Activities in UK
collection of other people's presentations

Shinji Machida
STFC/ASTeC/RAL

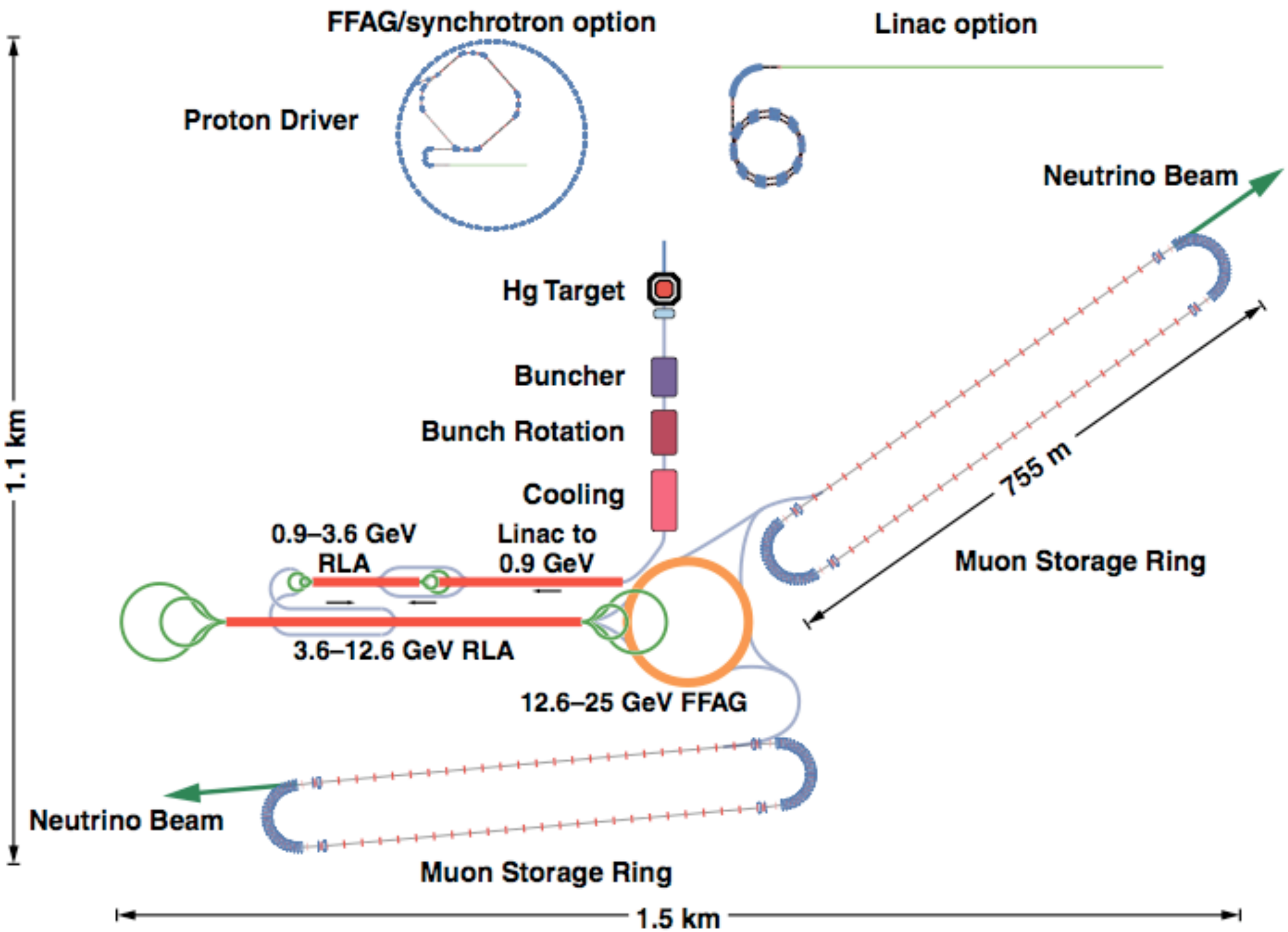
13 November 2009

Projects

- Neutrino Factory
  - Muon accelerators to 25 (50) GeV
- EMMA (electron model)
  - Electron accelerator of 10 to 20 MeV
- PAMELA (particle therapy)
  - 250 MeV proton and 400 MeV/u carbon
- Accelerator driven subcritical reactor
  - High intensity 1 GeV proton

Neutrino factory (1)

whole facility



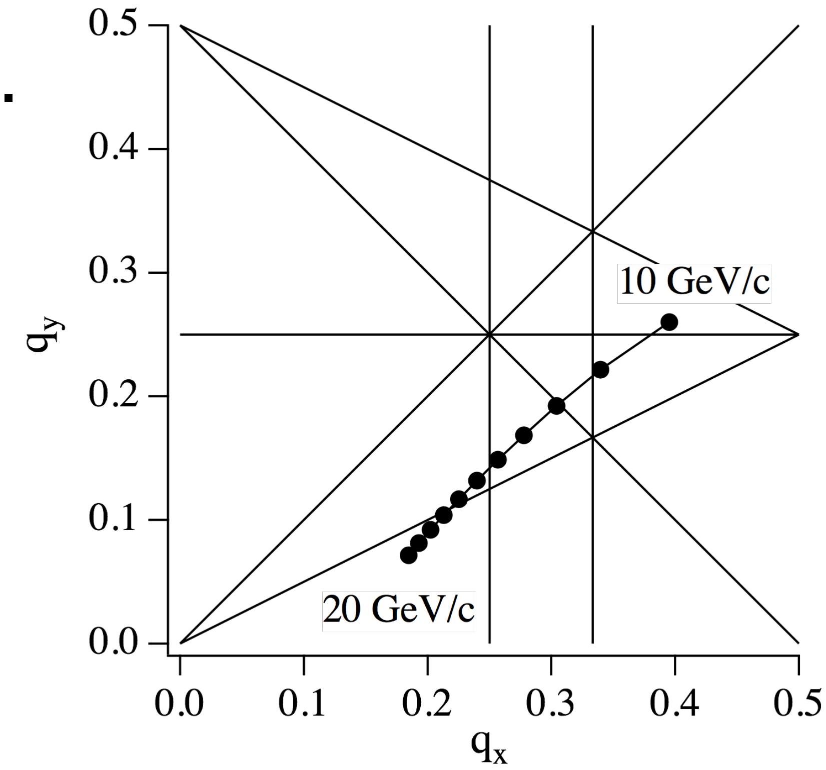
Neutrino factory (2)
muon acceleration

- Baseline scenario is
  - Linac to ~1 GeV
  - Two RLAs (recirculating linac) to 12.5 GeV
  - Nonscaling FFAG to 25 GeV

- FFAG has large acceptance and efficient use of rf cavities.

Neutrino factory (3)
issues 1

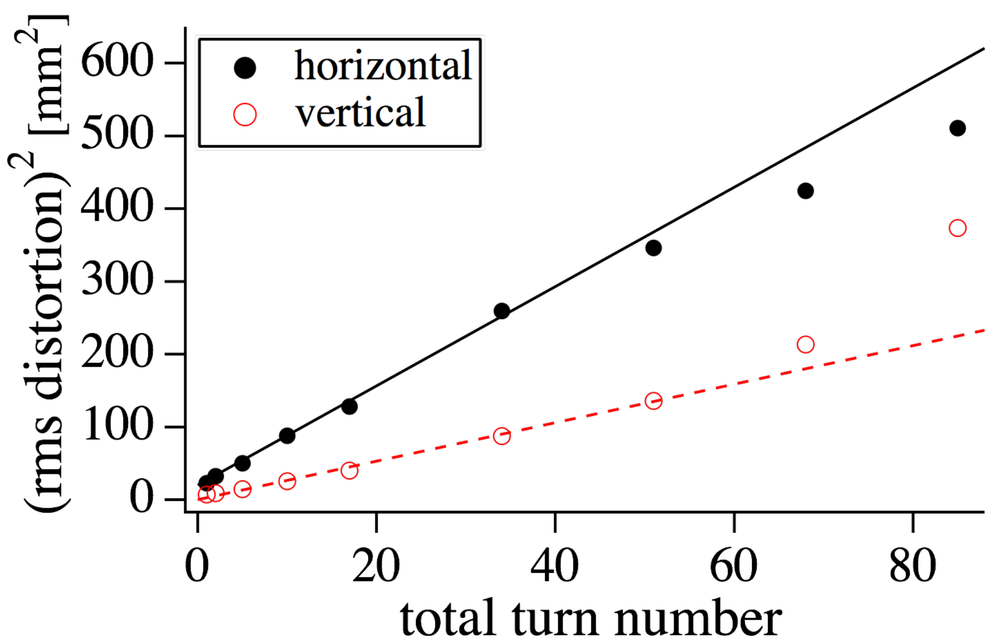
- Transverse stability with larger tune excursion.
- Resonance crossing.



Neutrino factory (4)

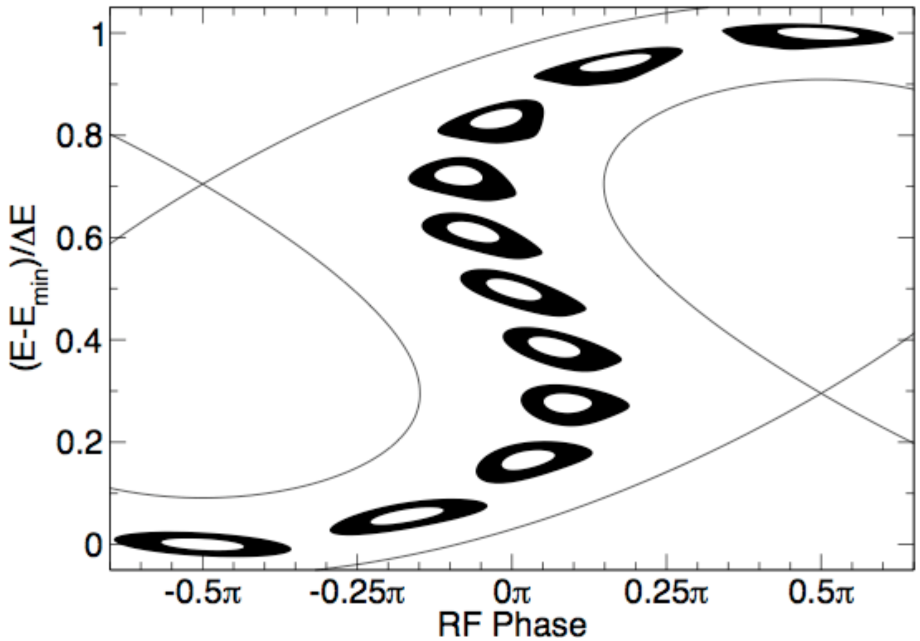
issues 1

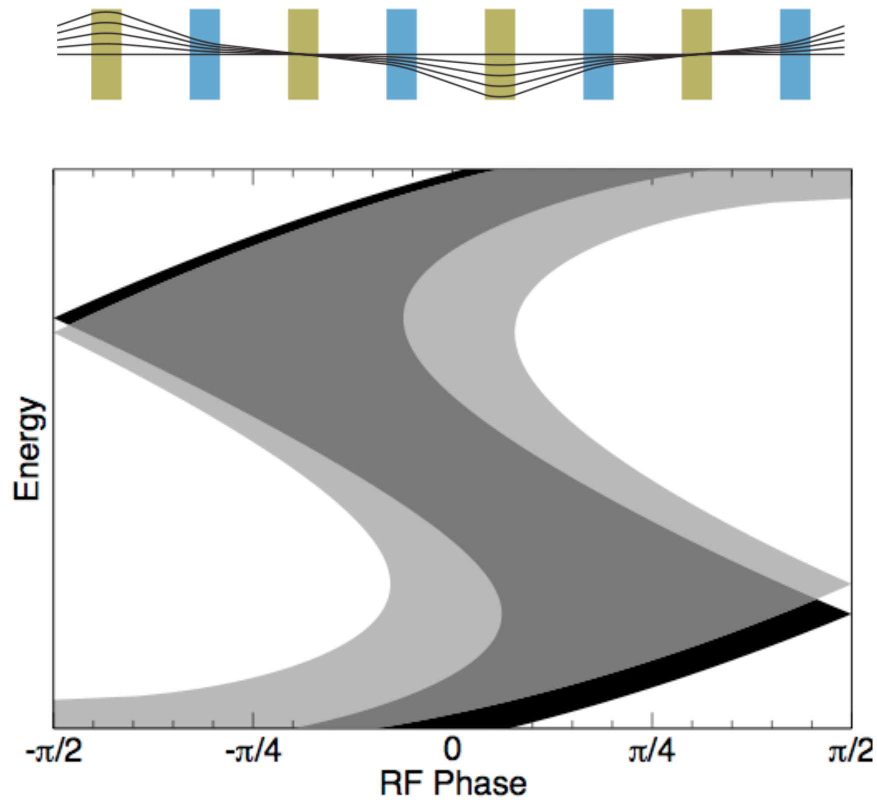
- No resonance type of growth occurs.
- Orbit distortion gets larger as a result of random kicks.



Neutrino factory (5)
issues 2

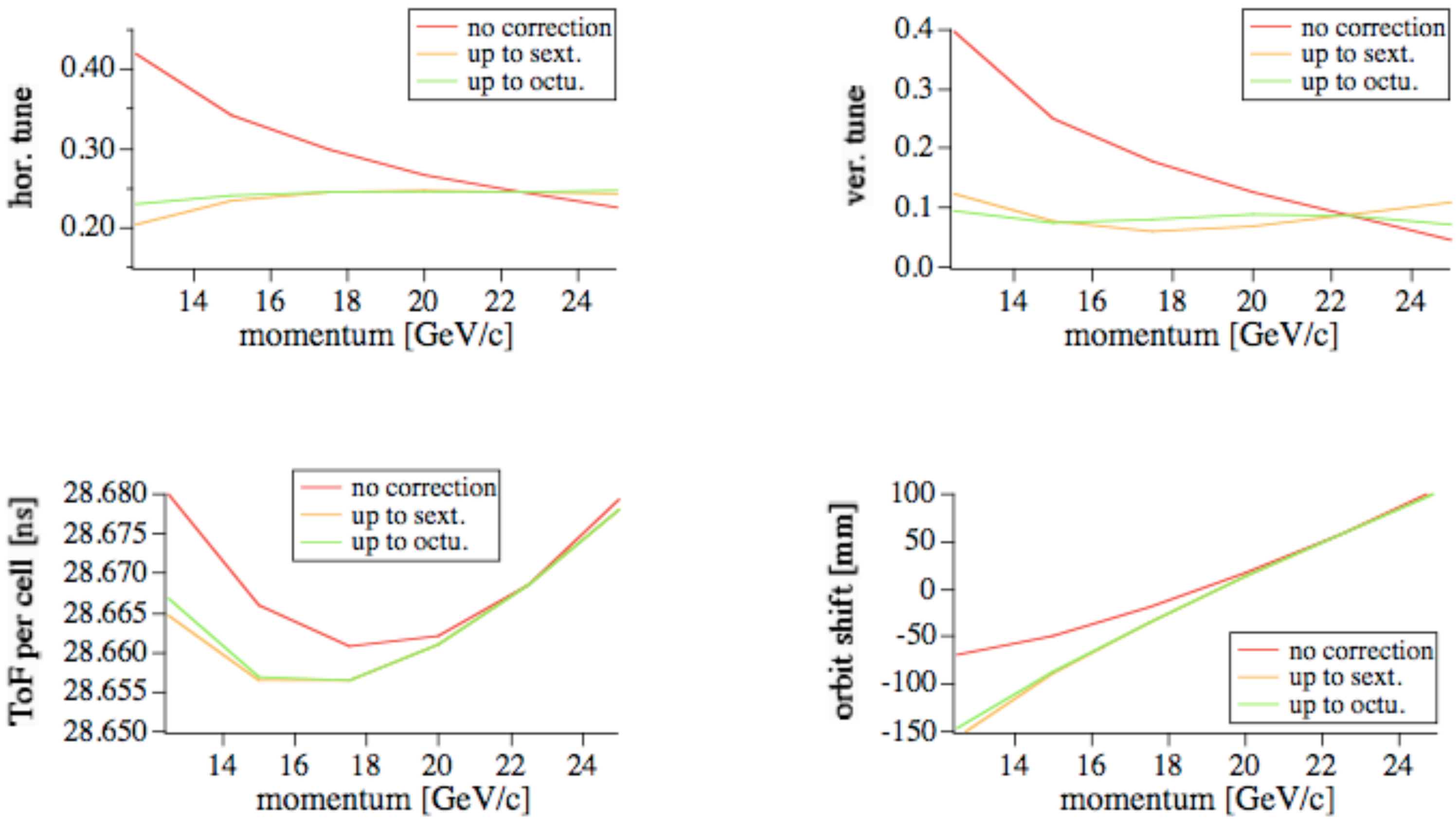
- Serpentine acceleration.
- Longitudinal phase space looks different.





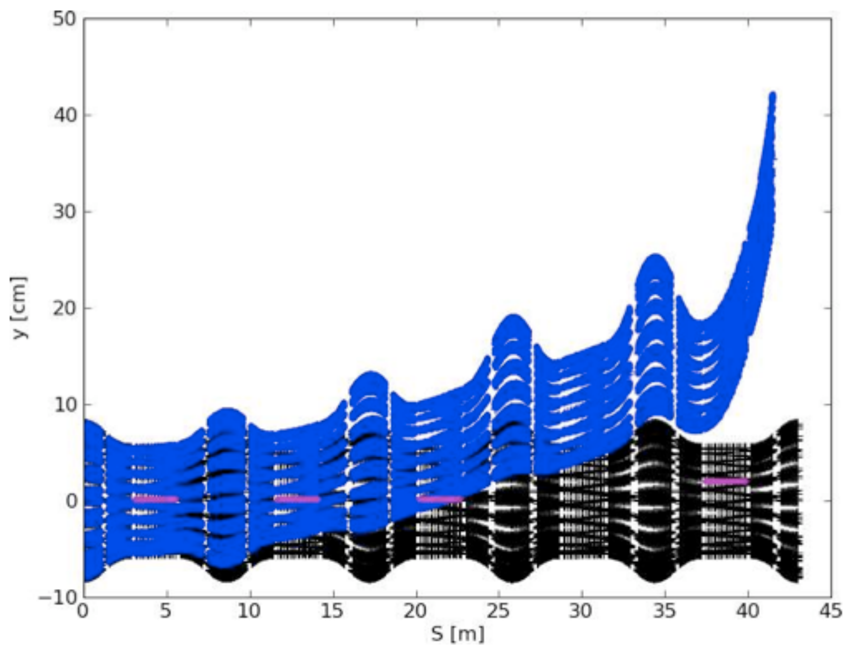
Neutrino factory (6)
issues 2

- Zero chromaticity fixes the problem



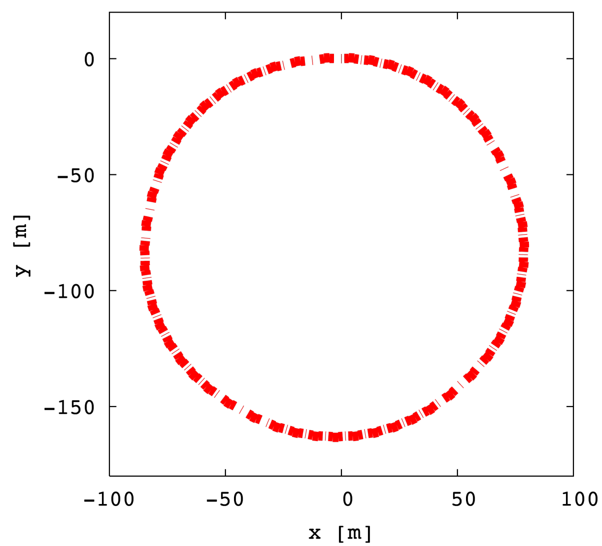
Neutrino factory (7)
issues 3

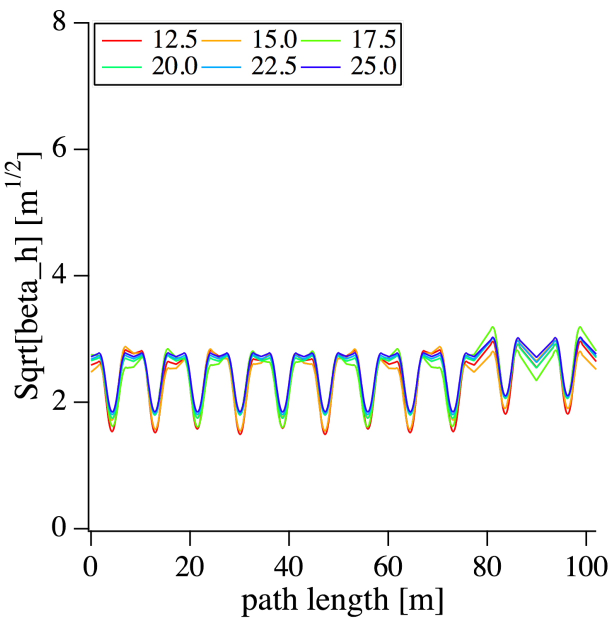
- Injection and extraction.
- Almost no space for kickers and septa.
  - Vertical extraction with a few kickers.

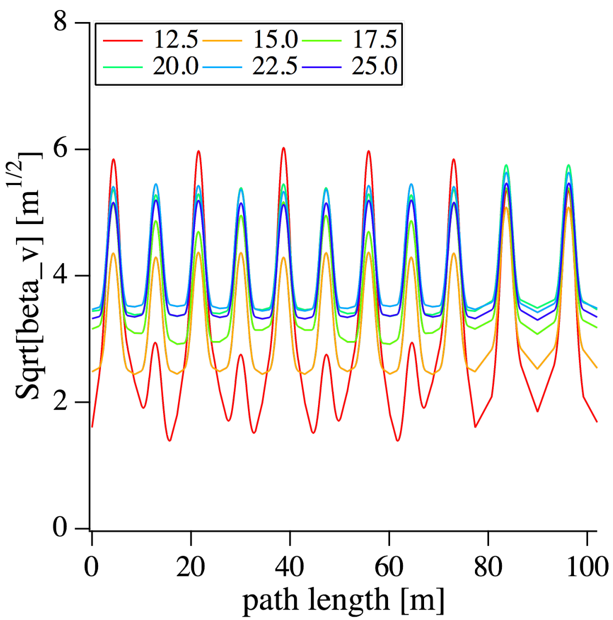


Neutrino factory (8)
issues 3

- Superperiodic structure with insertions provides a space.
  - 2 of 5 m drift and 1 of 7 m drift every 11 cells.





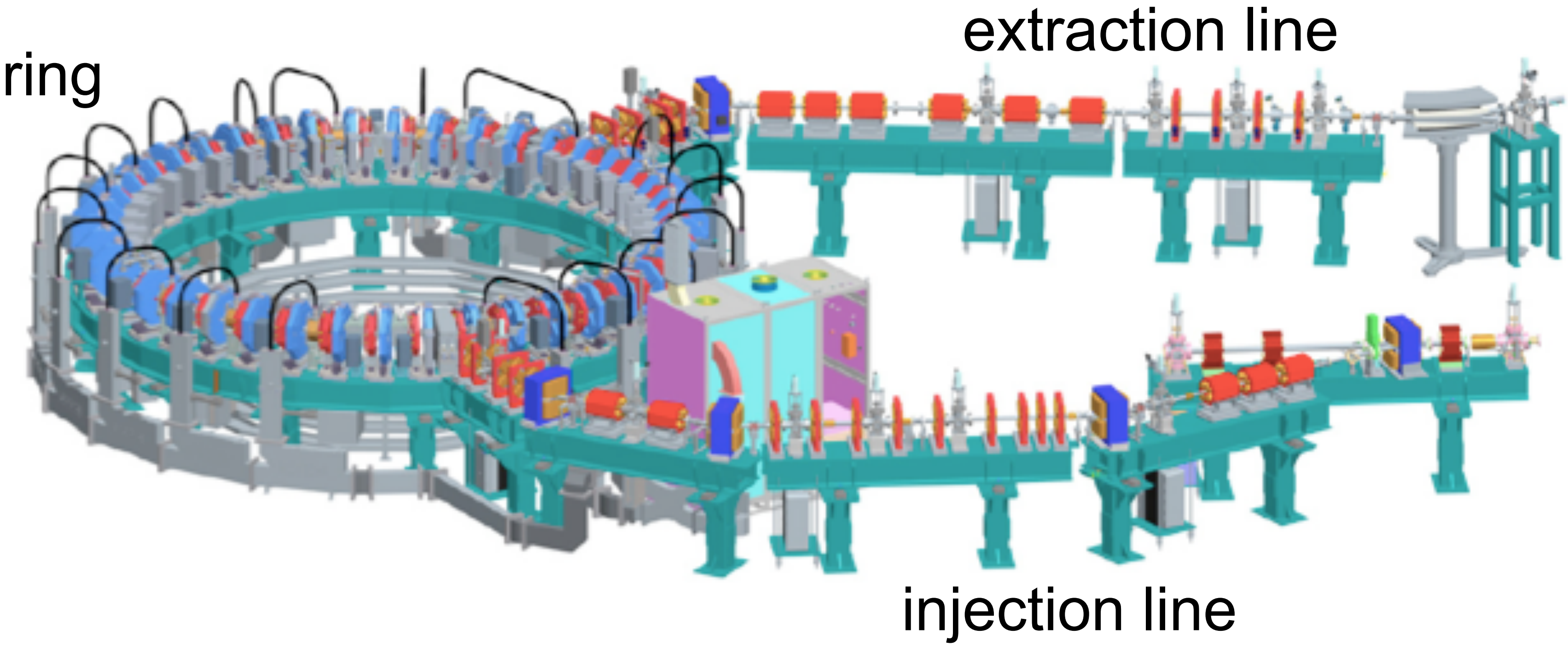


Neutrino factory (9)
but…

- No nonscaling FFAG has been built.

EMMA

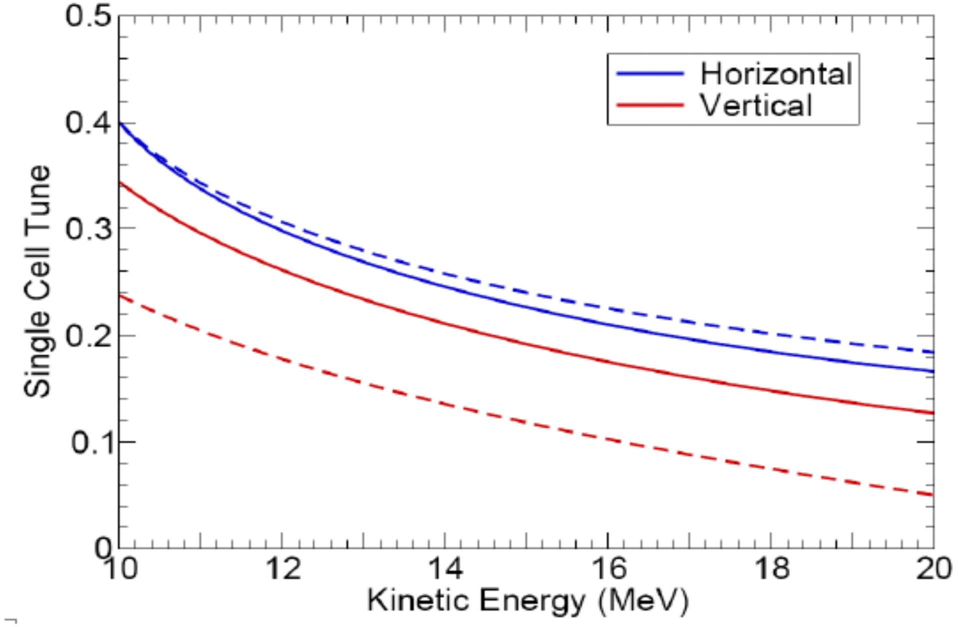
electron model of muon acceleration



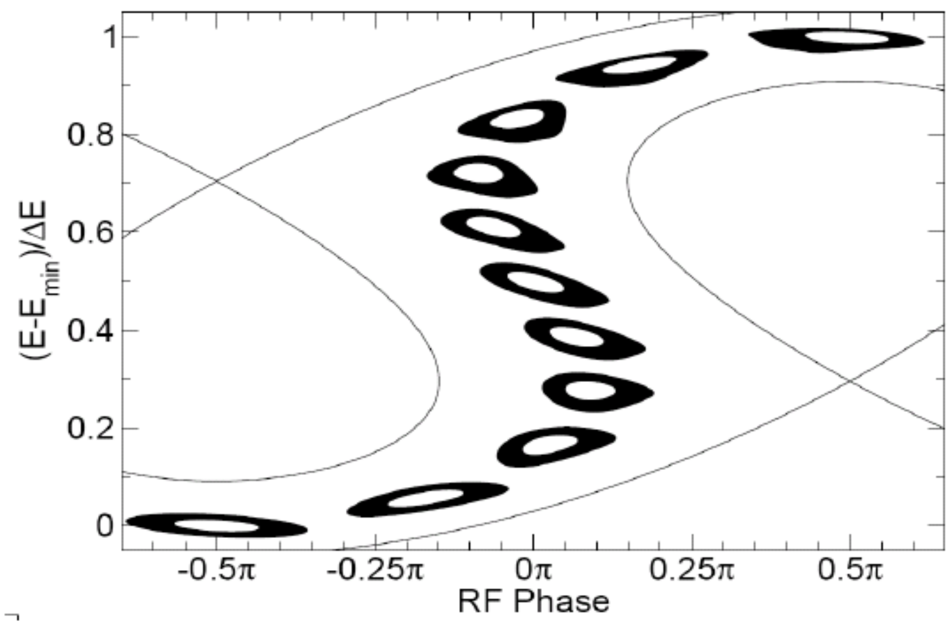
EMMA

goals

(1) Rapid acceleration with large tune variation (natural chromaticity)



(2) Serpentine acceleration (results from parabolic ToF)



(3) Map the transverse and longitudinal acceptances.

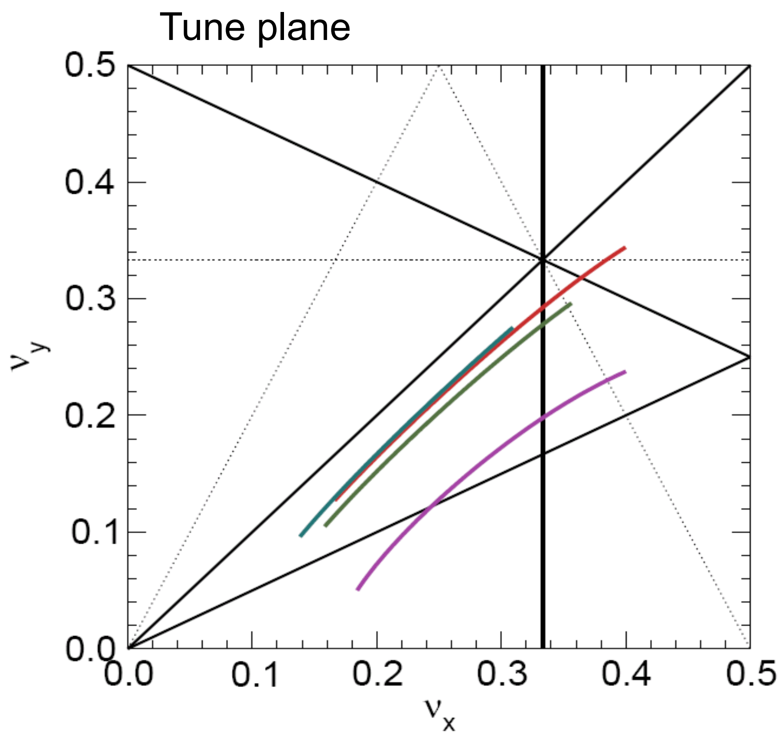
Graphs courtesy of Scott Berg BNL

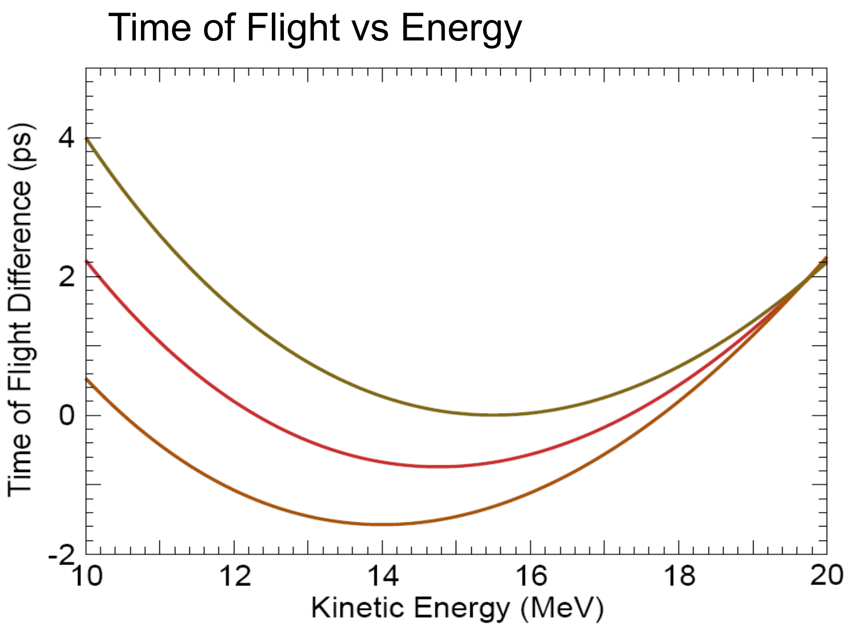
BROOKHAVEN NATIONAL LABORATORY

Lattice Configurations

Understanding the NS-FFAG beam dynamics as function of lattice tuning & RF parameters

- Example: retune lattice to vary resonances crossed during acceleration



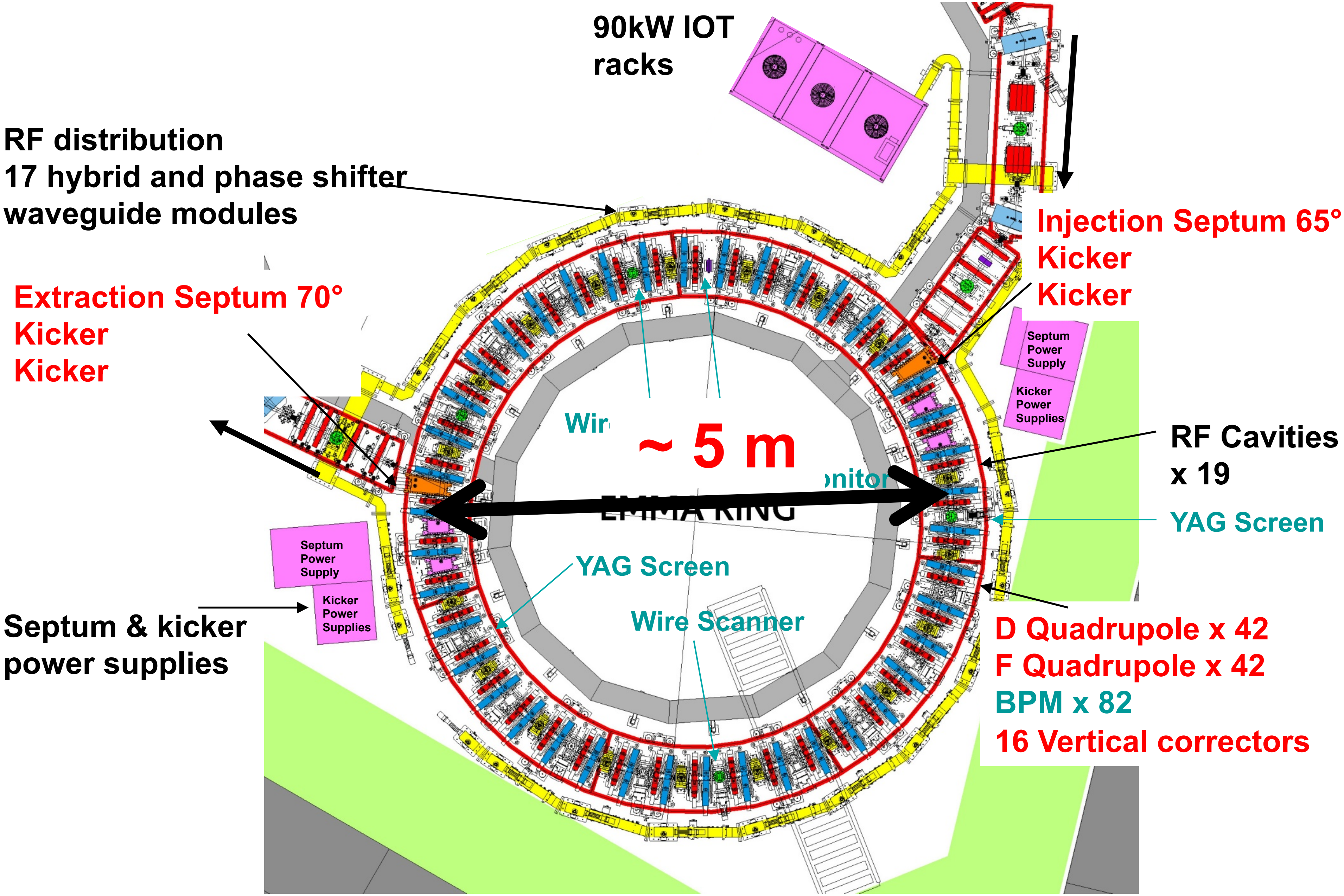


- Example: retune lattice to vary longitudinal Time of Flight curve, range and minimum

Graphs courtesy of Scott Berg BNL

BROOKHAVEN NATIONAL LABORATORY

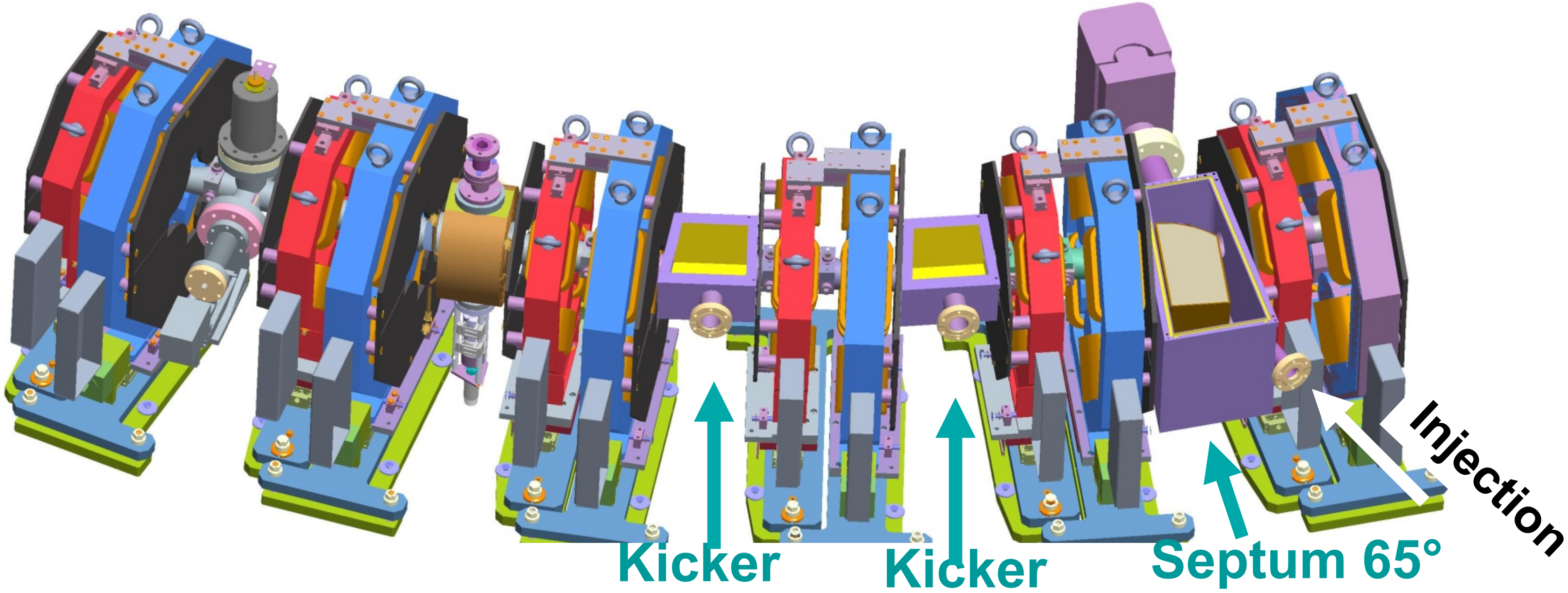
EMMA Ring


90kW IOT racks
RF distribution
17 hybrid and phase shifter waveguide modules
Extraction Septum 70°
Kicker
Kicker
Injection Septum 65°
Kicker
Kicker
Septum Power Supply
Kicker Power Supplies
~ 5 m
RF Cavities x 19
YAG Screen
YAG Screen
Wire Scanner
Septum Power Supply
Kicker Power Supplies
Septum & kicker power supplies
D Quadrupole x 42
F Quadrupole x 42
BPM x 82
16 Vertical correctors

Injection & Extraction

- Large angle for injection (65°) and extraction (70°) very challenging !!
- Injection/Extraction scheme required for all energies (10 – 20 MeV)
- Many lattices and many configurations of each lattice required
- Very limited space between quadrupole clamp plates for the septum and kickers construction

Extensive 3D magnet modelling conducted to minimise the effect of stray septum fields on circulating beam



RF Requirements

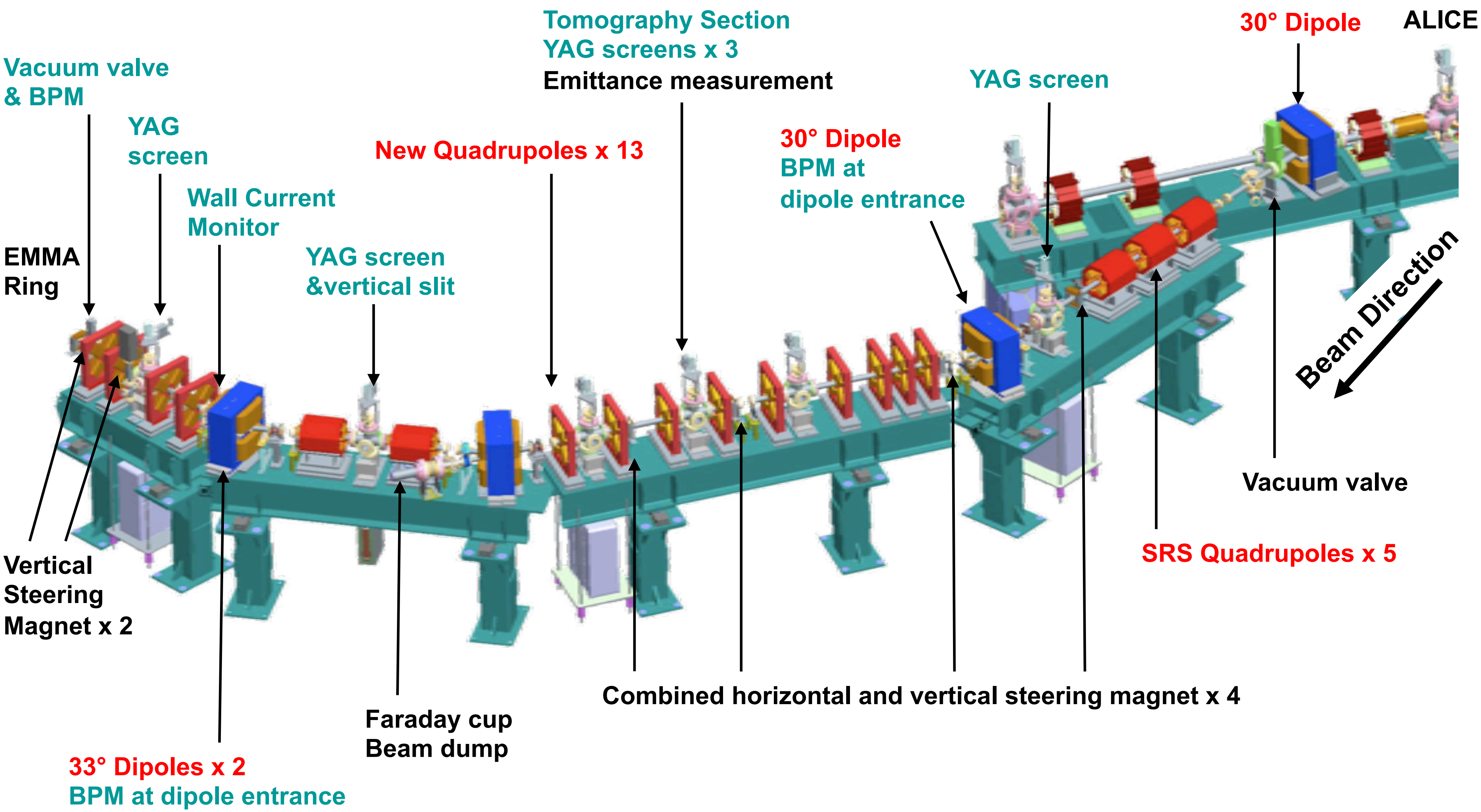
- Voltage:
  - 20 - 120 kV/cavity essential, based on 19 cavities
  - Up to 180 kV/cavity desirable (future upgrade)
- Frequency:
  - 1.3 GHz, compact and matches the ALICE RF system
  - Range requirement 5.6 MHz
- Cavity phase:
  - Remote and individual control of the cavity phases is essential

Commissioning

- Preparing the accelerator for beam
  - set-up DAQ & controls & hardware
  - set-up diagnostic devices required
- Getting beam into the accelerator
- Making sure all desired properties are achieved
  - Set-up the accelerator (orbit correction, dispersion-free sections, setting desired optics, phases on cavities etc.)
  - Characterise the bunch
- Making all the desired measurements
- Set-up accelerator for particular experiments
  - Injection at different energies
  - Phase space painting
  - Extraction, acceleration etc.

Extensive simulations of the accelerator, beam physics, the diagnostics and the controls algorithms will be needed!

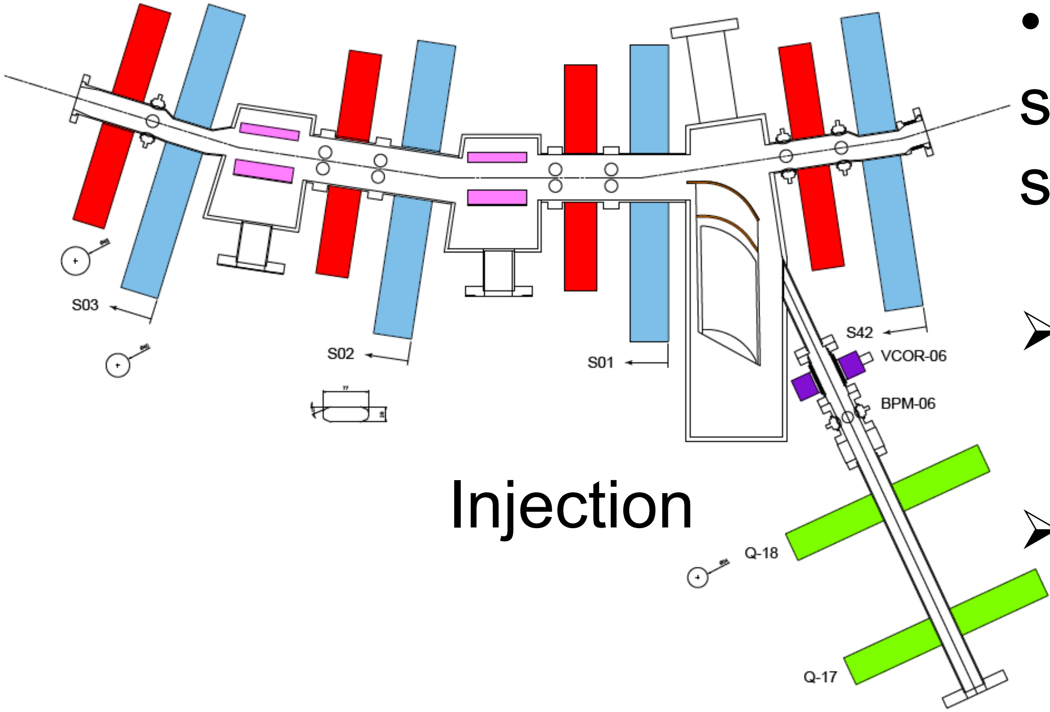
EMMA injection line



Measurements in Injection Line

- **Emittance**
  - Tomography section
  - Quadrupole scans
- **Bunch length**
  - Zero cross method with 2nd linac cavity used as a buncher and YAG screen in dogleg
- **Charge**
  - Faraday cup after 1st dipole of arc or tomography section
- **Energy & Energy spread**
  - Slit & YAG in last dispersive section

First Injection



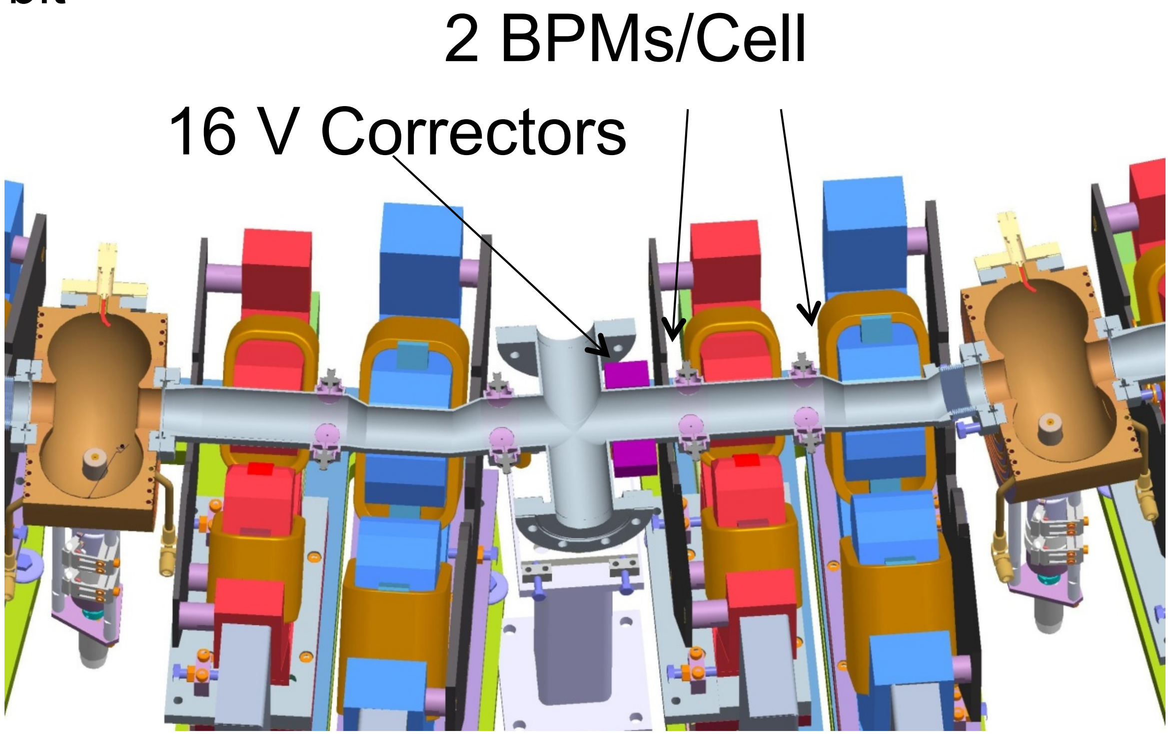
- Trajectory through septum (position and angle should be available online)

➢ What energy
  - Injection energy? 10 MeV
  - "Easy energy"? 17 MeV

➢ What phase?
  - Reduced kicker strengths
  - Simple kicker setup
  - Reduced aperture
  - Closed orbit error sensitivity
  - Avoid resonances

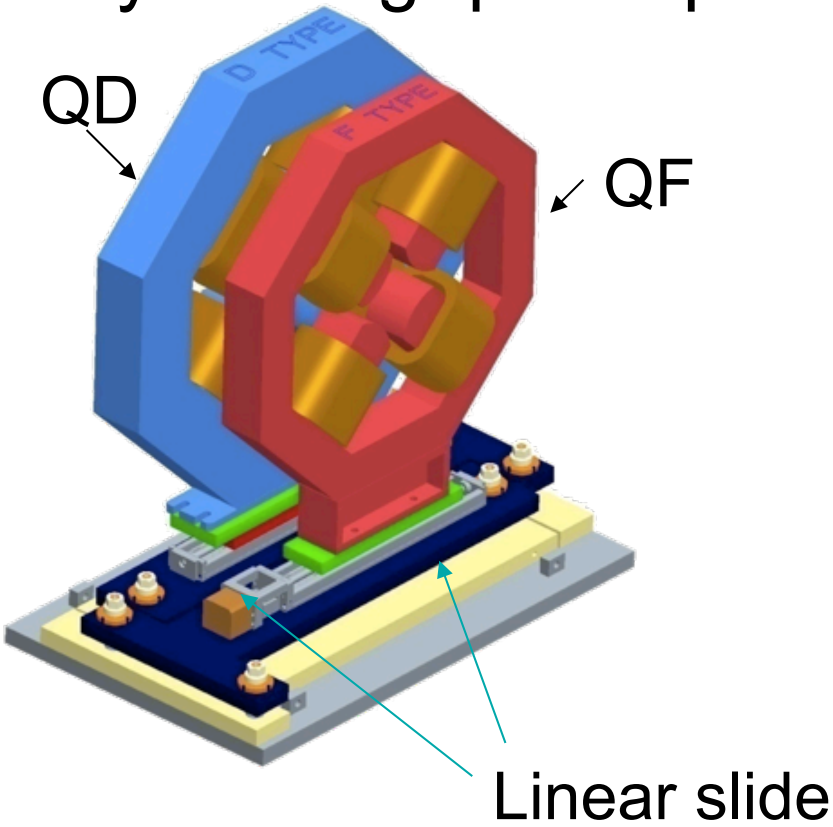
Establishing orbits

- Record Beam Position Monitor (BPM) one by one from the injection point on 1st and hopefully subsequent turns, investigate de-coherence, tune measurement etc.
- Use BPM readings to establish closed orbit
- Correct gross orbit errors
- Injection on to closed orbit



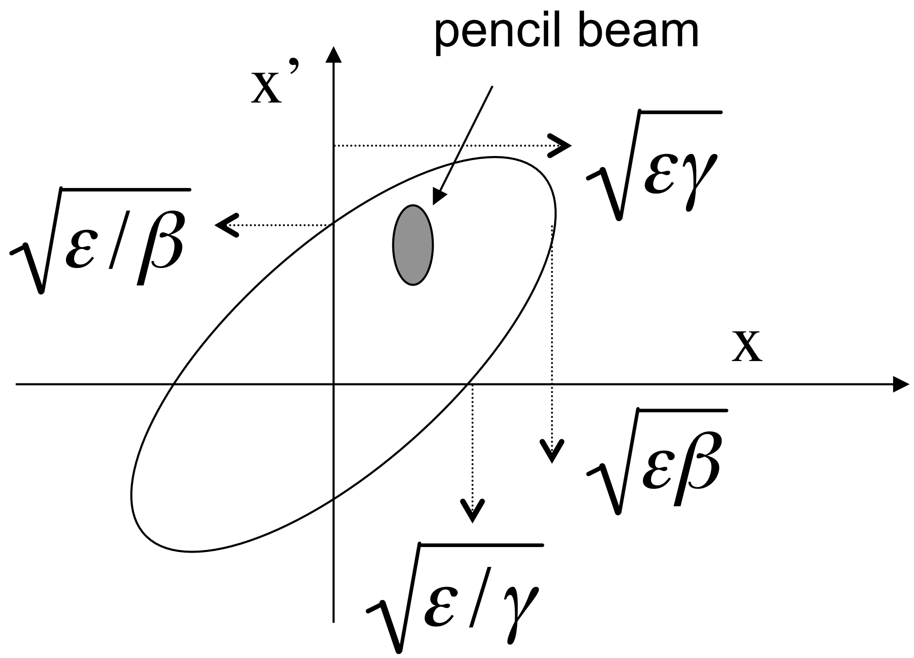
Establishing desired lattice

- Double focusing lattice (QF and QD)
- Bend fields are created by shifting quadrupoles
- 4 knobs
  - QF and QD strength
  - QF and QD position (horizontally)
- 4 parameters to fit
  - Q_x and Q_y
  - TOF shape and offset
- Should have model to predict 4 parameters according to desired lattice



Phase Space Scanning

- Phase space at injection
- Scan aperture in phase space with a pencil beam
- Use steerers vertically & kickers horizontally

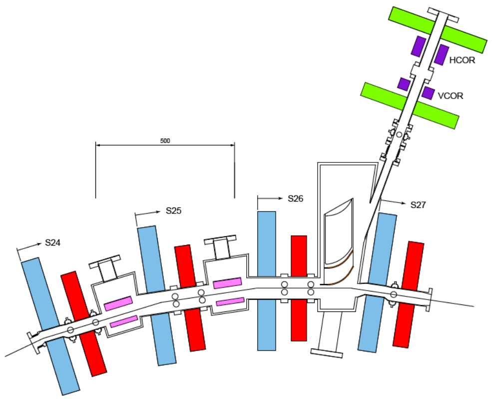


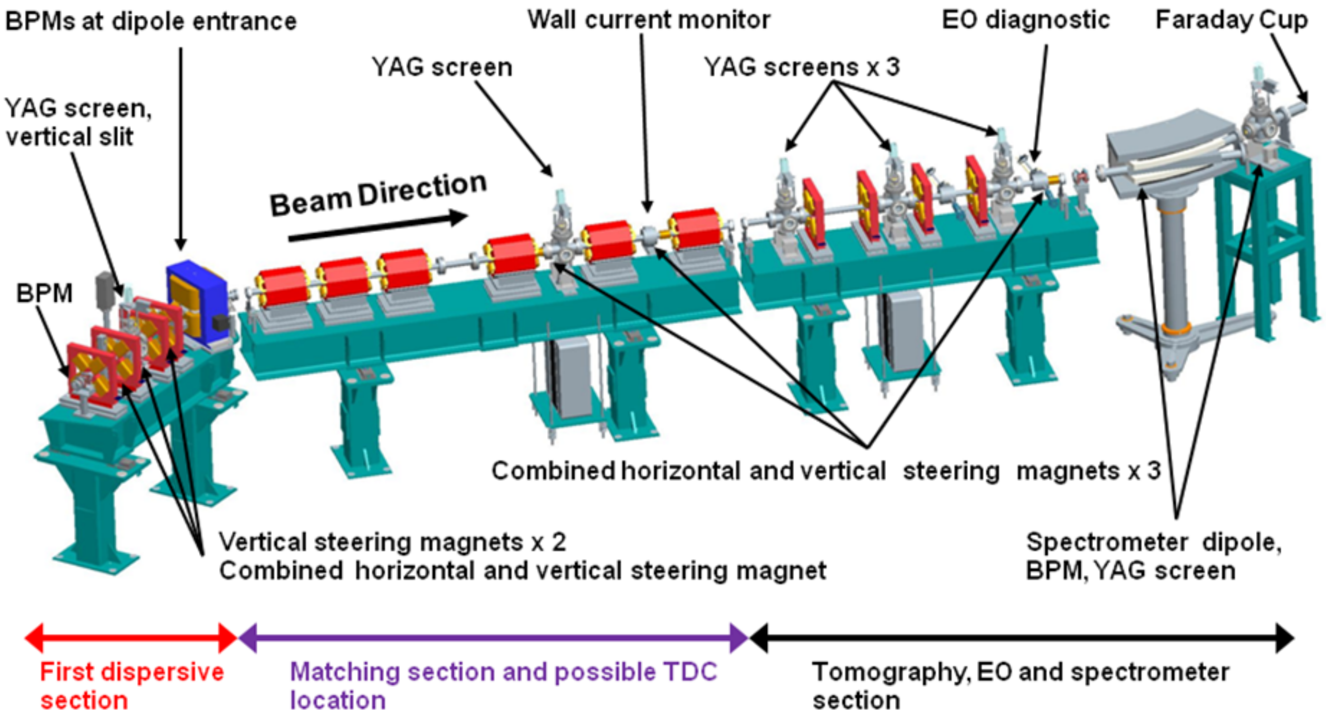
- Verify reasonable acceptance

Towards Acceleration

- Establish details of RF phase setting and control and synchronisation
- Characterise lattice as at a few chosen energies including injection and extraction energy
- Use orbit/corrector data to predict global correctors required for energy ramp
- Commission extraction and diagnostics line at chosen extraction energy
- Accelerate!

Extraction Line





Measurements in Extraction Line

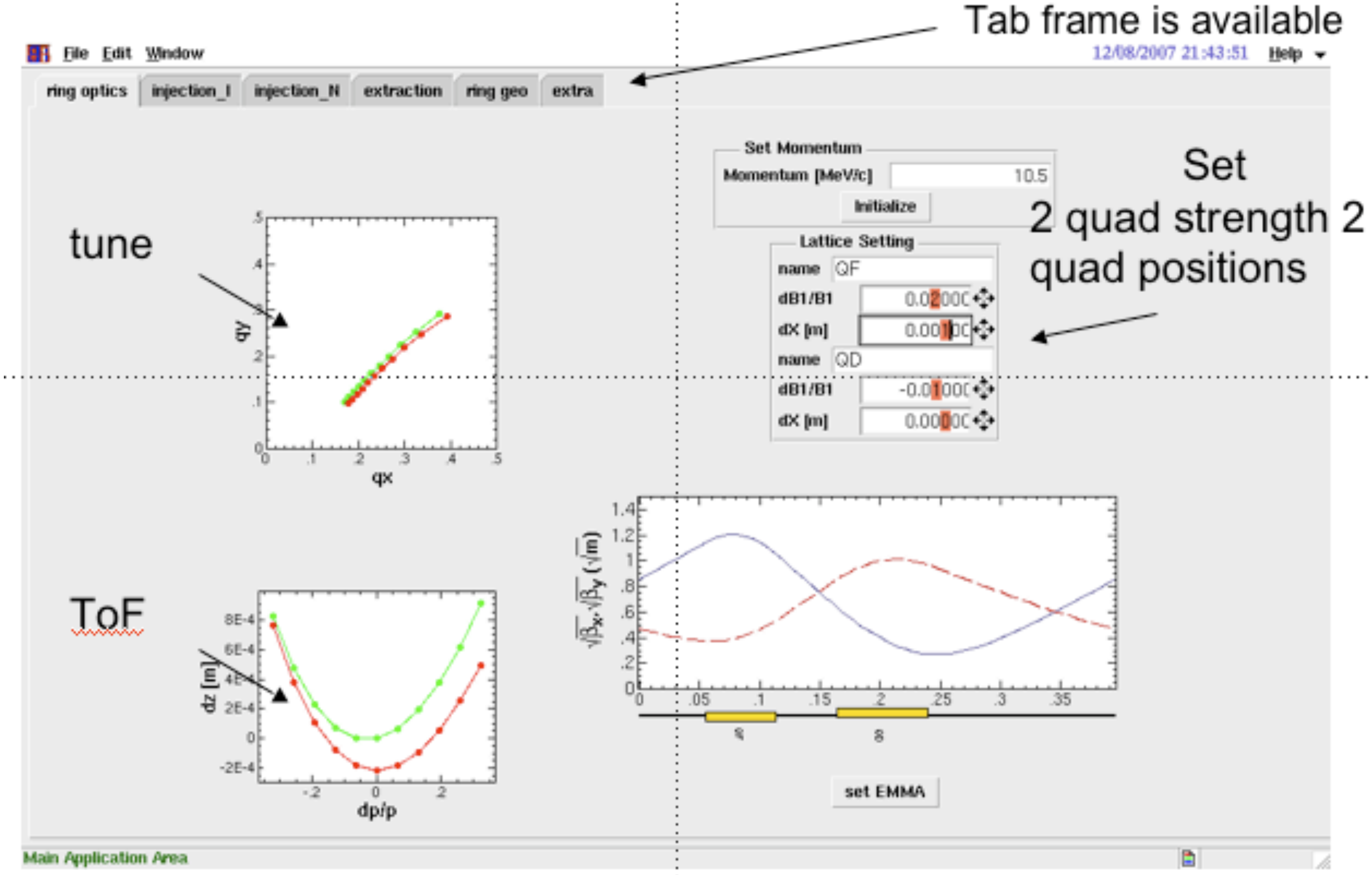
- **Emittance**
  - Tomography section
- **Slice emittance**
  - Transverse deflecting cavity (TDC) & screen in tomography section
- **Bunch length**
  - Electro-optic monitor and / or TDC
- **Charge**
  - Faraday cup after spectrometer dipole
- **Energy spread**
  - Slit & YAG in first dispersive section / spec. dipole
- **Slice energy spread**
  - TDC & spectrometer dipole

Online Model

- Collaboration has agreed that ZGOUBI would be core to on-line model
- Python wrap around will interface to EPICS controls and ZGOUBI programme
- Other codes will be used and tested through the database. E.g One code simulating the accelerator the other testing algorithms...
- Will develop a series of interfaces between the physicist/ operators and the accelerator using the model to predict lattice parameters.
- Test functionality on ALICE to EMMA commissioning line
- Commissioning will assist in “correcting the model”

Online Modelling

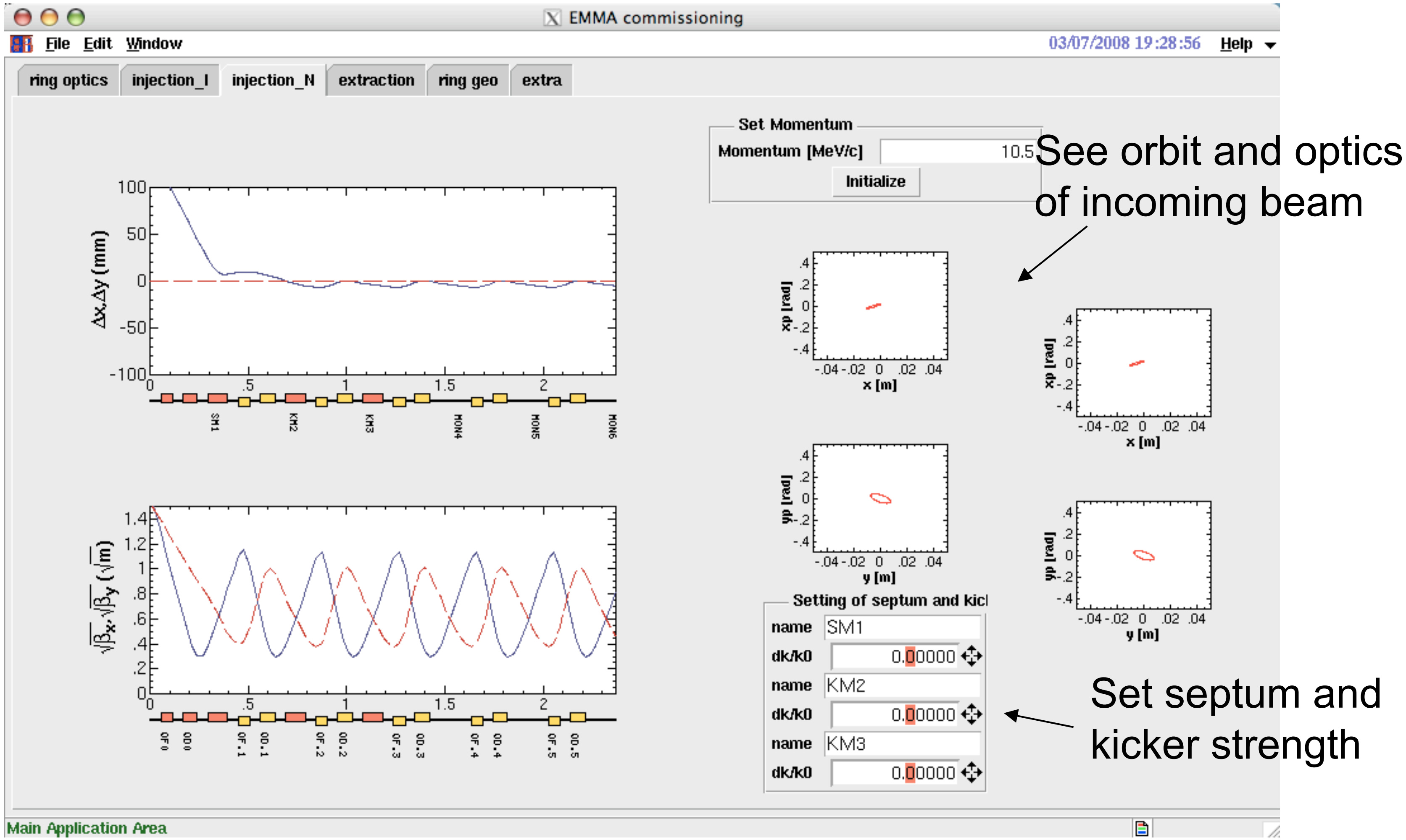
- Ring optics – what things may look like.



courtesy S. Machida

Online Modelling

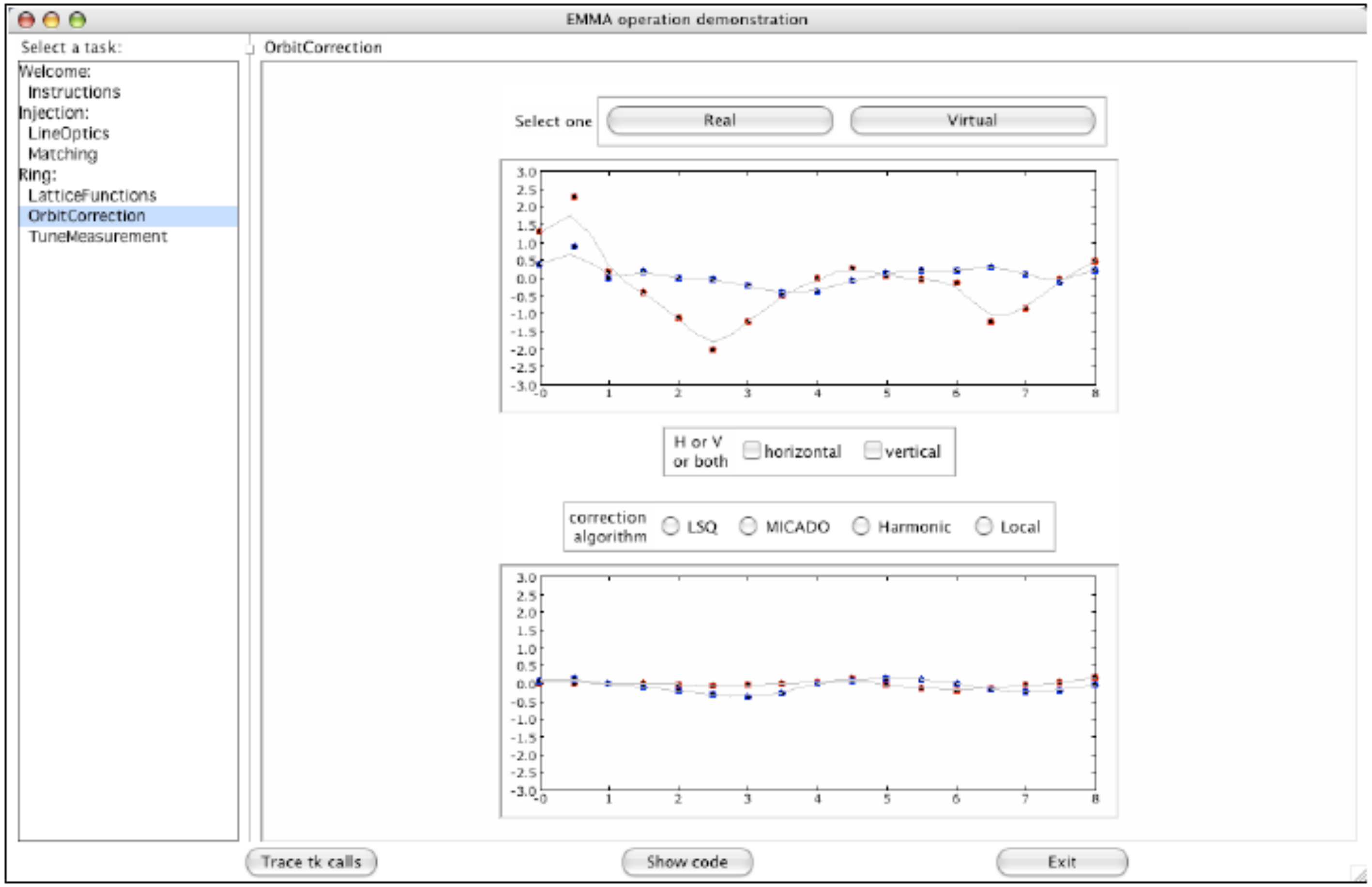
- Injection orbit and optics - what things may look like



courtesy S. Machida

Online Modelling

- Orbit correction - what things may look like



courtesy S. Machida

Quick and dirty (clean) setup

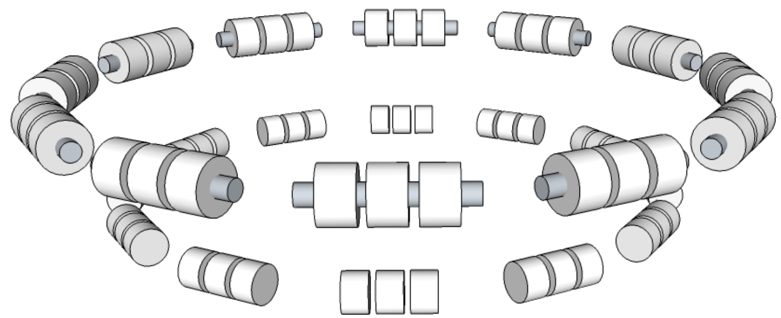
- I am in charge.
- Minimum steps to announce “success”.
  - Serpentine acceleration
  - Resonance crossing

Commissioning Programme

1. Identify major commissioning tasks (June 09)
2. Estimate resources available, identify groups and individuals who will take responsibility for tasks (Sept 09)
3. First ALICE for EMMA experiments (Oct 09)
4. Beam through ALICE to EMMA injection line (Dec 09)
5. Identify & describe in more detailed procedures (Nov 09)
   – TOF / Tunes / Orbit correction / Experiments / other ?
6. Hold second commissioning workshop (Nov/Dec 09)
7. Review major procedures (fast Vs detailed) (at workshop)
8. Prepare a detailed programme of work (Feb 09)
9. Develop online model (Dec 09
   1. Specify model requirments
   2. Test and verify procedures
   3. Benchmark different codes (Feb 09)
10. Lay out a commissioning plan (Feb 09)
11. Schedule tasks and physicist to shifts (March 09)

PAMELA – Overview

- “Particle Accelerator for MEdicaL Applications”
- 250MeV Protons
- 400MeV/u Carbon 6+



Possible layout: two stacked near-concentric rings

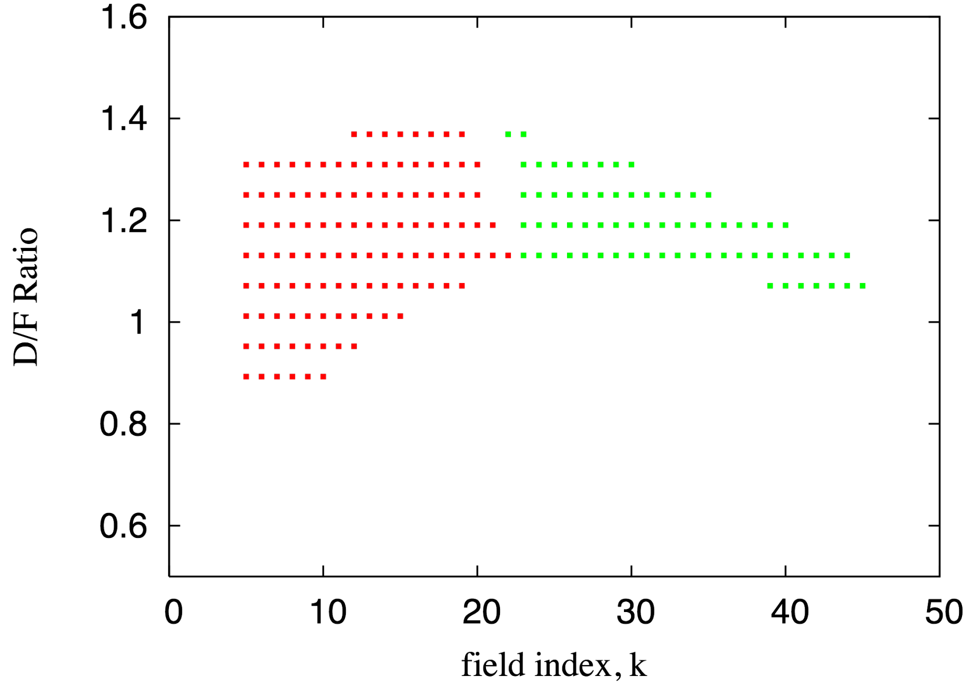
DESIGN – Procedure

- New design concept – S. Machida
- Minimise tune variation
- Start with scaling FFAG, FDF focusing
- Break scaling law
    1. Truncate expansion of scaling law
    2. Make magnets rectangular
    3. Align on straight line
- Use 2nd stability region of Hill's equation

Phys. Rev. ST Accel. Beams paper finished and pending submission

DESIGN – 2nd stability region

180°< Hori. tune <360°
0°   < Vert. tune < 180°



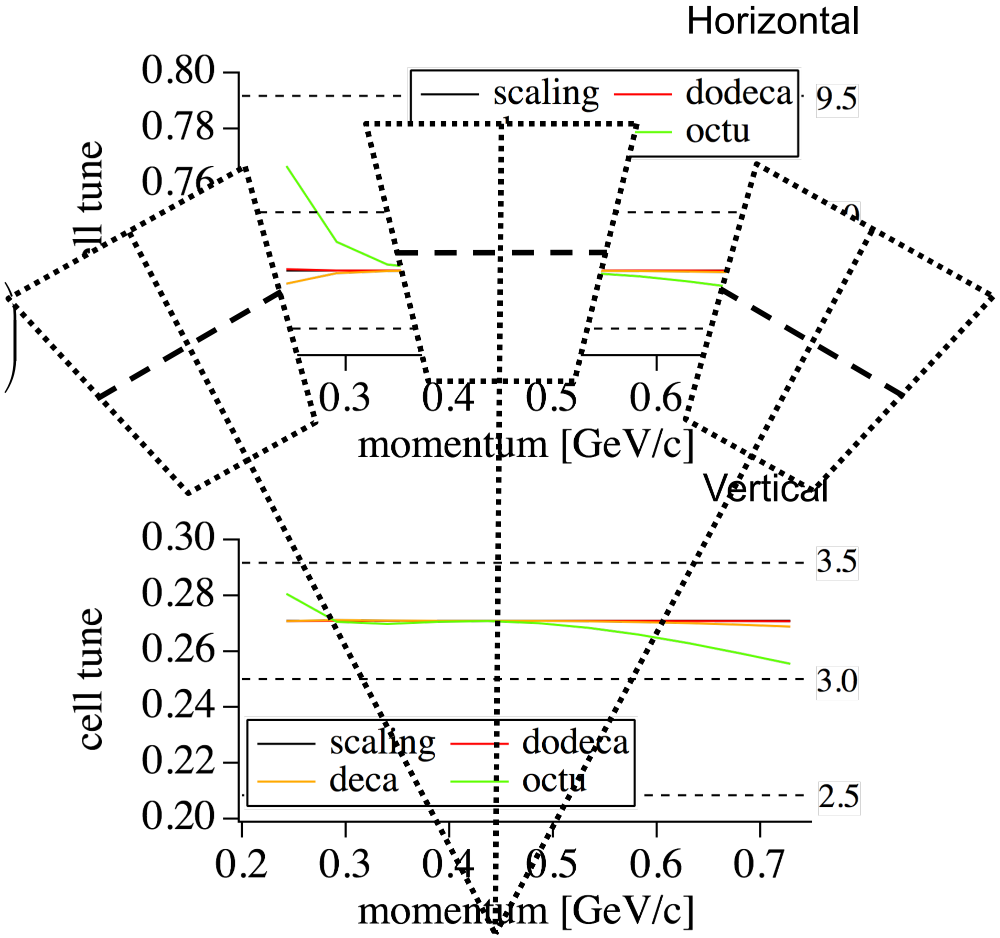
DYNAMICS: Tune variation

- Wedge shaped magnets on an arc

$$B_z = B_{z0}\left(\frac{r_0 + r}{r_0}\right)^k = B_{z0}\left(1 + \sum_{n=1} \frac{1}{n!}\frac{k(k-1)\cdots(k-n+1)}{r_0^n} r^n\right)$$

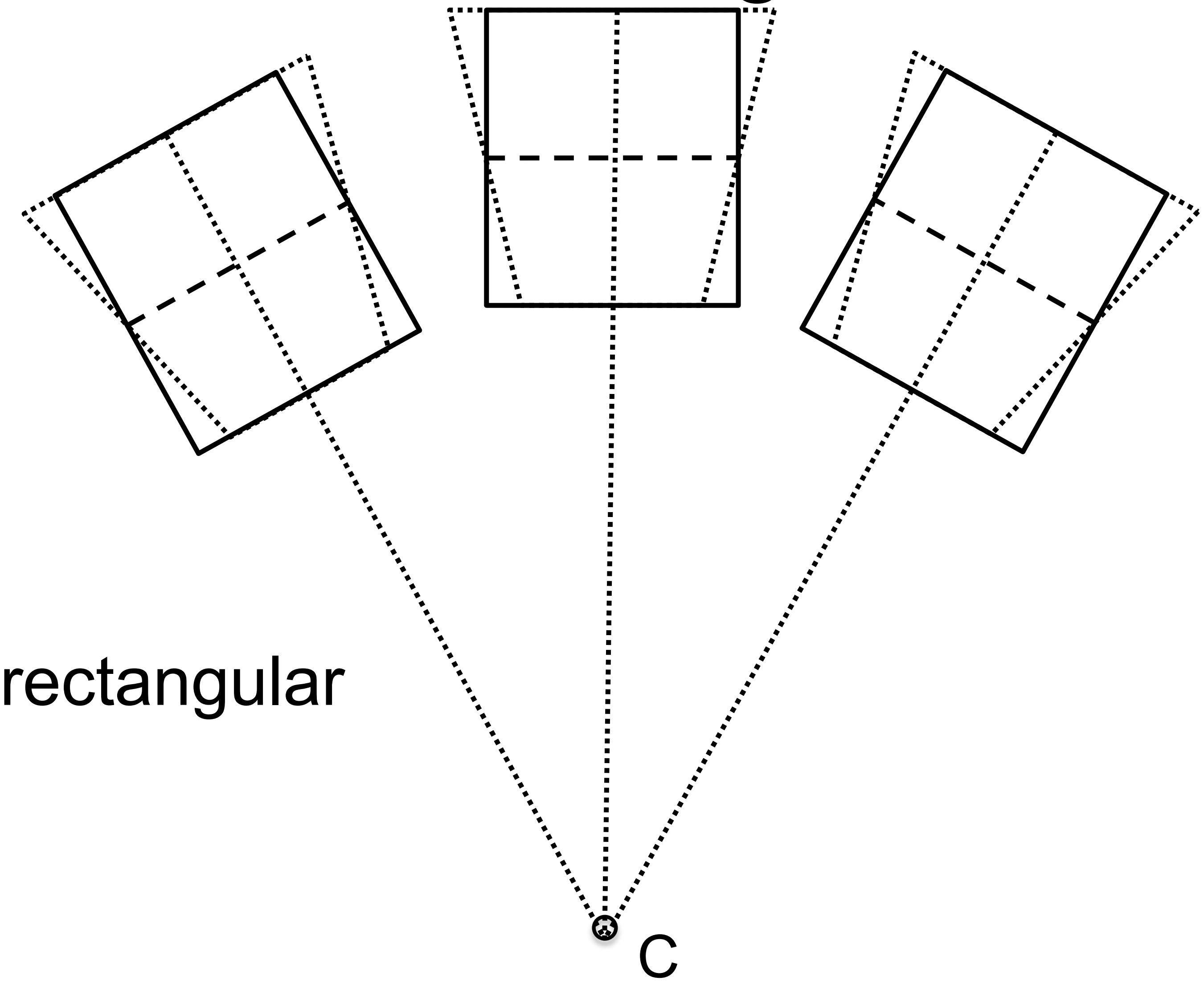
- Truncate scaling law

Total tune variation:
(for decupole case)
ΔQh=0.057
ΔQv=0.017



Nb. Simulations in ZGOUBI

DESIGN - rectangular



Next step:

Convert to rectangular magnets

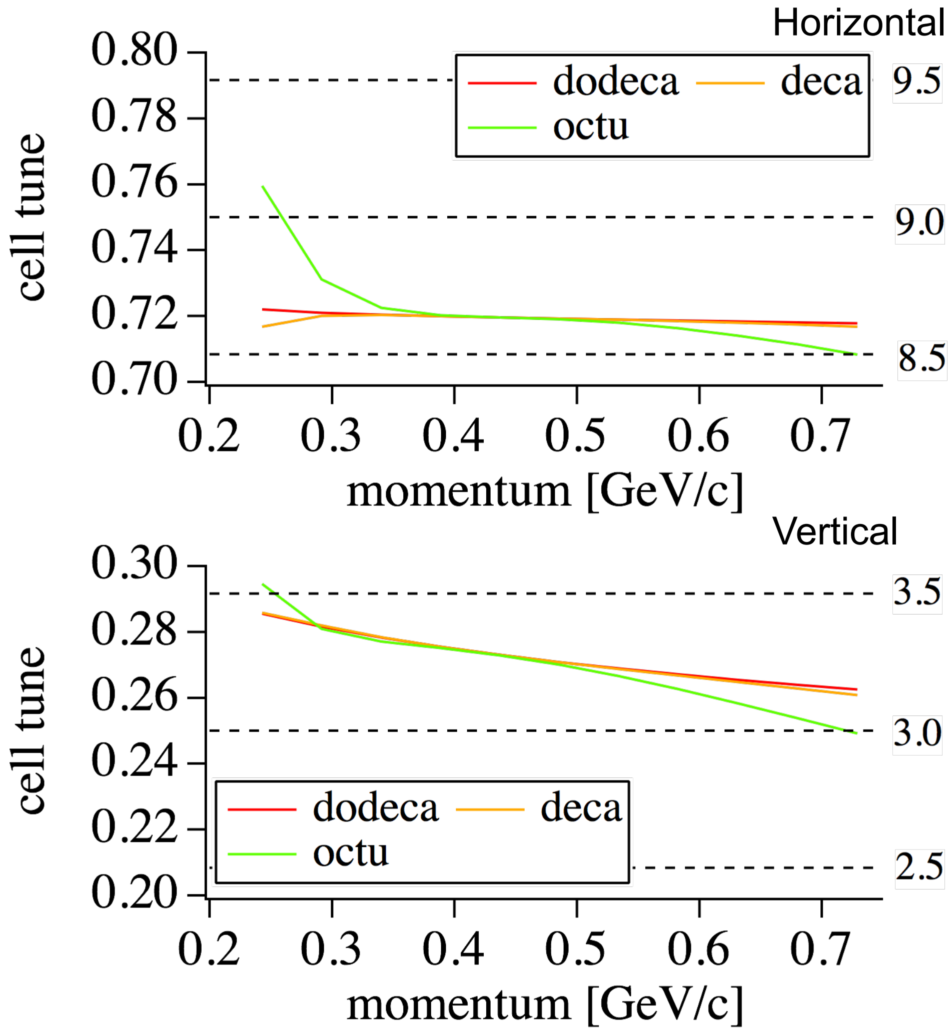
DYNAMICS: Tune variation

Total tune variation:

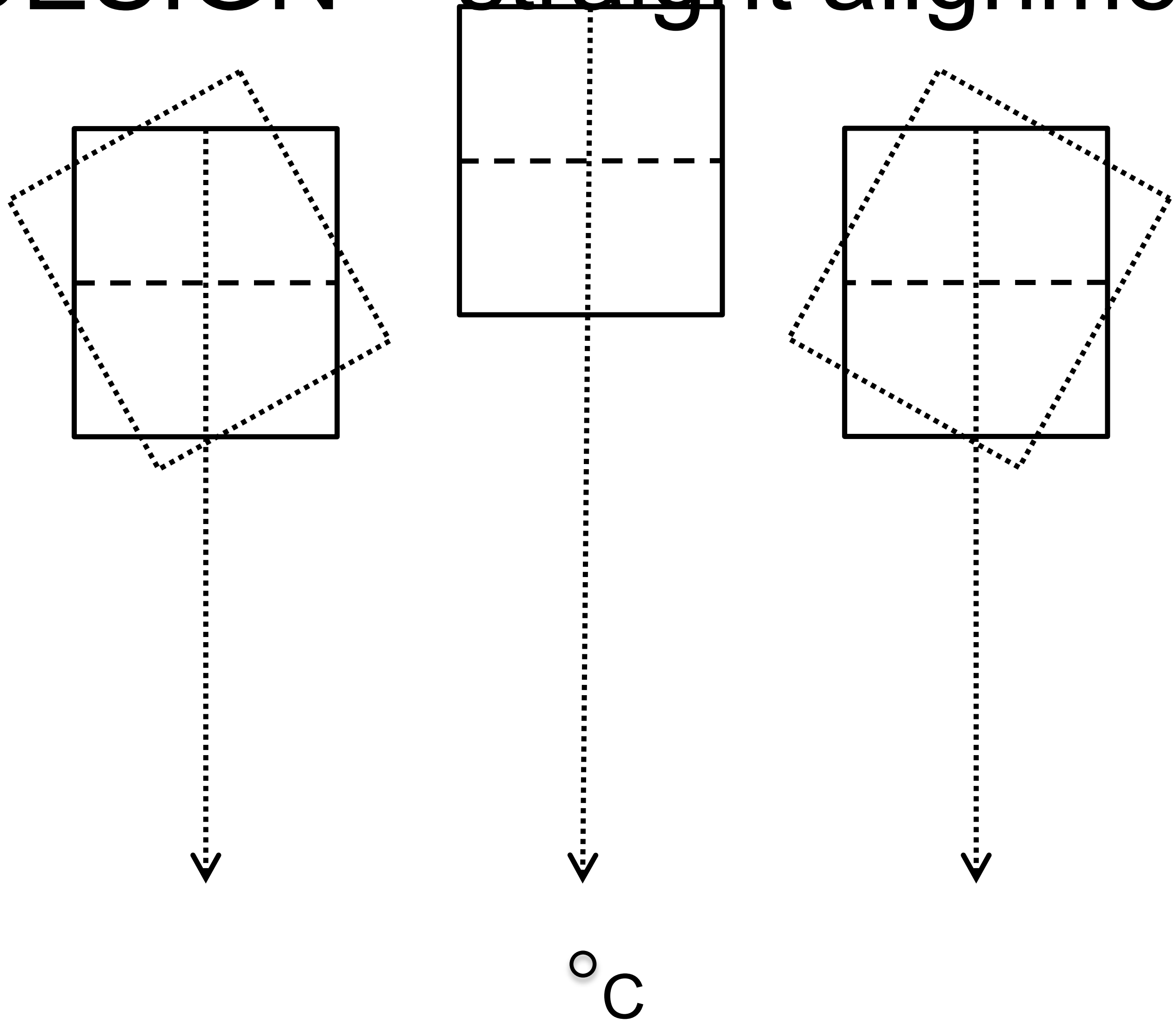
$\Delta Qh=0.042$

$\Delta Qv=0.300$

(for decupole case)

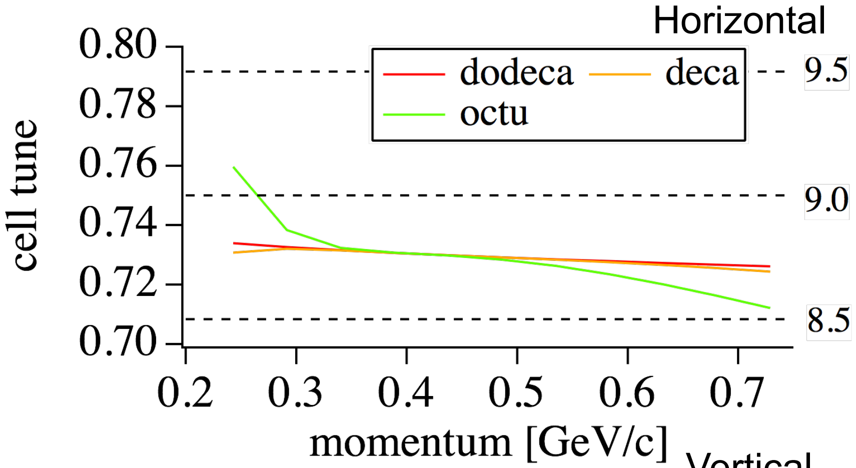


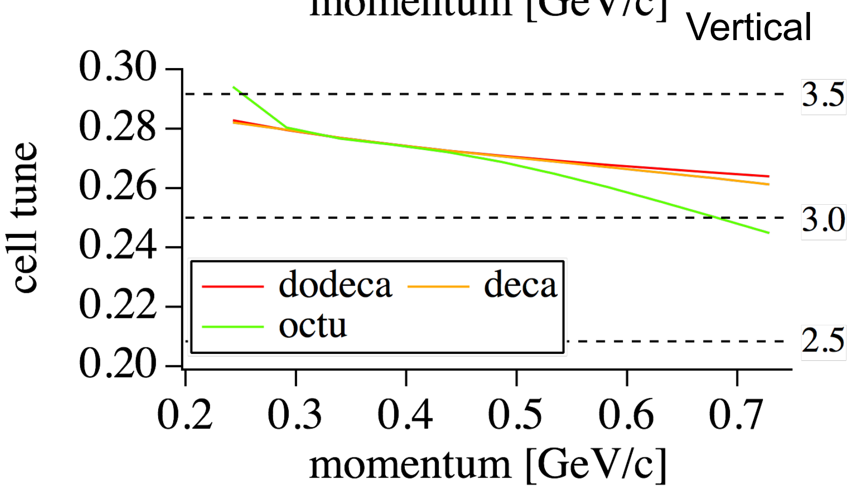
DESIGN – straight alignment



DYNAMICS: Tune variation

Total tune variation:
ΔQh=0.050
ΔQv= 0.250
(for decupole case)

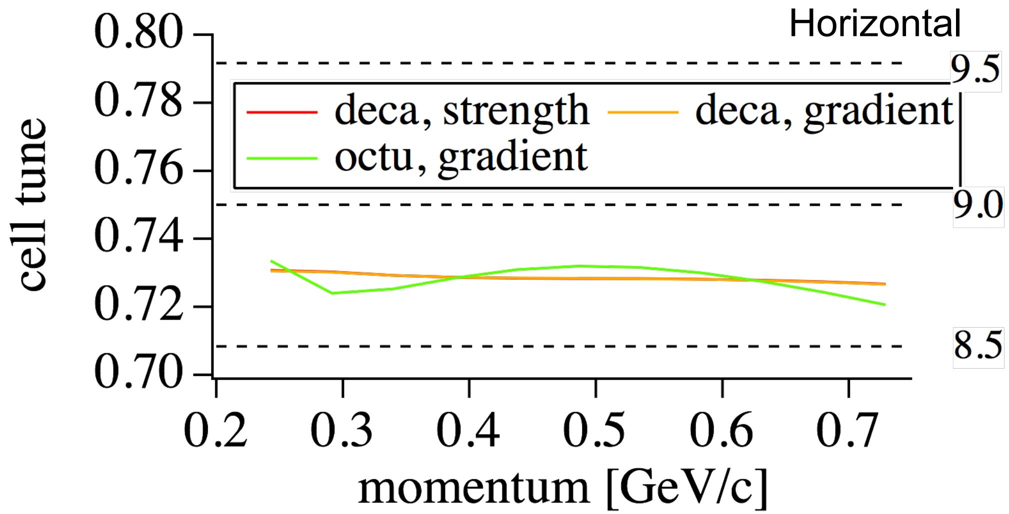


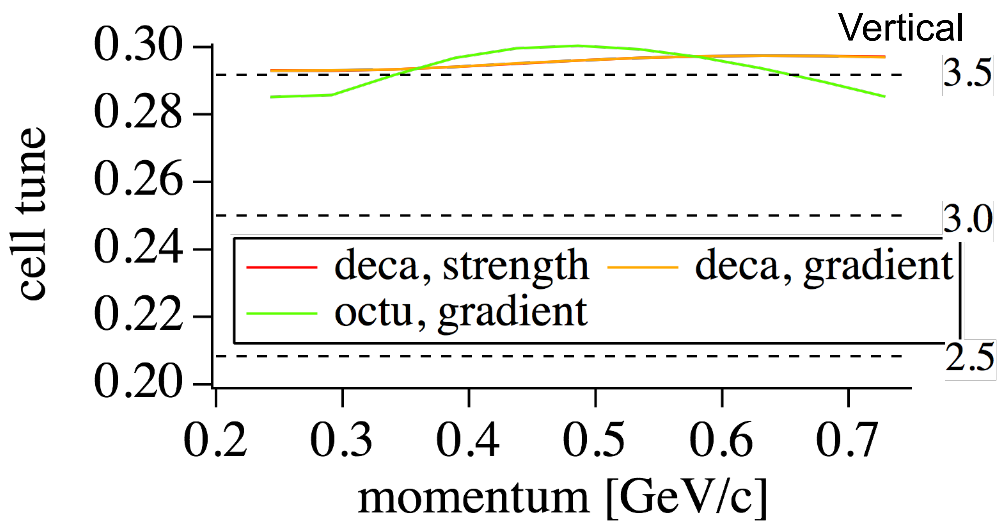


DYNAMICS: Tune variation

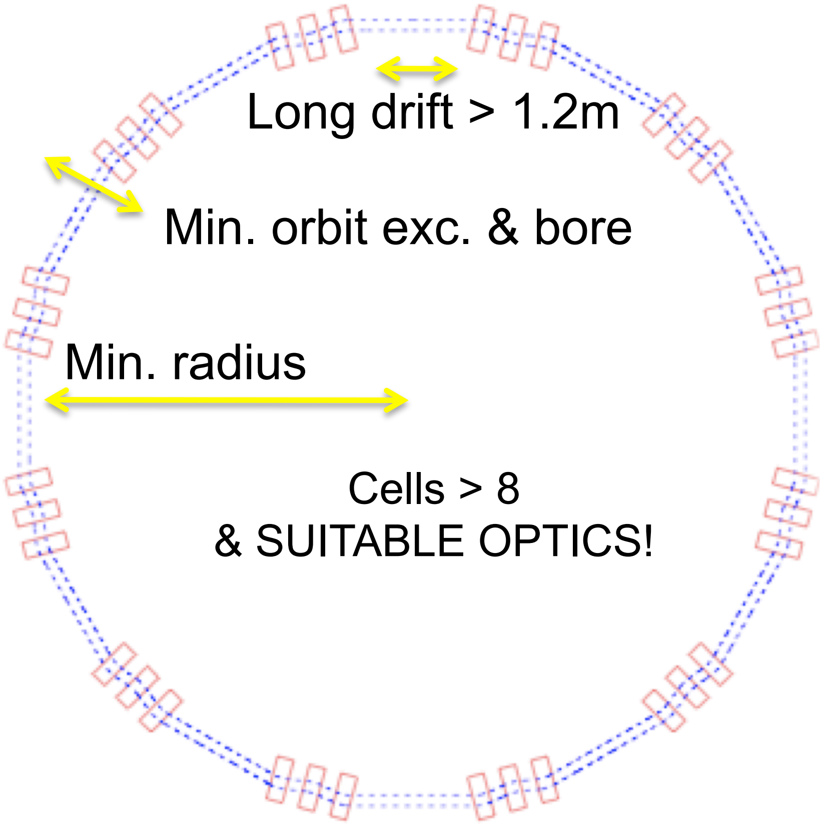
Total tune variation:
(for decupole case)
ΔQh=0.049,
ΔQv=0.054

Total tune variation:
(for octupole case)
ΔQh=0.156,
ΔQv=0.182



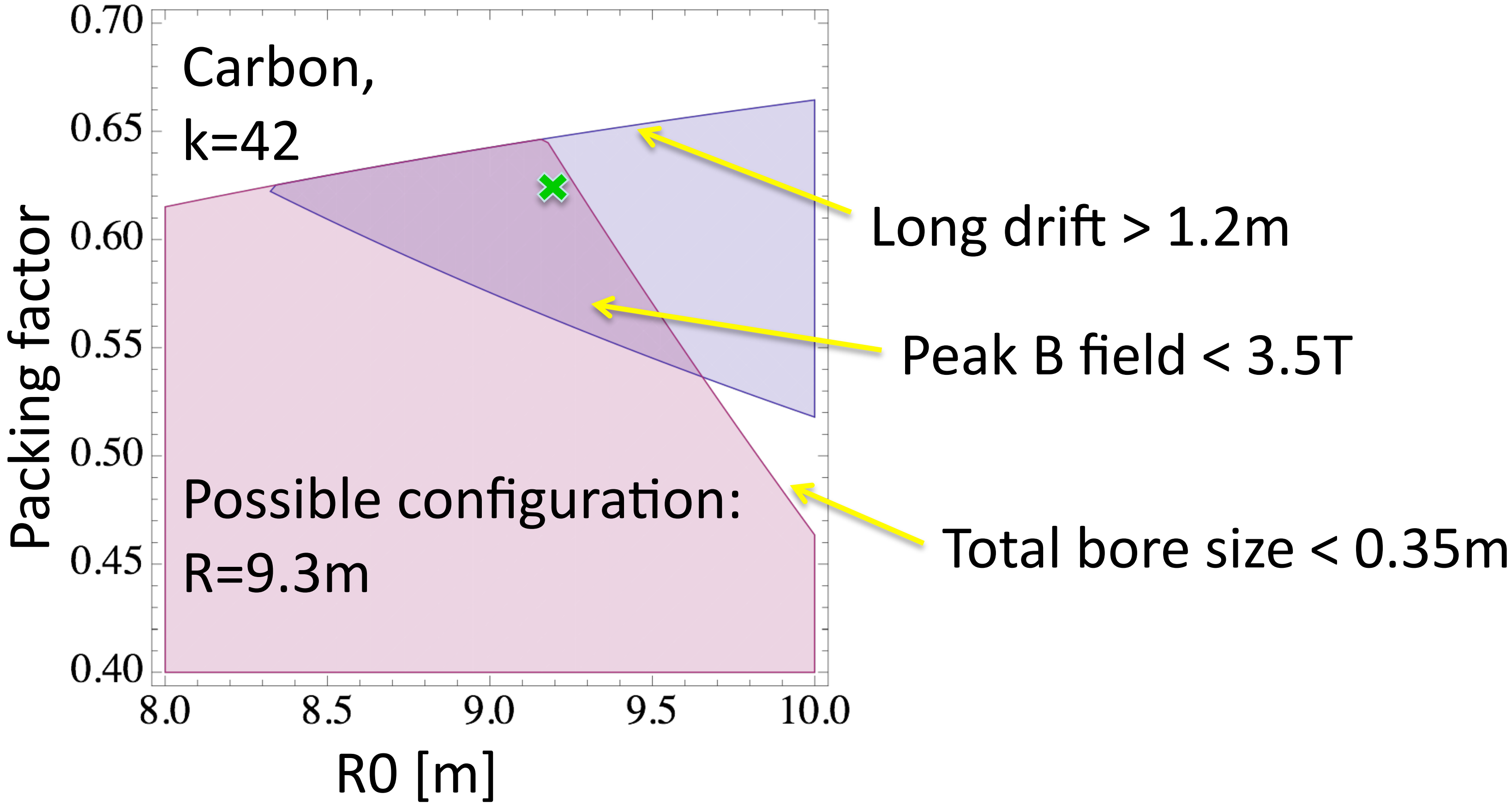


CARBON RING



Long drift > 1.2m
Min. orbit exc. & bore
Min. radius
Cells > 8
& SUITABLE OPTICS!

Carbon Ring


Carbon,
k=42
Possible configuration:
R=9.3m
Long drift > 1.2m
Peak B field < 3.5T
Total bore size < 0.35m
Packing factor
0.70
0.65
0.60
0.55
0.50
0.45
0.40
8.0
8.5
9.0
9.5
10.0
R0 [m]

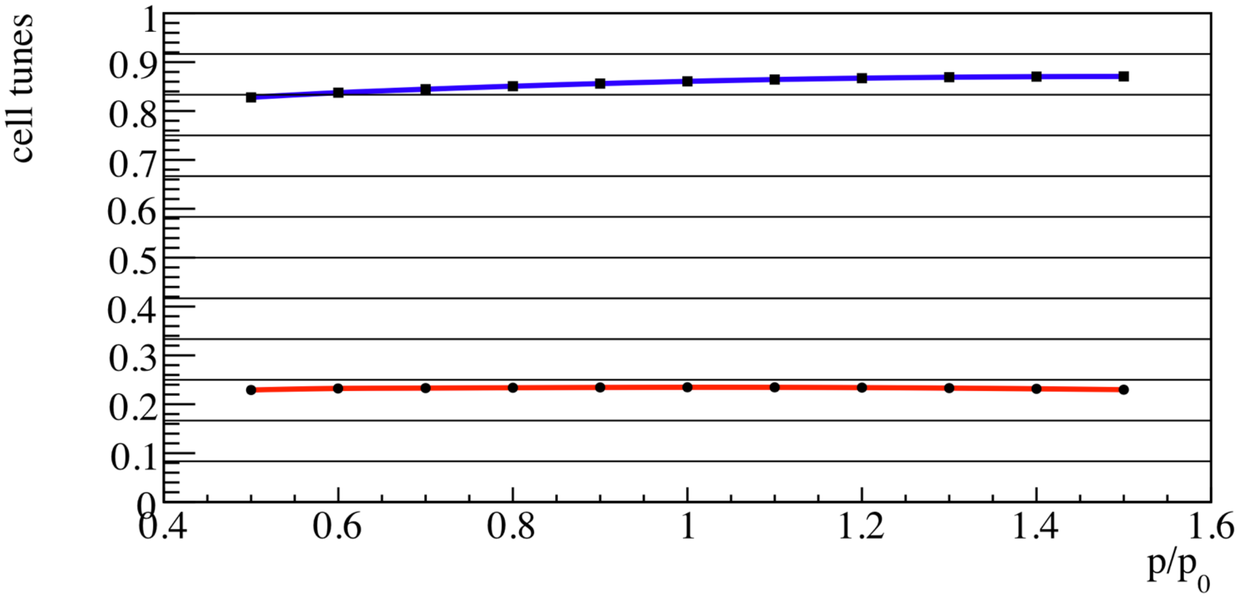
Carbon Ring

Total tune variation (before optimization)

- (for decupole case)

ΔQh=0.406,

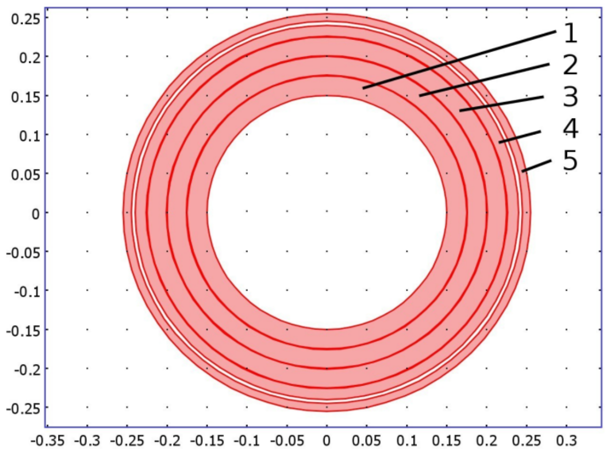
ΔQv=0.108

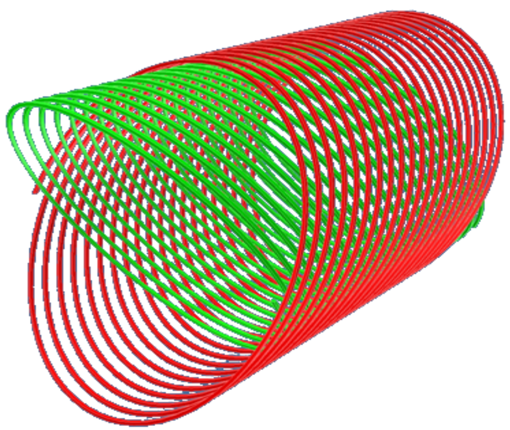


Parameter Table

Particle	H+			C6+				
Ring	1 inj	1 ref	1 extr	1 inj	1 ref	1 extr 2 inj	2 ref	2 extr
Kin. En./u [MeV]	30.95	118.38	**250**	7.8394	30.977	68.357	208.749	**400**
Bρ [Tm]	0.81071	1.62142	2.43213	0.81071	1.62142	2.43213	4.40092	6.36971
	Ring 1				**Ring 2: Option**			
Radius [m], pf	6.251, 0.48				9.3, 0.65			
K-value	38				42			
LSS [m] (real)	1.4506				1.1979			
SSS[m] (real)	0.0628				0.1266			
L(magnet,real) [m]	0.5656				1.1395			
Orbit exc. [m]	0.1834				0.2459			
Bore size [m]	~0.24				~0.35			

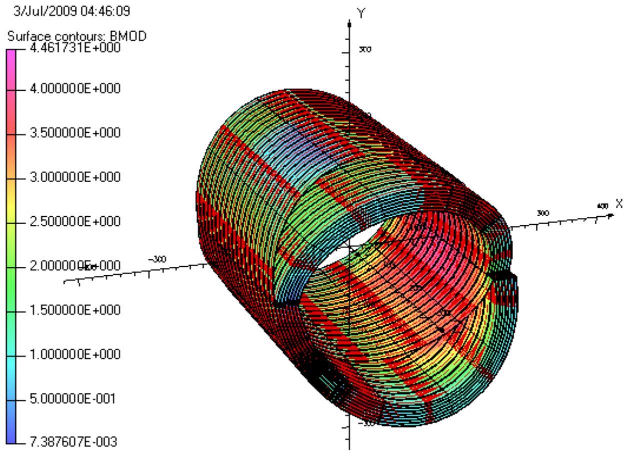
IMPLEMENTATION - Magnet Concept

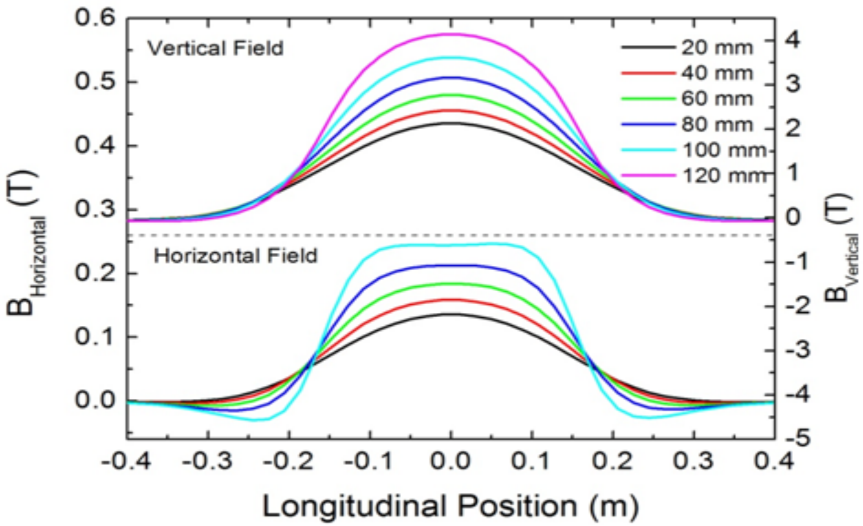




- Requirements
  - Multipole expansion of scaling law
  - Dipole to octupole/decapole field components
- Concept
  - Superconducting helical coils
  - Allows to create any multipole
  - 4 (5) separate helical coils nested in each other – allows tuning of multipoles
- Advantages
  - No nasty coil end effects
  - Excellent field quality
- Disadvantages
  - Winding scheme more complicated

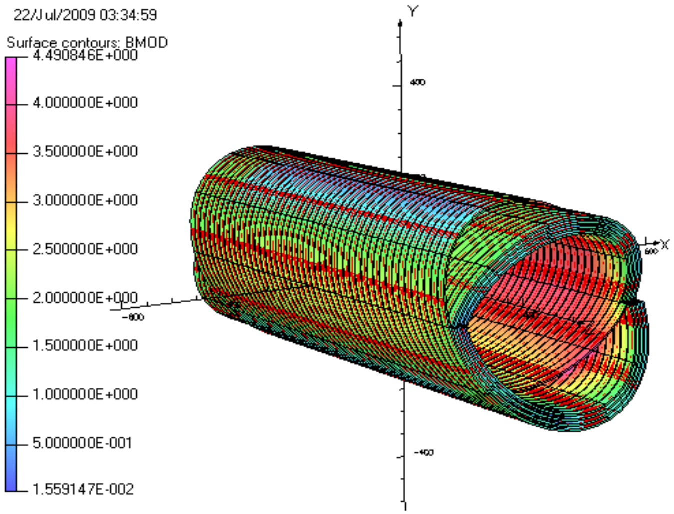
Magnets for Proton Ring

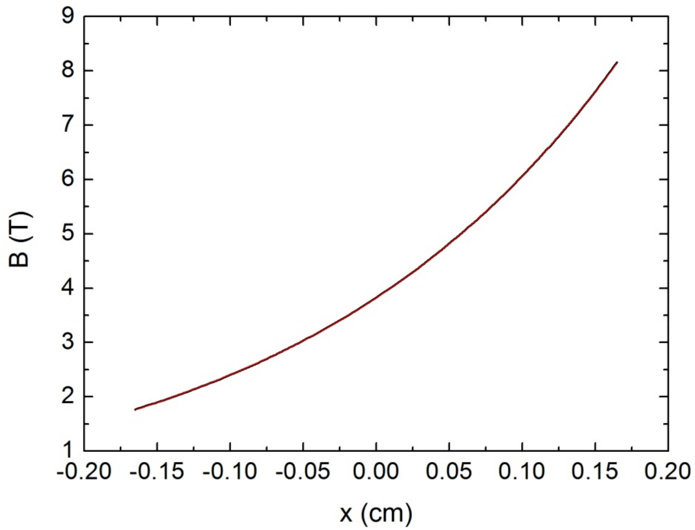




- Two designs
  - Rutherford cable
  - Single filament
- Dimensions
  - Length < 560 mm
  - Bore 280 mm
- Magnetic energy: 200 kJ
- Temperature margins >1.6K
- Current densities: Lower than 300 A/mm^2
- $B_{peak,\ wire}$<5.05T
- NbTi superconductor
  - Cu:Sc ratio 1.3:1
  - OST 54 filament standard conductor
- Preferred solution: Single filament
  - Lower current – better for current feed throughs

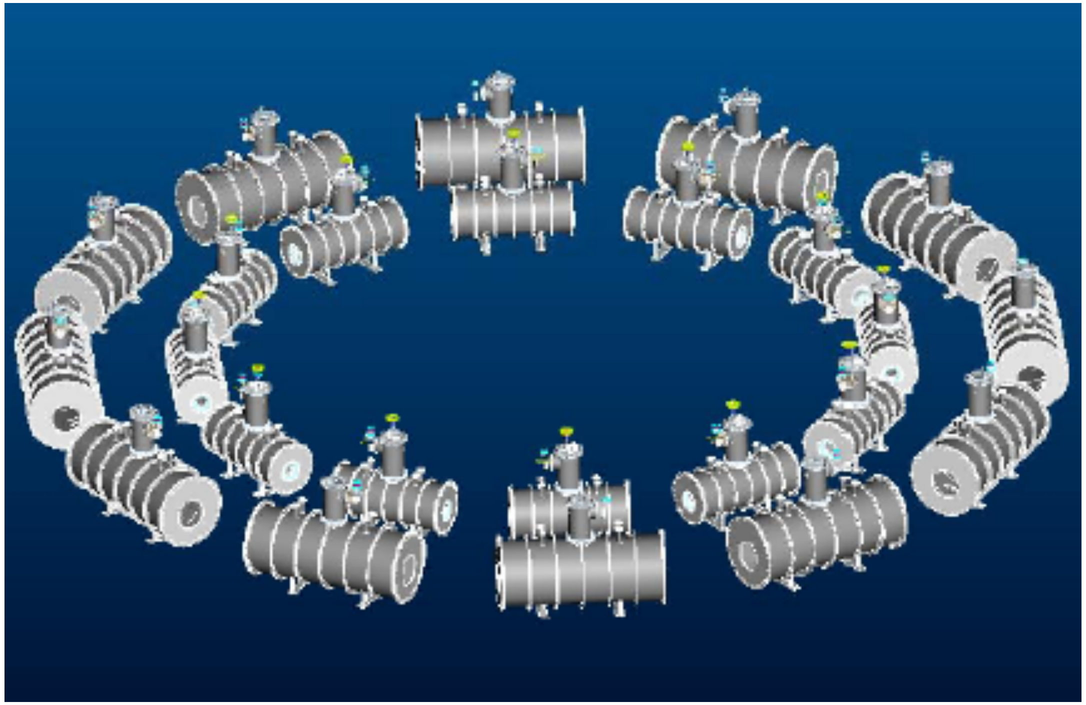
Carbon Lattice





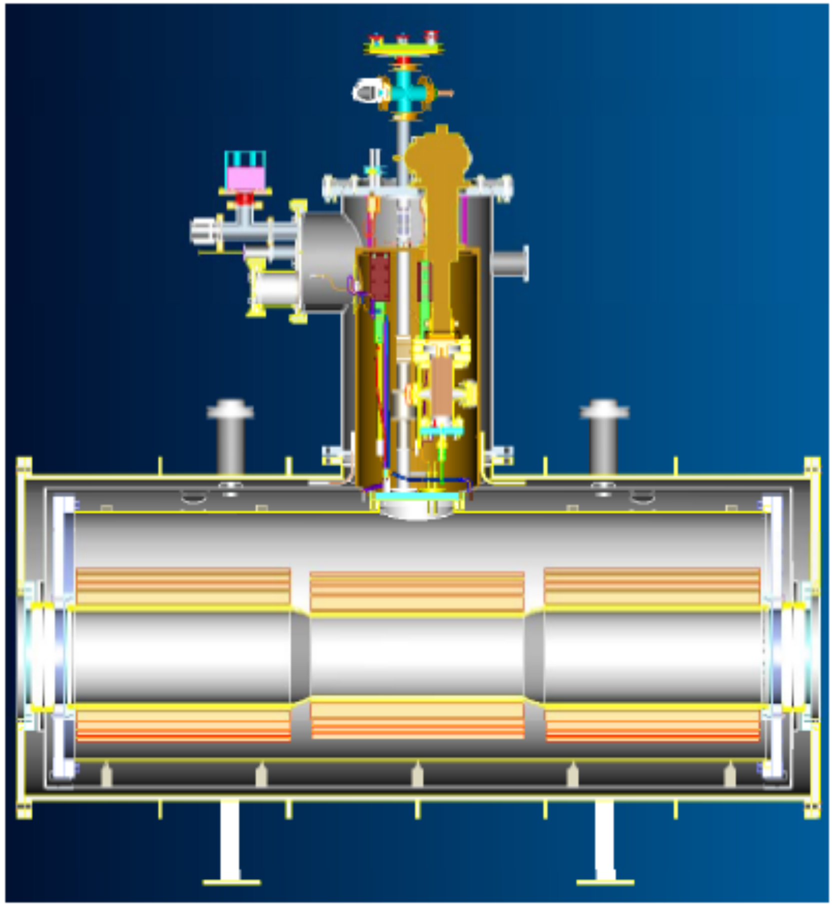
- (Preliminary design)
- Dimensions
  - Length: <1200 mm
  - Bore 340 mm
  - Magnetic length: 445 mm
- $B_{peak,\ wire}$<4.8 T
- Current density < 240 A/mm^2
- Cu:Sc ratio 1.3:1
- Temperature margins: >2K

Cryostat

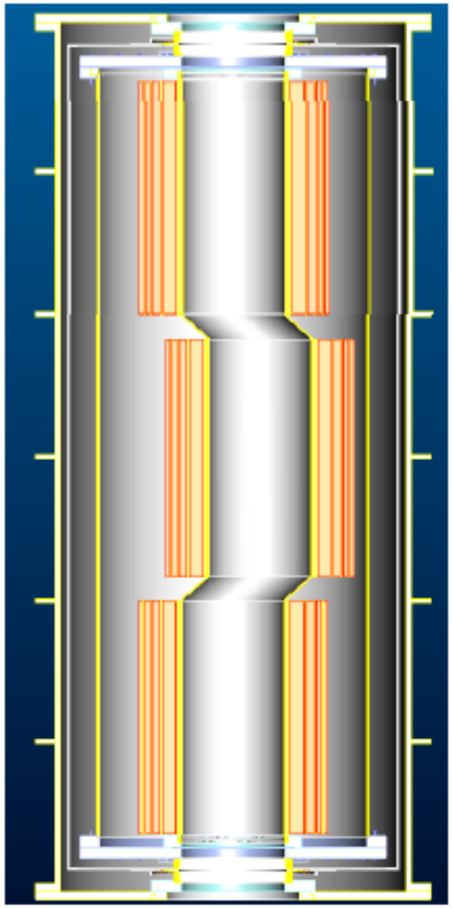


- Concept: Recondensing bath cryostat

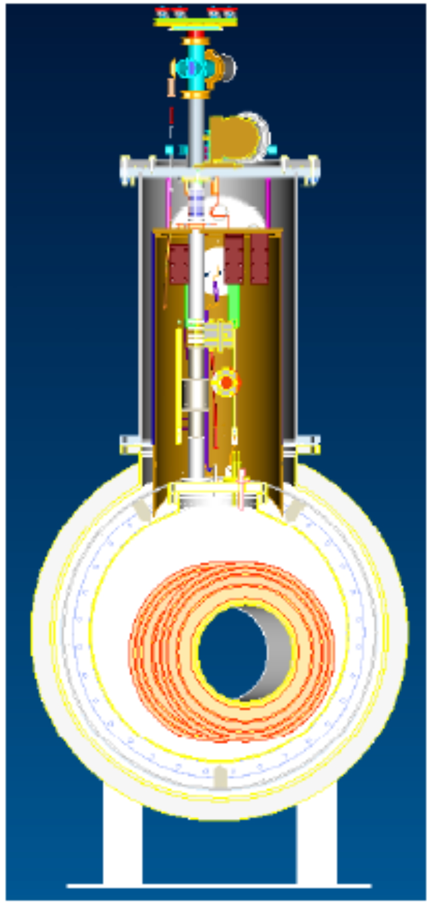
Courtesy of Neil Bliss and Shrikant Pattalwar (STFC Daresbury)



Elevation



Plan



End

Courtesy of Neil Bliss and Shrikant Pattalwar (STFC Daresbury)