Status of Diamond Light Source and the Diamond-II Upgrade

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on behalf of the Diamond team

33rd European Synchrotron Light Source Workshop
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Talk Outline

1) Diamond Status:
   - Operations summary
   - SLED operation
   - IDs
   - Solar installation

2) Diamond-II Status:
   - Project status
   - Vacuum
   - Magnets
   - Stripline testing
   - Beam abort system
   - IDs
   - Diagnostics
   - Lattice optimisation

3) Conclusions

Diamond Operations

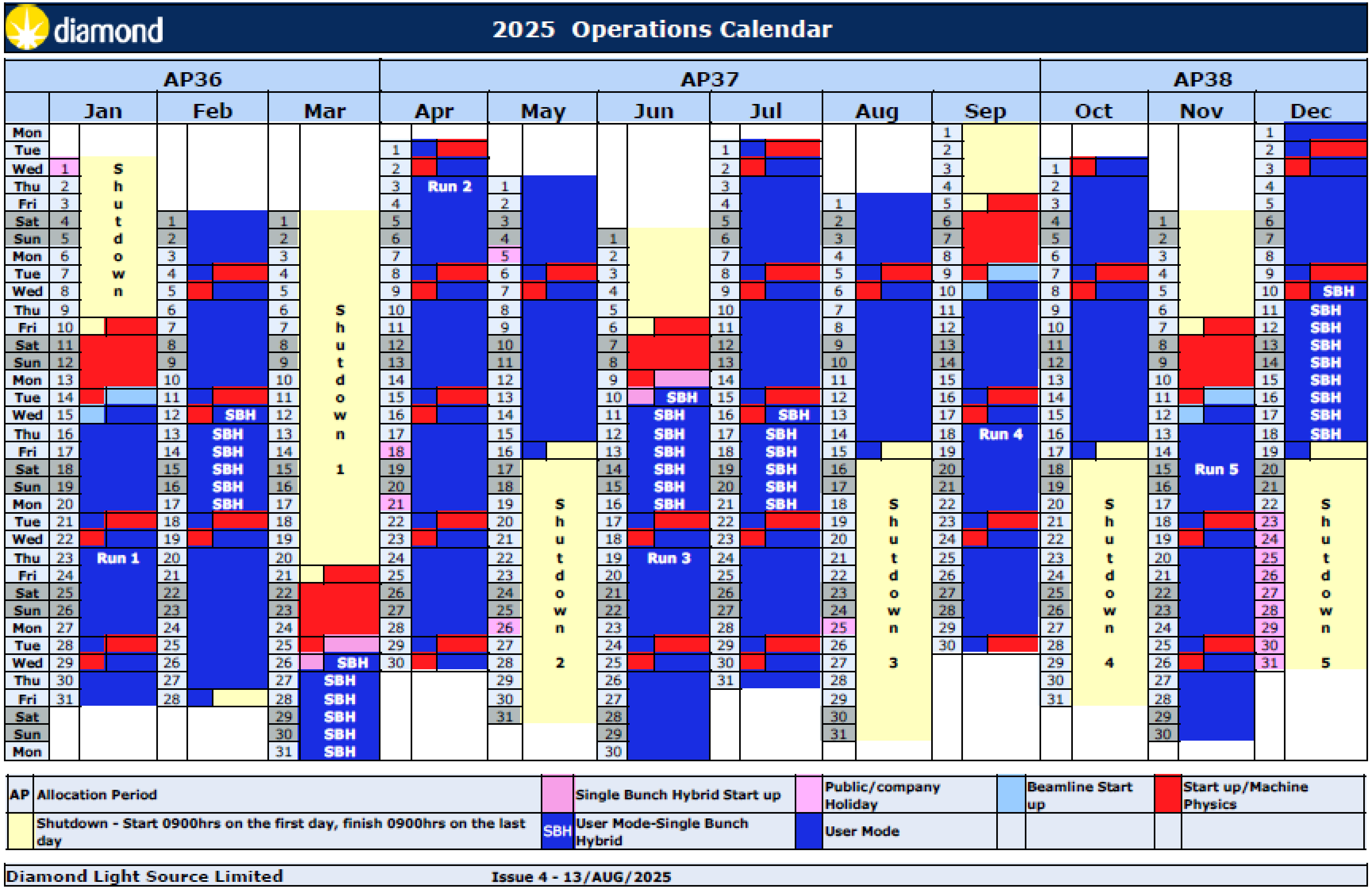
Diamond Operations

Diamond is UK's national synchrotron radiation facility

Operational since January 2007

Several operational modes on offer, only standard and hybrid requested by beamlines in last year:

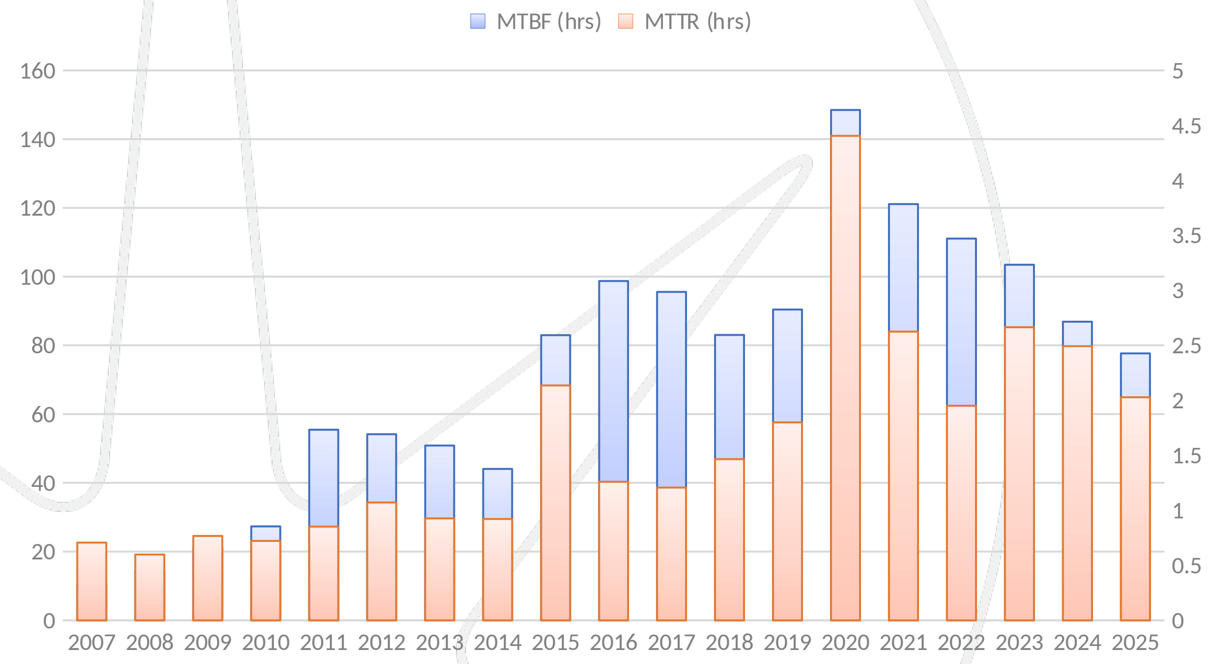
- Standard Fill (900 bunch)
- Hybrid mode (686+1 bunch)
- 156 bunch mode (timing)
- THz low-alpha
- Short-pulse low alpha

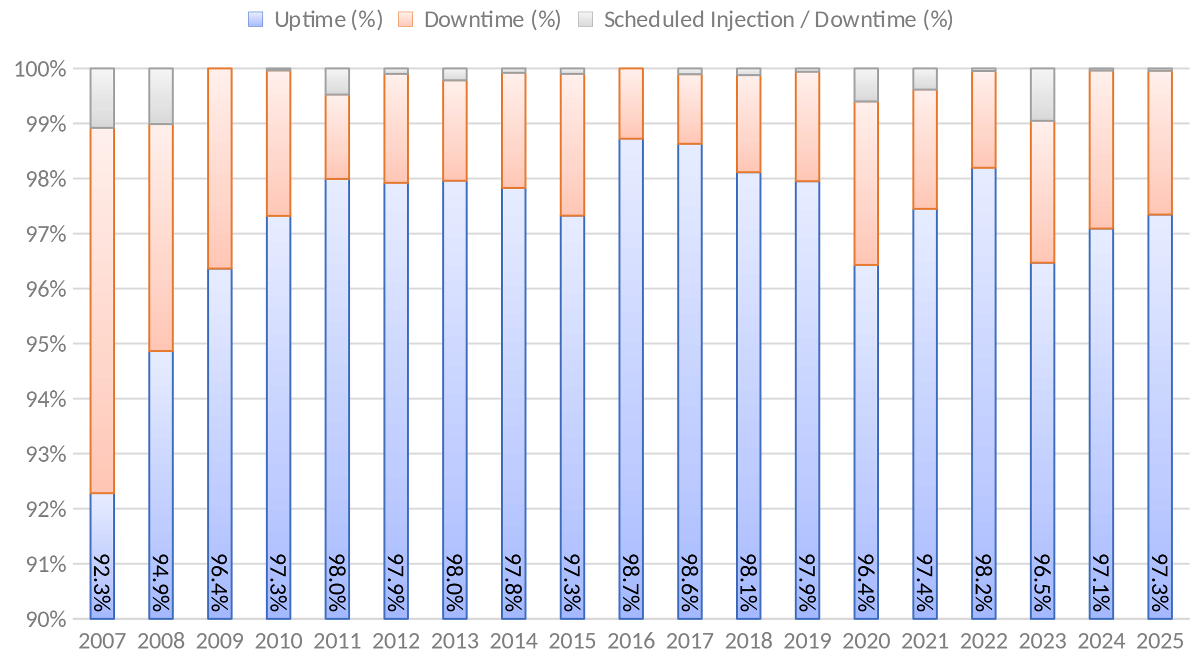


Diamond Operational Statistics

From Run 5 2024 – Run 4 2025 inclusive

- Three trip free weeks (machine day to machine day). 6 Uptimes >100 h.
- 24 uptime periods >72 hours (ignoring MD and SD)
- Longest Uptimes: 410 h, 382 h, 323 h and 291 h at end of Run 4, 2025.

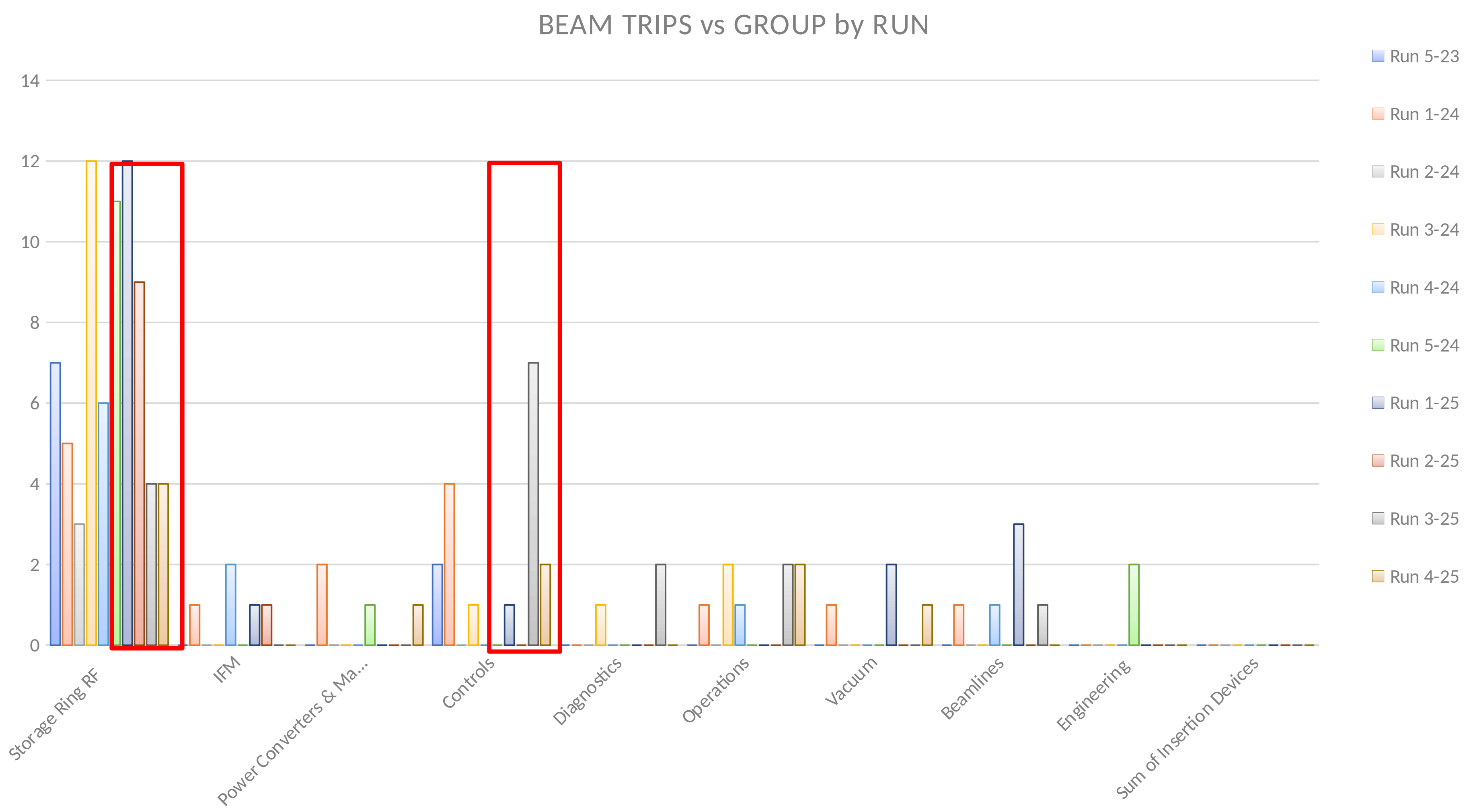




MTBF on downward trend due to RF issues, mixture of aging equipment faults and D-II preparation work.

Courtesy V. Winter

Diamond Operational Statistics



Courtesy V. Winter

Diamond Operational Statistics

Major events affecting downtime in last year:

Impact	Summary	Downtime (hrs)
Beam trip	Master oscillator failure	8.1
Beam trip	Beam instability – vertical instability in high charge hybrid bunch	5.1
Beam trip	K11 major water leak in optics hutch	4.8
Beam trip + beamtime delay	BOBL (PSS) failure, recovery delayed due to RF conditioning	4.7
Beam trip	MPS PLC failure	4.3
Beam trip	Valve crate failure	4.1
Beam trip	Cavity 3 vacuum trip	3.4

General Category	Total Downtime /h	# Trips	# Delays
SRRF CAVITY	34.81	22	2
TMBF / Instability / SETUP	11.65	1	4
PLC	11.35	4	0
IOT	11.23	7	0
Master Oscillator[1]	10.78	2	0

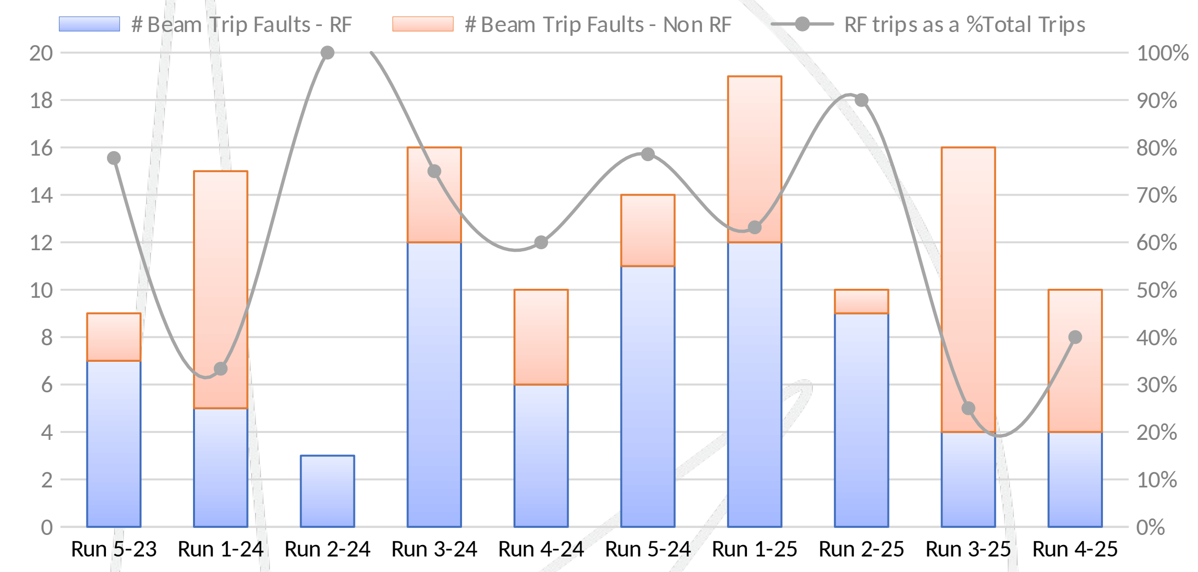
[1] Master Oscillator may be responsible for some inconclusive RF faults.

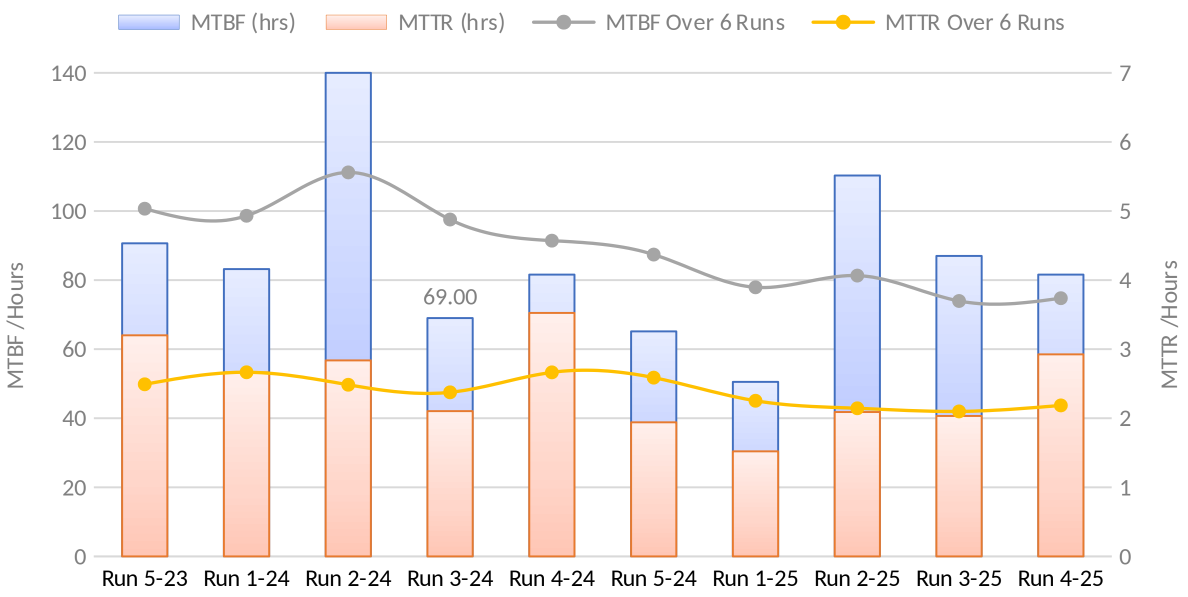
Courtesy V. Winter

diamond

Diamond Operational Statistics

Run 5 2023 – Run 4 2025



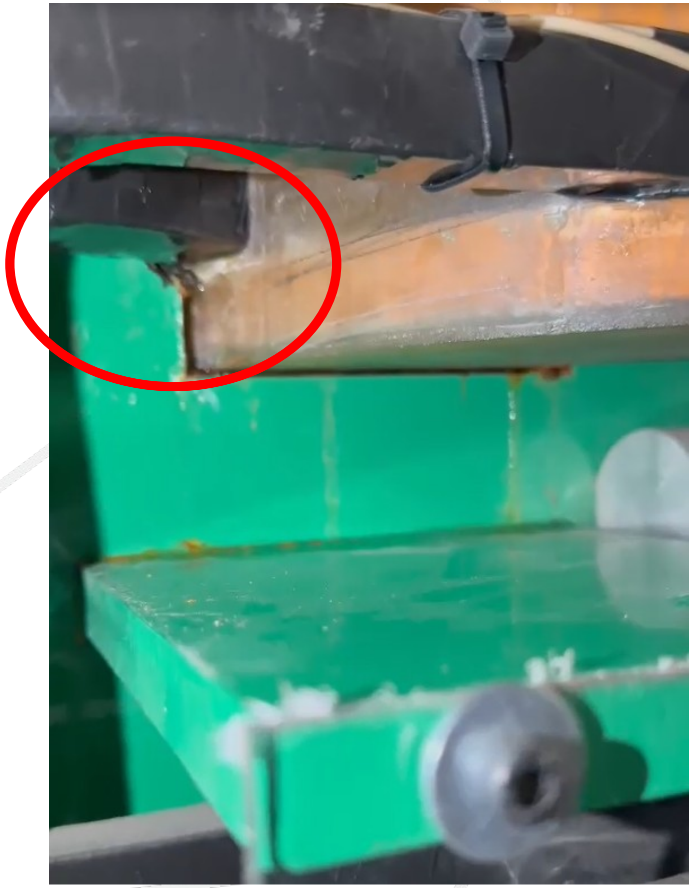


- 01/11/24 – Running on SCC 2 & 3, NCC 15 &16 (higher total voltage, reduced power on SCC). Cavity 18 tested at moderate voltages.
- 300mA dropped to 250mA near start run 5 following multiple cavity trips. Trip rate significantly improved following cavity 2 partial warm-up. Start Run 1 back to 300mA on 4 cavities
- From 11th February, cavity 16 off due to required soft start spares failure.
- From April 25 – RF conditioning Every MD and shorter preventative conditioning on most trips implemented with partial warm-up mid-way through run. Improvement seen in statistics from Run 2 2025
- From Run 3, non-RF issues dominated.

Courtesy V. Winter

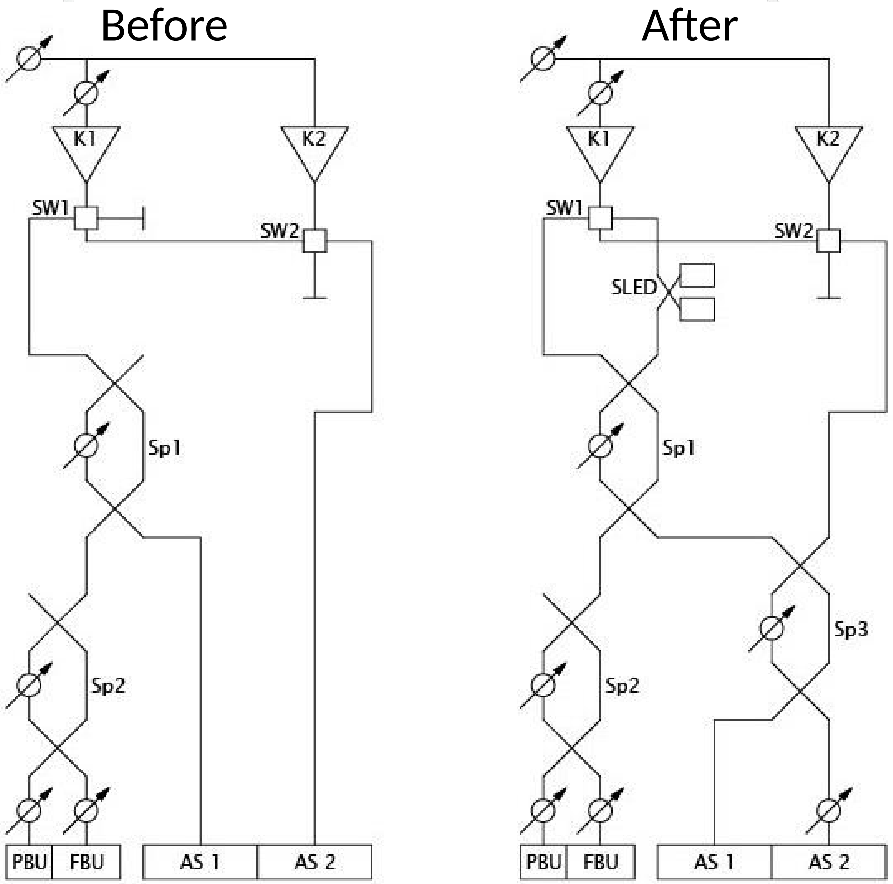
Dipole Leak

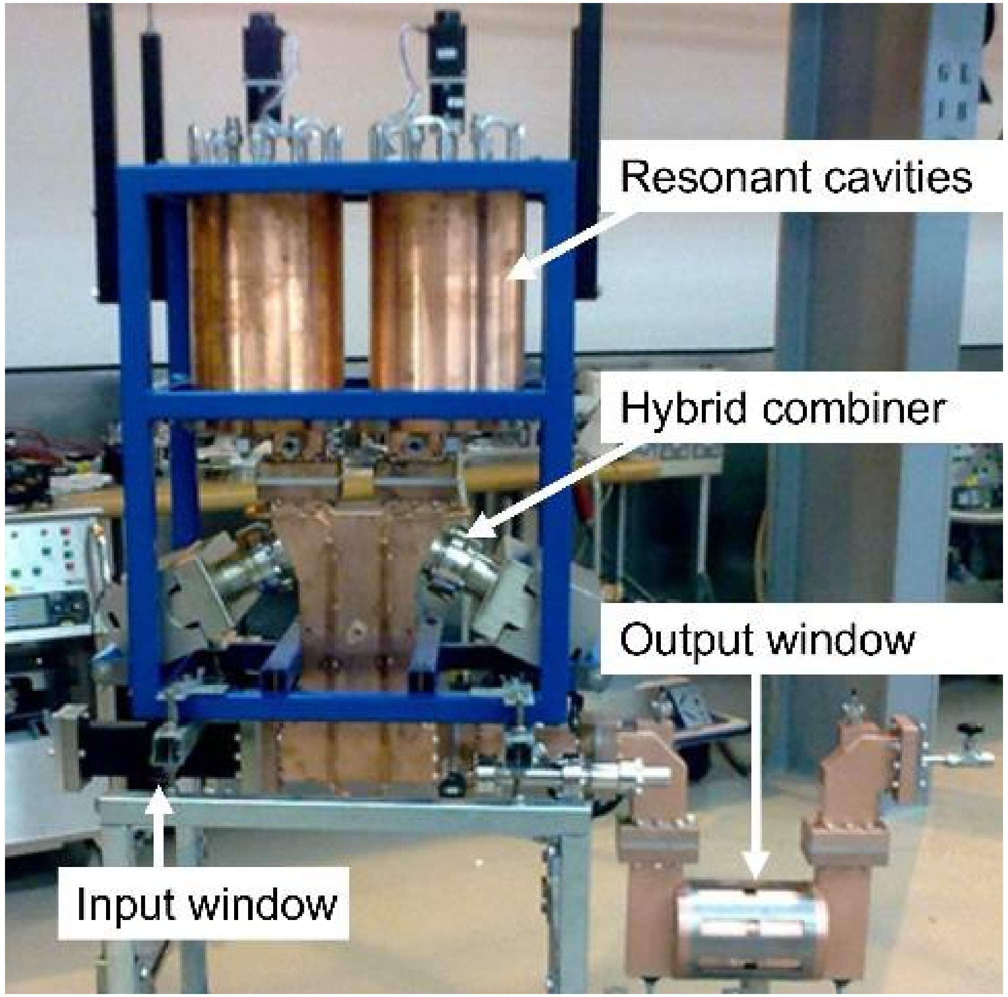
- March 2025 - Leak in coil of dipole in cell 17, dipole 2
- Easier to replace dipole with spare than to swap girder
- Difficult to remove dipole shims – partly rust, but also just wedged
- Ultimately repaired in place with rubber tape



SLED Cavity Operation

- SLED pulse compressor installed in linac
- Compress output from klystron to increase peak power
- Waveguide layout changed to accommodate SLED
- Operate both linac accelerating structures from one klystron
  - Improved resilience

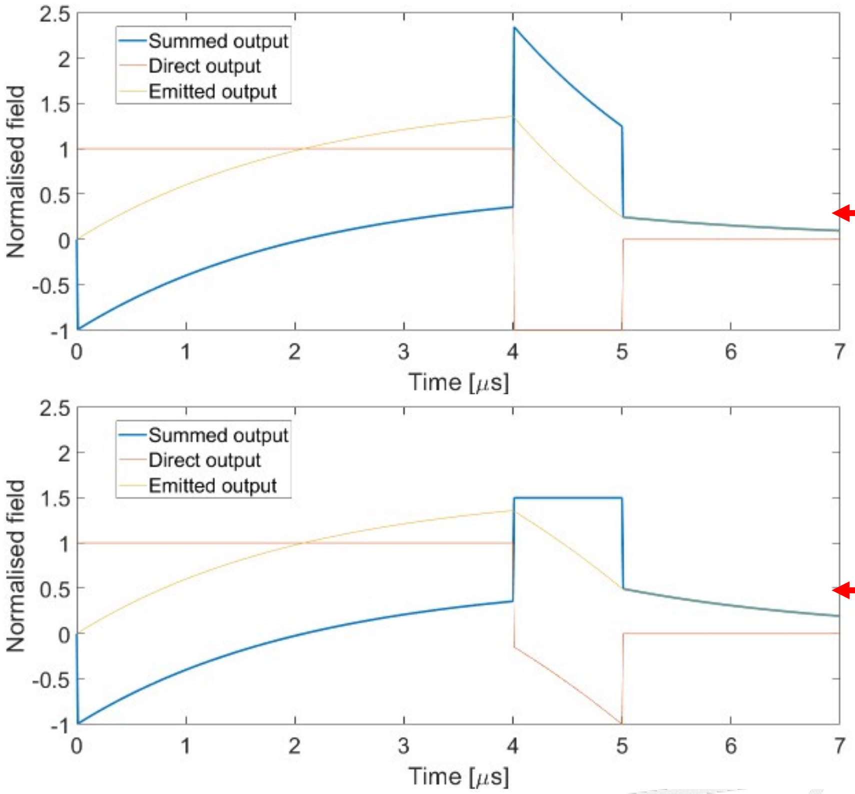




Courtesy A. Tropp

SLED Cavity Operation

- Amplitude modulation to shape flat top
- Operation since April 2025
- Multibunch possible, but requires careful shaping of pulse
- Only just long enough to fit 120 bunch train



Theoretical

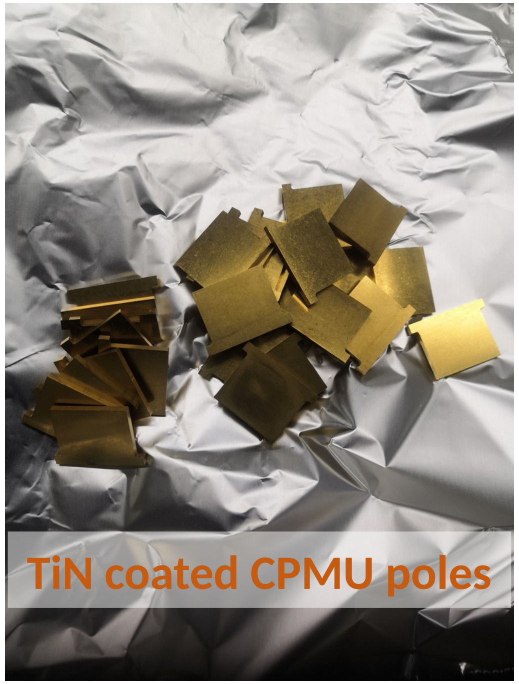
With modulation

Real

Courtesy A. Tropp

Insertion Devices Summary

- One CPMU installed Oct '24 in the DDBA straight
- Recommission of ID lab following 1 year shutdown (Jan '24 to Jan '25) for building works
- CPMU re-work ongoing. 2 devices suffered with a Cu-Ni foil buckling issue. First device is at the cold testing stage after:
  - Full strip-down & clean after smoke contamination from a fire in the building
  - Poles coated with TiN
  - Pole height set flush to magnets, full shimming performed
  - Foil pre-tensioned and reduced in width (50 mm -> 35 mm)
- Spare wiggler has arrived at site. Preparing for SAT


TiN coated CPMU poles


CPMU-5 Oct '24

Courtesy Z. Patel

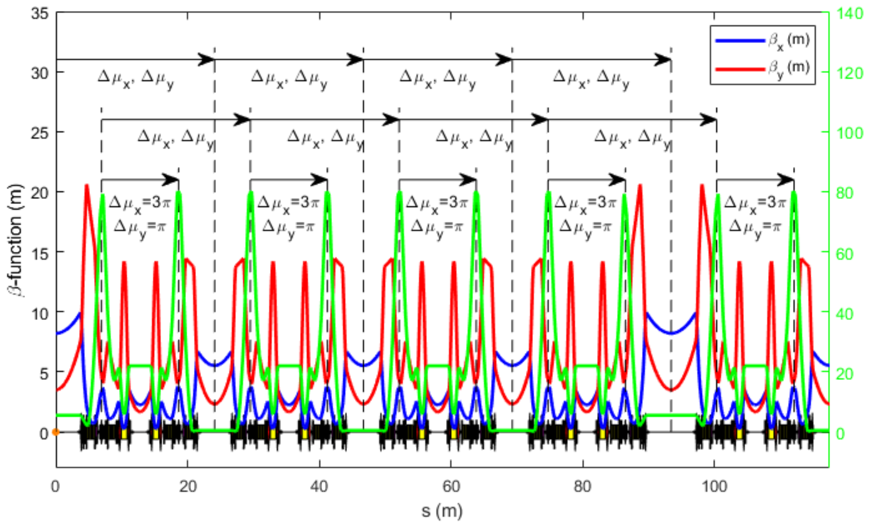
Solar Installation

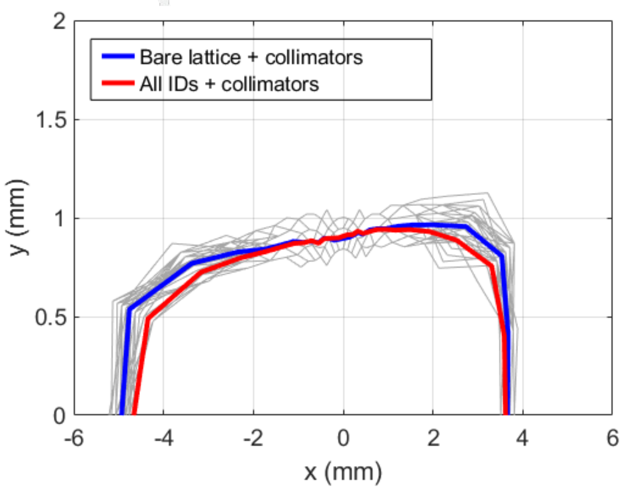
- Final stage of synchrotron building solar installation energised summer 2024
- 2.7 MWp capacity - predicted output 2.3 GWh/yr
- Actual output in the last year = 2.32 GWh

Diamond-II Updates

Diamond-II

- Modified Hybrid 6-Bend Achromat (M-H6BA) for low emittance
- Number of insertion straights increased from 24 to 48
- Off-axis injection for beam accumulation, top-up using kick-and-cancel (aperture sharing) double kick with striplines
- Passive SC harmonic cavity for lifetime / beam stability / IBS
- Development ongoing on options for low beta lattice

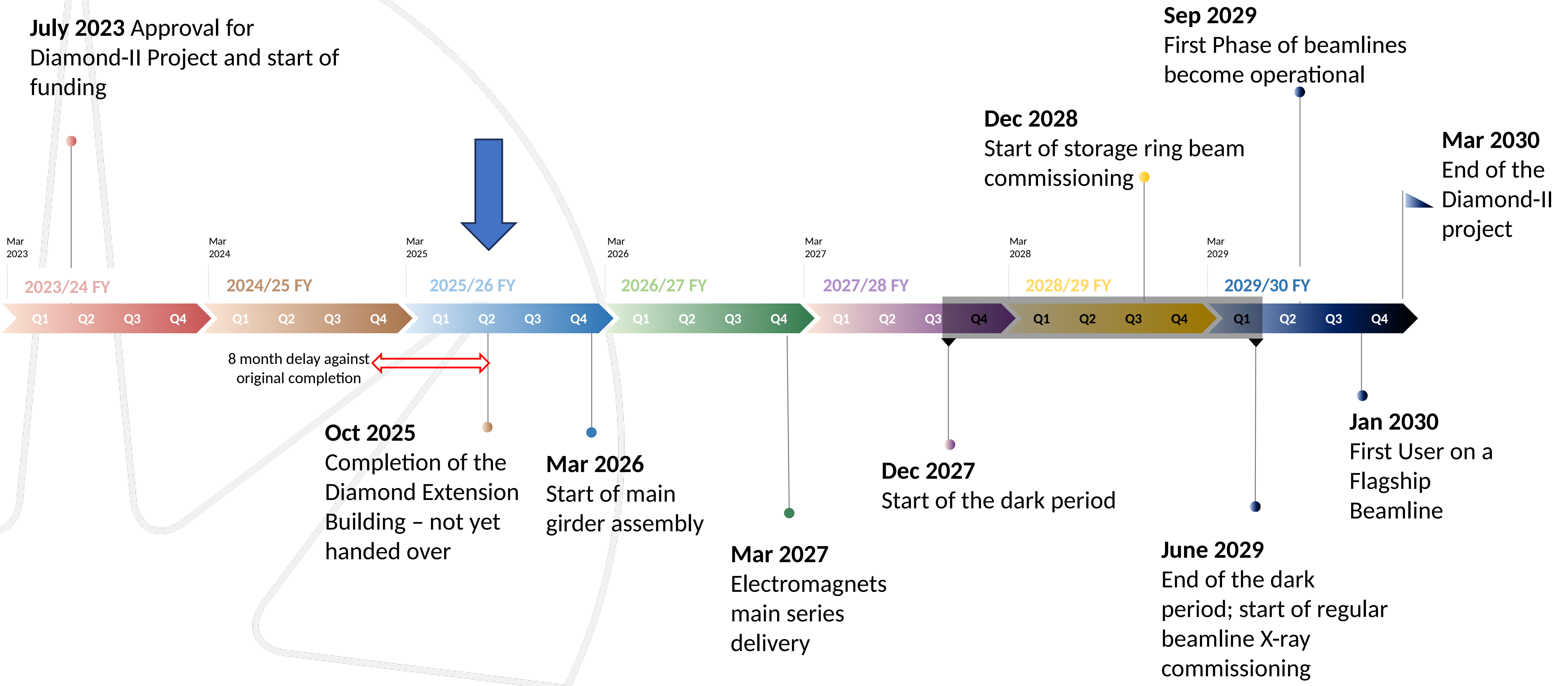




Parameter	Units	Diamond	Diamond-II
Energy	**GeV**	**3.0**	**3.5**
Circumference	M	560.6	560.560944
Harmonic Number	-	936	934
RF Frequency	MHz	499.654	499.511
Positive Bending Angle	deg	360.0	374.4
Reverse Bending Angle	deg	0.0	14.4
Total Bending Angle	deg	360.0	388.8
Betatron Tunes	-	[27.21, 12.36]	[54.14, 20.24]
Natural Chromaticity	-	[-79.0, -35.6]	[-68.2, -89.1]
Corrected Chromaticity	-	[1.7, 2.2]	[2.6, 2.6]
Mom. Compaction Factor	$\times10^{-4}$	1.70	1.03
Natural Emittance	**pm.rad**	**2729**	**162**
Energy Spread	%	0.096	0.094
Energy Loss per Turn	MeV	1.01	0.724
Natural Bunch Length	ps	11.4@2.4 MV	12.4@1.4 MV
Horizontal Damping Partition	-	1.00	1.88
Horizontal Damping Time	ms	11.1	9.4
Vertical Damping Time	ms	11.2	18.1
Longitudinal Damping Time	ms	5.6	16.1

Courtesy I Martin

Diamond II Project Status

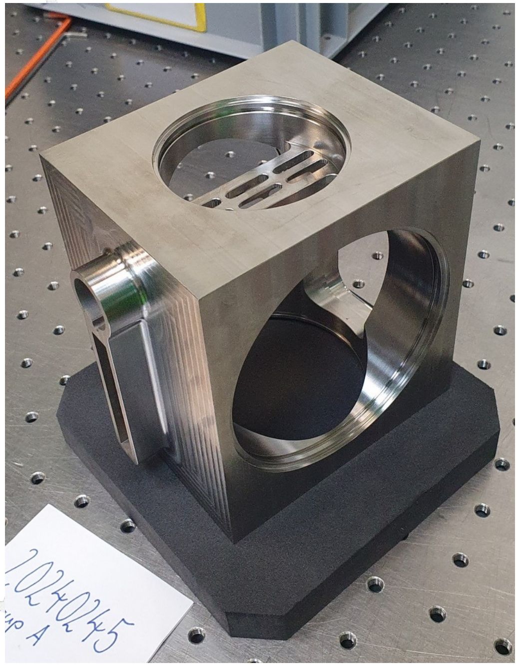


Diamond II Vacuum

- Orders placed for main arc vessels
- Still to order special vessels, straights, ceramic vessels, injection components

Planning dates
Start of pre-series vacuum string assembly Feb 2026
Start of girder vacuum string assembly Apr 2026
Start of dark period Dec 2027

- Issues with blistering on some copper vessels – Cu-OFS oxygen content measured 0.21-0.37%, should be <0.005% !
- Vessels to be remade with Cu-OFE



- Pumping block pre-series used 316L due to material availability
- Could not meet permeability spec
- Main series to use 316LN as specified

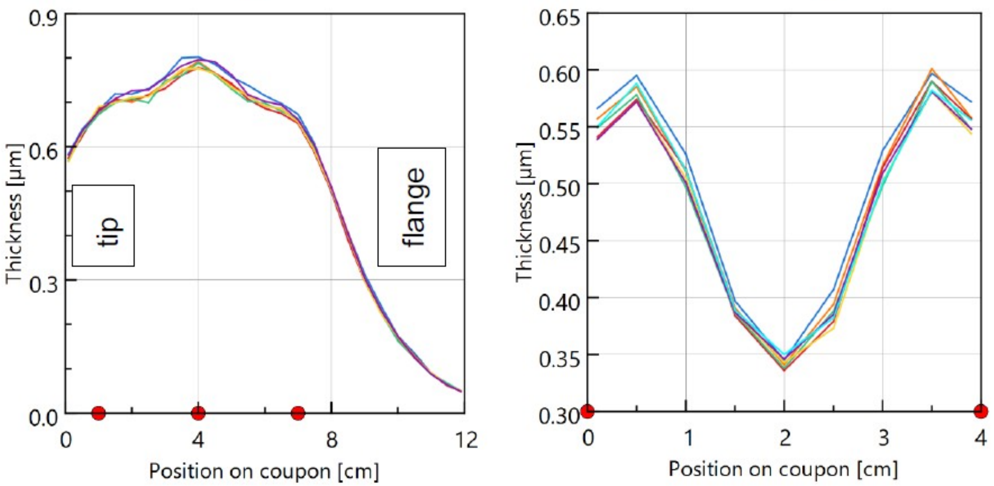
Courtesy M Cox

diamond

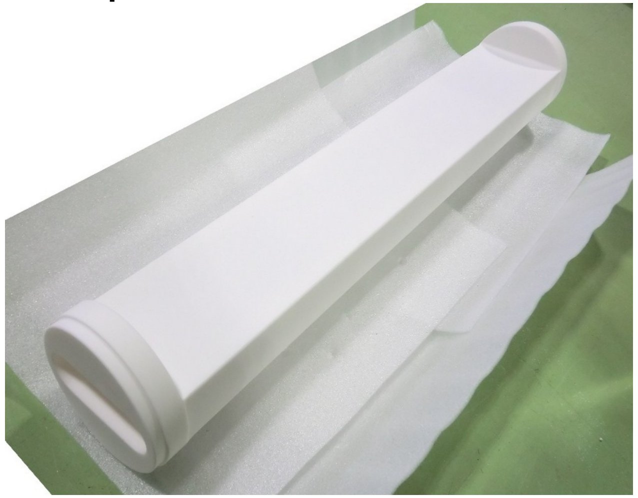
Diamond-II Vacuum

- Successful test NEG coating absorber

coating thickness as determined by XRF-spectroscopy



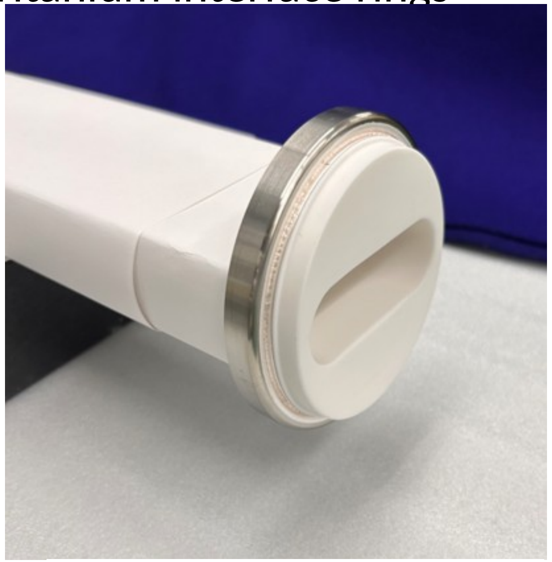
- Prototype ceramic kicker vessel
- Ti coating to be done by Polyteknik – coating 4 existing spare vessels as test



Monolithic Al_2O_3 ceramic body

Titanium interface rings

Titanium end flanges



Courtesy

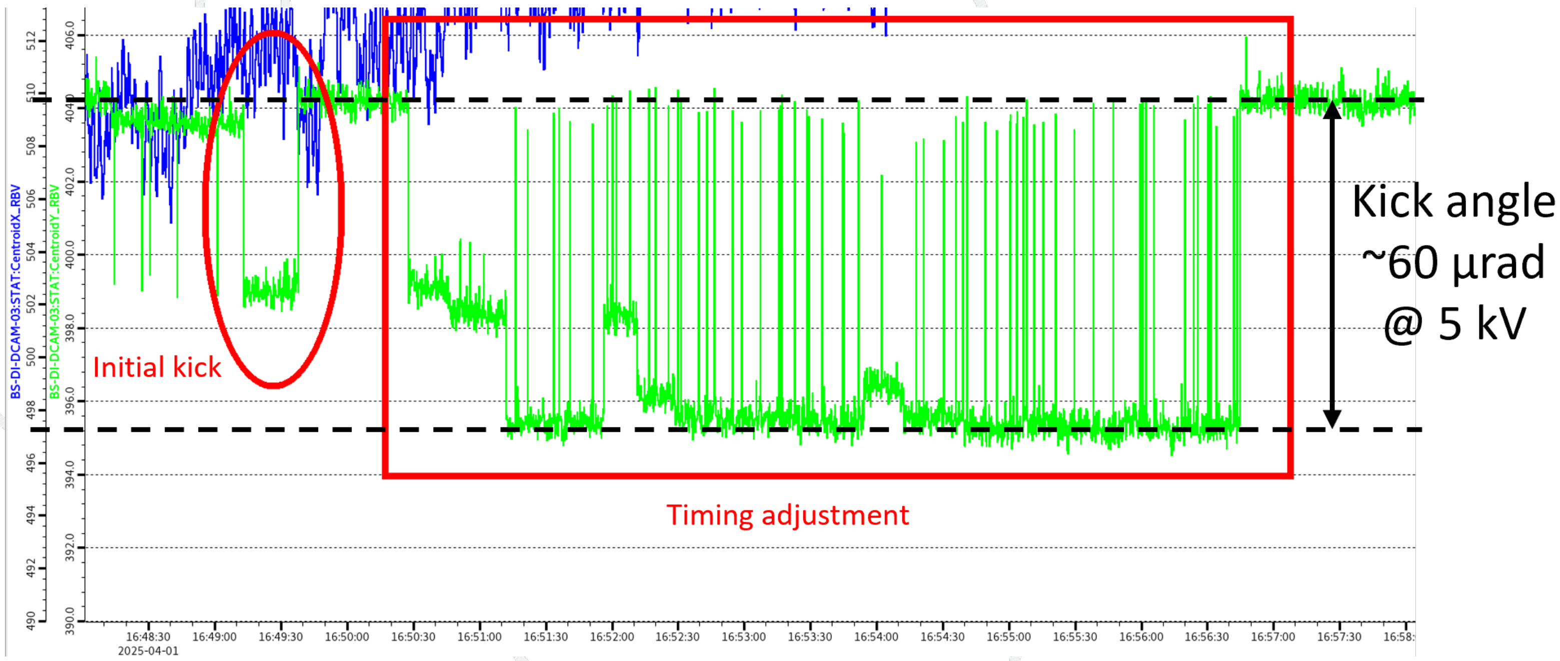
Ceramic body brazed to interface rings

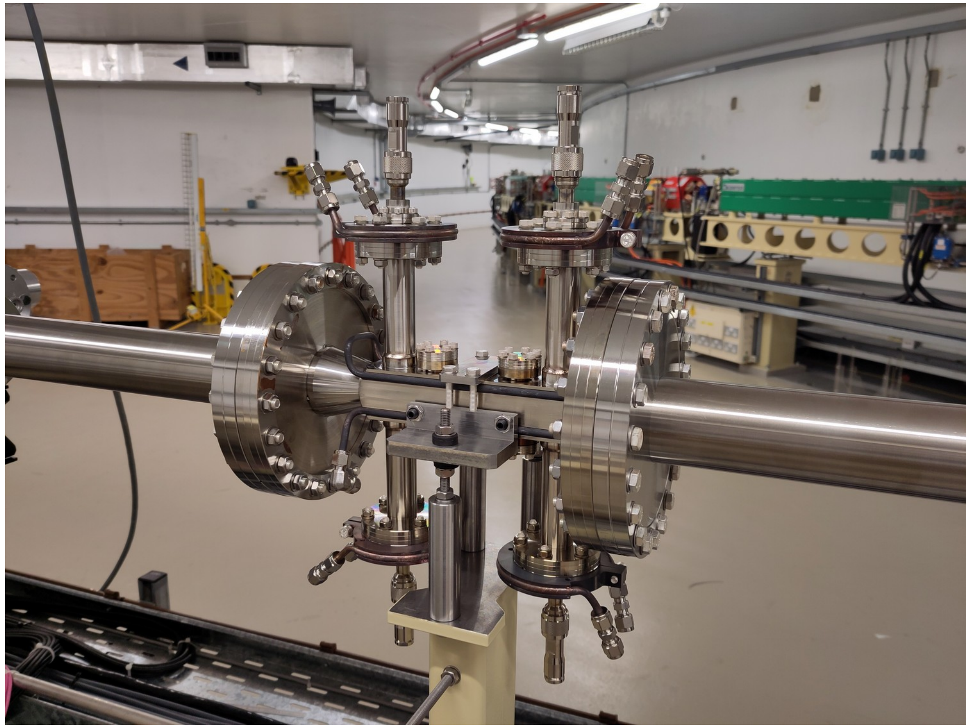
Diamond-II Magnets

- DL assembly in progress – tuning to be done later once DEB is available
- DQ – some delay due to difficulty meeting tolerance
  - FAT and site witness visit due end October
- Quadrupoles – 1 of 4 pre-series failed dimensional testing, new yoke to be machined
  - Plan to accept partial batches so assembly can begin as ready
- Sextupoles – pre series FAT OK, but toward limit of acceptable range
  - Further tests negotiated on examples of each type, any changes only to final machining
- Octupoles – FAT on schedule
  - Oct/corrector pre-series FAT Jan 2026
  - Fast corrector pre-series FAT Feb 2026
- Booster magnets all under construction
  - Dipole testing at ALBA in November 2025

Diamond-II Injection: Striplines

- Prototype stripline installed in booster-to-storage ring (BTS) transfer line in March 2025
- Tested with low power 5 kV pulser
- Amplitude of kick as expected once correct timing found

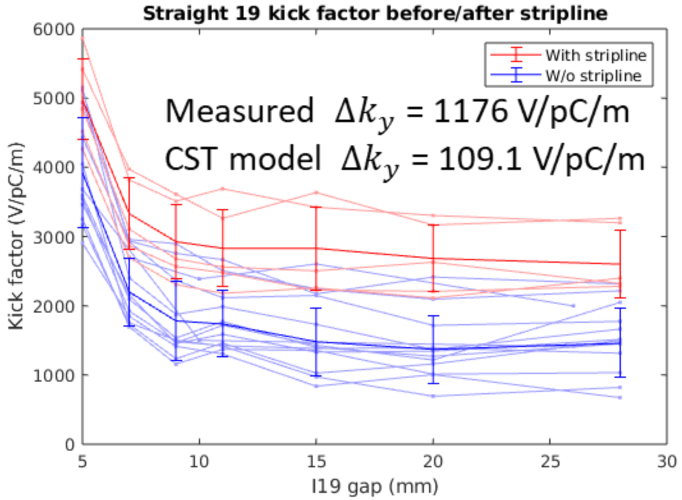


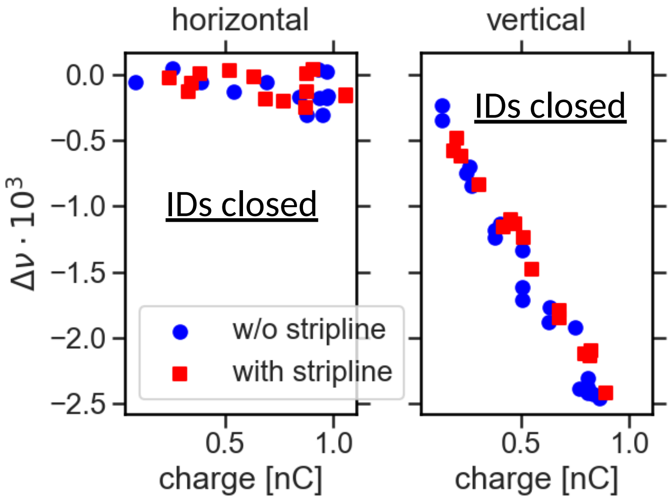


diamond

Diamond-II Injection: Striplines

- Removed from BTS and installed in storage ring in June 2025
- Initial test without pulser to test apertures, beam heating, impedance, etc.
- Can't measure blade temperatures directly, but no problems observed from external monitoring – as long as ports are connected to correctly matched loads!



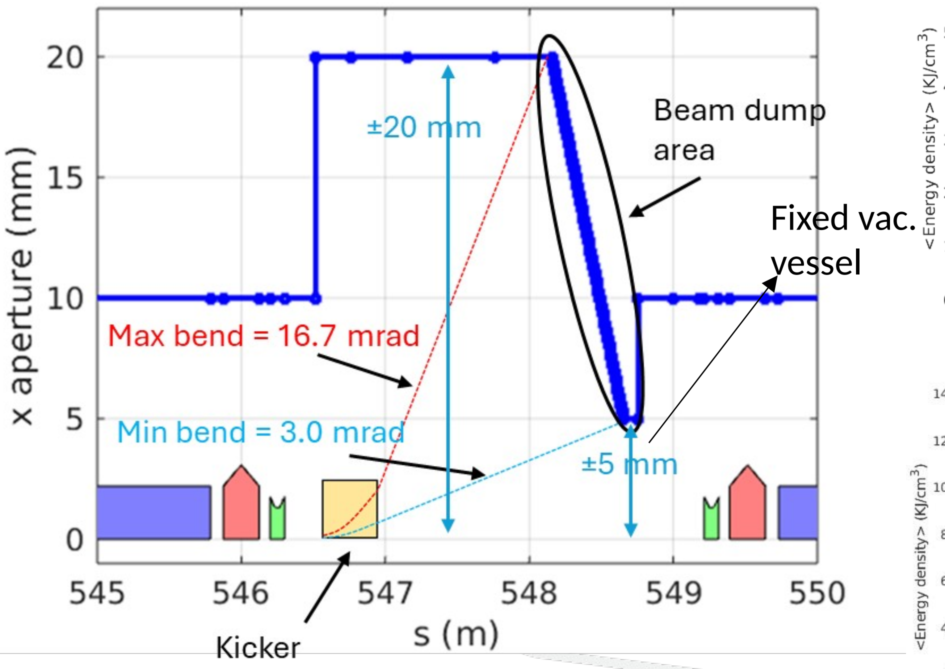


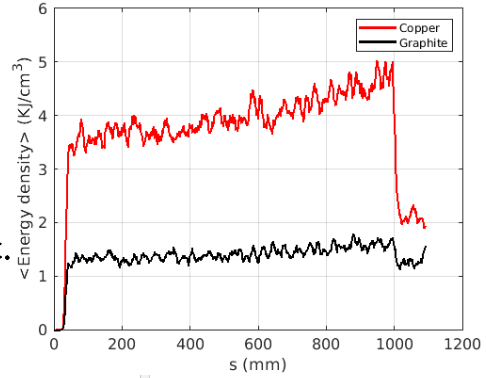
- Kick factor measured larger than expected, but very noisy and inconsistent between measurements
- No measurable impact on tune shift, bunch lengthening or microwave instability threshold

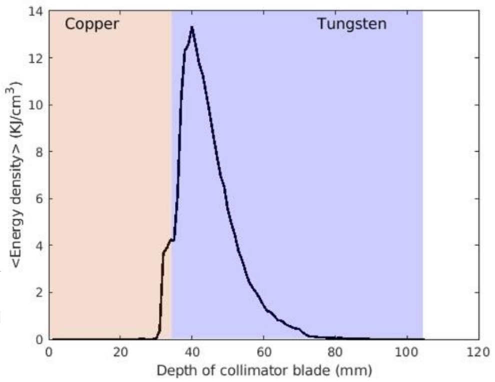
- Removed to replace feedthroughs with 7/16 type for high power
- Full assembly tested with 20 kV pulser last week – to be re-installed in ring this week

Diamond-II Beam Abort System

- Dedicated beam dump system required to prevent damage to machine on beam loss
- Preferred solution with kicker in K23 straight, tapered beam dumps in K23 and K24
- Based on SLS-II method
- Space for two kickers for redundancy, maybe vertical decoherence kicker







Copper beam dump: peak energy density = 5.0 kJ/cm^3 (likely to melt)

Graphite beam dump: peak energy density = 1.7 kJ/cm^3

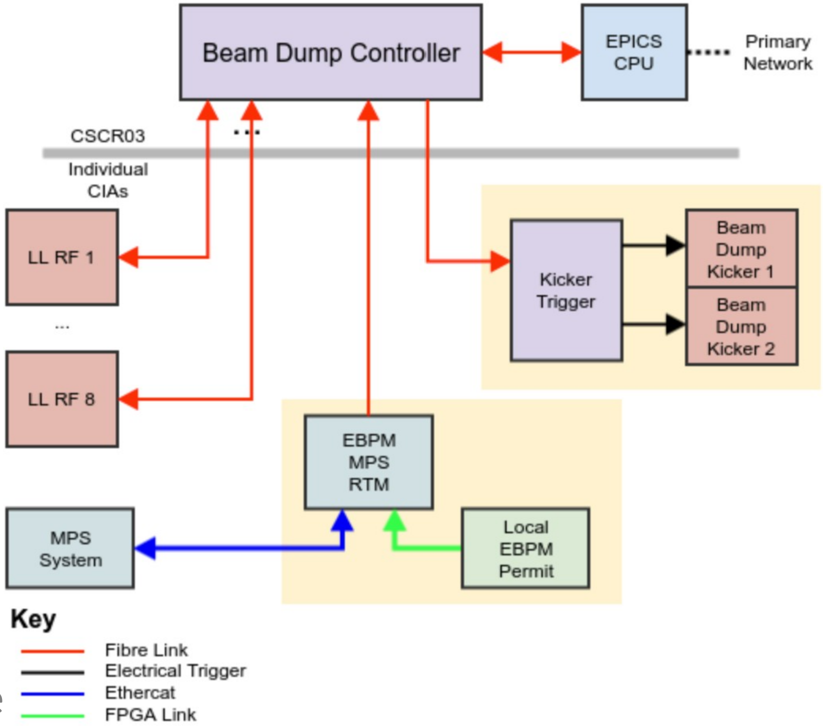
Copper section of the collimator is also likely to melt:

- Copper section = 4.3 KJ/cm^3
- Tungsten section = 13.1 KJ/cm^3 (below melting point)

Using linear pulse shape for kicker and spreading beam vertically should bring energy density within safe limits on beam dump and collimators (still WIP)

Diamond-II Beam Abort System

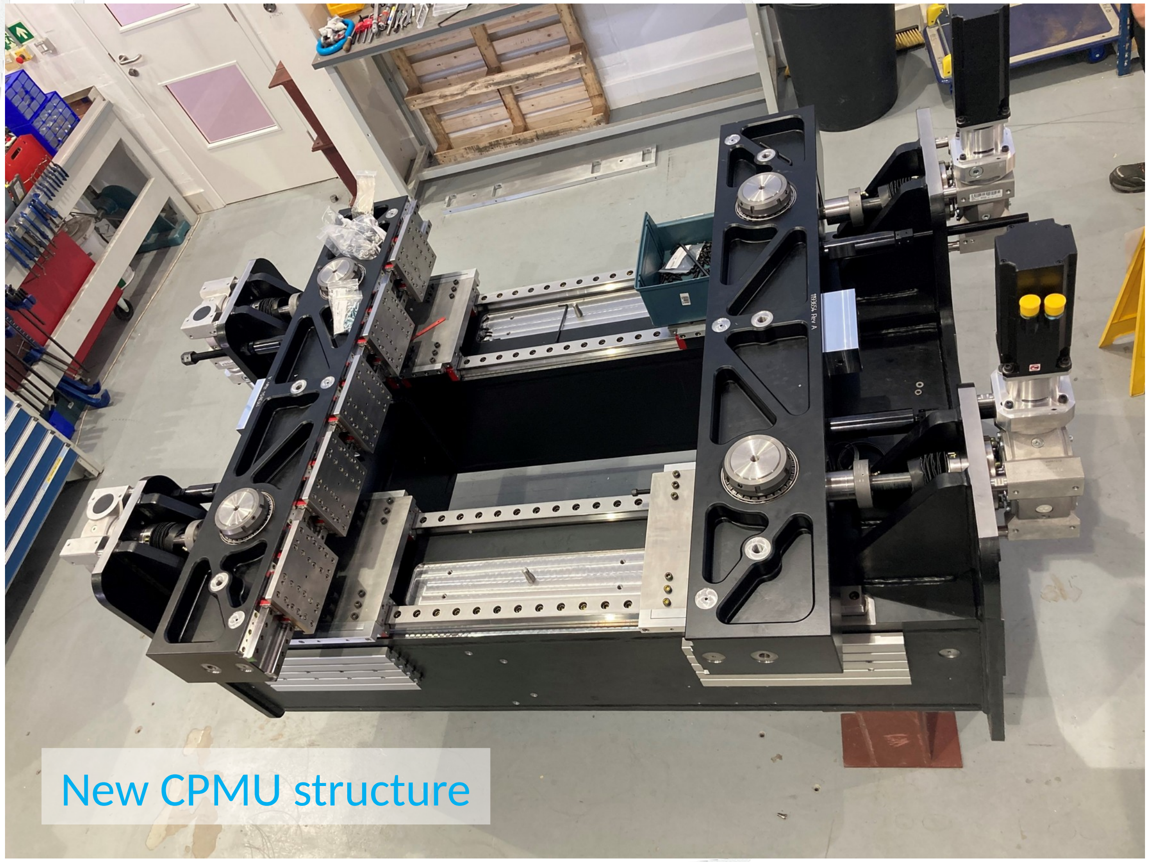
- Time budget is set by need to kill the beam before it starts to hit the collimator
  - RF trip: <90 turns (~170 µs)
  - Outside orbit interlock: <~115 µs (TBC – step change of slow corrector)
- Three response times for the BDC:
  - Fast: (<15 µs) direct fibre links to 8 LLRF systems
  - Medium: (<115 µs) orbit interlock from EBPMs in local CIA
  - Slow: (<400 µs) PSS triggers RF+PSU power down, triggering MPS



Source	Delay
RF decision	0.5 µs
Fibre Delay	1.8 µs
BDC FPGA	0.4 µs
Fibre Delay	1.8 µs
PSU Realisation	5-10 µs
Kicker Pulse	2 µs
Total	**11.5-16.5 µs**

Diamond-II IDs

- New IDs for Diamond-II are a mix of in-house development and procurement from industry:
  - 1 CPMU, 2 HPMUs, 5 APPLE-IIs, 1 APPLE-KNOT, 1 EMPHU, 1 vertically-canted 3PW, 1 MPW
- Large engineering effort made to simplify and stiffen the ID structures going forward



New CPMU structure

CPMU: 17.6 mm period, 1.5 long
- Currently being built in-house
- Magnets delivered by HPMG
- Controls commissioning and magnet mounting due to start imminently

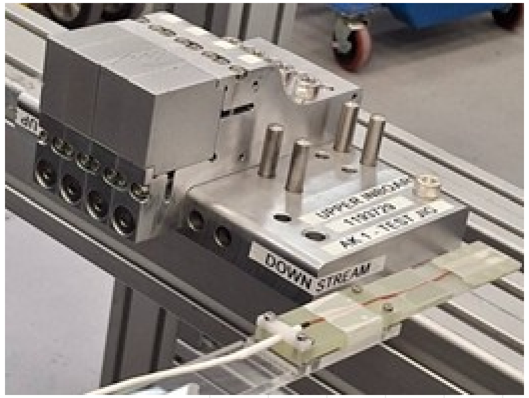
2 x HPMUs: 18.7 mm period, 1.5 m long
- Contract awarded to Kyma
- FDR to complete in next few weeks

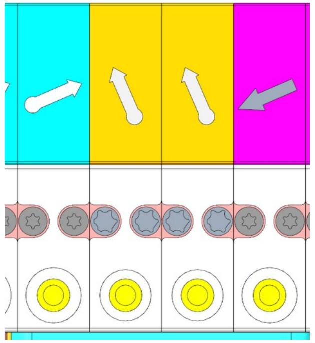
EMPHU: 56 mm period, 1.75 m long
- Based on Soleil's design
- Magnetic design validated, engineering design ongoing
- Stainless steel vessel to be used to avoid eddy currents

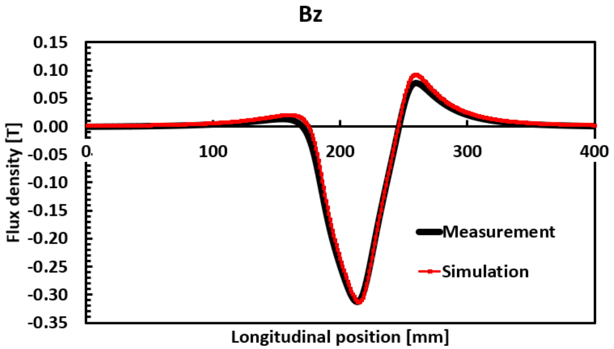
Courtesy Z. Patel

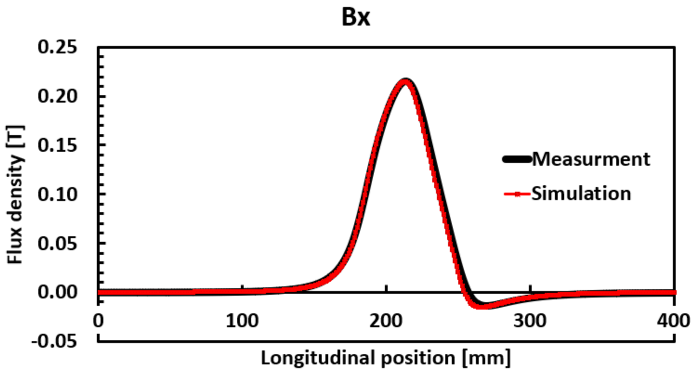
Diamond-II IDs

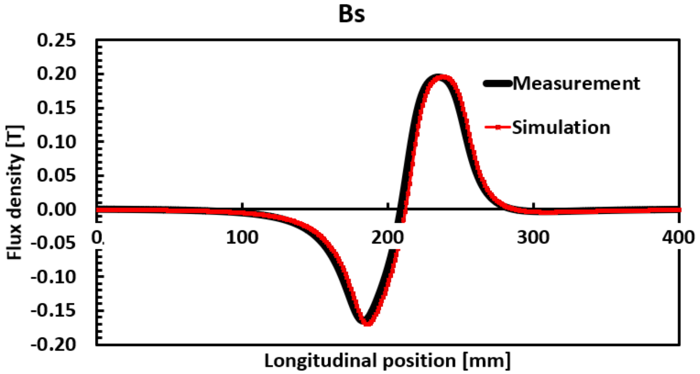
APPLE Knot: 140 mm period, 5 m long
- Magnets delivered from HPMG
  - QA ongoing
- Final prototype parts due end Oct.
- Small section of sample magnets measured on Hall probe bench match prediction from magnet model in Radia











1 x APPLE-II: 52 mm period, 5 m long
- Magnetic design ongoing

1 x APPLE-II: 64 mm period, 1.8 m long

1 x MPW: 116 mm period, 0.7 m long
- Procurement specifications started

2 x APPLE-IIs: 56 mm period, 2 m long

1 x APPLE-II: 56 mm period, 4 m long

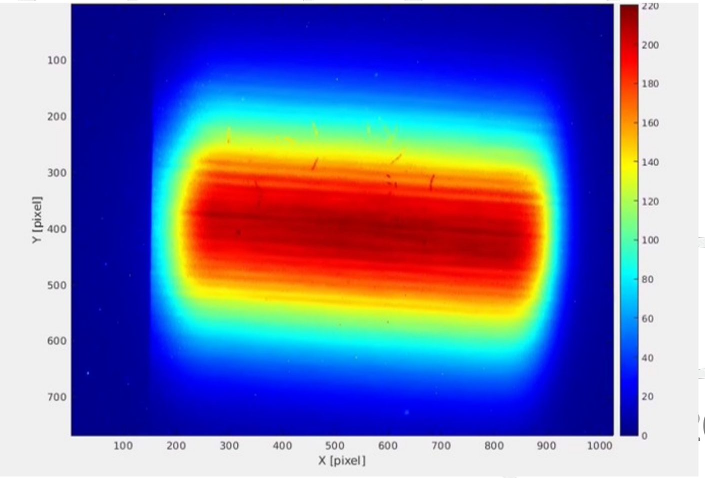
3PW: 1.4 T main radiator
- Procurement specifications almost complete

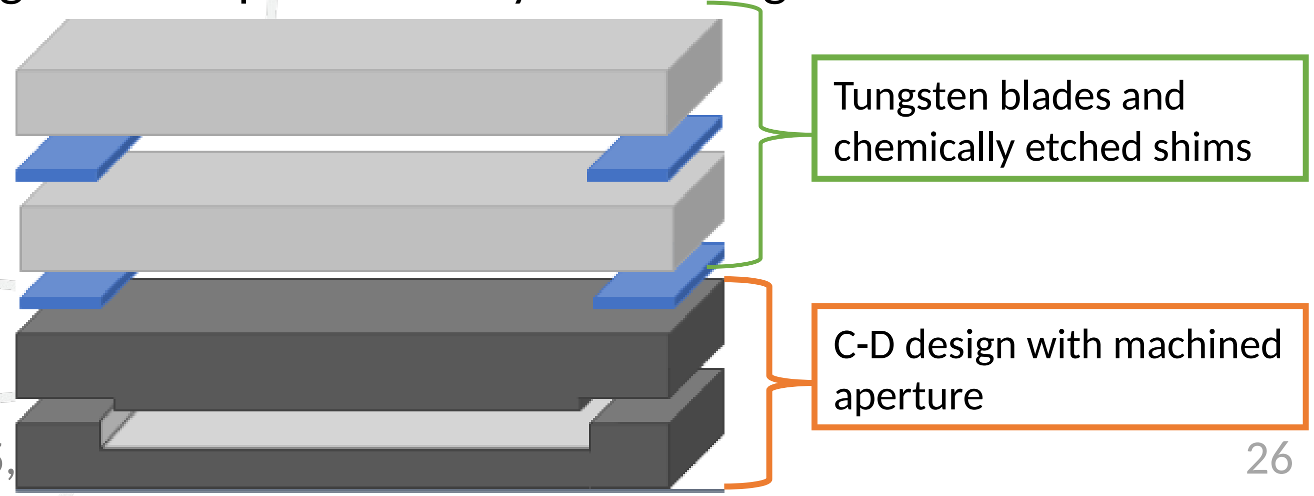
Courtesy Z. Patel

Diamond-II Diagnostics

- Received 1000/2000 BPM buttons
- Successful FAT and SAT tests (visual, dimensional, leak, capacitance)
- One failed button during handling/welding – joint intact but ceramic broke

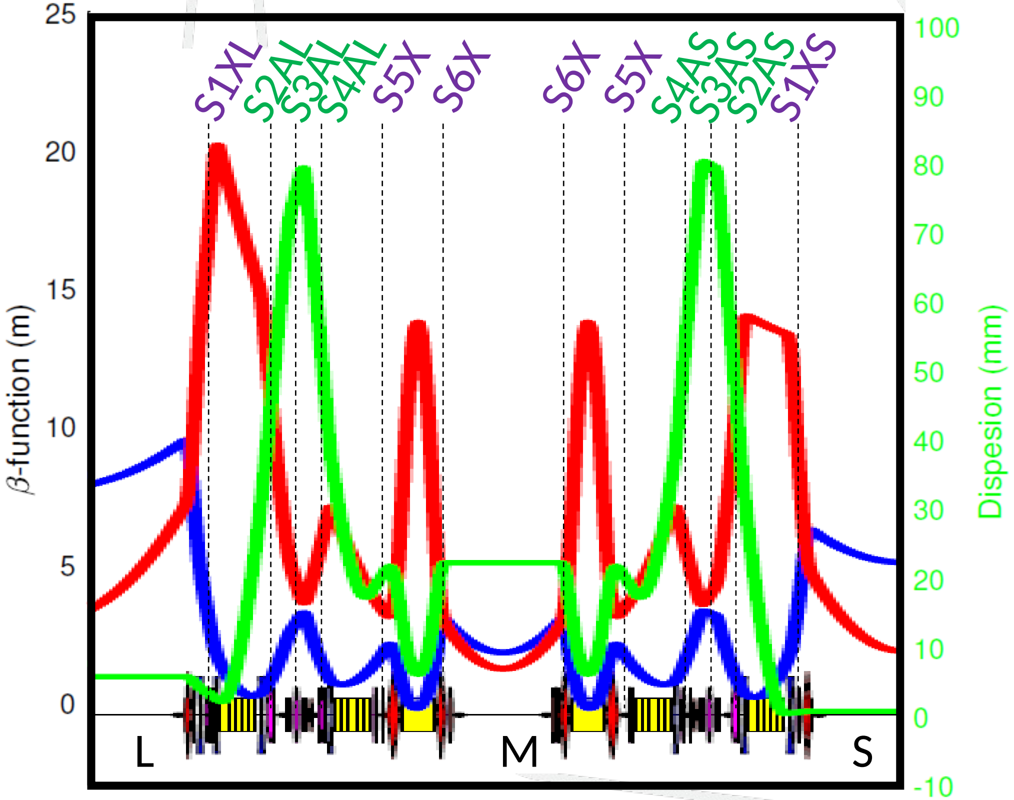
- X-ray beam extraction location to avoid fringe fields have been identified for all the pinhole cameras.
- Extraction window made of aluminium creates filamentation patterns, seen at Diamond, ESRF, HEPS and Soleil. Different solutions on overcoming this problem for Diamond-II are being investigated.
- New supplier for manufacturing a C-D shaped assembly out of tungsten

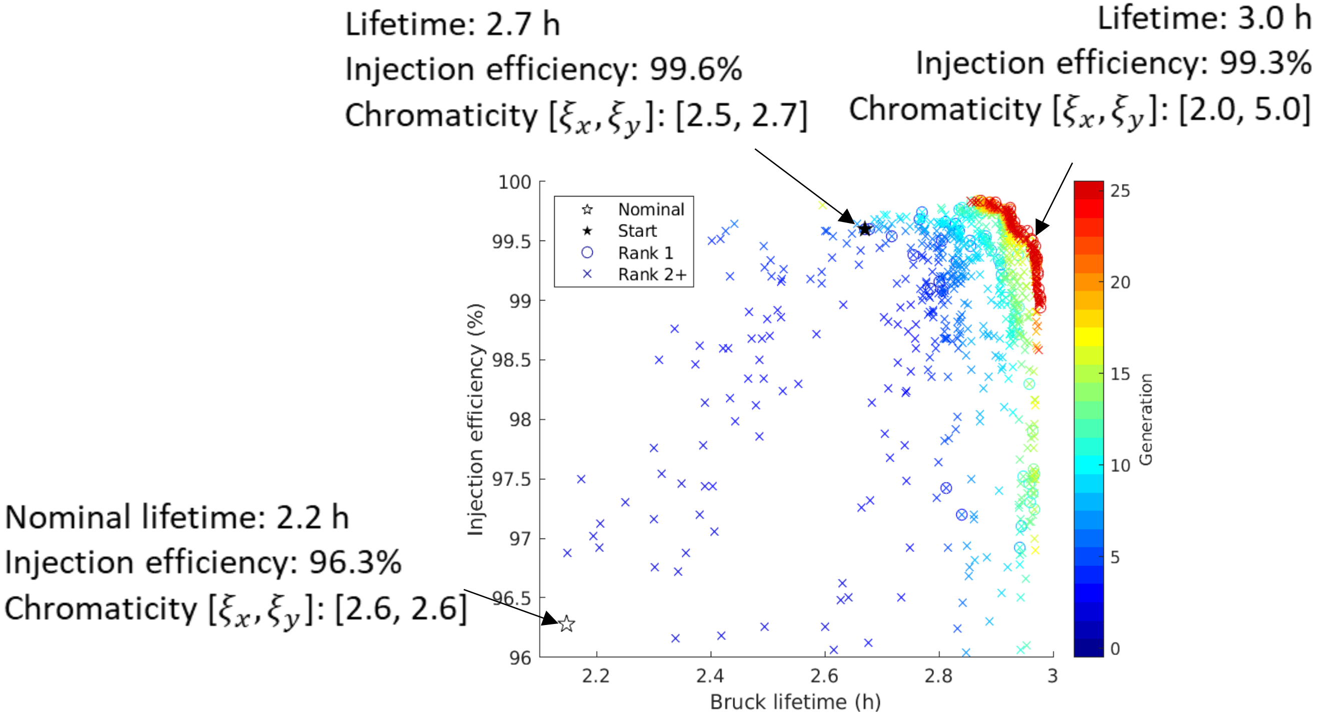




Diamond-II Lattice Update

- Ongoing optimisation of lattice (MOGA, AT)
- Introduce additional sextupole families where optics differ near long / standard straights





- Significant improvement in lifetime, although less with IDs closed
- Further improvement with higher RF voltage due to increased momentum aperture
- Lifetimes shown without 3HC – should have gain >*3 depending on fill pattern

Conclusions

Diamond

- Focus on supporting operations – improve resilience
- Rolling updates to IDs, RF and controls systems as part of Diamond-II preparations
- Testbed for Diamond-II – stripline prototype, accelerator commissioning, virtual accelerator…

Diamond-II

- Many major contracts placed, others following at pace
- Prototyping and pre-series testing underway on vacuum and magnet systems
- Beam abort system a concern, but design is progressing
- Hardware frozen, but optics optimisation still ongoing
- Some delays, absorbed by contingency in planning – still on target for Dec 2027 start to dark period

Acknowledgements

AP

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Diagnostics and Controls

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RF

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IDs

S Milward, A Ramezani Moghaddam, Z Patel, S Tripathi

Magnets

C Bailey, A Shahveh, S Ahamad

Others

A. Amiri, M Cox, P Vivian, R Walker, V Winter, V Zhiltsov

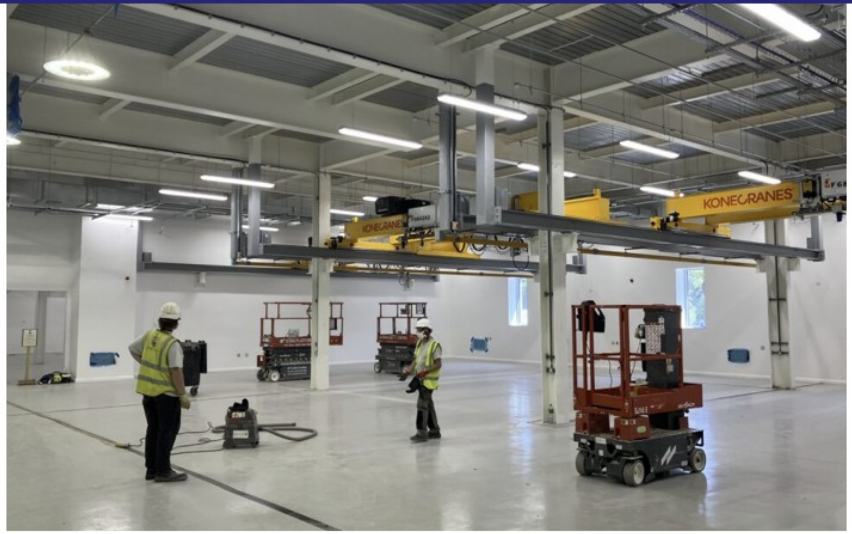
Extra Slides

Diamond II Project Status

- Contingency in plan –still on schedule for Dec 2027 start to dark period
  - 3 month contingency still kept before start of commissioning in case of further delays
- Regular internal and external reviews:
  - MAC – machine
  - SAC – science and beamlines
  - SSAC – software and controls
- Project Assurance Reviews in Sept. 2025, 2027, 2029
  - Rated Amber-Green – no critical issues, some risks which are understood
- Bi-annual internal readiness reviews in run-up to dark period, first in Dec 2025
- £79.1m contingency funds to cover risks
  - £10m released so far
    - 5th RF cavity, 8th RF amplifier
    - 1MW data centre
    - Additional data storage, UPS
    - Apple knot ID

Diamond II Project Status

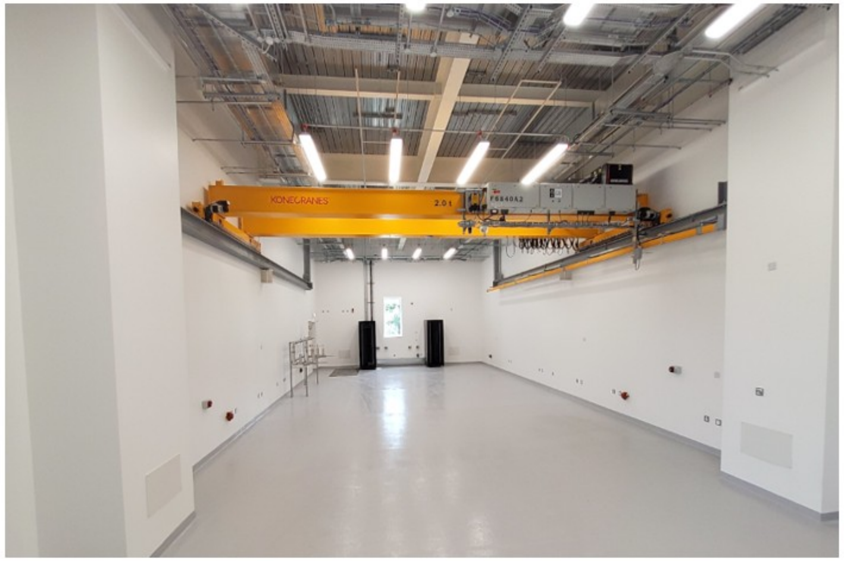
DEB



Girder Assembly

Vacuum Bake-out

Magnet Assembly



Beamline Assembly

Diamond-II Injection

Two injection schemes

1) Standard four kicker bump (SB or MB)

Robust, proven technology

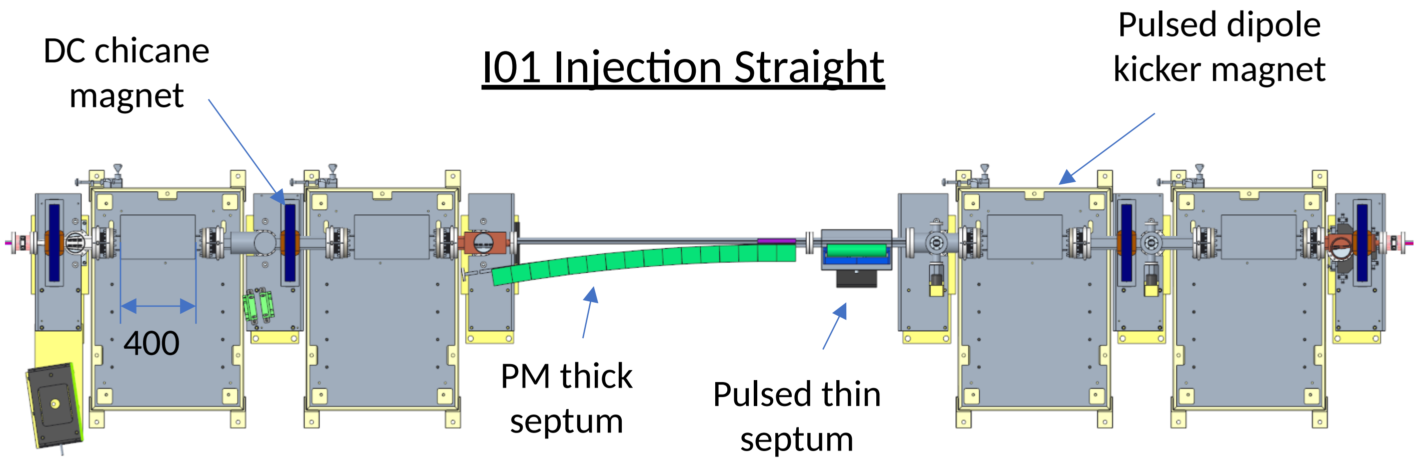
- Stage 1: single shot, on-axis injection
- Stage 2: off-axis accumulation with non-closed bump (improved capture efficiency)
- Stage 3: off-axis accumulation with closed orbit bump (improved transparency)

2) Fast stripline kickers (SB only)

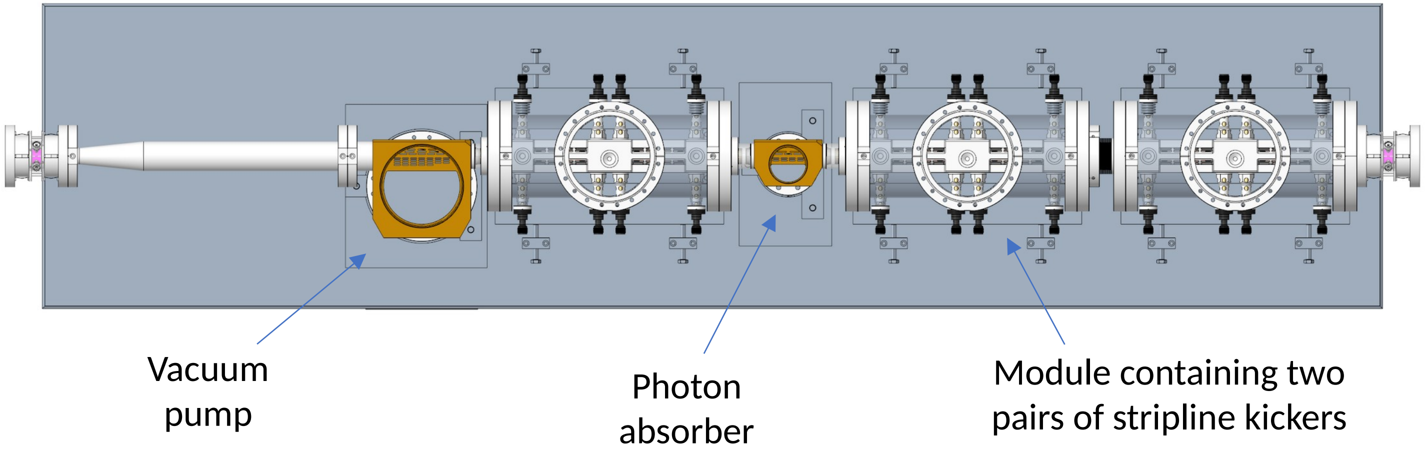
Pseudo-transparent injection

- Stage 4: top-up injection only

I01 Injection Straight



K01 Injection Straight



Courtesy V Zhiltsov

diamond

Beam Dump Options

Two options being considered for the beam dump:

Graphite beam dump (preferred)

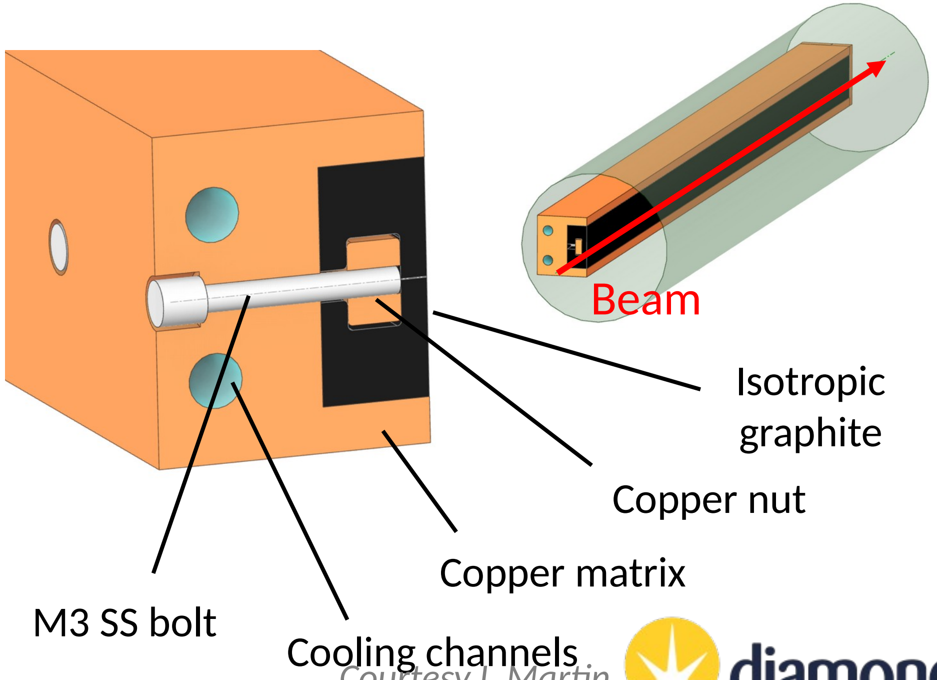
- High thermal shock resistance, high melting point
- Brittle material: likely to crack rather than melt
- Lower stopping power / extra shielding required
- Designed to be failure-free (would need replacing if damage occurs)

Copper beam dump

- Ductile material, tolerant to cracks
- Simpler design, replacement and manufacturability
- Higher stopping power / integrated shielding
- Lower melting point
- Designed to be tolerant to damage (functionality may degrade over time)

Graphite Beam Dump Concept

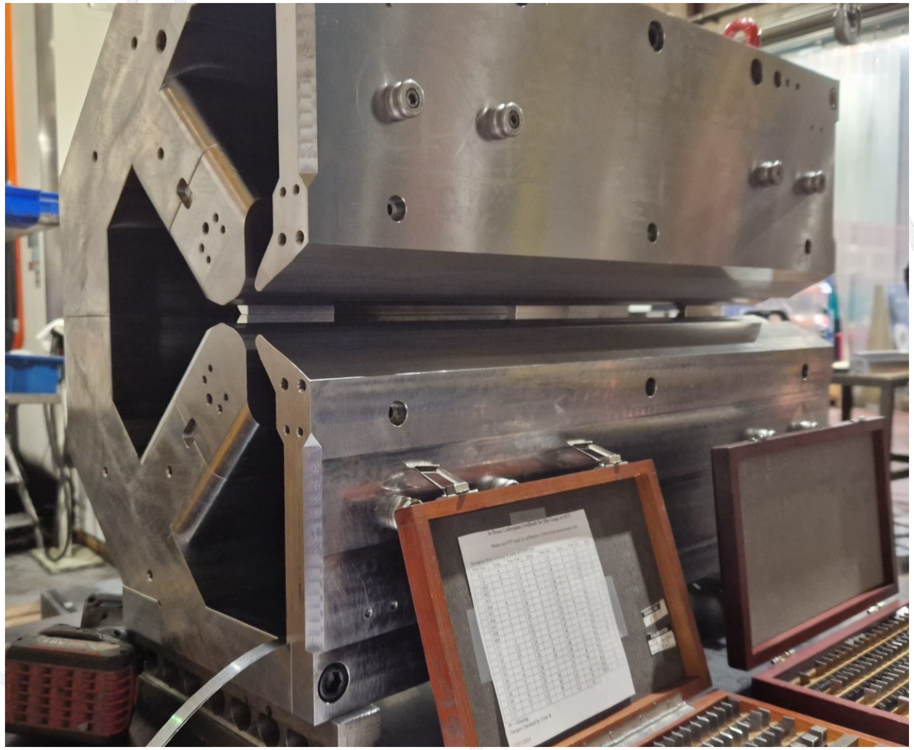
- Isotropic graphite to minimize thermal shock and improve manufacturability
- Copper holder to provide shielding
- Bolted joint to minimize thermal stress from synchrotron radiation
- Beam dump separated from vacuum vessel



Courtesy I. Martin

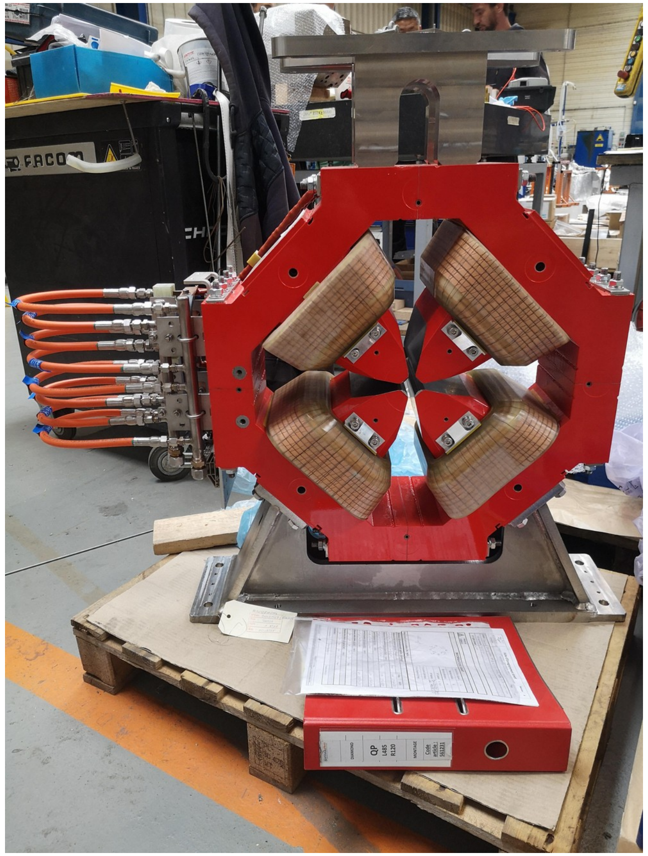
Diamond-II Magnets

DQ



DL

Quadrupole

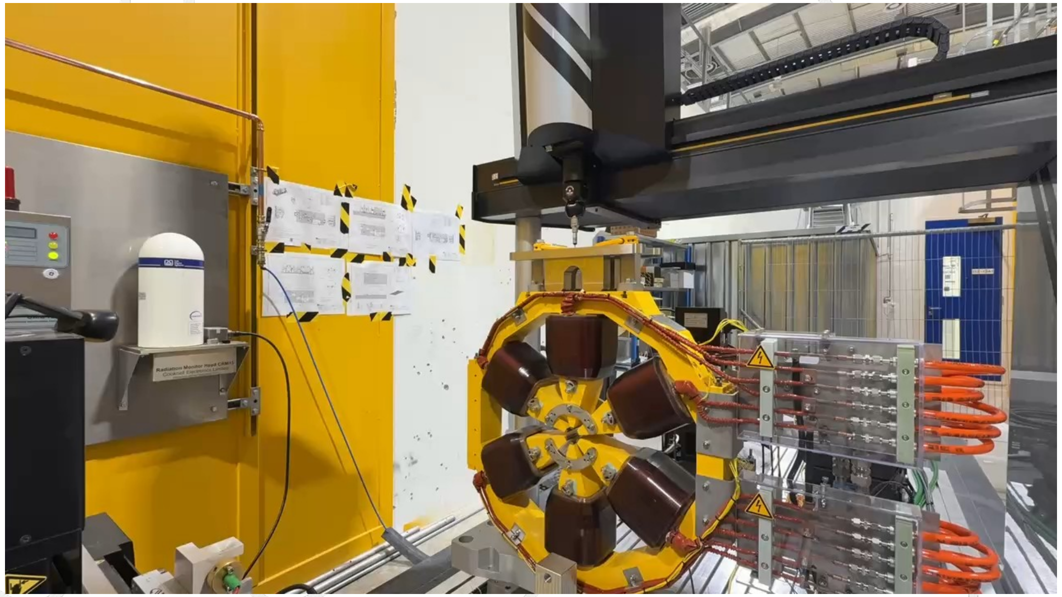


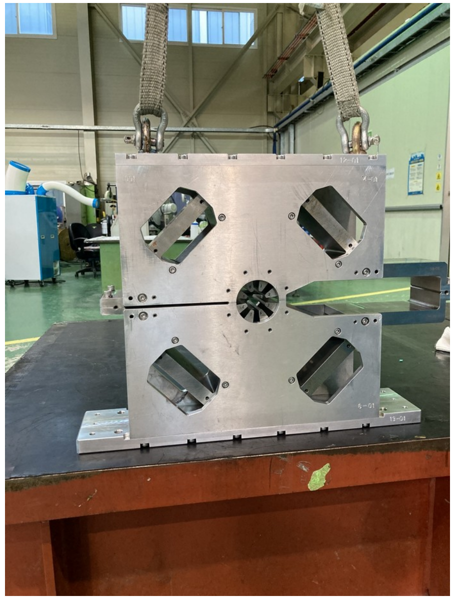
Courtesy C Bailey

Diamond-II Magnets

Sextupole

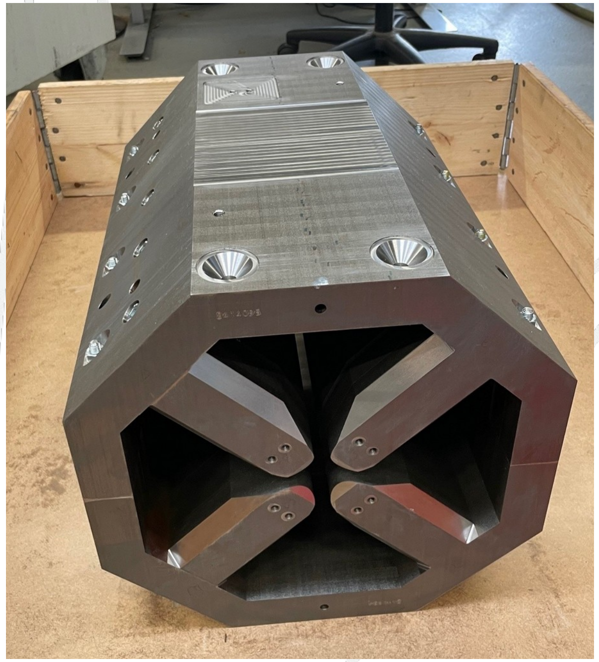
Octupole

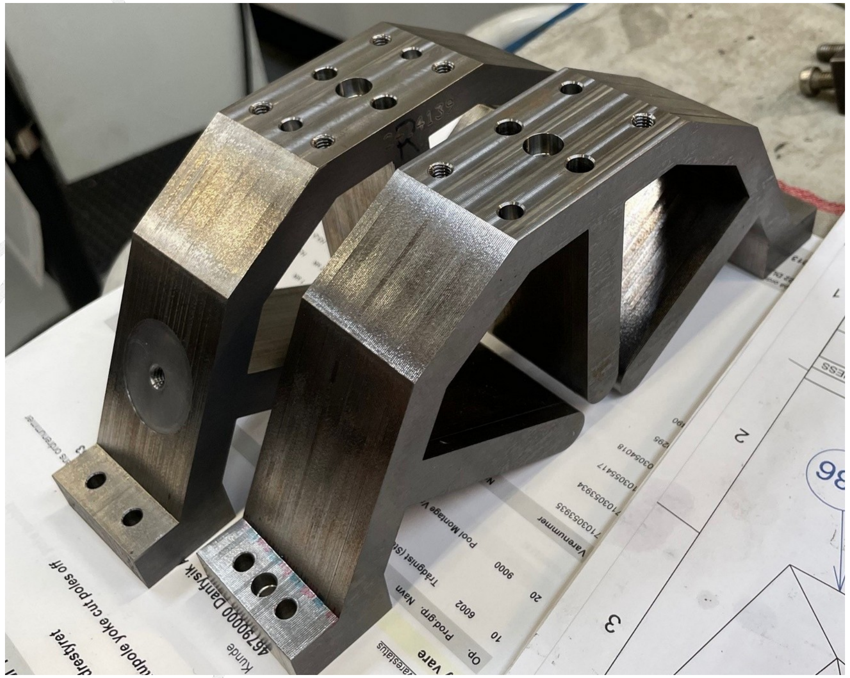


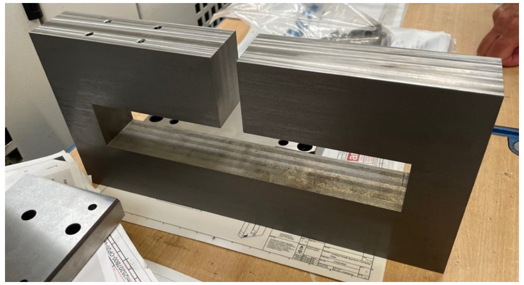


Courtesy C Bailey

Diamond-II Booster Magnets







Courtesy C Bailey