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Full Energy Beam Exploitation at CLARA: Opportunities for Advanced Accelerator Experiments

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M. Colling, B. Fell, G. Marshall, @ *STFC TD*.

Outline

- CLARA & *Full Energy Beam Exploitation* (FEBE) Overview
- FEBE Infrastructure supporting plasma acceleration
- Instrumentation & Diagnostics
- Potential types of experiments

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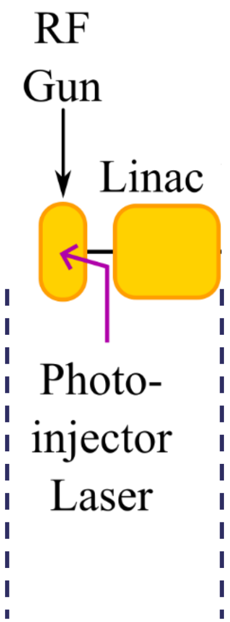
Overview of CLARA & FEBE

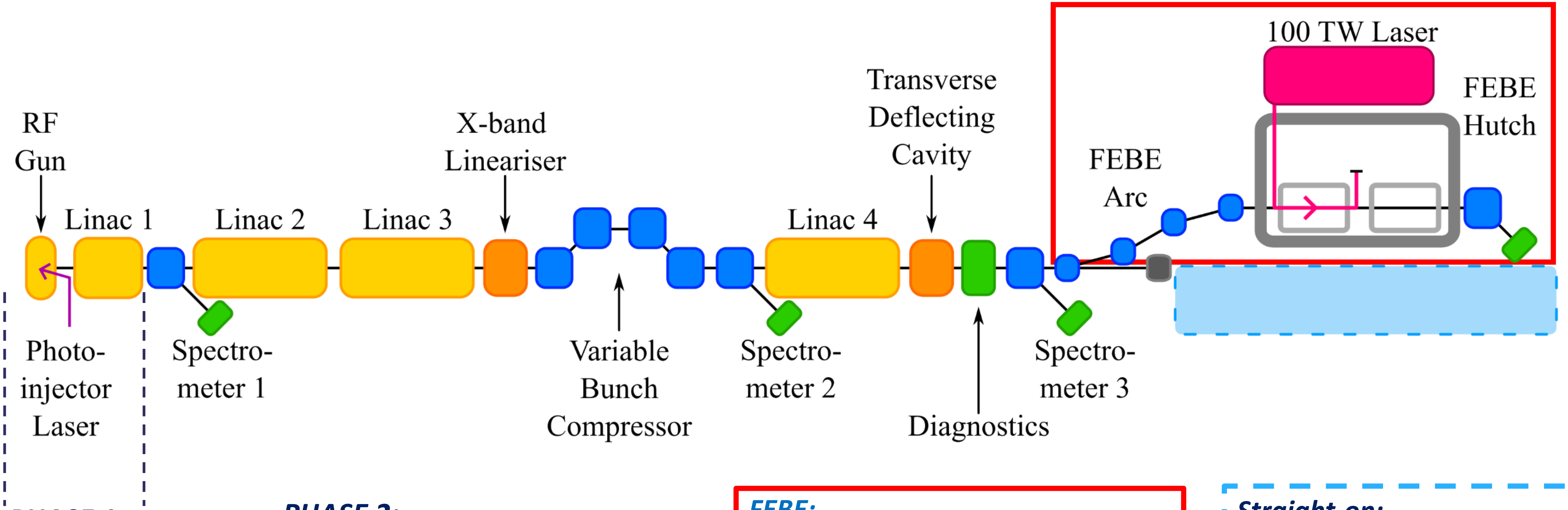
CLARA & FEBE Overview



PHASE 1:
50 MeV,
250 pC, 10 Hz

- User area Beam Area 1 (BA1)
- Beam exploitation, inc. novel acceleration

CLARA & FEBE Overview



PHASE 1:
50 MeV,
250 pC, 10 Hz

- User area Beam Area 1 (BA1)
- Beam exploitation, inc. novel acceleration

PHASE 2:
250 MeV ASSEMBLED & INSTALLED OFFLINE

- 2022/23: Installation
- 2023/24: Commissioning

FEBE:
SHIELDED USER FACILITY

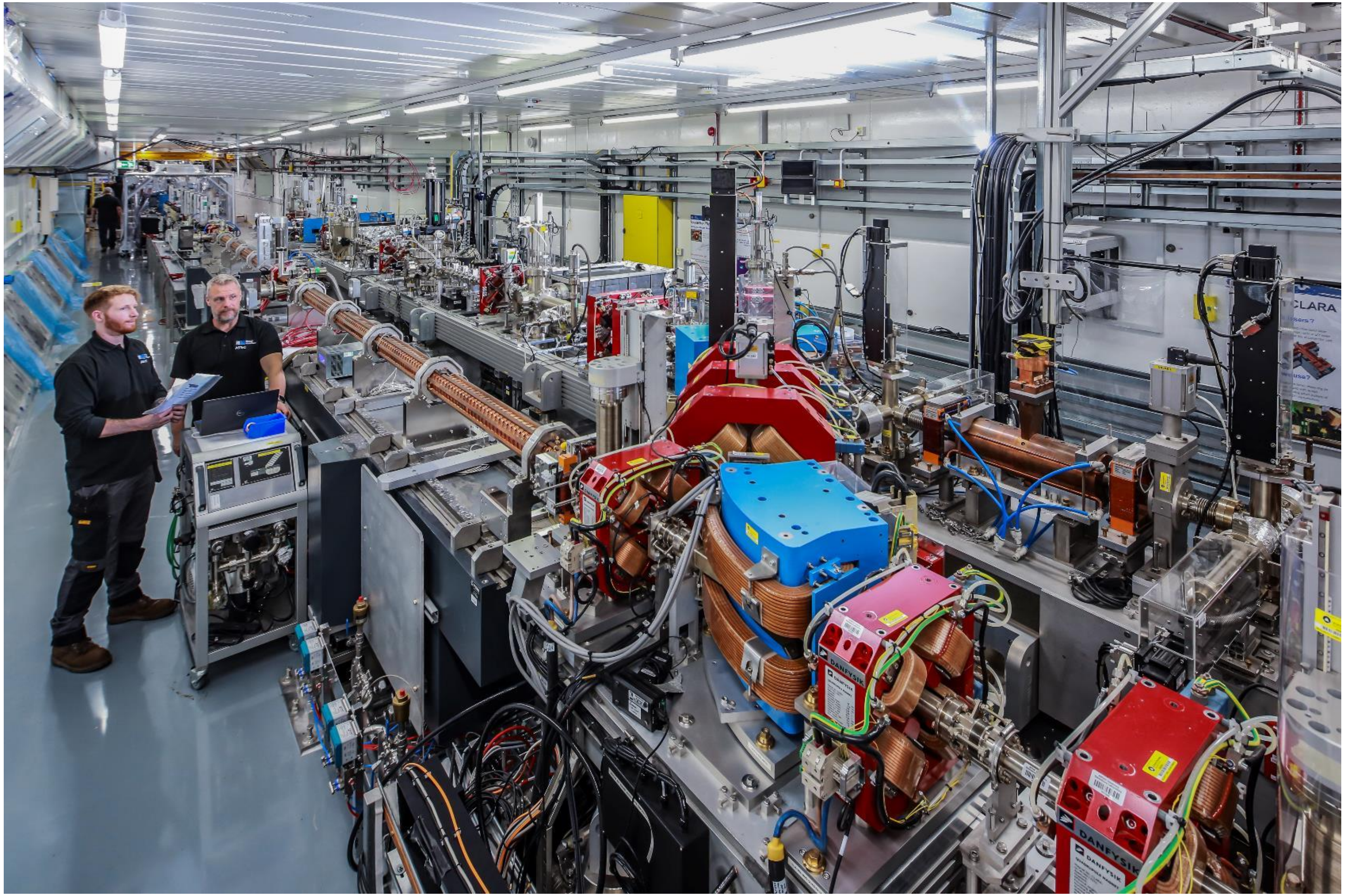
- Branch line to shielded hutch
- Flexible user exploitation space
- 100 TW class laser

Straight-on:
FEL technology development

NOT YET FUNDED

- Tied to UKXFEL CDR and decision on next stages

CLARA Now



Previous exploitation at CLARA

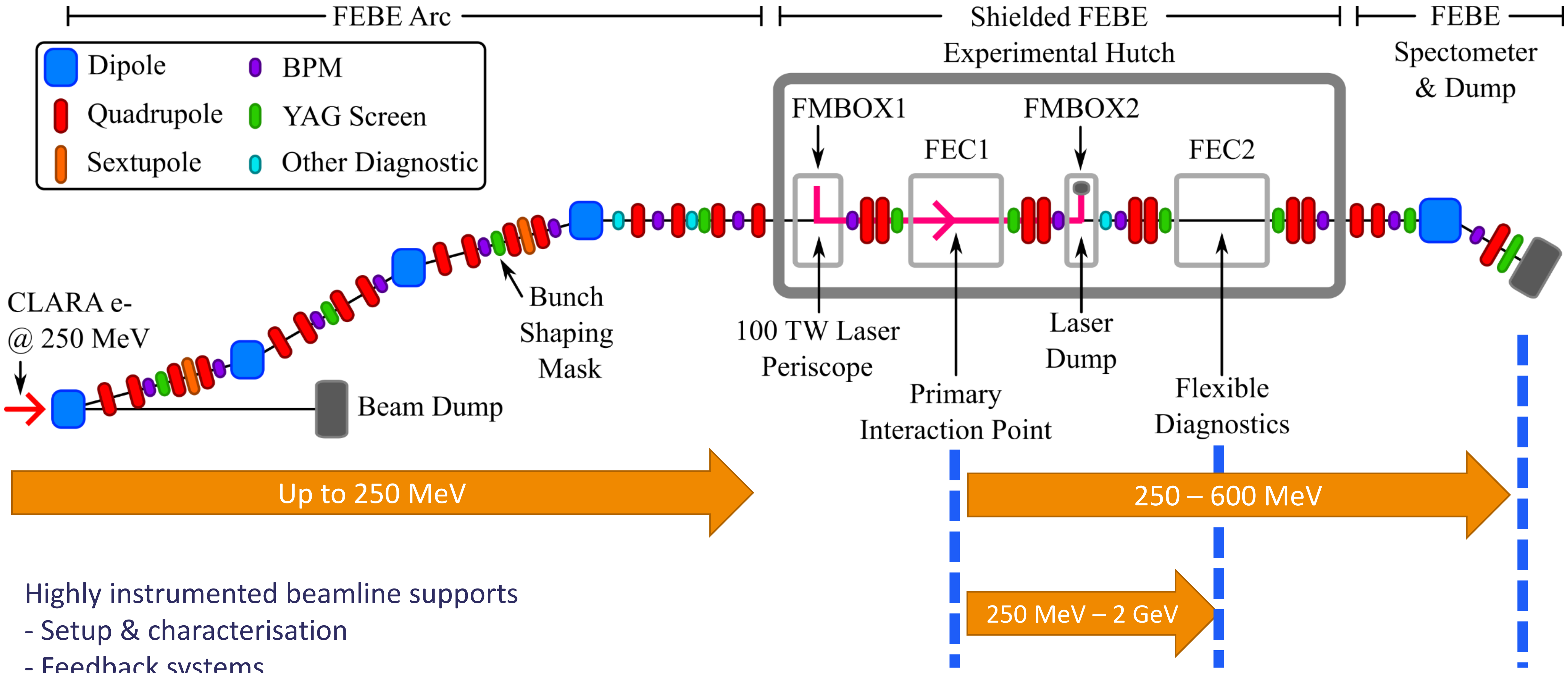
- Exploitation with 35 MeV electrons and with 10 TW class laser
- Competitive access periods
  - October 2018- April 2019 and October 21 – April 2022

- Oversubscribed by factor of 2

- Approximately 50 % of shifts '21-'22 awarded were for advanced acceleration concepts, including dielectric wakefield acceleration laser wakefield acceleration, THz acceleration, and plasma diagnostics.

- See Poster by Ed Snedden (Tuesday Session)

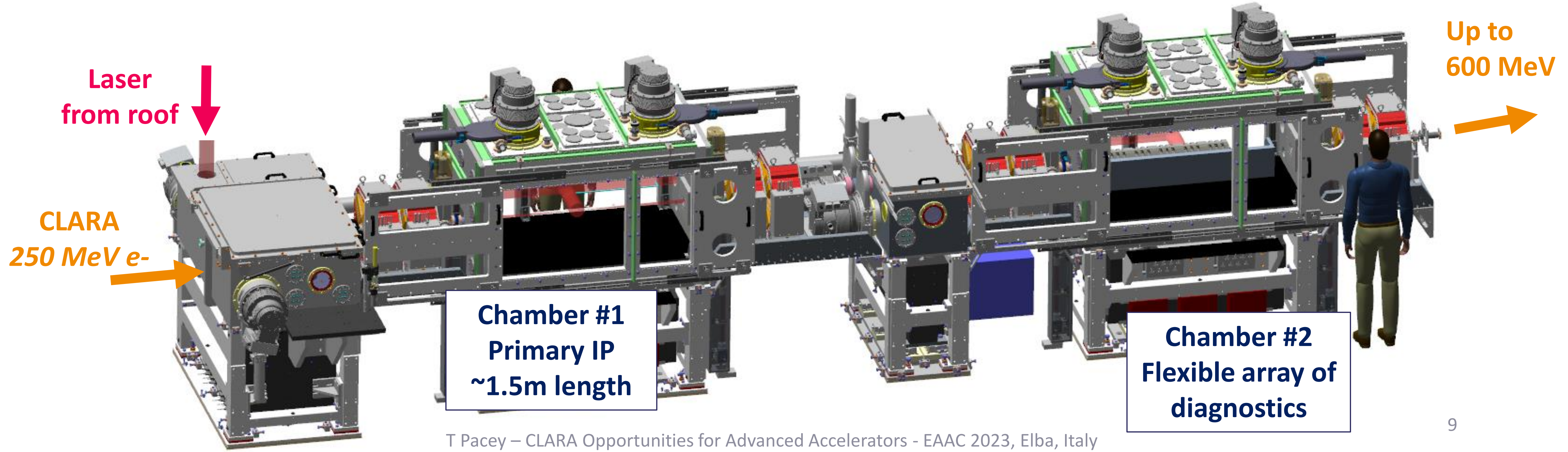
FEBE Beamline & Hutch



Highly instrumented beamline supports
- Setup & characterisation
- Feedback systems

FEBE Chambers

- Flexible platform for novel acceleration studies
- 2 identical chambers: Double IP configuration
- Dedicated laser in-out coupling chambers
- Accelerated beam up to 2 GeV possible in hutch



Beam parameters – “Day 1”

Parameter	High charge	Low charge
Energy [MeV]	250	250
Charge [pC]	250	5
RMS t [fs]	100	50
σ_E/E [%]	<5	<1
RMS x [µm]	100	20
RMS y [µm]	100	20
ε_N x [µm]	5	2
ε_N y [µm]	5	2

Important: all parameters to be confirmed through measurement using appropriate diagnostics.

Beam parameters – Future potential

Parameter	High charge	Low charge
Energy [MeV]	250	250
Charge [pC]	250	5 → <5
RMS t [fs]	100 → 50	50 → <50
σ_E/E [%]	<5 → 1	<1
RMS x [µm]	100 → 50	20 → ~1
RMS y [µm]	100 → 50	20 → ~1
ε_N x [µm]	5 → <5	2 → 1
ε_N y [µm]	5 → <1	2 → <1

R&D: Meeting these parameters will require upgraded and/or new diagnostics

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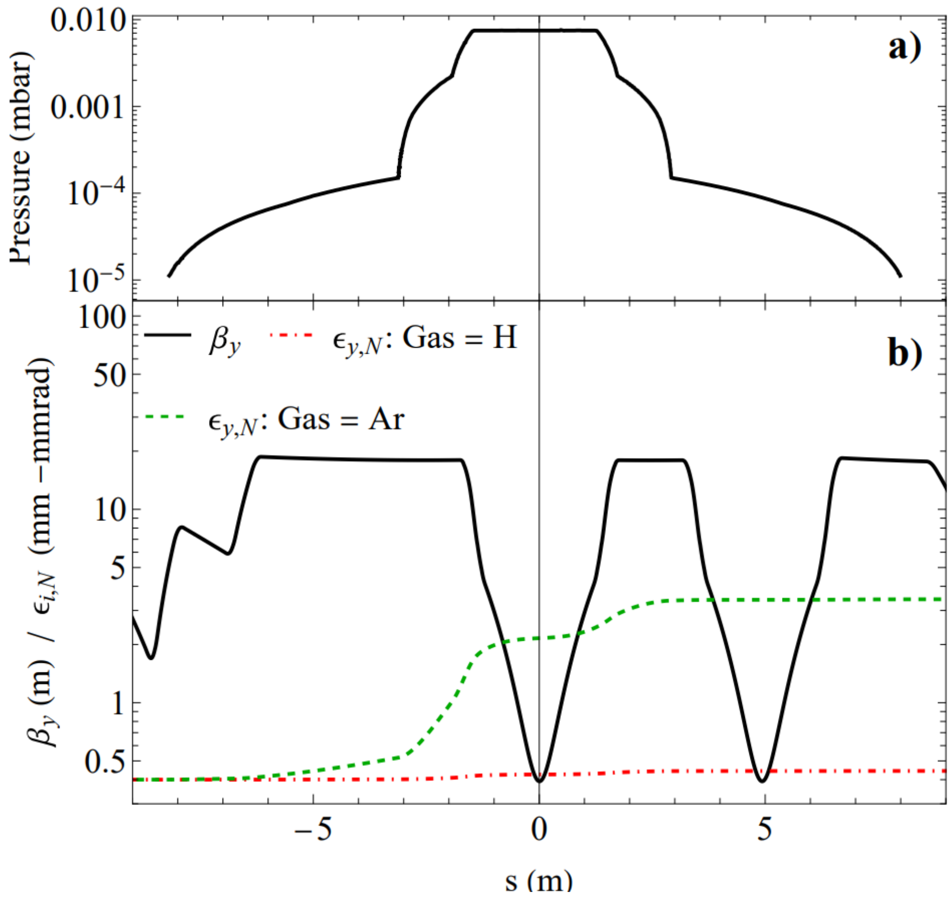
Infrastructure supporting plasma acceleration

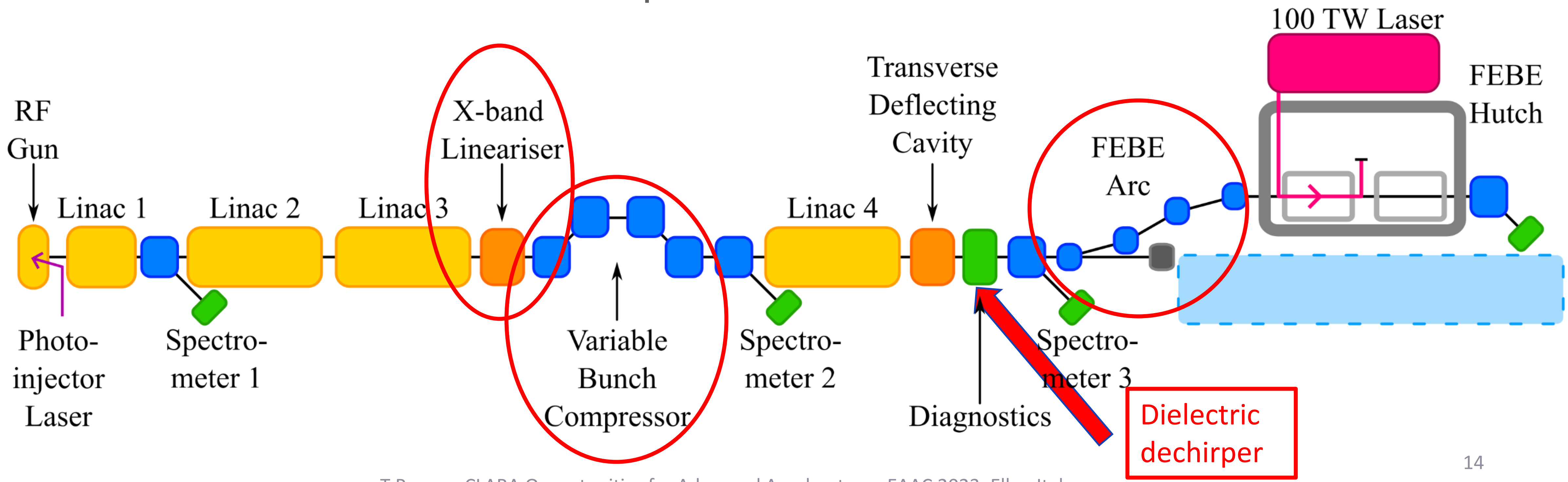
Gas Management

- Invested in large volume turbos on experimental chambers & mirror boxes – 6 at ~ 2000l/s
- Upstream irises and apertures to reduce gas propagation
- Negligible modelled emittance growth for Hydrogen,
  - Limited growth for heavier species, e.g. Argon



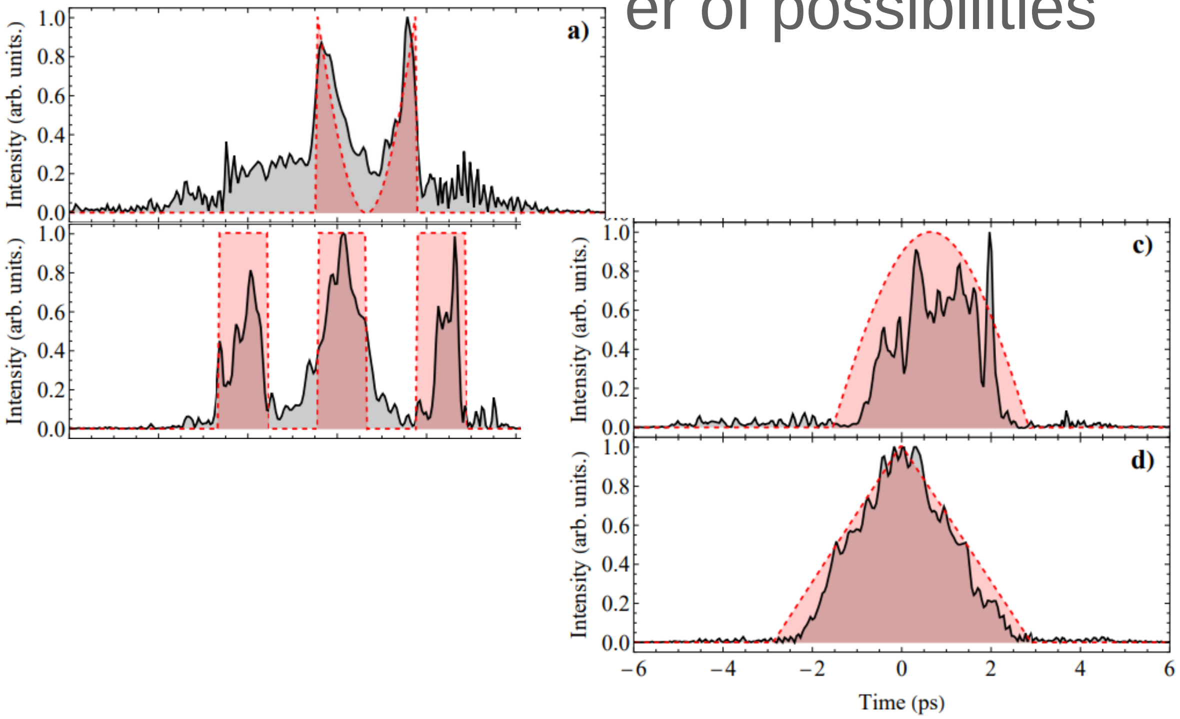
Beam driven acceleration

- Benefitting from high quality beam designed for FEL R&D
- Flexible delivery and fine control of longitudinal phase space:
  - Variable R56 in chicane compressor & in FEBE arc
  - Dielectric wakefield dechirper

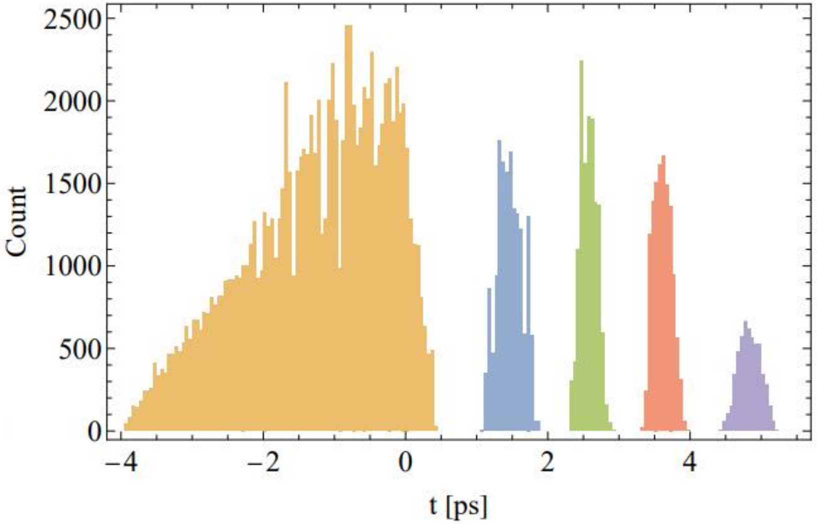


Electron beam pulse shaping

- Photoinjector Laser longitudinal shaping
  - Machine Learning driven
  - er of possibilities



- Tungsten mask in FEBE Arc
  - Configurable and changeable
  - Drive-witness, pulse trains…all possible

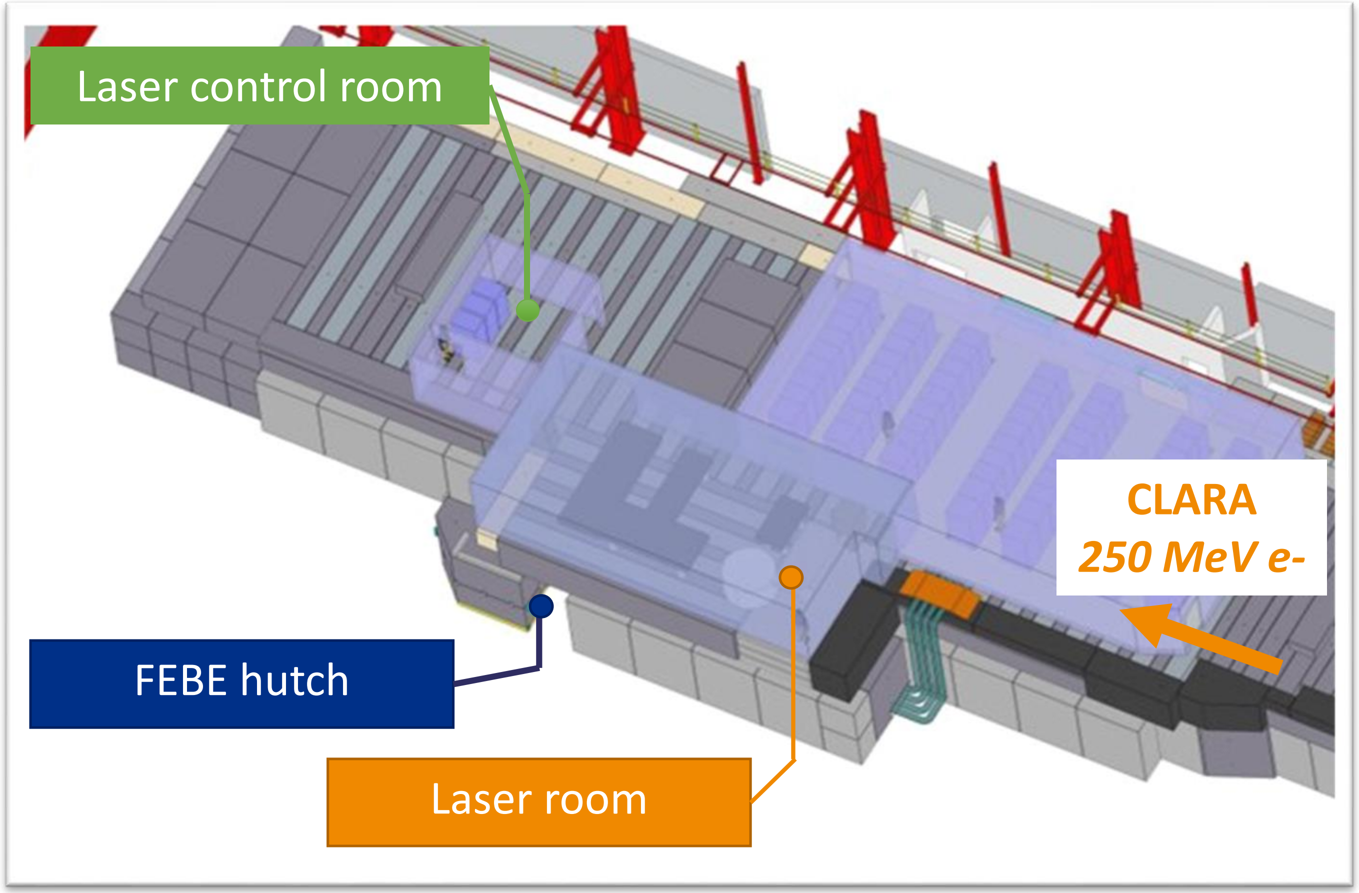


FEBE Laser

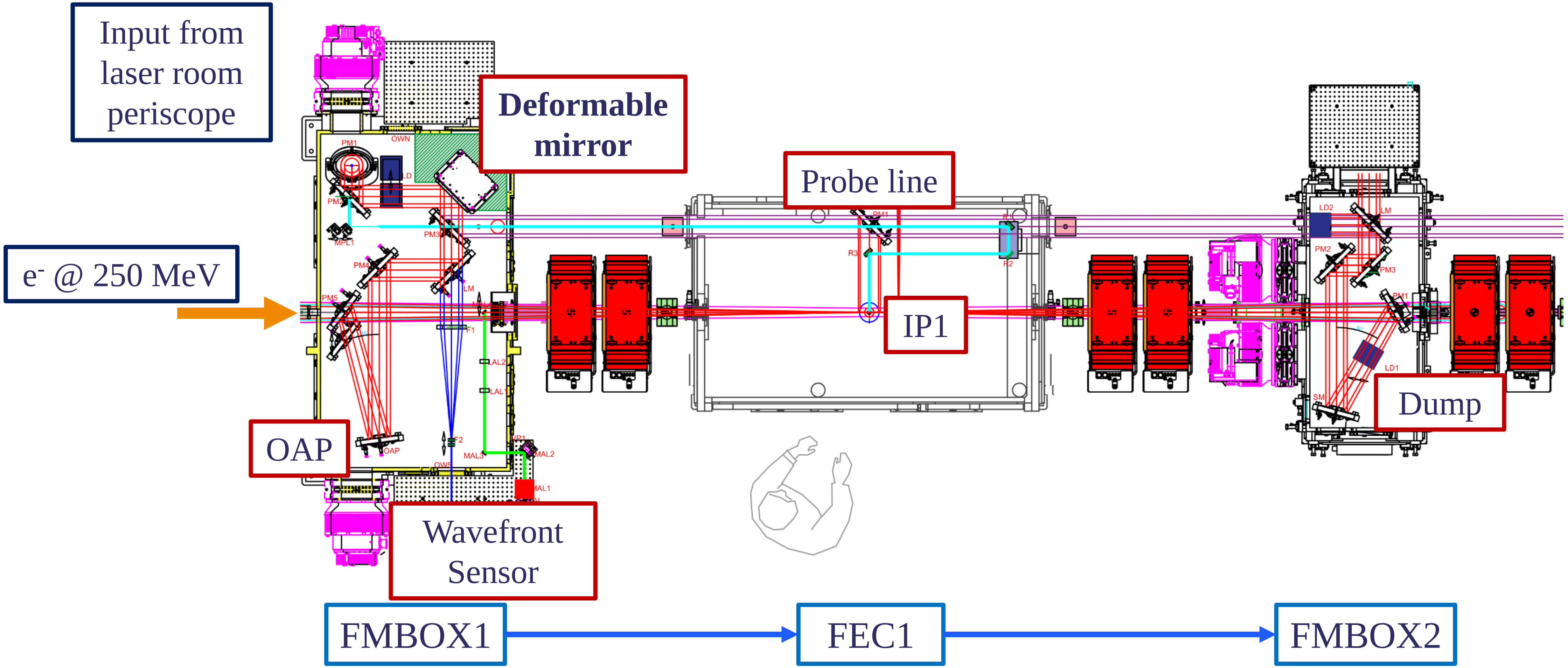
120 TW, 5 Hz laser (Arco, Amplitude).

- The laser is housed immediately on top of the FEBE hutch
- Photons to target via a shielded periscope.

- Installation scheduled for second half of 2024,
- Laser ready for exploitation at the beginning of 2025.



Laser delivery to IP



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Diagnostics & Instrumentation

Laser synchronization & TOA jitter measurement

FEBE laser oscillator will be optically synchronized to the CLARA optical clock:

- Ultralow noise optical clock (complete)
- Stabilized <10 fs over 24 hr (design and testing complete)
- Two-colour laser-laser locking (testing underway, all-fibre upgrade design in progress[1])
- **On track to provide <10fs locking of FEBE laser to optical reference**

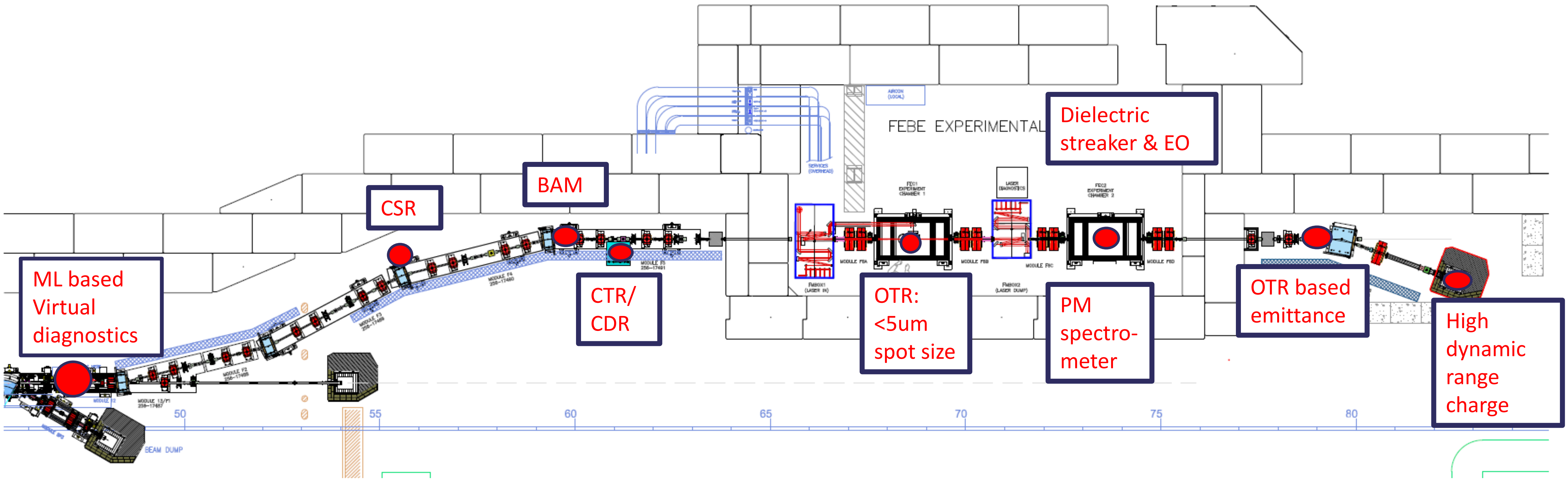
Beam arrival monitor (BAM) R&D:

- Targeting 10fs arrival time measurement @20 pC with cone pick-ups design[2]
  - Installation and commissioning in early 2024
- Collaboration with DESY & THM to deliver low charge BAM based on PCB substrate and rod pick-ups[3]
- Push 10 fs @<5pC beam charge with low charge BAM.

1 – THPA073 IPAC23
2 – PhysRevSTAB.18.012801
3 – IBIC2021 WEPP19

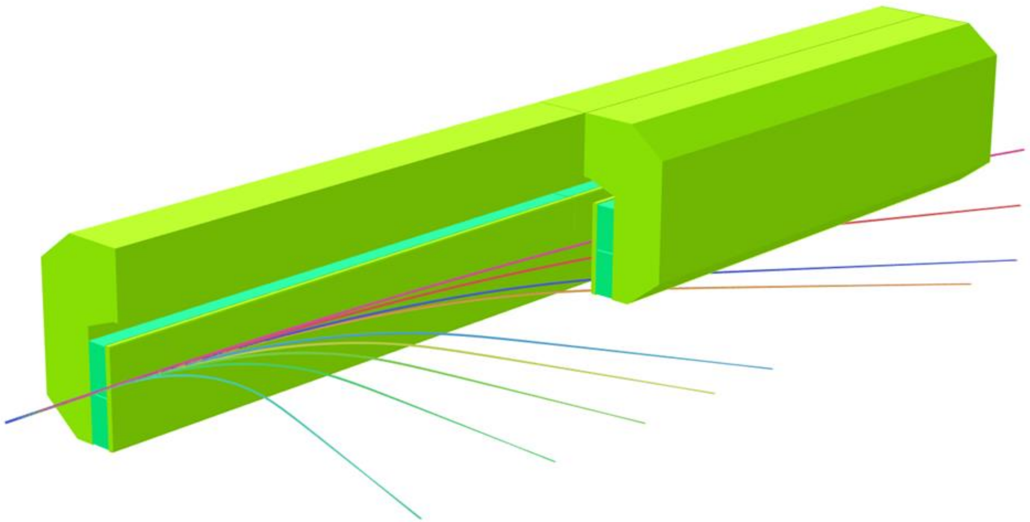
6D Diagnostics R&D across FEBE beam line

- Diagnostics undergoing active R&D
- All supplemented by well developed diagnostics, e.g. BPMs, YAGs, ICTs



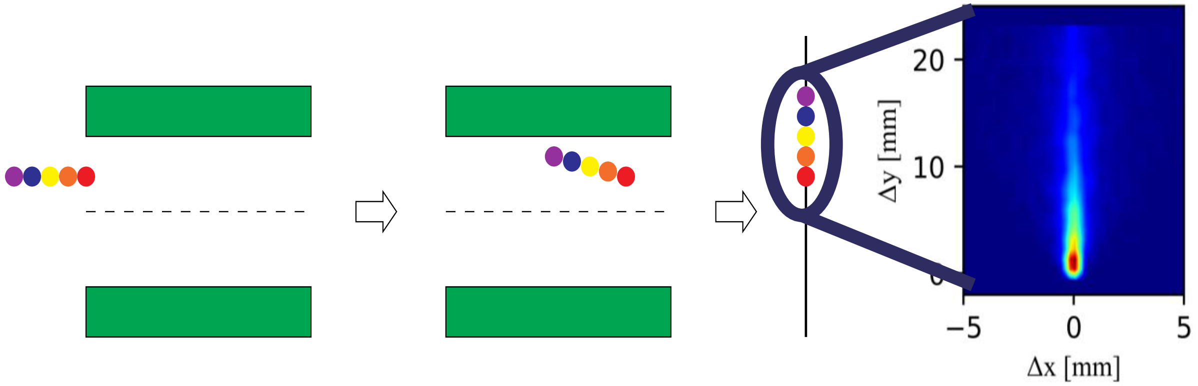
FEBE Chamber options

2 options, more in R&D



Dielectric wakefield streaker

- Passive, robust, single shot bunch length measurement
- RMS estimate or full profile reconstruction
- Broadband, <50 fs > 1 ps
- Resolution improved using pairs orthogonally orientated plates



Permanent Magnet Spectrometer

- Can be deployed in second chamber for commissioning beams with energy > 600 MeV
- Energy range 50 MeV - 2 GeV
- Upstream quad. doublet + correctors for matching into dipole
- Modular design, 200mm blocks, 5 modules for 2 GeV

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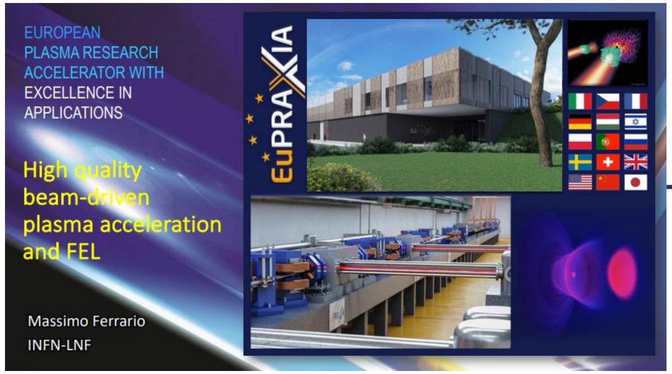
Potential Experiments: Putting options together

Only ideas/examples!
Many potential possibilities!
Suggestive, not prescriptive!

Future areas of interest

R&D challenges

ASTeC R&D will be guided by challenges to establish a plasma FEL user facility (e.g. those targeted through EuPRAXIA). ASTeC will consider a plasma-booster option for one of the UK XFEL beam lines.

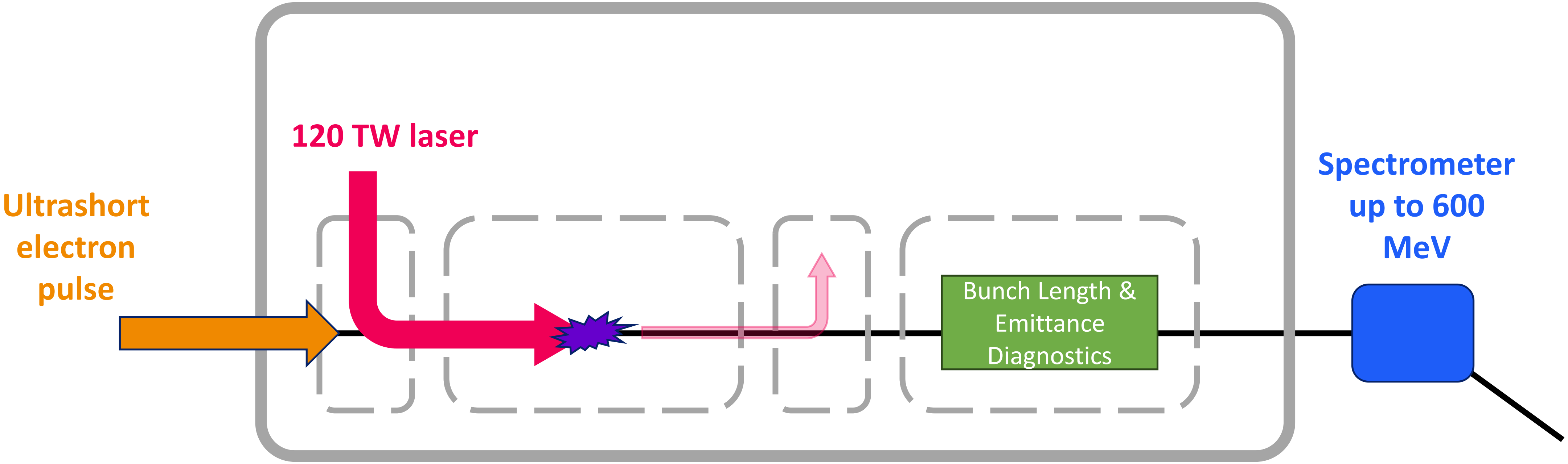


Plasma FEL R&D Challenges	
Emittance, tolerances and mitigation of instabilities	Hybrid, new or alternative schemes
Efficiency, including drive beam and laser issues	Low emittance beam sources (including positrons)
Energy spread	Plasma stability / repeatability (including targets)
Maximum bunch intensity / charge	Synchronization systems, other support systems
Simulation code development and outreach	Controls systems and optimisation (including machine learning)

ASTeC with our users would be well placed to contribute to many of these areas.

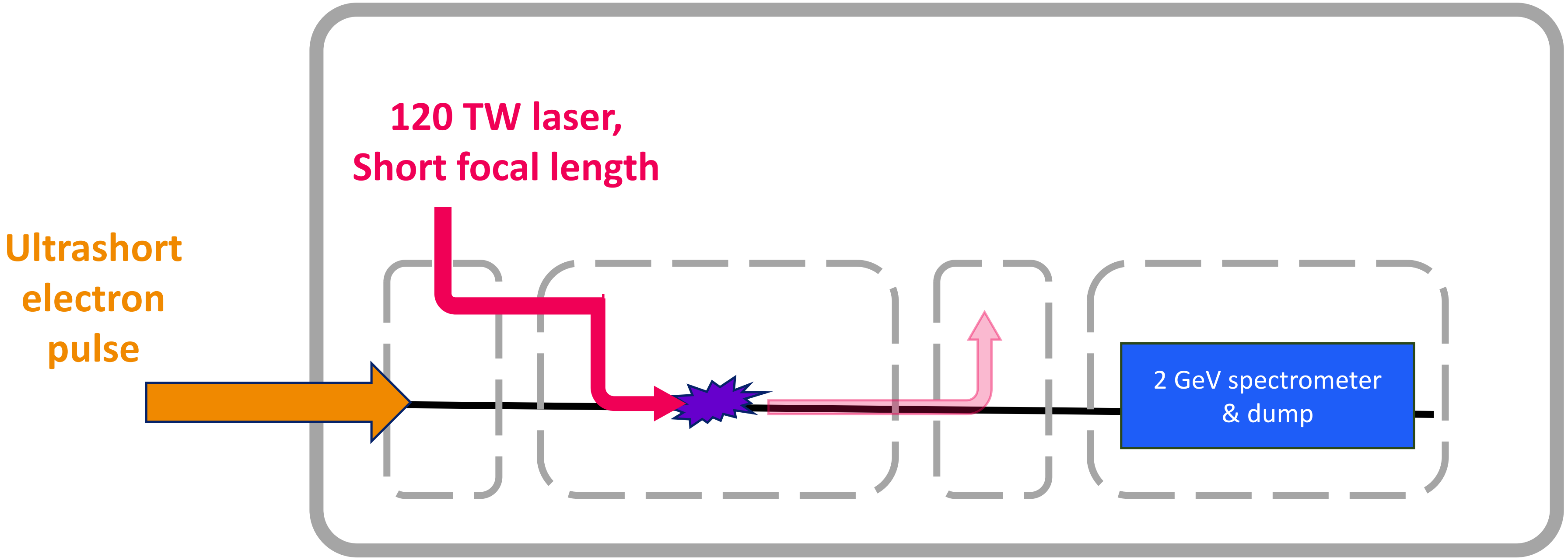
External injection - LWFA

- Witness beam stability & Staging challenges



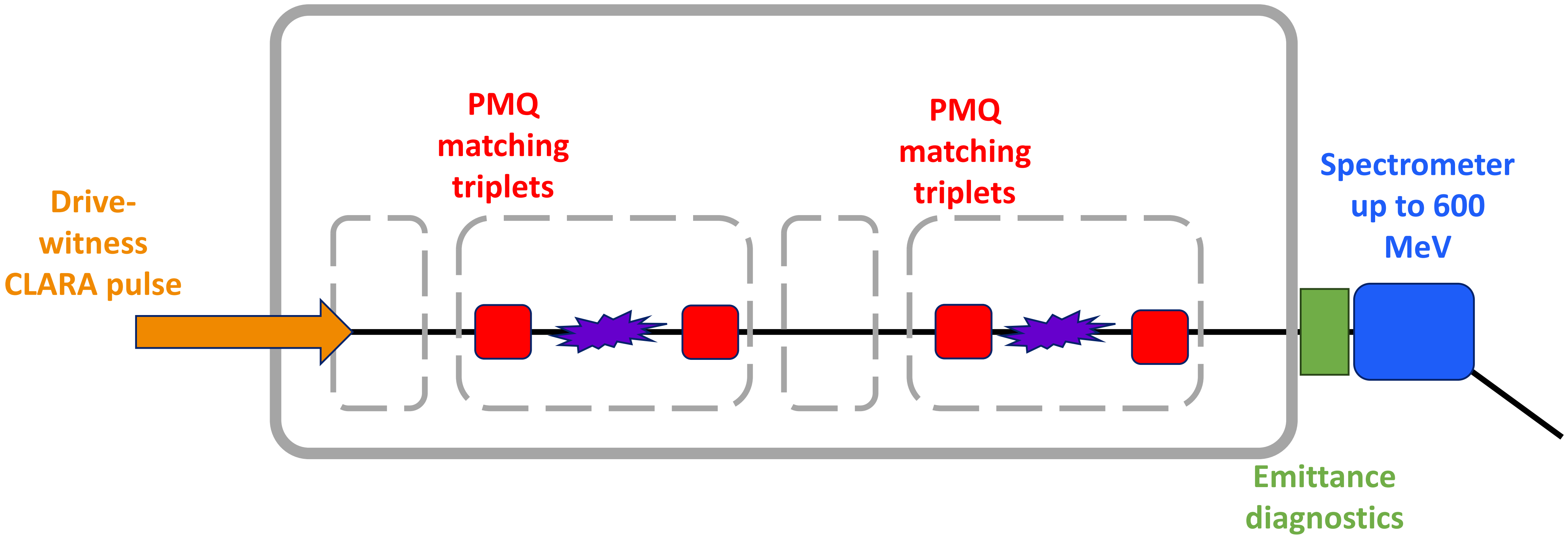
External injection LWFA

- High energy gain & energy stability

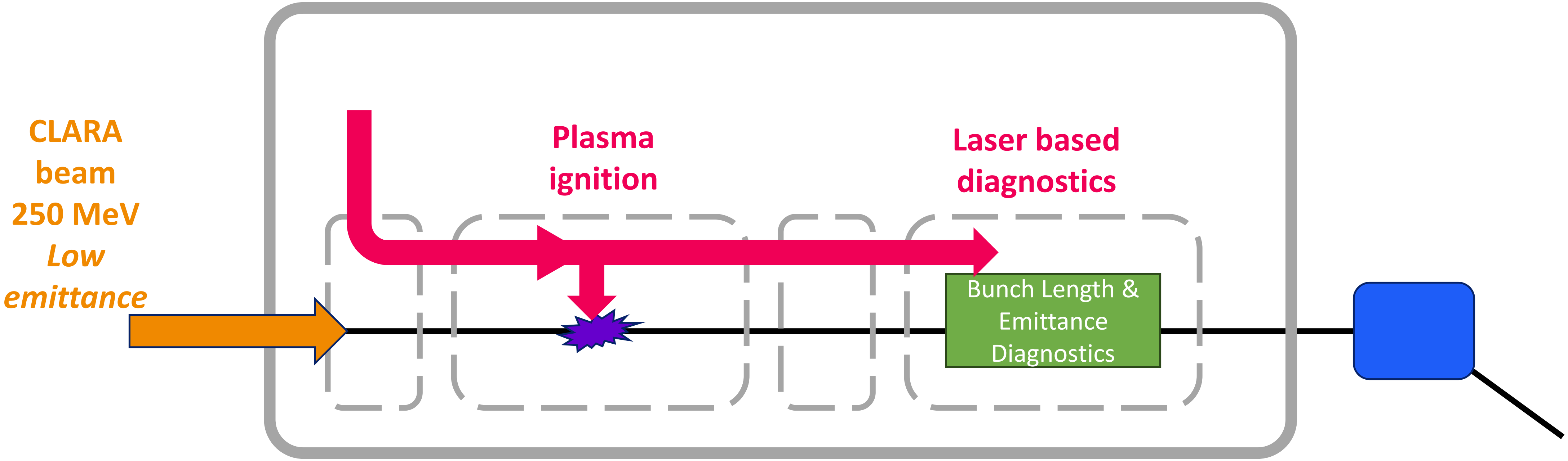


PWFA staging

- Witness beam stability & Staging challenges



Plasma based beam manipulation & instrumentation



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Summary

- FEBE represents a step change in our infrastructure and potential to perform advanced acceleration experiments

- Flexibility is at the heart of the design to support & futureproof for our community.
  - Have the potential to exploit this for strategically important R&D

- FEBE will leverage the full CLARA R&D project
  - FEL quality beam, synchronisation, modelling, controls, machine learning optimisation, etc.

- Beam commissioning starts in 2024
- First exploitation in 2025 – more information to come in 2024

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Acknowledgements

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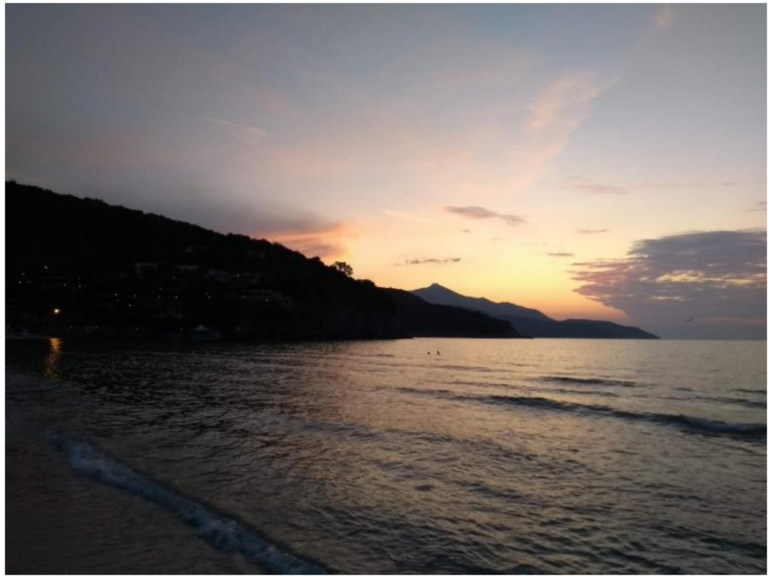
- CLARA Team, across ASTeC and STFC Technology Dept.

- EAAC'23 Organisers and Scientific Committee



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Questions?