High Intensity Challenges of the FAIR Project

Oliver Boine-Frankenheim, GSI, Darmstadt



Nov. 7, 2007: FAIR project start event



Communiqué
on the Official Launch of the
Facility for Antiproton and Ion Research (FAIR)

Darmstadt, 07 November 2007

Representatives of the FAIR partner countries have met in Darmstadt today, 07 November 2007, to jointly announce the beginning of the realization of the FAIR project in Darmstadt. The FAIR partner countries have issued statements on their intended contributions to funding FAIR. Furthermore, the signatory representatives declare the following:

Dr. A. Stoklaska
Federal Ministry of Science and Research
Austria

Dr. A. Schavan
Federal Minister of Education and Research
Germany

J. Doncel
Ministry of Education and Science
Spain

M. Arajärvi
Ministry of Education
Finland

Dr. G. Bloch
Director-General
Ministry of Higher Education and Research
France

Dr. O. Gaj
Ministry of Science and Higher Education
Poland

Prof. Dr. A. Anton
President of the National Authority
for Scientific Research
Romania

V.I. Rachkov
Federal Agency for Atomic Energy
Russian Federation

M. Johnsson
Ministry of Education, Research and Culture
Sweden

Prof. Dr. J. Womersley
Science and Technology Facilities Council
United Kingdom

R. Koch
Minister-President
State of Hesse

German Minister Ms. Schavan on November 7, 2007

Partners signing communiqué:
Austria, Germany, Spain, Finland, France, Poland, Romania, Russia, Sweden, Great Britain

FAIR start event

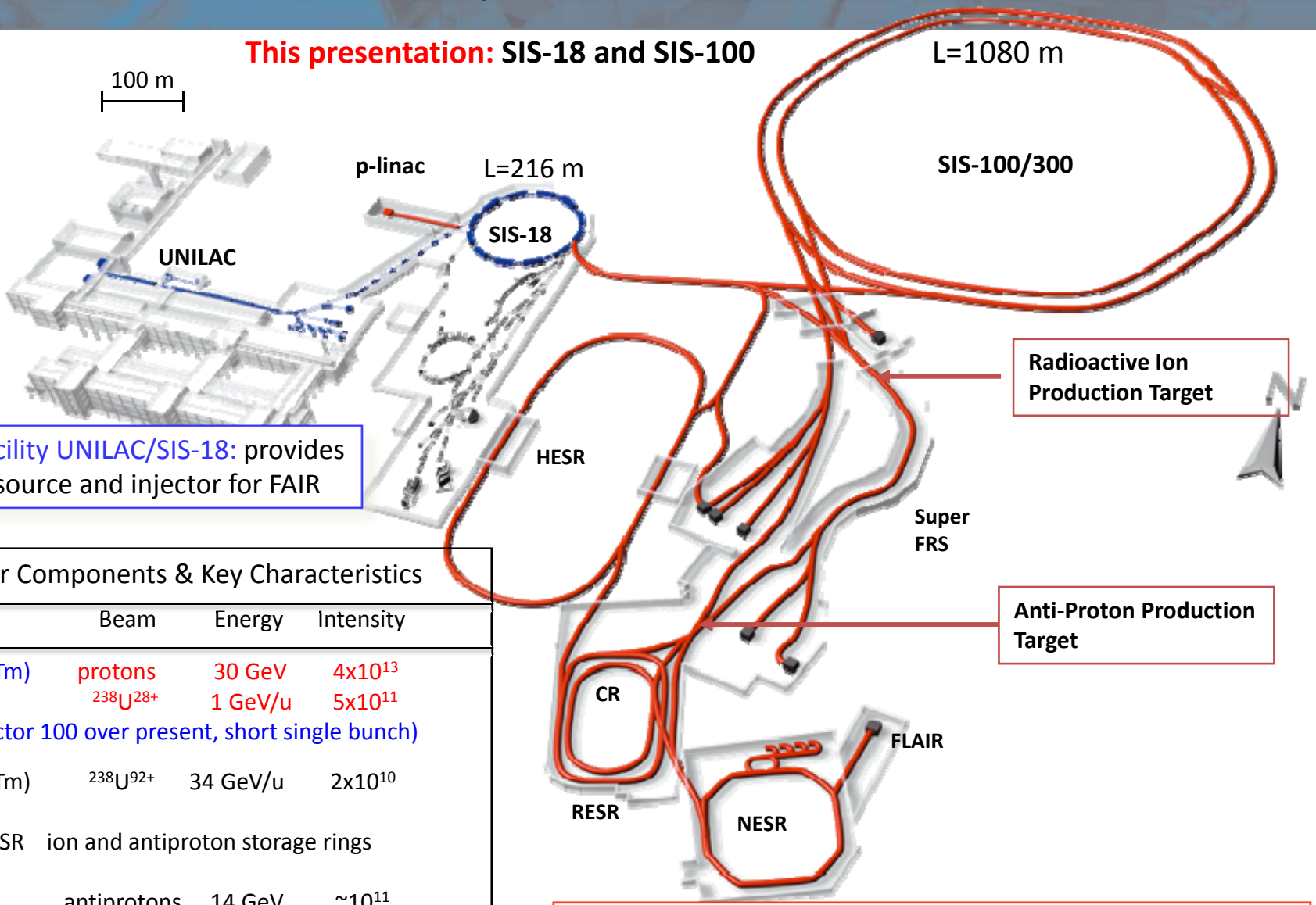


- 1400 international participants
- 500 international scientists attended the symposium on the Physics of FAIR

FAIR rings and parameter

baseline layout

This presentation: SIS-18 and SIS-100



Existing facility UNILAC/SIS-18: provides ion-beam source and injector for FAIR

Accelerator Components & Key Characteristics			
Ring/Device	Beam	Energy	Intensity
SIS100 (100Tm)	protons	30 GeV	$4x10^{13}$
	$^{238}U^{28+}$	1 GeV/u	$5x10^{11}$
(intensity factor 100 over present, short single bunch)			
SIS300 (300Tm)	$^{238}U^{92+}$	34 GeV/u	$2x10^{10}$
CR/RESR/NESR	ion and antiproton storage rings		
HESR	antiprotons	14 GeV	$\sim10^{11}$
Super-FRS	rare isotope beams	1 GeV/u	$<10^{9}$

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

Required FAIR beam intensities

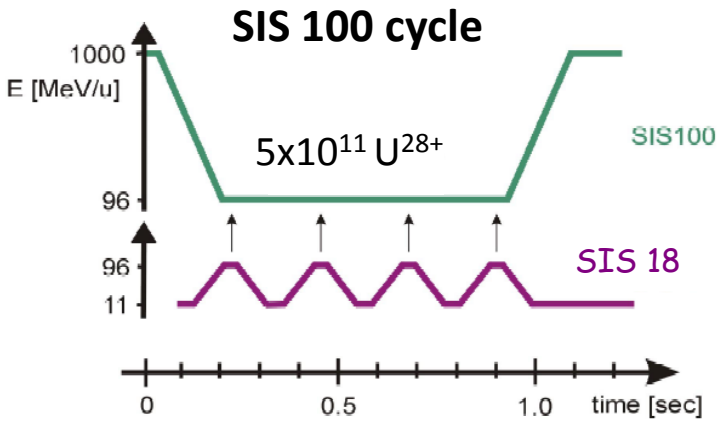
Heavy ions

	SIS-18 today*	After upgrade	After upgrade (to SIS 100)	SIS 100
Reference ion	U^{28+} / U^{73+}	U^{73+}	U^{28+}	U^{28+}
Maximum energy	0.2 / 1 GeV/u	1 GeV/u	0.2 GeV/u	2.7 GeV/u
Maximum intensity	$5x10^9$ / $3x10^9$	$2x10^{10}$	$1.5x10^{11}$	$5x10^{11}$
Repetition rate	0.3 Hz	1 Hz	2.7 Hz	0.7 Hz
Bunch length	> 100 ns	50 ns	-	60 ns

*UNILAC studies: L. Gröning's talk, Tuesday

FAIR specific beam dynamics challenges:

- Intensities at the 'space charge limit'
- High beam quality (weak or lost Landau damping)
- Long accumulation time (1 s) in SIS-100
- Reducing beam loss induced pressure increase



SIS-18 intensities

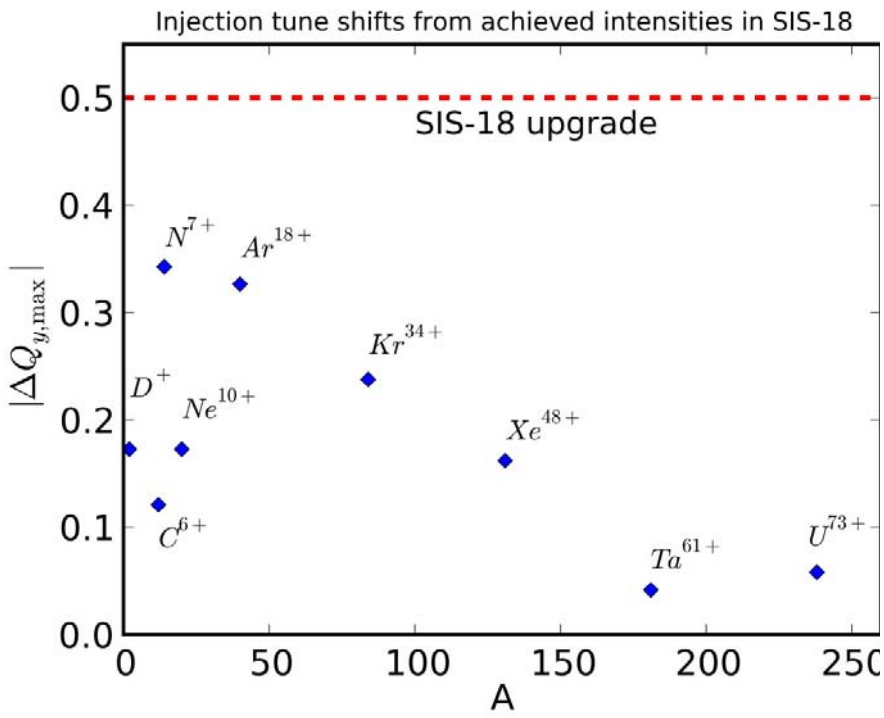
status and upgrade parameters

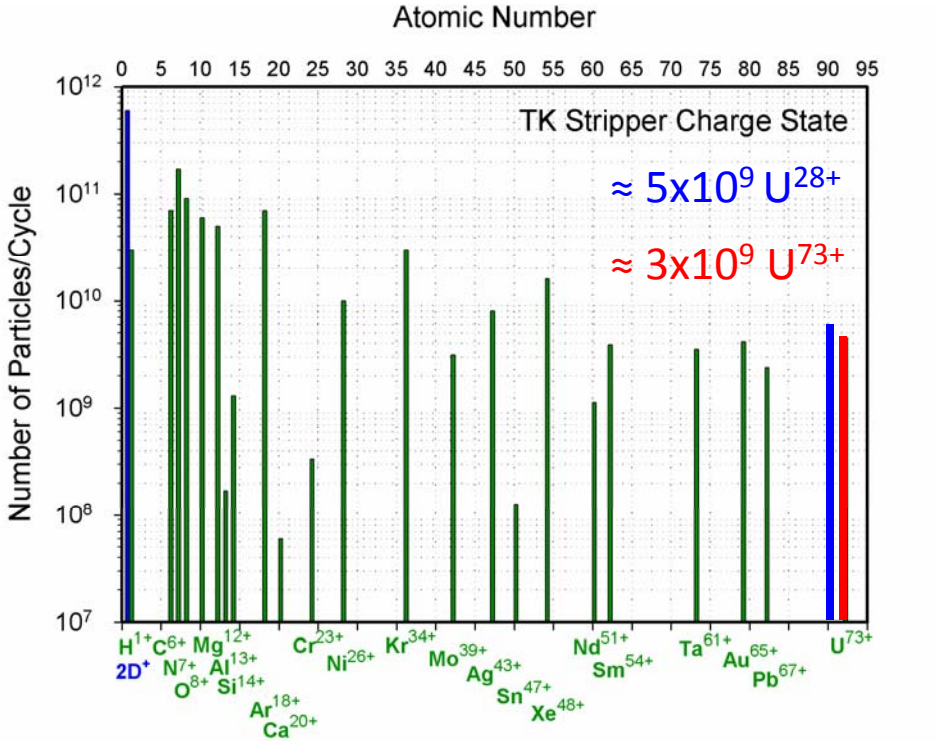
Injection energy: 11.4 MeV/u

(acceptance)

(long. space charge effect on the UNILAC micro-bunches)

Incoherent space charge tune shift:





Challenge: Working point optimization and resonance compensation for low beam loss (< 10 %).

G. Franchetti's talk on Tuesday

U^{28+} lifetime in SIS-18

low beam intensities

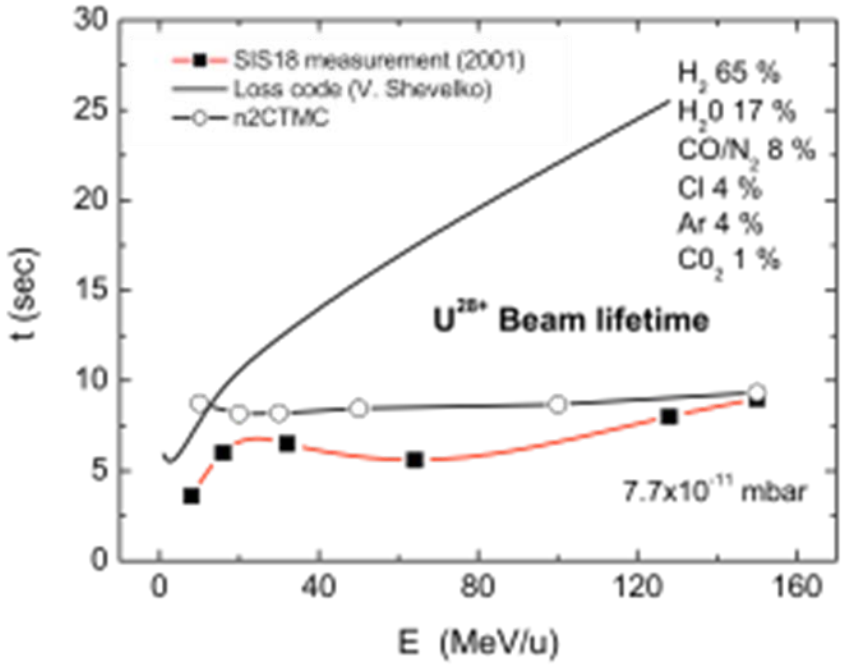
Loss of one or more electrons:

(Lifetime)$^{-1}$:

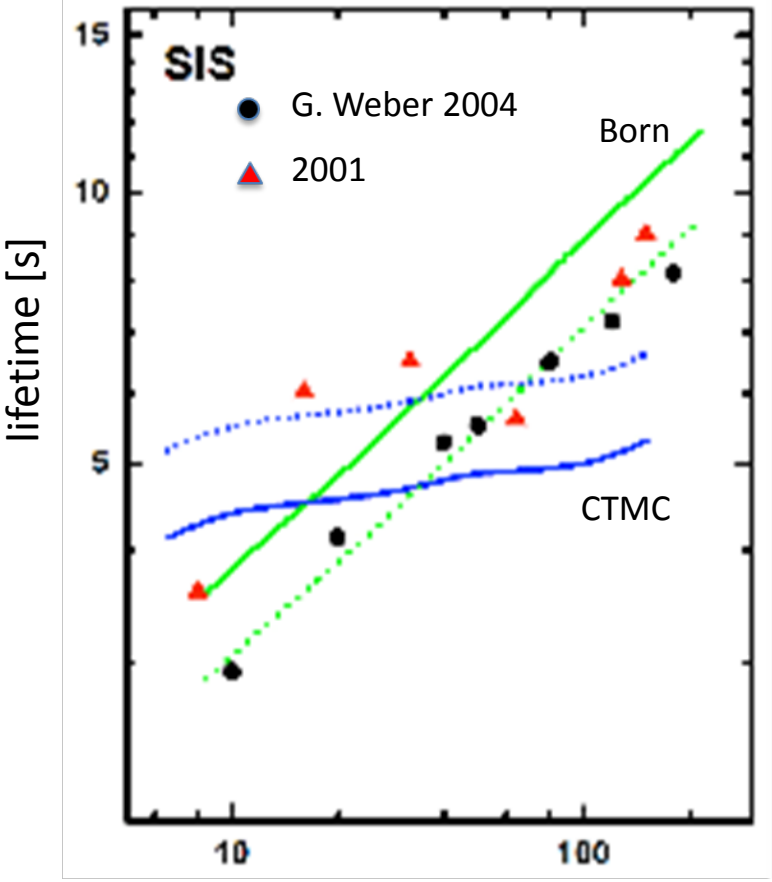
Born approximation:

CTMC simulations:

R. Olson et al., J. Phys. B (2004)



G. Weber, Heidelberg, 2006



SIS-18 upgrade

Control of the dynamic vacuum pressure

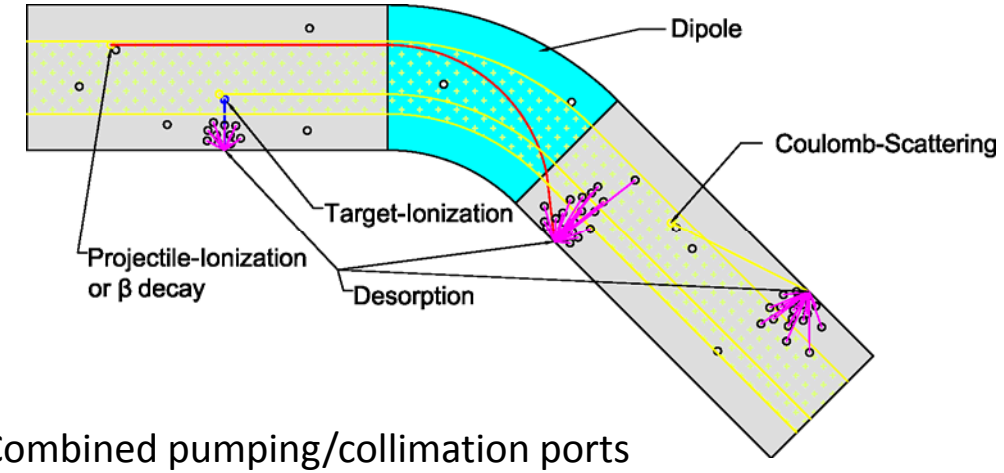
Dynamic pressure:

Desorption coefficient:

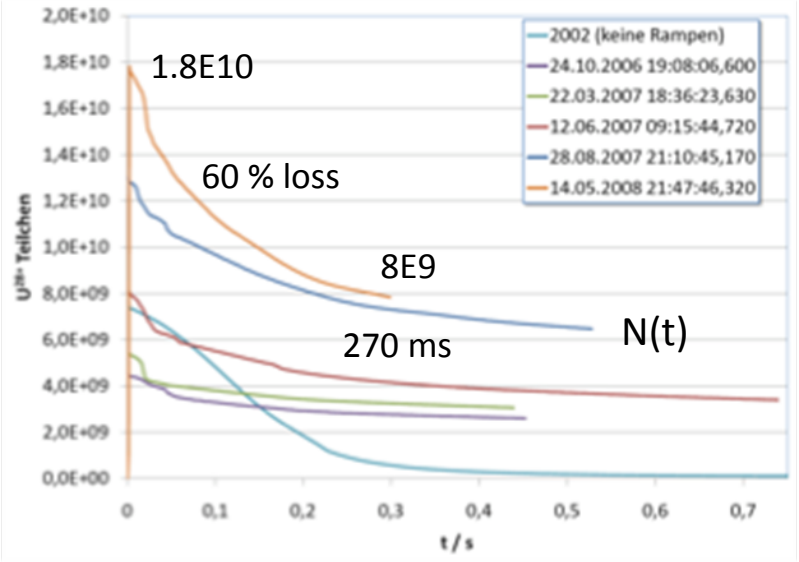
Beam loss mechanisms:

U^{28+} -> U^{29+} (stripping)

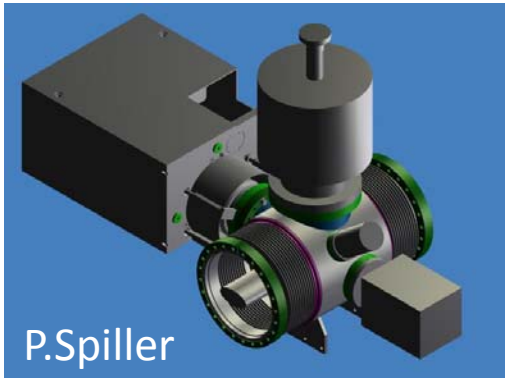
U^{73+} -> U^{72+} (capture)



U^{28+} lifetime in SIS-18 (C. Omet)



Combined pumping/collimation ports behind every dipole group.



NEG coated vacuum chambers

Challenges:

- increase pumping speed
- localize beam loss
- minimize desorption

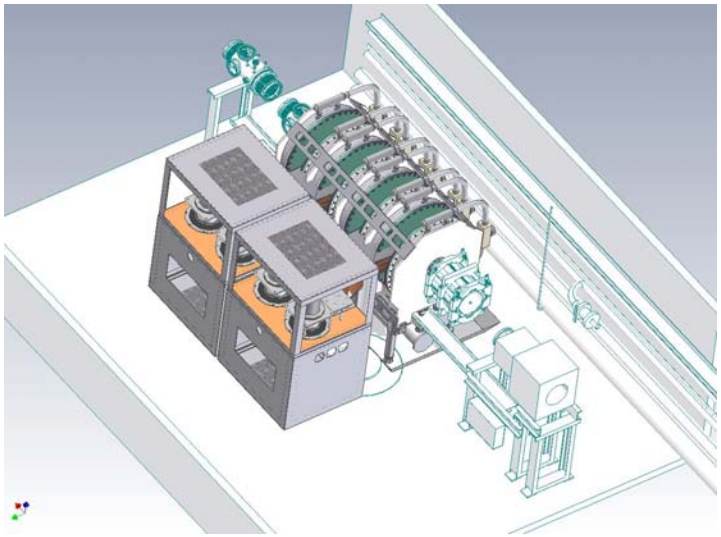
SIS-18 upgrade

new dual rf system

For SIS-18 operation with 2.7 Hz the existing rf voltages are not sufficient.

	V_0 [kV]	f [MHz]	harmonic
MA	40	0.43-2.8	2
Ferrite	16	0.86-4.2	4

Magnetic Alloy (MA) filled rf cavity



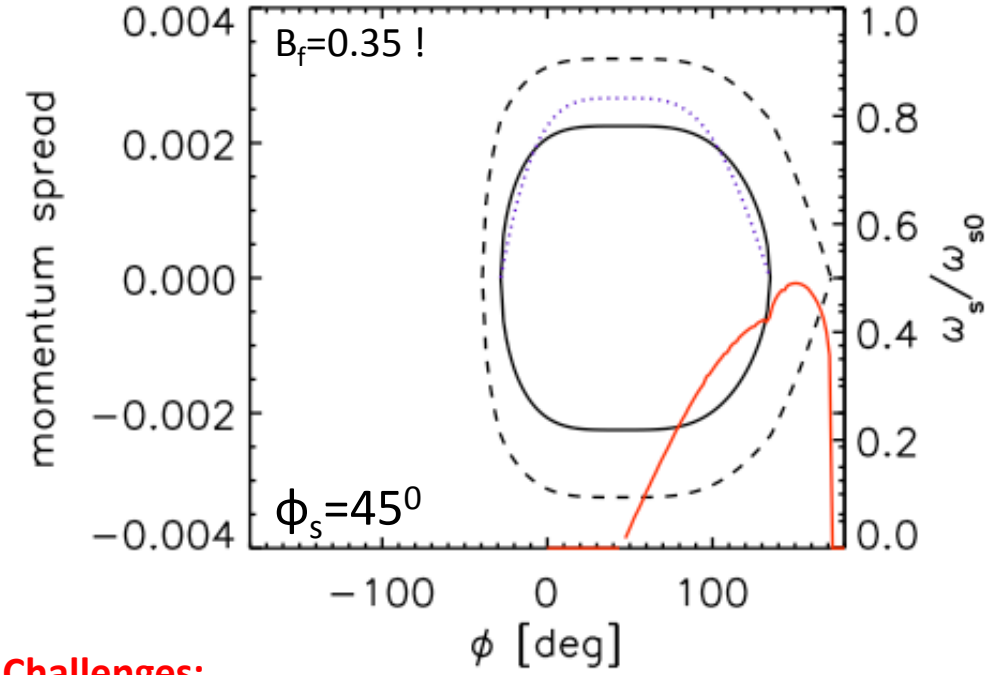
P. Hülsmann et al.

Additional compact rf cavity system:

+ increase rf bucket area

+ flattened bunch profiles

Bucket filling factor U^{28+}: 2/3

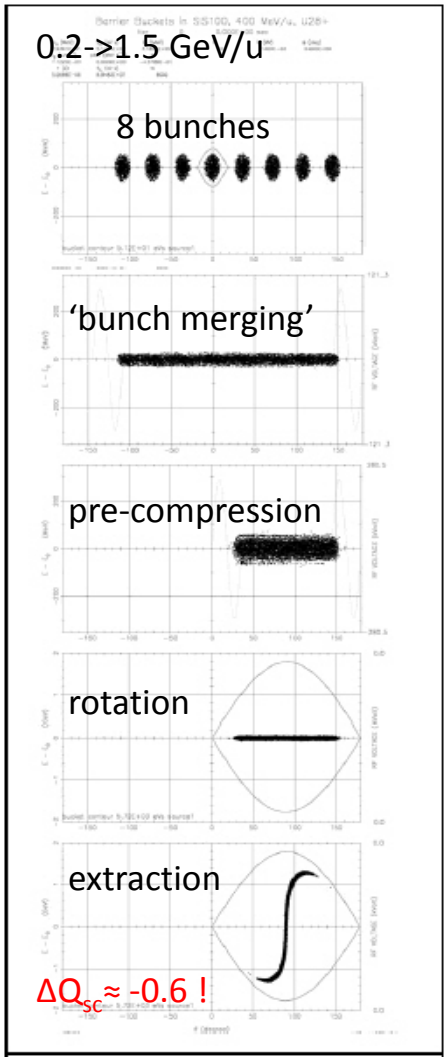


Challenges:

- Space charge induced voltage reduction: ≈40 %
- Bunch stability with space charge
- Control of bunch deformation due to beam loading (low Q)

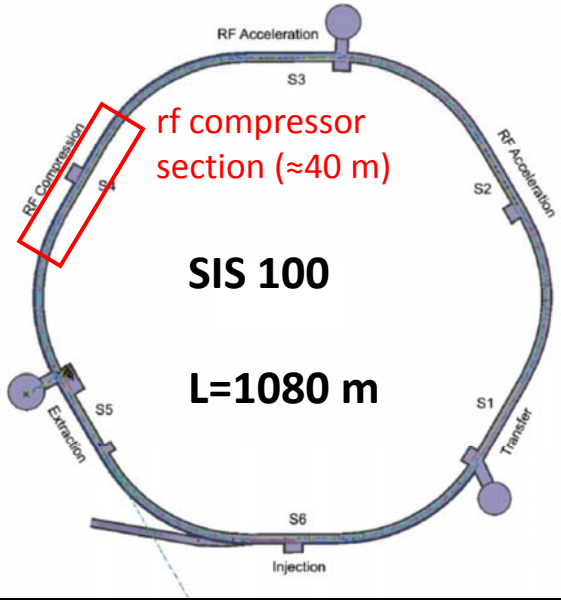
SIS-100 bunch compression

Single bunch formation



bunch compressor
loaded with 20 MA cores





RF cavity systems in SIS 100:

	#cavities	Voltage [kV]	Frequency [MHz]	Concept
Acceleration	20	400	1.1-2.7 (h=10)	Ferrite
Compression	16	600	0.4-0.5 (h=2)	MA (low duty cycle)

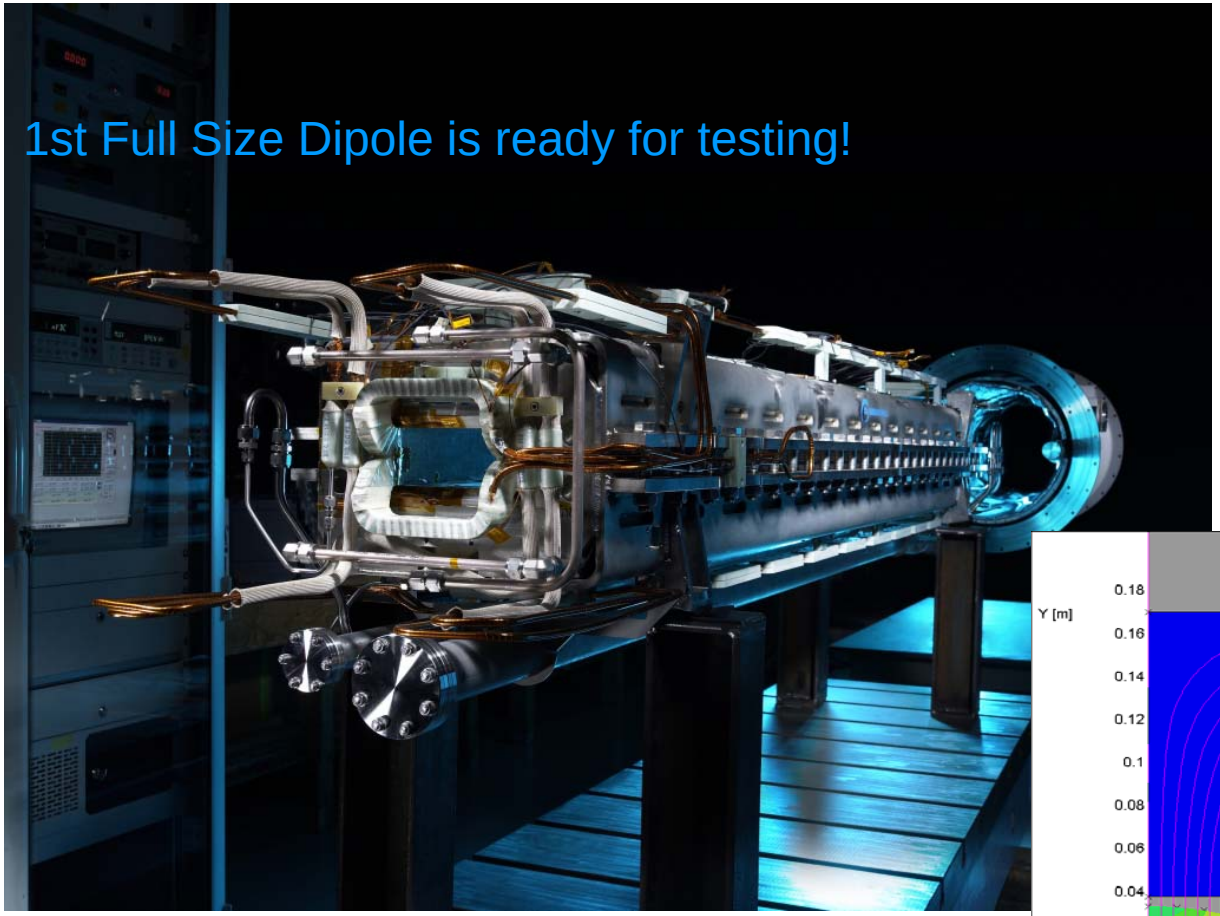
Final bunch parameters:

	Particles/bunch	bunch length
1.5 GeV/u U^{28+}	5×10^{11}	60 ns
29 GeV/u p	$2\text{-}4 \times 10^{13}$	25 ns

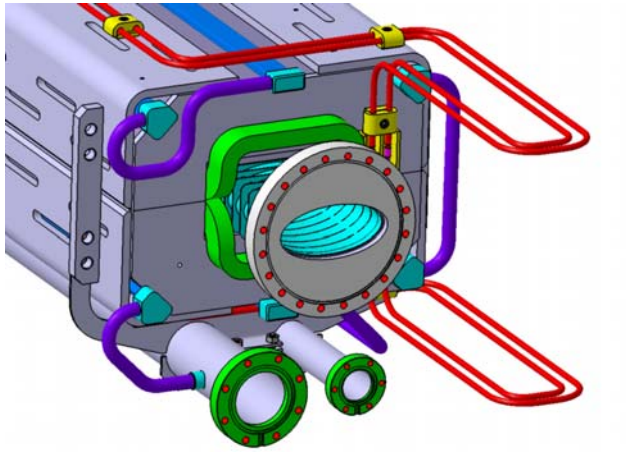
SIS 100 dipole magnets

full size model from Babcock Noell GmbH

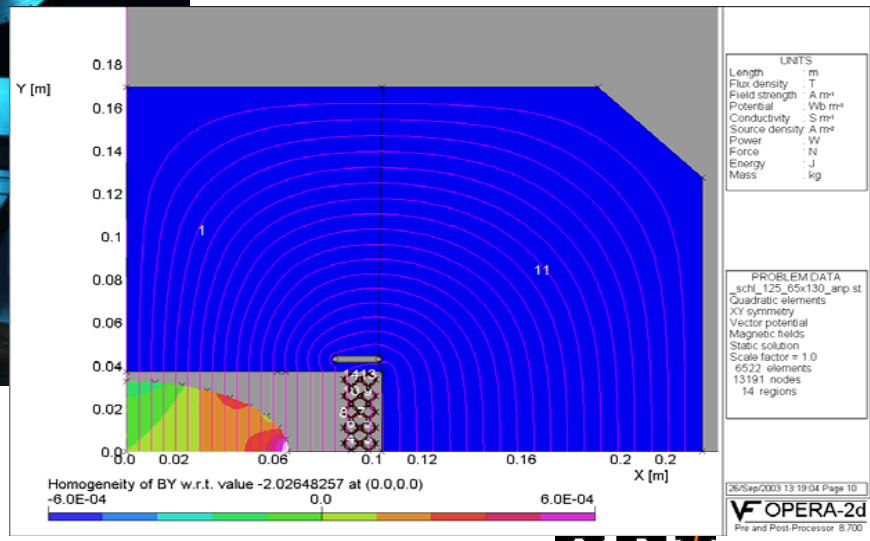
Superconducting magnet with 4 T/s and B_{max}= 1.9 T



Dipole magnet with elliptical beam pipe



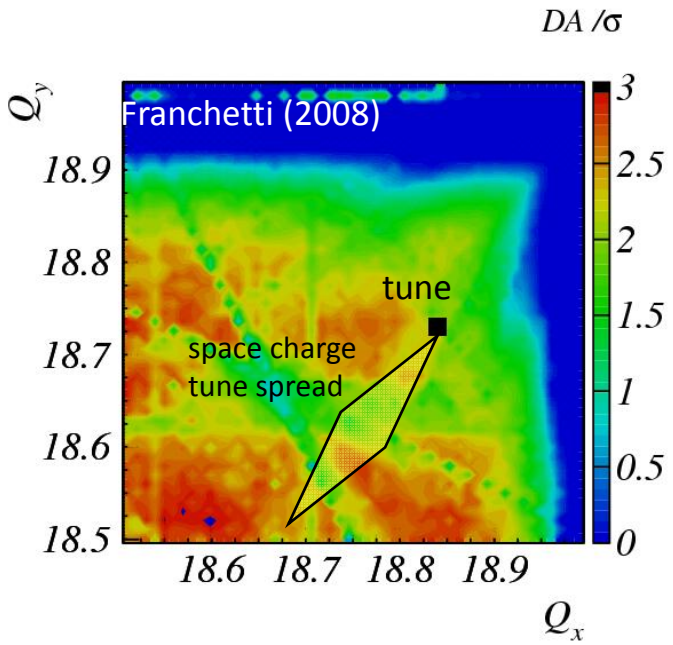
2D/3D field calculations



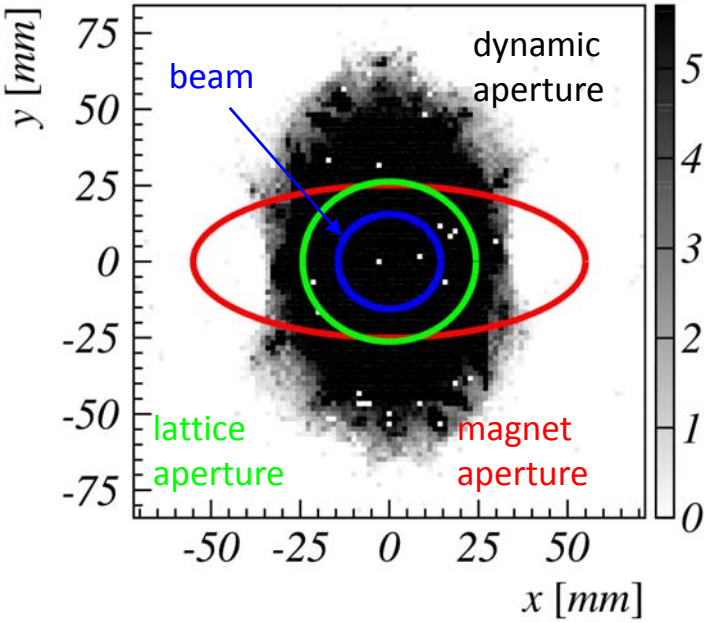
P. Spiller, SIS-100, Tuesday afternoon

SIS-100 field quality and beam loss
at injection energy 0.2 GeV/u

Simulation scan of the **SIS-100 dynamic aperture**



SIS-100 transverse apertures at injection (0.2 GeV/u)



Long-term (up to 1 s) 3D particle tracking studies with 'frozen' space charge indicate a space charge limit at 3×10^{11} U^{28+} (design 5×10^{11}).

G. Franchetti, SIS-100 technical design report (2008)

High intensity challenges for SIS-100:

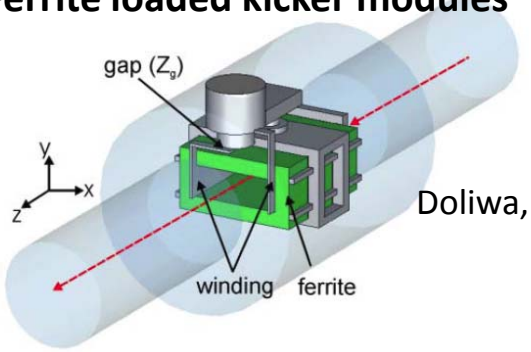
- Long time scales up to 10^6 turns (1 s)
- Space charge tune shift of ΔQ_{sc}=-0.25
- 'Thick' medium energy beams (2/3 filling factor)
- Optimized working point for < 5 % loss.

Transverse impedances in SIS-18/100

Specific SIS-18/100 impedance issues:

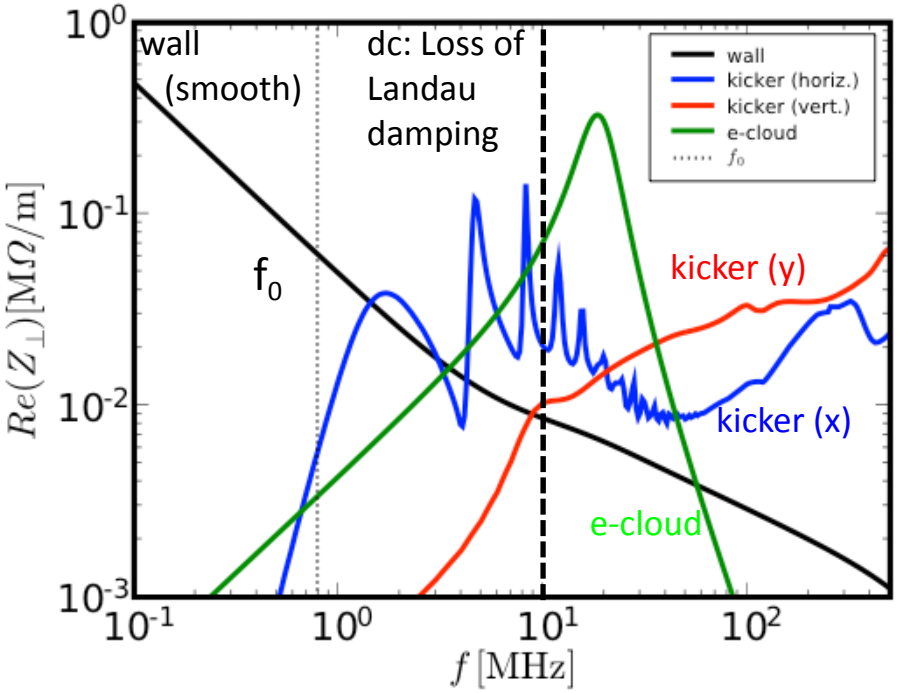
- Low frequencies and beam energies
- Thin (0.3 mm) stainless steel pipe (**optional** corrugated)
- Ferrite or magnetic alloy loaded ring components
- Distributed collimation system

Ferrite loaded kicker modules



Doliwa, Weiland (2006)

SIS-18 transverse impedance spectrum (200 MeV/u)



'Space charge impedance':

e-clouds ?:

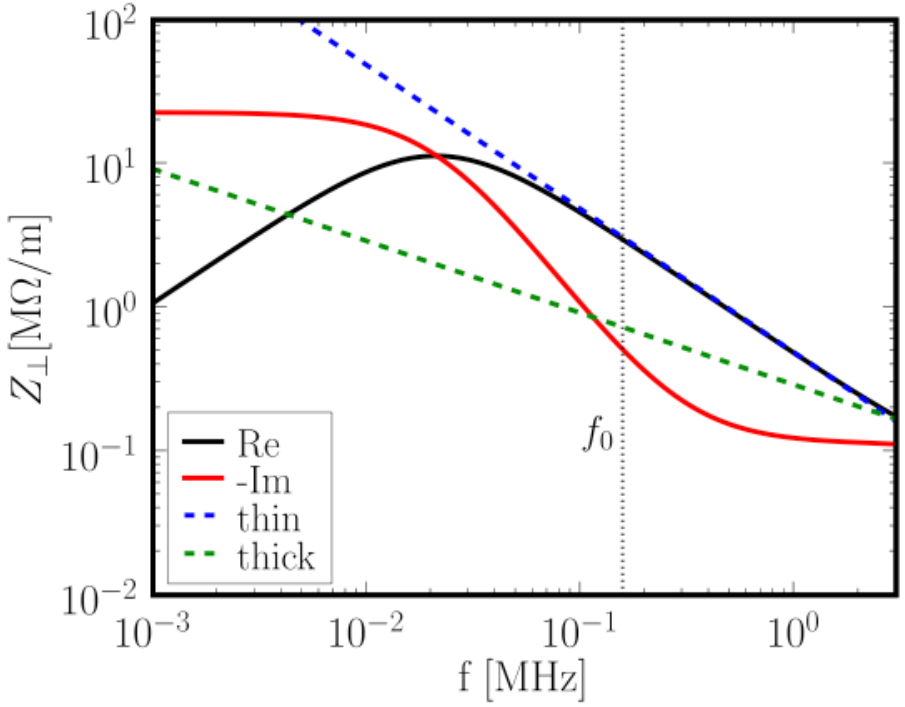
- electrons from residual gas ionization and beam loss.
- e-accumulation: survival rate in bunch gaps ?
- transv. 'impedance': Ohmi, Zimmermann, PRL (2000)
- long. impedance: Al-khateeb et al. NJP (2008)

Resistive (thin) beam pipe in SIS-100

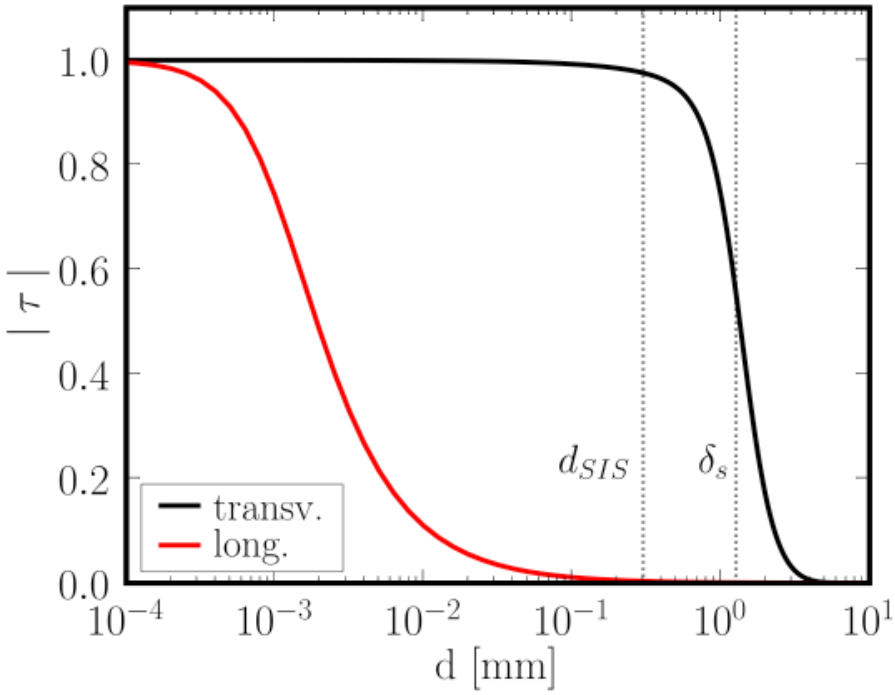
Transverse impedance and shielding

In SIS-100 the thin (0.3 mm) beam pipe is the dominant transverse impedance contribution !

SIS 100 transverse resistive wall impedance (200 MeV/u)



Transmission coefficient !



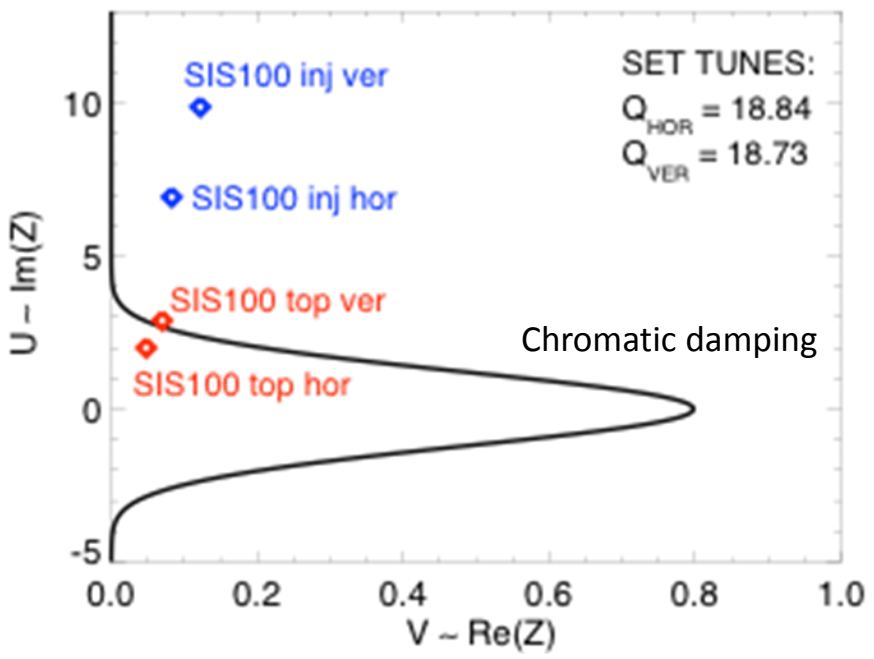
Transmission: Structures behind the pipe might contribute !

SIS-18: Measured growth rate of the resistive wall instability agrees with impedance formula.

Al-khateeb, Hasse, Boine-F., Daqa, Hofmann, Phys. Rev. ST-AB (2007)

Transverse Impedance Budget with Space Charge

coasting beam stability boundaries (from dispersion relation)



Specific issues for SIS-100:

- Long time scales (up to 1 s)
- Image current and space charge effects
- Long bunches and 'dc-like' barrier rf beams

Potential cures:

- octupoles and nonlinear space charge
  (Kornilov et al. PRST-AB 2008)
- feedback systems

Challenges:

- Octupoles and dynamic aperture
- 3D space charge and image current effects

Head-tail instability in SIS-100 (talk by V. Kornilov this Monday afternoon):

-Sacherer's formula predicts head-tail modes with 70 ms growth rate in SIS-100 !

-3D simulation studies including: resistive wall impedance, image currents, space charge, nonlinear rf.

-'Mode coupling regime': (ν_s: synchrotron tune)

Transverse Schottky signals with space charge

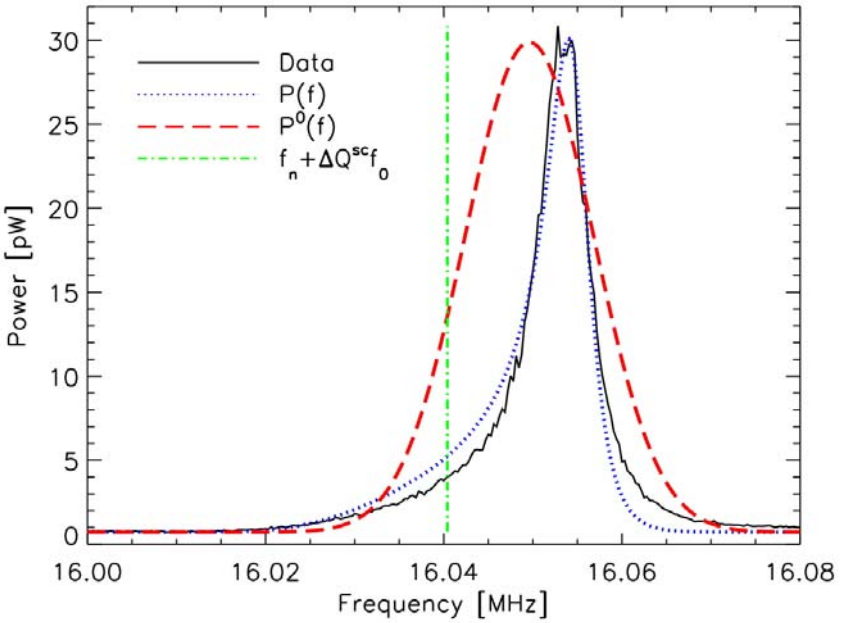
Understanding signals from stable beams with space charge

coasting beam (measurement in SIS-18)

coherent betatron frequencies:

Modified Schottky band:

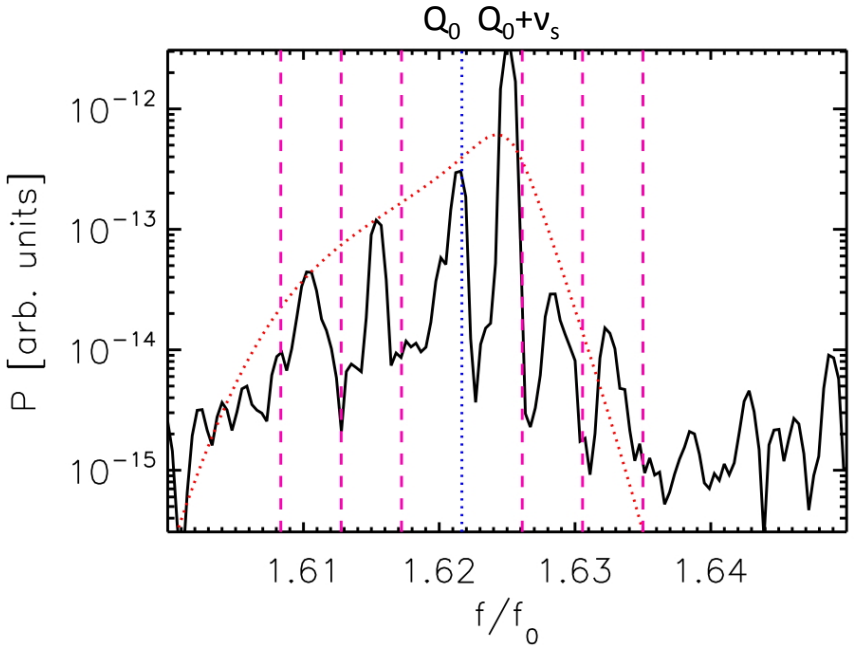
The measured Schottky band (upper sideband) with space charge is deformed, but not shifted.



Boine-Frankenheim, Kornilov, Paret, PRST-AB (2008)

bunched beam (simulation)

Central line is not shifted, but synchrotron satellites are. Amplitudes seem to follow the dc results P(z).



Transverse Schottky signals from real or from computer beams provide important information on the mode structure and Landau damping with space charge.

Summary

A next design iteration of the FAIR synchrotron facilities has been finalized.
(see latest Technical Reports.)

For high intensity operation a number of optimization challenges have still to overcome.

Of outmost importance is to further increase the beam intensity and quality in the UNILAC/SIS-18 injector.

SIS-18/SIS-100 high intensity challenges:

- Working point and resonance compensation for low beam loss.
- Control of the dynamic vacuum pressure for heavy ions.
- Complex RF manipulation at high beam intensities.
- Control of coherent beam instabilities.

FAIR related talks:

V. Kornilov, Coherent instabilities in SIS-100, Monday afternoon
G. Franchetti, Space charge resonances in SIS-18, Tuesday afternoon
P. Spiller, SIS-100, Tuesday afternoon
L. Gröning,Emittance grwoth stdy in the UNILAC, Tuesday morning

FAIR in 2016



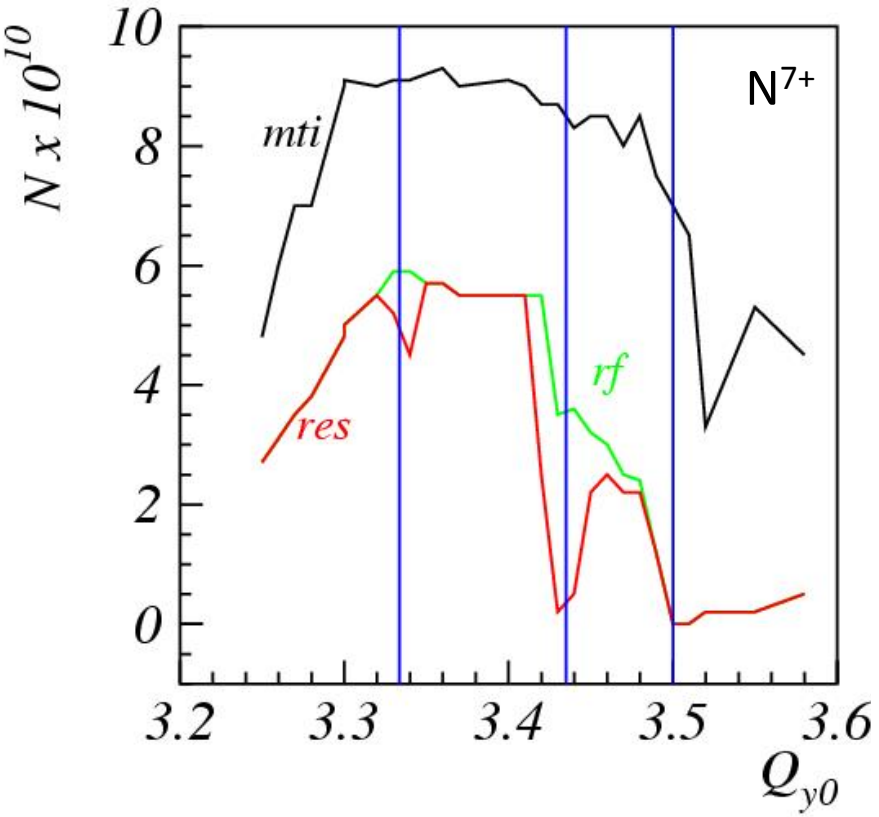
Observers:

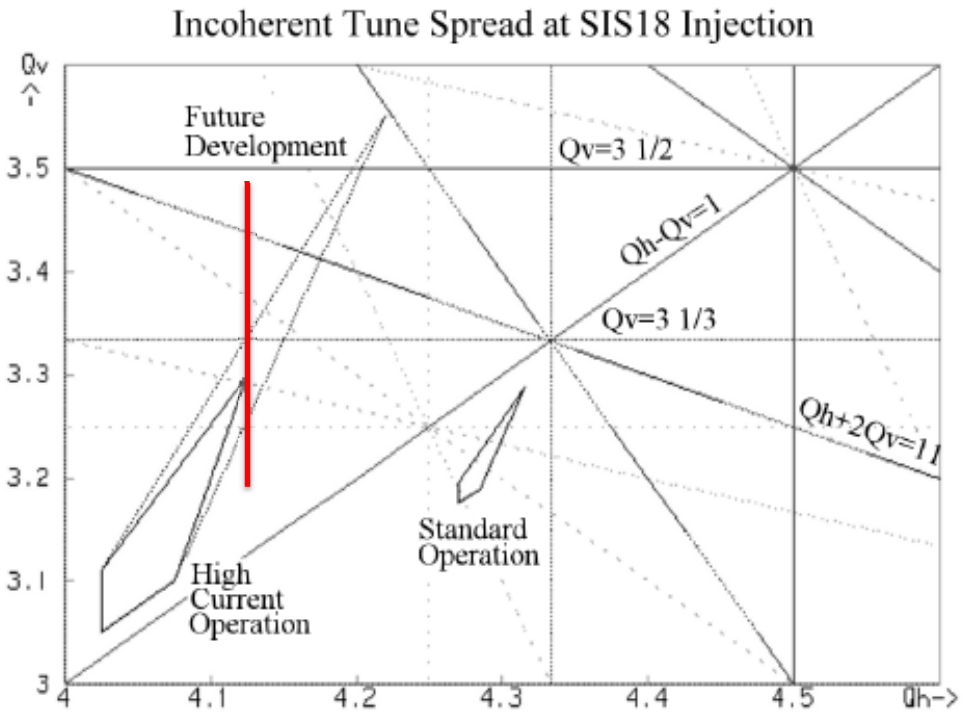
Thank you !

Austria China Finland France Germany Greece India Italy Poland Slovenia Spain Sweden Romania Russia UK

SIS-18 working point and resonance compensation

$Q_{x0} = 4.13$





G. Franchetti's talk on Tuesday

Challenge: Multi-turn injection (MTI) and working point optimization for low beam loss (< 10 %).