中国散裂中子源

Study on the particle distribution and beam parameters during the injection process for CSNS/RCS

HB2014, 12 Nov, 2014

Ming-Yang Huang

Accelerator Physics Group

Institute of High Energy Physics

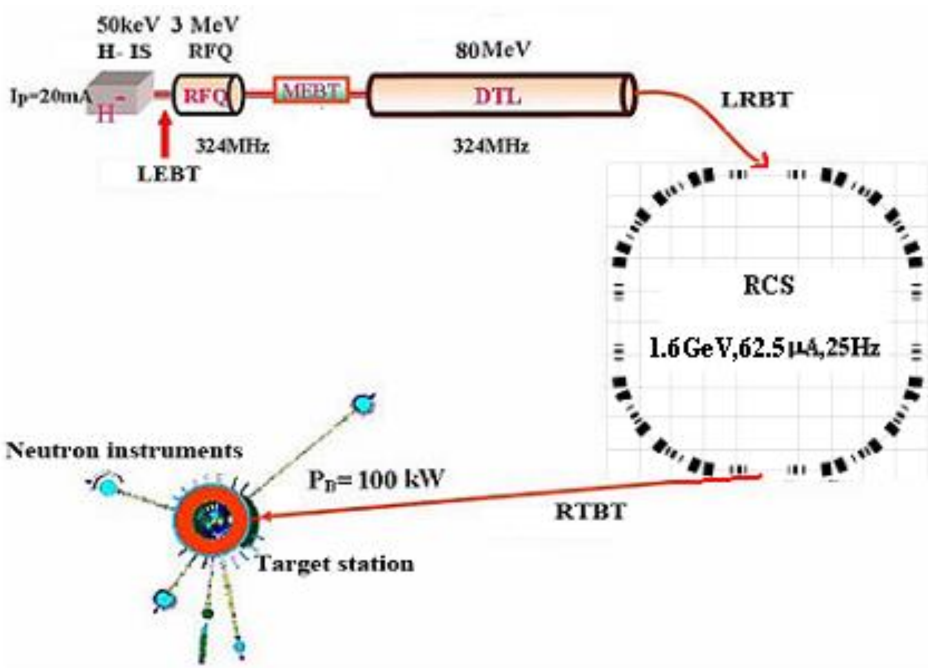
CSNS CHINESE ACADEMY OF SCIENCES

Content

- Introduction
- Optimization of the injection beam parameters
- The particle distribution during the injection process for CSNS
- The injection control software for CSNS
- Summary

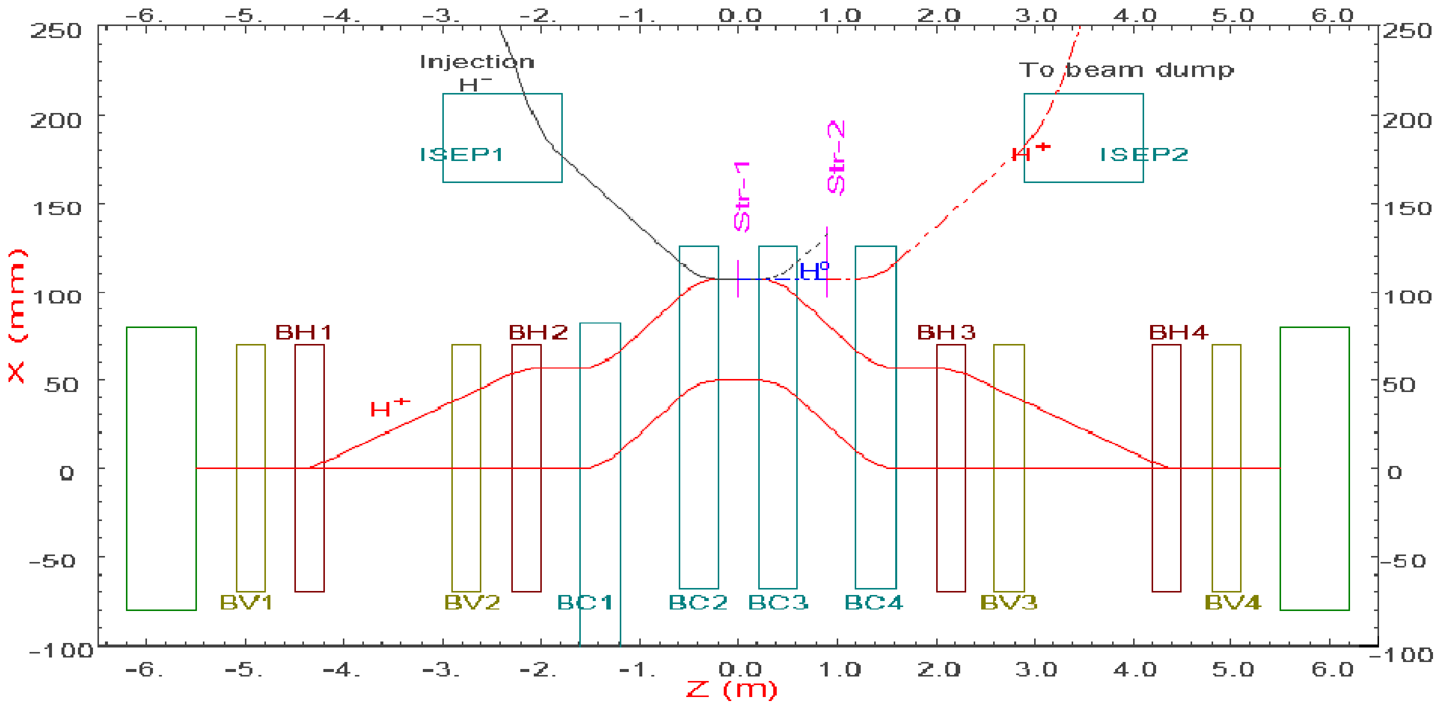
I. Introduction

- The CSNS is a high power proton accelerator-based facility.
- The phase-I CSNS facility consists of an 80-*MeV* H^- linac, a 1.6-*GeV* RCS, 2 beam transport lines, a target station, and 3 instruments.
- Upgradable to 500*kW* at repetition rate of 25*Hz*.
- The design is almost fixed with the officially start of the project.



CSNS injection system

- For CSNS, a combination of the H^- stripping and the phase space painting method is used to accumulate a high intensity beam in the RCS.
- For the beam injection, three kinds of orbit-bumps are prepared: a horizontal bump (BH1-BH4) for painting in x-x' plane; a vertical bump (BV1-BV4) for painting in y-y' plane; a horizontal bump (BC1-BC4) in the middle for an additional closed-orbit shift of 57 *mm*.

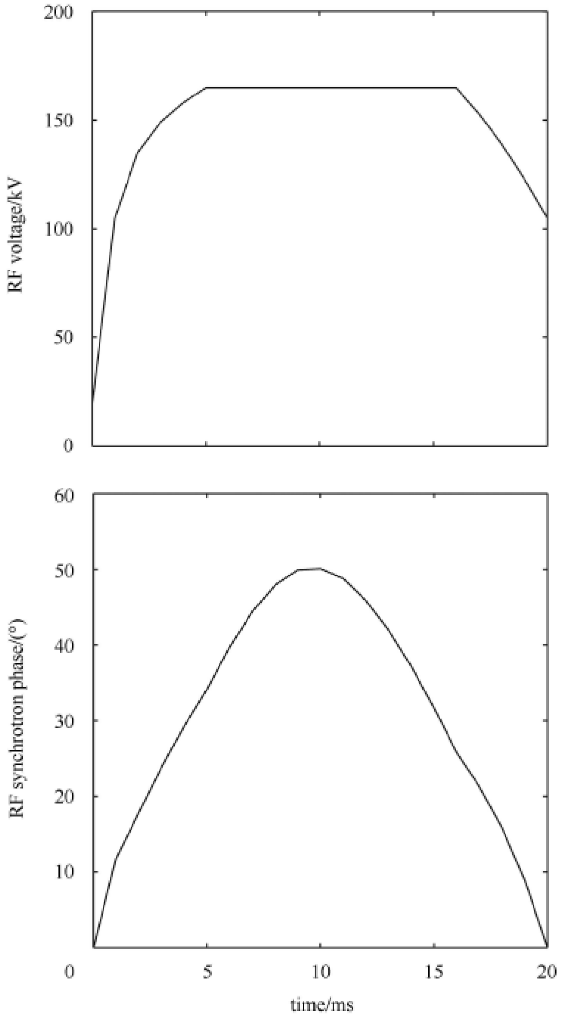


Main injection parameters of CSNS/RCS

parameters/units	values
circumference/m	227.92
injection energy/GeV	0.08
extraction energy/GeV	1.6
injection beam power/kW	5
extraction beam power/kW	100
nominal betatron tunes	4.86/4.78
RF frequency/MHz	1.0241–2.3723
RF voltage/kV	165
harmonic number	2
repetition rate/Hz	25
number of particles per pulse	1.56×10^{13}
momentum acceptance (%)	1
painting scheme	anti-correlated
chopping rate (%)	50
turn number of injection	200

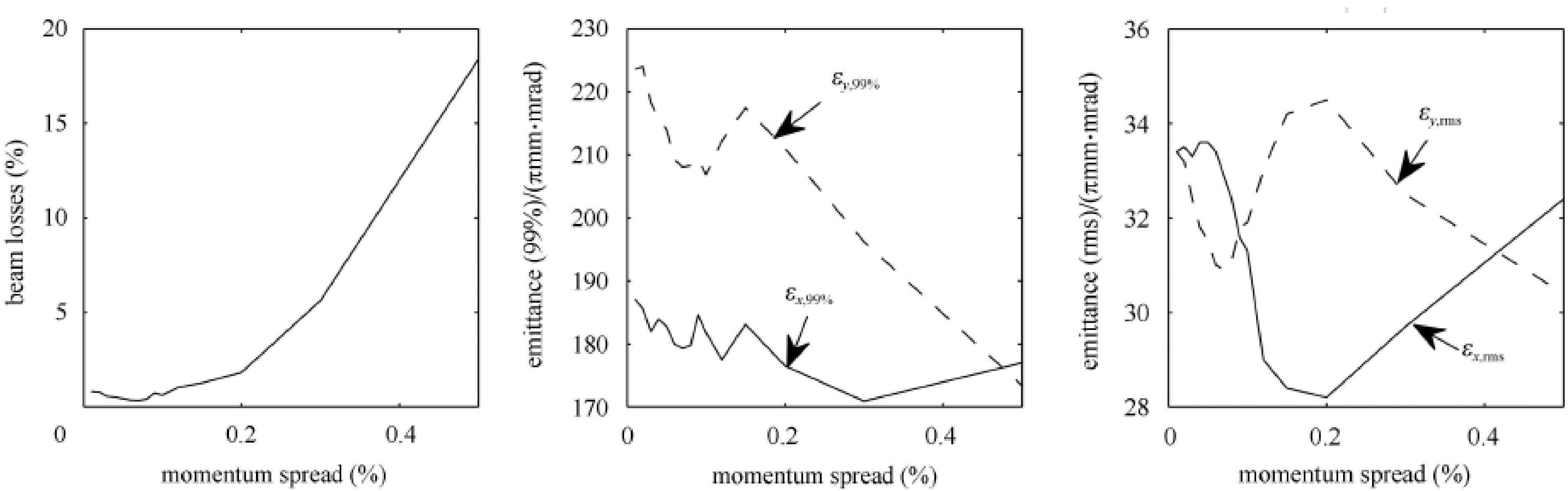
II. Optimization of the injection beam parameters

- During the injection process, there are some factors which can affect the injection results.
- The dependence of the painting beam on the injection beam parameters was studied in detail and, with the code ORBIT, the simulation was done for injection with different momentum spreads, different *rms* emittances of injection beam, and different matching conditions.
- During the simulations, the chopping rate is 50% , the patterns of the RF voltage and synchrotron phase are given in right figure, and the space charge effects are considered. The turn number of the injection painting process is 200, and the first 2000 turns in the acceleration process are considered.

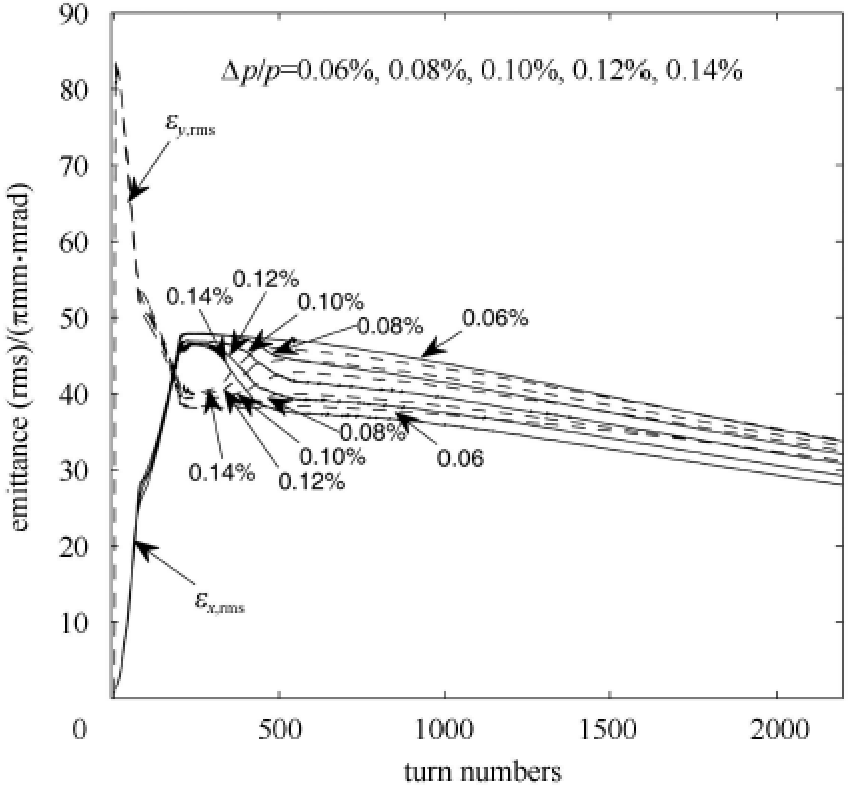


Momentum spread

- In order to study the effects of the momentum spread, the injection processes with the momentum spread between 0.01% and 0.5% were simulated.
- It can be found that the beam loss decreases firstly and then increases with the increasing momentum spread. While the momentum spread is smaller than 0.1%, the beam loss is smaller than 1%, the 99% and *rms e*mittances are constrained in reasonable ranges.



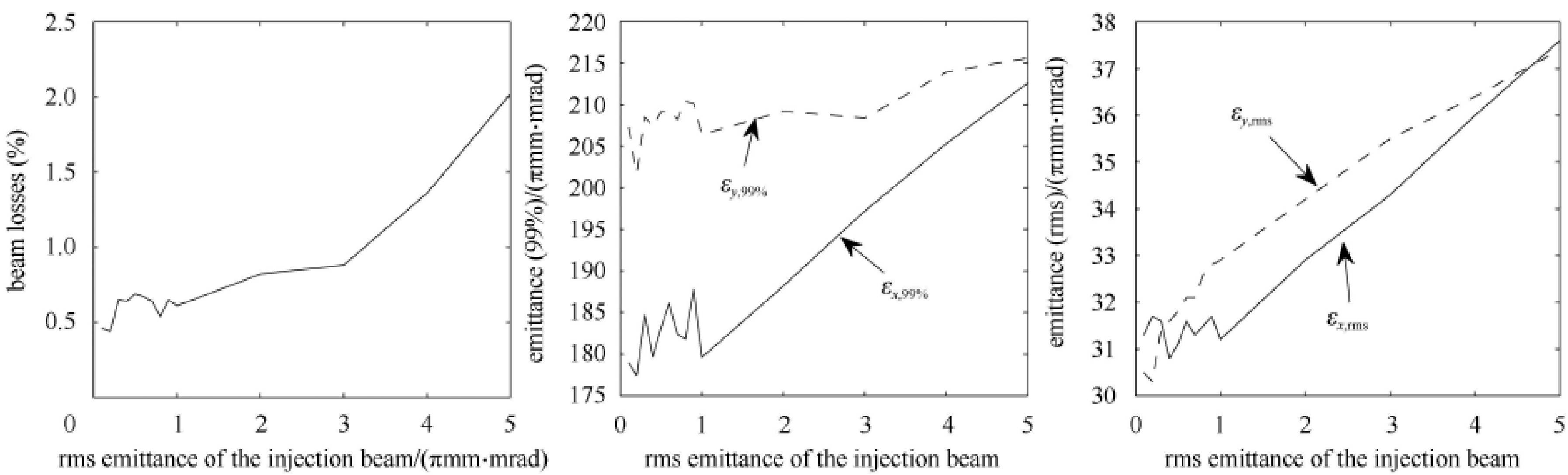
- There is transverse coupling which depends on the momentum spread.
- When the momentum spread is below 0.1%, the coupling becomes stronger with the increasing momentum spread. However, when the momentum spread is above 0.1%, the coupling becomes weaker with the increasing momentum spread.
- The momentum spread of 0.1% is a optimal value for injection.
- This simulation results are consistent with the operation experience in J-PARC.



rms emittance of injection beam

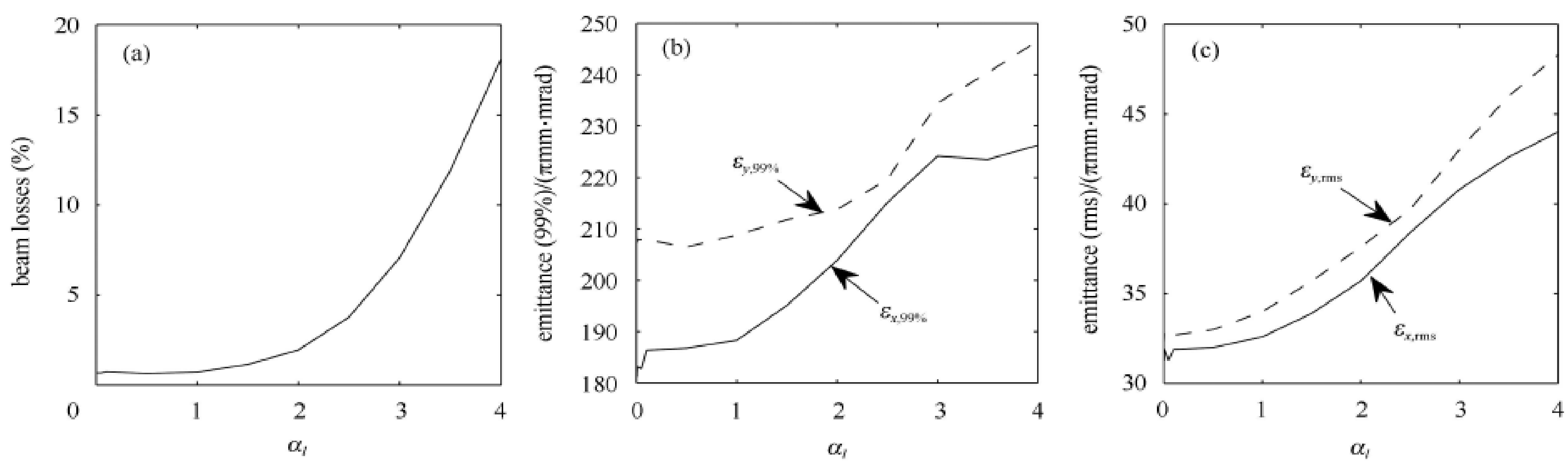
- In order to study the effects of the *rms* emittance of injection beam, the injection processes with the *rms* emittance between 0.1 *mm mrad* and 5.0 *mm mrad* were simulated.

- It can be found that the beam loss, 99% and *rms* emittances all increase with the increasing *rms* emittance of injection beam. In addition, while the *rms* emittance of injection beam is smaller than 1.0 *mm mrad*, the beam loss is smaller than 1%, the 99% and *rms* emittances are constrained in reasonable ranges.



Mismatch injection twiss parameters

- For the RCS design, it has been a primary concern to match the emittance of the linac beam to the RCS acceptance at the injection point.
- In order to study the effects of the injection twiss parameters mismatch, for a fixed β_l, different α_l were discussed. The injection processes with (α_{lx}; α_{ly}) between (0.0, 0.0) and (5.0, 5.0) were simulated.
- It can be found that the beam loss, 99% and *rms* emittances all increase with the increasing α_l. While (α_{lx}; α_{ly}) is smaller than (1.0, 1.0), the beam loss is smaller than 1%, the 99% and *rms* emittances are constrained in reasonable ranges. However, while (α_{lx}; α_{ly}) is larger than (1.0, 1.0), the beam loss, 99% and *rms* emittances are much larger than that of the matching case.



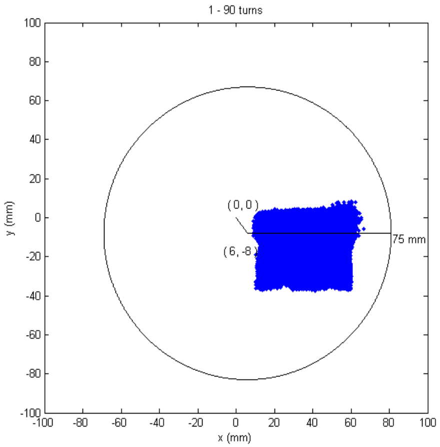
III. The particle distribution during the injection process for CSNS

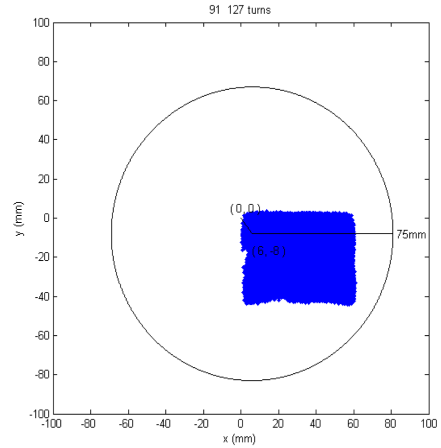
- Since the aperture of the BH3/BV3 position during the injection region for CSNS/RCS is very small now and the space is too narrow, the injection painting range and the particle motion distribution during the injection process need to be studied in detail.

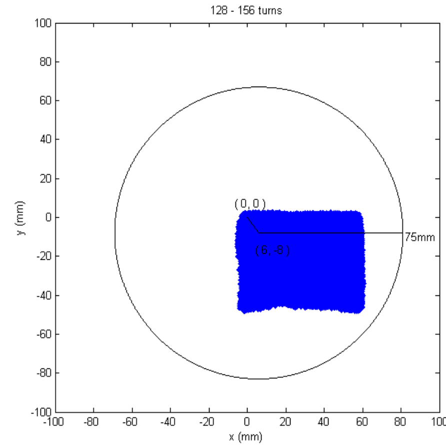
- With the code ORBIT, the injection processes with different painting methods and different painting ranges were simulated in detail. The painting image and particle motion distribution of each turn can be obtained. Then, with the code MATLAB, the particle distribution data of each turn can be analyzed and the data of all 200 turns can be combined together. Therefore, it can be found that whether the aperture size is suitable for the injection painting process.

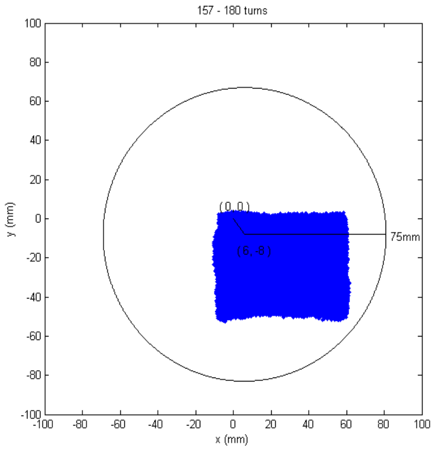
- In the following figures, the horizontal painting range: 57mm→24mm; the vertical painting range:0→25.7mm.

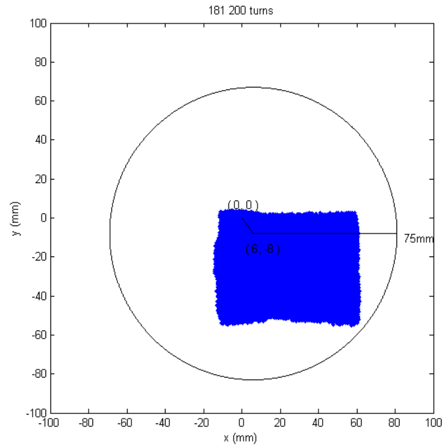
Correlated painting method



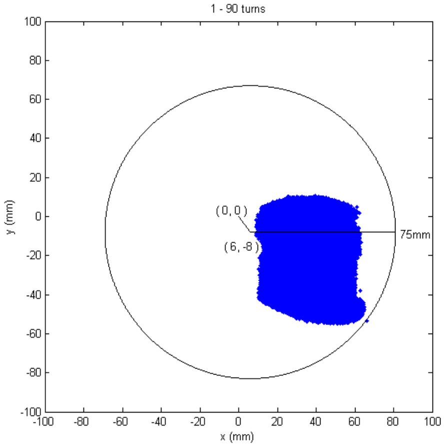


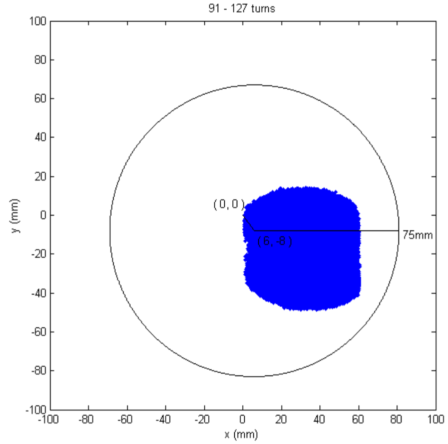


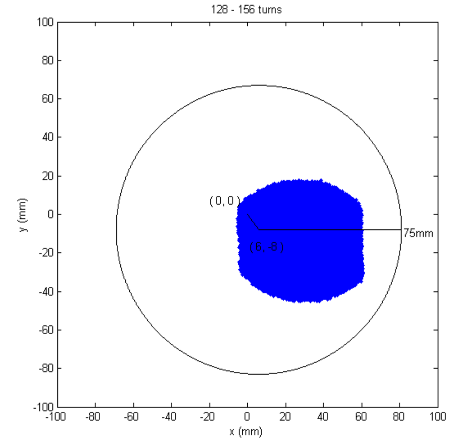


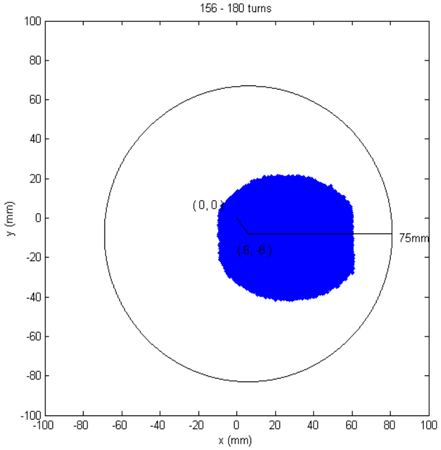


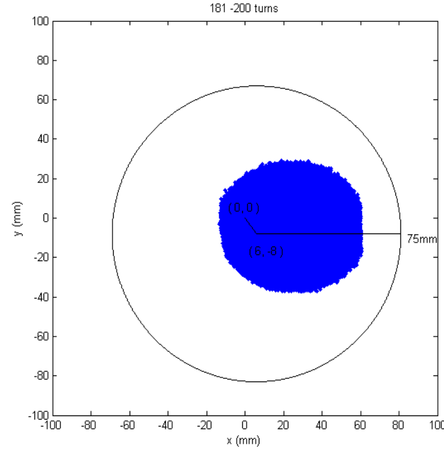
Anti-correlated painting method











- It can be found that:

(1) For the correlated painting method, the aperture is suitable during the early stage of the injection process while it is very narrow during the later stage.

(2) For the anti-correlated painting method, the aperture is suitable during the later stage of the injection process while it is very narrow during the early stage.

(3) There are some particles can be lost due to the stripping foil scattering and space-charge effects.

(4) In general, compared with the correlated painting method, the anti-correlated painting method has more advantages.

IV. The injection control software for CSNS

- The development of new accelerator application software plays an important role for CSNS/RCS.

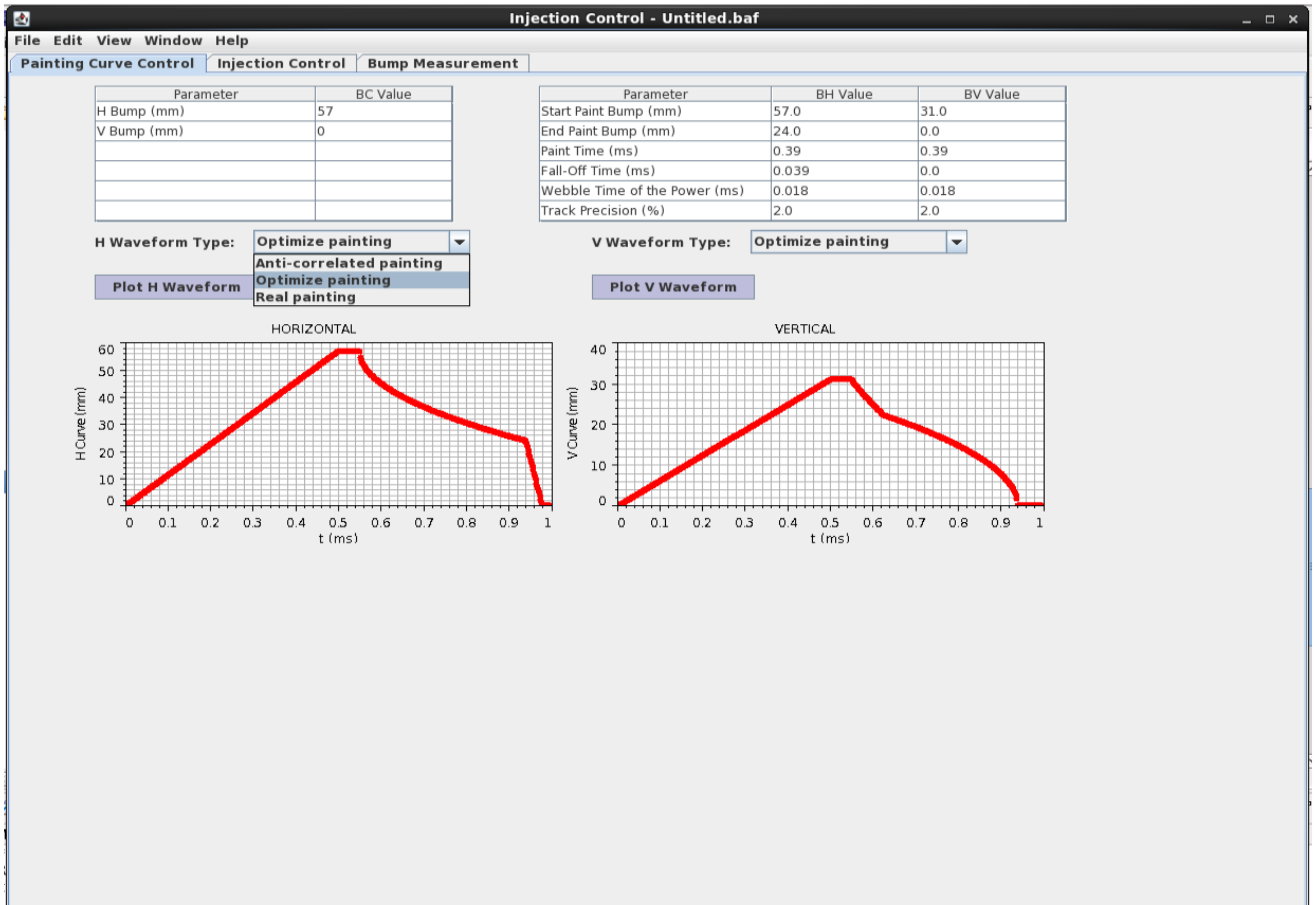
- The injection control software is the key part of the new application software.

- The injection control software for CSNS contains two parts currently: painting curve control and injection control. The injection control part contains four sections: single-bunch-beam calculation, LRBT beam control at foil, injection orbit correction and Trim control.

- The follow-up work of the injection control software need to be continued.

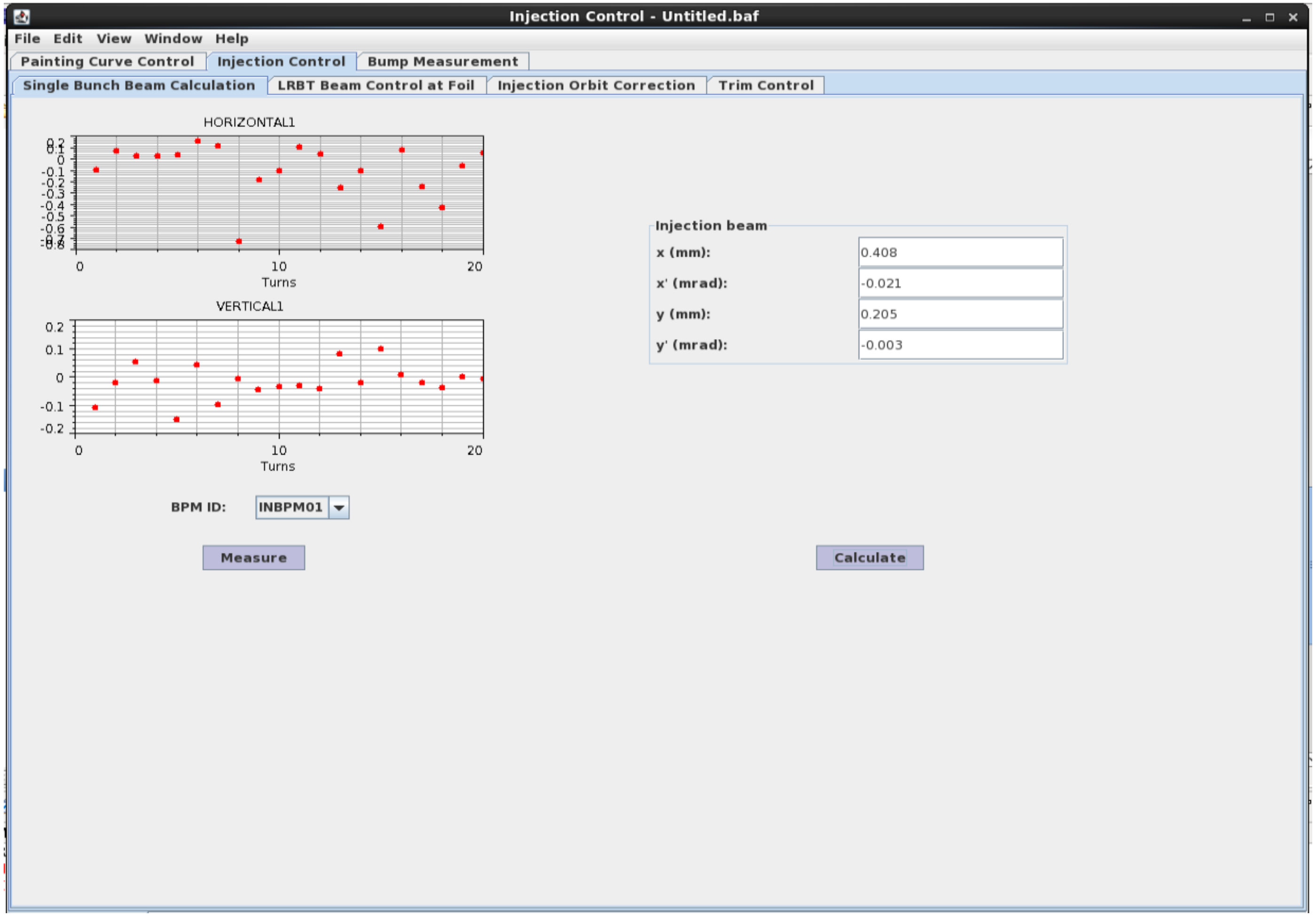
Painting curve control

- Three kinds of painting curves can be selected and saved: anti-correlated painting; optimize painting; real painting.



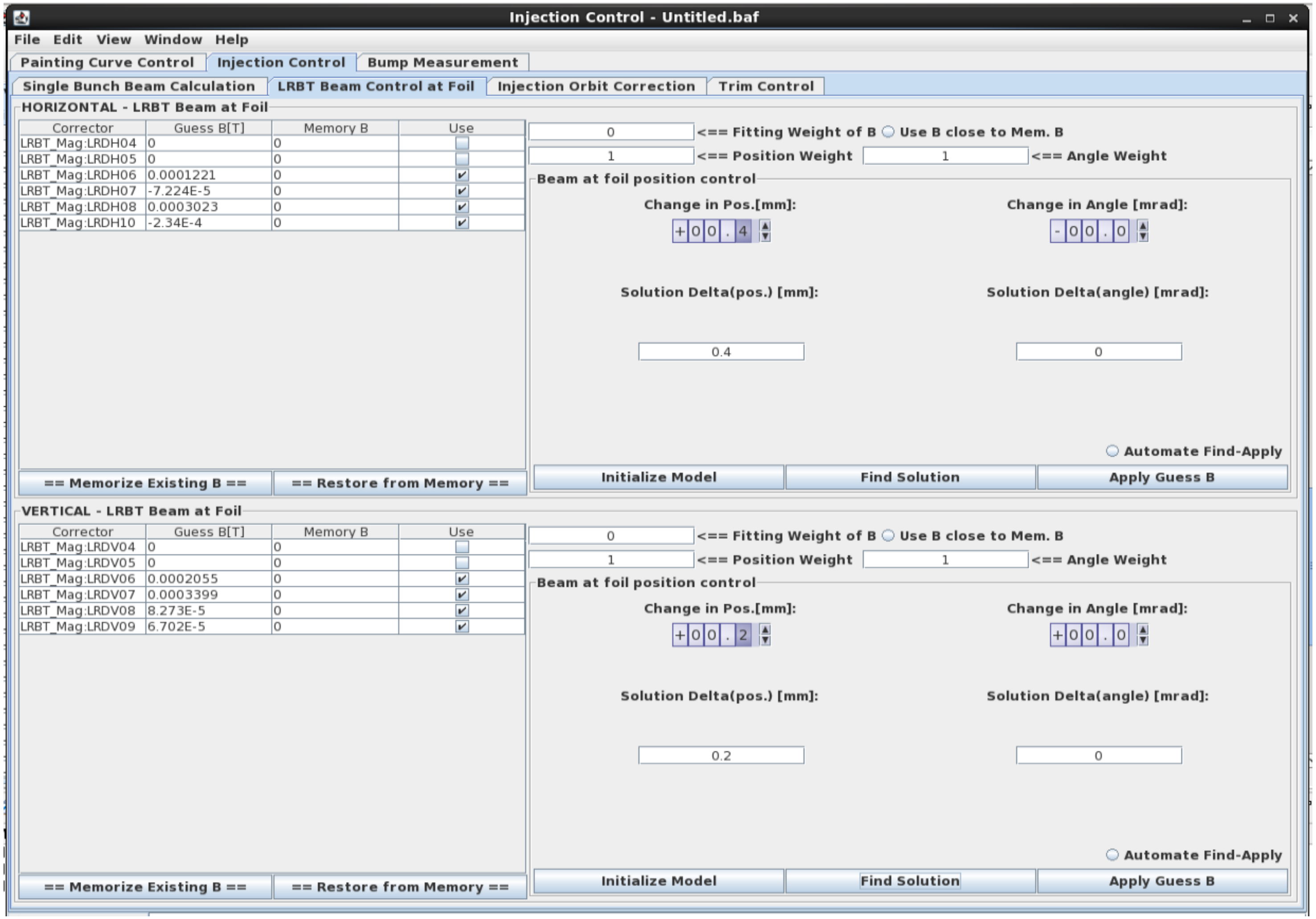
Single-bunch-beam calculation

- Two BPMs (INBPM01 and INBPM02) are used to measure the positions of the single-bunch-beam. If the position and direction of injection beam are not suitable, with the transmission matrix, the correct position and direction of injection beam can be calculated.



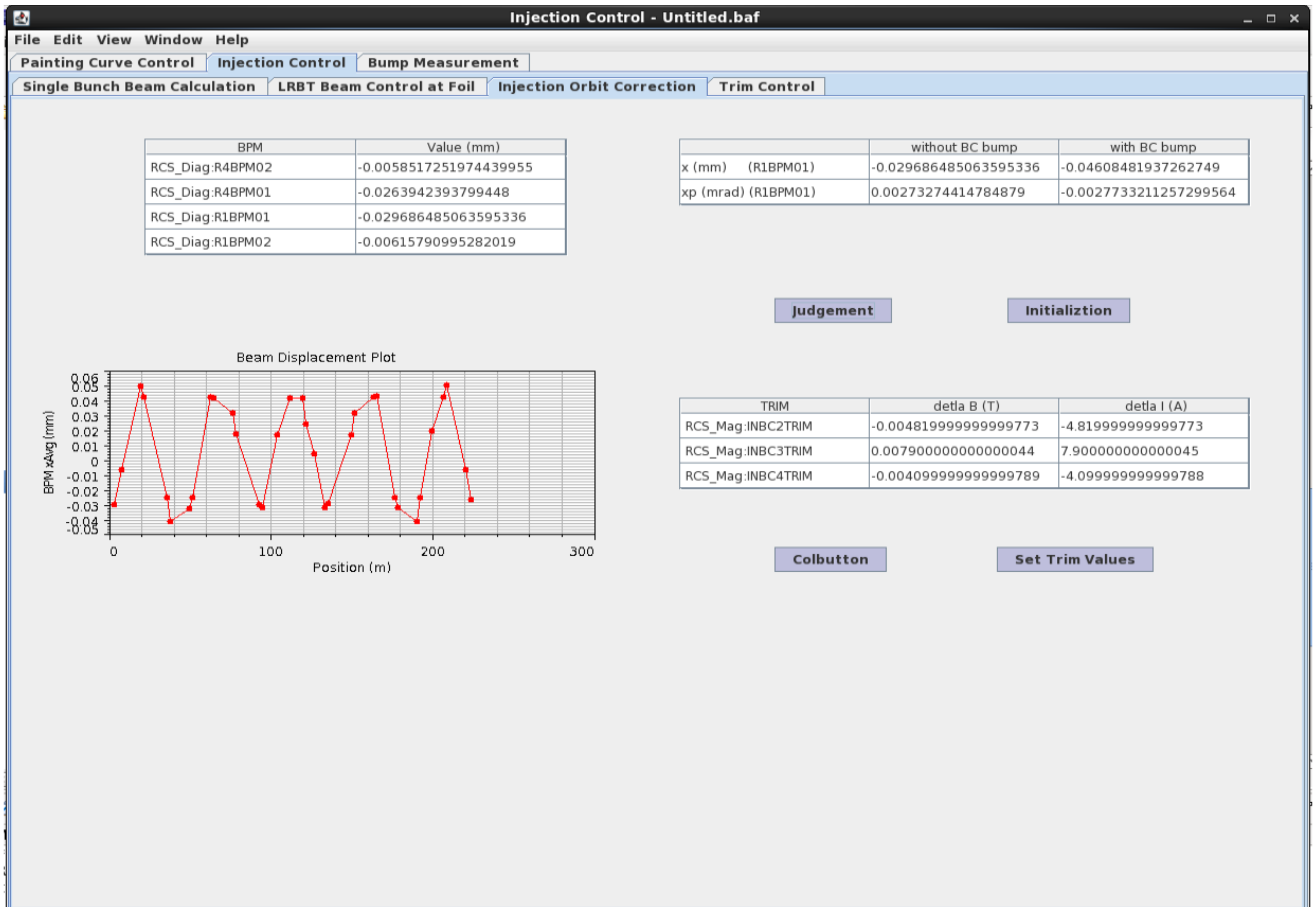
LRBT beam control at foil

- While the correct position and direction of injection beam can be obtained, with the correctors of LRBT, the injection beam can be corrected to fit for the RCS orbit.



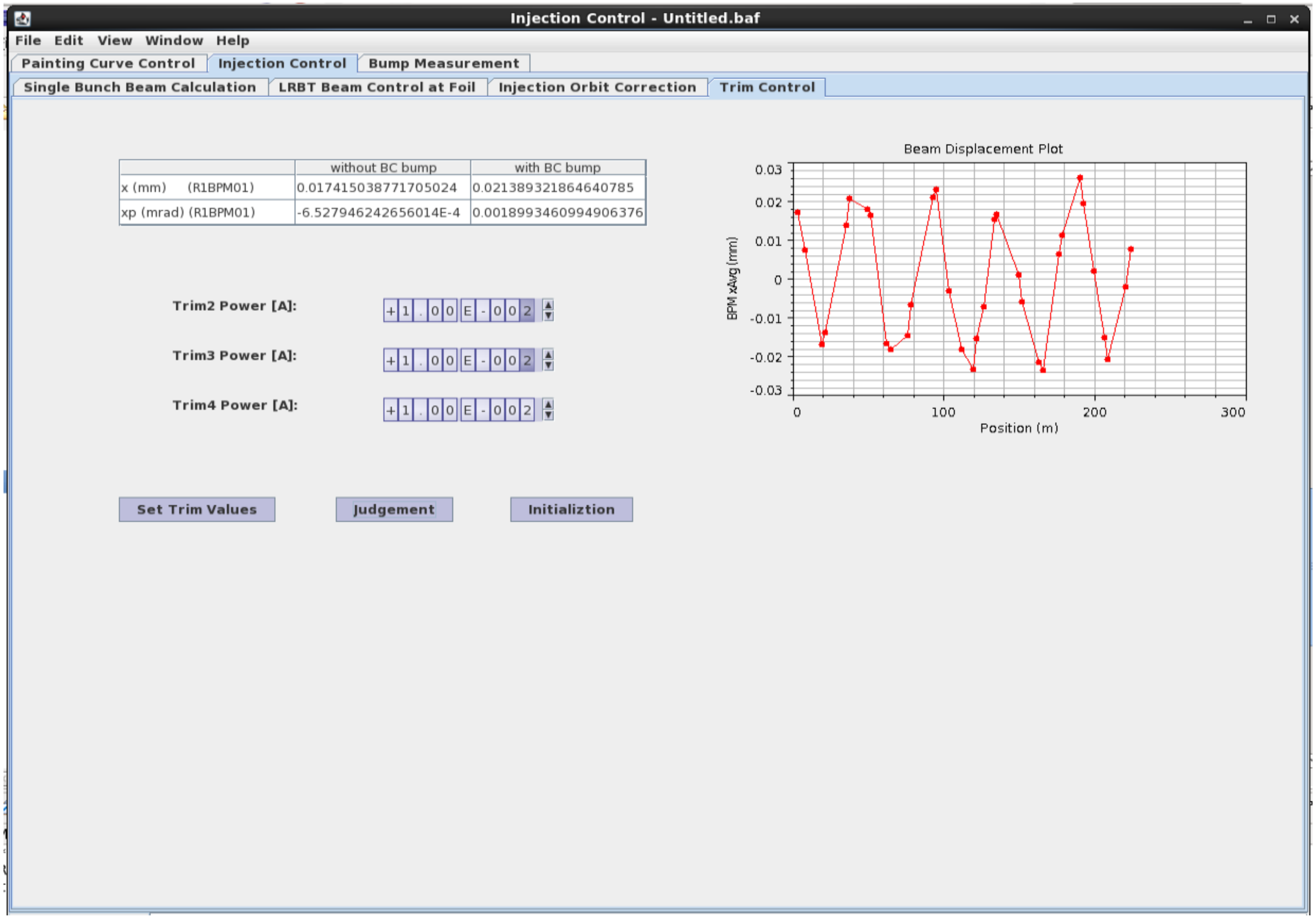
Injection orbit correction

- If the injection orbit with BC bump gives away, with the transmission matrix, the optimized solutions of the three trim powers of BC magnets can be calculated, and then the injection orbit can be corrected.



Trim control

- If the suitable solutions of the trim powers can not be given by the above program, it will be need to sharp tuning the three trim powers respectively.



V. Summary

- The dependence of the painting beam on the injection beam parameters for CSNS/RCS were studied, and the simulation was done for different momentum spreads, different *rms* emittance of injection beam, and different matching conditions.

- The optimized ranges of the injection beam parameters were obtained.

- The particle distribution during the injection process for CSNS was studied, and the optimized painting range and painting method can be found.

- The injection control software for CSNS was introduced and discussed.

Thank you for your attention!