Light Sources Update

I. Martin

JAI Advisory Board Meeting

19th April 2021

Talk Outline

Overview of light source activities at JAI

Update on Diamond-II:

- general introduction / reminder of the project
- project status

Example topics from JAI members:

- BPMs for FELs (A. Lyapin)
- electron beam energy measurement using resonant spin depolarisation (N. Vitoratou)
- integrated optics design for diffraction-limited storage rings (J. Li)
- feasibility Studies of Cherenkov Diffraction Radiation BPMs (D. Harryman)
- new studentships (S. Wilkes, +1)

Conclusions

Overview of Light Source Activities

JAI contributes to light source design across broad range of topics:

Storage Rings	Diamond-I (short pulses, THz emission / diagnostics, energy measurement, …)
	Diamond-II (lattice design, beamline optimisation)
Free Electron Lasers	CLARA (novel FEL schemes, multi-pulse / multi-colour operation, diagnostics, …)
	NLS/UK-XFEL (facility design, diagnostics, short pulses, peak power, coherence, …)
LPWA	(beam transport, spontaneous emission, FEL)

JAI contributors (past and present)

Staff:	R. Bartolini (now at DESY), S. Boogert, P. Karataev, A. Lyapin
PDRA:	A. Alekou, M. Korostelev, K. Lekomtsev
PhD/DPhil:	M. Atay, S. Bajlekov, T. Chanwattana, K. Fedorov, A. Finn , D. Harryman, J. Li, I. Martin, T. Pulampong, J. Puntree, W. Shields, N. Vitoratou

Diamond-II: Design Goals

Design goals for Diamond-II storage ring:

1) Improve quality of photon beams delivered to users:

- Increase spectral brightness
- Increase transverse coherence
- Reduced source size, line-width
- Optimise spectral range

Achieved via reduction in natural emittance, increase in beam energy, new IDs, (phase space matching - WIP)

2) Increase number of straight sections:

- Space for new beamlines (up to nine)
- Choice of source for existing dipole beamlines (ID / wiggler / bespoke 3-pole wiggler)
- Space for ancillary components (RF cavities, diagnostics equipment, injection components, …)

Unique approach: Diamond-II combines both low emittance with high capacity

Diamond-II: Lattice

Lattice structure is a ‘Modified-Hybrid 6-Bend Achromat’, combining:

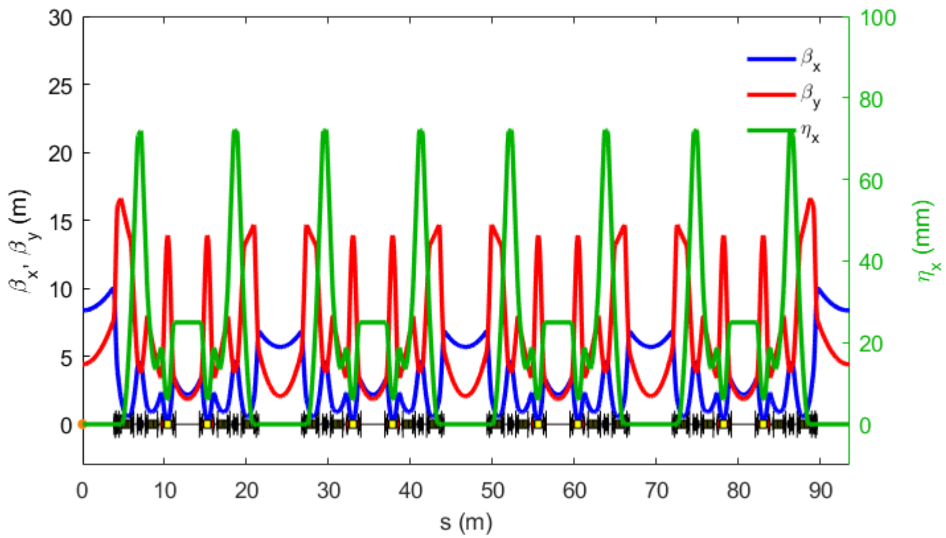
ESRF-EBS Hybrid 7BA cell
Mid-straights from Diamond Double-Double Bend Achromat

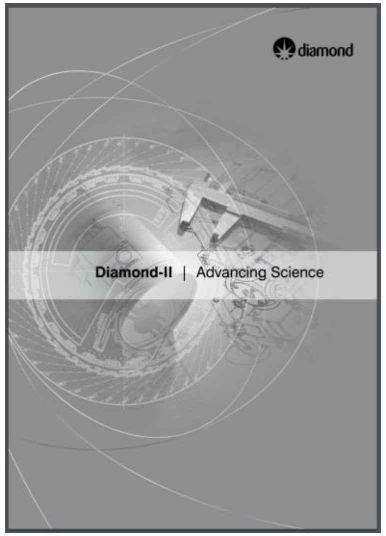
Each cell consists of:

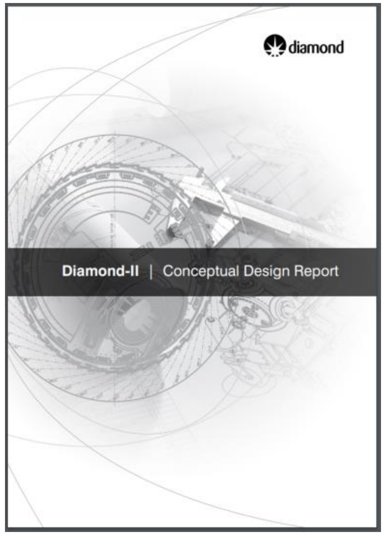
4 longitudinally-varying dipoles
2 transverse gradient dipoles
16 (17) quadrupoles, 96 of which are displaced as anti-bends
12 sextupoles
2 octupoles

Conceptual Design Report (May 2019):
https://www.diamond.ac.uk/Home/About/Vision/Diamond-II.html

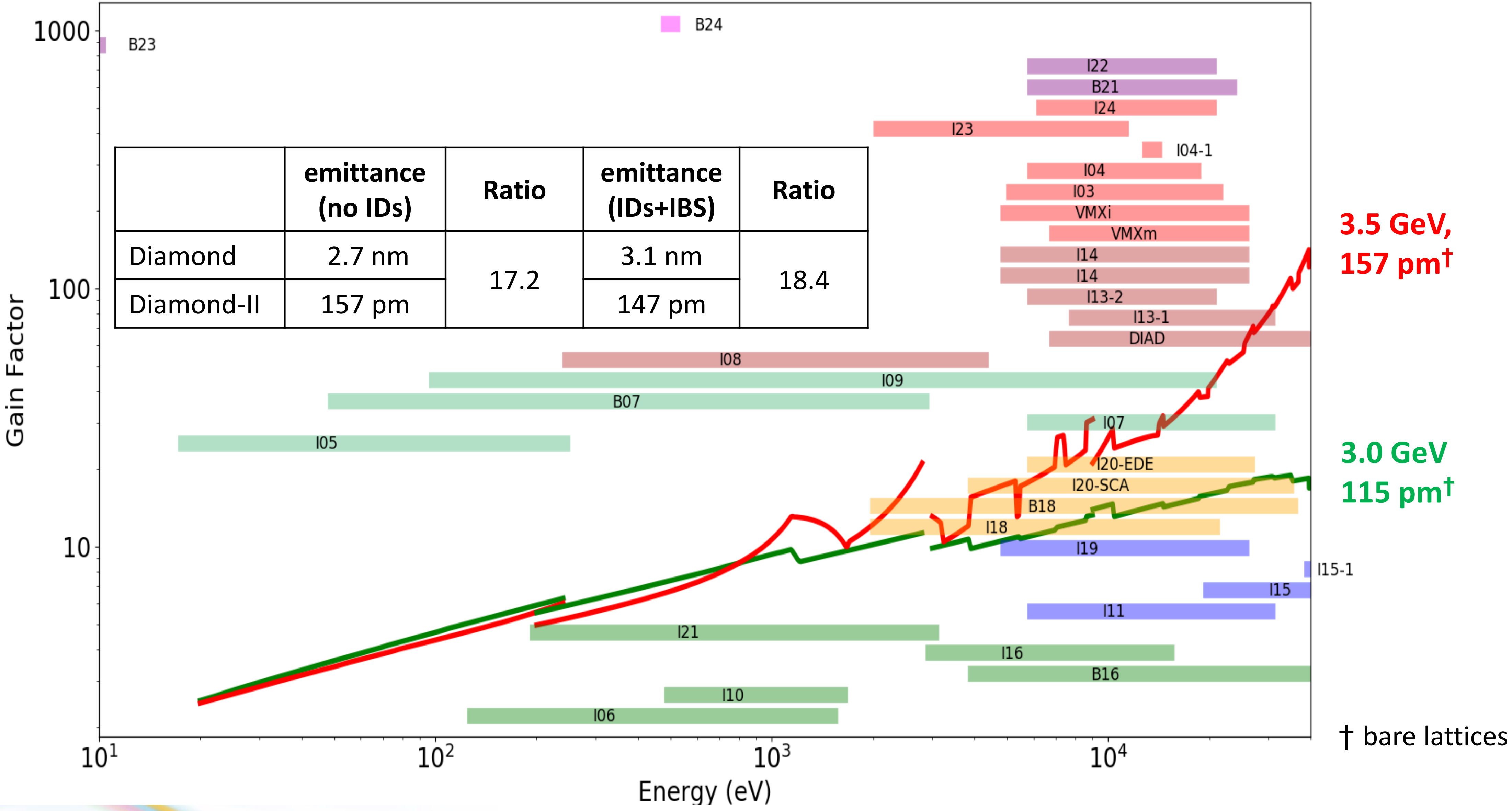
Emittance (bare lattice) 2.7 nm.rad (3 GeV) => 160 pm.rad (3.5 GeV)







Diamond-II: Brightness Gain for CDR Lattice



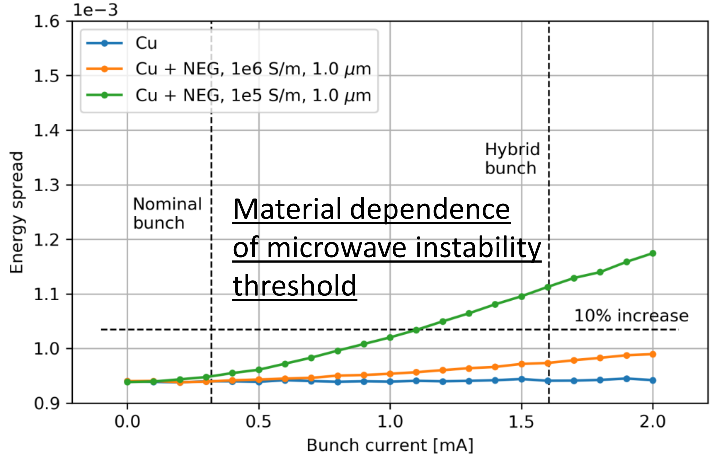
	emittance (no IDs)	Ratio	emittance (IDs+IBS)	Ratio
Diamond	2.7 nm	17.2	3.1 nm	18.4
Diamond-II	157 pm		147 pm	

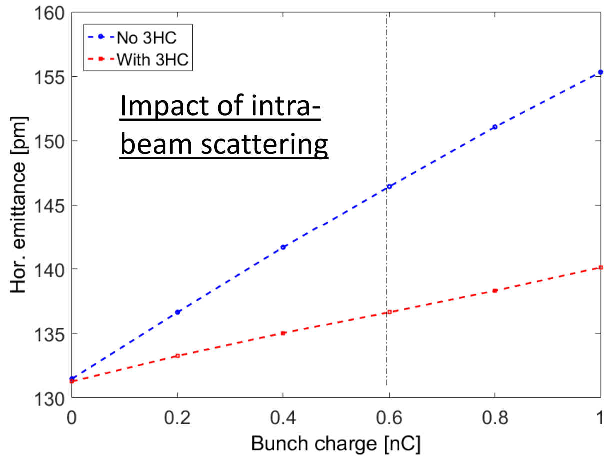
Diamond-II: Ongoing AP Activities

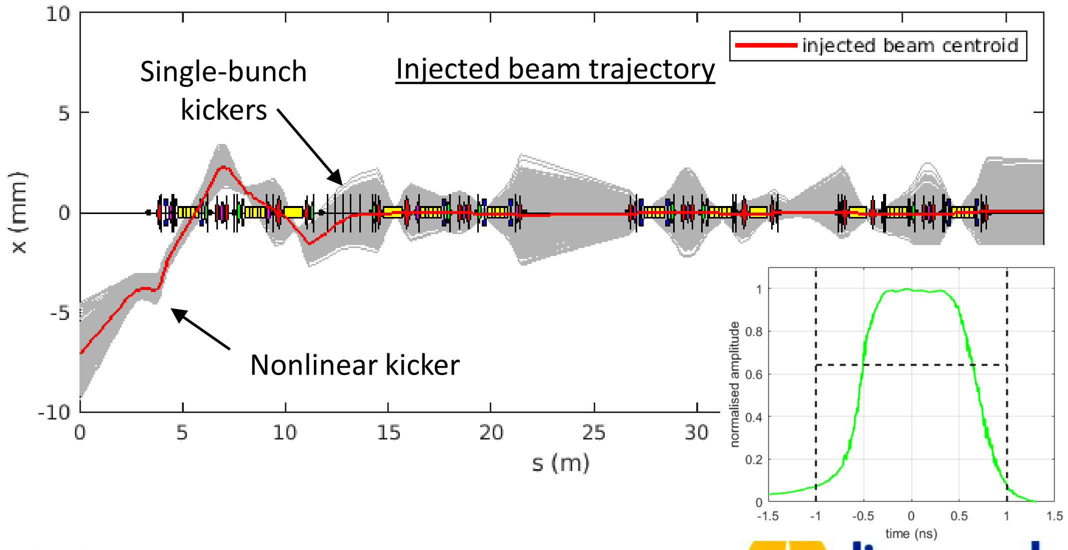
Lattice structure frozen since Feb. 2021 to allow Engineering, Vacuum and Magnet design work to progress.

Main focus for AP is now shifting towards characterisation and optimisation:

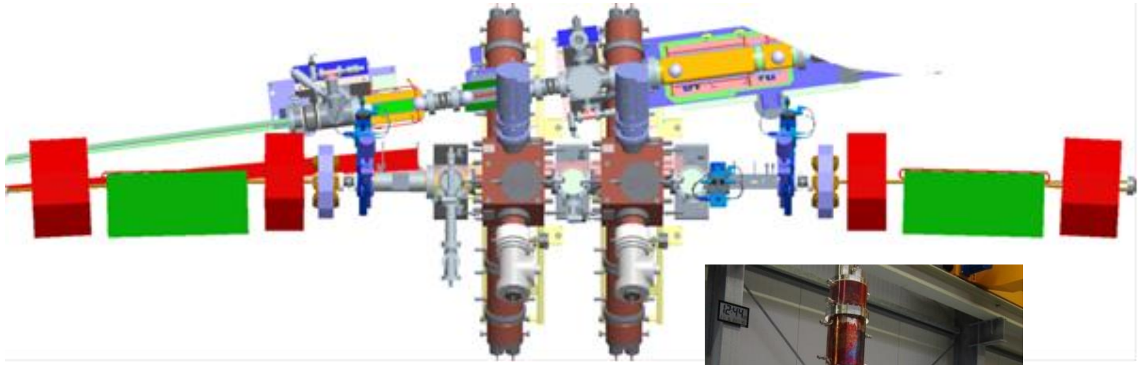
- Develop transparent injection scheme using nonlinear kicker, possibly with fast single-bunch kickers
- Studying collective effects / instability thresholds / intra-beam scattering
- Choice of harmonic cavity for bunch lengthening (passive vs. active, normal conducting vs. superconducting)
- Impact and compensation strategy for insertion devices
- Lifetime with IDs, harmonic cavity, wakefields, IBS, predicted pressure distribution => collimation
- Commissioning strategy starting from on-axis first turns through to user beam, etc., etc., ……..



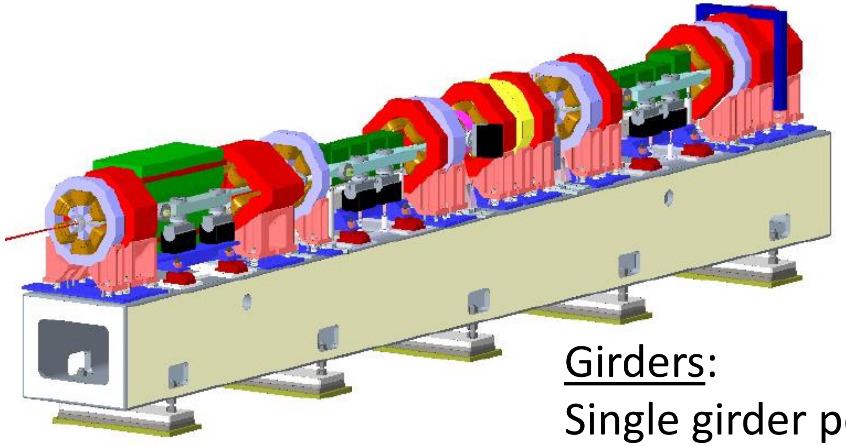


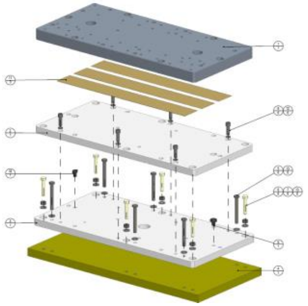


Diamond-II: Technical Design

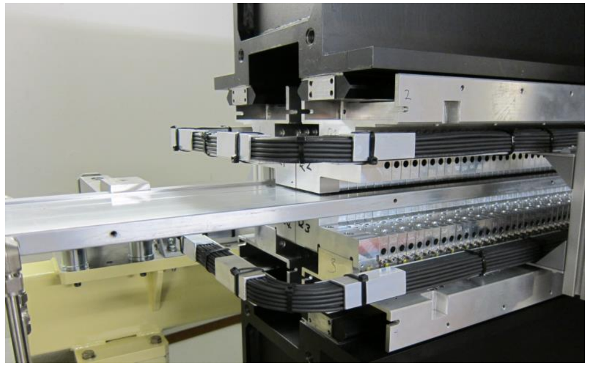


RF: 8 NC EU HOM-damped
Digital LLRF
Solid-state amplifiers

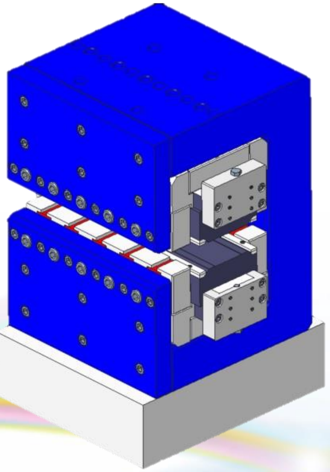


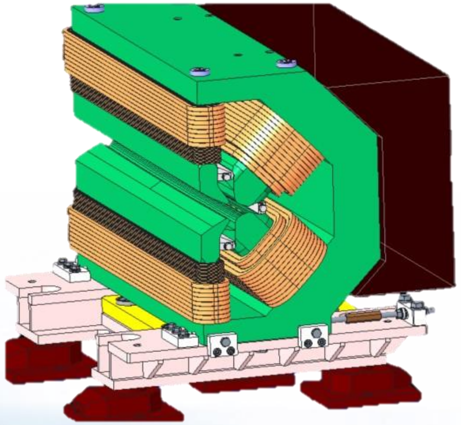


Girders:
Single girder per half-cell (8m)
Viscoelastic tape in base-plates

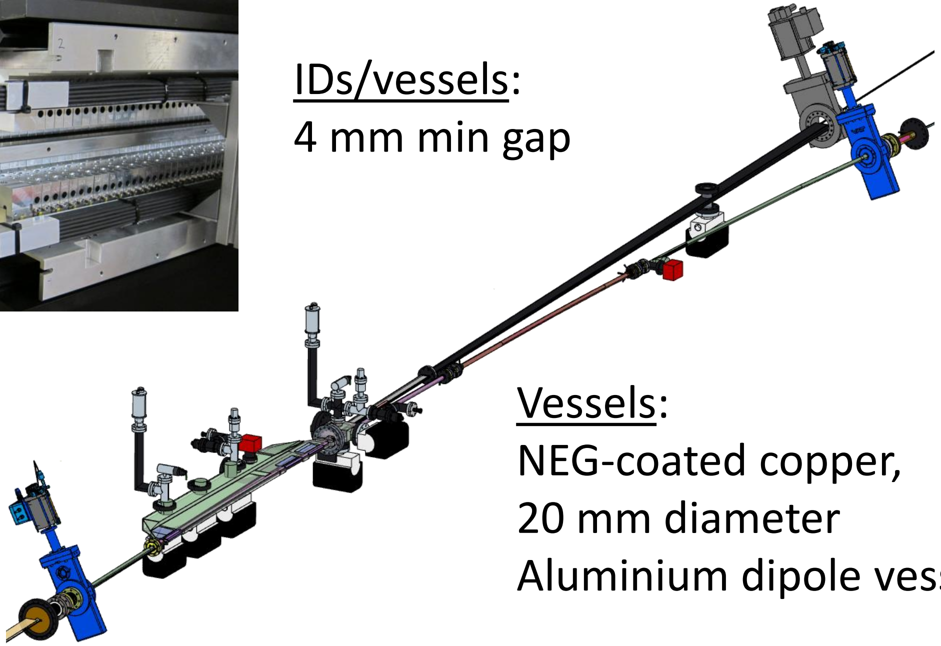


IDs/vessels:
4 mm min gap





Magnets:
PM long. varying dipoles
EM magnets elsewhere



Vessels:
NEG-coated copper,
20 mm diameter
Aluminium dipole vessels

Diamond-II: Timeline

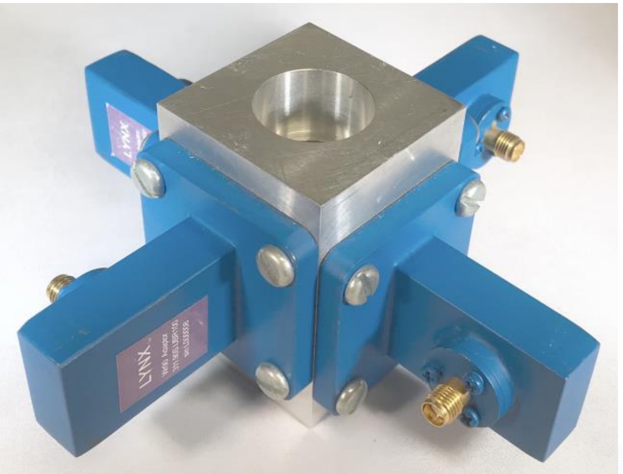
- Diamond-I funded as a Joint Venture between two sources (UK Government/STFC 86% and Wellcome Trust 14%)
- Same funding structure planned for Diamond-II
- Decision from both bodies anticipated within next 12 months
- STFC CD-0 and CD-1 stages already complete, CD-2 and CD-3 outstanding

- Nominal Timeline presented in CDR (TBC):

Event	Date
CDR Published	May 2019
Draft TDR	Dec. 2021
Start of funding and procurement	Apr. 2022
Start of shutdown	Dec. 2025
Resume full User Mode	Jun. 2027

BPMs for FELs (A. Lyapin, RHUL)

Project partner FMB-Oxford commercialized the cavities



Prototype WGBPM built for bench testing

Cavity BPMs:

- High precision position diagnostic, roots in LC research
- Supported by STFC IPS grant 2013-2017
- A design suitable for FELs now commercialized
- Smaller aperture design better suited for undulator beamlines in progress (would be a candidate for CLARA and UK XFEL)
- Compact higher operating frequency designs considered
- More details in industrialization talk

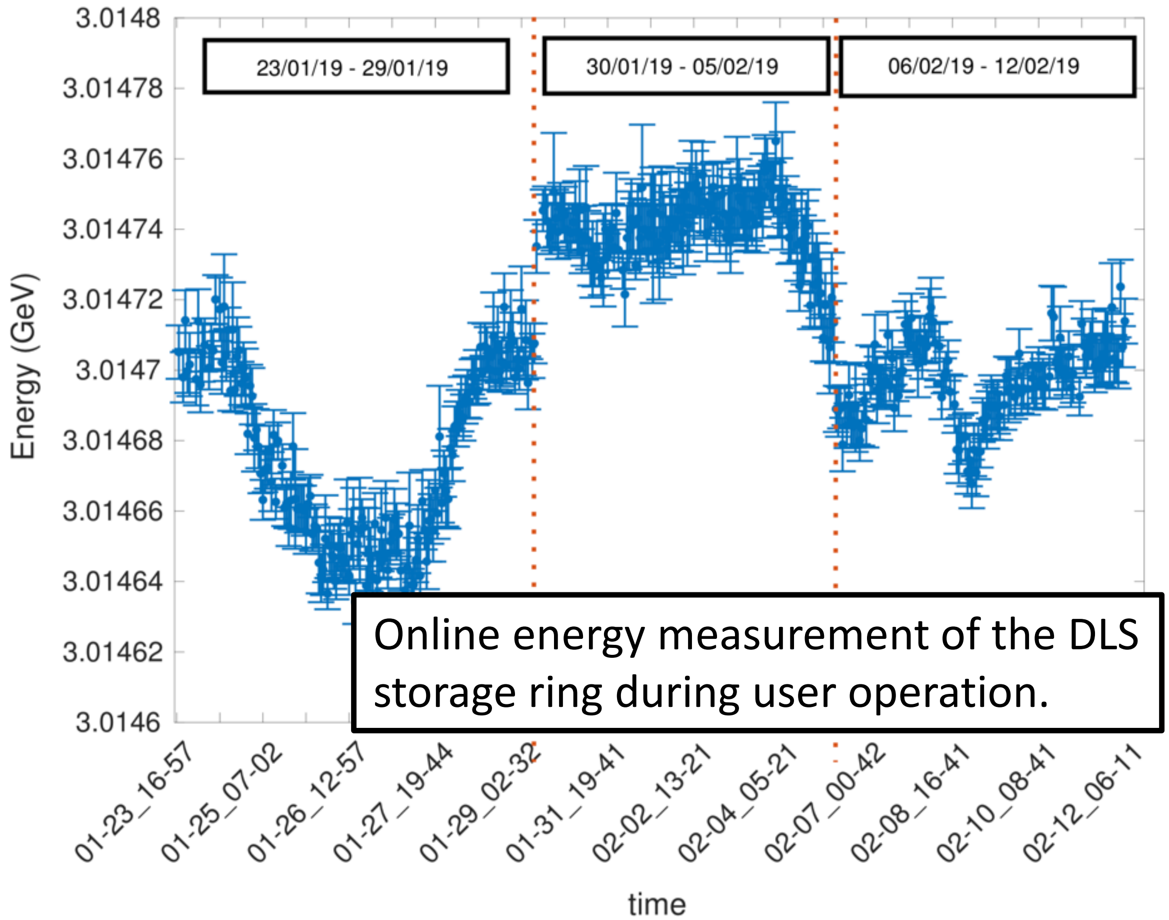
Waveguide BPMs:

- Spin-out from cavity BPM work
- Faster and cheaper than cavity BPMs, suitable for ns feedbacks
- Require no tuning
- But need wideband signal processing and have lower resolution potential
- STFC Follow-on Fund grant now in progress, extensive simulations resulted in several candidate designs
- A vacuum prototype WIP, slowed down by the pandemic

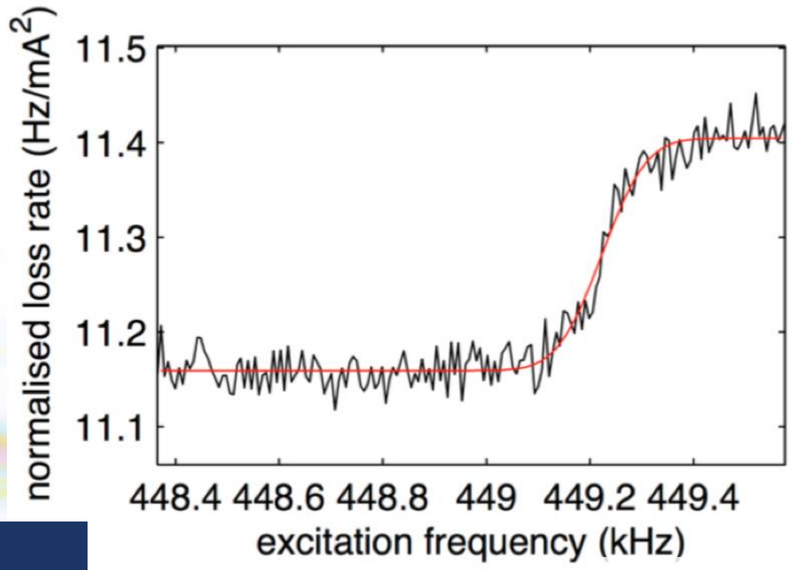
PhD Student: N. Vitoratou (2016-2020)

“Continuous Energy Measurements of the Electron Beam in the Storage Ring of Diamond Light Source”

- The spin gradually aligns antiparallel with the main guide field of the bending magnets.
- The polarised beam is excited by a horizontal magnetic field produced by striplines.
- When the magnetic field oscillates at a frequency which matches the spin precession frequency the beam is depolarised.
- The frequency at which depolarisation occurs corresponds to the beam energy.



Online energy measurement of the DLS storage ring during user operation.



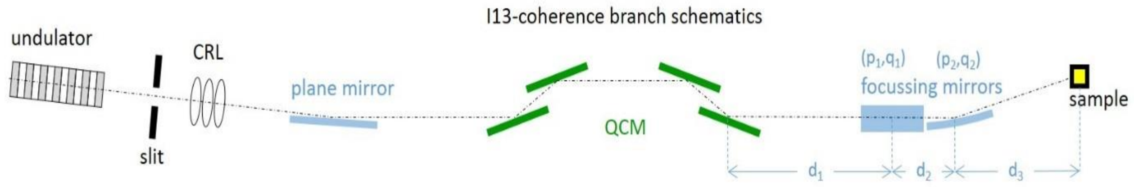
N. Vitoratou, P. Karataev and G. Rehm, Phys. Rev. Accel. Beams, 22, 122801 (2019)

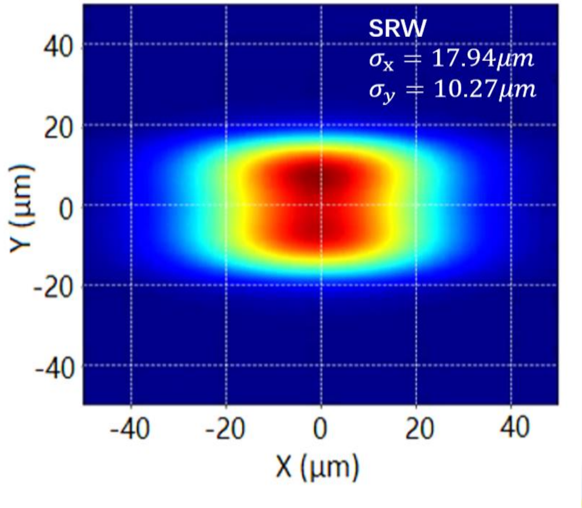
Supervisors: P. Karataev and G. Rehm

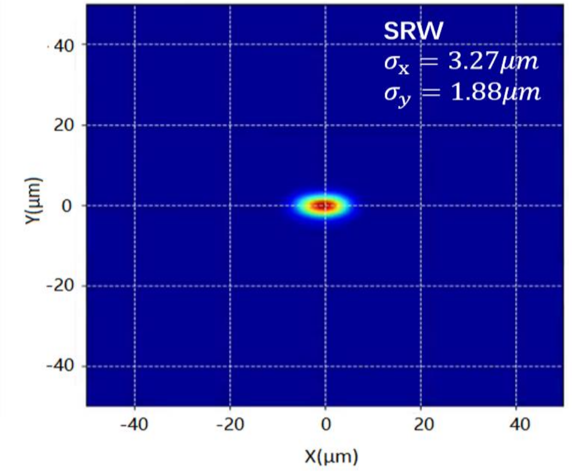
PhD Student: J. Li (2017-2021)

“Studies on Integrated Optics Design for Diffraction Limited Light Sources”

The goal is to **integrate the design of electron and photons source** to find the **best trade off between accelerator and photon optics** performance and guarantee the production of photon beam with best properties.







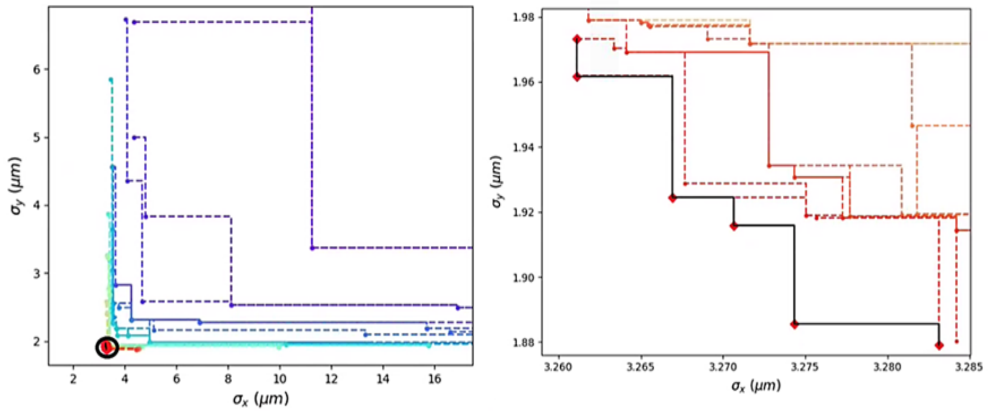
Integrated design:electron to sample (E2S)

Beamline parameters

Elegant → **SRW** → **Flux / Brightness, Tuning curves, Power density, Beam-spot intensities**

Beamline optimiser

SRW / SHADOW → **NSGA II** → **Better beamline configuration**

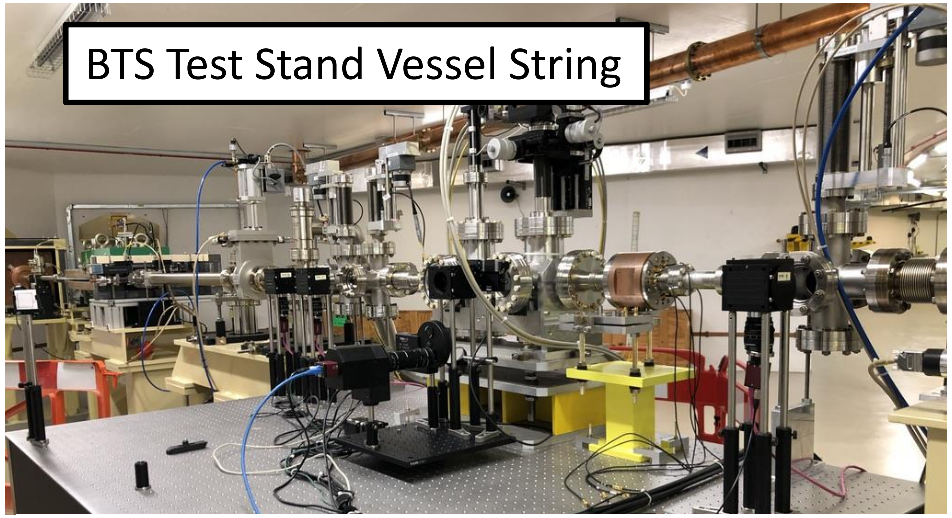


Supervisors: R. Bartolini and P. Burrows

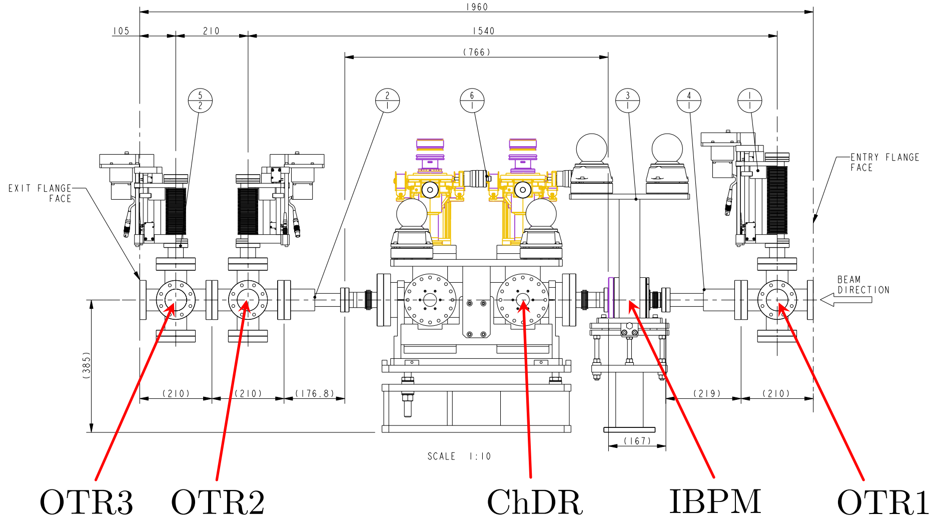
PhD Student: D. Harryman (Started 2018)

"Feasibility study on the use of incoherent Cherenkov Diffraction Radiation to develop a non-invasive BPM"

- Cherenkov Diffraction Radiation (ChDR) is a type of polarisation radiation. It occurs when a charged particle moves in the vicinity a medium.
- The photon yield of ChDR is dependent upon the distance between the charged particle and the dielectric medium.
- Thus ChDR can be exploited for novel beam position monitors (BPM), where traditional rf pick-ups are challenging.



Standard BTS Parameter	Value
Beam Energy	3 GeV
Horizontal Beam Size σ_x	1.27 to 1.42 mm
Vertical Beam Size σ_y	0.57 to 0.6 mm
Extraction Rate	5 Hz
Max Bunch Charge (single bunch extraction)	0.2 nC
Min Bunch Charge (single bunch extraction)	0.02 nC
Max Charge per 120 Bunch Train (train extraction)	1.3 nC
Bunch Spacing (train extraction)	2 ns
Bunch Length	$\approx$ 2.5 mm



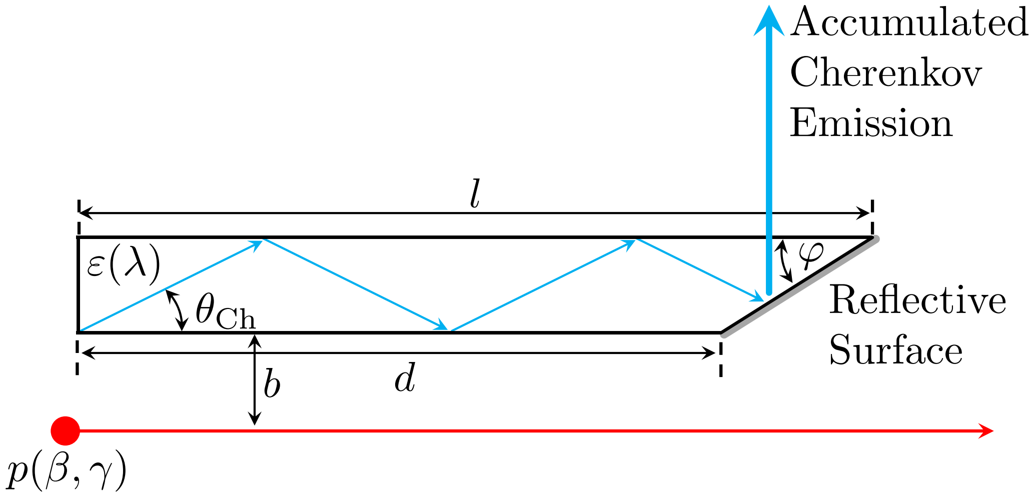
D. M. Harryman et al., Proc of IBIC'19, Malmo, Sweden, WEPP037
D. M. Harryman et al, Proc of IBIC'20, Santos, Brazil, THPP05

Supervisors: P. Karataev and L. Bobb

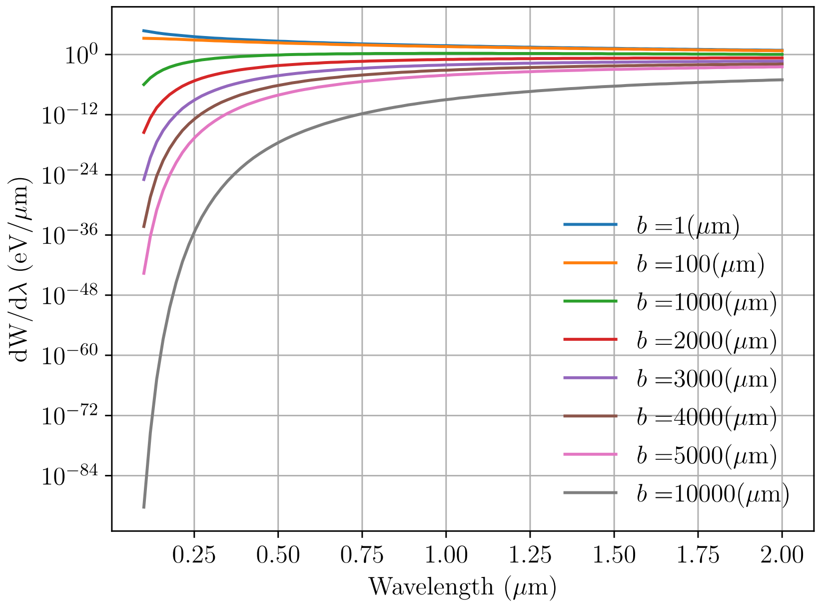
PhD Vacancy at RHUL

"Feasibility study on the use of incoherent Cherenkov Diffraction Radiation to develop a non-invasive BPM"

This work is part of a wider research group* exploring the applications of ChDR for beam diagnostics in collaboration with CERN, Tomsk and Royal Holloway, Uni of London, with experimental setups at CERN, KEK and Diamond Light Source.



*R. Kieffer et al., Phys. Rev. Lett. 121, 054802 (2018)



We are **currently advertising for a PhD student to continue this research** to investigate BPM applications using a new target geometry and/or IR wavelengths.

PhD Info: https://www.diamond.ac.uk/Careers/Students/Studentships/2021-projects/2021-STU0397.html

Applications: https://www.findaphd.com/phds/project/feasibility-of-cherenkov-diffraction-radiation-beam-position-monitor-for-high-energy-electron-machines/?p114635

Supervisors: P. Karataev and L. Bobb

D.Phil. Student: S. Wilkes (Starting Sept. 2021)

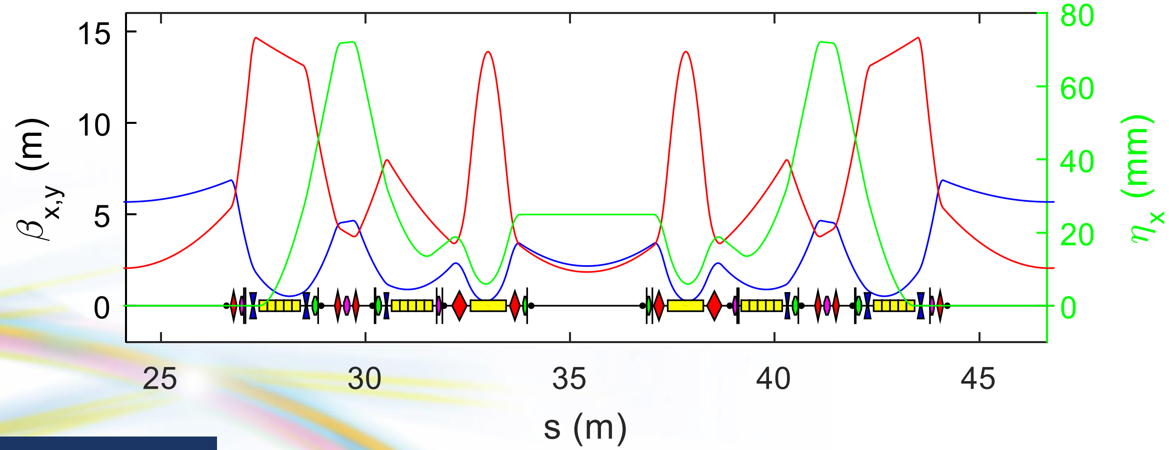
"Provision for Timing Mode Users at Multi-bend Achromat Synchrotron Light Sources"

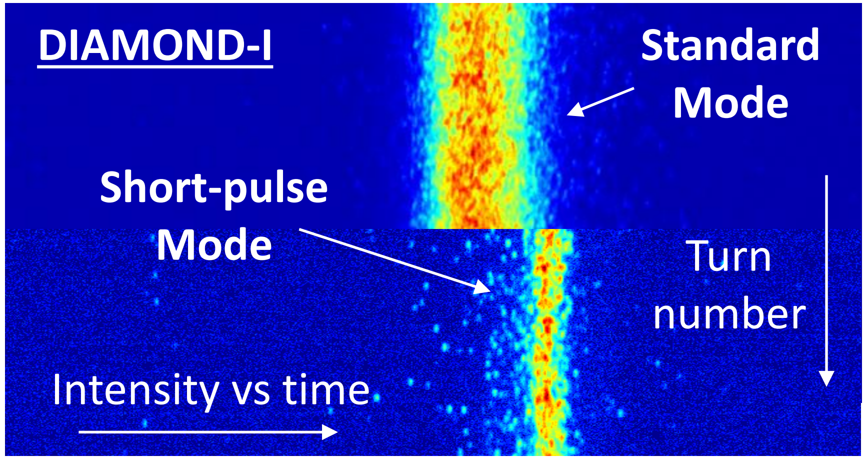
The **Diamond-II storage ring** design uses a multi-bend lattice to reduce the emittance by a factor 20 whilst increasing the space for beamlines

An open question is how best to **provide short, isolated x-ray pulses** for time-resolved studies

The student will study different options:

- '**hybrid-mode**' filling pattern
- **Resonant excitation** of a single bunch to increase the vertical beam size
- Use of a **higher-harmonic RF cavity** to manipulate the longitudinal potential well





Supervisors: P. Burrows and I. Martin

Conclusions

JAI continues to be active in a number of areas of light source design and operation:

- Facility design
- Enhanced performance
- Special operating modes
- Photon / electron beam diagnostics

Diamond-II / UK-XFEL / CLARA key projects

Providing training and expertise for next generation of accelerator physicists:

- New PhD Studentships starting September 2021
- Proposal for Joint Diamond / JAI PDRA to work on Diamond-II under consideration