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Low Level RF at FAIR

Dejan Tinta

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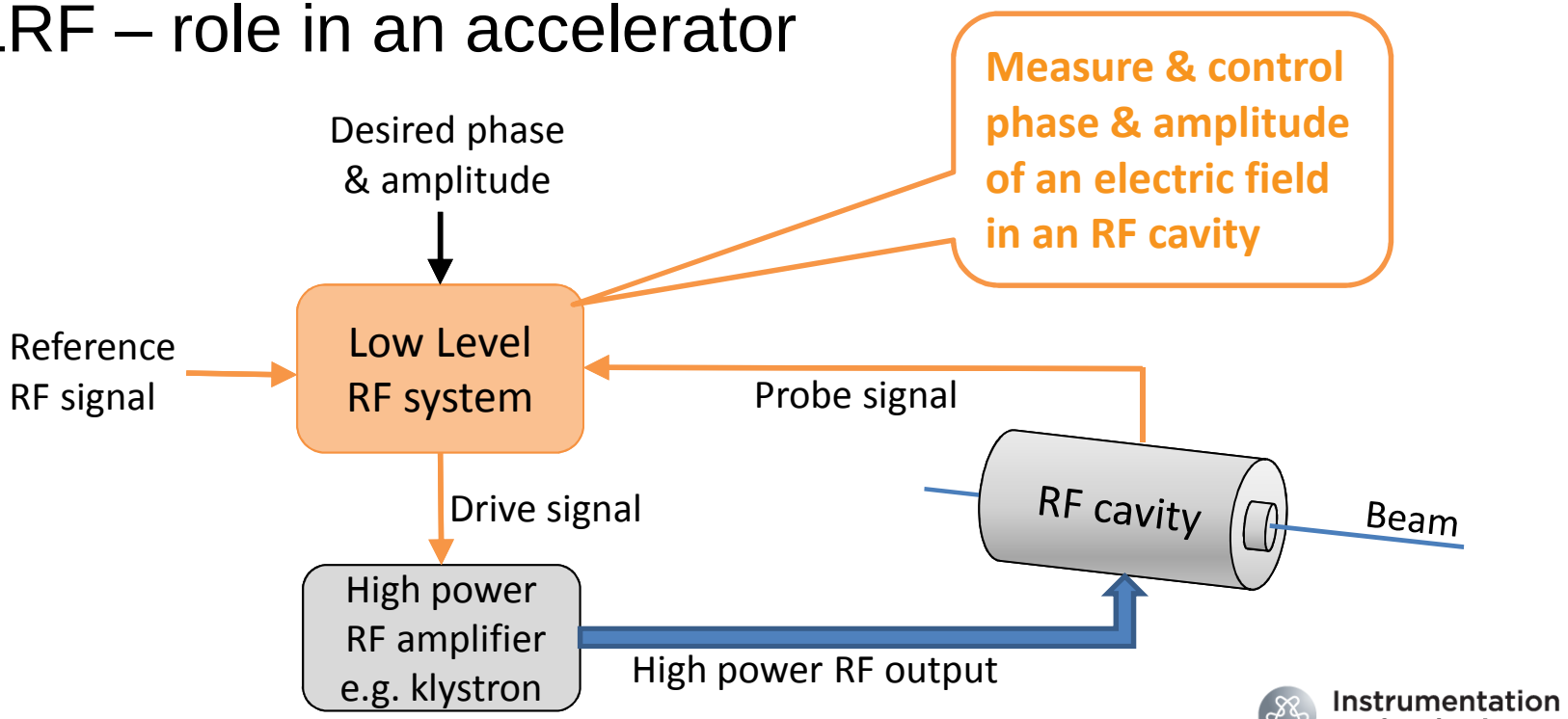
LLRF – role in an accelerator



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LLRF system specifics

Different accelerators require different features:

- Different RF frequencies
- Circular machines, linacs
- Continuous wave, pulse mode of operation
- Standing wave structure, traveling wave structure
- Superconducting, normal conducting RF cavities
- Analog, digital LLRF
- ...

No standard solutions for LLRF systems

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p-Linac LLRF – initial inputs for design

- Experience with existing analog LLRF system at UNILAC
- Requirements for p-Linac
- Instrumentation Technologies digital LLRF system

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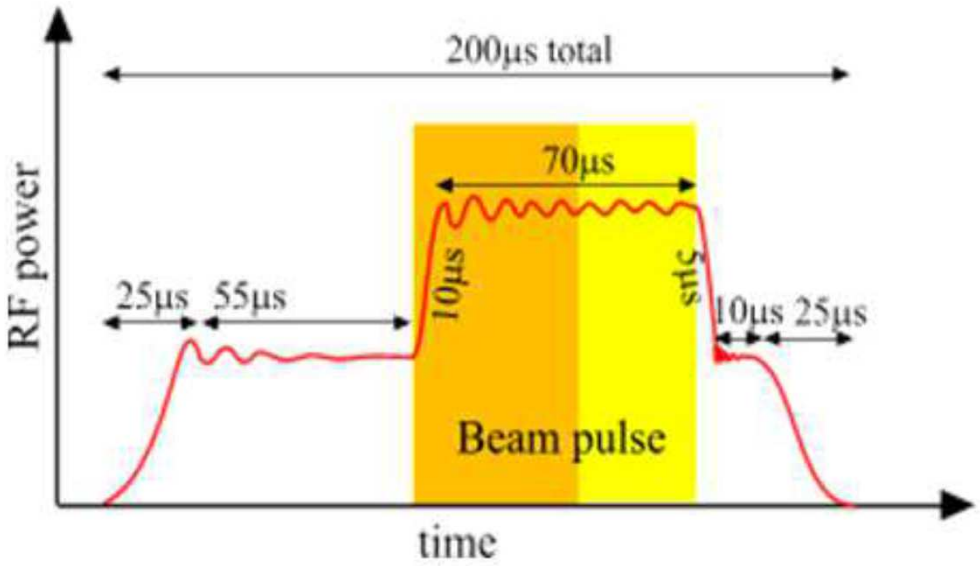
p-Linac LLRF requirements

- RF frequency: 325.224 MHz
- RF pulse length: 200 µs
- Beam pulse length: up to 70 µs
- Pulse repetition rate: up to 5 Hz
- Amplitude stability: 0.1% RMS
- Phase stability: 0.33º RMS
- Latency: <1 µs



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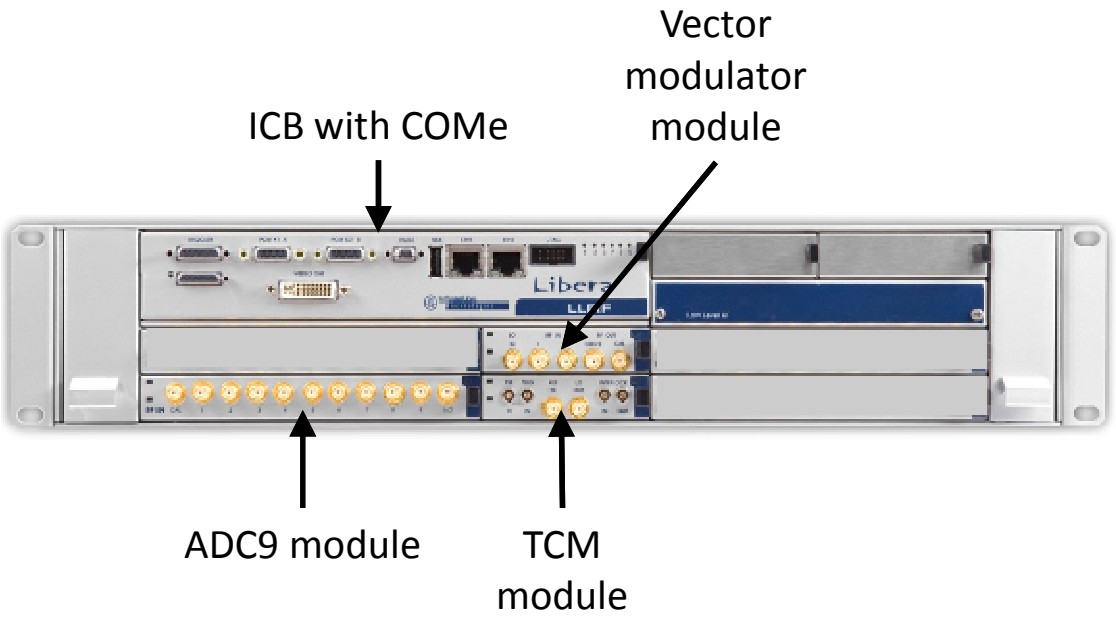
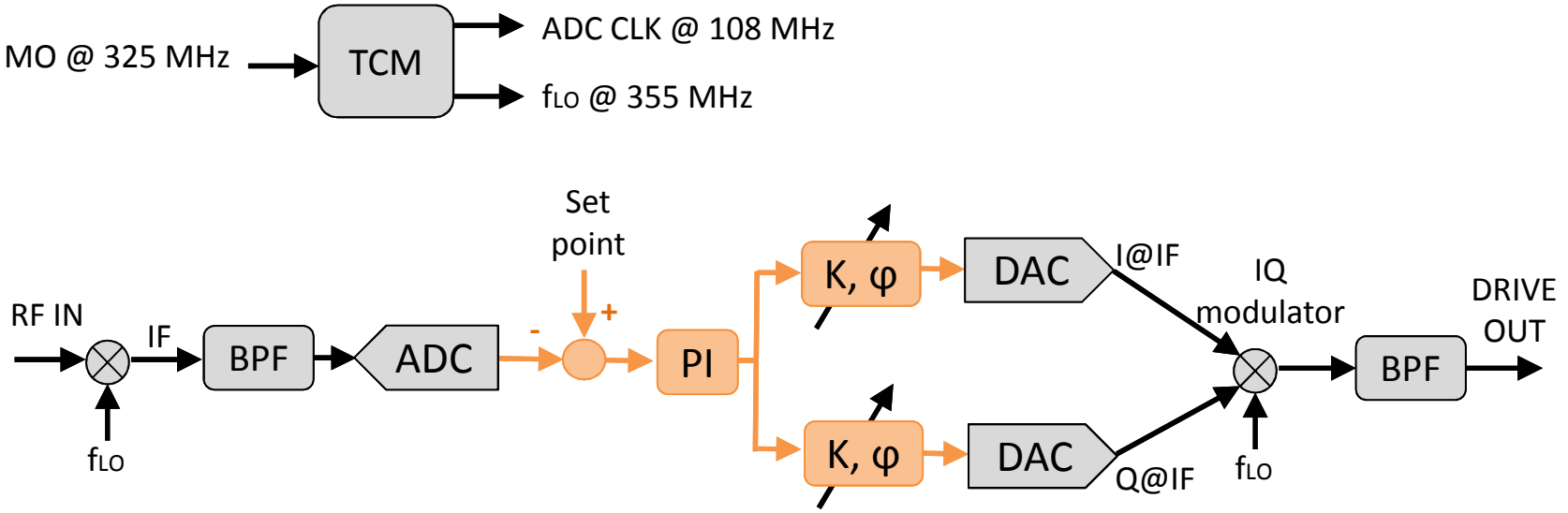
p-Linac LLRF requirements (cont.)

- Diagnostic data at different rates
- RF cavity resonant frequency tuning, applied through states
- Machine protection: intermittent interlock, persistent interlock and AER
- Virtual accelerator time multiplexed operation (Multi pulse operation)
- Integration of FAIR timing receiver (FTRN / White Rabbit)
- Real-time operating system (CentOS)
- Local/Normal operation mode with Expert GUI

Libera LLRF system



Libera LLRF – signal processing in main control loop



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Libera LLRF – preliminary lab tests at GSI

Author: G. Schreiber, GSI

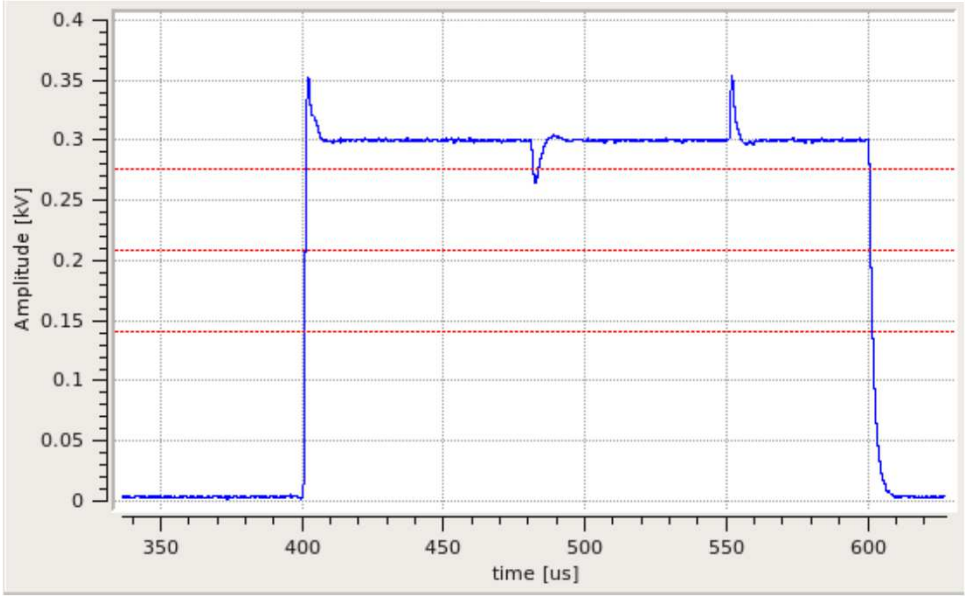
The LLRF was adapted to p-Linac RF, only rough tunning was done

Tests:

- Step response
- Beam loading

Conclusions:

- Smooth leading edge pulse pre-shaping (AWG) is needed
- Heavy beam loading compensation is recommended



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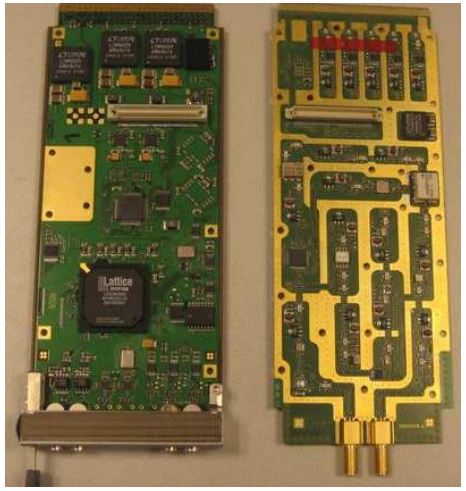
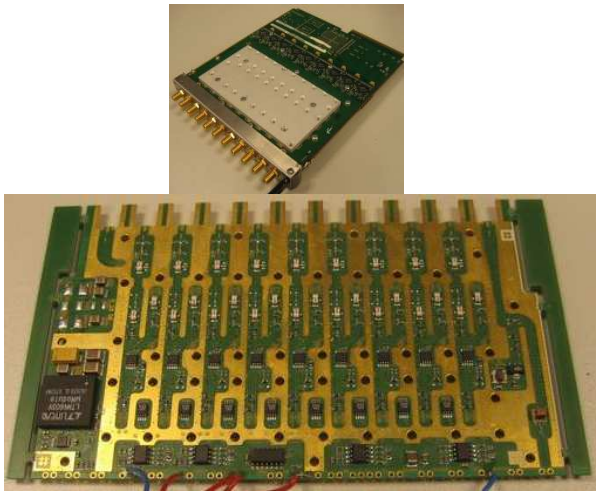
HW adaptation to p-Linac RF frequency

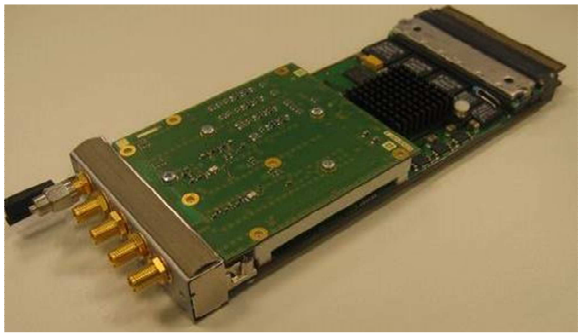
Analog boards of the Libera LLRF modules were adapted to 325 MHz RF



TCM module

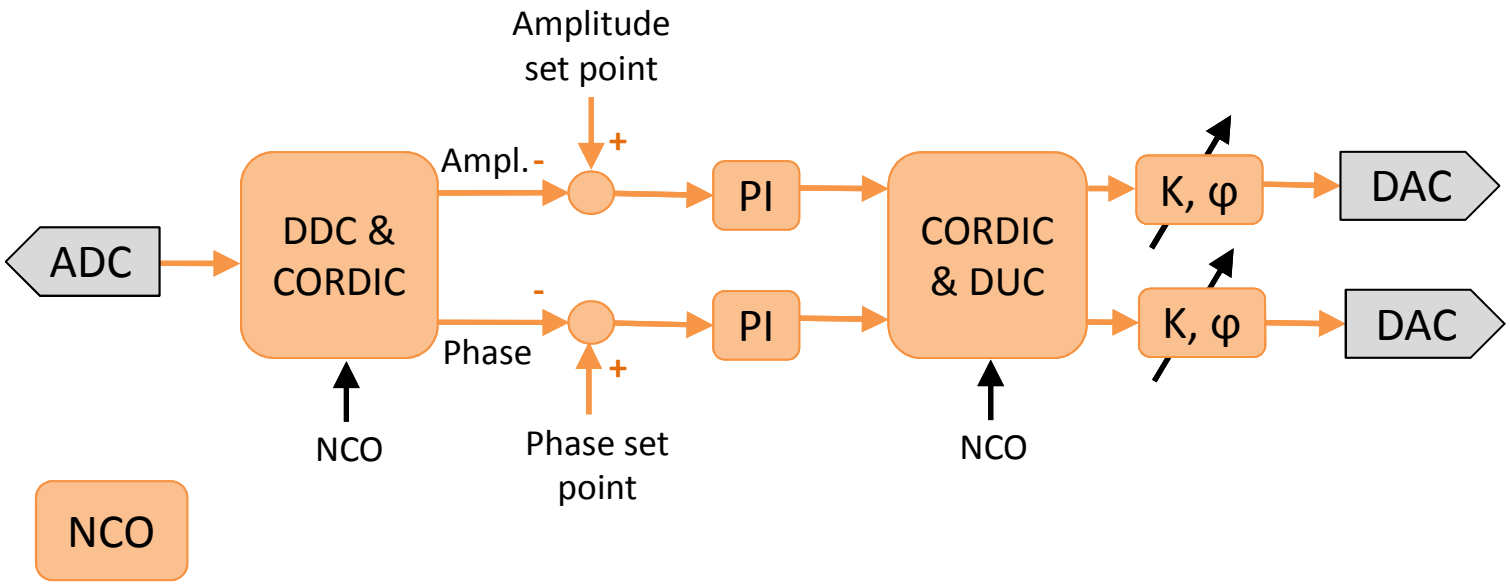


ADC9 module



Vector modulator module

DSP modification – separate ampl. & phase control



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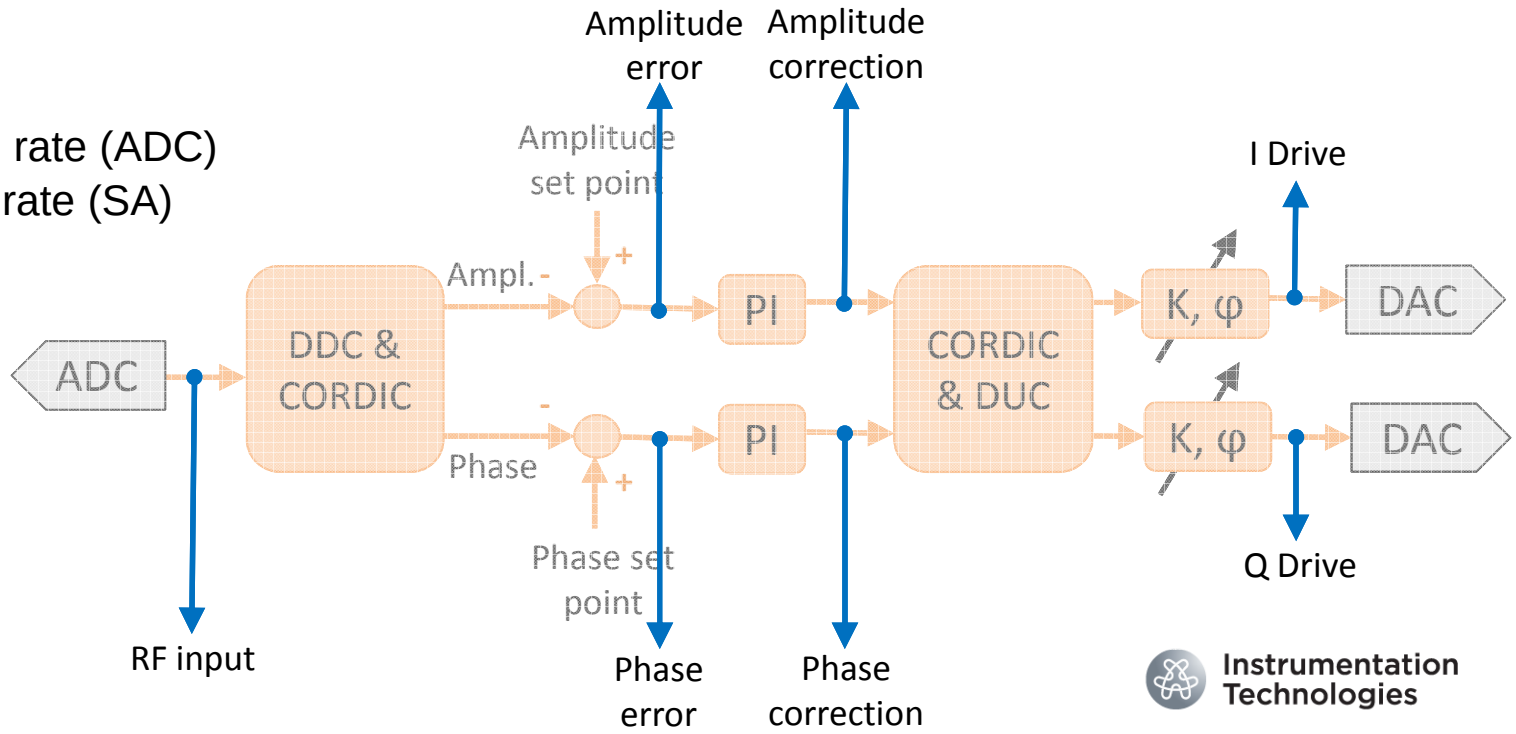
Diagnostic data

Available at:

- 108 MHz rate (ADC)
- 3.4 MHz rate (SA)



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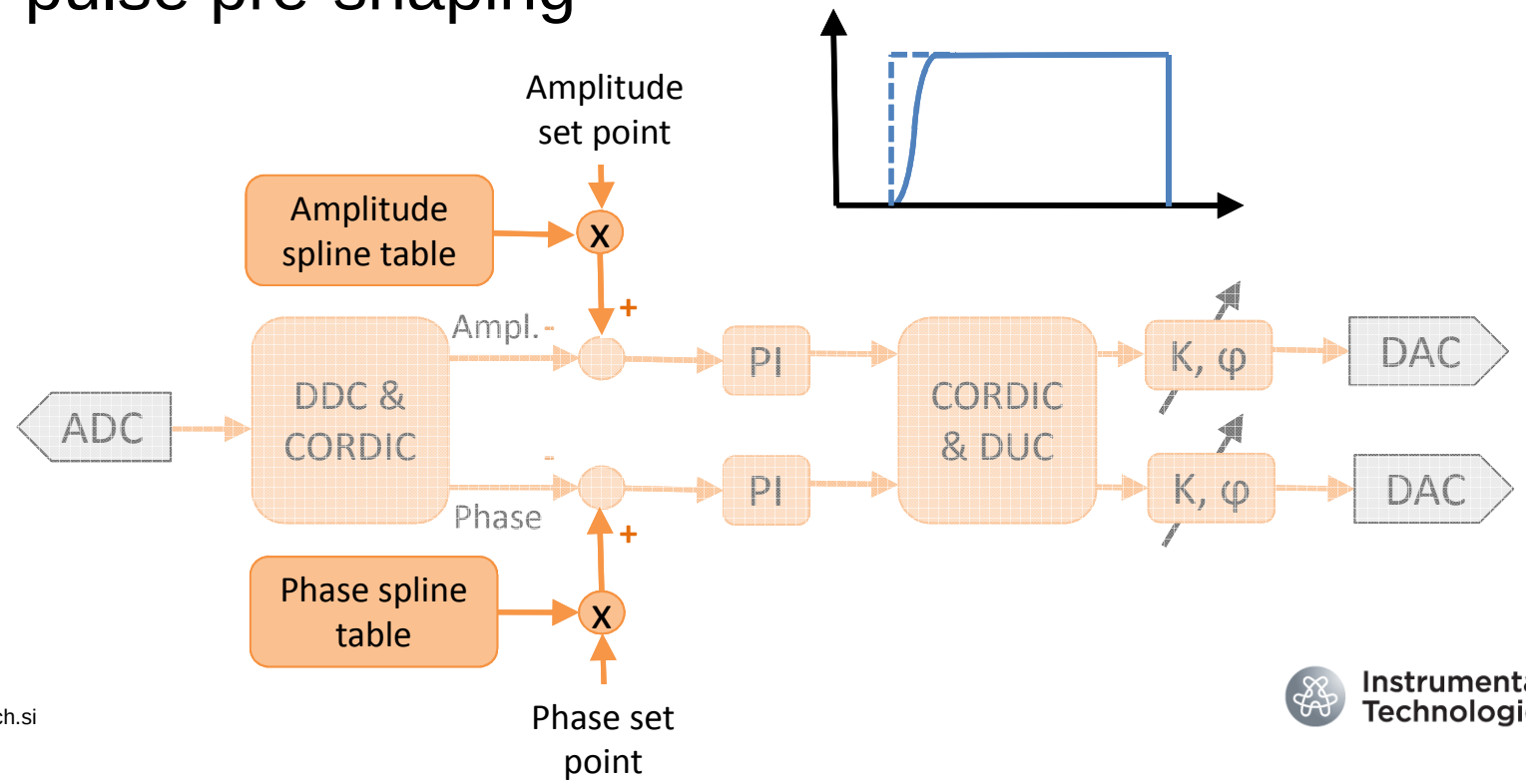
RF pulse pre-shaping



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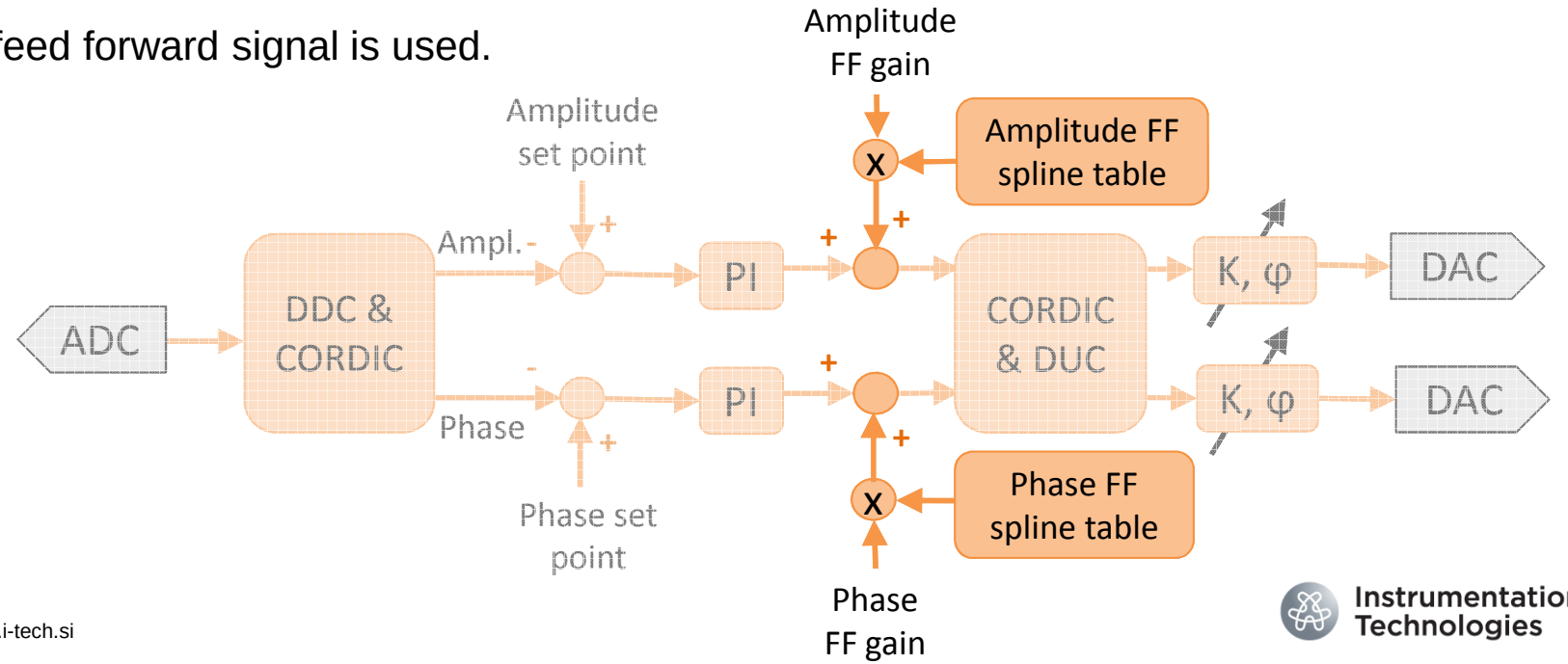
Beam loading compensation

A feed forward signal is used.



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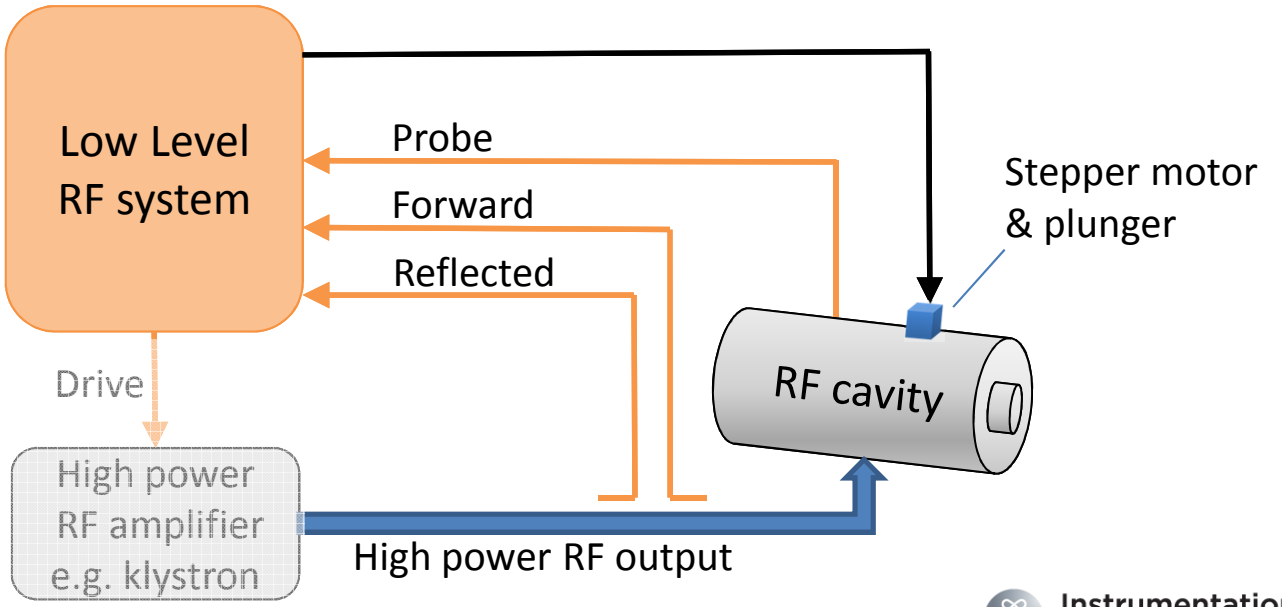
RF cavity resonant frequency tuning

Slow feedback control loop at up to 5 Hz rate



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Forward & reflected signal analysis

- Ratio of the signals i.e. Reflected/Forward defines magnitude of the movement
- Phase difference between the signals defines direction of the plunger movement

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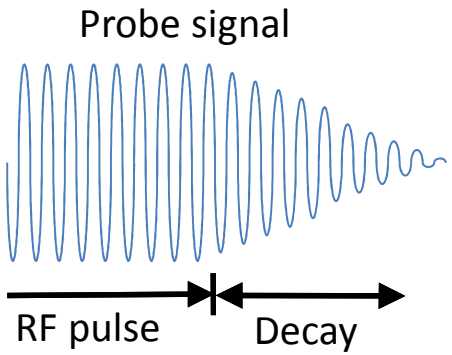
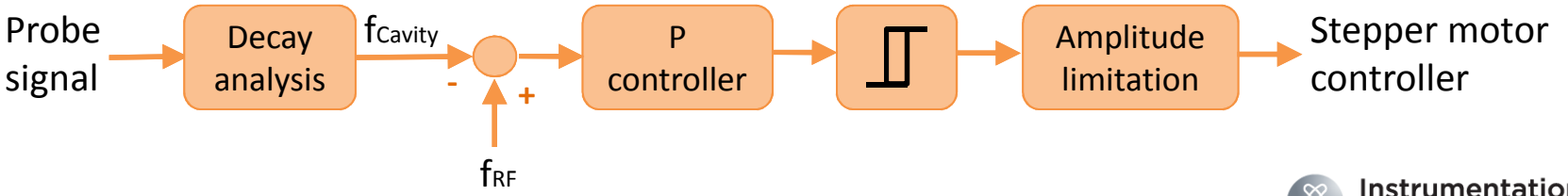
Decay analysis





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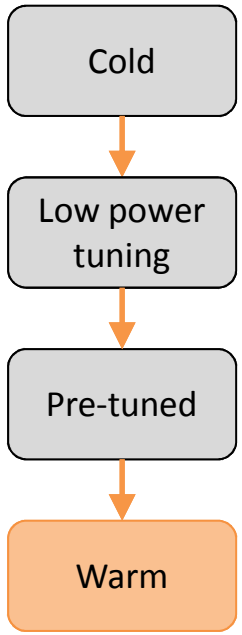
Cavity tuning state machine

- **Cold:** initial state
- **Low power tuning:** open loop operation at 1-10% of nominal voltage, Fwd+Refl analysis is used for cavity tuning
- **Pre-tuned:** closed loop operation, cavity voltage ramp-up to nominal voltage, decay analysis is used for cavity tuning
- **Warm:** normal LLRF operation at nominal voltage, decay analysis is used for cavity tuning

Automatic and manual transition between the states is possible.



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Machine protection

- Interlock (suspends RF drive output, reaction time is < 5 µs):
  - Input
  - Output
- Advanced Error Reporting (AER): LLRF controller error signal monitoring within a predefined timeframe.

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Interlock output

Intermittent interlock:

- Sources:
  - Exdeeded threshold for a predefined duration: Probe, Forward, Reflected, Drive output
  - Exdeeded average power: Drive output
- RF drive output is suspended within the same RF pulse and it is restored for the next pulse.

Persistent interlock:

- Source: More consecutive intermittent interlocks causes a persistent interlock.
- RF drive output is suspended and it remains disabled until user reset

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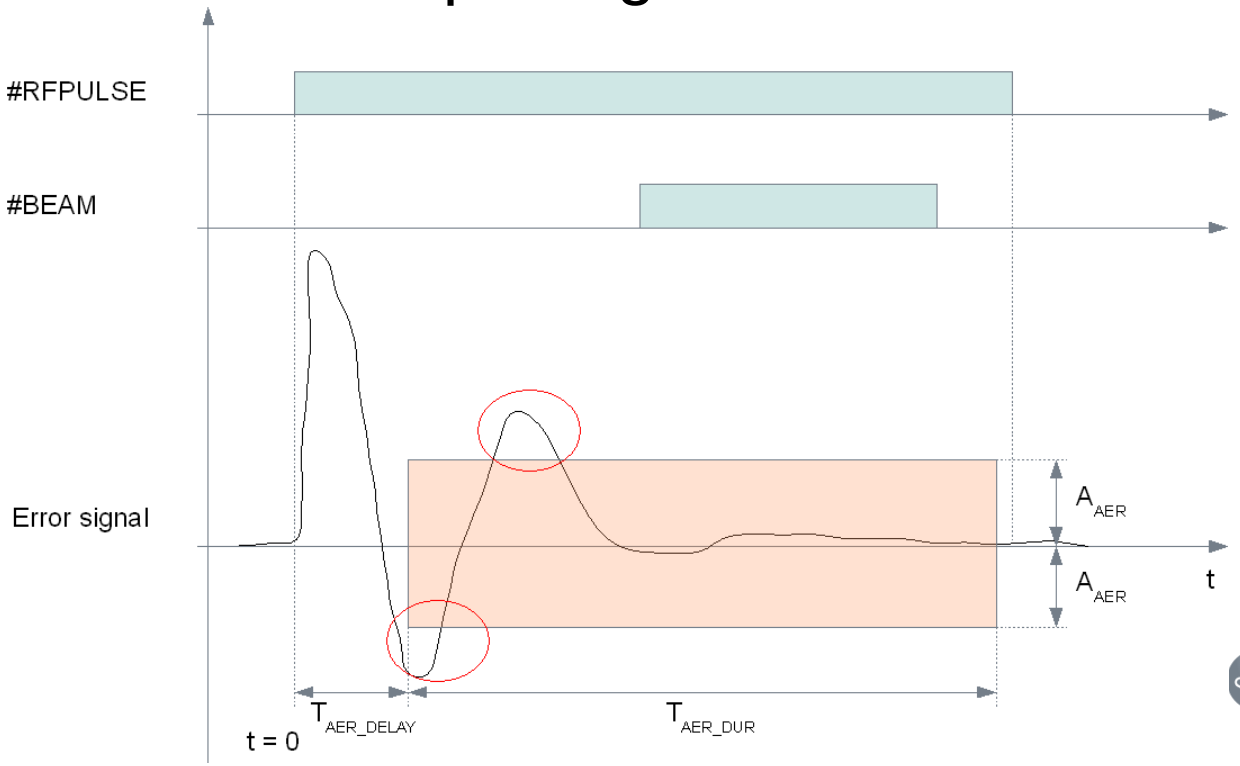
Advanced Error Reporting



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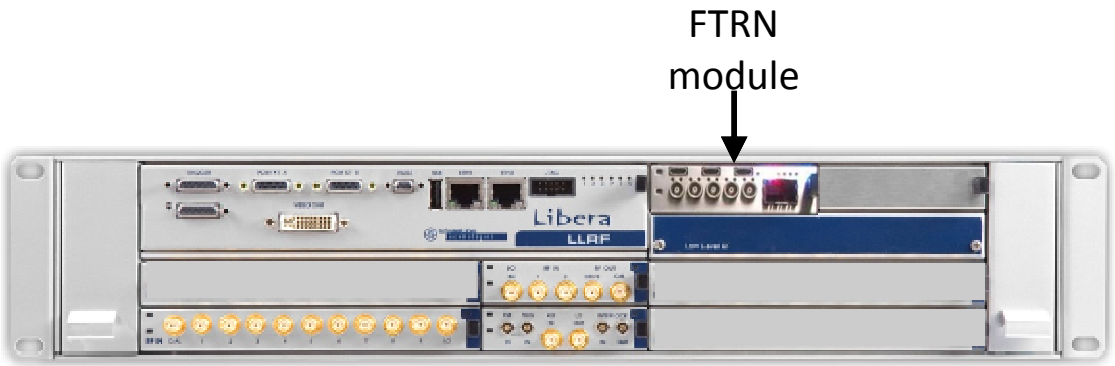
FAIR timing receiver integration

µTCA FTRN module with White Rabbit functionality:

- Provides RF pulse trigger/gate
- Provides beam trigger/gate for beam loading compensation
- Receives the timing system events



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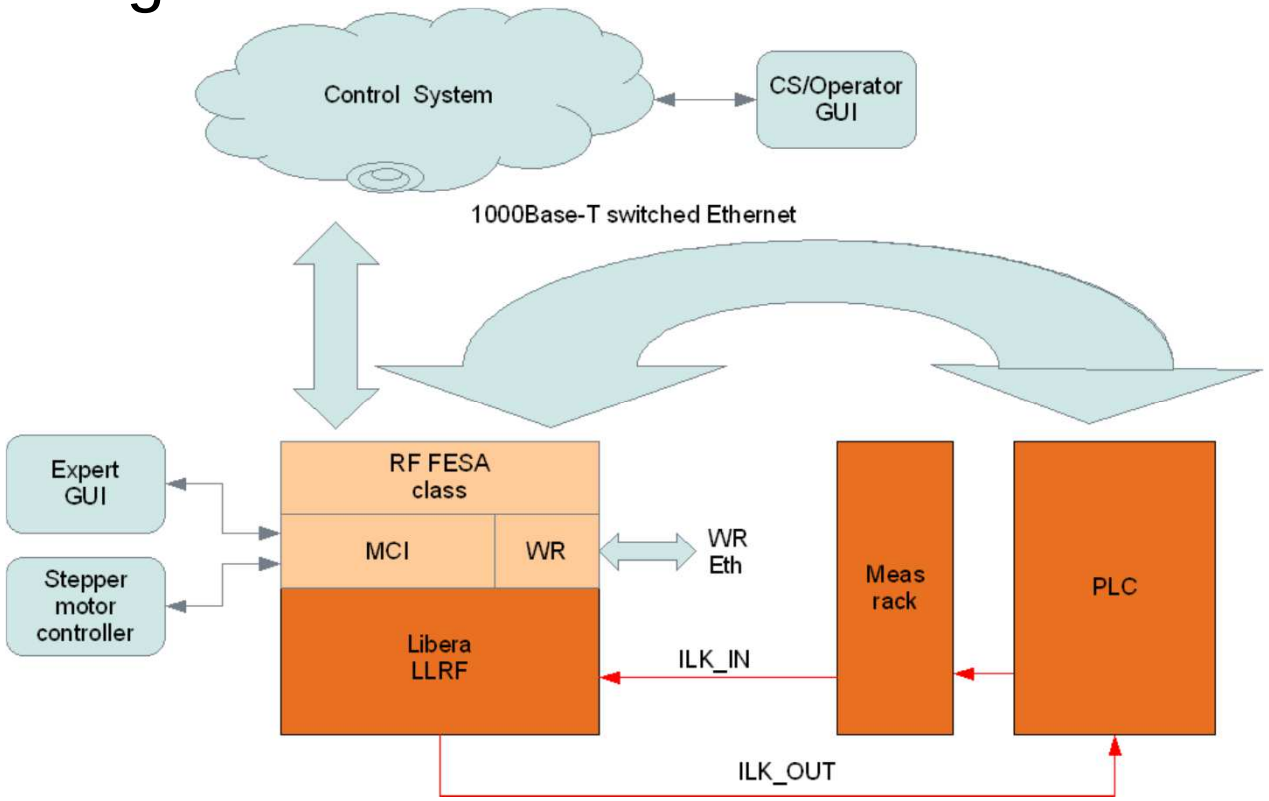
LLRF integration



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Virtual accelerator time multiplexed operation

Procedure:

- FTRN receives a new VA notification via White Rabbit
- FTRN triggers the FESA RT action by sending an event
- FESA RT action sets the active VA parameters via MCI

Precondition: Real-time operating system (CentOS + RT patch)

Local operation mode

- Intended for LLRF experts
- Full access from expert/local GUI only
- Pause mode of operation i.e. RF pulse and beam aren‘t present at the same time. It is achieved by FTRN/timing configuration.
- Automatic VA rotation is stopped

Expert GUI


File
Data record
Calibration
Pulse shape
Sensors
MANUAL TUNING
FW&REFL
-170
Decay
-150
Steps
10
-
+
OUT
IN
Interlock
ILK input
AER
Clear
Timeout
Clear
Cavity
Low-power
Local
Op. mode
Local
Tuning
Drifts
Amp. loop
Ph. loop
RF
Libera LLRF
Connected
Hostname
10.0.1.197
Connect
Disconnect
ADLLR3, CH1
Amplitude
1000 V
Phase
40 deg
History
ADLLR3, CH2
Amplitude
1000 V
Phase
40 deg
History
ADLLR3, CH1
Amplitude
1000 V
Phase
40 deg
History
VA:
1
Signal:
ADLLR3, CH1
Pause/Resume
Slow acquisition
Amplitude [V]
Phase [deg]
Time [us]
Time [us]
Refresh
Data on demand
Amplitude [V]
Phase [deg]
Time [us]
Time [us]
SET-POINT
Amplitude
1000 V
Phase
10 deg
TUN. FEED-FORWRD
Amplitude
1000 V
Phase
10 deg
BEAM FEED-FORWARD
Amplitude
1000 V
Phase
10 deg
PI AMPLITUDE
kp
1000
ki
500
PI PHASE
kp
1000
ki
500

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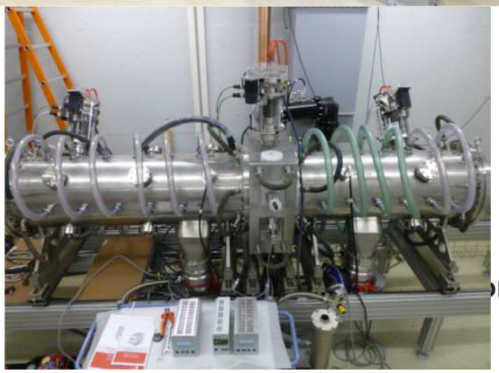
Conclusions

- LLRF systems are specific for different accelerators
- Conceptual design for p-Linac LLRF was done in collaboration with GSI experts
- Presented solutions fulfill p-Linac requirements
- Implementation is in progress
- Testing at GSI on real test bench is foreseen in Q1/2018
- Delivery is foreseen at the end of 2018

GSI test bench, source: GSI



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Thank you for attention

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