SPEAR3: lifetime, dynamic aperture and FMA

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ESRF nonlinear beam dynamics workshop, 2008

Overview of SPEAR3

- A 3rd generation light source
  - 234m racetrack layout, 18 DBA cells
  - 3GeV, 100mA (500mA tested)
  - 11 nm horizontal emittance (with dispersion-leak)
  - 3.2MV, 476.3MHz rf cavities.
- Lattice upgrade
  - Original lattice to double waist lattice (2006)
  - Achromatic DW lattice to low emittance lattice (2007)
- Topics in this presentation
  - Lifetime measurement and modeling
  - Dynamic aperture measurement, modeling and improvement
  - Ongoing effort to measure Frequency Map

Lifetime measurement

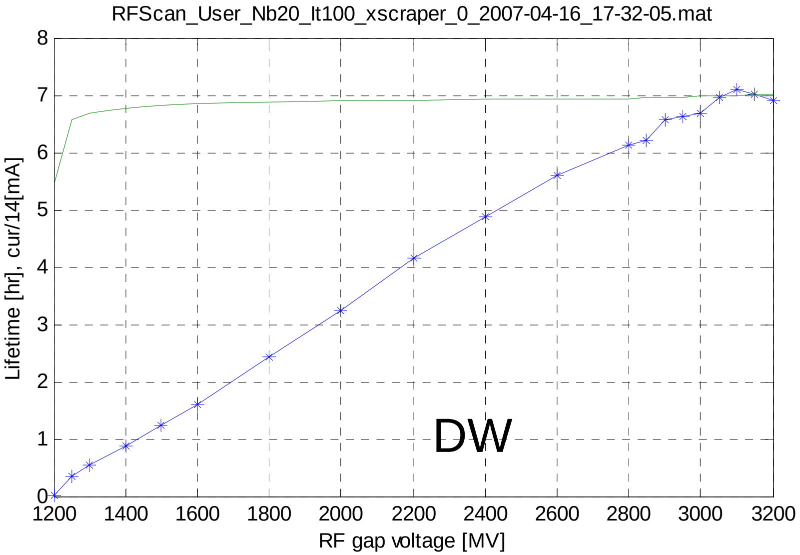
1. Separation of Touschek lifetime and gas scattering lifetime using various fill patterns and single bunch currents *.

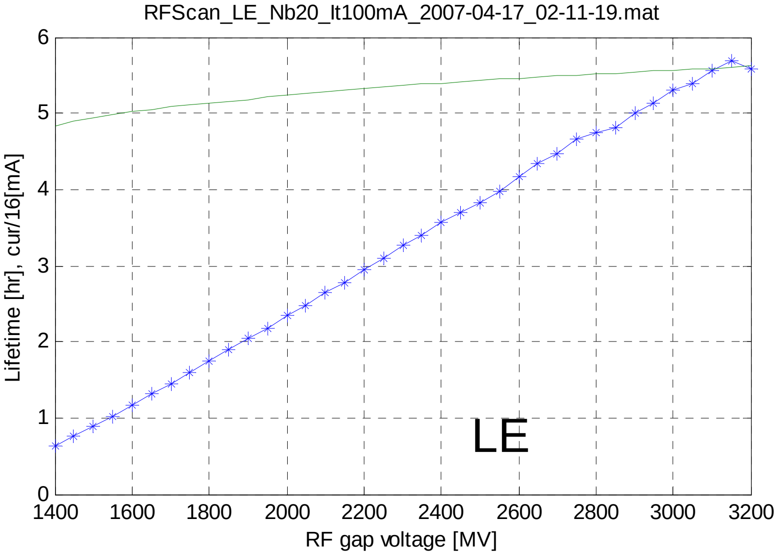
$$\frac{1}{\tau} = a + bI_{\text{tot}} + cI_0$$

Gas scattering lifetime at 100mA,
LE = 104.4 hrs
DW = 101.2 hrs

Touschek lifetime at 100mA/280bunch,
LE = 66.3 hrs, coupling 0.112%
DW = 91.3 hrs, coupling 0.064%

2. Lowering rf voltage to detect momentum aperture

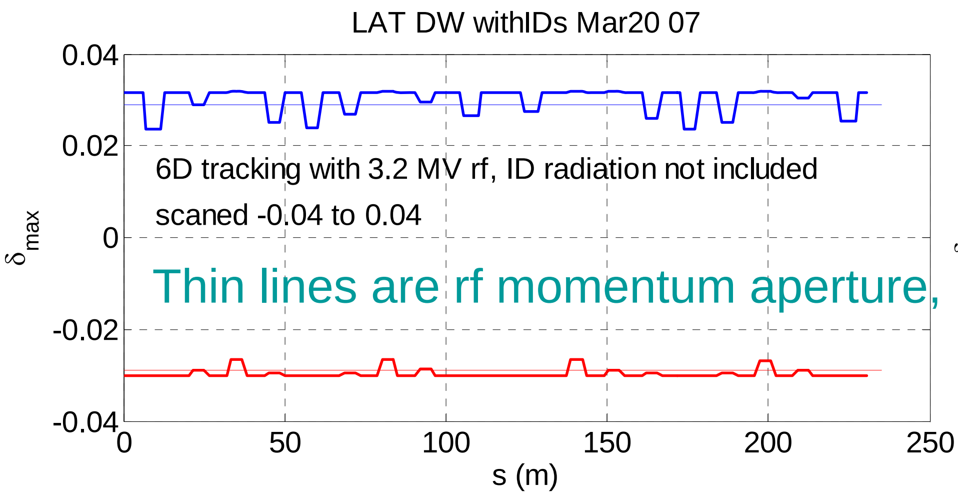


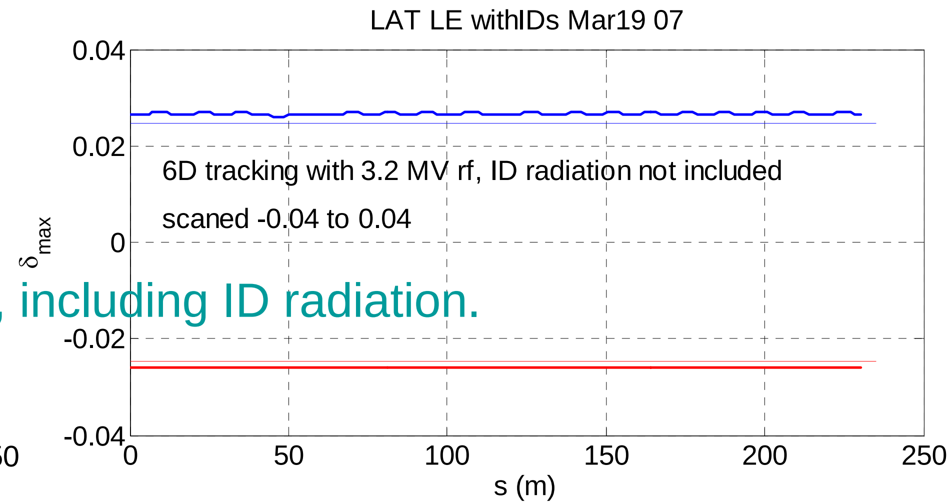


* J. Corbett, PAC'07

Touschek Lifetime modeling and calculation

- 6D tracking (with AT) to obtain momentum aperture
  - Initial coordinate [0, 0, 0, 0, ±δ,0]'
  - Physical aperture at the septum set to [-25, 25, -5, 5] mm





Thin lines are rf momentum aperture, including ID radiation.

Double waist (DW):
U0=1.04 MeV, sigE/E = 0.001
Coupling 0.064% (from LOCO)
Emitt_x = 18 nm
➔Tau_t = 96.7 hrs at 100mA/280
Compared to 91.3 hrs measured

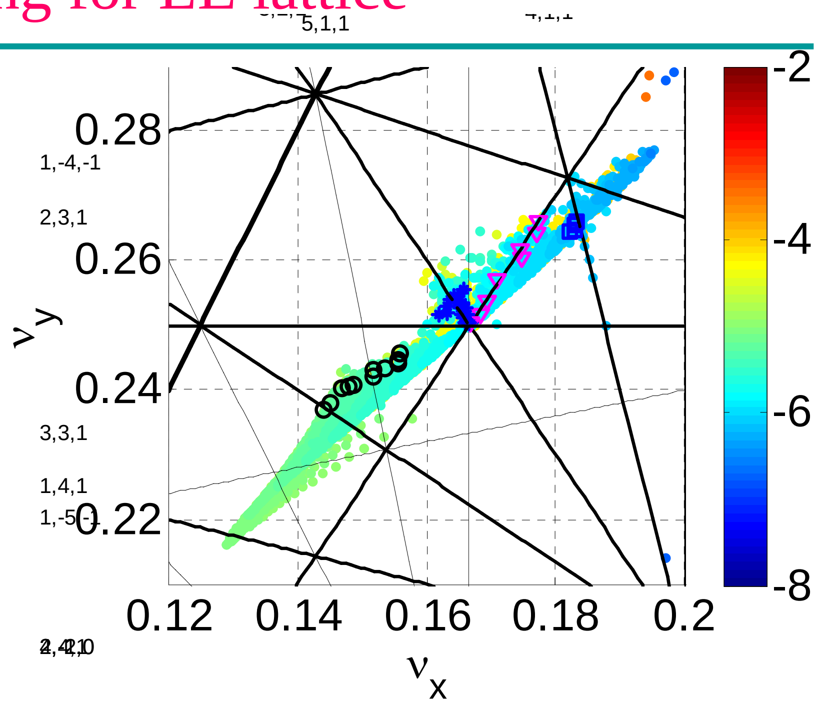
Low emittance (LE):
U0=1.04 MeV, sigE/E = 0.001
Coupling 0.112% (from LOCO)
Emitt_x = 11.2 nm
➔Tau_t = 61.3 hrs at 100mA/280
Compared to 66.3 hrs measured

Momentum aperture for SPEAR3 low emittance lattice is determined by rf parameters.

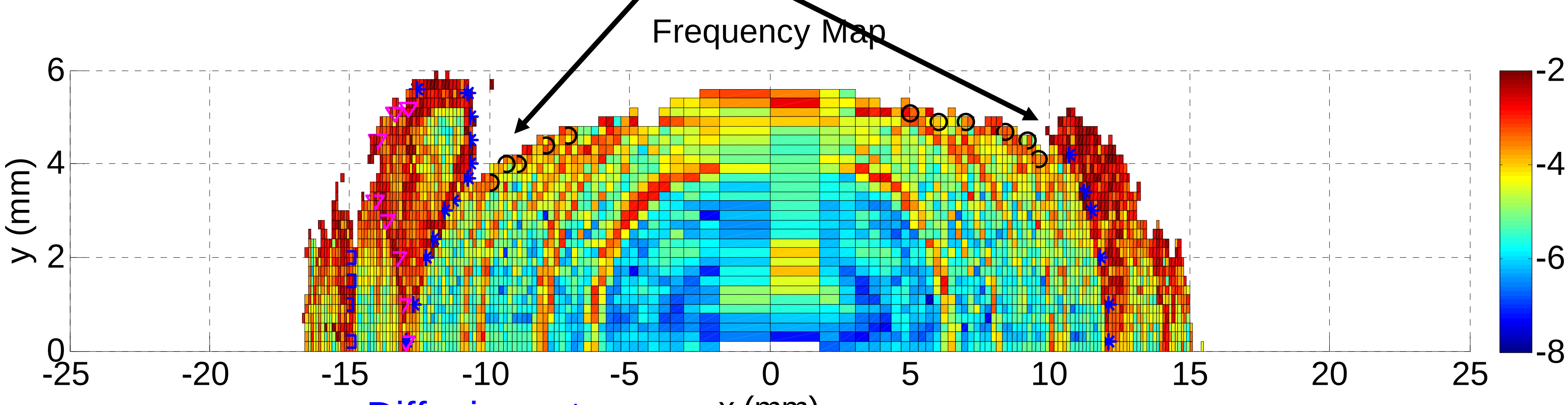
Modeling with Tracking for LE lattice

1. Tracking with AT.
2. LOCO lattice with insertion device in model.
3. Radiation off and rf off for FMA tracking.

Would it help to move the tunes away from the node of 4 nuy=1 and 6 nux=1?

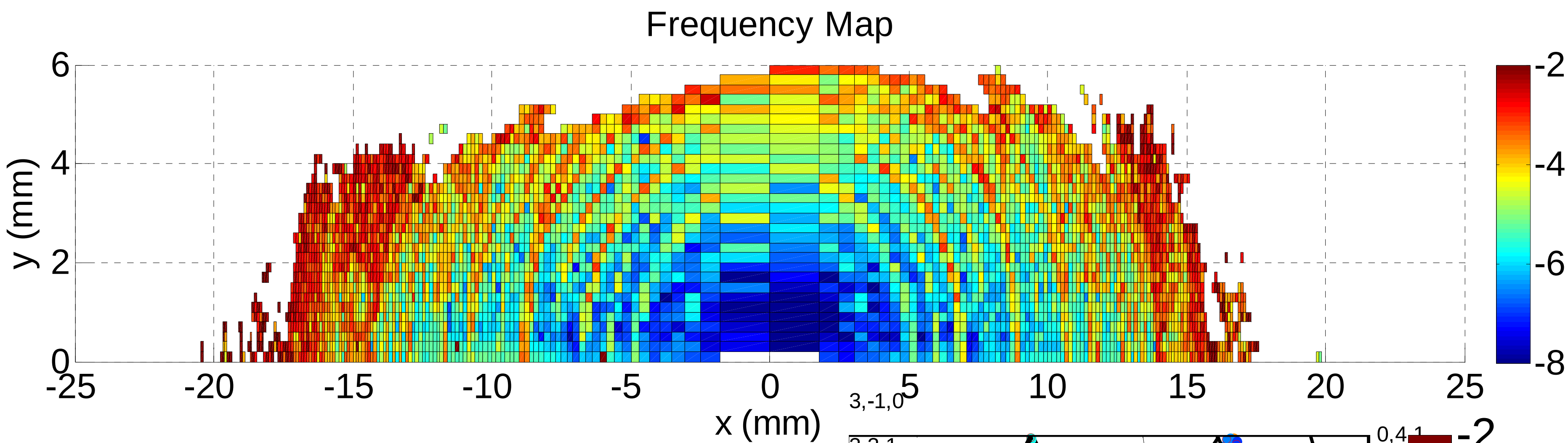


4 nuy=1

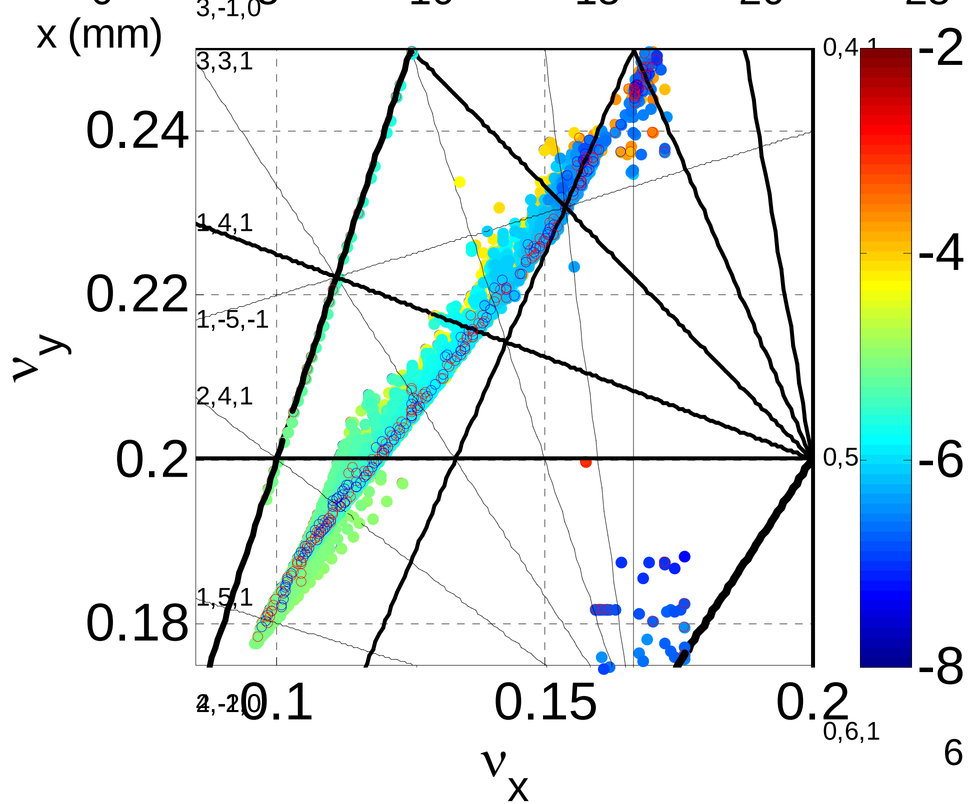


Diffusion rate

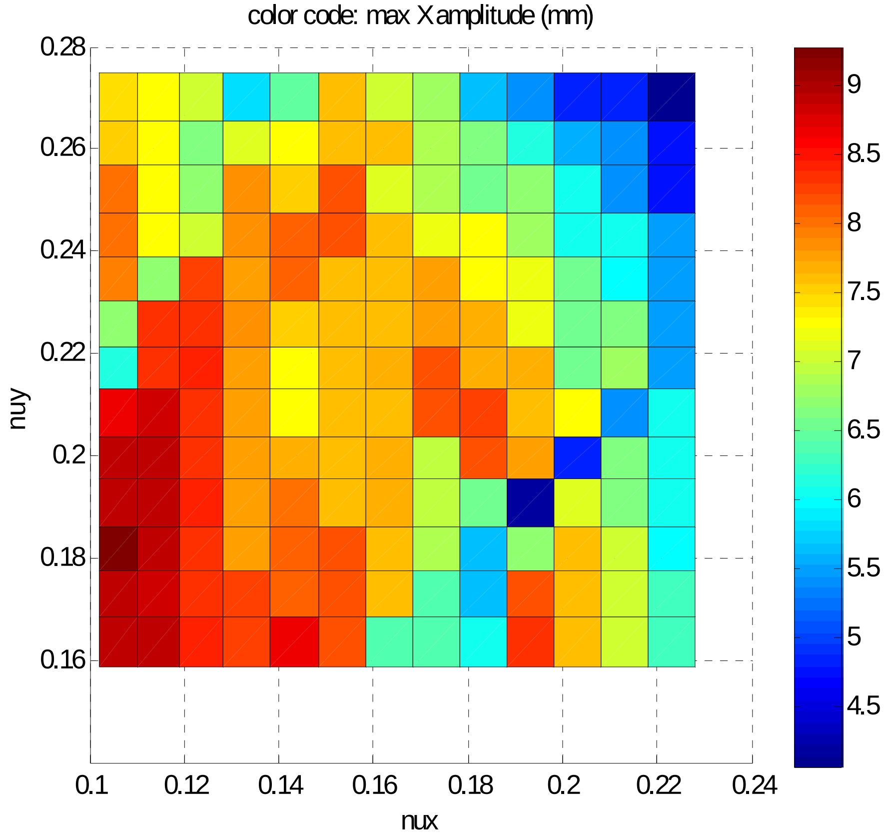
A low tune lattice

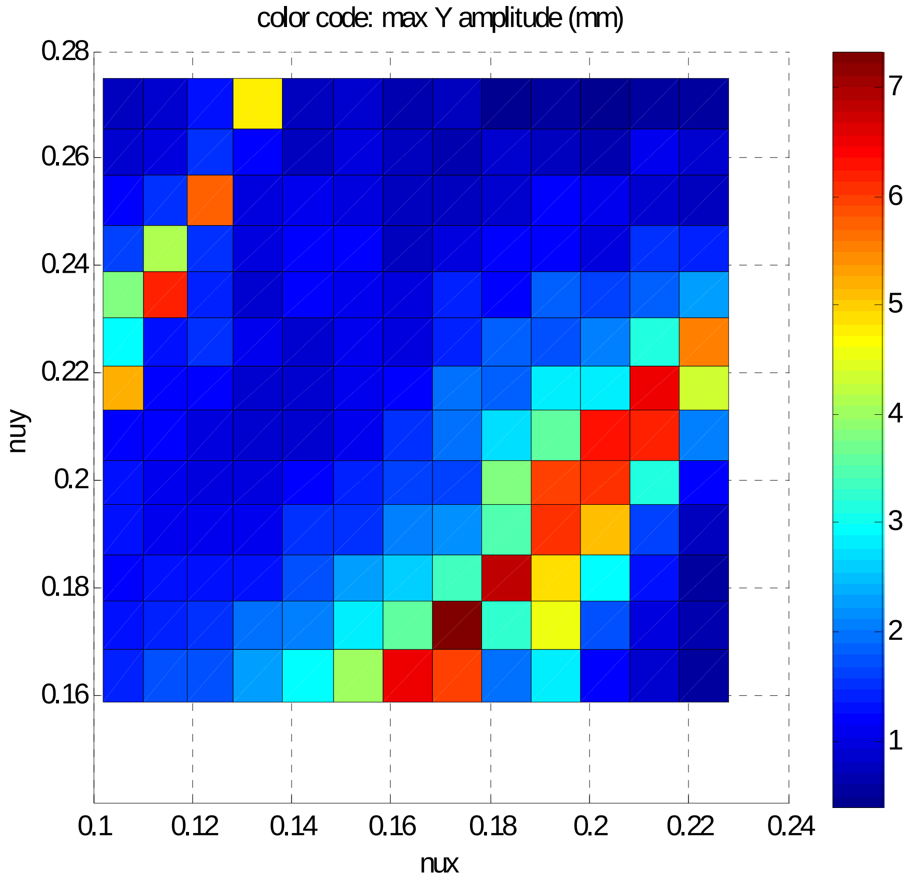


Tunes are [14.096, 6.178]
Re-matched with MAD to prevent beta beating.
This lattice was implemented and had better injection efficiency.



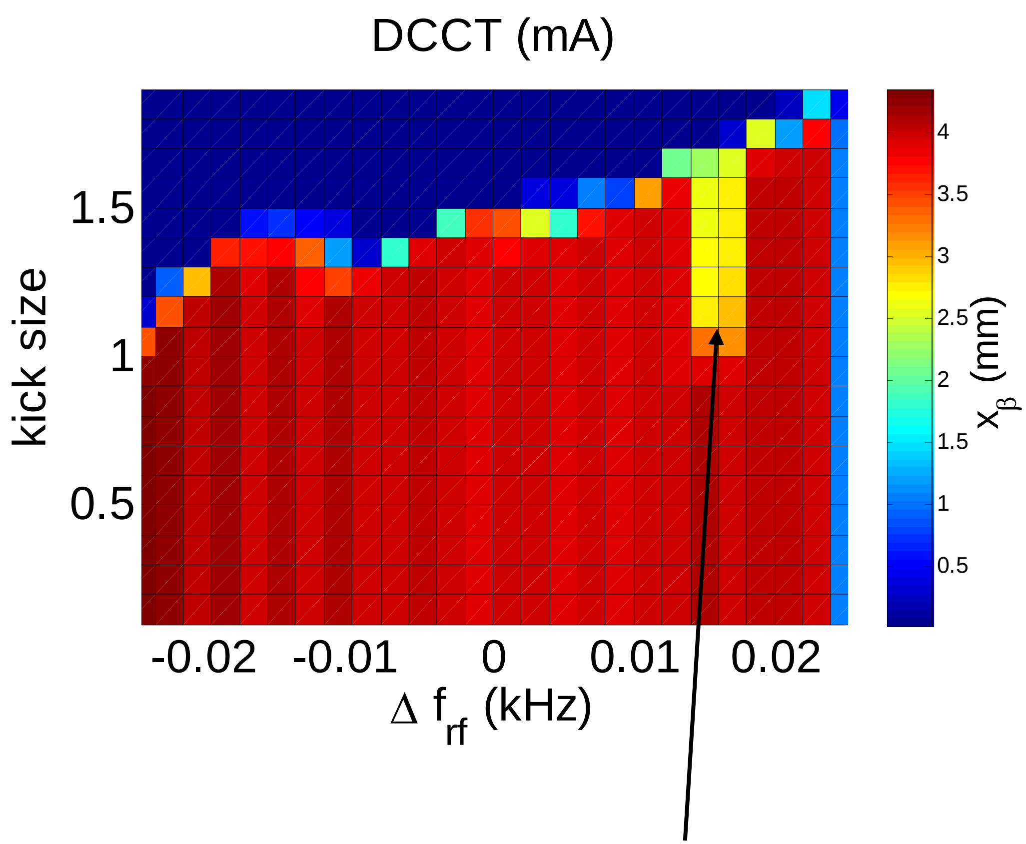
Tune scan for Dynamic Aperture

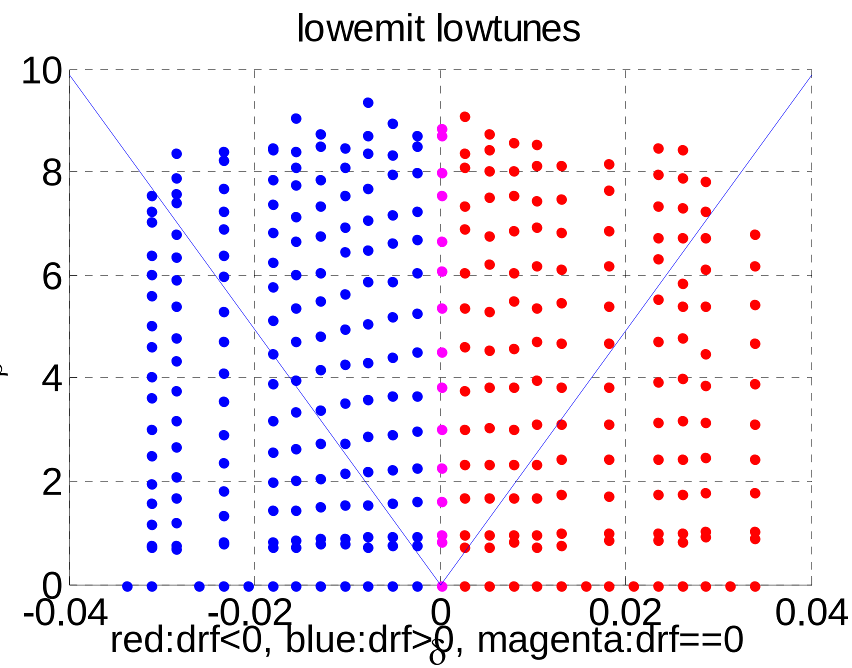


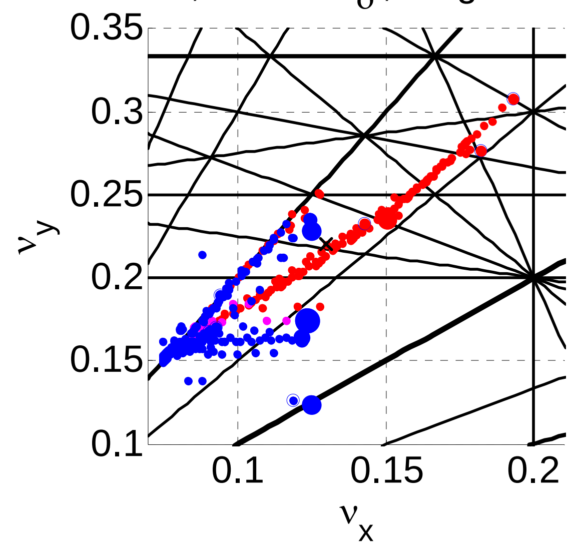


Change tunes and at each working point and find the maximum horizontal amplitude with the kicker.

Low tune lattice [0.096, 0.178]





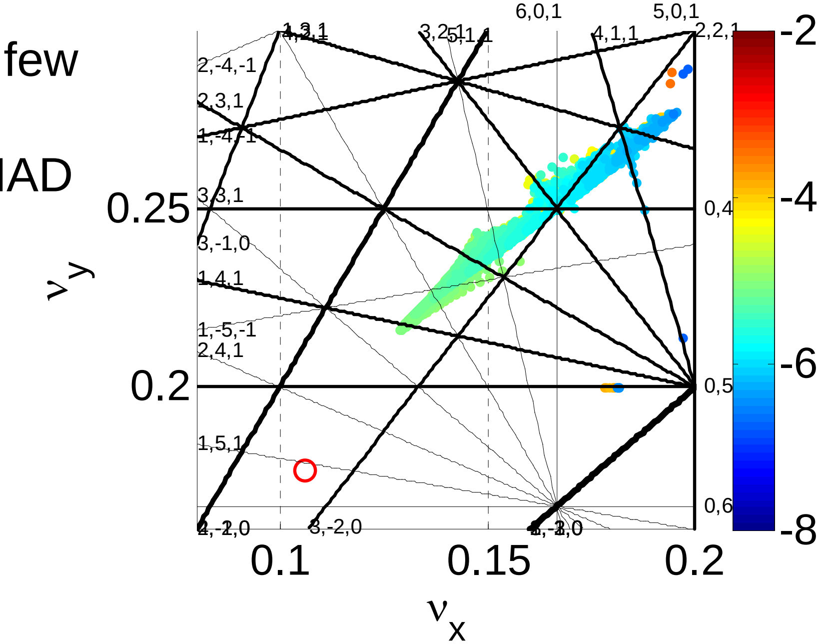


This working point is too close to the 2 nux-nuy=0 resonance line for off-momentum particles.

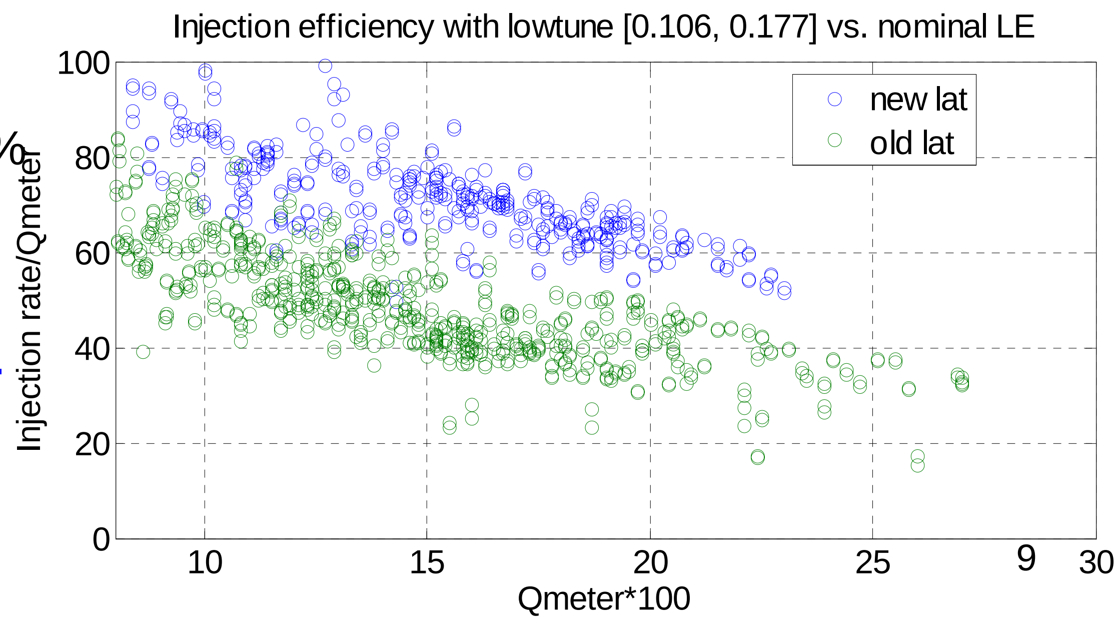
So we have adjusted the tunes.

Implementing a low tune LE lattice

1. Choose the new tune [0.106, 0.177] after a few trials.
2. Obtain a new matched design lattice with MAD
3. Dial in and use LOCO to correct optics.



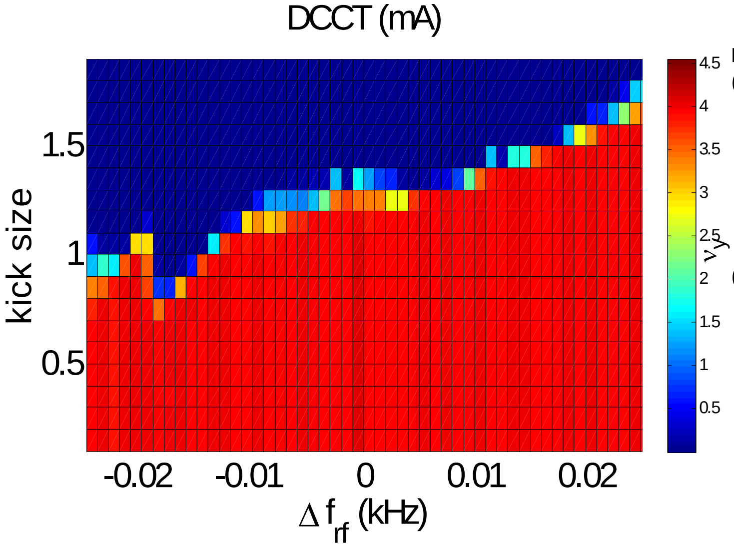
Injection efficiency improved by 25%



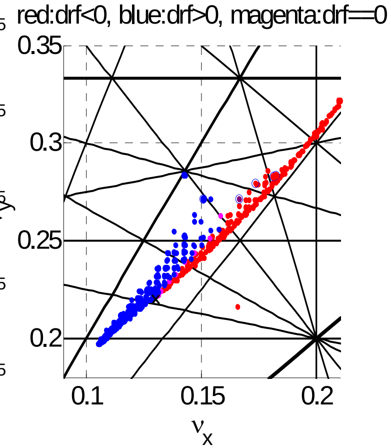
Qmeter (a.u.) is a measure of Booster beam current at ejection.

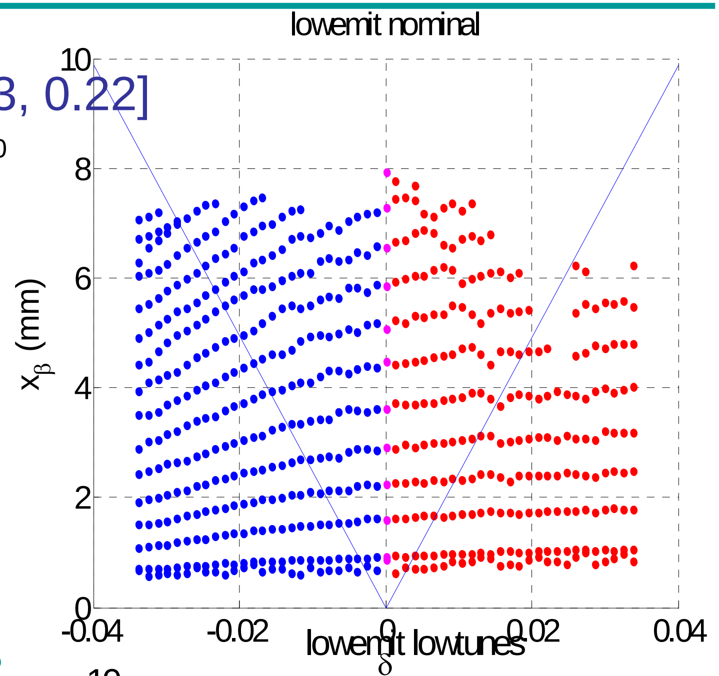
Dynamic aperture measurement

Horizontal kick and rf frequency scan.

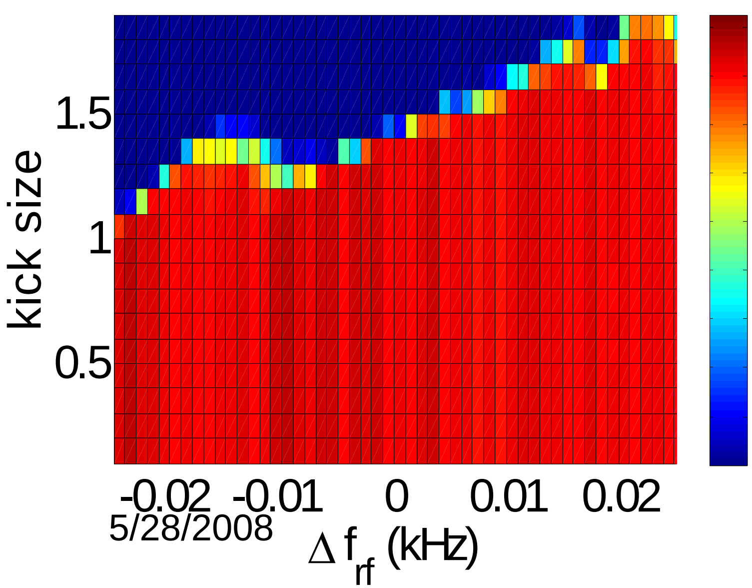


LE [0.13, 0.22]

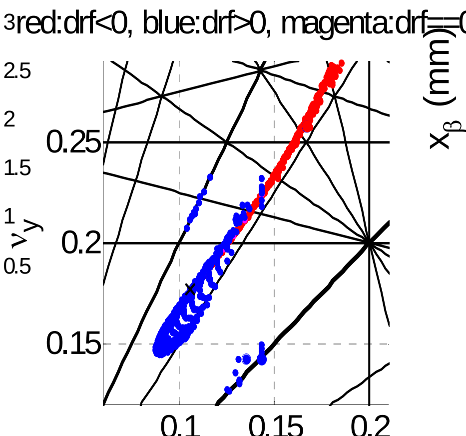


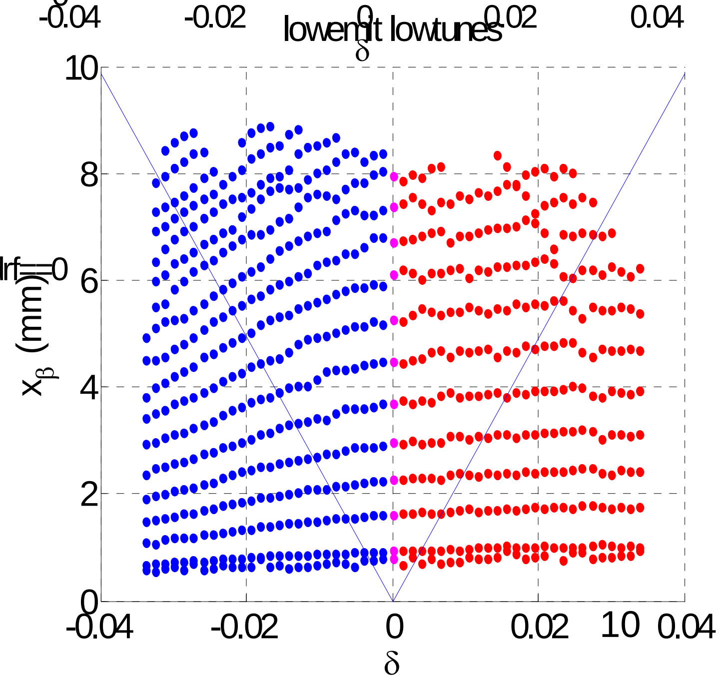


Betx_BPM = 3.46
Betx_septum=9.02

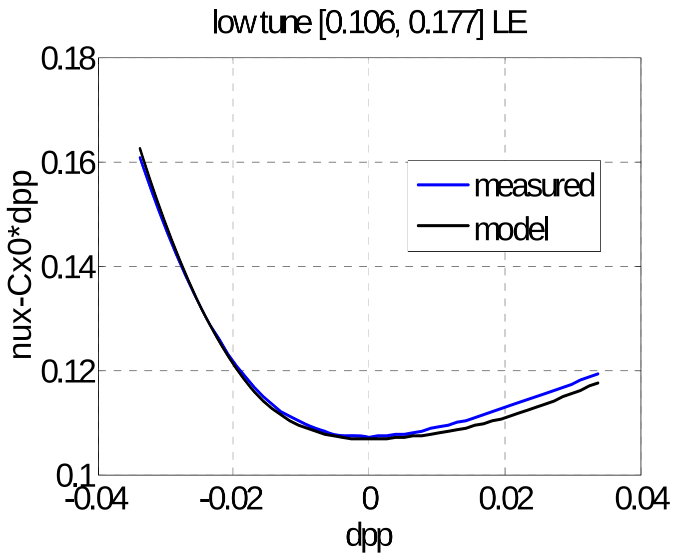


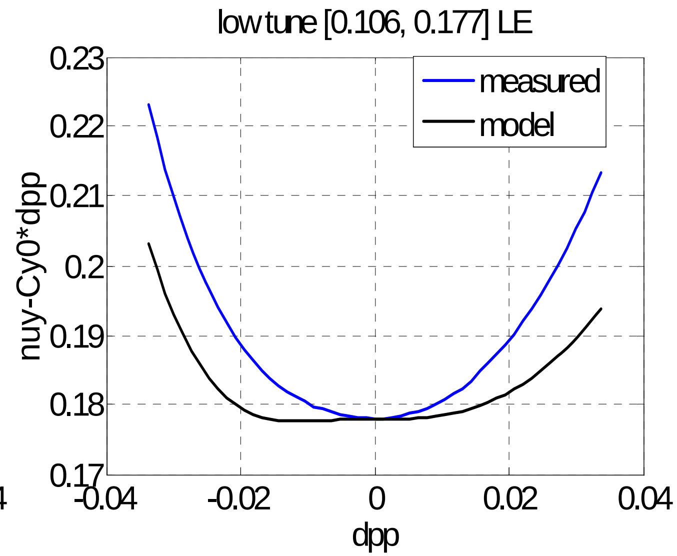
LE low tune
[0.106, 0.177]



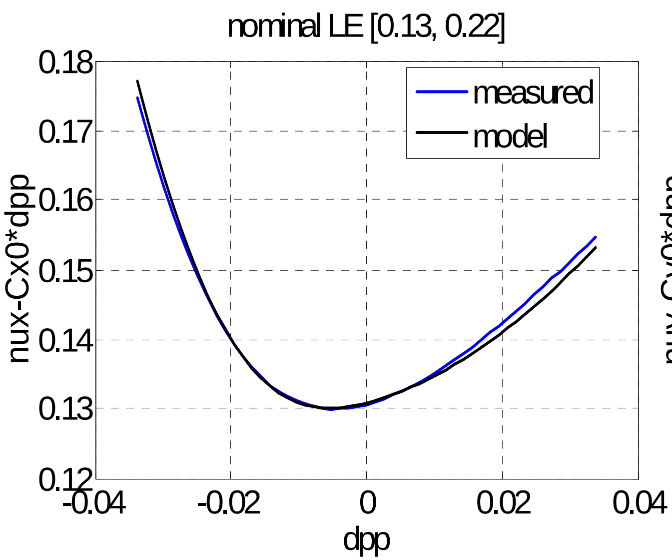


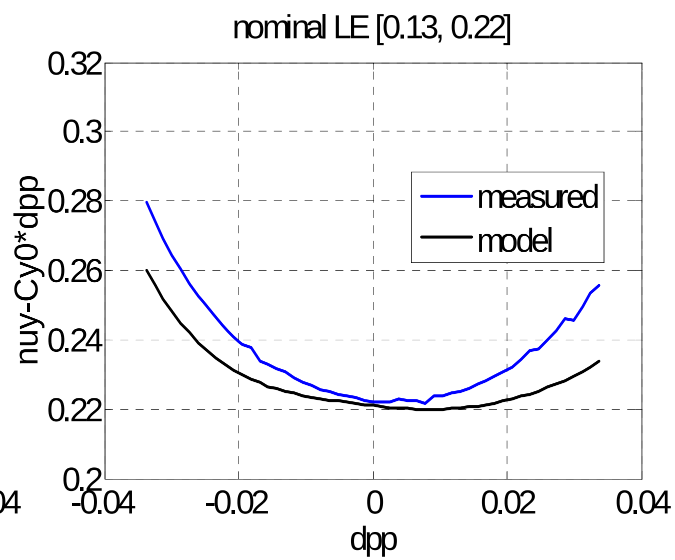
Comparison of high order chromaticities





Low tune	model	measured
chrx0	*	1.725
chrx1	28.8	28.35
chrx2	-569.0	-545.2
chry0	*	2.081
chry1	16.65	30.29
chry2	-207.0	16.3

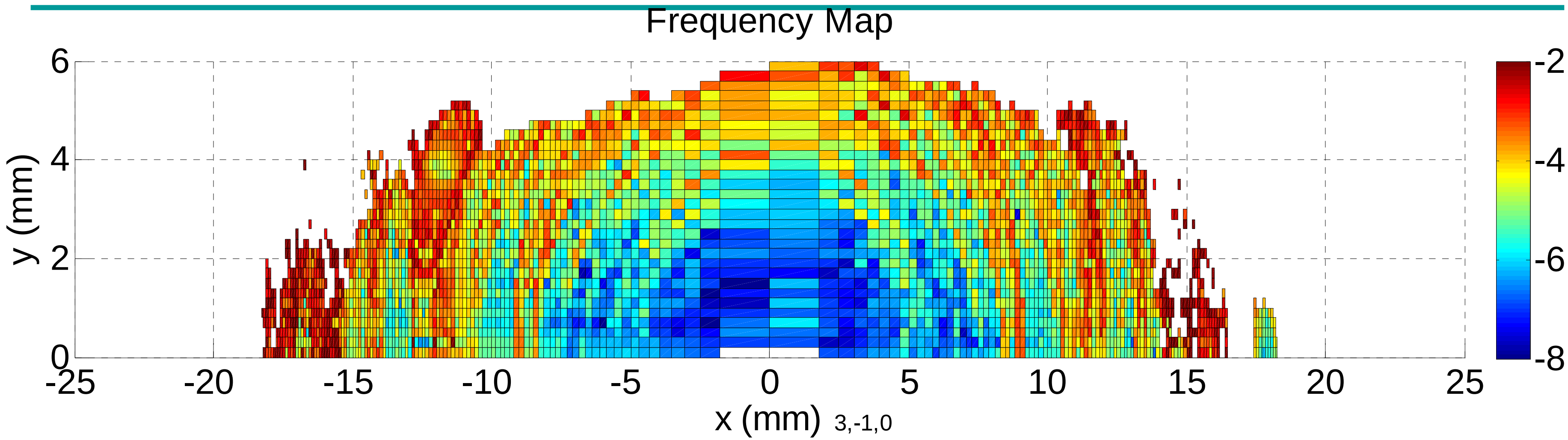




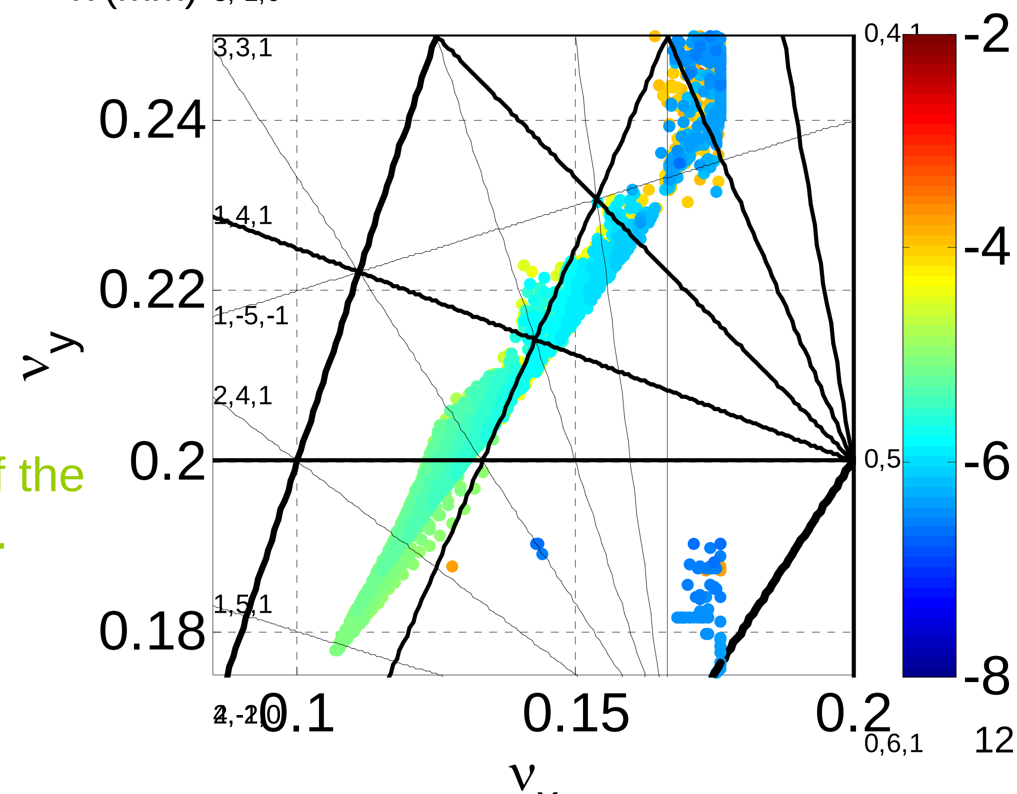
LE	model	measured
chrx0	*	1.974
chrx1	29.58	29.47
chrx2	-520.7	-481.0
chry0	*	1.867
chry1	21.43	34.70
chry2	-217.1	20.9

*Model chromaticity is set to measured values.
Linear term taken out to facilitate the comparison.

But FMA of this new lattice does not look as good

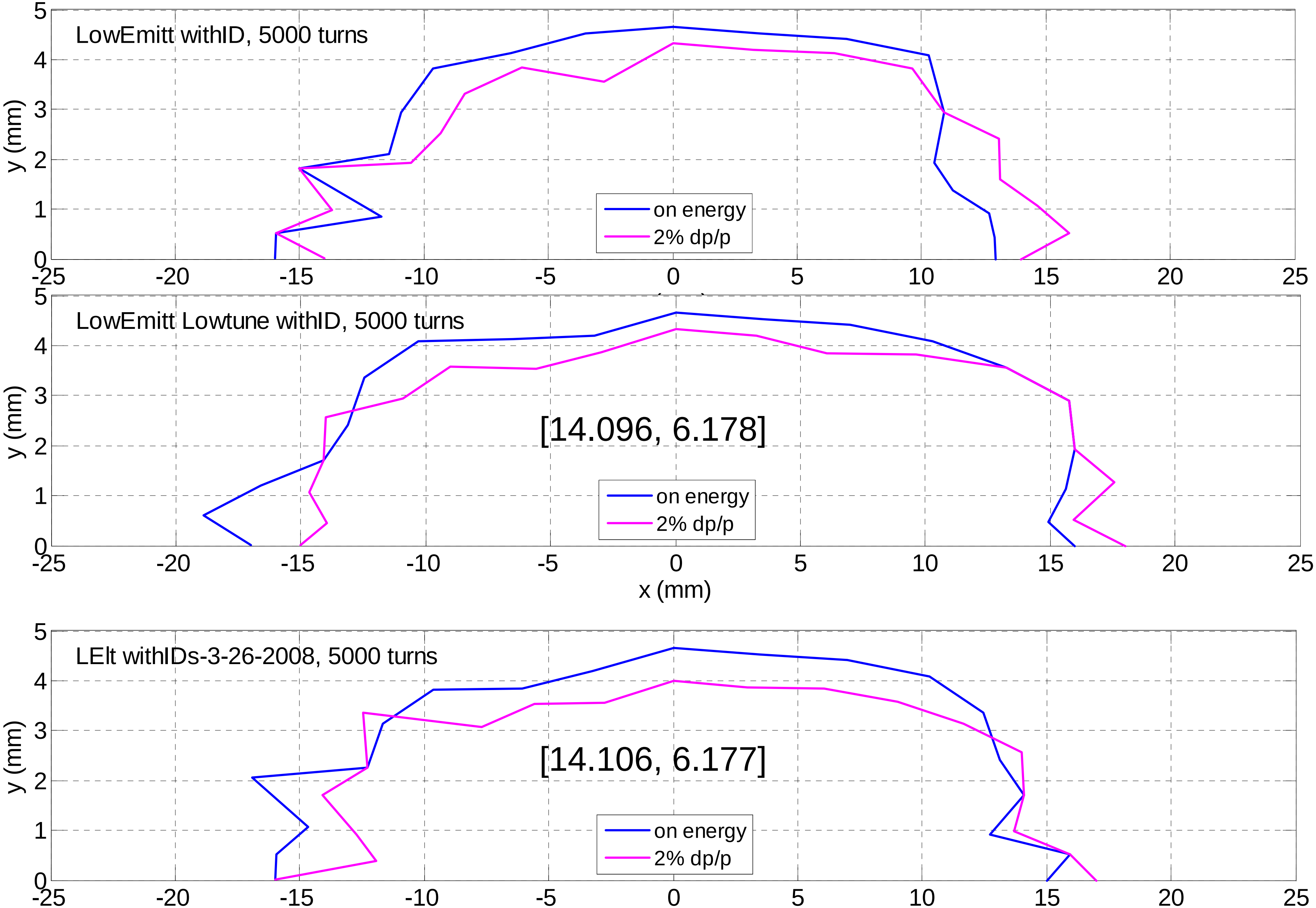


LE low tune [0.106, 0.177]



We need a better nonlinear model of the machine to explain the observations.

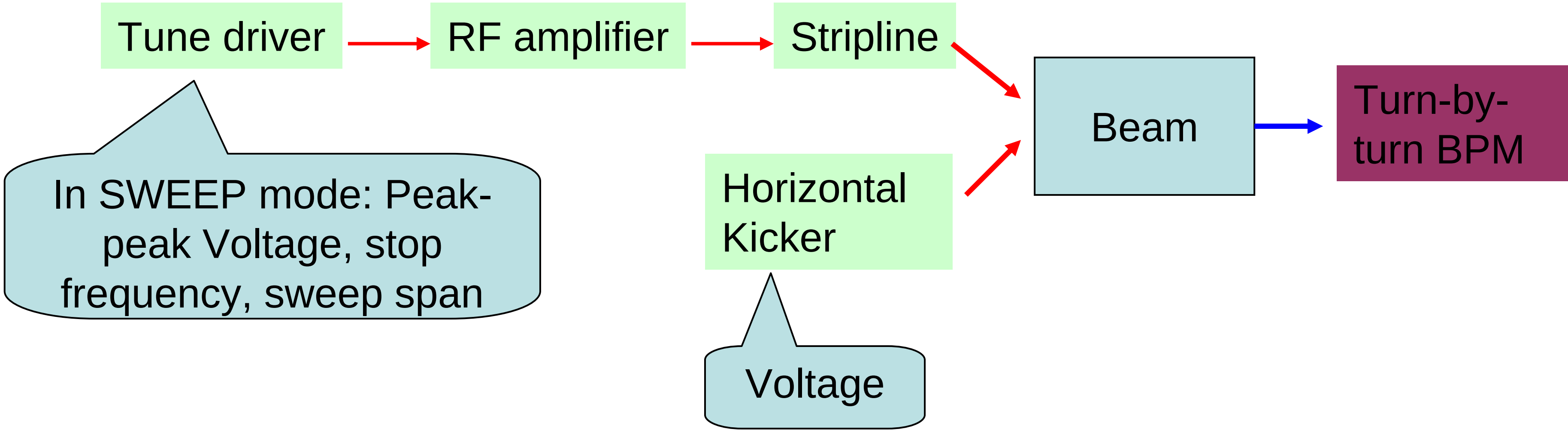
Dynamic aperture comparison



Frequency map measurement at SPEAR3

- Setup

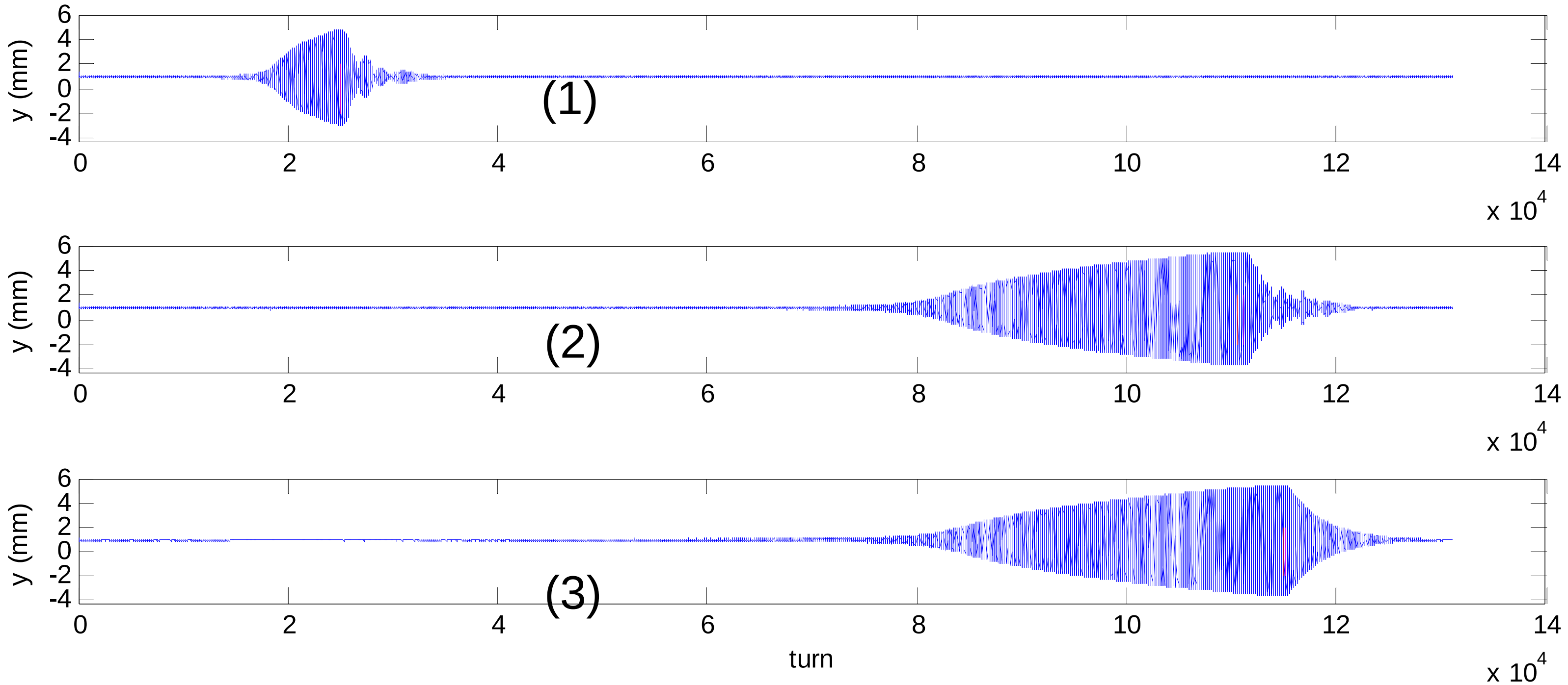
We don't have a vertical kicker or pinger. So we excite vertical beam resonantly. The challenge is to drive the vertical beam motion up and synchronize it to the horizontal motion.



1. Tune driver, horizontal kicker and turn-by-turn BPM are all triggered by the same 10Hz signal.
2. Delay is set to the tune driver so that the sweep stops when the kicker is fired.
3. 100ms BPM turn-by-turn data is saved.
4. RF driving signal applies to both horizontal and vertical planes through the stripline.

Kicker is fired when the vertical motion is driven to high amplitude. At this moment the driving signal switches to lower frequency. So both horizontal and vertical motion are 'free' afterwards.

Finding the stop frequency

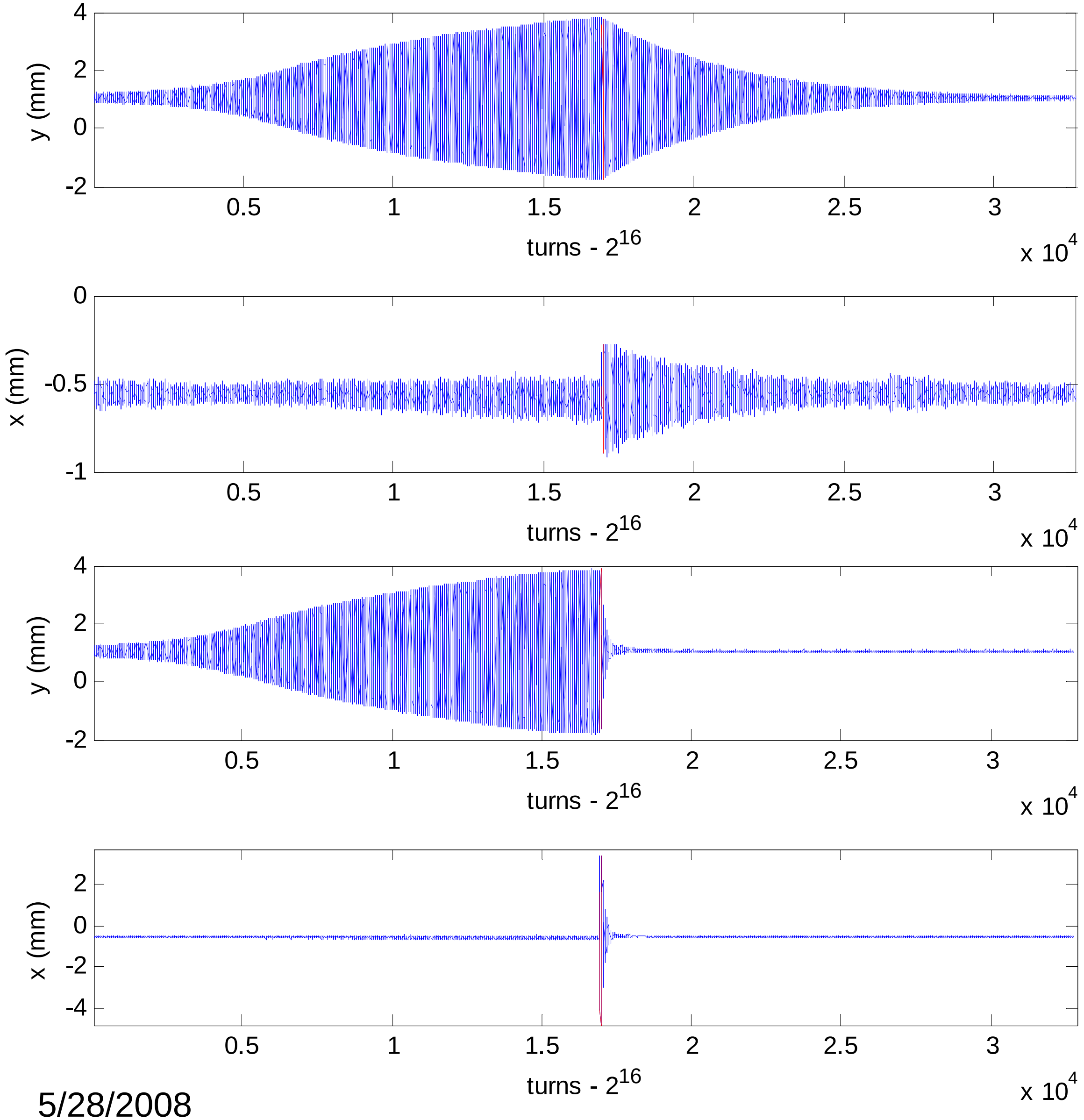


For any given driving voltage, the stop frequency is found in three steps:

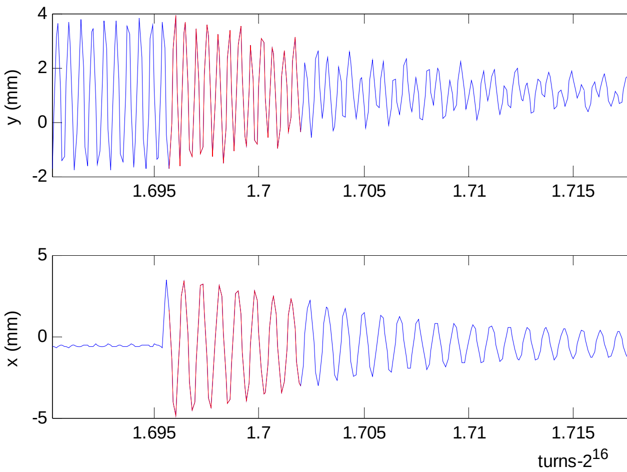
1. Use a wide span (70kHz) sweep with a safe stop frequency
2. Use a narrow span (20kHz) sweep using the resonance frequency plus 2 kHz overhead as stop frequency
3. The resonance frequency in step 2 is used as the stop frequency.

Examples

The first 2^16 turns are not shown.



Oscillation damps down fast when horizontal amplitude gets large.



64 turns in red

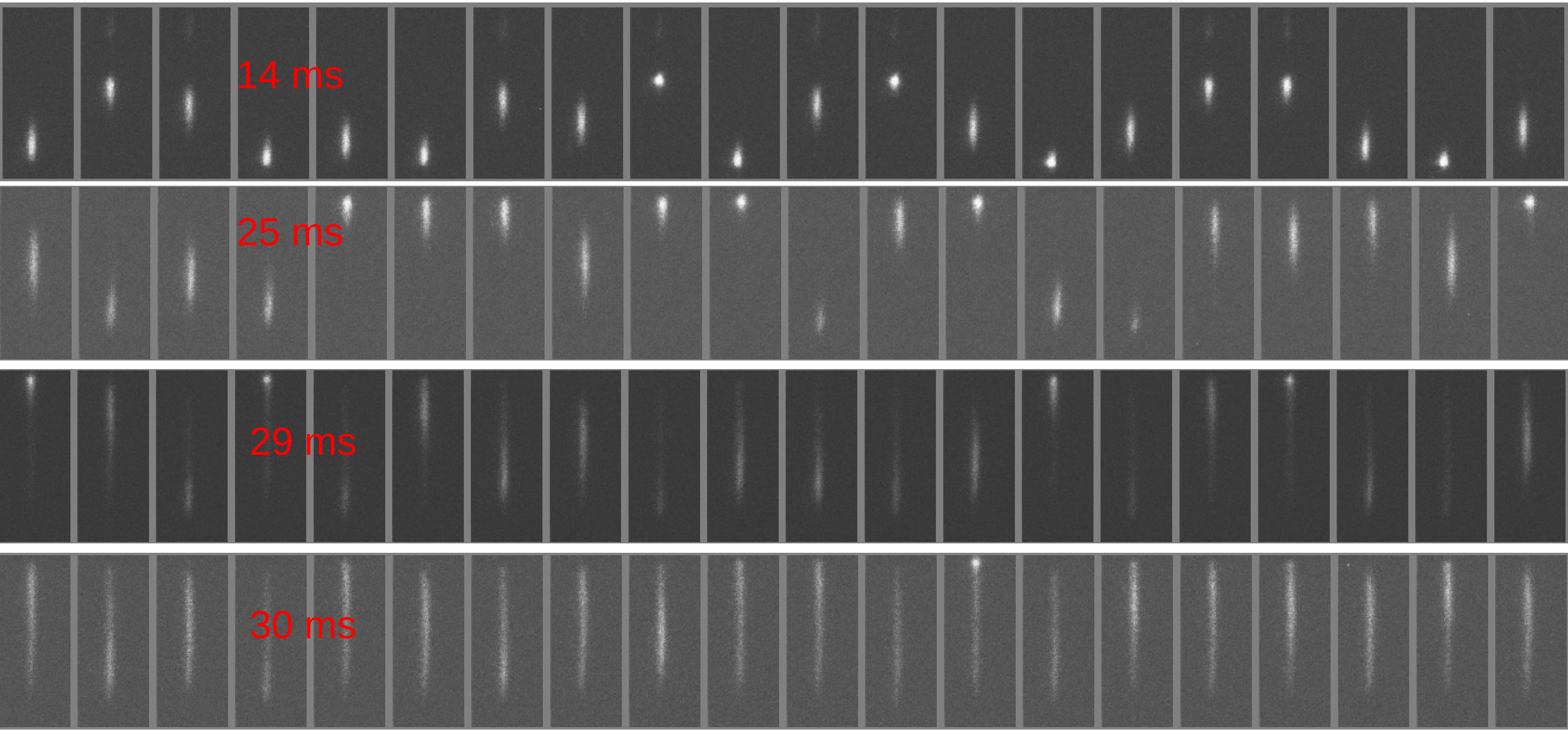
Issues and observations

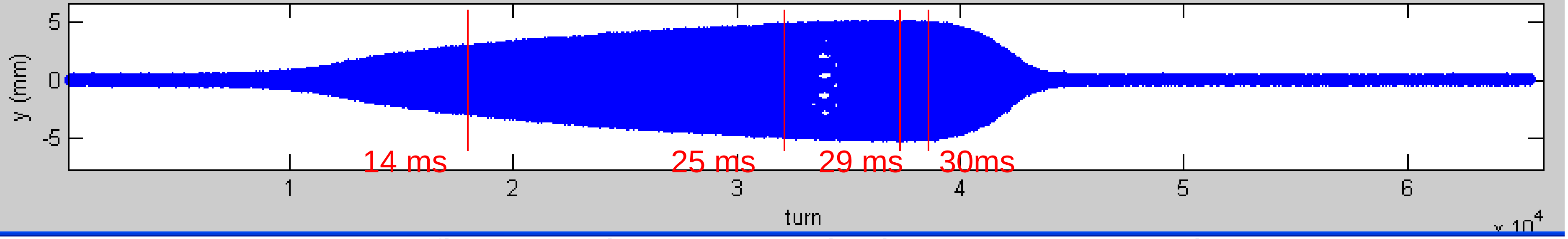
- The achieved amplitude depends on single bunch current
  - Small single bunch current ➔ high amplitude.
- Amplitude does not depend on sweep rate when it is slow enough (below 20kHz/100ms).
- The vertical ramp is not quite reproducible.
- In dual-sweep (driving both planes) mode, large horizontal and vertical motion are not compatible.
- Fast damping at high amplitude
- Filamentation affects BPM readings

Filamentation

Measurement by J. Corbett and A. Terebilo on 5/20/2008

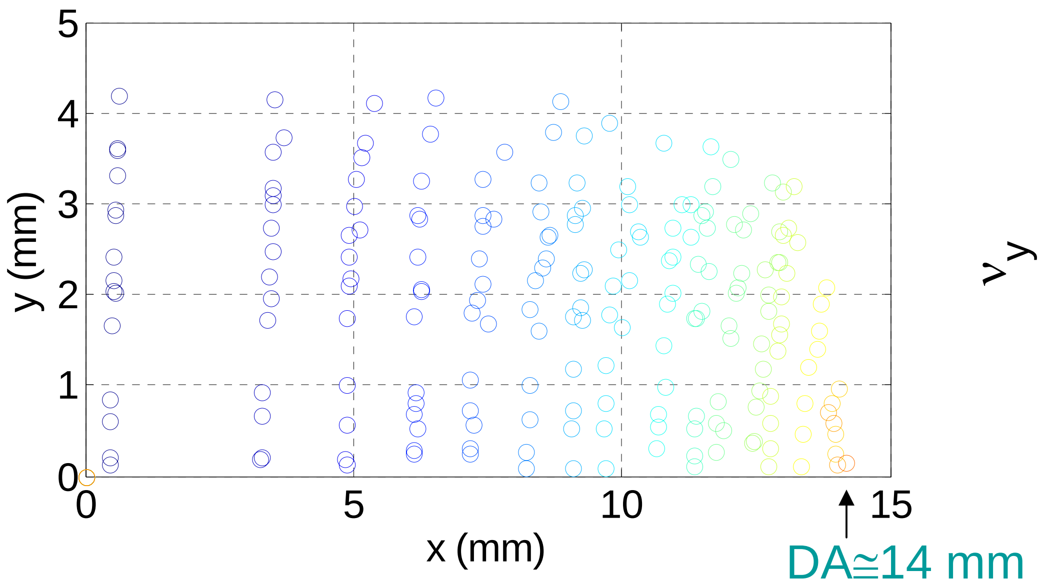
Vertical profile on the ramp

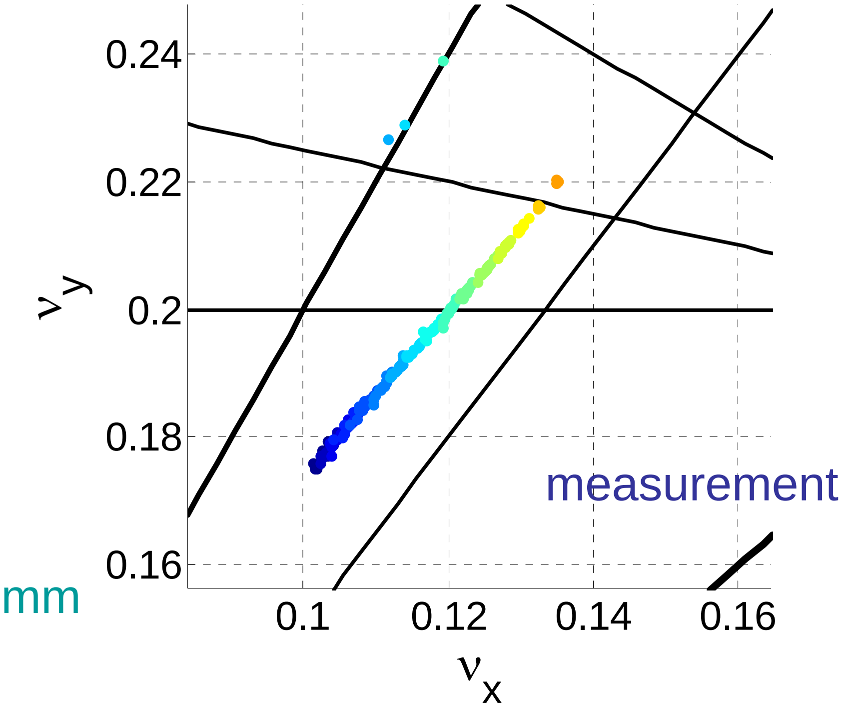




Severe filamentation appears in the resonance region.

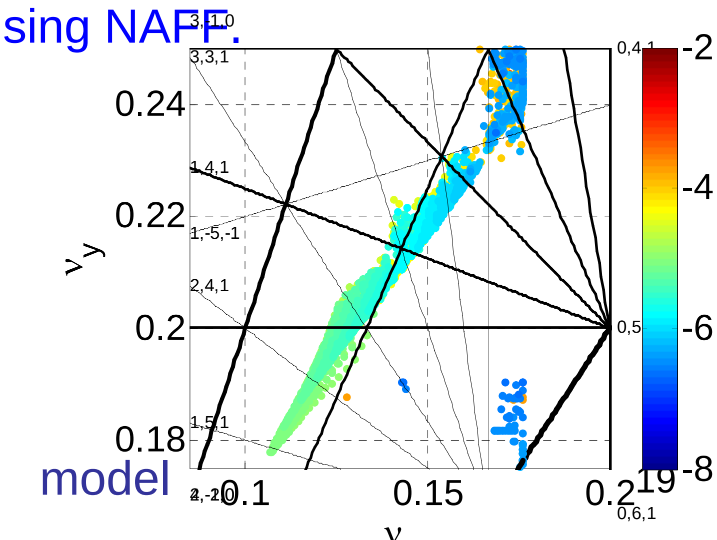
Result: ID closed



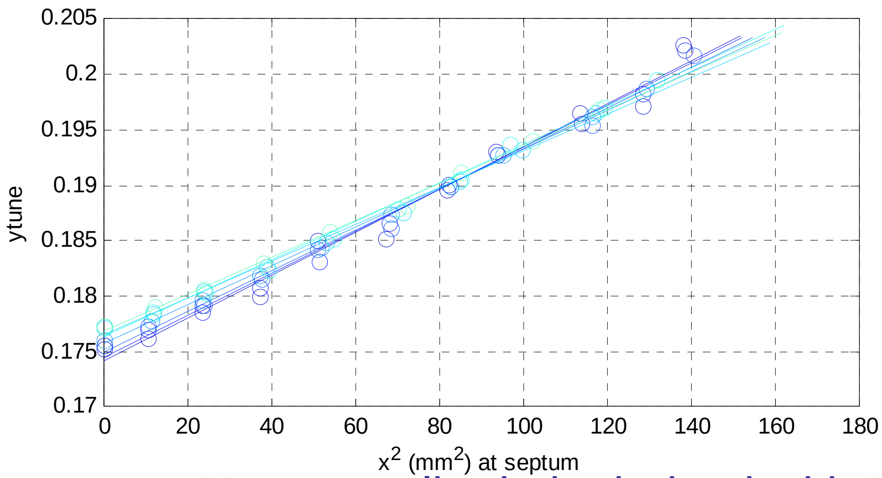


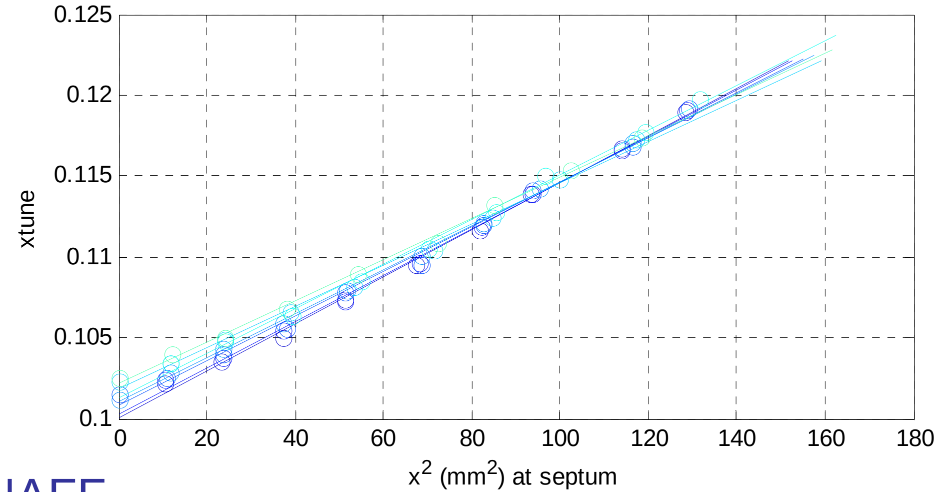
Data measured at 4mA/80bunches.
Amplitude scaled to the septum
Amplitude and tune derived from 64 turns of data using NAFF.

Clear difference between the measured and model FMA tune graph:
(1) The direction of tune with amplitude.
(2) The tune span due to vertical amplitude.

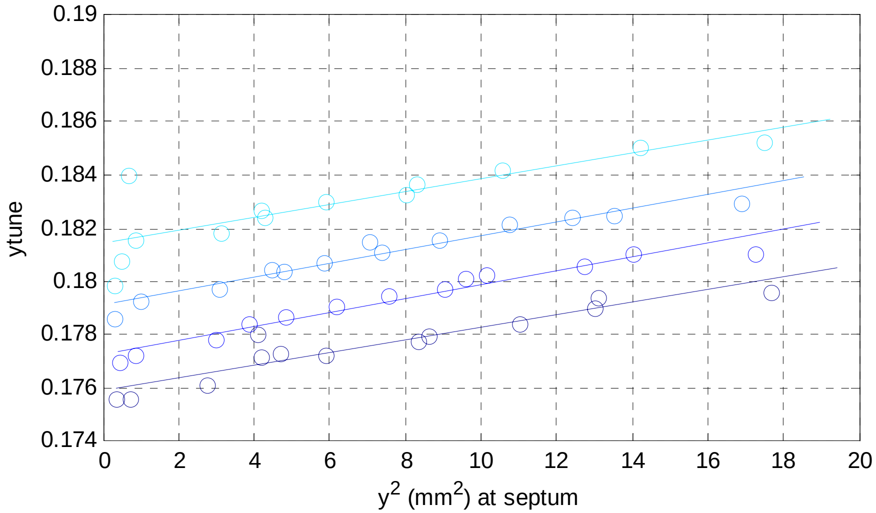


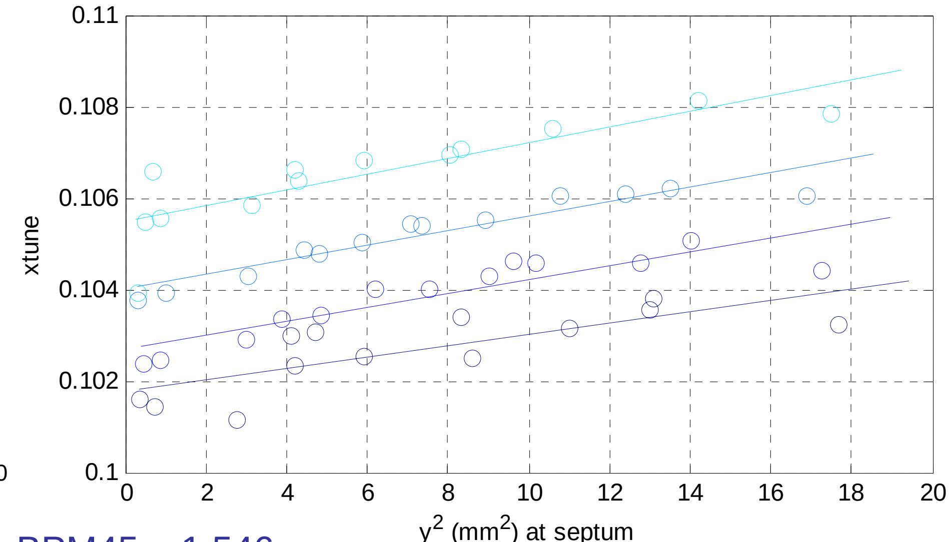
Tune vs. amplitude





Note: amplitude is derived with NAFF.



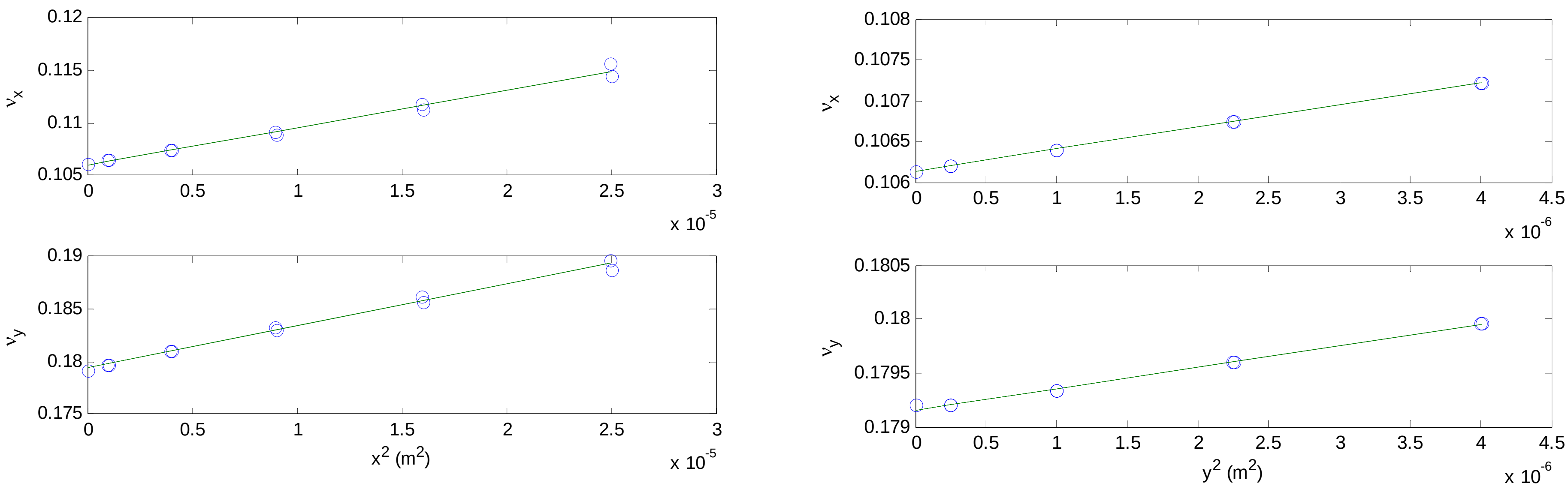


betaxBPM45 = 1.546
betayBPM45 = 11.755
betaxSeptum = 9.021
betaySeptum = 5.176

dnuxy_dx2y2=
[140.9, 151.9
185.7, 248.9]

→ dnuxy_dexey=
[1270.9, 786.2
1675.0, 1288.3]

Model: ID closed

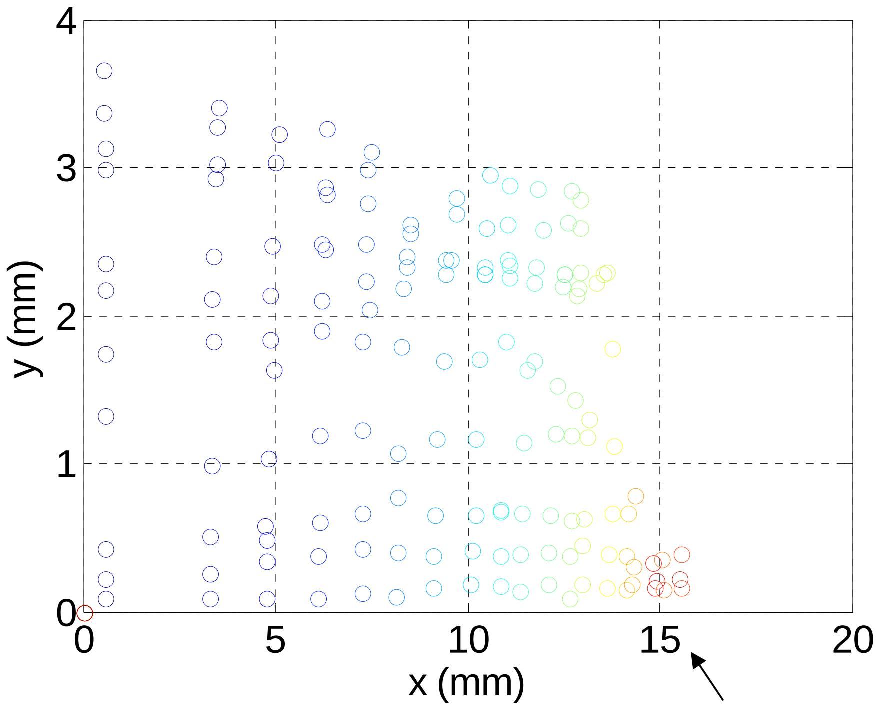


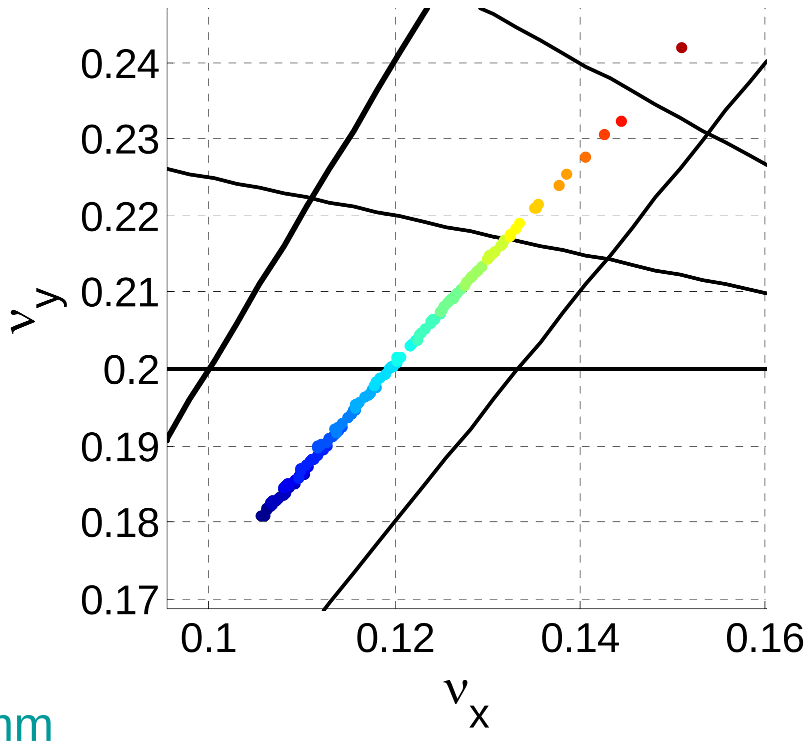
Measurement:
dnuxy_dexey=
[1270.9, 786.2
1675.0, 1288.3]

↔

Model:
dnuxy_dexey=
[1804.8, 2466.0
2015.0, 1815.7]

IDs open

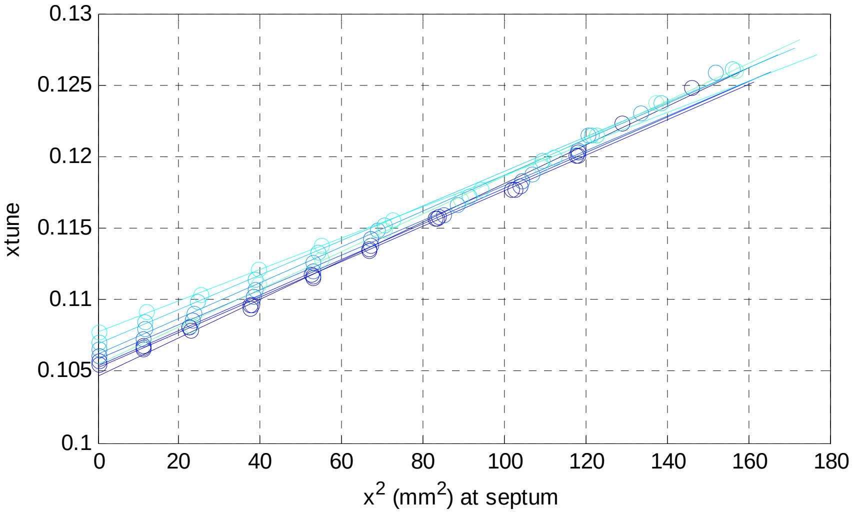


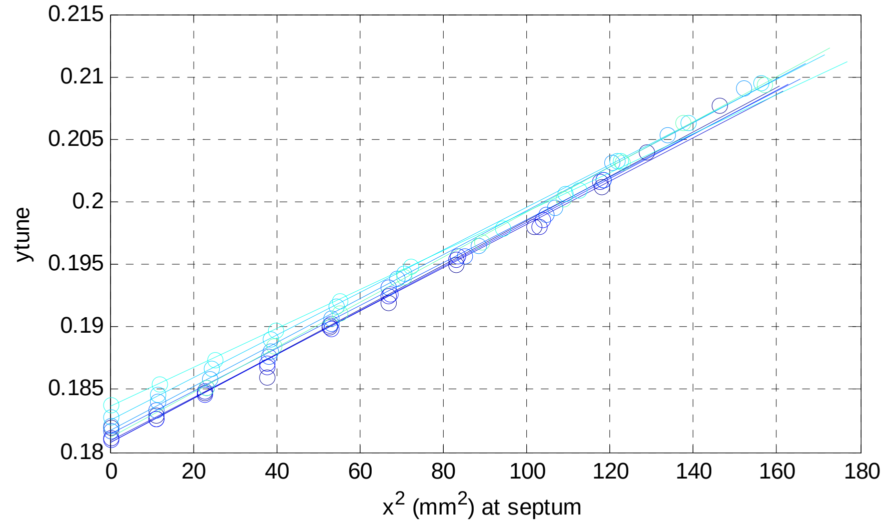


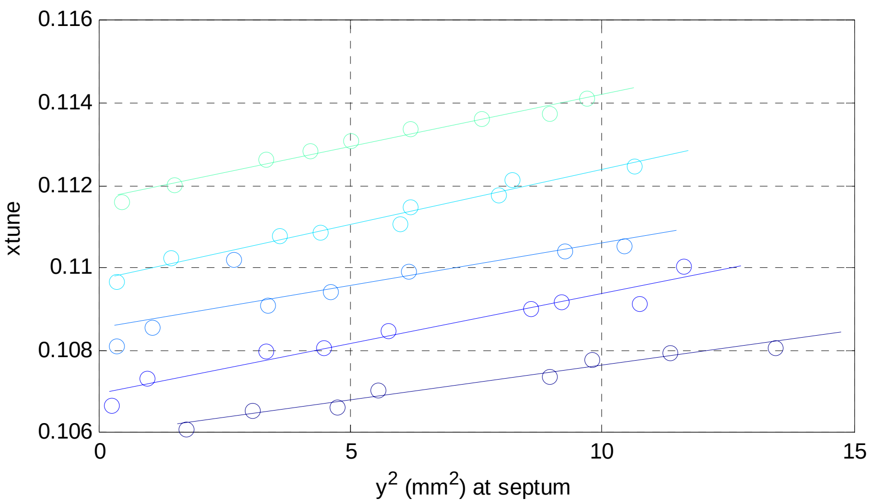
DA≅16mm

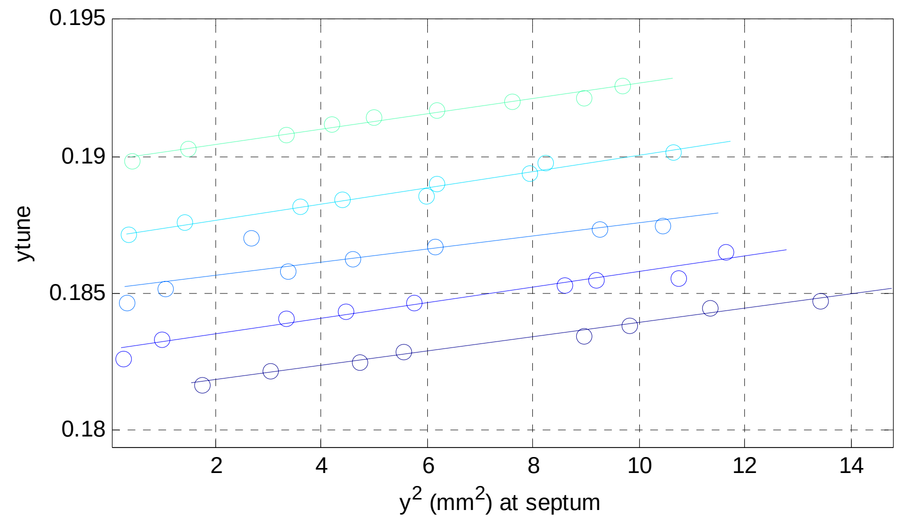
Measurement interrupted by a fault. Later we didn't have time to go to higher peak-peak voltage.

Tune vs amplitude: IDs open







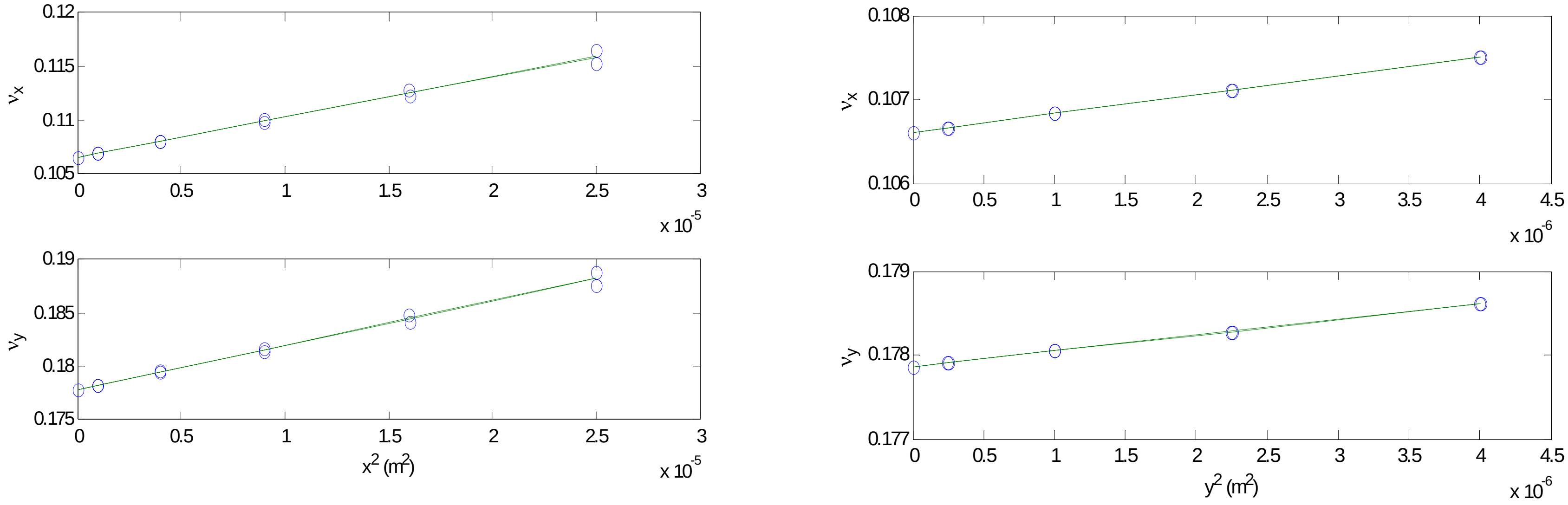


dnuxy_dx2y2=
[125.5, 221.3
174.3, 269.8]

→

dnuxy_dexey=
[1132.0, 1145.7
1572.2, 1396.4]

Model: IDs open



Measured:
dnuxy_dexey=
[1132.0, 1145.7
 1572.2, 1396.4]

↔

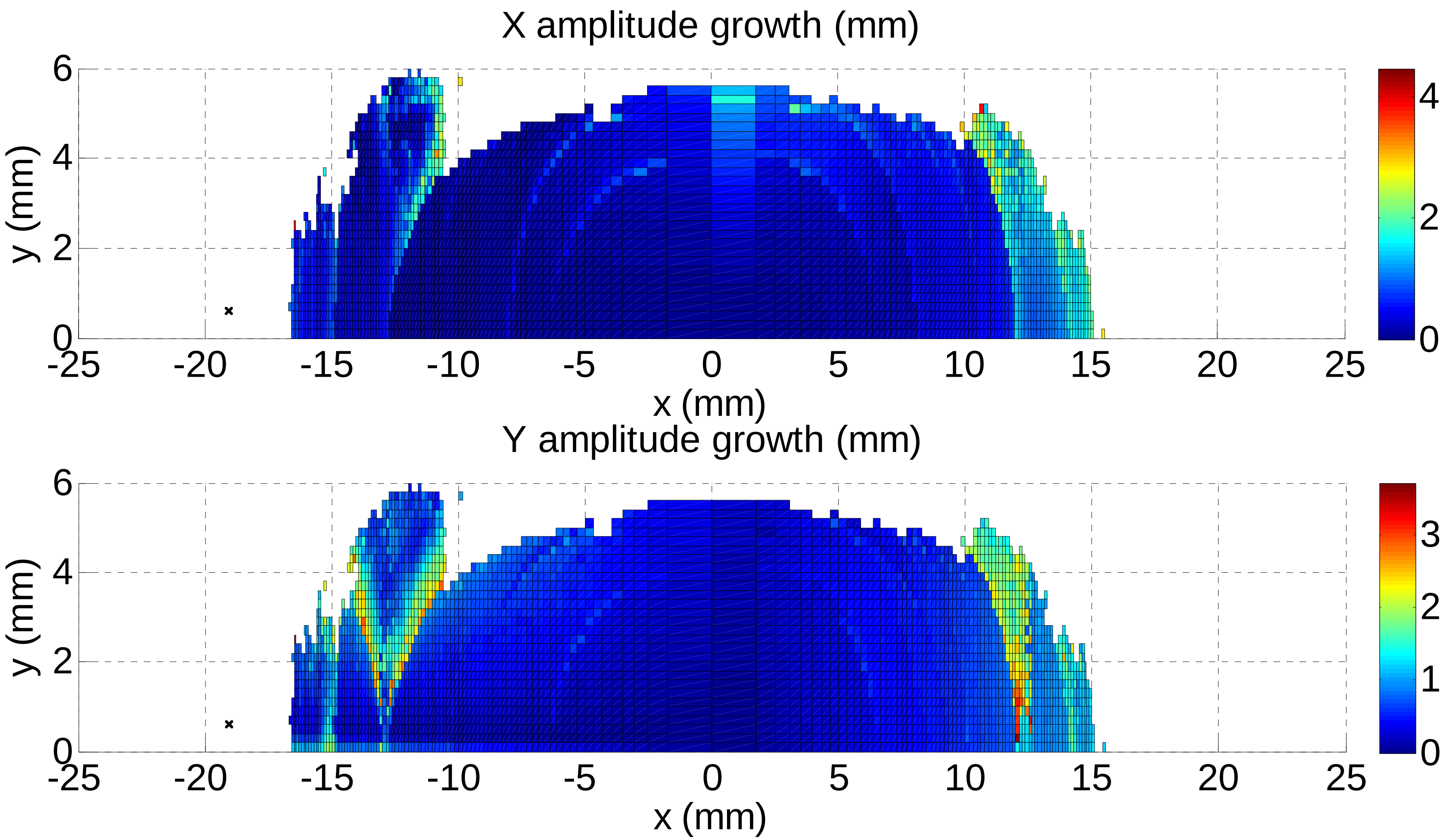
Model:
dnuxy_dexey=
[1873.0, 2047.1
 2081.2, 1684.9]

The diagonal elements are supposed to be equal.

Conclusion

- SPEAR3 Touschek lifetime is mainly determined by rf acceptance.
- Frequency map has guided us to find a working point with better dynamic aperture which led to better injection efficiency.
- Some agreement of the nonlinear behavior between model and measurements are seen. But the nonlinear lattice model still need to be improved.
- A FMA measurement setup is ready at SPEAR3. Preliminary results are available.
- But more needs to be understood about this system
  - Filamentation
  - reproducibility

Amplitude growth (LE lattice)



More examples