Slow Extraction from SIS-100 affected by Space Charge

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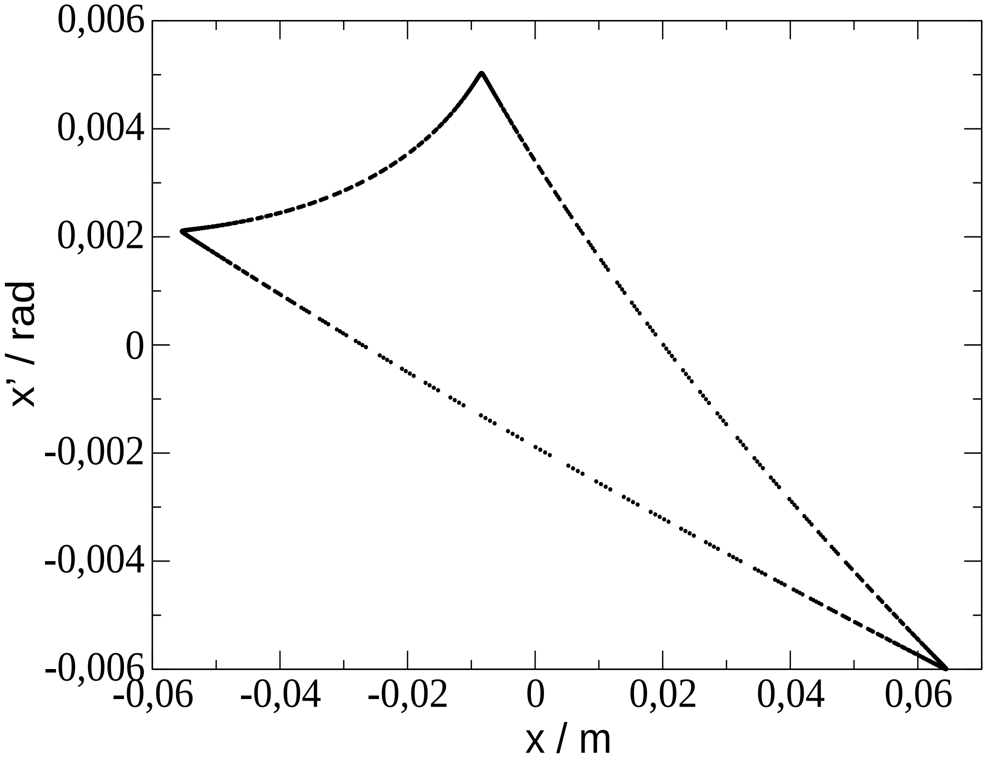
Introduction

Slow extraction from SIS-100, WP: $\nu_x = 17.3, \ \nu_y = 17.8, \delta = 0$



- **Slow extraction based on excitation of 3rd order resonance due to sextupoles**
- **Formation of stable phase space area**
- **Particles leave this area along separatrices**

Introduction

- Two open topics:
  - Optimisation of SIS-100 sextupole settings to reduce particle loss at blade of Electro-Static (ES) Septum
  - Influence of Space charge effects
- Focus on Space charge effects
  - Possible sources in SIS-100: high intensity ion beams, electron clouds
  - Space charge force is non-linear
    - Shift and spread in betatron tune
    - Tune shift of a particle can change

Parameters

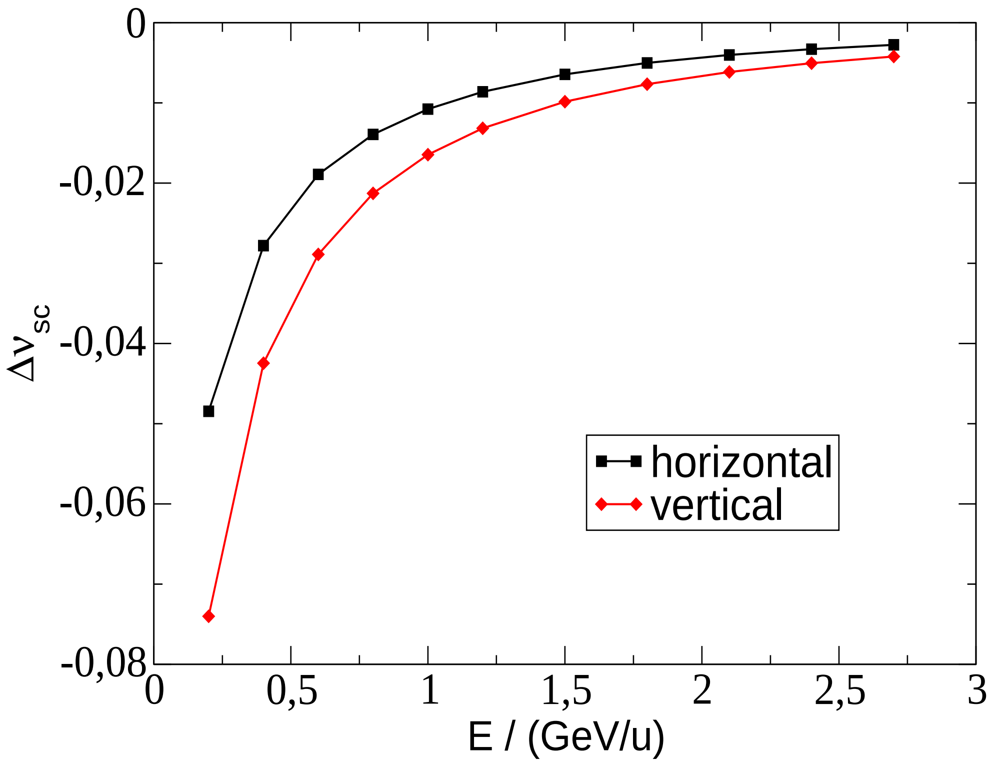
Circumference	1083.6 m
Reference ion	U^{28+}
Time structure assumed here	Coasting beam
Number of ions per pulse	$5 \cdot 10^{11}$
Injection energy, E_{inj}	200 MeV/u
Injection transverse emittance (2σ), $\epsilon_h \times \epsilon_v$	(35×15) mm mrad
Energy range	$(0.4 - 2.7)$ GeV/u
Horizontal emittance (2σ)	$(24 - 6.4)$ mm mrad
Vertical emittance (2σ)	$(10 - 2.7)$ mm mrad
Final RMS momentum spread	10^{-3}

Laslett tune shift

Analytic formula for coasting Gaussian beam

Start from[1] $$\Delta\nu_{sc,z} = \frac{N_p r_0}{2\pi\beta^2\gamma^3\sqrt{\epsilon_z}\left(\sqrt{\epsilon_x}+\epsilon_y\right)}\,, \quad z = x, y$$

- **Formula written with particle number N_p and for different emittances**
- **$\epsilon_z = \sigma_z^2/\beta_z$ – transverse RMS emittance**
- **$r_0 = \frac{q^2}{4\pi\epsilon_0 m_0 c^2}$ – particle radius**
- **β, γ – relativistic factors**



Small energy → large tune shift and emittance: influence of further non-linearities

[1] **A. Hofmann, CERN, "Tune Shifts from Self Fields and Images", p. 336**

Status

- Thin lens tracking using MAD-X
- Introduce frozen space charge by `beambeam` element:
  - Locate `beambeam` elements at equidistant positions around the ring
  - Varied number of `beambeam` kicks between 48 and 180
  - Transverse charge distribution with Gaussian shape, RMS width given by beta function and emittance
  - 4D simulation, i.e dependence only on transverse coordinates

Insertion of the `beambeam` elements (V. Kapin)

- Create thin lens tracking (MAD-X)
- Generate Twiss table, write it in file (MAD-X)
- Apply small auxiliary C programme to read elements and their parameters from Twiss file, to put `marker` elements in between, and to write modified lattice sequence in a sequence file which can be read by MAD-X
- Use new lattice in MAD-X and generate new Twiss file
- Apply small auxiliary C programme to replace `marker` elements by `beambeam` elements and to write modified lattice into sequence file
- Use sequence with `beambeam` elements in MAD-X

Matching `beambeam` elements

- **Read location s of a `beambeam` element and the corresponding beta function from Twiss file**

- **Calculate parameter `width`**

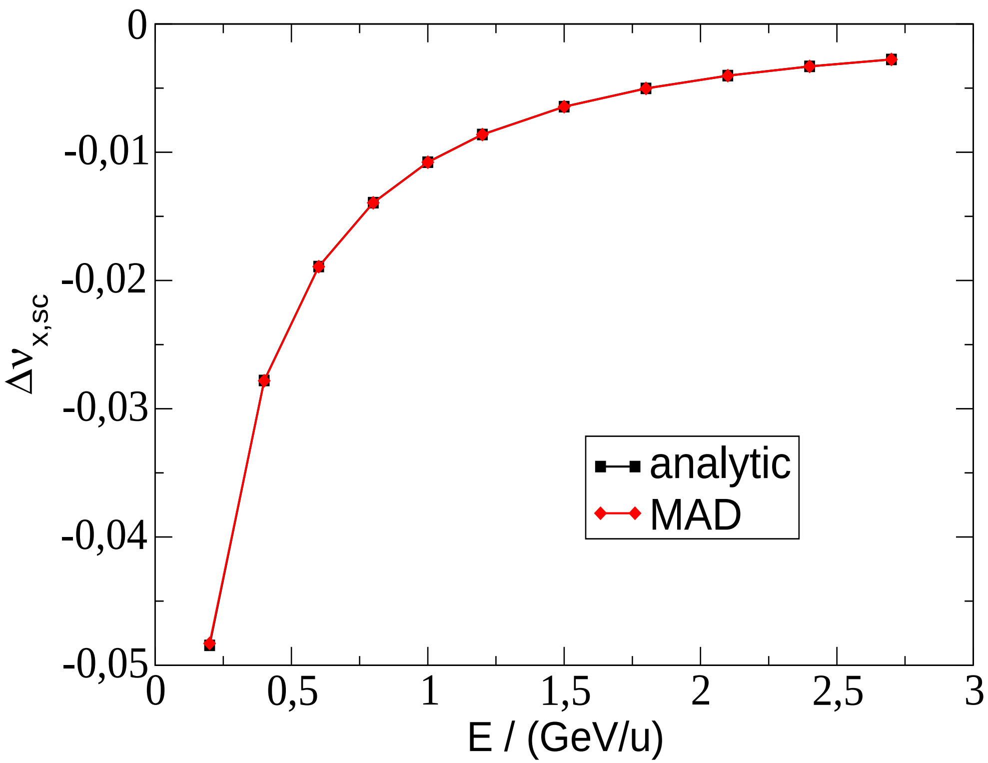
$$\texttt{width} = \sqrt{\beta(s)\epsilon_{rms}}$$

with

$$\epsilon_{rms} = \epsilon(2\sigma)/4.$$

- **Every `beambeam` element gets particle number divided by `beambeam` number**

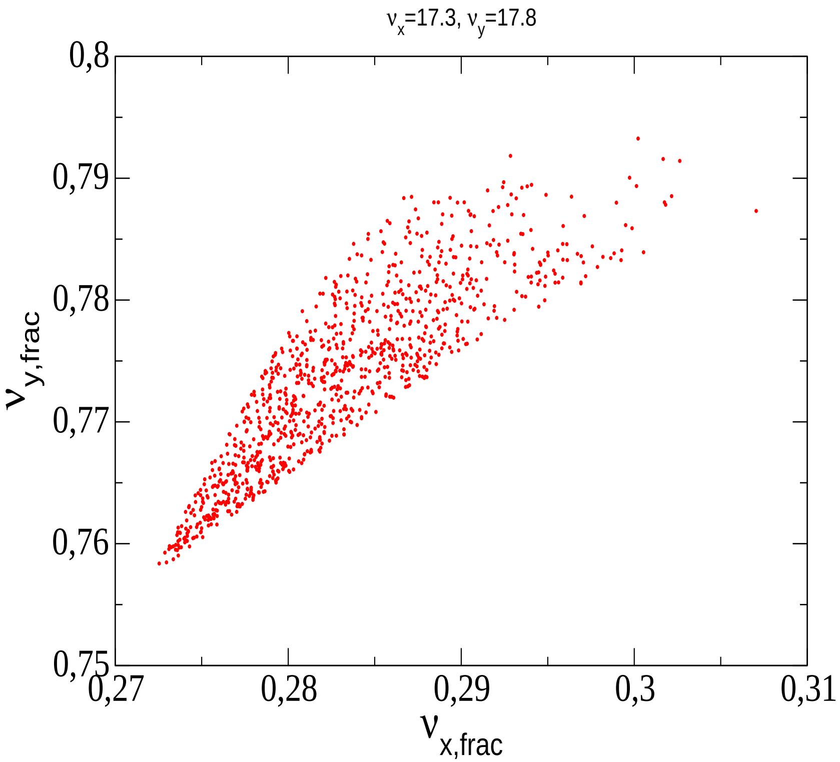
Horizontal Laslett tune shift, analytic formula vs. MAD simulation



- **Simulated tune shift determined using** `dynap` **module in MAD-X**
- **Very good agreement also in case of vertical tune shift**
- **Results do not depend on number of** `beambeam` **elements**

Particle Simulation

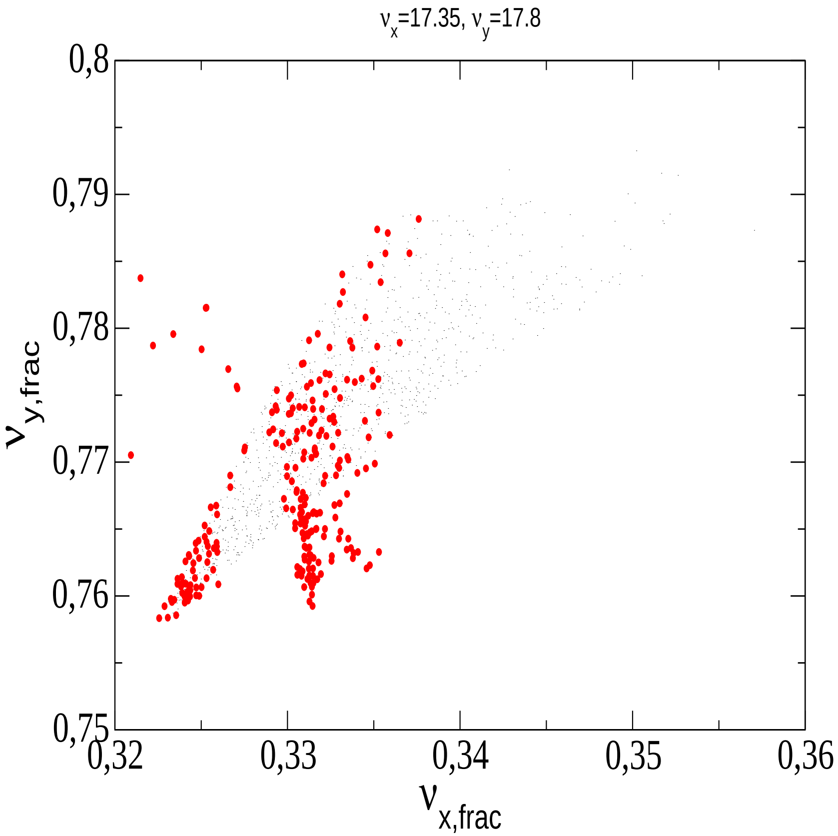
Tune spread for $E = 400\ \mathrm{MeV/u}$, WP: $\nu_x = 17.3,\ \nu_y = 17.8$



- **Tune spread calculated with `dynap` module in MAD-X**
- **Sextupoles to excite 3rd order resonance at $\nu_x = 17.33333$ are on**
- **Space charge moves tune further away from resonance tune**
  - **no excited resonance is crossed**
  - **no significant influence**
- **Possibly resonance excitation due to magnet imperfections**

Particle Simulation

Tune spread for $E = 400\ \mathrm{MeV/u}$, WP: $\nu_x = 17.35,\ \nu_y = 17.8$



- **Tune spread calculated with `dynap` module in MAD-X**
- **Sextupoles to excite 3rd order resonance at $\nu_x = 17.33333$ are on**
- **WP is artificially chosen to generate resonance crossing**
  → horizontal tune above resonance tune not proper for slow extraction
- **Possible scenario if electron clouds are present**

Summary

- **Focused only on space charge of the ion beam**
- **If resulting tune spread does not cross excited resonance self field does not affect beam**
- **Under considered conditions, tune spread is too small to cross excited resonance and, in addition, space charge of the beam moves tune further away from 3rd order resonance → on the first view no significant influence**
- **Possibly change of situation due to**
  - **Magnet imperfections leading to excitation of further resonances**
  - **Electron clouds because tune is moved towards 3rd order resonance**