Operation of the CERN X-band test stand (X-box1)

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CERN

On behalf of the CLIC structure test team

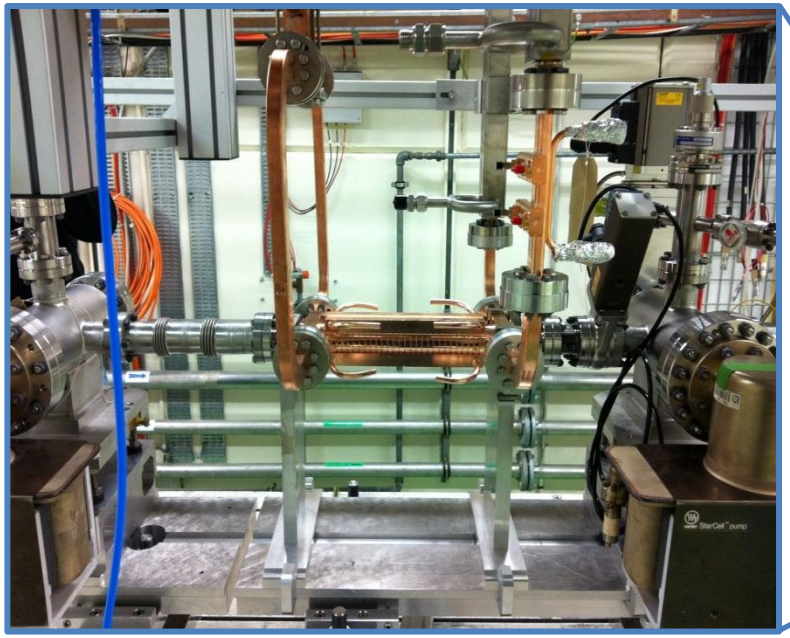
Layout of the CERN x-band test stand (X-box1)

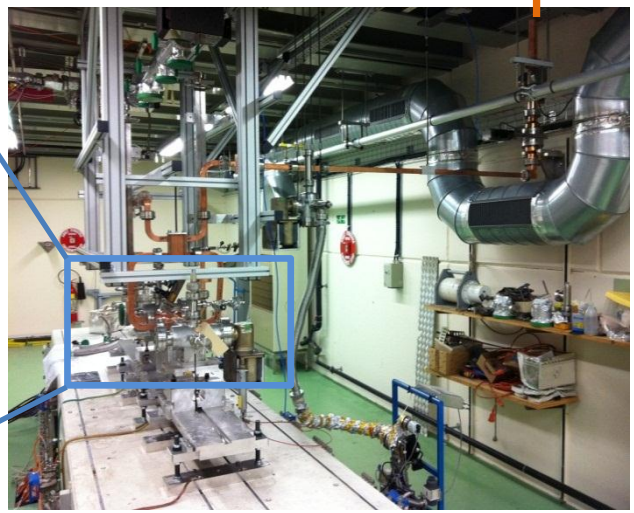
Clockwise from top-left:

- Modulator
- Pulse compressor
- DUT + connections
- Accelerating structure

Gallery

Bunker





Components of X-box1

Klystron (SLAC XL5, #1 prototype)
50 MW, 1.5us pulse width, 50Hz rep. rate

Modulator (ScandiNova K2-3X solid state, #1 prototype)
Max. 450kV, 350A, 3.5us pulse width, 50Hz rep. rate

Pulse compressor (GYCOM Russia, #1 prototype)
50MW, 1.5us rf → 140MW, 250ns rf

DUT (CLIC TD24R05 accelerating structure)
11.99424GHz, 24 regular cells, 2 coupling cells, HOM damped

And several other new high-power rf components like valves, directional couplers, mode converters etc.

Status of X-box1

1. Hardware installation finished last summer
2. Development of control and DAQ software on-going
3. Waveguide network including pulse compressor conditioned up to 20MW av., 1.5us, 50Hz into compressor, 170ns, 30MW, 50Hz out of compressor into structure. Pulse compressor needed about 200h of rf cleaning to reduce outgassing (chem. cleaning/baking not possible)
4. SC solid state modulator is running without major problems, pulse-to-pulse stability is excellent (10^-4)
5. Klystron output window showed activity when arriving in the 20MW, 1.5us regime, but calmed down after ~25h of conditioning

24/7 operation now possible after integration of pulse compressor stabilization routine

The pulse compressor before installation

SLED1 type pulse compressor made by GYCOM, Russia

-Pulse compressor was assembled and rf measured, tuning plunger realignment iterations necessary

- First pulse compression with synthesized low power input pulse and phase program

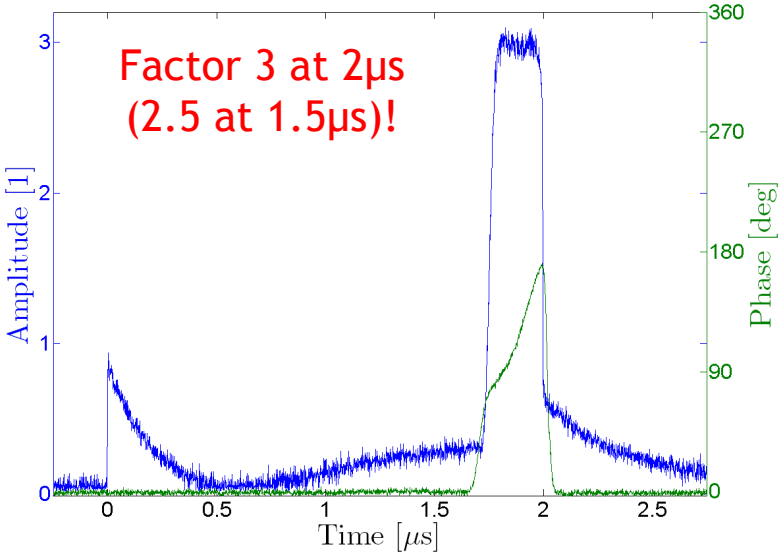
- Very sensitive to detuning, requires temp. stabilization to 0.1K, failsafe tuning mechanism and fast interlocks on reflection

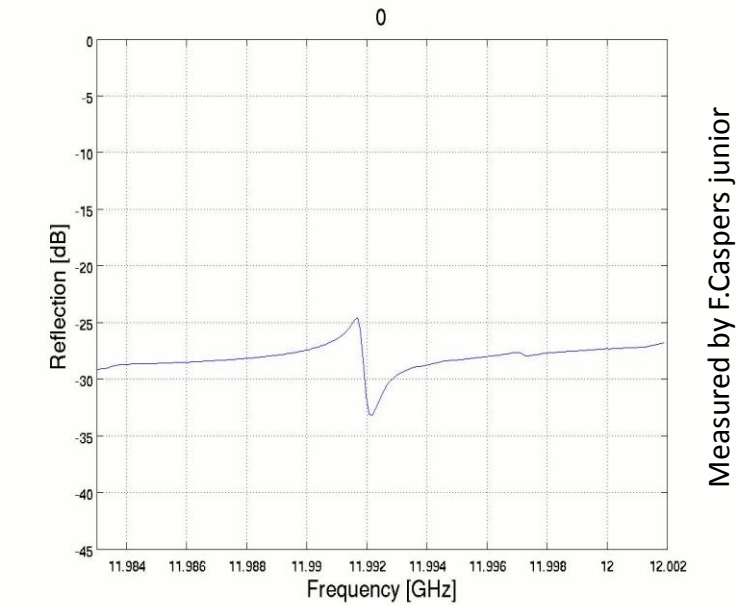
Measured parameters at delivery:

Qloaded = 26300
(design: 25000)
Q0 = 90000 – 100000
(design: 150000)
β = 2.4

Max. compression 2.5
(design: 2.7)

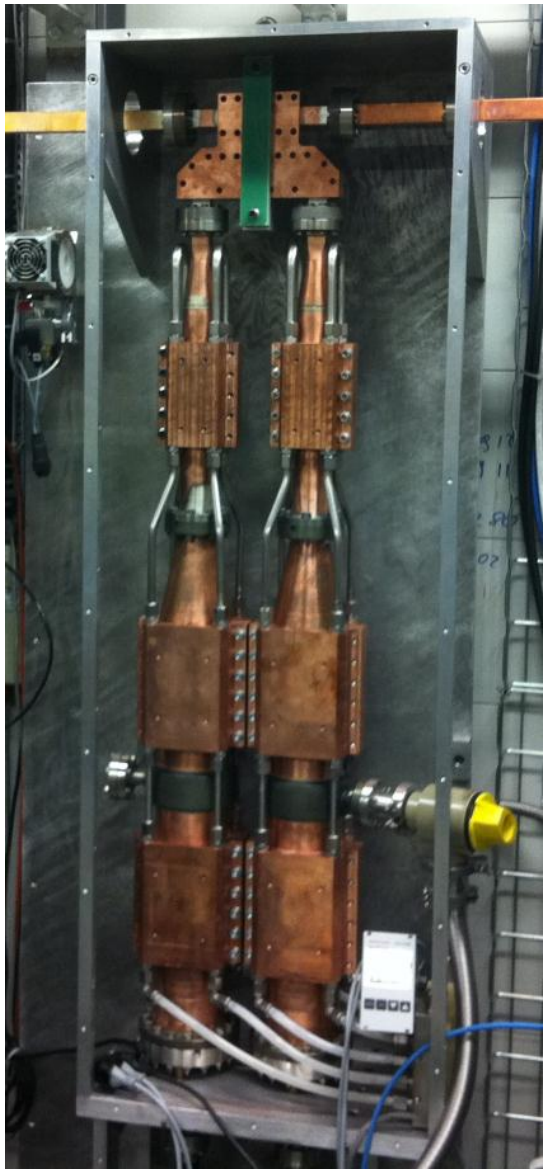
Reflection to klystron:
-20dB





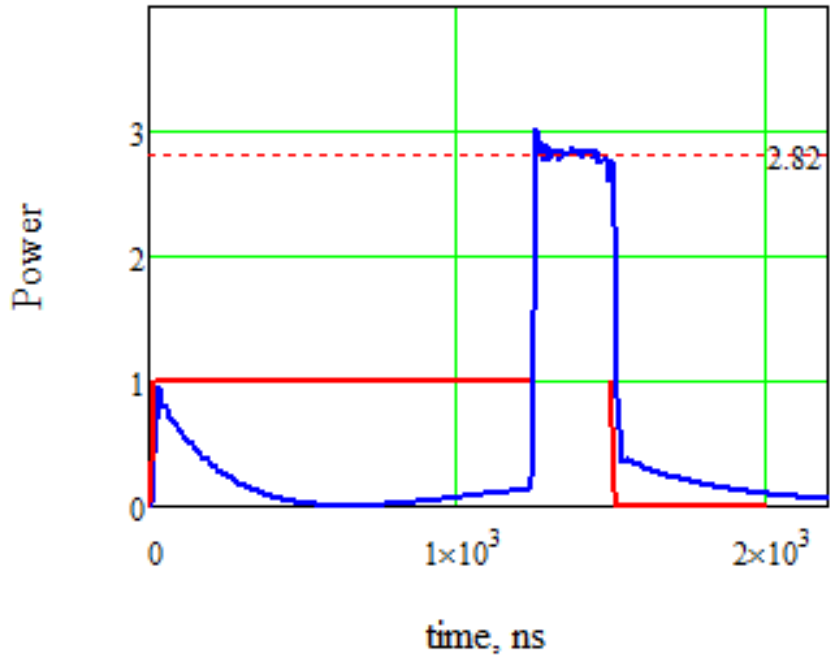
Reflection (detuning in stepper motor steps)

The pulse compressor after installation



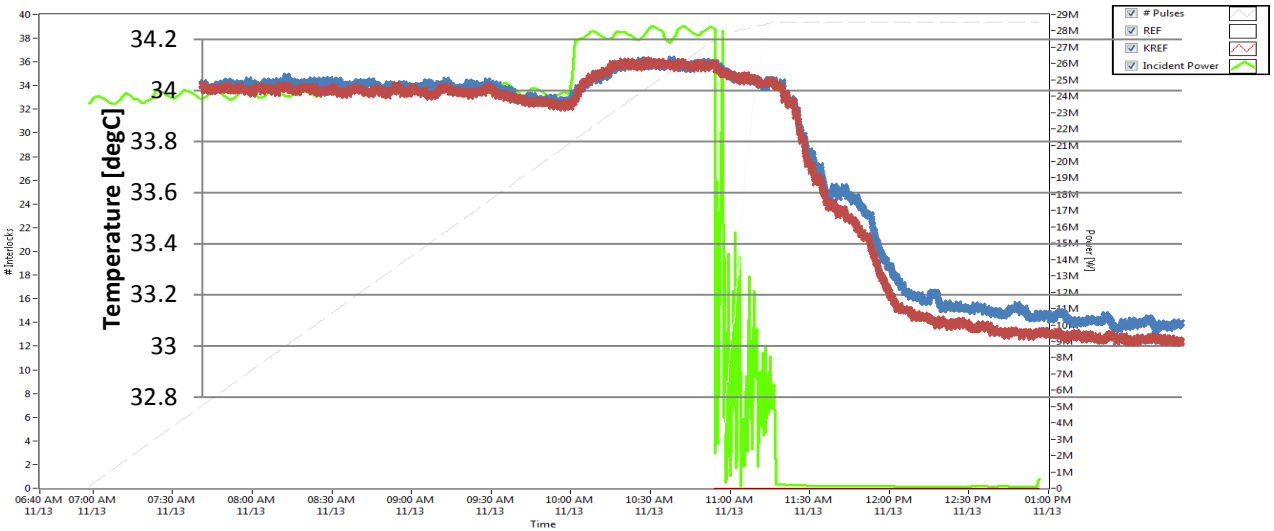
Pulse compressor with temp. stabilization installed in test stand.

- Power gain of 2.82 calculated from s-parameters measured at low power after installation and tuning in 12GHz test stand (under vacuum)
- $Q_{loaded} = 2.375 \times 10^4$, Beta = 4.27, $Q_0 = 1.31 \times 10^5$
- 5% power loss in compressor
- Temperature stabilization better than 0.1K
- LLRF phase programme controlled by AWG and analogue phase shifter (~25MHz BW)

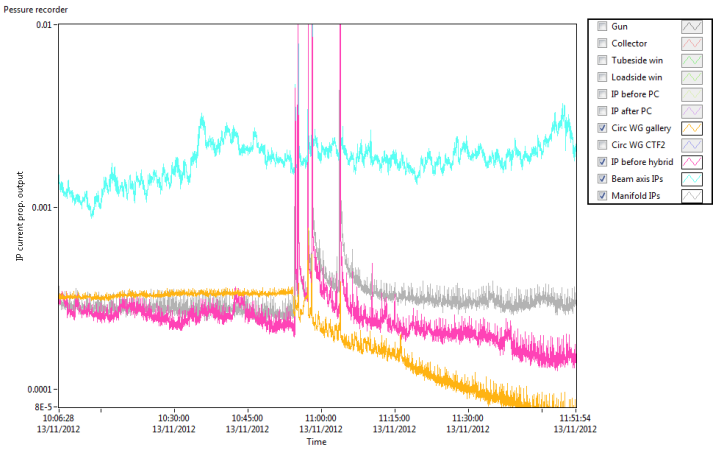


Pulse compressor stability problems

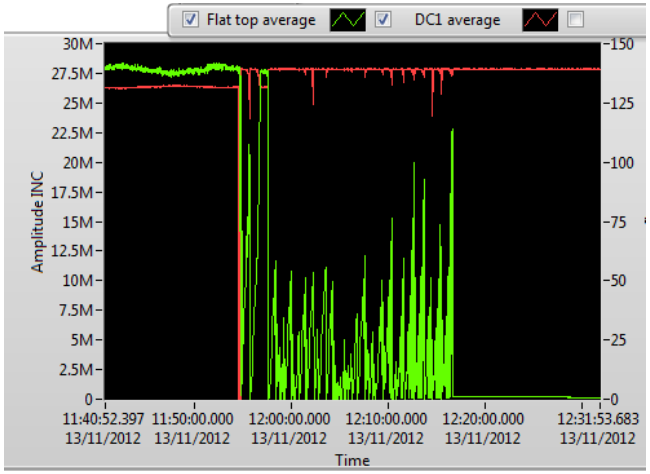
Started routine conditioning of first structure in summer 2012, but needed to solve pulse compressor stability problems in parallel to normal operation:



Breakdown: RF off, PC cools down and detunes, RF ramped back without flat top (peak power overshoot), next breakdown due to high peak fields, RF off again, PC cools down even more, and so on…



Vacuum history of BD cluster



Power/DC history of BD cluster

Pulse compressor stability problems

Implementation of pulse compressor stabilization routine and AGC systems end of 2012 increased output power stability and system reliability:

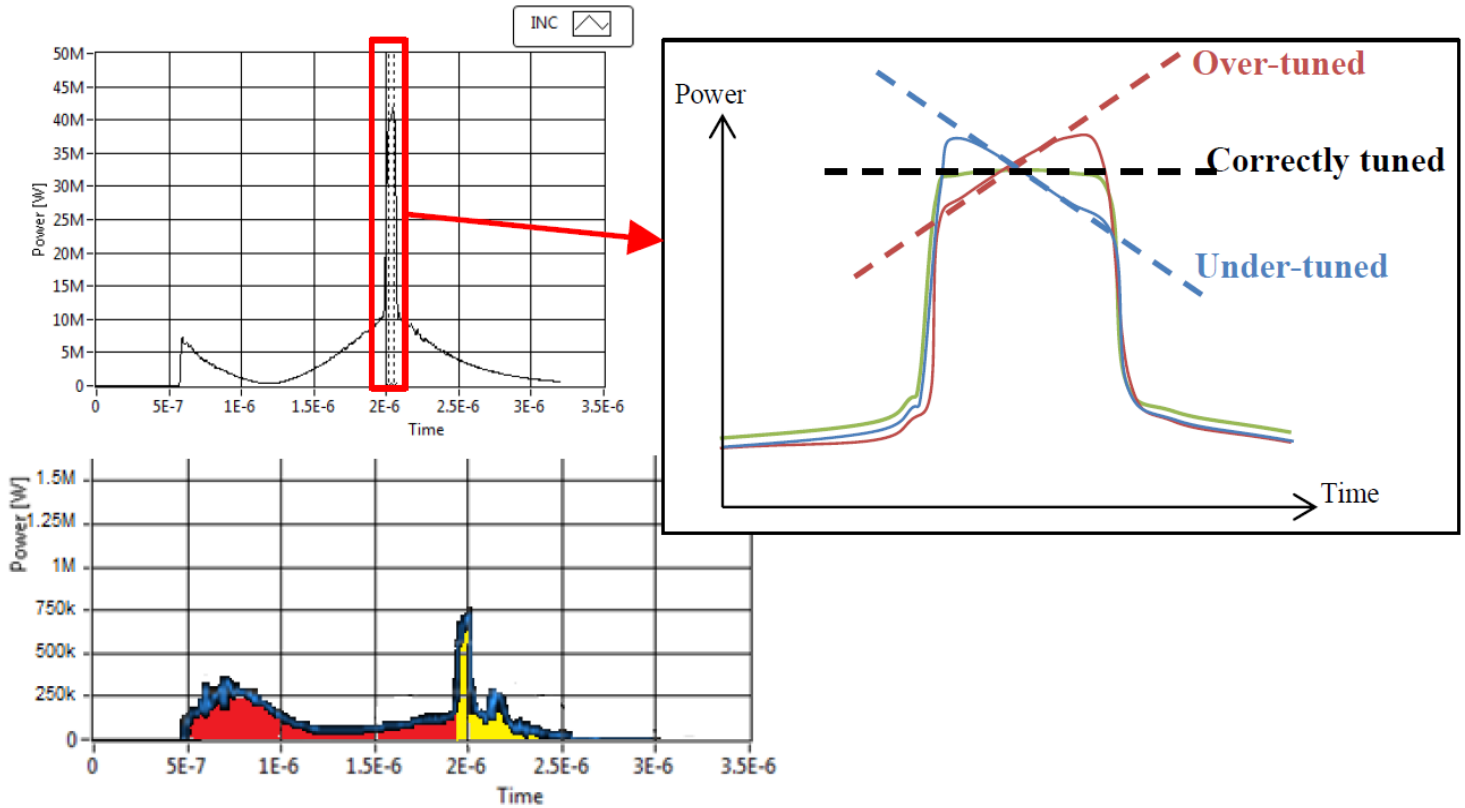
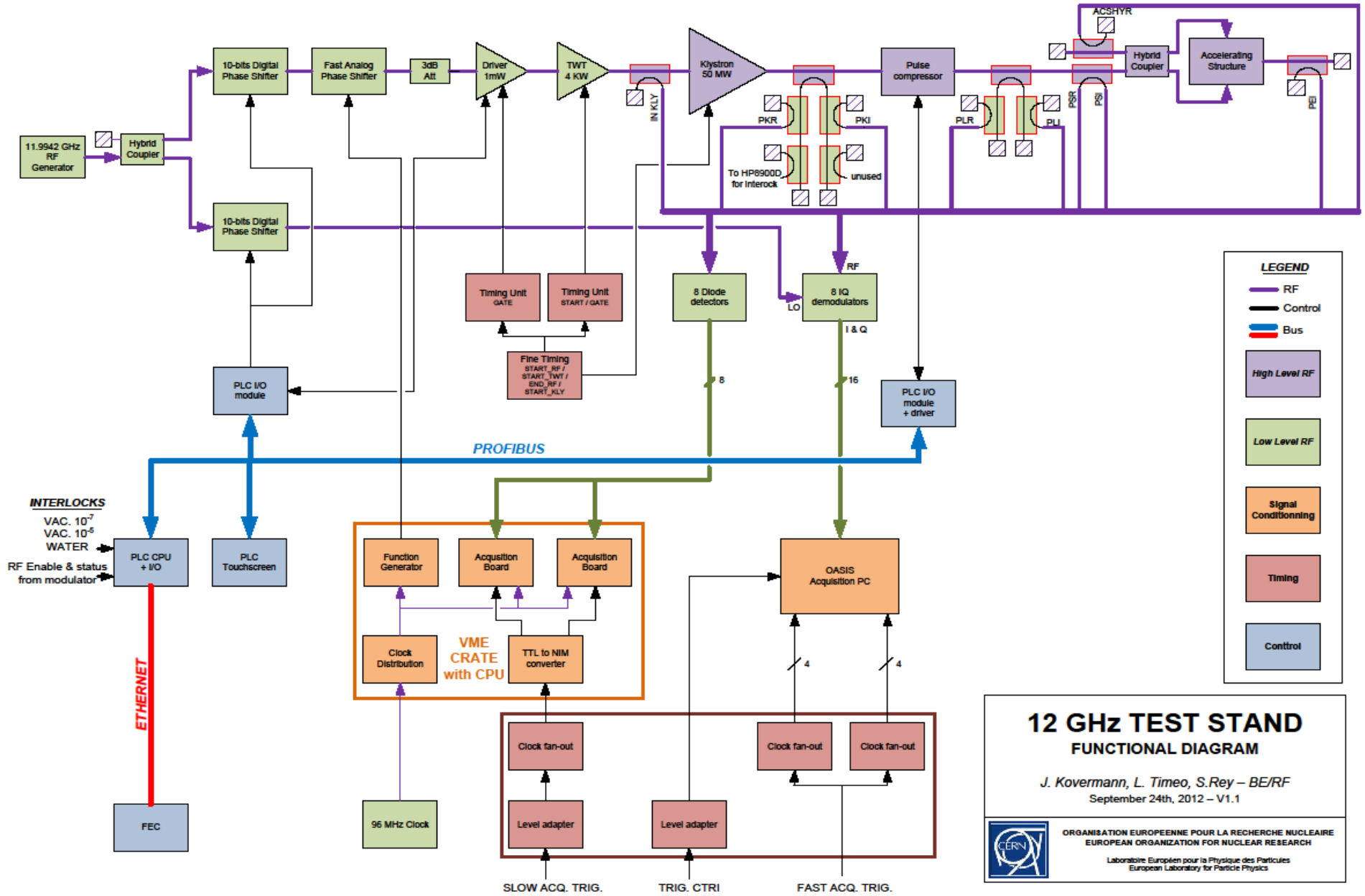


Figure 2 shows a typical, compressed output pulse taken during klystron operation (top left), with expanded views of the peak for different tuning regimes (right). Also shown is the reflected power back to the klystron from the pulse compressor (bottom left).

Ben Wooley and Joseph Tagg

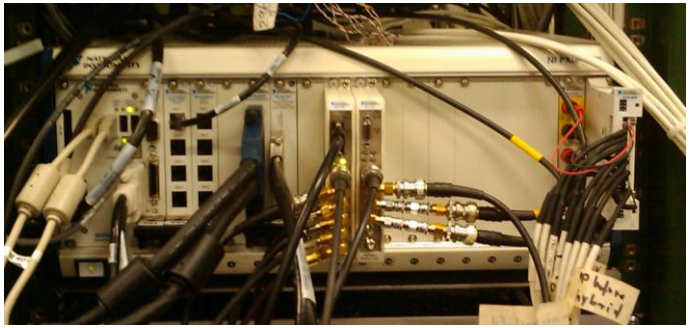
The X-box1 RF layout

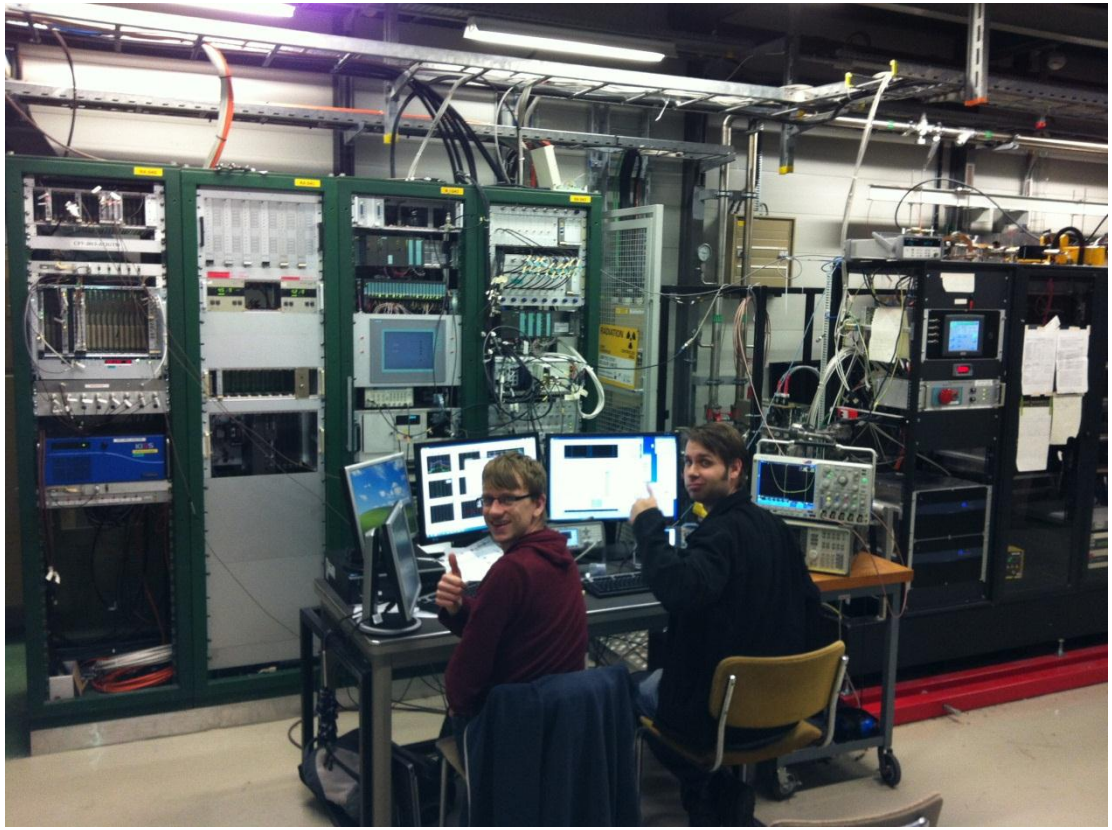


The final X-box1 RF layout

Due to the delays caused by the klystron repairs, the conditioning software based on the CERN control system could not be finished ➔ Urgent need for control, interlock and feedback systems!

➔ Decision to use a National Instruments PXI based system for all Xbox-1 controls and DAQ



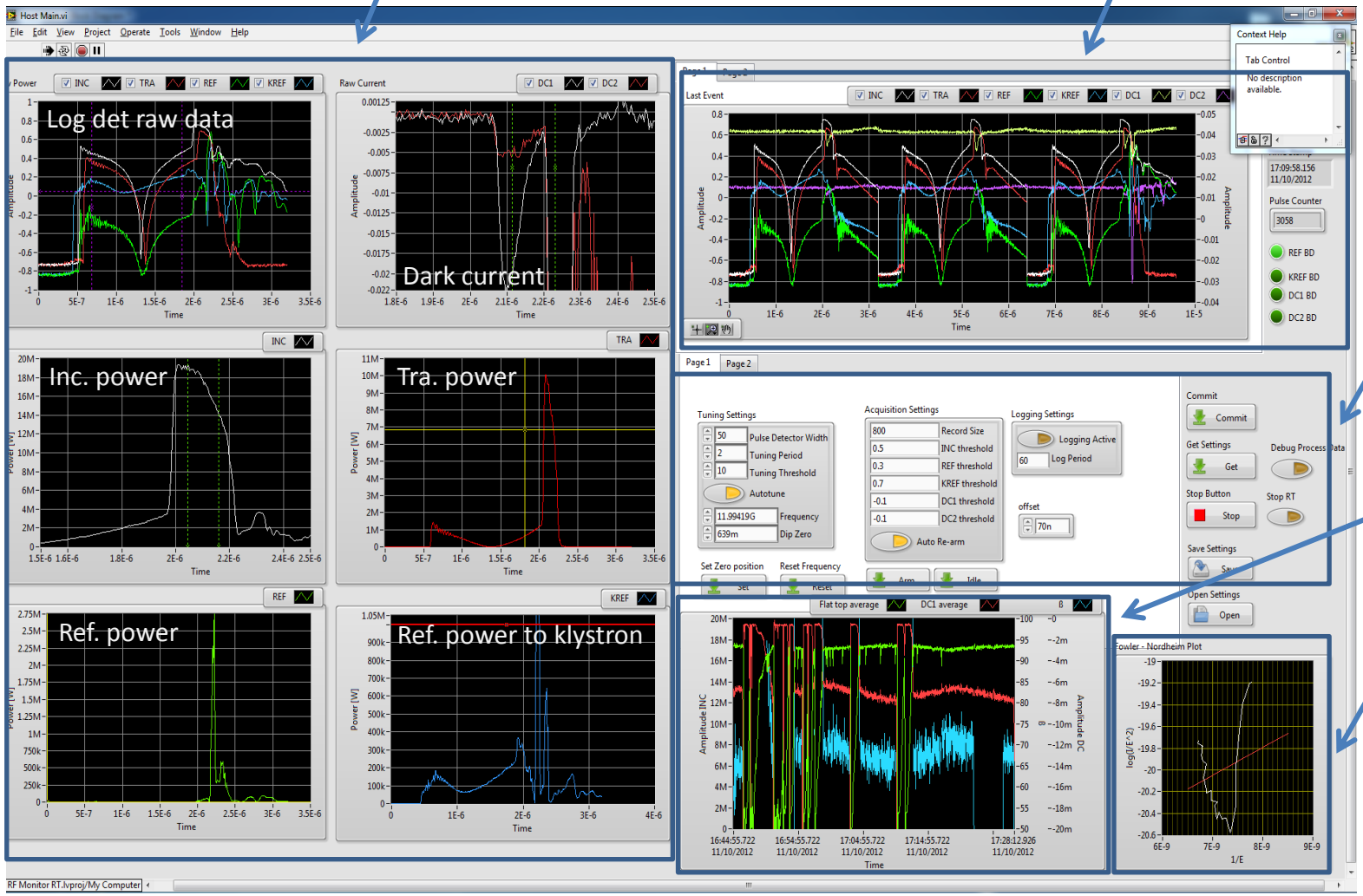


- 8ch 250MSps/s 14 bit ADCs for RF (log detectors) and DC sampling, one FPGA for 4chs used for interlocking on reflected power and DC spikes
- I/Os for temp. gauges and interlock signals
- Stepper motor control and encoder read back
- Ion pump current readout for all pumps

The new X-box1 control and DAQ software (September 2012)

50dB log detector into 14bit 250MSps/s ADC for controls

Last interlock event display (plus two previous pulses)



Interlock levels, calibration etc.

Power, DC, beta history

Single shot FN-plot

All at 50Hz rep. rate! 400Hz possible!

Screenshot of X-Box1 controls (Mid Dec 2012)

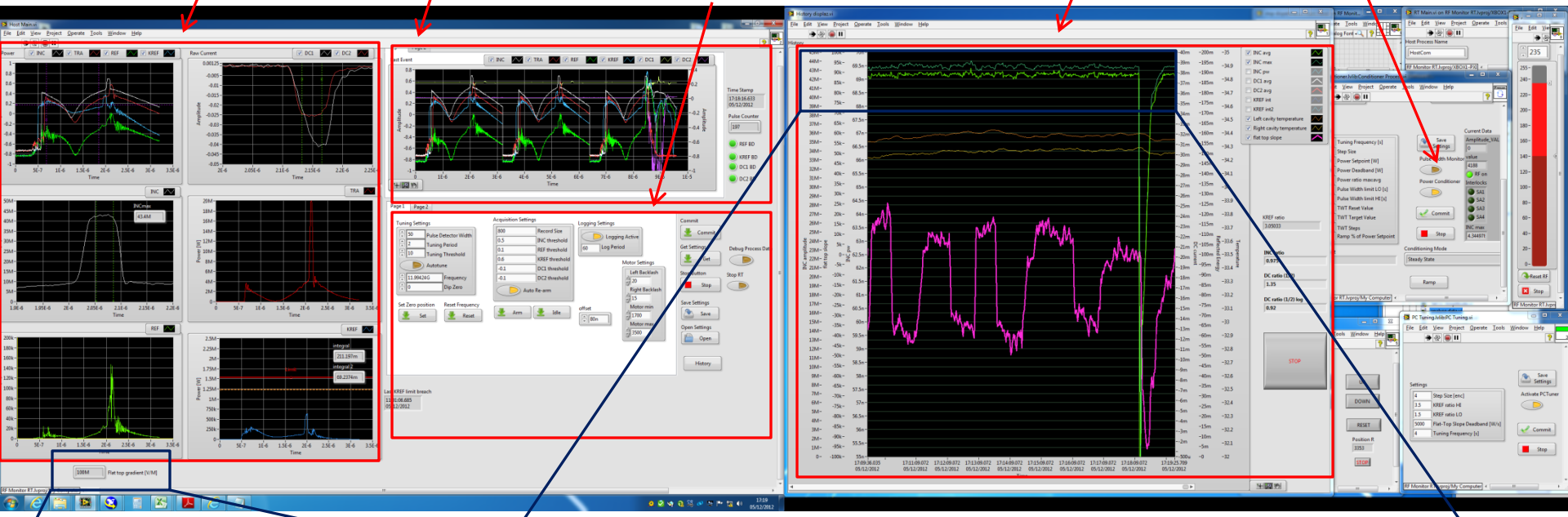
50dB log detector into 14bit 250MSps/s ADC for controls

Last interlock event display (plus two previous pulses)

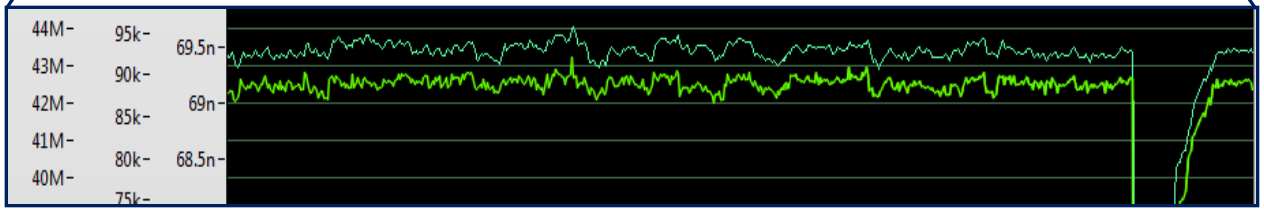
Interlock levels, calibration etc.

Configurable history plot

Controls for tuning, power, motors etc.

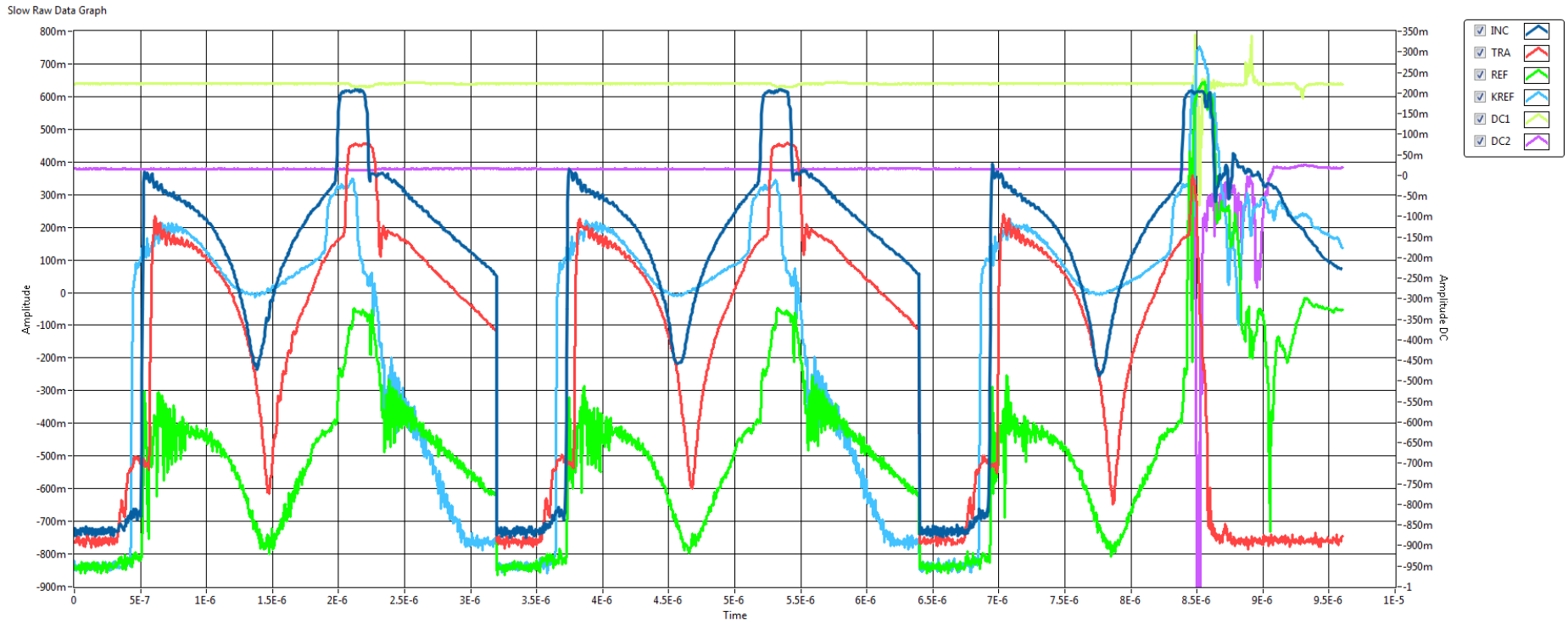


Real-time gradient display



Power history plot (peak and average)

X-band log detectors



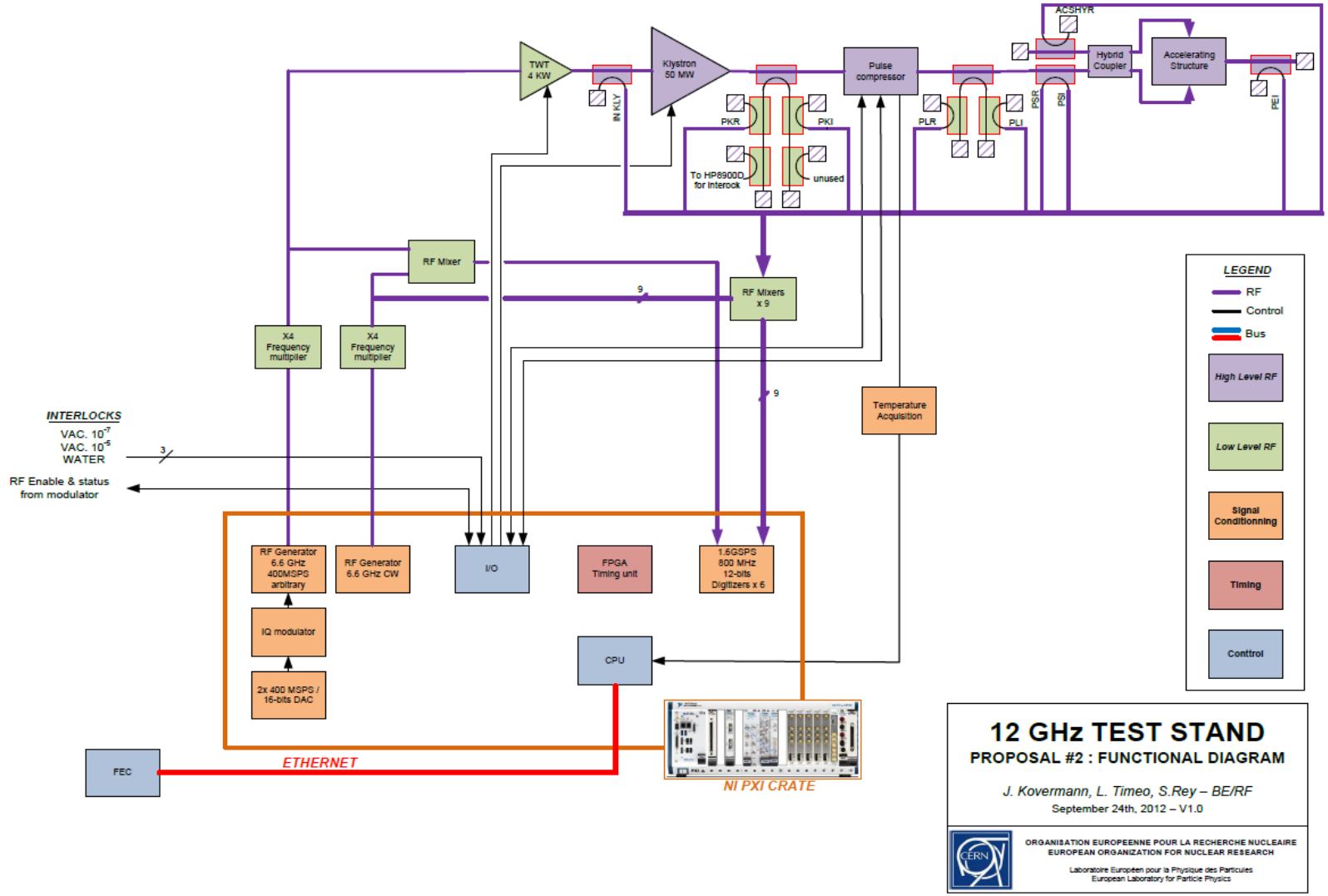
Hittite HMC662 8-30GHz log power detector, approx. 50dB dynamic range

➔ Eases operation and PC tuning at all power levels

➔ Good resolution of reflected power signals without saturation effects during BDs

The future X-box1 and X-box2 RF system

The main weaknesses of the X-box1 system are the difficult to calibrate and rather non-linear I/Q demodulators and the dependency on the CERN control system (necessary for X-box1 only for the timing but not for the future test stands) ➔ Proposal for an upgrade under evaluation



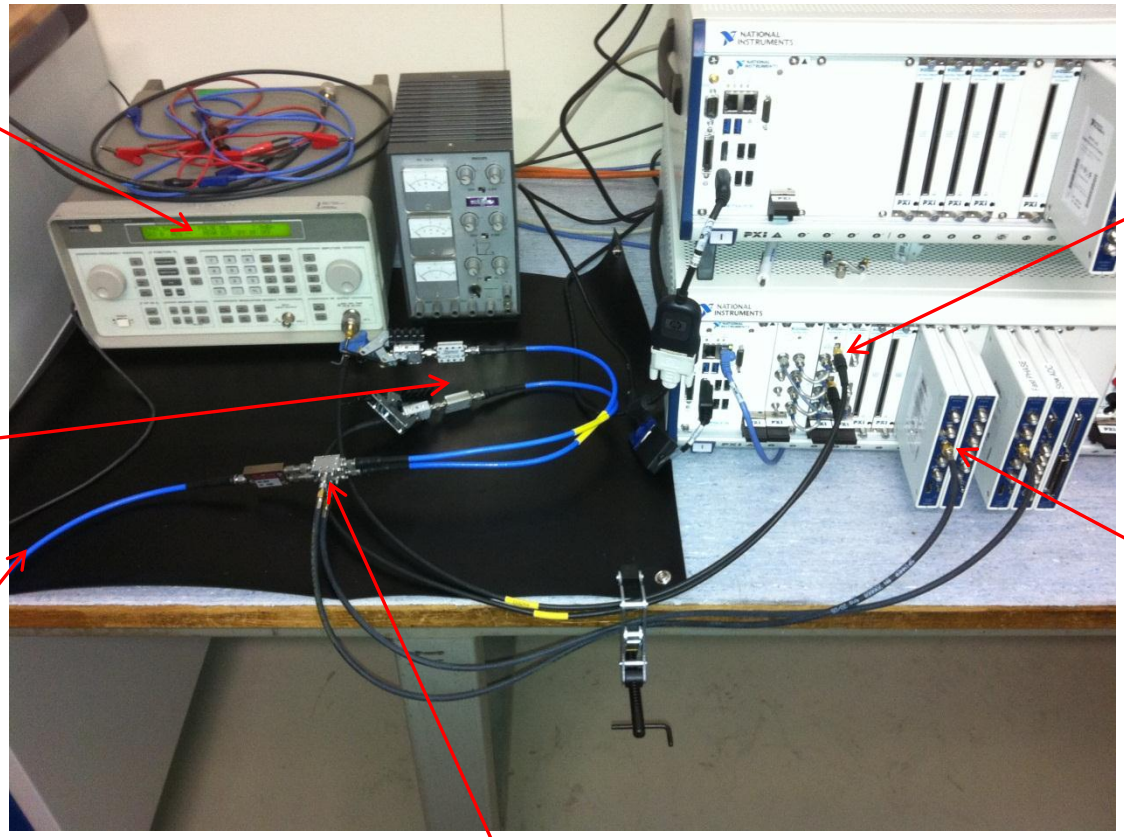
The future X-box1 and X-box2 RF system

Test system to show performance under evaluation, first lab prototype ready including basic software for data acquisition and phase/amplitude calculation

3GHz source (will be replaced by PXI synthesizer and quadrupler)

3GHz to 12GHz active frequency quadruplers

11.6GHz LO generator (will be replaced by PXI synthesizer at 2.9GHz and quadrupler)

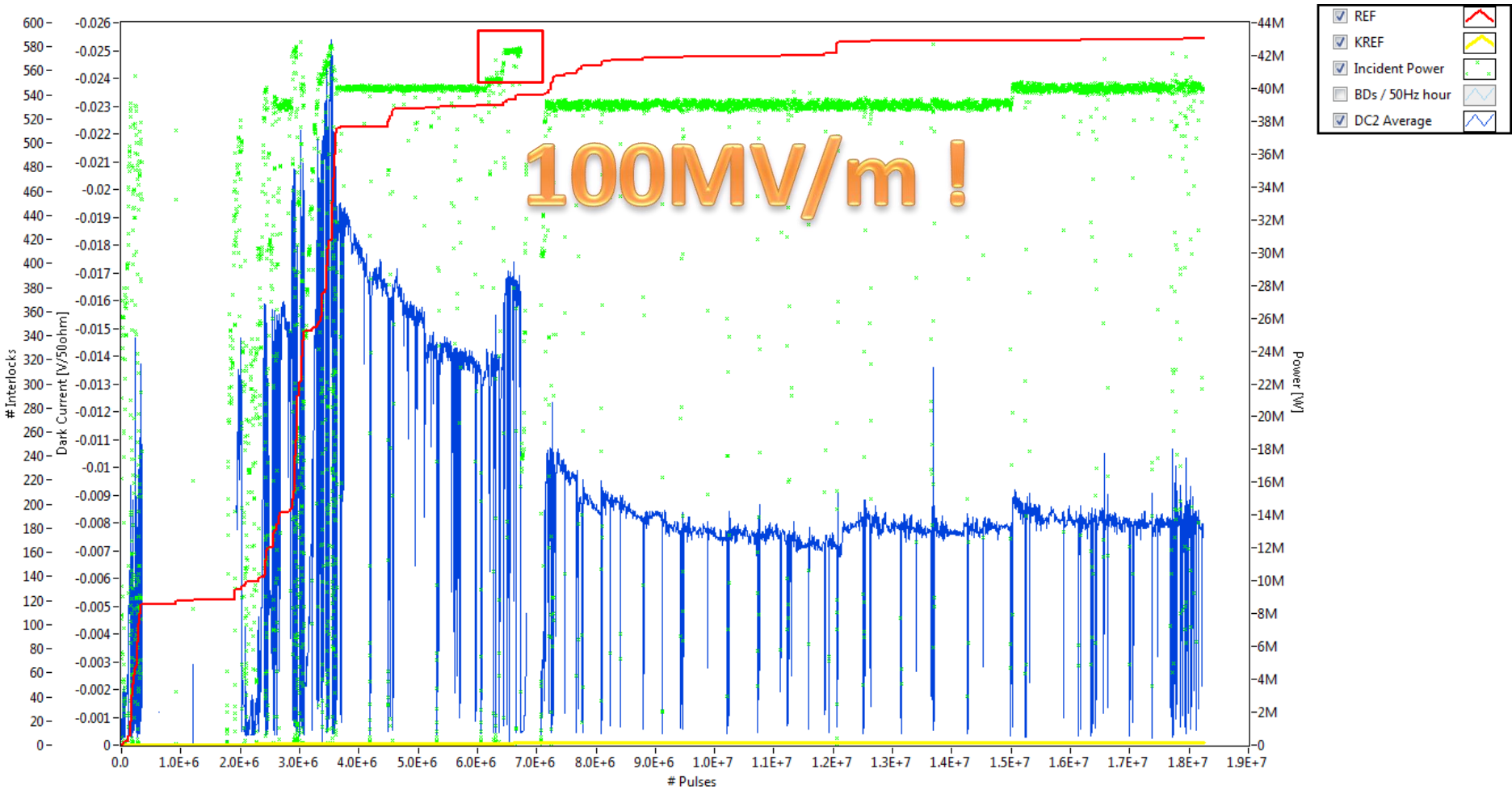


6.6GHz I/Q vector signal modulator

1.6GSps/s 12bit ADCs for direct IF sampling with FPGA digital data processing

Mixers to go to 400MHz IF

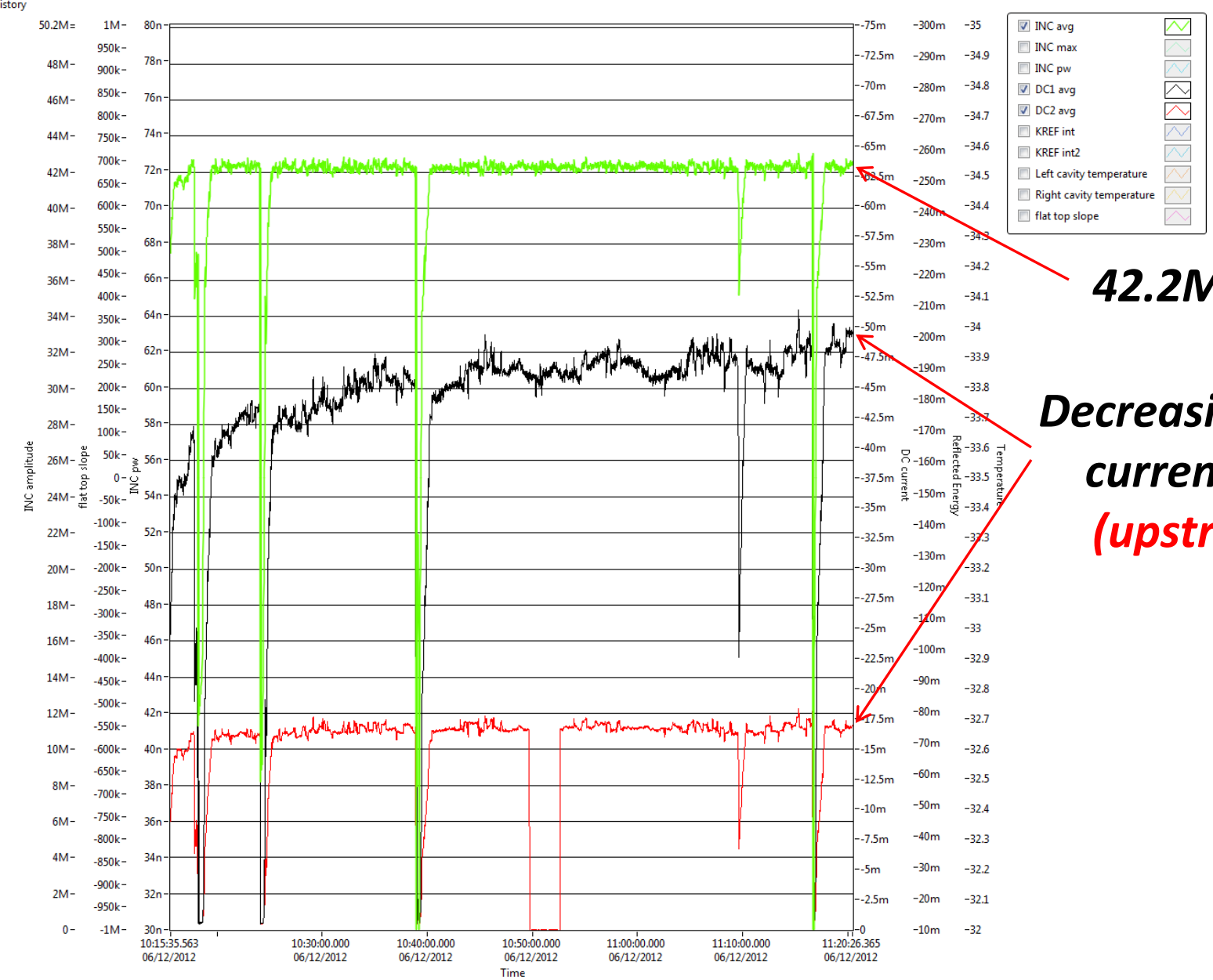
Status of the first CLIC T24 structure tested at CERN



Run 7.12.2012 to 10.12.2012

- Stable pulse compressor output power due to constant automatic tuning and gain control
- Reached 100MV/m stable operation for ~1.5h
- Observed decreasing dark current for the first time

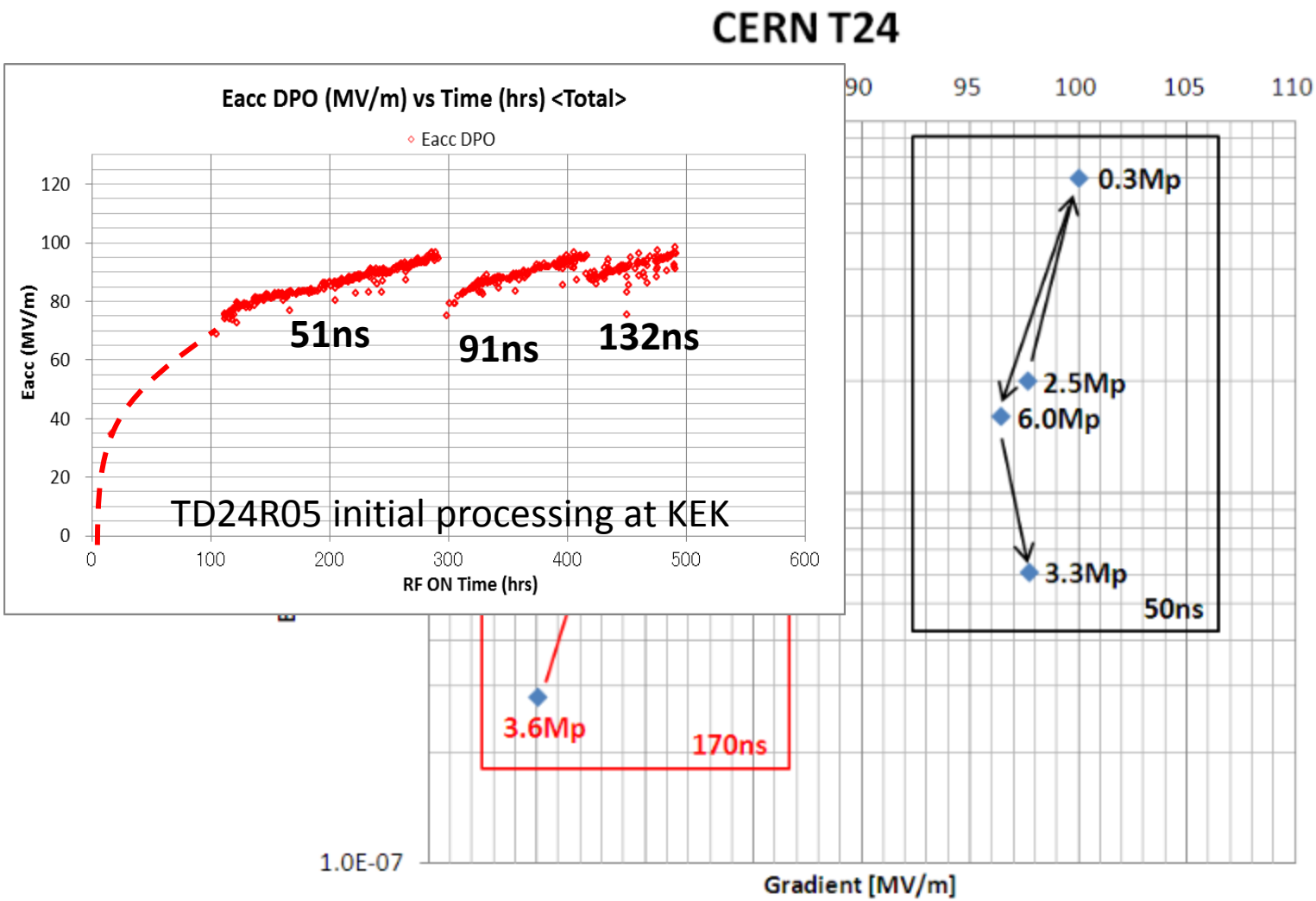
The first 100MV/m at 50ns in detail (operator display)



42.2MW

Decreasing dark current (e^-!)
(upstream)

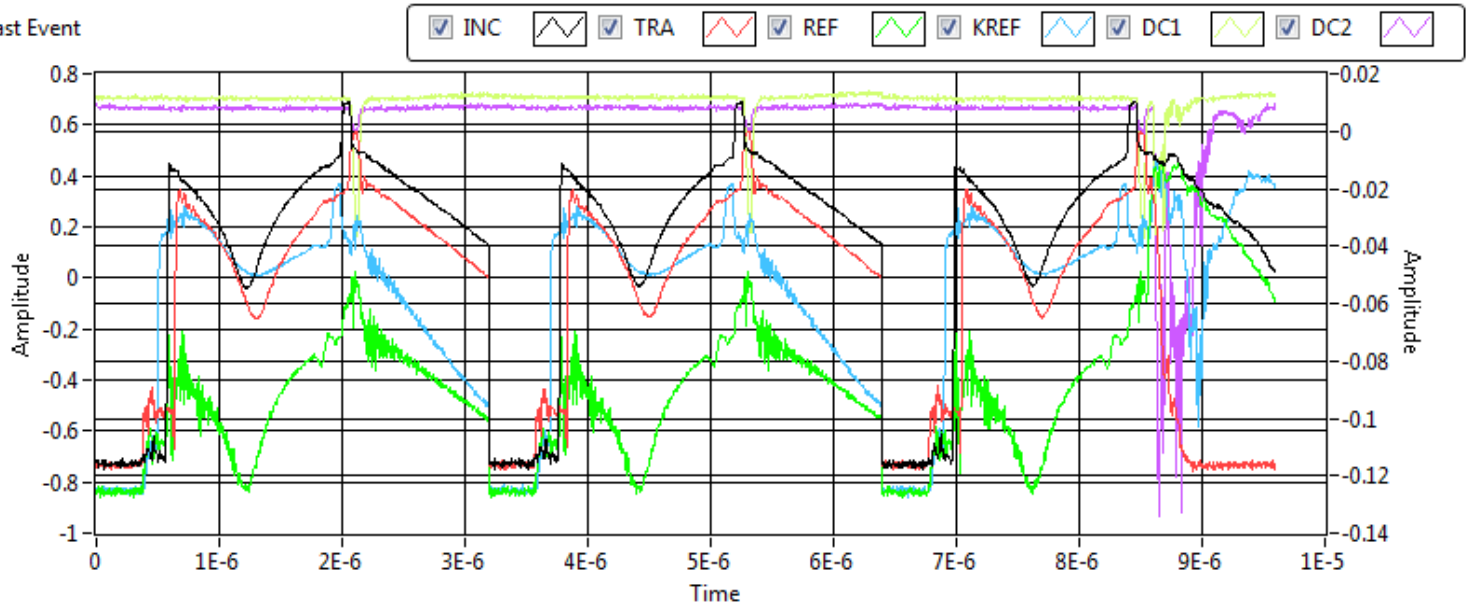
Status of the first CLIC T24 structure tested at CERN

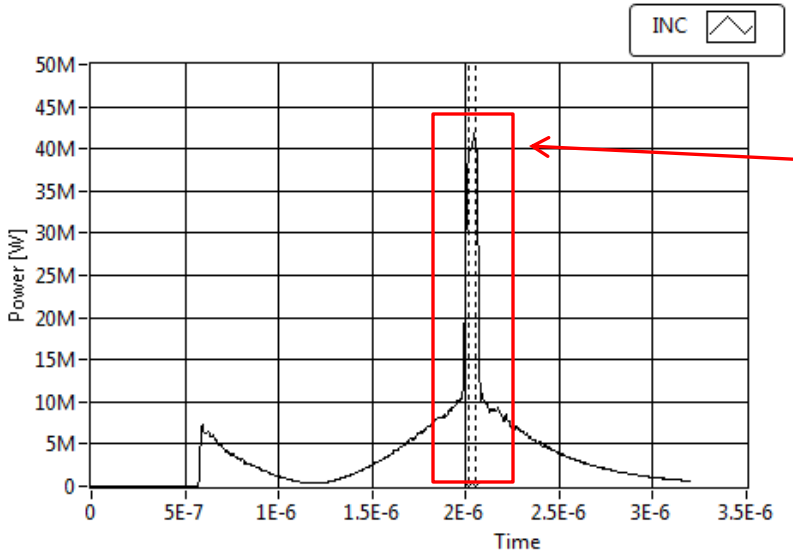


Total conditioning time at 50ns ~ 300hrs

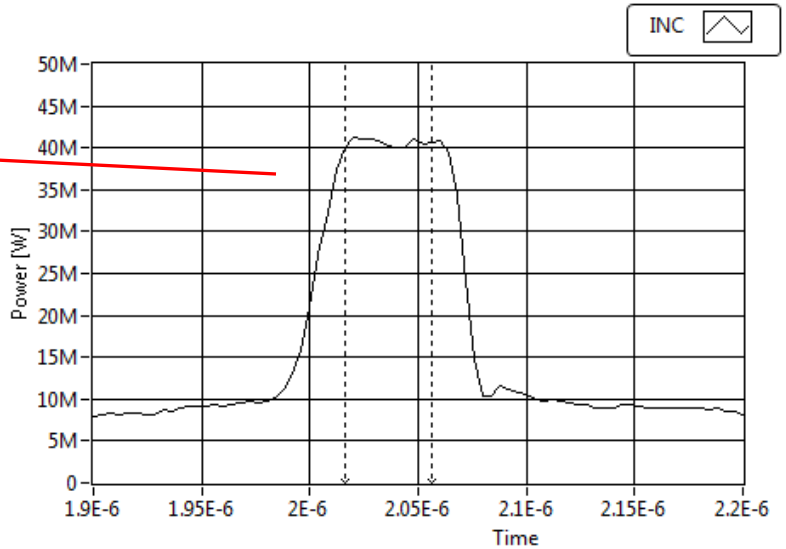
Some example waveforms at 50ns

Log detector!



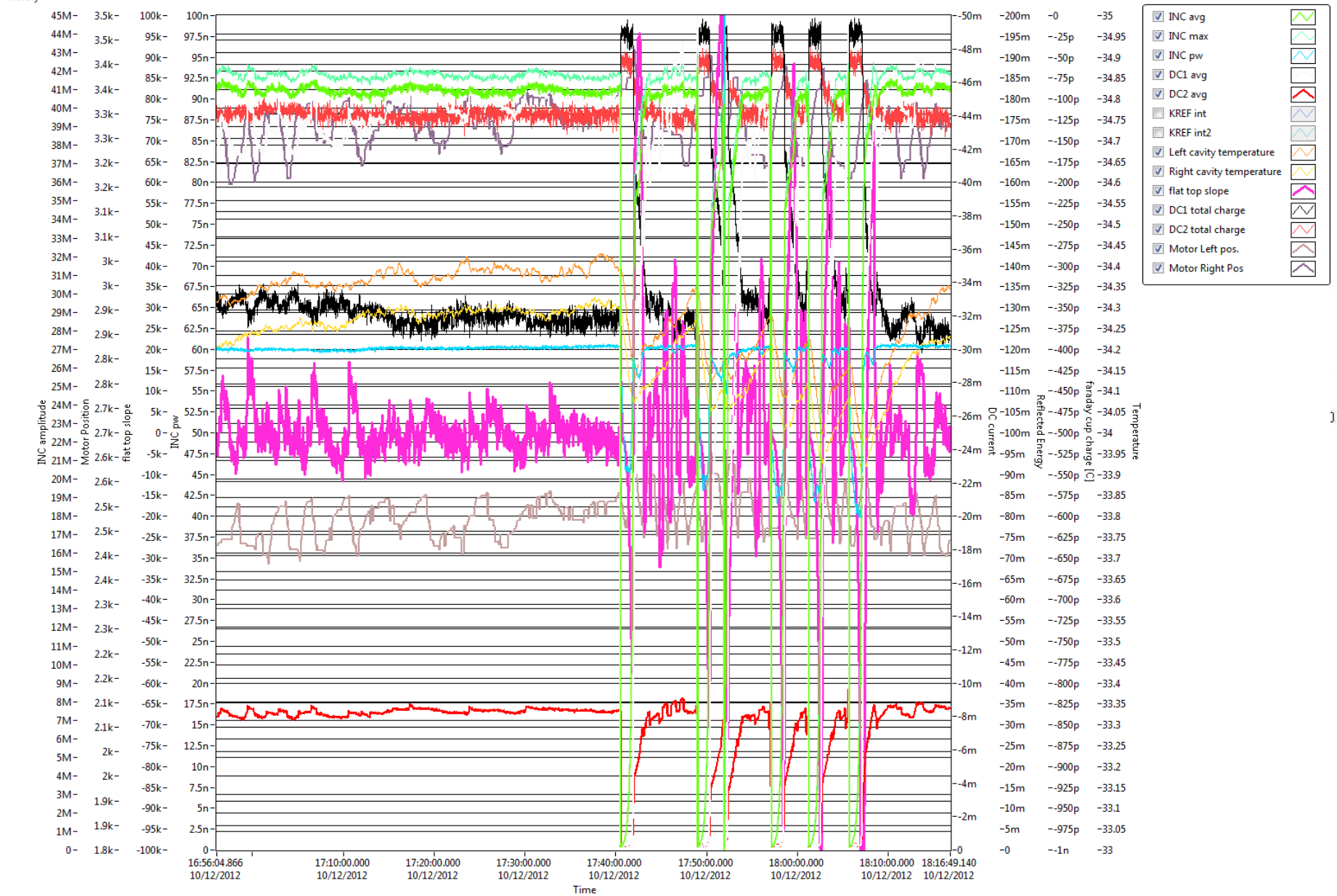


Compressed INC pulse into structure



50ns flat top pulse into structure

Started data analysis on 170ns data (Wilfrid Farabolini)



Conclusion

Still quite some work to be done, but we are ready for a routine structure test right now!

➔ *TD24R05 will be tested in 2013 using a test scheme comparable to the ones used at SLAC and KEK*

You are welcome to visit the test stand!

Thank you!