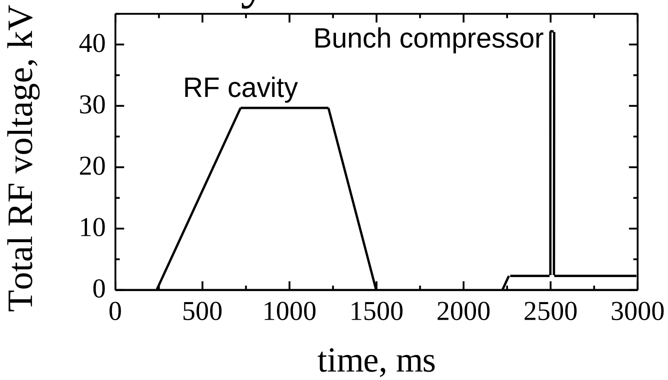
Fast compression of intense heavy ion bunches in SIS 18

O. Chorniy
O. Boine-Frankenheim
P. Spiller
P. Hülsmann

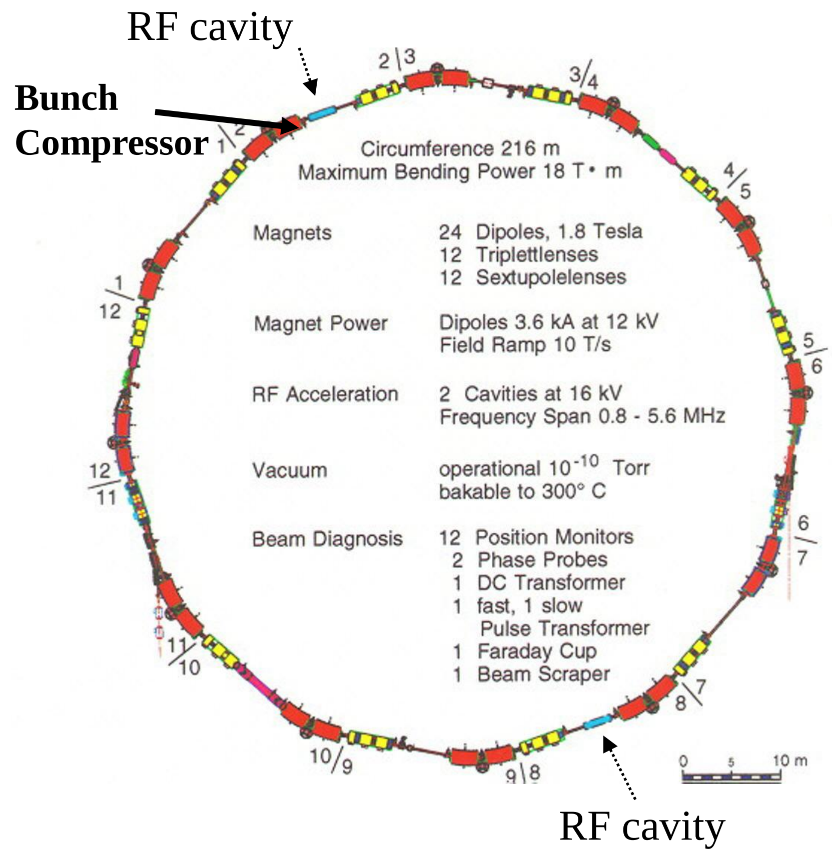
Introduction

RF cycle in SIS18

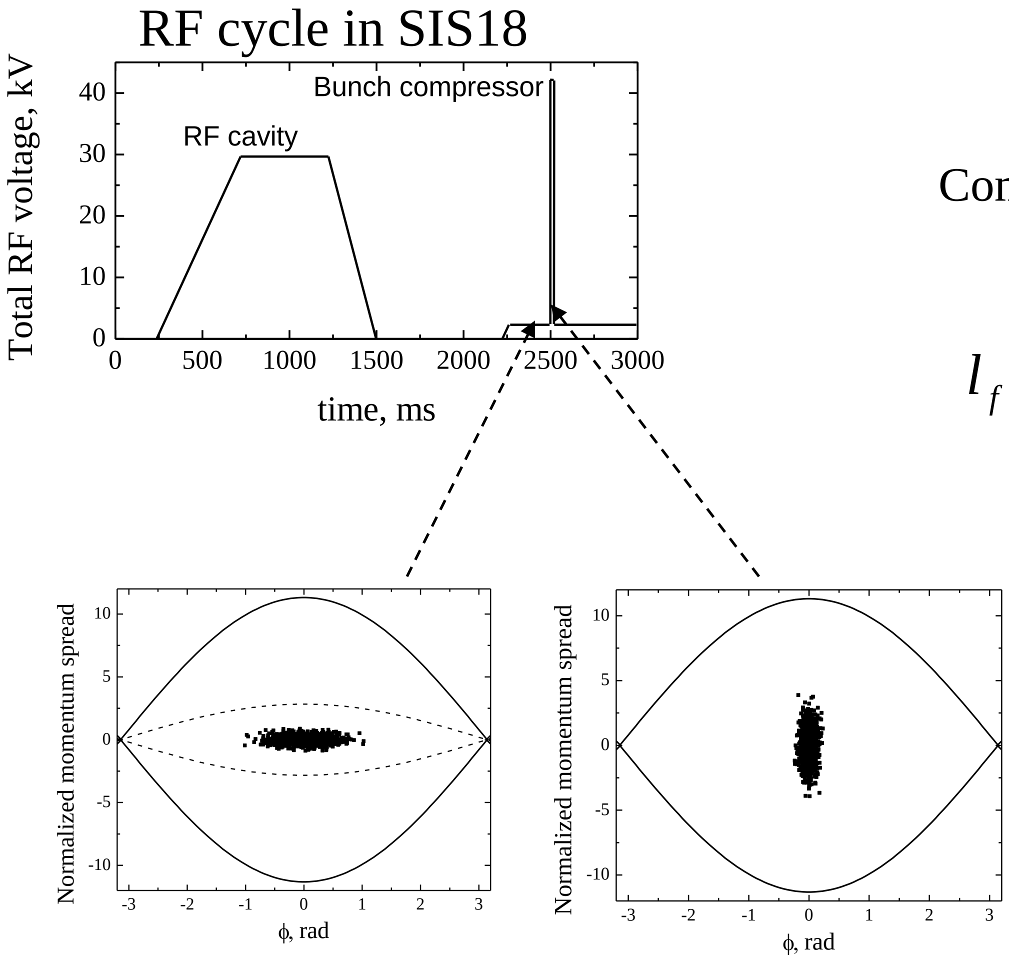


	SIS Cavity	Compressor
Inductive Load	Ferrites	Magnetic Alloy
Frequency tuning range [MHz]	0.85-5.4	0.8
Peak RF-voltage [kV]	16	40
Length [m]	2.9	0.7
Pulse duration [μs]	cont.	100
Duty cycle [%]	100	0.01
Voltage rise time [μs]	150	≤ 30
Power dissipation - Peak [kW]	40	500
Power dissipation Mean [kW]	40	0.05
Cooling of cores	water	air
Gap impedance [kΩ]	2.5	0.68

Synchrotron SIS18



Introduction



Compressed bunch length:

$$l_f = \sqrt{\frac{V_{BK} + V_{RF}}{V_{RF}}} \cdot l_i$$

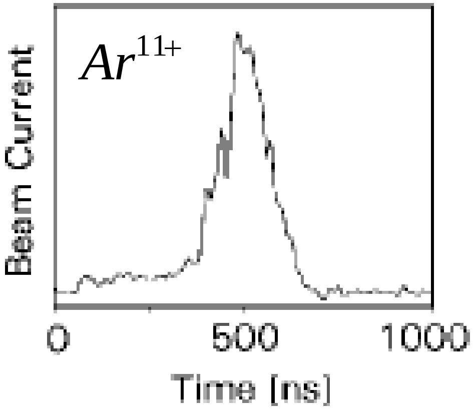
Bunch compression with 90 degree fast rotation (example)

Introduction

Strategy for Achieving High Target Power Density with a Modified SIS18 and the New High Current Injector (U^{28+}), R. W. Müller, P.Spiller, GSI Report, 1996

Bunch Compression in the Heavy Ion Synchrotron SIS at GSI, K. Blasche et al., GSI Report, 1997

Compression with two ferrite cavities



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Generation of high power heavy ion beams at GSI, P. Spiller et al., 1999

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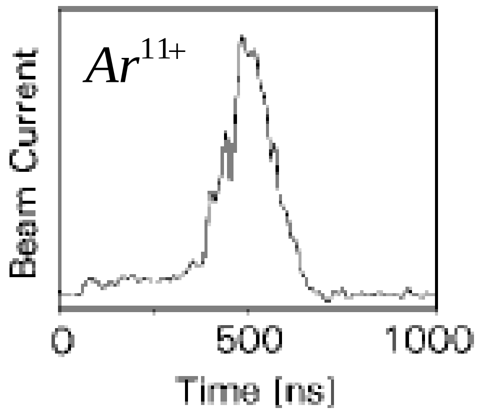


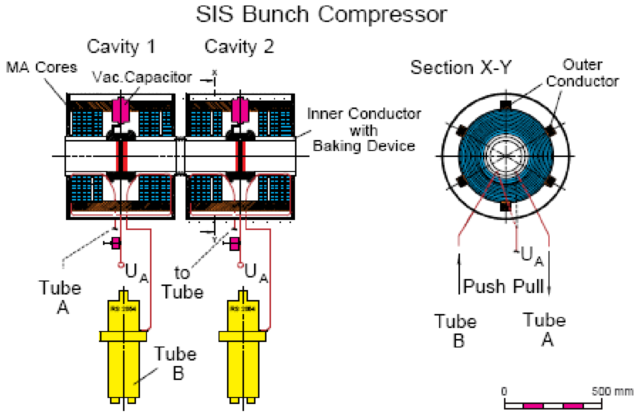
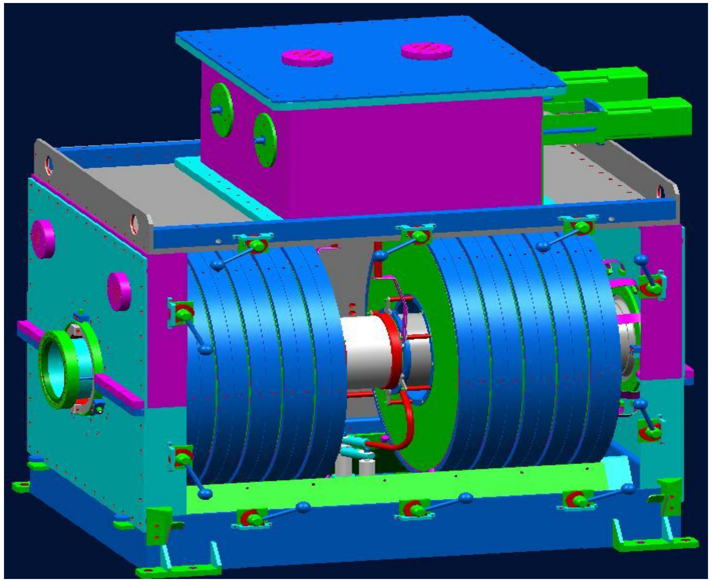


Figure 4: Schematic of a SIS bunch compressor cavity based on magnetic alloy cores. Shown are two out of six cavities. Each cavity is driven by a final stage in push-pull operation.

Introduction

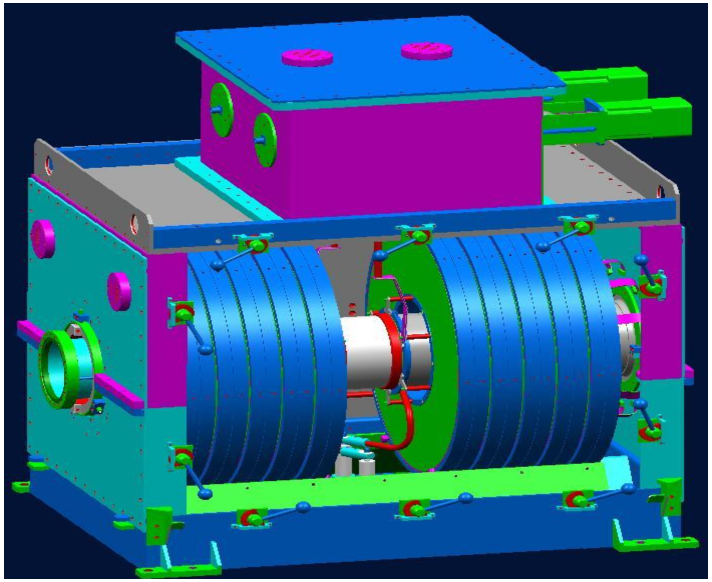
Design for the bunch compressor



The bunch compressor system for SIS 18 at GSI, P. Hülsmann et. al, EPAC 2004

Introduction

Design for the bunch compressor



The bunch compressor system for SIS 18 at GSI, P. Hülsmann et. al, EPAC 2004

Bunch compressor cavity (2008)

Bunch compressor for FAIR, P. Hülsmann et. al, PAC 2009

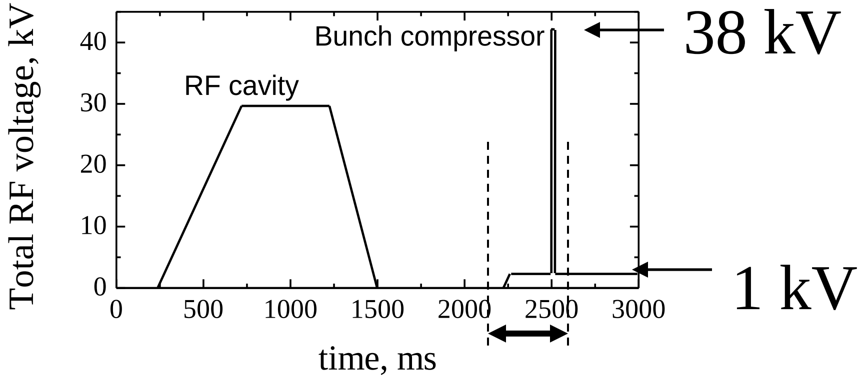
Introduction

Intensity parameters for the upgraded SIS 18: U^{+28}

	injection	extraction
Number of particles	>1.5*10e11	1.5*10e11
Energy, MeV/u	11.4	200
Momentum spread	1*10-3	5*10-4
RF harmonic	4	1
ΔQ_{sc}	-0.5	-0.4
$\sum$	1	0.1

Recent measurements with bunch compression

RF cycle in SIS18



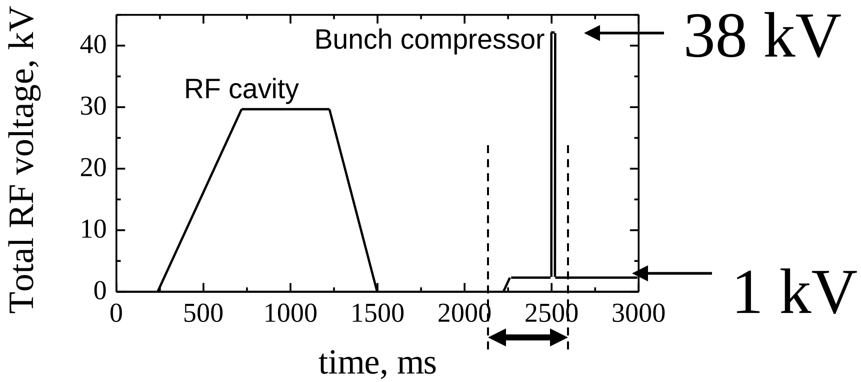
Main parameters

Ion:	U^{+73}
Energy:	295 MeV/u
Pre-bunching RF amplitude:	1 kV
Bunch Compressor amplitude:	38 kV
Particles in the ring:	$1 \cdot 10^9$

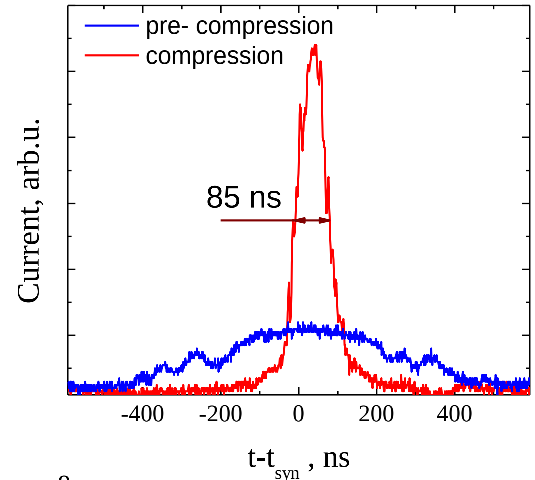
Low intensity

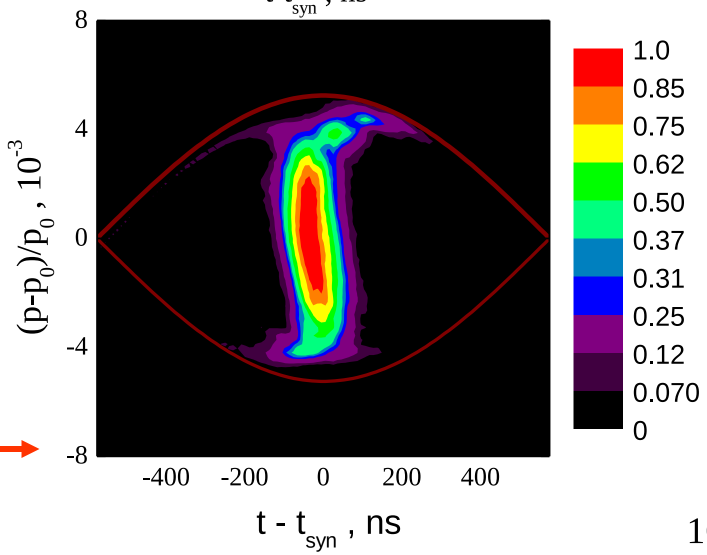
Recent measurements with bunch compression

RF cycle in SIS18



Profiles before and during compression





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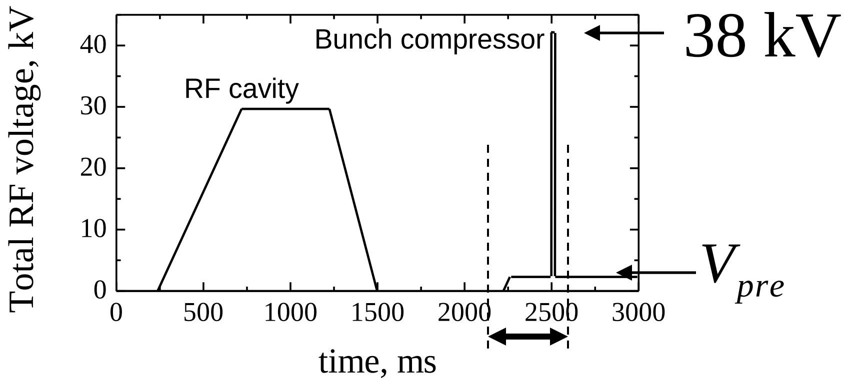
Tomographically reconstructed phase space of the compressed bunch

Recent measurements with bunch compression

RF cycle in SIS18

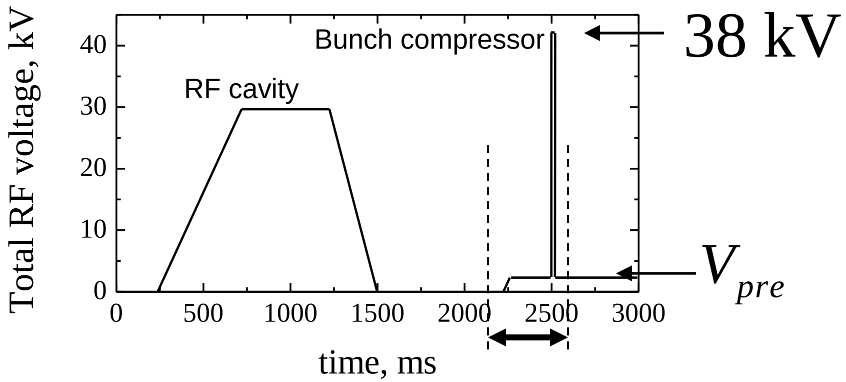


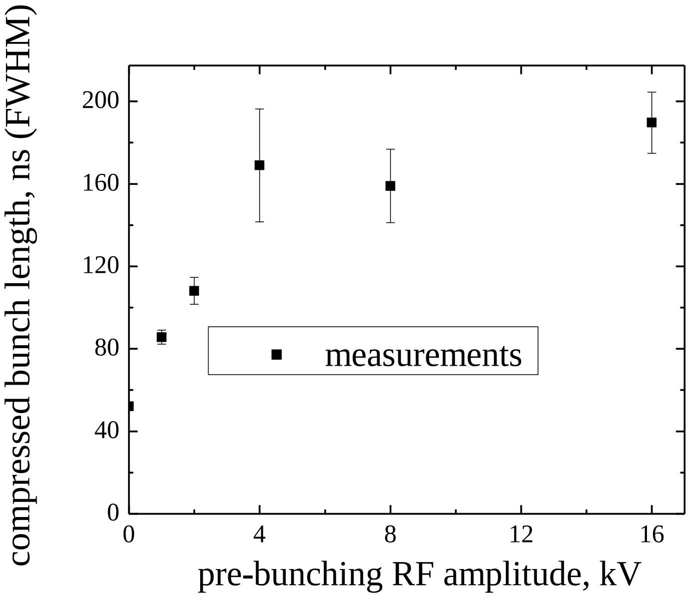
Main parameters

Ion:	U^{+73}
Energy:	295 MeV/u
Pre-bunching RF amplitude:	1, 2, 4, 8, 16 kV
Pre-compression time:	6 ms
Bunch Compressor amplitude:	38 kV
Particles in the ring:	$1 \cdot 10^9$

Recent measurements with bunch compression

RF cycle in SIS18





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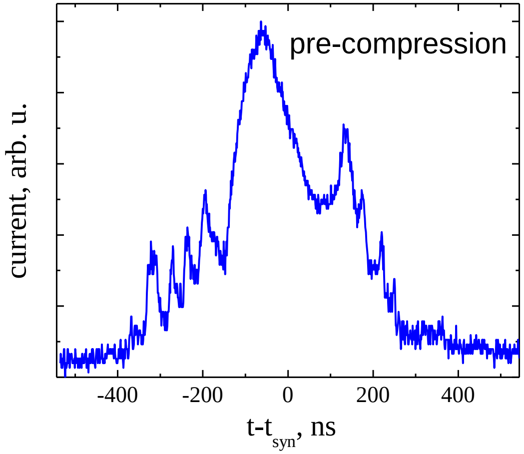
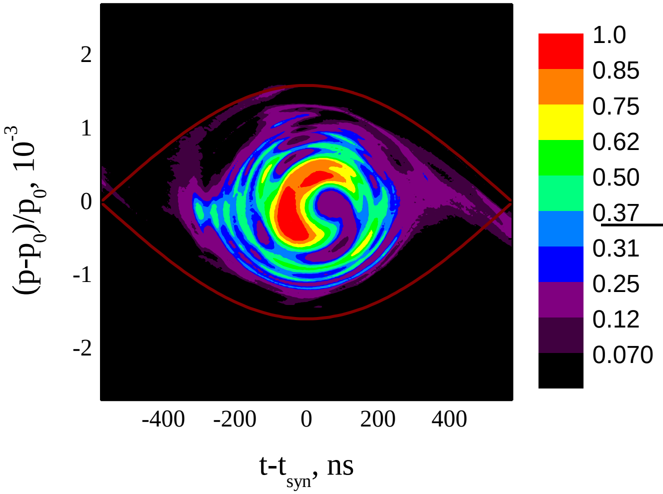
Recent measurements with bunch compression

Measured pre-compressed bunch with 4 kV



Reconstructed phase space



Mismatched pre-compression:
Frequency offset
Too fast pre-compression time

Recent measurements with bunch compression

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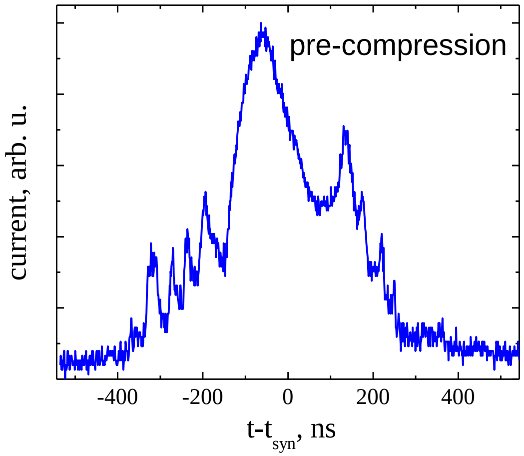

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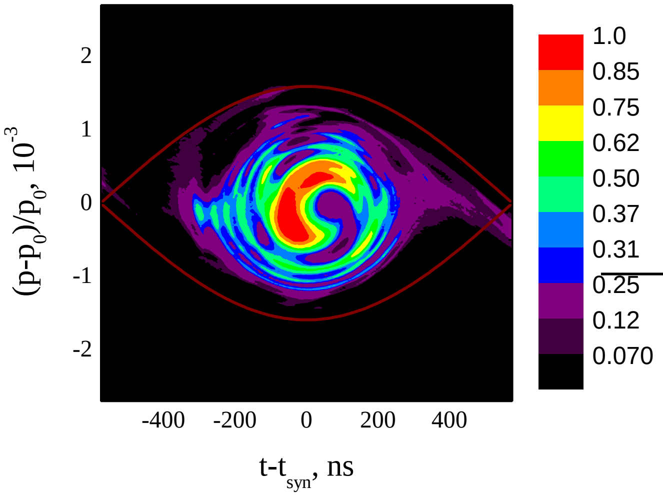

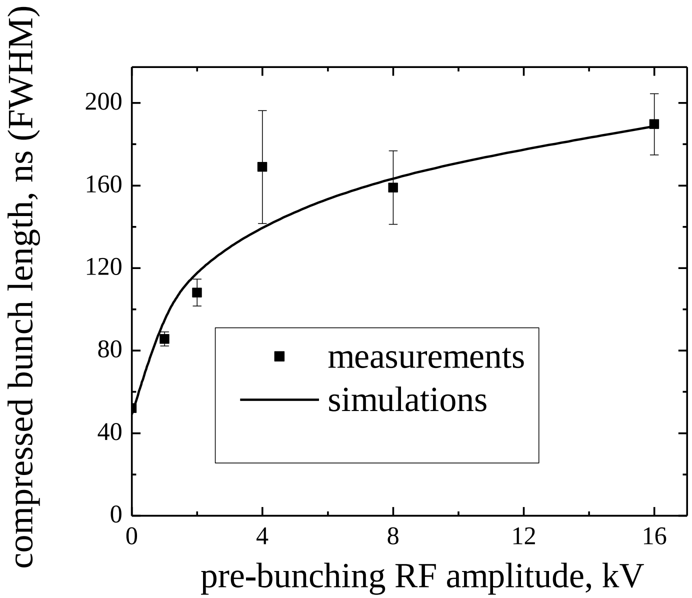

Mismatched pre-compression:

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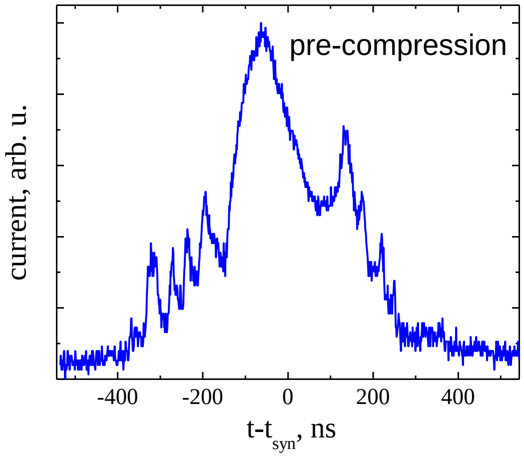
Recent measurements with bunch compression

Measured pre-compressed bunch with 4 kV



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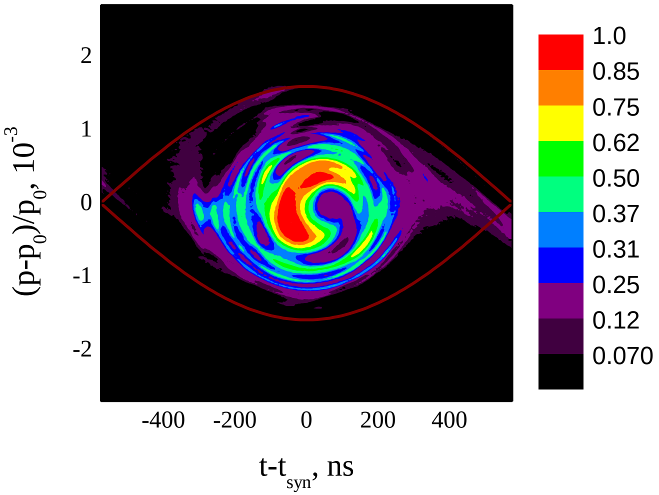
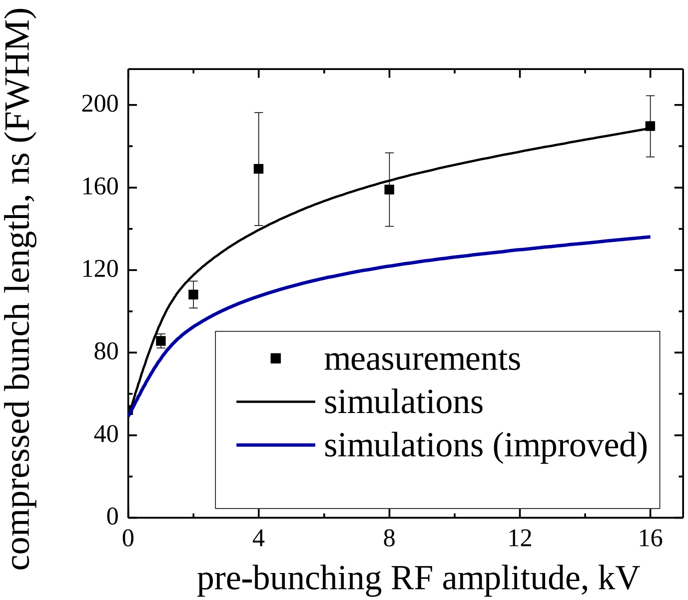
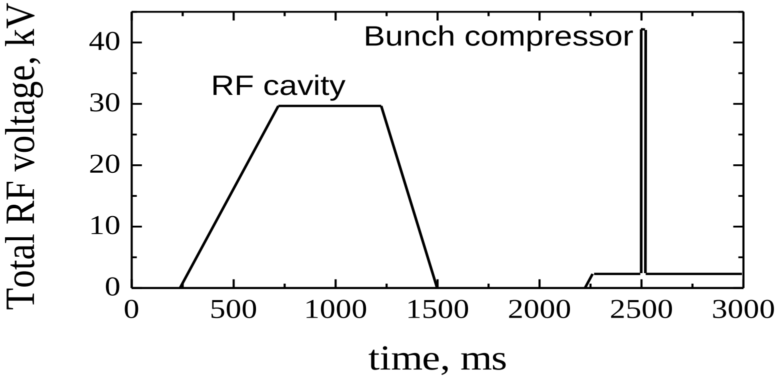




Simulations without frequency offset and longer pre-compression time (40 ms) show the improvement of the compressed bunch length

Increase of the longitudinal beam emittance along the cycle

RF cycle in SIS18



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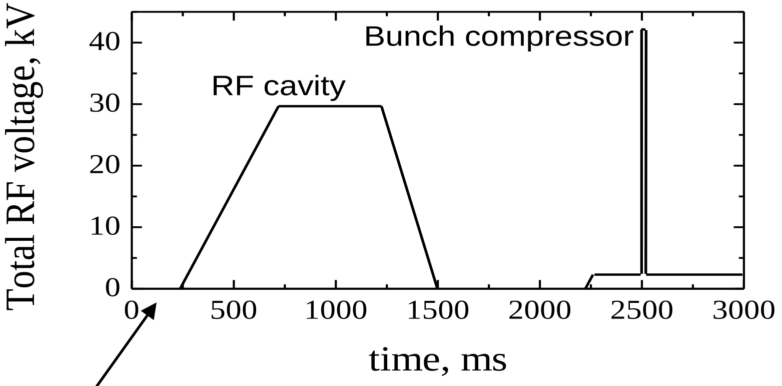
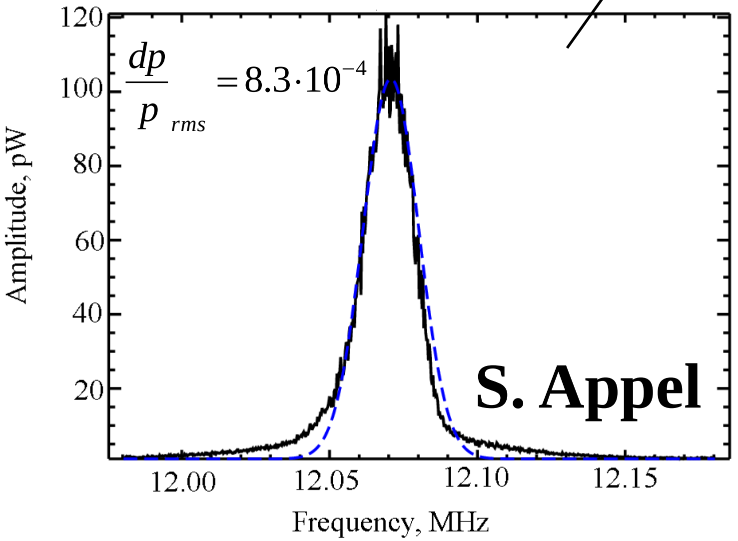


Schottky spectra
of coasting beam
at injection energy



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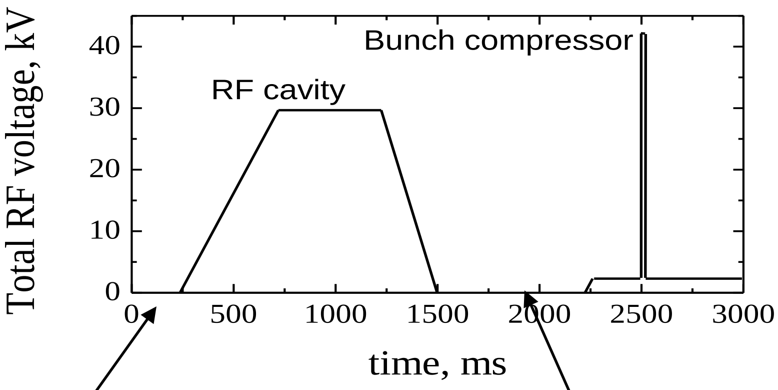

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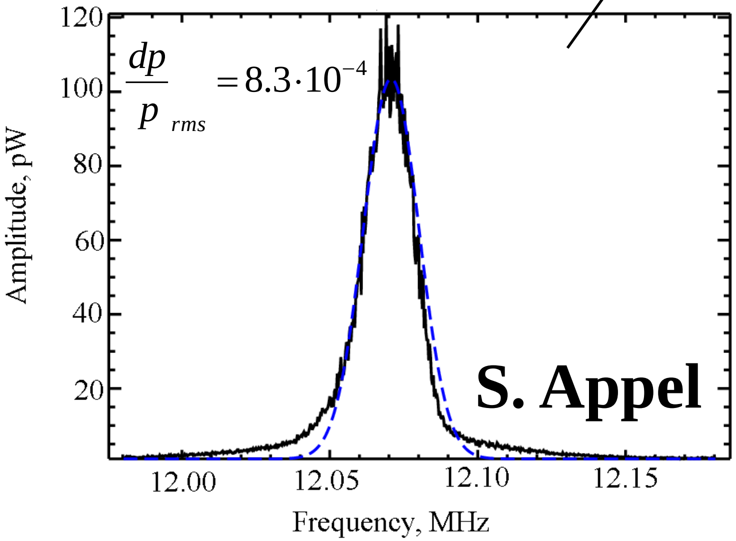
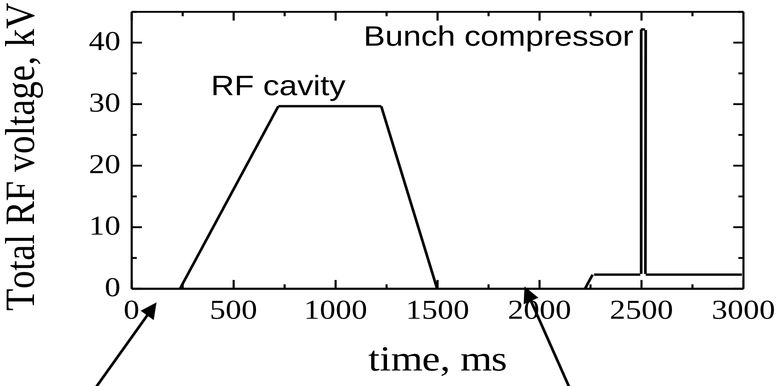


Expected momentum spread at top energy

$$\frac{dp}{p}_{rms} = 1.5\cdot10^{-4}$$

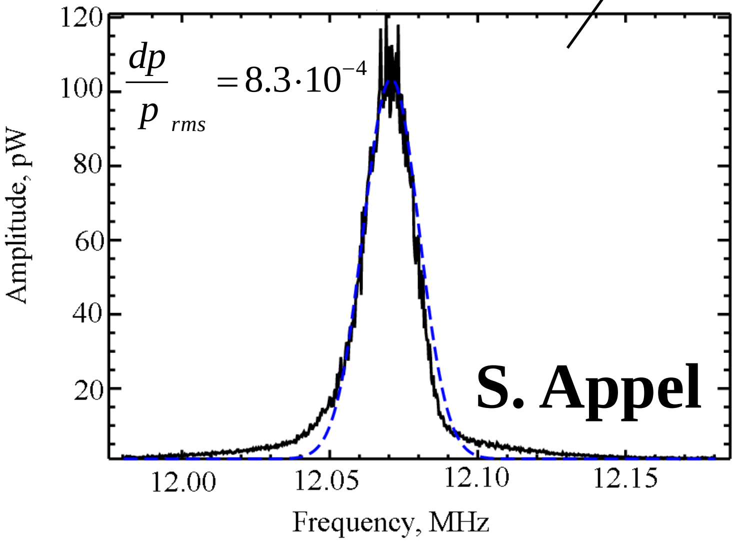
Increase of the longitudinal beam emittance along the cycle

RF cycle in SIS18



$$\tau_{compr}(FWHM) \approx 50ns$$

Schottky spectra of coasting beam at injection energy



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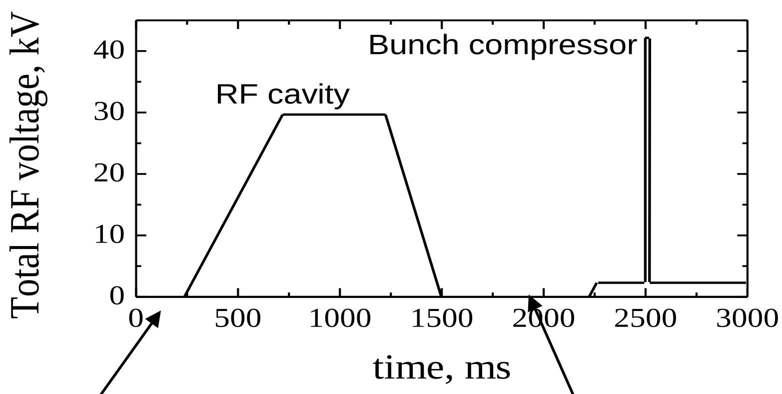
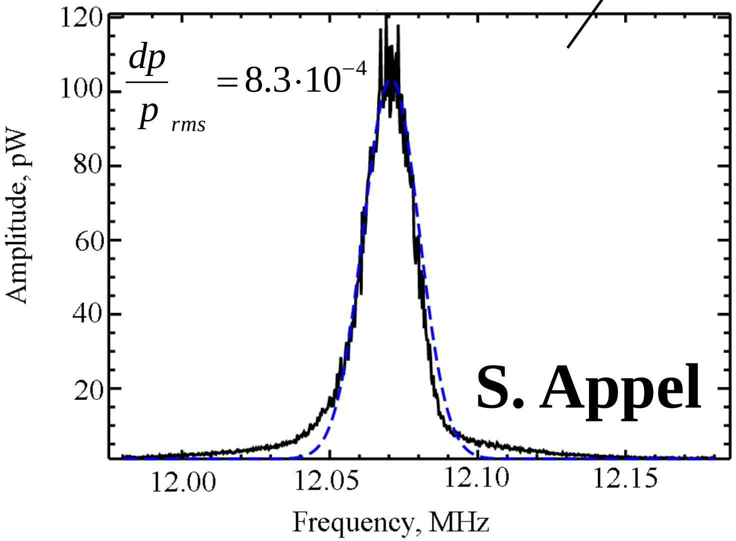


$\tau_{compr}(FWHM) \approx 50ns$

Schottky spectra of coasting beam at injection energy



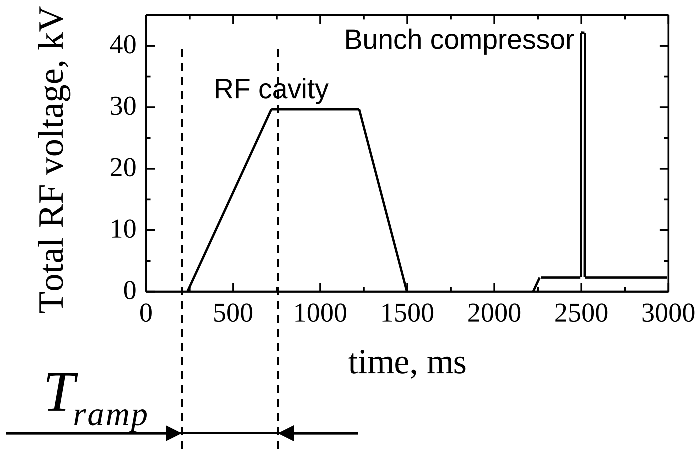
Expected momentum spread at top energy $\frac{dp}{p}_{rms} = 1.5\cdot10^{-4}$

Momentum spread extracted from measurements $\frac{dp}{p}_{rms} = 2.5\cdot10^{-4}$

Along the cycle the rms longitudinal emittance increases by factor of 1.7

Measurements of RF capture at injection energy

RF cycle in SIS18



Main parameters

Ion: Ar^{18}

Energy: 11.4 MeV/u

Ramping time: 3 ms

Particles in the ring: $2 \cdot 10^{10}$

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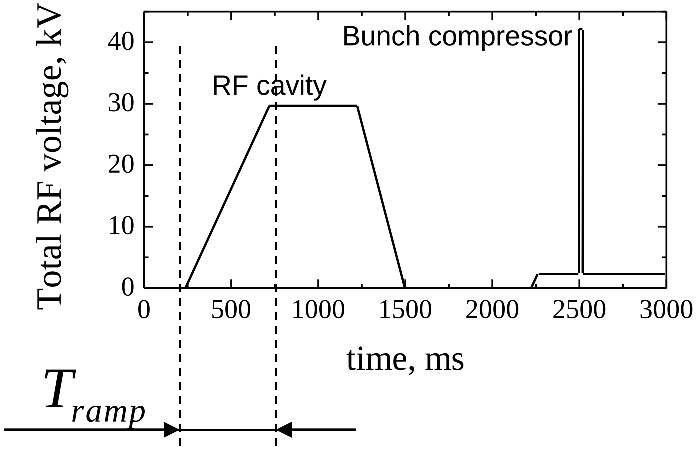

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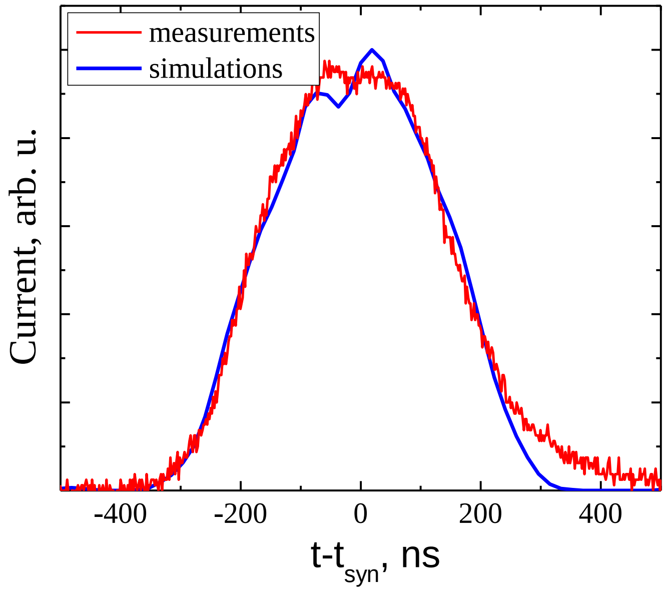
Comparison of measures and simulated profiles



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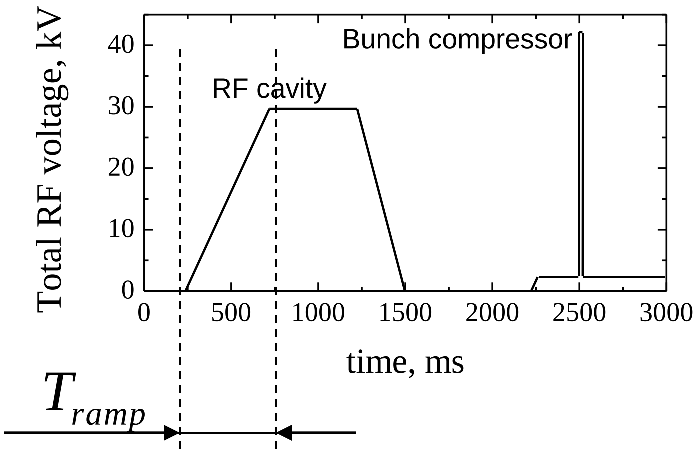


Main parameters

Ion: Ar^{+18}

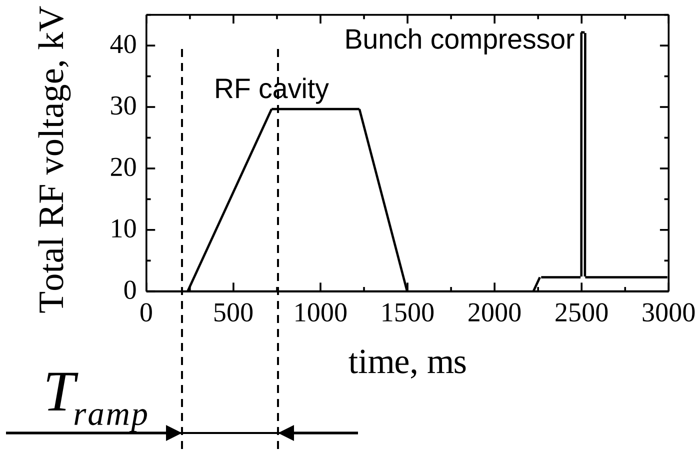
Energy: 11.4 MeV/u

Ramping time: 1,2,3,5,10,15,20 ms

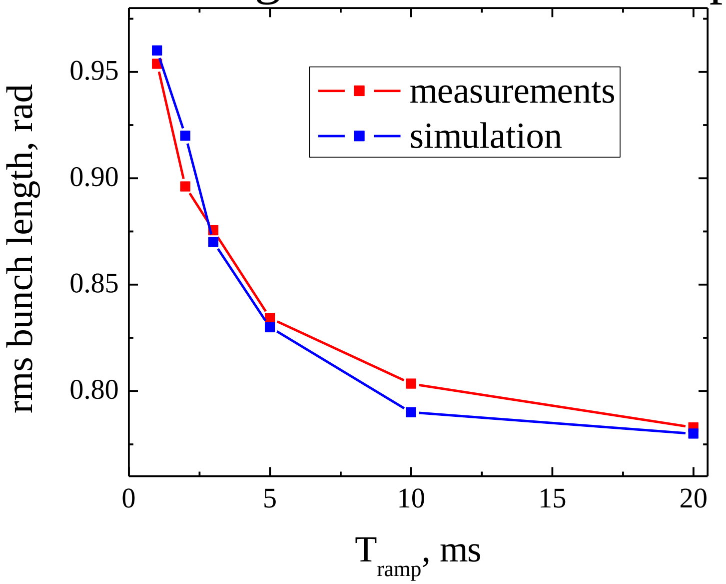
Particles in the ring: $2 \cdot 10^{10}$

Measurements of RF capture at injection energy

RF cycle in SIS18



Bunch length at the end of rf capture



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Measurements of RF capture at injection energy

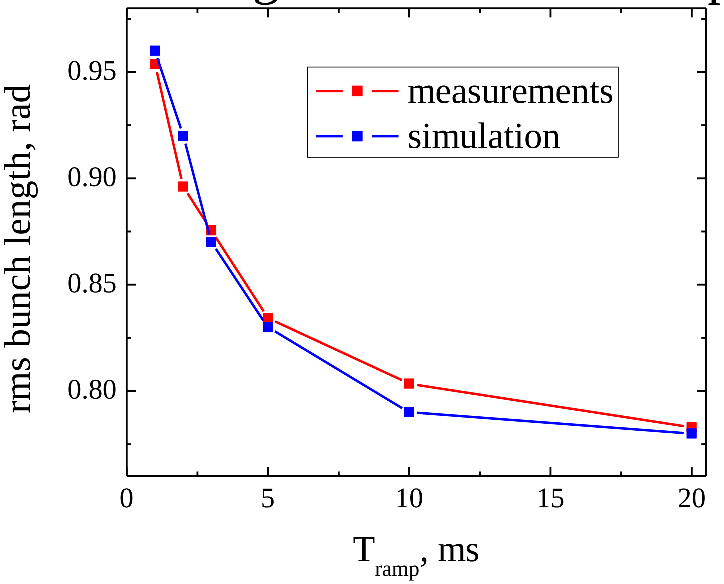
Linear RF capture can be characterized with adiabaticity parameter :

$$\mu_c = \frac{\tau}{T_{ramp}} = \frac{R}{h\upsilon_m} \cdot \frac{1}{T_{ramp}}$$

$$\tau = \frac{R}{h\upsilon_m}$$ -time of flight between RF bucket ends

$$\upsilon_m = \sqrt{5}\ \eta\beta c \left.\frac{dp}{p}\right._{rms}$$ -maximum velocity in the coasting beam

Bunch length at the end of rf capture



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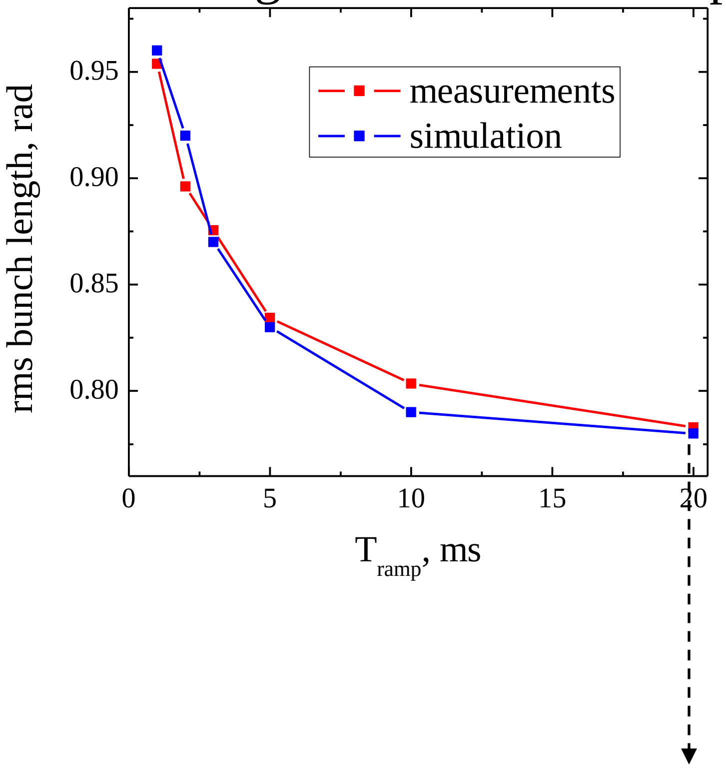


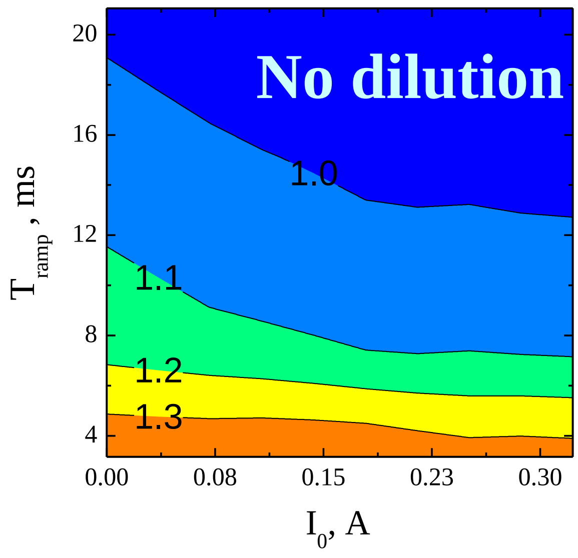
Adiabaticity parameter where no dilution occurs $\mu_c = 0.018$

Simulation of RF capture with space charge

Simulation parameters

Ion:	Ar^{+18}
Energy:	11.4 MeV/u
Ramping time:	3,5,10,15,20 ms

Normalized longitudinal emittance at the end of rf capture



De-focusing space charge allows the RF capture at shorter ramping times without longitudinal emittance increase

Simulation of RF capture with space charge

Simulation parameters

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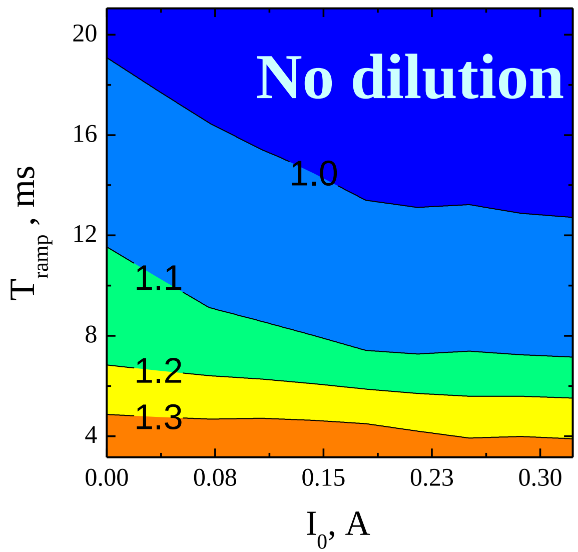

The coherent velocity of the longitudinal space charge waves *:

$$c_s = \sqrt{\frac{q\, X_s I_0}{2\pi\, m^*}} \qquad X_s = \frac{g}{2\varepsilon_0 \beta c \gamma^2}$$

* RF barrier compression with space charge, O.Boine-Frankenheim, Phys. Rev. ST-AB 13, 2010

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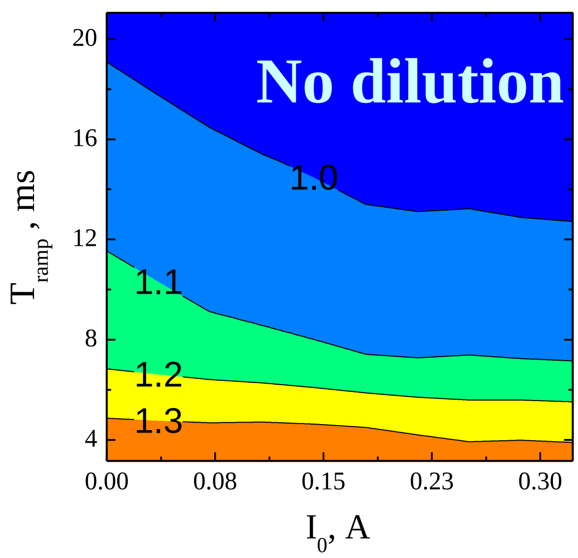

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Time of flight between RF bucket ends :

$$\tau = \frac{R}{h\upsilon_m} \xrightarrow{\text{Assumption}} \tau_{sc} = \frac{R}{h\sqrt{\upsilon_m^2 + c_c^2}}$$

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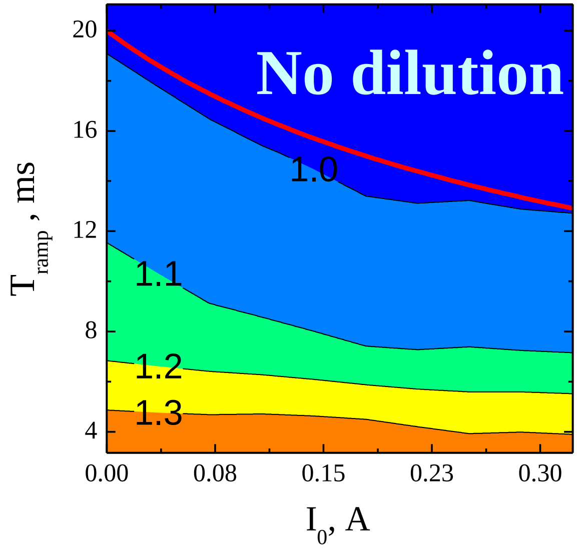

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The dilution-free ramping time:

$$T_0 = \mu_c \cdot \tau_{sc} = \mu_c \frac{R}{h} \frac{1}{\sqrt{\upsilon_m^2 + c_s^2}}$$

Summary and outlook

- Comparison of the simulation and measurements at low intensity show that the performance of the bunch compression can be improved.
- Space charge does not produce longitudinal emittance grows during RF capture.
- Next aim: study the transverse emittance evolution during rf capture and bunch compression.