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BERKELEY LAB

Strong-Strong Simulations: benchmark with LHC observations

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LARP/HiLumi-LHC Collaboration Meeting
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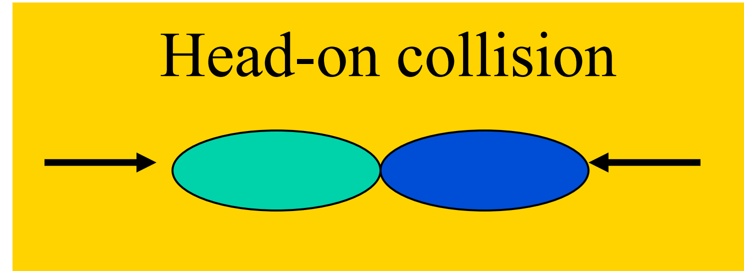
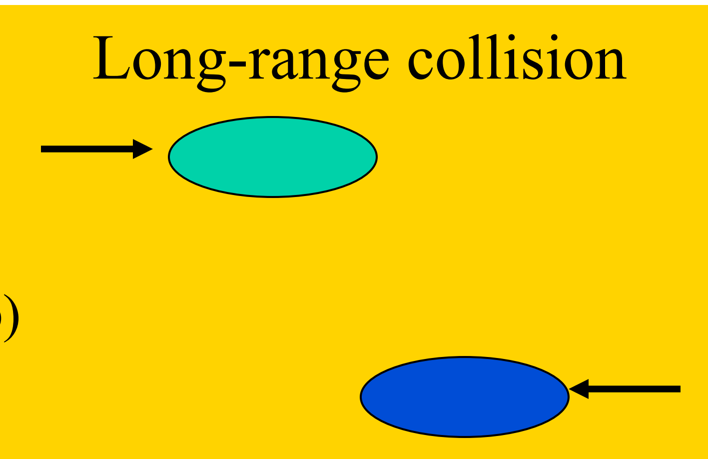
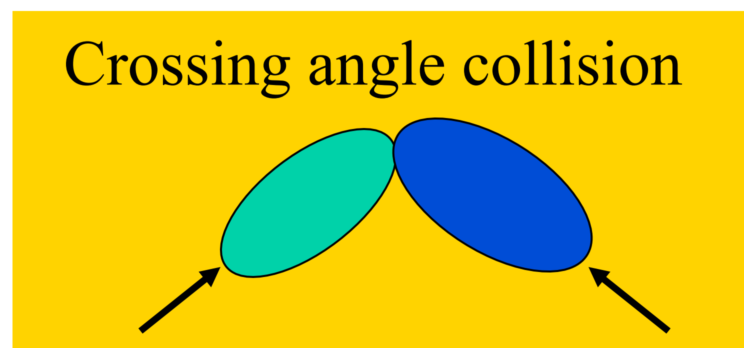
Simulation Tool: BeamBeam3D
A Parallel Strong-Strong/Weak Beam Beam Code

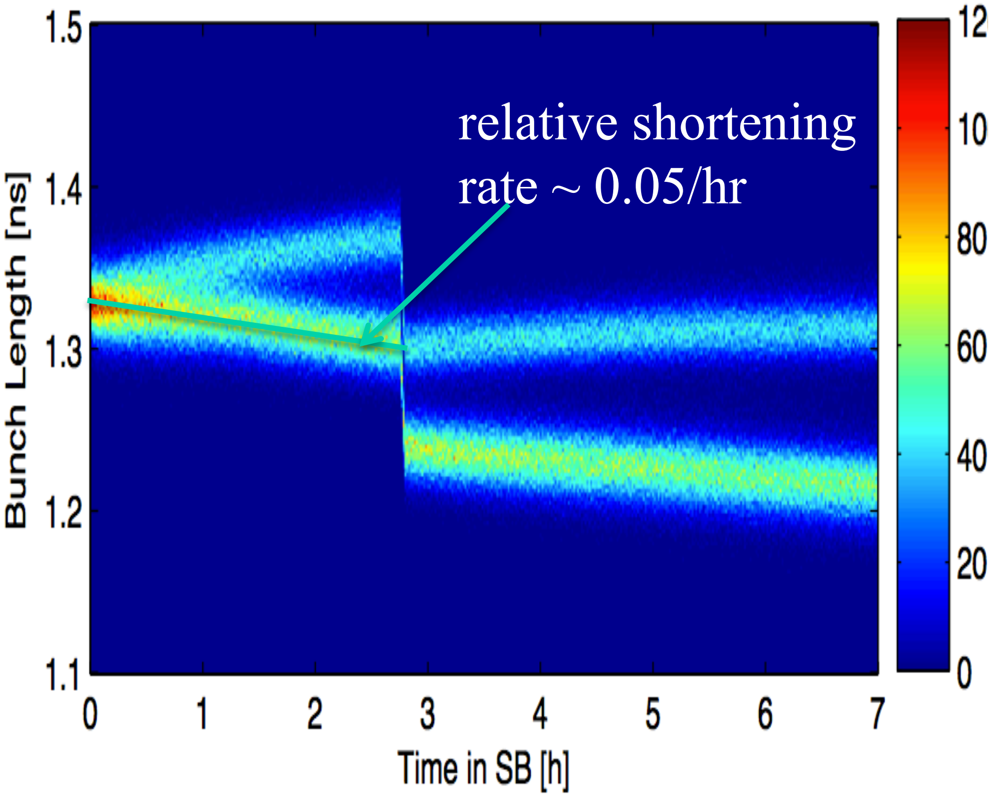
- Beam-Beam forces – integrated, shifted Green function method with FFT – O(N log(N)) computational cost
- Multiple-slice model for finite bunch length effects
- Parallel particle-based decomposition to achieve perfect load balance
- Lorentz boost to handle crossing angle collisions
- Arbitrary closed-orbit separation (static or time-dep)
- Multiple bunches, multiple collision points
- Linear transfer matrix + one turn chromaticity +thin lens sextupole kicks
- Conducting wire, crab cavity, and electron lens compensation

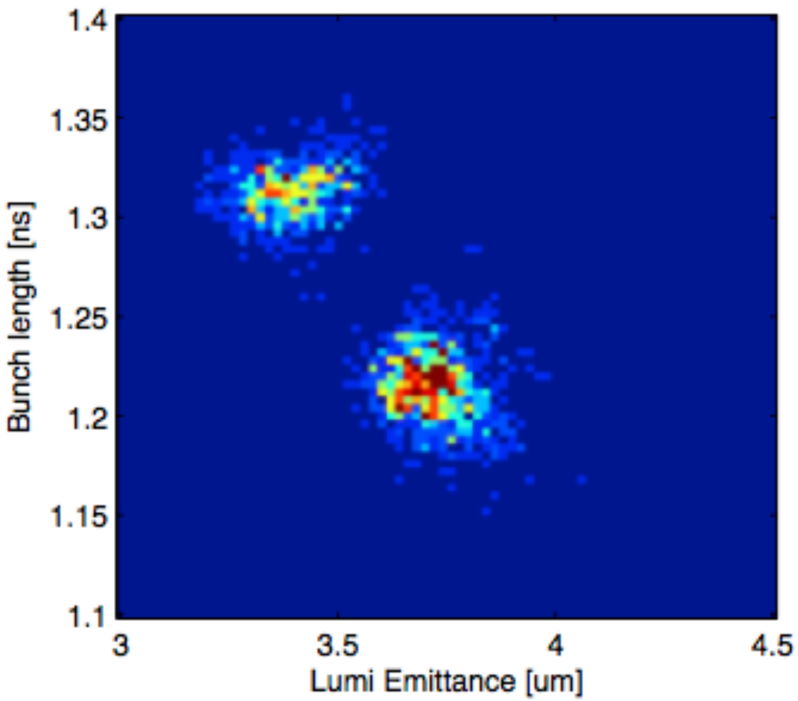






LHC Observations (1)





“The observed splitting of the bunch length histogram for LHC beam is an effect of the selective transverse emittance blow-up which occurs at the end of the squeeze beam mode (when present).”

M. Hostettler et al., CERN-ATS-Note-2013-003

Simulation Model and Parameters

1) Two IPs + feedback model + 4 sigma aperture size

2) Initial beam parameters

- Np = 1.5 x 10^{11}, E = 4 TeV
- ε_1 = 2.5 um, ε_2 = 3.5 um, dp/p = 0.11x10^{-3}
- $\beta_x = \beta_y$ = 0.6 m, σ_z = 9.74 cm
- half crossing angle = 145 urad
- Tune X = 64.31, Tune Y = 59.32, Tune Z = 0.0019
- dQx = dQy = 15

3) Numerical parameters:

- 1 million macroparticles/beam
- 8 slices/beam
- soft-Gaussian model

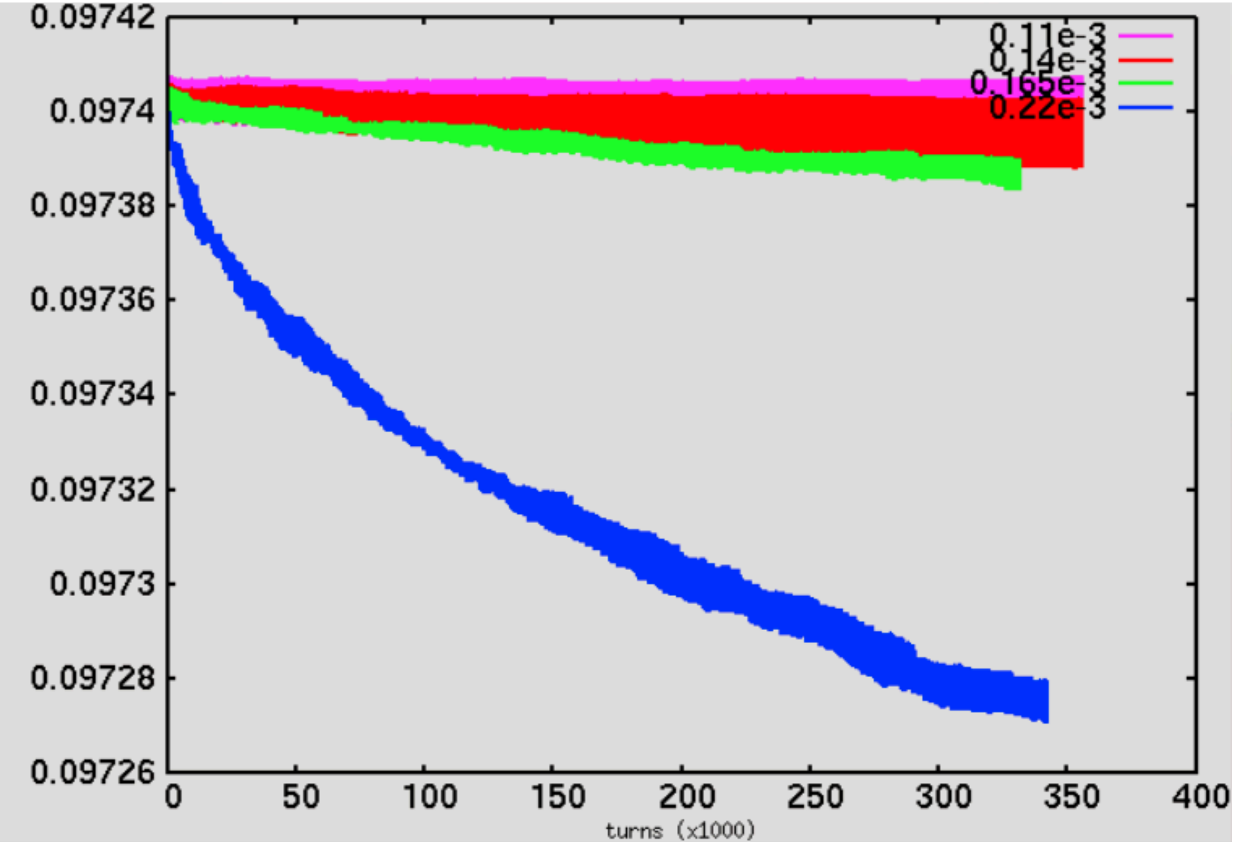
4)Varying parameters:

- dp/p – (0.11, 0.14, 0.165, 0.22)x10^{-3}
- crossing angle – (0, 72.5, 145, 290) urad
- synchrotron tune – (0, 0.0019, 0.0085)
- Chromaticity – (0, 5, 15)

Effects of Initial Momentum Deviation dp/p (I)

Rms bunch length evolution of beam 2

σ_z

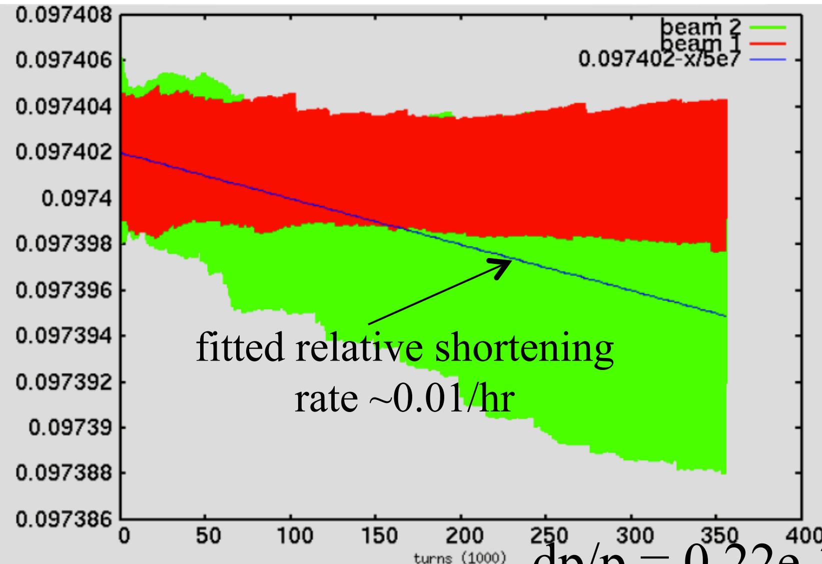


turn (1000)

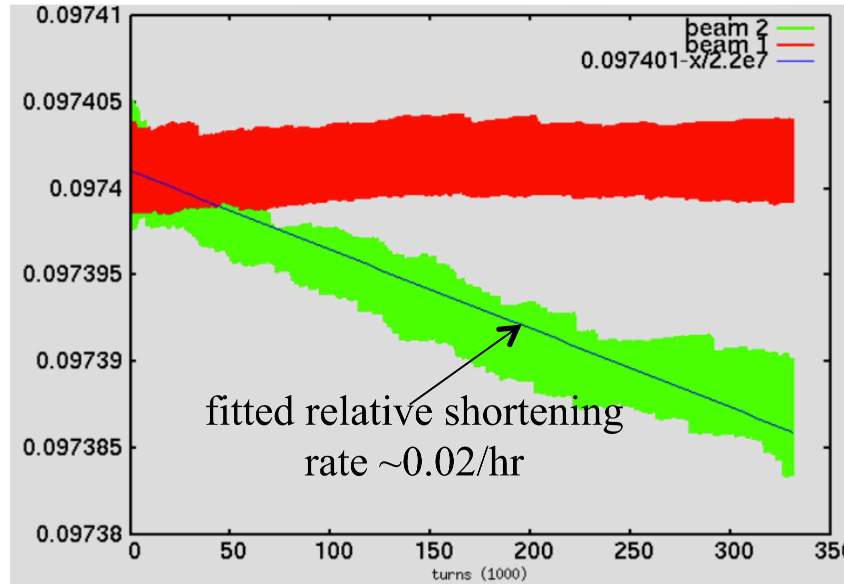
Larger bunch shortening observed for larger dp/p

Effects of Initial Momentum Deviation dp/p (II)
(bunch length evolution for both beams)

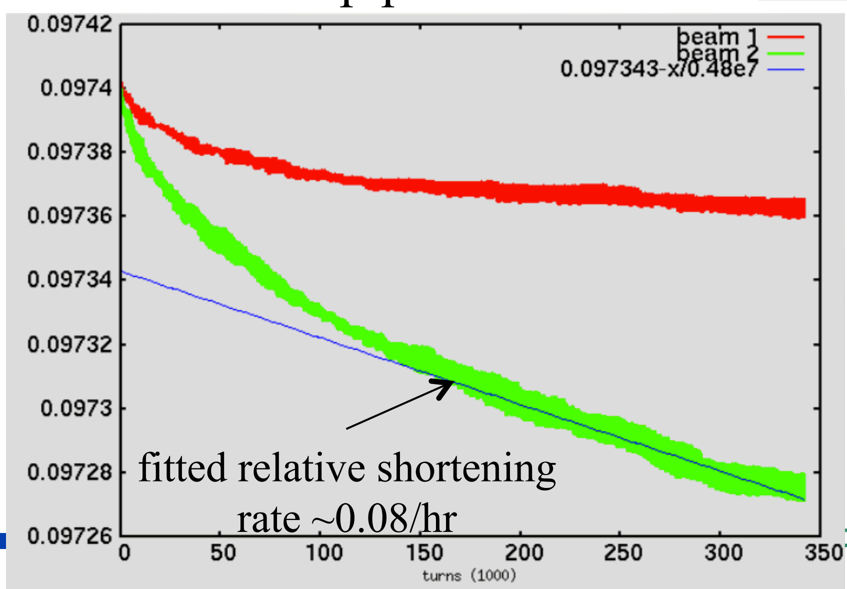
dp/p = 0.14e-3



dp/p = 0.165e-3



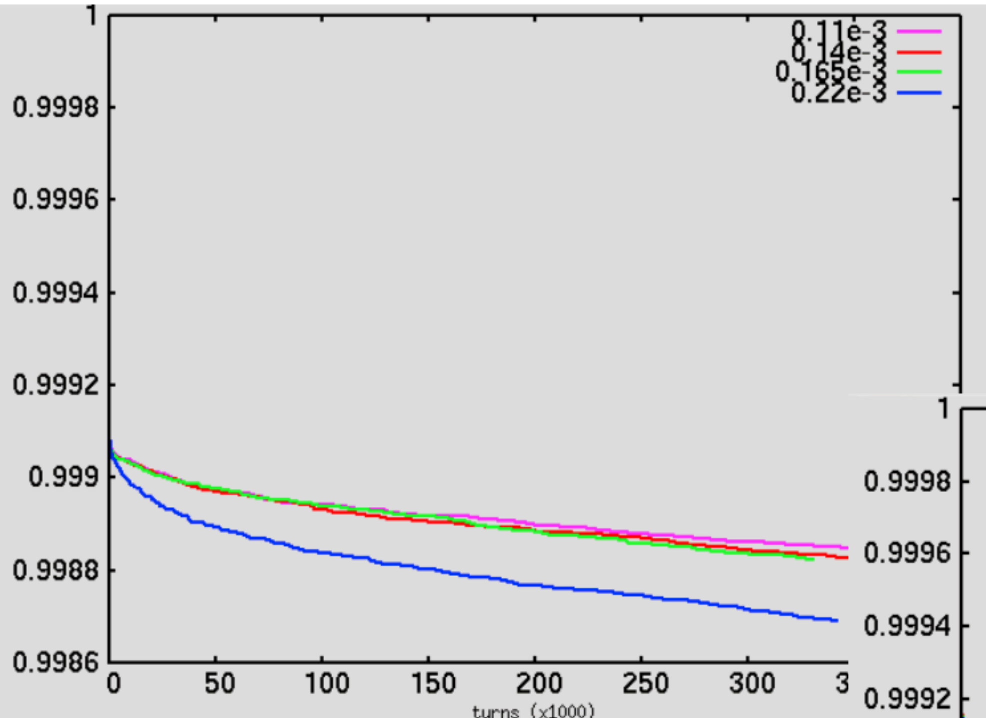
dp/p = 0.22e-3



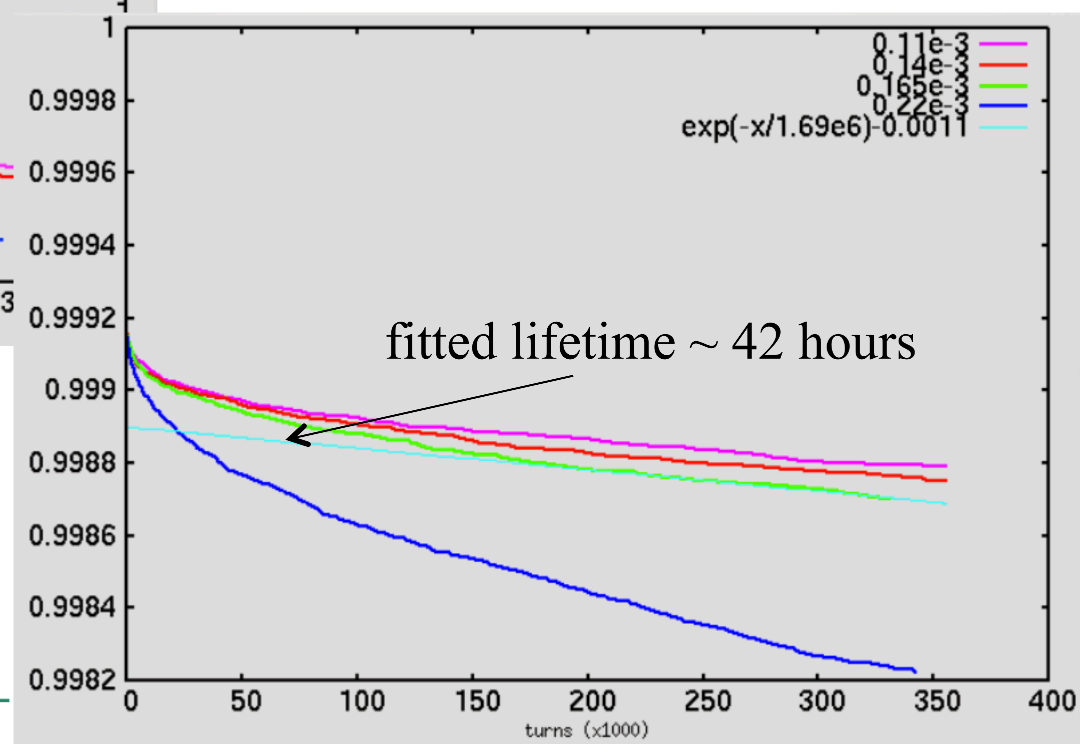
Fitted bunch shortening rates show reasonable agreement with experimental observation.

Effects of Initial Momentum Deviation dp/p (III) (evolution of particle survival fraction for both beams)

beam 1



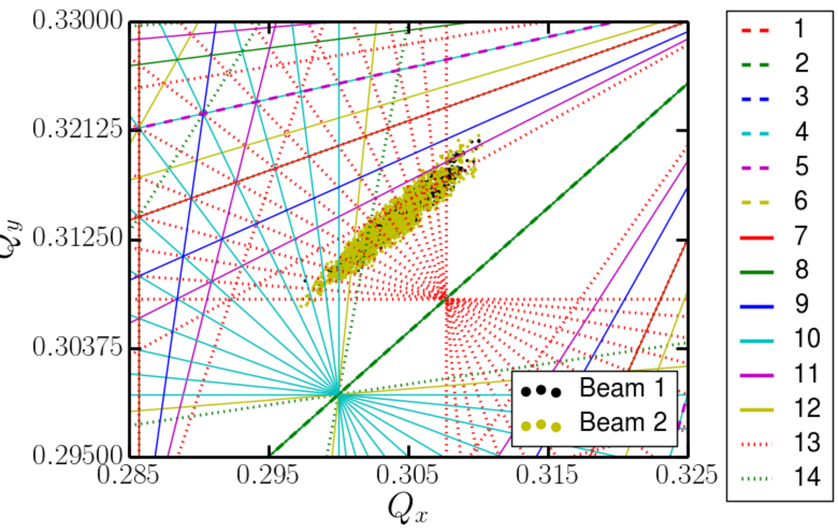
beam 2



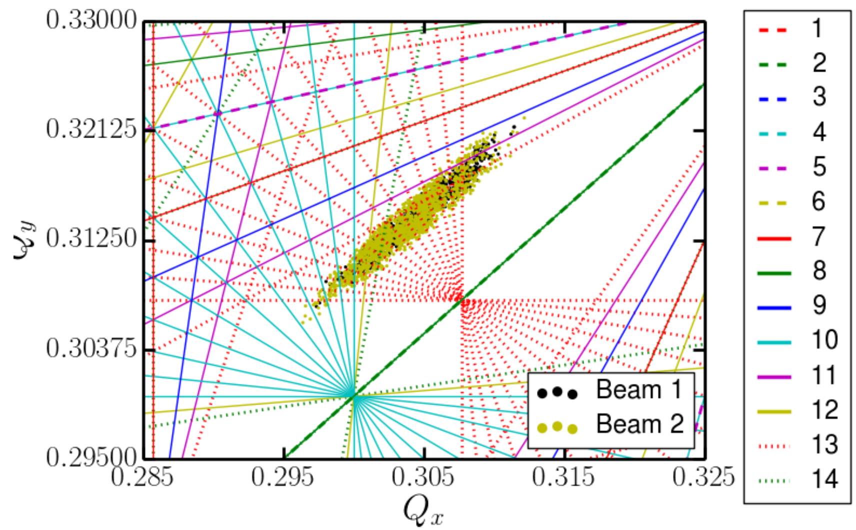
Fitted lifetime is consistent with experimental observation

Effects of Initial Momentum Deviation dp/p (IV)
(tune footprint for both beams)

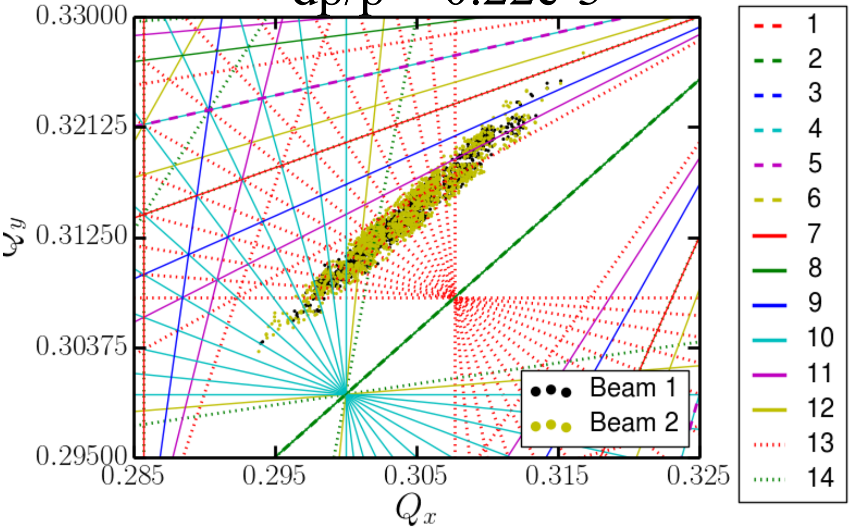
dp/p = 0.11e-3



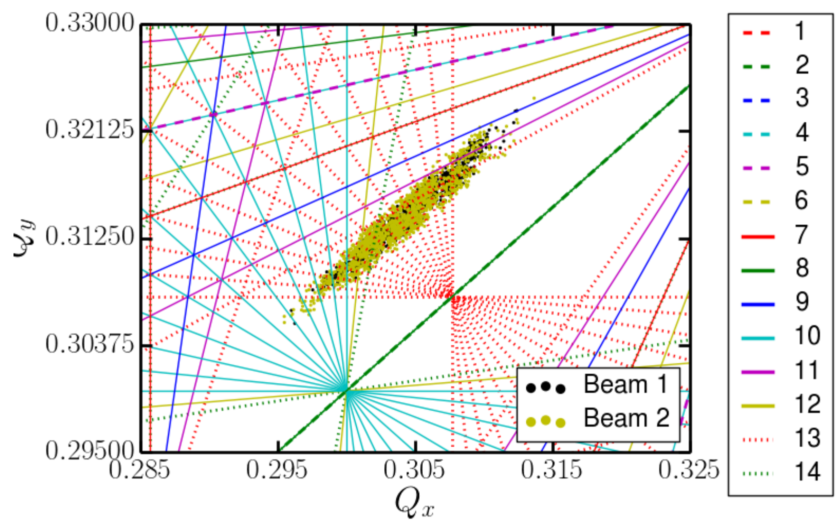
dp/p = 0.14e-3



dp/p = 0.22e-3

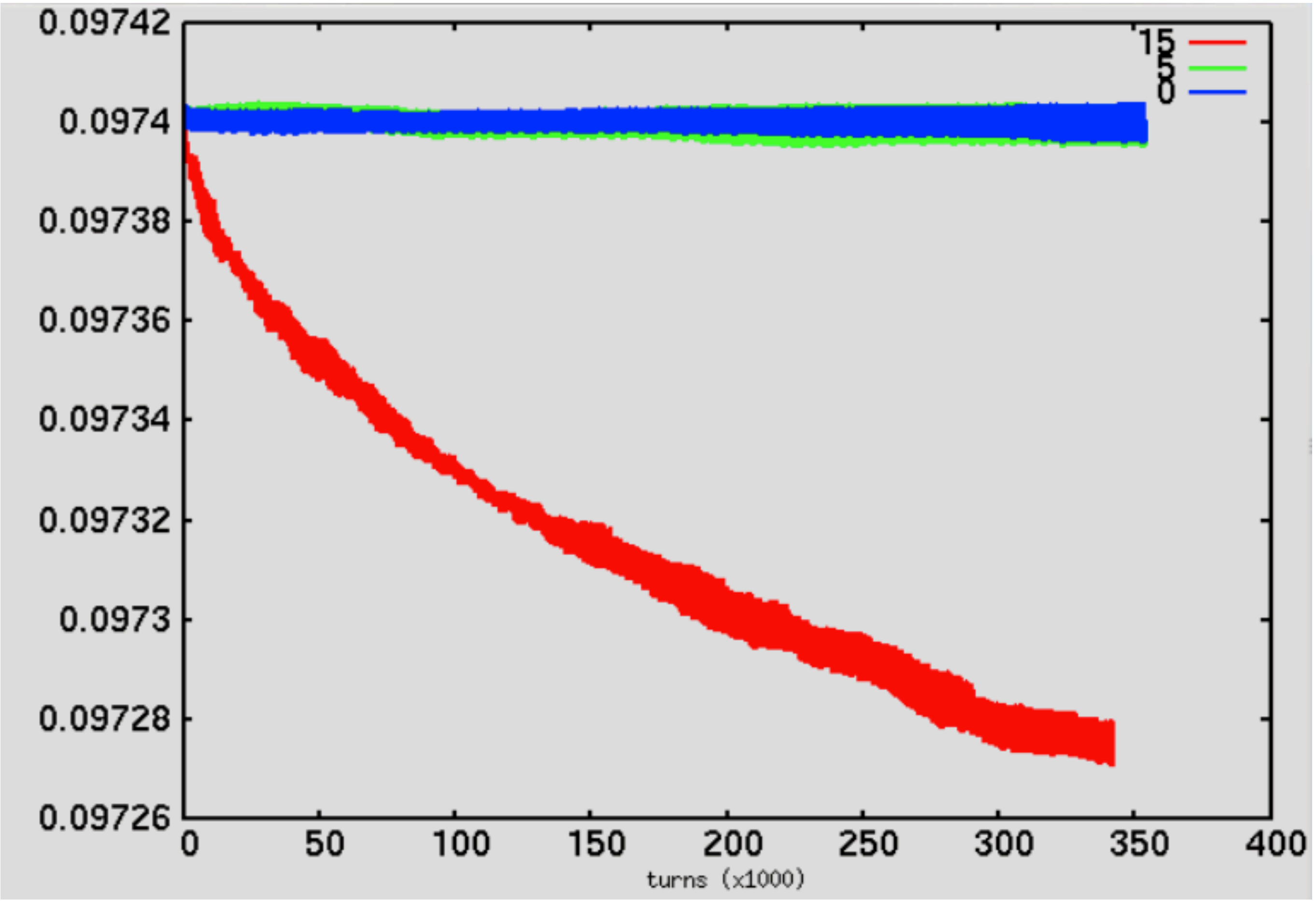


dp/p = 0.165e-3



- more particles fall into the 10th order resonance with the increase of dp/p

Effects of Chromaticity (I)
(evolution of rms bunch length for beam 2)



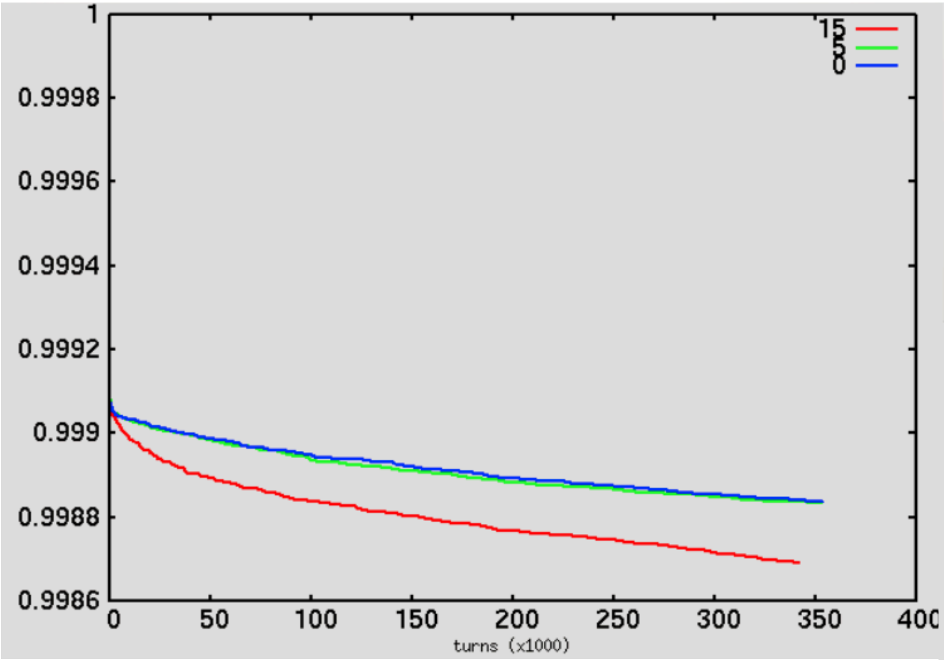
σ_z

turn (1000)

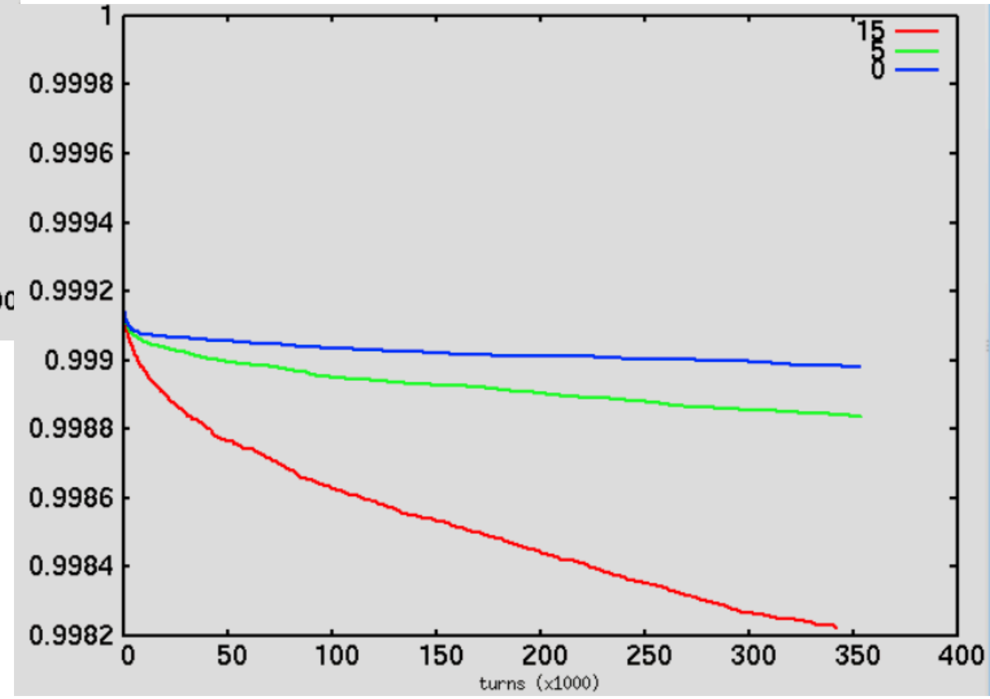
larger bunch shortening observed for significant larger chromaticity

Effects of Chromaticity (II)
(evolution of particle survival fraction for both beams)

beam 1

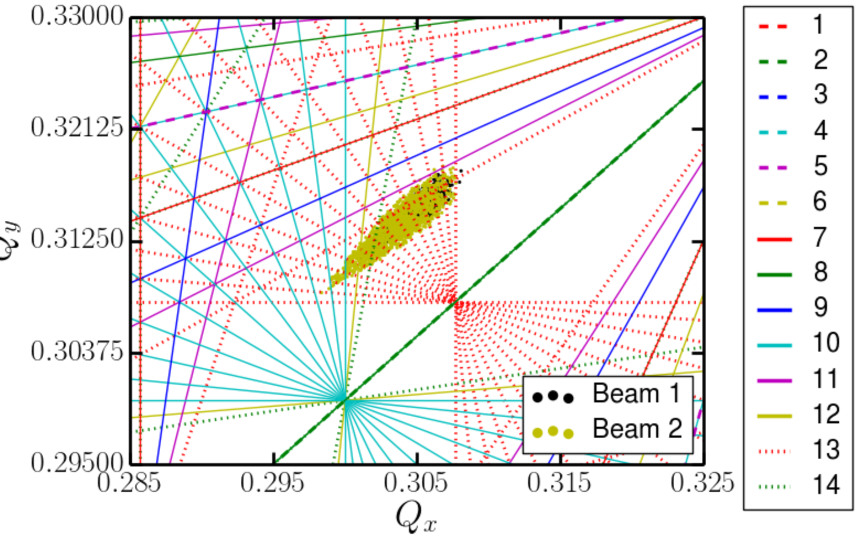


beam 2

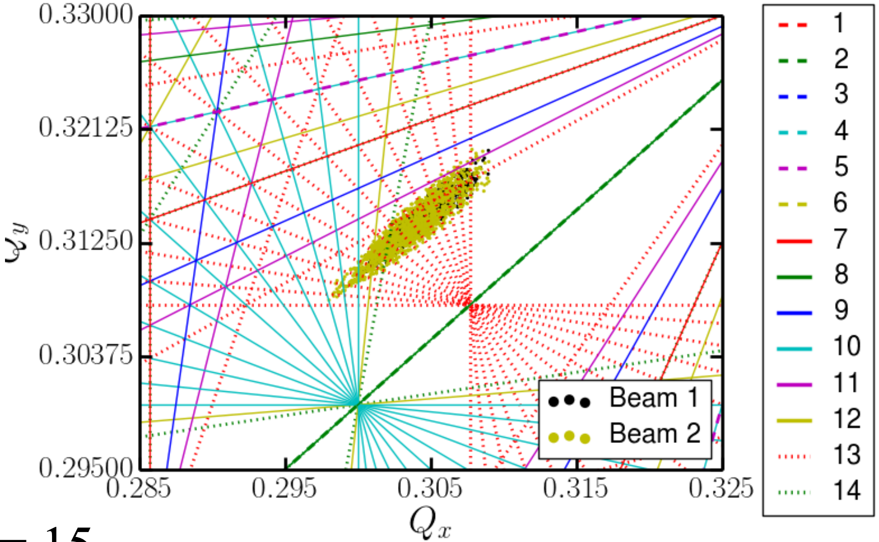


Effects of Chromaticity (III)
(tune footprint for both beams)

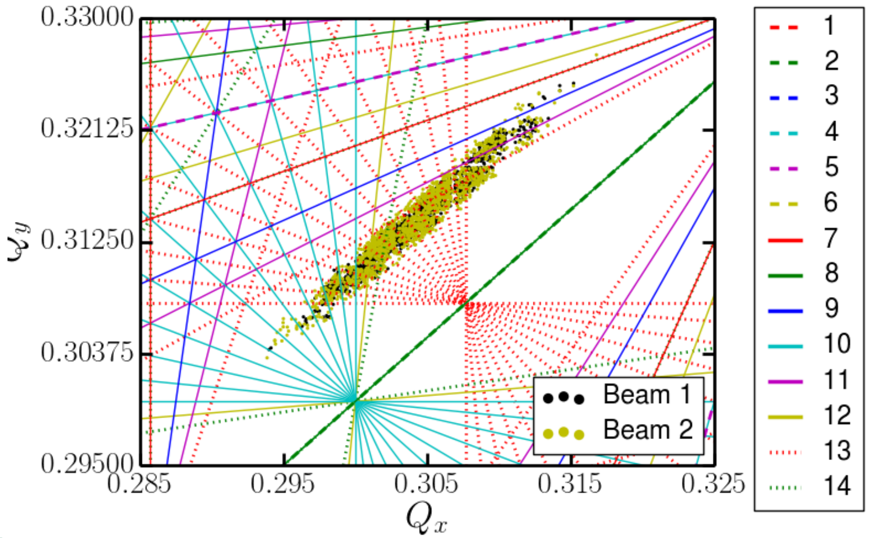
dO = 0



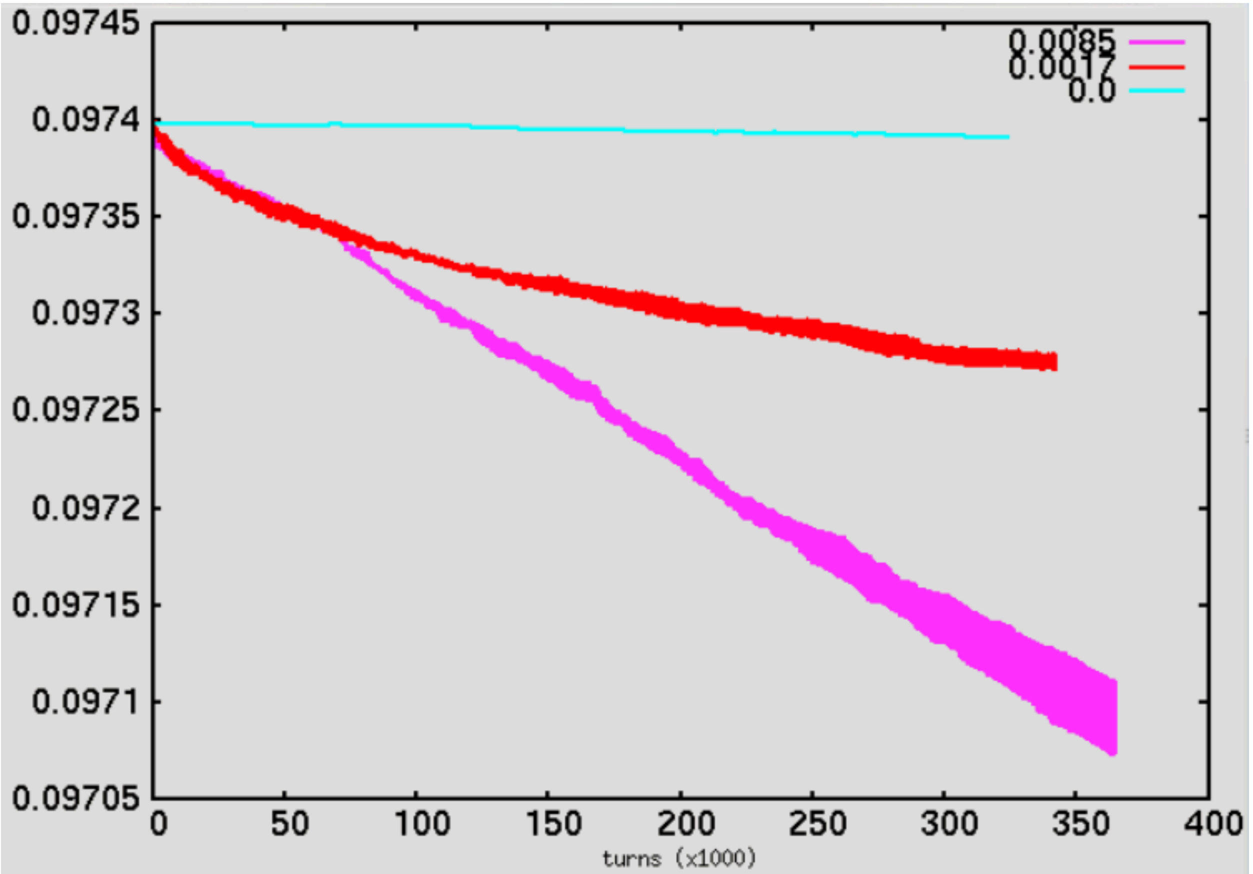
dO = 5



dO = 15



Effects of Synchrotron Tune(I)
(evolution of rms bunch length for beam 2)



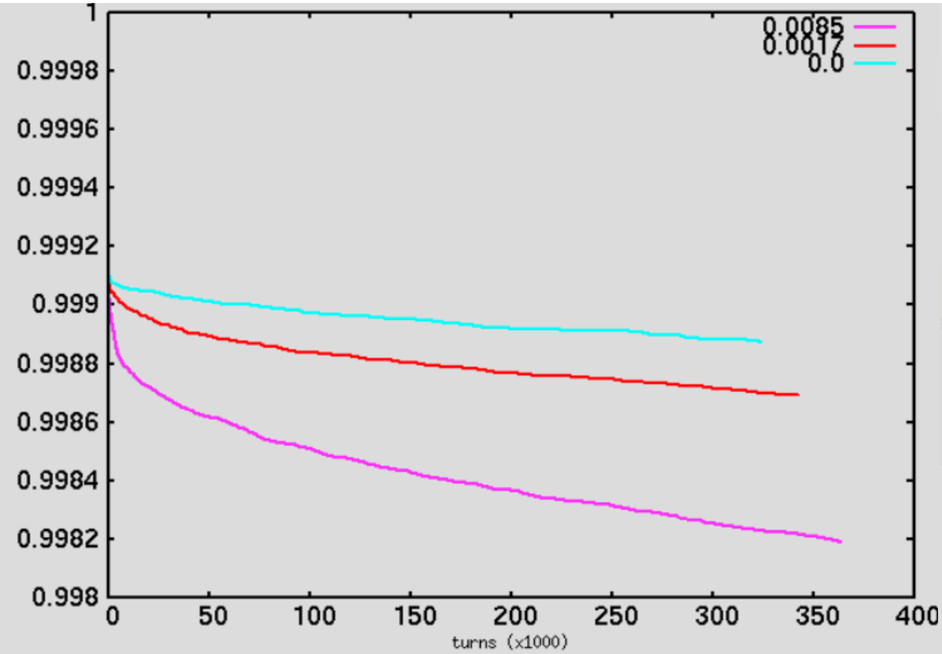
σ_z

turn (1000)

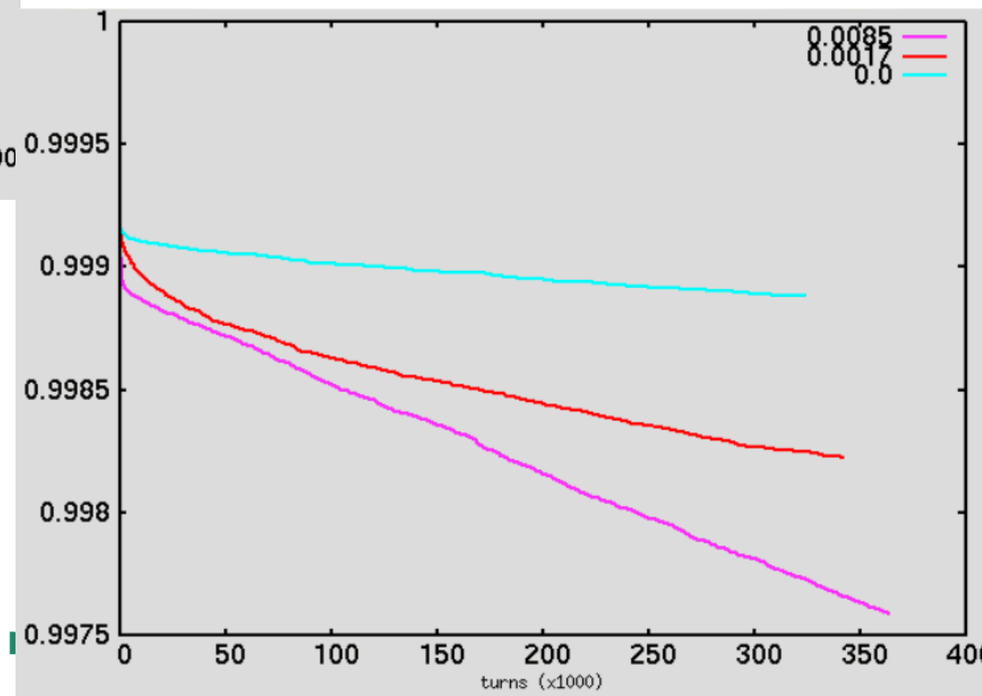
longitudinal synchrotron motion causes dynamic crossing of the resonance lines and induces larger particle losses and bunch shortening

Effects of Synchrotron Tune (II)
(evolution of particle survival fraction for both beams)

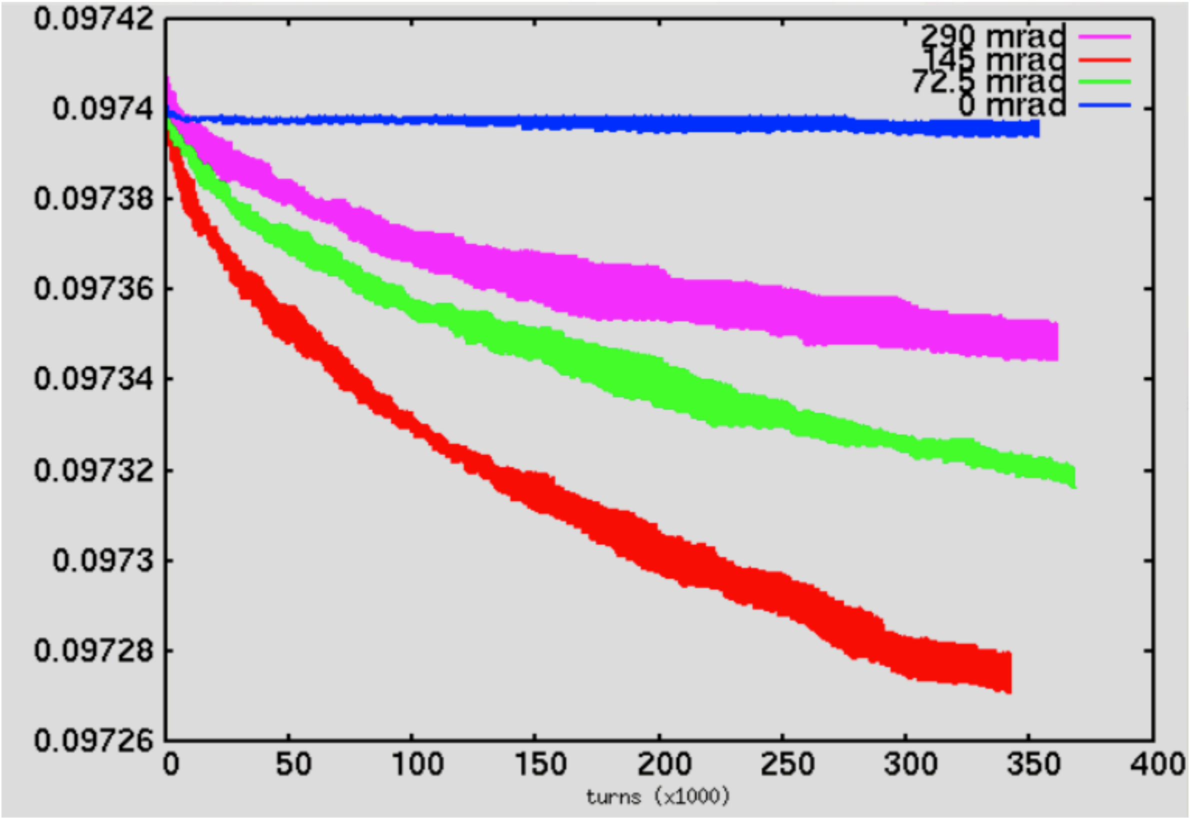
beam 1



beam 2



Effects of Crossing Angle (I)
(evolution of rms bunch length for beam 2)



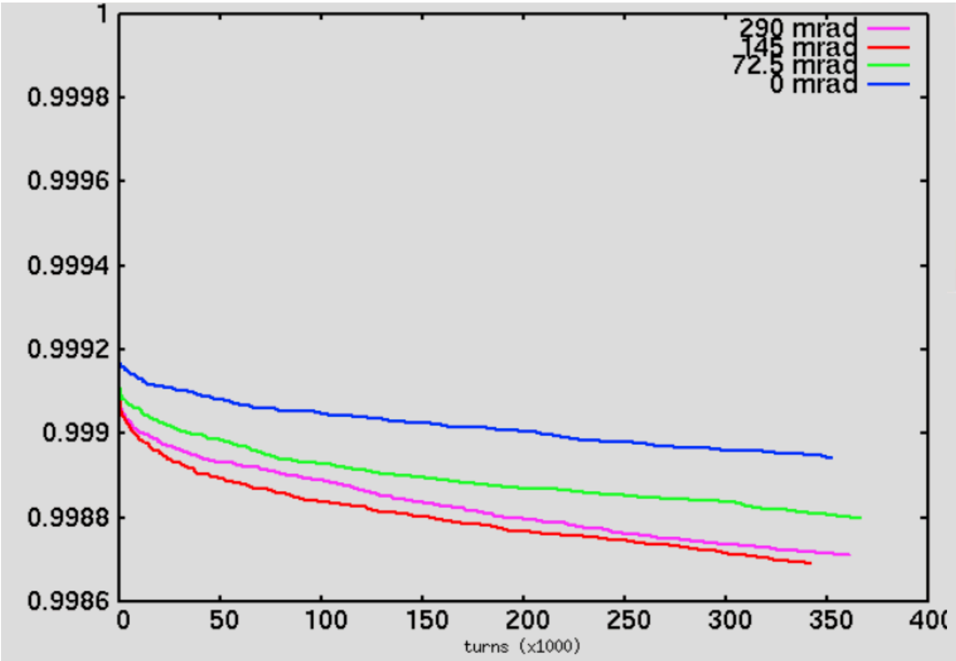
σ_z

turn (1000)

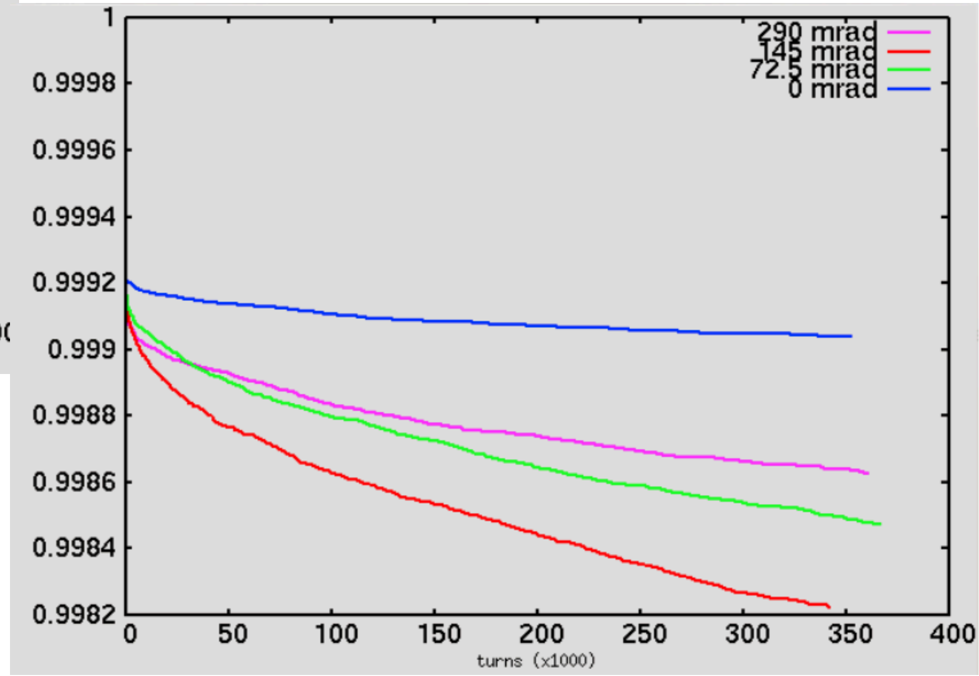
Zero crossing angle or too large crossing angle leads to less bunch shortening

Effects of Crossing Angle (II)
(evolution of particle survival fraction for both beams)

beam 1

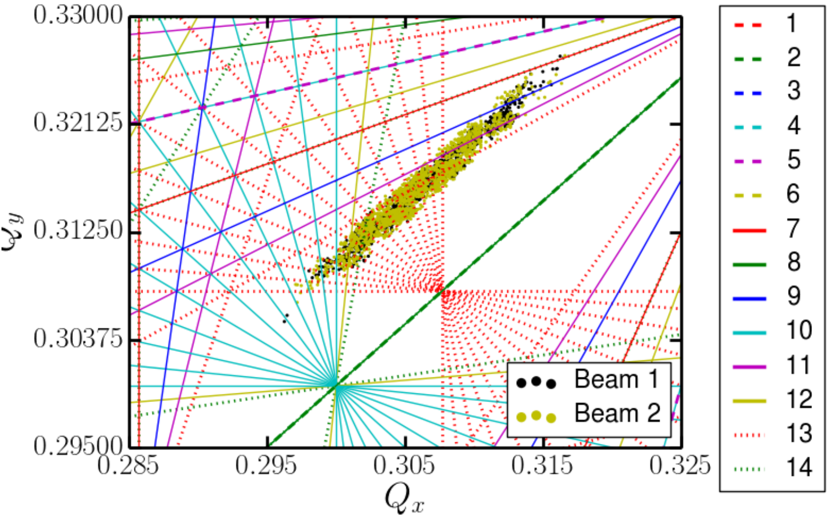


beam 2

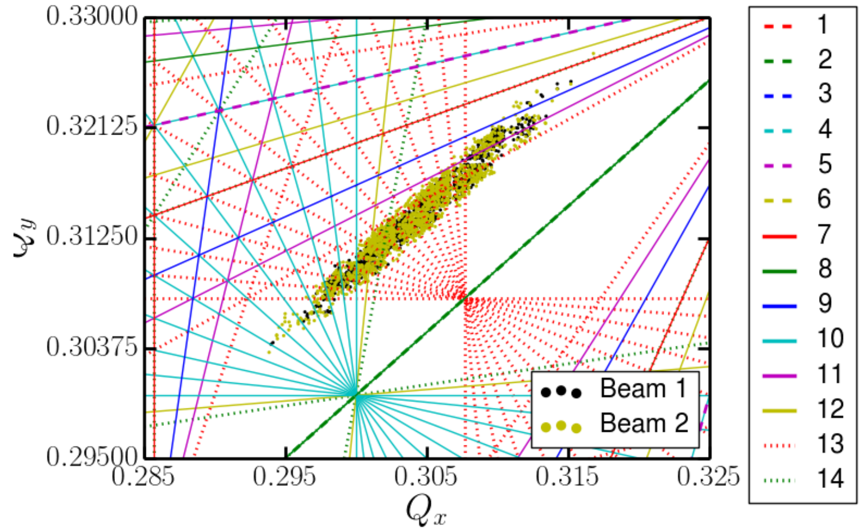


Effects of Crossing Angle (III)
(tune footprint for both beams)

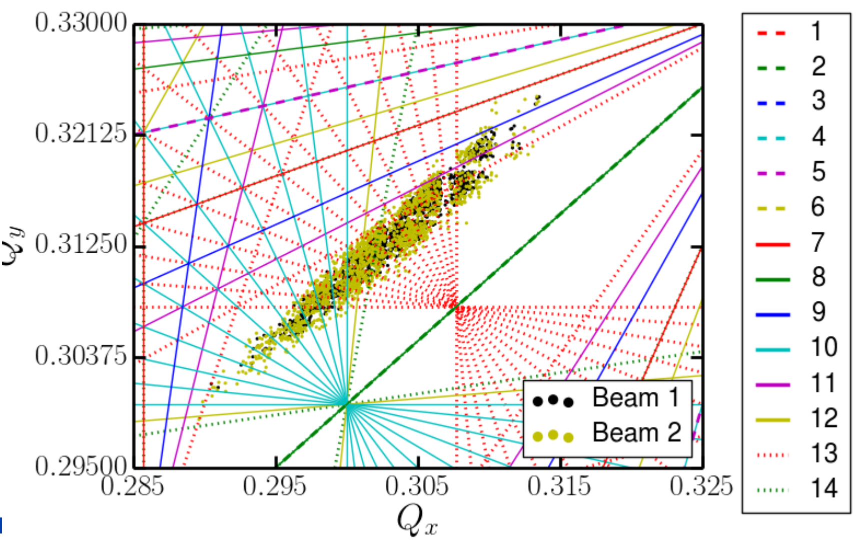
290 mrad



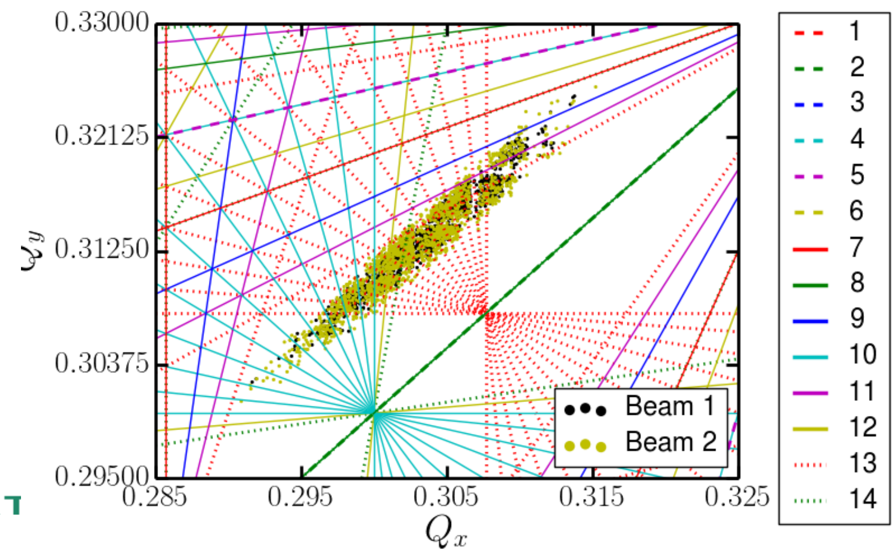
145 mrad



0 mrad



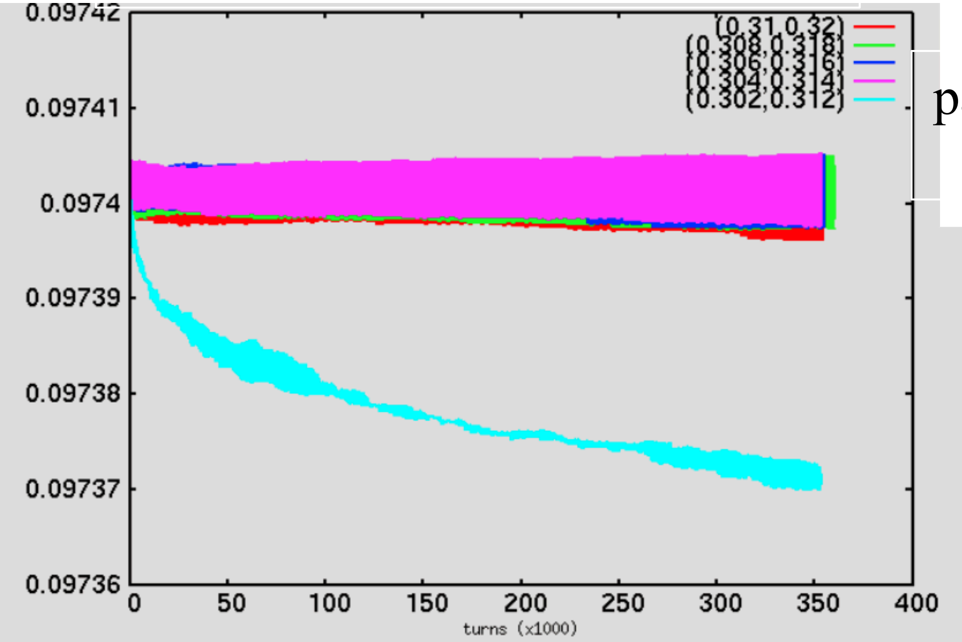
72.5 mrad



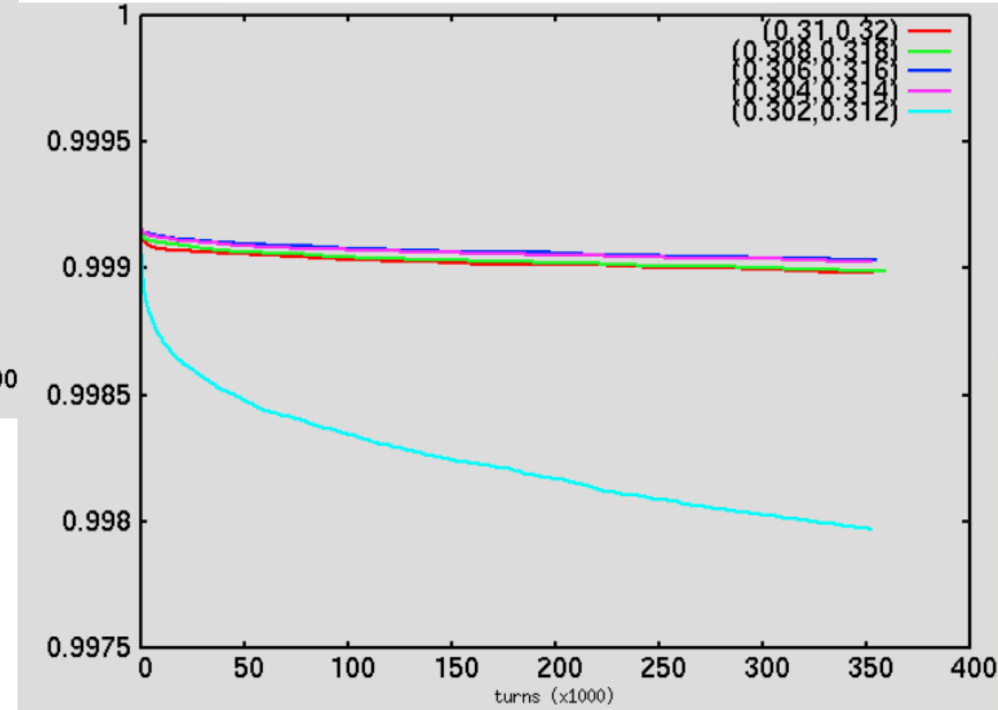
Effects of Beam 2 Working Point (I)
(bunch length and particle survival evolution of beam 2)

(0 chromaticity)

bunch length evolution of beam 2
with different working points

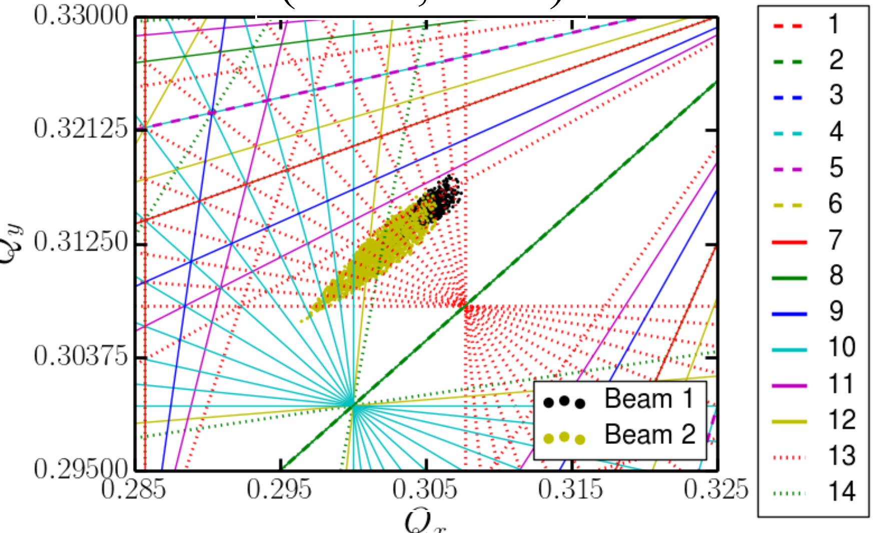


particle survival fraction evolution of beam 2
with different working points

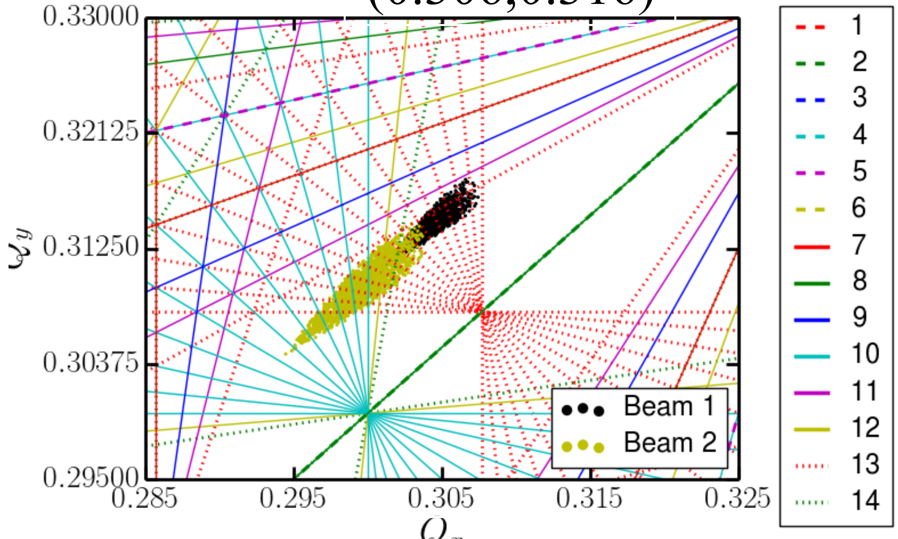


Effects of Beam 2 Working Point (II)
(tune footprint for both beams, 0 chromaticity)

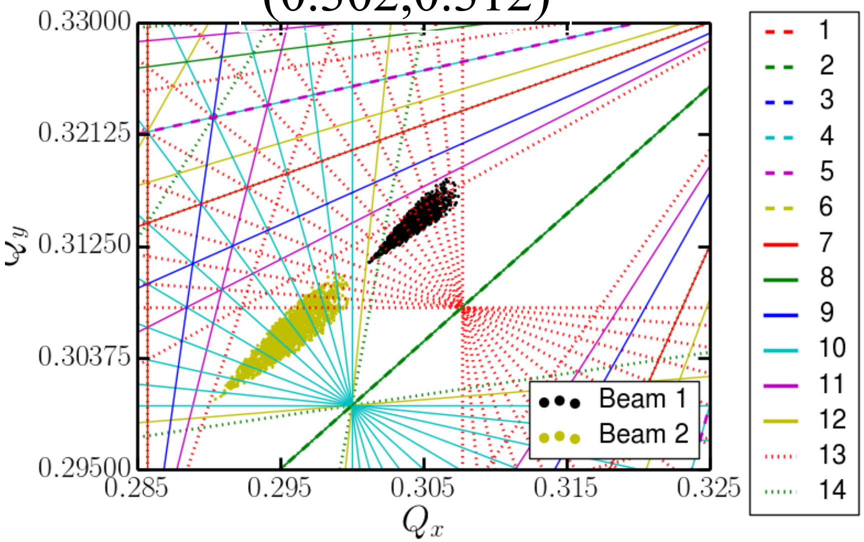
(0.308,0.318)



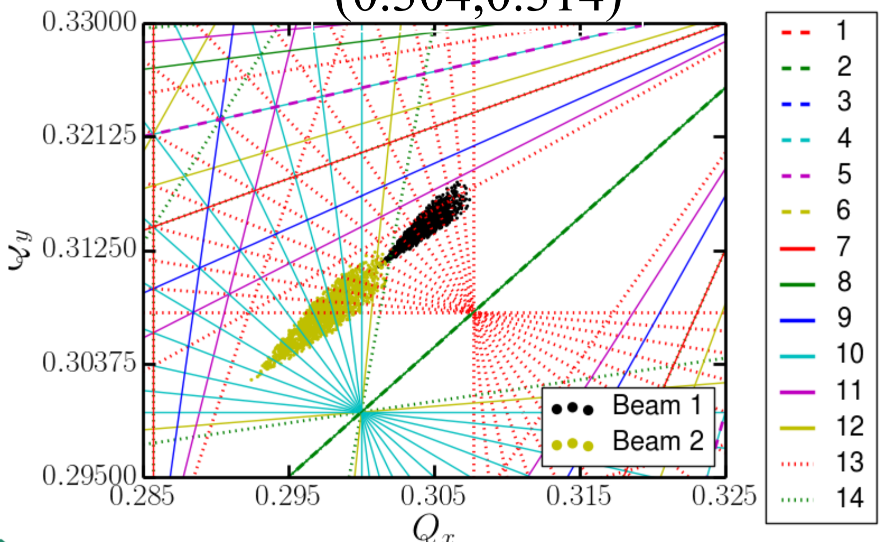
(0.306,0.316)



(0.302,0.312)

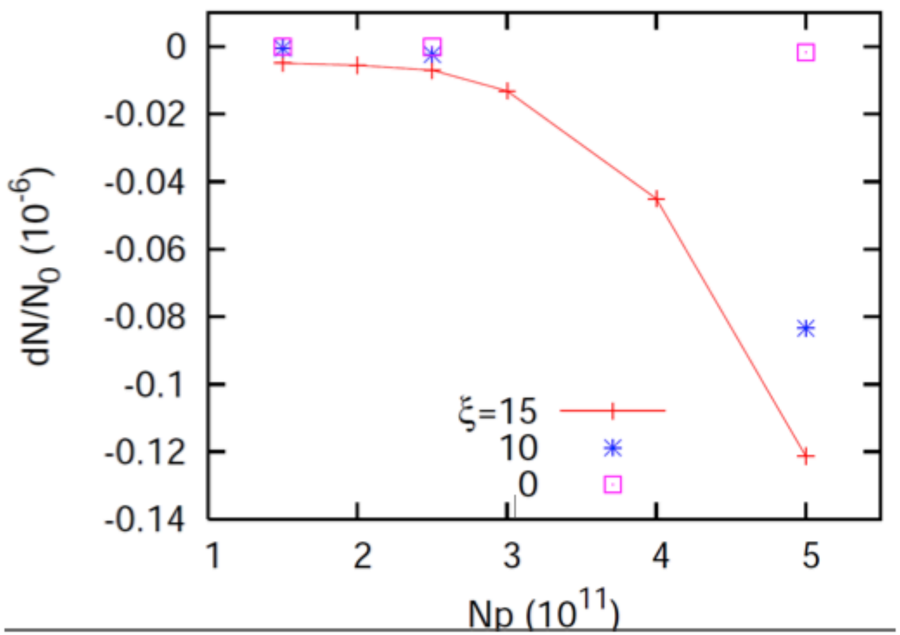


(0.304,0.314)

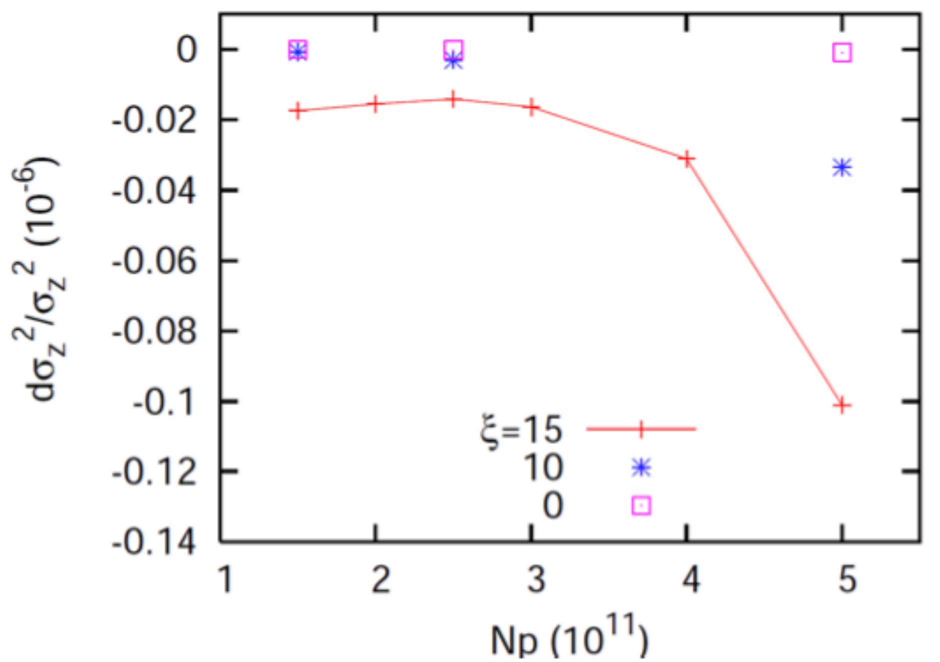


Effects of Bunch Intensity

particle loss rate vs. bunch intensity



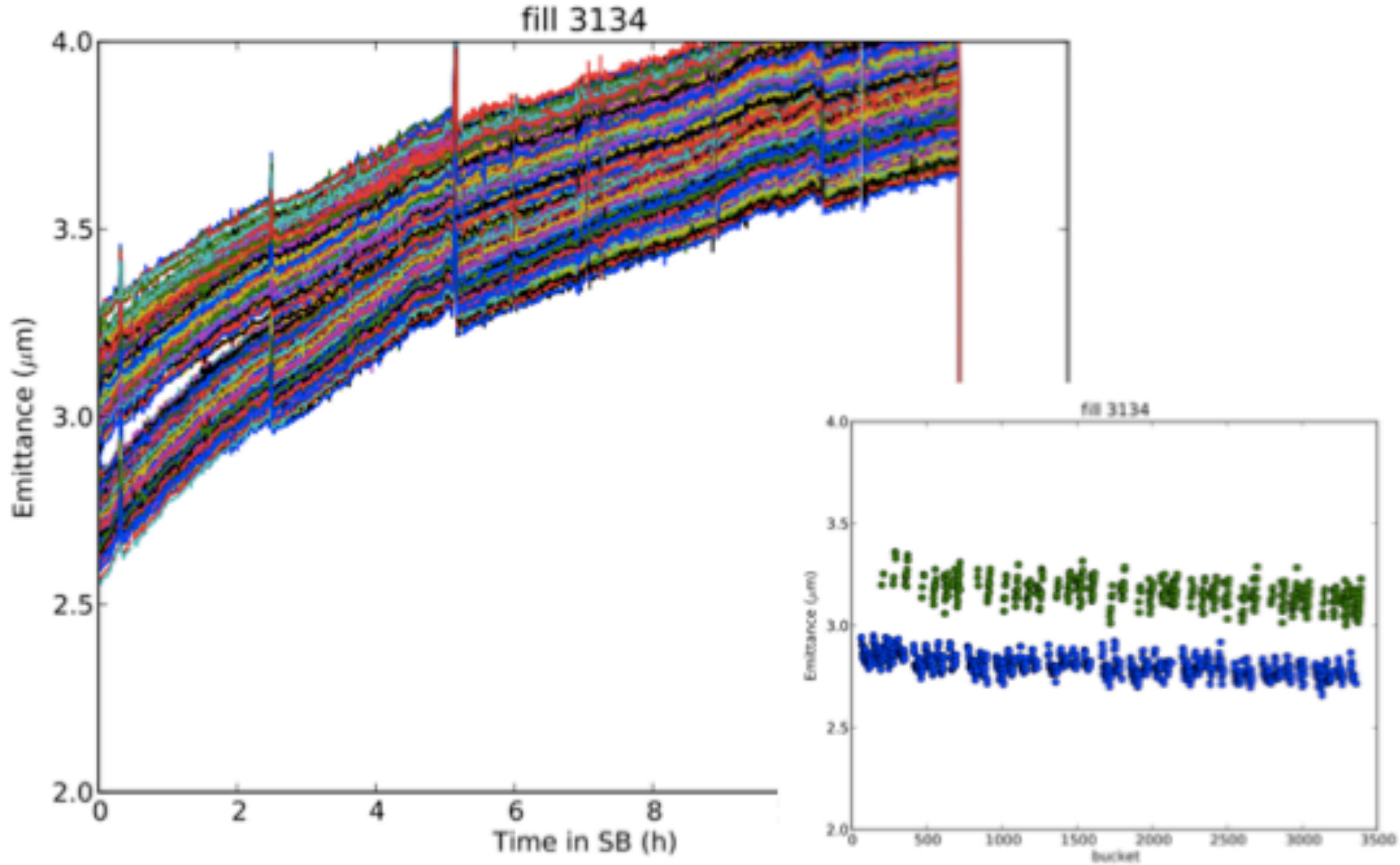
bunch shortening rate vs. bunch intensity



Courtesy of K. Ohmi

LHC Observations (2)

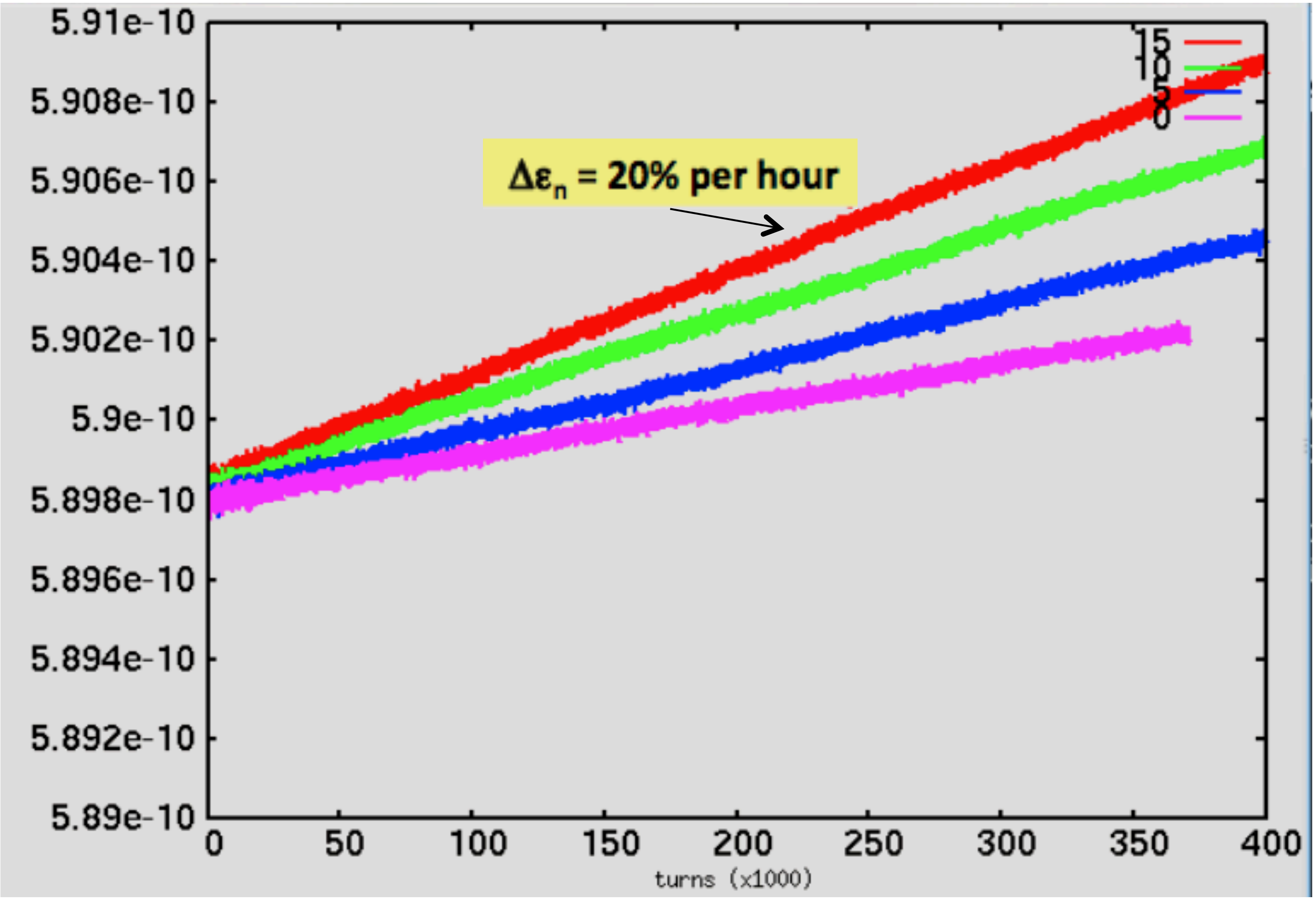
During physics fills also emittance blow-up after MYC:



We had emittance blow-up in collision of around 10% per hour
Is it BB related?

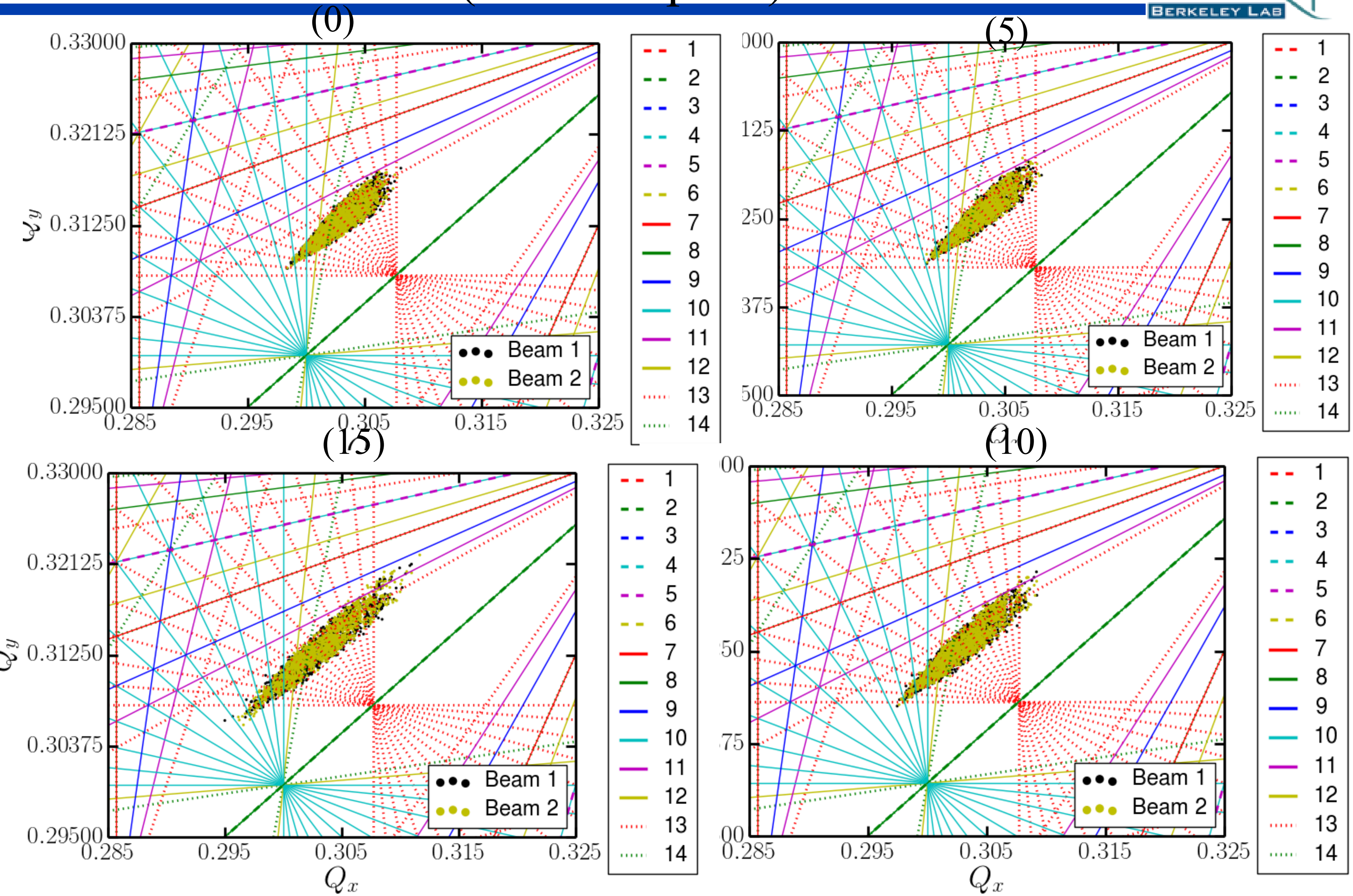
Courtesy of T. Pieloni

Effects of Chromaticity with Equal Emittance Beam(I) (averaged emittance evolution)



Turn (x1000)

Effects of Chromaticity with Equal Emittance Beam(II) (tune footprint)



Conclusion and Future Plan

- Simulations show reasonable agreement with experimental observations
- Longitudinal bunch shortening is related to particle losses
- This effect is enhanced with larger chromaticity and momentum deviation
- Synchrotron motion causes dynamic crossing of multiple resonance lines and leads to more particle loss and bunch shortening
- Cross angle collision enhances synchro-betatron coupling
- Higher bunch intensity leads to larger particle loss and bunch shortening

❖ Further understanding of the loss/bunch shortening mechanism
❖ Apply the simulation to the crab cavity beam-beam effects
❖ Determine the noise tolerance level of the crab cavity on beam emittance growth