EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA
Preparatory Phase

EPAC as the R&D Centre for 5GeV beams

Rajeev Pattathil (EPAC, UK)

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101079773. It is supported by in-kind contributions by its partners and by additional funding from UK and Switzerland.

EuPRAXIA Annual Meeting, September 20-26, 2026
Isola d'Elba, Italy

CB decision: EPAC as R&D centre for 5GeV beams

Funded by the European Union

EuPRAXIA PP CB Decision

Submitted bid-books

March 25, 2025

- Adopt the **ELI Beamlines** facility (part of ELI ERIC) as **EuPRAXIA`s second user site**. It will be the pillar for a laser driven, plasma-based Free-Electron Laser for users, in accordance with the EuPRAXIA CDR and ESFRI applications. **The facility will launch with an initial stage operating at 1 GeV electron beam energy (EuPRAXIA Phase-1)**

- Support **EPAC**'s proposal to act as the **EuPRAXIA Centre for R&D on a 5 GeV electron beam** that is produced in a compact laser-plasma accelerator and that has sufficient beam quality for the FEL application.

- Support **CNR-INO** as the **EuPRAXIA National Node in Italy for Laser R&D**, as a test facility and as an additional formal link between the two EuPRAXIA pillars in Italy and the Czech Republic.

Extreme Photonics Applications Centre (EPAC)

A new £120M facility at RAL for applications of plasma accelerators

Funded by the European Union

- Will host a 1PW laser at 10Hz driving plasma accelerators
- Designed for 10GeV electron beams and energetic protons, ions and secondary radiations
- Exploit plasma accelerators for a range of applications in industry, medicine, defence, and security as well as for fundamental science

- Installation/commissioning underway
- Operational in 2027

Laser capable of driving >5GeV beams

Funded by the European Union

Front End (OPCPA)

High gain, compact, low noise amplification.

Petawatt @ 10Hz Compressor

Large Aperture Optics in Vacuum.

Precise Alignment (µRads).

Thermal Management (500W).

Beam Transport to Experiments

High Stability Optics

Wavefront Control

Operations to multiple Experimental Areas

EPAC Phase 1

1PW@10Hz

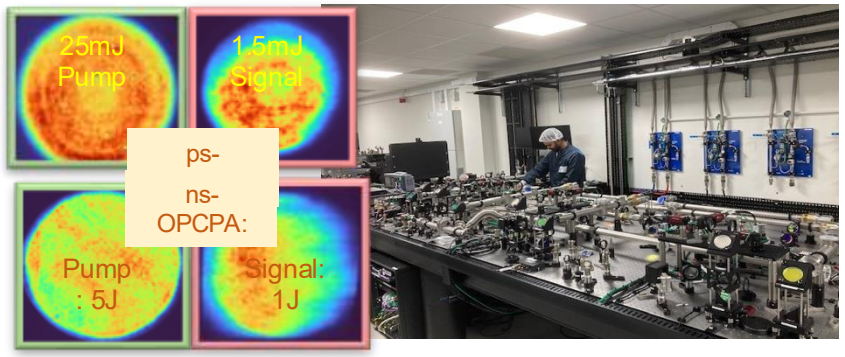
- Output Energy 30 J
- Pulse duration ≤ 30 fs
- 10 Hz, 1 Hz, SoD
- ~1% energy stability

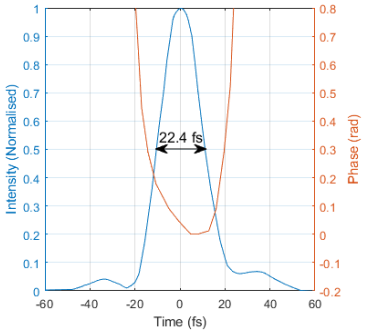
EPAC Phase 2

- Another 100J pump and another amplifier (auxiliary beamline
- Additional space for future laser and experimental areas (eg. a 100Hz system under development)

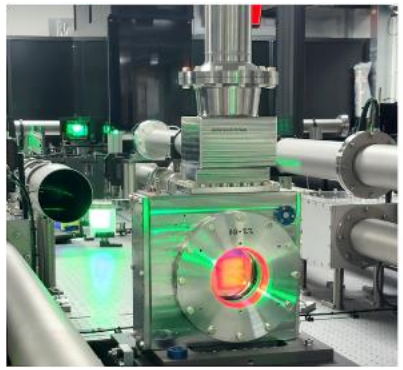
Laser commissioning in its final phase

Funded by the European Union

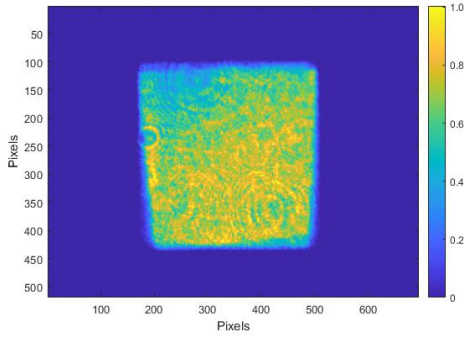




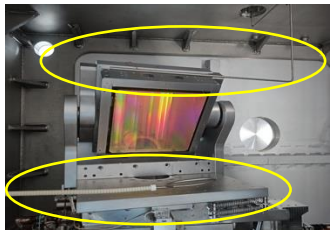
OPCPA front end: achieved 1J@ 10Hz signal output



Final Ti:Sapph amplifier: amplification of the broadband seed beam from 330mJ to 4.7J at a 1Hz pulse rate



DiPOLE pump laser operating at 100J, @ 1Hz
>70% conversion to green tested



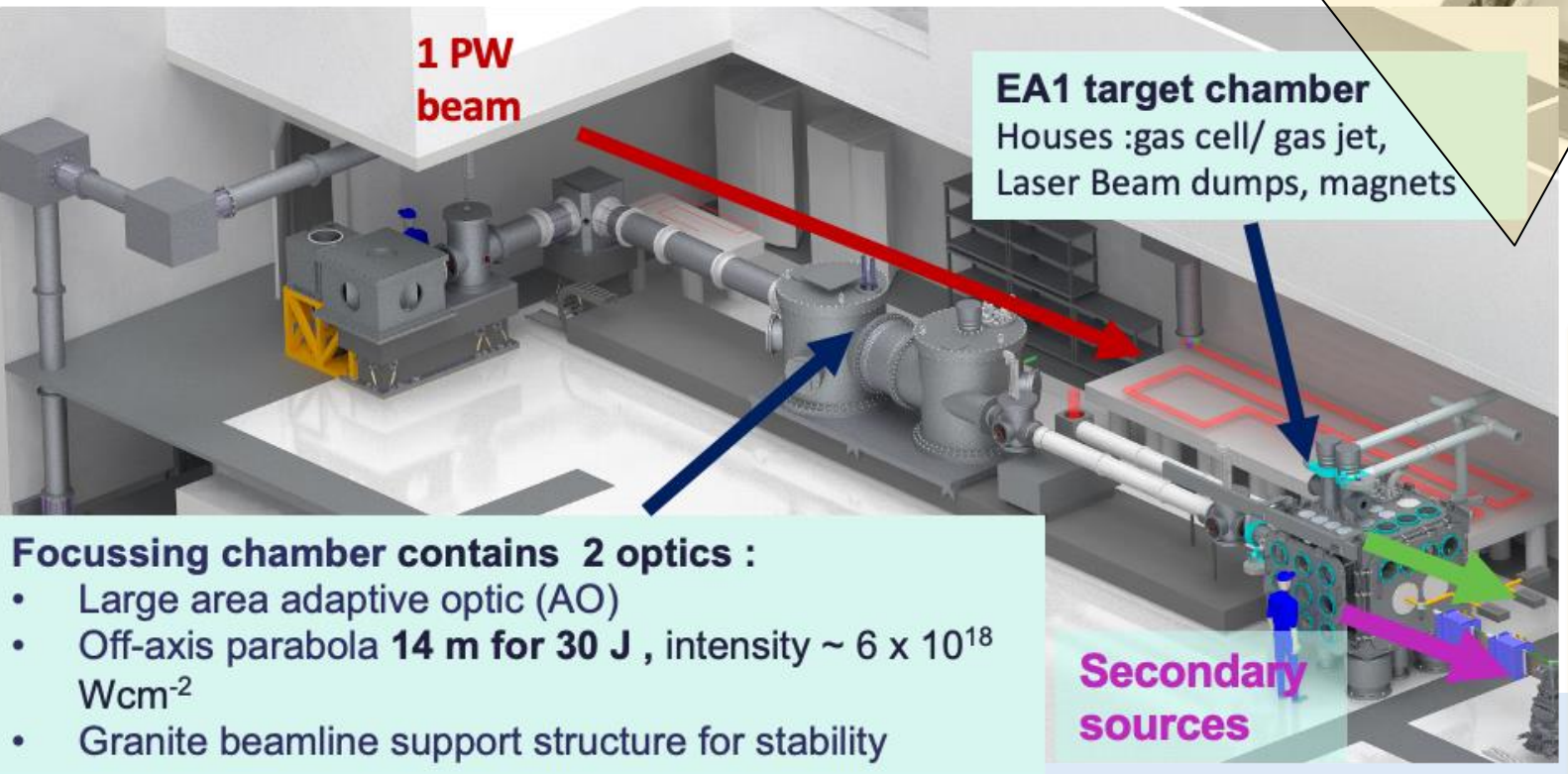
Gratings installed; aligning compressor now
Starting off with gold gratings – restricted to 1Hz operation

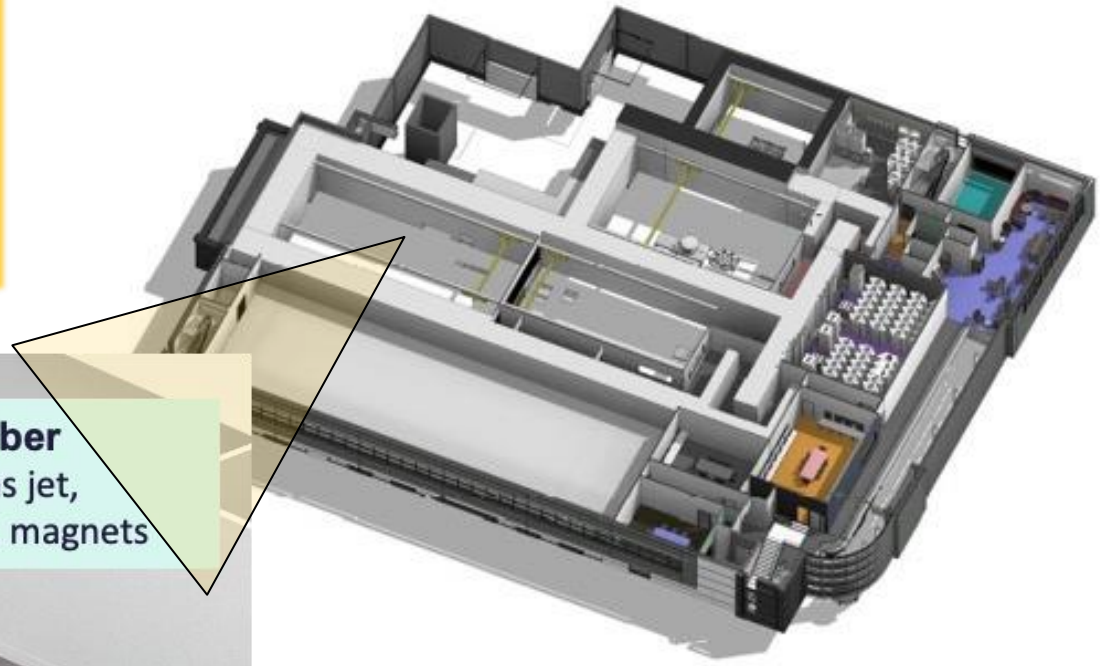
EA1 is configured for LWFA

Funded by the European Union

EPAC 1 PW drives a laser plasma accelerator

- Focused to relativistic intensity (above 10^{18} Wcm^{-2})
- Target is a few cm of gas
- Creates a plasma with extremely high accelerating fields
- Generates multi-GeV electron beams and x-rays





Focussing chamber contains 2 optics :

- Large area adaptive optic (AO)
- Off-axis parabola **14 m for 30 J** , intensity ~ 6 x 10^{18} Wcm^{-2}
- Granite beamline support structure for stability

Timeline:

2026: Commissioning with internal laser

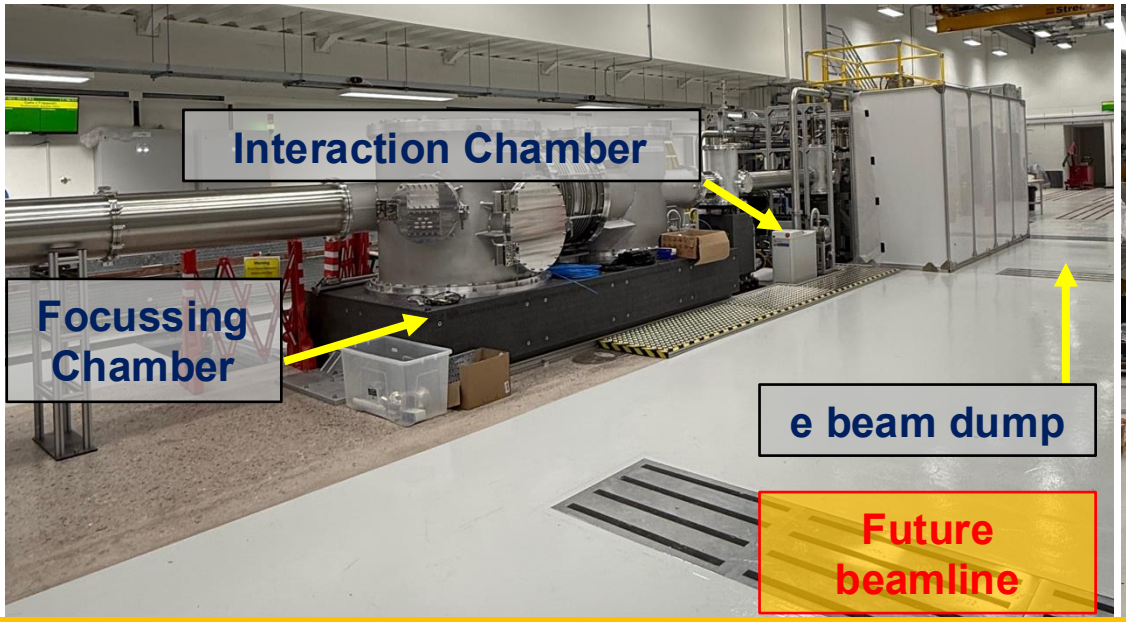
2027: Pulsed beam delivery and commissioning

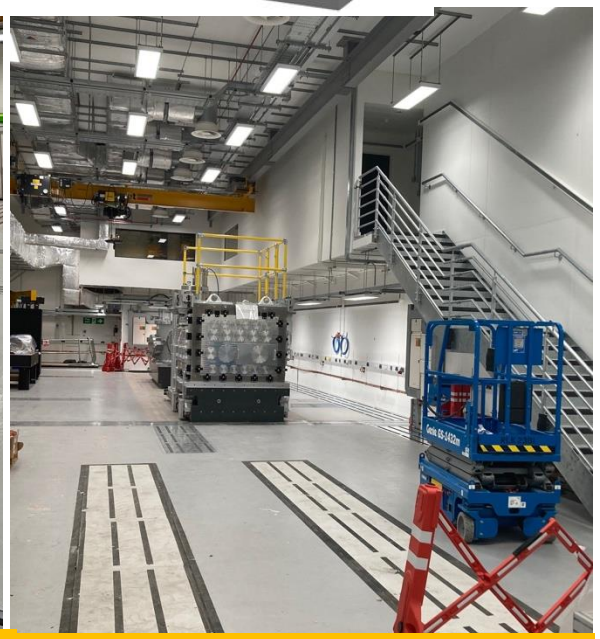
2027: Secondary source optimization

2027: Operational user facility

EA1 is getting ready for plasma accelerator commissioning

Funded by the European Union





Source area

Applications area

EA1 setup for wakefield acceleration

- Focused to relativistic intensity (above 10^{18} Wcm^{-2})
- Target is a few cm of gas

Flexible 20m x 9m area

- Electron diagnostics
- X-ray detectors
- Sample stages
- Specialist rigs

Secondary source parameters

- 0.1 – 10 GeV electrons
- 50 – 200 keV betatron
- 0.5 – 50 MeV ICS
- Muons, e^+, neutrons, γ-rays

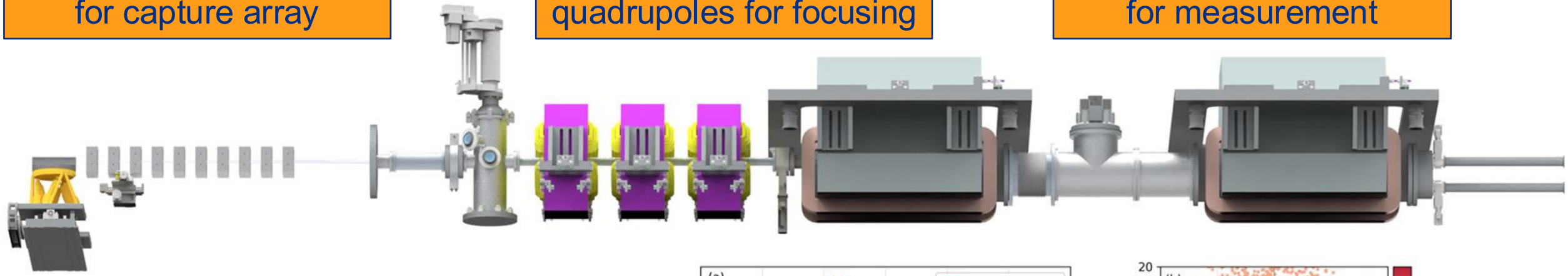
Electron beam transport will be installed during commissioning

Funded by the European Union

Permanent quadrupoles for capture array

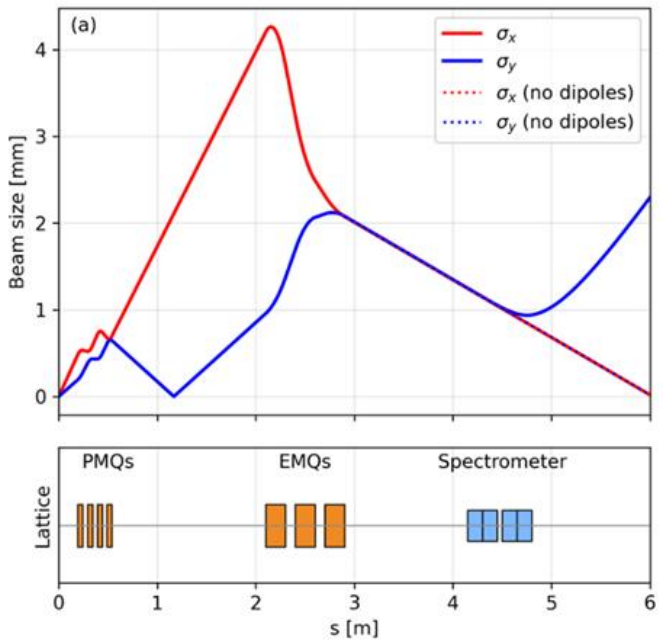
Electro-magnet quadrupoles for focusing

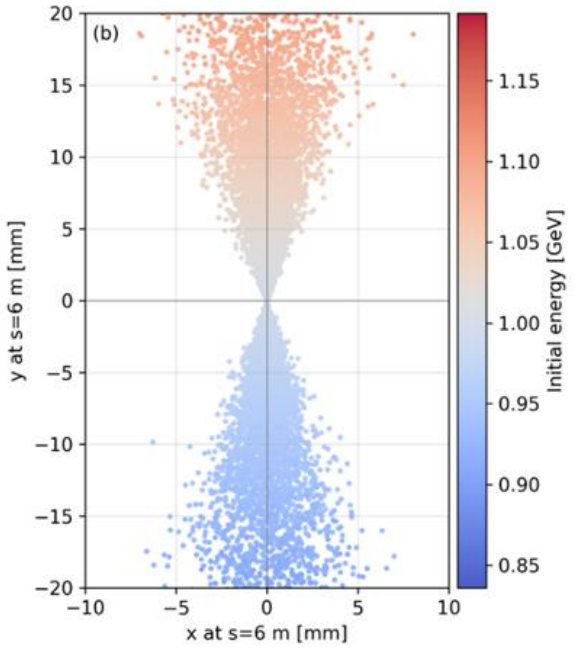
Electro-magnet dipoles for measurement



Electron focusing for:

- Diagnostics
- Irradiation applications
- Electron-laser collisions
- FEL experiments

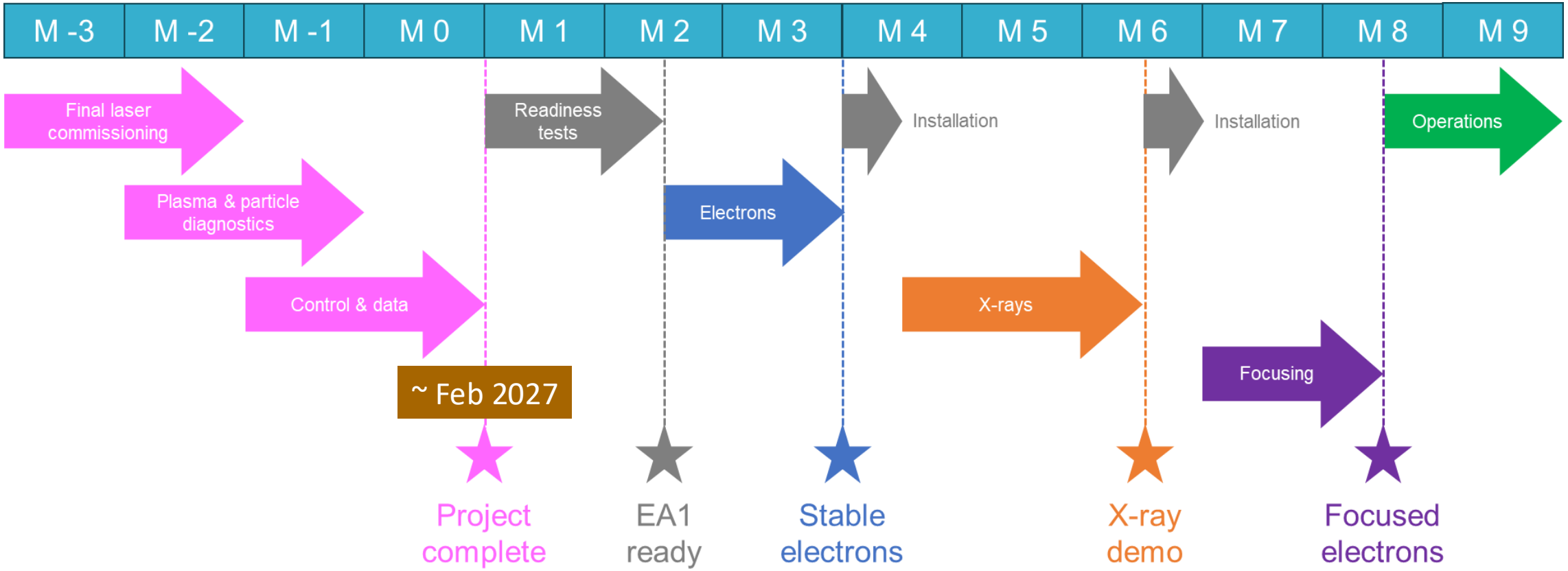




Muratori et al, PRAB (2026)

Plasma accelerator commissioning timescale

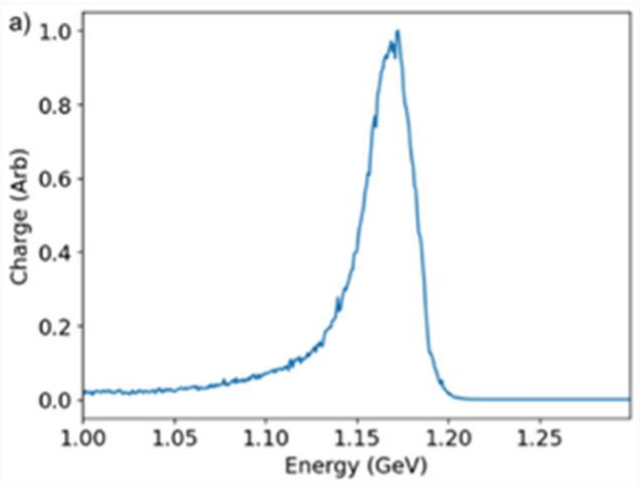
Funded by the European Union



- Testing essential requirements are ready for operations
- 3 Distinct Commissioning Phases: Optimisation of electrons, x-ray imaging and beam manipulation - estimate about 6 months
- **User involvement throughout**

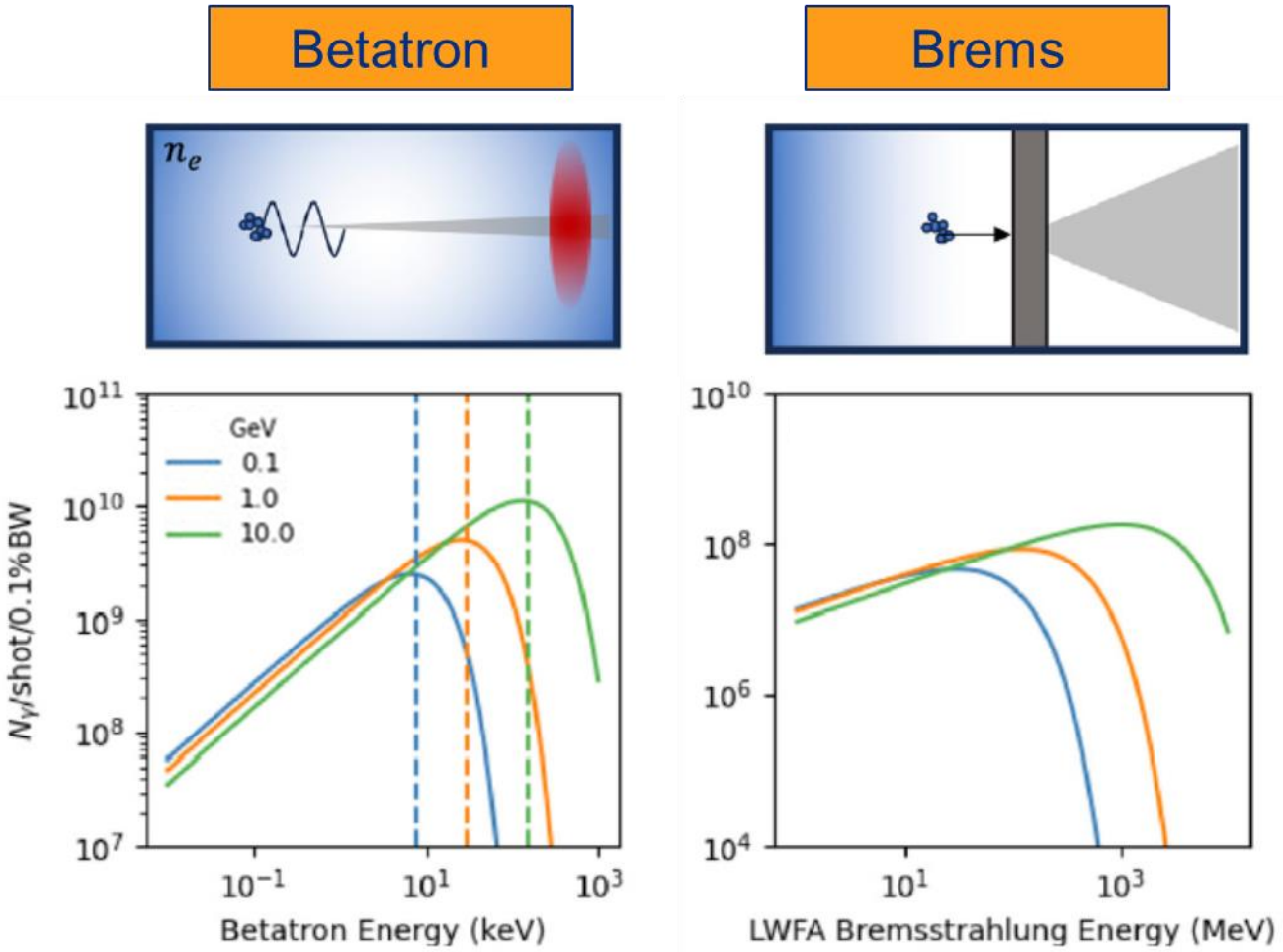
Expected parameters after the initial commissioning

Funded by the European Union



Parameter	Value
Median energy	1.17 GeV
RMS Energy Spread	2.1% (in core of beam)
Charge	200 pC (in core of beam)
Nozzle Length	20 mm

1 GeV, 200 pC
10^{10} ph/s @ 30 keV
10^{11} ph/s @ 1 MeV

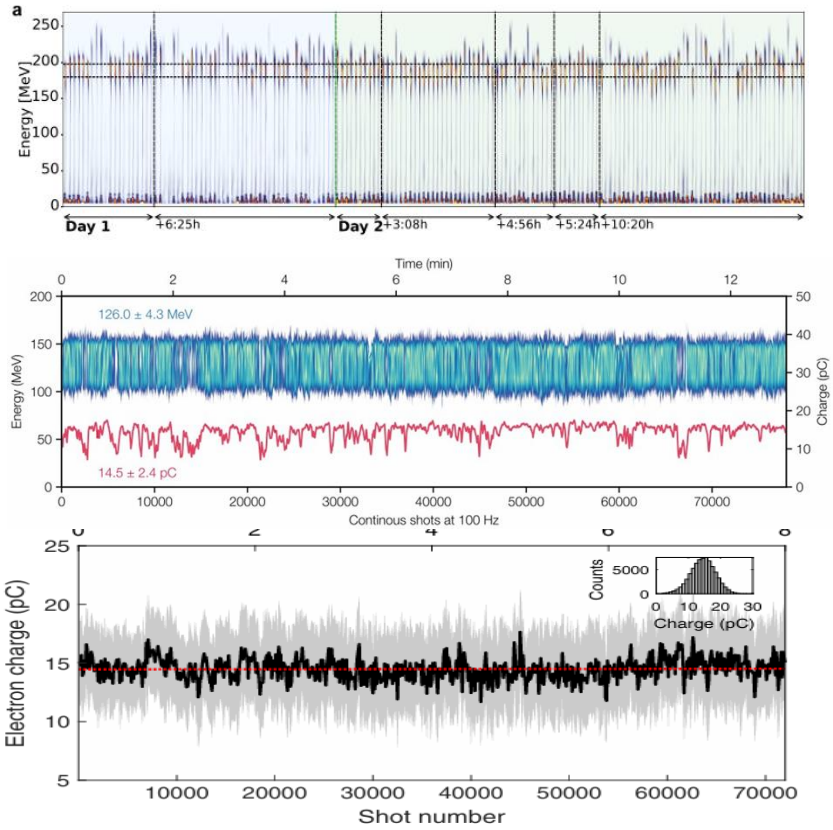


Armstrong 2023, DOI 10.3389/fphy.2023.1286442

Focusing on stable electron beam operations in the beginning

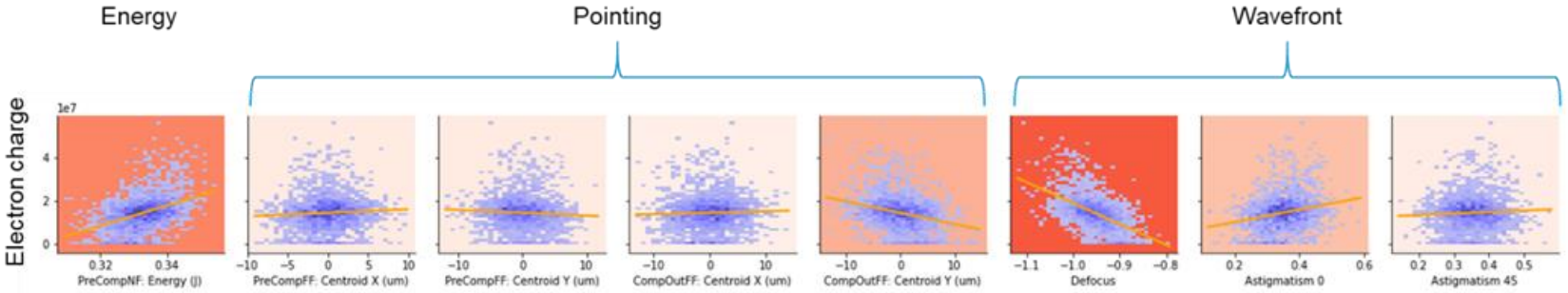
Funded by the European Union

- Stable operation over extended periods has now been shown by multiple groups (eg. DESY, BELLA…)
- We aim to match this level of performance in the PW / GeV range



© DESY, LBNL

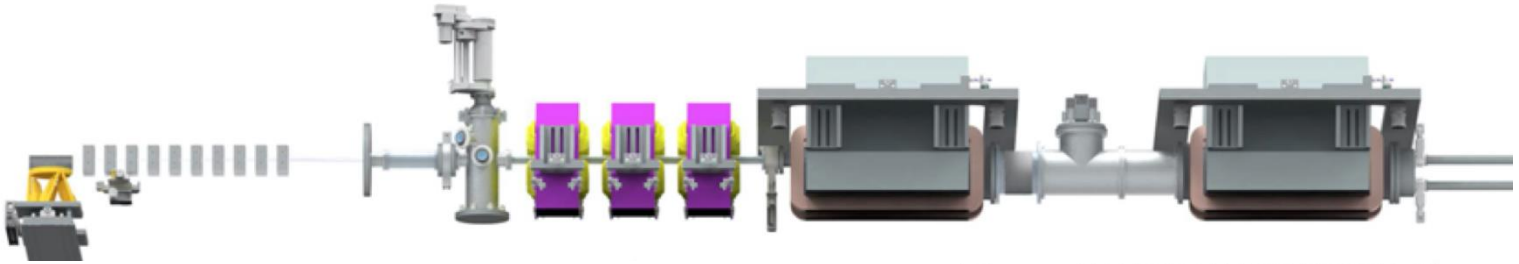
Active stabilisation systems will enable this

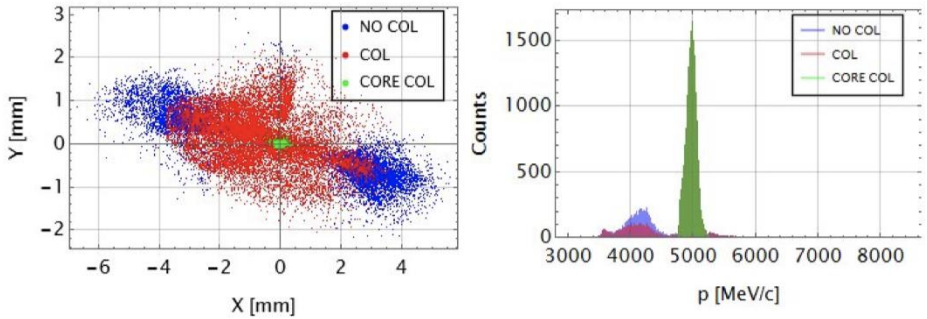


Stronger shading = stronger correlation

Moving onto high-quality multi-GeV beams: initial simulations

Funded by the European Union





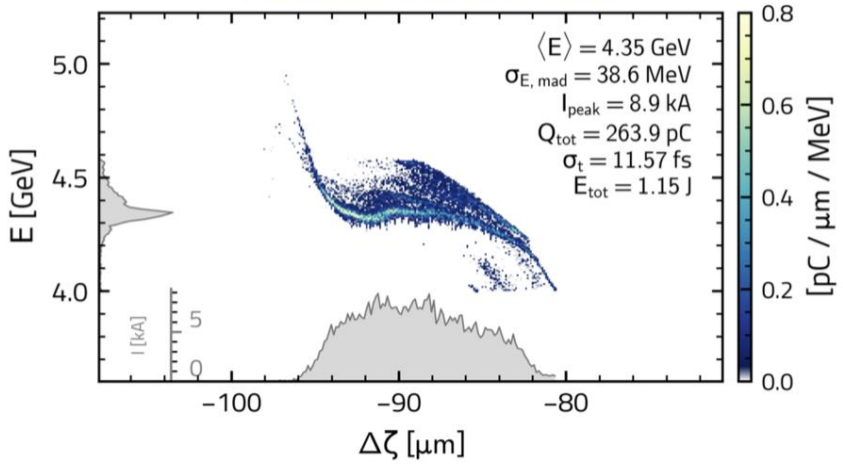
Input plasma parameters:

n_{e0} [10^{17} cm^{-3}]	L_p [mm]	Δt [ns]
2.7	200	4.5

Final electron bunch parameters:

E_b [GeV]	σ_E [%]	Q [pC]	σ_t [fs]
4.35	0.9	264	11.6

LPS at end of "acceleration" simulation



Preferred Electron Injection Scheme (Starting with Ionization Injection, moving on to Density Down-ramp Injection and Truncated Channel Injection). Details are given earlier in this Section.
An external RF injector be installed in principle, at a later phase of EPAC
Maximum energy: 10GeV possible but 5GeV case is being analysed here

Rms Energy Spread: 0.2% - 1%, depending on the configuration and optimisation routnes
Charge per bunch: 20pC-300pC, depending on the configuration and optimisation routnes
Rms pulse length: 10fs – 20fs
Rms normalized emittance (h/v): ~1 – 5 mm mrad
Rep rate: 10Hz – 100Hz

However, these simulations have limitations

Initial simulations are quite limited in accuracy

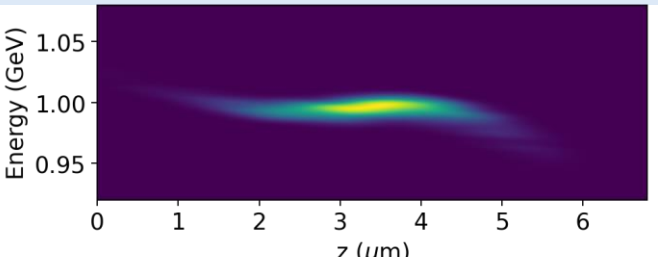
Funded by the European Union

Two types of simulations:

(a) FBPIC using the initial gas jet for 1GeV, which was then evolved into 5GeV

(b) Simulations based on HOFI scheme

- HOFI requires a ~ 500mJ – 1J channel forming beam, which is not available on day-1
- Our simulations presently assume rather simplistic target conditions – not realistic ones
- Only approximate projected and slice energy spreads
- ML based optimisation of LWFA is planned and it is possible to optimise the 6D phase space required for FEL. But do they work at multi-GeV level?
- REMPI could work but need more energy. Hybrid scheme might work (but requires work to improve TRL)
- We might need better tools to get 1mm-mrad beams



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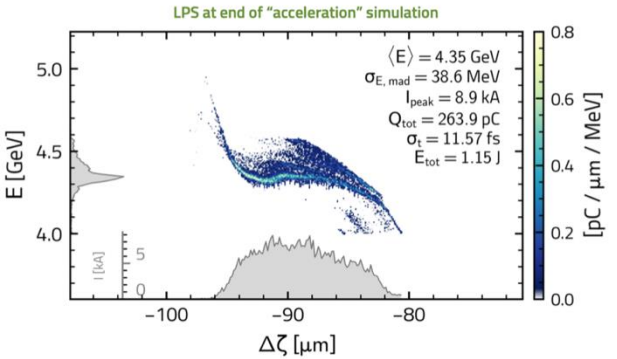

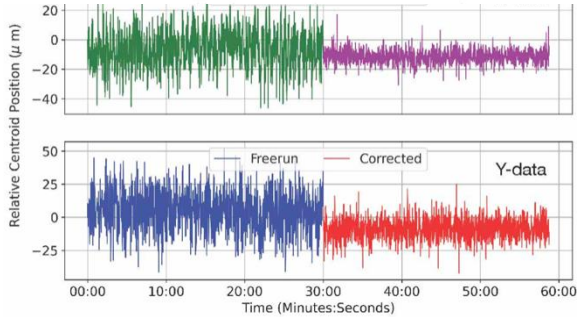

Comparison of freerun and ML-corrected jitter over one hour (Credit: Dan Wang/Berkeley Lab)

New tools and R&D required for this

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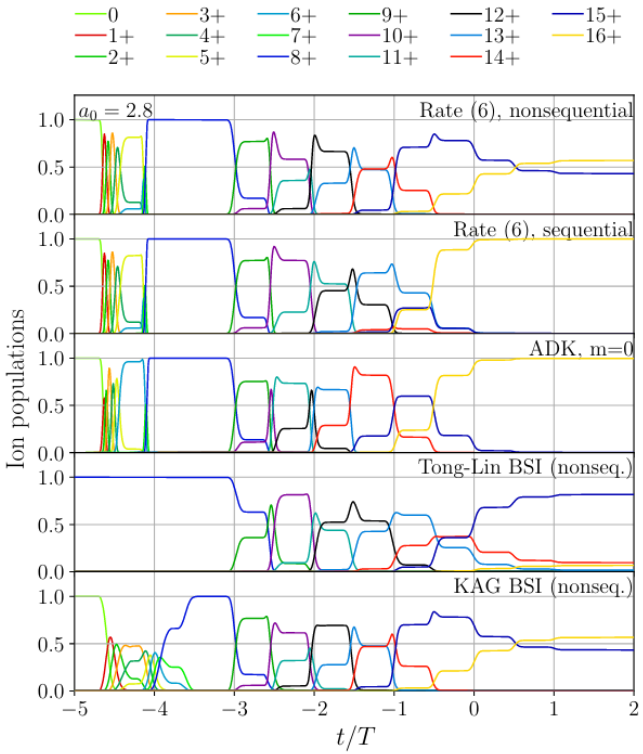
Incorporating ionisation in simulations

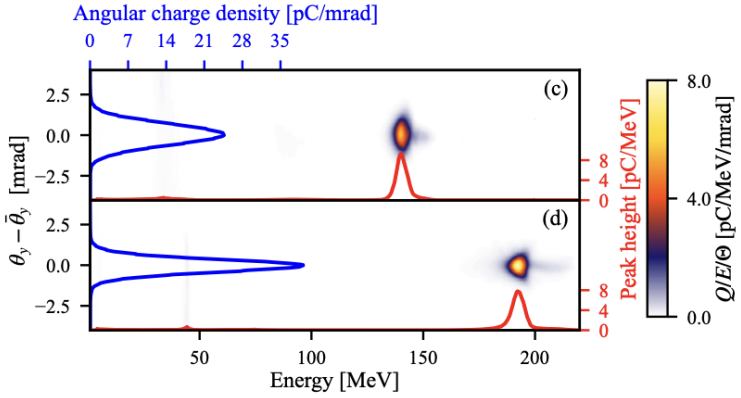


A. Mironov et al., Phys. Rev. E, Sep. 2025.

© Jorge Viera, WP8-EuPRAXIA PP

Plasma shaping

- Q = 40 pC
- E = 193 MeV, ΔE/E < 3%
- Divergence = 0.5 mrad

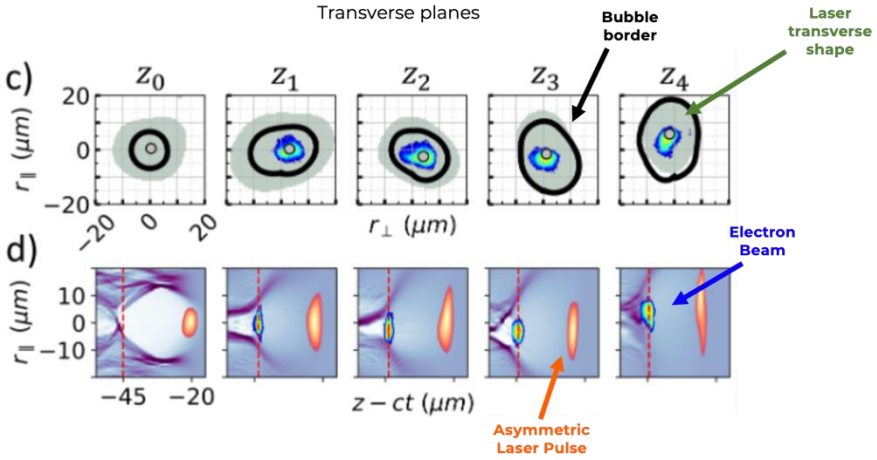


https://arxiv.org/pdf/2506.18047

Can this be done at multi-GeV levels?

@Brigitte Cros

Minimising aberrations across the focal volume



Moulanier et al., EAAC2023 Proceedings
https://hal.science/hal-04727699

Can you generate FEL-quality 5GeV beams?

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the European Union

- R&D and tools required
- Require end-to-end simulations ideally
- Proof-of-principle tests at multiple places, including ELI-BL and EPAC
- KALDERA/PETRA IV work will be a key contributor (although they don't have the temporal structure restrictions)
- Interesting works starting in BELLA with GeV-FEL drivers

- Programmatic access needs to be considered for this R&D
- MoU/Collaboration agreements can incorporate options:
  - Direct funding during EuPRAXIA implementation phase
  - Separate Horizon grants
  - UK's international collaboration funding schemes (eg. ISPF)