Reconstruction of Particle Distributions at RFQ Exit at SNS Beam Test Facility

Zhouli Zhang

Department of Physics and Astronomy, University of Tennessee, USA
Spallation Neutron Source, Oak Ridge National Laboratory, USA

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- Reconstruction of initial particle distribution at RFQ exit
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    - *Influences of beam parameters and quadrupole gradients*
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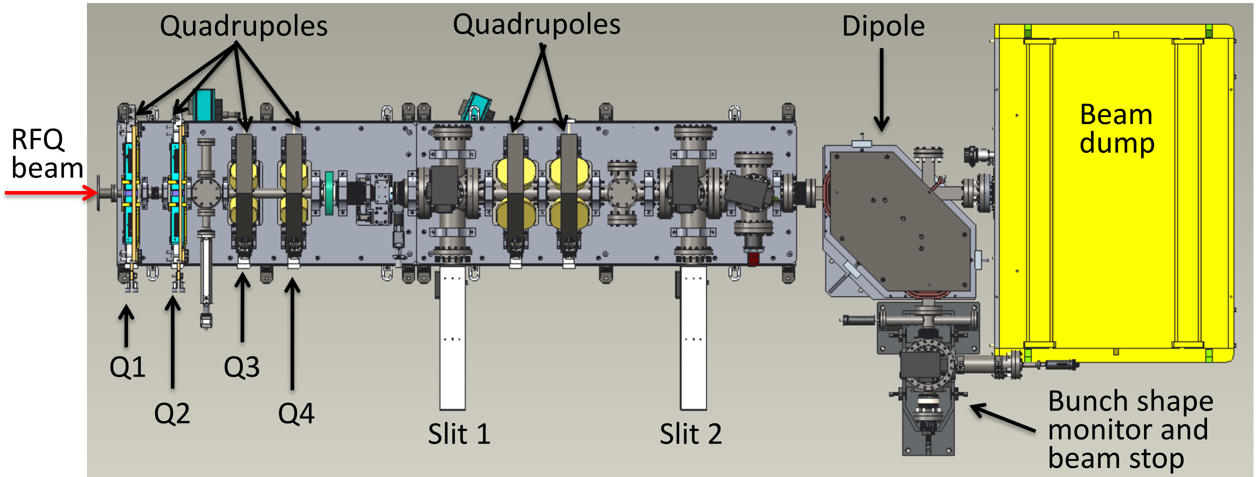
Background of the work

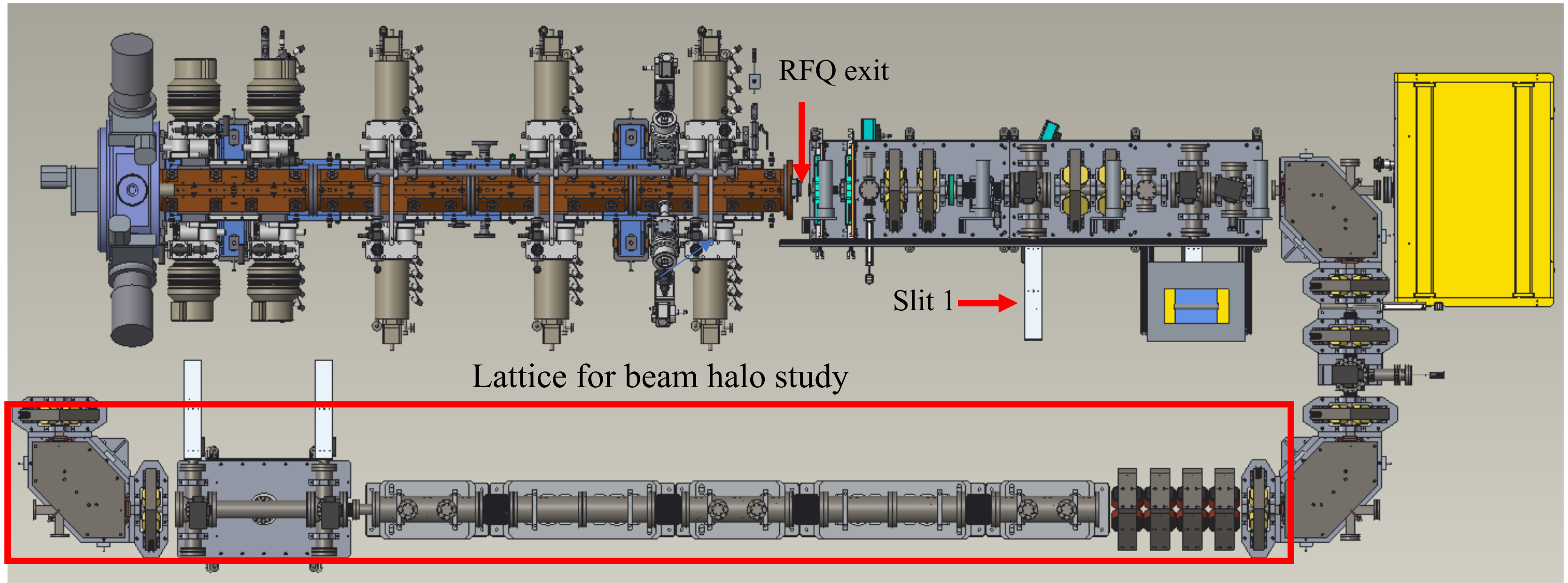


Layout of beam test facility at SNS

High dynamic transverse and longitudinal beam diagnostic devices are installed. BTF is built to provide a platform for conducting R&D for novel accelerator physics and technological concepts related to high intensity hadron beam generation, acceleration, manipulation and measurement.

One of the main goal is to conduct the first direct 6D phase space measurement of a hadron beam which will be used for high intensity **beam halo study**.

Background of the work



Beam measured at slit 1, reconstructed at RFQ exit, used for beam halo study.

BTF lattice extension

Reconstruction of particle distributions from 6D measurement is not an easy task:

1 How to reconstruct the initial particle distribution?

2 What will affect the reconstruction of initial distribution?

3 How to evaluate the accuracy of the reconstructed distribution or how to get the real initial distribution?

To answer the questions and to obtain experiences, reconstruction of distributions from measured 2D distributions is carried out as the first step.

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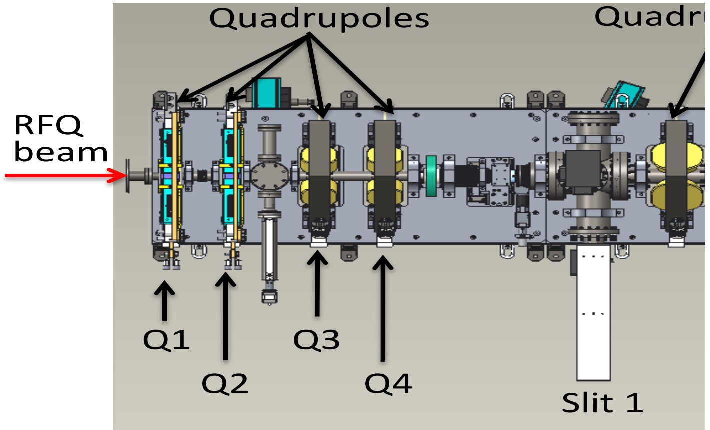
Back-tracking simulation code

General methods to reconstruct the initial particle distributions with PIC simulation code:

- *Fitting the RMS beam sizes of the measured distributions*
- *Tomography-like technique*

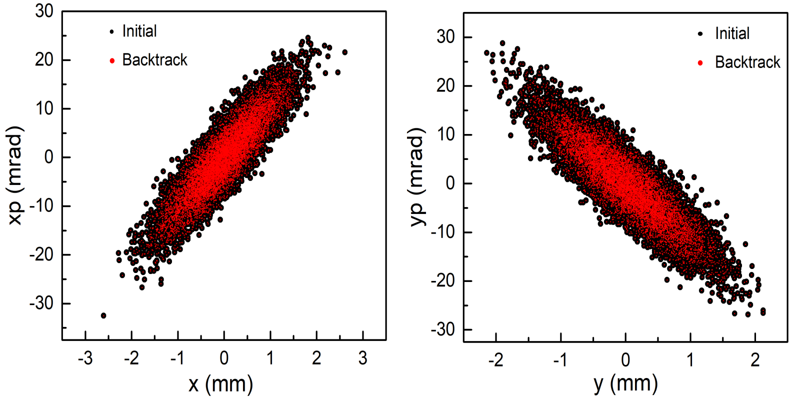
At SNS, a direct method based on emittance data in both transverse directions and the backward tracking ability of PyORBIT has been developed. In this method, The back-tracking simulation code transforms measured particle distributions into bunches for backward tracking, creates backward lattice to track the bunch from measurement location to entrance of the lattice.



Lattice for beam measurements

Back-tracking simulation code

Tested with ideal Gaussian distributions

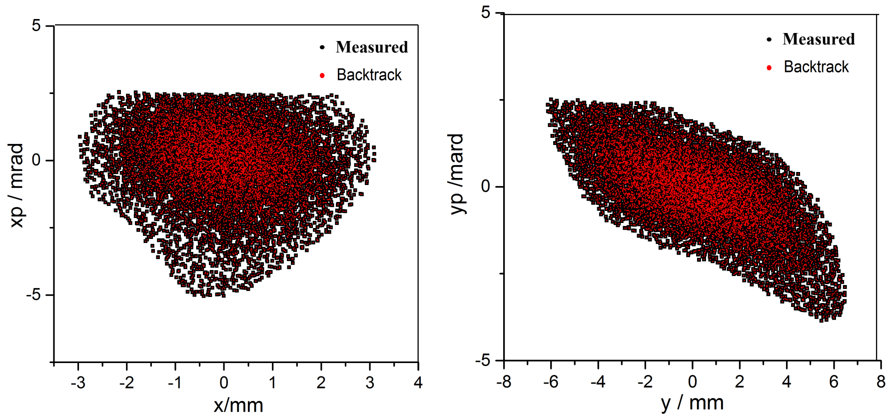


Backtrack distribution is produced by backward tracking and then forward tracking the ideal distributions.

maximum particle coordinate discrepancies

	0 mA (mm, mrad)	50 mA (mm, mrad)
x-xp	*(5.65e-5, 5.05e-4)*	*(6.37e-5, 8.21e-4)*
y-yp	*(5.0e-5, 5.0e-4)*	*(5.31e-5, 8.6e-4)*

Tested with measured distributions



Backtrack distribution is produced by backward tracking and then forward tracking the measured distributions.

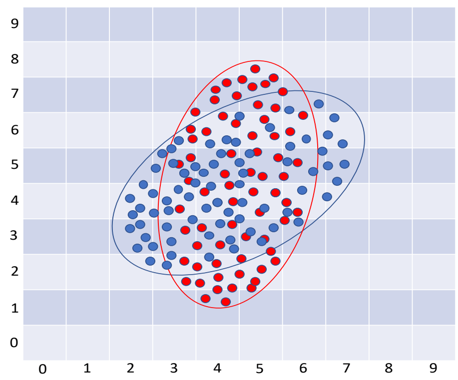
maximum particle coordinate discrepancies

	20 mA (mm, mrad)
x-xp	*(3.47e-5, 1.10e-4)*
y-yp	*(7.89e-5, 8.8e-5)*

The back-tracking code is capable of accurately reconstructing a distribution!

Concept of Distribution Discrepancy

- ✓ Due to the uncertainties of quadrupole gradients and fluctuations of beam current during measurements, initial distribution that reconstructed by one measured distribution may deviate from the ***real*** initial distribution.
- ✓ Real initial distribution needs to be confirmed by two or more measured distributions produced by different quadruple settings.



Concept of distribution discrepancy is proposed to calculate coincidence of two distributions:

$$DistD = \sum_{i,j} \left| \frac{N^r_{i,j}}{TN^r} - \frac{N^b_{i,j}}{TN^b} \right|$$

where, i and j are the grid number in x and xp direction, r and b mean the red distribution and blue distribution, $N^r_{i,j}$ and $N^b_{i,j}$ stand for the particle number of red distribution and blue distribution in the (i,j) square, TN^r and TN^b are total particle number in the red distribution and blue distribution, respectively.

A small distribution discrepancy means the two distributions are not only close to each other but also close to the real initial distribution which was obtained when $DistD = 0$.

$Minimum\ DistD$ → Quasi-real initial distribution (very close to real distribution) is obtained.

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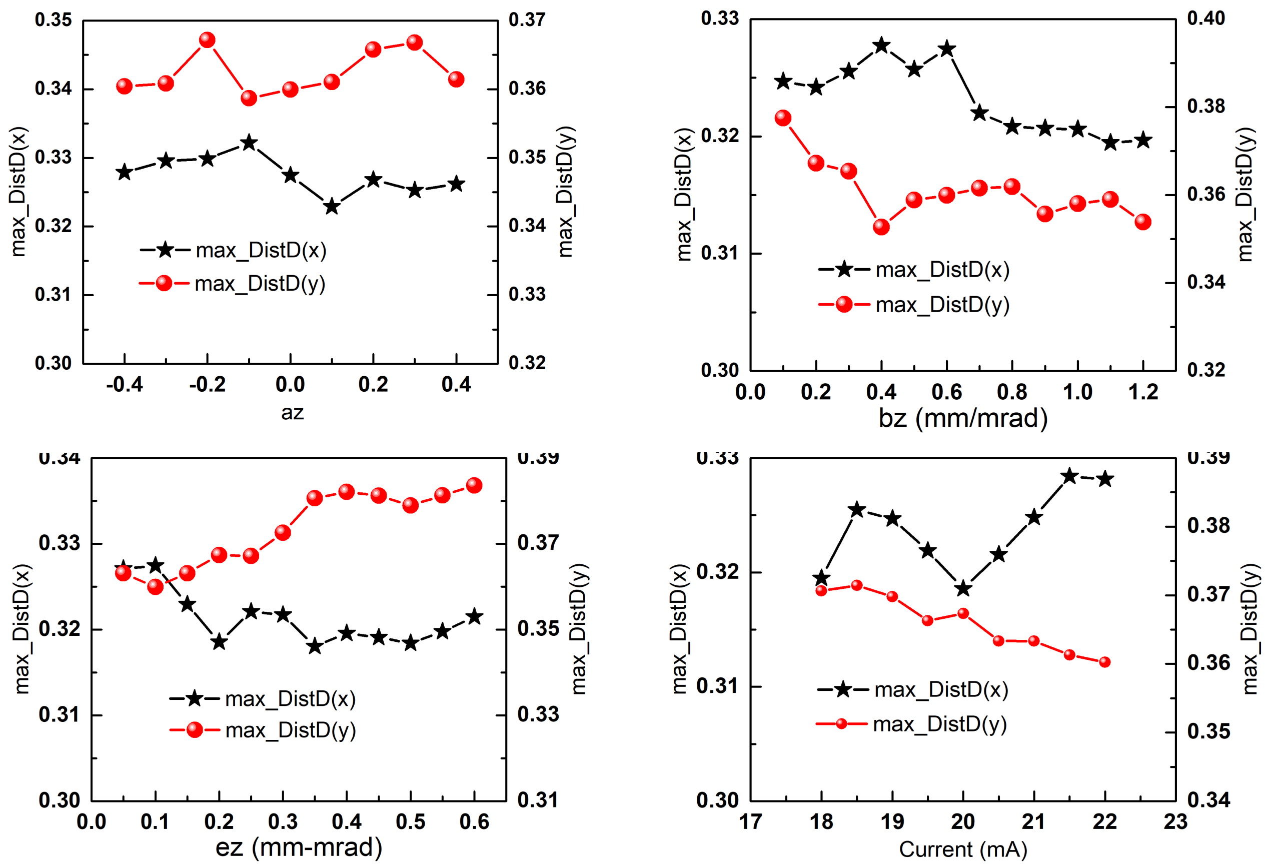
Influences of beam parameter variations

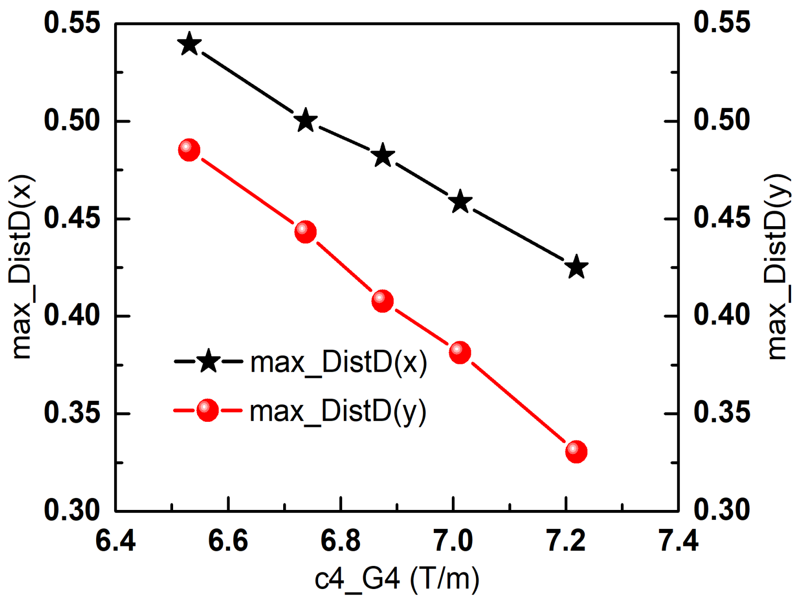
- Assigned longitudinal distribution
- Beam current



Variations of beam parameters nearly has no influences on distribution discrepancy!

Influences of quadrupole gradient uncertainties

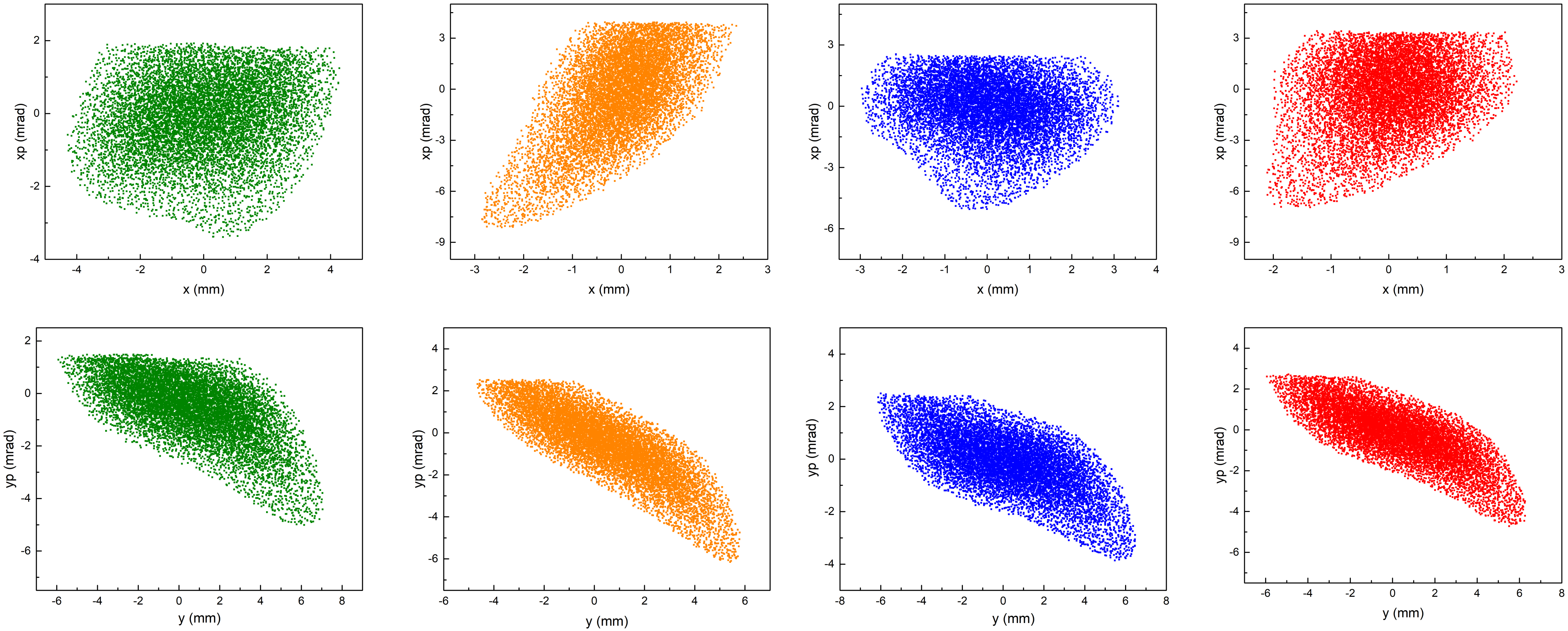
The power supplies of the the quadrupoles are stable, influences of quadrupole come from uncertainty of the current readings. Fluctuation of current reading ranges from -5% to 5% .



Variations of distribution discrepancies are about 27% and 45% in x-xp phase space and y-yp phase space.

Uncertainties of quadrupole gradients has a big influence!

Measured distributions



Produced by four different quadrupole settings

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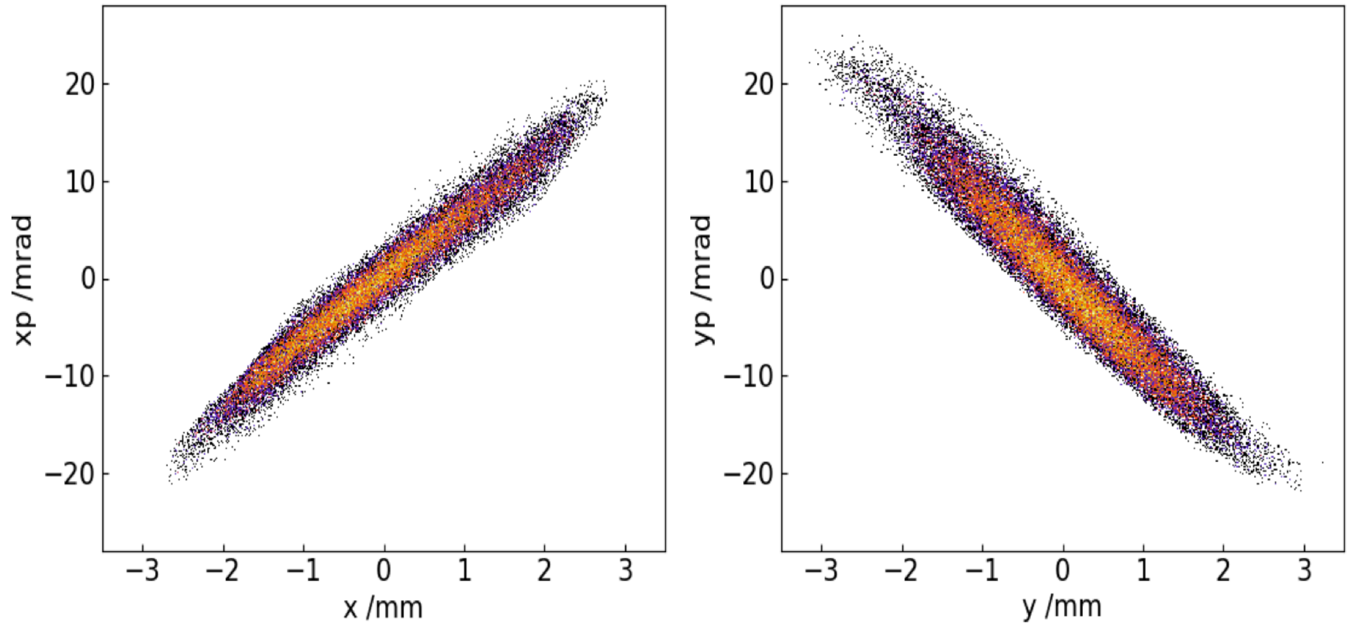
Generation of Initial Particle Distributions

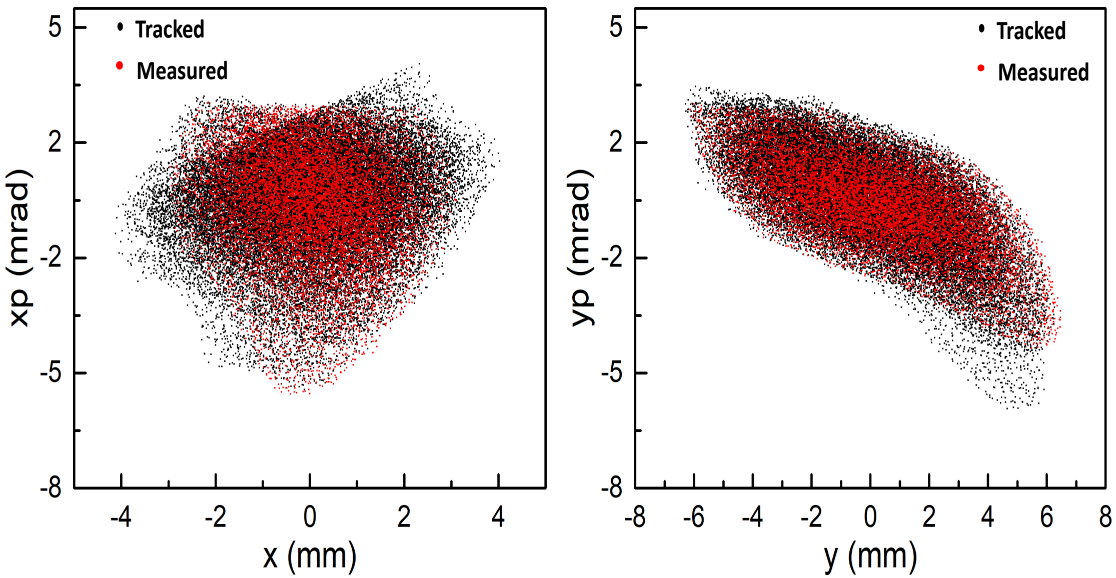
Influences of all quadrupole gradient uncertainties have been investigated, initial distribution is obtained when distribution discrepancy is minimum value.

$DistD(x) = 0.281$
$DistD(y) = 0.270$



Combined initial distributions of the four measured case

Comparison between measured distributions and forward-tracking distributions



Twiss parameters and emittances

Distribution	Measured	Tracked
α_x	0.11	-0.10
$\beta_x\ (mm/mrad)$	0.80	1.09
$\varepsilon_x\ (mm \cdot mrad)$	1.71	1.81
α_y	0.91	0.95
$\beta_y\ (mm/mrad)$	3.10	2.79
$\varepsilon_y\ (mm \cdot mrad)$	2.27	2.25

Distributions agree well except a small area with low particle density.

Using the minimum distribution discrepancy to obtain the real or quasi-real initial distributions is reliable.

Summary

- Reconstruction of particle distributions from 6D measurement is required to do beam halo study, but it is not easy, so reconstruction from measured 2D distributions is carried out as the first step.
- Accuracy of the back-tracking code is verified.
- The concept of distribution discrepancy is proposed to find the real initial distribution.
- Effects of beam parameter fluctuations on reconstructed initial distributions are small, while influences of quadrupole gradient uncertainties are big.
- Using the minimum distribution discrepancy to obtain the real or quasi-real initial distributions is reasonable.

Acknowledgements

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