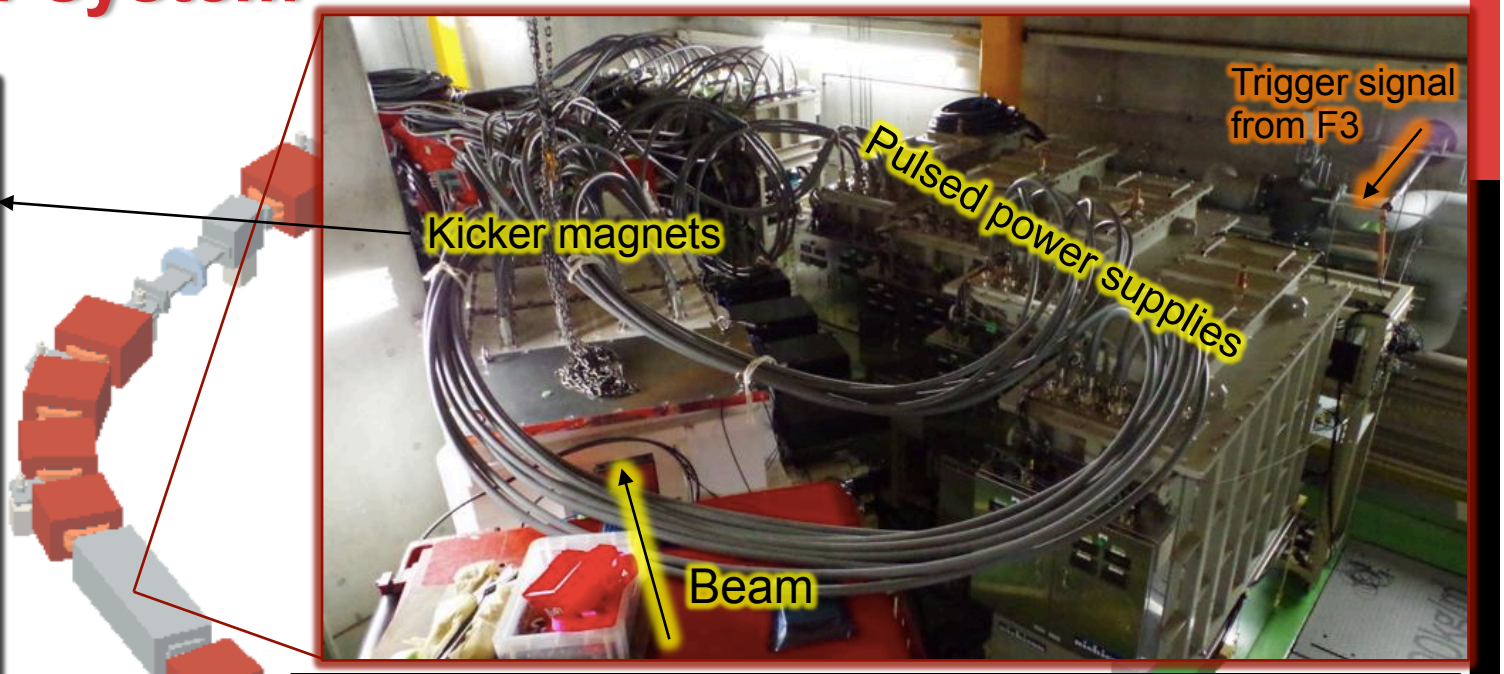


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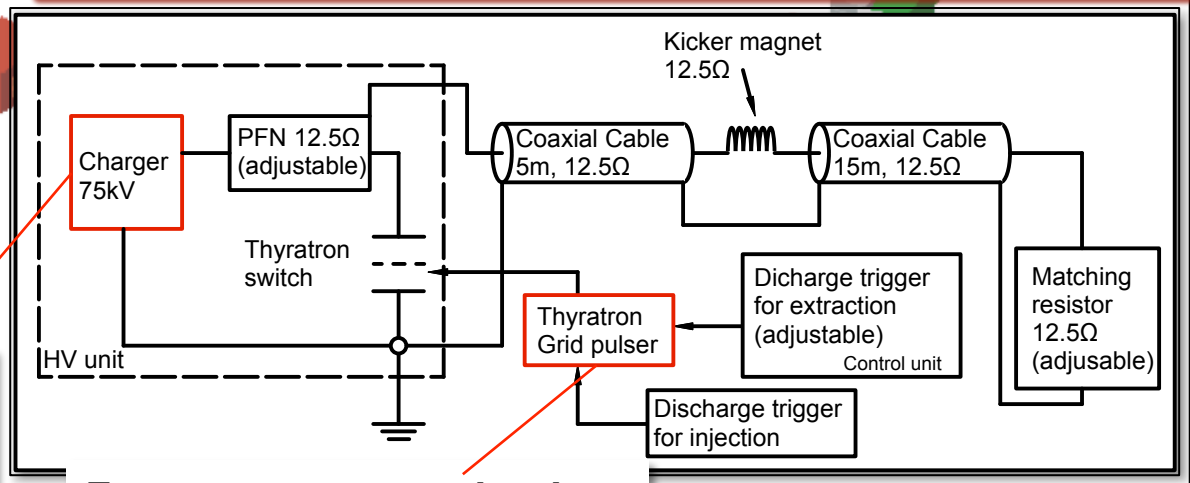



**Fast-recharging mechanism**

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

**Fast-response mechanism**

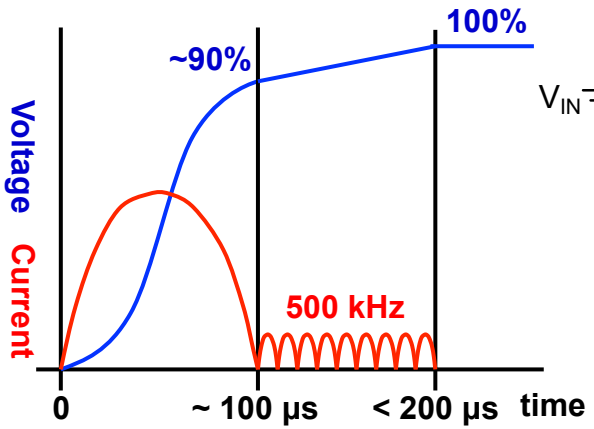
new gate board for Thyratron
to excite a kicker magnet as fast as possible.

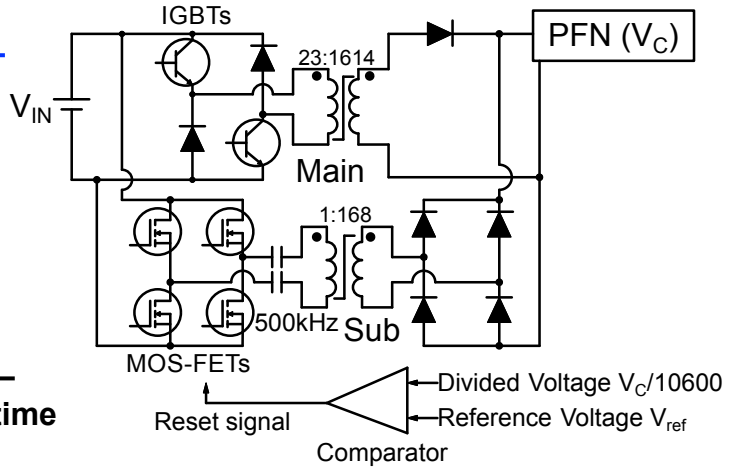
# Fast-recharging mechanism

## Hybrid charging system

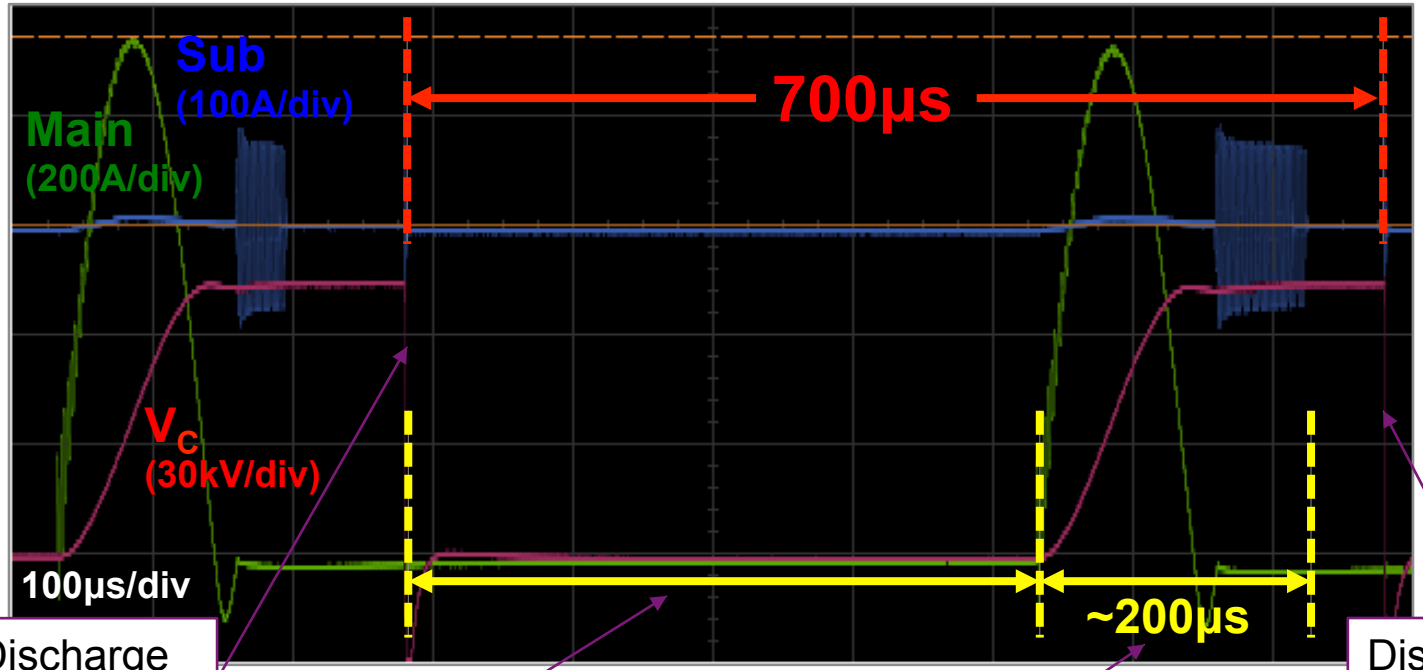
**Main charger**
- Half sinusoidal waveform
- 90% charging in 100μs

**Sub charger**
- 500kHz resonance
- +10% charging within 100μs
- Keep $V_C$ 100±1% to discharge at any time




PFN charging waveform (1set)



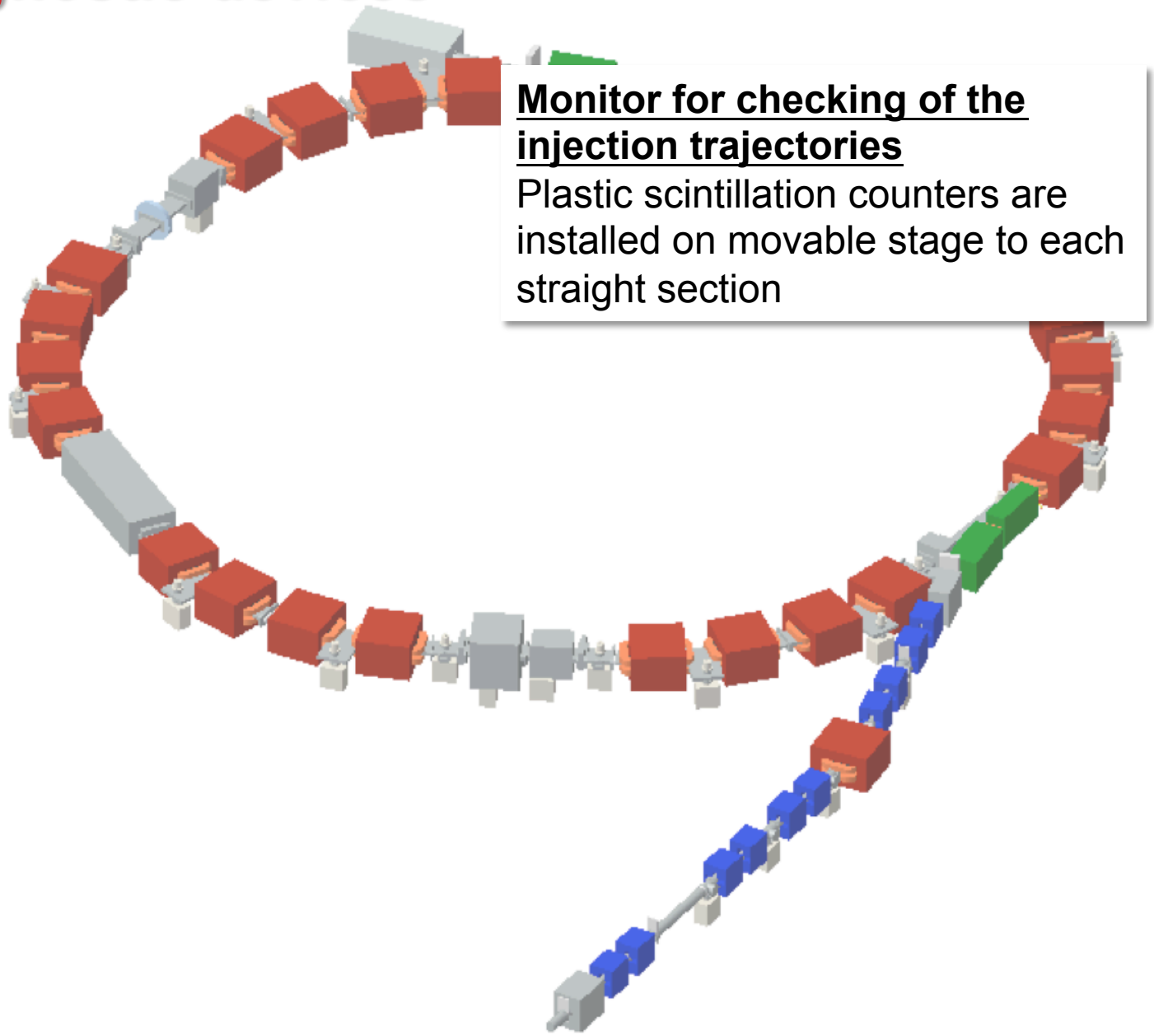

Discharge for injection

Interval for thyratron recovery

Recharging time

Discharge for extraction

# Beam diagnostic devices



**<u>Monitor for checking of the injection trajectories</u>**

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

# Beam diagnostic devices

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

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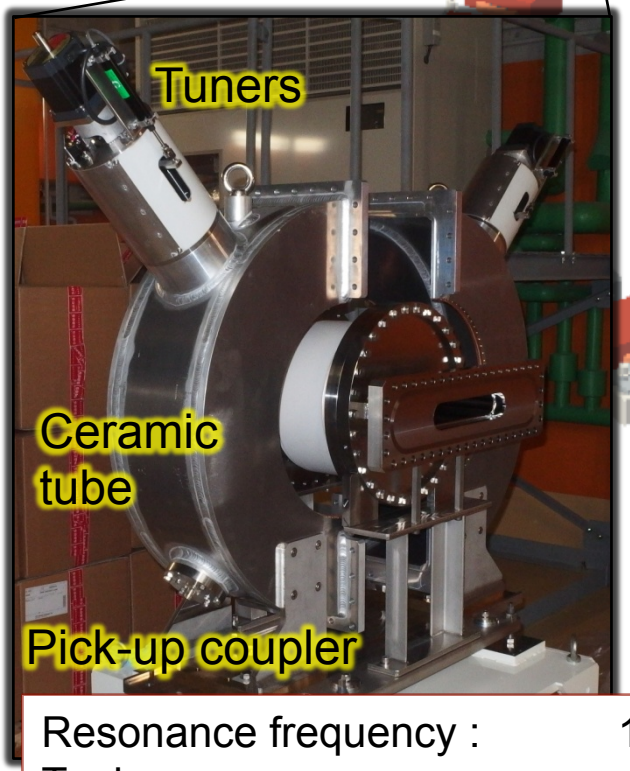


| | |
|---|---|
| Resonance frequency : | 173MHz ($TM_{010}$) |
| Tuning range : | ±1.5MHz |
| Shunt Impedance $R_{sh}$ : | 161kΩ |
| Quality factor $Q_0$ : | 1880 |
| Ceramic tube size : | 290mmΦ, 15mm thickness |

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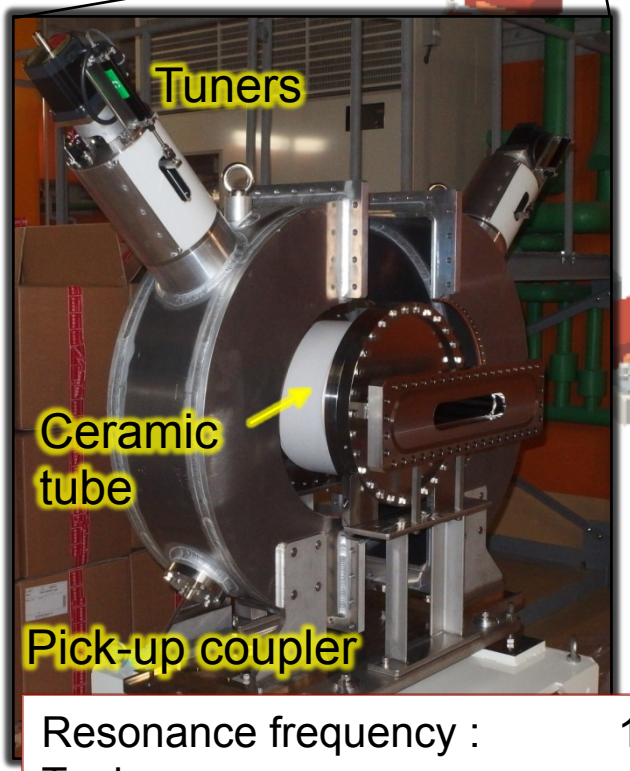


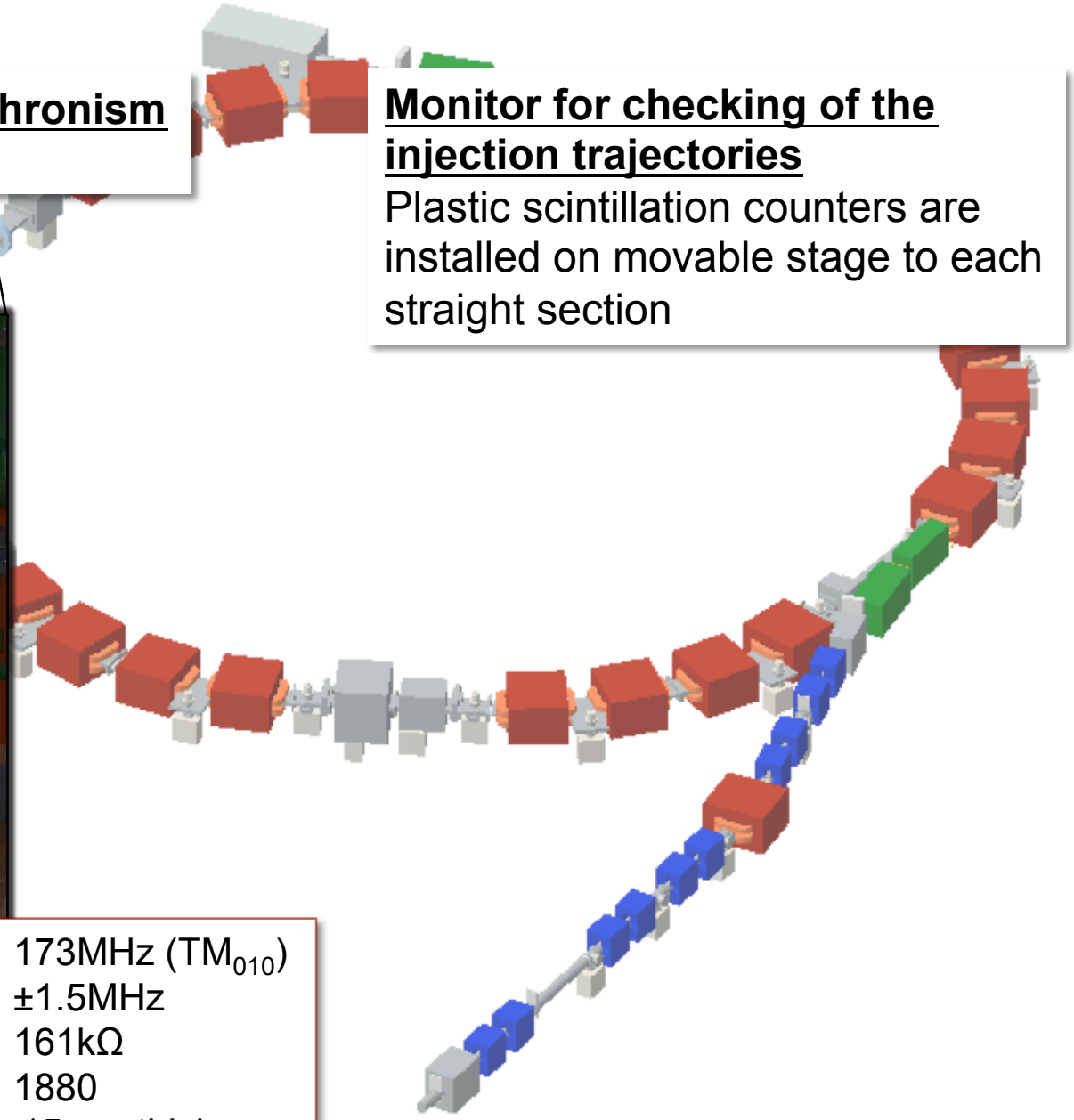

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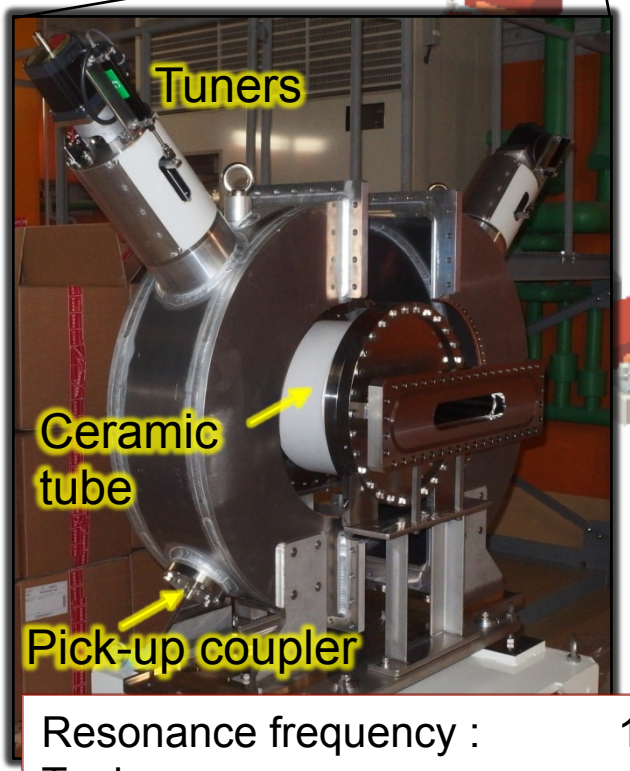


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Resonant Schottky pick-up

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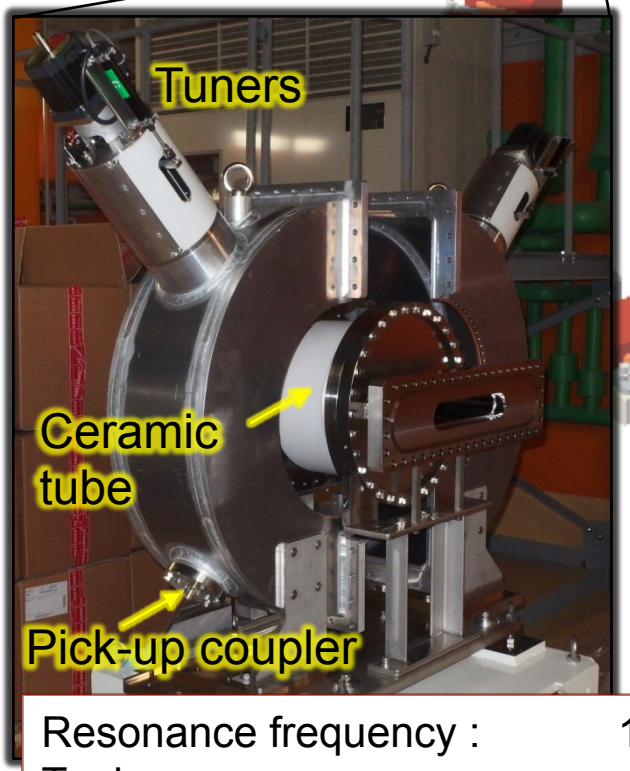
**Monitor for circulating particle**
C-foil + MCP timing monitor

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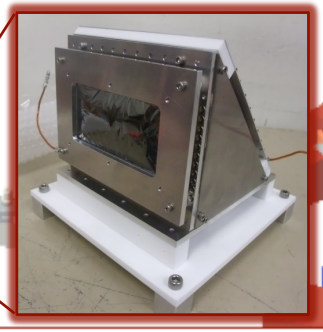


C-foil (60μg/cm$^2$)
MCP secondary electron detector
- Window size : 100×50 mm$^2$
- Position sensitivity : less than 10mm
- Efficiency : ~ 75 %
- Time resolution : σ ~ 130ps with $^{84}$Kr 200MeV/u

# First commissioning of R3 using $^{78}$Kr beam

**Items**

0. Beam transport
1. Individual injection using self-trigger mechanism
2. Detect the circulating particles using C-foil + MCP
3. Extraction the circulating particles
4. Isochronous condition with TOF vs. F6x information
5. Resonant Schottky pick-up with single $^{78}$Kr ion

**Beam conditions**

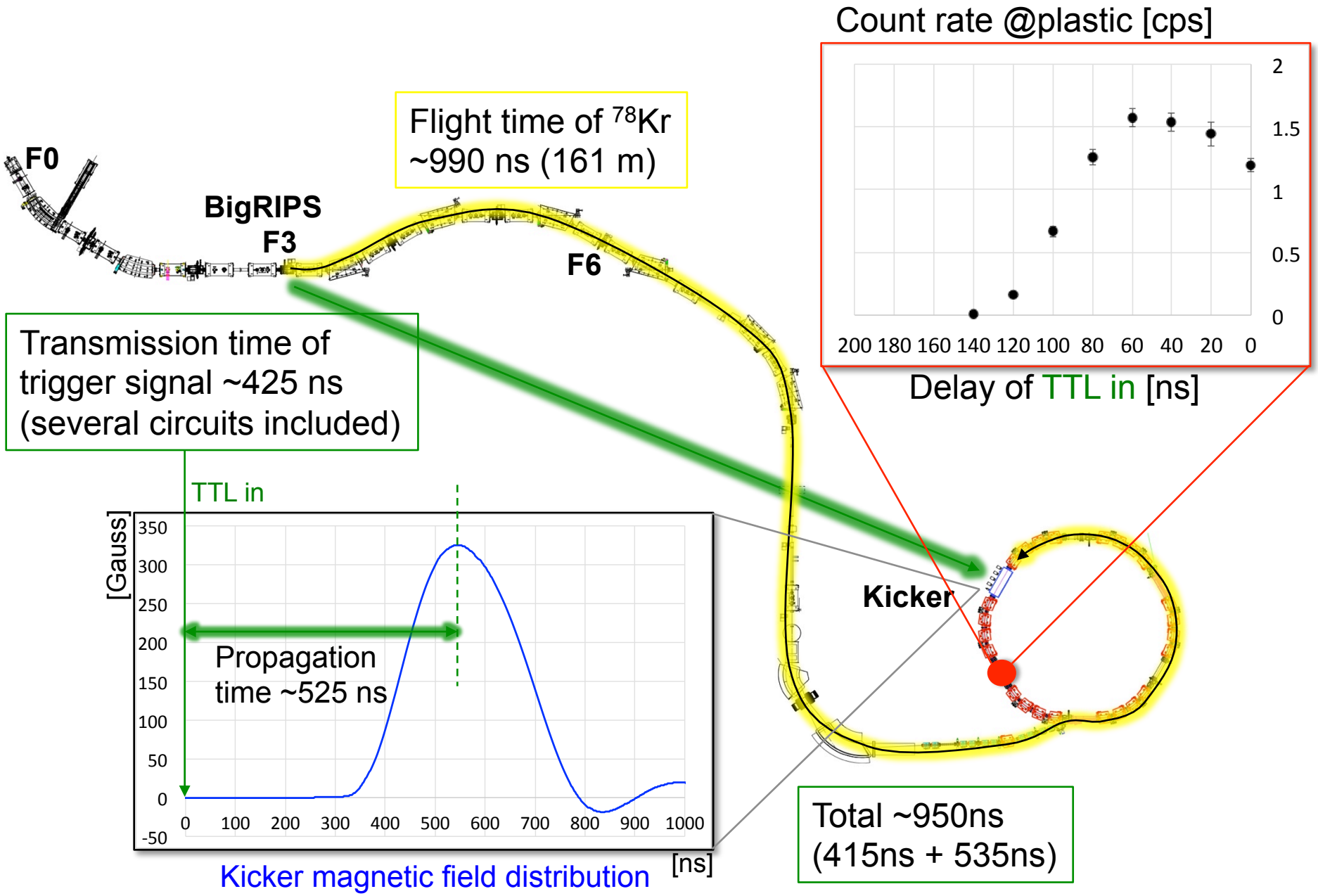
- Energy : 345 MeV/u → 168 MeV/u @R3
- Injection repetition rate : ~90 Hz (@F3 circuit)

**Ring conditions**

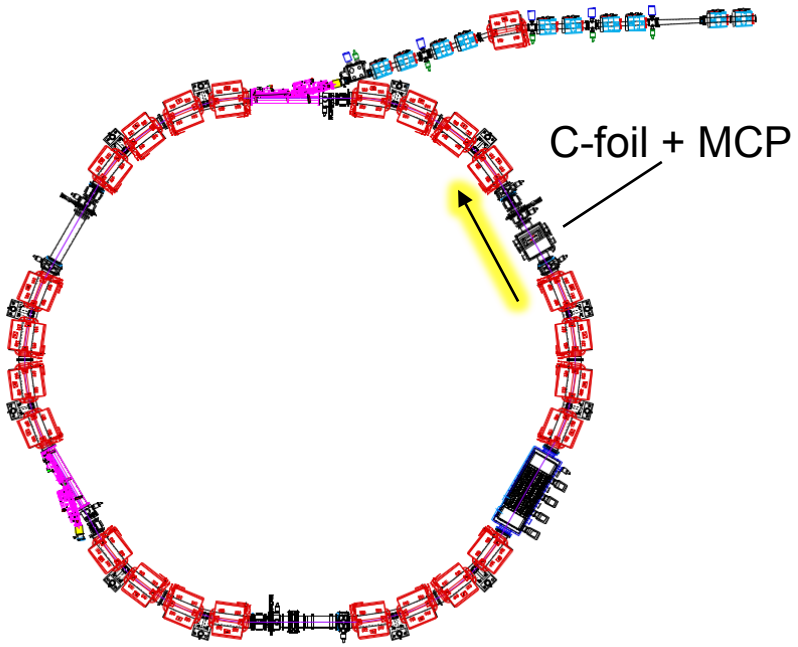
- Transition $\gamma_{tr}$ : 1.18
- Betatron tune : $v_x$ = 1.18, $v_y$ = 0.93
- $\beta$ function : $\beta_x$ = 8.4 m, $\beta_y$ = 11.9 m
- Dispersion : 70 mm/%
- Kick angle : ~11 mrad

# 1. Individual injection

Proposed by I. Meshkov NIMA523(2004)262



# 2. Detect the circulating particles

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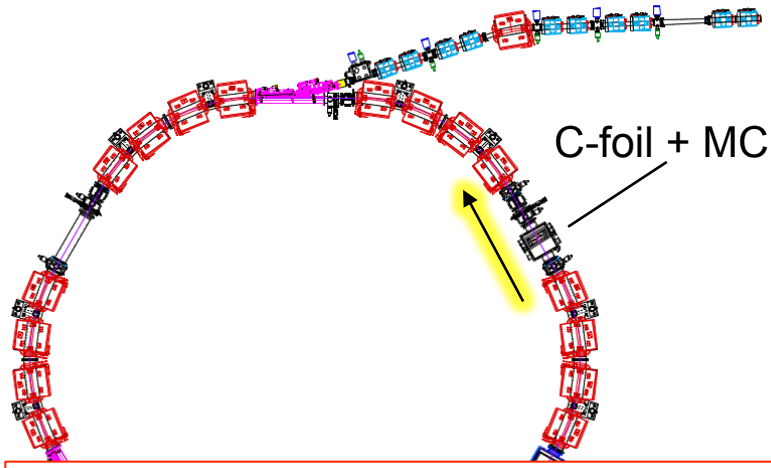
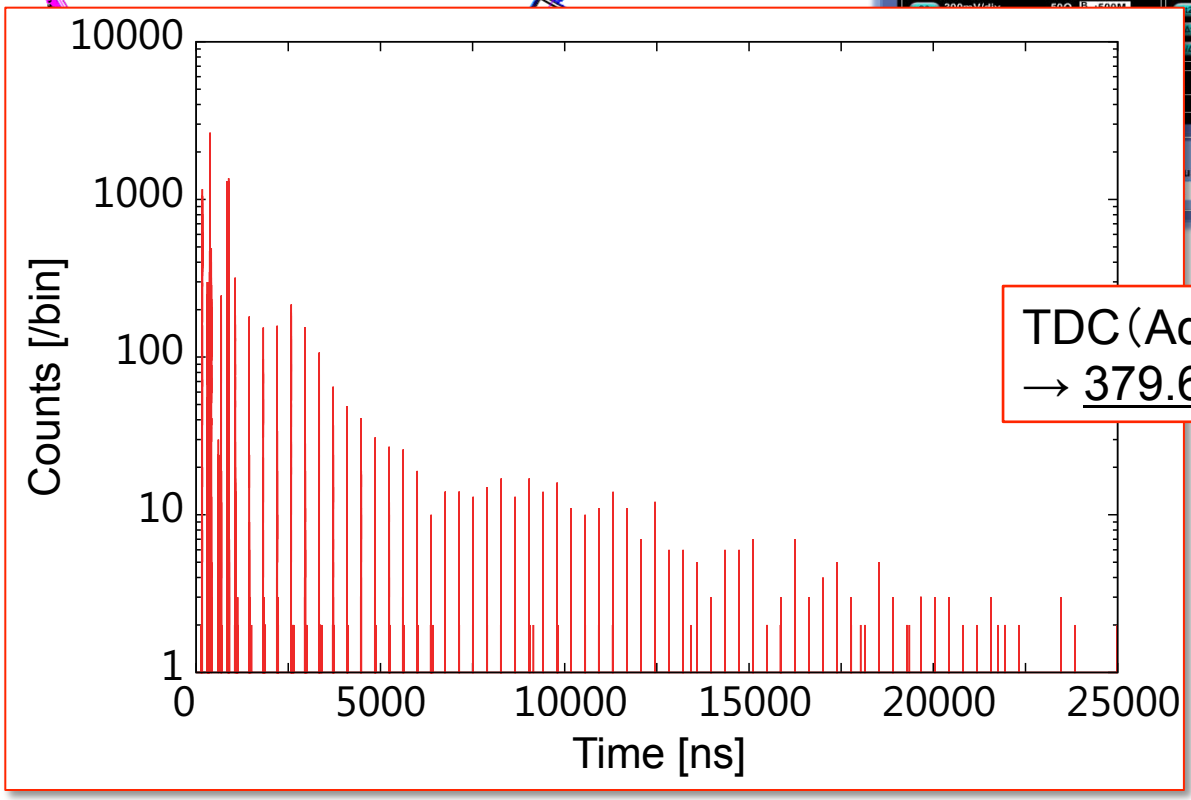


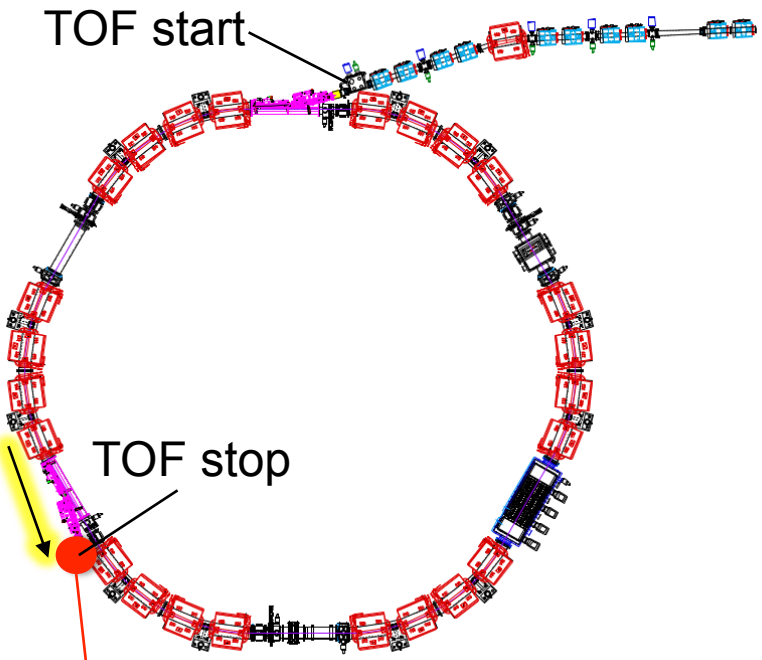




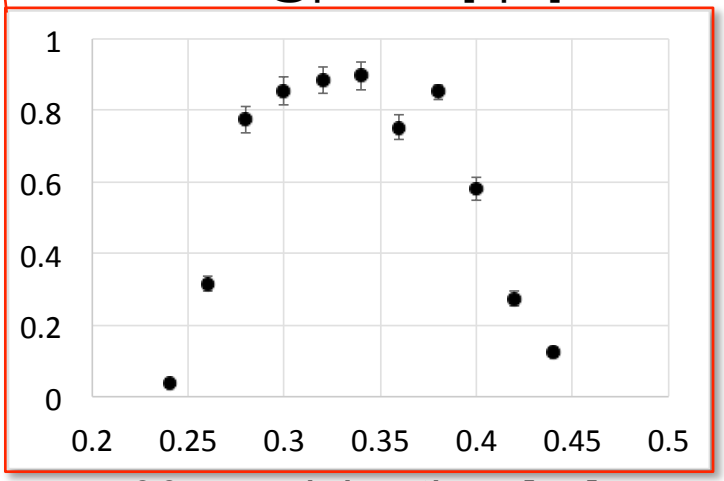

TDC（Aquiris TC890）
→ 379.65 ns / turn

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

# 3. Extraction



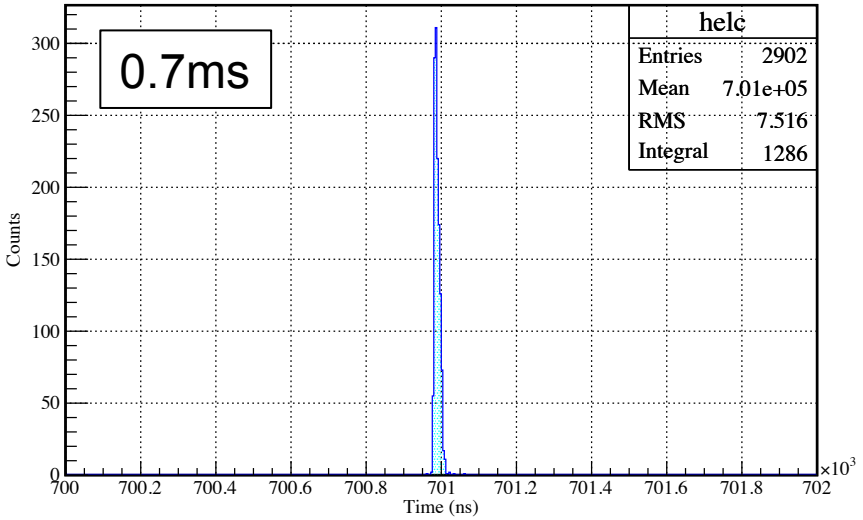

Count rate @plastic [cps]



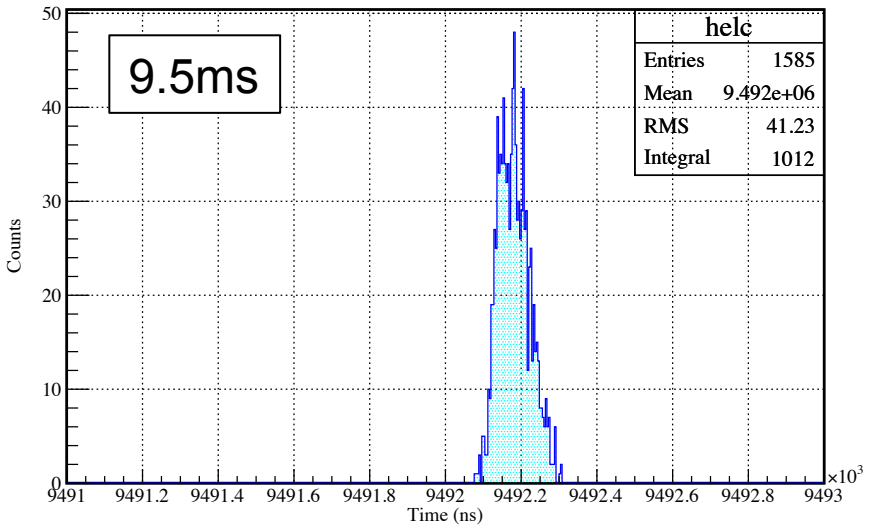

700μs + delay time [μs]

**TOF spectra**

for the difference extraction timing

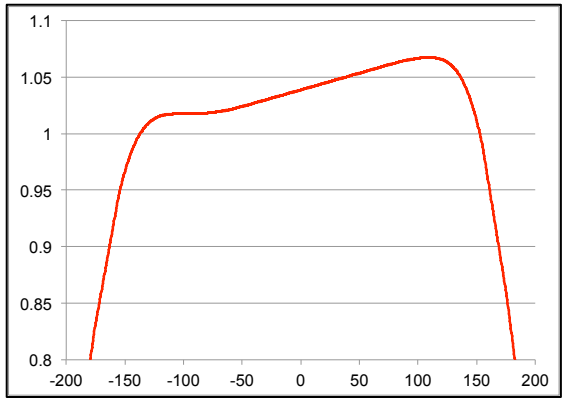



ELC

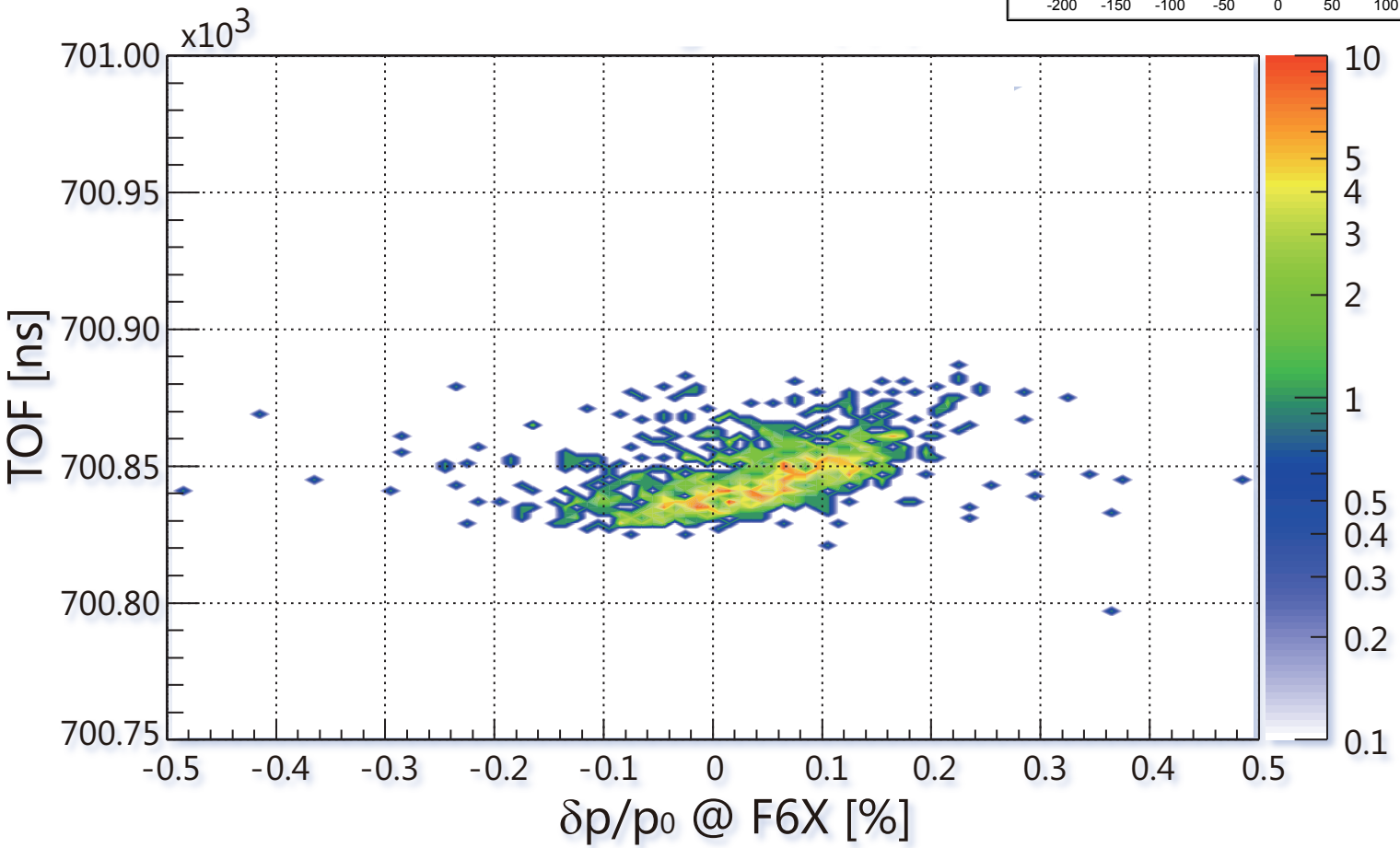


# 4. Isochronous condition

Magnetic field distribution

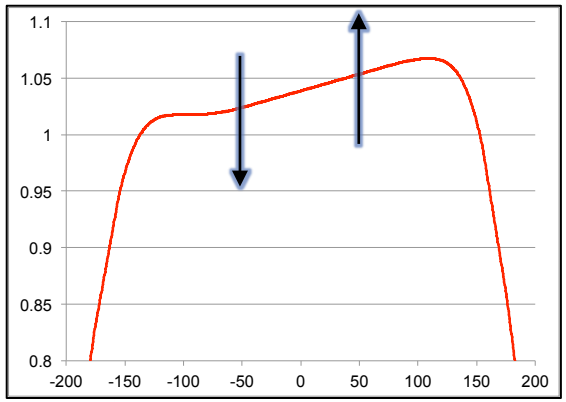



First-order trim field : $(dB/dr)/B_0$=0.277



# 4. Isochronous condition

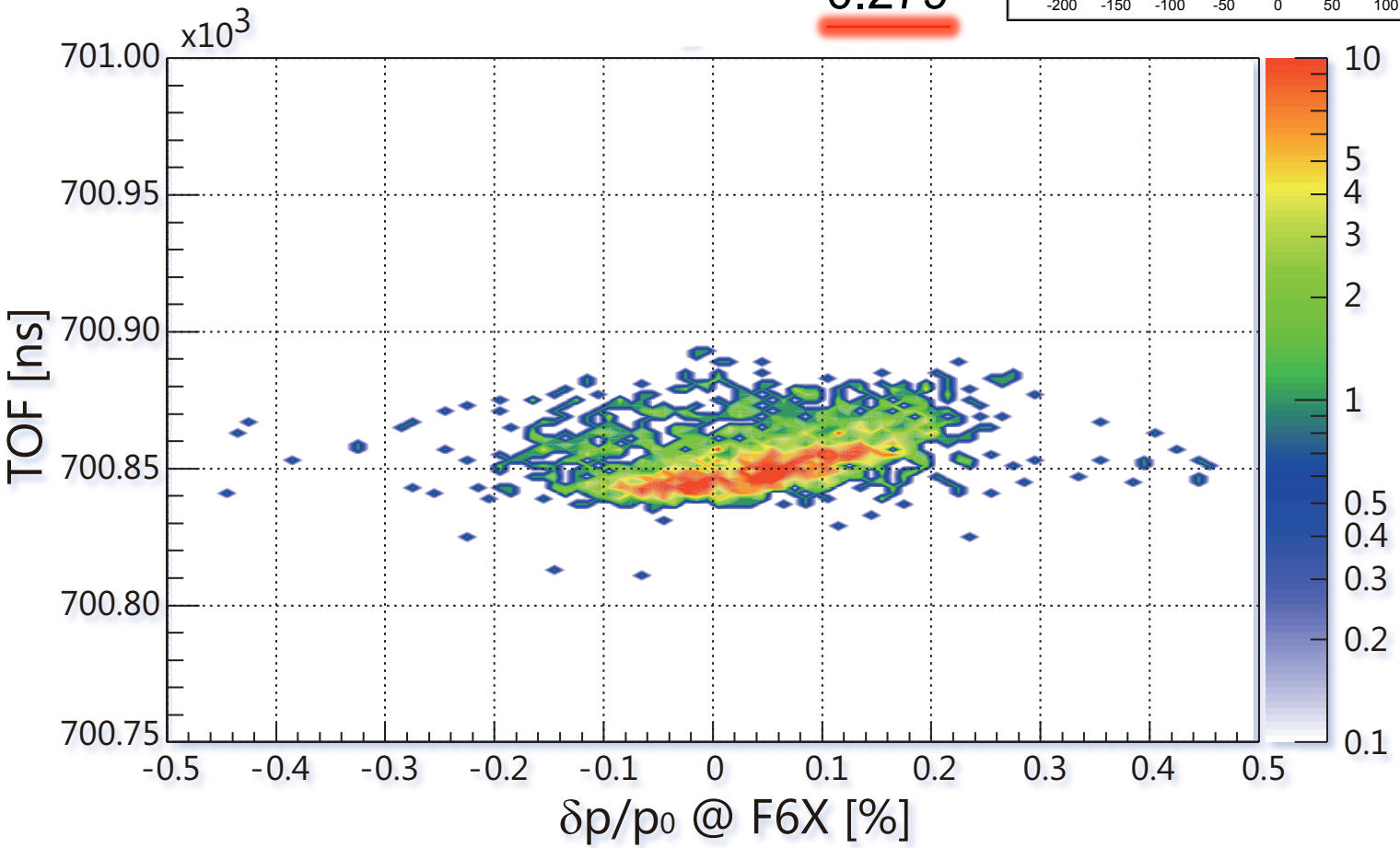
Magnetic field distribution




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

↓

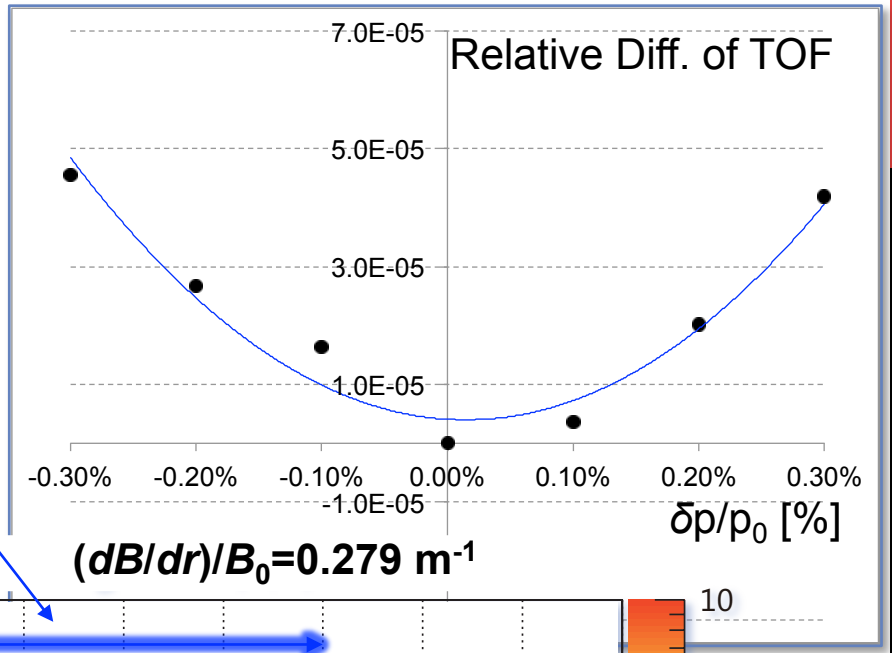
0.279

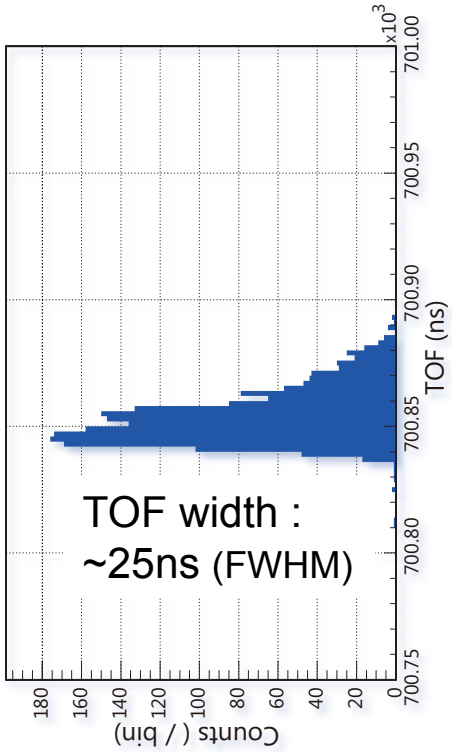


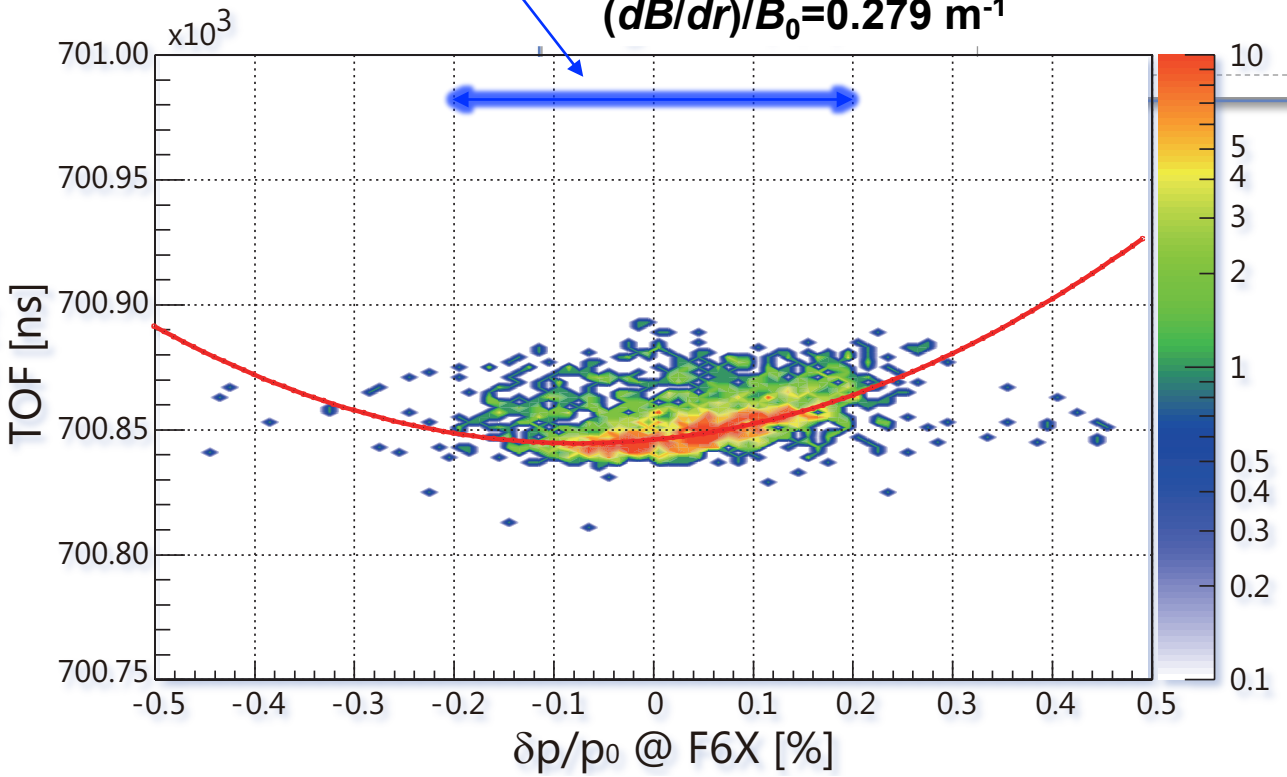
# 4. Isochronous condition

- Extractable momentum width : ±0.2%
- Degree of isochronism : ~3.5x10$^{-5}$ (10-ppm order including the tail)

## Result of numerical analysis

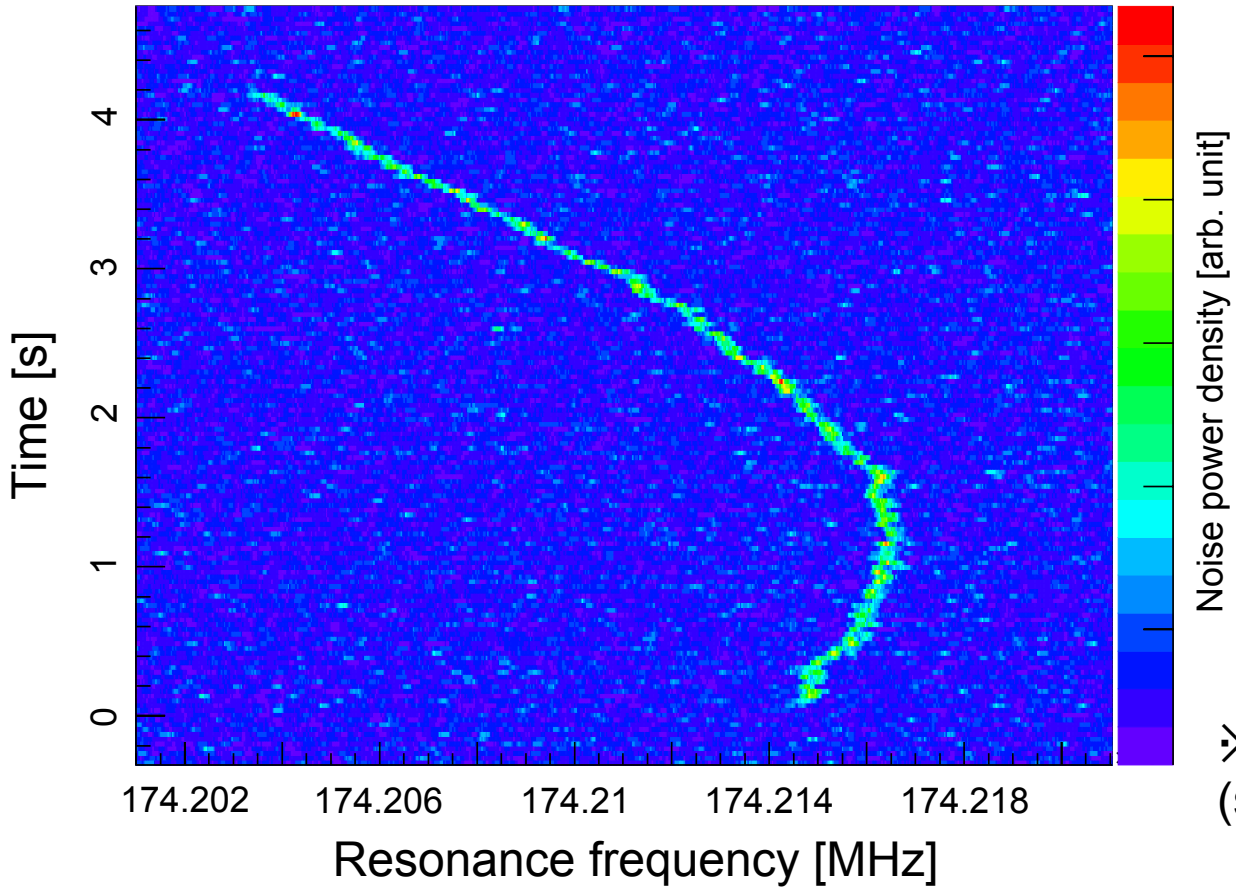


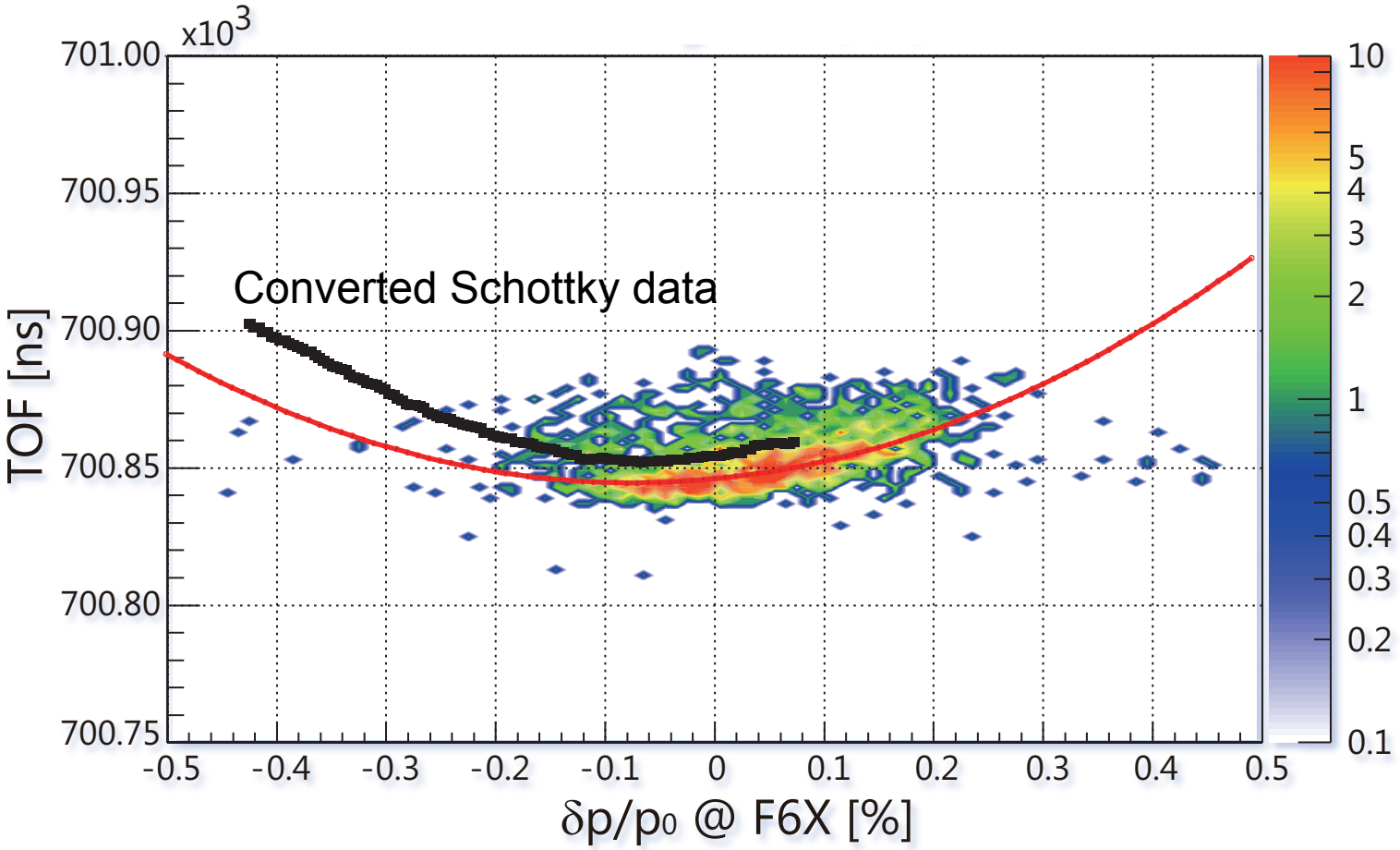
# 5. Resonant Schottky pick-up (in storage mode)

- Succeeded in detecting the single $^{78}Kr^{36+}$ ion → high sensitivity
- Frequency resolution : ~1.3x$10^{-6}$ (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.




※ 34 events in total !
(stored time > 1 sec.)

# Preliminary consideration




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

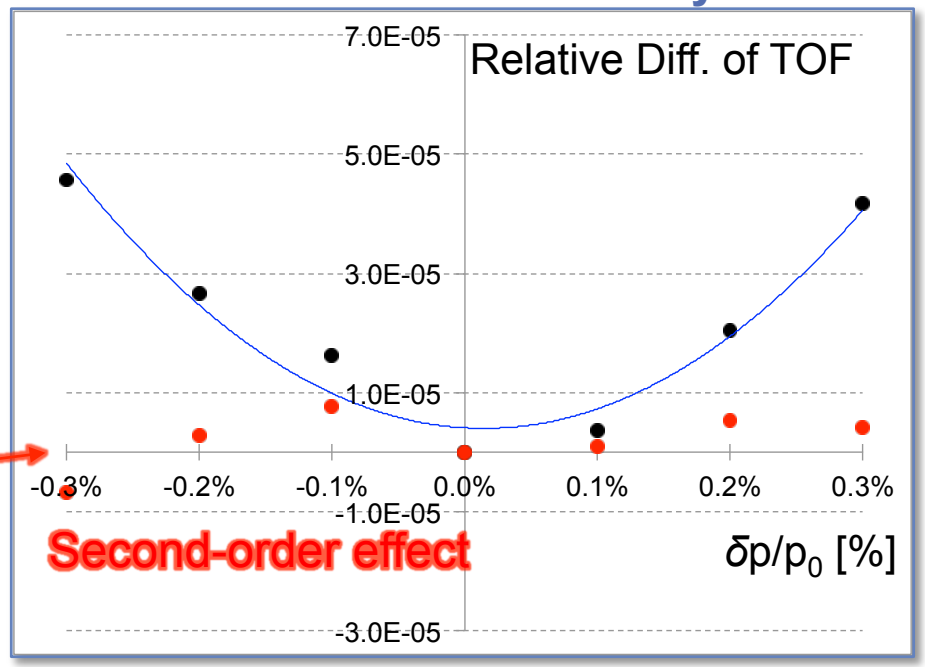
# Summary

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

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

• 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.**

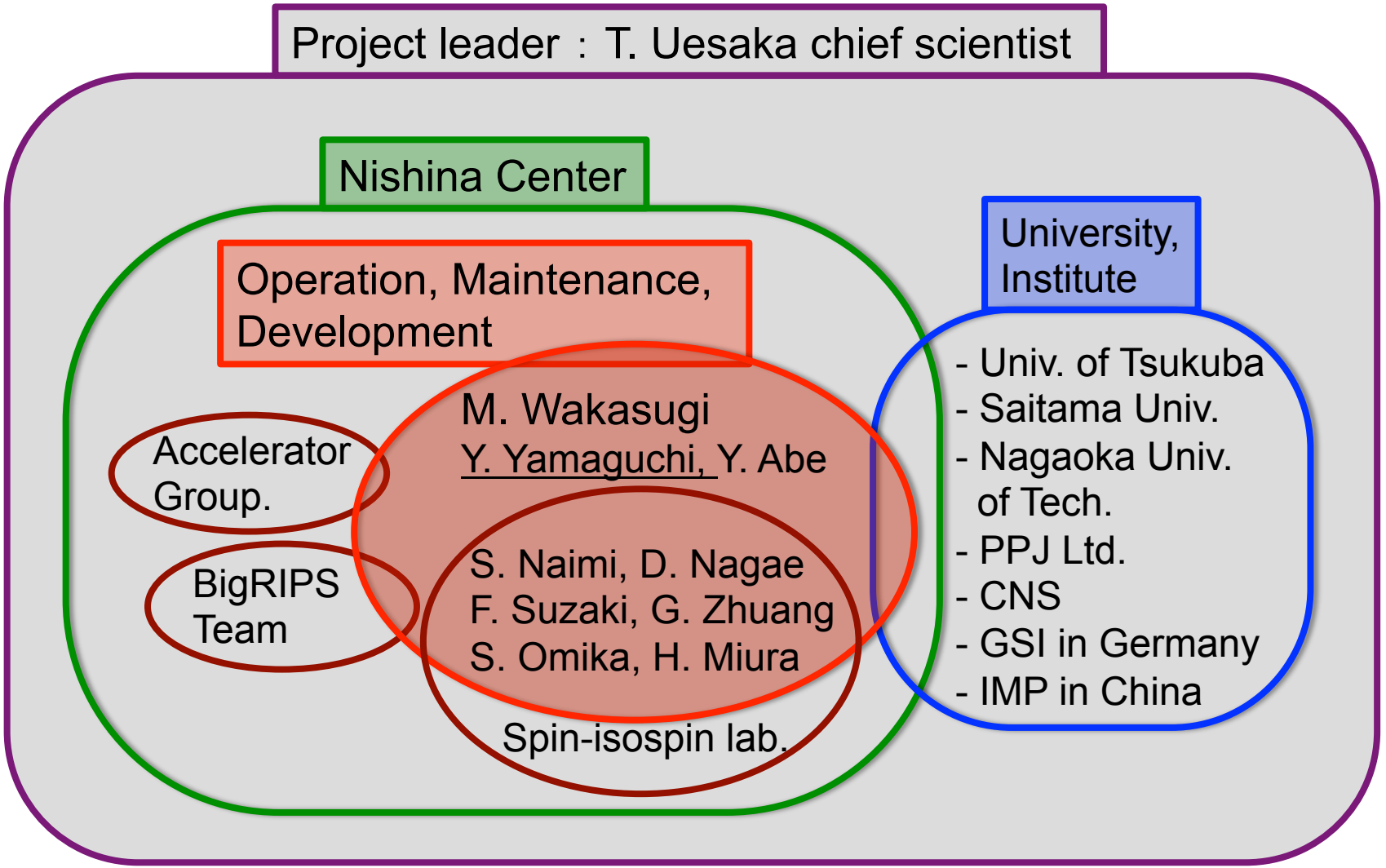
• Verification of the principle of relative mass measurements

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

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

**We will start mass measurement experiments from 2016.**

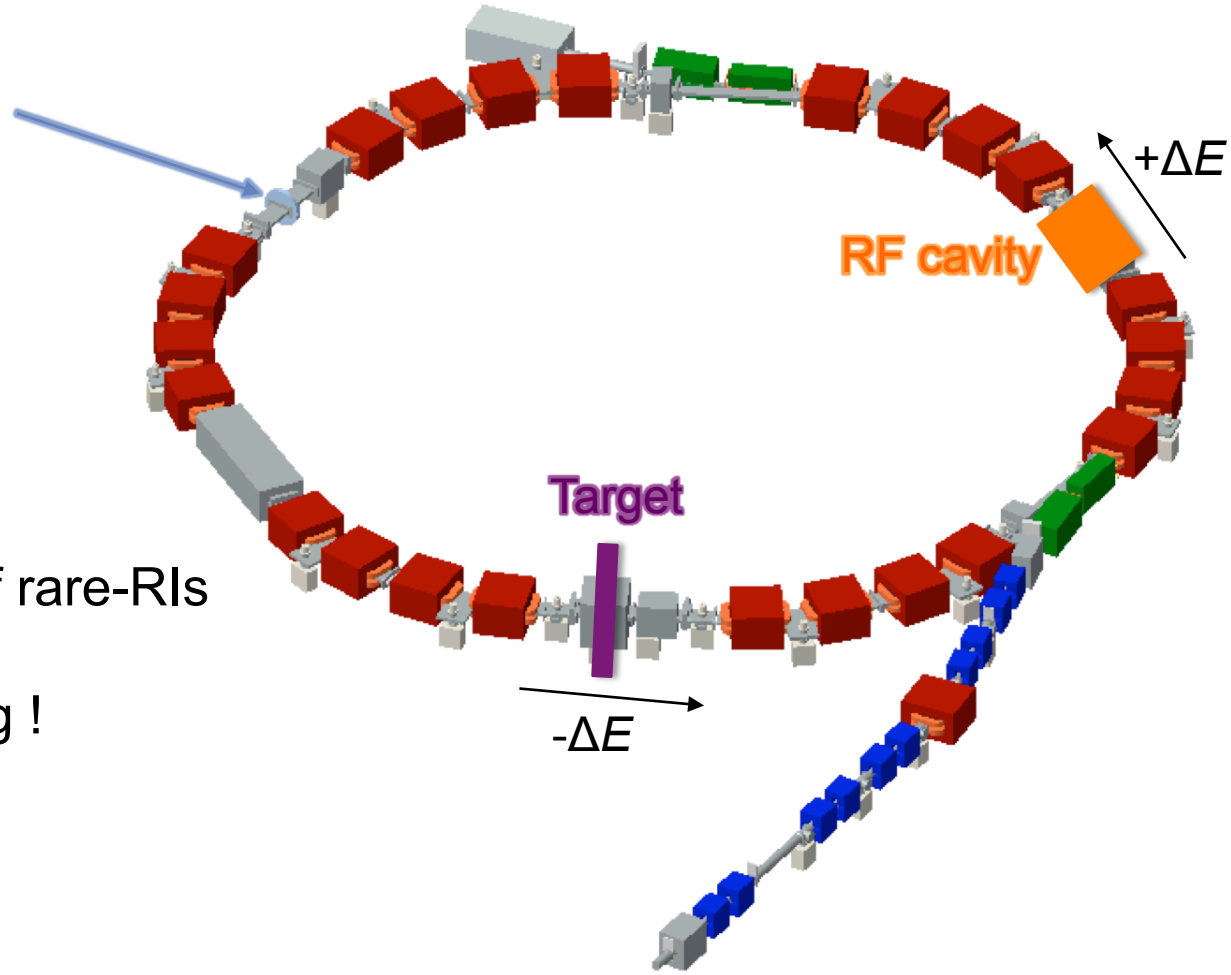
# Thank you for your attention



# Prospects

R3 will be improved as a **ppm-order machine** in a few years.
→ precision mass measurement even only one event / day

Resonant Schottky pick-up
→ lifetime measurements
of rare-RIs




In the future:
Nuclear reaction study of rare-RIs
will be performed at R3
with help of beam cooling !