# Studies on Spill Quality Improvement at J-PARC

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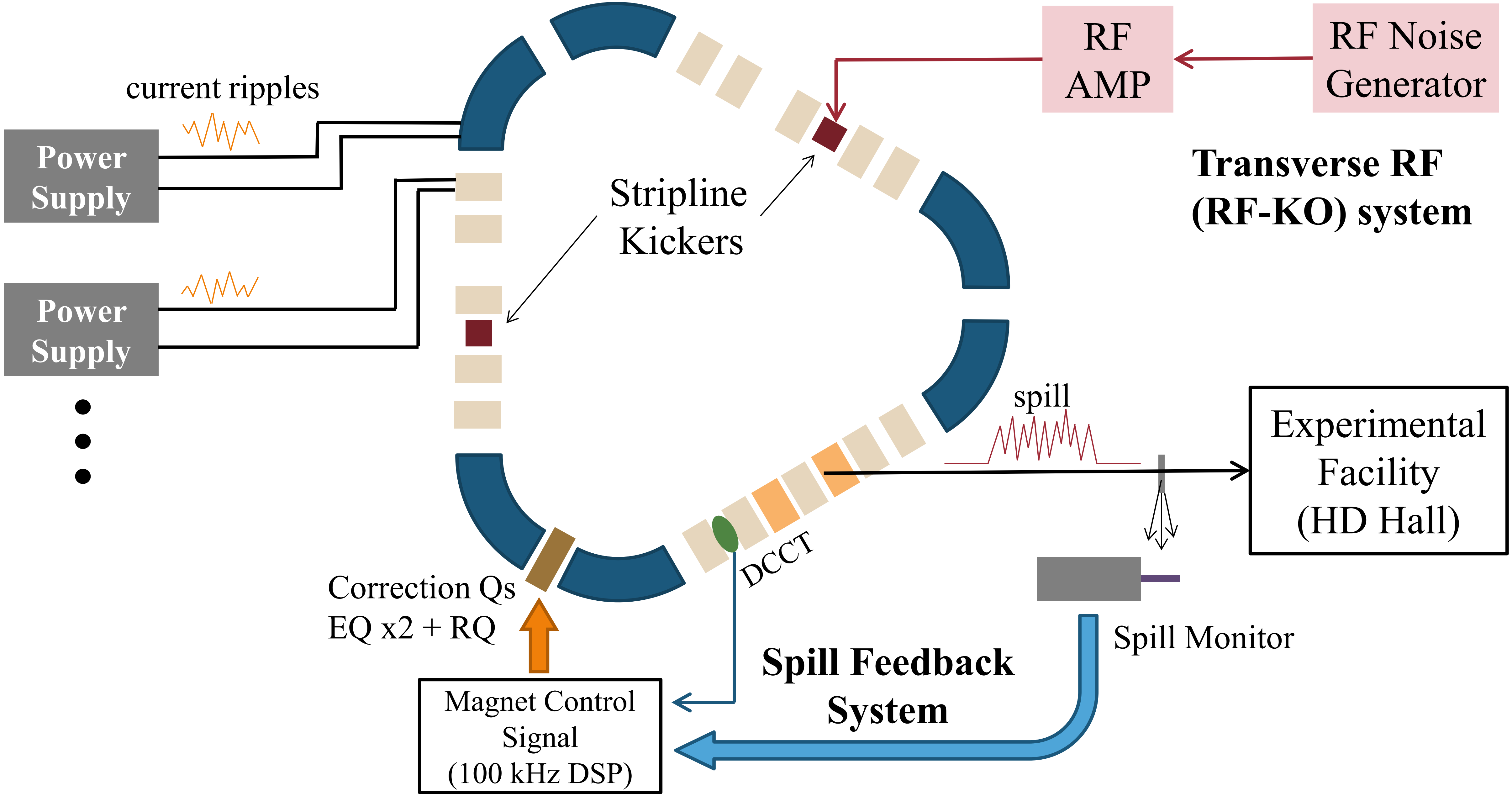
KEK/J-PARC

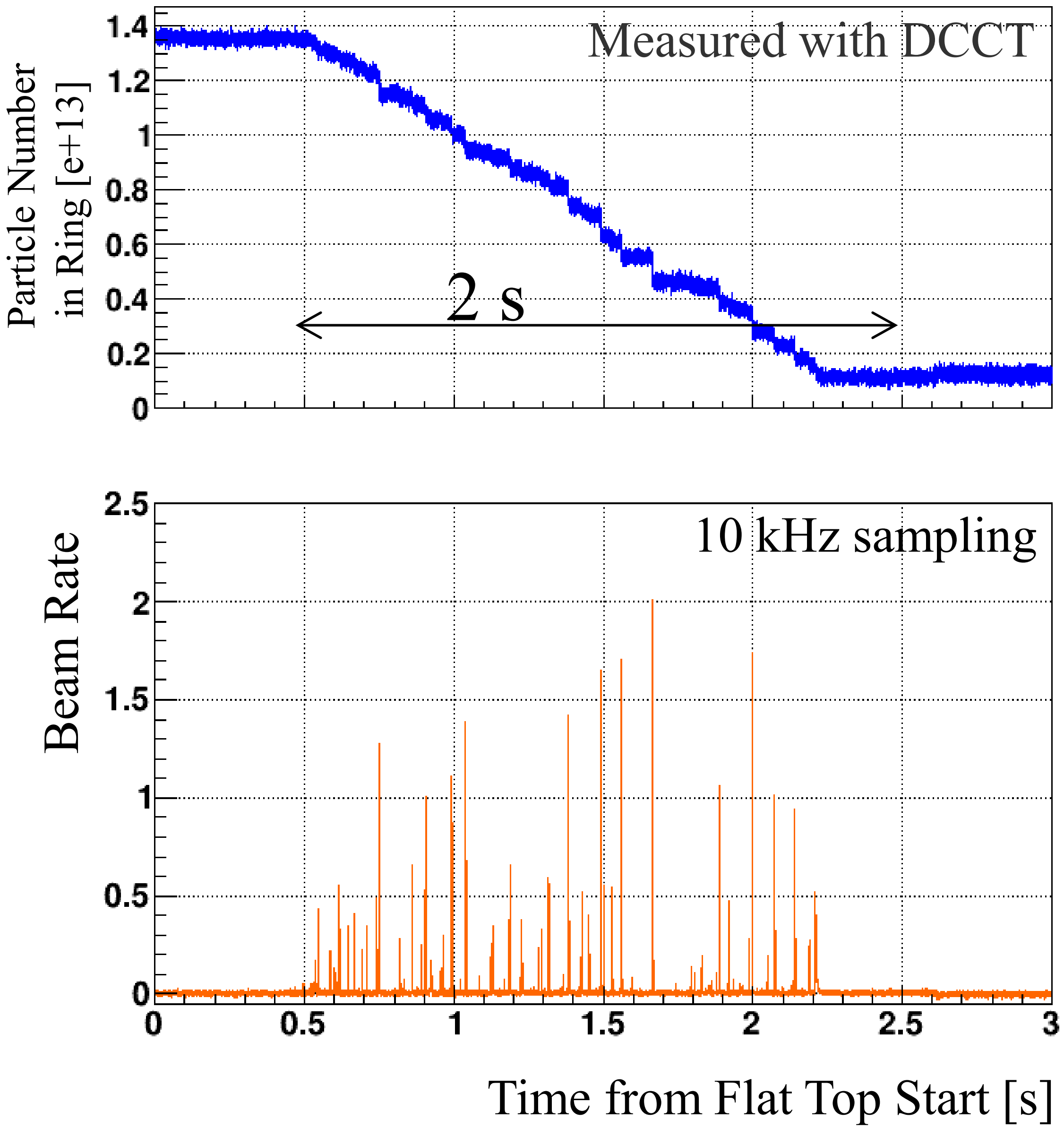
# Outline

- Introduction of the Spill Regulation System at J-PARC
- Improvement of the Spill Structure
  since Previous Slow Extraction Workshop (2024-Feb)
- Spill Structure Evaluation by Physics Experiment
- Short Pulse Beam
- Plans for Further Spill Structure Improvement

# Spill regulation systems at J-PARC MR



# Spill structure without tune ripple mitigation



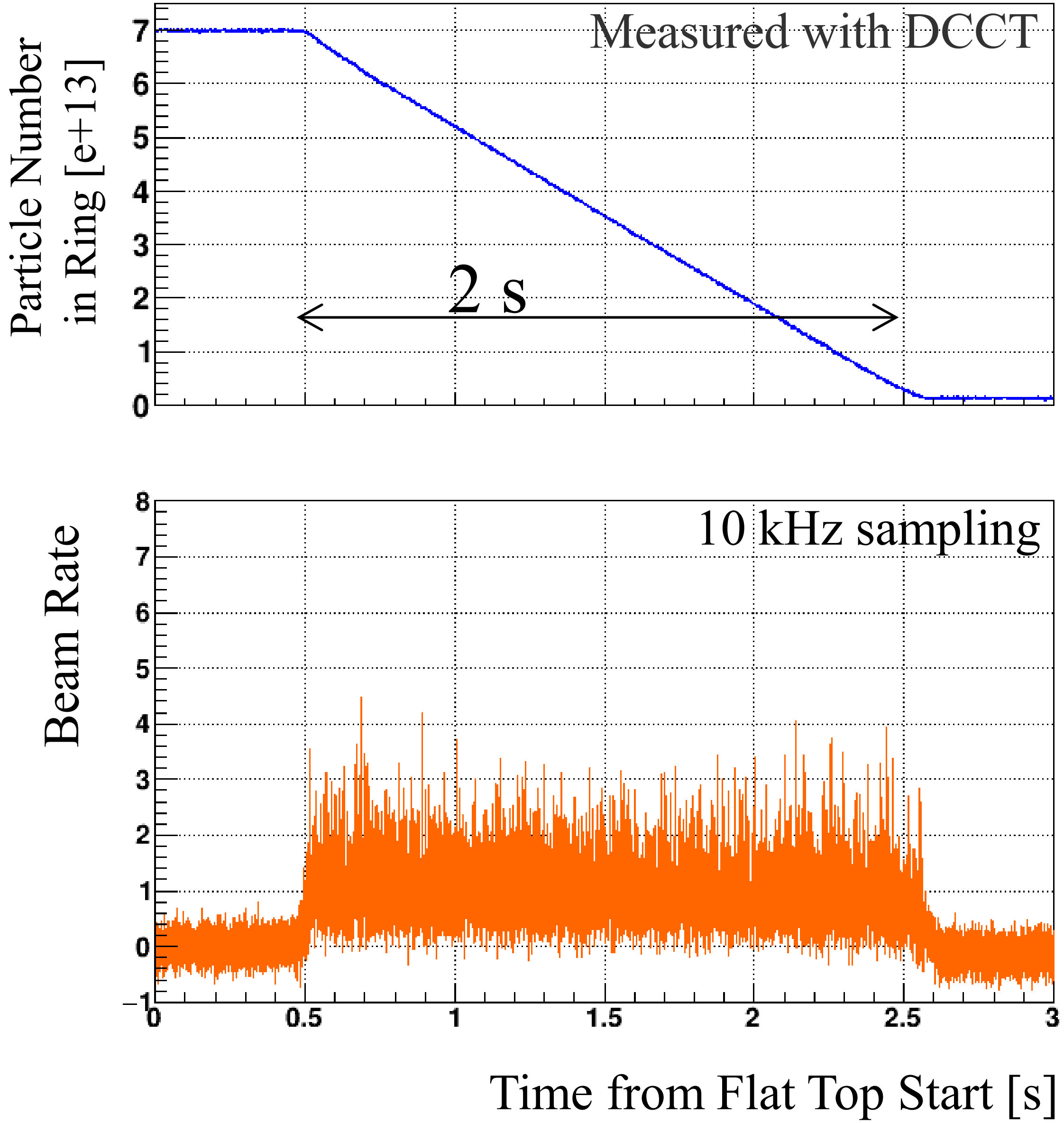

2020-June

With macro structure regulation only

Spill Duty Factor : $\frac{\langle I \rangle^2}{\langle I^2 \rangle} \sim 4\%$
(10kHz Sampling)

Large spikes in beam spill
come from current ripples
in main magnet power supplies

# Spill structure before MR upgrade




**2021-June**
**Before MR Upgrade**

Beam power : 64 kW with 5.2 s repetition
(7.0 x $10^{13}$ particle/pulse)

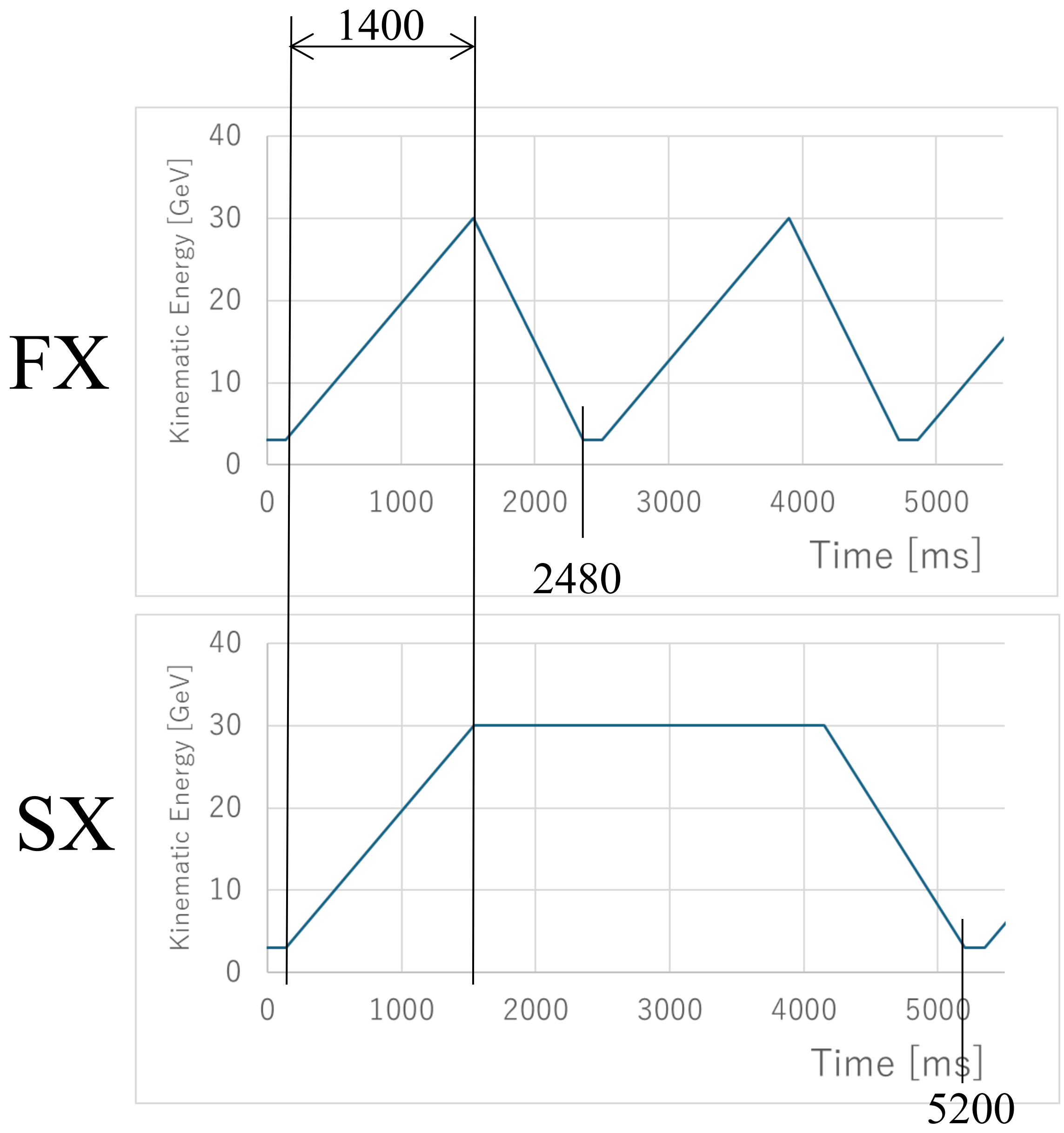
Spill Duty Factor : $\frac{\langle I \rangle^2}{\langle I^2 \rangle}$ ~ **78%**
(10kHz Sampling)

# J-PARC MR Upgrade (2022-2023)

Goal: Shorten the acceleration time to increase the repetition rate

Upgrades of

- Main Magnet Power Supplies
- RF cavities & LLRF
- Injection and Fast Extraction Devices
- MR Collimators



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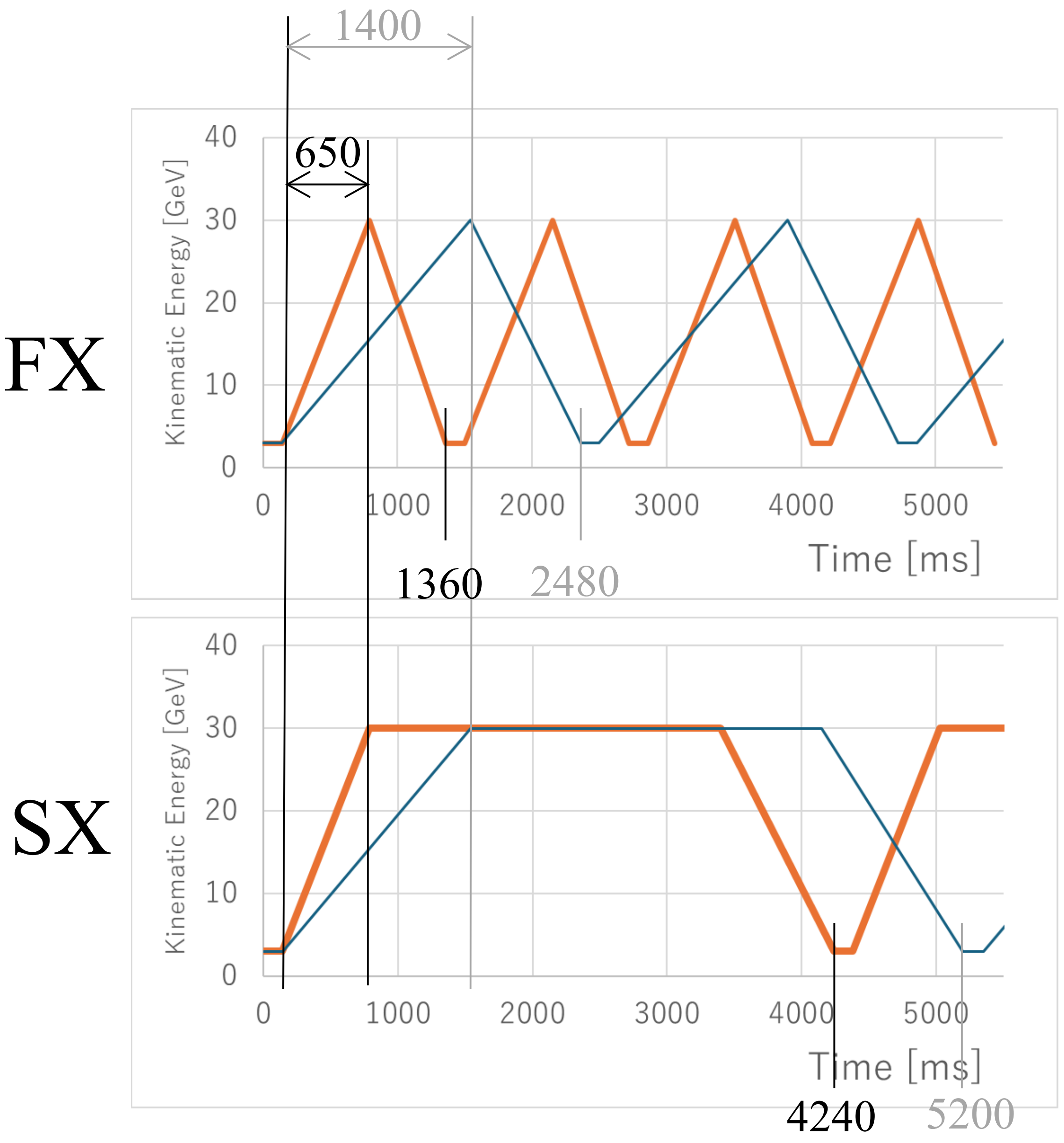
Upgrades of
- Main Magnet Power Supplies
- RF cavities & LLRF
- Injection and Fast Extraction Devices
- MR Collimators

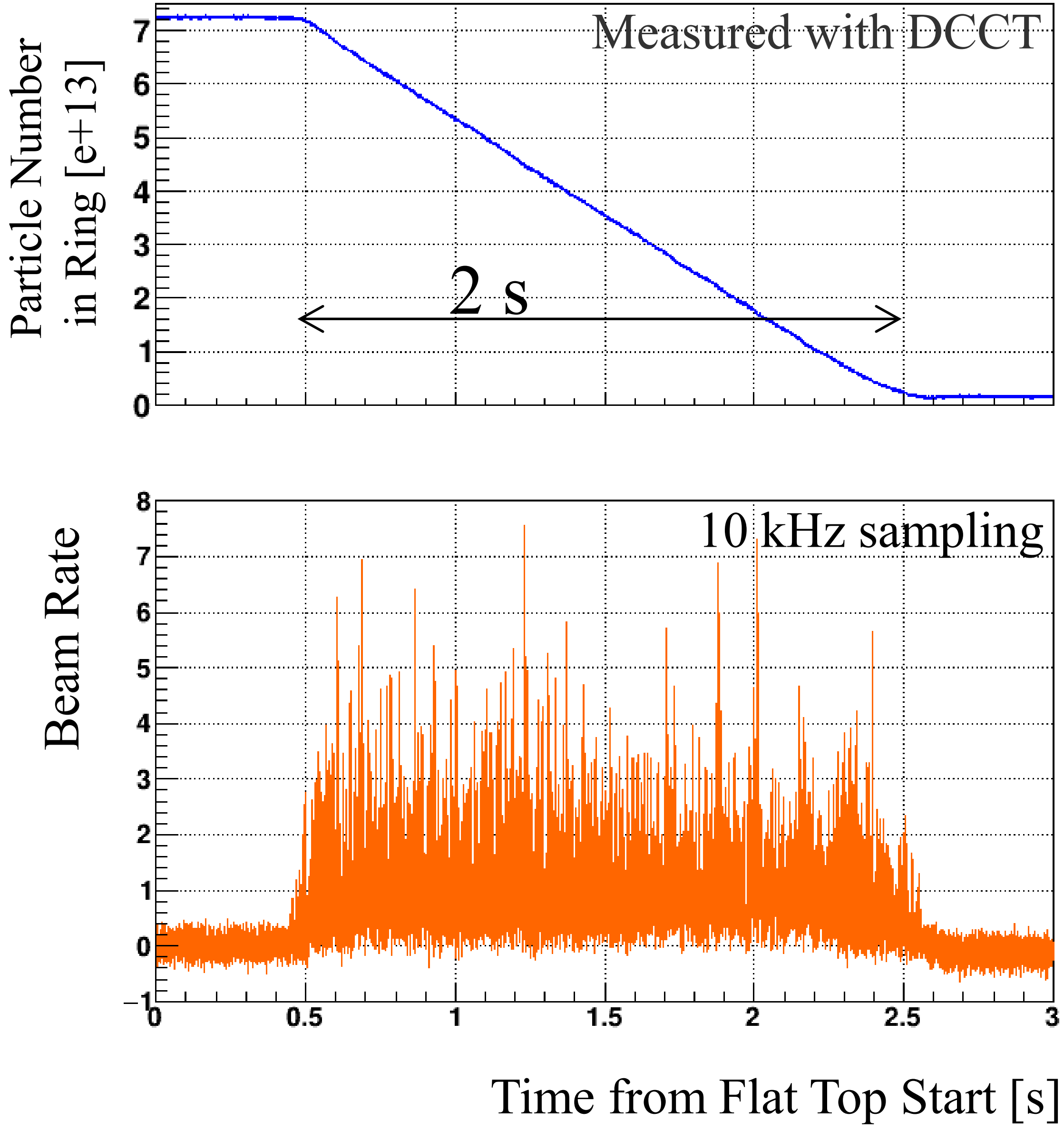
| | Before MR upgrade | After MR upgrade |
|---|---|---|
| ACC time | 1.40 s | 0.65 s |
| FX repetition | 2.48 s | 1.36 s |
| SX repetition | 5.20 s | 4.24 s |

Flattop length of 2.61 s is not changed

Beam power with the same particle number increased by a factor of 1.23 in SX



# Spill structure after MR upgrade

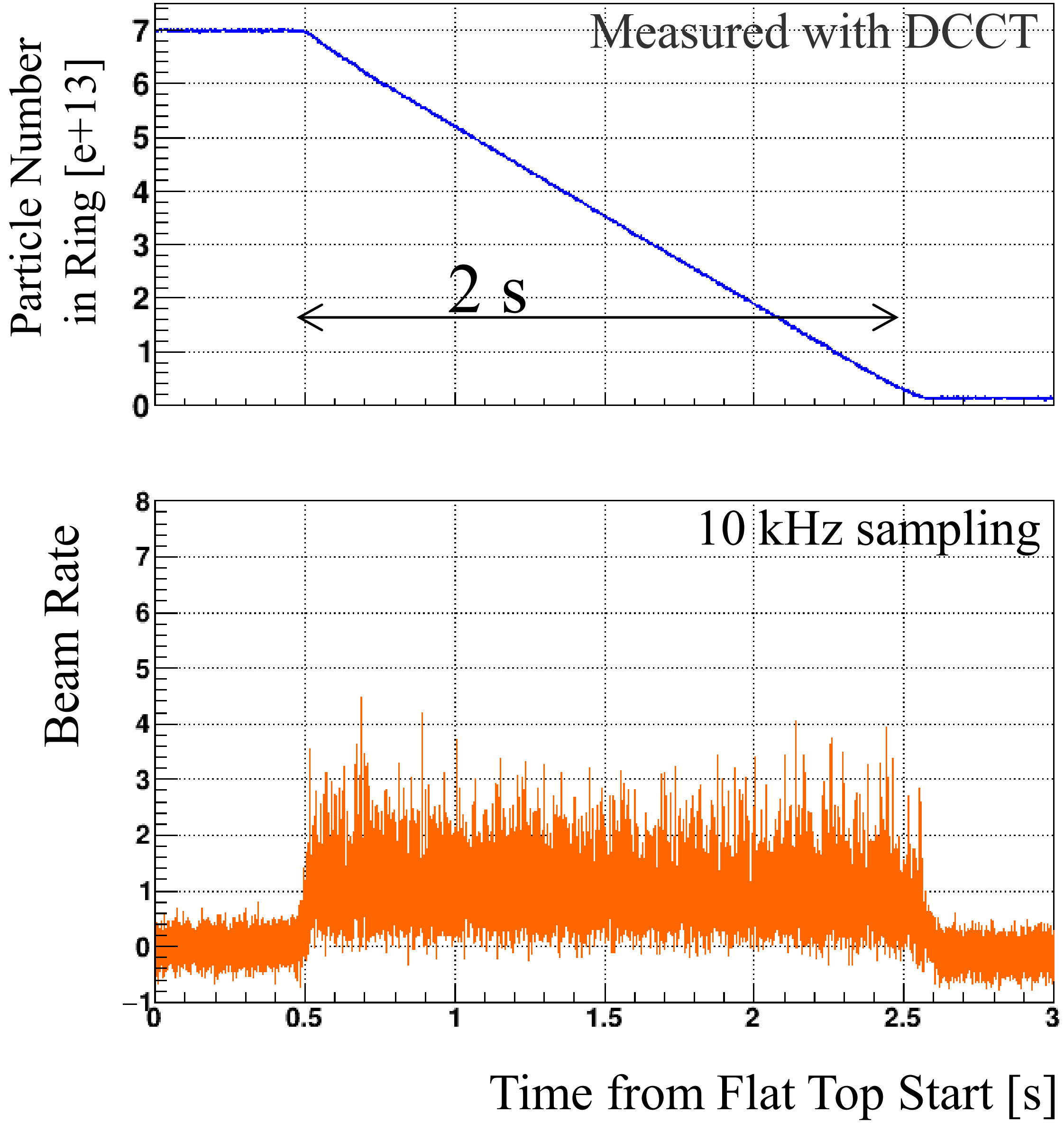



**2024-Apr**
**After MR Upgrade**

Beam power : 81 kW with 4.24 s repetition
($7.2 \times 10^{13}$ particle/pulse)

Spill Duty Factor : $\dfrac{\langle I \rangle^2}{\langle I^2 \rangle} \sim$ **61%**
(10kHz Sampling)

# Spill structure before MR upgrade




**2021-June**
**Before MR Upgrade**

Beam power : 64 kW with 5.2 s repetition
($7.0 \times 10^{13}$ particle/pulse)

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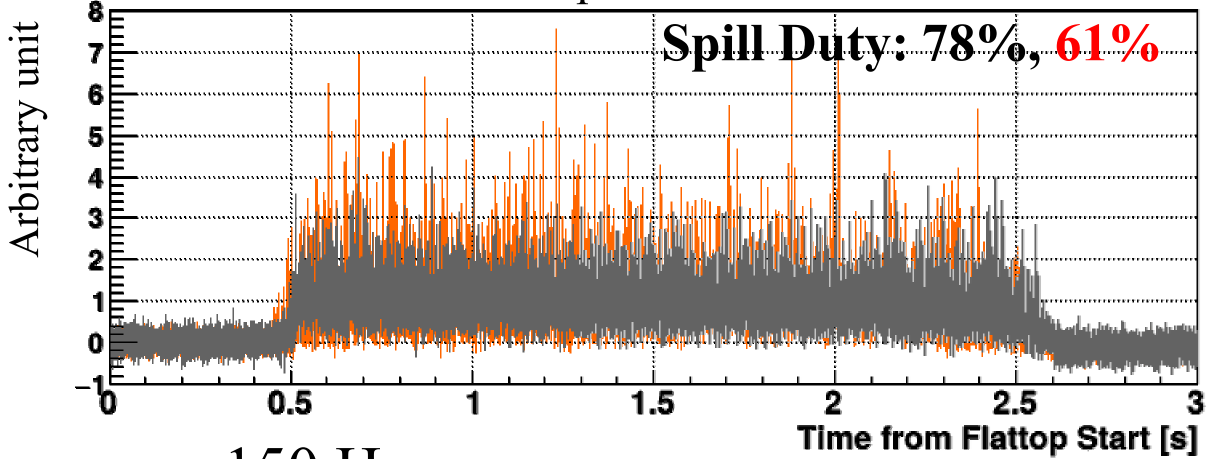
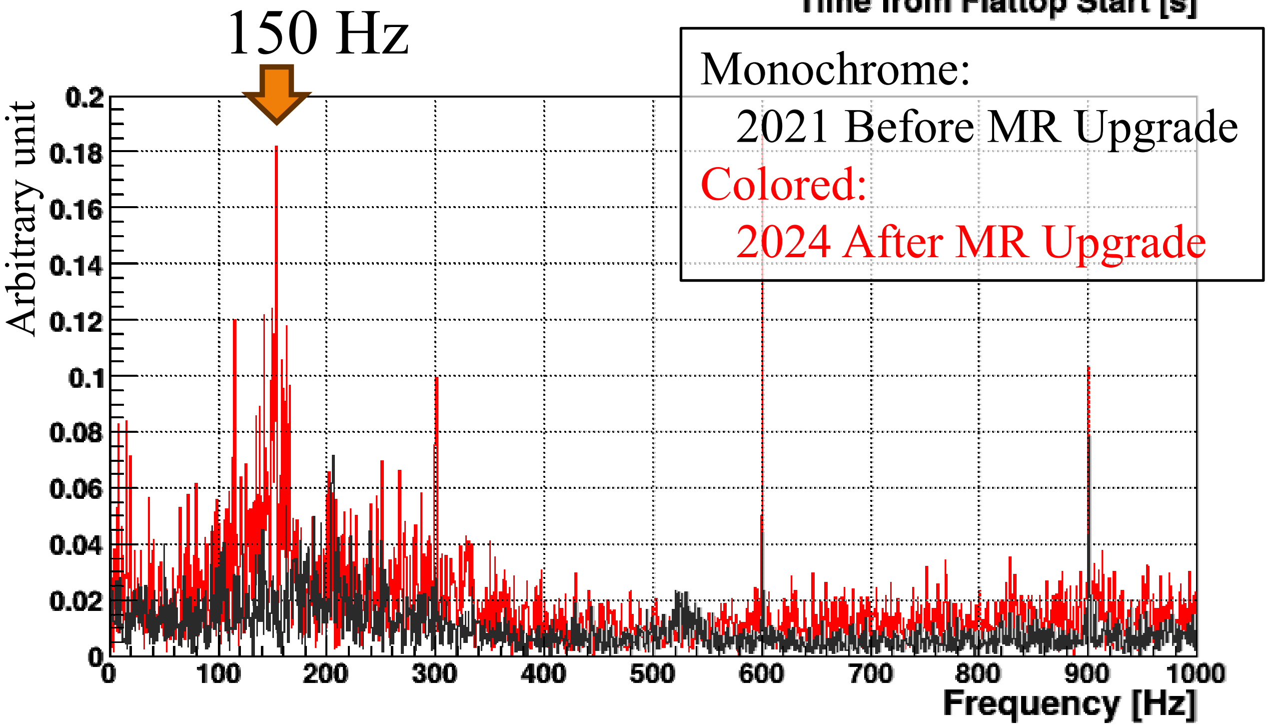
(10kHz Sampling)

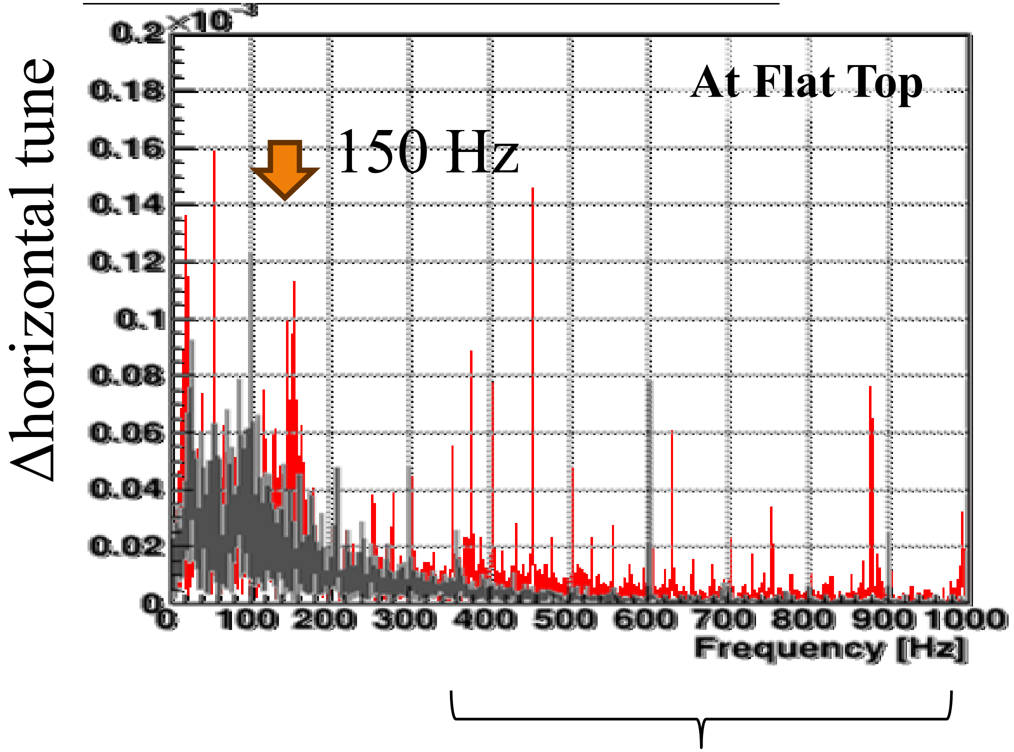
# Comparison of beam spill structure

Beam Spill Structure



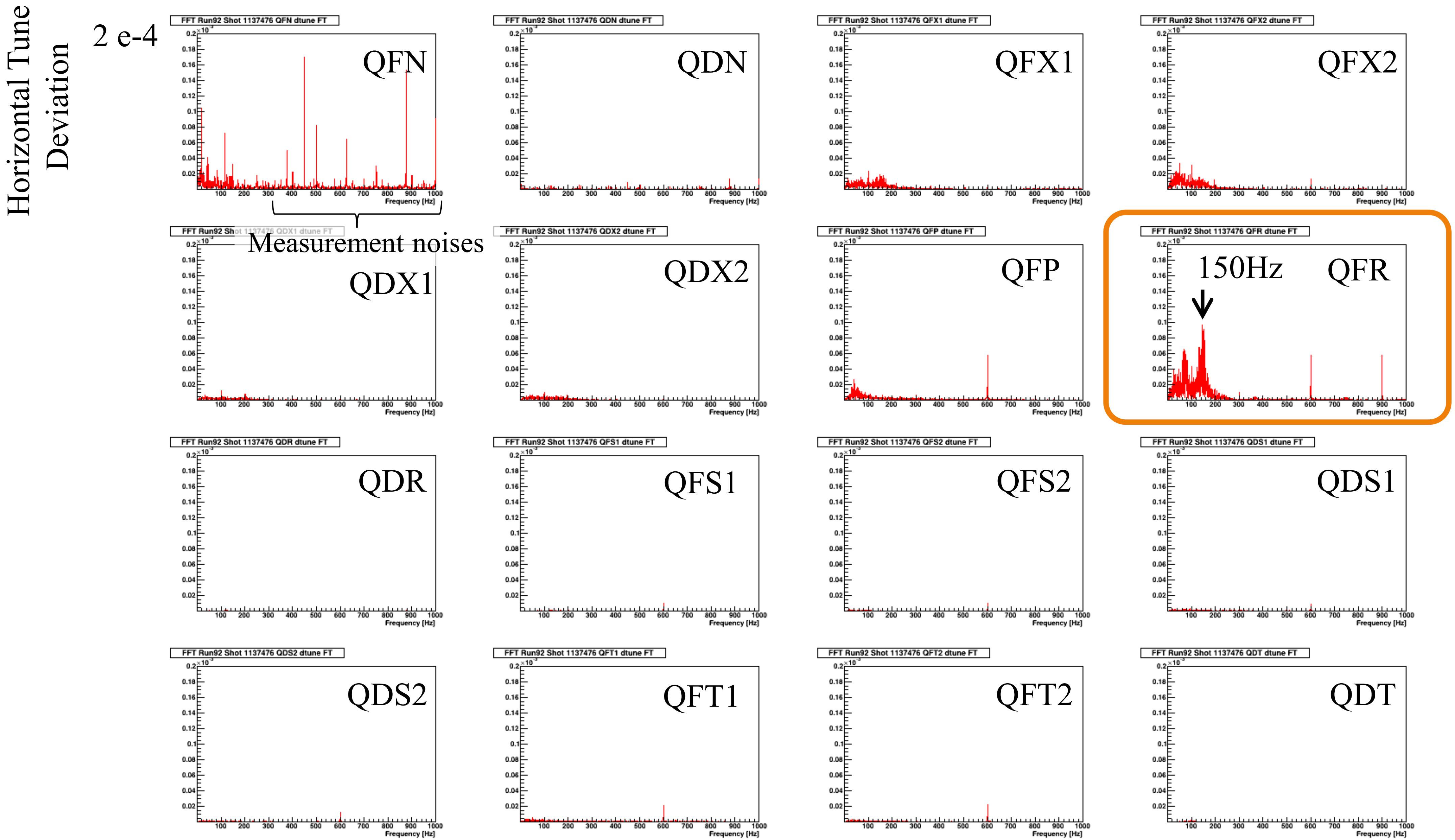




**Main Mags' Current Ripple**

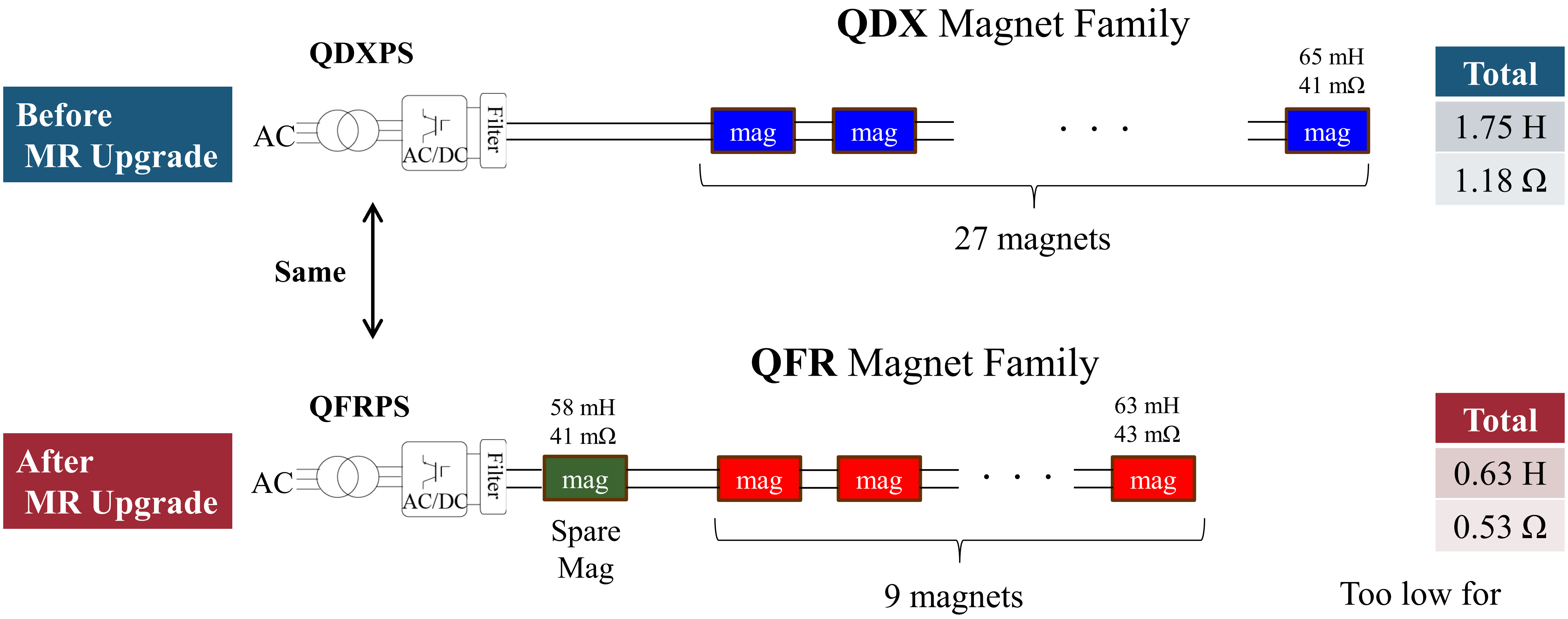



Red line contains peaks from measurement noises

# Source of 150 Hz Ripple



# Configurations of QFRPS and Magnets

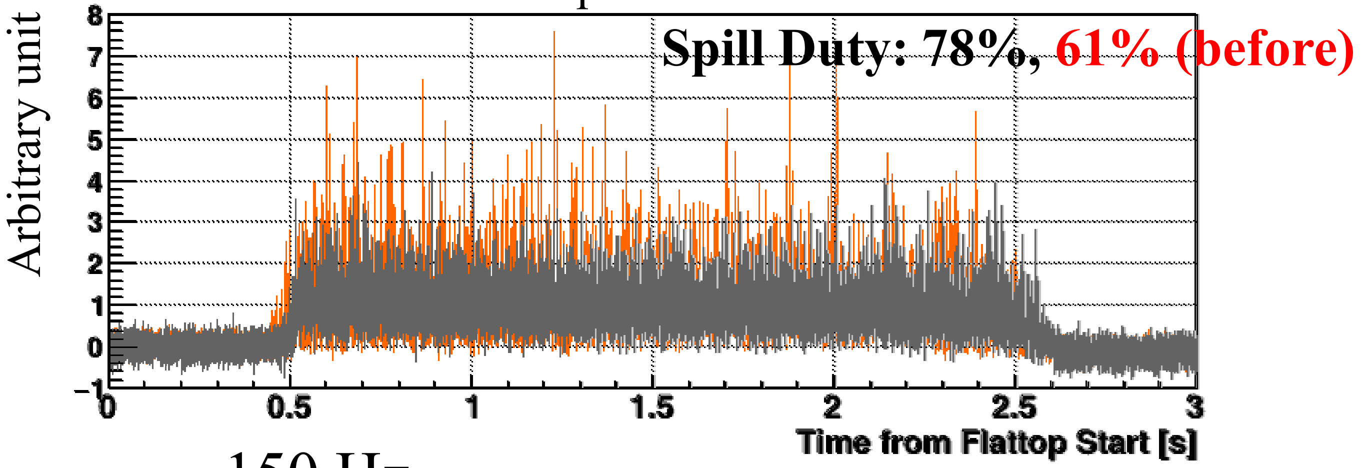


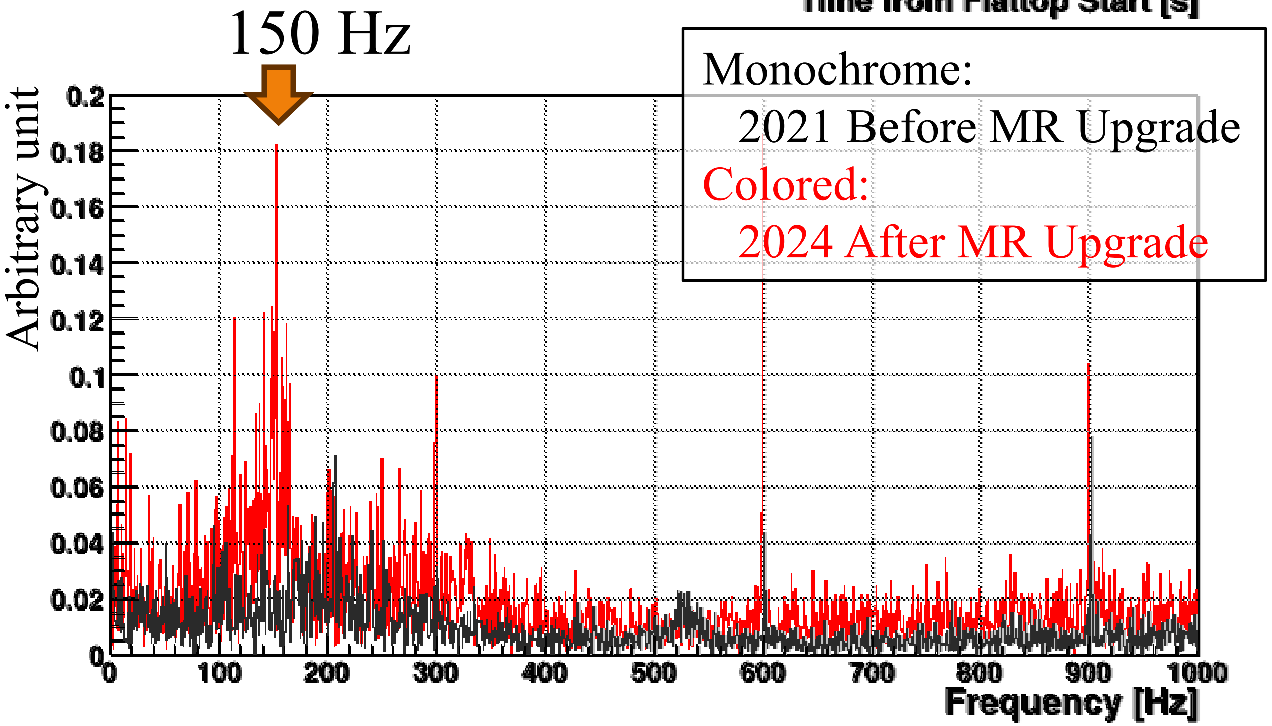

Too low for
QFRPS
(= former QDXPS)

**Long-term Solution: Fabrication of a new PS**

# Improvement on spill regulations with new main PSs

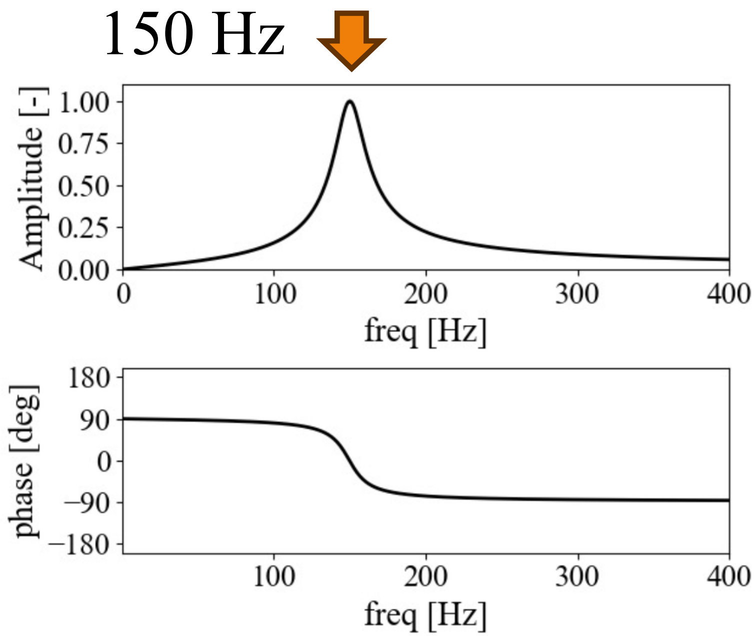
Beam Spill Structure




**RQ Gain Adjustment with bandpass filter**

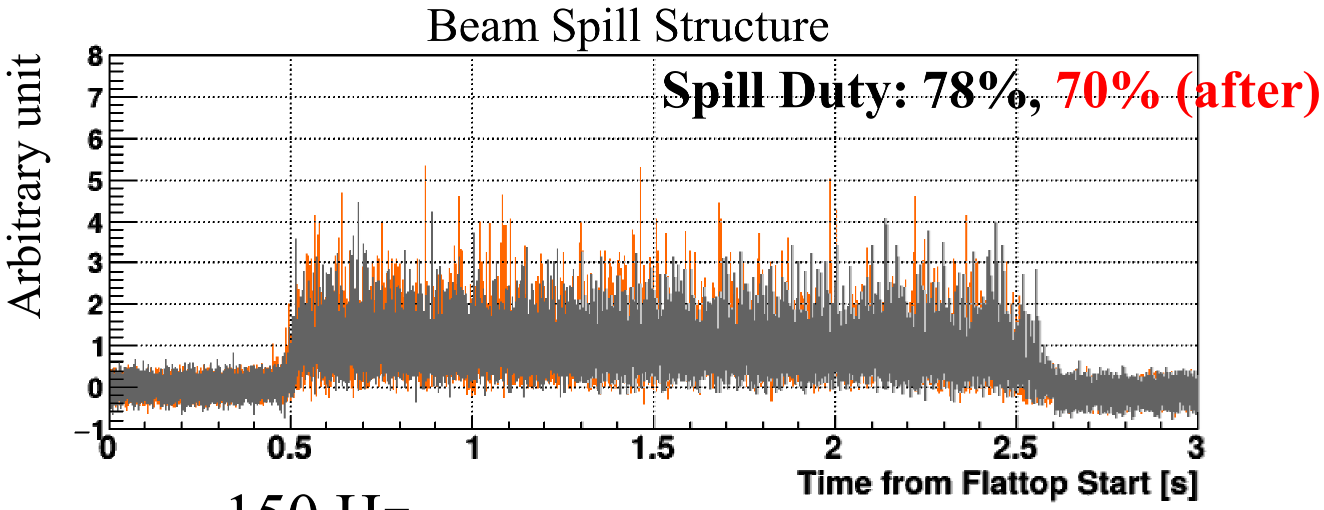
$$G(s) = \frac{\Delta\omega s}{s^2 + \Delta\omega s + \omega_0^2}$$

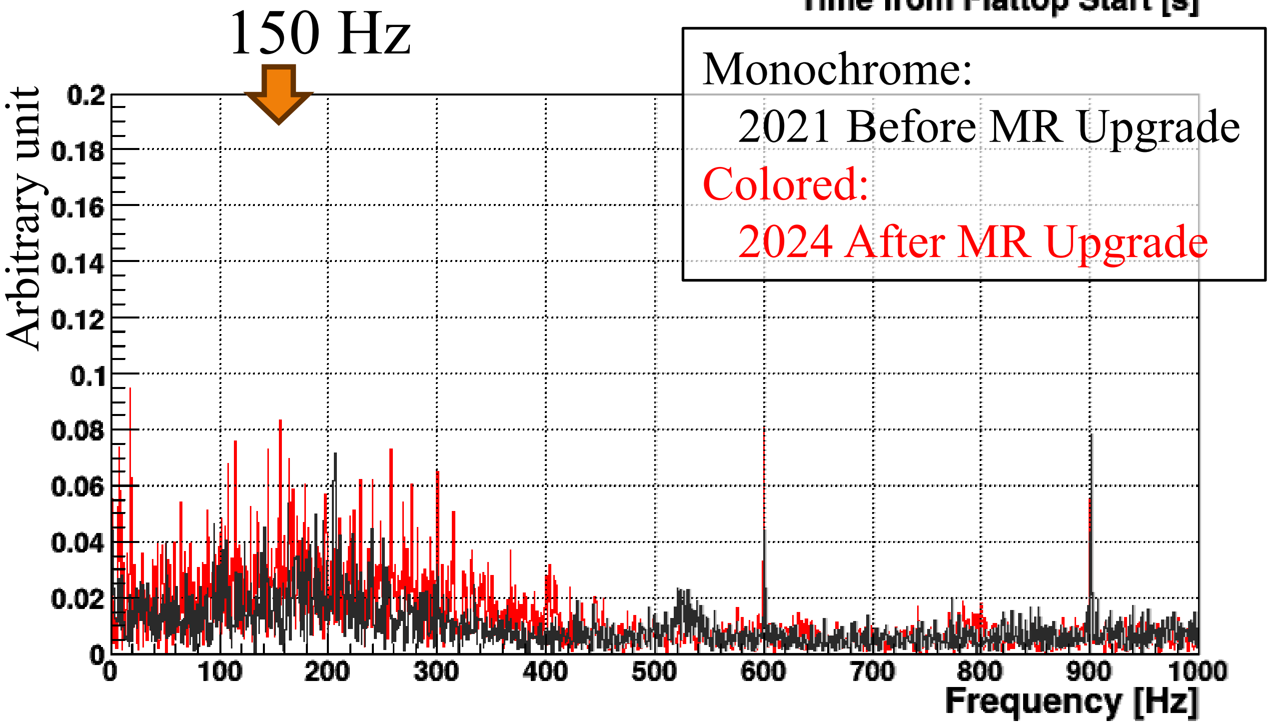



**RQ Gain x 3 around 150 Hz**

T. Asami

# Improvement on spill regulations with new main PSs

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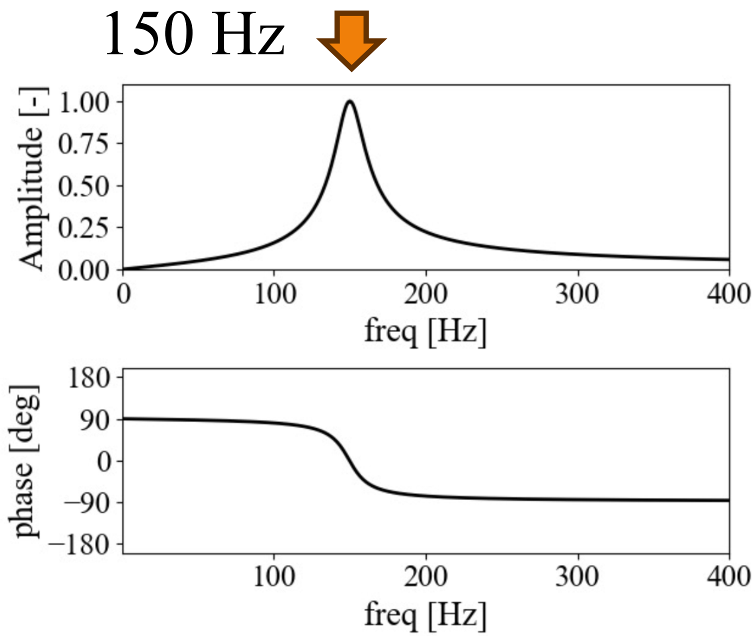
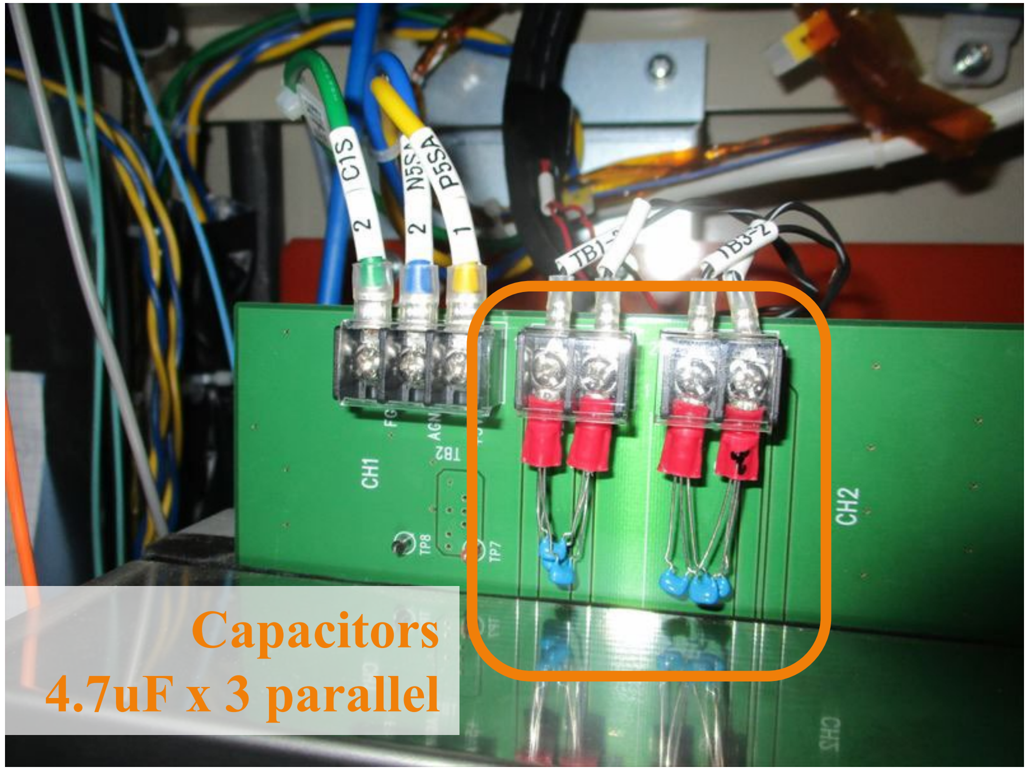



**RQ Gain x 3 around 150 Hz**

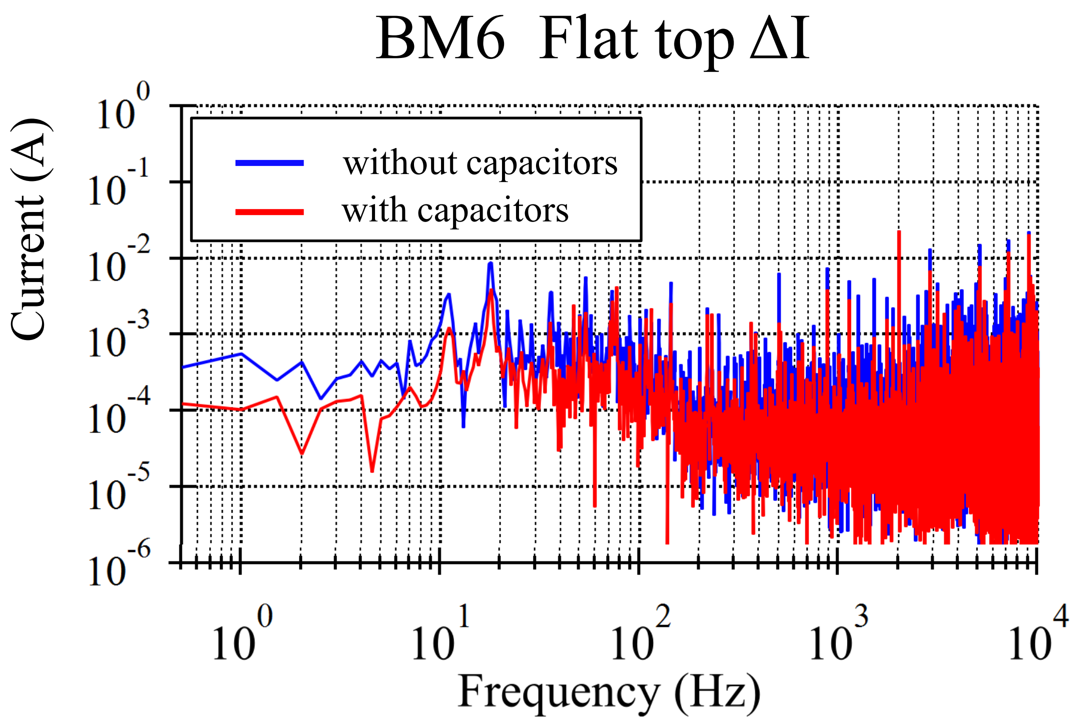
T. Asami

# Effort to reduce current ripples in power supplies

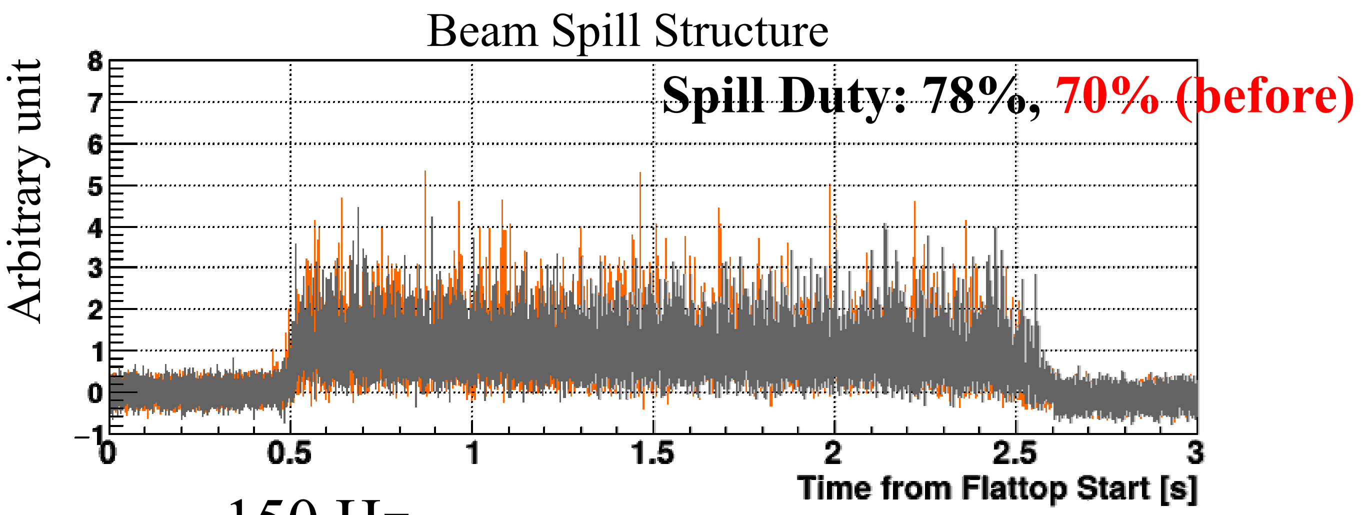
Input filter for A/D board was added

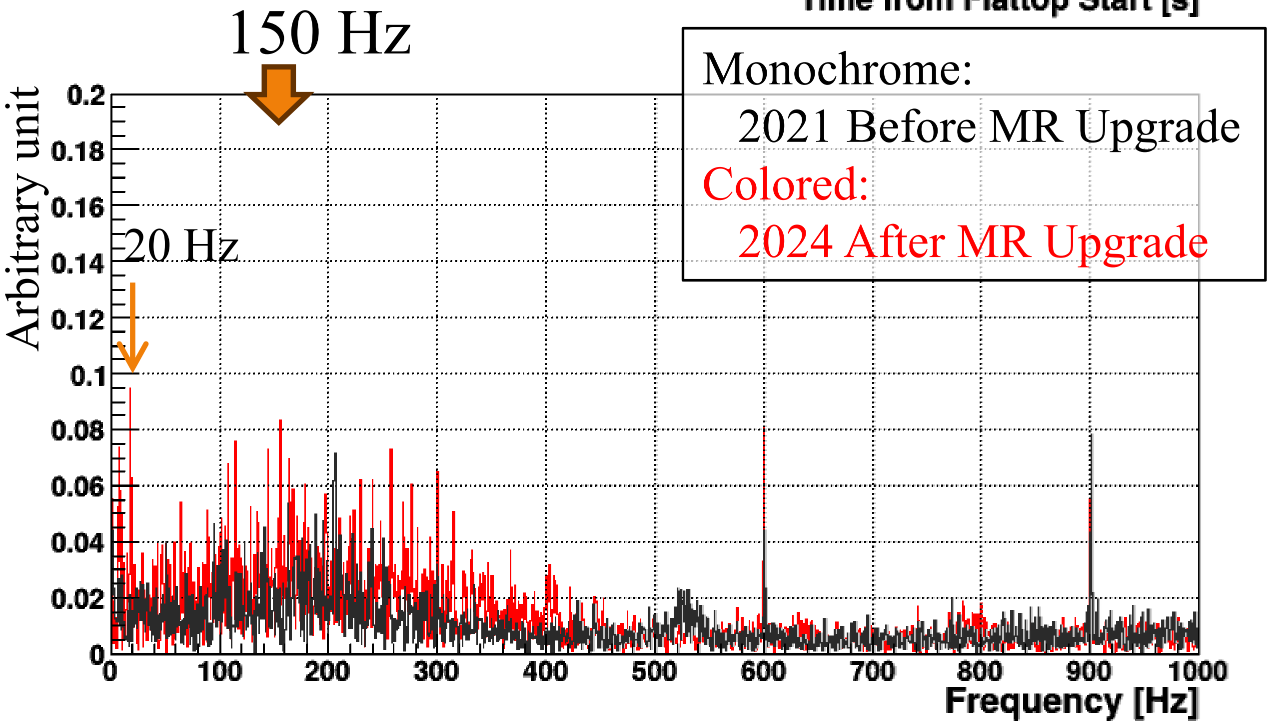



BM1~6, QFN, QDN, QDR, QDT, SD

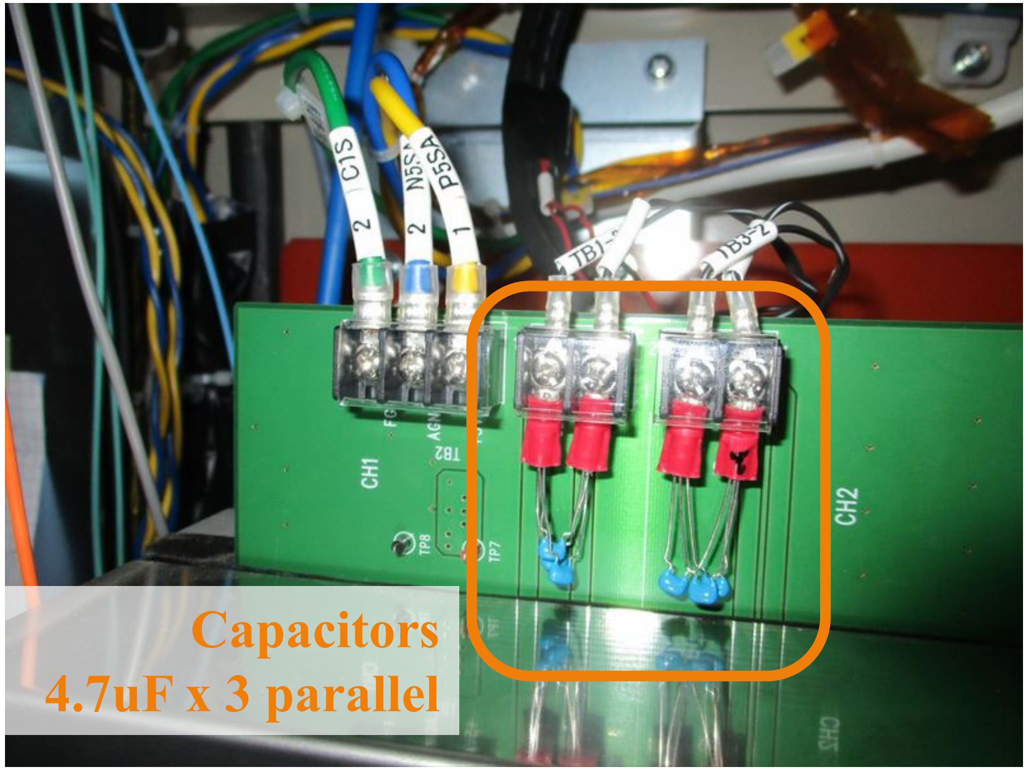


# Improvement on spill regulations with new main PSs




Input filter for A/D board was added



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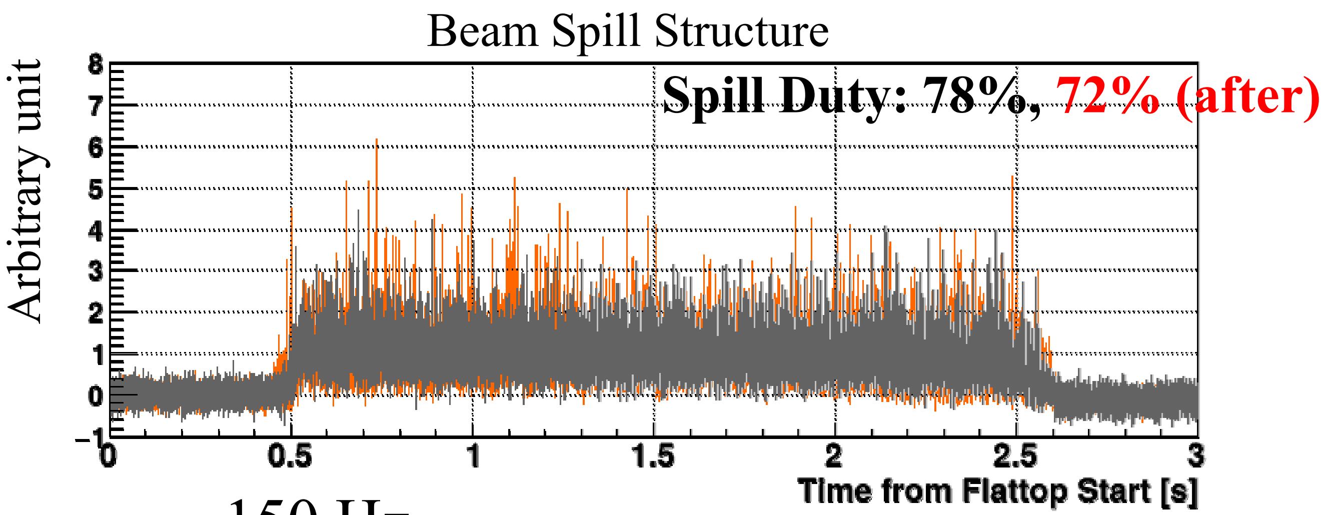


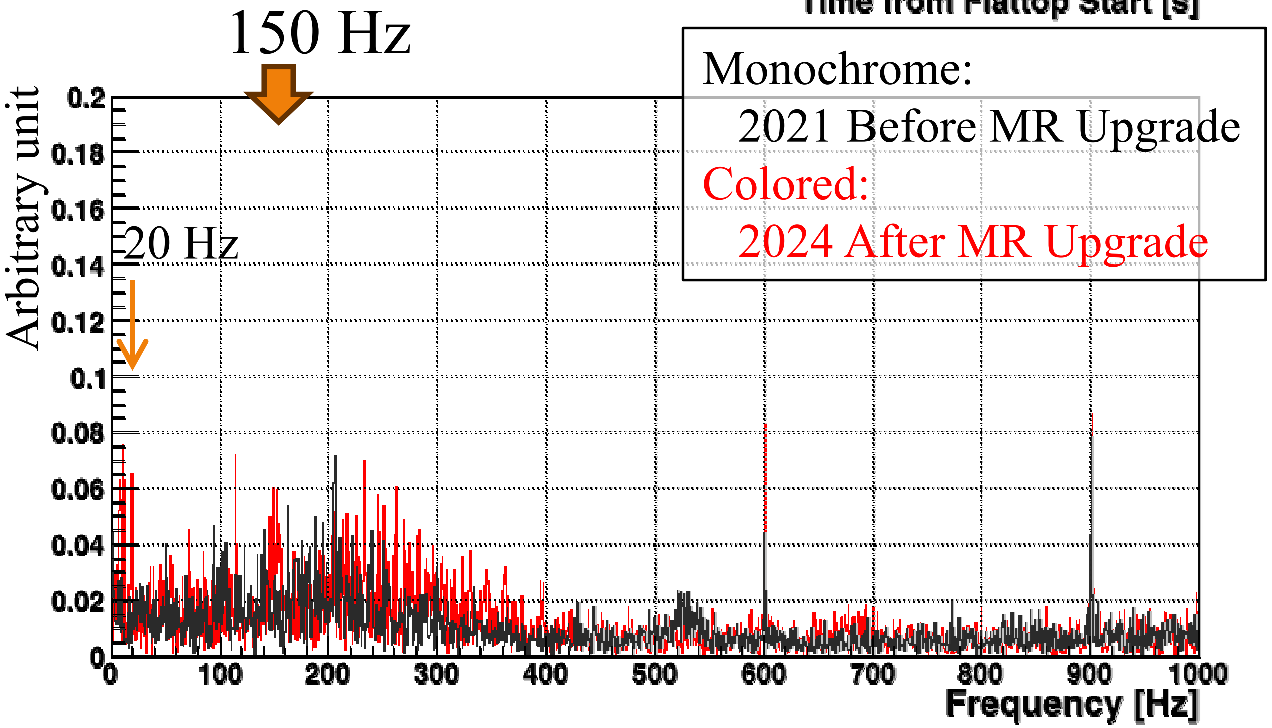


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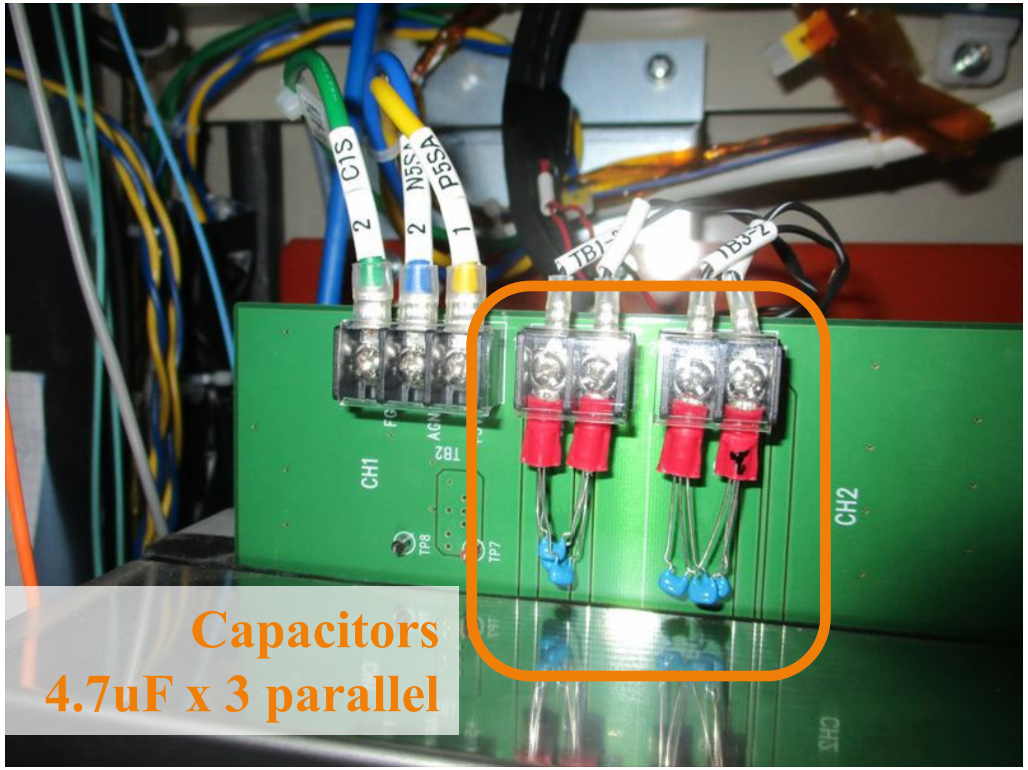

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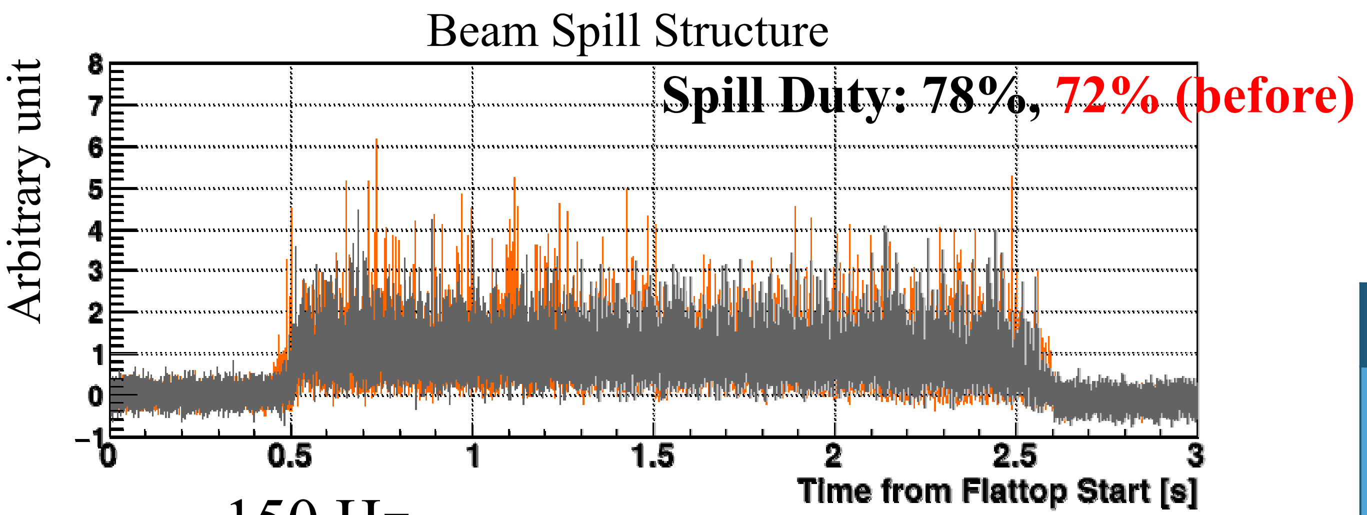
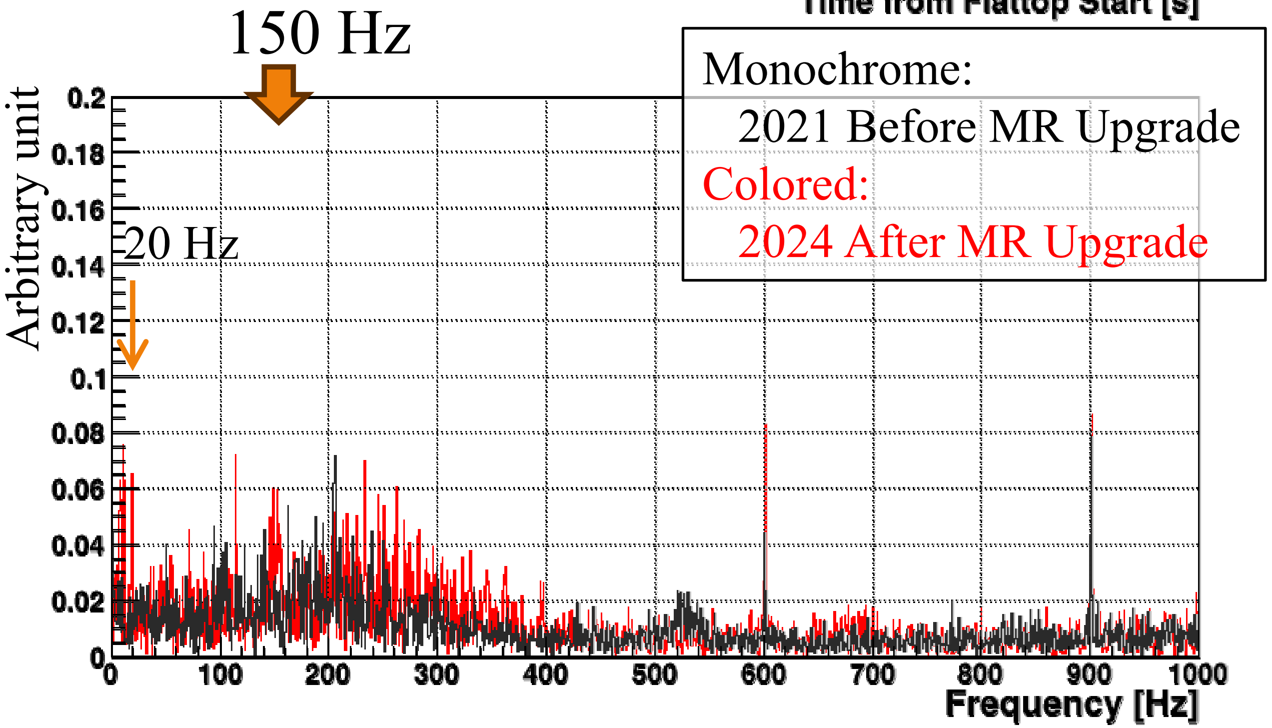
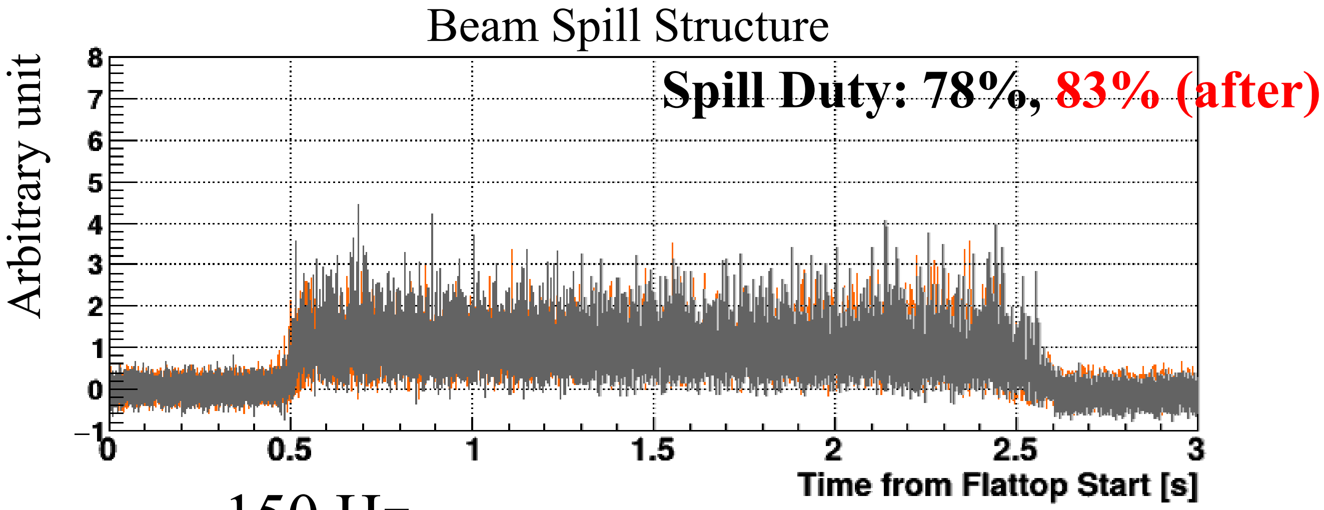


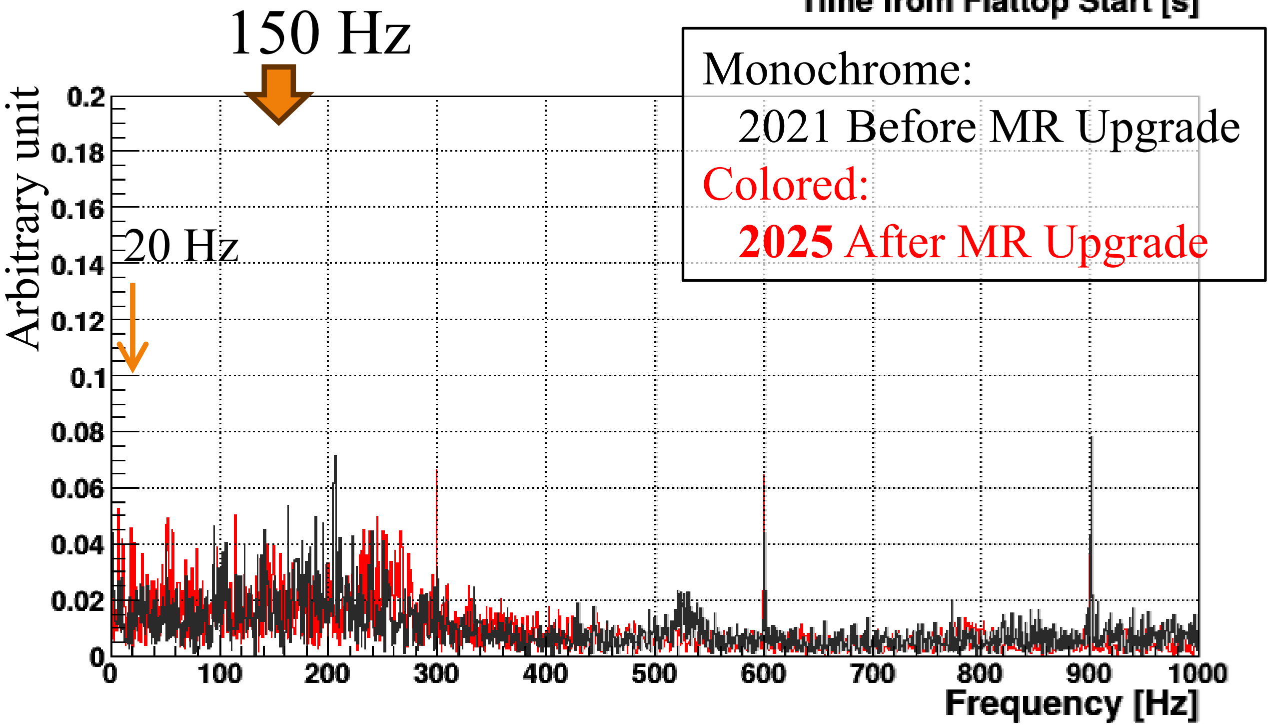




## Optimization of transverse RF

| | | Before | After |
|---|---|---|---|
| Exciter 1 | Qex | 0.2390 | 100.3236 |
| | ΔQex | 0.0820 | 0 |
| | Center Freq. [MHz] | 0.255 | 19.2786 |
| | Signal Strength | 2 dBm | 9 dBm |
| Exciter 2 | Qex | 248.3266 | 248.3274 |
| | ΔQex | 0.0003 | 0 |
| | Center Freq. [MHz] | 47.4719 | 47.4721 |
| | Signal Strength | 0 dBm | 3 dBm |

# Improvement on spill regulations with new main PSs

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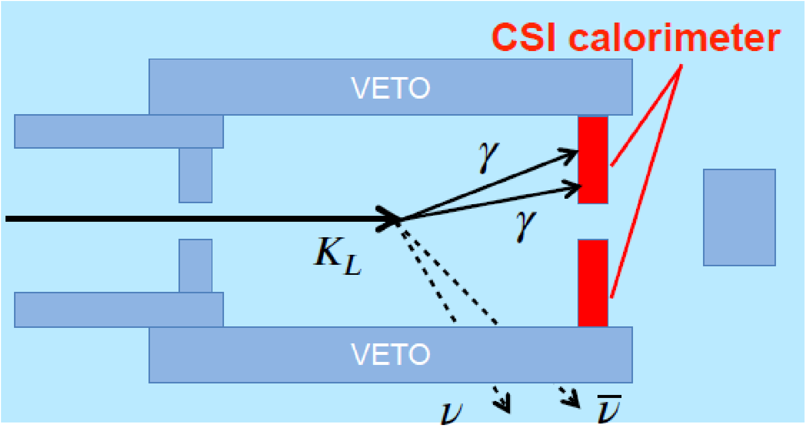
We carried out user operations under this condition

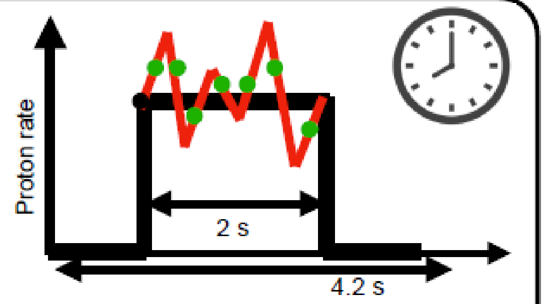
# Spill Quality Evaluation by KOTO Experiment

KOTO: $K_L \to \pi^0 \nu\bar{\nu}$ study at J-PARC



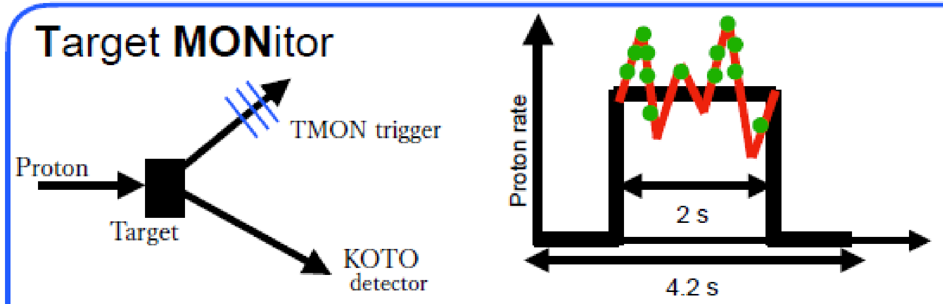

Two types of our accidental data

CLOCK trigger




Random trigger independent of the beam rate

TMON trigger




Beam-intensity weighted trigger
= similar to the situation in physics run

$$\mathrm{Rate_{CLOCK}} = \frac{N_{hit}\,(\mathrm{CLOCK})}{N_{tot}(\mathrm{CLOCK})\ \times W}$$

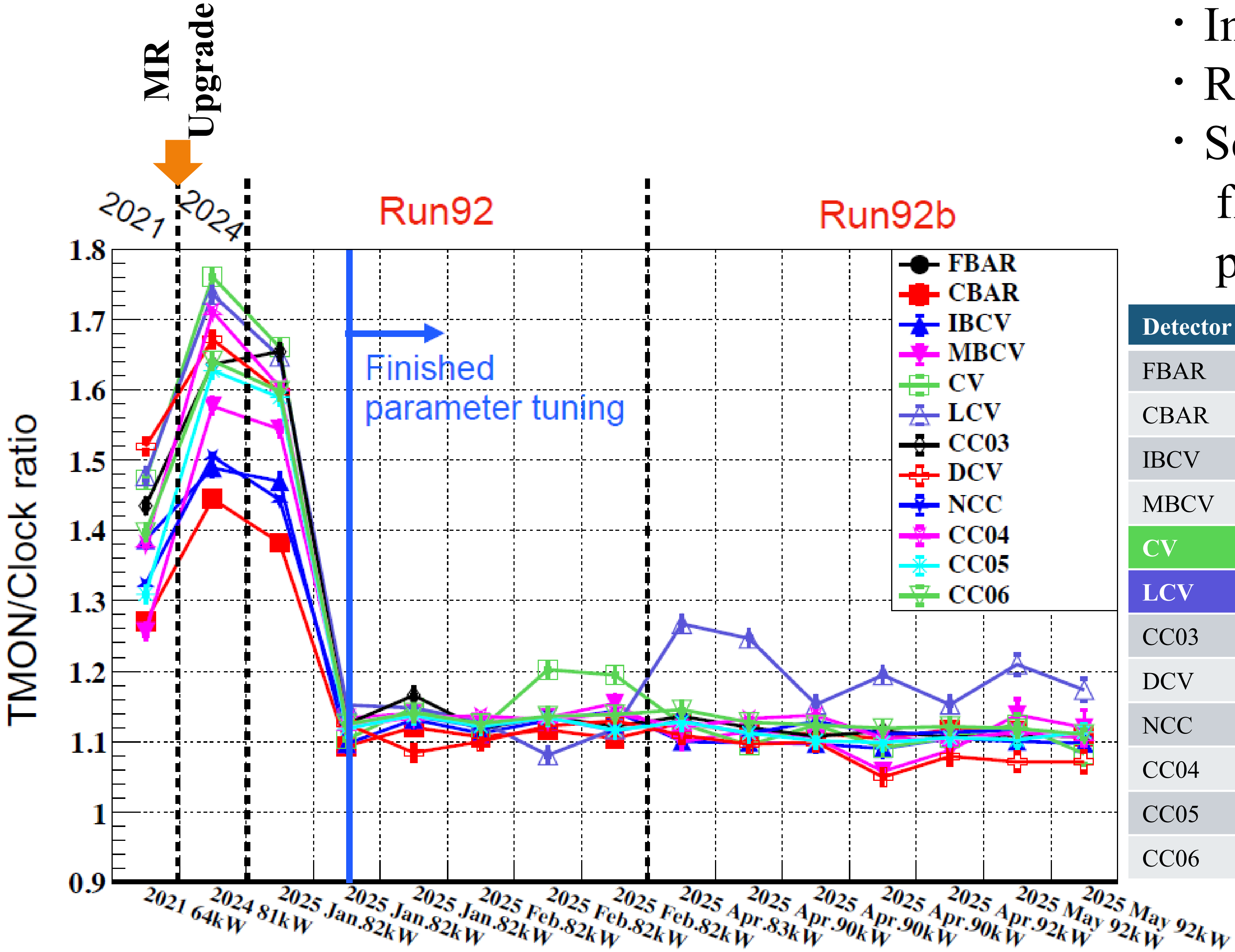
$$\mathrm{Rate_{TMON}} = \frac{N_{hit}\,(\mathrm{TMON})}{N_{tot}(\mathrm{TMON})\ \times W}$$

W: Time window for detector hit

$$\mathbf{Q_{spill}} = \frac{\mathbf{Rate_{TMON}}}{\mathbf{Rate_{CLOCK}}}\ (\geq 1)$$

$\mathrm{Q_{spill}} = 1$ for the ideal spill structure

# Spill Quality Evaluation by KOTO Experiment




- Improvement was clearly seen
- Room for improvement: ~12%
- Several detectors have fluctuations even after parameter tuning was finished

| Detector | Window [ns] |
|---|---|
| FBAR | 51 |
| CBAR | 40 |
| IBCV | 60 |
| MBCV | 60 |
| CV | 20 |
| LCV | 30 |
| CC03 | 60 |
| DCV | 60 |
| NCC | 40 |
| CC04 | 50 |
| CC05 | 50 |
| CC06 | 50 |

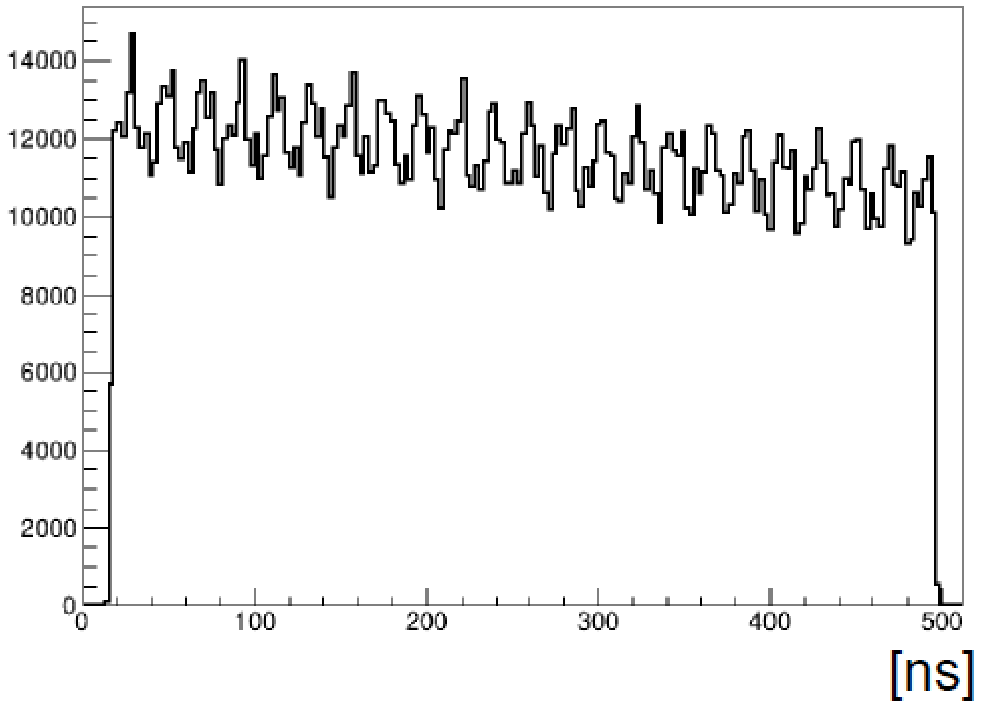
Sensitive to ~50 MHz structure

# Spill Quality Evaluation by KOTO Experiment

Accidental hit time distribution of the in-beam photon detector (BHPV), taken by TMON trigger

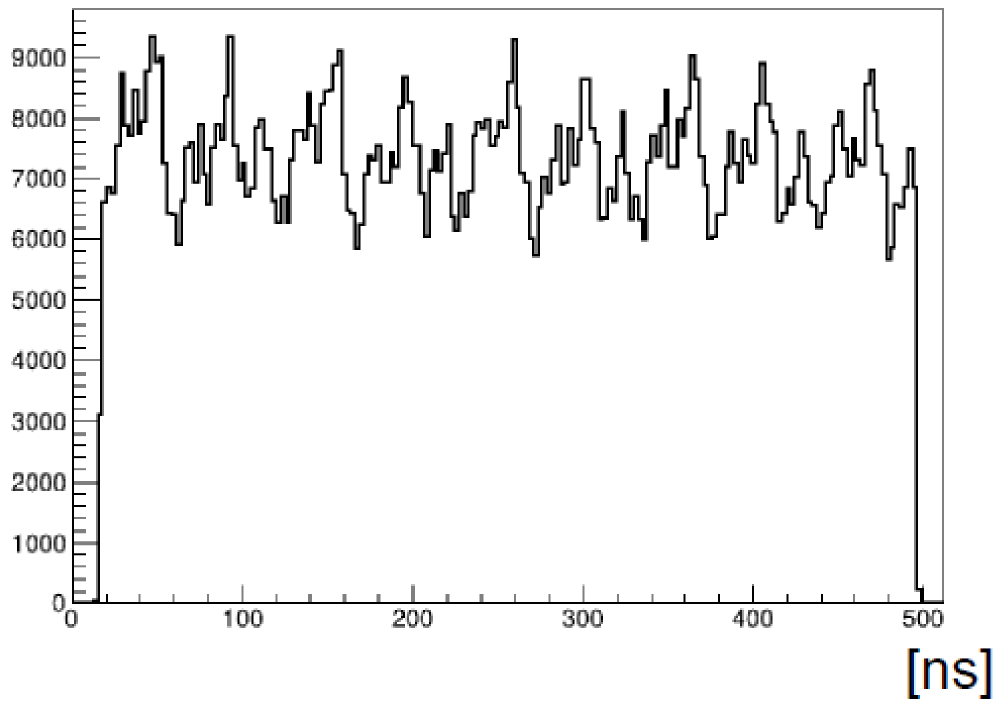
Run92 before tuning

- tr-RF freq. = 47MHz + 250kHz




Run92 after tuning

- tr-RF freq. = 47MHz + 20MHz

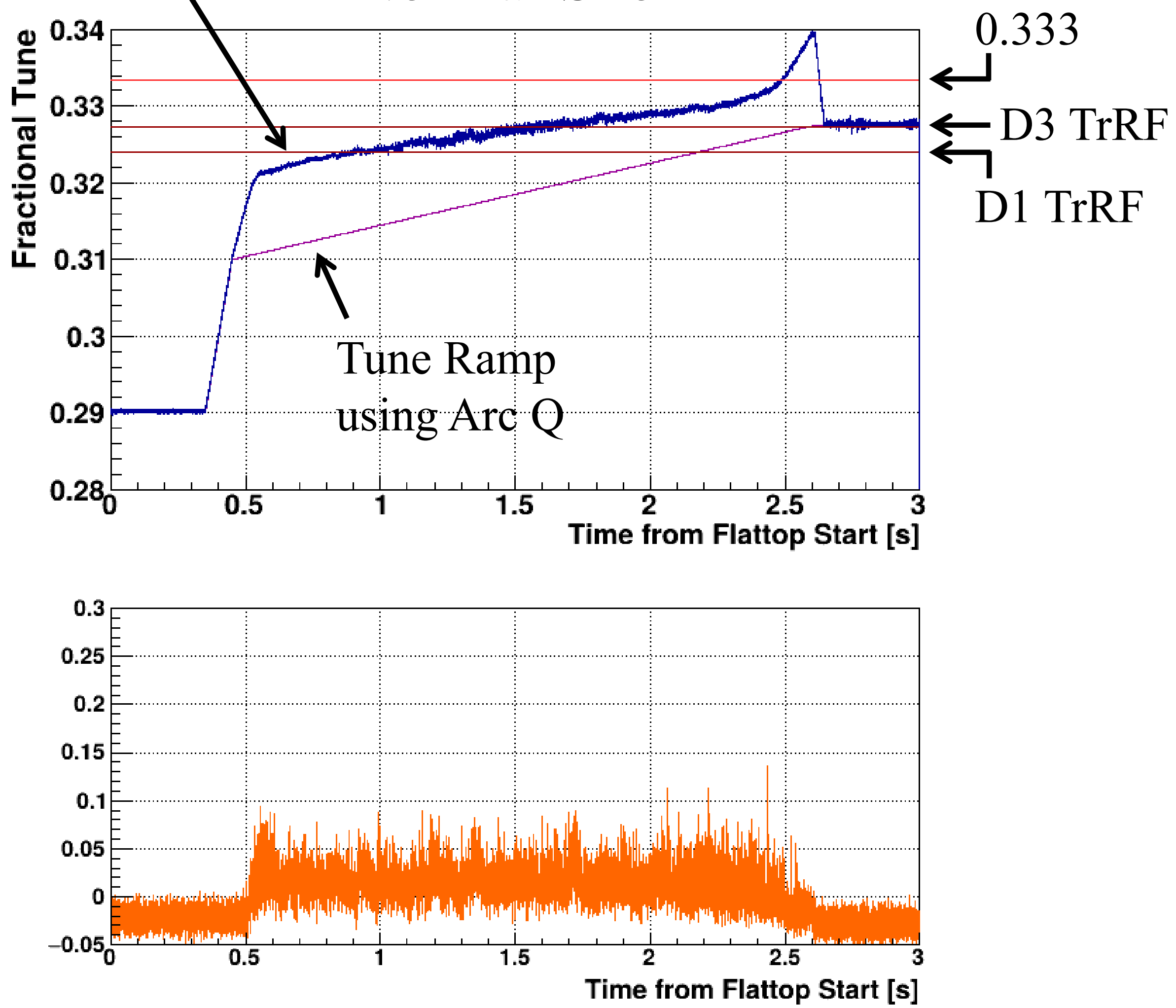



It would be good to have a spill monitor on the accelerator side that can see high-frequency components

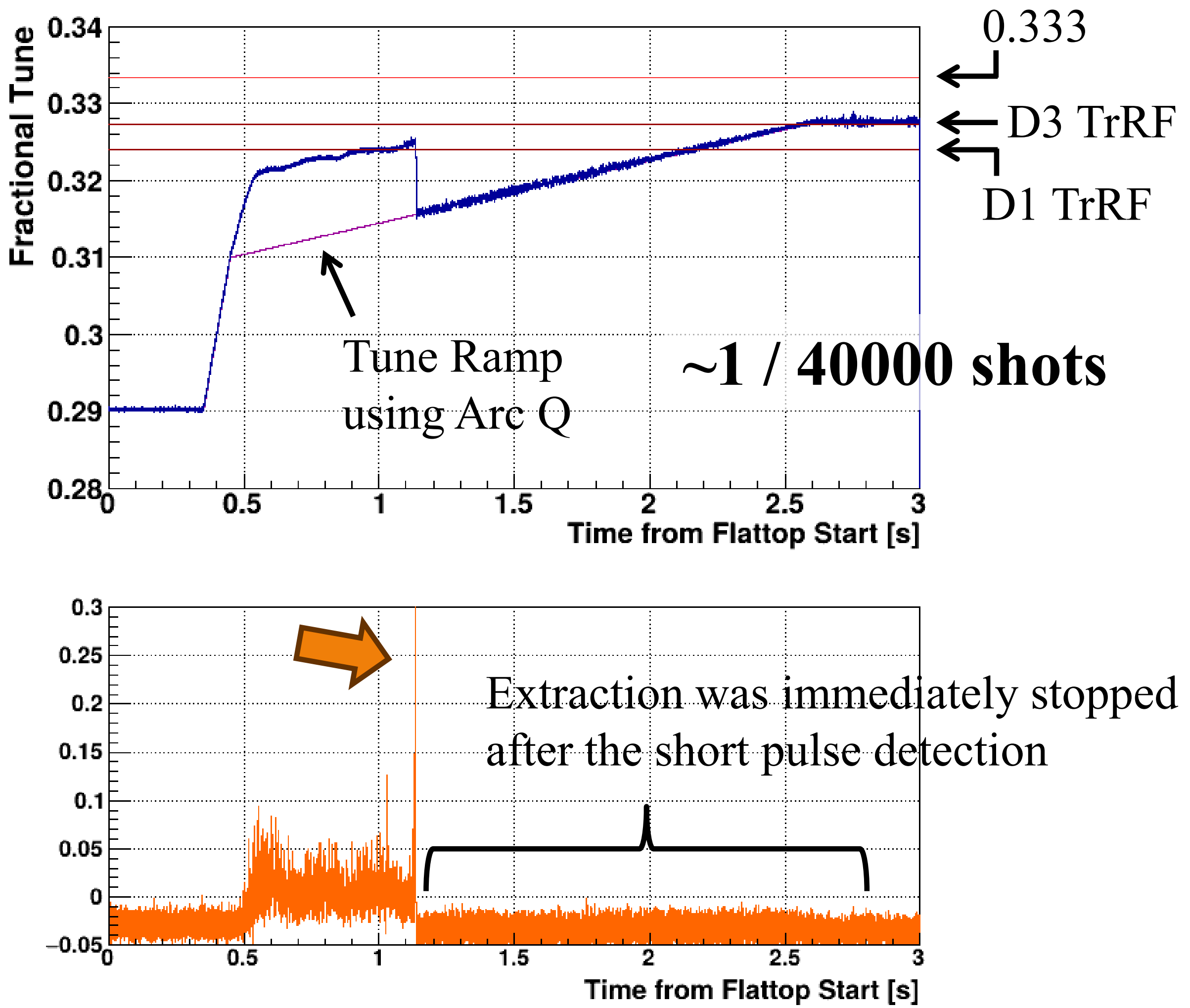
# Short Pulse Shots

Contribution of spill regulation Qs (EQ, RQ)

Normal Shot

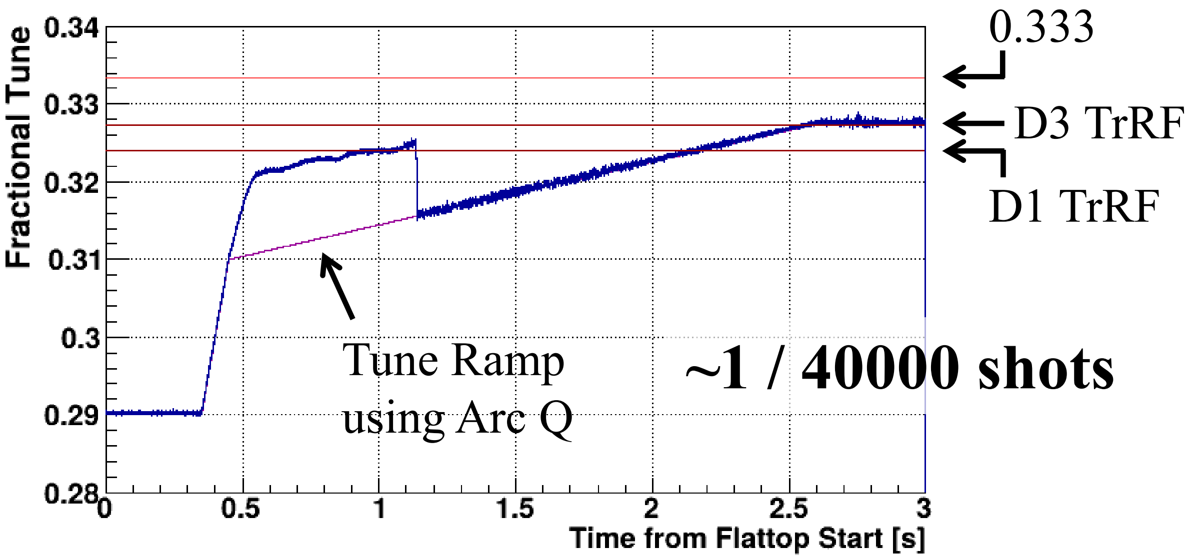



Short Pulse Shot

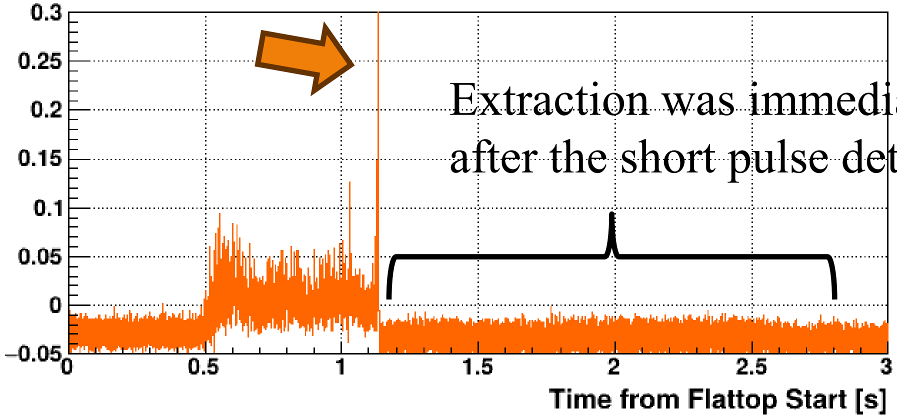


# Short Pulse Shots

Short Pulse Shot

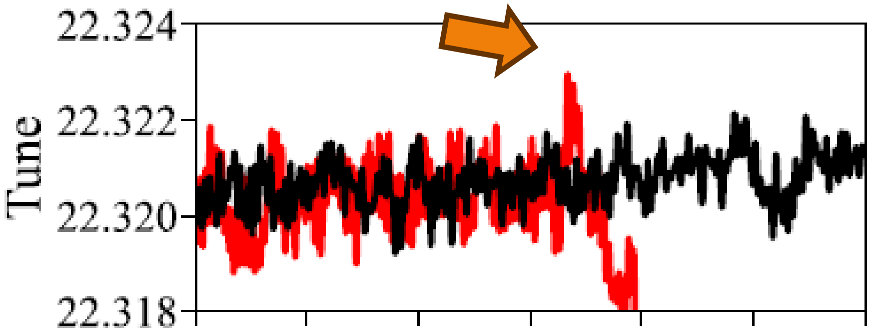



**~1 / 40000 shots**




Extraction was immediately stopped
after the short pulse detection

Betatron trune reconstructed by the PS currents



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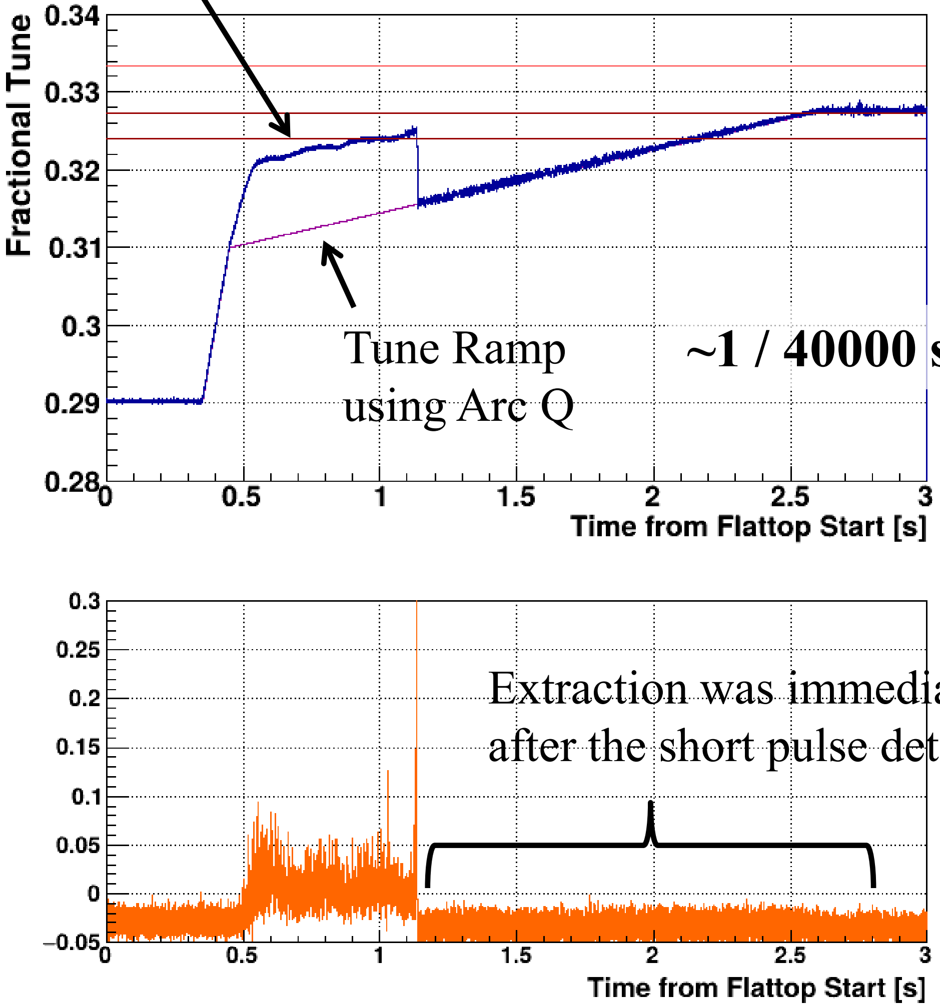
Contribution of spill regulation Qs (EQ, RQ)

## Short Pulse Shot

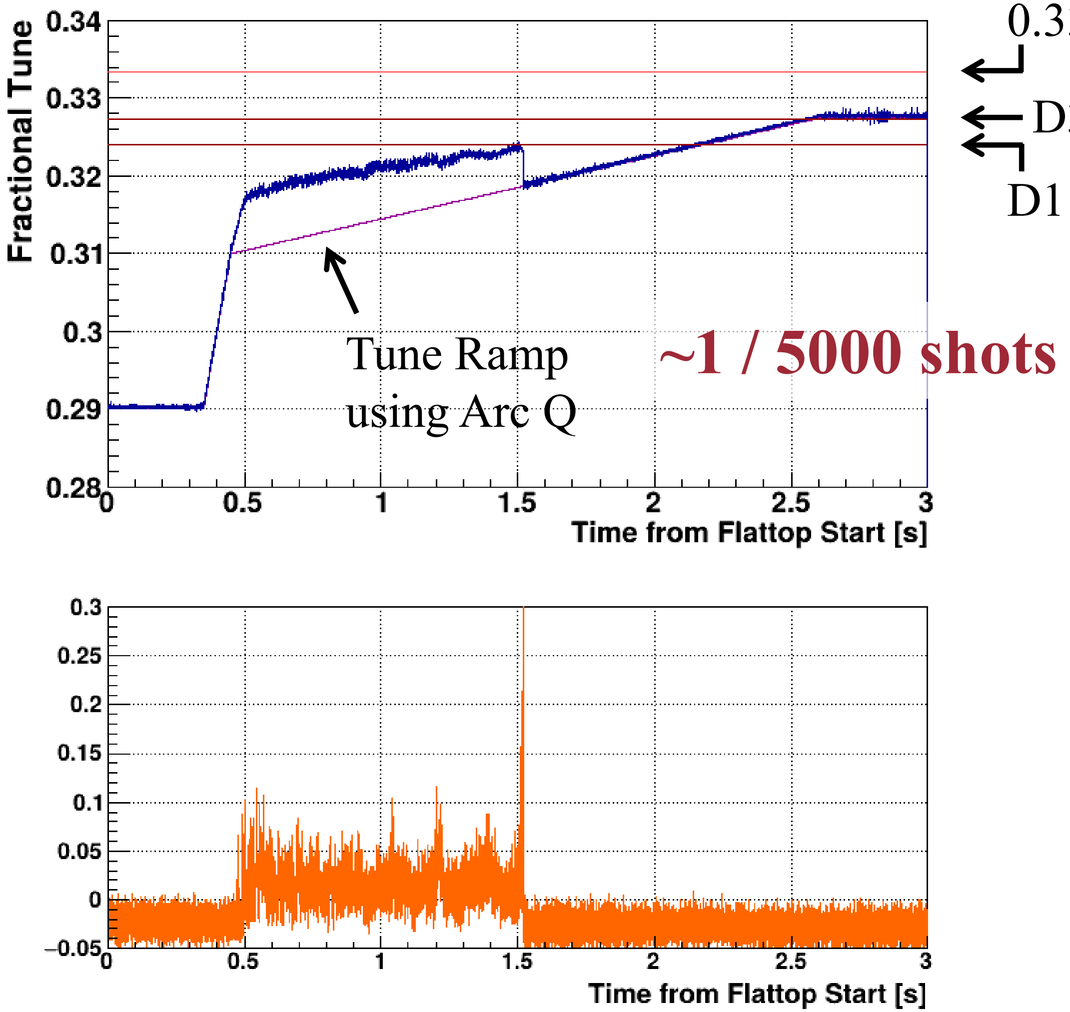



0.333

D3 TrRF

D1 TrRF

## Short Pulse Shot After EQ gain tuning



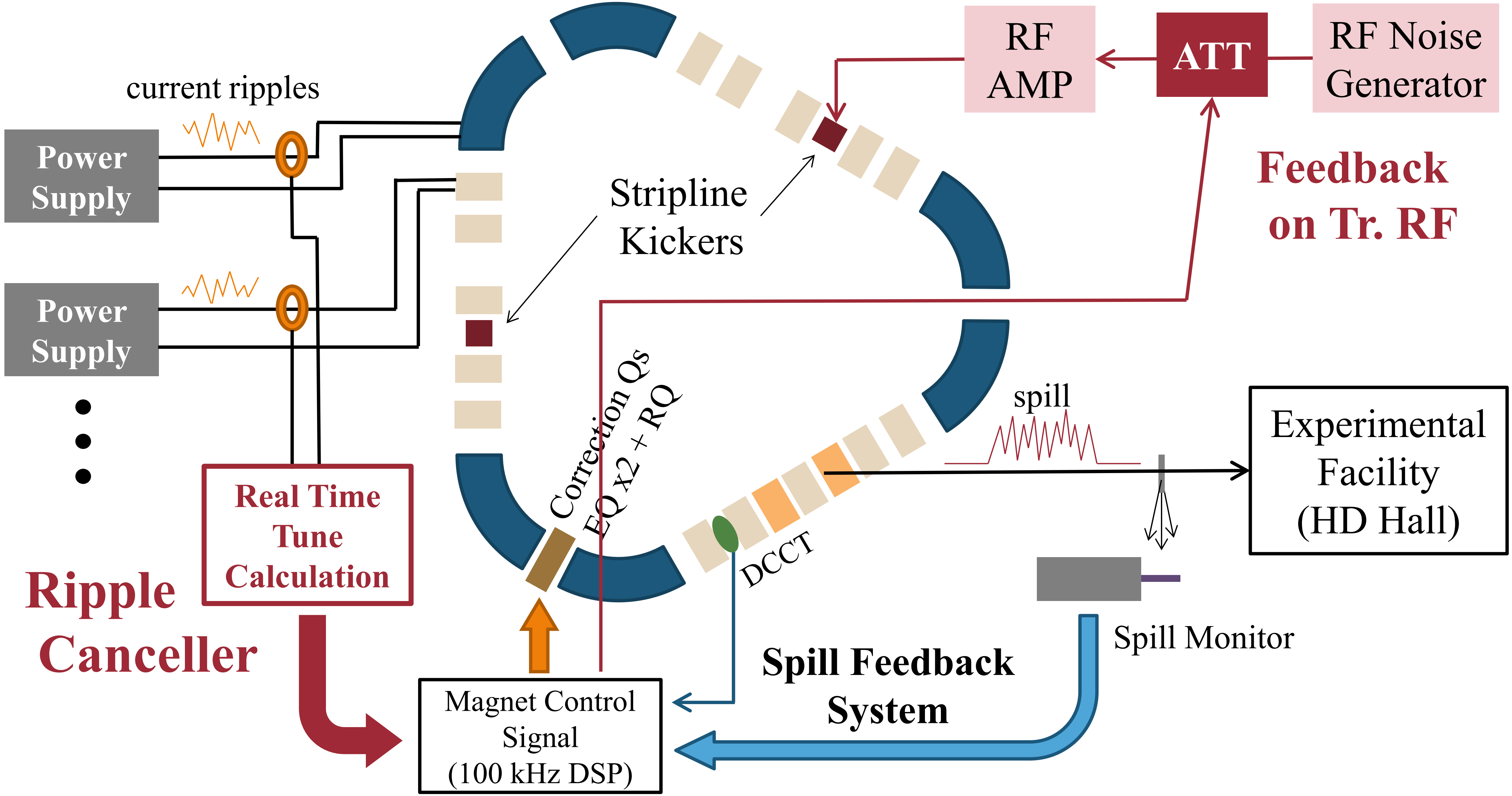

0.333

D3 TrRF

D1 TrRF

# Plans for Further Improvement

# Improvement Plans for Spill Regulation System



# Summary

We optimized the spill feedback gain and the transverse RF parameters along with the efforts to reduce the current ripples in power supplies, resulting in the improvement of spill duty factor from 61% to 83%.

Evaluation by physics experiment is consistent with our spill structure measurement.

We observed short pulse shots and attempts to reproduce the phenomena in simulation is ongoing.

We aim to further improve the spill structure by introducing a ripple canceller system and feedback control on the transverse RF signals.