Rapid Accelerations: techniques

Shinji Machida

ASTeC/STFC/RAL

23 October, 2007

http://www.astec.ac.uk/intbeams/users/machida/proc/topical2007/machida_20071023.pdf & ppt

Contents

- Muon accelerators in a neutrino factory (8 slides)
- Muon accelerators in a muon collider (8)
- Summary (2)

Muon accelerators in a neutrino factory

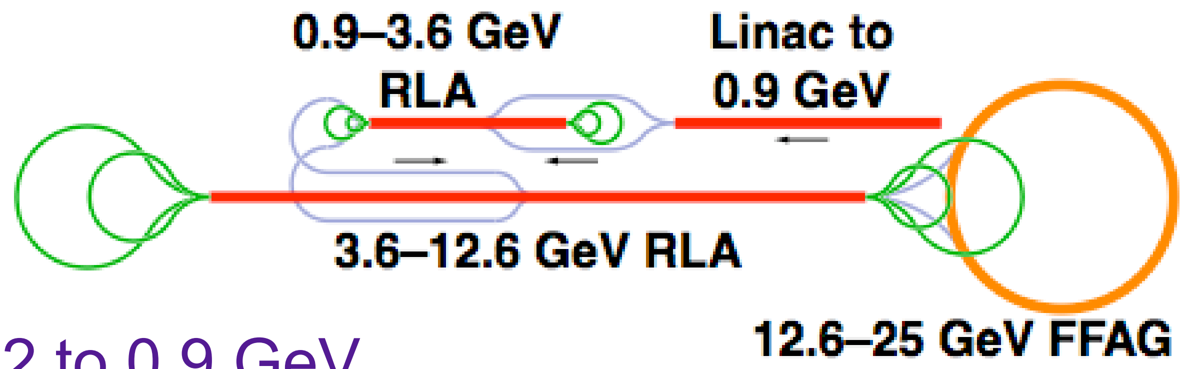
Muon acceleration in a neutrino factory (1)

requirements of muon accelerator

- Quick acceleration
  - Short lifetime of 2.2 μs.
  - A few MV/m as an average energy gain.
- Large acceptance
  - Muon is a tertiary particle.
  - Muon emittance is a few tens of thousand π mm mrad (or 30 π mm).
- Cost consideration
  - Accelerators are the most costly part of a neutrino factory.
  - In particular, efficient use of rf system is essential.
- Acceleration of bunch train with 201 MHz structure
  - 80 bunches after phase rotation and cooling.
  - That uniquely determines the choice of rf frequency.

Muon accelerators in a neutrino factory (2)

proposed complex with ISS



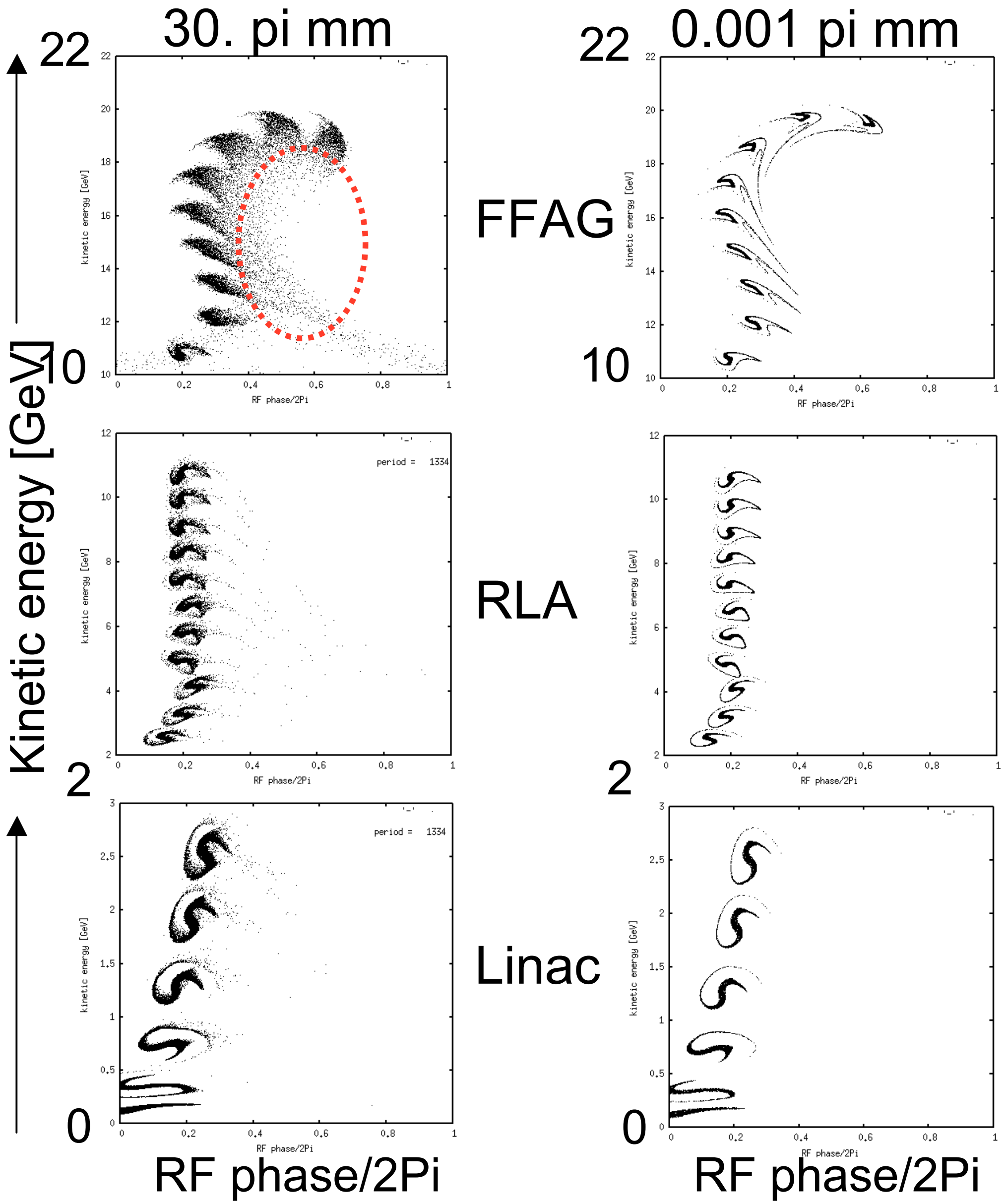
- Linac: 0.2 to 0.9 GeV
  - \+ Simple and straightforward.
  - – Costly.
  - – Large amplitude particles lag behind the correct phase (phase slip).
- Recirculating Linac (RLA): 0.9 to 12.6 GeV
  - \+ Cost effective way of using linac. Arc can compensate the phase slip.
  - – Is switchyard problem solved?
- Linear nonscaling FFAG: 12.5 to 25 (or 50 GeV)
  - \+ Lower cost.
  - – The phase slip problem.
  - – “Resonance” crossing.

Muon accelerators in a neutrino factory (3)

RLA or FFAG? - phase slip problem -

- "End to end simulation" shows deterioration of longitudinal emittance in a nonscaling FFAG.

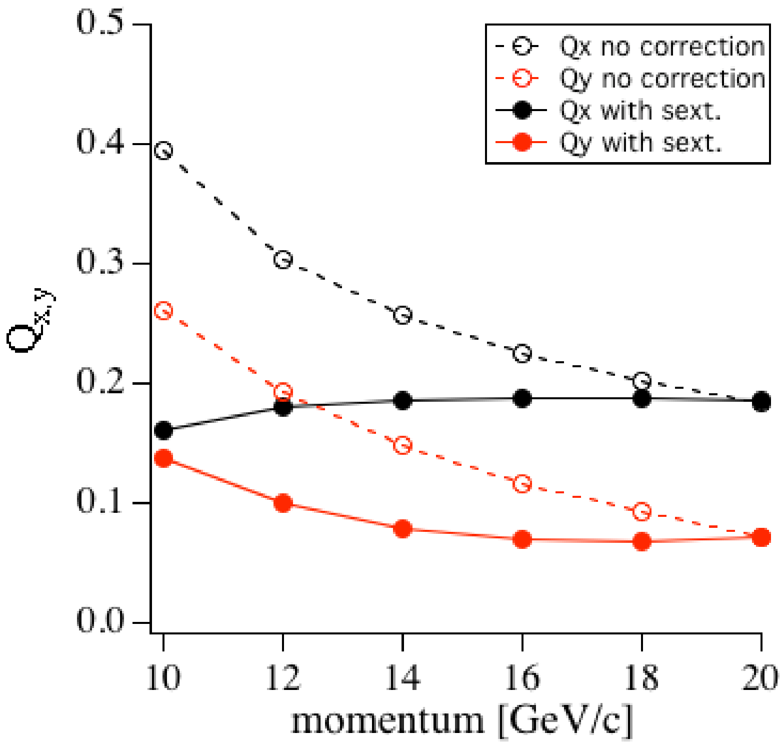
- The phase slip problem determines
  - Transition energy between RLA and FFAG.
  - whether a cascade of FFAG is feasible.



Muon accelerators in a neutrino factory (4)

chromaticity correction

- Chromaticity correction eliminates the problem (Berg).
  - Reduction of dynamic aperture becomes a concern.
- Make a lattice with chromaticity correction.
  - 30 π mm acceptance is needed.



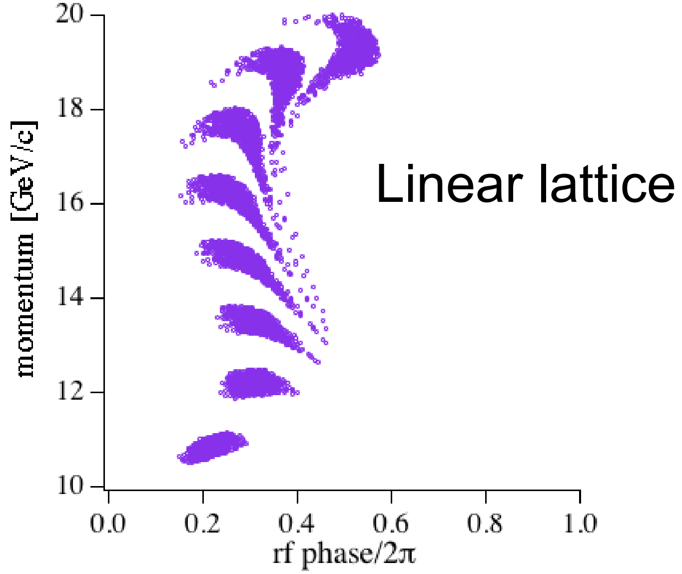
Dynamic aperture of 100 turns

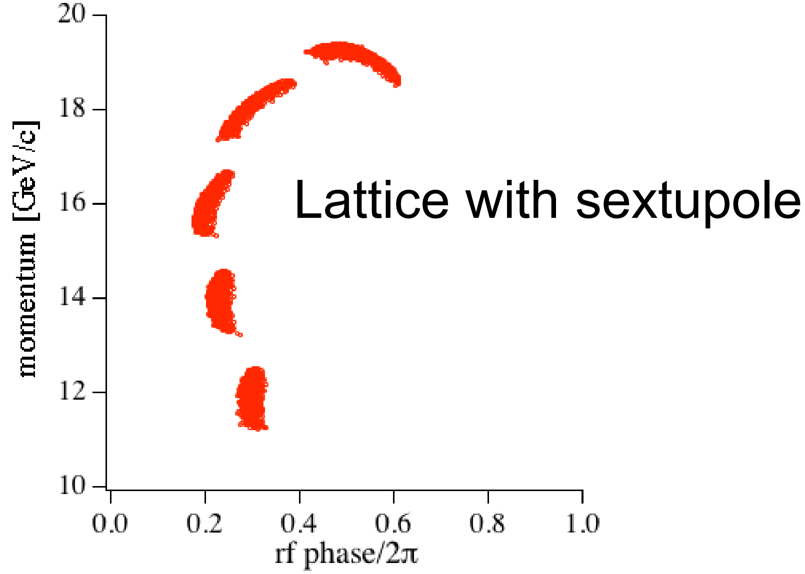
Momentum [GeV/c]	Dynamic aperture [πmm]
10	18
12	9
14	6
16	9
18	15
20	18

Muon accelerators in a neutrino factory (5)

simulation results

- Sextupole mitigates the phase slip problem.
- Muon beam with 30 π mm emittance is accelerated without beam loss.
  - Even though dynamic aperture of 100 turns does not give acceptance of 30 π mm.



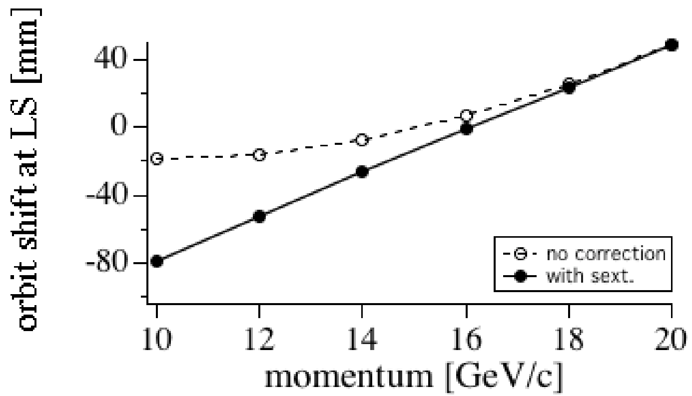


- EMMA can simulate these results?

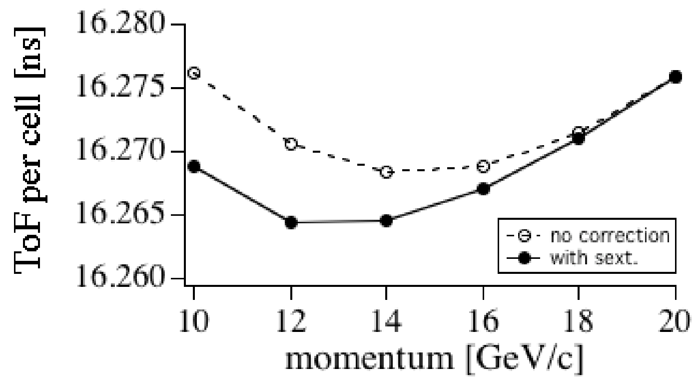
Muon accelerators in a neutrino factory (6)

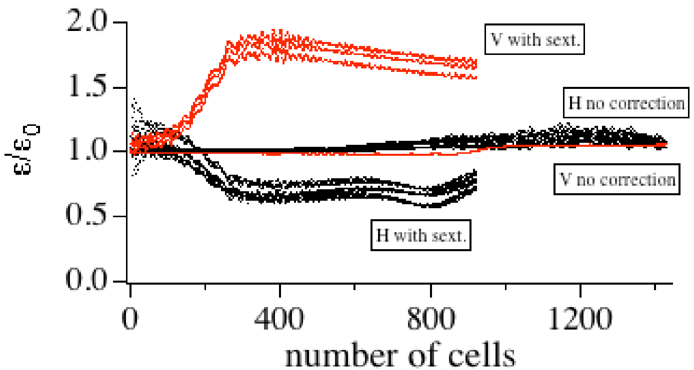
price we have to pay

- Orbit shift becomes as twice as much.
  - Need a bigger aperture magnet.



- Time of flight range increases 50%.
  - Need a higher voltage.



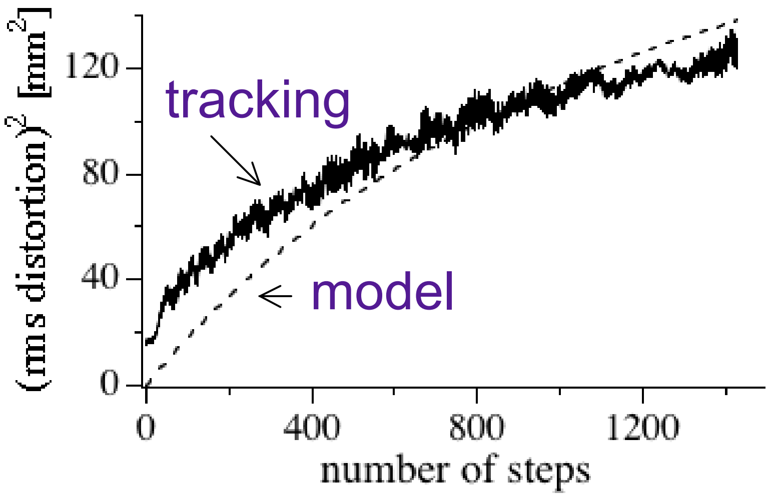


- Exchange of transverse emittance.
  - Can be cured by tune choice?

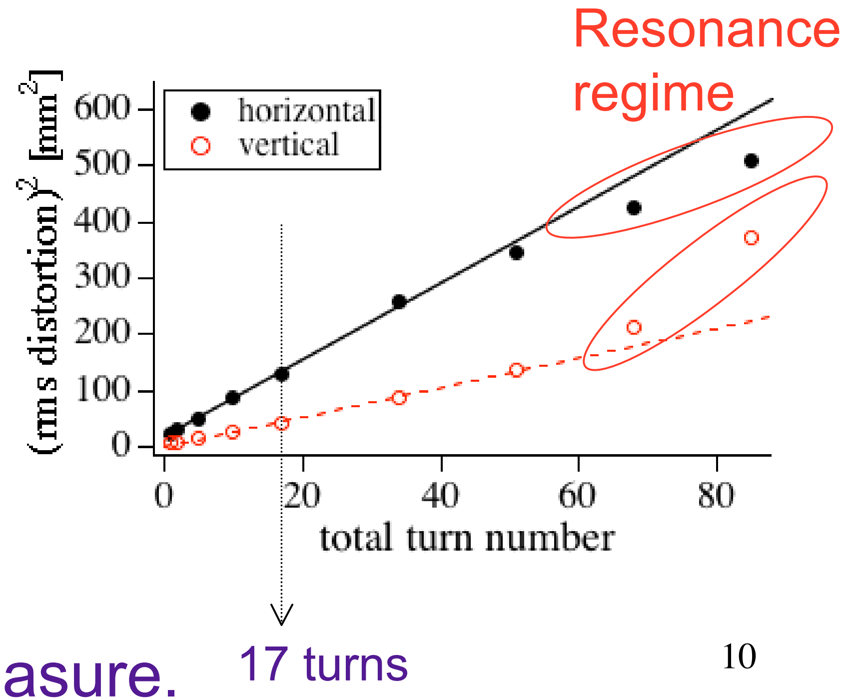
Muon accelerators in a neutrino factory (7)

"resonance" crossing

- rms orbit distortion due to alignment errors agrees with random walk model.



- Distortion for different acceleration rate.
  - Circles are simulation results.
  - Lines are random walk model.



"local" correction is the only measure.

Muon accelerators in a neutrino factory (8)

summary

- ISS design choice is pretty much optimized *except*
- Transition energy between RLA and FFAG is still debatable.
- Phase slip problem can be corrected.
  - Chromaticity correction is a realistic solution.
  - The idea of a few FFAG cascade is feasible.
- "Resonance" is not correct physics. However, it becomes a concern if the tune changes 5 times slower.

Muon accelerators in a muon collider

Muon acceleration in a muon collider (1)

requirements of muon accelerator

- Quick acceleration (high gradient acceleration)
  - Life time is boosted: becomes an order of ms.
  - Required gradient is the same: ≥ MV/m.
- ~~Large acceptance~~
  - Muon is a tertiary particle.
  - Beam is cooled and emittance is small: 0.025 π mm (30 π mm in N.F.)
- Cost consideration (always an issue)
  - Accelerators are the most costly part of a neutrino factory.
  - In particular, efficient use of rf system is essential.
- ~~Acceleration of bunch train with 201 MHz structure~~
  - Single bunch (Palmer).
  - No constraint on rf frequency.

Muon acceleration in a muon collider (2)

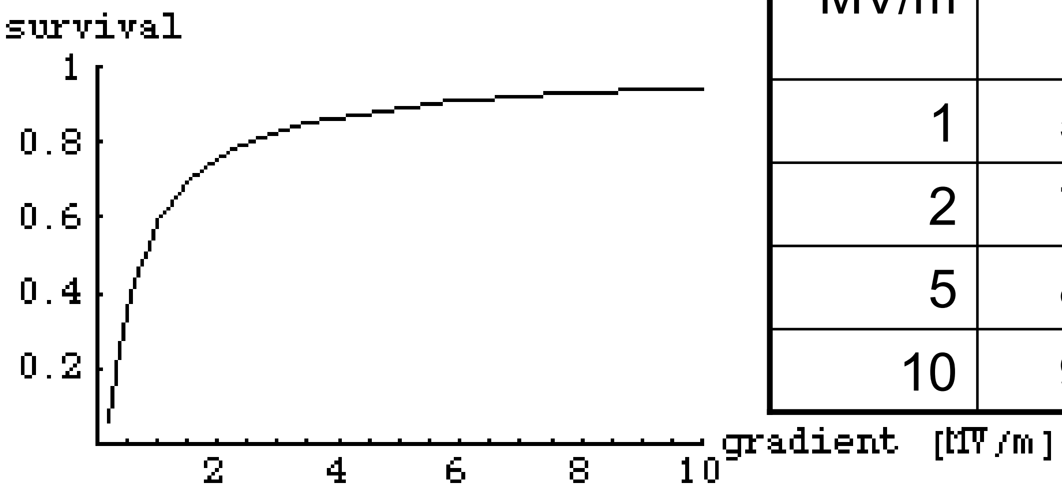
muon decay

- Muon survival

$$\frac{n_f}{n_i} = \left(\frac{\gamma_f}{\gamma_i}\right)^{-\frac{m_\mu c^2}{c\tau g}}$$

  - Where τ is muon life time at rest, g is field gradient.
  - Once γ_f / γ_i is fixed, required field gradient is independent of γ.

- When $\gamma_f / \gamma_i = 40$ (50 to 2000 GeV)



MV/m	%	ms (50 to 2000 GeV)
1	57	6.5
2	76	3.3
5	89	1.3
10	95	0.65

Muon acceleration in a muon collider (3)

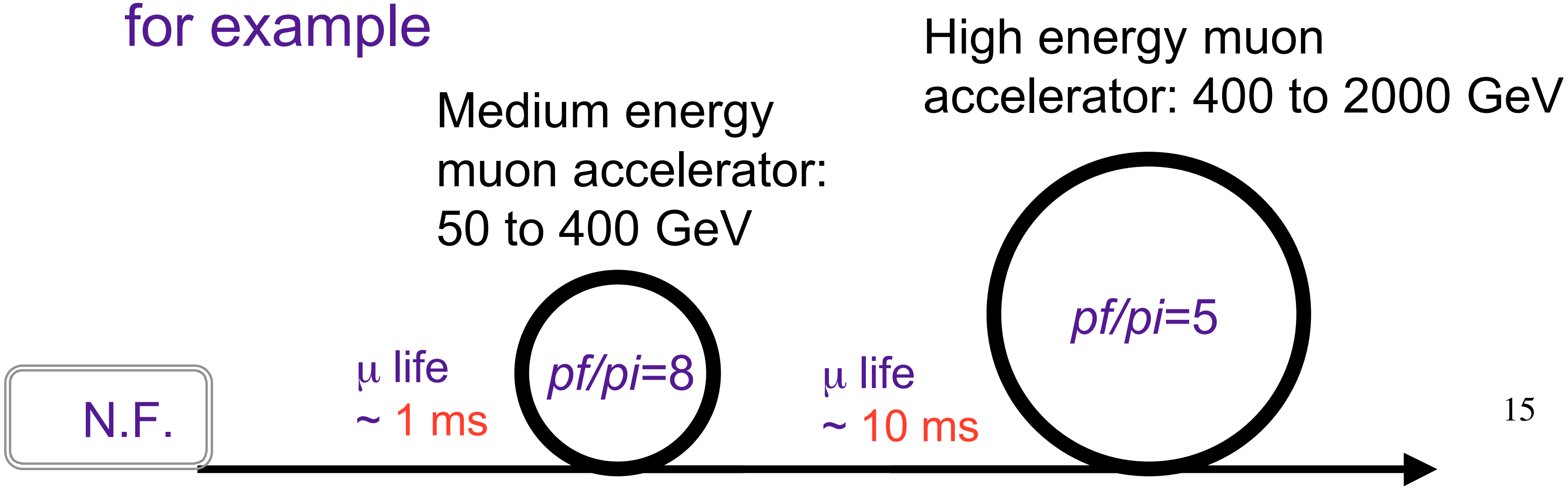
ring option

- Another structure(s) is needed to accelerate 40 times more.
  - *pf/pi* = 40. (50 GeV to 2000 GeV)

- Linac or RLA is a straightforward option. However, ring accelerators can be a possible alternative.

- At least, two stages are necessary,

  for example



Muon acceleration in a muon collider (4)

possible choice of medium energy muon accelerator

- 50 to 400 GeV

MV/m	%	ms
1	73	1.2
2	85	0.6

- Linear nonscaling FFAGs
  - Limit of *pf/pi*=2 means three rings.
- Pulsed magnet synchrotron
  - Less than 1 ms acceleration time may be still too fast.

- Scaling or nonlinear nonscaling (chromaticity corrected) FFAG
  - Wider range of *pf/pi* is possible.
  - No constraint on the rf frequency, can be low such as a few MHz.

Muon acceleration in a muon collider (5)

FFAG as MEMA example

- Machine parameters of a scaling FFAG

energy	50 to 400 GeV
lattice	doublet
radius	1500 m
# of cell	375
QF/QD	7.5 / 7.5 m
short straight	0.5 m
long straight	9.6 m
k-value	6238
orbit shift	0.5 m
cell tune	0.378 (H) / 0.073 (V)
Bfield at orbit	+9.1 T / -6.8 T

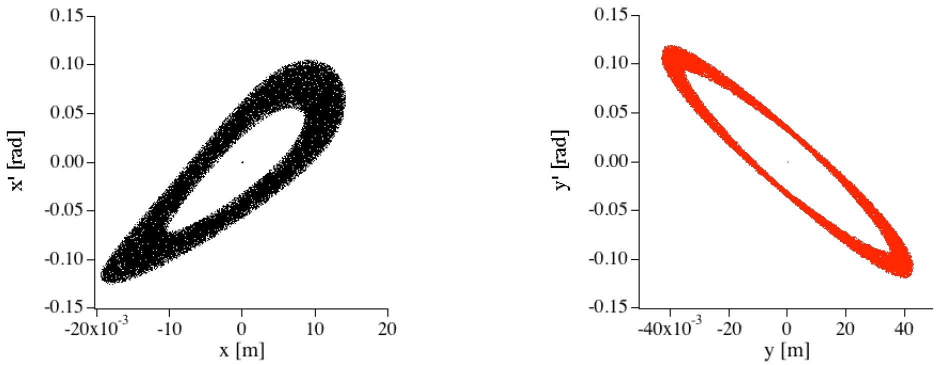
- Time scale and rf of a scaling FFAG

revolution time	31.4 μs
# of turn with 1 MV/m	38
cycle time	1.2 ms
gradient at cavity	4 MV/m
frequency swing *df/f*	+-1.67 10^{-4}

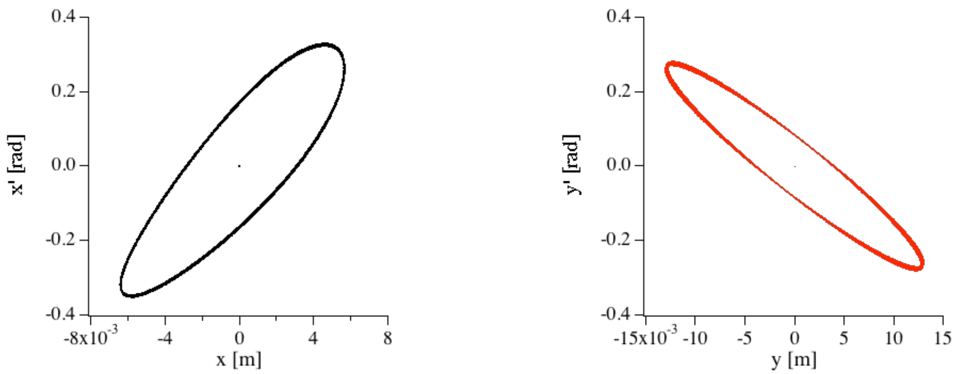
Muon acceleration in a muon collider (6)

acceptance of scaling FFAG

- Dynamic aperture (100 turns) is more than 10 π mm.
  - at 50 GeV



  - at 400 GeV



Muon acceleration in a muon collider (7)

possible choice of high energy muon accelerator

- 400 to 2000 GeV

MV/m	%	ms
1	78	5.3
2	89	2.7

- Linear nonscaling FFAG
  - Limit of *pf/pi*=2 means at least 2 or 3 rings.
  - Make sure it is not a “resonance regime”.

- Pulsed magnet synchrotron
  - A few ms acceleration time.
- Scaling or nonlinear nonscaling (chromaticity corrected) FFAG
  - Wider range of *pf/pi*
  - No constraint on the rf frequency, can be low such as MHz.

Muon acceleration in a muon collider (8)

summary

- Some requirements are the same, and some are different.
  - Necessary rf field gradient is the same (tha same sort of R&D).
  - Acceptance is much smaller: similar to an ordinary proton one.
  - No constraint on rf frequency (Palmer’s high emittance option).

- Scaling or nonlinear nonscaling FFAG for medium and high accelerator.
  - Large momentum range (*pf/pi*) is one of advantages.

- Pulsed magnet synchrotron.
  - Possibly for high energy accelerator.

Summary

- Accelerator chain for neutrino factory is pretty much optimized.
- Nonscaling FFAG with chromaticity correction mitigates the phase slip problem.
- Scaling or nonlinear nonscaling FFAG can be an alternative option to RLA for muon collider.
- Pulsed magnet synchrotron can be an option of High energy muon accelerator (>400 GeV).

Democratic choice?

• Linac:	0.2 to 0.9 GeV
• Recirculating Linac (RLA):	0.9 to 12.6 GeV
• Linear nonscaling FFAG:	12.5 to 50 GeV
• Scaling FFAG:	50 to 400 GeV
• Pulsed magnet synchrotron:	400 to 2000 GeV

Maybe a good starting point because we cannot think of more variety.