Measurements of transverse Schottky signals and BTF in SIS18

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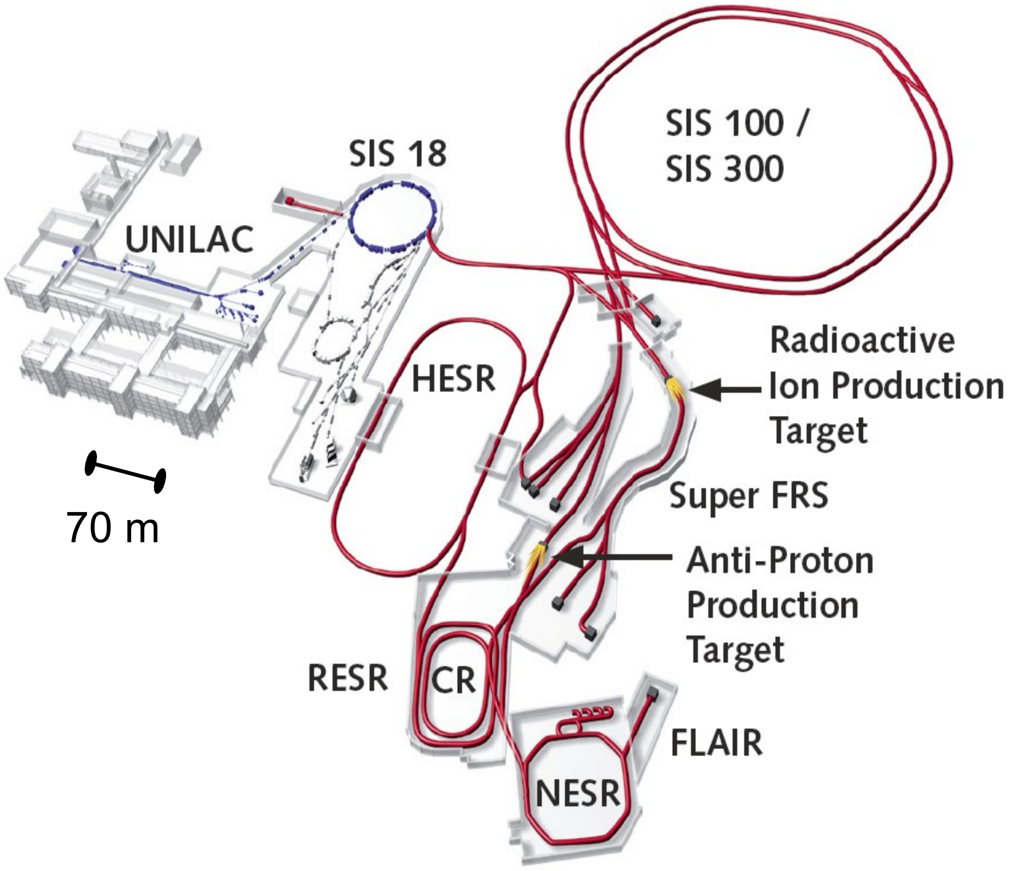
Outline

- Motivation
- Linear space charge
- BTFs with space charge
- Schottky spectra with space charge
- Experimental results
- Conclusions

Motivation

- FAIR will provide beams of high intensity, low emittance and low momentum spread
- in SIS18 the beams will have low energies (11 MeV/u to 1.5 GeV/u)
- space charge and impedances strongly affect these beams and could destabilize them
- collective effects in the transverse plane are investigated theoretically, e. g. by Kornilov*
- in SIS18 collective effects are studied experimentally



* V. Kornilov et al, submitted

Experimental setup

•the equipment for of the beam diagnostics group was used

•measurements were performed between 10 MHz and 30 MHz because collective effects in coasting beams are strongest at low frequencies

•a non-resonant plate capacitor was used as detector for the Schottky and BTF measurements
an equal device was used as exciter for the BTFs

•the Schottky probes do not operate below 10 MHz

•for the Schottky measurements a Tektronix real time spectrum analyzer (RSA3303A) was used
the BTFs were measured with a Hewlett Packard network analyzer (4396A)

•the emittance was measured with a residual gas monitor

Linear space charge

•in first order and neglecting the beam pipe's influence on the self field, space charge shifts the tune of a coasting elliptical beam by *

$$\Delta Q = -\frac{r_p N Z^2}{\pi A \beta^2 \gamma^3 (\epsilon_1 + \sqrt{\epsilon_1 \epsilon_2 Q_1 / Q_2})}$$

with the classical proton radius r_p, the particle number N, the ion's charge Z and mass A, the relativistic factors β and γ, the emittance ε_1 and tune Q_1 in the plane being considered and ε_2 and Q_2 in the perpendicular plane, respectively

•in SIS18 the maximal tune shift currently observed is $\Delta Q = -0.05$

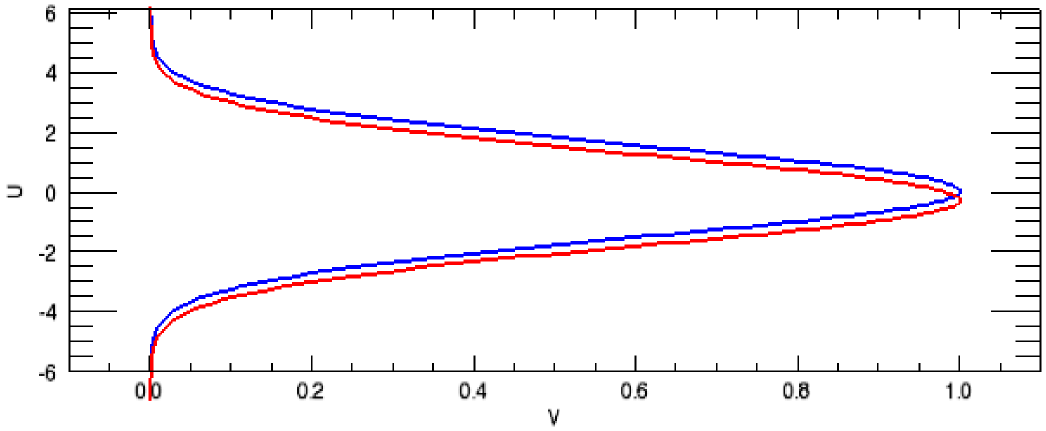
•after the upgrade a shift of $\Delta Q = -0.3$ is expected

* K. Schindl, Space charge, Proceedings of the CERN Accelerator School 2006

Linear space charge in BTF

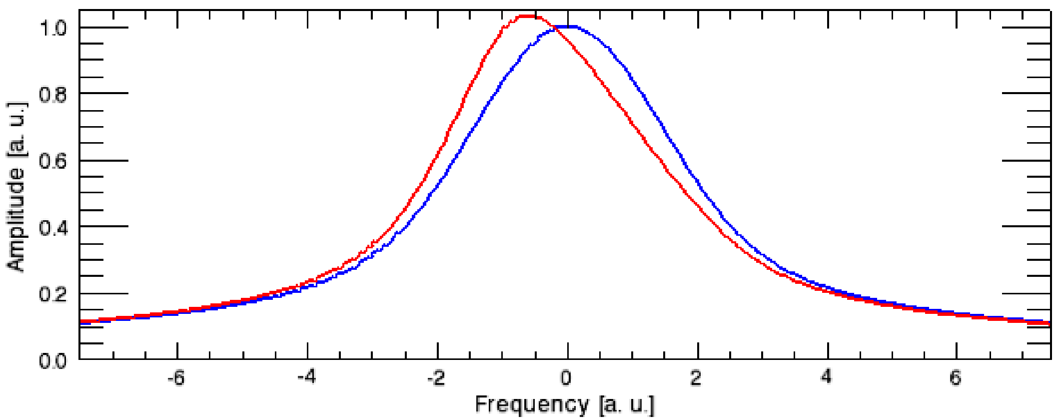
the stability diagram obtained from a **beam transfer function** *
measurement will be shifted by linear collective effects according to

$$\frac{1}{r} = \frac{1}{r_0} + i\chi$$



where r_0 is the pure beam transfer function and χ the **space charge parameter** defined by

$$\chi = \frac{f_0}{\sigma_f}\Delta Q$$



with the revolution frequency f_0 and the width of the band σ_f

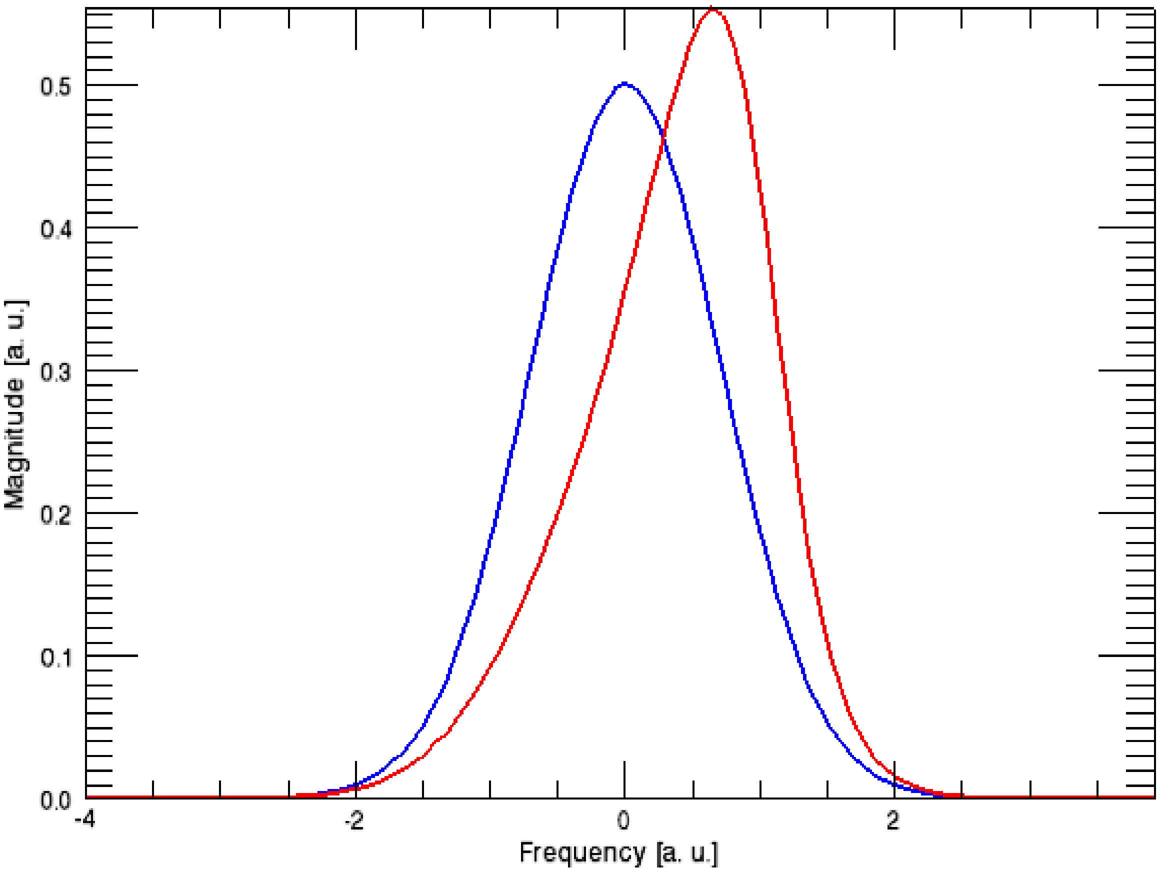
* J. Borer, G. Guignard, A. Hofmann, E. Peschardt, F. Sacherer and B. Zotter, Information from Beam Response to longitudinal and transverse excitation, IEEE Transactions on Nuclear Science, 1979

figures: stability diagram and amplitude of the BTF of a Gaussian momentum distribution without space charge and with space charge

Space charge in Schottky bands

similarly the transverse Schottky side bands P_0 are distorted as well *
the shape of the distorted band P is given by

$$P(\omega) = \frac{P_0(\omega)}{|1 - i\chi r_0(\omega)|^2}$$

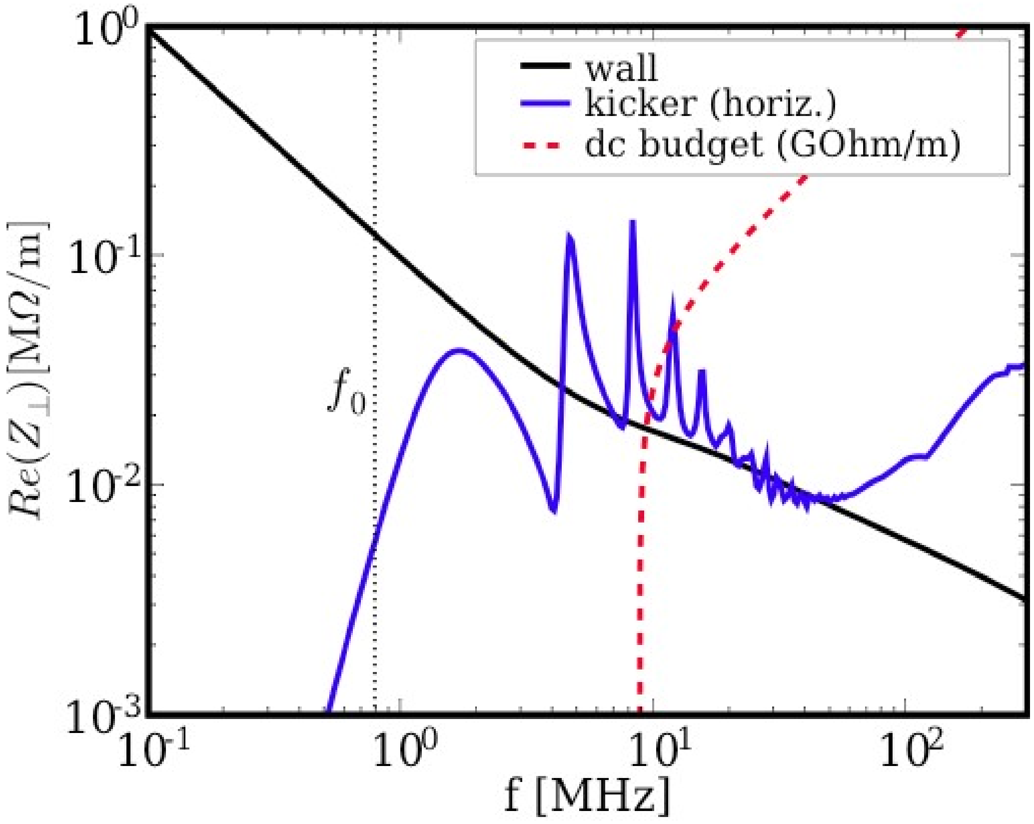


transverse Schottky band corresponding to a Gaussian distribution without space charge and with space charge

* S. Chattopadhyay, Some fundamental aspects of fluctuations and coherence in charged-particle beams in storage rings, CERN 84-11, 1984

Impedances

•impedances also shift the stability diagram
•the most important sources of impedance in SIS18 are the resistive wall and the kickers
•the kicker's impedance has been computed numerically*
•the wall's impedance can be computed analytically**
•impedances also shift the stability diagram, but orders of magnitudes less than space charge in SIS18



Impedances of kicker and resistive wall in SIS18 at 200 MeV/u

* B. Doliwa, H. DeGersem, T. Weiland, Numerical Calculation of Coupling Impedances for Kicker Modules, PAC 2005
** A .M. Al-Khateeb, R. W. Hasse, O. Boine-Frankenheim, W. M. Daqa and I. Hofmann, Phys. Rev. ST Accel. Beams 10, 064401 (2007)

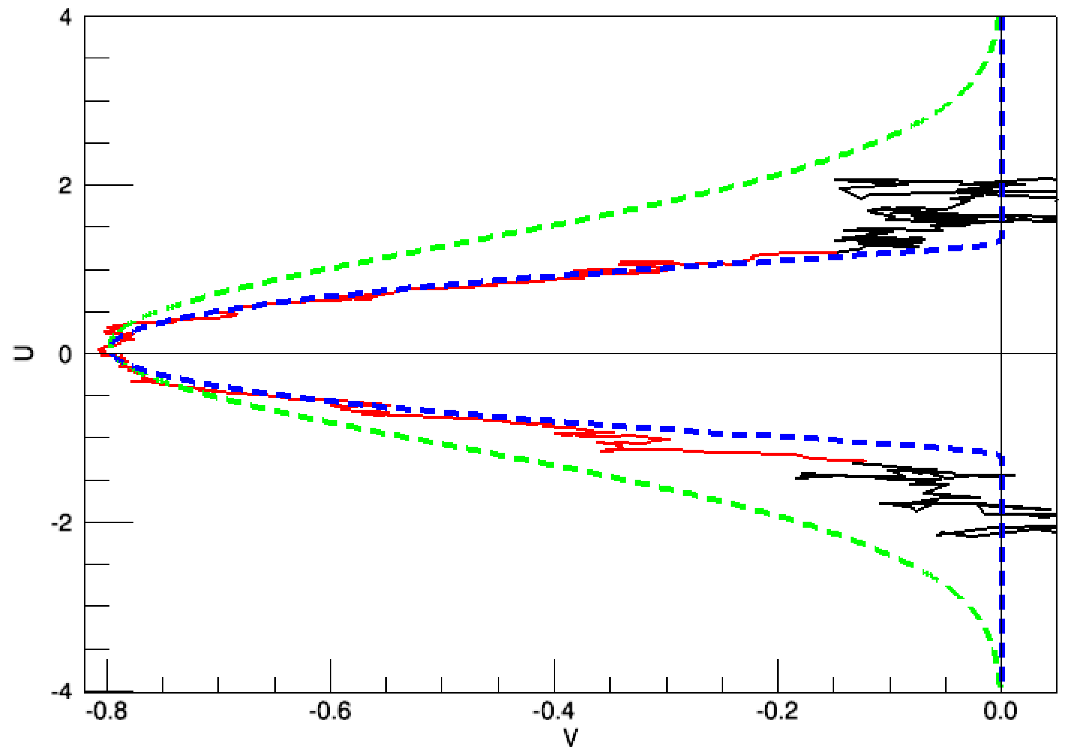
Beam parameters and tune shift

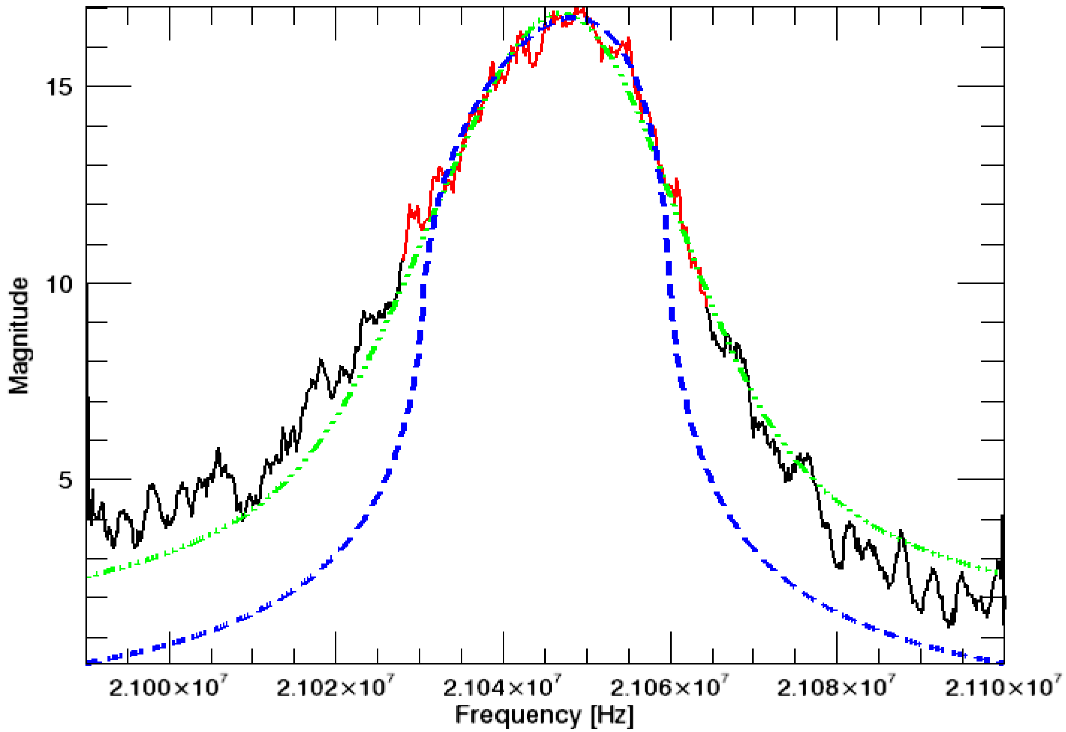
Ion	$^{40}Ar^{+18}$	$^{40}Ar^{+18}$	$^{40}Ar^{+18}$
Energy / MeV	11.4	11.4	500
σ_f / kHz	10	8.2	3.7
$\frac{\Delta p}{p}$ / 10^{-4}	5	6.7	5.9
Frequency / MHz	21	16	15.8
N / 10^9	2	7	2.3
ϵ_{hor} / (mm mrad)	7.8	5.7	2.5
ϵ_{ver} / (mm mrad)	4.6	4.6	1.2
χ_{sc}	0.13	1.6	0.16

parameters of the beams used in the experiments: two at injection energy with different particle numbers and one at 500 MeV/u

BTF after injection

- the stability diagram shows good agreement with a parabolic momentum distribution
- the amplitude shows thicker tails
- the fit included $\chi_{meas}=0.06$
- expected was $\chi_{theo}=0.13$





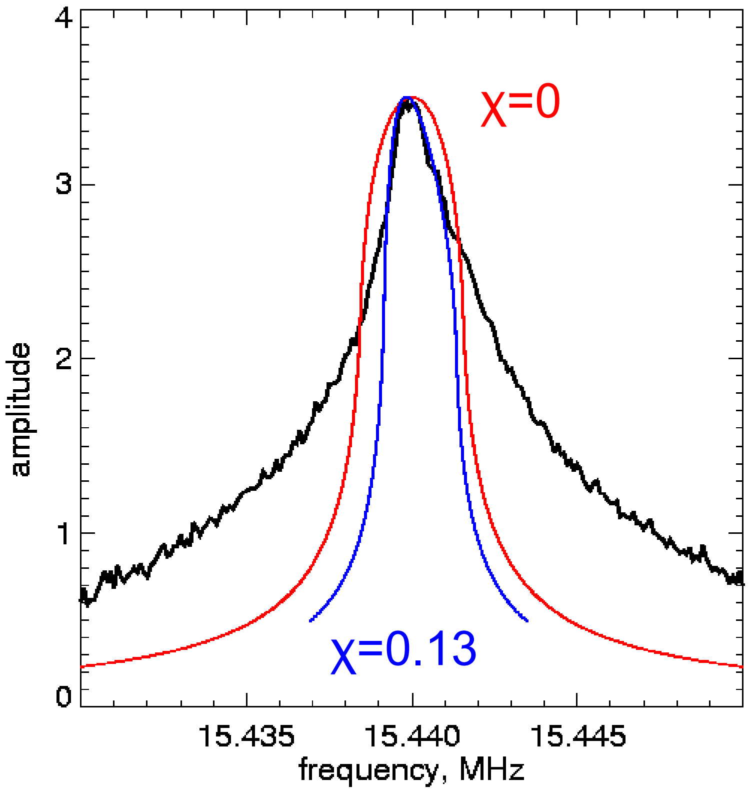
measured BTF with Gaussian and parabolic models

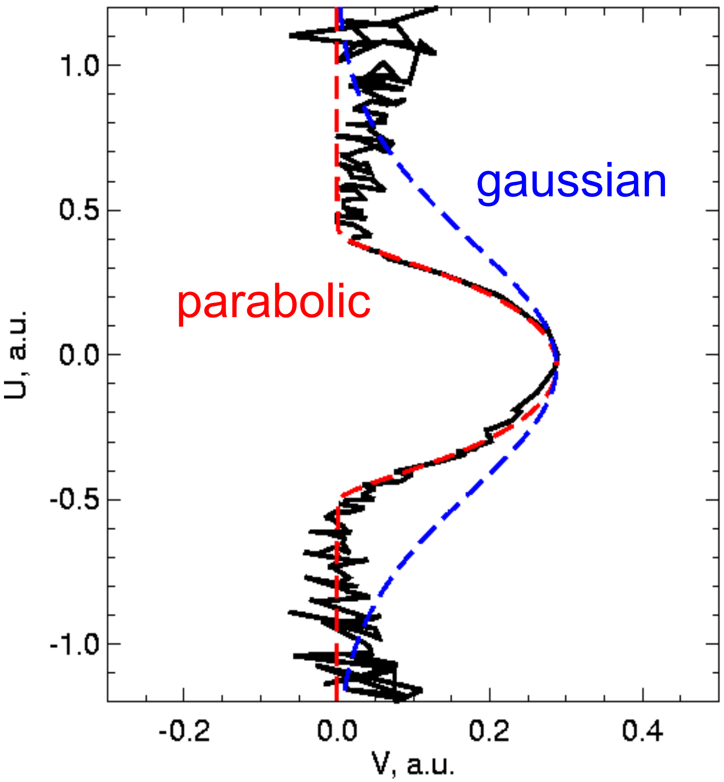
$^{40}Ar^{18+}$, 11.4 MeV/u, $2\cdot 10^{9}$ ions, upper side band

BTF at 500 MeV/u

- also at 500 MeV/u a parabolic momentum distribution with an asymmetry was found

- again the space charge parameter was smaller than expected:
  χ_{meas}=0.13
  χ_{theo}=0.16

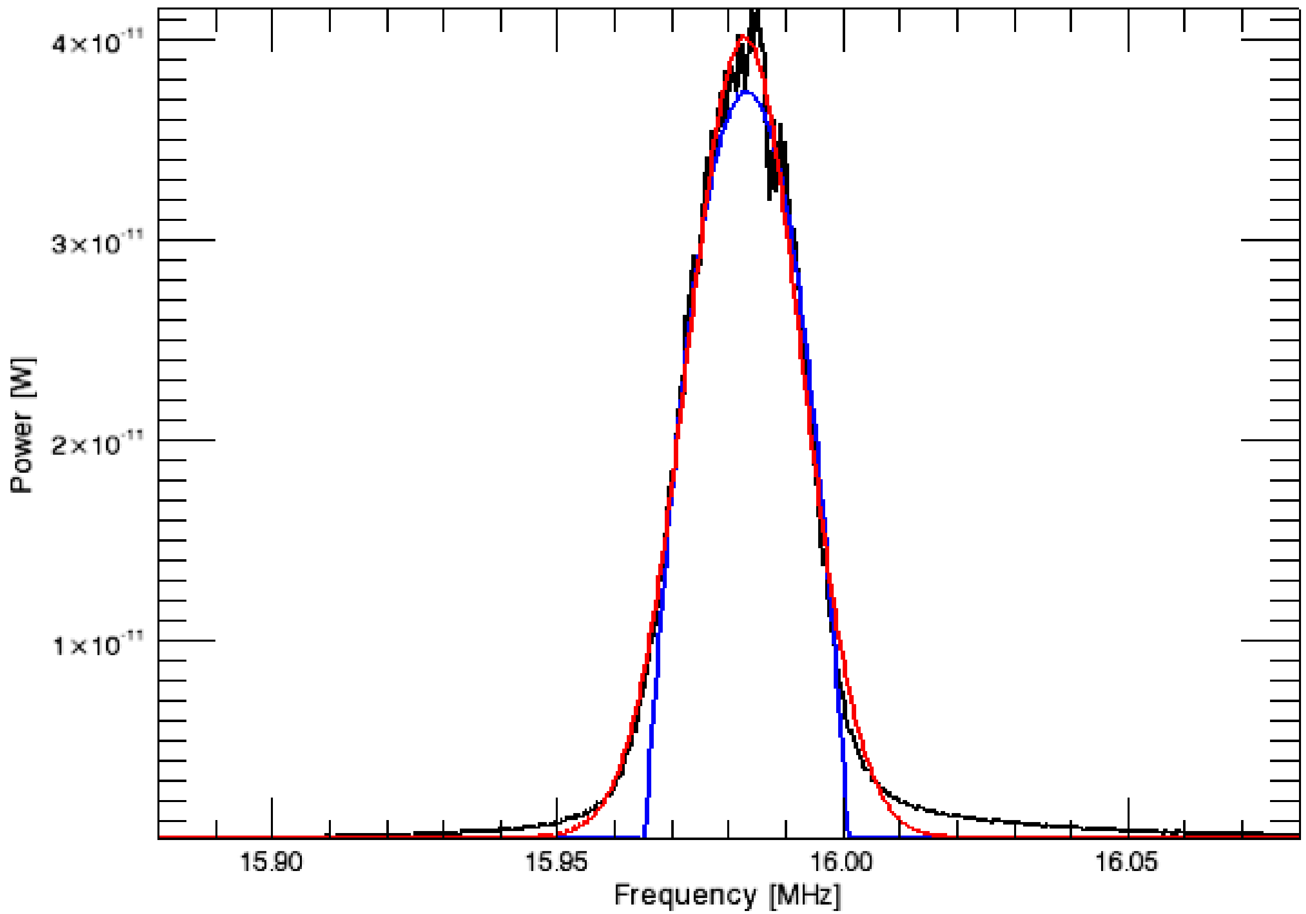




left: amplitude without space charge and with space charge
right: measured BTF with parabolic and Gaussian model
$^{40}Ar^{18+}$, $2\cdot10^9$ ions, 500 MeV/u, 15th harmonic

Schottky at injection

longitudinal Schottky band with fitted Gaussian and parabolic momentum distribution

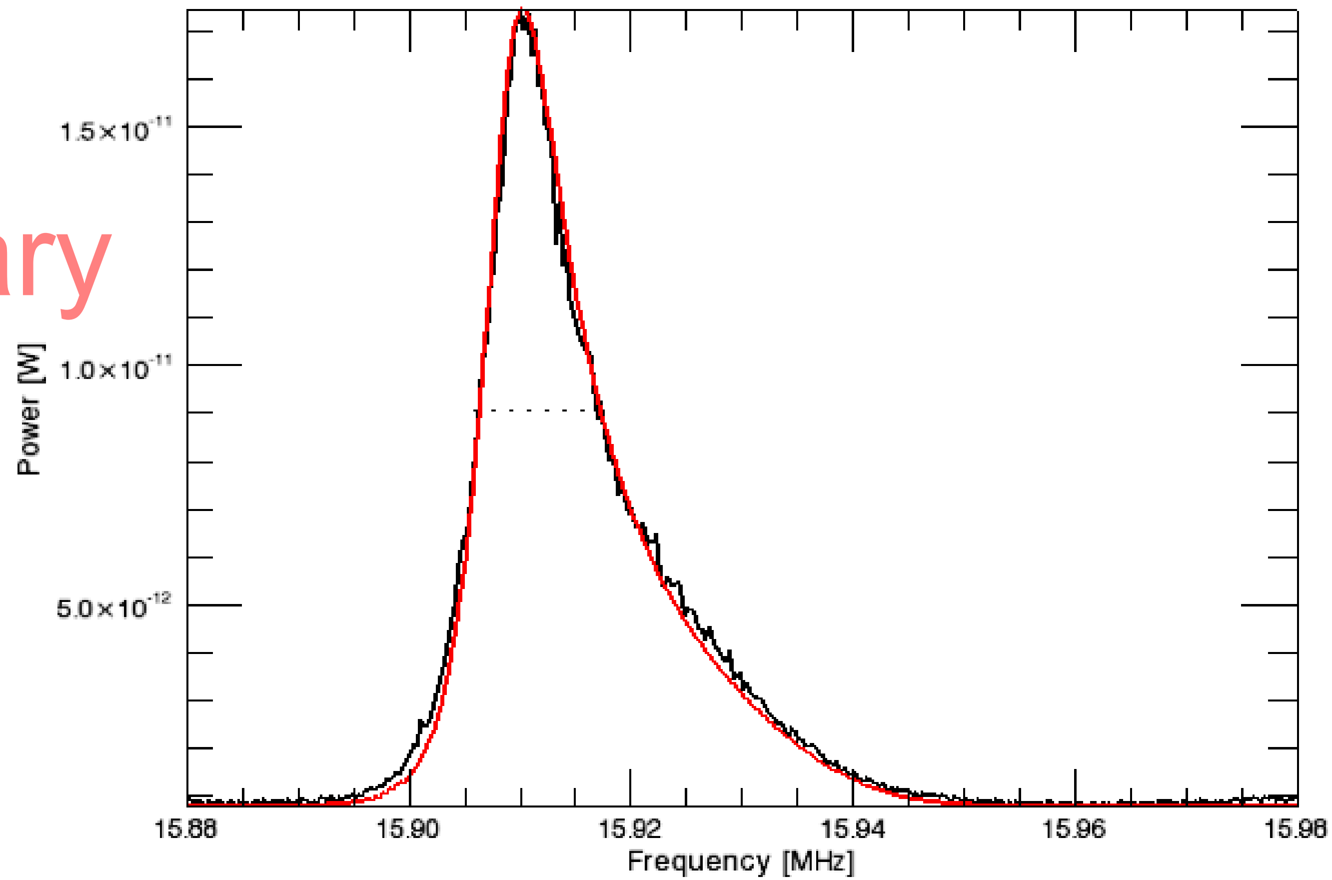


$^{40}Ar^{18+}$, 11.4 MeV/u, $7{\cdot}10^{9}$ ions, central band, 75th harmonic

Schottky measurements

lower side band with parabolic model, including a space charge parameter χ_{meas}=1.0 expected was χ_{theo}=1.6

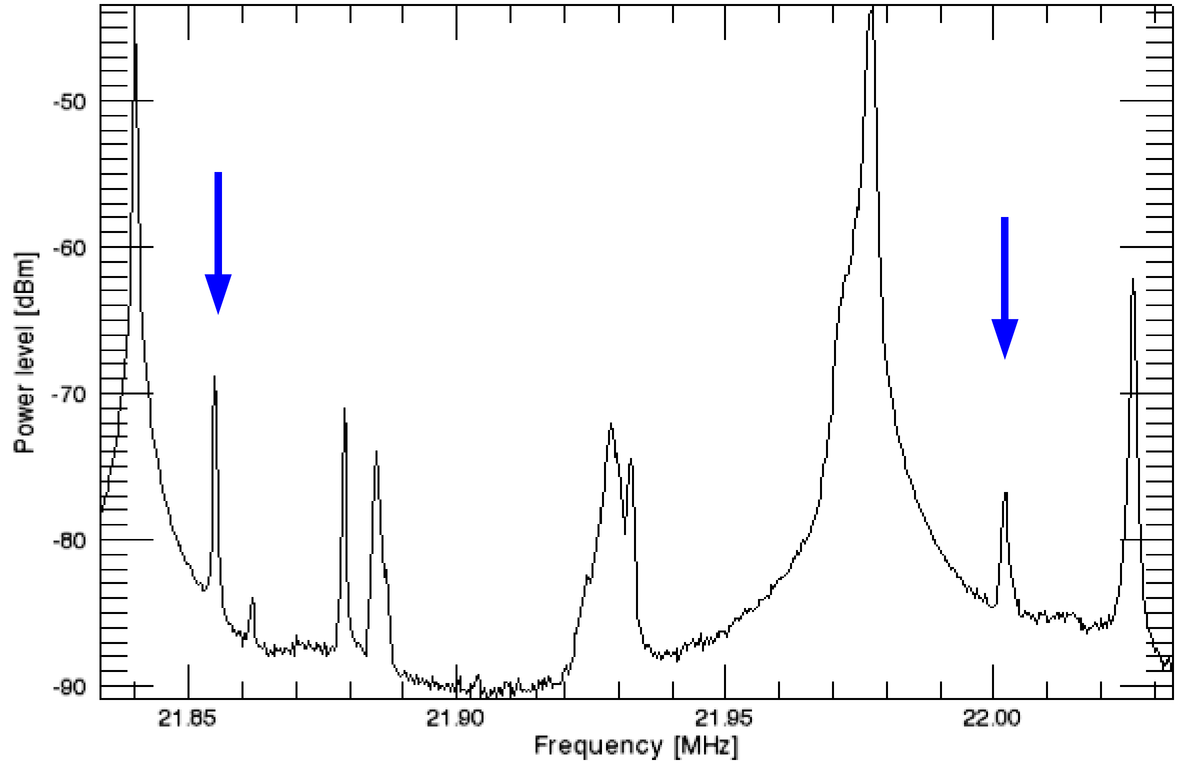
preliminary



$^{40}Ar^{18+}$, 11.4 MeV/u, $7 \cdot 10^9$ ions, lower side band, 75th harmonic

Cold beam

due to low emittance and momentum spread space charge is particularly strong in cold beams
but Schottky bands are superposed by other signals



transverse Schottky spectrum with two sidebands marked with arrows
$^{40}Ar^{18+}$, 11.4 MeV/u, $2 \cdot 10^9$ ions, 103th harmonic, ε_h=2.5 mm mrad, ε_v=0.8 mm mrad, $\Delta p/p=1.3 \cdot 10^{-4}$

Conclusions

- Schottky and BTF measurements were performed with intense coasting ion beams at low and intermediate energy
- the linear space charge model could be used to describe the distortion of the transverse Schottky bands and the BTFs
- the corresponding space charge parameters were smaller than expected, likely because of the uncertainty of the emittance and momentum spread
- the measurements with a cold beam are difficult to analyze due to disturbing signals
- simulations will be performed using PATRIC for further studies of transverse collective effects