TLMs at Pbar/Muon
Progress since 12/15/12

Meeting #5

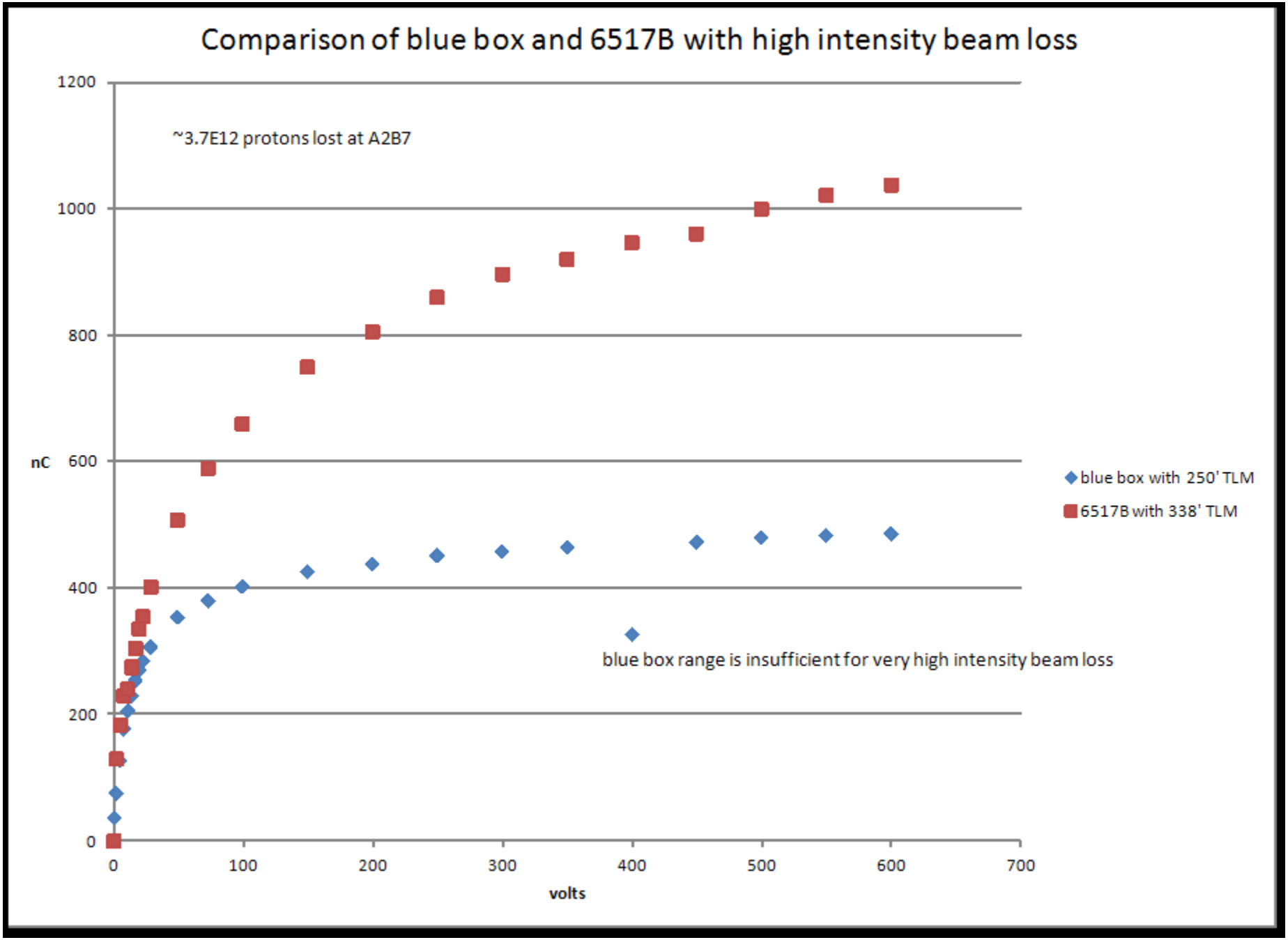
February 10, 2012

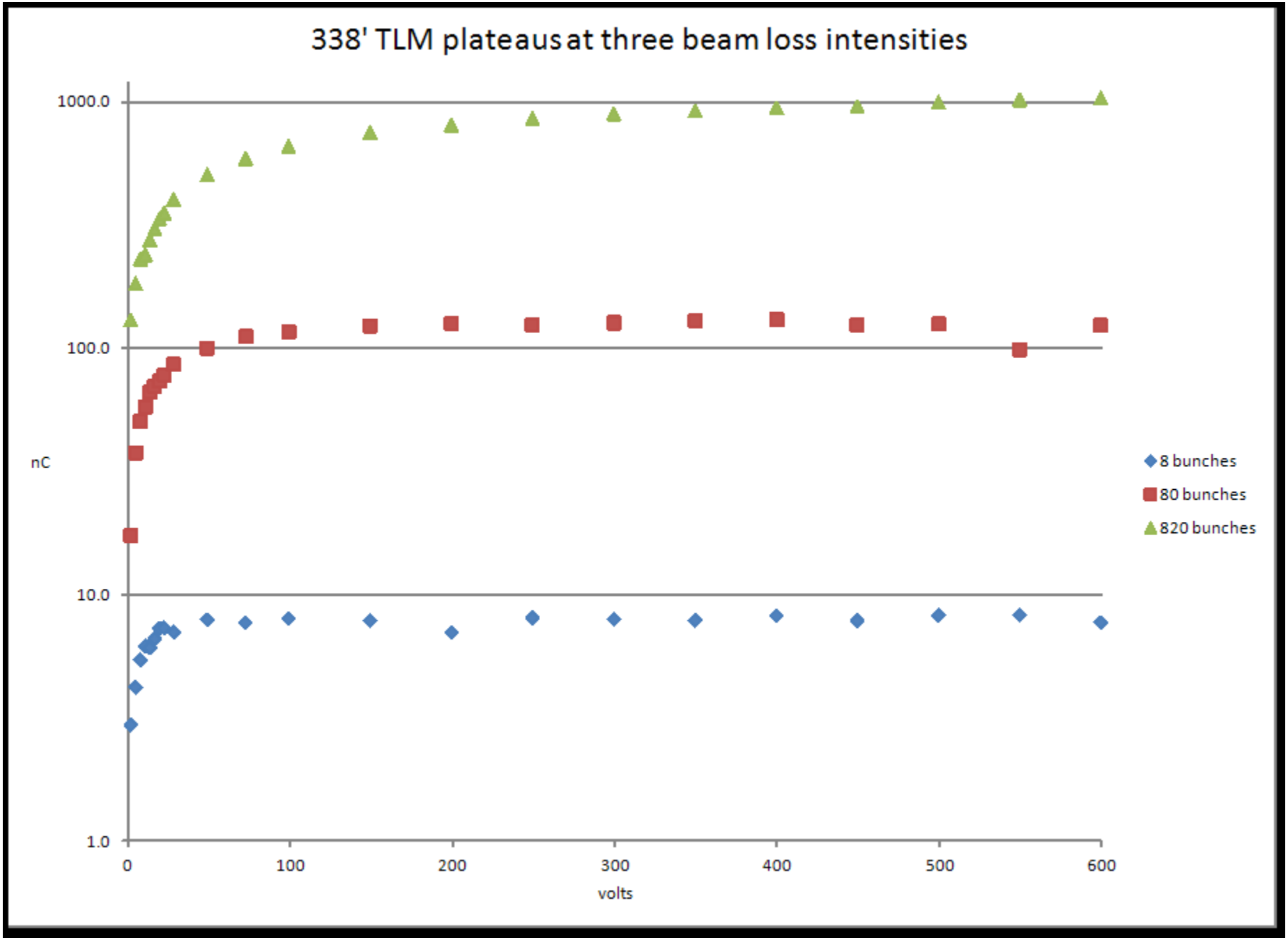
TLMs History at Pbar/Muon (1 of 2)

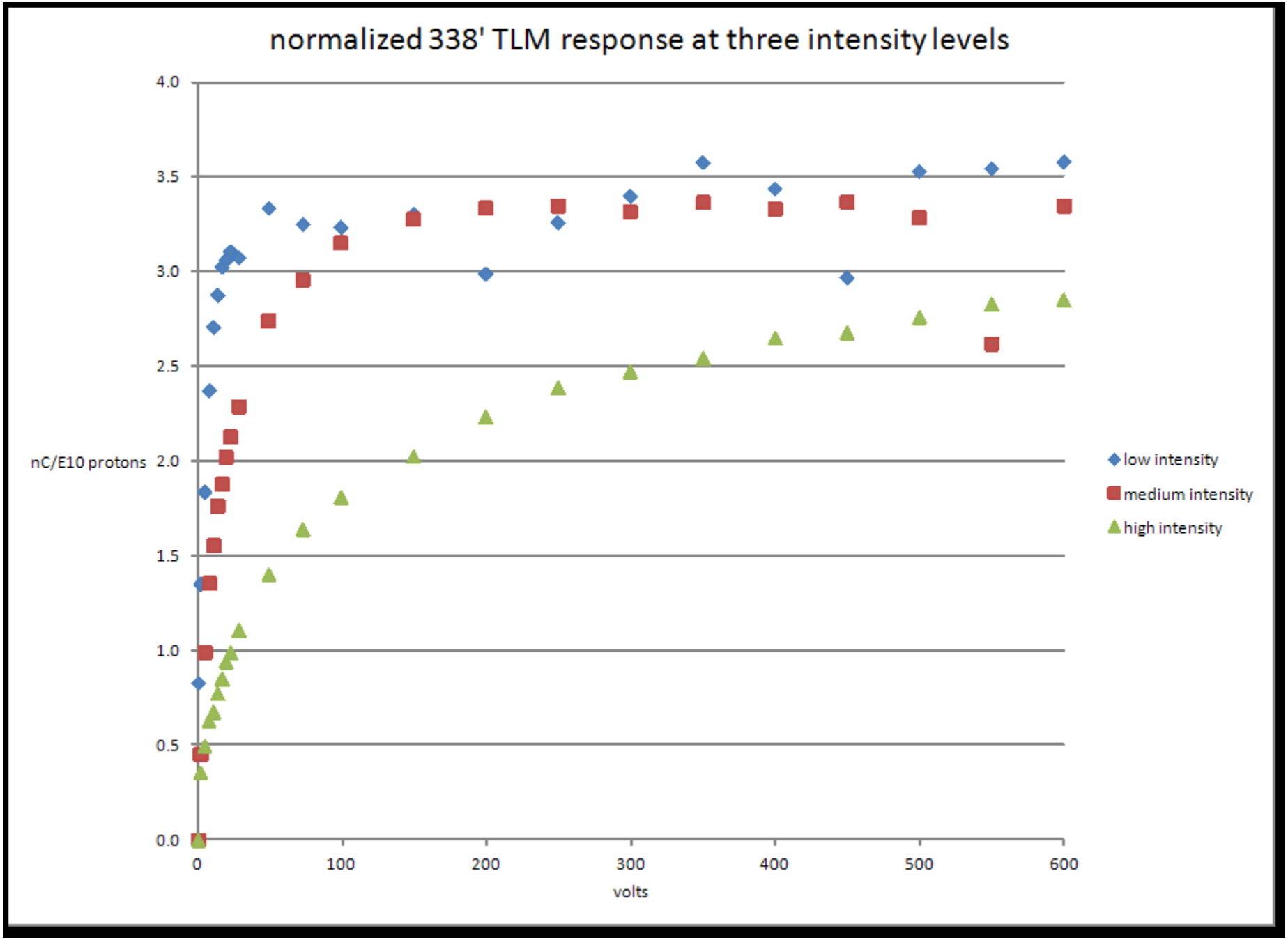
- 5/4/2011 - Director's review for mu2e
- 6/16 - first TLM meeting
- 6/29 - first 2 TLMs installed with 6 decade rate BLM cards
- 7/14 - first TLM signal
- 7/19 – second meeting
- 7/19 – first BLM integration cards installed
- 8/18 - Chipmunk digitizer circuit installed (Blue box)
- 8/25 – third meeting
- 8/26 - Installed 16 bit VME scalar for higher counting rate from blue box (1 kHz)
- 9/1 - Installed third TLM of different length 103 m (338')
- 9/2 - Standardized ACNET TLM responses on all electrometers to nC
- 9/13 – changed to 32 bit VME scalar
- 10/6 – Tried to pressurize TLMs – 6 psig 0.1 lpm
- 10/11 – reverted to unpressurized TLMs – 0.05 lpm
- 10/14 - Meeting with ES&H Section to get turnover for blue box construction
- 10/18 – Strategy for setting trip levels becomes apparent
- 10/26 – installed 1' TLM at A2B7
- 10/31 – begin plateau measurements – suggested by ES&H section
- 10/31 – Established remote operation of TLM HV supply
- 11/18 – sequencer driven data collection for plateaus established
- 11-21 – low and medium intensity plateaus completed
- 11/23 – TOR910 rescaled for high intensity
- 12/8 – Marv provides 6517B electrometer for high intensity plateaus – suggested by ES&H section
- 12/8 – ES&H Section requests charge collection time measurement (TLMS on scope terminated in to 50 Ω)
- 12/15 – 4th meeting

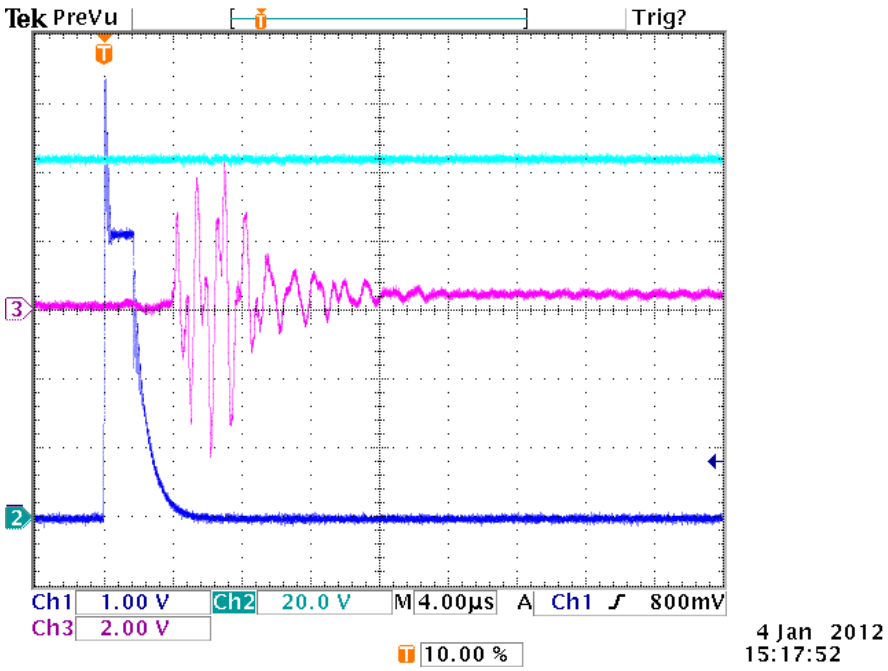
TLMs History at Pbar/Muon (2 of 2)

- 12/15 – 4th meeting
- 12/21 – Started data collection for high intensity plateaus with 6517B
- 1/3/12 – nonlinear response of TLMs at high intensity becomes a concern
- 1/5/12 – observed HV sag for high intensity pulses
- 1/5- measured TLM response with scope terminated into 50 ohms
- 1/6- added in line capacitance to HV supply to reduce HV sag
- 1/9- Started making measurements with 6517B in voltage mode using capacitor voltage divider circuit
- 2/1 – Finished draft of TLM dynamic range requirements document
- 2/10 – 5th meeting

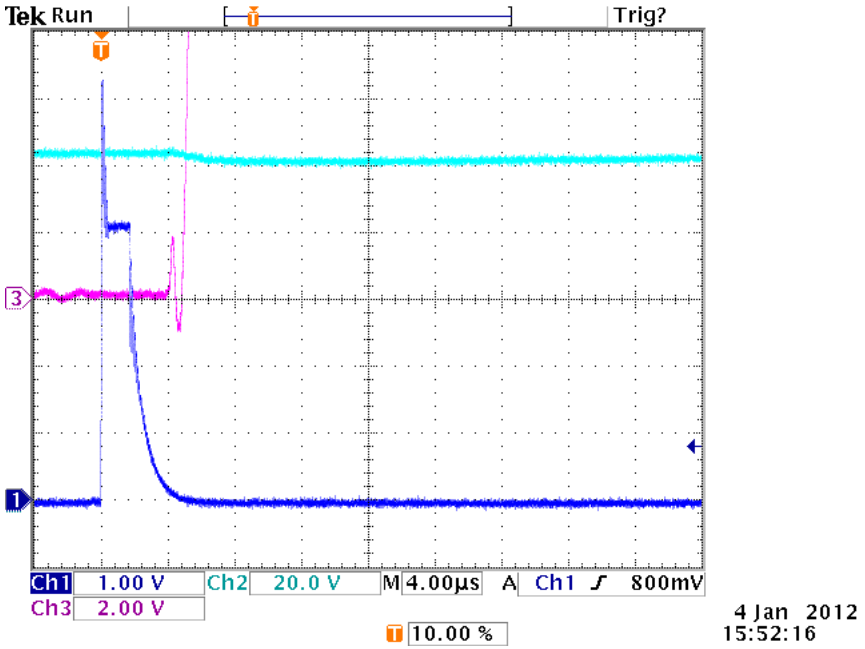

Comparison of blue box and 6517B with high intensity beam loss
~3.7E12 protons lost at A2B7
blue box range is insufficient for very high intensity beam loss
blue box with 250' TLM
6517B with 338' TLM
nC
volts
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700


338' TLM plateaus at three beam loss intensities
1000.0
100.0
10.0
1.0
nC
0
100
200
300
400
500
600
volts
8 bunches
80 bunches
820 bunches


normalized 338' TLM response at three intensity levels
nC/E10 protons
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
volts
low intensity
medium intensity
high intensity

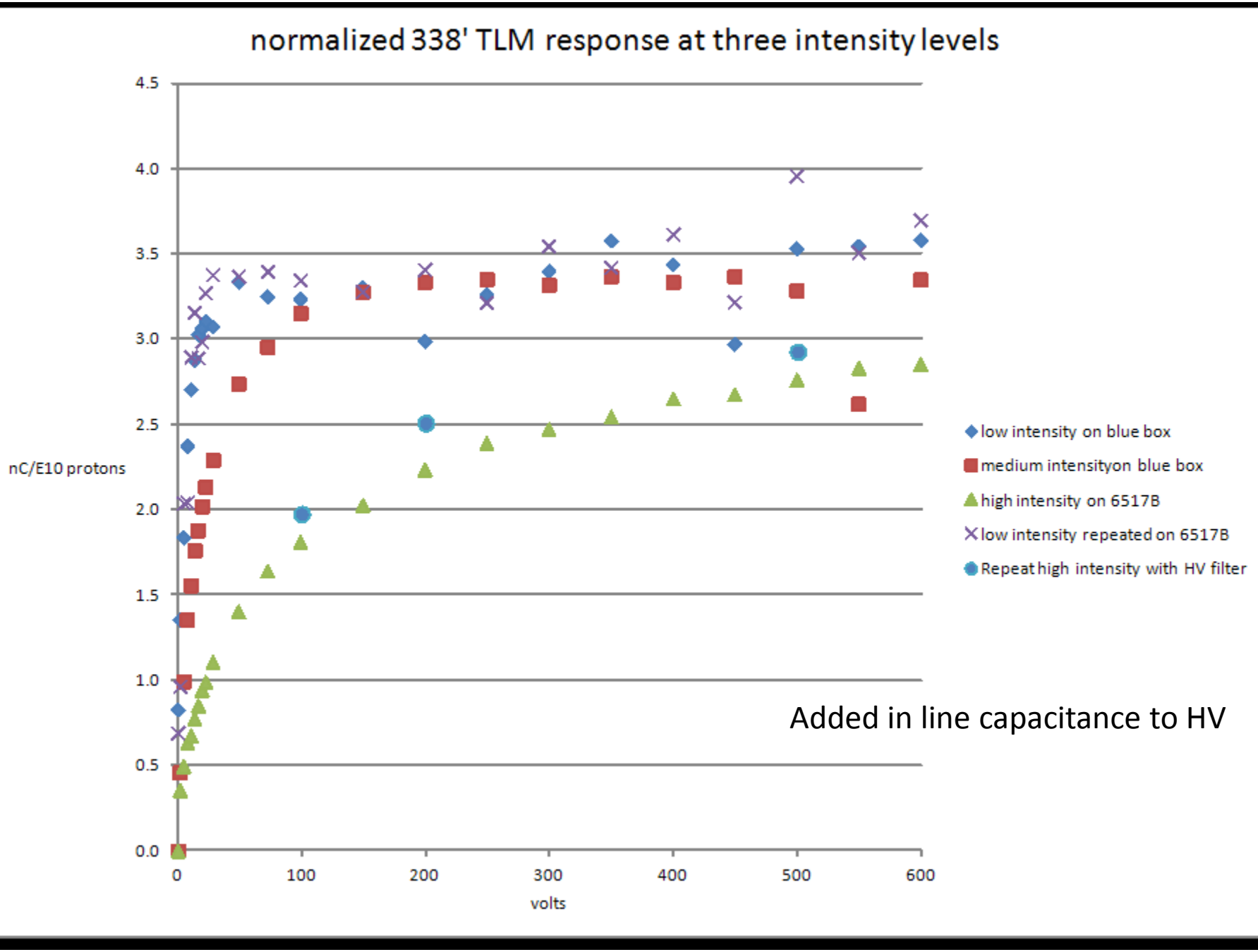


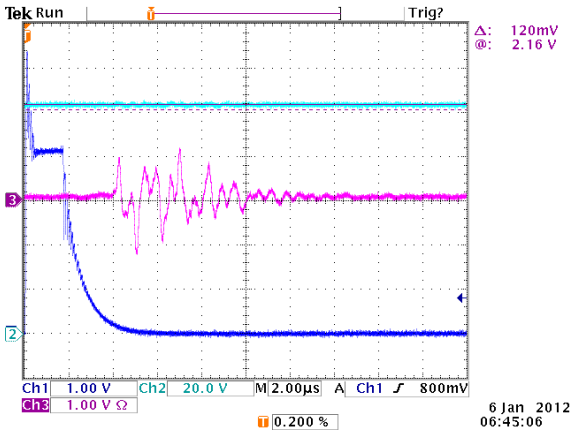
3.1E10 protons

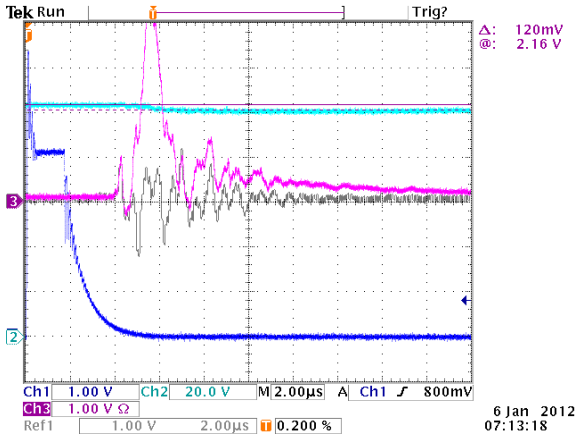


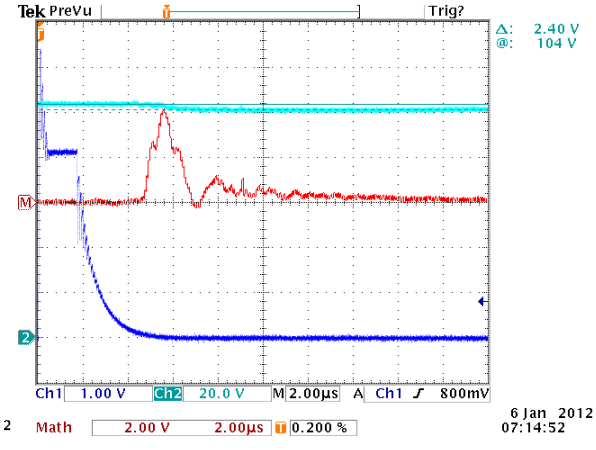
3.35E12 protons

Scope terminated into 1 Mohm

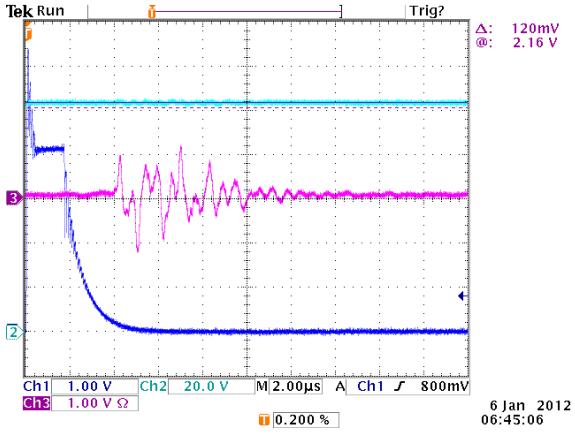

normalized 338' TLM response at three intensity levels
nC/E10 protons
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
volts
low intensity on blue box
medium intensityon blue box
high intensity on 6517B
low intensity repeated on 6517B
Repeat high intensity with HV filter
Added in line capacitance to HV

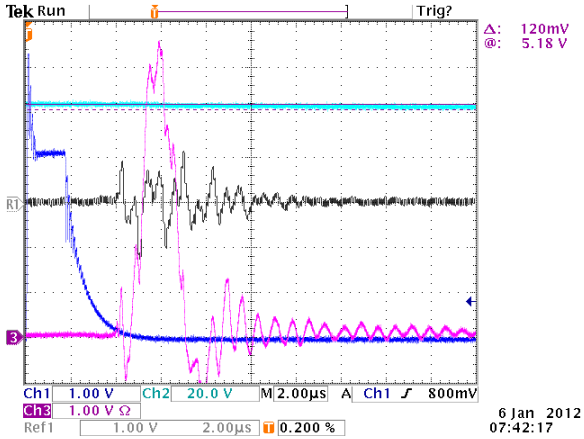


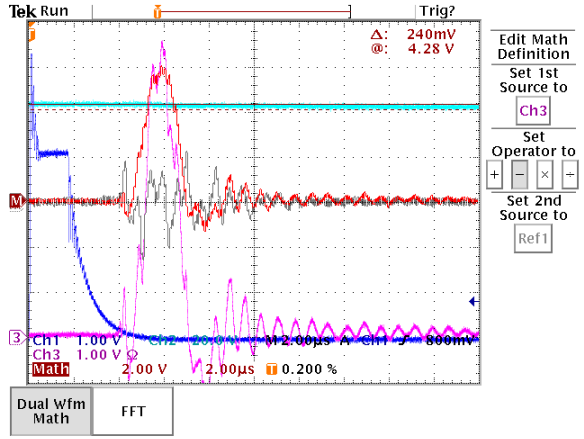




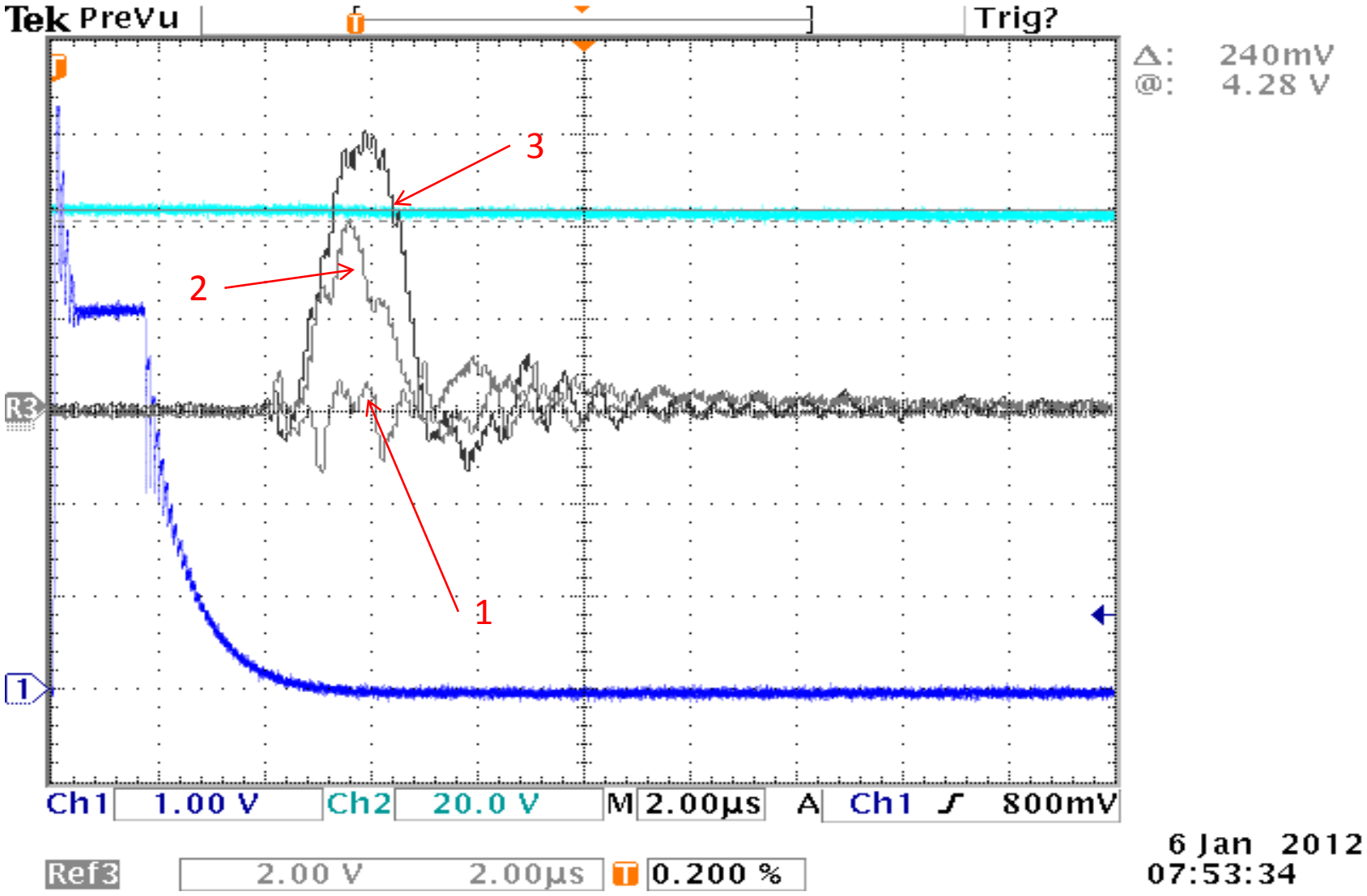
without inline HV capacitance







with inline HV capacitance



Three traces: 1- background, 2 – without HV cap, 3 – with HV cap

Compared Scope measurement with 6517B for similar beam loss

- With TLM HV at 100 volts
  - Scope with no HV filter – 155 nC
  - Scope with HV filter – 145 nC
  - With 6517B – 660 nC

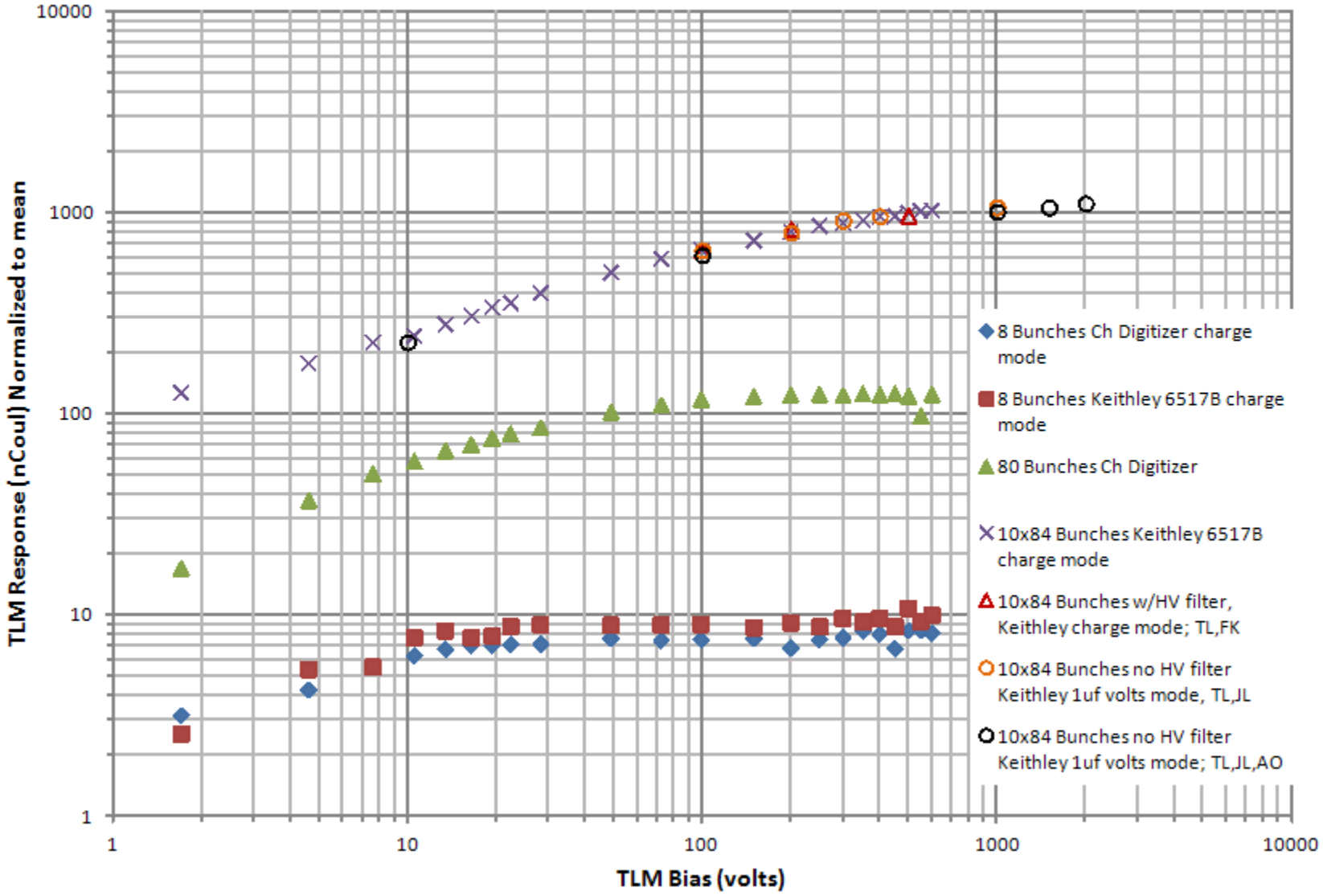
- Scope technique didn’t work

Continued high intensity plateau measurements

- Used capacitor voltage divider and 6517B in voltage mode
- Results are similar to direct charge measurements with 6517B
- Did a few additional points at higher voltages, up to 2000 volts

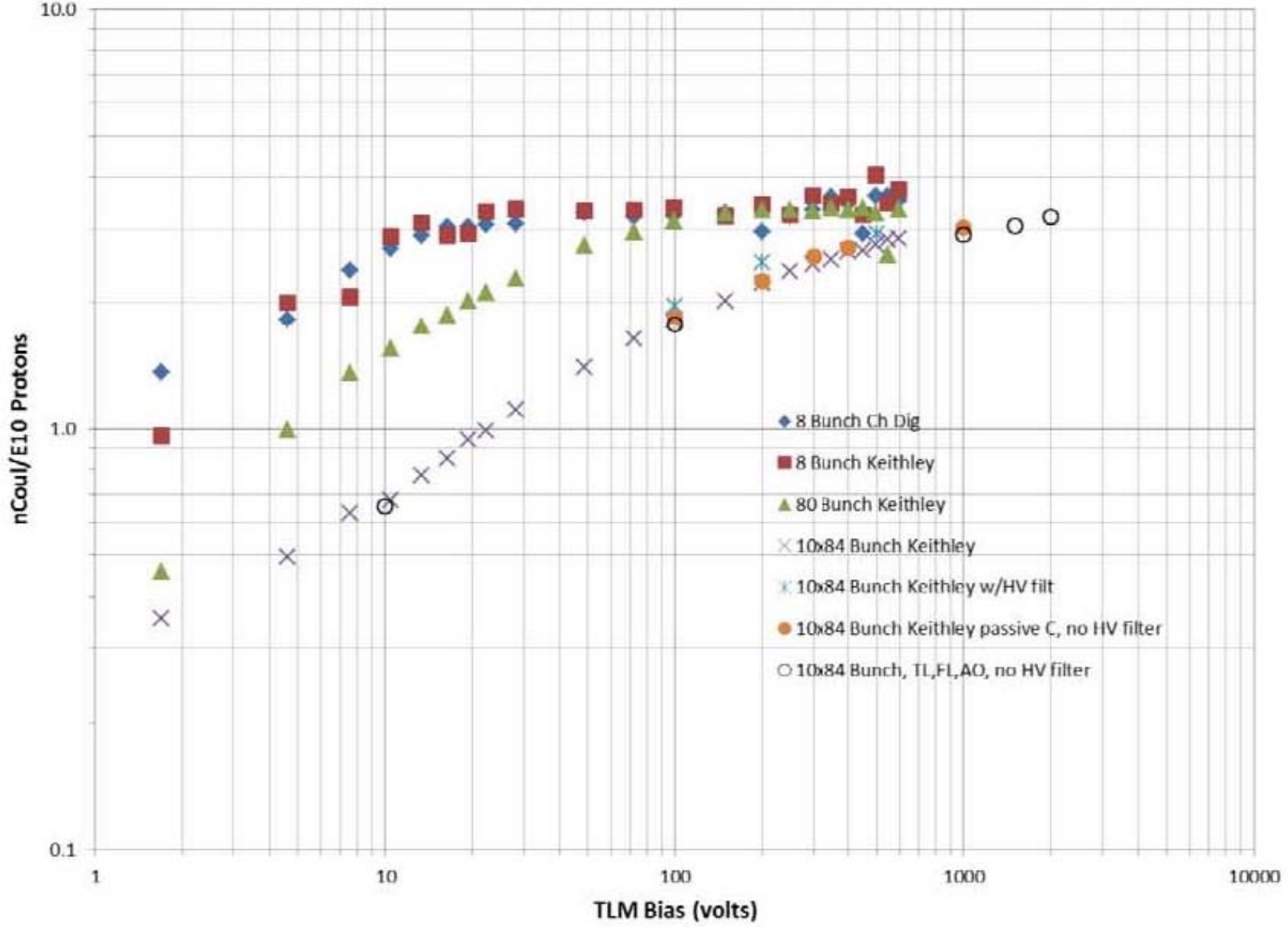
338' TLM Plateau Series; Data from:

T. Leveling; J. Larson; F. Krueger; A. Olson, 1/13/2012.



Normalized 338' TLM at 3 Intensity Levels

Data from T. Leveling, F. Krueger and J. Larson; 1/11/2012, fk.



TLM use at the intensity Frontier

- Clearly, beam intensity could be high enough to saturate TLMs
- All measurements to date at 8 GeV
- Response of TLM at 120 GeV expected to be:

$(E_{120}/E_8)^{0.8}$ X 3.2nC/E10 protons = 28nC/E10 protons

Dynamic Range

- A key question
- Draft document has been written
- Tentatively, 1 uC/beam pulse looks like a reasonable target

8 GeV TLM response constant	TLM baseline energy	Energy scalling factor		Baseline TLM distance to beam center
3.2 nC/E10	8 GeV	0.8		5.5 feet

Machine/Condition	Note	Beam power (KW)	Energy (GeV)	Protons per hour	Average intensity per second	Nominal Shielding feet	Magnet to ceiling distance	Shield Category or application basis	beam loss limit (p/s)	normal loss limit p/s	% of beam loss	nC/min **(per meter in bold)**
Mu2e Service Bldg.	1	4	8	1.13E+16	3.13E+12	10	5.5	skyshine	3.3 watts	2.58E+09	0.082%	50
Mu2e Service Bldg.	1	8	8	2.25E+16	6.25E+12	10	5.5	skyshine	3.3 watts	2.58E+09	0.041%	50
Mu2e Shielding Berm	2	4	8	1.13E+16	3.13E+12	13	5.5	1A	3.26E+10	1.63E+09	0.052%	31
Mu2e Shielding Berm	2	8	8	2.25E+16	6.25E+12	13	5.5	1A	3.26E+10	1.63E+09	0.026%	31
Booster May 2013	5	64	8	1.80E+17	5.00E+13	14	4	2A	2.20E+11	1.10E+10	0.022%	399
Booster 2016	5	80	8	2.25E+17	6.25E+13	14	4	2A	2.20E+11	1.10E+10	0.018%	399
Booster (any pwr)	3		8			14	4	1 W/m	NA	4.69E+10		1,701
Main Injector	2	700	120	1.31E+17	3.65E+13	24	5	1A	2.61E+13	1.31E+12	3.582%	265,094
Main Injector	2	2,300	120	4.31E+17	1.20E+14	24	5	1A	2.61E+13	1.31E+12	1.090%	265,094
Main Injector	3	700	120	1.31E+17	3.65E+13	24	5	1 W/m	NA	1.82E+11	0.499%	36,960
Main Injector	3	2,300	120	4.31E+17	1.20E+14	24	5	1 W/m	NA	1.82E+11	0.152%	36,960
Nova	2	700	120	1.31E+17	3.65E+13	26	3	1A	4.87E+13	2.44E+12	6.675%	1,372,243
LBNE	2	2,300	120	4.31E+17	1.20E+14	26	3	1A	4.87E+13	2.44E+12	2.030%	1,372,243
Nova	4	700	120	1.31E+17	3.65E+13	26	3	10 ppm	NA	3.65E+08	0.001%	206
LBNE	4	2,300	120	4.31E+17	1.20E+14	26	3	1 W/m	NA	**5.21E+07**	0.000%	**29**

Notes:

1 Distributed or concentrated loss limits public exposure to 1 mrem per year

2 Single point loss limits berm surface normal condition dose rate to 0.05 mrem/hr

3 Total charge limit in tunnel beam loss to 1 W/m - distributed among some number of TLMs

4 Limit total beam loss to 1 part in 1E5

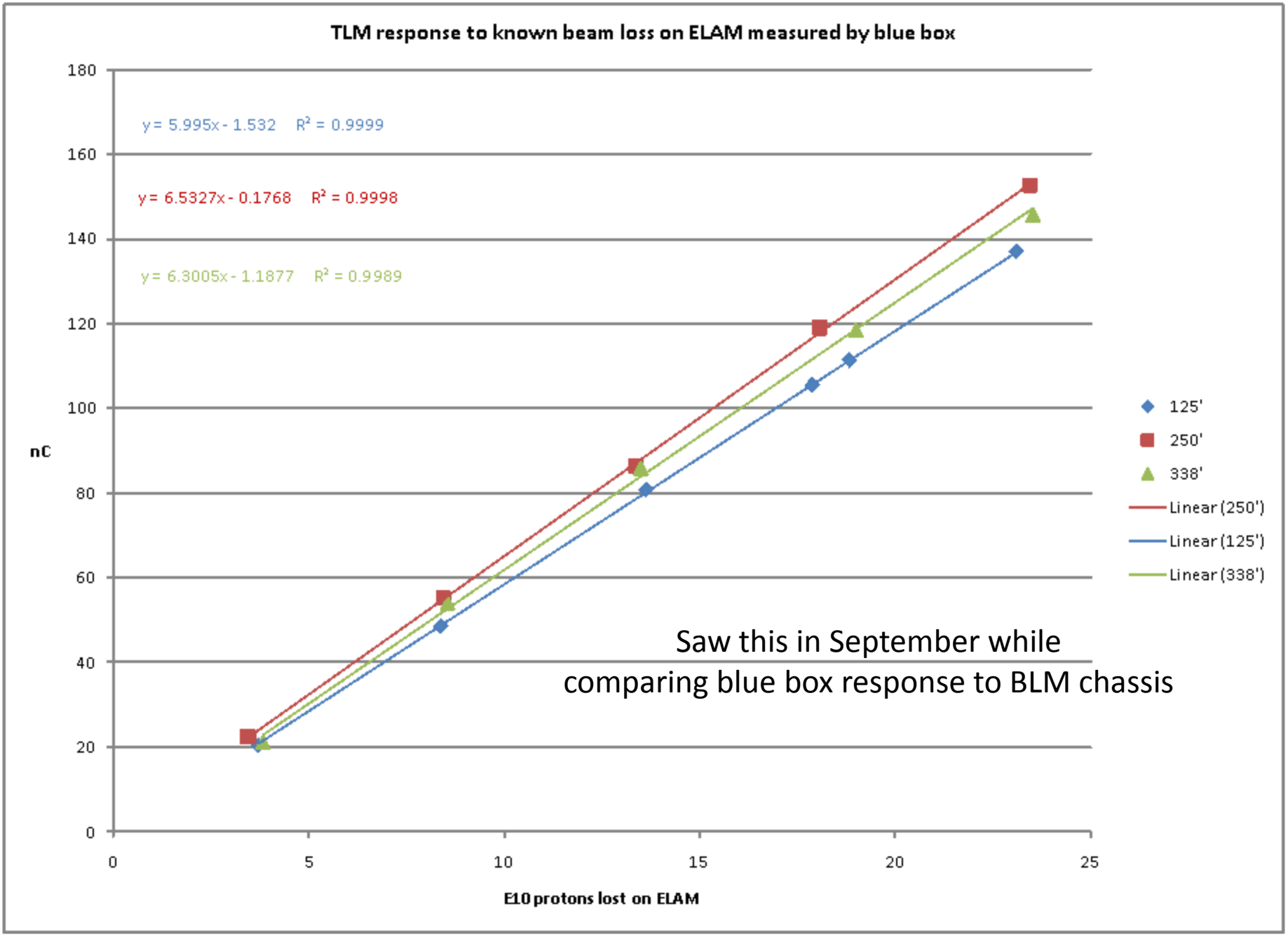
5 Single point loss limits berm surface normal condition dose rate to 5 mrem/hr

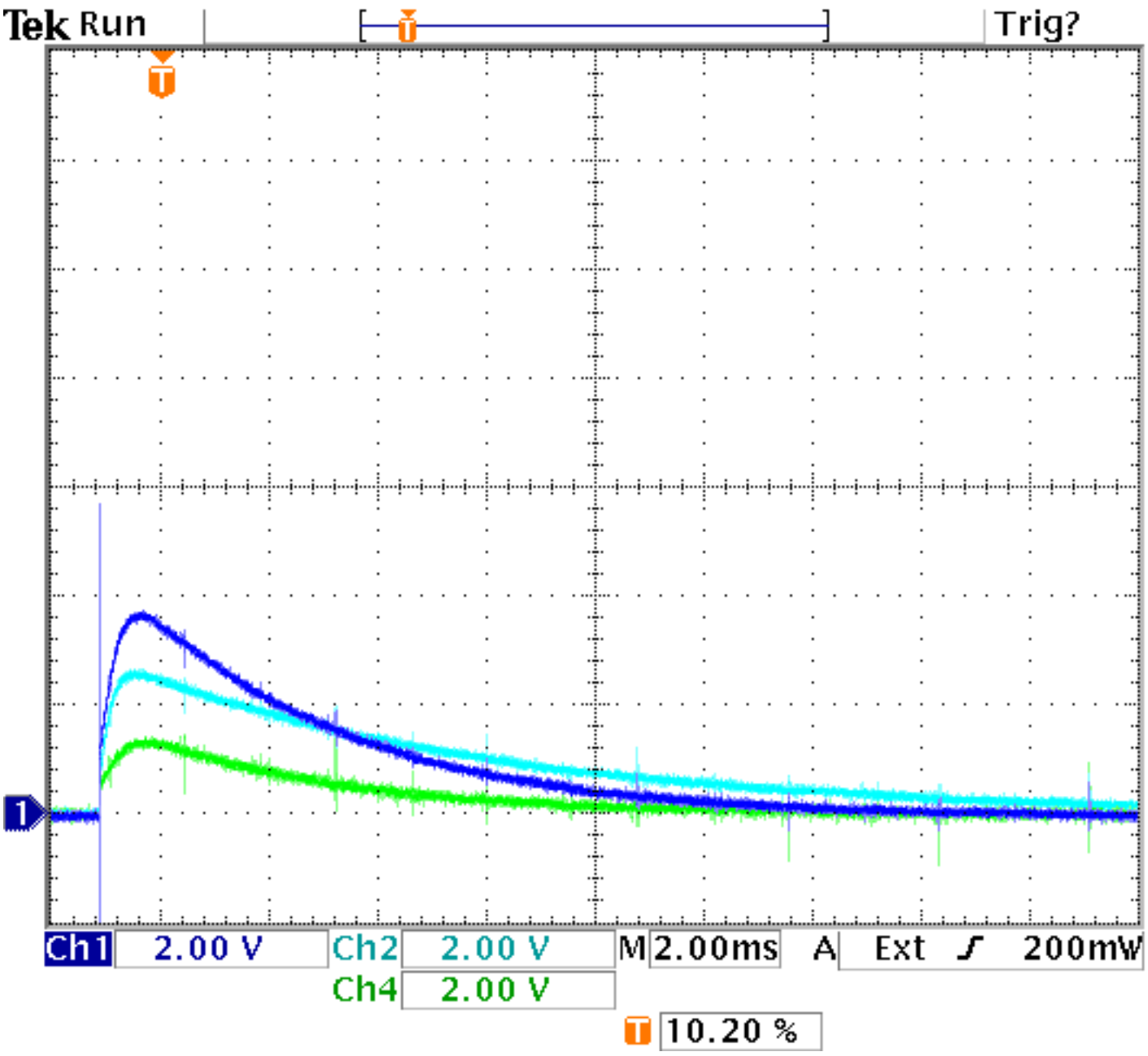
Not recommended

What's next

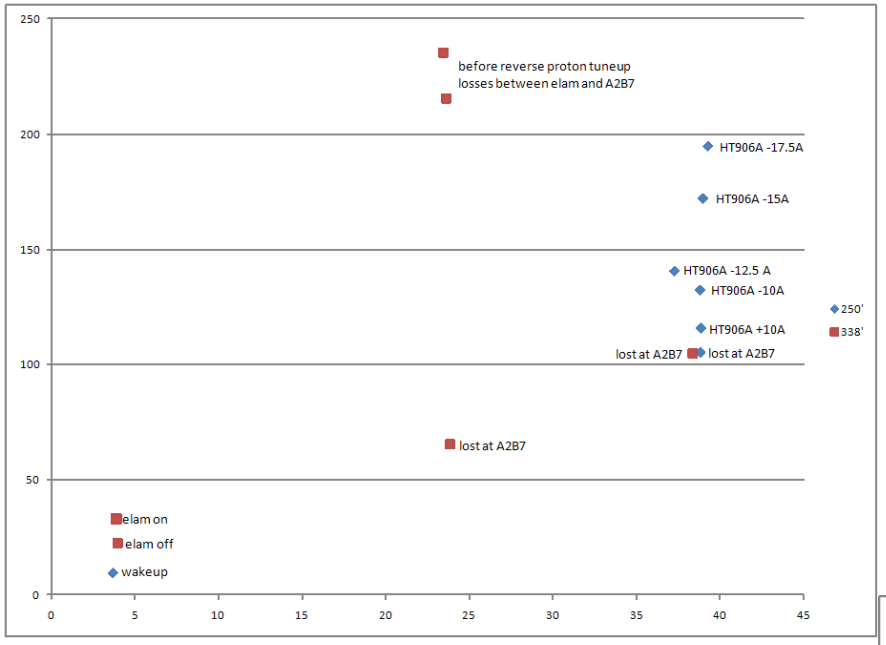
- High intensity plateaus for 250' and 125' TLMs
  - With the beam loss at A2B7
  - Compare with 338' high intensity response
  - Fewer points required
  - Requires moving 125' downstream about 50 feet
- Continue discussion with ES&H regarding dynamic range requirements
- Check a long detector response uniformly irradiated
  - E.g., coil up 125' at A2B7
  - Or find a short (10') piece from RF dept.

Backup slides


TLM response to known beam loss on ELAM measured by blue box
y = 5.995x - 1.532 R² = 0.9999
y = 6.5327x - 0.1768 R² = 0.9998
y = 6.3005x - 1.1877 R² = 0.9989
nC
E10 protons lost on ELAM
125'
250'
338'
Linear (250')
Linear (125')
Linear (338')
Saw this in September while
comparing blue box response to BLM chassis

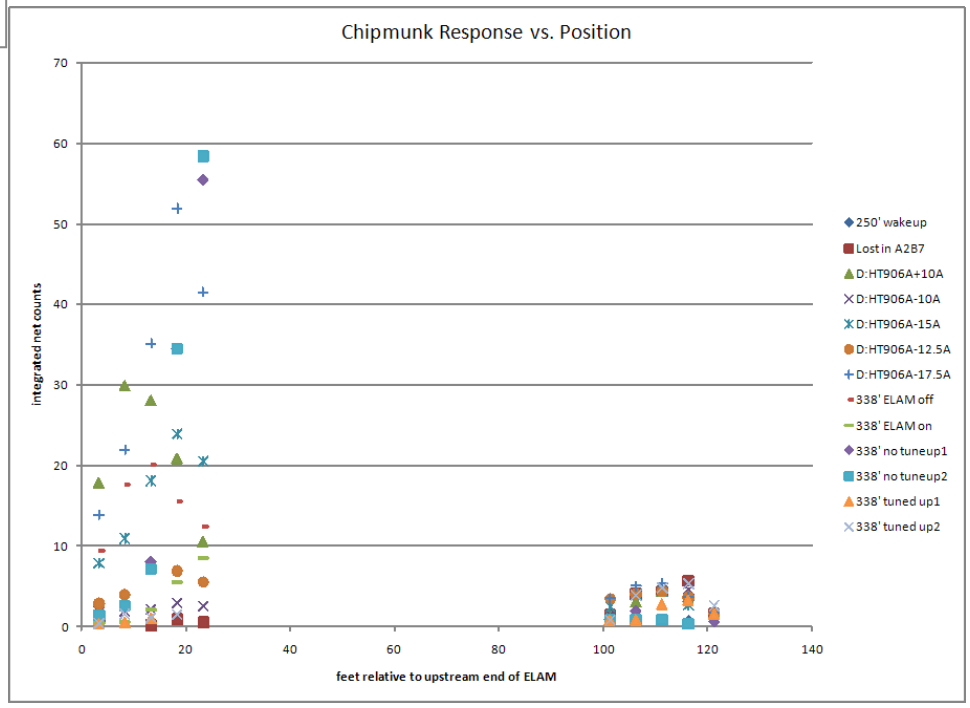


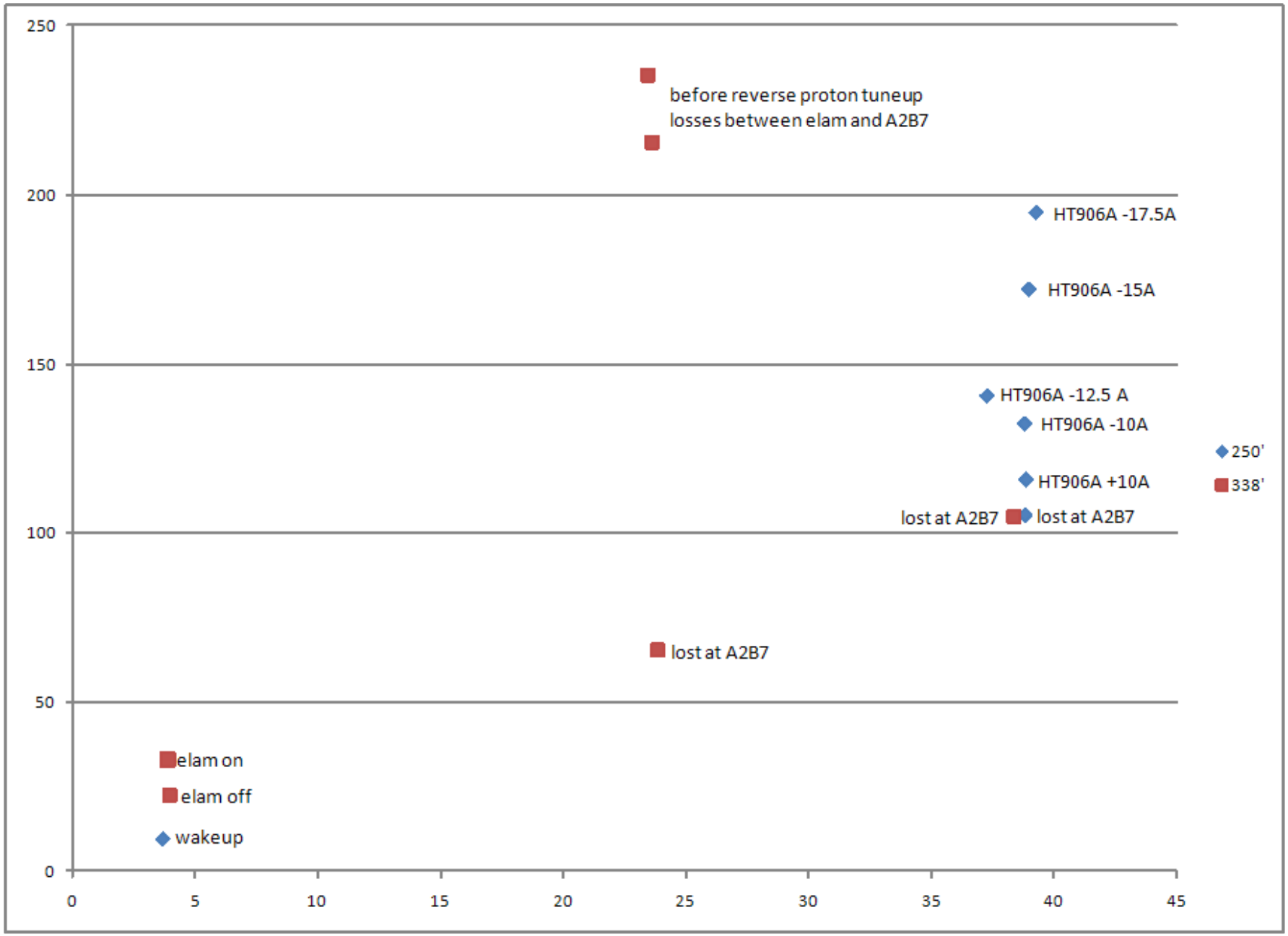
Ch1 – 125’
Ch2 – 250’
Ch4 – 338’

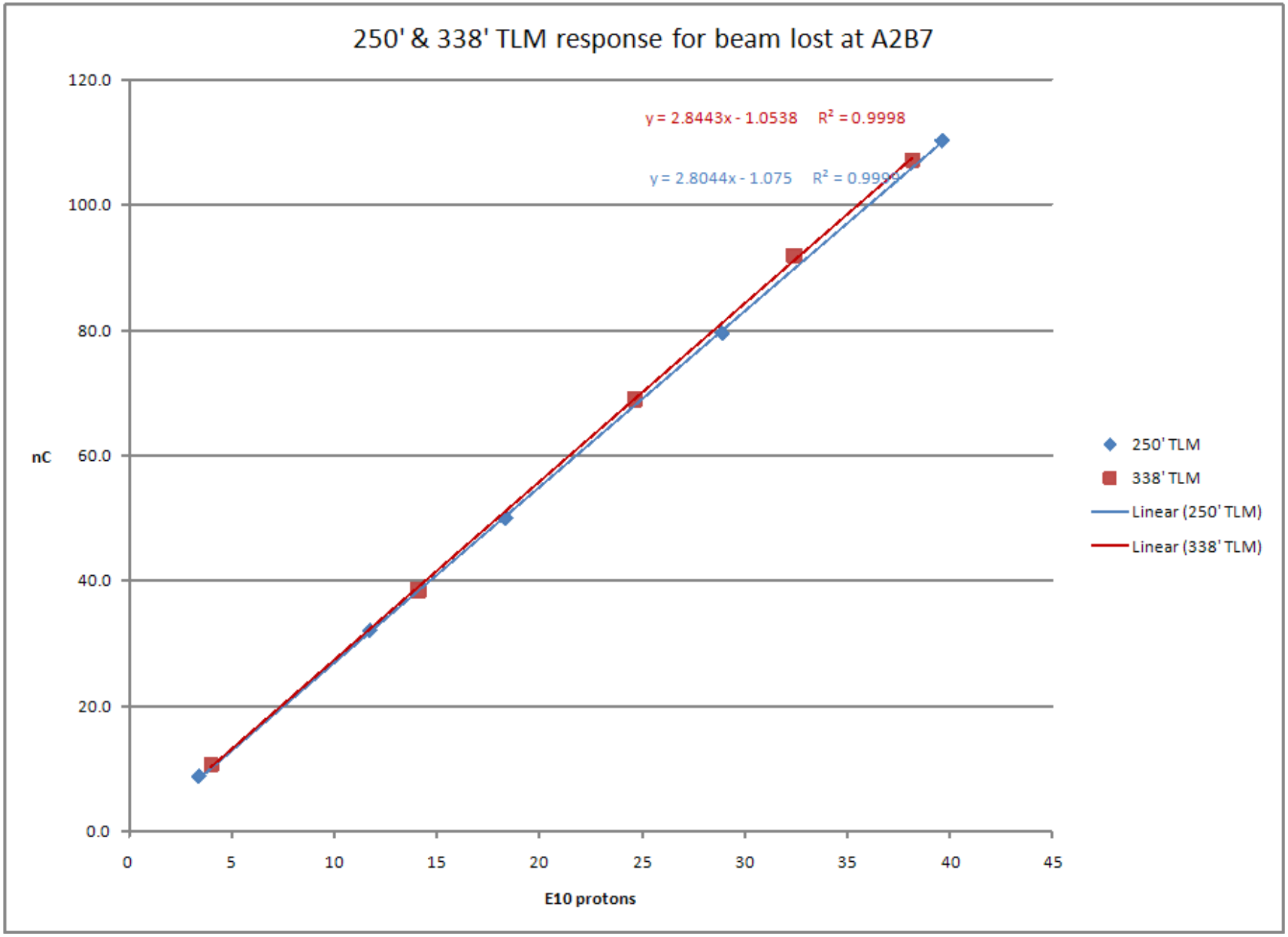


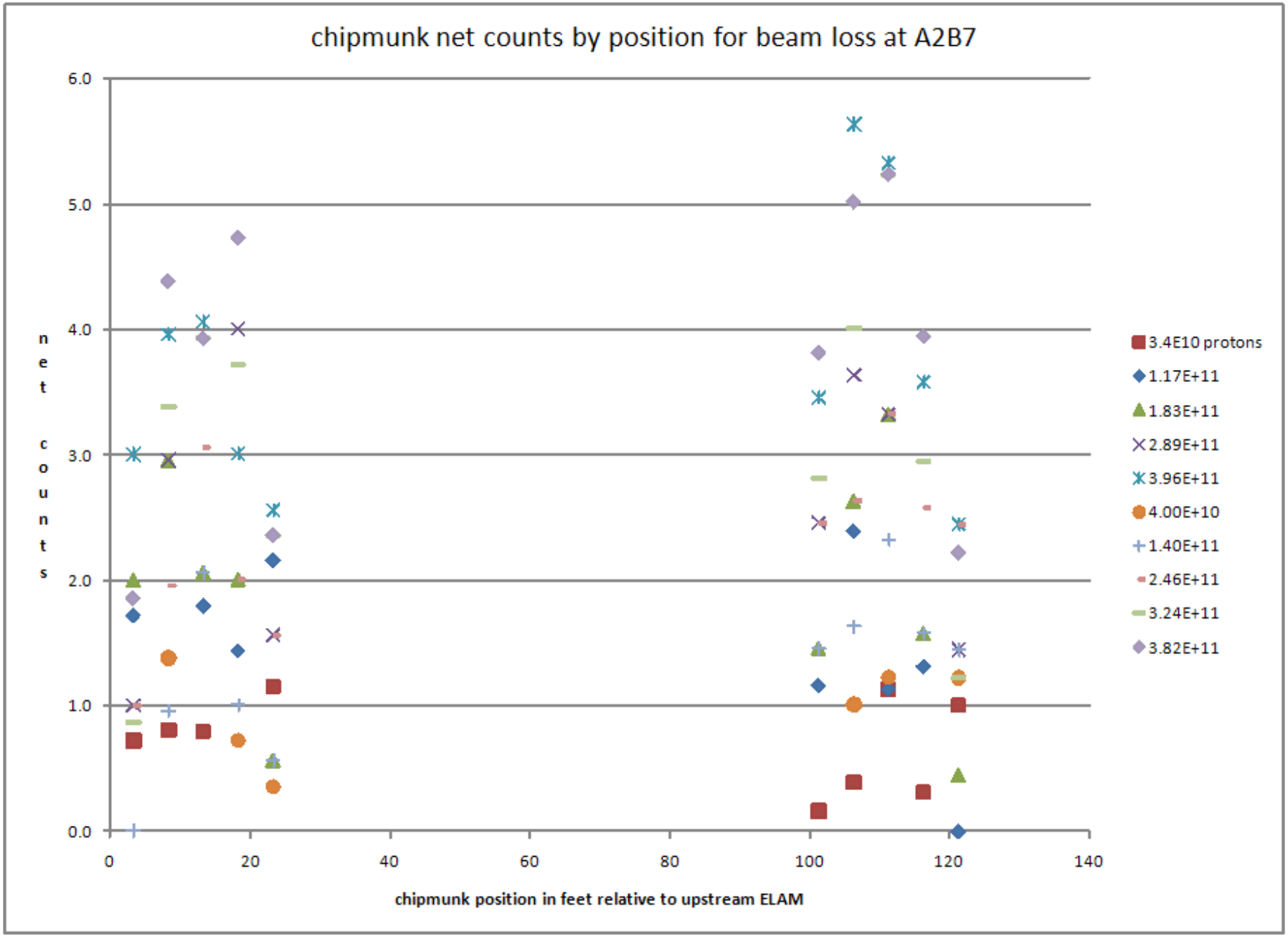
TLM response varies
with different loss mechanisms

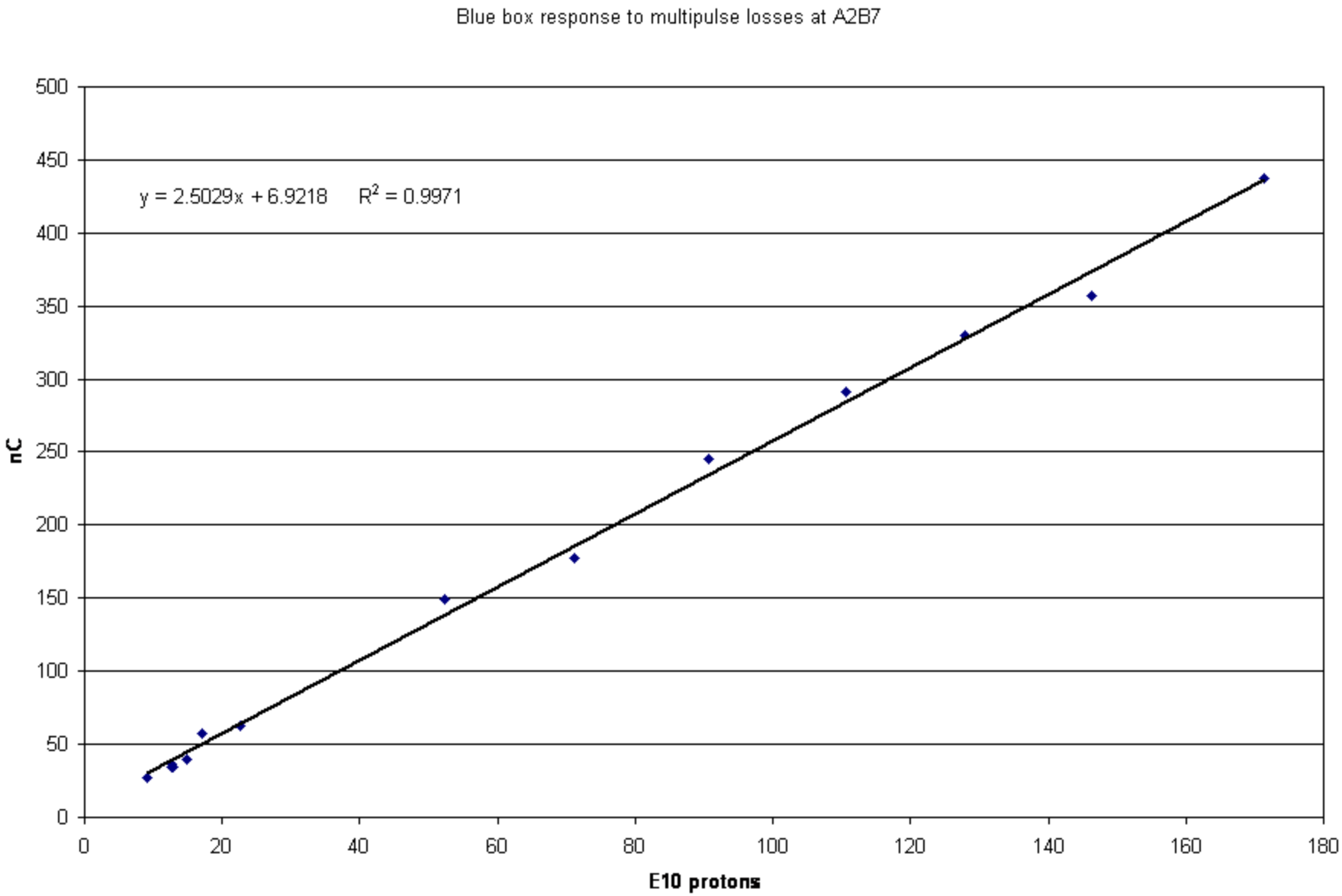
Use the most conservative condition
to establish safety system trip

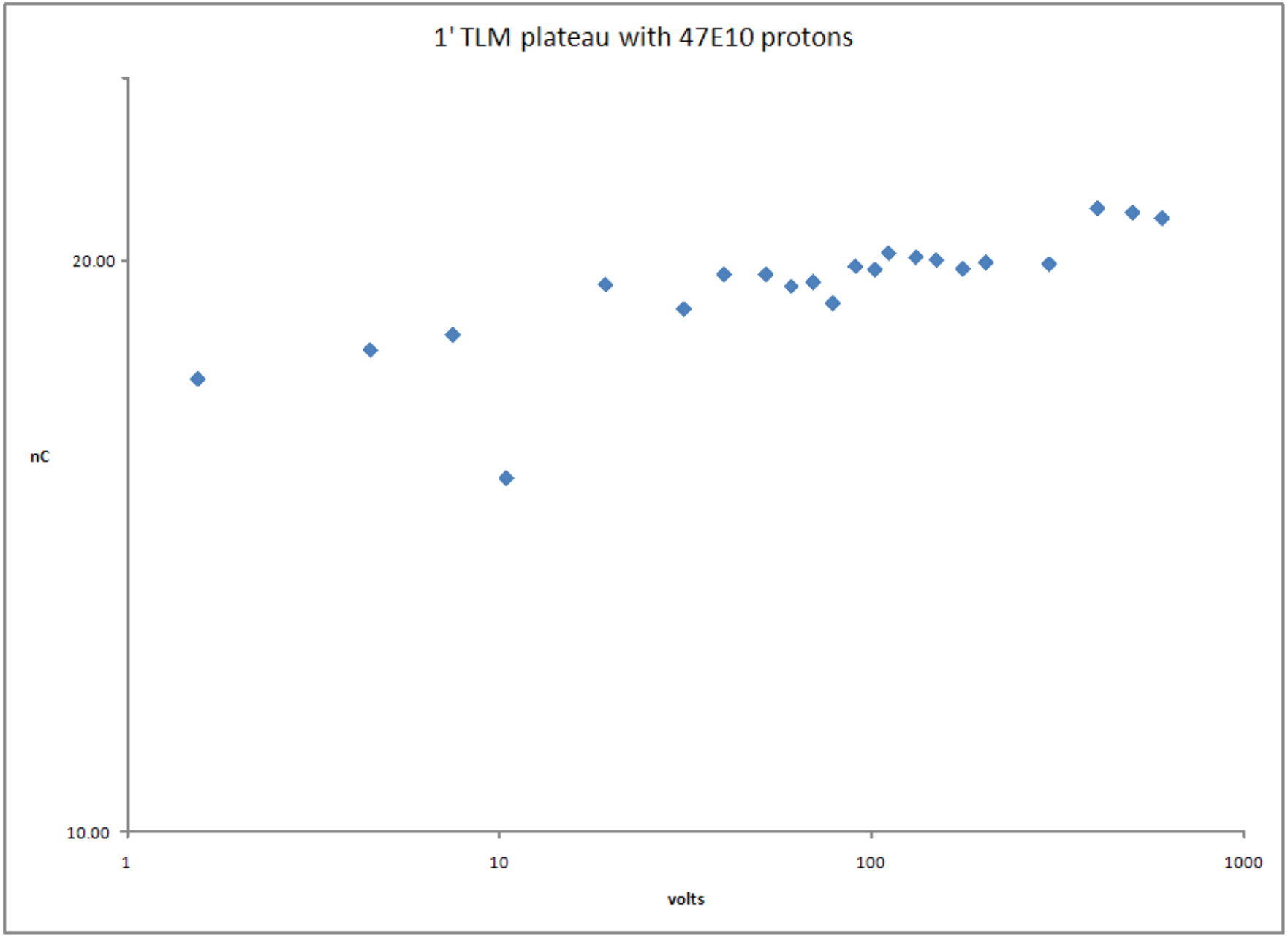


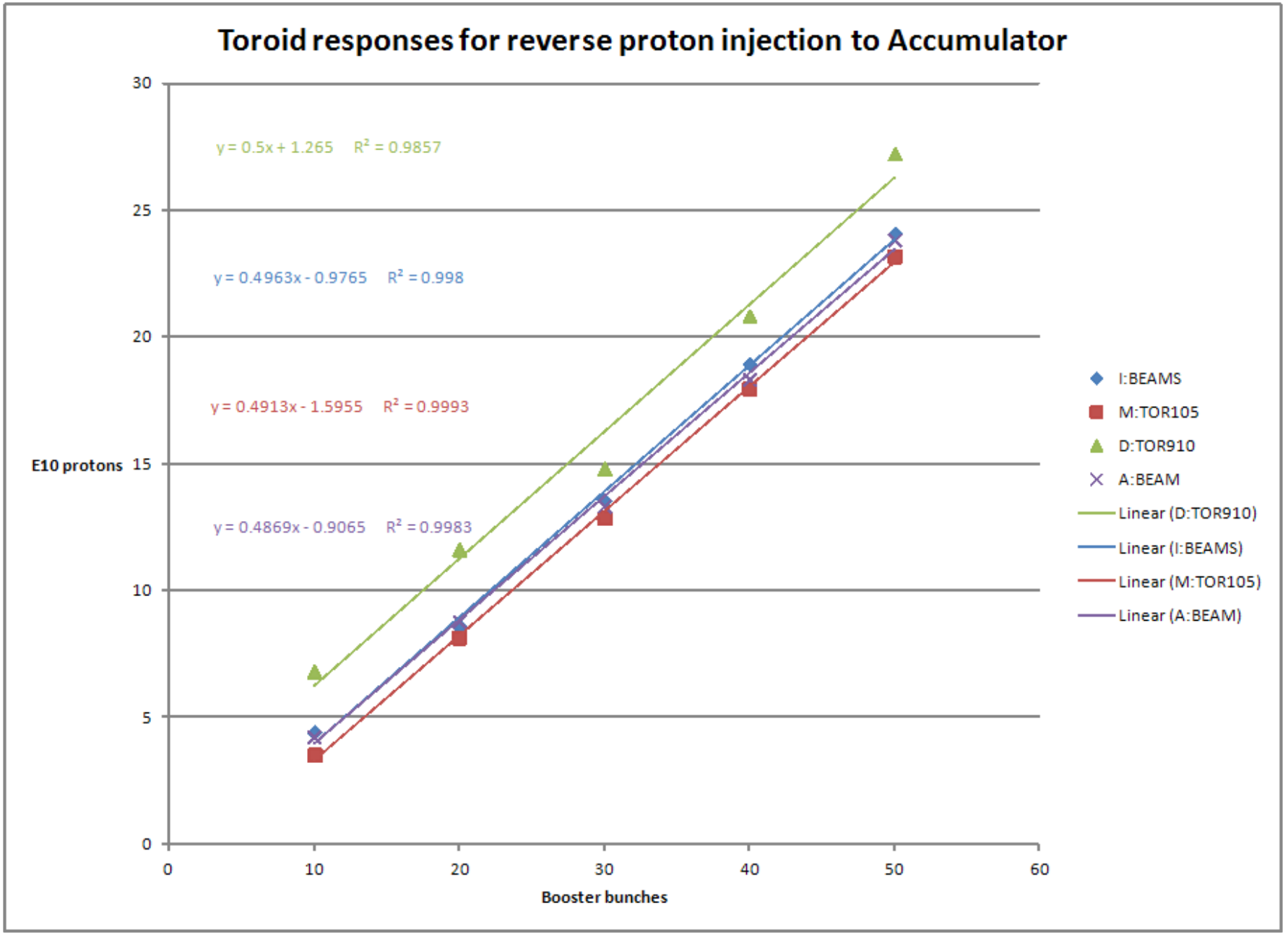

250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
before reverse proton tuneup
losses between elam and A2B7
HT906A -17.5A
HT906A -15A
HT906A -12.5 A
HT906A -10A
250'
HT906A +10A
338'
lost at A2B7
lost at A2B7
lost at A2B7
elam on
elam off
wakeup

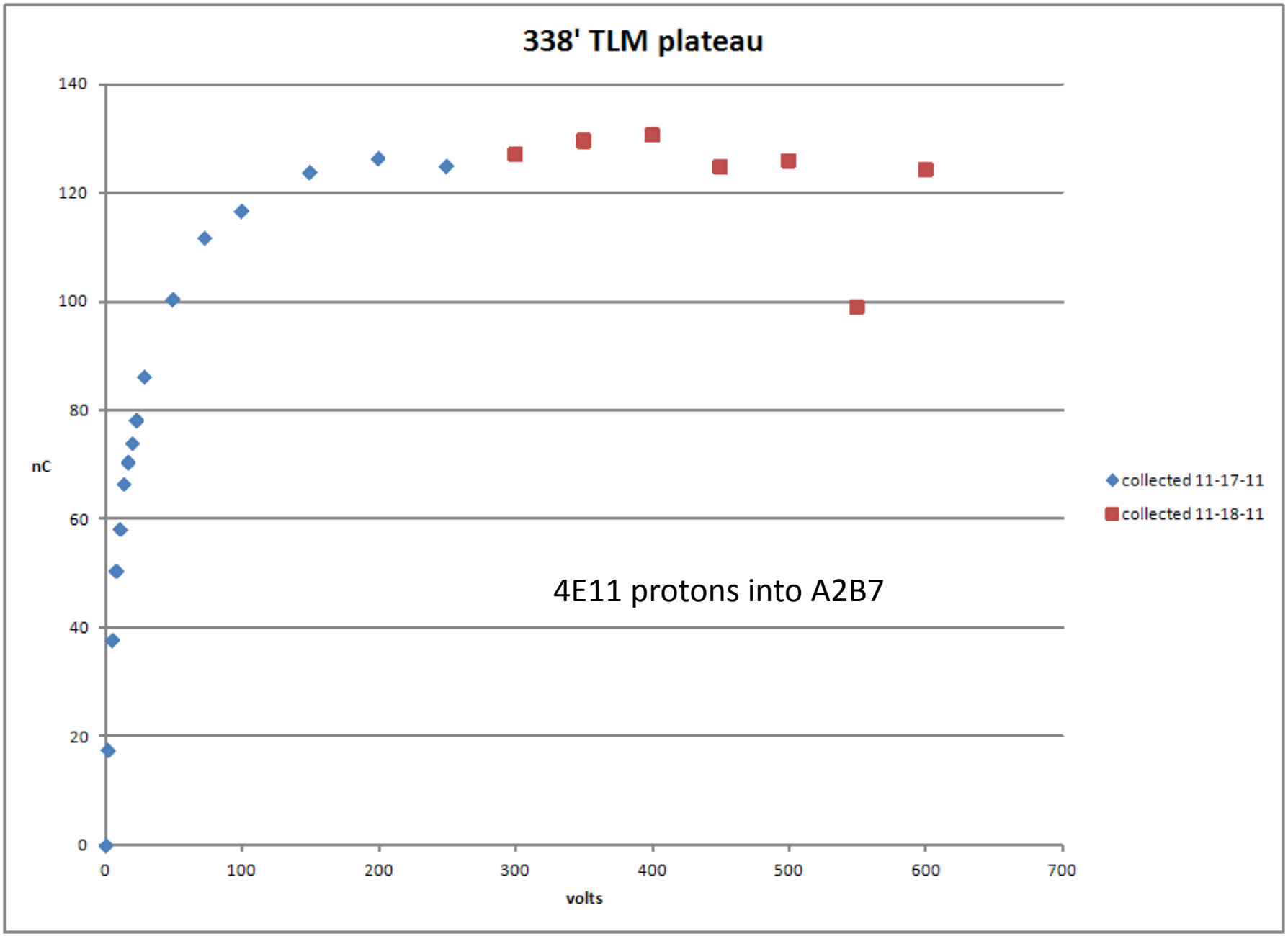

250' & 338' TLM response for beam lost at A2B7
y = 2.8443x - 1.0538 R² = 0.9998
y = 2.8044x - 1.075 R² = 0.9999
120.0
100.0
80.0
60.0
40.0
20.0
0.0
nC
0
5
10
15
20
25
30
35
40
45
E10 protons
250' TLM
338' TLM
Linear (250' TLM)
Linear (338' TLM)

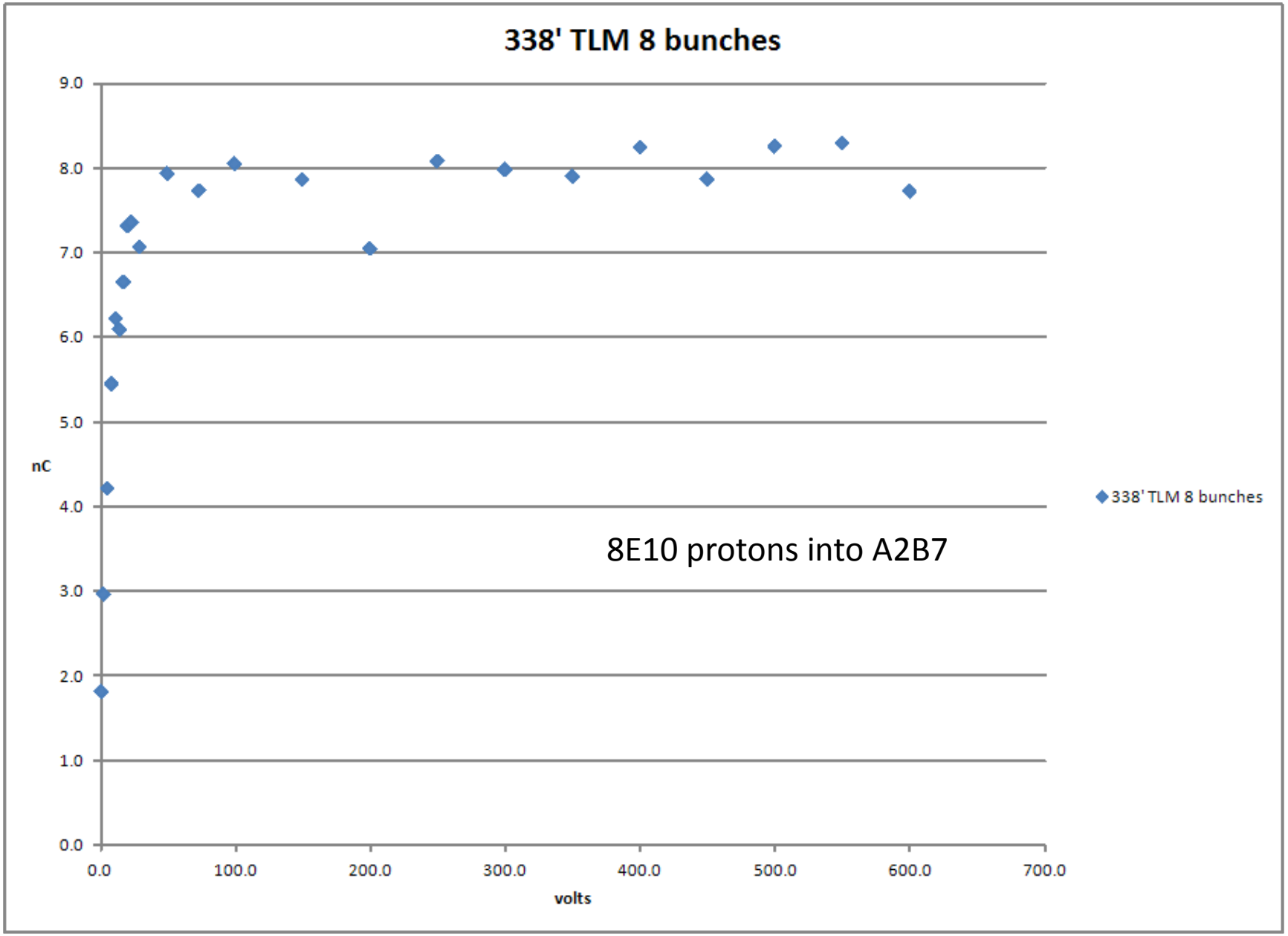

chipmunk net counts by position for beam loss at A2B7
net counts
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
20
40
60
80
100
120
140
chipmunk position in feet relative to upstream ELAM
3.4E10 protons
1.17E+11
1.83E+11
2.89E+11
3.96E+11
4.00E+10
1.40E+11
2.46E+11
3.24E+11
3.82E+11

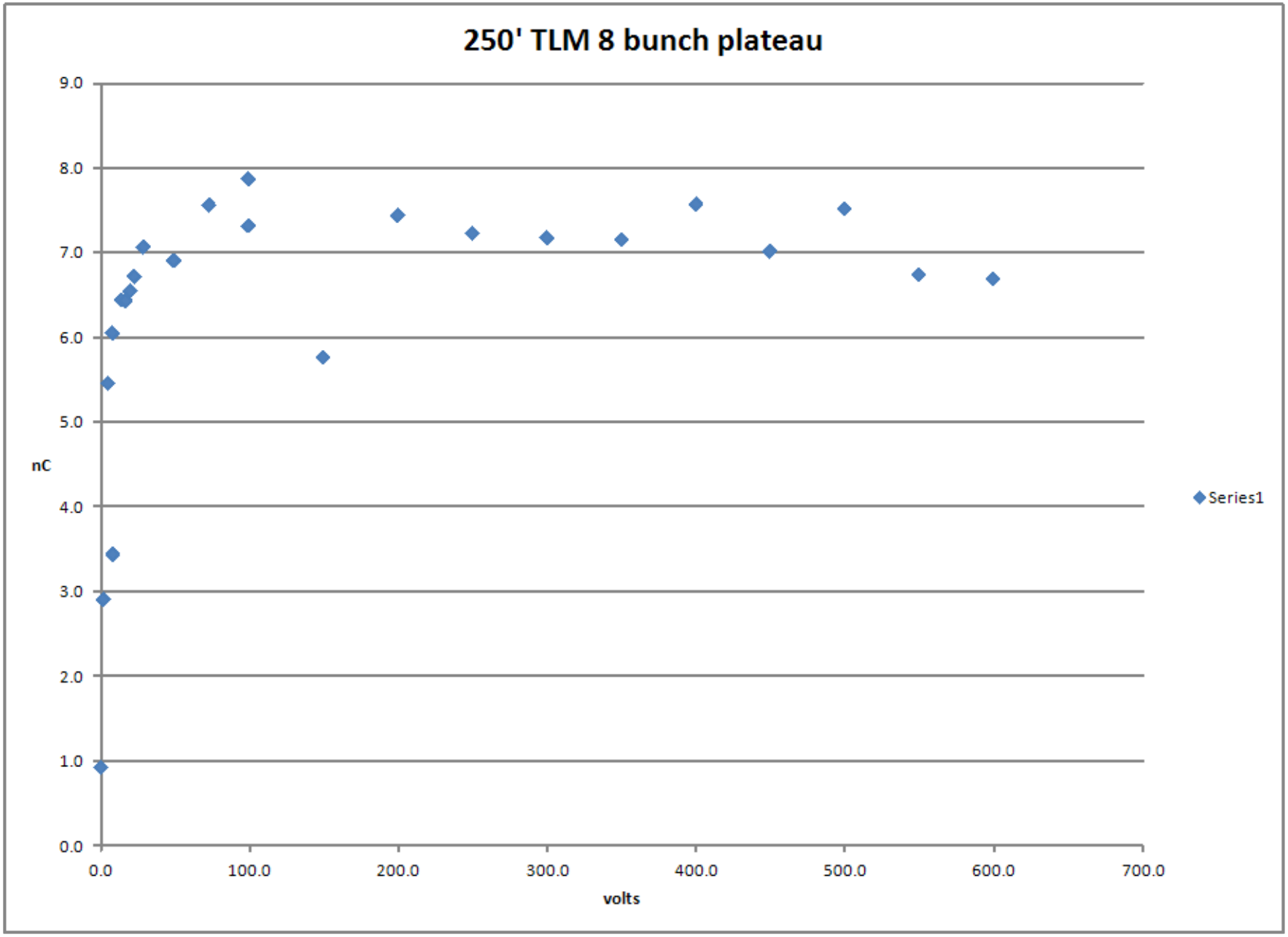

Blue box response to multipulse losses at A2B7
y = 2.5029x + 6.9218
R2 = 0.9971
nC
E10 protons
0
50
100
150
200
250
300
350
400
450
500
0
20
40
60
80
100
120
140
160
180

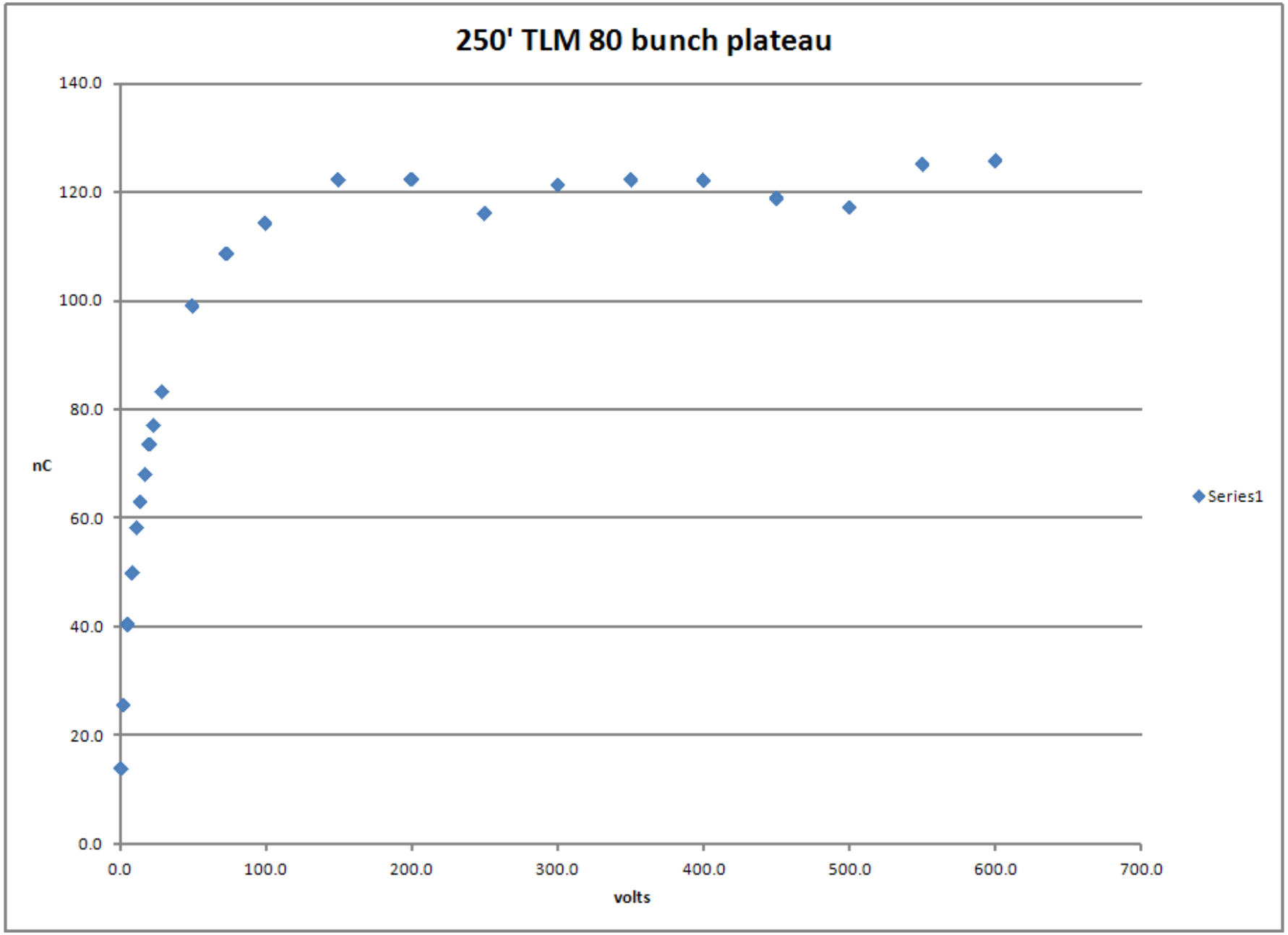

1' TLM plateau with 47E10 protons
20.00
10.00
nC
1
10
100
1000
volts

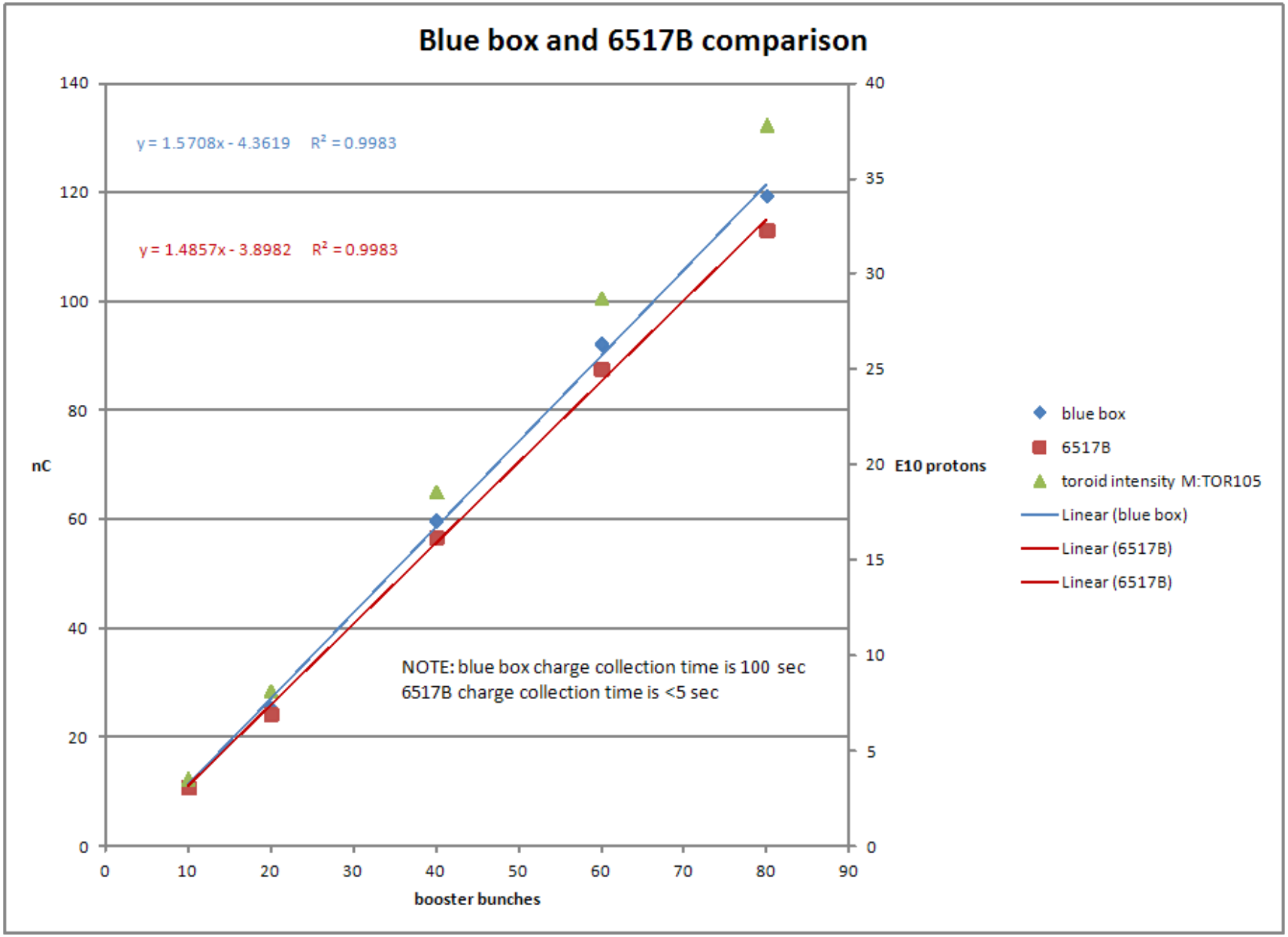

Toroid responses for reverse proton injection to Accumulator
y = 0.5x + 1.265 R² = 0.9857
y = 0.4963x - 0.9765 R² = 0.998
y = 0.4913x - 1.5955 R² = 0.9993
y = 0.4869x - 0.9065 R² = 0.9983
E10 protons
Booster bunches
0
5
10
15
20
25
30
0
10
20
30
40
50
60
I:BEAMS
M:TOR105
D:TOR910
A:BEAM
Linear (D:TOR910)
Linear (I:BEAMS)
Linear (M:TOR105)
Linear (A:BEAM)


338' TLM plateau
140
120
100
80
60
40
20
0
nC
0
100
200
300
400
500
600
700
volts
collected 11-17-11
collected 11-18-11
4E11 protons into A2B7


338' TLM 8 bunches
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
nC
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
volts
338' TLM 8 bunches
8E10 protons into A2B7


250' TLM 8 bunch plateau
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
nC
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
volts
Series1


250' TLM 80 bunch plateau
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
nC
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
volts
Series1


Blue box and 6517B comparison
y = 1.5708x - 4.3619 R² = 0.9983
y = 1.4857x - 3.8982 R² = 0.9983
NOTE: blue box charge collection time is 100 sec
6517B charge collection time is <5 sec
nC
E10 protons
booster bunches
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
blue box
6517B
toroid intensity M:TOR105
Linear (blue box)
Linear (6517B)
Linear (6517B)

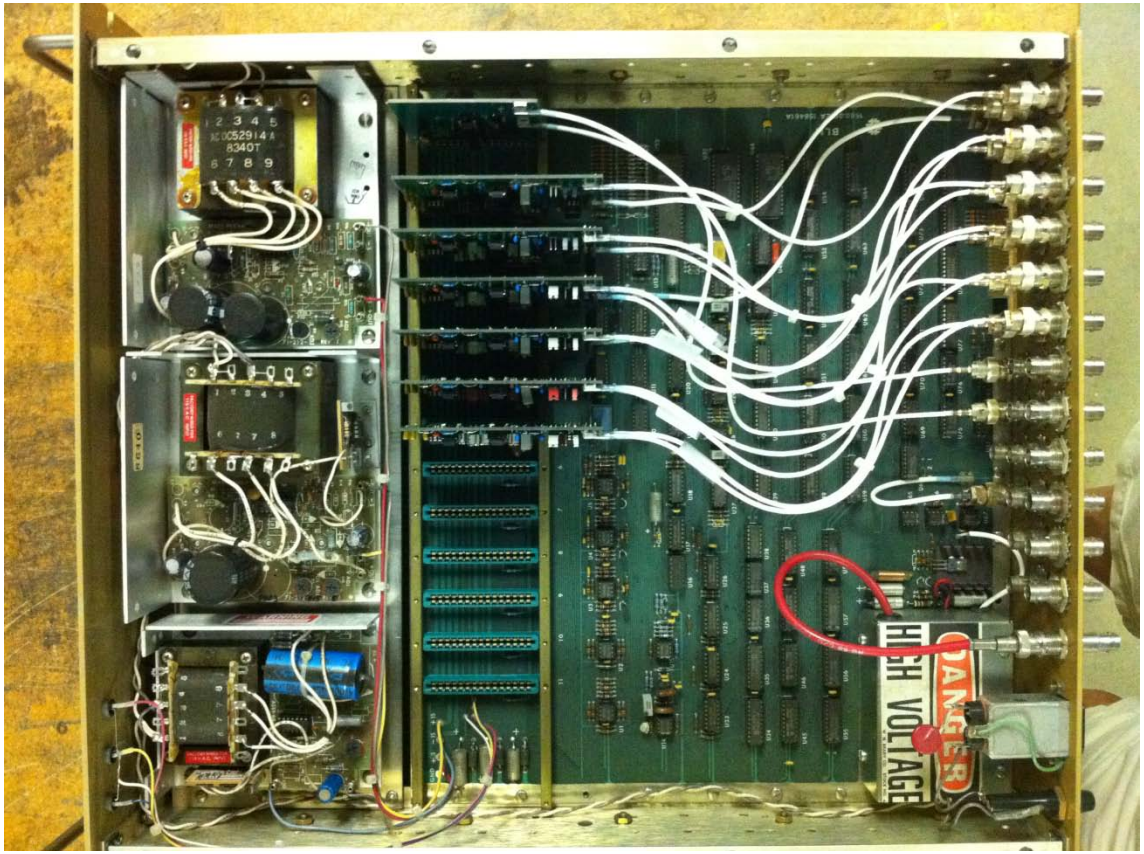
Next steps

- Finish charge collection time measurement
  - Probably requires max intensity to get a signal
- Do high intensity plateaus for 250’ and 338’ TLMs
  - Use 6517B for one and blue box for the other
  - Then switch
  - Look for roll off in blue box response

TLM electronics development resources

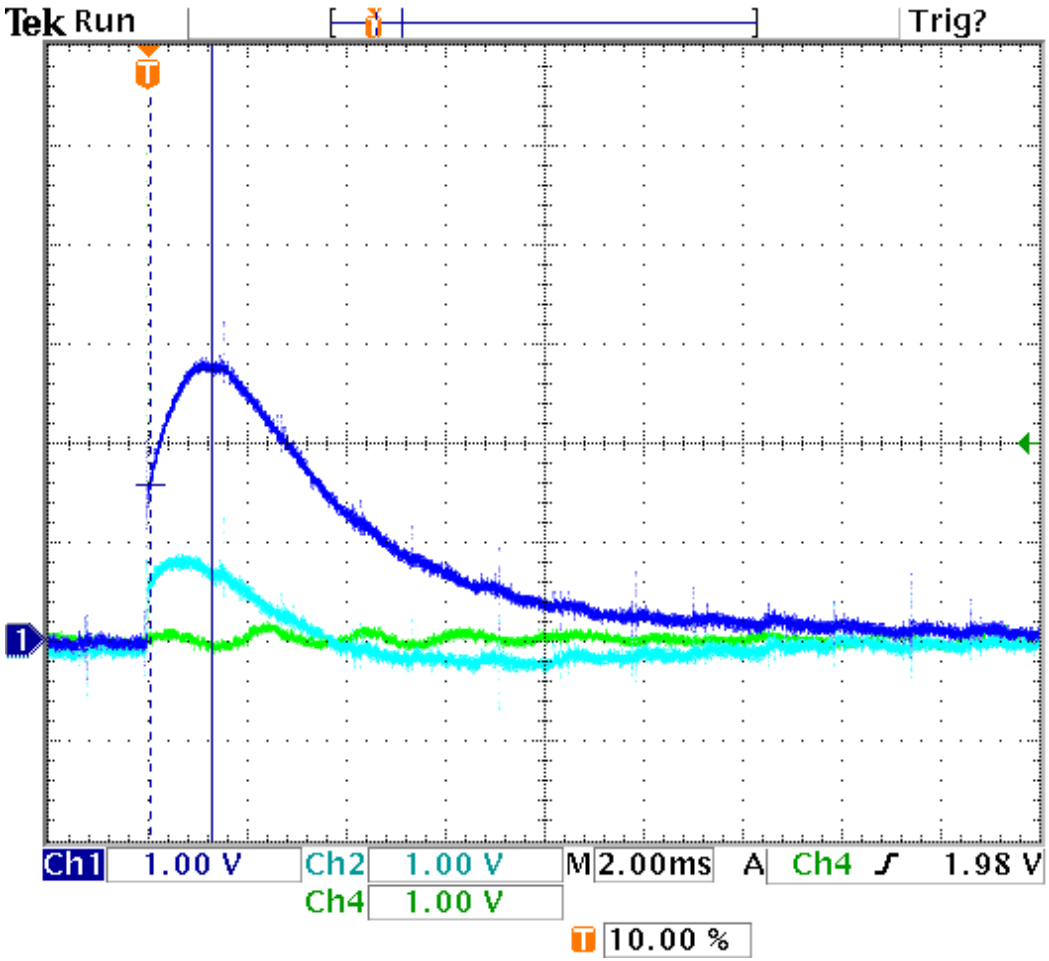
- Management
  - EE?
  - ES&H?
- M&S
  - Probably need a budget for this
    - First, need an estimate?
    - Funded by users?
      - ES&H
      - Mu2e
      - Pixie
      - Others
- Resources
  - ES&H files
- Labor
  - Marv
  - Others?

Since the last meeting



Current BLM chassis contains:
6 decade log rate cards
0.014 RADS
0.14 RADS
1.4 RADS
14 RADS

Scope pictures

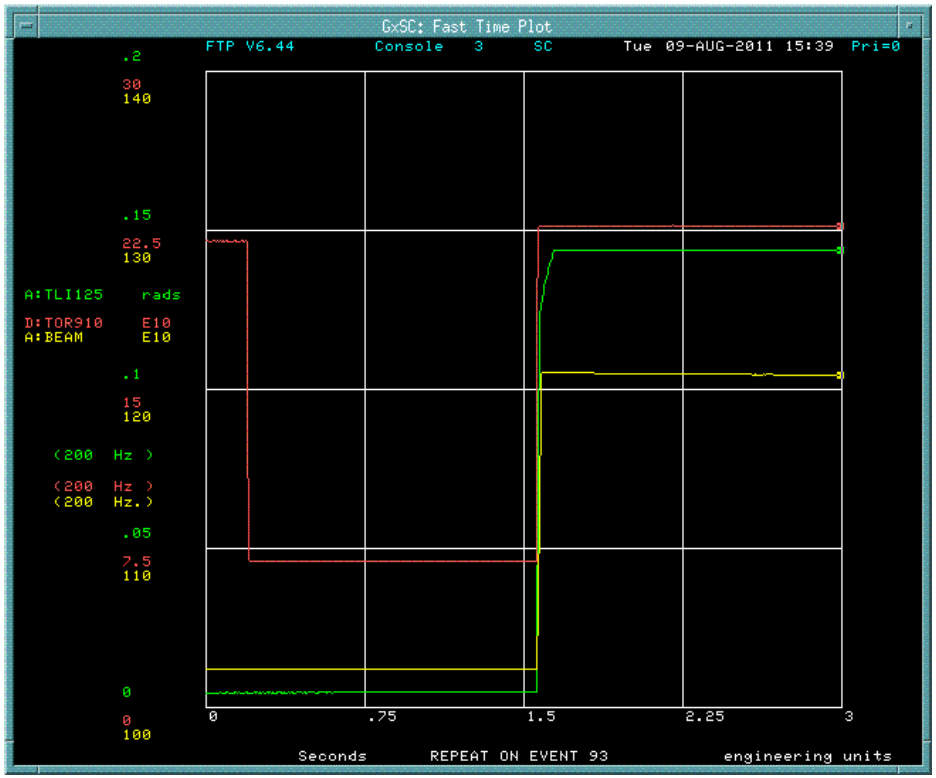


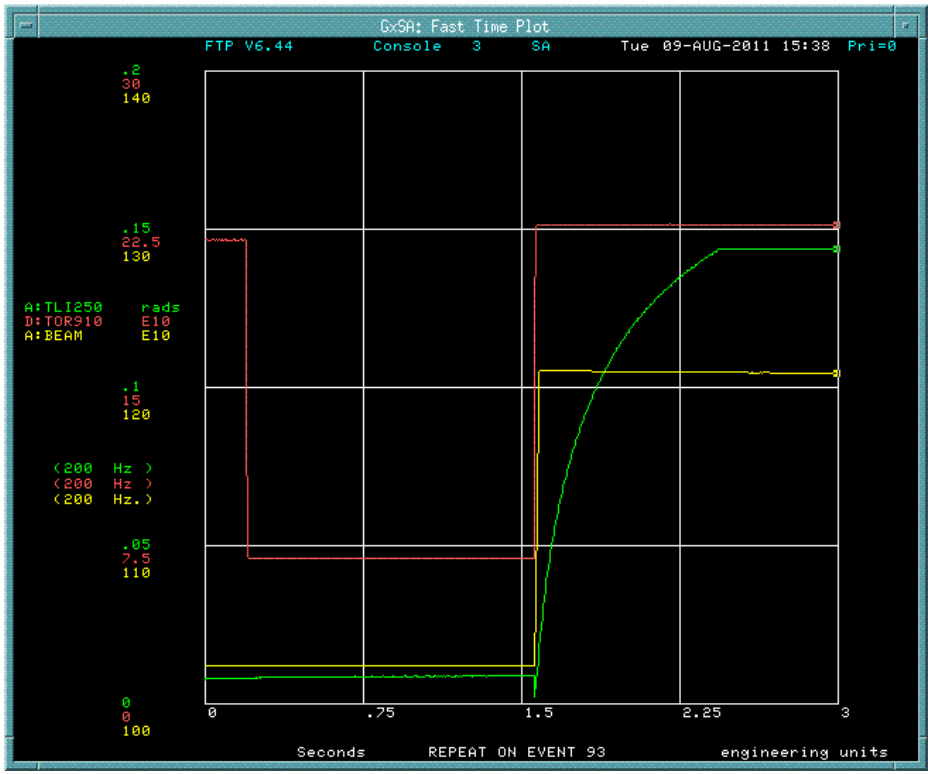
125 foot response

250 response

50 Booster bunches
Partial scraping loss on elam

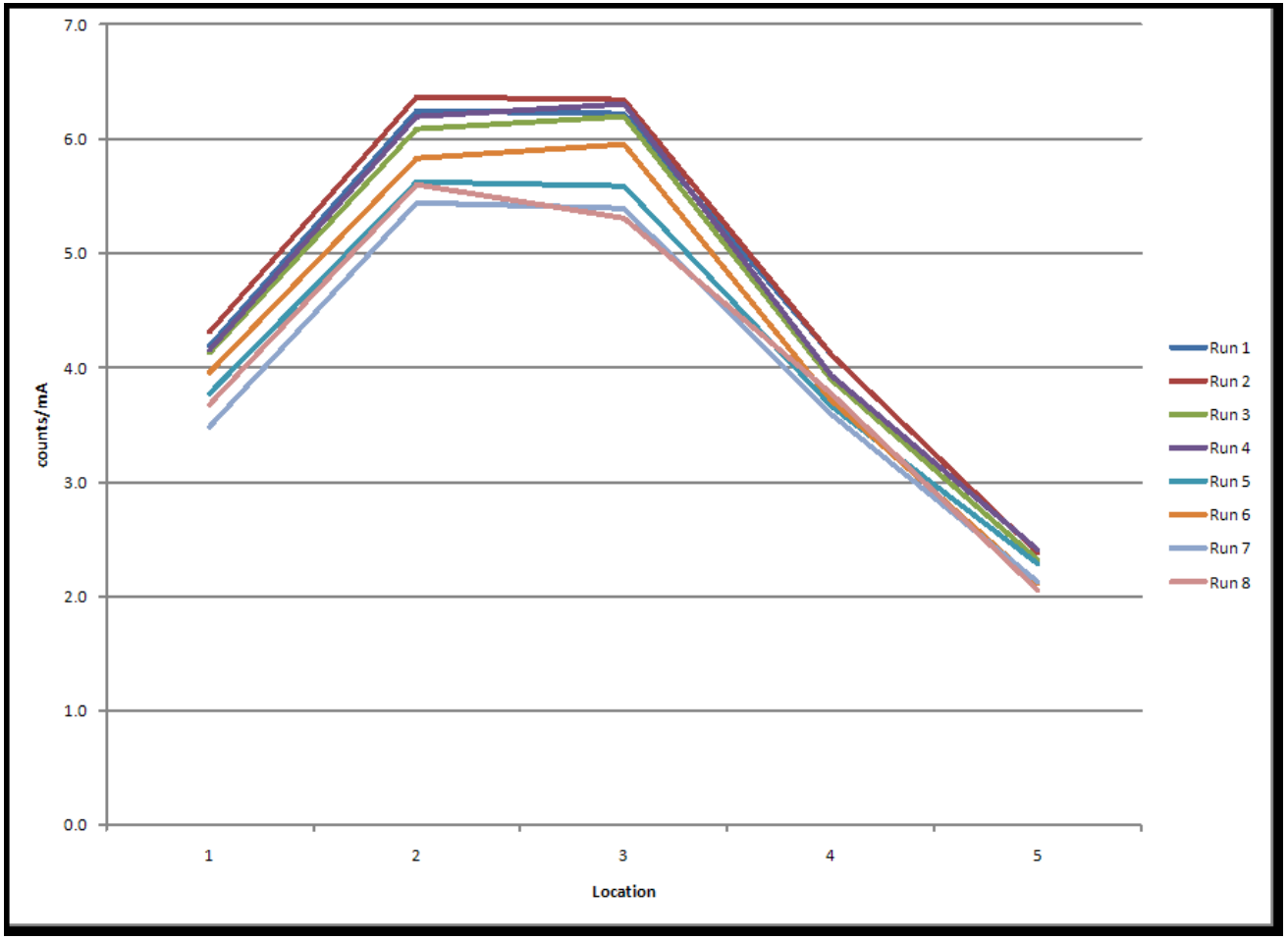
0.14 RAD cards saturate





Partial scraping loss on ELAM
50 Booster bunches
D:HT906A + 10A

Repeated 2000 Pbar SA measurement

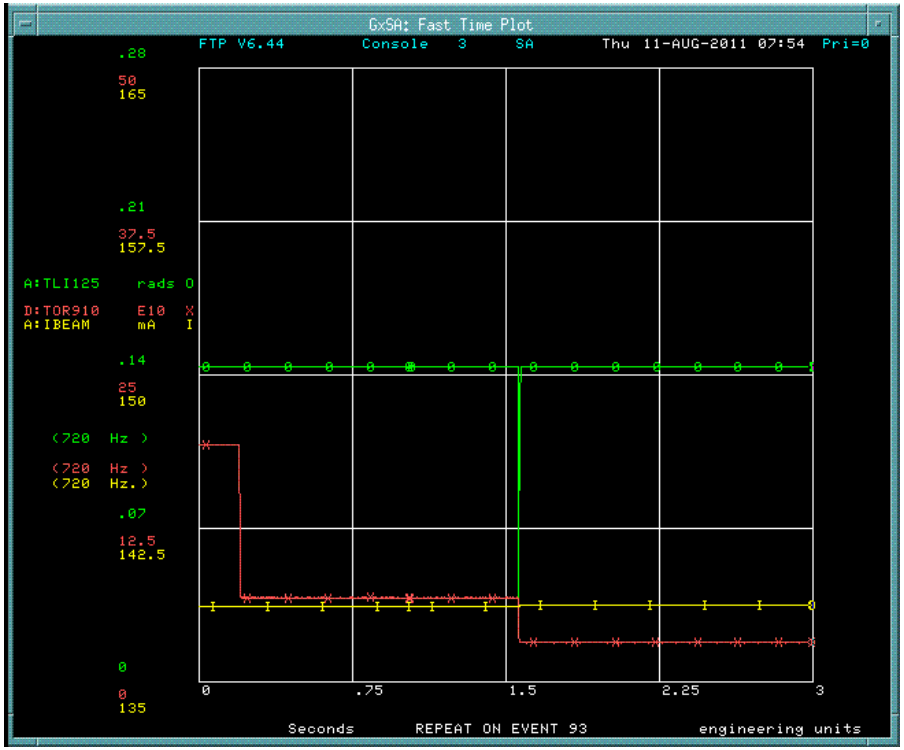


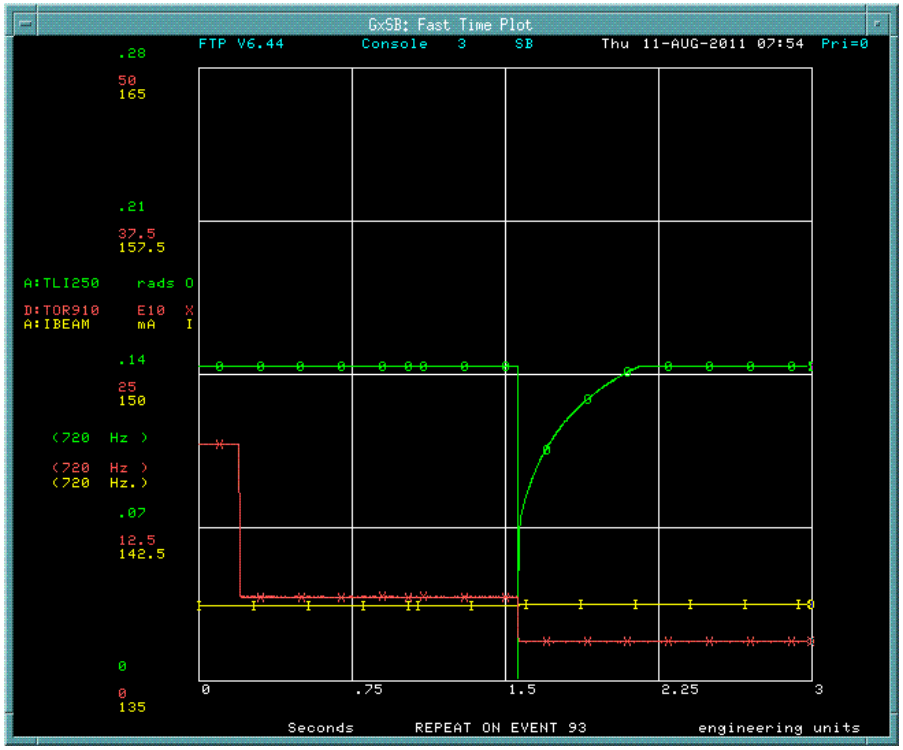
Counts per mA lost

Expected these curves to be consistent

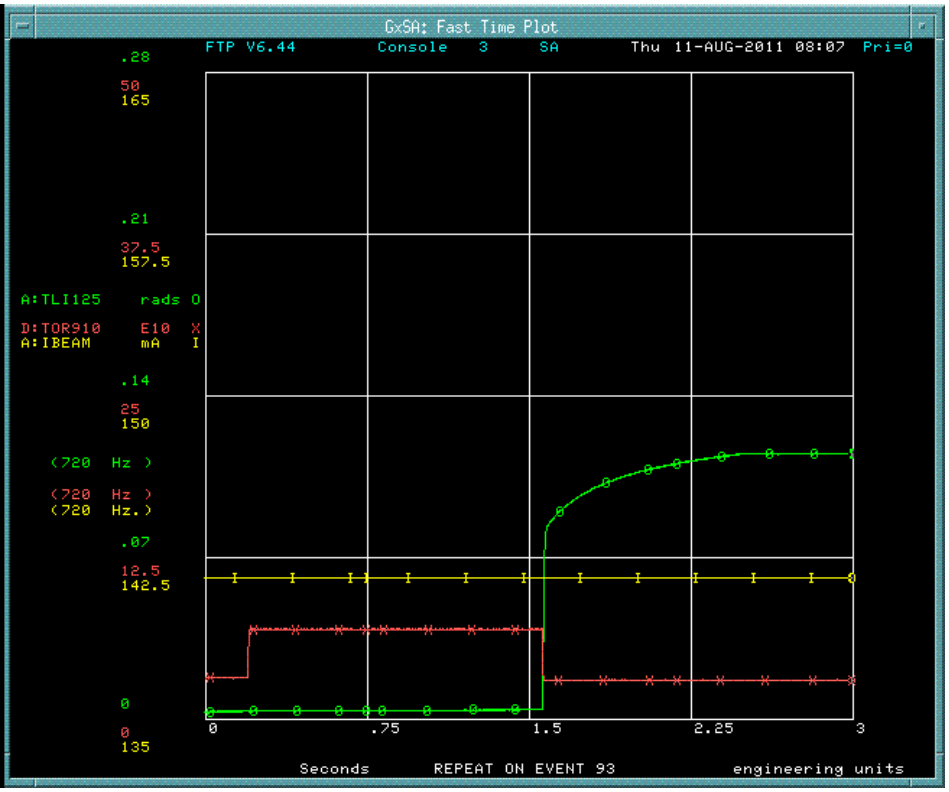
Demonstrates that scraping loss is unreliable technique to establish response

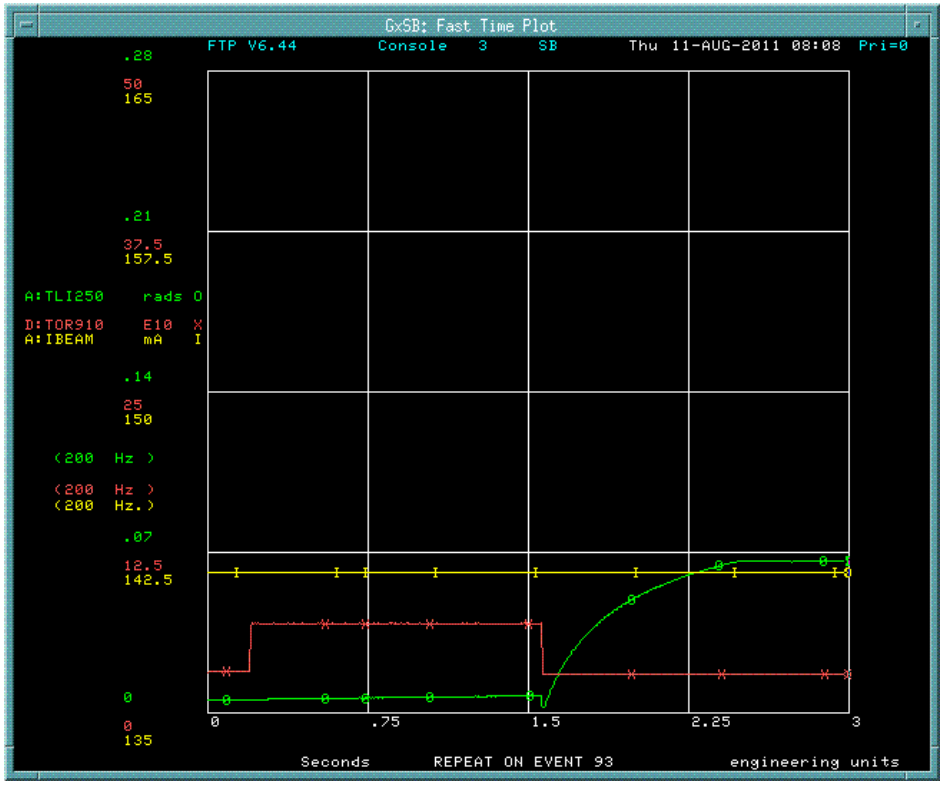
Single resets do not clear BLM cards in all cases





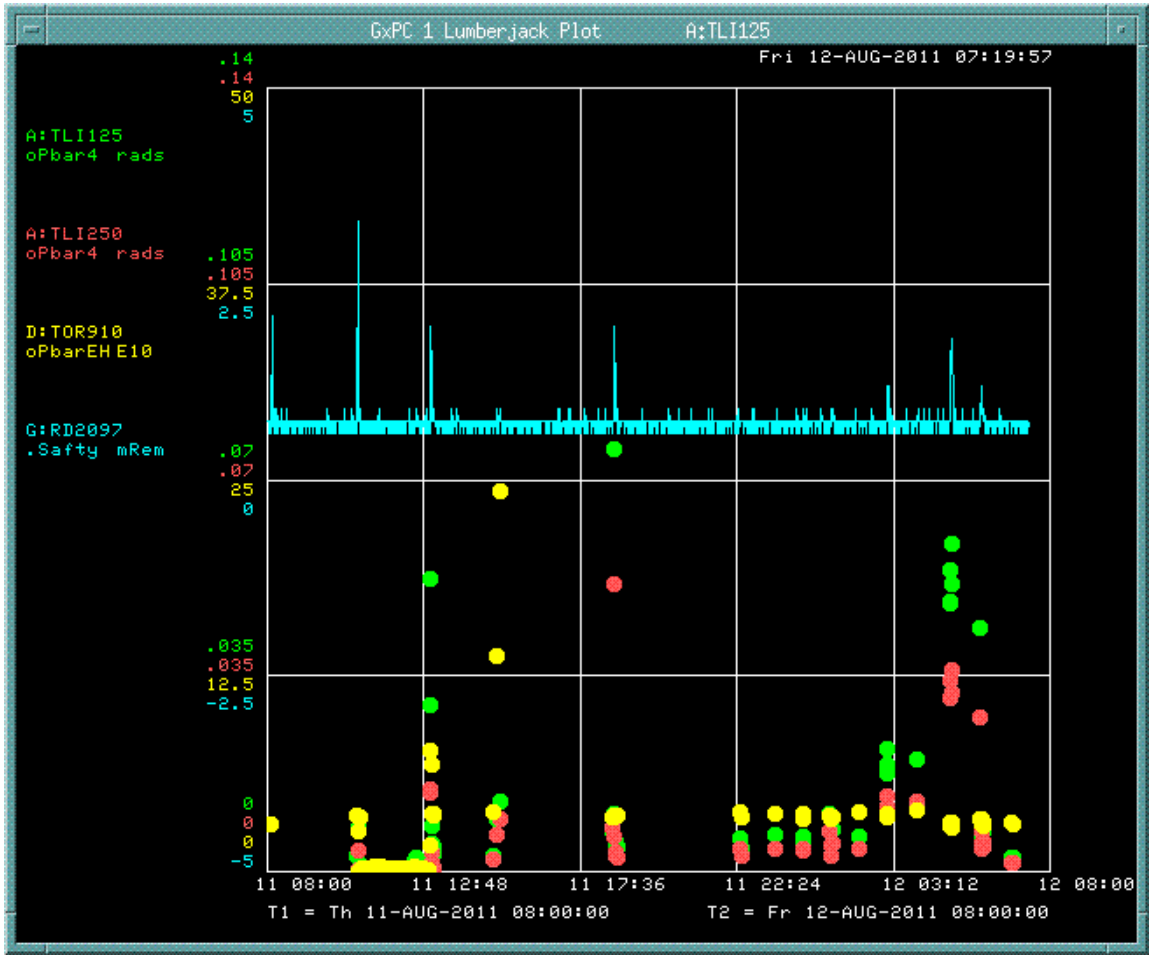
Clear on 00 event and 93 event





Used reset at beginning of transfer timeline to clear integrator

TLMs samples on 93 reverse proton tuneup event



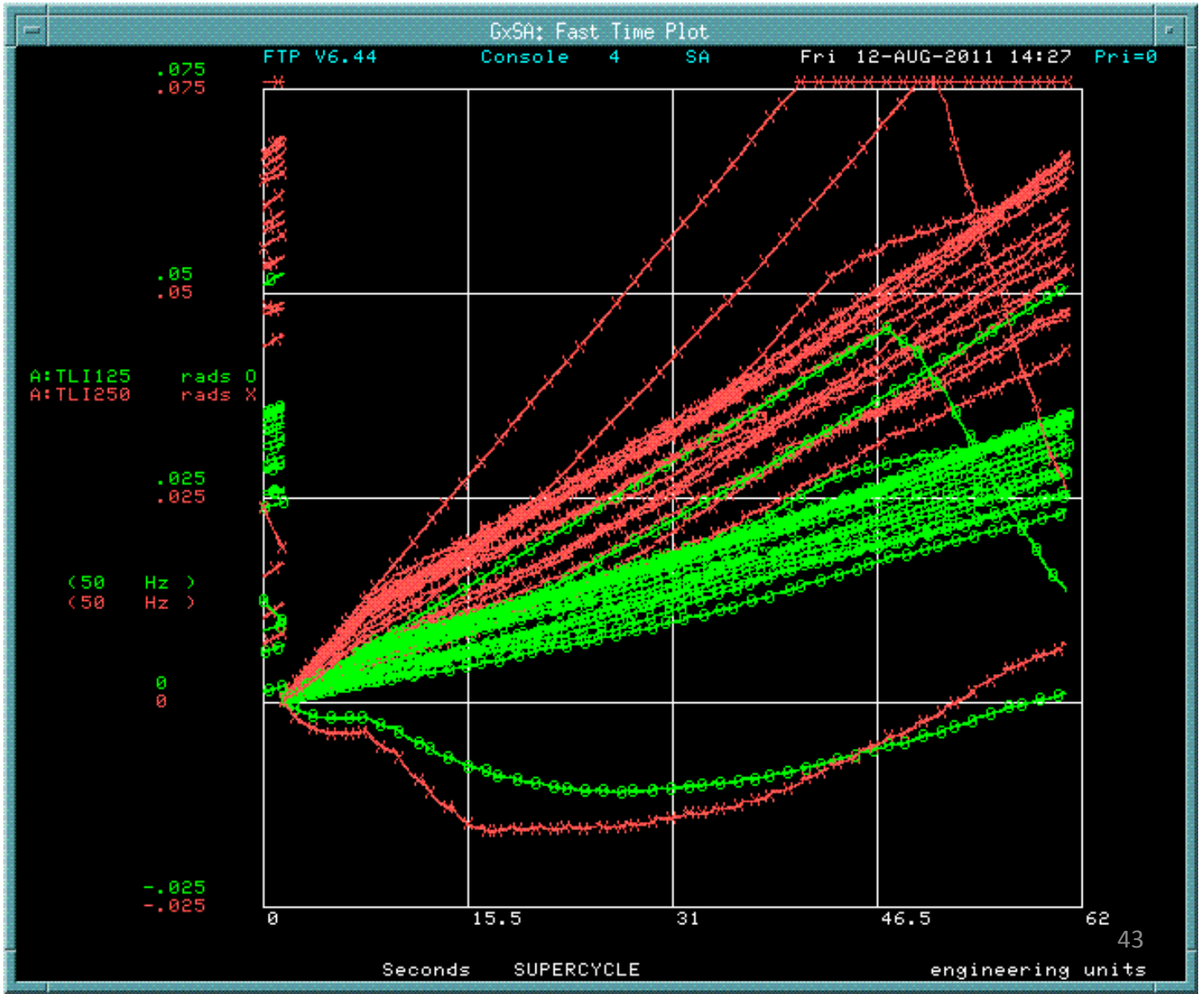
Transfers over 24 h period

TLM response coincident with chipmunk response outside of shielding

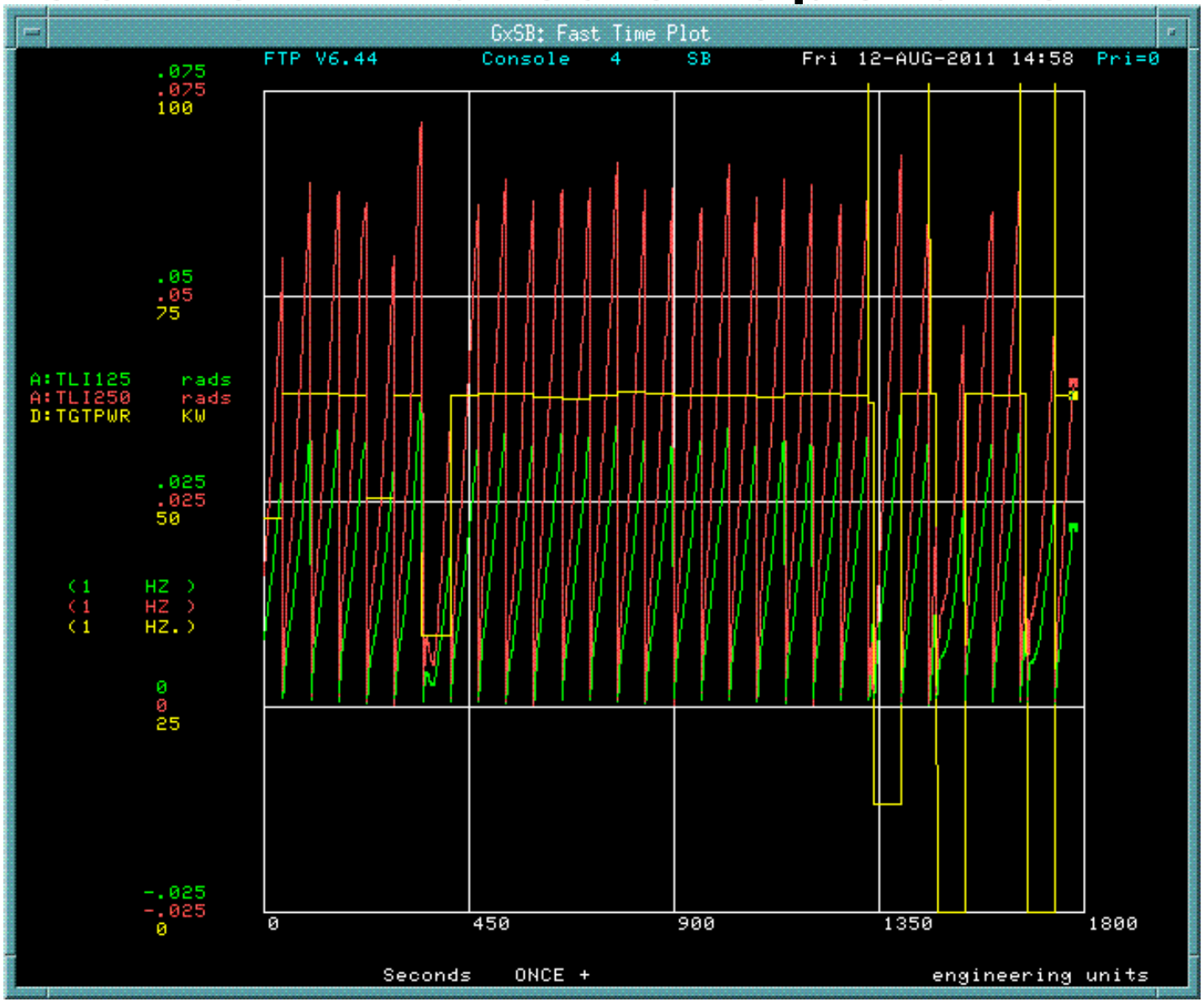
Small negative currents occur

e.g. when beam goes away

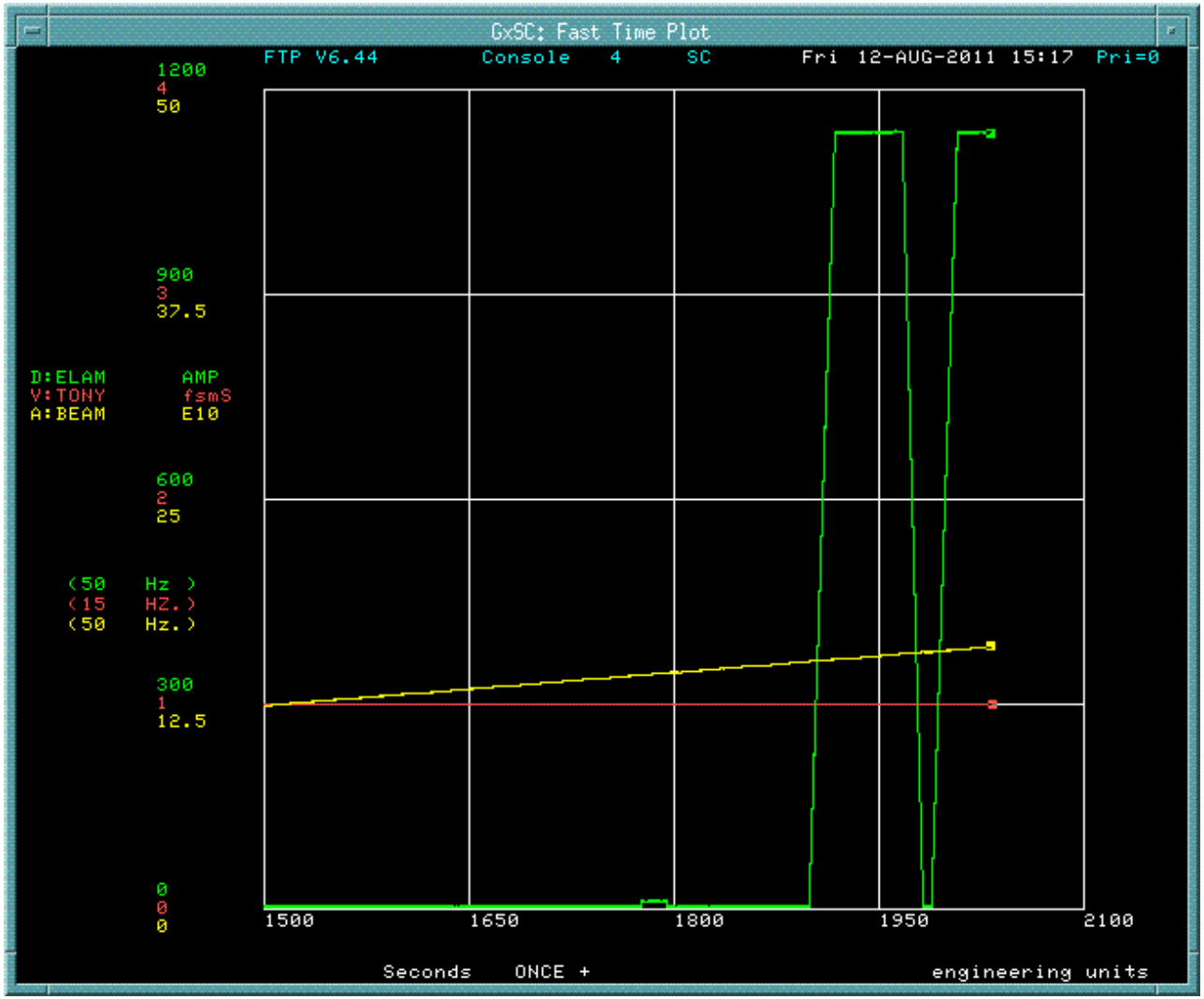
Chipmunks have Cs-137 source to drive current



Some minutes of operation

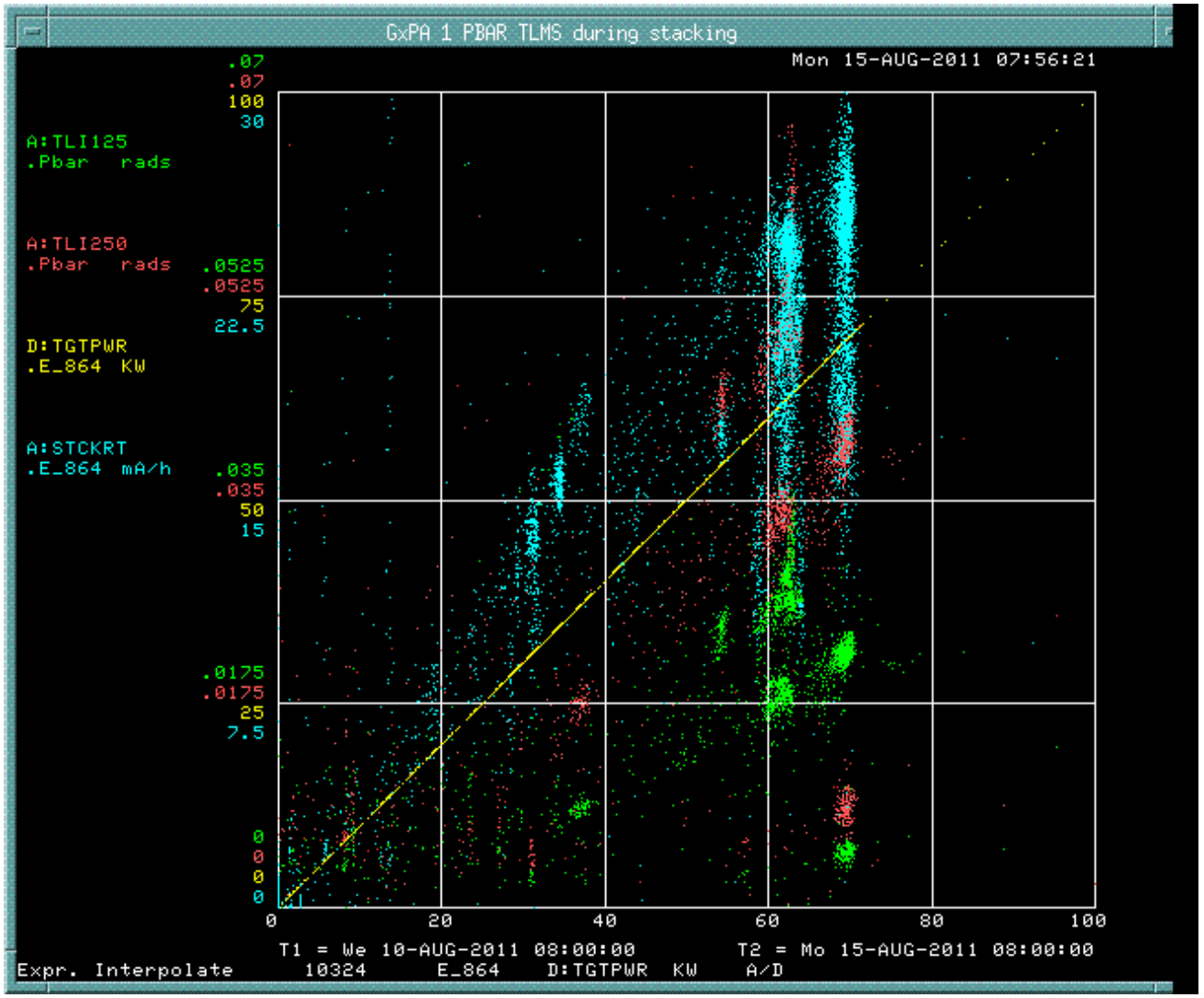


Script has been written to ramp elam simplifies beam loss studies

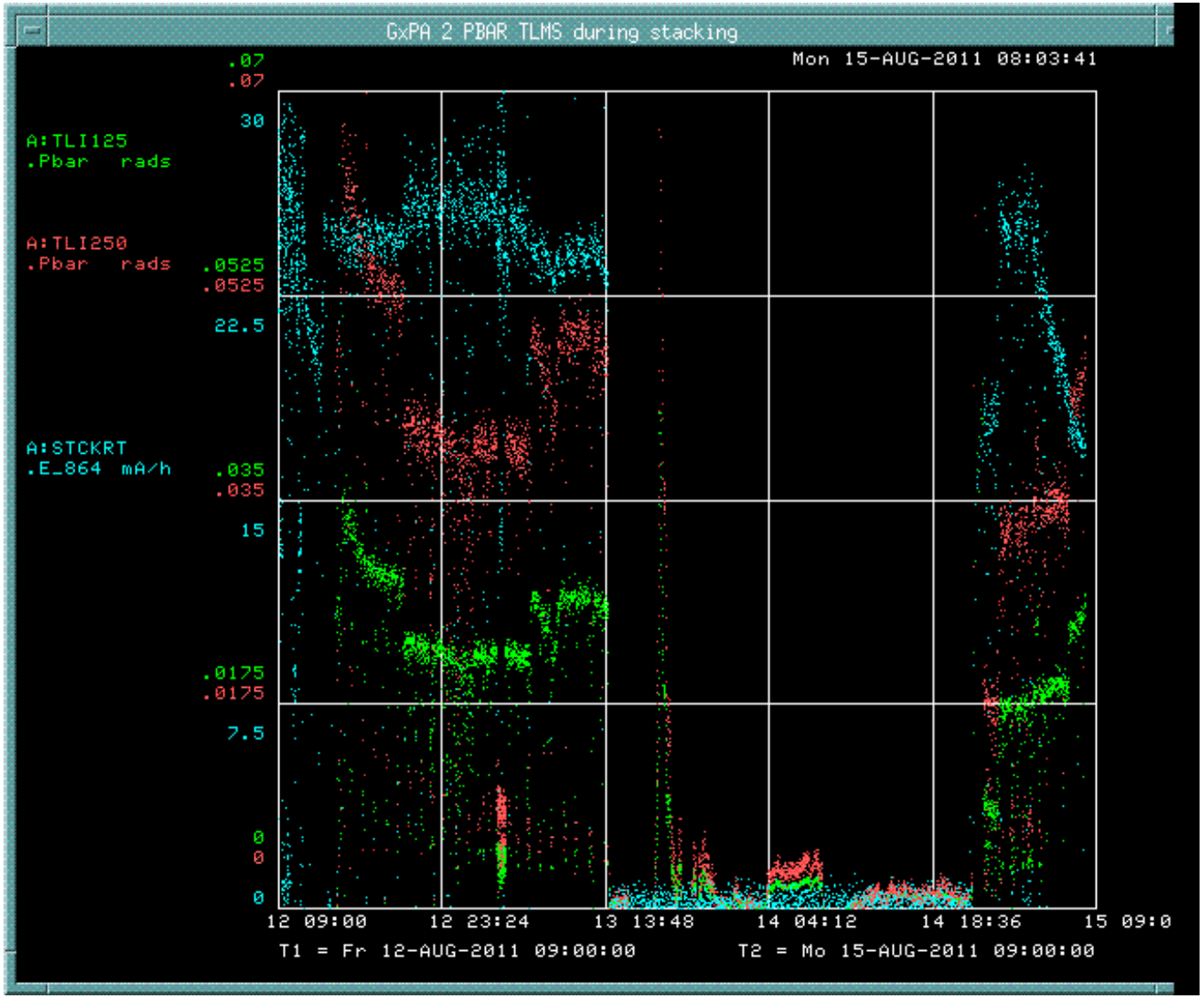


Script by DVM

TLM response correlated with beam power on target by timeline variation



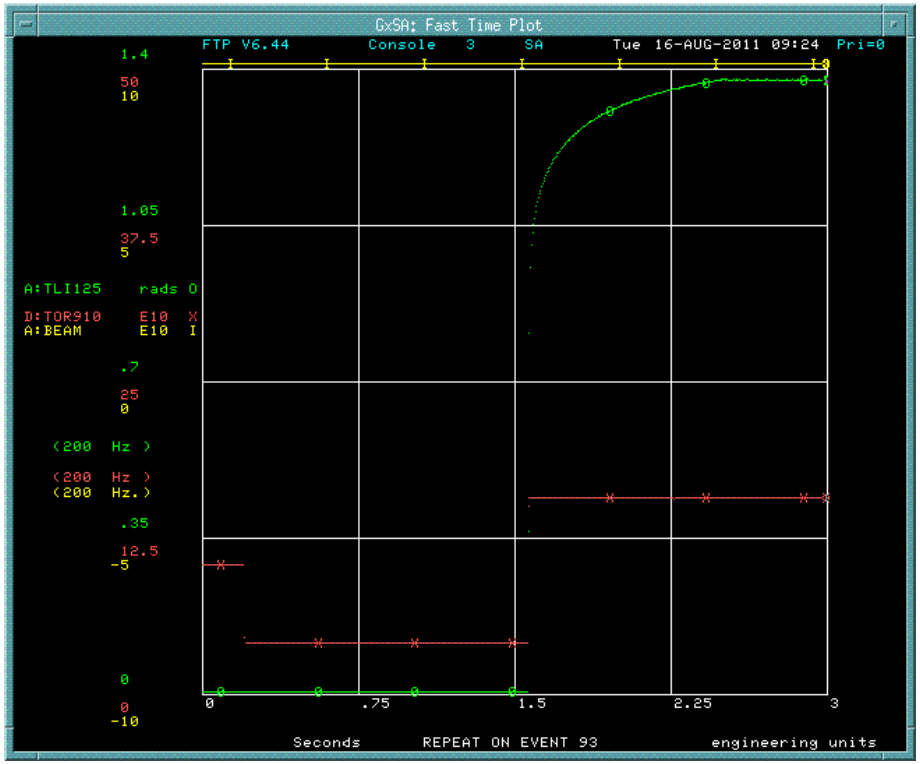
TLM response correlated with stacktail performance

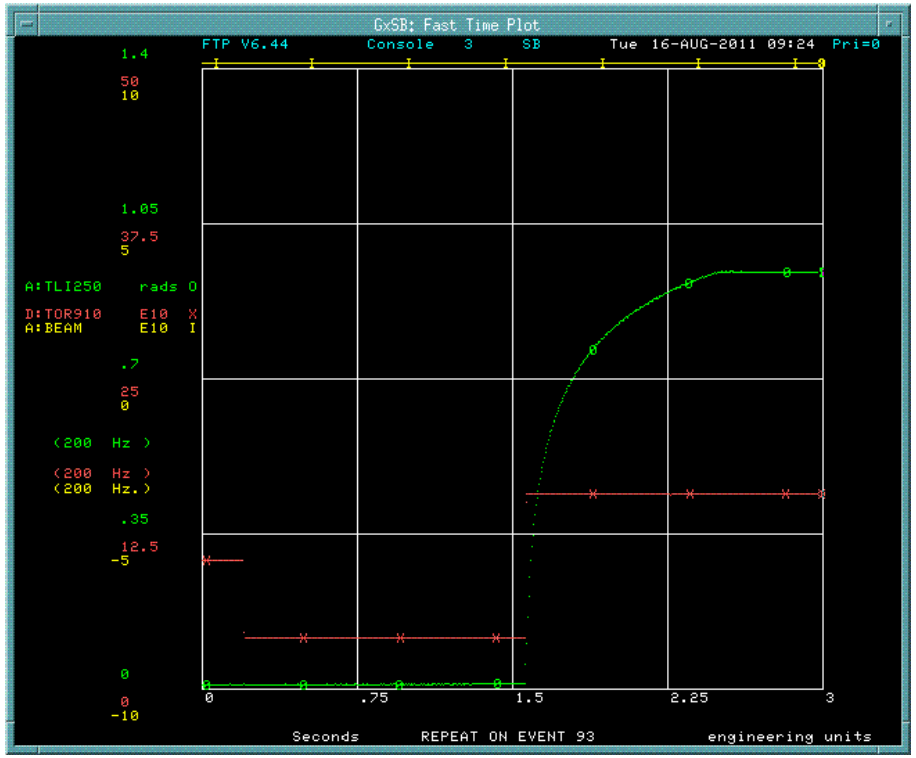


TLM response to very subtle effects

Suggests good sensitvity

A series of measurements have been variable beam loss

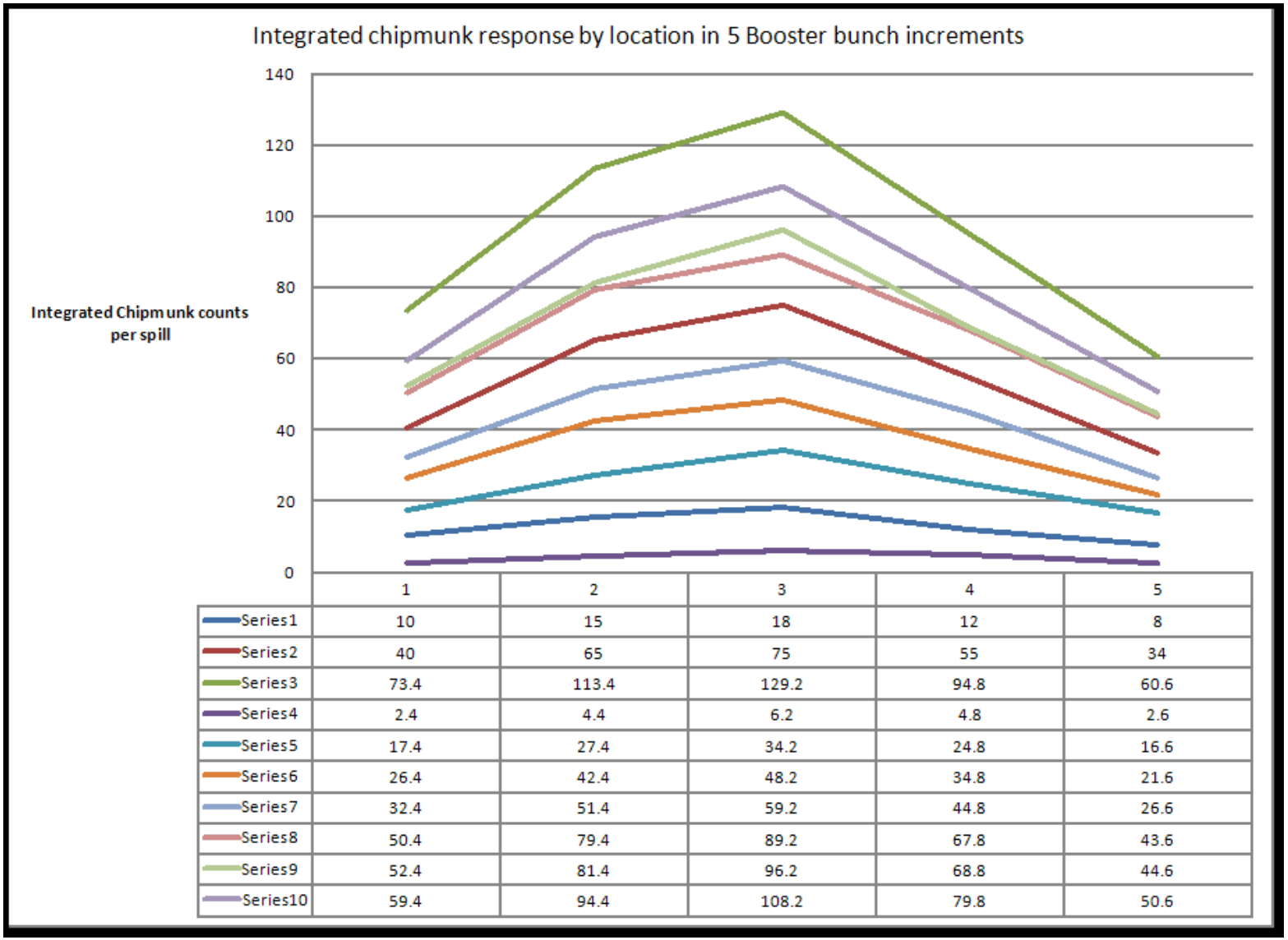




35 Booster buckets - 15.7E10 protons

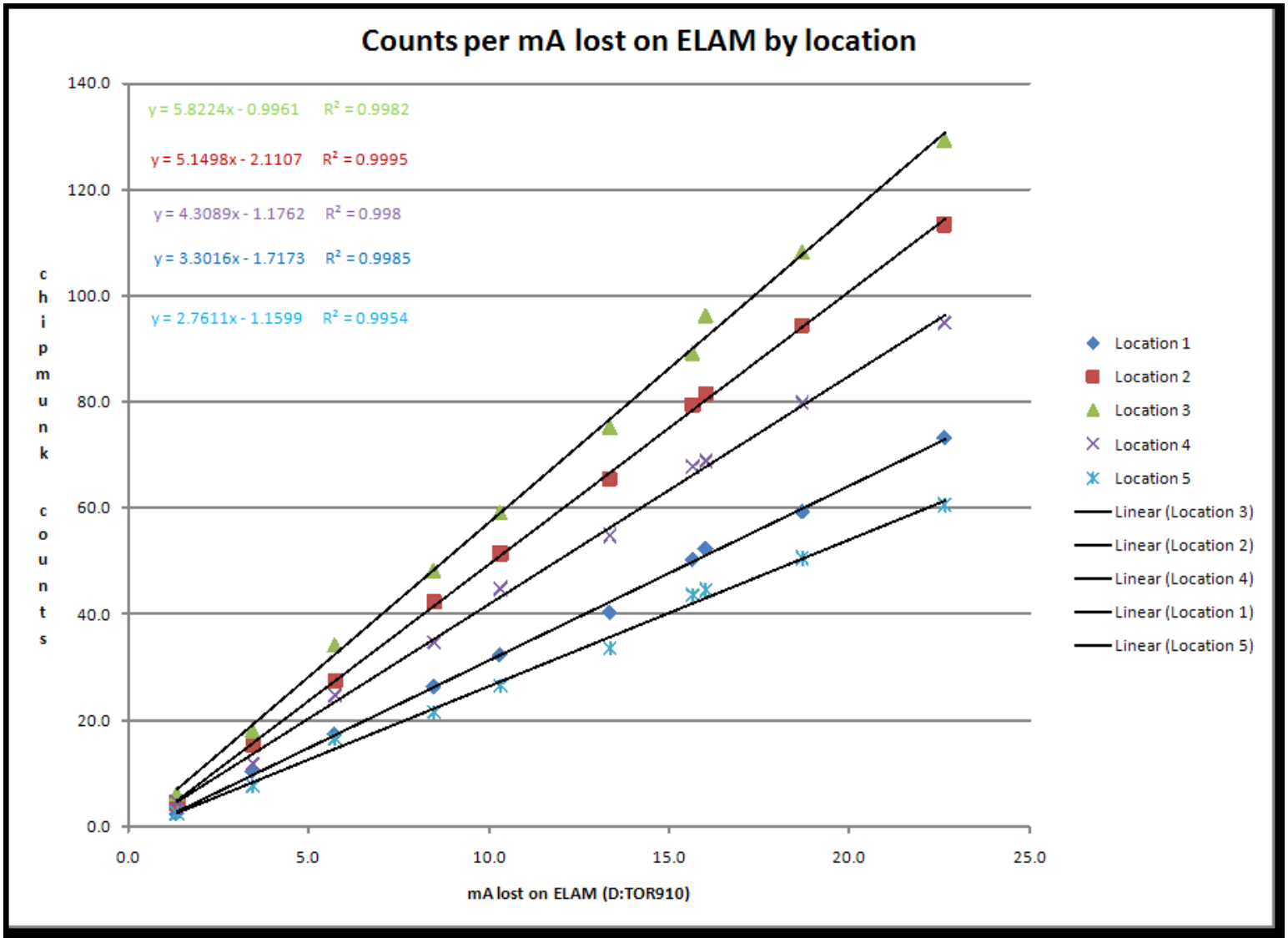
Others in 5 bucket increments from 5 to 50

Recorded response of 5 chipmunks



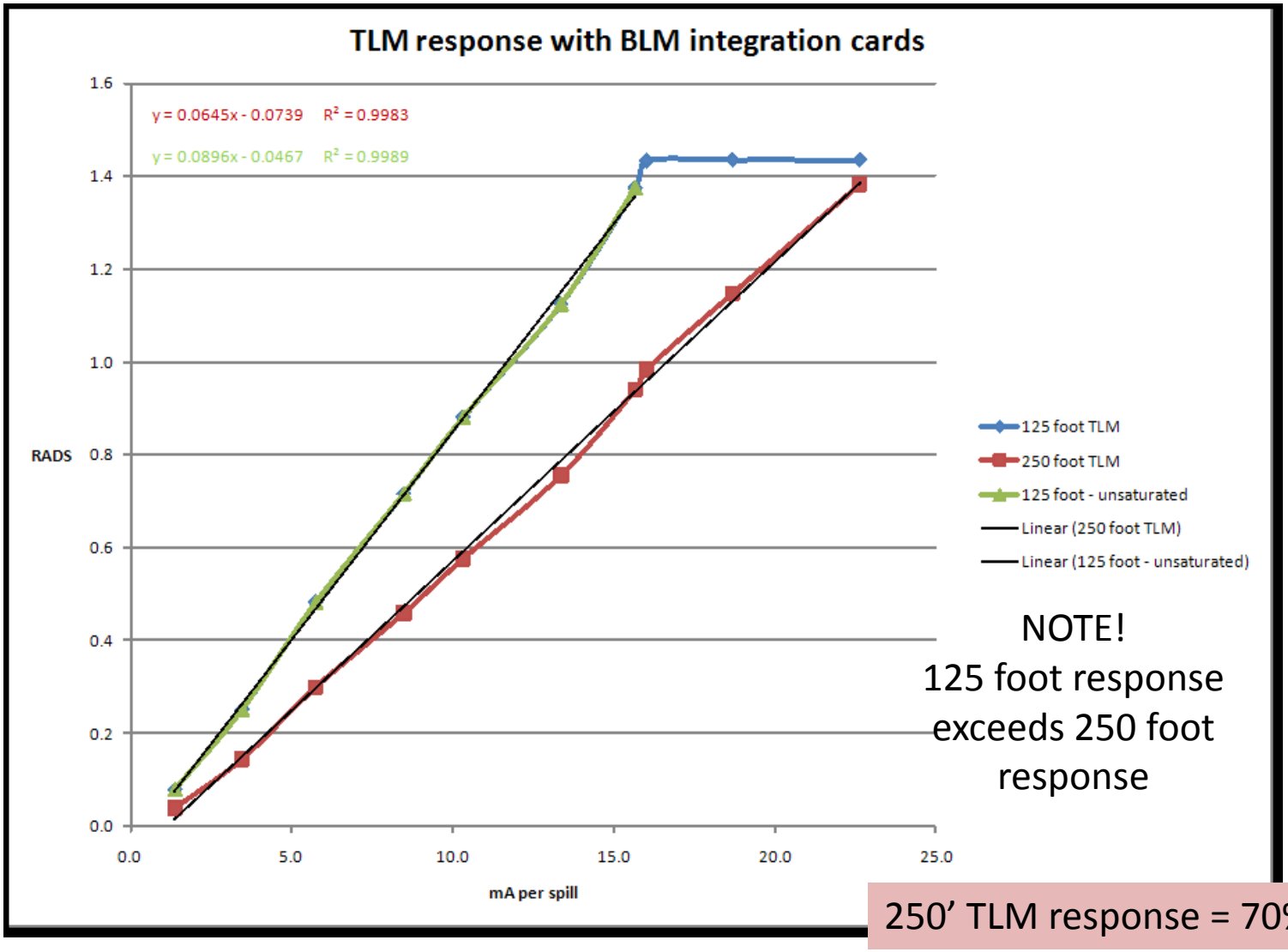
	1	2	3	4	5
Series1	10	15	18	12	8
Series2	40	65	75	55	34
Series3	73.4	113.4	129.2	94.8	60.6
Series4	2.4	4.4	6.2	4.8	2.6
Series5	17.4	27.4	34.2	24.8	16.6
Series6	26.4	42.4	48.2	34.8	21.6
Series7	32.4	51.4	59.2	44.8	26.6
Series8	50.4	79.4	89.2	67.8	43.6
Series9	52.4	81.4	96.2	68.8	44.6
Series10	59.4	94.4	108.2	79.8	50.6

Chipmunk response is linear with number of protons lost



An expected result

TLMs also have linear response!



A required result

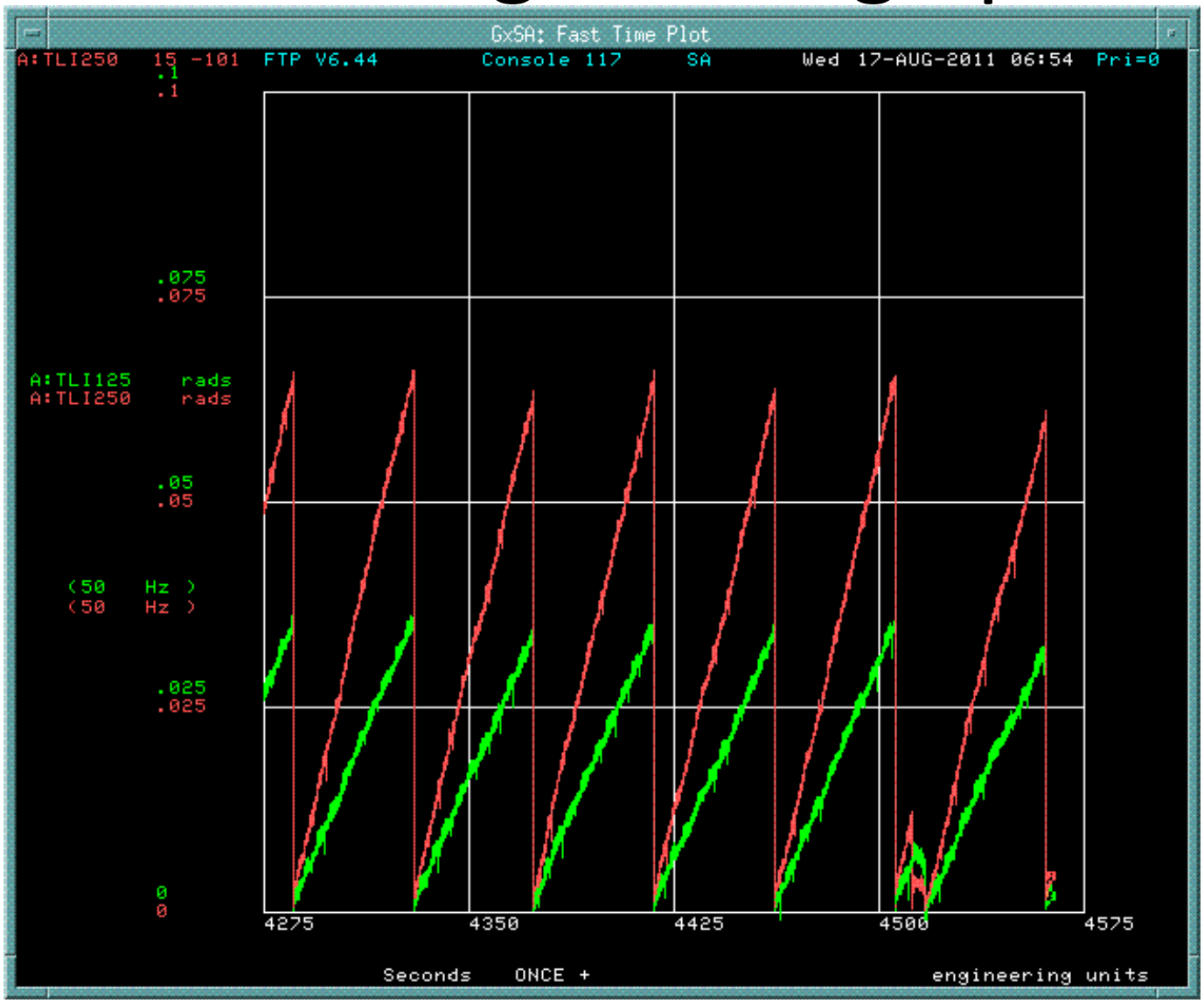
NOTE!
125 foot response exceeds 250 foot response

250' TLM response = 70%*125'response

TLM response as a function of length

- Need another TLM installed to determine this!

During stacking operations

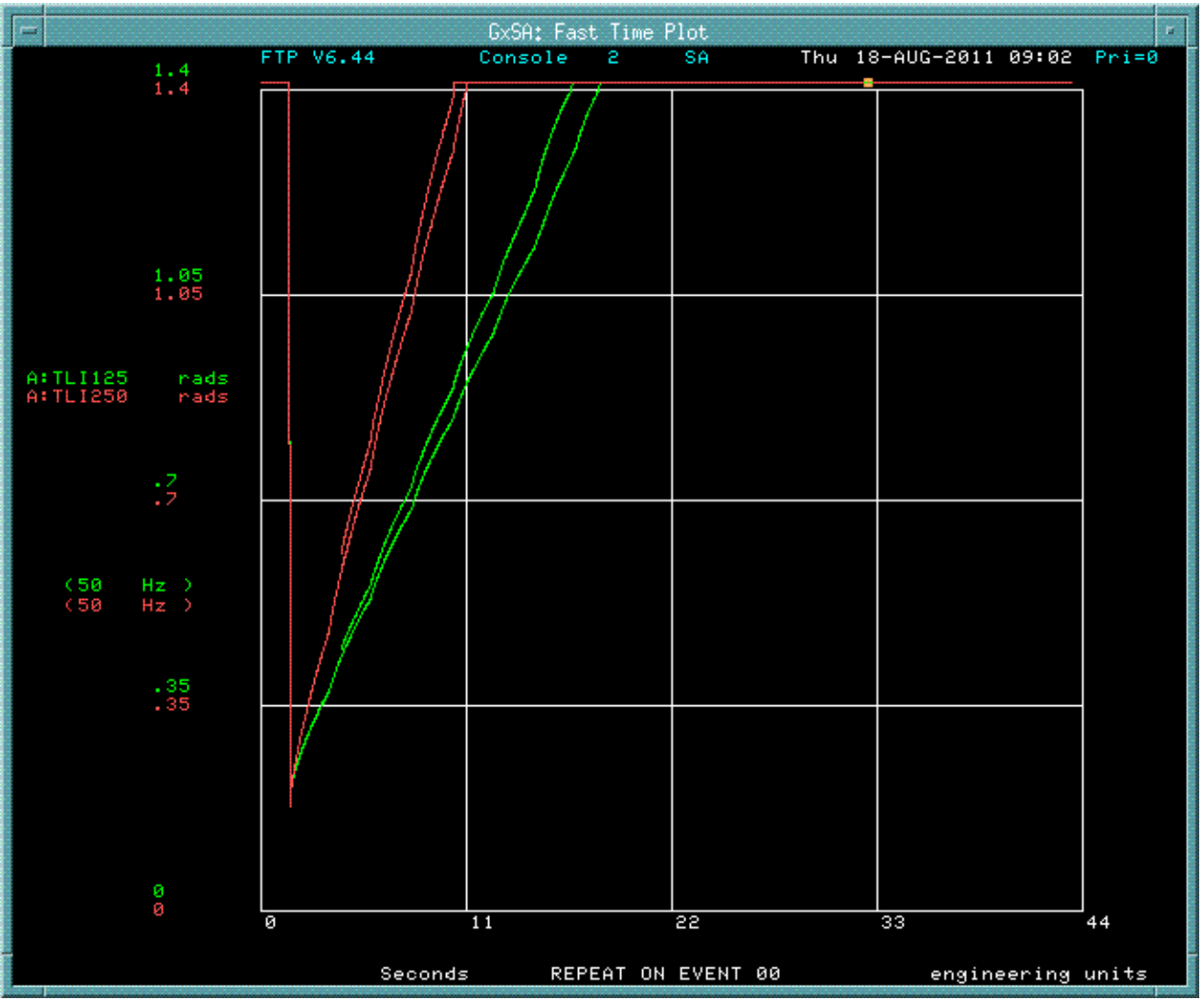


250’ cable response exceeds 125’ response during normal stacking operations

Could be losses in the second half of 250’ TLM not seen by 125’ TLM

A reverse proton cycle mixed in with stacking cycles

Tried reversing HV and signal roles of the TLM cable



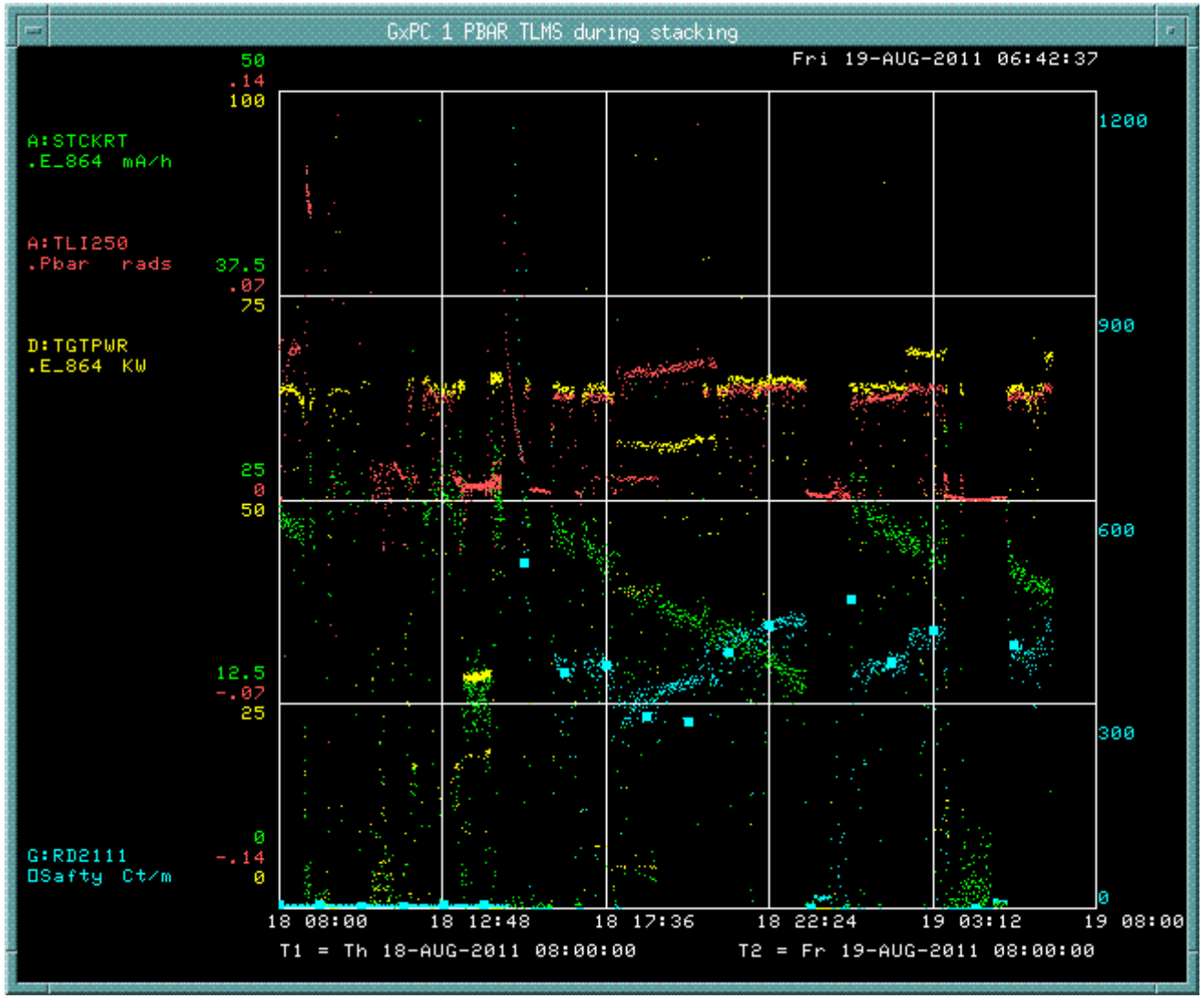
Huge apparent increase in sensitivity

Perhaps should be repeated – ensure conductors are grounded before turning on HV

Blue box is in service connected to 125’ TLM

Blue box is in service connected to 125’ TLM

Blue box is in service connected to 125’ TLM



5 pC/count

Follows BLM card response on 250’ TLM

Next steps (1 of 3)

- Install VME scalar for higher counting rate from blue box (1 kHz)
  - MUX good for 70 Hz
  - VME scalar good for 15 kHz
- Repeat series of measurements with blue box and BLM chassis two ways
  - Blue box/125’ & BLM chassis/250’
  - Blue box/250’ & BLM chassis/125’
  - Determine dynamic range requirement for digitizer circuit for TLM application

Next steps (2 of 3)

- Install third TLM of different length 103 m (338’)
  - Determine TLM response as function of length
    - Can’t do this with just 2 cables
  - Repeat measurements (5 Booster bunch increments)
- Determine how AD instrumentation can make additional blue boxes
  - In collaboration with ES&H Section
  - Would help to speed up development of this resource

Next steps (3 of 3)

- Distributed loss study
  - e.g., Scrape at ELAM with Accumulator bend bus off (October 2011?)
- Determine blue box trip levels for 14 TLM cables required for mu2e
  - Needed to finalize radiation safety plan for mu2e