Spill Structure with Newly Upgraded Main Magnet Power Supplies in J-PARC Main Ring

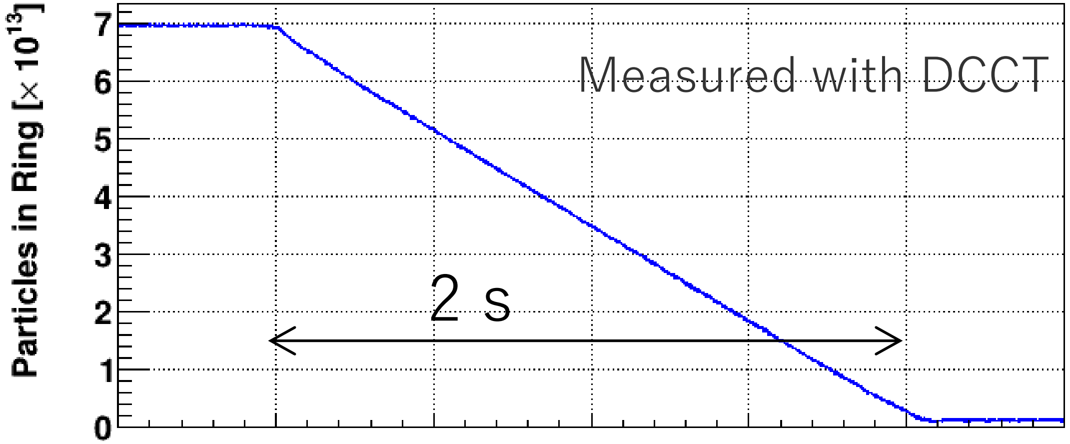
Ryotaro Muto
J-PARC/KEK

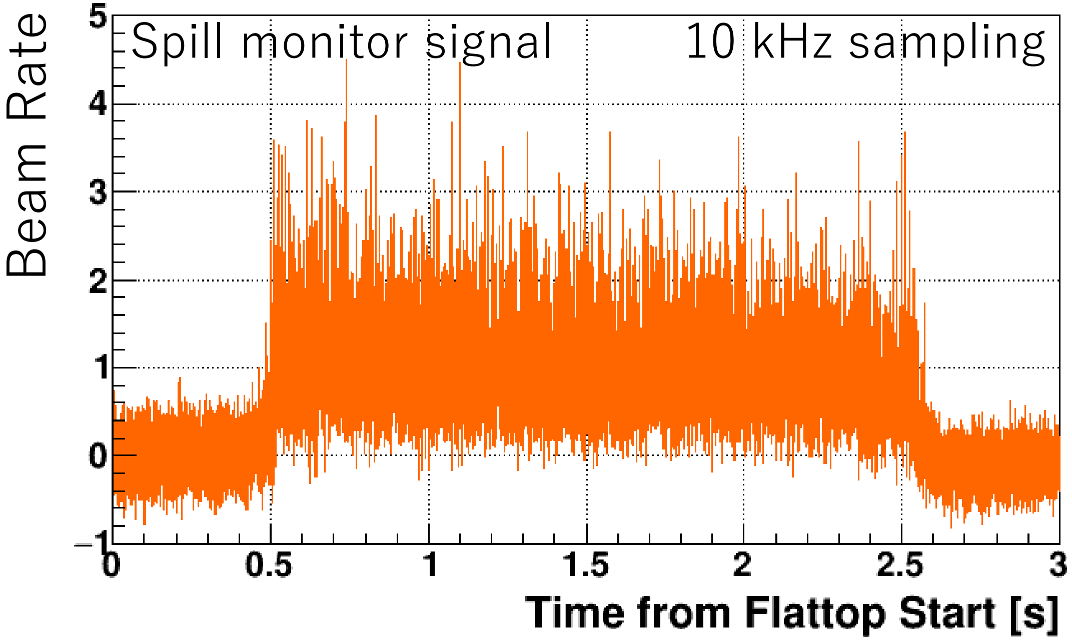
2024-Feb
Slow Extraction Workshop 2024

Outline

- Spill Structure before and after the Upgrade of Main Magnet Power Supplies
- Current Ripples in New Main Magnet PSs
- Plan for Spill Structure Improvement
- Summary

Spill structure before the Main Mag PSs Upgrade





Spill structure in the previous user operation (June 2021)

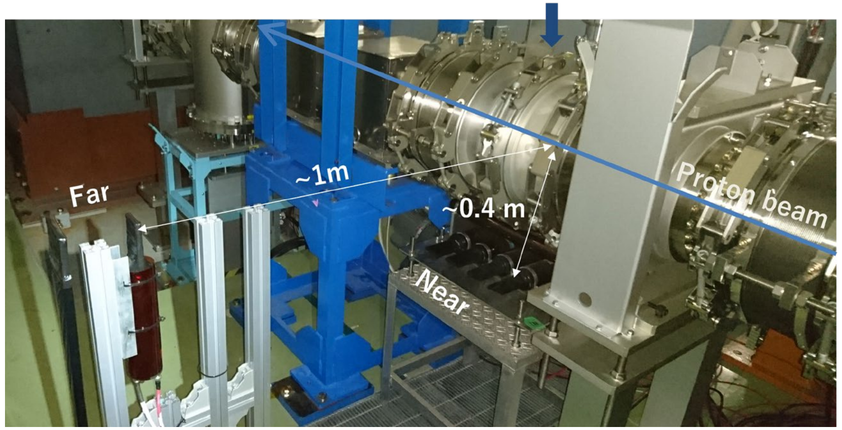
Beam power : 64 kW with 5.2 s repetition
(7 x 10^{13} particle/pulse)

Spill Duty Factor : $\frac{\langle I \rangle^2}{\langle I^2 \rangle}$

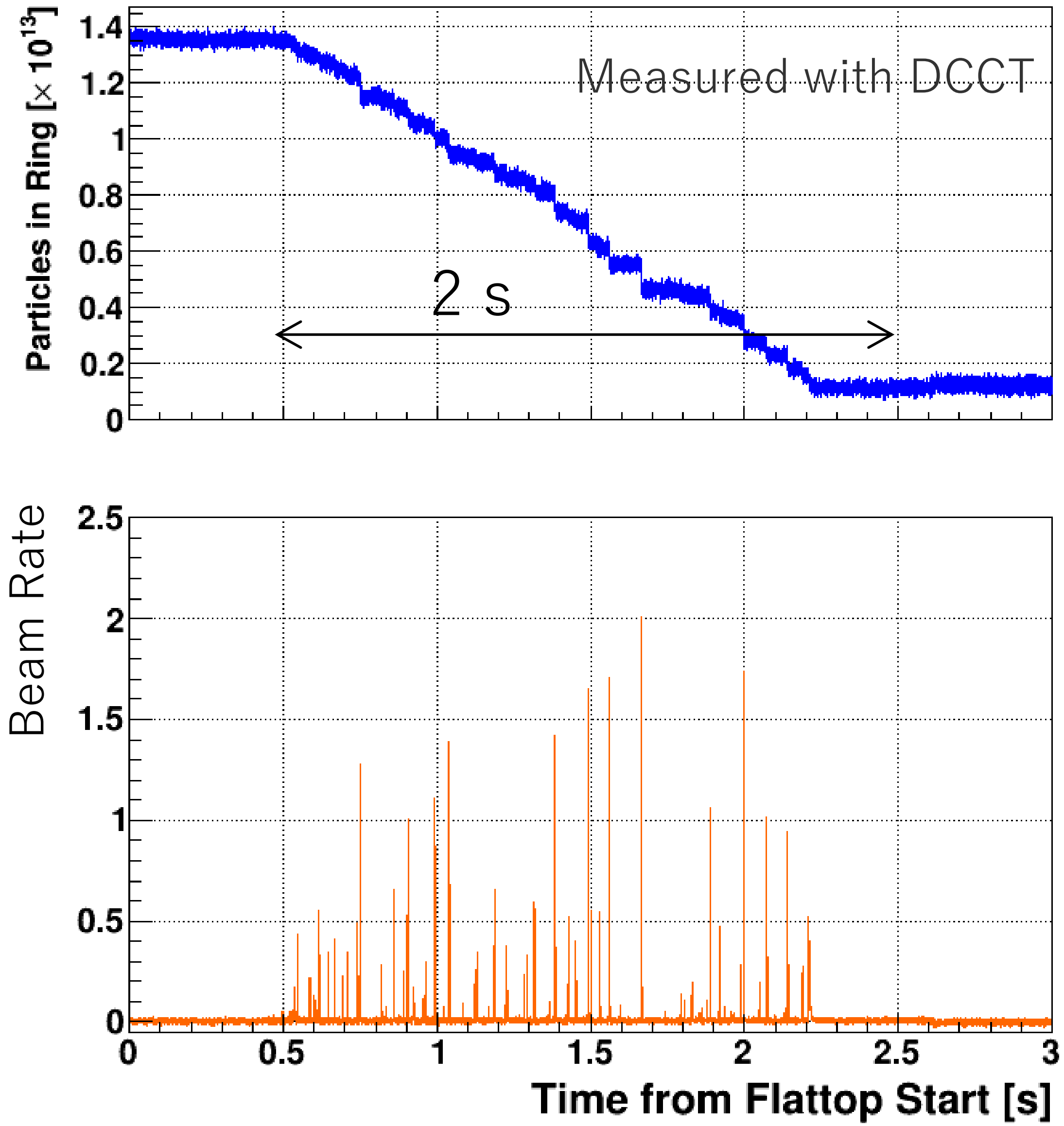
~ 60% with 10kHz LPF + 100kHz sampling

Vacuum partition (Al, t0.1 mm)

Spill Monitor



Spill structure without tune ripple mitigation



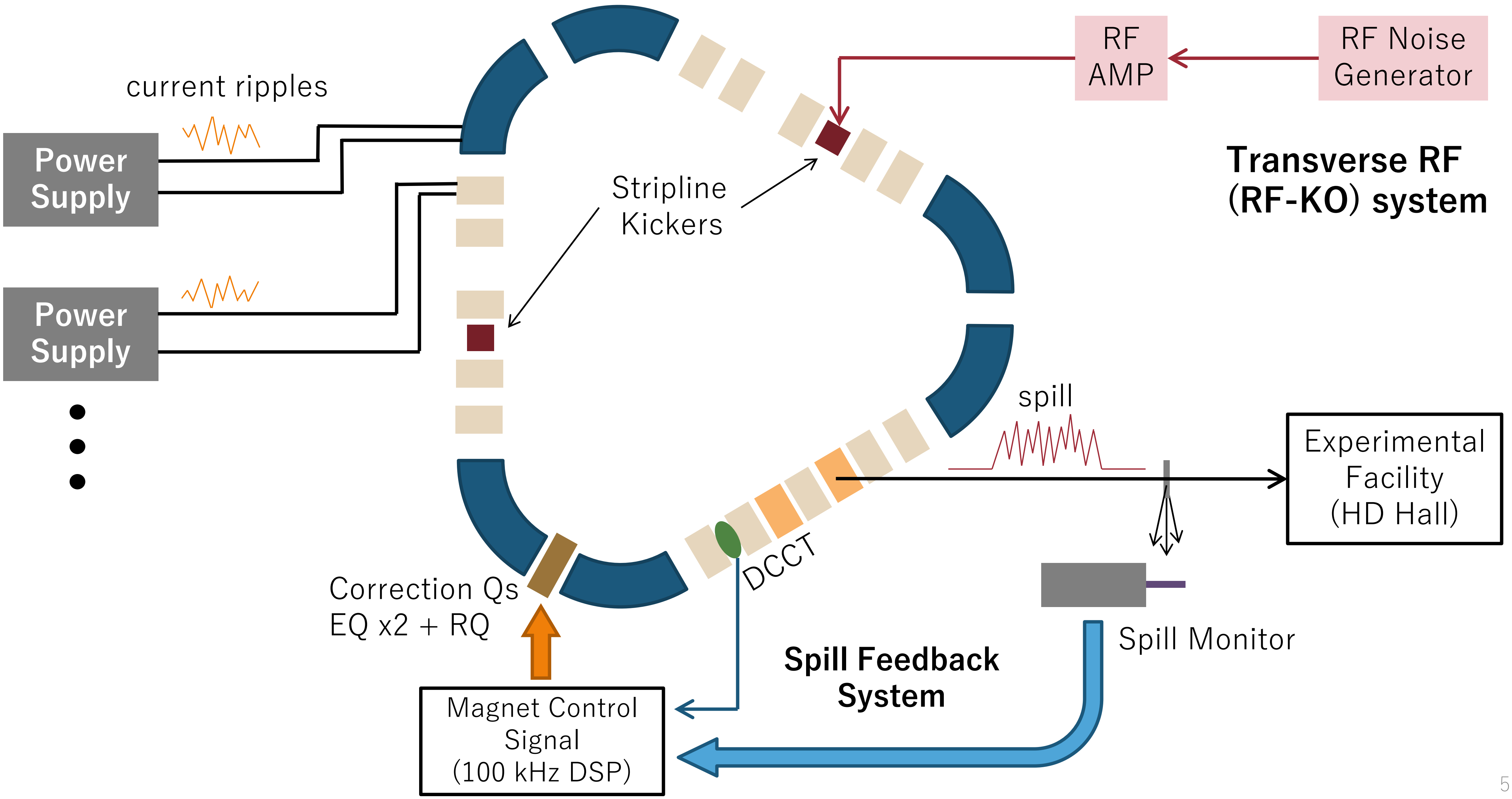
With macro structure regulation only

Spill Duty Factor : $\frac{\langle I \rangle^2}{\langle I^2 \rangle}$

$\sim 4\%$

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

Spill regulation system at at J-PARC MR



MR upgrade during long shutdown (2021-2022)

To shorten the acceleration time
1.4 s → 0.65 s

Repetition cycle :

FX : 2.48 s → 1.36 s

SX : 5.20 s → 4.24 s
(F.T. length (2.61 s) are same)

- **Main magnet power supplies**
- **RF cavities & control**
- **FX devices**
- **Collimators**

were upgraded

Main magnet power supplies upgrade

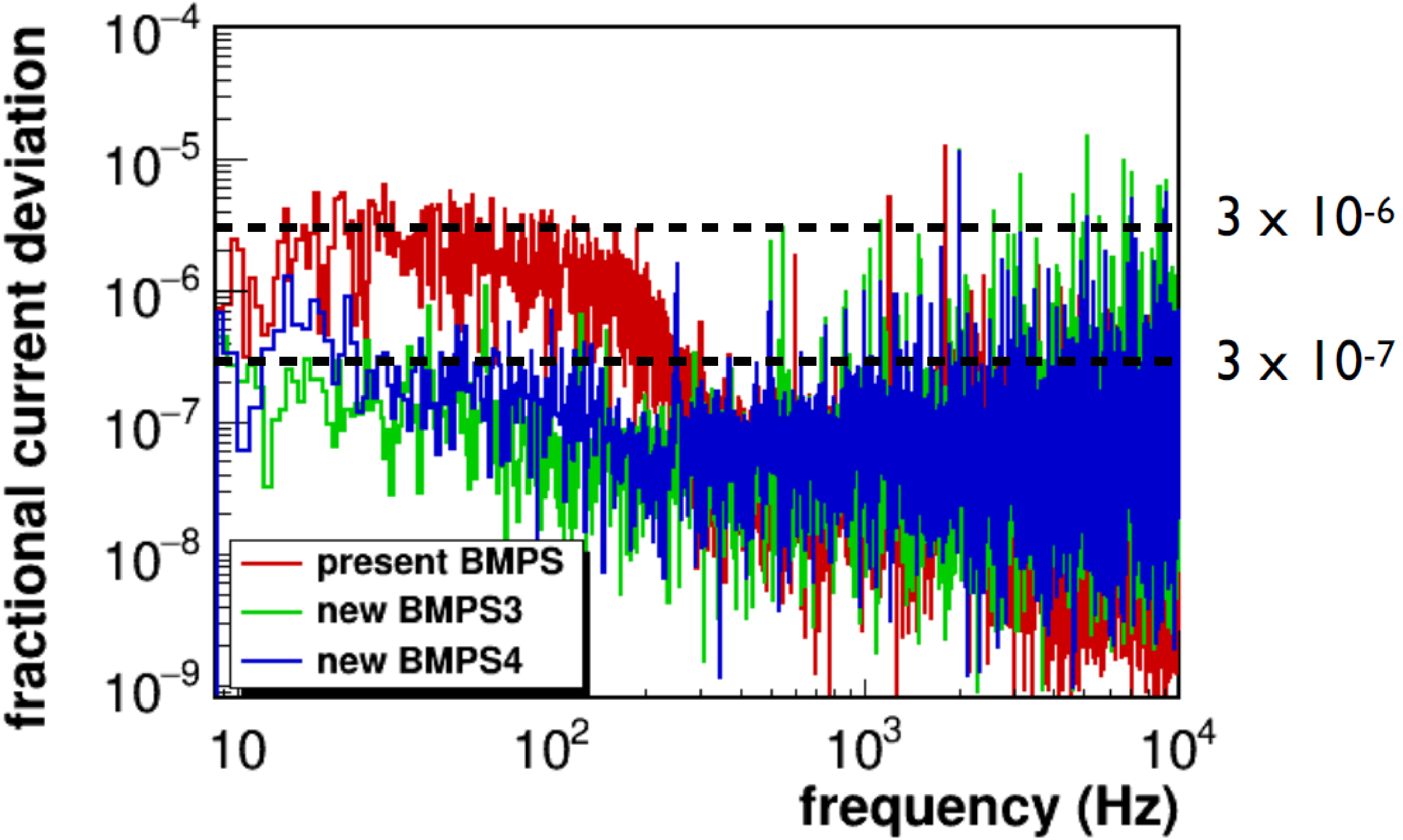
S. Igarashi

All the magnet families were modified
in power supplies (and the cables).

Family Label	Number of Family	Number of magnets	Magnet	Inductance (H)	Current @ 30 GeV (A)	Upgrade strategy
BM	6	16 each	B	1.47	1600	New PSs with capacitor bank
QFN, QDN	1 each	48 each	Q	2.93, 3.46	750	
QFX	1→2	48→24 each	Q	2.39	750	Reuse of Present PSs (divided)
QDX	1→2	27→14(13)each		1.75	750	
QDS	1→2	6→3 each		0.35	900	
QFS, QFT	1→2 each	6→3 each		0.3, 0.32	900	
QFP	1	6		0.2	900	Reuse of Present PSs
QFR	1	9		0.57	850	
QDR, QDT	1 each	6 each	Q	0.44, 0.37	900	New PSs w/o capacitor bank
SFA	1	24	S	0.41	200	
SDA, SDB	1	48	S	0.82	200	

Current Ripples in New Main Magnet Power Supplies

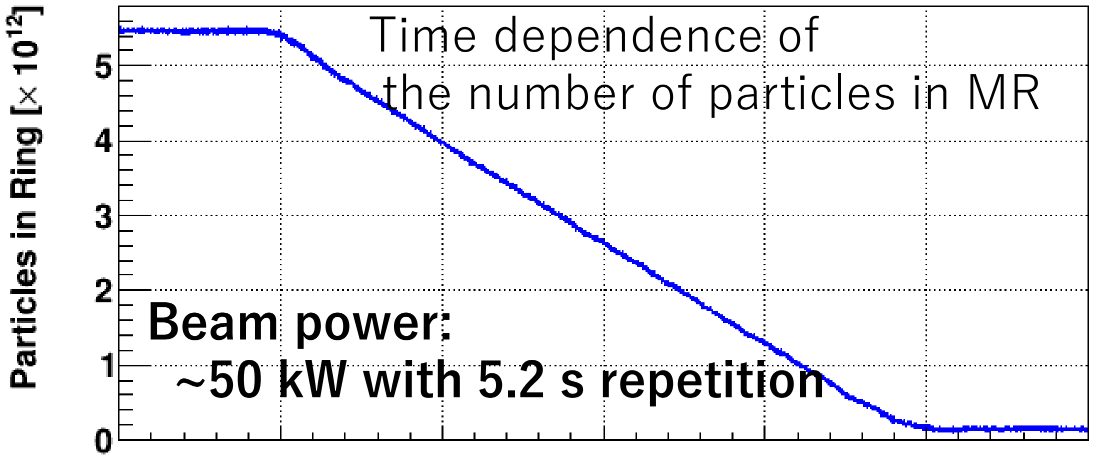
Current ripples of bending magnet
in <200Hz are suppressed to ~1/10

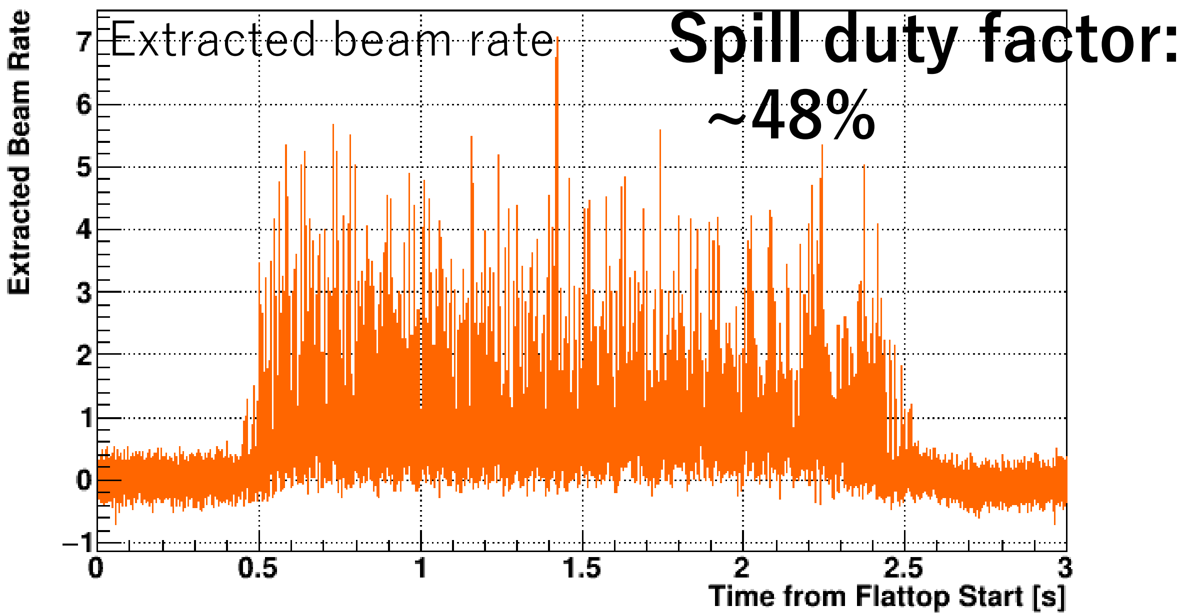


By T. Shimogawa (J-PARC MR Main Magnet Group)

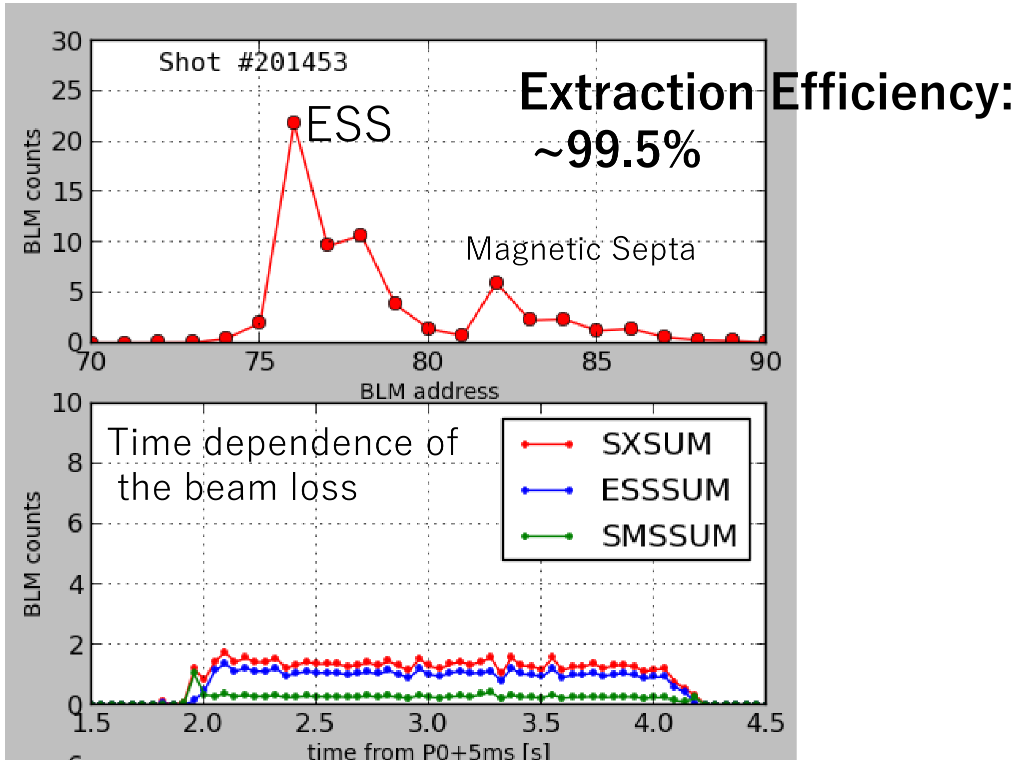
Slow Extraction after MR Upgrade

2023-Jun





Beam loss distribution in SX straight section



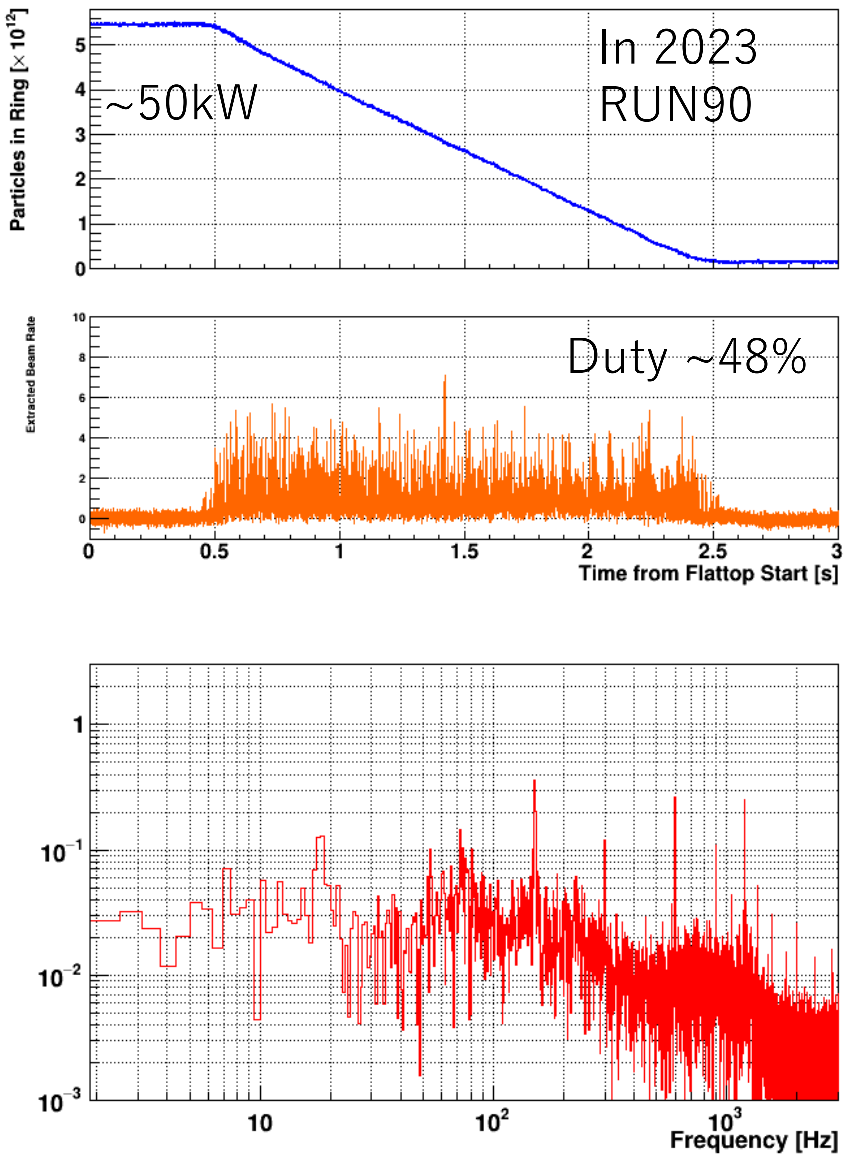
The extraction efficiency of 99.5% before the main power supply upgrade was well reproduced.

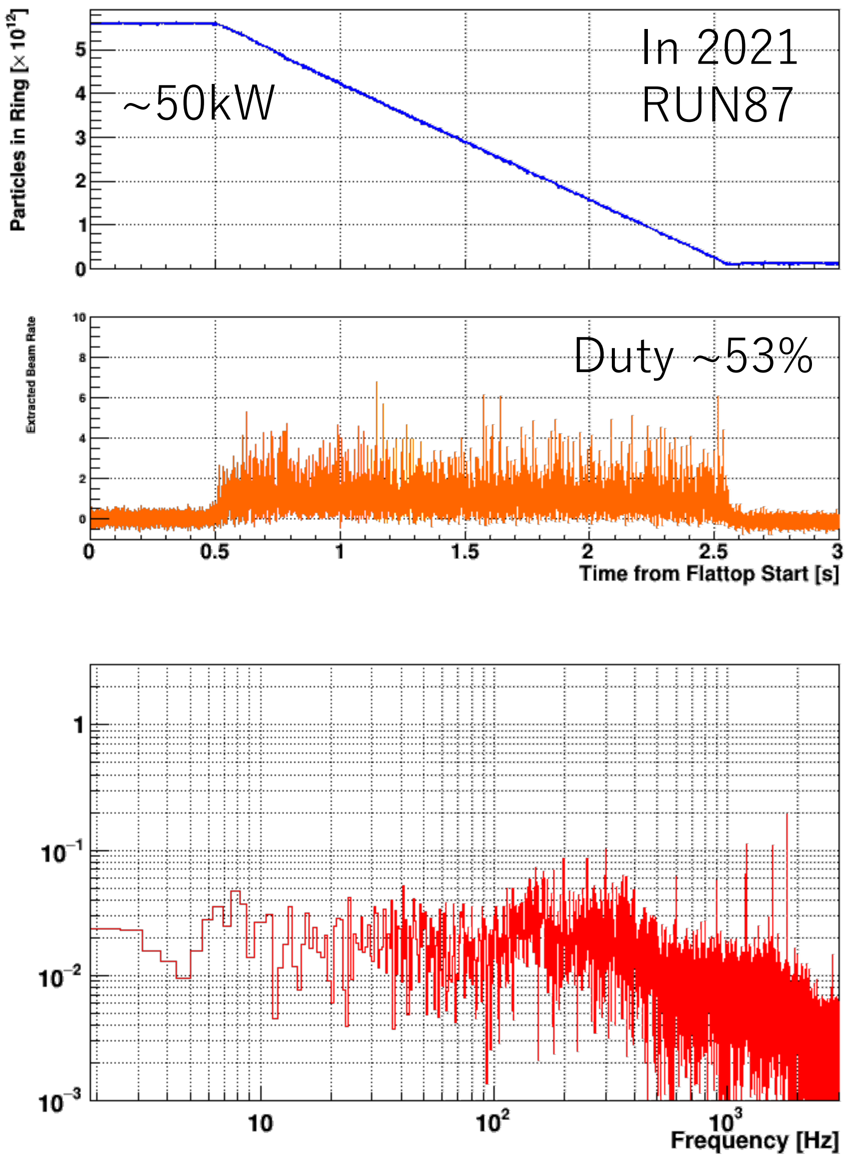
Spill Structure Comparison RUN90 (2023) vs RUN87 (2021)

DCCT

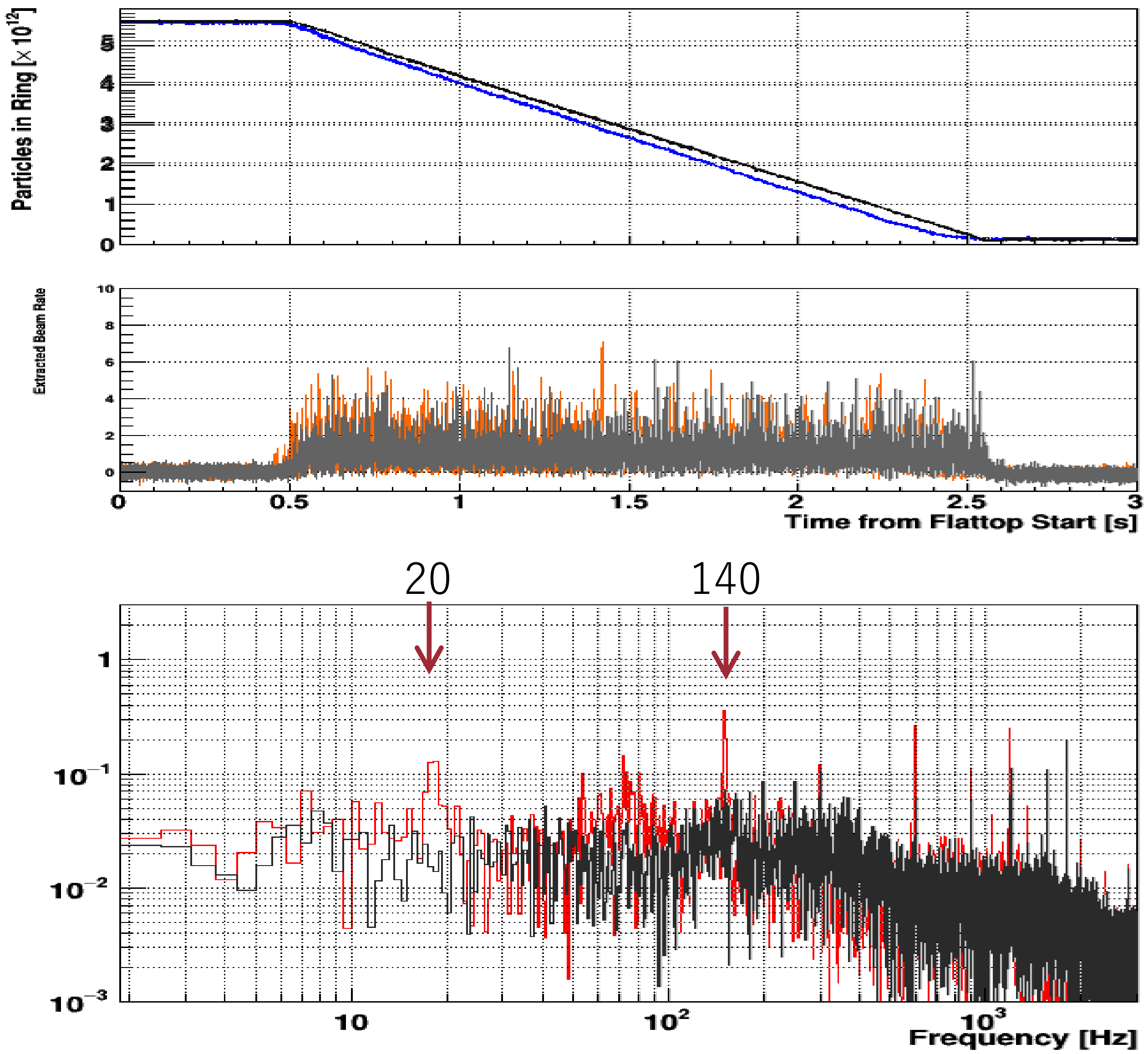
Spill Monitor

Spill Monitor FFT





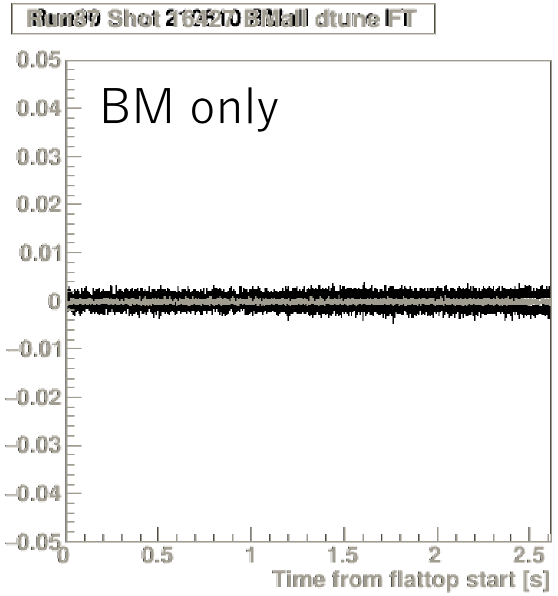
Spill Structure Comparison RUN90 (2023) vs RUN87 (2021)

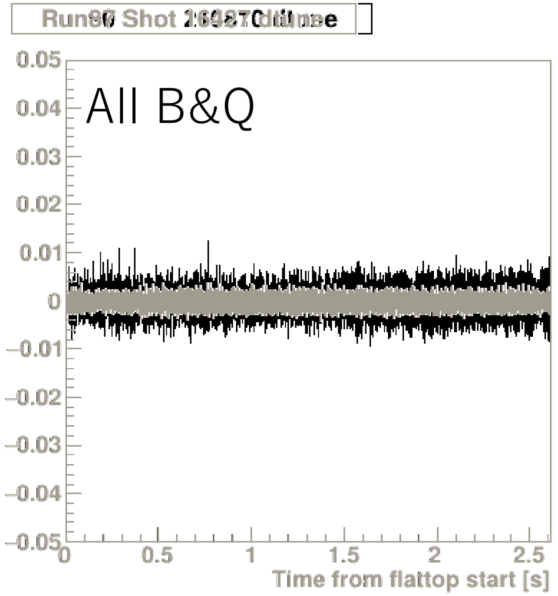


Red : RUN90(2023)
Black : RUN87(2021)

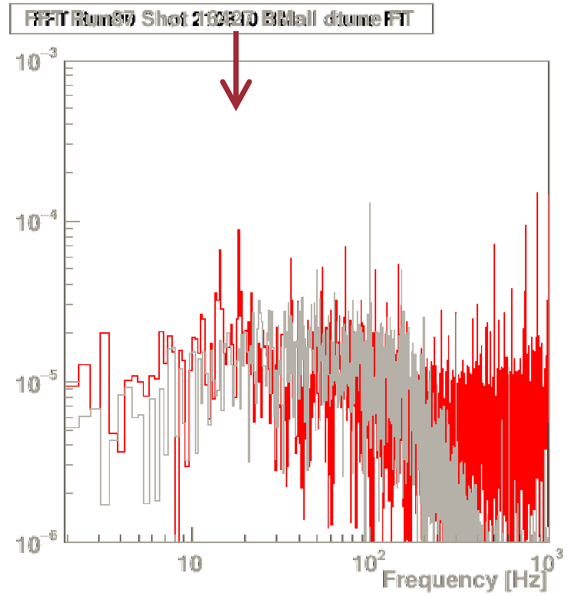
Comparison of Current Ripples in Main Magnet Power Supplies (Δtune @ FT)

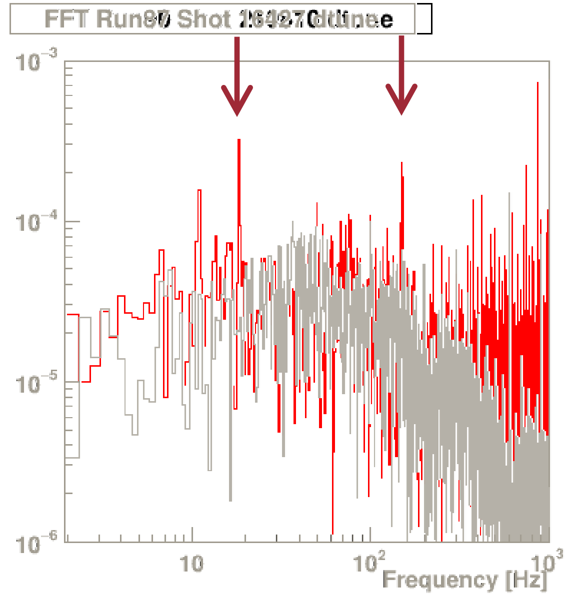
black&blue: new PSs (2023)
grey: old PSs (2021)





red: new PSs (2023)
grey: old PSs (2021)

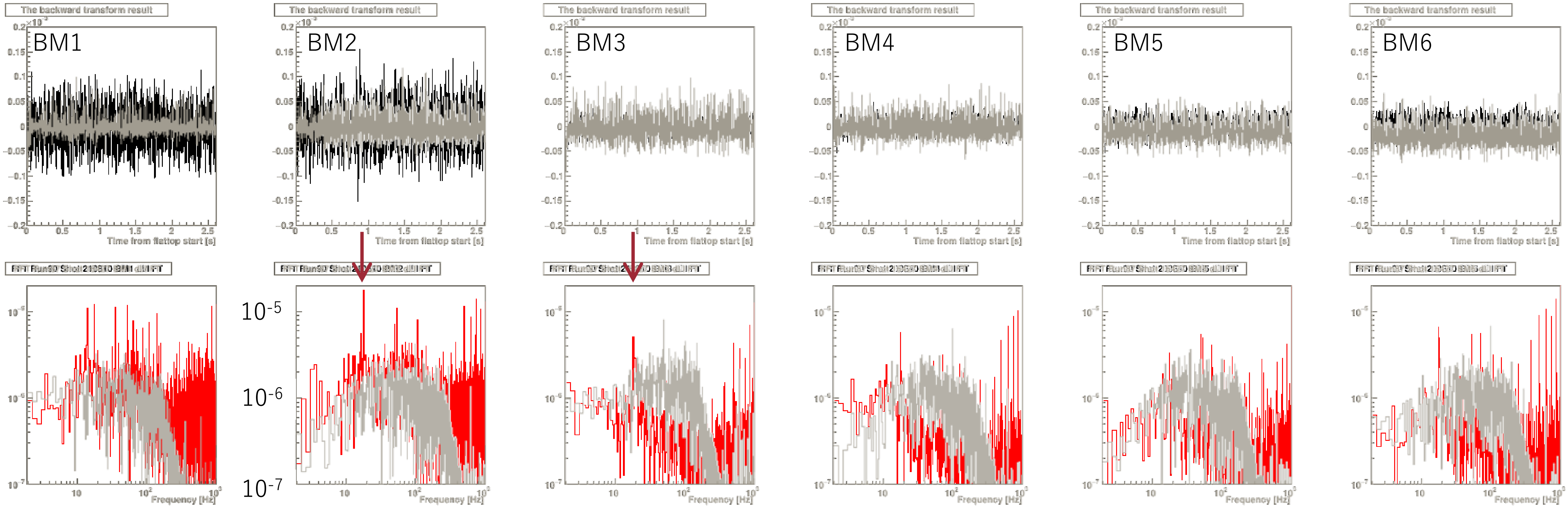




Mag.	ΔtuneH for ΔI=1e-04
QFN	0.002063
QFX	0.000803
QFR	0.000322
QFT	0.000251
QFP	0.000137
QFS	0.000089
BM1~6	0.002826 / 6

Comparison of Current Ripples in Main Magnet Power Supplies (BM @ FT)

Black: New PSs (2023)
Grey: Old PSs (2021)

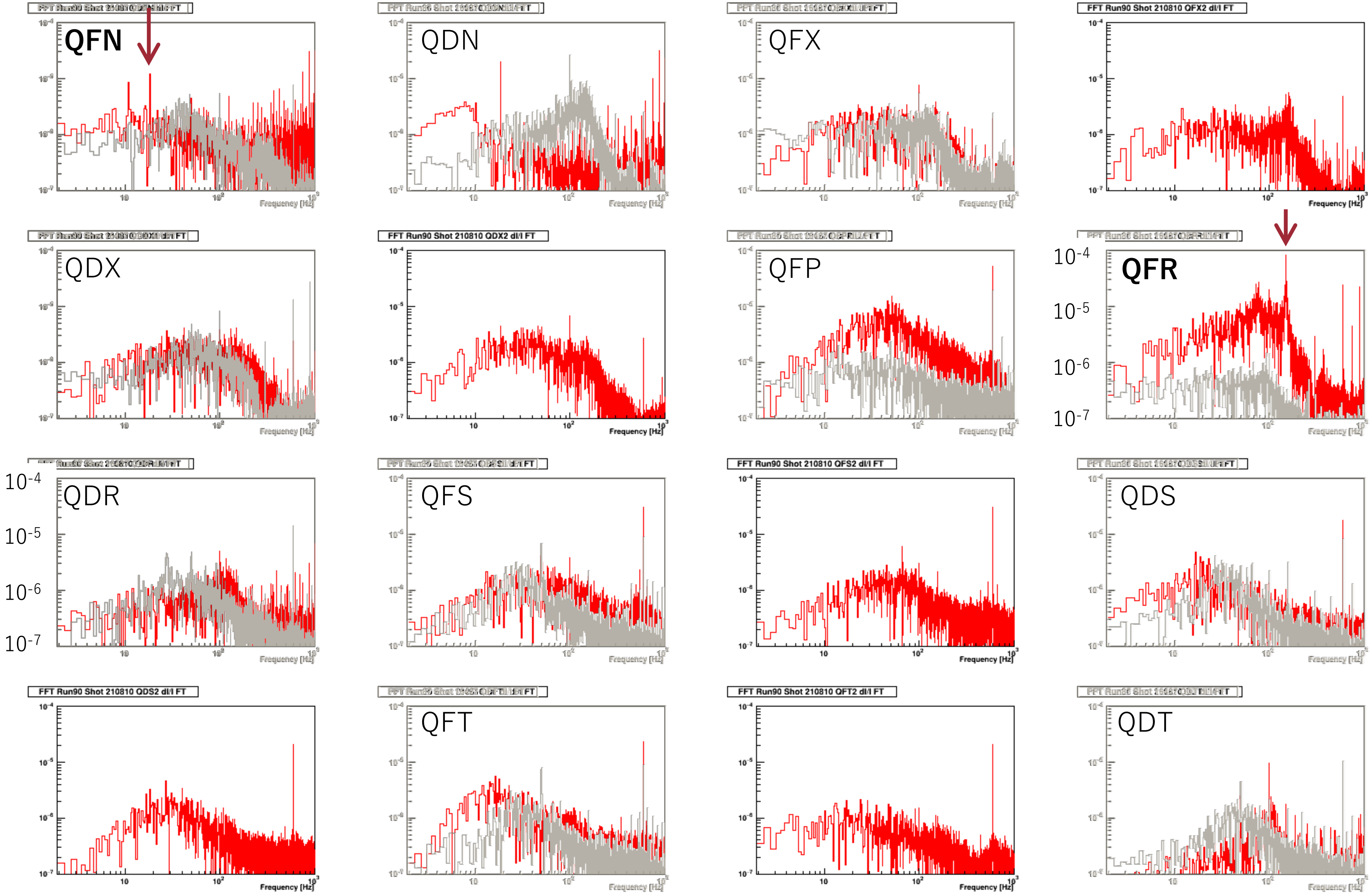


Red: New PSs (2023)
Grey: Old PSs (2021)

Comparison of Current Ripples in Main Magnet Power Supplies (QM @ FT)

Red:
New PSs
(2023)

Grey:
Old PSs
(2021)



QFR is small family but current ripple is so large that it affects the spill structure

Mag.	ΔtuneH for ΔI=1e-04
QFN	0.002063
QFX	0.000803
QFR	**0.000322**
QFT	0.000251
QFP	0.000137
QFS	0.000089
BM1~6	0.002826 / 6

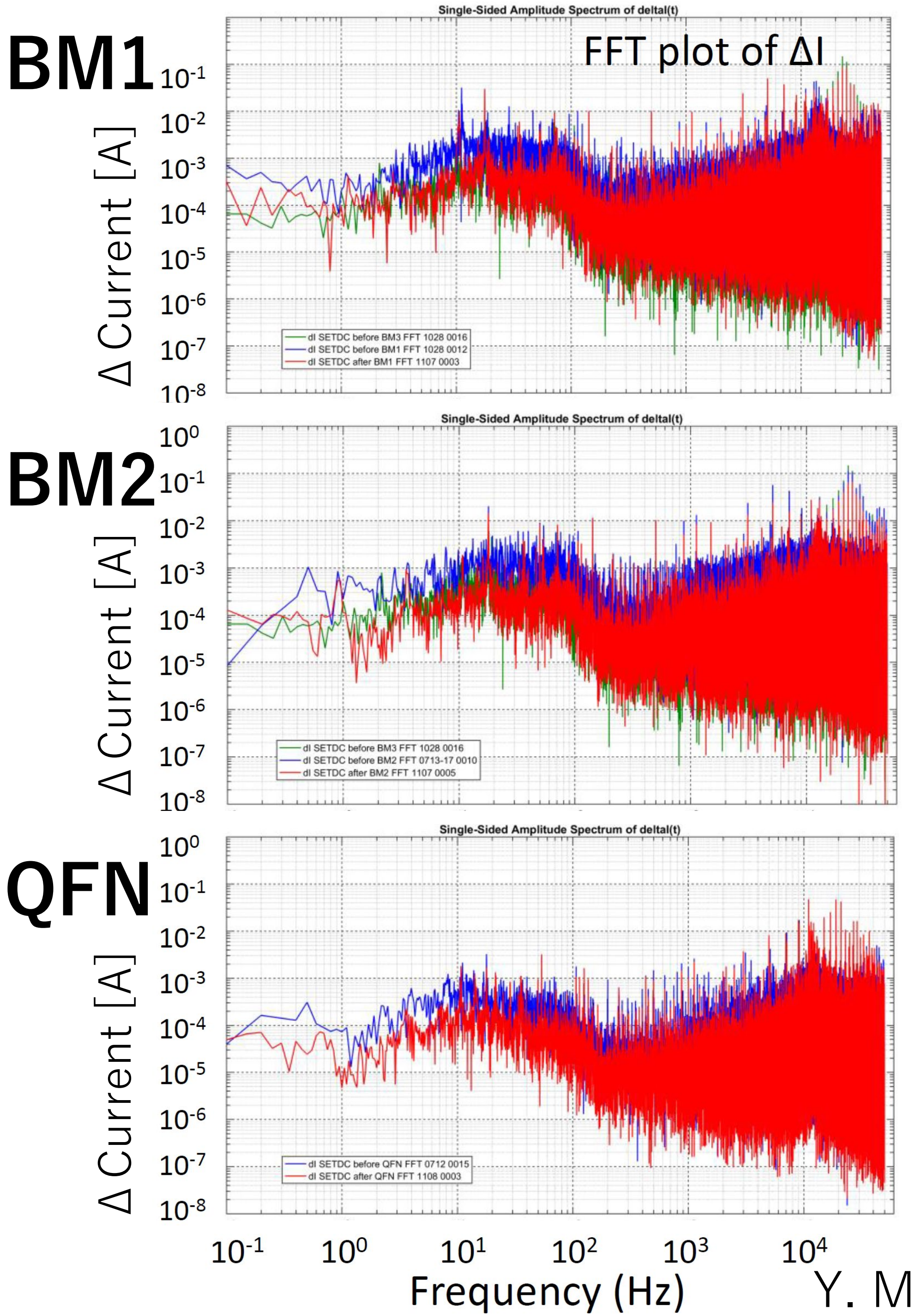
Improvement of the Beam Spill Structure

- **Current Ripple Reduction on Main Magnet Power Supplies (partly done)**

- Improvement of Spill Feedback using Fast Qs(EQs and RQ)
  - Improve the feedback algorism (introducing machine learning?) especially for the reduction of 140 Hz component in spill structure
  - Use of main magnet power supplies' current ripple information as a feedback input (Future Plan)

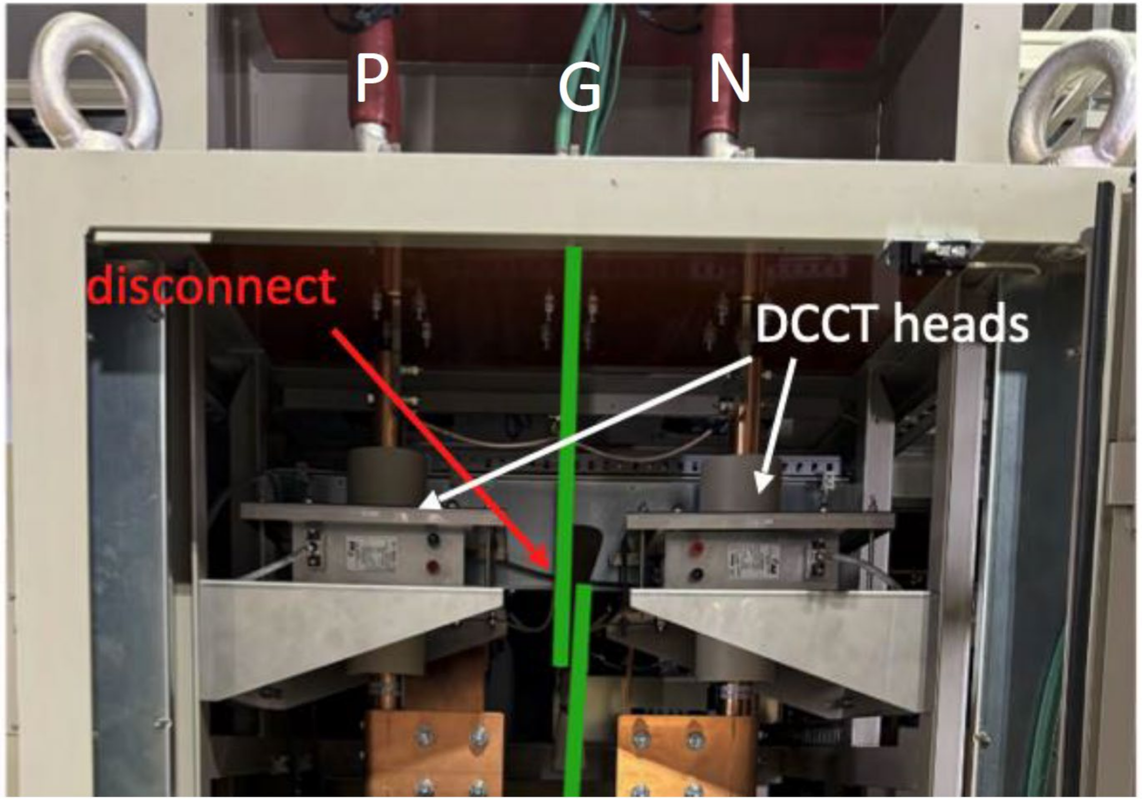
- Improvement of Spill Structure using Transverse RF
  - Introduction of Feedback System (Future Plan)

Current Ripple Reduction



Y. Morita

Ground-route change was applied and ripple reduction was observed in **BM1**, **BM2**, BM4, **QFN**



QFR: mismatch of the loads and power supplies causes the large current ripple and is difficult to resolve by short-term countermeasures

Improvement of the Beam Spill Structure

- Current Ripple Reduction on Main Magnet Power Supplies
  (partly done)

- **Improvement of Spill Feedback using Fast Qs(EQs and RQ)**
  - Improve the feedback algorism (introducing machine learning?)
  especially for the reduction of 140 Hz component in spill structure
  We are now carrying out simulation studies
  - Use of main magnet power supplies' current ripple information
  as a feedback input (Future Plan)

- Improvement of Spill Structure using Transverse RF
  - Introduction of Feedback System (Future Plan)

Simulations for Beam Spill Structure

Henon map :

$$\begin{pmatrix} x \\ x' \end{pmatrix}_{n+1} = \mathbf{R}(2\pi Q_n) \begin{pmatrix} x \\ x' + S \cdot x^2 \end{pmatrix}_n$$

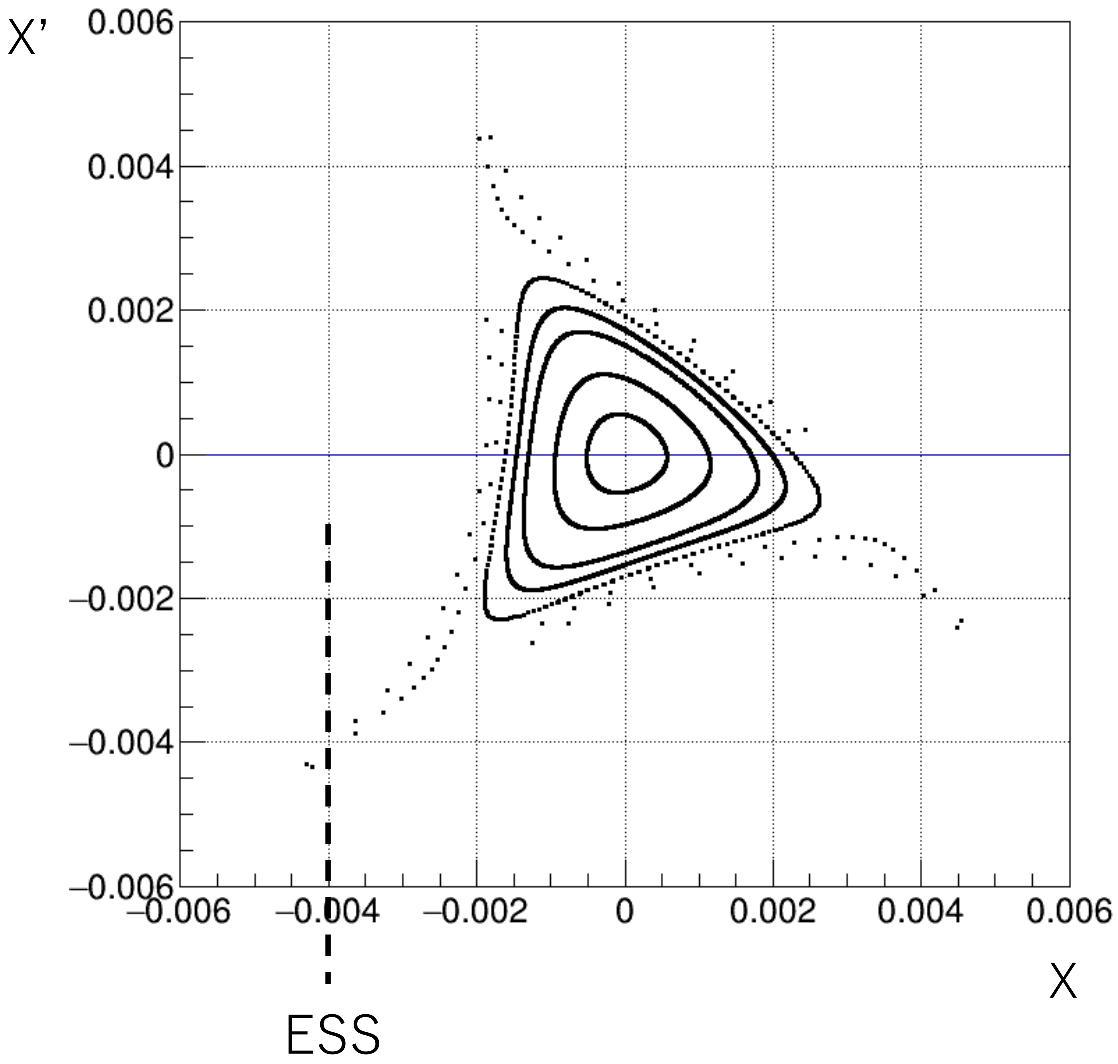
Q_n : horizontal betatron tune

S : normalized sextupole strength
combine 8 sextupole magnets in the ring for 3rd-order resonance excitation.

$$S\exp(3i\mu) = \sum_n S_n \exp(3i\mu_n)$$

Dispersion in the straight section : ~0
Chromaticity : ~0

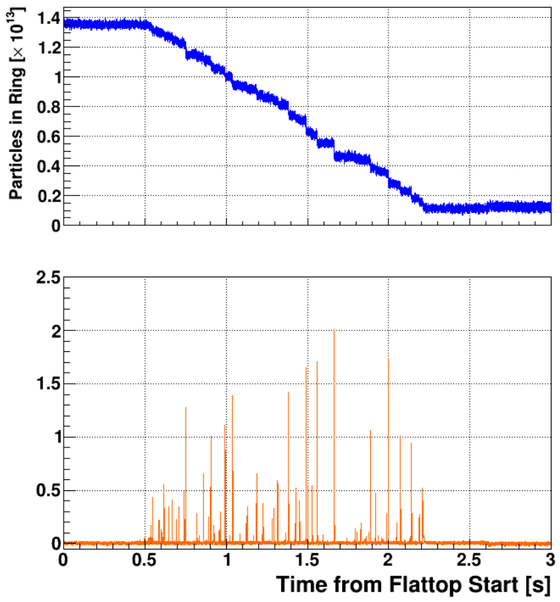
Q = 22.322



Comparison btwn. Meas. & Sim. (No Spill Feedback)

Measurement

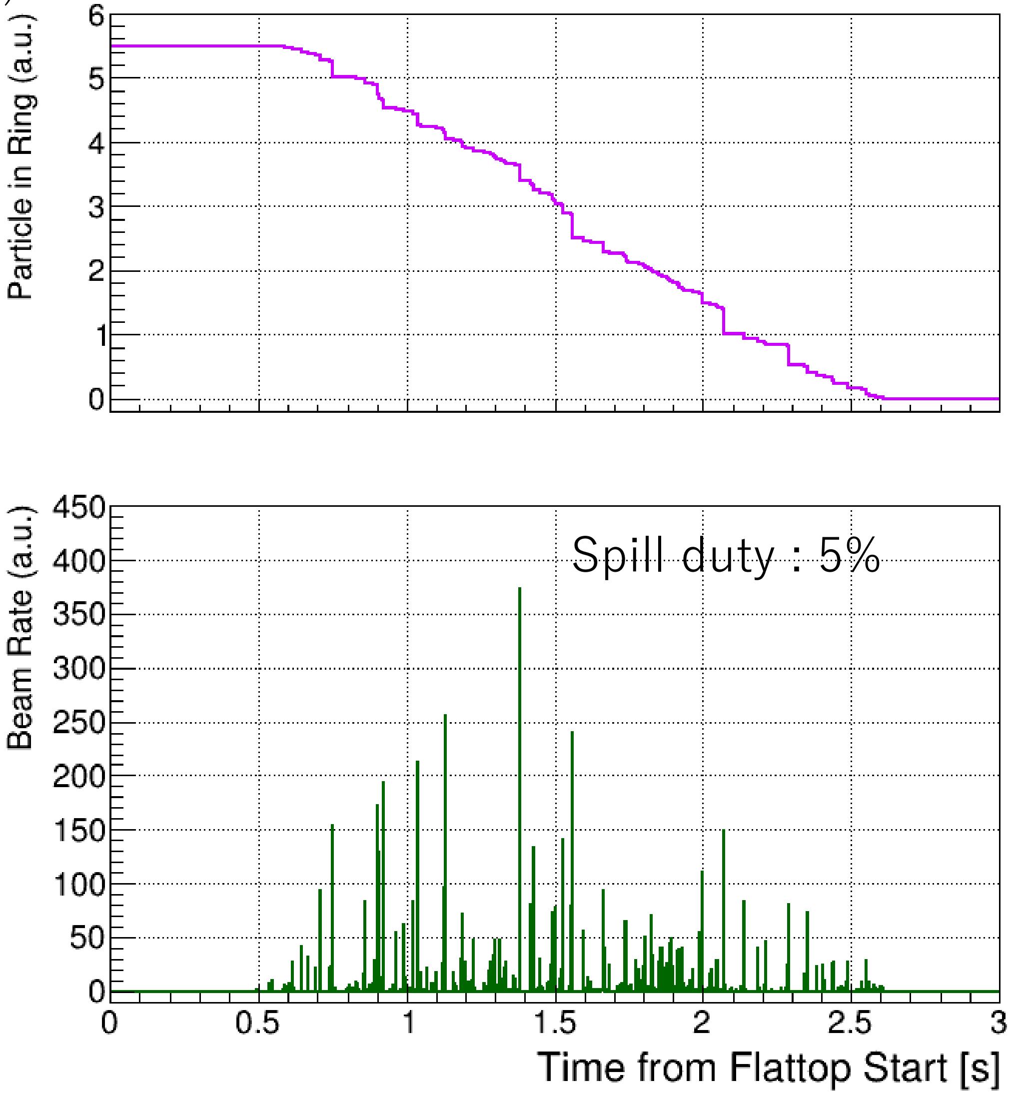
No FB(macro spill regulation(FF) only)



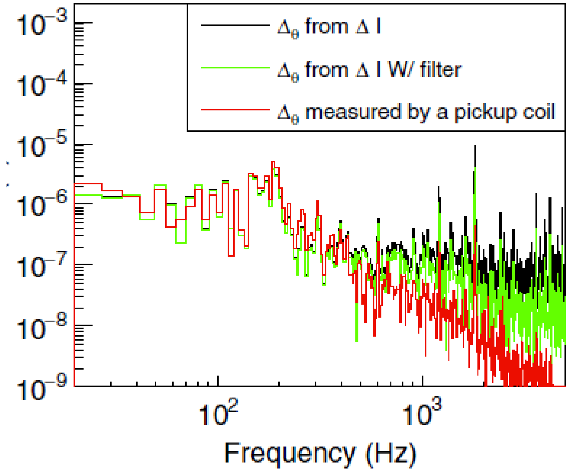
Spill duty : 4%

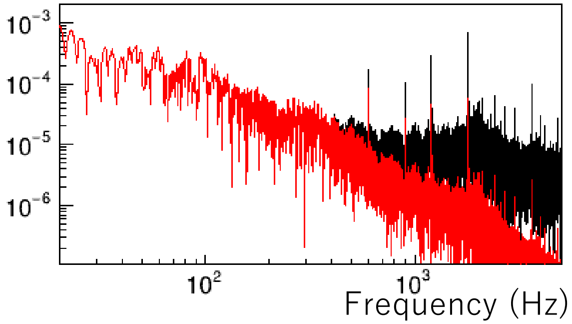
Simulation

No FB(macro spill regulation(FF) only)



Measurements for B Field Ripples

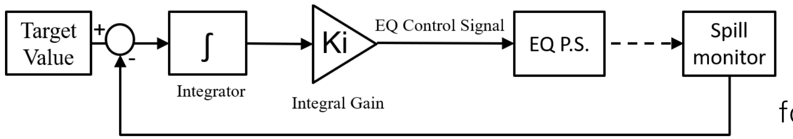




Black: Tune Ripple Estimated by Measured Current Ripple

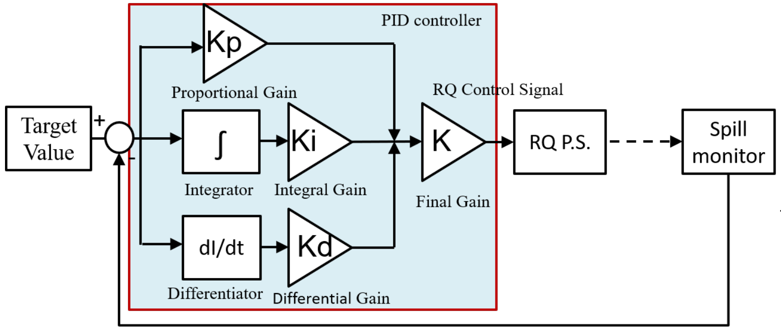
Red: Tune Ripple in Sim. Components with >400Hz are reduced according to B Field Ripple Measurement

Introducing Fast Qs Feedback and TrRF in Sim.



EQ

for macro spill shaping



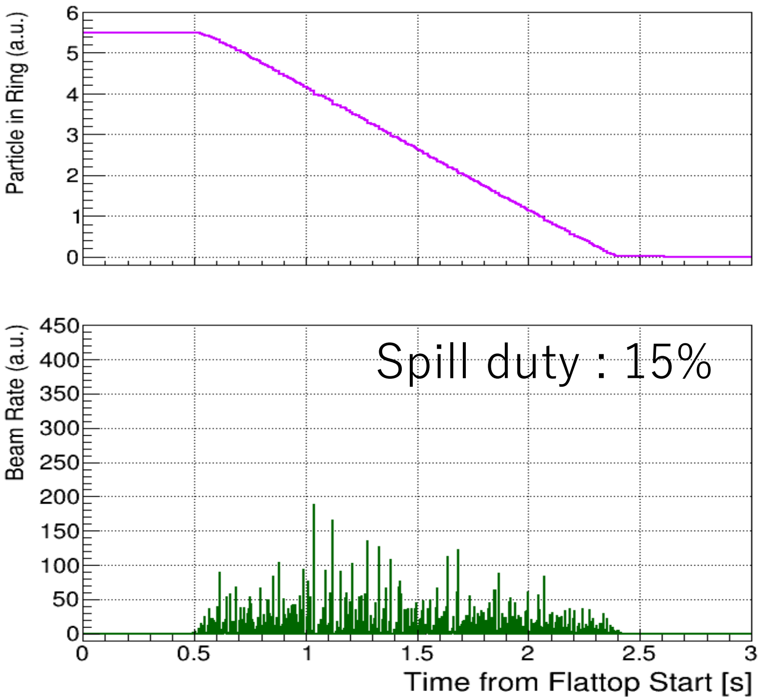
RQ

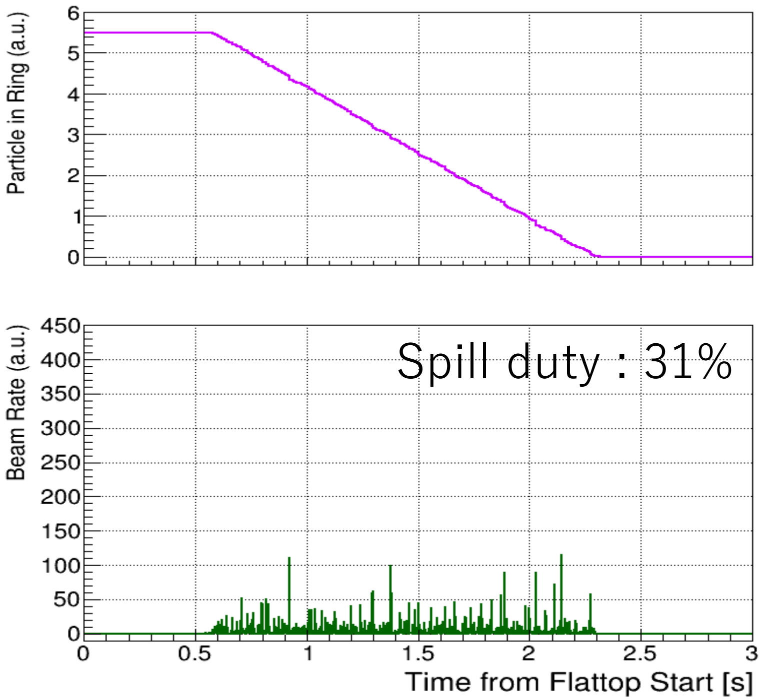
for tune ripple correction

Transverse RF

Frequency Setting in Beam Operation:
exciter 2 : 248.3263 ~ 248.3266
exciter 1 : 1.250 ~ 1.414

In Simulation:
exciter 2 : 248.32705

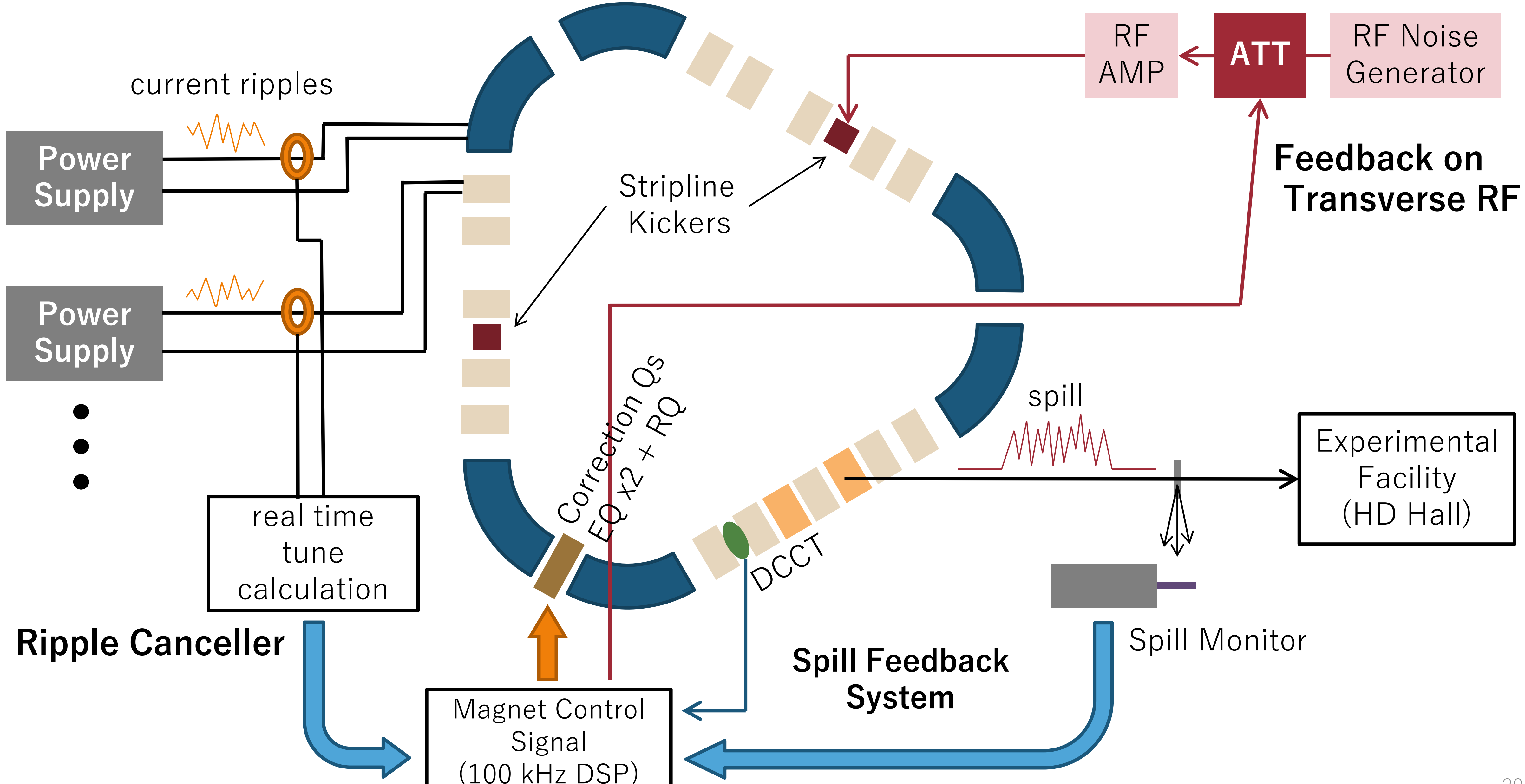




	Meas.	Sim.
No FB	4%	5%
FB	25%	15%
FB + TrRF	46%	31%

Simulation qualitatively reproduced the measurements

Plans for Improvement of Spill Regulation System



Summary

After the MR upgrade, we found the spill structure worse than before the upgrade.

This is because the current ripple reduction of the new power supplies was not yet sufficient.

- BM, QFN: changing the ground route was effective for the current ripple reduction. → will be checked in the next beam study
- QFR: mismatch of the loads and power supplies causes the large current ripple and is difficult to resolve by short-term countermeasures

→ It is necessary to improve spill regulation systems.
We are currently conducting simulation studies to search the better parameters for the spill regulation systems.

Future Plans:

implement current ripple information in spill feedback system

introduce feedback in transverse RF system