Injection Painting Improvements in the J-PARC RCS

J-PARC/JAEA

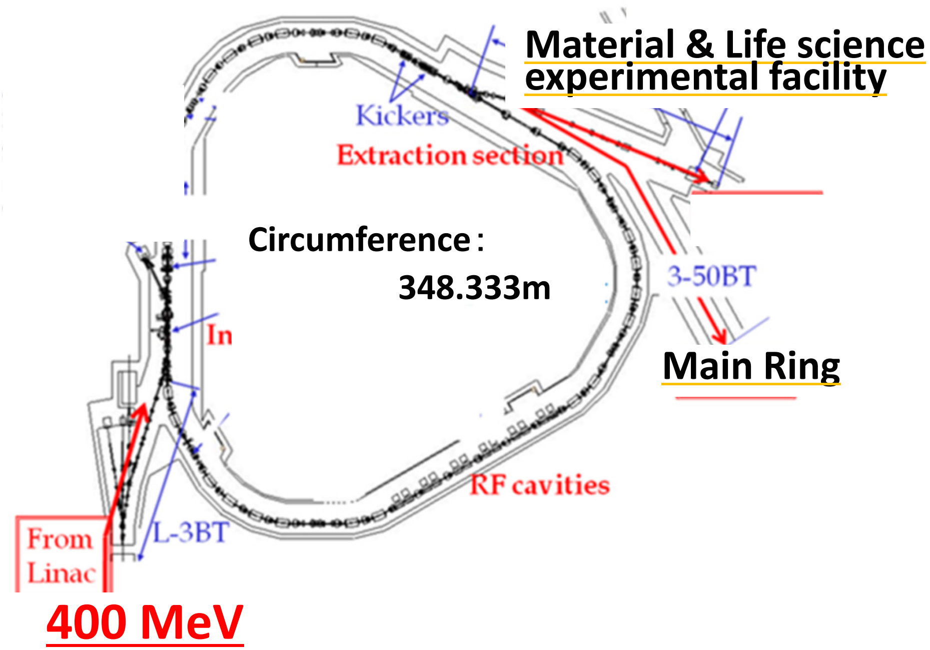
Shinichi Kato

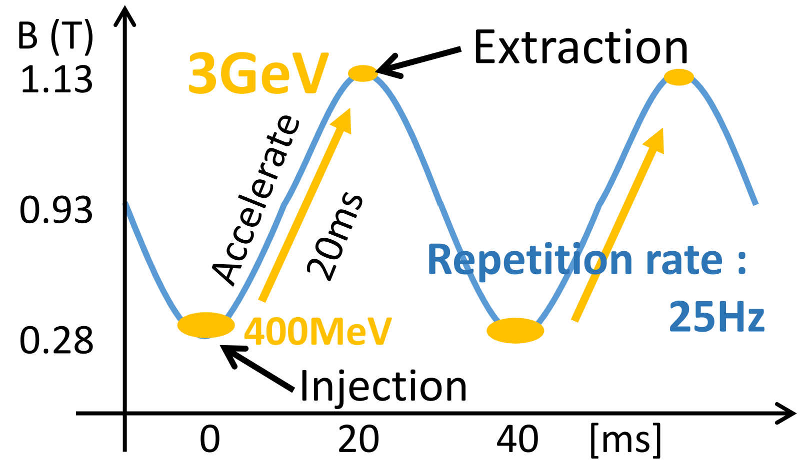
for RCS beam commissioning team

Contents

1. Introduction

J-PARC 3GeV RCS



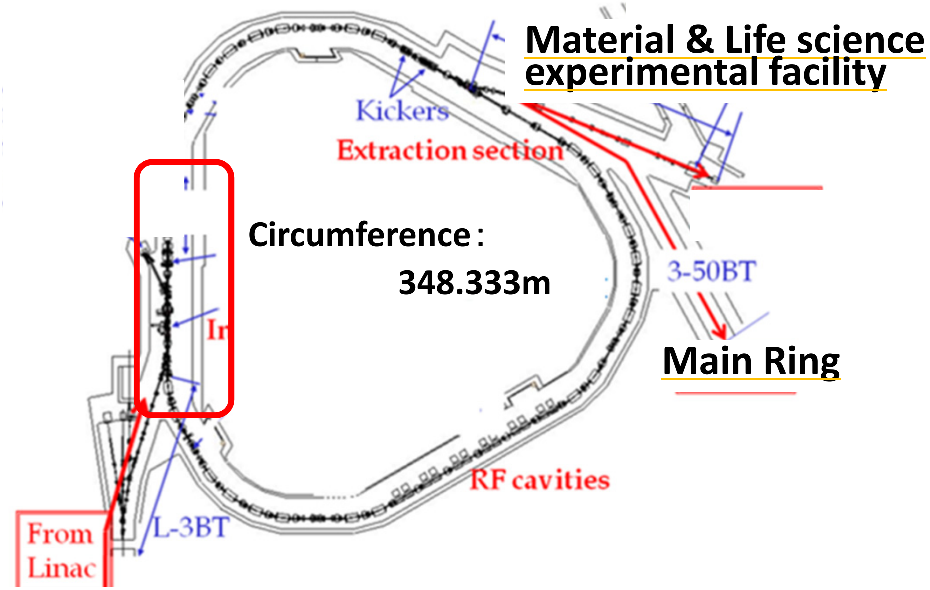


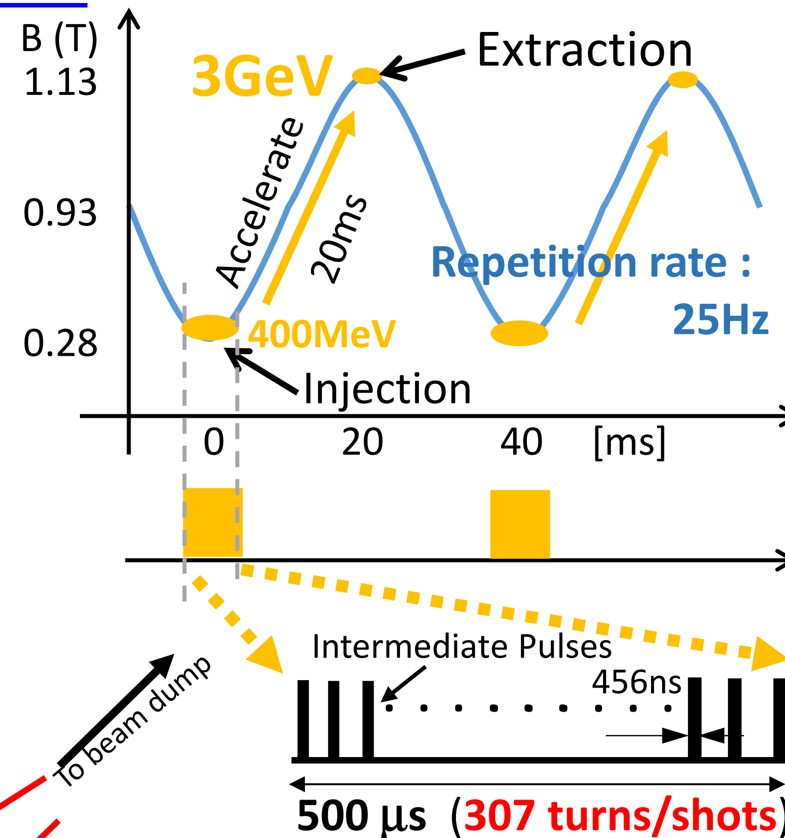
To storage lots of particles…

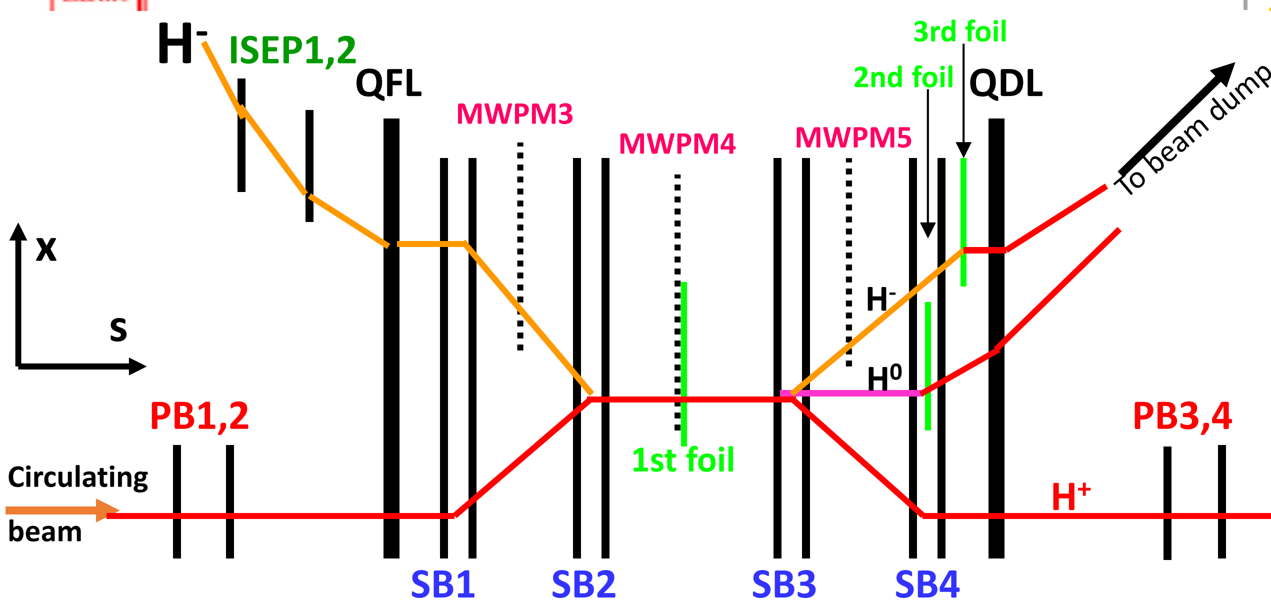
Multi-turn H^- stripping injection

Injection Painting

Multi-turn H- stripping injection







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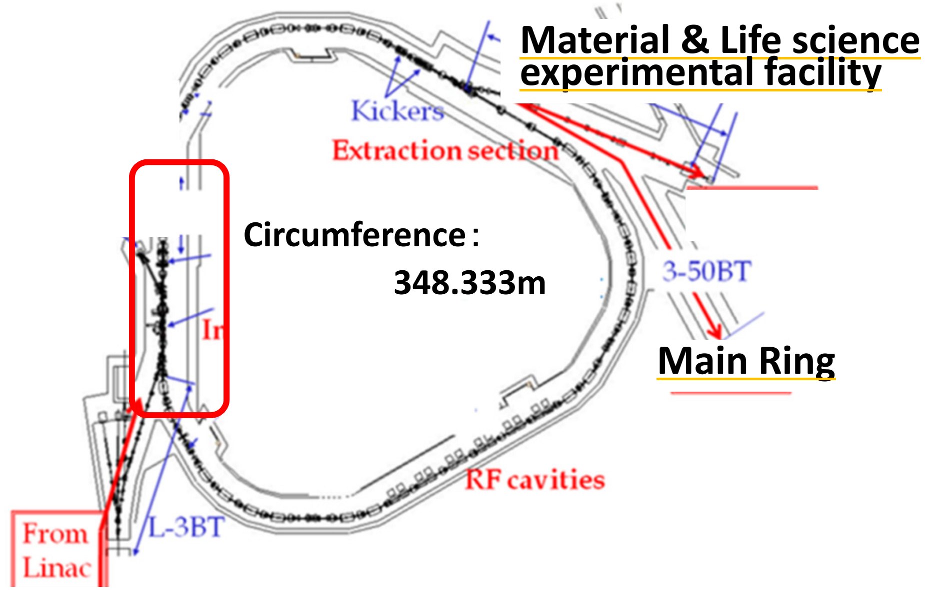

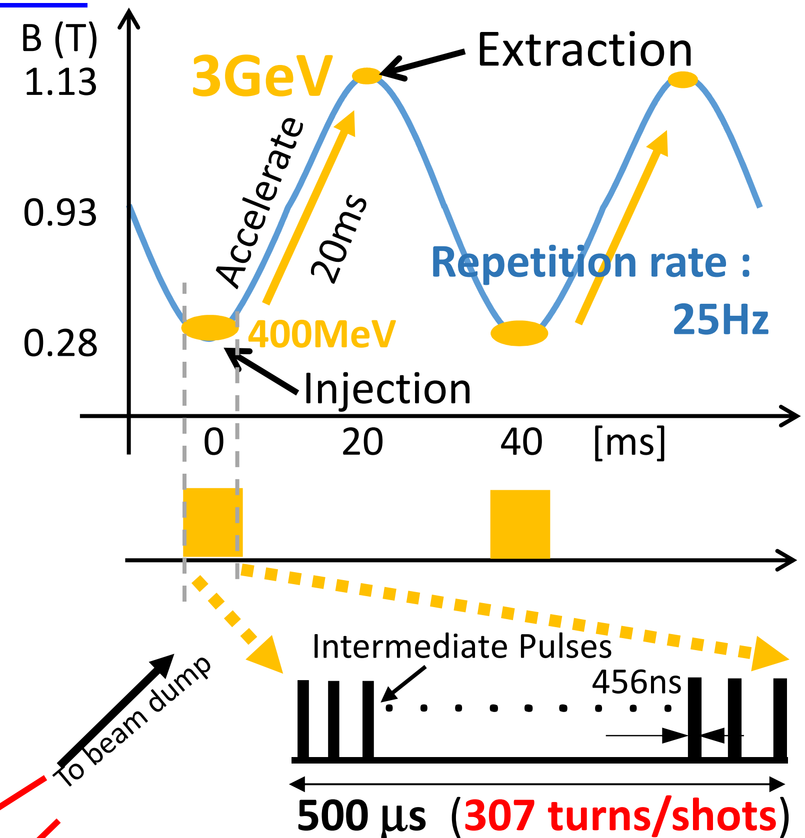

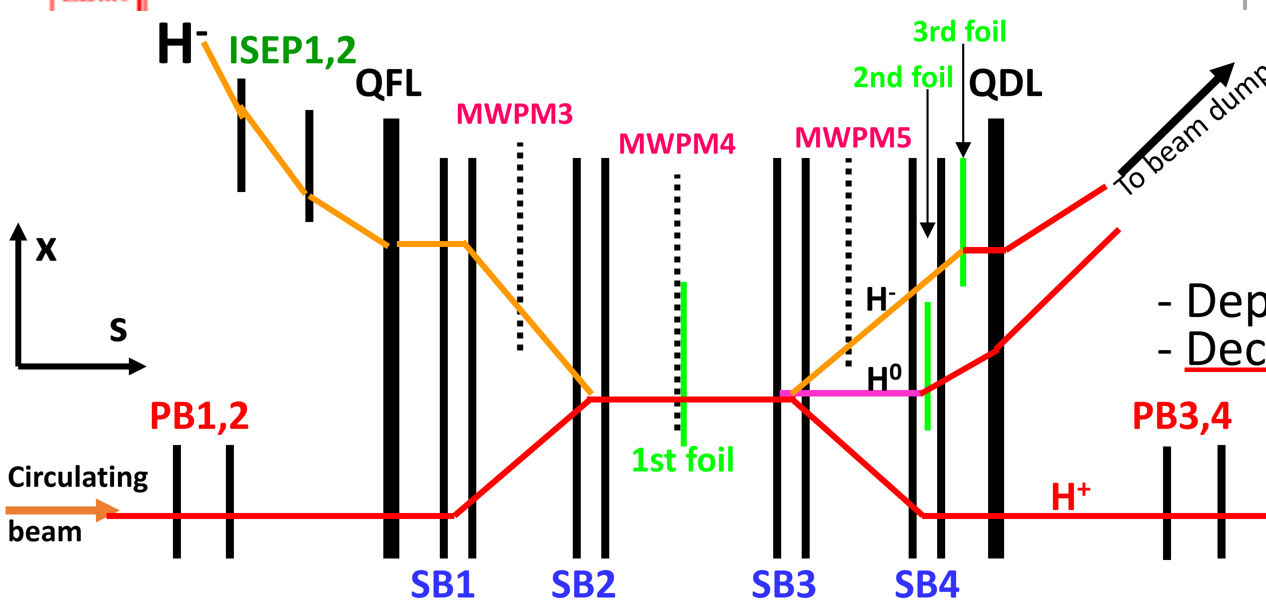

- Depress the beam density
- Decrease the number of foil hits

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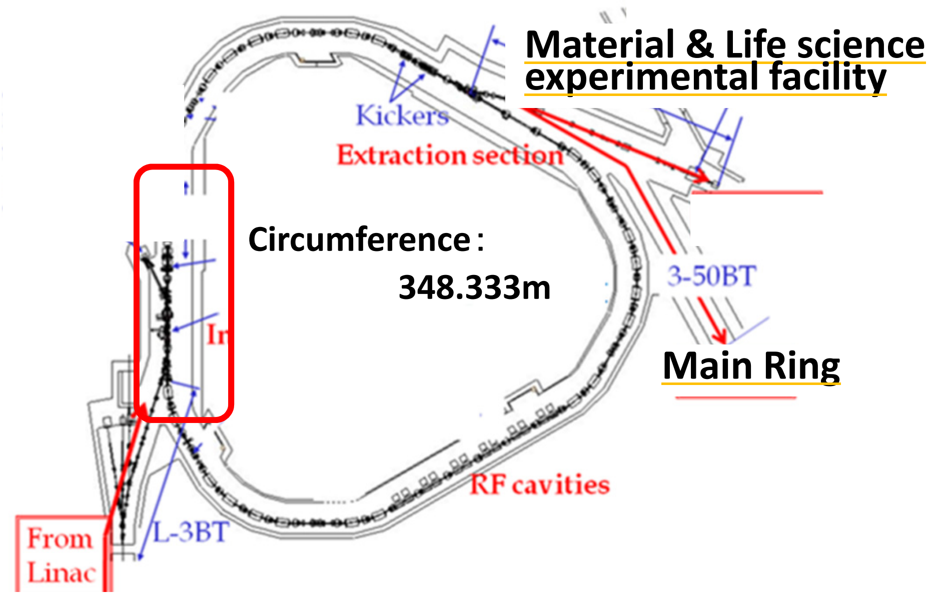

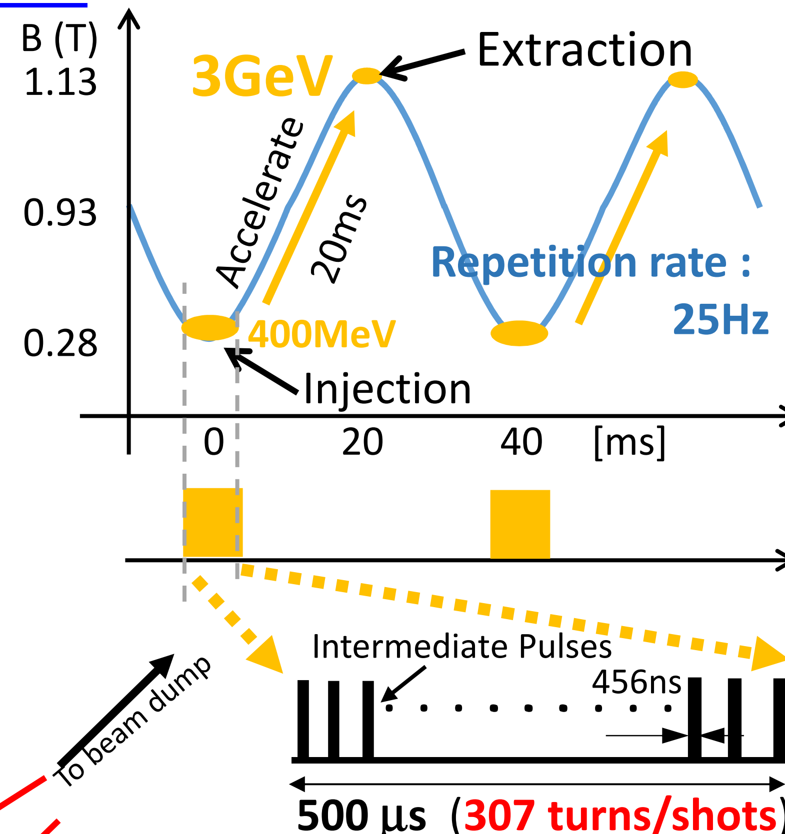

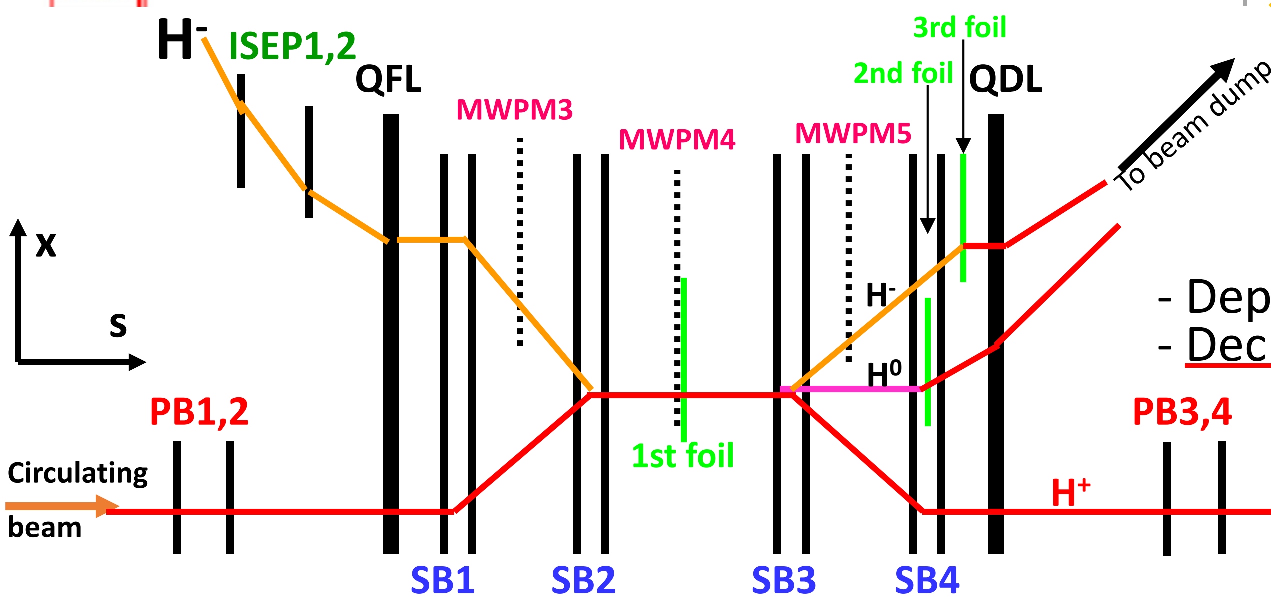

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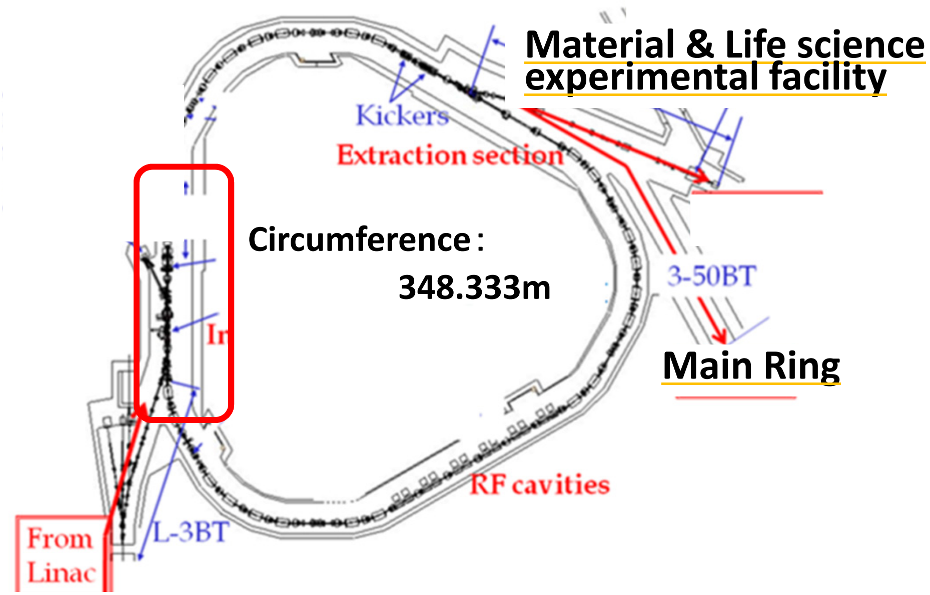

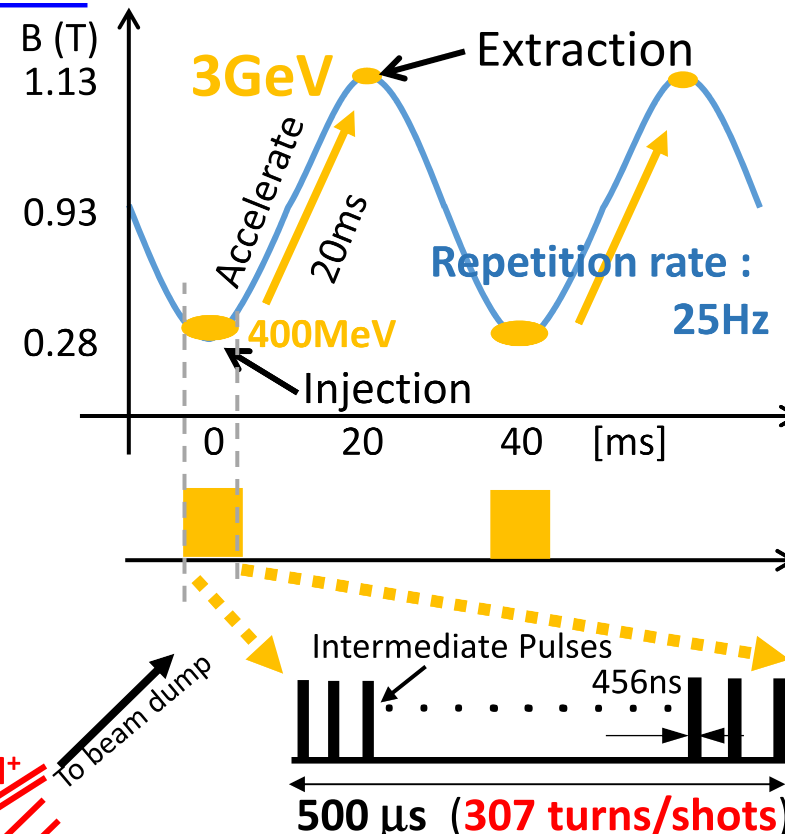

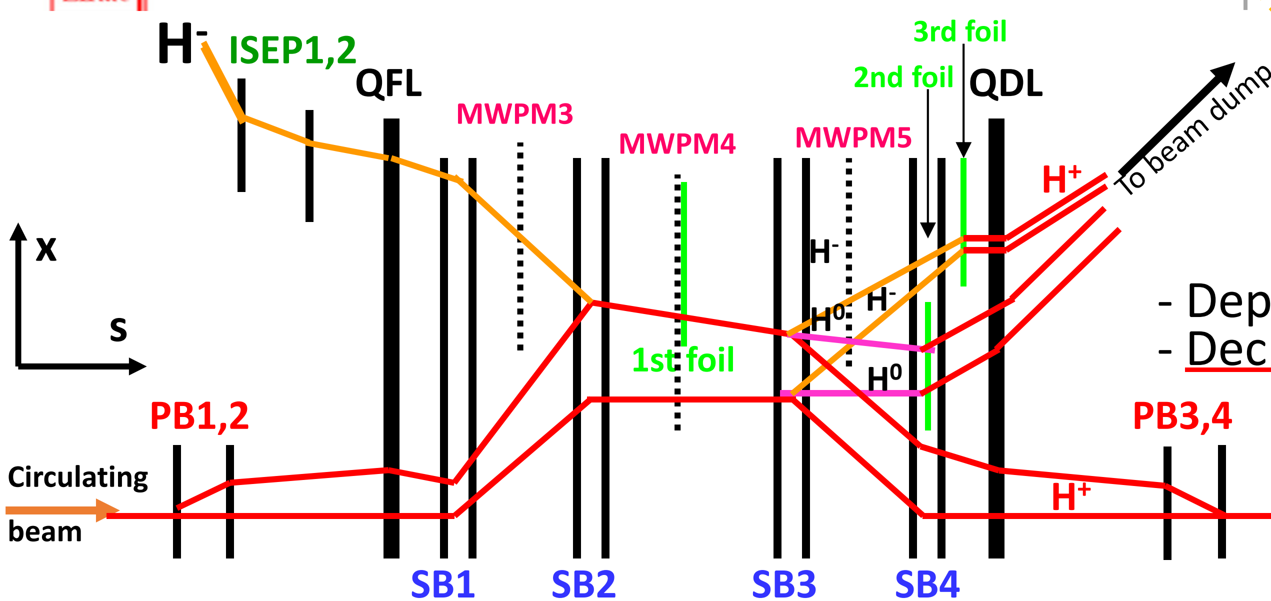

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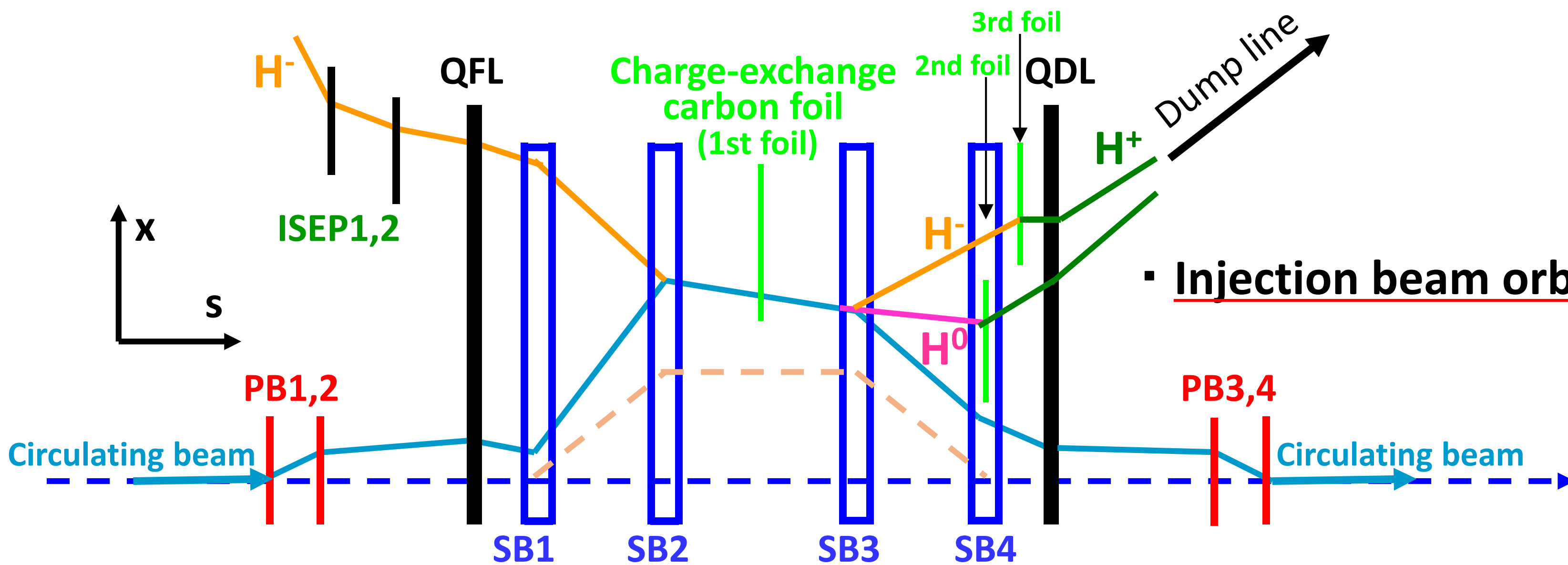
Injection Painting

Horizontal Painting scheme



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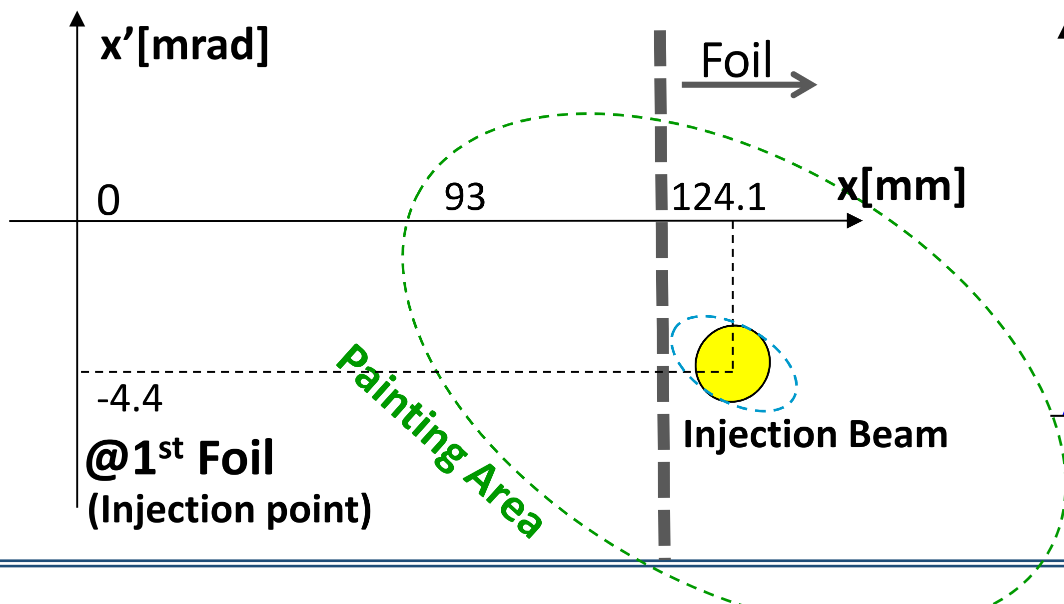

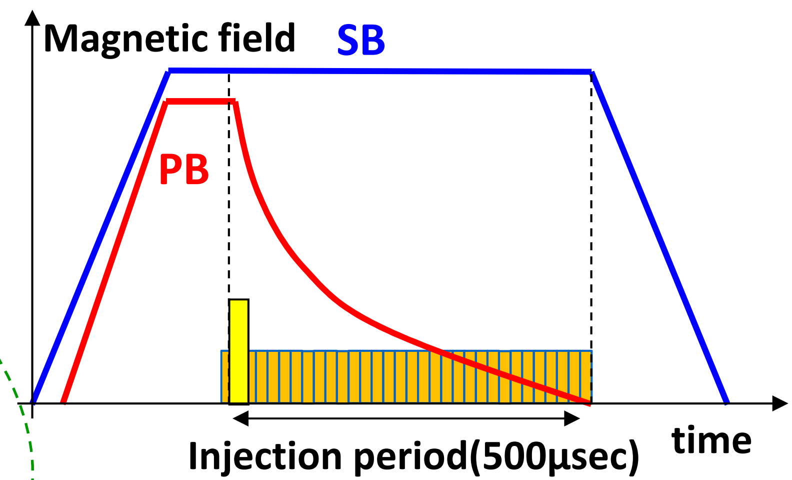

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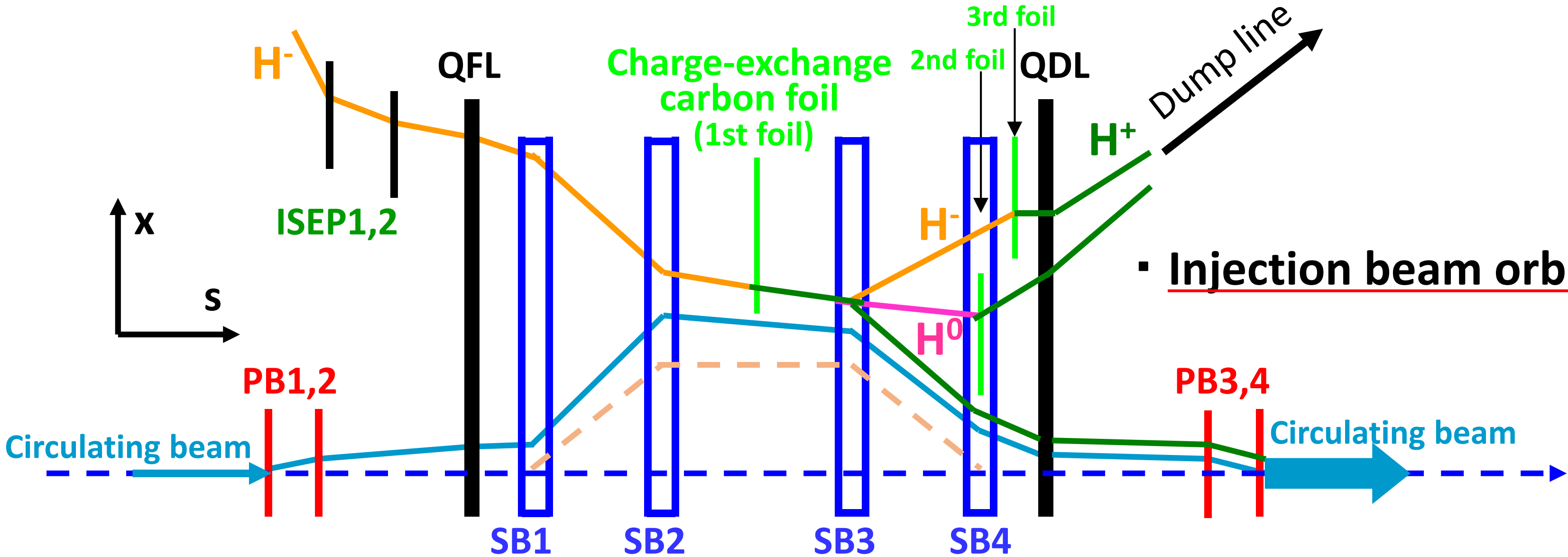

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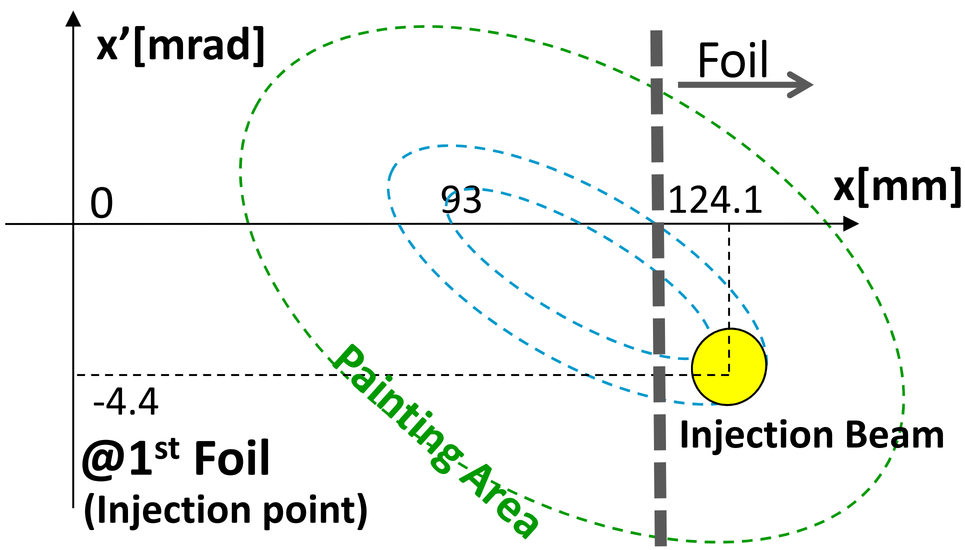

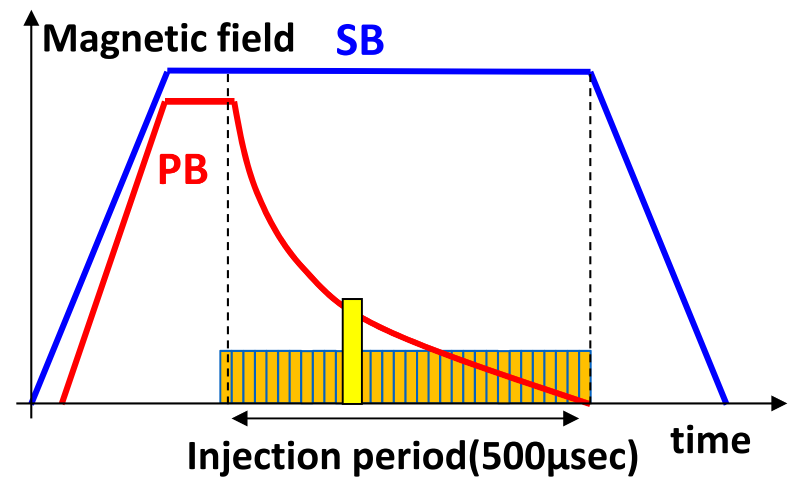

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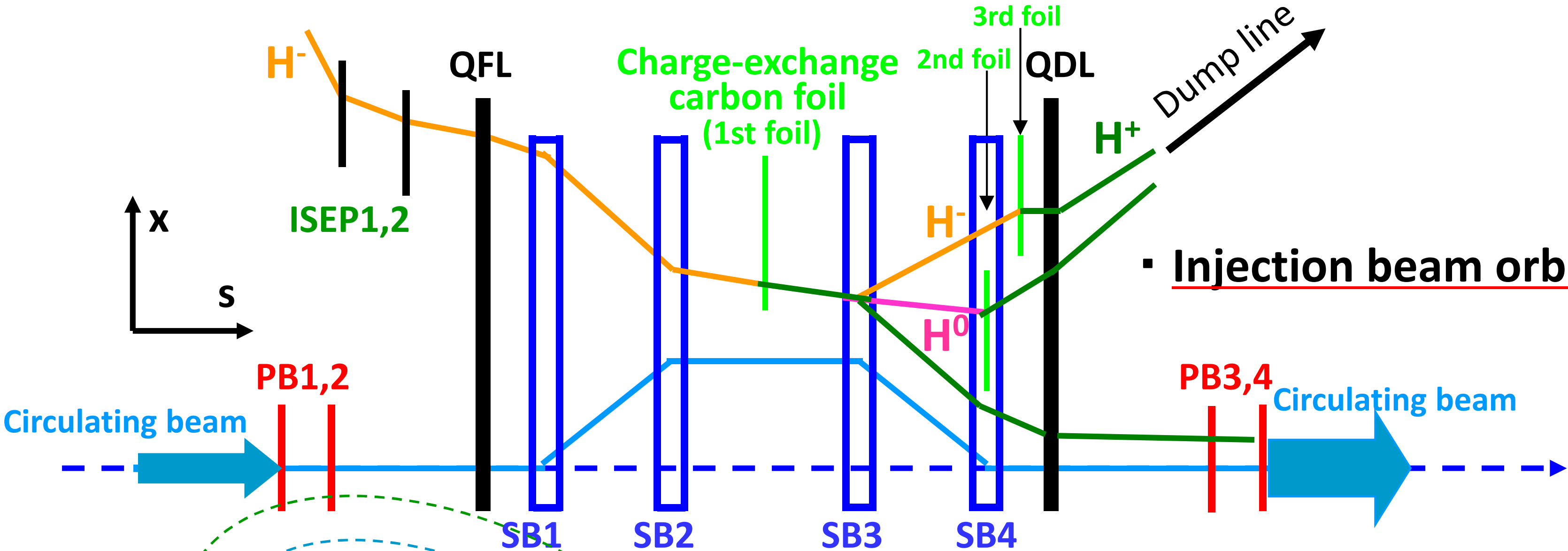

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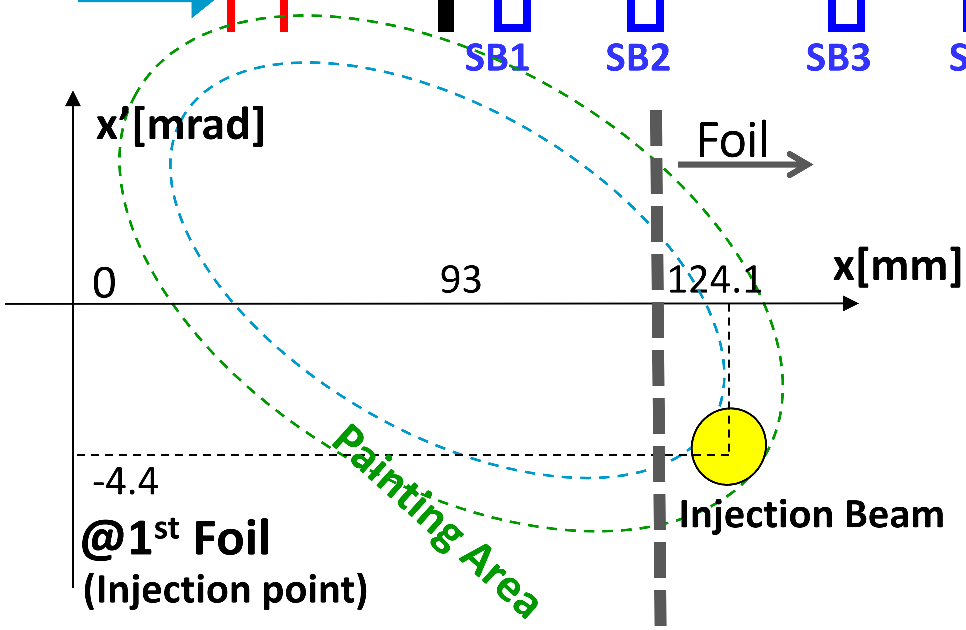
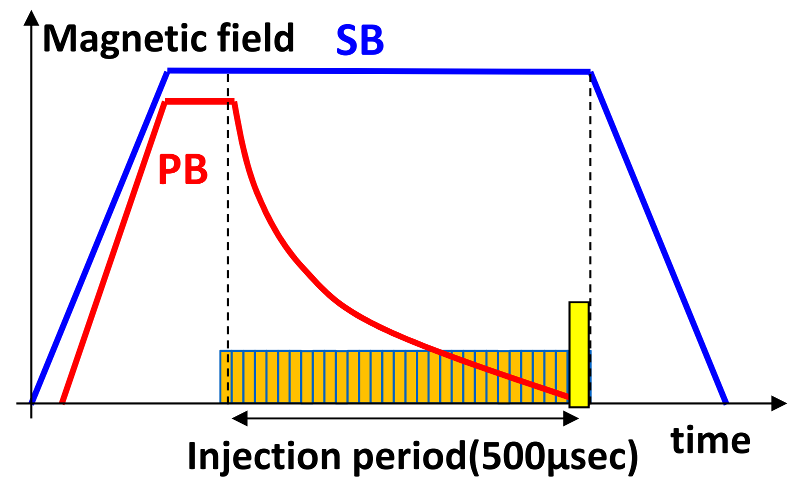




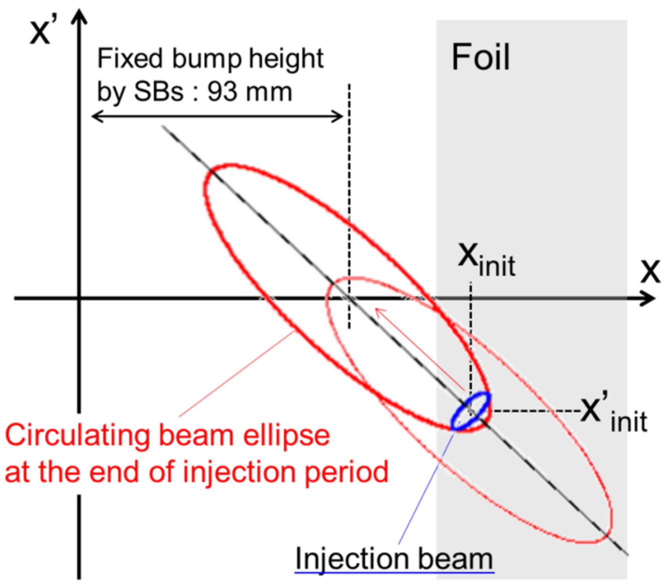
Tuning process of injection painting

1. Derivation of the initial PB current

Using…
- Online simulation model
- Measured beam parameter

For arbitrary painting area size
(ex. 200 π mm mrad, 150 π, 100 π…)

The injection beam coordinate is determined to match the painting area at the end of injection period.



2. Control of the PB current

3. Measurement of the footprint of the painting process (and painting area)

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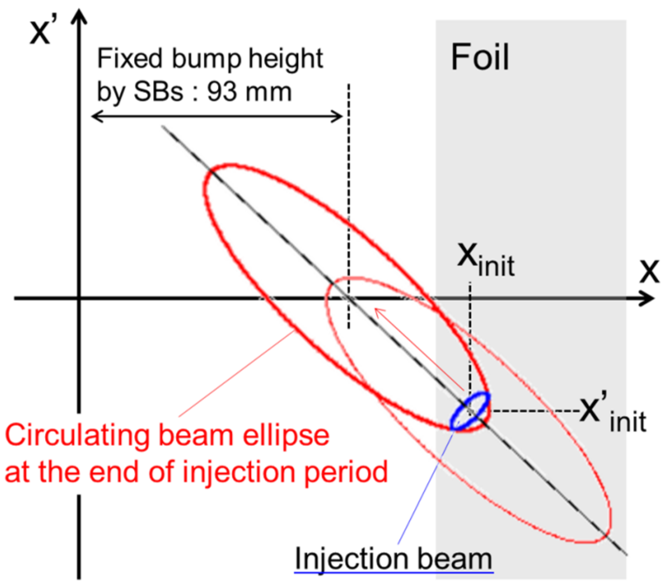

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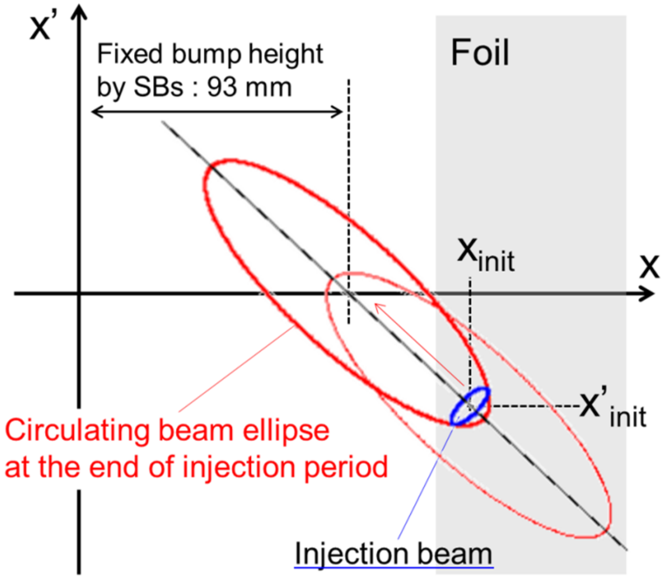


For arbitrary painting area size
(ex. 200 π mm mrad, 150 π, 100 π…)

The injection beam coordinate is determined to match the painting area at the end of injection period.

same with…

The **Initial bump orbit (x_{init}, x'_{init})**.

By model fitting…
Initial kick angles of PBs

By converting kick angle to current…
We can get **Initial output current** of PBs

2. Control of the PB current

3. Measurement of the footprint of the painting process (and painting area)

Improved processes in this time

1. Derivation of the initial PB current

2. Control of the PB current

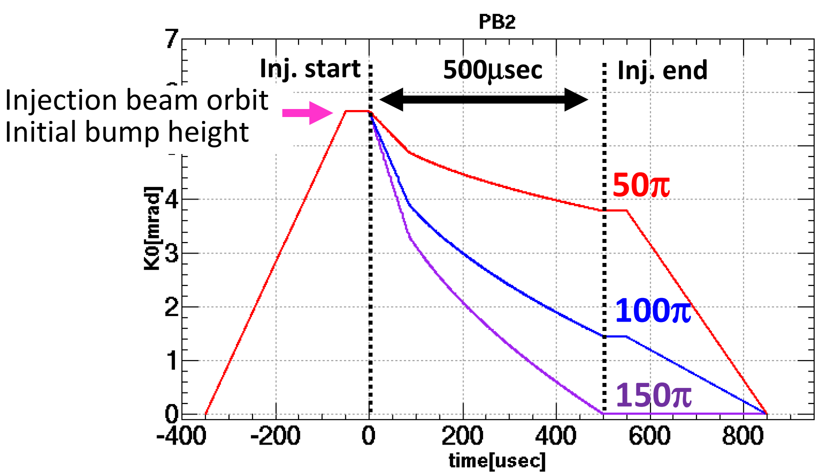
It was required to distribute the injection beam

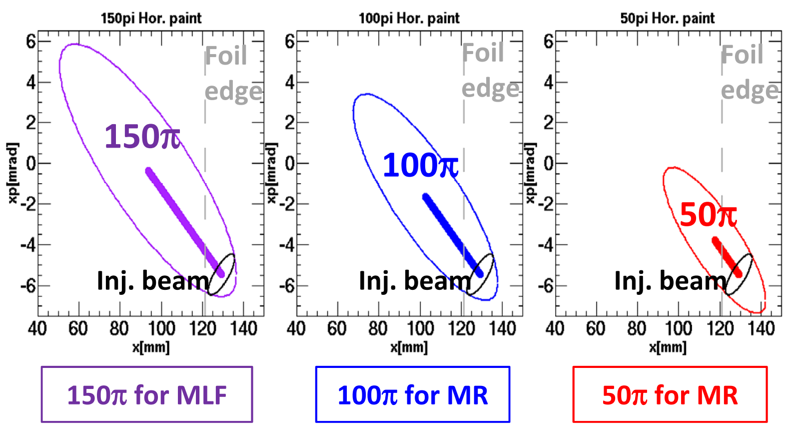
in the **determined area** following the **radial direction** **correctly**.

To reduce the **COD** excited by the error current (unbalance of PBs output).

To form **various current patterns** such as the combined time decay function.

…because the RCS should switch the transverse painting size between **MLF** and **MR** pulse-by-pulse.





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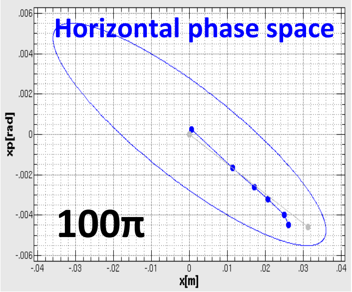
3. Measurement of the footprint of the painting process (and painting area)

It was required to confirm whether the **painted area size** and the **footprint** of the painting process was correct or not.



In particular…
The footprint was only measured with 100 μs step (6 points) because of constraints of the beam tuning time.

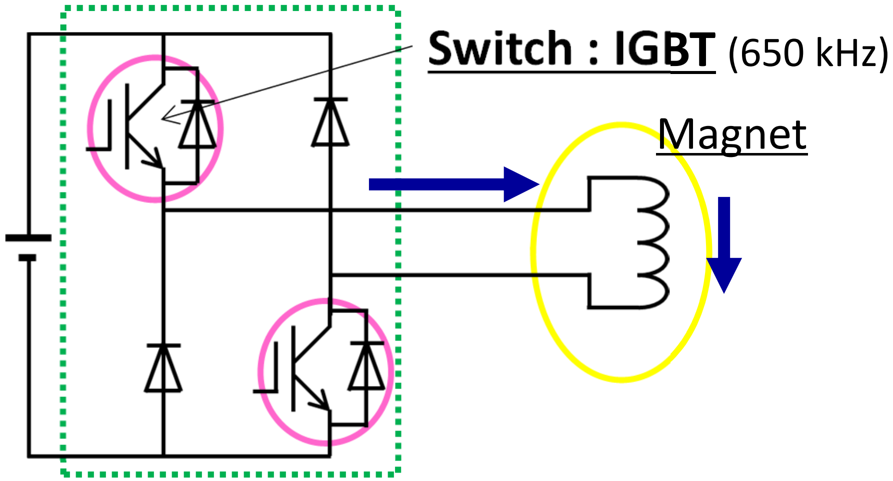
⇨ It was required to **measure the footprint** **continuously**.

We improved these processes to perform **efficiently** with **high accuracy**.

⇨ We achieved the precise **adjustment of the painting area**.

2. Control of the magnet power supply

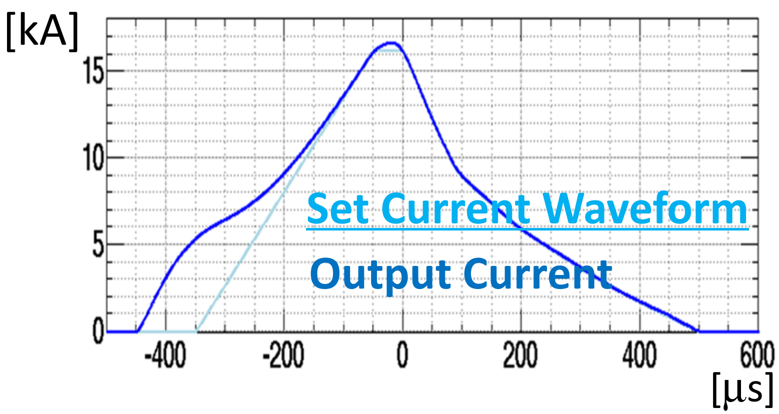
Power supply of PB



Basic construction is…

Two quadrant chopper circuit

Output **current** and **voltage**
depend on IGBT open/close time



To generate IGBT control signal…

Set Current Waveform (feedback signal)

This corresponds to **target current pattern**.

Output follows by the automatic angalog feedback.

However…

→ The time delay is approximately 20 μs.

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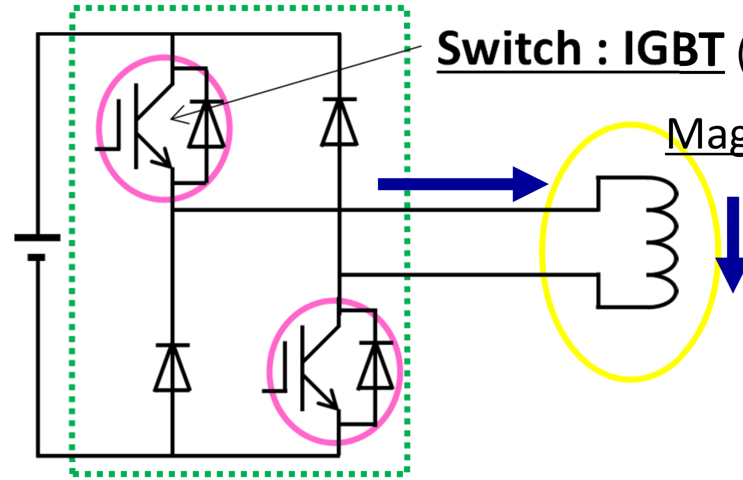
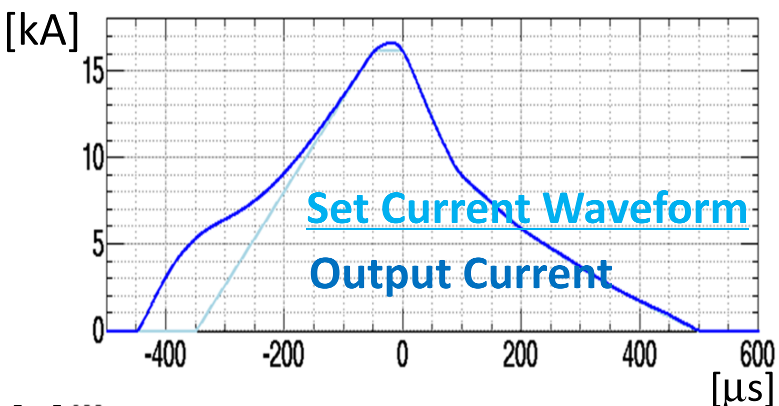
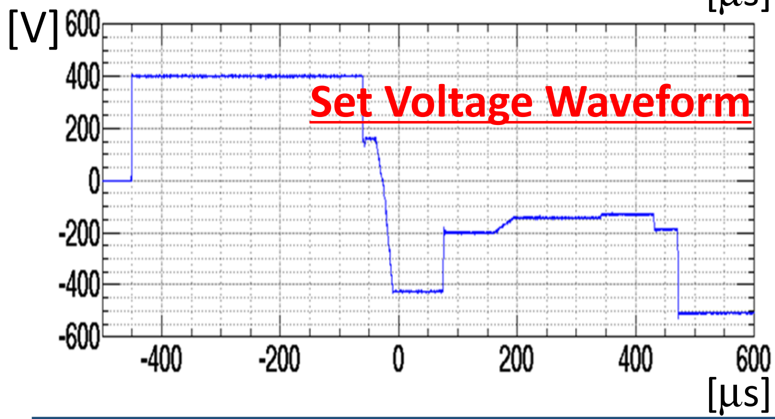






To generate IGBT control signal…

Set Current Waveform (feedback signal)

This corresponds to **target current pattern**.

Output follows by the automatic angalog feedback.

However…

→ The time delay is approximately 20 μs.

Set Voltage Waveform (feedforward signal)

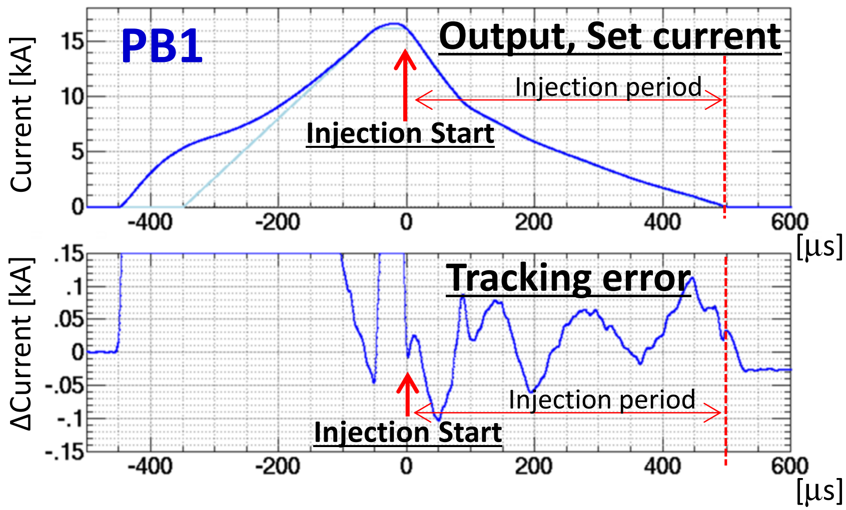
This value corresponds to IGBT open/close time.

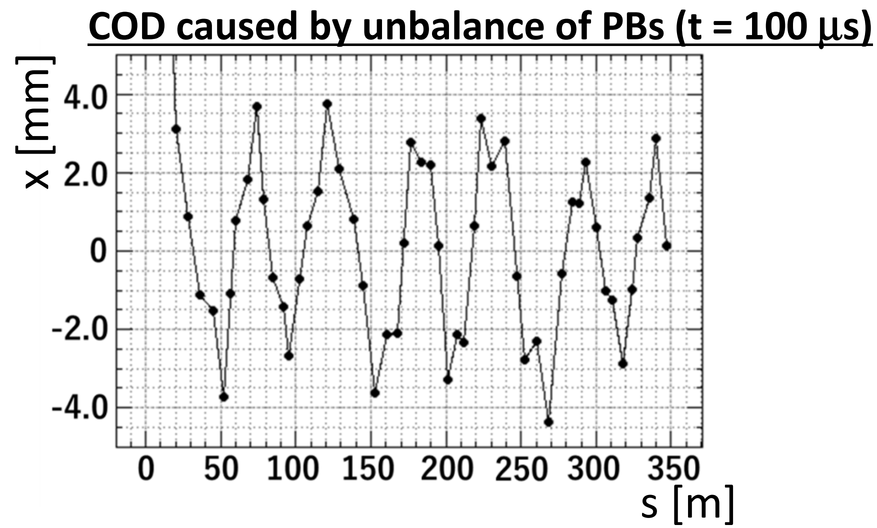
→ **target voltage pattern**

In the output adjustment…

We should optimize this **Set Voltage**.

Issues of the previous adjustment





Large tracking error (Output current deviation from **Set Current**)

The tracking error was more than **±100 A** by the manual optimization of the set voltage.

Over 4 mm COD occurred during injection by the **unbalance of 4 PBs**.

Long adjustment time

In the previous adjustment…

Adjustment time of output current was 1 hour for each power supply.

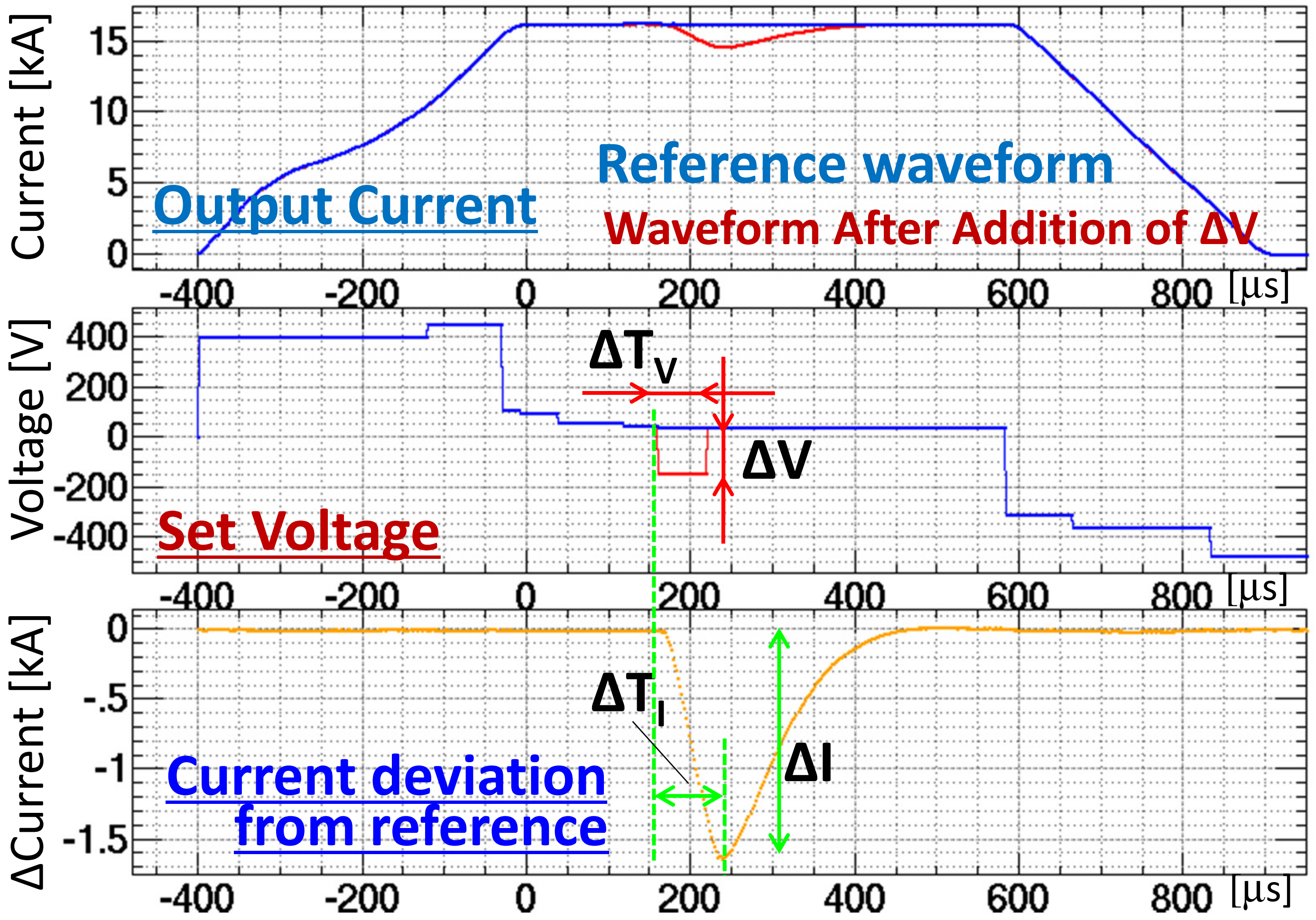
(4 horizontal + 2 vertical) ⇨ Over **6 hours** for one painting area

⇨ We developed the **accurate** and **quick** adjustment technique.

Response measurement

For accurate & quick adjustment…

The output current response to the **Set Voltage** was measured in detail.



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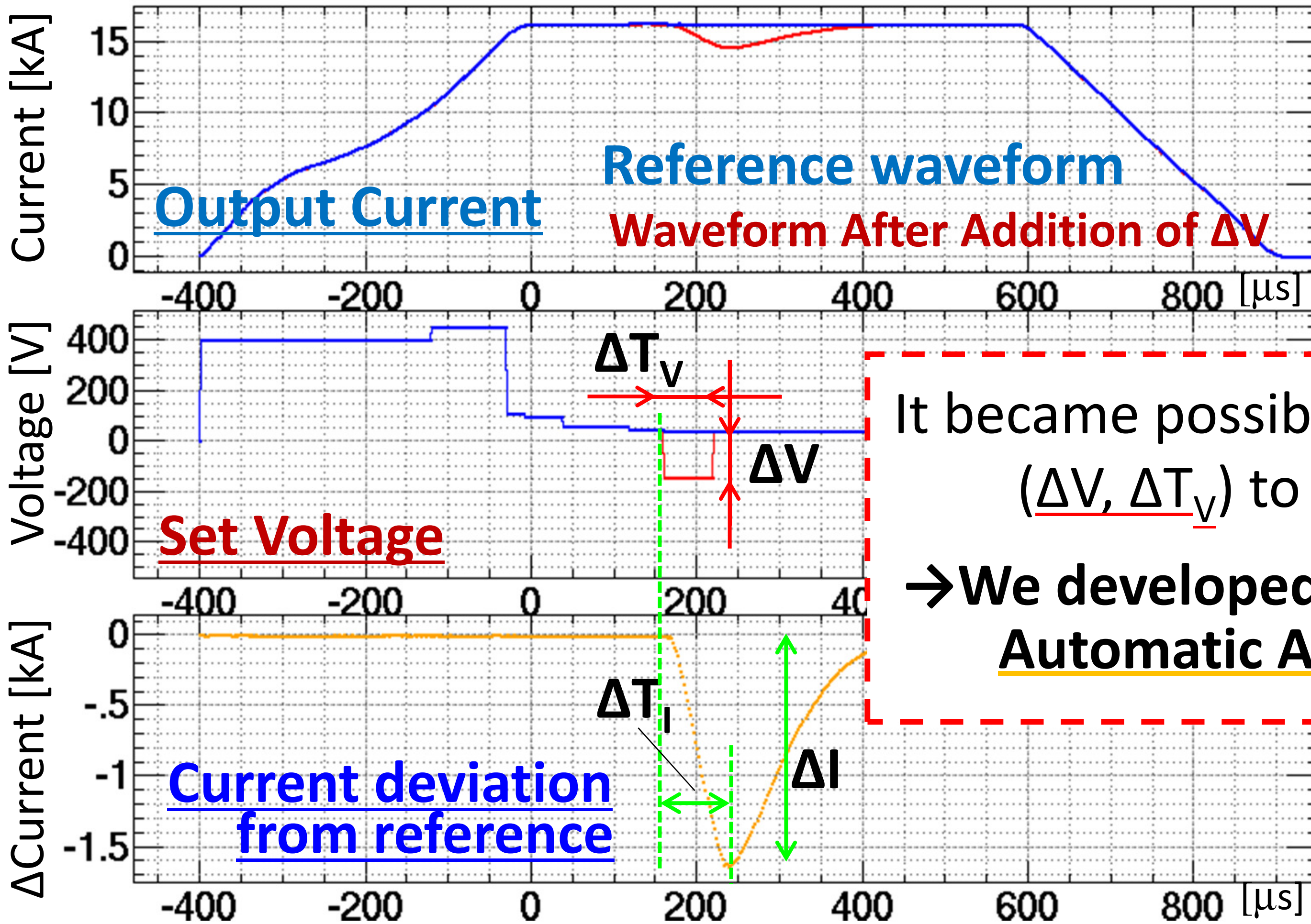
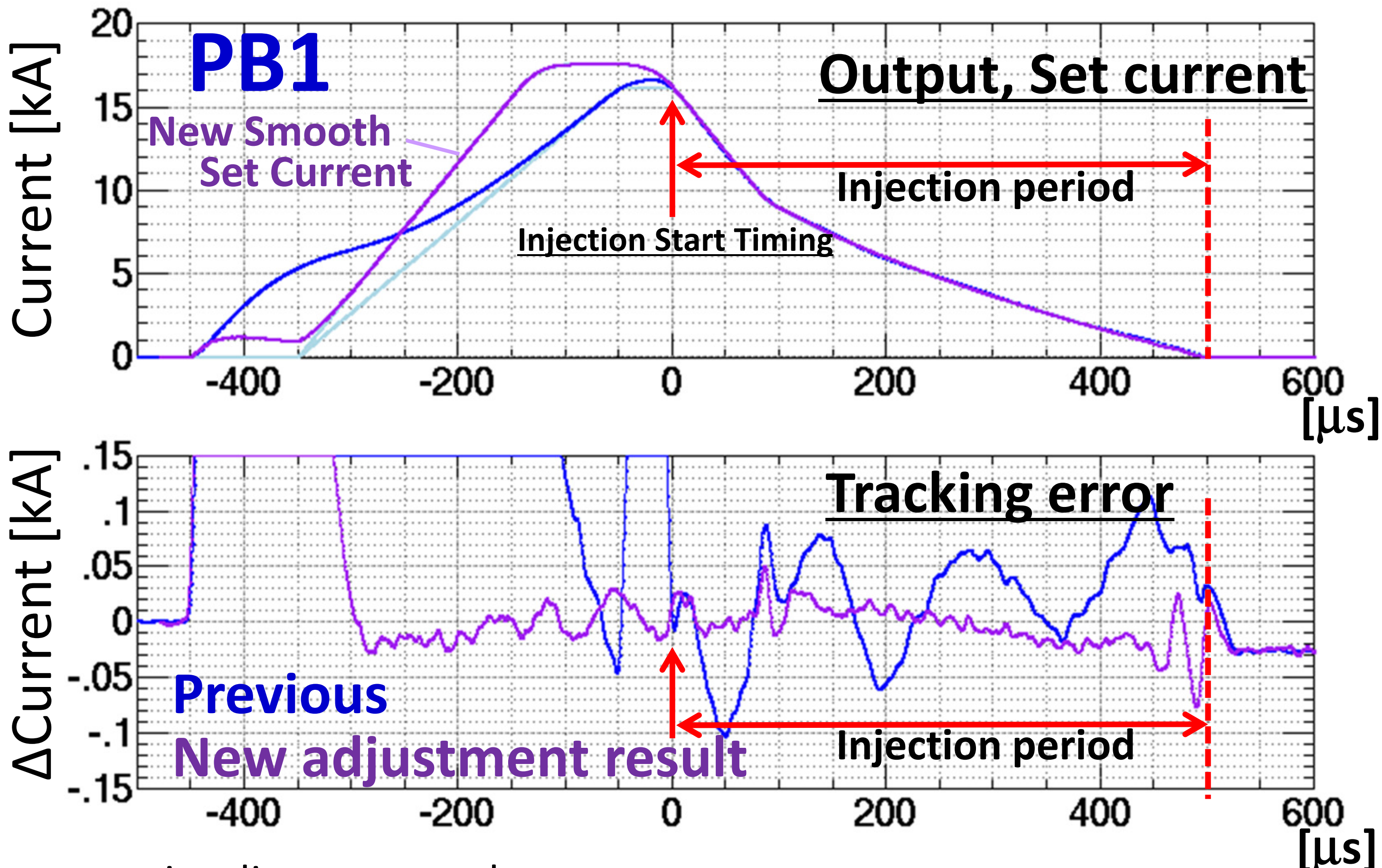


It became possible to calculate (ΔV, ΔT_V) to correct (ΔI, ΔT_I).

→**We developed Automatic Adjustment Tool.**

Adjustment Result



By the automatic adjustment tool…

Adjustment time : 1 hour ⇒ **20 minutes** for each power supply

Tracking error : >±100 A ⇒ **<±50 A**

3. Measurement of the footprint of the Painting process

Measurement method (1)

To obtain the footprint of the painting process on the phase-space…

Measurement method was developed

using **COD measurement** & **Online simulation model fitting**

COD measurement during injection period

Waveform signal of BPMs (having 4 electrodes) are analyzed.

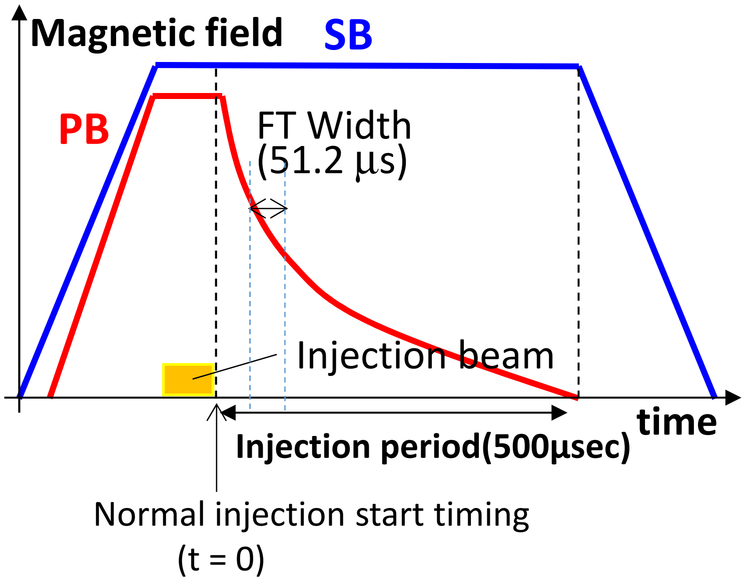
By using Fourier Transform (FT)…

⇨Amplitudes at the revolution frequency are obtained for each electrodes.

From the balance of these amplitudes…

⇨ Beam position can be obtained.

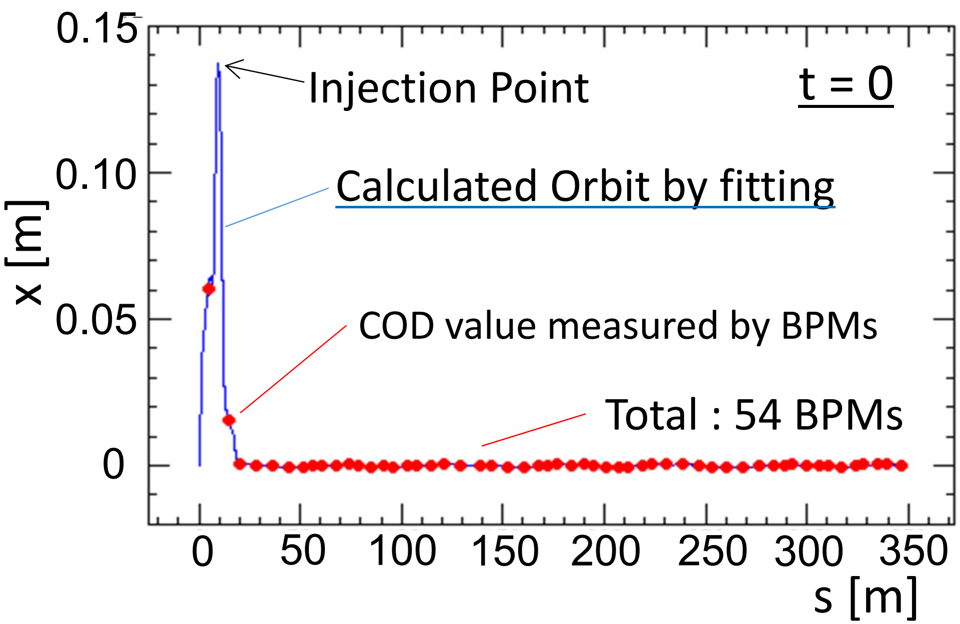
- Injection Timing was shifted just before normal timing to complete injection until t = 0.
- Shorter Fourier Transform width was chosen (typical : 100 μs).
- Waveform was analyzed with 1 μs step continuously.



We could obtain the 500 points **COD** from t=0 to 500 μs **continuously**.

Measurement method (2)

Online simulation model fitting & Painting area measurement



For the COD, **Model Fitting** is performed.

By using the difference of COD between **with/without** PB…

Only 4-kick angles of 4-PBs are required as the free parameters.

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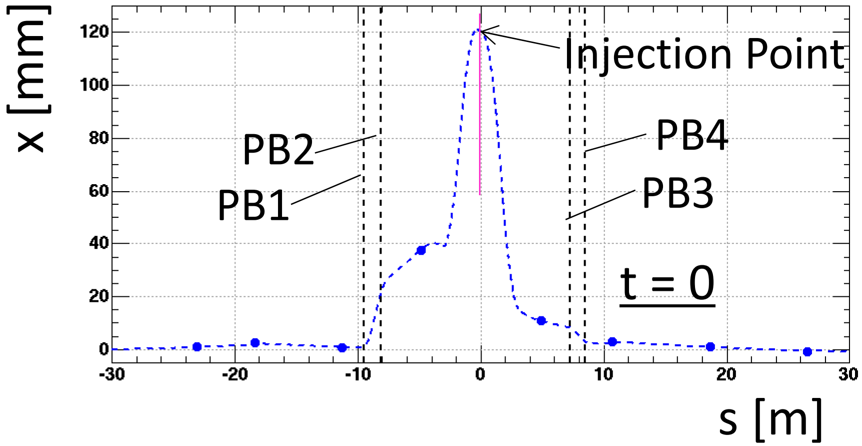

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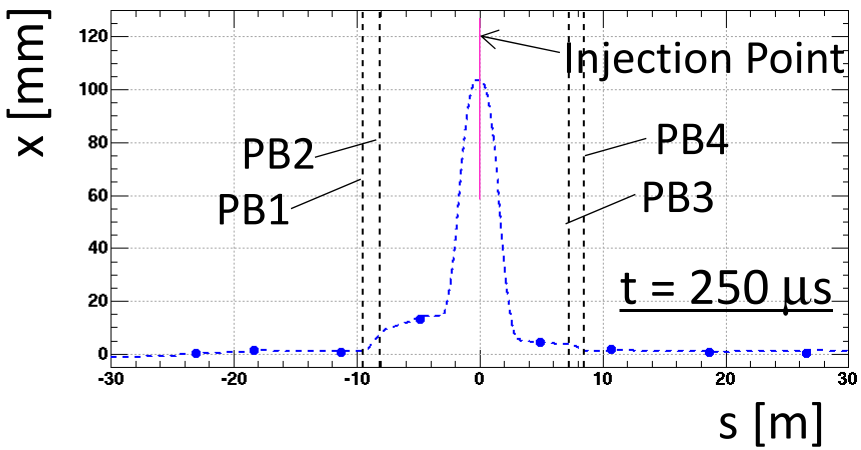

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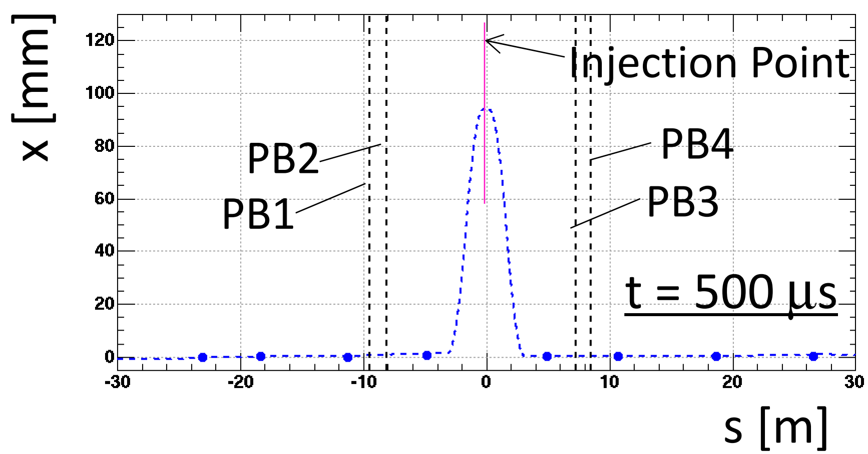

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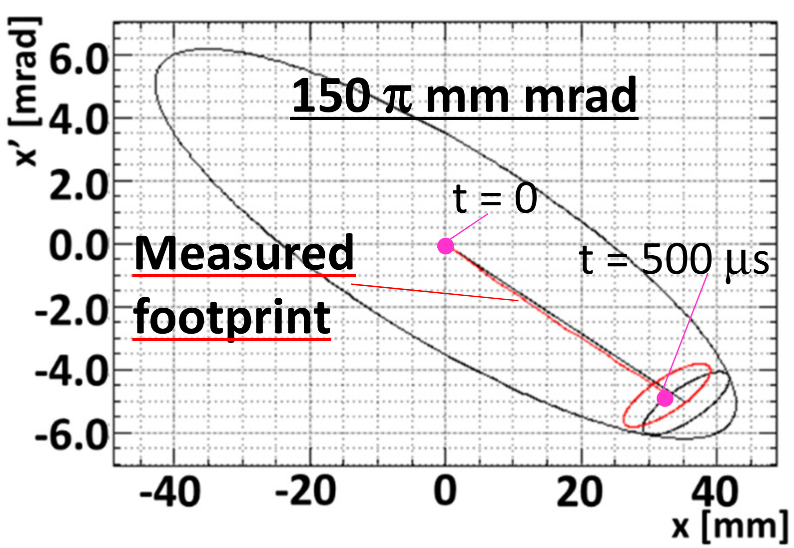


It is possible to estimate not only time variation of **kick angles** but also that of the **bump height**.

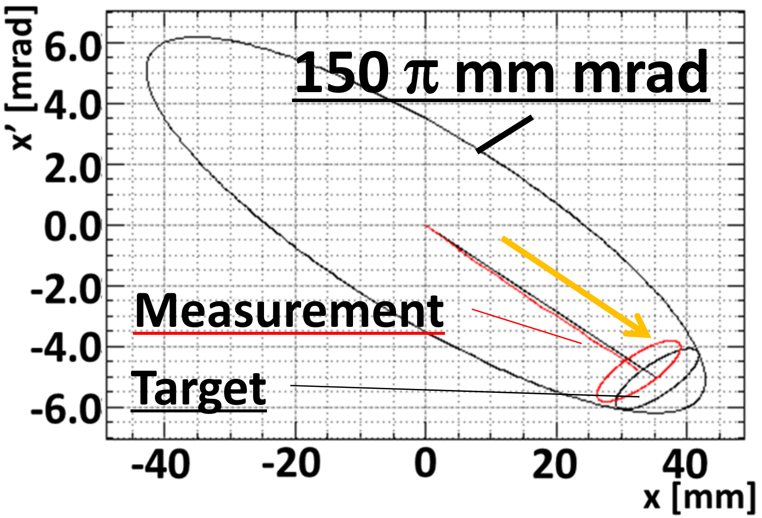
We could get the footprint of the painting process **continuously**.

We could confirm the Painting Area.

4. Adjustment of the Painting Area

First adjustment result & correction

Measurement result of the painting area



The moving distance of the injection beam was **insufficient**.

This result is equivalent to…

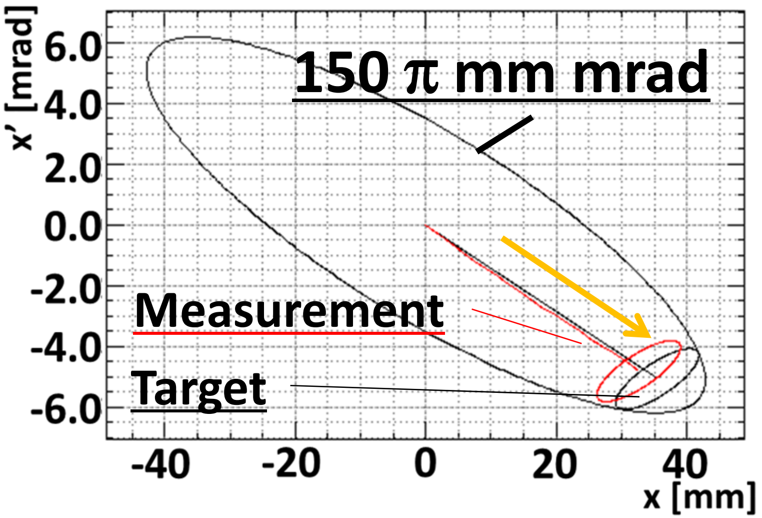
The initial bump orbit height (magnetic field) was insufficient.

The footprint was also different from the target.

The cause was the difference between the **current monitor value** and the **output field** due to the **response lag** of the current monitor circuit.

First adjustment result & correction

Measurement result of the painting area



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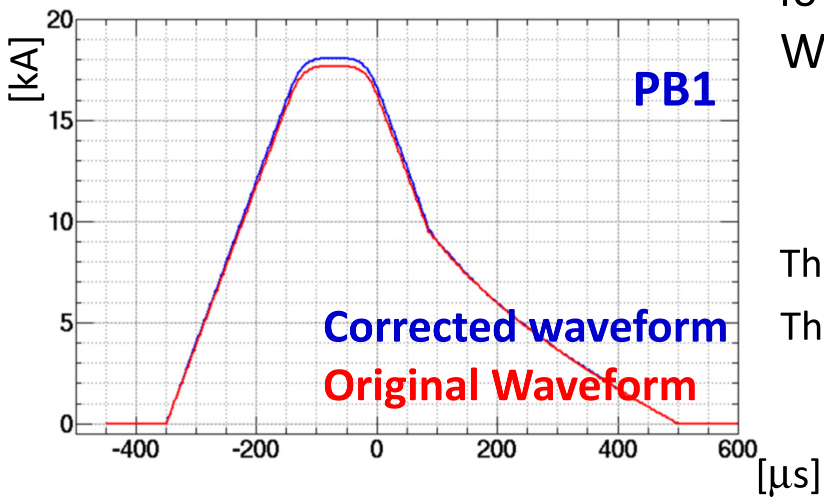


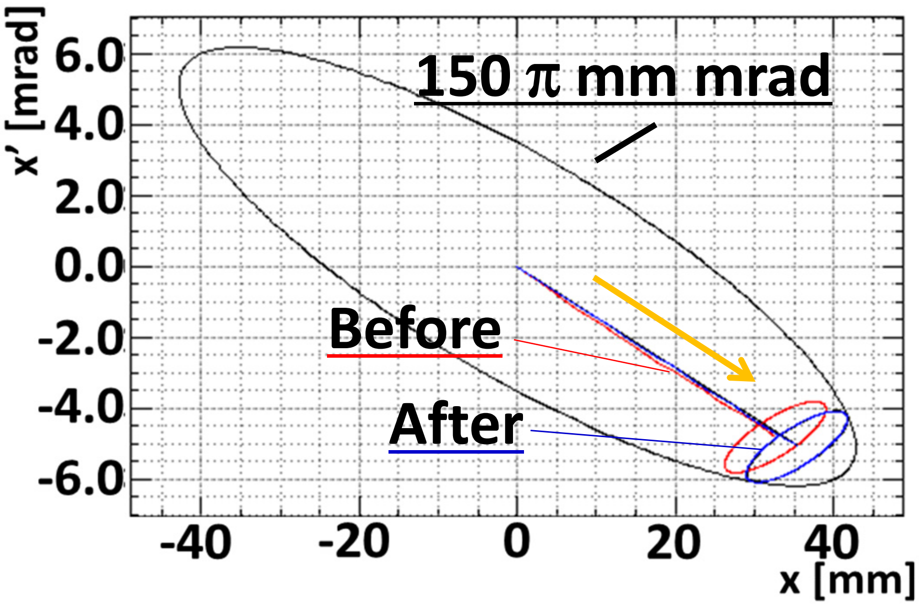
To correct the insufficiency of the PB output…
We **regenerated** the new Set Current by adding the analysed shortage current and **readjusted** the output current.

This is like the feedback based on the measured result.

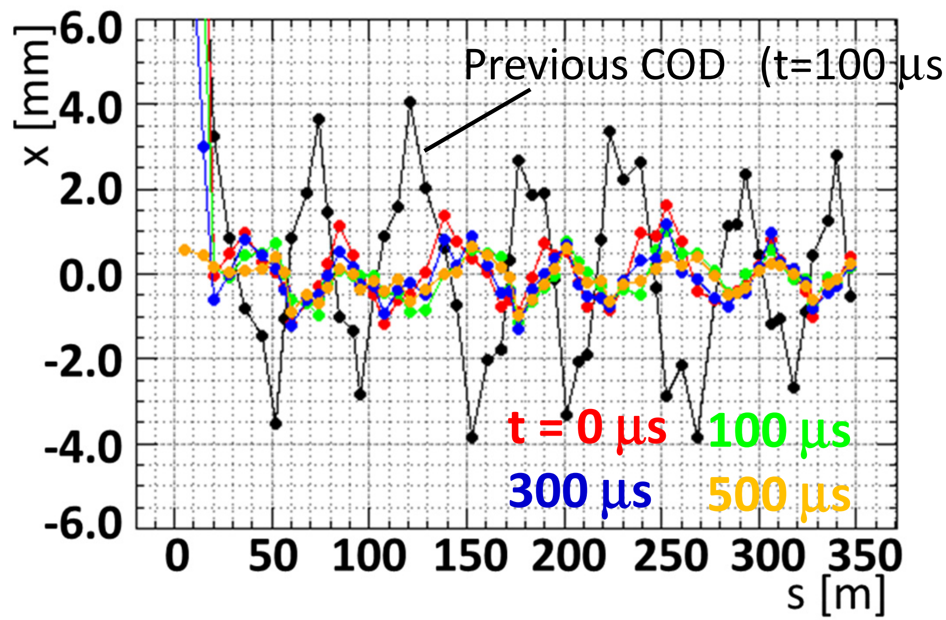
This correction could be performed by the **precise control of current** and the **measurement of footprint** (kick angle & bump height).

Adjustment Result

Results before and after readjustment



CODs during injection period



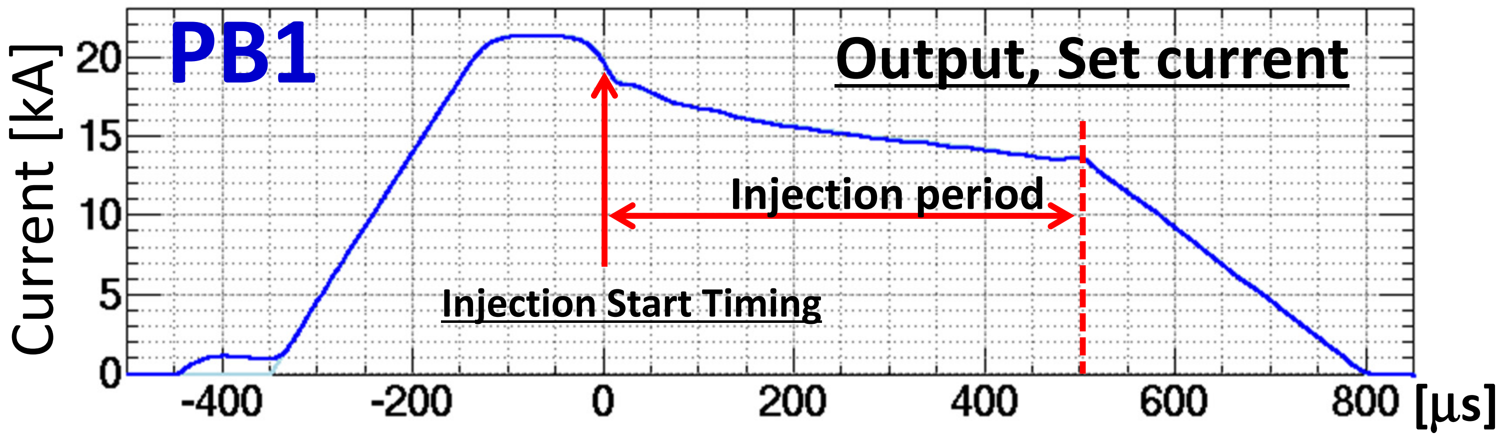
The moving distance (bump height) was **enough improved** by only one correction.

The footprint **followed the radial direction** more accurate.

The output **balance** between PBs was improved
and COD could be reduced to approximately **±1 mm**.

➡ We achieved the precise **adjustment of the painting**

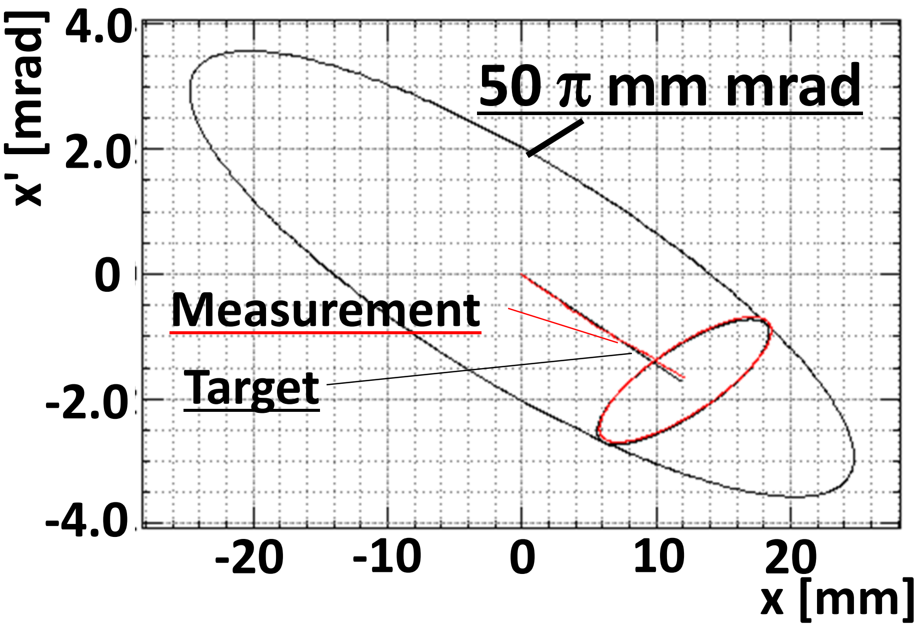
Adjustment Result (2)



For **combined time decay function…**

We also achieved
the precise **adjustment of the painting.**

Pulse-by-pulse switching
of the transverse painting size
between **MLF** and **MR**
has been operated **successfully**.



5. Summary

We established the control of injection painting with high accuracy.

In particular, we developed…

Control of PB current

By the response measurement & developing the automatic tool,

Adjustment time : **1/3** (20 minutes)

Tracking error : **1/2** comparing with previous one

Measurement of the footprint of painting process

It became possible to obtain the painting process **continuously**.

After that…

Adjustment of the Painting Area

We could distribute the injection beam on the **target paint area correctly**.

The output balance of the PBs was improved.

It became possible additionally

to make the various time function of painting flexibly

for control of the beam distribution and density.

Our results lead to the experimental study of the space-charge effect.