Possible Failure with a 40~ms Delayed Abort

Yun, Angelika, Ian, Jason, Jonathan, Wolfram

2016 RHIC Retreat, July 28-29, Hamilton Seminar Room

Thanks go to John Morris, Peter Oddo, Greg Marr, Jon Sandberg, Henry Ashby, Peter Ingrassia for discussion and help.

Motivation

- RHIC abort system uses thyratrons, which caused abort kicker pre-firings and made damages to detector elements in 2012 & 2015.
- One solution is to use mechanical series switch which is more robust and eliminates abort kicker pre-firing.
- However, series switch adds 40ms delay to beam abort.

  Is it efficient to protect accelerator?
- This talk addresses:

  1) How fast RHIC beam got lost seen by BLMs ?

  2) Possible failures with 40ms abort delay with series switch ?

Beam Loss Cause I: Electrical

single dipole corrector/qudrupole PS trip-off

multiple magnet power supplies PS trip-off

MPS failure

power dip

Injection kicker pre-firing

dump kicker pre-firing

RF cavity trip-off, voltage unstable, etc.

Beam Loss Cause II : Mechanical

vacuum valve plunging into beam pipe

CEC YAG screens

collimators

Roman Pots

CNI polarimeter target frames

RF tuner/coupler movement (shifting freq.)

Stochastic cavity gap closing-up

Beam Loss Cause III: Instabilities

coherence motion due to chromaticities

tunes too close to resonances

failed tune/coupling feedback

head-tail instability & TMCI

RF HOM: multi- bunch instability

electron cloud: transition, re-bucketing

unidentified falling objects (UFO)

Transition is most vulnerable to instabilities because of short bunch length

Permit Pull and Beam Aborts

- Machine Protection:

  Permit system is designed to protect accelerators.
  Beam abort system is used to intentionally dump beams locally.

- **Permit inputs**:

  Beam Loss Monitor: accumulated loss, slow/fast thresholds
  Quench Link Interlock
  Injection kicker
  Abort kicker
  RF: Accel, 56MHz, 9MHz, **Storage(?)**
  Access control system
  Vacuum valves
  CEC mirror, Roman Pot
  ……

- **Beam loss monitors** are used to monitor the dose of radiation.
  BLM can pull permit and cause beam abort.
  BLM records radiation dose from all beam aborts.

Statistics: All Beam Aborts

	2013	2014	2015	2016
Beam aborts	759 (100%)	400 (100%)	717 (100%)	804 (100%)
Permit pulled	715	390	711	776
BLM	545 (72%)	124 (31%)	415 (58%)	473 (59%)
Slow Threshold	534	117	408	460
Fast Threshold	11	7	7	7
RF	82 (11%)	149 (37%)	168 (23%)	137 (17%)
Blue Accel.	35	70	64	64
Yellow Accel.	11	60	47	62
56 MHz	0	17	2	0
9 MHz	36	0	52	0
Abort Kicker	21 (3%)	42 (11%)	38 (5%)	48 (6%)
Blue abort kicker	9	17	13	28
Yellow abort kicker	12	23	22	19
QLI	25 (3%)	56 (14%)	15 (2%)	75 (9%)
Blue QLI	17	36	7	45
Yellow QLI	8	20	8	30

Statistics: Where Beam Aborted

	2013	2014	2015	2016
Total	759	400	717	804
At store	77 (10%)	74 (19%)	79 (11%)	82 (10%)
On ramp	84	43	92	96
At flattop	114	61	140	104

Definitions:

1) Store : abort happened between lumi and lumi-off
2) Ramp: abort happened between accramp and endramp
3) flattop: abort happened after endramp, but no lumi event

Most aborts happened at injection, machine startup, even without beam.

Statistics: Kinds of Beam Aborts

AT STORE

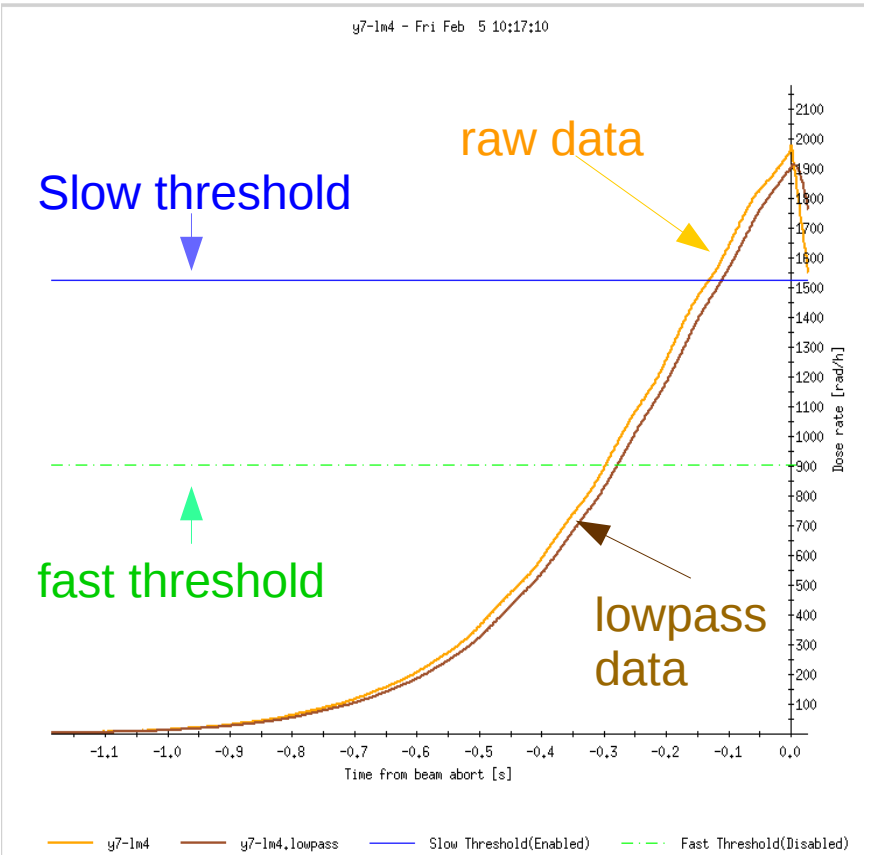
	2013	2014	2015	2016
Total	77	74	79	82
Slow threshold	47	33	23	40
Fast threshold	**2**	**3**	**4**	**6**
RF	3	6	8	7
Blue QLI	13	13	33	13
Yellow QLI	2	14	11	6

ON RAMP

	2013	2014	2015	2016
Total	84	43	92	96
Slow threshold	59	25	81	61
Fast threshold	**8**	**4**	**1**	**0**
RF	2	1	1	3
Blue QLI	4	4	2	5
Yellow QLI	3	7	5	19

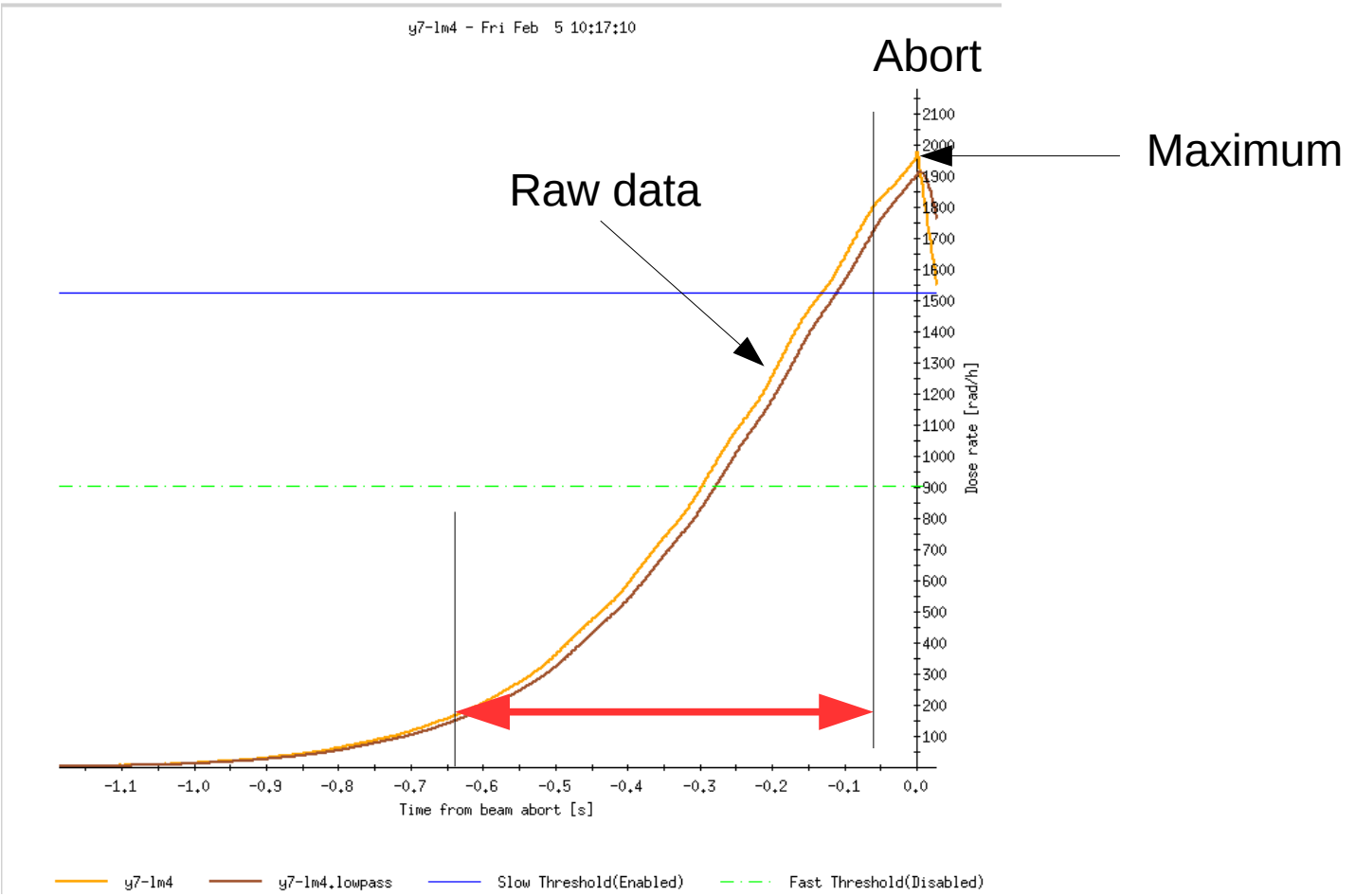
Radiation Dose Seen by BLM

Input Channel - Loss Monitor 1 - Fri Feb 05, 2016 10:17:10.759748



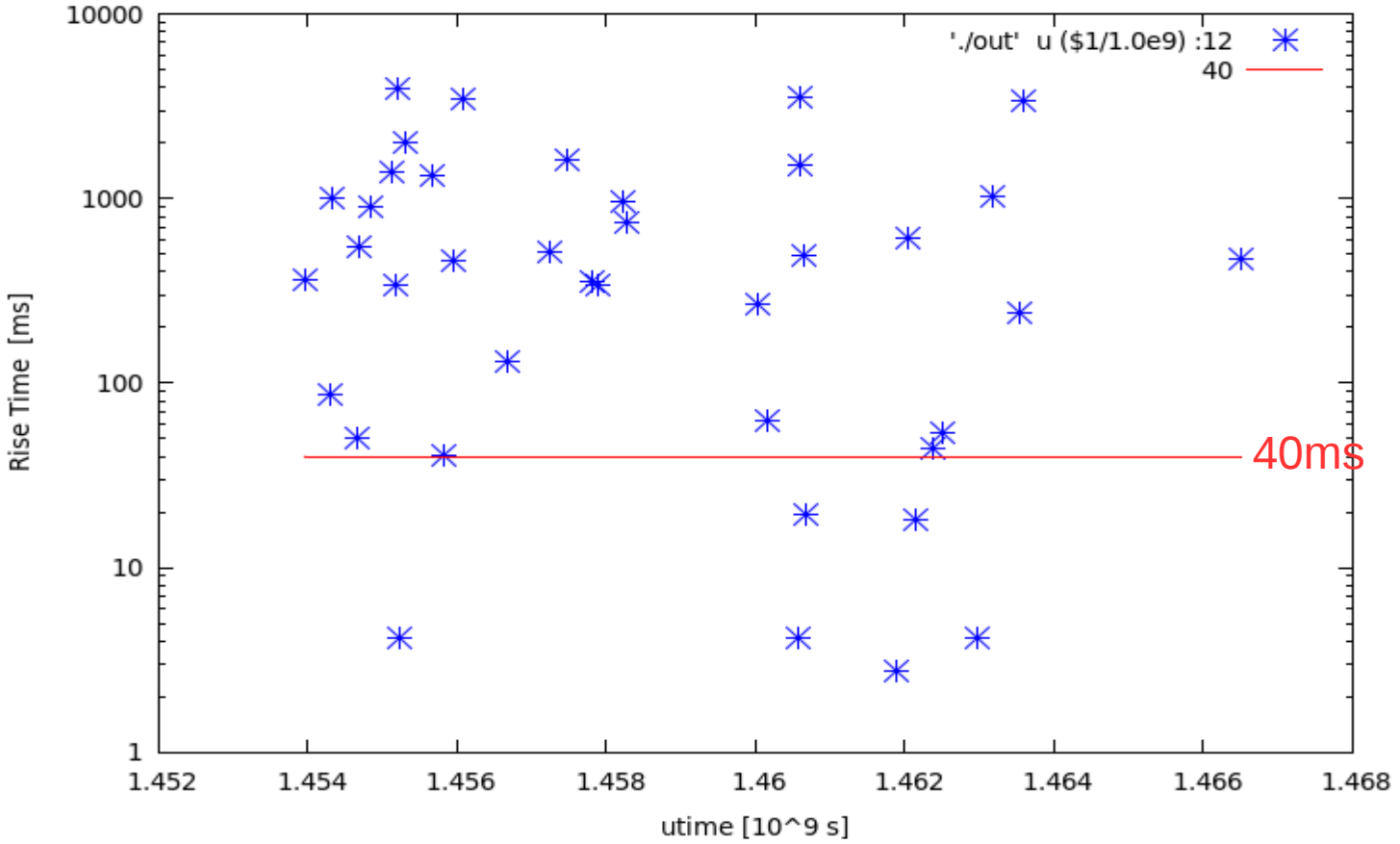
To estimate rise time of beam loss, we are interested in **beam aborts with slow loss threshold pulled permit**. Fast threshold pulled permit and other non-BLM pulled permit are not relevant to beam instabilities.

Rise Time of BLM Dose



For simplicity, I **define the rise time** as the time period between 90% –10% of the maximum received BLM dose. **Raw data** are used.

Store 'Slow Threshold' Pulls : 2016



Totally **7 out of 40 (18%)** 'slow threshold' BLM pulled cases with BLM signal rise time < 40ms .

Store Cases with Rise Time < 40ms

rise time

2016 Au-Au run :

1) g10-lm20 SlowLoss Loss Monitor 2 Thu Jan 28, 2016 03:19:10 0.0ms
Travis : .010 mrad angle bump at IR8

2) g8-lm5 SlowLoss Loss Monitor 1 Thu Feb 11, 2016 17:21:10 4.16ms
Guillaume (APEX): squeeze to 50cm in Blue

3) g8-mlmx.1 SlowLoss Loss Monitor 2 Wed Apr 13, 2016 16:29:16 4.16ms
Chuyu (APEX): angle steering at IR6 during lumi leveling

4) g8-lm5 SlowLoss Loss Monitor 1 Thu Apr 14, 2016 16:24:19 19.4ms
MCR : store following 56MHz study, caused by 10Hz PS

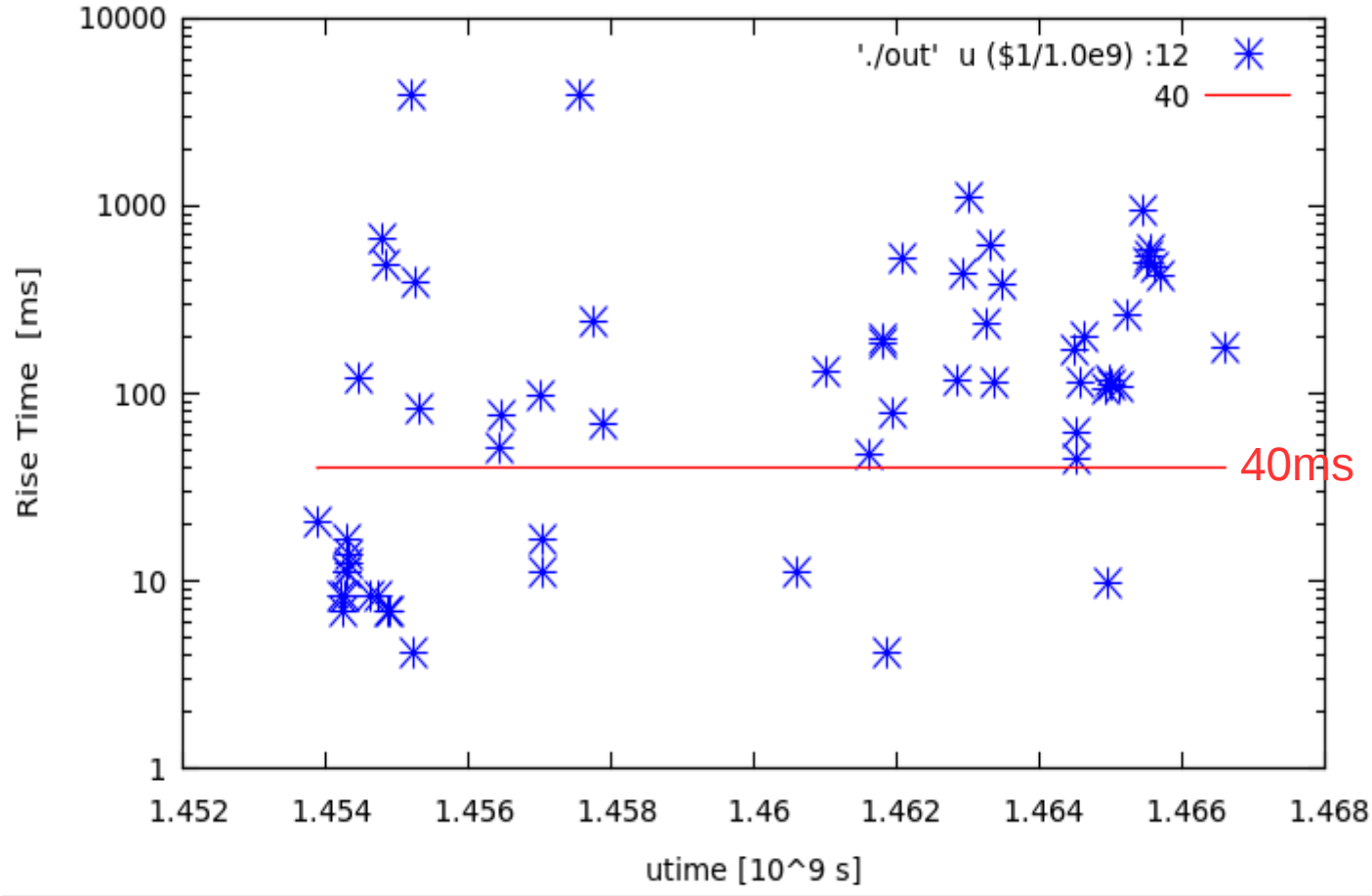
5) b8-lm4 SlowLoss Loss Monitor 1 Thu Apr 28, 2016 18:26:40 2.77ms
MCR : likely linked to 56MHz

6) g2-lm16 SlowLoss Loss Monitor 1 Sun May 01, 2016 19:16:49 18.0ms
MCR : Blue longitudinal pickup error

2016 d-Au run:

7) g8-mlmx.1 SlowLoss Loss Monitor 2 Wed May 11, 2016 09:59:19 4.16ms
MCR : y8-q6 QLI

Ramp 'Slow Threshold' Pulls : 2016



19 out of 61 (31%) 'slow threshold' BLM pulled cases with BLM signal rise time < 40ms .

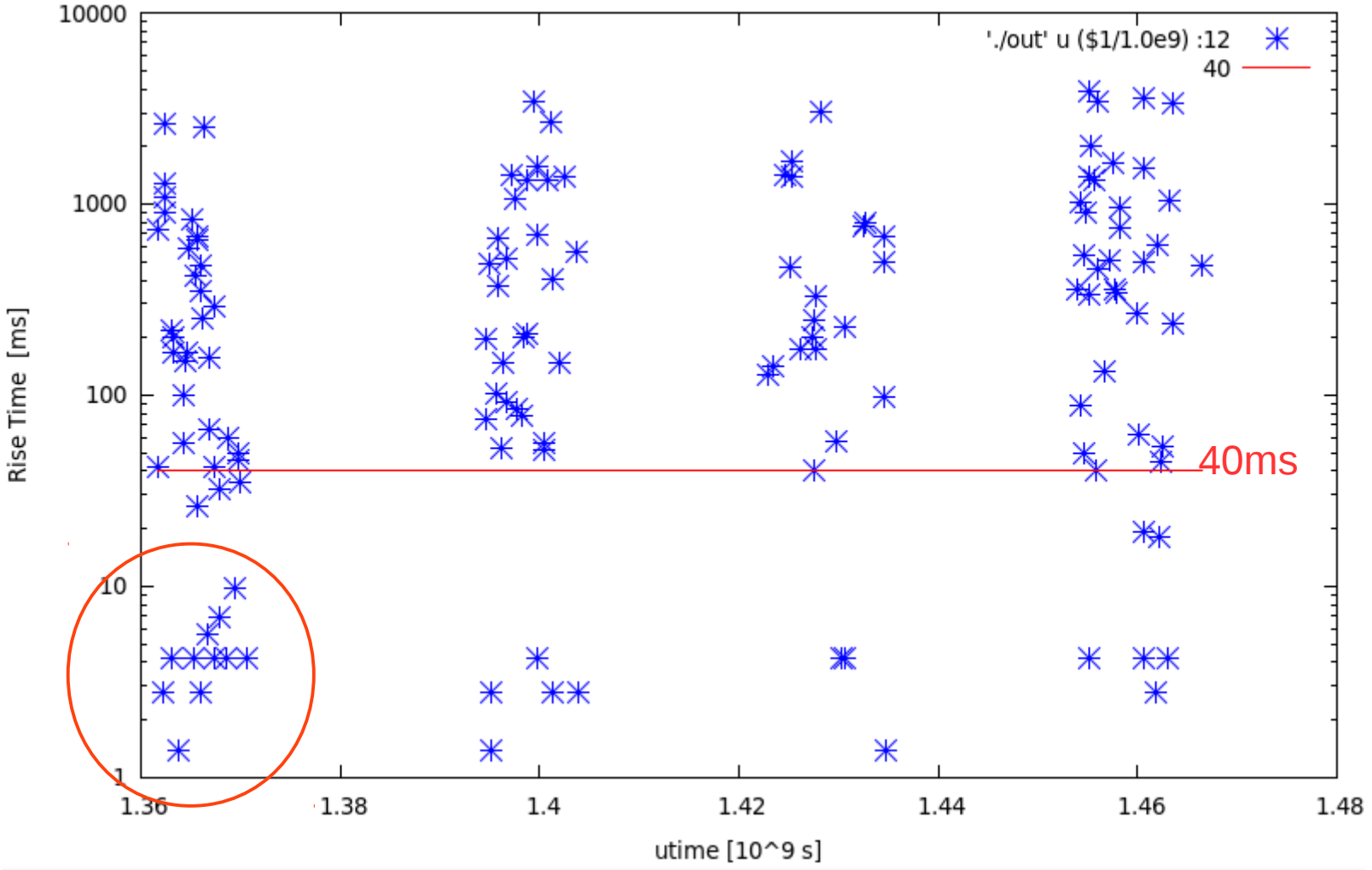
Ramp Cases with Rise Time < 40ms

During 2016 ramps

rise time

b6-lm3.1	SlowLoss	Loss Monitor 1	Wed Jan 27, 2016 05:50:18.27421	20.83ms
g8-lm5	SlowLoss	Loss Monitor 1	Sun Jan 31, 2016 01:04:19.61315	8.333ms
b8-lm4	SlowLoss	Loss Monitor 1	Sun Jan 31, 2016 06:27:03.24841	6.944ms
b8-lm4	SlowLoss	Loss Monitor 1	Sun Jan 31, 2016 15:17:12.26446	8.333ms
b8-lm4	SlowLoss	Loss Monitor 1	Sun Jan 31, 2016 22:54:12.35886	11.11ms
b8-lm4	SlowLoss	Loss Monitor 1	Sun Jan 31, 2016 23:24:34.3260	11.111ms
g8-lm5	SlowLoss	Loss Monitor 1	Mon Feb 01, 2016 00:55:05.19286	16.66ms
b8-lm4	SlowLoss	Loss Monitor 1	Mon Feb 01, 2016 06:42:19.29654	13.88ms
b8-lm4	SlowLoss	Loss Monitor 1	Mon Feb 01, 2016 07:16:06.31081	12.50ms
y8-lm3.1	SlowLoss	Loss Monitor 1	Thu Feb 04, 2016 21:09:11.82871	8.333ms
y8-lm3.1	SlowLoss	Loss Monitor 1	Fri Feb 05, 2016 21:40:45.25083	8.333ms
y8-lm3.1	SlowLoss	Loss Monitor 1	Sun Feb 07, 2016 14:54:04.2604	6.9444ms
y8-lm3.1	SlowLoss	Loss Monitor 1	Sun Feb 07, 2016 19:31:48.29697	6.944ms
g8-lm5	SlowLoss	Loss Monitor 1	Thu Feb 11, 2016 17:21:10.9782	4.1666ms
g8-lm5	SlowLoss	Loss Monitor 1	Thu Mar 03, 2016 18:24:01.14675	11.11ms
g8-lm5	SlowLoss	Loss Monitor 1	Thu Mar 03, 2016 18:57:14.14834	16.66ms
g8-lm5	SlowLoss	Loss Monitor 1	Wed Apr 13, 2016 19:57:49.19588	11.11ms
y2-lm3	SlowLoss	Loss Monitor 1	Thu Apr 28, 2016 11:36:40.19945	4.166ms
g3-lm13	SlowLoss	Loss Monitor 1	Fri Jun 03, 2016 11:24:13.65062	9.722ms

Store 'Slow Threshold' Pulls : 2013-2016



Totally **34 out of 143 (24%)** 'slow threshold' BLM pulled cases with BLM signal rise time < 40ms . **Half cases are from run 13.**

Cases with rise time < 40ms: (2014 & 2015)

rise time

g8-lm5 SlowLoss Loss Monitor 1 Mon Mar 17, 2014 17:23:13.0748 2.78
MCR: FEC reboot while gap cleaning cause a lot of loss

y3-lm4 SlowLoss Loss Monitor 1 Tue Mar 18, 2014 21:28:05.70424 1.39
MCR: Lisa steering with a bad activation

g8-lm5 SlowLoss Loss Monitor 1 Sun May 11, 2014 13:20:13.08524 4.17
MCR: FEC reboot while gap cleaning cause a lot of loss

g10-lm5 SlowLoss Loss Monitor 1 Tue May 27, 2014 23:19:34.37033 2.78
MCR: Blue abort kicker prefire

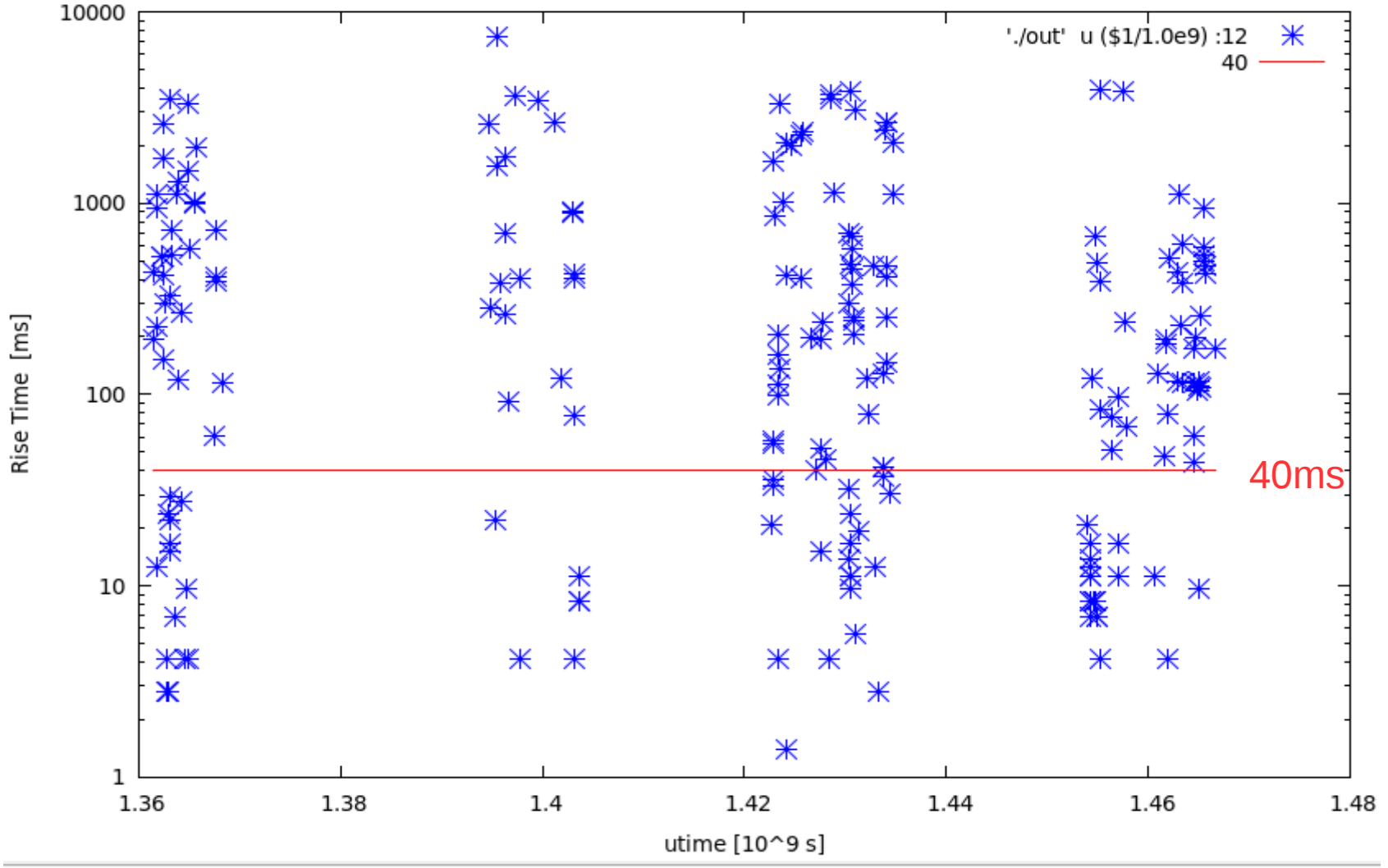
g10-lm5 SlowLoss Loss Monitor 1 Thu Jun 26, 2014 19:06:28.17538 2.78
APEX (Haixin): Fins of the target clipped through the beam Tail

b10-lm4 SlowLoss Loss Monitor 1 Wed Apr 29, 2015 23:17:45.68332 4.17
MCR : Ramp development, abort reason not found in elog

y9-lm4 SlowLoss Loss Monitor 1 Sun May 03, 2015 01:49:00.14260 4.17
MCR: Taking a "quick" polarimeter.

b6-lm3.1 SlowLoss Loss Monitor 1 Fri Jun 19, 2015 09:28:47.54749 1.39
MCR: Blue Quench Link Interlock, BS2 tripped off early

Ramp 'Slow Loss' Pulls : 2013-2016



Totally **62 out of 226 (27%)** 'slow loss' BLM pulled cases with BLM signal rise time < 40ms .

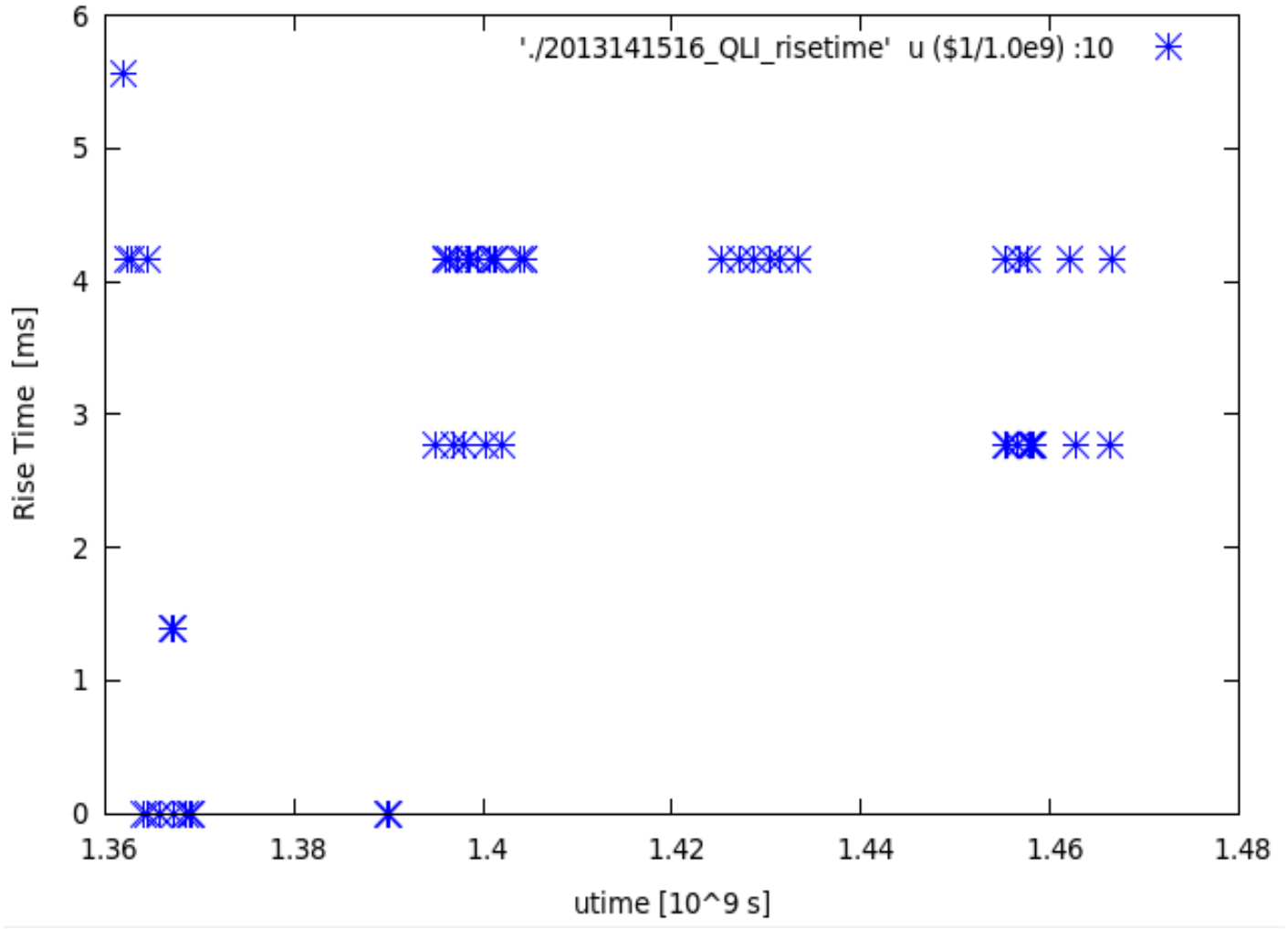
```
b5-lm3.1 FastLoss  Loss Monitor 1    Sat Jan 30, 2016 05:37:57
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Feb 02, 2016 01:35:33
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Feb 02, 2016 04:31:56
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Feb 16, 2016 22:12:45
y8-lm3.1 FastLoss  Loss Monitor 1    Thu Feb 25, 2016 01:00:40
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Apr 12, 2016 01:24:31
y8-lm3.1 FastLoss  Loss Monitor 1    Sun Jun 19, 2016 21:24:33

y9-lm7.1-snk, FastLoss  Loss Monitor 1    Mon Mar 02, 2015 03:
y8-lm3.1 FastLoss  Loss Monitor 1    Mon May 11, 2015 08:28:56
b6-lm3.1 FastLoss  Loss Monitor 1    Thu May 21, 2015 15:20:47
y8-lm3.1 FastLoss  Loss Monitor 1    Thu May 28, 2015 21:24:04
y8-lm2.1 FastLoss  Loss Monitor 2    Mon Jun 01, 2015 04:41:17
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Jun 02, 2015 09:25:35
y8-lm3.1 FastLoss  Loss Monitor 1    Fri Jun 05, 2015 01:50:47

b5-lm3.1 FastLoss  Loss Monitor 1    Tue Mar 18, 2014 09:25:40
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Mar 18, 2014 22:04:55
y7-lm-srt.w FastLoss  Loss Monitor 1    Thu Mar 27, 2014 08:02
b5-lm3.1 FastLoss  Loss Monitor 1    Fri Apr 11, 2014 14:36:19
b5-lm3.1 FastLoss  Loss Monitor 1    Thu May 15, 2014 00:47:29
b5-lm3.1 FastLoss  Loss Monitor 1    Fri May 30, 2014 04:12:26
y6-lm3.1 FastLoss  Loss Monitor 1    Mon Jun 30, 2014 05:39:27

y6-lm3.1 FastLoss  Loss Monitor 1    Sun Mar 03, 2013 05:03:33
b6-lm3.2 FastLoss  Loss Monitor 1    Tue Mar 05, 2013 23:38:01
y6-lm3.1 FastLoss  Loss Monitor 1    Tue Mar 26, 2013 05:24:02
y6-lm3.1 FastLoss  Loss Monitor 1    Wed Mar 27, 2013 07:21:40
b5-lm3.1 FastLoss  Loss Monitor 1    Tue Apr 09, 2013 17:49:49
y7-lm3.1 FastLoss  Loss Monitor 1    Fri Apr 12, 2013 04:49:13
b5-lm3.1 FastLoss  Loss Monitor 1    Fri Apr 19, 2013 01:04:03
y7-lm-srt.w FastLoss  Loss Monitor 1    Sun May 05, 2013 02:27
y8-lm2.1 FastLoss  Loss Monitor 2    Wed May 15, 2013 19:57:46
y7-lm3.1 FastLoss  Loss Monitor 1    Sat May 25, 2013 14:51:39
y7-lm3.1 FastLoss  Loss Monitor 1    Mon Jun 03, 2013 22:37:07
```

Fast Threshold Pulled Permit Cases

For **fast threshold** pulled aborts, mostly from abort kicker **pre-firing** with beams.

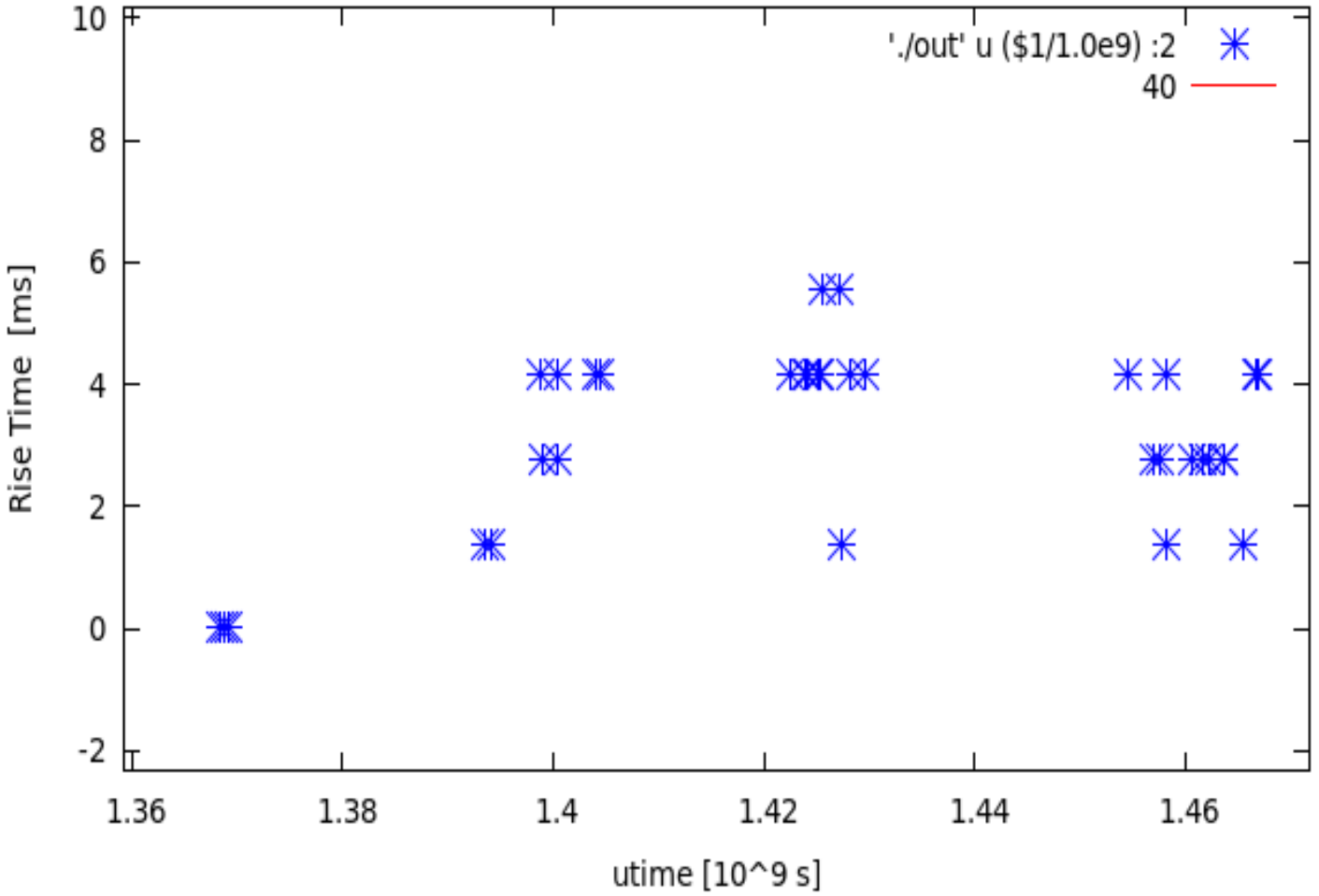
For them, BLM dose rise time about a few ms.

QLI Pulled Permit Cases



Only including aborts from QIL accompanied with BLM reaching slow threshold BLM dose rise time from QLI aborts faster than **a few ms** .

RF Pulled Permit Cases



Only including aborts from RF accompanied with BLM reaching slow threshold . BLM dose rise time from RF aborts is about **a few ms** .

Summary of BLM Data Analysis

1) Permits pulled by slow loss threshold:

- 20%-30% of such beam aborts with dose rise times < 40ms
- Double such beam aborts on ramp than at store
- Can be initiated by beam activities, QLI, RF, and so on

2) Permits pulled by fast loss threshold:

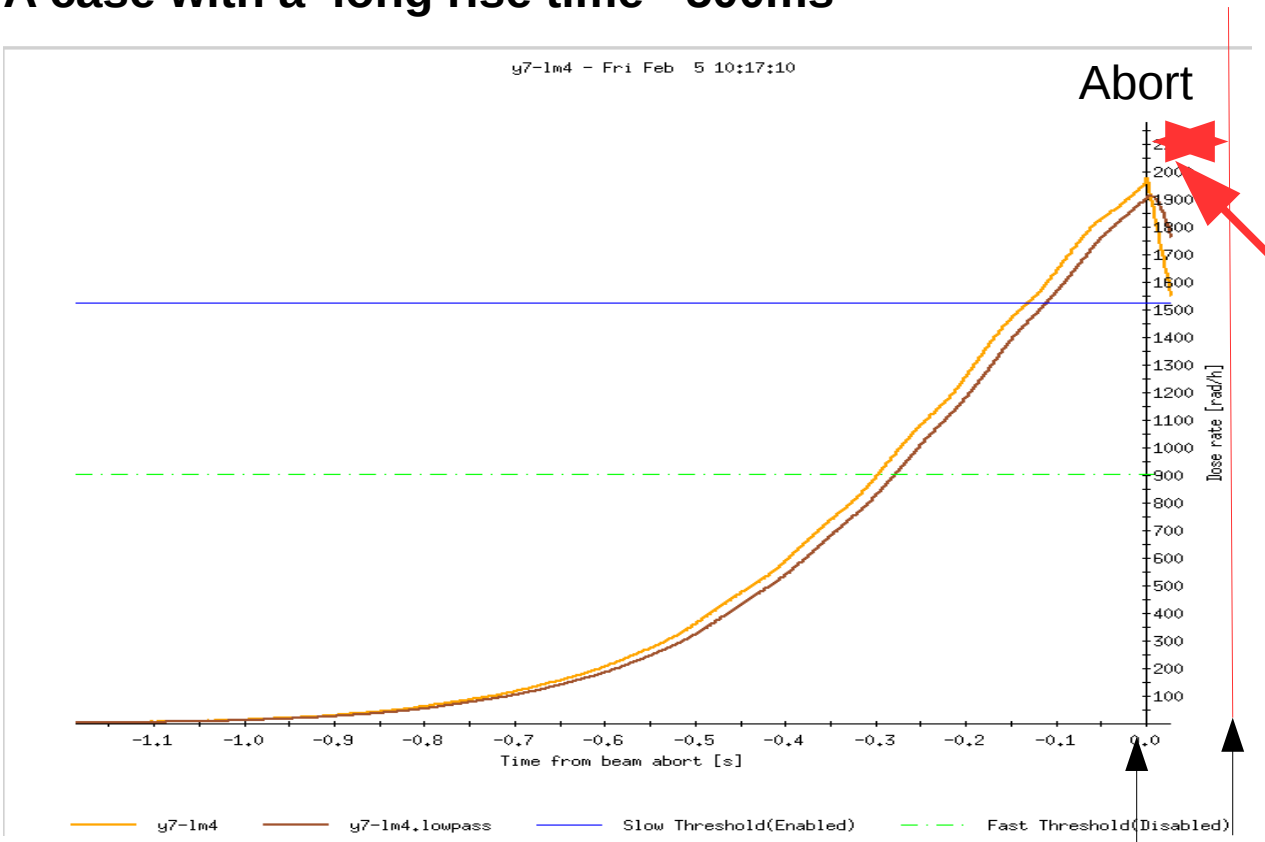
- Most of them are abort kicker pre-firing with beam
- More abort kicker pre-firing at store than on the ramp in 2015/2016

3) Permit was not pulled by BLM:

- BLM signal rise time normally a few ms
- This rise time actually reflects the fastest BLM response time

What 40ms Abort Delay Mean

A case with a long rise time ~500ms



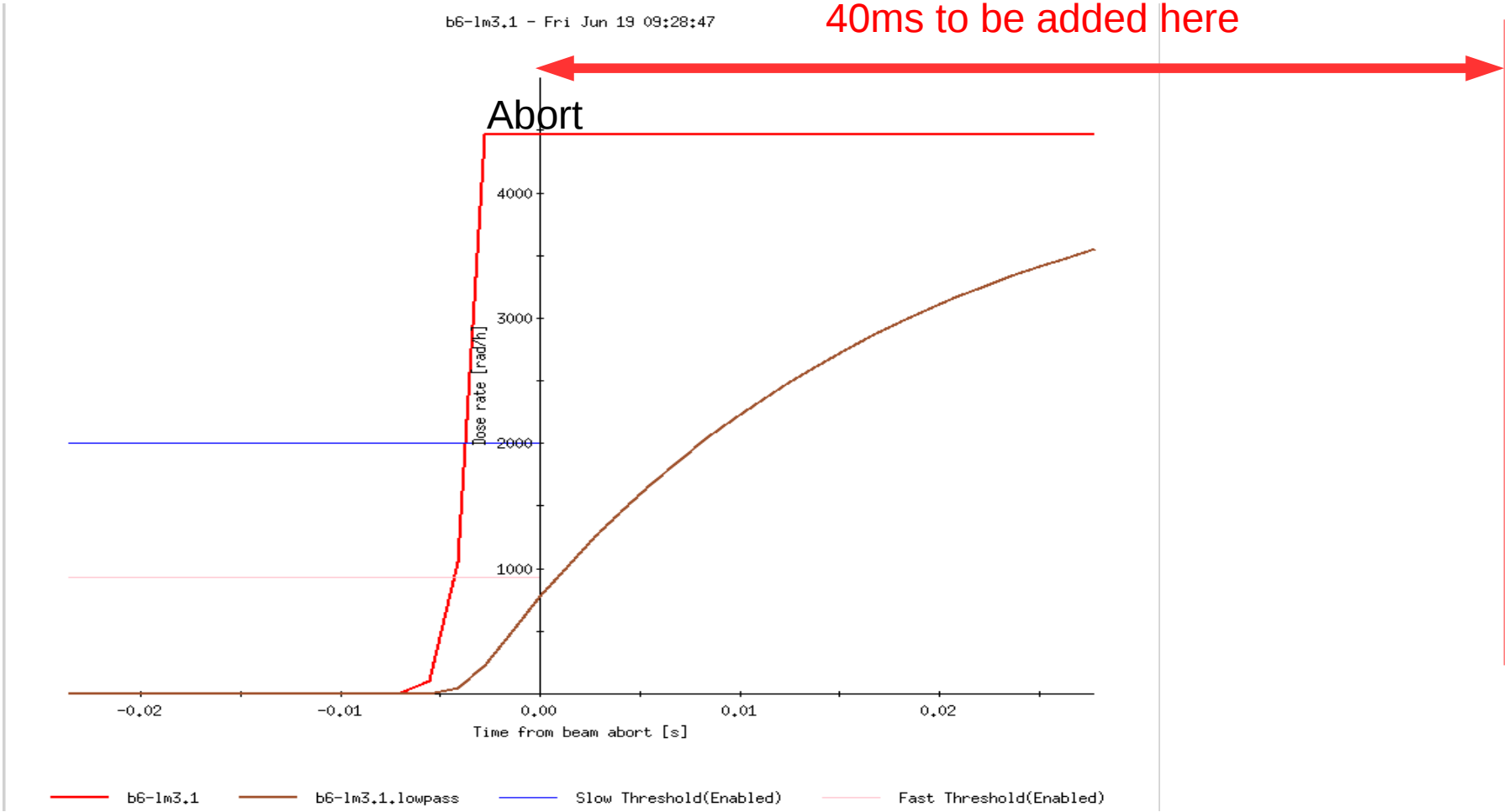
40ms to add with series switch

series switch (40 ms)

Thyratron (< 12.8us)

With thyratron, it takes maximum 12.8 us to actually abort beam.
For series switch, it takes 40 ms to actually abort beam.

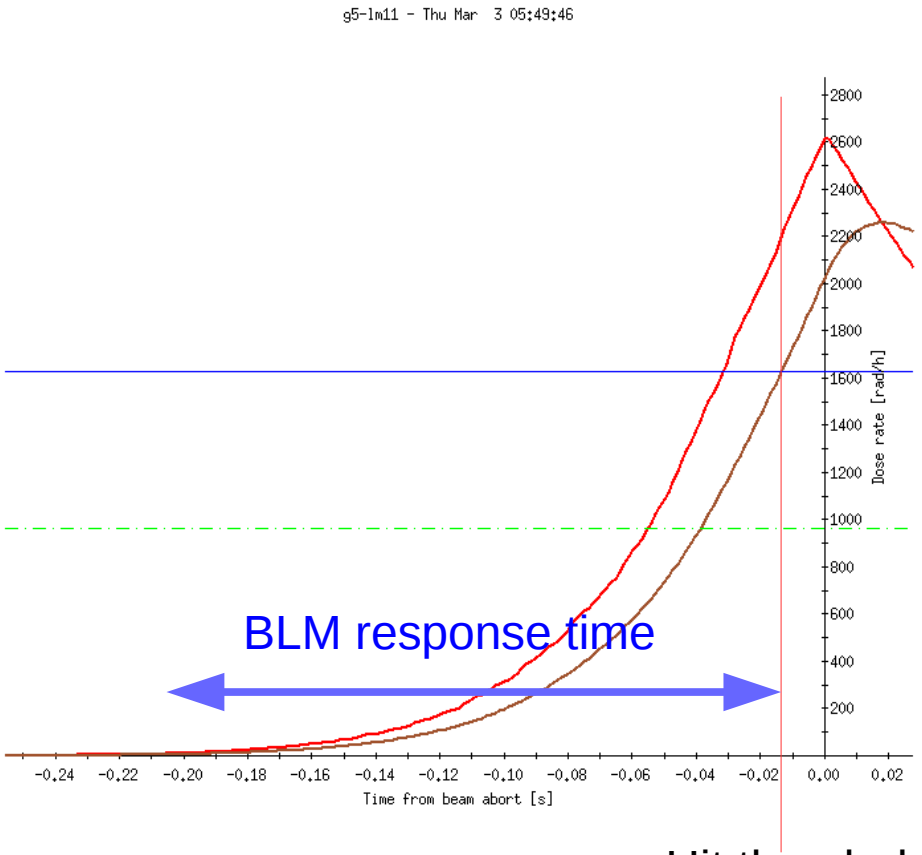
A case with a very short rise time ~ 1.4ms
cause: Blue QLI, may caused by **BS2 tripping** (why not in permit)

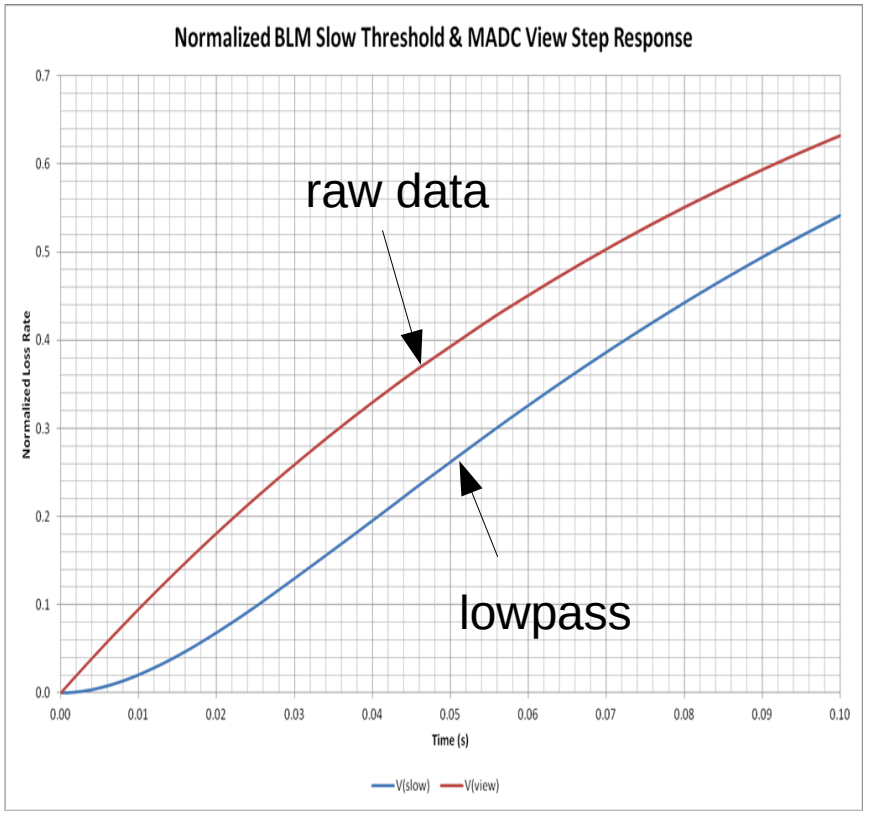


40ms abort delay is too late to intercept the very fast beam loss with dose rise time ~ a few ms.

BLM Response Time

Peter Oddo

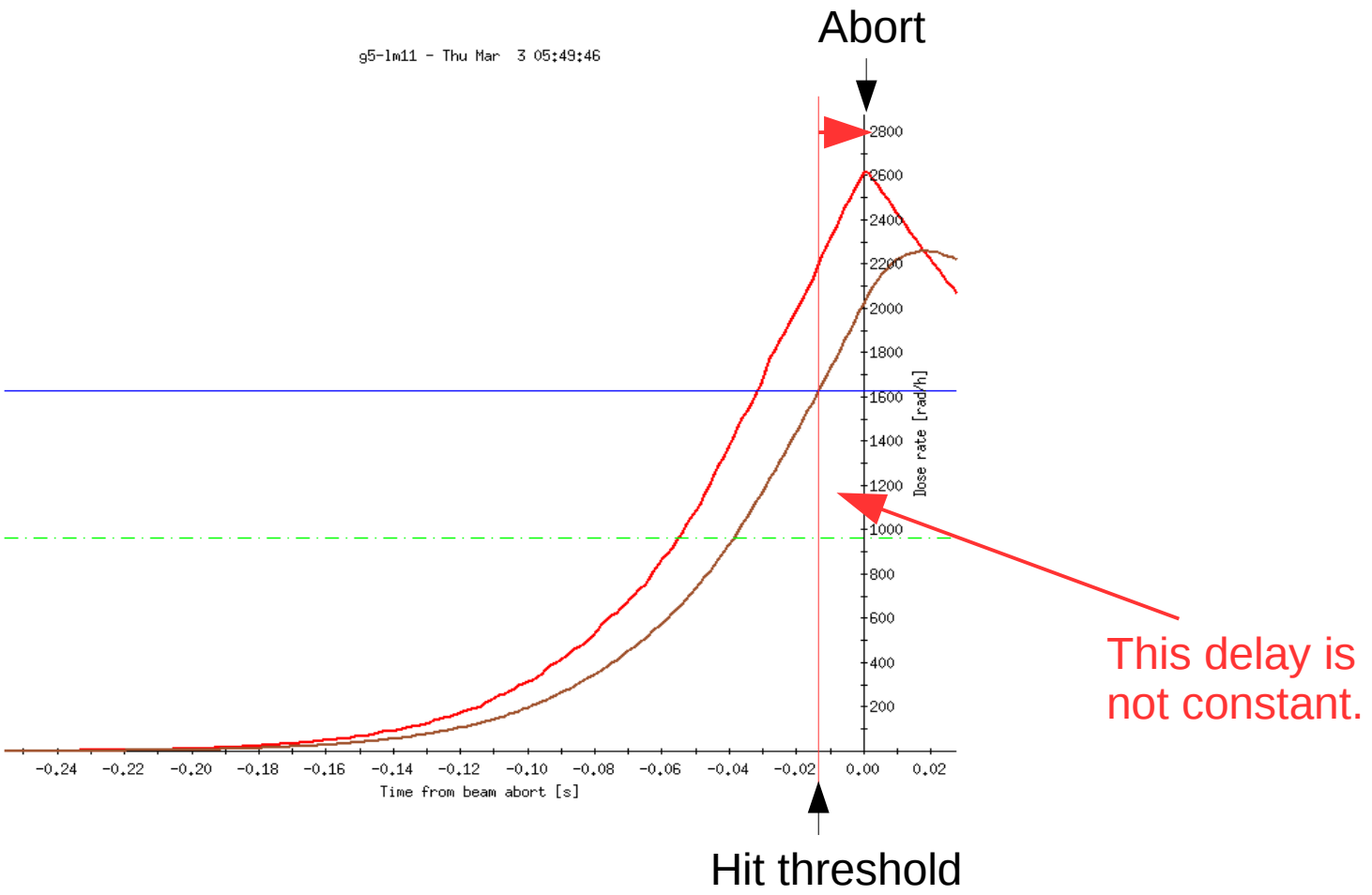




Simulation: For a step input at least 12x greater than the threshold, the system should respond within 23ms. For 5x greater, it will respond within 40ms.

From non-BLM pulled permit, the fastest BLM response time is probably a few ms.

Between 'threshold hit' and Abort



There is a delay between 'hit threshold' and 'abort'. **This delay is not constant, can be 100ms, 40~ms, or a few ms.**
Where does the delay come from ? control software ?

Failure with 40 ms Abort Delay

With series switch, even permit pulled much earlier (say 10% of maximum), there are still 20%-30% cases will hit the slow thresholds before got aborted. Less protection to accelerator, more quenches to be seen, but definitely not many more.

Luckily, beam loss pulled by BLM very differs from pre-firing :

Particles lost in many turns

Beam loss without a certain pattern

Particles spread out along the ring,

Mostly particles will end at collimators, dumps, IRs.

Even particles lost in IR6/8, but not likely with huge dose

Most important is : without abort kicker pre-firing, detectors are much safer. There is no protect bump anymore, diode failure (a major down time) **likely won't happen.**

Radiation Doses w/o 40ms Delay

For slow beam loss with a long dose rise time > 100 ms:

- Radiation dose will not be doubled with 40ms abort delay
- Factor 2 more dose should be acceptable.
- More than half cases with rise time > 100ms.

For very fast beam loss with dose rise time ~ a few ms:

- We saw a few ms delay before actual abort.
- It's late to intercept particles even without 40ms delay.

For slow beam loss with dose rise time ~ 40 ms:

- Big difference in accumulated doses w/o 40ms delay.
- Better to shorten the delay time before abort.

Measures with 40~ms Abort Delay

1) Only use it during physics when detectors are on

Angelika suggested, 100% agree.

- First more abort kicker pre-firing at store than on ramp.
- Secondly detectors only on during store

2) Very tight collimator settings to intercept very fast loss

Different from pre-firing, even very fast beam loss should take dozens of turns and mostly ends at smallest physical aperture.

3) **Shorten BLM response time** (Peter Oddo)

– lower the BLM slow thresholds

– enable fast thresholds

4) For non-BLM permit inputs,

Is it possible to pull permit earlier ? (RF , PS)

5) Shorten delay between 'threshold hit' and 'abort'

(John Morris)

– where is the delay time from ?

– Can we minimize it ?

Summary

We studied all beam aborts in the past 4 years. We found there are 20-30% of 'slow threshold' BLM pulled permit with radiation rise time shorter than 40ms.

Series switch with 40 ms abort delay will be less efficient than the thyratron switch to protect the accelerator elements. However, It eliminates abort kicker prefiring and gives detectors much better protection.

Series switch is suggested to be used during physics when detectors are on. Suggestions are made to shorten the time before abort and to use tight collimation settings to intercept very fast beam loss in dozens of turns.