

Beam Losses and Beam Induced Quenches at RHIC

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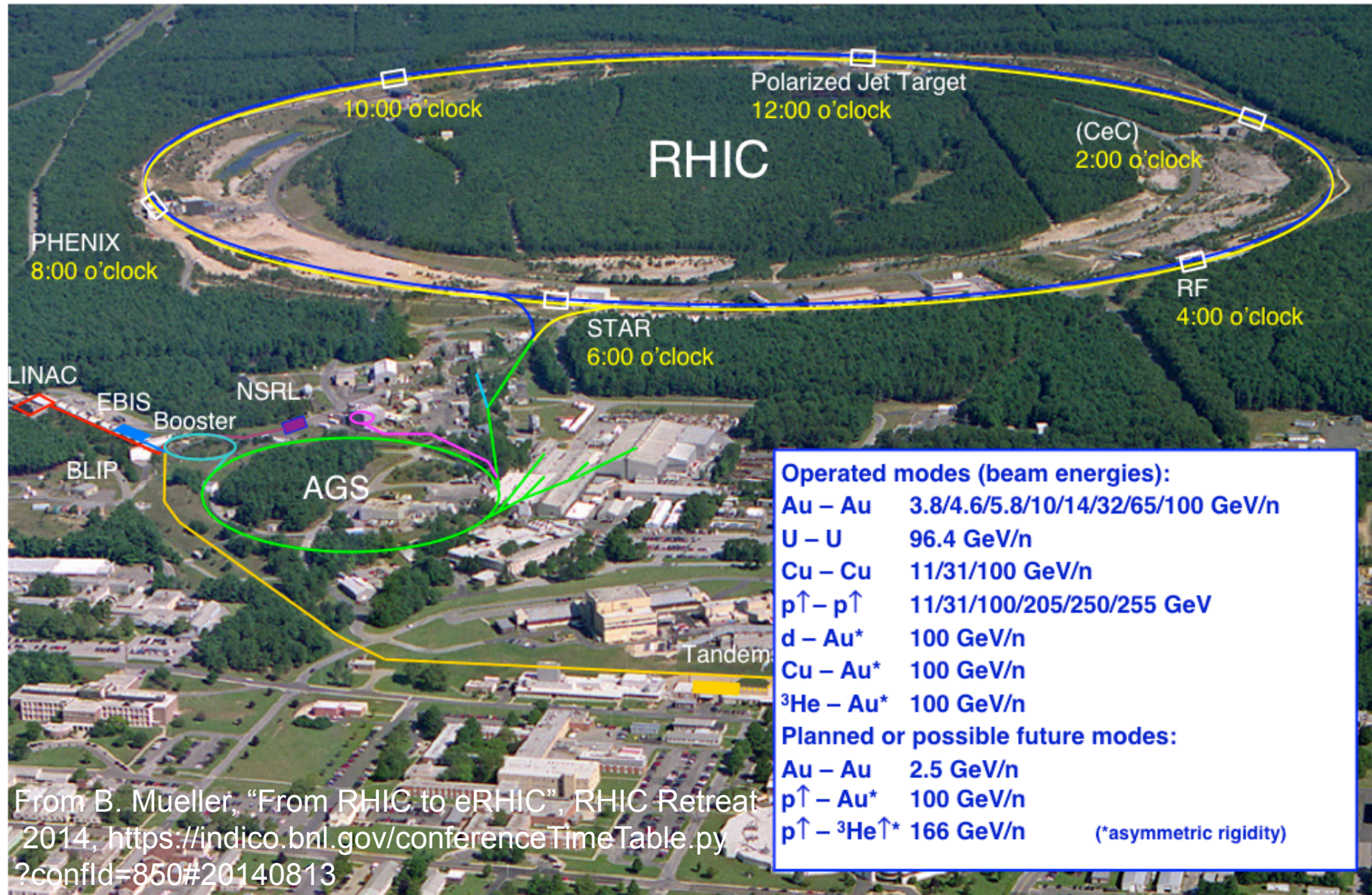
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Outline

- RHIC beam loss monitor system
 - Design goals and specifications
- Beam Losses at RHIC
 - System failures
 - Magnet, RF cavity, abort kicker, etc
 - Orbit requirement
 - Beam dynamics
- RHIC beam induced quenches
- Summary

RHIC – a High Luminosity (Polarized) Hadron Collider



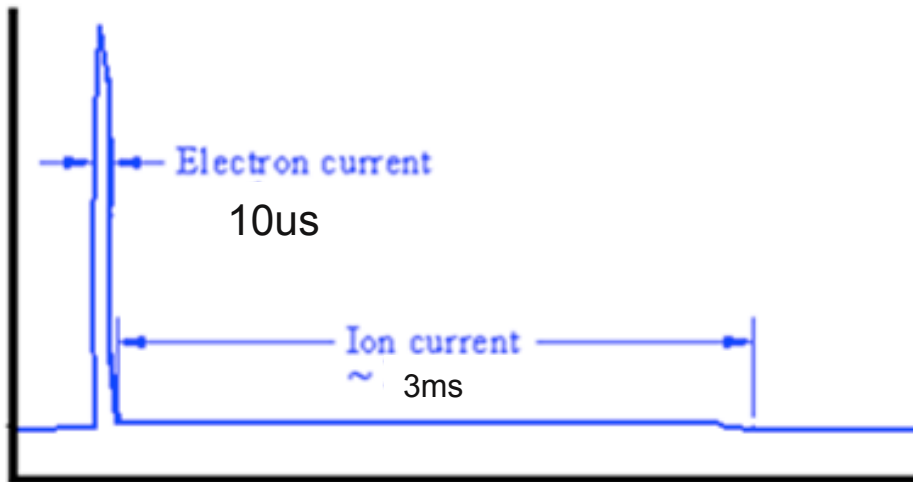
Operated modes (beam energies):	
Au – Au	3.8/4.6/5.8/10/14/32/65/100 GeV/n
U – U	96.4 GeV/n
Cu – Cu	11/31/100 GeV/n
$p\uparrow - p\uparrow$	11/31/100/205/250/255 GeV
$d - Au^*$	100 GeV/n
$Cu - Au^*$	100 GeV/n
${}^3\text{He} - Au^*$	100 GeV/n
Planned or possible future modes:	
Au – Au	2.5 GeV/n
$p\uparrow - Au^*$	100 GeV/n
$p\uparrow - {}^3\text{He}\uparrow^*$	166 GeV/n

(*asymmetric rigidity)

From B. Mueller, "From RHIC to eRHIC", RHIC Retreat 2014, <https://indico.bnl.gov/conferenceTimeTable.py?confId=850#20140813>

RHIC Beam Loss Monitor System

- A total of 431 Argon gas filled ion chamber detector distributed around the ring
 - Typical sensitivity of the detector is $\sim 19.6 \pm 1.5$ pA/R/hr at 1450V
 - In the 6 arcs. Each monitor attached on the quadrupole cryostat between the two accelerators (Blue ring and Yellow ring)
 - Separate monitors for each ring in the interaction areas



RHIC Beam Loss Monitor System

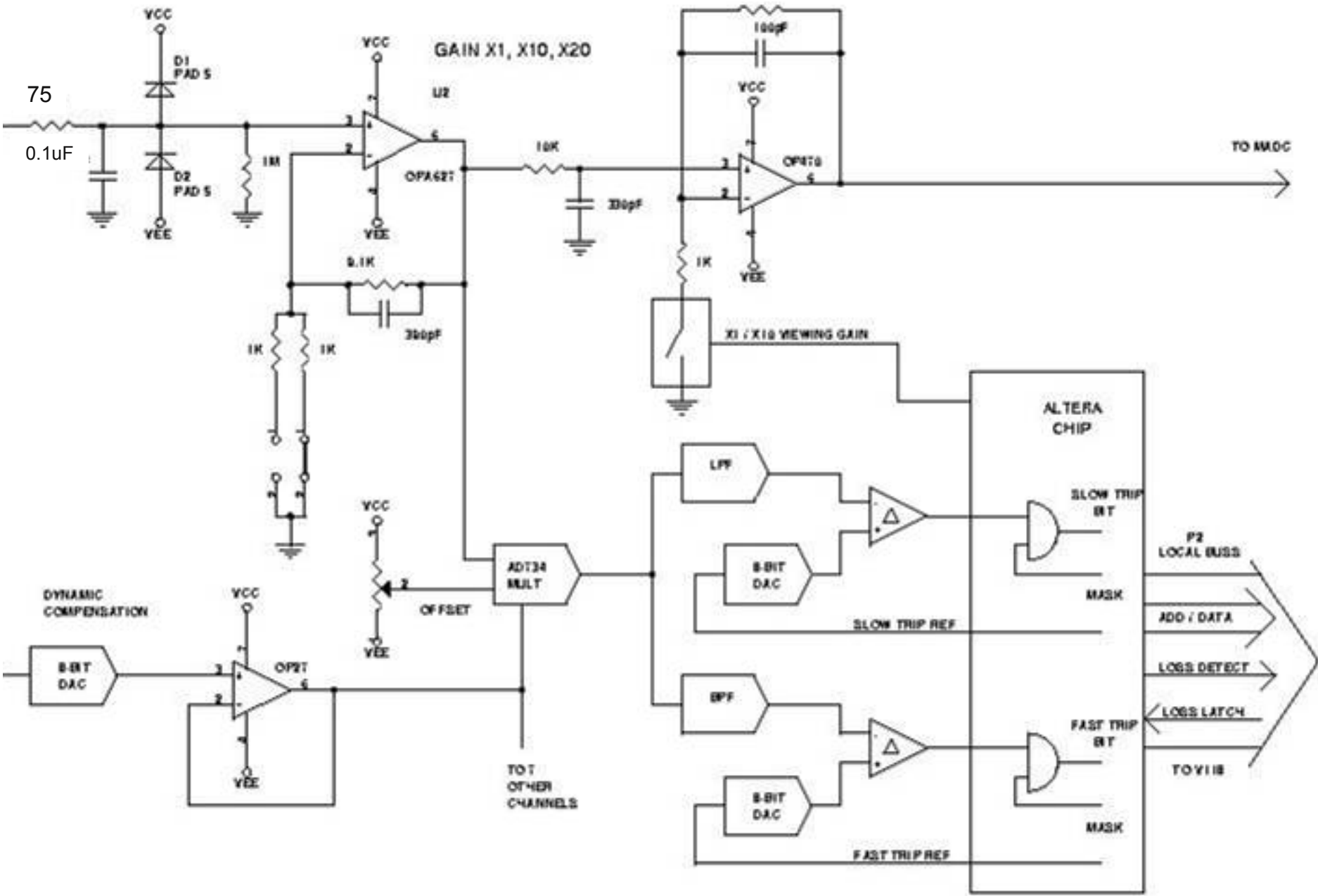
■ Monitoring

- Analogue signal from ion chamber is amplified and then digitized by a standard RHIC VME multiplexed ADC (MACD) at 720 Hz
- The time constant of the circuit is $\sim 100\text{ms}$

■ Machine protection

- Analogue signal from ion chamber gets digitized by a 8-bit DAC, and then goes out parallel into a LPF for SlowThreshold system and BPF for FastThreshold system
- Both are designed to abort/inhibit beam against excessive beam losses
- SlowThreshold: time constant 20ms, designed to protect superconducting magnets against excessive slow beam losses

RHIC Beam Loss Monitor Circuit Diagram



RHIC Beam Loss Monitor Data

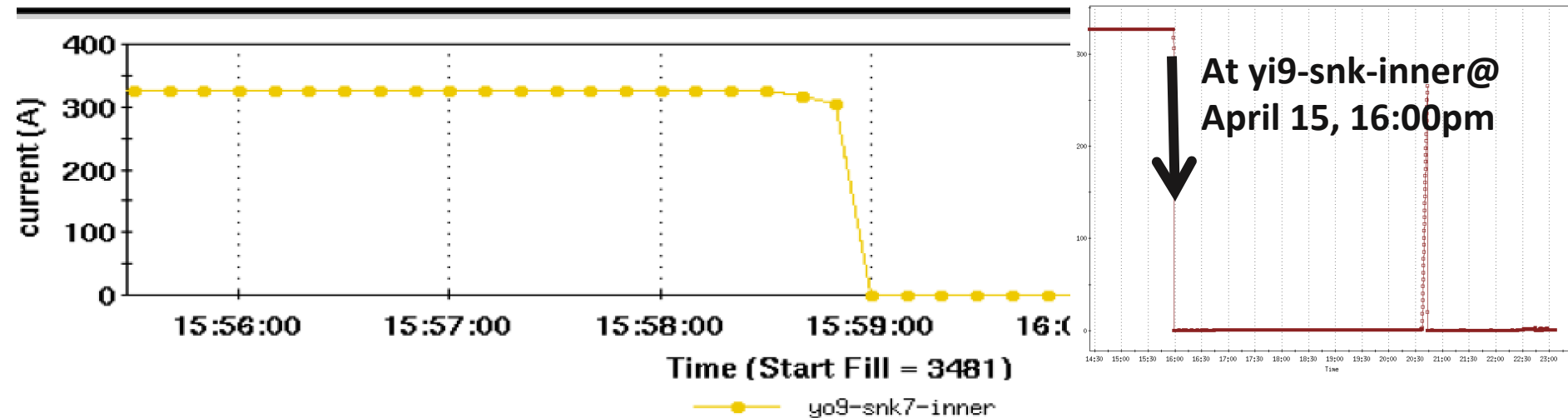
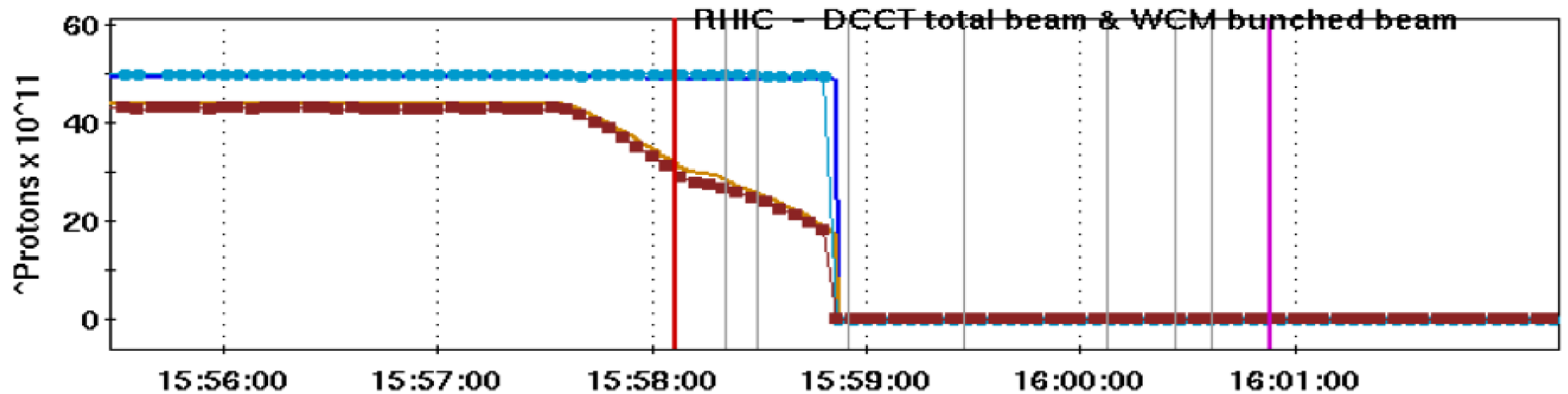
- RhicLossMonitor for viewing
 - For ring mode, graphically showing the 720 Hz beam loss monitor data averaged at 1 sec rate
 - For injection mode, the snapshot of the 720 Hz beam loss data at the event of RHIC injection is shown
- RhicLossThreshold for controlling/configuring threshold setups
- PMViewer for collecting and viewing beam loss monitor data for Post Modem analysis
 - All beam loss monitor data are saved at 720 Hz from 10 sec before beam-abort till beam-abort
 - This limits us to know exactly the time structure of beam loss for fast losses

RHIC Magnet Quench

- Beam power
 - Polarized proton @250GeV/c, 110 bunches with 1×10^{11} protons per bunch
 - ~440kJ
 - Au@100GeV/c/n with 110 bunches with 1×10^9 ions per bunch:
 - ~347kJ
- Superconducting magnet
 - The estimate of RHIC superconducting magnet quench at 2mJ/g for fast losses and 8mW/g for slow losses. This is equivalent to 78.3 krad/s at injection (49.3 krad/s at 100 GeV/c) for uniform loss over a single turn and 0.25 rad/s at injection (4.07 rad/s at 100 GeV/c) for slow losses (A. Stevens)

Damage of beam-induced magnet quenches

- Radiation damage of helical dipole: April 15, 2003, yo9-snk-inner
 - Large beam scraping in the dump area. The snake blm in sector 9 didn't see substantial radiation based on PMViewer data



Typical Beam Loss Patterns at RHIC

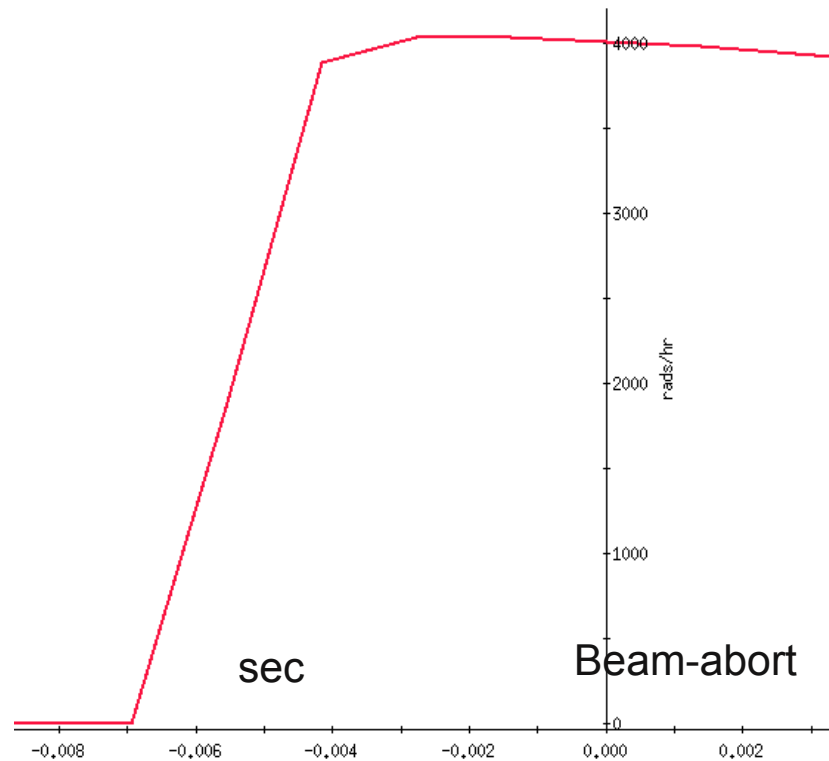
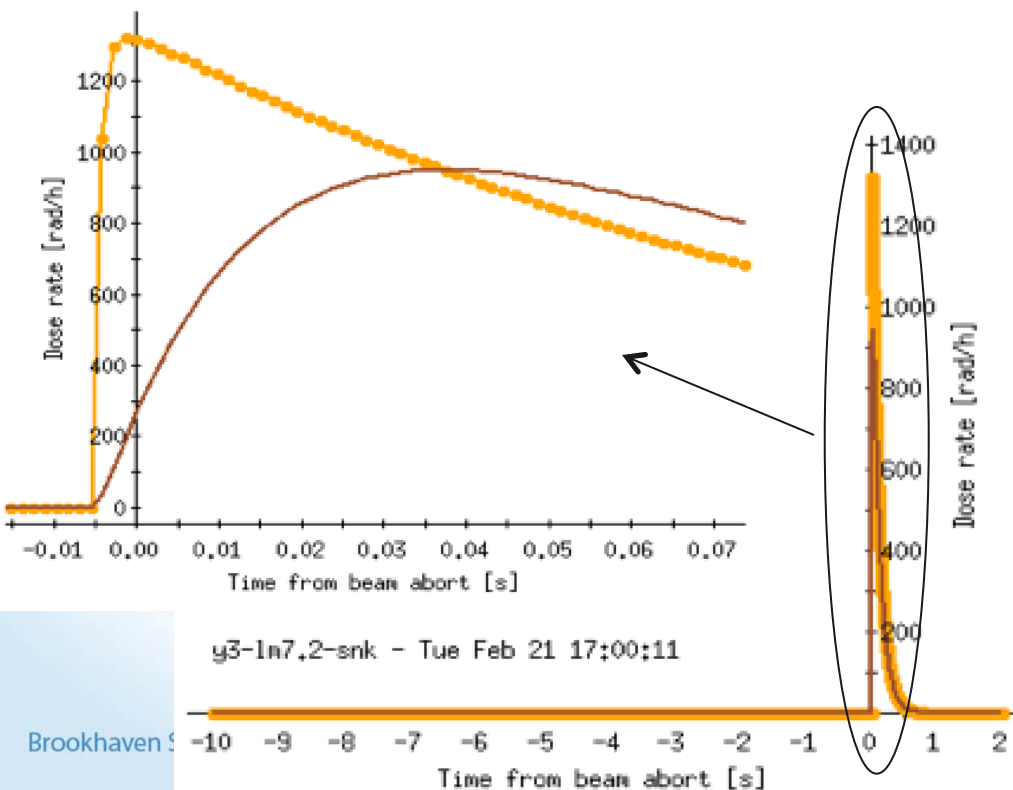
Beam losses at RHIC

- Injection mis-match
- Poor beam lifetime
 - Bad orbit, working point, chromaticity
 - emittance growth due to weak resonances, beam-beam, intra-beam, beam-gas interactions
- Beam instability
 - Transition crossing, strong orbital resonance, etc
 - Can be fast
- system failure
 - Injection kicker mis-timing, Injection damper mis-phasing
 - oscillation of a magnet power supply
 - abort kicker dis-functioning
 - RF cavity failure
 - Cause de-bunched beam

Fast beam losses at RHIC

- Injection mis-match, bad injection kicker timing, ripple of the injection kicker pulse
- Beam abort kicker mis-behaviors
 - Pre-fire, mis-fire, failed to charge, ...
- Fast beam instabilities

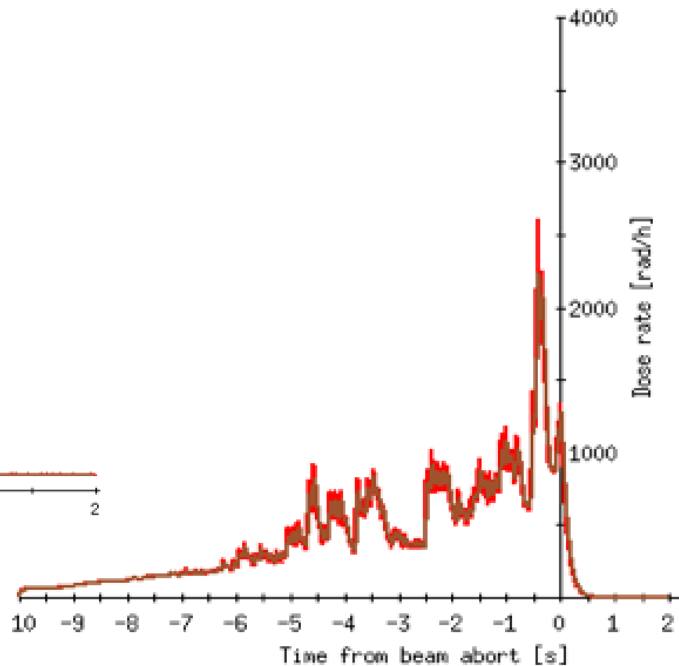
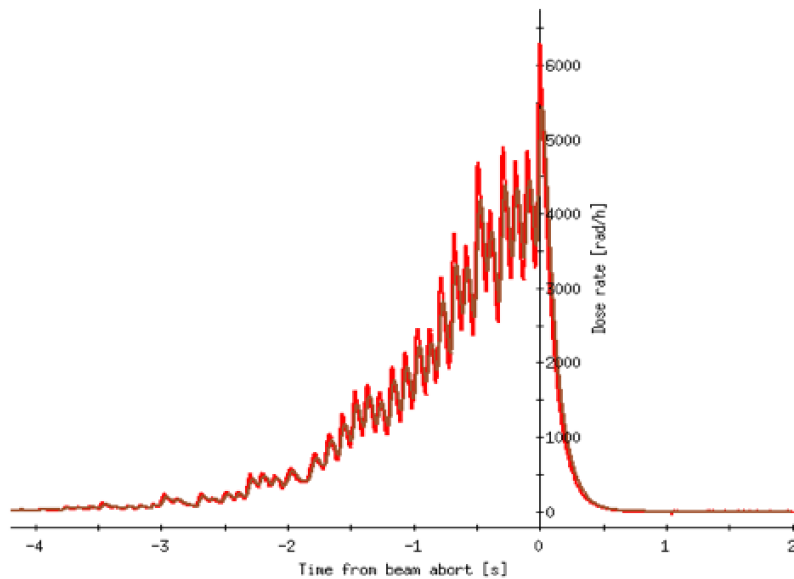
g8-lm1 - Fri Feb 7 23:00:07



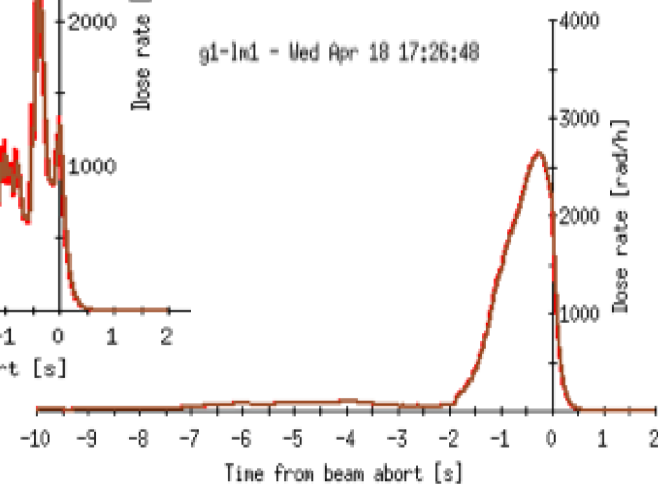
Slow beam losses at RHIC

- Beam scraping mostly at the aperture limits
 - Triplets of interaction points with squeezed beta*
 - Injection area
 - Dump area

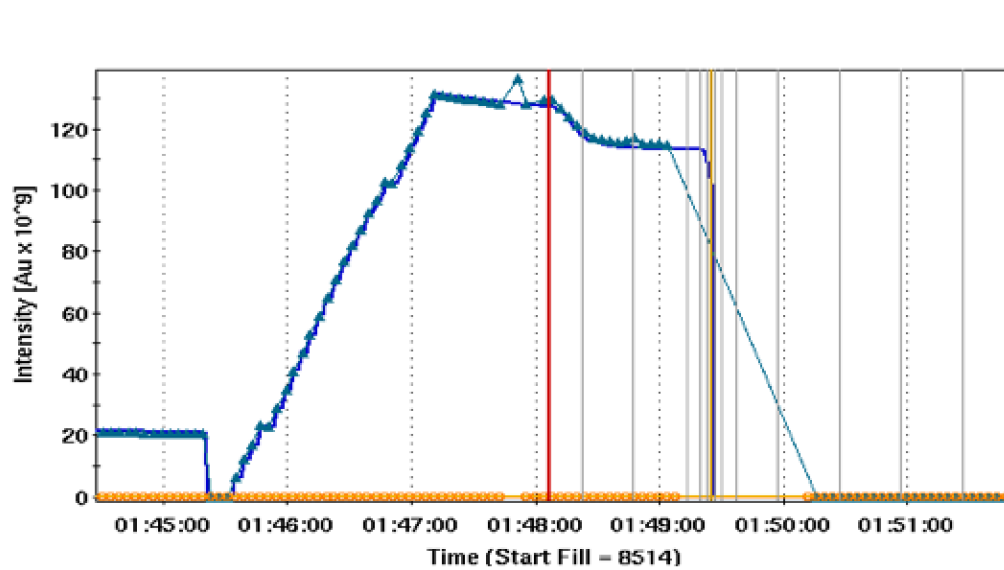
b7-1n2.1 - Thu Jun 22 23:40:22



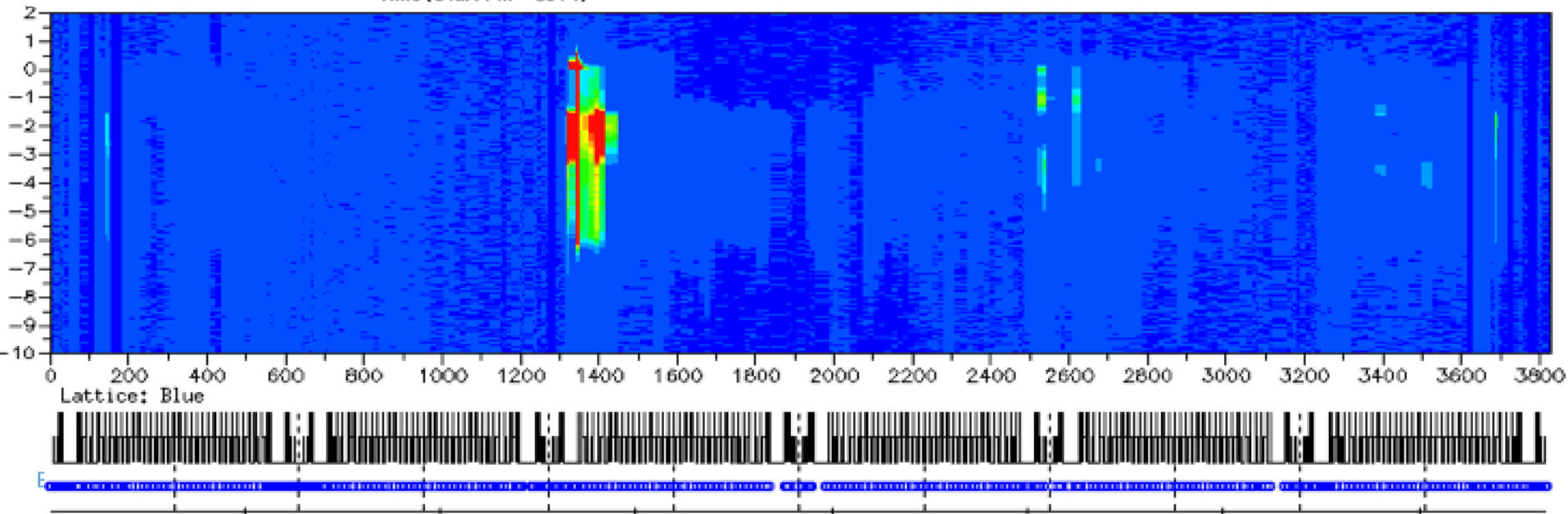
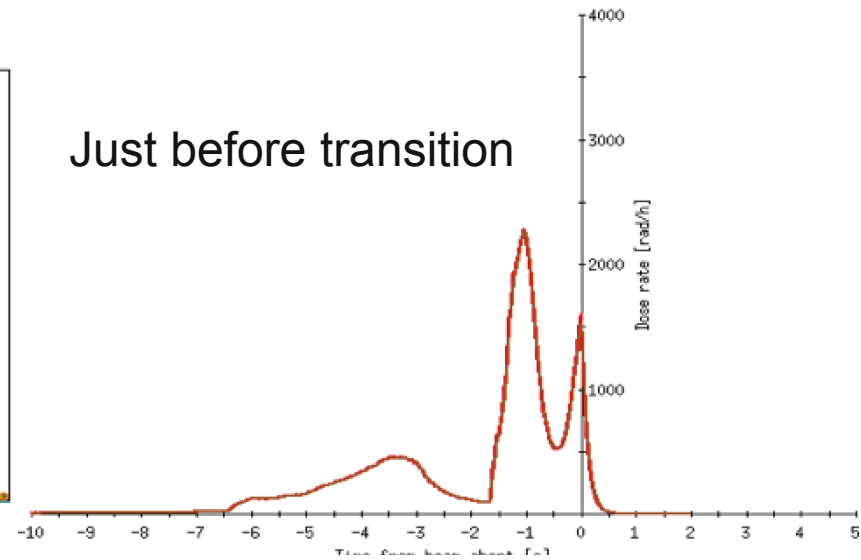
g1-1n1 - Wed Apr 18 17:26:48



slow beam losses

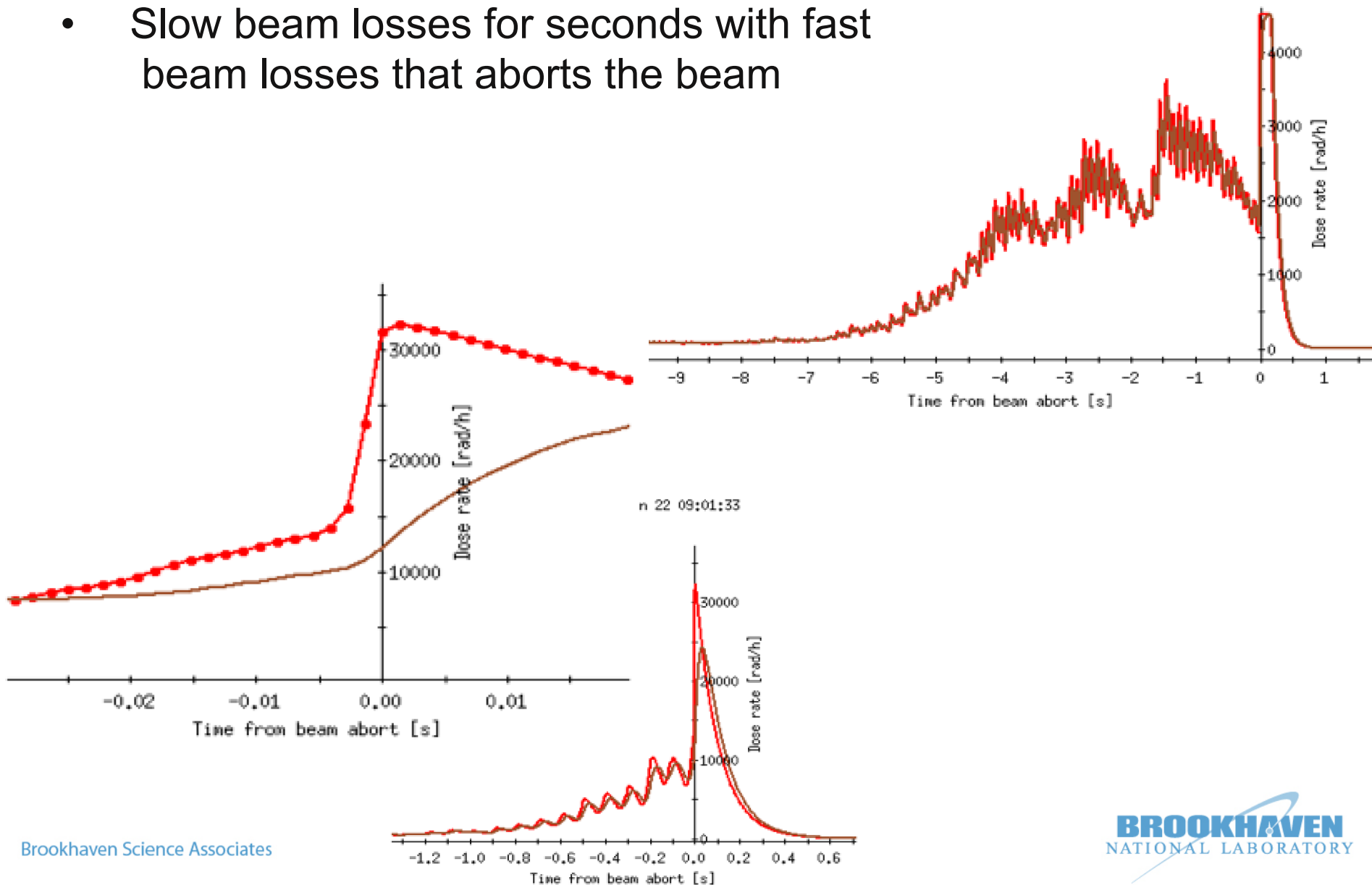


Just before transition



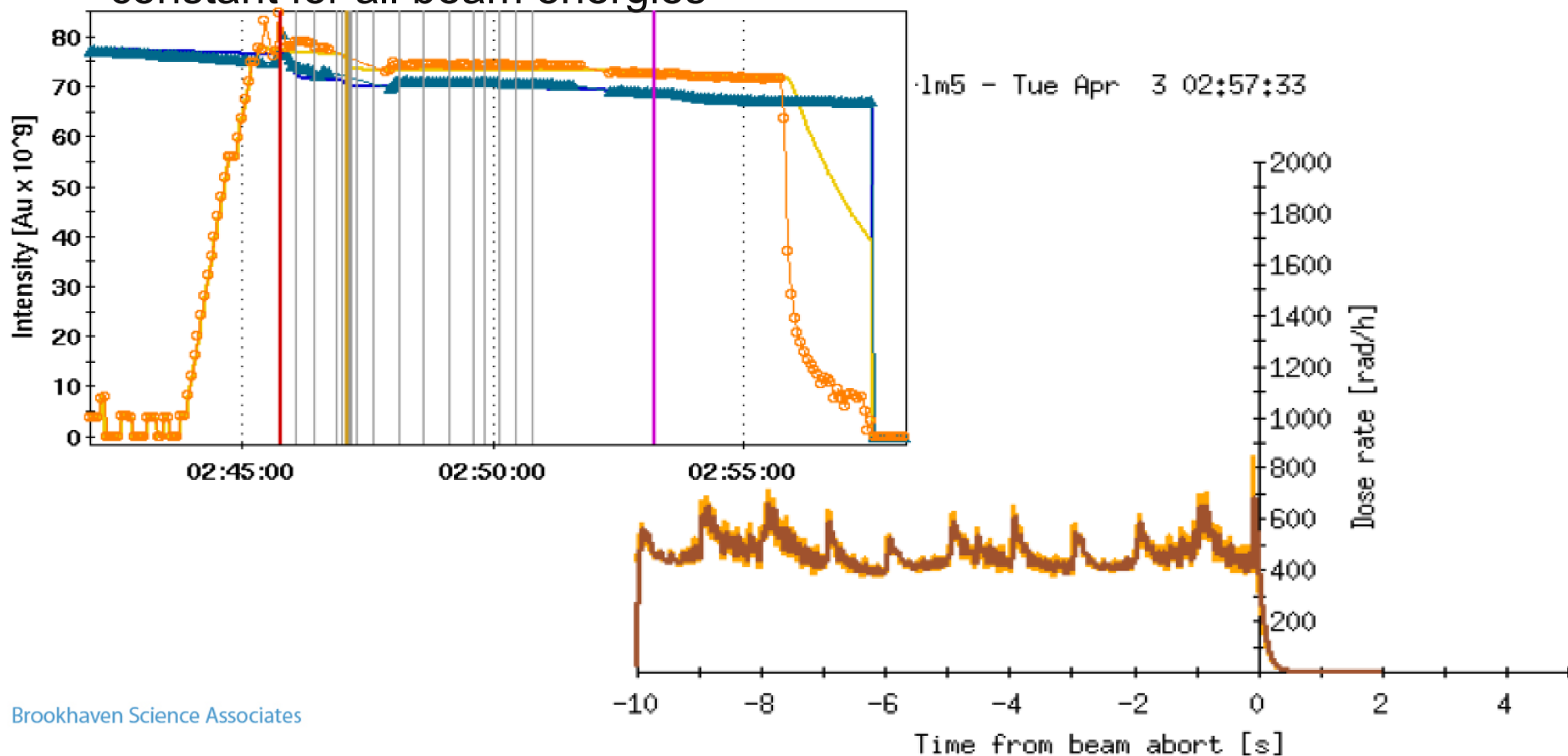
Combined loss pattern

- Slow beam losses for seconds with fast beam losses that aborts the beam



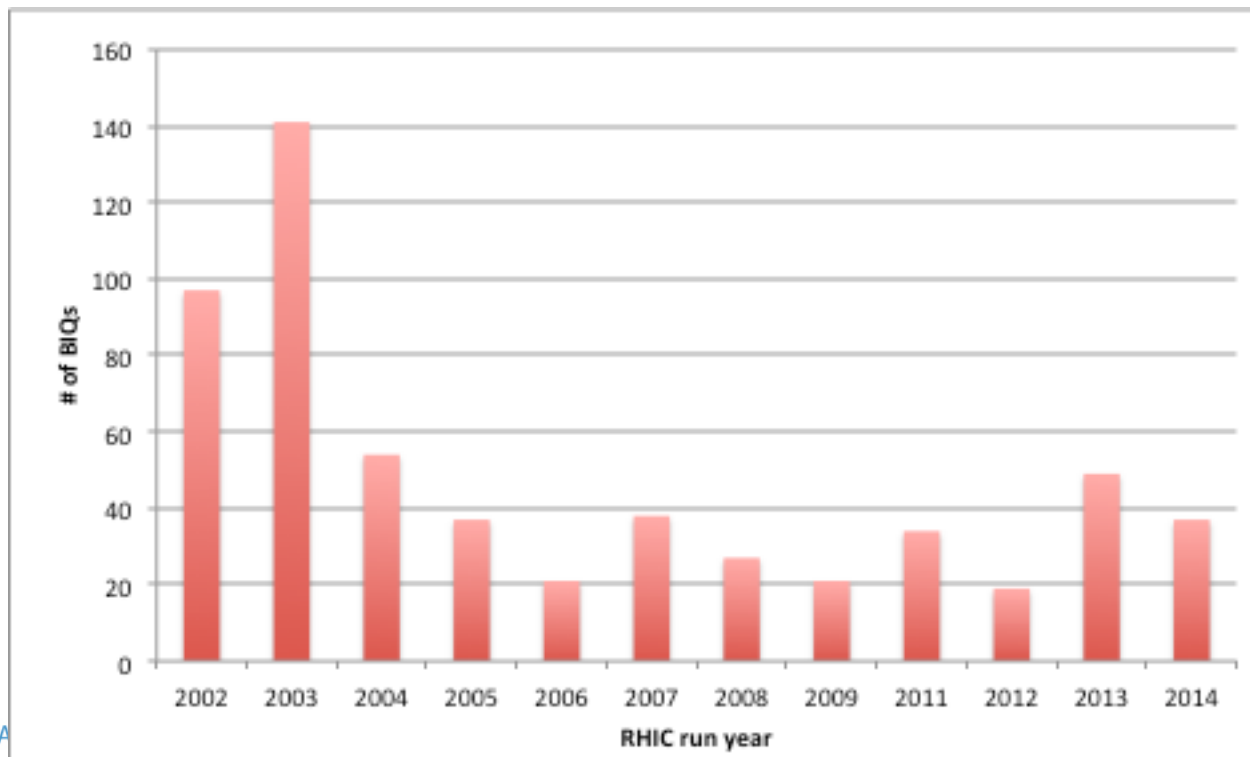
Constant beam loss

- This was mitigated by implementing the accumuLoss threshold to inhibit the beam when excessive beam losses are detected
- The sum of beam losses is calculated for every 10 sec window. If the total amount of losses exceeds the set-limit, permit is pulled
- Only applied to the blms at low-beta* triplets and loss limit is a constant for all beam energies



RHIC Beam Loss Monitor Threshold

- The blm thresholds including when to activate BLM threshold during the ramp were in generally set empirically during RHIC operation
 - All blm thresholds were masked out during injection as well as low energy except blms at snakes for pp operation
 - Most blms FastThresholds are masked out. This excludes blms at snake and spin rotator plus a few selected triplet BLMs at low beta* triplets
- Significantly reduced # of beam induced magnet quenches

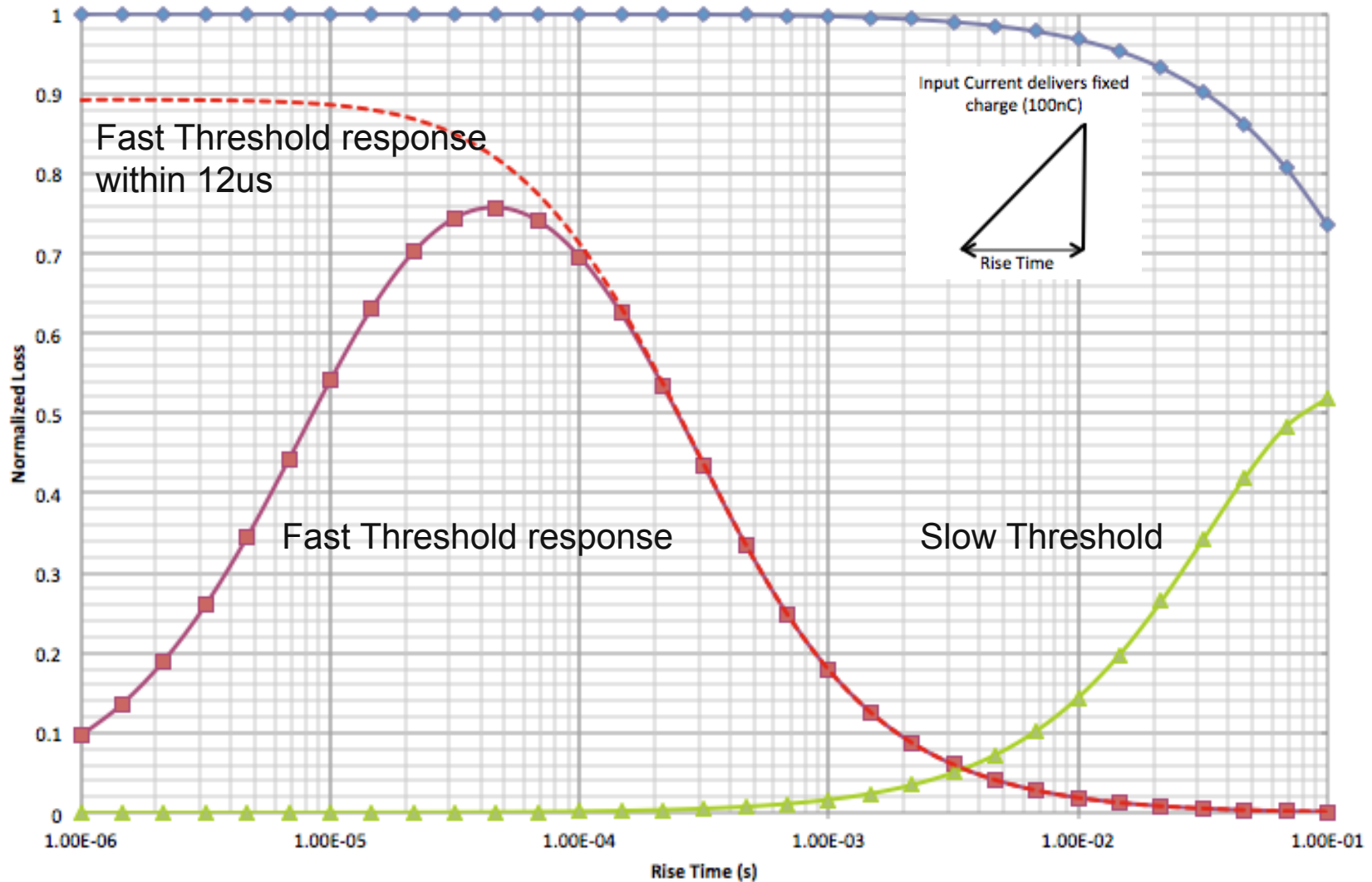


RHIC Beam Induced Magnet Quenches

- Remaining beam induced magnet quenches are
 - Beam abort kicker dis-function
 - Significant de-bunched beam
 - Blms thresholds are not enabled in the beam permit
 - at injection and low energy
 - At the end of the store. BLMs are removed from permit to minimize the false permit pull due to the spread of beam losses downstream of dump area
 - Blm's blind spot due to localized losses that only a few beam loss monitors see excessive beam losses (fill 10488, 10496, etc)
 - Enabling or lowering these BLM thresholds can help to reduce the risk but at a price of making false beam aborts due to large losses from beam halo instead of beam core
 - Inappropriate setting of threshold settings
 - Threshold set value is too high than the actual radiation that caused BIQ
 - Losses that are too fast for SlowThreshold yet too slow for FastThreshold
 - Blind spot of accumuLoss threshold system since its setting is fixed for all energies

FastThreshold Response

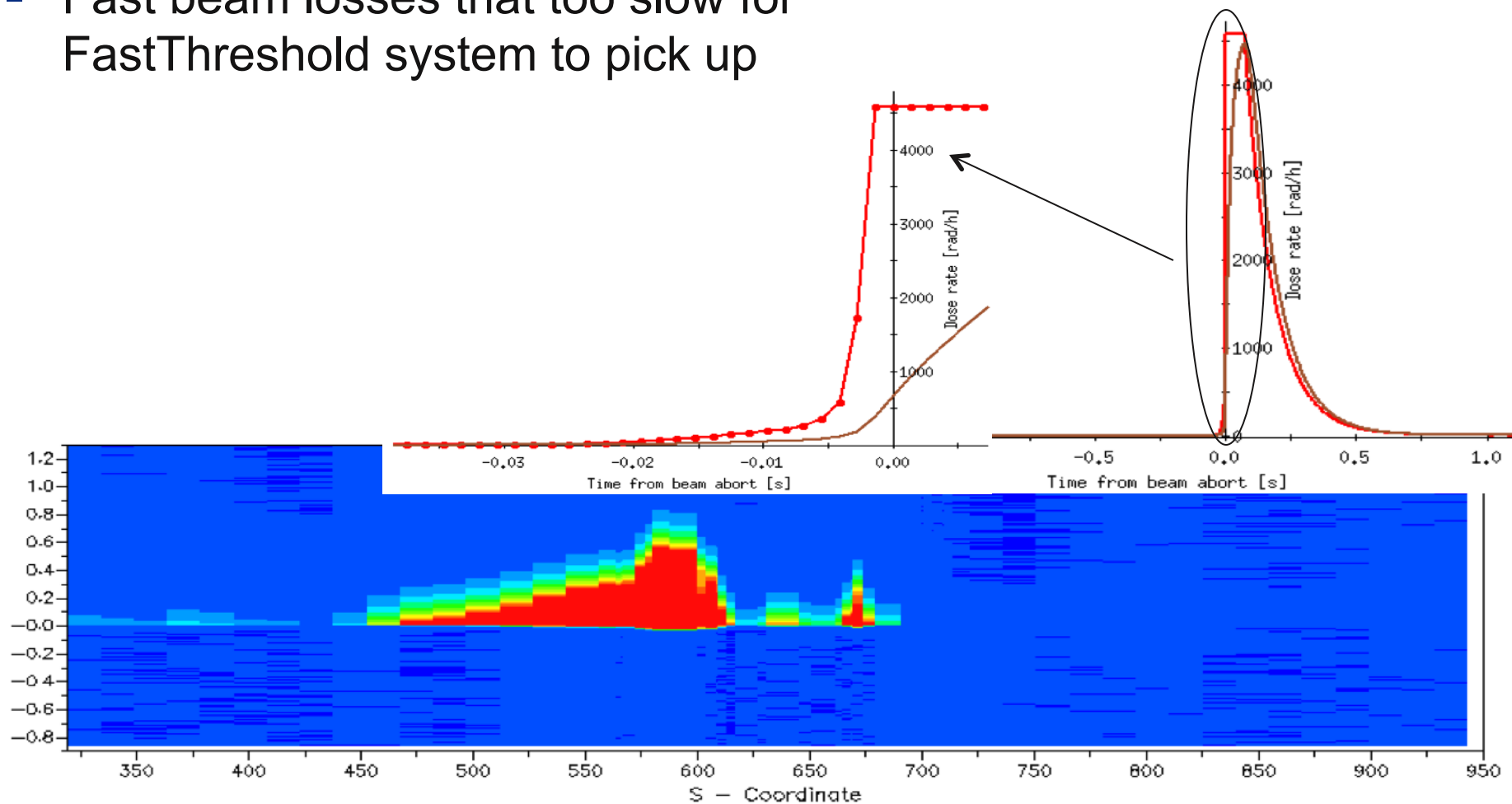
- Time constant $\sim 3.2\mu\text{s}$ - $100\mu\text{s}$ to collect the fast loss



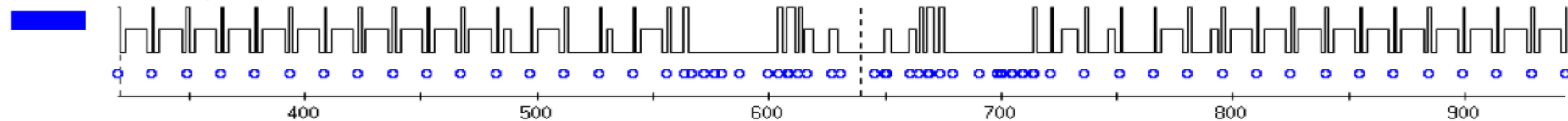
Courtesy of P. Oddo

Fill 7685: example of fast beam losses

- Fast beam losses that too slow for FastThreshold system to pick up

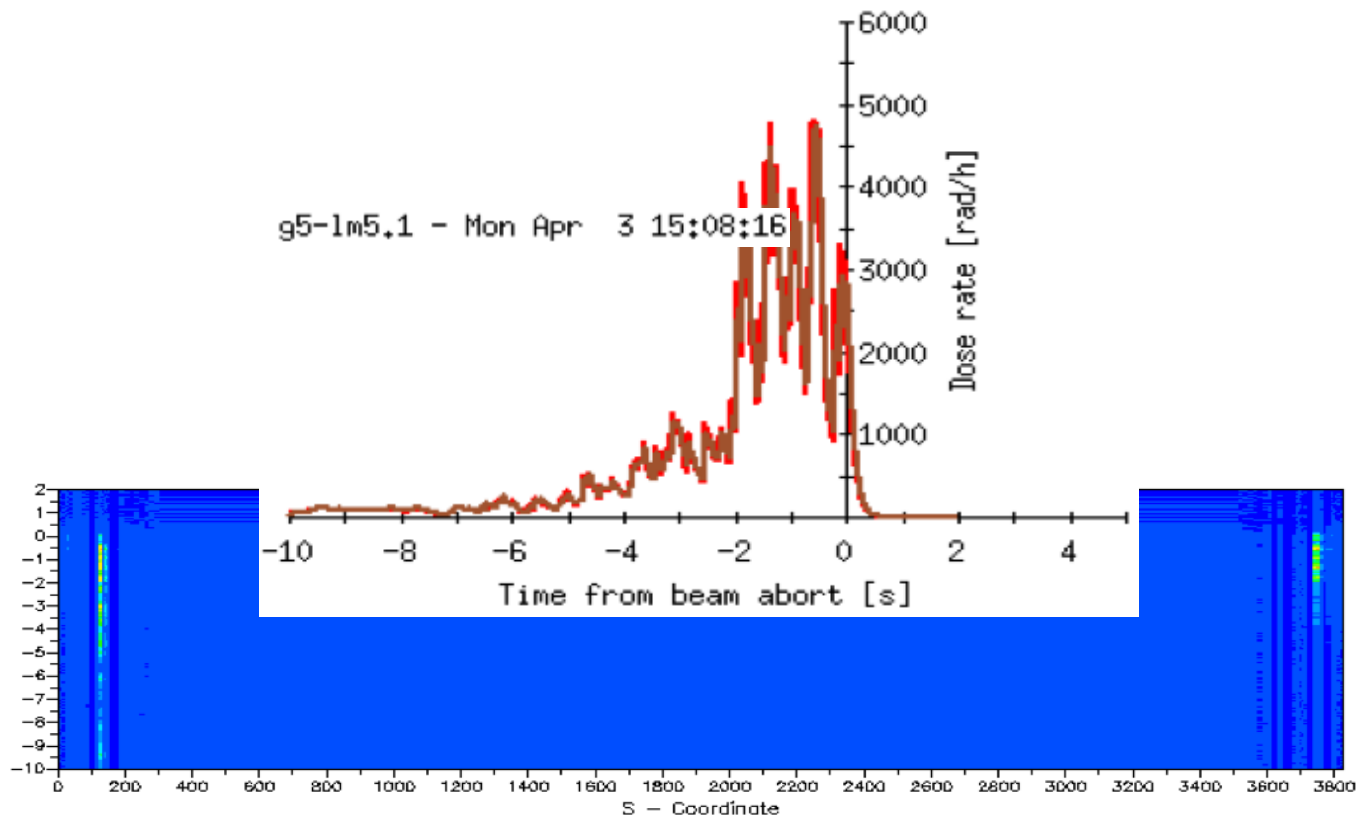


Beam ==> Lattice: Blue

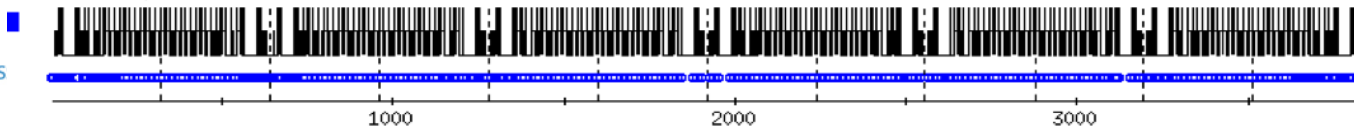


Fill 7695: example of no BLM protection

- heavy losses during the early part of the ramp
- BLM thresholds were all masked out of the beam permit link until 20 secs after the peak of the heavy losses

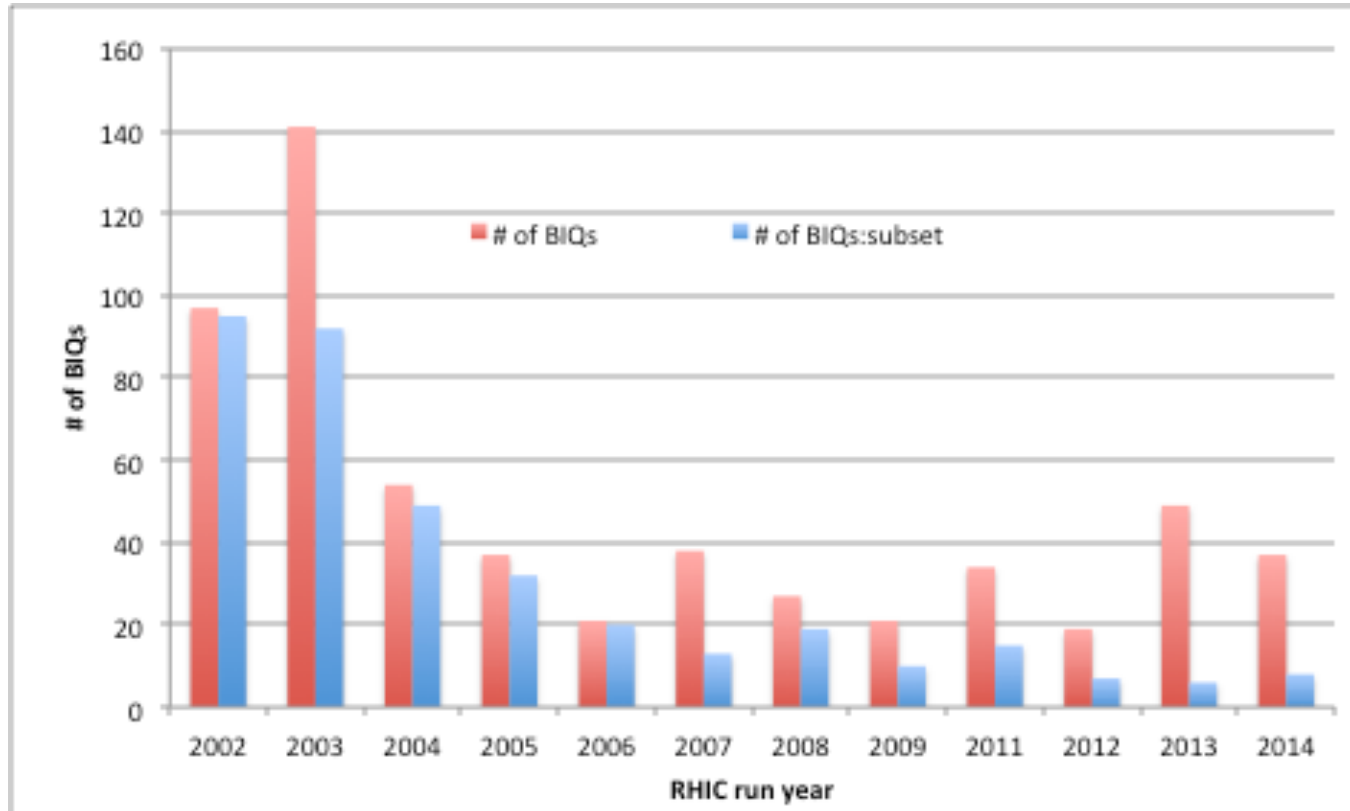


=> Lattice: Blue



RHIC Beam Induced Magnet Quenches

- Excluding the un-preventable BIQs, the # of BIQs

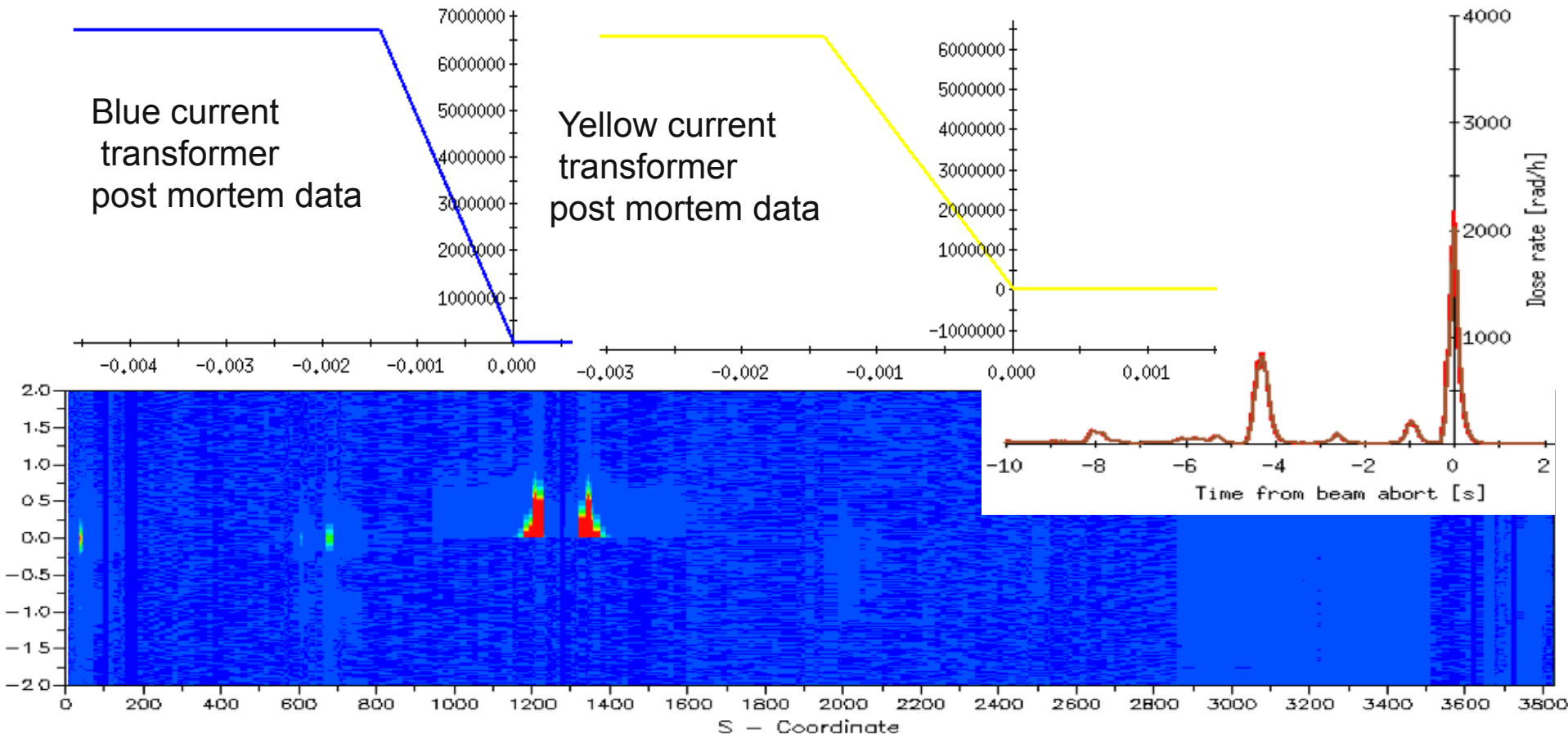


Summary

- # of beam induced magnet quenches was reduced over the years of RHIC operation with
 - improved BLM threshold settings
 - Implementation of accumuLoss threshold
- Remaining BIQs are dominated by dis-function of beam abort kicker system as well as de-bunched beam at high energy
 - So far, no damage of any magnet due to beam losses
- To fully eliminate BIQs without the risks of over-protection that causes false permit pulls, one needs
 - Re-optimize the HPF part of the FastThreshold system to a few ms instead of its current 100us
 - Allow the accumuLoss set value to be scaled with energy during the ramp
 - Provide a few channels of BLMs with fast DAQ
 - Establish comprehensive simulations
 - Since 2012, RHIC orbit is also saved as part of post mortem data

Fill: 10362

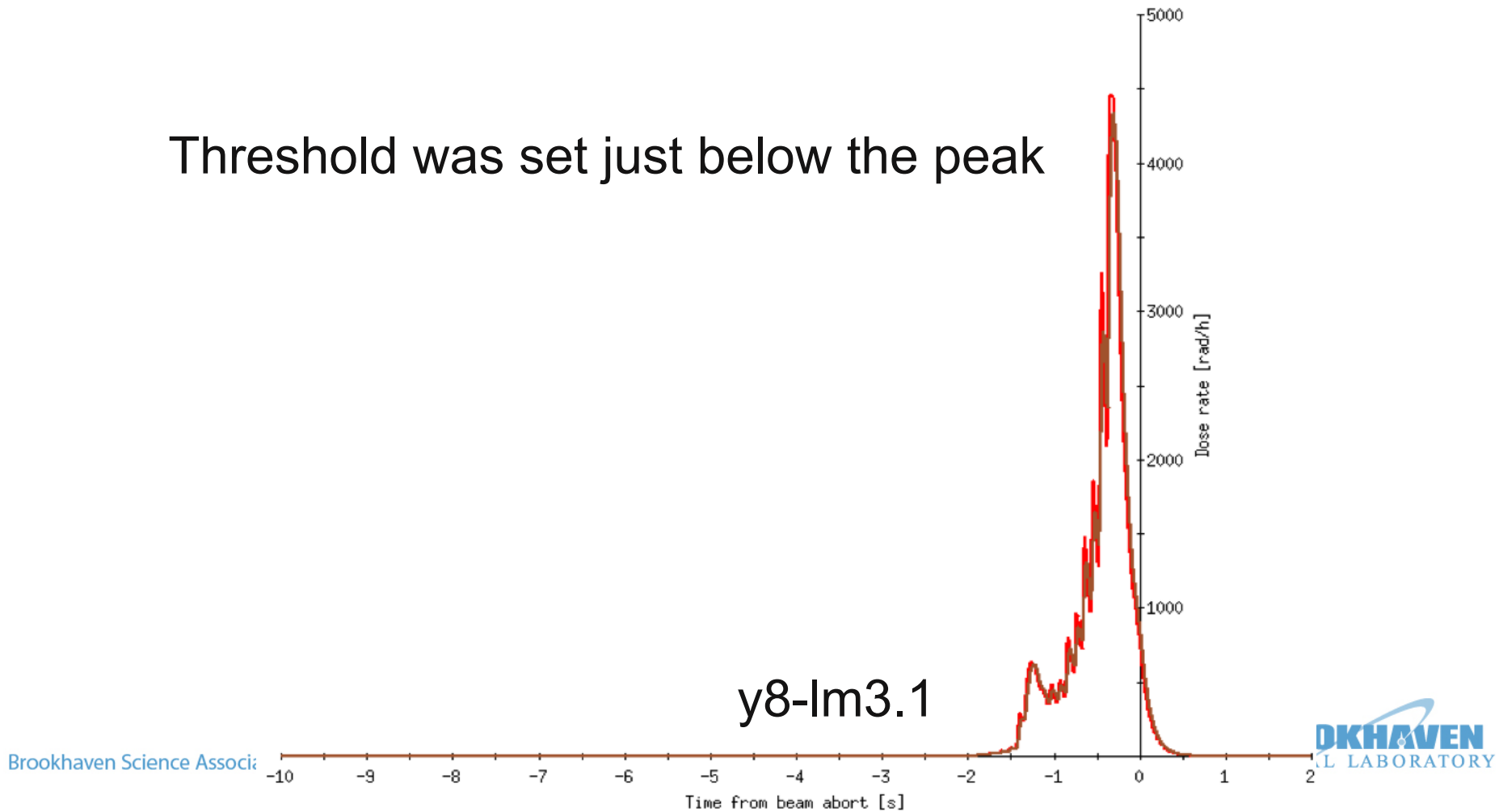
- b6-Im3.1 saw large losses, but beam current data show no losses until the beam abort
- This could be due to the scraping of beam halo instead of beam core



Fill 7496

- blms were activated, but threshold was set too high
- b8-q3 was quenched just at the end of rotator ramp due to excessive beam losses

Threshold was set just below the peak



Fill 7417

- When blms were masked out
- b8-qd2 was quenched

