IOTA Design

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Input from
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IOTA Review

Outline

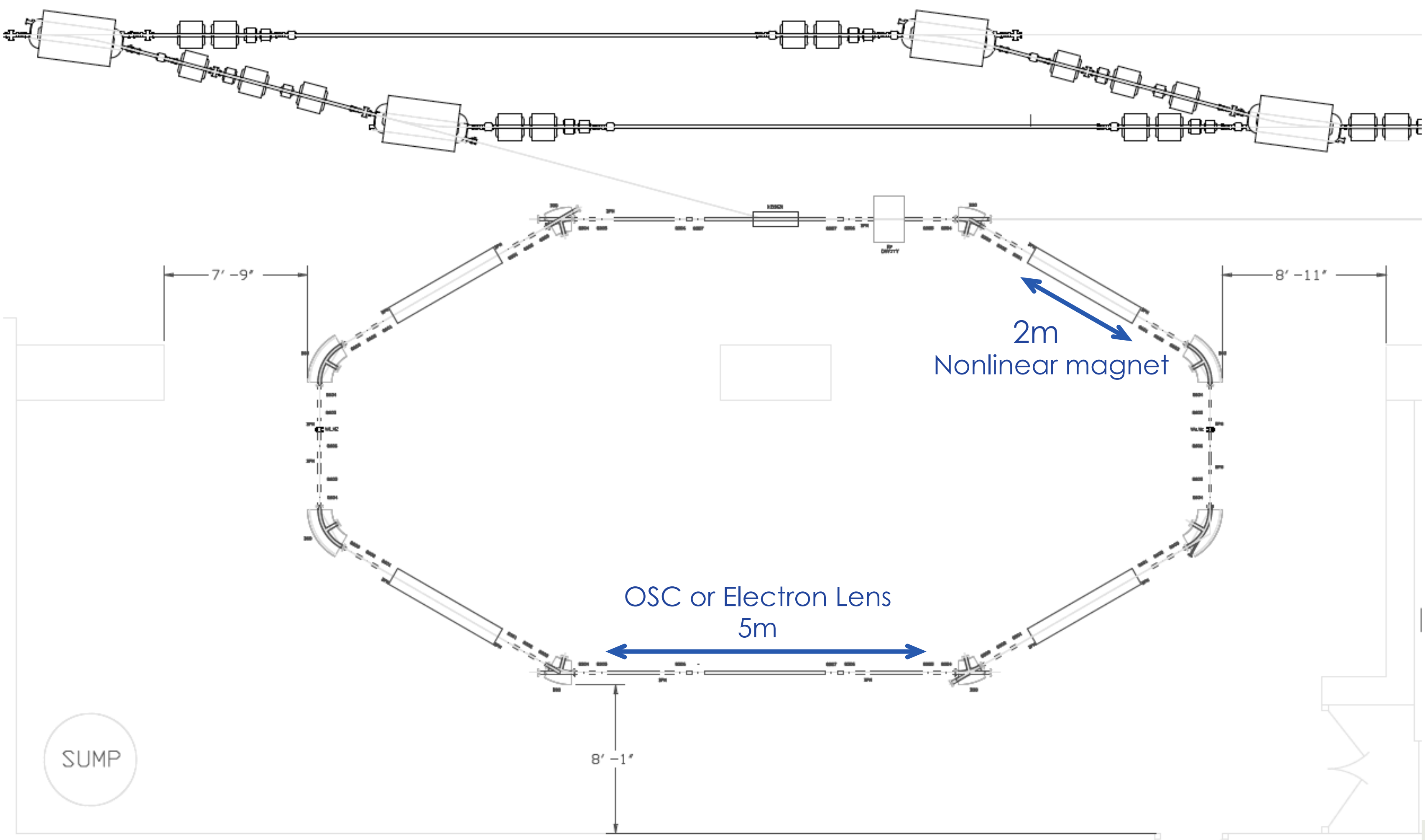
- Design goals
- Layout and Lattice Options
  - Thin electron lens (Experiment 1)
  - Thick electron lens (Exp. 2)
  - Octupoles and special magnets (Exp. 3,4)
  - Corrections
- Systems
  - Power supplies
  - Diagnostics
  - RF
  - Vacuum
  - Nonlinear magnet

Design Goals

- Machine lattice must provide enough flexibility to accommodate
  - An Electron Lens (2 m)
  - 1, 2, or 4 sections for nonlinear magnets (2 m each), and corresponding number of elements of periodicity
  - Optical stochastic cooling (5 m for undulators and chicane)
- Since we intend to sample the nonlinearities with a pencil beam
  - machine aperture must be large enough -beam pipe D=2”
  - must have a h-v kicker
- The machine must fit in the hall area
- Be inexpensive and reuse components from the Tevatron

IOTA Layout

- In the ultimate integrable optics scenario 4 elements of periodicity (cells) with 4 2m-long drifts for nonlinear magnets
- 5m-long straight section for the Optical Stochastic Cooling experiment.

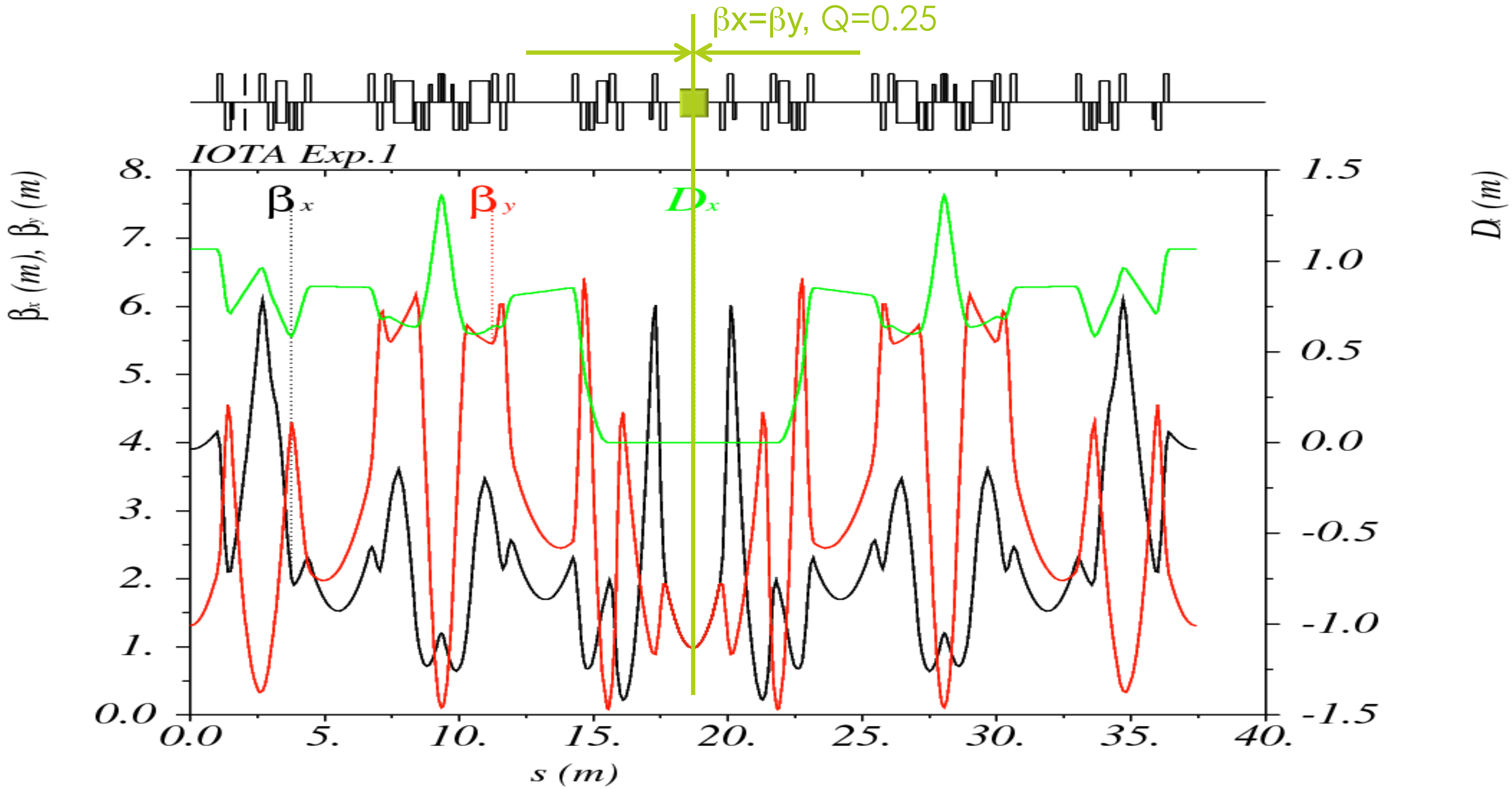


IOTA Parameters

Parameter	Value
Nominal beam energy	150 MeV(γ=295)
Nominal beam intensity	1×10^9
Circumference	38.7 m
Bending field	0.7 T
Beam pipe aperture	50 mm dia.
Maximum β-function	6 ÷ 9 m
Momentum compaction	0.015 ÷ 0.1
Betatron tune	3.5 ÷ 7.2
Natural chromaticity	-5 ÷ -10
Transverse emittance r.m.s.	0.02 ÷ 0.08 μm
SR damping time	0.5s (5×10^6 turns)
RF V,f,q	75 kV, 162.5 MHz, 21
Synchrotron tune	0.005 ÷ 0.01

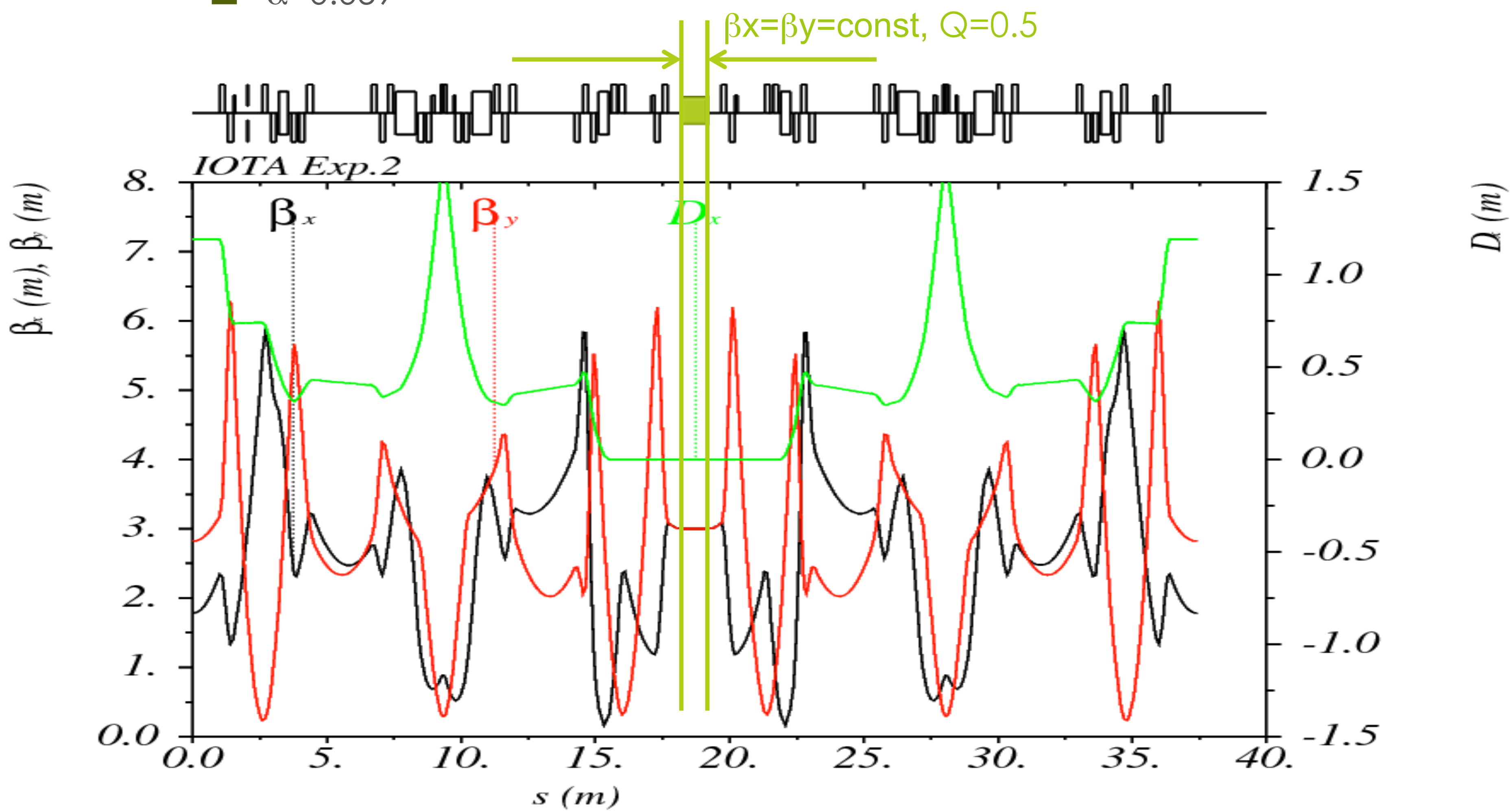
Thin ELens Lattice (Exp. 1)

- Equal beta-functions, tunes Qx=3.75 Qy=4.25
- Dispersion=0 in the ELens
- Maximum amplitude in the ELens=10 mm
- α=0.09



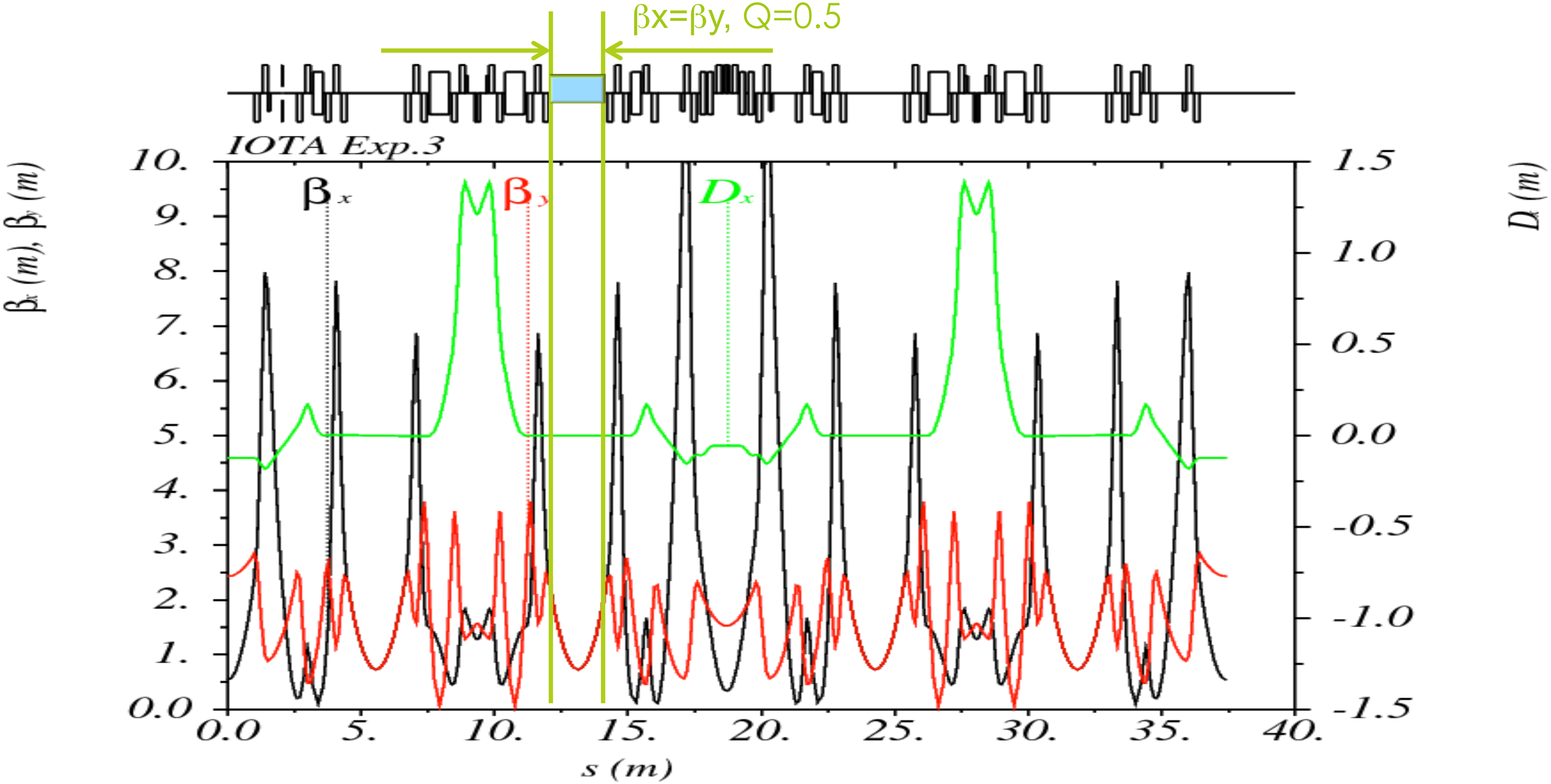
Thick ELens Lattice (Exp. 2)

- Equal beta-functions, matched in the solenoid. Qx=3.5, Qy=3.5+0.1
- Dispersion=0 in the ELens
- Maximum amplitude in the ELens=17 mm
- α=0.059



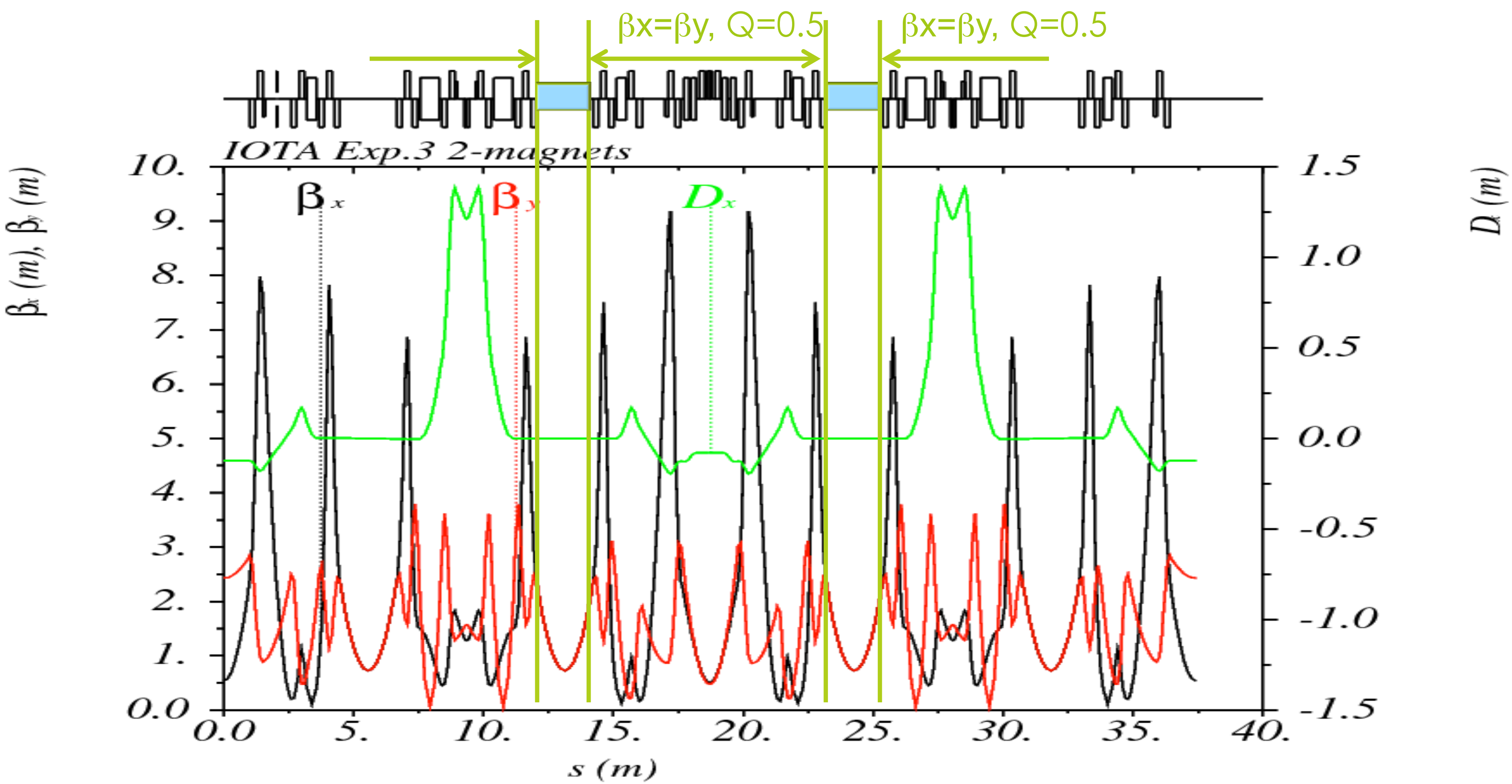
1-Magnet Lattice (Exp. 3-4)

- Equal beta-functions, Qx=6.5+0.3, Qy=5.5+0.3
- Dispersion=0 in the Nonlinear Magnet
- Maximum Vertical amplitude in the NM=11 mm
- α=0.015



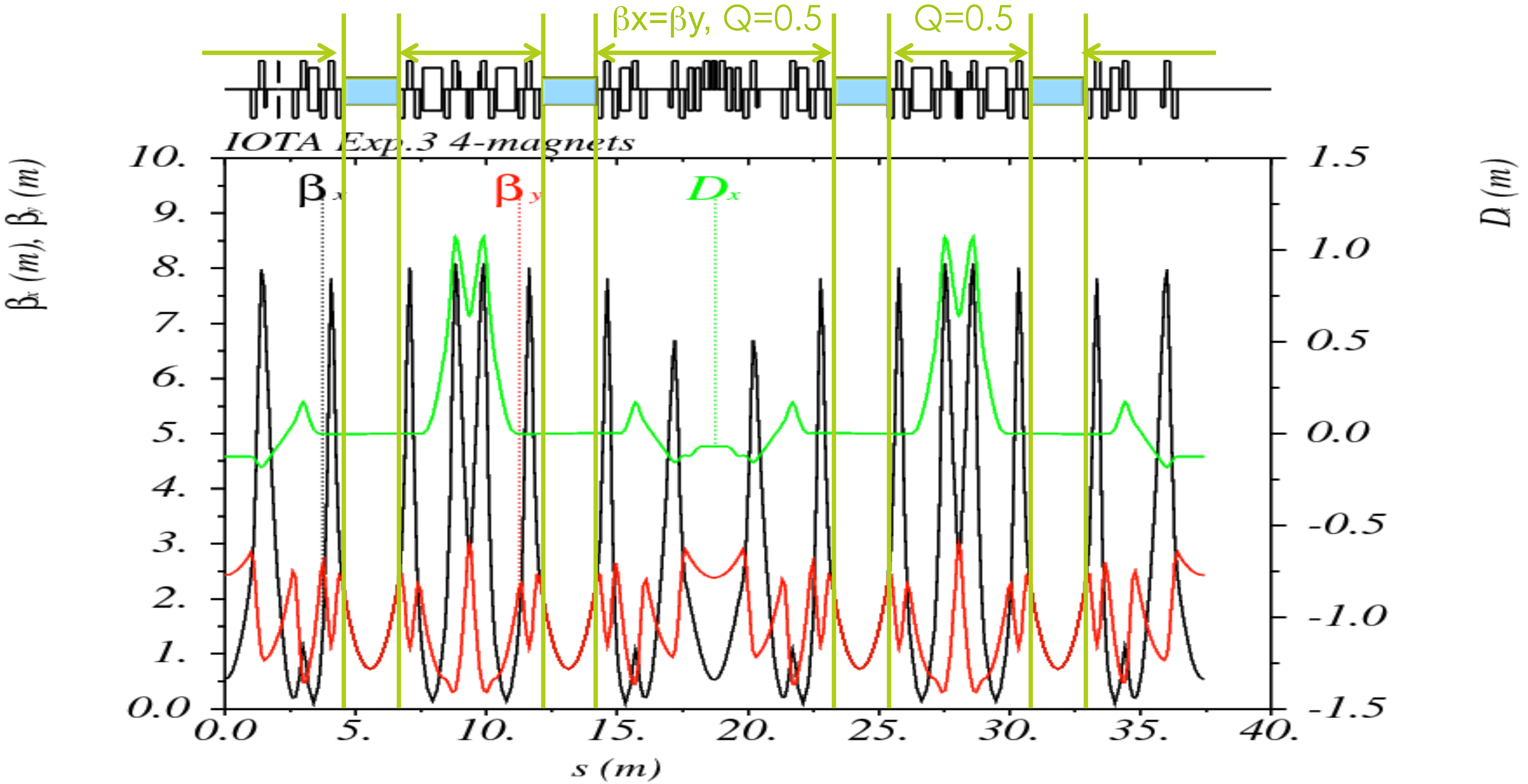
2-Magnet Lattice (Exp. 3-4)

- Equal beta-functions, Qx=6.0+0.3×2, Qy=5.5+0.3×2
- Dispersion=0 in the Nonlinear Magnet
- Maximum Vertical amplitude in the NM=11 mm
- α=0.015



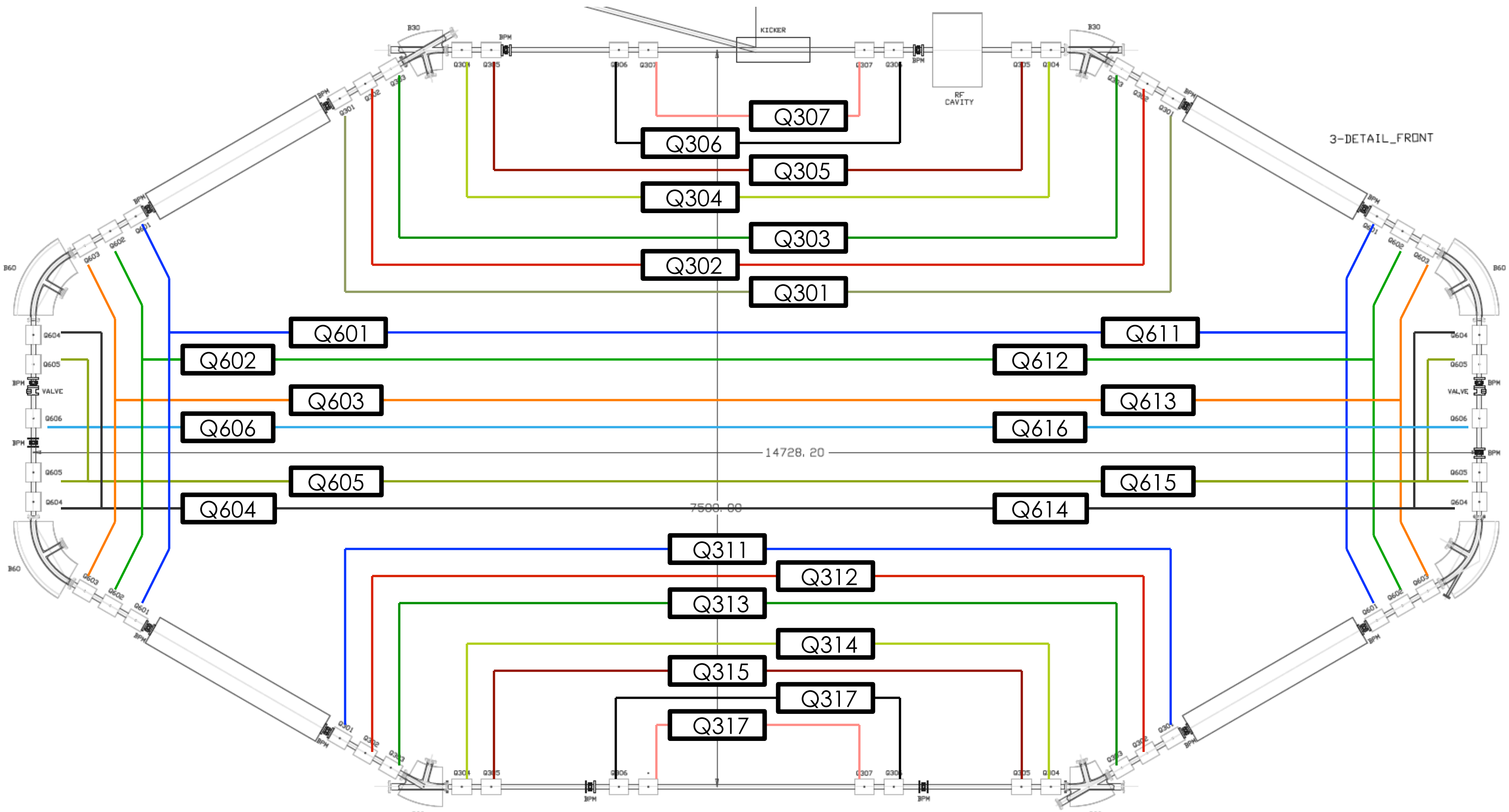
4-Magnet Lattice (Exp. 3-4)

- Equal beta-functions, Qx=5.0+0.3×4, Qy=4.0+0.3×4
- Dispersion=0 in the Nonlinear Magnet
- Maximum Vertical amplitude in the NM=11 mm
- α=0.015



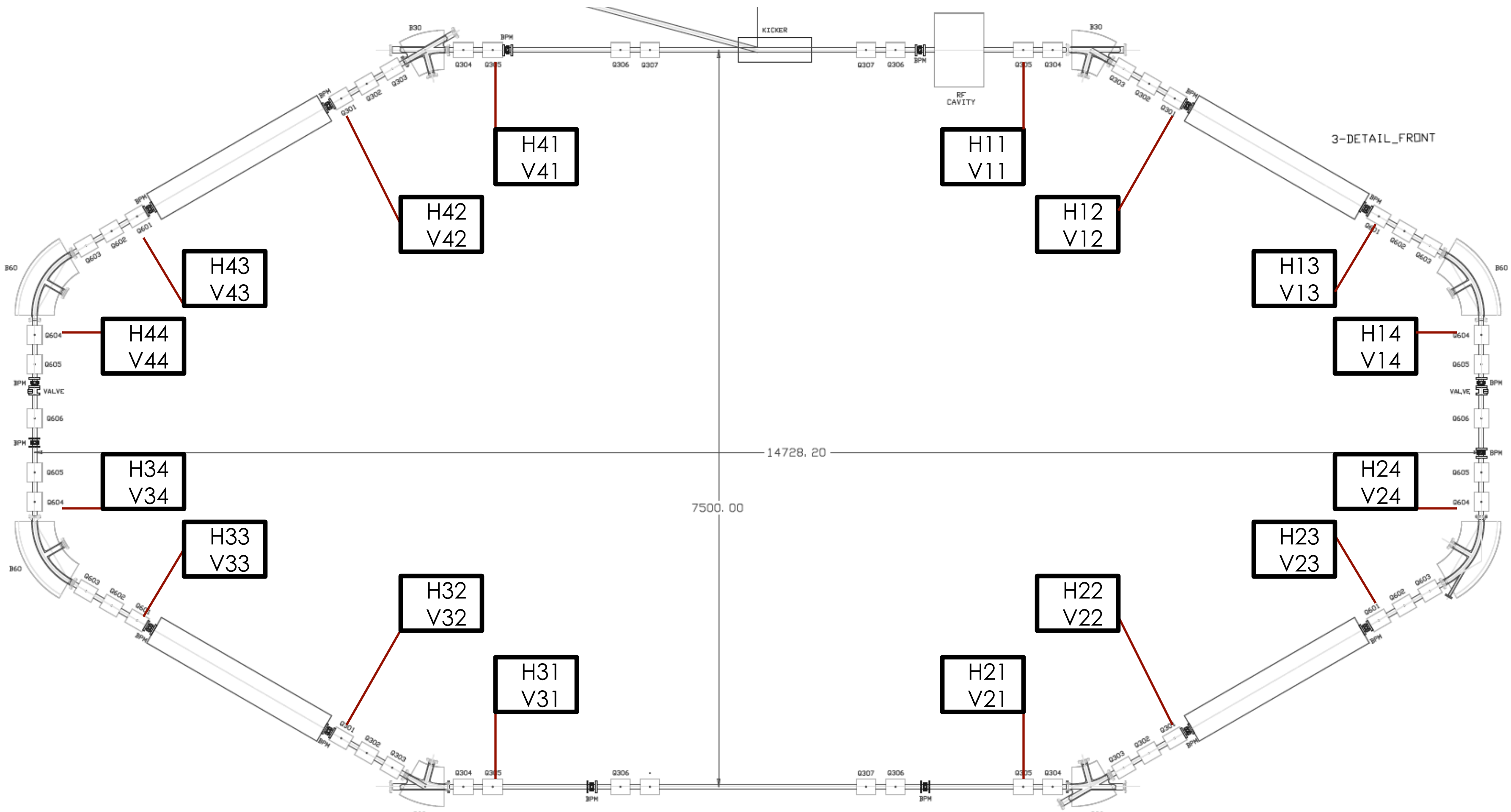
Quadrupole Circuits

- The ring has 50 quadrupoles
- The above lattices were obtained with 20 quad families
- To allow even more flexibility, 27 families could be used



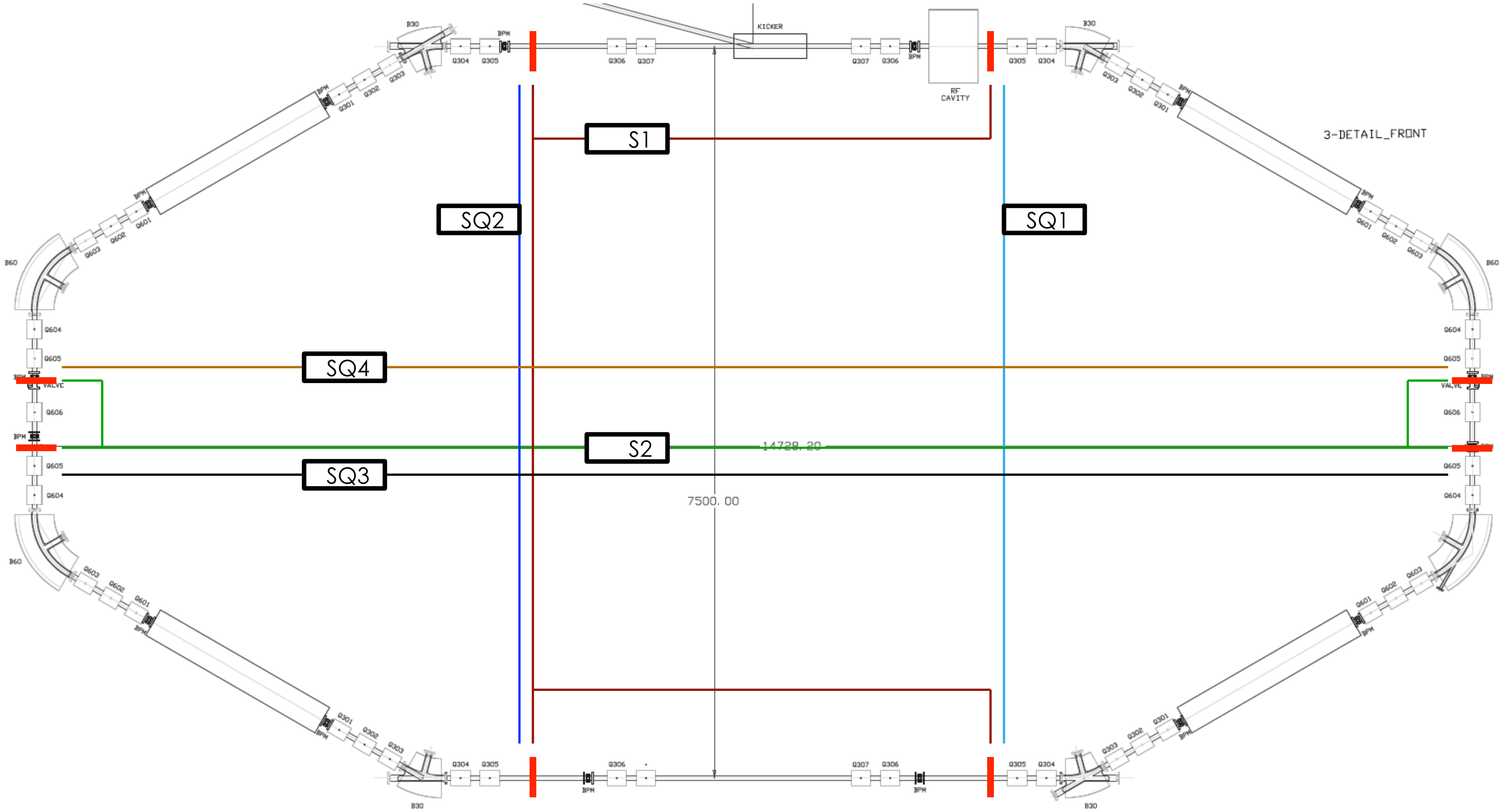
Dipole Correctors

- Orbit correctors will be incorporated into quadrupoles as additional coils.
  - 16 H and 16 V correctors



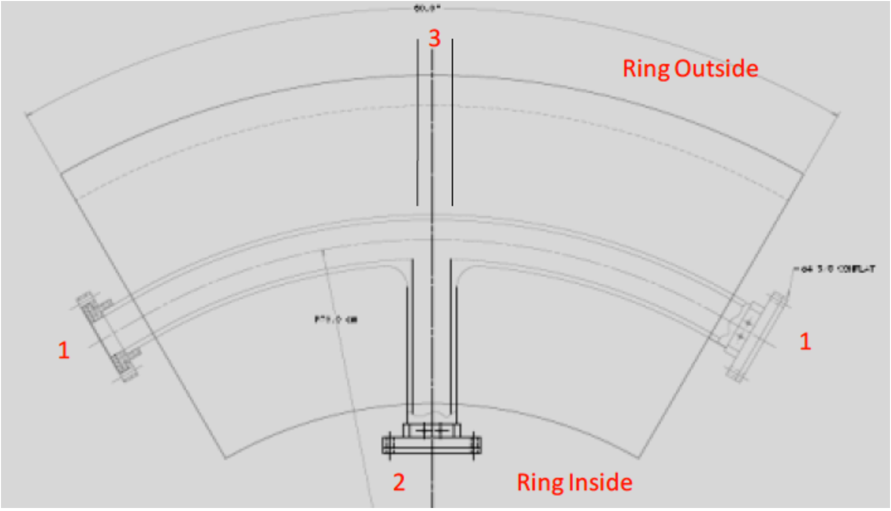
Coupling and Chromaticity

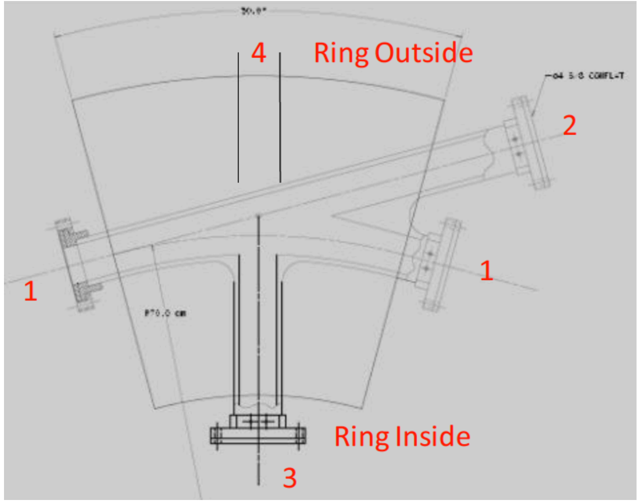
- Sextupoles and skew-quadrupoles combined.
  - 2 sextupole families
  - 4 skew families
- No coupling correction in the NM straights – beam-based quad alignment.



Dipole Magnet Parameters

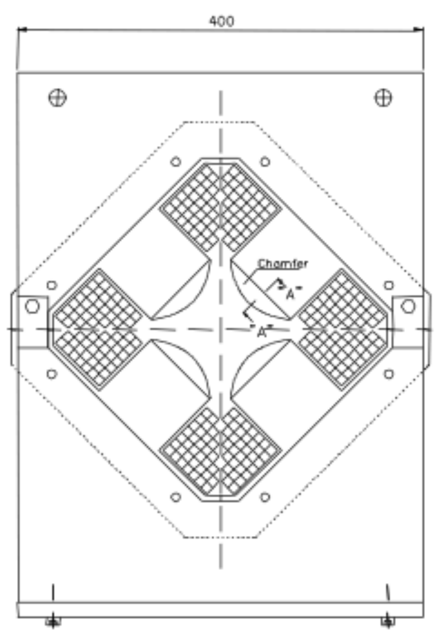
- 4-30° and 4-60° magnets
- C-shaped (vacuum pump port)
- B=0.7, R=0.7m, gap=66 mm, good field aperture 48 mm (10^{-3})
- I=200A, 650V(130 kW)
  - 190 turns, 0.5Ω for 60°
  - Will be powered by a single 300A/800V PS
  - In the process of requesting quotes

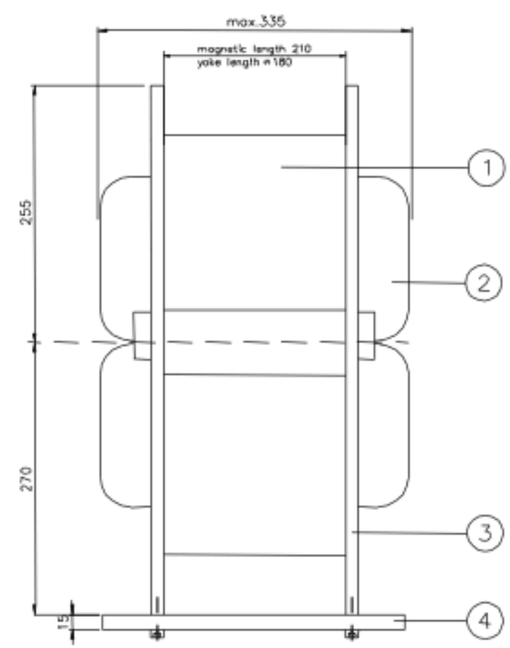




Quadrupole Magnet Parameters

- 50 quadrupoles
- 20 cm length, bore 54 mm, good field aperture 48 mm (10^{-3})
- G=20 T/m
- I=200A, 15V (3 kW) each
  - 27 turns, 0.02Ω
  - 20 200A/60V power supplies (200A/275V are available)
  - 32 AmPS quadrupoles may be available at JINR, requesting quotes



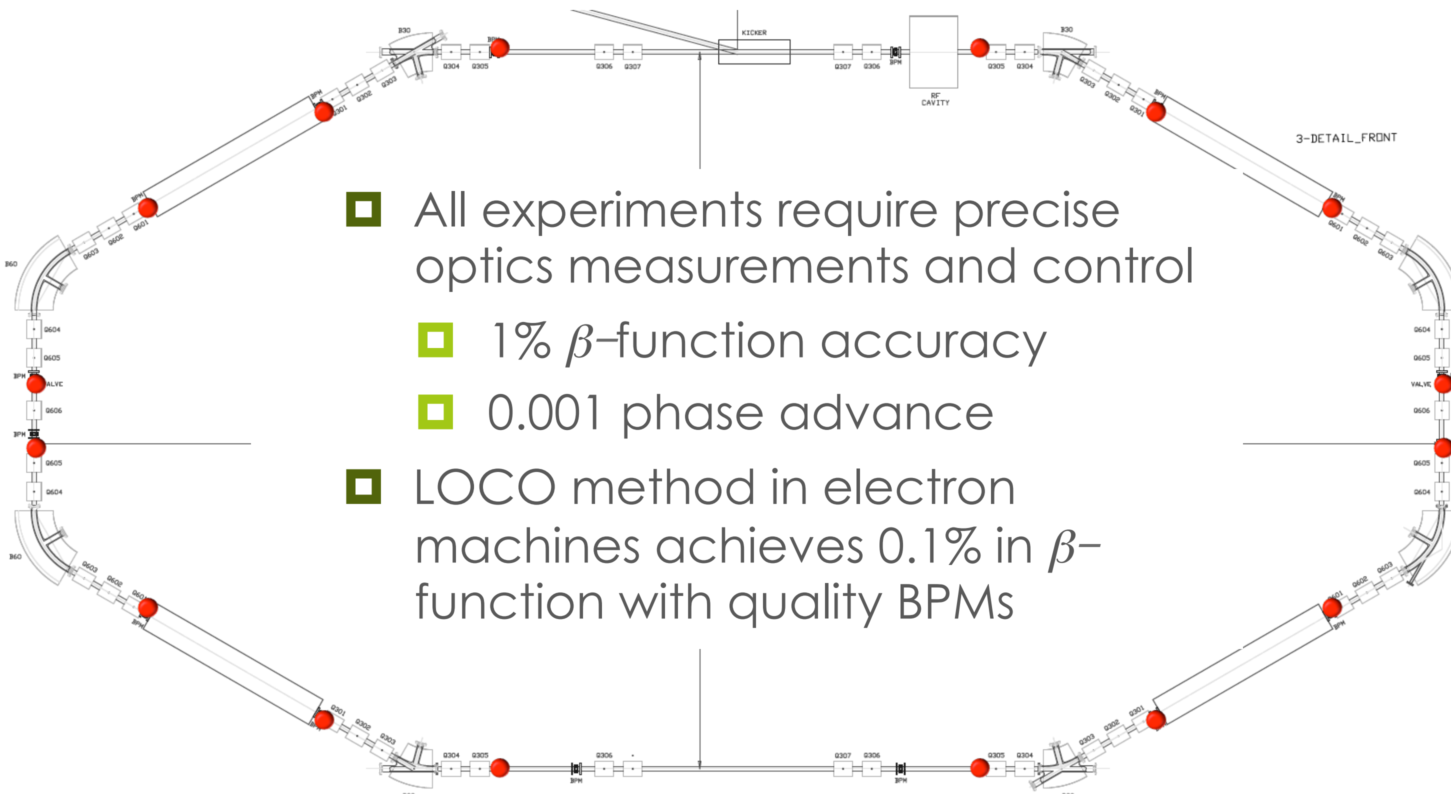


Corrector Parameters

- 32 dipole correctors, 4 skew, 16 quad correctors
- Air-cooled coils: 2A/5V
  - 270 turns
  - 2.5×10^{-3} T×m
- Power supplies from E-Cool: ±15V, 2A
- Cable also available

Diagnostics

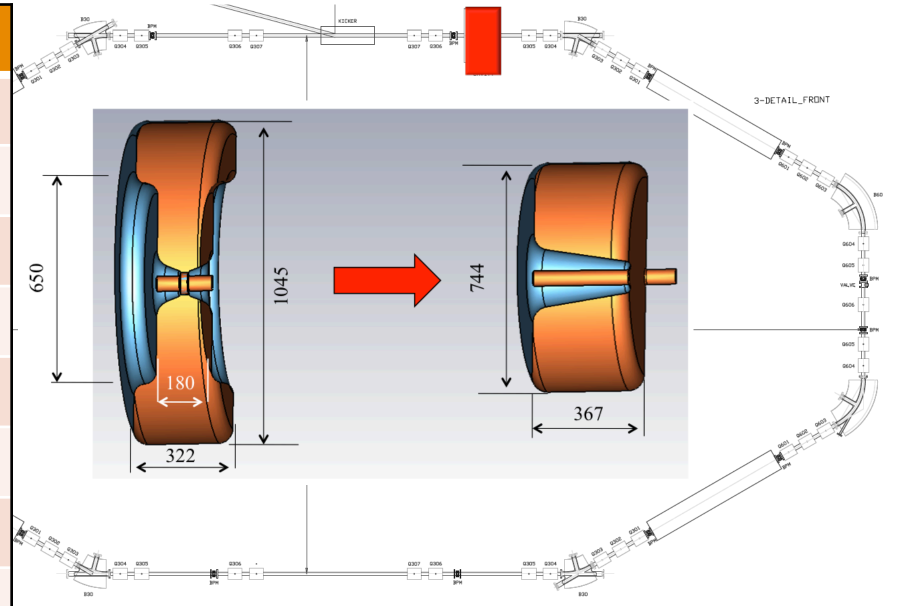
- 16-H and 16-V BPMs
  - Button-type
  - 1μm closed-orbit resolution
  - 100μm turn-by-turn resolution
  - Components have been procured
- Current gauge
- 4 SR ports for beam size measurement

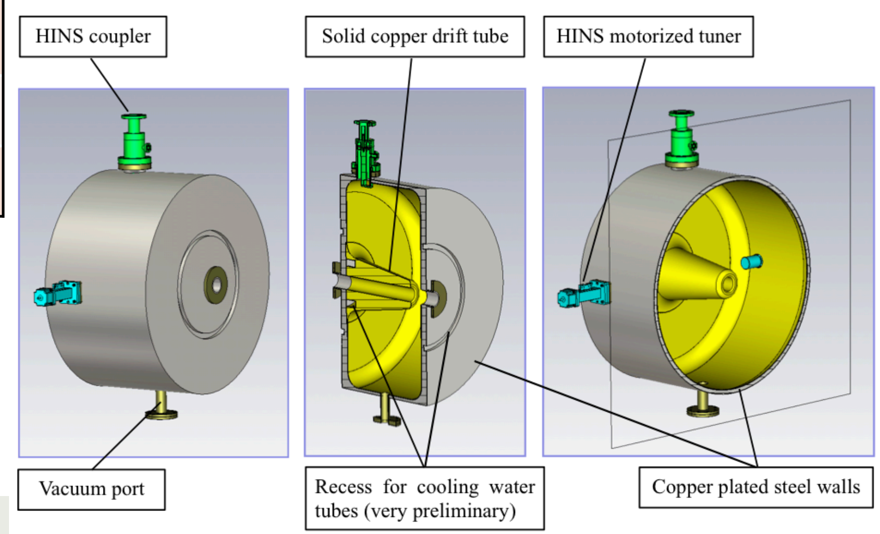


- All experiments require precise optics measurements and control
  - 1% β–function accuracy
  - 0.001 phase advance
- LOCO method in electron machines achieves 0.1% in β–function with quality BPMs

RF Cavity

Parameter	Value
Frequency, MHz	162.5
Q factor	30245
Aperture radius, mm	25
Gap, mm	50
Electron relative velocity, β	1
Effect. shunt impedance, Ohm	6.9e6
Max. energy gain, kV	75
Power (losses in copper) , kW	0.82
Max. electric surface field, MV/m	1.6
Flange to flange distance, mm	500
Tuning range, kHz	420

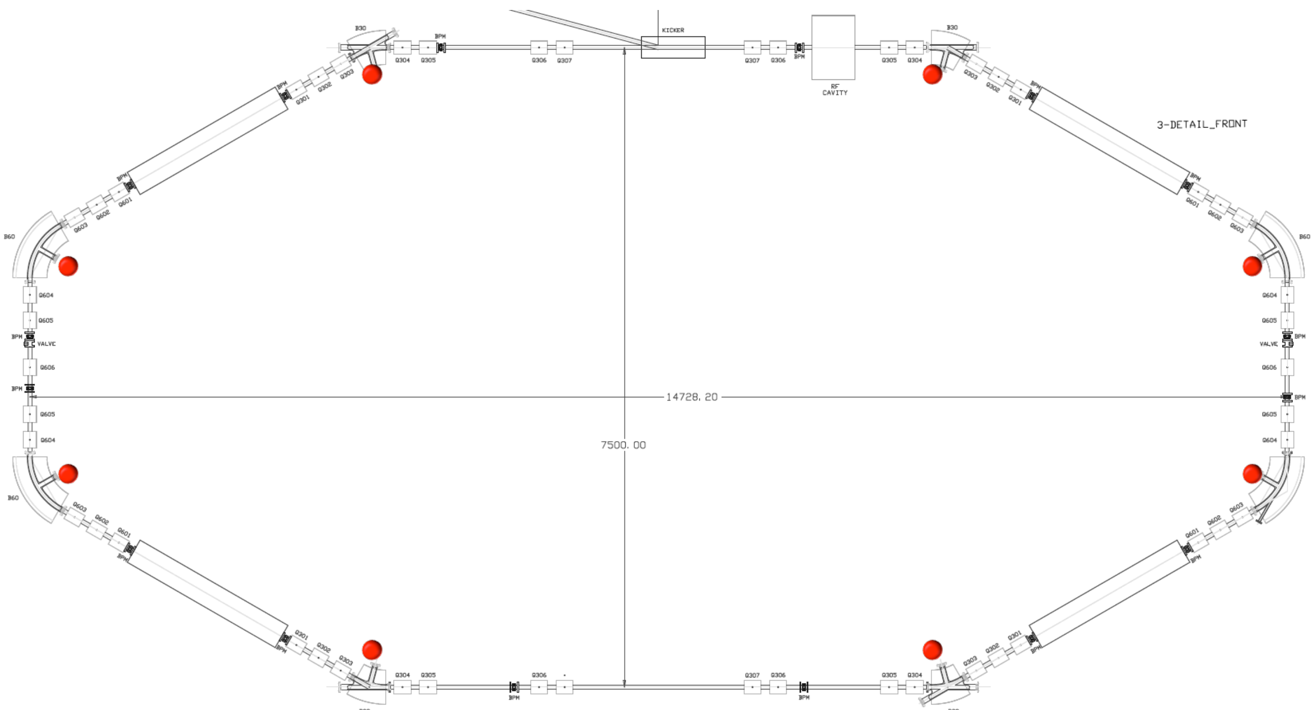




G. Romanov

Vacuum System

- Experiments with O.S.C. require good beam life time (≈0.5 h)
  - Vacuum requirements: Ar 3×10^{-9}, CO+H2 3×10^{-8} Torr
  - Baking required
- 8 vacuum pumps – in dipoles
- 2 gate valves
- Components purchased in 2011

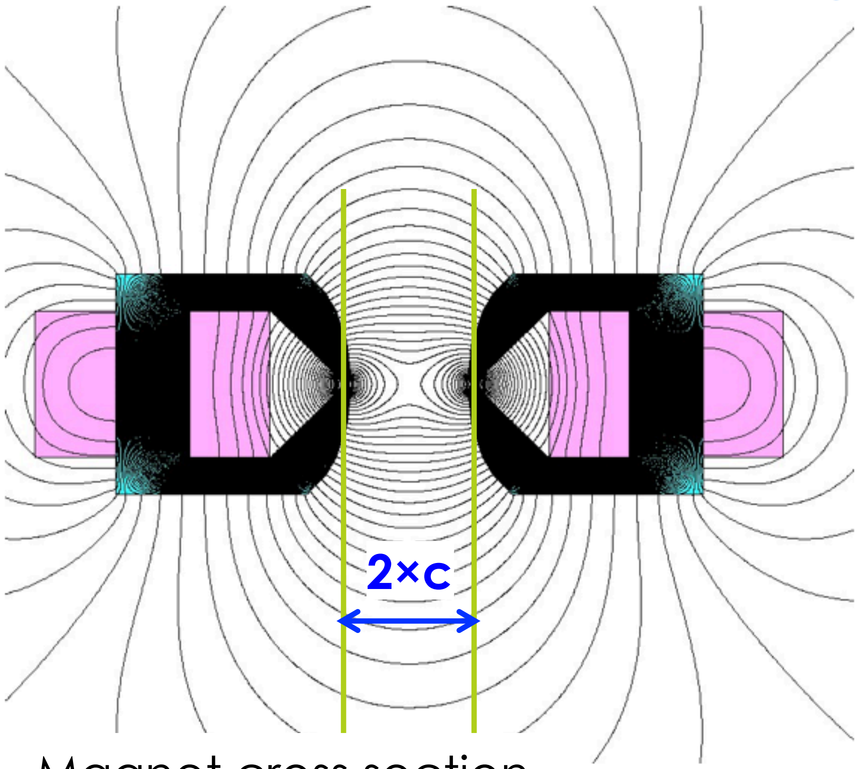


Kicker

- Injection in the horizontal plane
  - Orbit bump + magnetic septum + strip-line kicker
  - No need for multi-bunch injection or top-up
  - No extraction envisaged
- Experiments on non-linear optics require H+V kicker
  - 1 m-long 50Ω H+V strip-line, 50 mm gap
  - 10 kV pulse, rise-time 50 ns. No need for rep. rate

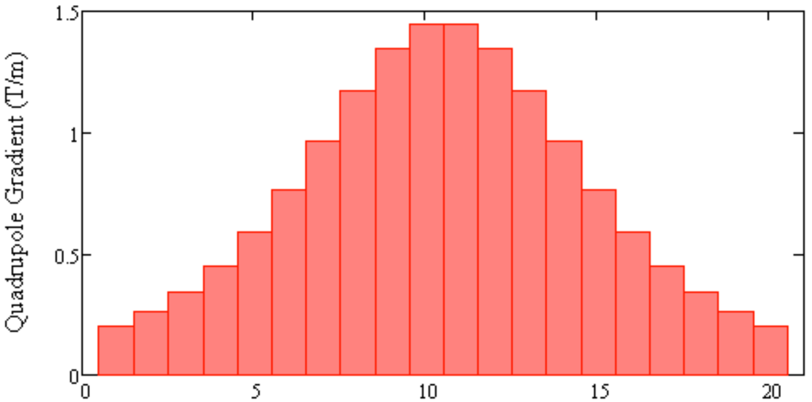
Nonlinear Magnet

- Practical design – approximate continuously-varying potential with constant cross-section short magnets

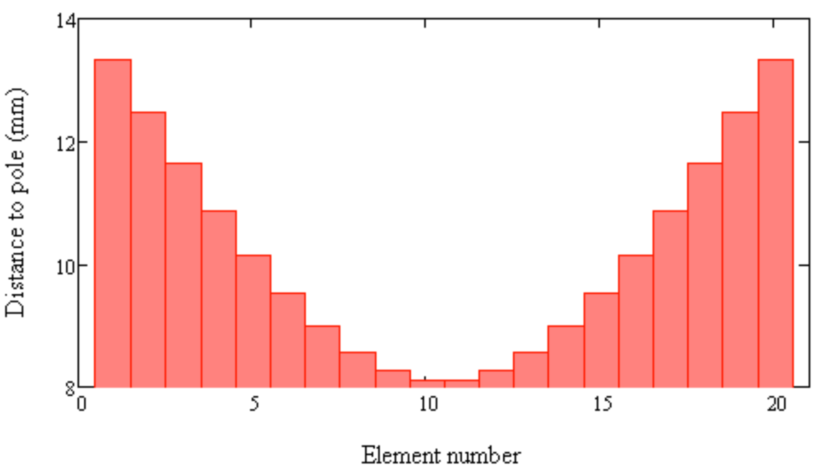


Magnet cross section
V.Kashikhin

Quadrupole component of nonlinear field



Distance to pole **c**



Comment on Magnet Aperture

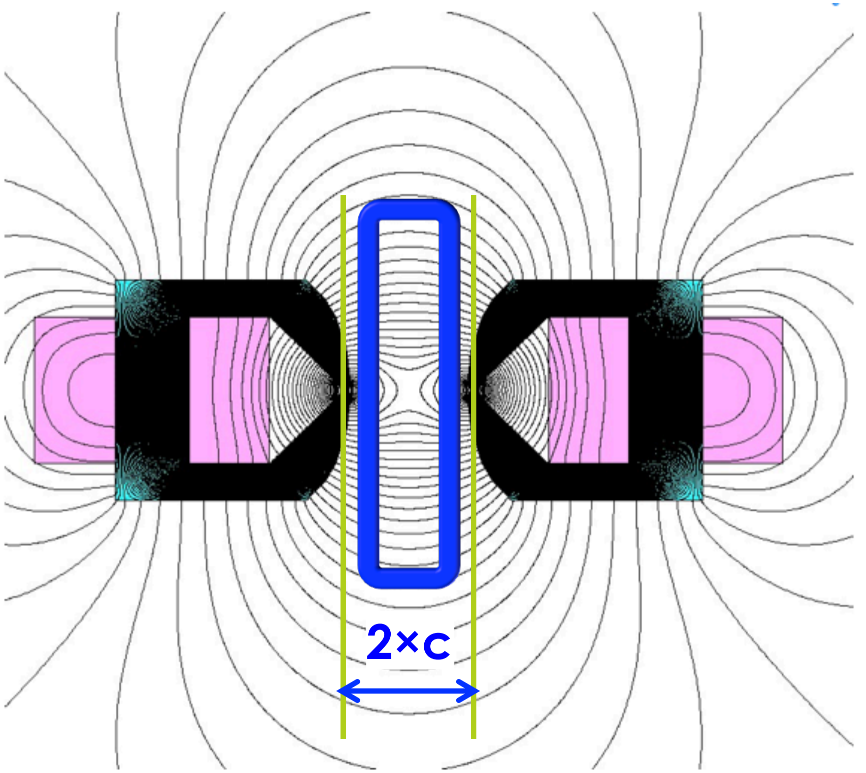
- In order to sample the nonlinearity and achieve high tune shifts, one needs to create vertical oscillation amplitudes > c

- In a small machine the effect of path lengthening due to transverse oscillation is not small and causes large energy shift

$$\delta \approx -\frac{1}{2\alpha}\frac{a^2}{\beta^2}$$

- For IOTA
  - α=0.015 in 'ultimate' 4-cell lattice
  - β=2 m
  - c=8 mm➔a=12 mm
  - δ=1.2×10-3

- How to overcome this issue?
  - Increase α – hard is D=0 is required
  - Decrease c(a) – place poles inside vacuum

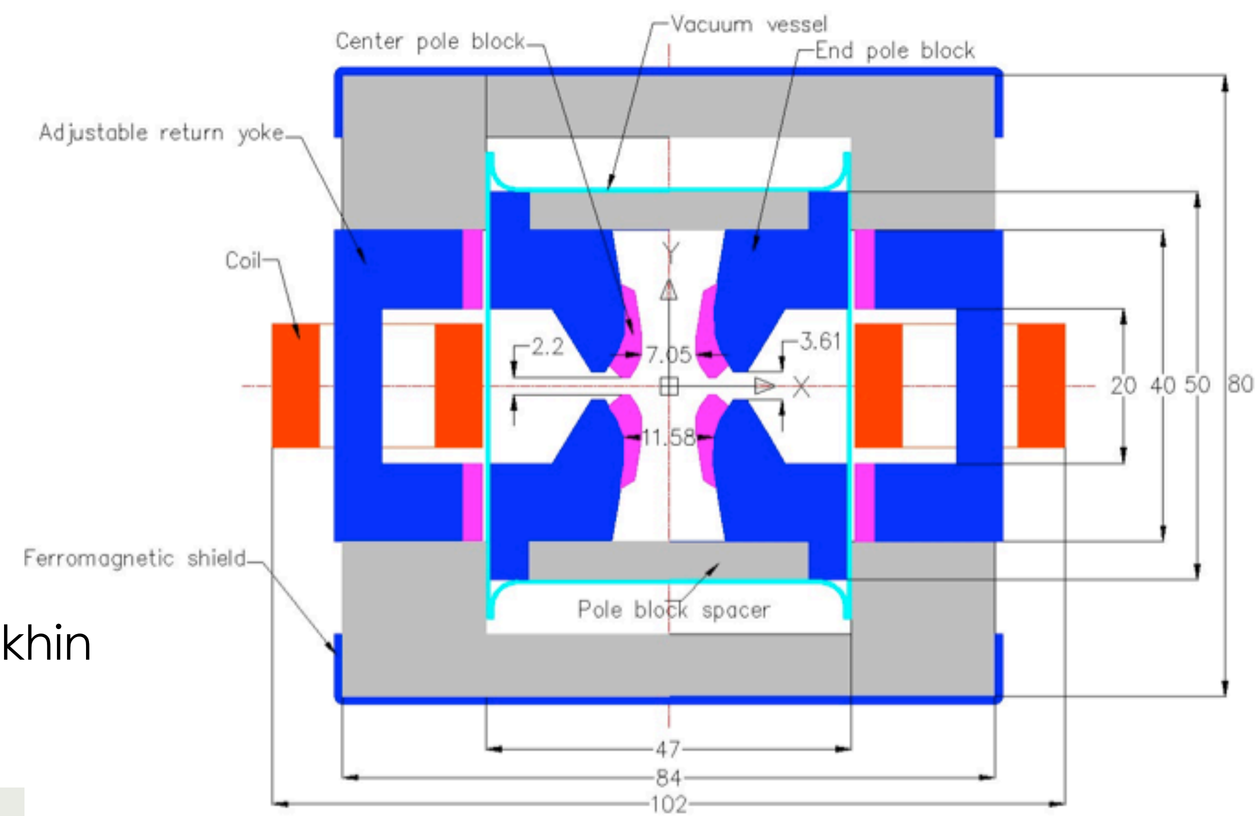


- Octupoles have no singularity - are free from this issue

- With E-Lens, α=0.1 – large amplitude ok

Nonlinear Magnet Design

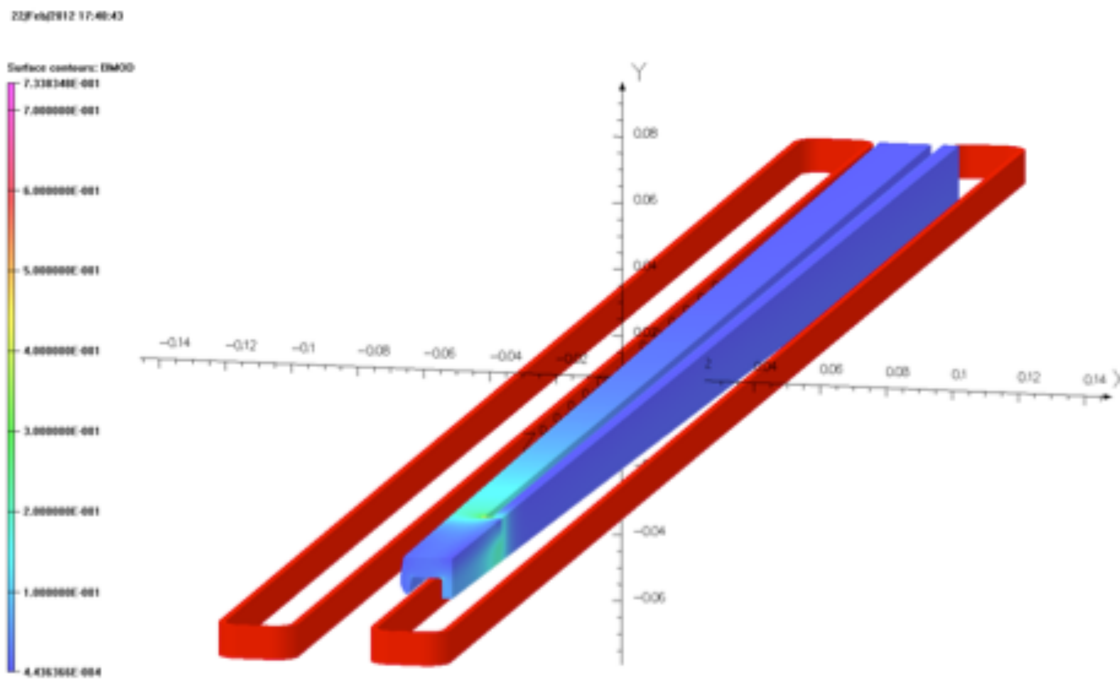
- Place poles inside the vacuum chamber
- A single coil outside the vacuum – one power supply
- Field in individual slices is controlled by the gap in the return yoke
- With this design c_{min} is 6 mm
- Poles can be precisely machined and aligned during assembly
- Magnet can be efficiently shielded from external fields

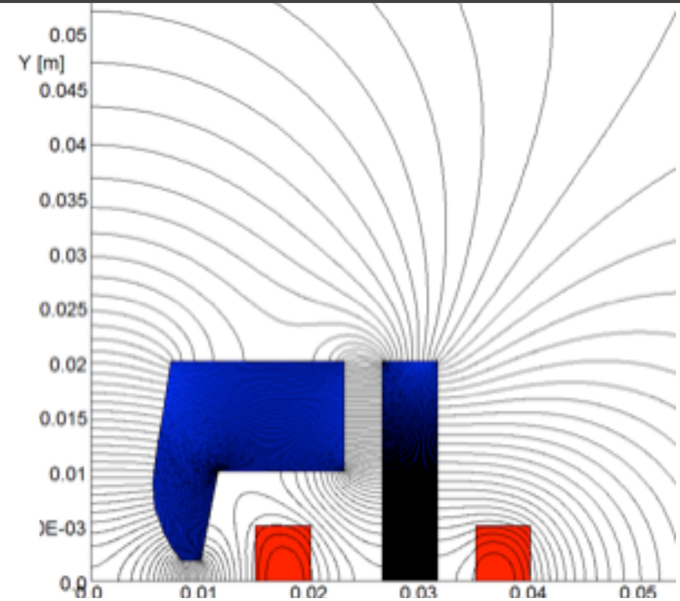


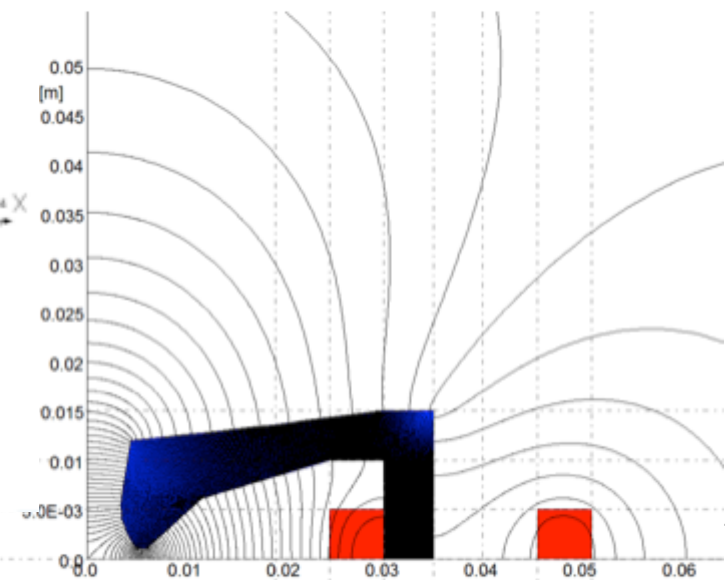
V.Kashikhin

Nonlinear Magnet Design

- Middle section field is obtained by simple translation of end section
- Iron poles are separated by aluminium shims
- Currently optimizing the 3-D field configuration and preparing mechanical design







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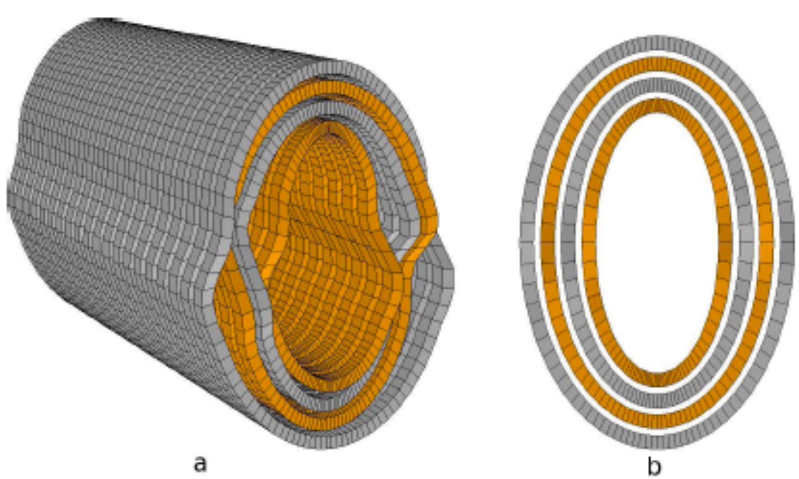
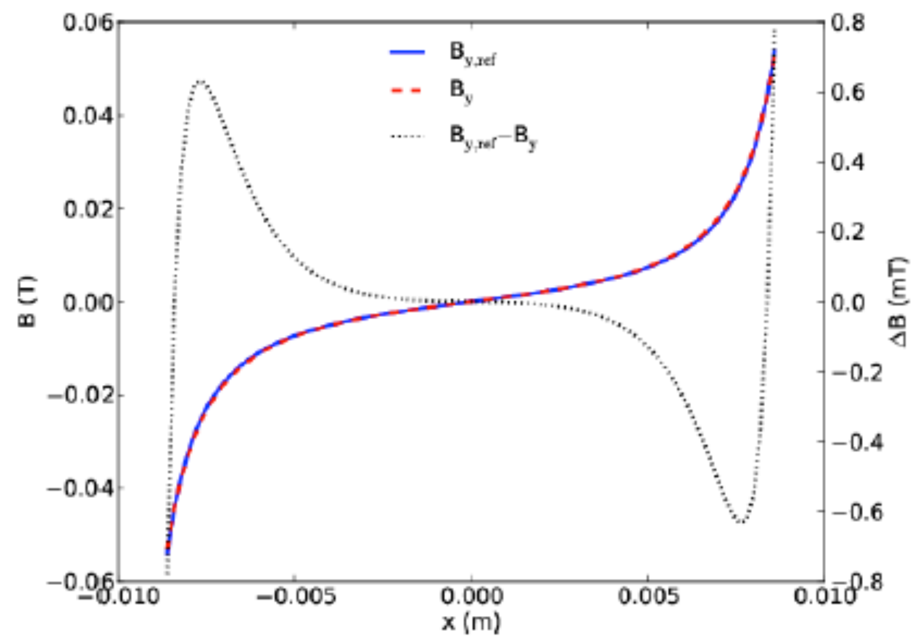
Helical Coil Nonlinear Magnet

- 3D design making use of modified helical coil method with two layers of conductor intersecting at an angle



Magnet cross section
(a) isometric perspective
(b) frontal view



Comparison of the desired and achieved vertical magnetic field on the centre plane

H.Witte, A.Seryi (JAI)

Things not Covered

- Electron Lens
  - TEL-1 is available with all its components
  - Replace the main superconducting solenoid with 1m-long 0.5T warm solenoid
- Optical Stochastic Cooling requires
  - 2 undulators
  - Chicane, consisting of
    - 4 dipole magnets, L=0.15 m, B=0.4 T
    - 3 quadrupoles, G=10 T/m
  - Undulators restrict aperture, hence experiments with O.S.C. and nonlinear optics must be performed separately - e.g. replace E-Lens with O.S.C.

End

- Thank you for Your Attention!