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LPSC, Grenoble

FFAG for muon acceleration
Summary of Monday's session

Contents

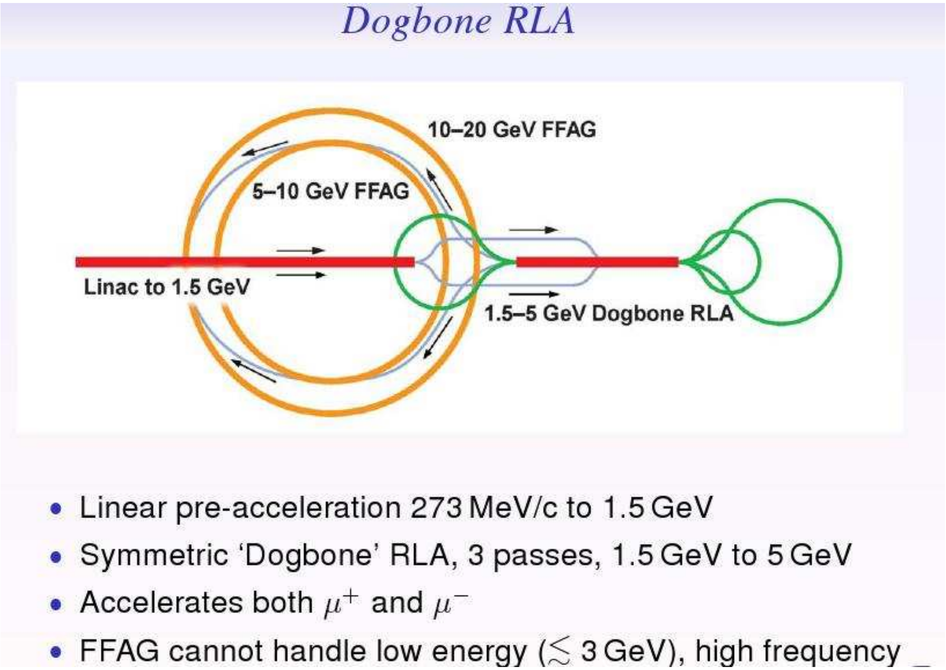
- **Hypothesis that motivate interest in FFAG method for the acceleration of muons :**
  - **possibility of obtaining requested 10^{21} μ decays / year in decay ring,**
    thanks to fast acceleration, more than 1 MV/m,
    and to large transverse acceptance, 3 πcm
  - **at cost potentially lower than RLA**

1 The ISS for a NuFact - C. Prior

- A status of ISS as of RAL 24 - 28 April, from proton driver to muon decay ring.

The two muon acceleration schemes of concern : linear FFAGs / scaling FFAGs

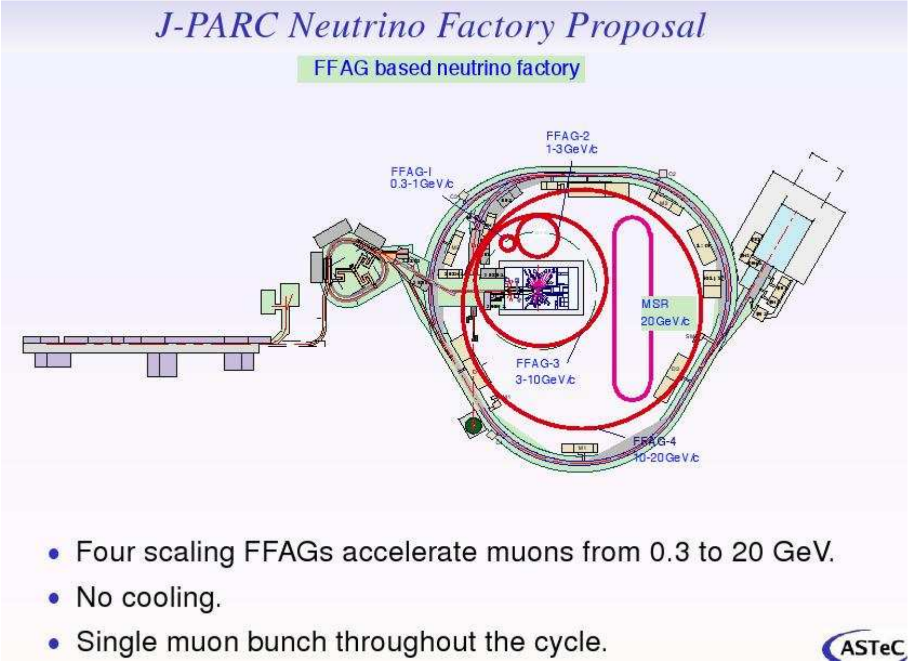
US Study 2a



Dogbone RLA

- Linear pre-acceleration 273 MeV/c to 1.5 GeV
- Symmetric 'Dogbone' RLA, 3 passes, 1.5 GeV to 5 GeV
- Accelerates both μ^+ and μ^-
- FFAG cannot handle low energy ($\lesssim$ 3 GeV), high frequency

Japan NuFact



J-PARC Neutrino Factory Proposal

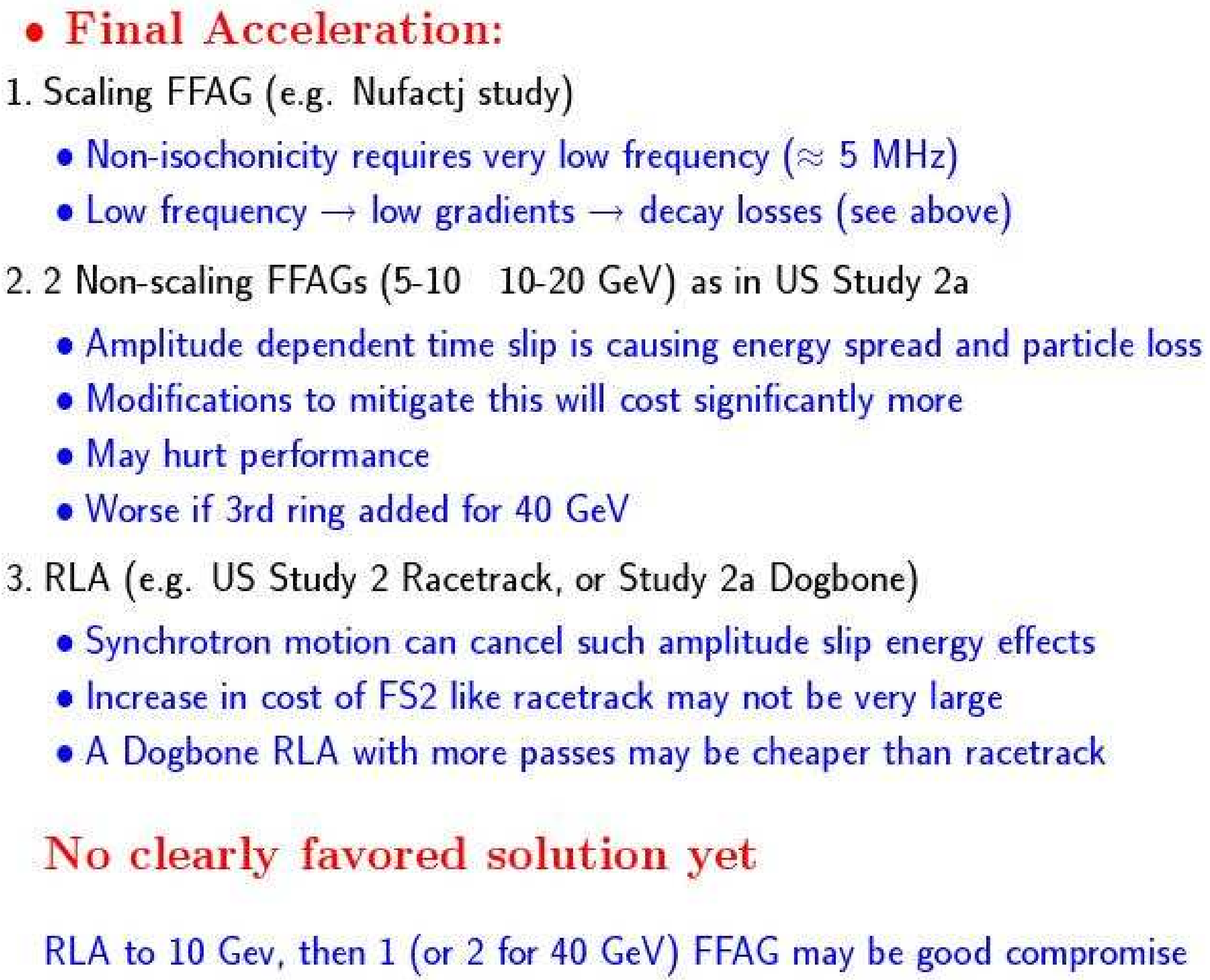
FFAG based neutrino factory

- Four scaling FFAGs accelerate muons from 0.3 to 20 GeV.
- No cooling.
- Single muon bunch throughout the cycle.

Goals of the ISS accelerator study

- Study alternative configurations
- Arrive at baseline specifications for a system to pursue
- Develop and validate tools for end-to-end simulations of alternative facility concepts
- Compare the different schemes on equal footing (RLA, FFAGs)
- Prepare scenarios for different values of acceptance
- Matching between accelerator
- Carry out cost evaluation
- Develop R&D list as we proceed

- B Palmer's views of present status of the



- **Final Acceleration:**

1. Scaling FFAG (e.g. Nufactj study)
   - Non-isochonicity requires very low frequency (≈ 5 MHz)
   - Low frequency → low gradients → decay losses (see above)
2. 2 Non-scaling FFAGs (5-10 10-20 GeV) as in US Study 2a
   - Amplitude dependent time slip is causing energy spread and particle loss
   - Modifications to mitigate this will cost significantly more
   - May hurt performance
   - Worse if 3rd ring added for 40 GeV
3. RLA (e.g. US Study 2 Racetrack, or Study 2a Dogbone)
   - Synchrotron motion can cancel such amplitude slip energy effects
   - Increase in cost of FS2 like racetrack may not be very large
   - A Dogbone RLA with more passes may be cheaper than racetrack

No clearly favored solution yet

RLA to 10 Gev, then 1 (or 2 for 40 GeV) FFAG may be good compromise

EMMA

“Electron Model for Muon Acceleration”

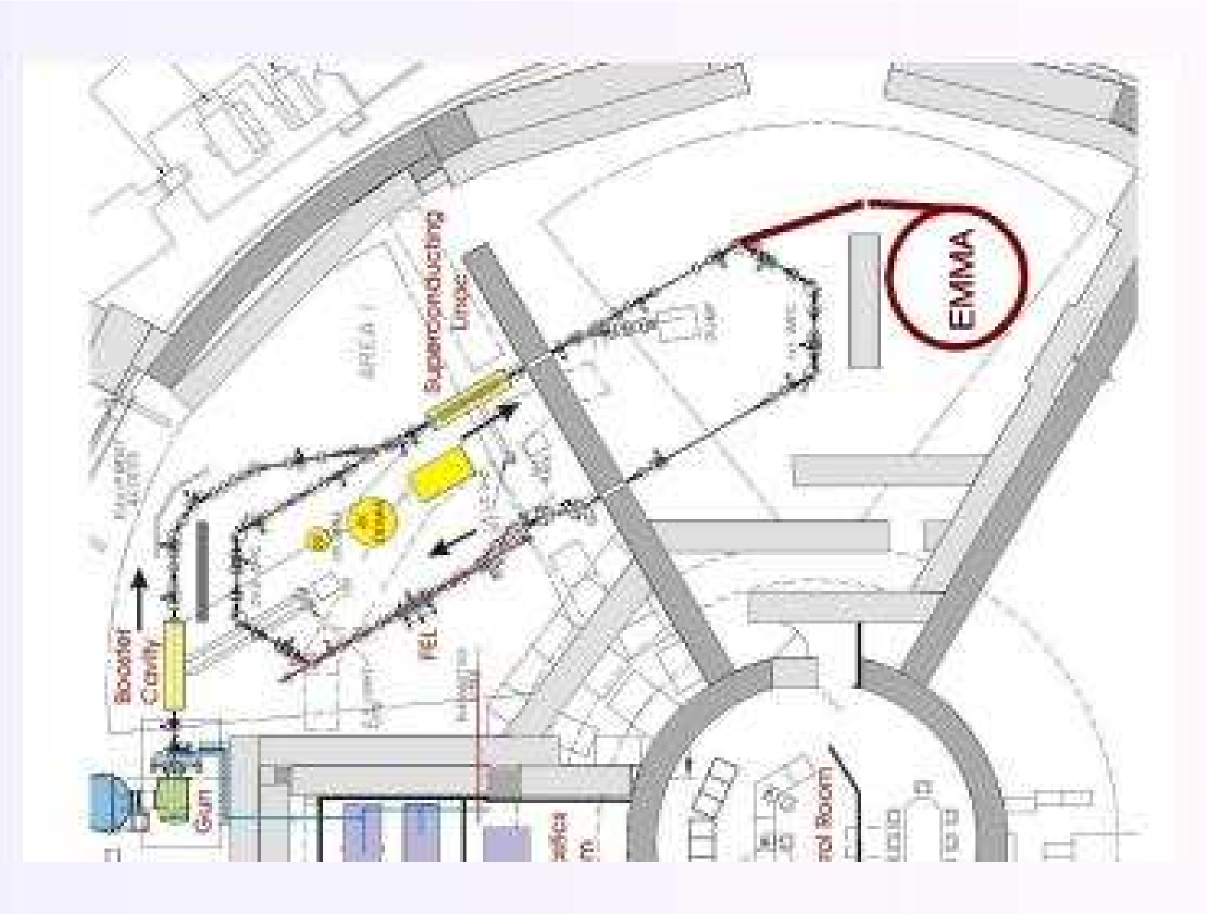
- UK proposes construction of a POP machine at Daresbury.

EMMA folks now looking for fundings in UK.

- Good progress in design study,

including status about every 2 weeks - phonemeetings

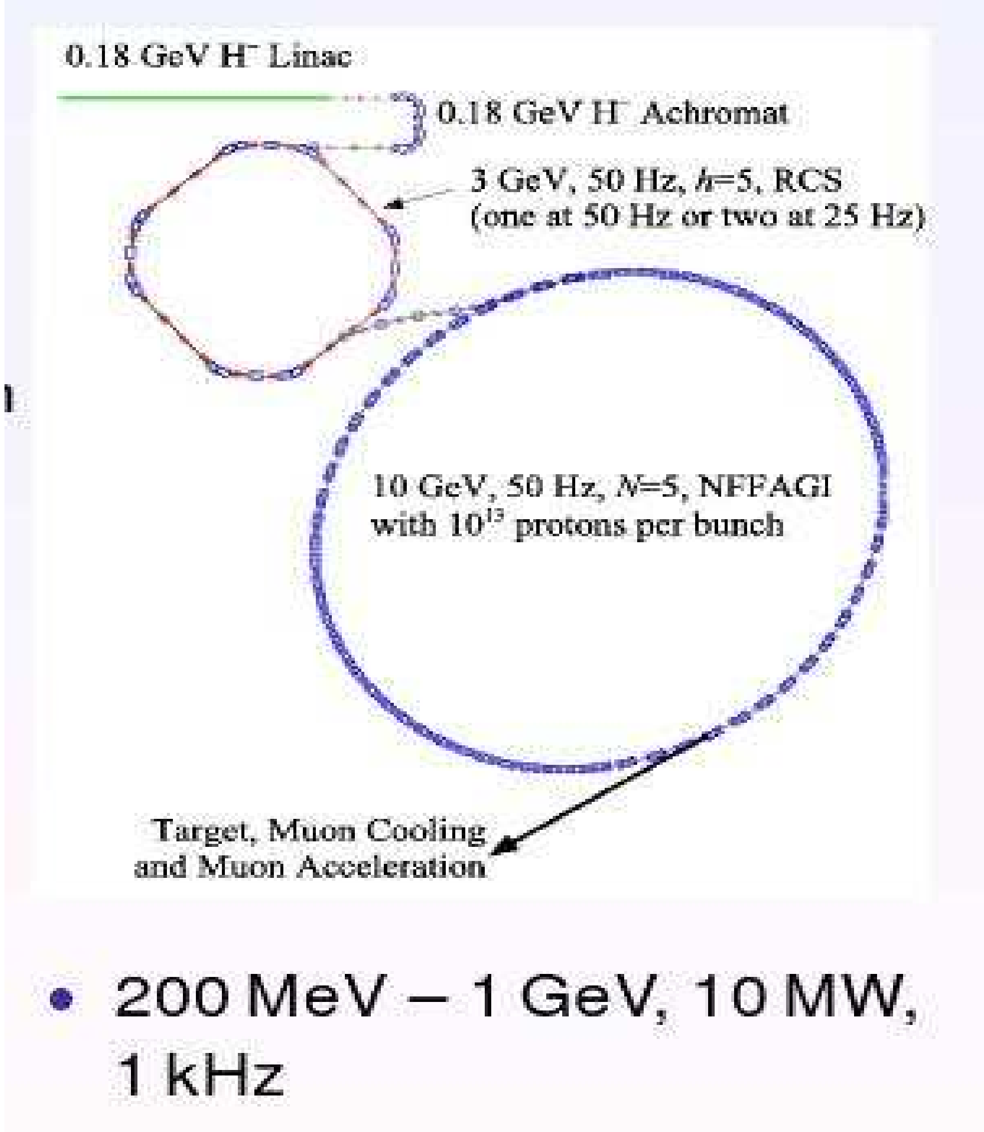
- Progress in magnet studies (FNAL, Daresbury), costing of POP (Daresbury)



Without forgetting that,

- muon production starts with a proton driver,

a version of which has been proposed (and for muons as well !),
which uses a 1 GeV FFAG based on a non-linear lattice, with constant tunes, of the “pumplet” type.

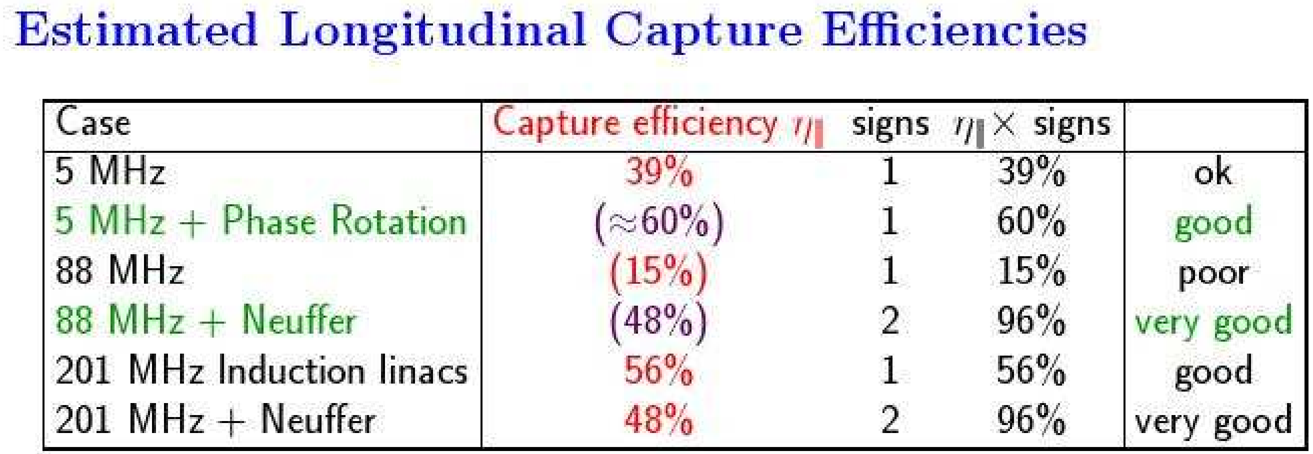


- 200 MeV – 1 GeV, 10 MW, 1 kHz

ISS decision on acceleration

- No decision yet

- Discussion on



Estimated Longitudinal Capture Efficiencies

Case	Capture efficiency $\eta_\parallel$	signs	$\eta_\parallel \times$ signs	
5 MHz	39%	1	39%	ok
5 MHz + Phase Rotation	(≈60%)	1	60%	good
88 MHz	(15%)	1	15%	poor
88 MHz + Neuffer	(48%)	2	96%	very good
201 MHz Induction linacs	56%	1	56%	good
201 MHz + Neuffer	48%	2	96%	very good

Comparable efficiencies for one-sign captures,
raise the question of the necessity / cost of two-sign capture.

2 Status of FFAG for muons - J. S. Berg

- Scaling FFAGs
  - NuFact-Japan scheme as it exists seems expensive.
  - Need to get optimized, need to provide trackable lattices (capture / transmission) for all rings
  - Need to understand costing of low-frequency RF
  - Study on the use of high gradients : seems difficult, scaling scheme is forced to low frequency
  - Plans to assess application of the “harmonic jump” technic
- Isochronous FFAGs
  - Initial lattice has poor DA ($<$0.1 cm)
  - Yet, plans for lattice with insertions and less chromaticity
- Linear FFAG
  - Problem with TOF dependence on transverse amplitude.

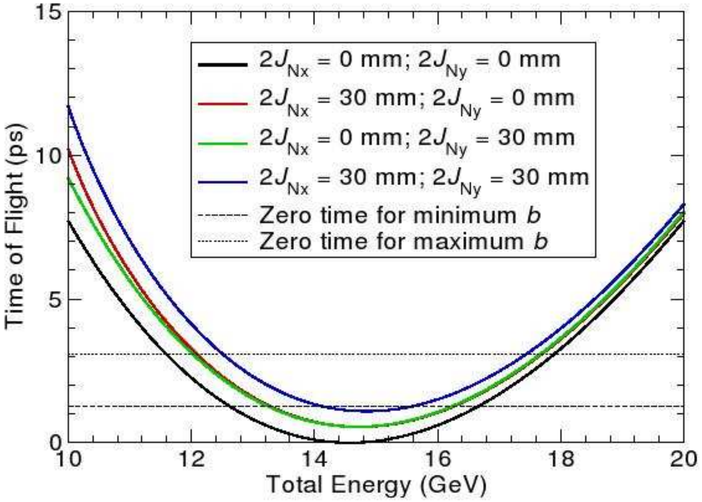
TOF spread is large, and longer for larger amplitude, a problem for matching to next stage.

- Tentatives to improve dT/dA by low dose of several ingrdients :

  * introduce small amount of sextupole to correct chromaticity

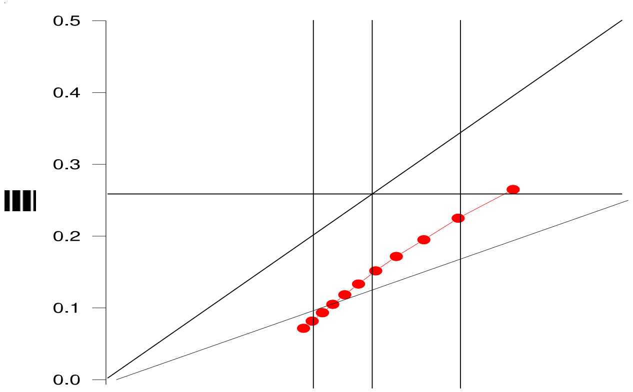
  * introduce RF harmonic

  * higher RF voltage.
- Cost will be higher than originally envisioned
- May lead to avoid FFAGs at low energy

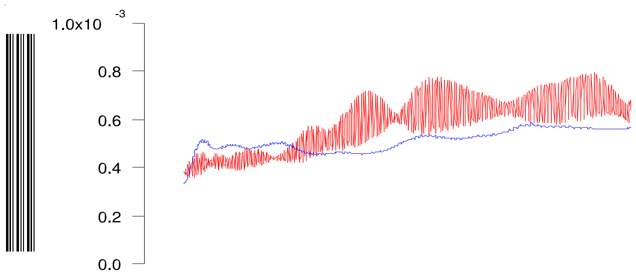


3 BD issues of linear FFAGs - S. Machida

- An exposé of a large variety of BD effects - as mentioned previously - in view of improving bunch behavior in the course of acceleration in the 5-10 and 10-20 GeV linear rings.
  - (i) Resonance crossing effects :



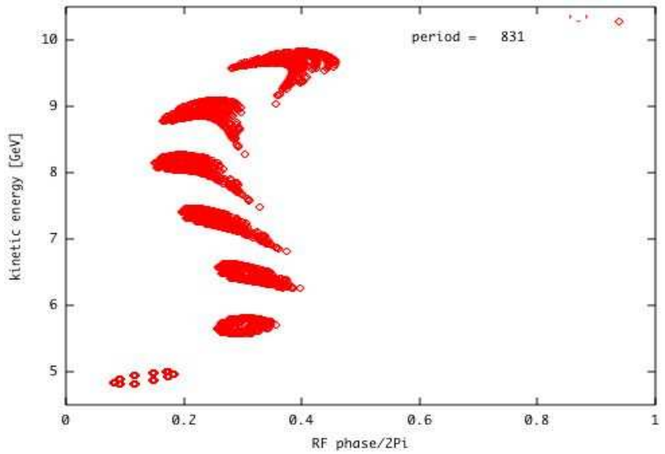
- Crossing of structure resonances (Qx = 2 Qy), harmful in presence of vertical amplitude



- Crossing of integer resonances, harmful in presence of alignement defects.
  This imposes the upper limit of alignment and gradient errors.

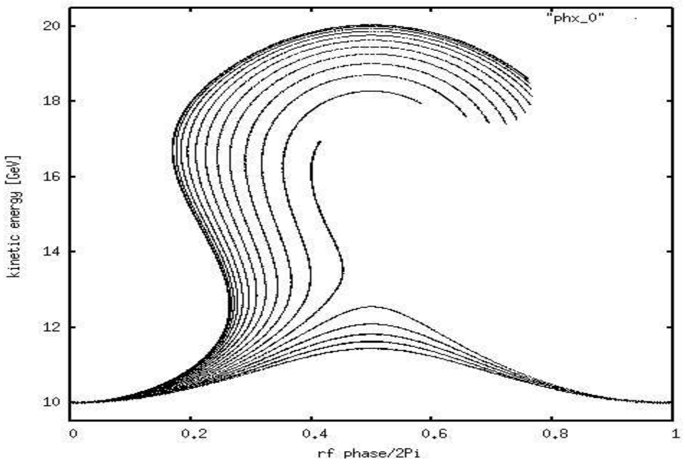
- (ii) Acceleration with large transverse amplitude,

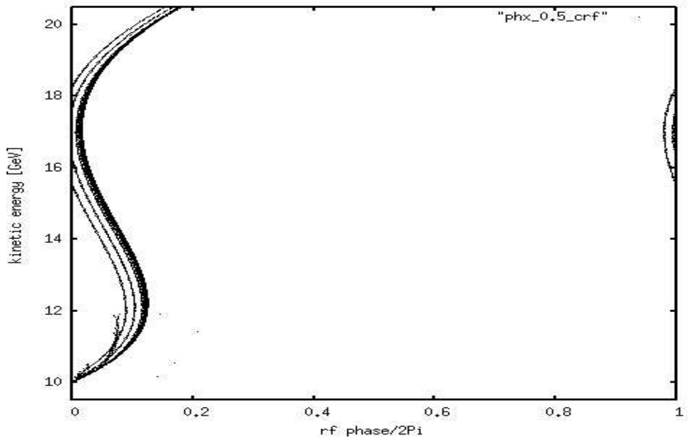
  possible cures : increase voltage, decrease RF frequency, flattten RF wave by harmonic.



* All these ingredients have positive effects on amplitude effects, however all at the expense of more RF voltage.

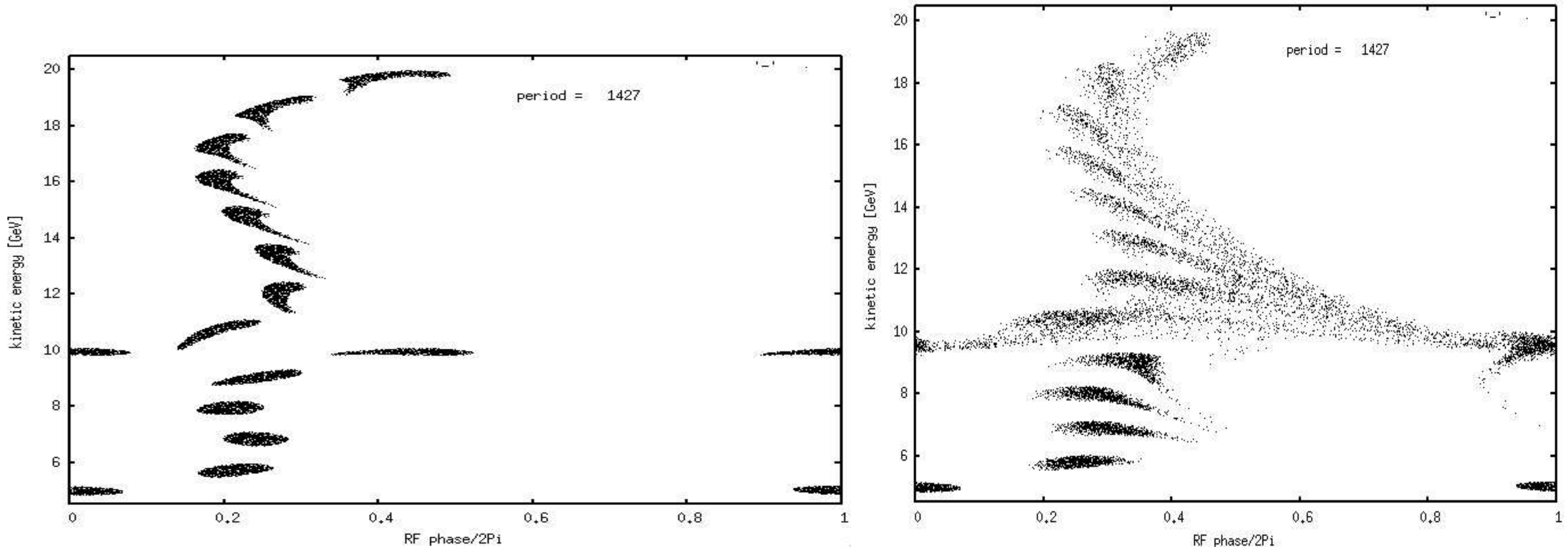
- (iii) Sextupole correction to dT/dA (proportional to ξ)





  - Sextupole reduces time of flight variation with transverse amplitude.
  - There is reduction of dynamic aperture with sextupole.

- (iv) Matching from upstream FFAG to downstream one.



Good behavior in case of zero transverse emittances

Strong distorsions at full emittance

- Possible cures under study

4 Status of computer codes - F. Méot

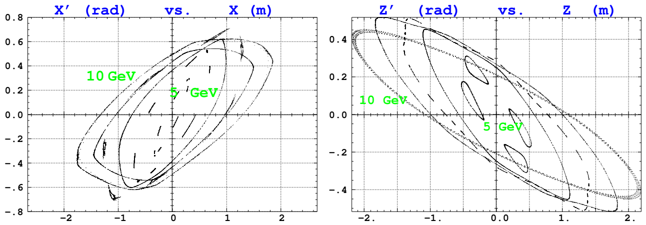
DA's of concern - orders of magnitude

- **DA's to explore are large, possibly *very* large - requires high precision codes.**

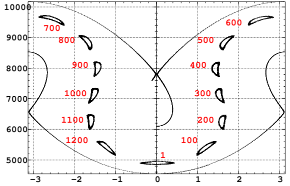
Linear, non-scaling

FD doublet

Muon :
$\gg 3\pi$cm norm.



$> 0.5\ \pi$eV.s



EMMA (electron) :
$\gg$200-300 πmm.mrad norm.

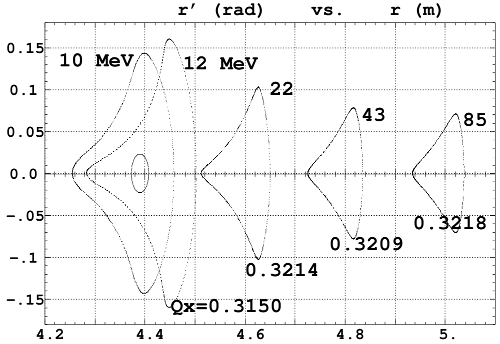
Proton :
10s πmm.mrad norm.

Non-linear, scaling

DFD triplet, doublet, spiral

$0.3-20$ GeV muon :
$> 3\pi$cm norm., $1.5\ \pi$eV.s

Proton :
10s πmm.mrad norm.



Non-linear, non scaling

Pumplet lattice

$8-20$ GeV muon
isochronous
$\approx \pi$cm norm. $-0.5\ \pi$eV.s

p-Driver :
10s πmm.mrad norm.

electron model :
100-300 πmm.mrad norm.

Adjusted field profile
p apps.,
10s πmm.mrad norm.

Codes known to (or to have) handle(-d) FFAG problems

code	seen in company of (sort of POP)	allows FF overlap	allows field map	has performed 6-D tracking
COSY	linear FFAG			no
ICOOL	muon ; scaling DFD	yes	yes	yes
MAD-PTC	muon, EMMA		no	linear FFAG
J-RK4	typical of J R&D		yes	yes
S	linear ; scaling		yes	yes
Zgoubi	all types of FFAGs	yes	yes	all types
. . .				
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Probably needs completion

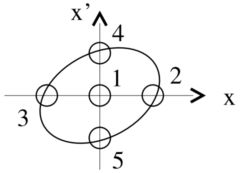
Comparisons between codes

S / Zgoubi comparison (1)

Time of flight in muon linear FFAG.

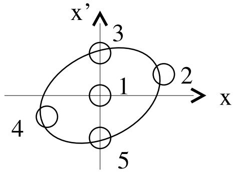
Time of flight of 30 π mm particles per turn

Zgoubi



PID	Trev	ΔTrev
1	.964504	
2	.964807	.000303
3	.964819	.000315
4	.964813	.000309
5	.964804	.000303

S-code



PID	Trev (μs)	ΔTrev
1	.950106	
2	.950416	.000310
3	.950406	.000300
4	.950398	.000292
5	.950394	.000288

(Tentative) conclusions

- **We dispose of three-four 6D-LAT codes**
- **It's probably enough, it's not too much, the difficulty of the FFAG problem deserves it**
- **Carry on cross checks**
- **Carry on upgrade of codes and optics libraries**