Status of Beam Posiotion Monitors at SIS-18

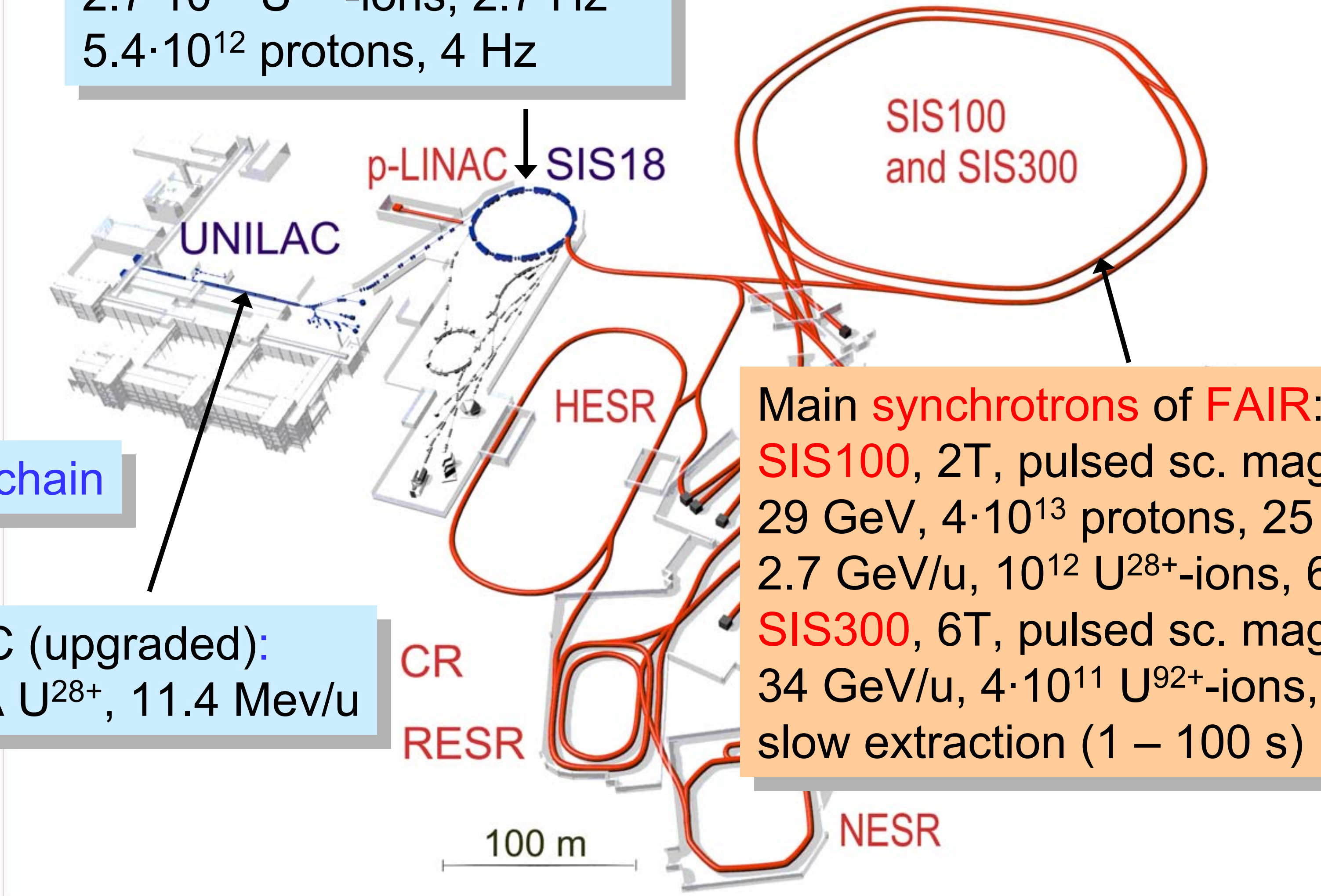
Piotr Kowina for the GSI Beam Diagnostic Group

Outline

- Short introduction to SIS-18 Parameters
  - BPM Requirements
- Former BPM readout
- New realization:
  - Impedance matching
  - Low imp. amplifiers
  - Direct digitalization
  - Algorithm for position evaluation
- DAQ
  - Data structure
  - Data flow, synchronization, triggering
- Tune measurements
- Closed orbit correctors
- Summary and outlook

FAIR – Basic Layout

Booster synchrotron SIS18:
$2.7 \cdot 10^{11}$ U^{28+}-ions, 2.7 Hz
$5.4 \cdot 10^{12}$ protons, 4 Hz



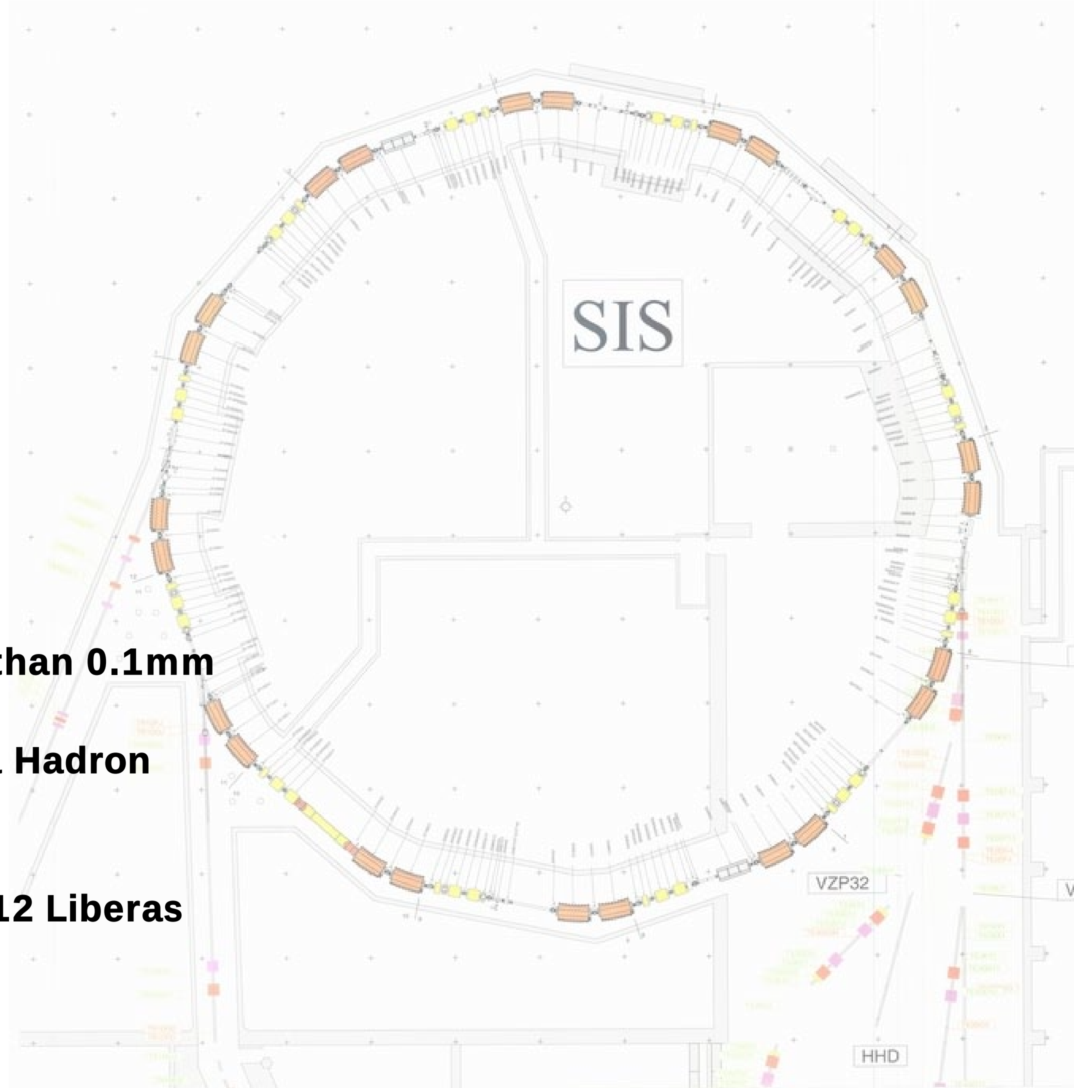
Injector chain

UNILAC (upgraded):
15 emA U^{28+}, 11.4 Mev/u

Main synchrotrons of FAIR:
SIS100, 2T, pulsed sc. magnets,
29 GeV, $4 \cdot 10^{13}$ protons, 25 ns
2.7 GeV/u, 10^{12} U^{28+}-ions, 60 ns
SIS300, 6T, pulsed sc. magnets,
34 GeV/u, $4 \cdot 10^{11}$ U^{92+}-ions,
slow extraction (1 – 100 s)

Parameters of SIS-18 BPMs

- 12 BPM stations
- Measurements and display:
  closed orbit, Raw Data,
  Bunch by Bunch beam position ,
  Tune, Calibration und Status control,
  Feedback
- Scaleable concept for future SIS100



Requirements:

- Bunch frequency (RF): 850 kHz – 5 MHz (SIS100 = 6 MHz)
- Harmonic number: typically 4
- Position measurement accuracy: better than 0.1mm
- Bandwidth Pick-Up: 0.1 MHz to 200MHz
- Digitization: 125MS/s, 14Bit, 12 x Libera Hadron

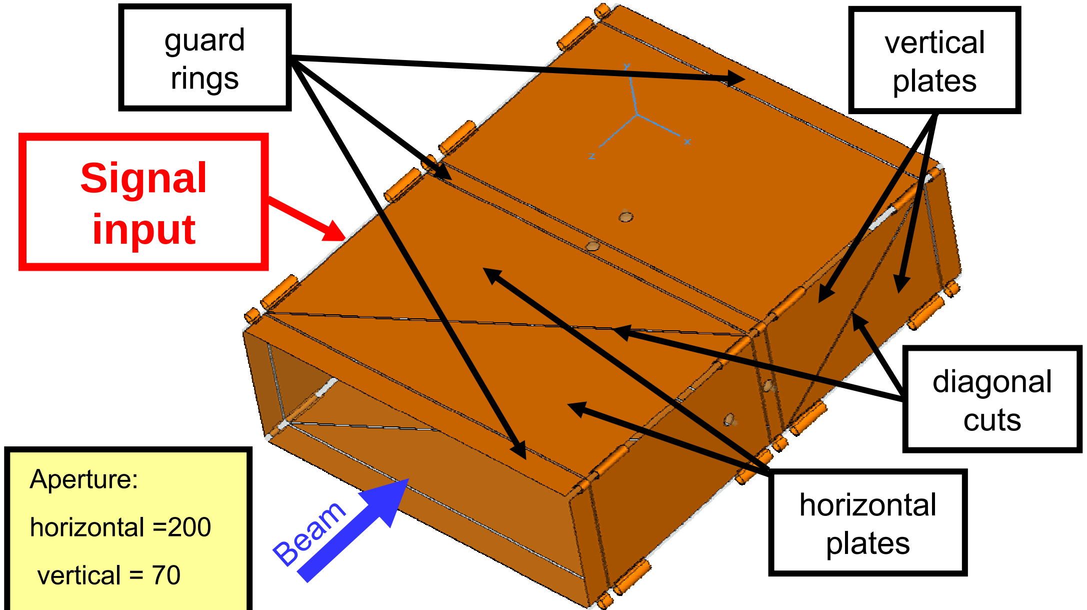
Bunch To Bunch:

Maximal data rate: 96 Bit/Bunch x 6MHz x 12 Liberas
= 864MB/s (max!)

Row data:

4 Electrodes x 125MS/s x 14Bit x
= 875 MB/s pro station

BPM: (capacitive PU, diagonal – cut type)

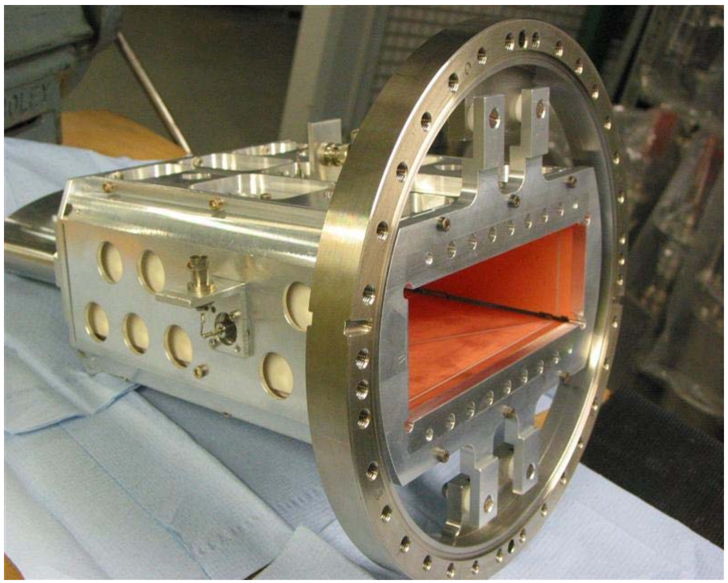


Aperture:
horizontal =200
vertical = 70
length = 260`

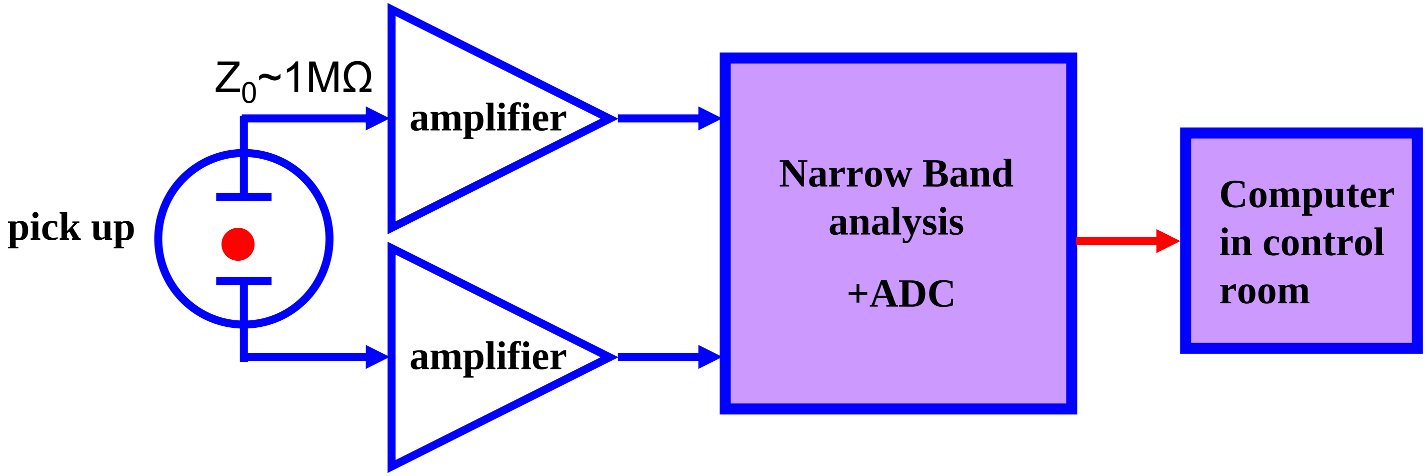
SIS 18 BPM

(1989)

Also called: shoe-box see e.g. P. Forck et al. Proc. CAS school, Dourdan, France (2008)



Former BPM readout (still in operation)

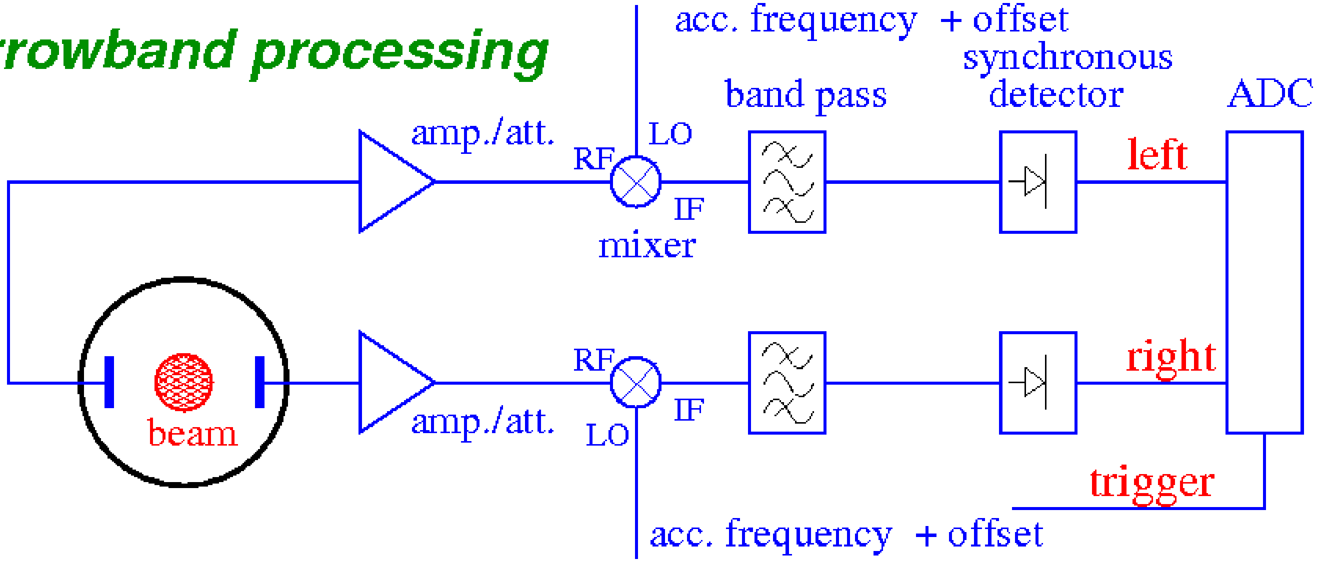


- bunch frequency: 0.8MHz – 5MHz
- bunch length: 50ns – 500ns

- high Z_0 amplifier mounted directly on pick-up.

Former BPM readout: position evaluation

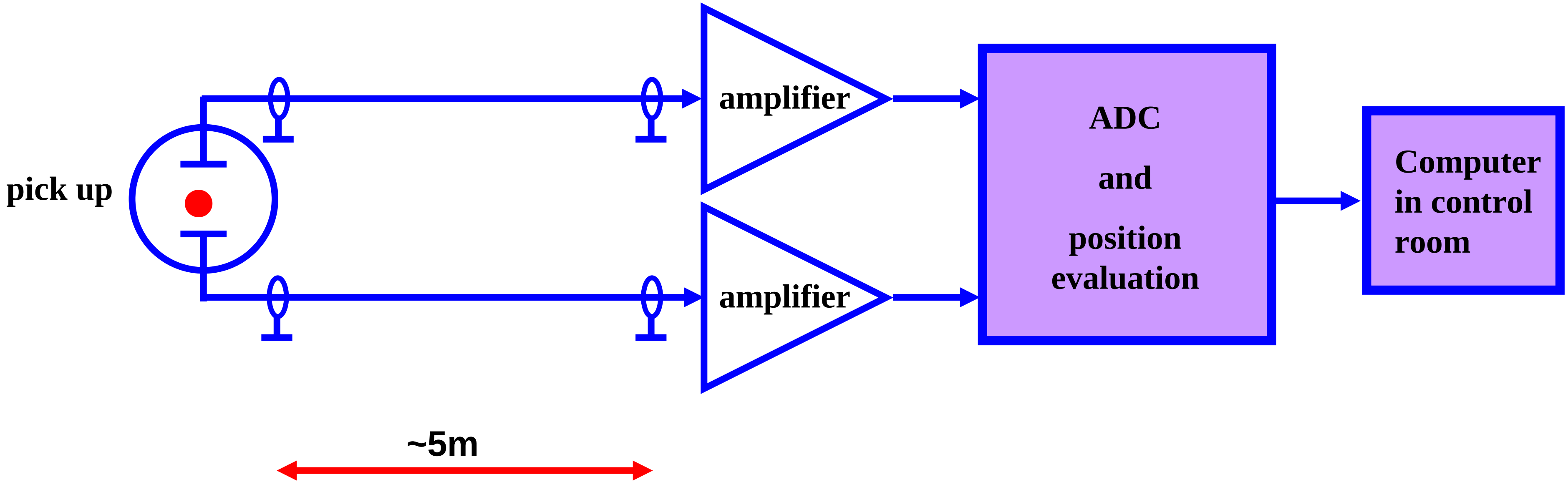
Narrowband processing



See e.g. P. Forck et al. Proc. CAS school, Dourdan, France (2008)

- **Advantage**:
  - Analog based solution
  - No fast ADC needed (important issue in 1989)
  - Noise reduction due to band limitation
- **Disadvantage**:
  - No observation possible in the bunch-by-bunch scale.

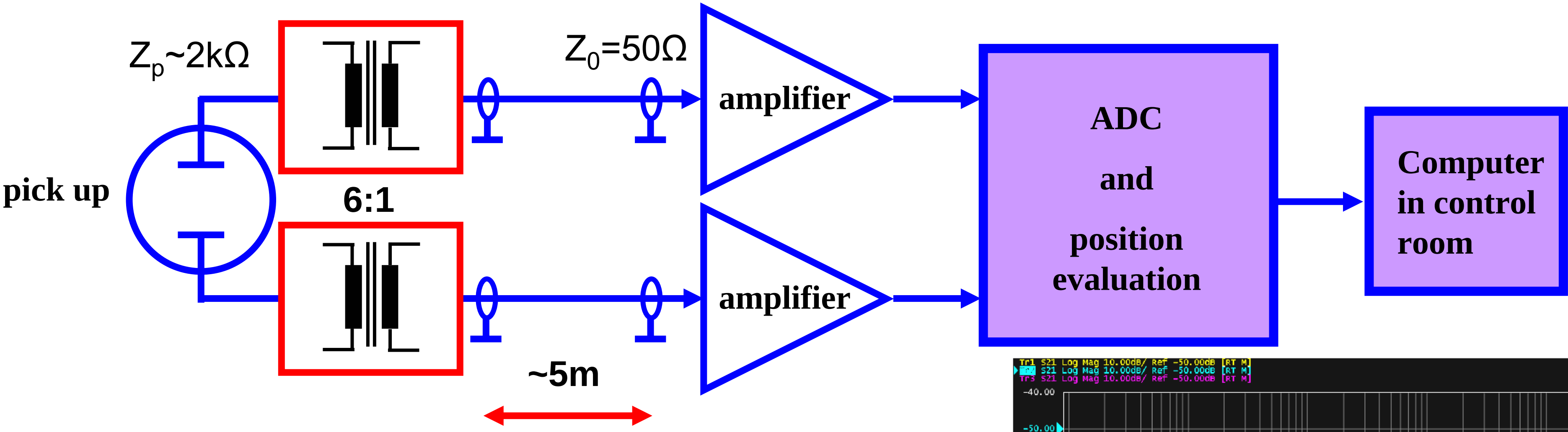
Future need: Long cables

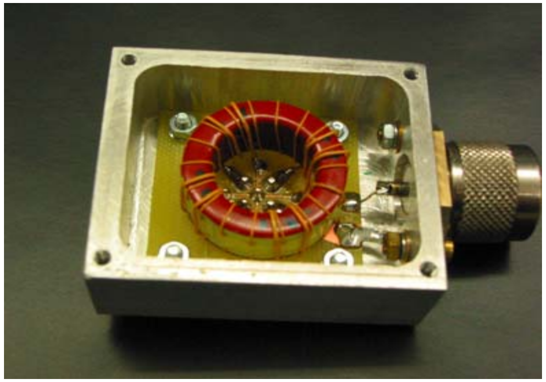


- High radiation -> long cables
  - For amplifier with high Z_0 : Long cables = high capacity = reduced transfer impedance (signal amplitude).

$$|Z_t| = \frac{A}{\pi a} \frac{1}{\beta c C} \frac{\omega/\omega_{cut}}{\sqrt{1+\omega^2/\omega_{cut}^2}}$$

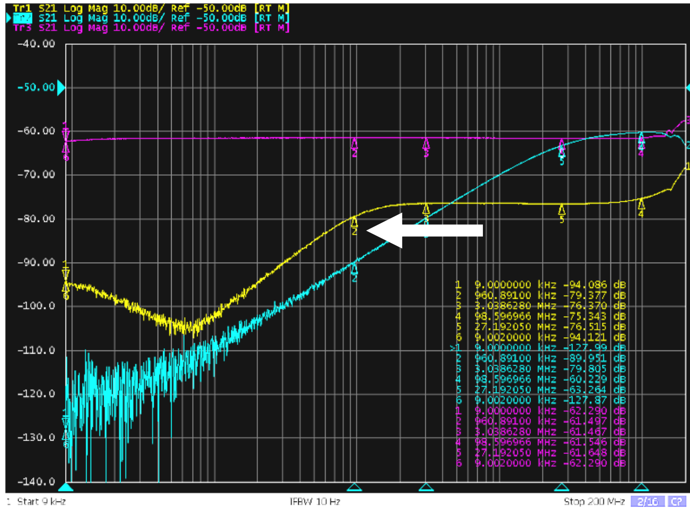
Matching transformer





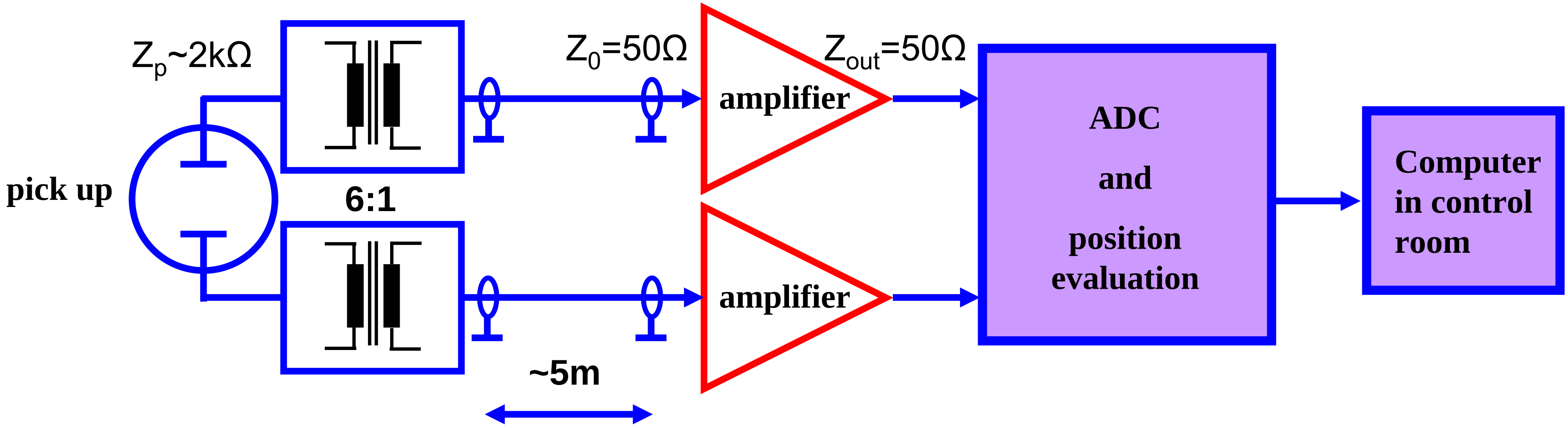
M. Freimuth, et al.,

GSI Ann. Rep. 2008



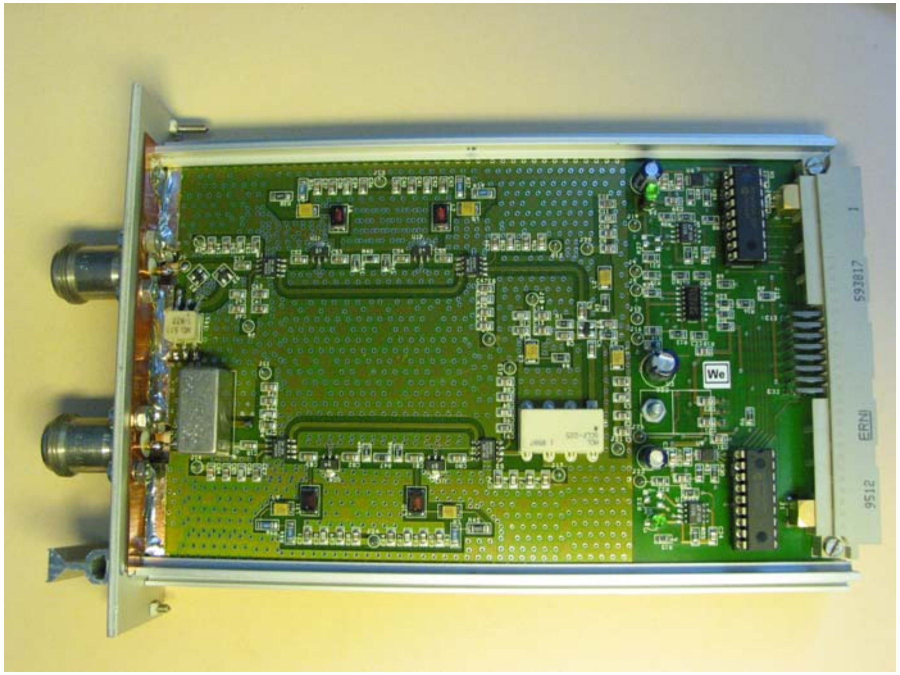
- Low thermal noise (allows for higher amplification).
- Weak influence of the cable capacity on signal height.

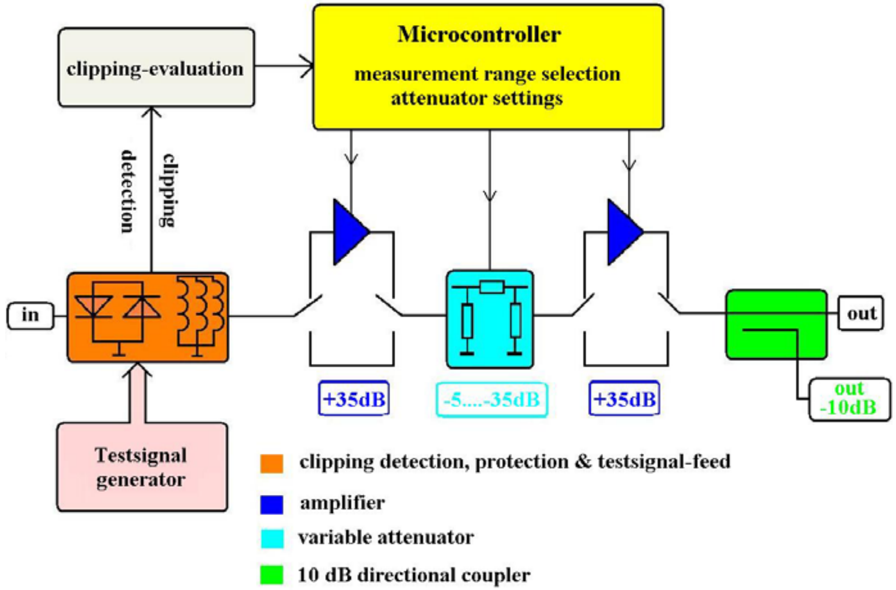
RF amplifier – requirements



- Requirements for amplifier:
  - 4 channels
  - Dynamic range from 1x10^8 to 1x10^{13} charges per bunch
    i.e. 120dB dynamic range of signal amplitude
  - Common mode gain matching better than 0.1dB each PU-plate pair
  - Bandwidth 0.2MHz-200MHz
  - Z_0=50Ω
  - Z_{out}=50Ω
  - Common mode gain matching better than 0.1dB for each PU-plate pair

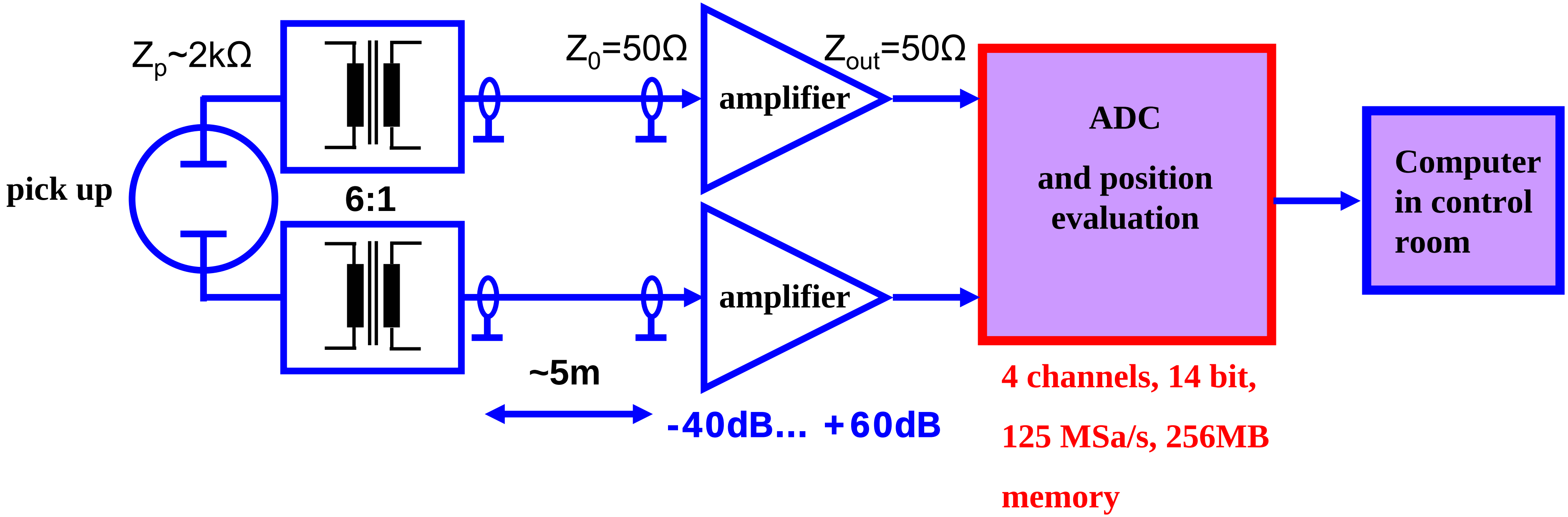
RF amplifier – realization





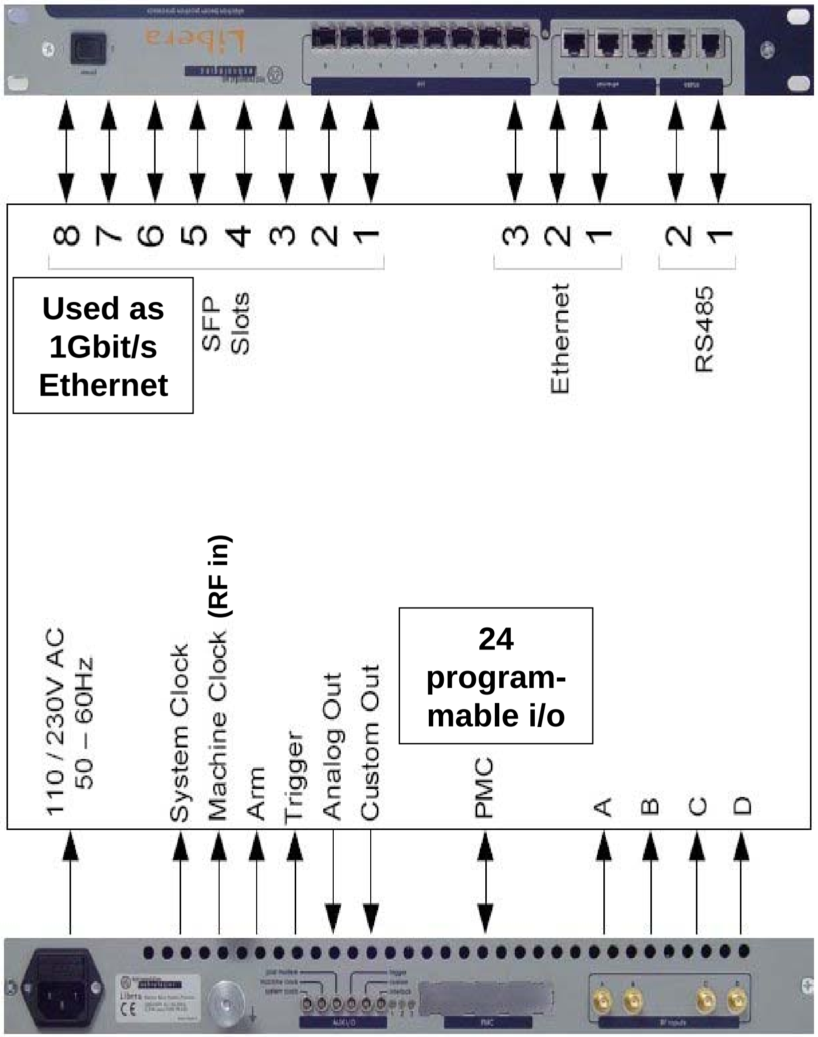
- Two 35dB amplifier stages.
- Steeples variable PIN-diode attenuator -5dB…-35dB.
- Individual amplification/attenuation adjustment for each channel and measurement range -> up to 64 ranges (6 bits)
- Used elements
  - Amplifiers Minicircuits GALI-52 and GALI-4
  - PIN-diodes Infineon PAR-61

Broad band position evaluation



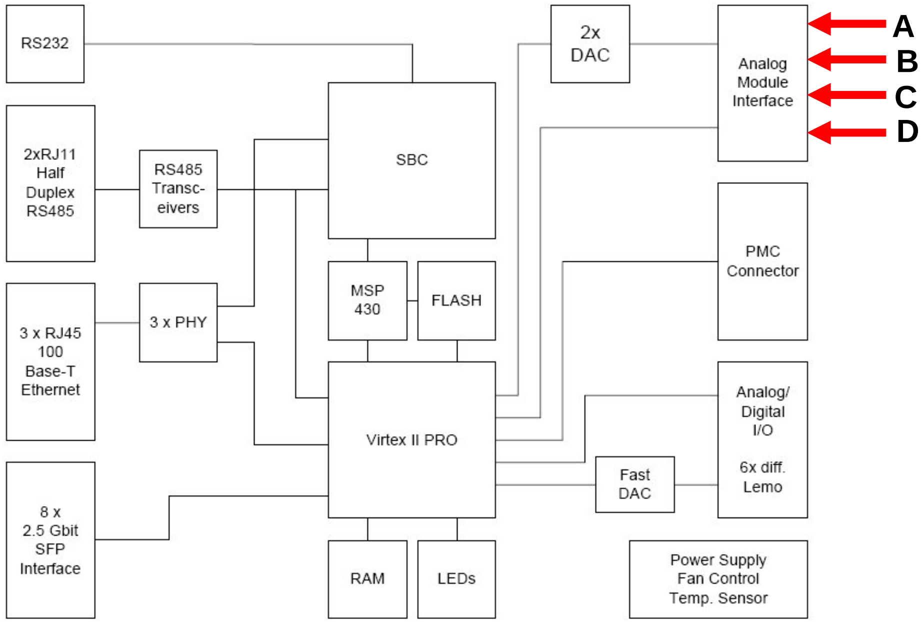
- Bunch frequency 0.8MHz – 5MHz
- 4 Bunches per cycle
- Positions calculated:
  - bunch by bunch
  - closed orbit
  - Q-measurement

Beam Position Processor (Libera Hadron)



Almost only ADC + FPGA

(no commercial position evaluation software)



Analog module Interface:

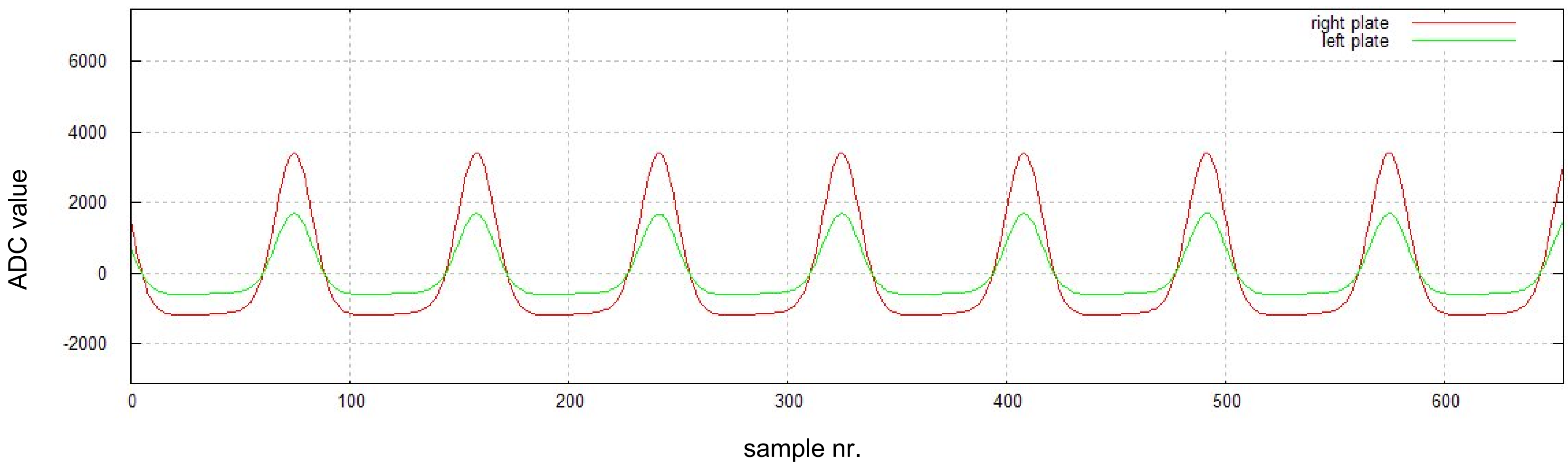
- 4 ADCs
- 125MSa/s
- 14 Bit pro channel

RAM:

- DDR2
- 128MB (256MB)

Broad band position evaluation

BPM Plate signals 1,5MHz -6dBm



Position for one bunch: $$\Delta x = K \frac{\int \Delta U}{\int \Sigma U} + \delta$$

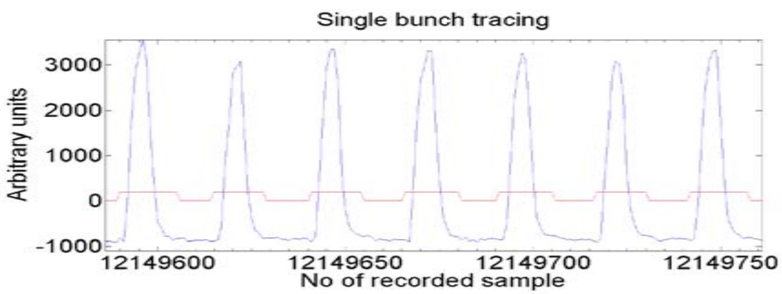
K = PU-constant

δ = offset

- Issues needed for integration:
  - gate (window) generation
  - restoration of the base-line shift caused by AC coupling.

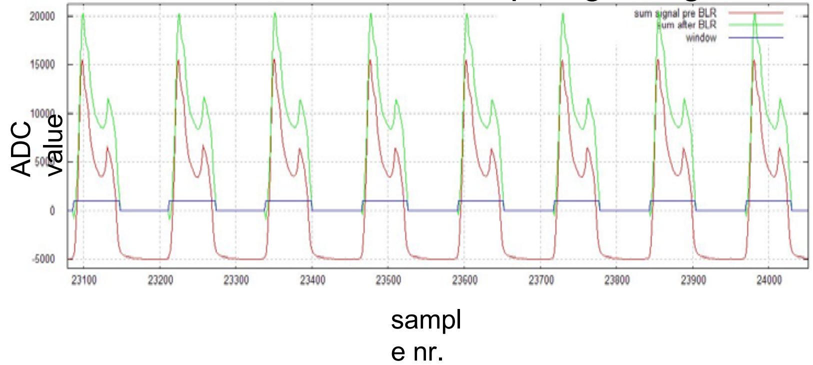
Window generation and Base Line Restitution

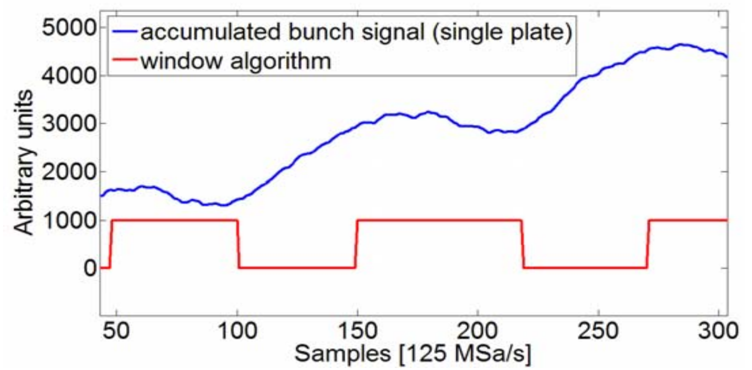
Beam Position Measurement using four integrated bunch signals from each pick-up. Integration windows (red) derived from bunch-signals (blue) itself.



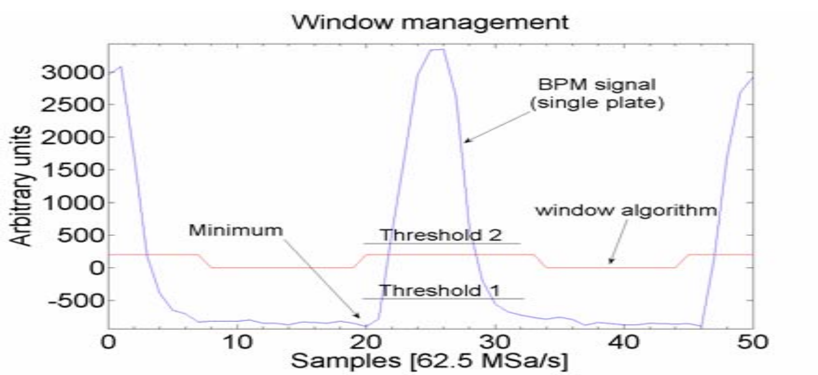
Base **L**ine **R**estitution
using inverted and shifted signal

Cooled beam – ramp beginning



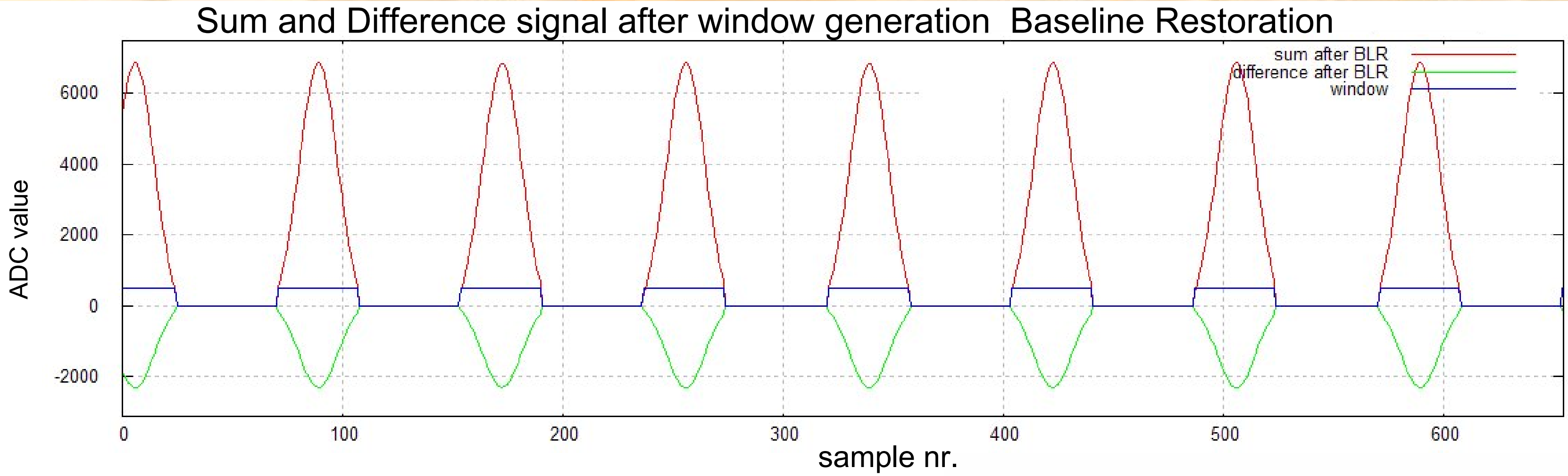


Window generation with algorithm that uses accumulated and median-filtered values (developed by A.Galatis)



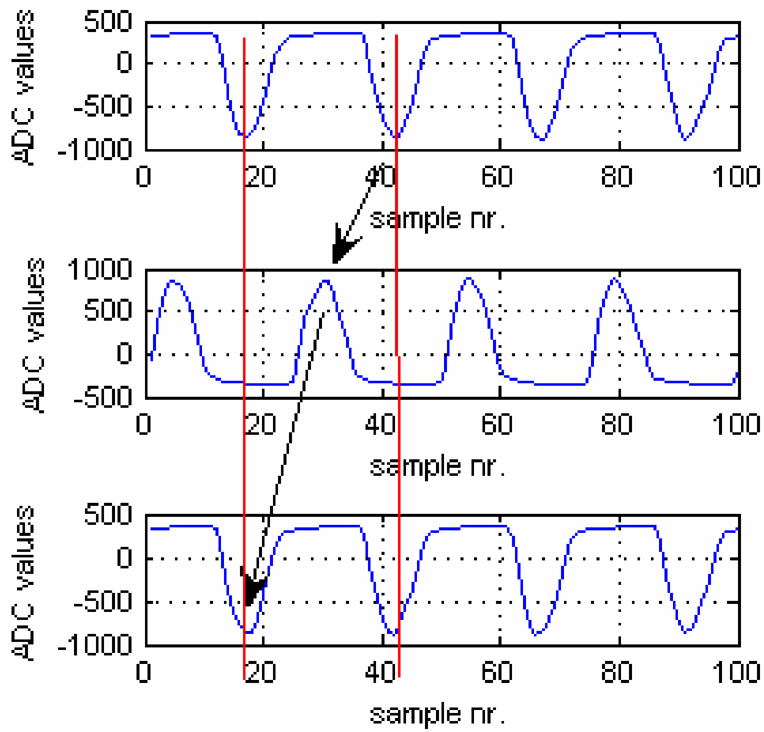
Window generation with algorithm based on double threshold comparator (developed by U.Rauch)

Base Line Restoration (BLR)

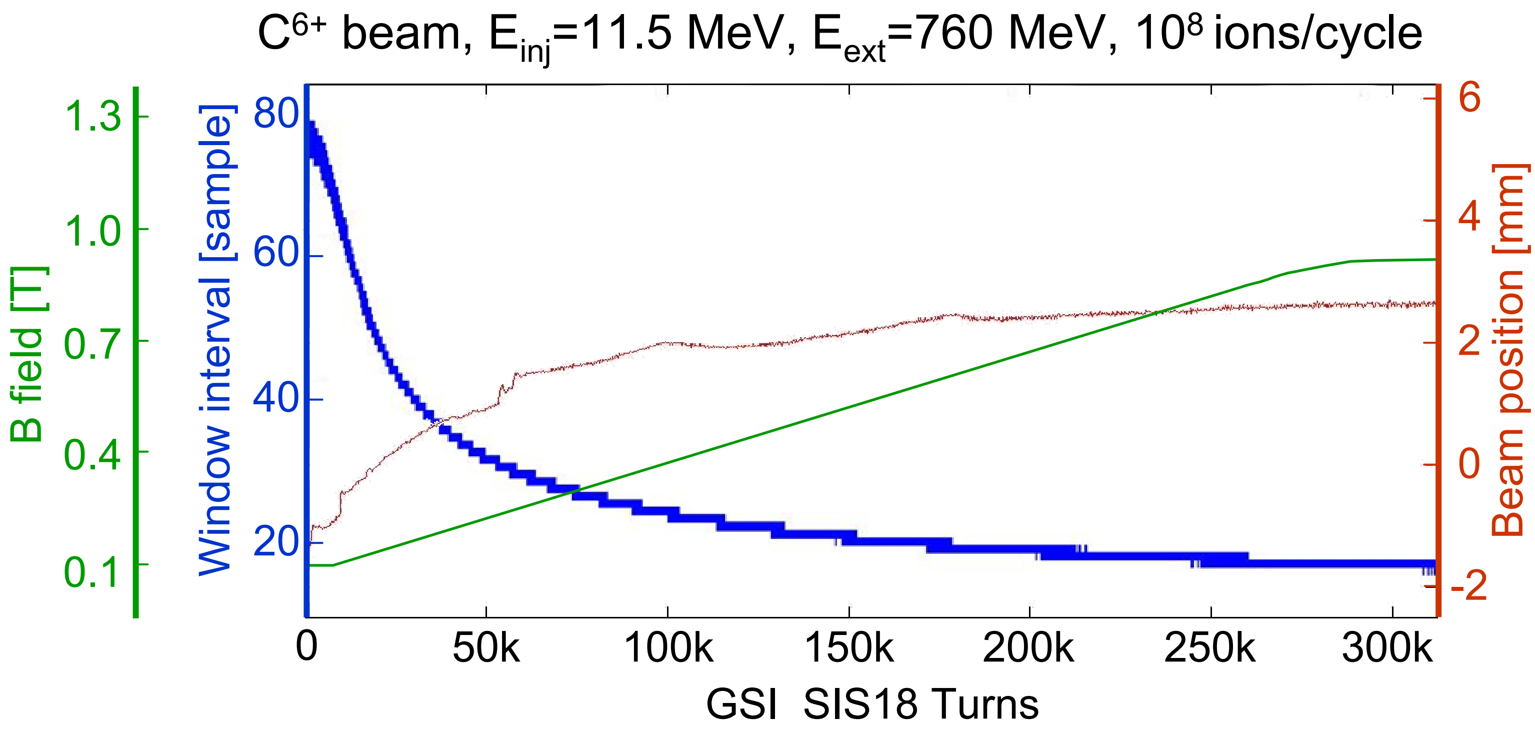


- Base line shift caused by AC coupling falsify the signal integration.
- Method:

$$
\begin{cases} \text{Trig.}=1: \quad y = x_t - \dfrac{(x_{(t-T/2)} + x_{(t+T/2)})}{2} \\ \text{Trig.}=0: \quad y=0 \end{cases}
$$



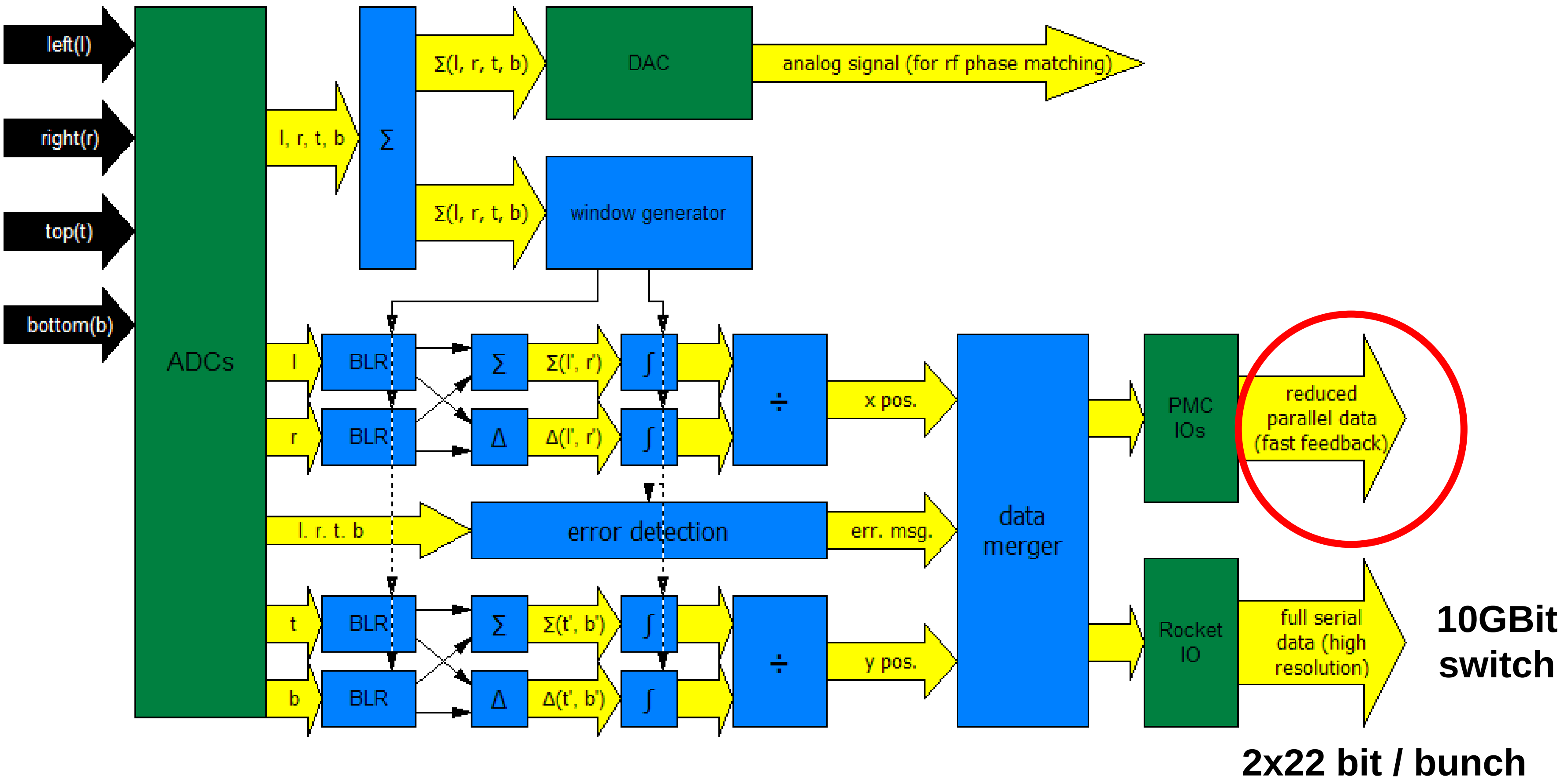
Beam position: off-line results



- windows generated with double threshold comparator,
  ⇨ no window dropout for more than 1.000.000 bunches

- Position accuracy 0.03 mm with averaged data over 1000 turns, whereas turn by turn data allows calculation of betatron oscillation.

Algorithm implementation in FPGA



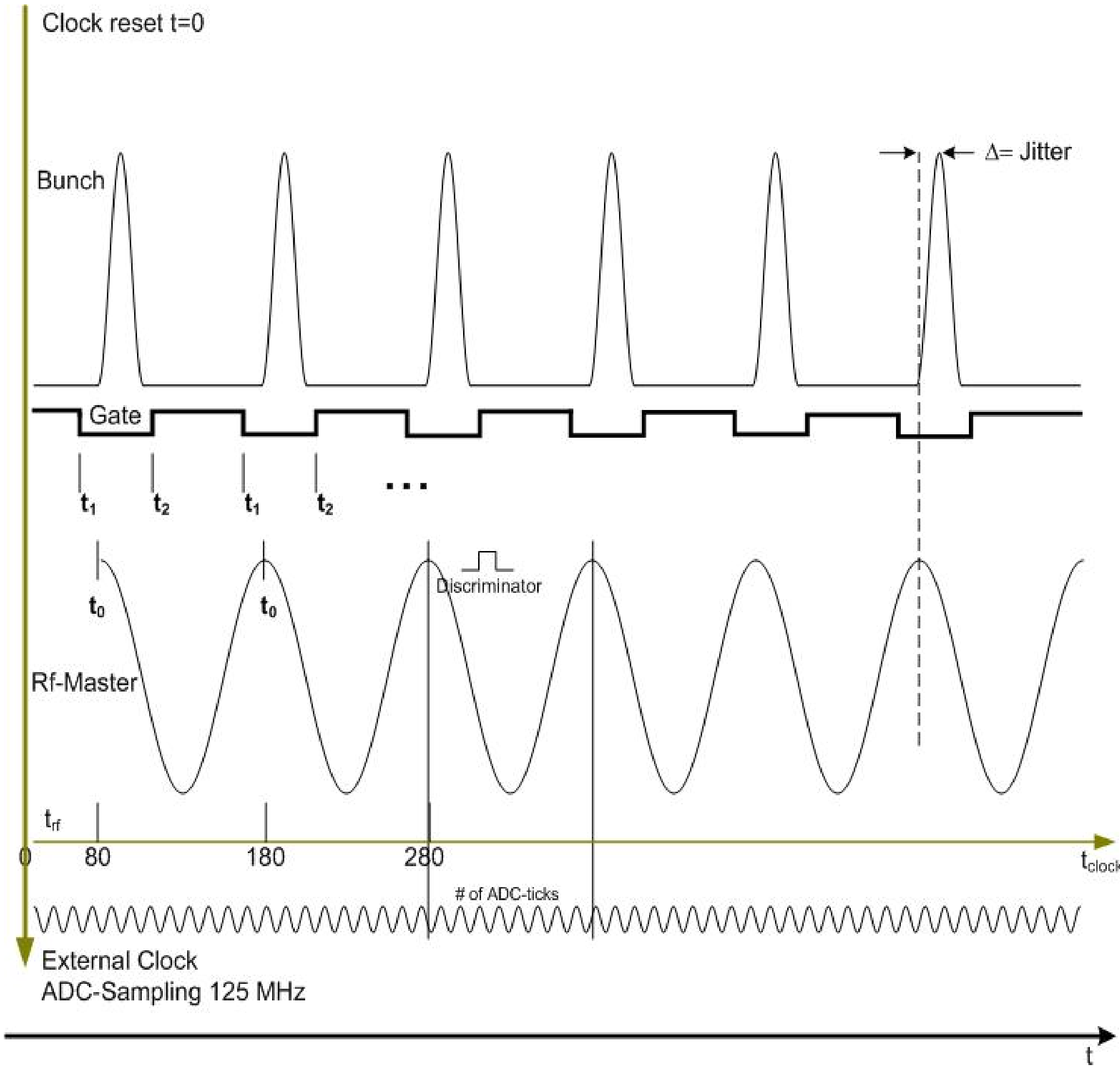
Xilinix – License at GSI:

Presently ISE 10.1 as Campus License

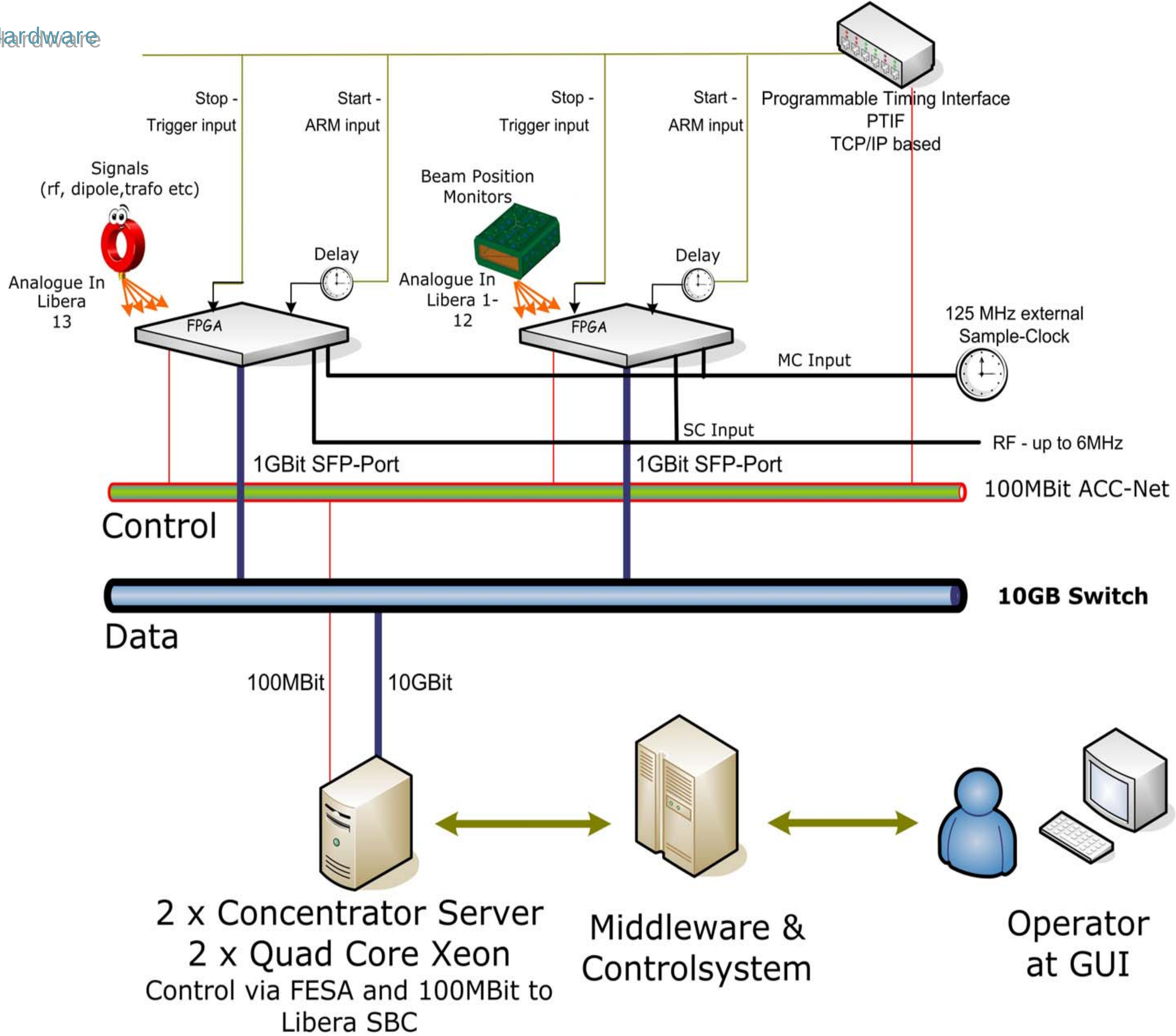
Upgrade for about 500 EUR every second year
second license available

Additional timing information

- Information used for consistency check and bunch numbering
- Total among of data 96 Bit / bunch:
  - 2x22 bit for vertical horizontal position,
  - rest – status bits, RF, gate start and stop
- Total data rate 580 MBit/s per BPM



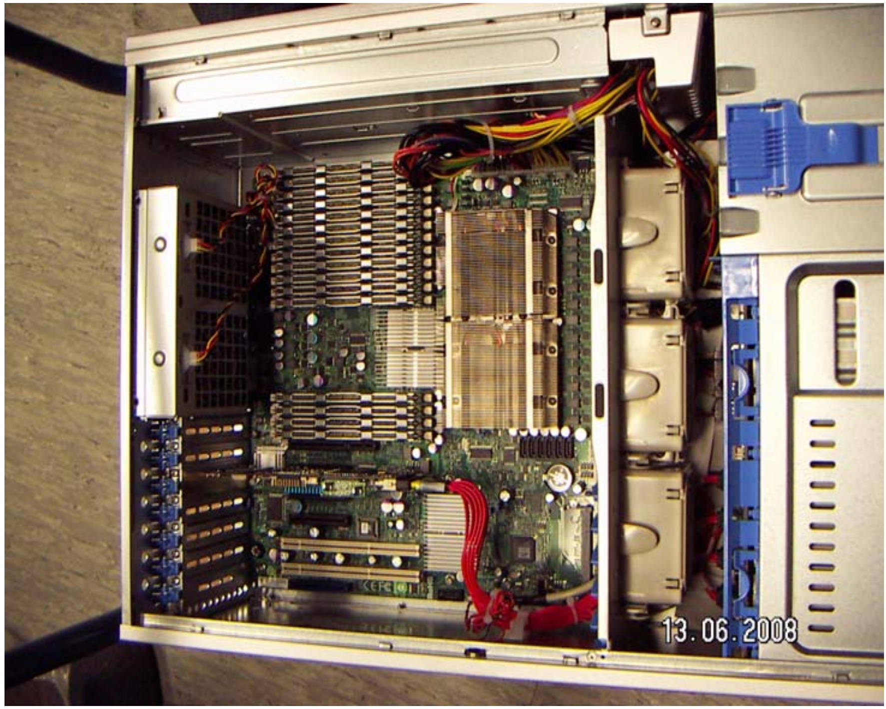
Hardware



Stop - Trigger input
Start - ARM input
Stop - Trigger input
Start - ARM input
Programmable Timing Interface
PTIF
TCP/IP based
Signals
(rf, dipole,trafo etc)
Beam Position Monitors
Delay
Delay
Analogue In Libera 13
Analogue In Libera 1-12
FPGA
FPGA
125 MHz external Sample-Clock
MC Input
SC Input
RF - up to 6MHz
1GBit SFP-Port
1GBit SFP-Port
100MBit ACC-Net
Control
10GB Switch
Data
100MBit
10GBit
2 x Concentrator Server
2 x Quad Core Xeon
Control via FESA and 100MBit to Libera SBC
Middleware & Controlsystem
Operator at GUI

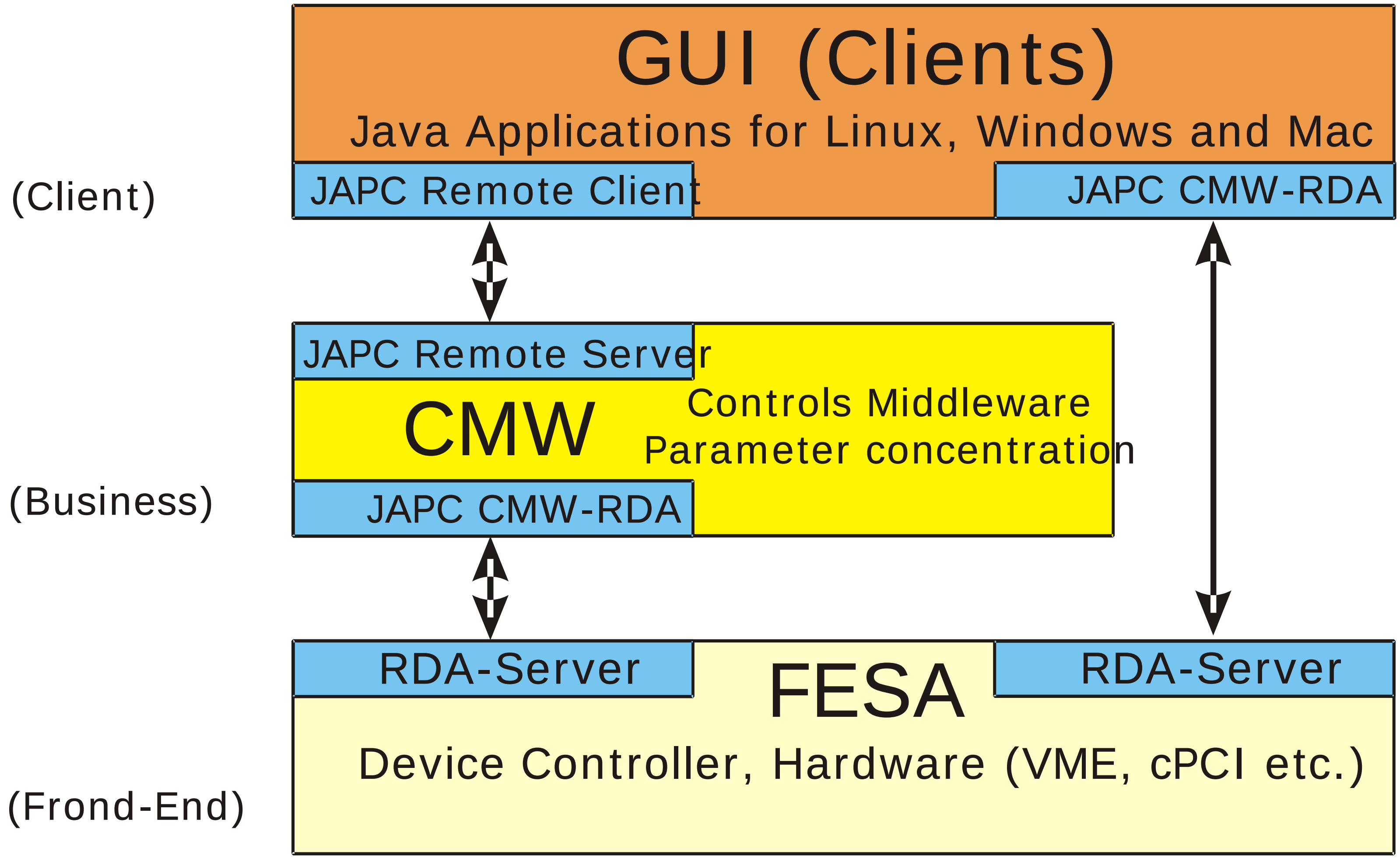
Concentrator Server (or if you like: CCCP)

Concentrator and **C**ontrol **C**om**p**uter
CCCP

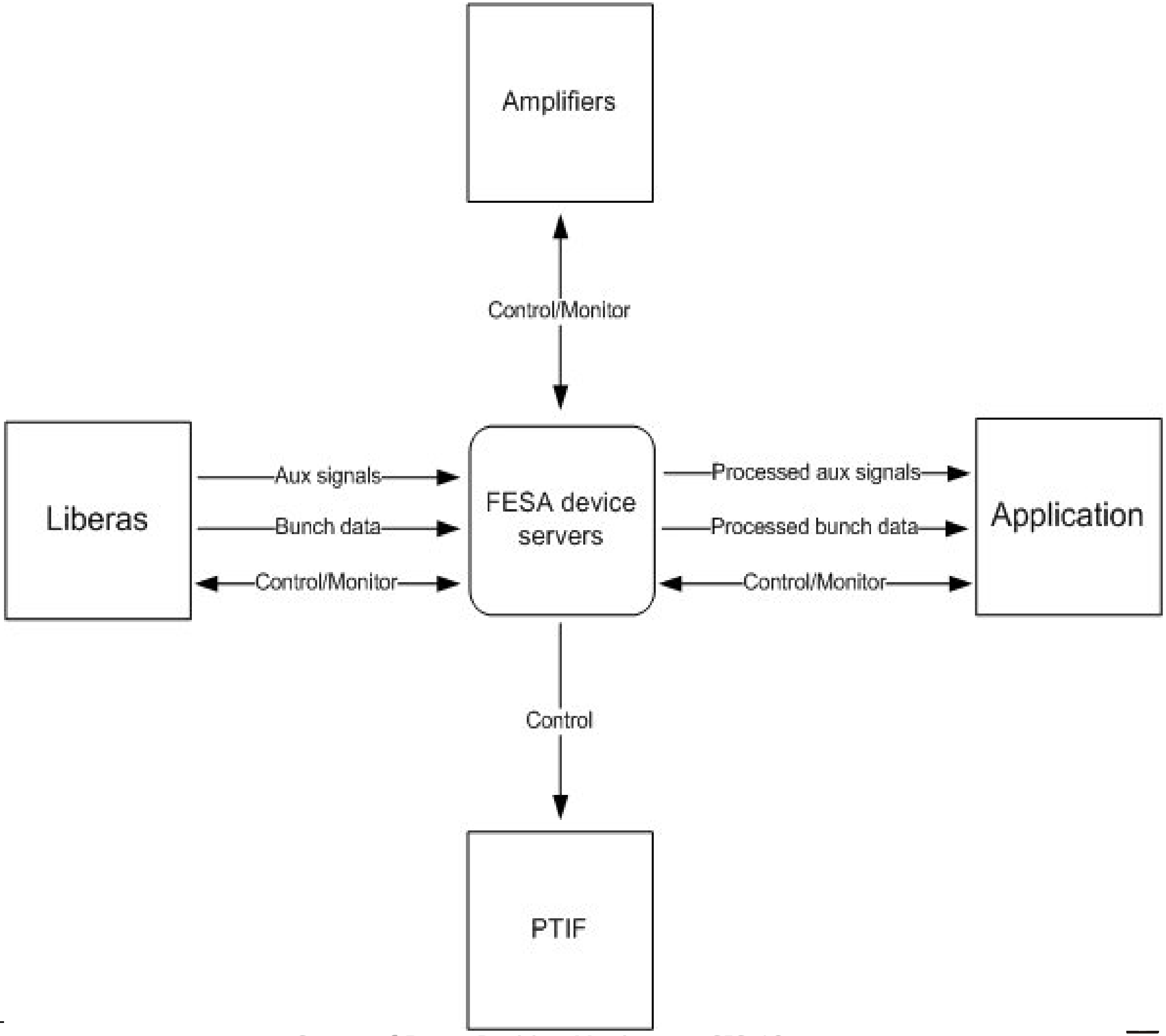


- 2x QuadCore CPUs, 2GHz
- 32GB RAM
- 146GB RAID 0, 10.000 U/s
- 160GB RAID 1, System

Fair Control System architecture (prototype)

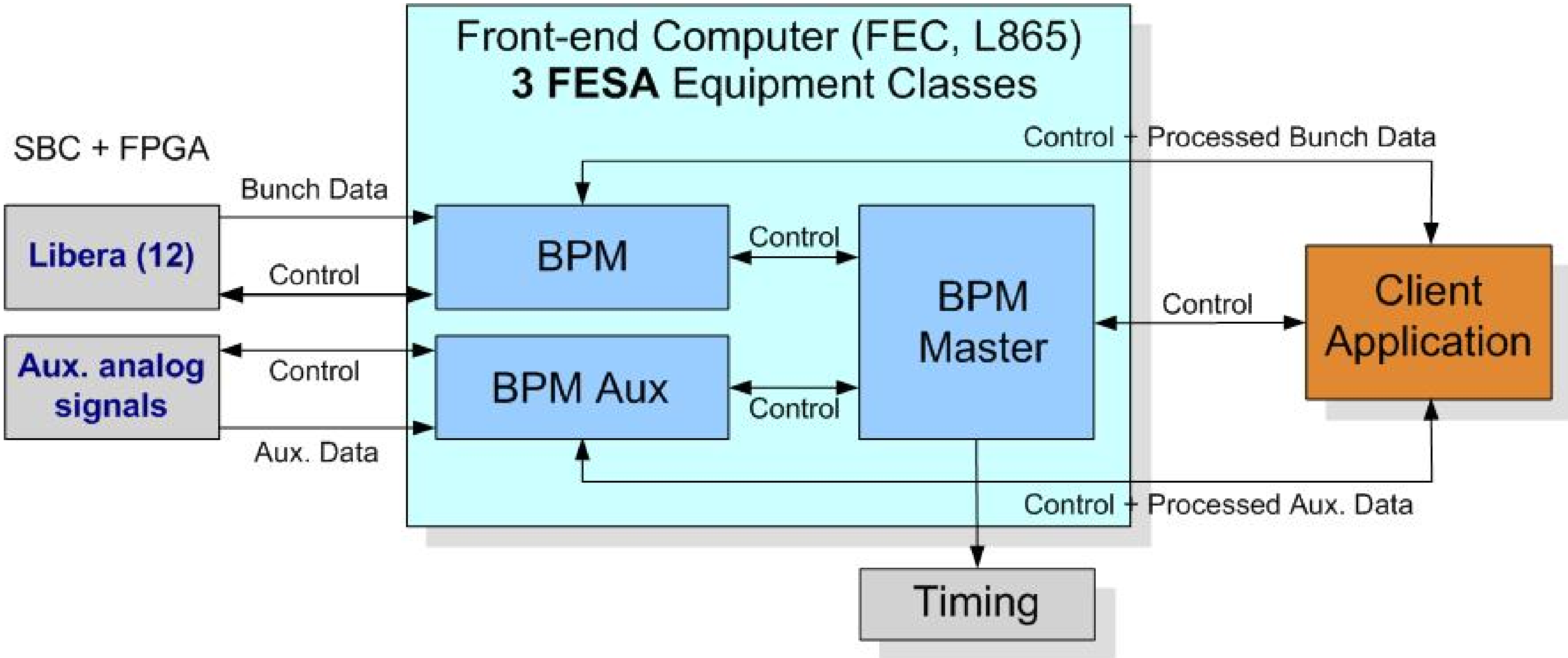


Software


Amplifiers
Control/Monitor
Liberas
Aux signals
Bunch data
Control/Monitor
FESA device servers
Processed aux signals
Processed bunch data
Control/Monitor
Application
Control
PTIF

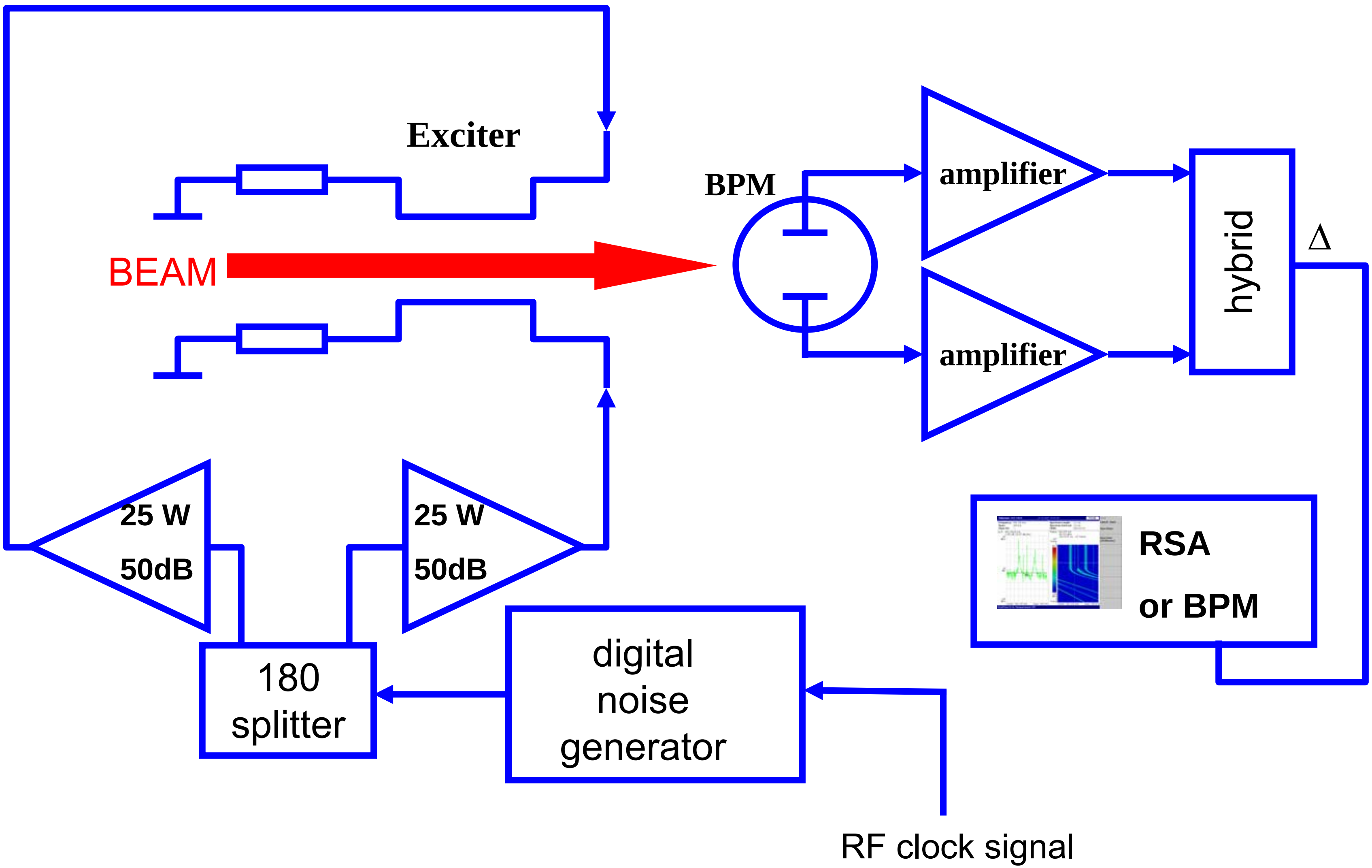
Software

- 3 FESA Classes:
  - BPM
  - BPM Master (Concentrator)
  - AUX Libera (Transformer, RF etc.)




File View Options BPM Mode Help
Time & Date & Info
03. Apr 2009 02:06:23
11
11 18 2 300 40 AR TS HHD
Amplifier Settings
Amplifier Gain [dB]:
-10
PTIF Settings
Start Event: 43 Ramp start
Start Delay: 1 ms
Stop Event: 49 Kick start 1
Virtual Accelerator
Virtual Accelerator:
Vrt. Acc. 11
Calibration Info
Zero Line Calibration: 23:52:54 02. Apr 2009
Position Offset Calibration: 01:51:48 03. Apr 2009
Status
S01DX S02DX S03DX S04DX S05DX S06DX
S07DX S08DX S09DX S10DX S11DX S12DX
AUX BPM:
Master:
Advanced...
Operation Controls
Start Stop
Continuous Binary Archive Over./Under. Status
One Shot ASCII Archive Intensity
Sub Modes
Closed Orbit Over./Under. Status Trending Trending Mean Value
Intensity Tune AUX Signals Consistency Check
Closed Orbit
Averaging Bin Size [bunches]: 500 Point in Time: 500 ms
Legend
Horizontal
Vertical
Position [mm]
20 10 0 -10 -20 -30
S12DX S01DX S02DX S03DX S04DX S05DX S06DX S07DX S08DX S09DX S10DX S11DX
BPM
Consistency
BPM: S05DX
Legend
Consistency
Window Length
70 60 50 40 30 20
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
Time [ms]
02:06:22 – Intercepted Communication Error: S03DX BPM::getIntensity: no data available.

Tune Measurement



Tune measurement (off-line analysis)

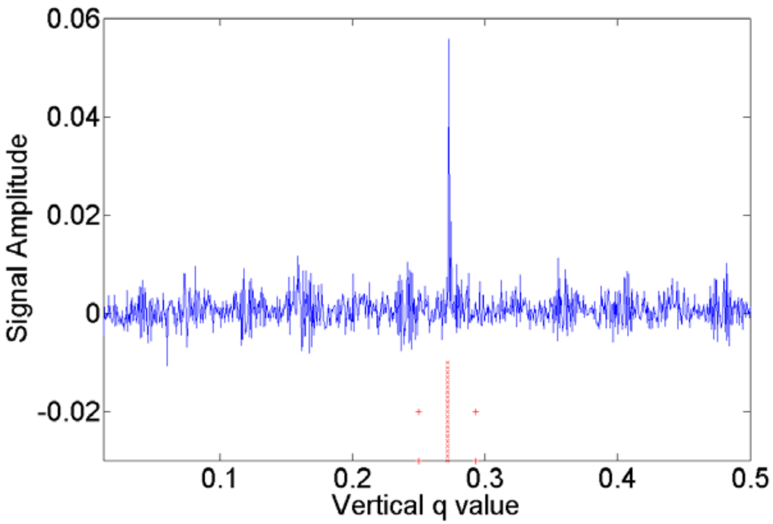
Detecting the bunch position on a turn-by-turn basis the tune can be determined:

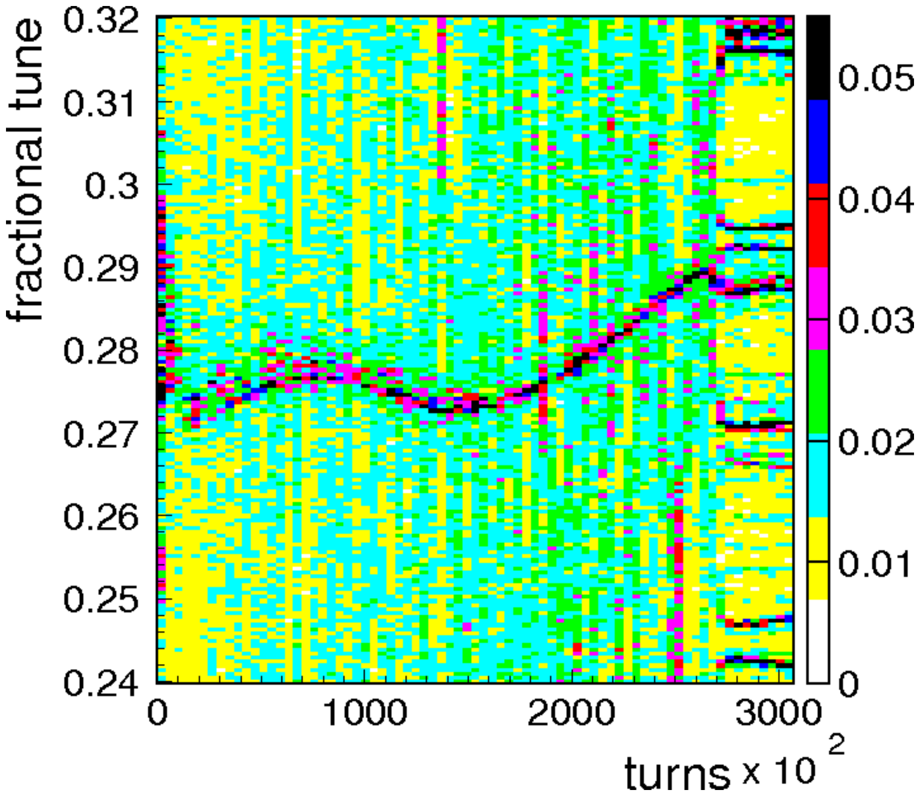
Fourier transformation of position data

→ tune within 2000 turns corresponding ≈5 ms time resolution

Beam parameters at GSI Synchr.:

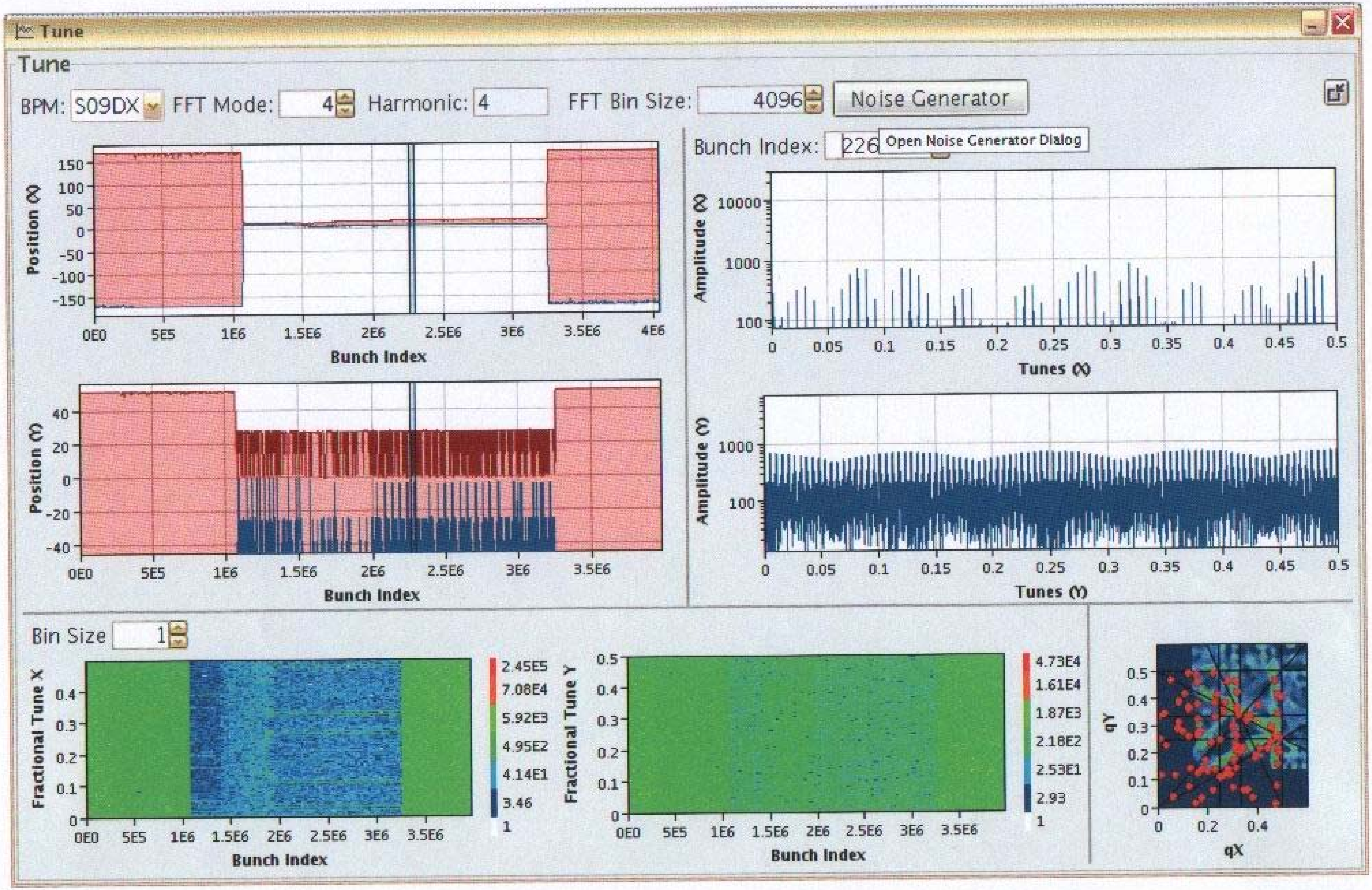
U^{73+} acc. 11 → 250 MeV/u
within 500 ms,
Noise excitation corresponding ΔQ=0.04
of power 1.5 W





U. Rauch et al., GSI Ann. Rep. 2008

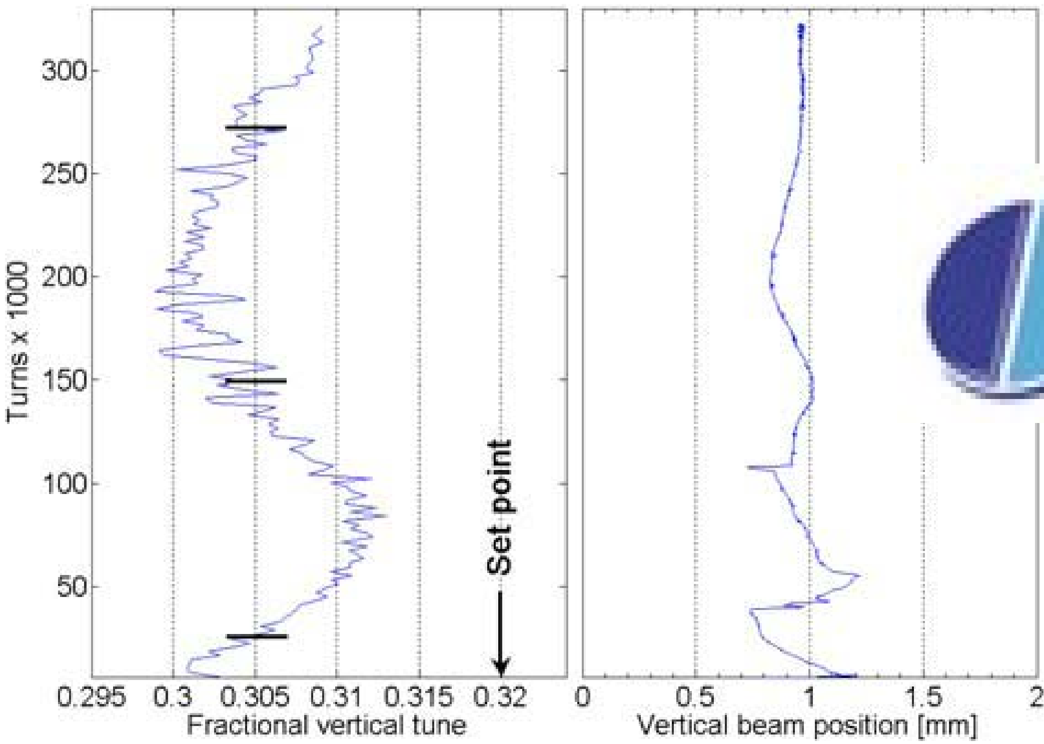
On-line Tune measurement (not yet fully functional)



Motivation for fast feed-back

- Closed orbit correction needed due to relative reduce aperture (SIS100)
- Precisely corrected orbit essential for precise tune measurement and correction.
- Presently only feed forward: 1 at injection, 2 at extraction.
- Tune measurement crucial for high intense beams!

Idea: T. Hoffmann



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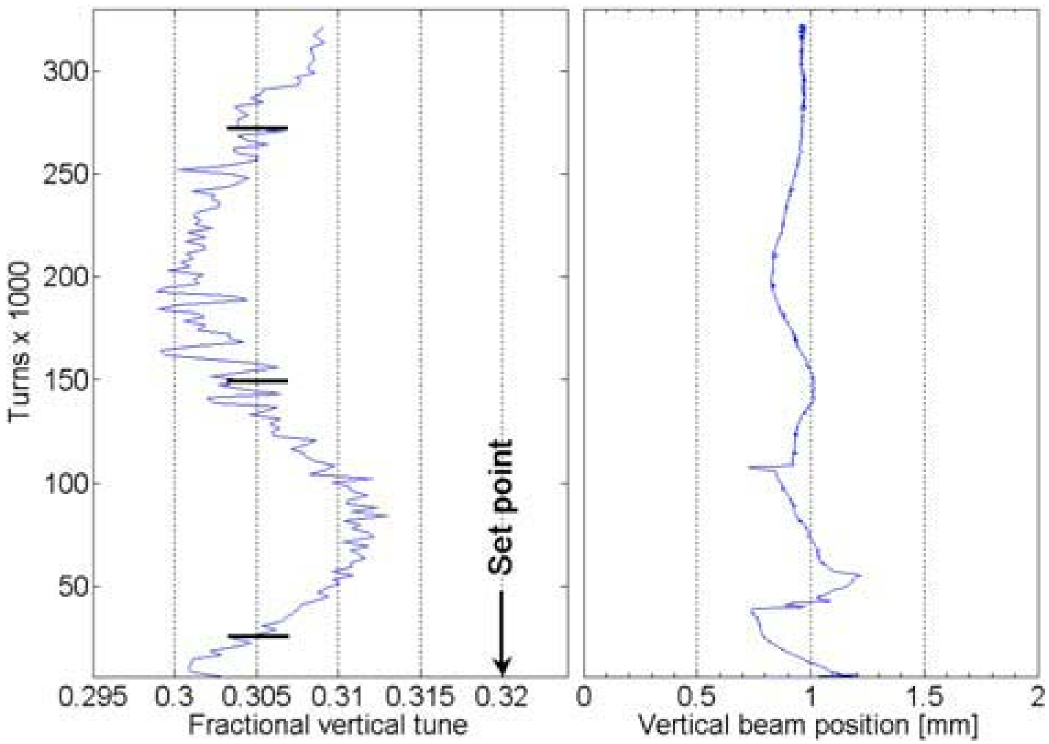
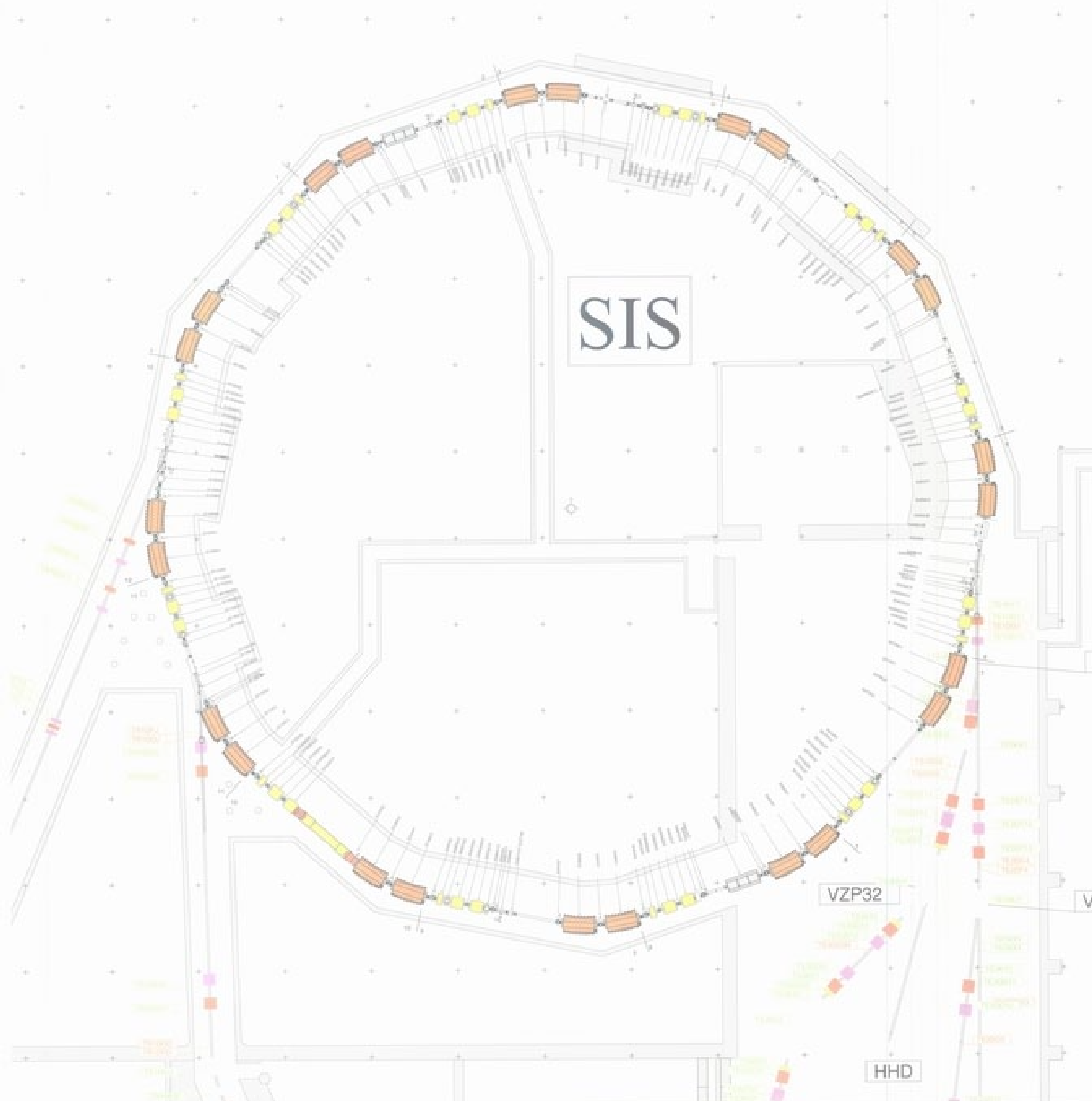


Closed orbit feed-back: BPM vs. correctors (steerers)

- 12 BPMs
- 12 vertical steerers (one per period)
- 24 horizontal steerers integrated with dipoles. Only 12 can be used for closed orbit feed back (see table next page).
- Digital or analog control (see D. Schupp, APC specification)



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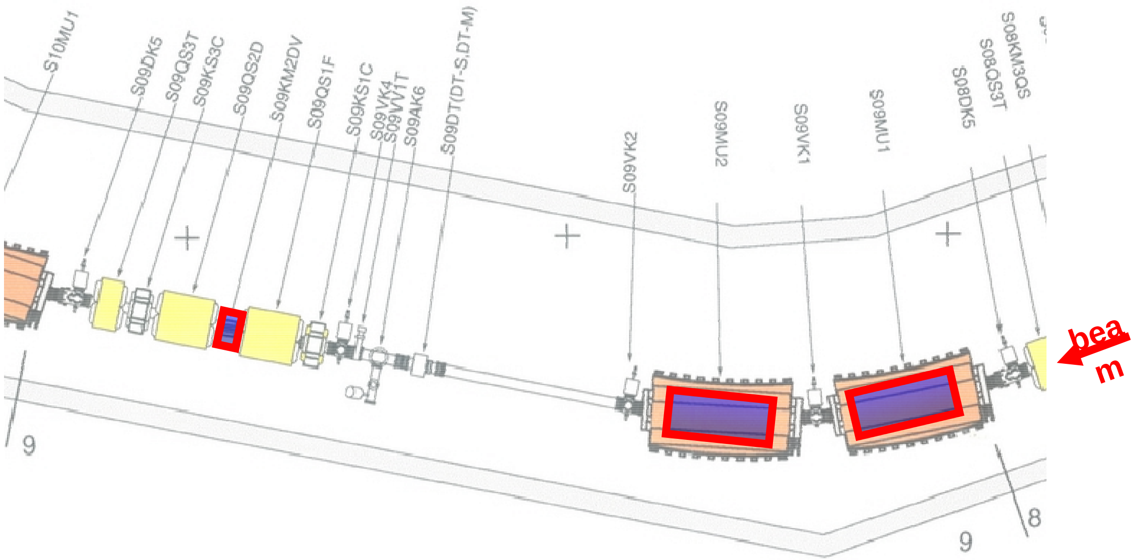


One SIS18 period

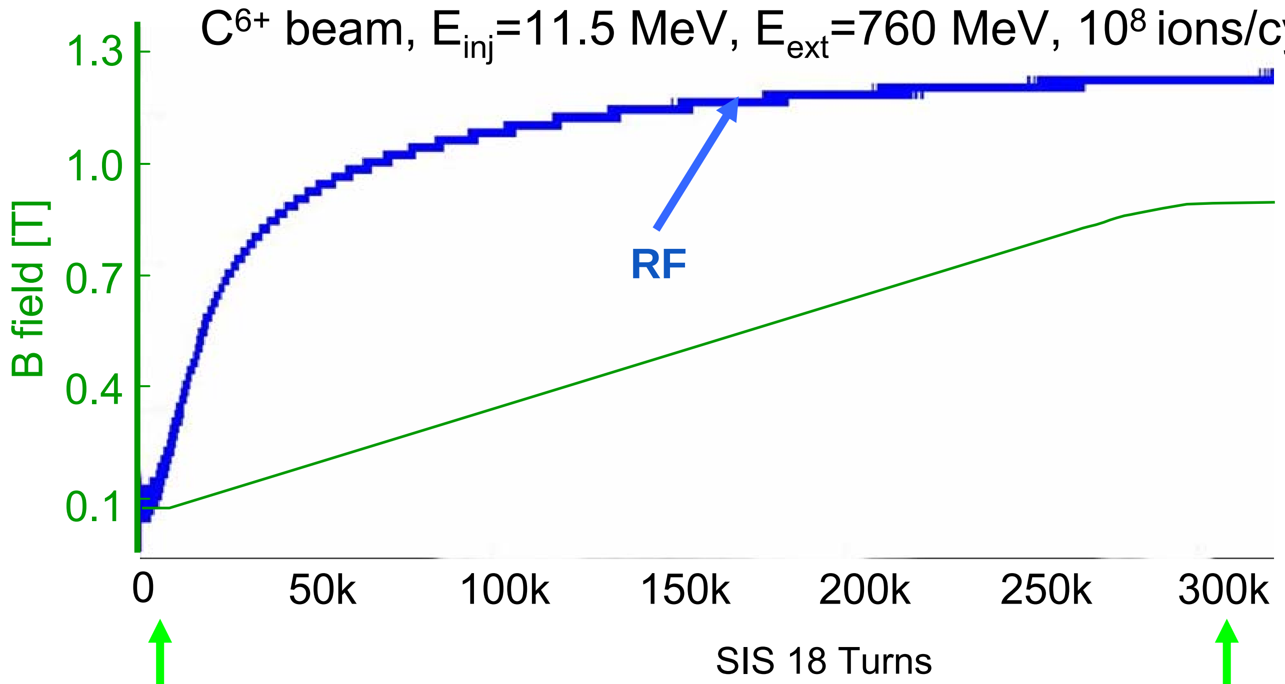
Closed orbit correctors (steerers) table

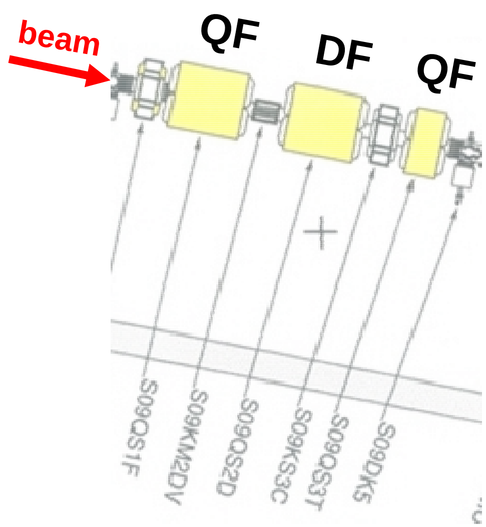
- Not always the same steerer in the period lattice are available
- Some of them have presently only unipolar power supply.

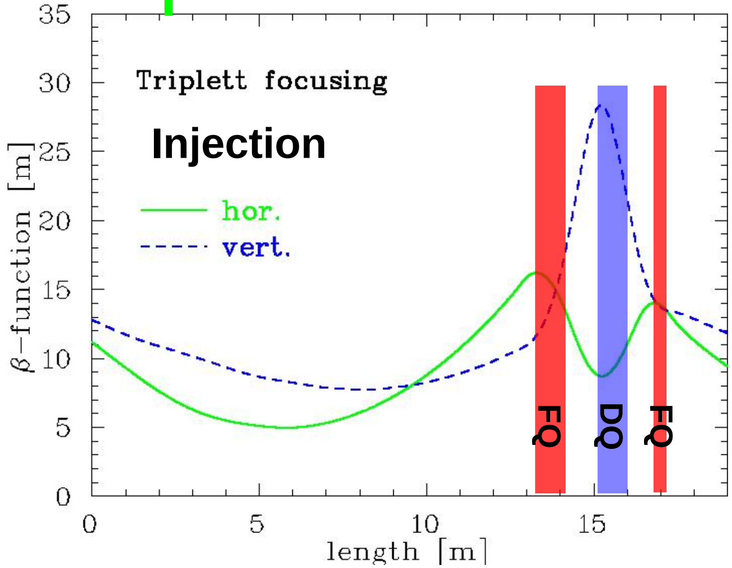
Dipolmagnete	Korrekturmagnte	Netzgeräte Typ SVE 10A-SIS 40A	10B-SIS 250A	22 -SI 60A	10.1A-SIS 60A	Polarität (NG) 05.04.2009
S01MU1	S01MU1A	S01MU1A				1
S01MU2	kein Kabel					
S02MU1	S02MU1A				S02MU1A	0
S02MU2	kein Kabel					
S03MU1	S03MU1A	S03MU1A				1
S03MU2	kein Kabel					
S04MU1	S04MU1A		S04MU1A			
S04MU2	S04MU2A				S04MU2A	0
S05MU1	S05MU1A	S05MU1A				-1
S05MU2	S05MU2A		S05MU2A			
S06MU1	S06MU1A		S06MU1A			
S06MU2	S06MU2A	S06MU2A				**1**
S07MU1	S07MU1A				S07MU1A	0
S07MU2	S07MU2A		S07MU2A			
S08MU1	S08MU1A				S08MU1A	0
S08MU2	kein Kabel					
S09MU1	S09MU1A	S09MU1A				1
S09MU2	kein Kabel					
S10MU1	S10MU1A			S10MU1A		0
S10MU2	S10MU2A		S10MU2A			
S11MU1	S11MU1A			S11MU1A		0
S11MU2	S11MU2A		S11MU2A			

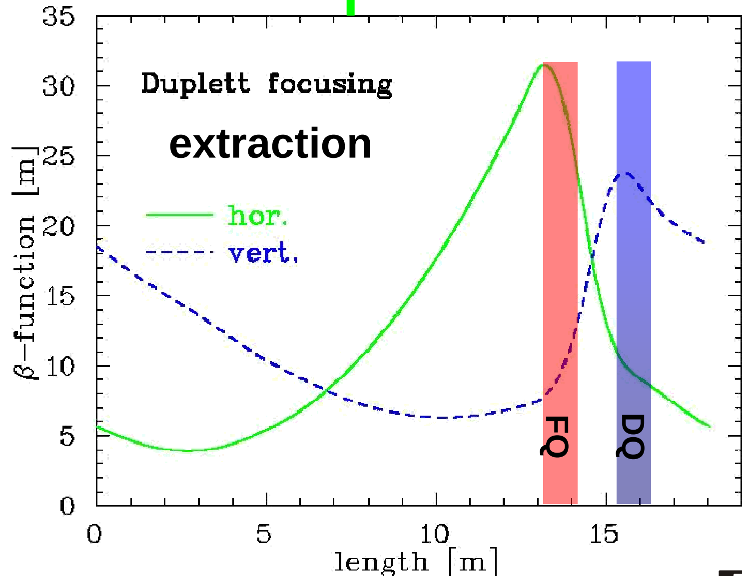
**H. Ramakers,
GSI EET Dept.**

Triplet vs. duplet focusing (challenge).









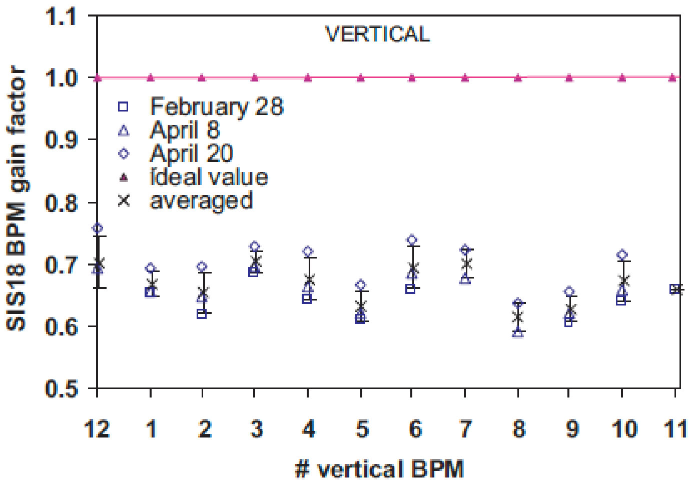
Theory sources ;)

Linear optics study: ORM	A. Parfenova, C. Omet, et al.
Closed orbit correction	A. Parfenova, C. Omet et al.
High order linear optics: chromaticity	A. Parfenova, S. Paret, S. Appel, W. Daqa
Study of linear coupling	W. Daqa
Studies on the 3rd order resonance	S. Sorge
Reconstruction of Nonlinear components	A. Parfenova
High intensity effects on resonances Study on collective effects	O. Boine-Frankenheim G. Franchetti, V. Kornilov

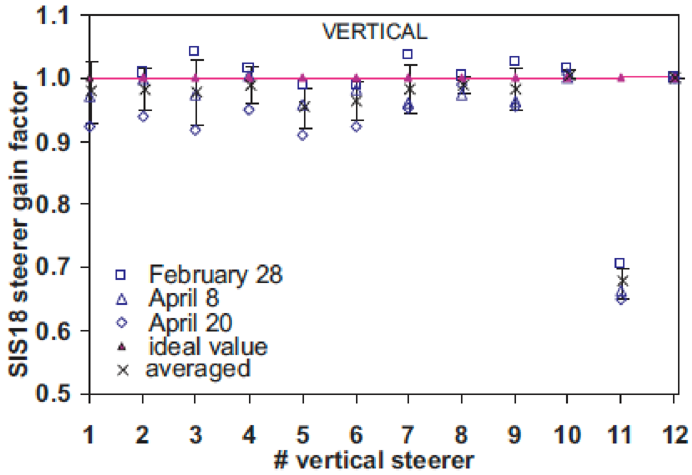
SIS18 closed orbit correction using a local bump method
A. Parfenova, G. Franchetti, B. Franczak, M. Kirk, C. Omet
GSI-Acc-Note-2006-11-001

Orbit response matrix method applied to SIS18 for lattice optimization
A. Parfenova, G. Franchetti, C. Omet, S.Y. Lee
ACC_RD_note-2007-001

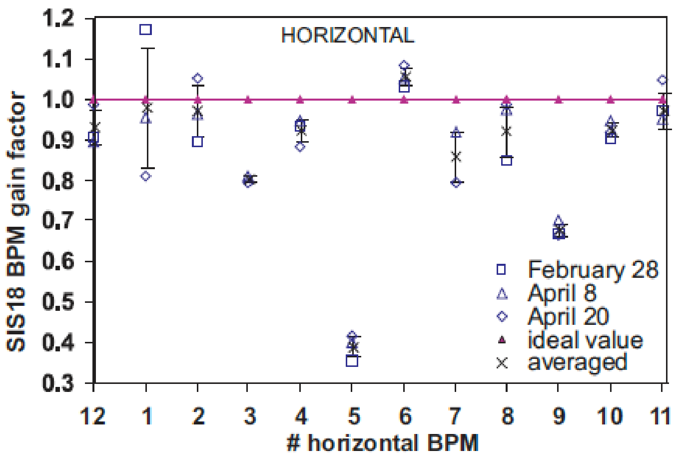
BPMs vs. Steerers calibration



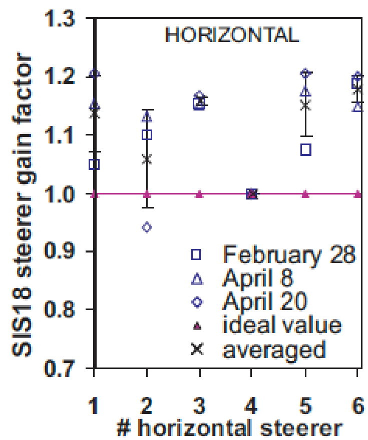
a) Vertical BPM calibration factors



b) Vertical steerer calibration factors



a) Horizontal BPM calibration factors



b) Horizontal steerer calibration factors

Angelina's PhD

Summary and outlook

Position mesurement:
- Commissioning of FESA based system (April 2009)
- System test and eventual optimization in operation
- Test for data consistency and system stability
- Installation High Precision Clock (EE)

Hardware/software upgrade of BPM system:
- Upgrade of 50 Ohm preamplifier
- Test generator for each BPM station
- Timing conceptual design based on RT Actions.
- 64 Bit Version FESA und Timing.

Calibration of BPMs and Steerers (beam based)

Feed back for closed orbit and ...

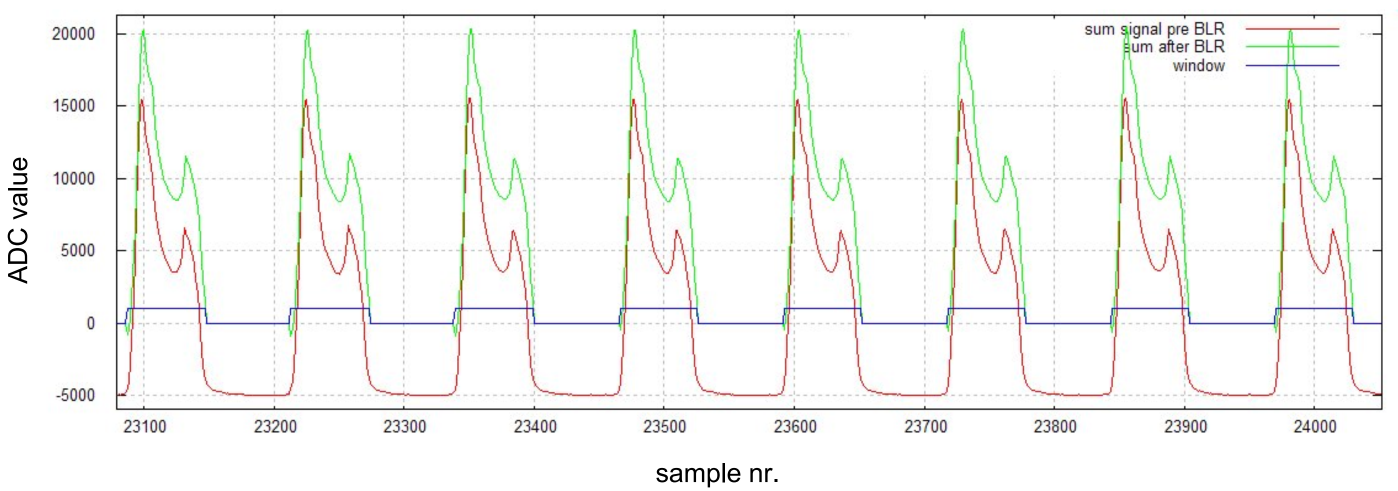
- Conceptual design of algorithm
- Communication with correctors and data basis
- Concept for the corrections transition for triplet/duplet optics
- Coexistence with feed forward, local bumps (time constants etc)
- Scaleable system topology

Thank you for your attention!

Advantages and challenges of the method

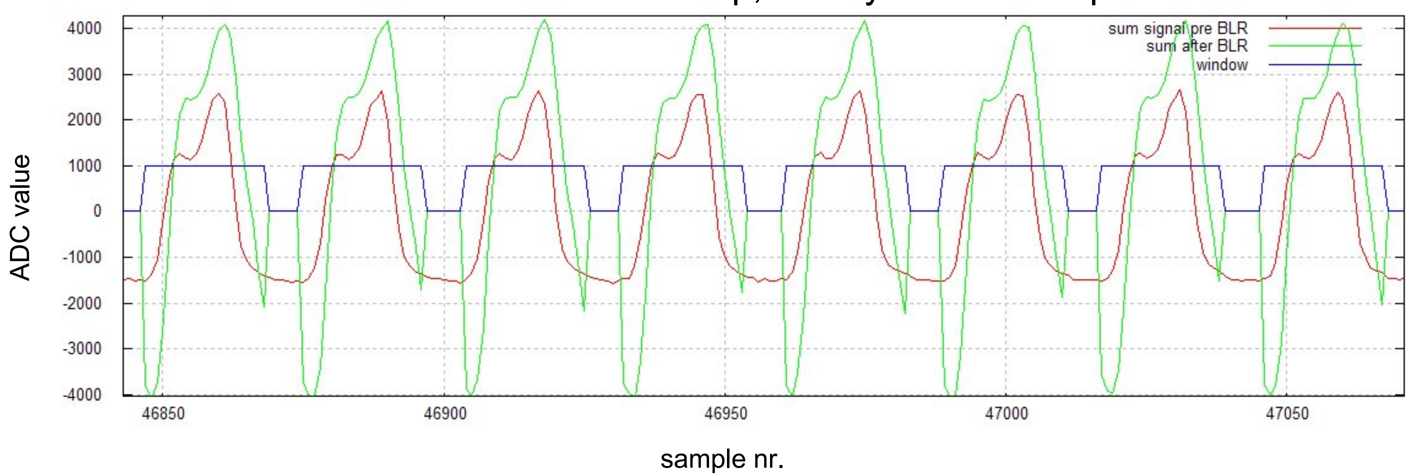
- It works even for strong deformed bunches.

Cooled beam – ramp beginning

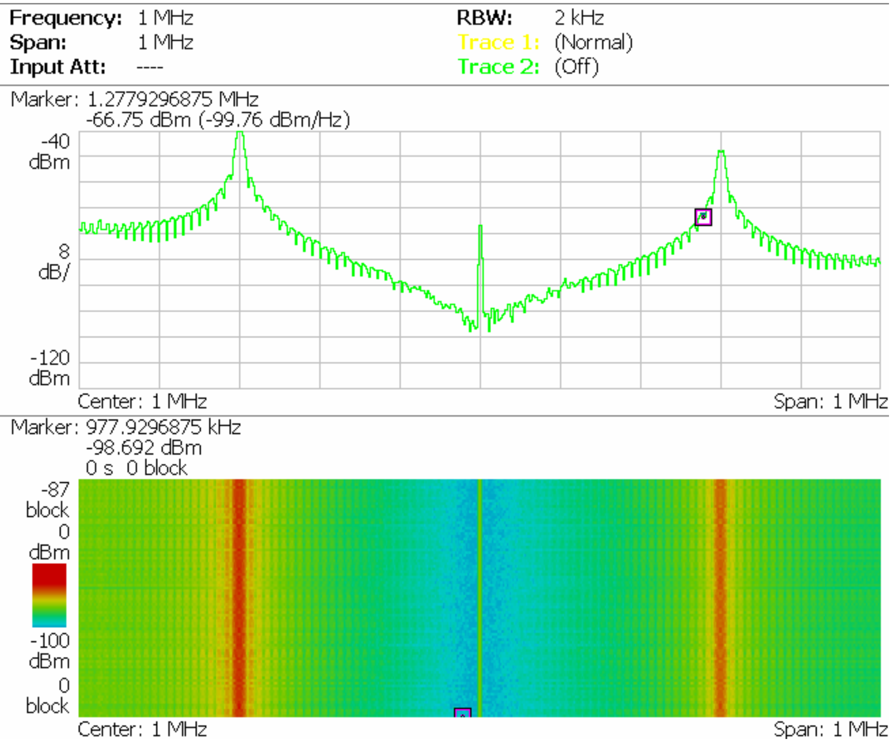


- But it has problem when bunch length > bunch distance.

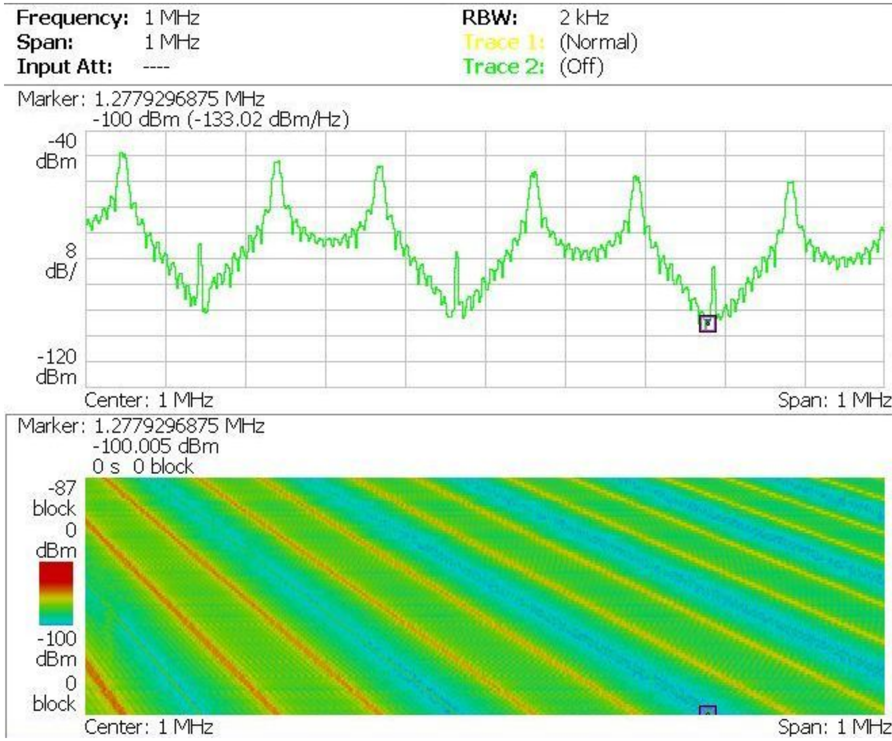
Cooled beam – ramp, shortly for the flattop



Digital Random Noise Generator



1 MHz carrier frequency
Number of harmonics : 1
q is set to 0.3 with a dq of 0.01



Frequency sweep (pseudo-RF as input)
Number of harmonics : 4
q is set to 0.3 with a dq of 0.03

Amplitude and width of excitation can be modified also remote controlled