Beam Losses and Beam Induced Quenches at RHIC

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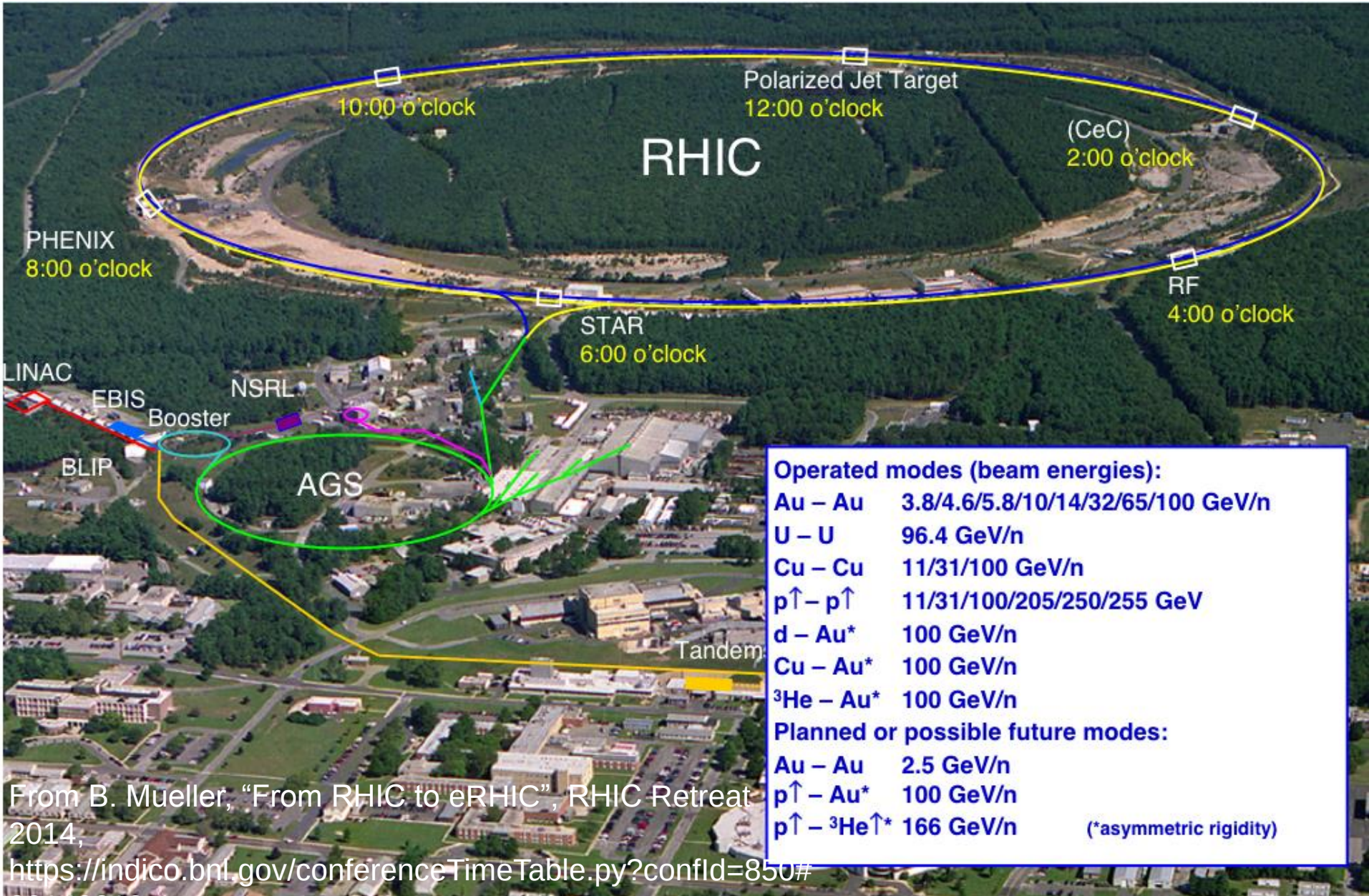
Outline

- 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

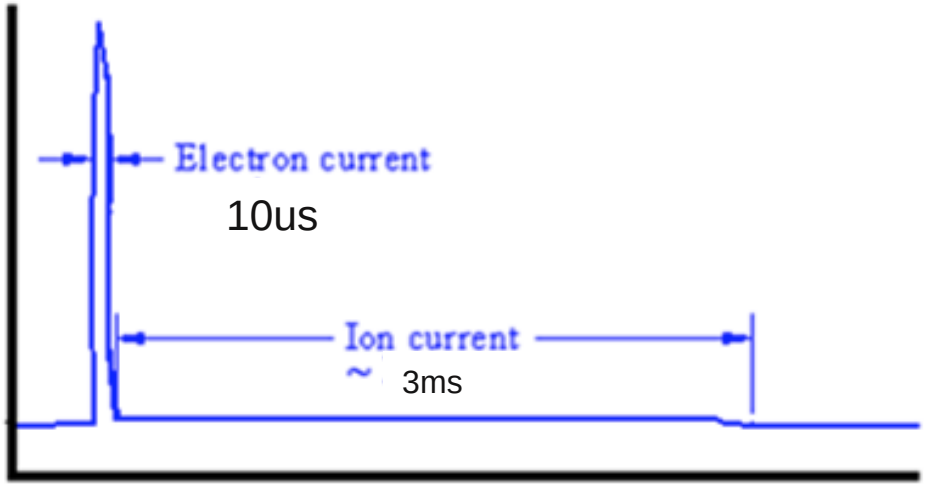


Operated modes (beam energies):	
Au – Au	3.8/4.6/5.8/10/14/32/65/100 GeV/n
U – U	96.4 GeV/n
Cu – Cu	11/31/100 GeV/n
p↑ – p↑	11/31/100/205/250/255 GeV
d – Au*	100 GeV/n
Cu – Au*	100 GeV/n
^{3}He – Au*	100 GeV/n
Planned or possible future modes:	
Au – Au	2.5 GeV/n
p↑ – Au*	100 GeV/n
p↑ – ^{3}He↑*	166 GeV/n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

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

RHIC Beam Loss Monitor System

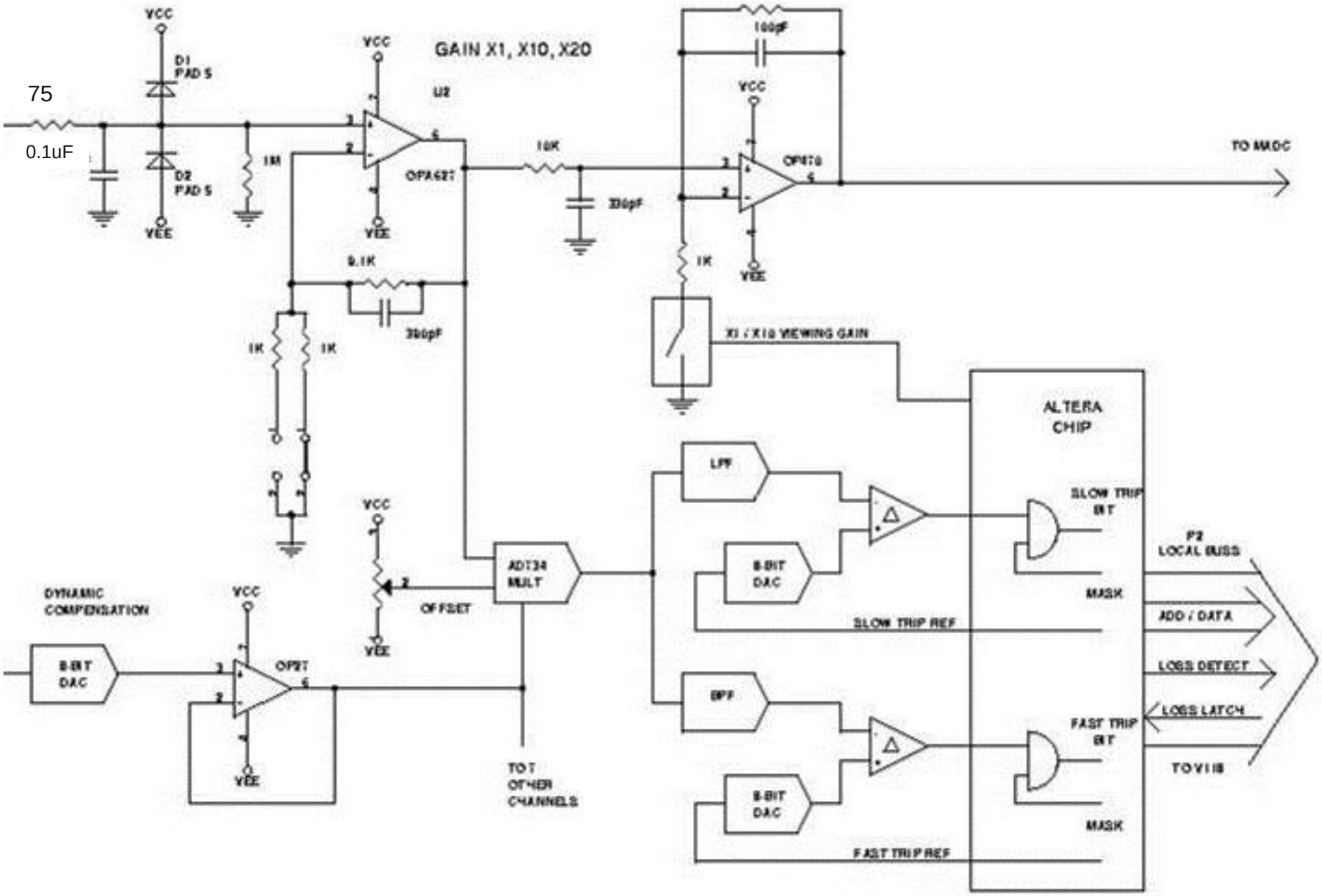
- A total of 431 Argon gas filled ion chamber detector distributed around the ring
  - Typical sensitivity of the detector is ~19.6+-1.5 pA/R/hr at 1450V
  - In the 6 arcs. Each monitor attached on the quadrupole cryostat between the two accelerators (Blue ring and Yellow ring)
  - Separate monitors 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 ~ 100ms
- Machine protection
  - Analogue signal from ion chamber gets digitized by a 8-bit DAC, and then goes out parallel into a LPF for SlowThresold 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

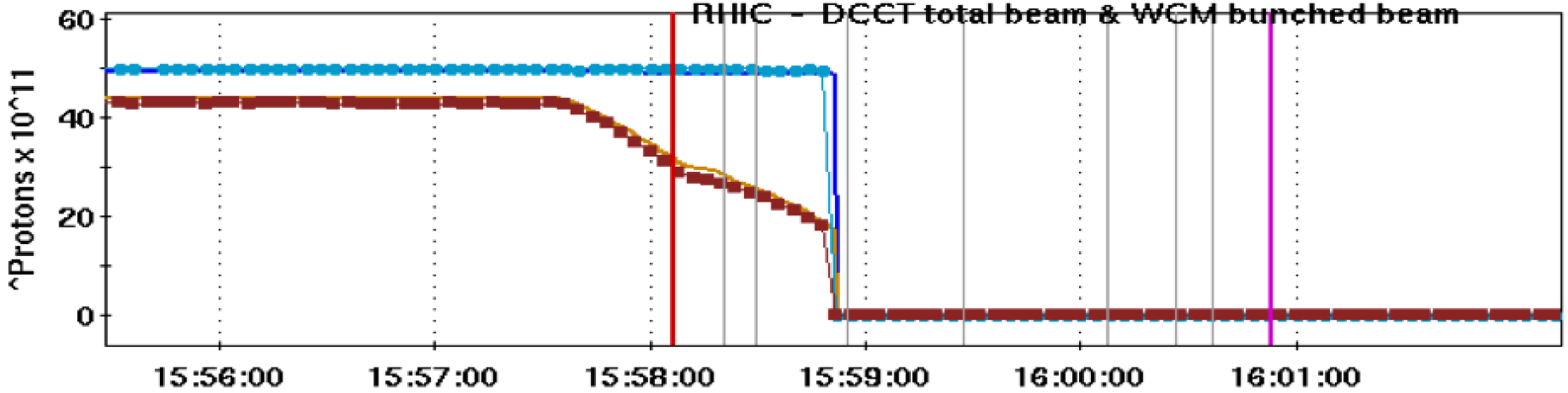
- PMViewer for collecting and viewing beam loss monitor data for Post Modem analysis
  - All beam loss monitor data are saved at 720 Hz from 10 sec before beam-abort till beam-abort
  - This limits us to know exactly the time structure of beam loss for fast losses

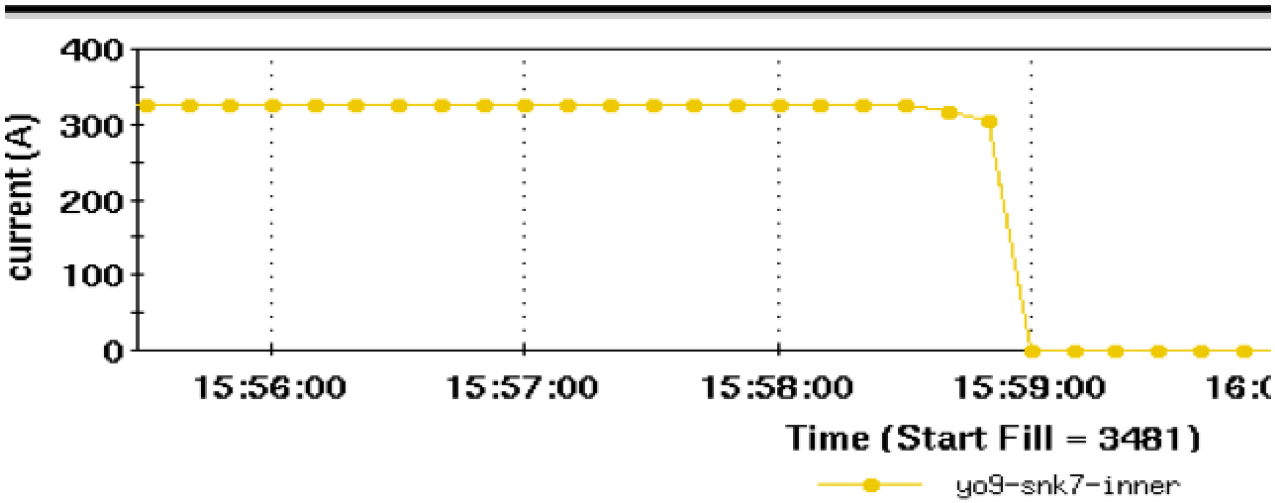
RHIC Magnet Quench

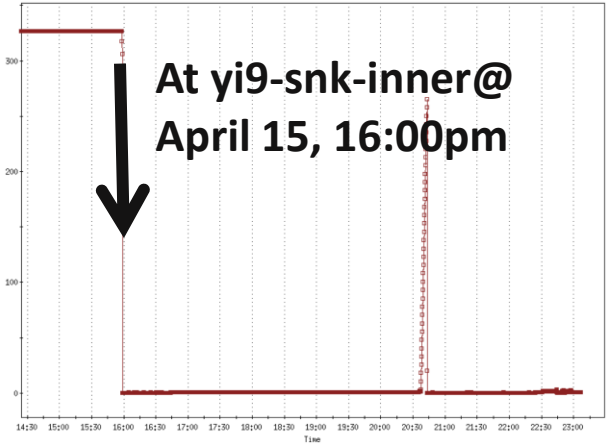
- Beam power
  - Polarized proton @250GeV/c, 110 bunches with 1x10^11 protons per bunch
    - ~440kJ
  - Au@100GeV/c/n with 110 bunches with 1x10^9 ions per bunch:
    - ~347kJ
- Superconducting magnet
  - The estimate of RHIC superconducting magnet quench at 2mJ/g for fast losses and 8mW/g for slow 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







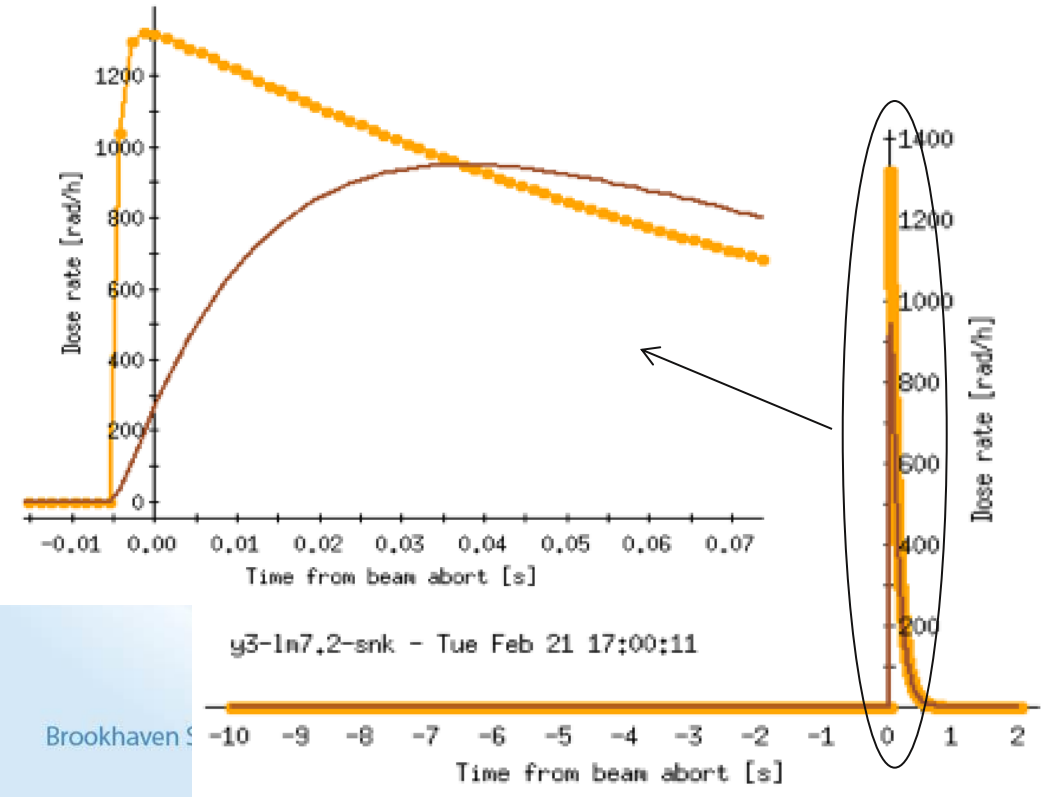
Typical Beam Loss Patterns at RHIC

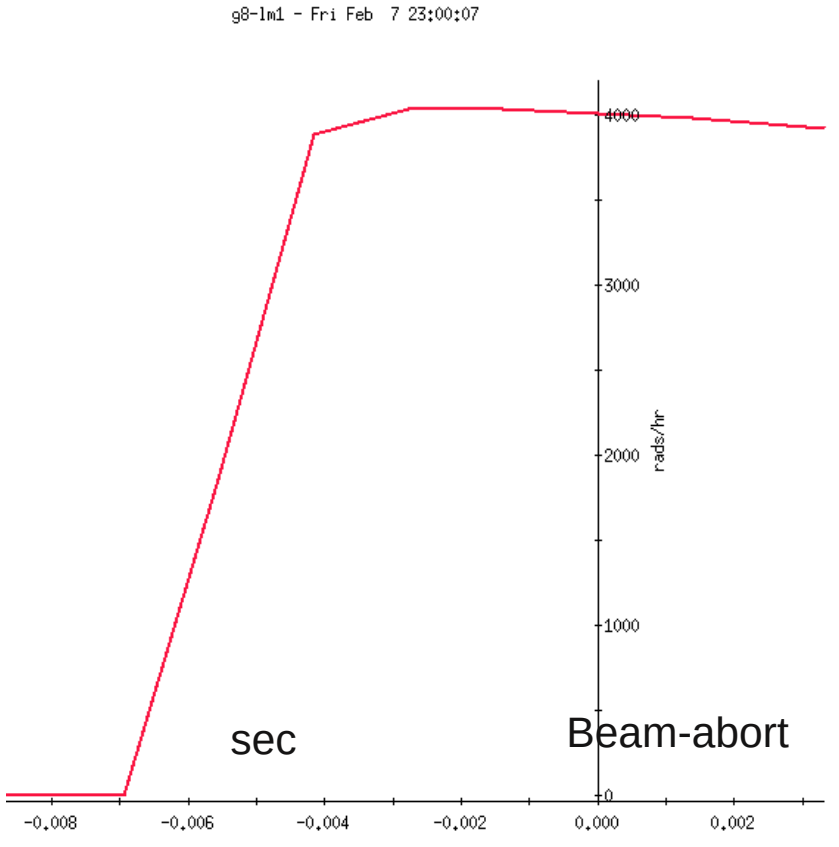
Beam losses at RHIC

- 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

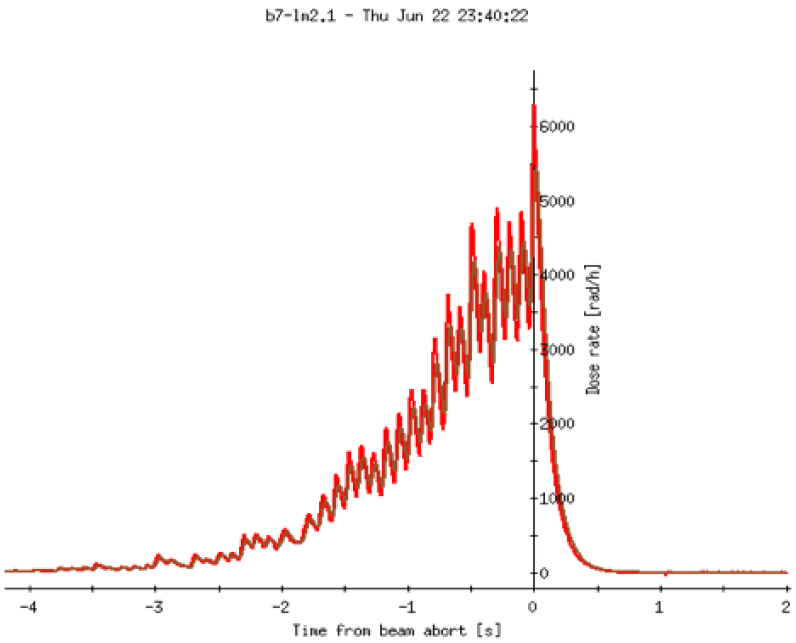
- Injection mis-match, bad injection kicker timing, ripple of the injection kicker pulse
- Beam abort kicker mis-behaviors
  - Pre-fire, mis-fire, failed to charge, …
- Fast beam instabilities

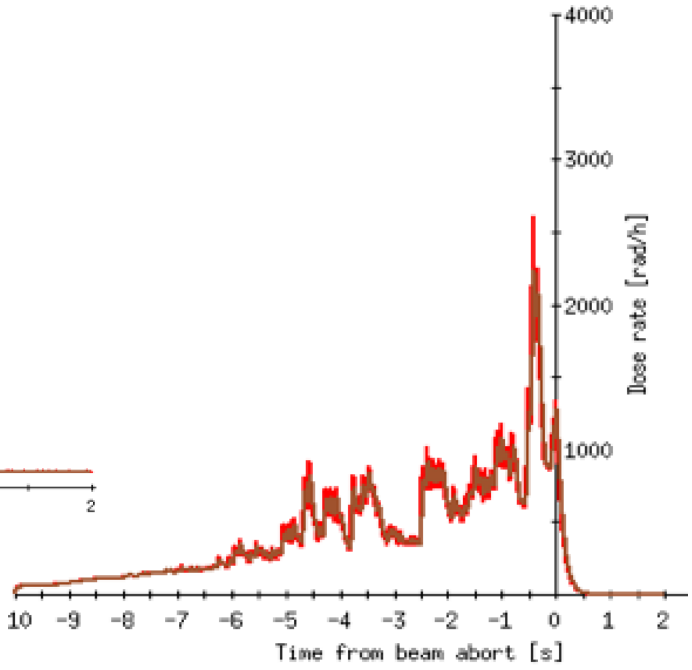


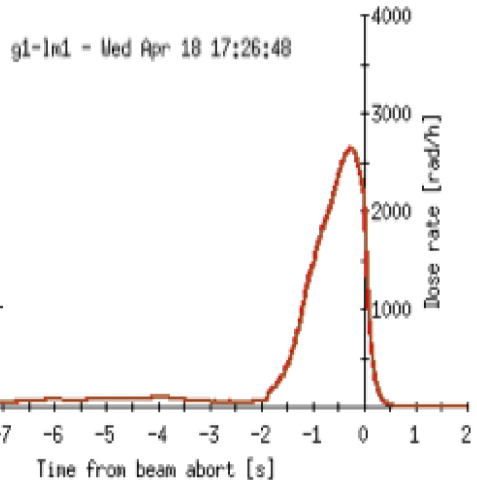


Slow beam losses at RHIC

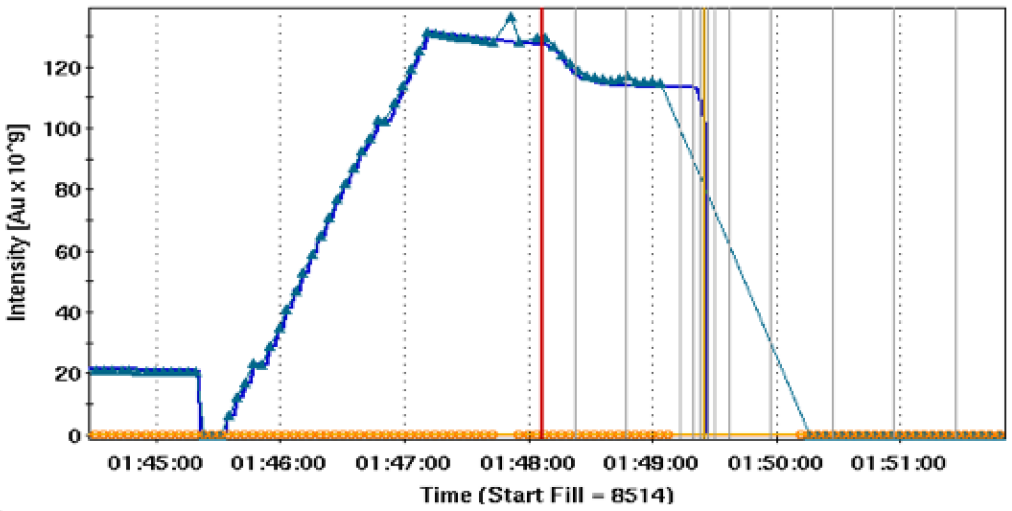
- Beam scraping mostly at the aperture limits
  - Triplets of interaction points with squeezed beta*
  - Injection area
  - Dump area



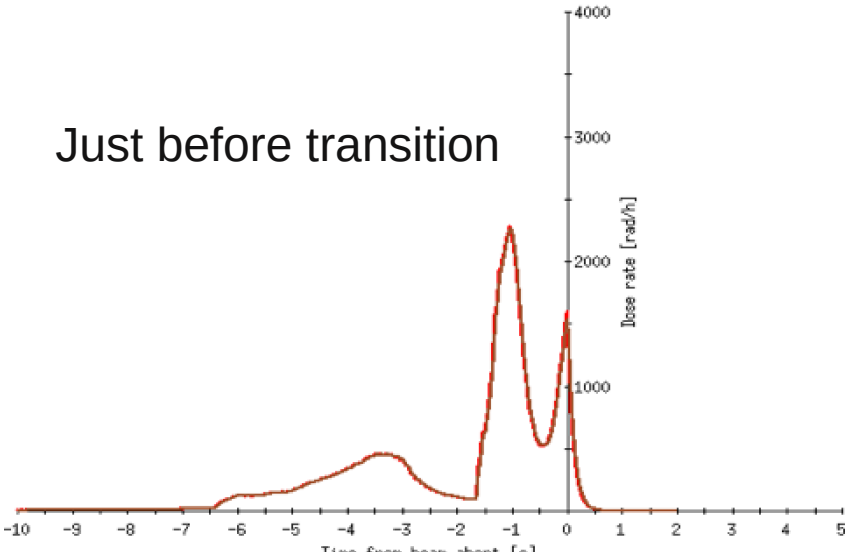


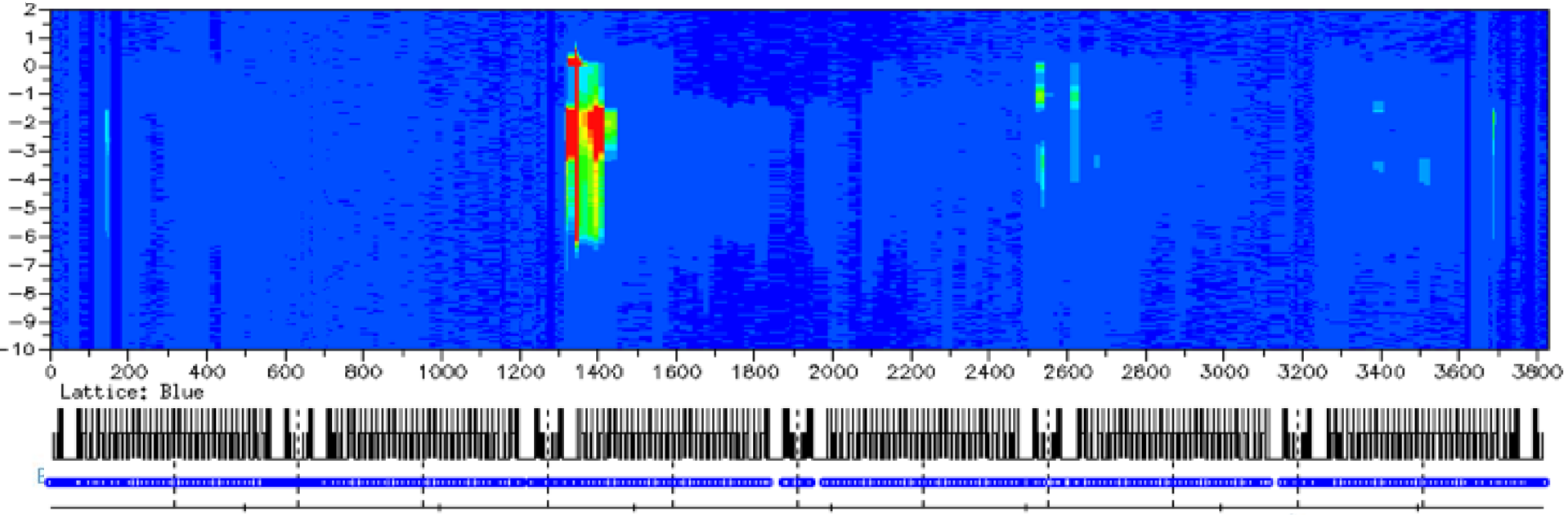


slow beam losses



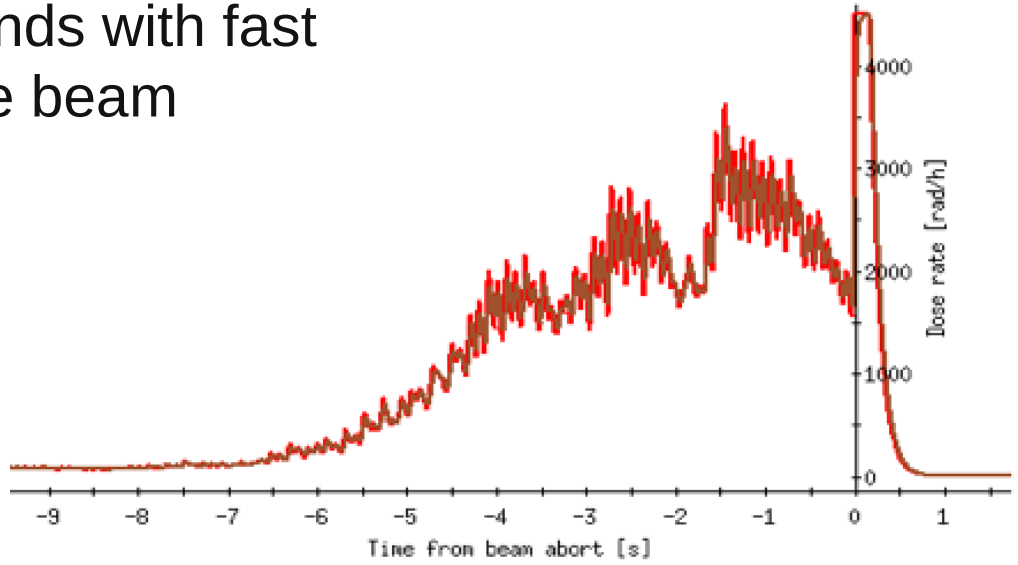
Just before transition

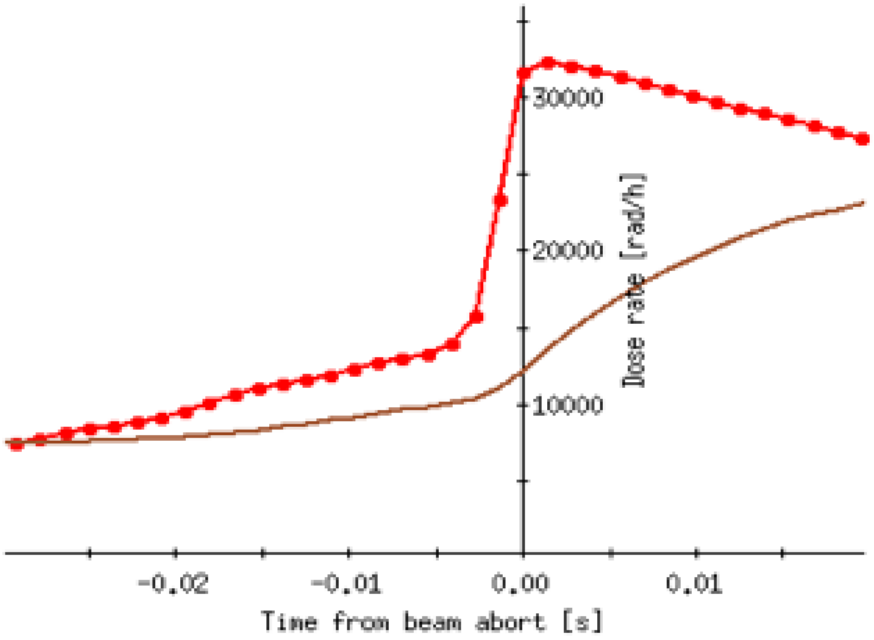


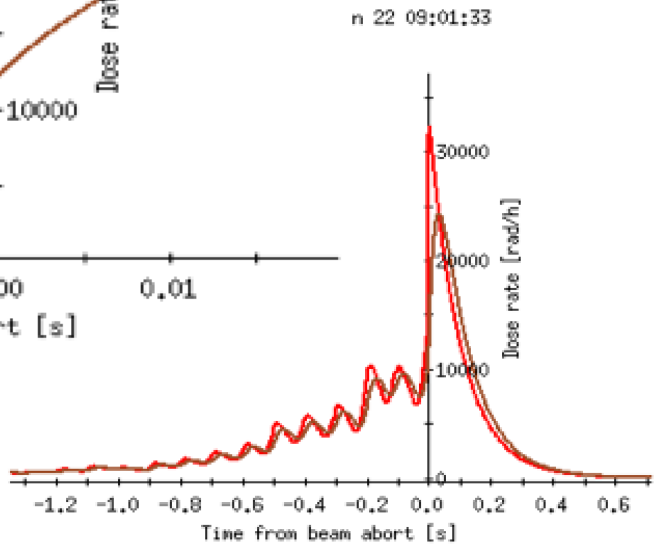


Combined loss pattern

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

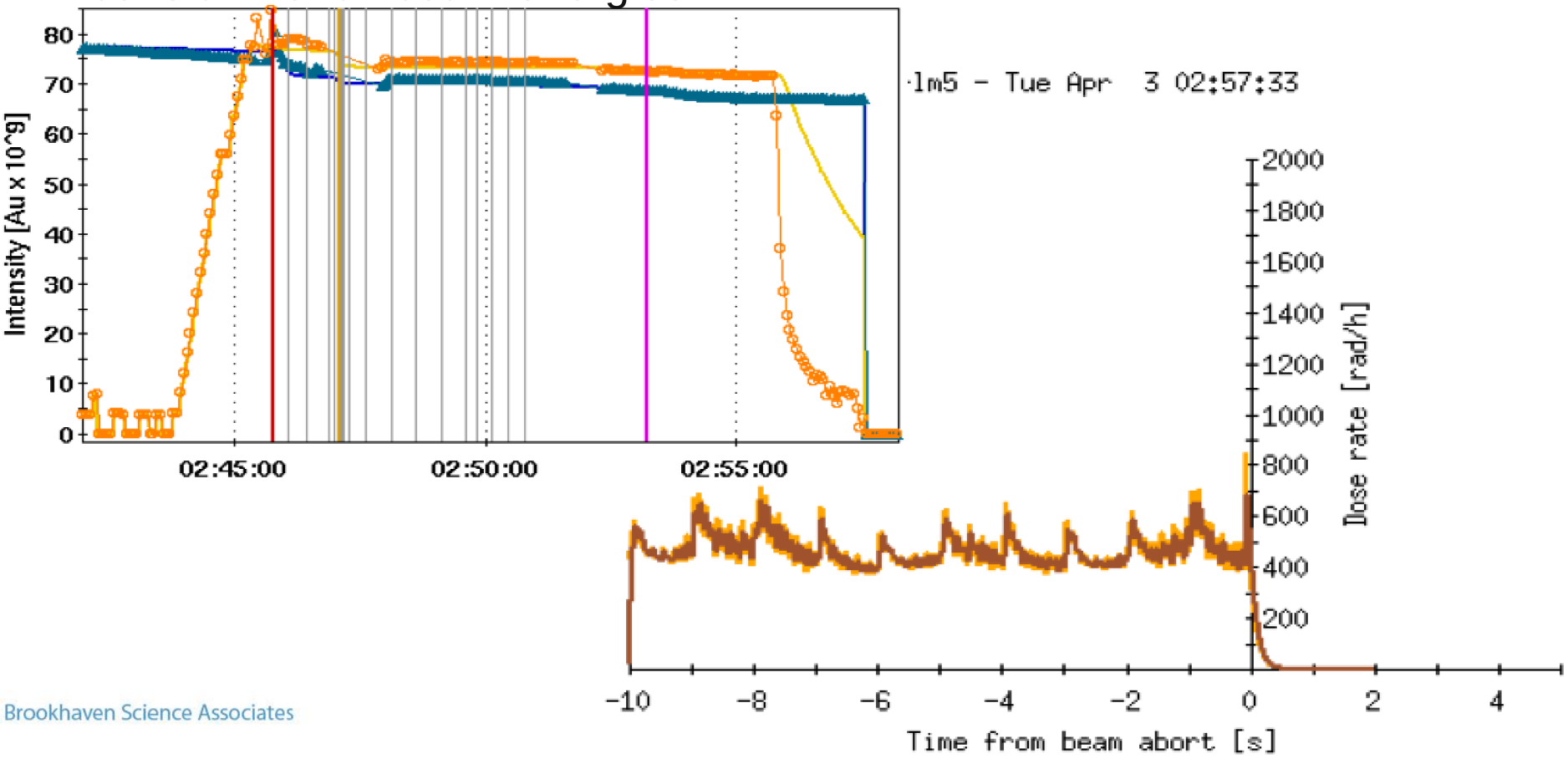






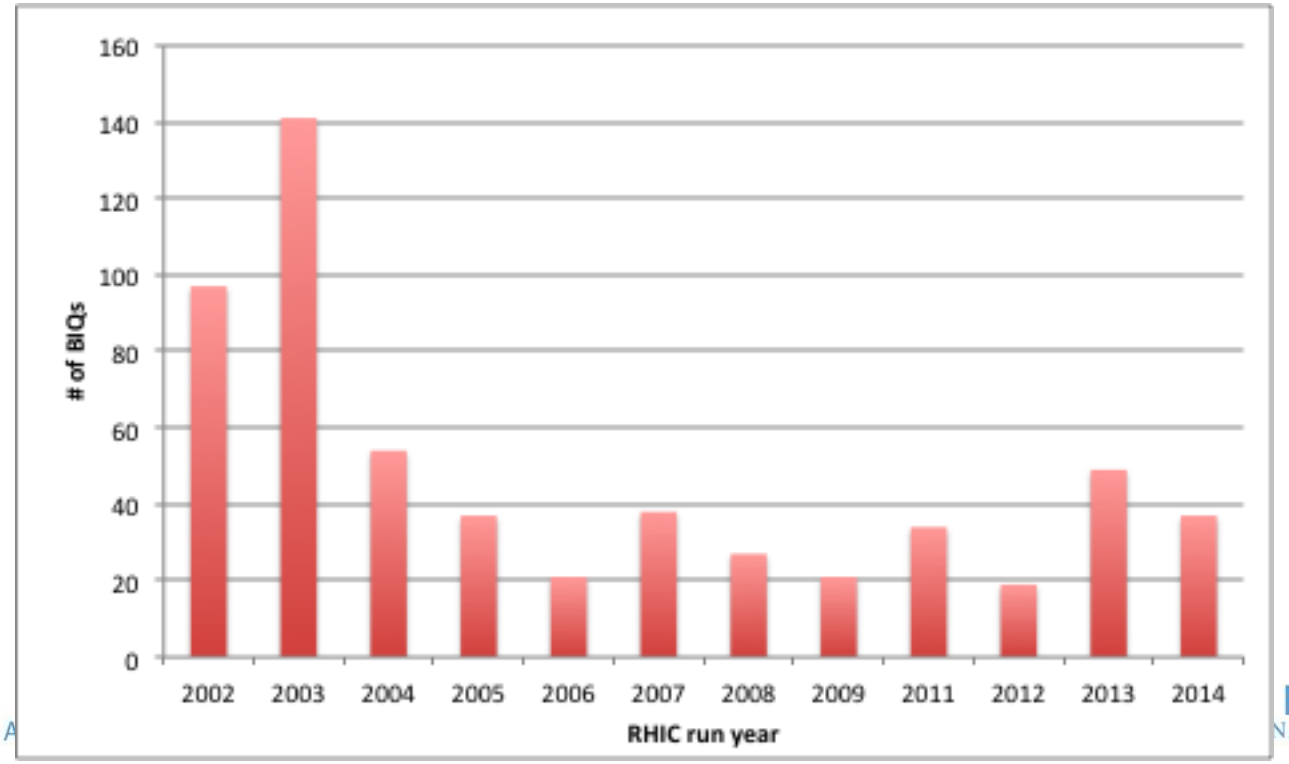
Constant beam loss

- 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 BLMsat low beta* triplets
- Significantly reduced # of beam induced magnet quenches

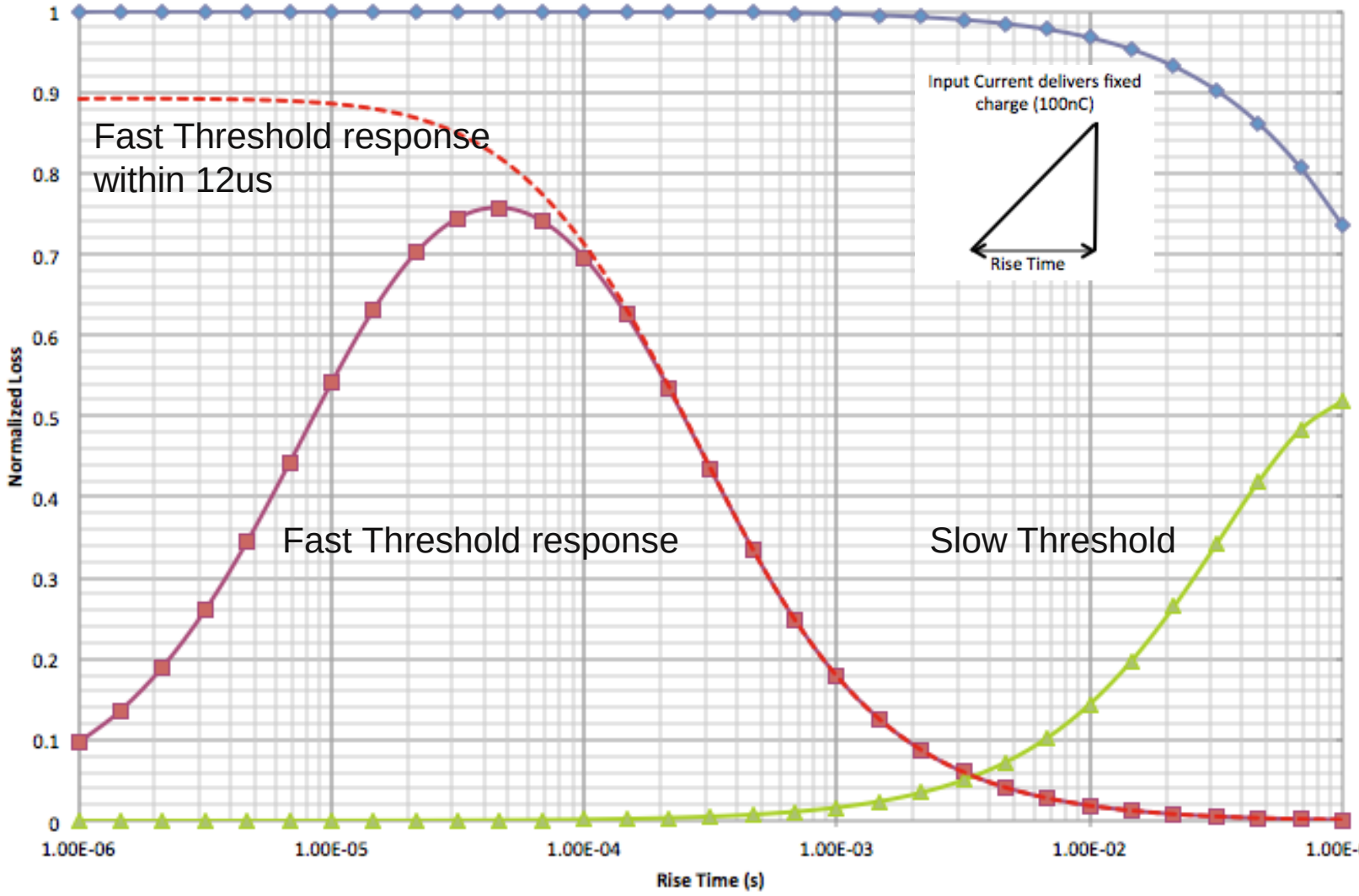


RHIC Beam Induced Magnet Quenches

- 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

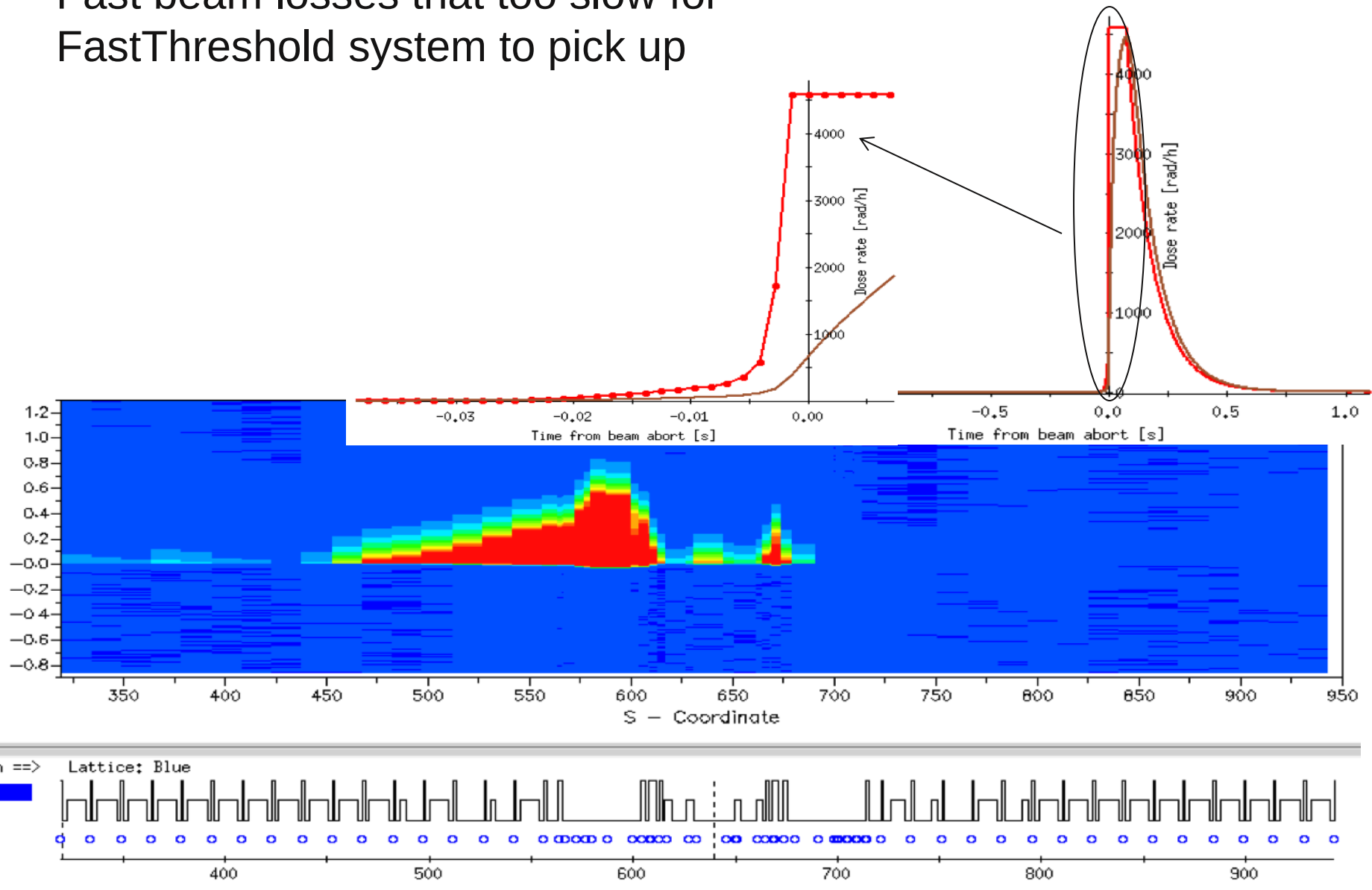
- Time constant ~3.2us-100us to collect the fast loss



Courtesy of P. Oddo

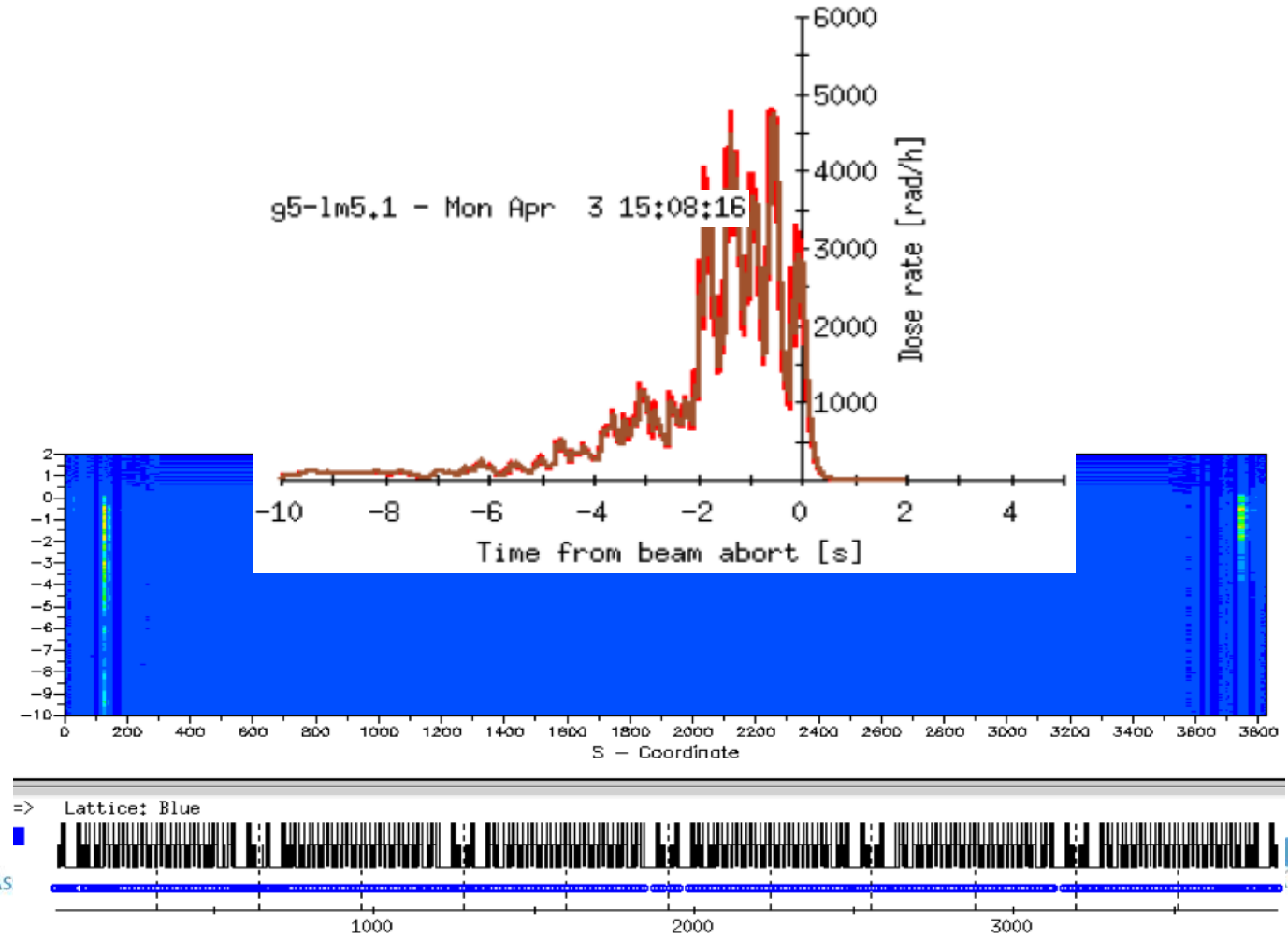
Fill 7685: example of fast beam losses

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



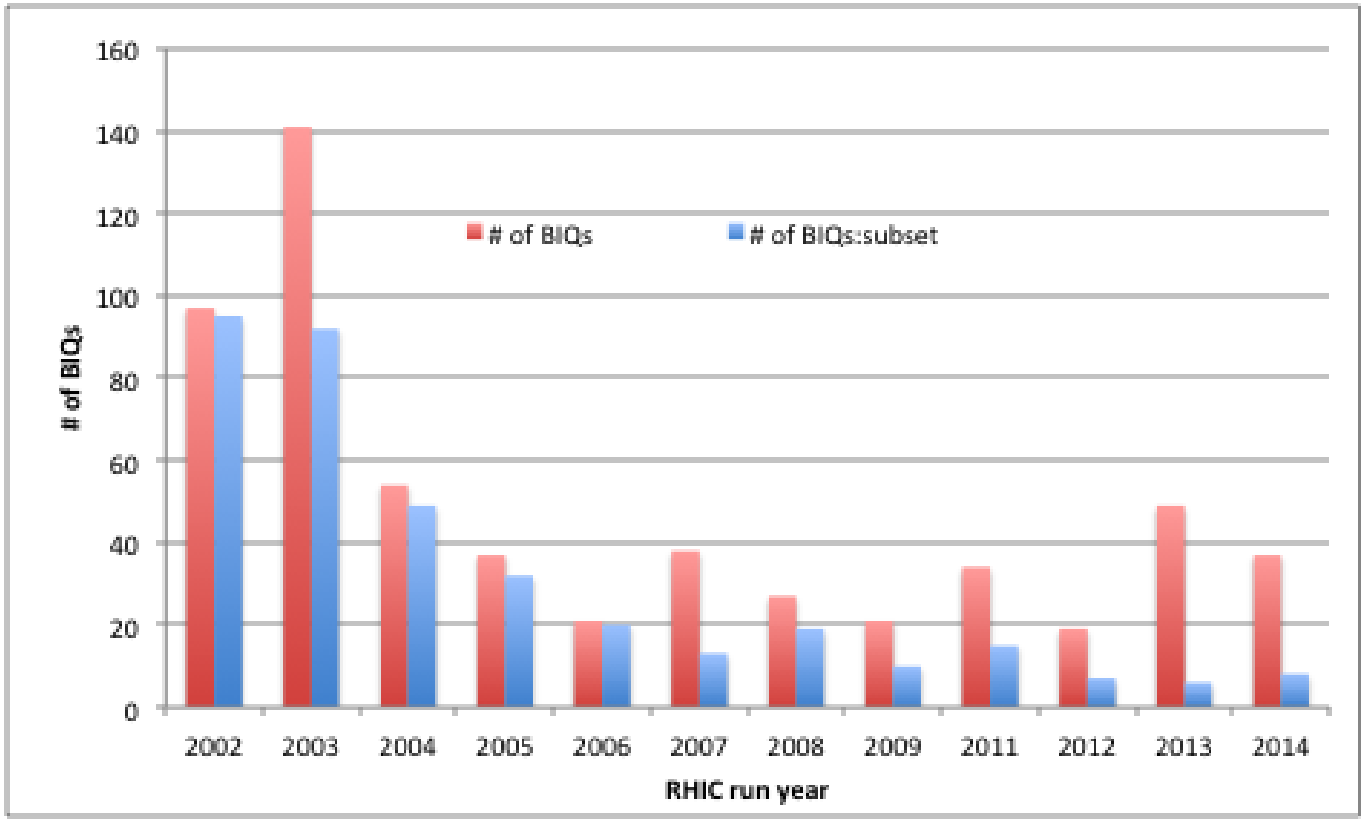
Fill 7695: example of no BLM protection

- 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



RHIC Beam Induced Magnet Quenches

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

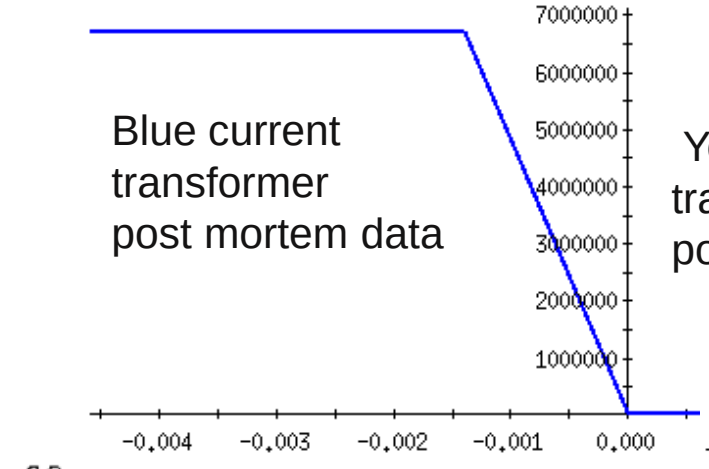


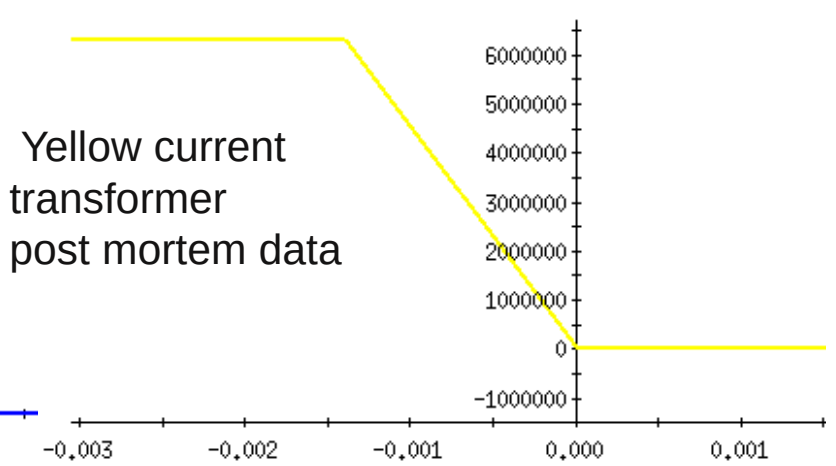
Summary

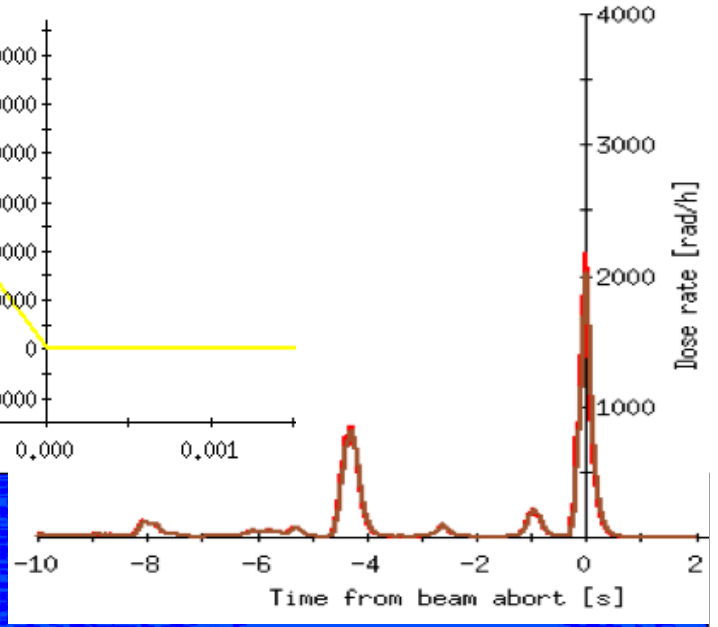
- # of beam induced magnet quenches was reduced over the years of RHIC operation with
  - improved BLM threshold settings
  - Implementation of accumuLoss threshold
- Remaining BIQs are dominated by dis-function of beam abort kicker system as well as de-bunched beam at high energy
  - So far, no damage 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

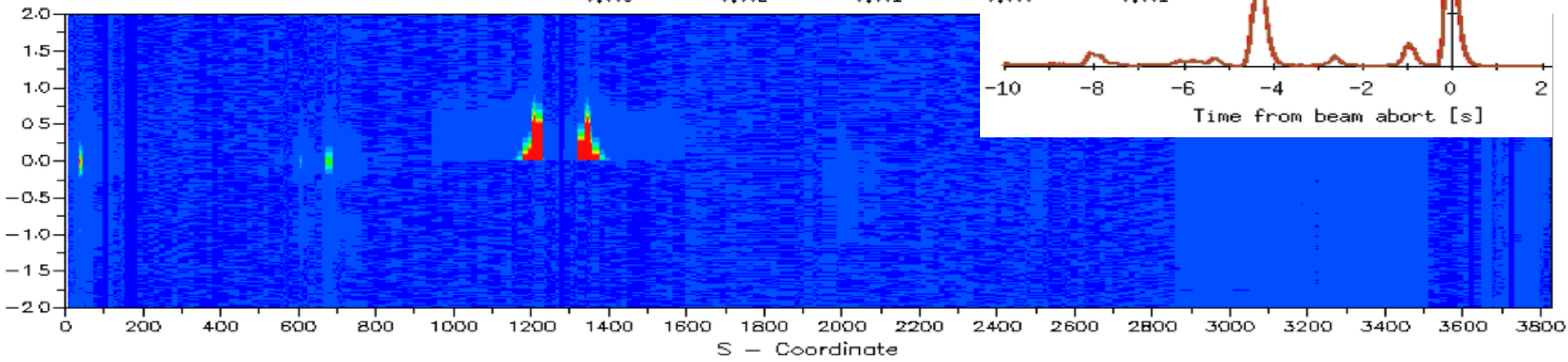
Fill: 10362

- b6-lm3.1 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





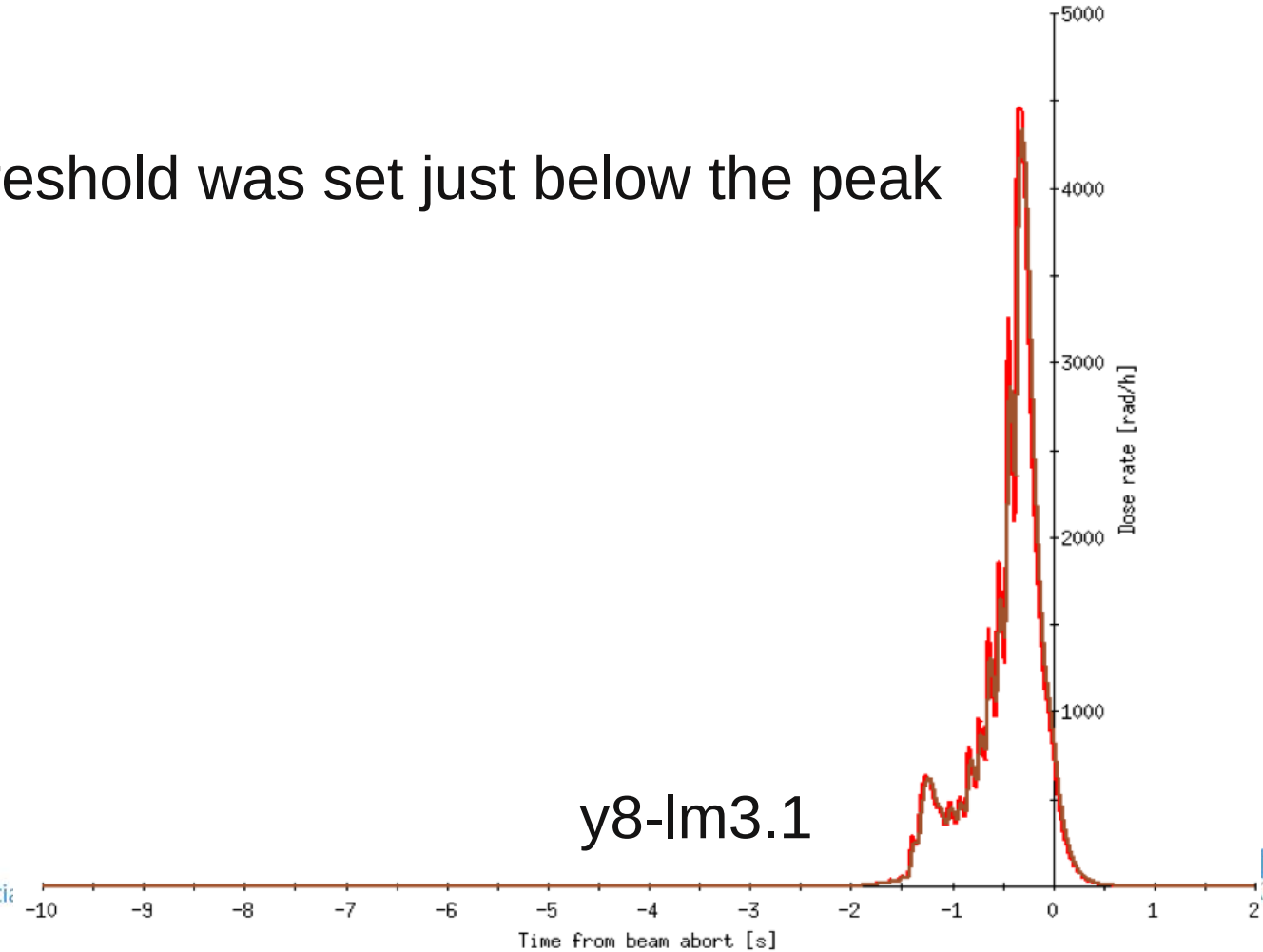




Fill 7496

- 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



y8-lm3.1

Fill 7417

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