Errant Beam Update

Accelerator Advisory Committee

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Accelerator Operations Machine Specialist

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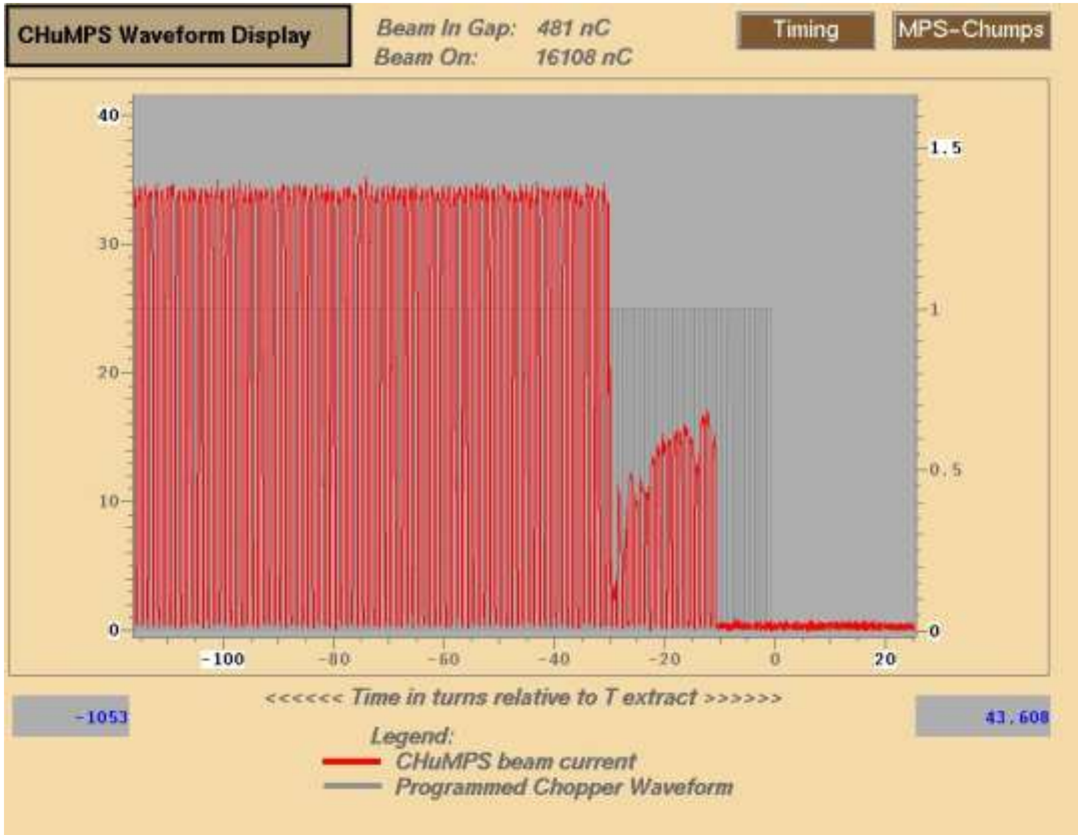
Why is errant beam important

- Errant beam mechanism
  - Beam hitting cavity surface desorbs gas or particulates creating an environment for arcing
- Super Conducting Linac (SCL) cavity performance degrades over time
  - SCL cavities do not trip with every errant beam pulse, but the probability for a trip increases with time
  - Cavity fields have been lowered and cavities have been turned off which results in lower beam energy
- SCL cavity performance degradation from errant beam can be restored (except for cavity 06c)
  - Requires cavity warm up during a long shutdown and then RF conditioning before beginning beam operation
  - Cryomodules have been removed from the tunnel for cavity RF coupler repairs but this takes months

Our definition of errant beam

- Abrupt beam loss caused by
  - Low current or partial beam pulses
  - Beam pulses with incorrect energy
- SCL Beam Loss Monitors (BLM) are the primary indication of errant beam



Fast beam current monitor in MEBT

Oak Ridge National Laboratory
MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

Machine Protection System (MPS) contributed to errant beam conditions

- Discovered in 2009 that problems with MPS system were contributing to SCL cavity performance degradation
  - When a fault occurred, in some instances 300 microseconds or more of beam was accelerated before MPS turned beam off (goal is 25 microseconds)
  - Long delays found throughout MPS
  - Root cause traced to low pass filters added to reduce false trips due to electrical noise – fixed in early 2010 by removing filters
- Also reduced set point for number of BLM trips in 1 second needed to shut off beam ("chatter faults", reduced from 2 to 1)
- Also reduced BLM trip limits

In response to the AAC the errant beam taskforce was established

- Correcting the MPS and tightening BLM limits reduced the impact of errant beams but did not eliminate them
- SCL cavity performance continued to degrade
- In February 2012 a task force was created to further understand the errant beam mechanisms
- Plans for the taskforce were
  - Measure errant beam
    - How much is being lost
    - How often it is occurring
  - Find the causes for errant beam
  - Reduce errant beam faults
  - Reduce the impact of errant beam

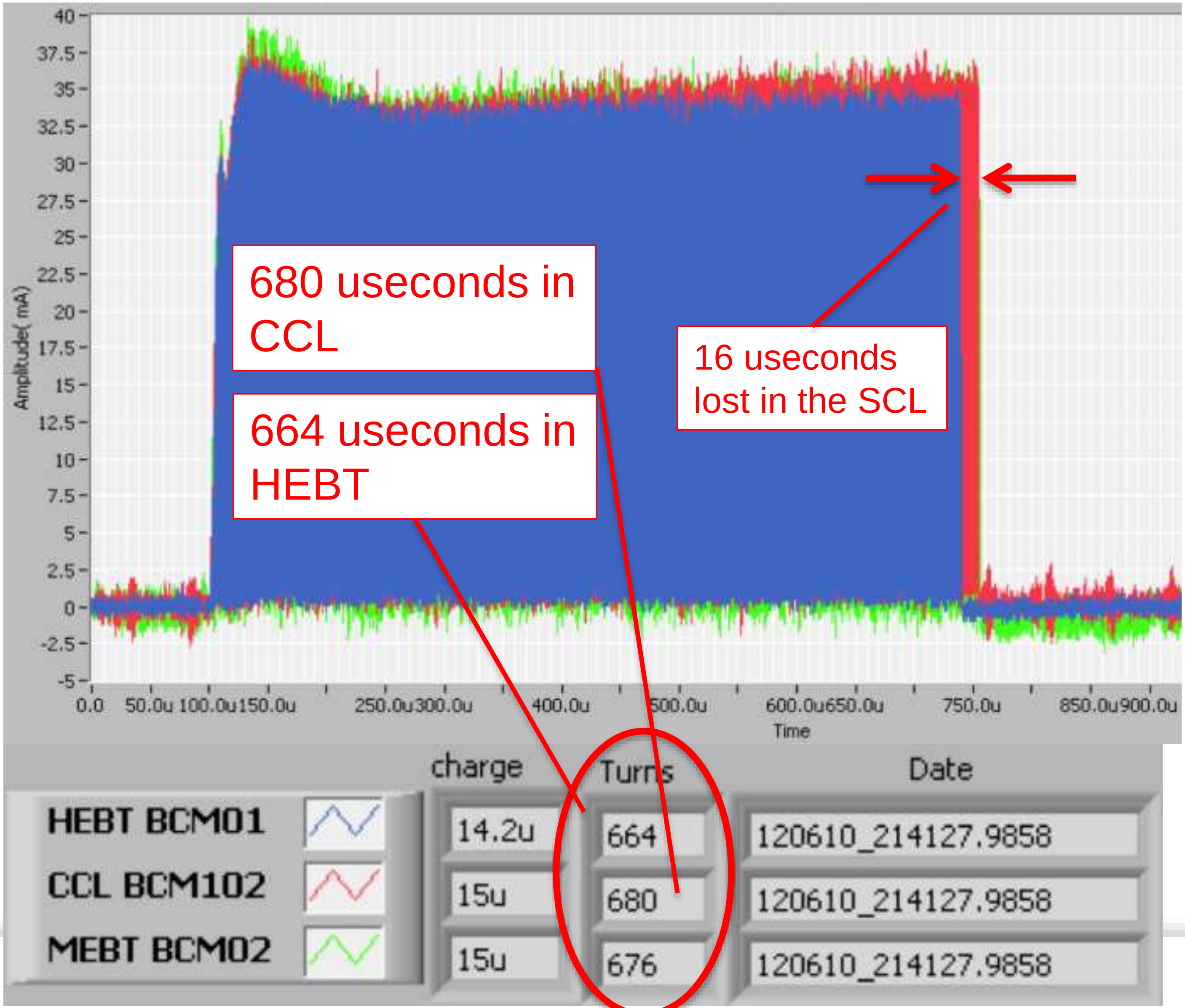
Beam diagnostics used

- Differential Beam Current Monitor (BCM) systems
  - Use BCMs in the MEBT, CCL, and HEBT to see how much beam is lost in the SCL
- BLM systems
  - 76 ion chamber detectors along the SCL
- Automated report system
  - SCL BLM trip occurs
    - Record BCM waveforms, BLM waveforms, BLM signal level
    - Send data to a webserver for immediate viewing

How much beam is lost

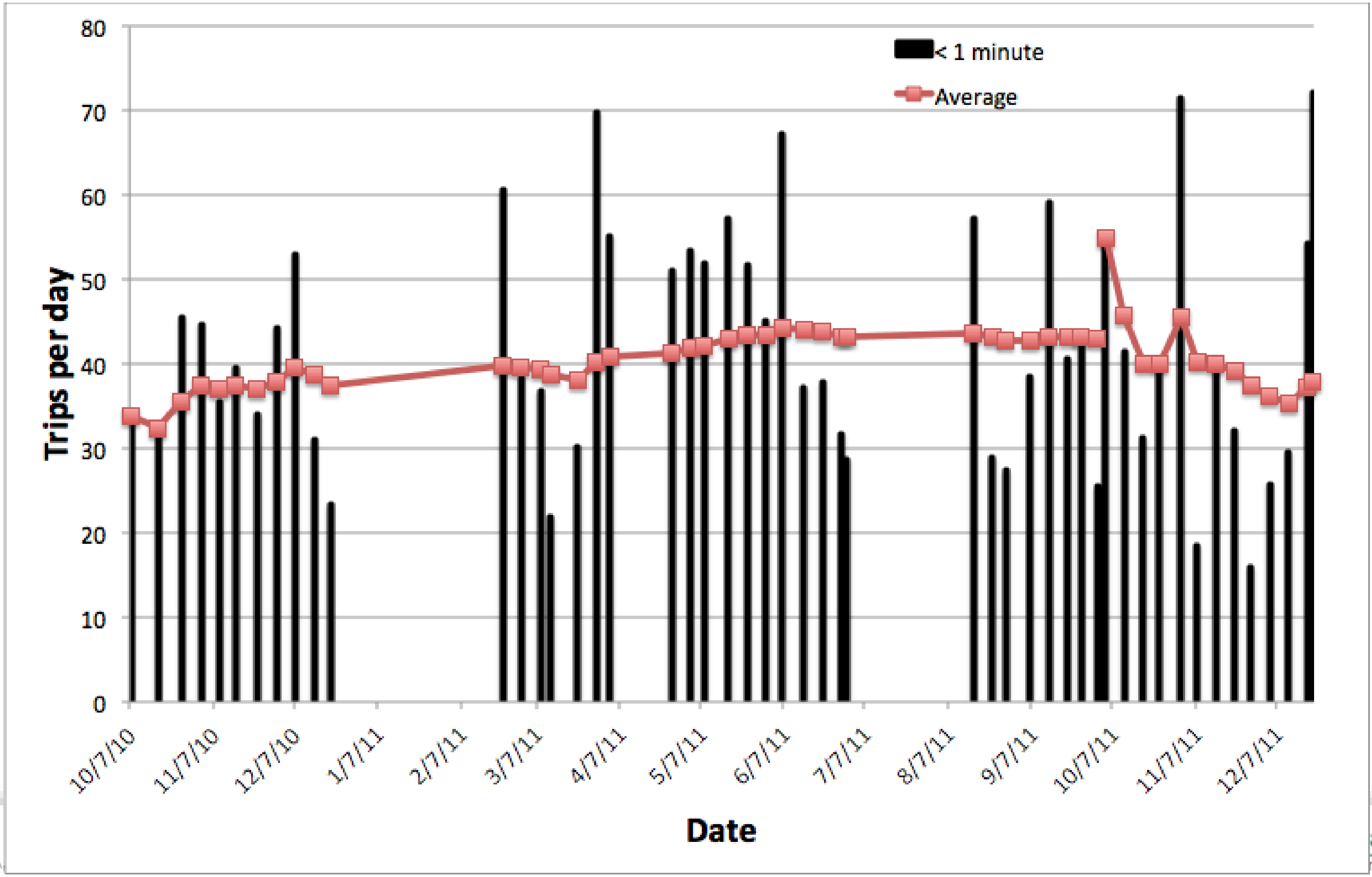
16 useconds
End of DTL = 30 J
End of CCL = 66 J
End of SCL = 350 J

- Differential BCMs showed different types of faults
  - Averaged 15-20 usec of beam lost in the SCL
- Verified MPS is working properly

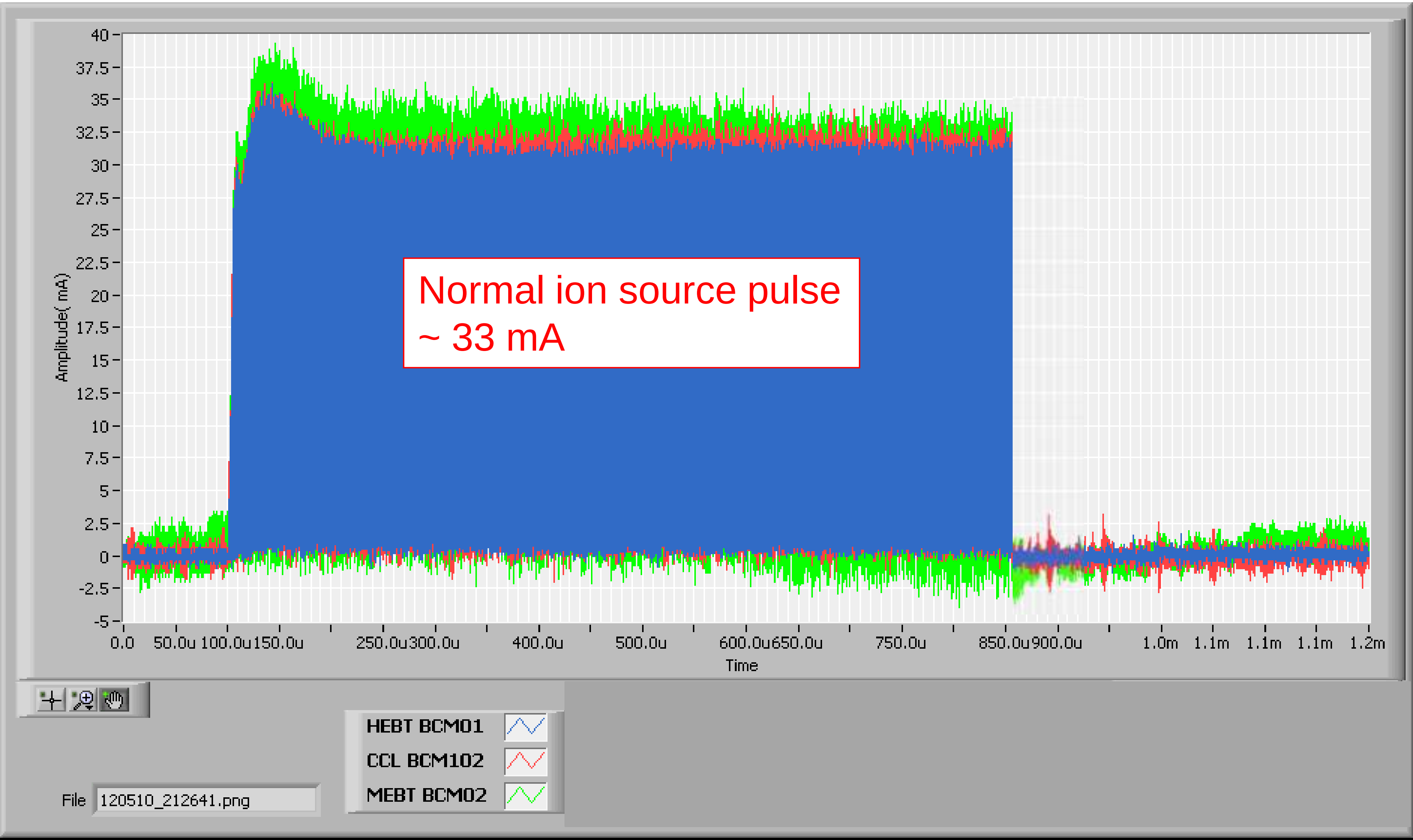


Short beam trips and errant beam

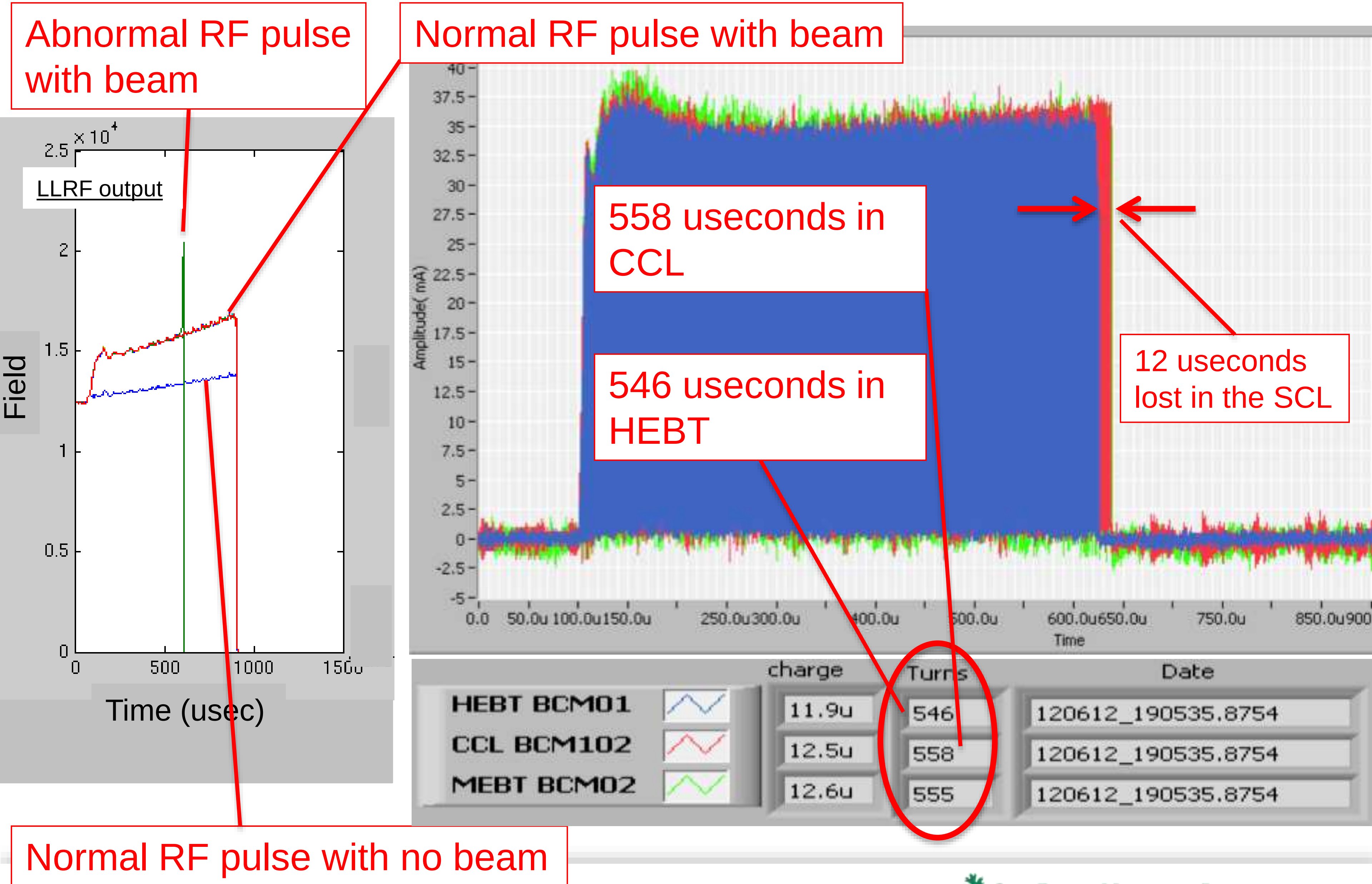
- September 2010 to December 2011
  - On average >75% (30 per day) of short trips were caused by errant beam



Ion source/LEBT is one cause of errant beams



Warm Linac RF are the other causes



The majority of trips originate in the Warm Linac

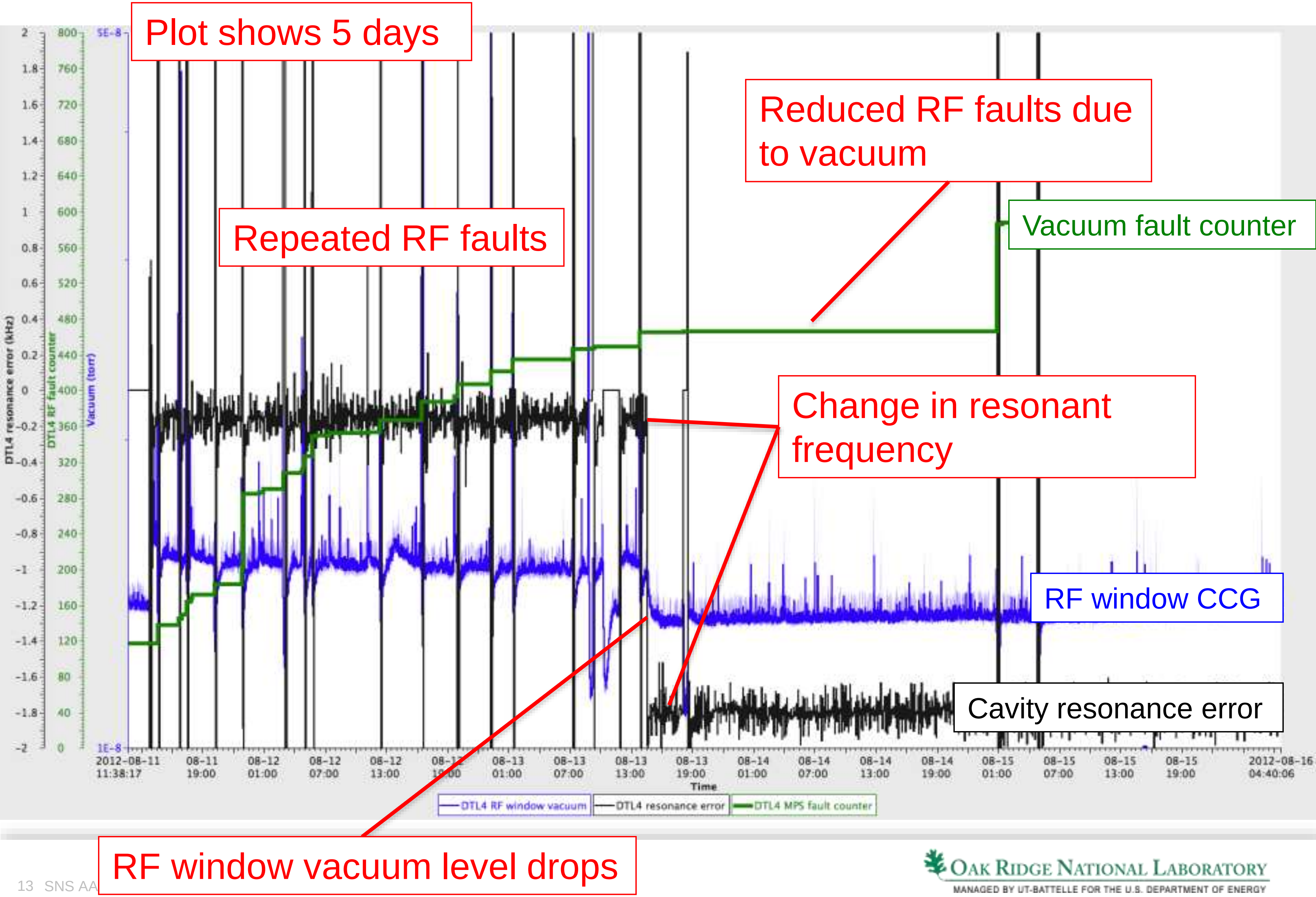
- < 10% of BLM trips were due to the Ion source/LEBT
  - Most ion source induced BLM trips occur during the first week of a new source installation
    - High voltage arcing
- > 90% of BLM trips were due to Warm Linac RF faults
  - RF faults occur at different times during the pulse
    - Faults during the RF fill had reproducible times
    - Faults during the RF flattop were random
  - Focused on improving warm linac operation

RF fill faults can be reduced

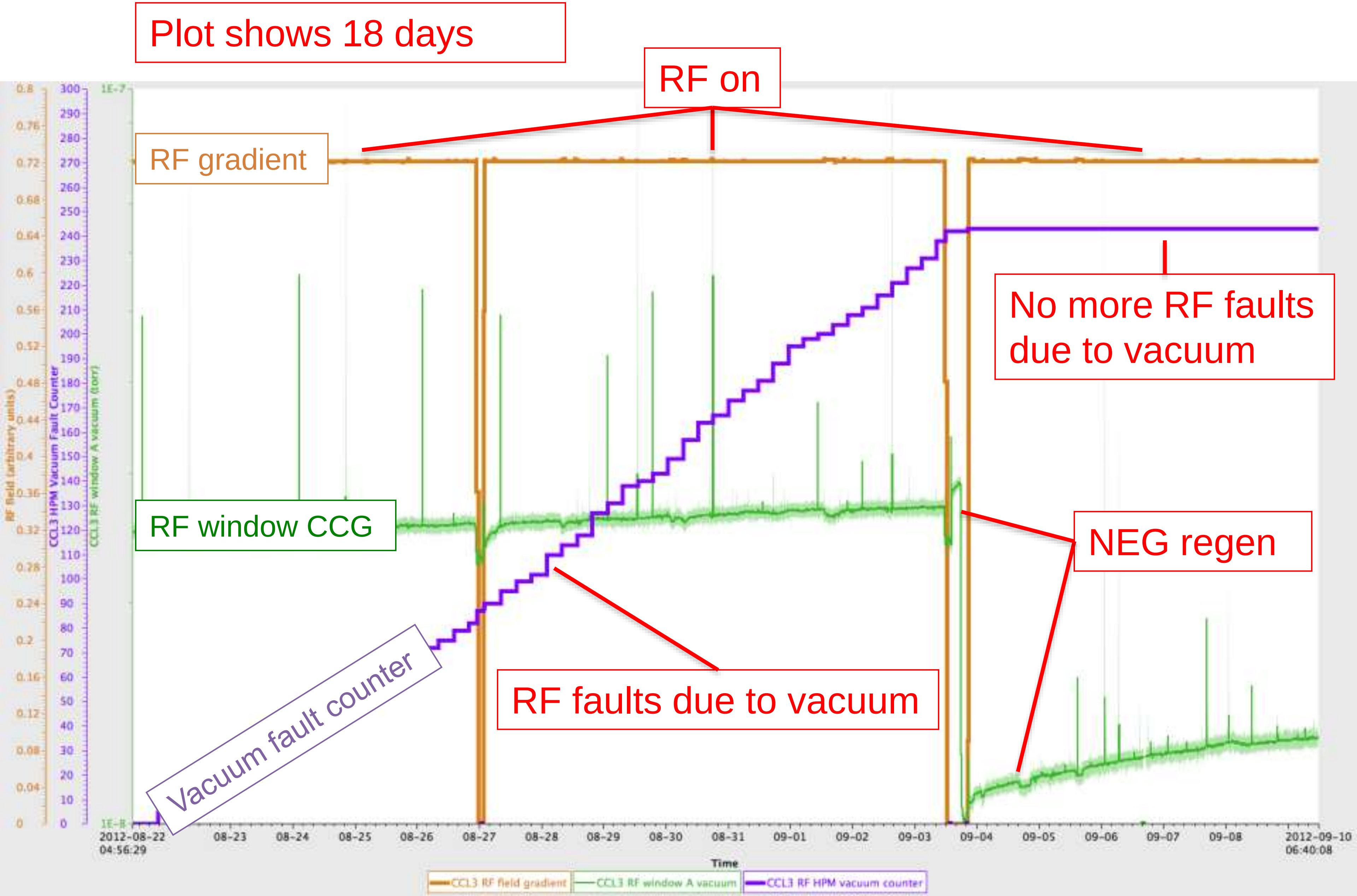
- Adjust the RF field
  – Move below or above multipacting band
- Adjust RF fill time
  – Ramp speed through multipacting bands
- Change cavity resonant frequency
  – Move multipacting band
- Vacuum maintenance
  – Maintain low vacuum near RF window

DURING BEAM OPERATION

Resonant frequency change improves trip rate

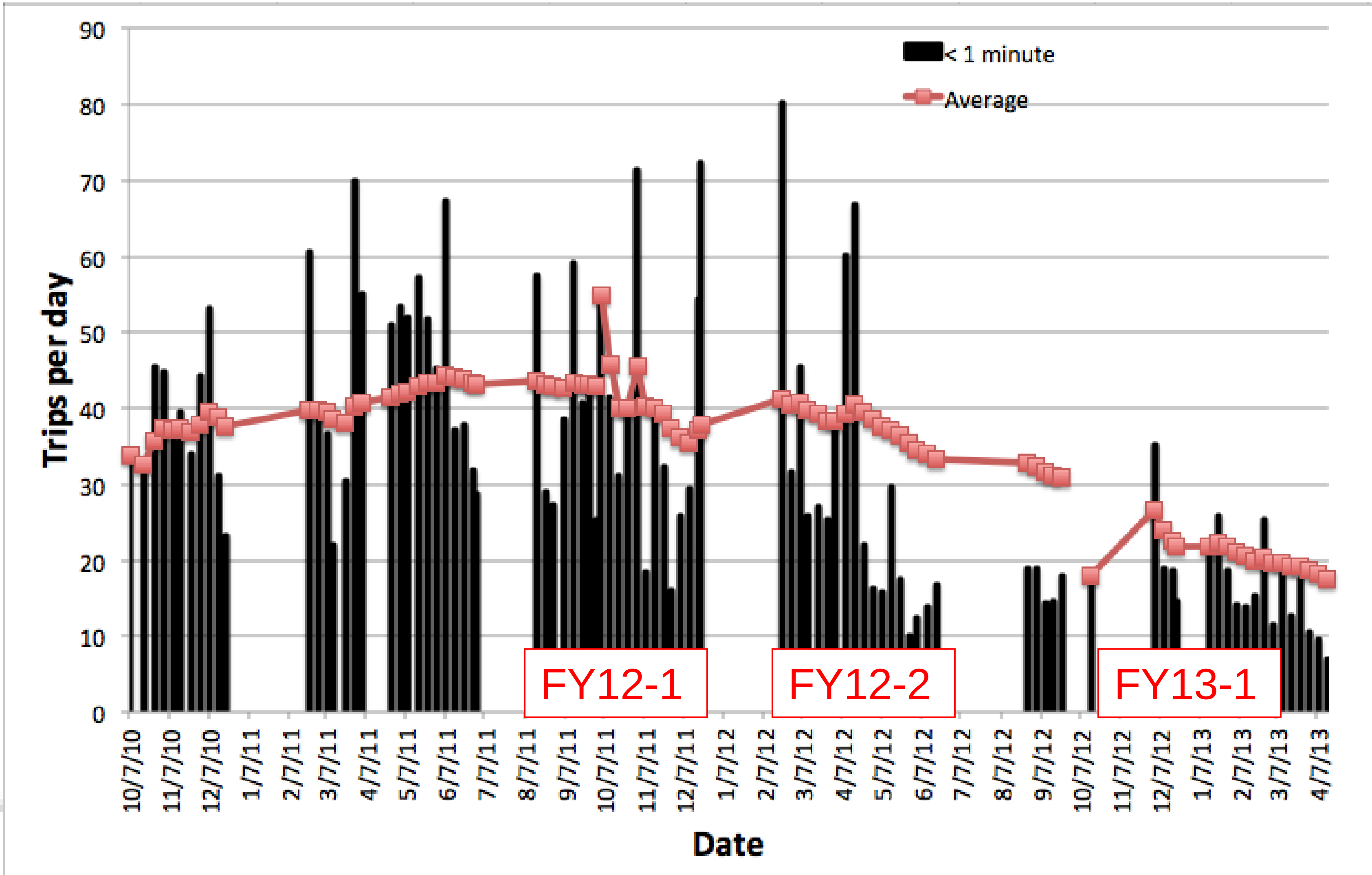


Non-Evaporable Getter regeneration improves trip rate



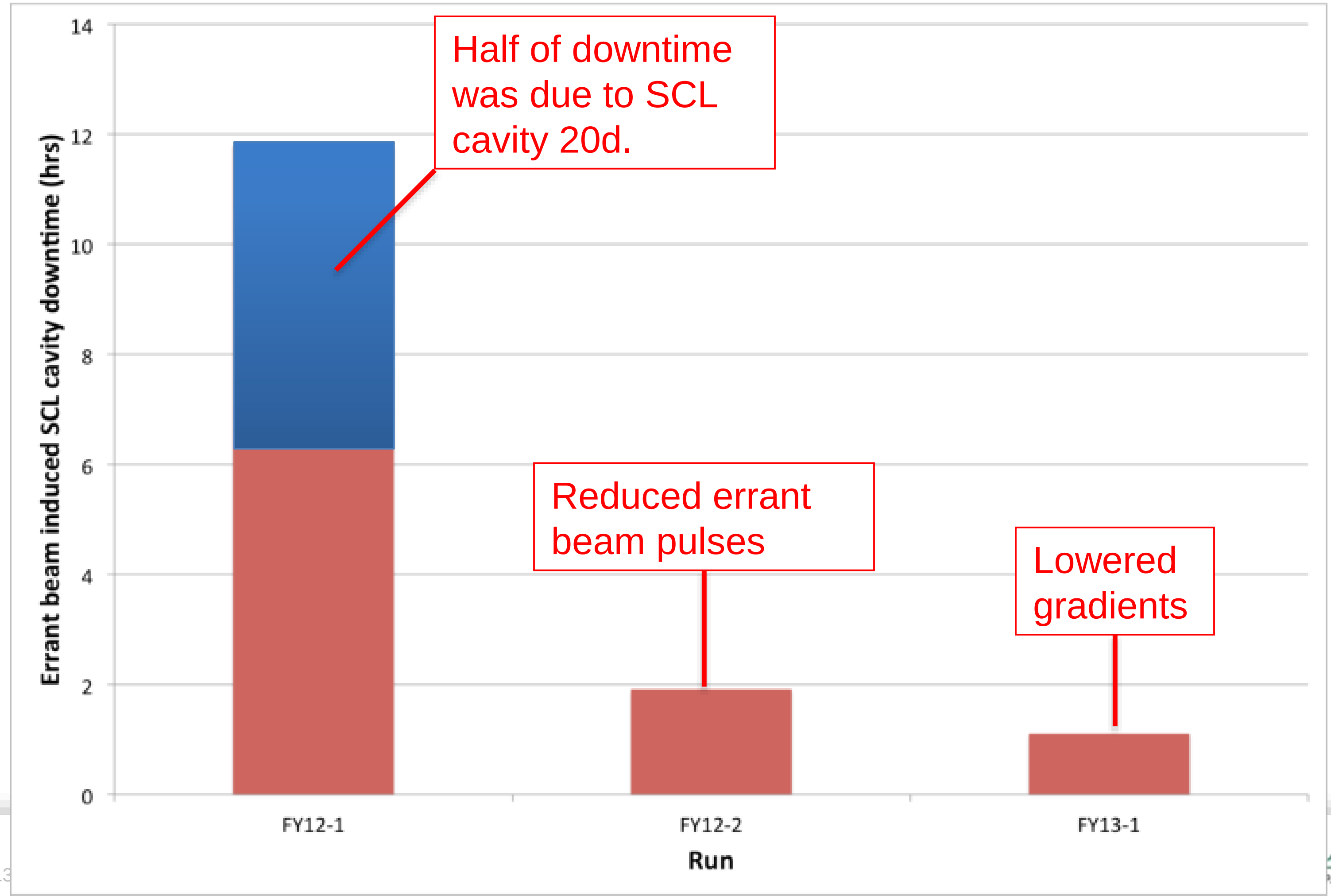
Errant beam trips reduced

- By May 2012
  - < 15 errant beam pulses per day



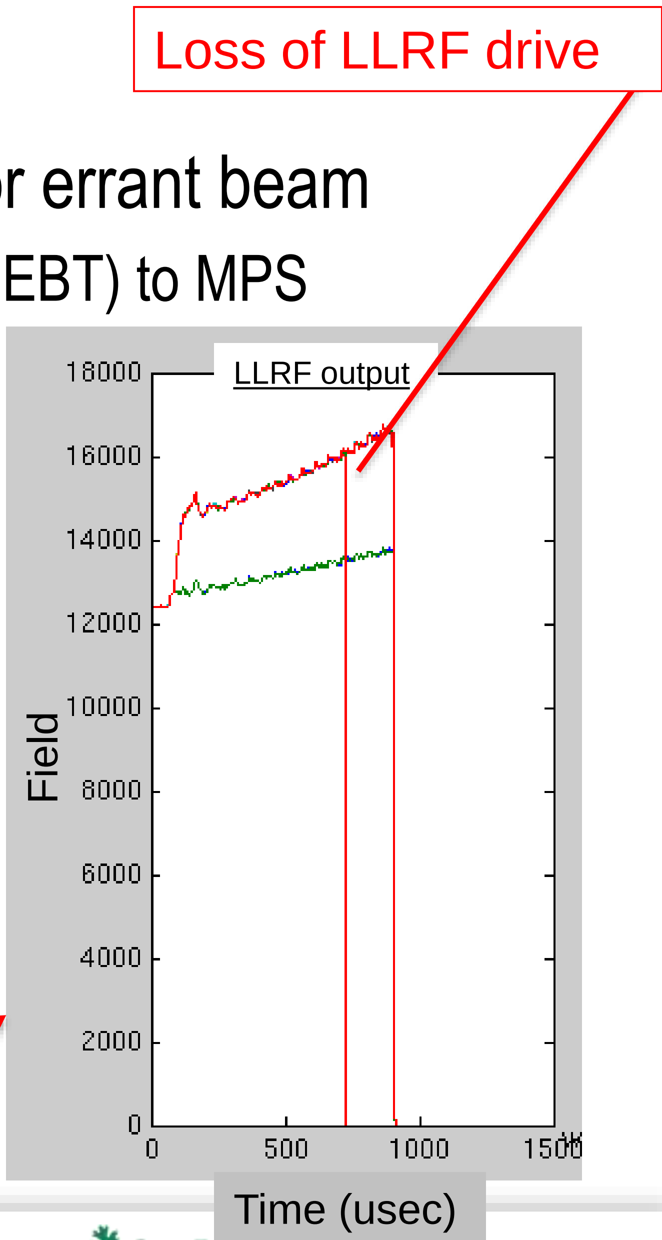
SCL cavity downtime reduced 6x

- Reducing errant beam pulses reduced errant beam induced SCL cavity downtime by factor of 3
- Lowering the gradient on problematic cavities reduced downtime by factor of 2
  - Lowering gradients a few percent is done during beam operation



Future plans to further reduce the impact

- Decrease the response time of the MPS for errant beam
  - Add SCL differential BCM system (CCL and HEBT) to MPS
  - Add dedicated line to MPS (minimal delays)
  - Goal is beam off time of 5 microseconds
  - Summer 2013
- Ion source pulse by pulse discriminator
  - If ion source pulse differs significantly from the previous then turn beam off
- Further reduce Warm Linac RF faults
  - One type of unexplained RF fault remaining

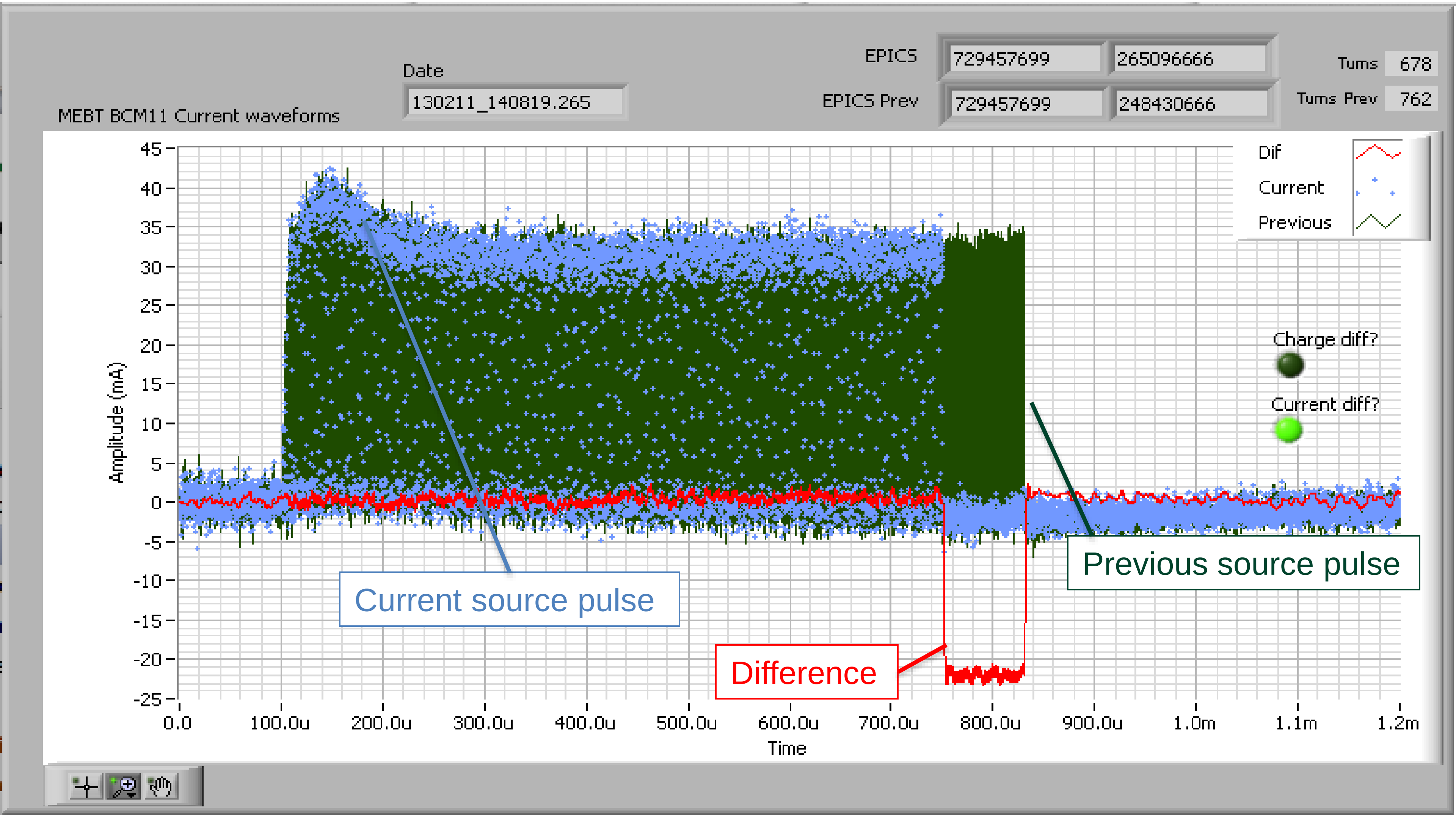


Summary

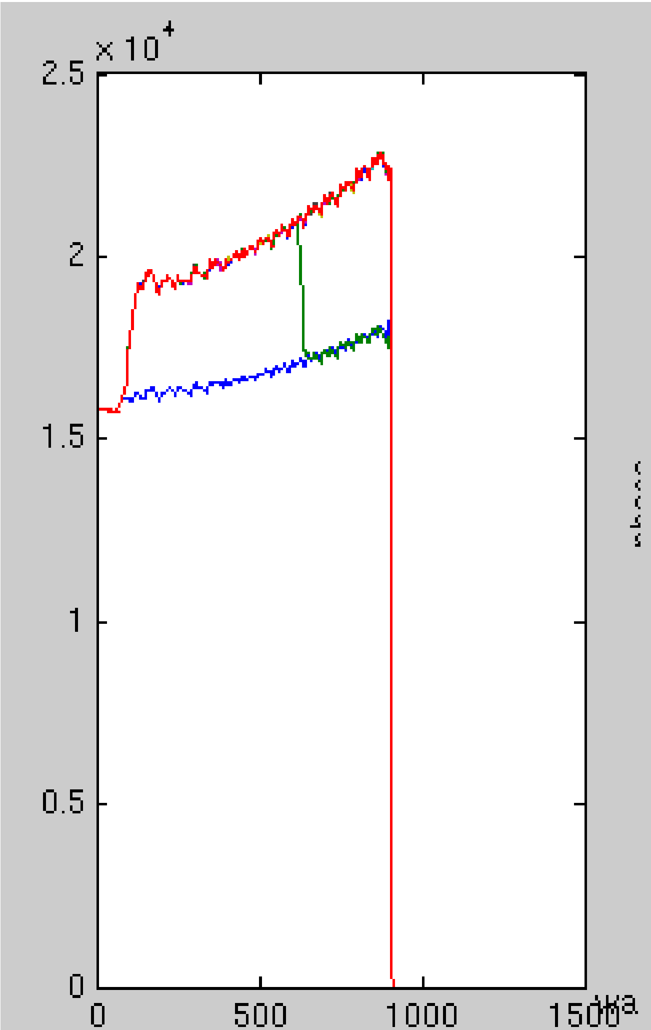
- Errant beam BLM trips have been reduced by > 2x
- Continuing to mitigate errant beams
  - Ion source/LEBT high voltage and RF conditioning
  - Routine maintenance of vacuum systems
  - Operational experience with DTL and CCL cavities
- Cavity degradation continues
  - Lowering gradients helps reduce downtime
  - Cavity warm up and conditioning during long shutdowns
- Reduction in MPS beam turn off time coming in summer 2013
- Protection of the SCL against performance degradation is much more challenging than initially expected

Additional slides

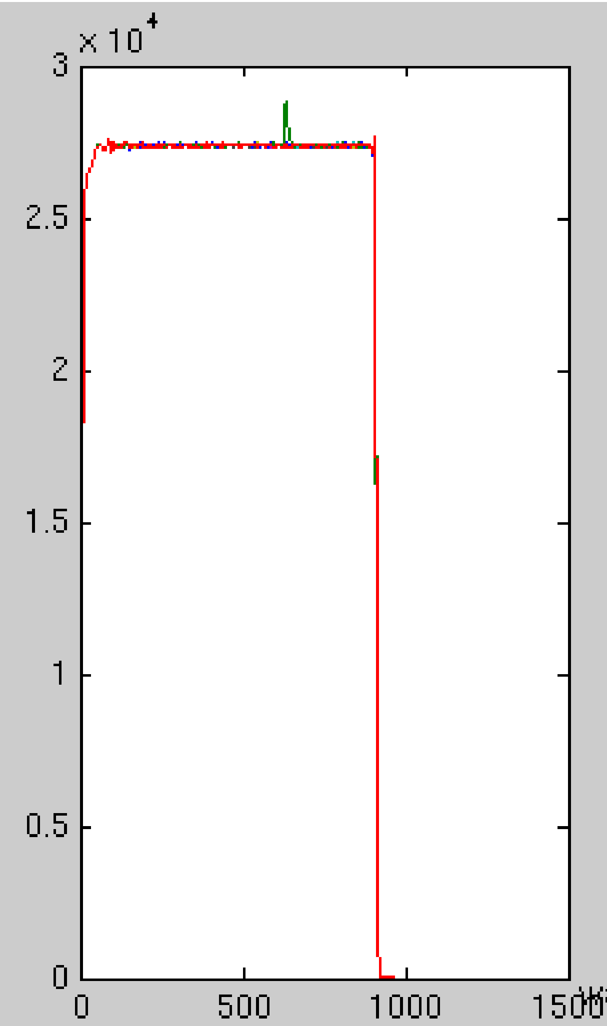
Example of ion source pulse by pulse differential BCM



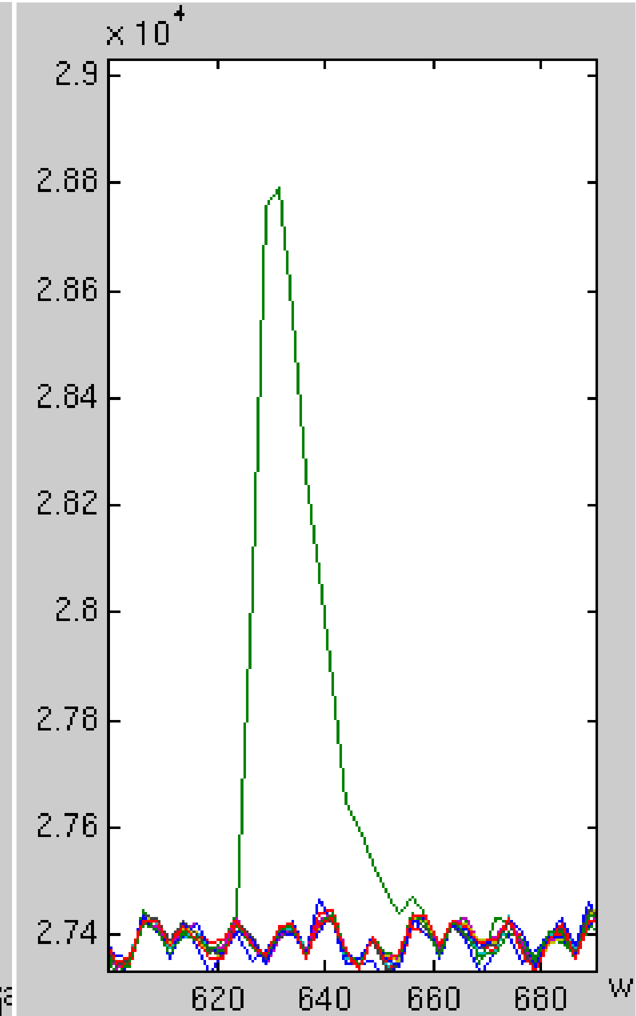
Normal RF waveforms during SCL BLM trip



RF Drive

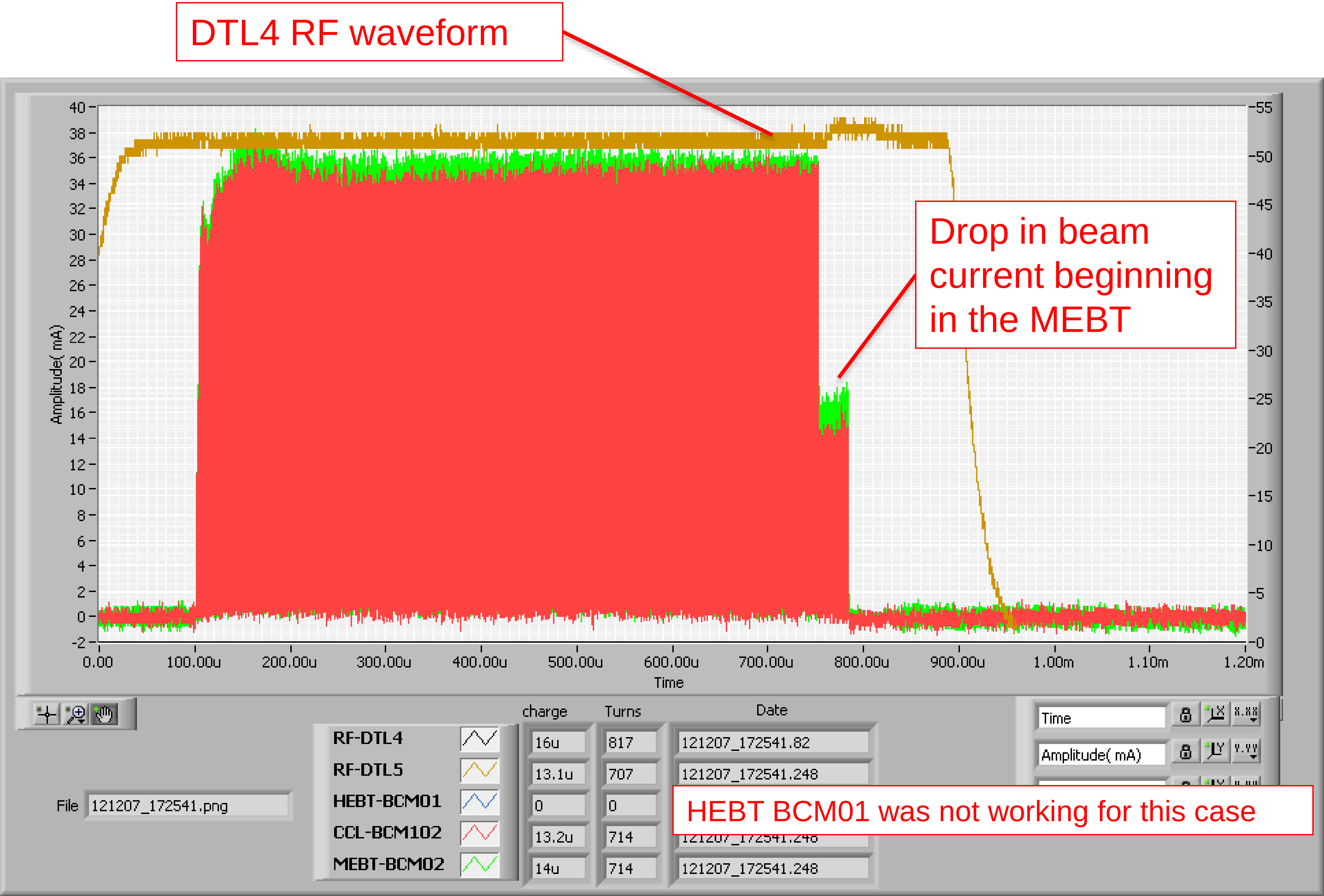


Cavity field

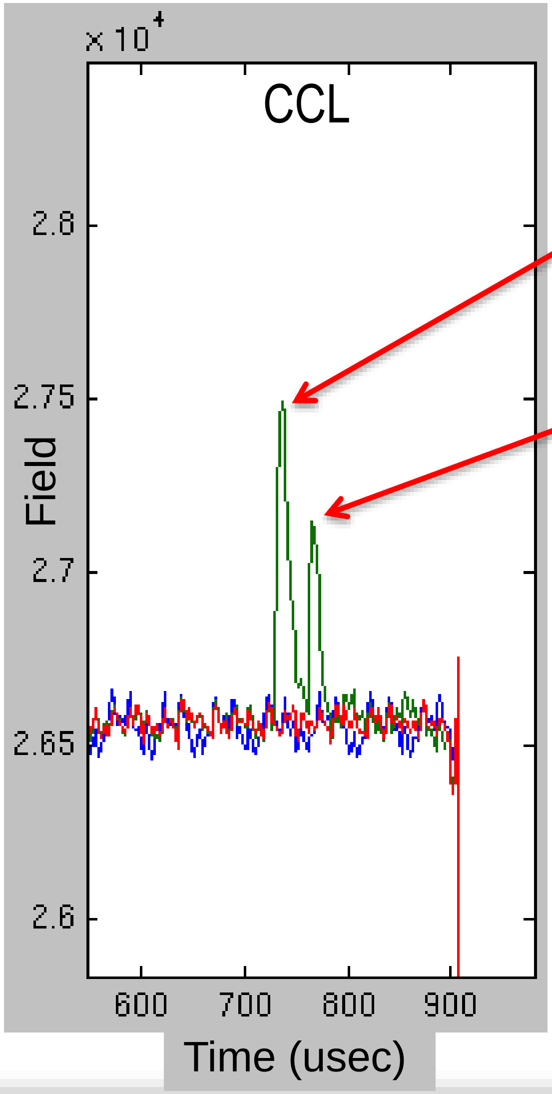


Cavity field zoomed

Ion source/LEBT errant beam example

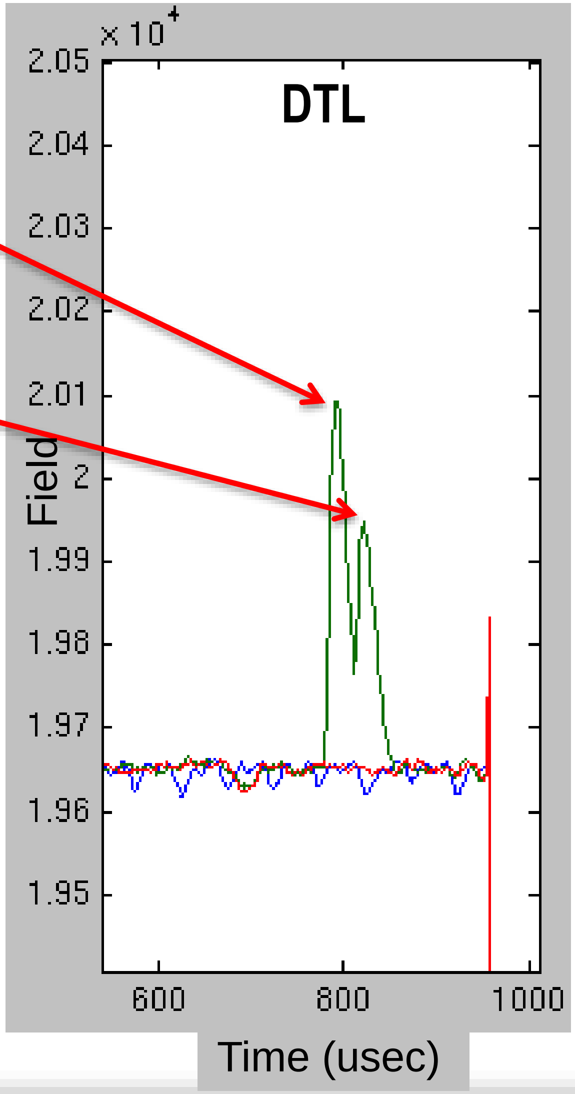


Warm Linac cavity response with beam current drop



Beam current drop

SCL BLM trip



SEQUENCE

- Beam current drops
- RF field jumps and LLRF corrects
- SCL BLMs trip
- RF field jumps and LLRF corrects