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

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ï Introduction

ï Design Parameters

ï Injection System

ï Hardwares

ï 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

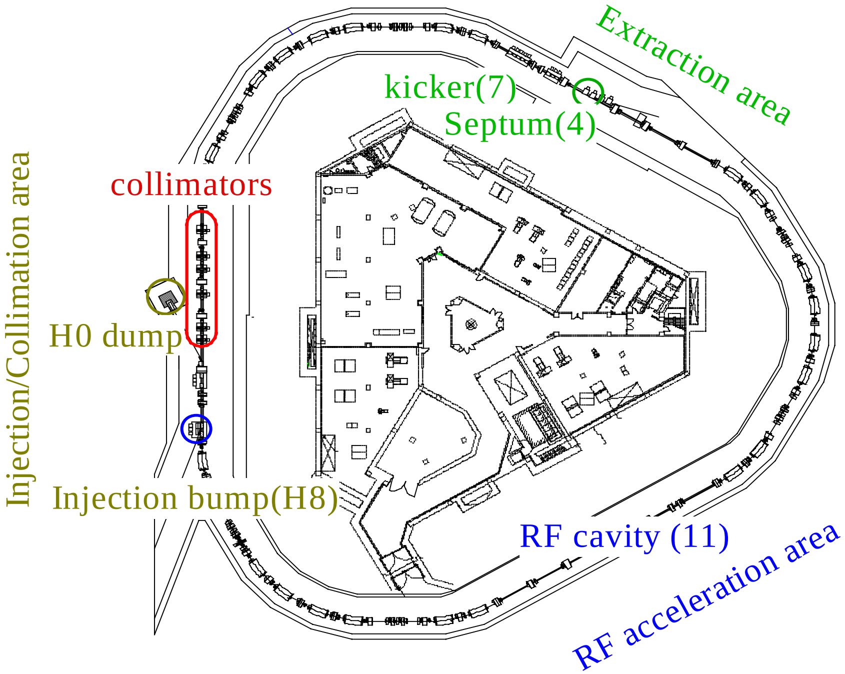
- RCS (3-GeV Rapid-Cycling Synchrotron)

  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

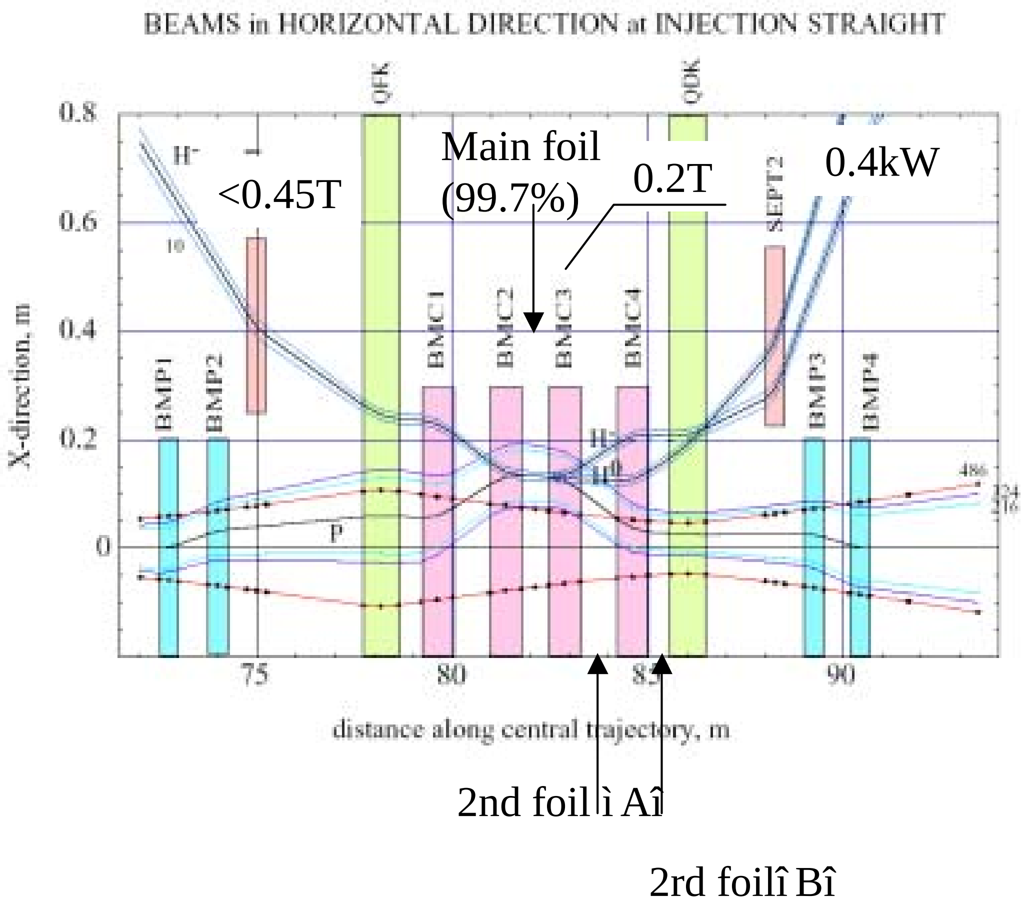
- ï Linac and its transport line
  - After Collimation 4π mm mrad
- ï The painting emittance
  - For 180-MeV injection 216π mm mrad
  - For 400-MeV injection 216π mm mrad for 3GeV facilities
  - 144π mm mrad for 50GeV ring injection.
- ï The collimater acceptance 324π mm mrad.
- ï The machine acceptance 486π Mm mrad.

- ï The ring will be filled with 308 turn H- foil-stripping charge-exchange injection in 500ms.
- ï 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)

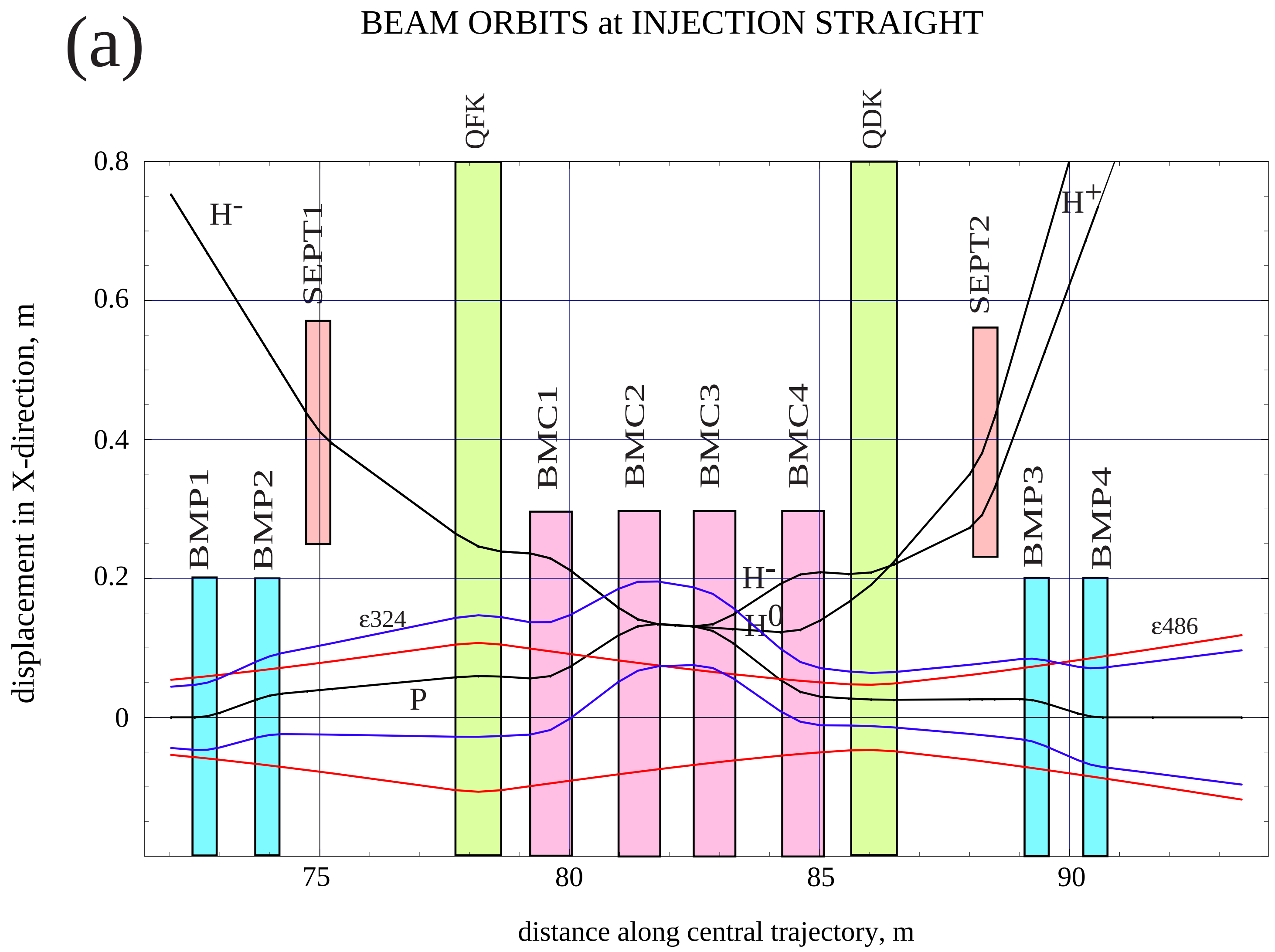
- Injection line
  - Lorentz stripping loss
    - 0.14W/m (B<0.45T)
  - H0,H- beam
    - 0.4kW (exchange efficiency 99.7%)
  - Excited H0 loss
    - 5.5W (n≥6)

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



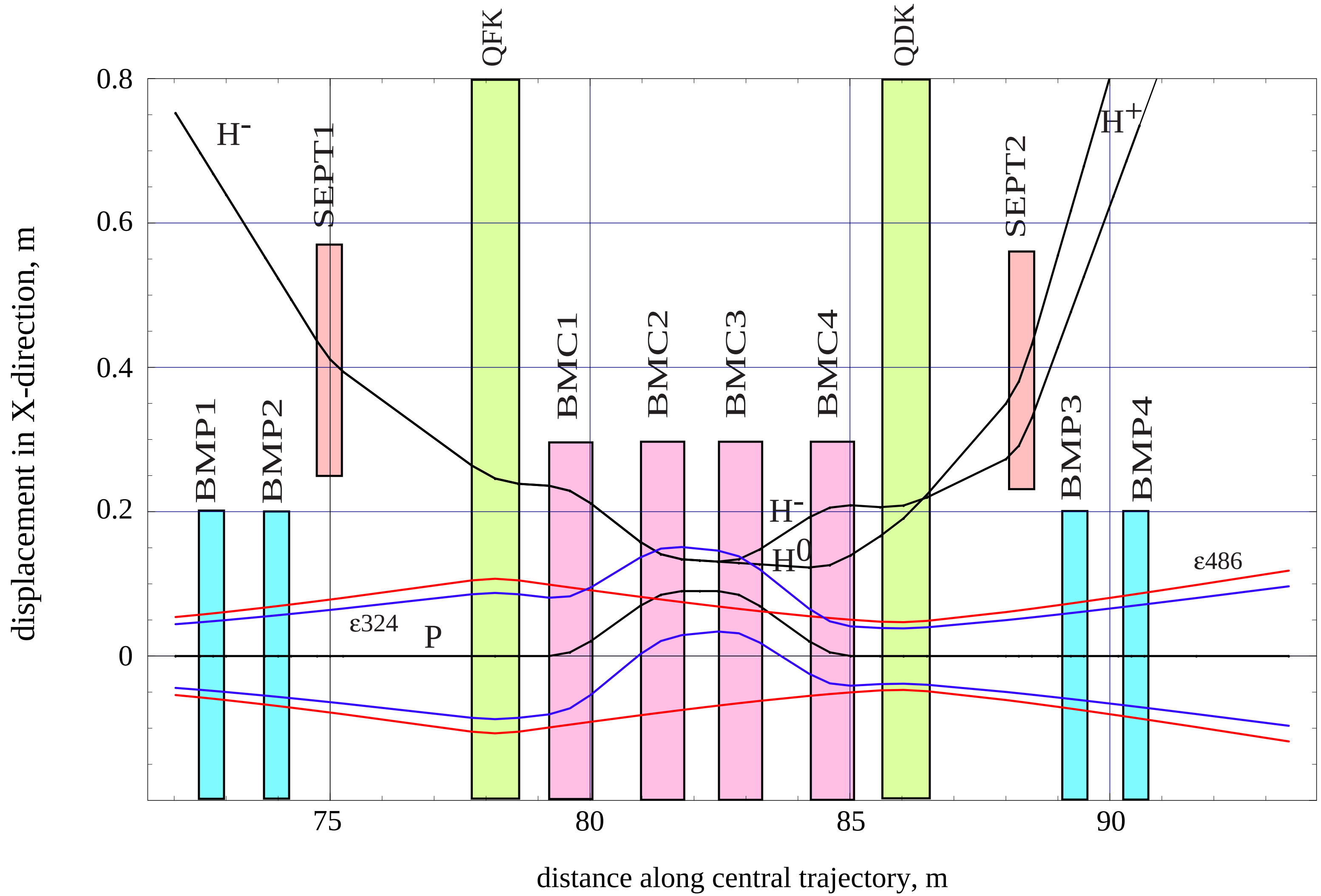
Schematic Layout of Beam Orbit at Painting Injection Start

(a)



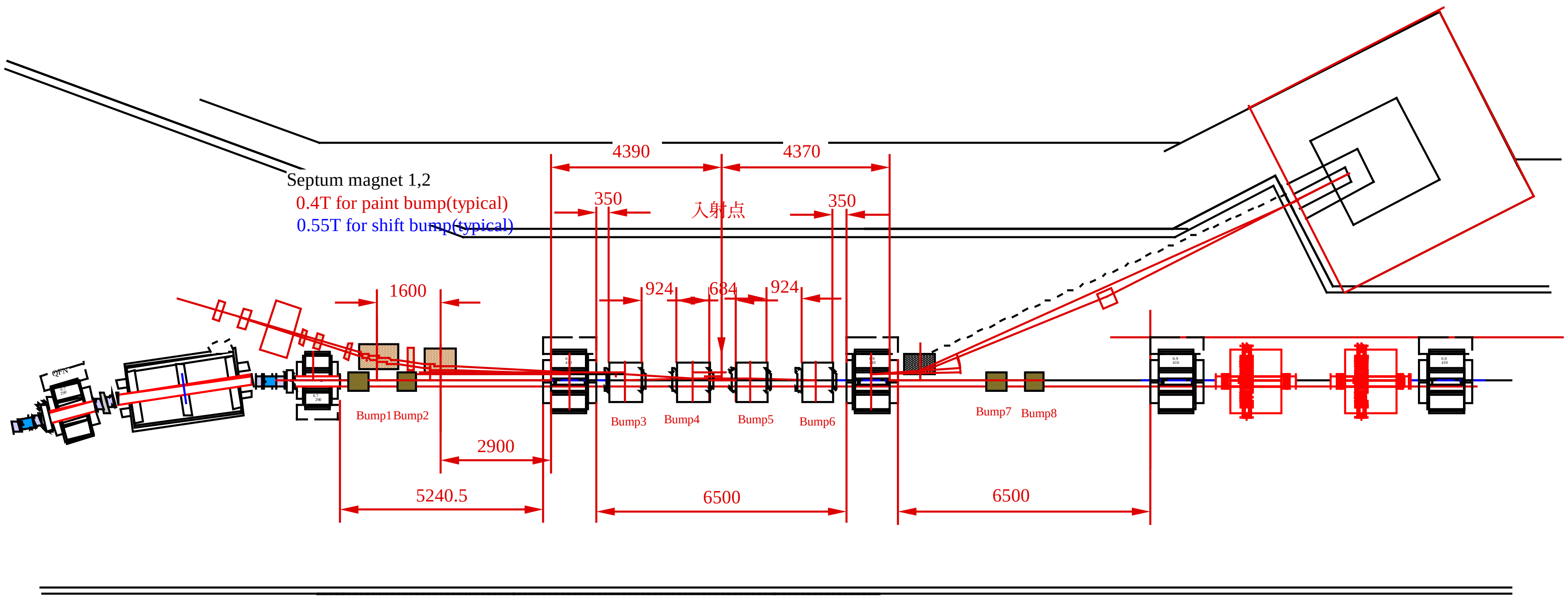
Schematic Layout of Beam Orbit at Painting Injection End

(b)



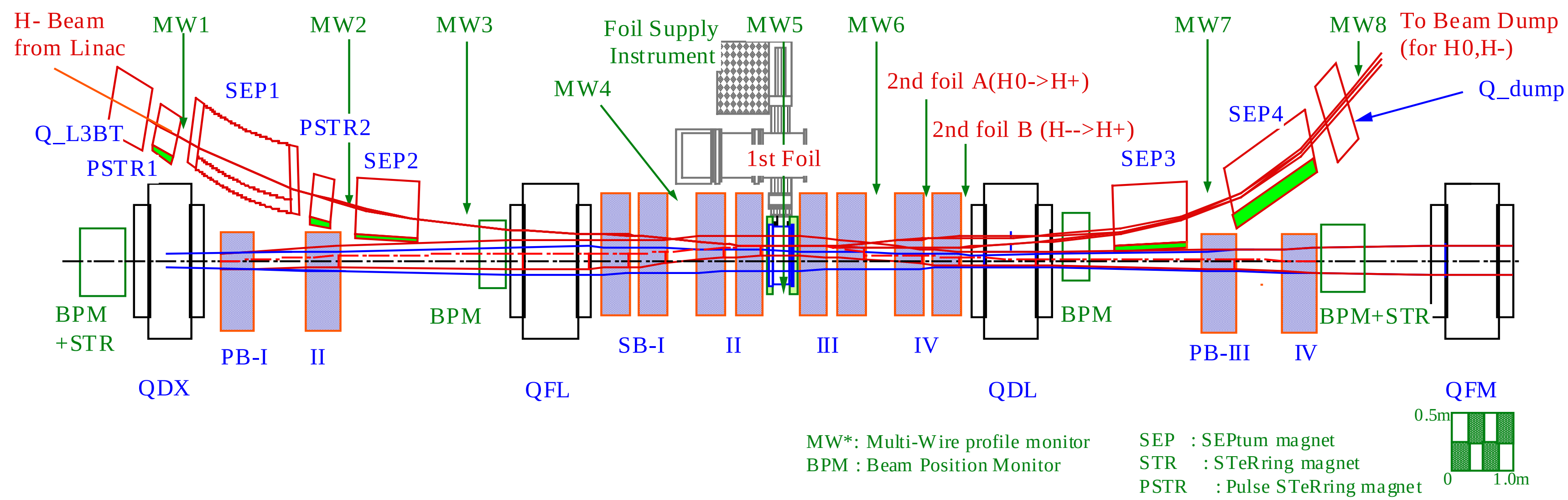
Outline of the Injection System

1/150



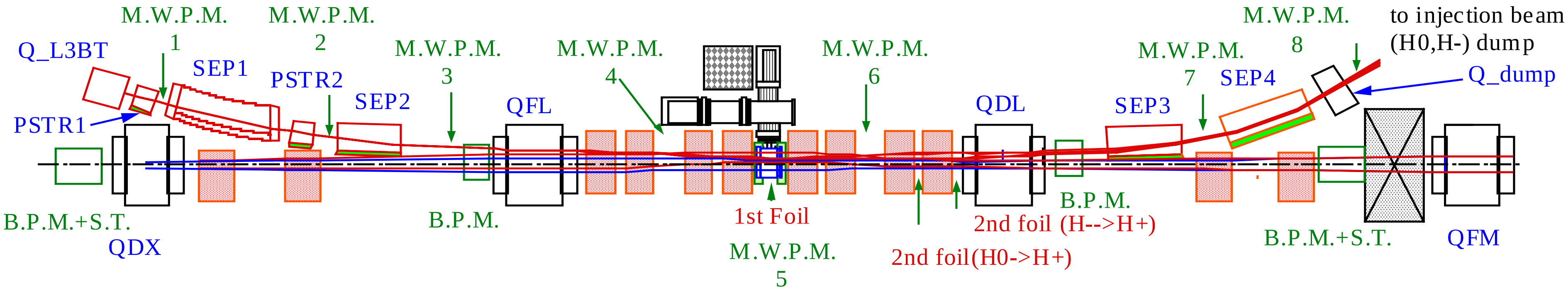
H- Painting Injection System for the J-PARC

3GeV High Intensity ProtonSynchrotron



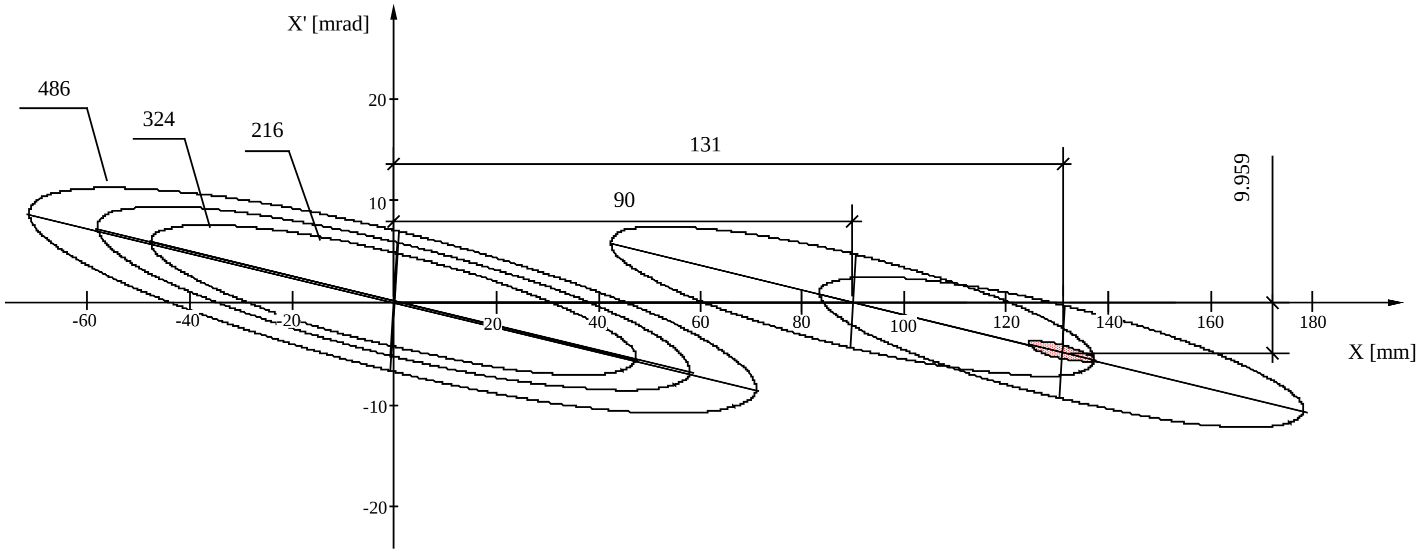
- The injection system is designed to be constructed in the FODO structure, which has rather short drift space.
- The bump orbit for painting injection has a full acceptance for the circulating beams.
- The H- injection line and the H0,H- disposal lines can be designed so as to have a sufficient acceptance 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

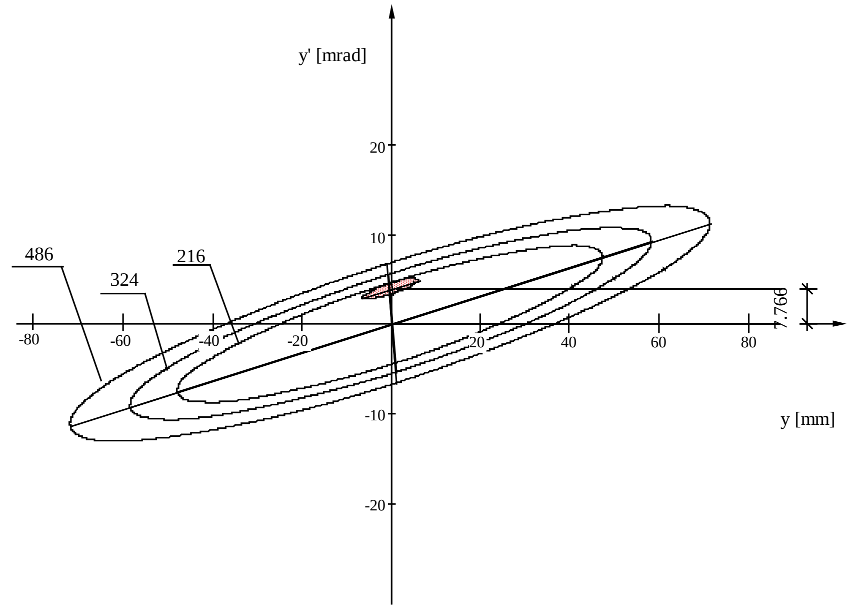


[Real Scale]

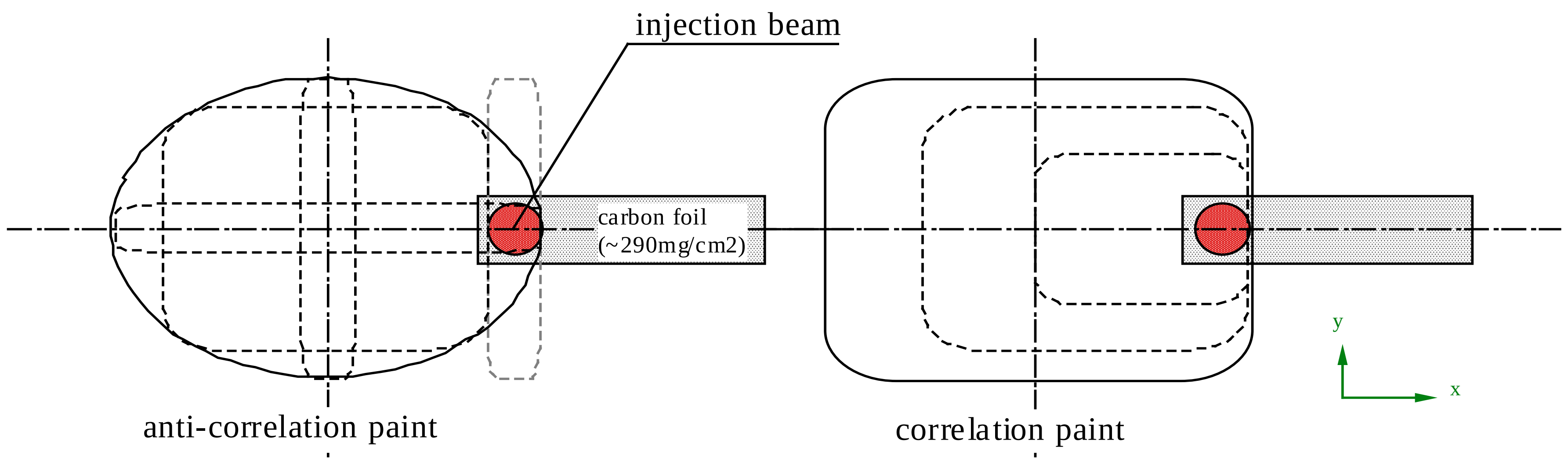
- ***Horizontal painting area***
  - correlated painting or anti-correlated painting
  - for 3GeV users or for 50GeV MR ---within one cycle(20ms)
  - beam study
- ***Changing painting area***
  - Shift bump and painting bump are changed
  - xí of injection beam can be changed with pulse magnets



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



Correlate and Anti-correlate Painting in Real Space



Examples of painting simulation
(anti-correlated)

- Painting functions

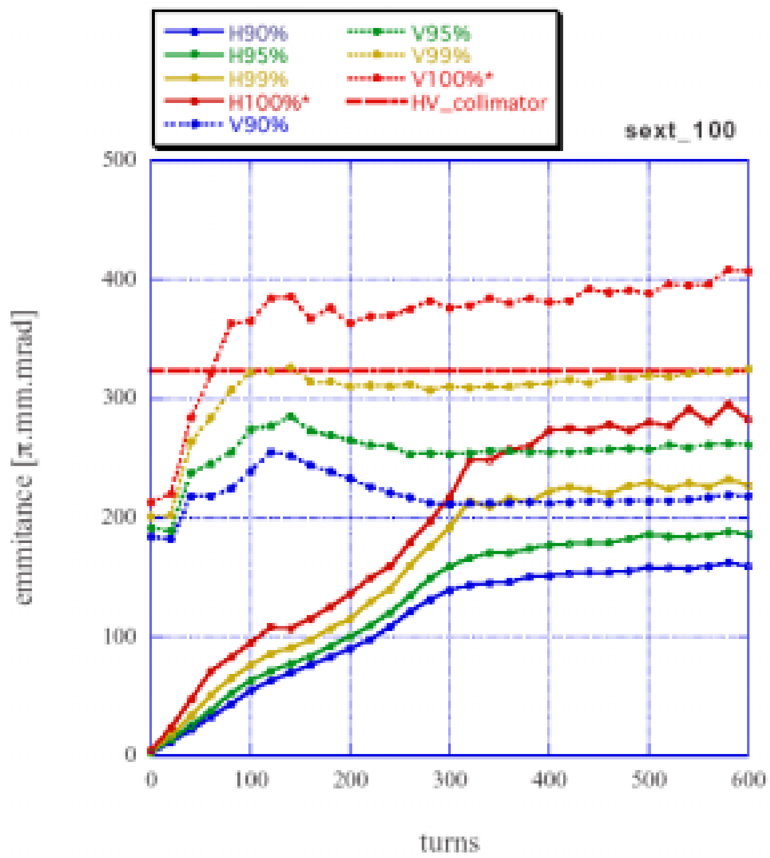
$$x = 91 + 41\sqrt{1 - t/T}\ [mm]$$

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

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

  - n/ε is ideally constant

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



Examples of painting simulation
(correlated)

- Painting functions

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

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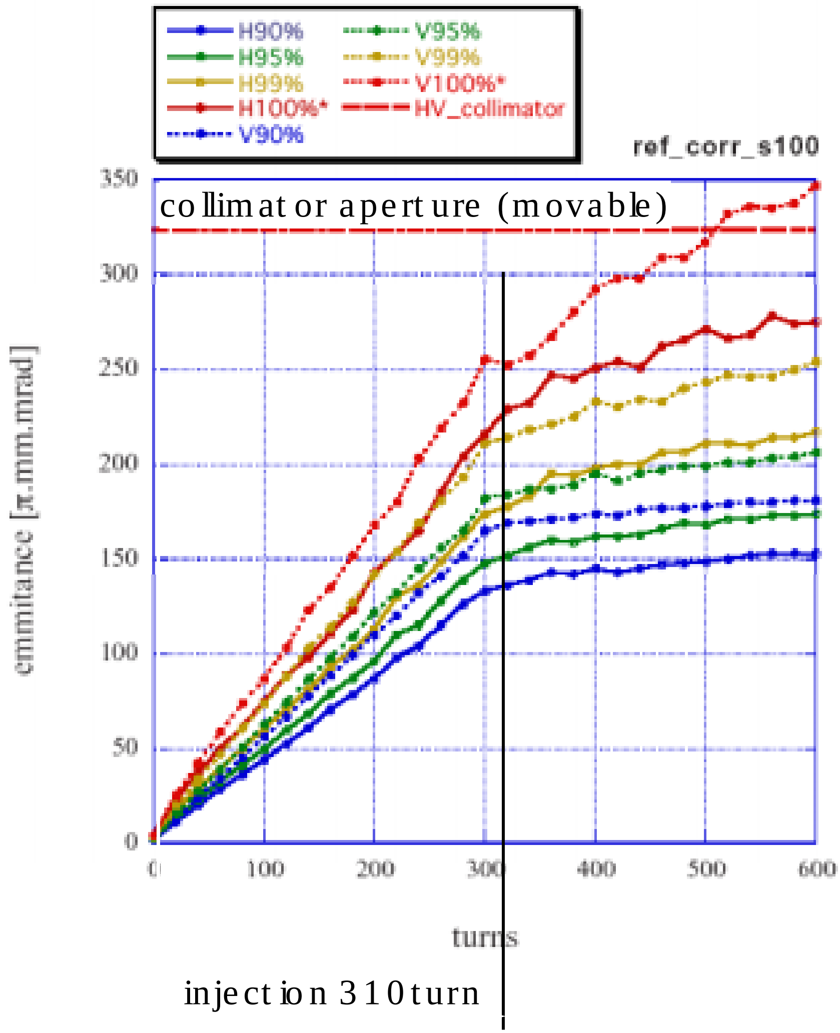


Lorentz stripping

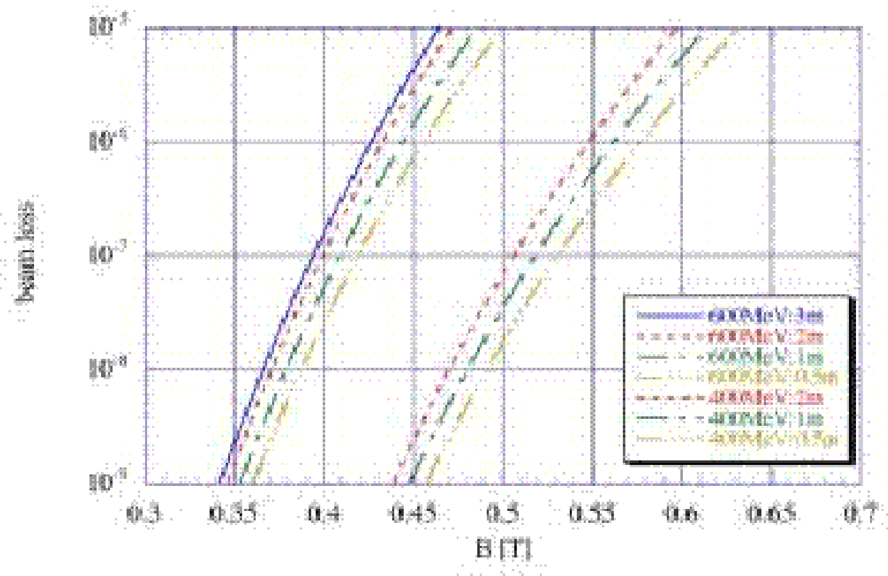
ï Binding energy of second electron is about 0.754eV

  ñ Itís very weakly bound

  ñ H^- ion is converted to a H^0 atom with Lorentz force in an electromagnetic field

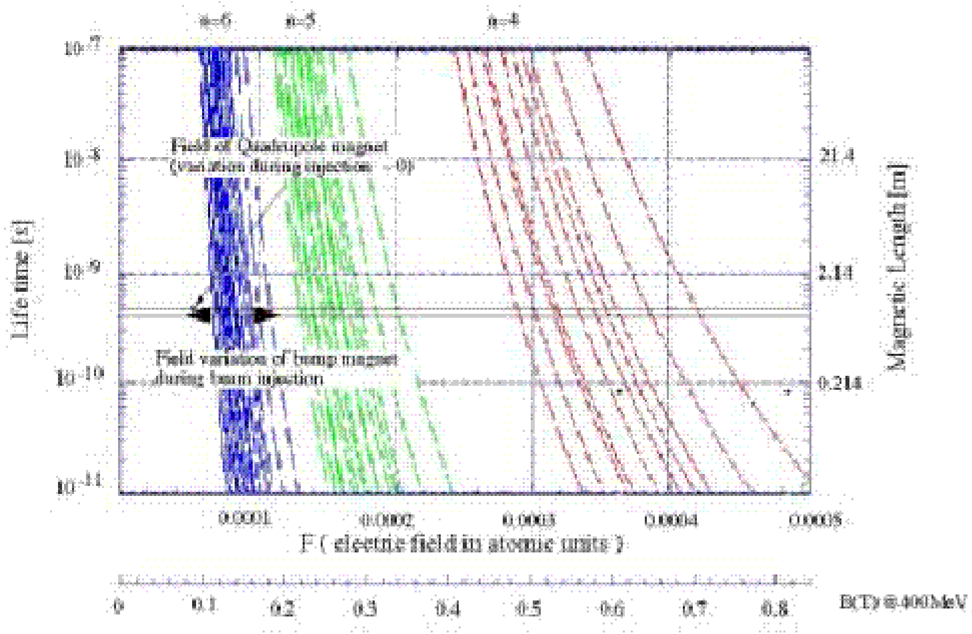
ï H- ion with velocity βc in a transverse magnetic field B

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



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)

ï **In the upstream of the stripping foil**

The maximum magnetic field is estimated to be 0.55 T

The beam loss rate is less than 10^{-6}

The injection beam power is 133 kW

Losses by Lorentz stripping is less than 1.3 W

ï In the downstream of the stripping foil

The magnetic field of the bump magnet is set to be about 0.2 T.

Excited H^0 with a principal quantum number of $n \geq 6$ becomes the uncontrolled beam

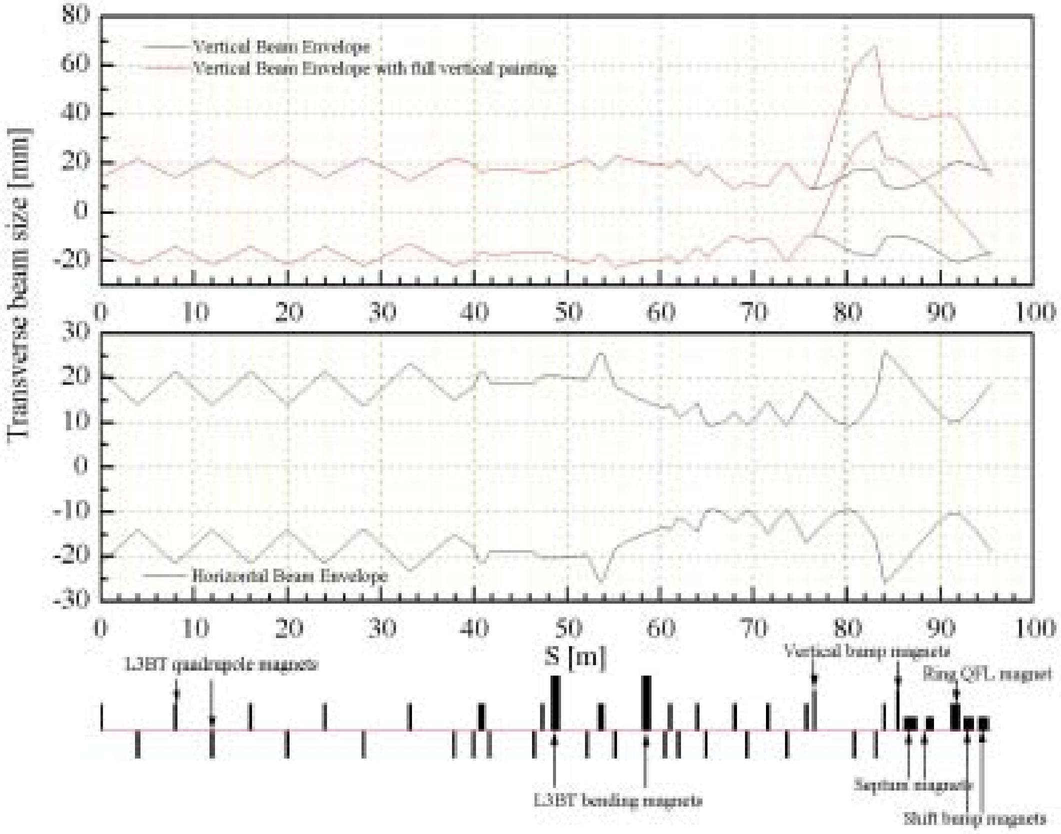
Yield of $n \geq 6$ is 0.0136

The total H^0 beam power is 0.4 kW

The maximum uncontrolled beam loss is about 6 W

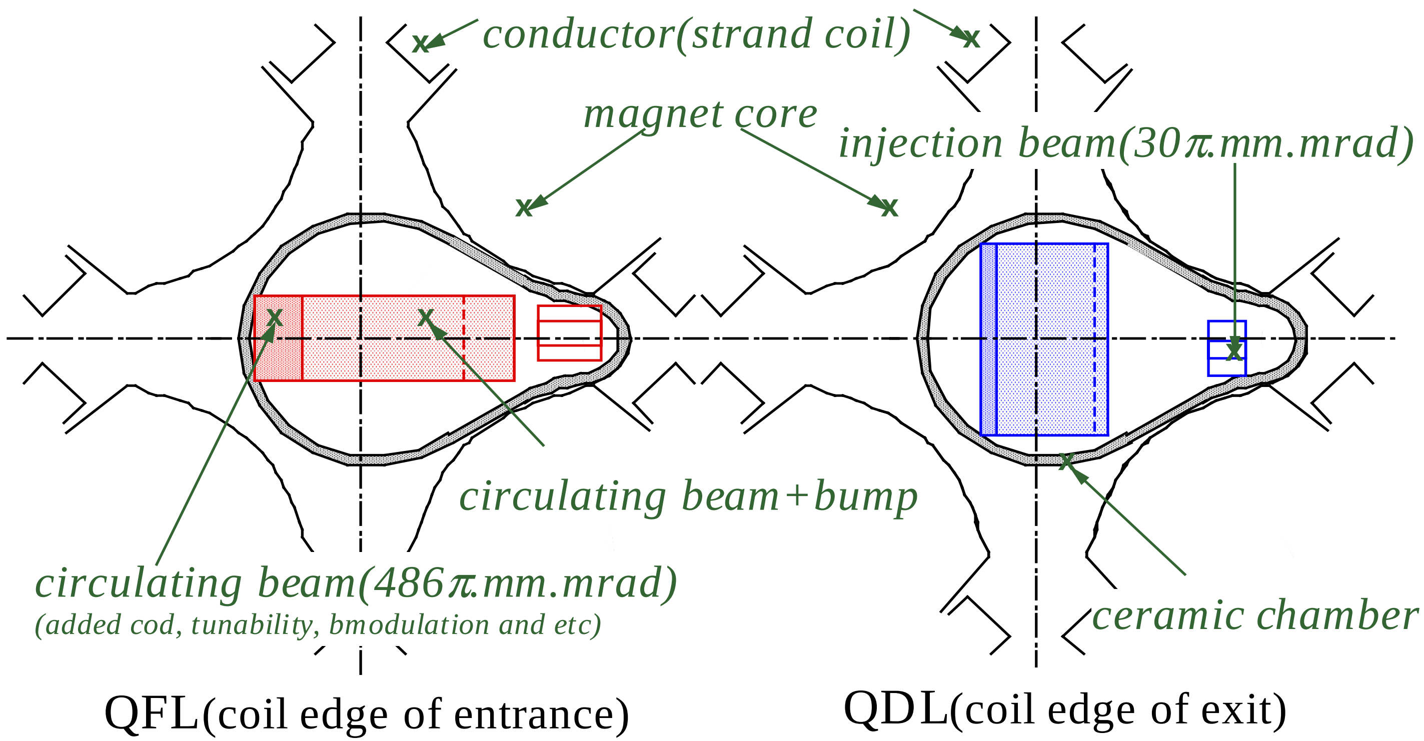
The magnetic field at the foil is designed to be less than the value at which the bending radius of the stripped electrons is larger than 100 mm.

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.

Aperture Requirement for the F and D Quadrupoles



- The beam needs to be injected vertically off-center for vertical painting.
- The corner of the F and D quadrupole magnets are thus required to have additional aperture for the injection/disposal beam lines

Separation of H^0 & H^- disposal beam from H+ circulating beam on the bump orbit

ï In the FODO structure, the beam envelope at the down-stream of F quadrupole, tilts down stream.

ï The injection beam line for horizontal painting must be tilted accordingly.

ï The separation angle of the H^0 beams and circulating H^+ beam envelope of the bump orbit become tight.

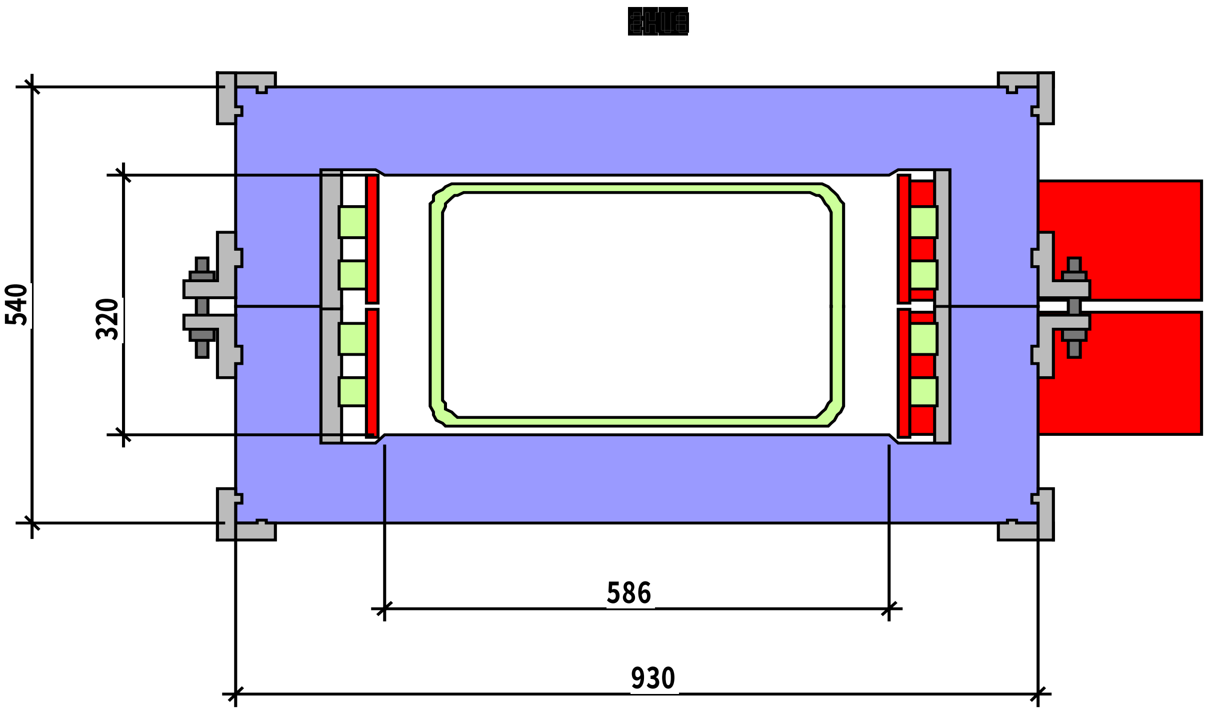
ï The H^0 beams, which are estimated to be 0.3% of the incoming beams, must be converted to H^+ by a second foil to divert to the beam dump.

ï To solve this problem the split-type bump magnet has been investigated.

ï The second foil ìAî is inserted in the middle of the fourth bump magnet, by a split at the center of the core.

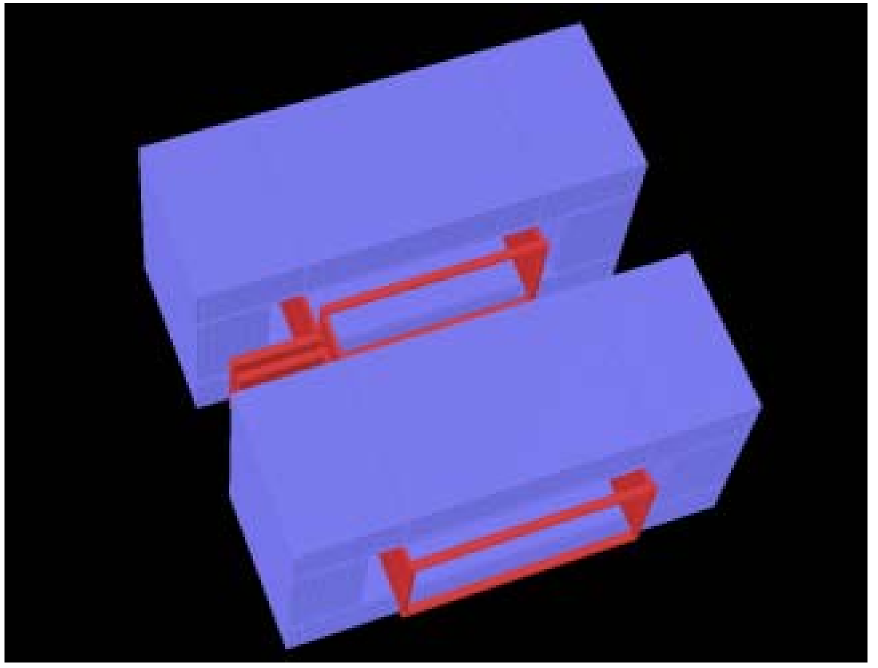
ï H^- beams, which are estimated to be $3x10^{-4}$ % of the incoming beams, are also converted to H^+ by another second foil,îBî, set at the entrance of the D quadrupole magnet,îODKî

Fixed Closed-Orbit Bump Magnets "SB-I~SB-IV"



- Four dipole bump magnets named "SB-I~SB-IV" are identical in construction and are powered in series to give a symmetrical beam bump.
- The dipoles are out of vacuum and ceramic vacuum chamber is included in the magnet gap.
- The structure of the magnet is composed of two-turn coils and window frame core made by laminated silicon steel cores of which thickness is 0.1 mm.

Structure of the Split-type Bump Magnet



- The exitation current is supplied in the middle of the core trough the split to form a symmetrical distribution of magnetic field along the longitudinal direction.
- To insert the second foil
- Symmetrical power supply for a symmetrical field distribution along the longitudinal axis

The Waveform of Magnetic Field

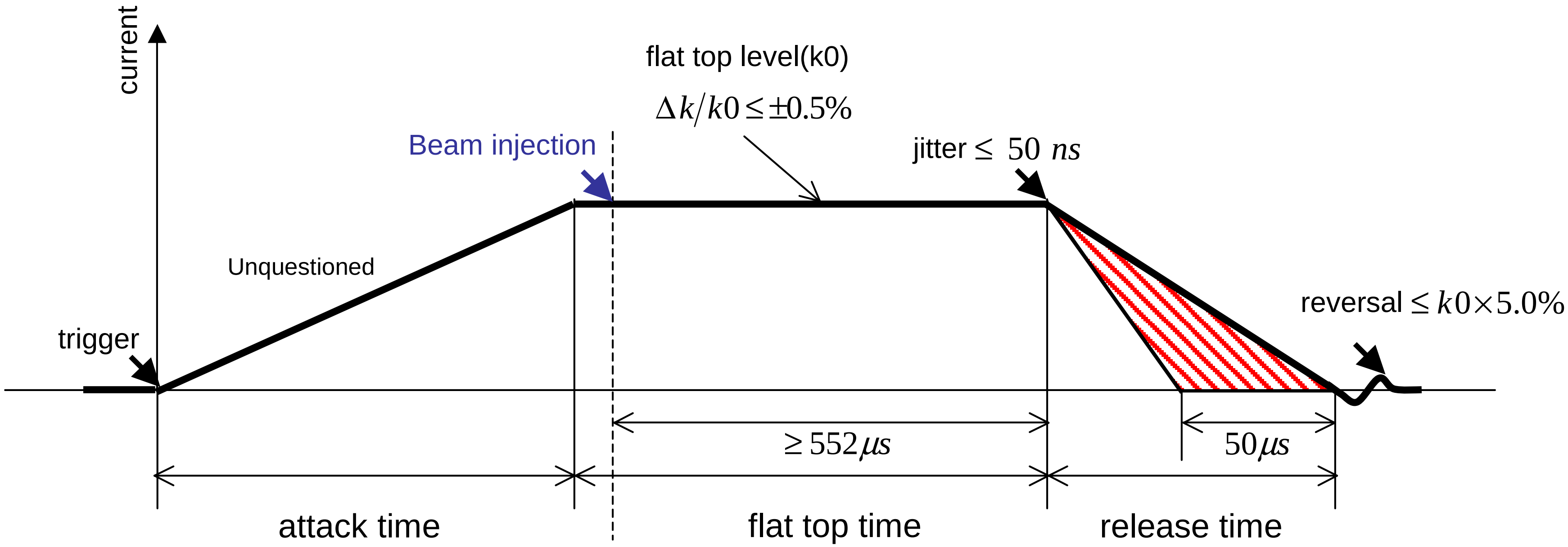
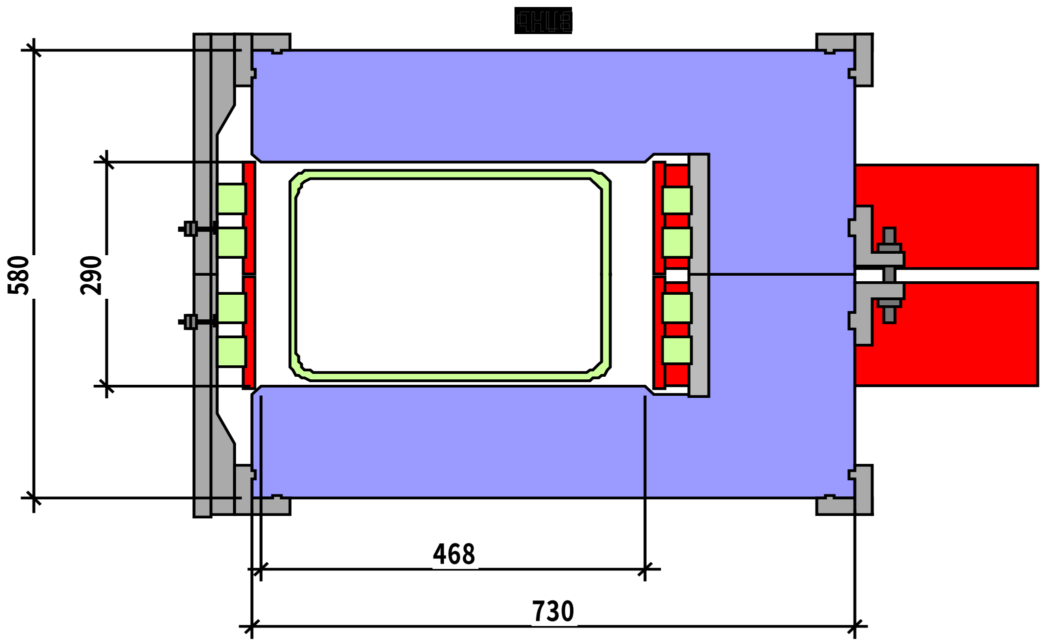


Fig.1 Current pattern of the power supply of the shift bump magnet in horizontal

Horizontal painting bump magnets

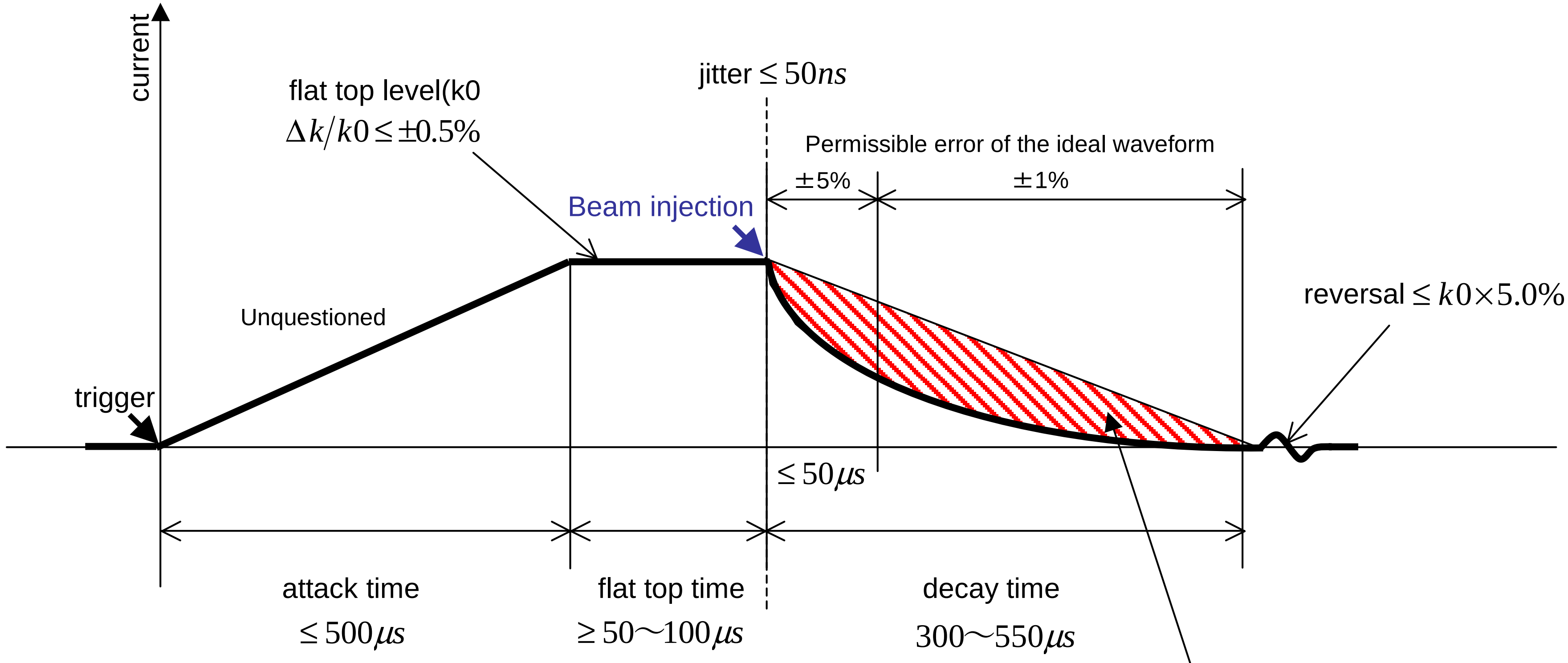


ï Two sets of bump magnet pairs in the upstream of the F quadrupole magnet and the downstream of the D quadrupole magnet.

ï These four painting bump magnets will be excited individually.

ï To form a local closed orbit include the F and D quadrupole magnets

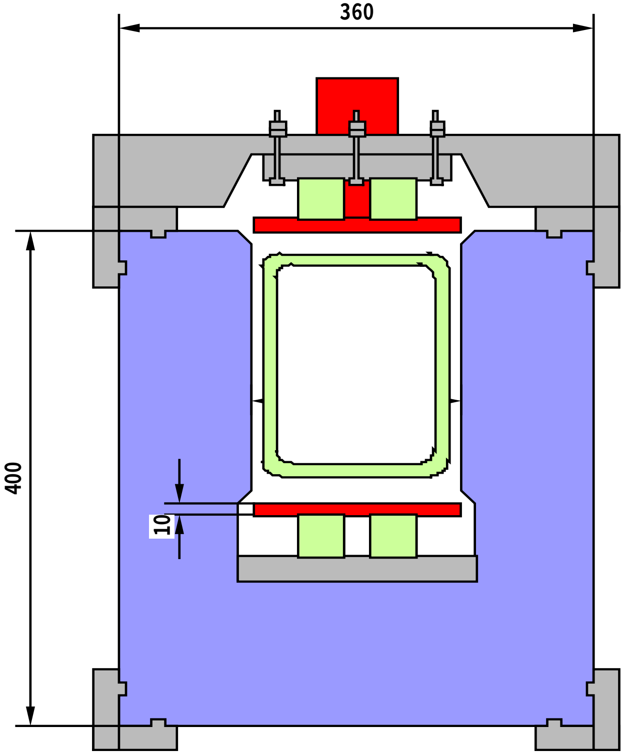
Waveform of Horizontal Painting Bump Field



ïIdeal wave form
K0{ 1−sqrt(t/ τ)}
ïDesign wave form
k0【1+[sqrt(ε / τ)-sqrt{(t+ ε)/ τ }]/[sqrt{(τ + ε)/ τ }-sqrt(ε / τ)]】
ïDifferentiation same as the above
0.5k0/[sqrt{(τ + ε)/ τ }-sqrt(ε / τ)]/sqrt{(t+ ε)/ τ }/ τ

Fig.2 Current pattern of the power supply of the painting bump magnet in horizontal

Vertical Painting Magnets



- In the vertical plane, two steering magnets are installed on the beam-transport line at a upstream point led by p . from the foil.
- Painting injection in the vertical plane is performed by sweeping of the injection angle.
- Both correlated and anti-correlated painting injections are available by changing the excitation pattern of the vertical painting magnet

Waveform of Vertical Painting Bump Field

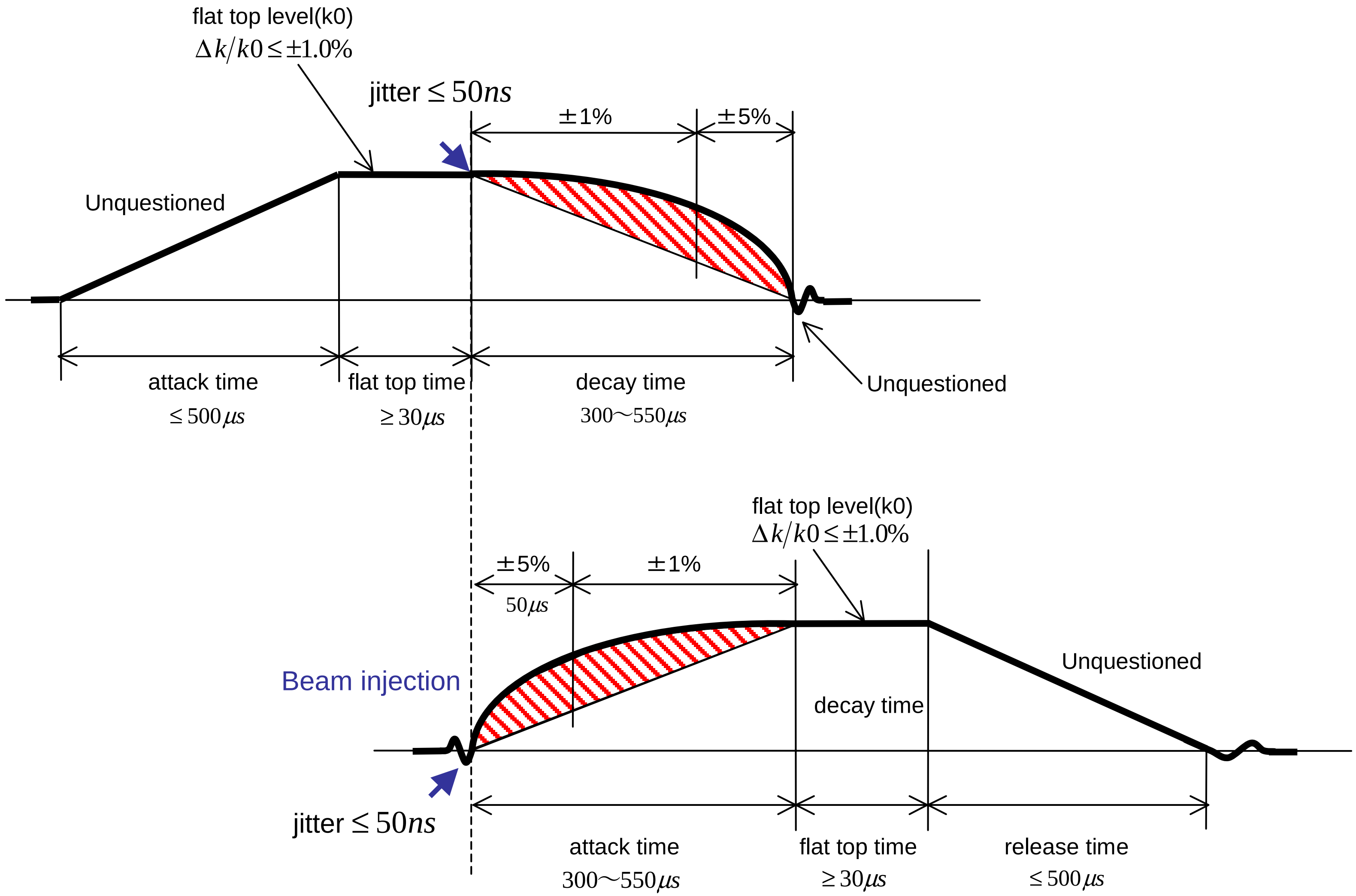
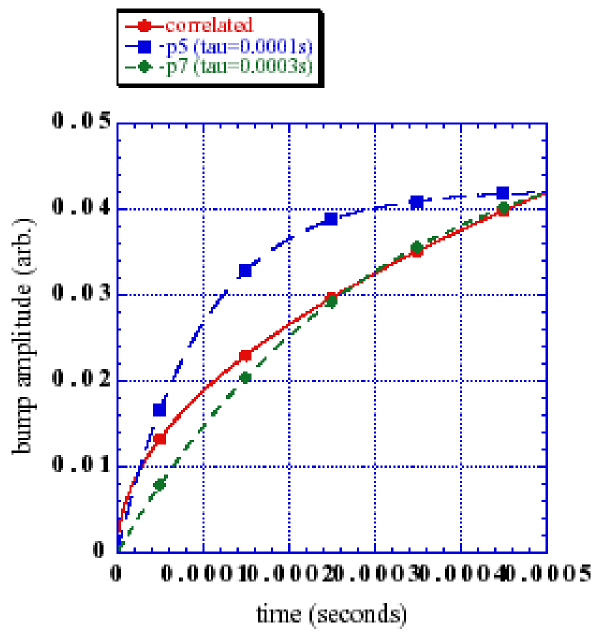
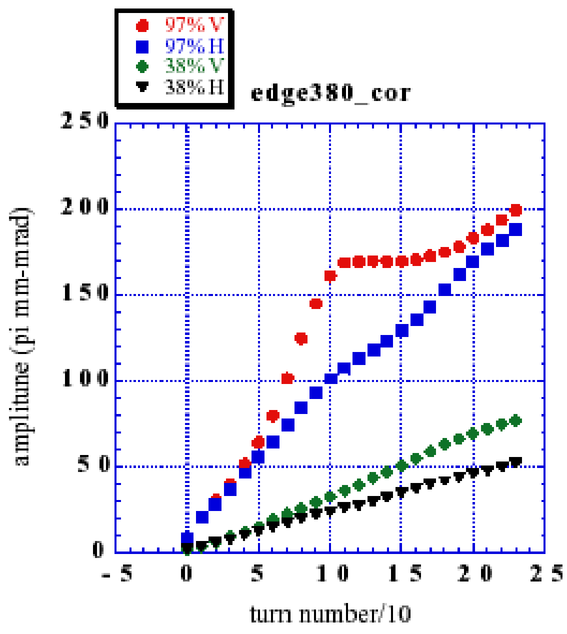


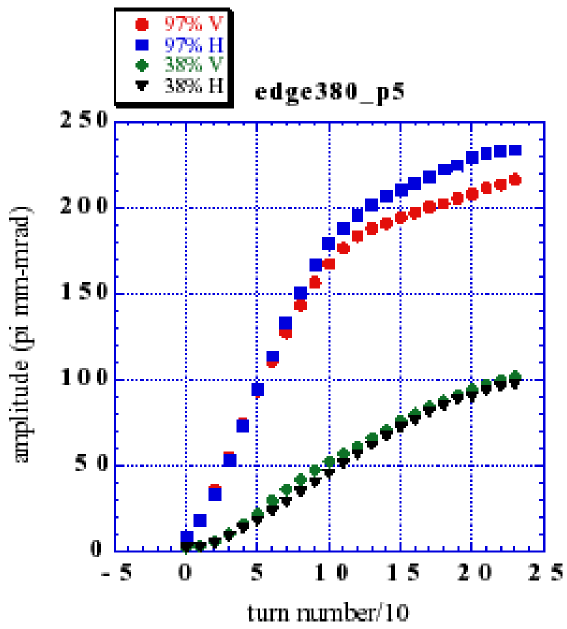
Fig.2 Current pattern of the power supply of the painting bump magnet in vertical



correlated
-p5 (tau=0.0001s)
-p7 (tau=0.0003s)
bump amplitude (arb.)
time (seconds)



97% V
97% H
38% V
38% H
edge380_cor
amplitune (pi mm-mrad)
turn number/10



97% V
97% H
38% V
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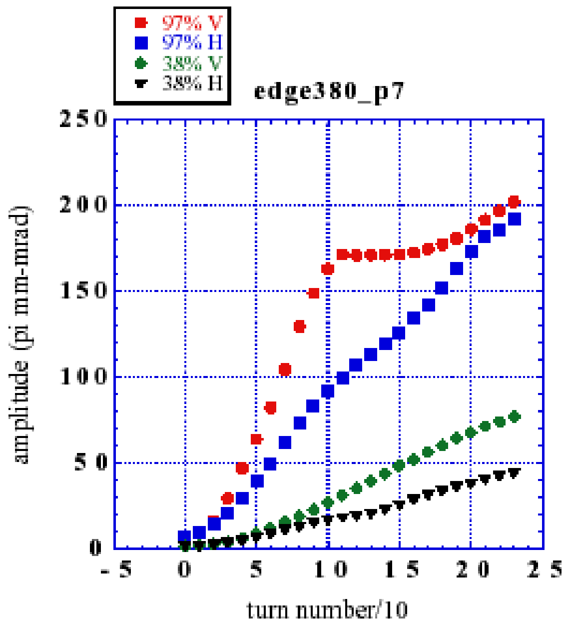
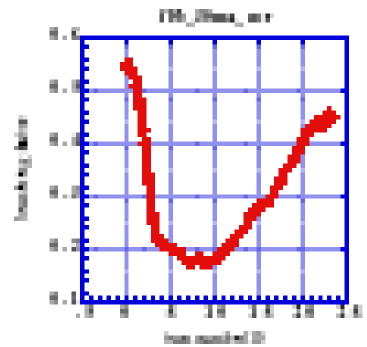
edge380_p5
amplitude (pi mm-mrad)
turn number/10



97% V
97% H
38% V
38% H
edge380_p7
amplitude (pi mm-mrad)
turn number/10



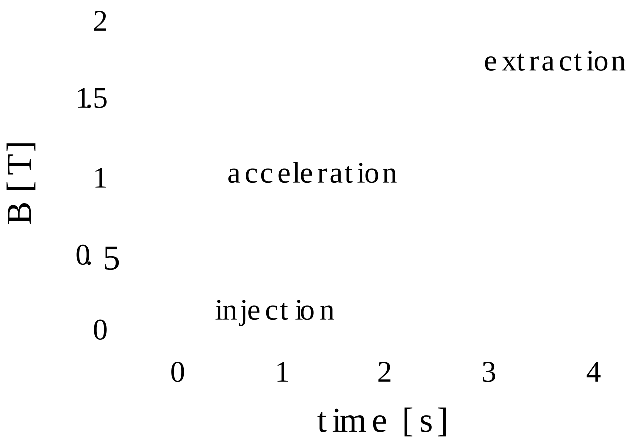
Development of Stripping Foil

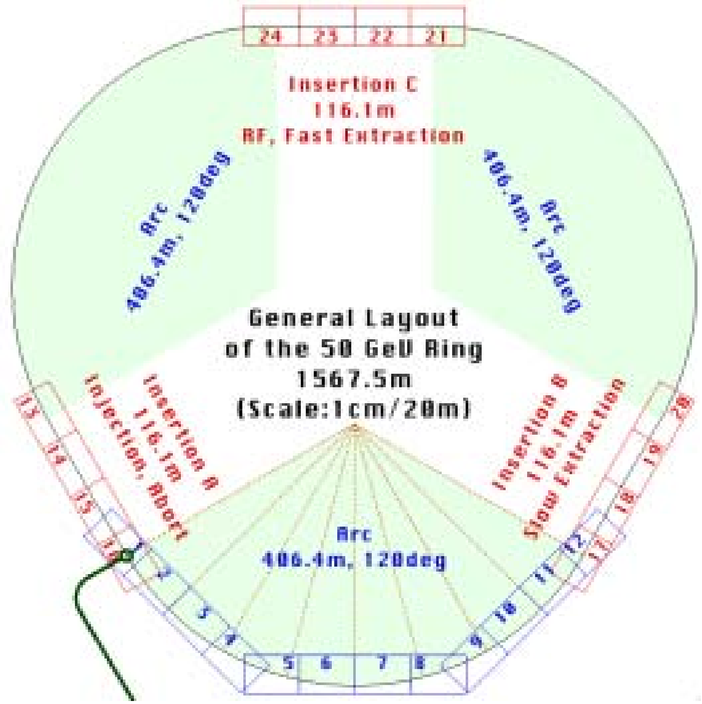
- Self–supported stripping foil.
- Having a horizontal length of 105mm and a vertical height of 30mm to make sure a full acceptance of 486 p.mm.mrad at the stripping foil.
- Curved structure around the long axis and one side of the foil is fixed on the outside frame.

Injection system of JKJ 50GeV MR

ï Overview of JKJ 50GeV MR
- ñ Circumference 1567.5m
- ñ Injection energy 3GeV
- ñ Extraction energy 50GeV
- ñ Repetition rate 0.3Hz
- ñ output power 0.78MW
  - ñ 3.2e14 particles/pulse

ï parameters of injection
- ñ injection pulse 4pulses (8 bunches)
- ñ injection period 120ms
- ñ Emittance
  - ï Injection 54π.mm.mrad
  - ï extraction 4.1π.mm.mrad





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