Tune Measurements with High Intensity Beams at GSI SIS-18*

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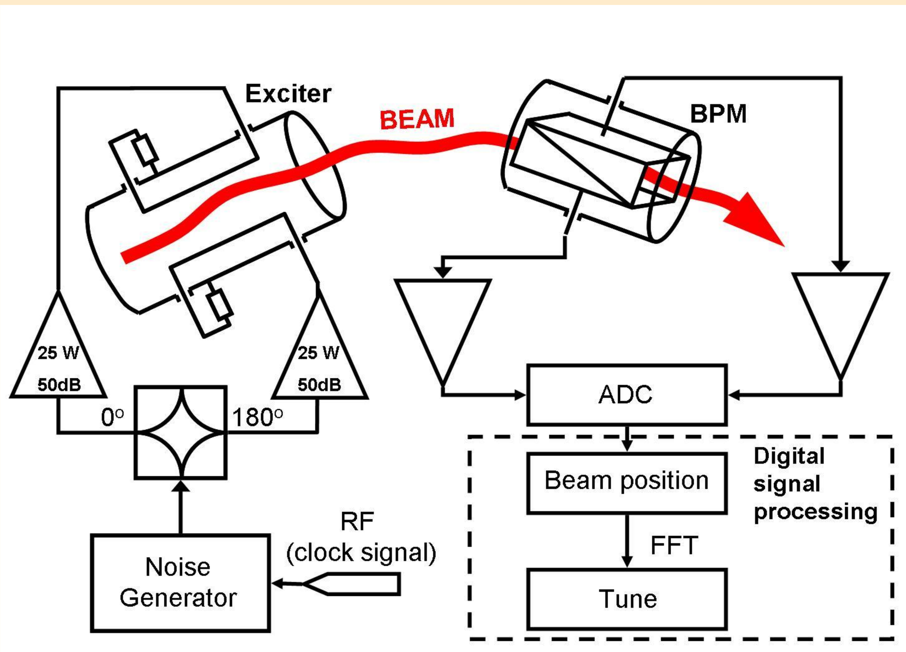
3rd DITANET SCHOOL ON BEAM DIAGNOSTICS

Abstract

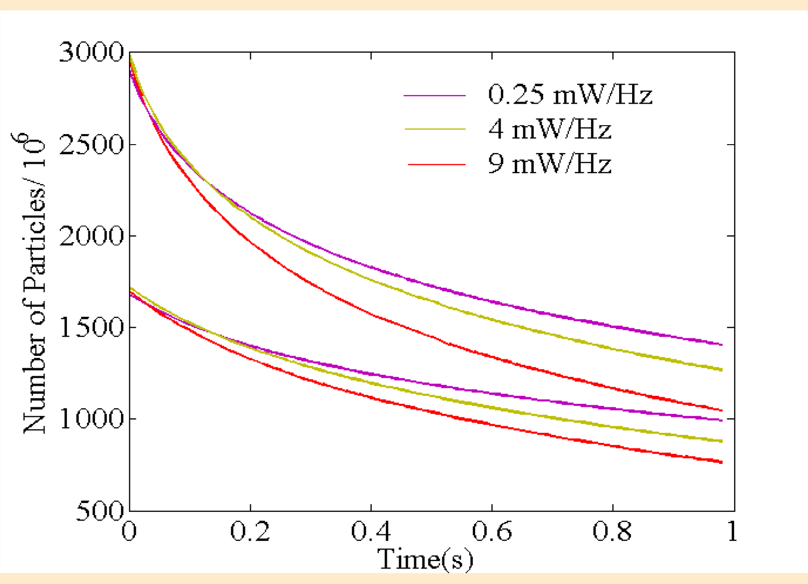
To achieve a high current operation close to the space charge limit, a precise tune measurement during a full accelerating cycle is required. A tune measurement system was recently commissioned at GSI SIS-18, which allows evaluation of tune using digital position data. Using this system, the space charge effects were observed by correlating the current levels to tune shifts in the GSI synchrotron SIS-18. The experiment was conducted at injection energy of 11.4 MeV/nucleon using a $^{238}U^{73+}$ ion beam with stored number of particles from 2.5* 10^7 to 2.5*10^9. A significant broadening of the tune spectrum in dependence of the stored number of particles was detected. This proves the reliability of the measurement method and opens the possibility of detailed beam physics investigations.

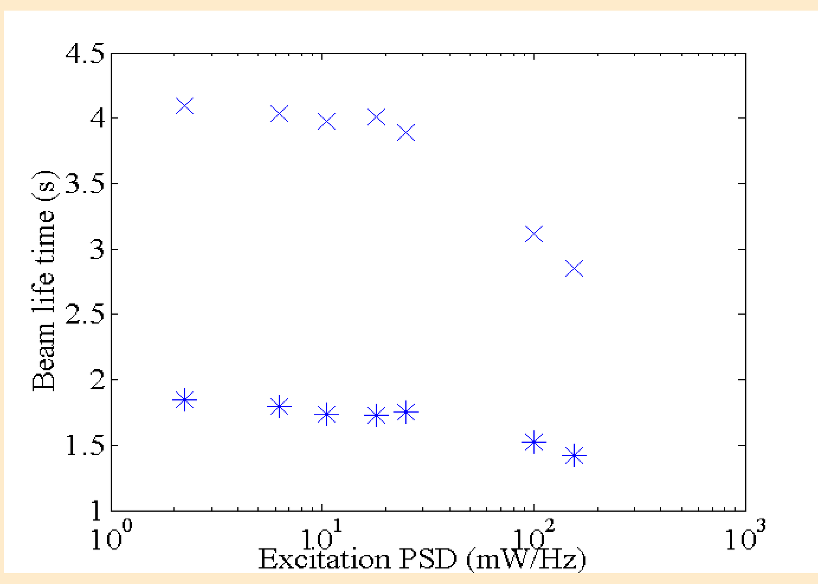
Tune measurement system



•Beam is excited using band limted noise.
•Shoe-box type beam position monitors used to measure the beam signal in vertical and horizontal planes.
•Fast 125 MSa/s ADCs are used to digitize the acquired data from pick ups
•Position is calculated in real time in the FPGA.
•Position is transferred to the concentrator PCs from all the 12 BPMs.
•Tune is calculated by frequency transformation of position data for typically 512 turns.

Beam life time

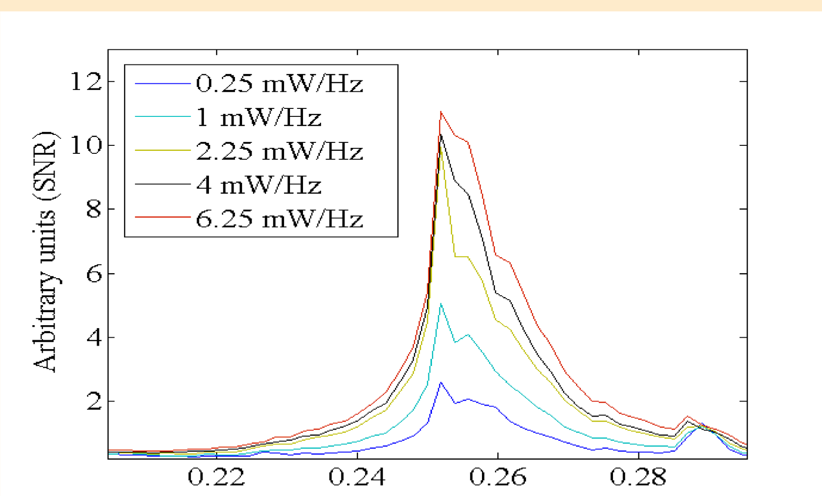


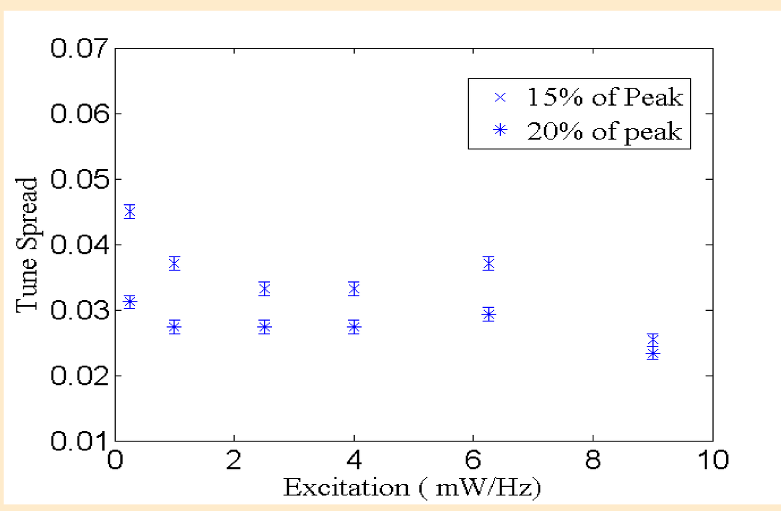


•Beam life time measured at two injection current levels with different noise excitations.
•Beam life time depends on ion induced desorption, noise excitation and postion of frozen tune.

•Reduction in beam life time with noise excitation observed.
•Beam life time is calculated by fitting the fitting curve to an exponential function.

Change in tune spread with beam excitation

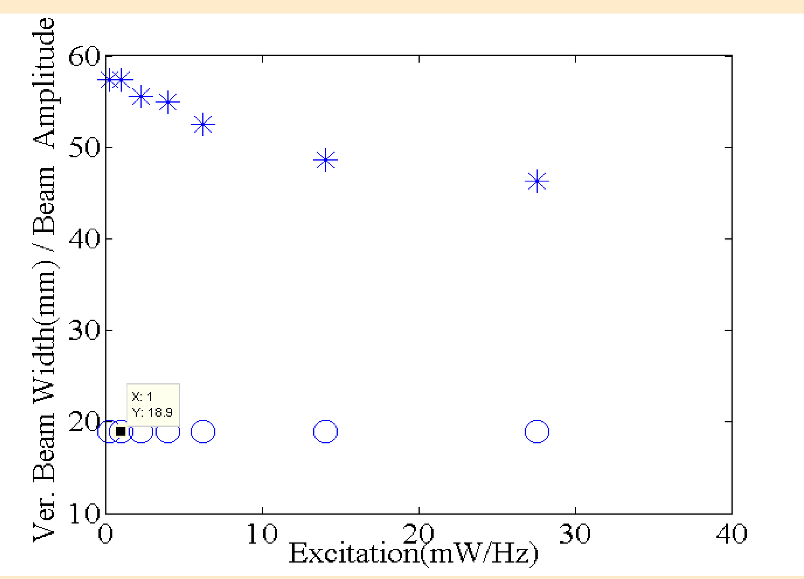


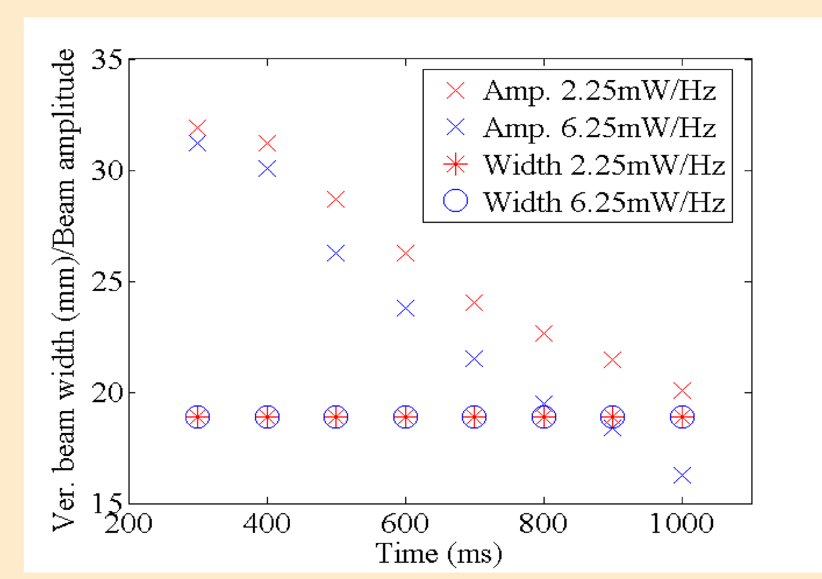


•Increase in noise excitation gives bigger kick to the particles thus resulting in a more accurate position measurement. This gives us a better SNR in tune spectrum.

•The width of the tune spectrum is independent of noise excitation.
•The resolution of the tune is given by the number of position points taken for FFT.

Effect of beam excitation on emittance





•Vertical Beam width does not increase with increase in excitation in our experiments.
•Beam amplitude reduces with increase in excitation which signifies particle losses.
•This behaviour can be attributed to stationing of tune near fourth order resonance.

•Evolution of vertical emittance and beam amplitude during 1s on injection flat top.
•No increase in emittance, but continous and uniform particle losses with time.

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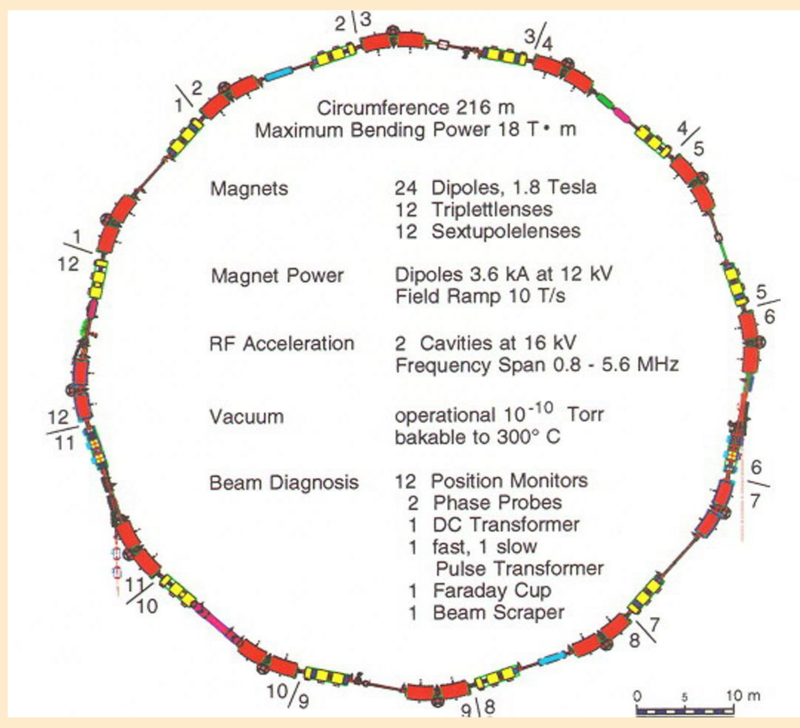
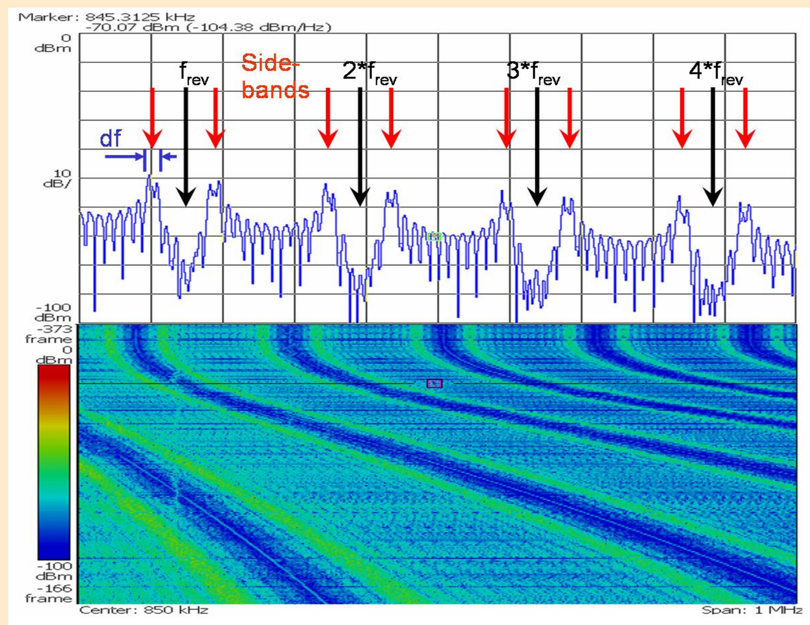
SIS-18



Important parameters of SIS-18:

- Circumference 216 m
- Inj. type Multiturn
- Energy range 11 MeV → 2 GeV
- Acc.RF 0.8 → 5 MHz
- Acc. harmonic 4 (no. of bunches)
- Bunching factor 0.6 → 0.2
- Ramp duration 0.3 → 1.5 s
- Typical tune h/v 4.319 3.29
- Ion range (Z) 1 → 92 (p to U)
- Design beams 2 x 10^{11} U 28+
1 x 10^{13} p

Noise exciter



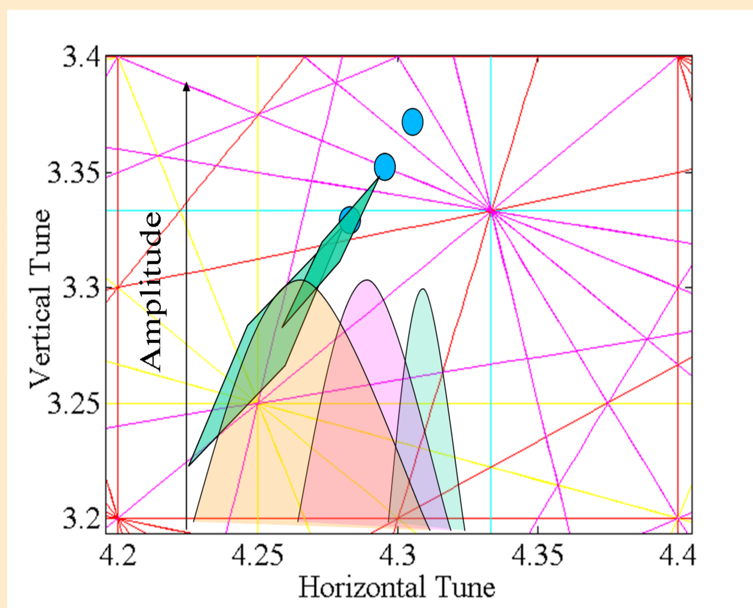
Noise output spectrum moving with rf frequency during ramping.

- Band limited noise excitor is required for :

1. Low power continous excitation of hadron beams causing least disturbance to the beam parameters.
2. Measuring tune while ramping, which is not possible with other comparable methods.

- Working principle → Modulation of tune frequency using pseudo random sequence, resulting in tunable noise bandwidth.
- It can supply power between 2.5 W to 300W after amplification.
- Noise bandwidth is tunable upto 0.5*f_{rev}.

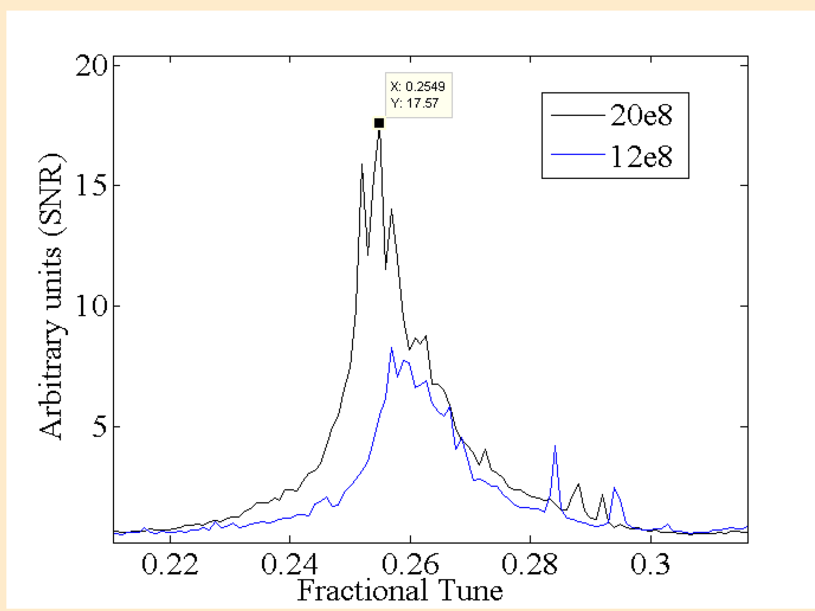
Space charge effects



Coherent tune shift : The effect of boundary conditions e.g beam pipe and other devices result in the movement of barycentre of the tune spectrum.
Incoherent tune shift : The interaction of fields of individual charged particles in the beam changes the tunes of individual particles, resulting in the spread of tune spectrum.

•Directly proportional to current level
•Inversely proportional to particle energy and beam width

Tune shift



•Our investigations were done at injection energies and thus Incoherent tune shift was the dominant effect.
•Set vertical and horizontal tune were 3.26 and 4.18 respectively.
•Tune spread observed in the vertical plane only for highest currents(20*10^8 particles).
• For currents lower than 15*10^8, expected vertical tune spread was lower than chromatic tune spread (~ 0.01)
•The asymmetry of the tune spectrum hints the effect of fourth order resonance line.

	Calculated(rms)		Measured(rms)	
Number of particles	20 * 10^8	12 * 10^8	20 * 10^8	12 * 10^8
Horizontal Incoherent tune shift(max)	0.008	0.005	0.004	0.004
Vertical Incoherent tune shift(max)	0.028	0.017	0.021	0.012

Summary and Outlook

- Tune measurement was done with low power noise excitation of the beam without disturbing the beam emittance significantly.
- Incoherent tune shifts were observed for high currents.
- Tune spectrum is independent of power of noise excitation.
- Influence of noise excitation on the beam life time was observed.
- Investigations of the noise excitation on the emittance was done.
- This system can be used for continous monitoring of the tune, with time resolution of 512 turns.
- This system can be a useful tool for beam physics investigations.
- It is an easy to use tool for the operators.
- The experiment has to be repeated with higher currents and with other ion types.