Muon acceleration
- amplitude effects in non-scaling FFAG -

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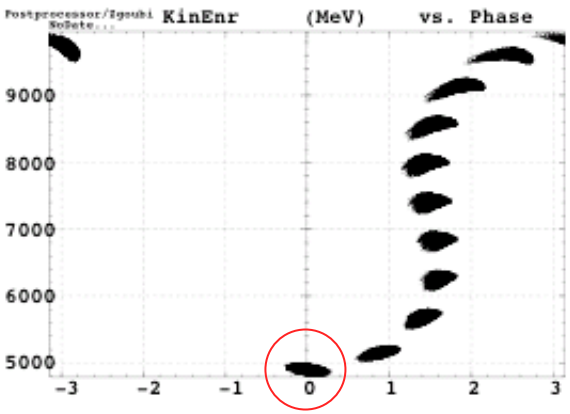
26 April, 2006
http://hadron.kek.jp/~machida/doc/nufact/ffag/machida_20060426.ppt & pdf

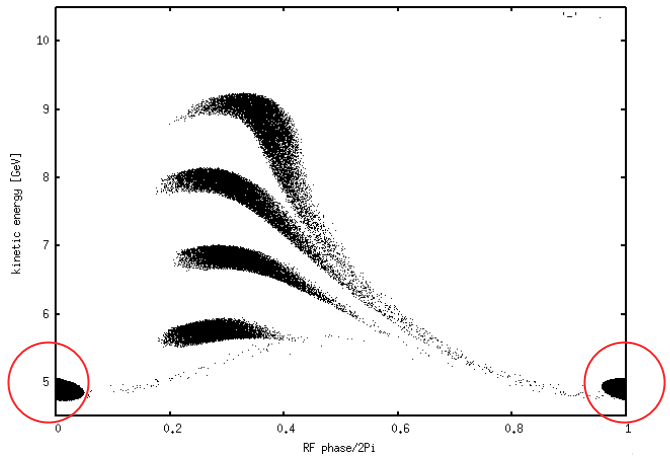
Contents

- Code benchmarking
- Possible cures of “amplitude problem”
- Matching between two FFAG rings
- Next steps

Code benchmark (1)

- Zgoubi and S(hinji's)-code had discrepancy (?)





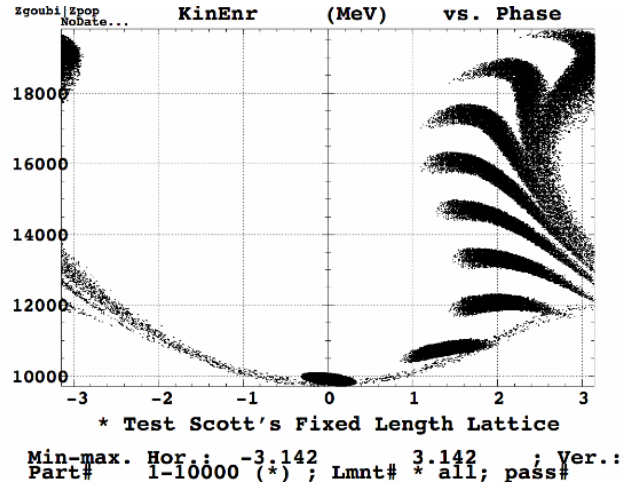
Zgoubi S-code

(5 to 10 GeV: 30 π mm in transverse, 0.05 eVs in longitudinal.)

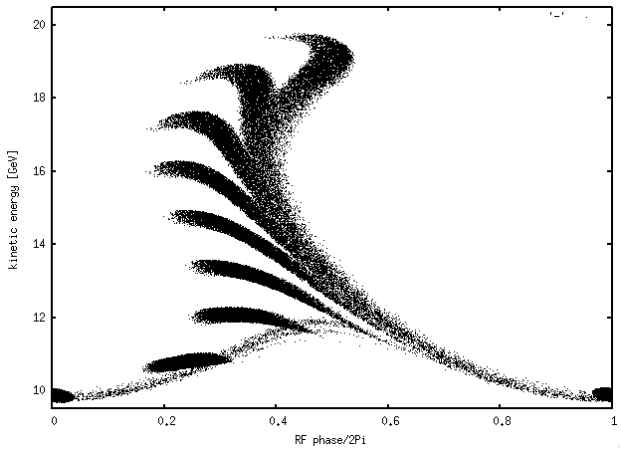
- Initial distributions were different.
  - Zgoubi assumed 6-D ellipsoid. S-code assumed 2-D ellipse independently in horizontal, vertical, and longitudinal space.

Code benchmark (2)

- With the same initial condition: independent in each plane.



Zgoubi

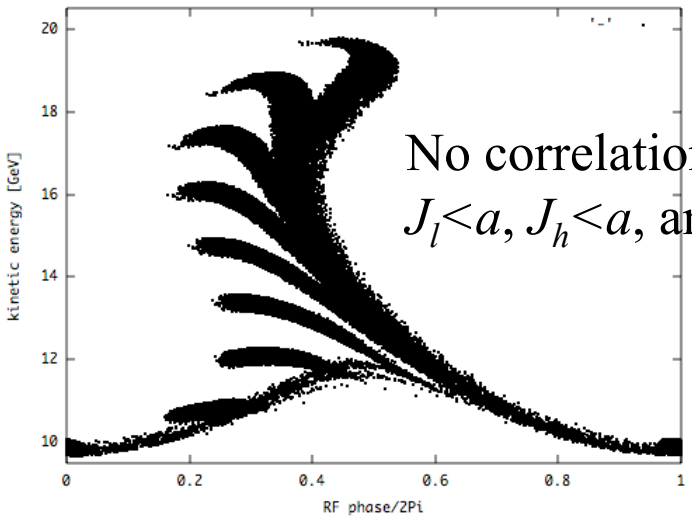


S-code

(10 to 20 GeV: 30 π mm in transverse, 0.05 eVs in longitudinal.)

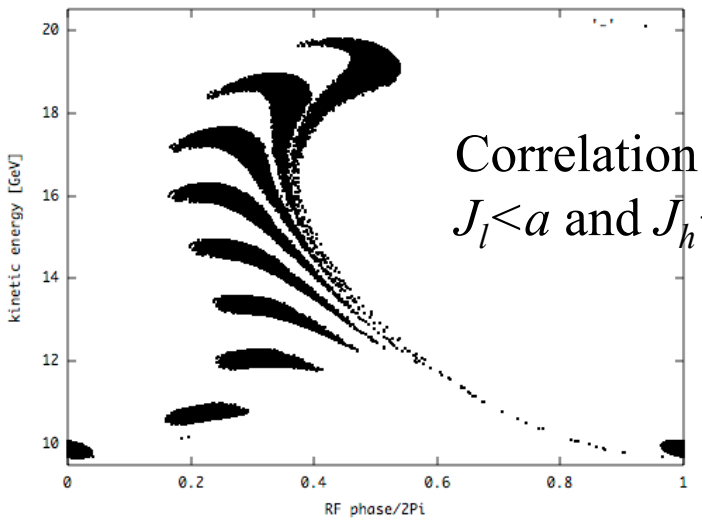
- Large amplitude particles make a problem also on Zgoubi.
- Another confirmation of the problem by Keil with MAD.

Code benchmark (3)

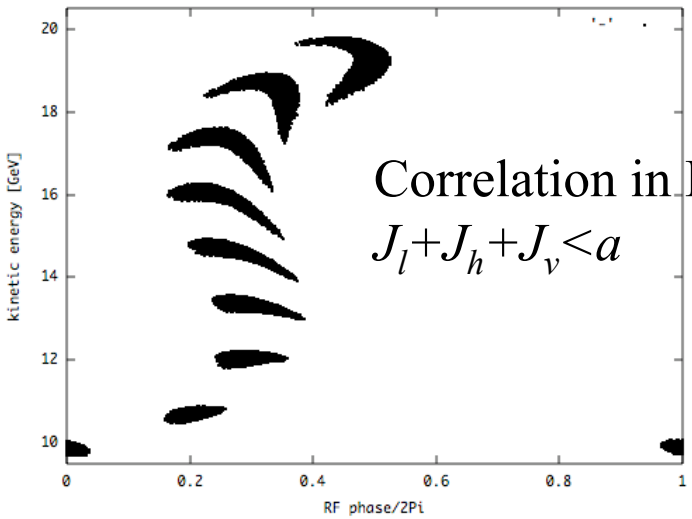


No correlation
$J_l<a$, $J_h<a$, and $J_v<a$

⇨ Some particles are not accelerated.



Correlation in T only
$J_l<a$ and $J_h+J_v<a$



Correlation in L and T
$J_l+J_h+J_v<a$

⇨ Correlation between transverse and longitudinal space eliminates large amplitude particles in both planes.

(10 to 20 GeV: 30 π mm in transverse, 0.05 eVs in longitudinal.)

a is amplitude in normalized phase space.

Code benchmark (4)

- In real life, there will be some correlation between horizontal and vertical, but probably independent of longitudinal.

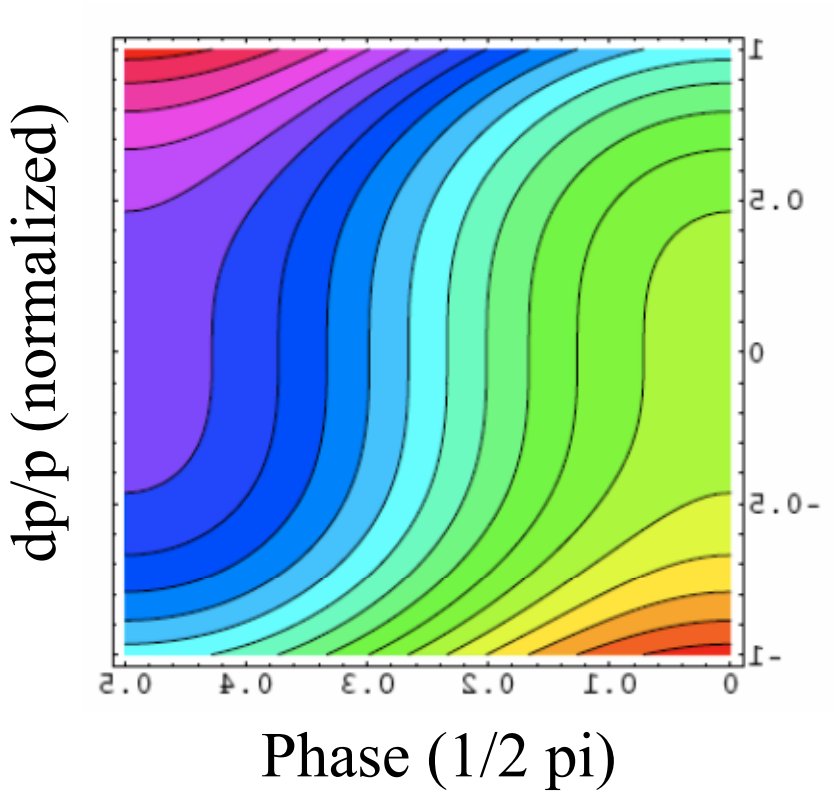
- The best way is to take particle distribution at the end of linac or RLA. Use it as an initial distribution to FFAG.

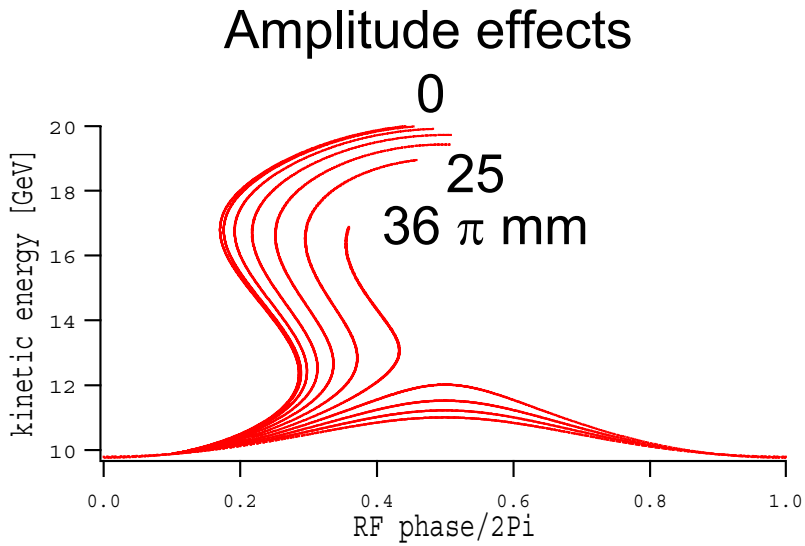
Possible cures (1)

- Longitudinal dynamics is parameterized by

$$a = \frac{qV}{\omega \cdot \Delta T \cdot \Delta E}$$ (Relative energy gain per phase slip.)

$$b = \frac{T_0}{\Delta T}$$ (RF frequency relative to revolution freq.)





Left figure is slightly different for finite amplitude particle.

Possible cures (2)

- Cure 1
  - Increase *V* to increase “a”.

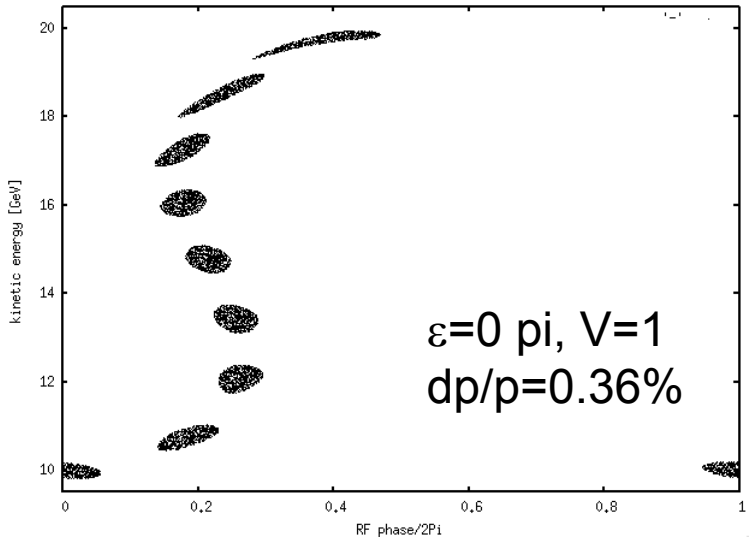
$$a = \frac{qV}{\omega \cdot \Delta T \cdot \Delta E}$$

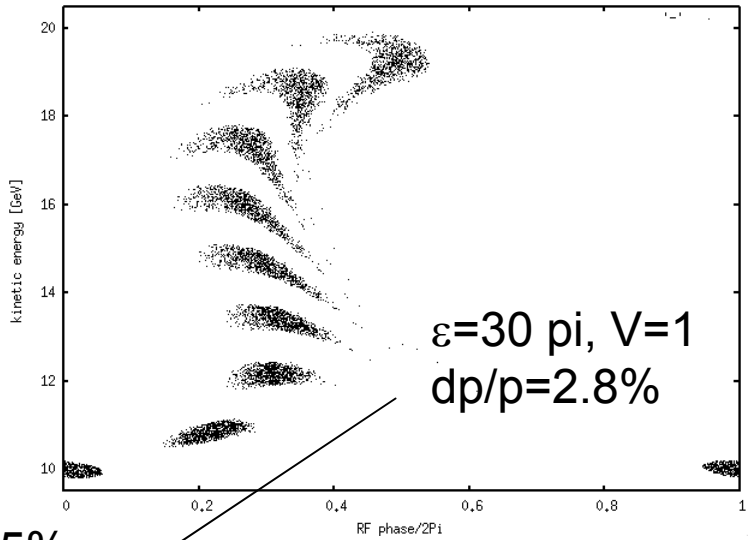
- Cure 2
  - Decrease ω to increase “a”.

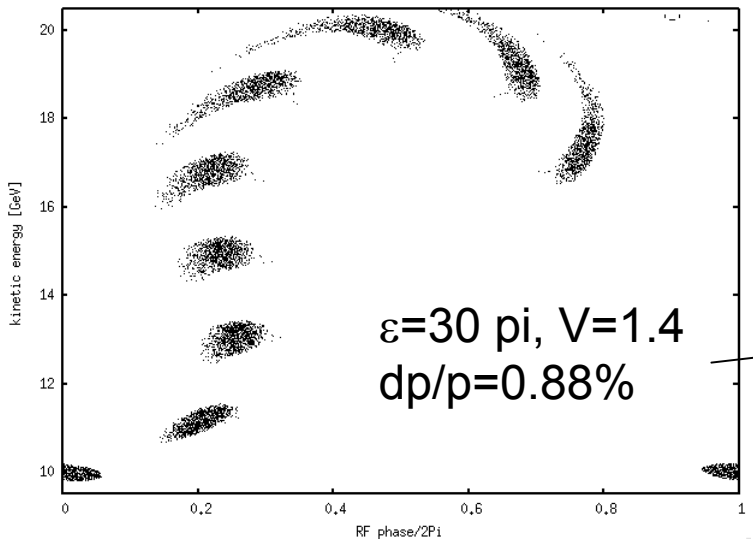
$$a = \frac{qV}{\omega \cdot \Delta T \cdot \Delta E}$$

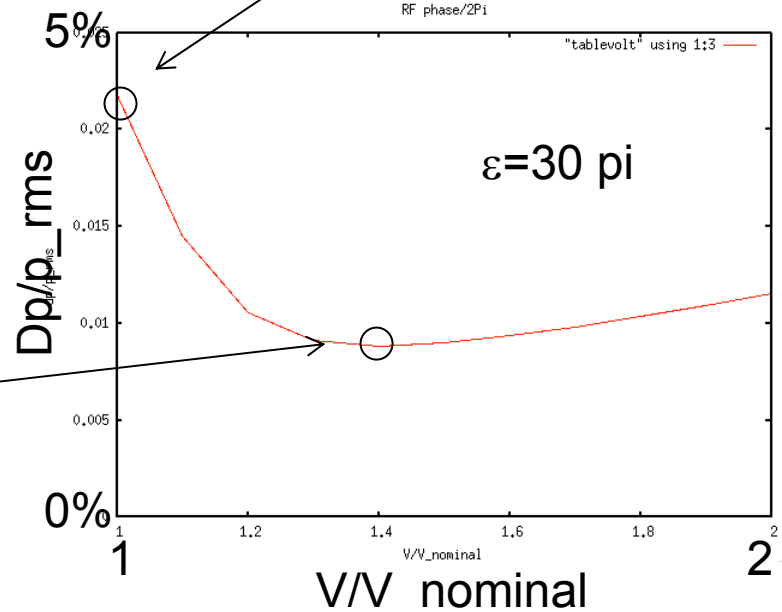
- Cure 3
  - Flatten crest by introduction of higher harmonics.

Possible cures (RF voltage)

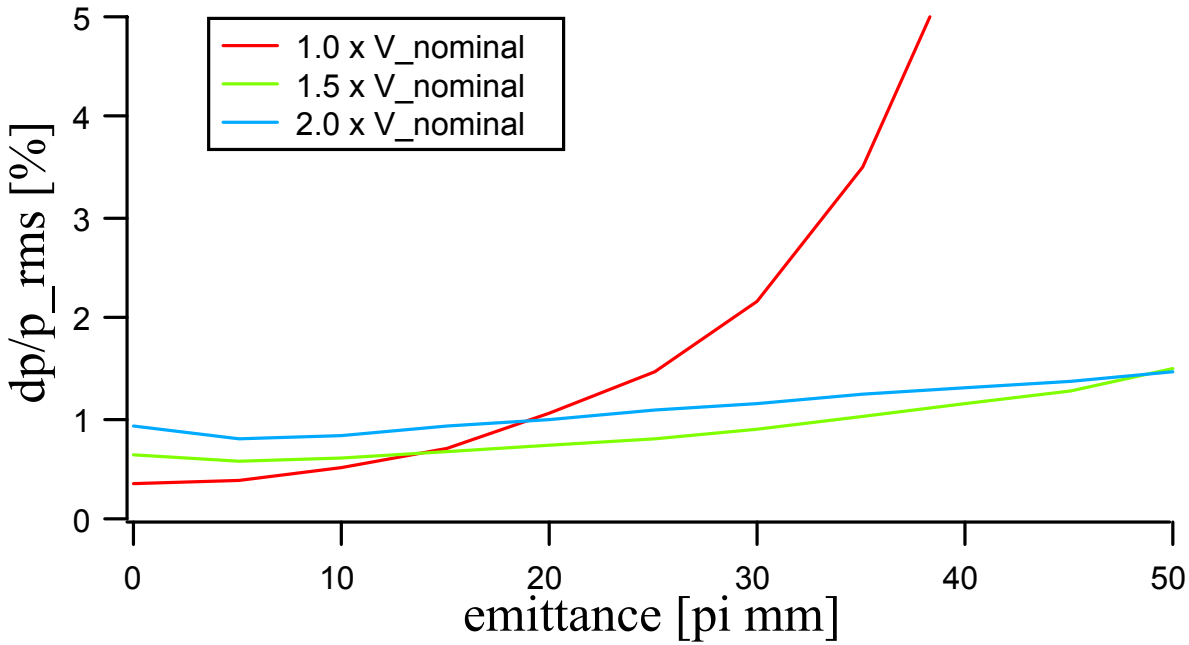






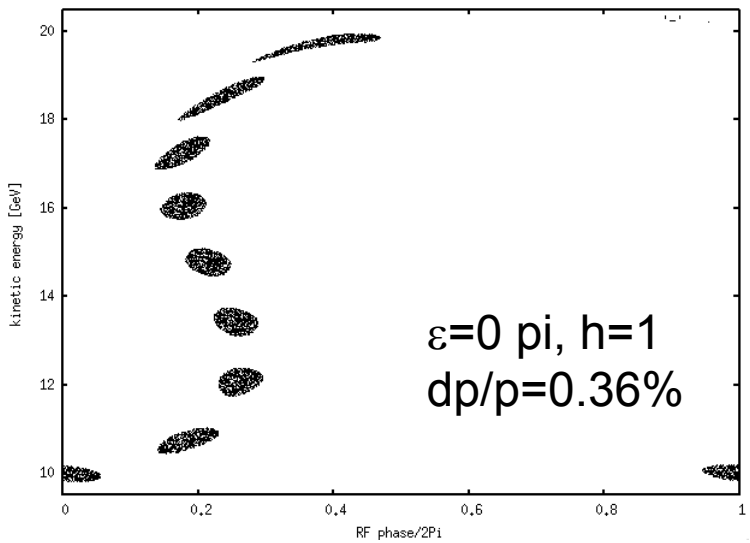


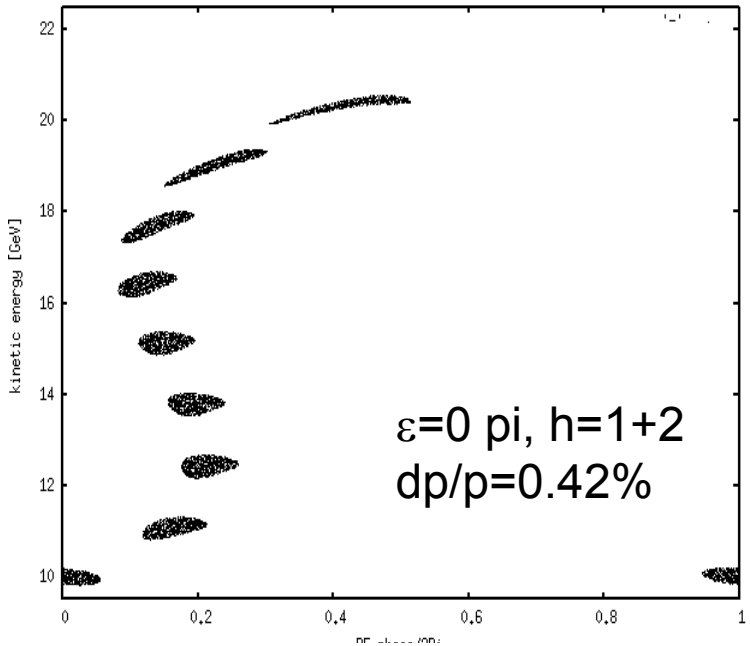
Possible cures (RF voltage)

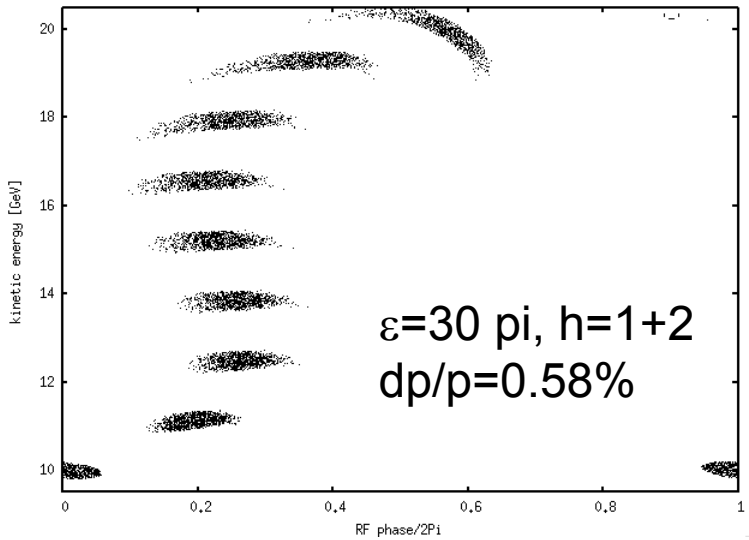


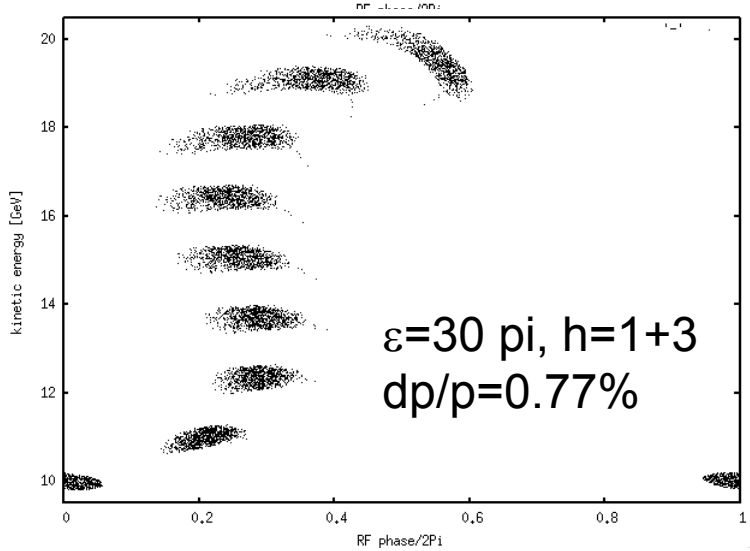
- 50% increase of RF voltage makes dp/p around 1% up to 50 pi mm.

Possible cures (higher harmonics)

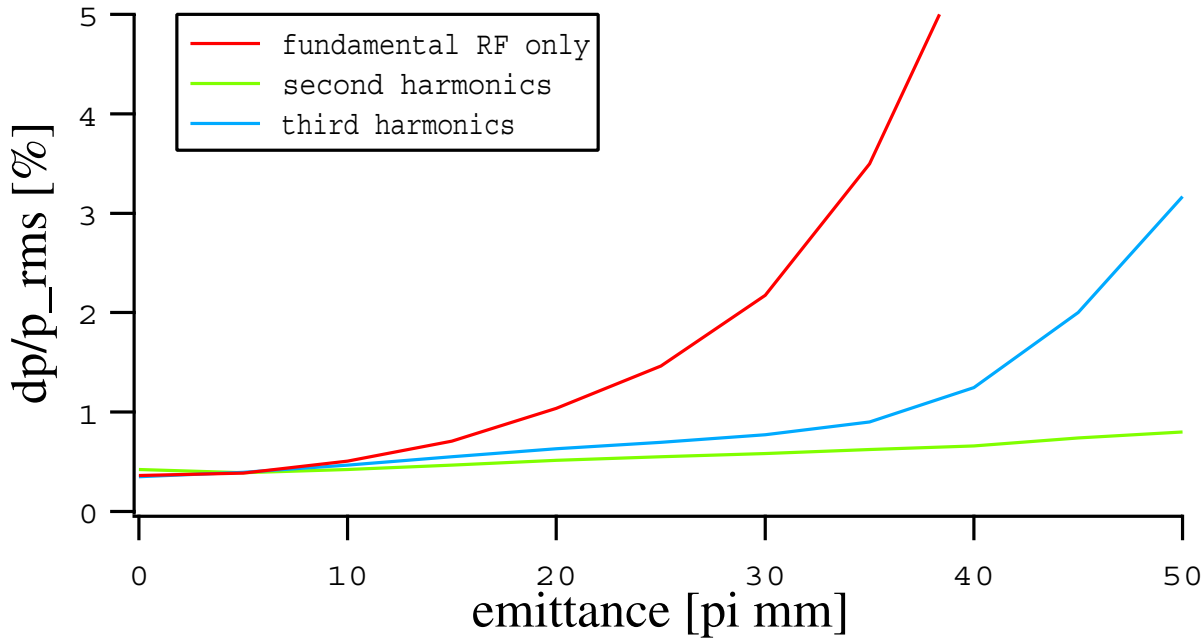






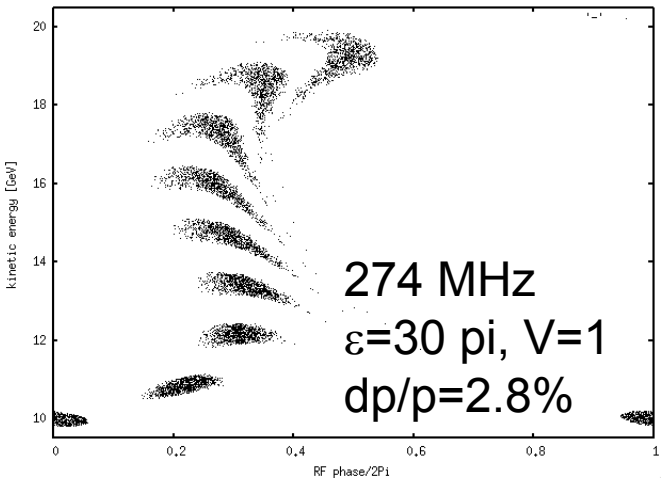


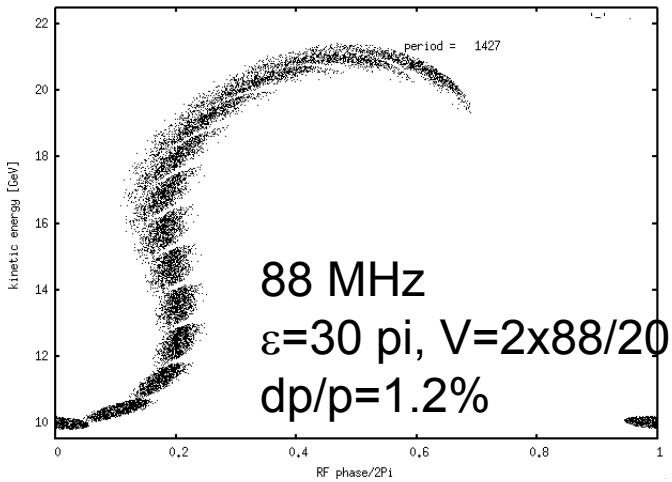
Possible cures (higher harmonics)

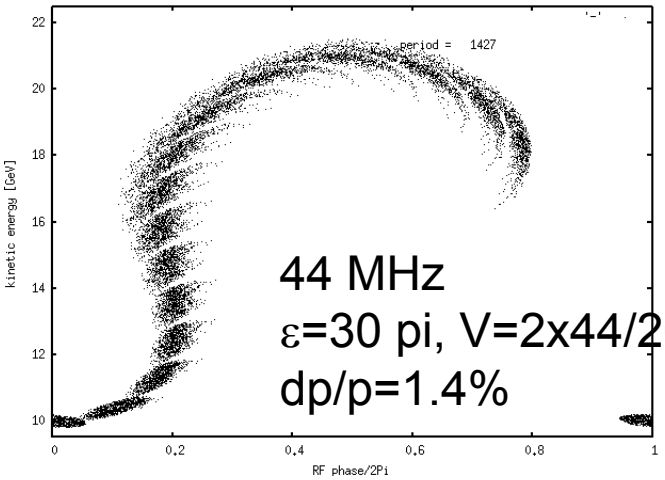


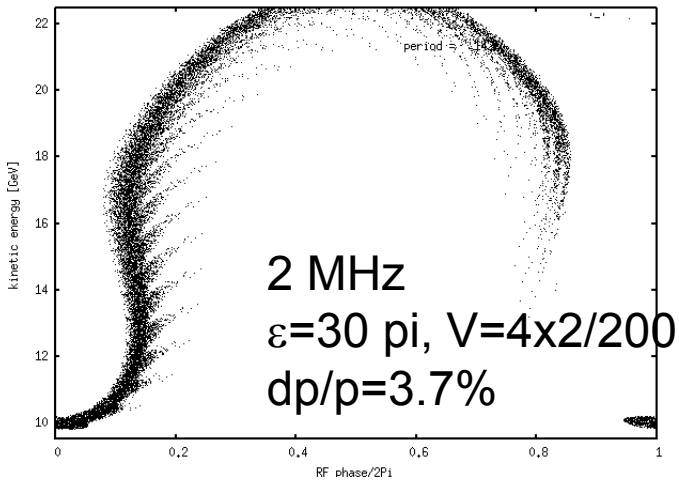
- Second harmonics makes dp/p around 1% up to 50 pi mm.
- It requires more RF power because second harmonics reduce peak voltage 25%.

Possible cures (lower frequency)

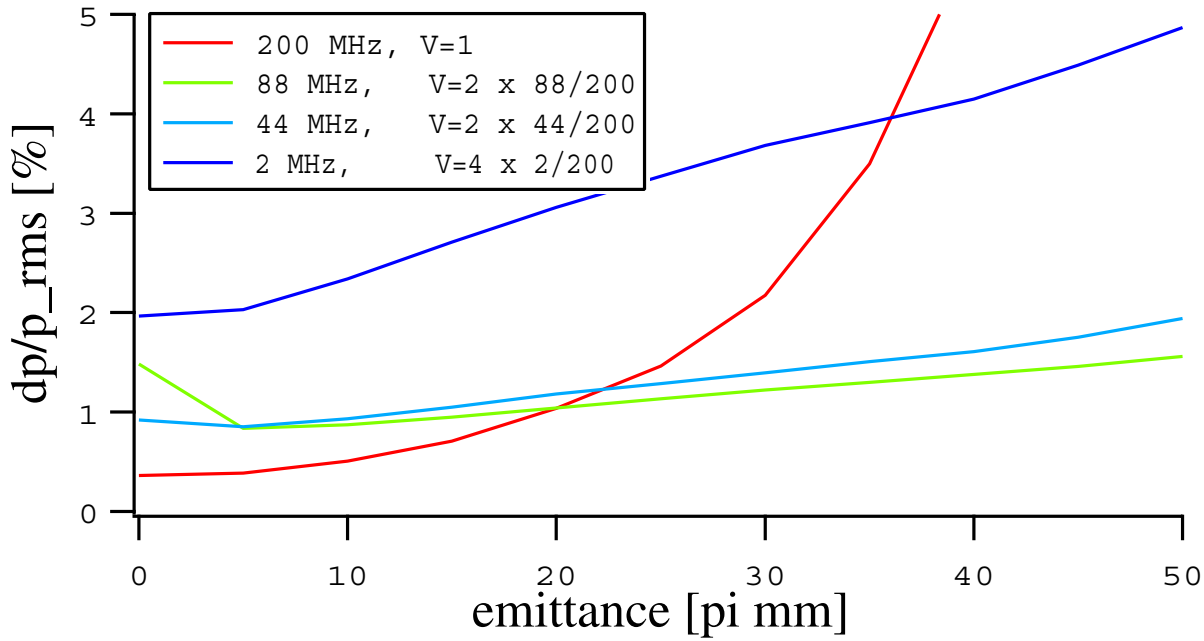








Possible cures (lower frequency)



- Lower frequency helps.
- However, it requires relatively higher voltage and time to complete acceleration.

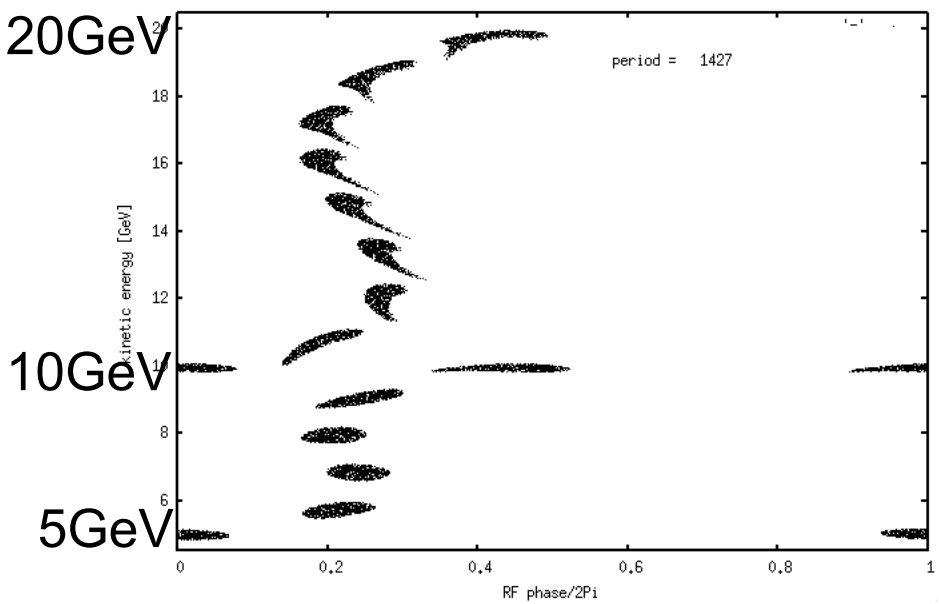
Possible cures (summary)

- Increase of a few 10% of RF voltage or second harmonics makes dp/p around 1% up to 50 pi mm beam.
- That requires additional RF power.
- Amplitude effects can be cured when there is only one FFAG.

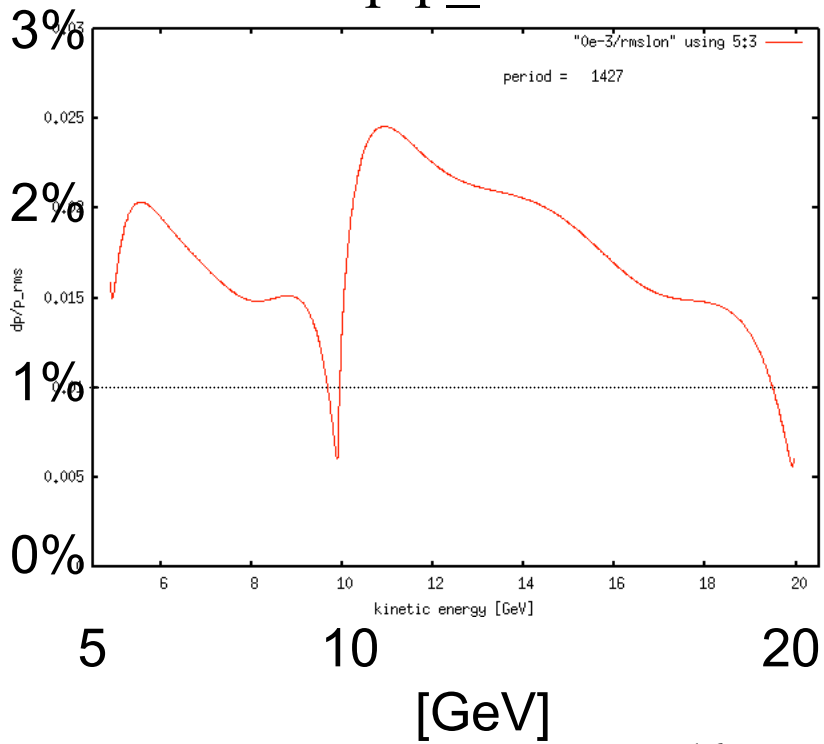
Matching between two FFAG rings (1)

- Zero transverse emittance beam has no problem of longitudinal matching.

longitudinal phase space

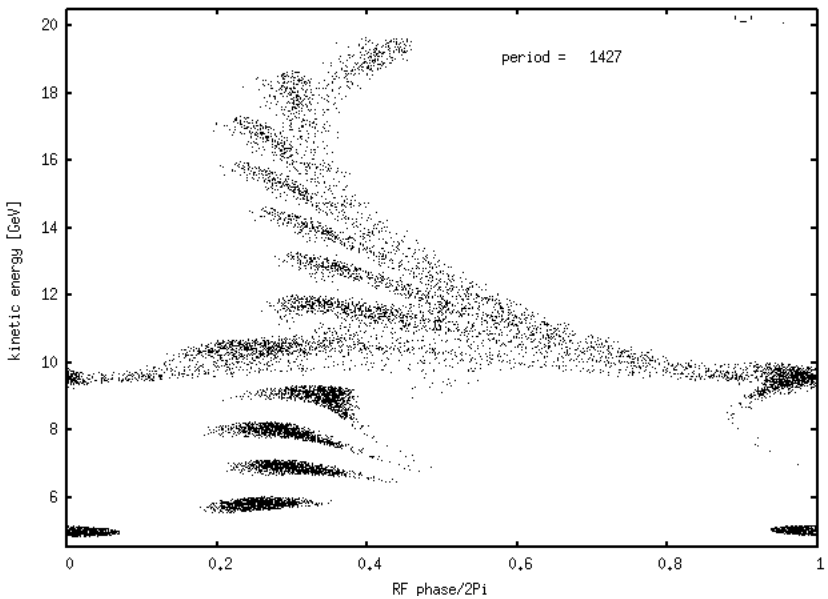


dp/p_rms

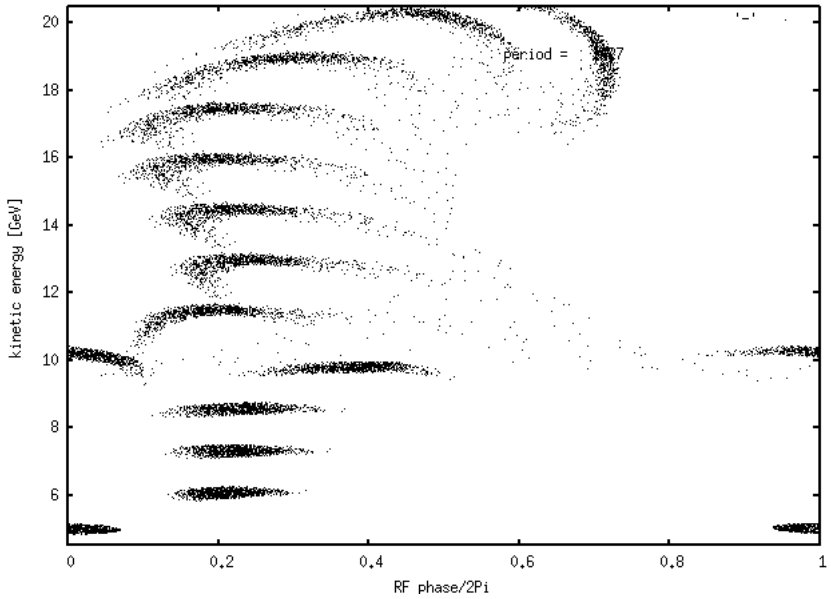


Matching between two FFAG rings (2)

ε=30 pi, h=1, V=1



ε=30 pi, h=1+2, V=1.1



- Second harmonics and 10% increase of RF voltage partially cure the problem.
- It depends decay ring acceptance if it is allowed.

Matching between two FFAG rings (3)

- Still many parameters we can play with.
  - Injection phase of the second ring (partially done).
  - Optical parameters of the first ring at injection (partially done).
  - Combination of 2 or more cures (partially done).
  - etc.

- Need criterion: how much dp/p is tolerable.

Next steps

- Scaling FFAG with “higher” RF frequency
  - Does 44 MHz, 88 MHz makes a reasonable bucket in scaling FFAG ?
  - How high is the *k*-value supposed to be if the frequency is fixed at 200 MHz ? (Berg)

    k=1800 (my number), 1100 (mori) vs. 800 (present lattice)

- How much dp/p can be allowed in the decay ring?
  - Need a target value for optimization.
  - RLA may have as much dp/p as FFAG with amplitude effects: a few percent ?
  - dp/p of scaling FFAG with either low and high frequency is unknown.