Optimization of the Booster Notch System

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APT Talk

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Booster Beam Notching

- Purpose of Notching
- Background
- Implementation
- Performance
- Modifications
- Current Operations
- Future Plans

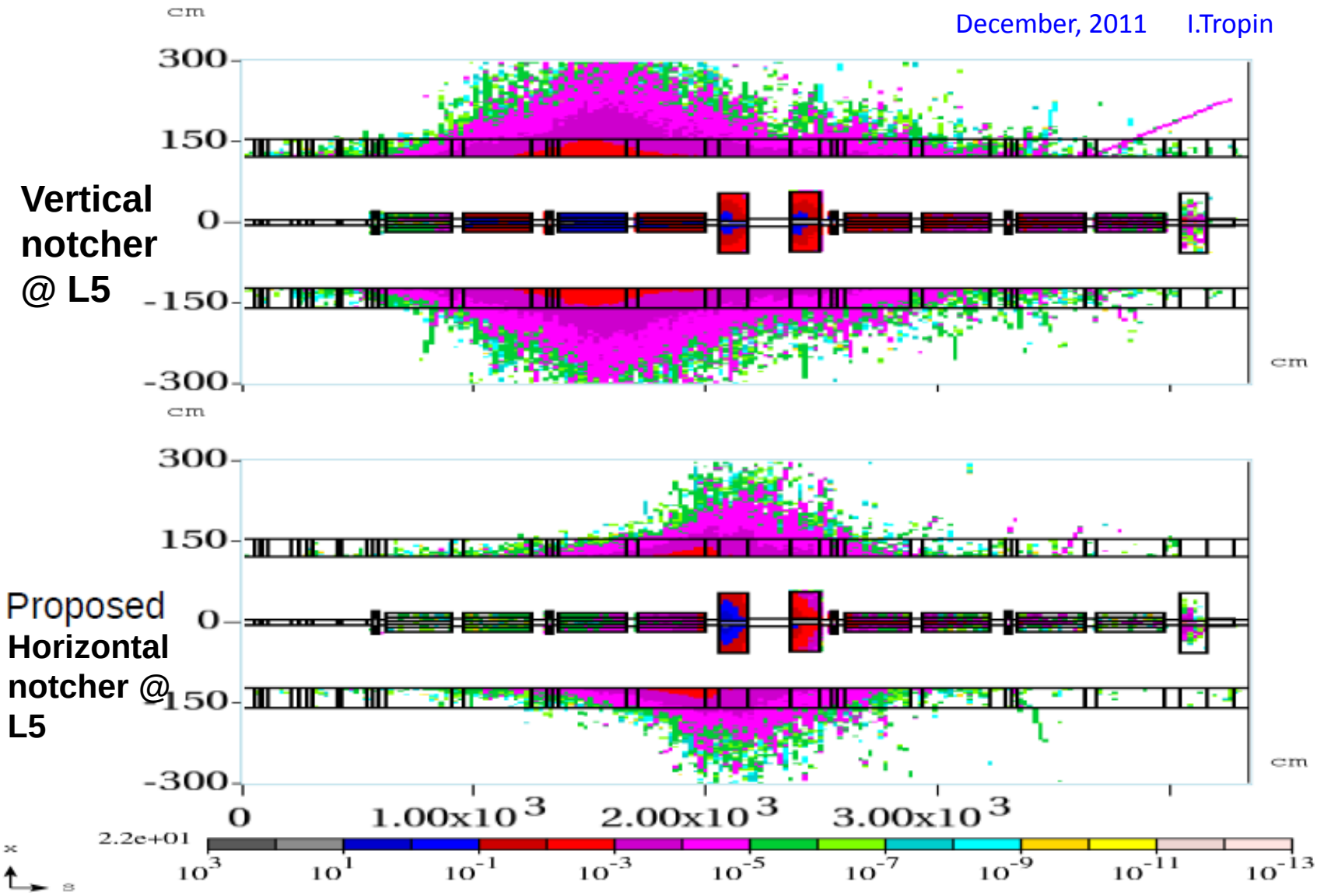
Purpose of Notching

- Notching is planned removal of selected proton bunches to facilitate a gap in the beam at extraction time.
- This gap allows the Booster extraction kicker magnetic fields to reach full value to allow extraction of the remaining bunches. Only 2 bunches need be removed but due to bucket jitter in the transfer to MI/Recycler, a third is removed as well. Thus 81 bunches are transferred
- Without the gap or “notch” in the beam, the extraction kickers would displace these bunches in a non-controlled fashion causing losses in the extraction region at 8GeV.
- In the past “notching” was less critical due to lower beam intensities and lower beam duty cycles. Losses were tolerable.

Notching Pre-Shutdown 2012/13

- A 3 bucket gap is created using kickers located at Long 5 and Long 12
- Notcher – A High Voltage(55kV) Kicker at Long 5
  - Noker - Lower Voltage Kicker (20-40 kV) at Long 12
    - Used to clean out remnant notched beam in buckets at ~700 MeV due to Cogging operations.
- Beam is kicked vertically into gradient magnet dipoles at L5 and L12. Some notched beam reaches the collimator region at Long 6 and beam pipe mask at Long 13. This worked and was best option at the time.
- Non-cogged notched cycles occurred at ~400 MeV.
- Cogged notch cycles occurred at ~700 MeV to allow for cogging synchronization process.

December, 2011 I.Tropin



Residual dose profiles, vertical cross section (30 days irradiation/1day cooling, mSv/hr).

Option 3 was chosen for horizontal notching

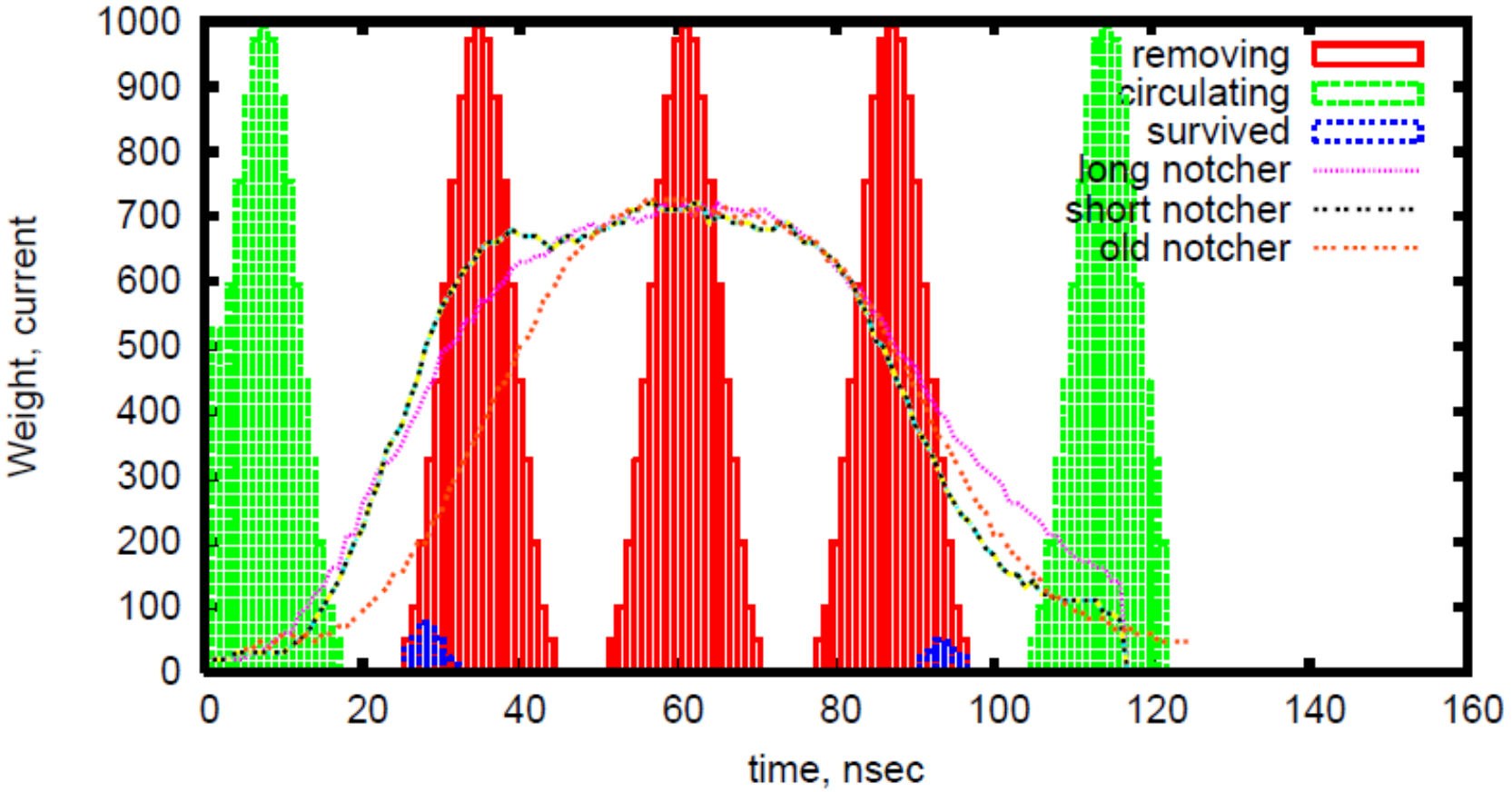
Conclusions

August, 2011 A.Drozhdin

1. One vertical notcher removes 87% of 3-bunch intensity, with 75% loss at pole tip of Booster magnets, 11% at collimator, and 0.5% on the rest part of the ring.

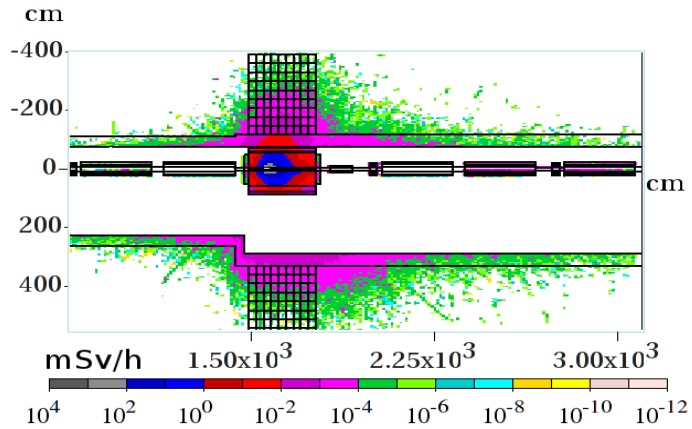
2. We propose to improve the notching efficiency and beam loss in the accelerator by rotating existing notcher and pinger by 90 degree, and increasing the aperture of Short-05 straight section from R57mm to R87mm. Using two horizontal notchers with shift of their pulses by +/-(4-7)nsec, is possible to remove 95% of 3-bunch intensity, with 93% loss at collimator and 2.6% on the rest part of the ring at 400 MeV.

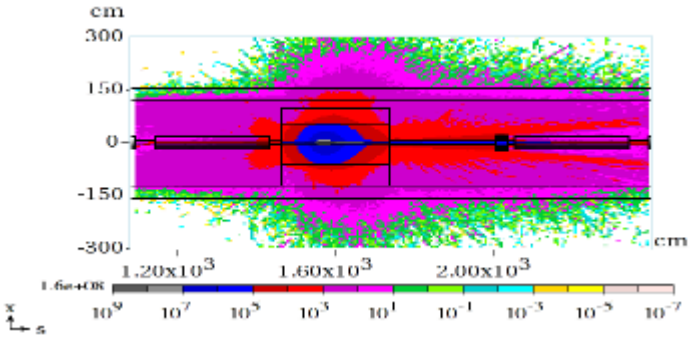
3. Using three horizontal notchers at Long-12, is possible to remove 98% at 400MeV and 94% at 700 MeV of 3-bunch intensity to the beam dump located at Long-13 straight section with increased aperture of Short-12 section to R87mm by aperture displacement to dX=20mm.



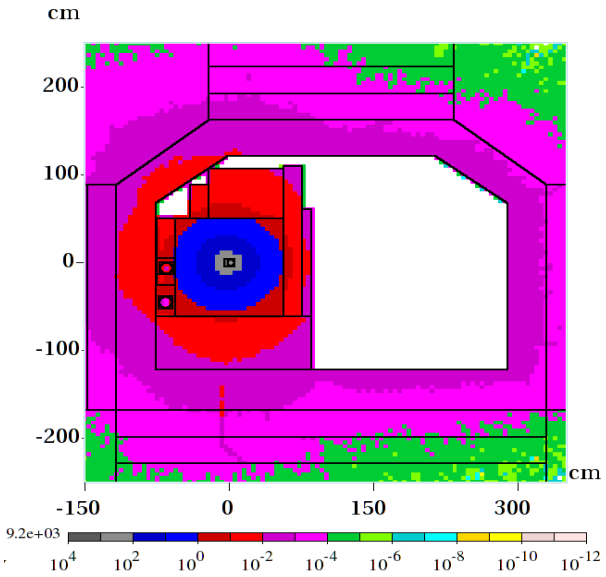
Longitudinal distribution of 3 removing (red), circulating (green) and survival at notching (blue) bunches, and long (1.08m) and short (0.54m) notchers waveform at Long-13, and 1.08-m notcher waveform for Long-05 straight section.

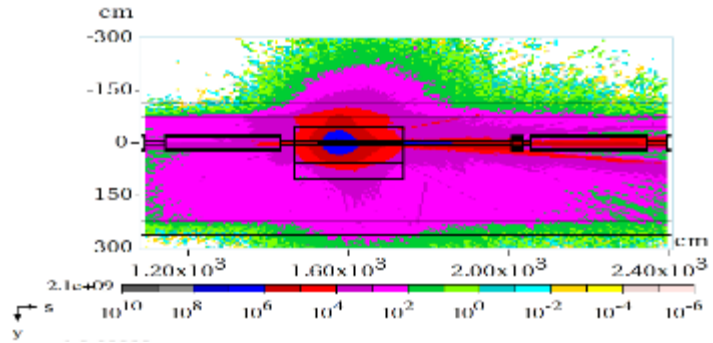
Long-13: Loss Simulations For Horz. Notching





Side view



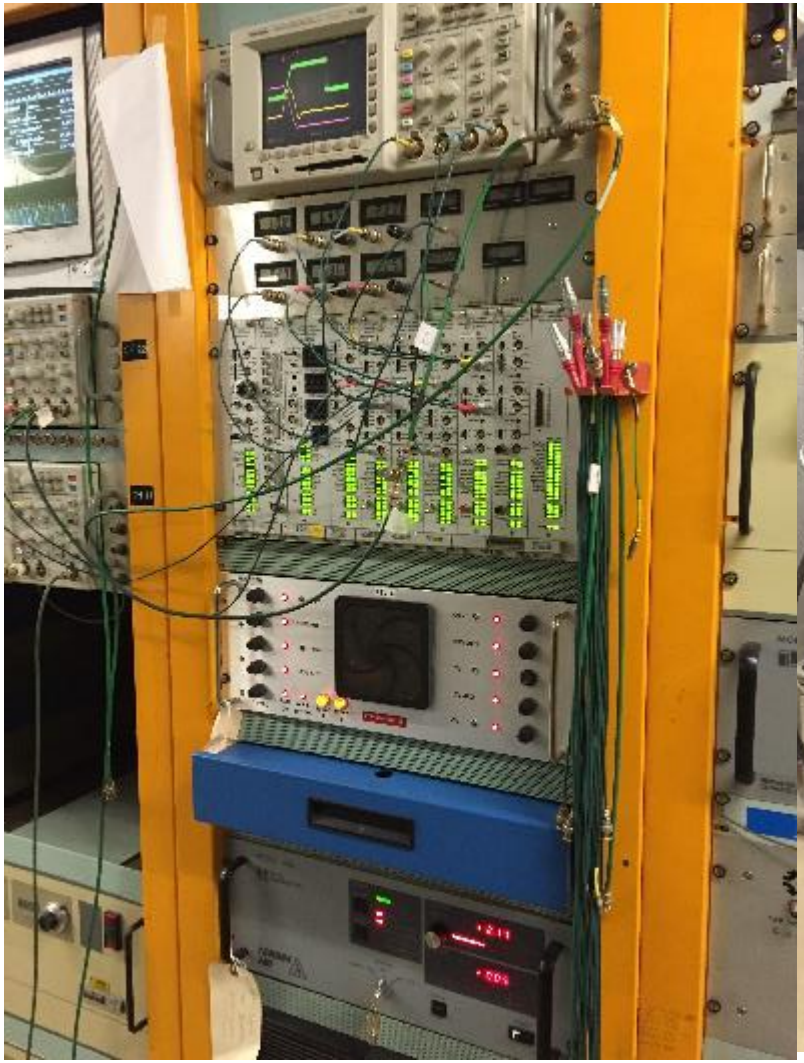


Top view

Implementation

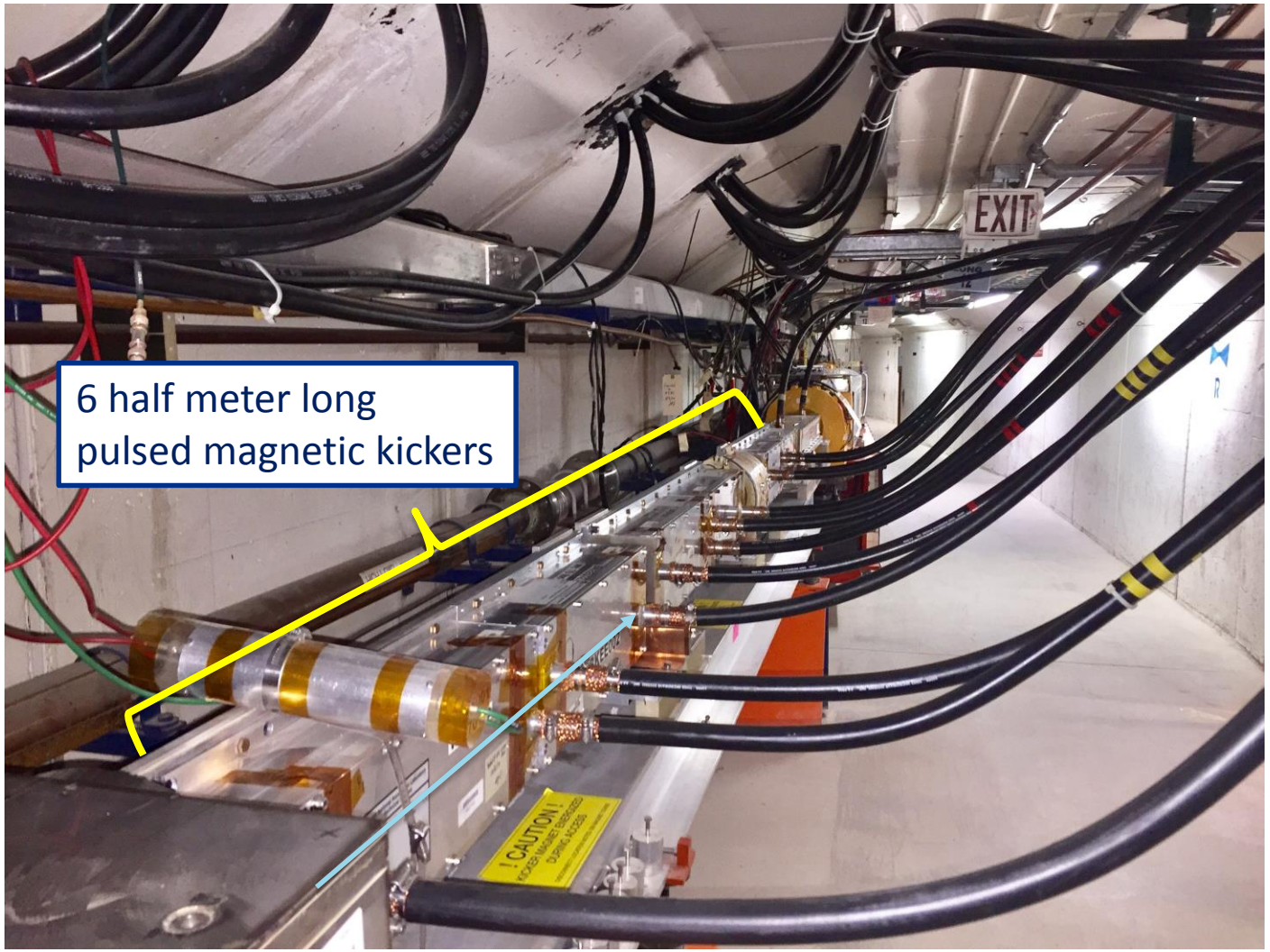
- Simulations for horizontal notching concluded that 3 kickers could be utilized to send beam between the 400-700 MeV energy range to a dedicated absorber.
- An ideal location would be L13 as this had the available space. L12 also had space for the notching magnets.
- Modifications where made to the standard S12 corrector spool to allow additional aperture.

Notching Pulser System using 2 CX2610 pulsed thyratrons

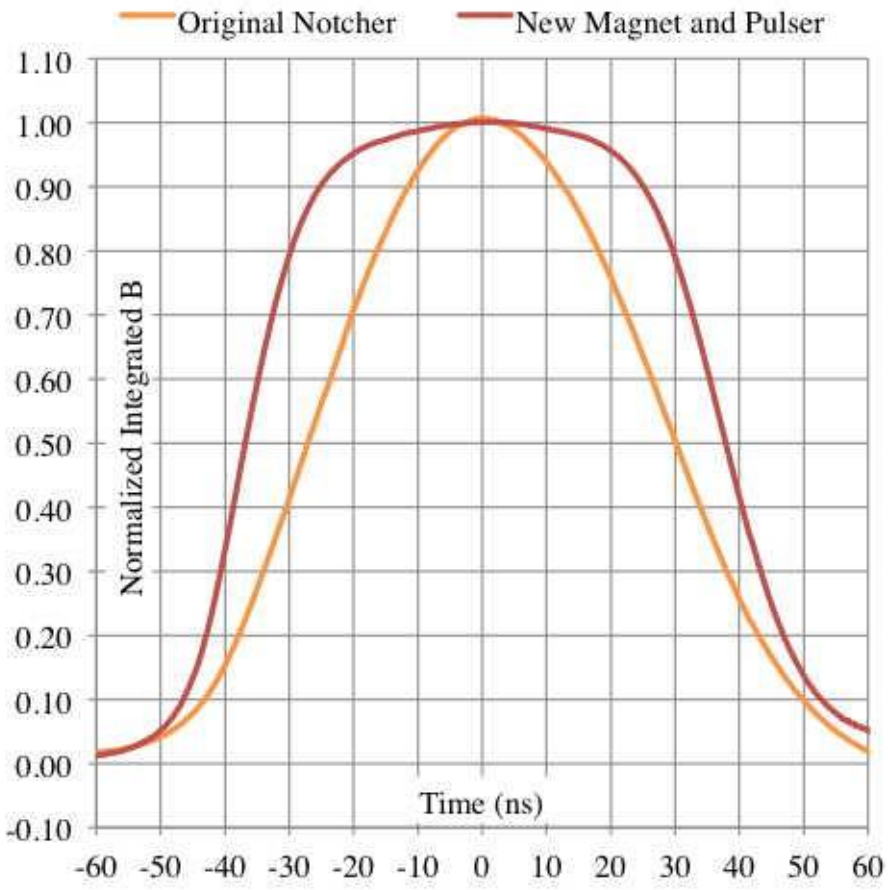


Fermilab

L12 Straight section



New Pulser system has faster rise/fill time



Long 13

Notched beam absorber

Used for clean-up of vertical notched beam L13

Dedicated L13 Notch Absorber

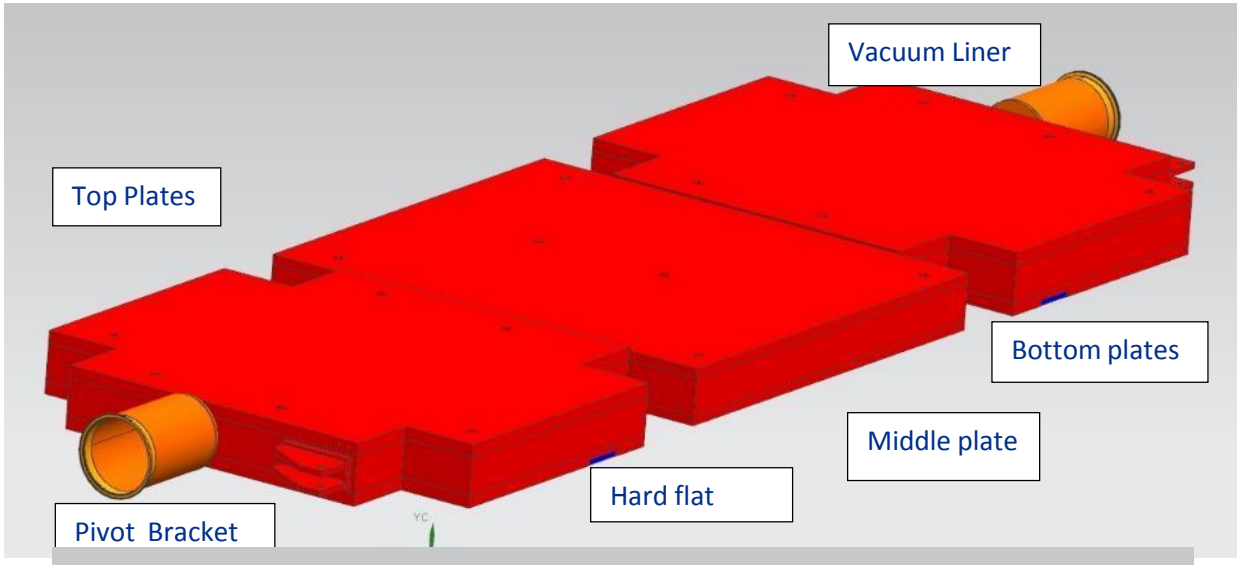
Long 13

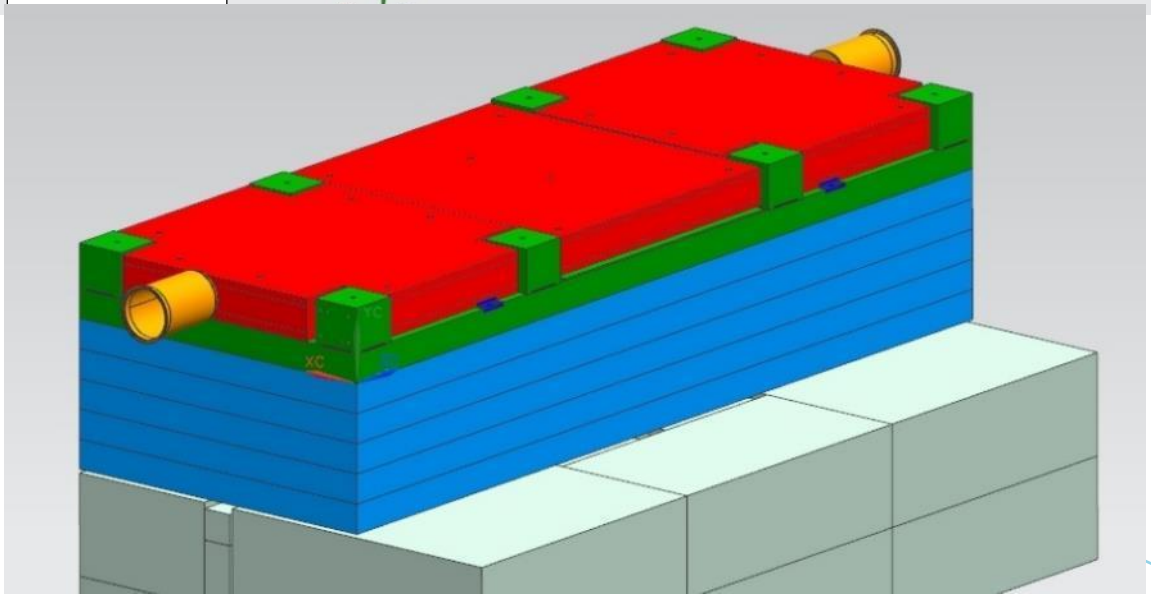
Former vertical notch clean-up area

Long 13 Notched beam Absorber downstream view

Absorber Moving Liner

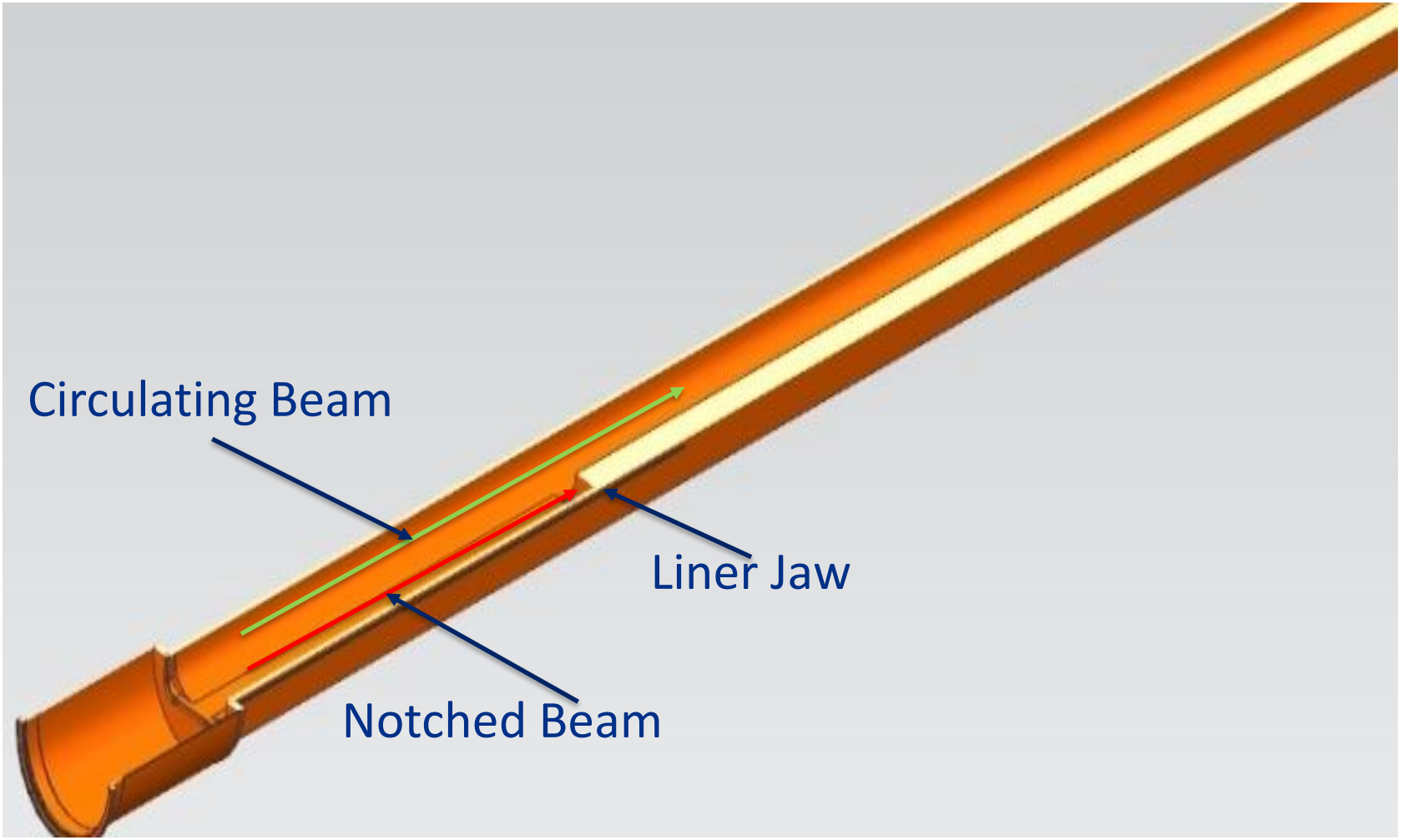
V. Sidorov



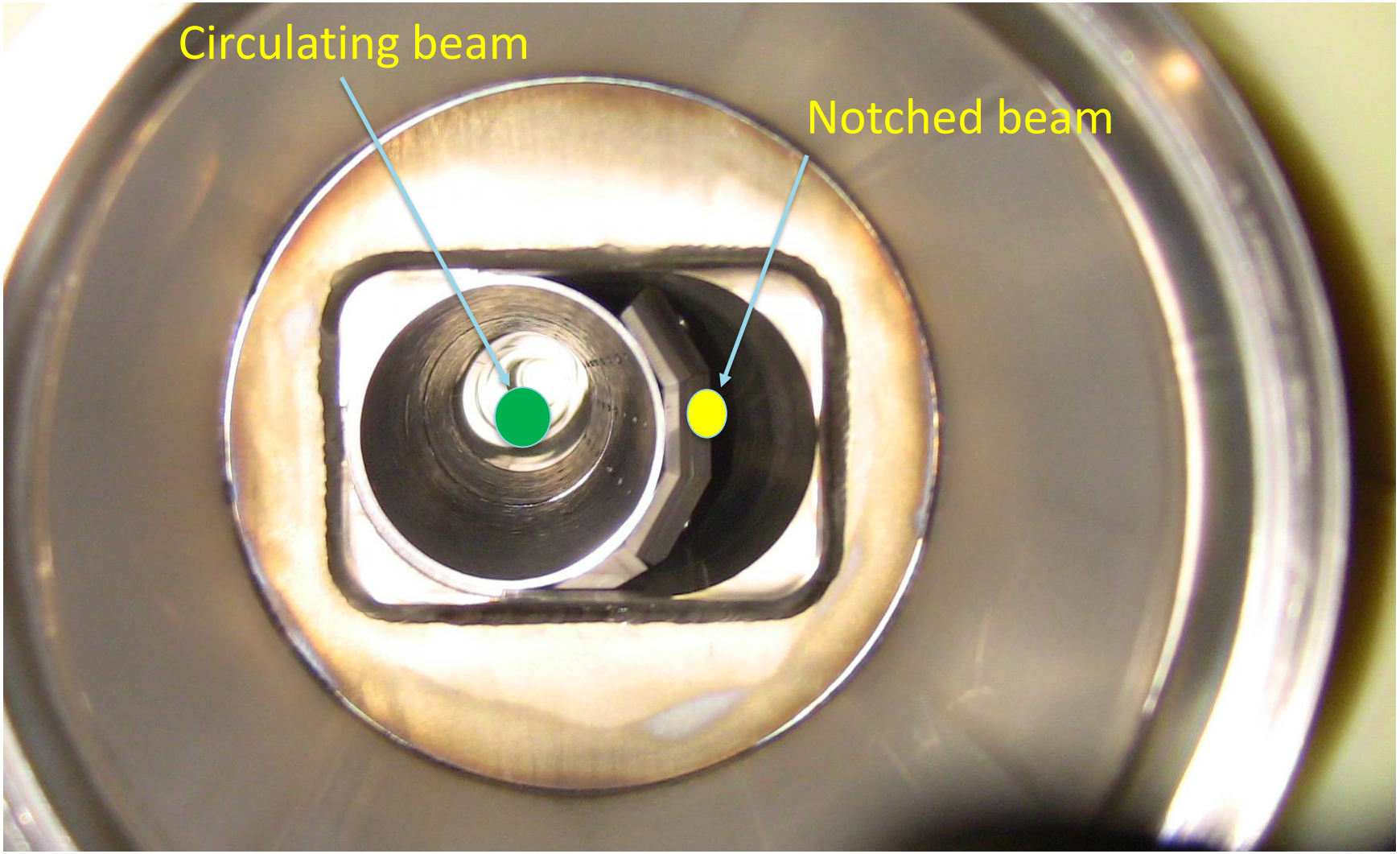


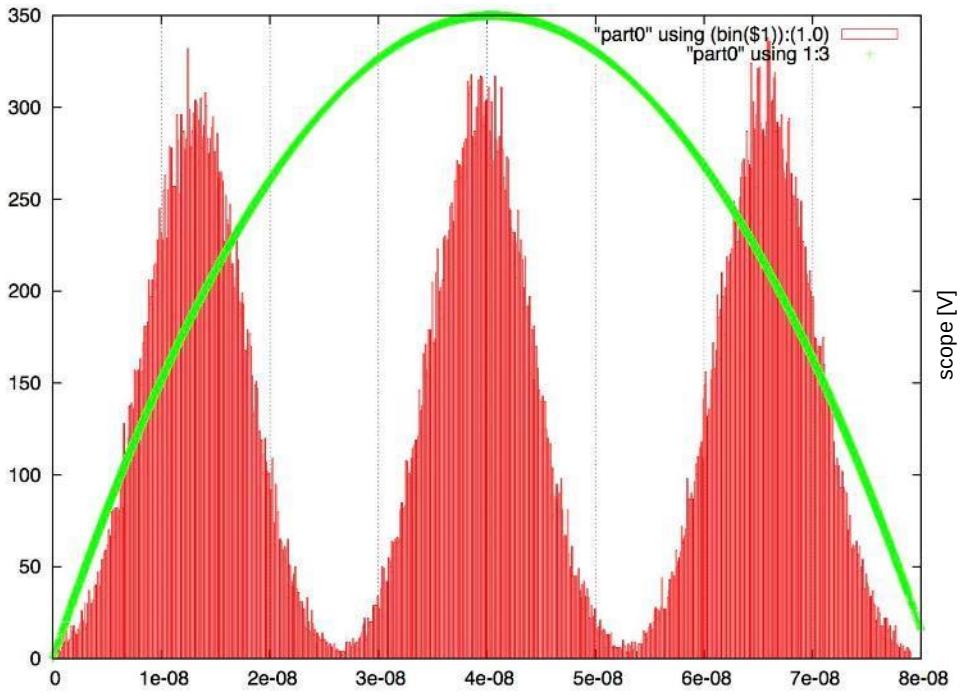
First Liner modification section

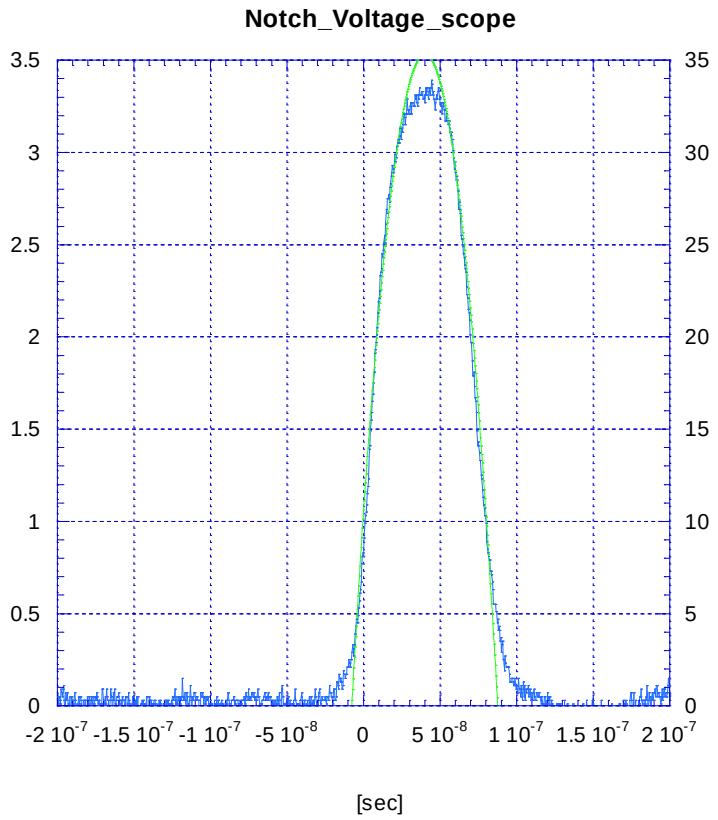
V. Sidorov



Notched Beam
Absorber Liner with 12” insert



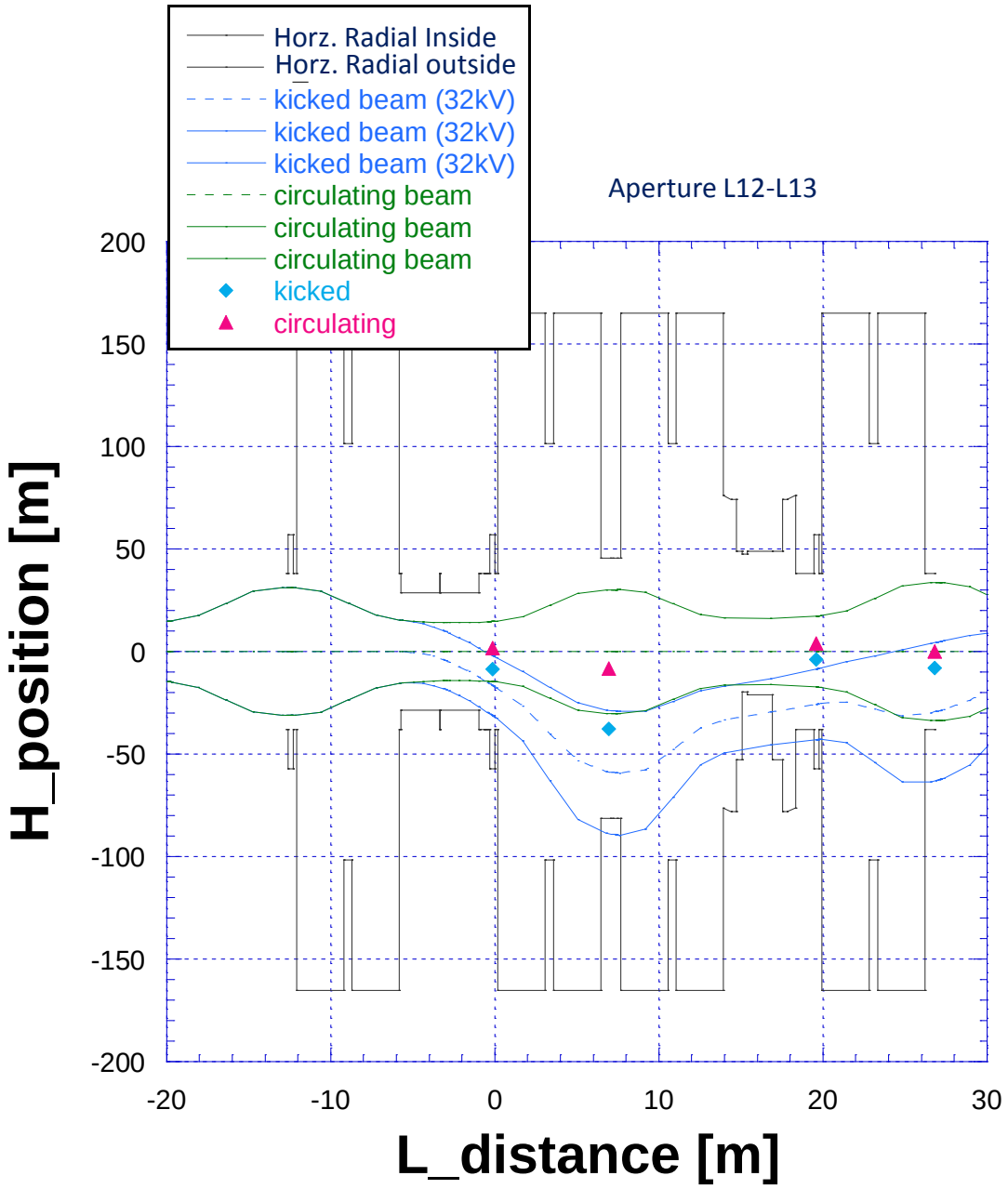


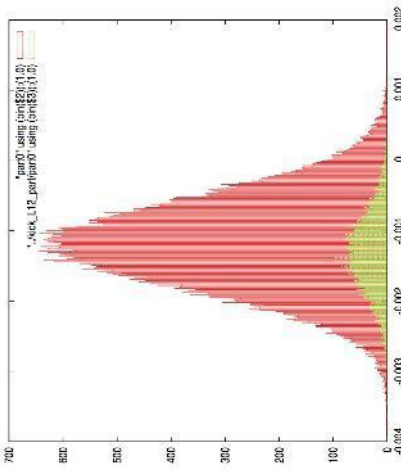


Bunch length: 4.5 nsec @ 1 sigma

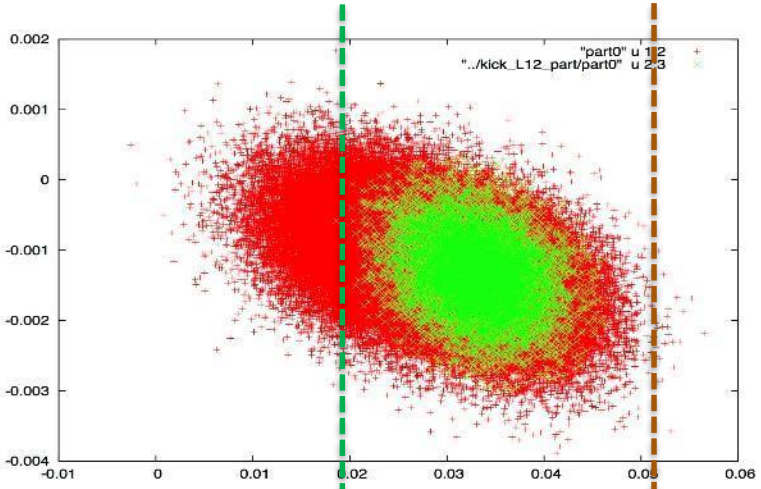
dp/p: 0.0011 @ 3 sigma

Notcher voltage: 34 kV @ peak

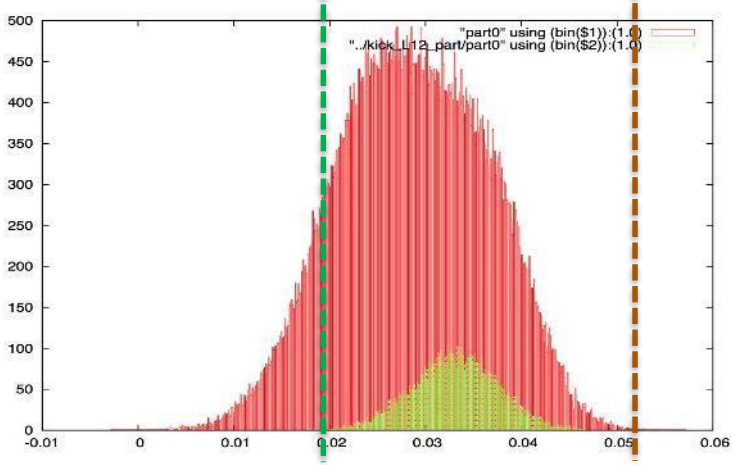

Horz. Radial Inside
Horz. Radial outside
kicked beam (32kV)
kicked beam (32kV)
kicked beam (32kV)
circulating beam
circulating beam
circulating beam
kicked
circulating
Aperture L12-L13
H_position [m]
L_distance [m]
200
150
100
50
0
-50
-100
-150
-200
-20
-10
0
10
20
30



X’



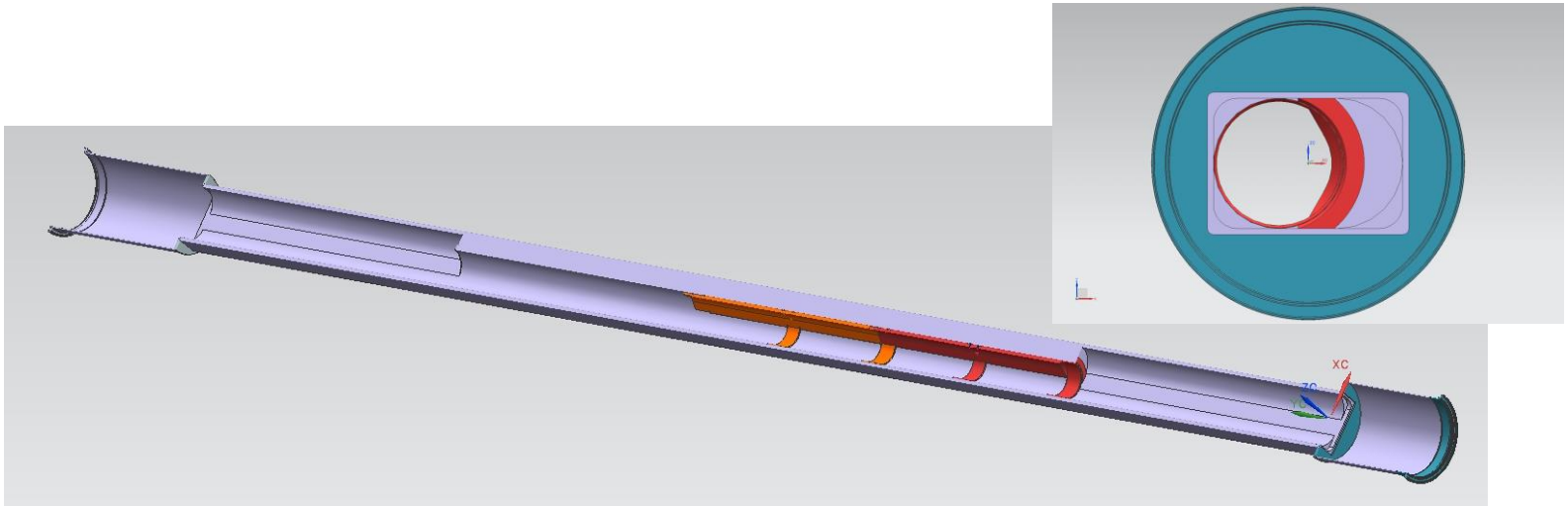
X



H_emittance: 16 pi mm mrad
V_emittance: 14 pi mm mrad
Size: 5 sigma

Absorber edge: 19.93 mm (set to 590 mils)Face: 51.69 mm

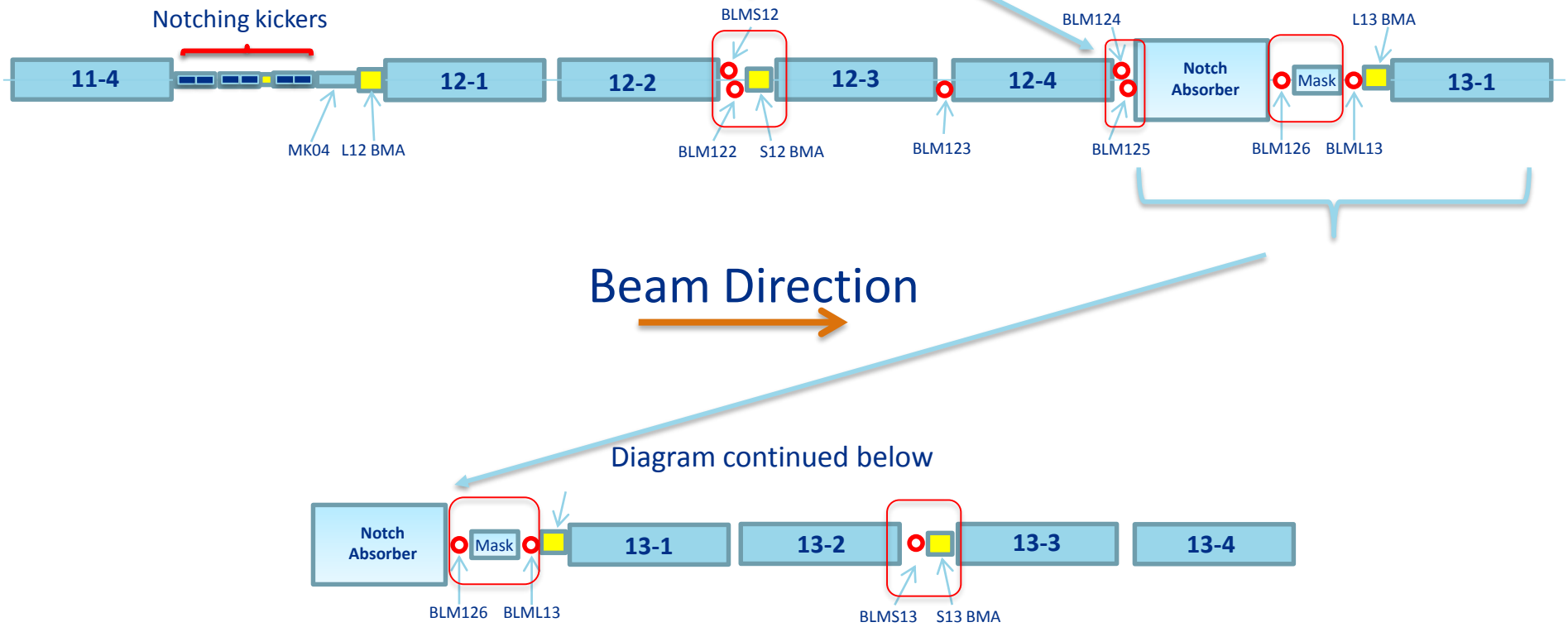
Second Liner modification Insert section



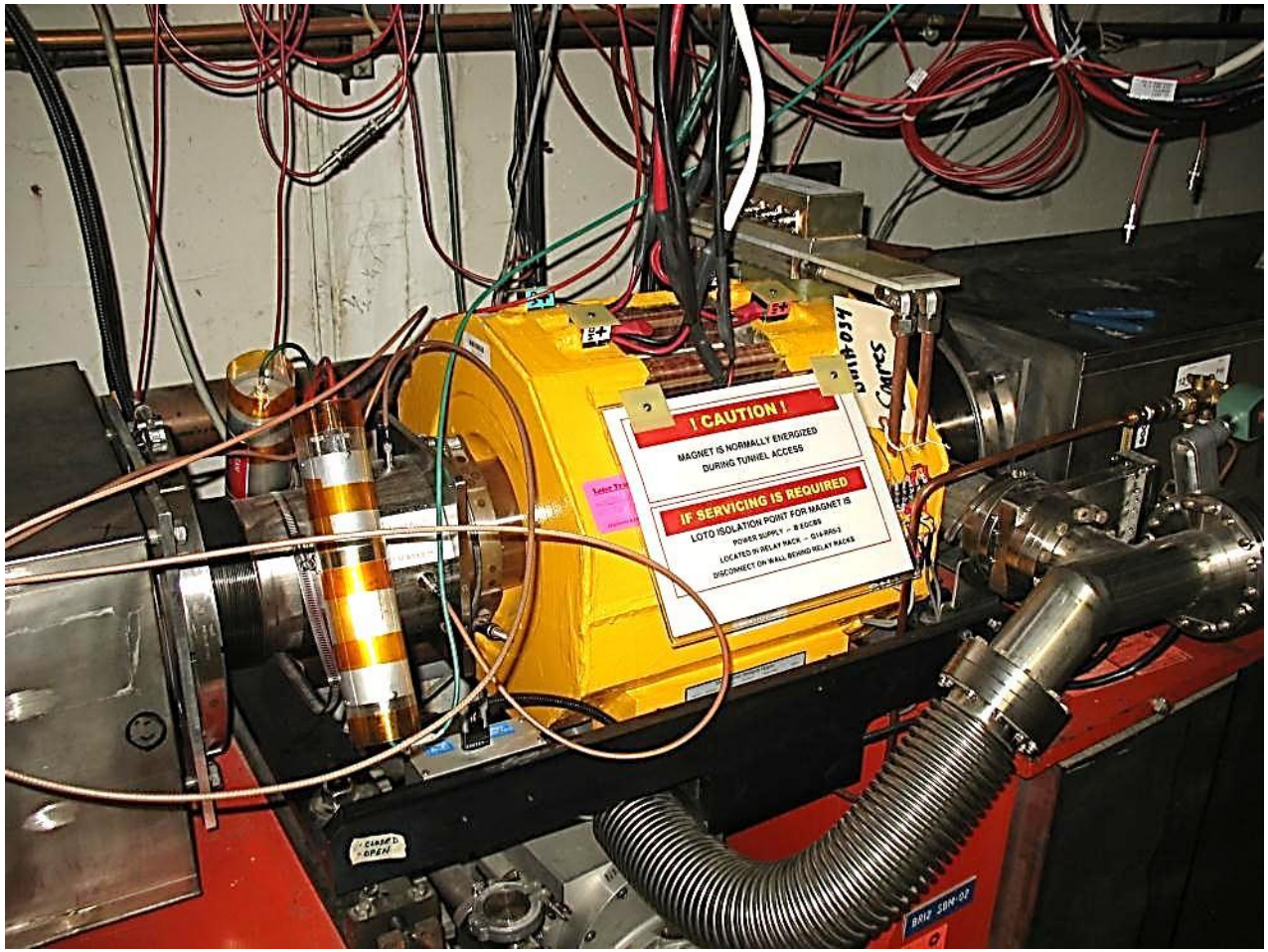
Areas of concern, in red boxes, due to notch losses.
They are managed but would prefer them lower

Notch Region

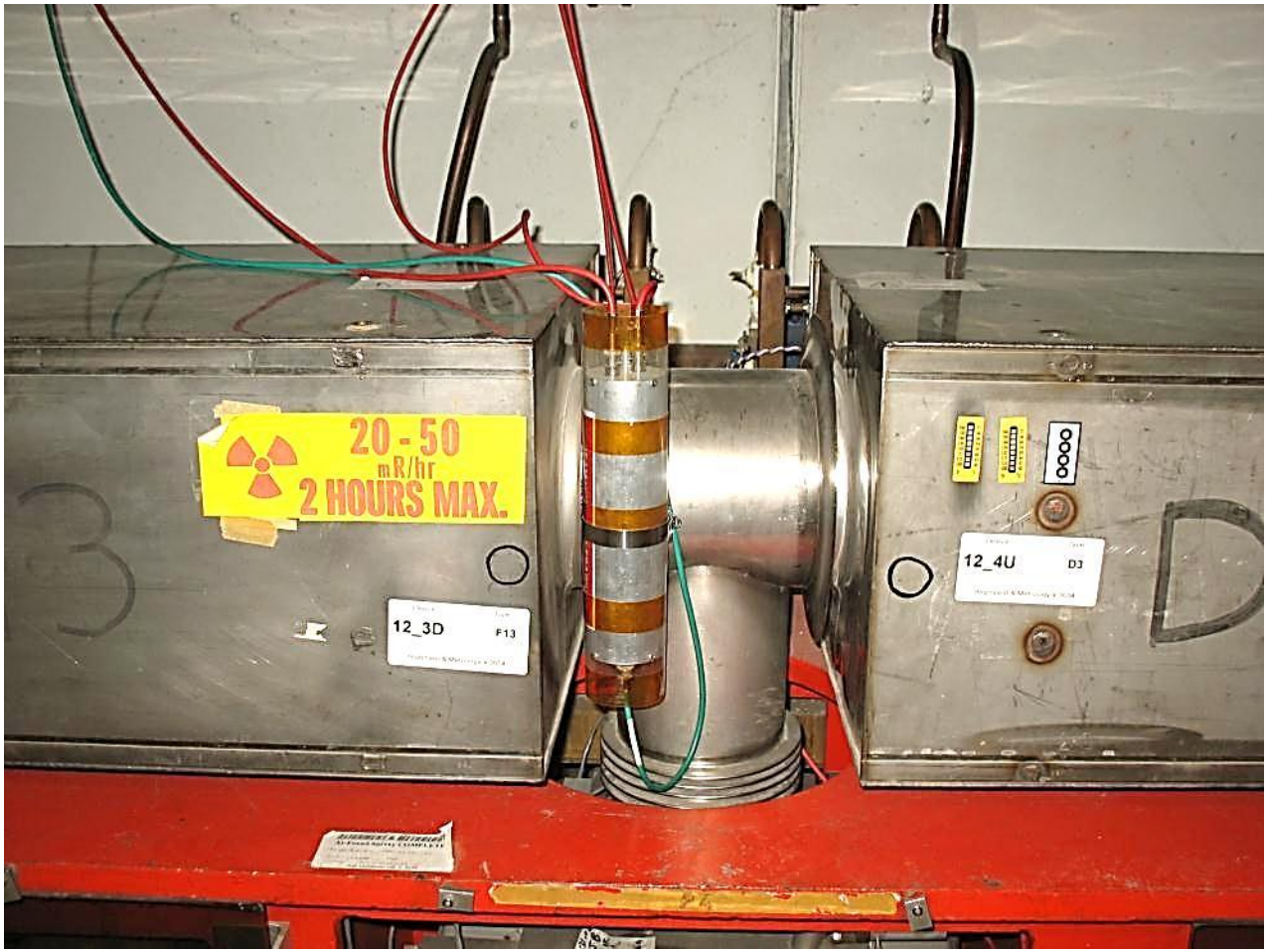
Top view of magnets



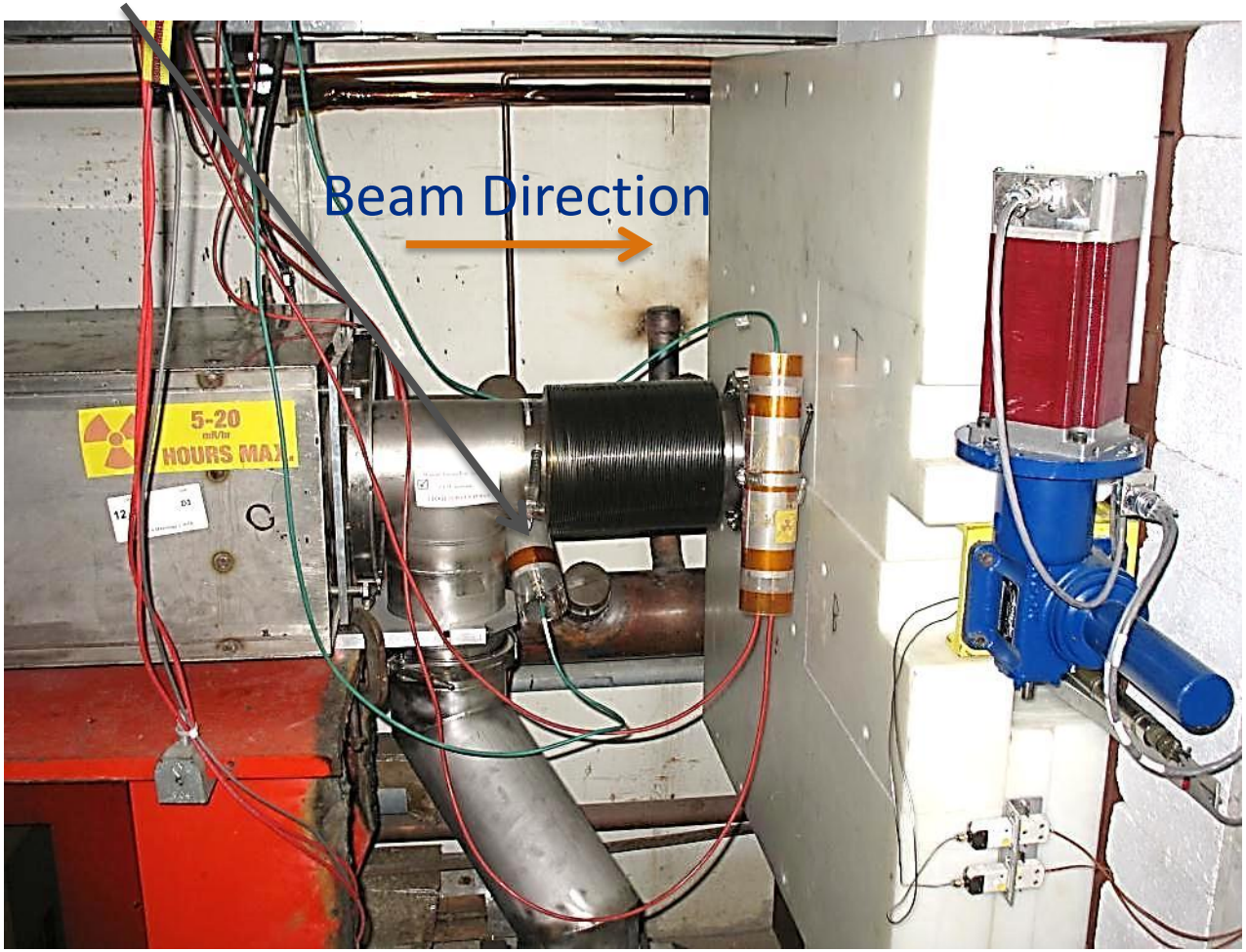
Short 12 Booster corrector with modified spool for Aperture



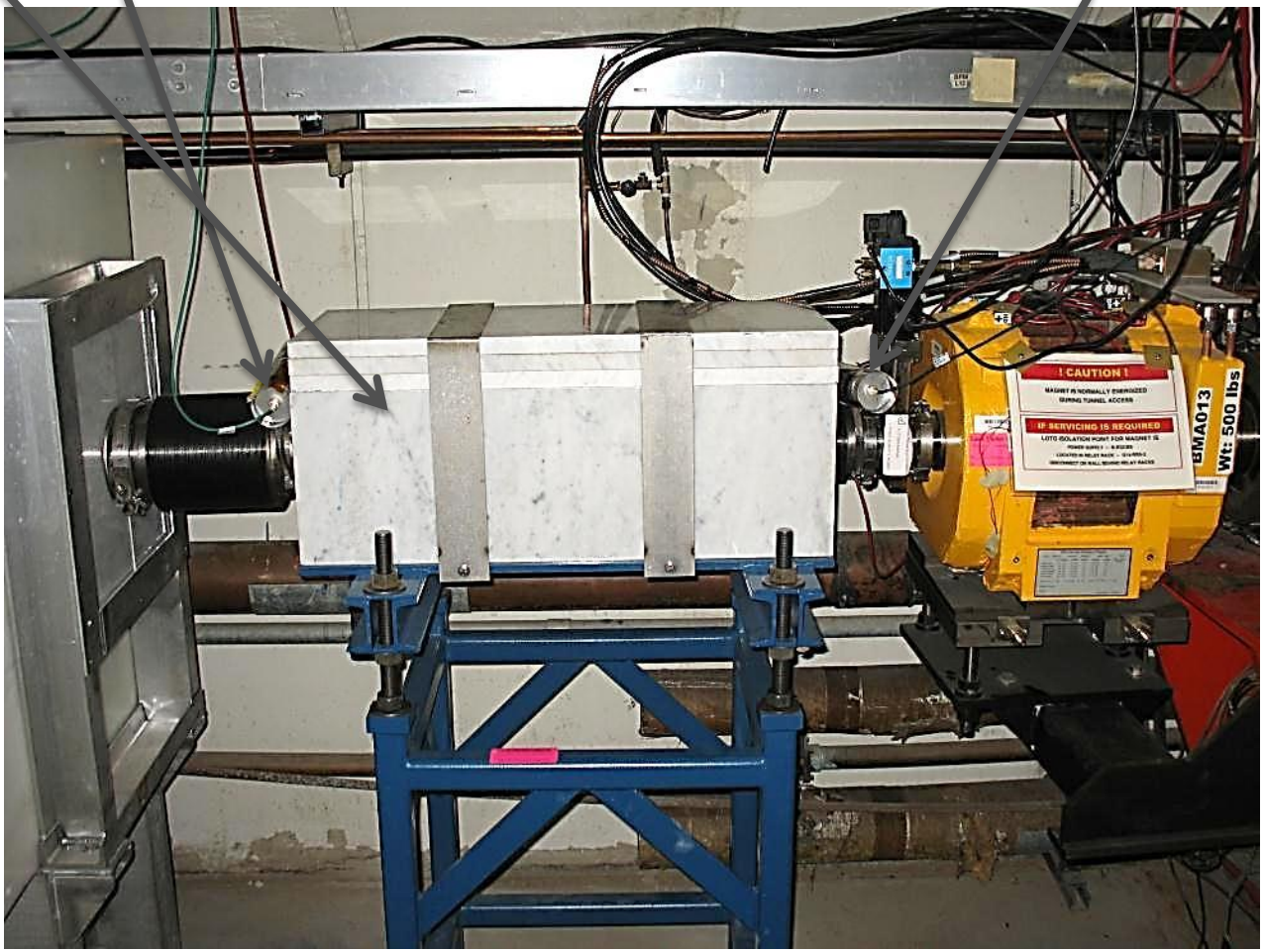
L12 Mini-straight



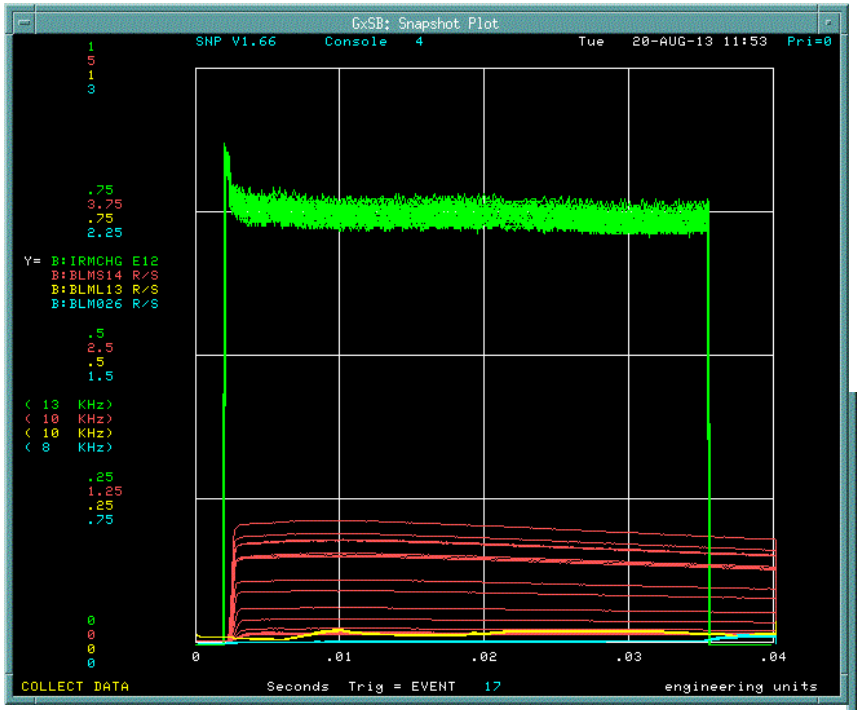
L13 Upstream notched beam Absorber

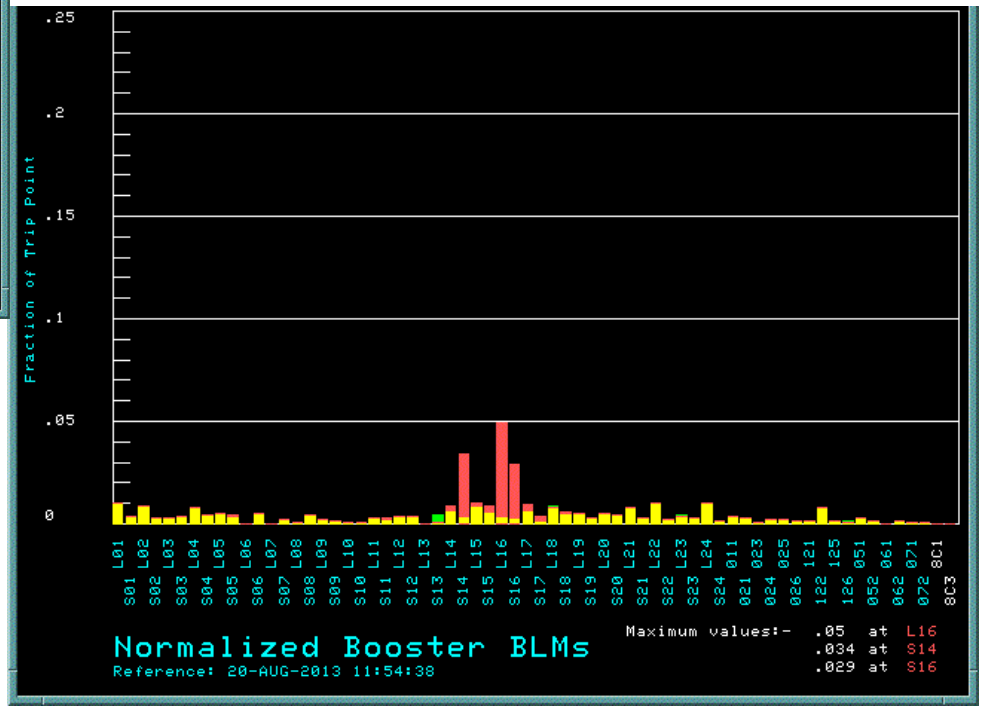


L13 downstream absorber mask

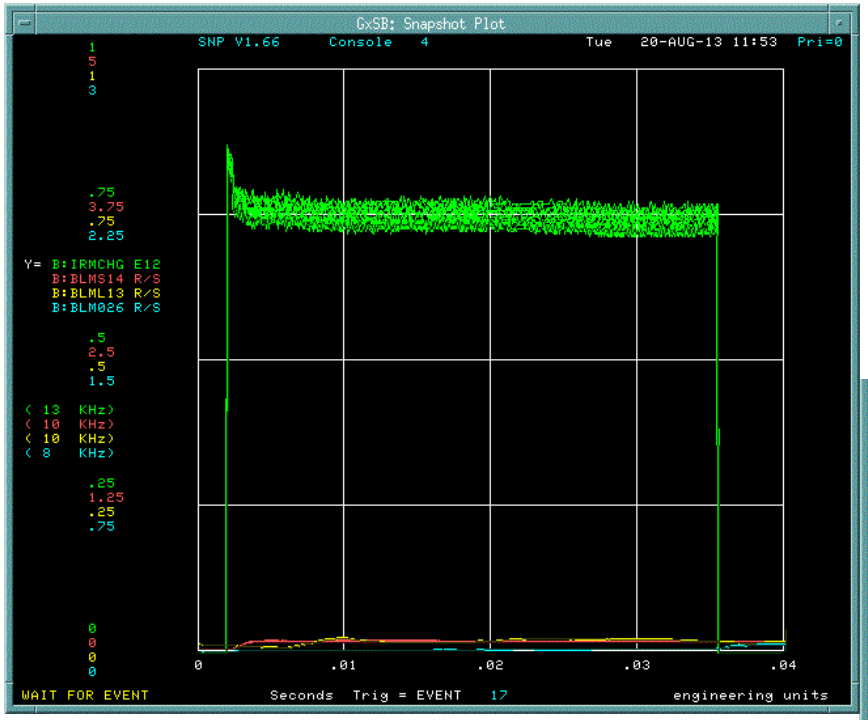


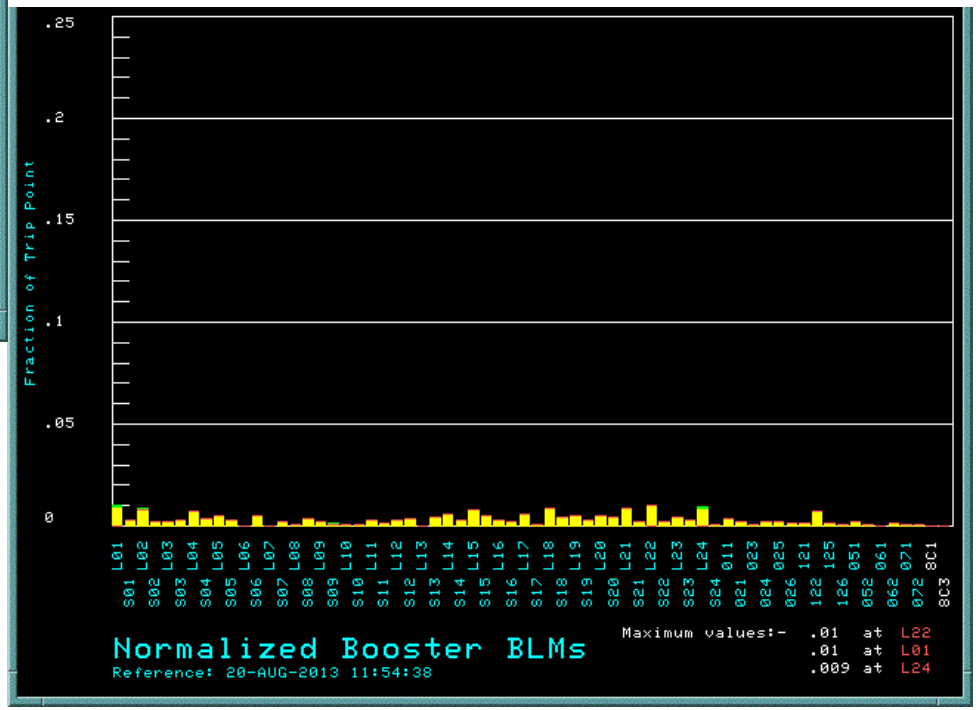
400 MeV Notched beam
Absorber Retracted





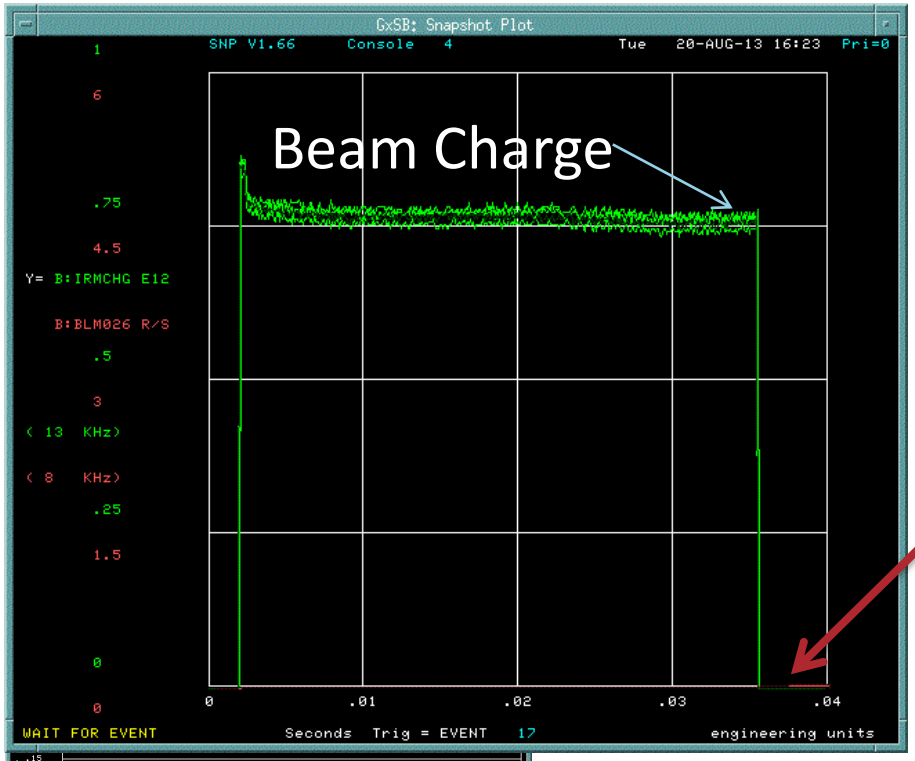
400 MeV Notched beam
Absorber in operational position

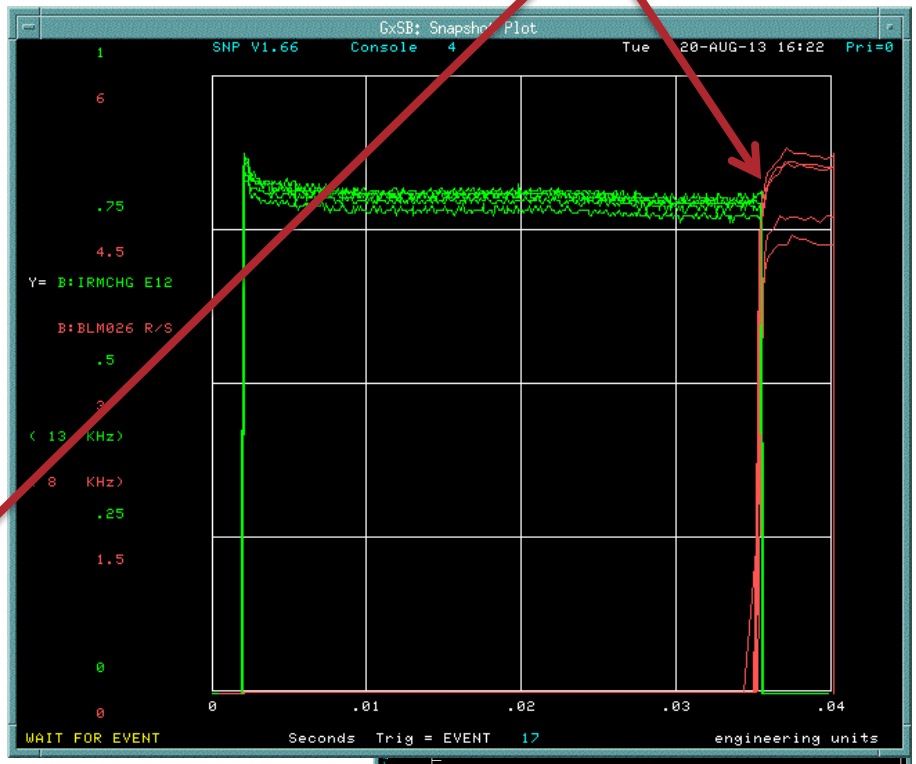


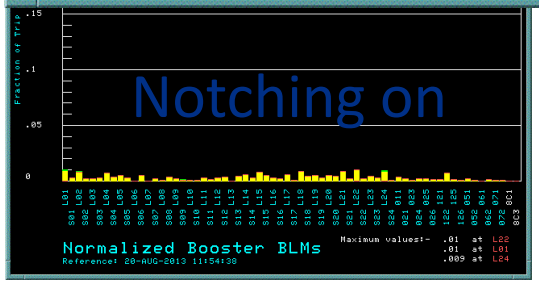


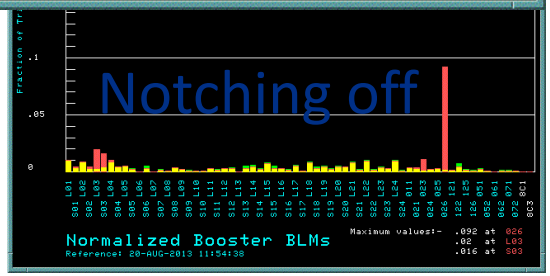
Notching turned On and Off

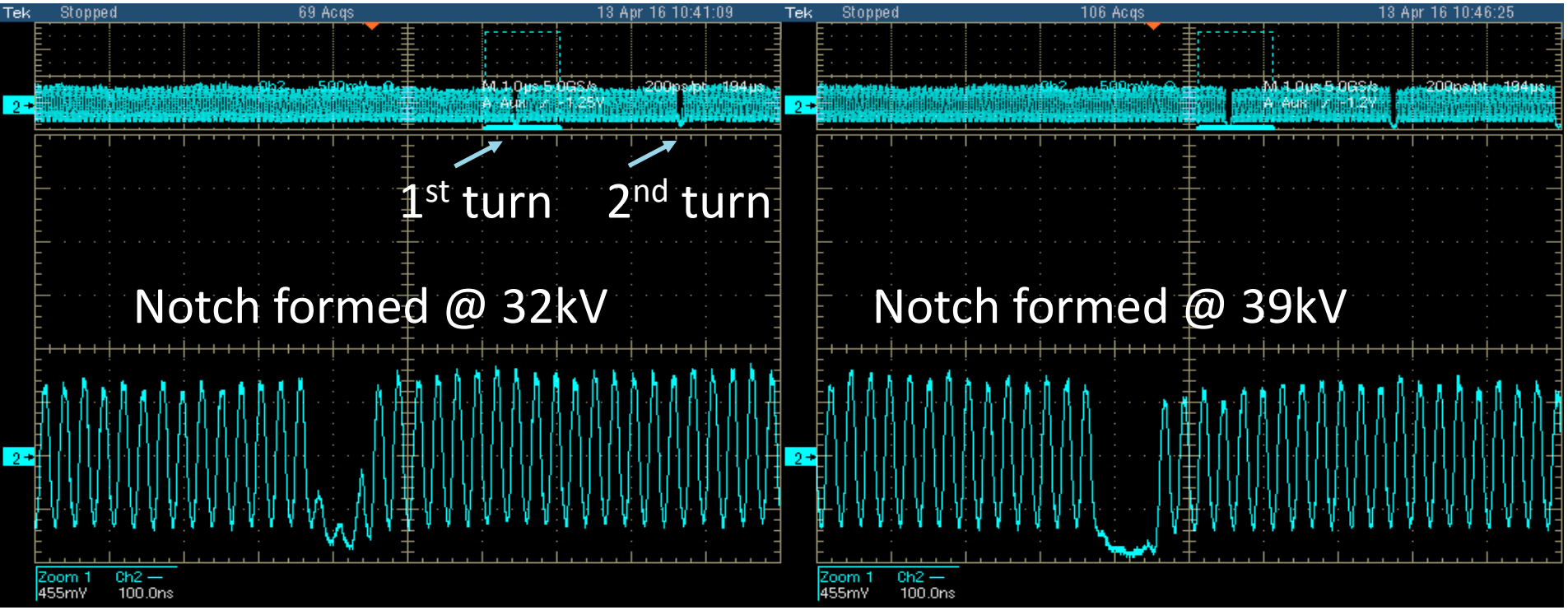
Extraction loss monitor



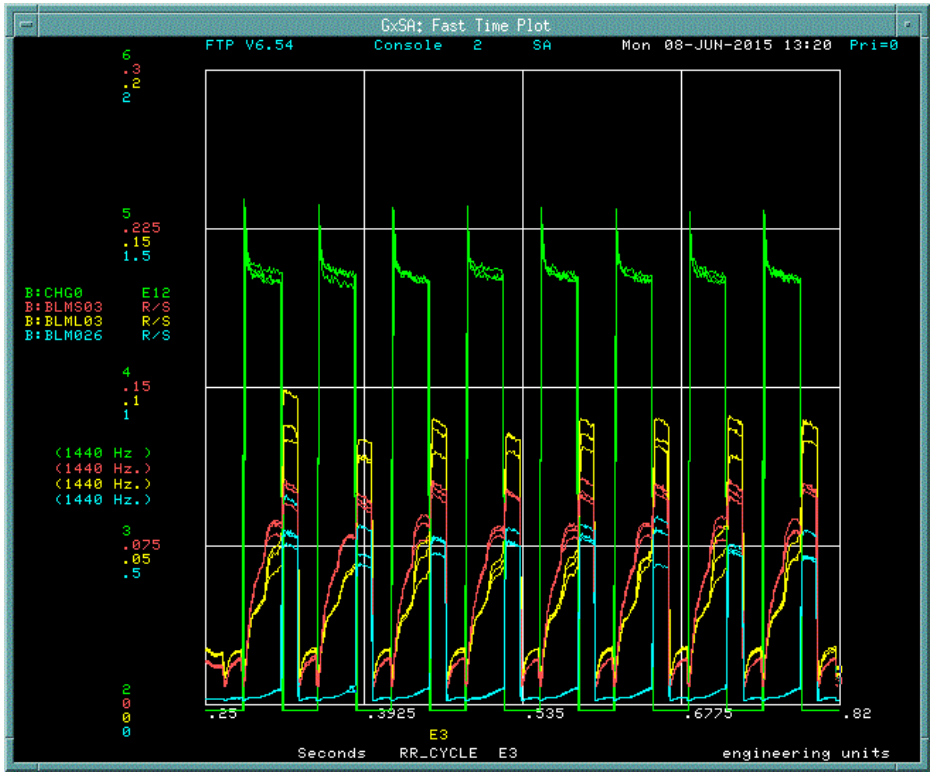




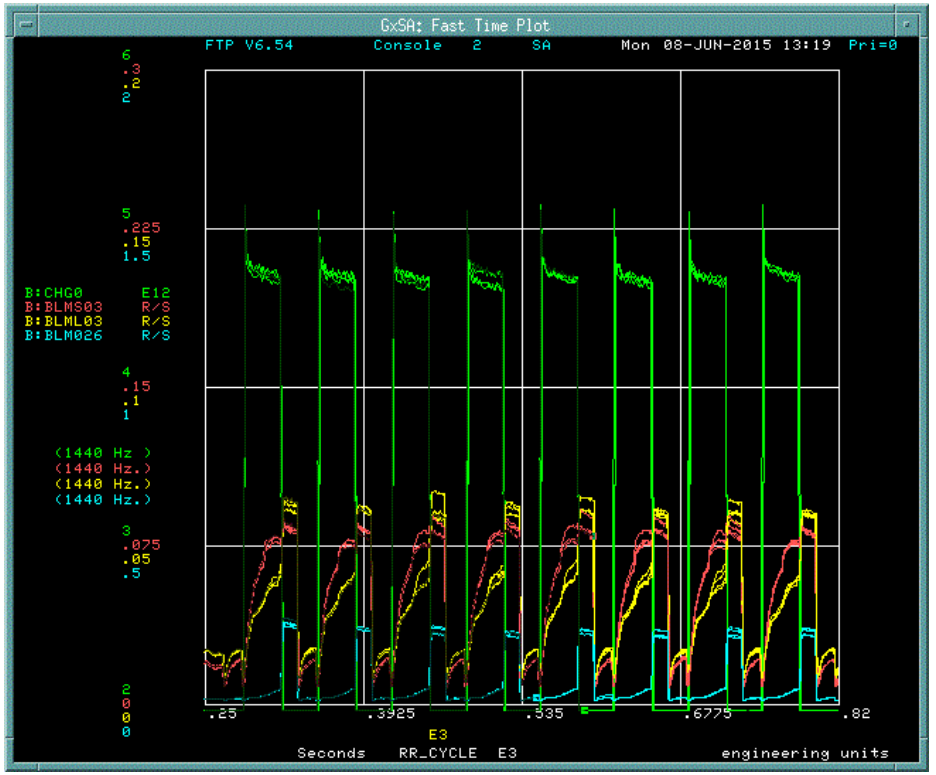



Tek Stopped 69 Acqs 13 Apr 16 10:41:09
1st turn
2nd turn
Notch formed @ 32kV
Zoom 1 Ch2
455mV 100.0ns
Tek Stopped 106 Acqs 13 Apr 16 10:46:25
Notch formed @ 39kV
Zoom 1 Ch2
455mV 100.0ns

Notch depth relative to extraction losses

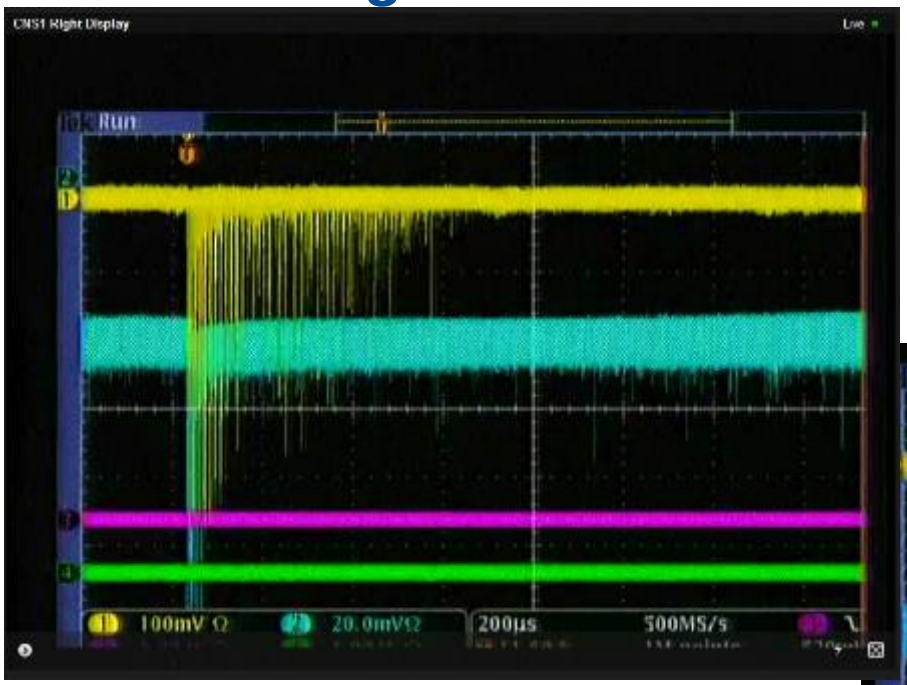


31kV kick



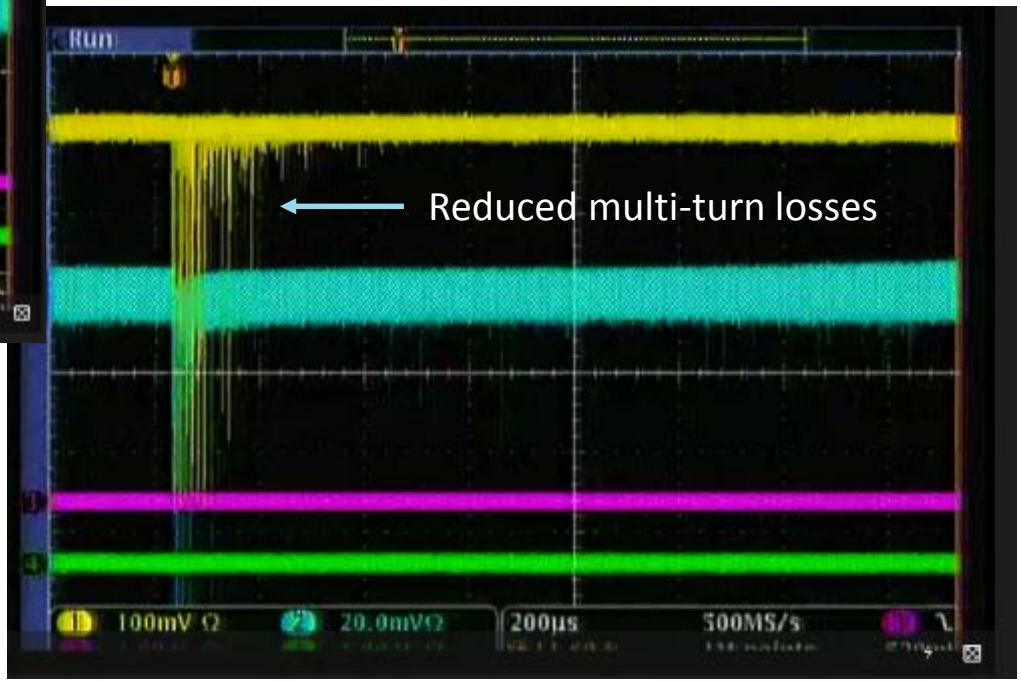
35kV kick

Fast loss Signals downstream of 5-3 and collimator 6b



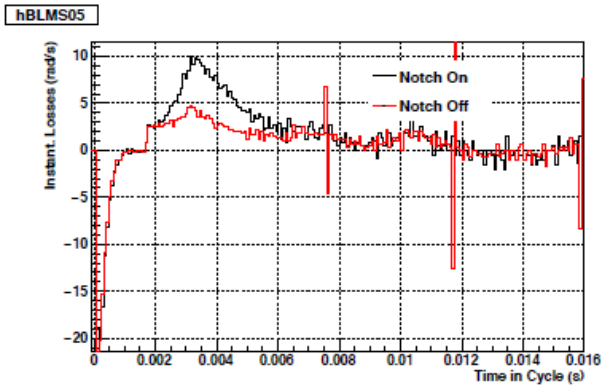
PMT signals

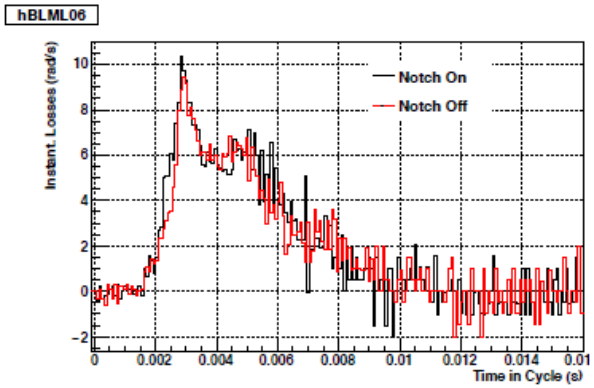
31kV kick

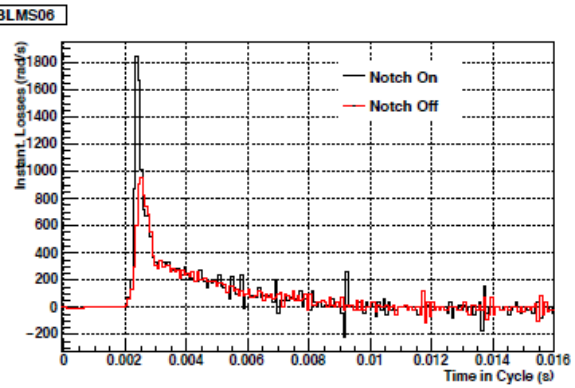


35kV kick

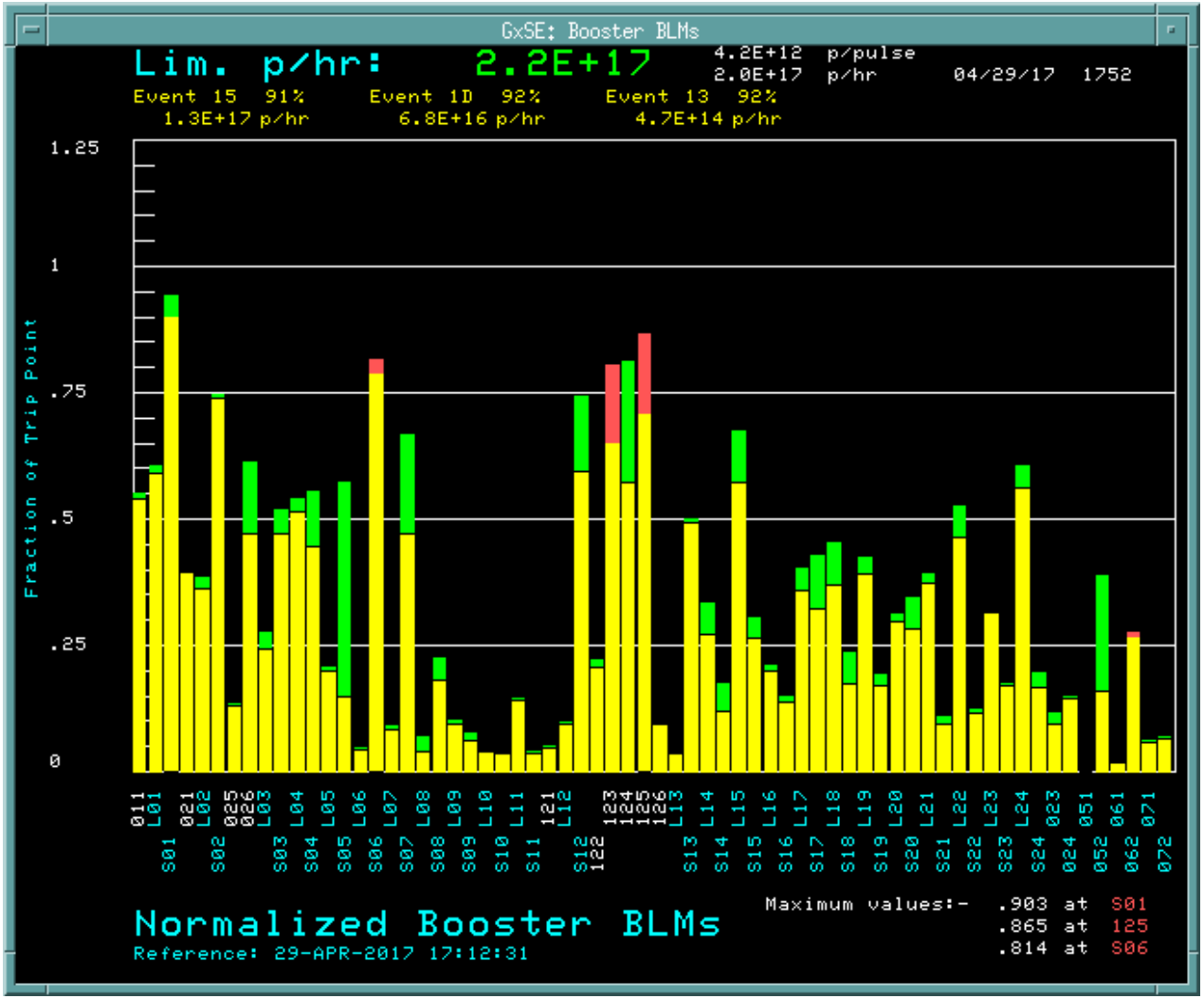
Losses at notch formation seen at other locations
Notch enabled and disabled for comparison







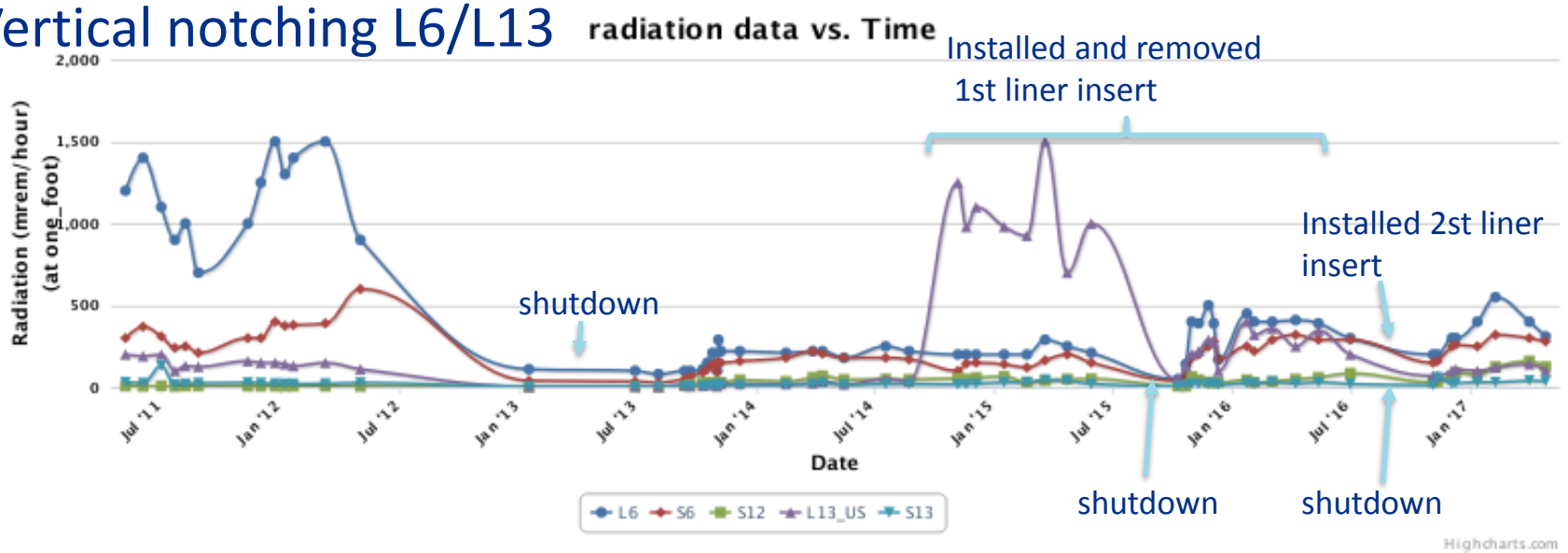
Notched loss difference when beam is aligned well



Transition from Notching at L5 (vert.) to L12(horz.)

Horizontal Notching L12/L13

Vertical notching L6/L13



Current Notching Status

- The gap is 3 bunches wide at 8GeV.
- We are able to maintain a 2 bunch gap now with cogging jitter compensation. Down stream machines currently can not utilize smaller gap. So we continue to notch 3 bunches
- We continue to try and optimize our orbits and tweak notch time relative to beam recapture time.
- Continuing to reduce multi-turn loss effect via studies
- Working towards improved diagnostic with fast loss detector implementation for routine tuning of notch loss.
- Will place additional shielding at upstream end of absorber.
- Will review improvements to downstream absorber mask.
- Look at ways to improve rise time of extraction kickers.

Conclusion

- Notching is currently working better than before.
- This allows us to run greater beam throughput and maintain/ reduce beam loss away from critical components.
- We need to further reduce losses in critical areas with another iteration of improvements to the current system.
- We gain more tuning capability with improved diagnostics.
- We have lowered beam losses be utilizing magnetic cogging to allow for all beam cycles to be notch at 400MeV rather than many at 700MeV.
- We will gain further margin with laser notching in the Linac
- Improved injection orbit management and better models will further determine areas of improvement.