Booster Lattice Studies

C.Y. Tan for Booster Lattice group
10 Aug 2017

People

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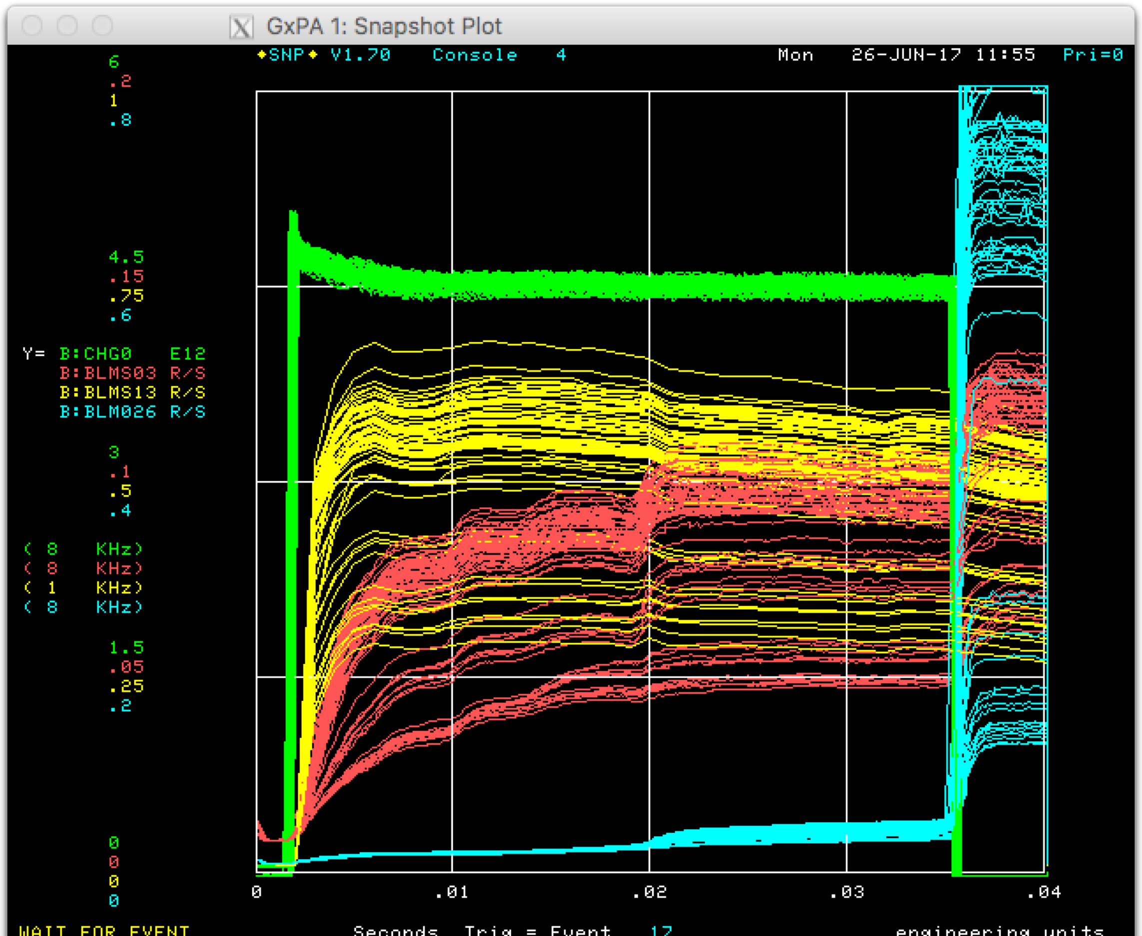
Group started meeting in Feb 2017.
All talks on beamdocs. Do a search for "Booster Lattice Meeting"

Goal

- Study why we are losing beam at the start of injection.
  - This is the location where there is significant beam loss. Can be as high as ~5%.
  - The suspicion was that the dogleg was causing lattice distortion and this was the cause of beam loss.
    - How do we verify that the dogleg was the problem?
    - Do we really believe simulations?
    - Or even theory?

Example of beam loss

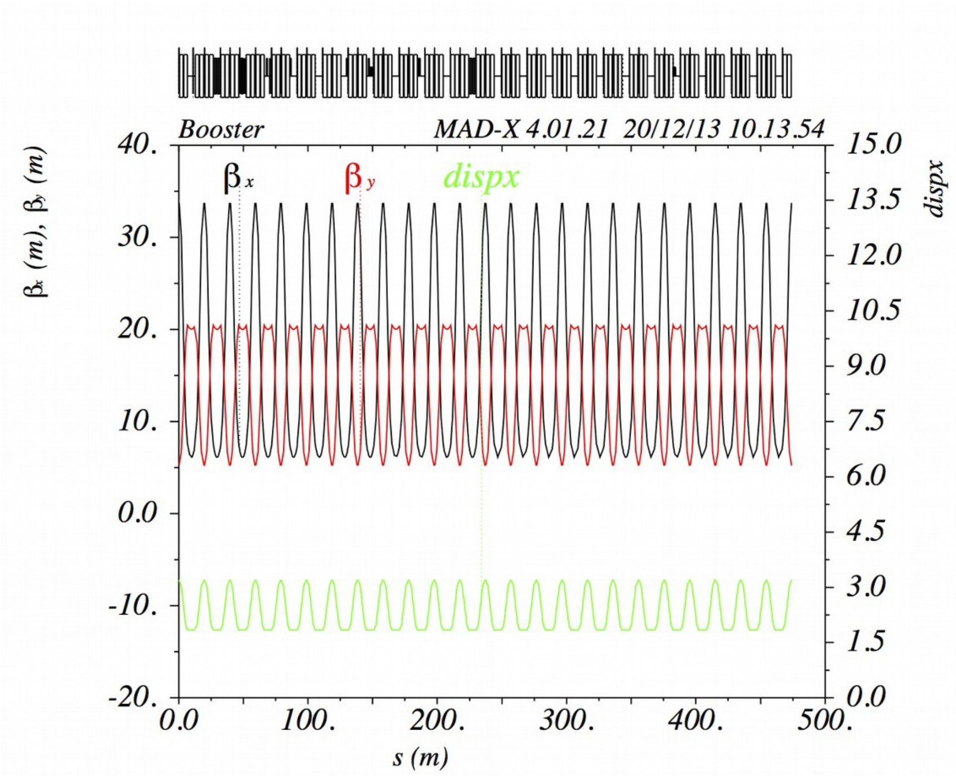


Baseline loss from 3 bunches out of 84 = 3.6%.

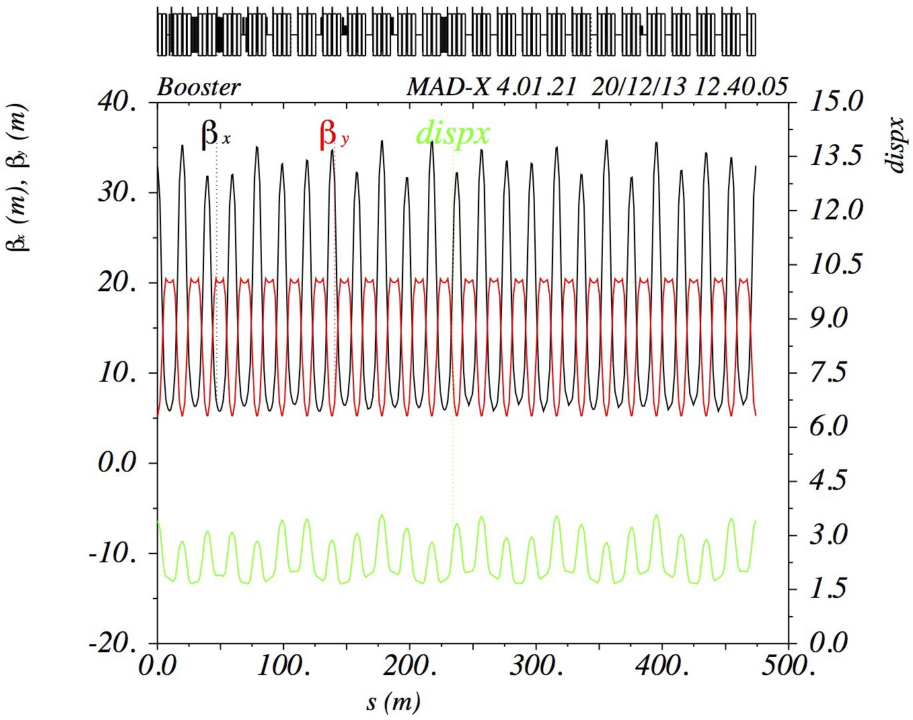
Injection at 2 ms. Injection loss starts from there until about 5 ms.

What's going on during this period?

Effect of Dogleg at L3 on lattice



Dogleg off



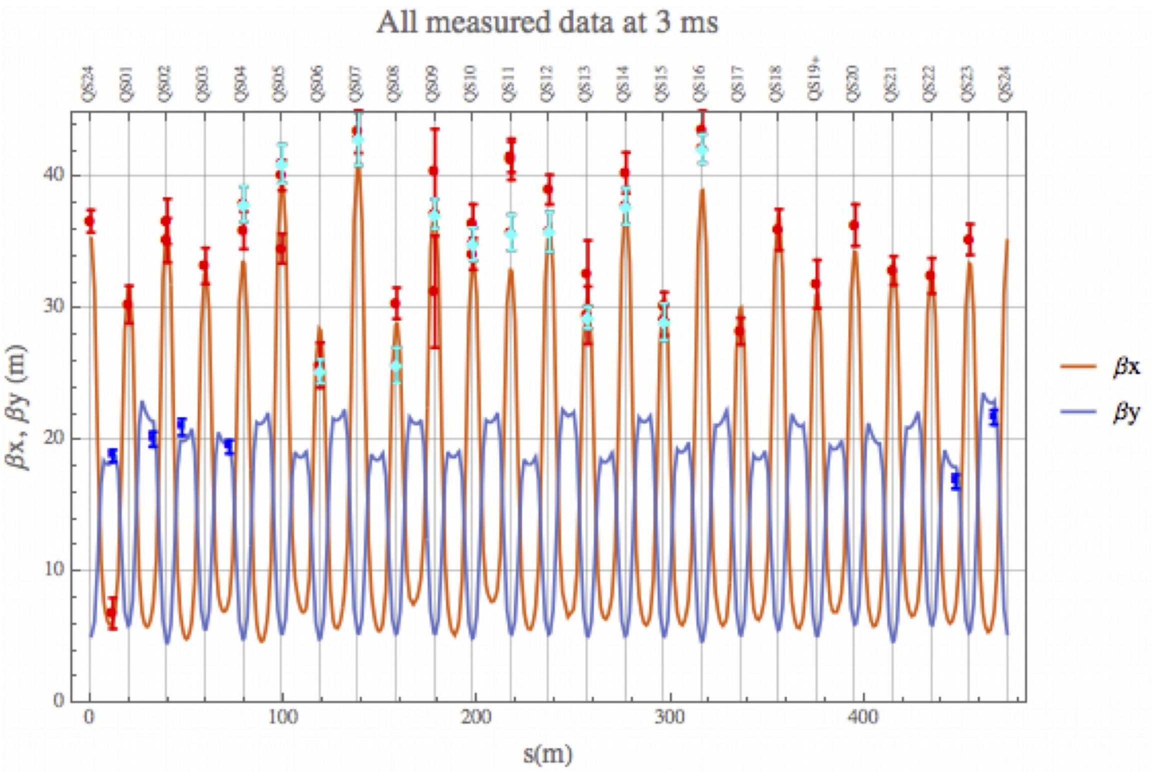
Dogleg on

Even in the ideal case where there are no other lattice errors, the dogleg introduces large errors in the horizontal beta's and also spoils dispersion.

This is the reason why the dogleg was originally suspected as the source of beam loss.

Can we check that dogleg is really the source of beam loss?

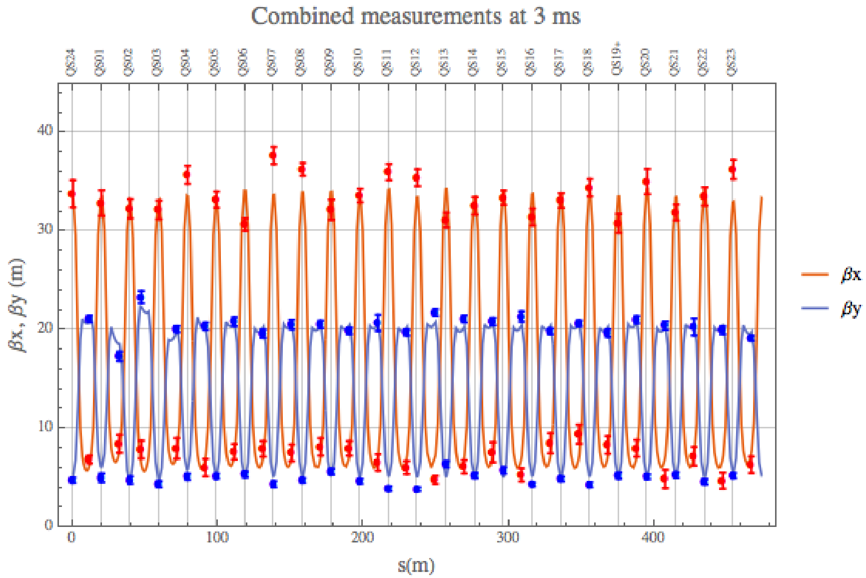
- YES! Let's make a pseudo-flat lattice and then see if there are any improvements to the lifetime, tune space.
- Before we can do this, we have to have a reliable and trusted MADX file.



As found Booster lattice measured with Tune response method (13 & 14 Feb 2017).

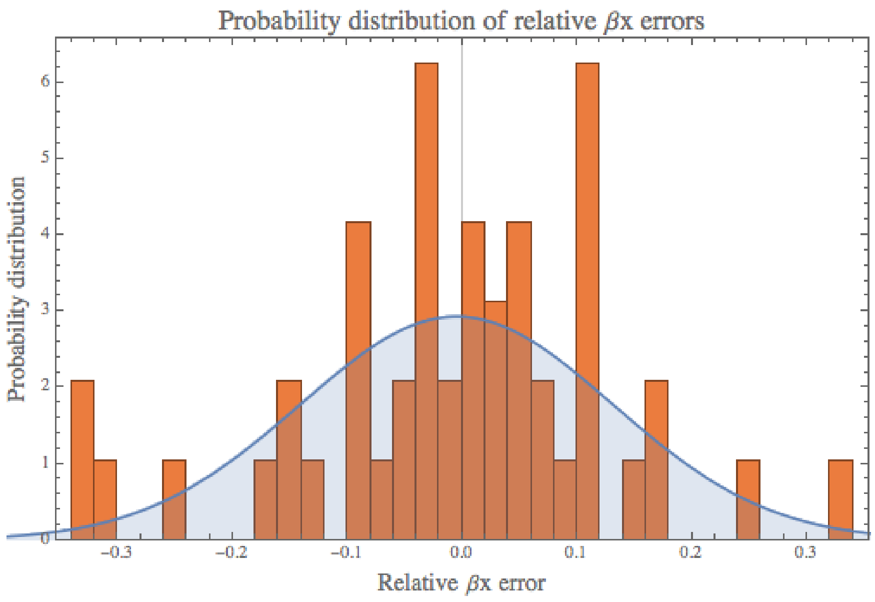
MADX model is verified!

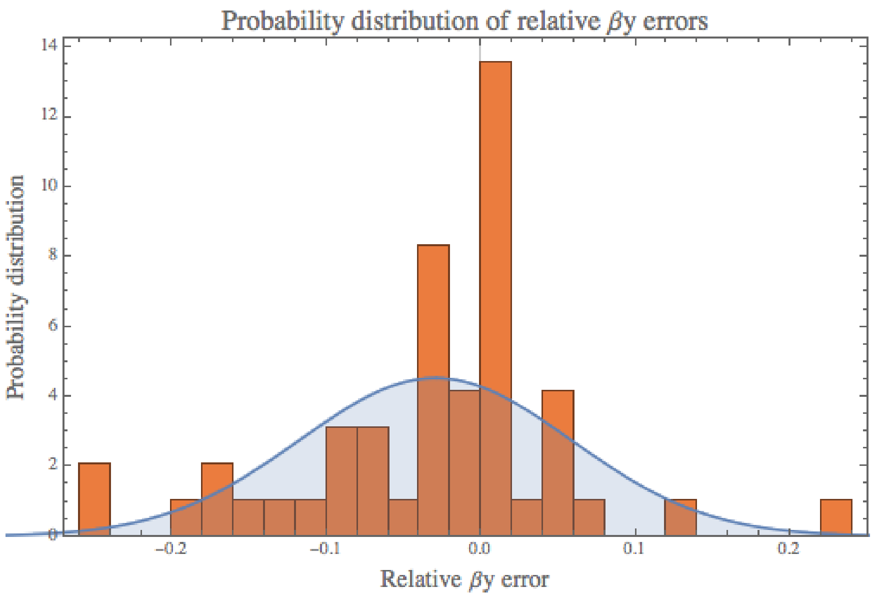
Let’s make a pseudo-flat lattice (v1)



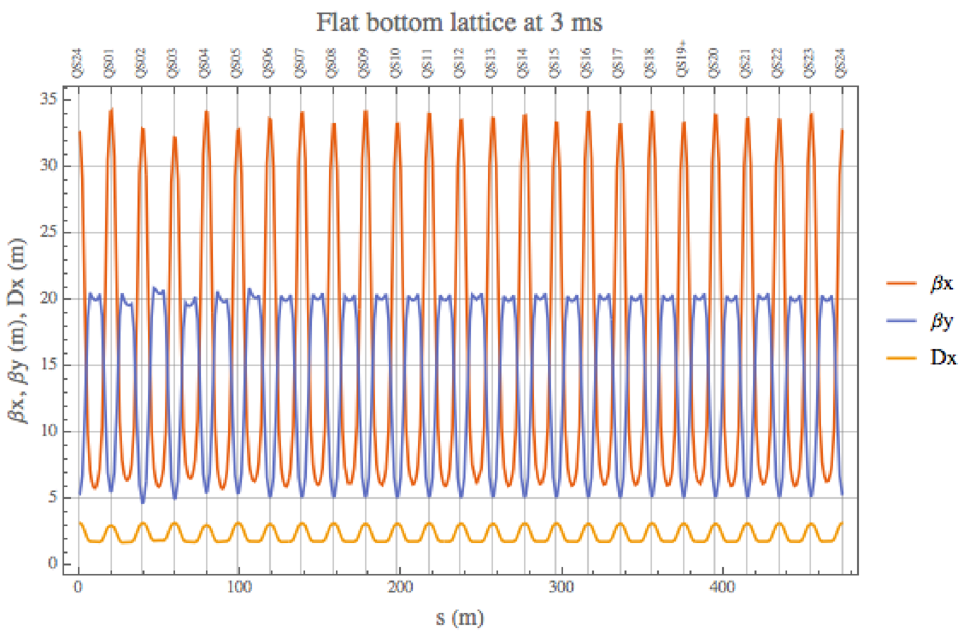
Combined spread in relative error between model and measurement is 14% for βx and 9% for βy.

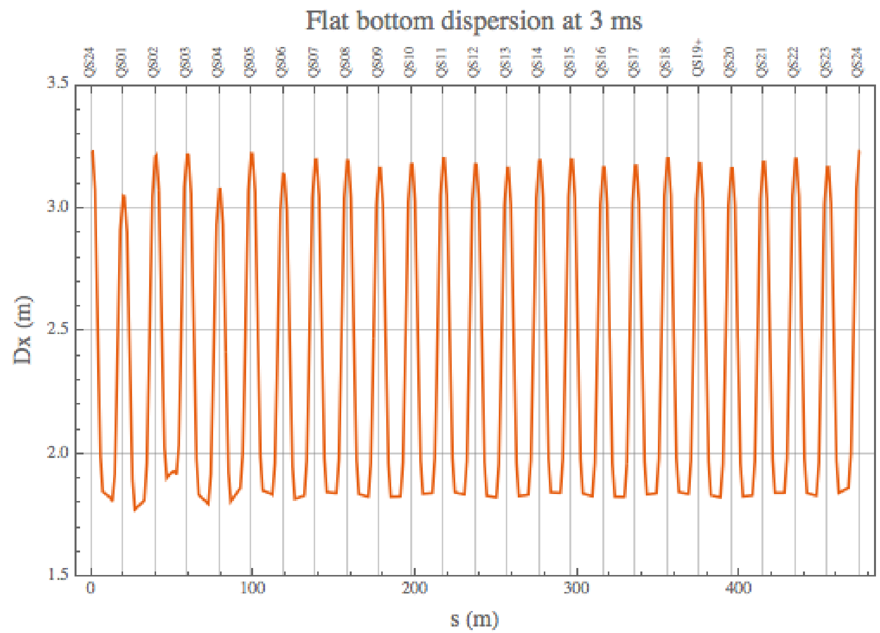
Note β relative errors dominated by low β’s.





Pseudo-flat2





βy is better that the pseudo-flat1, βx is worse than pseudo-flat1.

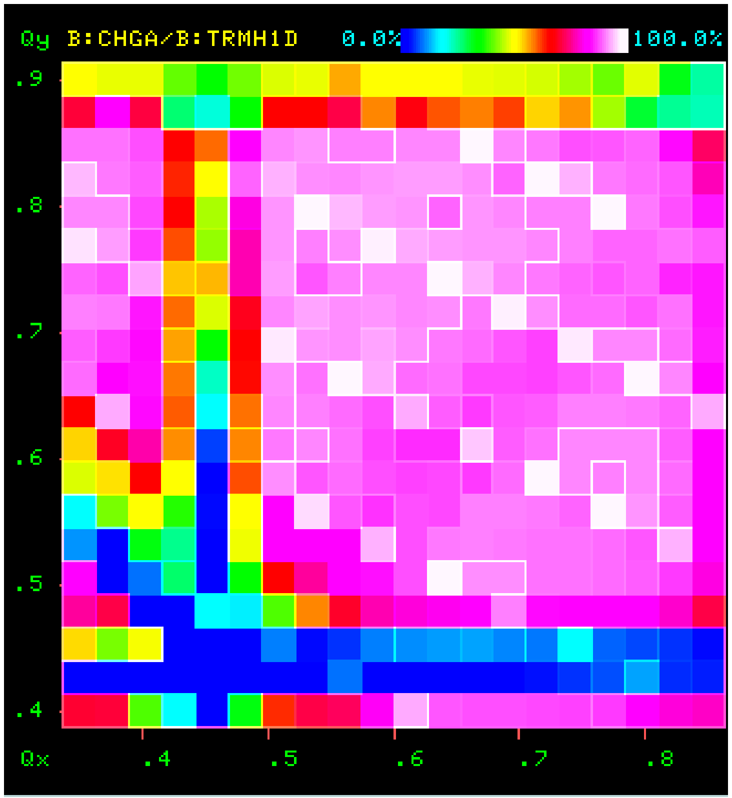
Improved εx and εy

Pseudo-flat 1 → Flat-top

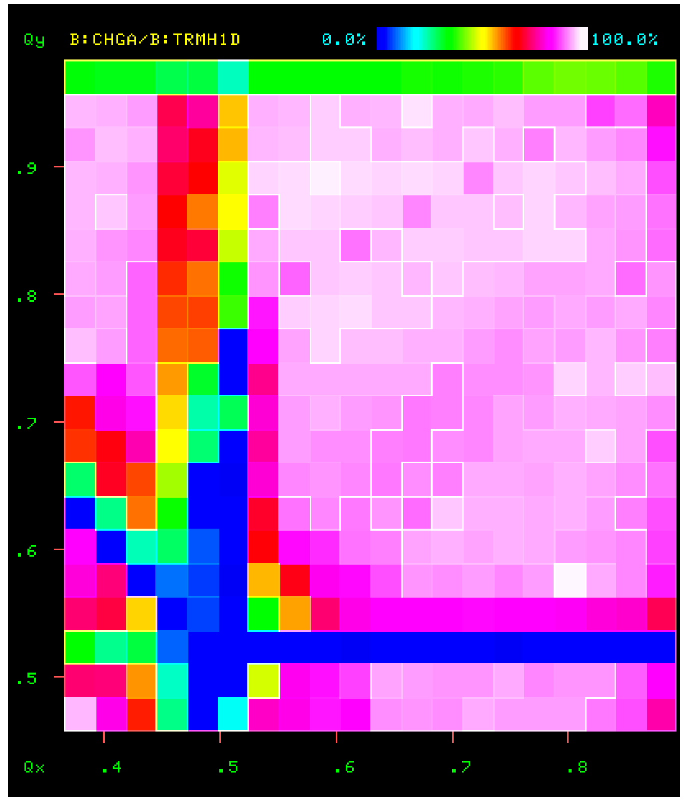
Pseudo-flat 2 → Flat-disp

Lattice	turn	N_surv	$\varepsilon_x^{(r.m.s.)}$	$\varepsilon_y^{(r.m.s.)}$	σ_{pt}	$\sigma_t \times c$
all	1	5000	2.462e-06	2.440e-06	0.00136	0.962
HEP	2000	2689	1.252e-5	6.367e-6	0.00113	0.982
Flat-top	2000	4985	3.639e-06	3.795e-06	0.00126	1.091
Flat-bottom	2000	4996	3.083e-06	2.991e-06	0.00127	1.071
Dogless	2000	5000	2.535e-06	2.534e-06	0.00127	1.065
Flat-disp	2000	4982	3.045e-6	2.894e-6	0.00126	1.085
Flat-disp*	2000	4976	3.219e-6	2.915e-6	0.00126	1.083

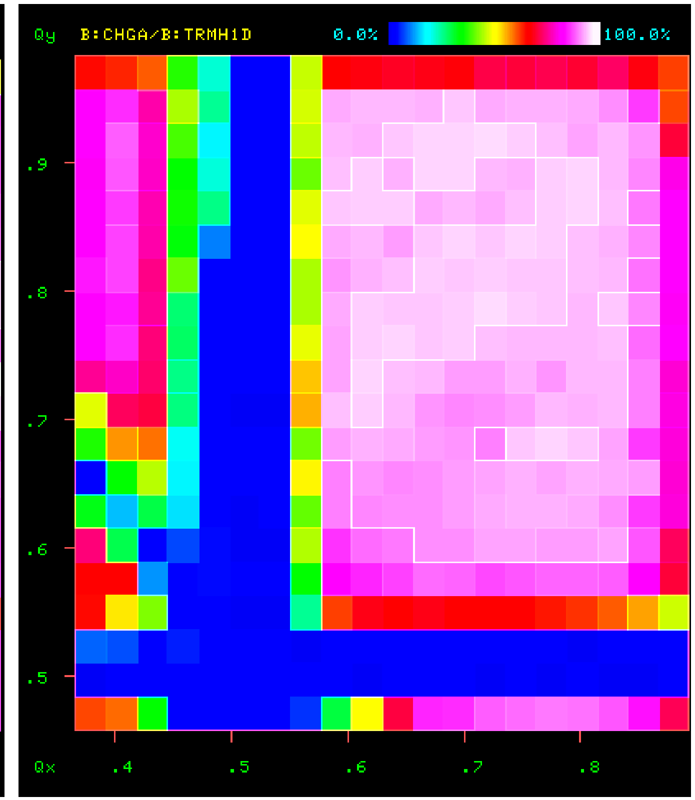
Tune scan



Pseudo-flat lattice 1



Pseudo-flat lattice 2



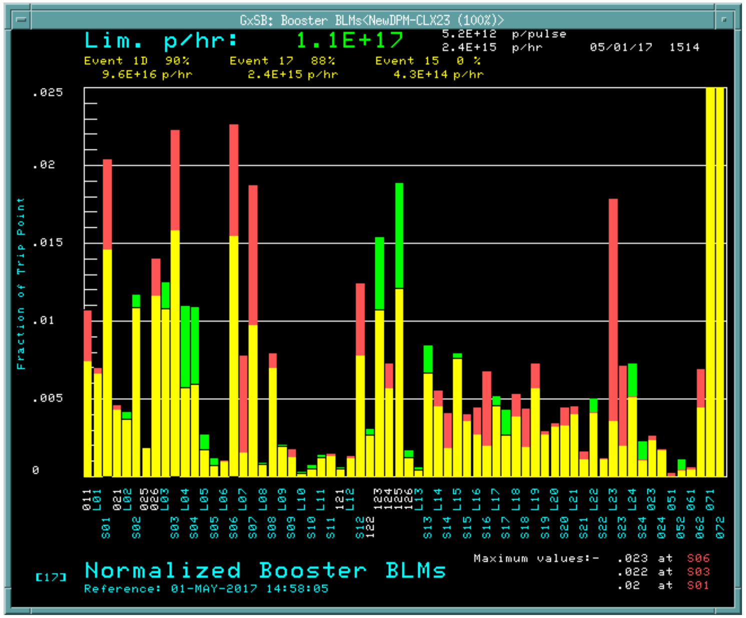
HEP

Pseudo-flat lattice 2 has smaller vertical 1/2 integer resonance and slightly larger horizontal 1/2 integer resonance.
Both pseudo-flat lattices are much improved over HEP lattice.

Efficiency not improved with Pseudo-flat lattice 2

- Efficiency is always ~1% lower than HEP
  - Tuned 400 MeV injection line quads. No improvement.
  - Smoothed 3 ms orbit to HEP orbit. No improvement.
  - Individual 3 bumps are aperture restrictions. No improvement.
  - Decoupling. No improvement

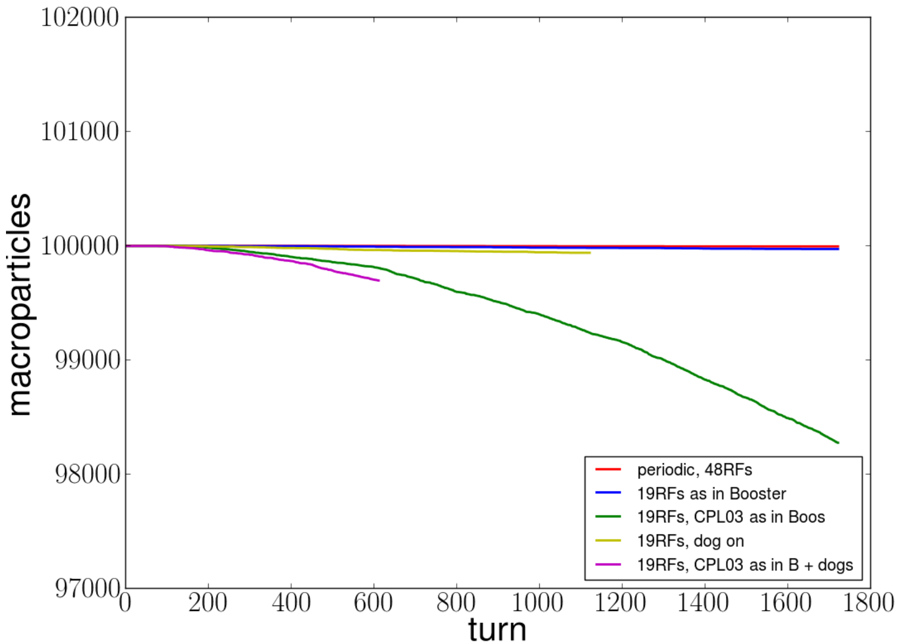
If the emittances are improved by > 2 from simulations, then we shouldn't be scraping!



So, maybe it is not the dogleg?

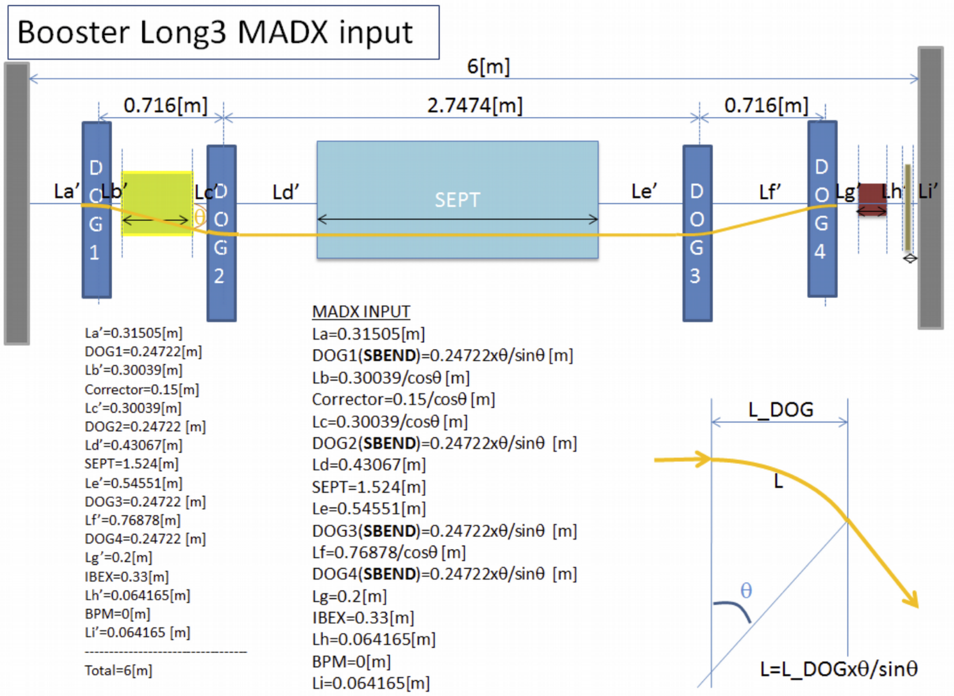
Let’s do more simulations ...

- If it is not doglegs, what else can cause losses?
- Alex noticed that the corrector package CPL03 is displaced by 5 m w.r.t. symmetric location (note: there is also a displacement at L1 as well but smaller)

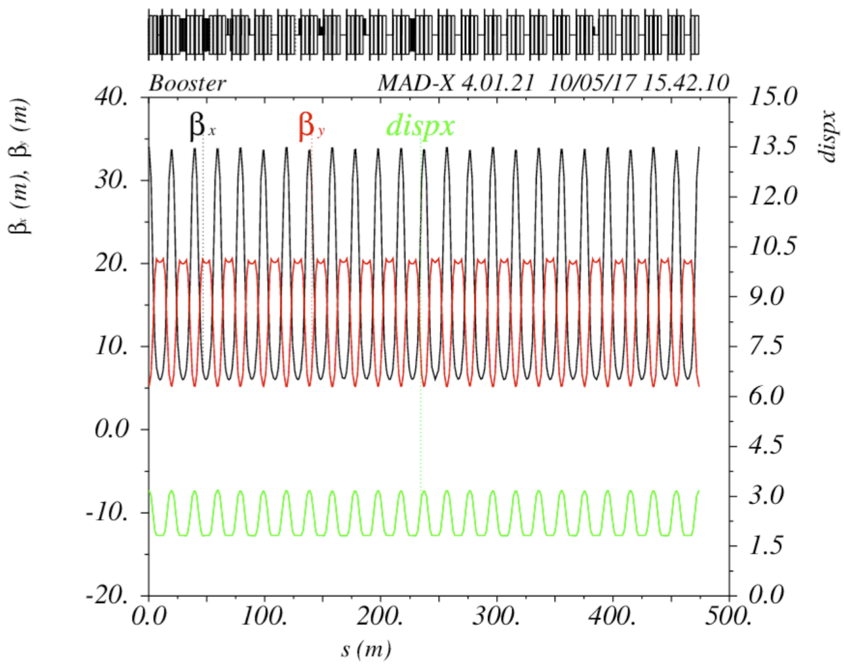


Notice largest contribution to beam loss is when CPL03 is displaced

to its location.



I would've never guessed … (Lattice doesn't change very much from CPL03 displacement)



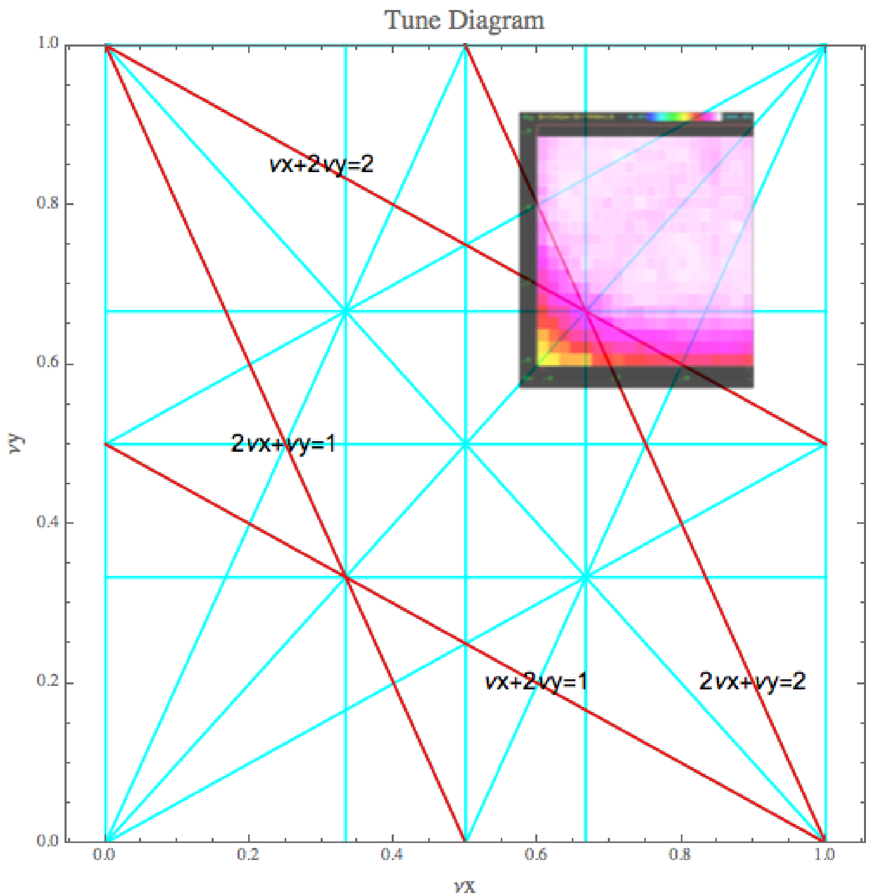
QL=-1.2 A and QS=-0.2 A to get Qx = 6.74 and Qy = 6.83

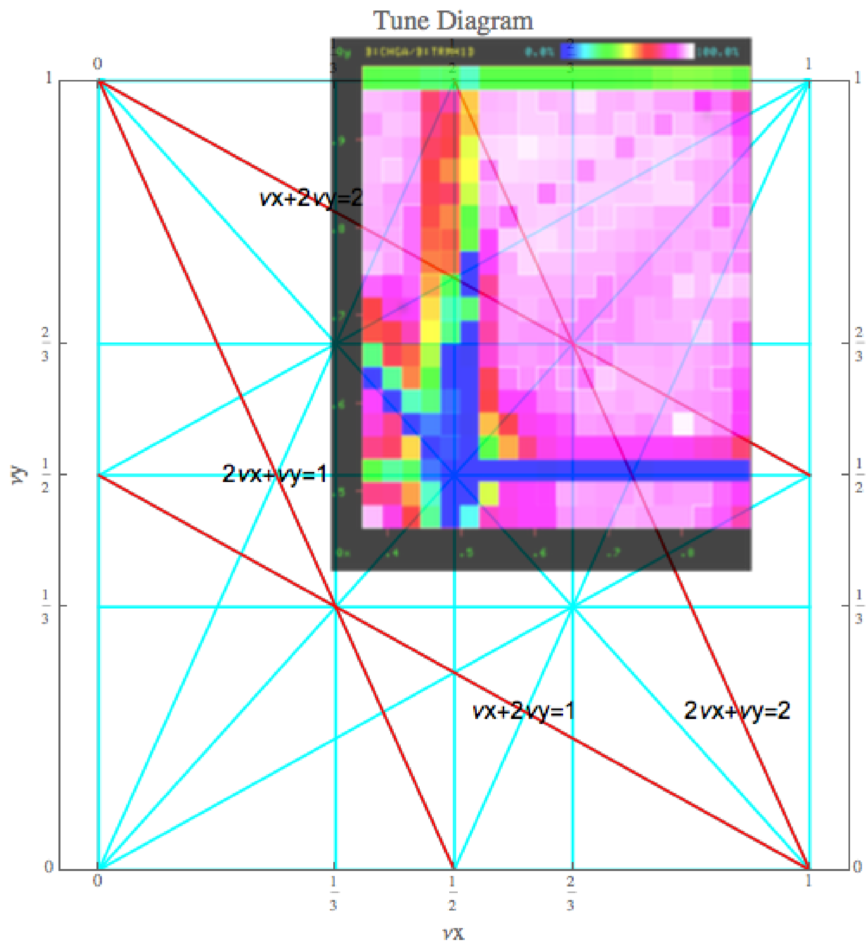
Very little change in lattice with CPL03 moved 5 m w.r.t. symmetric location:

At the dog leg
HL03 – DMAGU03 = (47.2759966747 – 44.9563116043) m=2.31968507 m
At L04
HL04 – DMAGU04 = (71.7538200019– 64.7168491019) m = 7.0369709 m
At L05
HL05 – DMAGU05 = (91.5143447890- 84.4773738890) m = 7.0369709 m

This is a **very** surprising result.
Further analysis showed that if this is the cause of the losses, then the losses would come from a 3rd order resonance. Candidate is the Qx+2Qy resonance.

Tune scan with high intensity

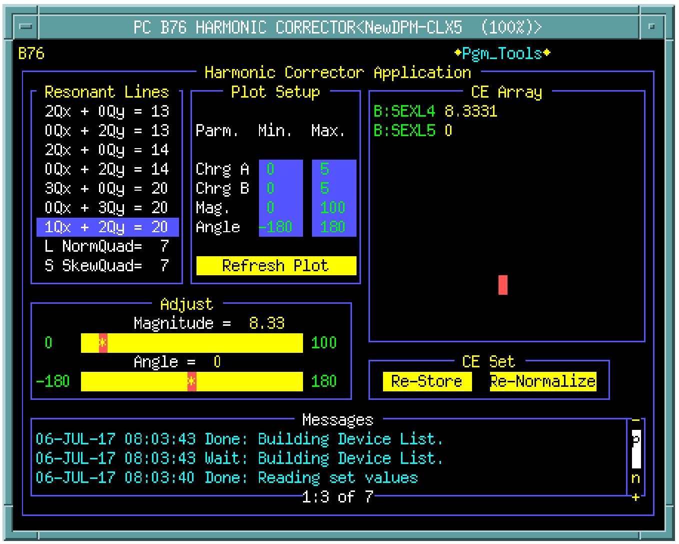


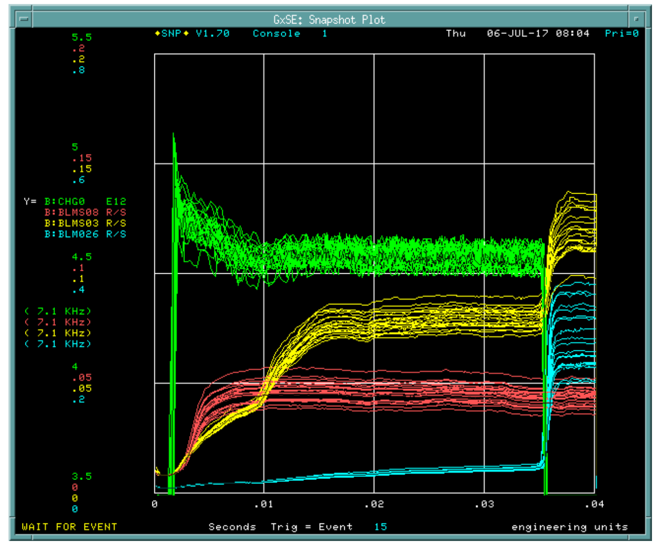


Are the losses (left pic) from 3rd order resonance or from 1/2 integer (very wide with high intensity) resonances because they became thicker? Yellow region may be intersection of 1/2 integer lines.

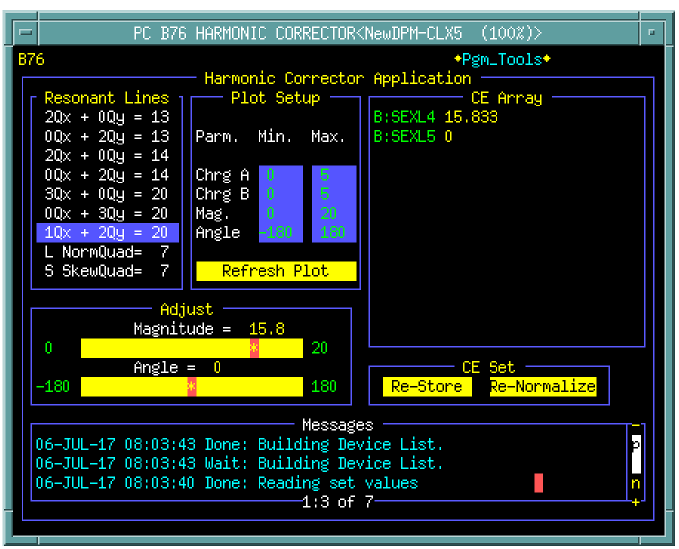
Intensity: 4.6e12, pseudo-flat lattice 2. Skew quad current is zero for first 5 ms.

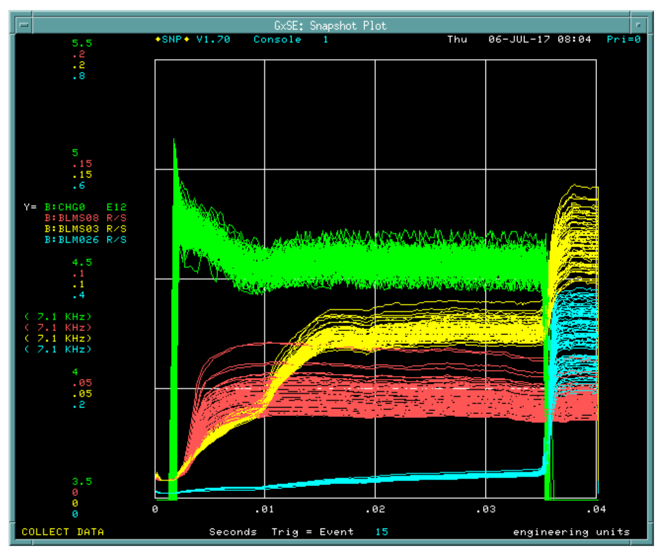
Behaviour of beam as function of Qx+2Qy=20 harmonic sexupoles





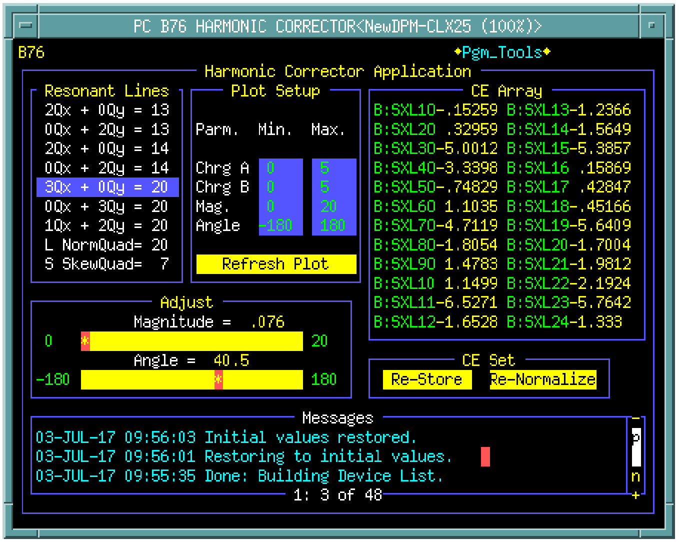
As found HEP

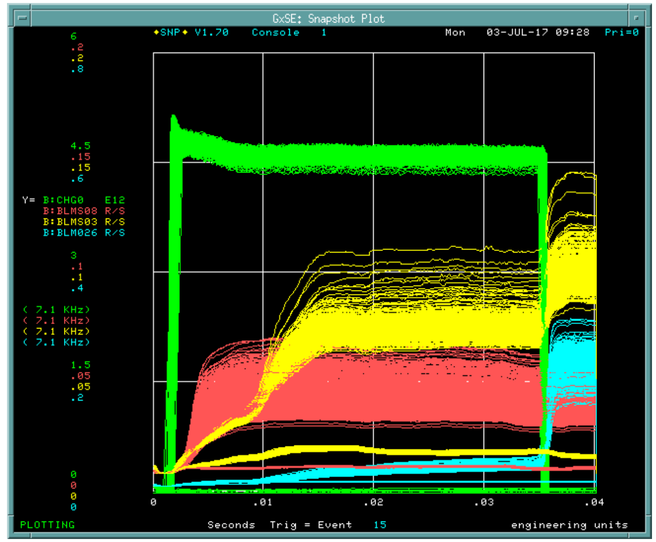


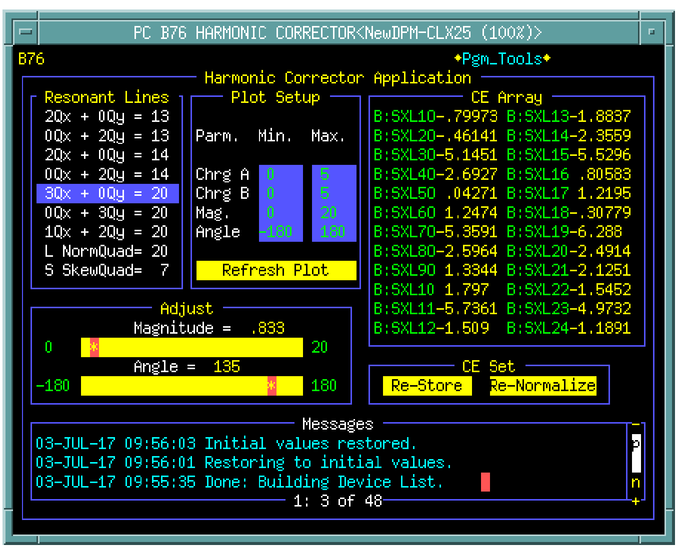


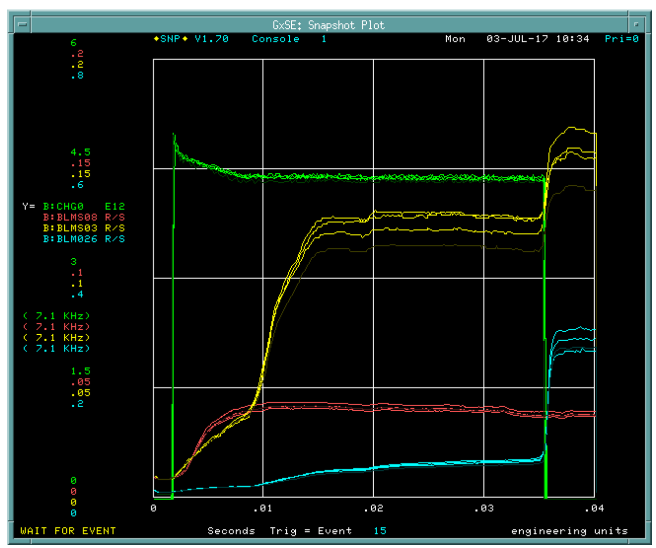
No obvious change in losses.
Also did it with 90 deg angle saved in logbook

Behaviour of beam as function of 3Qx=20 harmonic sextupoles









We took a 3 sets of data for different 3Qx=20 harmonic sextupole settings. Only 2 shown here.

<u>Qx+2Qy=20 harmonic sextupole settings have no effect on the losses.</u>

Magnet settings on that day used for HEP have also been saved.

Perhaps lowering chroms can help us?

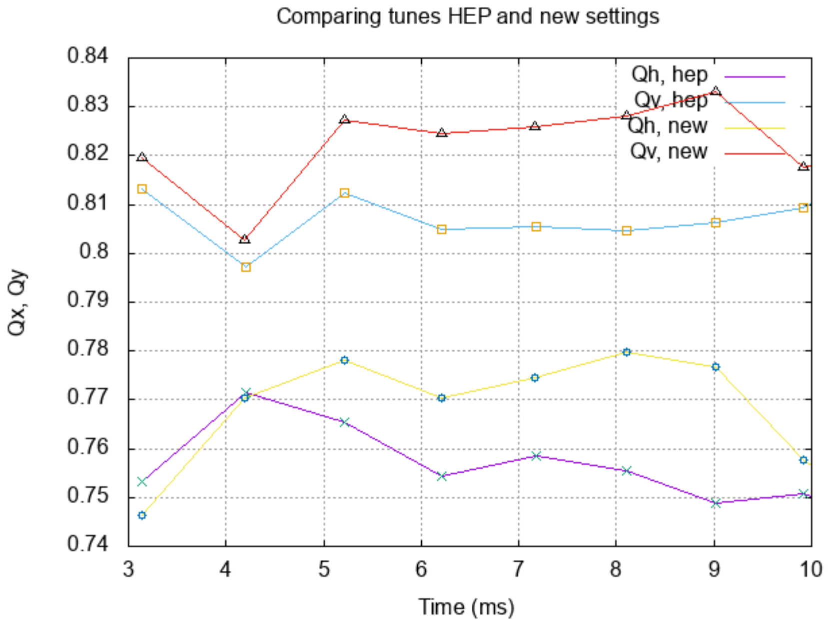
- Lowering chroms should reduce tune footprint and improves beam lifetime **but** reduces Landau damping, so must have dampers to keep beam stable.
  - Lowering chroms helped with pbar lifetime in Tevatron and beam lifetime in MI. What about Booster?
- Transverse dampers were commissioned in June and so we can actually do this!

SXL and SXS settings and results

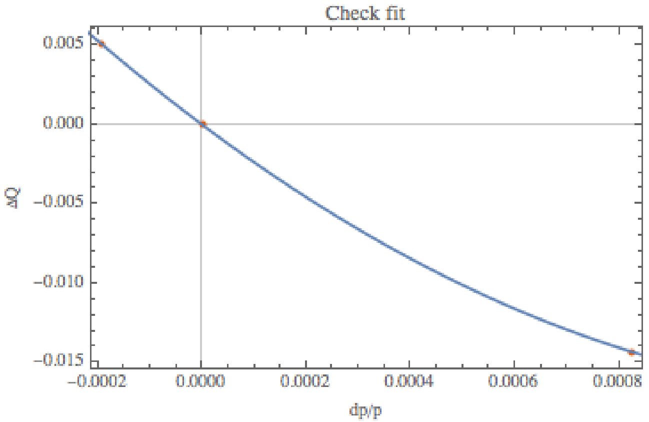
time	SXS
1.6	1.5
2.4	1.5
2.9	1.5
3.7	1.0
4.6	1.0
5.6	1.0
6.5	1.0
7.3	1.0
8.1	2.0
8.6	1.0
9.0	1.0

time	SXL
1.68	7.00
2.89	7.00
3.69	7.00
4.59	7.00
5.59	7.00
6.49	7.00
7.29	8.50

Moved tunes up by 0.02 in both horz and vert tunes from 5 ms to 9 ms.

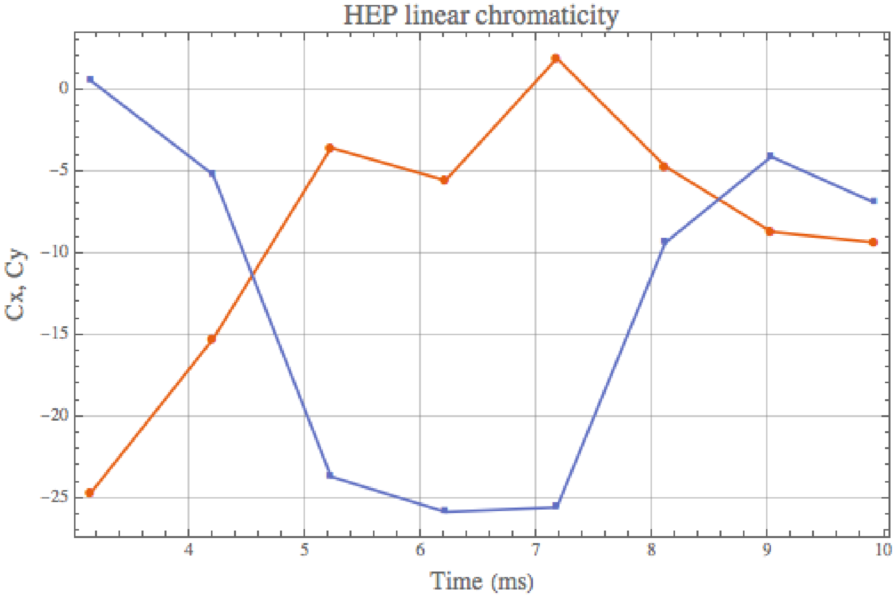


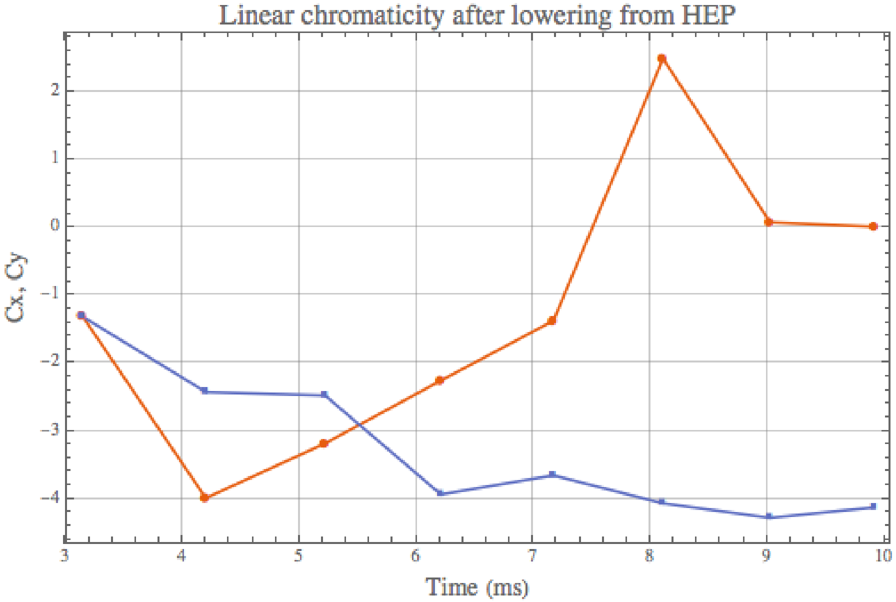
Measured and lowered chromaticity from injection until 10 ms



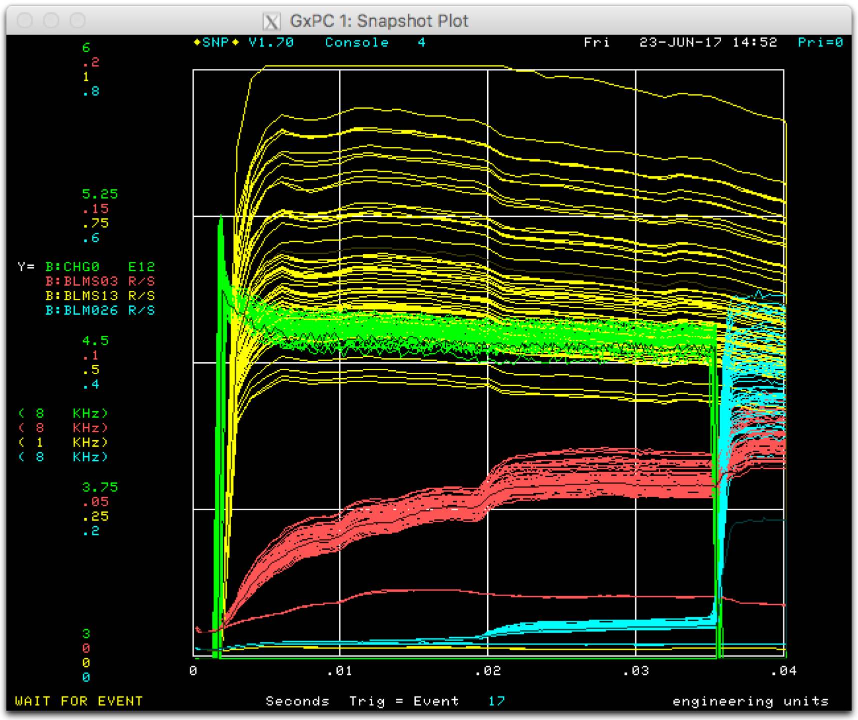
Chandra found that chroms were quite different for ROF=+1 mm vs -1 mm. So we did a 3 point fit to find Ch and Cv.

There is still an odd ball at 8 ms.





No change in injection efficiency



Used 12.4 turns like in $15.
No visible increase in efficiency ~90%.
No visible increase in losses.

Moving tunes UP away from 1/2 integer did not show improvement.

There is a limit of how much tune change is available even with dampers ON at this intensity:

- Max horz tune change +0.08
- Max vert tune change +0.04

Lowering chromaticity does not improve beam lifetime!

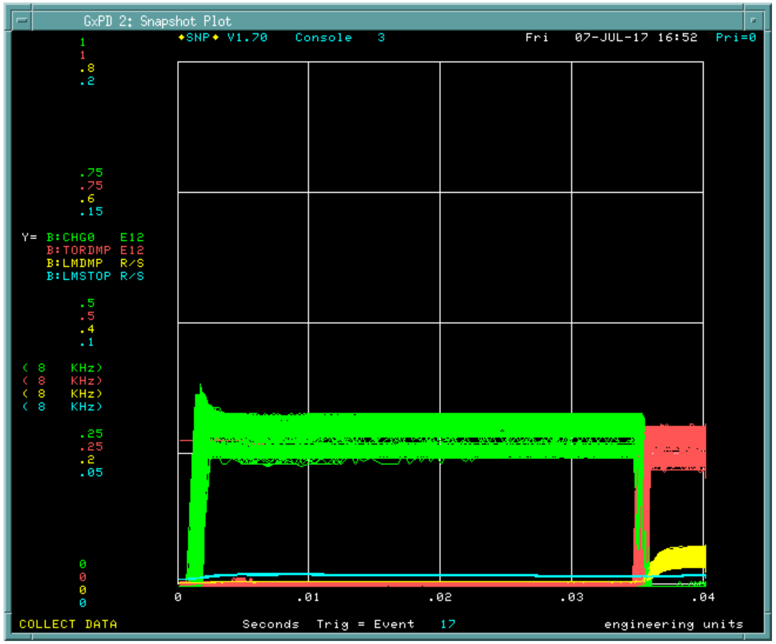
Summary of what we know so far

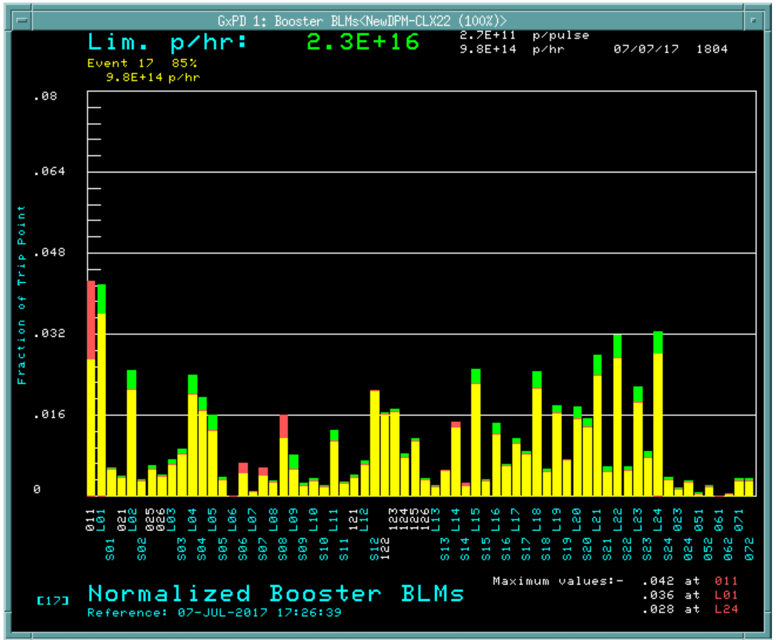
- Dog leg effect
  - Negligible (experimental)
    - Pseudo flat lattice does not show improvement in lifetime.
      - Tune space is improved with pseudo-flat lattice.
    - Simulations in Synergia and MADX shows small effect from dog leg.
- Displacement of CPL03 (and CPL01)
  - Simulations in Synergia and MADX shows large effect (> dogleg) in losses
  - Source is Qx+2Qy=20 (MADX simulations, 30 Jun 2017)
    - Tune scans do not show such a resonance.
    - Changing Qx+2Qy=20 with sextupoles do not change loss profile.
    - 3Qx=20 changes losses.
    - TBT may show something …, but BPMs don't really work well close to injection. Need 200 MHz BPMs in B38.
- Lowering chromaticity does nothing
  - Beam lifetime is not improved at injection with Ch and Cv lowered from Ch=-20, and Cv= -30 units (varies from 3 ms to 8 ms), to less than |-5| units does nothing to lifetime.
  - Tuning did not help with lifetime with lowered chromaticity.

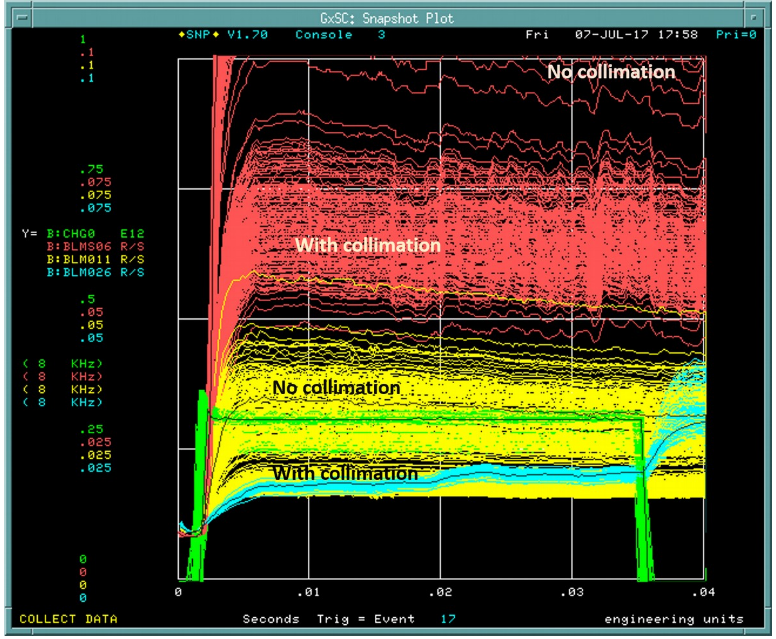
So what now?

Is this really a dynamics problem or something else?

Always blame the upstream machine ...transverse laser collimation at 750 keV (Pellico et al)







Laser collimation (vertical only) for 1 turn beam.
Loss profile better (beam current is lower overall)
No firm conclusion yet.

JPARC twin peak losses from injection bump magnet noise

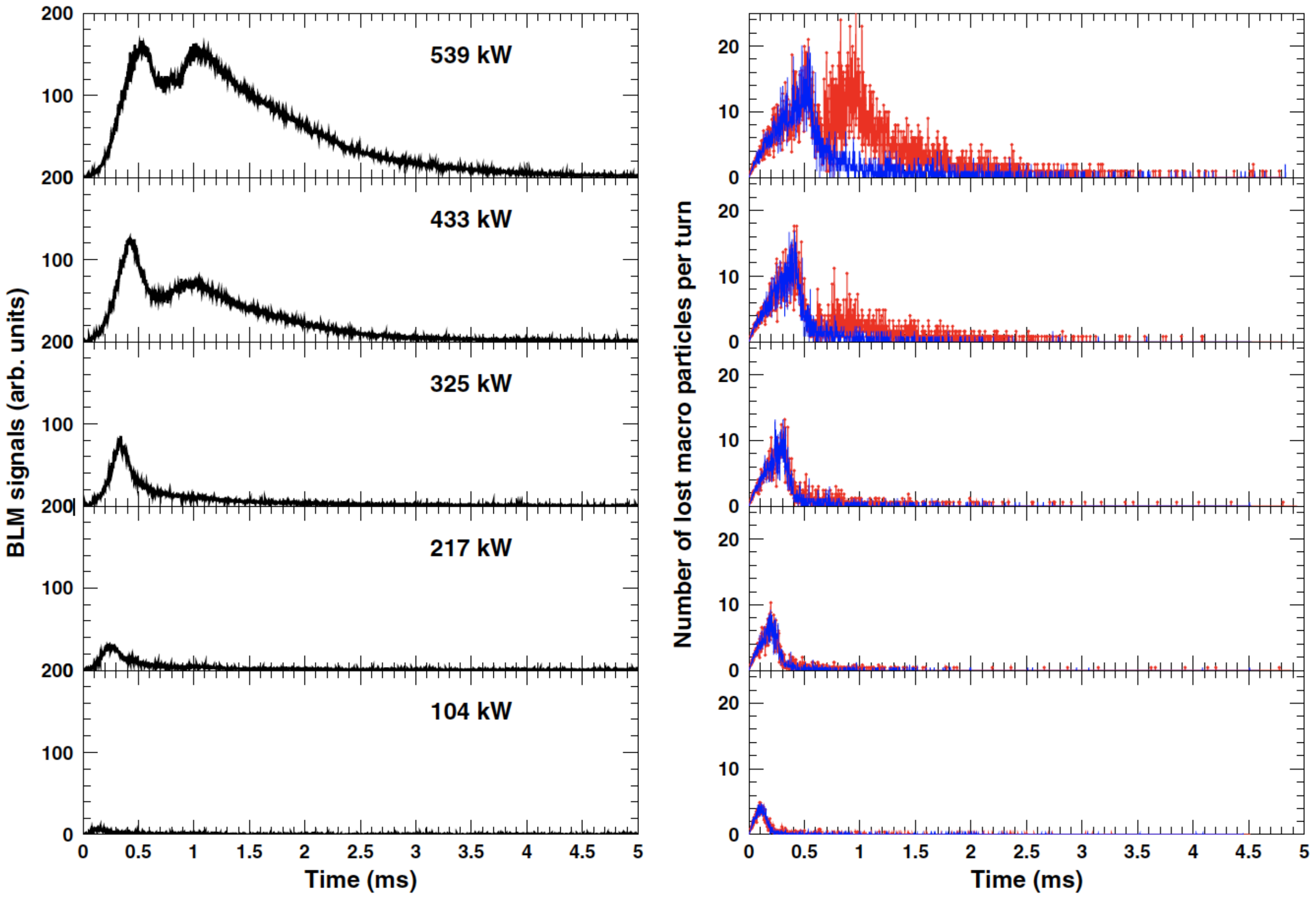
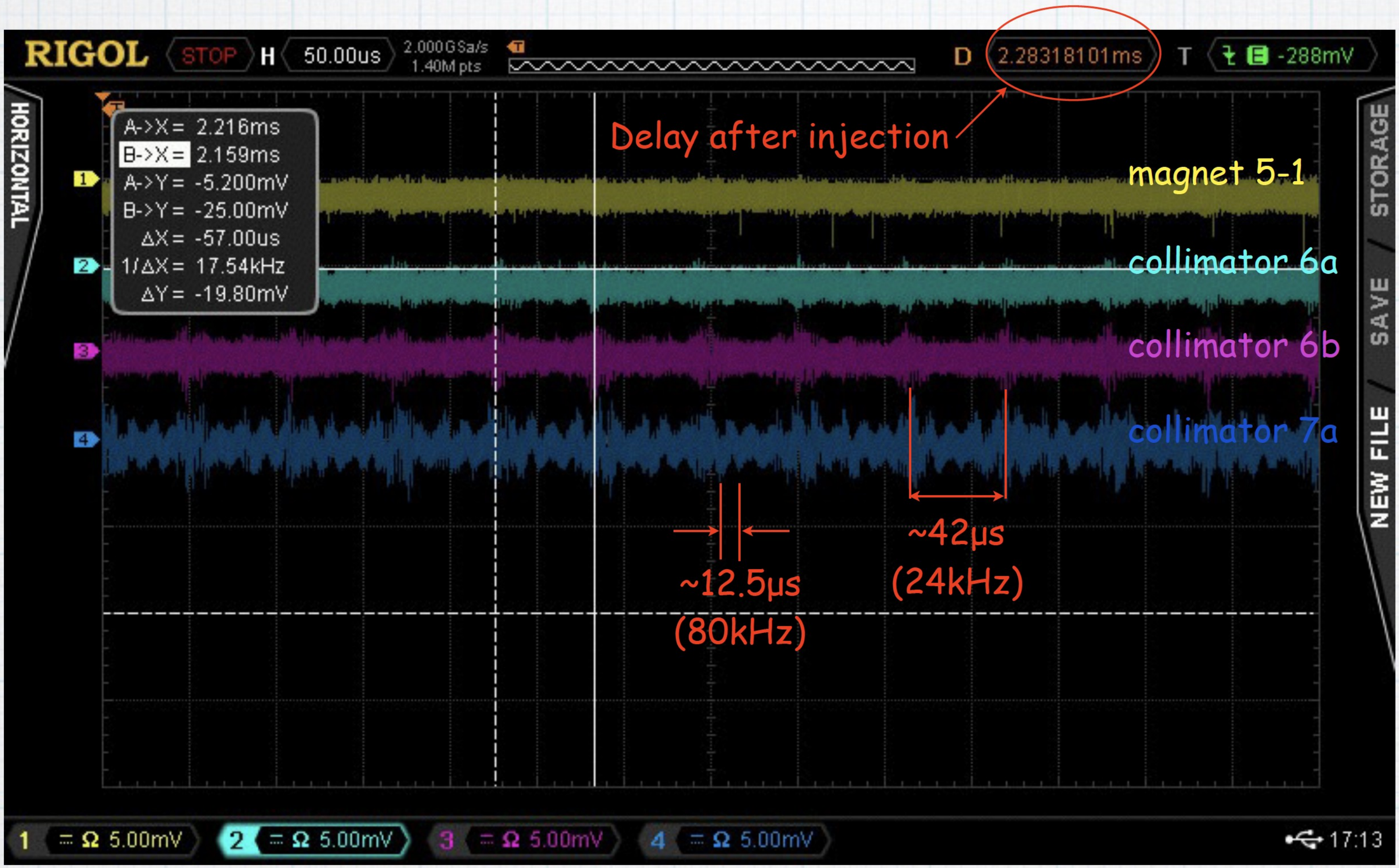


FIG. 12. (Left) Scintillation-type BLM signals for the first 5 ms measured at the collimator section with the injection painting parameter of ID 8 for various beam intensities from 104 to 539 kW. (Right) Corresponding numerical simulation results obtained with (red) and without (blue) the dipole field ripple.



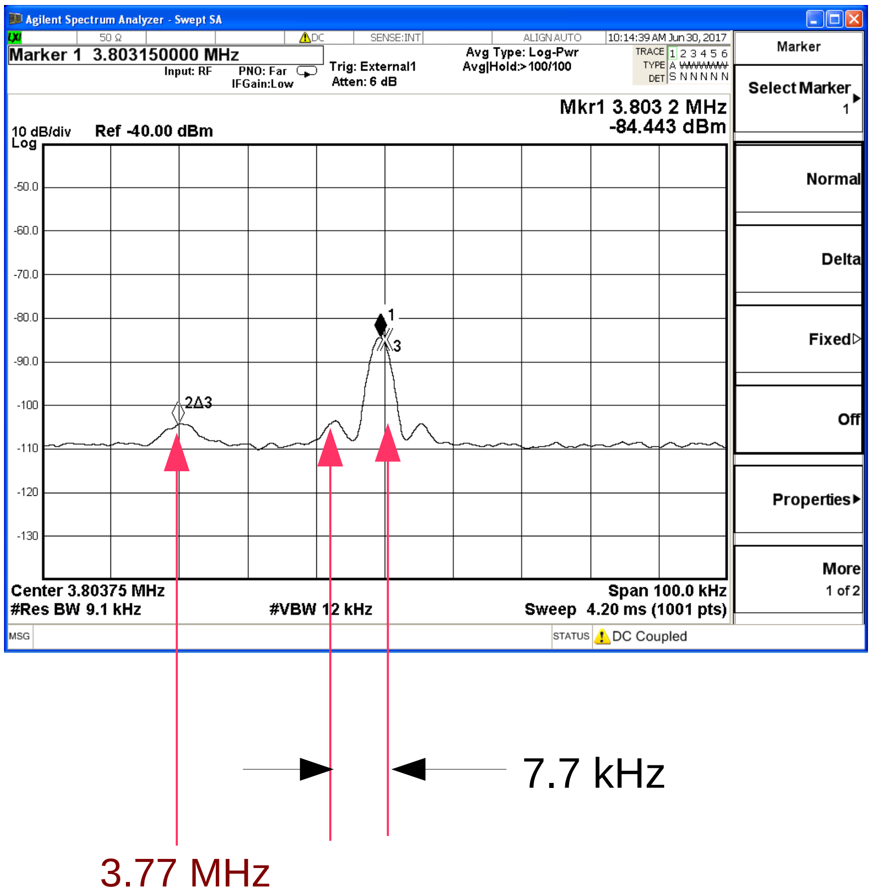
Filename: noise01.jpg
Event: $15
Single pulse

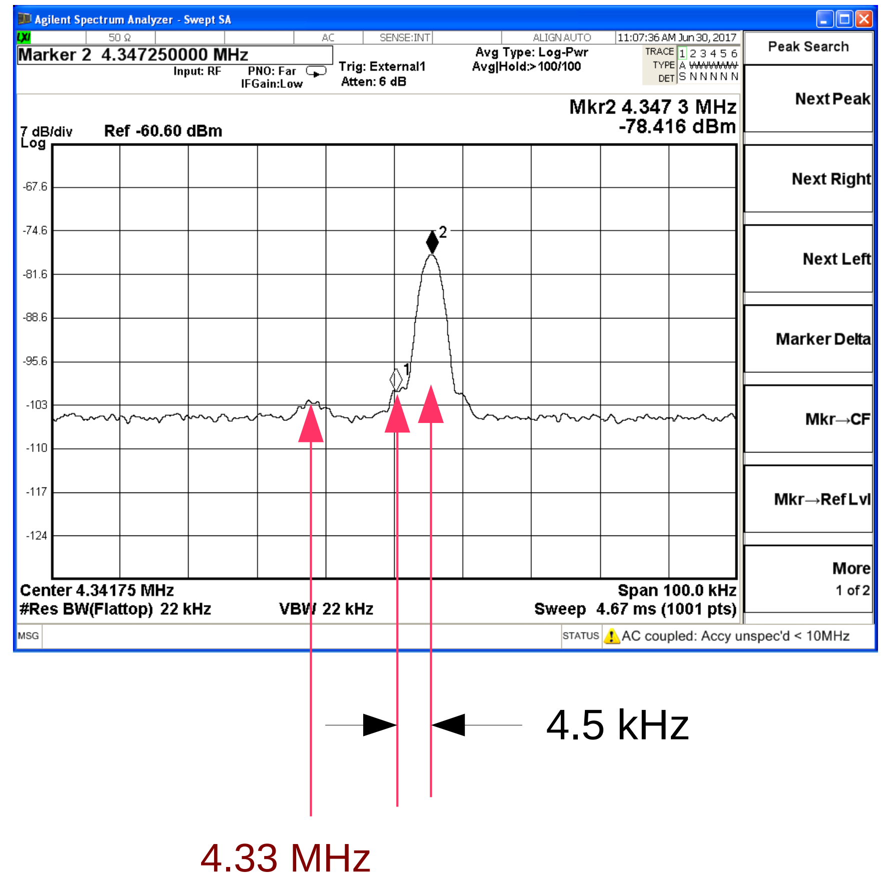
Data Taken: 6/26/17 ~17:00

Note delay after start of injection!

Measurements by R. Tesarek from fast BLMs at the locations indicated above.

Noise





Data taken using damper pickups in difference mode.
$1D ($15 not taking beam) used to trigger, 4.3 to 4.6 ms sweep. So that the FT is at the start of injection.
Odd ball bumps not associated with revolution harmonics may be “noise”.

Conclusion

- Dynamics may not be the problem
- Beam halo
  - Masks being made in 750 keV line which will be installed.
- Noise in dipoles
  - Will do noise hunt during shutdown.
- Yuri thinks there is still hope for 3rd order resonance.
  - Must add 200 MHz BPMs to TBT program (request sent to Bill Marsh)
- The hunt continues ...