EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA Preparatory Phase

WP8 - Overview of activities

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WP8 members and goals

Funded by the European Union

Objective: Steer the scientific and technical progress on Theory & Simulations of Plasma Accelerator and related application. The WP should also define the computing power needed to perform a full 3D numerical model of the Distributed research facility.

Institution	Role
IST	Leader
CEA	Co-leader
GSI	Participant
INFN	Participant
CNR	Participant
DESY	Participant
CNRS	Participant
ELI	Participant
CLPU	Participant
UCLA	Participant
Swiss FEL	Participant

Overview

- **Deliverable** D8.1 (M12) - Report on structures to be funded from national/bilateral/european level for simulation & theory
  - Definition of the Centre of Excellence (CoE) for theory and simulations
- **Deliverable** D8.2 (M24) - Report on results achieved in the field of theory and simulations
  - LWFA modelling studies for potential site 2 candidates (ELI and CNR – see talk by Paolo Tomassini Friday)
  - Start-to-end modelling (Talk by Maxence Thevenet)
  - Realistic laser modeling in simulations (Talk by Francesco Massimo)
  - A novel hybrid-target injector for high-charge laser-driven electron acceleration (Talk by Luca Fedeli)
  - Arbitrary injection of laser pulses (Talk by Jorge Vieira)
- **Deliverable** D8.3 (M46) - Report on status of EuPRAXIA simulated performances

Start-to-end modelling chain

Element in chain

- Laser
- Conventional beam lines
- Gas jet
- Plasma profile
- Plasma accelerator
- Free electron laser

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Start-to-end modelling chain

Element in chain	Code/algorithm
Laser	GSA algorithm
Conventional beam lines	Several codes: TaceWin, Trace 3D, MADX, Astra, GPT, Elegant, G4BL …
Gas jet	TBD
Plasma profile	Openfoam, Ansys/Fluent
Plasma accelerator	Osiris, Smiley, FBPIC, EPOCH
Free electron laser	Osiris, Genesis, Simplex

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Start-to-end modelling chain

Element in chain	Code/algorithm	Input
Laser	GSA algorithm	Laser fluence
Conventional beam lines	Several codes: TaceWin, Trace 3D, MADX, Astra, GPT, Elegant, G4BL …	6D phase-space (e.g., from PIC)
Gas jet	TBD	TBD
Plasma profile	Openfoam, Ansys/Fluent	none identified
Plasma accelerator	Osiris, Smiley, FBPIC, EPOCH	6D beam phase-space, laser e.m. profile, gas jet and plasma profile
Free electron laser	Osiris, Genesis, Simplex	6D beam phase-space from PIC

Start-to-end modelling chain

Element in chain	Code/algorithm	Input	Output
Laser	GSA algorithm	Laser fluence	Full spatiotemporal laser profile
Conventional beam lines	Several codes: TaceWin, Trace 3D, MADX, Astra, GPT, Elegant, G4BL …	6D phase-space (e.g., from PIC)	6D phase-space
Gas jet	TBD	TBD	TBD
Plasma profile	Openfoam, Ansys/Fluent	none identified	plasma spatial profile
Plasma accelerator	Osiris, Smiley, FBPIC, EPOCH	6D beam phase-space, laser e.m. profile, gas jet and plasma profile	Phase-space of accelerated bunch
Free electron laser	Osiris, Genesis, Simplex	6D beam phase-space from PIC	Radiation intensity evolution

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EPOC simulations show feasibility of compact LWFA for FEL applications at ELI

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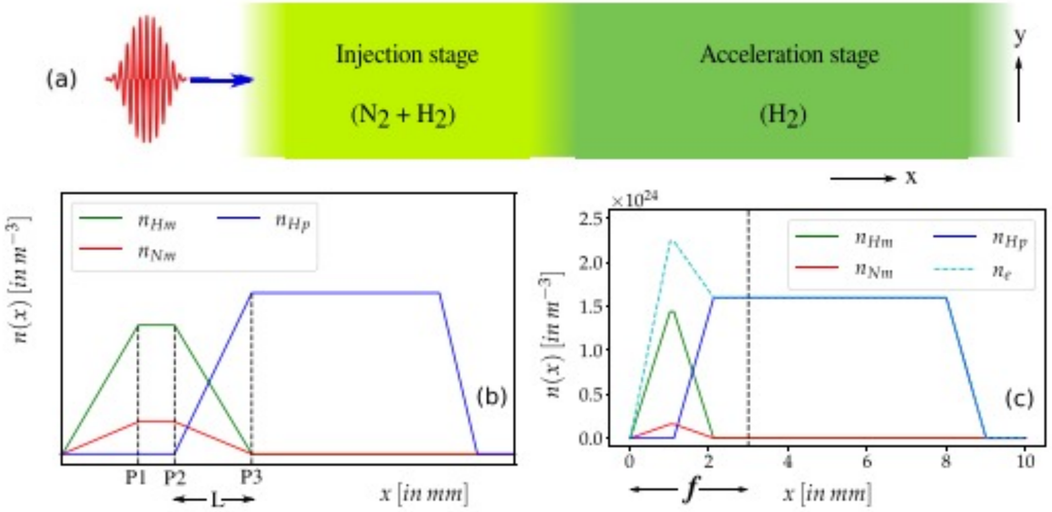
Truncated ionisation injection



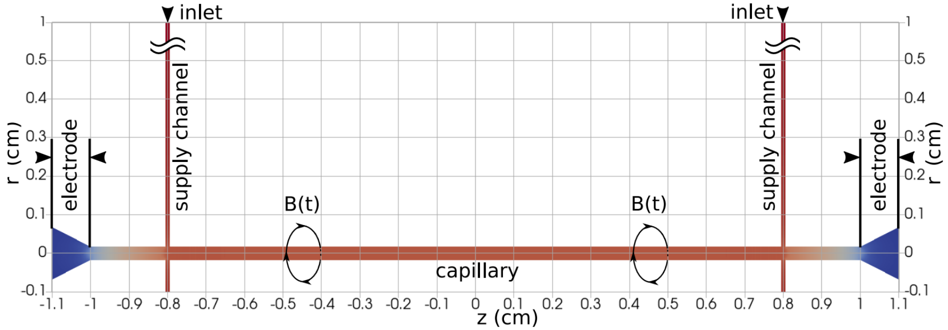
LWFA using parameters available at ELI:

- **500-600 MeV**
- **ΔE/E < 5%**
- **ε_N ~ 1.5 mm-mrad**
- **Q ~ 2-5 pC/µm**

Srimanta Maity et al., PPCF 66 No 3 Feb 7 (2024) **DOI** 10.1088/1361-6587/ad238e

Capilary repetition rate

- **Main goal**: to determine recovery time of the initial neutral gas distribution because it sets the highest possible rep rate.
- 3D MHD simulation of plasma dynamics during capillary discharge
- Simulation of plasma and gas dynamics between electric current pulses

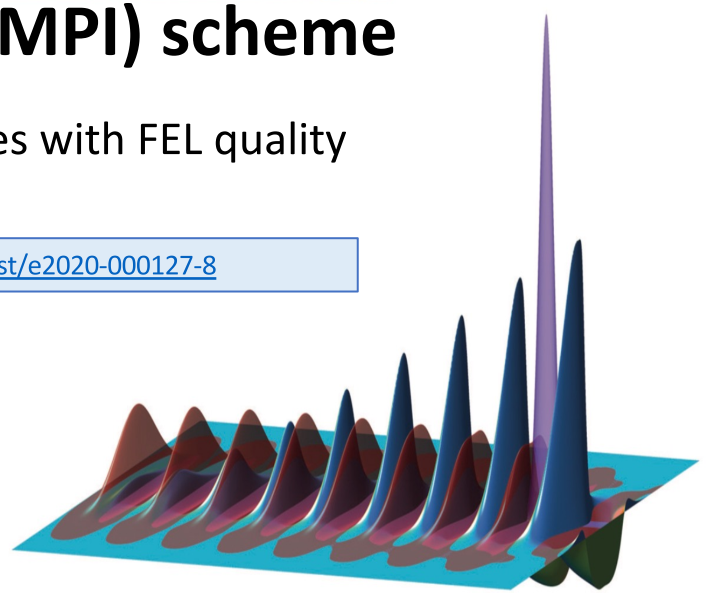


Conclusion: Our parameters allow 10 kHz repetition rate

P. Sasorov, et al. Phys. Rev. Res. **6**, 013290 (2024)

The REsonant Multi-Pulse Ionization Injection (REMPI) scheme

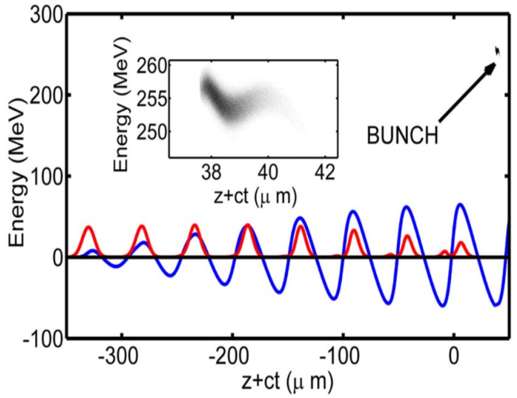
Motivation: Within the EuPRAXIA project we aim at generating 4.5/5GeV bunches with FEL quality



R. Assmann et al., "EuPRAXIA Conceptual Design Report" The European Physical Journal Special Topics **229**, 3675–4284 (2020); https://doi.org/10.1140/epjst/e2020-000127-8

Bunch specifications - GOAL:	dE/E SLICE	ε_n SLICE	Q	I_{peak}
	<0.1%	**<0.1 mm mrad**	>30 pC	>2kA

- This is a very challenging working point for a plasma-based accelerator.
- We developed a laser-driven scheme, the *Resonance Multi-Pulse Ionization Injection scheme (REMPI [1])*
- The REMPI scheme combines the most advanced concepts conceived to date in LWFA to deliver high quality electron beam to drive an X-ray FEL.



[1] P. Tomassini et al., "The resonant multi-pulse ionization injection," Physics of Plasmas 24, 103120, 2017.

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Conclusions

- **LWFA driven FEL modelling for second site candidates**
  - Second-site tailored electron acceleration studies
  - Simplified resonant multi-pulse ionisation injection: focus on ultra-short electron bunch production. Energy spread not yet compatible with FEL lasing in simulations
  - Ionisation truncated injection: need to further reduce energy spread to obtain lasing
- **New computing tools and concepts:**
  - Newly developed computational algorithms allow numerical modelling realistic lasers
  - Novel concept for superradiant emission in LWFA/PWFA
- **Additional future steps:**
  - Adding realism to numerical modelling
  - Superradiant radiation source concepts
- **Science issues**
  - The energy spreads for second site candidate simulations are not yet at the level compatible with FEL lasing
  - Need to include role of non-ideal conditions

27 nm FEL lasing using LWFA beams was demonstrated

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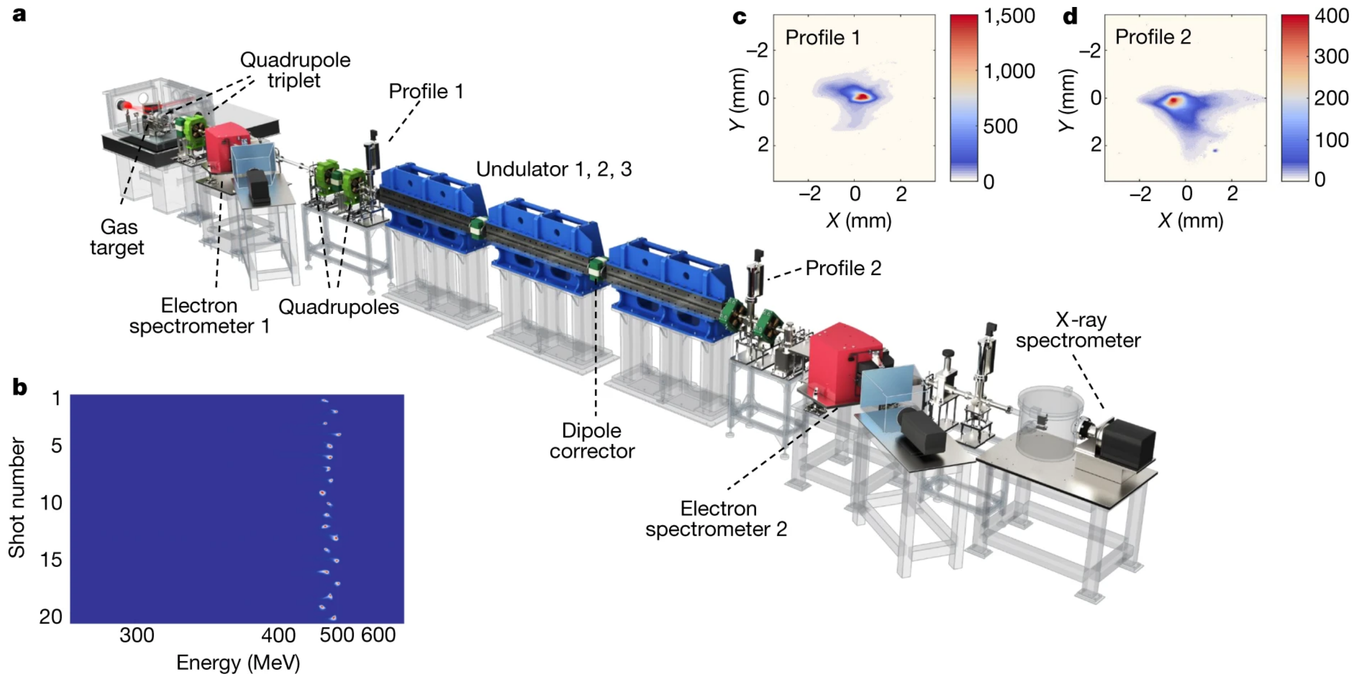
Proof of principle experiments of basic EuPRAXIA second site concepts exist. Main challenge: meet beam quality criteria (energy spread and emittance) to obtain lasing at higher electron energies.

Plasma down-ramp injection produce electron bunches with ΔE/E<1%



W. Wang *et al.* Nature **595**, pages 516–520 (2021)

Lasing experimental results