Diamond-II upgrade toward ultra-low emittance

T. Pulampong

University of Oxford

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Royal Holloway, London

John Adams Institute for Accelerator Science

diamond

UNIVERSITY OF OXFORD

Outline

Motivation for Diamond-II

Low emittance lattice for Diamond upgrade

- MBA for Diamond
  - 5BA, 7BA
  - 4BA

DDBA insertion

- one DDBA VMX
- Two DDBA

Conclusion

Low emittance light sources

Accelerator Design aim for

- <u>high brilliance</u>

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

- <u>transverse coherent fraction</u>

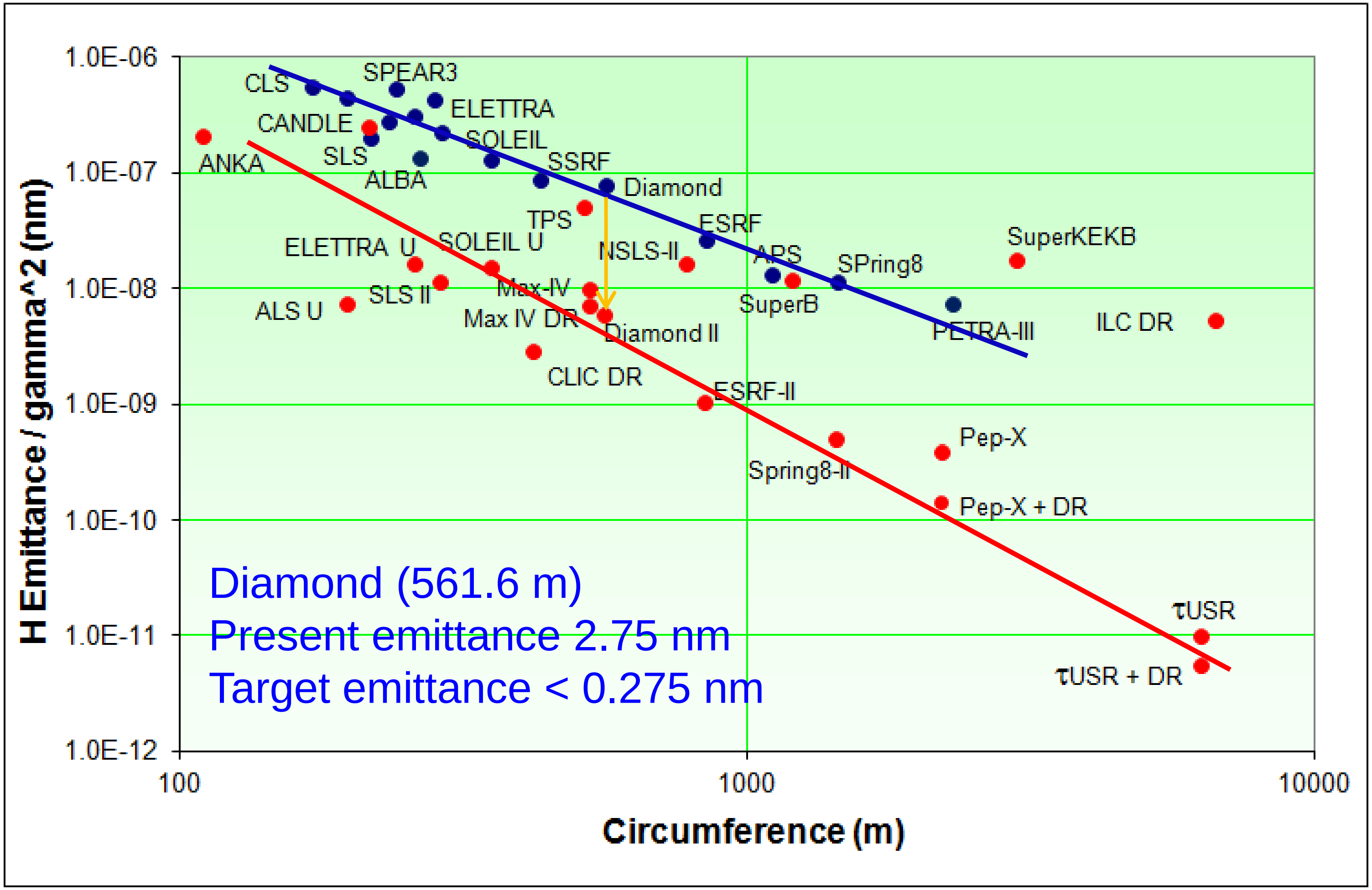
$$F = \frac{\lambda^2/(4\pi)^2}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

$$\Sigma_x = \sqrt{\sigma_{x,e}^2 + \sigma_{ph}^2} \qquad \Sigma_{x'} = \sqrt{\sigma_{x',e}^2 + \sigma'^2_{ph}}$$

$$\sigma_x = \sqrt{\underline{\varepsilon_x}\beta_x + (\eta_x \sigma_\varepsilon)^2} \qquad \sigma_{x'} = \sqrt{\underline{\varepsilon_x}\gamma_x + (\eta'_x \sigma_\varepsilon)^2} \qquad \sigma_{ph} = \frac{\sqrt{\lambda L_u}}{4\pi} \qquad \sigma'_{ph} = \sqrt{\frac{\lambda}{L_u}}$$

Higher brilliance and transverse coherence require **small emittance**

Light source,DR and B-factories



Courtesy: R. Bartolini

Minimising beam emittance

Low emittance lattice require small angle bending

Minimising beam emittance

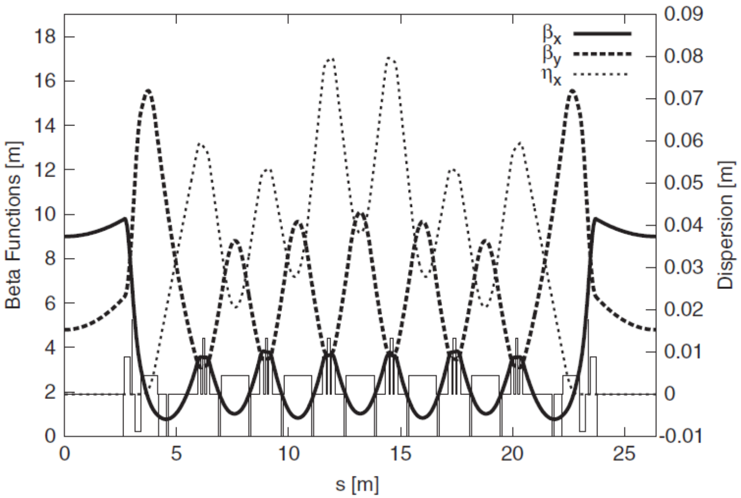
Bending angle

$$\varepsilon_x = C_q \gamma^2 K \frac{1}{12\sqrt{15}} \frac{\Phi^3}{J_x}$$

Quality factor
depends on lattice design, magnets ,
space requirement

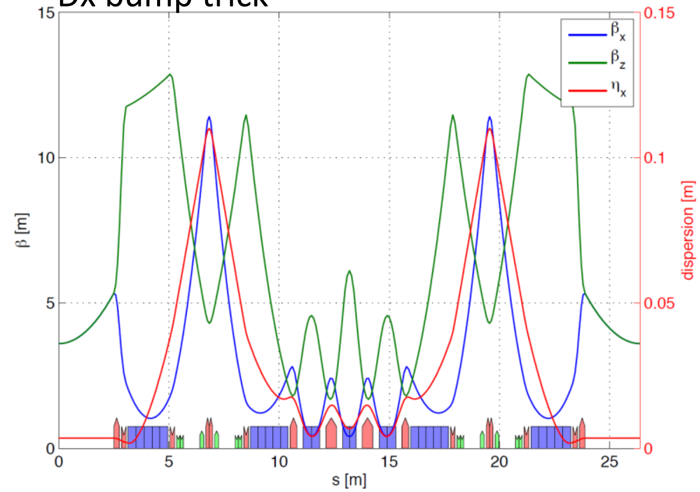
$$\varepsilon_x \propto \Phi^3 \propto \frac{1}{N_{bending}^3}$$

Need more bending magnets



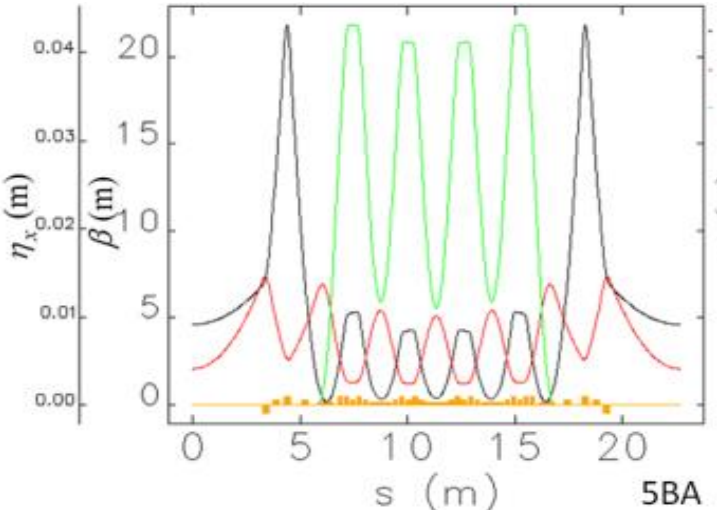
MAX- IV 7BA

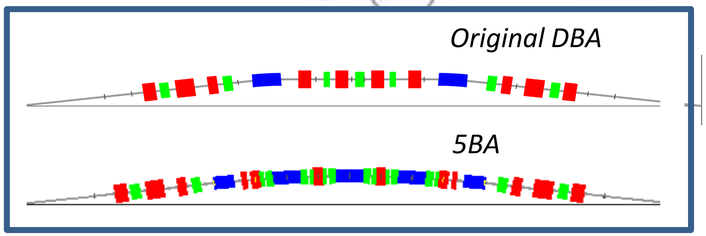
Dx bump trick

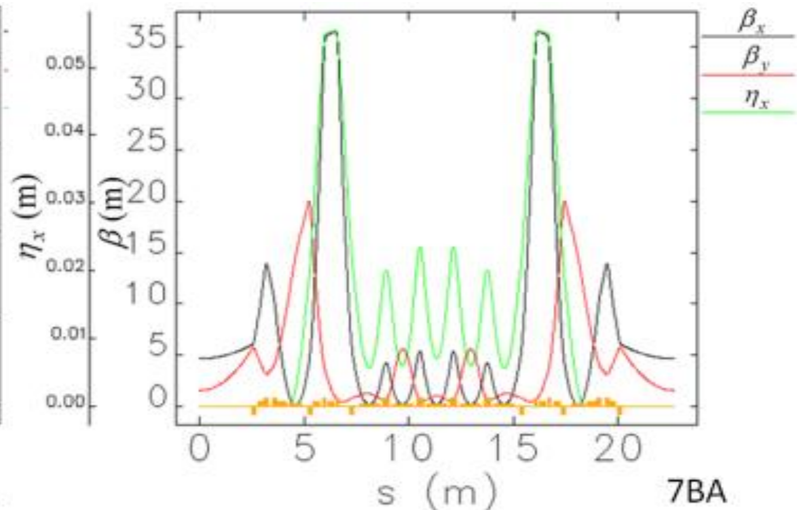


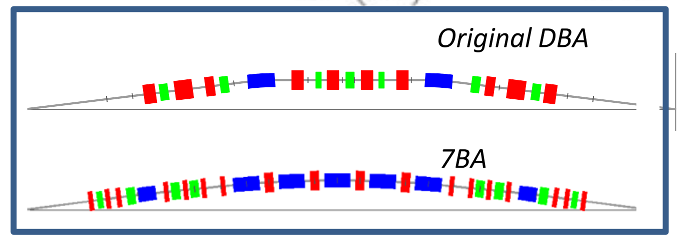
ESRF-II 7BA

Higher M BA lattices for Diamond





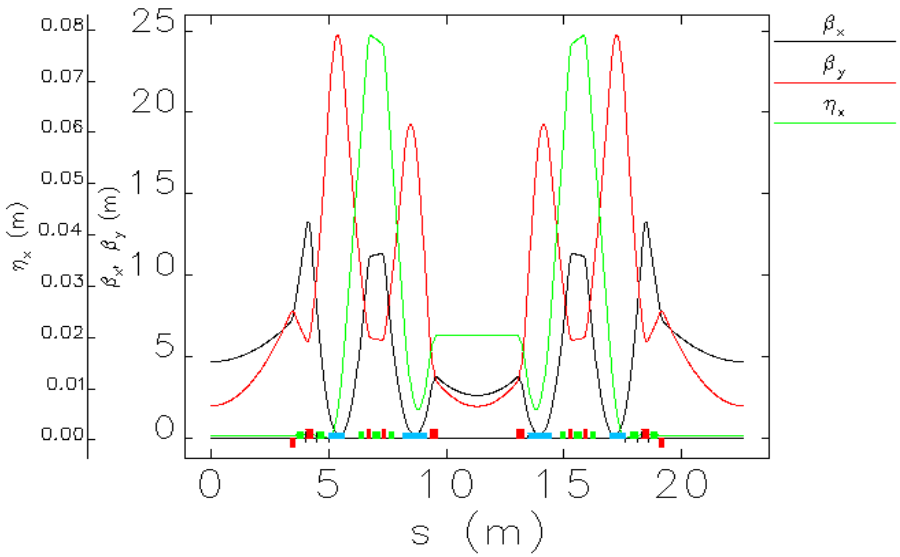




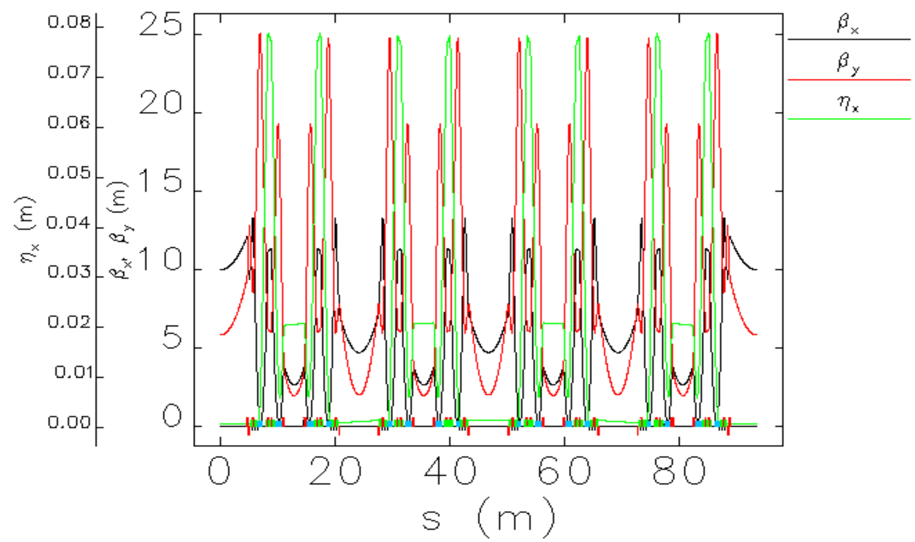
- No dispersion bump
- Phase advance matching
- 4 mm DA

- dispersion bump
- Phase advance matching
- Large detuning
- 1 mm DA

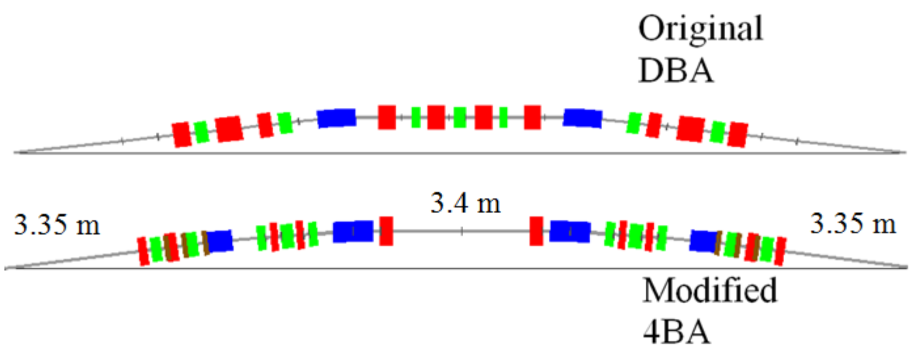
Modified 4BA lattices



4BA cell



Super period



- Double no. of beamlines per cell
- 10 fold smaller emittance
- **3.4m** middle straight
- simpler magnets (no.+strength)
- existing (ID) beamlines
  position realignment < 15mm

See IPAC13 : MOPEA067

MBA lattices for Diamond

- MBA cell with all elements within <23m (fighting for longer straight)
- Optimizing change for IDs positions
- Pushing down Beam emittance < **280** pm-rad
- Magnets availability

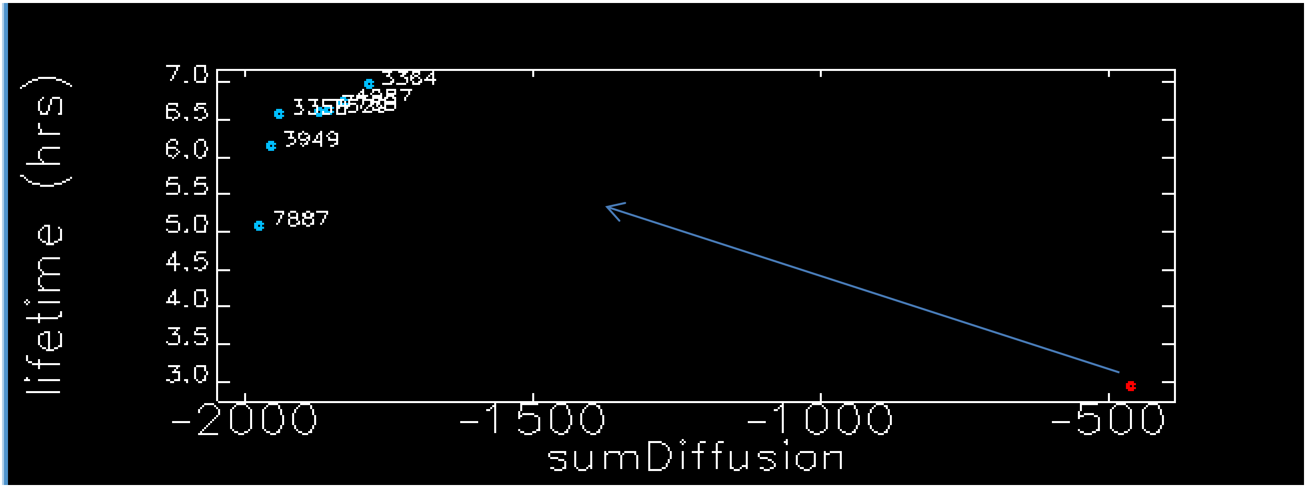
More challenging magnet design →

Parameters	DBA	**Modified 4BA**	5BA	7BA
Energy [GeV]	3.0	3.0	3.0	3.0
Circumference[m]	561.6	**561.0**	561.6	561.6
Emittance [pm.rad]	**2600**	**276**	**156**	**45.7**
Tune [Q_x / Q_y]	27.20/ 13.37	50.76/18.36	53.66/28.87	75.42/52.17
ξ_{x0} / ξ_{y0}	-80.4 / -35.6	-128/ -94	-130/-50	-348/-119
Straight [m]	11.3 / 8.3	**9.1 / 6.7 / 3.4**	9.5/6.5	8.0/5.0
α_c	1.66e-04	1.02e-04	1.30e-04	7.98e-05

See IPAC13 : MOPEA067

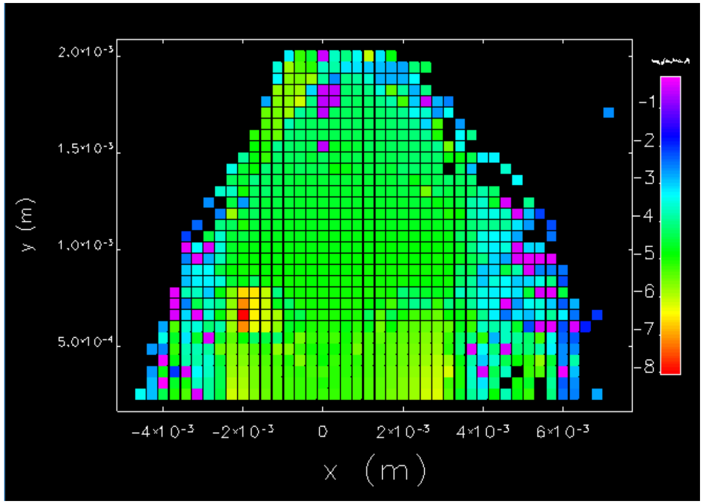
MOGA for DA and Lifetime (4BA)

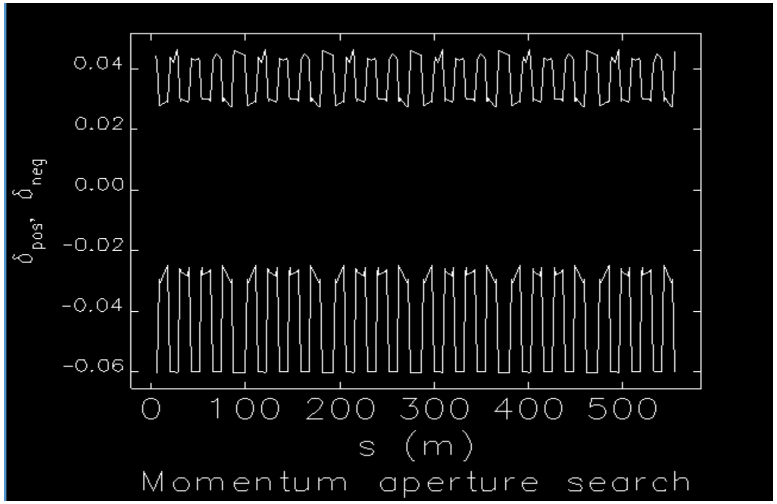
Multi-objective genetic algorithm (MOGA)



4BA full ring upgrade

Optimized DA, MA



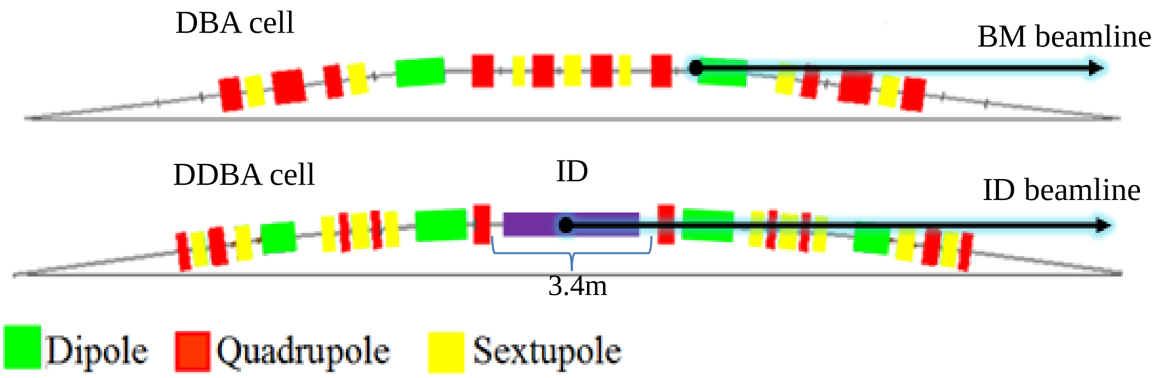


Tousheck Lifetime was calculated with
300 mA
10% coupling
900 bunches

One cell upgrade

Lattice modification

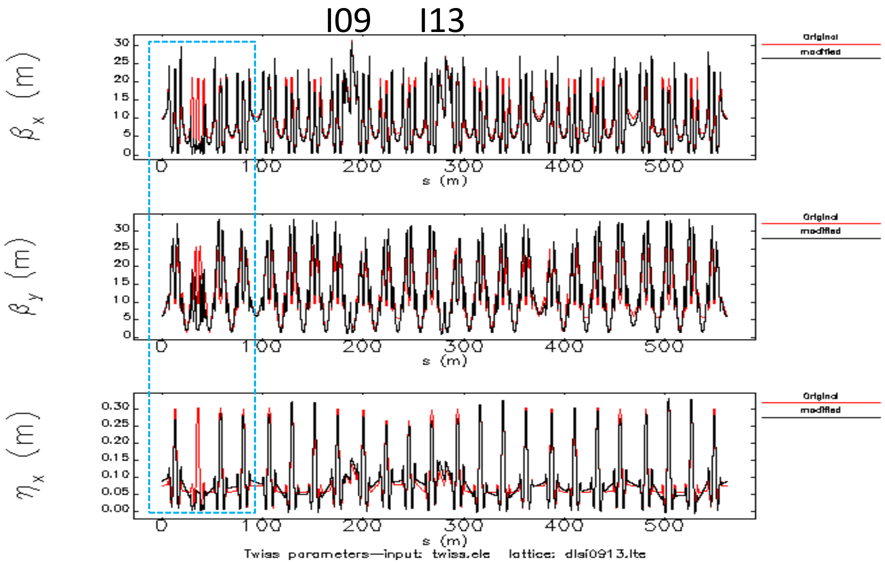
DDBA cell provides additional ID beamline

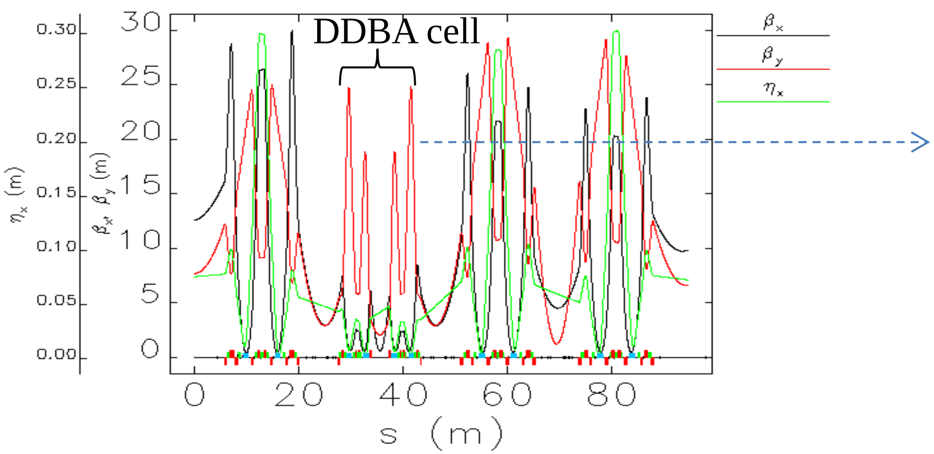


- Introduces an additional straight section (ID beamline)
- Serves as a **prototype** for low emittance lattice upgrade
- R&D required: magnet design, vacuum with small apertures, engineering integration, …
- Standardise magnet for one type one length

One cell upgrade

Optic modification

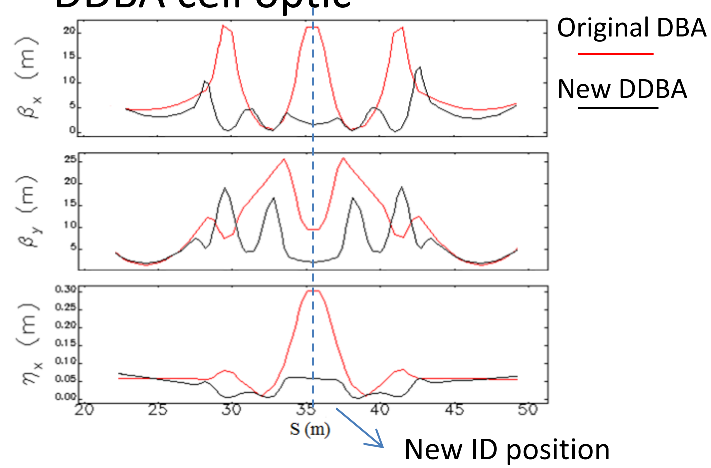




- Good optic for ID position
- Betatron tune below half-integer
- Small beta fn. in DDBA
- conserve beam emittance

Parameters	DLS	one DDBA
Energy [GeV]	3.0	3.0
Circumference [m]	561.6	561.571
Emittance [nm.rad]	2.75	2.69
Tune (Q_x/Q_y)	27.20/13.37	29.18/13.28
Chromaticity (ξ_x/ξ_y)	-80.4/-35.6	-78.4/-41.3
Mom. compaction	1.6e-04	1.5e-04

DDBA cell optic

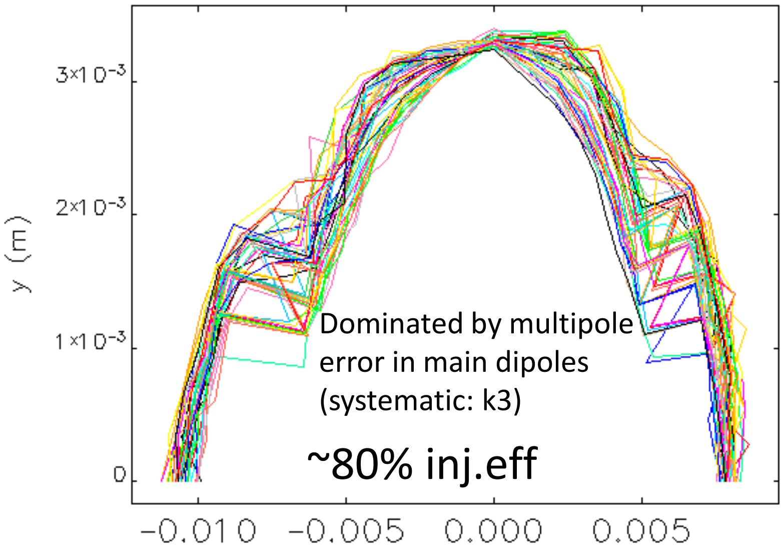


Optic functions are optimized to accommodate in-vacuum ID (5mm full gap)

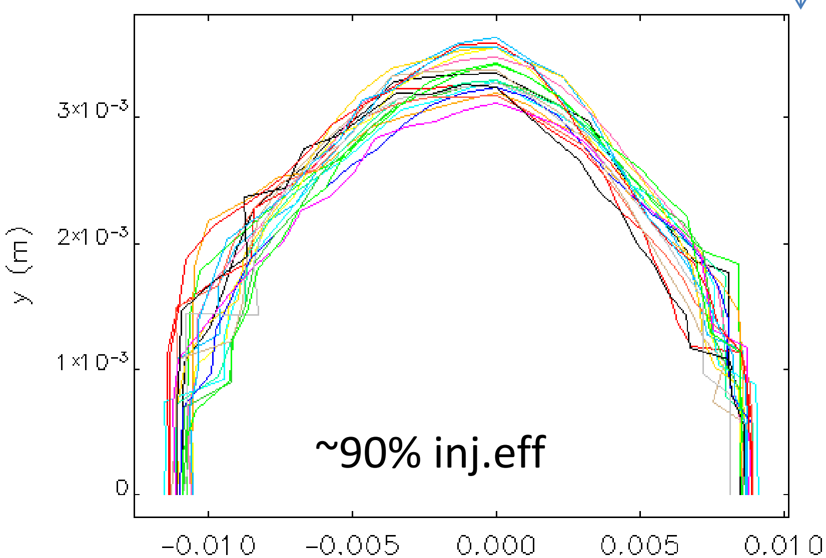
Engineering integration

Machine imperfection

- Systematic multipole error from magnet designs
- Random multipole error
- Misalignment, dx,dy,ds,tilt
- Power supply error (strength error)

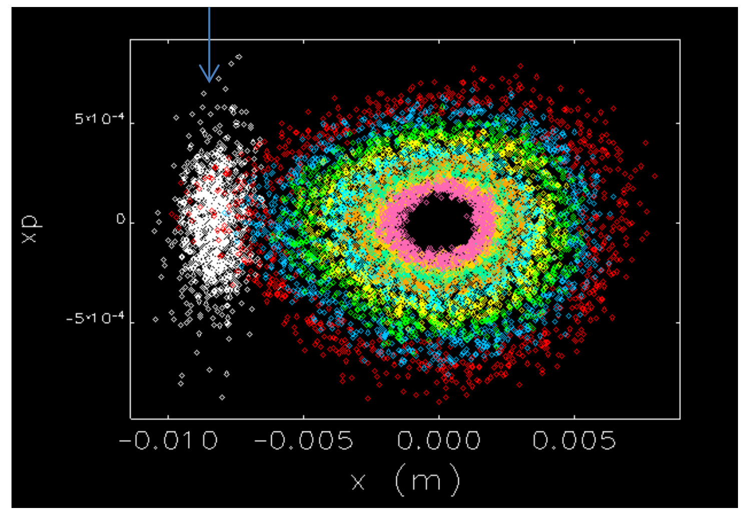


MOGA optimized



x (m)

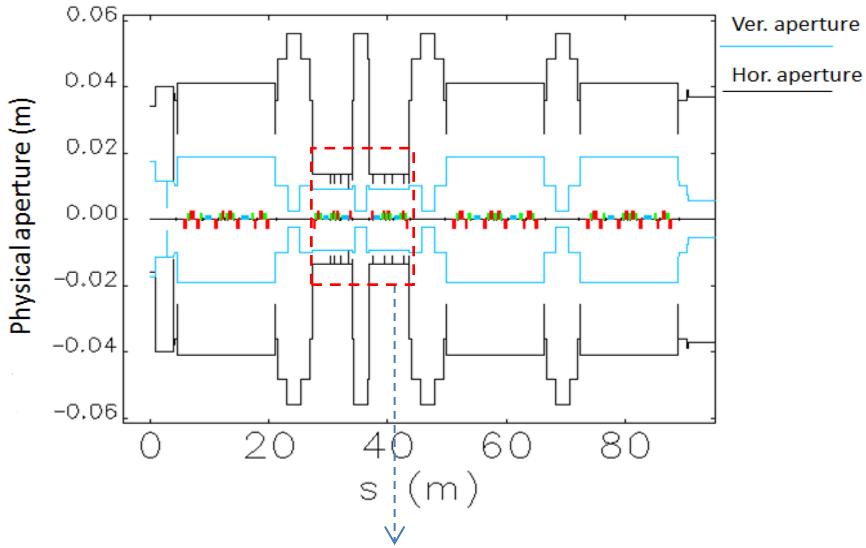
Injected beam at -8.3mm



- Injection eff. ~90% (at -8.3mm)
- Touscheck lifetime ~21 hrs

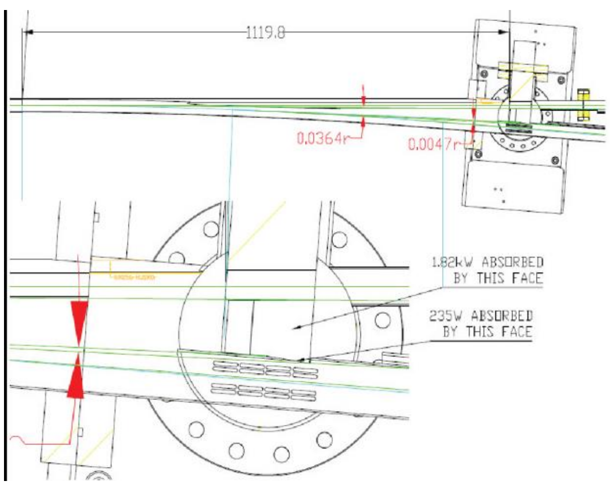
Engineering integration

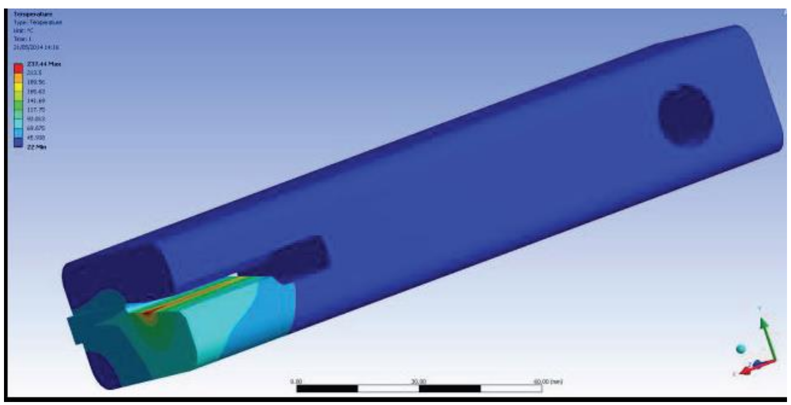
Realistic Physical aperture



- Horizontal, vertical Collimators
- Small ID gap 5mm (full gap)
- Ray-tracing and temp. analysis
- Radiation absorber in DDBA

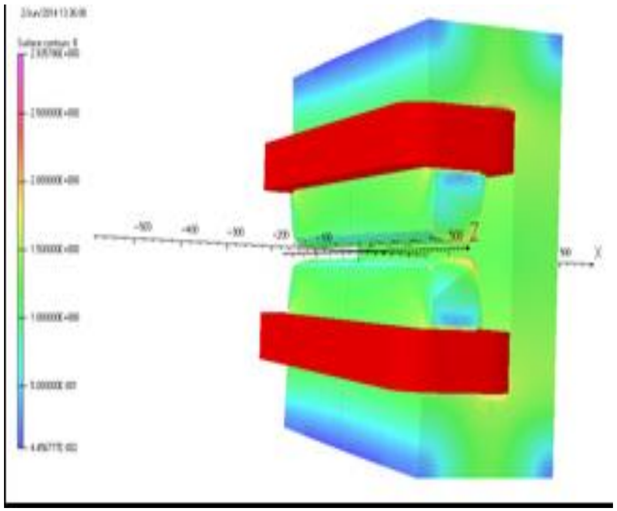
Allow fine momentum aperture search, particles loss analysis

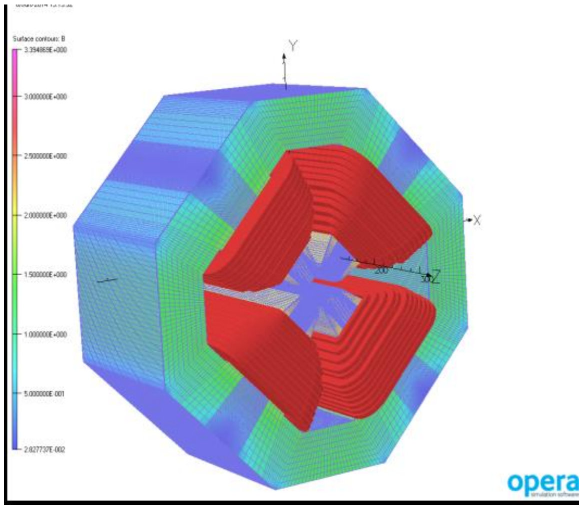


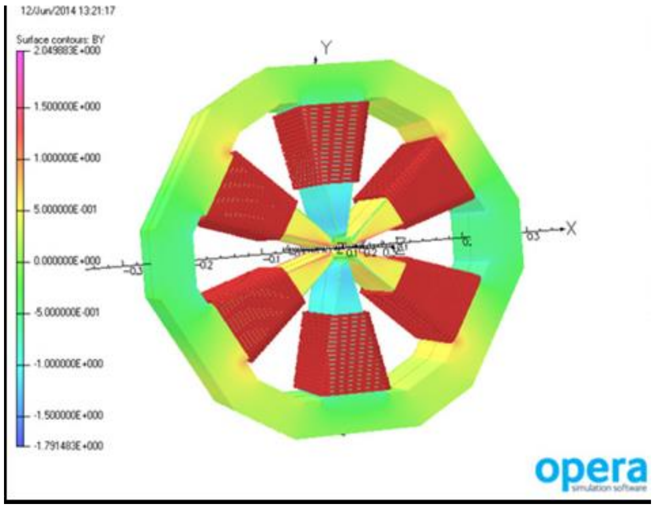


J.Kay, IPAC14, MOPRO102

Magnets design for new DDBA cell







Dipole (combined fn.)
Nominal field: 0.8 T
Gradient : 14.385 T/m

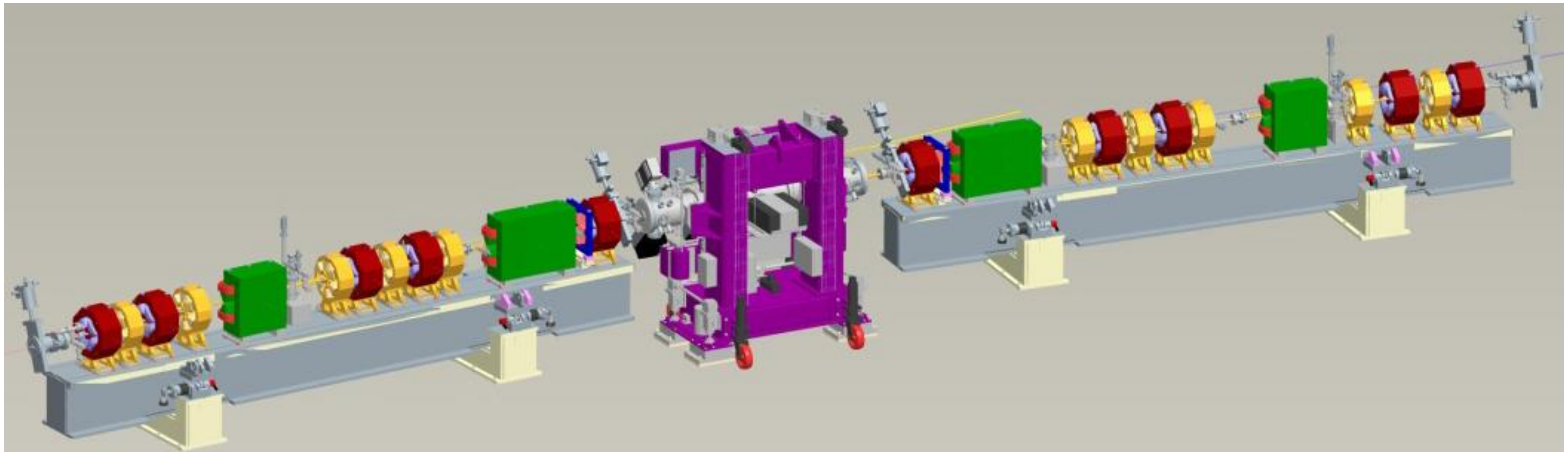
The mechanical tolerances on the pole profile are challenging with total budget of ±25 μ m

Quadrupole
Gradient : 70 T/m
Bore : 30 mm(diameter)

Sextupole
Gradient : 2000 T/m^2
Bore : 30 mm(diameter)
Corrector
Hor. : 8 mTm
Ver. : 8 mTm

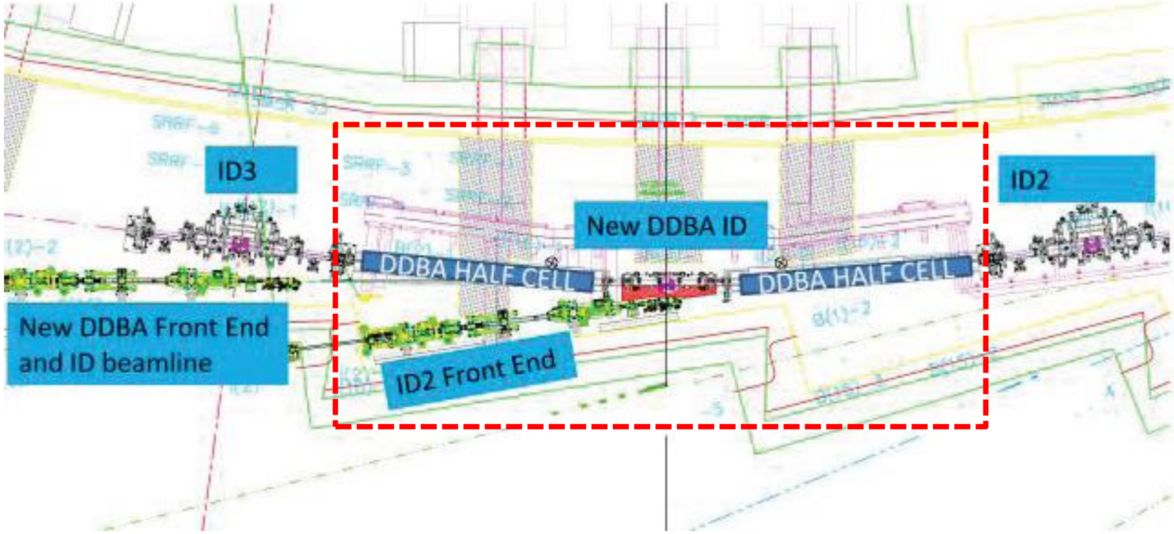
C. Bailey et al., IPAC14, TUPRO114

One cell upgrade



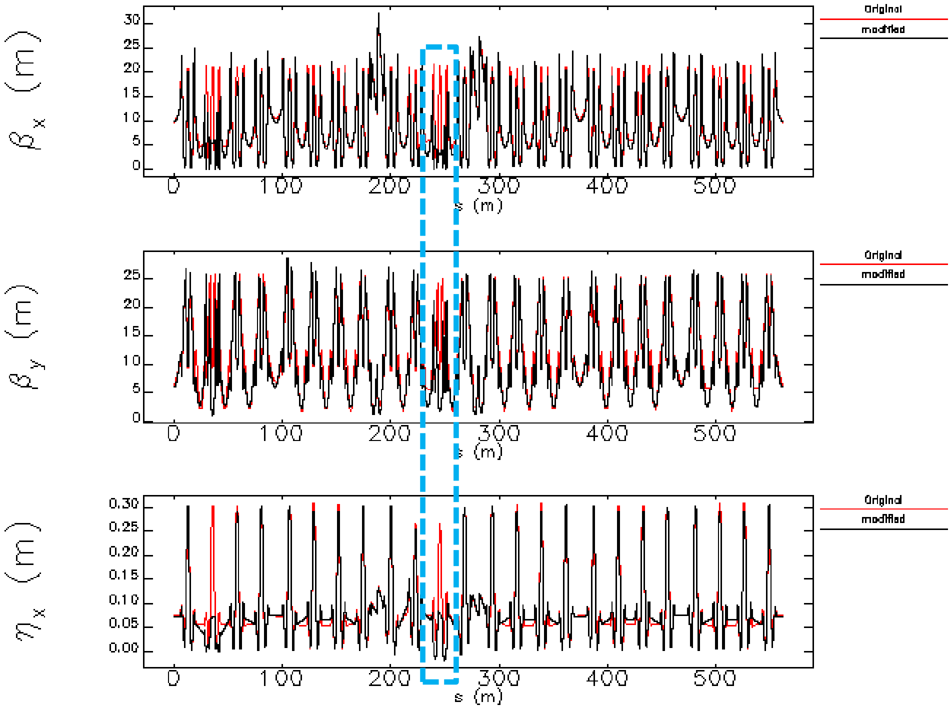
Engineering model of a standard Diamond in-vacuum undulator in one DDBA cell

DDBA Diamond cell 02

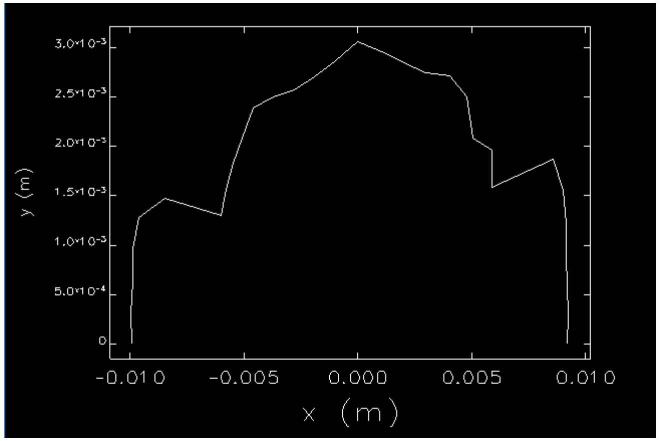


Second DDBA cell

Second DDBA replacing cell11
provides space for Dual imaging and diffraction (DIAD) beamline.



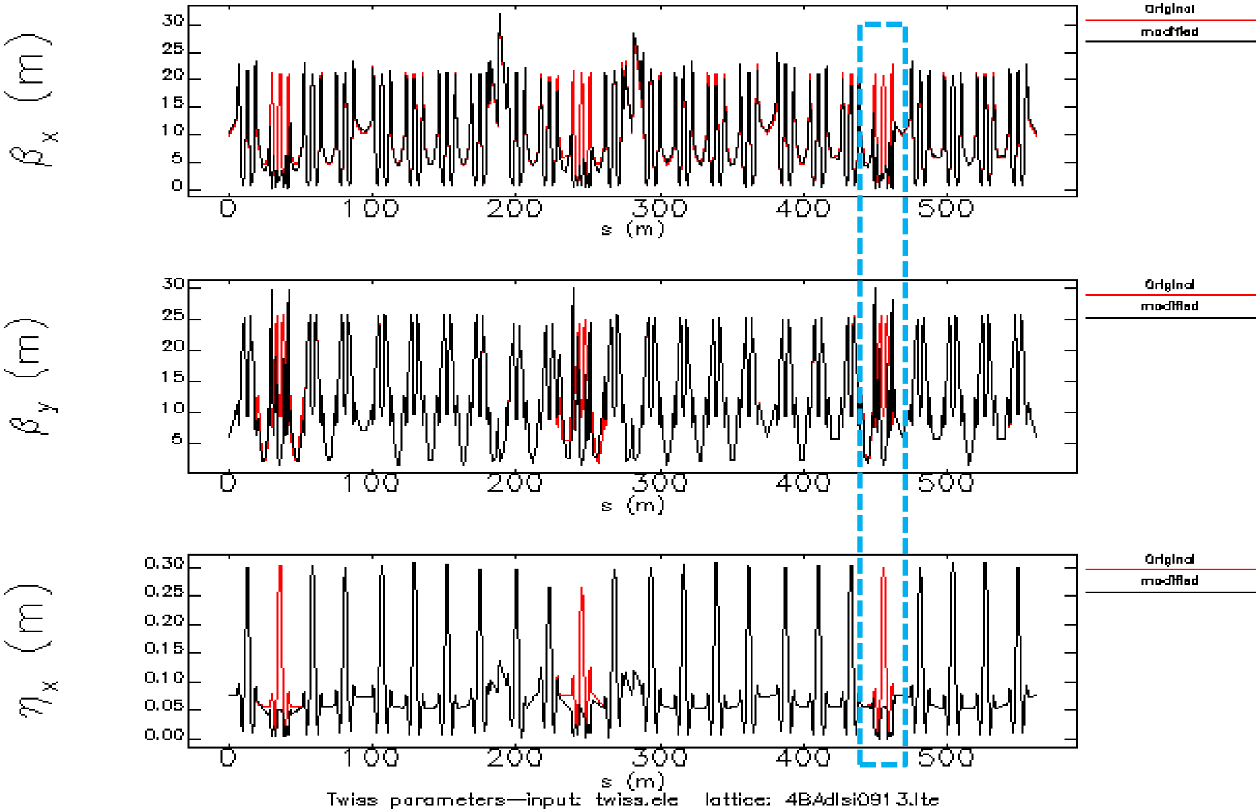
- Exact same combined fn. dipole design strength
- Same fractional tune
- Fixed Optic at IDs



Injection eff. ~85% (at -8.3mm)
Touscheck lifetime ~11 hrs WIP

Third DDBA cell

Possibility for the third DDBA cell providing an additional straight for 3rd Harmonic RF cavity



Conclusions

4BA (DDBA) is the promising candidate for Diamond upgrade.
- 10 times smaller emittance
- double beamline capacity
- Feasible magnets with conventional type

More BAs could be revisited for further emitttance reduction

One DDBA program is proceeding with complete study
- Lattice optimization found operable solutions
- Fully integrated engineering constraints, imperfection
- Commissioning plan is under consideration
- Expected commissioning ~Oct. 2016

Two DDBA and three DDBA are under investigation

Special thanks to Diamond AP group and Engineers

Beam emittance

$$\varepsilon_x = C_q \gamma^2 \frac{<H>}{J_x \rho}$$

minimize

$$\frac{\partial H}{\partial \beta_x} = \frac{\partial H}{\partial \eta_x} = 0$$

$$<H>_{dipole}^{min} = \frac{L^3}{12\sqrt{15}\rho^2}$$

Bending angle

$$\varepsilon_x = C_q \gamma^2 K \frac{1}{12\sqrt{15}} \frac{\Phi^3}{J_x}$$

Quality factor
depends on lattice design,
magnets , space requirement

where

$$H = \gamma_x \eta^2 + 2\alpha_x \eta' \eta + \beta_x \eta'^2$$

$$C_q = 3.84 \times 10^{-13}\,\mathrm{m}$$

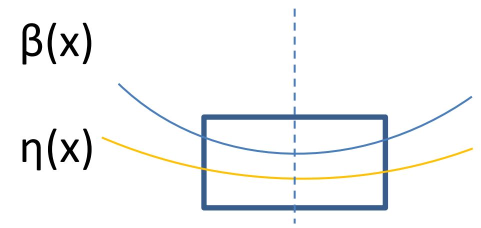
g

Low emittance lattice require small angle bending

$$\varepsilon_x \propto \Phi^3 \propto \frac{1}{N_{bending}^3}$$

Need more bending magnets

$$\frac{1}{\tau_{1/2}} = \frac{r_e^2 c_0 N_e}{8\pi\gamma^3\sigma_s}\frac{1}{C}\oint_C \frac{F\left[\left(\frac{\delta(s)}{\gamma\sigma_{x'}(s)}\right)^2\right]}{\sigma_x(s)\sigma_z(s)\sigma_{x'}(s)\hat{\delta}(s)}\,ds$$



Theoretical minimum emittance (TME) cell (K=1)