Simulation of space charge effects during multiturn injection with the codes PATRIC and pyORBIT

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Space charge workshop 2013, CERN

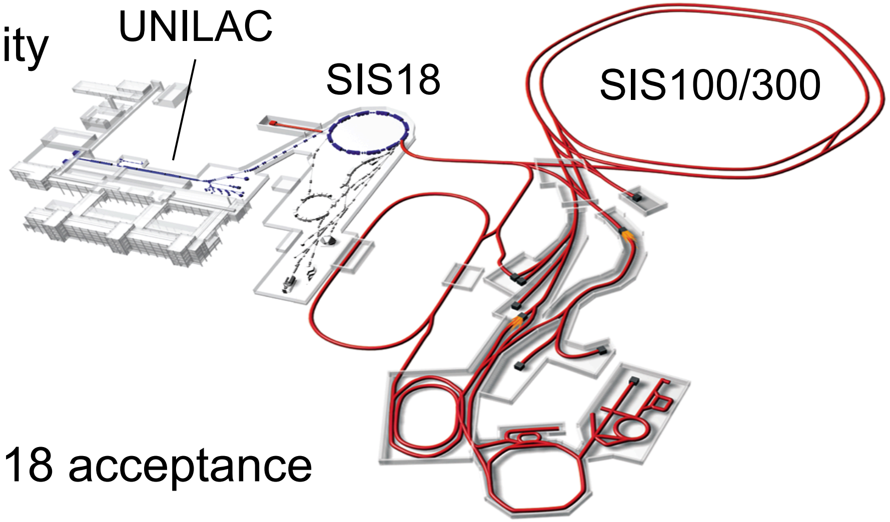
Outline

- SIS18 upgrade program for FAIR: Optimization of the multiturn injection
- Multiturn injection into SIS18: Horizontal betatron stacking
- Simulation code:
    - PATRIC
    - pyORBIT
- MTI simulation studies
    - Comparison between codes (low and high current)
    - Comparison between experiments and simulations (low current)
- Summary and Outlook

SIS18 upgrade program

Optimization of the MultiTurn Injection (MTI)

- SIS18 upgrade to increase the beam intensity
- Crucial point: **Optimization of MTI**
- Minimal beam loss:
  - To achieve design intensities
  - Dynamic vacuum pressure
- Max. number of inj. turns are limited by SIS18 acceptance and UNILAC beam emittance

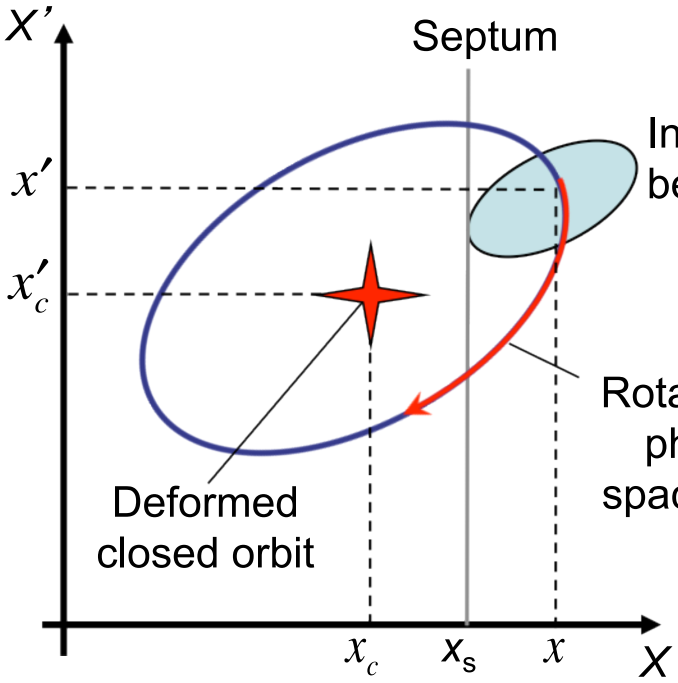


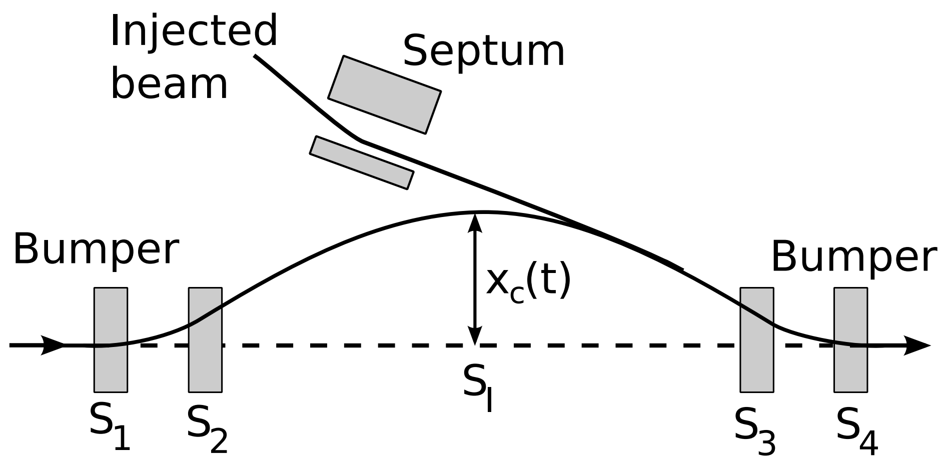
☑ Development of detailed simulation model
☑ Validation of the current model used in operation control program (SISMODI)
☐ Comparison between experiments and simulations for low and high currents
☐ Impact of space charge on MTI efficiency

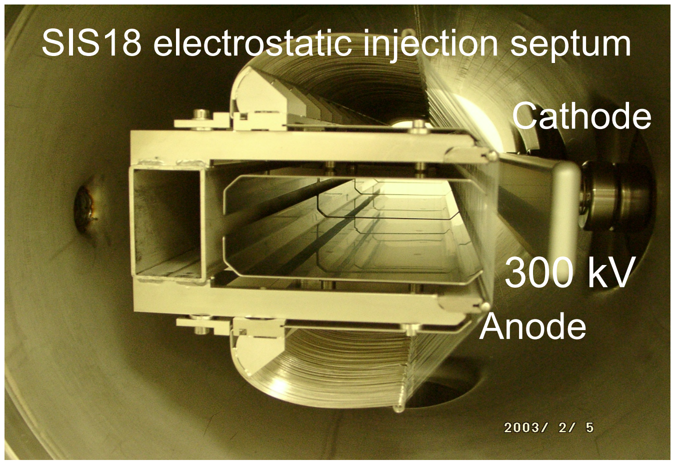
	UNILAC	SIS18
Reference primary ion	U^{28+}	U^{28+}
Reference energy (MeV)	11.4	200
Ions per bunch/ cycle	1.5E10	1.5E11
Hor. Emittance (rms)	2-3	50

Multiturn injection into SIS18

"Horizontal betatron Stacking"







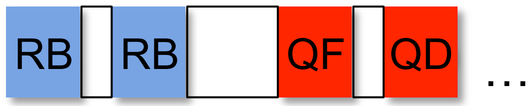
- Liouvile's theorem: Injection only into free phase space
- Betatron oscillation and changing of orbit bump
  ➔ free phase space
- Loss of ions at the septum due to the betatron oscillation
- Dilution during injection $D = \frac{\epsilon_f}{n_{mti}\epsilon_i}$

Simulation code

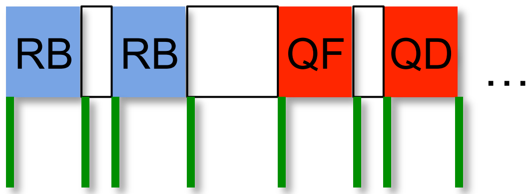
PArticle TRackIng Code (PATRIC)

- Pic class (representation of particles)
  - Number of particles increases during injection and decreases by losses

- SectorMap + BeamLine class (container for ion optical elements)
  - Input from MADX (thick lens)
  - Transport of particles

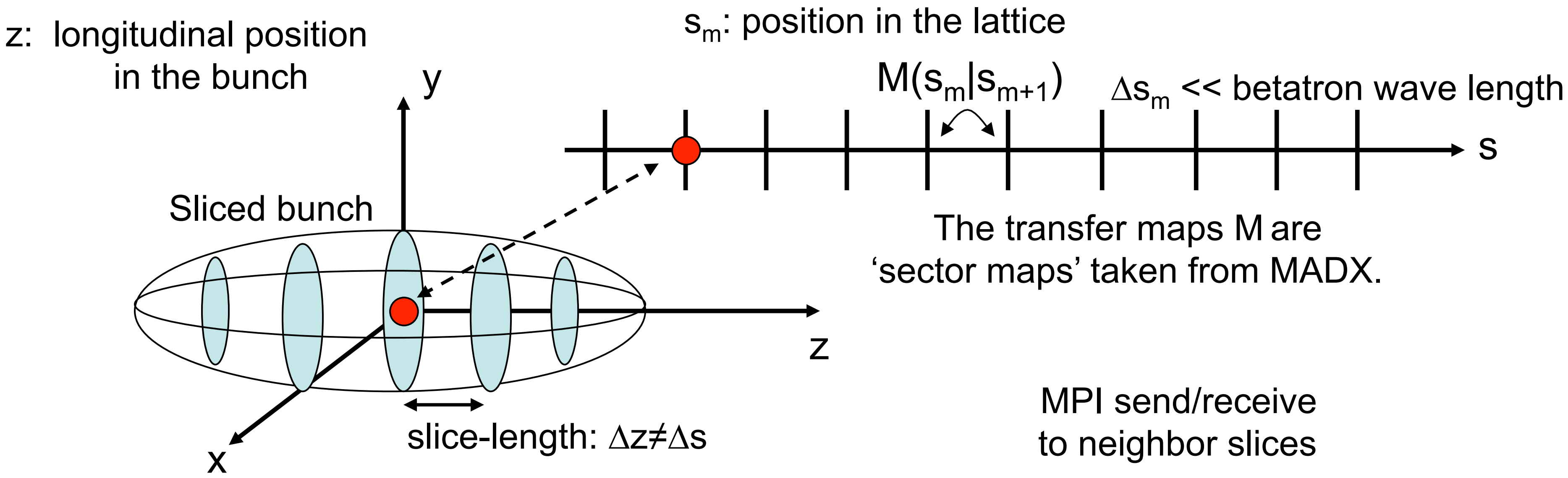


- Several classes to represent particle kicks
  - Self-consistent space charge kicks
  - Poisson’s equation is solved on 2D transverse grid

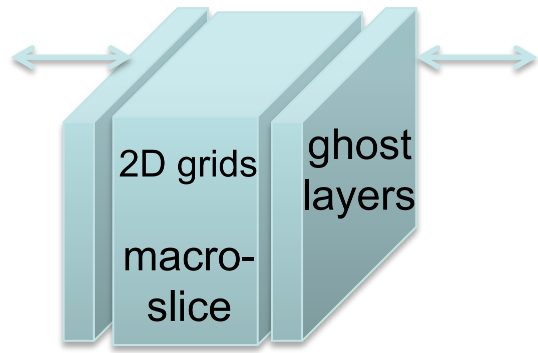


- Bump class (represents injection kickers)

PATRIC Code: Space charge solver



MPI send/receive to neighbor slices



2D space charge field for each slice:

$$\rho(x,y,z,s_m) = \sum_j Q_j S(\vec{x} - \vec{x}_j)$$ (3D bi-linear interpolation)

$$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} = \frac{\rho(x,y,\{z,s_m\})}{\varepsilon_0}$$ (fast 2.5D Poisson solver)

Transverse potential obtained for the 2D grid at z and lattice position s:

3D Grid-> Particle / Particle->Grid interpolation

- Grid slices "feel" all other slices

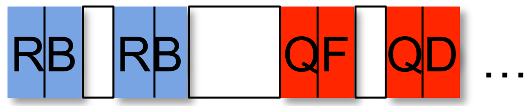
O. Boine-Frankenheim, ICAP 2012

Simulation code

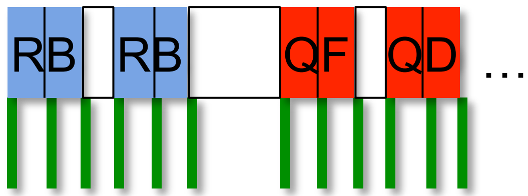
Python Objective Ring Beam Injection and Tracking (pyORBIT)

- Bunch class (representation of particles)
  - Number of particles increases during injection and decreases by losses

- Teapot class (container for ion optical elements)
  - Input from MADX (thin lens)
  - Notes for optical elements + collimator, injection, sc, …



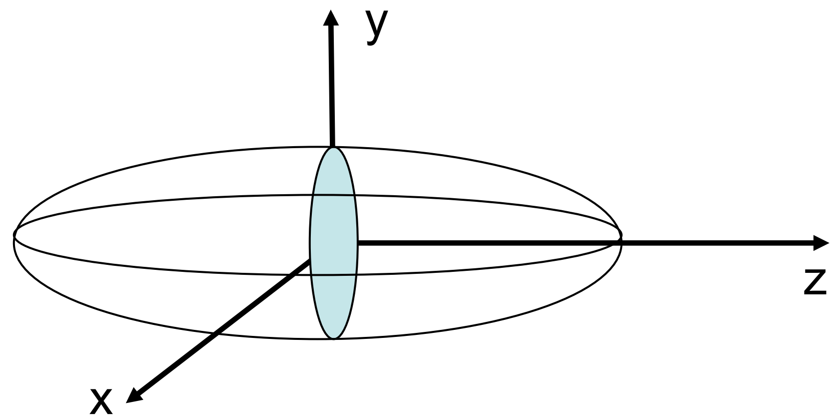
- Space charge solver
  - Self-consistent space charge kicks
  - Poisson’s equation is solved on 2D transverse grid



- Kickernodes class (represents injection kickers)

PyORBIT: Transverse Space Charge

- Solving Poisson equation on 2D grid
- Transverse momentum kicks between lattice elements



Particles are binned in 2D rectangular grid (momentum-conserving interpolation scheme)

→

Fast FFT solver
Space charge direct force solver

→

Particle kicks are obtained by interpolating the potentials
Kicks are weighted by local longitudinal density (bunch factor)

Source: Talks by S. Cousineau and J.A. Holmes, ORNL

MTI simulation studies

Comparison between codes

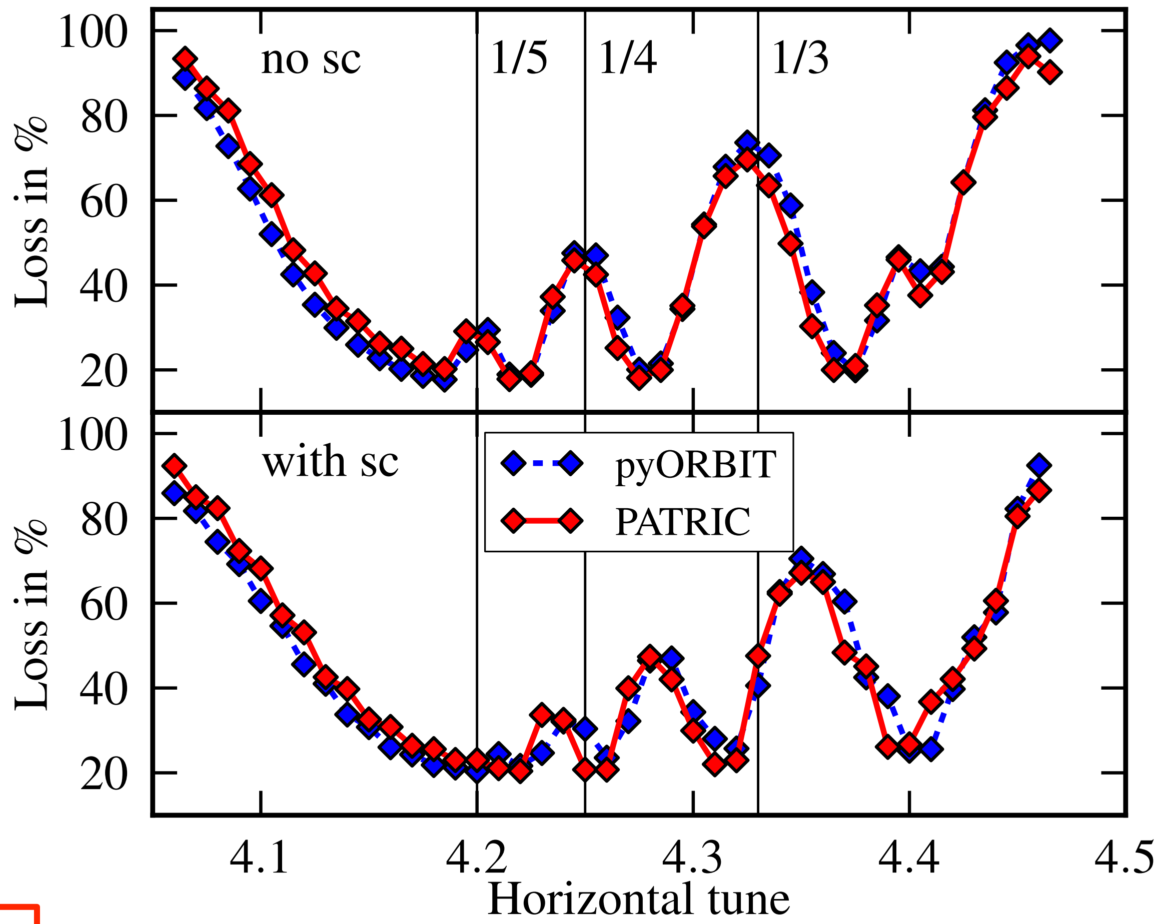
- Simulation settings:
  - KV+ Coasting beam
  - Injection of 20 beamlets
  - Linear orbit bump reduction
  - Linear SIS18 lattice
  - Collimation only at septum

- The loss maxima are located at 0, 1/2, 1/3, 1/4

- Both codes show the resonant character

- With space charge the maxima and minima of the efficiency are shifted

- Codes are in good agreement for loss calculation

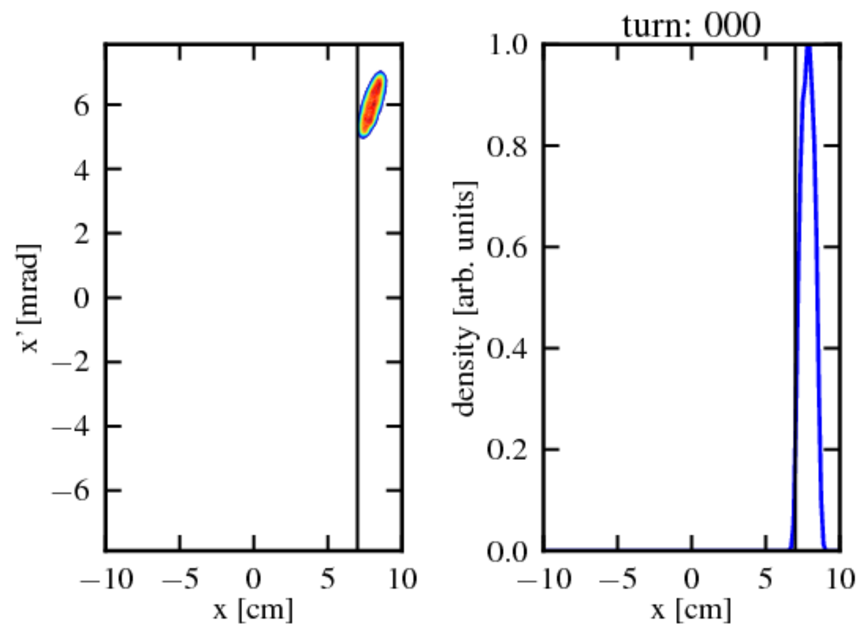


MTI simulation studies

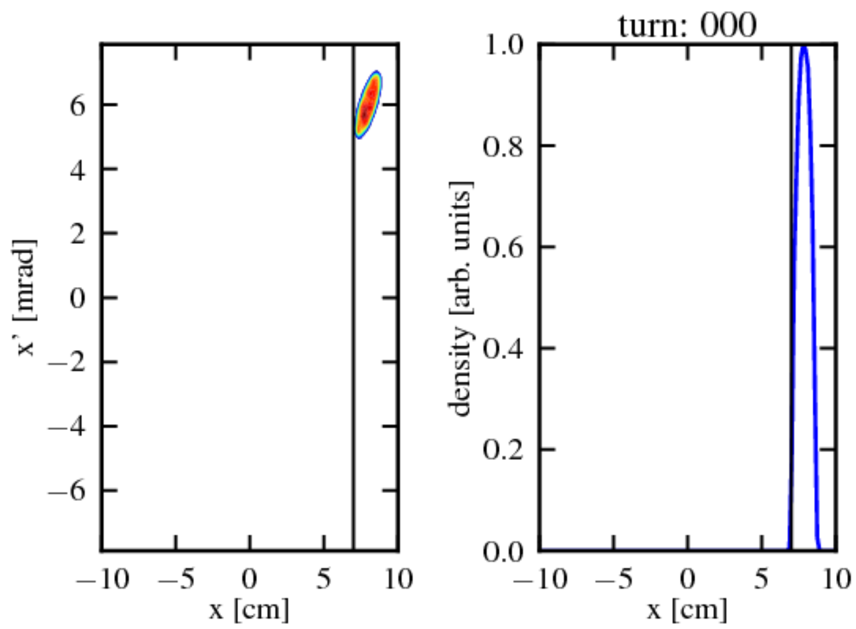
Comparison between codes

- Movie of a MTI without space charge effects

PATRIC



pyORBIT

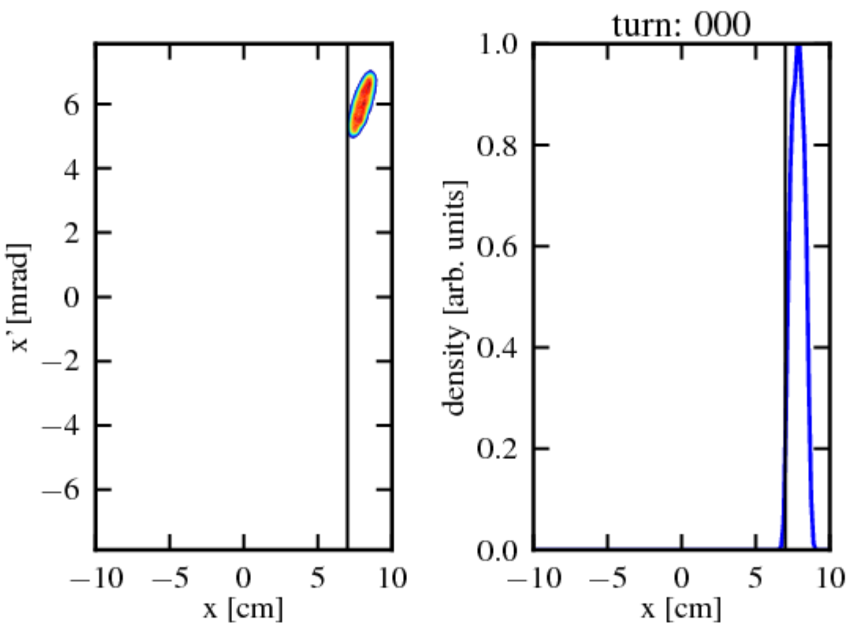


- Kaleidoscope images at injection point

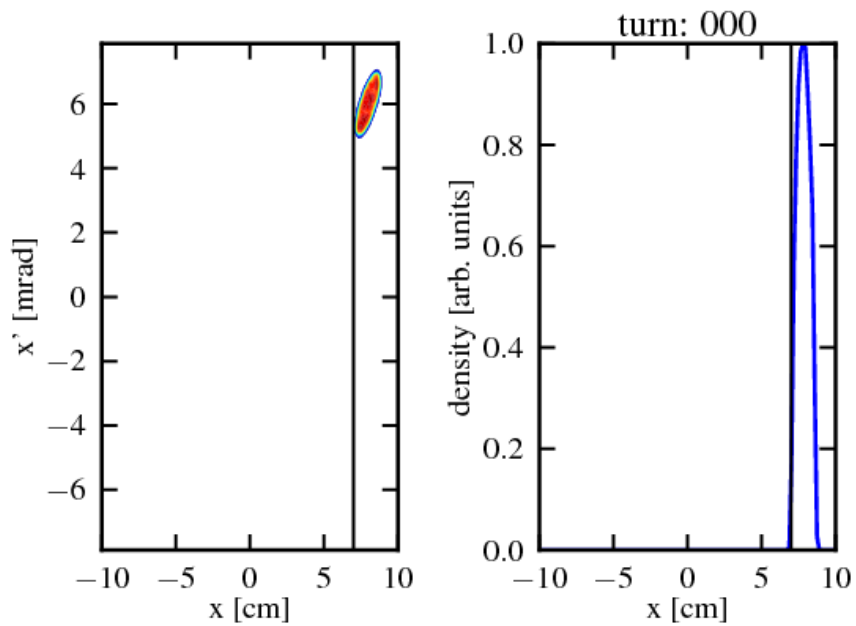
MTI simulation studies
Comparison between codes

- Movie of a MTI with space charge effects

PATRIC



pyORBIT



- Kaleidoscope images at injection point

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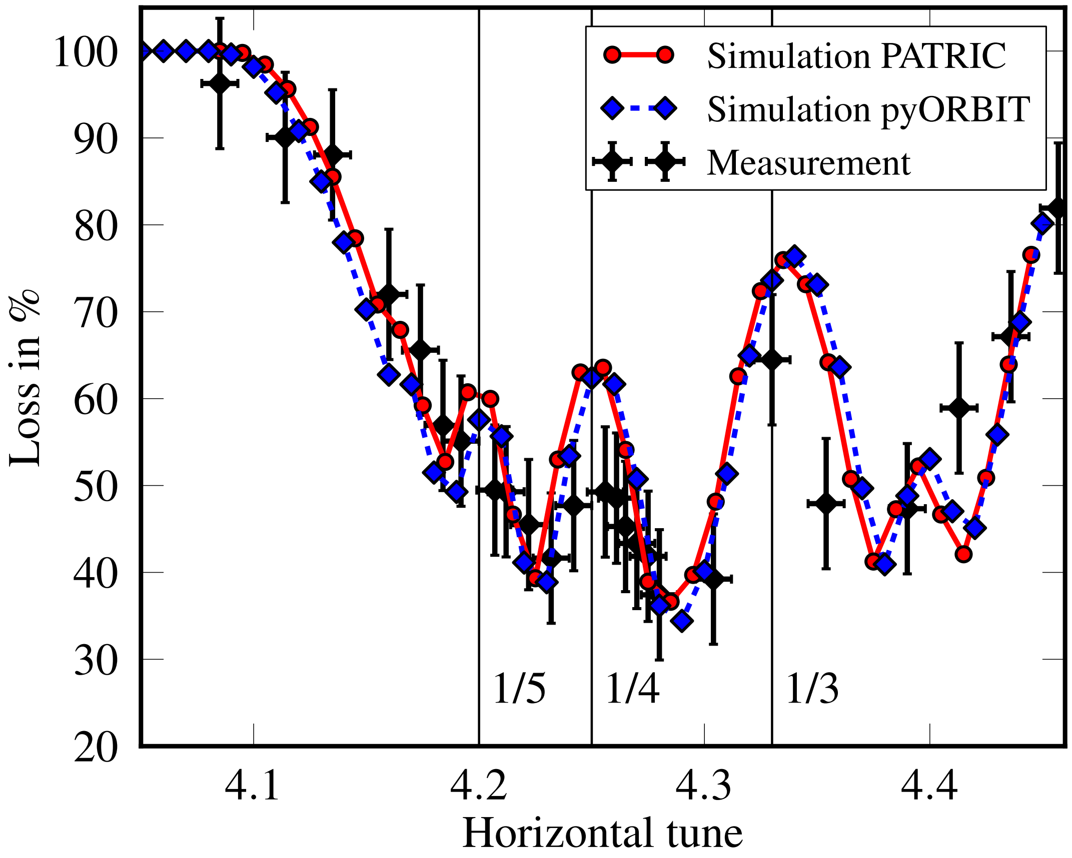
MTI simulation studies

Comparison between experiments and simulations

- Simulation settings:
  - Machine settings of x_c= 85 mm and Δx_c=2.5 mm per turn
  - SISMODI Model
  - Measured beamlet emittance
  - Injection of 21 beamlets
- Measurement results provided by Y. El-Hayek, GSI
  - Low current, no sc effects
  - Error bars: current fluctuation
- The loss maxima are located at the same fractional tunes



- Measurement and simulations are in good agreement

Summary

Summary:

- Comparison between codes
  - For loss calculation in good agreement
- Comparison between experiments and simulation
  - For low beam currents a good agreement is obtained
- Impact of space charge on MTI efficiency
  - Strongly changes the particle distribution
  - Affects the losses (strength depends on the horizontal tune)