Muon Acceleration with Scaling FFAG using Harmonic Number Jump

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Muon Acceleration with FFAG Accelerator

- ## Scaling FFAG
  - ### advantages
    - *no resonance crossing : zero chromaticity*
    - *large dynamic aperture*
  - ### problems (issues)
    - *not small beam pipe (may not be an issue)*
    - *variable rf frequency : broad-band (low frequency & low field)*
- ## Non-scaling FFAG
  - ### advantages
    - *rf acceleration : constant rf frequency (high frequency & high field)*
    - *small beam pipe : small momentum compaction*
  - ### problems (issues)
    - *resonance crossing*
    - *time of flight (path length) for large beam amplitude : cascade rings*

Scaling FFAG with HNJ(harmonic number jump) Acceleration

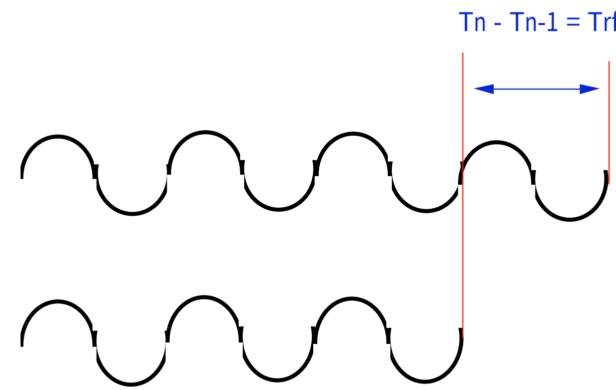
- Scaling FFAG + HNJ acceleration
  - constant rf frequency
    - *high frequency(200-400MHz) & high field (20MV/m) rf cavity*
  - good match with phase rotation & non-scaling FFAG
    - *Low energy (5-10GeV) muon accelerator as an injector of non-scaling FFAG to avoid path length problem of non-scaling FFAG*
    - *Scaling FFAG with HNJ for high energy (10-20GeV) ring*

HNJ Acceleration

- Revolution period for n-th turn

$$\left(\frac{T_n}{T_1}\right) = \left(\frac{C_n / v_n}{C_1 / v_1}\right)$$

  - C: circumference, v: particle velocity



Tn - Tn-1 = Trf x m

- Scaling FFAG $\frac{C_n}{C_1} = \left(\frac{p_n}{p_1}\right)^{\frac{1}{k+1}}$

- For muon acceleration (v~c)

  - When k increases, or ring size decreases,
    - *No. of turns decreases.*
    - *Energy gain/turn increases.*
  - Need optimization!

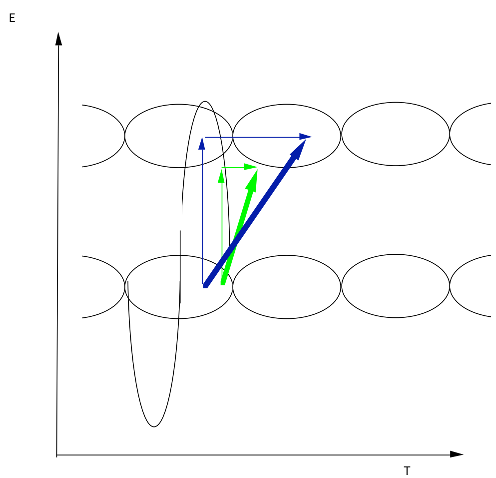
$$\frac{C_n}{C_1} = \frac{h_n}{h_1}, \quad p_n = p_1\left(\frac{h_n}{h_1}\right)^{k+1}, h_n = h_1 + n \times m$$

Scaling FFAG

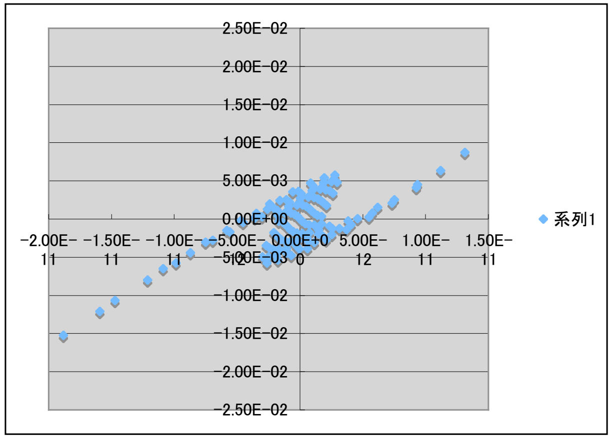
- ## Focusing
  - Spiral sector
    - *Focusing: body + edge*
    - *Small ring size*
    - *Rather large edge angle > 70 degree*
  - Radial sector
    - *Negative bend*
    - *doublet, triplet (DFD, FDF)*
- ## Basic parameters requested
  - Ring
    - *Energy P=5-10GeV*
    - *Bmax < 2T (Iron magnet :NC or super ferric)*
    - *Field index k : as small as possible*
    - *Orbit excursion <1m*
    - *Beam size : full aperture@10GeV < ~15cm*
  - RF
    - *RF frequency : 200-400MHz*
    - *RF field : ~10MV/m, Energy gain/m >1.5MeV/m*
- ## We choose "spiral sector".

Issues of HNJ

- Phase acceptance
  - Smaller for HNJ cf. synchronized acceleration
  - Because energy gain/turn is so large for HNJ that phase slip/turn should be 2π. If stable phase is away from $\pi/2$, phase slip/turn should be much less than 2π.

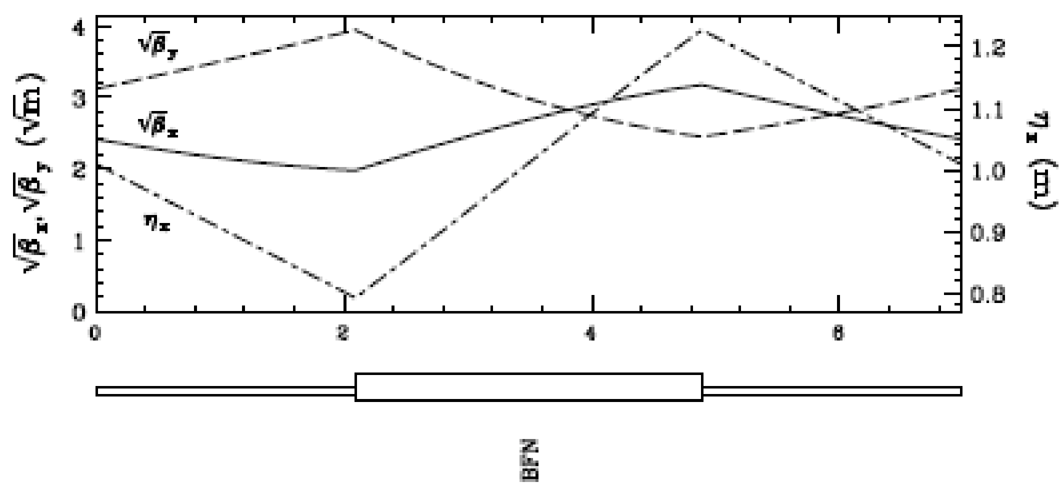


- Non-linear source dynamic aperture problems in longitudinal direction
  - Sinusoidal rf field contains non-linear components.
  - Synchroton tune is high enough to see non-linear resonances. mQs=n



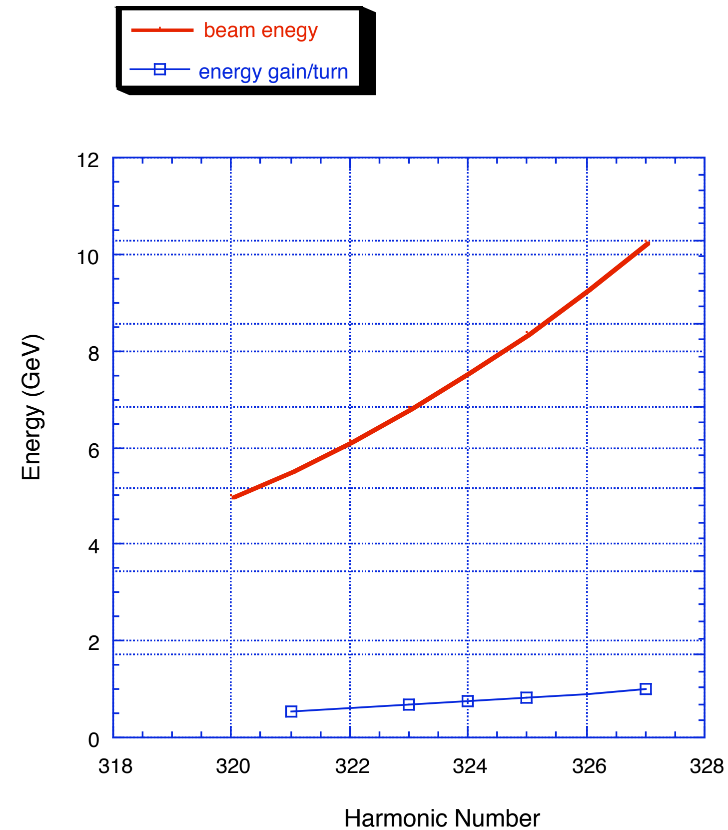
5-10GeV scaling FFAG spiral sector - design example

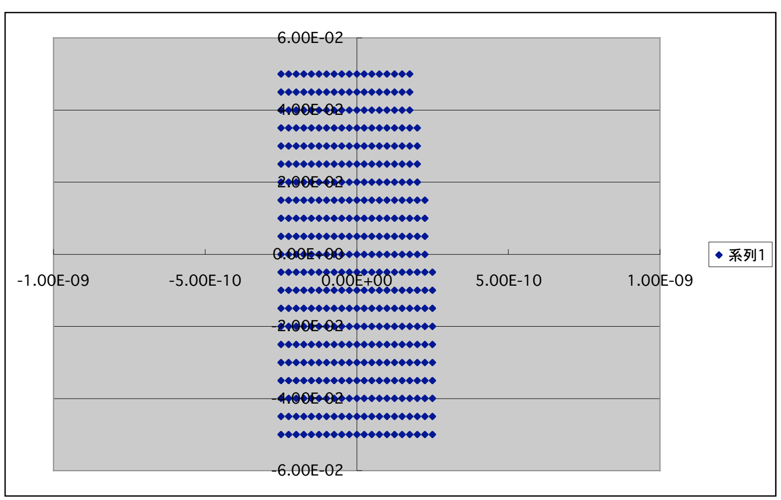
- Ring parameters
  - r=40m
  - N=32cells
  - spiral angle: 74degree
  - Bmax ~2.1T (p.f.=0.4)
  - k=38
  - Orbit excursion
    - *71.7cm*
  - Beam size(half, dp/p=0.03) at 10GeV
    - *H: 4.3cm+3.0cm=7.3cm,V=5.2cm @s.s.*
    - *H: 5.2cm+3.6cm=9.3cm,V=6.9cm @magnet*

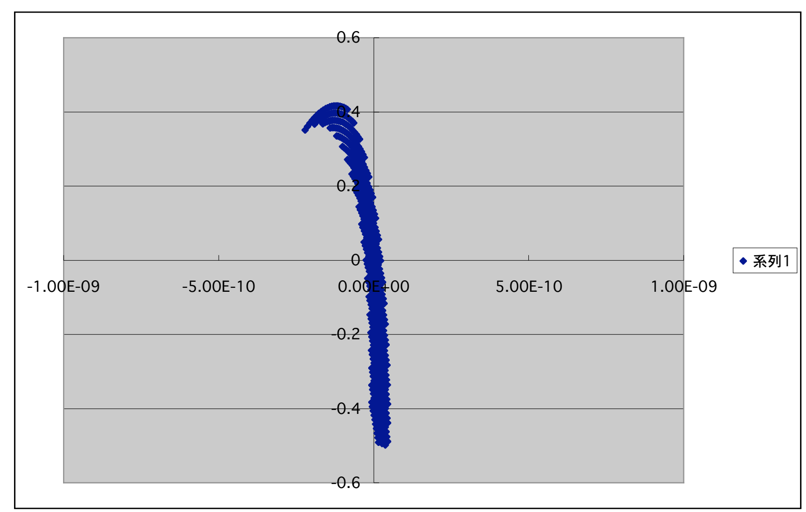


Spiral FFAG 5-10GeV

- ## Parameters
  - r=40m
  - k=38
  - rf parameters
    - *h=320*
    - *f=400MHz*
    - *fai_s=2 π /3*
    - *18.8MV/m:4-cell cavity*

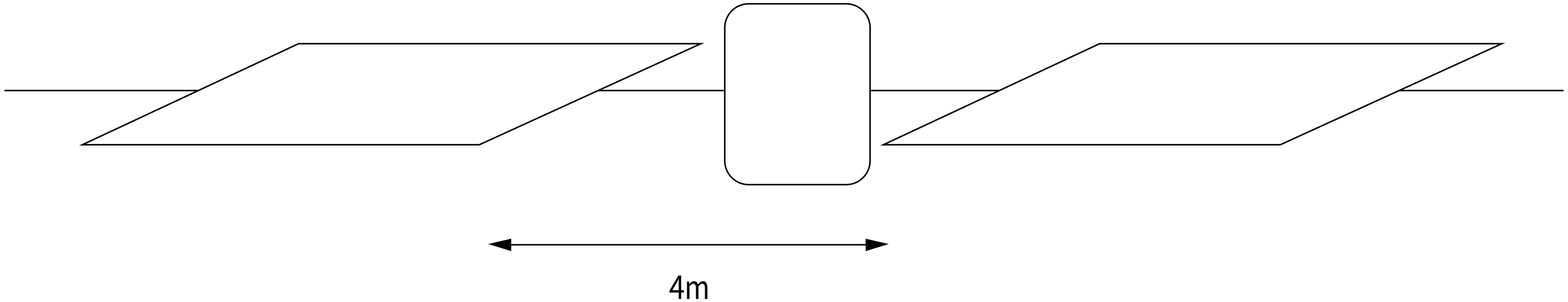






Spiral FFAG 5-10GeV

- Lattice
  - almost satisfied but more optimaization is needed.
    - *k-value:lower, Bmax:lower, packing factor, circumference etc.*
- HNJ acceleration
  - seems to have enough acceptance
  - frequency of rf cavity
    - *400MHz --->200MHz (depends on lattice design)*
  - No. of turns: should be larger >10 turns (now 7turns)
    - *reduce rf voltage 18.8MV/m --> 15MV/m*
  - Increase ring radius and reduce k-value



Summary

- Scaling FFAG with HNJ acceleration for Muon 5-10GeV (10-20GeV) looks promising but more optimization is needed.
- Flight time problem of non-scaling FFAG may be cured by scaling FFAG.
- Hardwares R&Ds are needed.
  - squashed(?) sc rf cavity
  - large spiral magnet