Status of the BNL LEReC Machine Protection System

S. Seletskiy for LEReC team

August 24, 2017

IBIC17

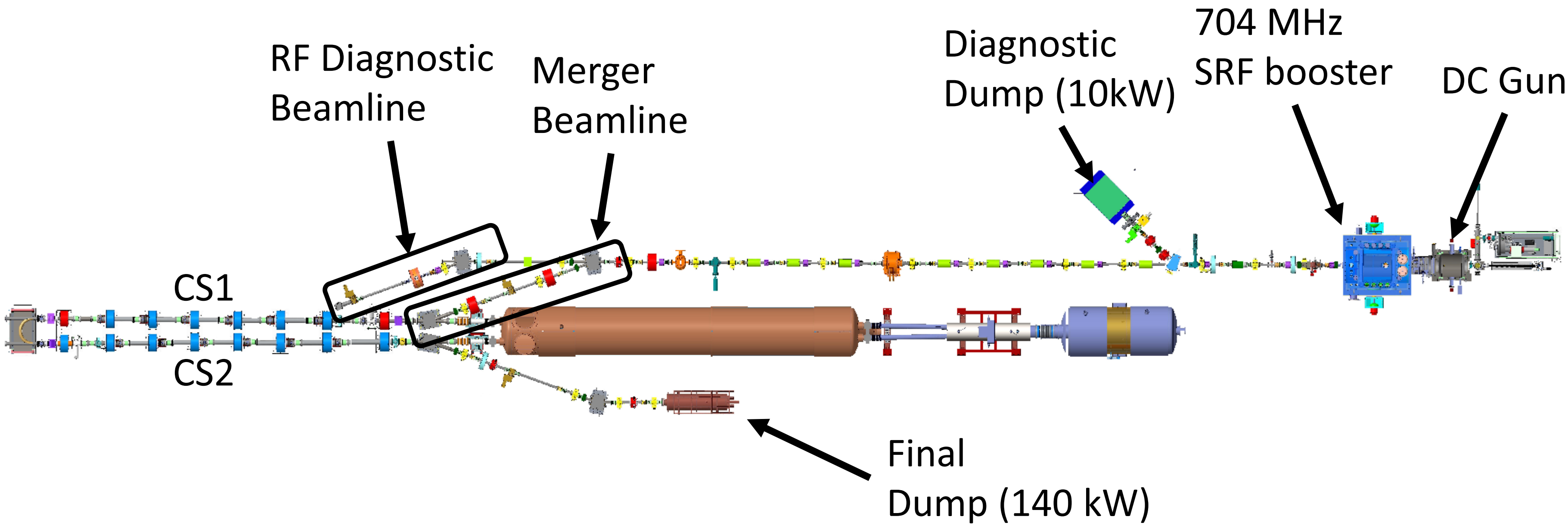
Contributors

Z. Altinbas, D. Bruno, M. Costanzo, A. Fedotov,
D. M. Gassner, X. Gu, L. Hammons, J. Hock,
P. Inacker, J. Jamilkowski, D. Kayran, J. Kewisch,
C. Liu, K. Mernick, T. Miller, M. Minty,
M. Paniccia, W. Pekrul, I. Pinayev, V. Ptitsyn,
K. Smith, Y. Than, P. Thieberger, J. Tuozzolo,
W. Xu, Z. Zhao

Overview

- LEReC layout, beam structure and operational beam modes
- Basic MPS parameters & considered failure scenarios
- MPS diagnostics and MPS to Laser interface
- MPS logic
- MPS in LEReC gun test
- Plans for 2018 run

LEReC layout



- Some machine parameters pertinent to the MPS design:
  - Beam energy out of the gun is 400 keV
  - Beam energy after the Booster is 1.6 – 2.6 MeV (the maximum possible energy is 3 MeV)
  - Operational beam current is 35-55 mA (baseline with trains); CW 85 mA (1.6 MeV), 67 mA (2 MeV)
  - Operational beam power is <140 kW
  - Typical transverse RMS beam size throughout the LEReC is >1 mm
  - The smallest transverse RMS beam size in the LEReC (Merger beamline) is 0.25 mm
- Missteered beam at full power can damage the vacuum chamber and in-vacuum beamline components.
- LEReC MPS shall protect machine from such a damage.

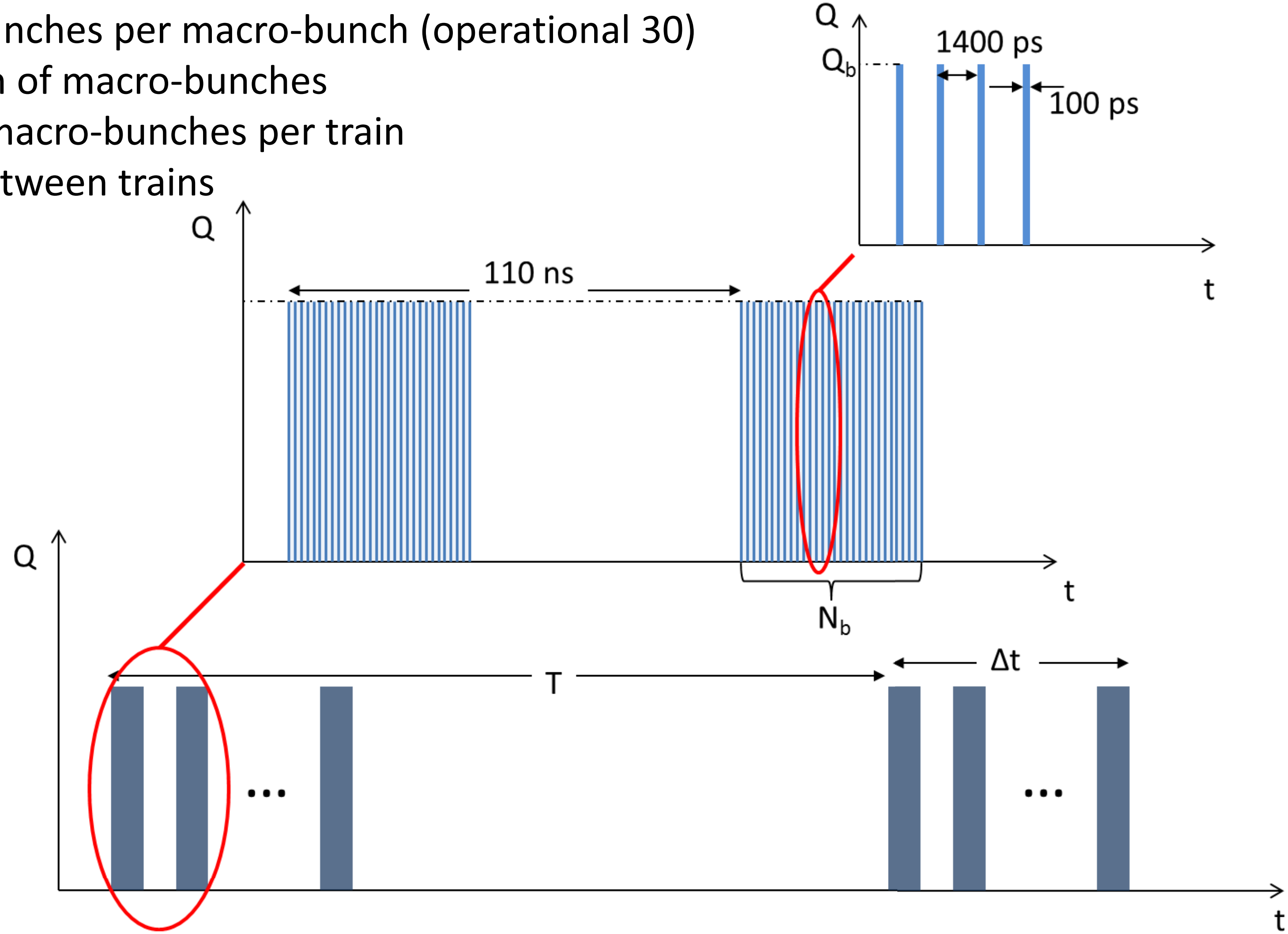
LEReC beam parameters

Electron beam requirement for cooling			
Kinetic energy, MeV	1.6*	2	2.6
Cooling section length, m	20	20	20
Electron bunch (704MHz) charge, pC	130	170	200
Effective charge used for cooling	100	130	150
Bunches per macrobunch (9 MHz)	30	30	24-30
Charge in macrobunch, nC	4	5	5-6
RMS normalized emittance, um	< 2.5	< 2.5	< 2.5
Average current, mA	36	47	45-55
RMS energy spread	< 5e-4	< 5e-4	< 5e-4
RMS angular spread	<150 urad	<150 urad	<150 urad

LEReC beam structure

- Continuous sequence of 9 MHz macro-bunches or
- Trains (of length Δt) of 9 MHz macro-bunches repeated with frequency 1/T

Q_b – charge per bunch (operational 130 pC)
N_b – number of bunches per macro-bunch (operational 30)
Δt – length of train of macro-bunches
N_{mb} – number of macro-bunches per train
T – time period between trains



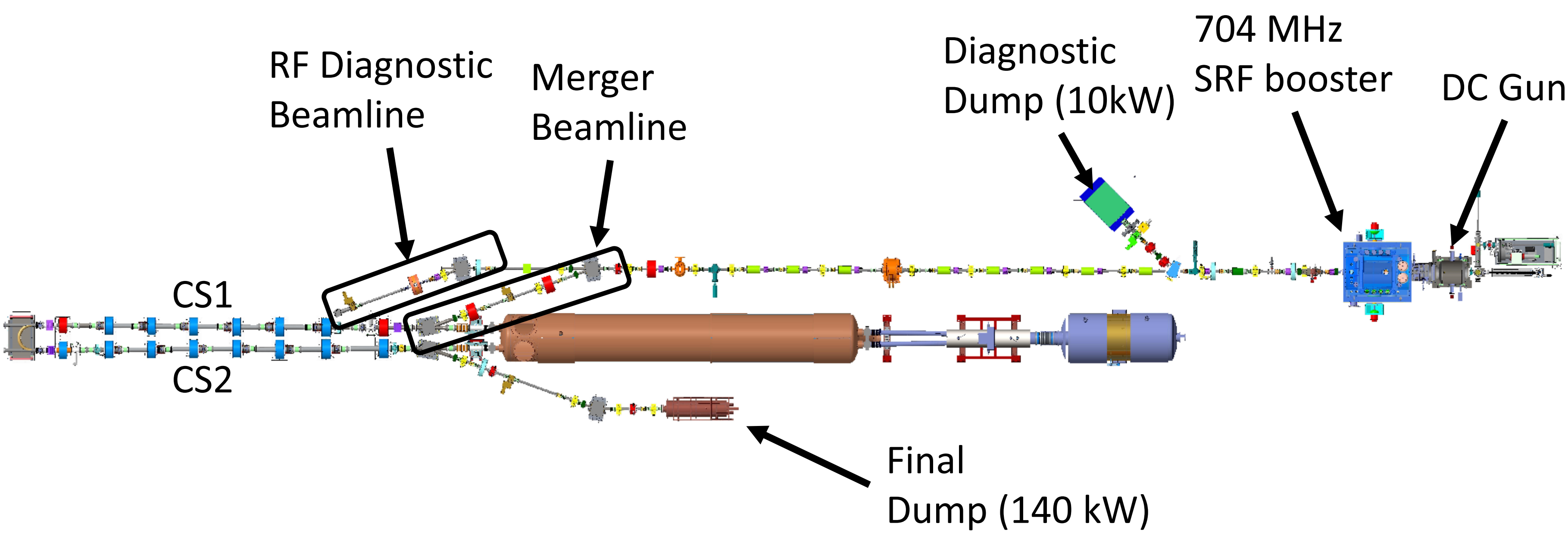
Beam modes

Timing Pattern	Beam modes	Goals	Power
N_b = 30 **N_{mb} = 1** **T = 1 s**	Low Current Mode (LCM); Q_b = 30 – 200 pC	Set beam optics & RF (roughly) for nominal Q_b. Measure envelope in the CS & beam emittance.	P ≤ 16 mW I ≤ 6 nA
N_b = 10,15,20,25,30 **Δt ≤ 250 us** **T = 1 s – 5 s**	RF Studies Mode (RFSM); Q_b ≤ 200 pC	RF fine-tuning. Study beam longitudinal phase space.	P ≤ 7 W I ≤ 3 uA
N_b = 30 **Δt =T**	Transition Mode (TM) ; Q_b ≤ 200 pC	Gradual transition from LCM to HCM.	P ≤ 142 kW I ≤ 55 mA
N_b = 30 **Δt = T**	High current Mode (HCM); Q_b = 130 – 200 pC	Getting nominal e-beam parameters in the CS.	P = 142 kW I = 55 mA
704 MHz CW	CW Mode (CWM); Q_b = 95 – 120 pC	Alternative to HCM.	P = 136 kW I = 68 - 85 mA

MPS parameters & failure scenarios

- We considered various failure scenarios resulting in the wrong power beam hitting various in-vacuum components: YAG screens, Vacuum Valves, Emittance Slits, Dumps, RF cavities and Vacuum Chamber
- As a result we identified the following basic MPS parameters:

Parameter	Value
Reaction time	40 us
Tolerable routine losses (starting point)	1 uA
Current threshold for ultimately safe operation mode (USOM)	40 nA



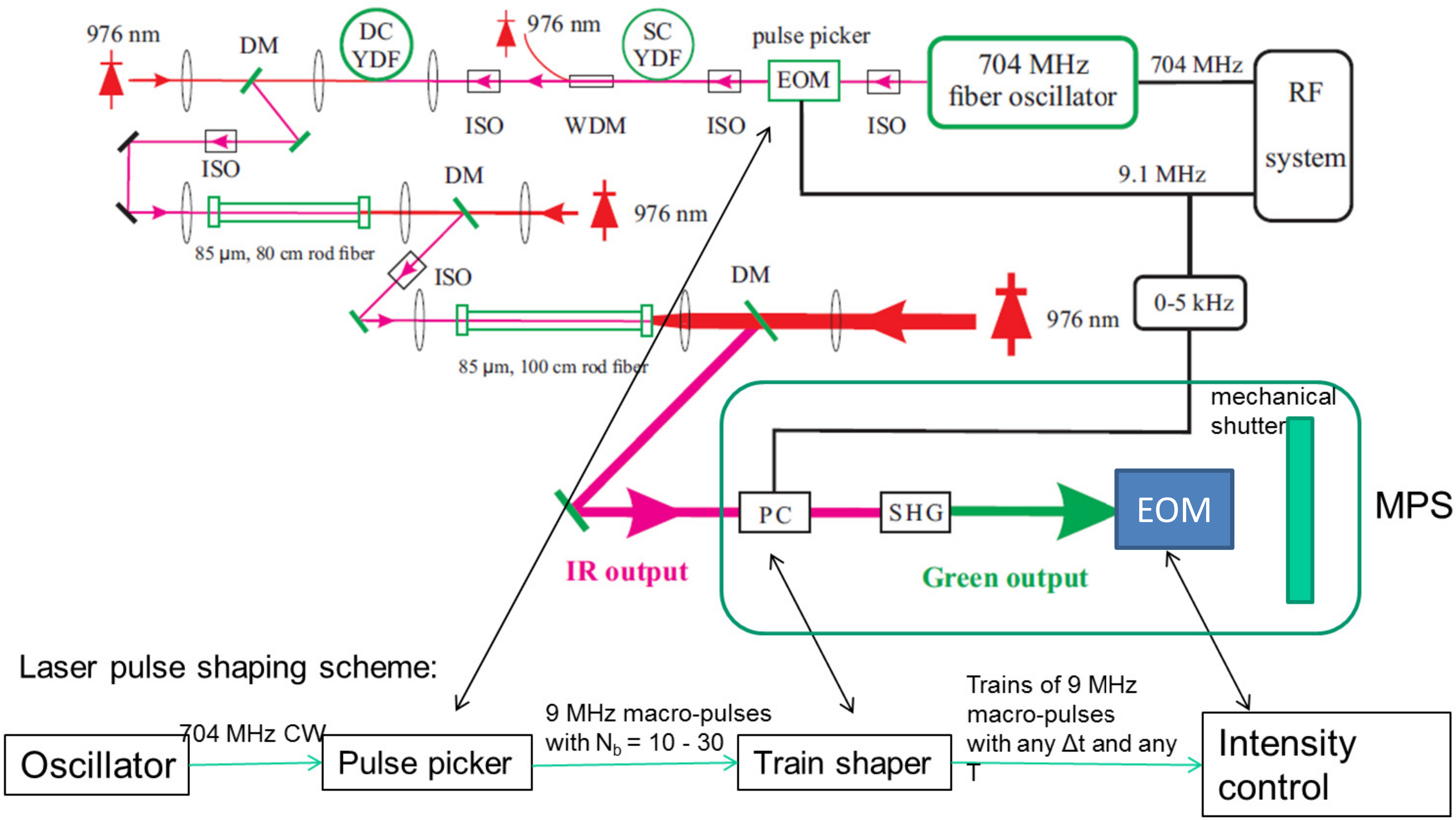
MPS Diagnostics

- BLMs – for fast loss detection (reaction time is a few us)
- FCTs – for measuring beam current. FCT processing scheme involves integrating charge accumulated in the 1 s moving window. (reaction time is ~10 us)
- Monitoring BPMs – to control beam trajectory (reaction time is ~12 us)
- Monitoring magnets to control beam trajectory and focusing

- MPS interlocks the machine by blocking the photocathode laser beam

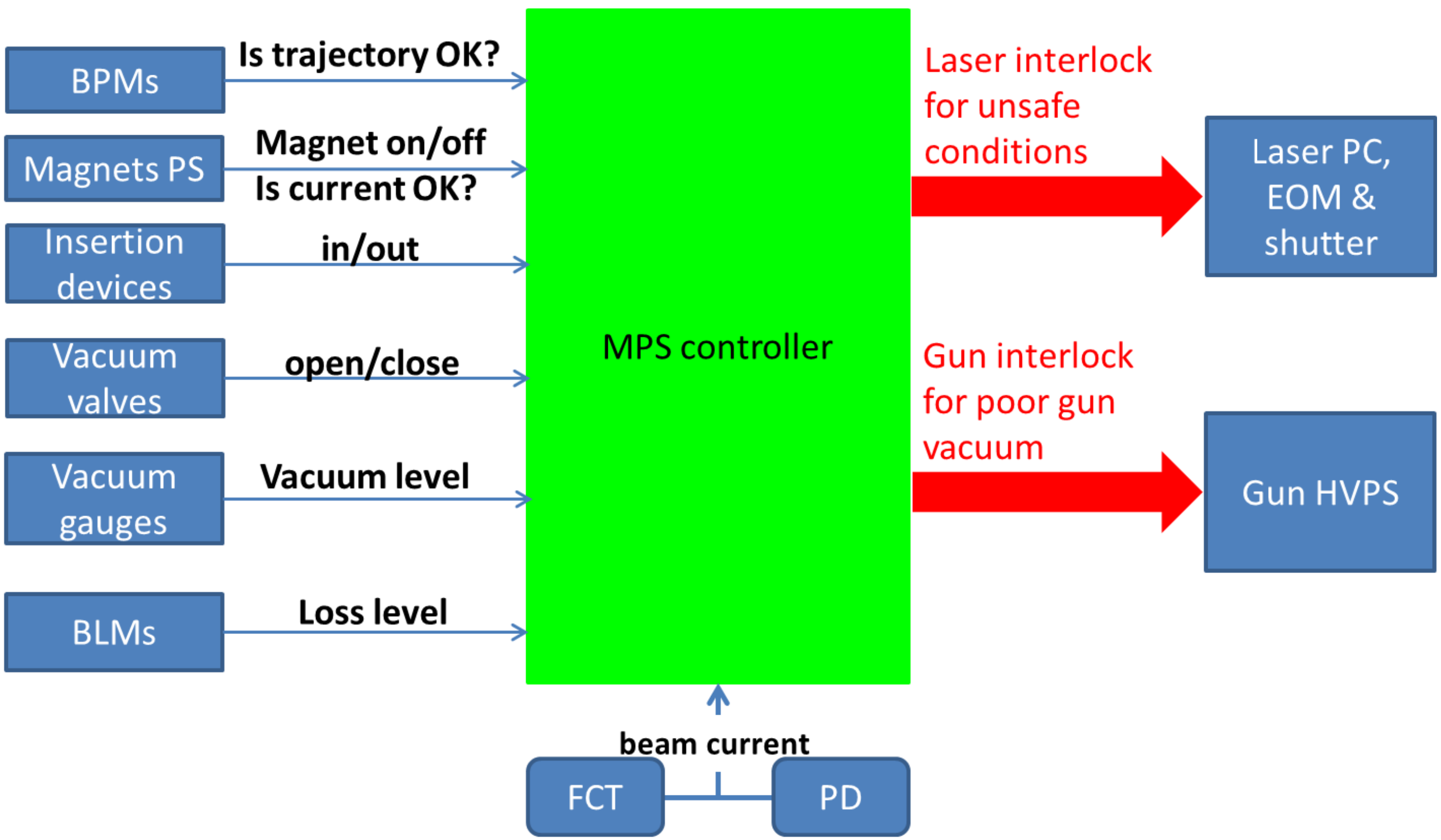
MPS–Laser Interface

- The MPS is interlocking the machine by closing the Pockels cell, the IC EOM and the mechanical shutter



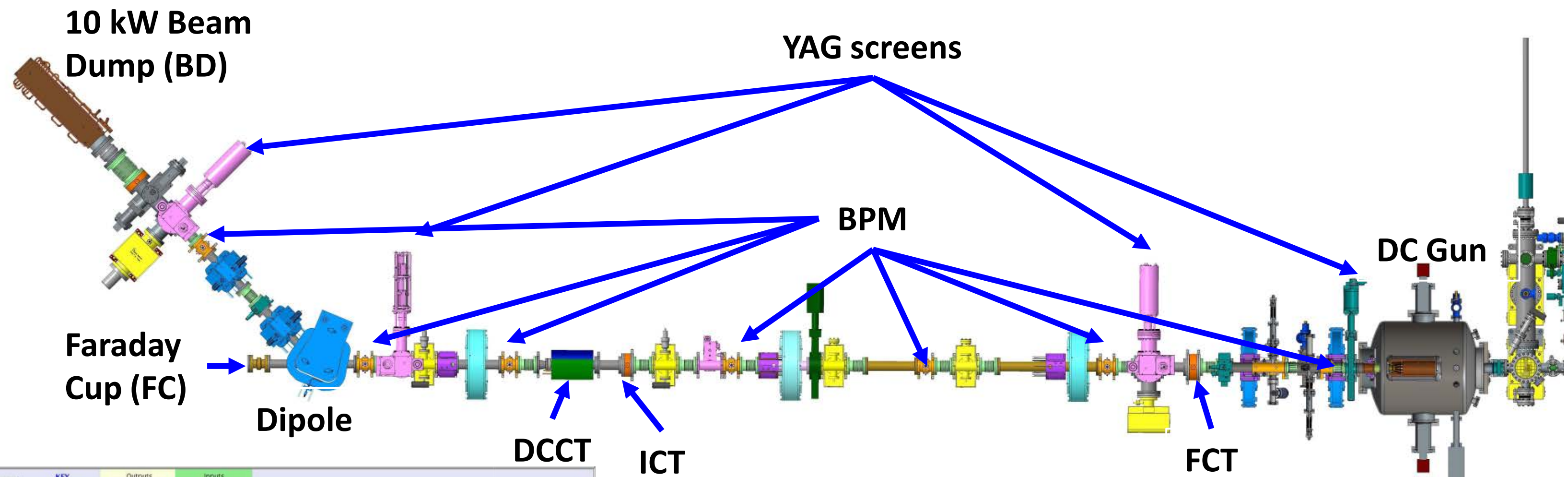
MPS Logic

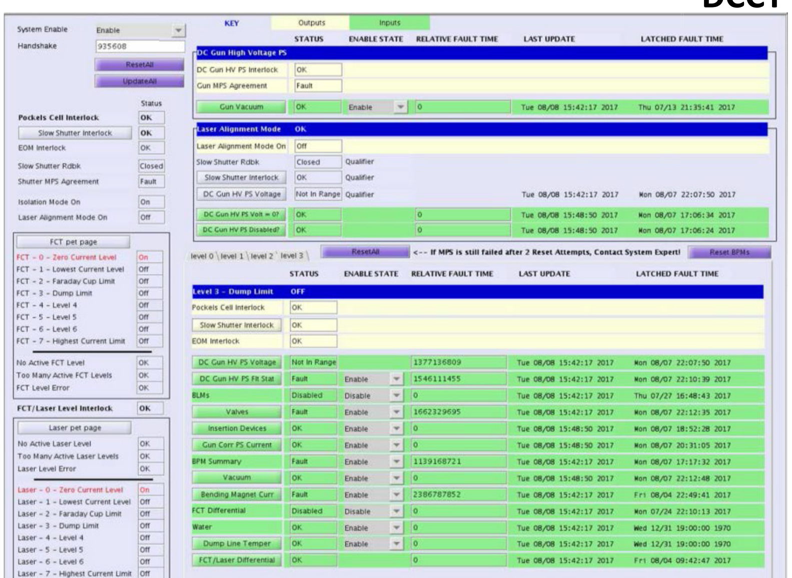
- MPS works with Machine Modes (MM)
- MM is defined by where the beam is supposed to land
- Each MM has the safe current (SC) associated with it
- Actual beam current (ABC) is measured by the FCT
- If ABC > SC then the beam is stopped

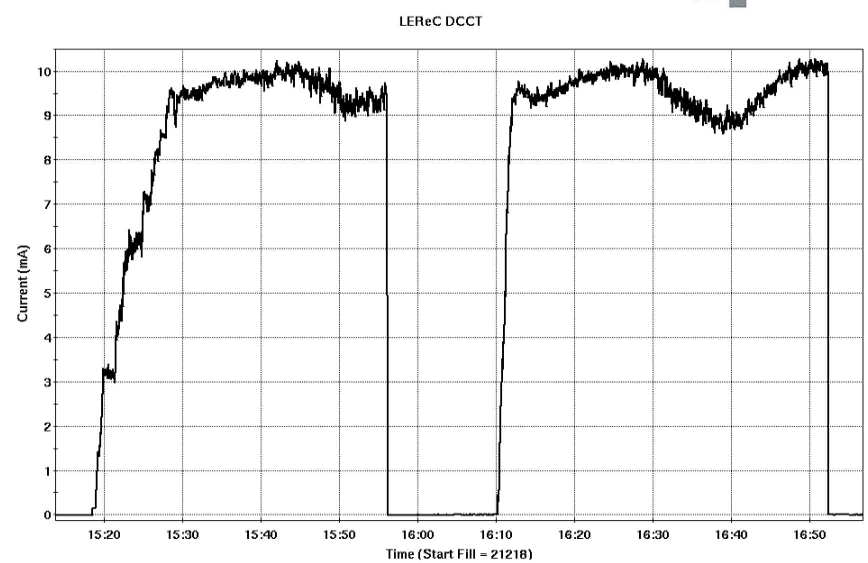


LEReC Gun Test run (April-August 2017)

- The beam energy was 300-400 keV.
- Tested both pulsed and CW modes.
- Achieved max current of 10 mA.
- Scaled down MPS was built, commissioned and utilized.





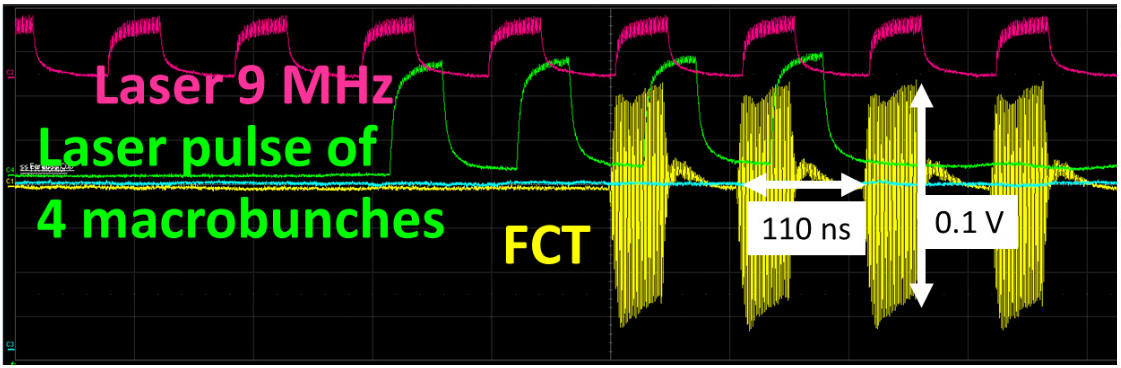


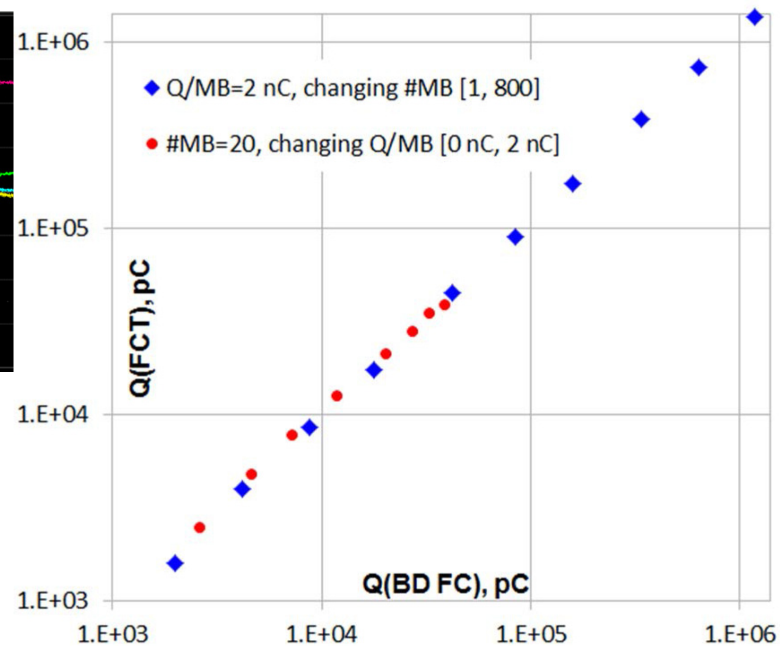
MPS commissioning (2017 run)

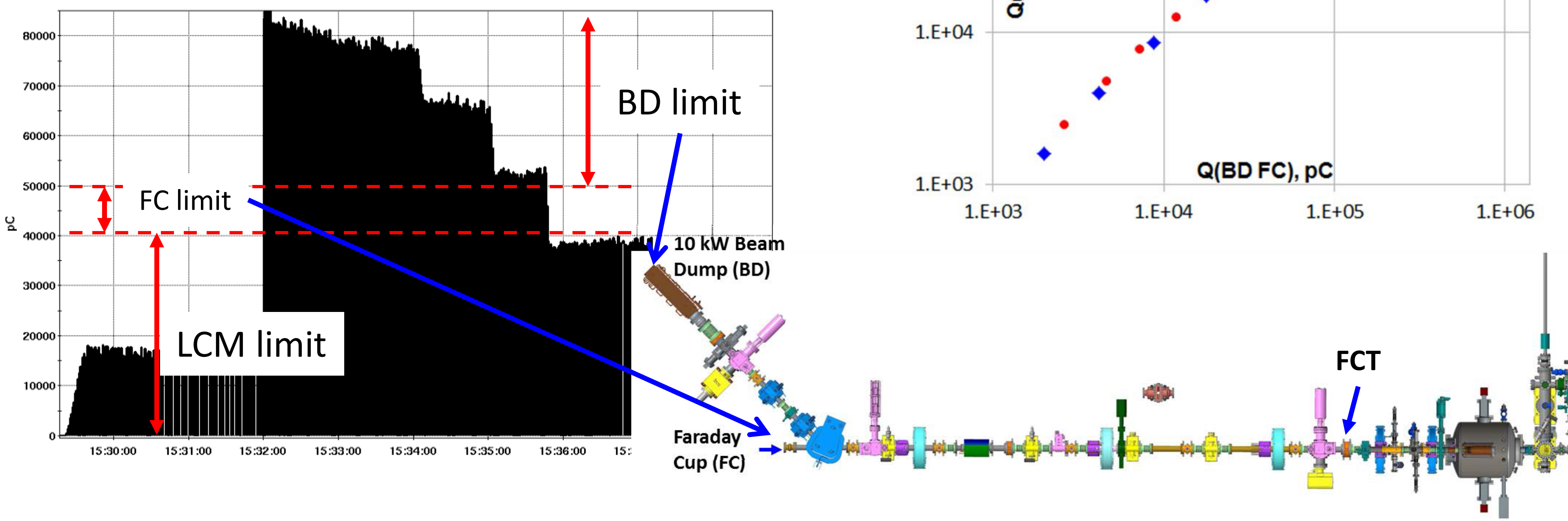
- The commissioning procedure of the scaled down LEReC MPS consisted of the three main blocks.
- **The integrated system test** consisted of checking the interaction between the MPS controller, the MPS diagnostic subsystems, the laser, and the gun HVPS.
- The second step was the **MPS test without the beam**. In that step we verified the logic of the MPS controller by emulating various fault conditions and observing the laser interlocks.
- **In the final step we commissioned the entire integrated LEReC MPS with electron beam**. Working in the LCM we successively adjusted the FC and BD current levels to the level below the current measured by the FCT, created all possible beam faults and observed the expected machine trips.

Experience with FCT (2017 run)

- First e-beam produced with real laser was obtained May 5th. FCT signal was observed right away.
- Beam-based calibration of the FCT involved comparing its response to the beam charge measured with ICT and various FCs.
- The FCT reliably determines and sets MPS current levels as long as charge/bunch ≥ 1 pC.

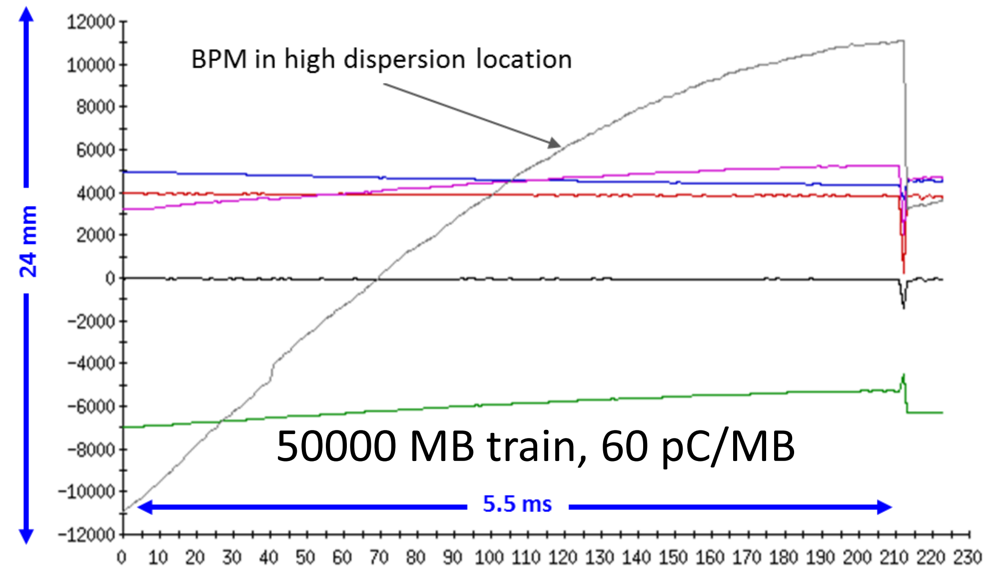


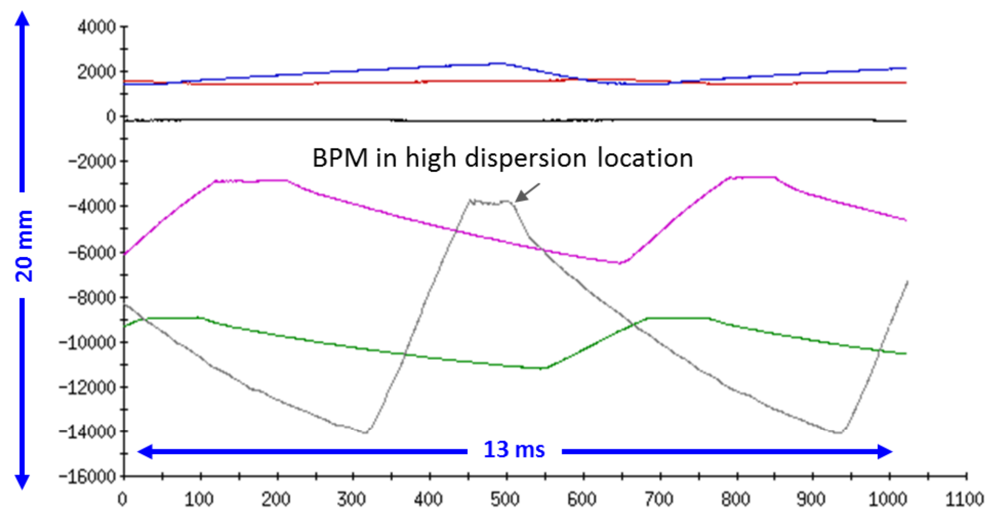




Experience with BPMs (2017 run)

- BPMs have been reliably interlocking the MPS whenever the beam trajectory was moved out of the allowed range both in the pulsed and in the CW modes.
- For instance, BPMs were interlocking the MPS because of trajectory change along the train of macrobunches due to the beam loading in the gun.

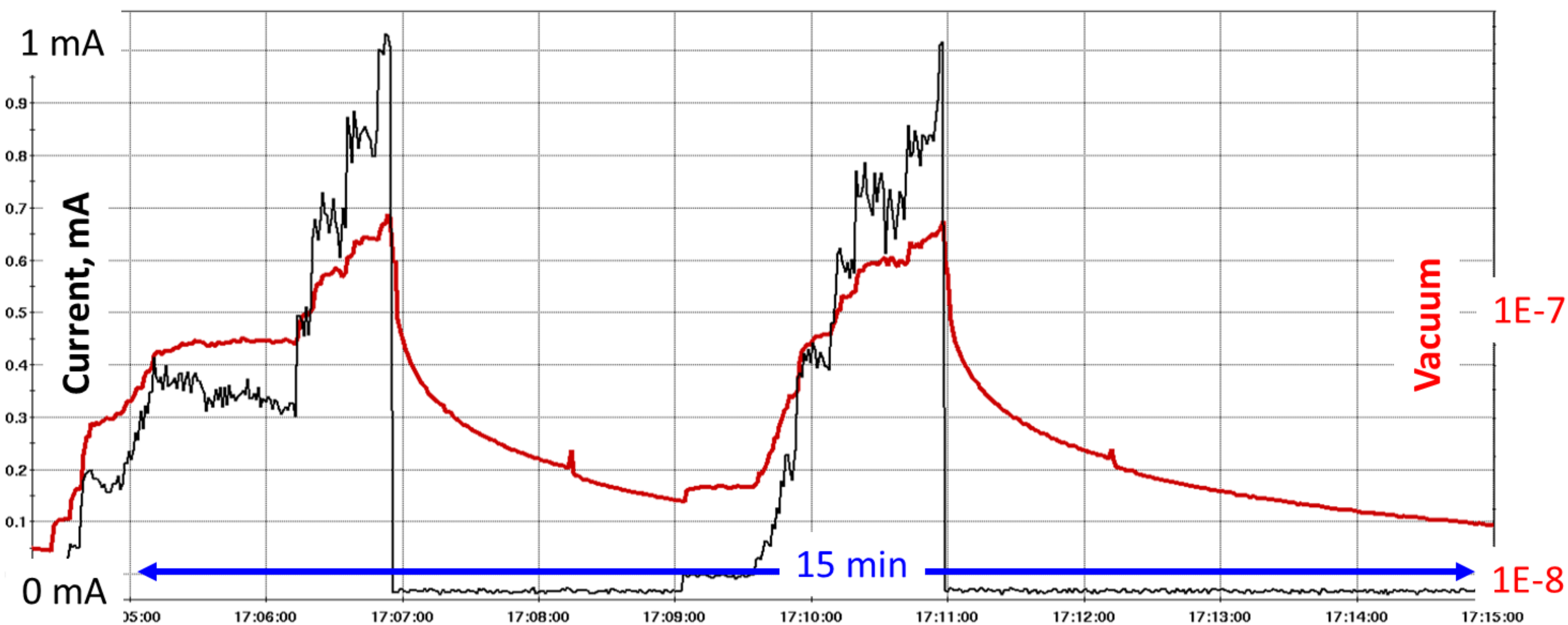




CW, 2.8 mA, regulation loop malfunctioning

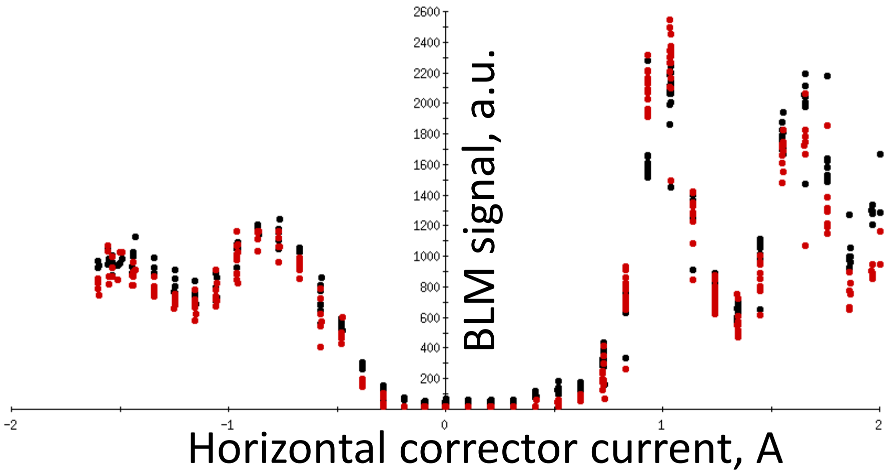
MPS experience with vacuum, temperature etc. (2017 run)

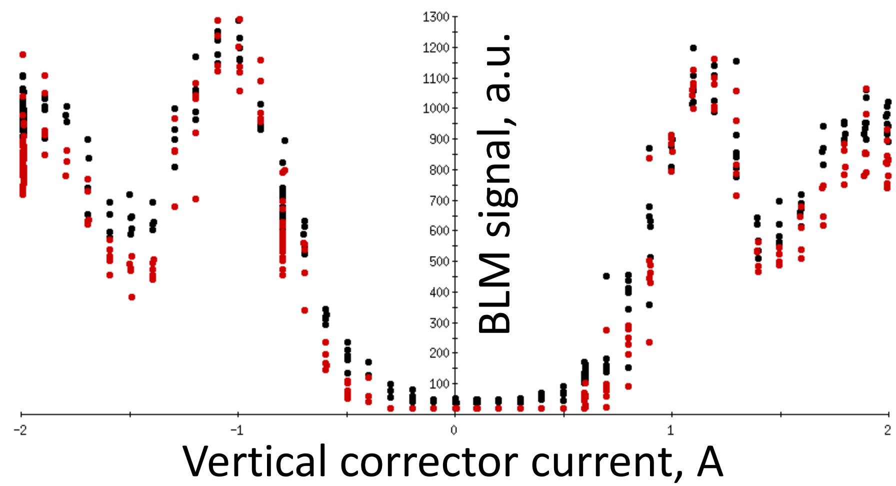
- The vacuum gauges, readback of the magnets PS currents, readback of position of various insertion devices, Gun HVPS readback and beamline and dump temperatures demonstrated proper and reliable interaction with the MPS during the whole 2017 run



BLMs experience (2017 run)

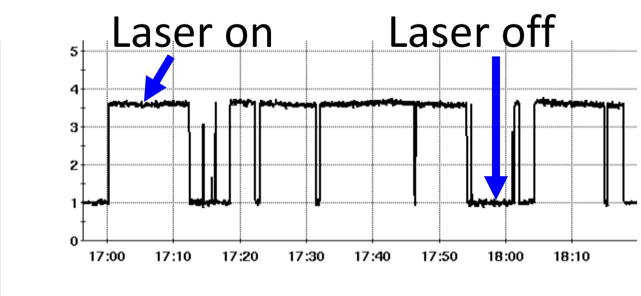
- BLMs – PMTs retrofitted with few feet long scintillating fiber were partially commissioned.
- The interaction of BLMs with the MPS was fully commissioned.
- BLMs show good sensitivity to direct losses in pulsed mode.
- Losses are detectable in all directions (up, down, left, right) by a single fiber installed on beam left along the beam line.
- There was an issue with noise scaling up with the signal (w.i.p.)
- BLMs commissioning in CW mode wasn't started due to schedule pressure (w.i.p.)

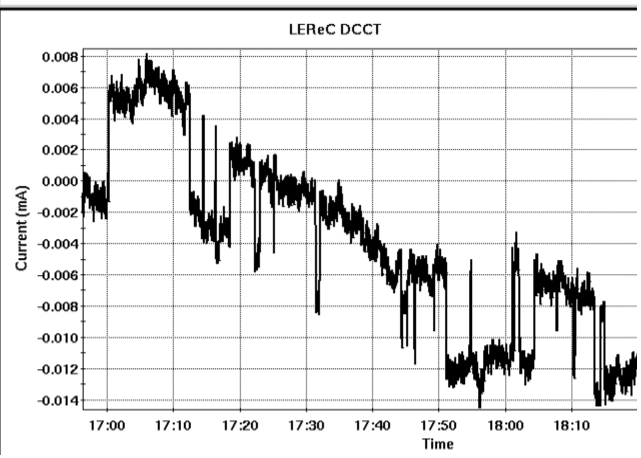


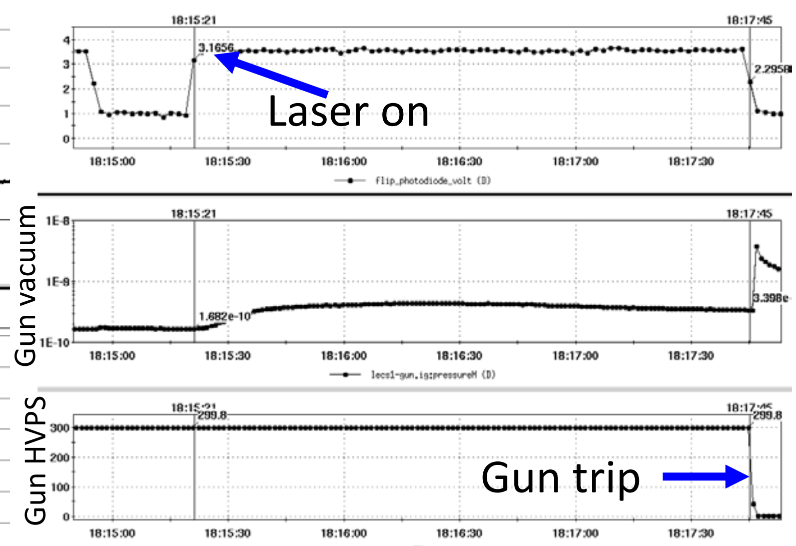


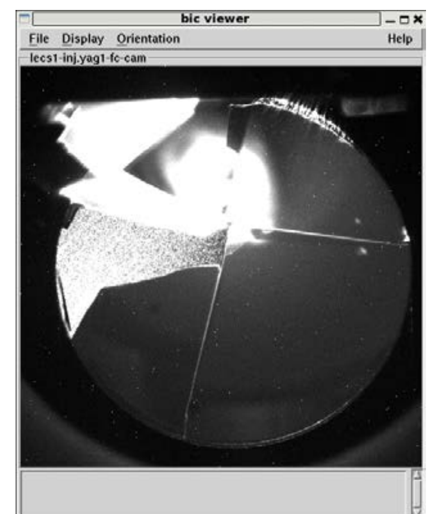
Unexpected failure mode – “laser leakage”

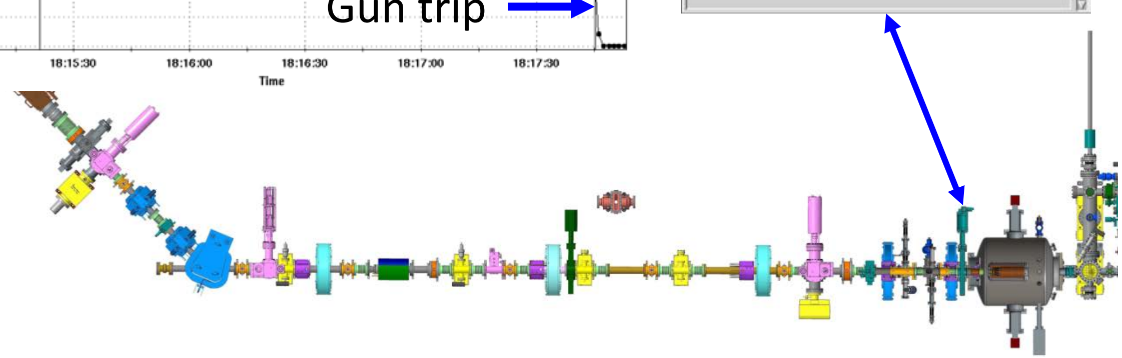
- During the very last hour of the very last shift (August 11) we destroyed one of our YAG screens.
- An unexpected (and unprepared for) failure that we dubbed “laser leakage”: in pulsed mode the laser was producing CW background too weak to be detected by the FCT but substantial enough to produce 8 uA DC current and to blow up YAG1 to pieces.











Plans for full LEReC commissioning (2018 run)

- The MPS will be scaled up for the full LEReC commissioning.
- Essentially new (and critically important) device that needs protection from direct beam hit is SRF Booster.
- We shall implement diagnostics that is able to detect small DC current out of the Gun.
- We will revisit possible laser failure scenarios and decide what MPS diagnostic needed in the laser room.

Conclusion

- We discussed the design of the Machine Protection System for the Low Energy RHIC Electron Cooling accelerator.
- The scaled down MPS was successfully commissioned and utilized in operation of the LEReC gun test.
- Presently we are expanding the commissioned system to include all the components necessary for the commissioning of the full LEReC in 2018.