Acceleration System Comparisons

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Glossary

- Scheme
  - Whole accelerator chain, e.g. US scheme.
- Scenario
  - Same as scheme

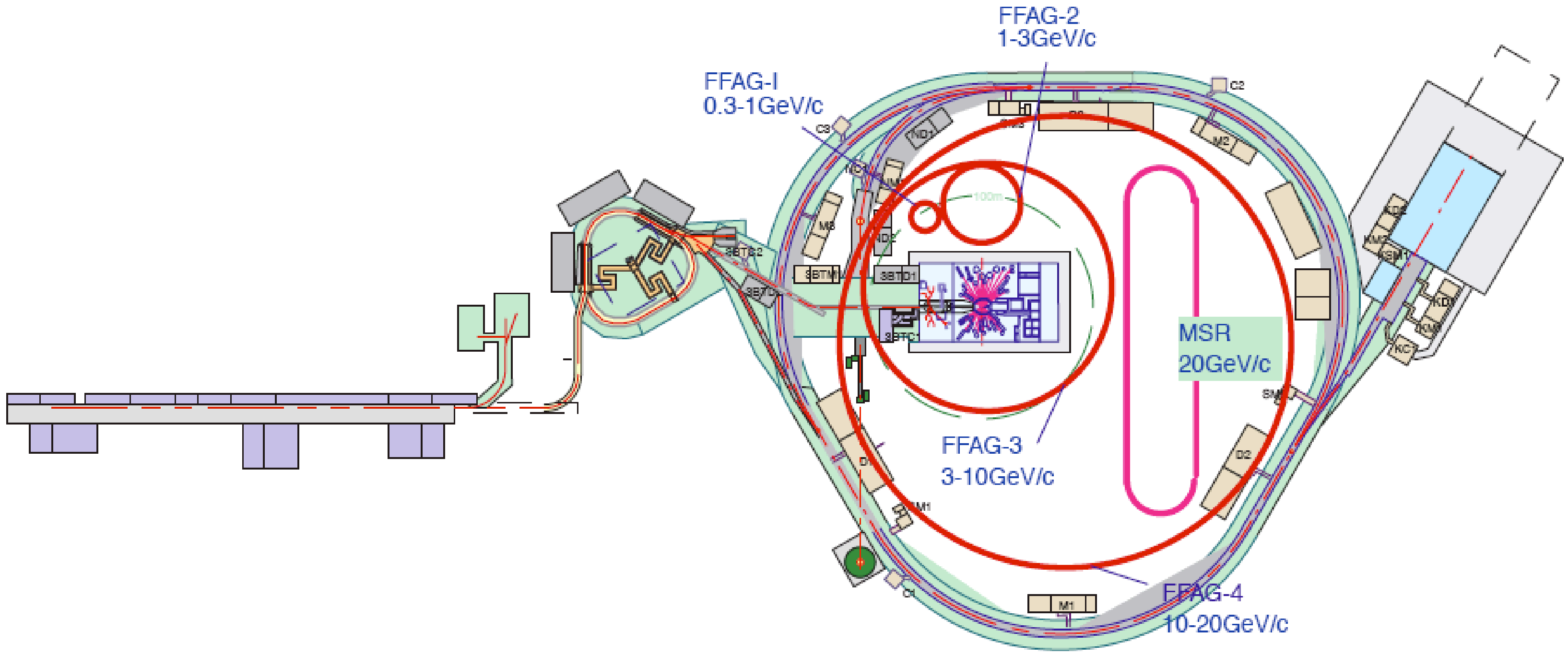
- System
  - Each component, e.g. non-scaling FFAG.
- Machine
  - Same as system

Contents

- Four major schemes
- System assumed
- Items compared
- Design progress and R&Ds
- Summary

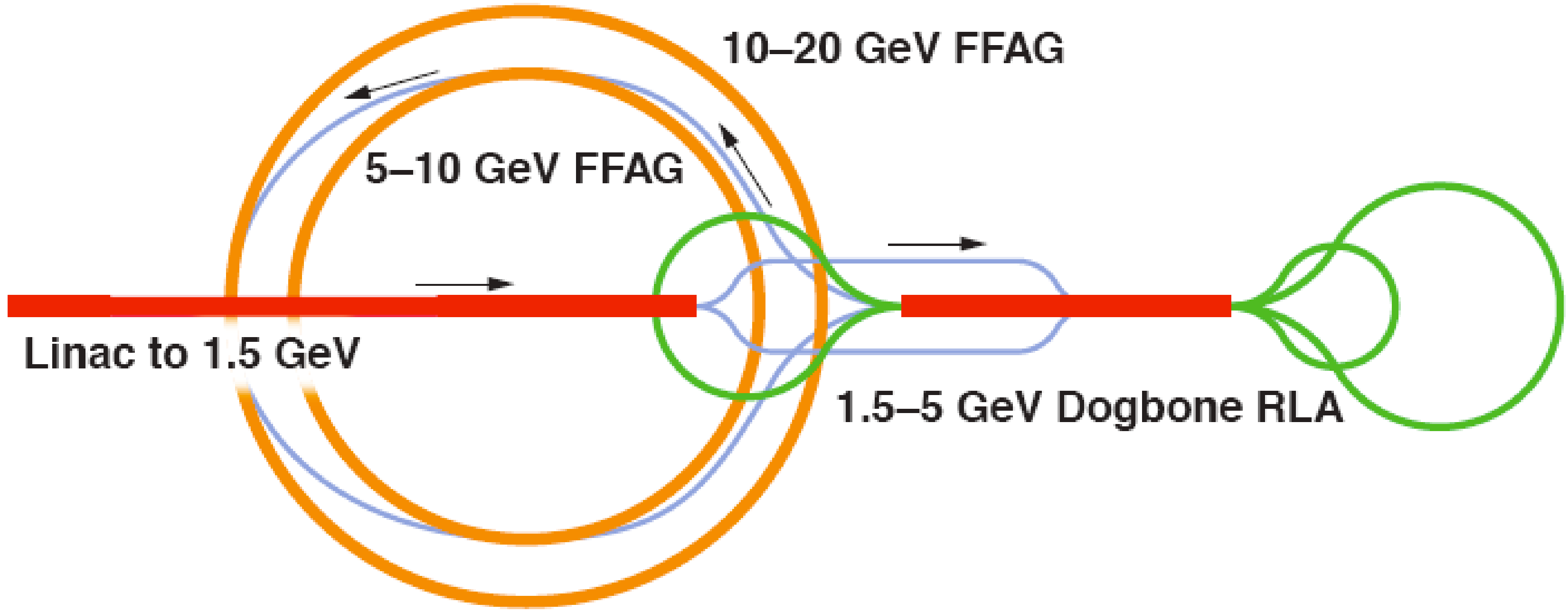
Four major schemes

Four major schemes (NuFactJ)



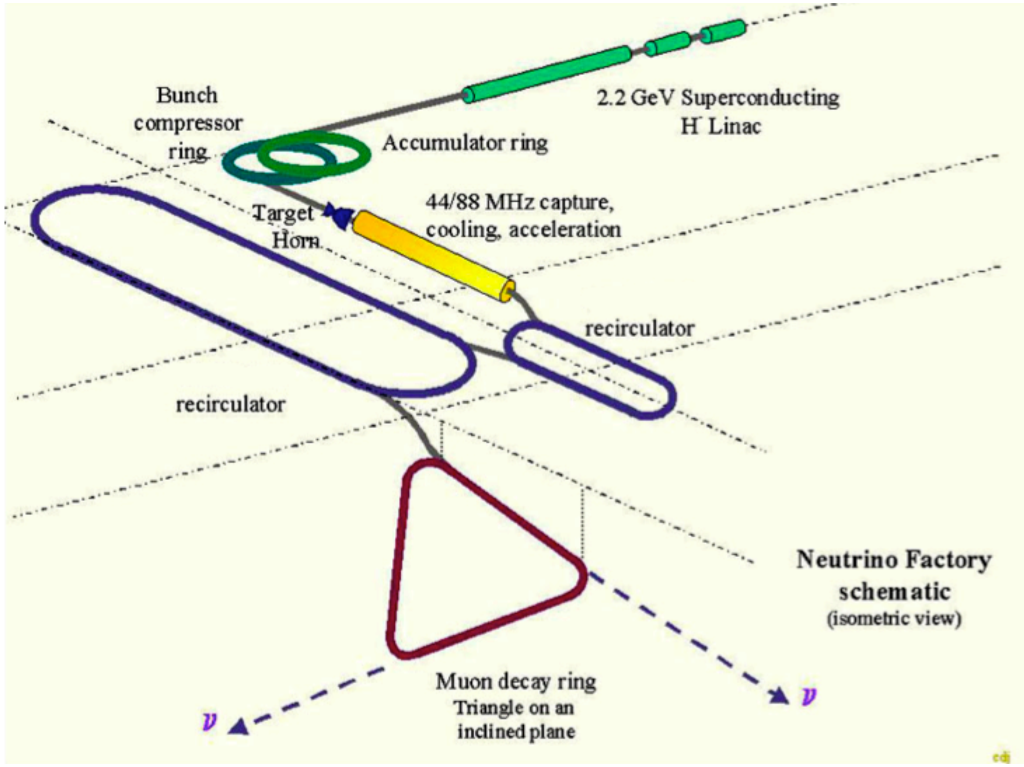
- J-Parc as a proton driver.
- Four scaling FFAG accelerate muons from 0.3 to 20 GeV.
- No bunching, no phase rotation, and no cooling.
- Single muon bunch throughout the cycle.

Four major schemes (US Study IIa)



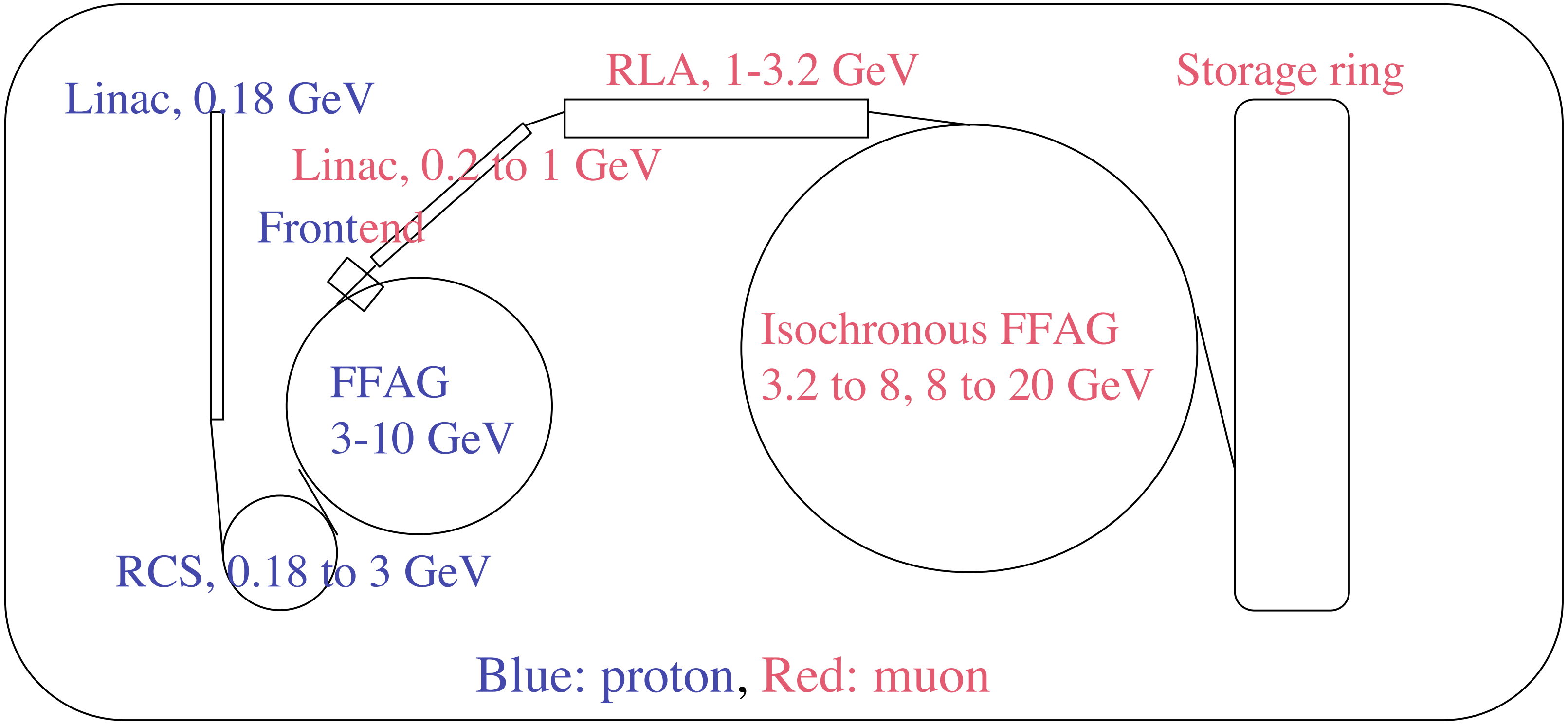
- AGS or Fermilab upgrade as a proton driver.
- Linac and RLA up to 5 GeV.
- Two non-scaling FFAG from 5 to 20 GeV.
- Bunching and cooling to create a multi bunches fit into 200 MHz RF.

Four major schemes (CERN NF)



- Linac and compressor ring as a proton driver.
- Linac and RLA up to the final muon energy.

Four major schemes (UK originated)



- Proton driver with FFAG.
- Linac and RLA up to 3.2 GeV.
- Two isochronous FFAG from 3.2 to 20 GeV in the same tunnel.
- RF frequency of IFFAGI can be any, pick up 200 MHz.

System assumed

System assumed (Linac and RLA)

- 201 MHz superconducting for both system.
- Arc for RLA.

System assumed (Scaling FFAG)

- Nonlinear field profile of r^k.
- Transverse tune is constant.
- Physical and dynamic aperture is supposed to be large.
- Orbit excursion is 0.1 to 0.5 m.
- Low frequency RF: 5 - 25 MHz.
  - Frequency modulation is possible.
  - or constant frequency to make stationary RF bucket.

System assumed (non-scaling FFAG)

- “linear” element only.
- Transverse tune varies, makes a resonance crossing.
- Physical and dynamic aperture is supposed to be large.
  - ICOOL results show 30 mm (normalized).
- Orbit excursion is tiny.
- High RF frequency: 201MHz.
  - Phase slippage is minimized.
  - “gutter” acceleration.

System assumed (Isochronous FFAG)

- Nonlinear field profile.
- Horizontal tune varies, but vertical tune is constant.
- Physical and dynamic aperture is being studied.
  - Study is most advanced.
- Long insertion for
  - Injection and extraction.
  - Collimation.
    - Constant tune in V make a collimator work though acceleration.
    - Beam loss is not small power.
- RF frequency can be any. It is 200 MHz at the moment.

System assumed (weekly non-isochronous and constant tune FFAG)

- Nonlinear field profile.
- Designed by Horst Schoenauer.
- RF frequency is 200 MHz.

Item compared

Item compared (transverse acceptance)

- Scaling FFAG has constant tune with nonlinear field profile.
- Non-scaling FFAG has linear field, but traverses many resonances.
- Isochronous FFAG has nonlinear field with constant tune in V and traverses resonance in H.
- How about RLA? Does Spr/Rec set some a limit on acceptance?

- **It is not clear which machine has the enough acceptance. Maybe all machines.**
- If collimator is necessary, the constant tune helps keep capture efficiency.

Item compared (transverse acceptance)

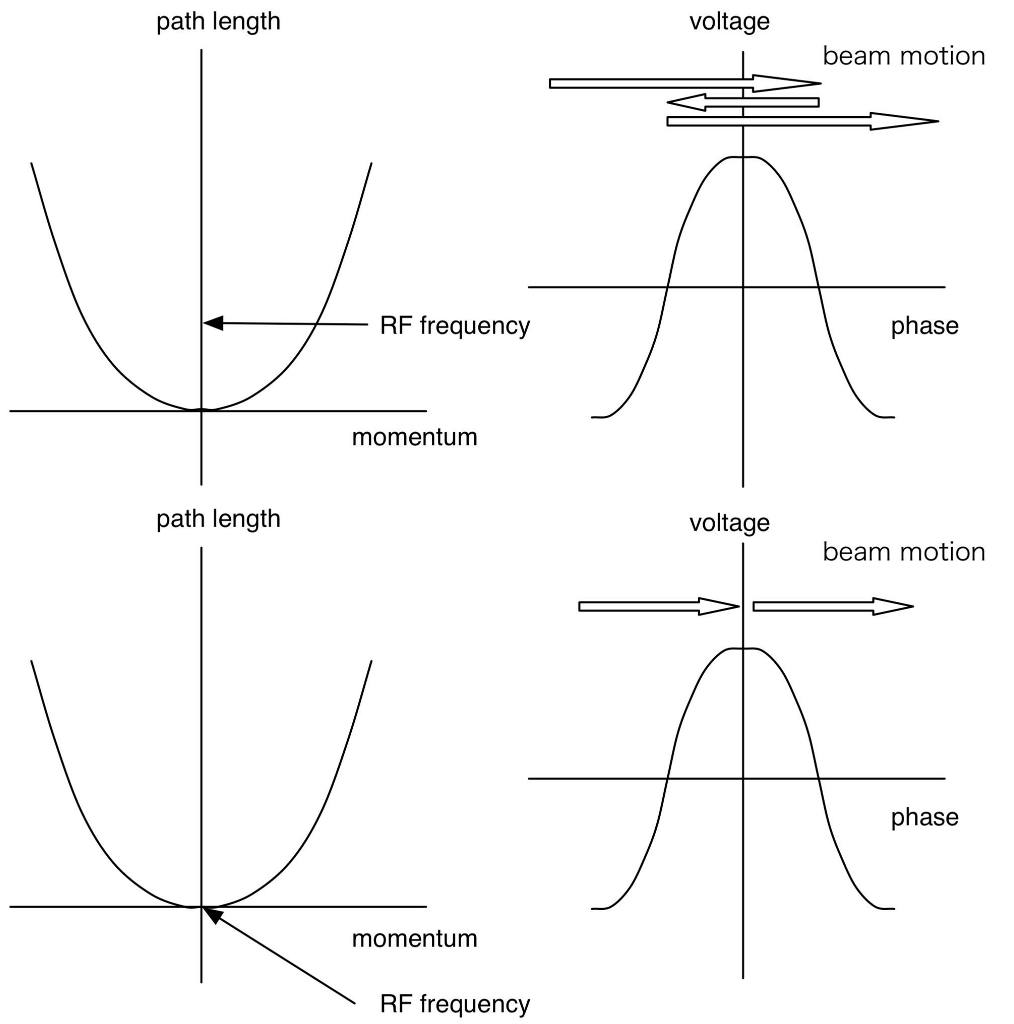
- Study exists, but we definitely need more.
  - Zgoubi for Isochronous FFAG.
  - ICOOL for non-scaling FFAG.
  - Runge-kutta integration for scaling FFAG
- Tools are available.
  - Zgoubi (Lemuet and Meot).
  - PTC and its offspring.
  - Runge-kutta integration.

- Different modeling of fringe fields.
- Misalignment, field tolerances, etc.

Item compared (way of acceleration)

- “gutter” acceleration.

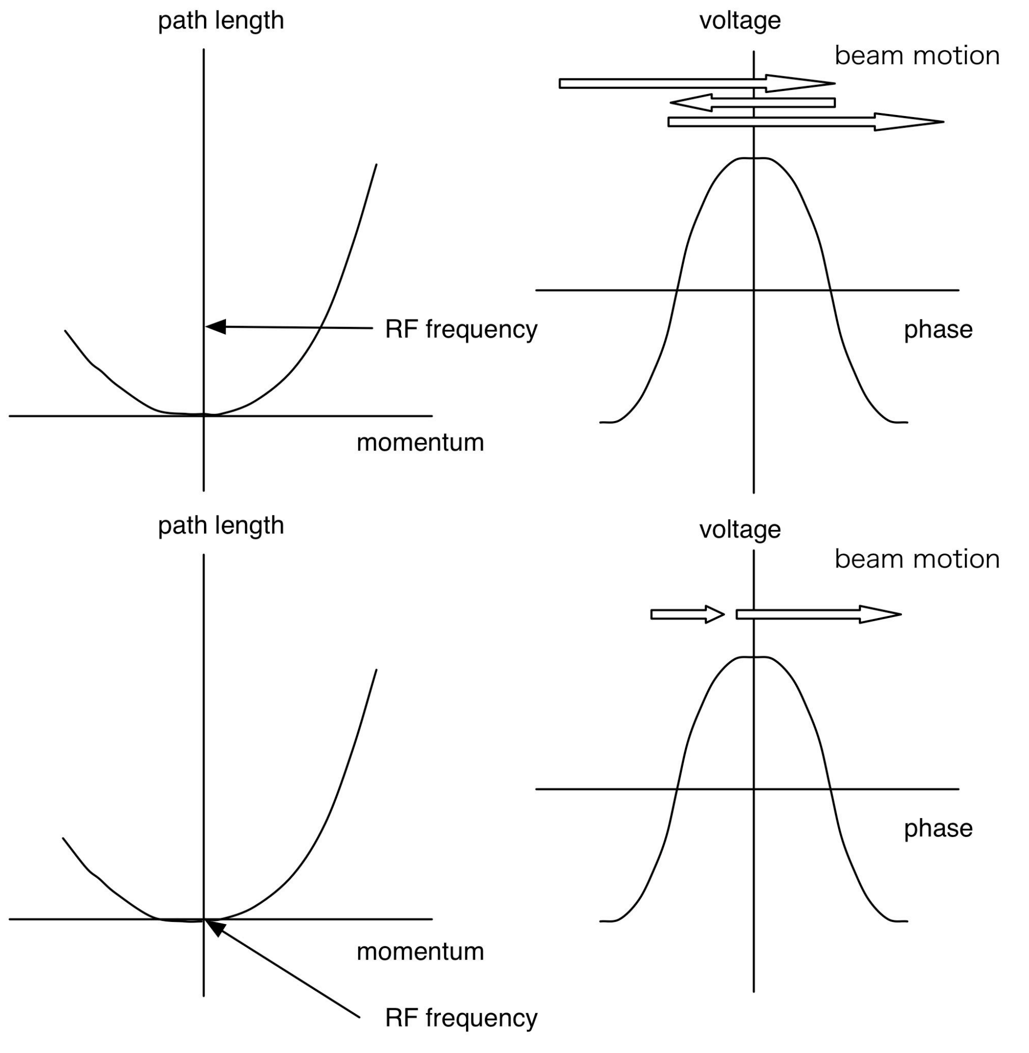
Depending of RF frequency, beam traverses crest once or three times.



Item compared (way of acceleration)

- Scaling FFAG with transition crossing.
  - 1st and 2nd FFAG have transition.

Similar scheme is possible at scaling FFAG with transition crossing.

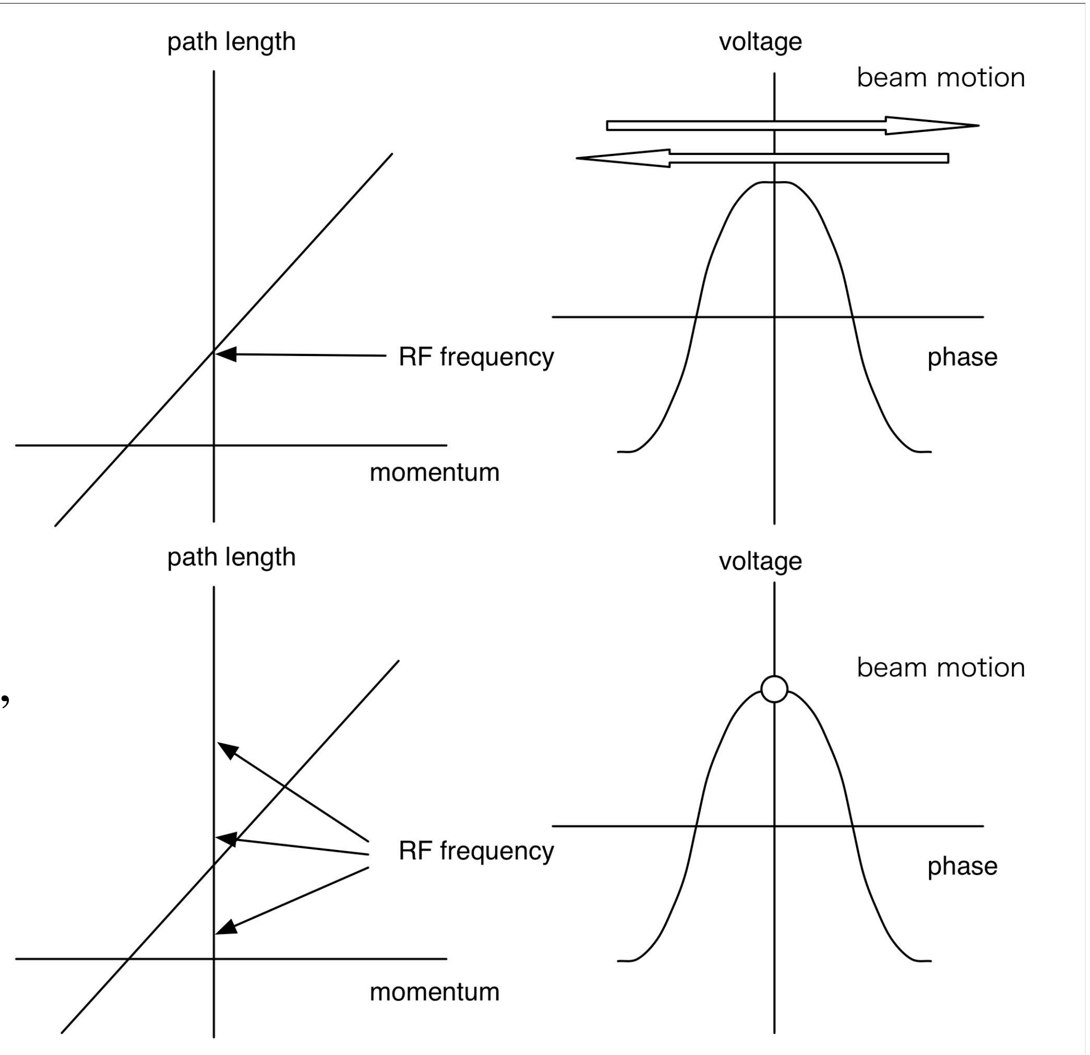


Item compared (way of acceleration)

- Scaling FFAG without transition crossing.
  - 3rd and 4th FFAG has no transition.

A beam traverses crest twice.

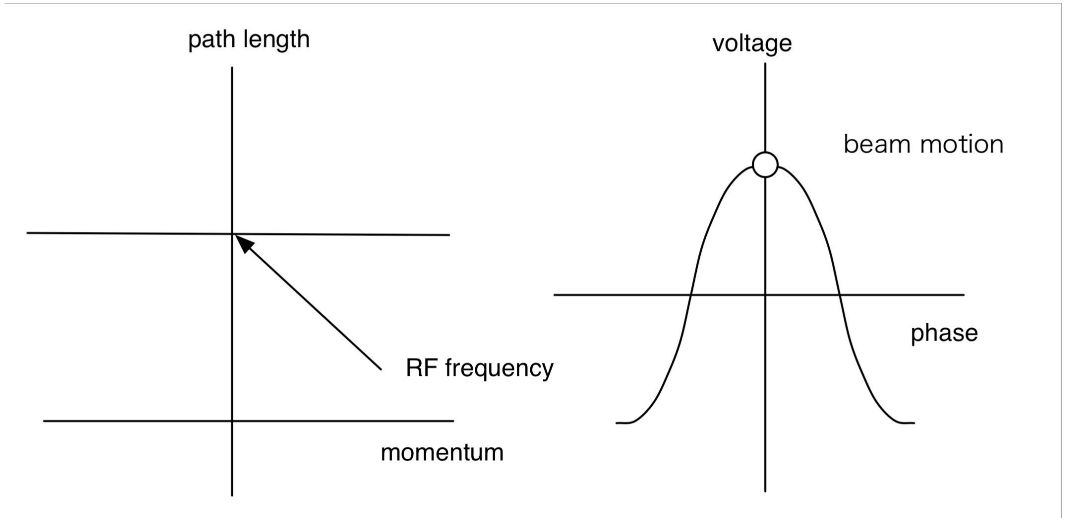
If RF frequency is modulated, a beam stay at crest.



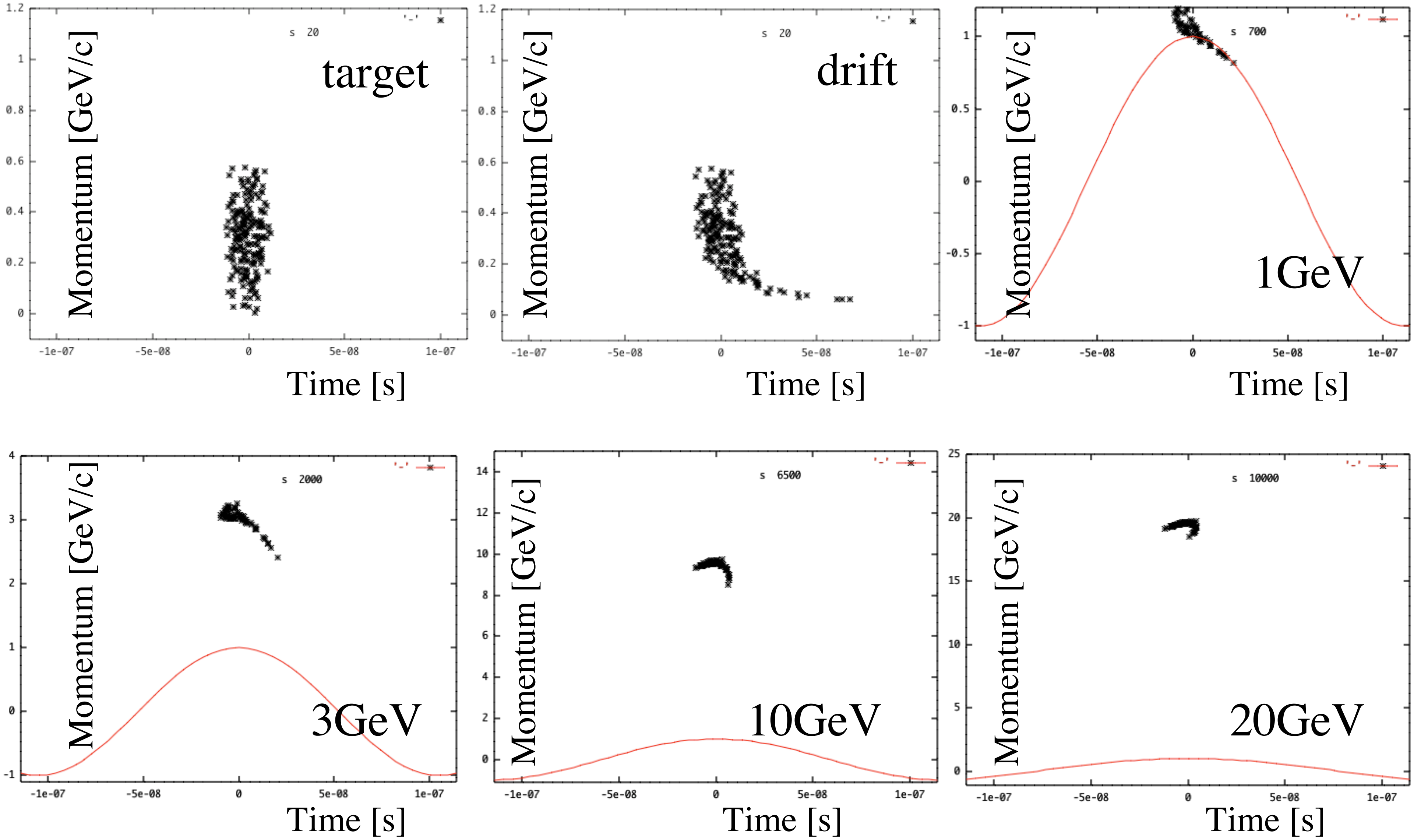
Item compared (way of acceleration)

- Isochronous FFAG

Beam stays at crest with
Constant RF frequency.



Item compared (way of acceleration, appendix)



Item compared (way of acceleration)

- In any system, phase slip of muons is small or zero.

- However, scaling FFAG has a bit larger phase slip so that high frequency RF system does not match.
- Instead, scaling FFAG has RF modulation, which is possible because of low frequency system.

- Non-scaling and isochronous FFAG can take any RF frequency in principle.

Item compared (RF frequency)

- Although gradient is higher with higher frequency, we need bunching and cooling section before acceleration.

- Frequency choice is independent of lattice. However, once linac (or RLA) is involved in the chains, high frequency is the only choice.
- NuFactJ is proposing frequency modulation during acceleration (~5 MHz).

Item compared (preceding system)

- Non-scaling FFAG
  - Assume high frequency, multi bunch structure, which is made by bunching, phase rotation, cooling, and linac (or RLA).
  - Momentum is around 0.3GeV, no more.
- Scaling FFAG
  - Direct capture of muon right after target.
  - Assume low frequency, single bunch structure.
  - Higher injection momentum is possible, and maybe preferable.

Item compared (magnet)

- Size
  - Non-scaling FFAG has the minimum orbit excursion.
  - Field index *k* determines orbit excursion in scaling FFAG.

- Maximum strength of field is 5 to 6 T in all system.

- How about field gradient?

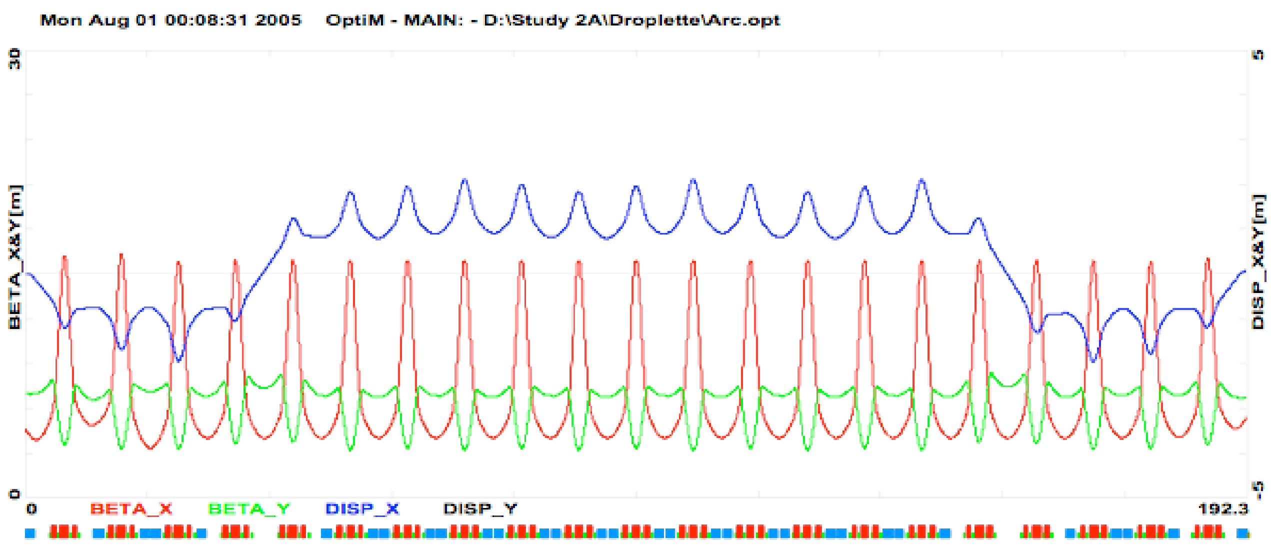
Item compared (cost)

- To be done.

Design progress and R&D

Design progress and R&D (Linac and RLA)

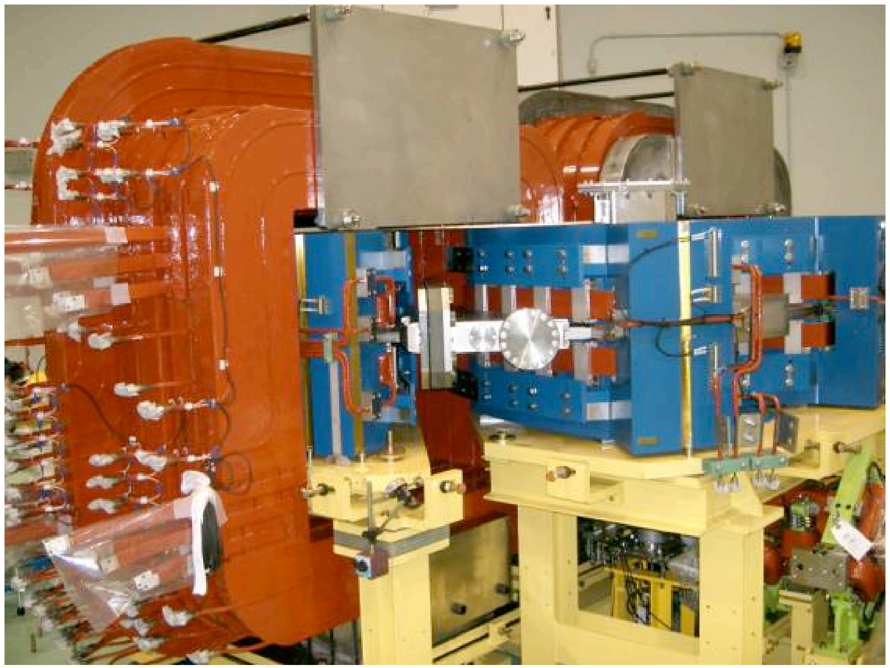
- Basic design is completed.
- Details can be found in an article of A. Bogacz.



Arc optics

Design progress and R&D (Scaling FFAG)

- POP FFAG was commissioned in 2000, 150 MeV FFAG is completed, and PRISM is under construction.
- Spiral FFAG at Kyoto Univ. accelerates a beam.
  - Crossing of integer resonance.
- Resonance crossing study in POP and HIMAC synchrotron.



Spiral FFAG from 0.1 to 2.5 MeV.

Design progress and R&D (low frequency RF)

- New version of MA (comparable to SY20)
  - Shunt impedance is 10 times higher.
  - Q value is 30 to 40. Frequency modulation is possible.

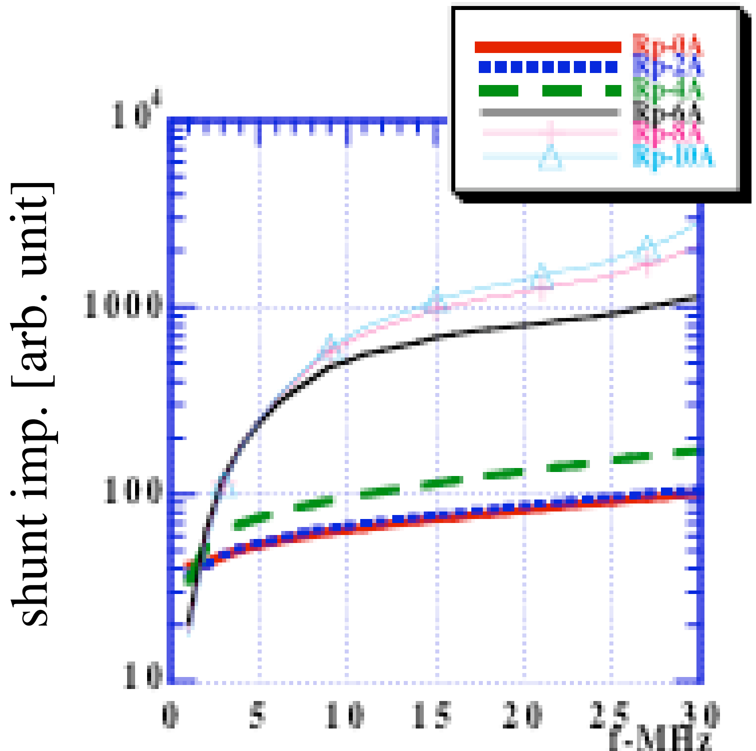


Fig.2 PF-Rp

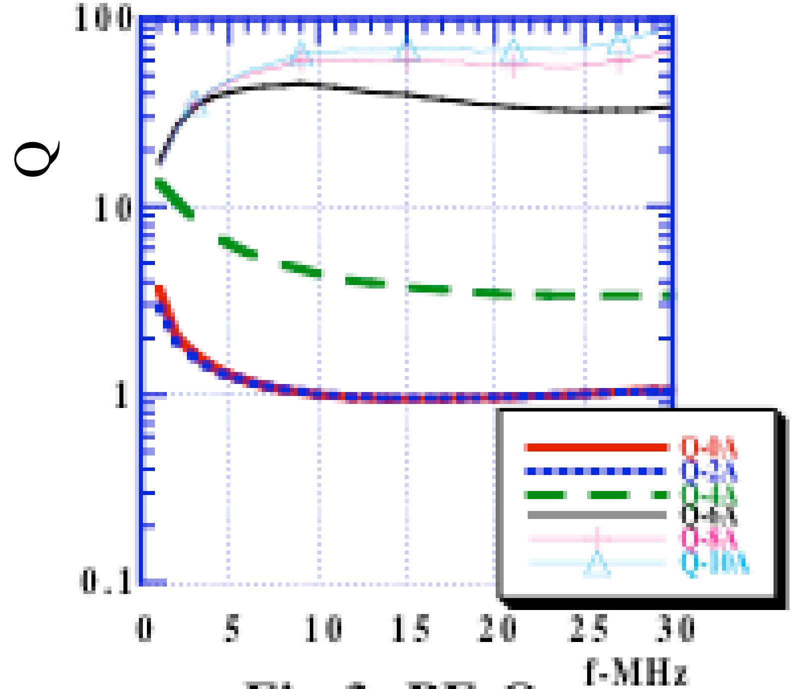
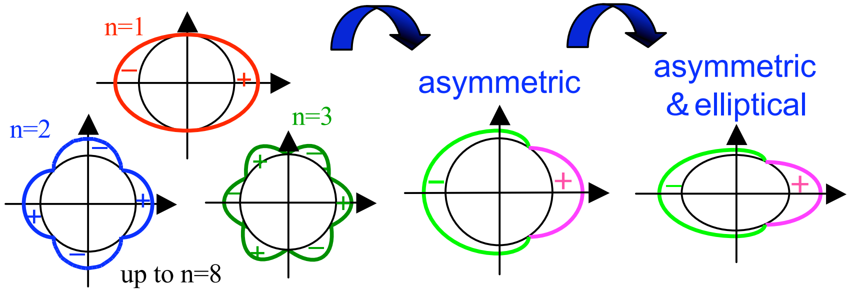
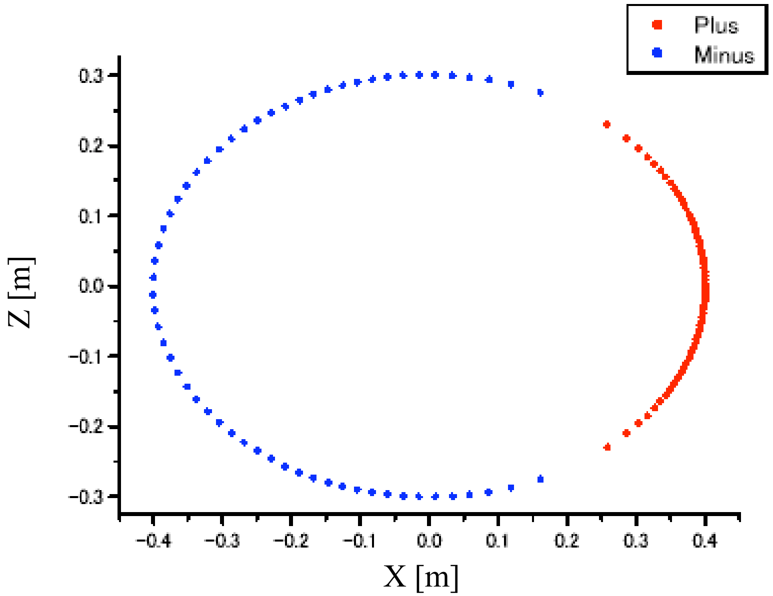


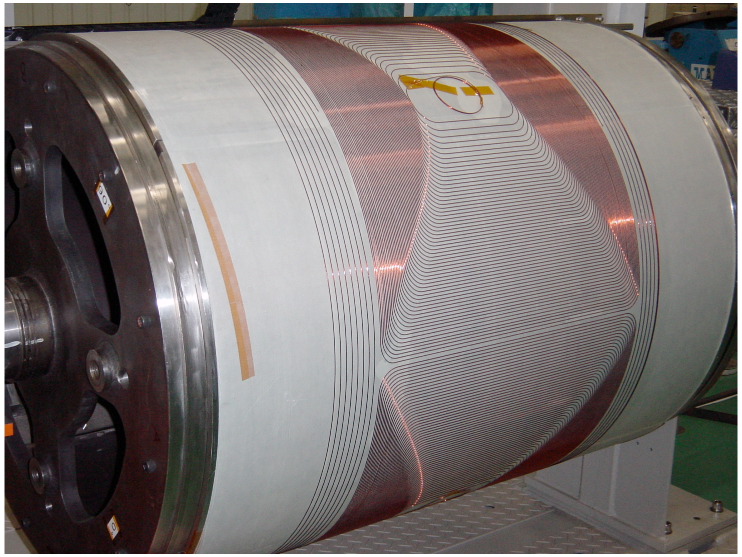
Fig.3 PF-Q

Design progress and R&D (Superconducting magnet)

- Fields for scaling FFAG.
- Model coil is made
  - ϕ 896 mm x 550 mm
  - NbTi/Cu, 0.9 mm





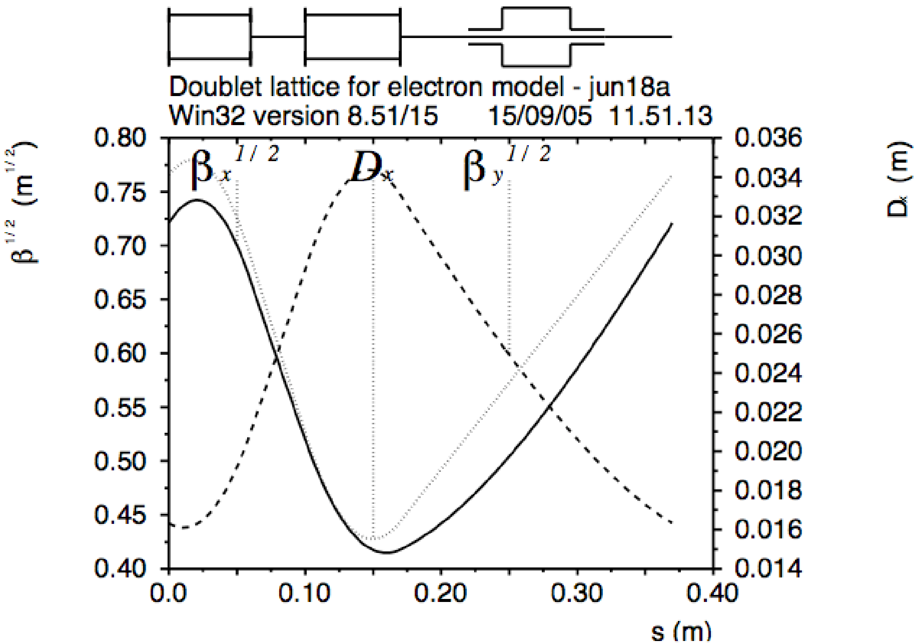


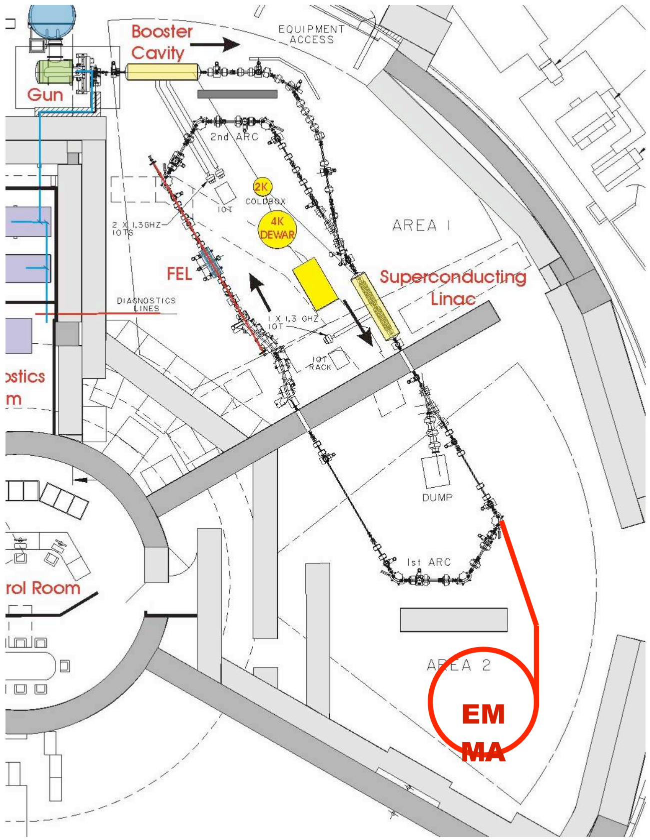
Design progress and R&D (non-scaling FFAG)

- Optimization study by S. Berg.
- Cost model by R. Palmer.
- Doublet lattice is chosen recently.

Design progress and R&D (non-scaling FFAG)

- EMMA
  - Choice of lattice is almost converged.
  - Hardware design is started.





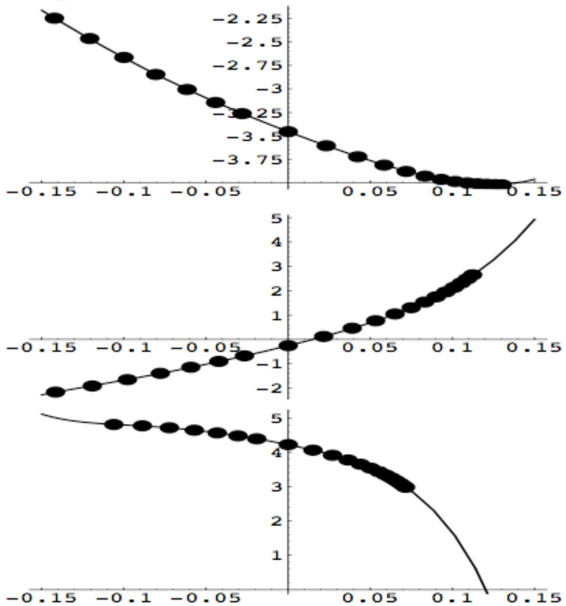
Design progress and R&D (high frequency RF)

- 201 MHz superconducting cavity

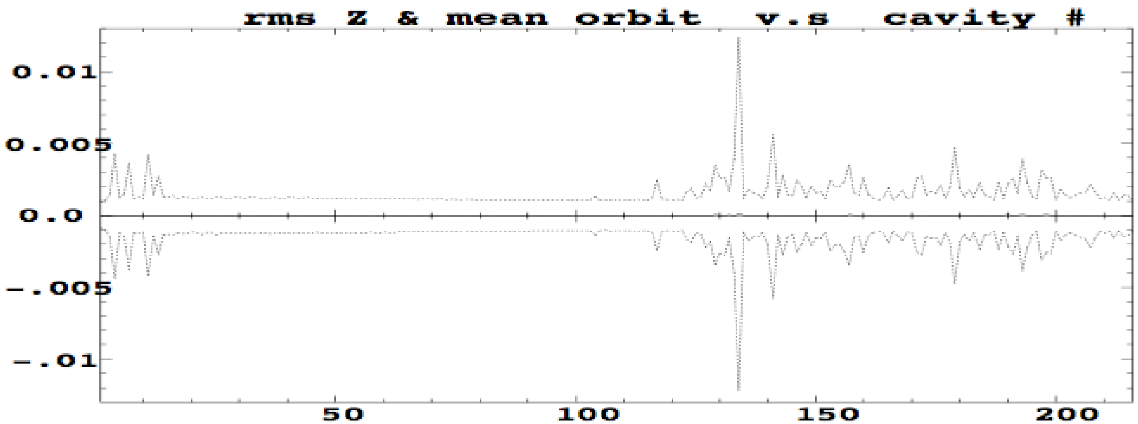
Design progress and R&D (Isochronous FFAG)

- Lattice design by G. Rees.
- Tracking by F. Lemuet and F. Meot.
  - New results will come soon.

Magnetic field in bd, BF and BD.



rms beam size from 8 GeV to 20 GeV :



Summary table

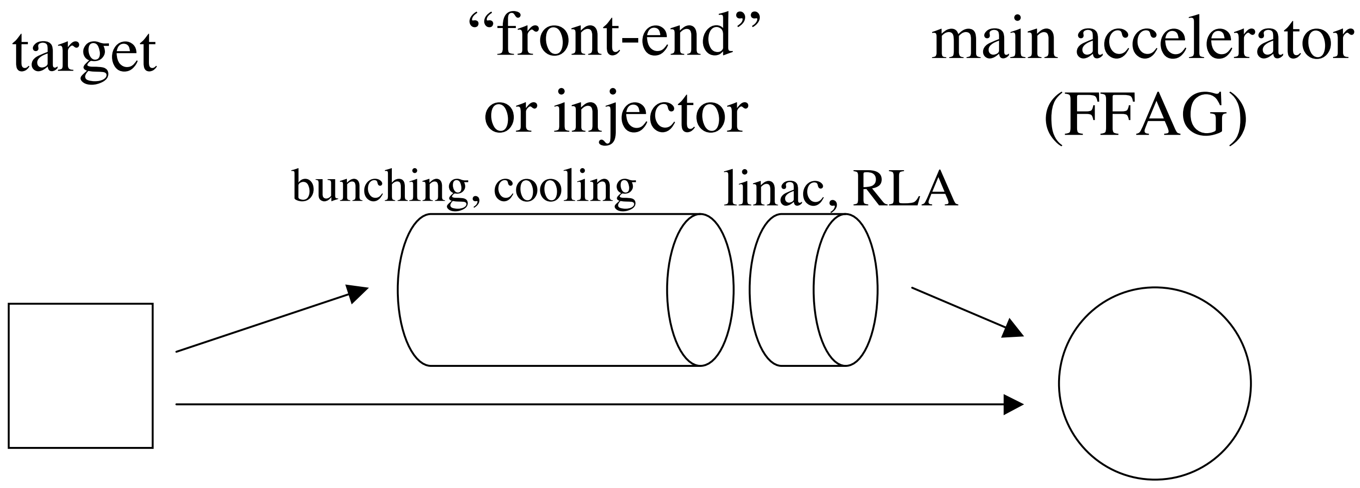
For high mometum			
	scaling	non-scaling	isochronous
acceptance	large	30 mm	being studied
way of acceleration	RF modulation or constant bucket	gutter	on RF crest
RF frequency	5-25 MHz	200 MHz	200 MHz
injection energy	3 GeV	5 GeV	3.2 GeV
R&D status	RF cavity SC magnet	RF cavity	

For low mometum		
	scaling	linac & RLA
acceptance	large	large
way of acceleration	RF modulation	RF bucket
RF frequency	5-10 MHz	200 MHz
injection energy	0.3-1 GeV	0.3 GeV
number of bunch	single	multi
requirement for front-end	directly from target	bunch, phase rotate and cooling

Concluding remarks

- System in high momentum (3 - 20 GeV) side is designed in detail and compared.
- One problem, at this point, is that each system design assumes a preceding system and is influenced.
- First and second stage of acceleration (up to 3 or 5 GeV) becomes a real issue, especially whether linac (or RLA) is the only choice and cost effective.

Another way of looking at acceleration scheme.



Linac and RLA should be categorized into "front-end".
Main accelerator is one of FFAGs.

Optimization process of main accelerator (FFAG) means

- Injection energy: How low can we accept?
- Acceptance: Is dynamic aperture enough? How much cooling?
- Way of acceleration: Gutter, on RF crest, or RF modulation?
- Frequency choice: Low(5-25MHz) or high(~200MHz)?
- Cost balance between "front-end" and main accelerator: Minimum requirement of front-end?