H^- Painting Injection System for the J-PARC 3-GeV High-Intensity Proton Synchrotron

I. Sakai, T. Shimada*, T. Takayanagi*, K Yamamoto*, Y. Arakida, I. Sugai, Y. Takeda, S. Machida, F. Noda*, K. Shigaki*, Y. Watanabe*, Y. Ishi **, T. Kawakubo, Y. Irie,
KEK, Tsukuba, *JAERI, Tokai, ** MELCO, Kobe; JAPAN

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- Introduction
- Design Parameters
- Injection System
- Hardwares
- Summary

Introduction

- The J-PARC Project accelerator complex

  180-MeV Linac (First Stage),
  400-MeV Linac (Second Stage)
  3-GeV rapid-cycling synchrotron
  50-GeV main synchrotron

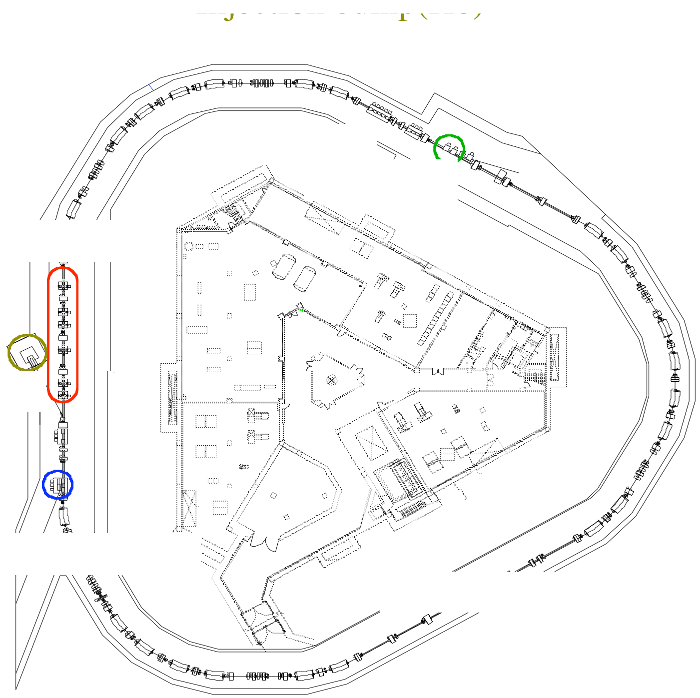
- RCS (3-GeV Rapid-Cycling Synchrotron)

  8.3×10^{13} protons per pulse for 400-MeV Injection
  25 Hz repetition rate
  The hardware of the 3-GeV ring is designed to accept 400-MeV injection beams

- Injection System

  The system is designed to fit the FODO structure.
  A full-acceptance bump orbit will enable both correlated and anti-correlated painting injection.

Outline of the 3GeV Rapid Cycling Proton Synchrotron



- Three-fold symmetric lattice
- DOFO structure
- Each super-period consists of 9DOFO
- Two 3DOFO modules with a missing bend
- 3DOFO modules in insertion straights
- The FODO structure requires modest quadrupole gradients.
- The alternating transverse beam amplitude easily accommodates correction systems,
- But lacks a long uninterrupted drift space for flexible injection.

Parameters for the painting injection

- Linac and its transport line
  After Collimation 4π mm mrad

- The painting emittance
  For 180-MeV injection 216π mm mrad
  For 400-MeV injection 216π mm mrad for 3GeV facilities
  144π mm mrad for 50GeV ring injection.

- The collimater acceptance 324π mm mrad.

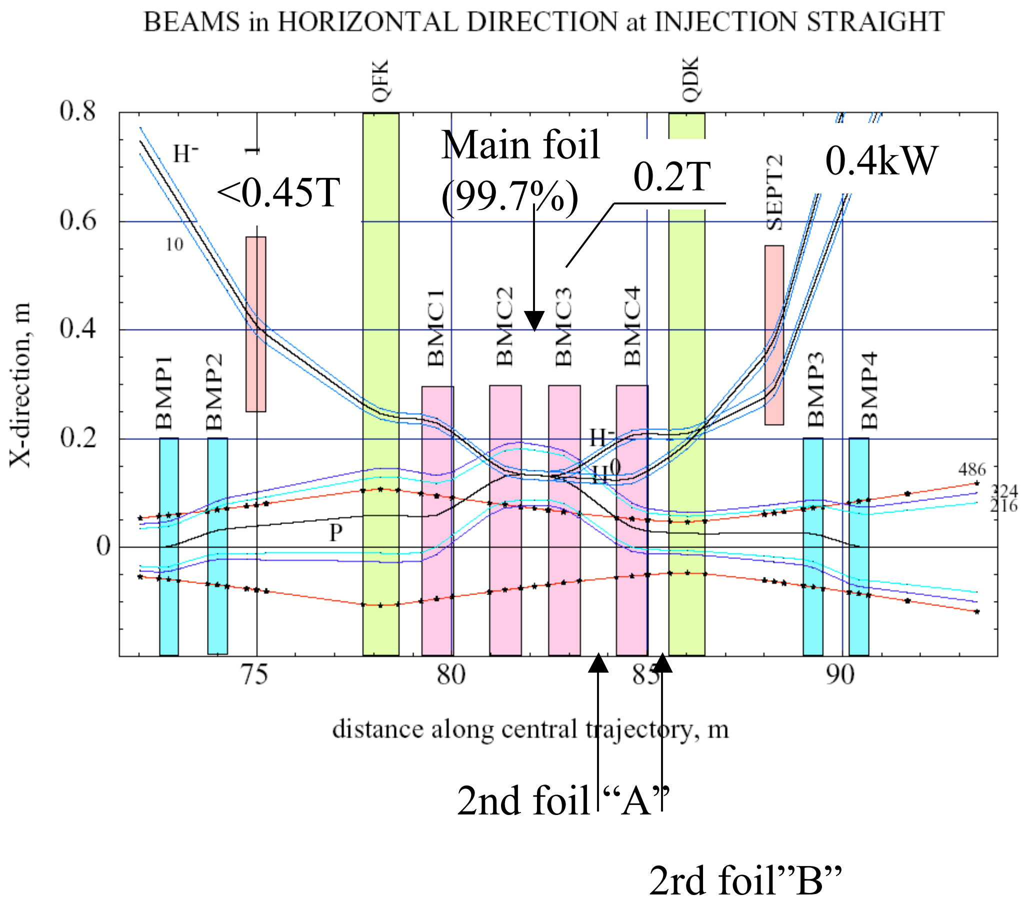
- The machine acceptance 486π Mm mrad.

- The ring will be filled with 308 turn H- foil-stripping charge-exchange injection in 500ms.
- The 500ms pulses from the Linac containing 8.3 x 10^{13} protons will be injected to two-bunch RF buckets in the ring.

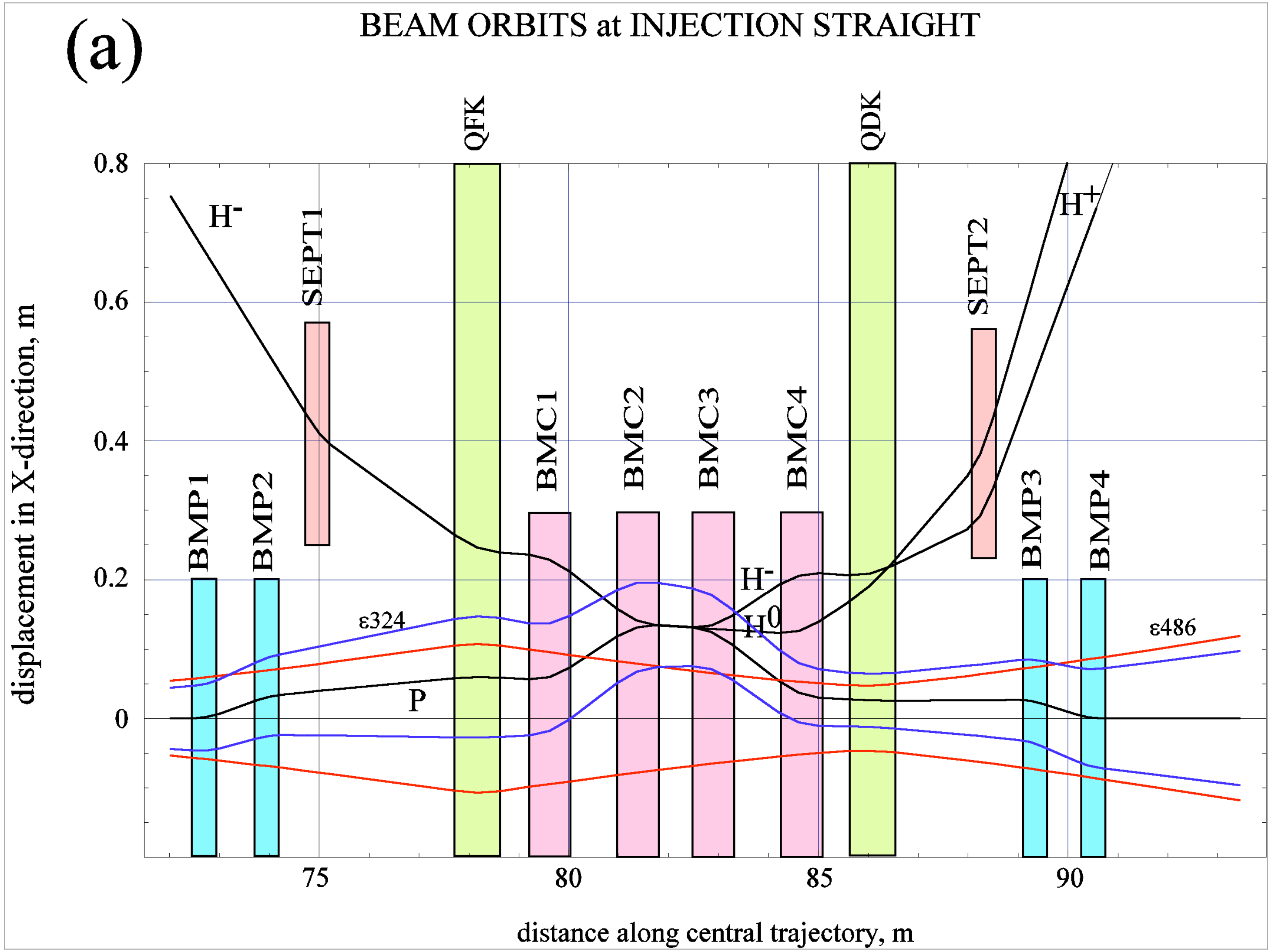
Injection beam line (Horizontal)

- Injection line
  - Lorentz stripping loss
    - 0.14W/m (B<0.45T)
  - H0,H- beam
    - 0.4kW (exchange efficiency 99.7%)
  - Excited H0 loss
    - 5.5W (n≥6)

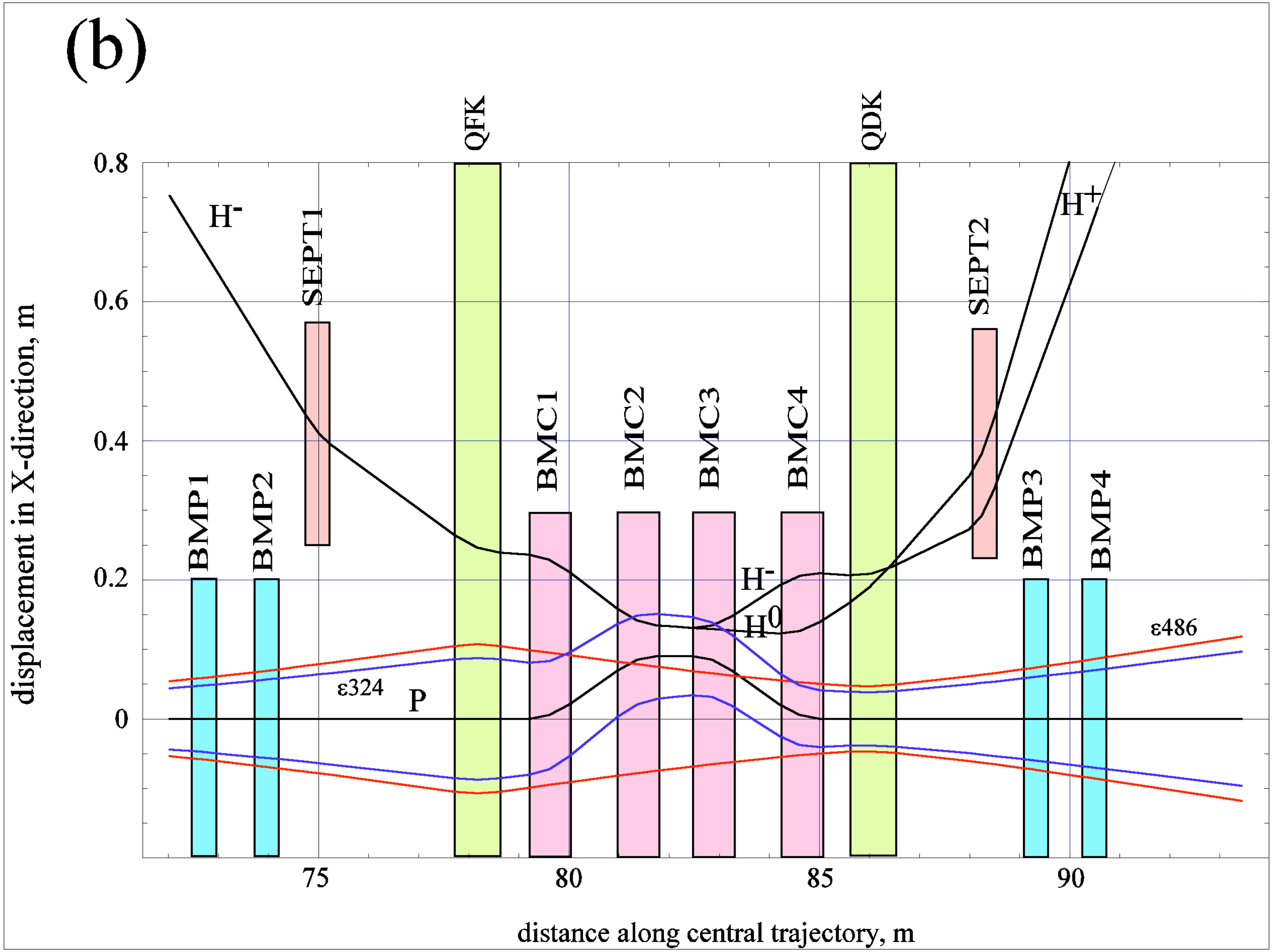
- H^- beam and H^0 beam are exchanged to H^+ beam by two 2nd foils "A&B"
  - Lead to beam dump
  - 0.4kW



Schematic Layout of Beam Orbit at Painting Injection Start

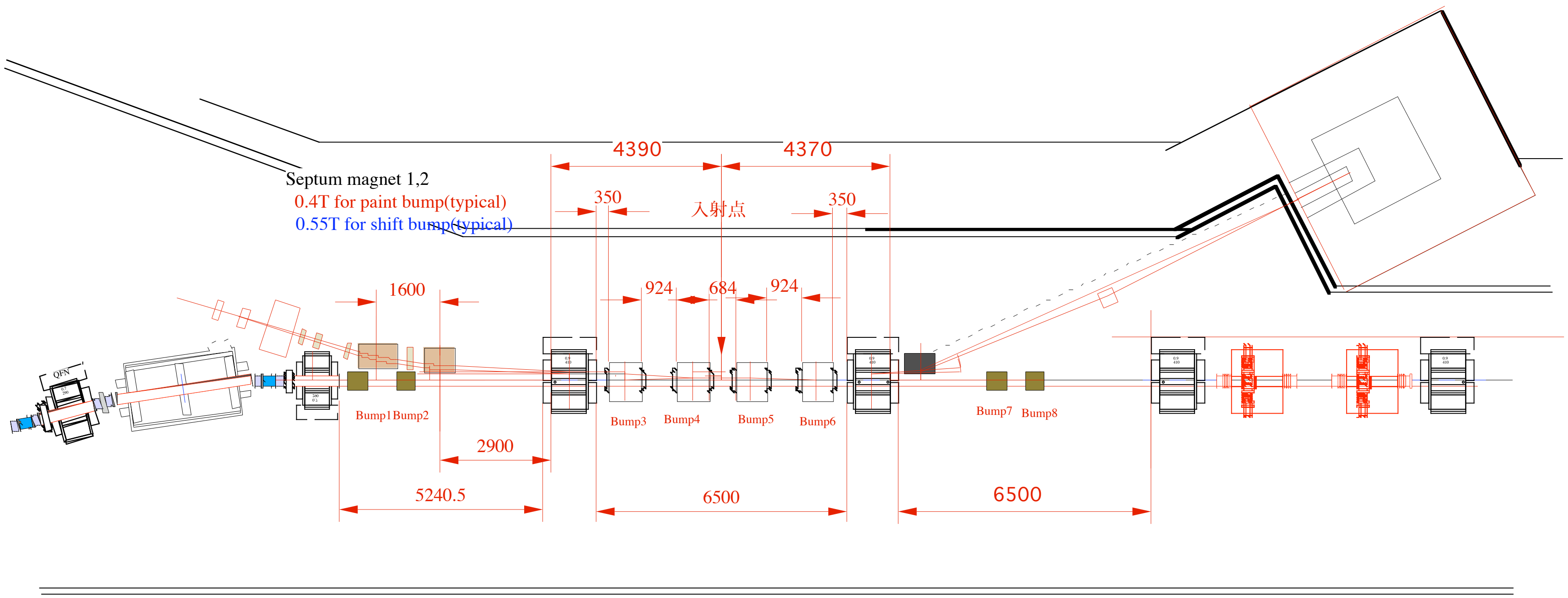


Schematic Layout of Beam Orbit at Painting Injection End

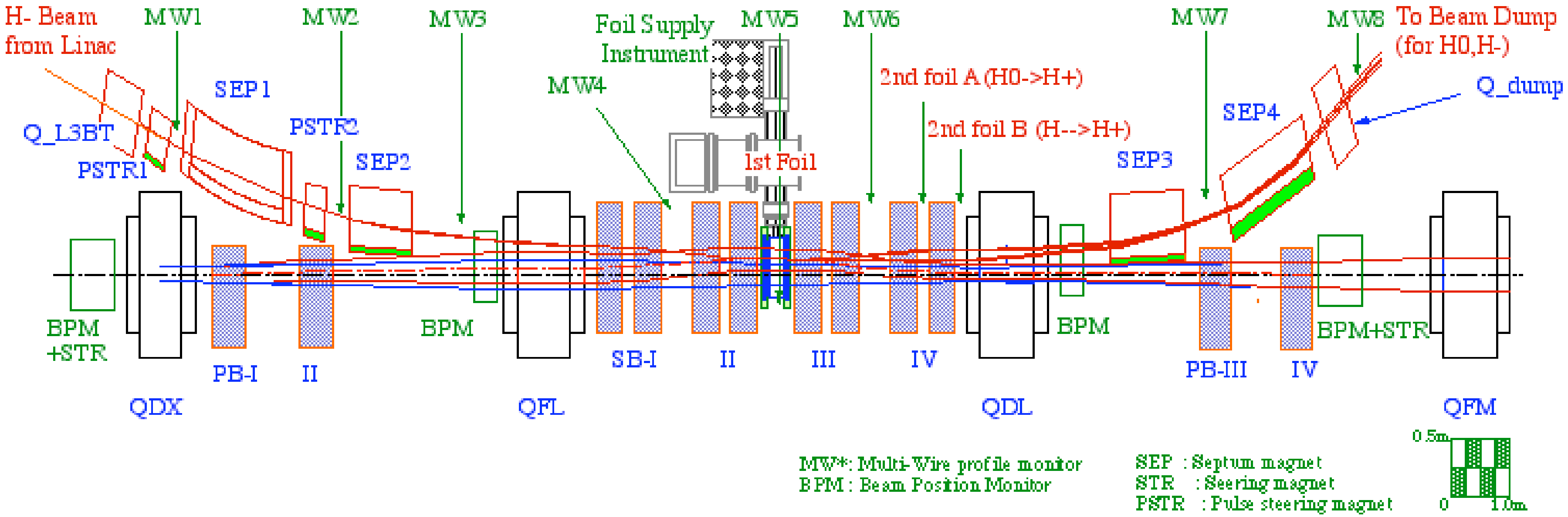


Outline of the Injection System

1/150

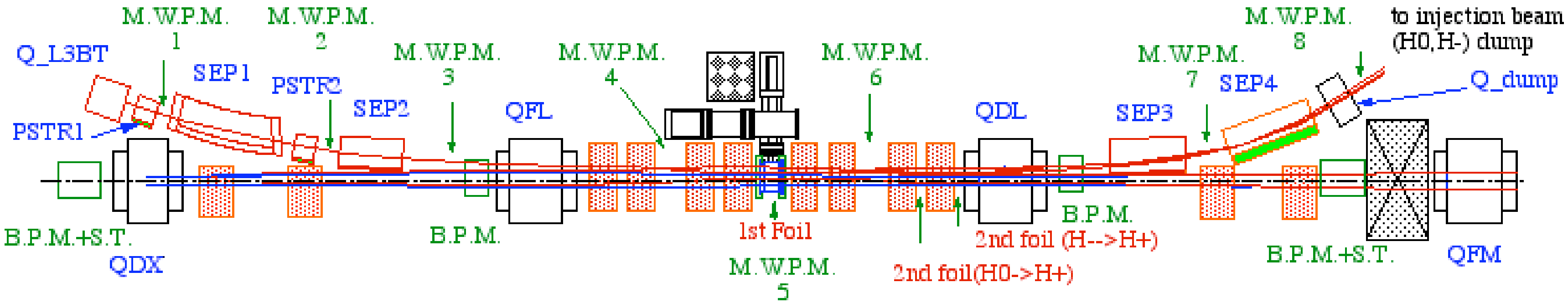


H- Painting Injection System for the J-PARC 3GeV High Intensity Proton Synchrotron



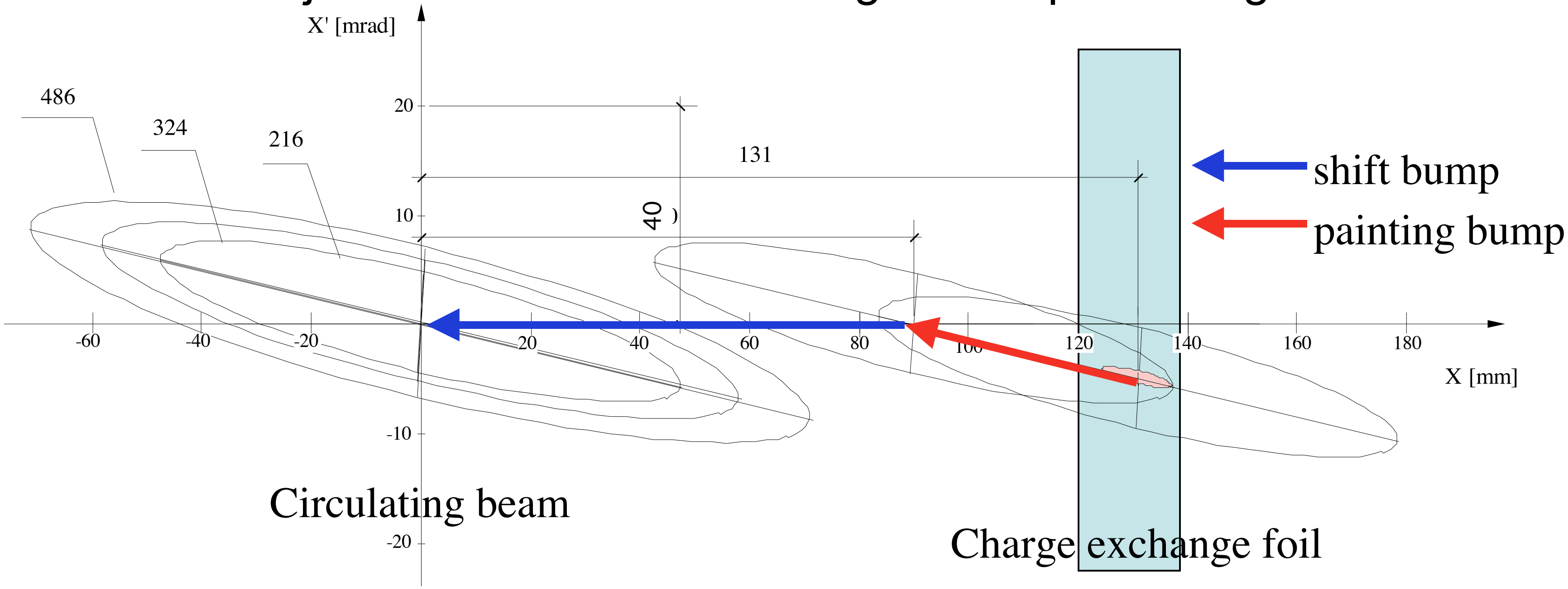
- The injection system is designed to be constructed in the FODO structure, which has rather short drift space.
- The bump orbit for painting injection has a full acceptance for the circulating beams.
- The H- injection line and the H0,H- disposal lines can be designed so as to have a sufficient acceptance for low-loss injection
- The painting area is optimized for both 3-GeV users and 50-GeV users in a pulse-to-pulse mode operation.

H- Painting Injection System for the J-PARC 3GeV High Intensity Proton Synchrotron in Real Scale

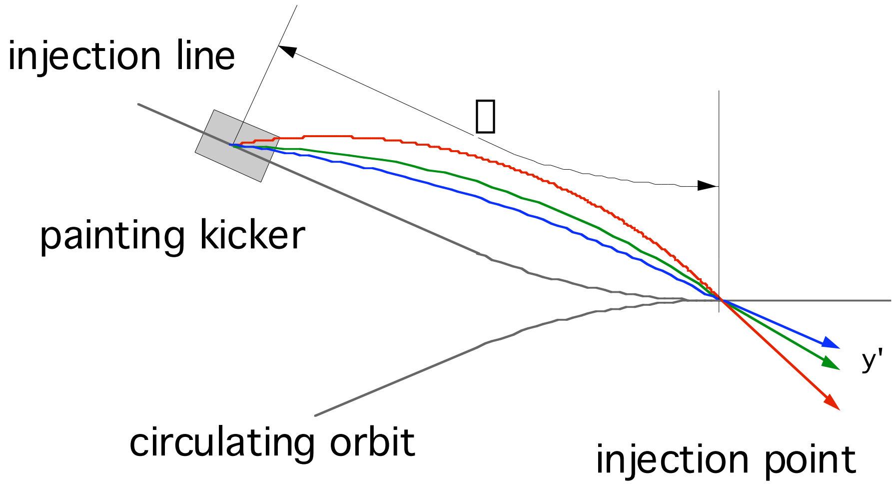


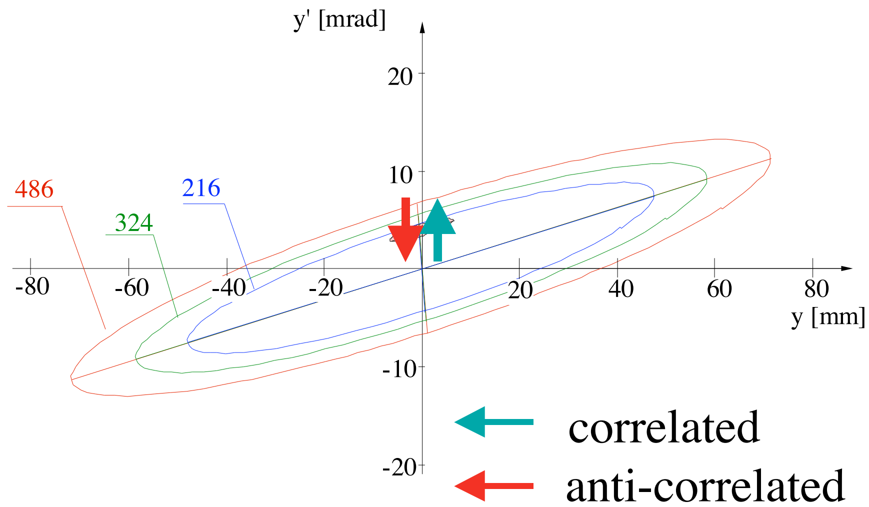
[Real Scale]

- ***Horizontal painting area***
  - correlated painting or anti-correlated painting
  - for 3GeV users or for 50GeV MR ---within one cycle(20ms)
  - beam study
- ***Changing painting area***
  - Shift bump and painting bump are changed
  - x' of injection beam can be changed with pulse magnets



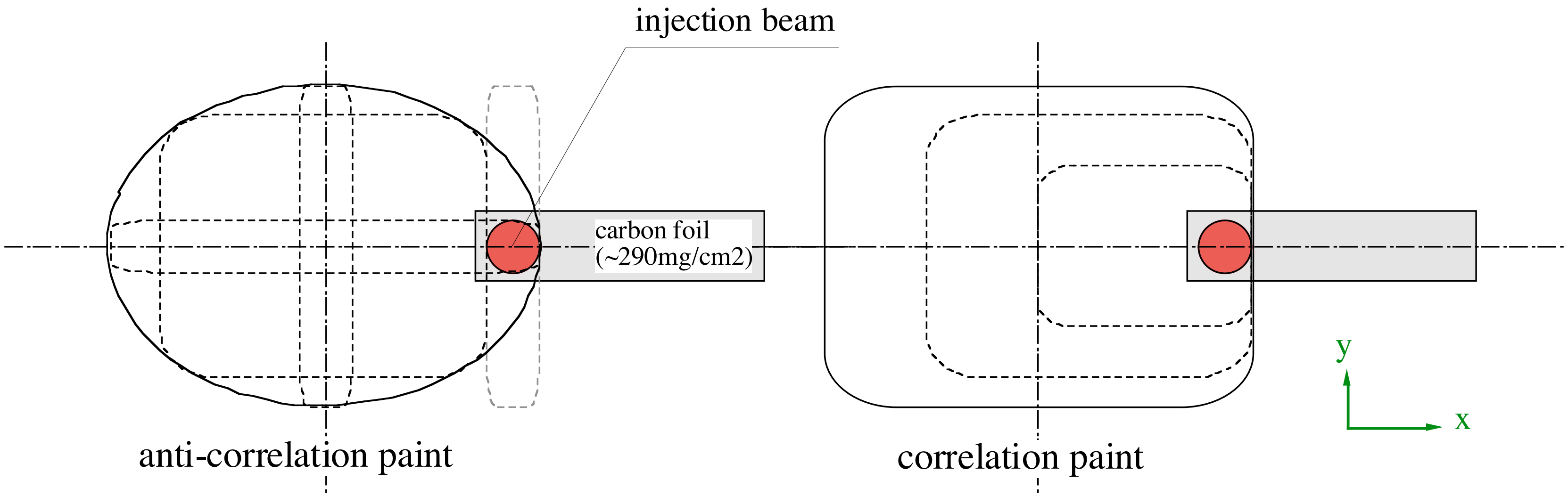
- ***Vertical painting :painting kicker magnet***
  - Correlated painting:center to outside
  - Anti-Correlated painting:outside to center
- ***y' depends on the field of kicker magnet, and y is constant(=0)***
  - Charge exchange foil is smaller, so foil hitting probability is reduced





Anti-correlation and correlation painting
-real space-

Emittance of painting area is 216π.mm.mrad.



Examples of painting simulation
(anti-correlated)

- Painting functions

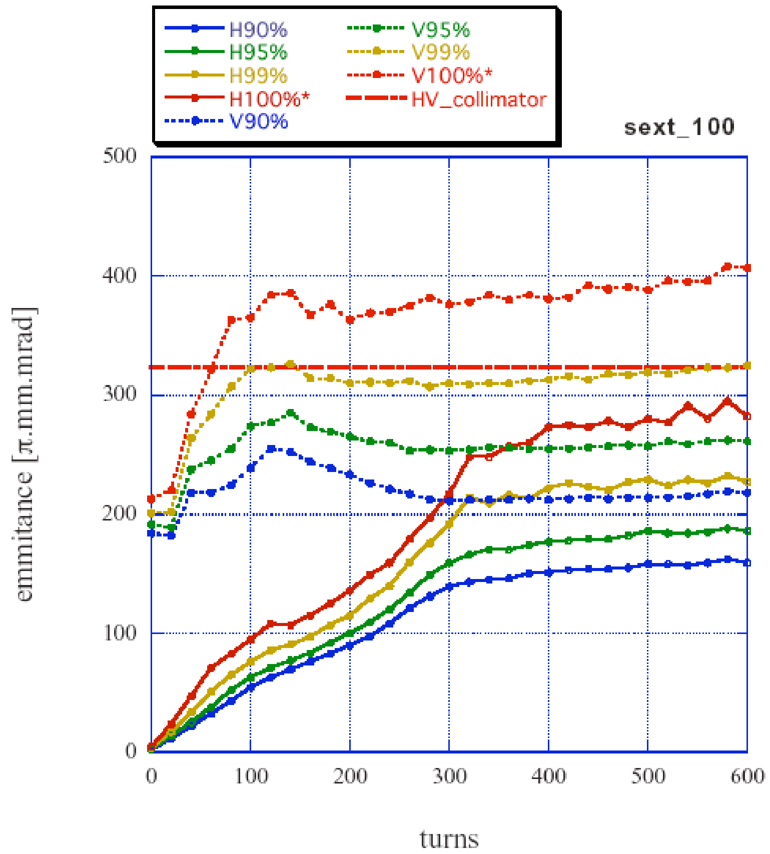
$$x = 91 + 41\sqrt{1 \square \, t/T} \ [mm]$$

$$x' = 5\sqrt{1 \square \, t/T} \ [mrad]$$

$$y' = 4\sqrt{t/T} \ [mrad]$$

  - n/□is ideally constant

- Time dependence of emmitance containing 90,95,99,100% particles is shown
  - not including longitudinal effect
- Collimator aperture is 324□.mm.mrad
  - movable



Examples of painting simulation (correlated)

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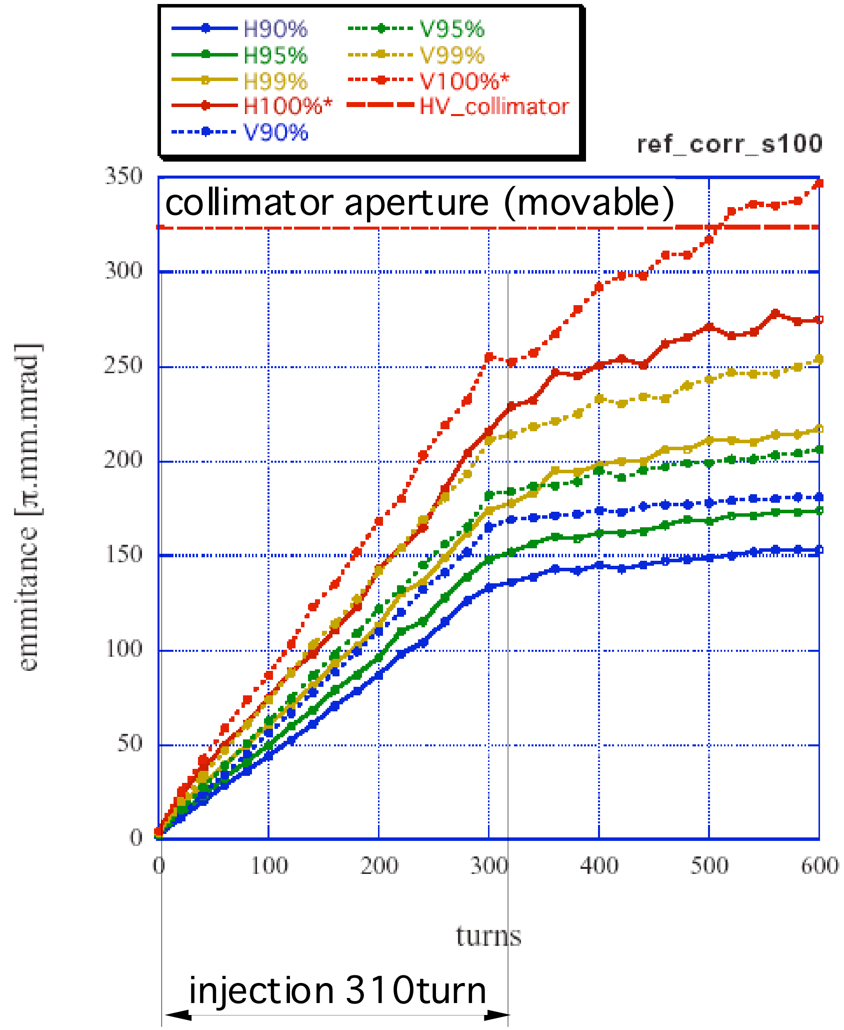
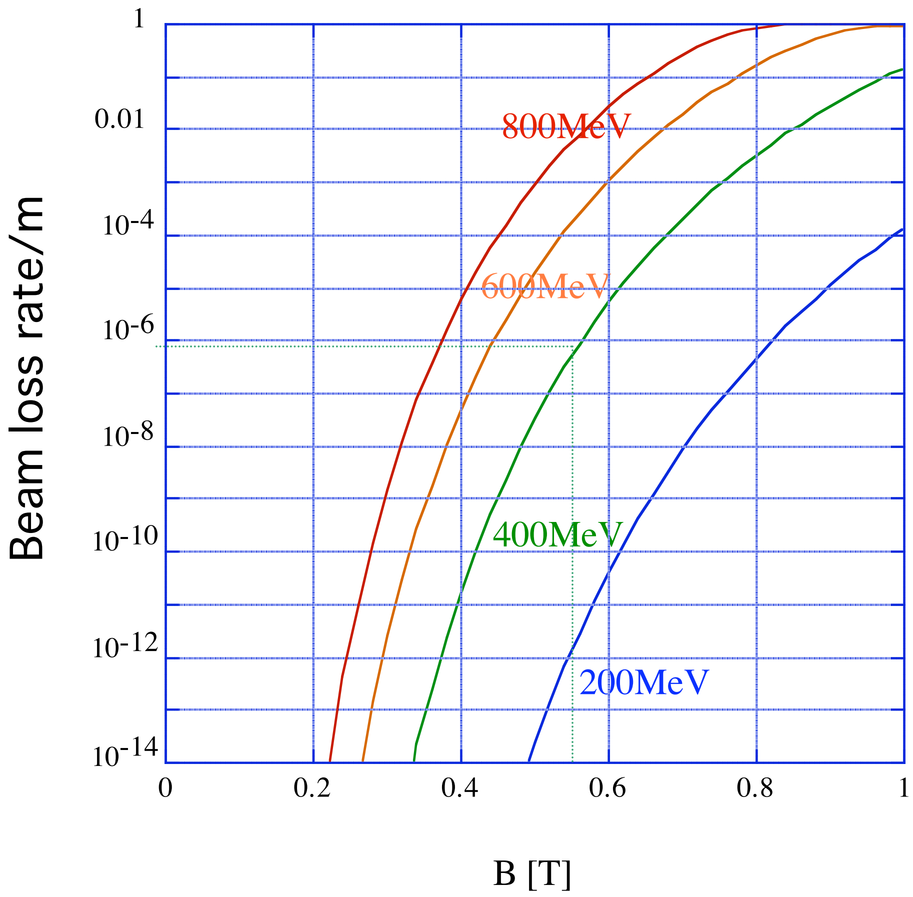


Lorentz stripping

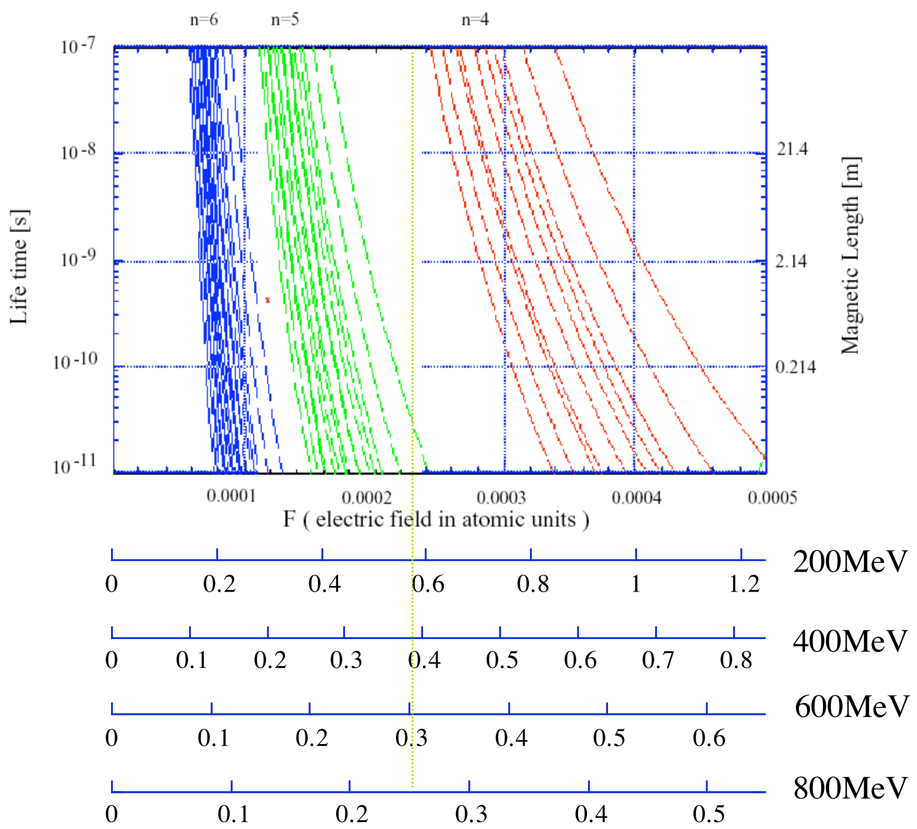
- Binding energy of second electron is about 0.754eV
  - It's very weakly bound
  - H^- ion is converted to a H^0 atom with Lorentz force in an electromagnetic field
- H- ion with velocity βc in a transverse magnetic field B

$$beam\ loss\ rate = 1 - \exp\left(-\frac{t}{\gamma\tau}\right)$$



Interaction with charge exchange foil (2) Excitation of H^0 atom

- Residual H^0 atom is excited to n^{th} level by interaction with foil. (*n* is the principal quantum number)
- Excited H^0 decays in electromagnetic field
- lifetime depends on both electromagnetic field and excited level
- total yield n≥m



DESIGN OF THE MAGNETIC FIELD

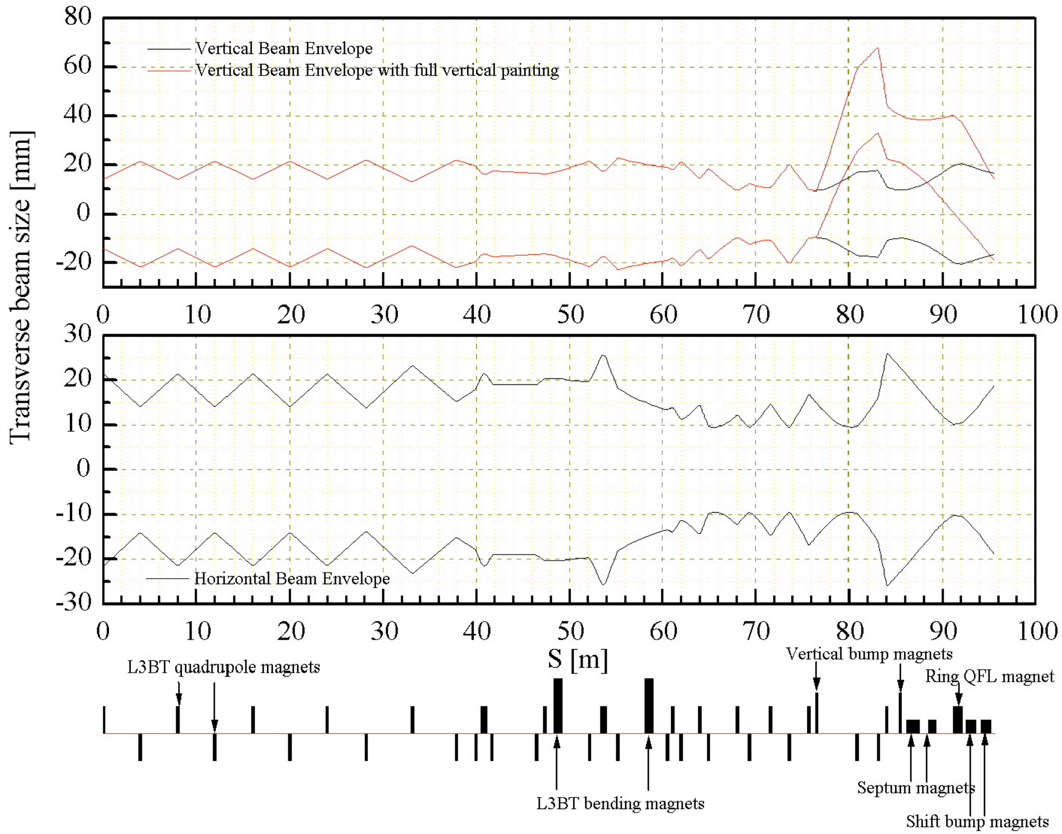
(For 400-MeV Injection)

- In the upstream of the stripping foil
  The maximum magnetic field is estimated to be <u>0.55 T</u>
  The beam loss rate is less than 10^{-6}
  The injection beam power is 133 kW
  Losses by Lorentz stripping is less than <u>1.3 W</u>

- In the downstream of the stripping foil
  The magnetic field of the bump magnet is set to be about <u>0.2 T</u>.
  Excited H^0 with a principal quantum number of $n \geq 6$ becomes the uncontrolled beam
  Yield of $n \geq 6$ is 0.0136
  The total H^0 beam power is 0.4 kW
  The maximum uncontrolled beam loss is about <u>6 W</u>

The magnetic field at the foil is designed to be less than the value at which the bending radius of the stripped electrons is larger than 100 mm.

DESIGN OF THE H^- INJECTION LINE AND H^-, H^0 DISPOSAL LINES



- Any other focusing magnets can not be inserted in the injection area which has a length of 20 m.
- The beam needs to be injected vertically off center for vertical painting.
- Designed to be insensitive to space-charge effect.
- Simulation results estimate that the space charge effect is not much of a problem under the designed bunch lengthes of 400 MeV and 180 MeV injection.