# Pulse-to-pulse transverse beam emittance controlling for the MLF and MR in the 3-GeV RCS of J-PARC

**Pranab K. Saha**

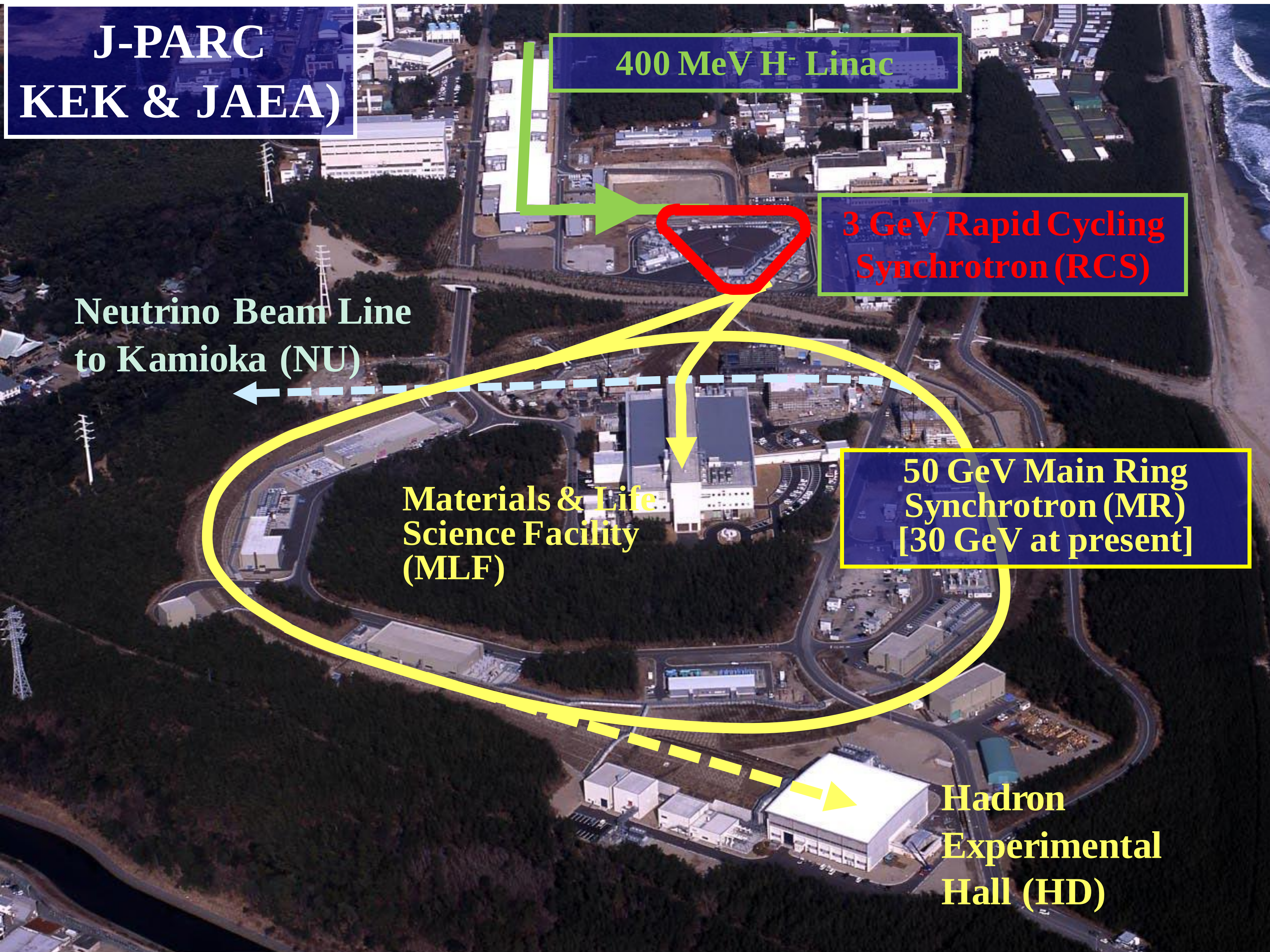
On behalf of RCS beam Commissioning group

**J-PARC, Japan**

*HB2014@East Lansing, MI, Nov. 2014*

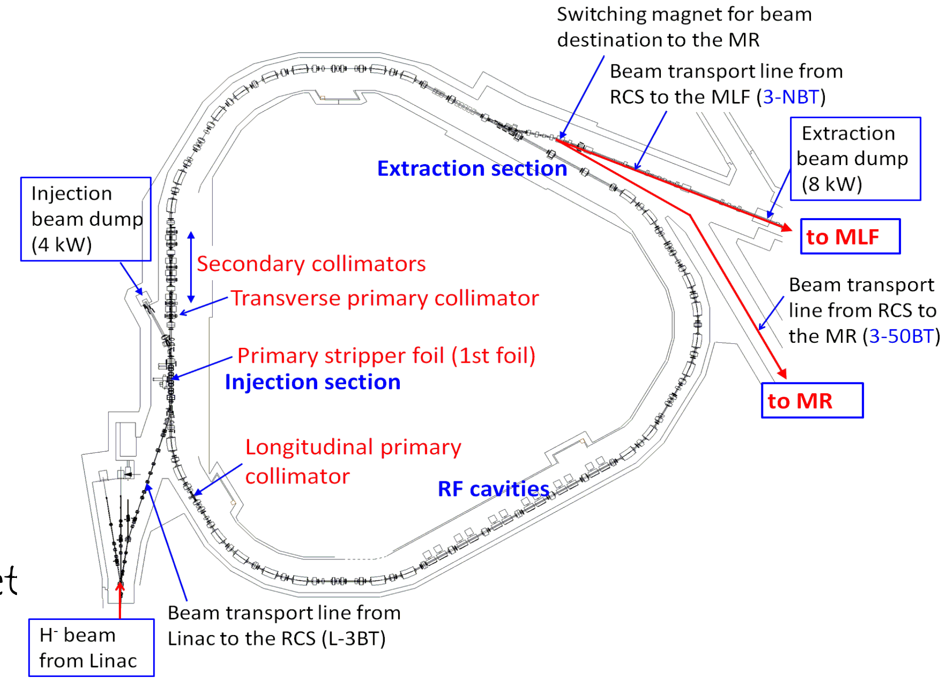
## Outline:

1. Introduction
2. RCS Injection and transverse Painting scheme
3. Methods for changing painting area pulse-to-pulse
4. Experimental and simulation results
5. Summary


J-PARC
KEK & JAEA)
400 MeV H- Linac
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line to Kamioka (NU)
Materials & Life Science Facility (MLF)
50 GeV Main Ring Synchrotron (MR) [30 GeV at present]
Hadron Experimental Hall (HD)

# Introduction

Not only the beam power itself but RCS has to control also the extracted beam emittance/profile pulse-to-pulse between MLF and MR.



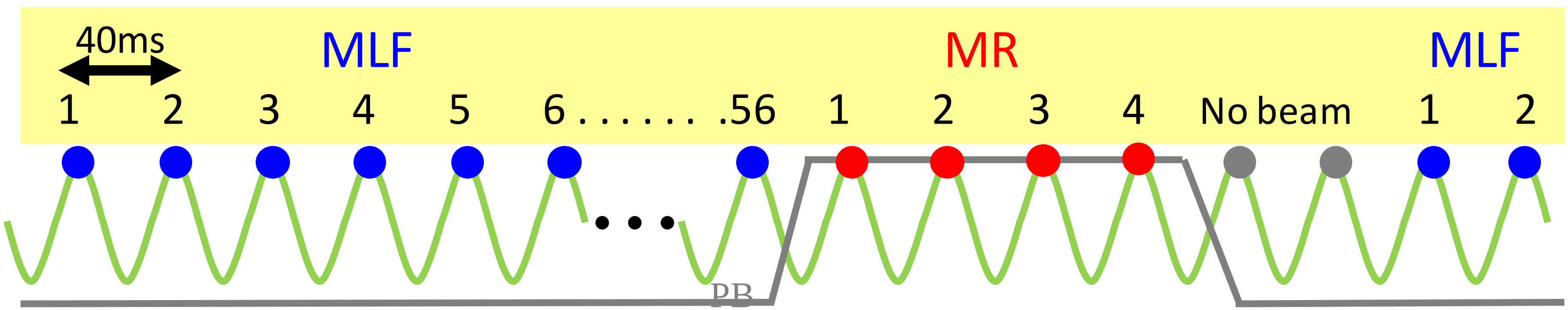

## *For MLF: Wider beam profile*

To reduce damage on the neutron production target

## *For MR: Narrower beam profile*

In order to reduce beam loss at the 3-50BT collimator as well as in the MR because of much narrower beam line aperture.

- *Multi-turn $H^-$ stripping injection.*
- *Injection Energy: (181) 400 MeV*
- *Extraction Energy: 3 GeV*
- *Repetition: 25 Hz*
- ***Beam power (design): 1MW***




Extracted beam is simultaneously delivered to the MLF and MR

# *Design apertures of 3-NBT, 3-50BT and MR*

3-NBT (Beam transport of RCS to MLF target) aperture:
**324π mm mrad** (Same as RCS primary collimator).

3-50BT (Beam transport of RCS to the MR) aperture:
**120π mm mrad.**
3-50BT collimator: **54π mm mrad.**
(limit: 2 kW)

MR aperture: **81π mm mrad.**
MR collimator: **70π mm mrad.**
(limit: ~2 kW)

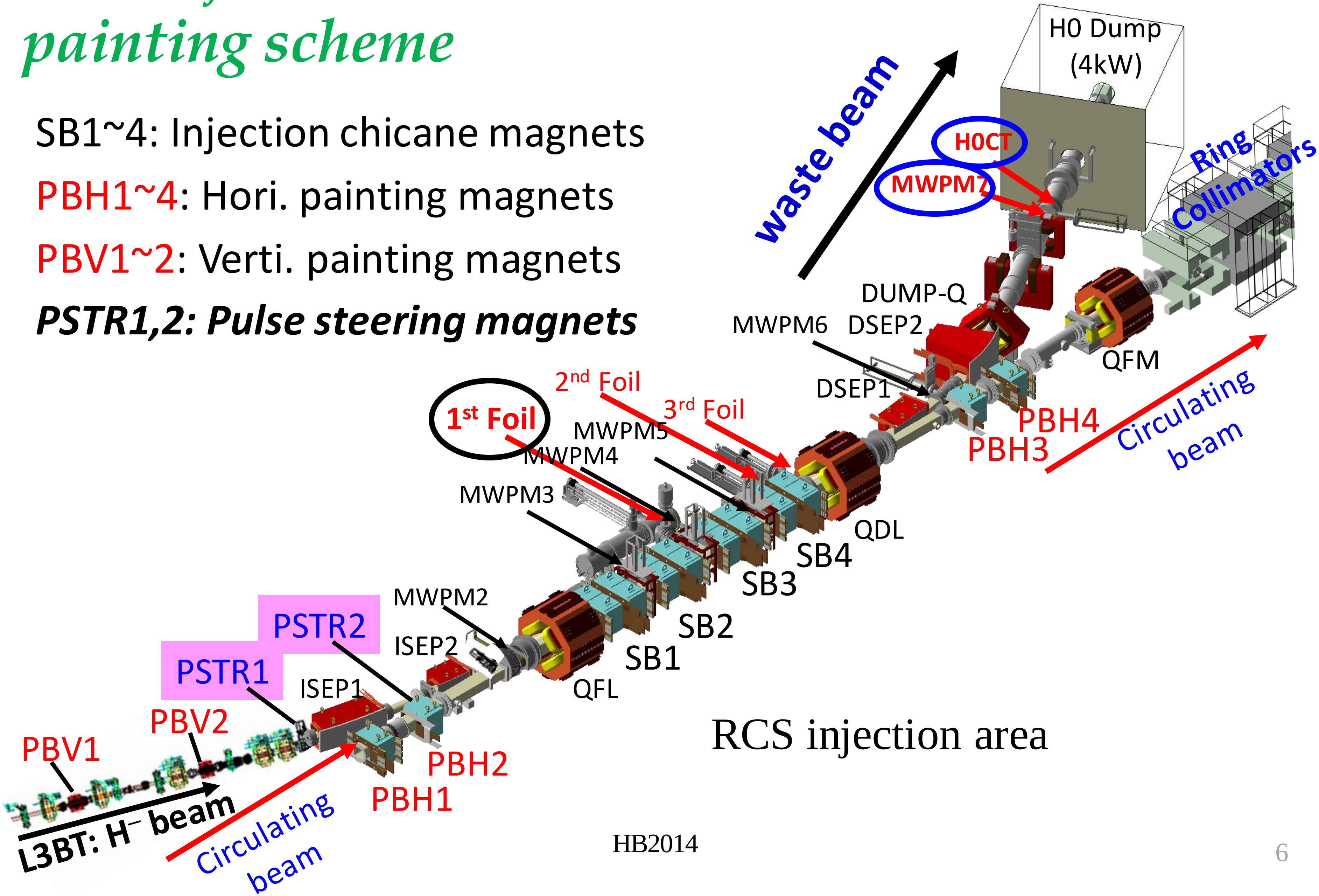
# *RCS injection and transverse painting scheme*

SB1~4: Injection chicane magnets

PBH1~4: Hori. painting magnets

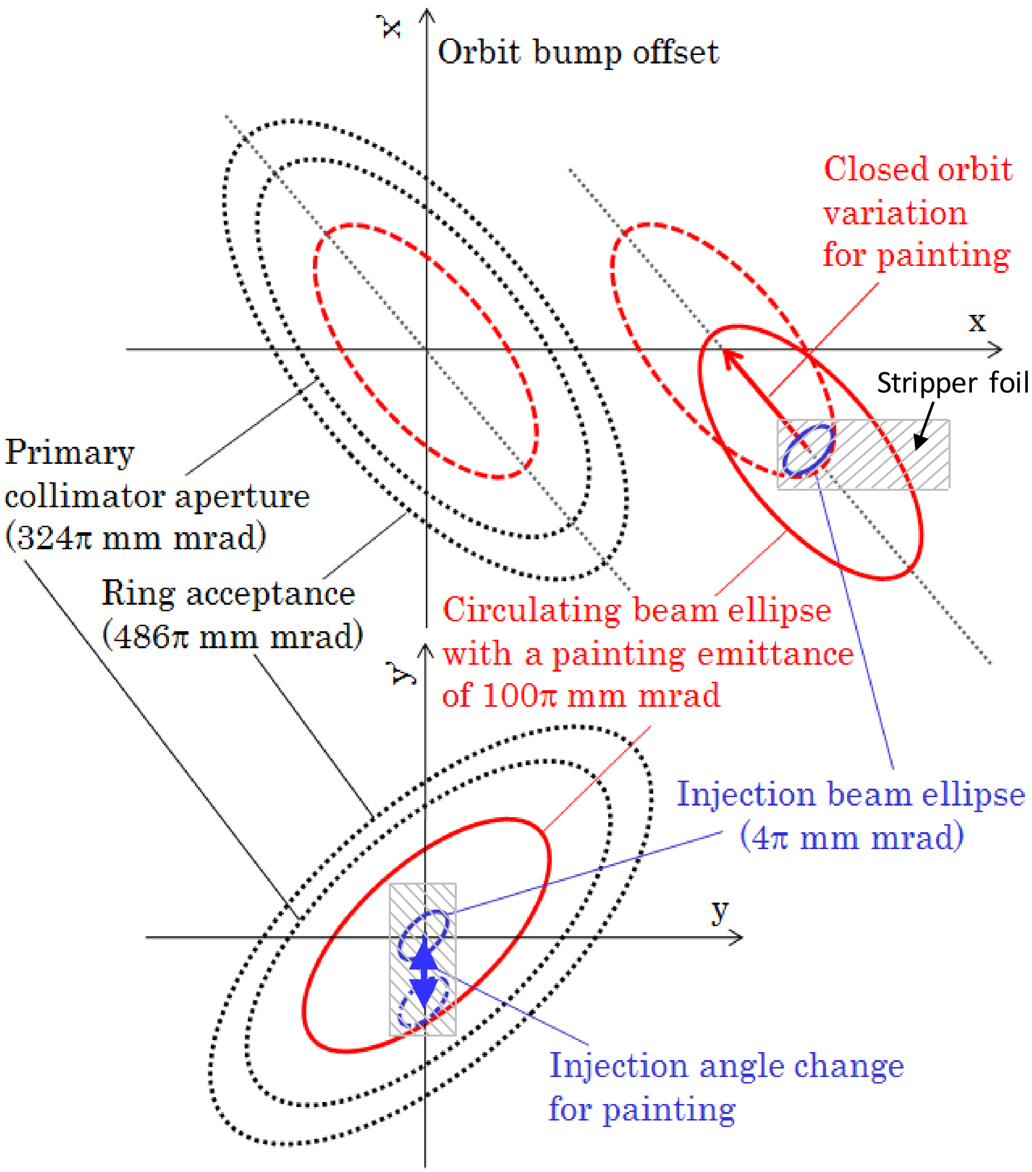
PBV1~2: Verti. painting magnets

***PSTR1,2: Pulse steering magnets***




RCS injection area

# Transverse injection painting method




## Horizontal plane:

Injected beam is fixed at foil.

Closed orbit is varied during injection for painting injected beam center to outside in the circulating phase space.

## Vertical plane:

Injected beam angle is varied during injection.

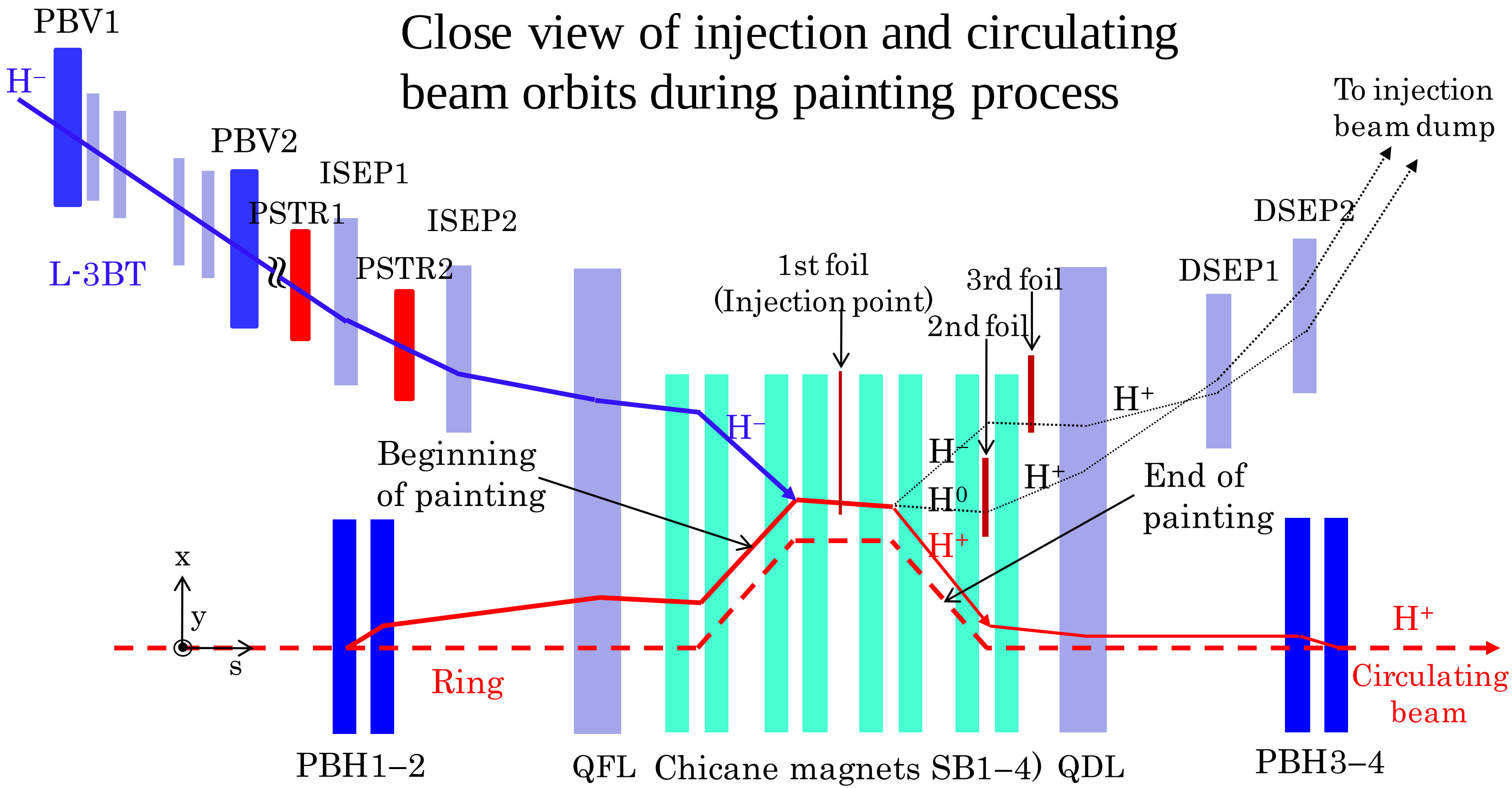
***Center to outside***

***→ Correlated painting***

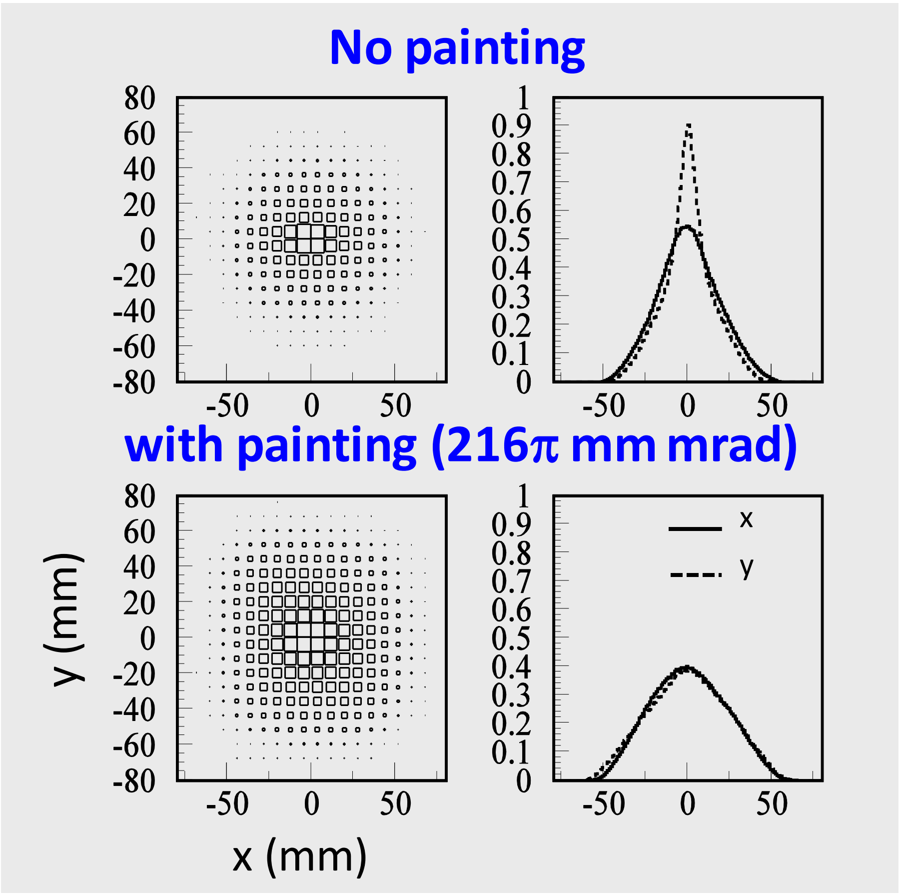
***Outside to center:***

***→ Anti-correlated painting***

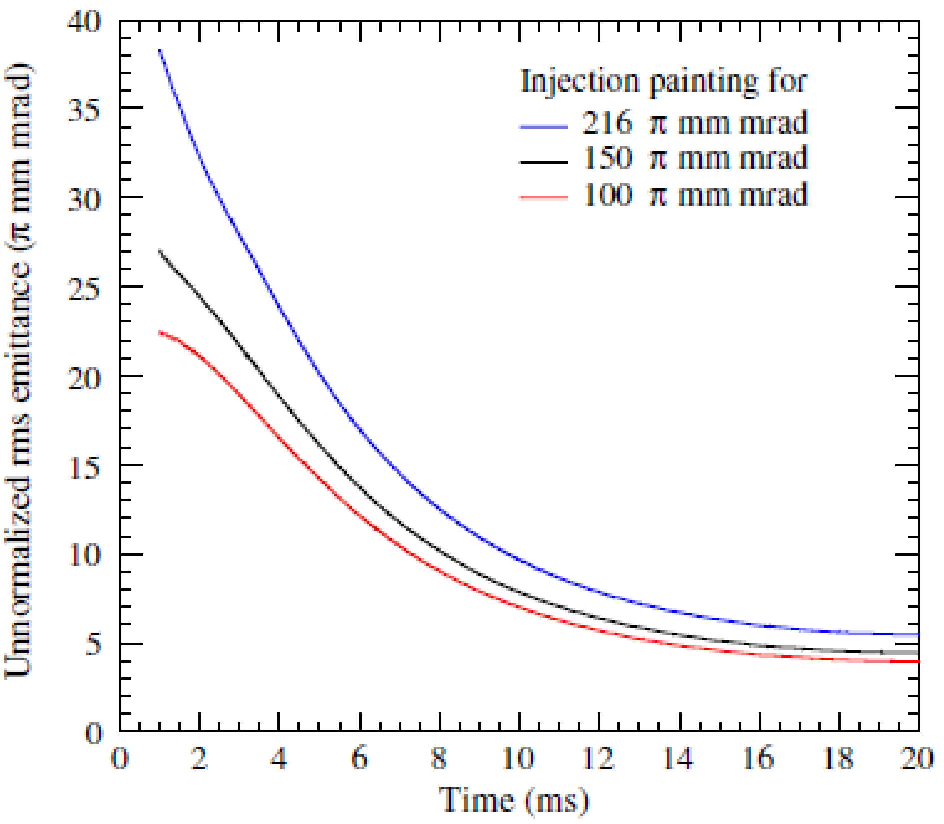
# Transverse injection painting method



# *Painting area vs. transverse beam profile and extracted beam emittance*




Uniformed transverse distribution is obtained by painting




216π → 100π injection painting
→ 25% reduction of rms emittance

# *Methods for changing painting area pulse-to-pulse*

**Horizontal direction:**

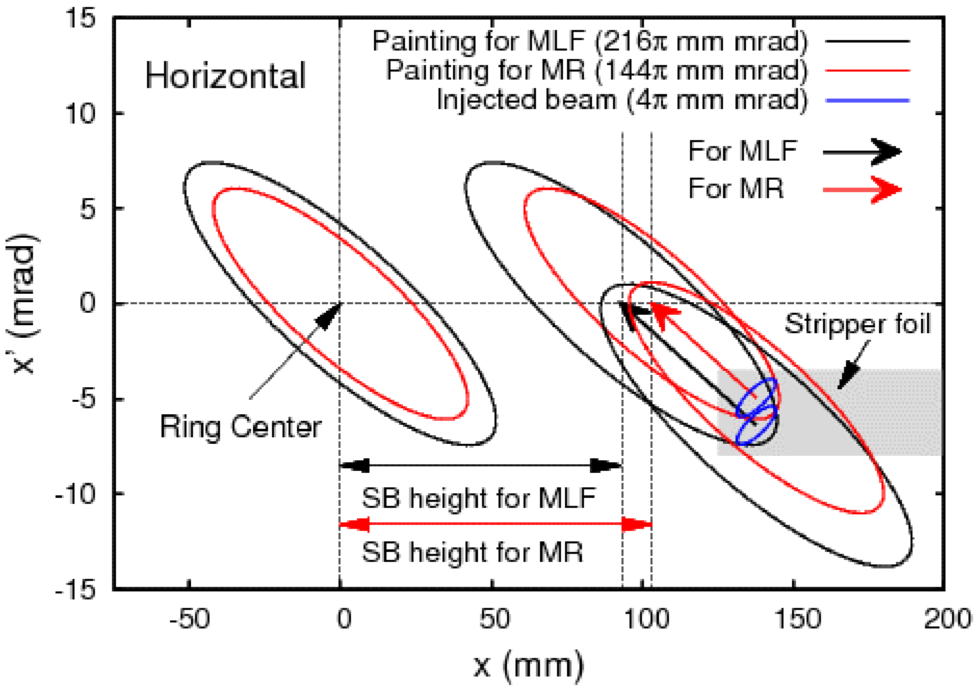
Method 1 : By using Pulse Steering magnets (PSTR1,2).
+ Horizontal painting magnets.

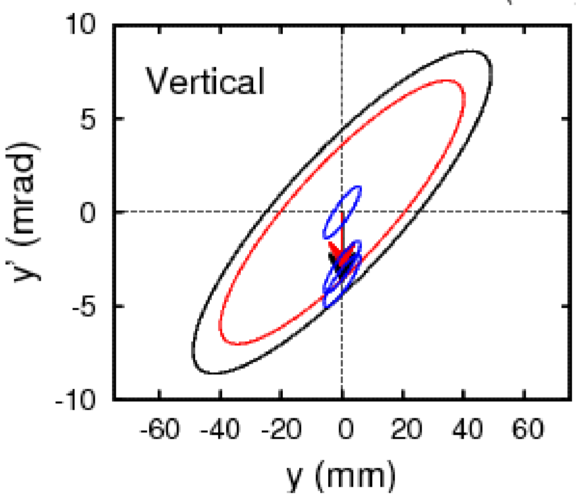
Method 2 : By using only Horizontal painting magnets.

**Vertical direction:**

By using vertical painting magnets.

# Method 1: To change painting area pulse-to-pulse by PSTR magnets




Center to outside in vertical plane: Correlated painting

Outside to center in vertical plane: Anti-correlated painting

- PSTR1,2 are placed in the injection beam transport line.
- For MLF, x and x' of the inj. beam at the foil In the hori. direction are adjusted and fixed by two Injection septa, ISEP1,2 (DC).
- For changing painting area MLF to MR, angle (x') of the injected beam at foil is controlled by PSTR1,2 keeping its position (x) unchanged.
- SB height for MR is also increased by ~10% than MLF.
- In the vertical direction, size of the injected beam angle (y') is controlled pulse-to-pulse for MLF and MR.

# Design specification of the PSTR magnets

Purposes:

**1**. To change horizontal painting area pulse-to-pulse between MLF and MR.

**2**. No painting (center) injection in to compensate inadequate power capacity of the ISEP2 (at 400 MeV inj.).

We considered two independent as well as bipolar power supplies for each magnets.

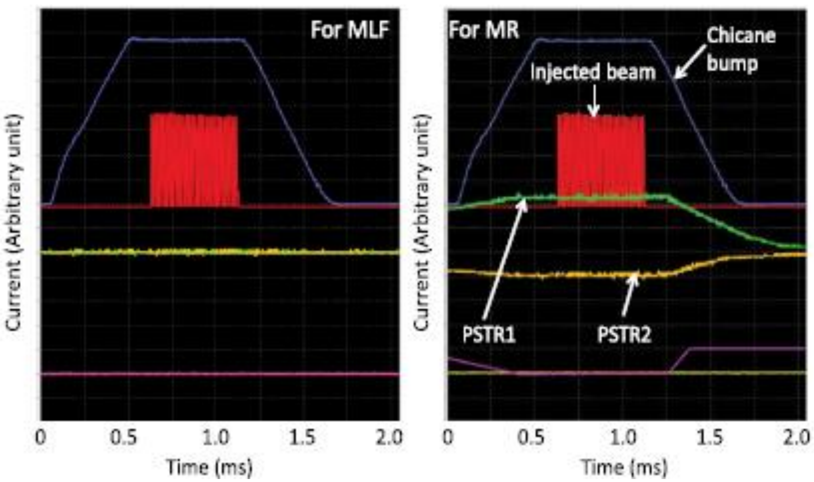
For **1**) AC PS with max **± 0.45 kA** (0.026 Tm ; 8 mrad)

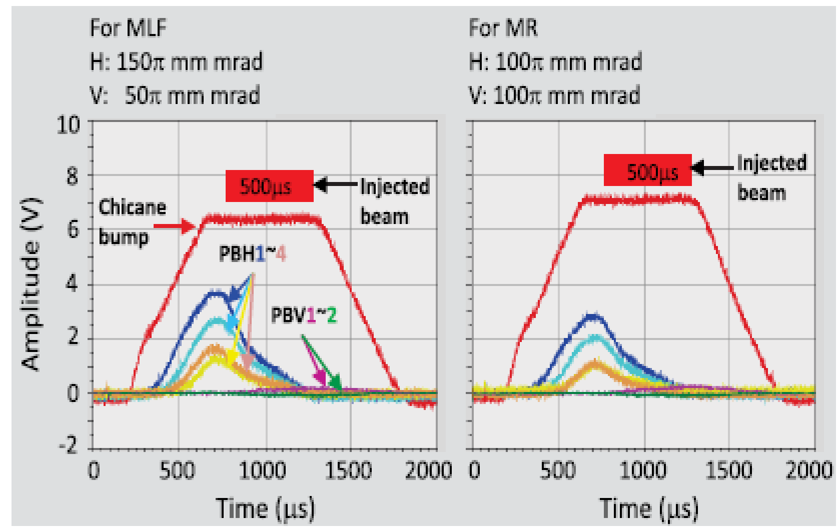
For **2**) DC PS with max **± 3.0 kA** (0.174 Tm ; 54 mrad)

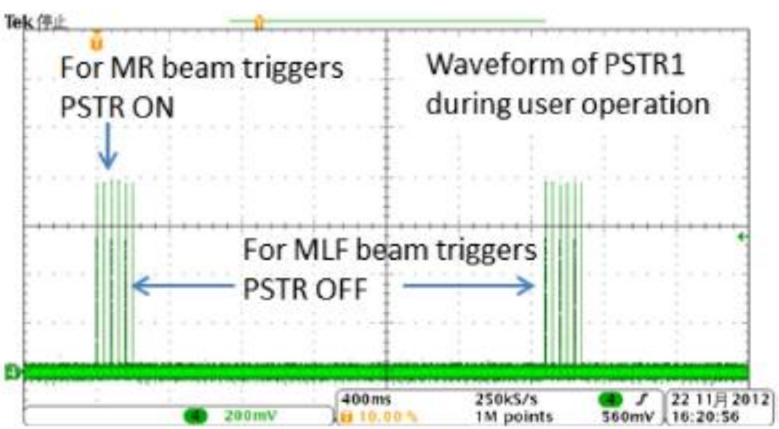
# Experimental study with PSTR magnets

Injection energy: 181 MeV
For MLF: 150π; For MR: 100π

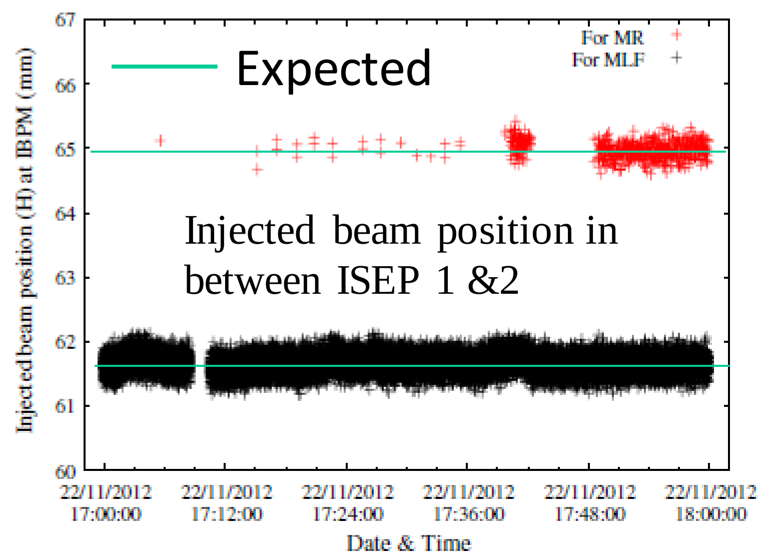
PSTR1: 33A ($-1.9\times10^{-3}$ Tm; 0.59mrad)
PSTR2: -15A ($0.86\times10^{-3}$ Tm; 0.27mrad)




PSTR1 WF online



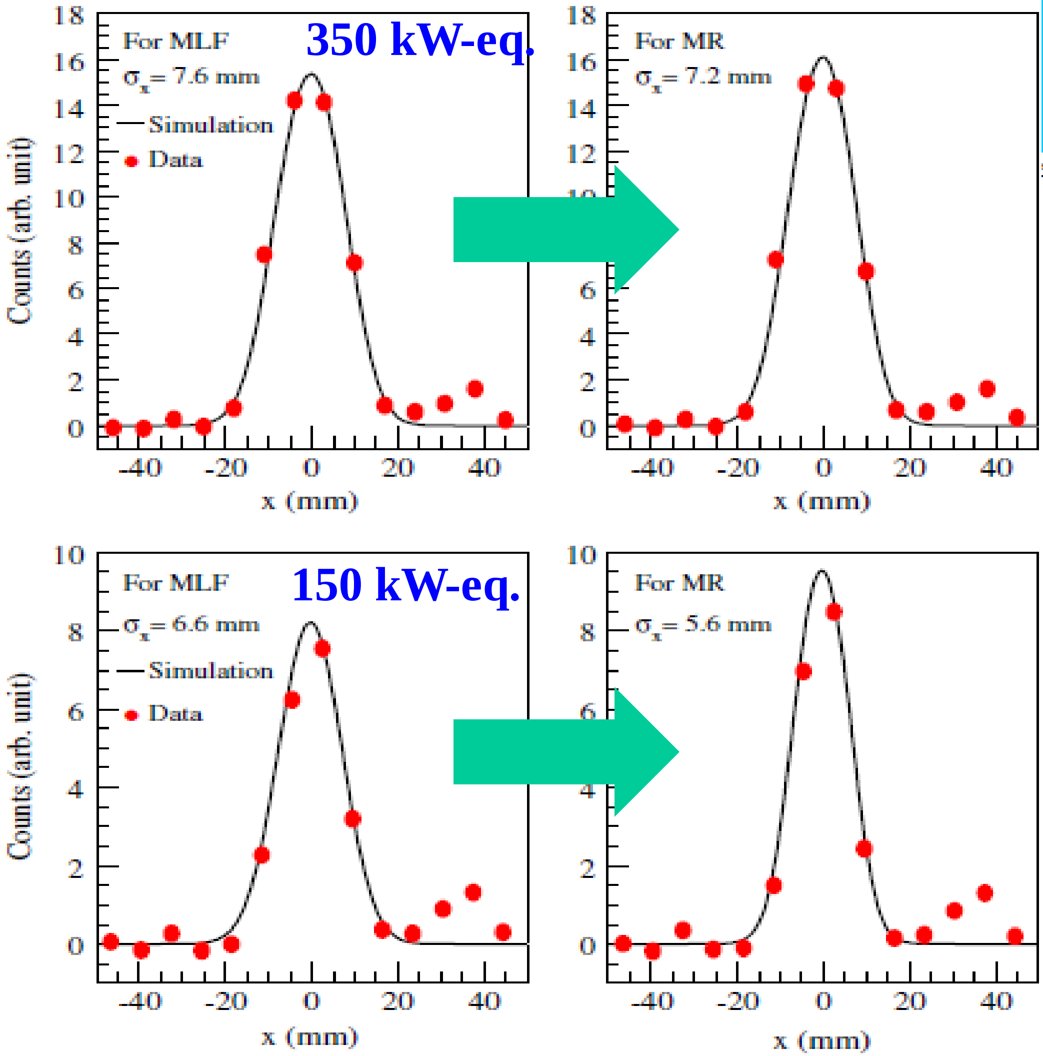
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 120102 (2013)

# Beam emittance control by changing injection painting area in a pulse-to-pulse mode in the 3-GeV rapid cycling synchrotron of Japan Proton Accelerator Research Complex

P. K. Saha,* H. Harada, N. Hayashi, K. Horino, H. Hotchi,

***Experimental demonstration of the pulse-to-pulse beam emittance control between MLF and MR***

d 9 December 2013)




The corresponding simulations were performed by using ORBIT 3-D code. The simulation results agreed well with experimental data.

**Transverse beam profiles are well controlled as expected!**

# Methods for changing painting area pulse-to-pulse

**Horizontal direction:**

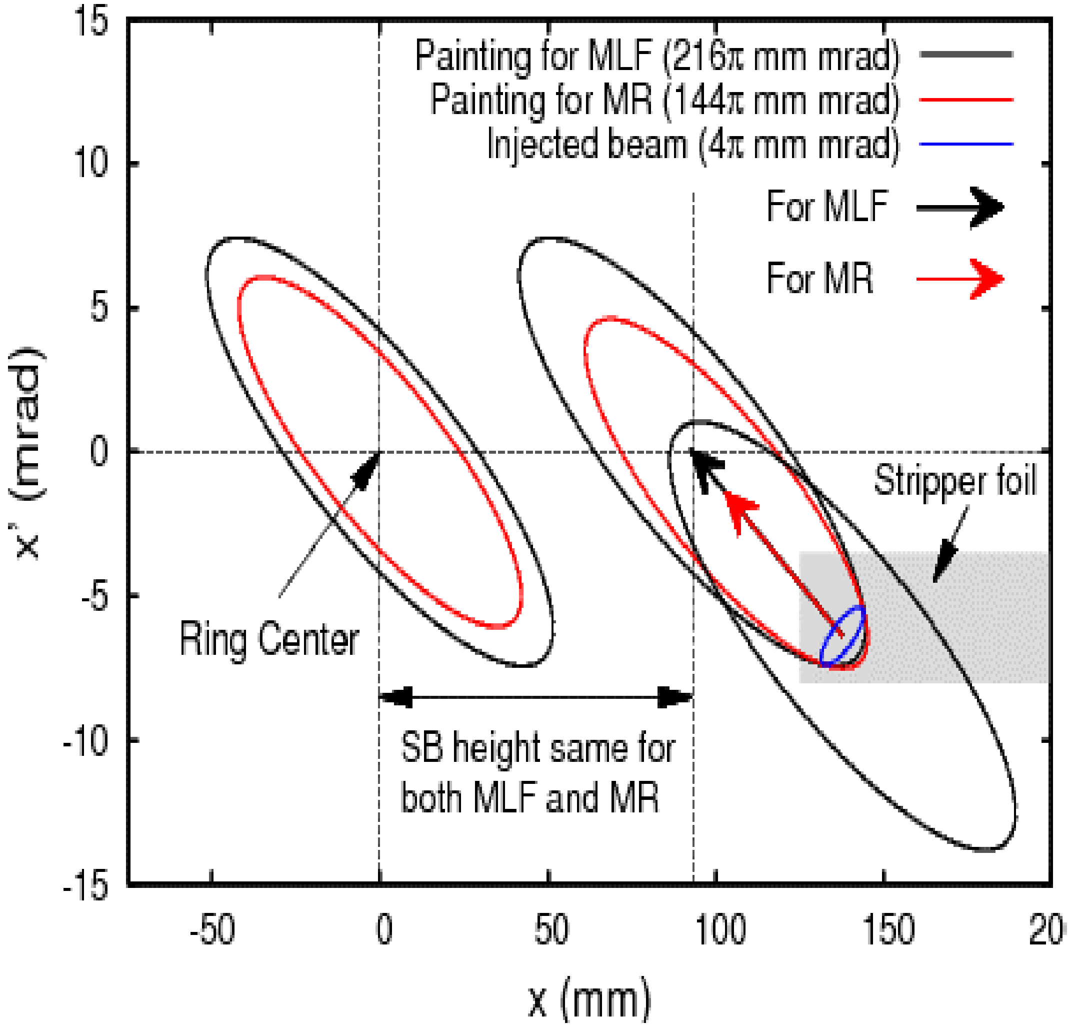
Method 1 : By using Pulse Steering magnets (PSTR1,2).
+ Horizontal painting magnets.

Method 2 : By using only Horizontal painting magnets.

**Vertical direction:**

By using vertical painting magnets.

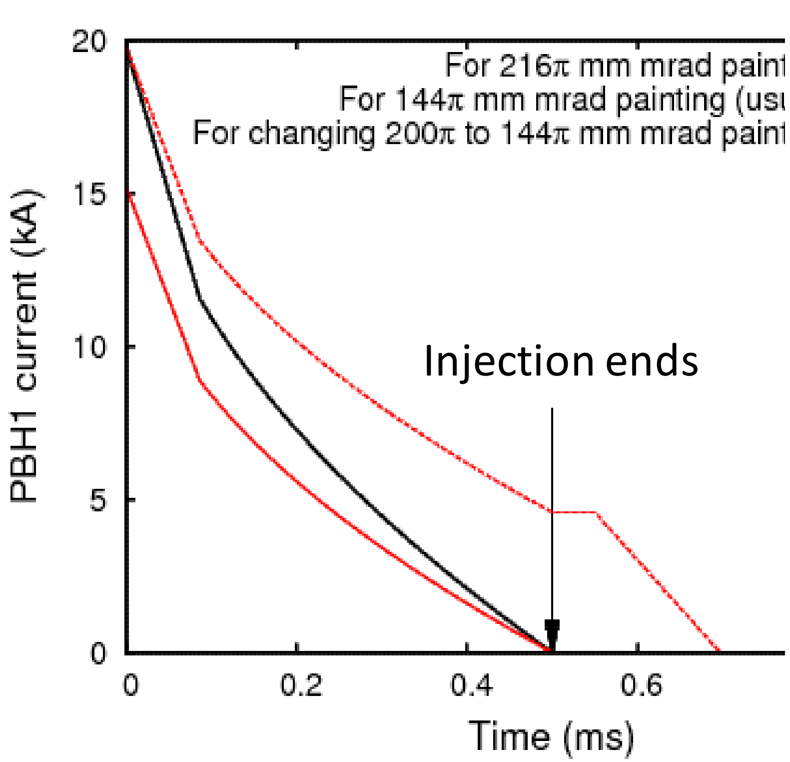
# *Method 2: Use only painting magnets for changing painting area pulse-to-pulse*

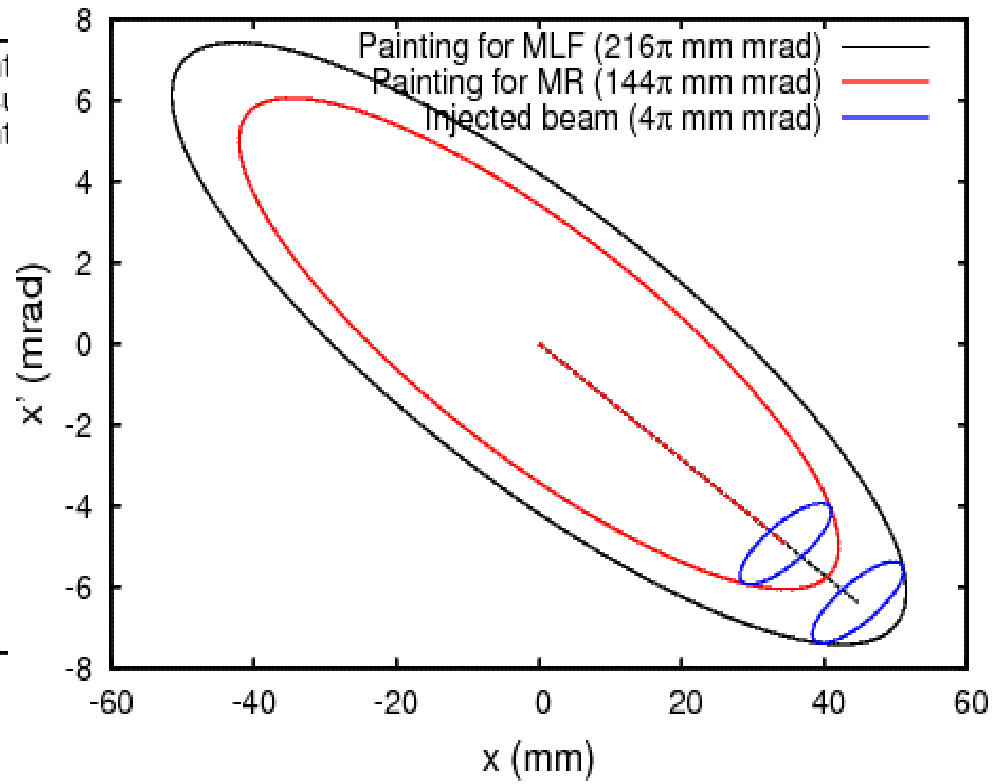



Both x and x' of the injected beam at foil is fixed for both MLF and MR.

PBH is used to control closed orbit variation for MLF and MR.

# Method 2 cont'd: PBH pattern for painting



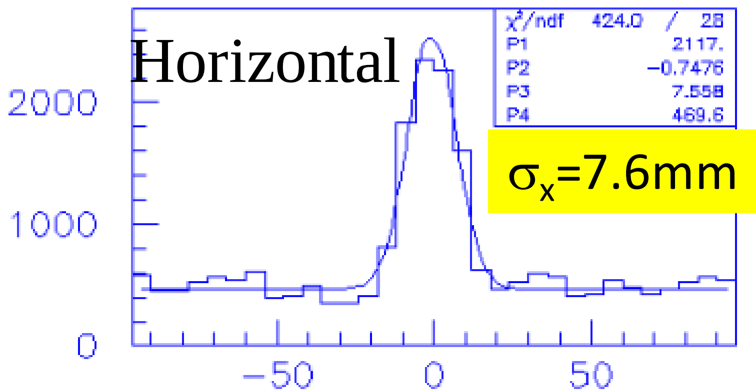

It was first tried after injection energy was upgraded to 400 MeV.
Upgraded PBHs PS now have enough margin and also better controllable.

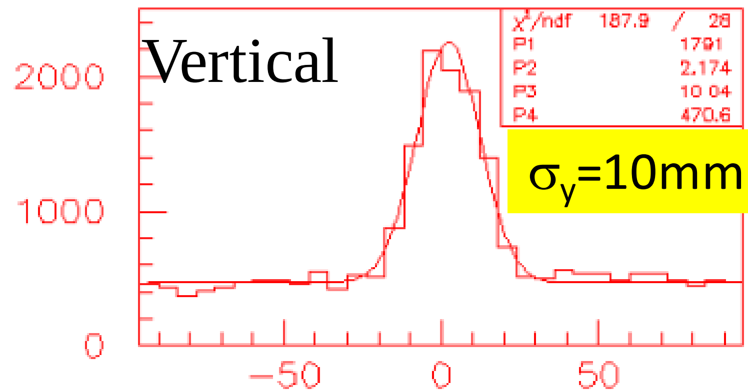
# Method 2: Experimental results

Injection: 400 MeV
Extraction: 3 GeV
Beam power: 553 kW-eq.

MWPM @ 3NBT

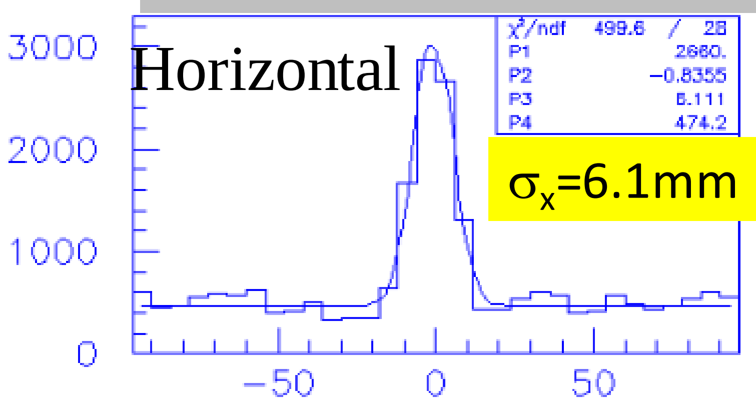
**100π mm mrad transverse painting**

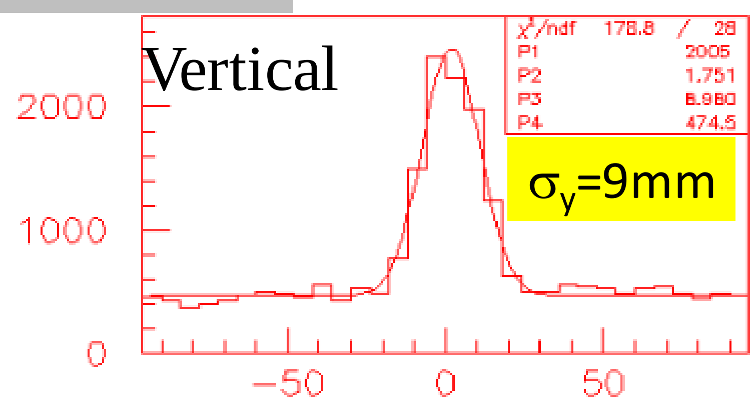



Courtesy: S. Meigo

**50π mm mrad transverse painting**

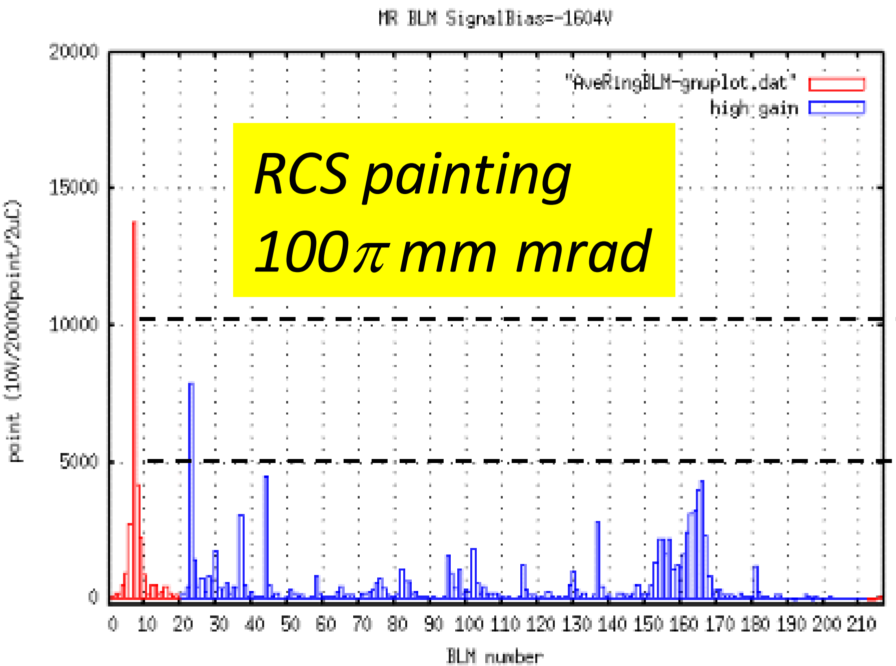


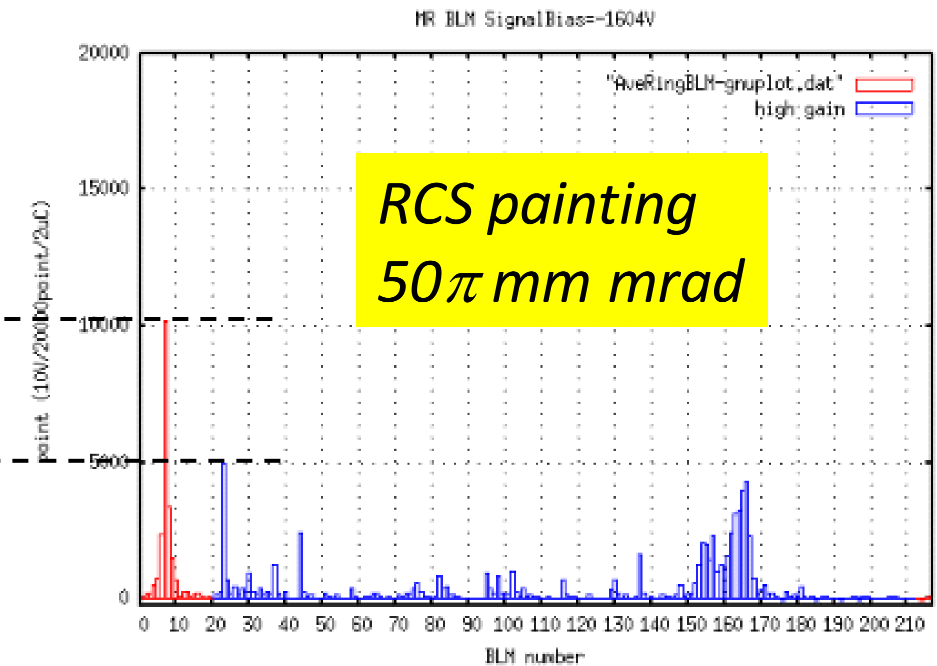




- ✓ Reduction of horizontal rms emittance ~34%
- ✓ Reduction of vertical rms emittance ~20%

# MR beam loss dependence on the RCS transverse painting

Courtesy: Y. Sato




| RCS painting | MR Power | MR Total loss |
|---|---|---|
| 100π mm mrad | 230 kW | ~250 W |
| 50π mm mrad | 230 kW | ~170 W |

**~30% loss reduction**

# Summary

- A pulse-to-pulse direct control of the injection painting emittance is considered and is also shown to be very effective for controlling extracted beam emittance in simultaneous operation.

- A reduction of 20~34% in rms emittance for the MR as compared to MLF is obtained for an equivalent beam power of 550 kW.

- Two independent methods, especially for changing painting area in the horizontal direction are considered and are also successfully applied in the real machine.

- The system is already in service with good reliability even for the present RCS operation with 300 kW beam power.