Instrumentation Technologies

Beam diagnostics for FAIR

NUSTAR

September 27, 2017

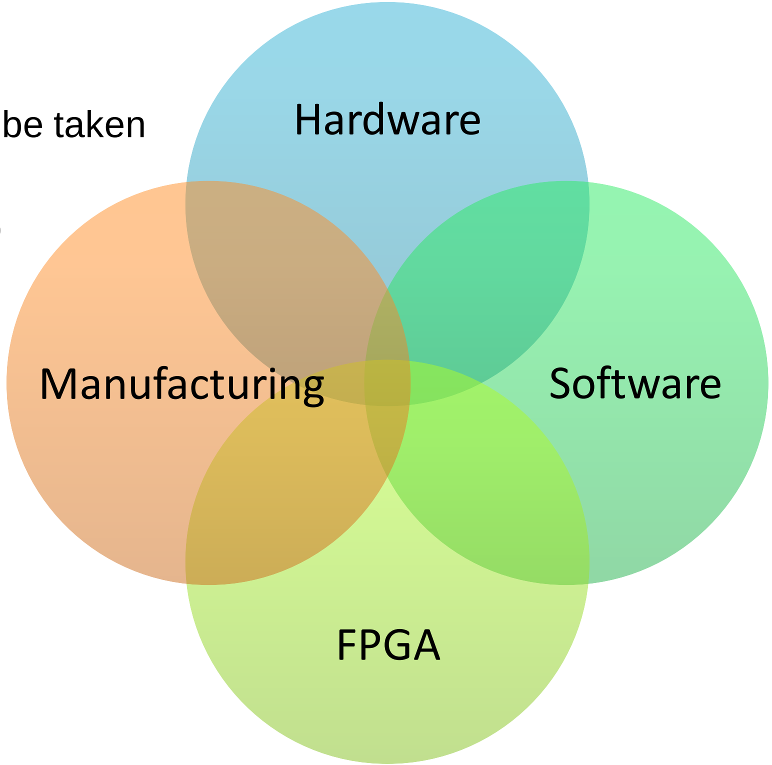
Outline

- Instrumentation Technologies
- Diagnostic instruments
- Instruments at FAIR
- SIS 100 BPM system
- Pulse detector at HEBT
- BPM for P-Linac

Where we play

- Specialized in design and development of High Performance Electronics and Systems

- Field of Particle Accelerators where extremely
  - Accurate, precise and stable measurements need to be taken
  - High frequency RF signals are treated *(MHz-GHz)*
  - Fast digitization is required *(up to 1 GS/s, 8 to 20 bit)*
  - Intensive FPGA Real-Time data processing is necessary *(~ns latency)*
  - High synchronization level between distributed systems is required *(ns to fs)*
  - **High level of reliability required**



Instruments

- Beam position monitors (electron and hadron machines, linear and circular), beam loss monitors, synchronization systems, LLRF system, beam phase measurement system …

- **FAIR project**
  - **Various BPM systems**
  - LLRF system

- BPM system components
  - Preamplifier – prepares the signal for BPM
  - Timing module – synchronization, triggering …
  - Beam position monitor – position measurement
  - Fast data exchange module – global position processing (COFB)
  - Magnet control module – provide position corrections to magnet power supply

Beam Position Monitor

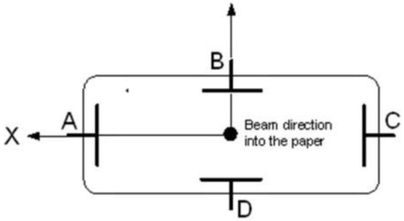
$$X = K_X \frac{(V'_A - V'_C)}{(V'_A + V'_C)} + X_{OFFSET}$$

$$Y = K_Y \frac{(V'_B - V'_D)}{(V'_B + V'_D)} + Y_{OFFSET}$$

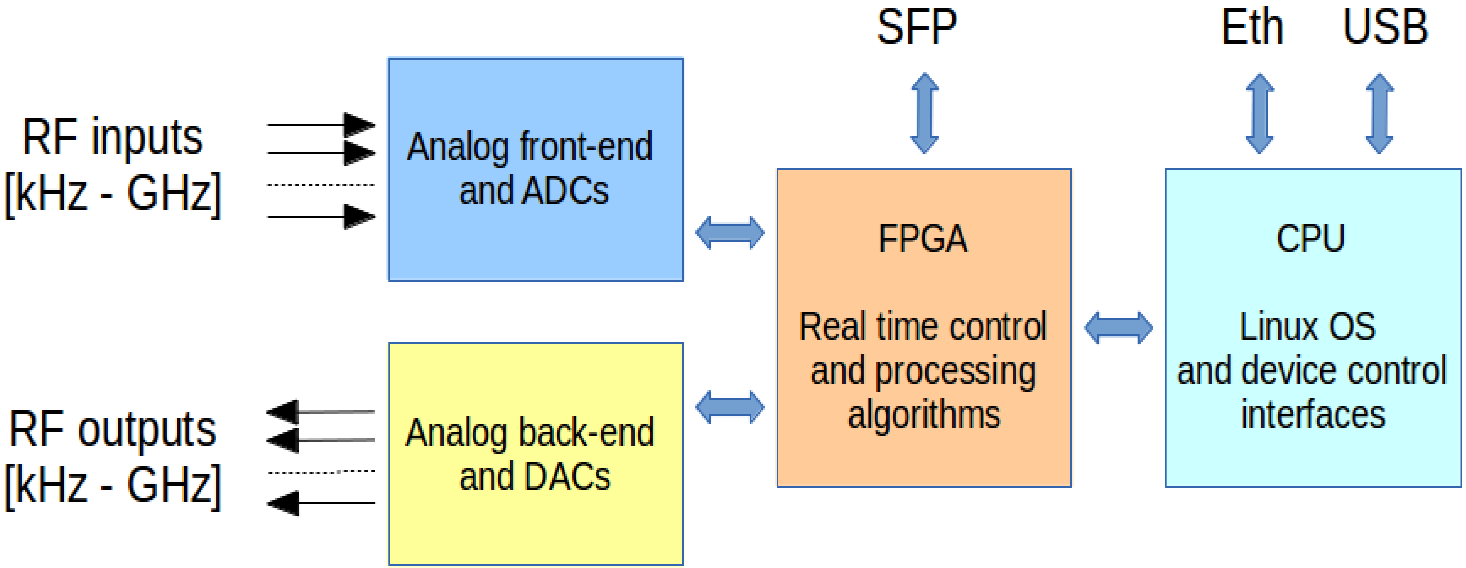
A beam position monitor measures the position of the particles in the accelerator pipe with *um* resolution enabling the real-time control of the particle trajectory.

The Challenges:

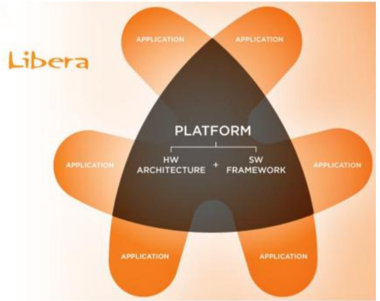
- Extraction of only useful data (bunches)
- Cover wide input signal dynamic range (commissioning phase, various operation modes)
- Maintain measurement stability under various conditions
- ….



Common System Overview



Instrument Development Platform

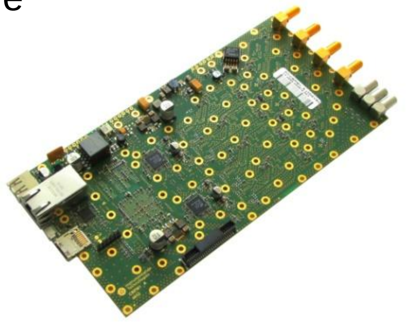


Modular (FAIR project)

- Xilinx Virtex 6 FPGA
- Intel core 2 processor
- Up to 9 input channels per module
- Up to 250 MHz / 16 bit ADCs
- Up to 4 GB SODIMM per module
- GDX module

Compact

- Xilinx Zynq-7020 or Xilinx Zynq-7035
- 4 input channels
- 125 MHz / 14 bit ADC or 500 MHz / 14 bit
- 1 GB data storage
- USB storage
- PoE supply



FAIR complex

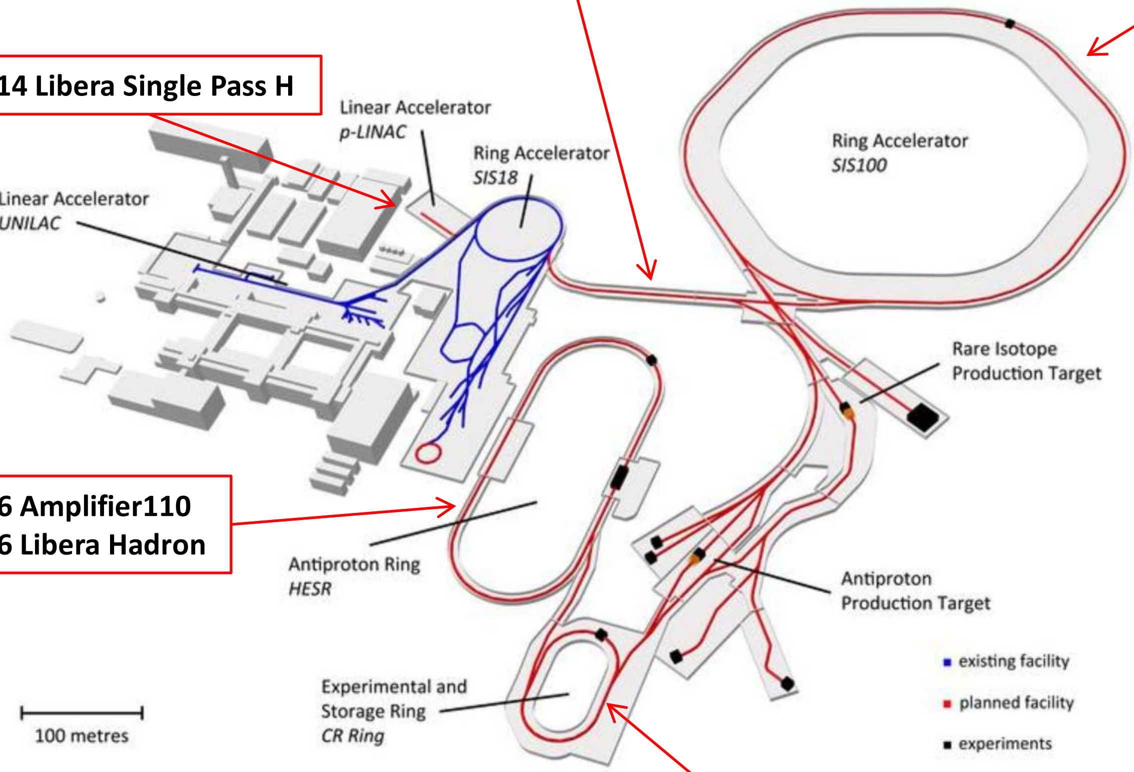
35 Libera Hadron pulse detector

84 Amplifier110
84 Libera Hadron
COFB (closed orbit feedback)

14 Libera Single Pass H

76 Amplifier110
76 Libera Hadron

18 Libera Hadron



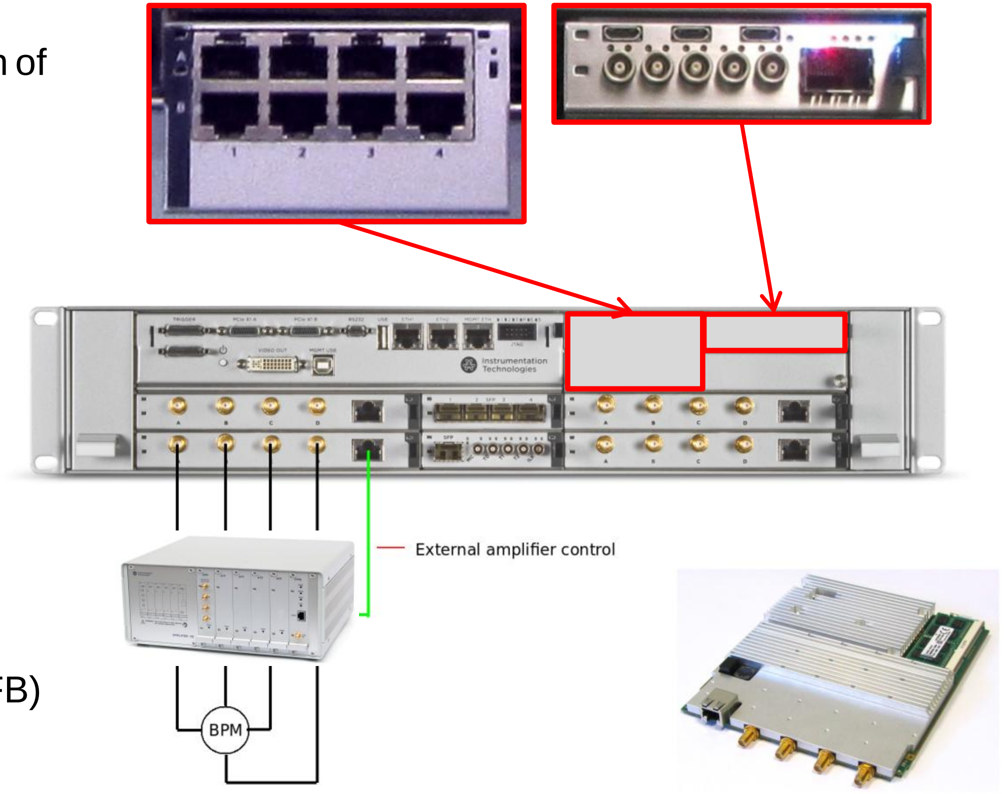
Libera Hadron BPM system (SIS 100 …)

Goal:

- Store and provide position information of all bunches in the acceleration cycle
- Control corrector magnets in order to assure stable position in the acc. ring

Libera Hadron system components:

- Software controlled Preamplifier
- FTRN timing module (COSYLAB)
    - WR protocol support
- SER module
    - Provides data to the magnet
- Fast data exchange GDX module
    - global position processing (COFB)



Amplifier 110

SIS 100 operate in different modes – signal intensity changes

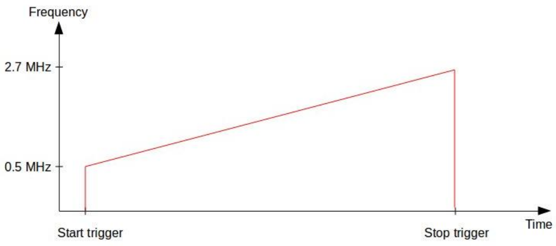
Amplifier 110 couples with Low / High signals

- Low noise amplifier
- Dynamic range: -50 dB … 60 dB
- Bandwidth: 40 kHz…55 MHz
- Range switching time: 1 µs - 20 us
- Output signal level: 2 Vpeak

Libera Hadron (SIS 100, HESR, CR)

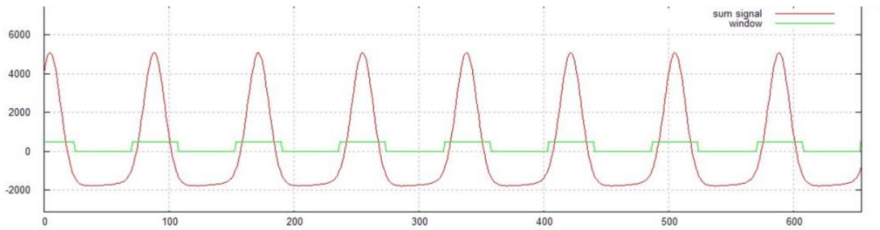
Beam position/charge monitor for circular hadron machines:

- Bunch repetition rate: kHz to few MHz
- Bunch length: several ns (after injection) down to some ns (at extraction)
- Cycle duration: up to several seconds



Injection - acceleration - extraction:

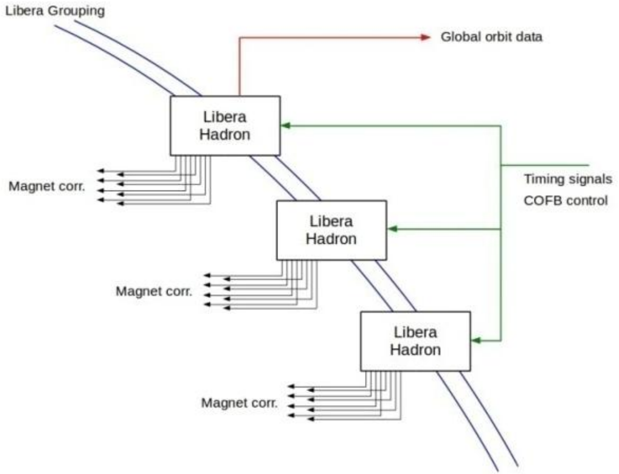
- Store ADC data (bunch shape observation)
- Detect bunches and store position of each (Bunch-by-bunch) – Studies
  - Calculate FFTs / FFT peaks
- Stream averaged position (10 Hz) - Monitoring purposes
- Stream averaged position (10 kHz) - COFB purposes
- Calculate correction factors and send to magnets

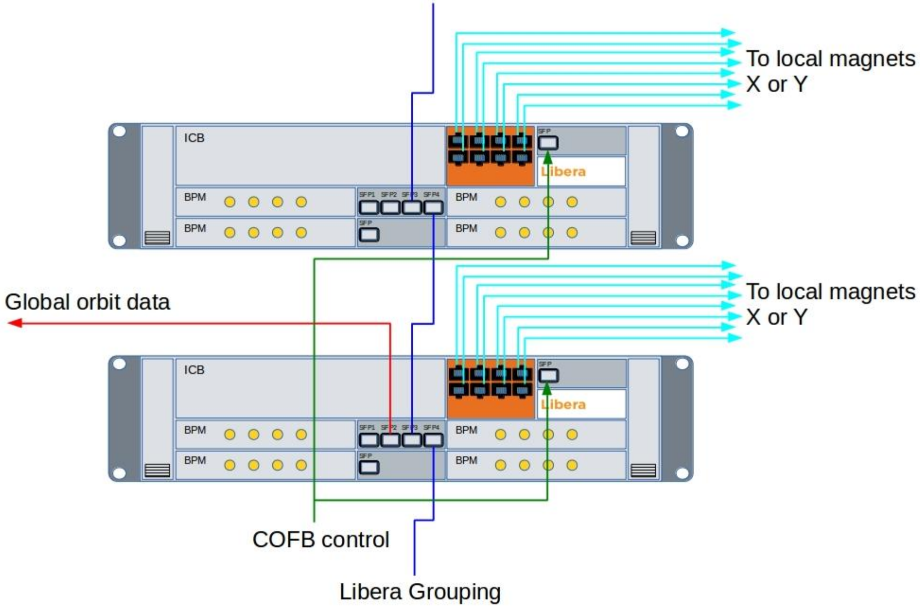


Libera Hadron COFB (SIS 100)

84 BPM modules connected in the (COFB) closed orbit feedback system

- Position data from 84 BPMs is grouped together
- Positions are compared with "GOLDEN ORBIT"
- Correction factors are calculated





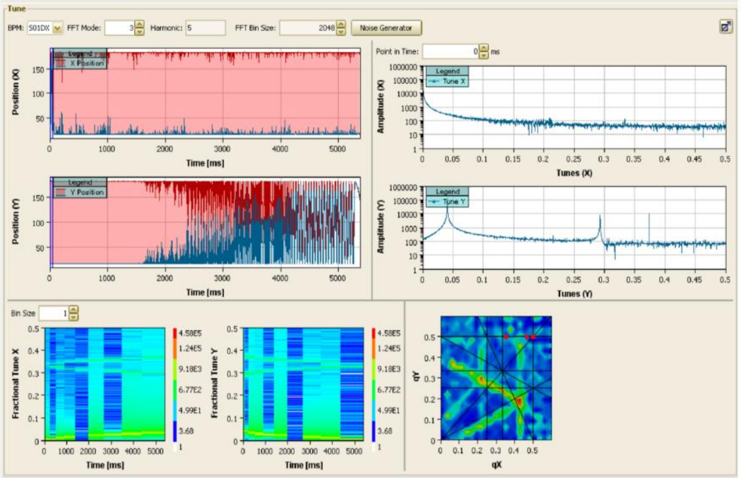
Libera Hadron (SIS 100)

Data provided to the user – Control room

- Beam Position
- Averaged position
- FFT
- FFT peak

X & Y position envelope vs. time/bunches. Obtained using bunch_synth (t_s , t_e , n)

Color coded FFT waterfall diagram vs. time. Obtained using FFT_synth (t_s , t_e , n)



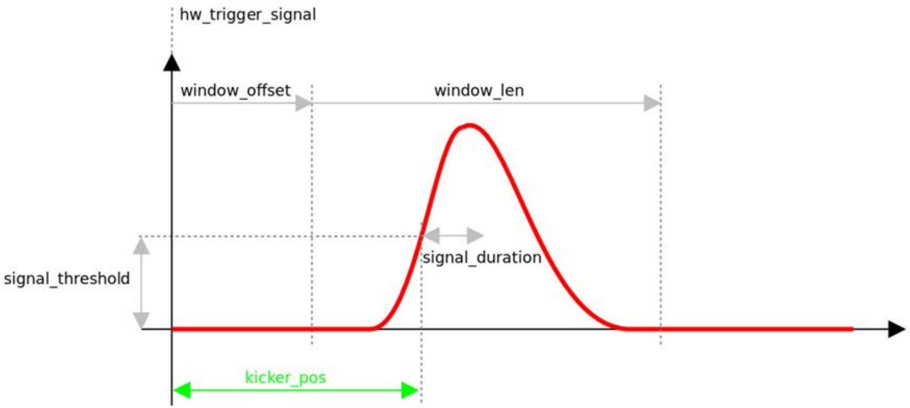
X & Y FFT plot corresponding to specific point in time. Obtained using FFT(t_s , n=1)

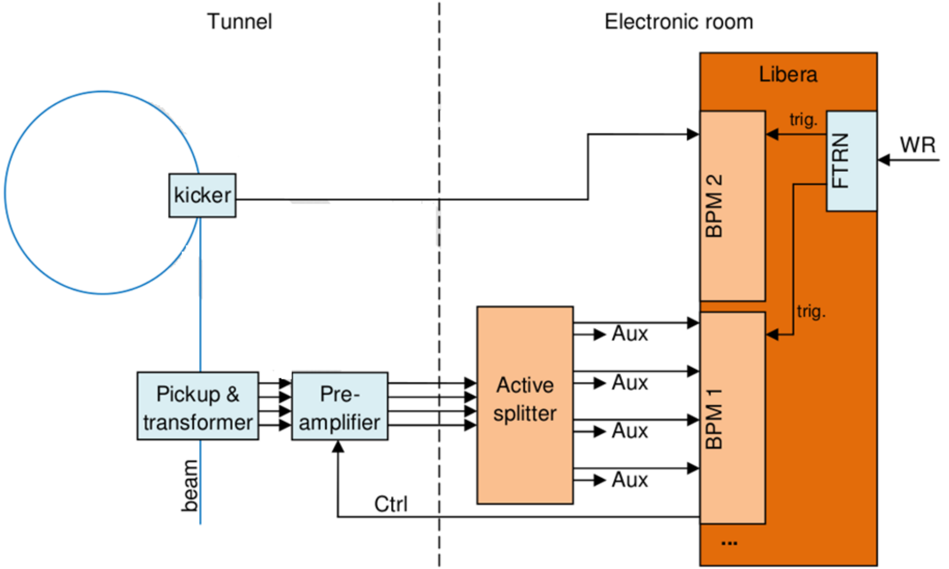
Tune point (X,Y) for a specific point in time. Obtained using FFT_peak (t_s)

Libera Hadron pulse detector (HEBT)

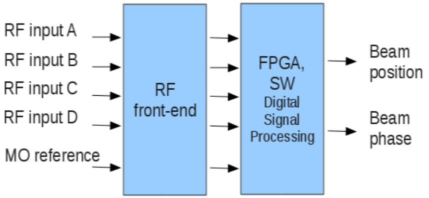
Kicker signal acquisition:

- Acquire 20 us of data
- Calculate time between WR event and kicker signal





Libera Single Pass H (P-LINAC)

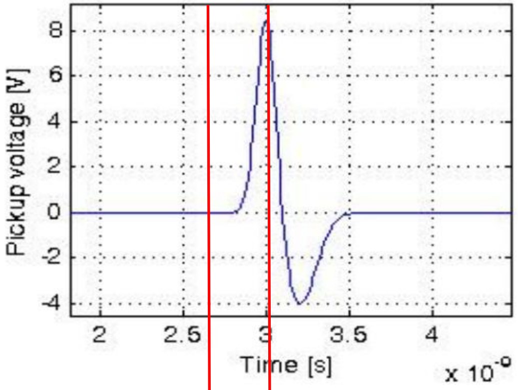


Beam position/phase/charge monitor for linear hadron machines

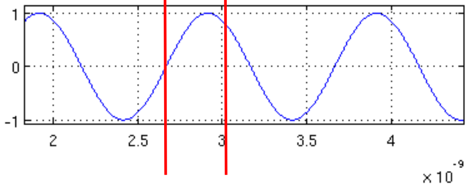
Phase information along the Linac!!!

Start processing on injection trigger:

- Process 130 us long macro-pulse
- Calculate position/phase/charge of 1 us long slices (130 results)
- Perform calculation on first end second frequency component



MO signal:



Conclusion

- In total more than 220 measurement locations will be equipped with Libera processors
  - Libera Hadron is confirmed and in production – first deliverables in the end of 2017

- Successful collaboration with GSI team

- We look forward to see the first beam