SIMULATION OF SIS-100 SLOW EXTRACTION WITH MAGNET ERRORS

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Outline

- Slow Extraction
- Magnet Errors and Space Charge
- Numerical Model and Results
- Conclusions

Slow Extraction

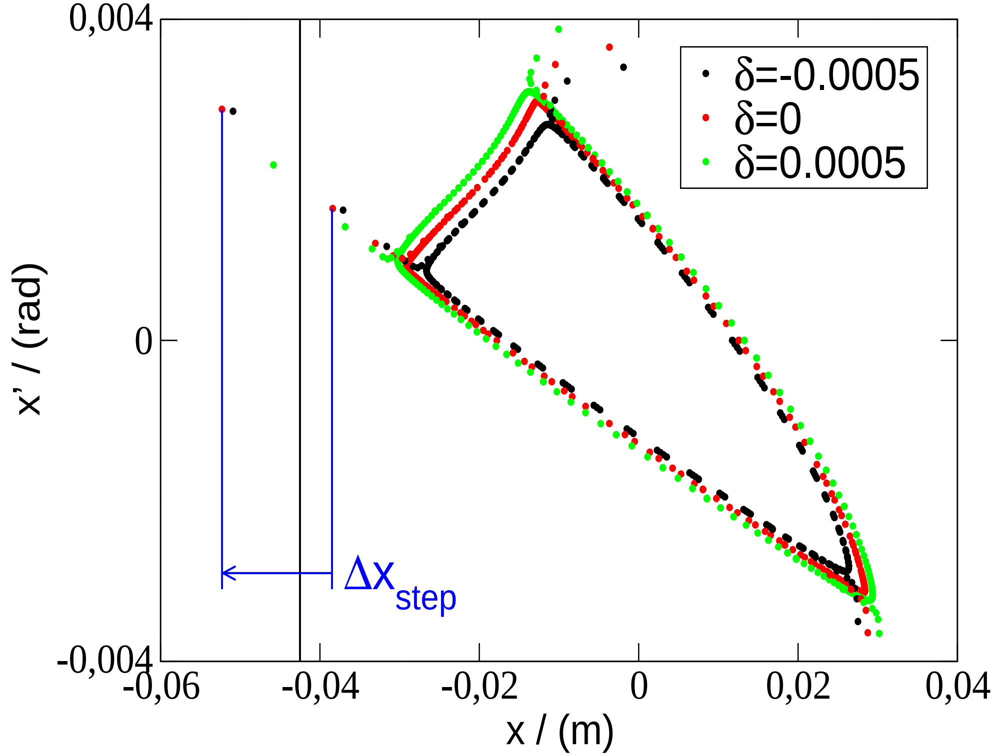
Slow Extraction I

Based on excitation of 3rd order resonance, SIS-100: $3\ \nu_{x,res} = 52$.

Resonance excited by means of 11 resonant sextupoles.

- Triangular stable phase space area.
- Particles leave along separatrices.
- Advance in real space during three turns: Spiral step Δx_{step}
- Spread in separatrices due to momentum spread.

$$\Delta\nu_x = \nu_x \cdot \xi_x \cdot \delta$$



Slow Extraction II

Spread in separatrices

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Inherent mismatch $\Delta x'$ between phase space angle of particle trajectory and septum blade.

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Effective thickness of septum blade d.

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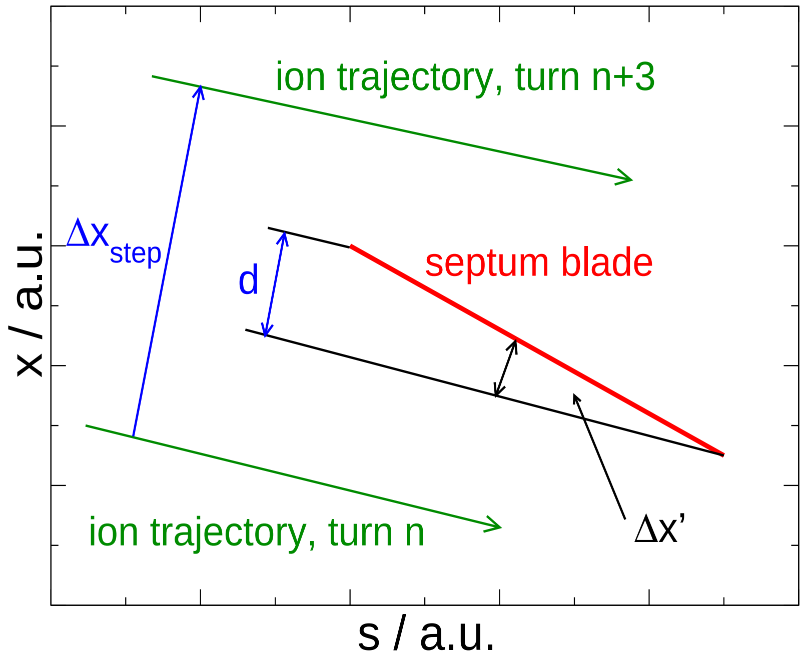


Inherent beam loss at septum blade due to particle collisions.

$$P_{loss} = \frac{d}{\Delta x_{step}}.$$

Consequences of Beam Loss in SIS-100

Beam loss at ES septum blade causes:

- **Energy deposition in ES septum blade and following quadrupole doublet.**
- **Vacuum degradation due to desorption in quadrupole doublet.**

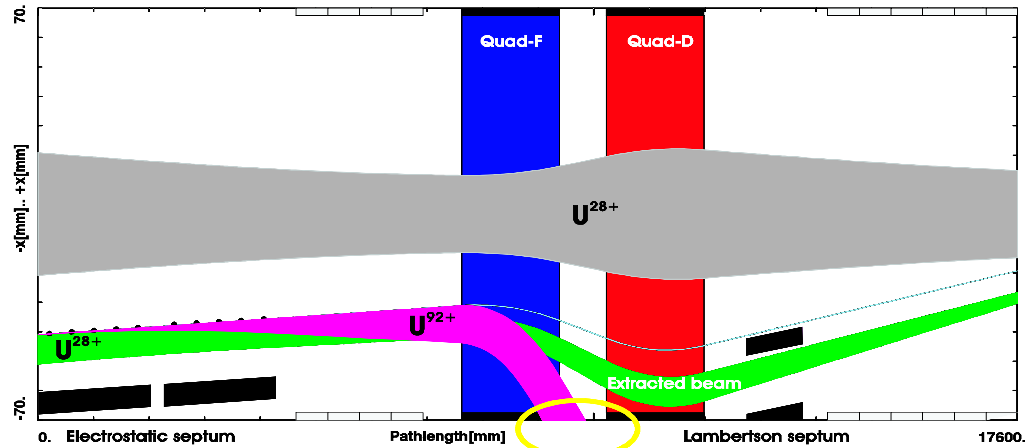
Loss budget:

Energy deposition:

$\sim$ 5 % at maximum energy.

Desorption: $\sim$ 5%

(Low desorption material)



Courtesy: N. Pyka

Question: How is beam loss modified by magnet errors and space charge?

Magnet Errors and Space Charge

Magnet Errors: Systematic Field Errors

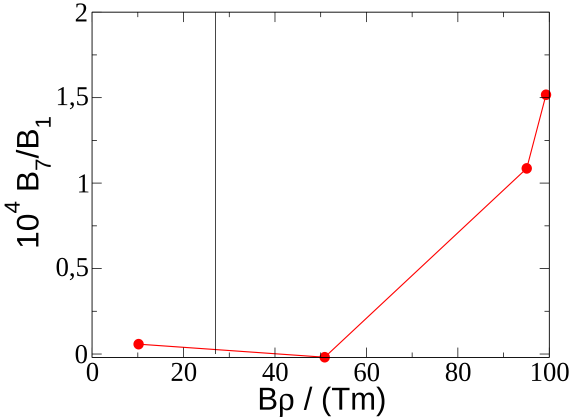
Magnet model CLSD8b dipole and 6 Turn quadrupole magnet from June 2010.

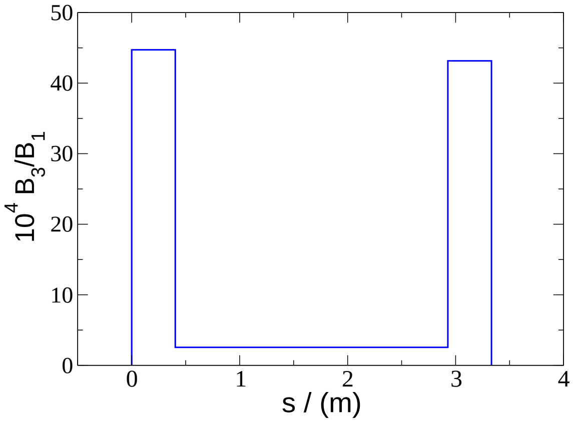
Error multipoles up to order $n = 16$, (dipole: $n = 1$). (Akishin *et al.*)

Errors depend on rigidity.

Example: $10^4 \cdot B_7/B_1$ of dipole

strongly increased for high energies.





Errors have longitudinal structure.

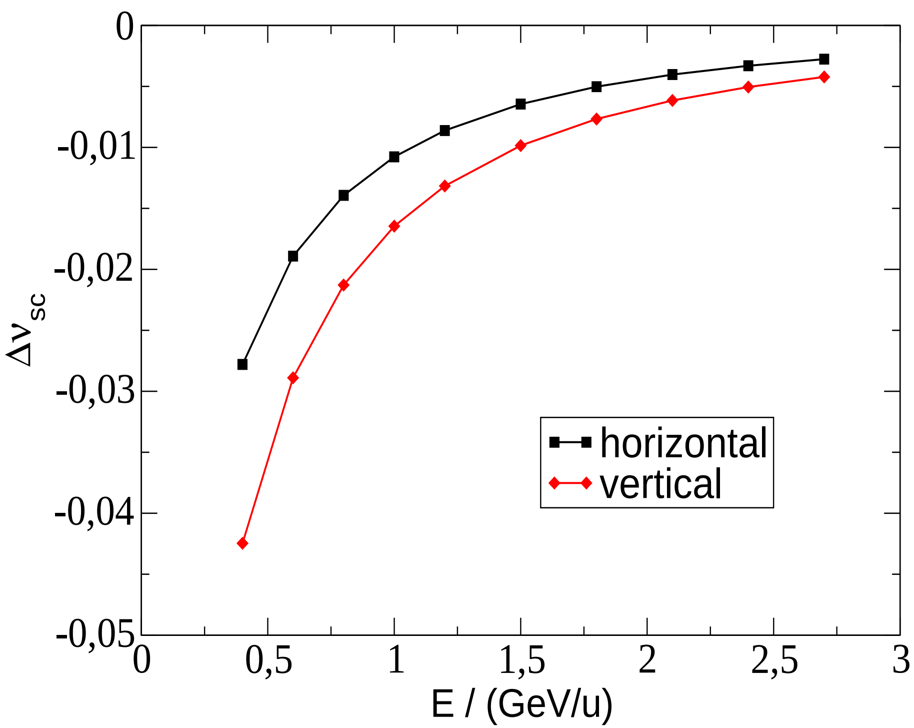
Example: $10^4 \cdot B_3/B_1$ of dipole, (schematic).

Data from V. Kapin

Space Charge

Laslett tune shift for coasting Gaussian beam

$$\Delta\nu_{sc,z} = \frac{N_p r_0}{2\pi\beta^2\gamma^3\sqrt{\epsilon_{z,rms}}\left(\sqrt{\epsilon_{x,rms}}+\sqrt{\epsilon_{y,rms}}\right)}\,, \quad z = x, y$$



- **Energy range for U^{28+}:**
  $E \in [400\ \mathrm{MeV/u}, 2700\ \mathrm{MeV/u}]$
- **Tune shift much larger for small energies.**
- **In simulations: non-linear kicks according to Gaussian shape.**

GSI

Multi-Particle Tracking

Multi-Particle Tracking: Parameters

Working point, ν_x, ν_y	$17.3, 17.8$
Time structure of the beam	Coasting beam
Reference ion	U^{28+}
Maximum number of ions per pulse	$5 \cdot 10^{11}$
Energy range for slow extraction	$(0.4 - 2.7)$ GeV/u
Transverse emittance at $E = 0.4$ GeV/u, (2σ)	(24×10) mm mrad
Transverse emittance at $E = 2.7$ GeV/u, (2σ)	(6.4×2.7) mm mrad
RMS momentum spread	$5 \cdot 10^{-4}$

Multi-Particle Tracking

- Thin lens tracking using MAD-X code.
- 5000 Test particles during 15000 turns, corresponding time interval:

  $\Delta t \in [0.056, 0.076]$ s, (realistic $\Delta t_{min} = 1$ s).

- "Frozen" space charge according to Gaussian beam introduced by 192 BEAMBEAM elements.
- "Knock Out" (KO) extraction:
  - Horizontal RF noise excitation to drive particle diffusion from stable phase space area.
  - To provide band width: 26 sinusoidal kickers: $\Delta x'(t) = \Delta x'_a \sin(2\pi f t)$
  - Large amplitude because of small time interval. → effect on beam loss?

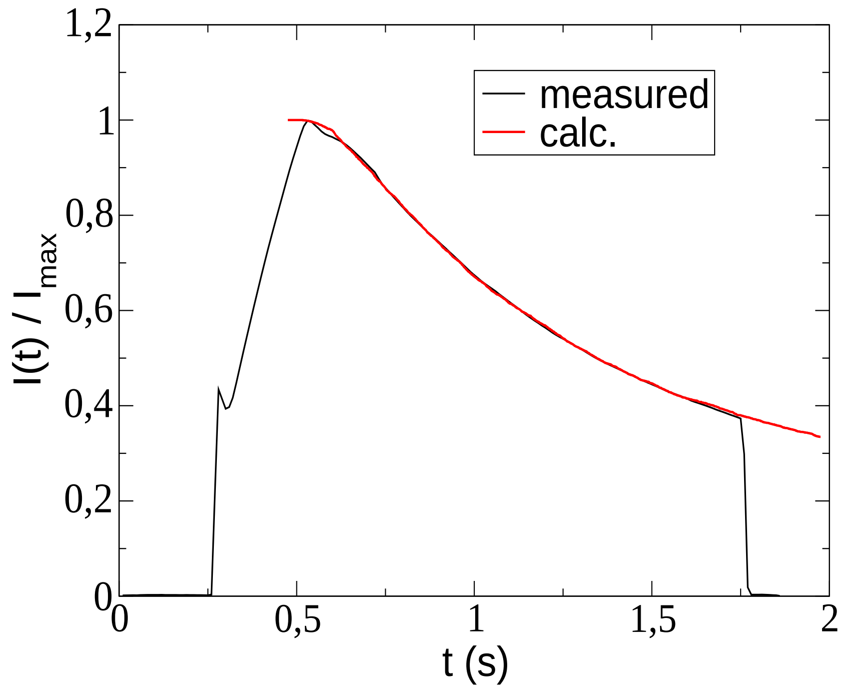
Multi-Particle Tracking: RF Noise Excitation

- RMS momentum kick in case of diffusion:

$$\langle (\Delta x')^2 \rangle \propto \frac{1}{\Delta t}$$

- RF noise generates diffusion. Proved by very good reproduction of noise generated beam loss measured in SIS-18 by computer simulation.

  (Study to measure acceptance of SIS-18)[1].

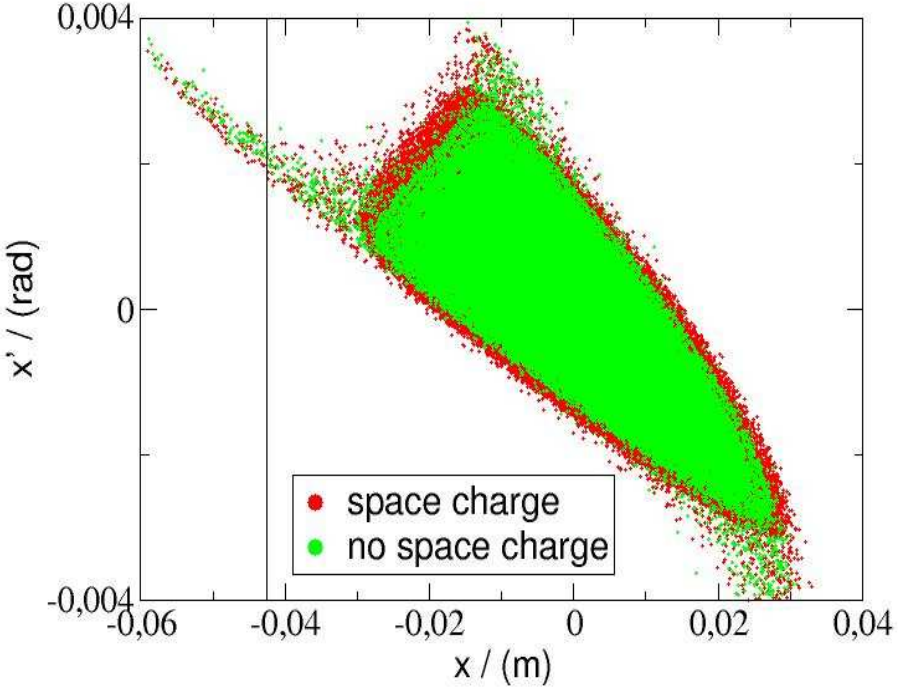


$\Downarrow$

Decrease in Δt by factor 20 $\longrightarrow$ Increase in $\sqrt{\langle (\Delta x')^2 \rangle}$ by factor ≈ 4.5, remains $< 10^{-5}$, cp. spread of separatrices due to momentum spread $\sim 10^{-4}$.

[1] S. Sorge, G. Franchetti, and A. Parfenova, IPAC 2010, Kyoto, Japan

Multi-Particle Tracking: Phase Space Plot



Formation of stable phase space area and separatrices also with magnet errors and/or space charge.

Figure: example without magnet errors,

100 test particles,

$E = 400$ MeV/u,

$(\Delta\nu_{sc,x}, \Delta\nu_{sc,y}) = (-0.028, -0.043)$.

Multi-Particle Tracking: Beam Loss

Low energy: $E = 400$ MeV/u

	without space charge	with space charge
without magnet errors	(3.8 ± 0.3) %	(5.2 ± 0.5) %
with magnet errors	(5.7 ± 0.3) %	(9.0 ± 0.7) %

High energy: $E = 2.7$ GeV/u

	without space charge	with space charge
without magnet errors	(3.6 ± 0.7) %	(3.6 ± 0.5) %
with magnet errors	(6.0 ± 0.8) %	(7.2 ± 0.7) %

Conclusions

- Tracking study on influence of magnet errors and space charge field of the beam to beam loss during slow extraction.
- Study suggests that slow extraction will still work.
- Beam loss is increased.
- Beam loss at low energy: possibly critical because of desorption.
  - Problem could be mitigated because of reduction of space charge during extraction.
  - Goes beyond frozen space charge model.
- Beam loss at high energy: Above loss budget. Possibly less critical because of opportunities to improve, e.g.
  - Realistic momentum spread is smaller.
  - WP can be chosen closer to resonance because of small emittance.
- Additional issue to later study: Influence of electrons from beam gas interaction