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Status of the FEBE laser system

Lewis Reid, on behalf of the CLARA team
STFC Daresbury Laboratory
3rd December 2024

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Introduction

- As a result of high demand from users in previous calls and the success of their experiments, a new high-power laser system has been procured that can be used in conjunction to the CLARA electron beam.
- This replaces the previous ~10 TW (LATTE) laser for user experiments.
- A contract with **Amplitude** started in April 2023 to provide a 120 TW peak power laser system.
- Amplitude are currently on-site building the laser system with sign off expected week 3 of December.

Users can benefit from:

- More than an order of magnitude higher laser intensity available to interact with targets.
- Advanced laser diagnostics and system monitoring.
- Wavefront control
- Ability to create a probe beam, synchronised to the main high energy pulse.
- Greater flexibility in experiment design through the FEC1/2 chambers.

All of these allow for more complex, more ambitious experiments than previously possible.

FEBE laser area

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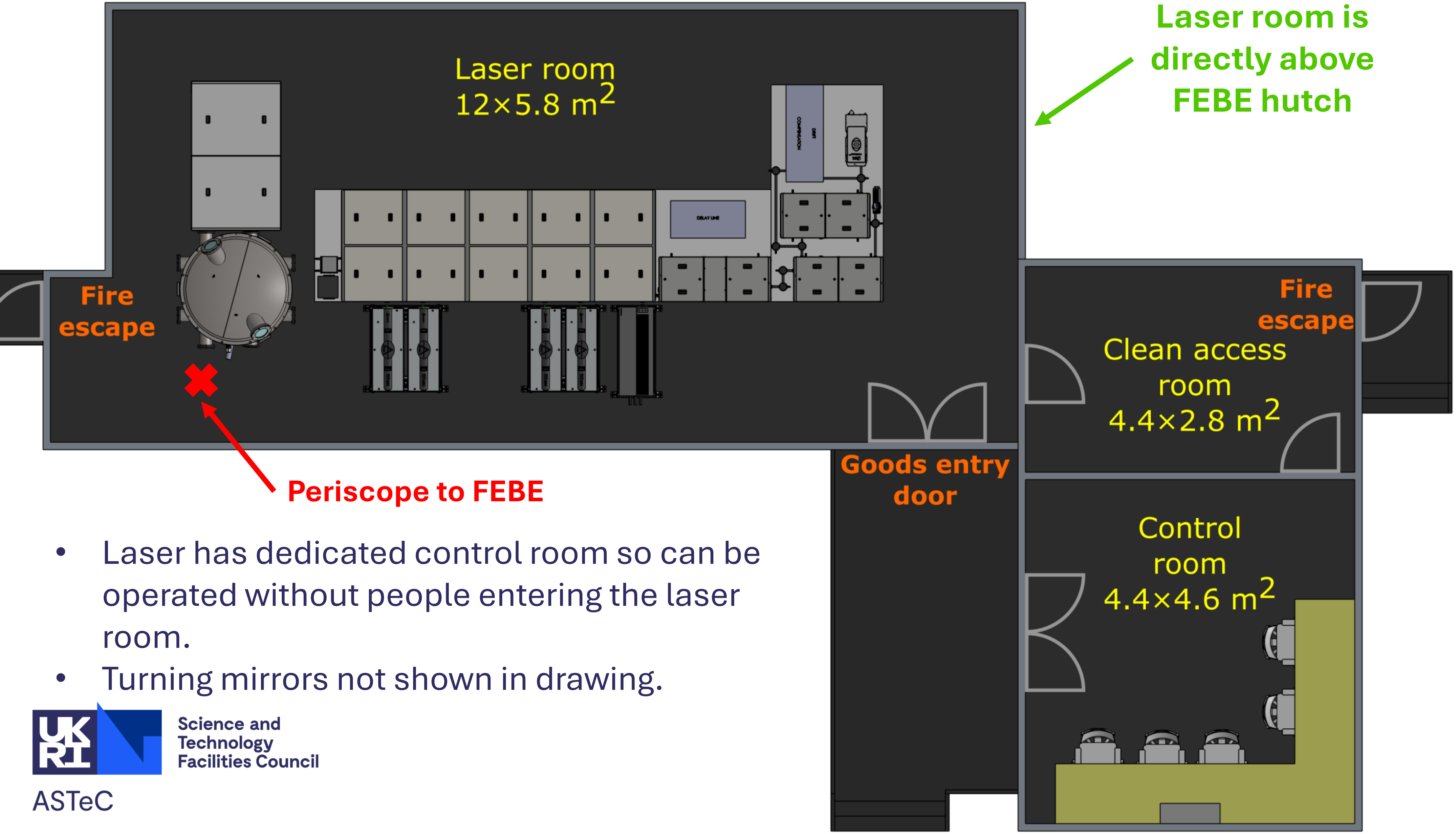
FEBE laser area



- Laser has dedicated control room so can be operated without people entering the laser room.
- Turning mirrors not shown in drawing.

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FEBE laser room

22nd March 2024

- Mature technical design of the laser room complete.
- Laser room completely empty. Blue sealant for air conditioning on the floor.

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FEBE laser room

16th July 2024

- Electrical work started around perimeter of room.
- Frame for HVAC installed.
- Support frames for pump lasers & compressor being installed.

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FEBE laser room

9th September 2024

Mechanical installation almost complete:

- False floor installed.
- Support frames complete.
- Optical tables installed.
- Fire suppression installed.
- Electrical work and PSS being installed.

Room tested to ISO7 clean environment standard with ±0.5°C temperature stability.

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FEBE laser room

3rd October 2024

All components of Amplitude laser system moved into the laser room.
Contractors on-site for laser assembly.

Full construction of laser room complete in less than 6 months.

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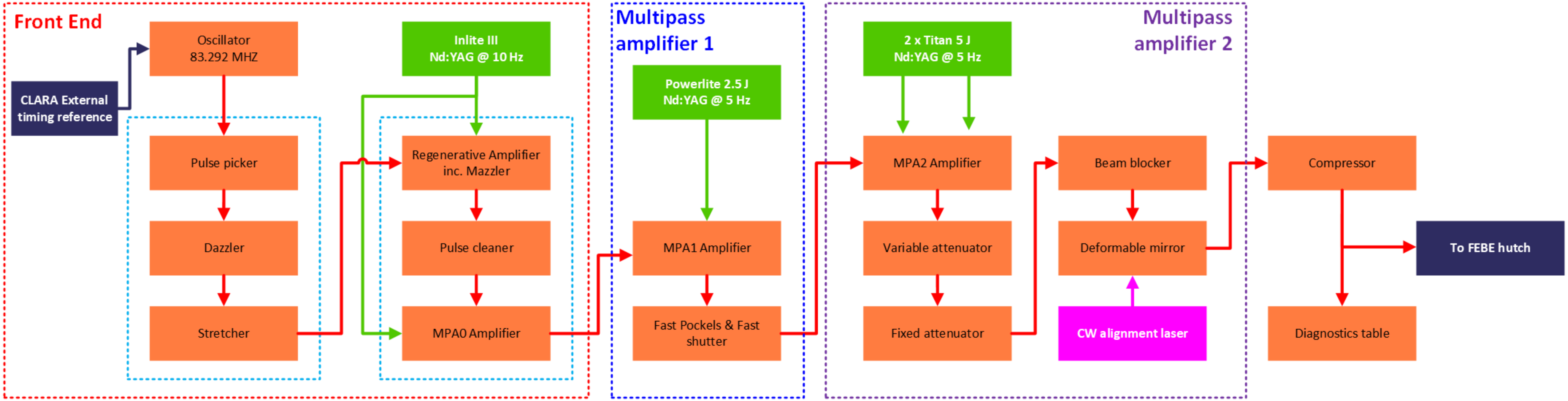
Laser specifications and properties

Laser configuration

- Standard Ti:Sapphire CPA laser layout.
- Laser system comprises of the front end operating at 10 Hz followed by two multipass amplifiers at 5 Hz.
- After compression, there is the option to send beam towards FEBE or to a diagnostics table to fully characterise the pulses.
- Low power CW laser available for set-up and alignment (inside MPA2 enclosure).



Laser properties

- Beam properties confirmed during factory acceptance testing in July 2024.
- Mirror driven into beam at exit of compressor re-directs it to a suite of laser diagnostics.

At compressor exit	
wavelength	807 nm
Peak Power	122 TW
Energy	2.8 J
τ_{laser}	23 fs
Rep Rate	5 Hz
w_{FWHM}	73 mm
Strehl ratio	0.90
Pointing stability	3 μrad
Energy stability	1%

Laser in Amplitude factory. July 2024

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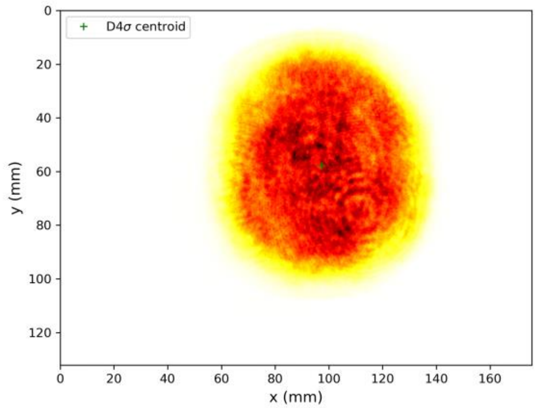
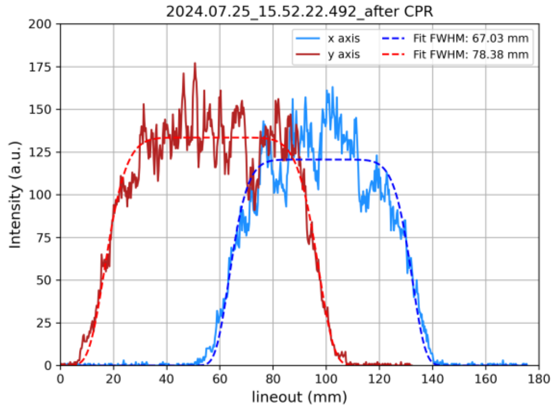
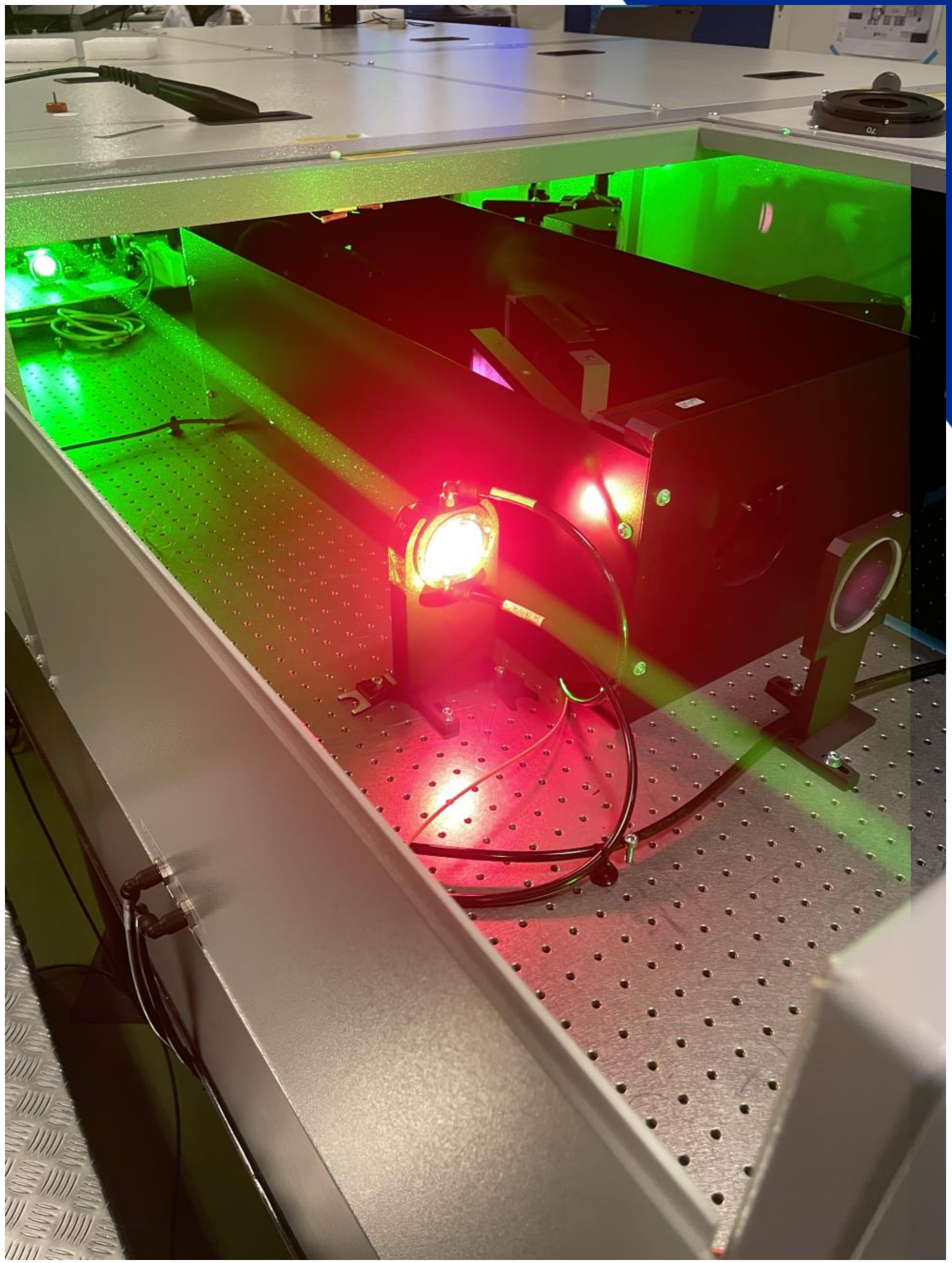
Laser properties

- Clear aperture diameter is ~100 mm with super-Gaussian of order 4 profile.





- Option of running the laser in single shot or 5/n Hz modes.
- Deformable mirror before the compressor allows for optimisation of the beam wavefront after amplification.
- The combination of a fixed and variable attenuator allow for control of beam energy from <1 mJ to 2.8 J.
- Compressor and Acousto-optic device (DAZZLER) for temporal and spectral pulse control.



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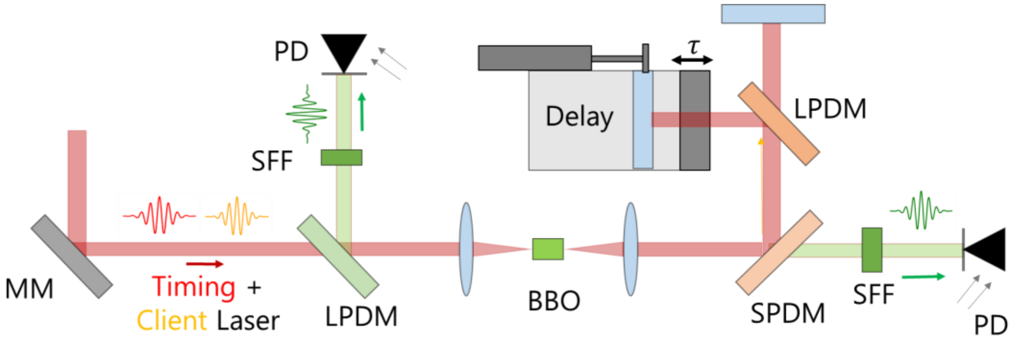
Timing and synchronisation

- Synchronisation between laser and accelerator is critical for user experiments.
- Commercial synchronisation unit to be used to lock the timing of the FEBE laser oscillator to the master RF reference signal.
    - ~50-100 fs integrated rms jitter stability with harmonic lock.
- Aim to upgrade to optical locking to 1560 nm optical master oscillator used to improve precision of temporal lock.
    - Aiming for <10 fs integrated rms jitter stability in oscillator output.
- Laser to electron beam time of arrival jitter to be measured before user exploitation.



Layout of two-colour correlator for use with 800nm FEBE oscillator and 1560nm timing laser.
MM – metallic mirror, LPDM – Low Pass Dichroic Mirror, SPDM – Short Pass Dichroic Mirror, SFF – Sum Frequency (Bandpass) Filter.

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Beam delivery to FEBE hutch

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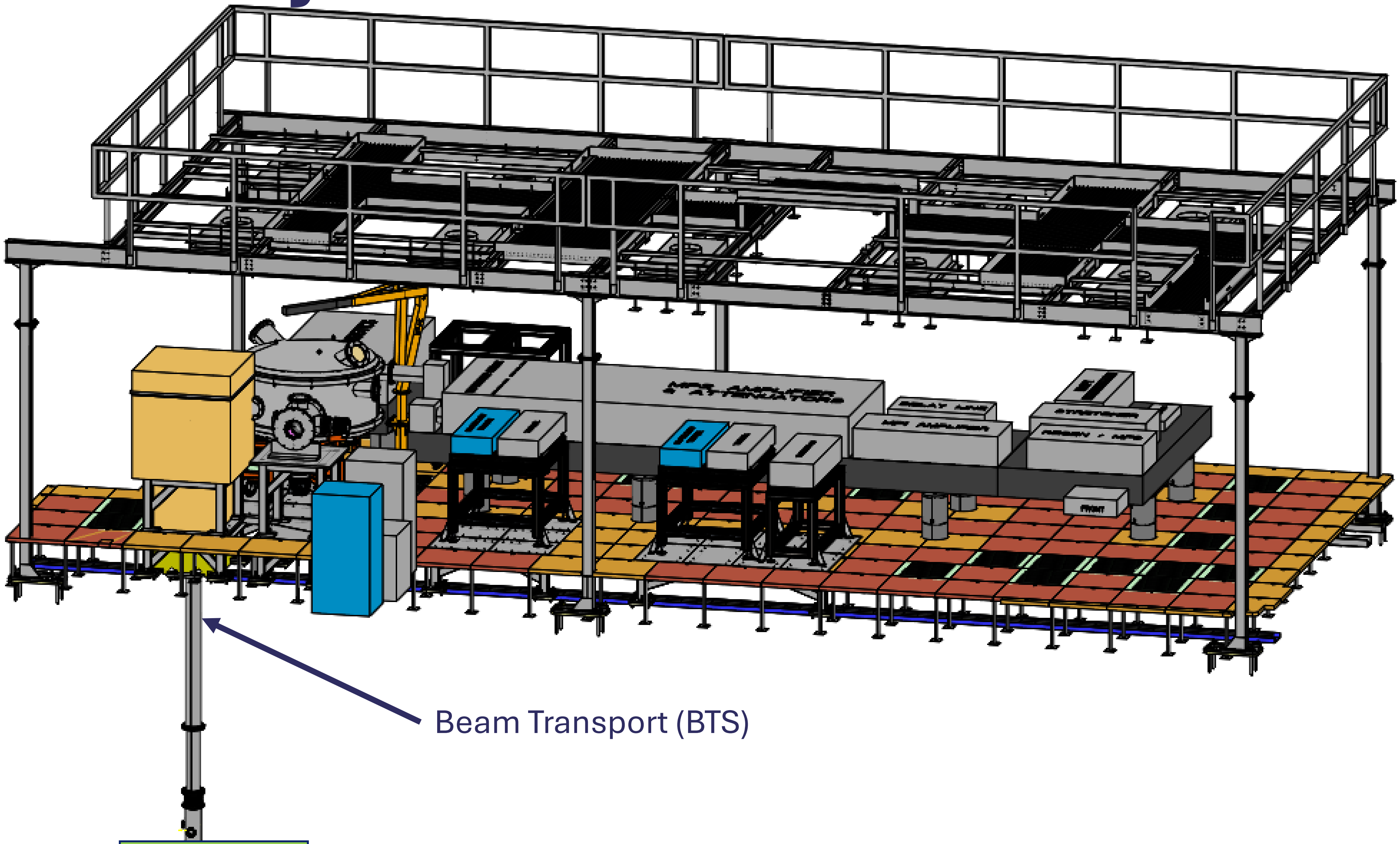
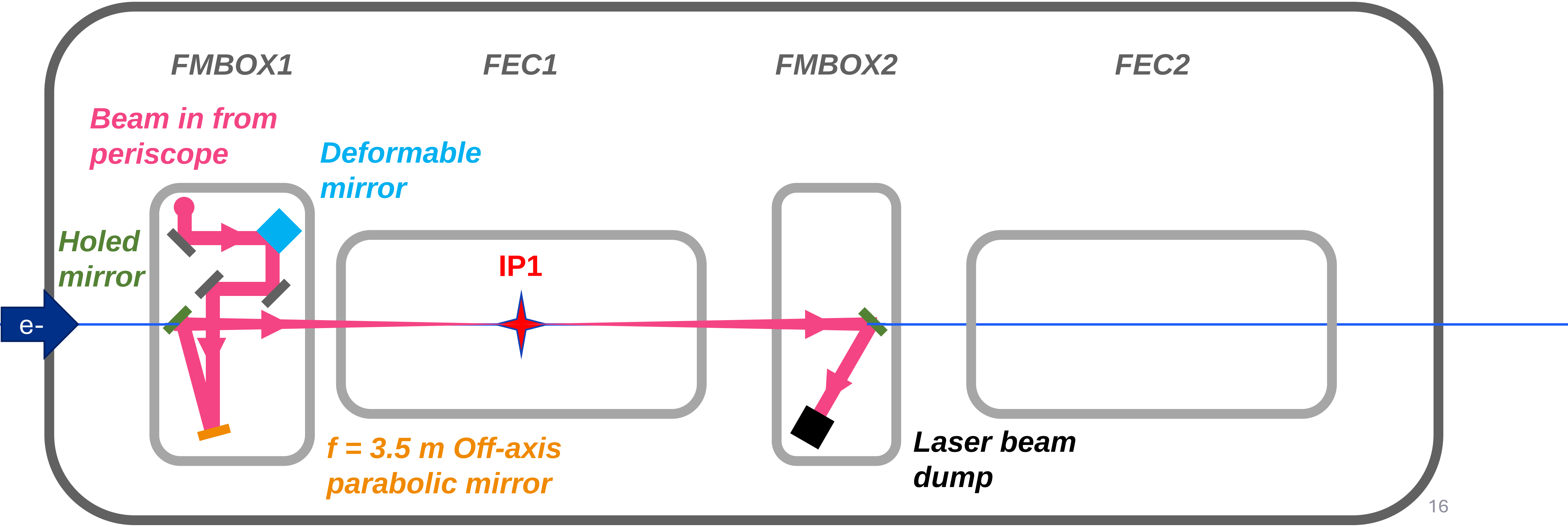
FEBE laser delivery

The laser room sits directly above the FEBE hutch.
After the laser pulse compressor the laser is brought into the first laser mirror box through a periscope.

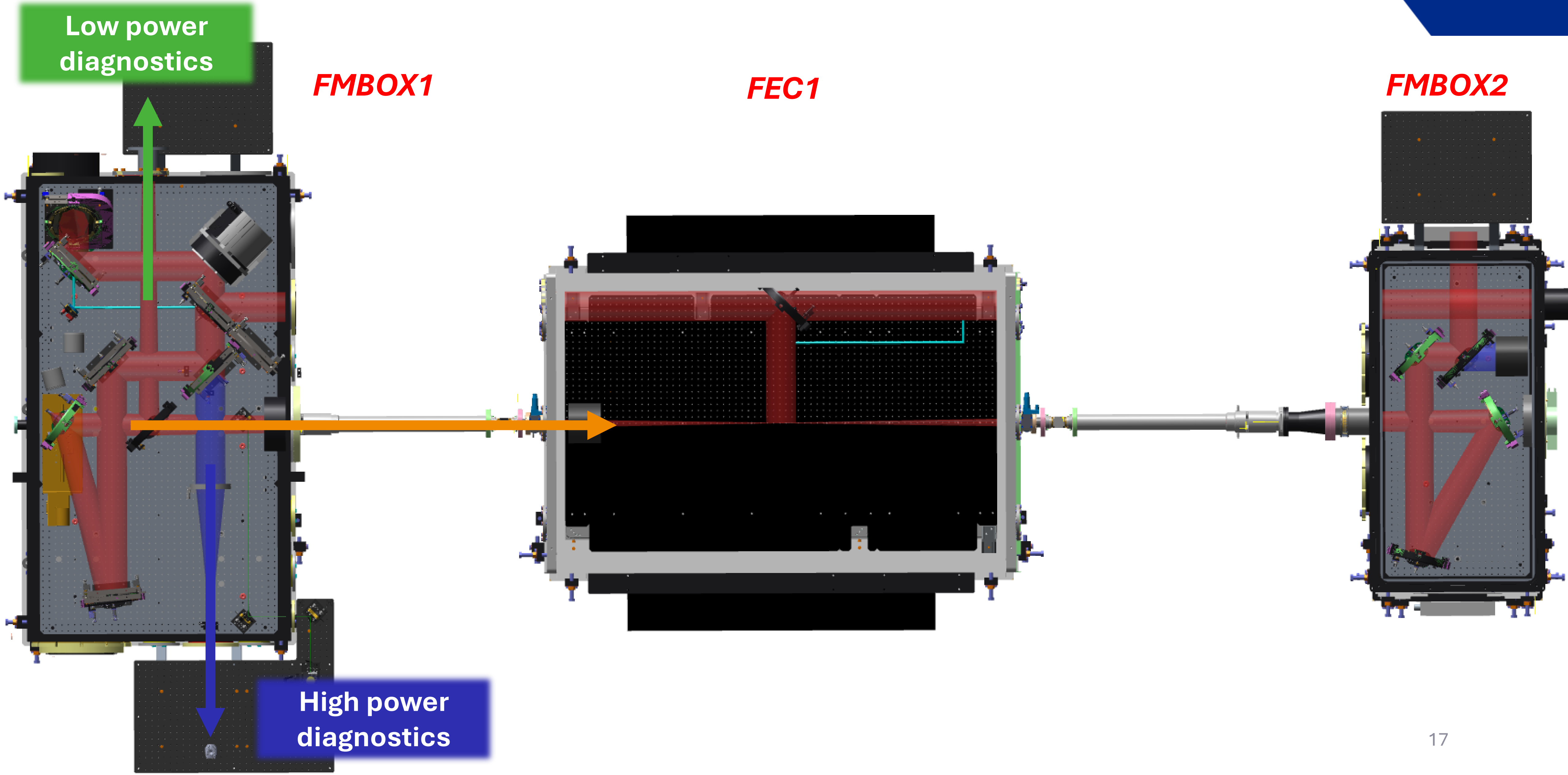


FEBE laser delivery

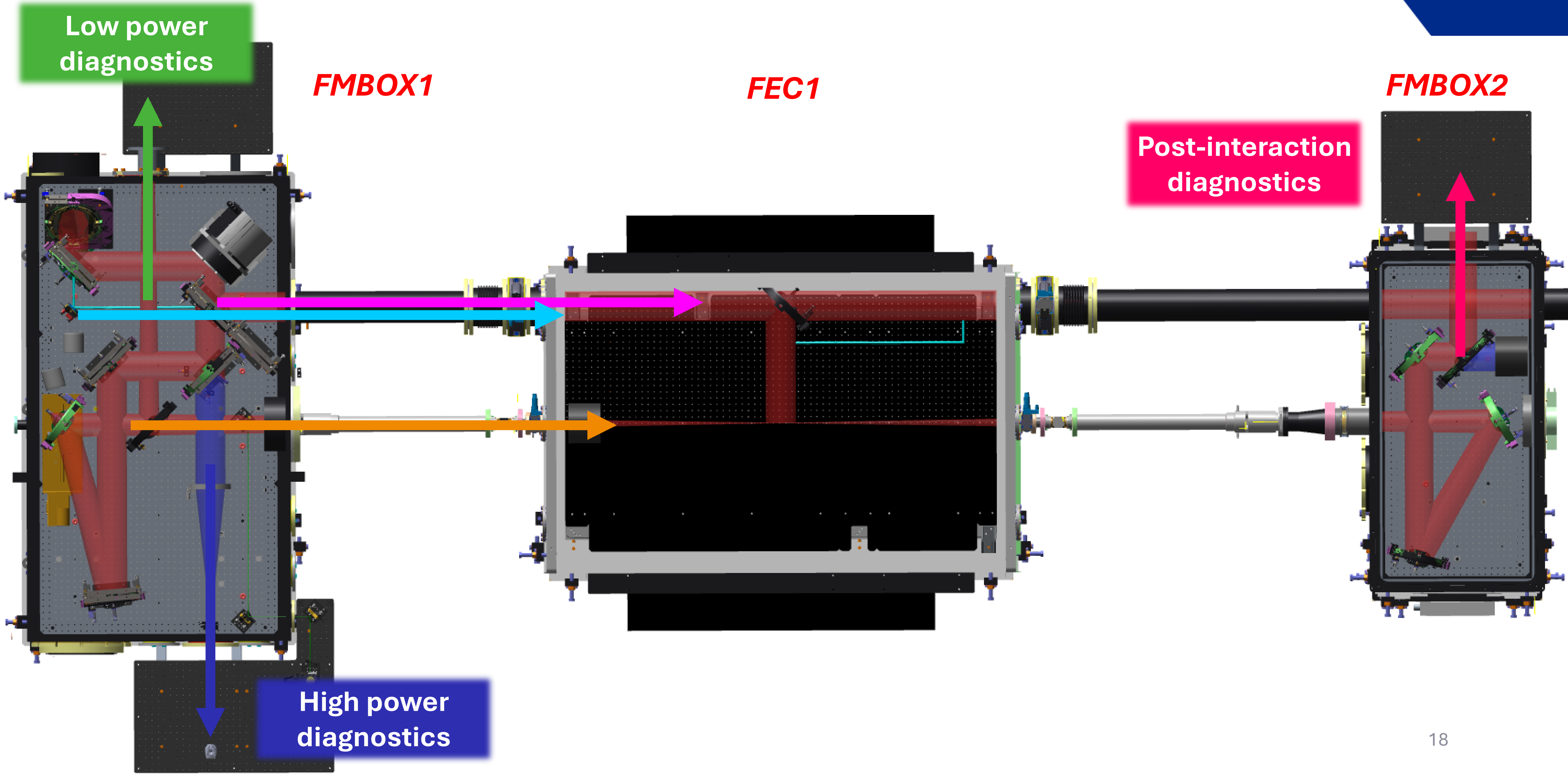
- Nominal laser delivery brings laser into FEBE hutch from laser room via periscope, reflects off deformable mirror and OAP before being sent into FEC1 co-linear to electron beam.
- Laser is dumped in FMBOX2 however there is space for post-interaction diagnostics in the future.
- OAP has focal length of f = 3566 mm for estimated ω_0 = 30 μm at IP1.
- Other laser geometries are possible via collimated pass-thru ports to FEC1 and FEC2.



Laser transport in hutch – Day one



Laser transport in hutch – Future



Laser parameters – "On target"

Estimated laser properties at interaction point using standard OAP with co-linear geometry.

Parameter	F = 3.5 m OAP
Wavelength [nm]	807
Energy [J]	2.6
τ_{FWHM} [fs]	23
ω_0 [μm]	30
I_{pk} [Wcm^{-2}]	8.0×10^{18}
a_0	1.95

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All parameters to be confirmed through measurement with appropriate diagnostics.

Laser operation

Laser operations team

Since laser user meeting, **three new members** of ASTeC staff have been appointed with responsibility for the 120 TW laser.
The teams' main responsibilities include:

- Laser switch on, warm up and daily optimisation
- Operating laser during user experiments
- Maintaining the laser system and fault fixing
- User engagement during planning stages of experiments
- Designing, developing and installing new laser diagnostics in FEBE hutch

Each experiment at FEBE involving the laser will be allocated a laser specialist to assist with experimental planning and integration of experiments to CLARA/FEBE as a whole.

Laser operation

- The ASTeC laser group will take responsibility for operating the laser, users will not be permitted inside the laser room.
- Minimum one operator will be on shift during periods of user experiments.
- Users will be responsible for their set-ups inside FEC1/FEC2.
- Low power CW laser (808 nm) and pulse laser at low power available for alignment.
- Full system operation will occur from the laser control room but some key equipment relevant to users will be available to control via EPICS from the CLARA control room.
  - Attenuators, grating separation etc.

- For first user run, we plan to run the laser at 1 Hz while we assess the stability of the transport line, wear and tear on optics and the thermal effects of the compressor gratings on the laser properties at the interaction point.

Summary

- New laser system for CLARA represents a significant step change in the capabilities for the CLARA facility.
- Laser peak power is more than an order of magnitude higher than previously available with the ability to control the properties of the beam on target.
- Improved laser diagnostics will provide continuous feedback to experimentalists.
- Dedicated laser operators have been appointed to run and maintain the system during user experiments and to assist with experiment planning and integration into CLARA.

Please contact lewis.reid@stfc.ac.uk if you are interested and would like to know more details concerning exploitation of CLARA using the 120 TW laser system.

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Thank you

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Back up slides

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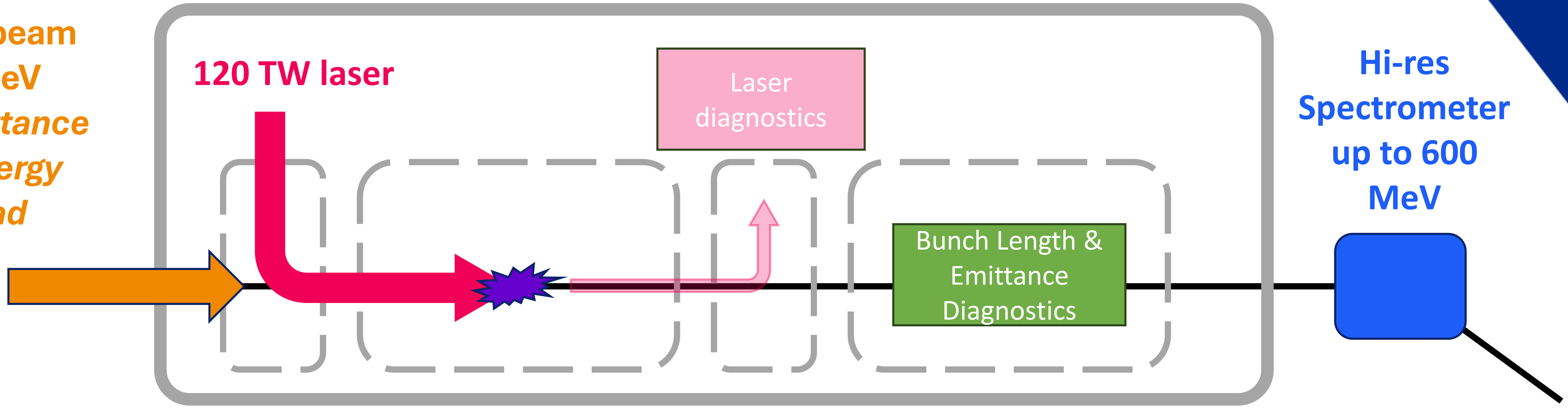
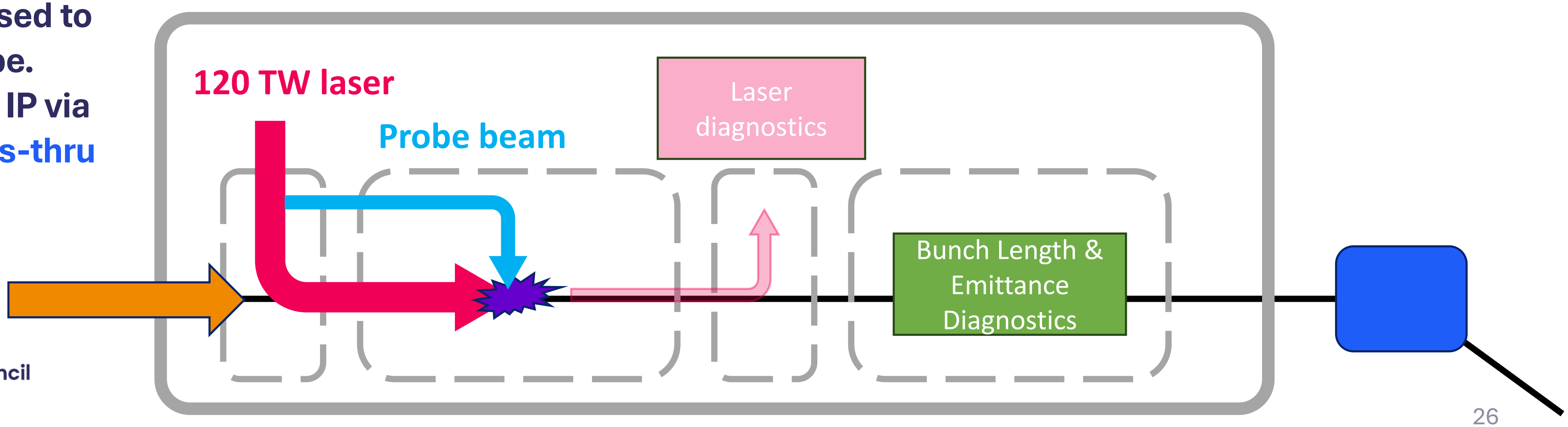
FEBE 120 TW laser

CLARA beam
250 MeV
Low emittance
Low energy spread



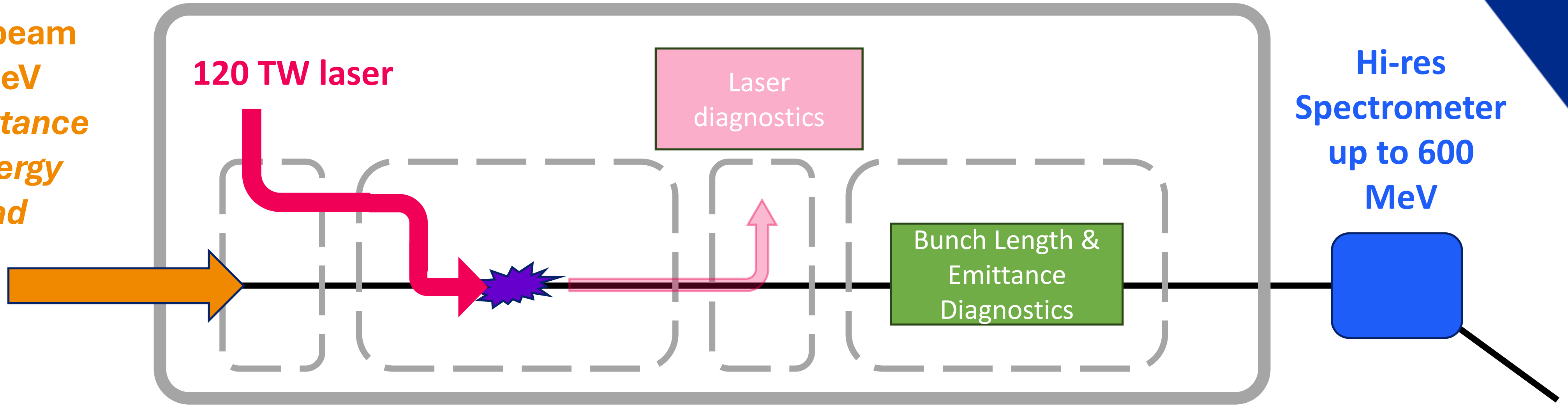
Hi-res Spectrometer up to 600 MeV

Pick-off from main beam can be used to form a probe. Transported to IP via collimated pass-thru port.

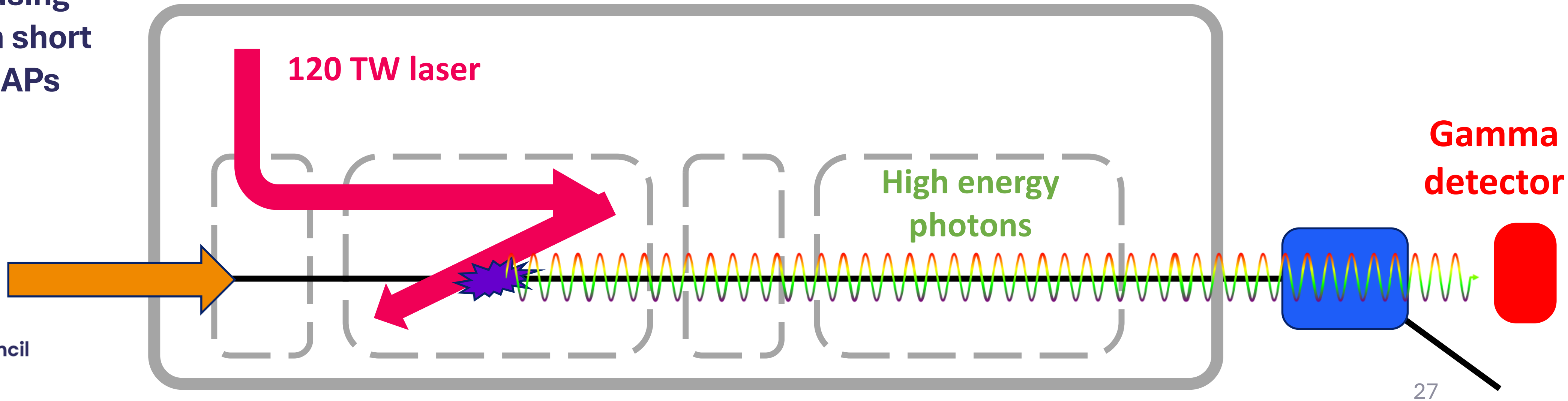


FEBE 120 TW laser - Future

CLARA beam
250 MeV
Low emittance
Low energy spread



Collimated pass thru allows for focusing geometries with short focal length OAPs



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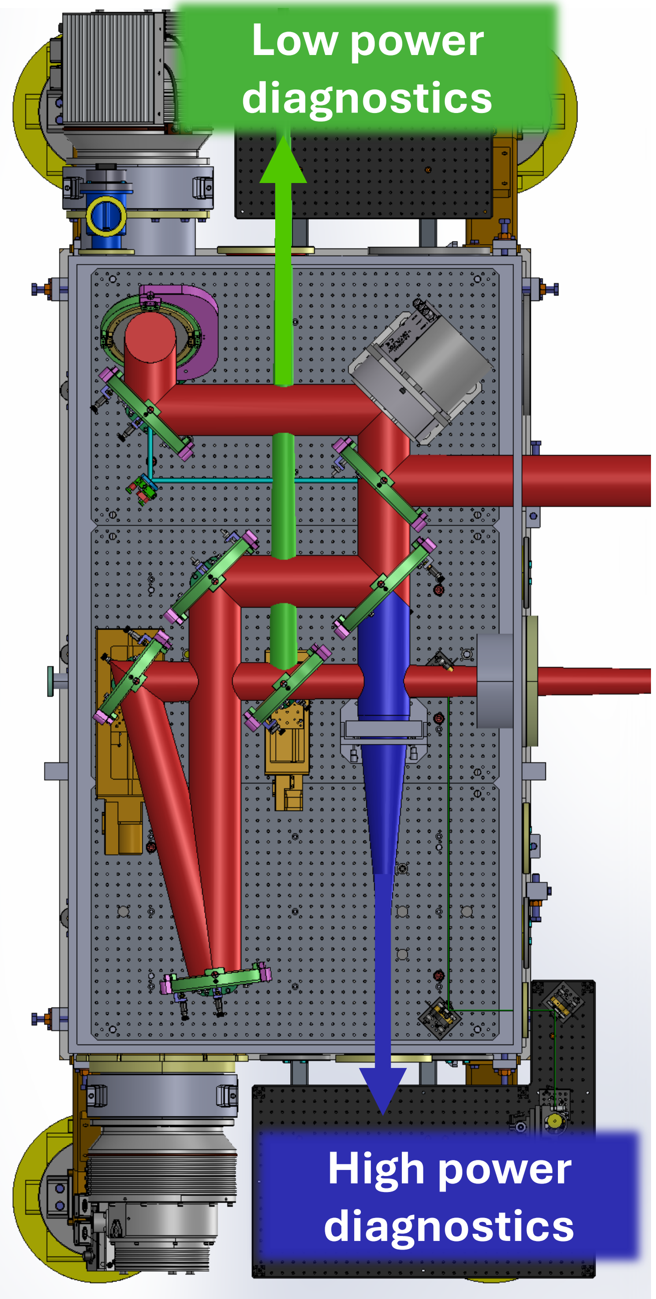
FMBOX1 diagnostics



FMBOX1 has two sets of “standard” laser diagnostics:

1. “Low power diagnostics”
   Can only be used with attenuated laser. Checks the beam alignment in transport from compressor to OAP. Measurements of laser focus and laser far field to be made.

2. “High power diagnostics”
   Leakage taken through a mirror to measure key laser properties “on-shot”. Wavefront sensor measurement taken here to feedback information to the deformable mirror.

FMBOX2 diagnostics

- Purpose of FMBOX2 is to remove laser light from FEBE and protect equipment in FEC2 from stray laser light.
- FMBOX2 has space for a set of “post-interaction” diagnostics.

- Design activity surrounding this planned for 2025.
- Laser will be dumped immediately after holed mirror for first user run.