Ultra-low emittance upgrade options for the Diamond Light Source

R. Bartolini, C. Bailey, M. Cox, N. Hammond, R. Holdsworth, J. Kay, E. Longhi, S. Mhaskar, T. Pulampong, G. Rehm, R. Walker

Diamond Light Source
and
John Adams Institute, University of Oxford

NA-PAC 13
Pasadena, 30th September 2013

Outline

- Motivations
- Diamond upgrade lattice studies
  - MBAs options considered
  - 4BA lattice and its evolution
- One cell modification in the present lattice
  - AP and ID performance for the modified beamline
- Future work and R&D on technical subsystems

Low emittance light sources

Low emittance lattice studies for

- high brilliance $\text{brilliance} = \dfrac{\text{flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$

$$\Sigma_x = \sqrt{\sigma_{x,e}^2 + \sigma_{ph}^2} \qquad \sigma_x = \sqrt{\varepsilon_x \beta_x + (D_x \sigma_\varepsilon)^2}$$

$$\Sigma_{x'} = \sqrt{\sigma_{x',e}^2 + \sigma'^2_{ph}} \qquad \sigma_{x'} = \sqrt{\varepsilon_x \gamma_x + (D'_x \sigma_\varepsilon)^2}$$

$$\sigma_{ph} = \frac{\sqrt{\lambda L_u}}{4\pi} \qquad \sigma'_{ph} = \sqrt{\frac{\lambda}{L_u}}$$

- transverse coherent fraction $F = \dfrac{\lambda^2/(4\pi)^2}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$

Higher brilliance and transverse coherence require small emittance $\varepsilon \le \dfrac{\lambda}{4\pi}$

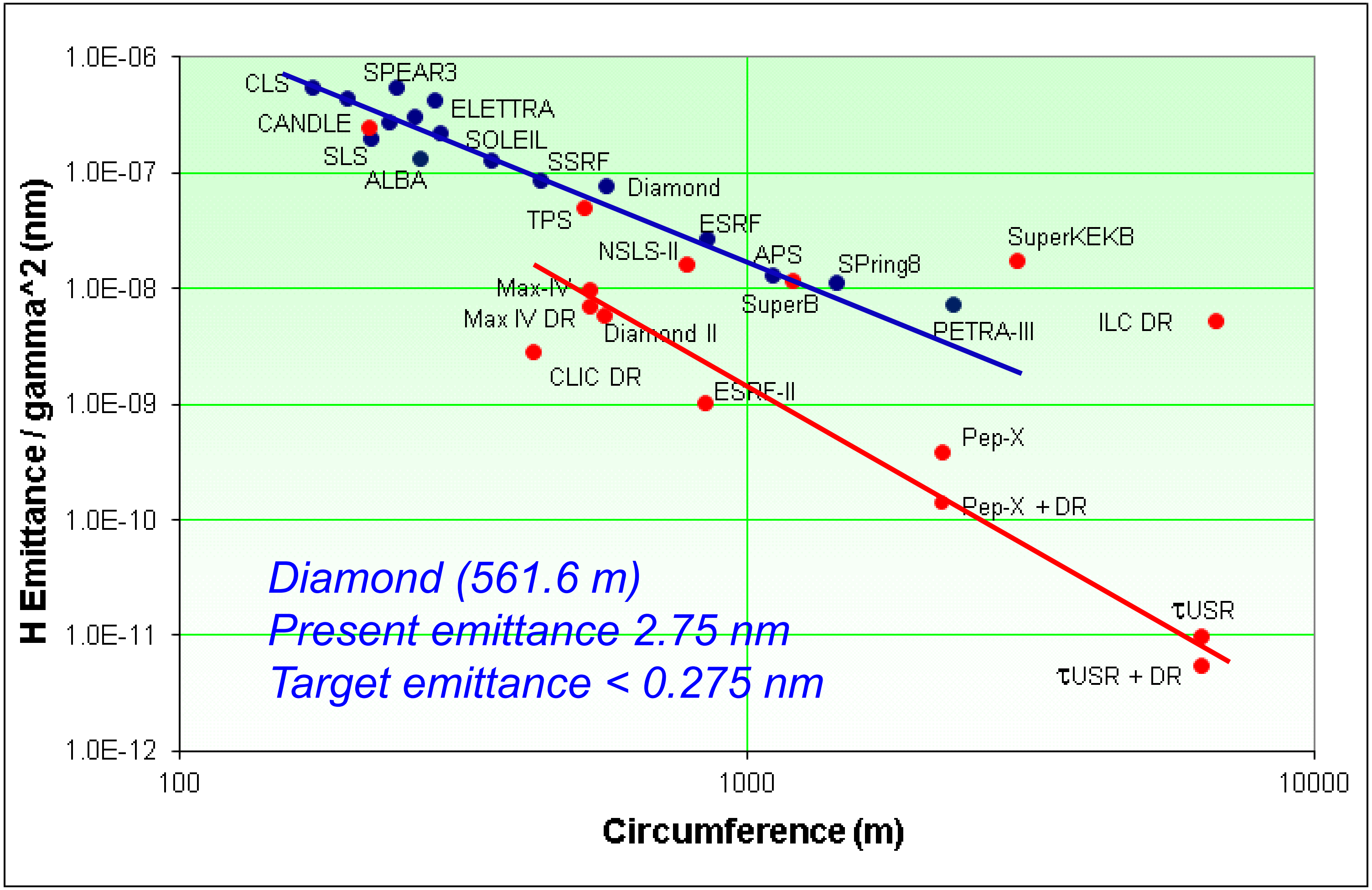
Diffraction limit at 0.1 nm requires 8 pm

Low emittance lattice require small angle bending

$$\varepsilon_x = C_q F \gamma^2 \theta^3 \propto \frac{1}{N_d^3}$$

MBA lattices (large rings favoured)

Low emittance rings community



John Adams Institute for Accelerator Science

NA-PAC 13
Pasadena, 30th September 2013

diamond

Lattice design at Diamond

- Initial criteria

  Reuse tunnel and beamlines
  Reuse as much hardware as possible
  Phased installation (avoid long shutdown)

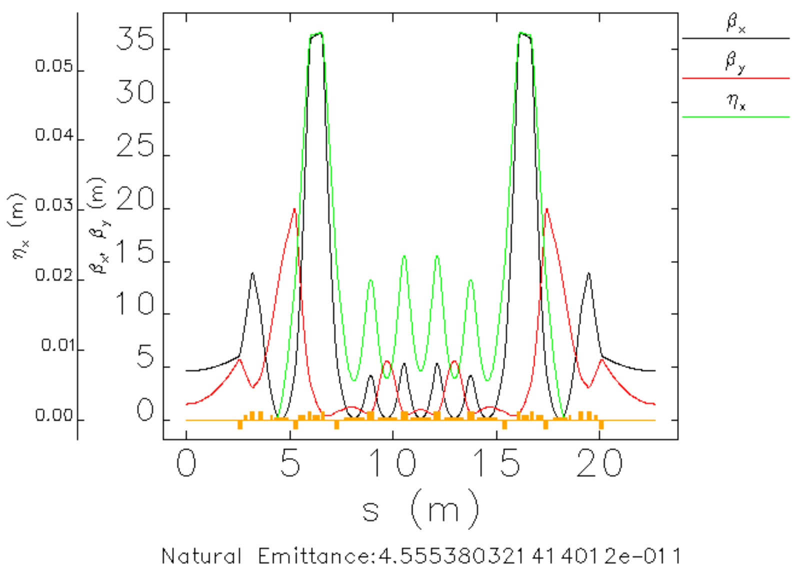
- Evolution of MBA design

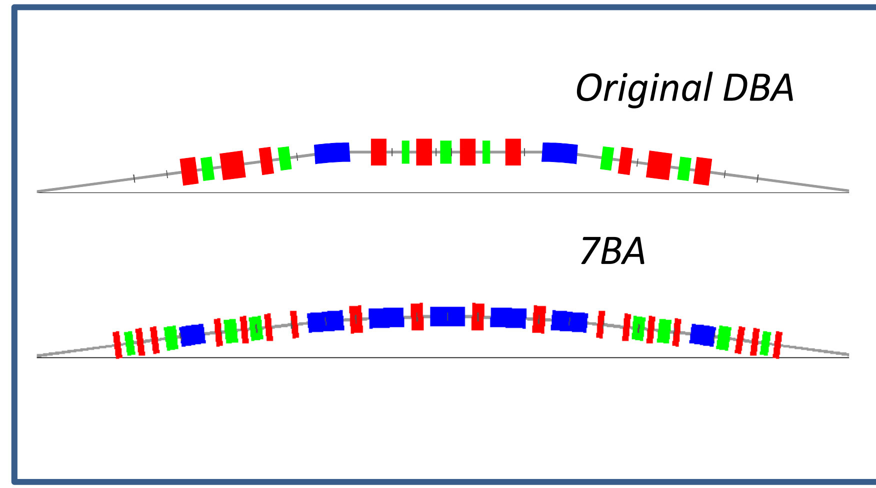
  Initial low emittance lattice design used standard MBA cells
  M = 7, 6, 5 and 4

It transpired that a 4BA cell can be modified to introduce an additional straight in the middle of an arc

while keeping the dispersion small and the emittance small

Summary of early studies with MBAs





Nonlinear dynamics

7BA lattice	45 pm	7BA DA ±1 mm
5BA lattice	140 pm	5BA DA ±3.5 mm
4BA lattice	270 pm	4BA DA ±5 mm

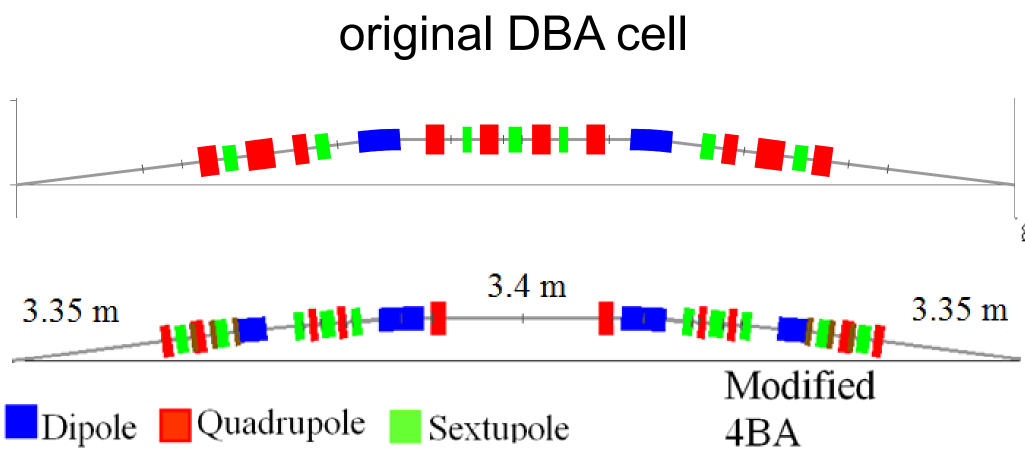
DA achieved (**WIP**)

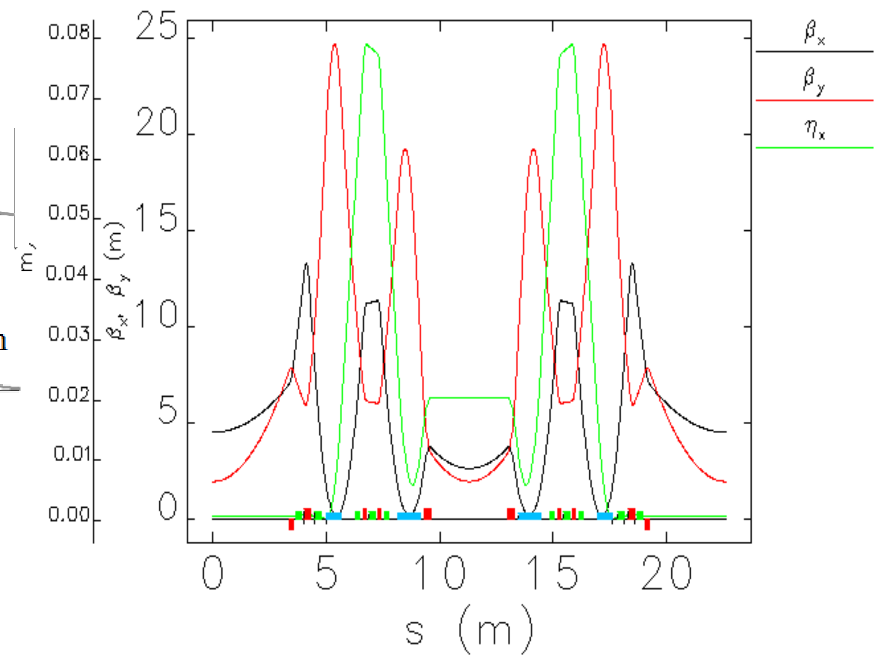
Fourth order and detuning terms very harder to compensate
Not enough freedom to set the cell phase advance as needed

IBS emittance

7BA	45 pm → 90 pm @ 300 mA	relative increase 100%
5BA	140 pm → 180 pm @ 300 mA	relative increase 30%
4BA	270 pm → 280 pm @ 300 mA	relative increase 5%

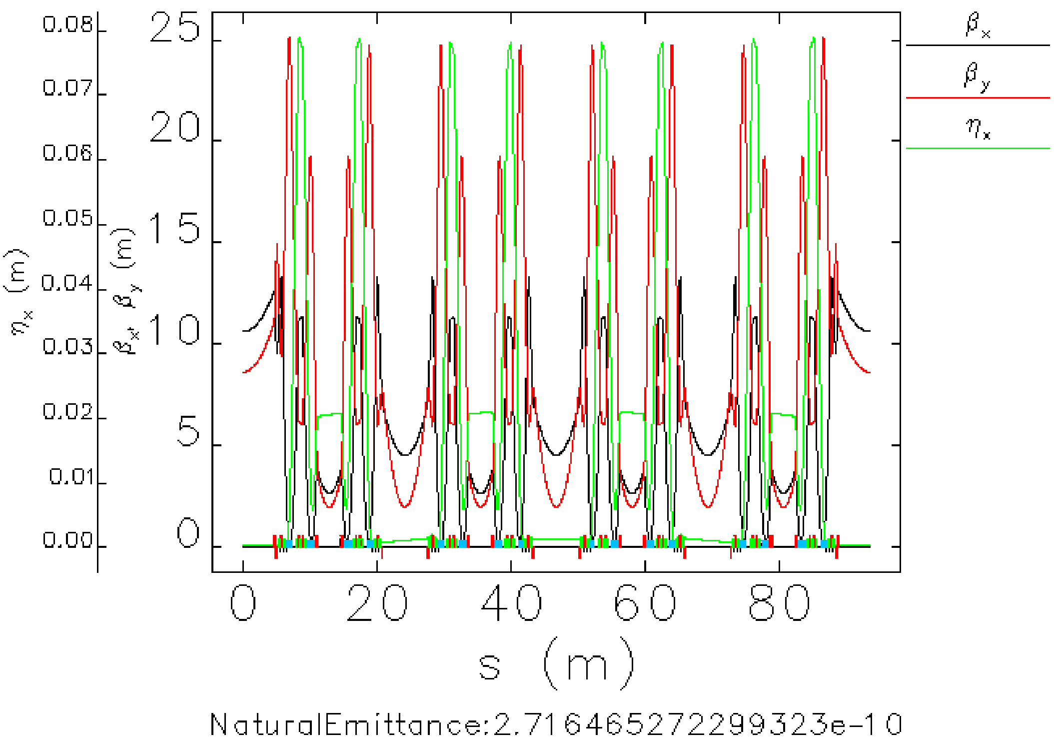
A modified 4BA lattice for Diamond-II





- Increase dispersion at chromatic sextupoles
- Optimize magnets positions and length leaving more distance between dipoles (no coil clash)
- removed sextupoles in the new straight
- Longer mid-cell straight section from 3m to 3.4 m – longer is unmanageable

One superperiod for Diamond-II

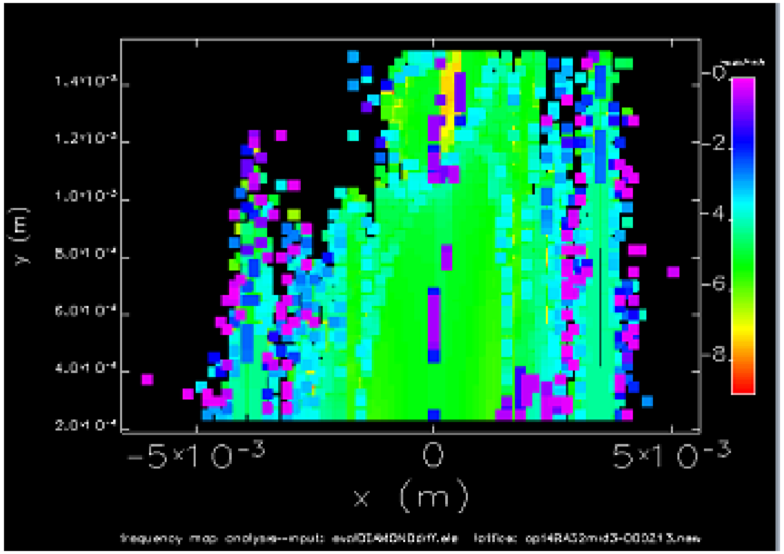


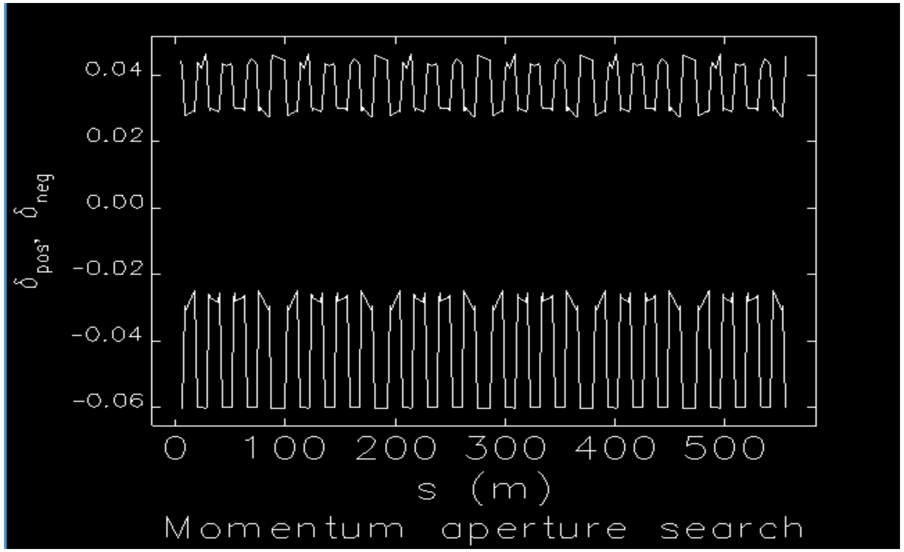
Parameters	Modified 4BA
Circumference [m]	561.0
Emittance [pm.rad]	275
Tune Point [Q_x / Q_y]	50.76/18.36
Chromaticity(ξ_x / ξ_y)	-128/ -94
straight sections [m]	9.1 / 6.7 / 3.2
Momentum compaction	1.02e-04
Bunch length [mm]	1.77
Energy spread (rms)	7.94e-4
Damping time h/v/s [ms]	14.78/19.60/11.70
Energy loss/turn [MeV]	0.573

This lattice combines the ideas of doubling the capacity of the ring with the low emittance

MOGA optimisation for DA and lifetime

Nonlinear beam dynamics optimised mostly with MOGA and resonance driving terms compensation





DA still under optimisation - ~5 mm (WIP)
Touschek lifetime ~ 2.2h without harmonic cavities

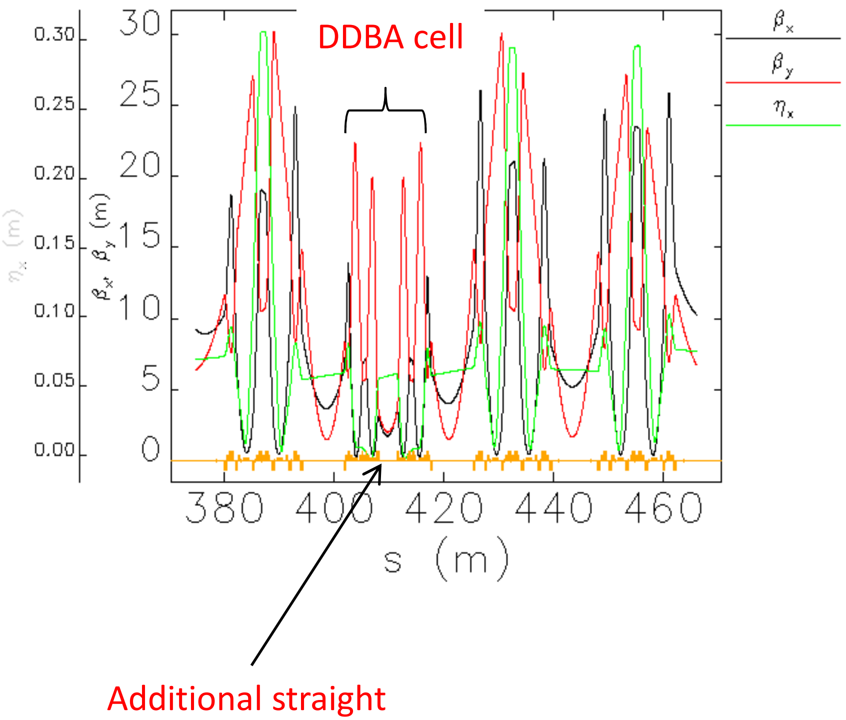
One (or more) modified 4BA cells in the present lattice

(called DDBA)

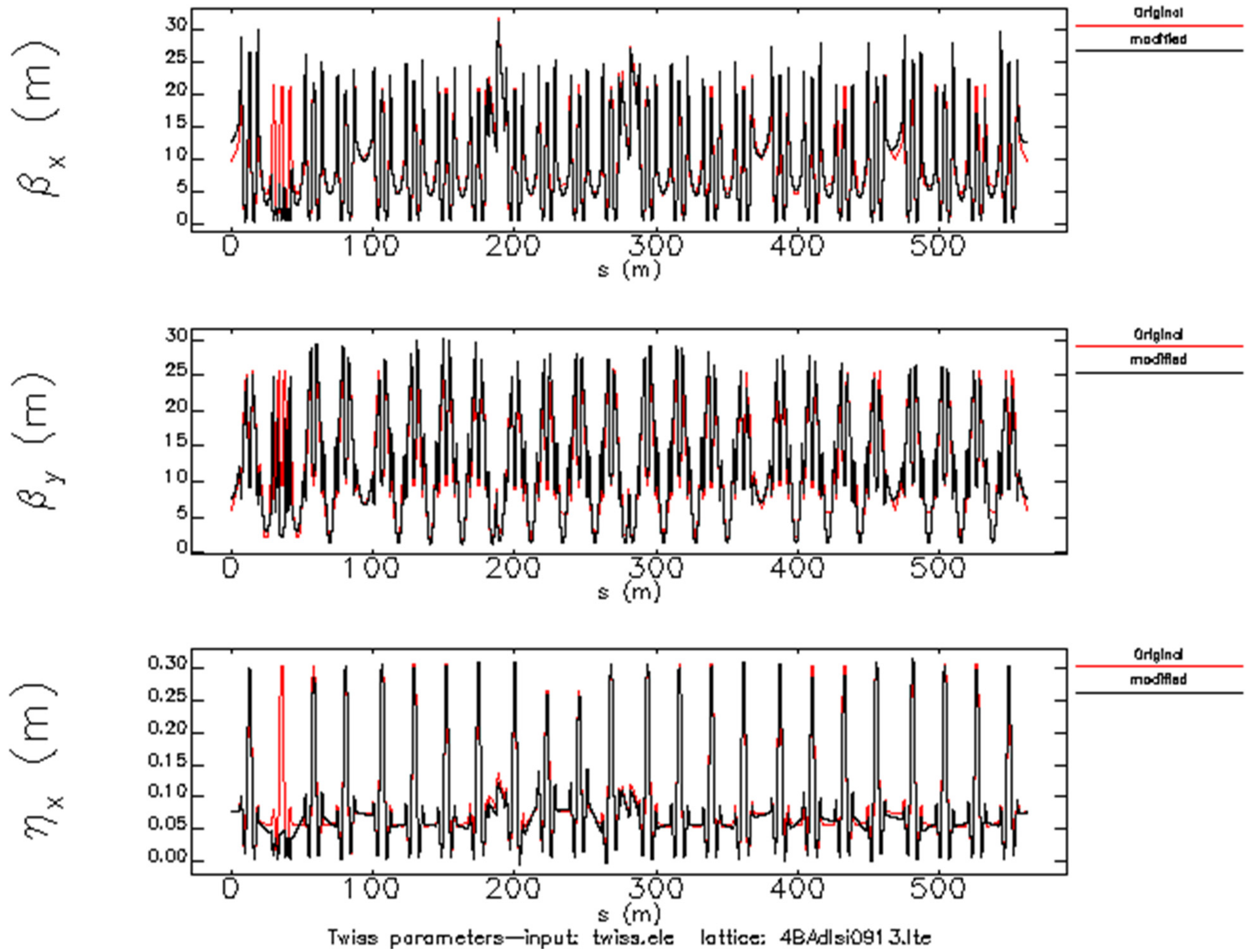
One DDBA cell in the existing lattice

Replacing the existing cell2 with a DDBA cell

- Introduces an additional straight section (**beamline upgrade** bending magnet to ID beamline)
- Serves as a **prototype** for low emittance lattice upgrade
- In line with phased upgrade
- Lots of **R&D** required (magnet design challenging, vacuum with small apertures, engineering integration, etc)



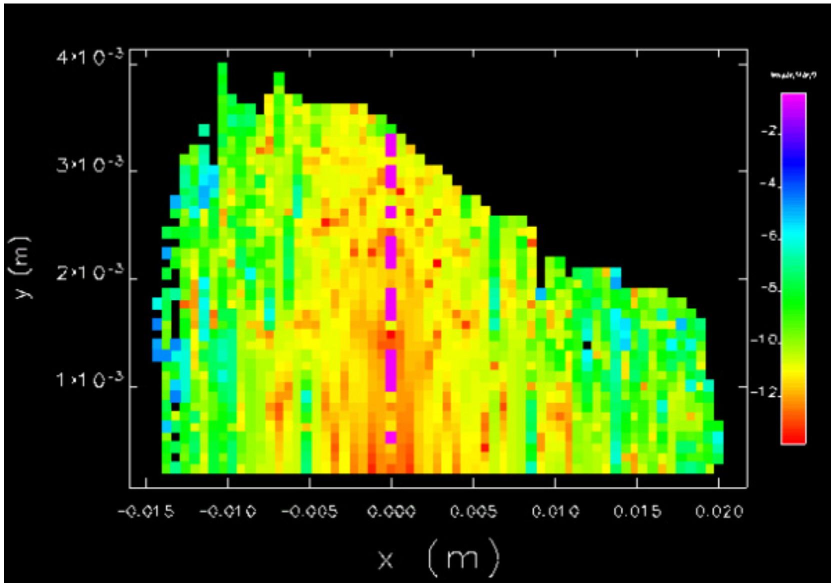
Ring optics with and without the DDBA cell in cell2

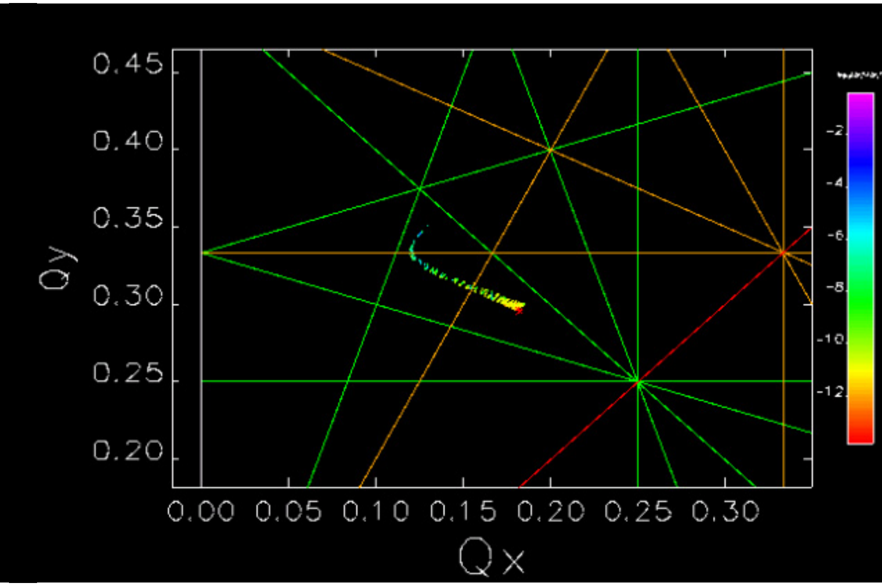


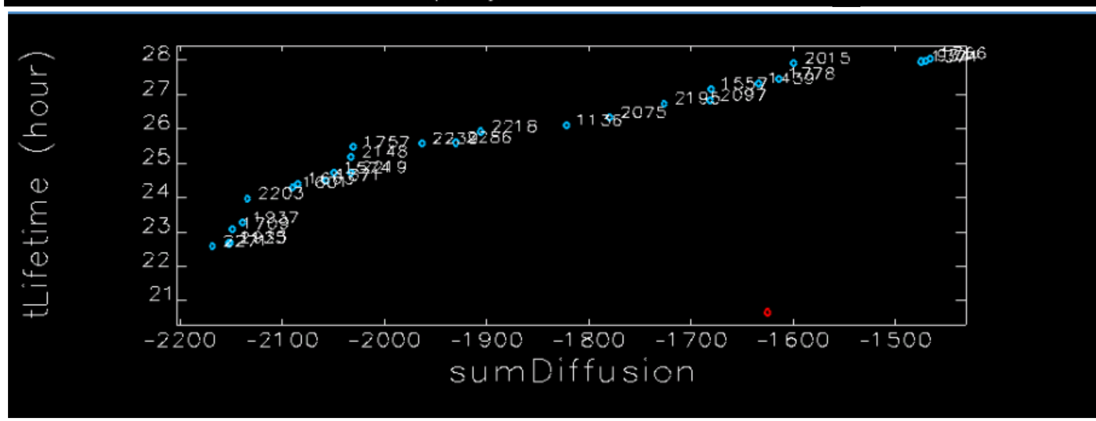
red = present lattice

black = new lattice with modified cell2

One DDBA: dynamic aperture and lifetime with MOGA

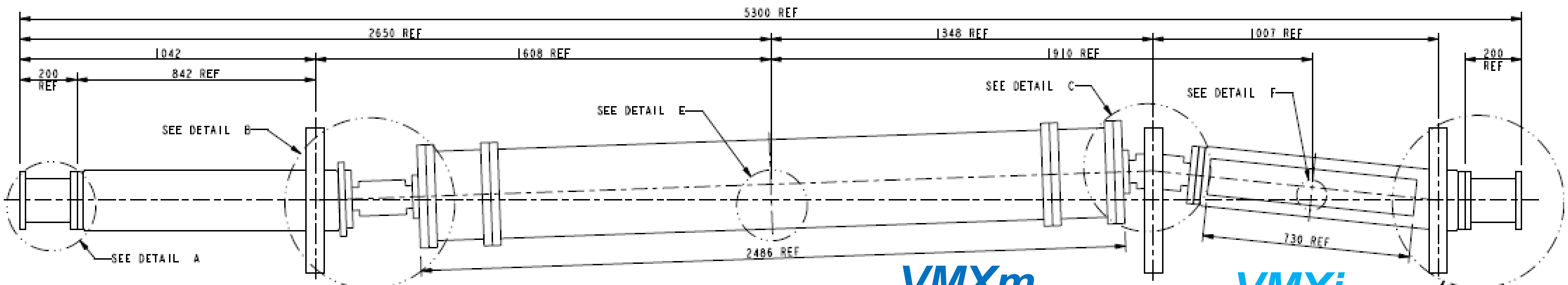






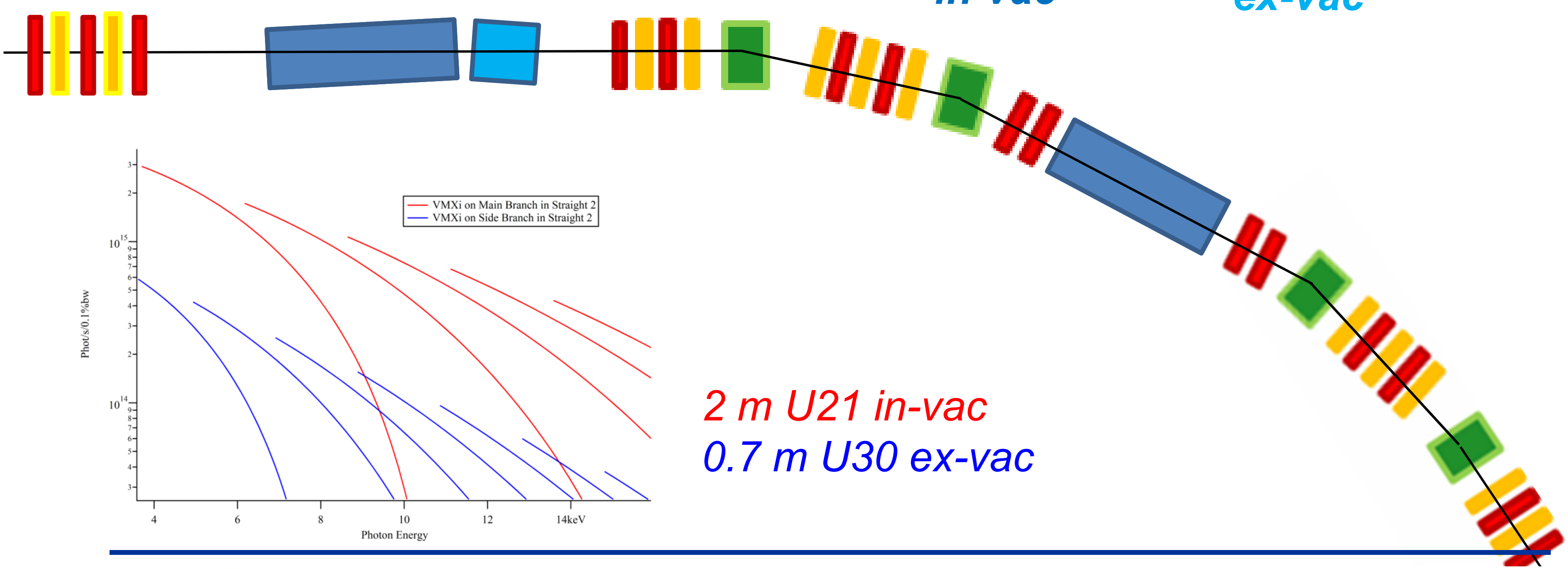
Parameters	
Emittance [m-rad]	2.5e-9
Tune x	28.18
Tune y	13.29
Chromaticity	2,2
Lifetime [h]	*27* (29)

Cell 2 upgrade for VMXi-VMXm



VMXm in-vac

VMXi ex-vac

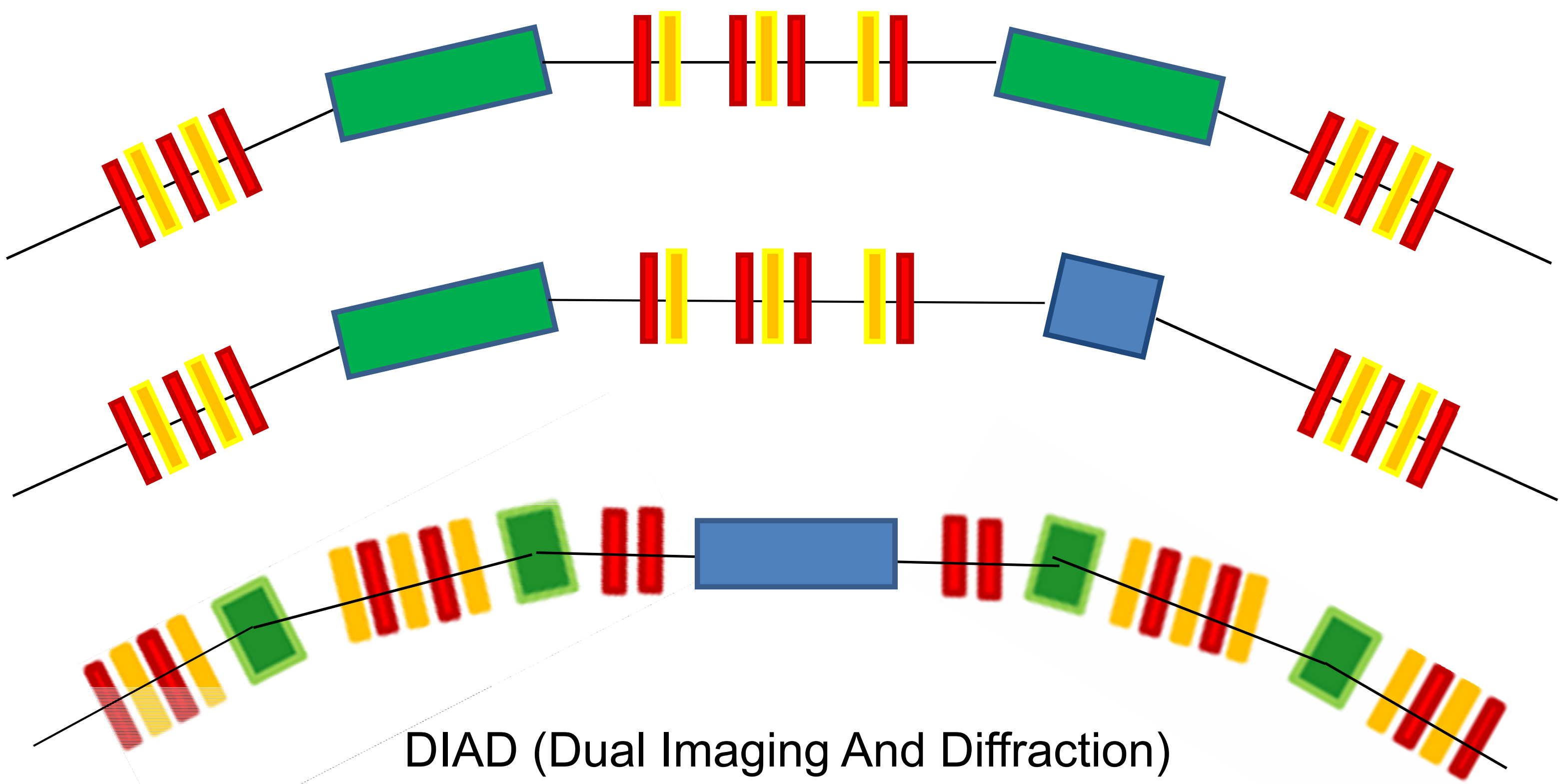


2 m U21 in-vac

0.7 m U30 ex-vac

Cell 11 upgrade for the DIAD beamline

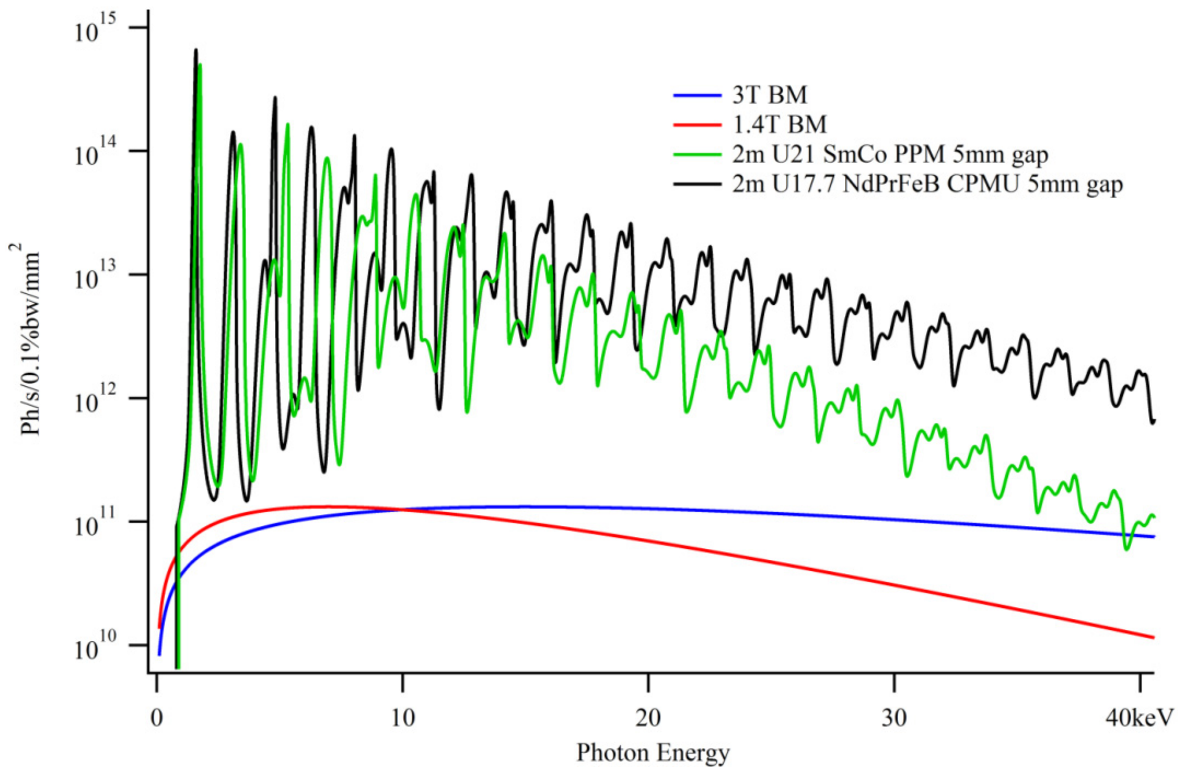
A second cell will be used to turn a superbend beamline into an in-vacuum ID beamline locating the in-vac ID in the mid straight section



DIAD (Dual Imaging And Diffraction)

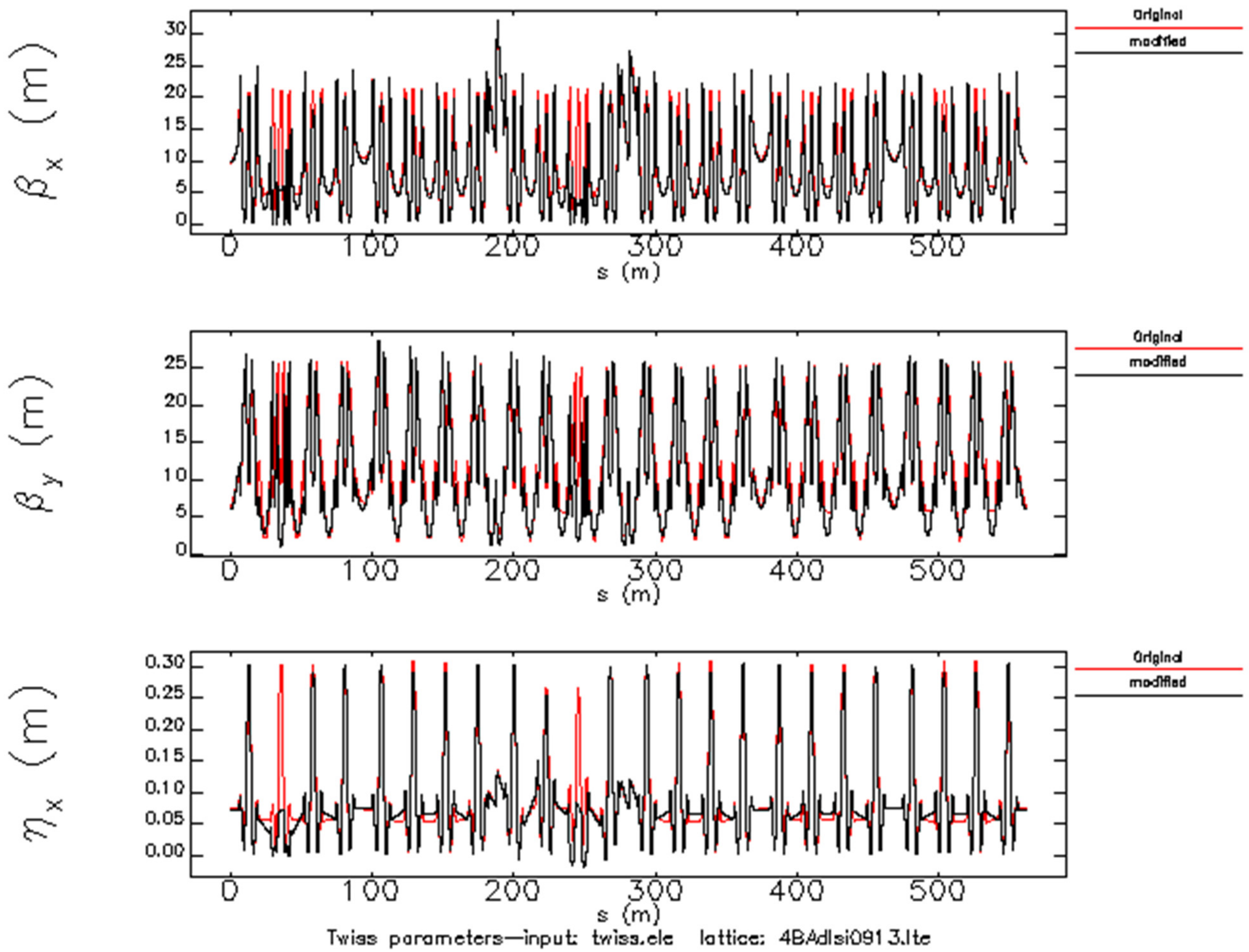
ID performance

Beamline B11 – bending vs superbend vs DDBA (in-vac or CPMU)

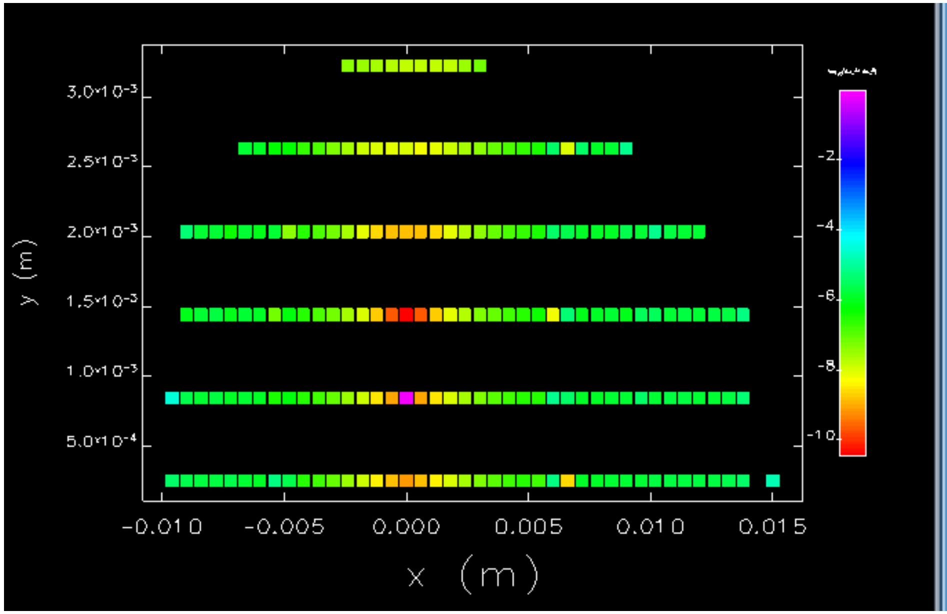


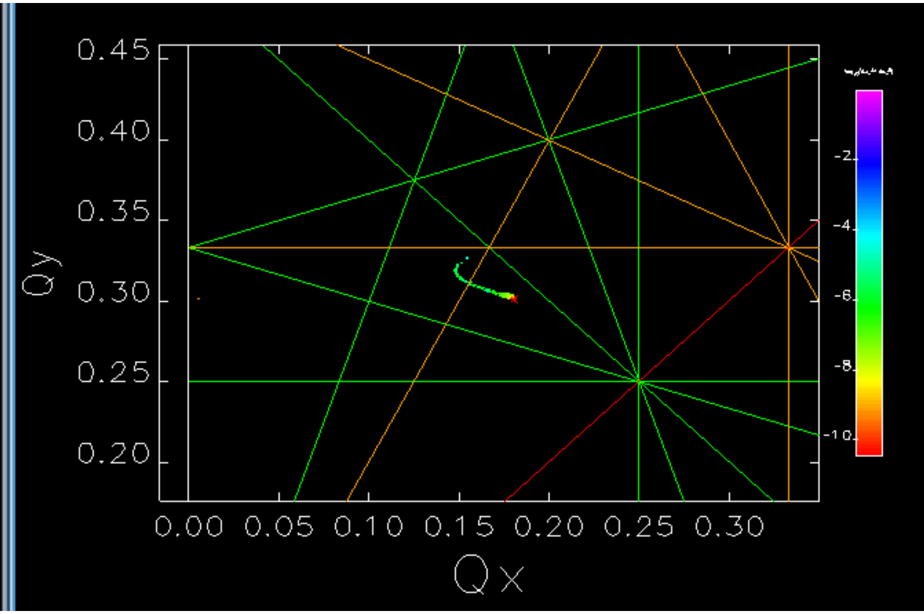
(courtesy E. Longhi)

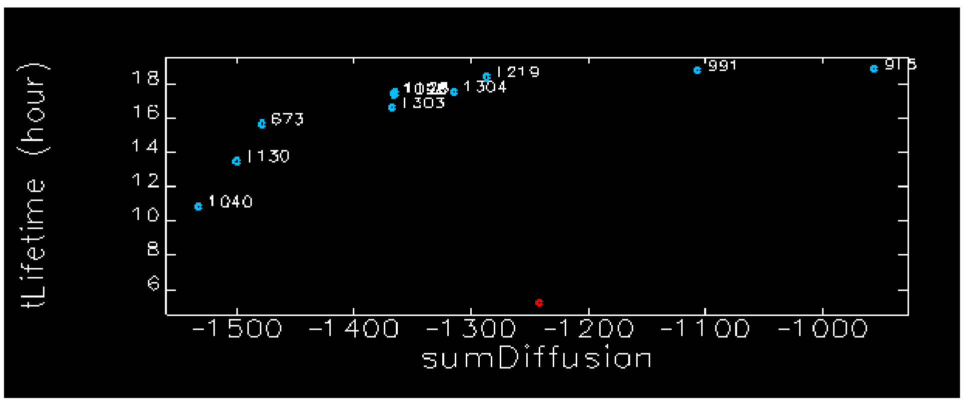
Ring optics with and without two DDBA cells



Two DDBAs: dynamic aperture and lifetime with MOGA

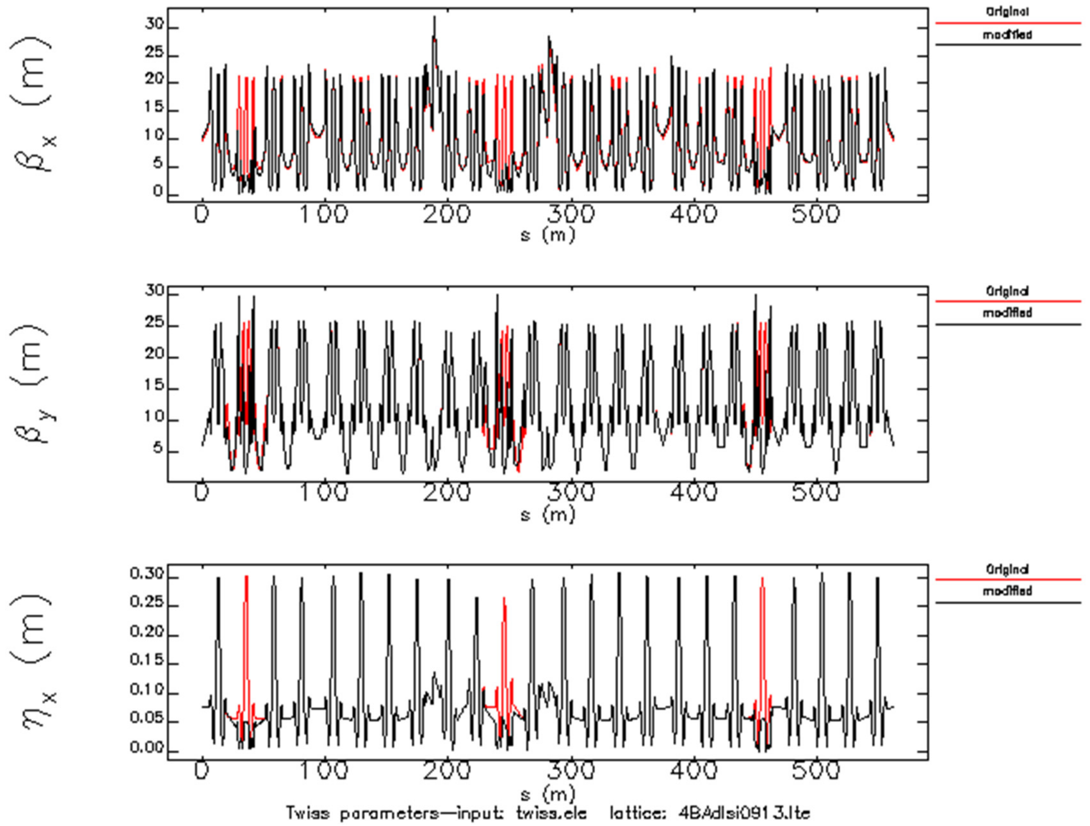






Parameters	
Emittance [m-rad]	2.64e-9
Tune x	29.18
Tune y	13.30
Chromaticity	2,2
Lifetime [h]	***18.4 (29h)***

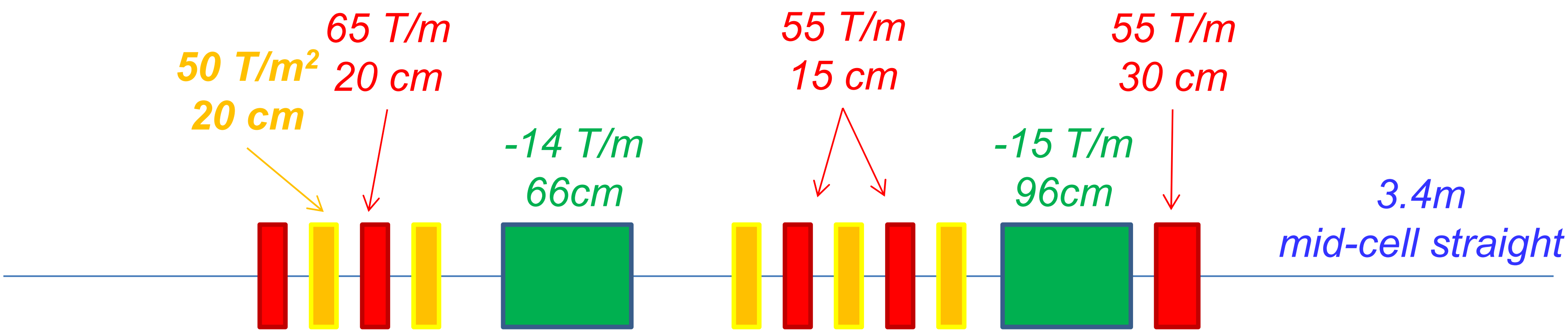
Ring optics with three DDBA cells



A bid for capital funds for a third DDBA will be put forward.
This will include a 3HC for bunch lengthening to be located in the third cell

(half) DDBA cell

Even if the minimisation of the emittance is not the primary target, the tight control of dispersion and beta functions requires very strong quads



Challenging magnets which require a small bore radius (15mm) but no showstoppers !

Other projects (e.g. ESRF) have more aggressive requirements

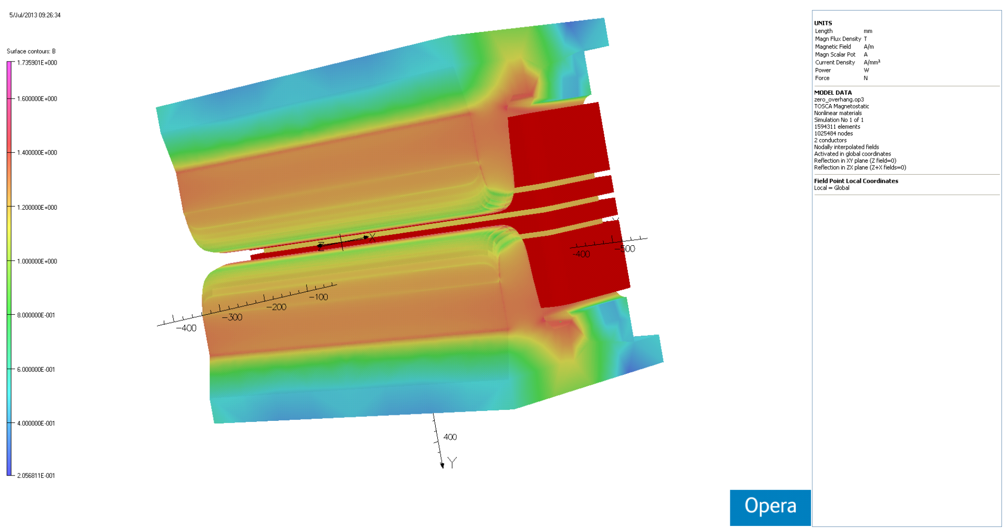
Magnet design

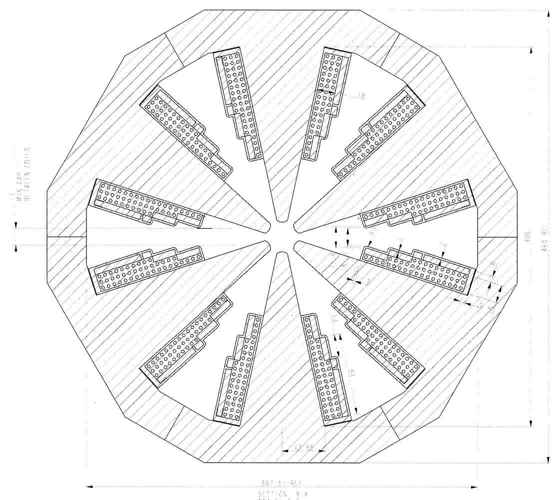
Gradient dipoles

dipole 0.8 T + quadruples 15 T/m

Small bore quads and sextupoles

15 mm radius (65 T/m – 4000 T/m^2)





Design tolerance on pole profiles ± 25 μm

Small apertures demand for NEG coating of complicated vessels (collaboration with CERN)

Conclusions

Diamond is investigating a full ring upgrade for Diamond – II

Various MBA options are under analysis. We concentrated on a modified 4BA (DDBA) that doubles the capacity and reduces the emittance by a factor 10.

The upgrade for cell2 is expecting the final decision in Dec 2013.

• AP-wise the design is feasible
• Many technical subsystems prove challenging but no showstoppers have been identified (magnets, vacuum, engineering integration, diagnostics,. …)
• Benefit for ID performance are noticeable

Cell 11 upgrade funding is under discussion and it looks promising

Underpins R&D for the full upgrade. Significant further detailed design is needed, as well as R&D for magnets, vacuum vessel fabrication and NEG coating.