Tune Measurement at GSI SIS-18: Methods and Results

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Outline

- Introduction
- Methods

  Tune, Orbit and Position Measurement System (TOPOS)

  Base Band Tune Measurement System (BBQ)
- Results
- Opportunities and Conclusion

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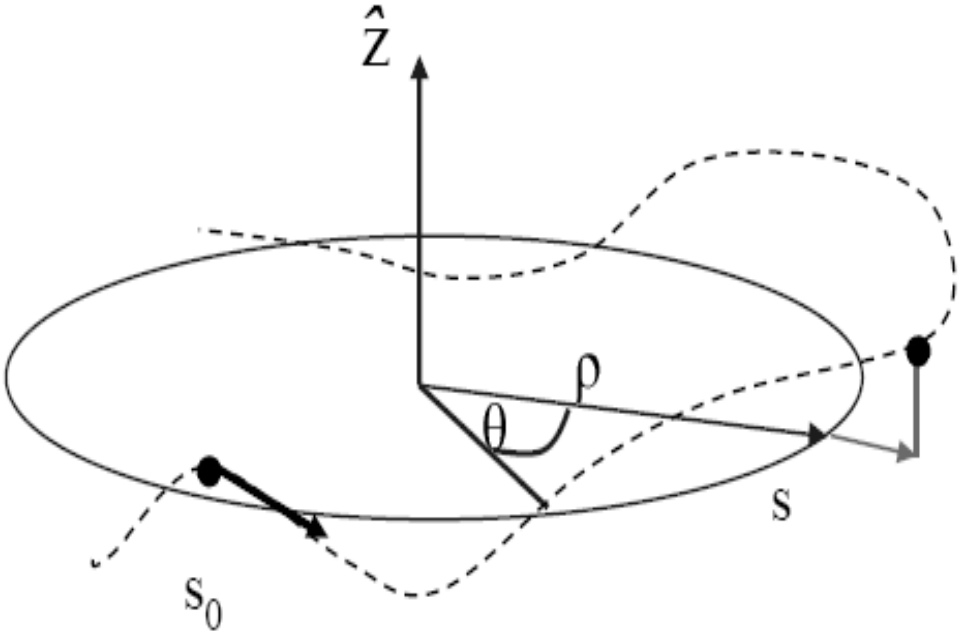
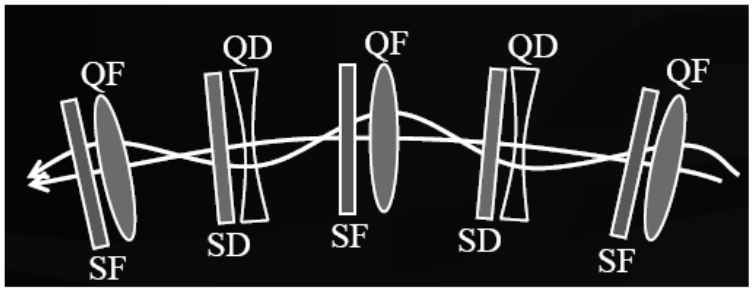
Introduction to Tune

- What is betatron tune ?
- Why is tune measured ?
- How is tune measured ?

What is betatron tune?

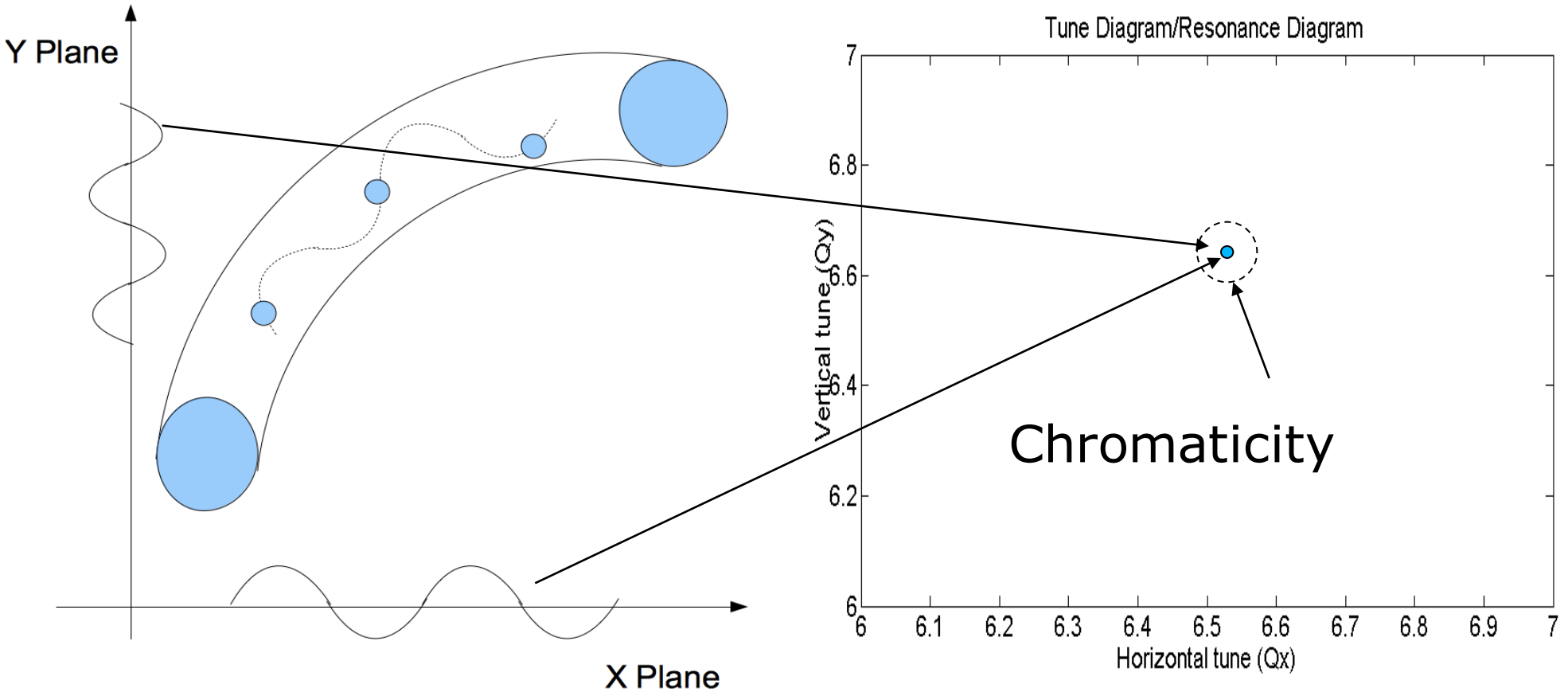




- The number of transverse oscillations, a particle traverses during one turn around the synchrotron

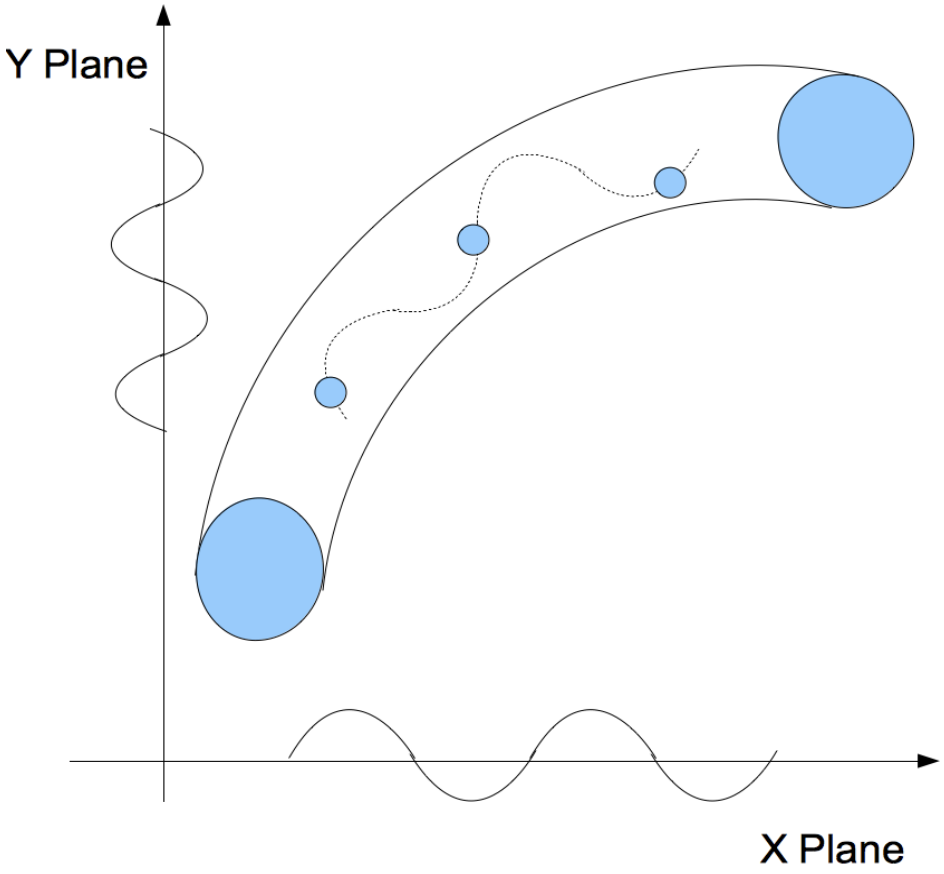
- Tune primarily depends on the optics of the synchrotron

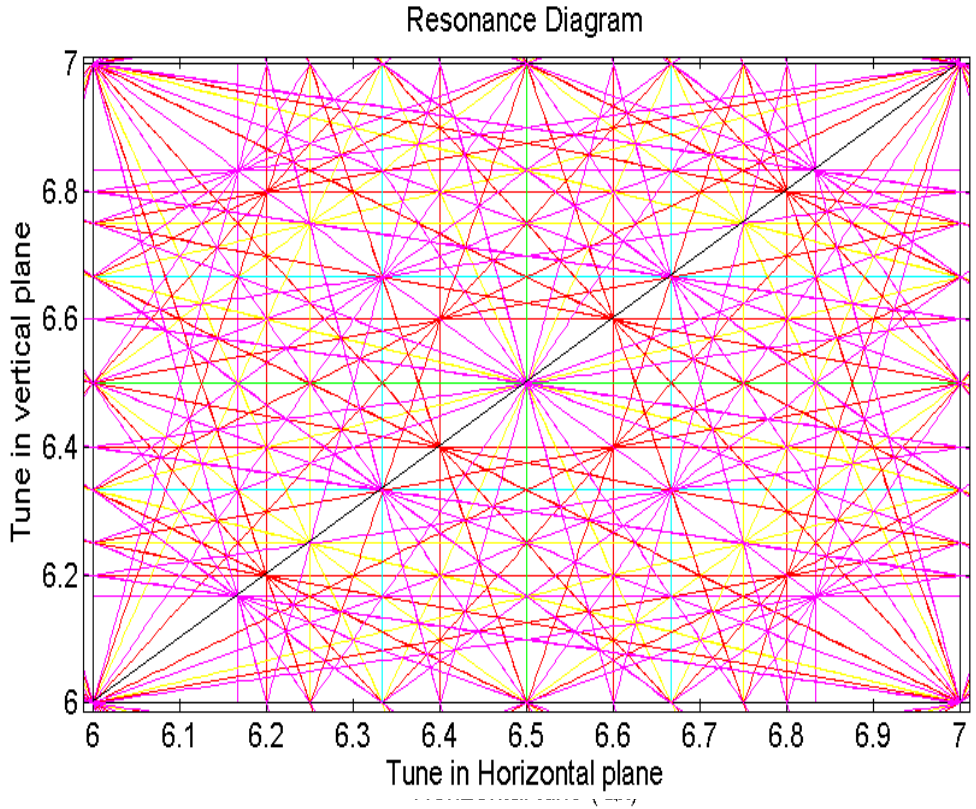
What is tune?



Tune spread due to momentum spread!

Why measurement of tune?



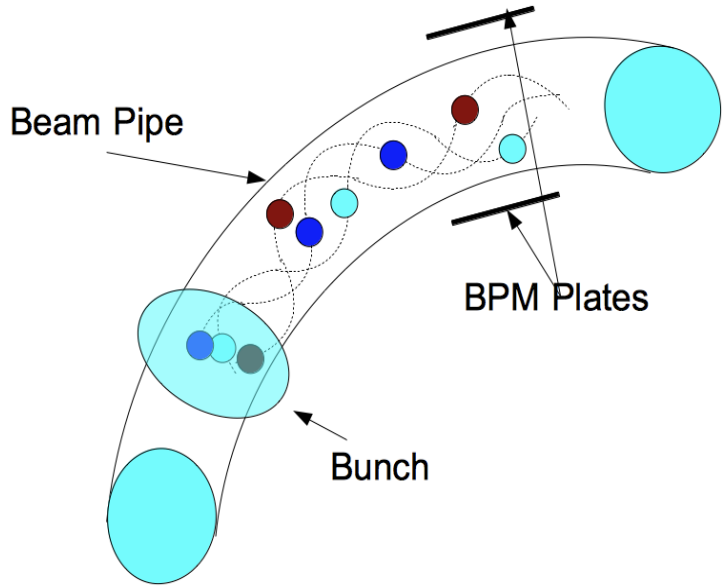


Why measurement of tune?

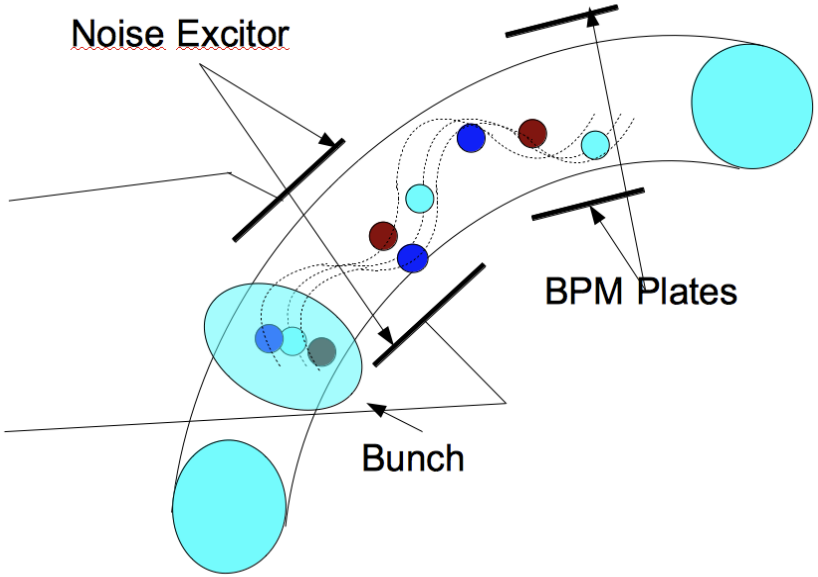
- Not to lose particles or lose particles at will(slow extraction)
- Correct unwanted tune movements, i.e control it
- Precise control of the tune is crucial for high current operations especially for the storage of low energy ion beams (Tune shifts depending on intensity)

How is tune measurement done?

Incoherent motion, BPM only measures centre of mass



Excite the beam with band limited noise



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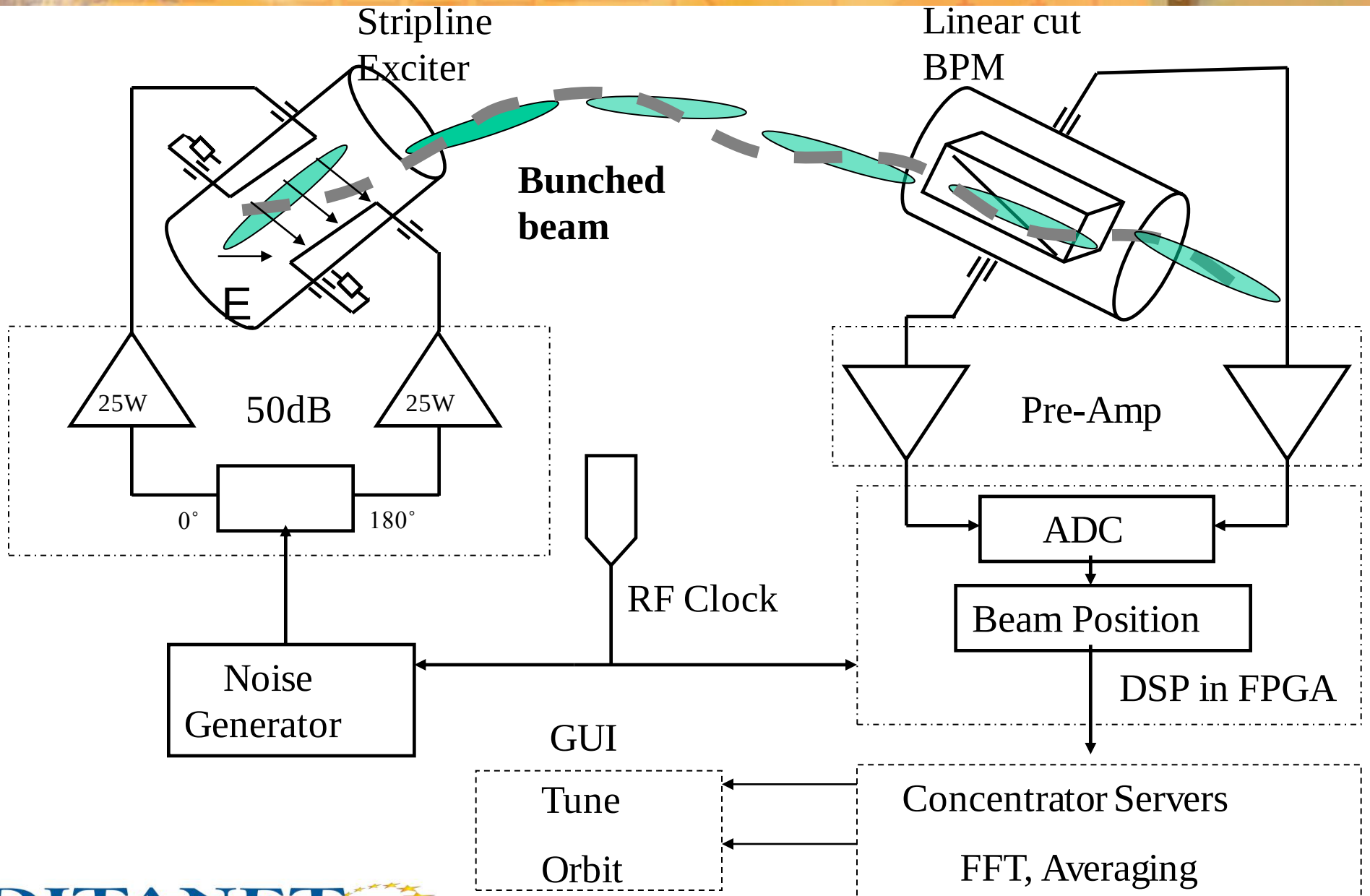
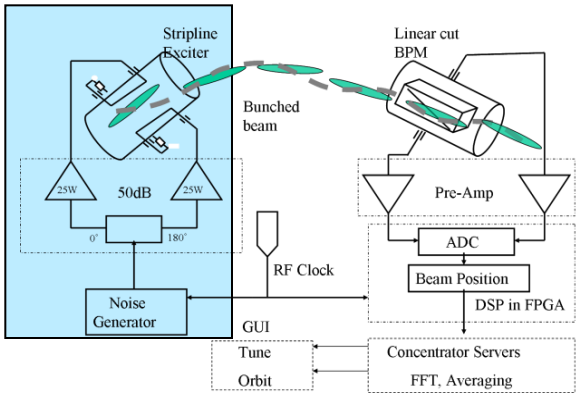
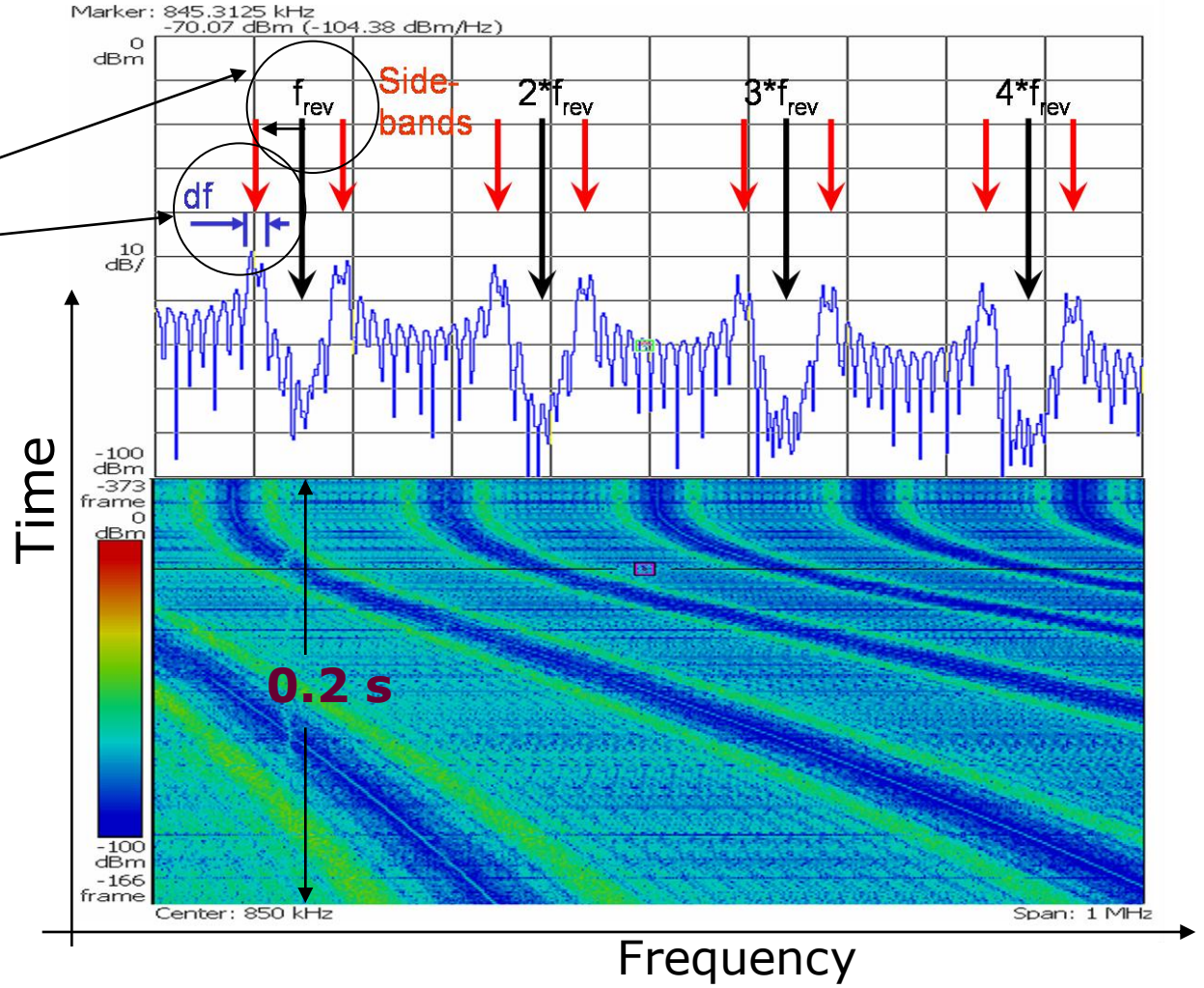
Tune Measurement System Details



Beam Exciter

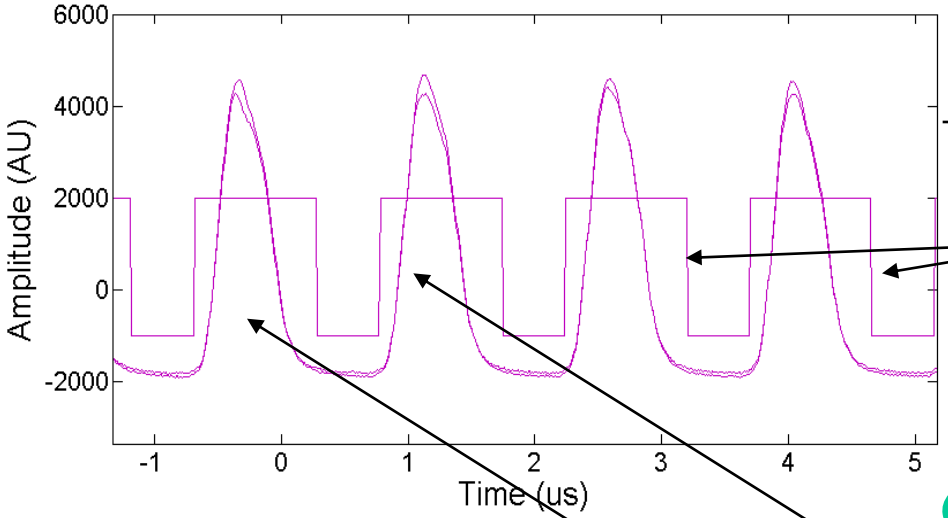
- Pseudo Random noise generator
- Tunable noise frequency and its bandwidth
- Strip line exciters with maximum power of 50W





Output of tunable noise generator over the ramp, frequency increasing with time

Position Calculation Algorithms



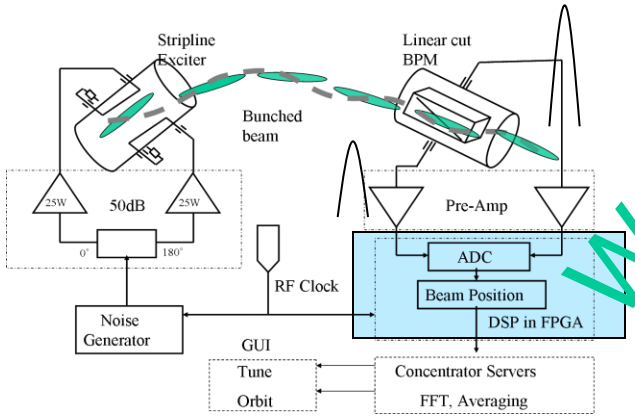
FPGA

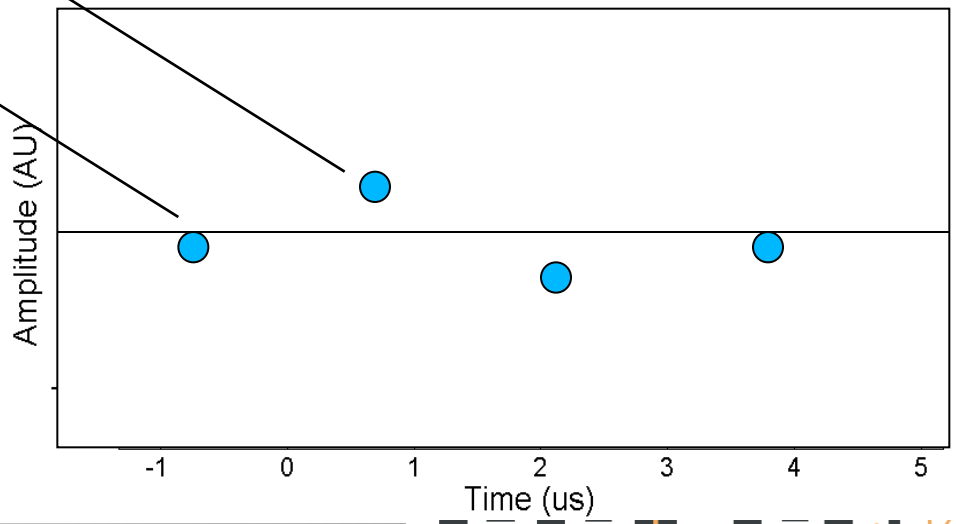
Bunch Detection

Time Windows

Position Calculation

- Baseline Restoration
- Linear regression (OLS)

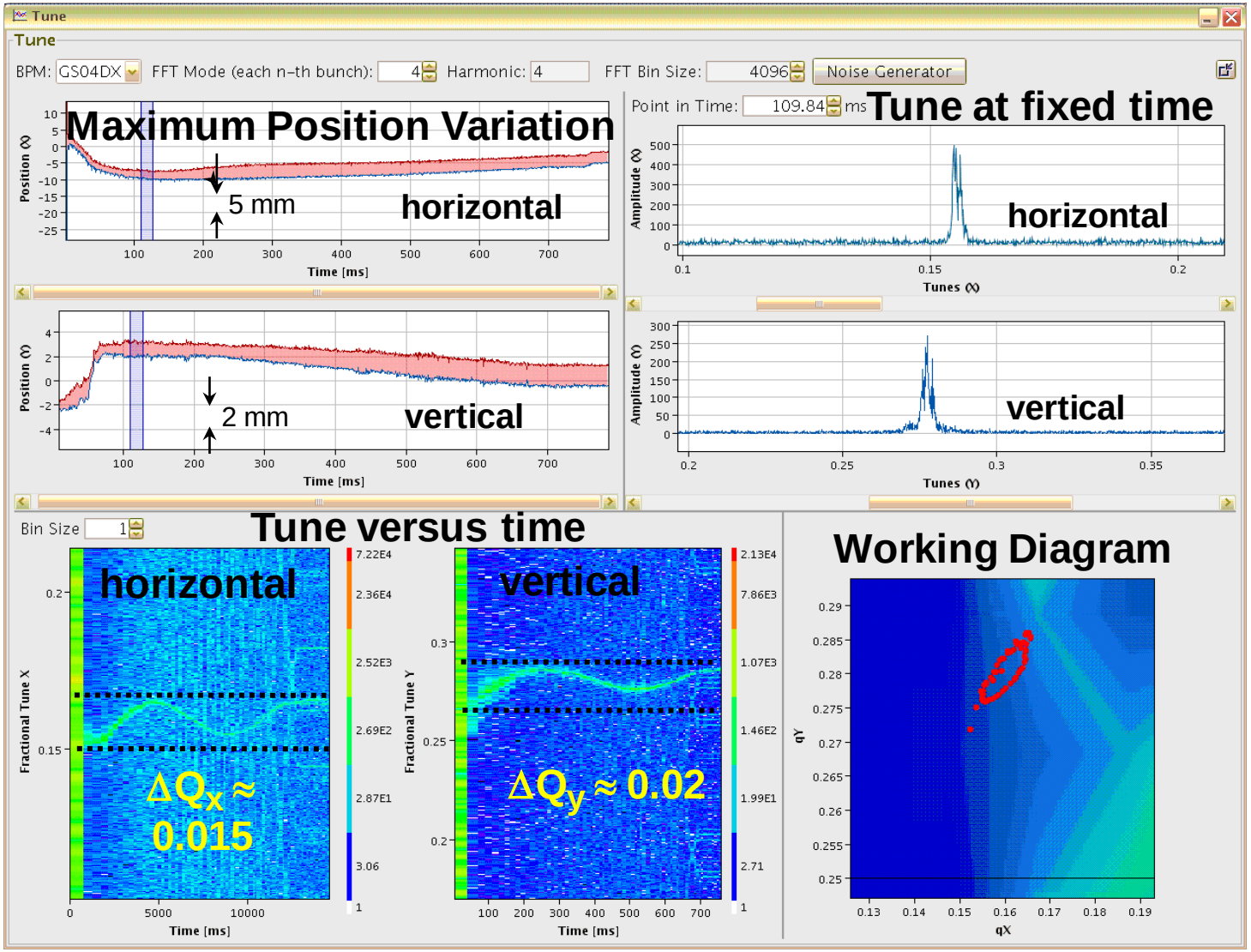


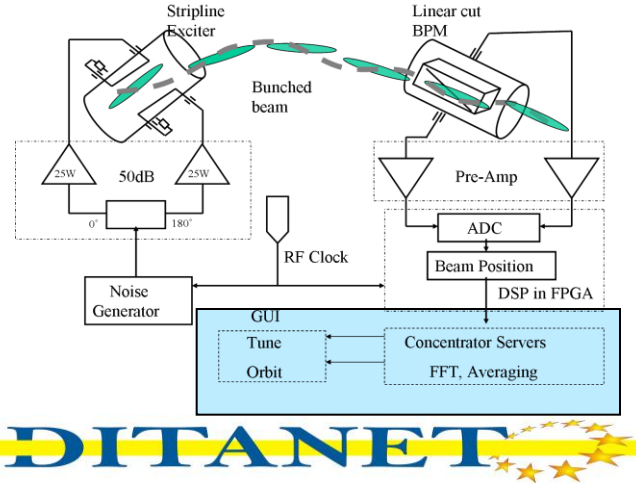


Welcome to my Poster!

GUI (TOPOS)

Online positon and tune measurement during the whole acceleration cycle





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Designed by Marek Gasior et al (BE/BI/QP), CERN

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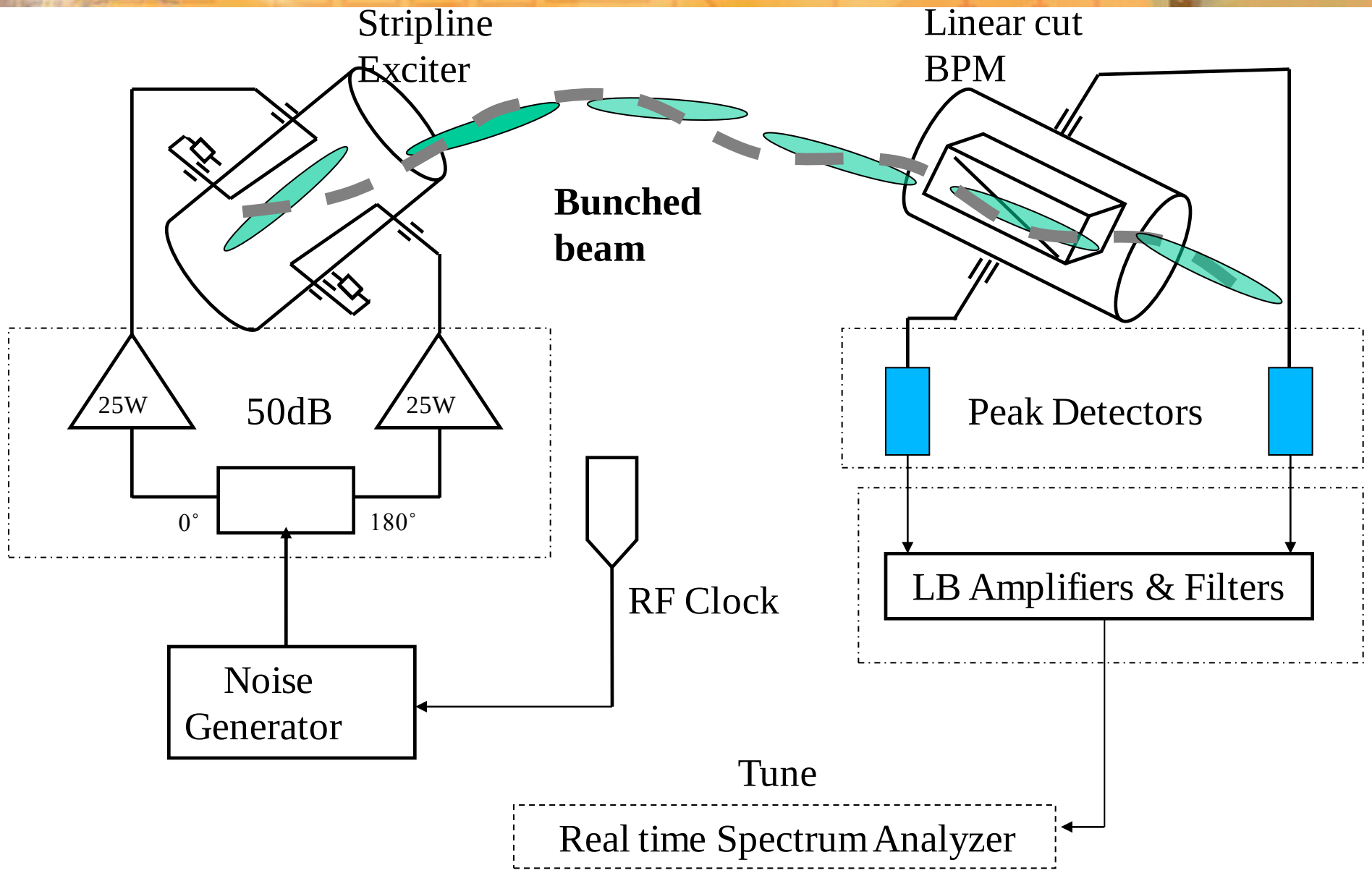
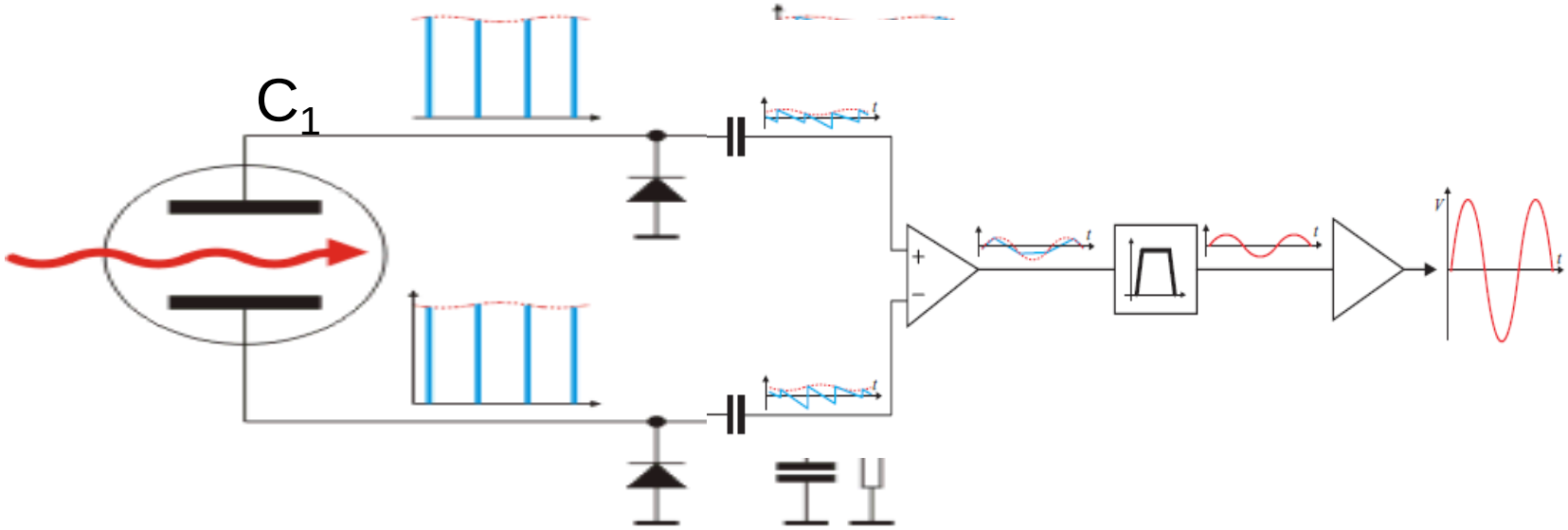
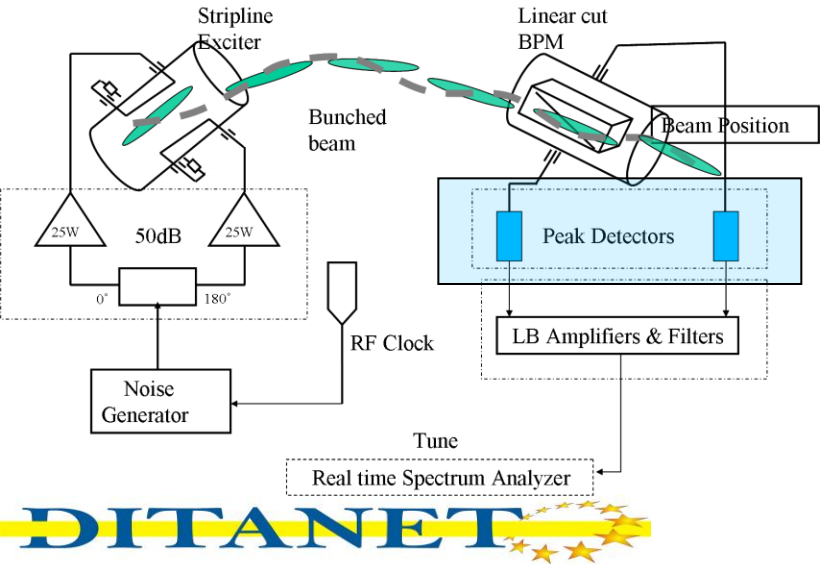
BBQ System Details



BBQ Details

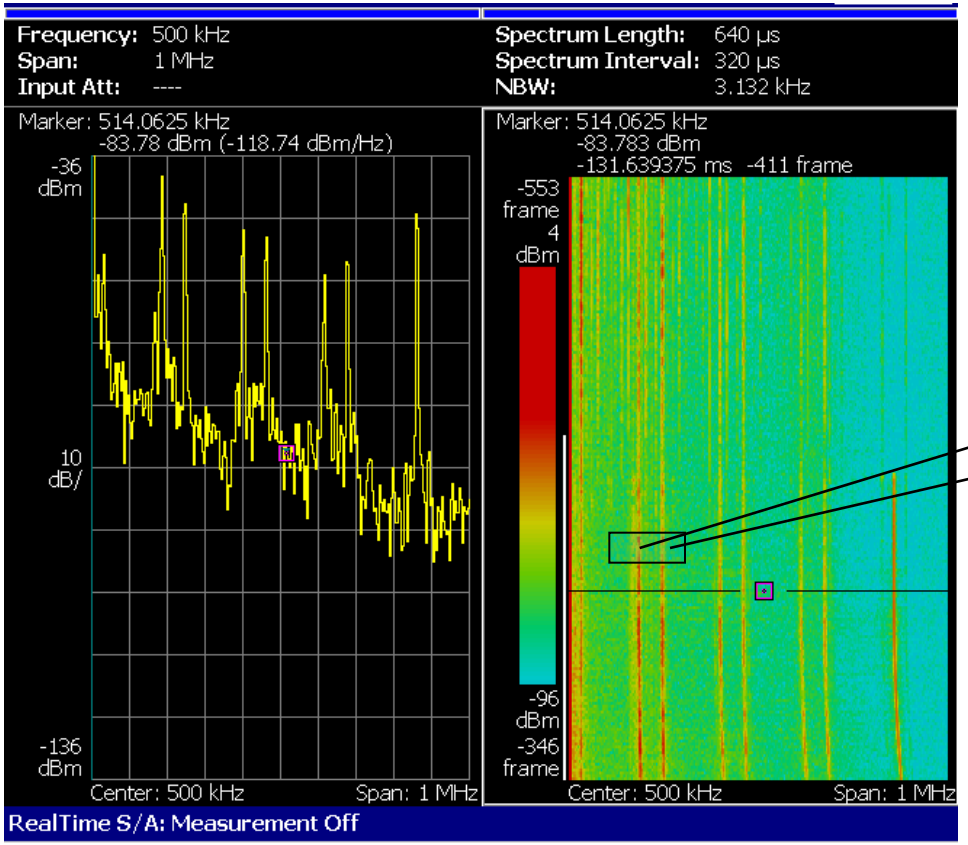




- Time constant ($R*C_2$) has to be optimized to be > $10*T_{rev}$ to suppress revolution frequency
- C_1/C_2 determines the transfer impedance
- Bandwidth 10 KHz to 1 MHz
- 50 dB common mode rejection (CMRR)
- Variable gain upto 65 dB

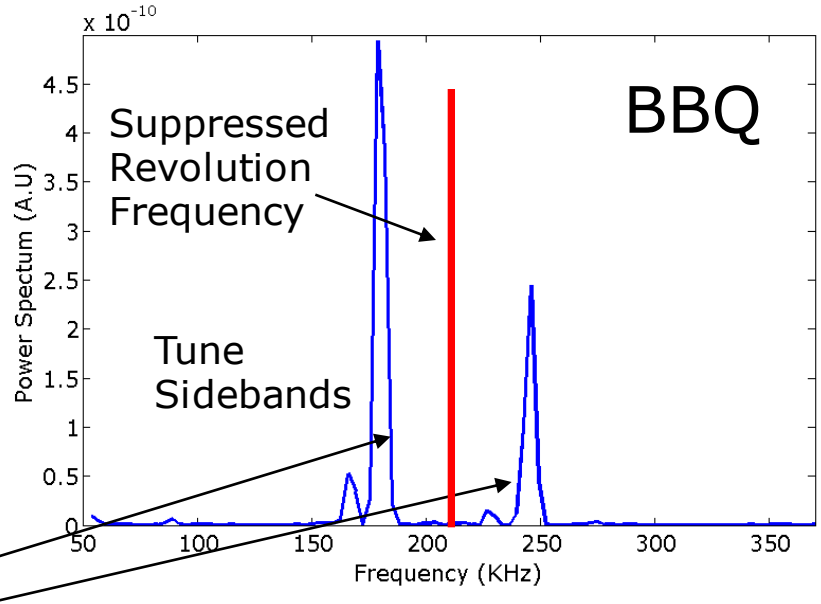
BBQ Results

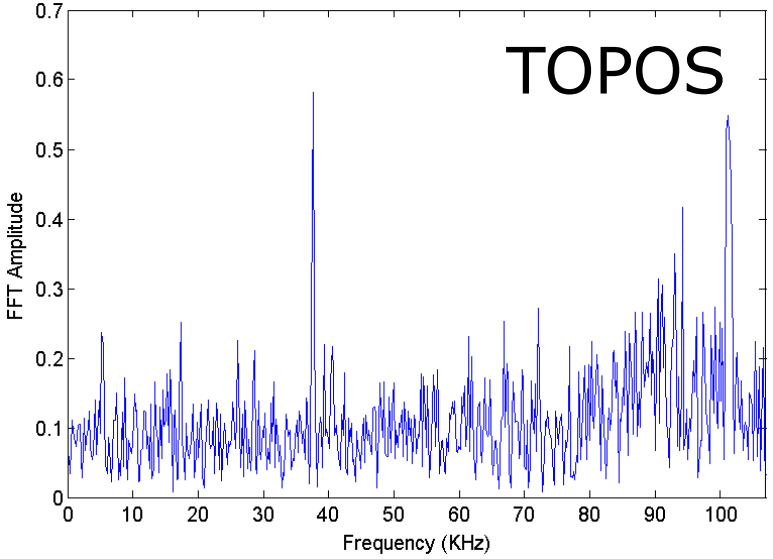
Particle numbers (U39+) ~ 7e8



Time

Frequency





40 V ~ 1mW/Hz

System Comparison

TOPOS	BBQ
• Position, orbit, tune, Longitudinal profile etc.	• Dedicated tune measurement
• Low sensitivity: It can detect ~ 0.5mm oscillations with 3dB Signal to Noise Ratio (SNR)	• Higher sensitivity: It can detect ~0.05 mm oscillations with 3dB SNR
• Fast ADCs required to resolve high frequencies in bunch structure	• Reduces the data directly in detectors, slower high res. ADCs could be used
• Operational system	• Test system

Both are needed, they have mutually exclusive applications!!!

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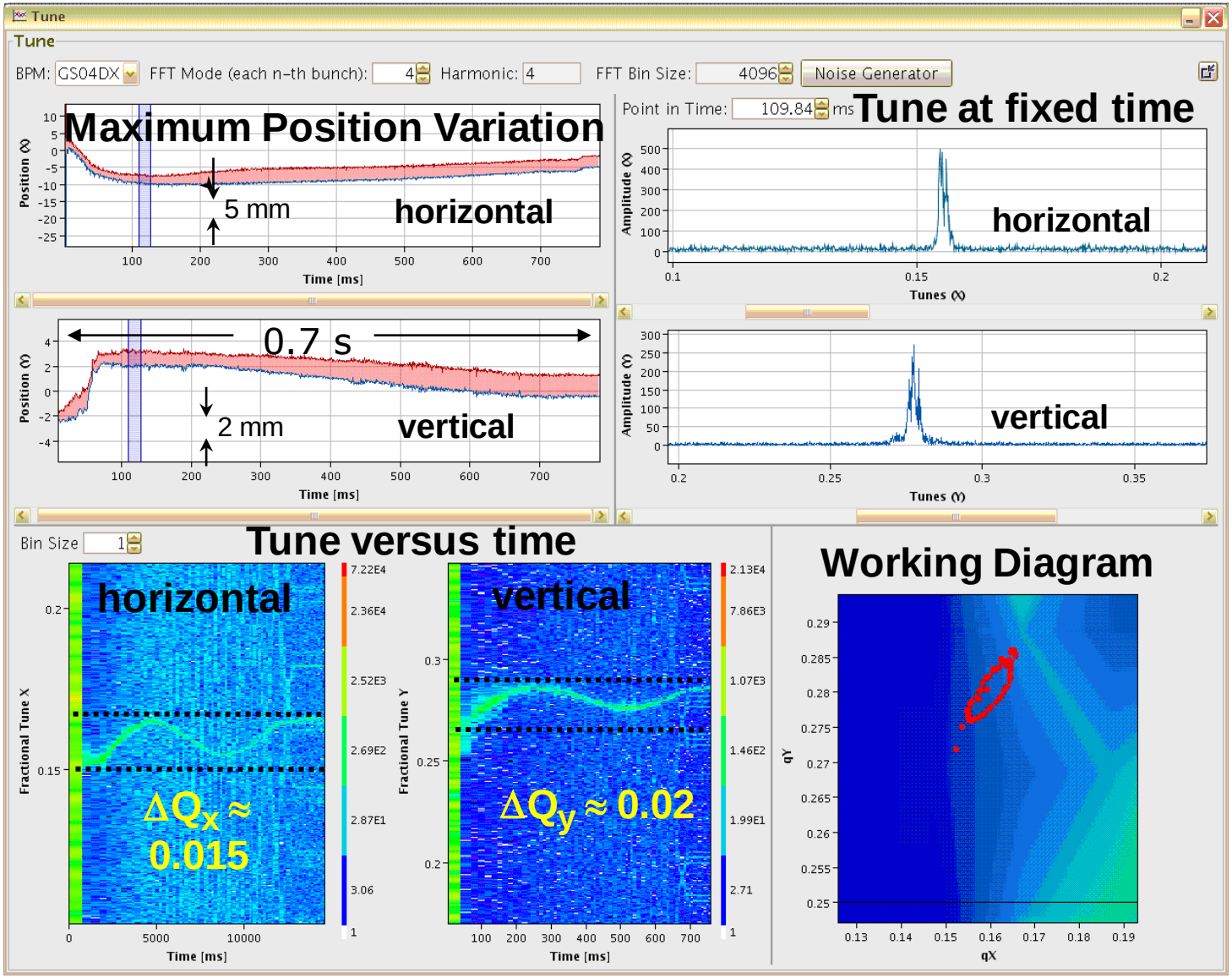
Results

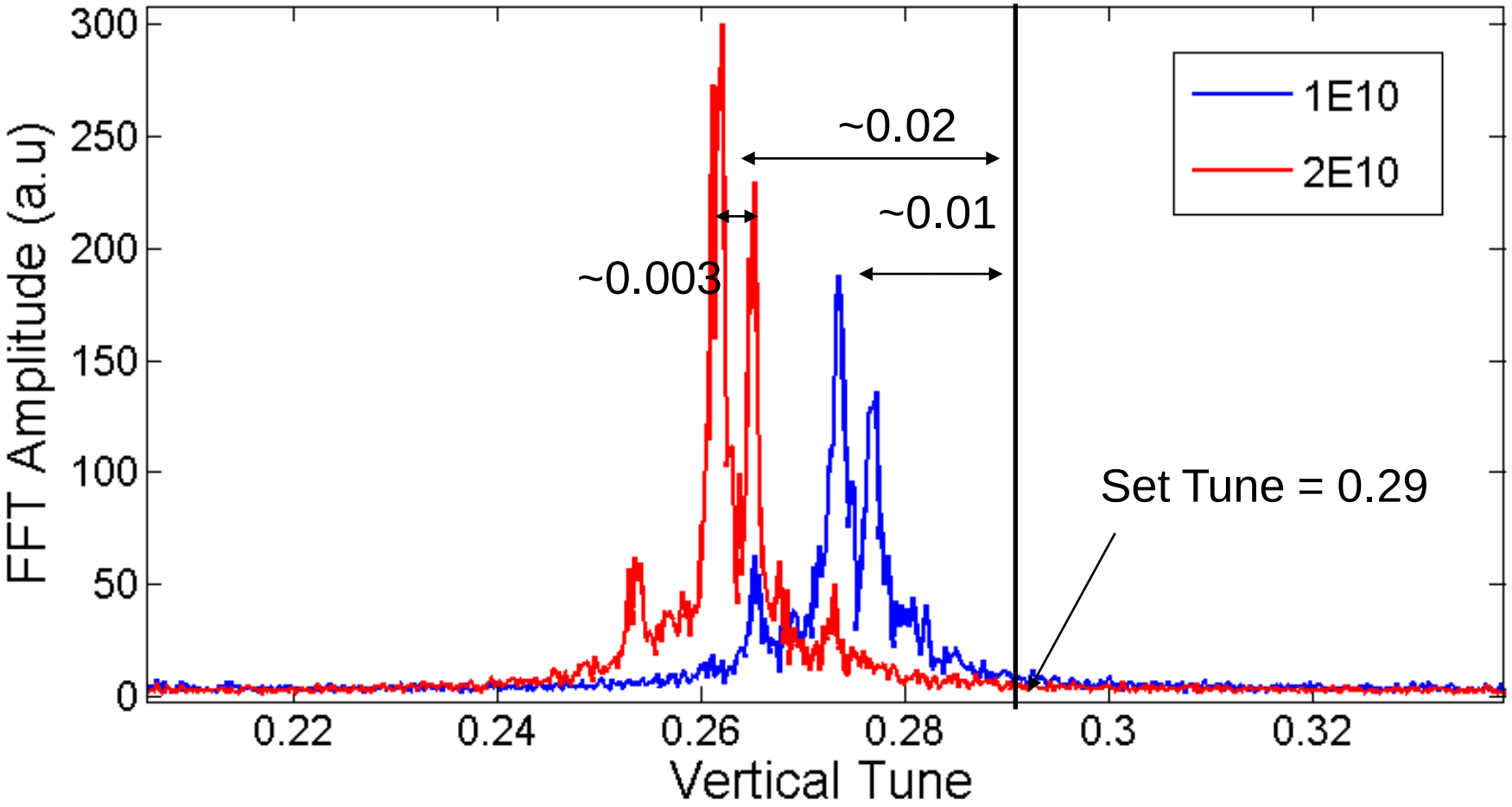
- Online tune measurements on acceleration ramp to observe the tune while changing optics
- Tune measurements at high intensity at injection energies to observe the coherent tune shift
- Tune measurements for determination of higher order resonances or the non linear components of magnetic fields

Tune Measurement on Ramp



- Tune measurement on Ramp
- Tune movement due to change in optics from triplet to doublet focussing

High Beam Intensity Effect on Tune

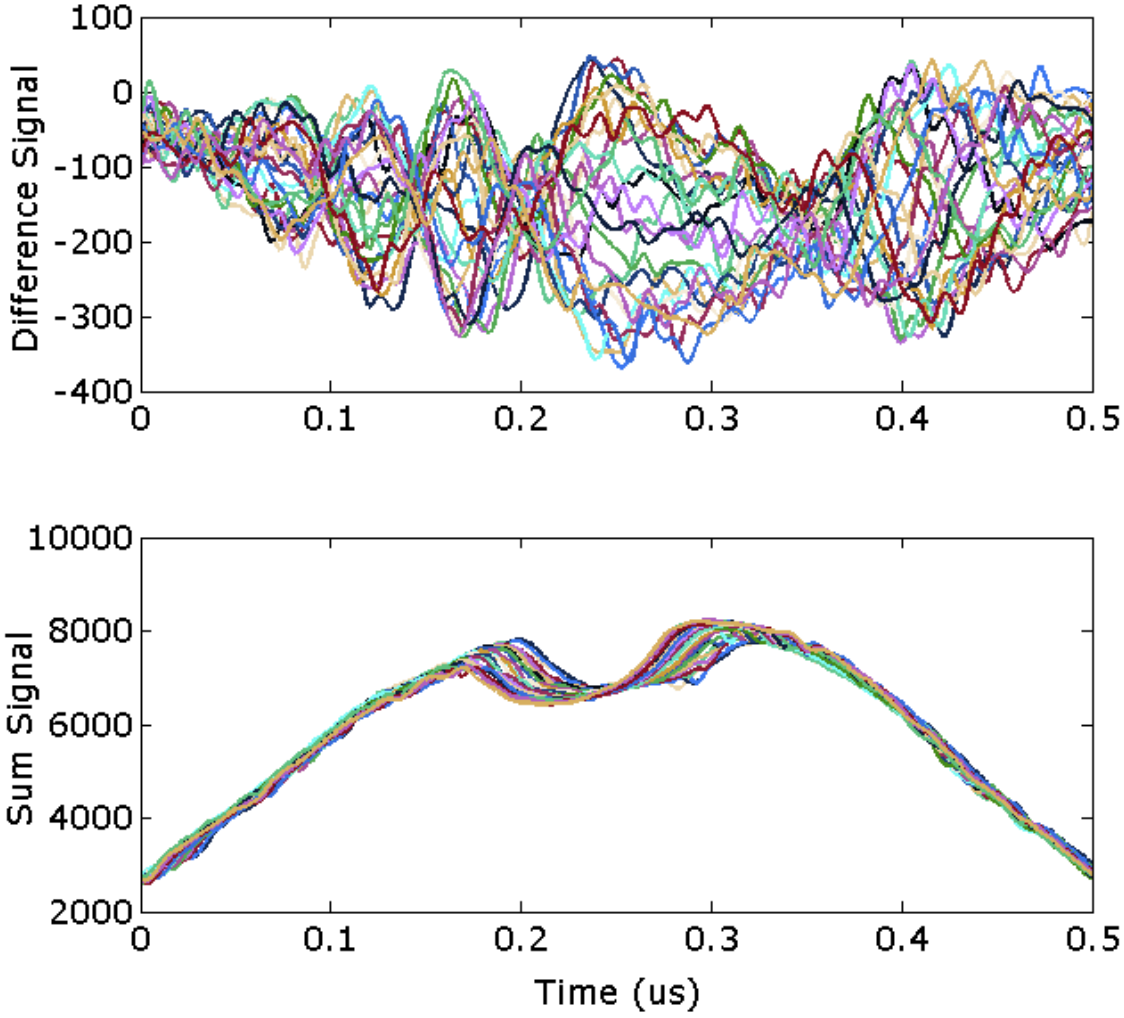


- Ar18+
- 11 MeV
- 600 ms

- Coherent tune shift in dependence of current visible.
- The various peaks in the spectrum are attributed to intra-bunch motion due to space charge, not well understood.

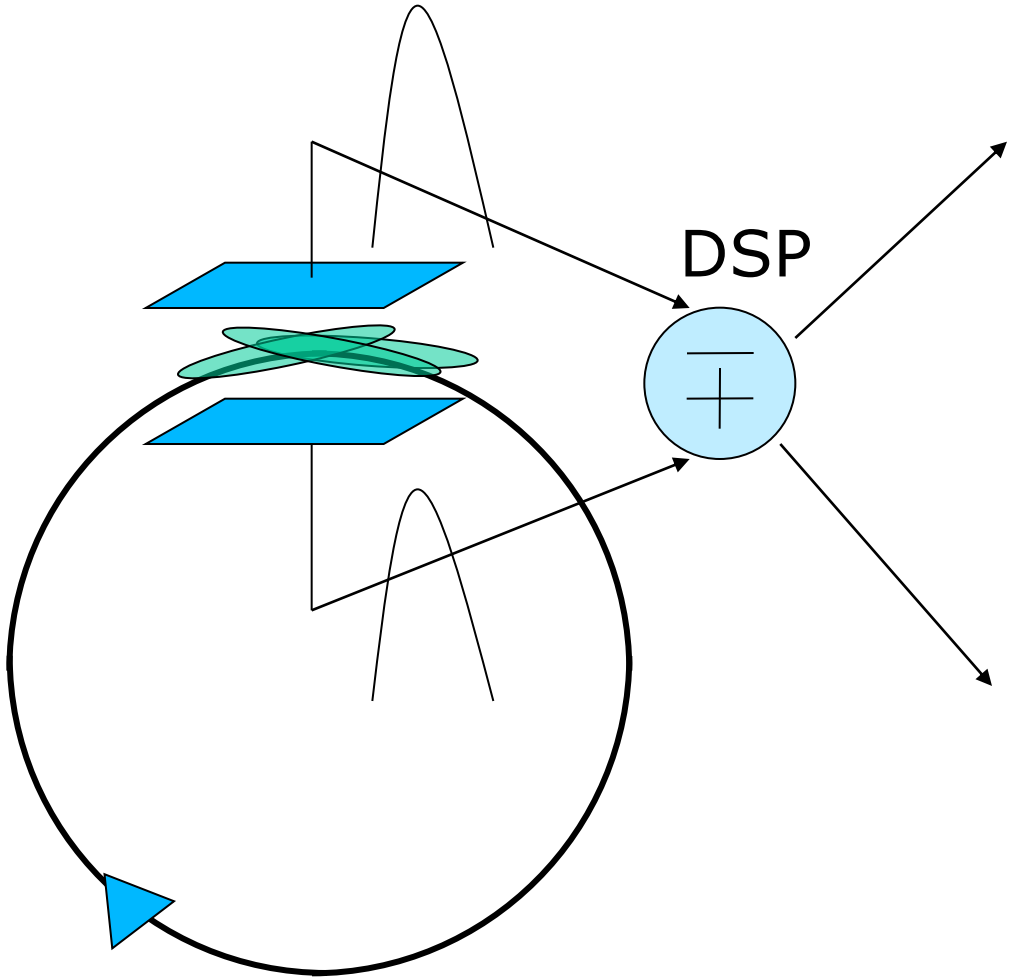
Intra Bunch Motion at High Intensity

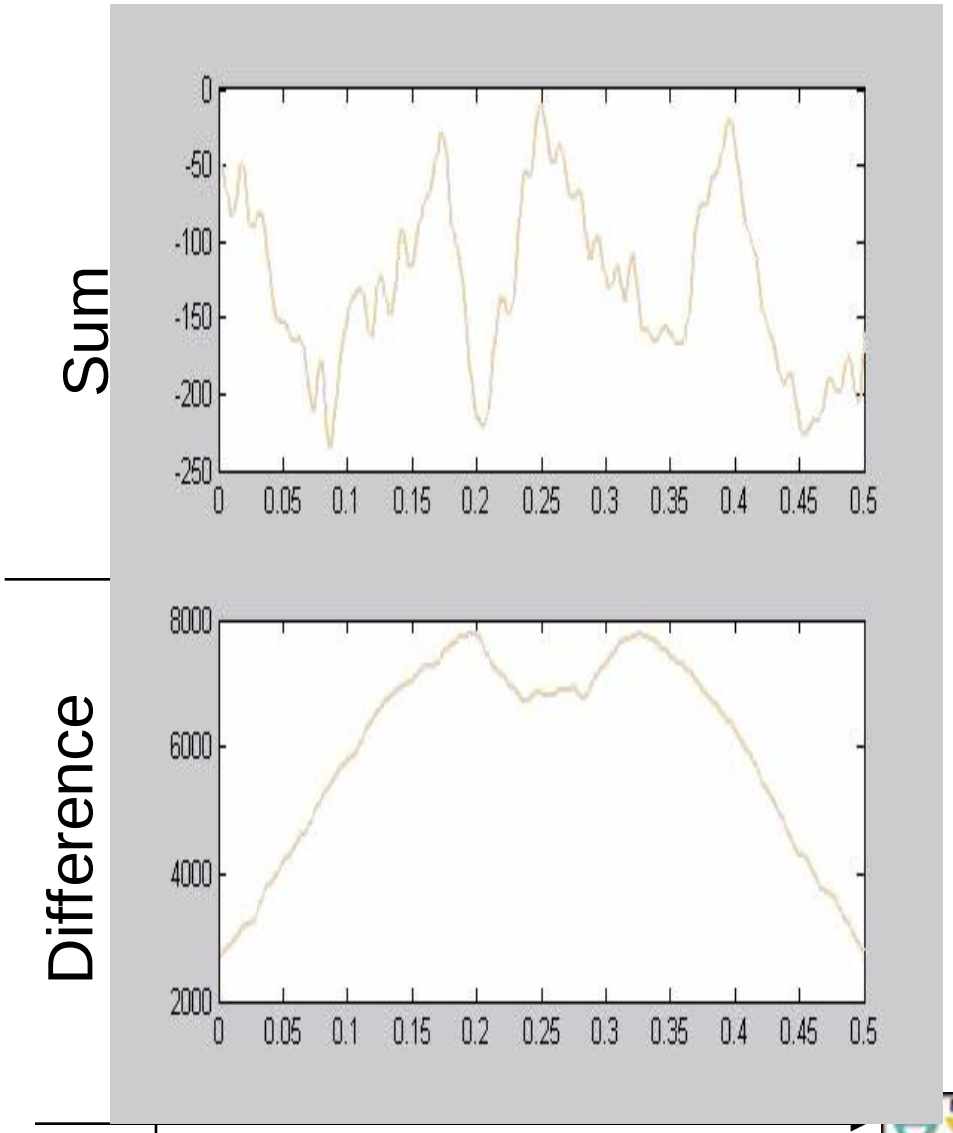
- No of stored Ar^{18+} Ions ~ 2e10
- Energy = 11.4 MeV/u
- F_{rev} = 214.5 KHz
- Excitation ~ 1mW/Hz
- Intra bunch oscillations i.e Head tail modes
- These effects are very important in view of FAIR



Bunch Length (μs)

Intra Bunch Movement





Conclusions

- Two parallel working tune measurement systems
- TOPOS offers opportunities for detailed beam investigations
- Insight into the beam physics at SIS-18

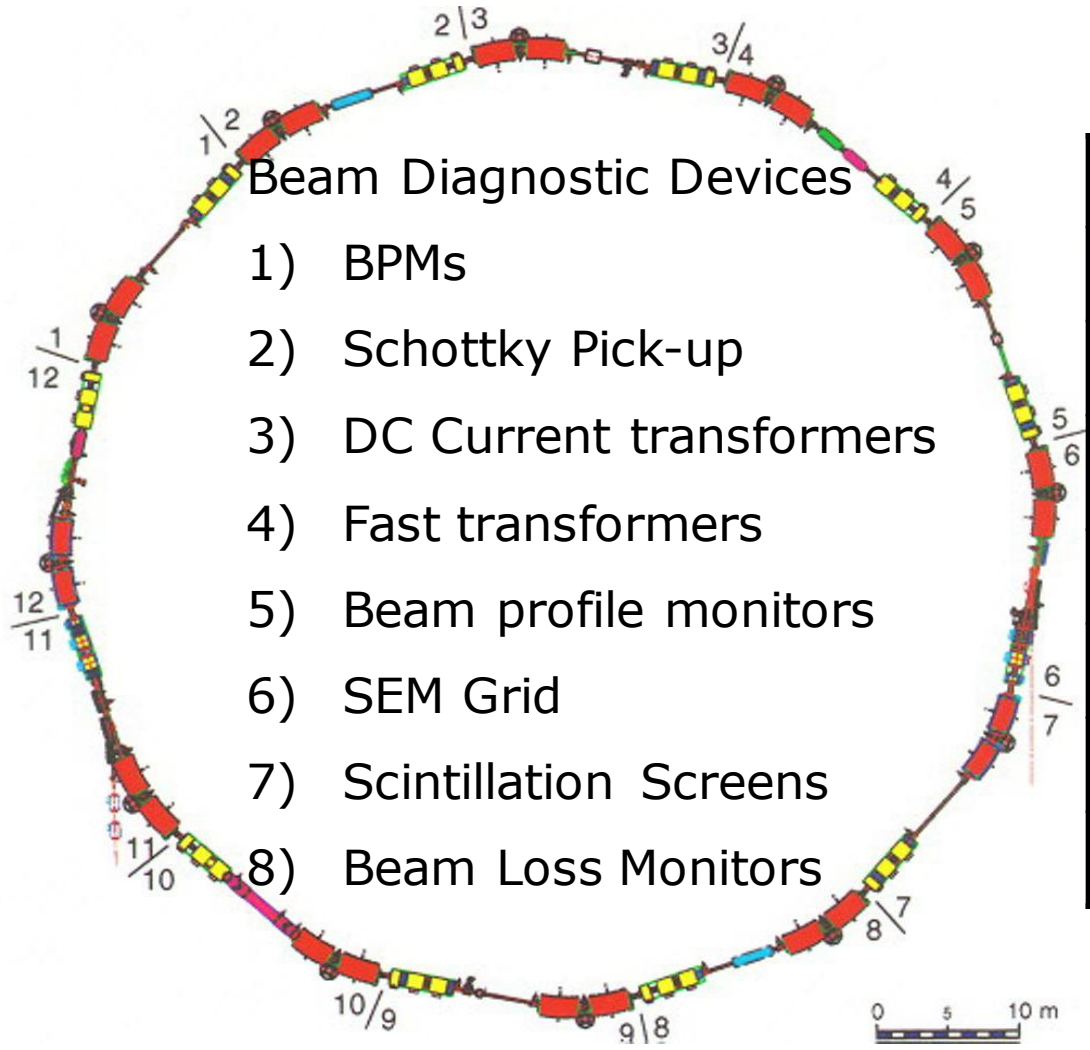
Acknowledgement

- European ITN- DITANET for funding the work and associated people to provide this opportunity
- CERN BI group especially M. Gasior for help on BBQ system
- Highly Supportive Beam Diagnostics Group at GSI

Thanks for attention! Questions?

Extra Slides

GSI SIS-18 Synchrotron



Beam Diagnostic Devices

1) BPMs
2) Schottky Pick-up
3) DC Current transformers
4) Fast transformers
5) Beam profile monitors
6) SEM Grid
7) Scintillation Screens
8) Beam Loss Monitors

Important parameters of SIS-18

Circumference	216 m
Inj. type	Multiturn
Energy range	11 MeV → 2 GeV
Acc.RF	0.8 → 5 MHz
Harmonic number	4 (no. of bunches)
Bunching factor	0.6 → 0.2
Ramp duration	0.06 → 1.5 s
Ion range (Z)	1 → 92 (p to U)

Opportunities

- Make a user friendly interactive system to determine Position/ tune/ bunch movements in real time
- Position calculation algorithms robust to beam conditions, bunch mismatch etc.
- Test and understand the limits of both TOPOS and BBQ systems

Tune Orbit and Position measurement system (TOPOS)

Tunable Pseudo Random Noise Generator

Stripline Line Exciter (50W Max.)

Shoe-Box BPM with high impedance termination

Fast ADCs with 125 MSa/s to digitize the BPM signals

Real time evaluation of BPM signals to calculate position of the bunches*

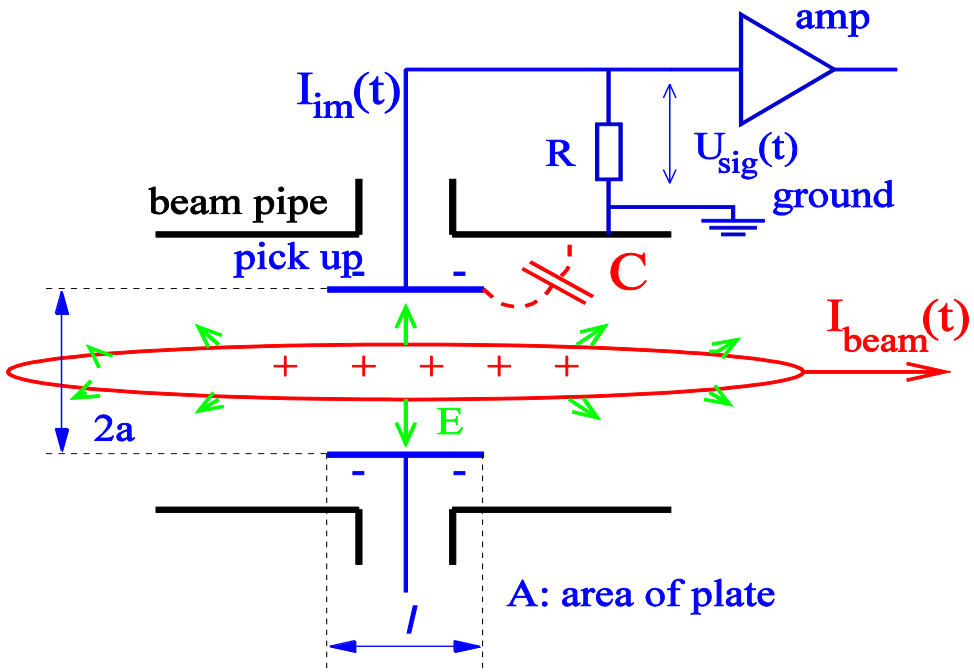
Position data transfer to the concentration servers for each BPM

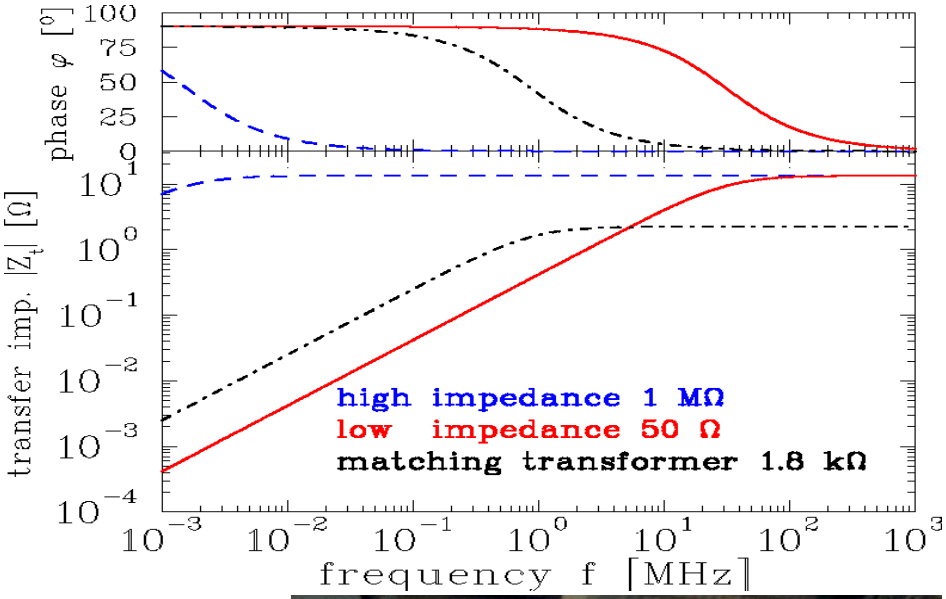
FFT of the beam position to acquire tune

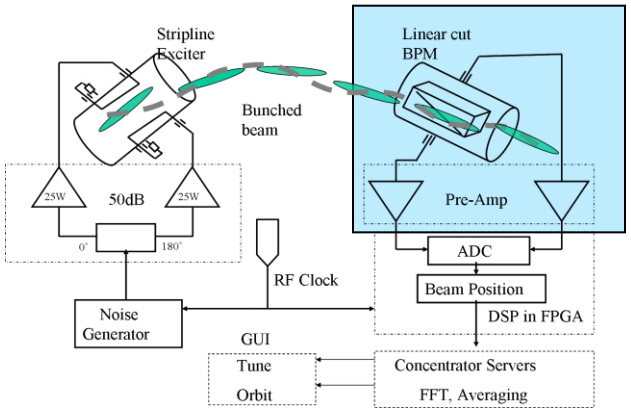
Display of tune and closed orbit in the control room

*Possibility to acquire raw bunch signals from all BPM plates simultaneously.

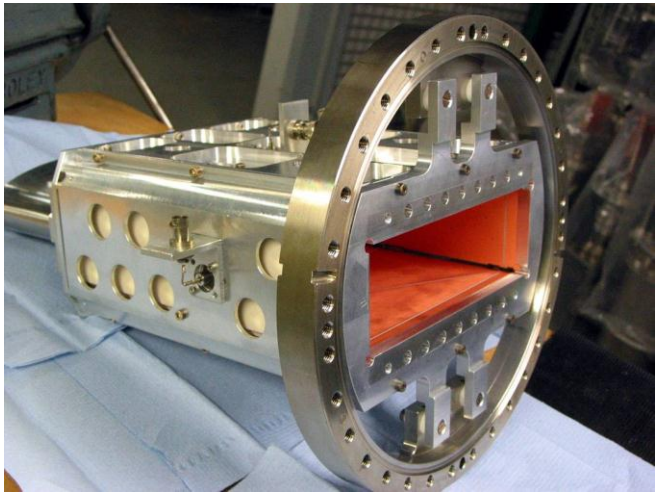
Shoe-Box BPMs







- Linear spatial sensitivity
- High pass with high input impedance of amplifier



What does sensitivity numbers mean?

How much sensitivity in terms on spatial oscillations?

- Output of BBQ = 10mVpp noise
- Input of BBQ = 100 uVpp noise
- Due to 1024 point FFT ~ 10 uVpp oscillation
- Assuming same sensitivity as shoebox = 10 um oscillations are visible (depends on current level), since only difference signal is treated

Tune Shifts

Number of stored Particles	1E10	2E10
Chromatic Tune Spread	~5E-03	~5E-03
Horizontal peak incoherent tuneshift	-0.0142	-0.0221
Vertical peak incoherent tuneshift	-0.0280	-0.0437
Horizontal coherent tuneshift (Expected)	-0.0020	-0.0040
Vertical coherent tuneshift (Expected)	-0.0115	-0.0211
Vertical coherent tuneshift (Measured)	**-0.012**	**-0.022**

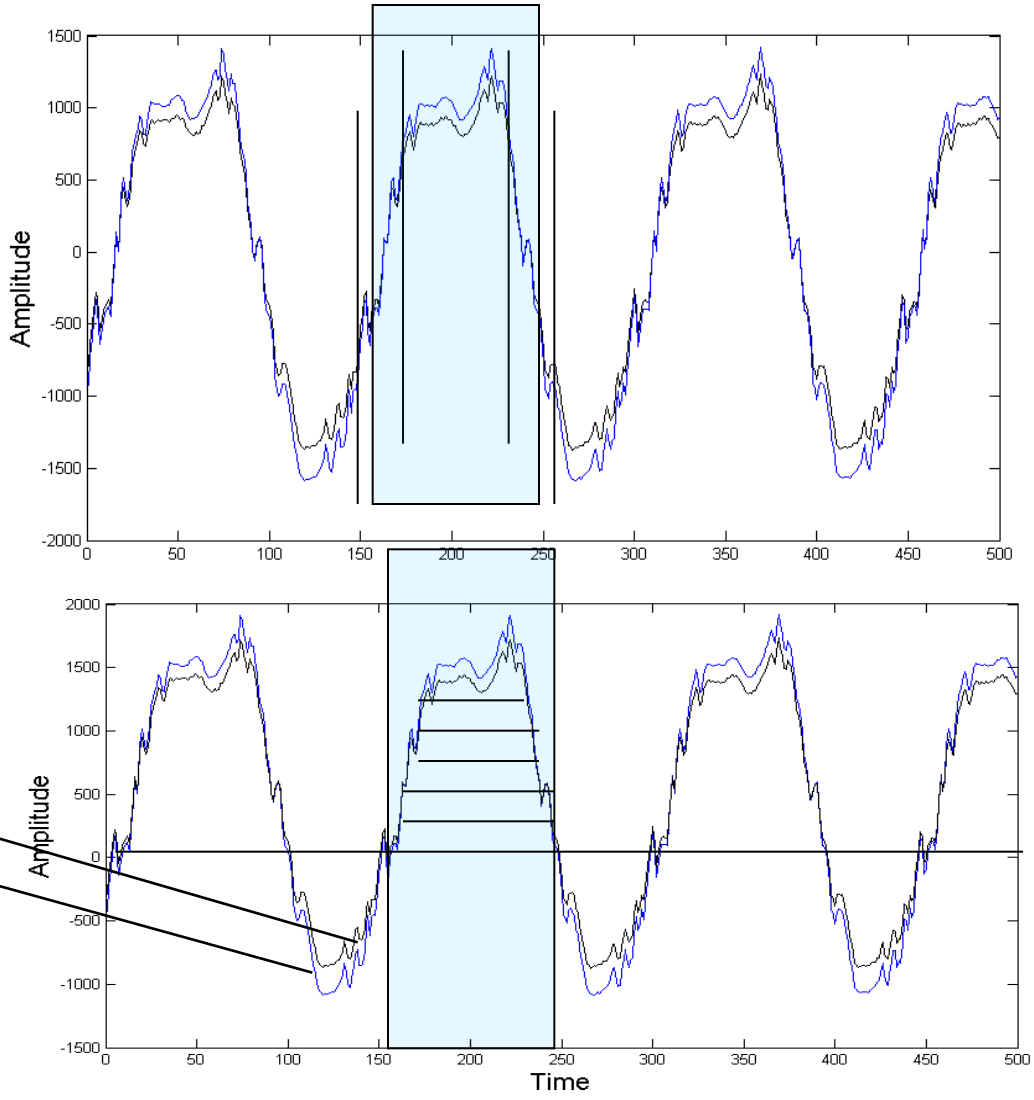
Algorithm for position calculation

Present algorithm :

Does the following steps on both upper and lower BPM plate

- Identifying bunches using double threshold algorithm.
- Finds appropriate windows
- Shifts the baseline inside the windows
- Integrates the values inside the windows

Calculates the position using
(X+) - (X-)/ (X+) + (X-)



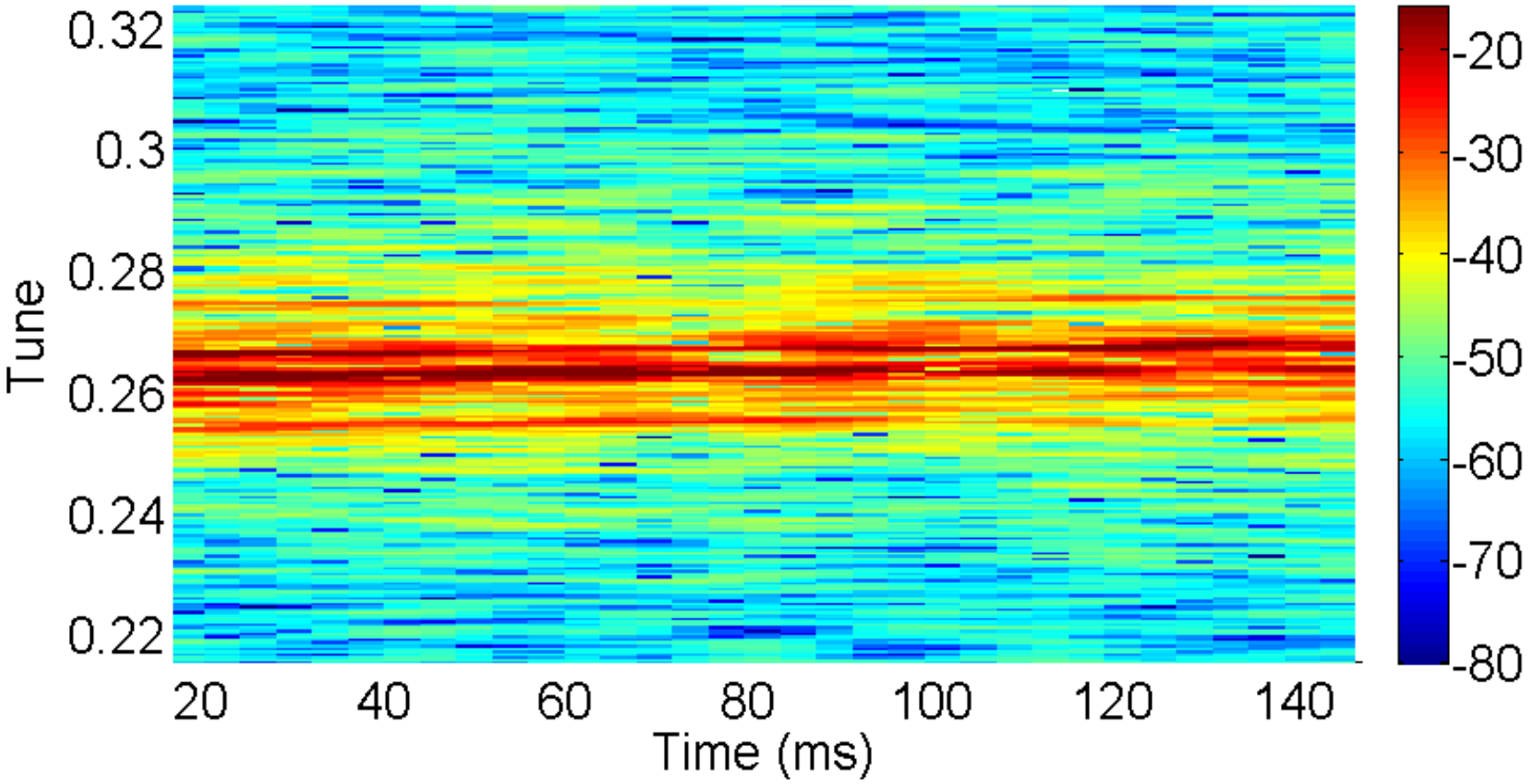
Beam Parameters during experiment

Parameter name	Typical Value	Units
Atomic Mass	40	
Charge State	18	
Energy per nucleon	1.14E+01	MeV/u
rms x size (radius)	1.50E-02	m
rms y size (radius)	1.20E-02	m
rms z size (bunch length)	5.00E-07	m
Accelerator radius	3.44E+01	m
Horizontal tune	4.16E+00	
Vertical tune	3.29E+00	
RF Harmonics	4.00E+00	
RF Voltage	4.00E+03	V
Particles in one bunch	5.00E+09	
Natural Chromaticity	-1.30E+00	
Radius of vacuum pipe (x,y)	0.1, 0.035	m

Beam Parameters 2

Magnetic Rigidity	1.08E+00	T-m
Betatron beta x	8.27E+00	m
Betatron beta y	1.05E+01	m
Relativistic gamma	1.01E+00	
Revolution time	4.60E-06	s
Relativistic beta	1.54E-01	
Slip Factor	1.02E+00	
Average current in the ring	1.25E-02	A
Peak current in a bunch	3.73E-02	A
Total particles in the ring	2.00E+10	
Total charge int the ring	5.76E-08	C
Synchrotron tune	7.54E-03	
Bunching factor	3.5E-01	
Horizontal emittance EH(2s)	2.72E+01	mm-mrad
Vertical emittance EV(2s)	1.38E+01	mm-mrad
Rms momentum spread	1.5E-03	

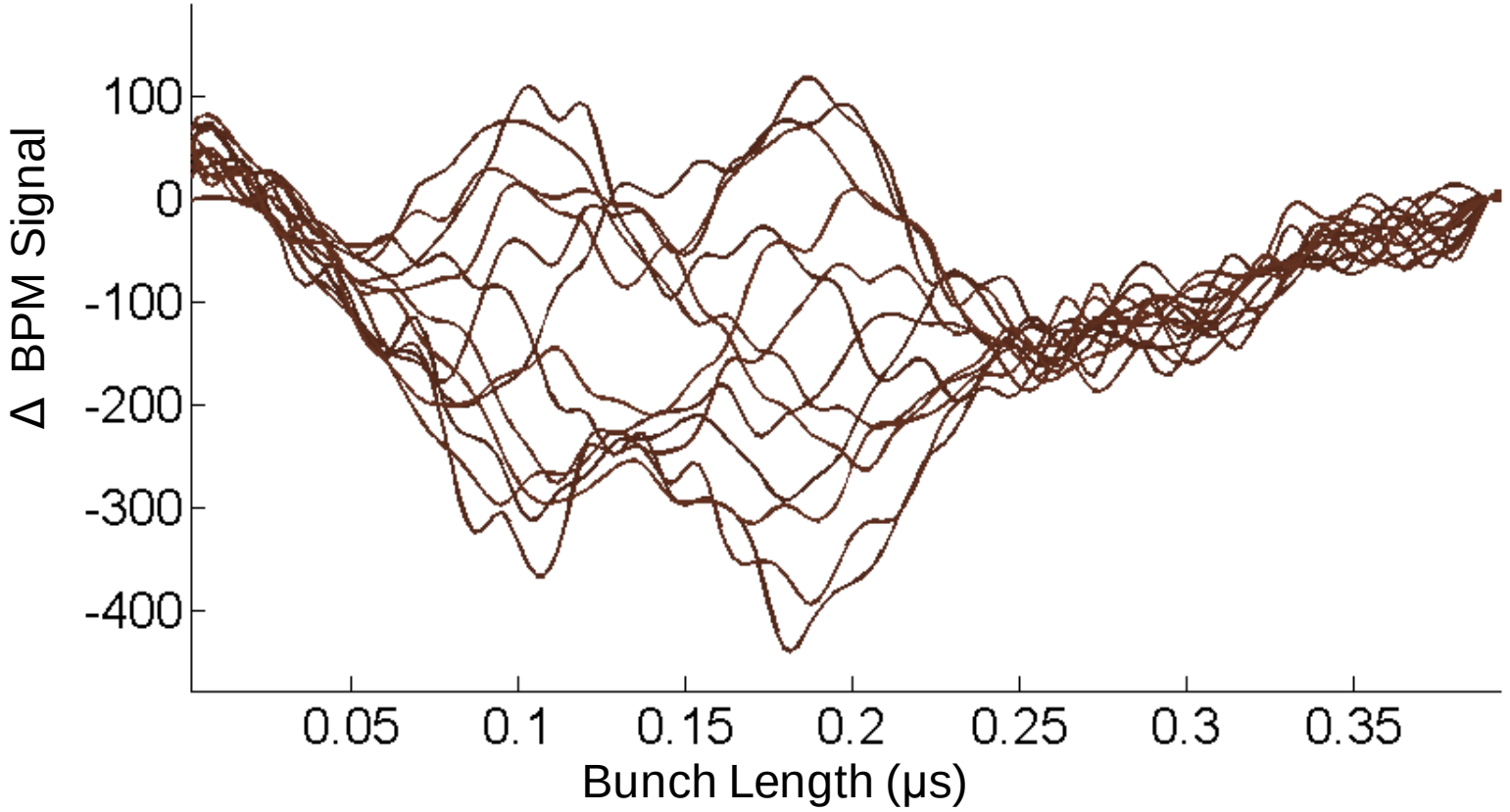
High Current Tune Spectrogram



Number of stored Ions ~ 2e10

Spectra changing with time!

Intra bunch motion – Acceleration

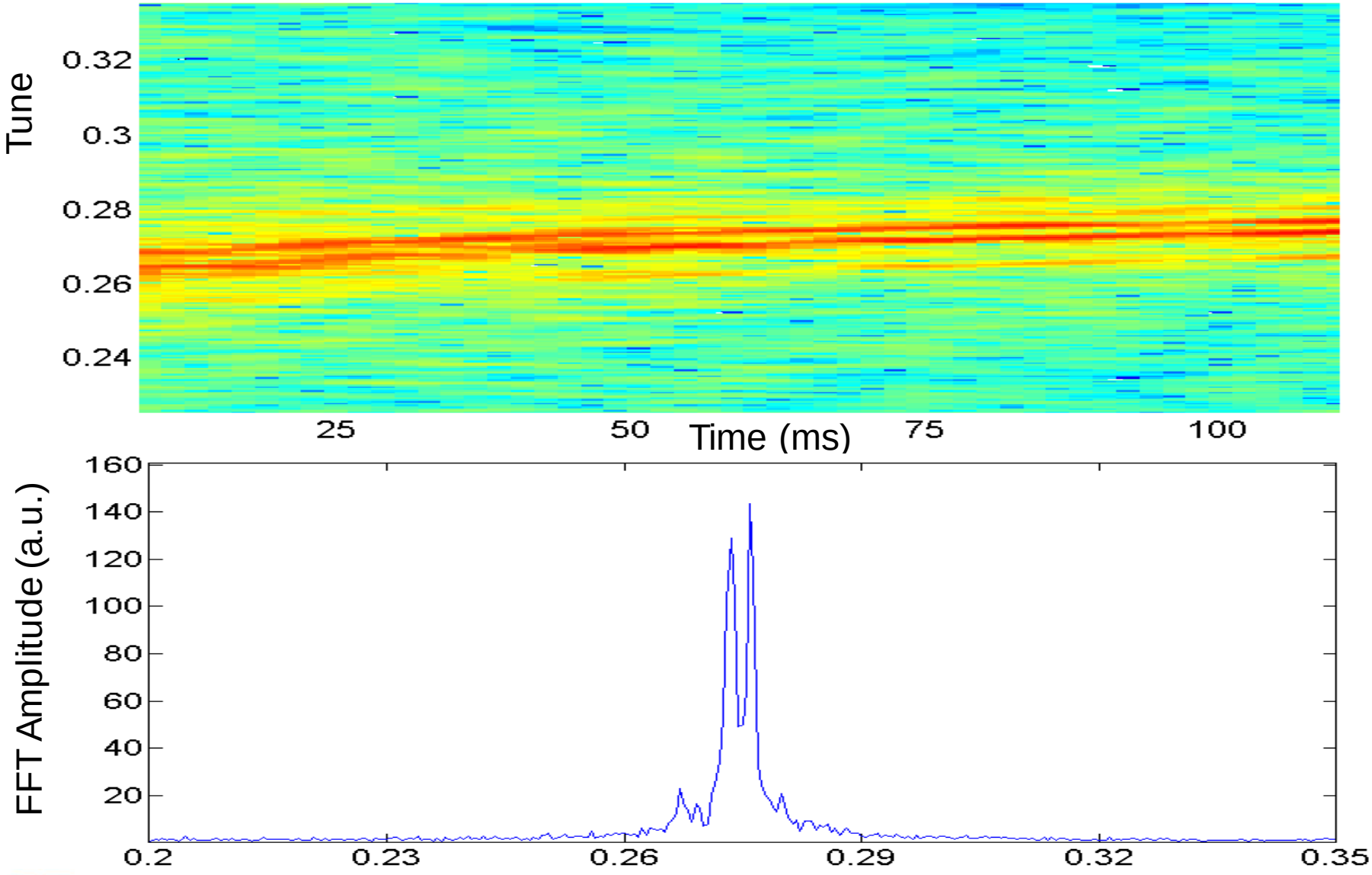


Beam parameter: Ar^{18+} acc. 11 → 300 MeV/u within 0.7 s

Number of stored Ions → 2E10

Excitation → 1mW/Hz

Tune Spectra during acceleration



Effect of excitation on tune spectra