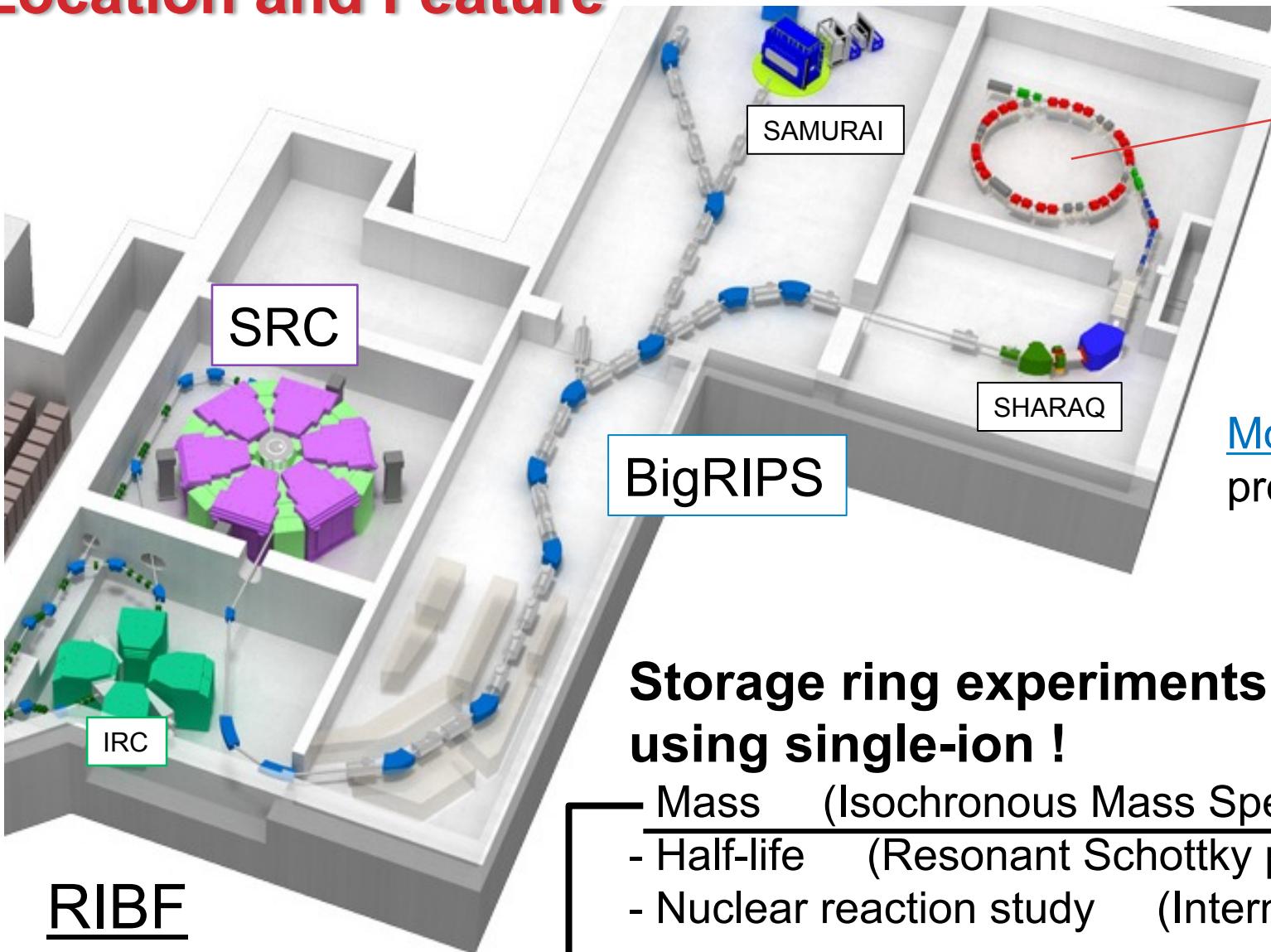


# The Rare-RI Ring at RIKEN RI Beam Factory



**Yoshitaka Yamaguchi on behalf of R3 collaboration**

# Location and Feature

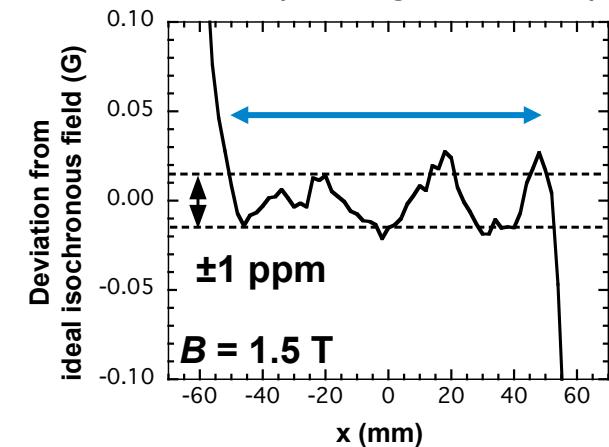


## R3 (Rare-RI Ring)

### Rare-RI

- Very short-lived (<10ms)
- Vert low production rate (1 particle / day)

Momentum acceptance is 1% with precise isochronous field. (design value)

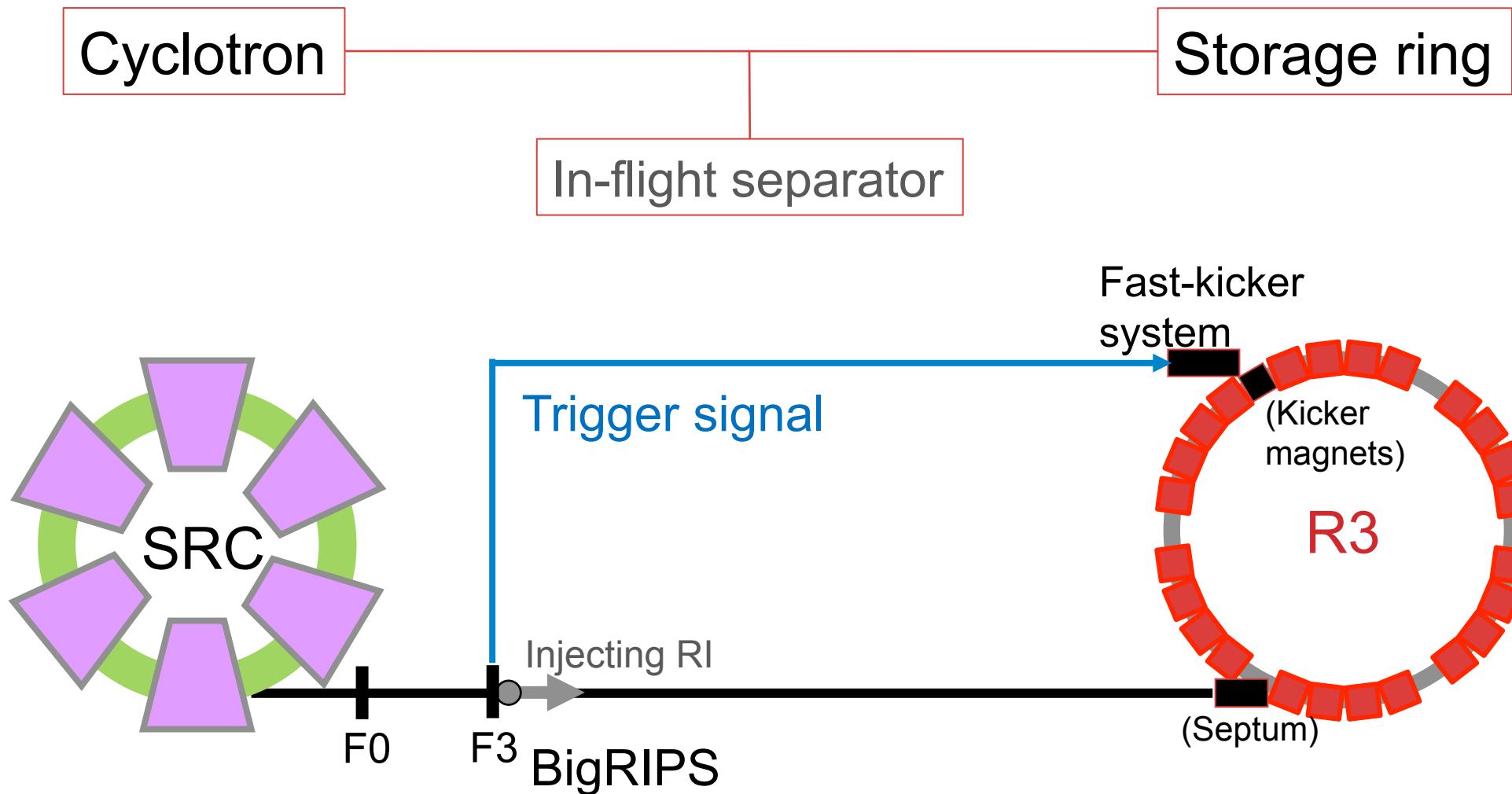


## Storage ring experiments using single-ion !

- Mass (Isochronous Mass Spectrometry)
  - Half-life (Resonant Schottky pick-up)
  - Nuclear reaction study (Internal target)

- Measurement time is as short as 1ms
- Expected precision for mass determination is in the order of ppm

# Self-trigger injection method

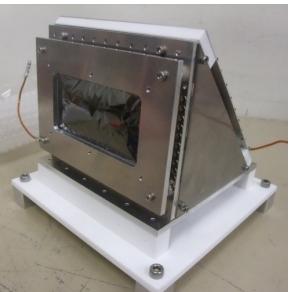


# R3 components and devices

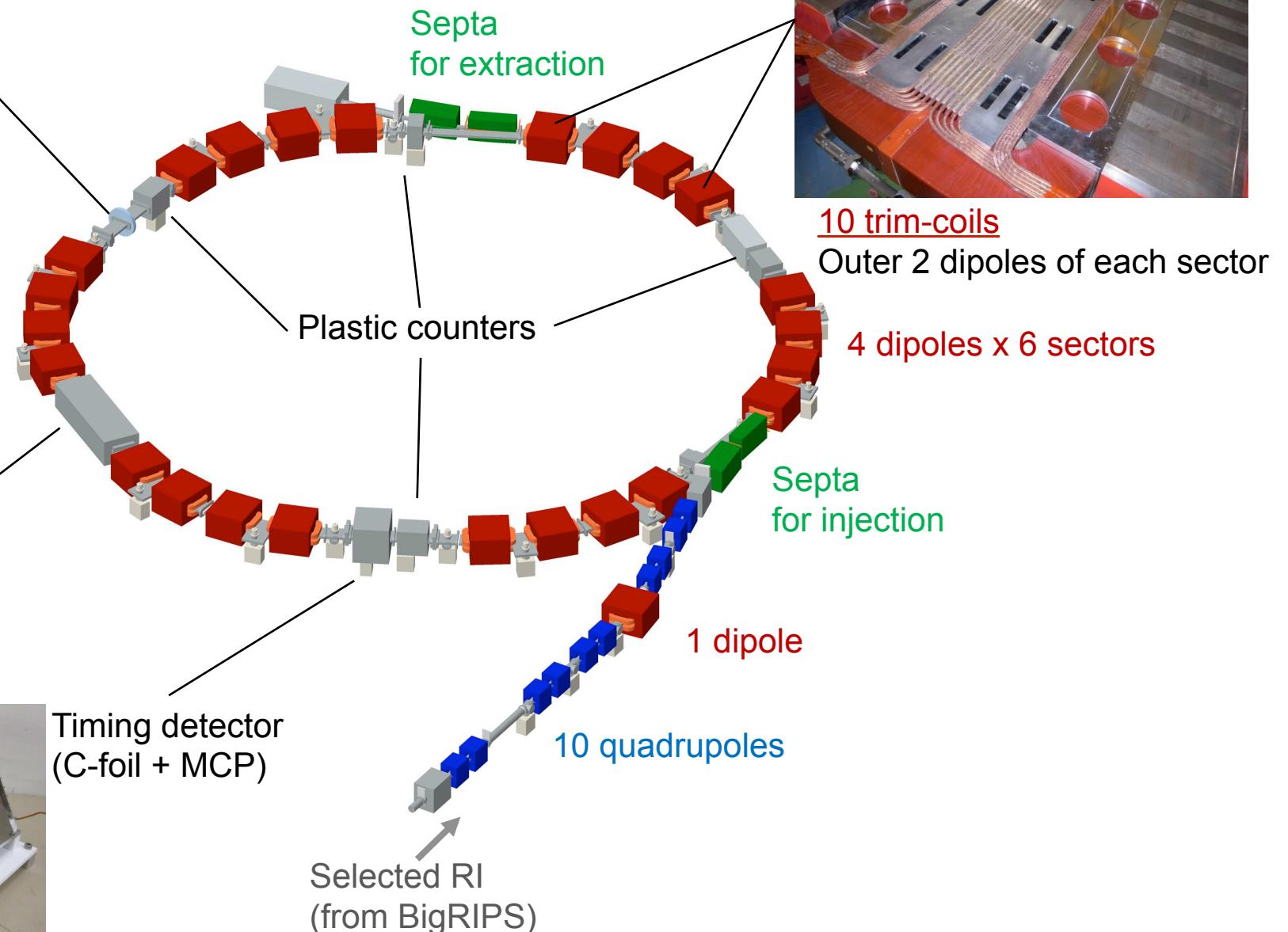
Resonant Schottky pick-up



Fast kicker system



Timing detector  
(C-foil + MCP)



10 trim-coils  
Outer 2 dipoles of each sector

4 dipoles x 6 sectors

Septa  
for injection

1 dipole

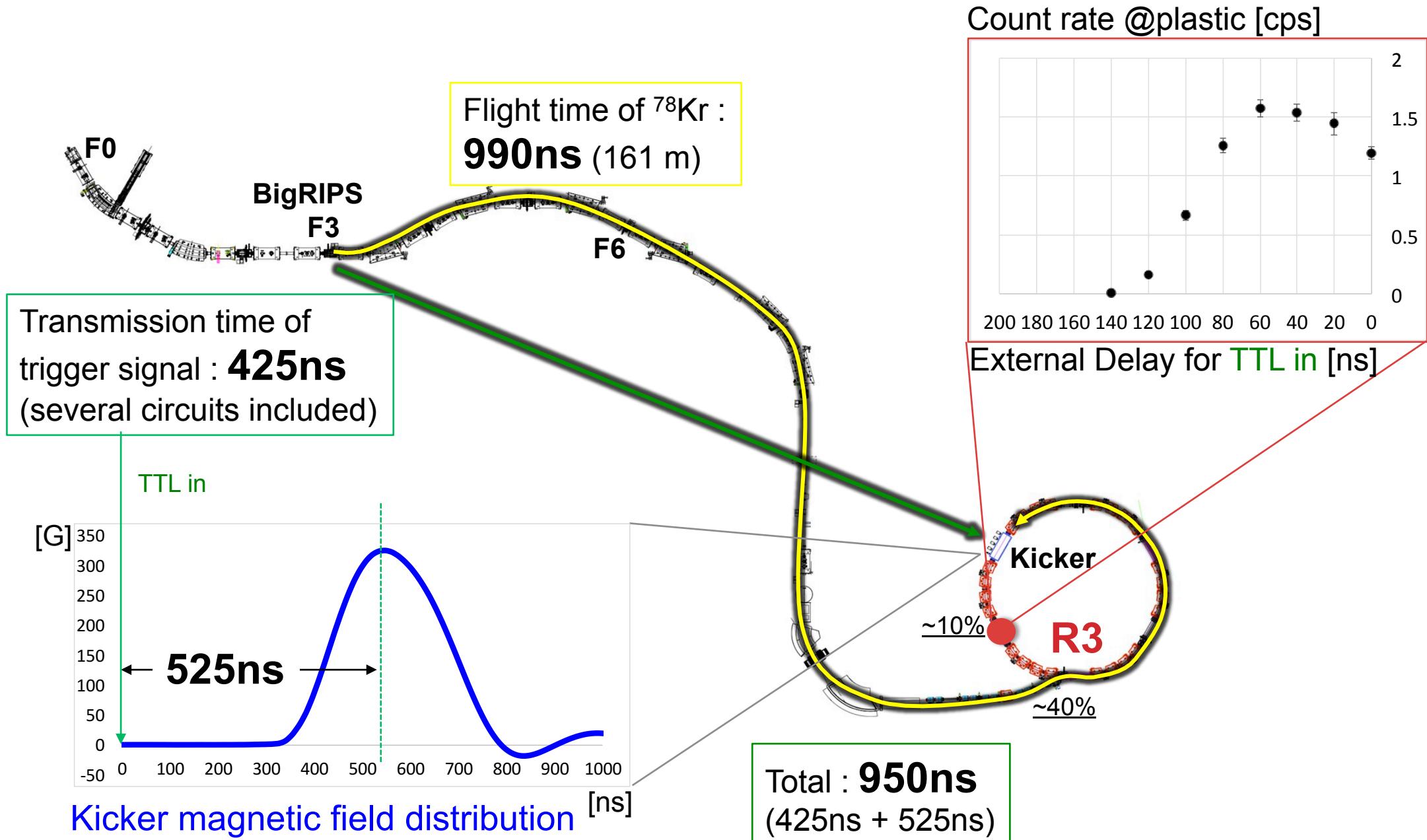
10 quadrupoles

Selected RI  
(from BigRIPS)

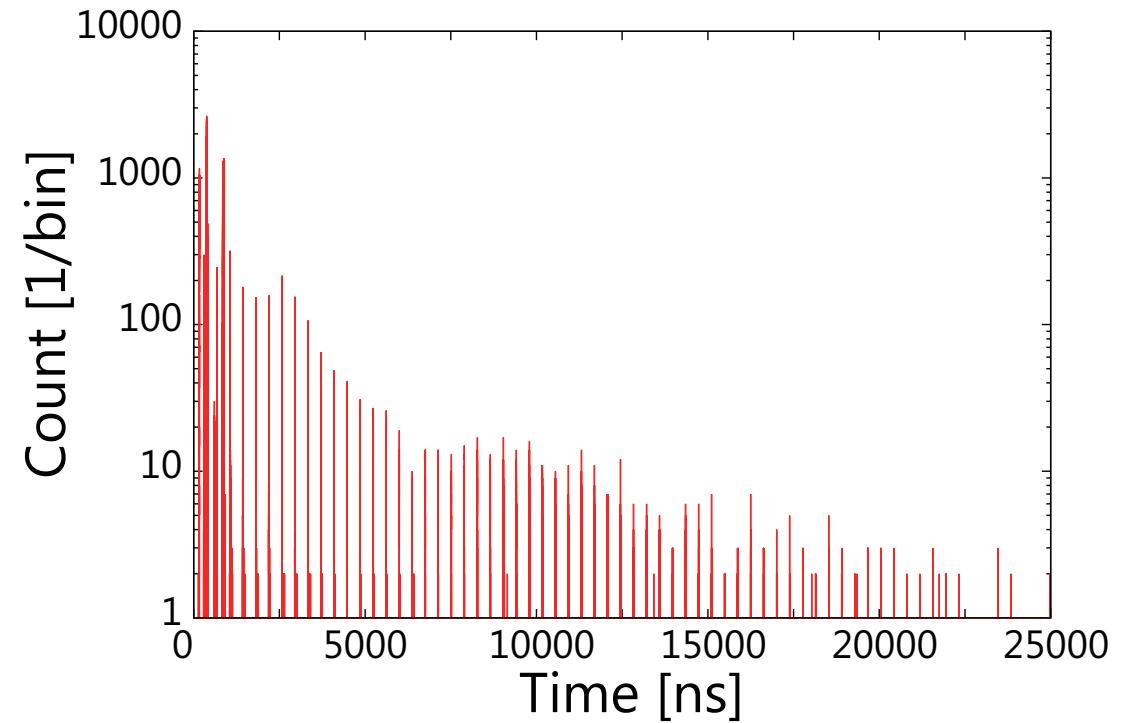
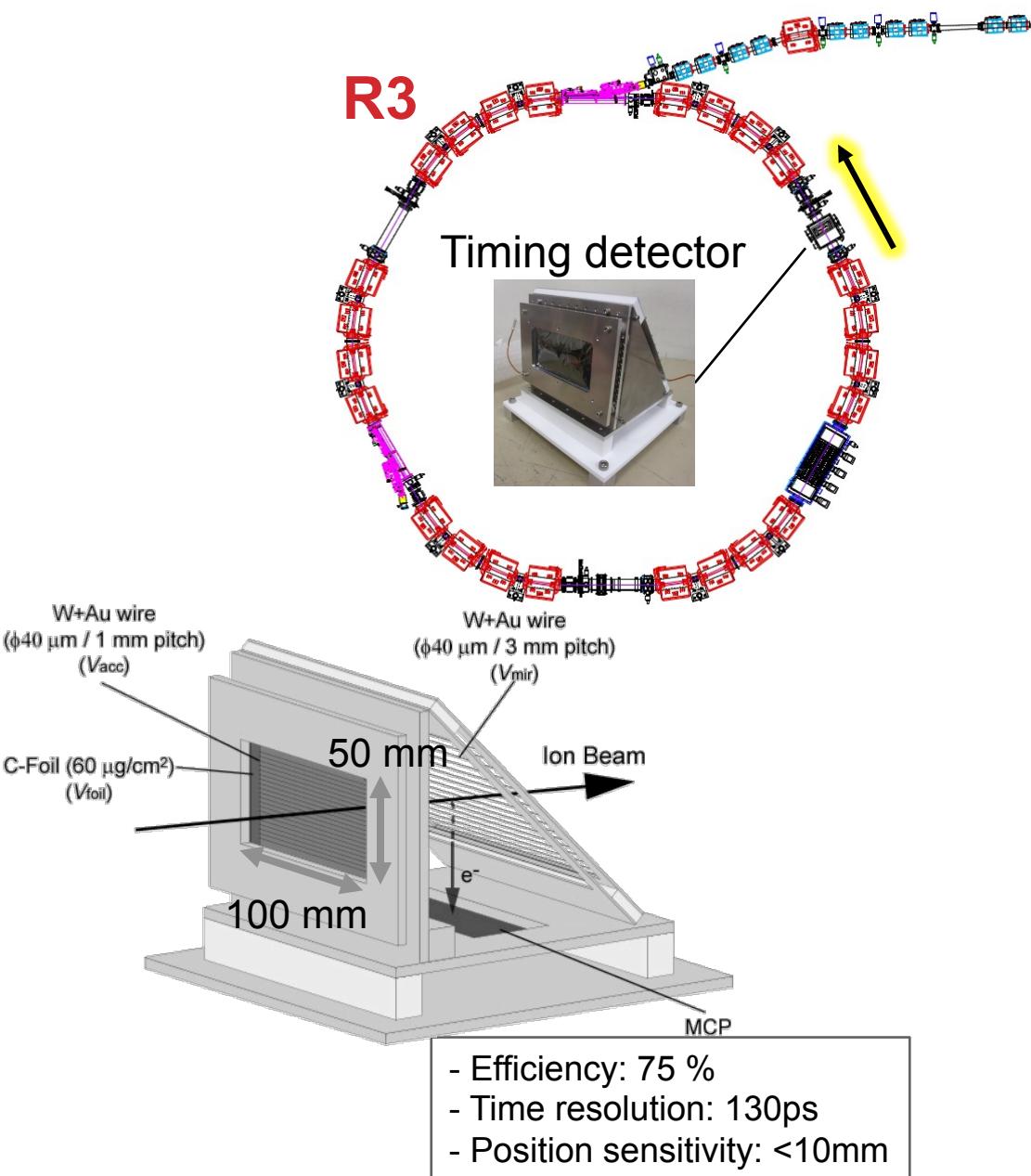
# We conducted the machine study in 2015

	MS01	MS02
<b>Beam conditions</b>		
Primary beam	$^{78}\text{Kr}$	$^{48}\text{Ca}$
Injection particle	$^{78}\text{Kr}$	Fragments ( $^{36}\text{Ar}$ , $^{35}\text{Cl}$ )
Injection energy	168 MeV/u	169 MeV/u for $^{36}\text{Ar}$
Repetition rate of injection	~ 90 Hz	~ 90 Hz
<b>Ring conditions</b>		
Transition $\gamma_{\text{tr}}$	1.18	1.18
Betatron tune	$Q_x = 1.18$ , $Q_y = 0.92$	$Q_x = 1.18$ , $Q_y = 0.92$
Dispersion	7.0 m	7.0 m
Trim-fields $(\text{dB}/\text{dr})/B_0$	Search	0.284 (fixed)
Kick angle	~ 11.4 mrad	~ 11.4 mrad

## - Establishment of the self-trigger injection method (@MS01)



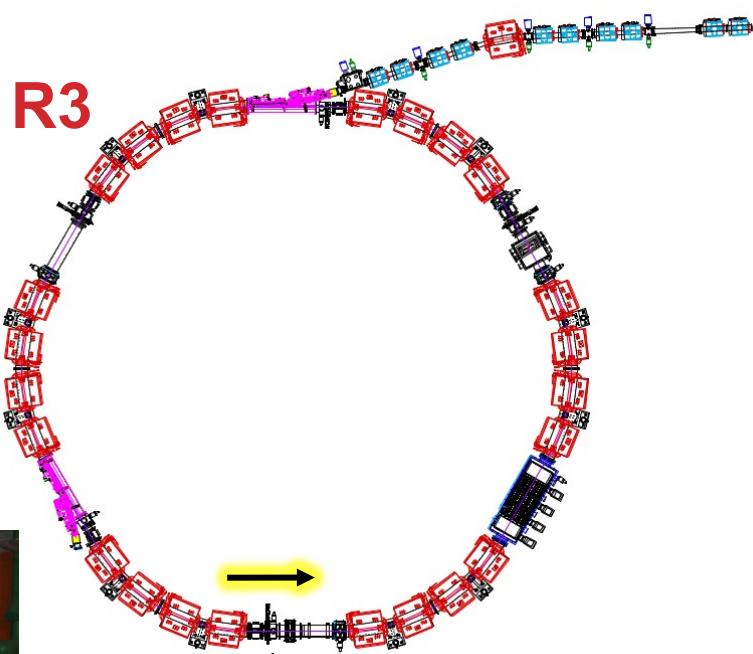
## - Storage of single-ion (@MS01)



TDC (Aqiris TC890)  
→ 379.65 ns/turn

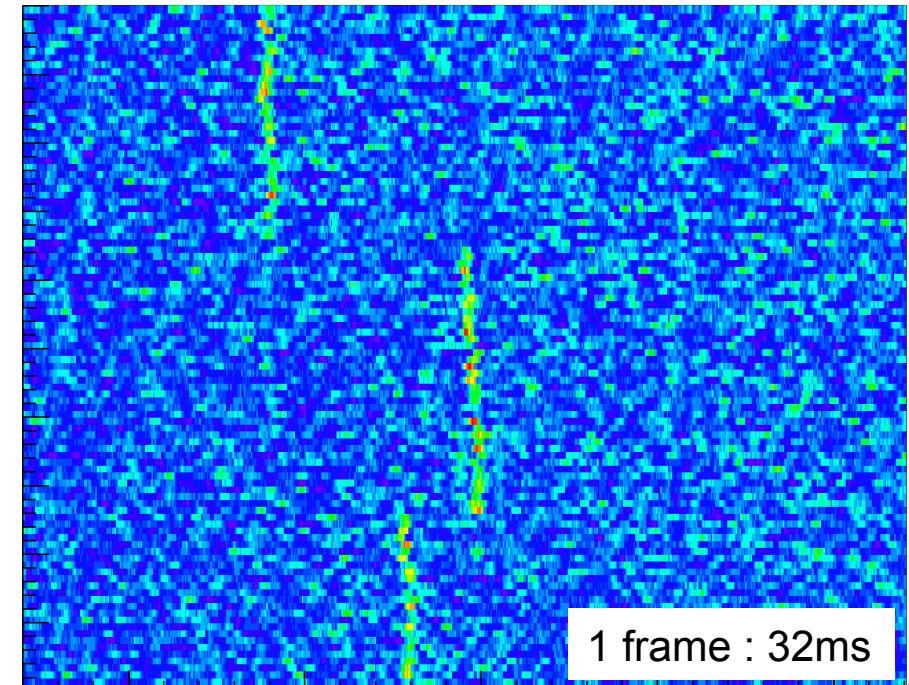
※ Useful information for determining  
the resonance frequency of Schottky pick-up.

## - Storage of single-ion (@MS01)



Resonance frequency : 173MHz ( $\text{TM}_{010}$ )  
Tuning range :  $\pm 1.5\text{MHz}$   
Shunt Impedance  $R_{sh}$  :  $161\text{k}\Omega$   
Quality factor  $Q_0$  : 1880  
Ceramic tube size : 290mmΦ, 15mm thickness

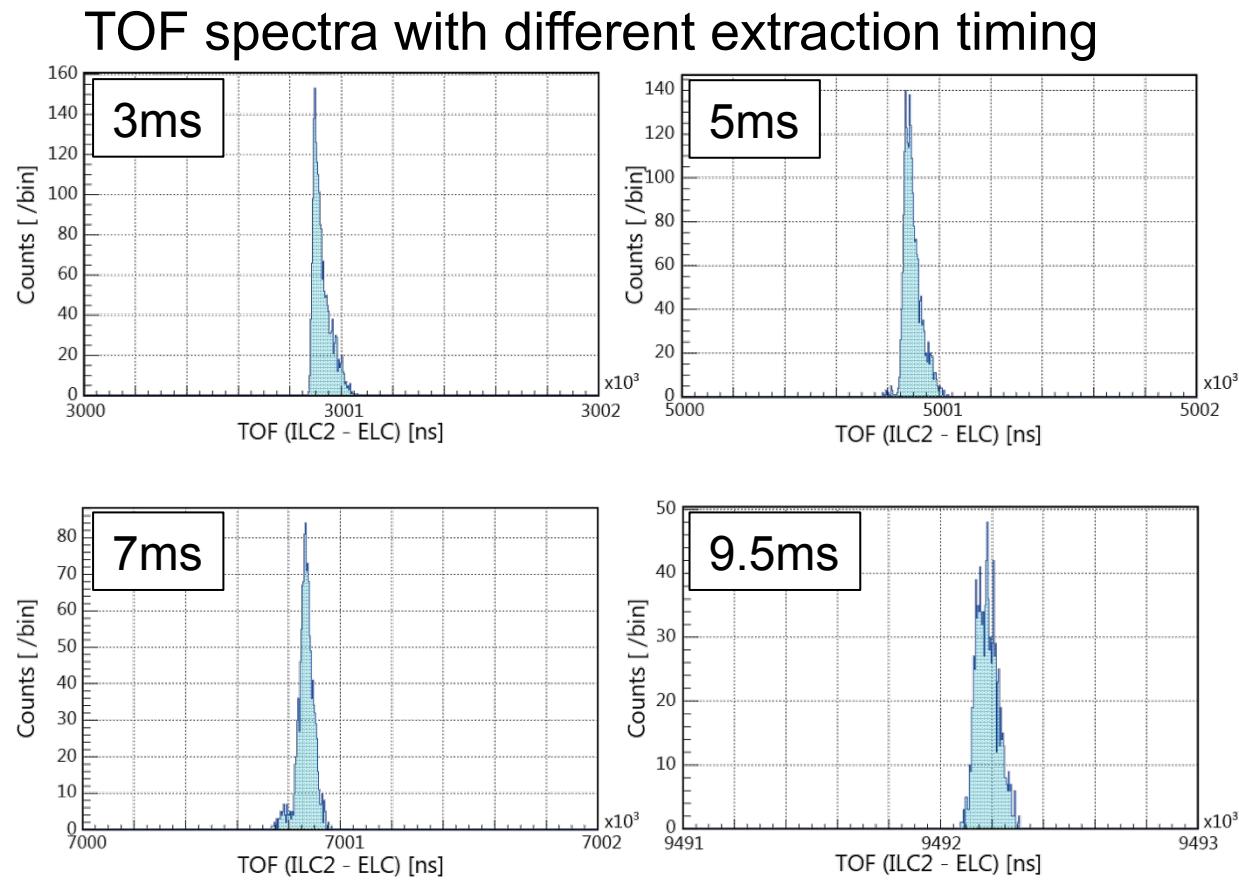
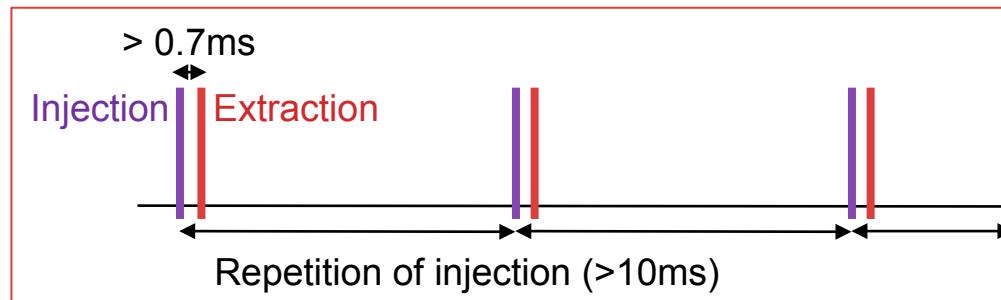
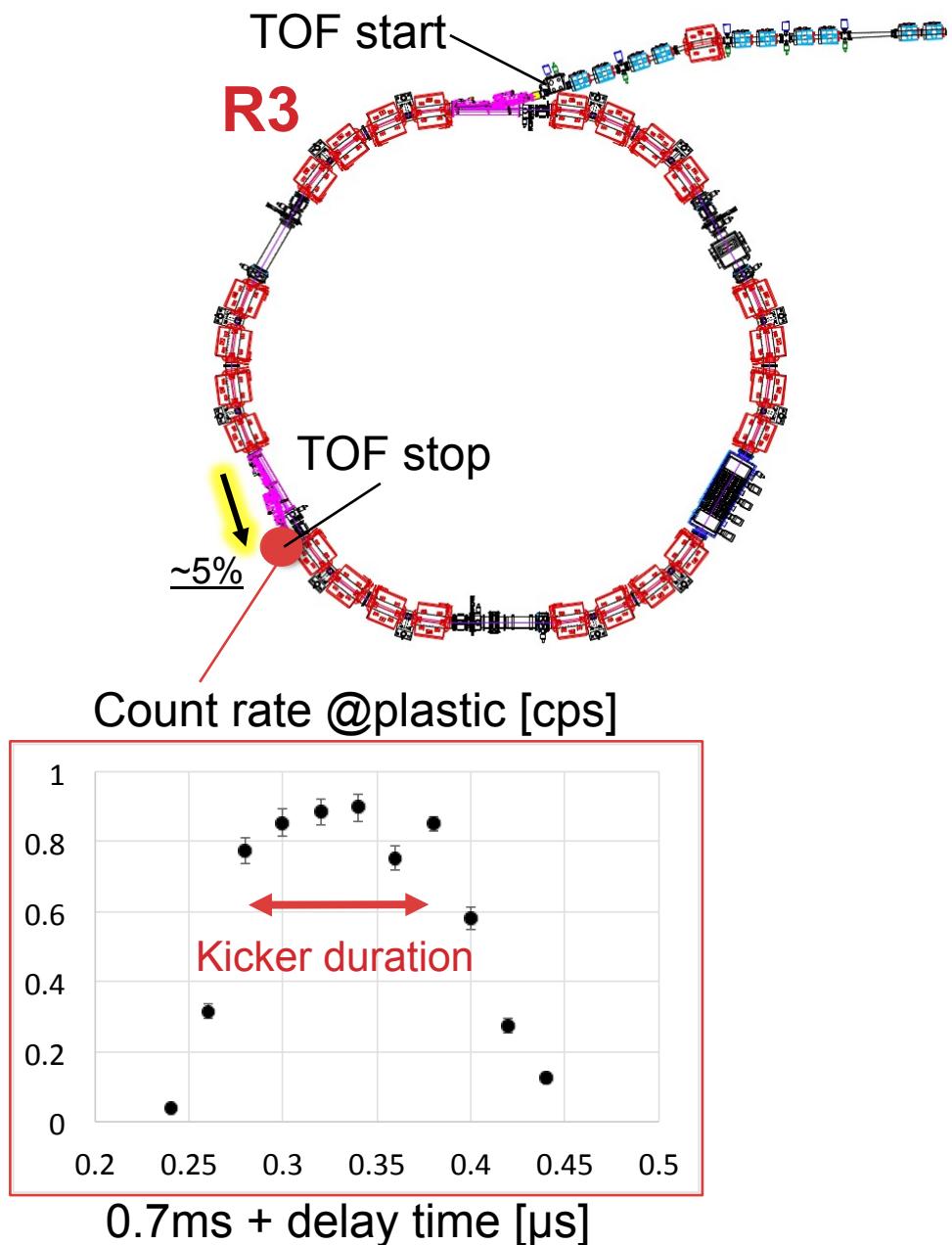
Repetition time of injection : 0.5s



173.81 173.82 173.83 173.84 173.85  
Resonance frequency [MHz]

- Succeeded in detecting the single  $^{78}\text{Kr}^{36+}$  ion
- Frequency resolution:  $\sim 1.3 \times 10^{-6}$  (FWHM)

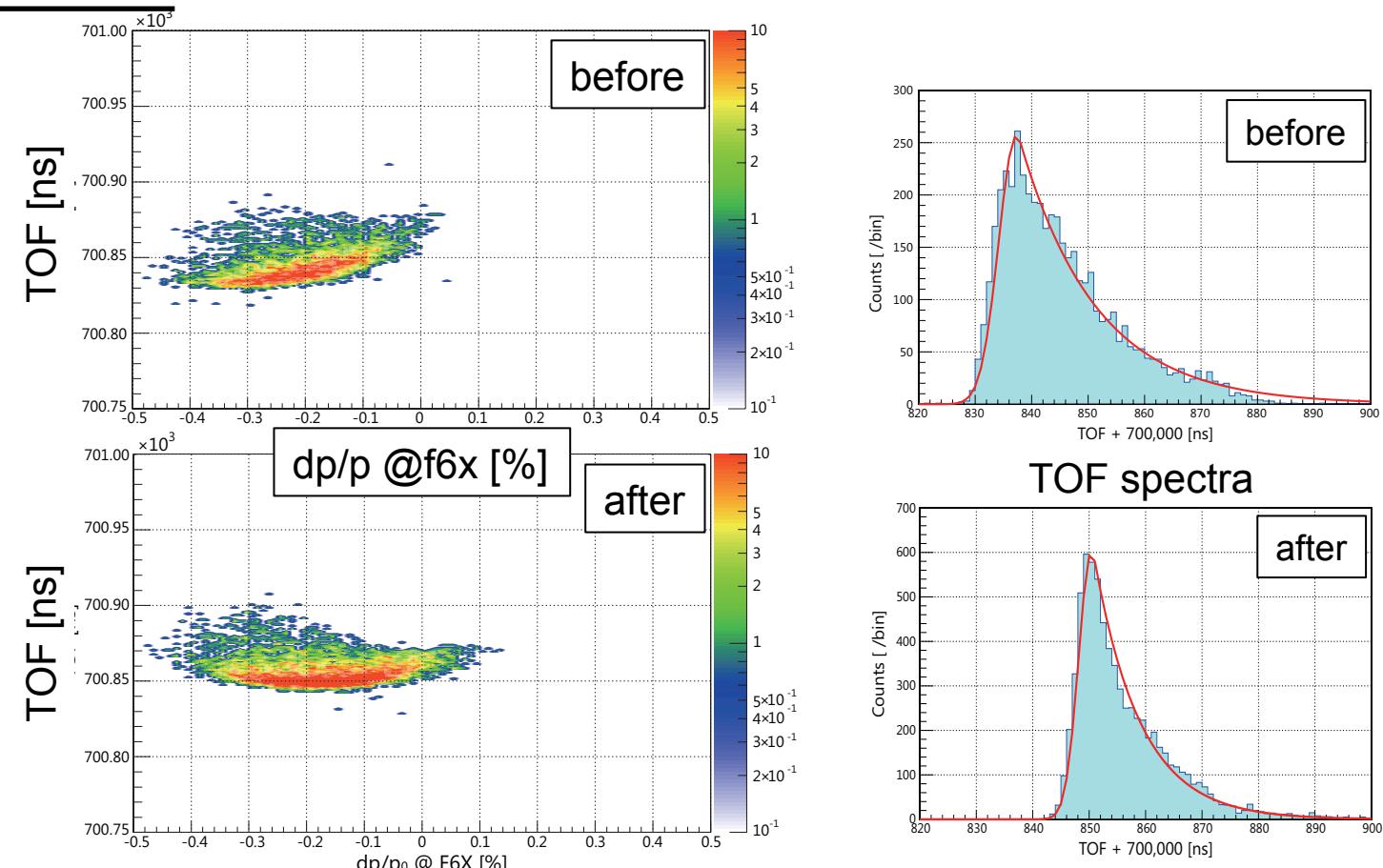
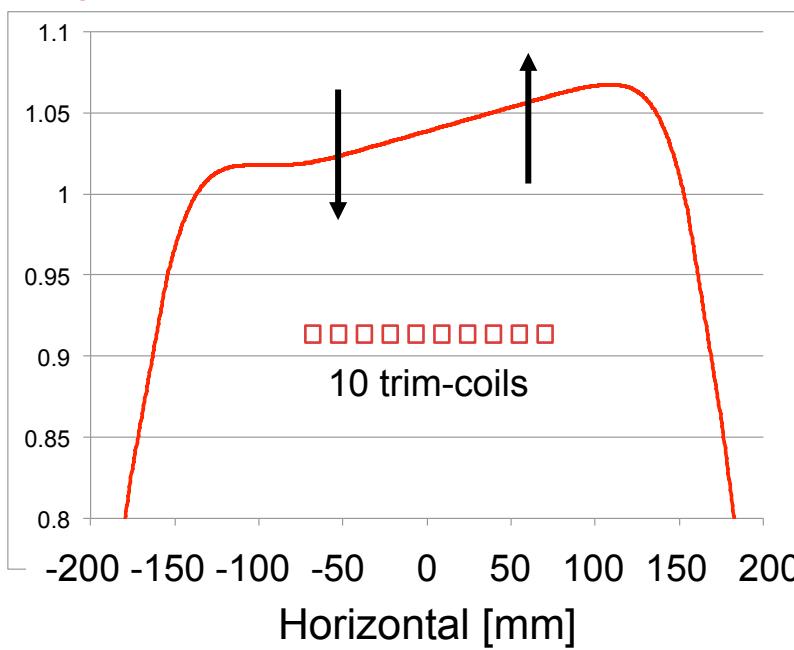
## - Extraction (@MS01)



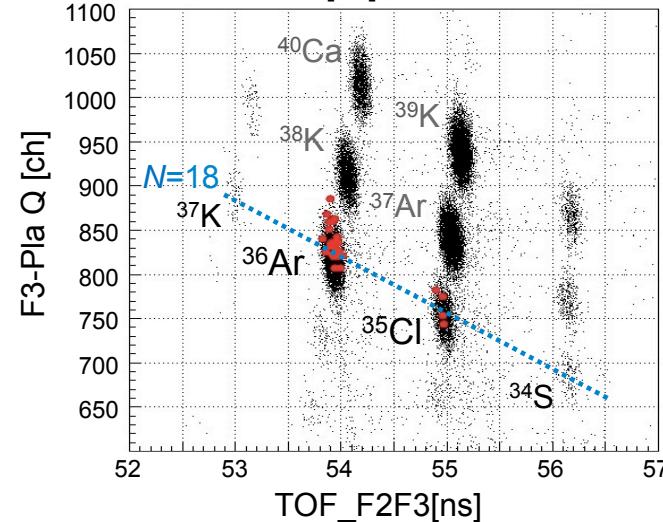
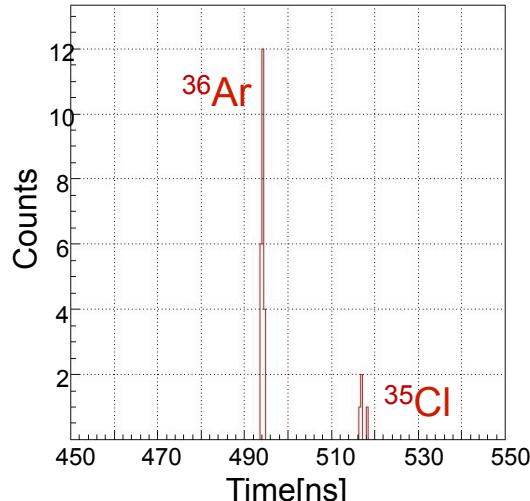
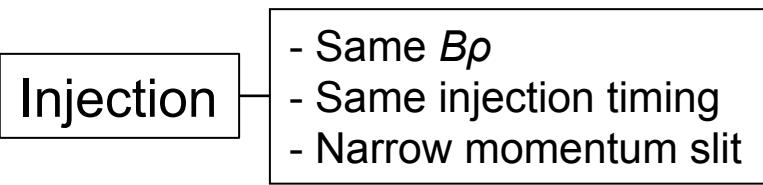
## - Trim-coils effects (@MS01)

	before	after
First-order Trim-fields (dB/dr)/B <sub>0</sub> =	0.279	0.284
TOF width (FWHM)	7.34(23)	5.34(9)
Isochronism	1.05(3) × 10 <sup>-5</sup>	7.62(16) × 10 <sup>-6</sup>
Including the tail	10-ppm order	10-ppm order

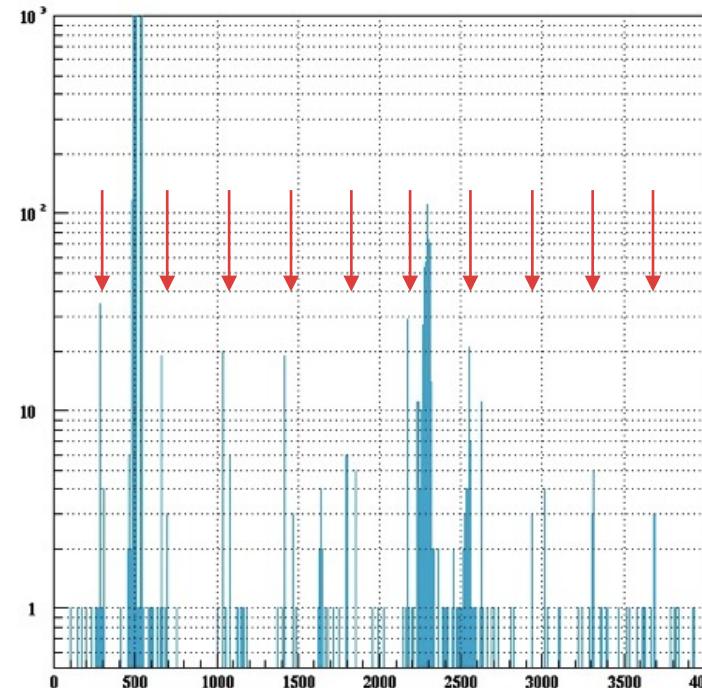
Magnetic field distribution



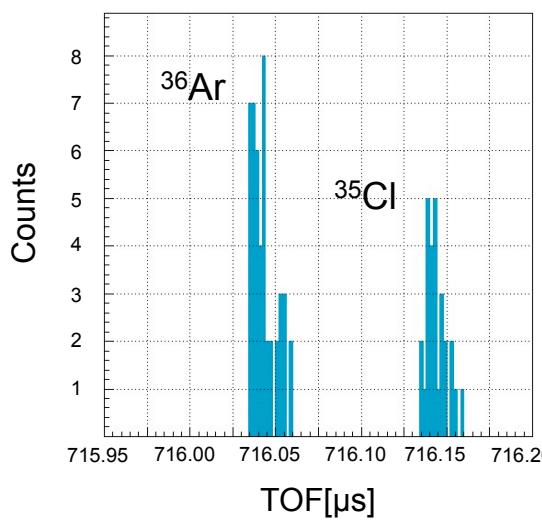
# - Injection/Extraction of two nuclei in the same setting (@MS02)



**Storage**



**Extraction**



TDC (Aqiris TC890)  
 $^{36}\text{Ar} \rightarrow 378.317(10) \text{ ns/turn}$   
 $^{35}\text{Cl} \rightarrow 386.332(56) \text{ ns/turn}$

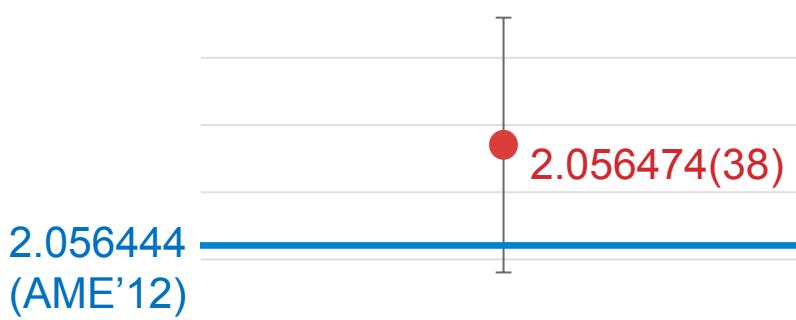
※ Same extraction timing,  
but 39 turns difference.

## - Demonstrate the feasibility of mass measurement (@MS02)

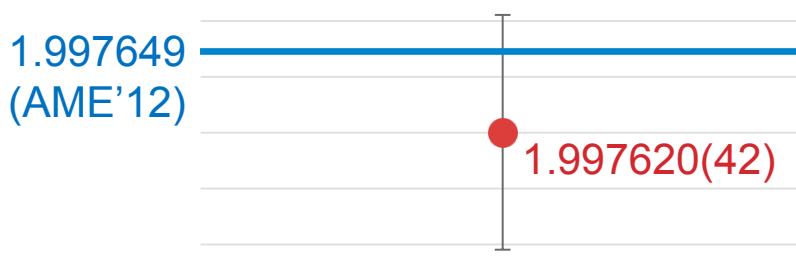
Relative mass measurement using a reference ( $m_0/q_0$ )

$$\frac{m_1}{q_1} = \left( \frac{m_0}{q_0} \right) \frac{1}{T_0} T_1 \sqrt{\frac{1 - \beta_1^2}{1 - ((T_1/T_0)\beta_1)^2}} = \left( \frac{m_0}{q_0} \right) \frac{1}{T_0} T_{1\text{corr}}$$

Determination the mass of  $^{35}\text{Cl}$  ( $m_1/q_1$ )  
with  $^{36}\text{Ar}$  as reference

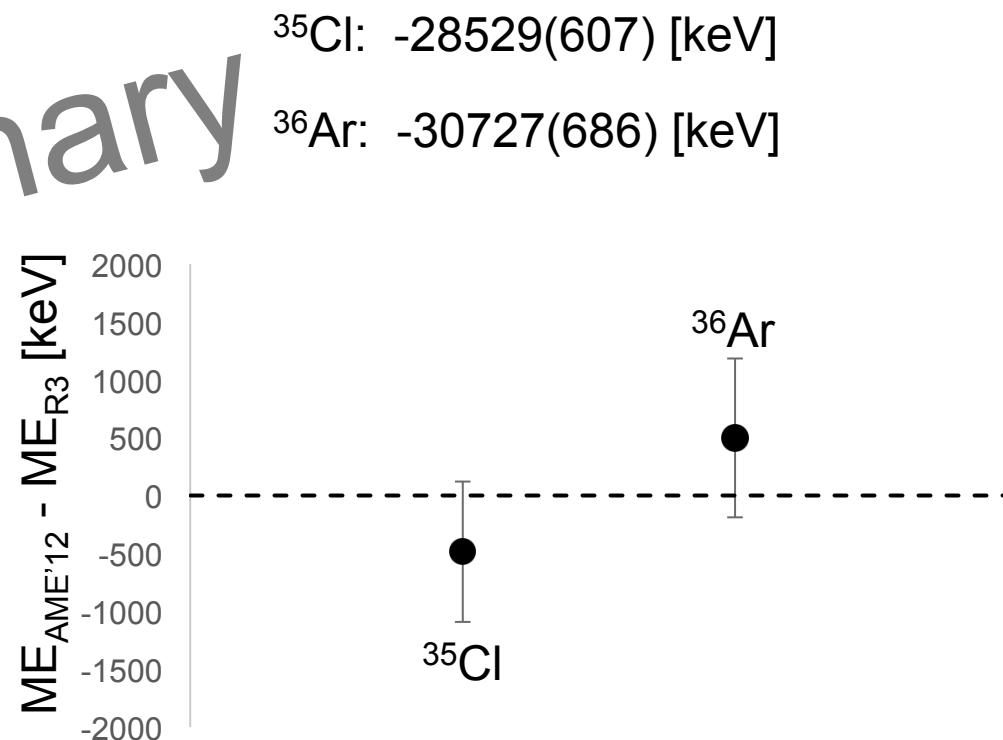


Determination the mass of  $^{36}\text{Ar}$  ( $m_1/q_1$ )  
with  $^{35}\text{Cl}$  as reference



Preliminary

### Mass Excess

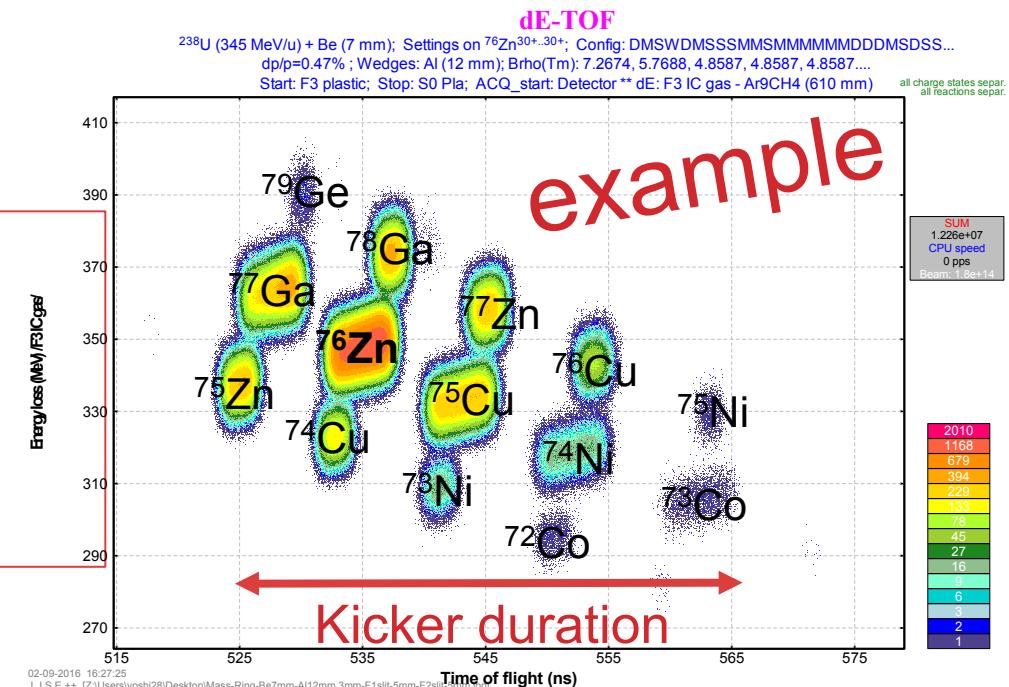


# Prospects

## Development of R3

Next machine study (MS03) is scheduled in Oct. 2016.

- Verification the principle of relative mass measurements using several unstable nuclei.
- Establishment of isochronous adjustment method using the resonant Schottky pick-up.



We should improve of experimental uncertainty for the mass determination in a few years.

(now)  $\sim 4.0 \times 10^{-5}$  from MS02 → not enough ! → Analyze the TOF data of MS01&MS02 again.

→ Next machine study gives us an important information.

## Experiment with R3

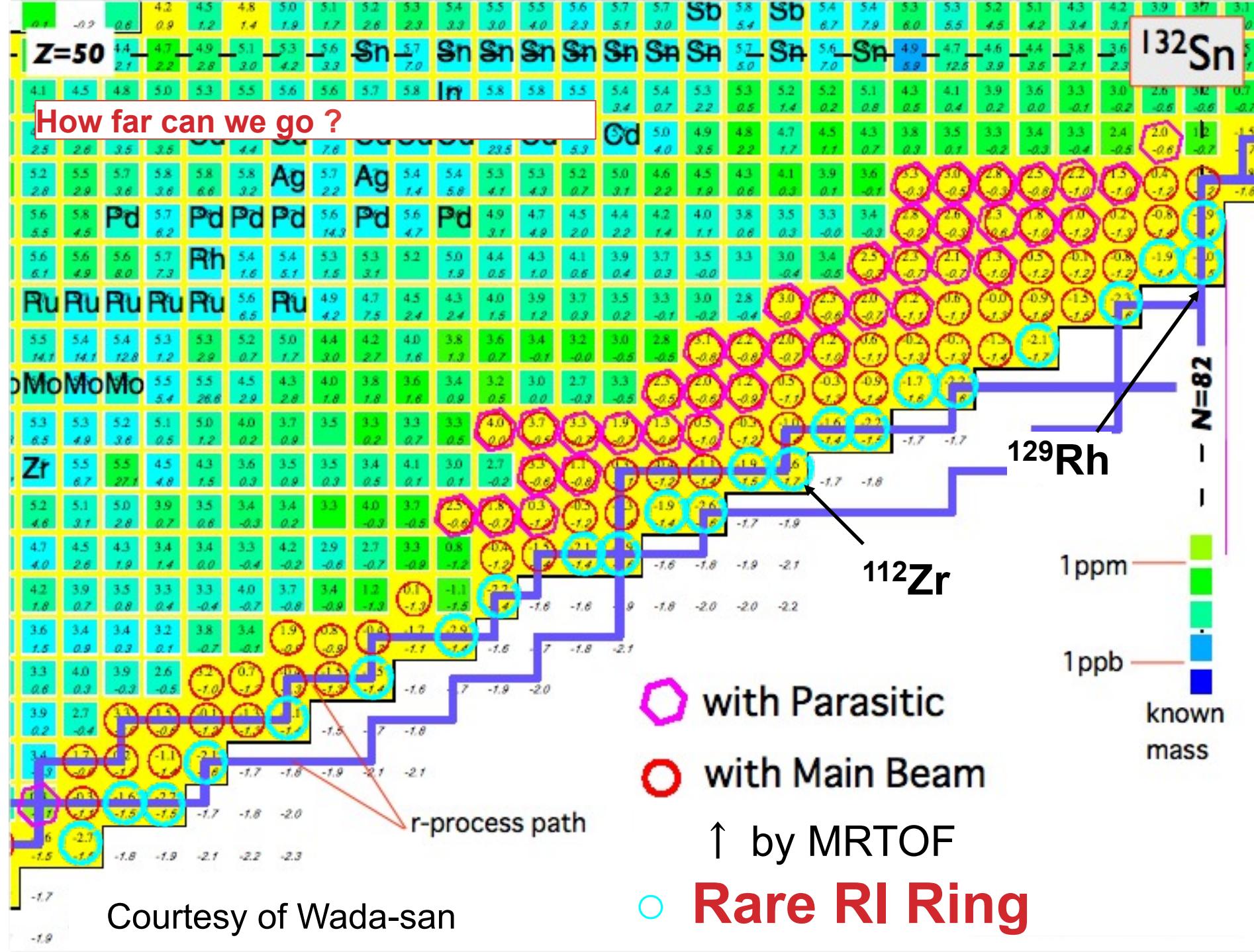
We decided to call for experiments with R3 from the coming 17<sup>th</sup> NP-PAC at RIBF.

Please be sure to contact us. ([R3-contact@riken.jp](mailto:R3-contact@riken.jp))  
Day-1 experiment will be held in next year ??

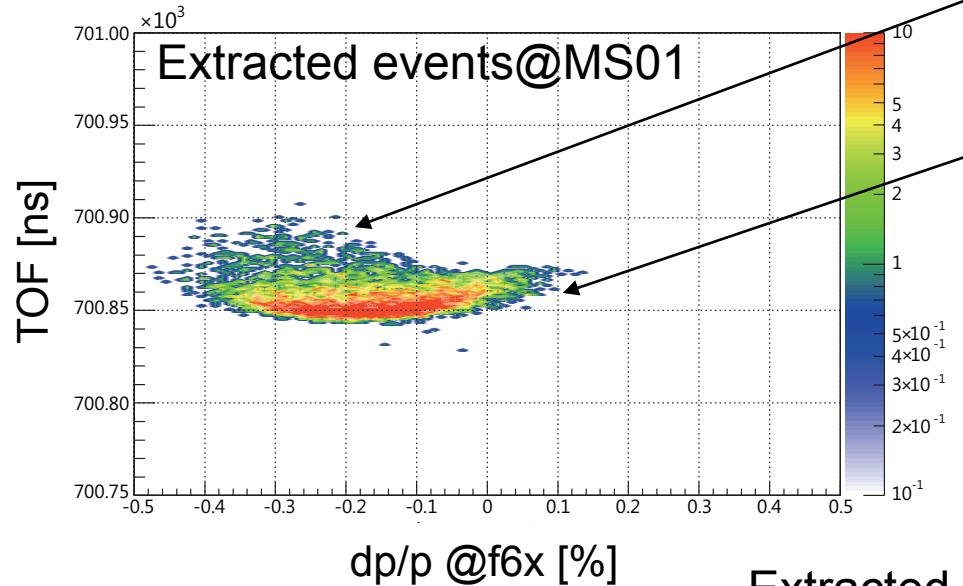
# Thank you for your attention



**Back up**

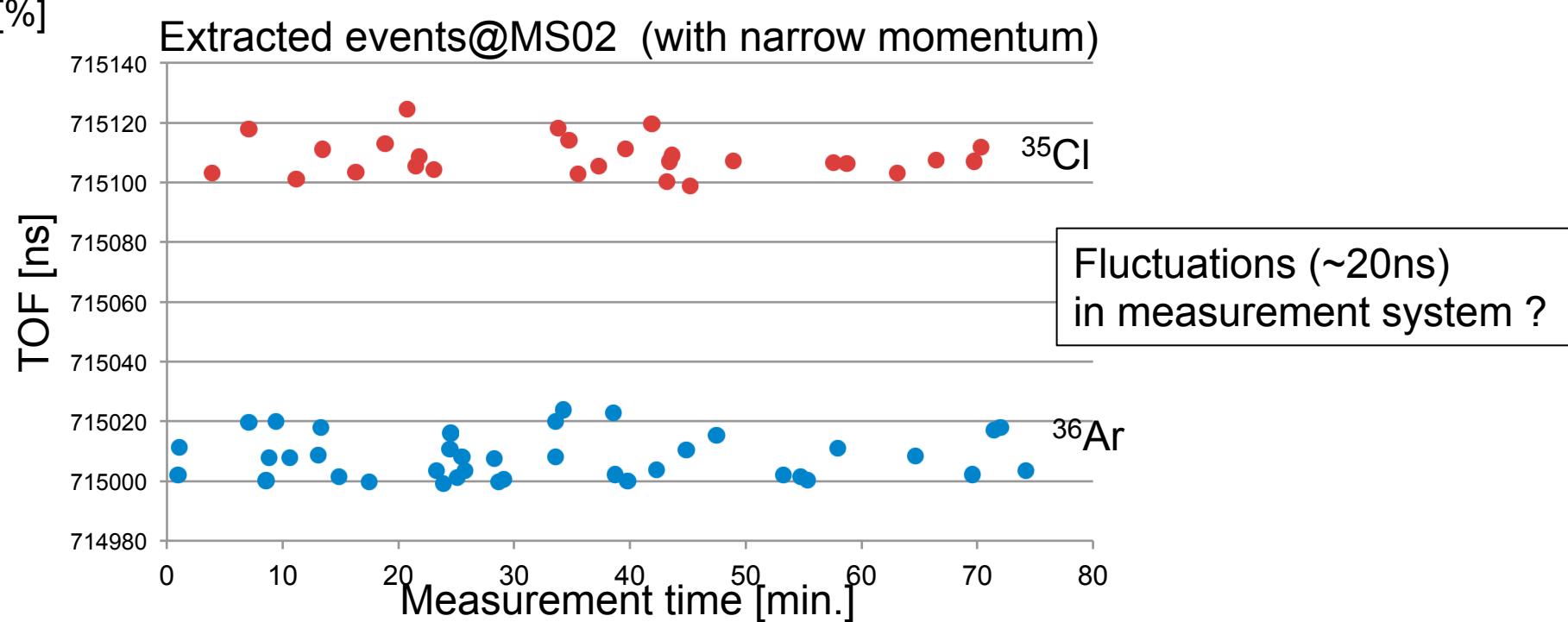


# Uncertainty of TOF



for the tail part  
- These events has large angular emittance.

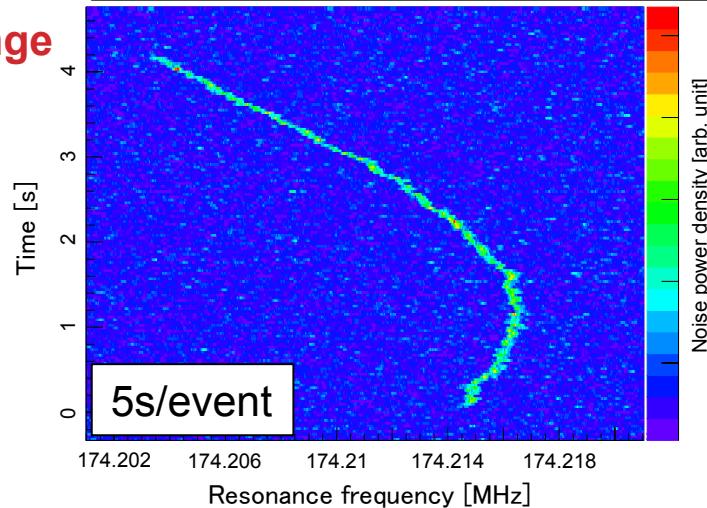
for the main part (width: ~20ns)  
- Drift of the magnetic field ? → may be no ( $< 3 \times 10^{-6}$  in 30 minutes)  
- Misalignment of the magnet ?  
- Detector resolution ?  
- Kicker fluctuation ?  
- Fluctuations in measurement system ?  
- Collisions with residual gas ? → no



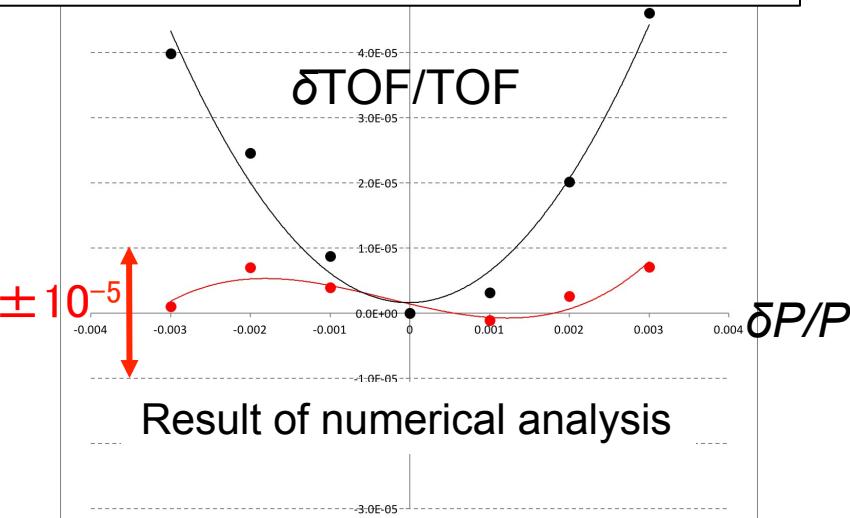
# Next machine study

- Establishment of isochronous adjustment method using the resonant Schottky pickup.

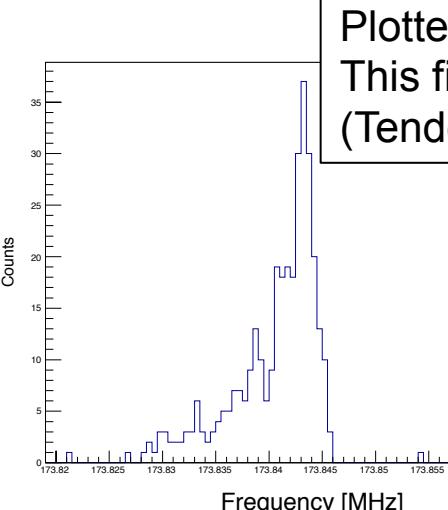
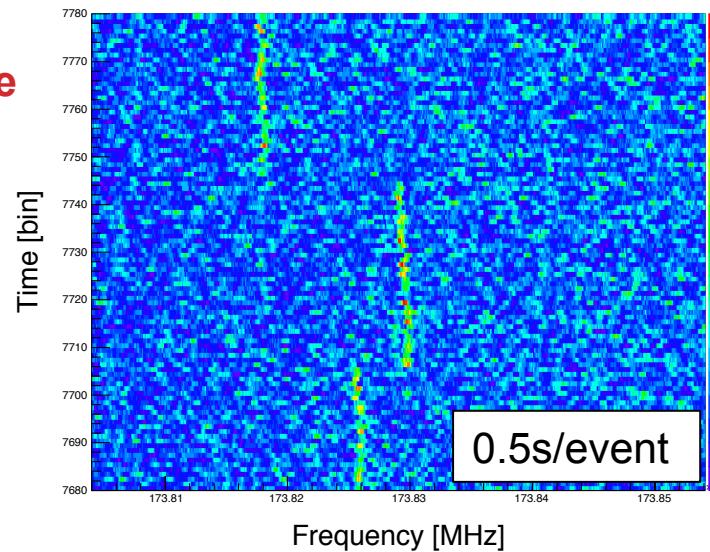
long range



Shape of curve indicates the isochronous conditions (momentum dependence)

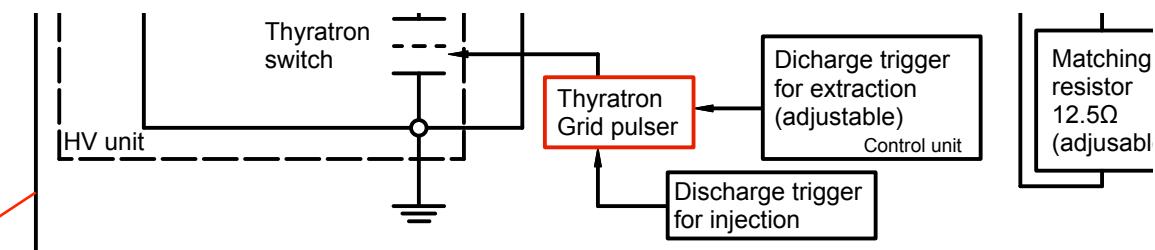
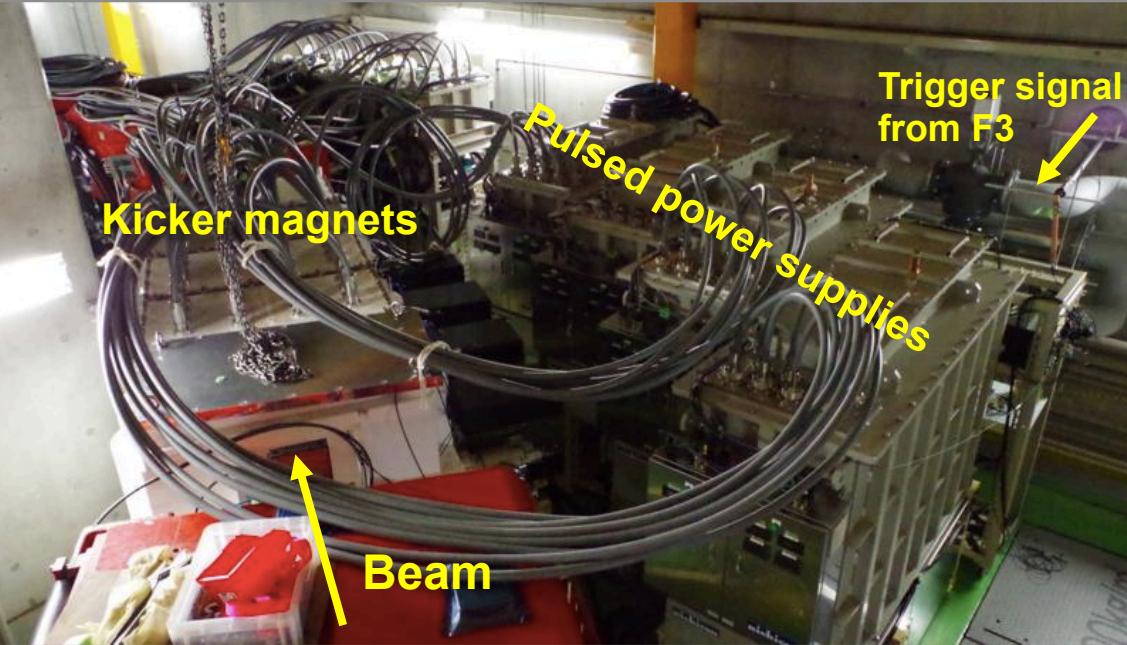


short range



Plotted the initial frequency of each event.  
This figure shows the degrees of isochronism.  
(Tendency is same as TOF result)

# Fast-kicker system



## 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 Thyatron  
to excite a kicker magnet as fast as possible.

# Fast-recharging mechanism

## Hybrid charging system

### Main charger

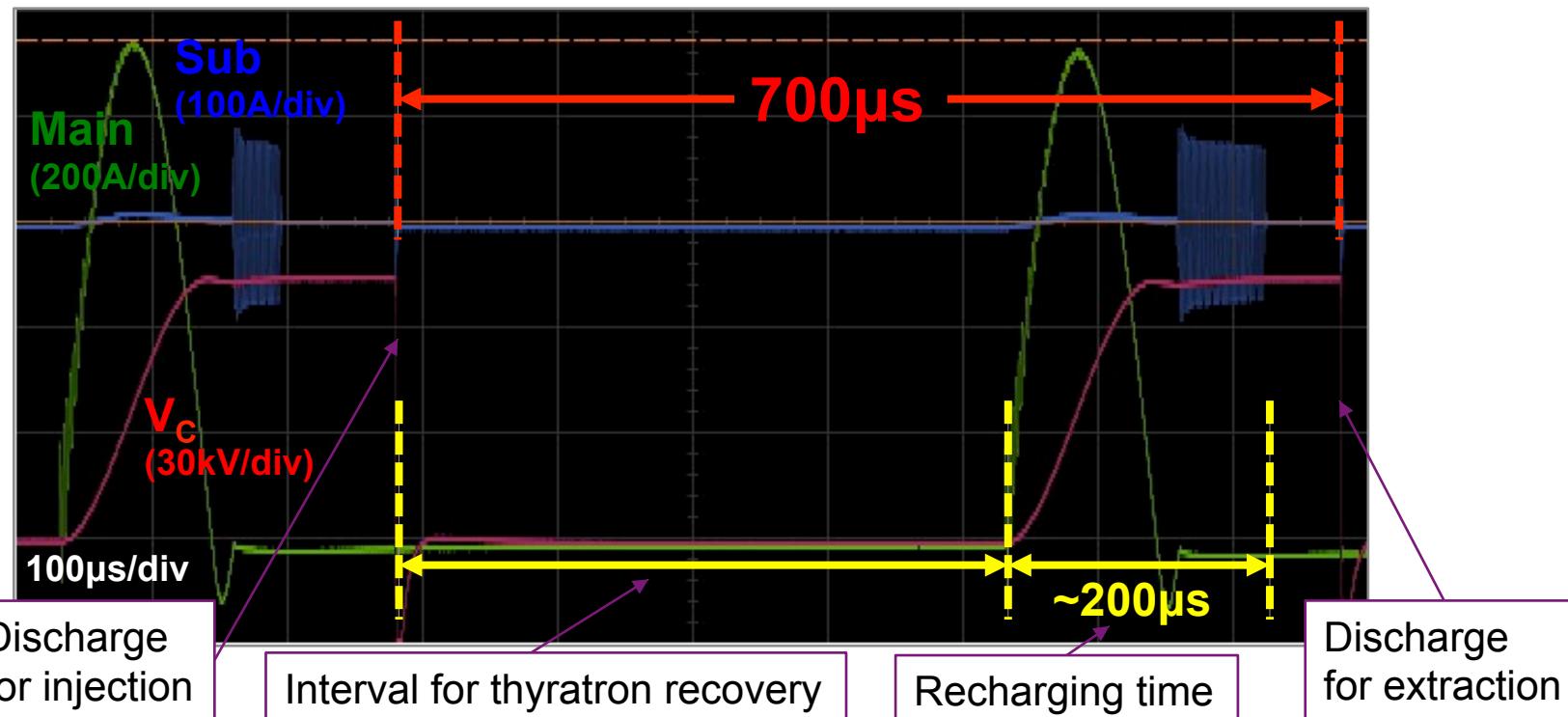
- Half sinusoidal waveform
- 90% charging in 100 $\mu$ s

### Sub charger

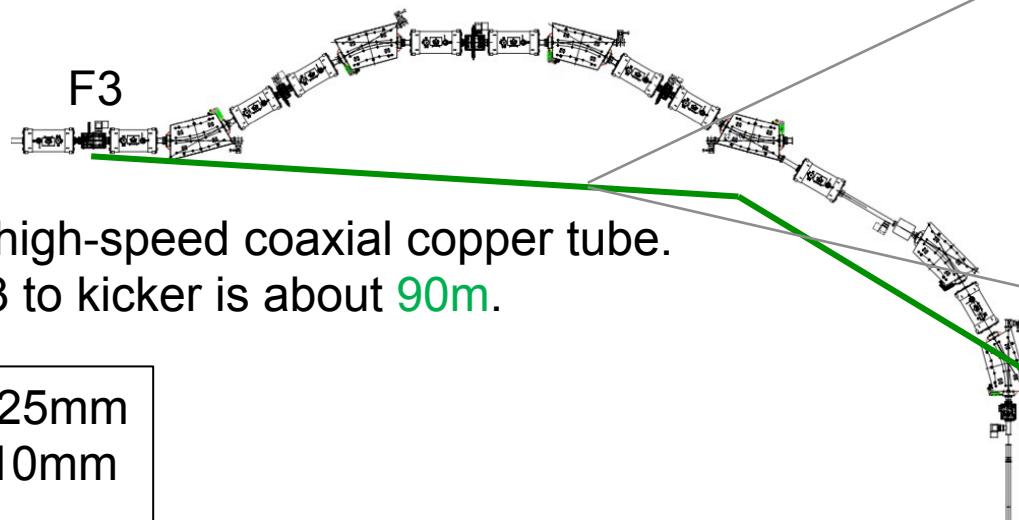
- 500kHz resonance
- +10% charging within 100 $\mu$ s
- Keep  $V_C$   $100\pm 1\%$  to discharge at any time



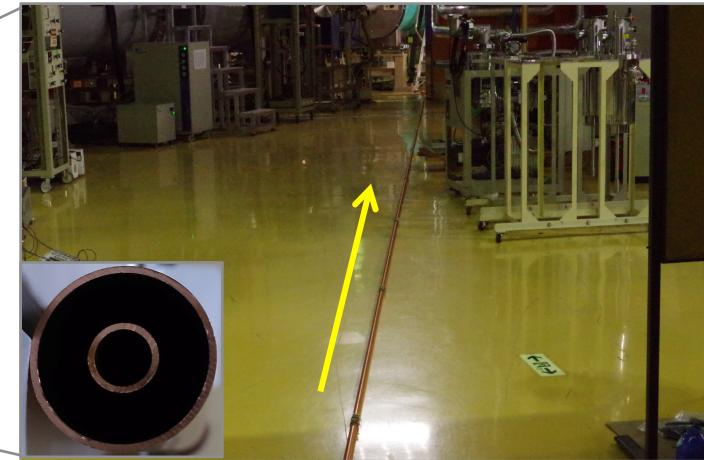
PFN charging waveform (1set)



# Trigger transmission tube



We fabricated the high-speed coaxial copper tube.  
The length from F3 to kicker is about 90m.



Outer diameter : 25mm  
Inner diameter : 10mm  
Thickness : 1mm  
 $\beta=v/c$  : 0.986

