TRIUMF

Design of a multi-harmonic buncher for TRIUMF 500 MeV cyclotron

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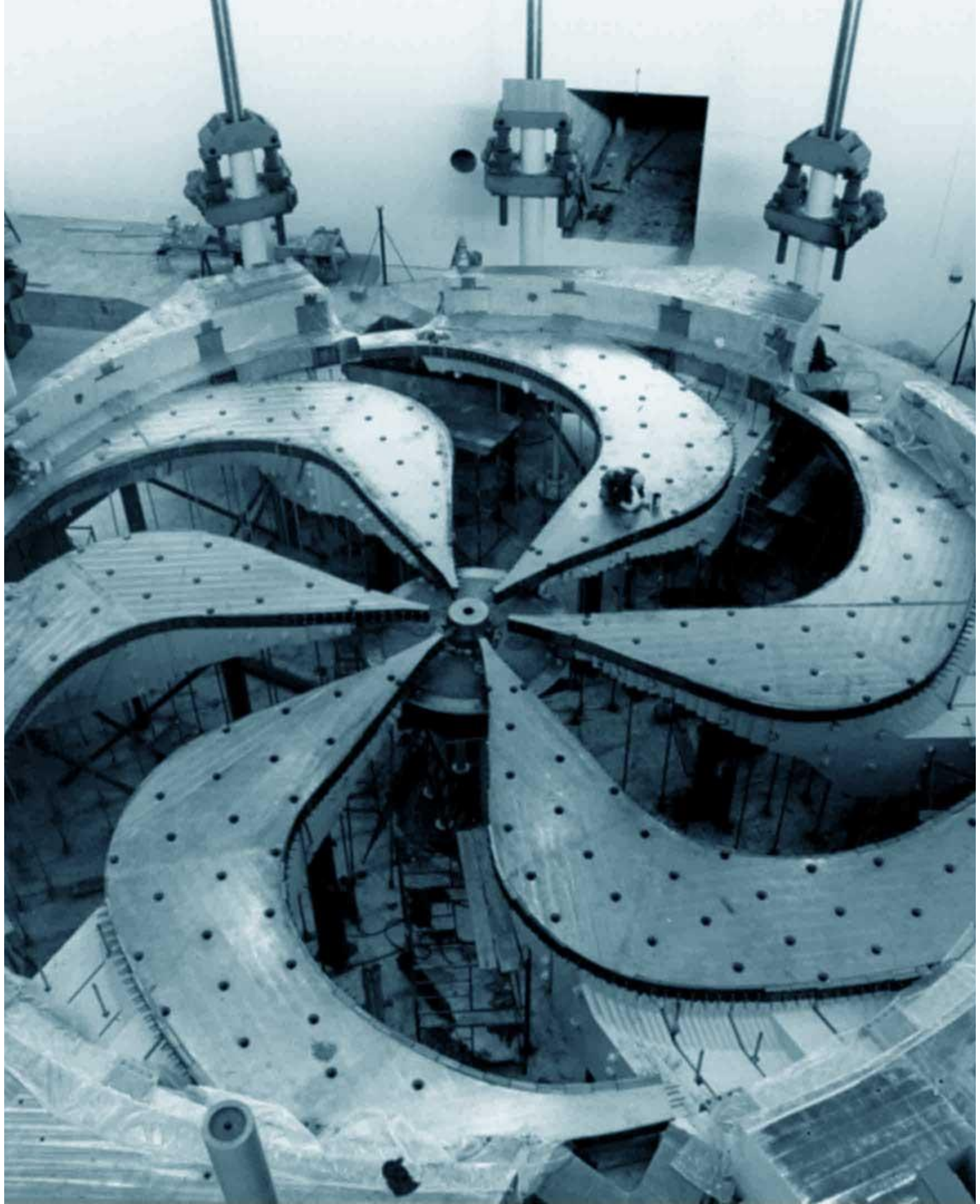
TRIUMF, Vancouver, BC, CANADA



2022-12-05

CYC2022, Beijing, China

Discovery, accelerated

Overview

- Motivation
- Status on the injection beamline upgrade program
- Present buncher system
- New buncher system
- Summary and outlook

Motivation

Growing demand for higher proton beams out of cyclotron (Total extracted current ~400 μA)

- **Injection beamline upgrade program**
  - Injection of high intense high brightness beams
  - Reliable operation of injection beamline

Beam species	H-
Beam energy	300 keV
Maximum beam intensity	1 mA
Duty cycle	0.1 % to 99 %
Bunching frequency	23.06 MHz

Table:1 Basic beam requirements

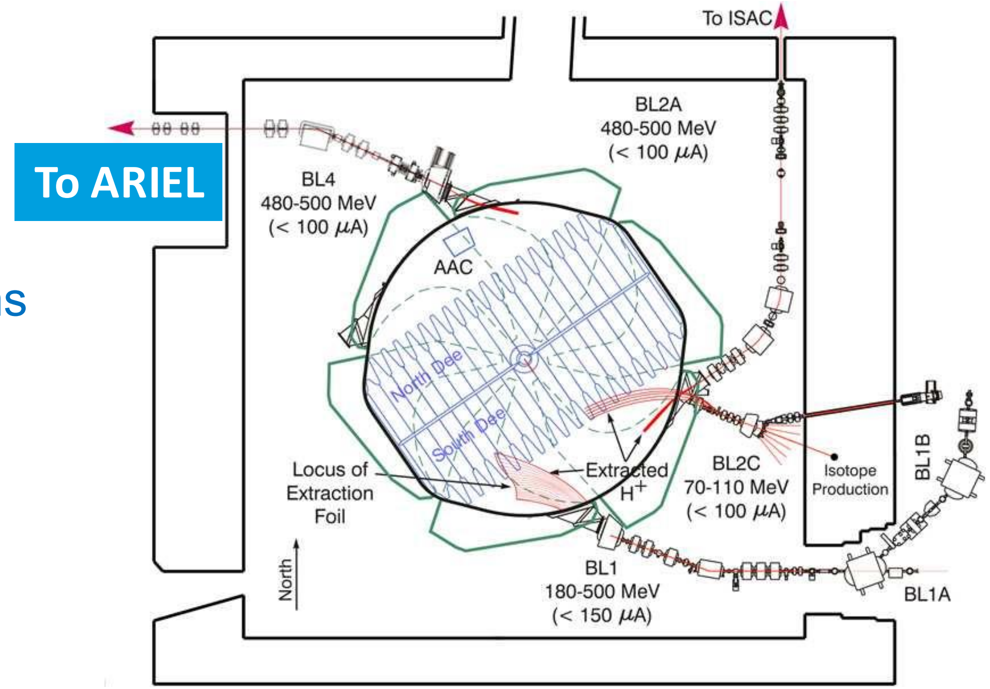


Fig. 1: TRIUMF 500 MeV H- cyclotron

Status on the injection upgrade program

Current deliverables:

- New ion source terminal (I2)
- New beam transport section from I2 to I1
- Transport section upgrade from I1 to vertical section
- **Bunching systems**
- Machine protection
- Magnetic stray field compensation
- Diagnostics
- Controls (EPICS)

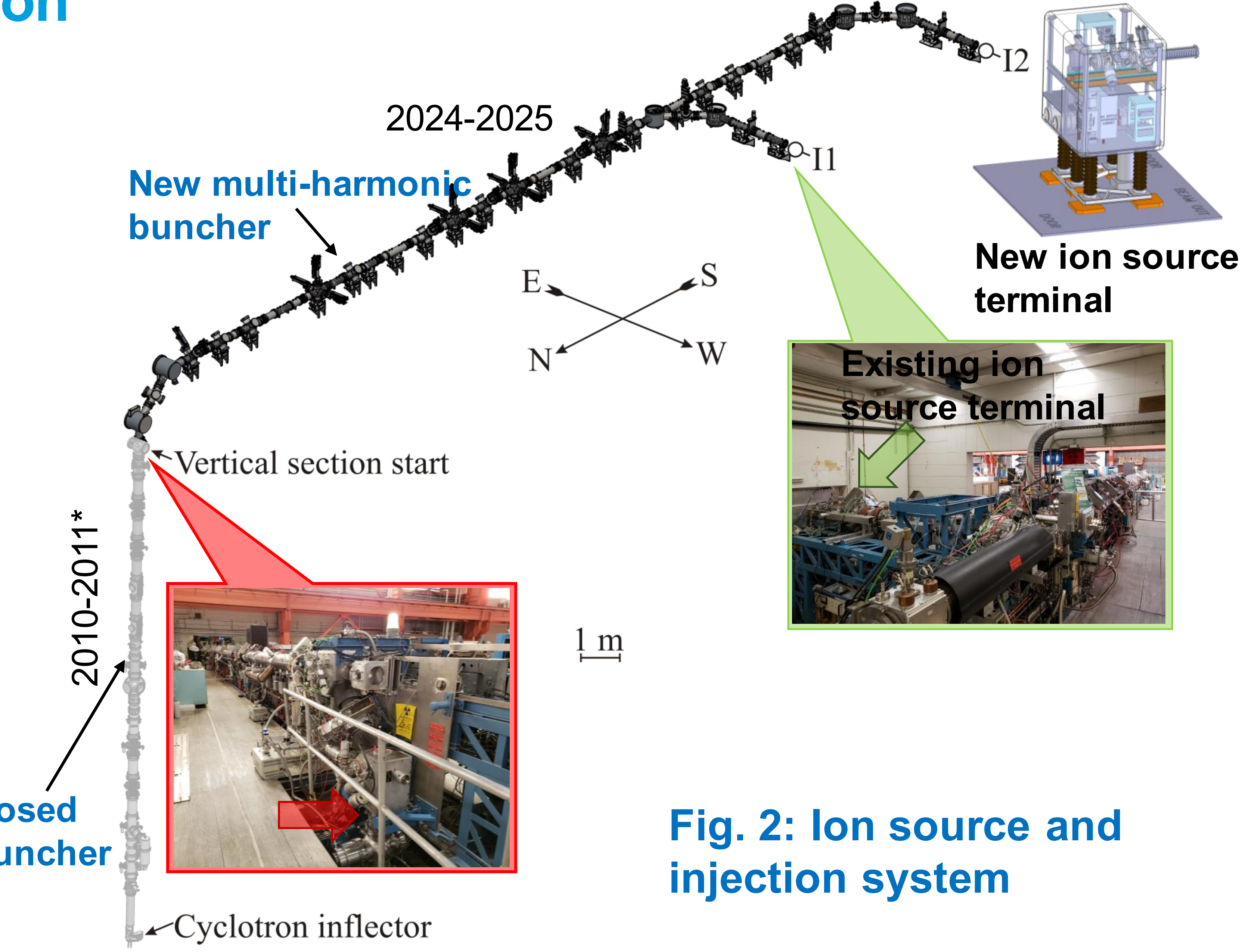


Fig. 2: Ion source and injection system

* R. Baartman, ``Optics Design of the ISIS Vertical Section Replacement", TRI-DN-09-11, TRIUMF document-22849

Present buncher system

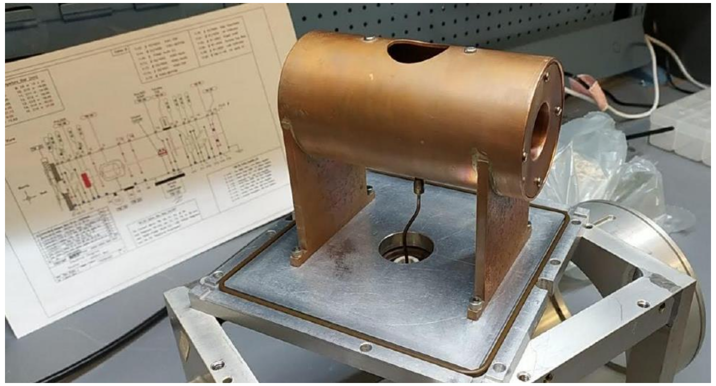


Fig. 3: Present 46 MHz 2nd buncher

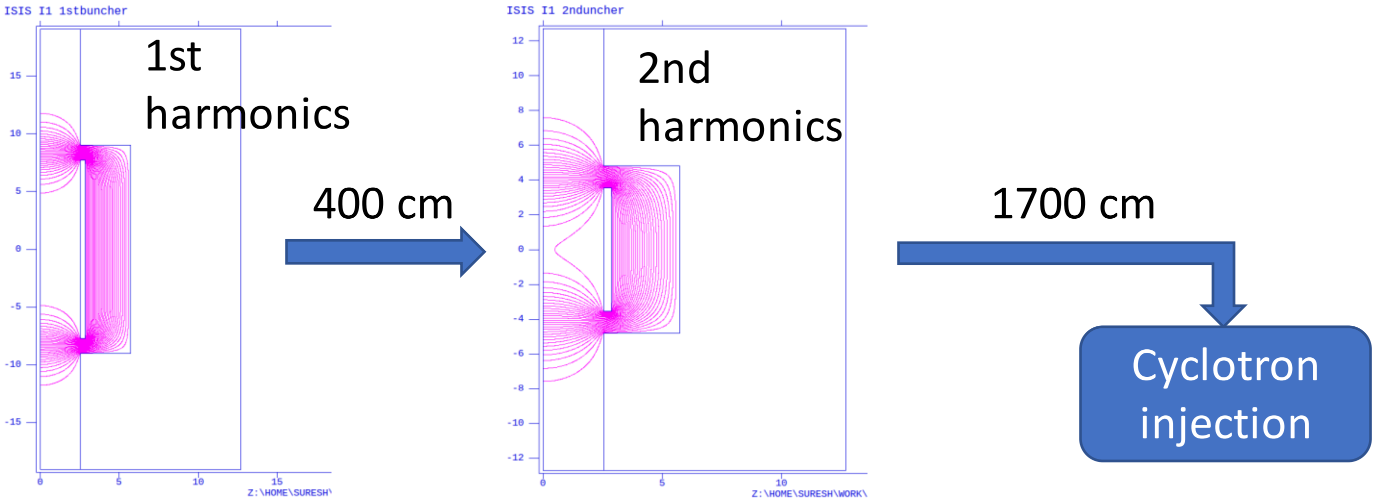


Fig. 4: Calculated electrostatic potential contour by using the code POISSON/SUPERFISH

Aperture radius	2.54 cm
1st harmonic	23.06 MHz
2nd harmonic	46.12 MHz
beta•lambda	33.53 cm

Table:2 Present buncher *

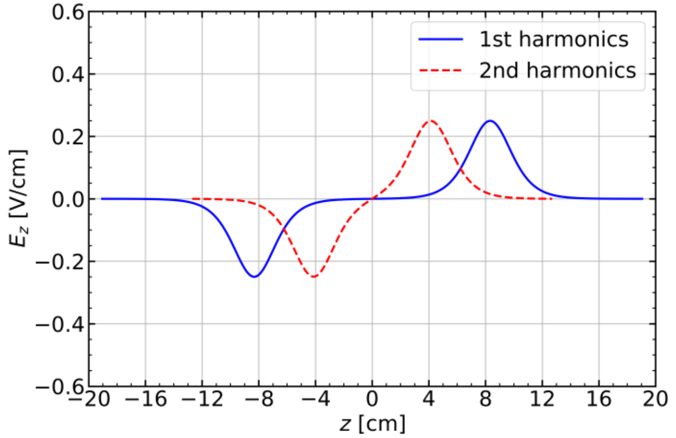


Fig. 5: Calculated electric field along the axis of the buncher with an applied potential of 1 V.

* Baartman, R A and Dutto, G and Schmor, P W, "The TRIUMF high efficiency beambunching system", Proceedings of the Tenth International Conference on Cyclotrons and their Applications, East Lansing, Michigan, US, 1984

A novel multi-harmonic buncher

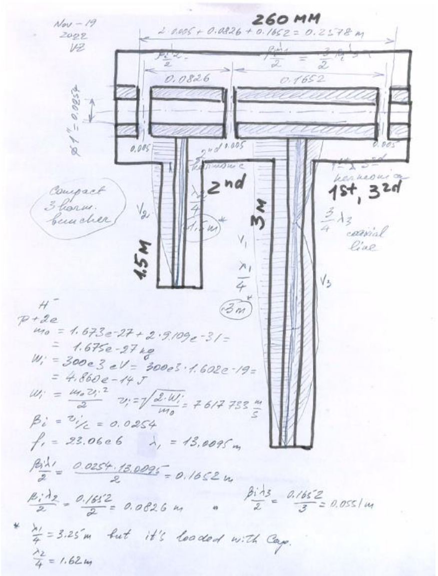


Fig. 6: A concept layout of the multi-harmonic buncher cavity *

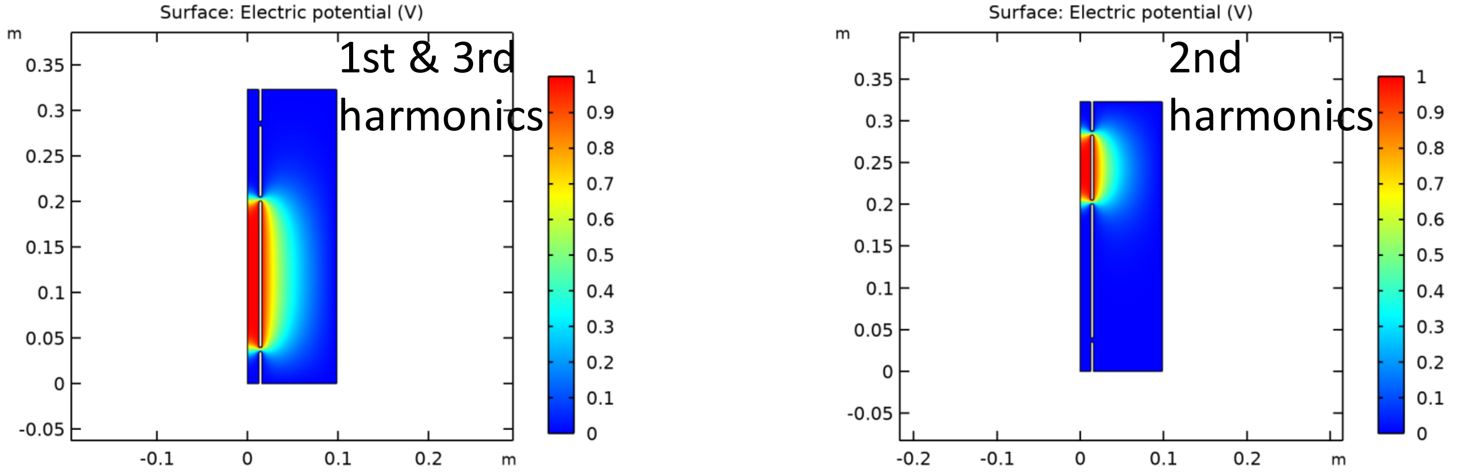
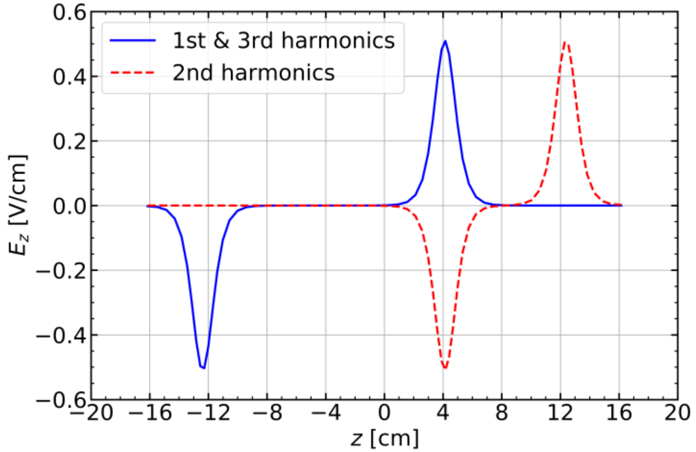


Fig. 7: Calculated electrostatic potential contour by using the code COMSOL



Aperture radius	1.27 cm
1st harmonic	23.06 MHz
2nd harmonic	46.12 MHz
3rd harmonic	69.18 MHz
Re-buncher	23.06 MHz

Table:3 New multi-buncher

Fig. 8: Calculated electric field along the axis of the buncher with an applied potential of 1 V.

Courtesy: * proposed by V. Zvyangintsev

Initial particle distributions

Simulation tool

- **Particle-in-cell code WARP ***

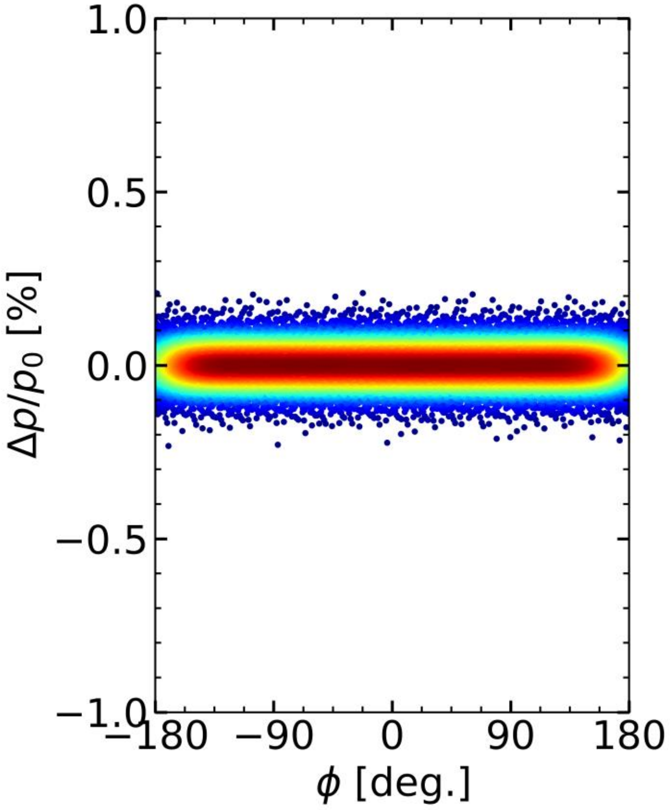


Fig. 9: Calculated initial longitudinal phase-space

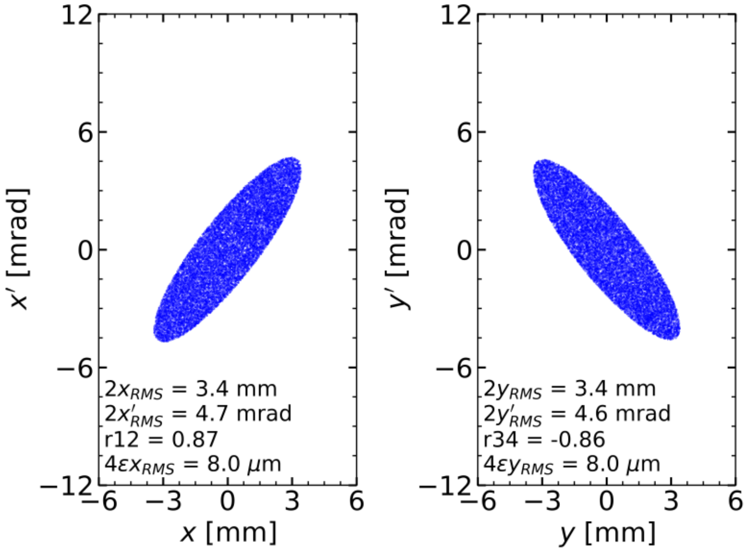


Fig. 10: Calculated initial transverse phase-space

A. Friedman et al., Computational Methods in the Warp Code Framework for Kinetic Simulations of Particle Beams and Plasmas, in IEEE Transactions on Plasma Science, vol. 42, no. 5, pp. 1321-1334, May 2014

Present 1st & 2nd harmonic buncher (I = 650 μA)

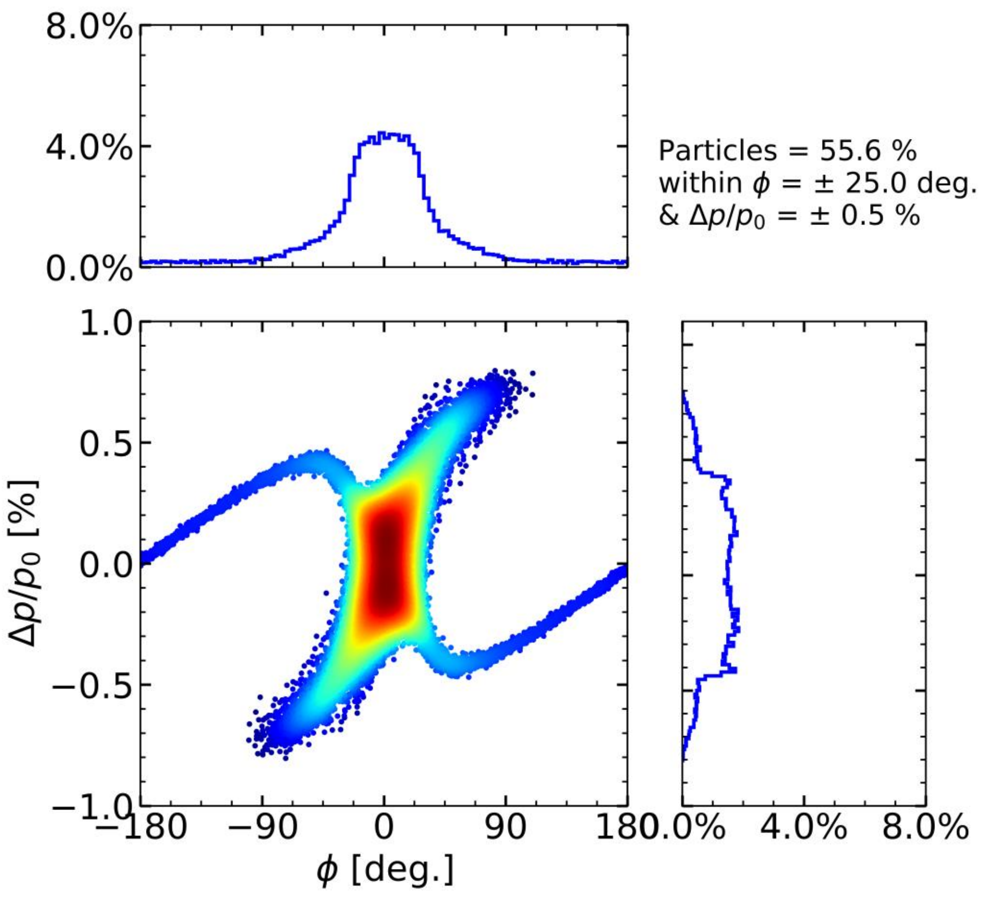


Fig. 11: Calculated longitudinal phase-space

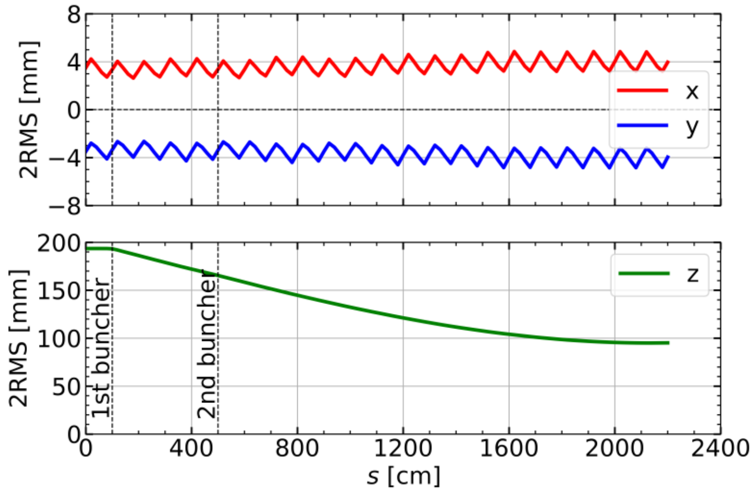


Fig. 12: Calculated beam envelope (2RMS, positive for x, negative for y, longitudinal for z)

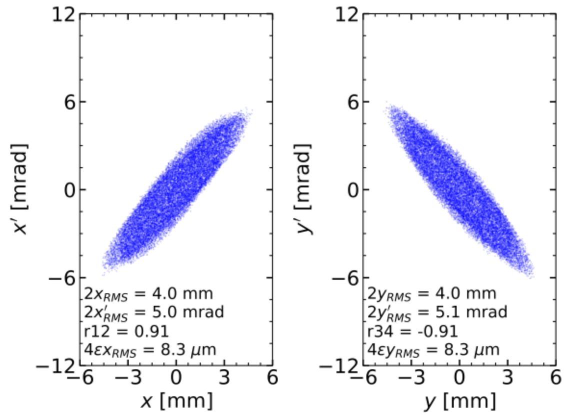


Fig. 13: Calculated transverse phase-space

New multi-harmonic (I = 650 µA)

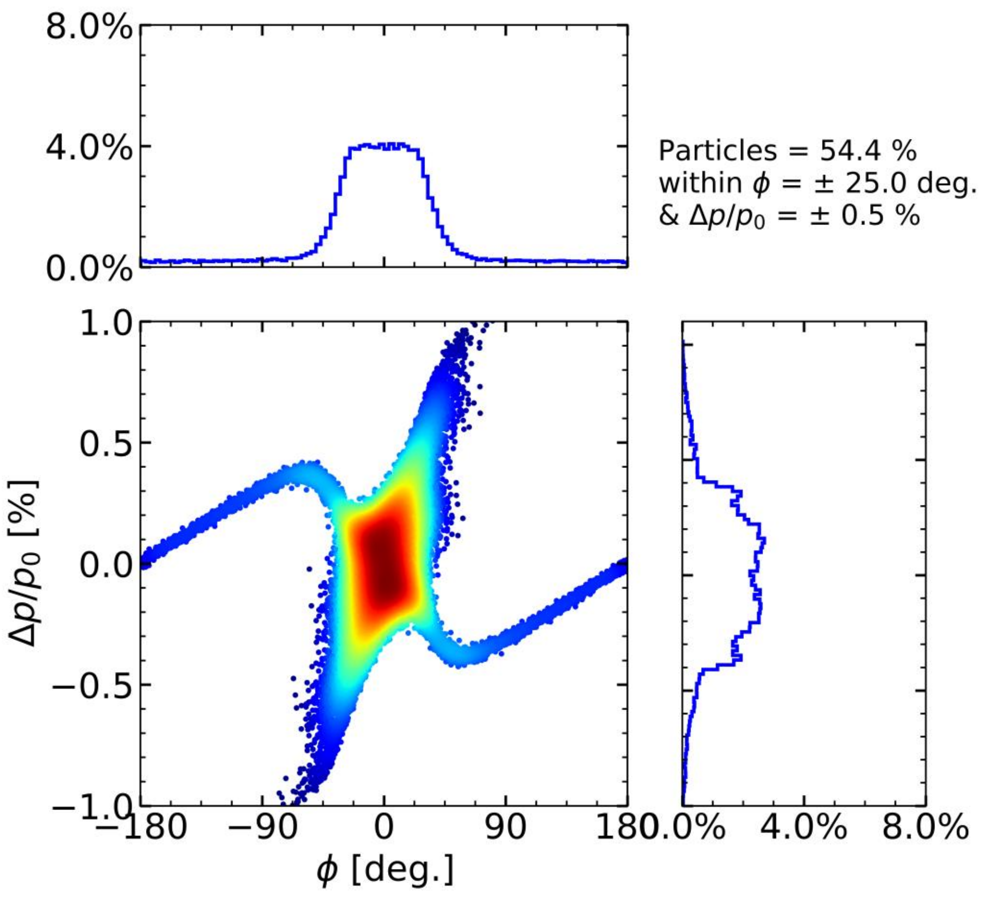


Fig. 14: Calculated longitudinal phase-space

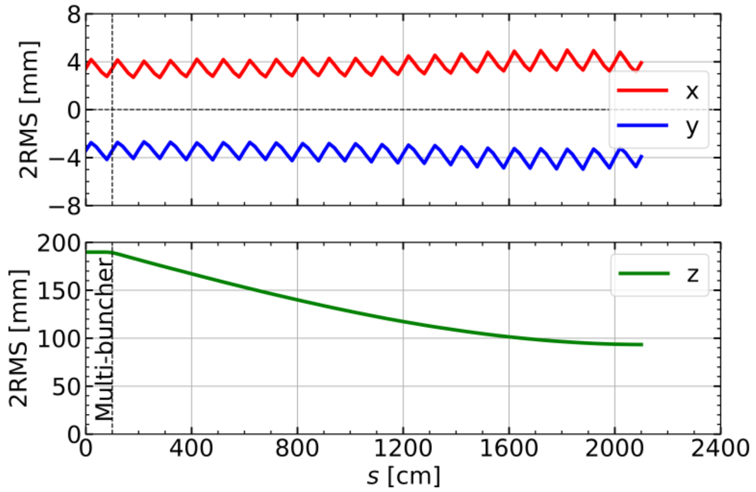


Fig. 15: Calculated beam envelope (2RMS, positive for x, negative for y, longitudinal for z)

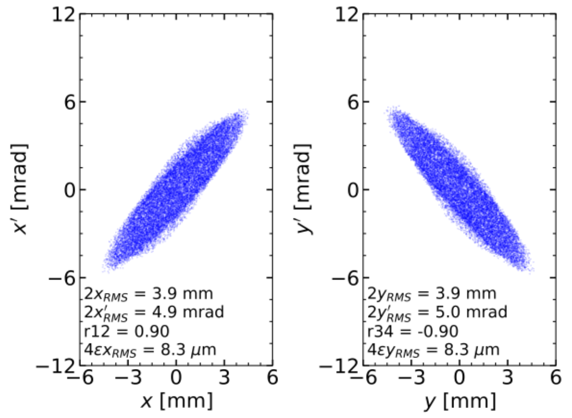


Fig. 16: Calculated transverse phase-space

New multi-harmonic with re-buncher (I = 650 µA)

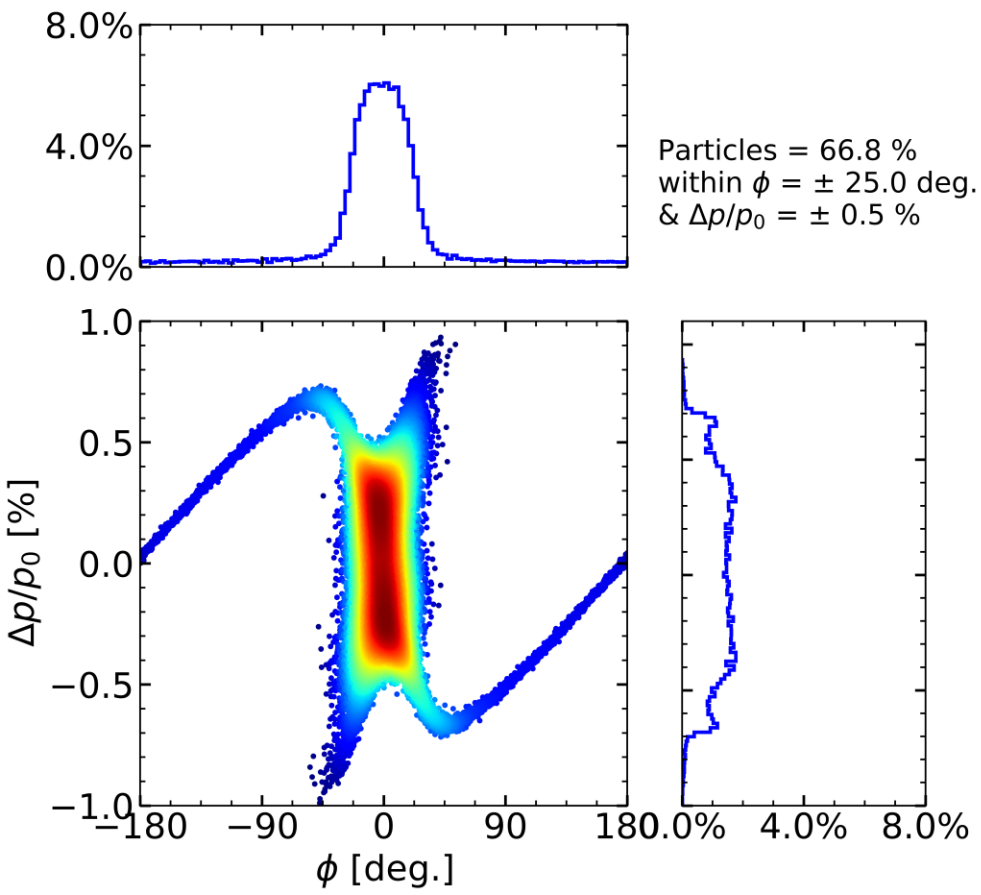


Fig. 14: Calculated longitudinal phase-space

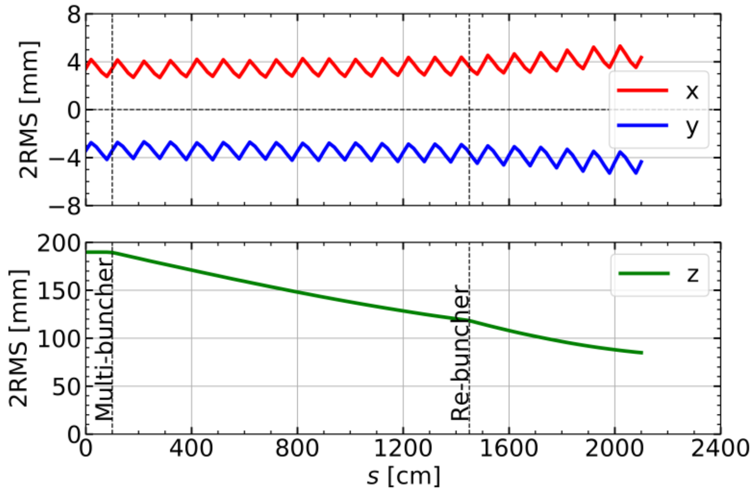


Fig. 15: Calculated beam envelope (2RMS, positive for x, negative for y, longitudinal for z)

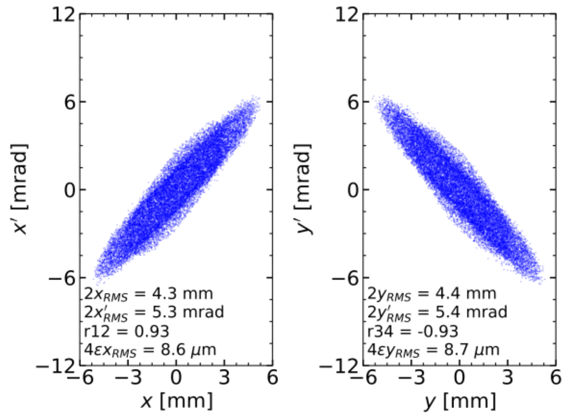


Fig. 16: Calculated transverse phase-space

New multi-harmonic with re-buncher (I = 1 mA)

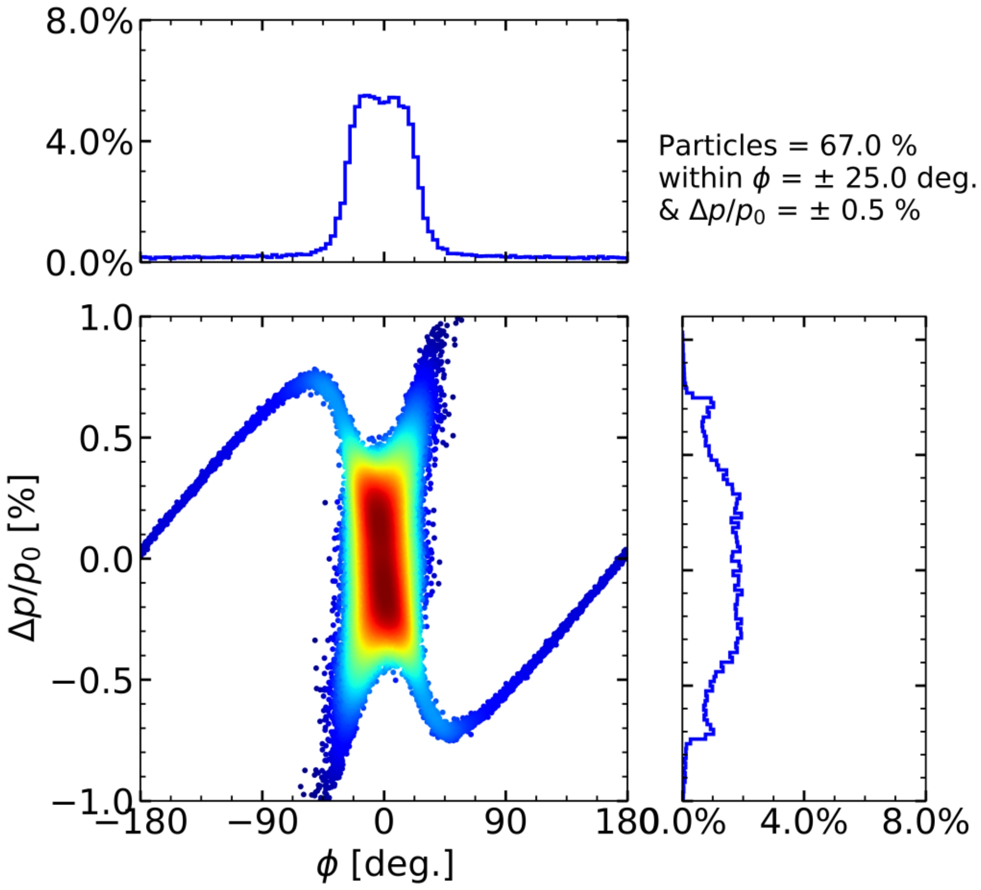


Fig. 17: Calculated longitudinal phase-space

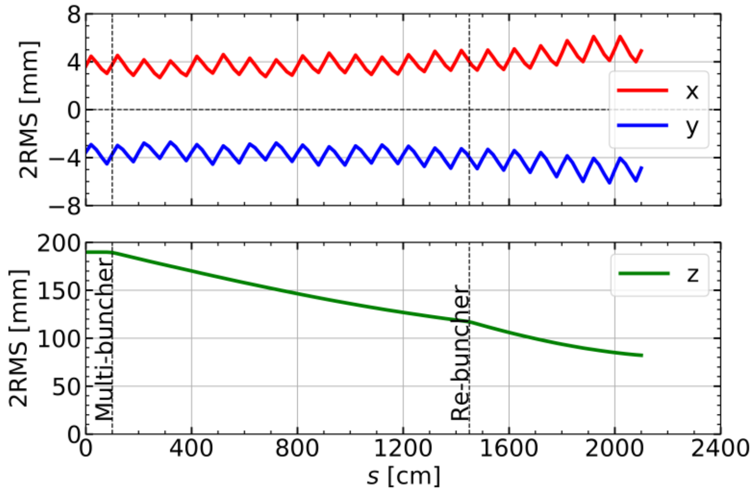


Fig. 18: Calculated beam envelope (2RMS, positive for x, negative for y, longitudinal for z)

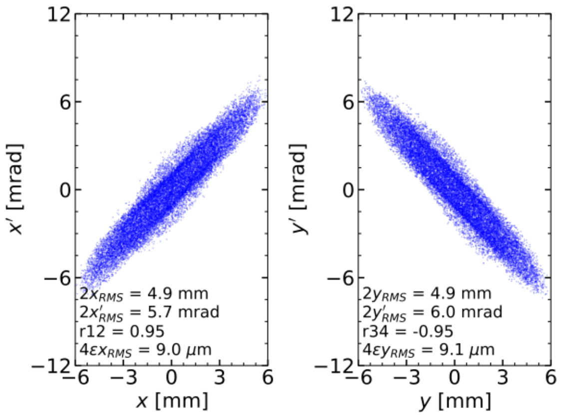


Fig. 19: Calculated transverse phase-space

Summary

- A novel multi-harmonic buncher system has been designed, which will be operated by up to three harmonics.

- The beam dynamics studies have been performed, including the space-charge effects using the particle-in-cell code WARP.

- The new bunching system will be a combination of multi-harmonic and re-buncher for transporting beam injection beamline intensity higher than 500 μA.

- Simulation results of longitudinal beam dynamics are presented for transporting beam intensity up to 1 mA.

- The bunching efficiency of this system is about 67 % (± 25 deg. and $\Delta p/p = \pm 0.5$ %) at 1 mA injection line current could support up to 650 μA extracted currents

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Thank you
Merci

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