

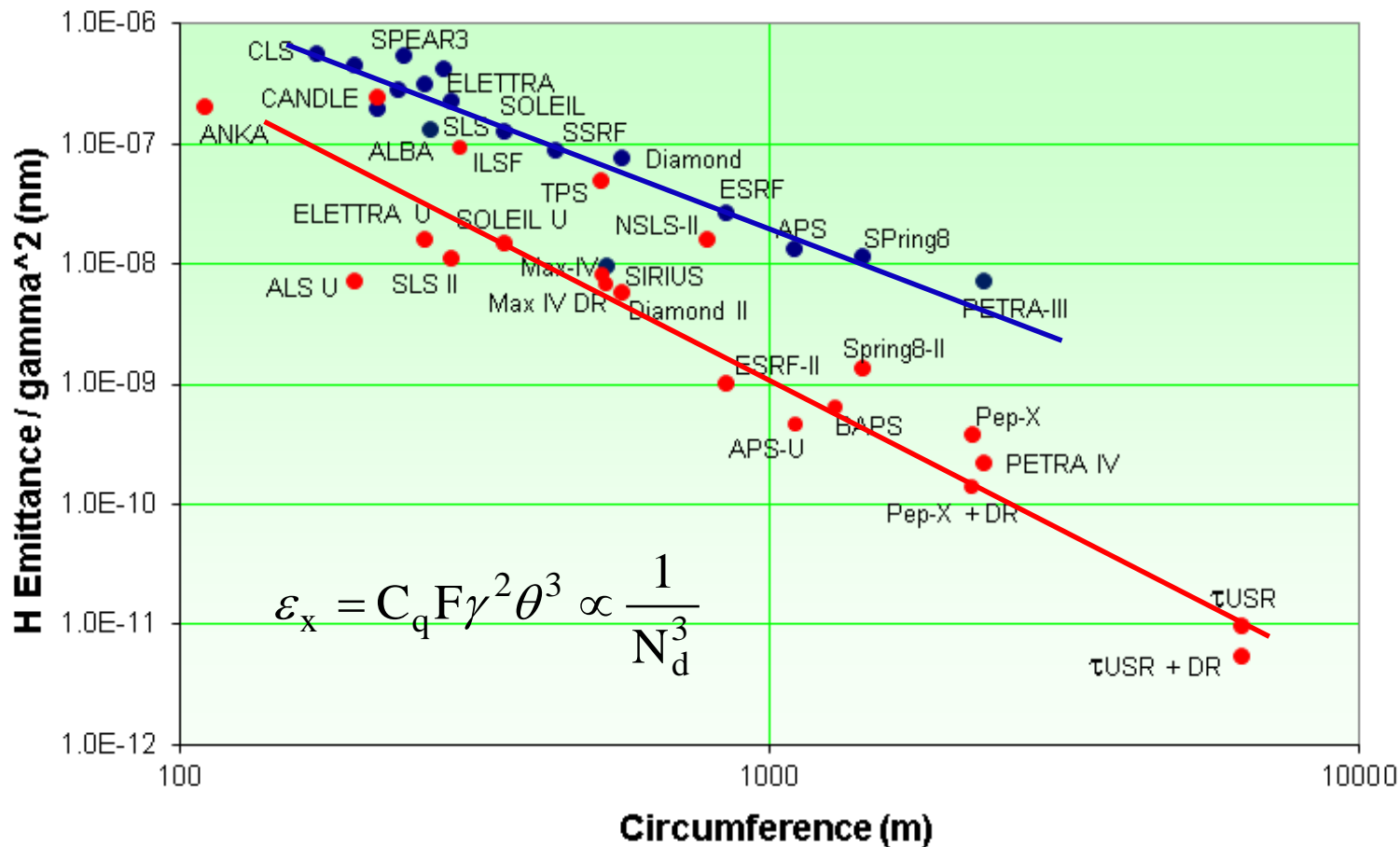
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# Light Source Upgrade Projects

***R. Bartolini***

***Diamond Light Source  
and  
John Adams Institute, University of Oxford***

# Survey of low emittance lattices for light sources



# Brilliance and transverse coherence

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## Photon flux and brilliance and coherent fraction

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

$\Sigma$ 's are the convolution of electron and photon beam size and divergence

$$\Sigma_x = \sqrt{\sigma_{x,e}^2 + \sigma_{\text{ph}}^2} \quad \Sigma_{x'} = \sqrt{\sigma_{x',e}^2 + \sigma_{\text{ph}}'^2}$$

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

$$\varepsilon_{e^-} \leq \varepsilon_{\text{ph}} = \frac{\lambda}{2\pi} \quad \begin{array}{l} 10 \text{ pm for diffraction limit} \\ \text{at } \sim 1 \text{ Angstrom} \end{array}$$

# Key drivers

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- **Stronger science case based on**
  - higher brightness
  - higher transverse coherence
  - small photon beam size
  - small photon beam divergence
  - cleaner spectral flux
- **Growing confidence (and first experience!) with MBA lattices**
  - linear optics, nonlinear optics, instabilities
- **Growing confidence (and first experience!) with technological subsystems**
  - magnets, vacuum, diagnostics, feedback

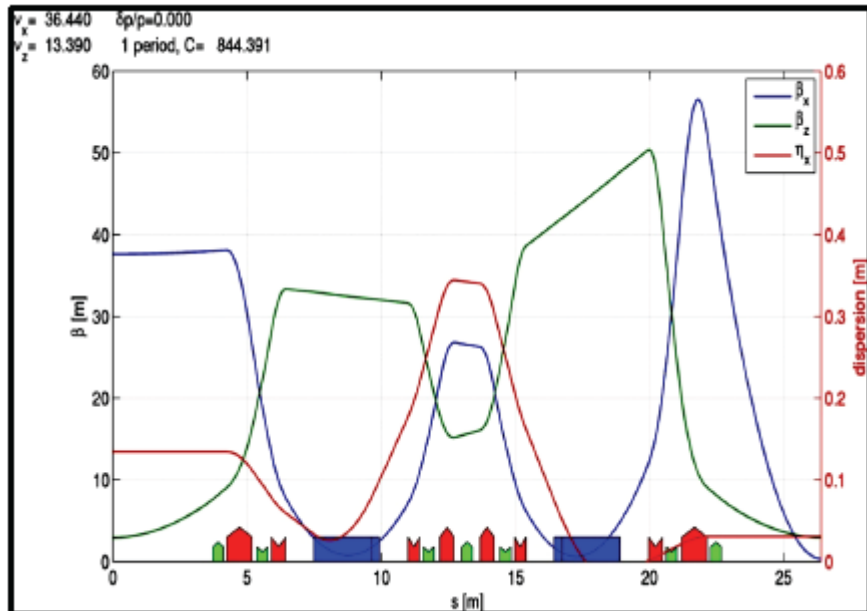
# Present status

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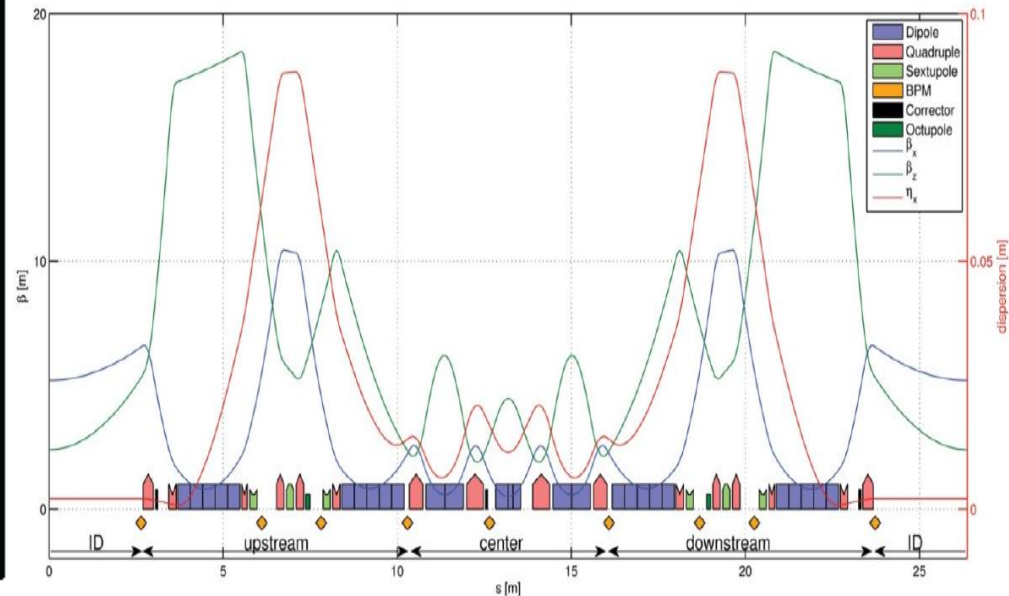
- **MAX IV under commissioning (see A. Andersson talk this afternoon)**
  - **ESRF placing contracts**  
magnets placed, large scale proc. mid 16; back in op. **2020**
  - **Sirius under construction**
  - **APS-U has passed CD1**
  - **ALS-U, BAPS got money for R&D programmes**
  - **SLS-II and Diamond II**  
advanced consultation with user community in view of CDR
  - **many labs are investigating options (SOLEIL, ELETTRA, ILSF, ...)**
-

# ESRF-EBS

## Original DBA cell



## Hybrid 7BA cell



**Hybrid 7BA cell features:**

**Dispersion bump for chromatic sextupoles;**

**$3\pi / \pi$  phase advance for cancellation of sextupole driving terms;**

**Longitudinal gradient bend for emittance minimisation;**

# ESRF-EBS (magnets)

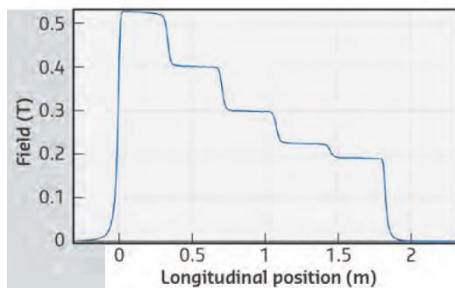
## Longitudinal gradient dipole

### Specifications

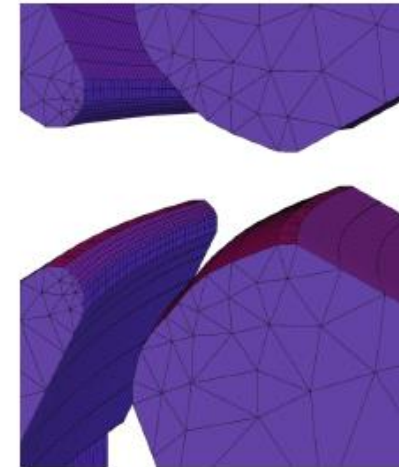
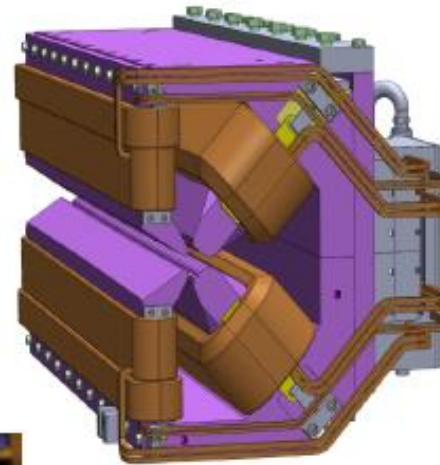
- 0.17 – 0.67 T field
- 5 modules of 357 mm each
- Larger gap for the low field module
- Allows the installation of an absorber

### Engineering design

- Final drawings produced



## transverse gradient dipole



DQ1 pole shape

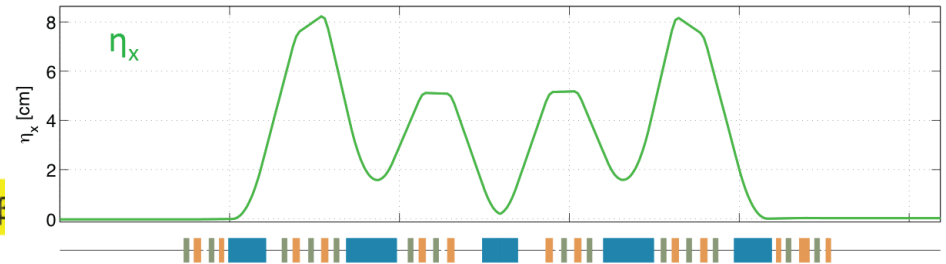
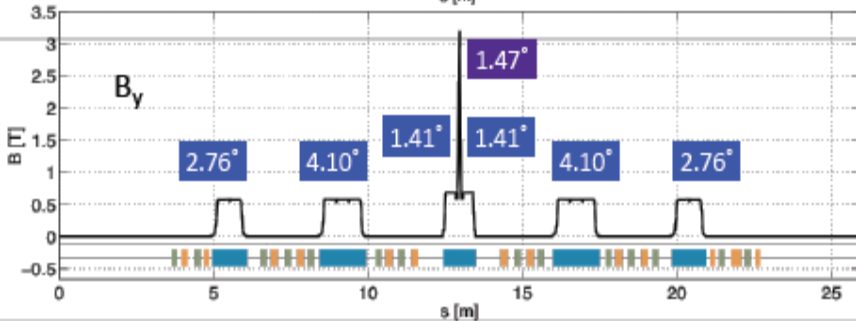
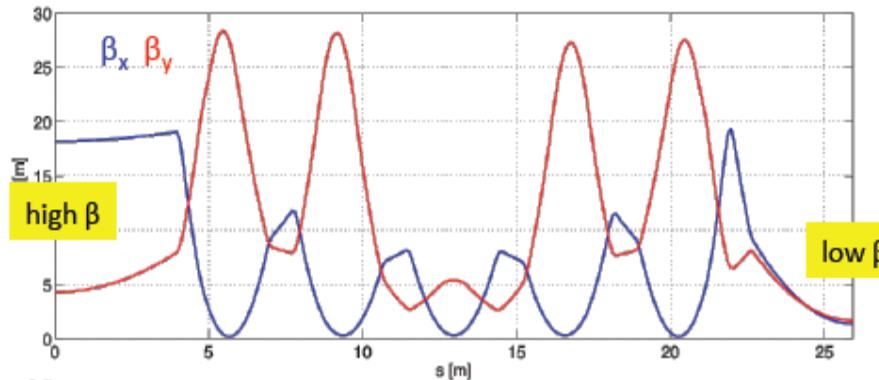
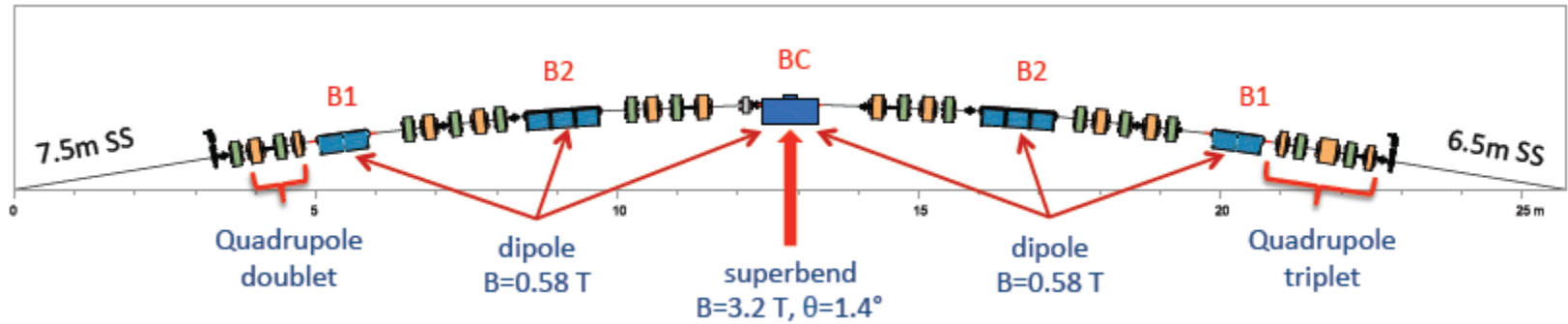
DQ1: 1.028 m, 0.57 T, 37.1 T/m

$\Delta G/G < 1\%$  (GFR radius 7 mm)

DQs are machined in 7 solid iron plates

**Final prototype to be built in coming months**  
**Measurements on one module within specs**

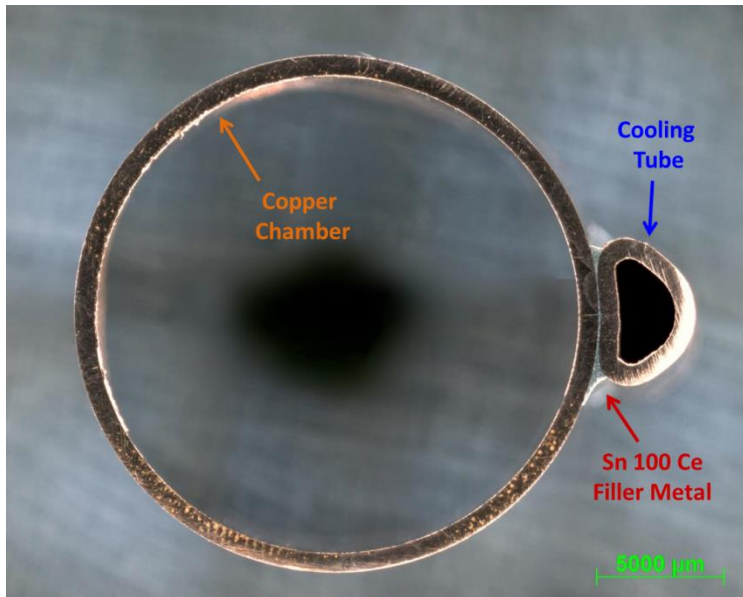
# SIRIUS (5BA lattice)



- 20 5BA arcs and 2 types of straight sections for insertion devices:
  - 10 **high  $\beta_x$**  straight sections of **7.5 m** – matching with quad **doublets**.
  - 10 **low  $\beta_x$**  straight sections of **6.5 m** – matching with quad **triplets**.
- 20 PM **superbends** (short slice sandwiched in the center dipole)
  - peak field of  $B_p = 3.2 \text{ T}$   $\rightarrow$  critical photon energy of  $e_c = 19.2 \text{ keV}$
- Low field (0.58 T) EM and PM dipoles with transverse field gradient (7.8 T/m)

# SIRIUS (NEG coated chambers)

Small diameter vacuum vessel 24 mm internal radius pumped with NEG coating - collaboration with CERN



Courtesy L. Lin

# SIRIUS site

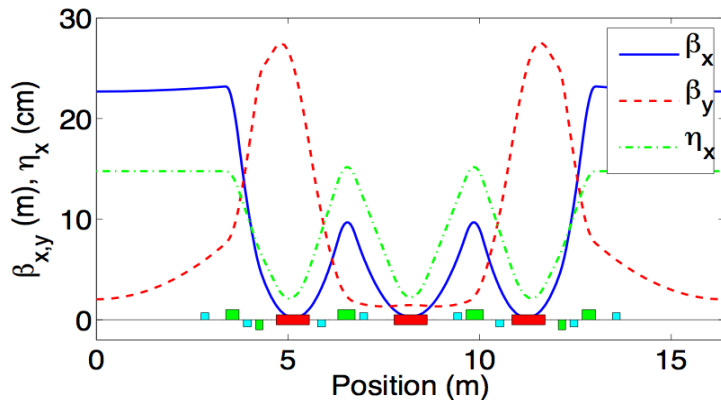
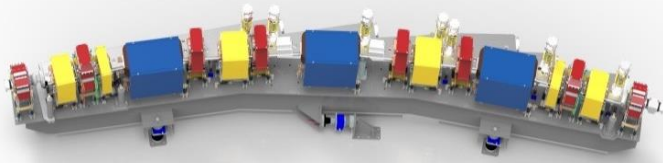
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**Building construction 20% completed (March 2016)**



# ALS-U: diffraction limited light source

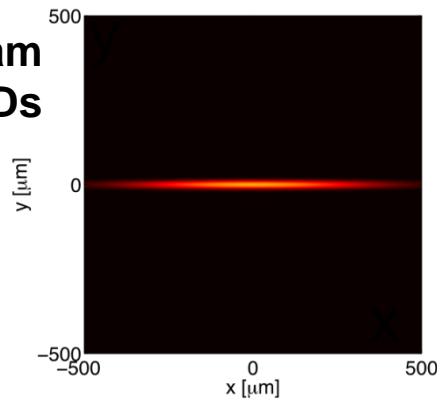
ALS today: 3BA @1.9 GeV



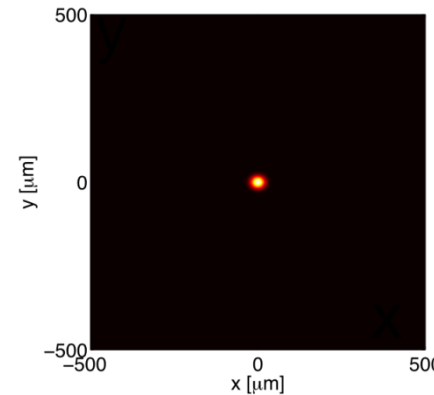
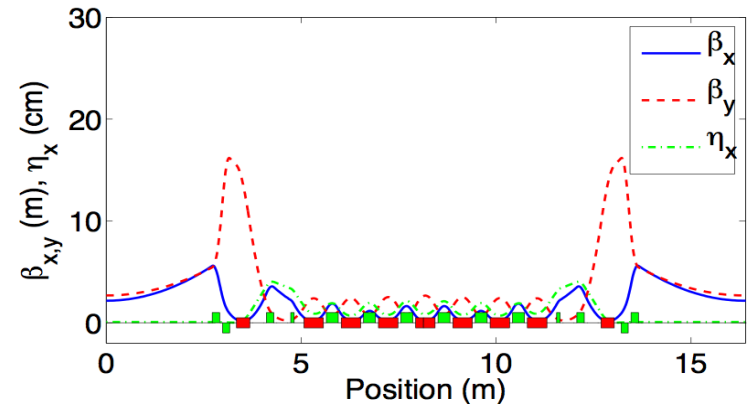
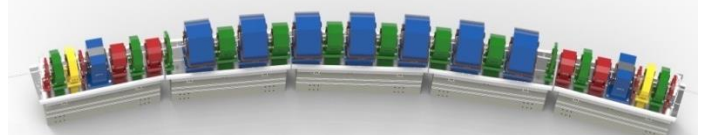
Electron beam  
at the IDs

$$\epsilon_x \approx 2000 \text{ pm}$$

$$\epsilon_y \approx 30 \text{ pm}$$



ALS-U: 9BA @2 GeV



With full coupling:

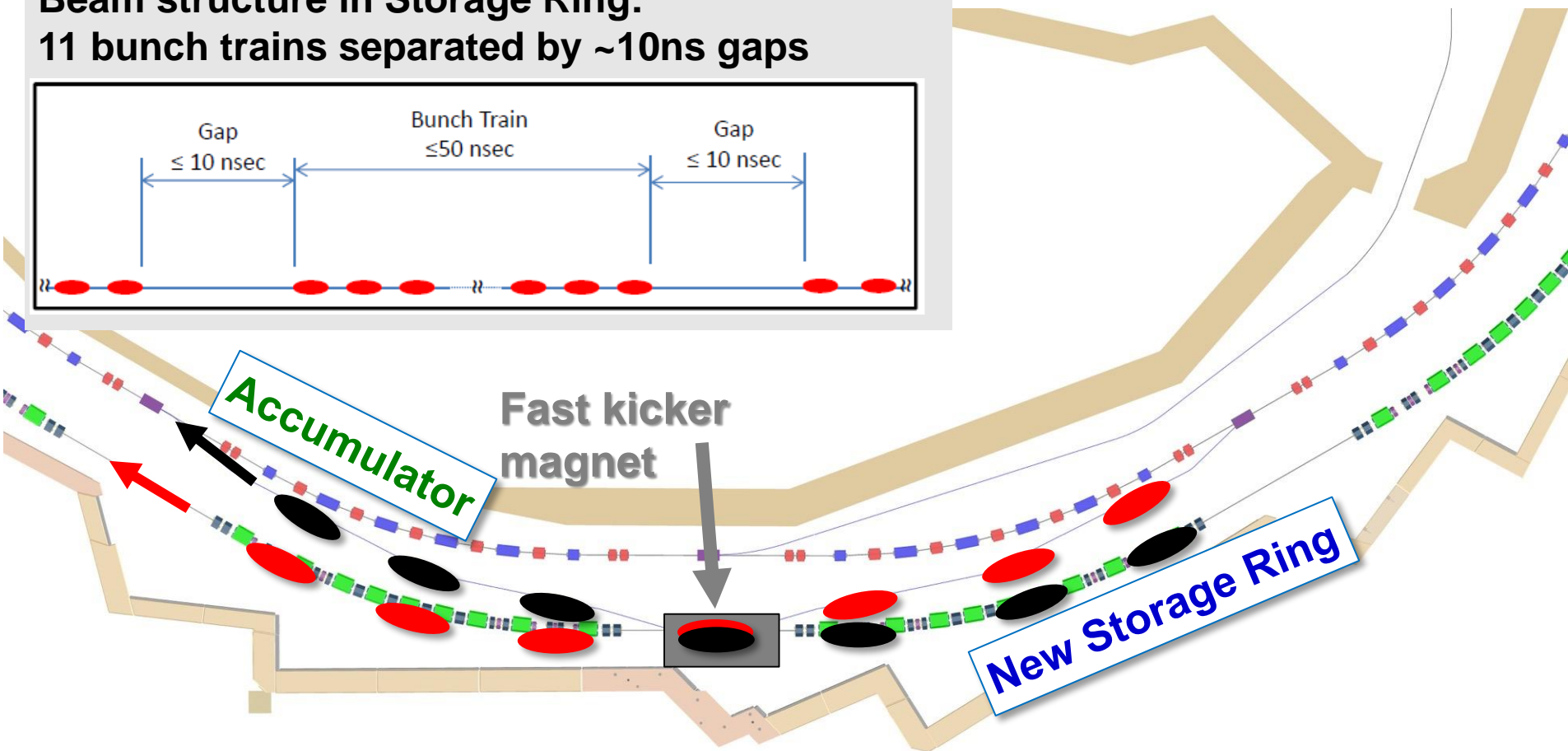
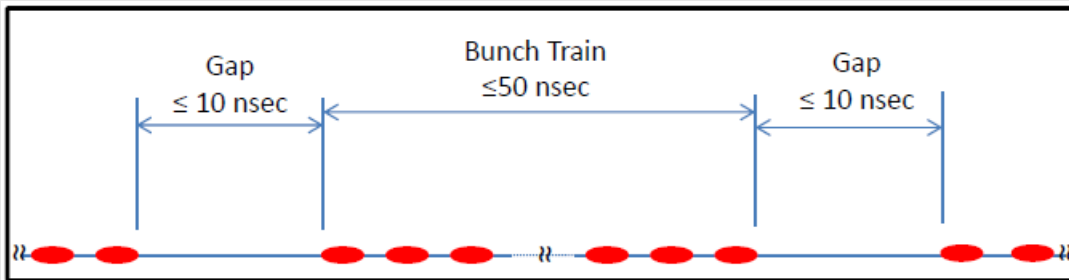
$$\epsilon_x \approx 50 \text{ pm}$$

$$\epsilon_y \approx 50 \text{ pm}$$

# ALS-U: swap out injection

Very aggressive design, but **small DA (few mm)** not allowing off-axis injection  
Accumulator will enable on-axis injection with bunch-train swap-out

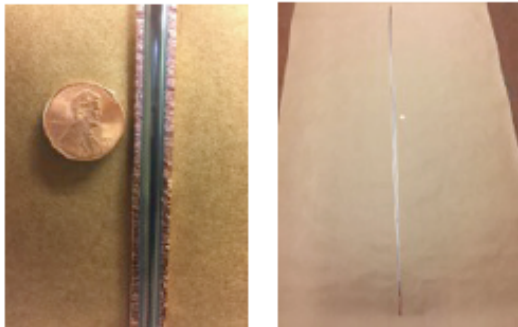
Beam structure in Storage Ring:  
11 bunch trains separated by ~10ns gaps



- Pulser prototype being developed at LBNL has demonstrated ~5ns rise/fall time
- Preliminary Accumulator design achieves  $\varepsilon_x < 2nm$  with 5BA lattice.

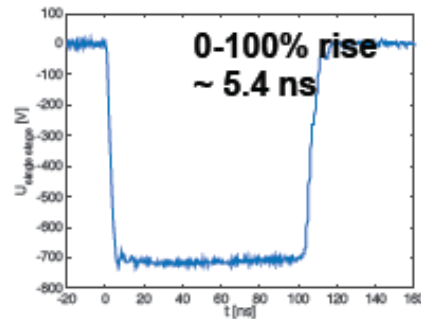
# ALS-U: R&D programme

Very small NEG coated vacuum chambers



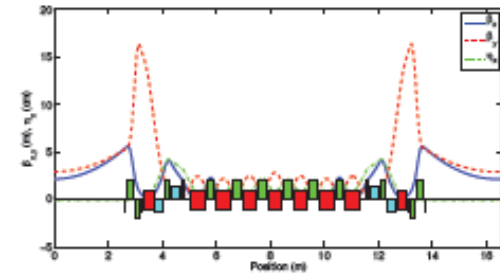
Coated 6 mm chamber (world record)

On-axis Injection – Fast pulsed magnets



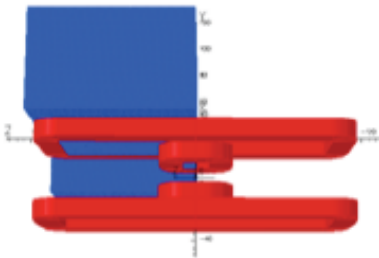
Adder achieves 5 ns rise (7 ns needed)

Optimization of Physics Design



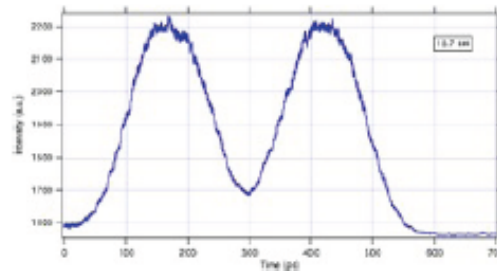
Released Baseline Lattice

Magnets – SR Production



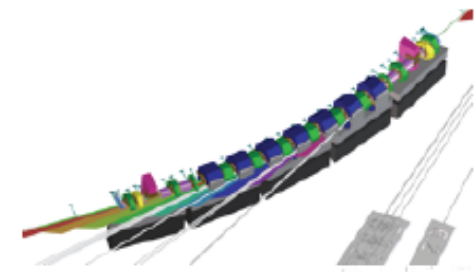
Evaluated Superbend options

Harmonic Cavities - Transients



Achieved needed bunch lengthening with ALS-U bunch trains in ALS (3HC)

Engineering



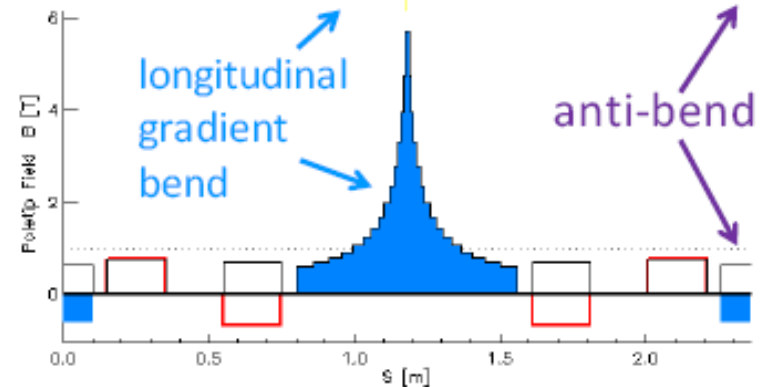
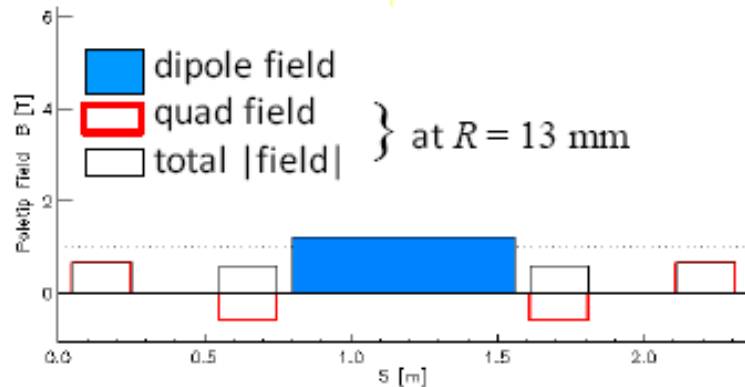
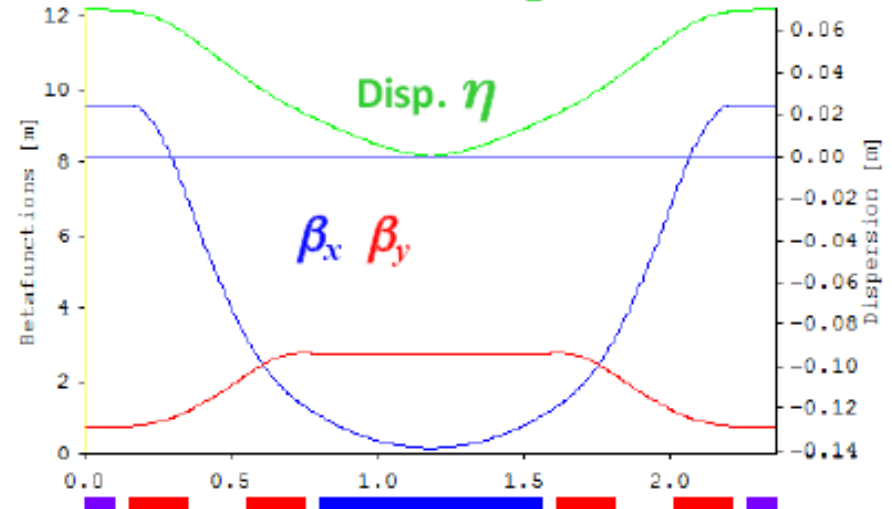
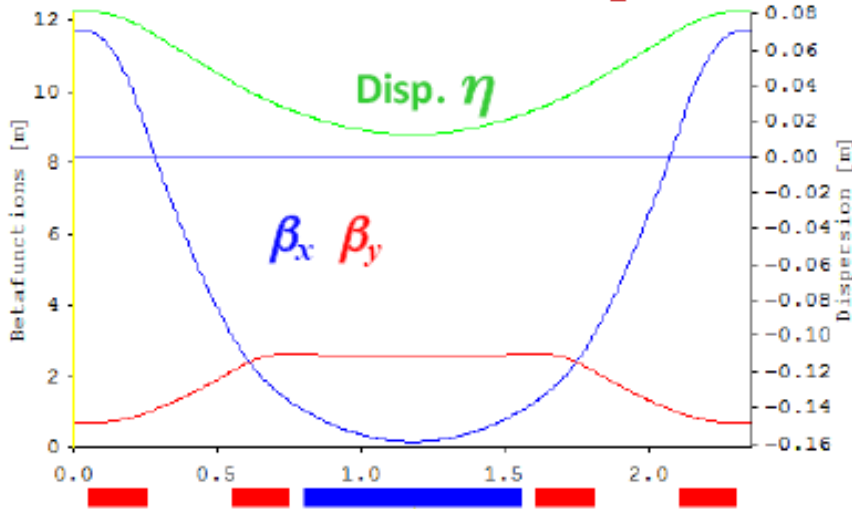
Automated iteration between physics and CAD model

# SLS-II

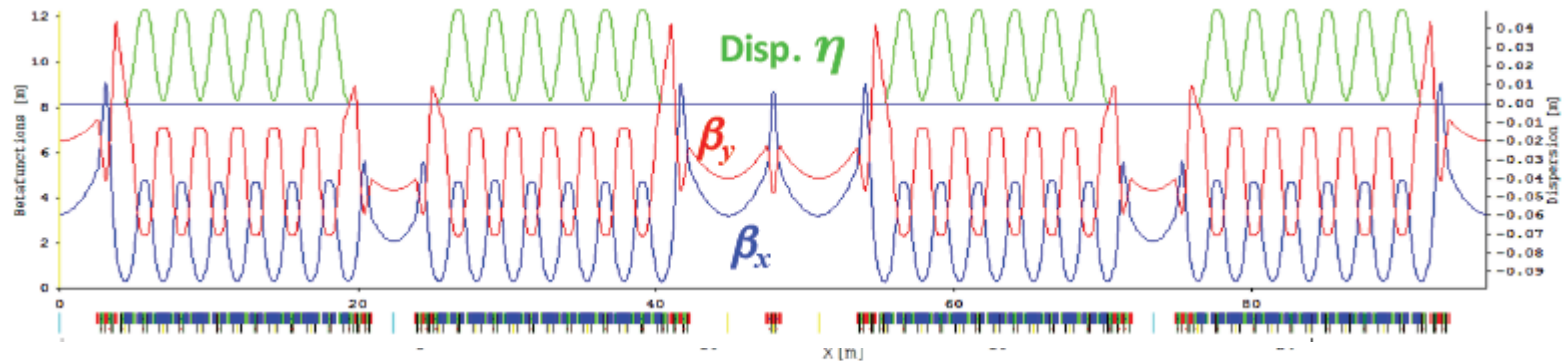
Combining **longitudinal gradient bends** and **reverse bends** to reduce the emittance

conventional:  $\varepsilon = 990 \text{ pm}$  ( $F = 3.4$ )

LGB/AB:  $\varepsilon = 200 \text{ pm}$  ( $F = 0.69$ )



# SLS-II

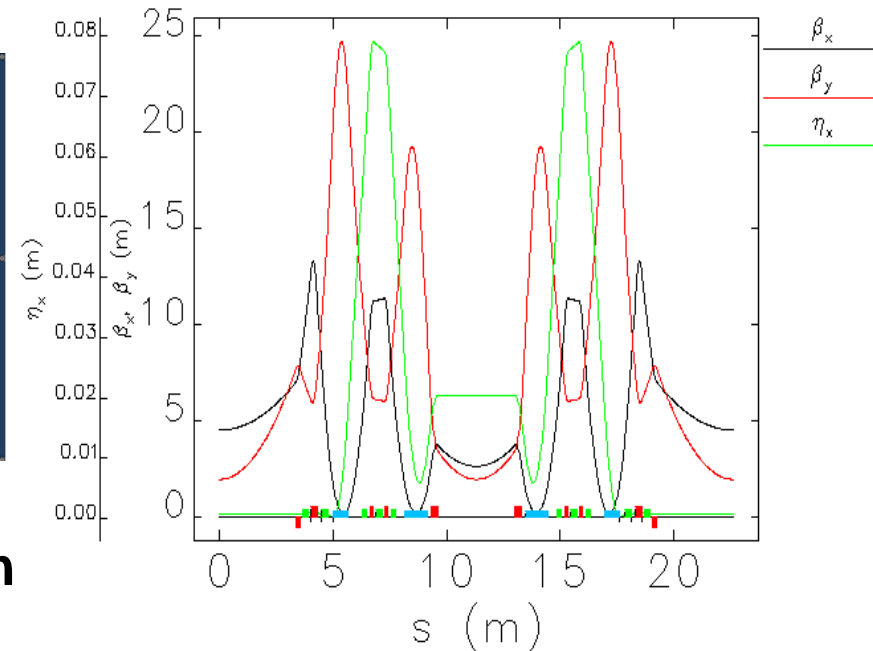
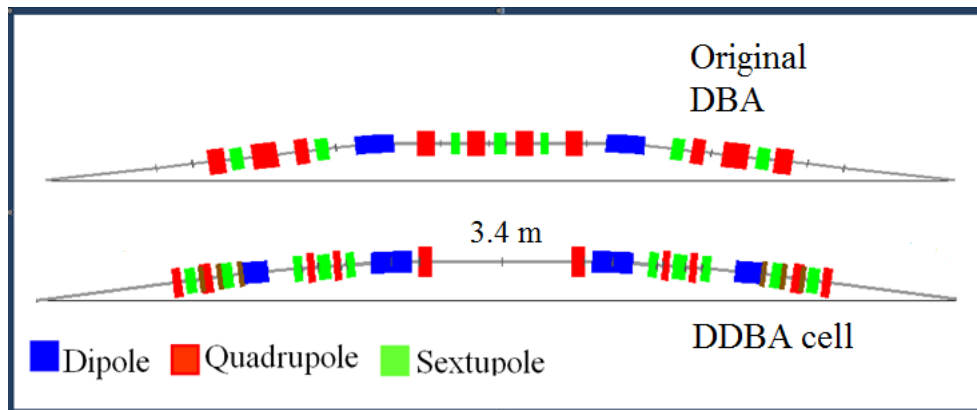


- ◆  $12 \times \text{TBA} \Rightarrow 12 \times 7 \text{BA}$  lattice:  $\frac{1}{2} + 5 + \frac{1}{2}$  cells of **LGB/AB** type
- ◆ Circumference  $288.00 \text{ m} \Rightarrow 287.25 \text{ m}$ 
  - in order to keep undulator positions (source points)
- ◆ Periodicity 3: 12 arcs and 3 different straight types:
  - $6 \times 4 \text{ m} \Rightarrow 6 \times 2.9 \text{ m}$      $3 \times 7 \text{ m} \Rightarrow 3 \times 5.1 \text{ m}$
  - split long straights:     $3 \times 11.5 \text{ m} \Rightarrow 6 \times 5.1 \text{ m}$
- ◆ beam pipe:  $64 \text{ mm} \times 32 \text{ mm} \Rightarrow \varnothing 20 \text{ mm}$ 
  - $\Rightarrow$  magnet aperture  $\varnothing 26 \text{ mm}$

**DA -4/+5mm to be improved WIP**

# Diamond II: 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.

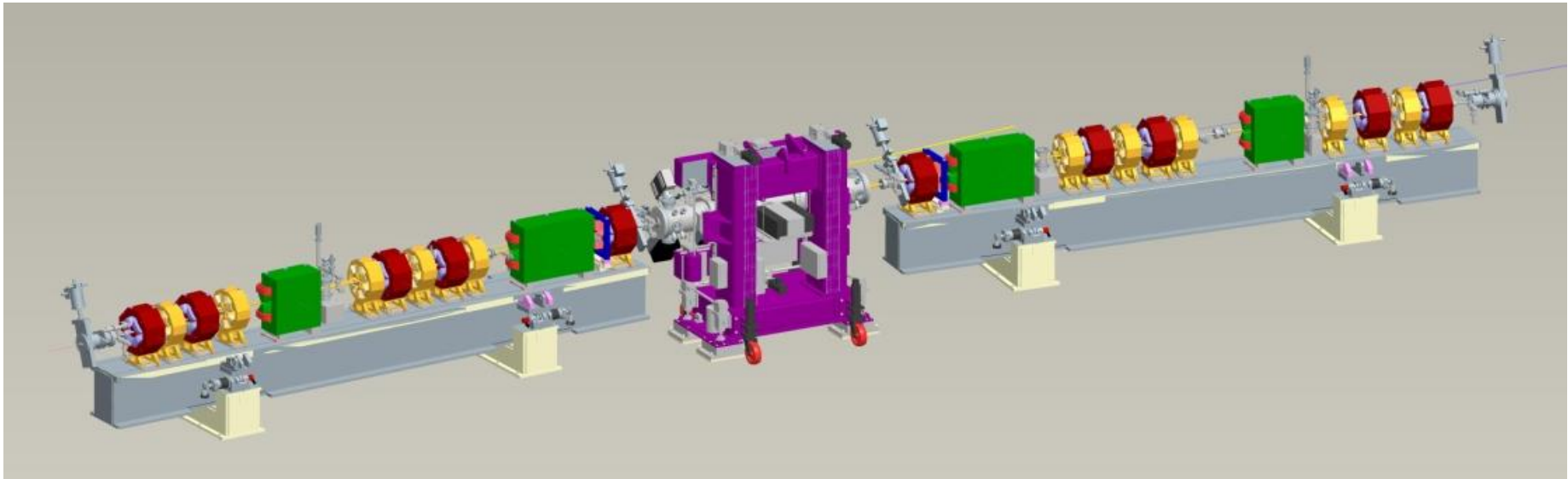
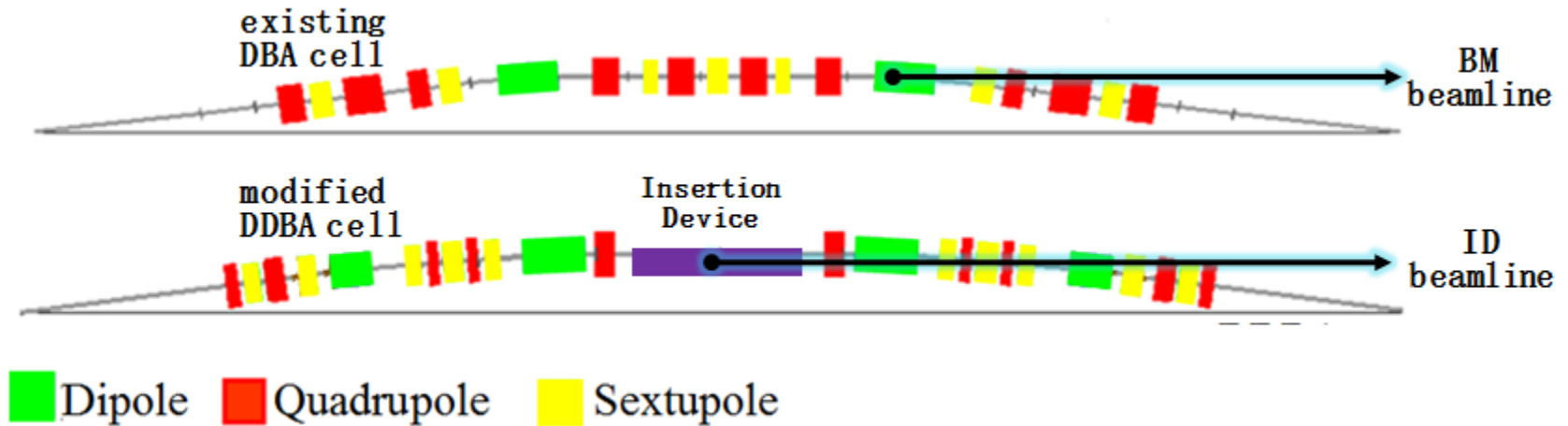


This lattice originated the modification of the existing cell2 too a DDBA cell

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

# One DDBA cell in the existing lattice

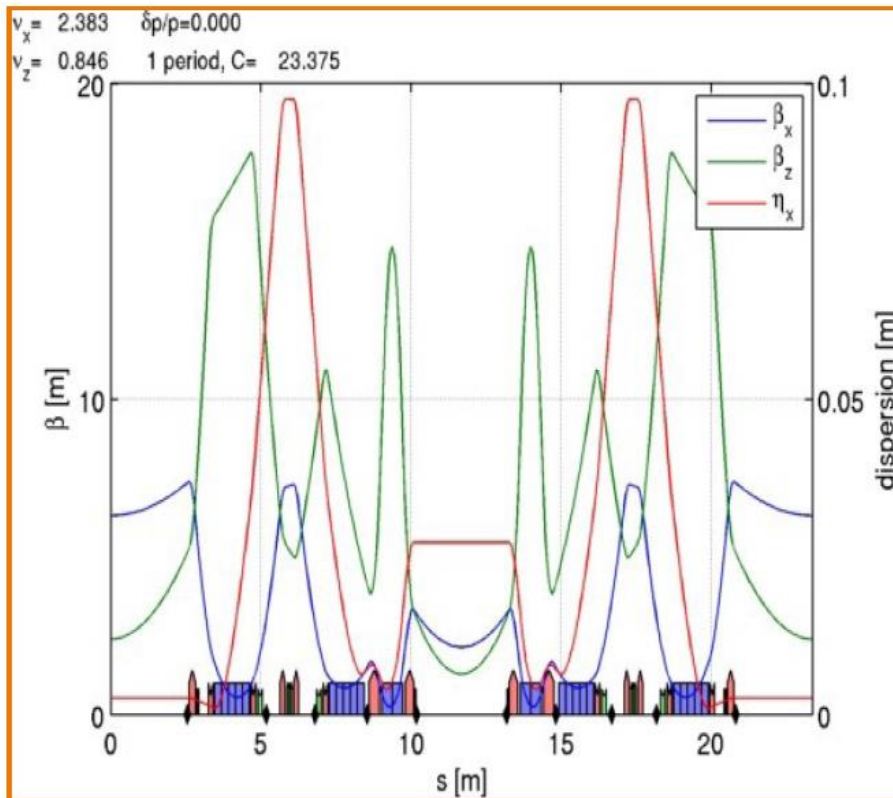
One DDBA cell is going to be installed in the existing lattice in order to have one more beamline (no significant gain in emittance)



# modified 6BA lattice – 100/140 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!**

# electron beam sizes (standard straight)

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Parameter (rms values)	Diamond	Diamond-II	Diamond II added straight
Horizontal size, $s_x$ [mm]	123.5	23.6	19.8
Vertical size, $s_y$ [mm]	3.5	3.5	4.0
Horizontal divergence, $s_x'$ [mrad]	24.1	5.1	6.9
Vertical divergence, $s_y'$ [mrad]	2.3	2.3	2.0
Product	$2.38 \cdot 10^4$	$9.60 \cdot 10^2$	$1.10 \cdot 10^3$
Electron beam brightness ratio	1	24.8	21.6

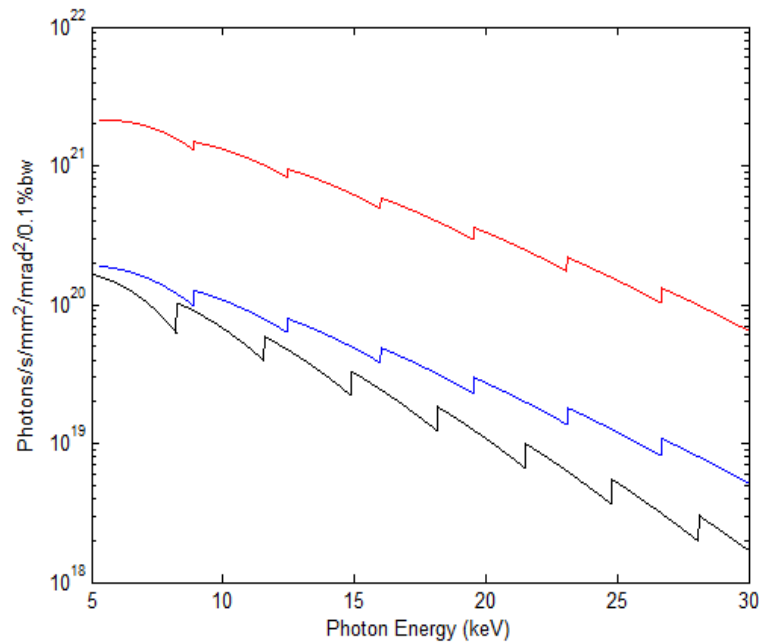
The electron beam brightness is improved by nearly a factor of 25.

# Brightness improvement with Diamond-II (120pm):

Hard X-rays undulator

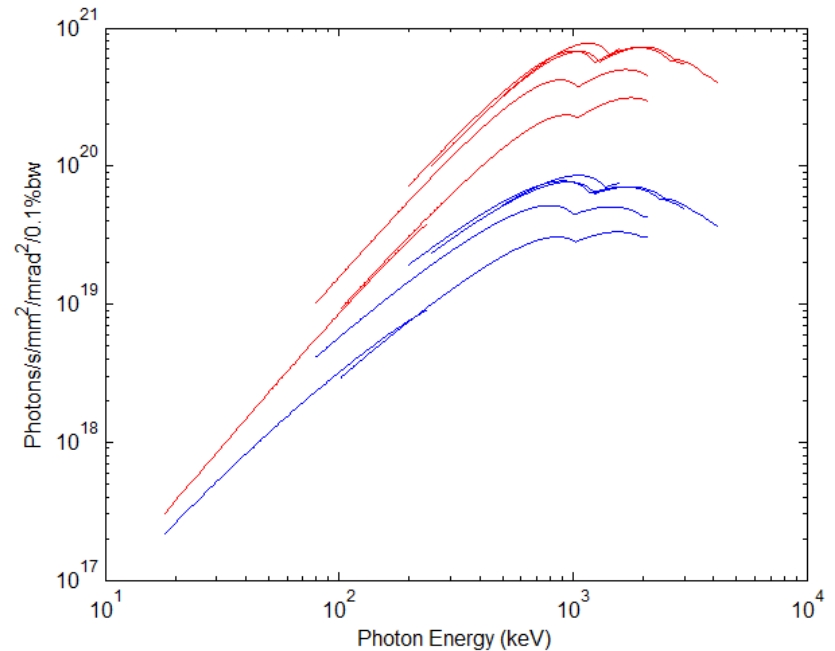
CPMU 300 mA 1%K

116 periods 2 m long with  $K_{\max} = 1.86$



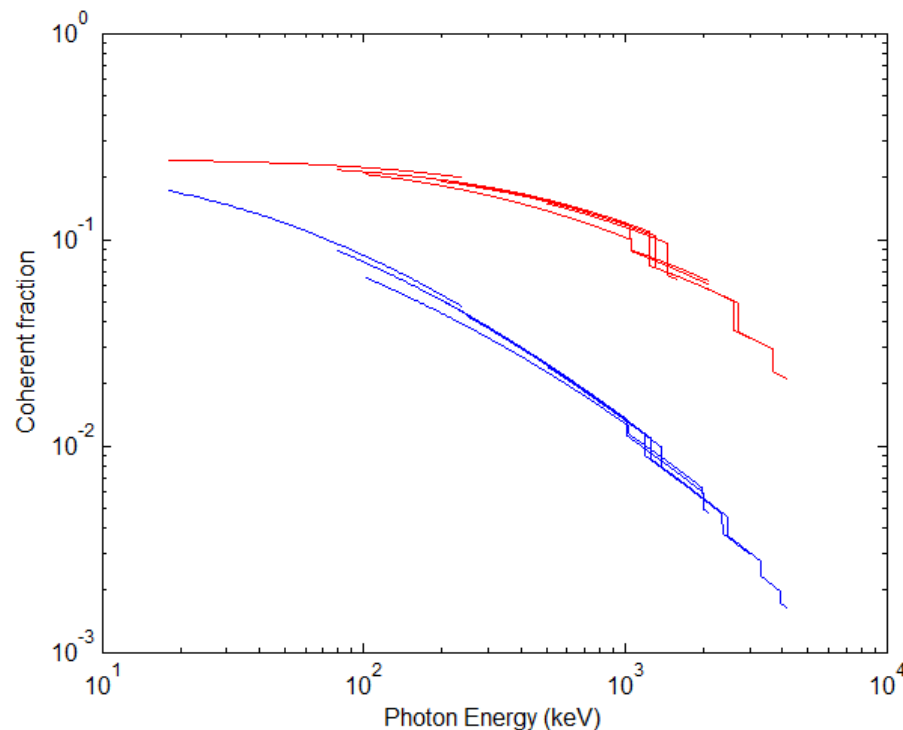
Soft X-rays undulators

APPLE-II for I05, I06, I08, J09, I10 and I21



# Coherent fraction improvement with Diamond-II (120pm):

Transverse coherence fraction with respect to present operation



$$F = \frac{\lambda^2 / (4\pi)^2}{\sum_x \sum_{x'} \sum_y \sum_{y'}}$$

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

# Conclusions

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Ultra low emittance rings are becoming reality

MAX IV in commissioning  
SIRIUS in 2018  
ESRF EBS in 2020

Many light sources are studying upgrades

R&D still required: magnets, vacuum, diagnostics for stability, but the technological challenges appears solvable

The next push is to get to true diffraction limited ring (tens pm emittance)  
**Eucard2 has been instrumental in fostering the collaboration of many laboratories and experts in EU and overseas (see Y. Papaphilippou's talk this afternoon)**

# EuCARD2 -TWIICE II workshop – Abingdon Feb 2016

The screenshot shows a web browser window with a dark blue header. The browser's address bar shows 'Europe/London' and 'English'. The page title is 'Second Topical Workshop on Instabilities, Impedance and Collective Effects (TWIICE 2)'. Below the title, the dates '8-10 February 2016' and location 'The Cosener's House' are listed. A search bar is visible. On the left, a navigation menu includes 'Overview', 'Scientific Programme', 'Timetable', 'Contribution List', and 'Participant List'. The main content area contains three paragraphs of text. The first paragraph announces the workshop. The second paragraph describes the workshop's aim. The third paragraph discusses the theme. A link for more information is provided at the bottom of the main content area. The browser's status bar at the bottom right shows '100%' zoom.

8-10 February 2016  
The Cosener's House  
Europe/London timezone

Overview  
Scientific Programme  
Timetable  
Contribution List  
Participant List

Diamond Events Team  
✉ events@diamond.ac.uk

We are pleased to announce that a second Topical Workshop on Instabilities, Impedance and Collective Effects will be organized by John Adams Institute and Diamond Light Source on the 8th, 9th and 10th February 2016 as a sub-series of Low Emittance Rings (LOWeRING) workshops.

The aim of the workshop is to bring together experts from the scientific community working on collective beam instabilities and related subjects for low emittance machines. This community includes light source storage rings, damping rings, test facilities for linear colliders, B-factories and future e+/e-circular colliders.

The theme will be collective effects and their potential limitations/remedies on the performance of running and future low emittance lepton rings.

Participants will benefit from the experience of colleagues who have studied such effects theoretically and experimentally, and have developed and operated countermeasures.

For more information please visit:  
<http://www.diamond.ac.uk/Home/Events/2016/TWIICE-2.html>

# EuCARD2 – ALERT 2016 Trieste (Sept. 2016)

## Advanced Low Emittance Rings Technology (ALERT) 2016 Workshop

14-16 September 2016  
Trieste, Italy  
Europe/Rome timezone

Overview

Scientific Programme

Timetable

Contribution List

Registration

Participant List

Venue

Accommodation



Trieste | 14-16 September 2016

A workshop on Advanced Low Emittance Rings Technology (ALERT 2016) is organized by ELETTRA on the 14th and 16th of September 2016, as a series of the Low Emittance Rings (LOWeRING) Workshops, supported by the EUCARD2 project.

This will be the 2nd workshop on Low Emittance Rings technology after the one organized in the [2014 in Valencia](#).

The state of the art in the design of accelerator systems in light source storage rings has today many challenges and issues in common with those of linear collider damping rings and future e<sup>+</sup>/e<sup>-</sup> circular