Simulation of space effects during multiturn injection into the GSI SIS18 synchrotron

Sabrina Appel, GSI, Accelerator physics department

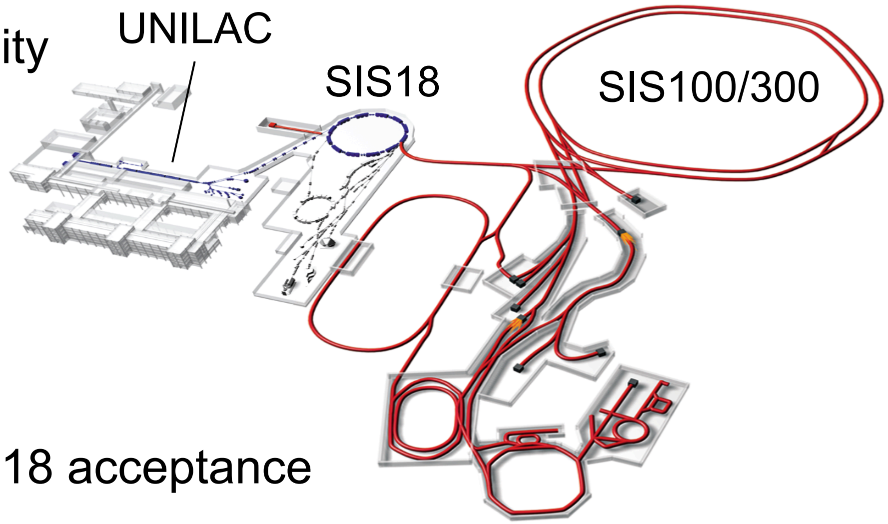
Outline

- SIS18 upgrade program for FAIR: Optimization of the multiturn injection
- Multiturn injection into SIS18: Horizontal betatron stacking
- Model of the injection bump
    - Analytic solution
    - Approximation
- Simulation code: PATRIC
- MTI simulation studies
    - Validation of the approximation
    - Comparison between experiments and simulations
    - Impact of space charge on MTI efficiency
- 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

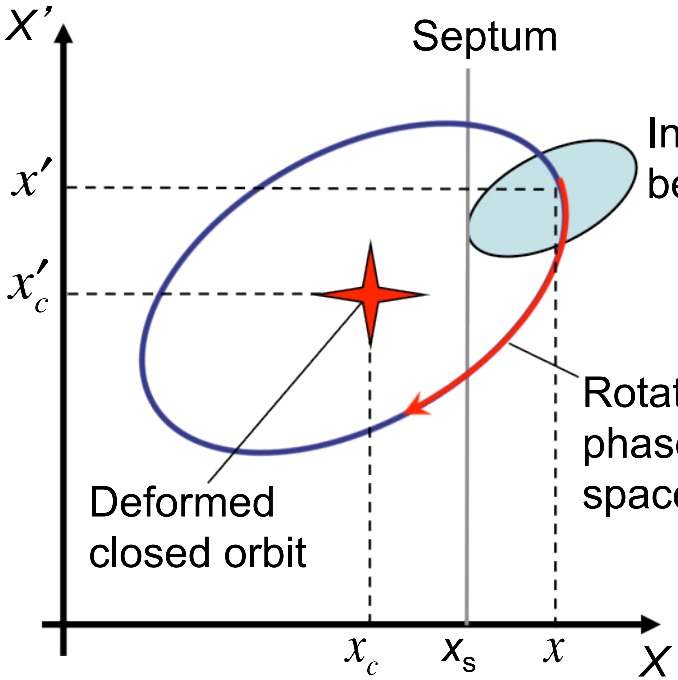


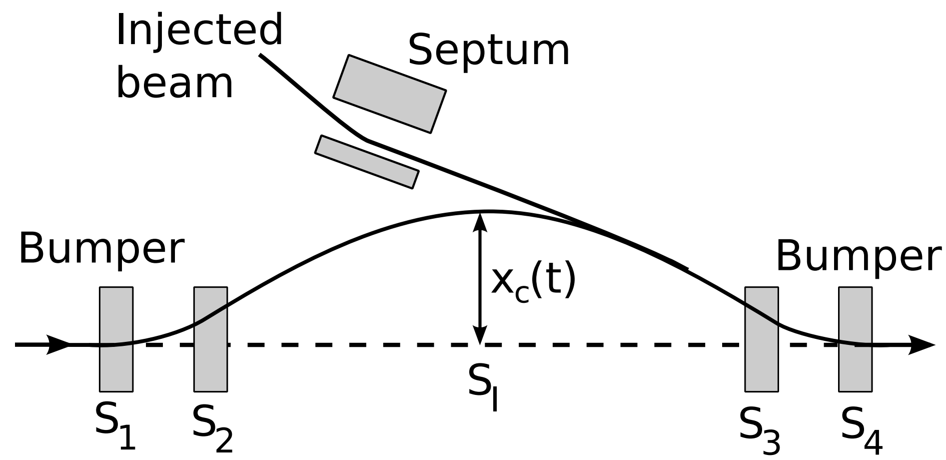
- Impact of space charge on MTI efficiency
- Development of detailed simulation model
- Comparison between experiments and simulations
- Validation of the current model used in operation control program (SISMODI)

	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

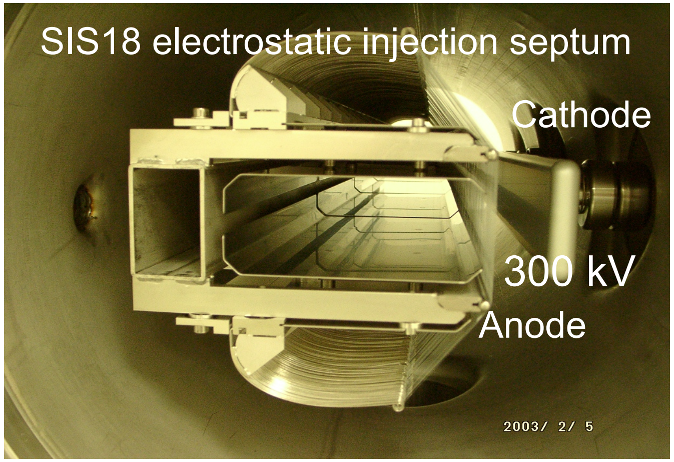
Multiturn injection into SIS18

"Horizontal betatron Stacking"



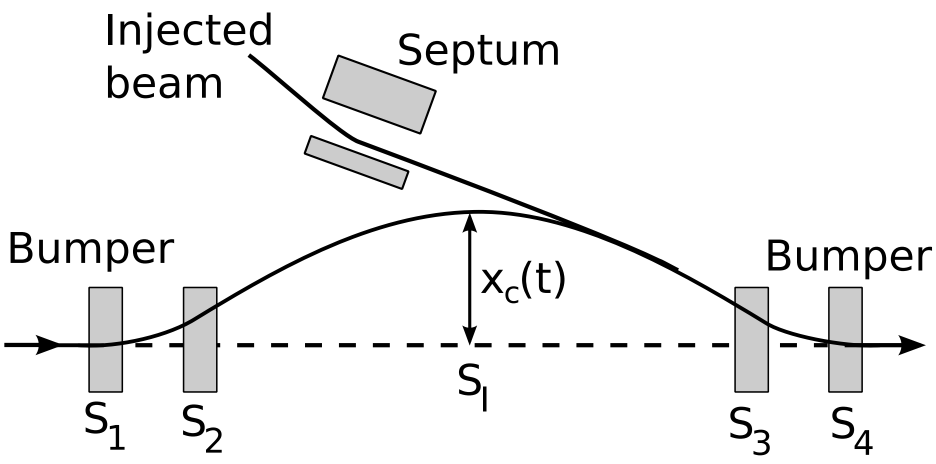


- Liouvile's theorem: Injection only into free phase space
- Betatron oscillation and changing of orbit bump
  ➔ free phase space
- Loss of ions at the septum due to the betatron oscillation
- Dilution during injection $D = \frac{\epsilon_f}{n_{mti}\epsilon_i}$



Model of the injection bump

Analytic solution



- The kick angle for given x_c and x'_c and no orbit distortion outside injection region

$$\varphi_1 = \frac{-b_{41}\varphi_3 - b_{42}\varphi_4}{b_{43}} \qquad \varphi_2 = \frac{b_{31}\varphi_3 + b_{32}\varphi_4}{b_{43}}$$

$$\varphi_3 = \frac{d_{I2}x_c - b_{I2}x_c'}{b_{21}} \qquad \varphi_4 = \frac{-d_{I1}x_c + b_{I1}x_c'}{b_{21}}$$

- Four bumpers:
  - No distortion outside injection region
  - Degrees of freedom x_c and x'_c

- Dependence on the beta function and phase advance

$$b_{ji} = \sqrt{\beta_j \beta_i}\,\sin(\phi_j - \phi_i)$$

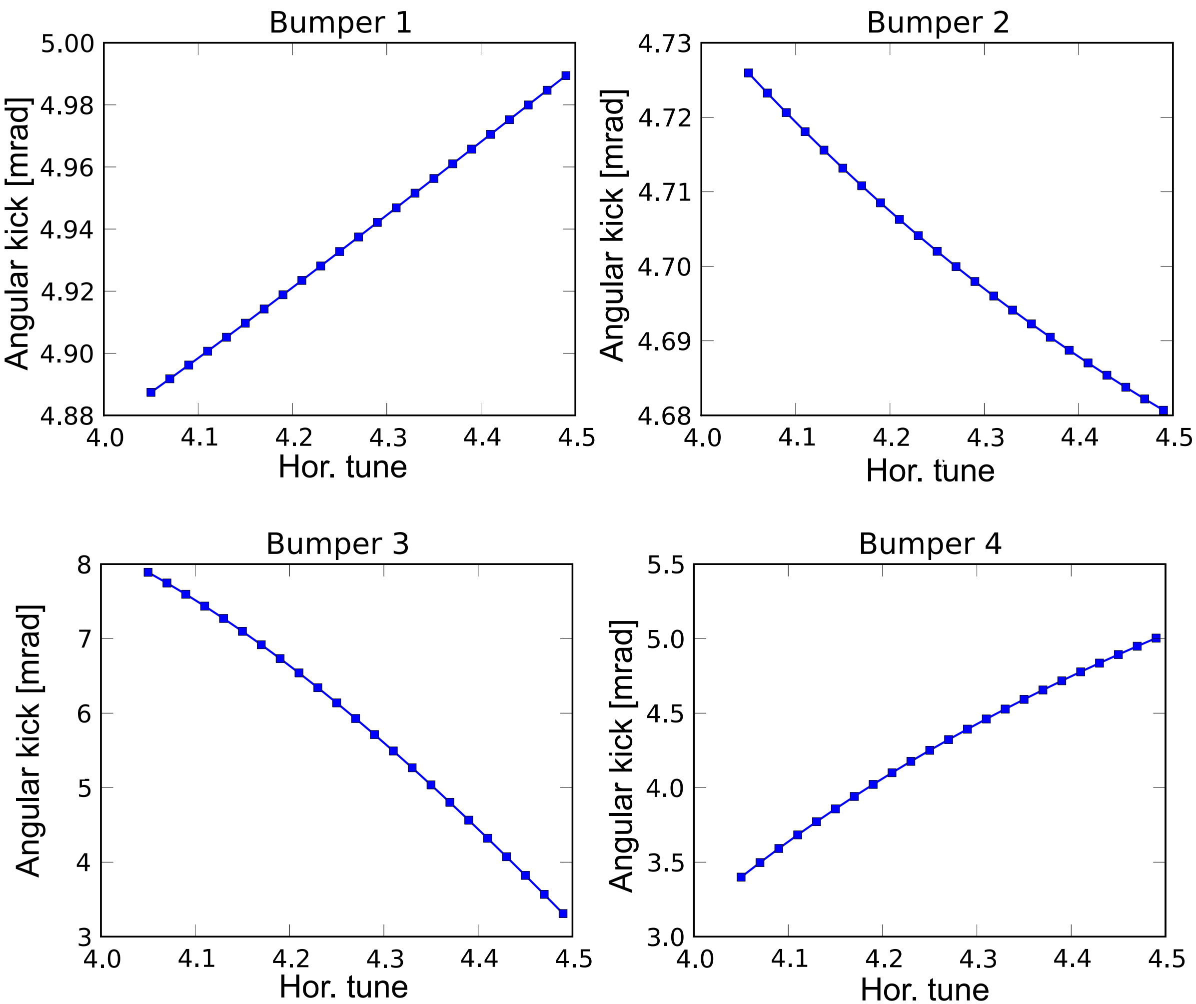
$$d_{ji} = \sqrt{\frac{\beta_i}{\beta_j}}\cos(\phi_j - \phi_i) - \frac{\alpha_j}{\beta_j} b_{ji}$$

C.J. Gardner, BOOSTER TECHNICAL NOTE NO. 197, 1991

Model of the injection bump

Approximation for SISMODI

Analytic solution gives:



- SISMODI does not know precisely the phase advance and beta function
- Approximation of analytic solution in SISMODI:
- Fix: x_c=77 mm, x_c'=6.5 mrad
- Calculate bumper kick angle for several tunes

  $\varphi_1;\varphi_2$ -> Linear function

  $\varphi_3;\varphi_4$ -> Quadratic function

- Degree of freedom x_c' now fixed, x_c stays free

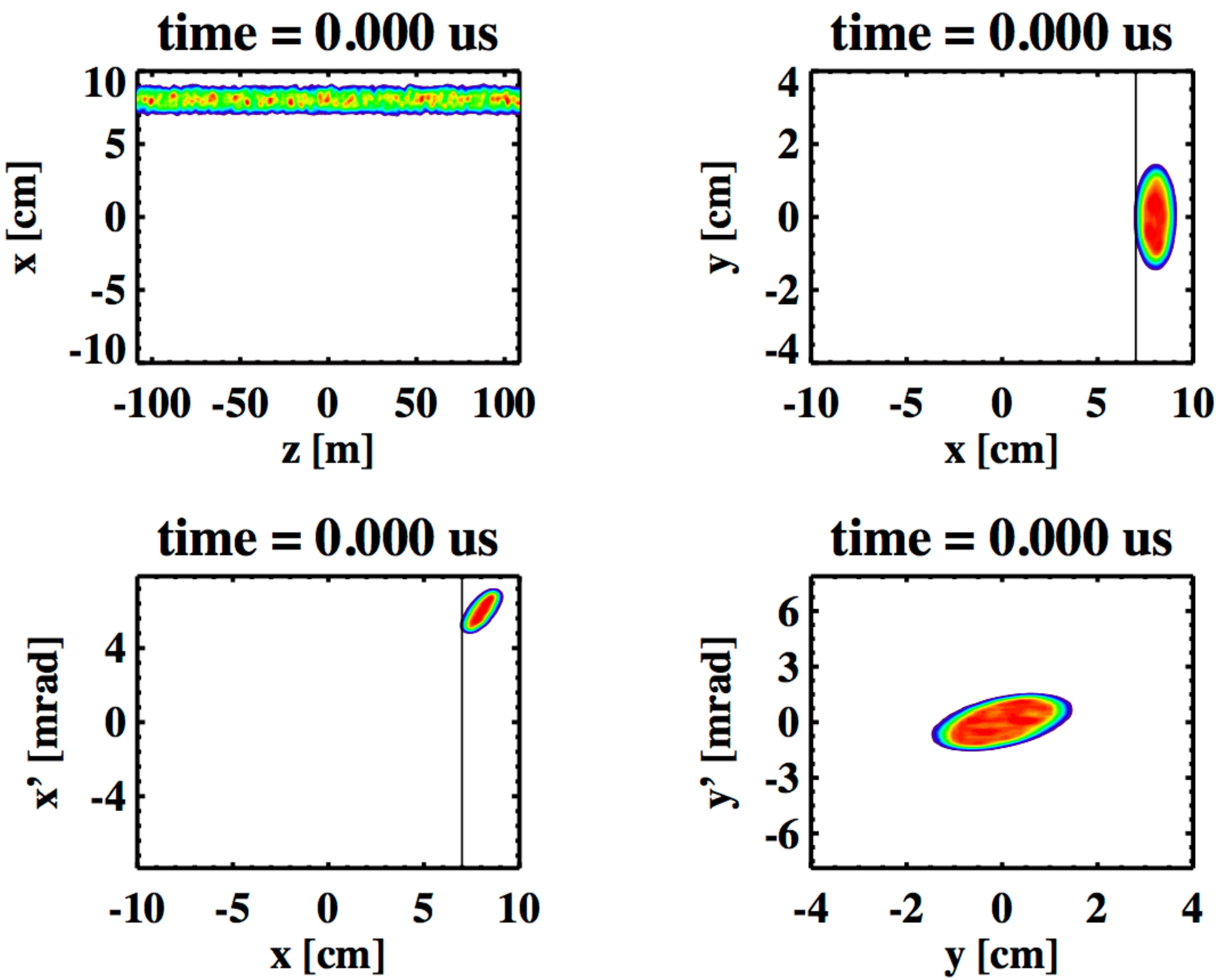
Simulation code

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
  - 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)
- Talk by O. Boine-Frankenheim in Tuesday morning session

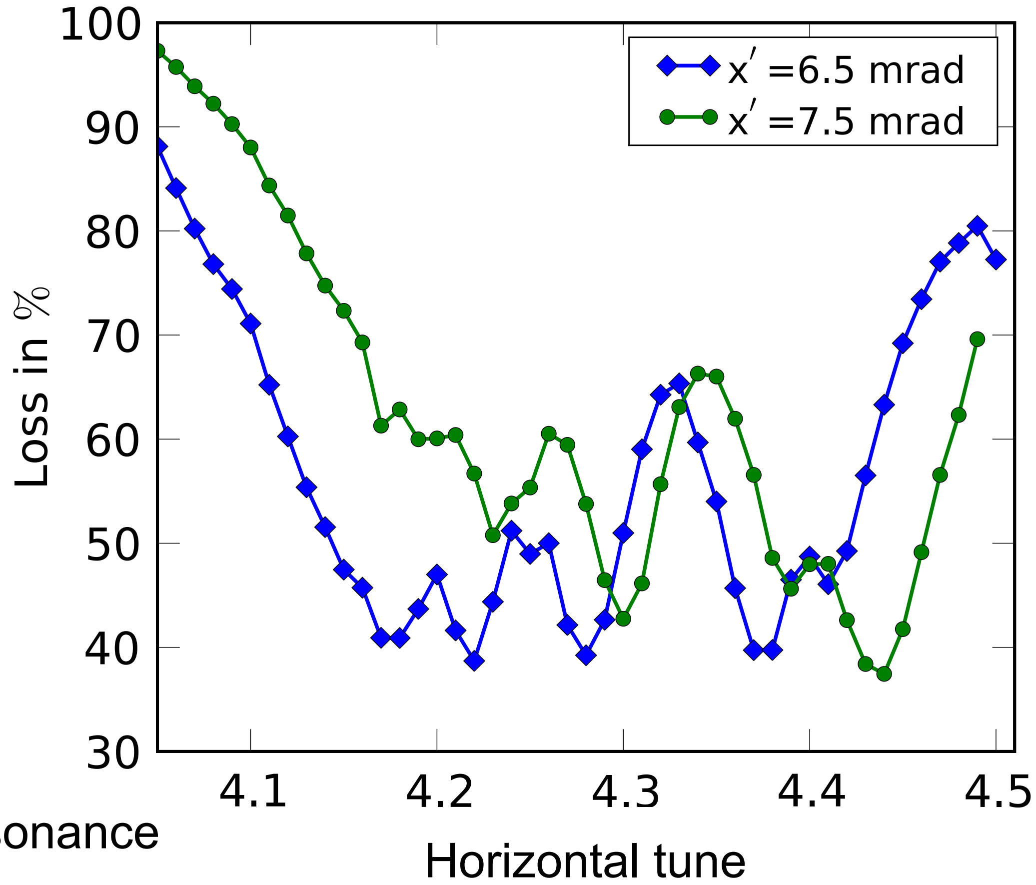
MTI simulation studies

Movie of a MTI without space charge effects



MTI simulation studies
Validation of the SISMODI model

- SISMODI expected are beamlets with x'= 6.5 mrad
- In transfer channel correction devices x and x' can be modified
- Not possible during injection to measure x and x'
- Effect of mismatched beam slope on the MTI efficiency:



  - Mated beam: Loss maxima at resonance condition ($q_x n=m$)
  - Mismatched beam: Larger losses between 4.0-4.3 + maxima are shifted

-> Change loss dependency on horizontal tune

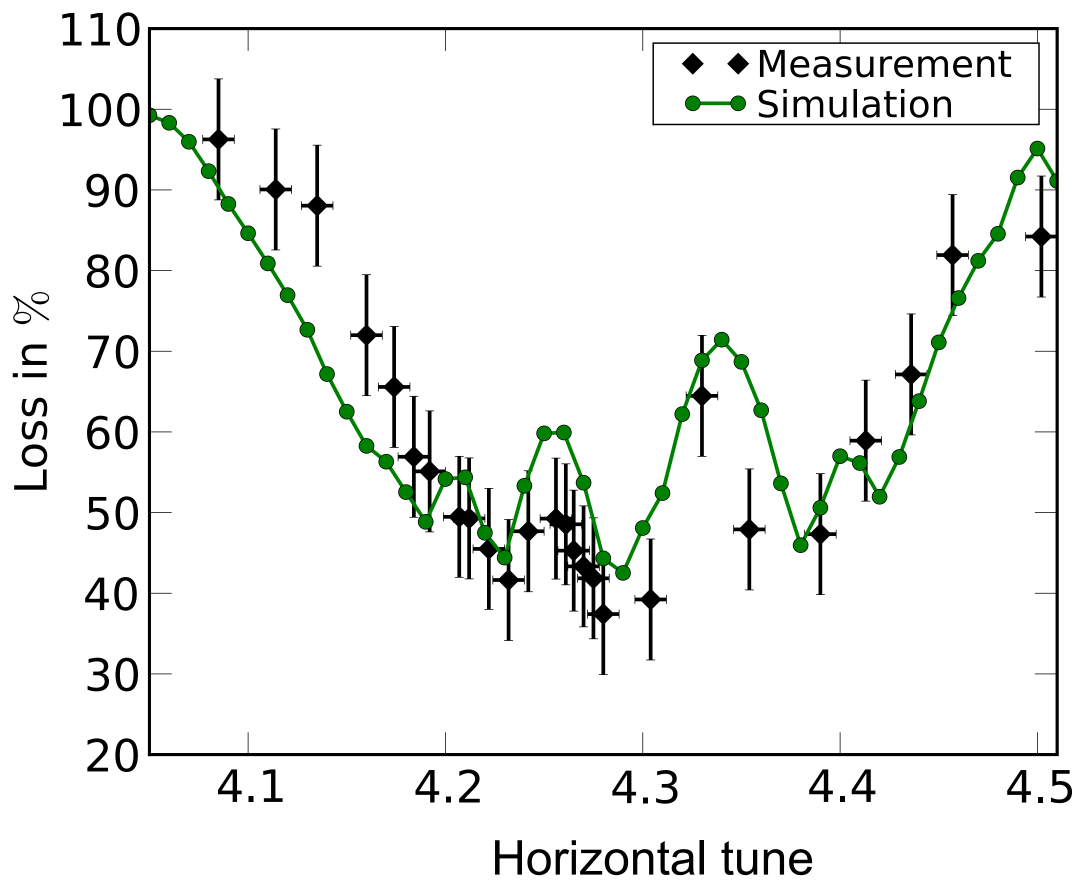
MTI simulation studies

Comparison between experiments and simulation

- Simulation settings:
  - Machine settings of x_c= 90 mm and Δx_c=2.5 mm per turn
  - SISMODI Model
  - Mesaured beamlet emittance

- Measurement results provided by Y. El-Hayek, GSI

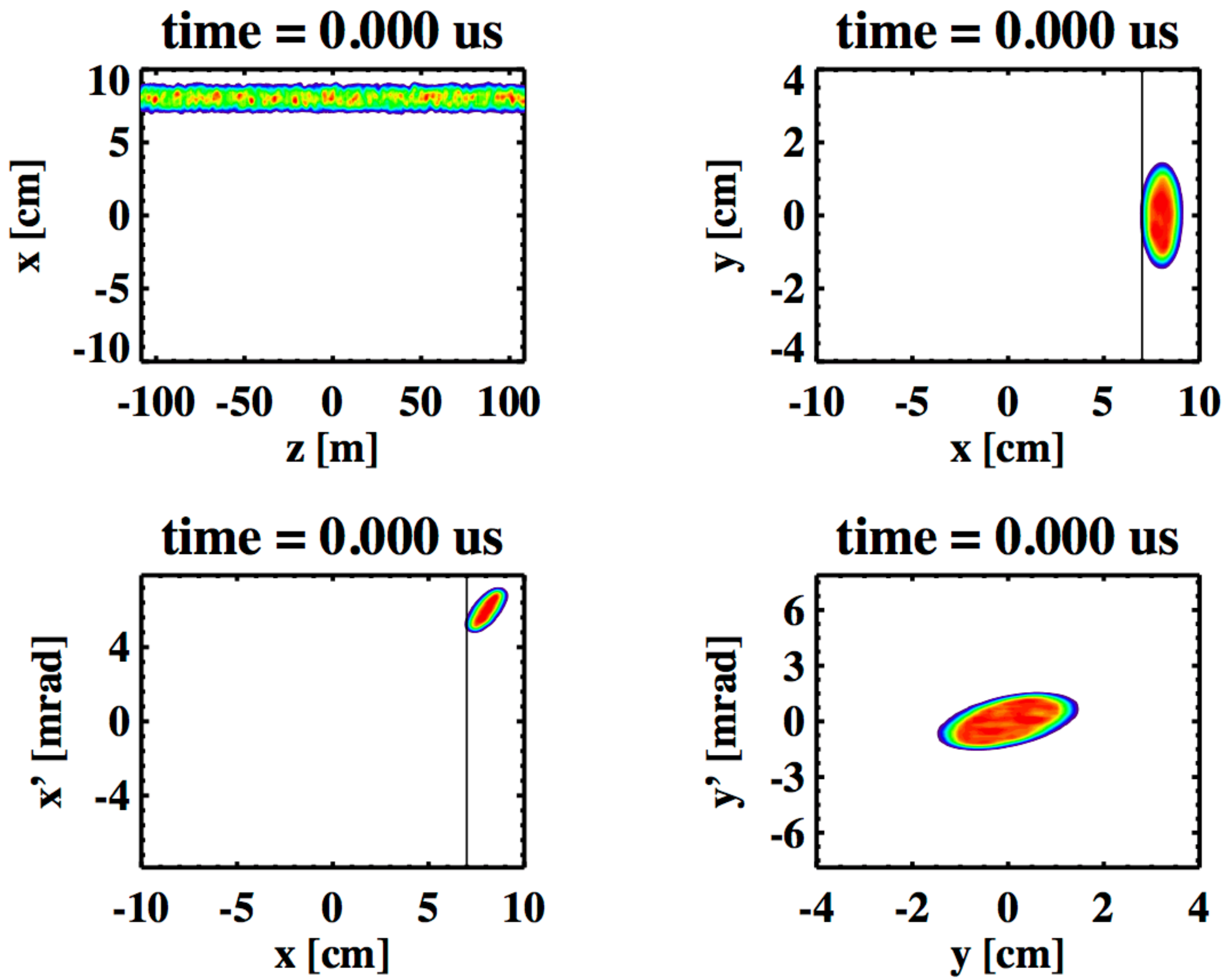
- The loss maxima are located at the same fractional tunes



- The choice of x' is important for the good agreement

MTI simulation studies

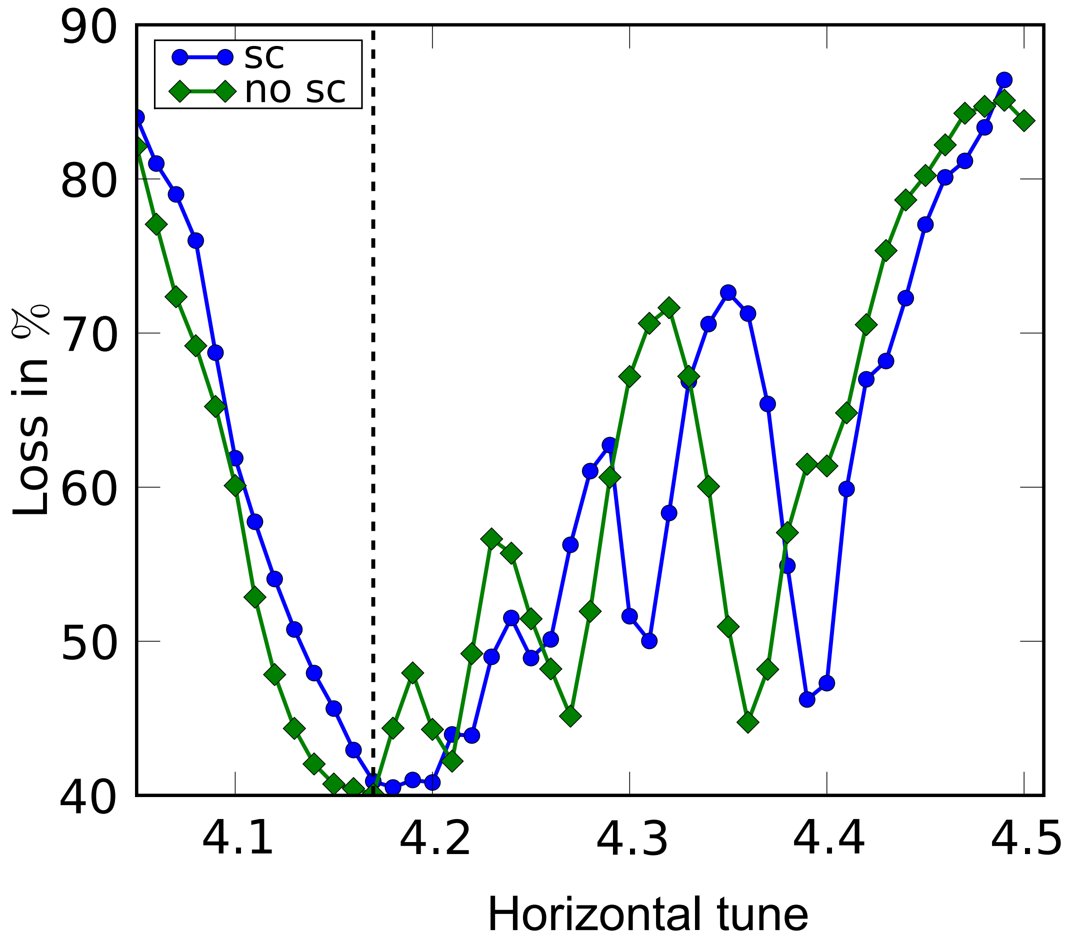
Movie of a MTI with space charge effects



MTI simulation studies

Impact of space charge on MTI efficiency

- The loss maxima and minima are shifted
- The maxima at 4.3 is shifted by ~0.03
- Single beamlet tune shift is dQ_x=0.06, dQ_y=0.04
- The high working point is Q_x=4.17



Summary and Outlook

Summary:

- Validation of the approximation
  - SISMODI model depends very sensitively on beamlet divergence angle
- Comparison between experiments and simulation
  - For low beam currents a good agreement is obtained
- Impact of space charge on MTI efficiency
  - Strongly changes of the particle distribution
  - Affects the losses (strength depends on the horizontal tune)

Outlook:

- Further well controlled measurements at low and high currents are planned
- Other injection schemes: like non-linear ramp
- Full 3D space charge simulations with PY-ORBIT are planned to validate and understand the space charge effects