Numerical Methods for Beam Position Evaluation at GSI

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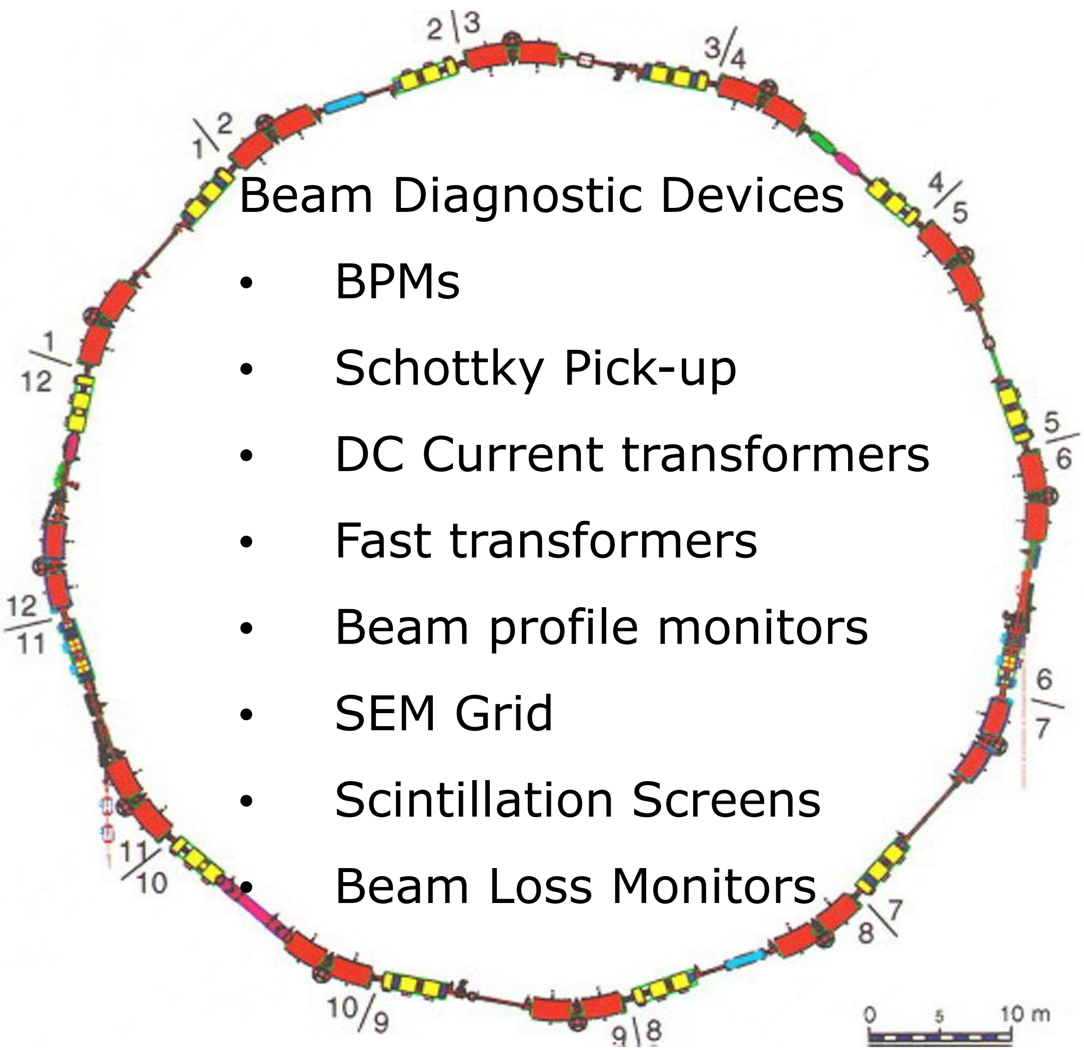
Outline

- Introduction
- Position Measurement System at GSI
- Position Evaluation Methods
  - ➢ Bunch Detection
  - ➢ Bunch Signal Processing
- Summary

GSI SIS-18 Synchrotron



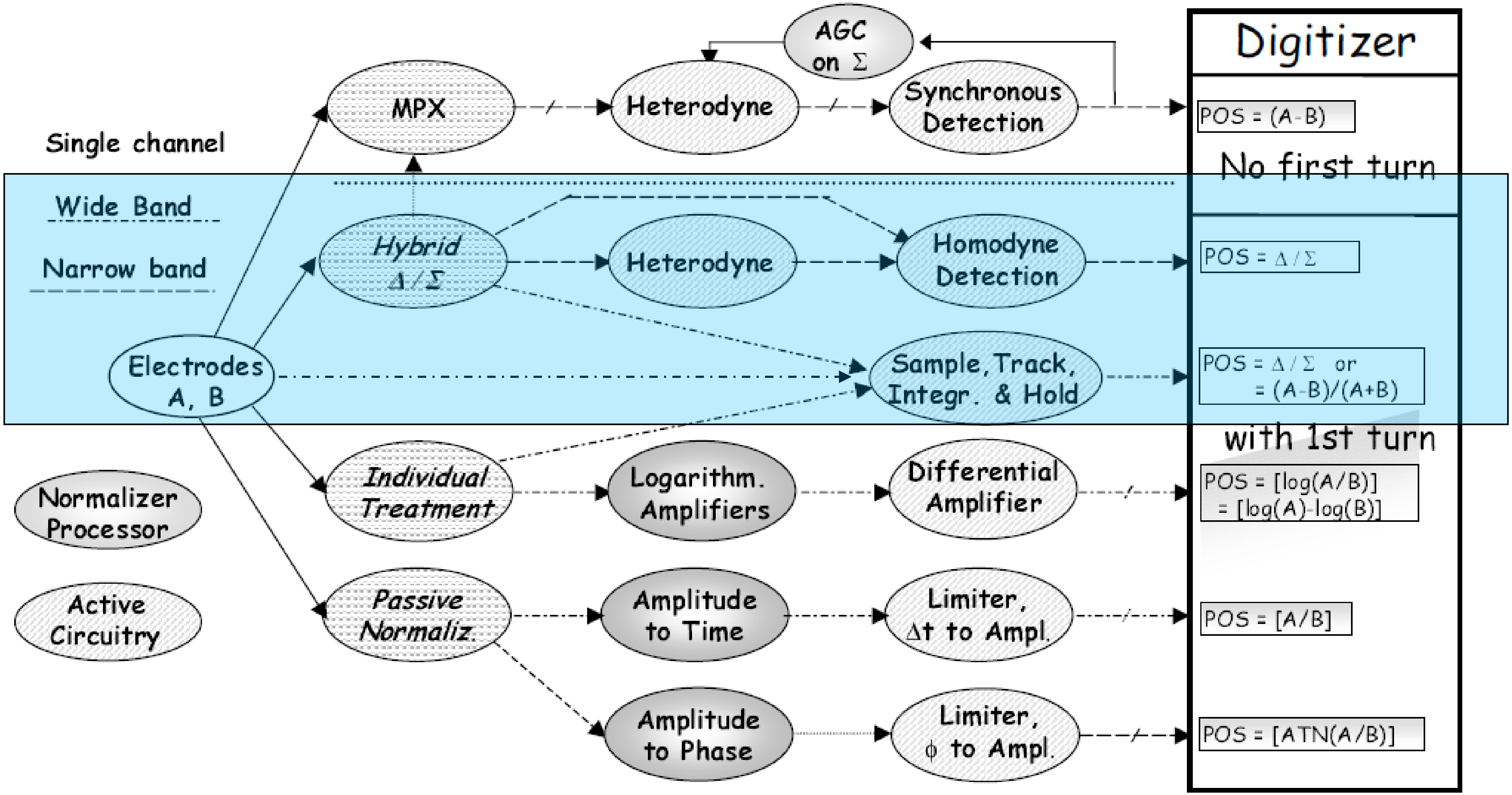
Beam Diagnostic Devices

- BPMs
- Schottky Pick-up
- DC Current transformers
- Fast transformers
- Beam profile monitors
- SEM Grid
- Scintillation Screens
- Beam Loss Monitors

Important parameters of SIS-18

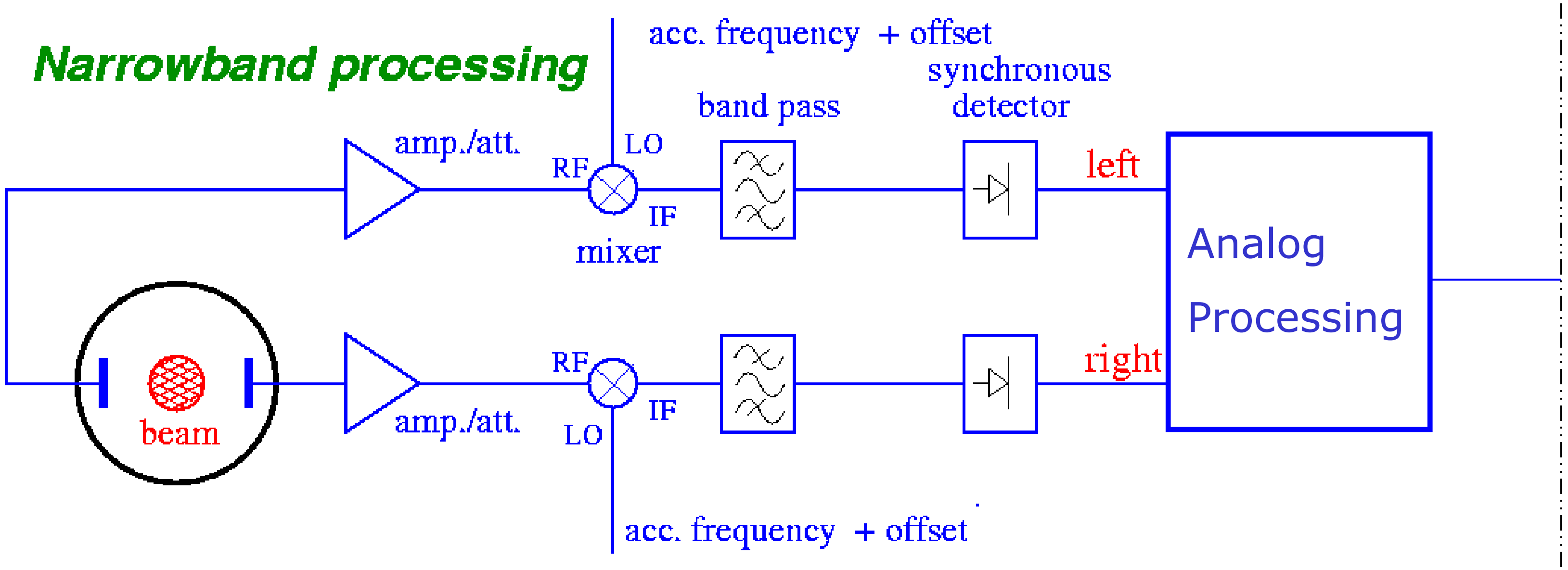
Circumference	216 m
Inj. type	Multiturn
Energy range	11 MeV → 2 GeV
Acc.RF	0.8 → 5 MHz
Harmonic number	4 (no. of bunches)
Bunching factor	0.6 → 0.2
Ramp duration	0.06 → 1.5 s
Ion range (Z)	1 → 92 (p to U)

Position Measurement Methods

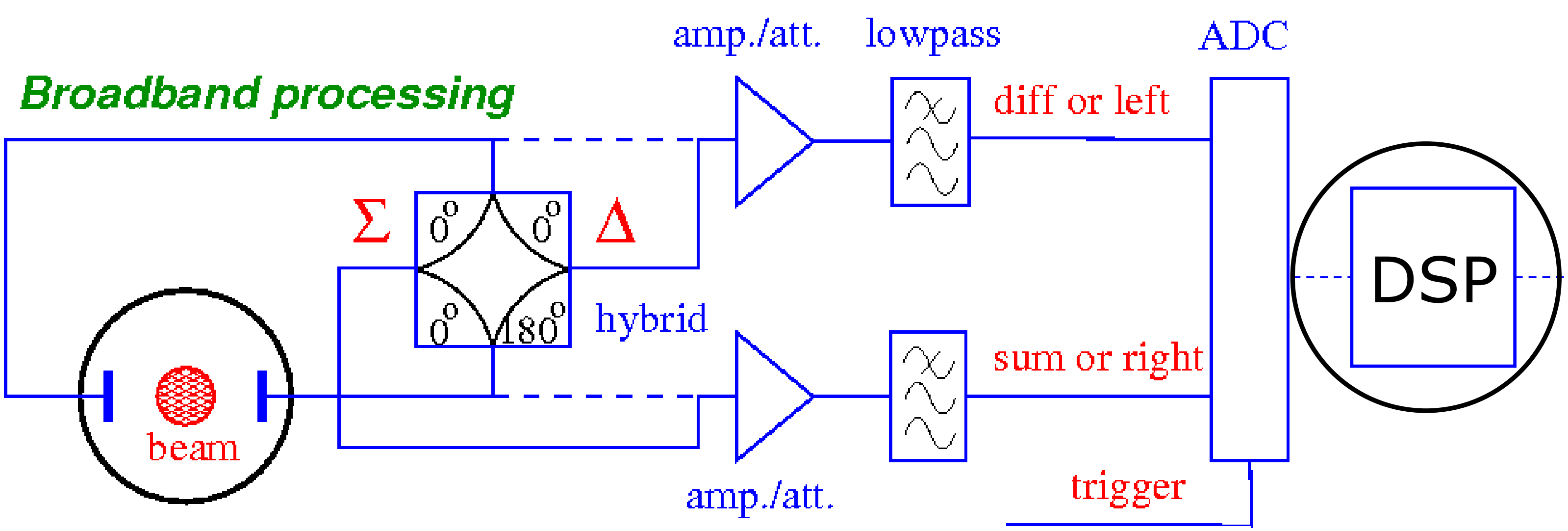


G. Vismara : DSM for BPM, BIW 2000

Position Measurement Principle at GSI



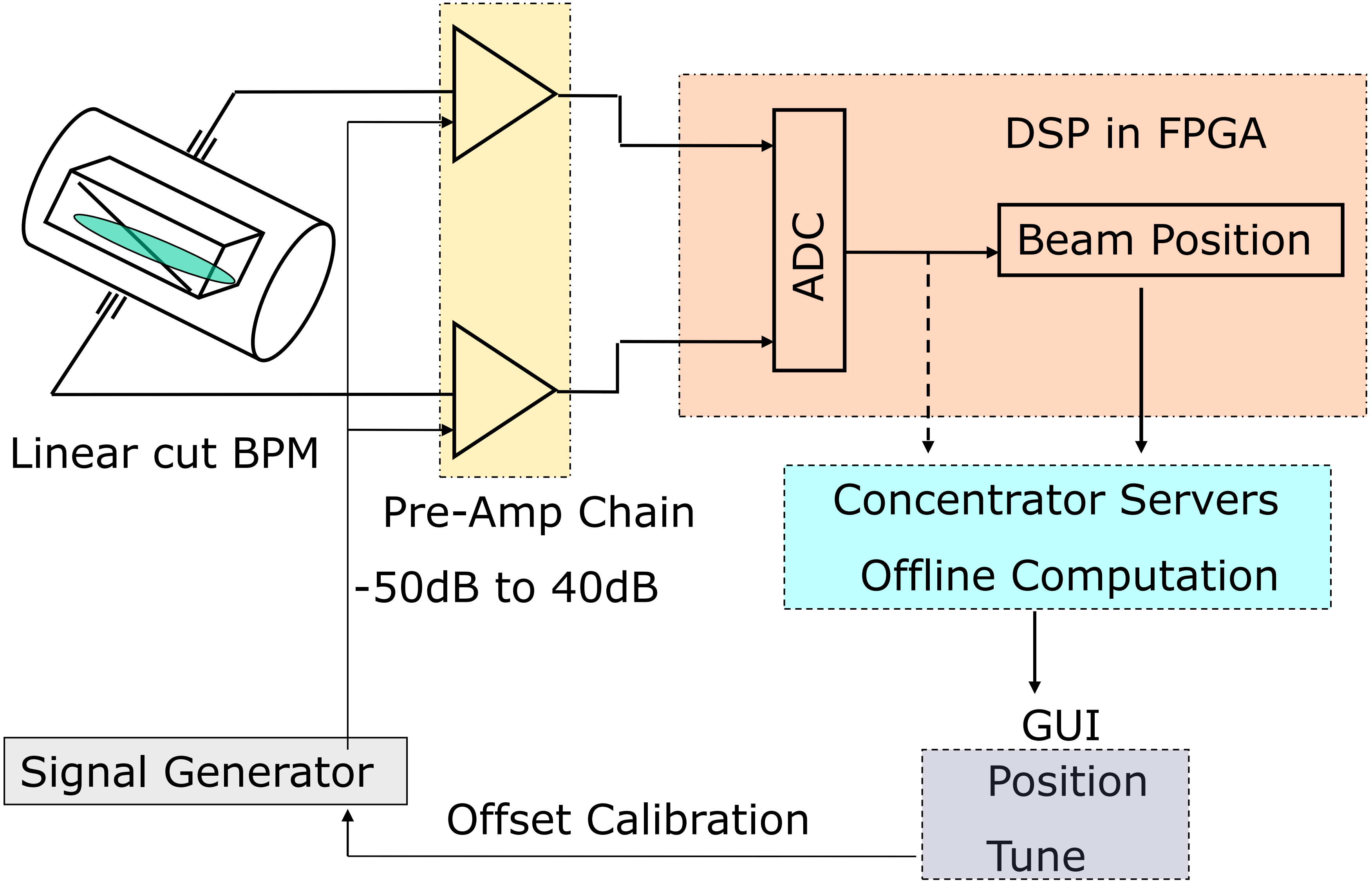
Orbit



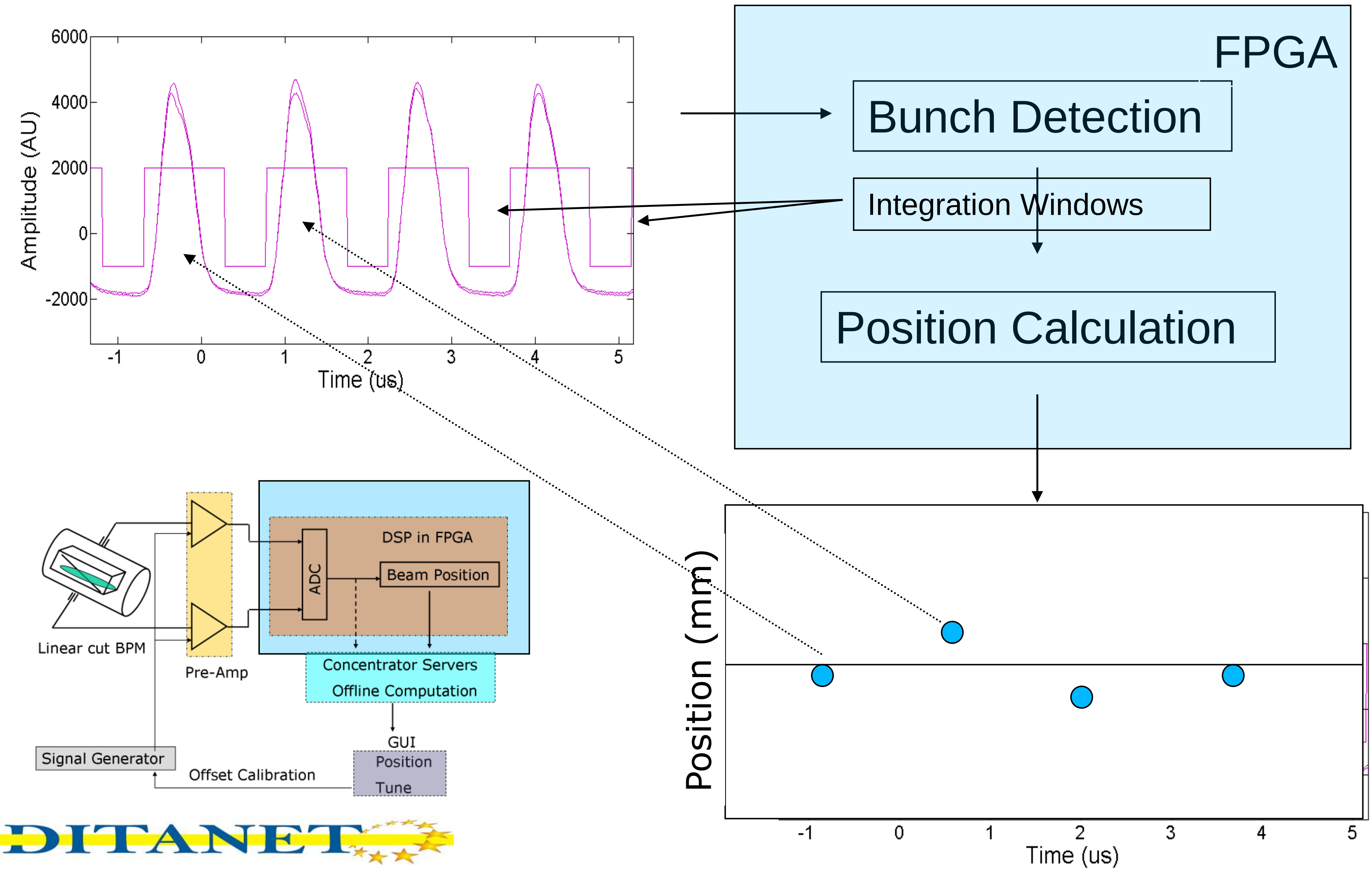
Bunch by Bunch Position

- Flexible System
- Trajectory
- Tune
- Orbit

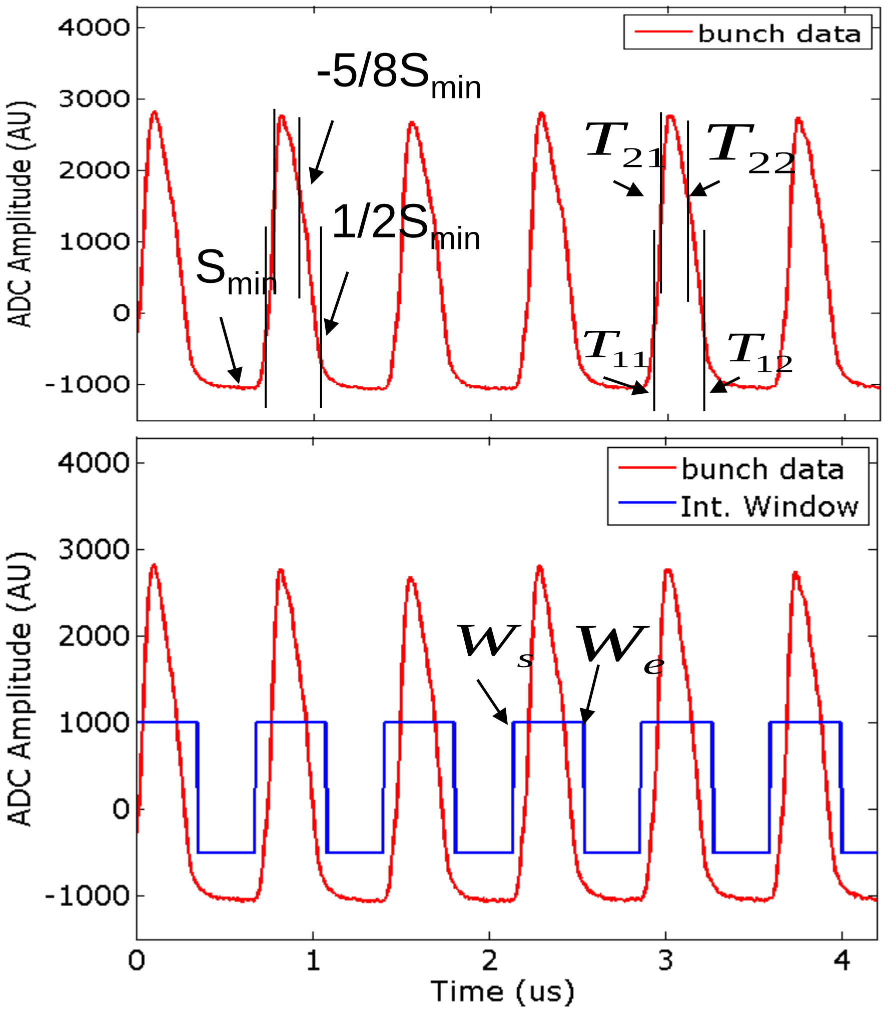
Digital Position Measurement System (TOPOS)



Position Calculation in FPGA



Bunch Detection- Double Threshold Algorithm



1) A minimum is found between two adjacent bunches.
2) Using the minimum level S_{min} two thresholds are calculated at $T_{1(1,2)} = \frac{1}{2} S_{min}$ and $T_{2(1,2)} = -\frac{5}{8} S_{min}$
3) When the bunch signal passes through all these thresholds, it is detected.
4) Time window for the bunch is calculated which is passed to position evaluation part of the algorithm.

$$W_{sn} = T_{11} - (T_{21} - T_{11})$$

$$W_{en} = T_{12} + (T_{12} - T_{22})$$

Bunch Signal Processing Algorithms

Characteristics :

- Fast : < 1μs
- Robust : Varying bunch lengths(500 ->100 ns), mismatch
- Minimize variance
- Unbiased : Should not add any offset

Methods :

- Baseline restoration and $\frac{\Delta}{\Sigma}$
- Linear regression fit

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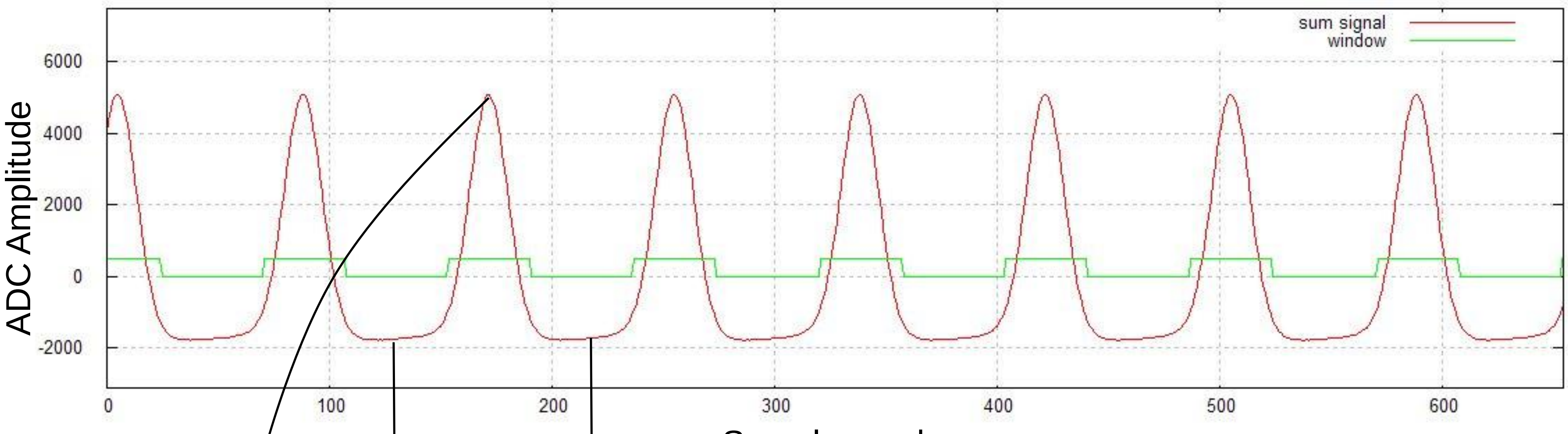
Baseline Restoration

Generated Gaussian Signal (1.5MHz period)



$$Rs_{ni} = R_{ni} - \frac{(R_{ni-N/2} + R_{ni+N/2})}{2}$$

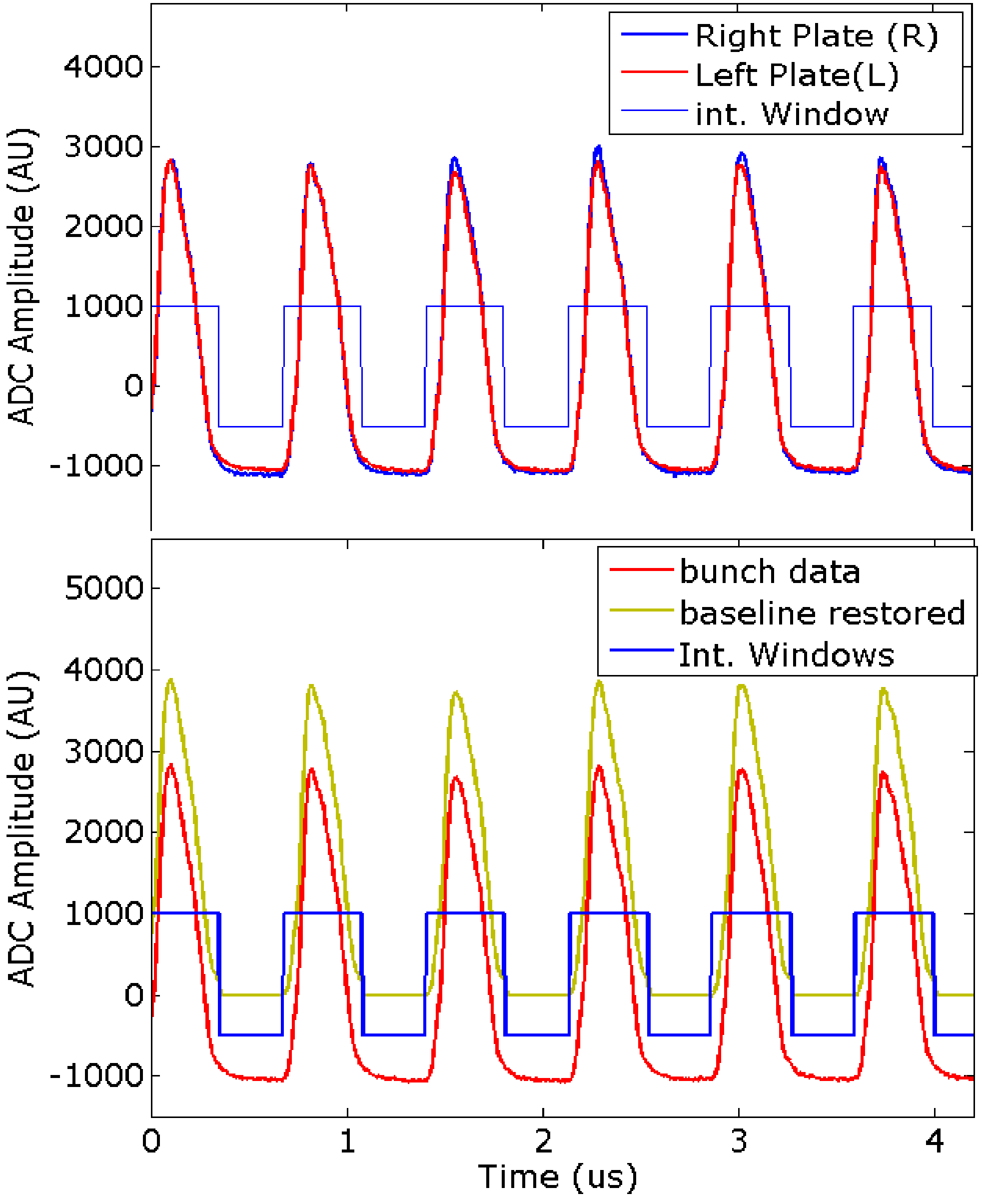
Max. period of T: 1.25µs (0.8KHz)

=> T/2 = 625ns = 79 samples

Baseline is calculated for each sample inside the integration window

* A. Galatis et al. DIPAC 2007

Baseline Restoration Algorithm



Let R_{ni} and L_{ni} be the signal of the nth bunch of both plates in the integration window of length *N* generated by bunch detection algorithm

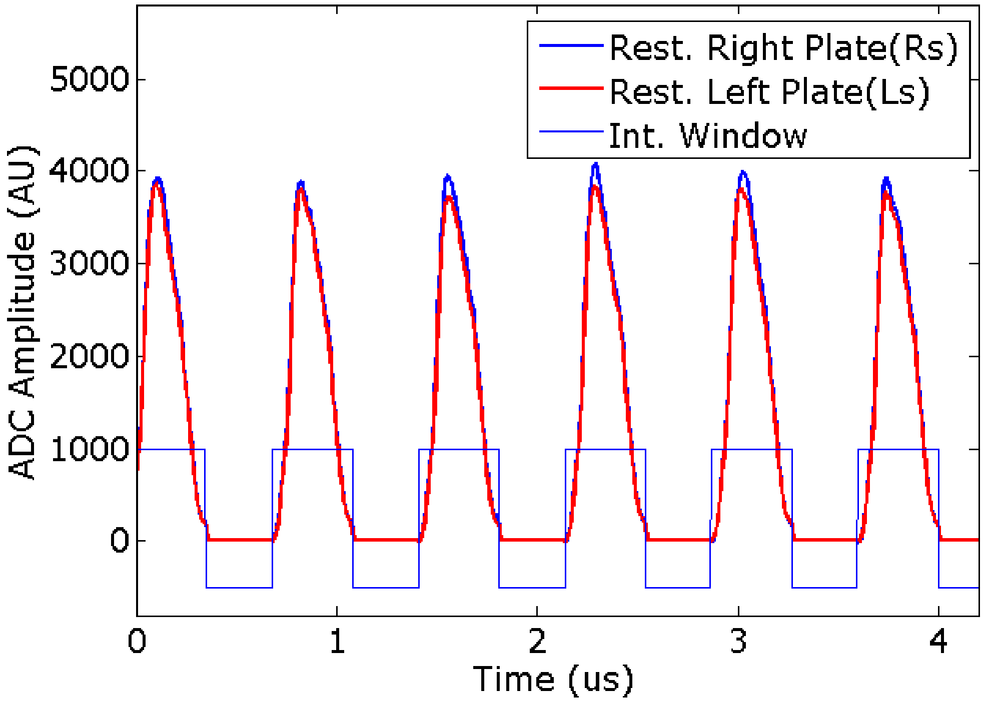
The steps in the algorithm for bunch n is :

1) The baseline for both the electrode signals is calculated and is given by br_{ni} and bl_{ni} respectively.

2) Add these baseline values to the original signal

$$Rs_{ni} = R_{ni} + br_{ni}; \quad Ls_{ni} = L_{ni} + bl_{ni};$$

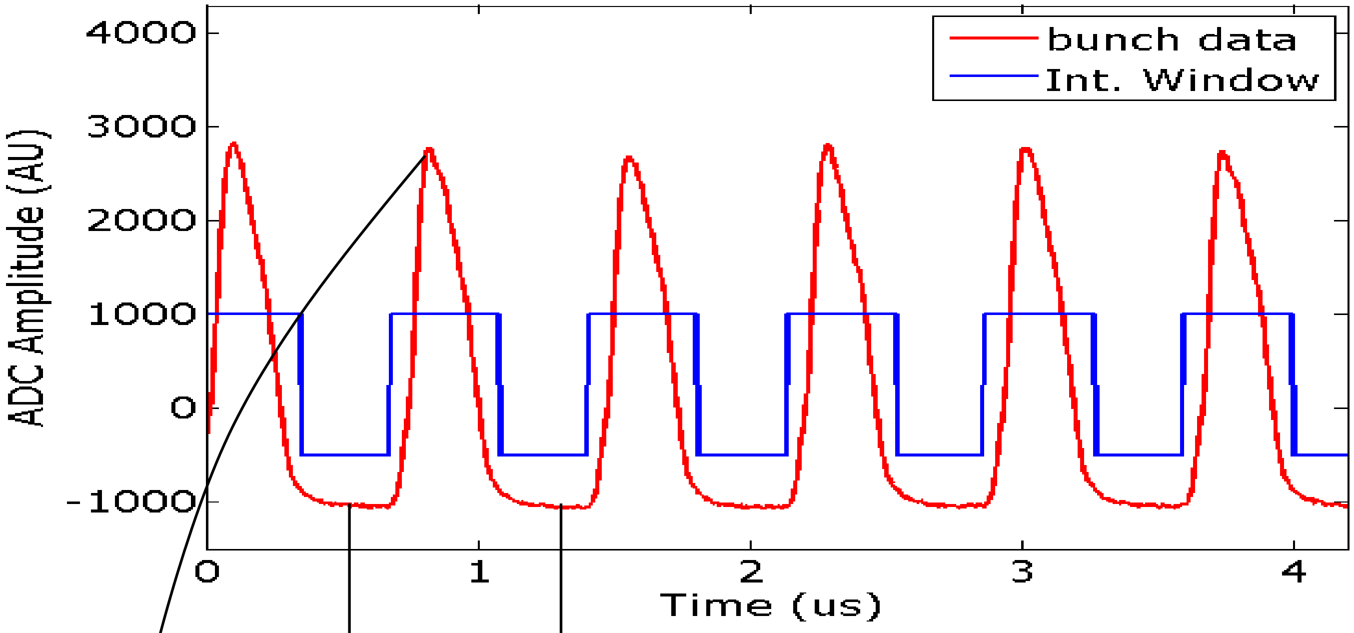
Baseline Restoration Algorithm



3) Integration of both plate signals and difference over sum

$$p_n \propto \frac{\sum_{i=W_{sn}}^{W_{en}} Rs_{ni} - Ls_{ni}}{\sum_{i=W_{sn}}^{W_{en}} Rs_{ni} + Ls_{ni}}$$

Baseline Restoration



$$Rs_{ni} = R_{ni} - \frac{(R_{ni-N/2} + R_{ni+N/2})}{2}$$

Problems!!

1) Issues with larger bunches at injection
2) Adds noise to the signal
3) High latency i.e takes 2/3 of total calculation time

Bunch Signal Processing Algorithms

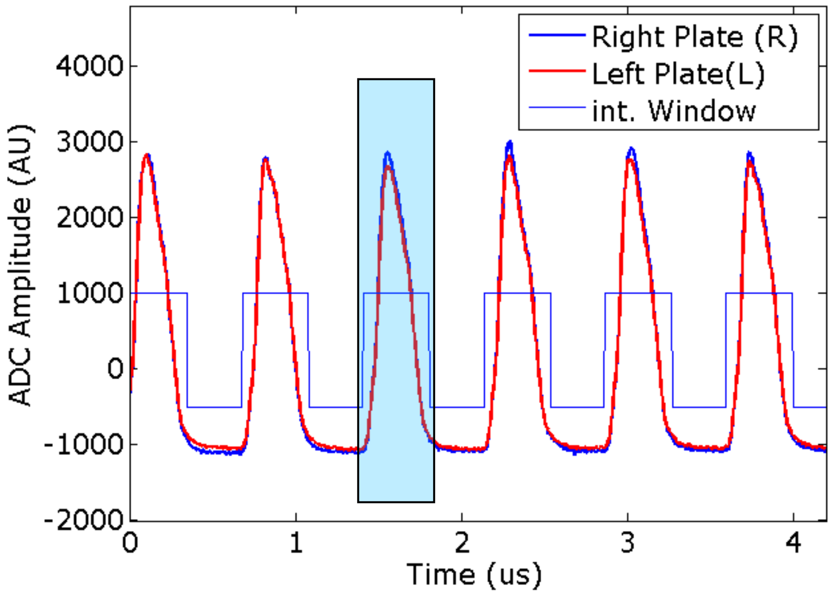
Characteristics :

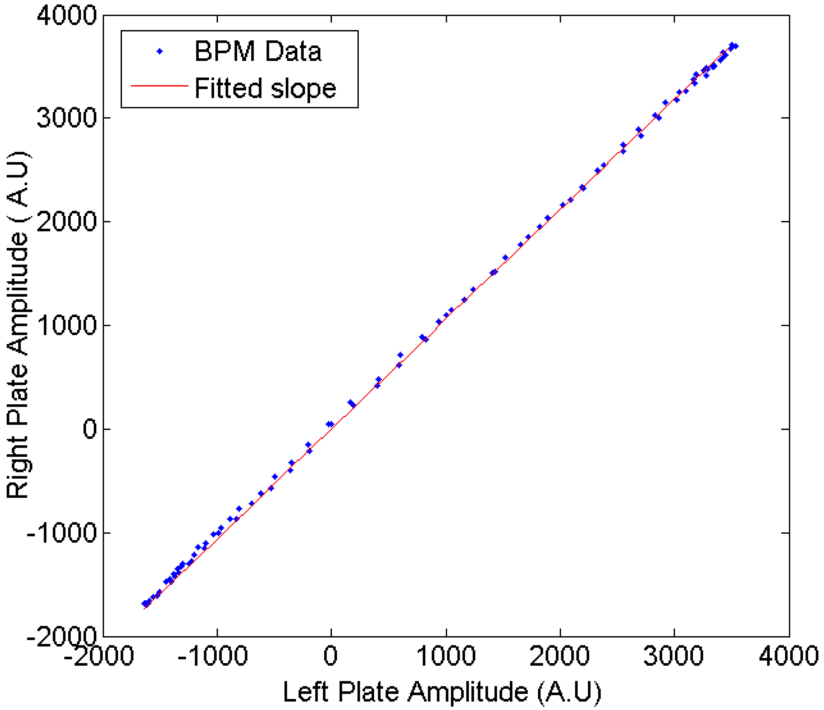
- Fast : < 1µs
- Robust : Varying bunch lengths from 100 to 500 ns
- Minimize variance
- Unbiased : Does not add any offset

Methods :

- Baseline restoration and $\frac{\Delta}{\Sigma}$
- Linear regression fit

Linear Regression



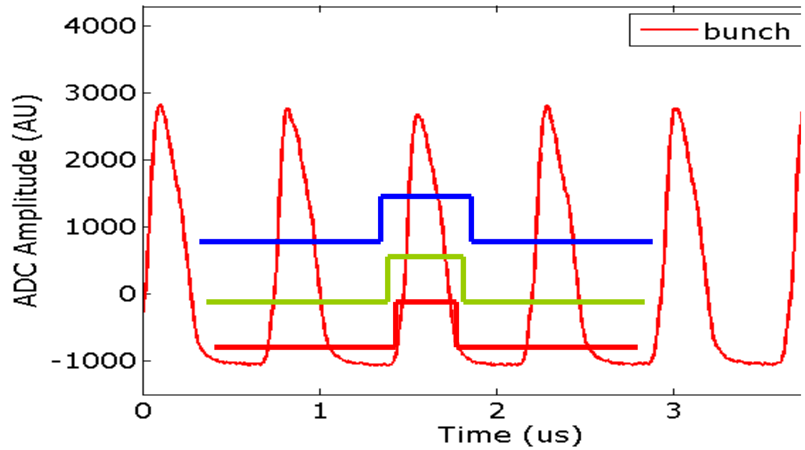


$$p_n \approx\propto \frac{1-s_n}{1+s_n}$$

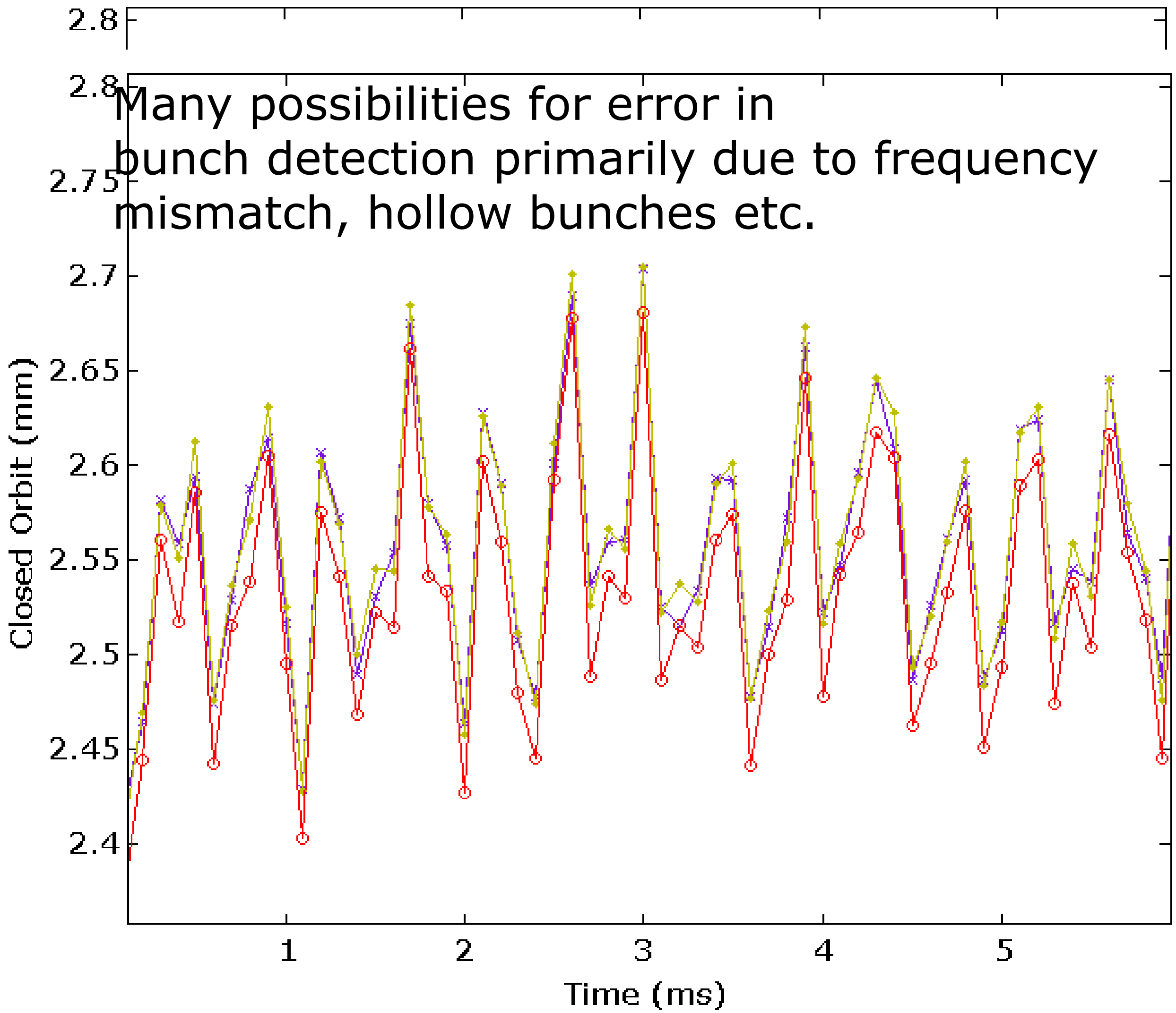
$$s_n = \frac{\sum_{i=W_{sn}}^{W_{en}} R_{ni} L_{ni}}{\sum_{i=W_{sn}}^{W_{en}} R_{ni}^2}$$

Assumption: Δ << Σ

Robust to bunch detection errors

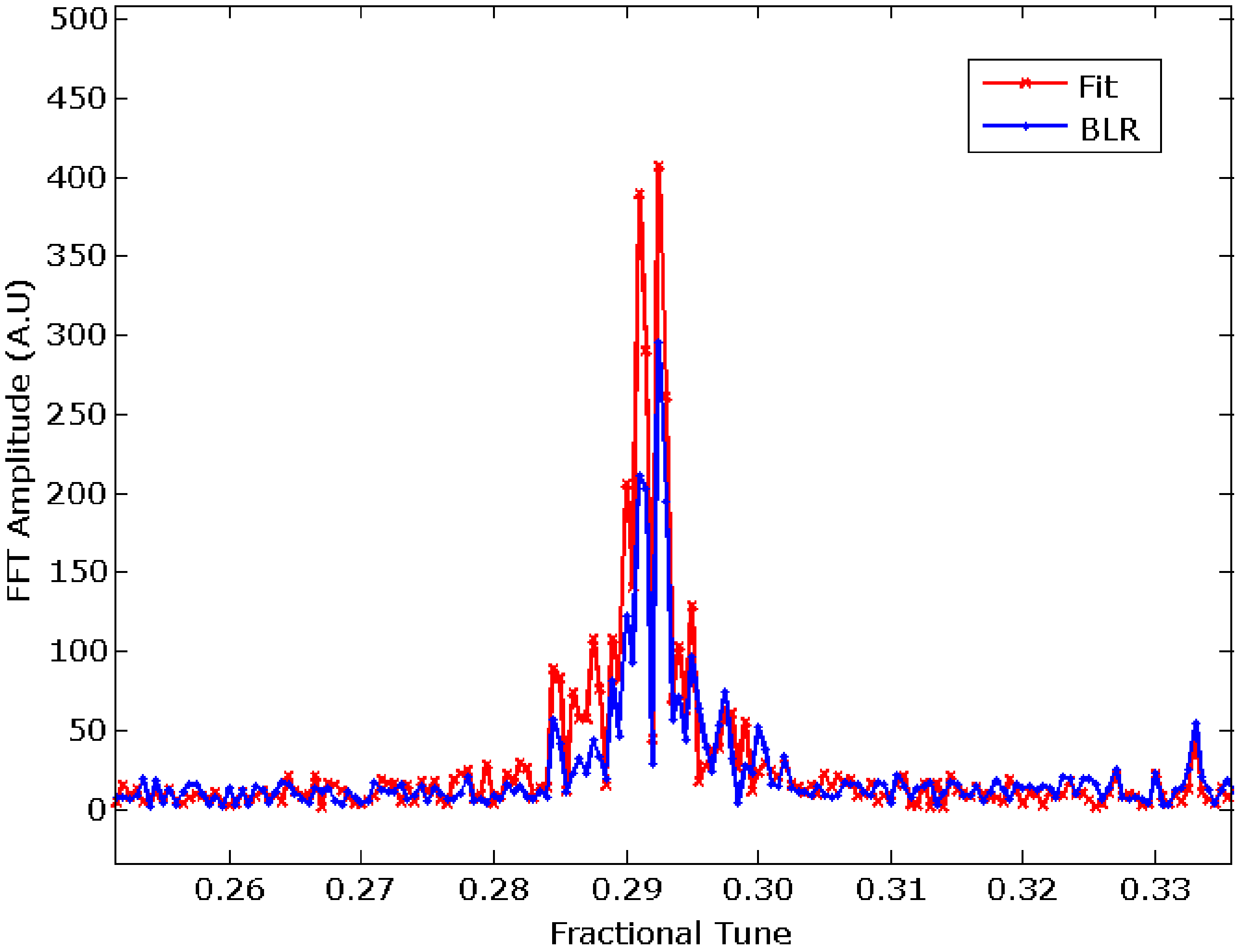


Many possibilities for error in bunch detection primarily due to frequency mismatch, hollow bunches etc.



Linear Regression

Variance



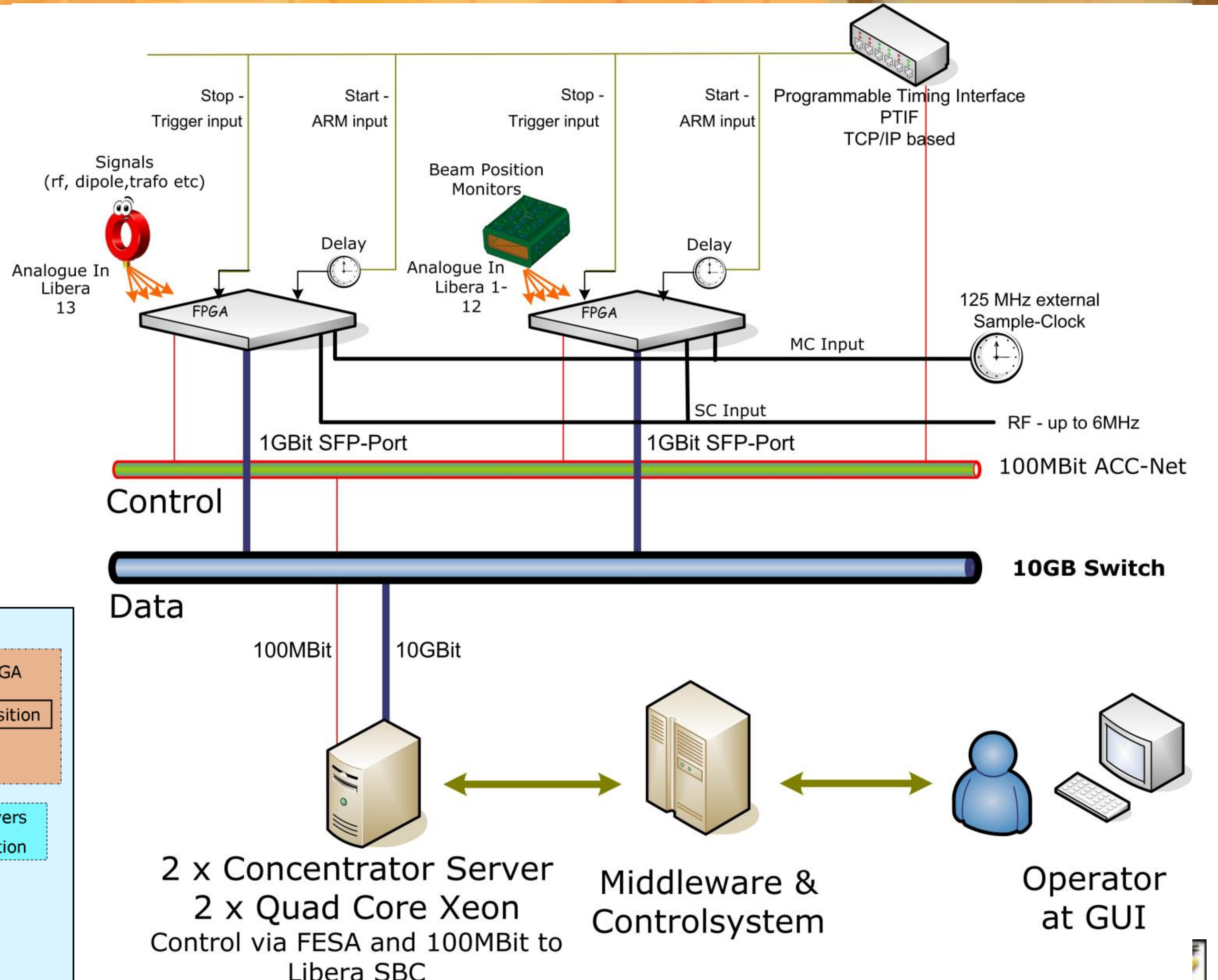
- Better Signal to noise ratio in the tune spectra for regression fit over BLR

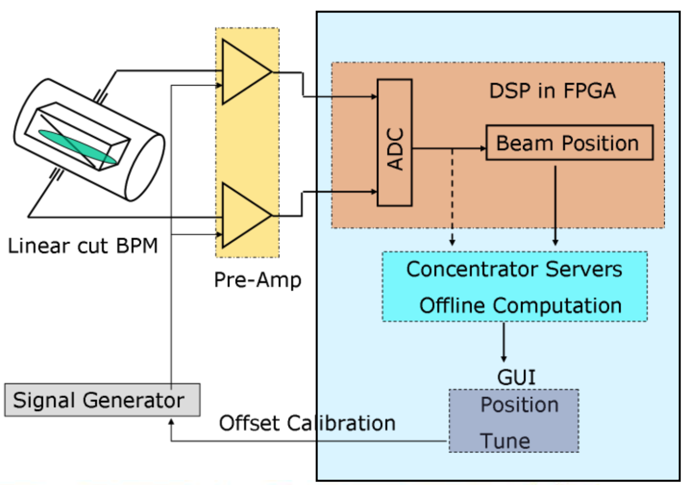
Comparision

Baseline Restoration Algorithm	Linear Regression Algorithm
Difference over sum	Ordinary least square estimator
Adds noise to the pick-up data due to baseline restoration	No baseline restoration
Higher latency due to BLR, takes around 150 clock cycles	No BLR, 50 clock cycles
High dependence of position calculation on integration windows	Minimal dependence
Operational	Under implementation

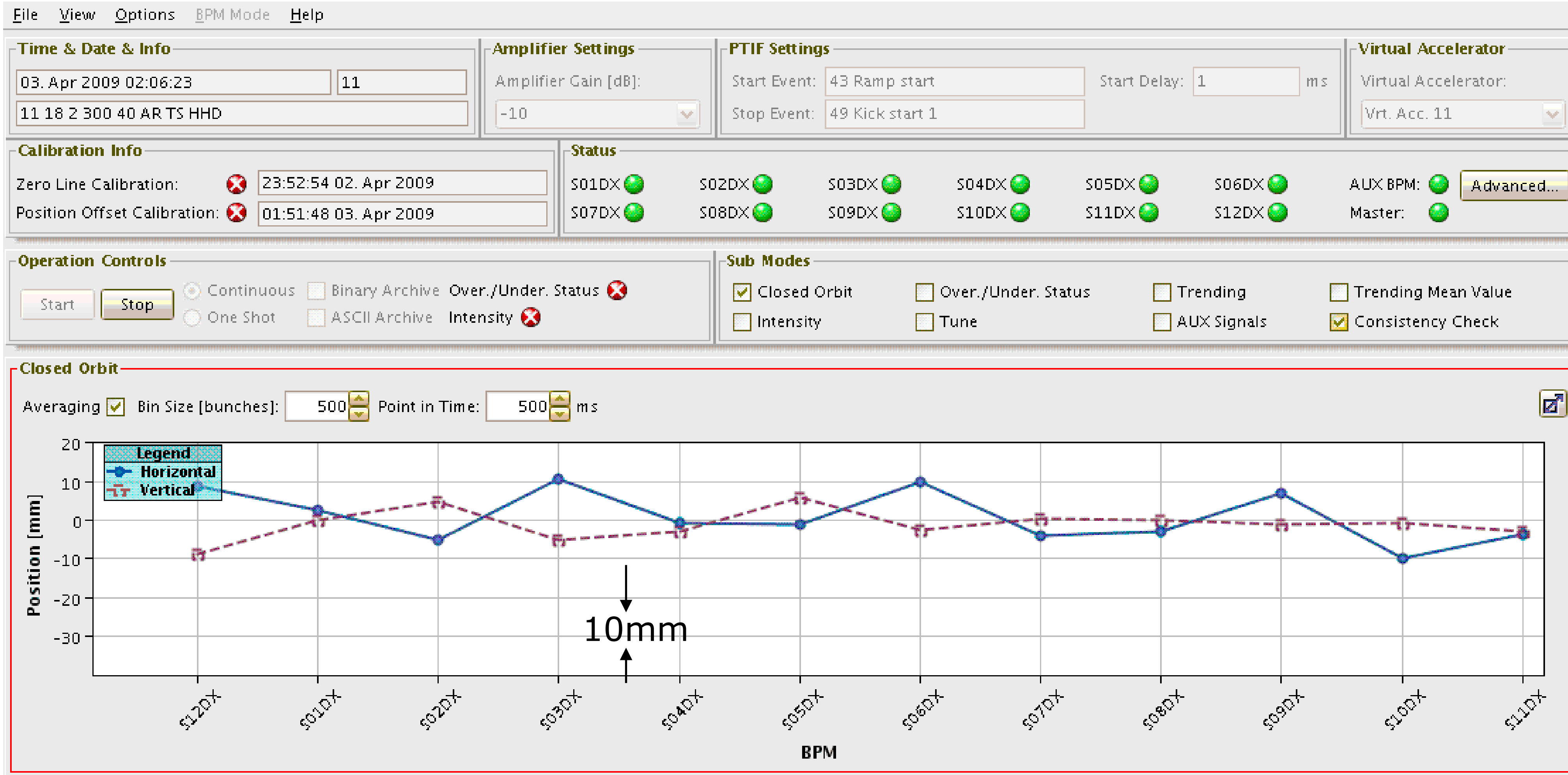
Data Acquisition Architecture

- 6 BPMs per Concentrator Server. One AUX in System
- Max. Data-Input of ≈ 400 MB/s per Concentrator Server via 10 GBit Ethernet
- Concentrator Server corrects the data with amplifier callibration and other offline calculations



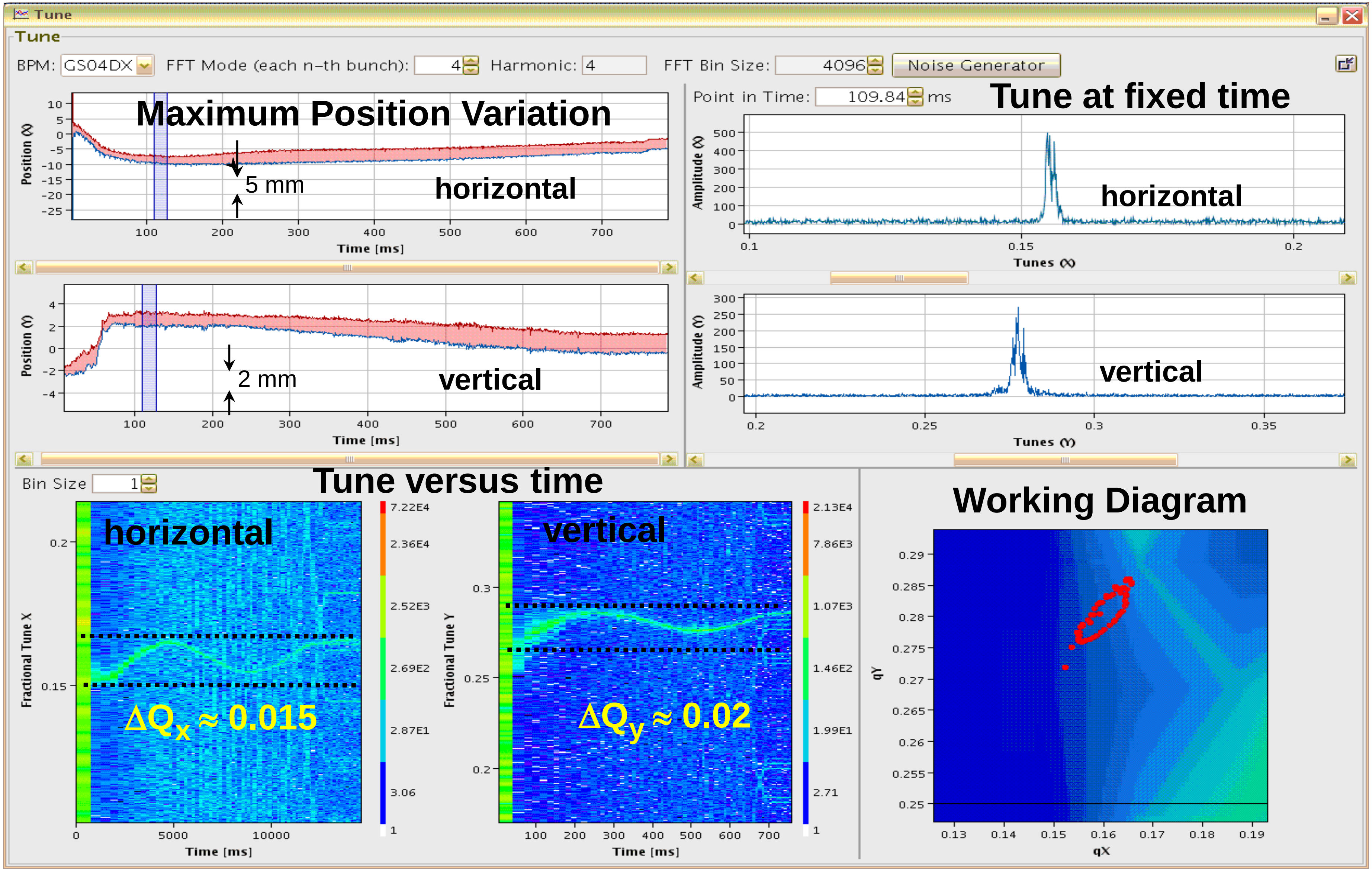


GUI – Closed Orbit Mode



Closed orbit at the 12 BPM locations around the ring

GUI – Position and Tune Mode



Summary

- Presented the digital position calculation method at GSI SIS-18
- Suggested regression fit as a method for position evaluation over traditionally used baseline restoration method
- The bunch by bunch digital position calculation method offers a flexible method for detailed beam investigations

Acknowledgement

European ITN- DITANET for funding the work and associated people to provide this opportunity

Thanks for your attention! Questions?

References

- G.Vismara ; BIW 2000; SIGNAL PROCESSING FOR BEAM POSITION MONITORS
- A. Galatis et al.; DIPAC 2007; FIRST TESTS WITH THE SIS18 DIGITAL BPM SYSTEM

Extra Slides

Position Characterstics

Accuracy : Calibration Offset (Electronics and Pick-up), Numerical Estimator Bias

Resolution : Noise defined, Signal Processing

Dynamic Range : Defined by hardware

Stability : Temperature, Beam Intensity, Defined by hardware

Basic analysis

$$x_i = Q(t_i)(O + k.p);\ y_i = Q(t_i)(O - k.p);$$

Where $Q(t)$ is the charge profile, O is the common mode and $k.p$ is the dipole mode

Diff over sum

$$\frac{\sum_{i=1}^{N}(x_i - y_i)}{\sum_{i=1}^{N}(x_i + y_i)} = \frac{k}{O}p$$

Linear regression

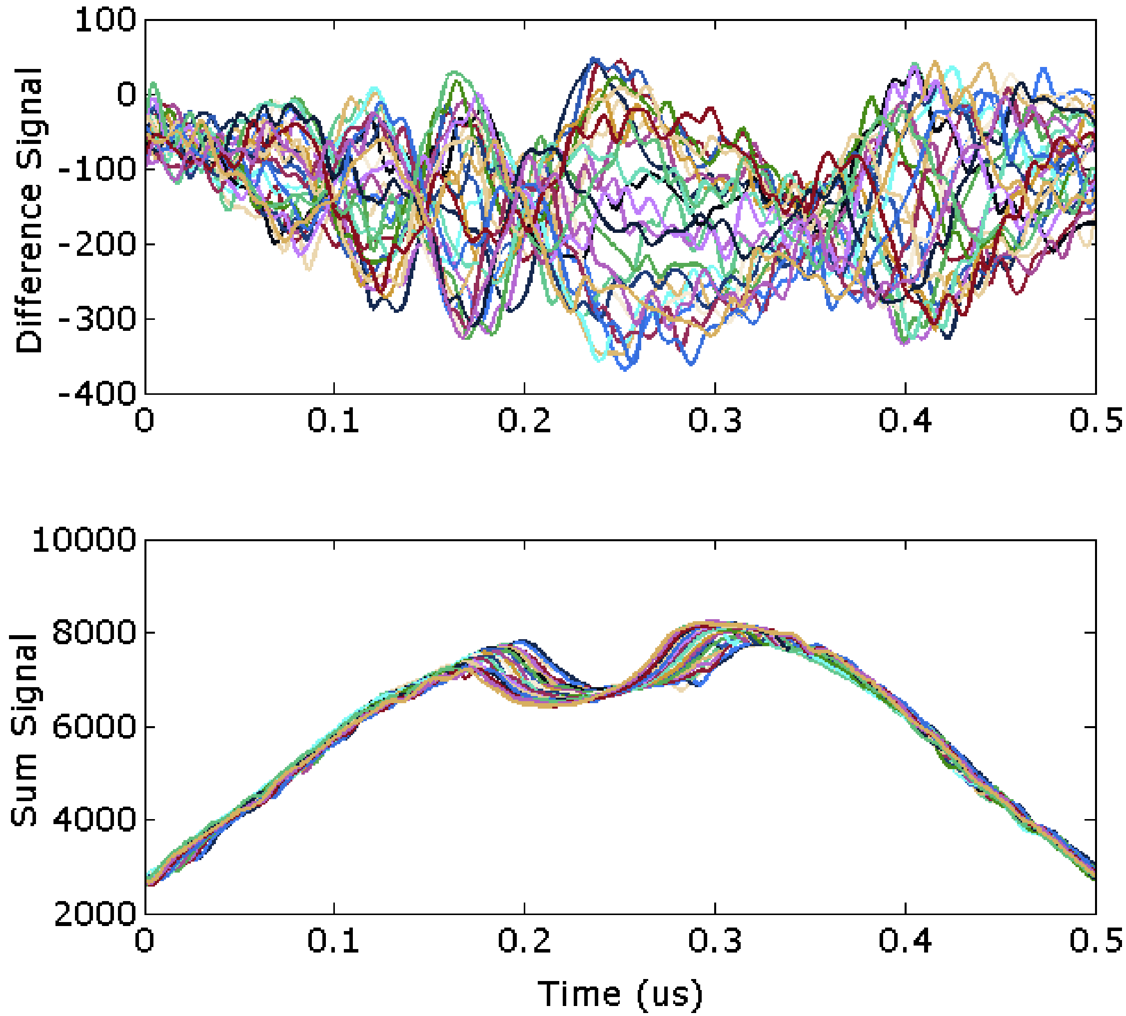
$$s = \frac{\sum_{i=1}^{N} x_i y_i}{\sum_{i=1}^{N} x_i^2}$$

$$\frac{1-s}{1+s} = \frac{\sum x_i^2 - \sum x_i y_i}{\sum x_i^2 + \sum x_i y_i} \approx \frac{k}{O}p$$

$$O >> kp$$

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

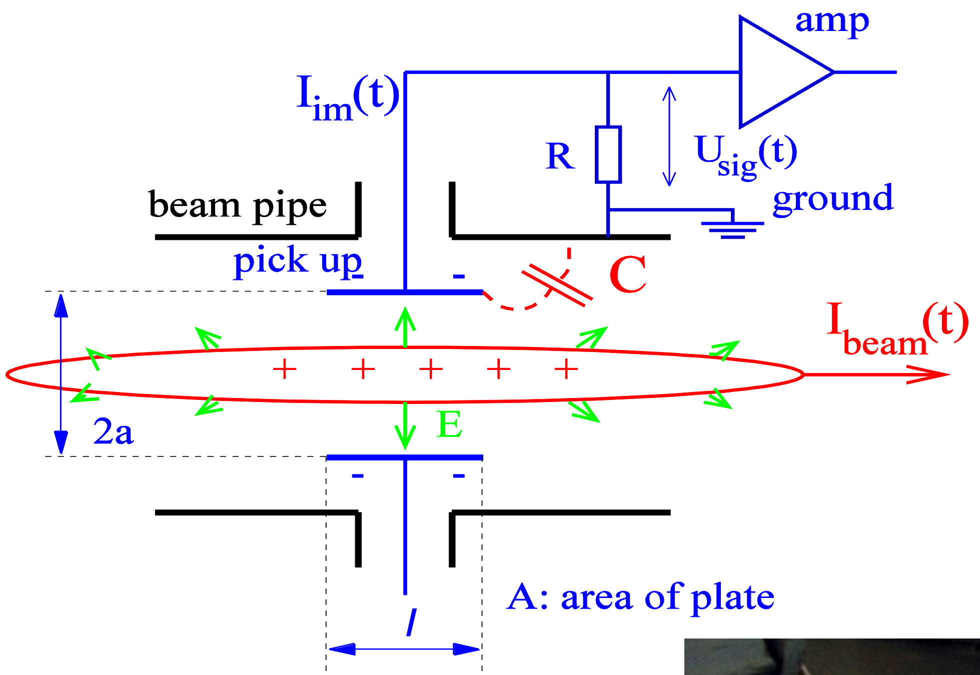


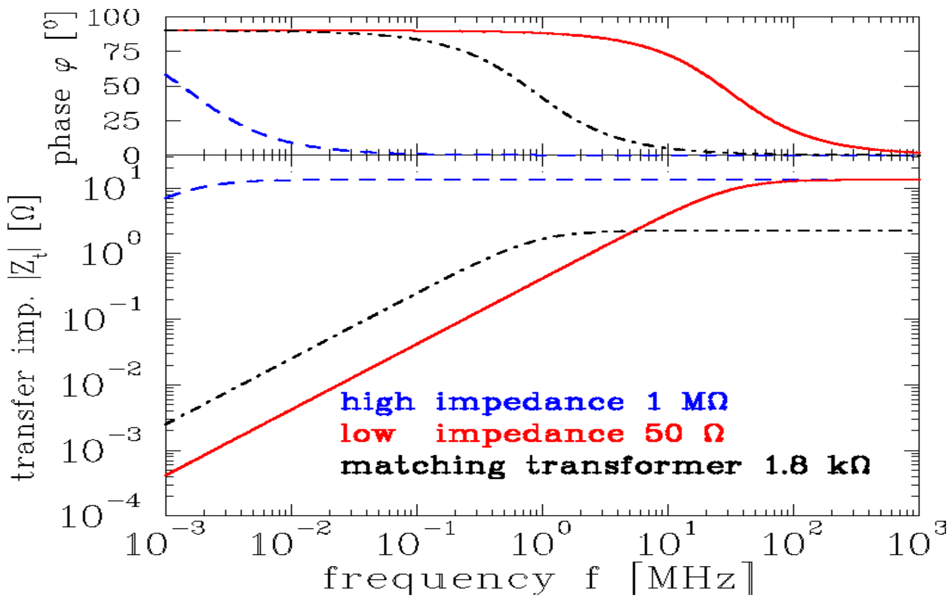
Bunch Length (µs)

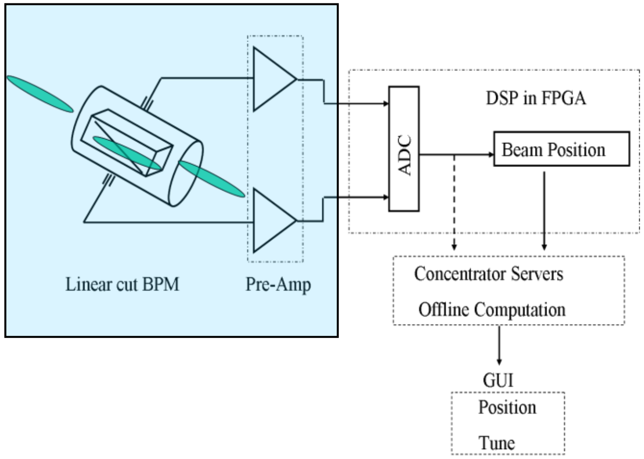
Linear Regression

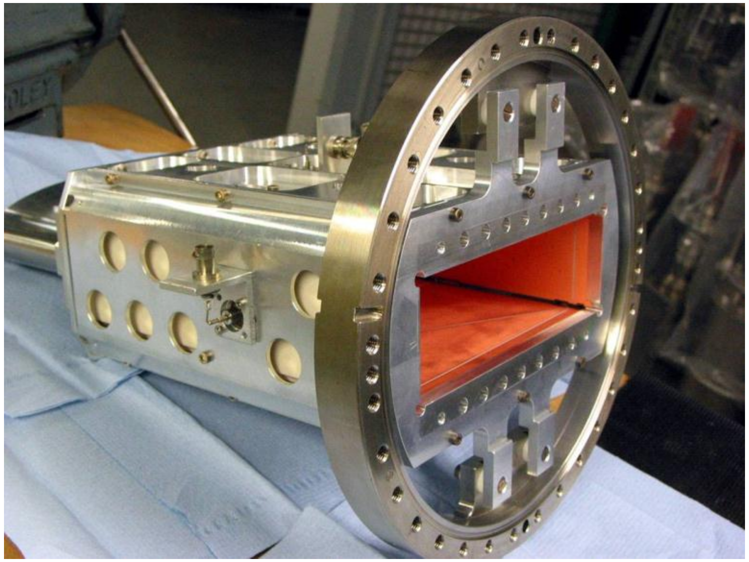
- Linear regression with ordinary least square estimator
- Removes the need for baseline restoration
- Less dependence of bias on time window selection
- Less variance i.e higher SNR in tune spectra

Shoe-Box BPMs

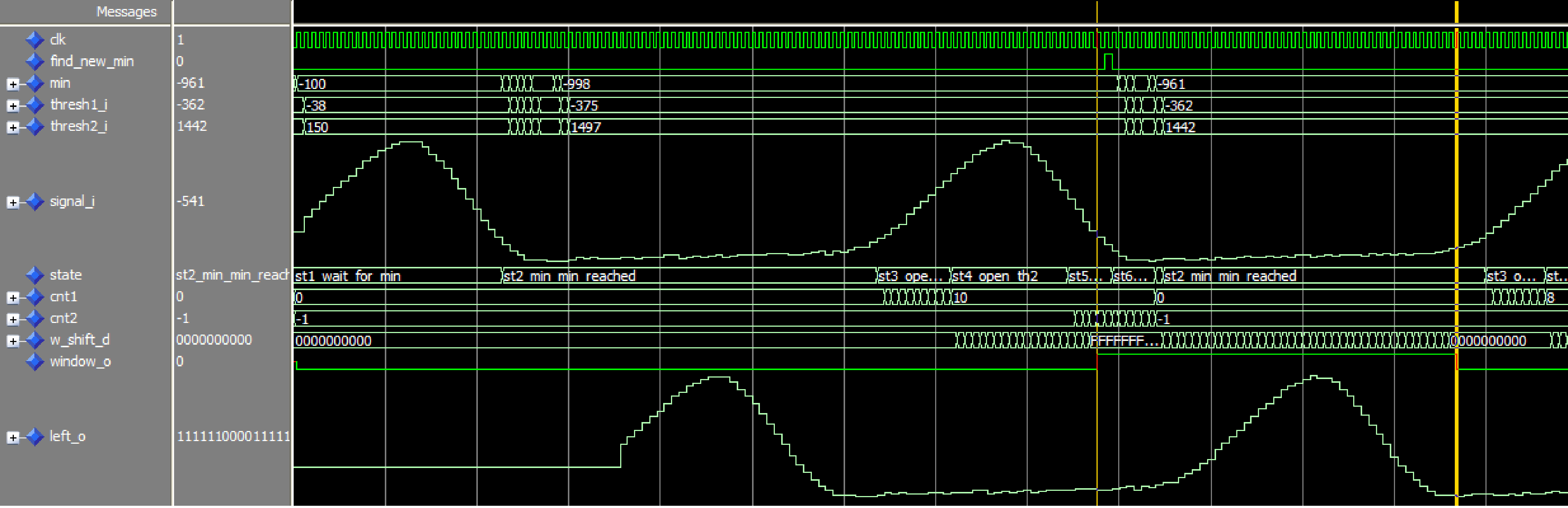








- Linear spatial sensitivity
- High pass response


Messages
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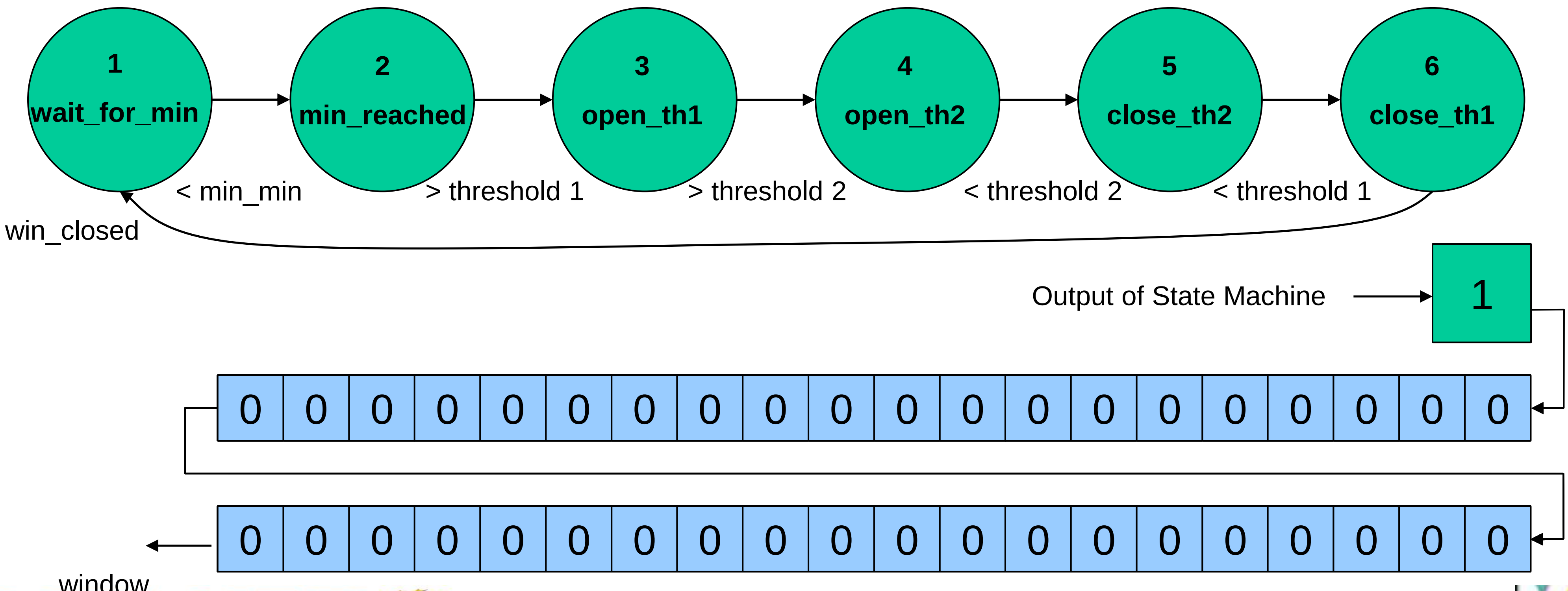
find_new_min 0
min -961
thresh1_i -362
thresh2_i 1442
signal_i -541
state st2_min_min_reach
cnt1 0
cnt2 -1
w_shift_d 0000000000
window_o 0
left_o 1111110000111111
-100
-998
-961
-38
-375
-362
150
1497
1442
st1 wait for min
st2 min min reached
st3 ope...
st4 open th2
st5...
st6...
st2 min min reached
st3 o...
st...
10
8
FFFFFFF...
0000000000


1
wait_for_min
2
min_reached
3
open_th1
4
open_th2
5
close_th2
6
close_th1
< min_min
> threshold 1
> threshold 2
< threshold 2
< threshold 1
win_closed
Output of State Machine
1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
window