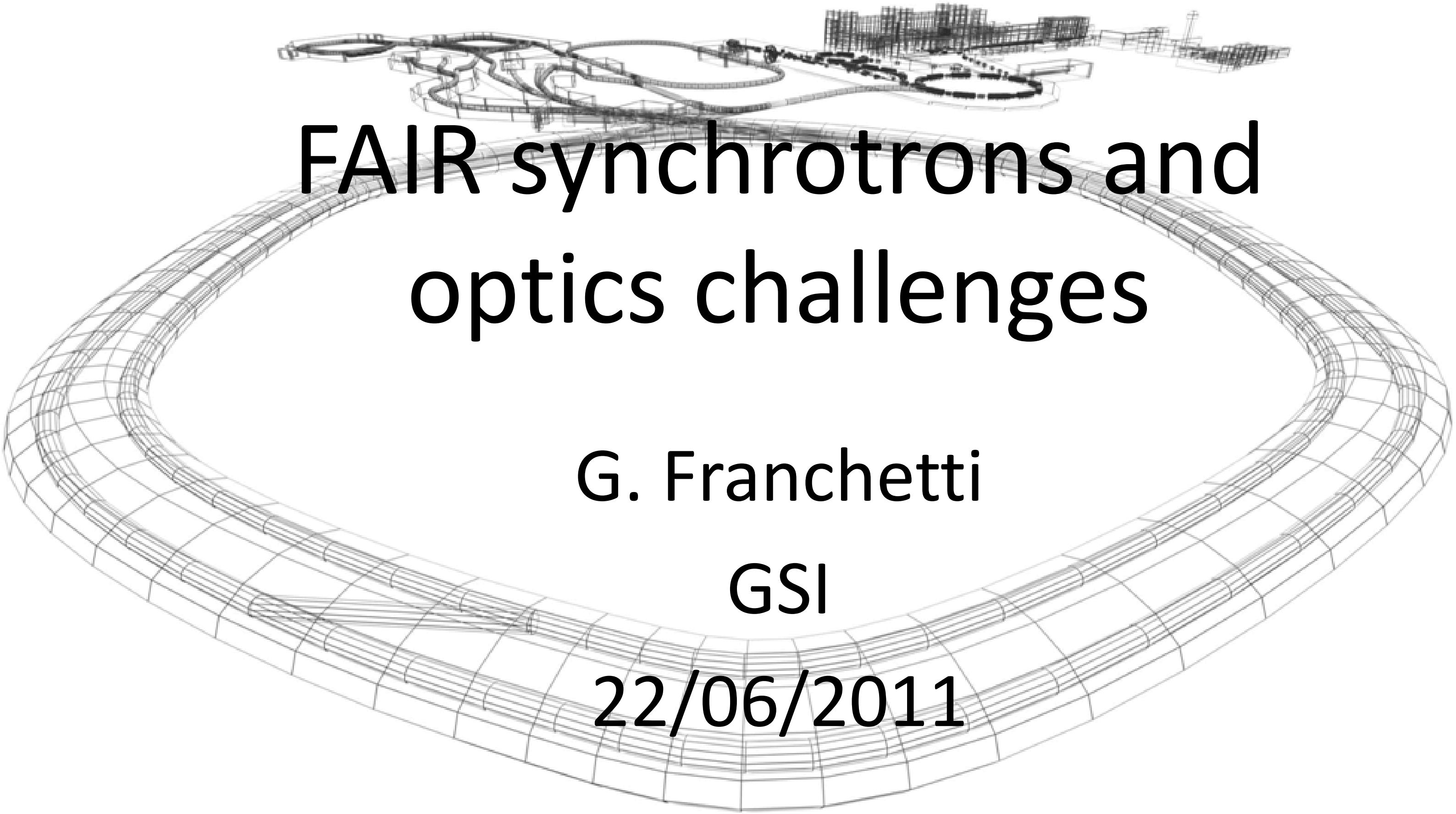


FAIR synchrotrons and optics challenges

G. Franchetti

GSI

22/06/2011

SIS18

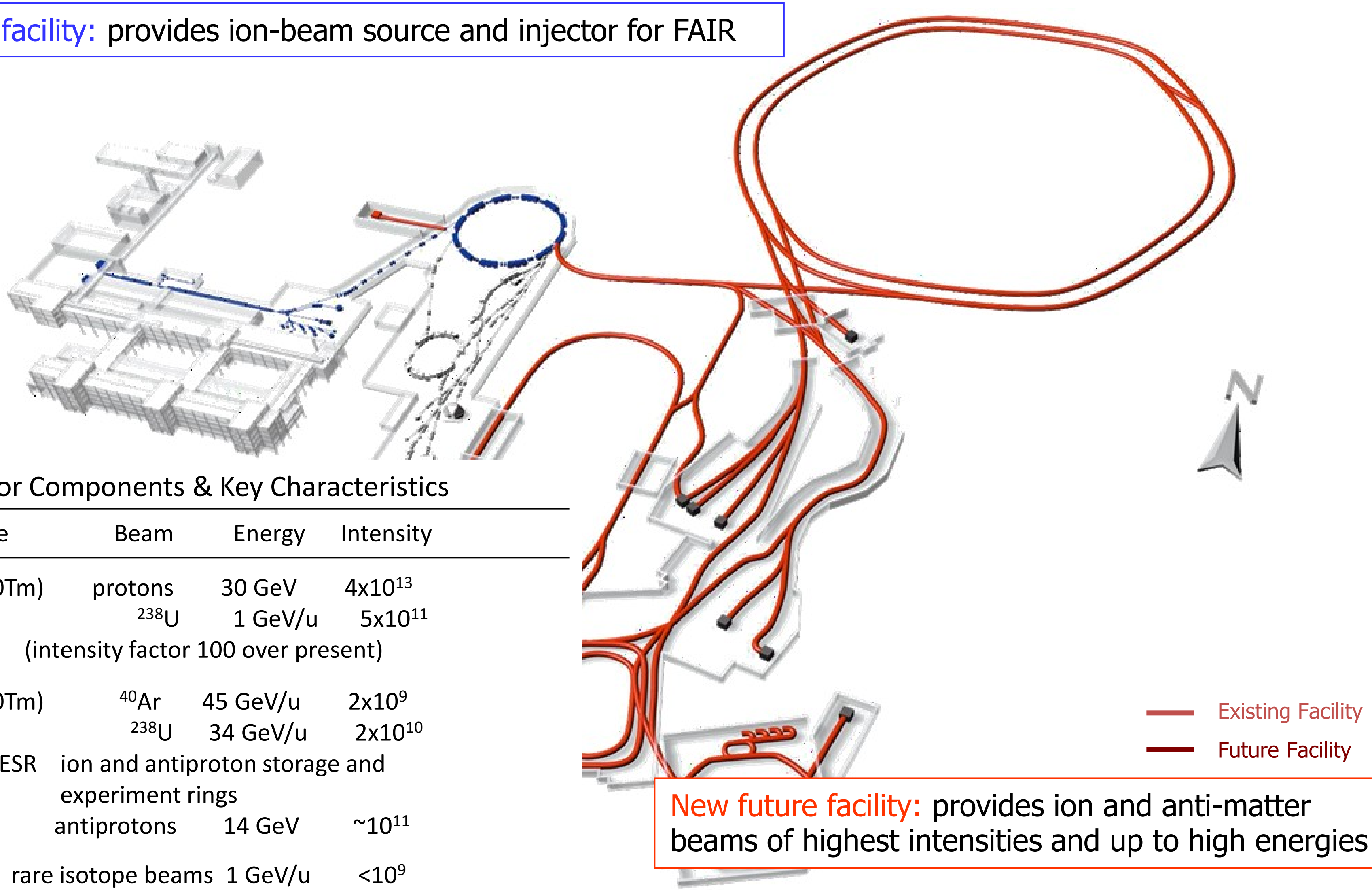
SIS100

SIS300

Future Challenges

Facility for Antiproton and Ion Research

Existing facility: provides ion-beam source and injector for FAIR

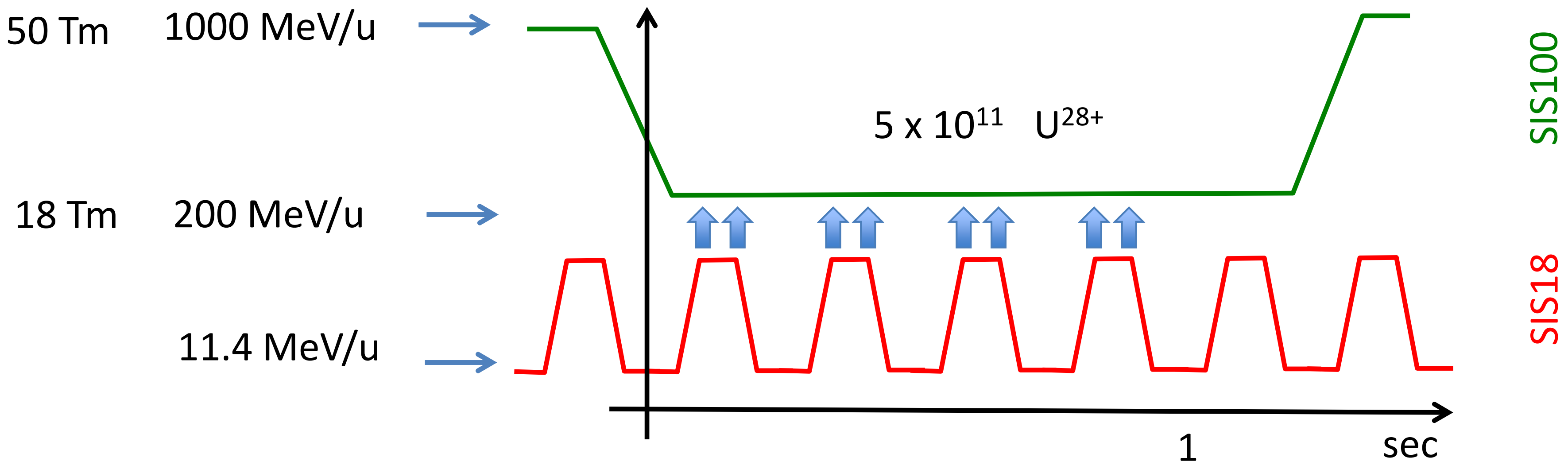


New future facility: provides ion and anti-matter beams of highest intensities and up to high energies

Accelerator Components & Key Characteristics

Ring/Device	Beam	Energy	Intensity
SIS100 (100Tm)	protons	30 GeV	4×10^{13}
	^{238}U	1 GeV/u	5×10^{11}
	(intensity factor 100 over present)		
SIS300 (300Tm)	^{40}Ar	45 GeV/u	2×10^{9}
	^{238}U	34 GeV/u	2×10^{10}
CR/RESR/NESR	ion and antiproton storage and experiment rings		
HESR	antiprotons	14 GeV	$\sim 10^{11}$
Super-FRS	rare isotope beams	1 GeV/u	$< 10^{9}$

SIS100 injection plateau scenario



First bunch @ 200 MeV/u

Nominal N_{ions} = 6.25 x 10^{10}/bunch
Beam1: $\varepsilon_{x/y}$ = 35/15 mm-mrad (2σ) $\Delta Q_{x/y}$= -0.21/-033
Turns = 1.57 x 10^5 (1 sec.)

Problem of control of beam loss for the bunched beams in SIS100 during 1 second

SIS18

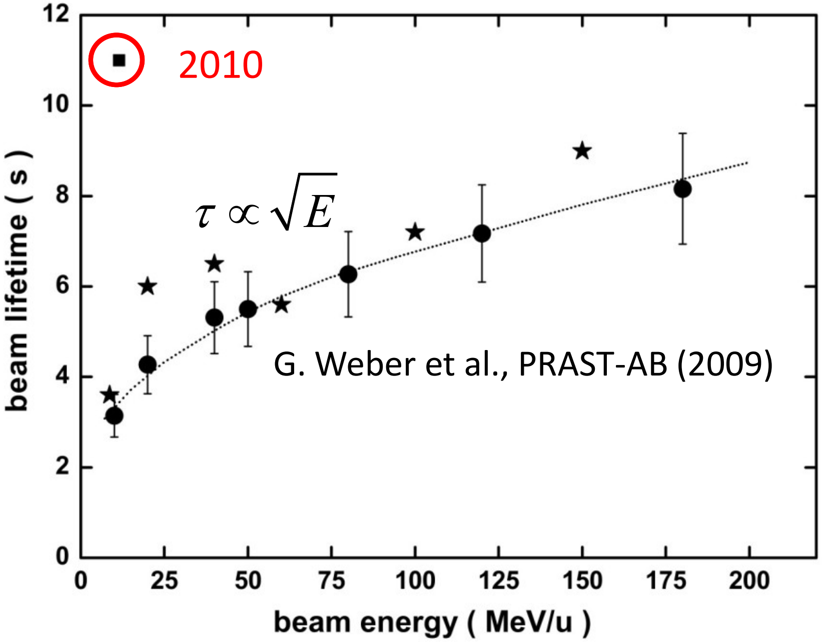
Beam loss in SIS-18: U^{28+} lifetime and residual gas pressure

Electron stripping: $U^{28+} + X \rightarrow U^{29+} + X + e$

(Lifetime)$^{-1}$: $\tau^{-1}(P) = \beta_0 c \sigma_{loss} \frac{P}{k_B T}$

Born approximation: $\sigma_{loss} \propto E^{-1}$

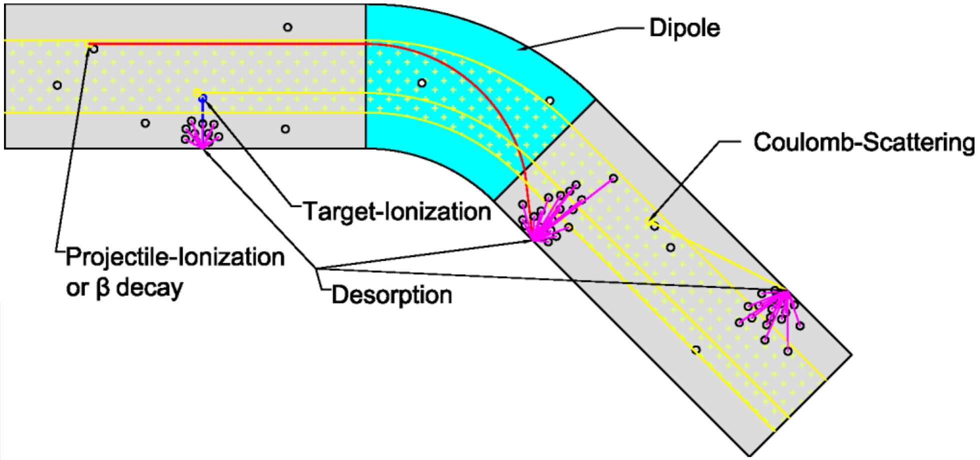
Measured U^{28+} life time for **low intensities**



G. Weber et al., PRAST-AB (2009)

Lifetime increase (factor 3) due to NEG coating

High intensities



$$\eta = \frac{\#\ \text{desorbed molecules}}{\#\ \text{incident ions}} \propto \left(\frac{dE}{dx}\right)^n$$

Stopping power: $\frac{dE}{dx} \propto \frac{Z^2}{A}$

H. Kollmus et al.,
J. Vac. Sci. (2009)

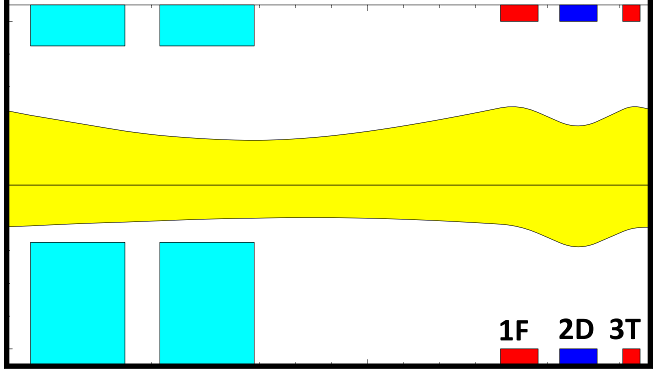
Dynamic pressure: $\frac{dP}{dt} = \tau_p^{-1}(P - P_0) + \alpha \eta_{loss} NP$

Challenge: Control of dynamic pressure.

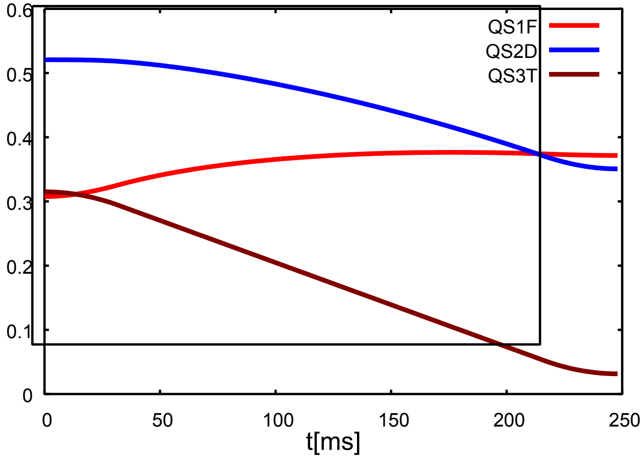
Slide by O. Boine-Frankenheim

SIS18: Optics Change During Ramp

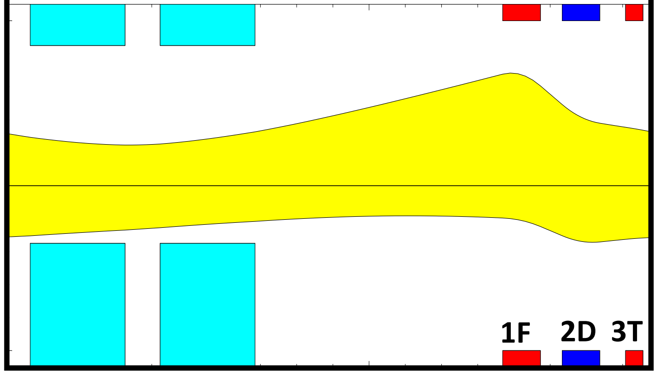
Triplet optic at injection:
Optimization of hor. acceptance



Evolution of quadrupole strengths during ramp



Dublet optic at extraction:
Large β_x for extraction devices



Slide from D. Ondreka

- Main challenge:
  - Optics dependent correction of closed orbit and tune
- Work in progress:
  - Software feed forward
    => *LSA Collaboration with CERN*
  - Real time feed back
    => *BI Collaboration with Univ. Dortmund*

SIS100

‘Beam loss budget’ in SIS-100

Beam loss induced effects in the vacuum chamber or accelerator components:

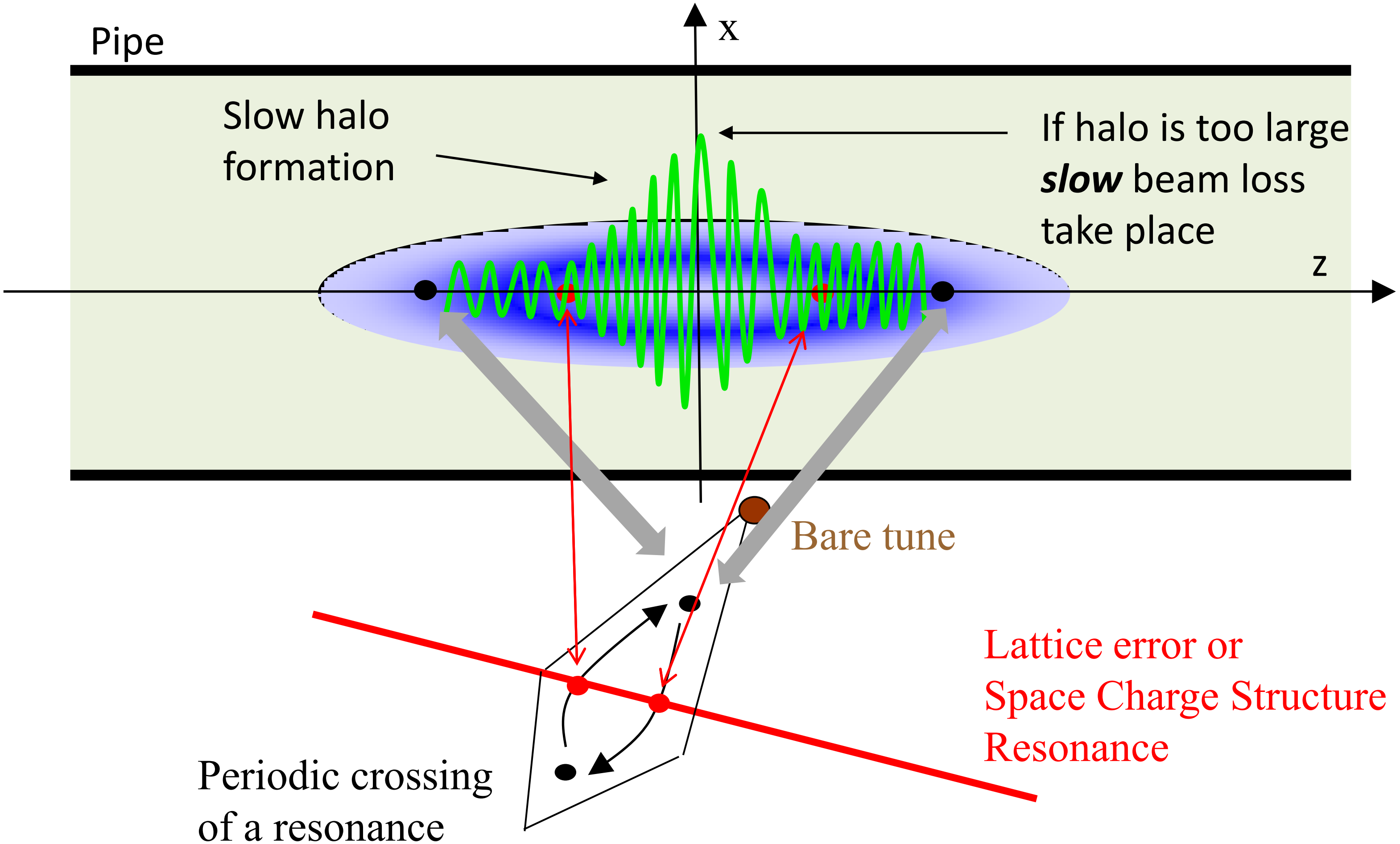
activation: loss of ‘hands-on-maintenance’
-> important only for localized losses e.g. during slow extraction

ion induced damage: persistent change of material properties
-> energetic heavy ions can cause higher damage than protons

ion induced desorption: increase of the vacuum pressure
-> distributed combined collimation/pumping system for ‘stripping’ losses in SIS-100

We presently expect that max. 5-10 % percent beam loss can be tolerated.

Multiple resonance crossing in bunched beams induced by space charge



Slow halo formation

If halo is too large ***slow*** beam loss take place

Lattice error or Space Charge Structure Resonance

Periodic crossing of a resonance

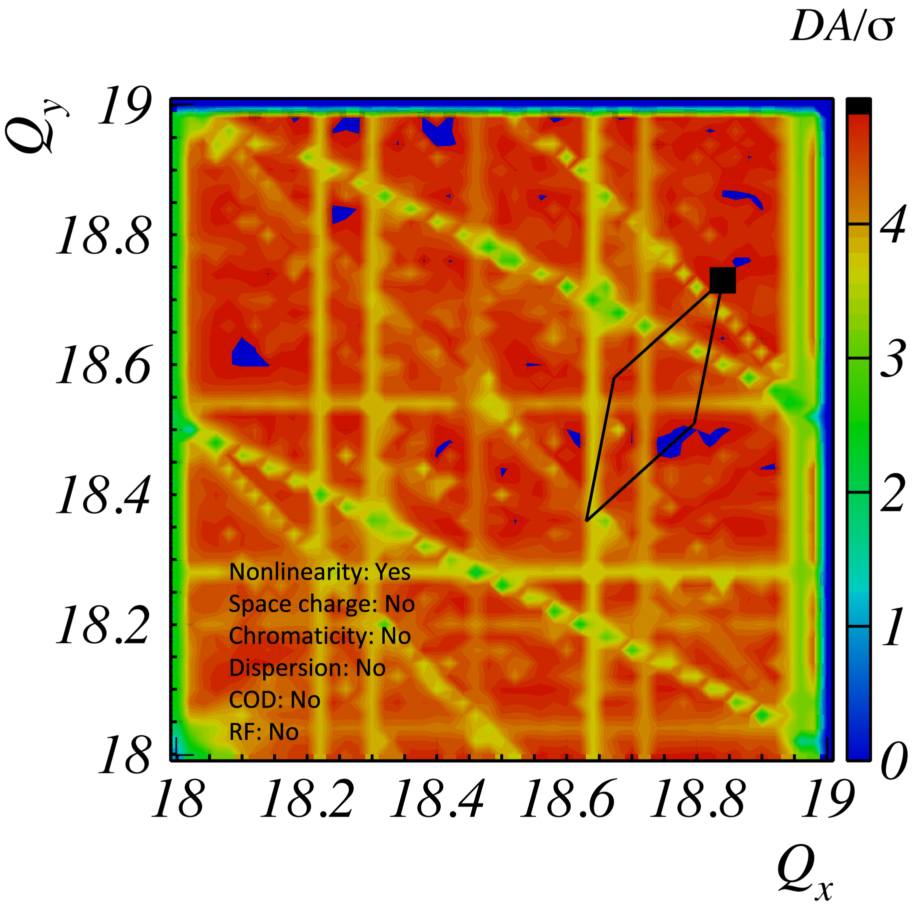
SIS100 Modeling

1) Linear Lattice
2) All insertions (i.e. each element sizes + all septums, NO Collimators)
3) Each magnet has nonlinear field modeled via 3 localized nonlinear kicks of the systematic errors
4) Displacement of quadrupoles is modeled by insertion of a dipolar kick in center of quadrupole
5) Inclusion of all magnet correctors: steerers and sextupole for chromatic correction and resonance corrector sextupoles (in addition with quadrupoles and octupoles)

Magnet design: CSLD *Pavel Akishin, Anna Mierau, Pierre Schnizer, Egbert Fischer 3. June 2010*

Magnet multipoles: V.Kapin, P. Schnizer, A. Mierau
Kapin, V.; Franchetti, G. ACC-note-2010-004
Lattice: J. Stadlmann, A. Parfenova, S.Sorge

Resonances excited by the "standard seed"

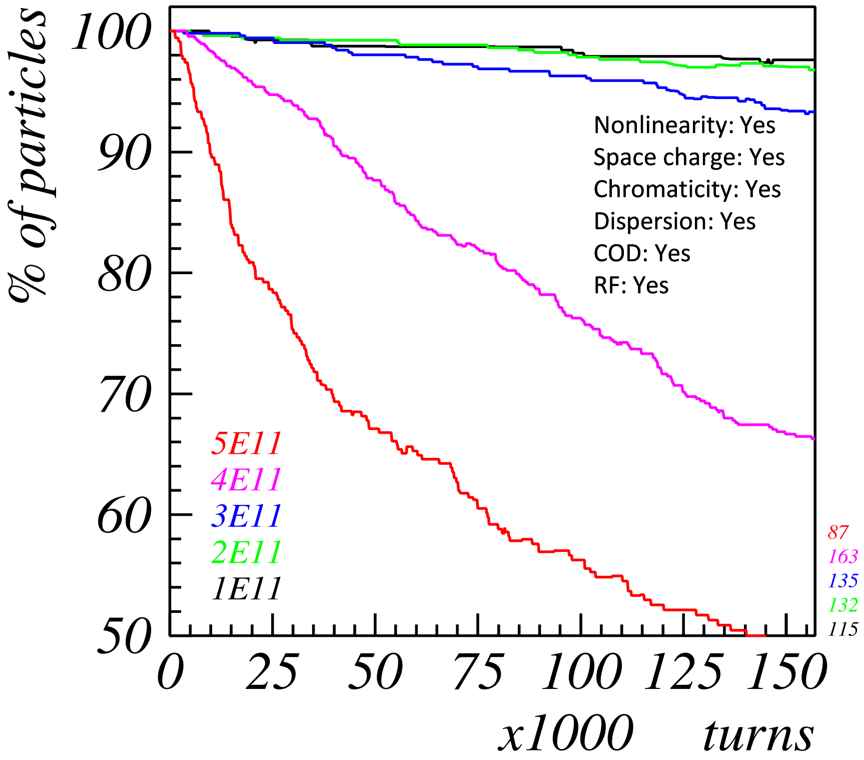


Resonances crossing the space charge tune-spread

- 2 Qy = 37
- Qx + 2 Qy = 56
- 3 Qx = 56
- 2 Qx + 2 Qy = 75
- 4 Qx = 75

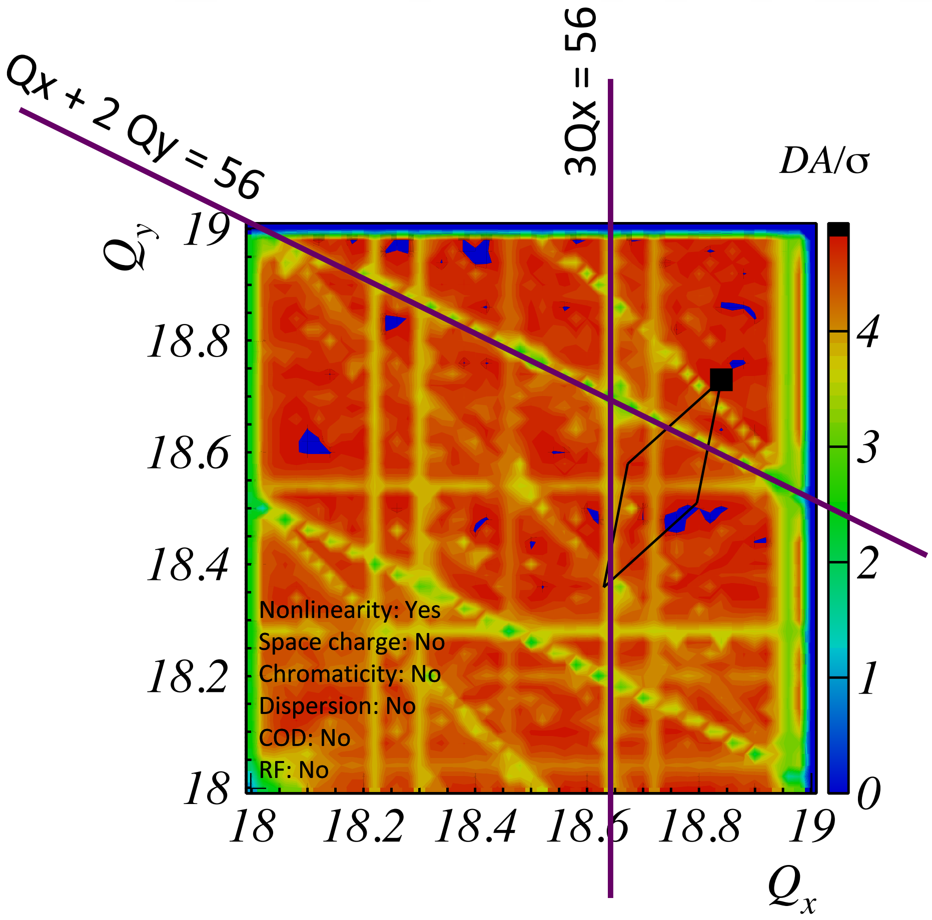
Beam loss versus beam intensity

First bunch



Finding: Beam intensity is relevant for beam survival

The 3rd order resonance was responsible of the periodic resonance crossing

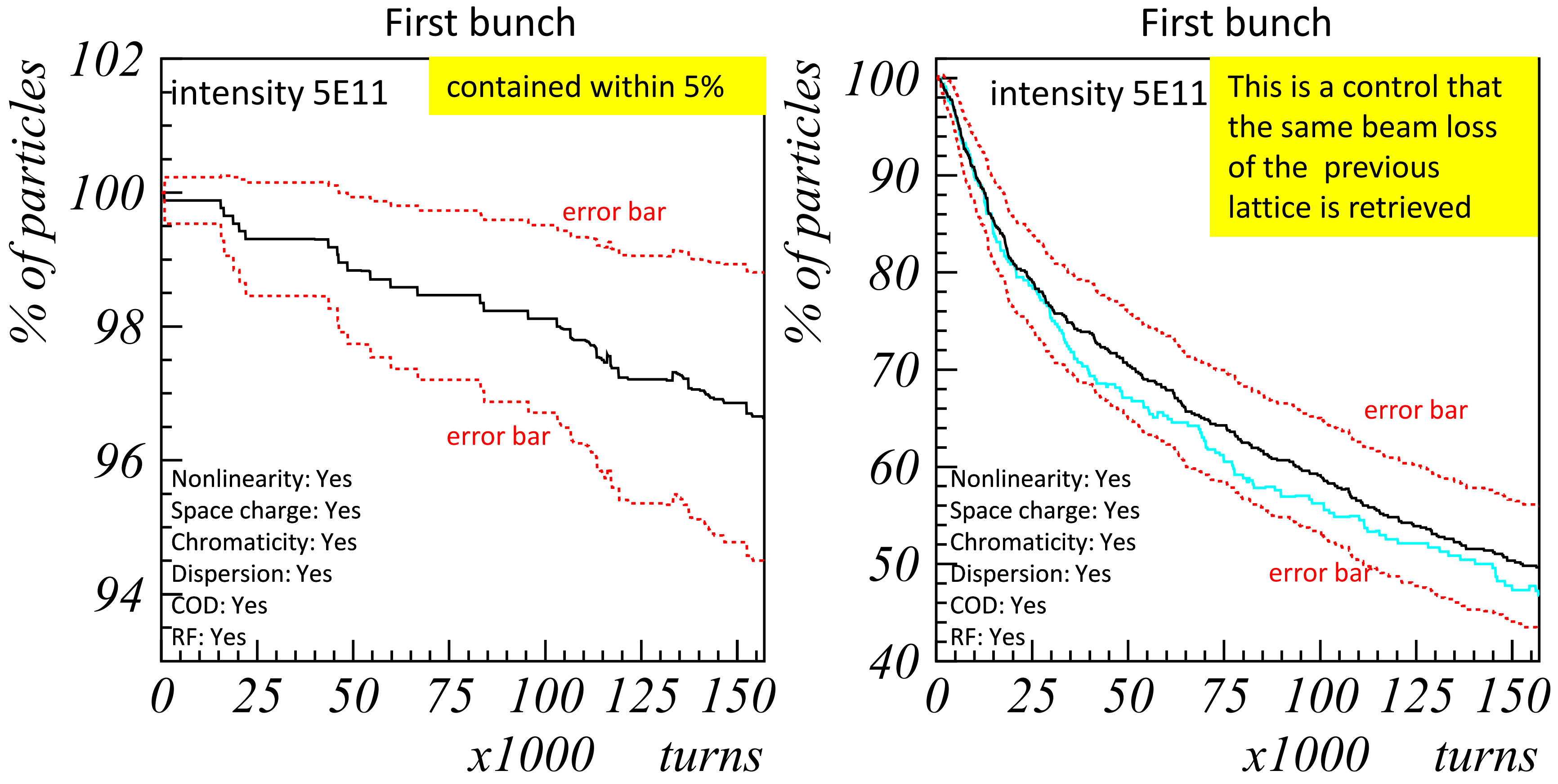


Proof obtained by

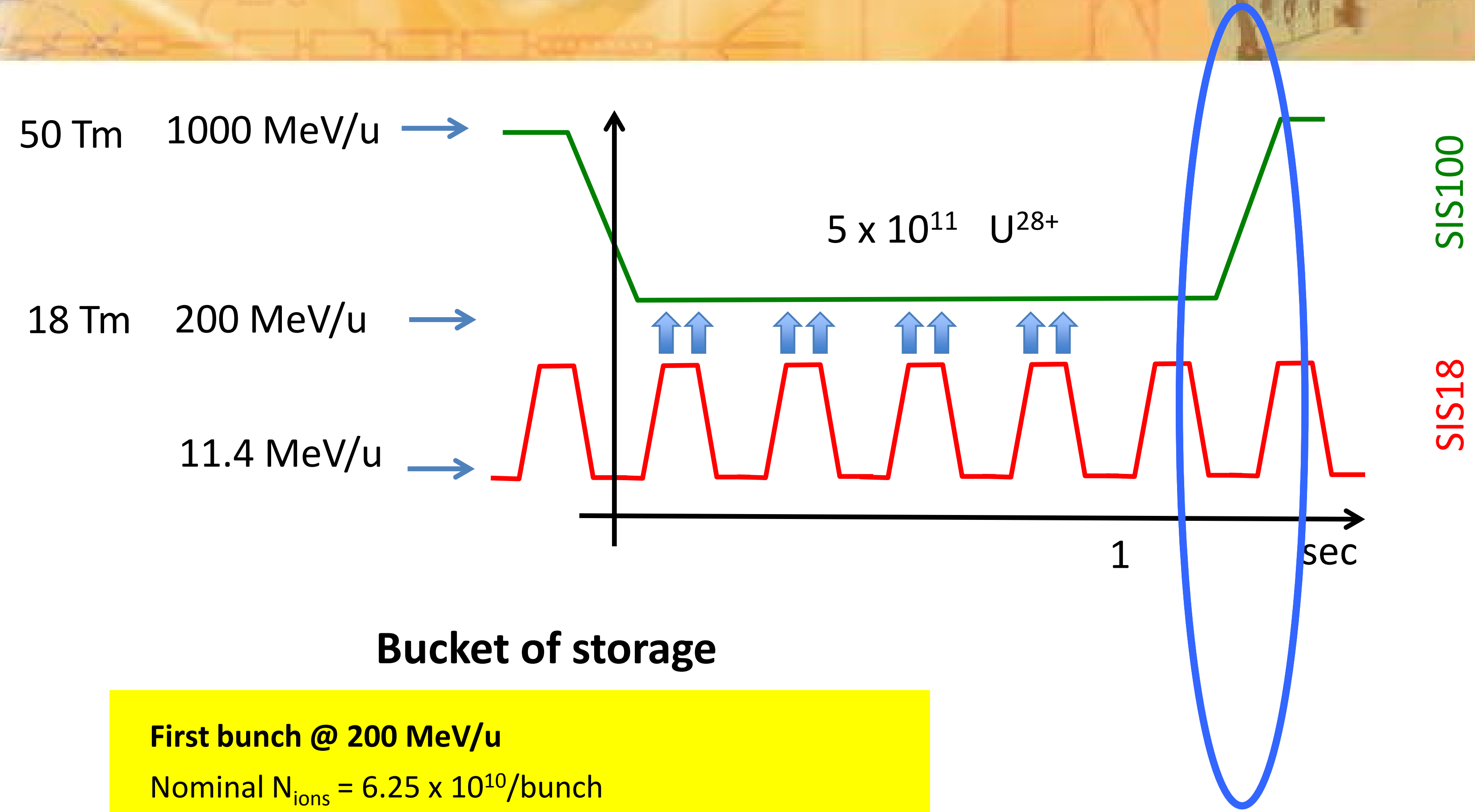
Compensating the resonance
Qx + 2 Qy = 56
without exciting the resonance
3 Qx = 56

Compensating the relevant resonance mitigates beam loss

Compensated **Standard seed** **Un-Compensated**



SIS100 acceleration



Bucket of storage

First bunch @ 200 MeV/u

Nominal N_{ions} = 6.25 x 10^{10}/bunch
Beam1: $\varepsilon_{x/y}$ = 35/15 mm-mrad (2σ) $\Delta Q_{x/y}$= -0.21/-033
Turns = 1.57 x 10^5 (1 sec.)

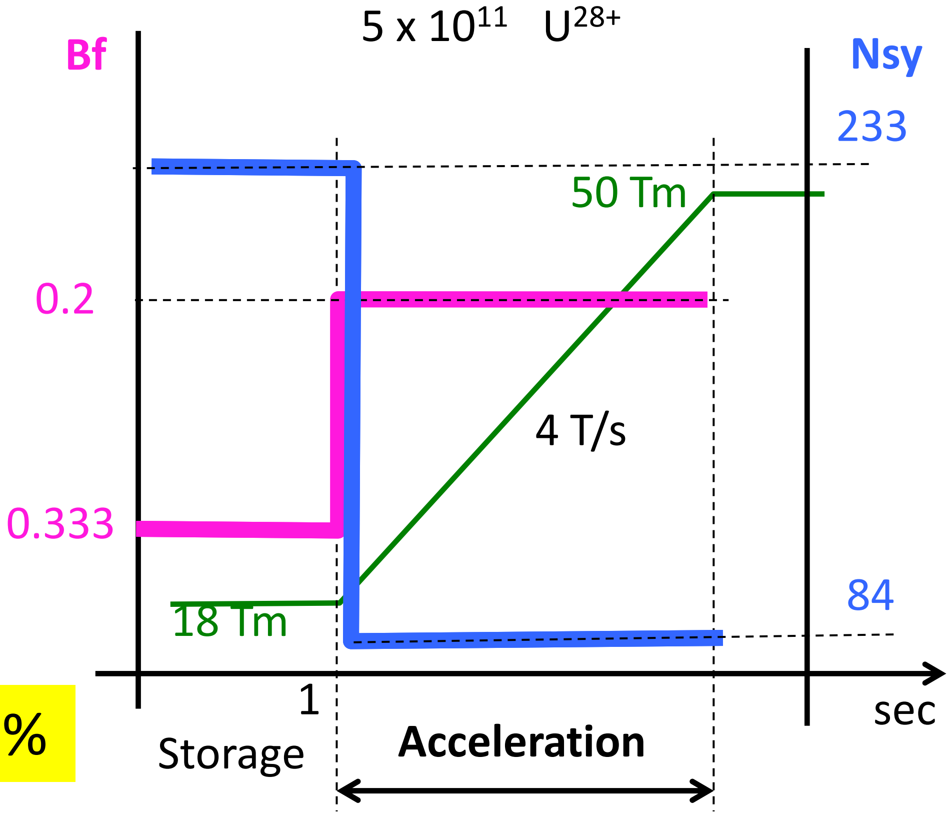
Acceleration

Change of RF bucket

1) The bunch length is kept constant
2) The longitudinal emittance
   is preserved

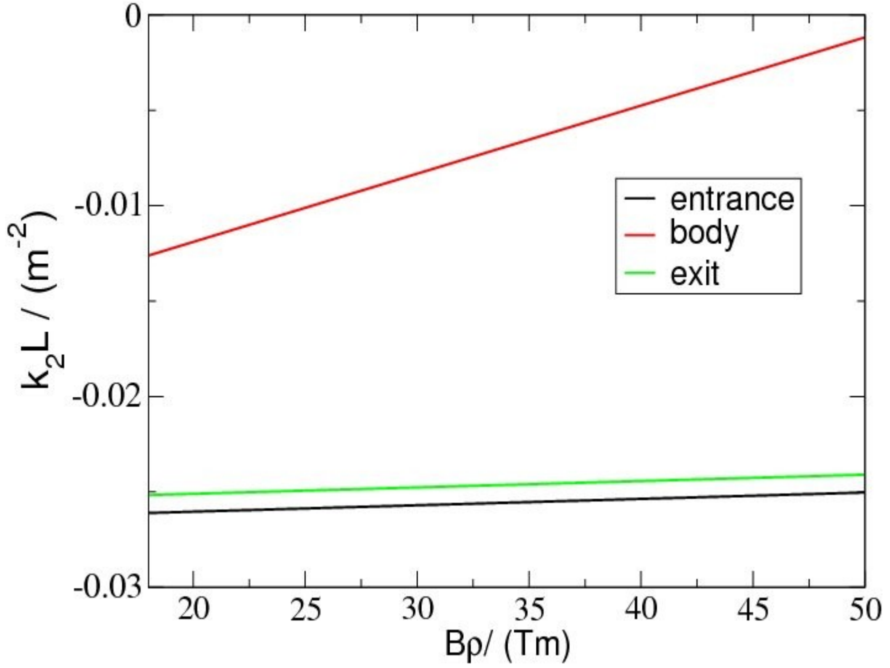
Synchrotron frequency changes
Bunching factor changes

peak tuneshift increases of ~60%

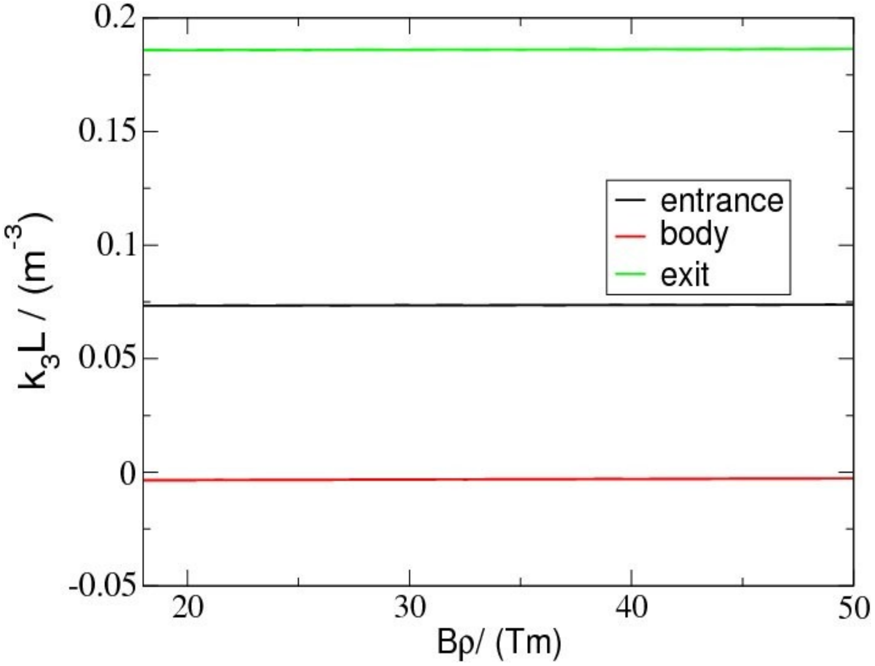


Magnet modeling during acceleration

Sextupolar
component
(without eddy current)



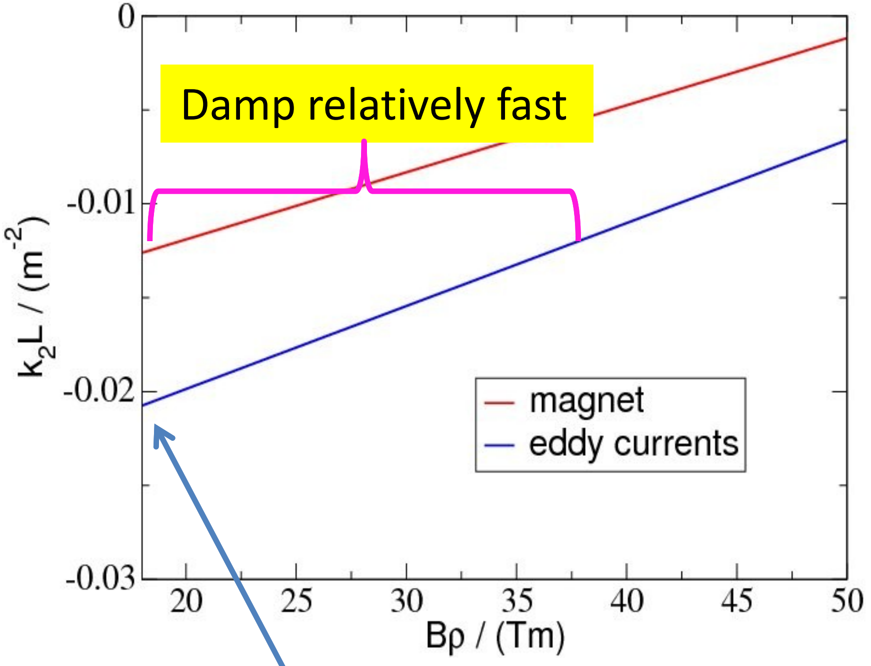
Octupolar
component
(without eddy current)



S.Sorge

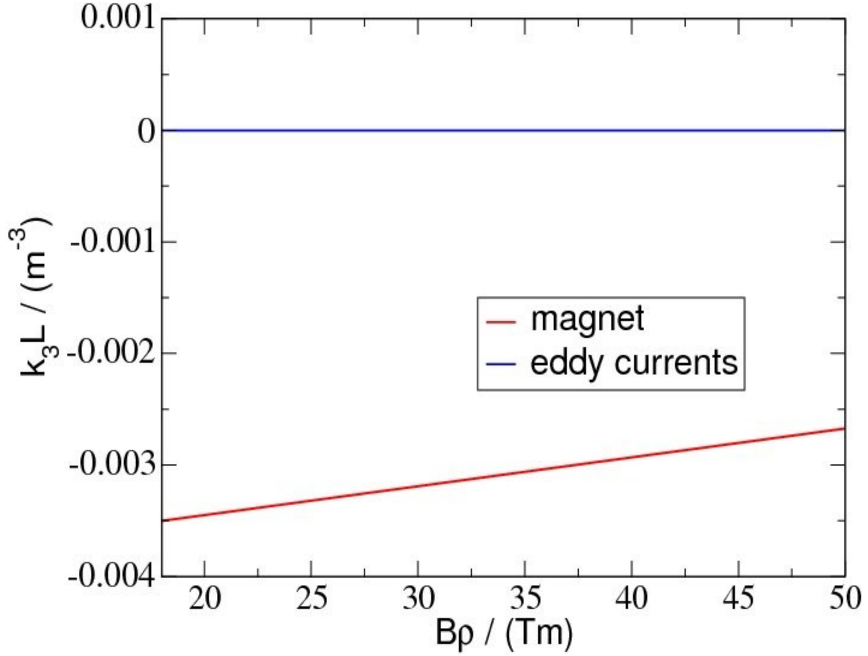
Effect of the eddy current

Sextupolar component
and eddy current



Damp relatively fast

Octupolar component
and eddy current

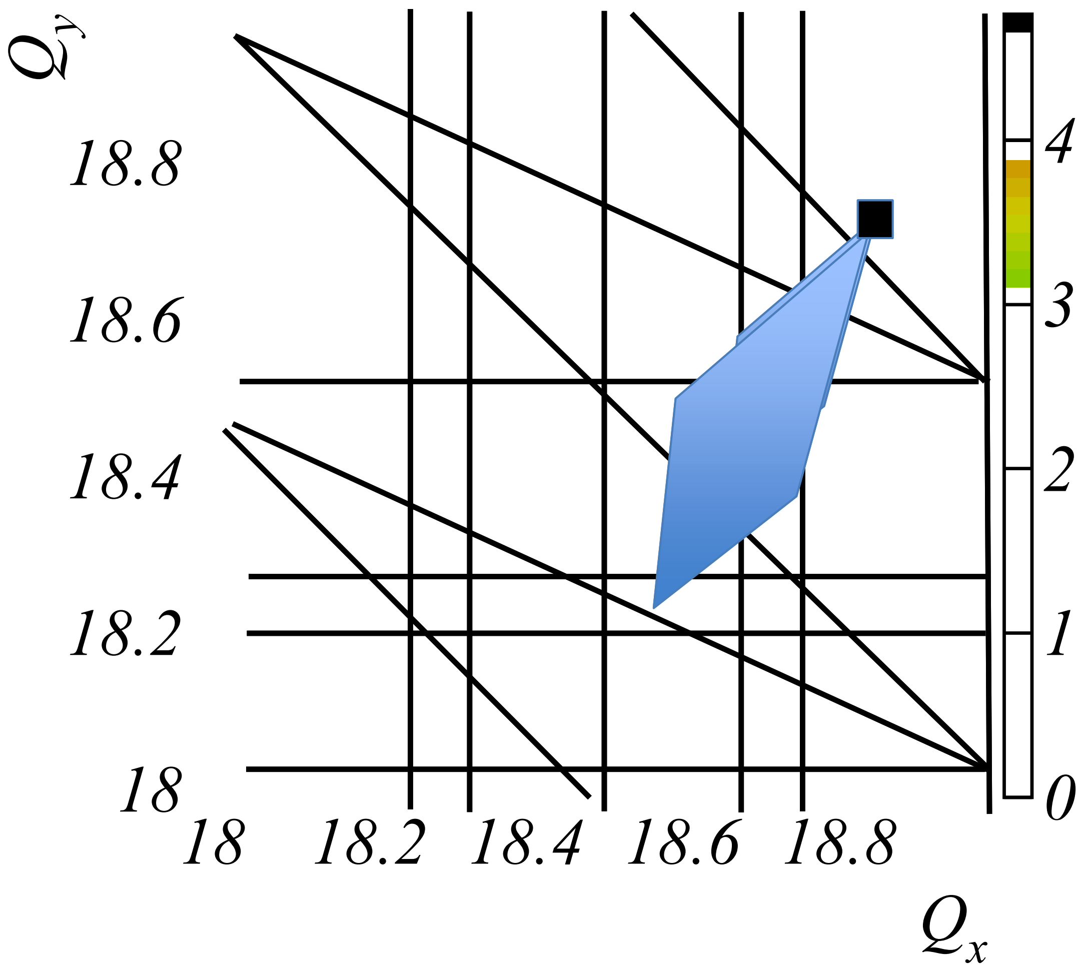


S.Sorge

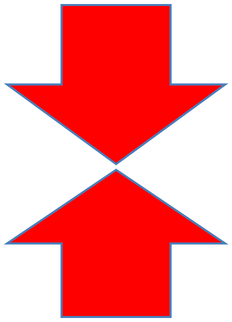
Created at the beginning of the acceleration ramp of 4 T/s enhances the systematic sextupolar strength

The beam dynamic issues

$[\langle DA \rangle - 3\, var(DA)]/\sigma$



Increase of energy damps beam size and space charge



periodic resonances crossing pushes beam out

Relevance of resonances varies during the ramp

Very complex process

Preliminary investigation

We keep conservative:

Keep the error seed of the storage also during the ramp

↓

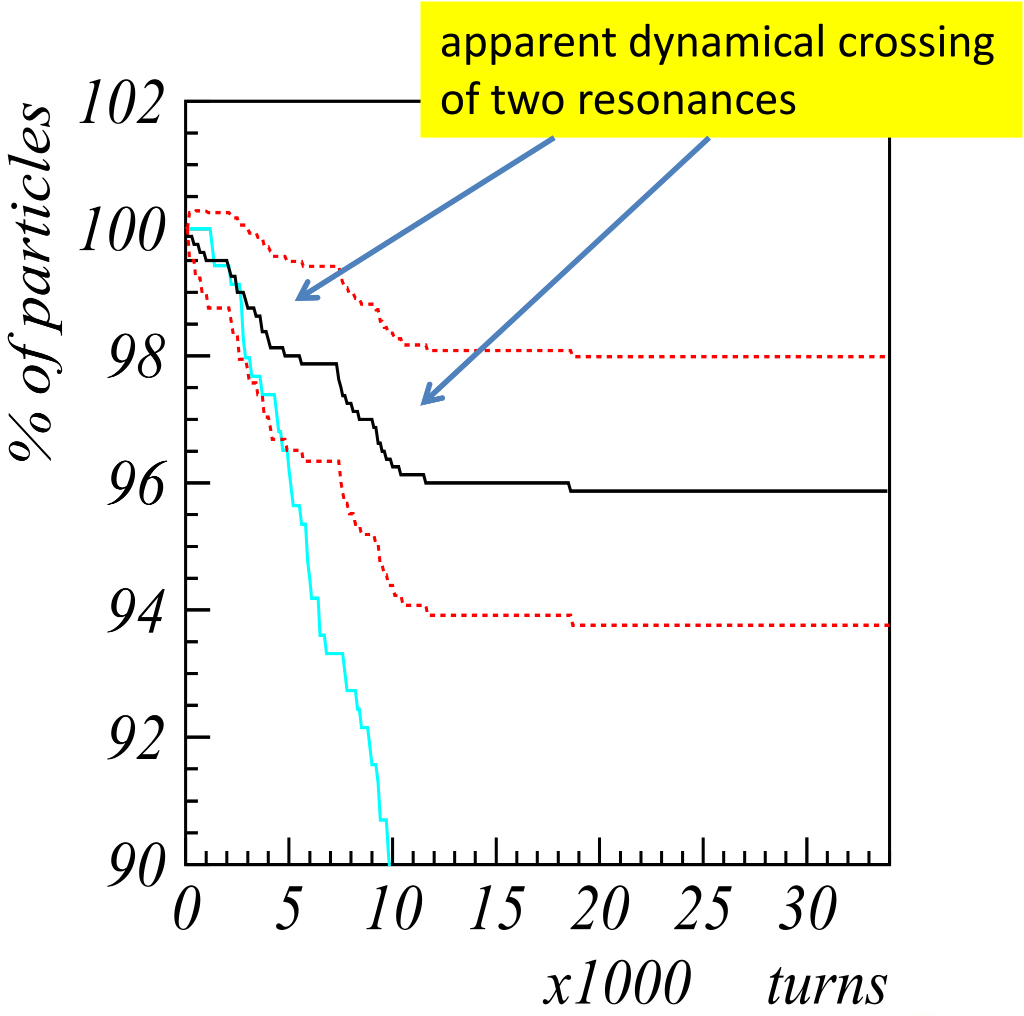
Closed orbit distortion remains during ramp
of the order of storage

Do not compensate any resonance

We study the higher intensity case I = 5x10^{11} ions

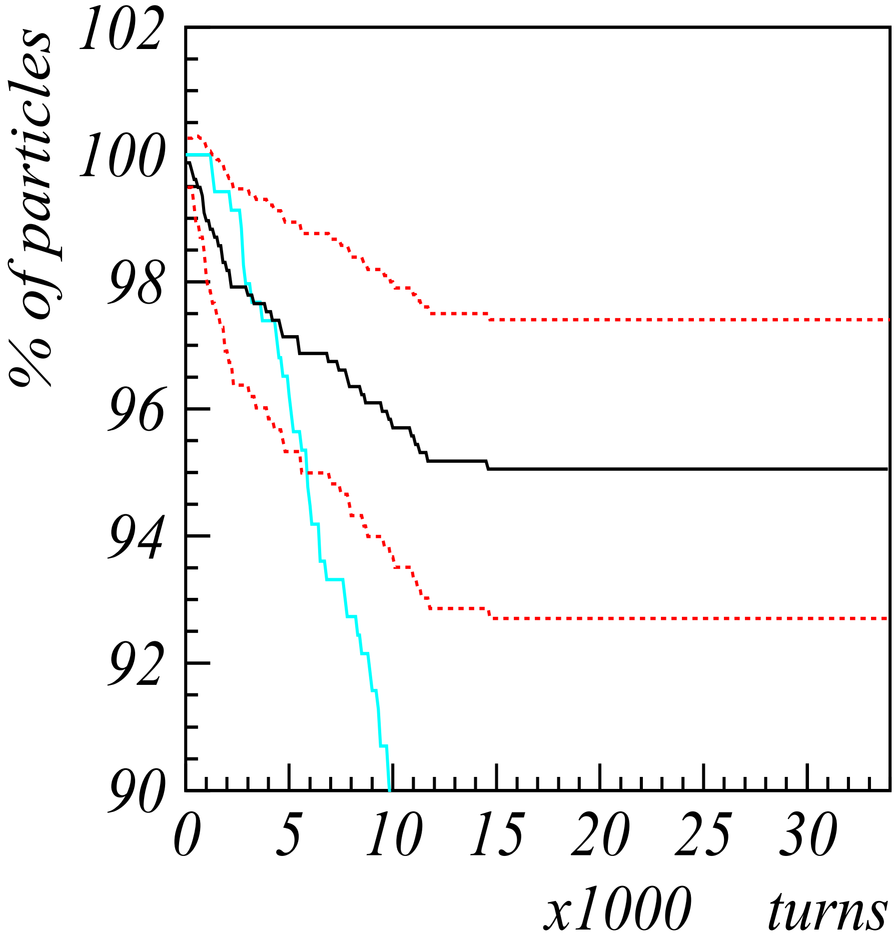
Beam survival without including eddy current

emittances: 35x15
dp/p: yes
Intensity: 5E11
Resonance: uncompensated
Ramp: 18Tm → 50Tm
random seed → yes
eddy current → no
bucket → Ramp


apparent dynamical crossing of two resonances

Beam survival
including eddy current

emittances: 35x15
dp/p: yes
Intensity: 5E11
Resonance: uncompensated
Ramp: 18Tm → 50Tm
random seed → yes
eddy current → yes
bucket → Ramp

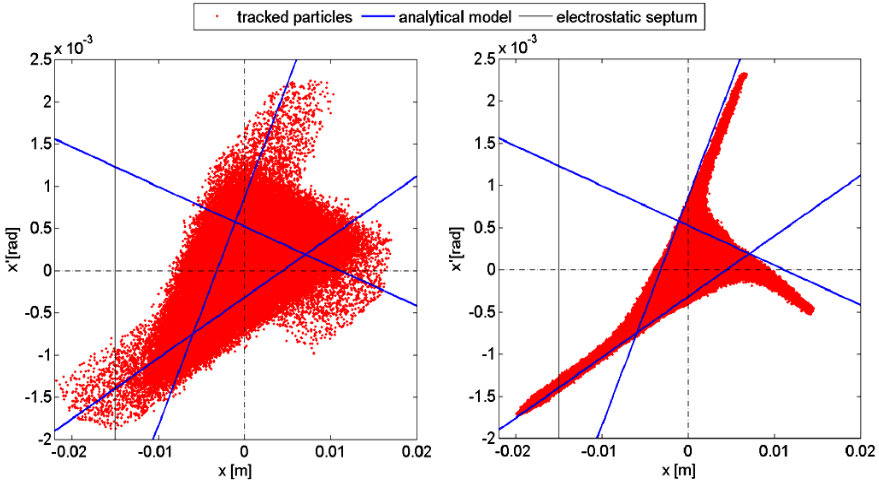


SIS300

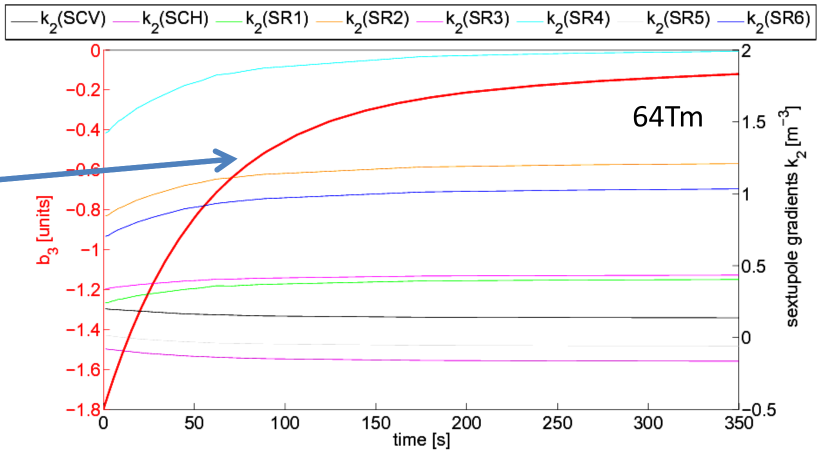
SIS300 slow extraction issues

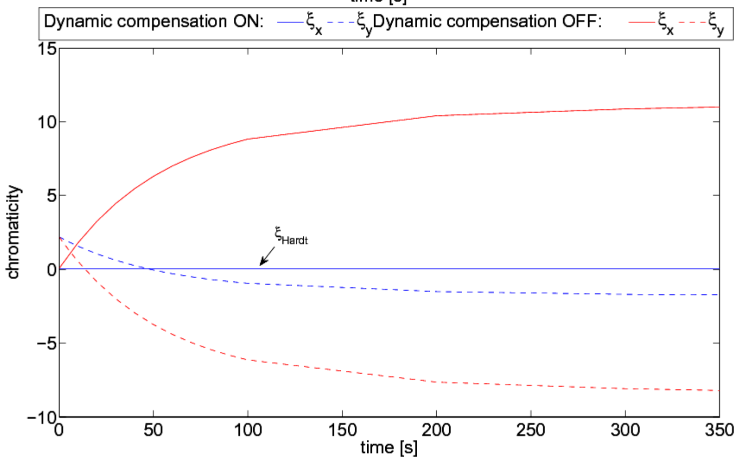
This synchrotron has superconducting magnets and is a fast ramping machine

slow resonant extraction with superconducting cos(θ) magnets (1st time worldwide)



time varying b3





"Design and Optimization of the Lattice of the Superconducting Synchrotron SIS300 for Slow Extraction"
*Angela Saa Hernandez **PhD Thesis** (to be published)*

A. Saa Hernandez et al. "Slow extraction from the superconducting synchrotron SIS300 at FAIR: Lattice optimization and simulations of beam dynamics". Proceedings of IPAC 2010, Kyoto.

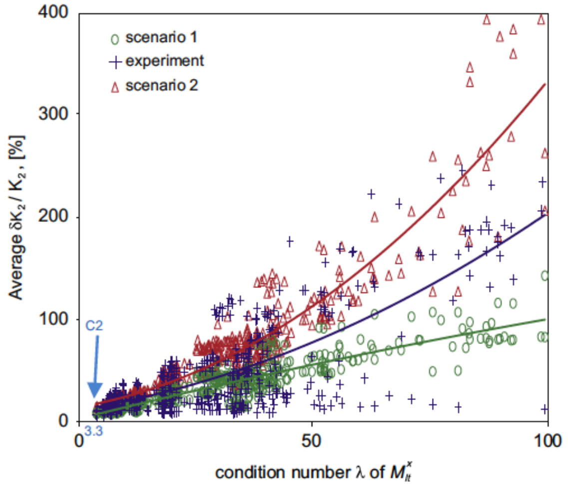
Getting Prepared…

Reconstruction of nonlinear errors

At GSI we have developed the NTRM approach which is used for modeling SIS18 (**A.Parfenova**)

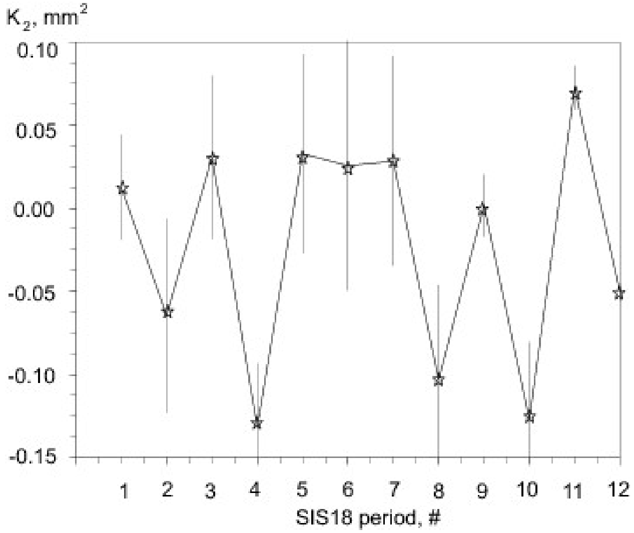
Proof of principle for sextupoles + general theory

Applicability of the method



A. Parfenova and G. Franchetti
Nucl. Instr. and Meth. A 646, (2011), 7-11.

Full reconstruction of sextupolar error in SIS18



(A. Parfenova. This workshop)

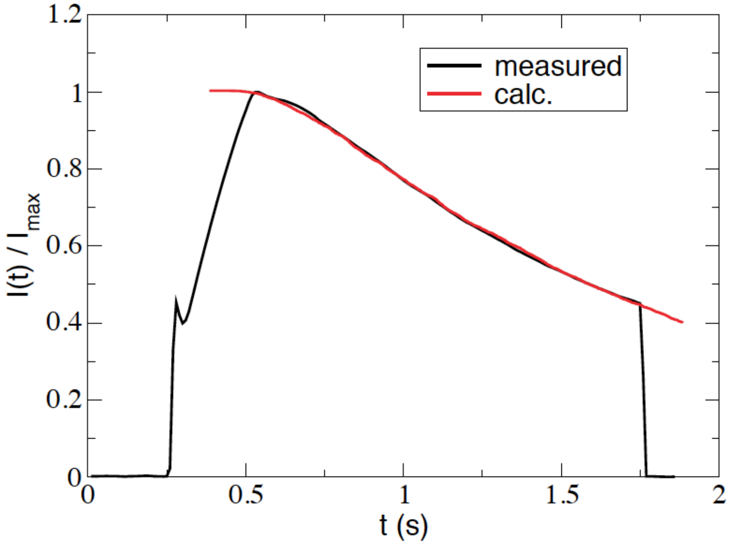
Resonance compensation of relevant resonance in SIS18 and benchmarking of the effectiveness of the compensation for high intensity beams

Linear and nonlinear machine apertures

After reconstructing the nonlinear component a check of acceptance and dynamic aperture is an important verification

See seminar of S.Sorge, Thursday 23rd

principle → a small beam is excited by noise and the curve of beam loss provides information on the machine acceptance



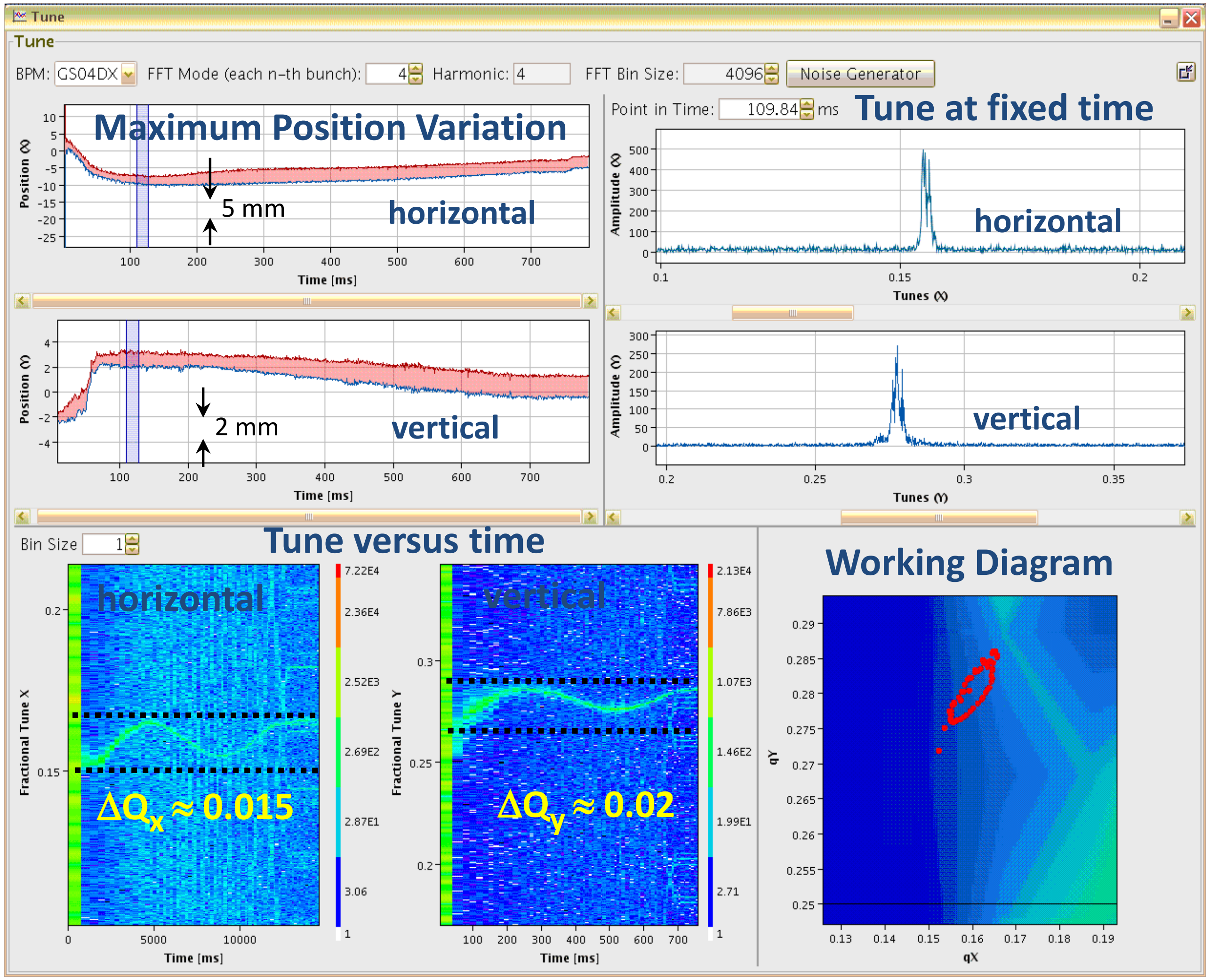
S. Sorge, G. Franchetti, A. Parfenova
Phys. Rev. ST Accel. Beams 14, 052802 (2011)

Future challenge

↓

extension of the method to approach a measurement of the dynamics aperture

Tune measurement/control



Tune

BPM: GS04DX FFT Mode (each n-th bunch): 4 Harmonic: 4 FFT Bin Size: 4096 Noise Generator

Point in Time: 109.84 ms

Bin Size 1

Maximum Position Variation

5 mm horizontal

2 mm vertical

Tune at fixed time

horizontal

vertical

Tune versus time

horizontal $\Delta Q_x \approx 0.015$

vertical $\Delta Q_y \approx 0.02$

Working Diagram

Development of noise based technique for measuring tune during the acceleration ramp

Rahul Singh

+

diagnostic group

Beam parameter: Ar^{18+} acc. 11 → 300 MeV/u within 0.7 s

Future challenges / Outlook

Beam dynamics affected by space charge makes the sensitivity to beam to optics more important (how much?)

Beam optics control and resonance compensation is essential for the high intensity scenarios

- Inventory of measured magnetic components of each elements before assembly
- Development of beam-based methods for measuring the machine optics and effective nonlinear components
- Studies on resonance compensation in presence of space charge
- Control of beam optics during acceleration:
  Do we need to compensate some specific resonance? when?

We should get prepared to the challenge to measure and to model the machine properties