Diamond upgrade

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Institute of Physics PABG 2017
RHUL, London

thanks and credits to:
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S. Liuzzo, P. Raimondi, N. Carmignani (ESRF)

- **Diamond today**
  - … and other facilities

- **Low Emittance**
  - Brilliance and coherence
  - From **2.7nm** to < **270pm**
  - Constraints on new machine

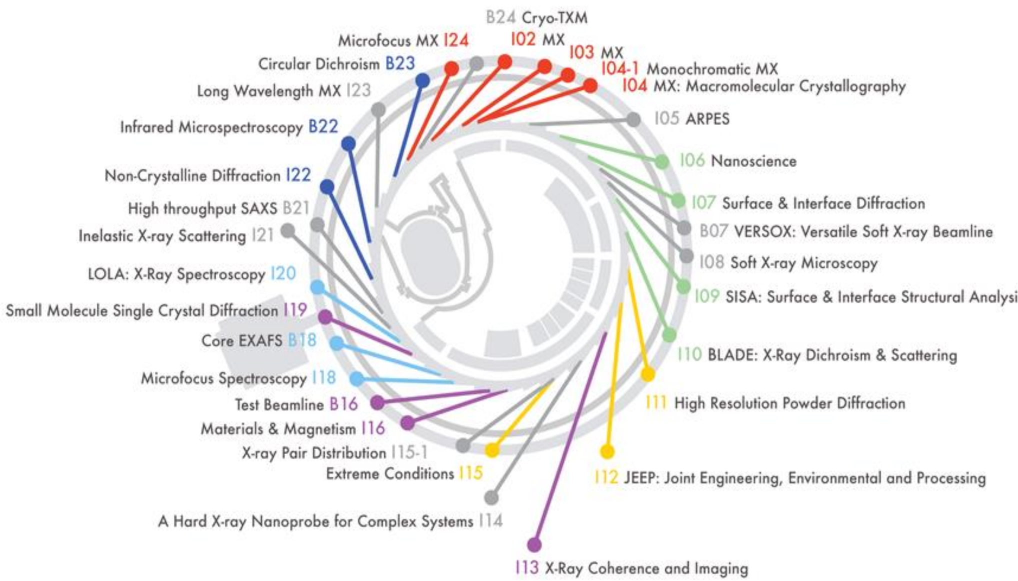
- **Evolution of Diamond-II low emittance lattice**
  - Double Double Bend Achromat (DDBA)
  - Double Triple Bend Achromat (DTBA)

- **Where we stand**
  - Optimizations
  - Open issues

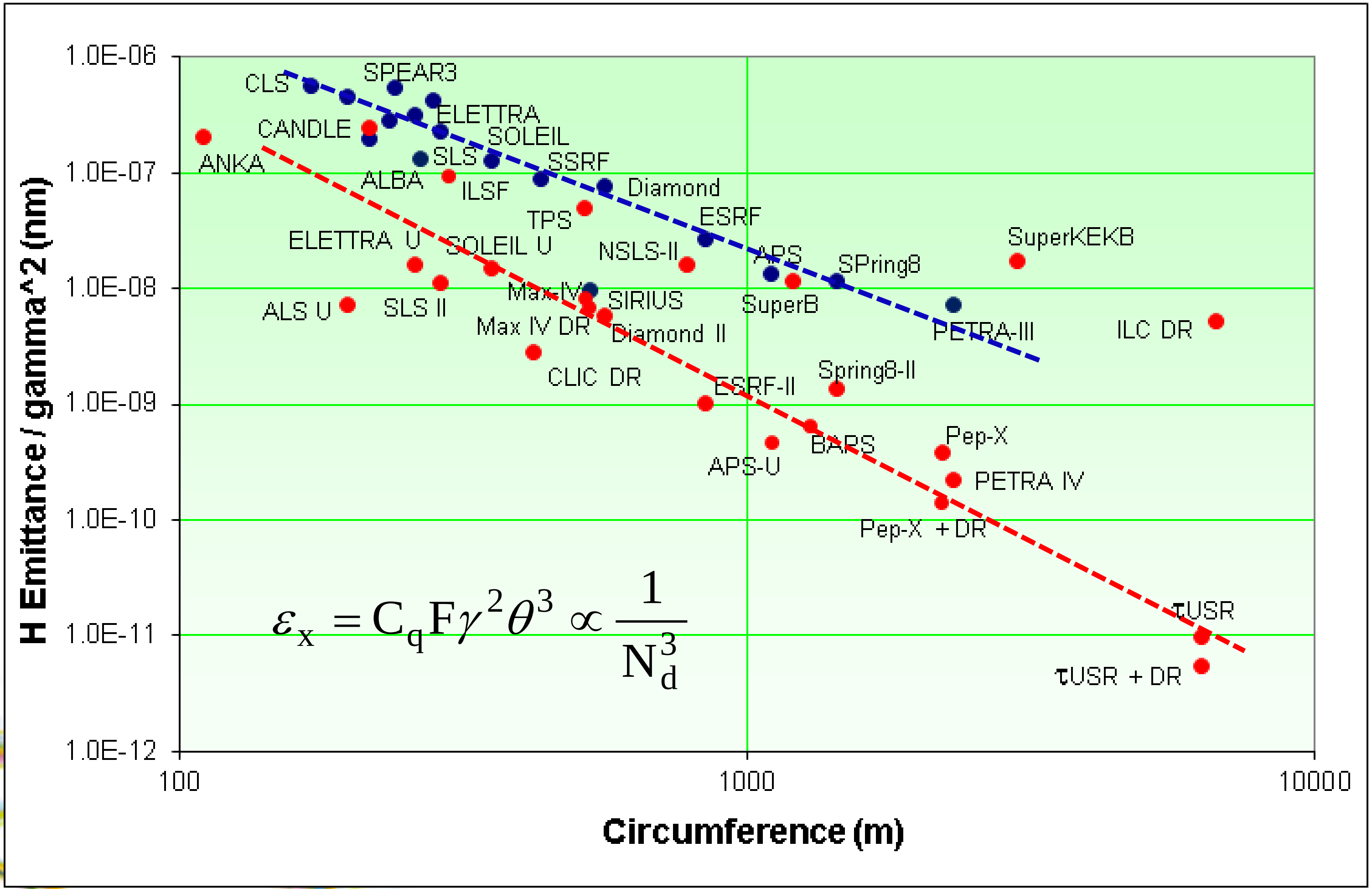
- **Summary**

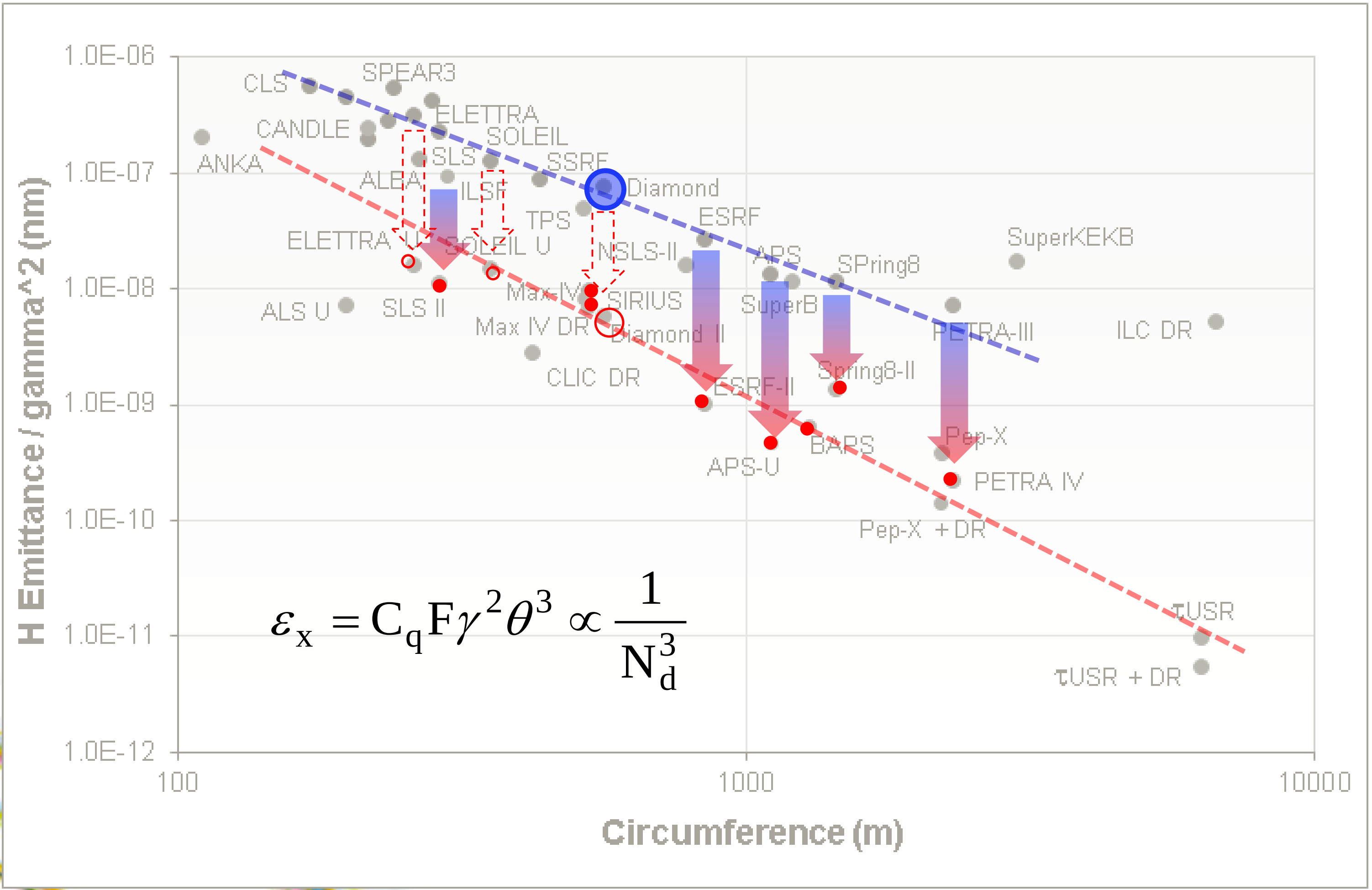
Diamond

- **3rd generation** synchrotron light source
- world class facility
- **31 beamlines**
  - **7 bending** magnet BLs
  - **24 undulator/wiggler** BLs
    - **2 SC wigglers** BLs
- **Machine parameters**
  - **E = 3.0 GeV**
  - **ε = 2.7nm** / **C=0.3%** / ν =(0.172,0.273) / ξ = (1.5,2) / **LT > 12 hrs** [usergaps/Wig-on/300mA] / **top-up** mode



- **MAX IV** (Sweden)**:** reached 200mA (end of 2016), first users
- **ESRF upgrade** (France)**:** placing contracts
  magnets placed, large scale prod. 2017-mid2018;
  assembly phase. Long SD end of 2018, back in op. 2020
- **Sirius** (Brazil) under construction
- **APS-U** (US) has passed CD1
- **ALS-U** (US) at CD0 stage
- **BAPS** (China) got money for R&D programmes (ready in 2022?)
- **SLS-II** (Switzerland) and **Diamond II**
  advanced consultations with PBSs and users in view of CDR
- many labs are investigating options (**SOLEIL**, **ELETTRA**, ILSF, ...)


H Emittance / gamma^2 (nm)
Circumference (m)
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
1.0E-11
1.0E-12
100
1000
10000
CLS
SPEAR3
ELETTRA
CANDLE
SOLEIL
ANKA
SLS
SSRF
ALBA
ILSF
Diamond
TPS
ESRF
ELETTRA U
SOLEIL U
NSLS-II
APS
SPring8
SuperKEKB
Max-IV
SIRIUS
SuperB
ALS U
SLS II
Max IV DR
Diamond II
PETRA-III
ILC DR
CLIC DR
ESRF-II
Spring8-II
BAPS
Pep-X
APS-U
PETRA IV
Pep-X + DR
τUSR
τUSR + DR
$\varepsilon_x = C_q F \gamma^2 \theta^3 \propto \frac{1}{N_d^3}$



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

electron beam sizes (standard straight)

Parameter (rms values)	Diamond	Diamond-II (DTBA)
Horizontal size, σ_x [μm]	123.5	23.6
Vertical size, σ_y [μm]	3.5	3.5
Horizontal divergence, $\sigma_{x'}$ [μrad]	24.1	5.1
Vertical divergence, $\sigma_{y'}$ [μrad]	2.3	2.3
Product	2.38 10^4	9.60 10^2
Electron beam brightness ratio	1	24.8

photon phase space at 12.4 keV (i=7)

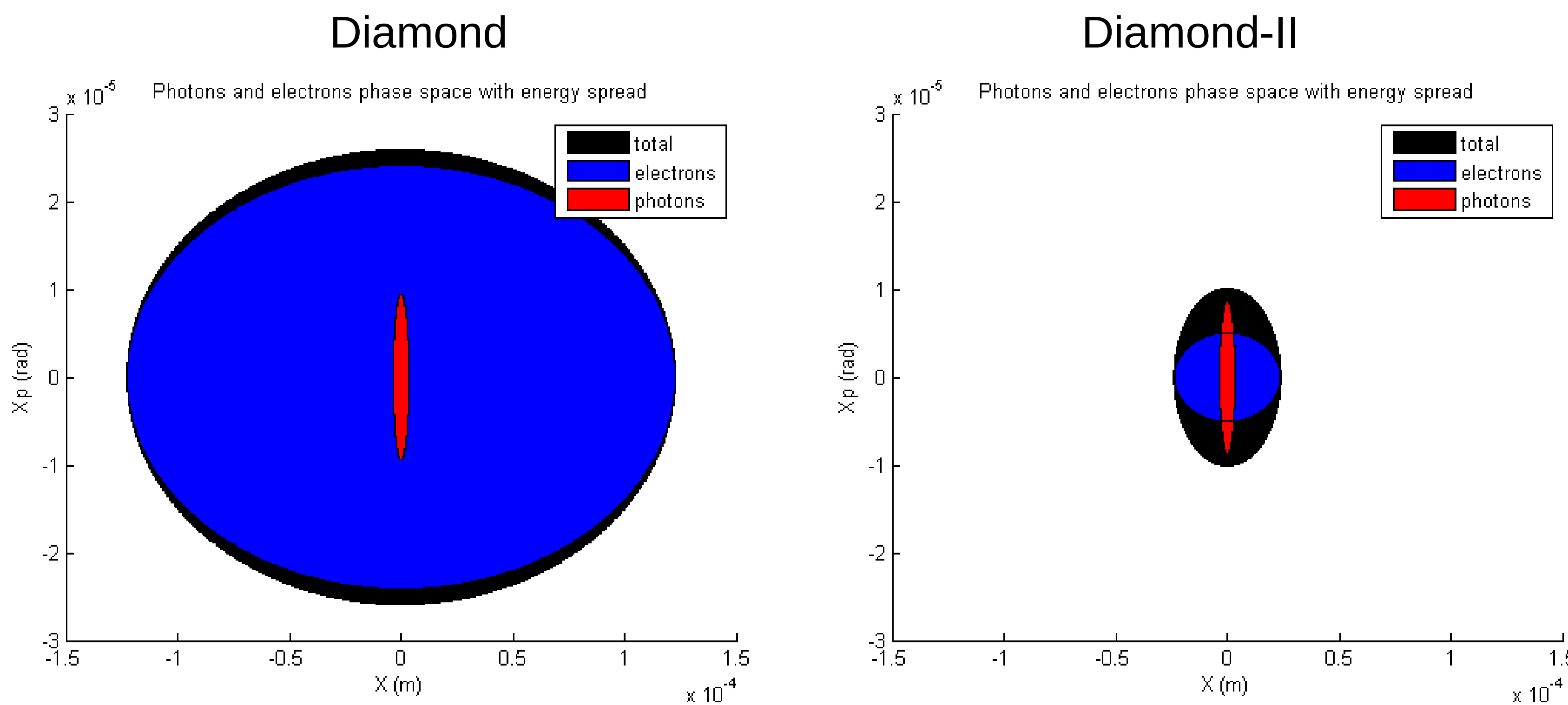
Parameter (rms values)	Diamond	Diamond-II
Horizontal size, Σ_x [μm]	123.6	23.8
Vertical size, Σ_y [μm]	4.7	4.7
Horizontal div. $\Sigma_{x'}$ [μrad]	25.8	10.5
Vertical div., $\Sigma_{y'}$ [μrad]	9.5	9.5
Product	1.44 10^5	1.13 10^4
Brightness ratio	1	12.7

The electron beam brightness is improved by nearly a factor of 25.

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

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

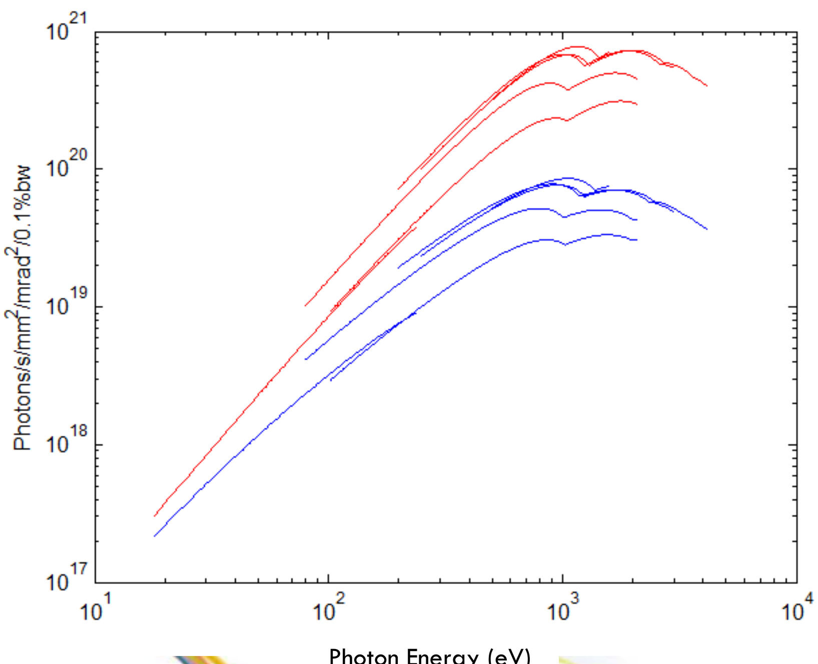
Comparison of phase space (at 1Å)

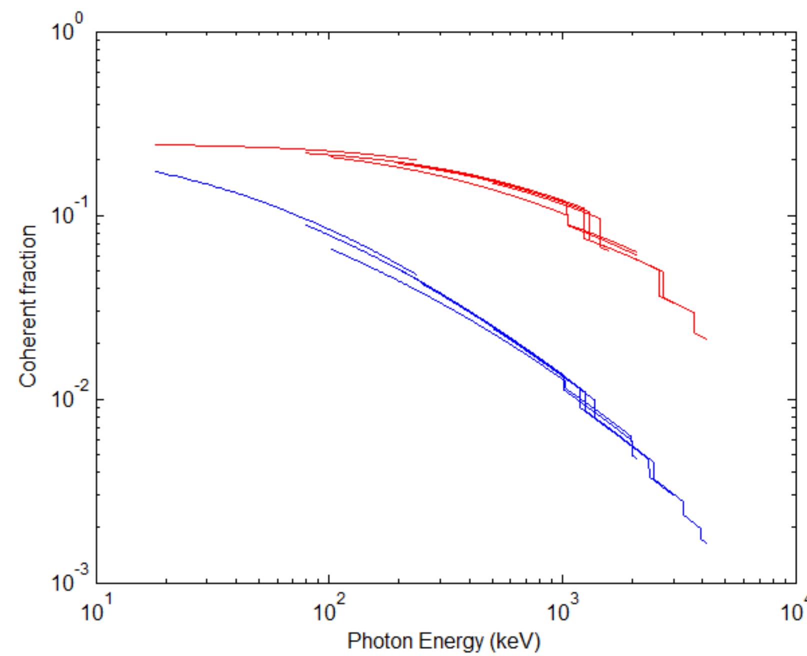


Brightness improvement with Diamond-II (120pm)

Soft X-rays undulators
APPLE-II for I05, I06, I08, J09, I10 ,I21

The improvement in brightness/coherence is approximately a factor of x3 at 100 eV and x10 at 1 keV, the main benefit coming from the reduction in horizontal source size and divergence

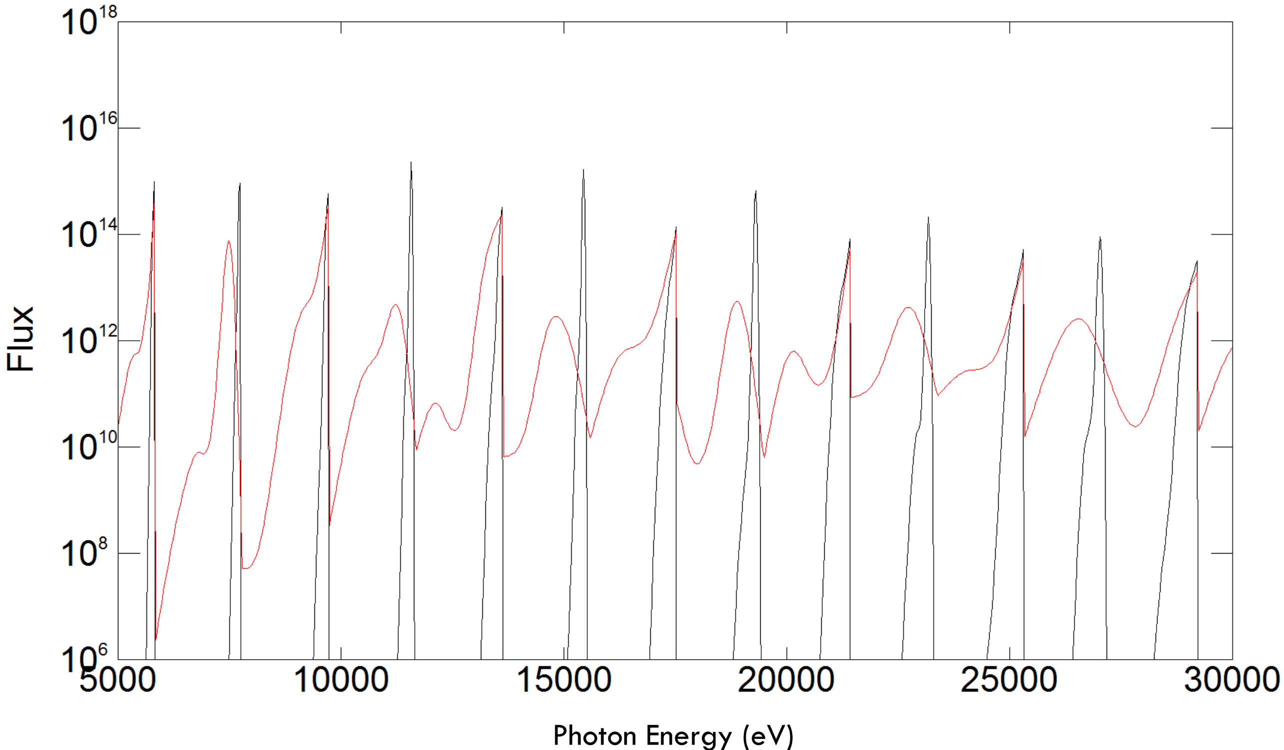




$$\text{brilliance} = \frac{\text{flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

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

Flux through an aperture



Flux through a 40 μrad * 40 μrad aperture for the Diamond CMPU in the existing ring (red) and in Diamond-II (black).

Diamond II wish list

- Emittance: from 2.7 nm to **< 270pm**
- **Minimal changes** to present machine
  - Keep **tunnel** / beamline structure
  - Leave **straight sections** as they are
  - Re-use **hardware** wherever possible (RF, magnets, …)
- Keep I09-I13 optics (**mini-beta** sections)
- Maintain **short pulse** operations
- Minimize *dead*-time
- Minimize technology risks

Broadly speaking, emittance reduction is achievable with usual approach, i.e.

$$\epsilon_x = C_q \frac{\gamma^2}{J_x} \frac{\oint \mathcal{H}(s)/\rho^3(s)ds}{\oint 1/\rho^2(s)ds} \sim C_q K \frac{\gamma^2\theta^3}{J_x} \propto \frac{\gamma^2}{N_b^3}$$

- Increase **n. of dipoles**
- Increase **Jx** with combined function dipoles
- **MBA** solutions with longitudinal gradient dipoles

However, reducing emittance may not be the only target

- increase **ratio of straight sections / C**

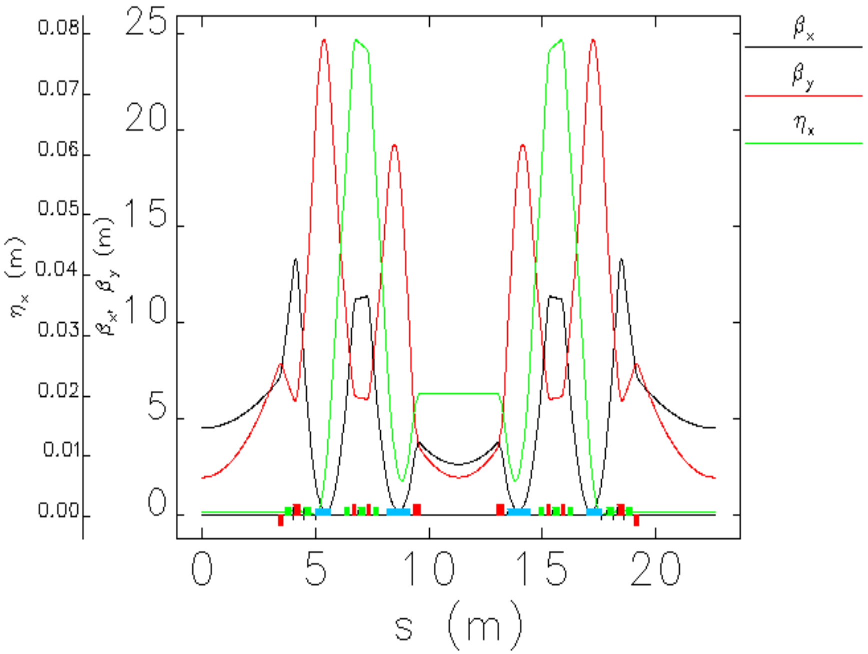
This twofold request leads to the **Double DBA** concept (DDBA)

- a **4BA cell** with a **central straight** for an extra ID

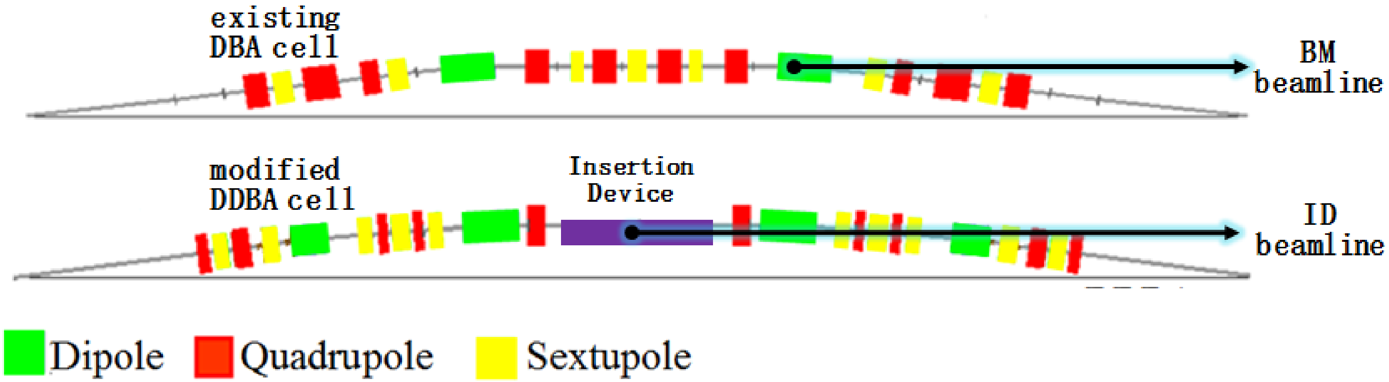
The **Double Double-Bend Achromat** concept (DDBA) is a modification of the standard Diamond DBA cell, where the central region has been “cleared” to host a new insertion device (VMX)

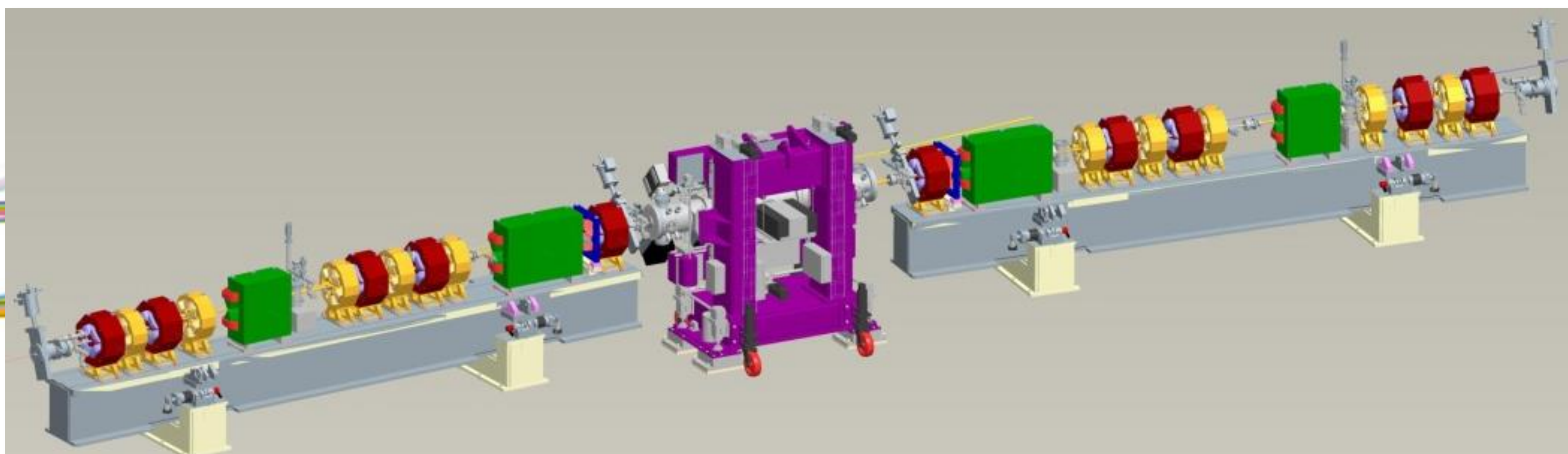
It is a **modified 4BA** with a **10x emittance reduction** factor and **2x n. of possible beamlines**

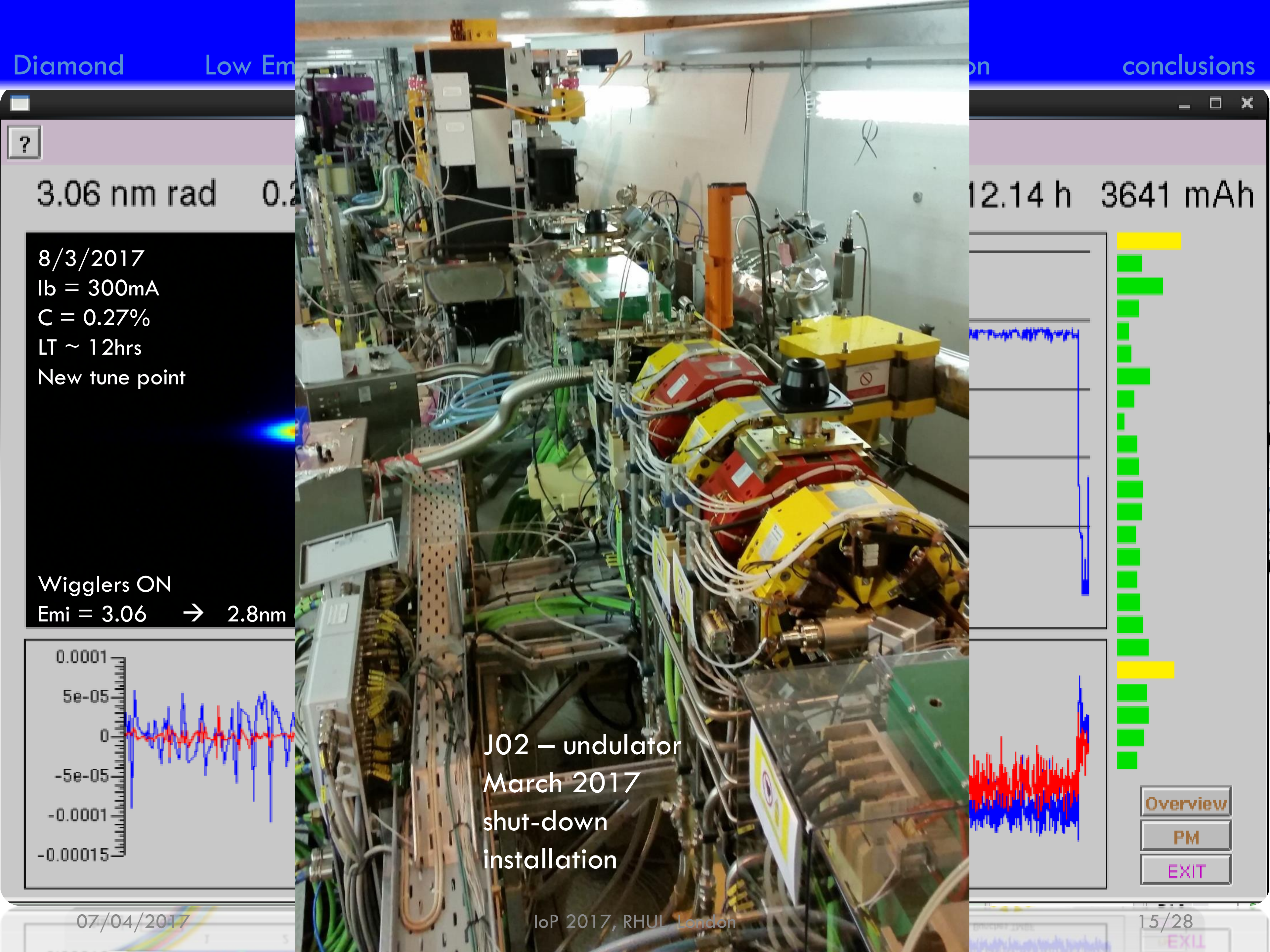
Baseline design for **Diamond-II** until the end of 2015



at present **one DDBA cell has been installed** in Diamond and **has been commissioned**






?
3.06 nm rad
12.14 h
3641 mAh
8/3/2017
Ib = 300mA
C = 0.27%
LT ~ 12hrs
New tune point
Wigglers ON
Emi = 3.06 → 2.8nm
0.0001
5e-05
0
-5e-05
-0.0001
-0.00015
J02 – undulator
March 2017
shut-down
installation
Overview
PM
EXIT

There were few reasons to go **beyond the DDBA** concept:

1. a request from **beamlines** for a **more aggressive scheme: 20x reduction in emittance**
2. Challenges in the **optimization** of Lifetime, Dynamic Aperture

Point (1) led to a **6BA-like approach**, where the **7BA ESRF cell** (HMBA) was modified to create a central ID straight

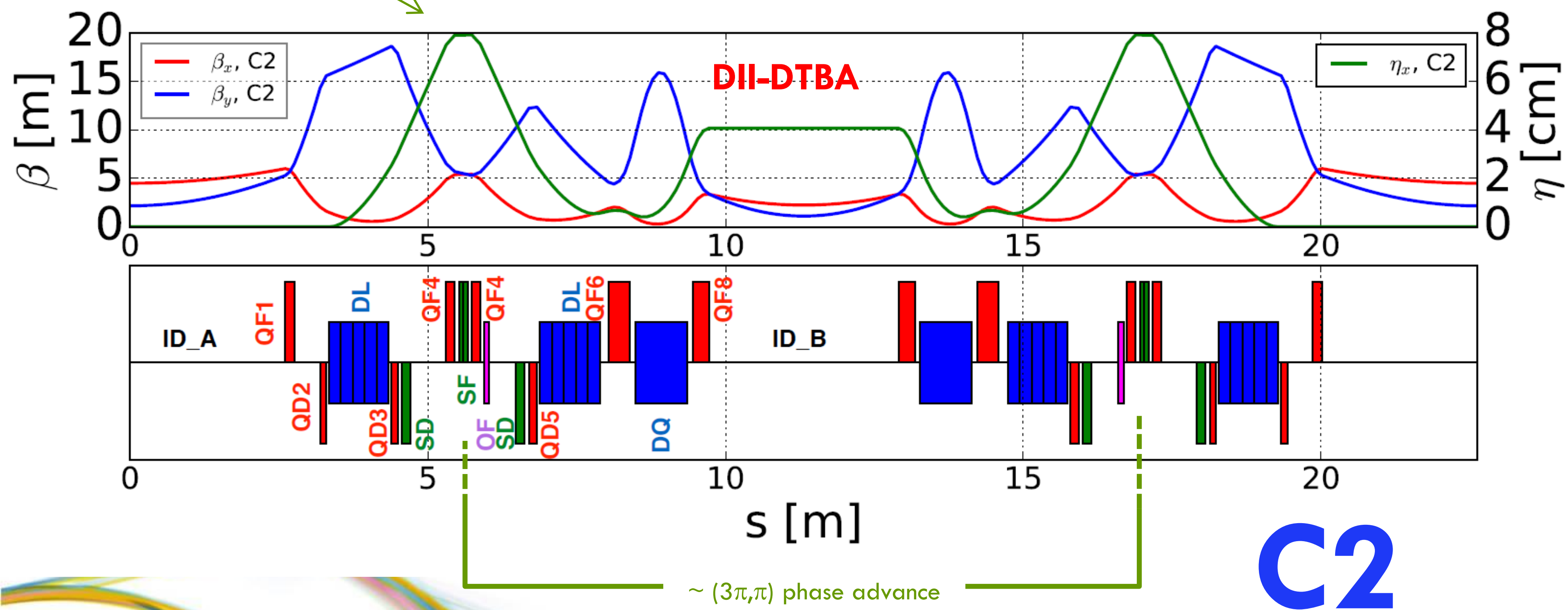
Collaboration with ESRF very fruitful in overcoming some design difficulties

Emittance → 140 pm

Sextupoles located at large η_x dispersion bumps

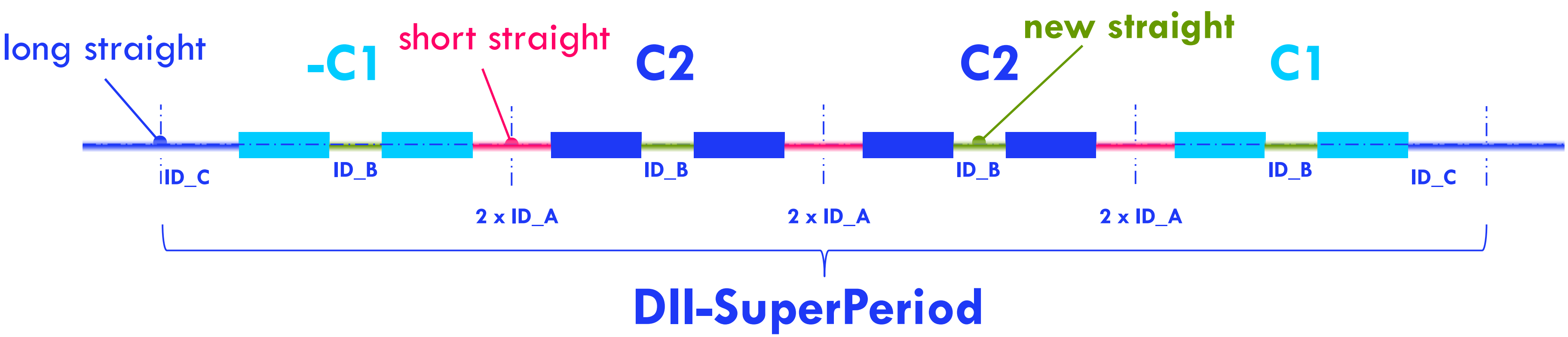
DII - **DTBA**
E: 3 GeV
Cell lenghts: 22.6m
C: 561m (24 cells)

Central DQ2 removed
Drift spaces kept equal
Magnet lengths shortened thanks to reduced gradient (6GeV → 3GeV)



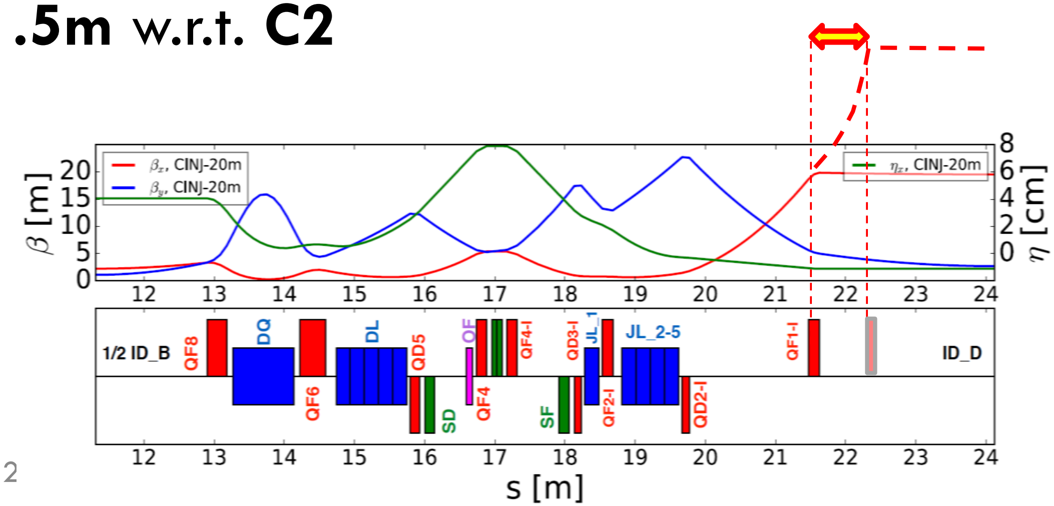
Porting the ESRF-HMBA concept into Diamond SR:
- by scaling magnet lengths while keeping the same inter-distances
- by shortening cells to fit Diamond length constraints

There are indeed **two kinds of cell, C1** and **C2,** used to reproduce the **SP-6 structure** of the present lattice (1long / 3 short straights):

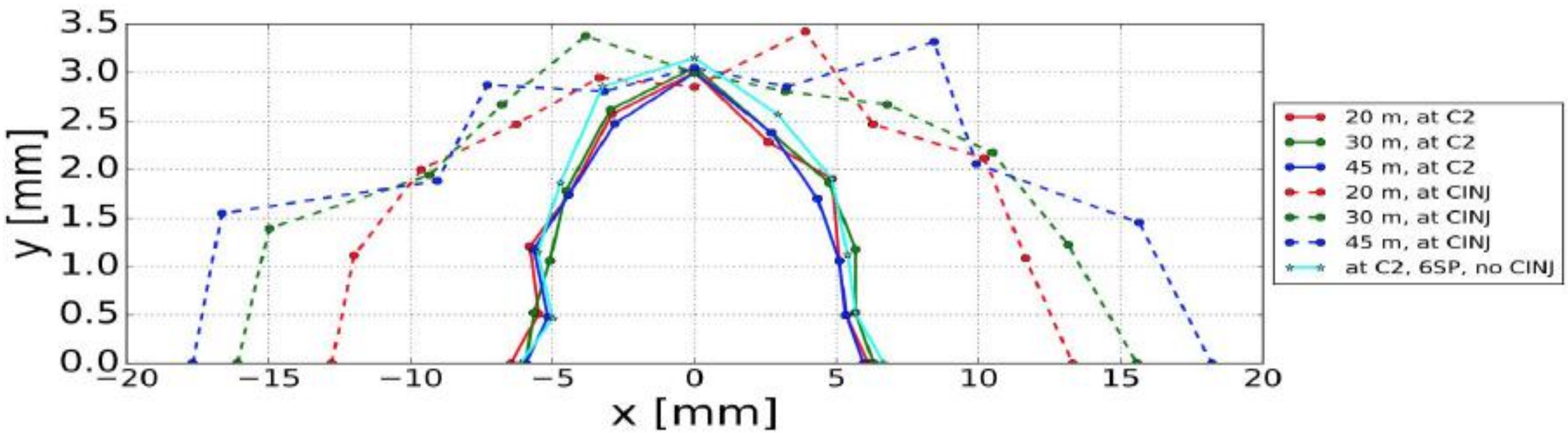


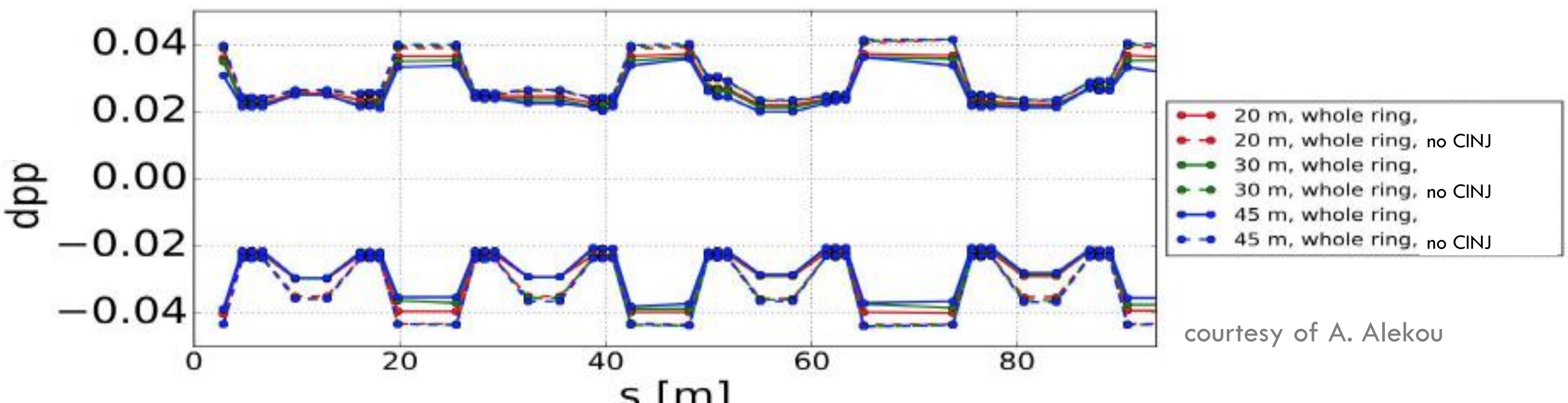
C1 is an **asymmetric cell: +1.5m** w.r.t. **C2**

a **modified C1** is needed as **injection cell (Cinj)**



DA@C2 independent from beta@injection
DA@Cinj grows with beta@injection
MA larger with **no inj cell**





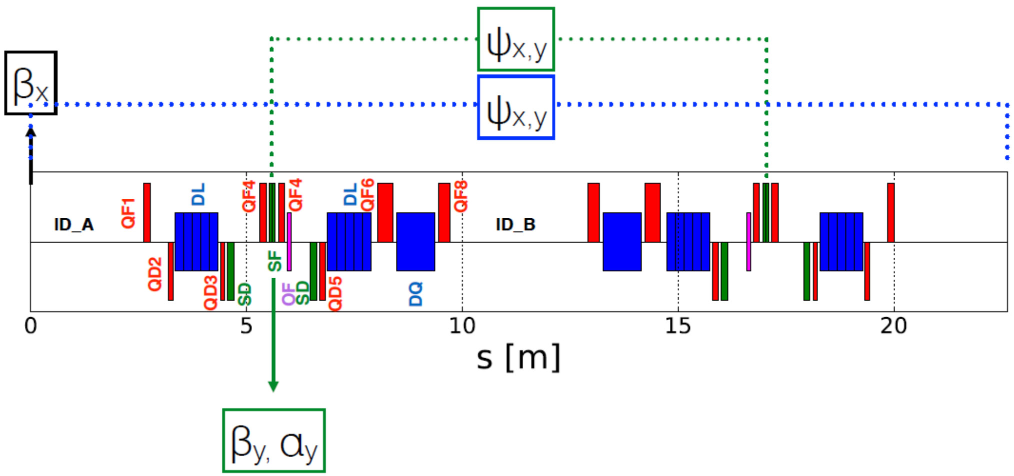
courtesy of A. Alekou

Optimizing the lattice:

- Matching technique
  - Analytic cancellation of non-linear driving terms
    - Cell-length adaptation
      - Injection Cell
        - MOGA (DA, LT, InjEff …)

cell matching technique:

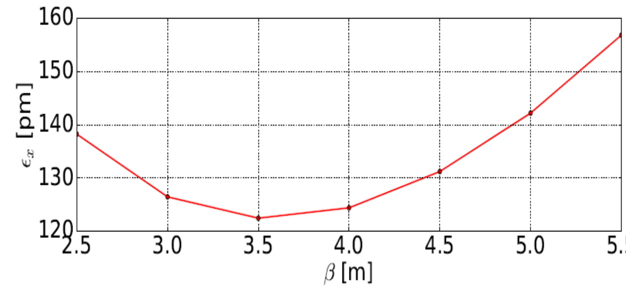
- β_x @ IDs
- β_y,α_y at central SF sextupoles
- $\varphi_{x,y}$ advance between sextupoles [$3\pi/\pi$]
- $\varphi_{x,y}$ advance in the cell

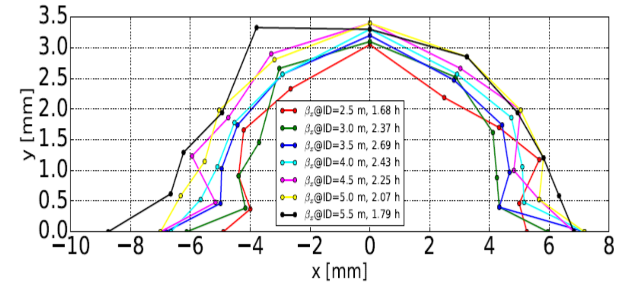


- β_x @ IDs → ε_x
- β_y @ sext → ε_x, ξ_x
- α_y @ sext → dQ_y/dy
- φ_y advance between sextupoles → dQ_x/dy

These parameters have been:

- **kept fixed** when changing **cell length** (HMBA → DTBA)
- **scanned** when tuning quads during DTBA optimization (later)

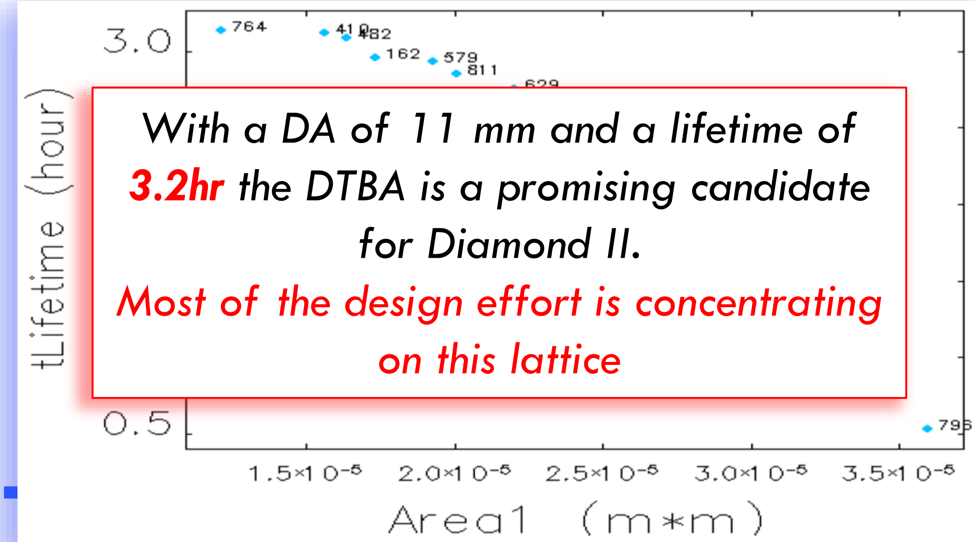




- **varied** with Multi-Objective Genetic Algorithm (MOGA) optimizer

MOGA optimization(*) on the **whole set** of parameters $(\beta_x, \beta_y, \alpha_y, K4, \varphi_{x,y}) \rightarrow (\tau, DA)$ [keep $\xi=(2,2)$]

Promising improvement, BUT still **errors** to be included

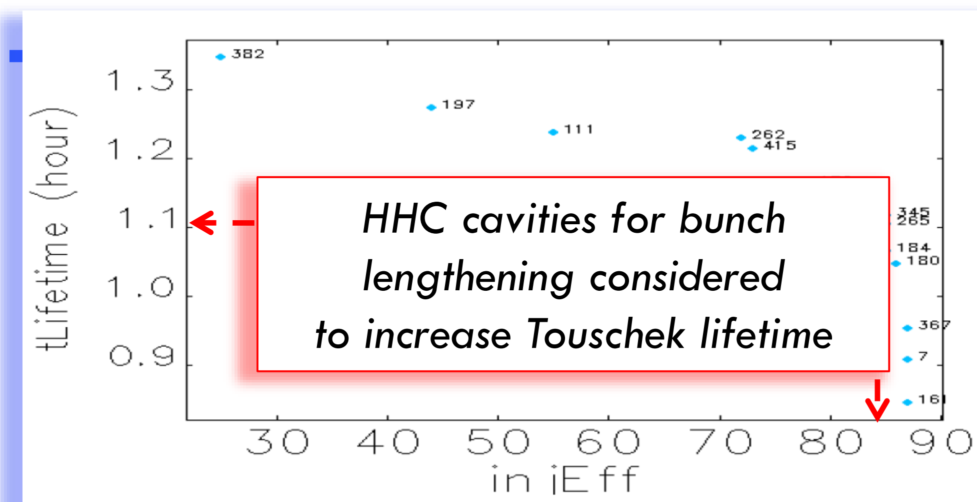


sextupoles / octupoles

chromaticity control (2,2)

(τ, DA) optimization

MOGA improvement in DA [no change in τ]

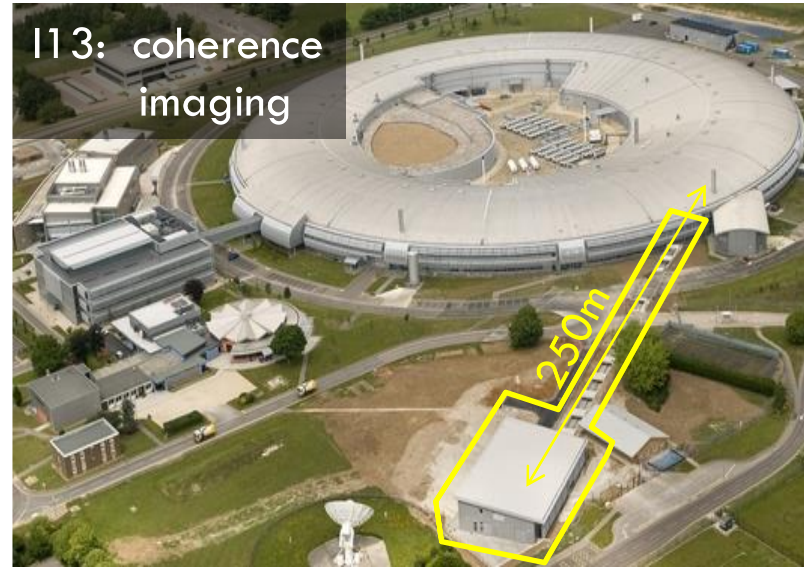


Injection Efficiency optimization → DTBA lattice with InjCELL

(τ, IE) optimization

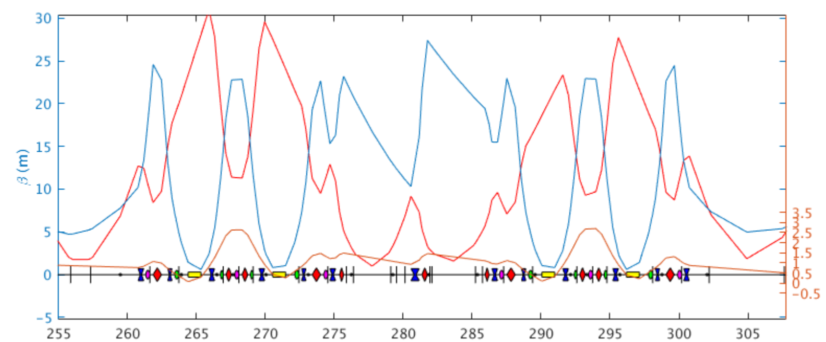
→ IE~85%, τ ~ 1.1hr

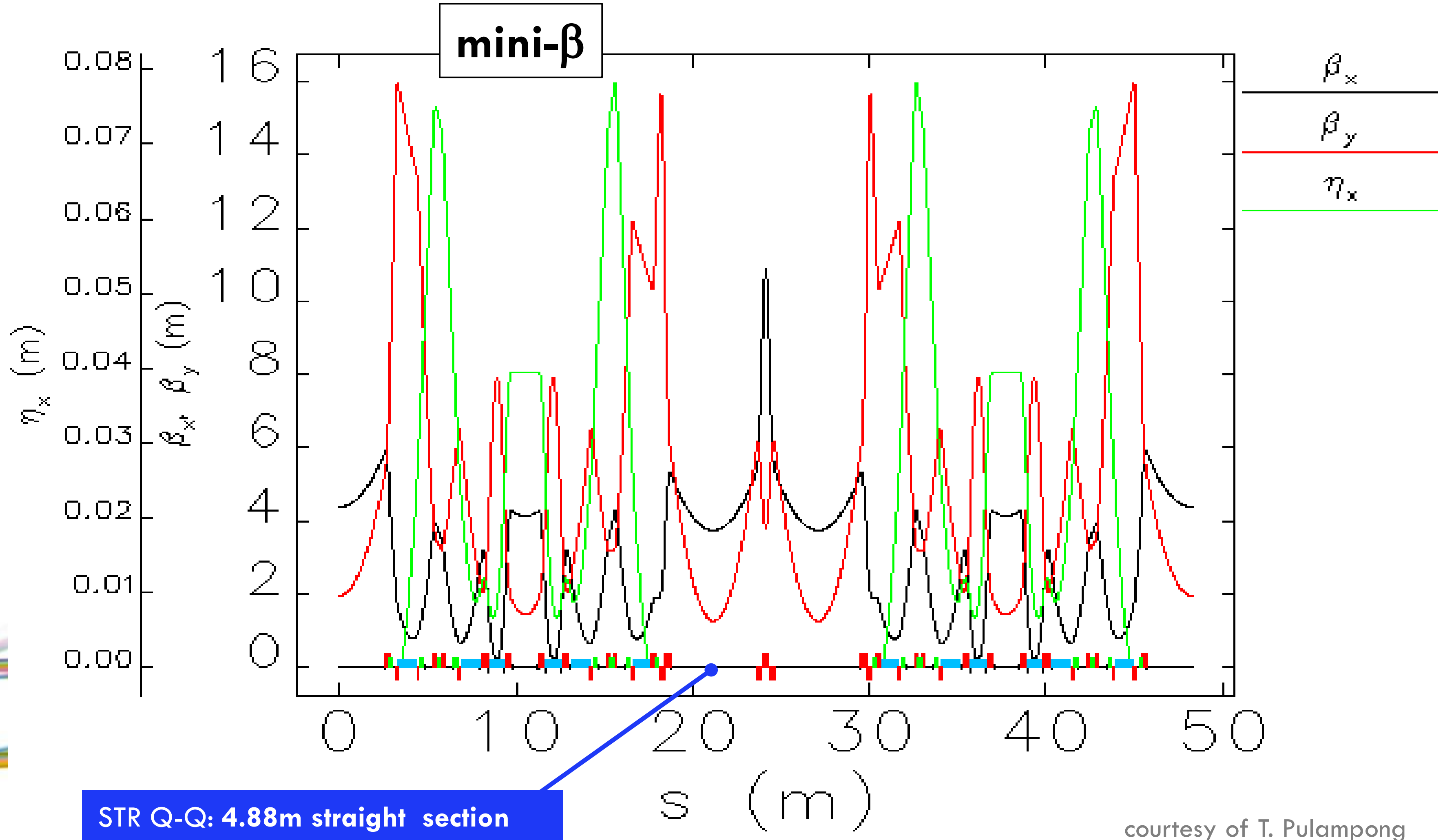
Issues : integration of present features into new lattice



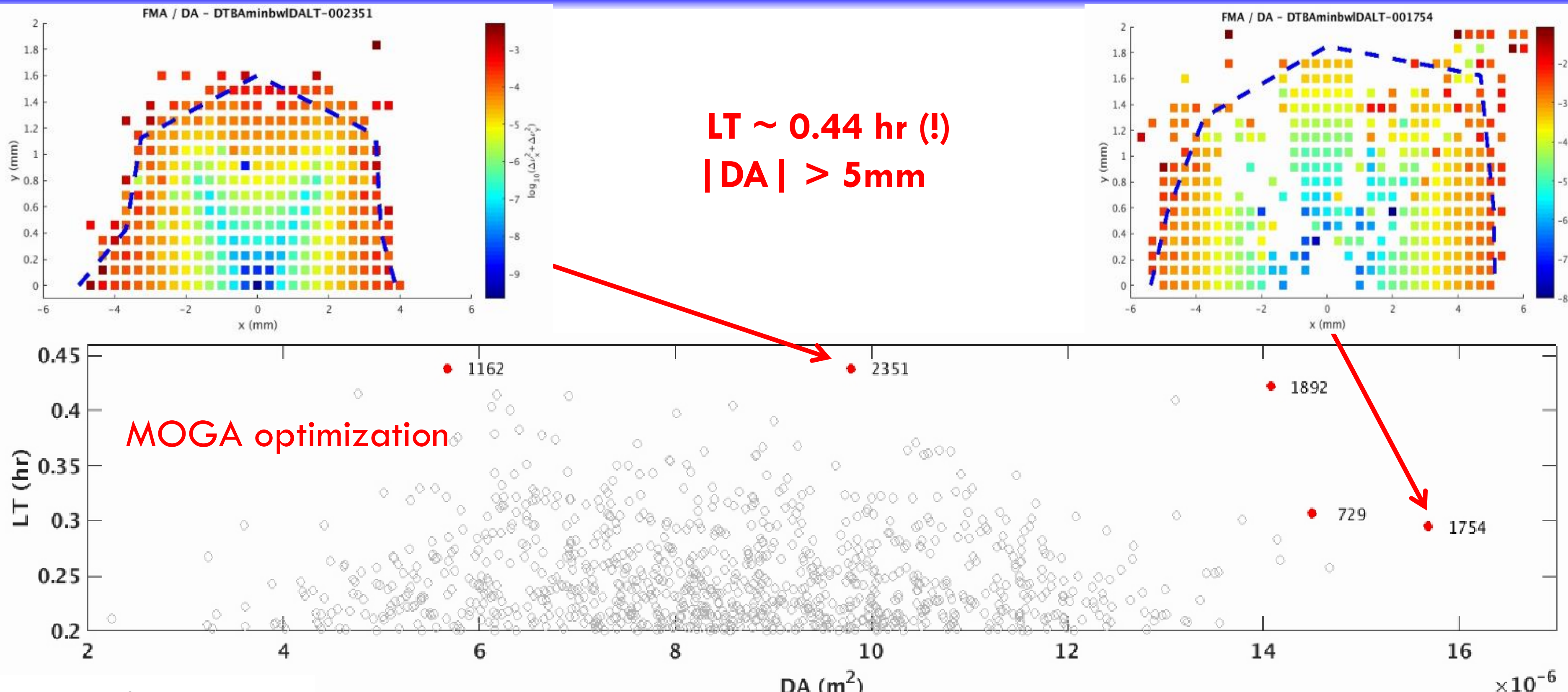
- I09 / I13 **straight @ mini-β**
- I21 strong focussing section
- Short-pulse

- improve performance @ BL
- mini-β straights critical, with low β_y and virtual focussing
- present proposed solution under study for mini-β cases





courtesy of T. Pulampong



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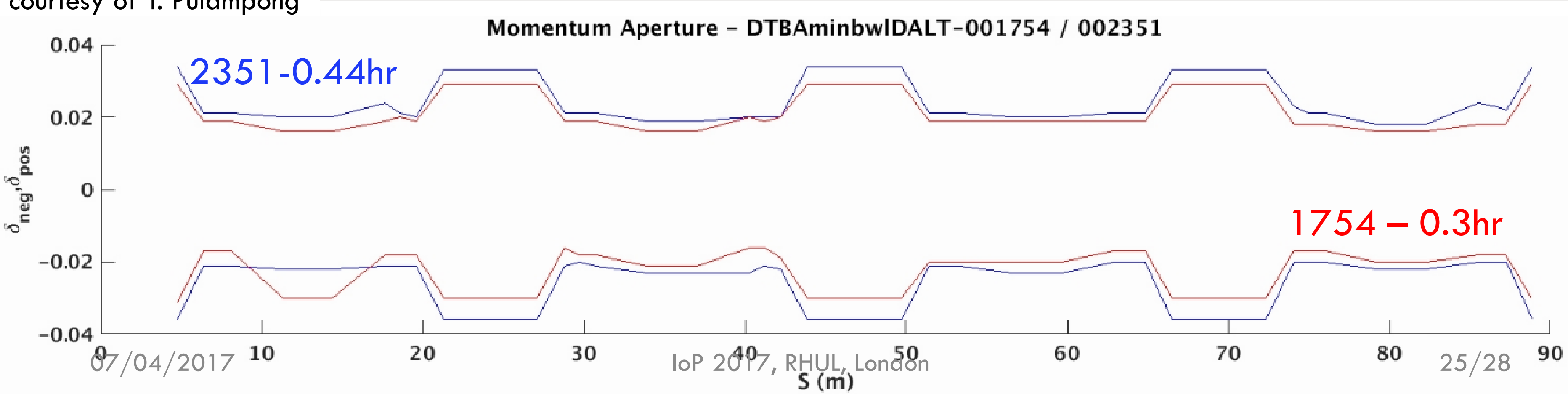
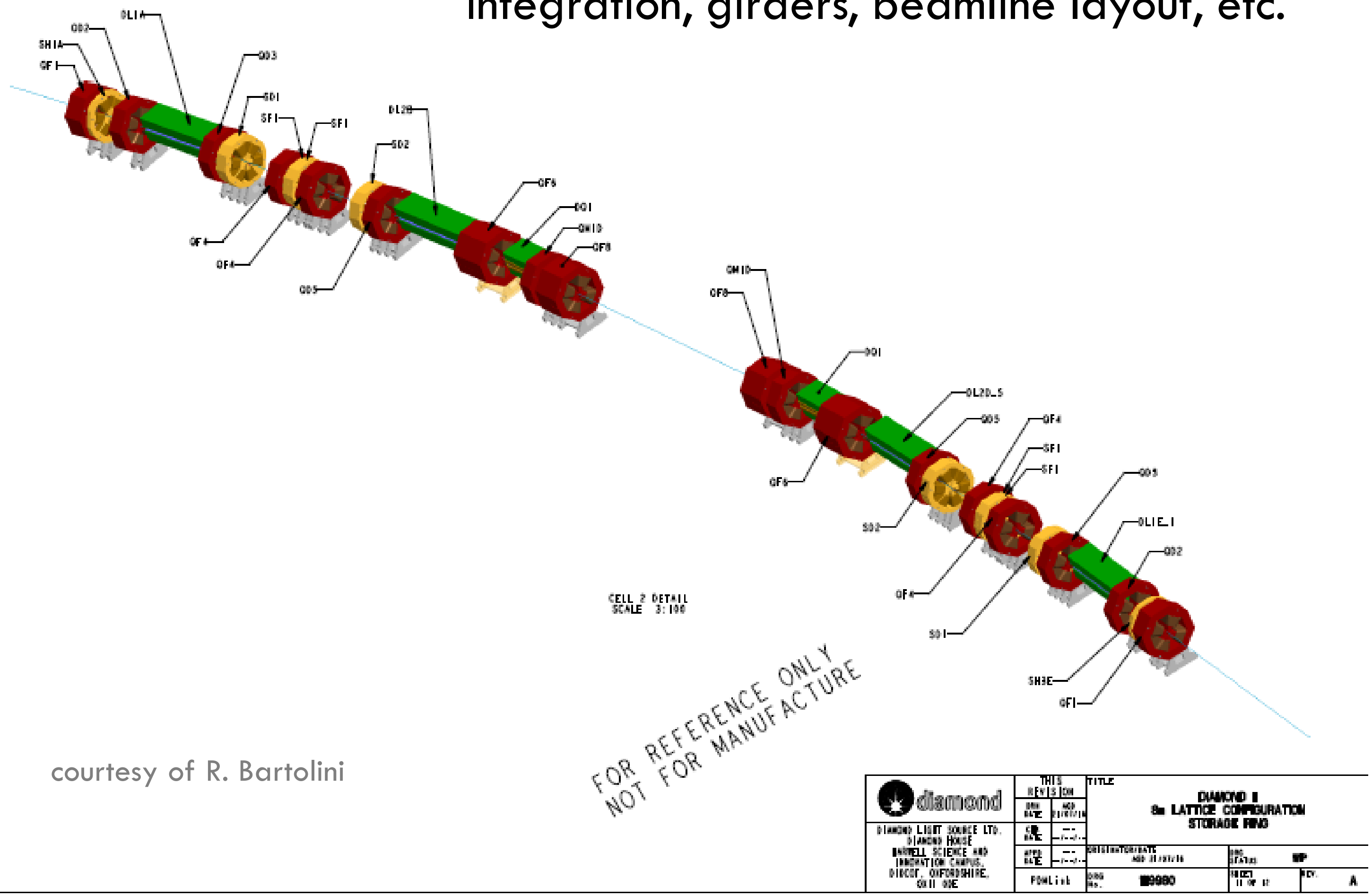


Initial consideration on layout, engineering
Integration, girders, beamline layout, etc.



courtesy of R. Bartolini

- Diamond is considering a **development** to **reduce emittance** by a factor 10x to **20x**

- Following the DDBA concept, and the expertise developed at ESRF the **DTBA concept** emerged, which should **double the n. of beamlines**

- Initial studies suggest a DTBA cells organized in 6-fold SP could fulfil the **20x emittance reduction**

- However **optimization process is underway** to ensure:
  - Good LT/DA are achievable
  - Non linearities can be controlled
  - Present machine requirements are met (mini-β / short-pulse operations)

Thanks for your attention