Diamond upgrade options

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Outline (and lattice evolution)

- **Motivations, wishlist and constraints for the Diamond II upgrade**

- **Initial designs and relative merits of MBA (M = 4,5,6,7)**
  - **4BA 270 pm (aka DDBA)**
    - **x10 reduction in emittance + double #beamlines**
  - **5BA 140 pm**
    - **x20 reduction in emittance**

- **(July 15) First consultation with PBSs → more aggressive designs**
  - **best of both DDBA and 5BA (low emittance + additonal straight)**
  - **6BA 120 pm (aka DTBA) modified ESRF cell + double #beamlines**

- **Onoging work and conclusions**
  - **further consultation with PBSs - comprehensive upgrade**
  - **fate of bending magnet beamlines (mini-workshop September 15)**

Brilliance and transverse coherence

Photon flux and brilliance and coherent fraction

$$\text{flux} = \frac{N_{ph}}{\Delta T \cdot \Delta\omega/\omega} \qquad \text{brilliance} = \frac{\text{flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}} \qquad F = \frac{\lambda^2/(4\pi)^2}{\Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

Σ's are the convolution of electron and photon beam size and divergence

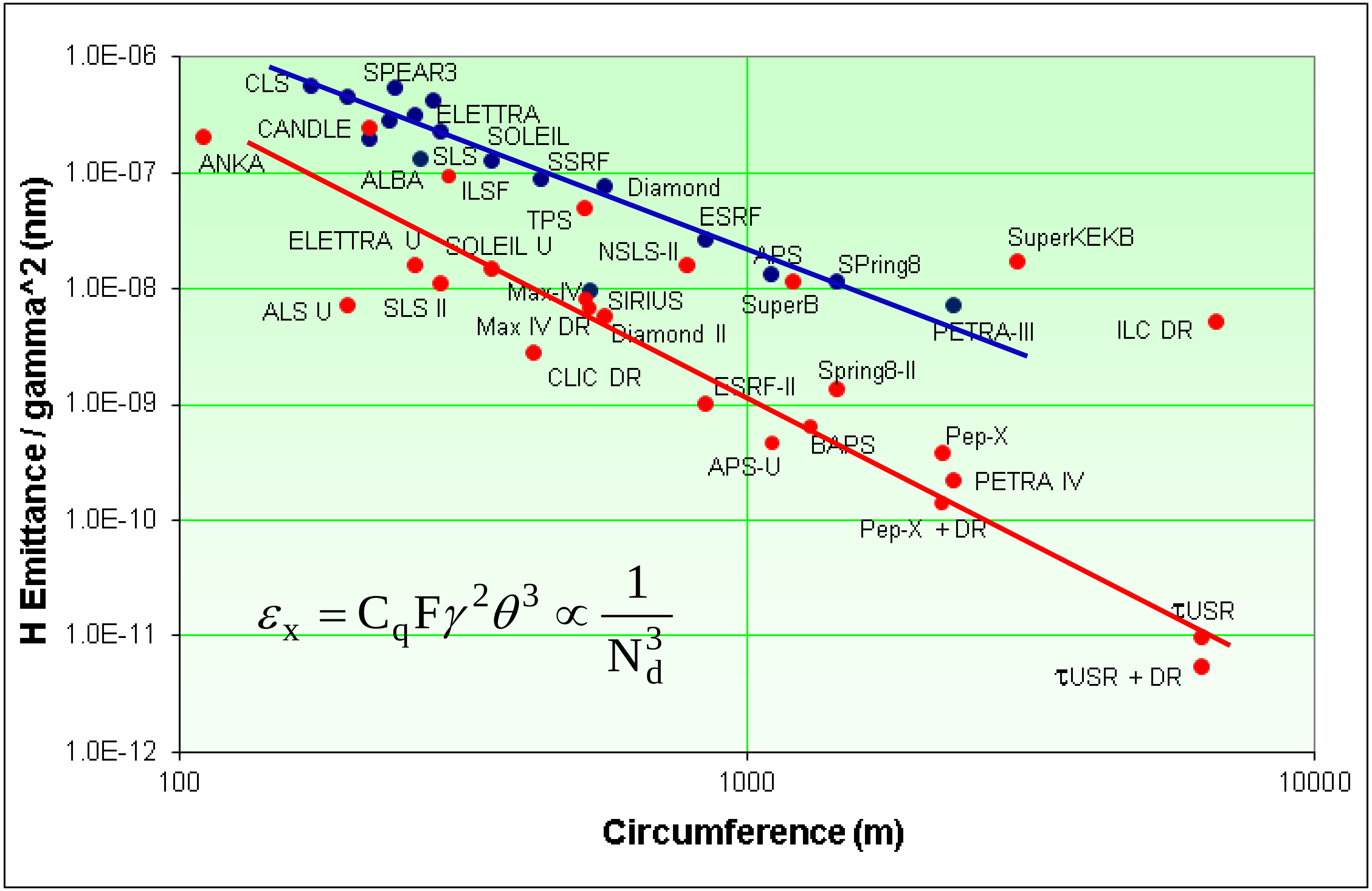
$$\Sigma_x = \sqrt{\sigma_{x,e}^2 + \sigma_{ph}^2} \qquad \Sigma_{x'} = \sqrt{\sigma_{x',e}^2 + \sigma'^2_{ph}}$$

Brilliance and coherent fraction are maximised for smaller emittances until the diffraction limit is reached

$$\varepsilon_{e^-} \leq \varepsilon_{ph} = \frac{\lambda}{2\pi}$$

10 pm for diffraction limit
at ~1 Angstron

Survey of low emittance lattices



Strategy and constraints

Wishlist for the Diamond II upgrade

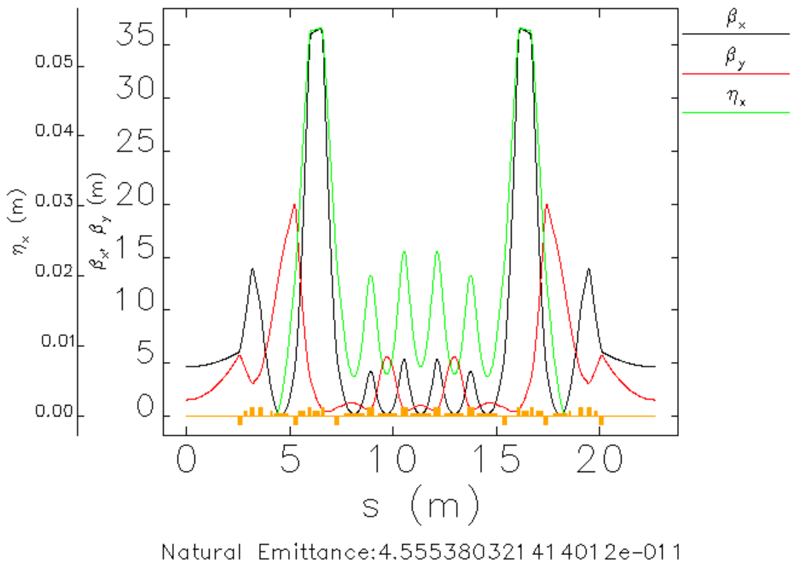
- **emittance reduced to 270 pm at least (*a factor 10 better than now*)**

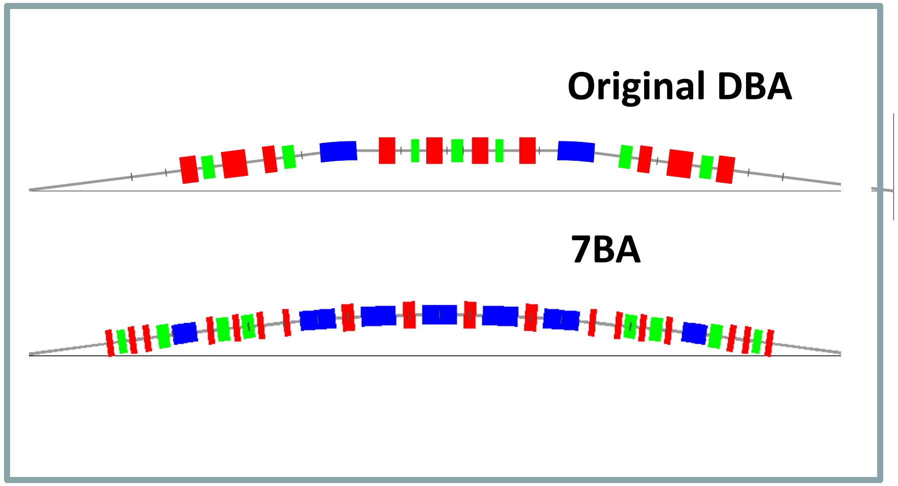
- **minimal changes to the machine**
  - **reuse tunnel and beamlines as they are (no offset or angle)**
  - **leave the straight sections as they are**
  - **reuse hardware if possible (girder, magnets, RF, etc)**

- **maintain I09-I13 optics**
- **maintain short pulse capabilities (low-alpha)**
- **avoid long interruptions**
  - **find options that can be phased**

- **minimise technology risks**

Evolution of lattice design at Diamond





7BA lattice	**45 pm**
5BA lattice	**140 pm**
4BA lattice	**270 pm**

DA achieved (WIP)
7BA DA ±1 mm
5BA DA ±3.5 mm
4BA DA ±5 mm

Nonlinear dynamics

Large natural chromaticity with ultra low emittance
Fourth order and detuning terms very hard to compensate

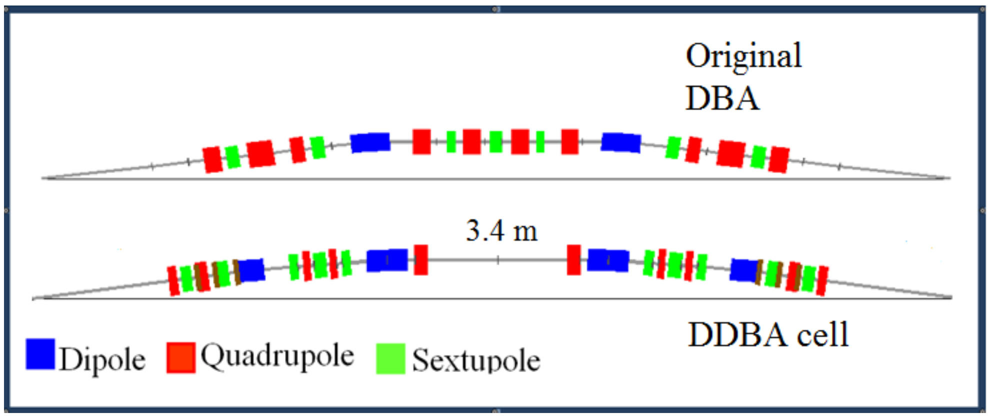
IBS emittance

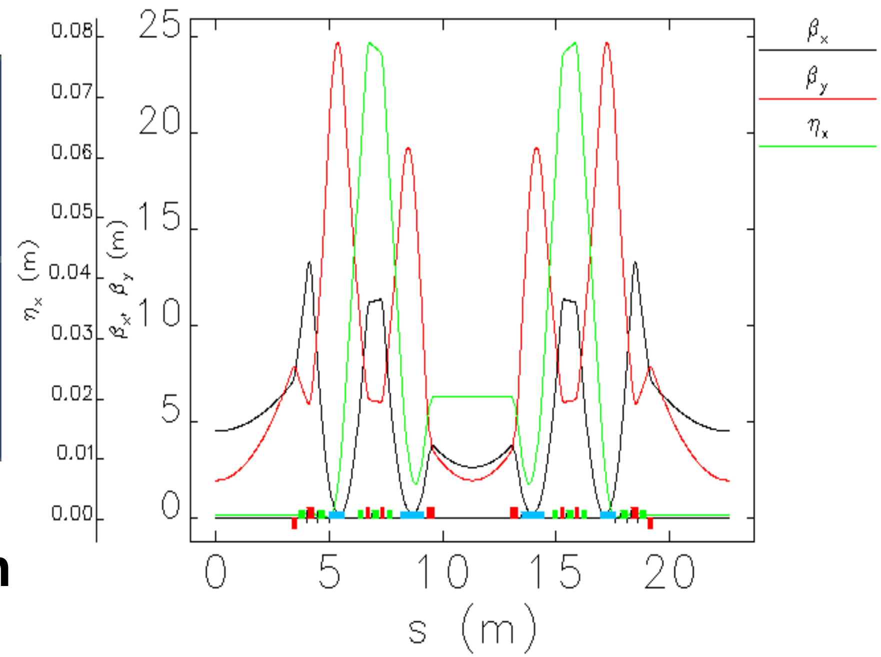
No HHC

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%**

Modified 4BA – 270 pm

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



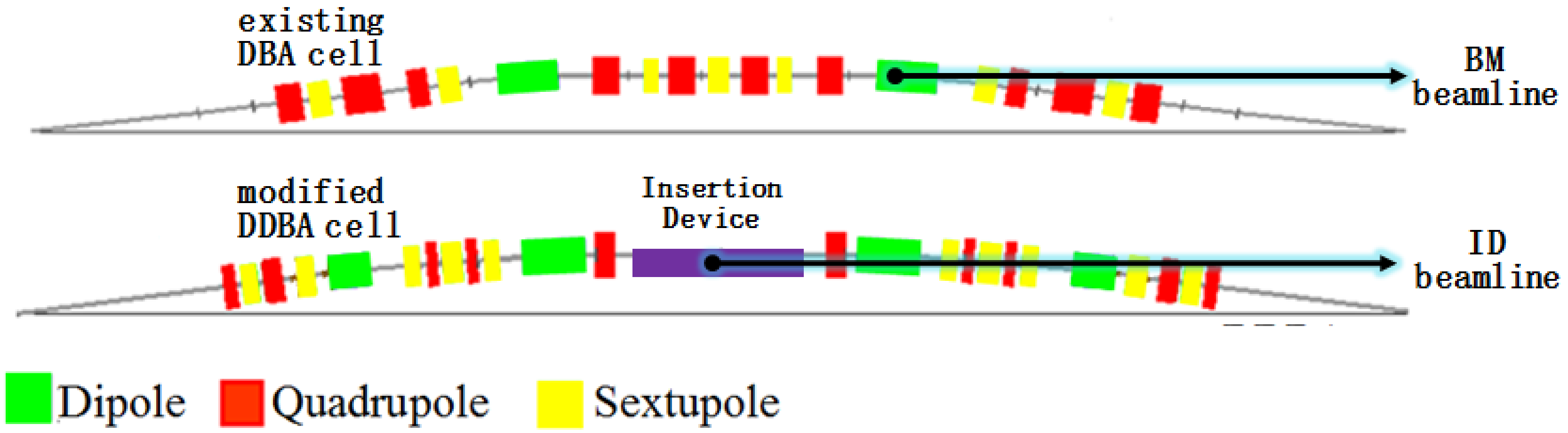


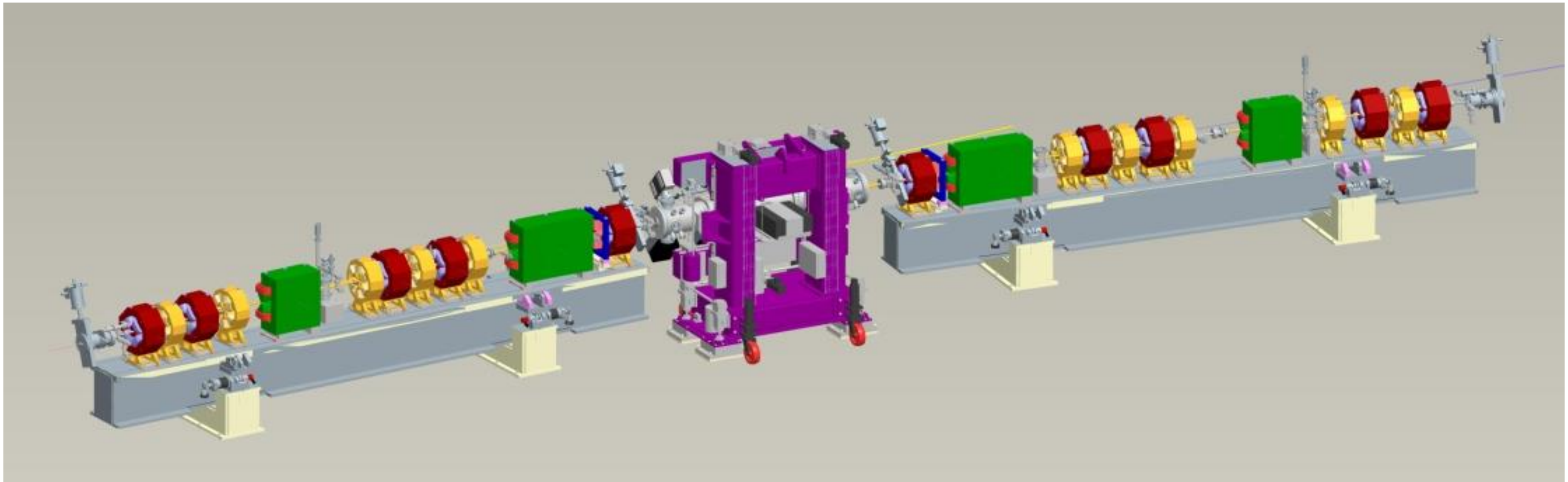
This lattice originated the modification of the existing cell2 too a DDBA cell

It is been the baseline design for Diamond II until end 2015

One DDBA cell in the existing lattice

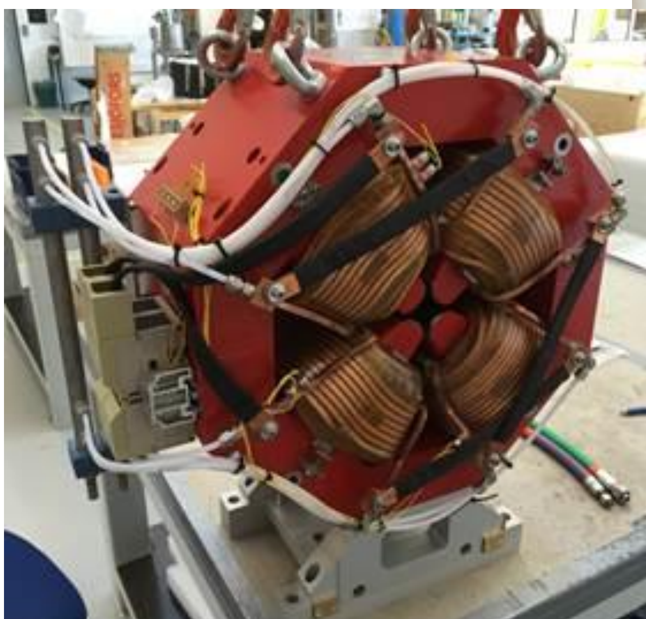
One DDBA cell is going to be installed in the existing lattice in order to have one more beamline (no significant gain in emittance)





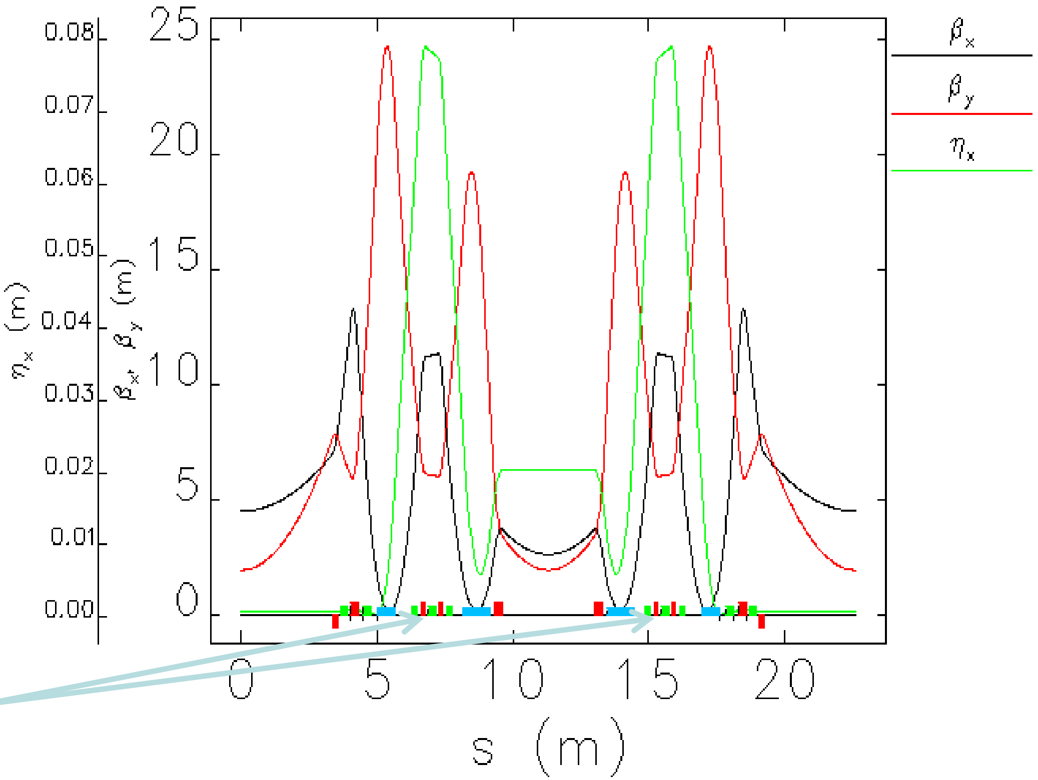
One DDBA cell in the existing lattice

Magnets and vacuum contract almost complete
Girder build ongoing. In situ alignment with stretch wire.
Installation and recommissioning within end of 2016



Issues with DDBA cell design

- 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

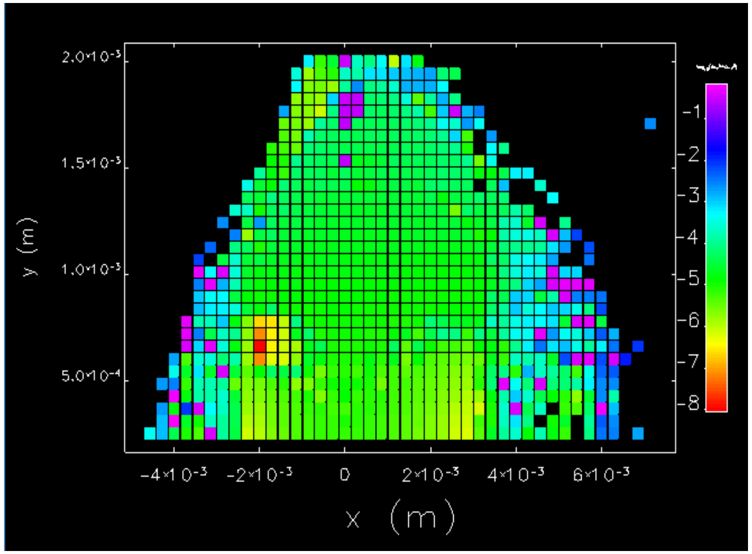


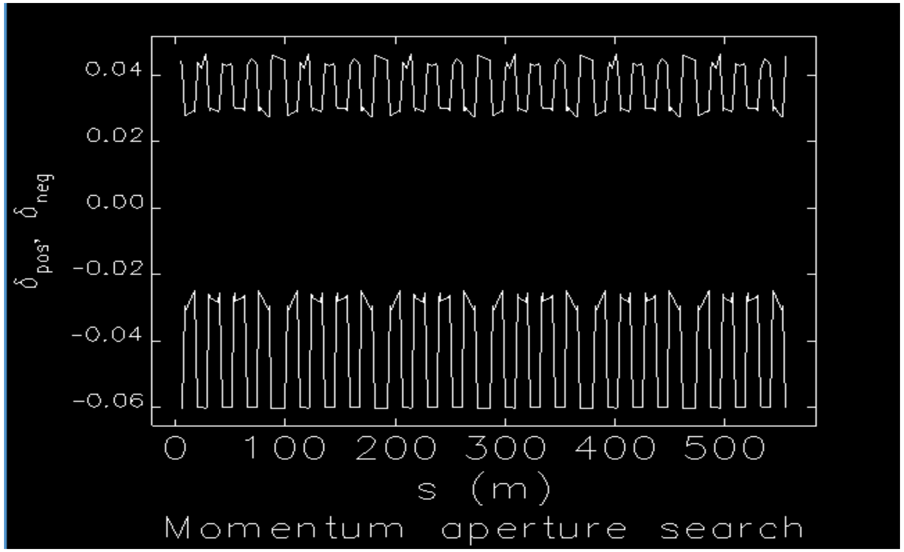
H phase advance is ~ 2π*0.8

Optics function tailored to add one more in-vacuum ID in the mid straight
Hard control of phase advance between chromatic sextupoles

MOGA optimisation for DA and lifetime (4BA)

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

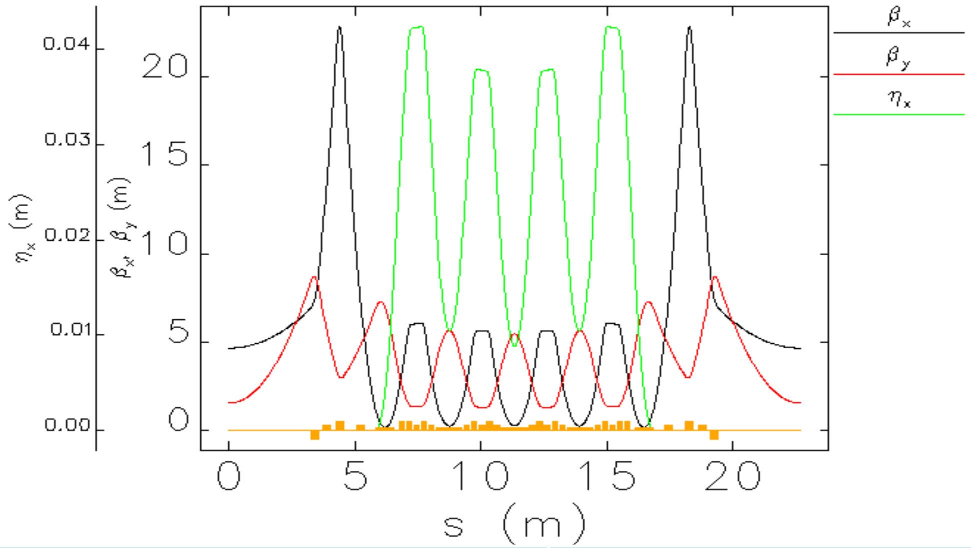




DA still under optimisation - ~5 mm (WIP)
Touschek lifetime ~ 7h without harmonic cavities

5BA lattice – 140 pm

Further reduction of the emittance (x20) with a 5BA cell



Parameters	
Total length	561.6 m
Natural emittance	142.5 pm-rad
Natural chromaticity : h./v.	-152/-53
Straight length : long/short	9.5 m/ 6.5

Straight section length slightly reduced

Gradient in bend < 15 T/m
Quads gradient < 55 T/m

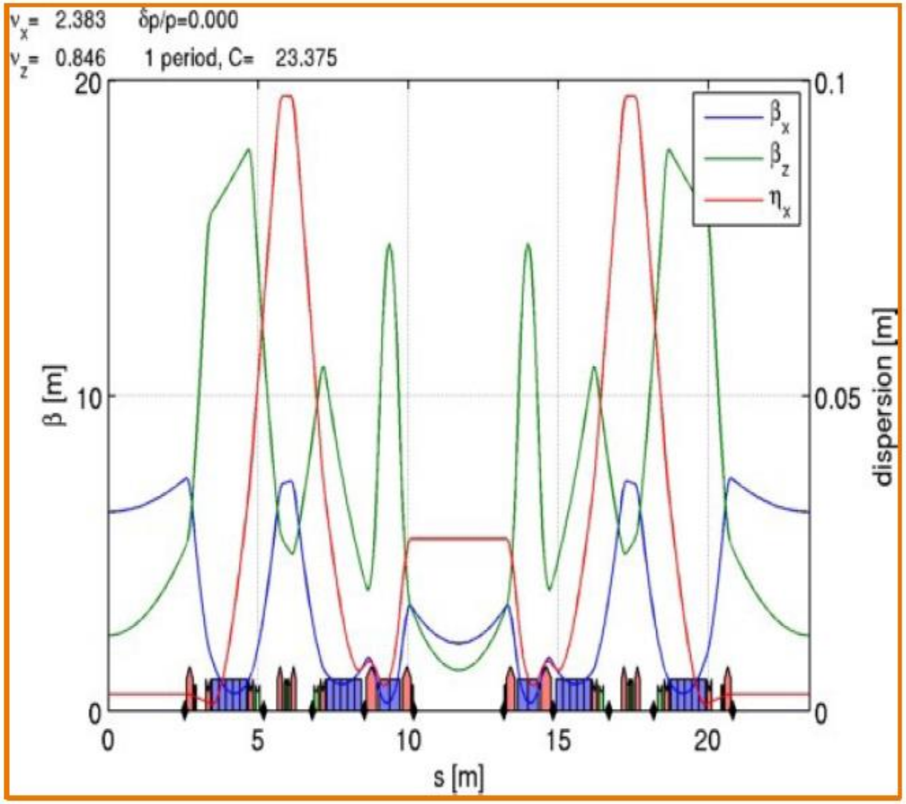
This lattice will need to accommodate new bending magnet beamlines (superbends a la Sirius?)

DA optimisation more difficult (3 mm now)

modified 6BA lattice – 120 pm

Initial studies on modified 6BA design proved difficult (a simple scaling of TBA doubling the cell did not work)

Collaboration with ESRF: Use the ESRF cell concept (7BA with longitudinal gradient dipoles) – removing the mid dipole to make it a 6BA with a straight at the centre



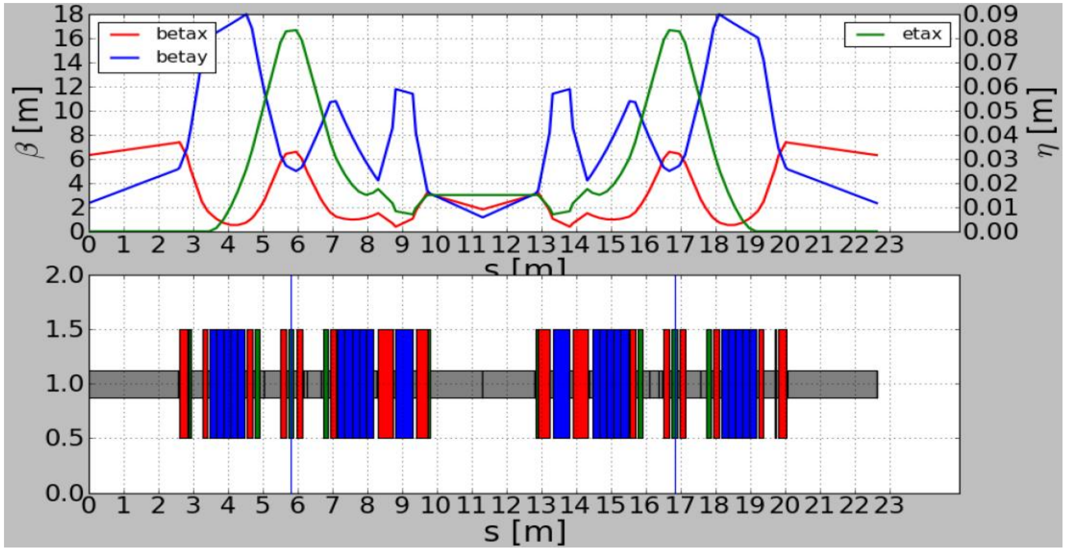
This design is promising!
First analysis shows it is as good as the 4BA

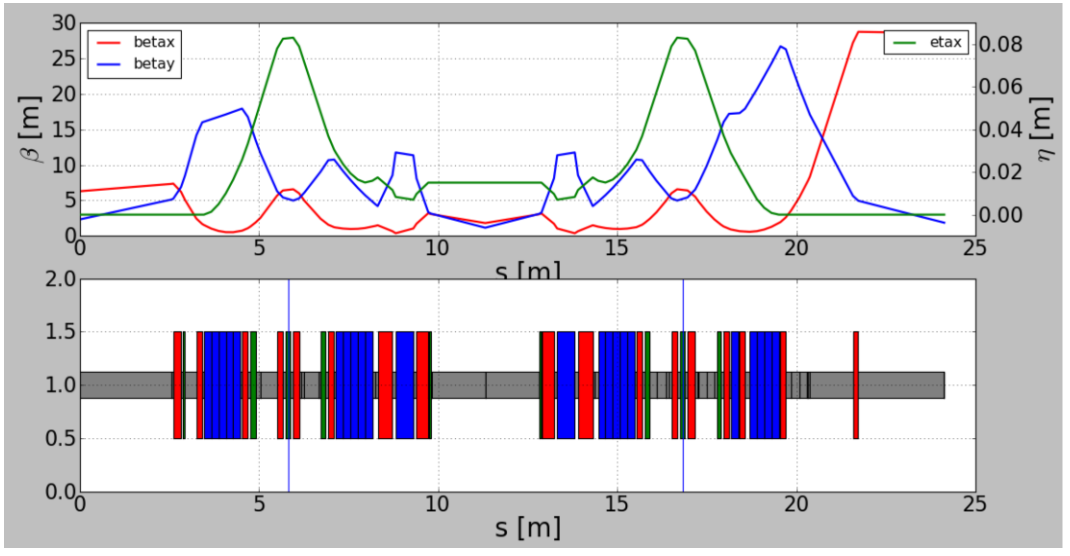
Longitudinal gradient dipoles + strong gradient dipole (up to 1.4 T 40 T/m)

~3 m mid-straight section

~2mm bunch length
work in progress!

Cell variants specific to Diamond design





Tailoring cell design to diamond specific features

The present work is concentrating on providing the 6-fold symmetry of diamond

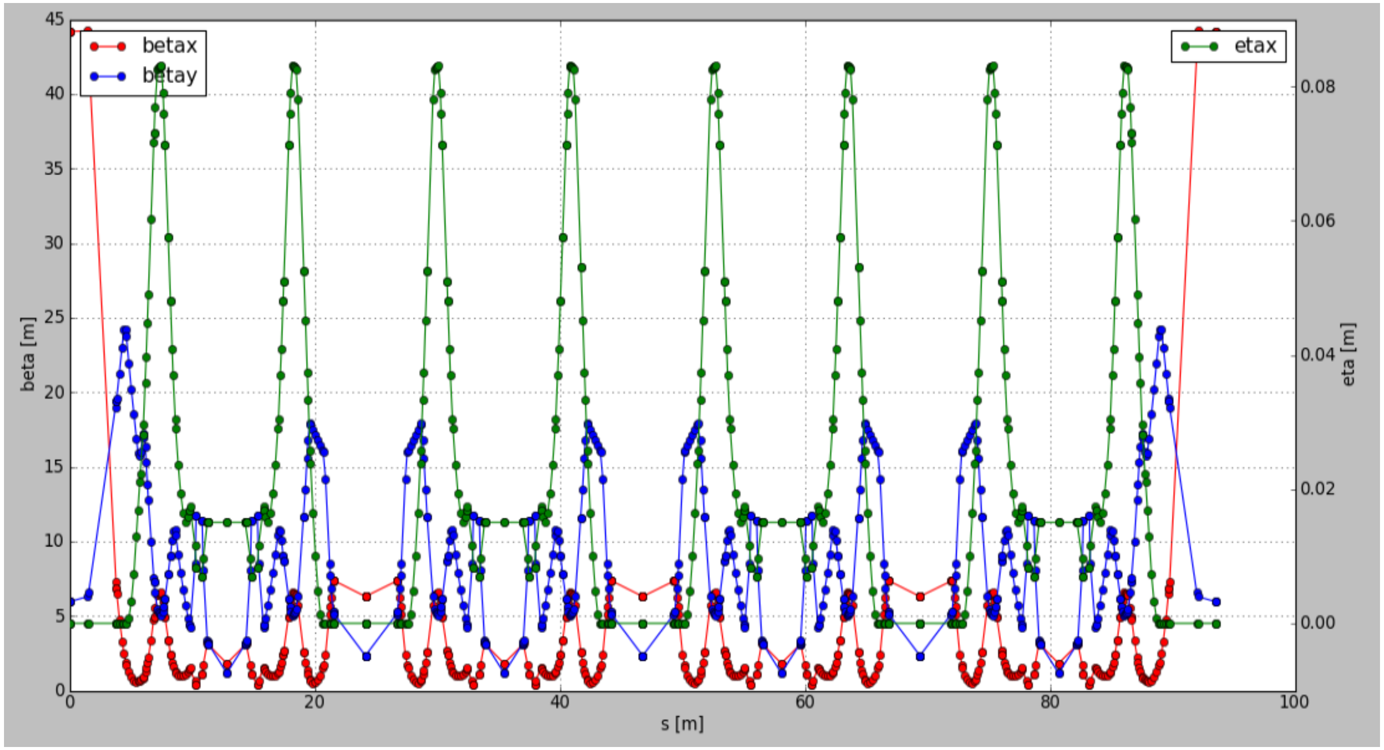
short straigth sections ~5m
long straight sections ~8 m
Mid-straight section ~3 m

Large beta x for injection under investigation

I09-I13 double minibeta sections to be included

Ditto for I21 stronger focussing sections

One superperiod



Main Ring Parameters

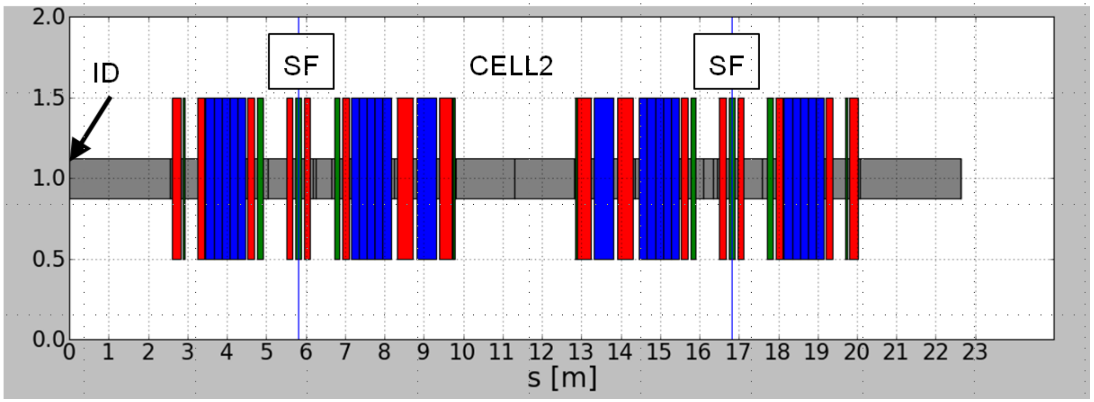
emittance [pm]	122 pm
natChrom H/V	**-79/-123**
tune H/V	57.20/20.30
momCompaction	1.1e-04
bunchLength	2.4 mm

Existing ring

emittance [pm]	2700 pm
natChrom H/V	**-54/-90**
tune H/V	27.20/13.36
momCompaction	1.7e-04
bunchLength	3 mm

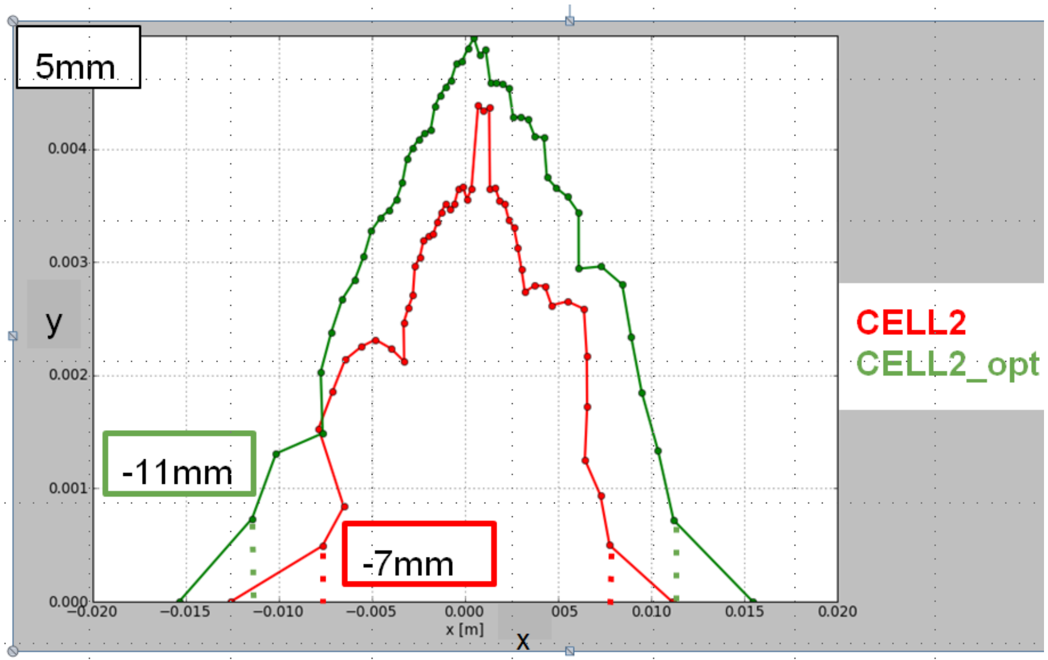
Cell optimisation

Parameter	Start	Optimal
alpha@SF	0.76	0.4
octupole	-16k	-48k
Psiy (SF-SF)	0.964	0.960
betax@ID (m)	6.30	7.50
beta@SF (m)	5.20	3.50
Eta@ (ID) (m)	0	0



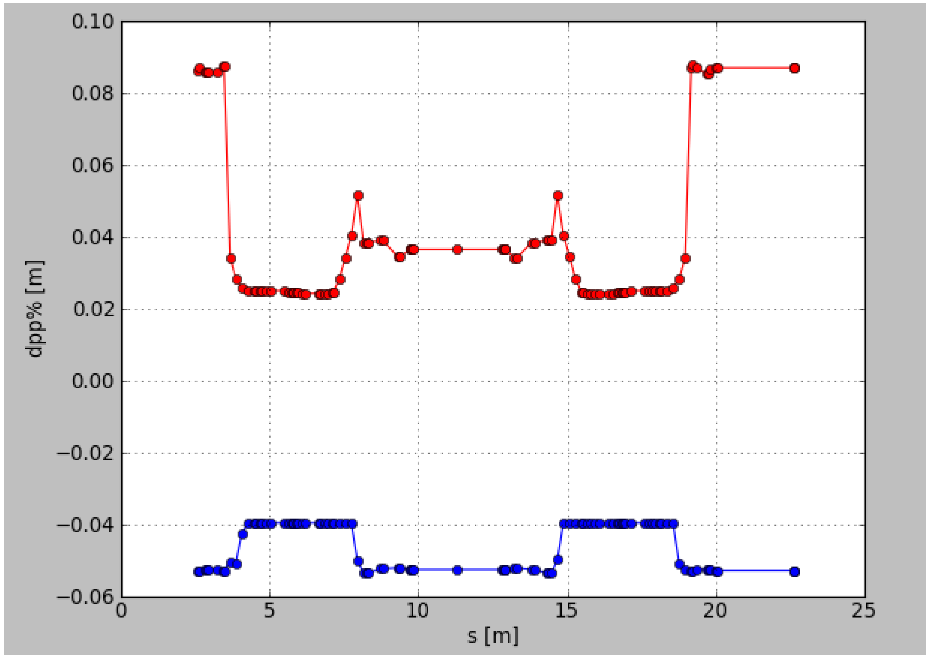
Linear ↔ Nonlinear optimisation

Following the ESRF approach we make a thorough scan of the linear optics that provides the best DA and MA (for a fixed chromaticity)
MOGA will follow (WIP)



Cell optimisation

Momentum aperture providing 3.25 h with 300 mA 900 bunches 1% coupling



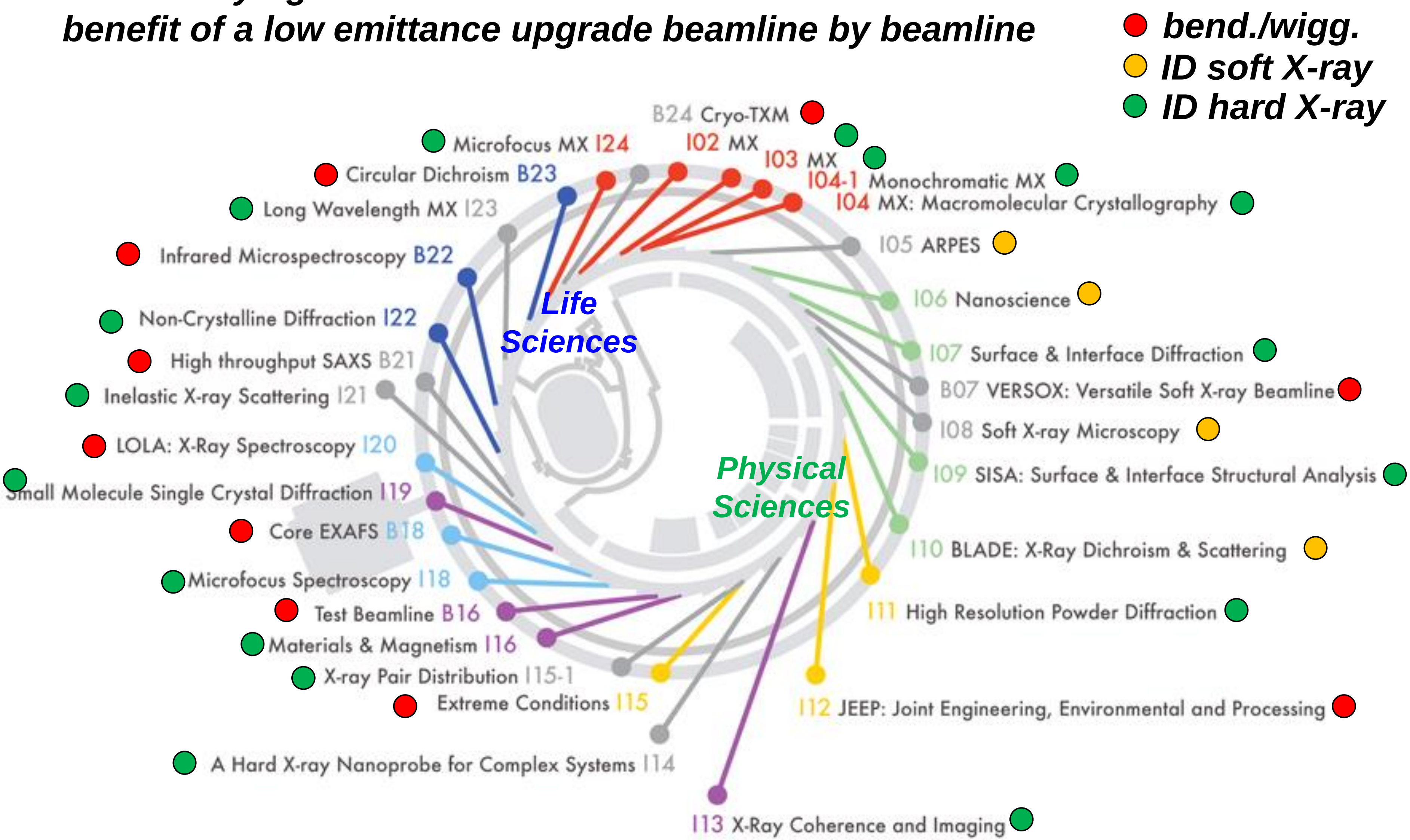
tLife: 3.25h; further optimisation underway

With a DA of 11 mm and a lifetime of 3.2h the DTBA is a promising candidate for Diamond II. Most of the design effort is concentrating on this lattice

Magnets challenging but gradient limits set the same as ESRF

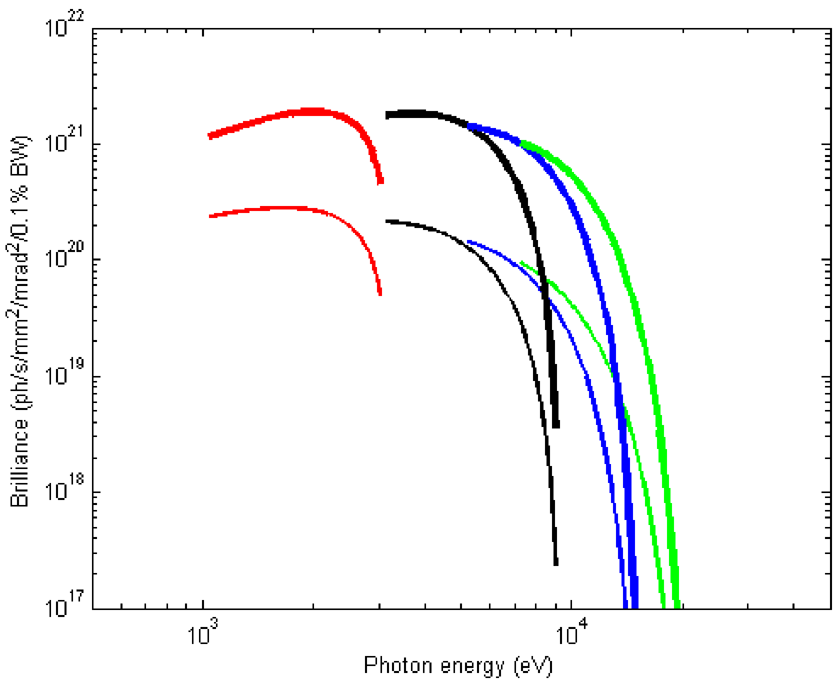
Assessing the benefits for the beamlines (@ SAC15)

We are trying to have a clear assessment of the overall benefit of a low emittance upgrade beamline by beamline



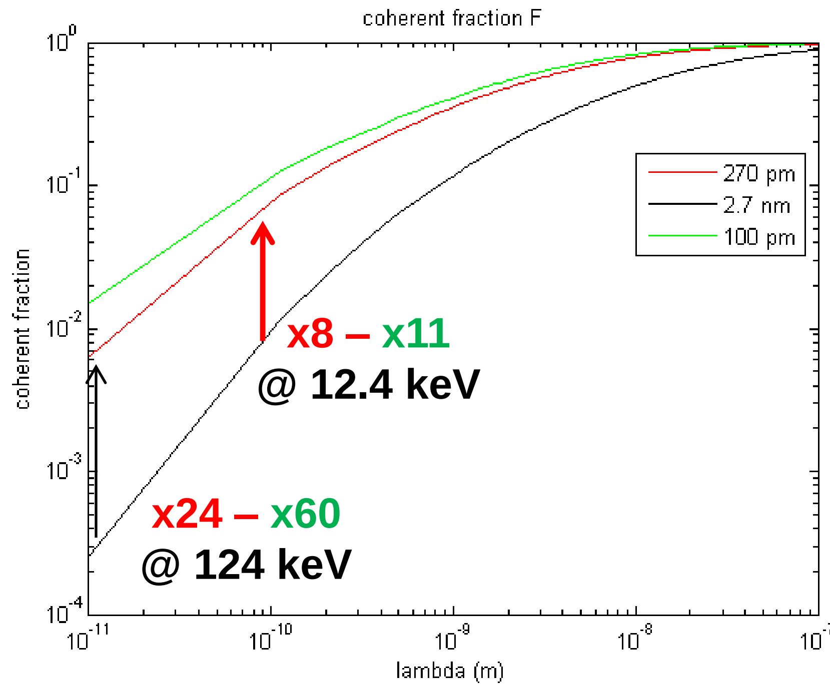
Upgrade with Diamond-II (200pm):

Brilliance plot using U27 300 mA 1%K 72 periods 2 m long with K_{max} = 2.02



Tuning curves computed with Spectra 8.0

Transverse coherence fraction with respect to present operation



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

Electrons and photon beam sizes (undulators)

	Electron Beam				Photon Beam at E = 12 keV (U21 2 m long)			
	DLS	DLS II 4BA	DLS II 5BA	Zero-emittance and energy spread	DLS	DLS II 4BA	DLS II 5BA	Zero-emittance and energy spread
σ_x [μm]	122.5	61	56	0	122.5	61	56	1.7
σ_y [μm]	3.5	1.1	0.8	0	3.85	2	1.8	1.6
$\sigma_{x'}$ [μm]	24	7.6	5.5	0	25.5	11	10	5
$\sigma_{y'}$ [μm]	2.3	0.73	0.52	0	8.5	8.4	8.3	5

Many beamlines benefit from X2(simgax) X2(simgax') X2(simgay)

- **Some beamlines clearly win (coherence – nanofocus)**
- **The others should not lose**
  - **protein crystallography ?**
  - **soft Xray (I05, …)**
  - **time resolved (I06, …)**
  - **THz**

Specific issues are dealt with (I09 energy resolution - I20 dispersive beamline)

Dipole beamlines in Diamond II

BM Critical energy

DLS-II 0.8 T ⇔ 4 keV from 8.4 keV at DLS

Broadband

at least x3 critical energy

DLS-II < 12 keV from ~25 keV at DLS

Brightness/flux

better aspect ratio

DLS dipole (@ centre)	37 μm H	25 μm V
$\div$10 $\rightarrow$ sqrt(10)	~12 μm H	~8 μm V
$\div$20 $\rightarrow$ sqrt(20)	~8 μm H	~6 μm V

divergence dominated by $1/\gamma$ = 170 urad

flux decrease with critical energy
penalizes strongly the hard X-rays bending beamlines

Dipole beamlines in Diamond II

MBA choice
proper ID (even-BA) vs 2PW, 3PW or bending or superbend (odd-BA)?

4BA
"flexibility" in the 3.4 m available for a new ID/BM
but "only" x10 emittance reduction

5BA
stay with bend, superbend (a la Sirius) or 2PW/3PW (a la ESRF)
but better emittance x20 reduction

6BA
will provide best of both

Most bending beamlines PBSs (7 bendings beamlines) expressed a clear preference for even-BA lattice option that will allow the flexibility of upgrading their source to an undulator or a wiggler or a 2PW or a 3PW if they wish

Building the science case

Diamond set up three main working groups to define the science case and the technical options of the upgrade. Report at the SAC on 27-th April

Some of the designs have still lots of flexibility in the technical choices

Need input from PBSs and Users

what emittance?, are round beams needed?

alternate high beta – low beta ? operating modes (e.g. low alpha, …)?

AP should explore tailoring the design to their specific beamlines

Notice that the upgrade of diamond is not only limited to the low emittance ring but will comprise

IDs,

beamlines,

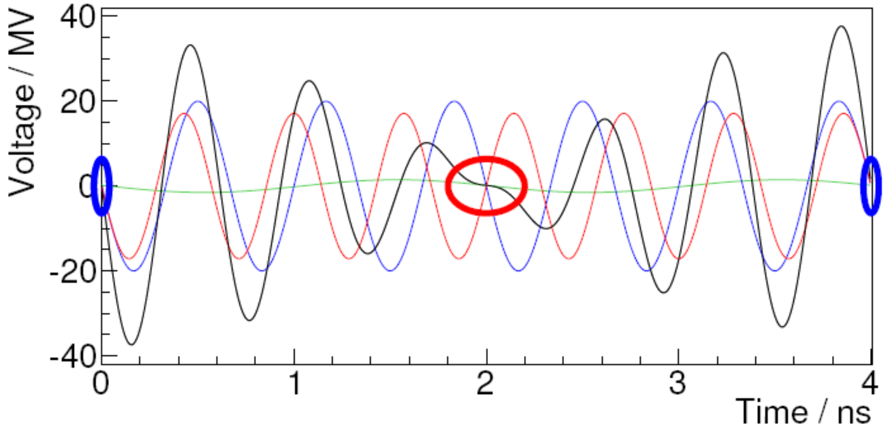
detectors,

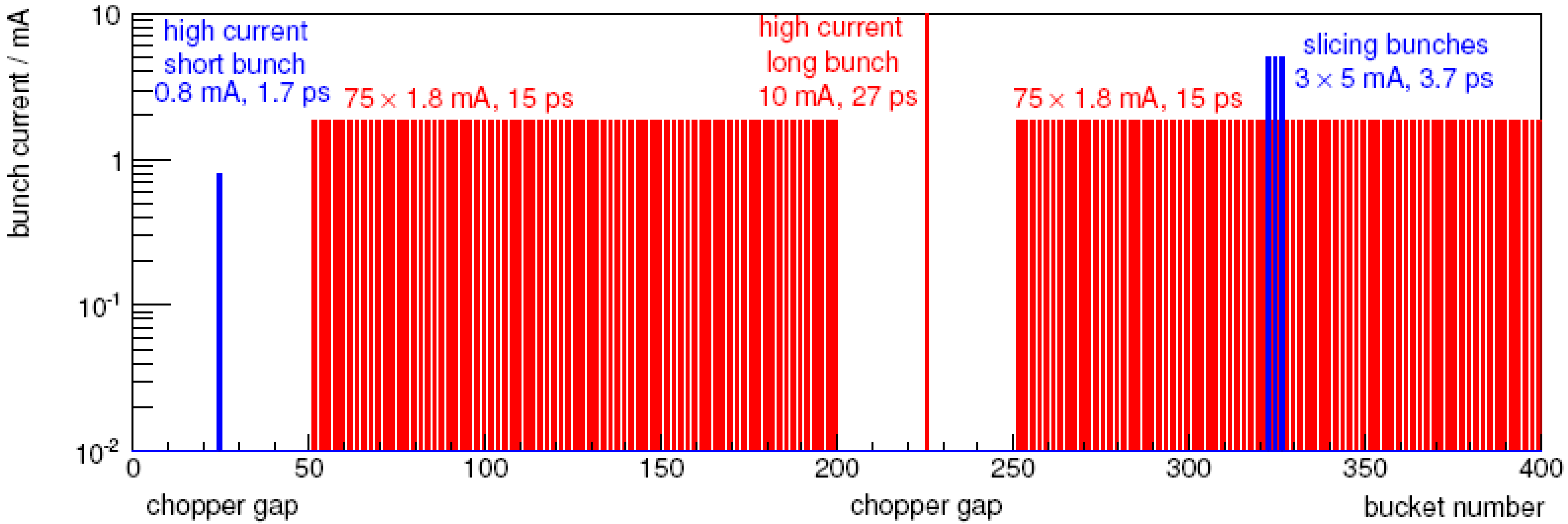
data analysis, ...

Integrating all of them, the gain in brightness will be much larger than ~10.

Time resolved science via Variable pulse length SR - VSR

Combining harmonic cavities at 1.5 GHz and 1.75 GHz to store simultaneously long and short pulses – SC RF





From Bessy VSR CDR and A. Jankowiak private communications

Conclusions

Diamond II design is striving to combine

low emittance and doubling the straight sections

The additional flexibility has so far paid off in winning the support of most bending beamlines and can be further used e.g.

more beamlines proper

additional RF (e.g. 100 MHz)

DTBA Lattice design promises to reach 120 pm emittance with conventional off axis injection

Possible new directions:

VSR-type of concepts or further reduction of emittance, e.g. DQBA

Open for collaboration with interested AP-technology Groups (beyond DLS/JAI/ESRF)

Acknowledgments

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Thank you for your attention !