

Non-scaling FFAG Issues

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<http://hadron.kek.jp/~machida/doc/nufact/>

ffag/machida_20060123.ppt & pdf

Issues

- Lattice and optics
 - Doublet or triplet
 - Injection and extraction
- **Beam dynamics**
 - Longitudinal: acceleration out of bucket
 - Transverse: resonance crossing
 - Large acceptance in both planes
- Hardware
 - 200 MHz superconducting cavity
 - End fields of a magnet
- Cost

Beam dynamics issues

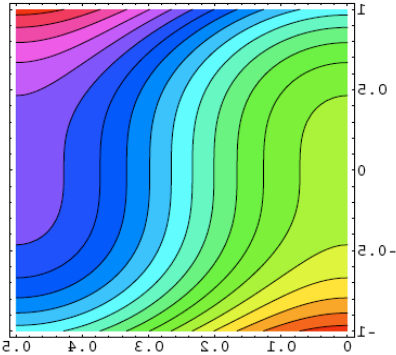
- Acceleration out of RF bucket. “Gutter” acceleration.
 - Mismatch in longitudinal and transverse .
 - With finite initial transverse amplitude.
- Crossing of many resonances during acceleration.
 - Structure resonance has some effects.
 - With alignment errors, integer resonances have to be considered.
- Huge acceptance ($30,000 \pi$ mm-mrad) for muons.
 - Dynamic aperture without acceleration at injection energy.

“Gutter” acceleration

Distortion of longitudinal emittance due to initial “mismatch”

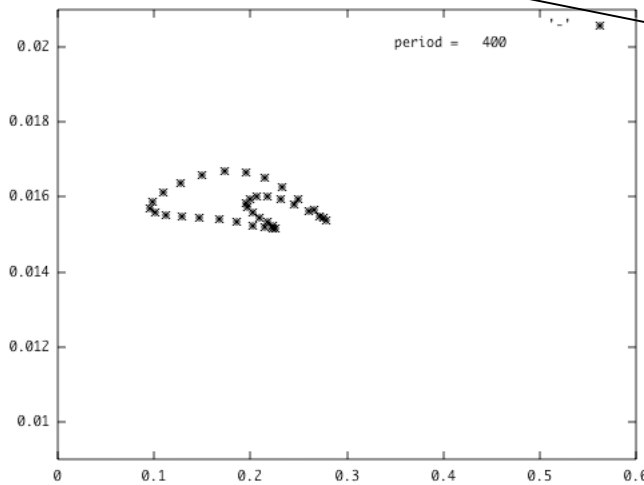
Issue #1a

dp/p (normalized)
Kinetic energy [GeV]



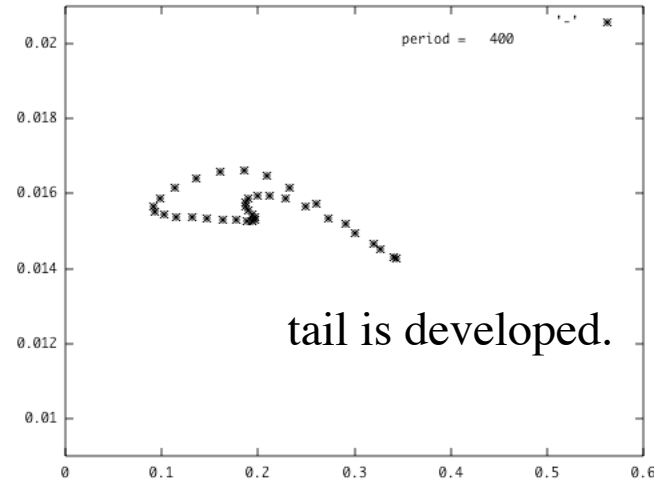
Phase (1/2 pi)

Matched

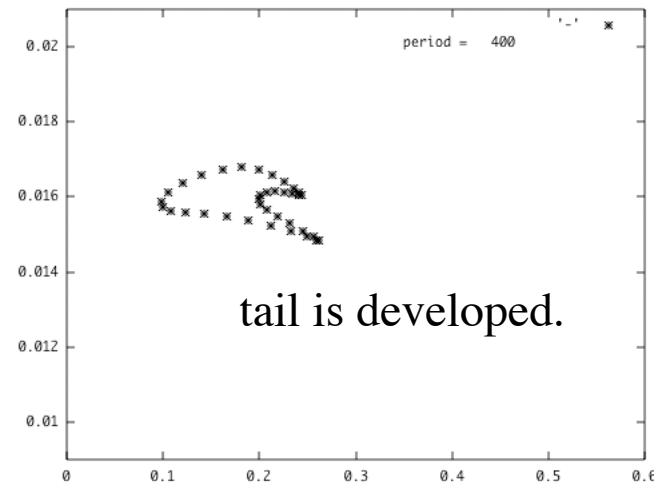


RF phase/2Pi

Less tilted (-50%).



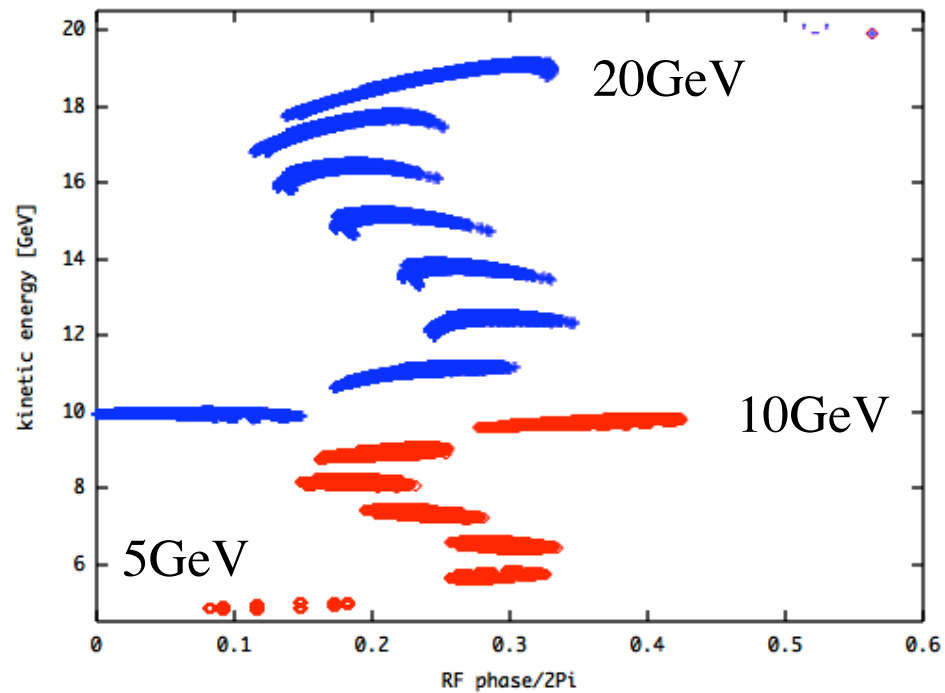
More tilted (+50%).



“Gutter” acceleration

Longitudinal matching with two rings.

- Over all optimization is necessary.
- What is the criterion?



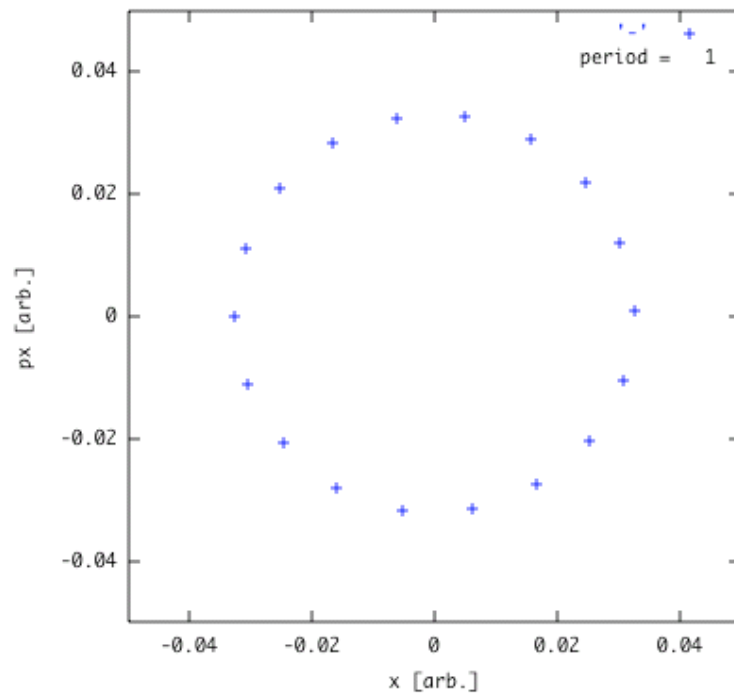
Tracking results

“Gutter” acceleration

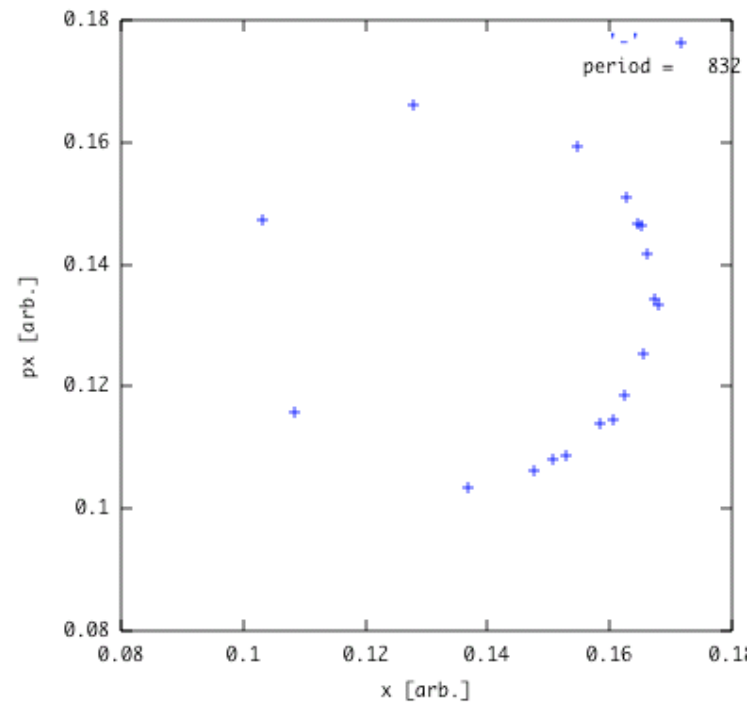
Effects on betatron oscillations

Issue #1b

- Starting with a circle of 10 pi mm (equally spaced).
- Accumulated betatron phase depends on initial betatron phase.
- Distribution becomes non-uniform after acceleration.



at 5 GeV (injection)



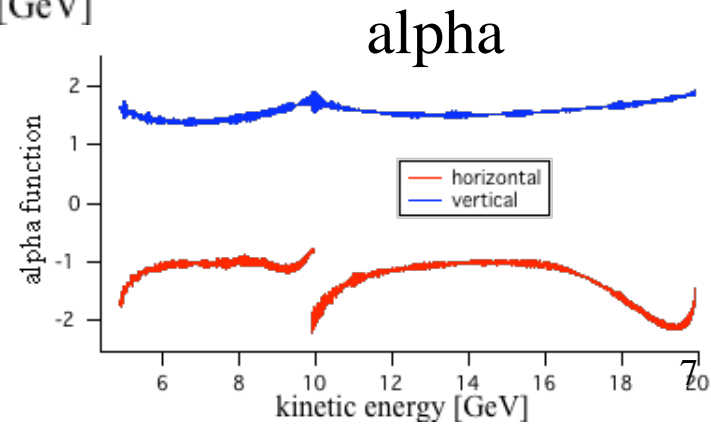
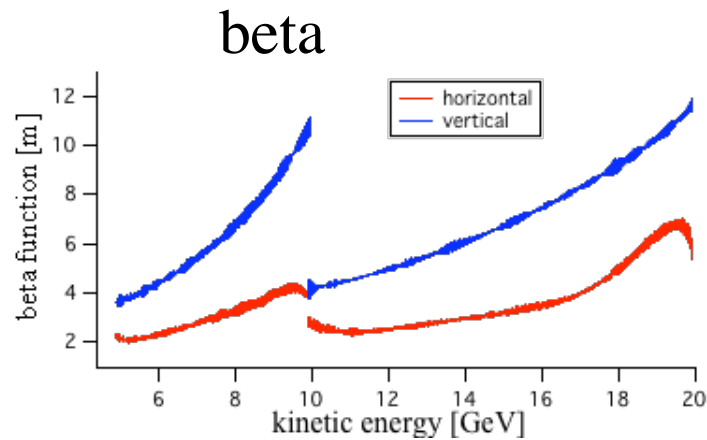
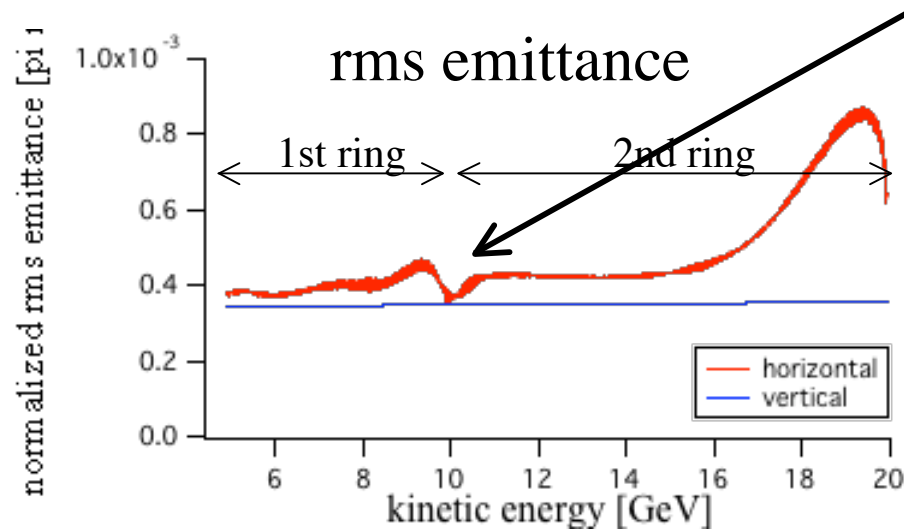
at 10 GeV (extraction) ⁶

“Gutter” acceleration

Transverse matching between two rings

- Does distribution mismatching make any problem?
- Optical matching can be done.

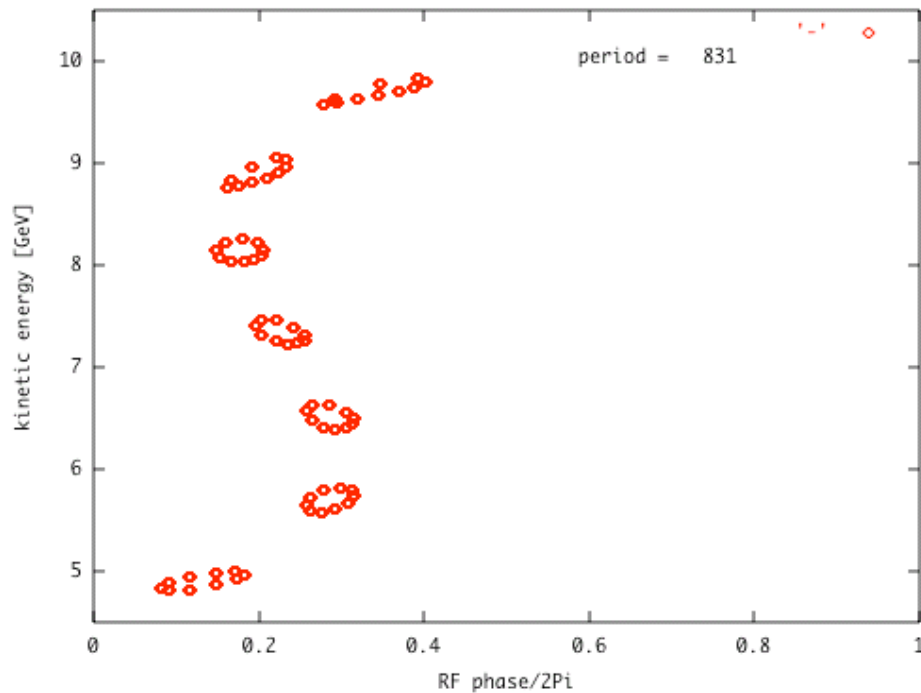
Mismatch is small maybe because of small emittance (0.5 pi mm).



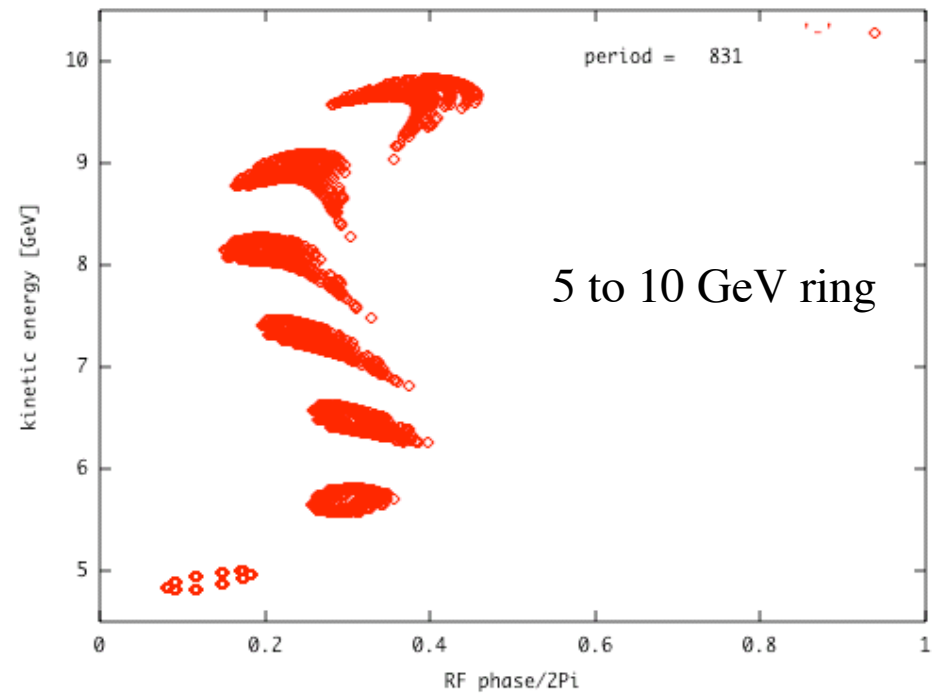
“Gutter” acceleration Finite transverse amplitude

Issue #2

Longitudinal phase space (phi, momentum)



without transverse amplitude



with finite transverse amplitude

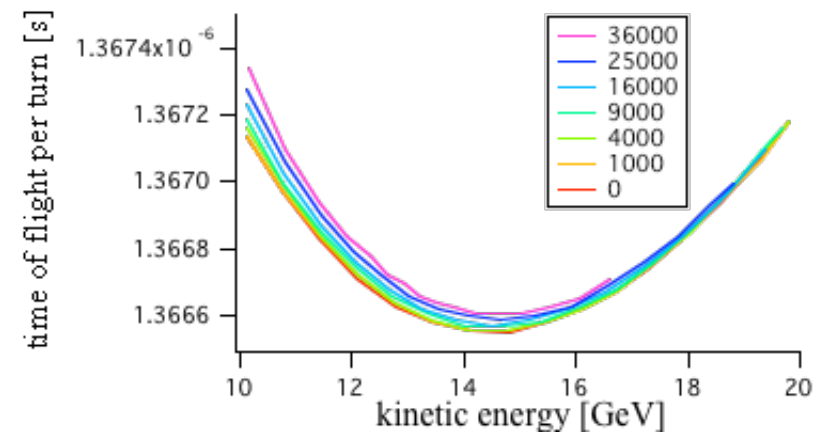
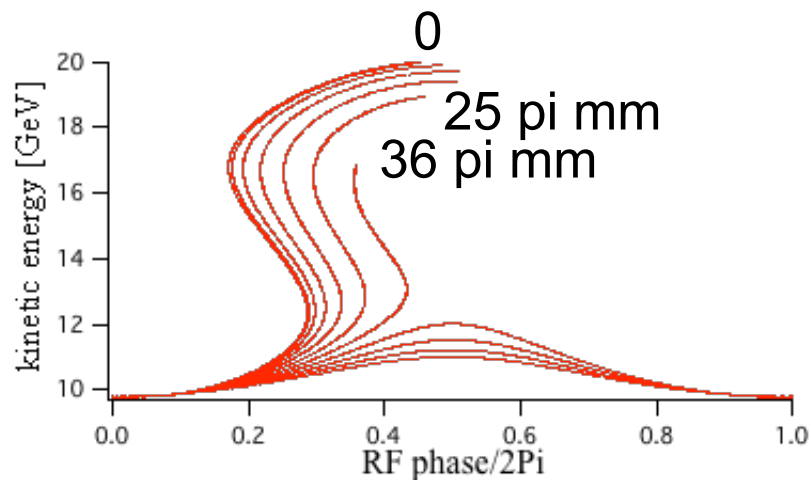
Horizontal is 5 pi mm
Vertical is zero

“Gutter” acceleration

Finite transverse amplitude

Issue #2

- Horizontal amplitude are
(0, 1, 4, 9, 16, 25, 36, 49, 64, 81, 100 π mm, normalized.)
- Vertical amplitude is zero.

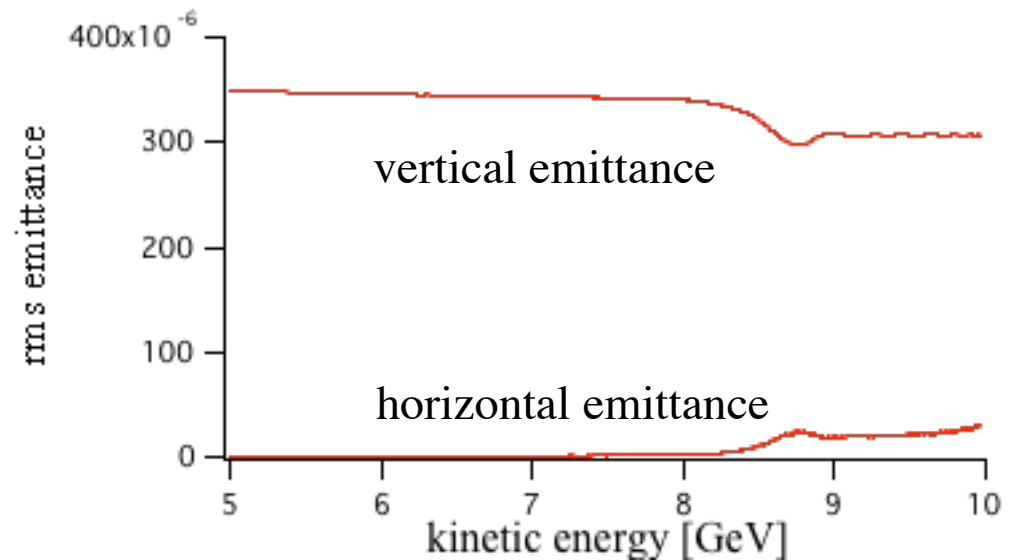
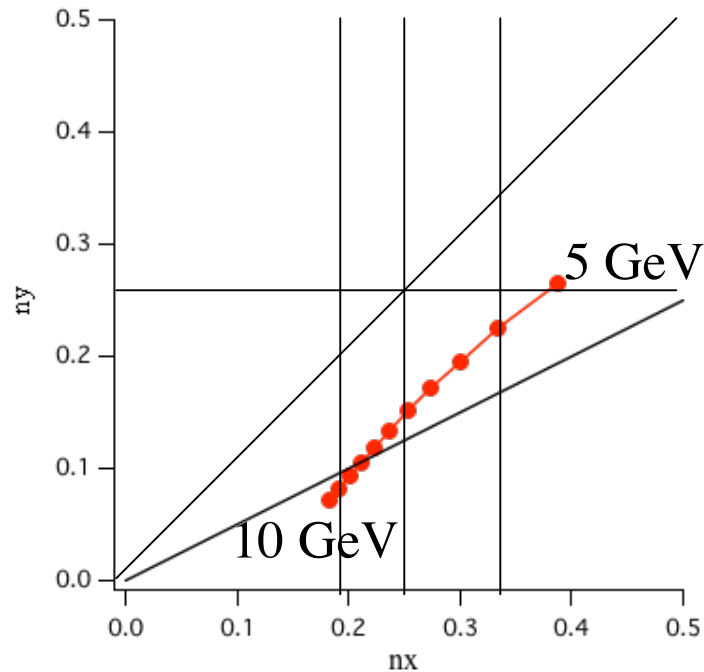


- Difference of ToF becomes smaller as accelerated.

Resonance crossing without errors

Issue #3

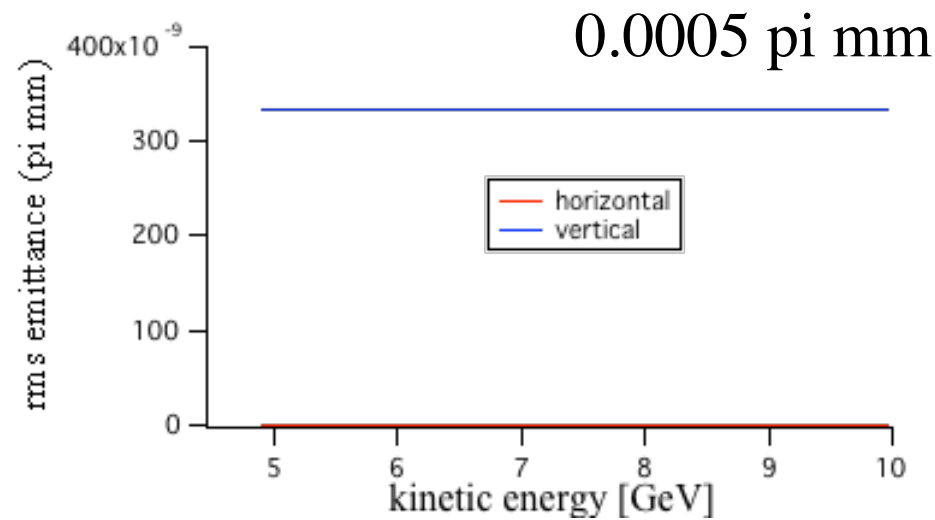
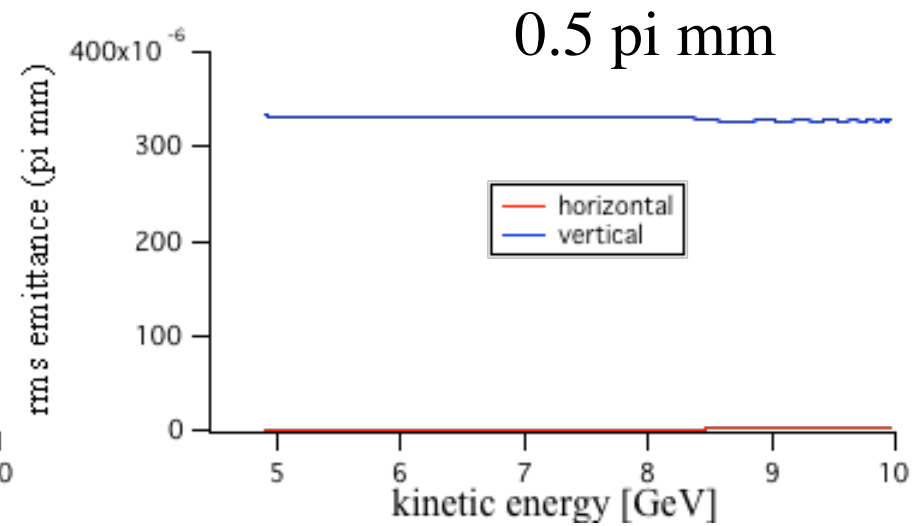
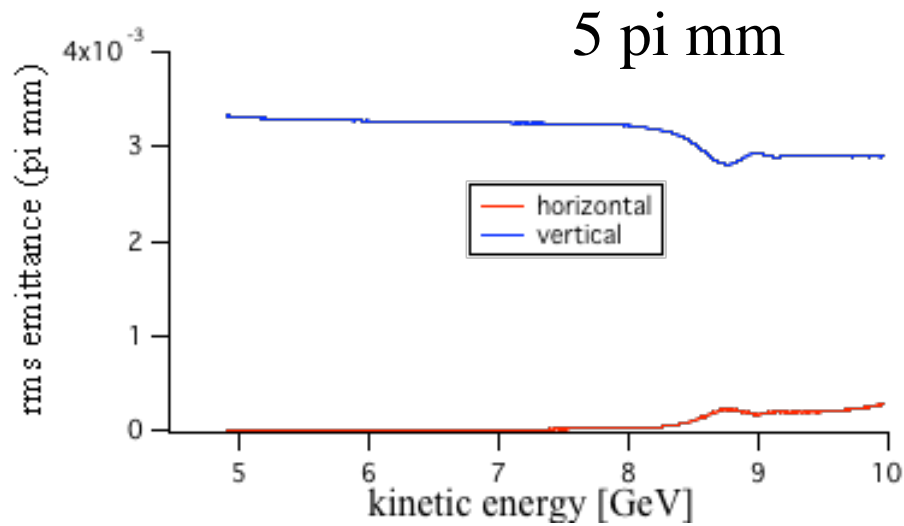
- Vertical is 5π mm, normalized, zero horizontal emittance.



- Shows the coupling due to $n_x - 2n_y = 0$ (structure) resonance.
- If we start finite horizontal and zero vertical emittance, no exchange of emittance.

Resonance crossing without errors, amplitude dependence

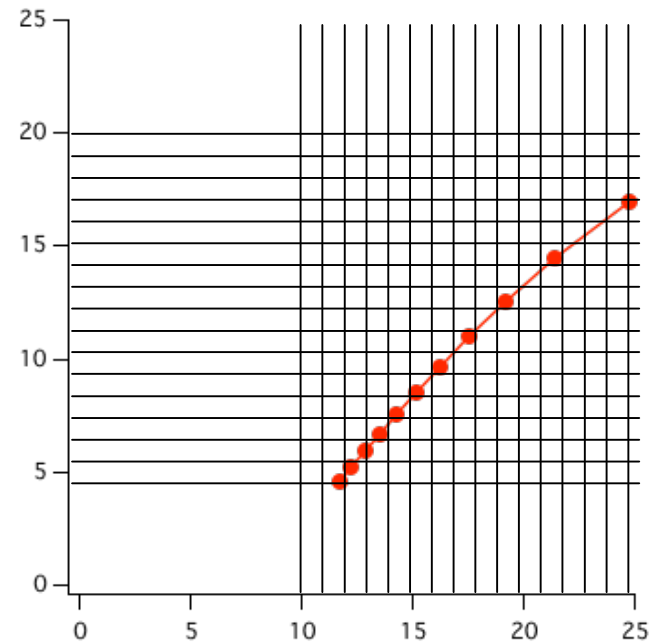
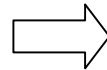
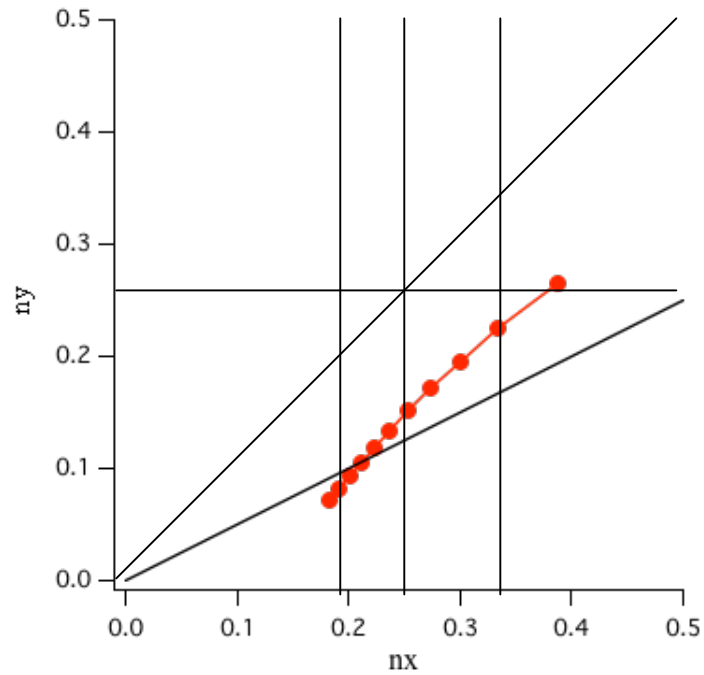
Issue #3



Resonance crossing with alignment errors

Issue #4

Beam has to face many integer tunes.

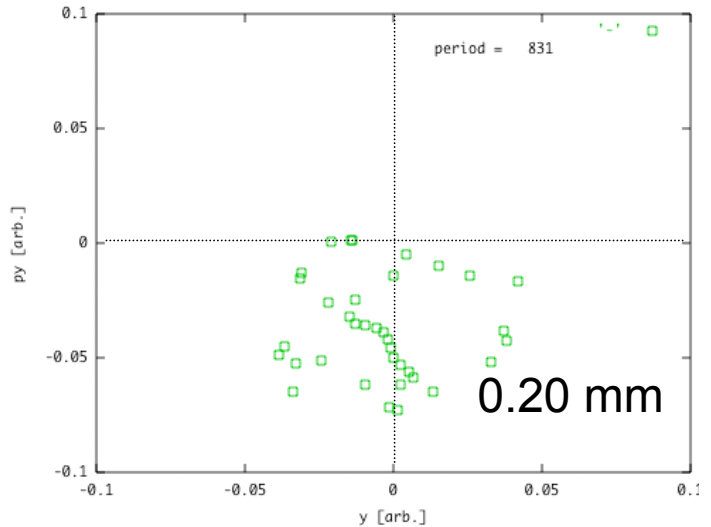
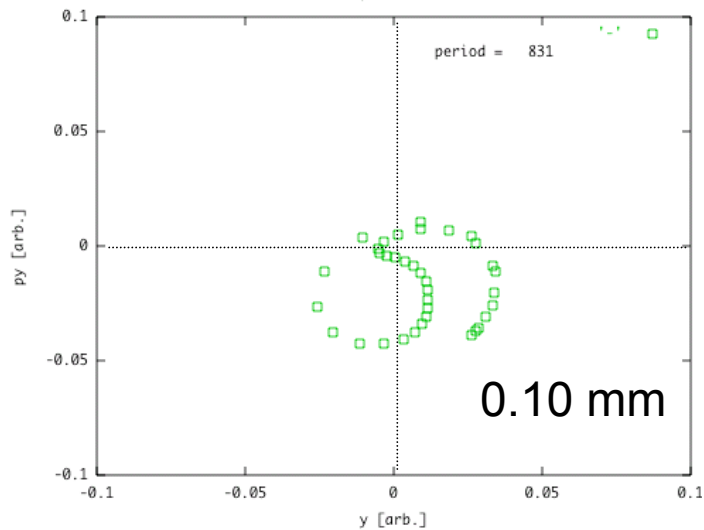
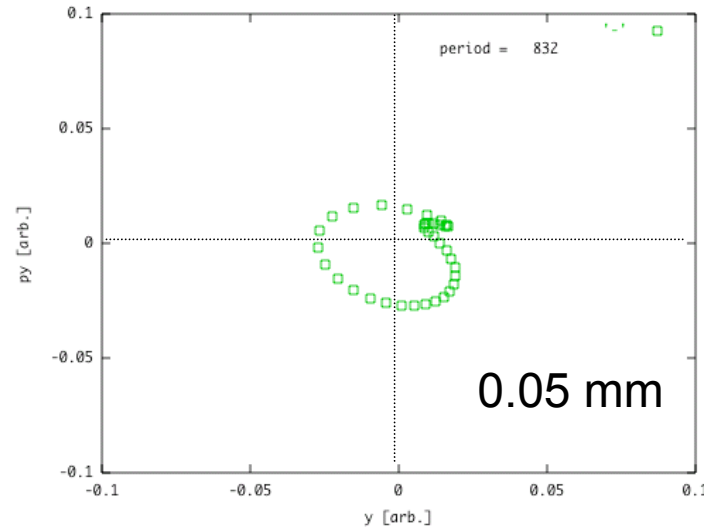
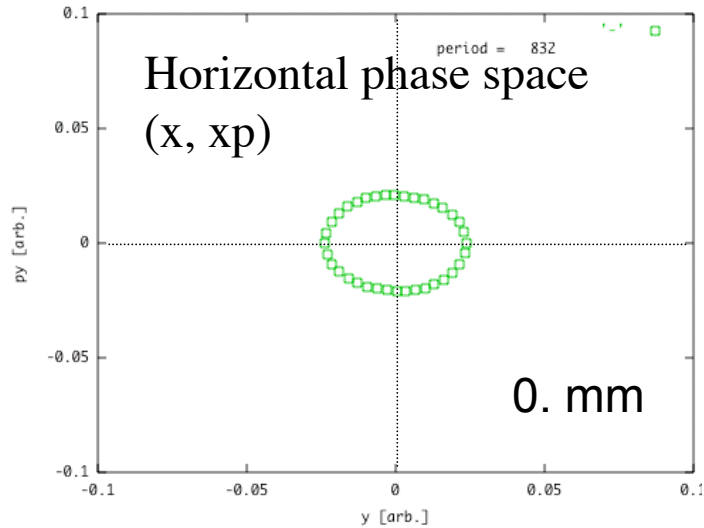


tune per cell

tune per ring

Resonance crossing with alignment errors, envelope

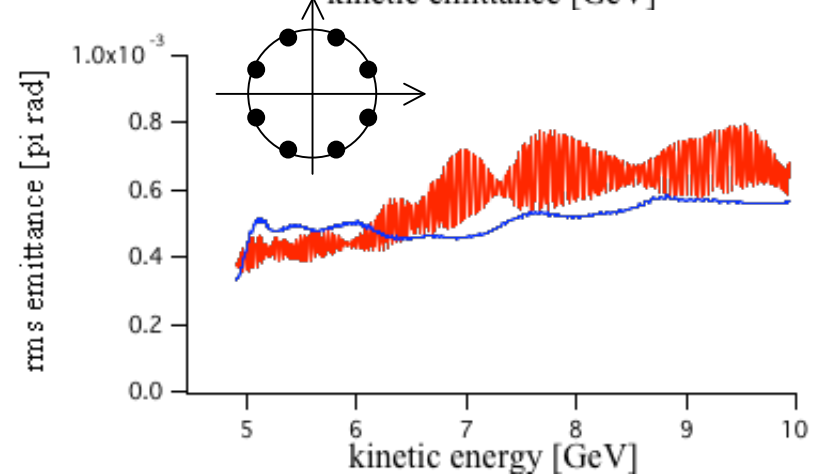
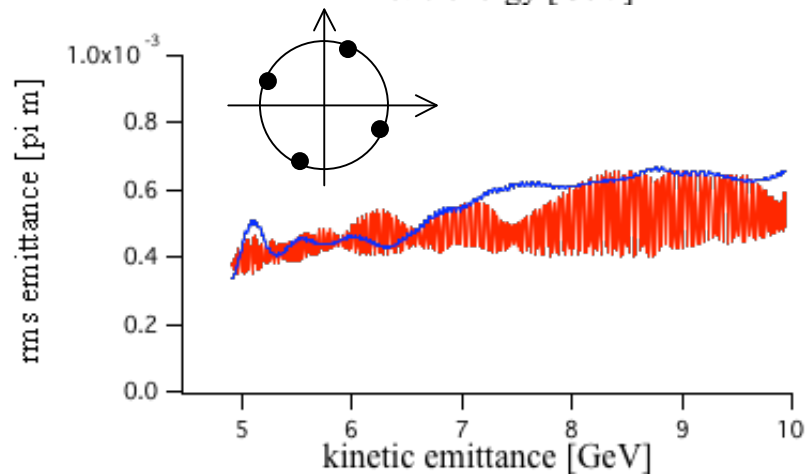
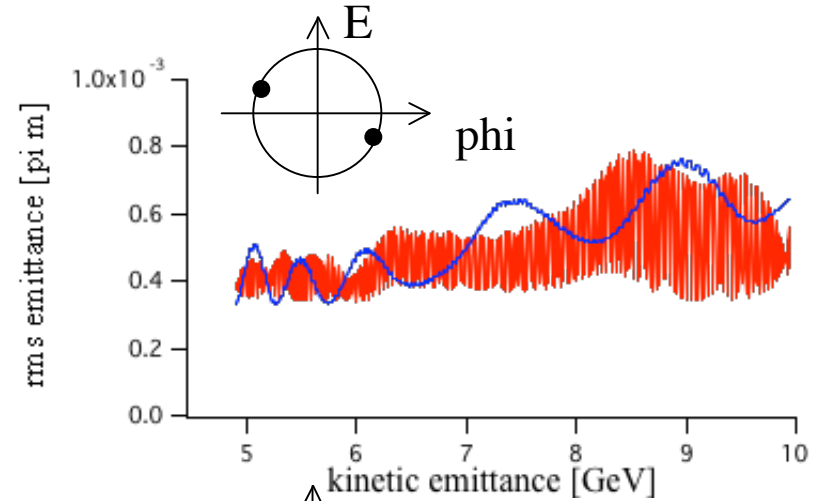
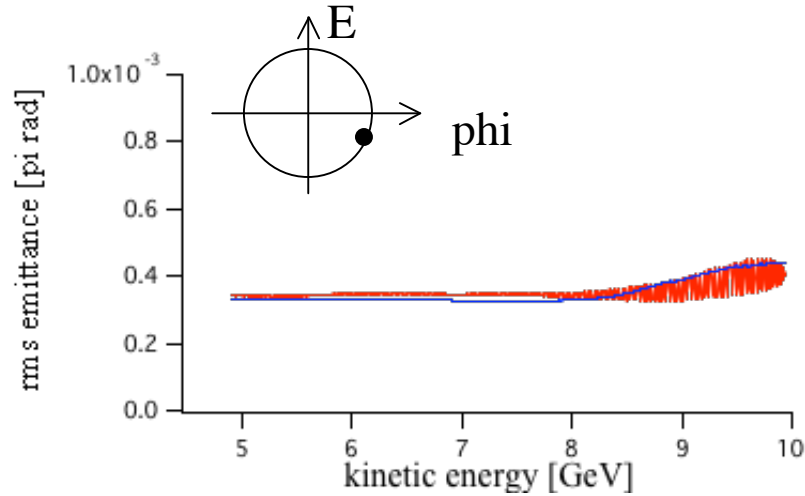
- Horizontal is 10π mm, normalized, zero vertical emittance.
- Errors of 0, 0.05, 0.10, 0.20 mm (rms).



Resonance crossing

with alignment errors (0.1mm), rms emittance

rms emittance: red(Hor.), blue(Ver.)



- ~16 turns are not enough to make decoherence.
- Each particle cross the resonance at difference time. That is another source of decoherence.

Summary

- Gutter acceleration is a scheme that introduces strong longitudinal and transverse coupling (due to finite chromaticity, small dispersion, and no synchrotron oscillations).
 - Matching between 2 rings (both longitudinal and transverse).
 - Finite transverse amplitude makes longitudinal distortion.
- Resonance crossing
 - Tune should avoid structure resonances if possible.
 - Distribution of longitudinal amplitude makes tune spread of transverse tune. That is a source of decoherence in transverse motion.