High Repetition Rate LWFA with all-optical guiding for user experiments at ELI Beamlines

Gabriele Maria Grittani

J. Šišma, M. Nevrkla, F. Vitha, S. Lorenz, I. Zymak, A. Špádová, A. Kollárová, M. Jech, A. Jančárek, D. Peceli, C. M. Lazzarini, L. V. N. Goncalves, P. Valenta, S. V. Bulanov (ELI Beamlines)

J. E. Shrock, E. Rockafellow, A. J. Sloss, G. Brewster, B. Miao, S. W. Hancock, H. M. Milchberg (UMD)

Advanced Accelerator Concepts, UCLA, 30th July 2026

A European Research Infrastructure Consortium

Acknowledgments

C. M. Lazzarini, M. Nevrkla, S. Lorenz, F. Vitha, J. Sisma, A. Spadova, A. Kollarova, L. Vilanova, M. Jech, I . Zymak, P. Valenta, A. Cimmino, D. Horvath, R. Versaci, B. Rus, P. Szotkowski, J. Novak, R. Antipenkov, A. Grenfell, V. Sobr, P. Bakule, D. Kramer, C. Kamperidis, D. Papp, N. Hafz, K. Hideghety, J. Dudas, R. Szabo, R. Molnar, S. V. Bulanov, P. Tomassini, D. Margarone

Kansai Photon Science Institute: A. Pirozhkov, T. Wei, M. Kando

H.-K. Liu, C.-E. Lin, P. Chen

CNR-INO Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche: L. Labate, L. A. Gizzi

J. Williams, B. Pagano, F. Treffert, S. Kerr

E. Gerstmayr, C. MacAnespie, K. Fleck, G. Sarri

B. Reagan, J. Rocca

J. Shrock, E. Rockafellow, A. Sloss, G. Brewster, S. Hancock, H. Milchberg

T. Ditmire, C. Hojbota, M. Hegelich

B. K. Russell

Berkeley Lab: S. S. Bulanov

University of Michigan: A. G. R. Thomas, R. Herbst, Y. Ma

- The Extreme Light Infrastructure and the ELI Beamlines User Facility
- Development of the laser electron acceleration user program at ELI Beamlines
- 0.2 Hz and 3.3 Hz LWFA with all-optical guiding in ELBA laser electron collider
- 1 kHz LWFA with all-optical guiding in ALFA beamline

The Extreme Light Infrastructure (ELI)

Bringing together a world of science

ELI is an international research infrastructure with the world's largest and most advanced collection of high-power and high-repetition-rate lasers

CZECH REPUBLIC HUNGARY ITALY LITHUANIA BULGARIA

GERMANY ROMANIA SLOVAKIA MONTENEGRO

ELI operates as a **European Research Infrastructure Consortium** (a legal entity under EU law, created by EU countries and partners to develop and operate pan-European research infrastructures).

AN ESFRI LANDMARK PROJECT

ELI User Portal

Integration of the ELI Facilities

Consistent excellence across three facilities

ELI Beamlines Facility

High-Energy Beam facility, develops and applies ultra-short pulses of ultra-intense radiation to explore extreme conditions or produce high-energy particles and radiation.

DOLNÍ BŘEŽANY, CZECH REPUBLIC
SINCE 1 JANUARY 2023

ELI Attosecond Light Pulse Source Facility

Attosecond Light Pulse Source, offers unique time-resolved investigation possibilities for both nonrelativistic and relativistic interaction of light with all the four states of matter.

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SINCE 1 JANUARY 2024

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MĂGURELE, ROMANIA

ELI User Portal

One user facility, three modes of access

A flexible model to serve a variety of users

A

Excellence-based Access

Evaluation of proposals by international peer-review panels.

RESULTS PUBLISHED AND OPEN

B

Mission-based Access

Thematic research granted on the basis of scientific missions. Proposals reviewed by international panels.

RESULTS PUBLISHED AND OPEN

C

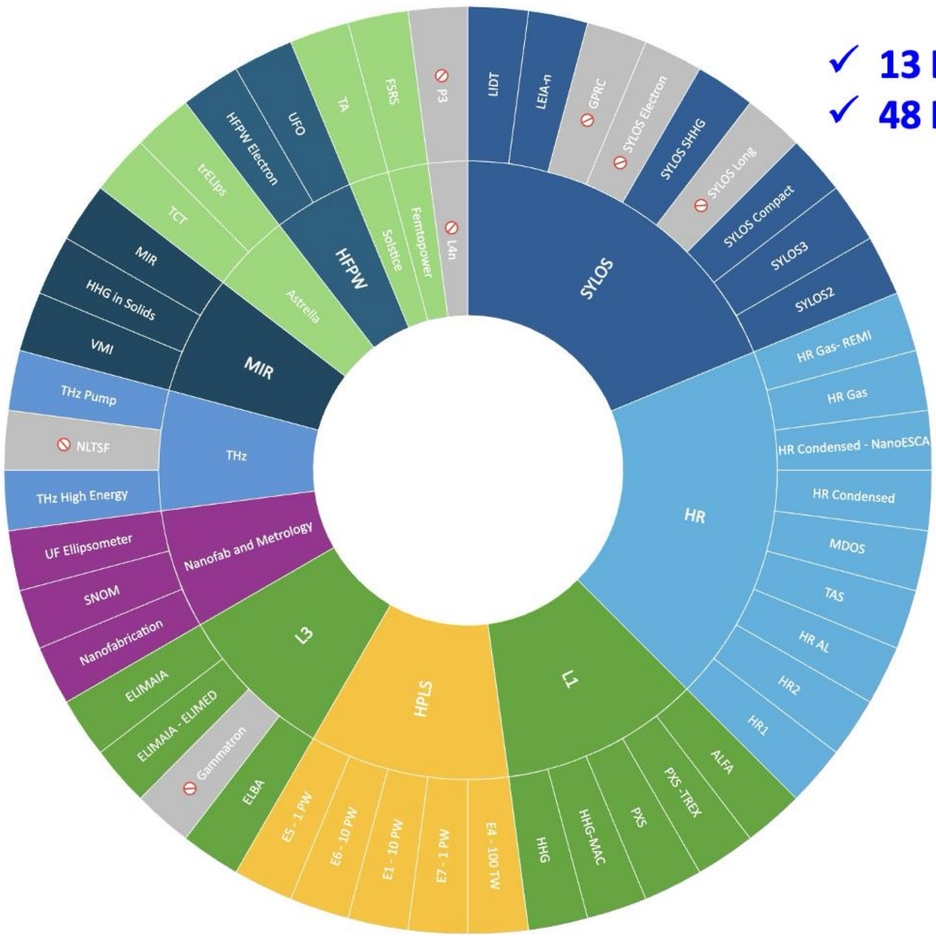
Proprietary Access

Paid access for industrial or other users.

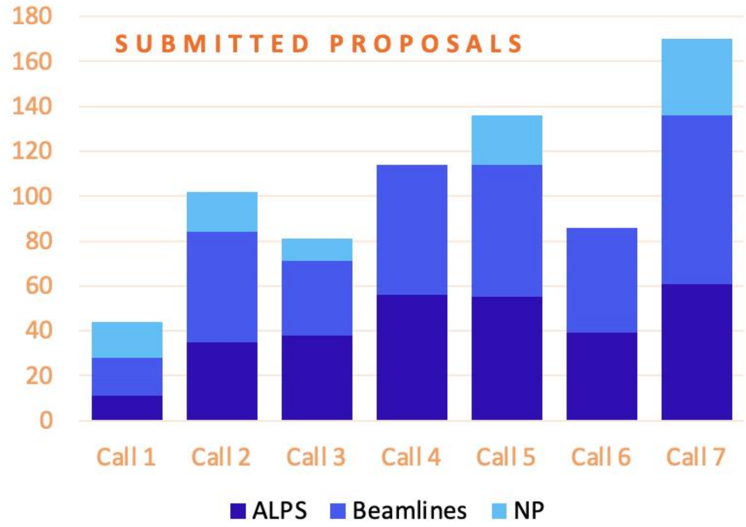
RESULTS RETAINED BY THE USER

The ELI User Programme

Growing user engagement from Call 1-7



✓ **13 Lasers**
✓ **48 Instruments**

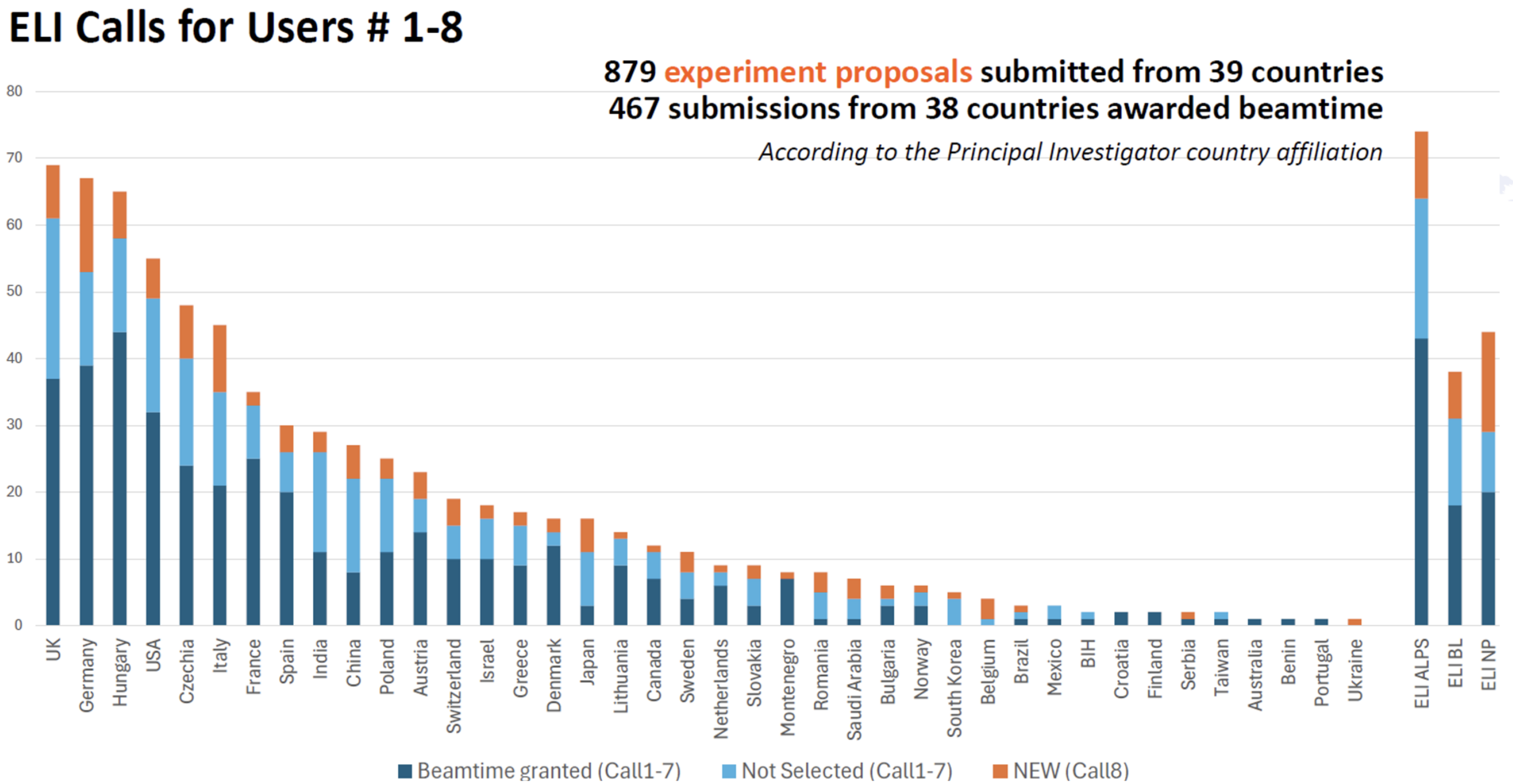


Experiment Proposals Submitted and Awarded Beamtime						
Year	User Call	ELI Facilities Combined		ELI Facilities Individually		
				Proposals Received / Proposals Accepted		
		Proposals Received	Proposals Accepted	ELI ALPS	ELI Beamlines	ELI NP
2022	1st	44	29	11/8	17/17	16/4
2023	2nd	102	67	35/32	49/31	18/4
2023	3rd	81	58	38/28	33/26	10/4
2024	4th	114	75	56/43	58/32	0/0
2024	5th	136	90	55/35	59/39	22/16
2025	6th	86	50	39/26	47/24	0/0
2025	7th	170	98	61/44	75/35	34/19
Total	**1-7**	**733**	**467**	**295/216**	**338/204**	**100/47**
Acceptance Rate		**≈ 64%**		**≈ 73%**	**≈ 60%**	**≈ 47%**

ELI User Portal

A growing user community

Submitted vs Granted ***Proposals***



ELI User Portal

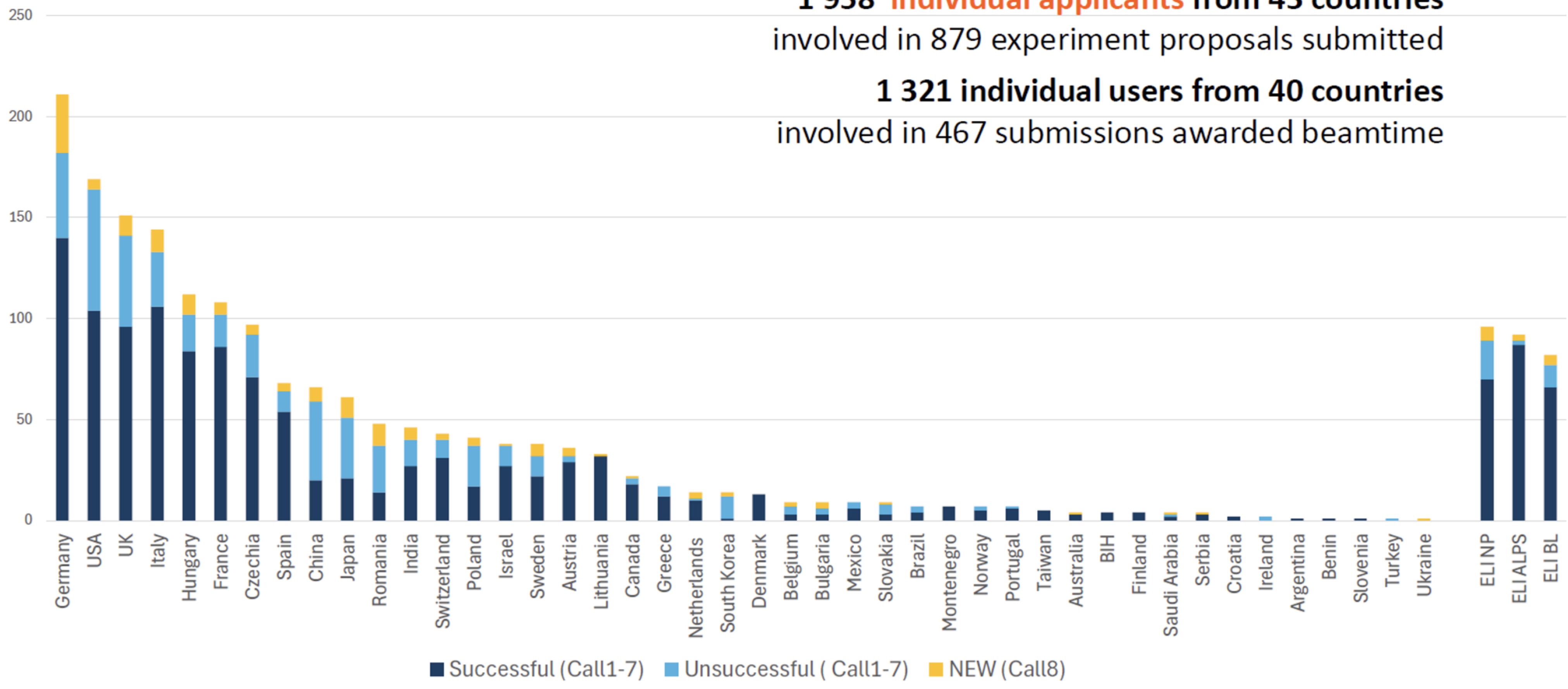
A growing user community

*Number of **Applicants** (Users)*

ELI Calls for Users # 1-8

1 958 **individual applicants** **from 43 countries**
involved in 879 experiment proposals submitted

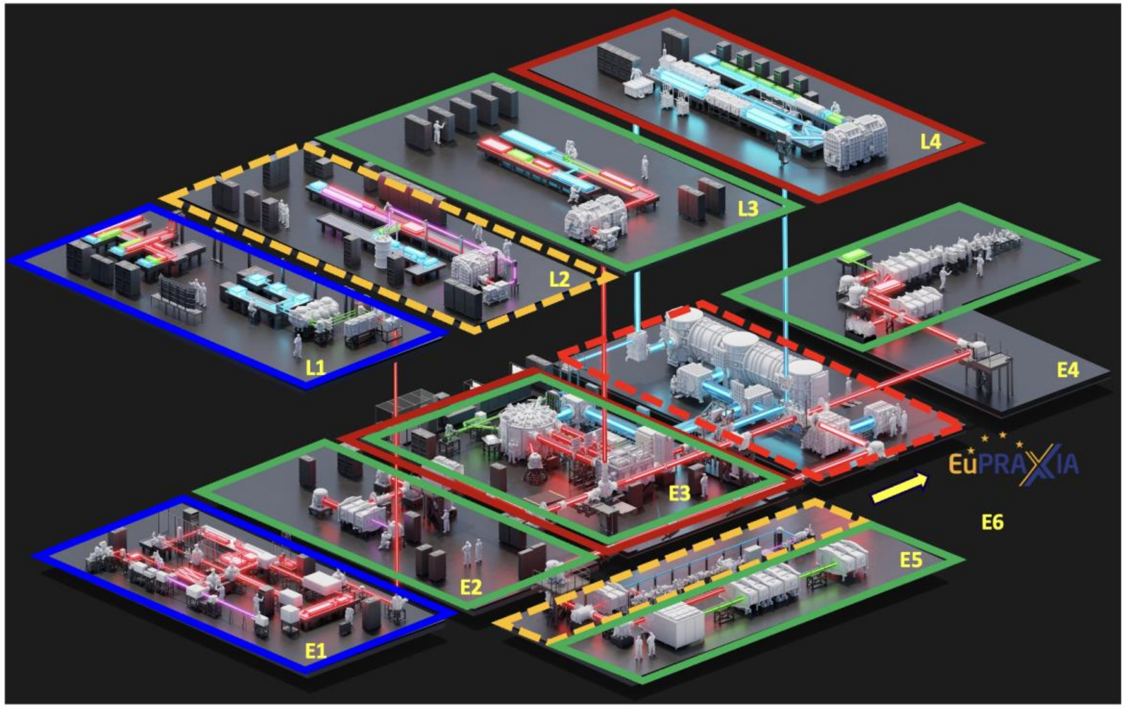
1 321 individual users from 40 countries
involved in 467 submissions awarded beamtime



ELI Beamlines Lasers

ELI User Portal

- L1-E1 user operation (Call1)
- L3-ELIMAIA user operation (Call2)
- L3-ELBA/ELIMED user operation (Call3)
- L3-Gammatron (Call5)
- L3-P3 SFL/LFL (IFE mission)
- L4n-P3 user operations (Call2)
- L4f 10PW (Call9)
- L2-LUIS (R&D)



User Science Areas and Mission

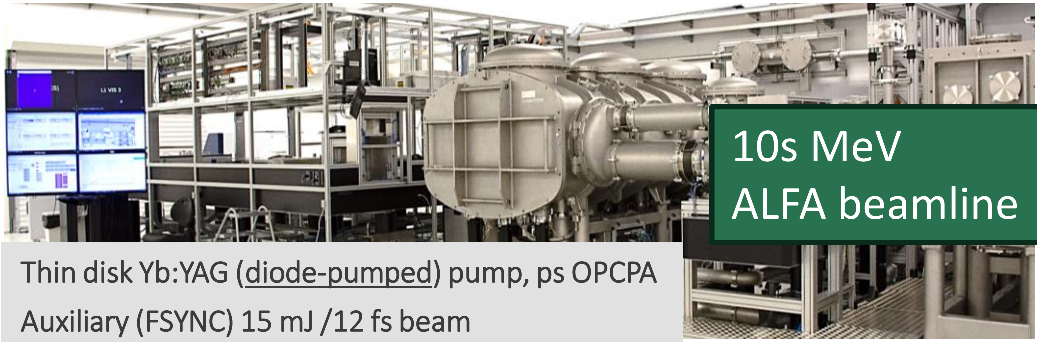
- ✓ Exploit **high-energy** and **high-flux particles and photons** through dedicated beamlines driven by high-energy and high repetition-rate (**high average power**) **PW-class** lasers for ultrafast **radiobiology**, ultrahigh dose-rate/FLASH **radiotherapy** research, **material** science, etc.
- ✓ Deliver **ultrahigh laser intensities** (>10^{22} W/cm^2) on target for **high-field** physics, including **SF-QED** (kJ-class and 10s-J-class, high rep. rate lasers)
- ✓ Exploit multi-beam configurations in exp. stations for **pump-probe** setups to study **ultrafast dynamics** in the **kHz** regime (**AMO** science and **structural biology**) and in the **kJ/ns** regime (**HEDP,** including **IFE** research)

ELI Beamlines Lasers

ELI User Portal

L1-ALLEGRA 100mJ/12fs/1kHz (>5TW) laser system

(in operation – 50mJ/15fs/1kHz)



10s MeV
ALFA beamline

Thin disk Yb:YAG (diode-pumped) pump, ps OPCPA
Auxiliary (FSYNC) 15 mJ /12 fs beam

L2-DUHA: 3J/20fs/20-100Hz (>100TW) laser system

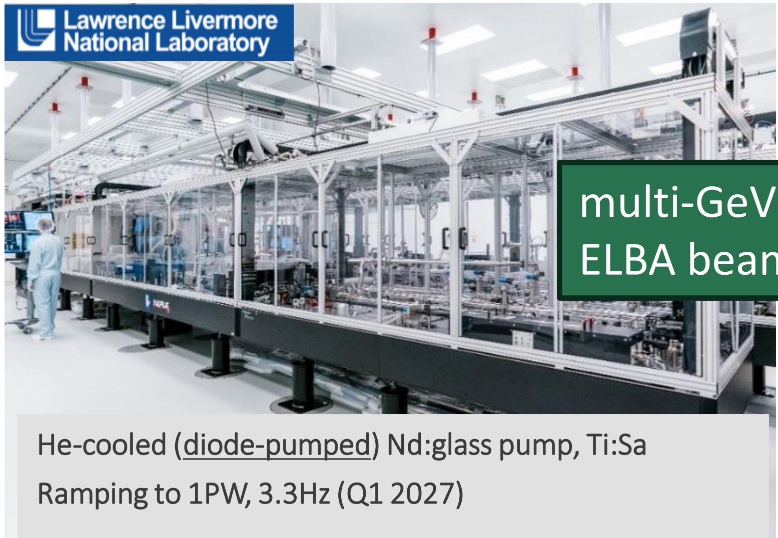
(under development)

EUPRAXIA

Cryogenic He-cooled slab Yb:YAG (diode-pumped) pump, ns OPCPA
Expected availability for commissioning experiments: Q4 2025

L3-HAPLS: 30J/30fs/10Hz (1PW) laser system

(in operation – 15J/27fs/3.3Hz)



multi-GeV –
ELBA beamline

He-cooled (diode-pumped) Nd:glass pump, Ti:Sa
Ramping to 1PW, 3.3Hz (Q1 2027)

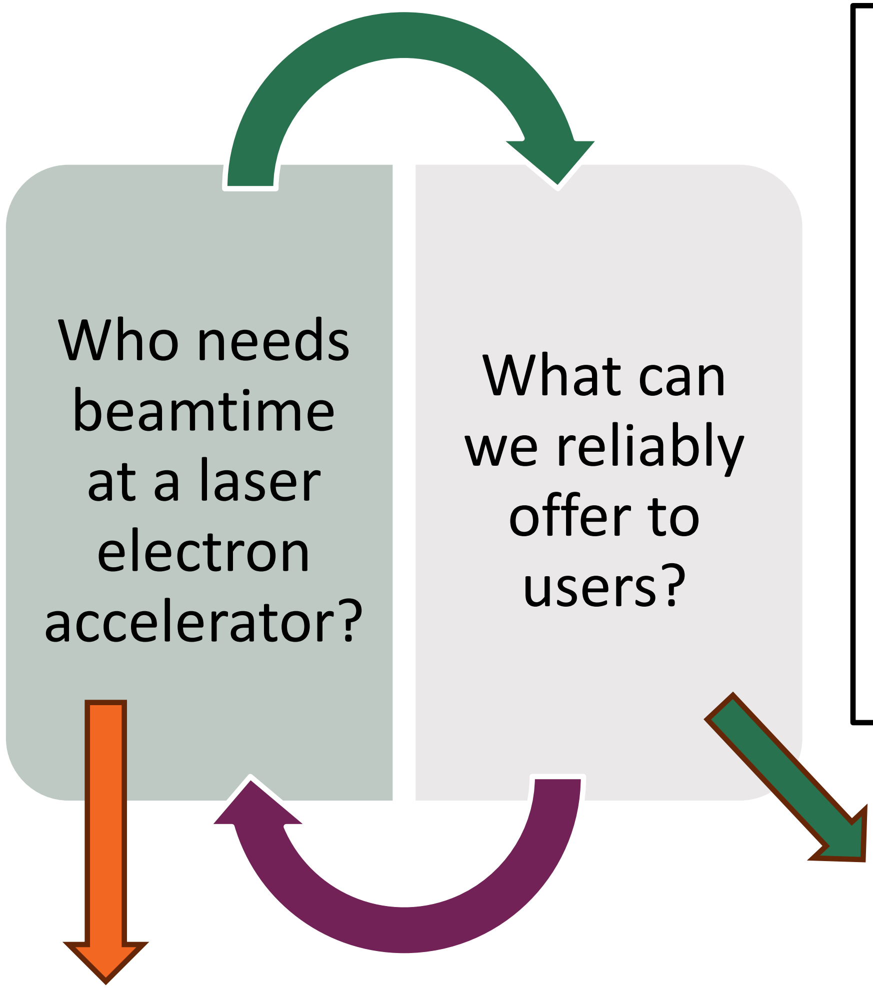
L4-ATON: 1.5kJ/150fs/1shot/min (10PW) laser system

(long pulse in operation – 1.2kJ (0.6kJ @2w)/2-10ns/1shot/min)

10s GeV / kJ LWFA future plans
[Ludwig et al., Sci. Rep. 15 25902 (2025)]

Mixed Nd:glass (>15nm spectral bandwidth)
ns-kJ pulses with programmable temporal shapi
10PW commissioning on target: Q4 2025

We had the laser parameters as an input. Our task was to design beamlines and to develop of a user program around them. We target 8-12 applications per instrument, per call (2 calls/year).



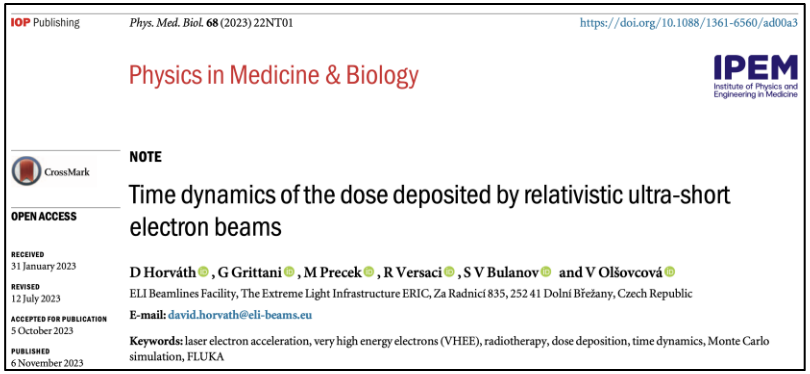
What we have been doing to answer to these questions:

- Dedicated User Conference (yearly)
- Dedicated technical reviews and workshops
- Intensive participation in LWFA experiments at other facilities
- Constant presence at related conferences and workshops
- Active involvement with the user community in discussing new ideas that could turn into a user proposal

- Develop robust technology
- Guaranteed and best-effort parameters philosophy
- Reliable LWFA beamline with all the latest toys

- LWFA Source development (e.g. guiding, hybrid)
- Detector and radiobiology (electron beam with fs duration and tunable parameters)
- Electron beam + high intensity laser experiments (e.g. QED, Compton, Flying Mirror)

A femto-second electron beam at the exit of the plasma will not necessarily deposit the dose in femto-second time scale.


IOP Publishing Phys. Med. Biol. 68 (2023) 22NT01 https://doi.org/10.1088/1361-6560/ad00a3
Physics in Medicine & Biology
IPEM Institute of Physics and Engineering in Medicine
NOTE
OPEN ACCESS
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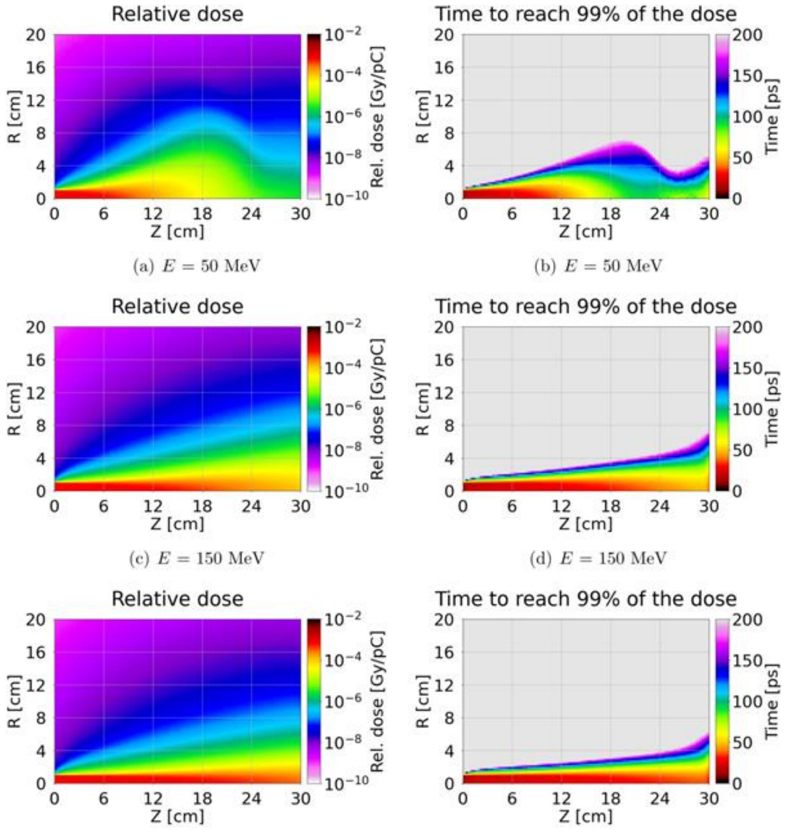
PUBLISHED 6 November 2023

Time dynamics of the dose deposited by relativistic ultra-short electron beams

D Horváth, G Grittani, M Precek, R Versaci, S V Bulanov and V Olšovcová
ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Za Radnicí 835, 252 41 Dolní Břežany, Czech Republic
E-mail: david.horvath@eli-beams.eu

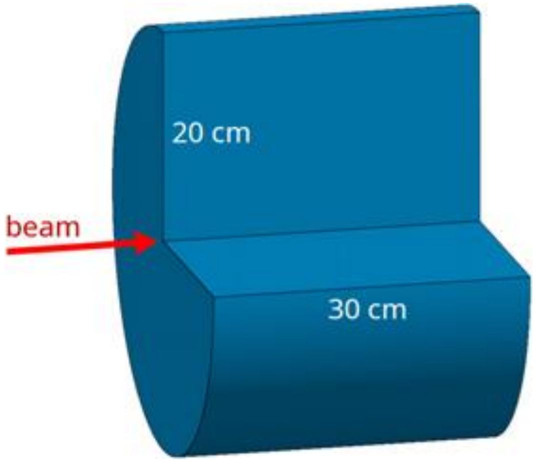
Keywords: laser electron acceleration, very high energy electrons (VHEE), radiotherapy, dose deposition, time dynamics, Monte Carlo simulation, FLUKA



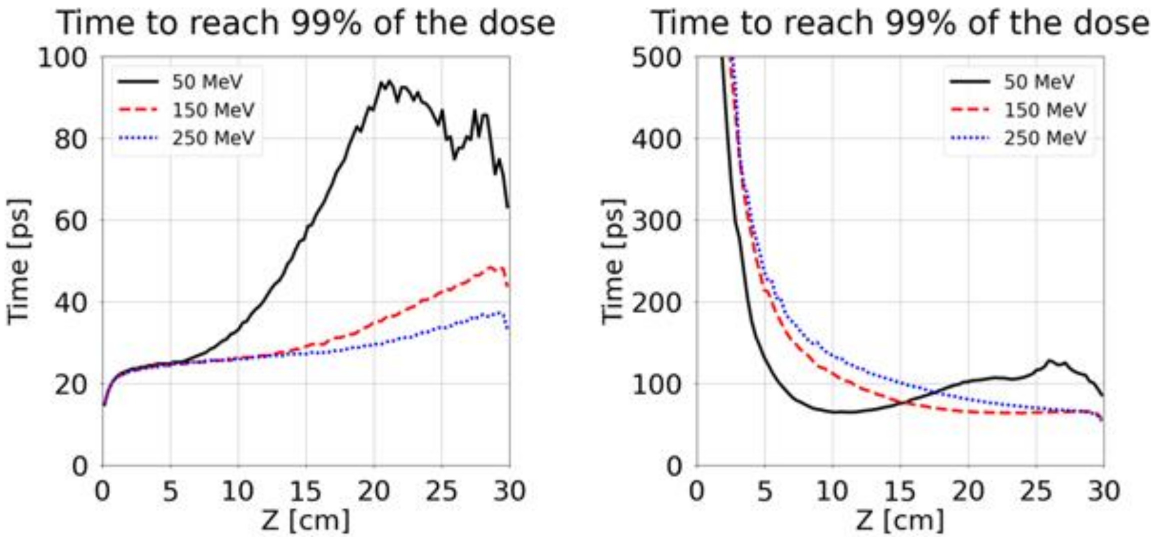
(a) $E = 50$ MeV (b) $E = 50$ MeV

(c) $E = 150$ MeV (d) $E = 150$ MeV

(e) $E = 250$ MeV (f) $E = 250$ MeV

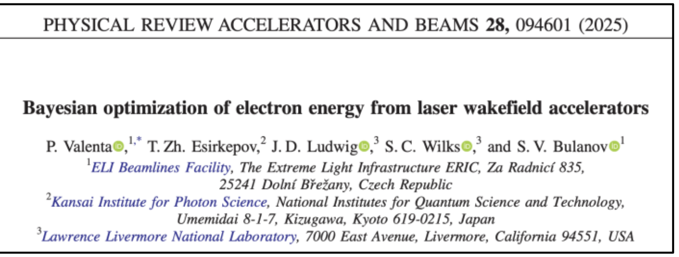


Depth [cm]	Bunch length [ps]
5	0.075
10	0.39
15	1.056
20	2.295
25	4.08
30	7.0



(a) $R = 0$ cm (b) $R = 2$ cm

When estimating the electron beam parameters for a laser electron accelerator, the fixed parameter is the laser energy.


PHYSICAL REVIEW ACCELERATORS AND BEAMS **28**, 094601 (2025)

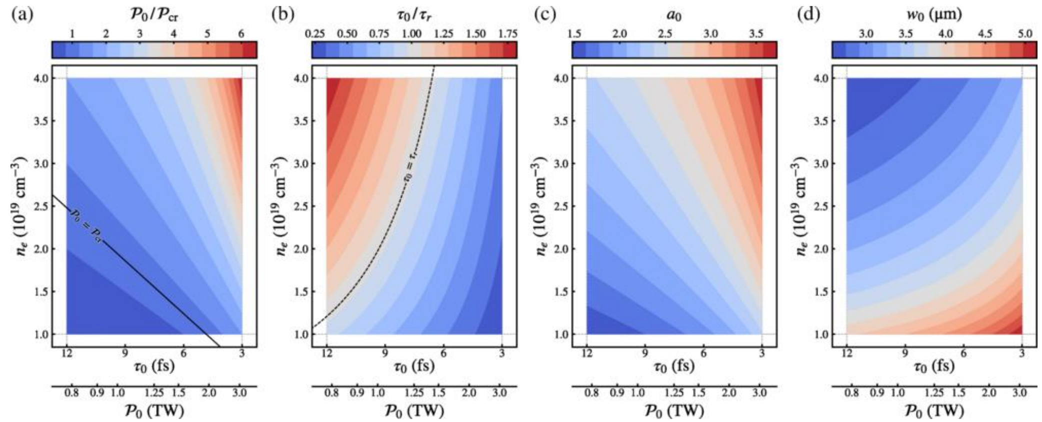
Bayesian optimization of electron energy from laser wakefield accelerators

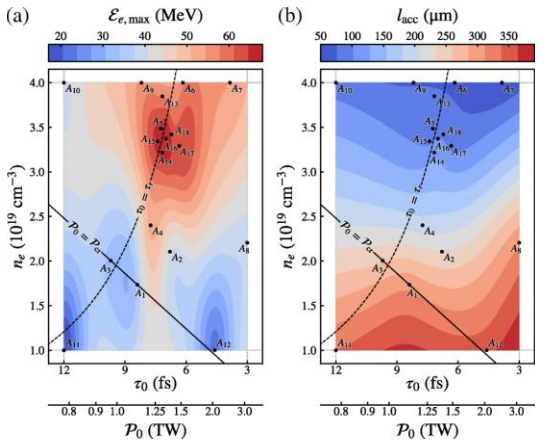
P. Valenta,[1,*] T. Zh. Esirkepov,[2] J. D. Ludwig,[3] S. C. Wilks,[3] and S. V. Bulanov[1]
[1] *ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Za Radnicí 835, 25241 Dolní Břežany, Czech Republic*
[2] *Kansai Institute for Photon Science, National Institutes for Quantum Science and Technology, Umemidai 8-1-7, Kizugawa, Kyoto 619-0215, Japan*
[3] *Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California 94551, USA*


Mach. Learn.: Sci. Technol. 7 (2026) 025030 https://doi.org/10.1088/2632-2153/ae51e0
MACHINE LEARNING Science and Technology
PAPER

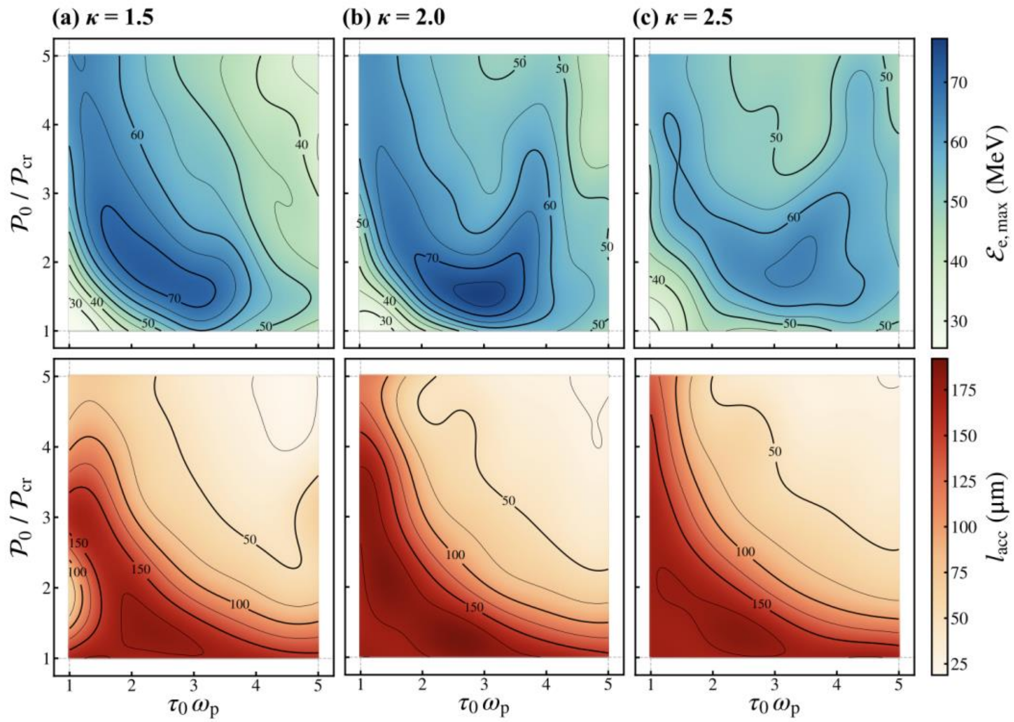
Optimized matching conditions for self-guided laser wakefield accelerators

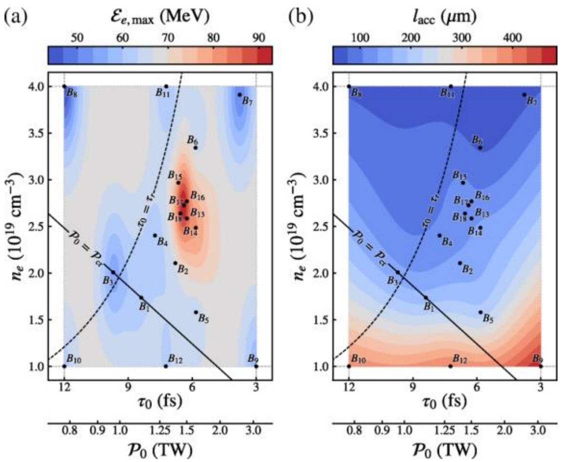
P Valenta[1,*], K G Miller[2], B K Russell[3], M Lamač[1], M Jech[1,4], G M Grittani[1] and S V Bulanov[1]
[1] ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Dolní Břežany, Czech Republic
[2] Laboratory for Laser Energetics, University of Rochester, Rochester, NY, United States of America
[3] Department of Astrophysical Sciences, Princeton University, Princeton, NJ, United States of America
[4] Faculty of Information Technology, Czech Technical University in Prague, Prague, Czech Republic





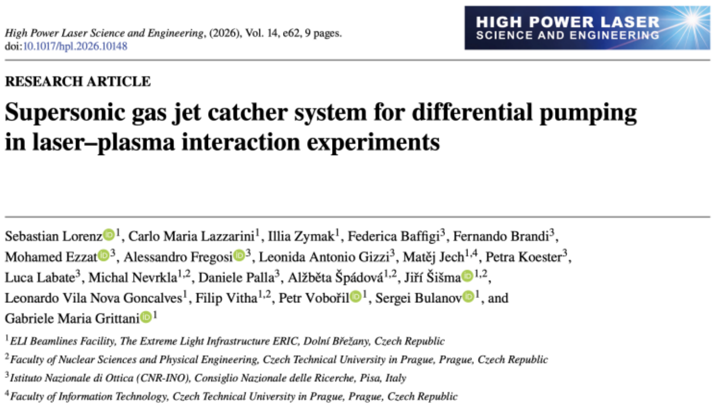
Self-guided LWFA





Guided LWFA

In-house developed differential pumping enables continuous flow operation of nozzles up to 2 mm at LWFA relevant backing pressures.

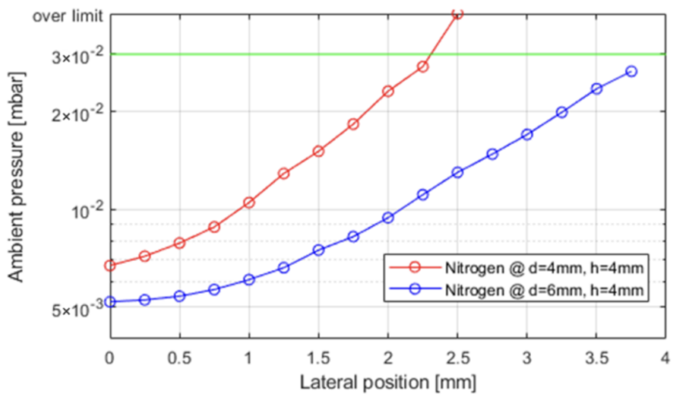

High Power Laser Science and Engineering, (2026), Vol. 14, e62, 9 pages.
doi:10.1017/hpl.2026.10148
HIGH POWER LASER SCIENCE AND ENGINEERING

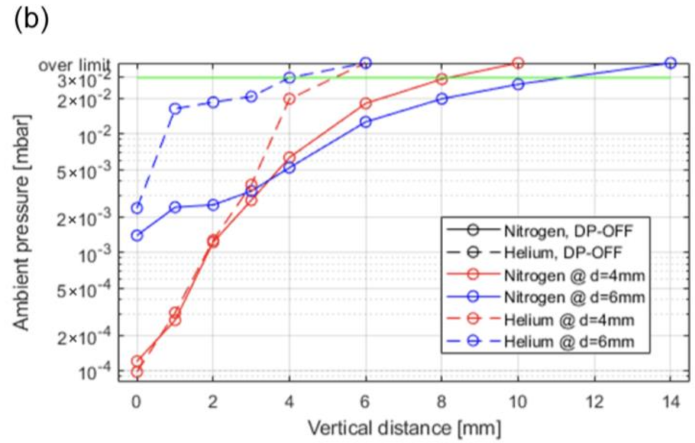
RESEARCH ARTICLE

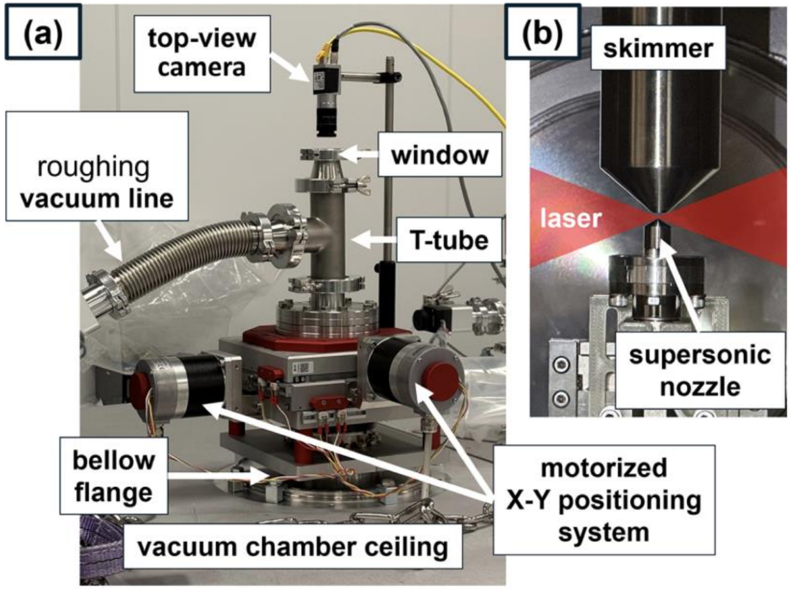
Supersonic gas jet catcher system for differential pumping in laser–plasma interaction experiments

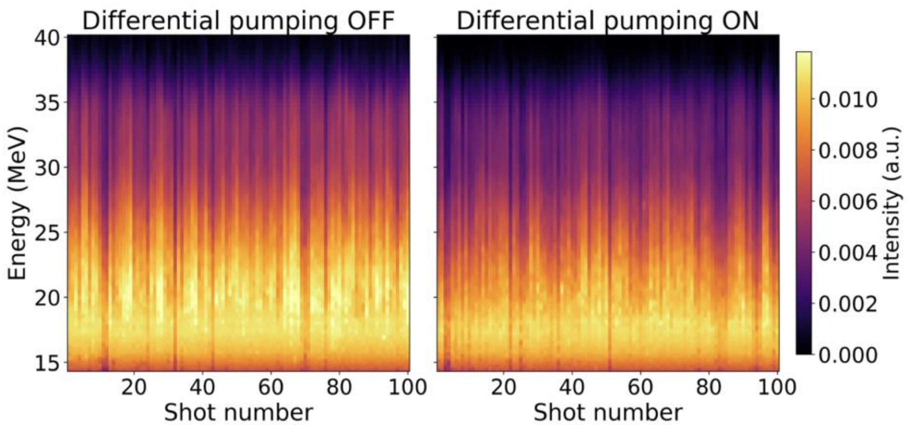
Sebastian Lorenz[1], Carlo Maria Lazzarini[1], Illia Zymak[1], Federica Baffigi[3], Fernando Brandi[3], Mohamed Ezzat[3], Alessandro Fregosi[3], Leonida Antonio Gizzi[3], Matěj Jech[1,4], Petra Koester[3], Luca Labate[3], Michal Nevrkla[1,2], Daniele Palla[3], Alžběta Špádová[1,2], Jiří Šišma[1,2], Leonardo Vila Nova Goncalves[1], Filip Vitha[1,2], Petr Vobořil[1], Sergei Bulanov[1], and Gabriele Maria Grittani[1]

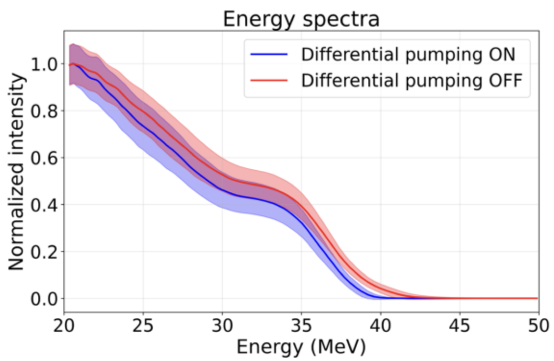
[1] *ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Dolní Břežany, Czech Republic*
[2] *Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic*
[3] *Istituto Nazionale di Ottica (CNR-INO), Consiglio Nazionale delle Ricerche, Pisa, Italy*
[4] *Faculty of Information Technology, Czech Technical University in Prague, Prague, Czech Republic*

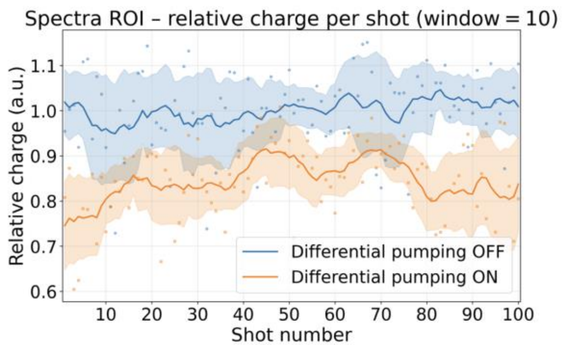




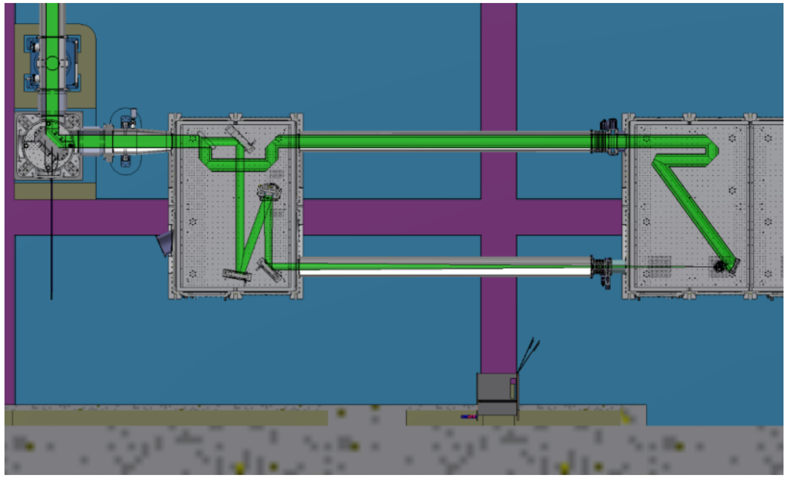








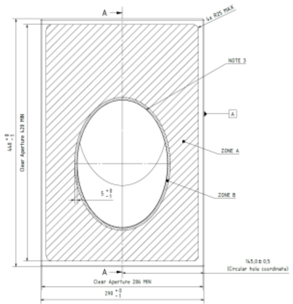
ELBA laser electron collider has been designed to approach parameters relevant for QED studies.

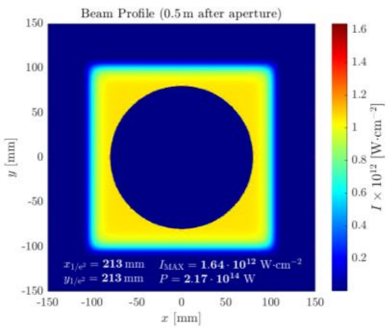


$$\chi_e \simeq 0.18\,\mathcal{E}_0[\mathrm{GeV}]\, I_0^{1/2}[10^{21}\ \mathrm{Wcm}^{-2}]$$

X~1 @ 5 GeV, 10^{21} Wcm^{-2}

Key Technology is 50:50 Wavefront Splitting to enable high temporal synchronization of the LWFA beam and the CP laser

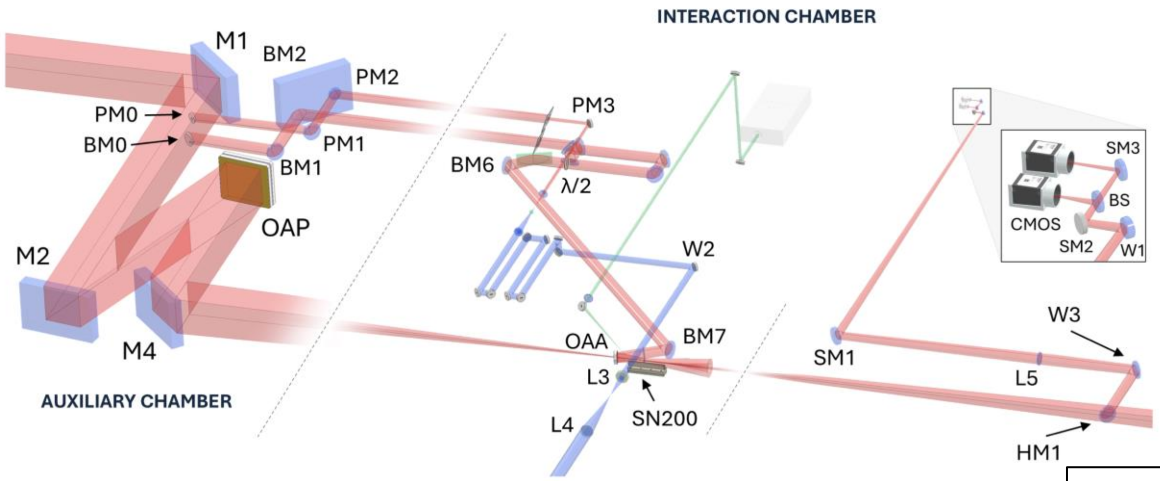




LASER | ELECTRON | CP LASER

Parameter	Current L3 Performance	Nominal L3 performance
Laser energy before WS splitting	15 J	30 J
Laser time duration	27 fs	30 fs
Repetition Rate	3.3 Hz	10 Hz
Laser Wavelength	800 nm	800 nm
Laser Energy for LWFA	13.5 J	> 10 J
Electron beam energy (mean of QME peak)	2.5 GeV	> 2 GeV
Energy spread (FWHM)	10 %	< 20%
Electron beam charge in QME peak	10s pC	> 40 pC
Electron beam divergence	0.7 mrad	< 2 mrad
Electron beam pointing stability	0.4 mrad	< 2 mrad
Laser Energy for Collider Laser	1.5 J	> 10 J
Focal number	1.5	1.5
Focal length	375 mm	375 mm
Focal spot FWHM	2 µm	< 2 µm
Peak intensity	1 x 10^{20} W/cm^2	>3 x 10^{21} W/cm^2
Collision angle	20°	0° and 40°

We attracted the UMD team to implement all-optical guiding, in order to reach 5 GeV and improve pointing stability. But we had to figure out how to do it with a single laser beam.



High Power Laser Science and Engineering, (2026), Vol. 14, e52, 12 pages.
doi:10.1017/hpl.2026.10154

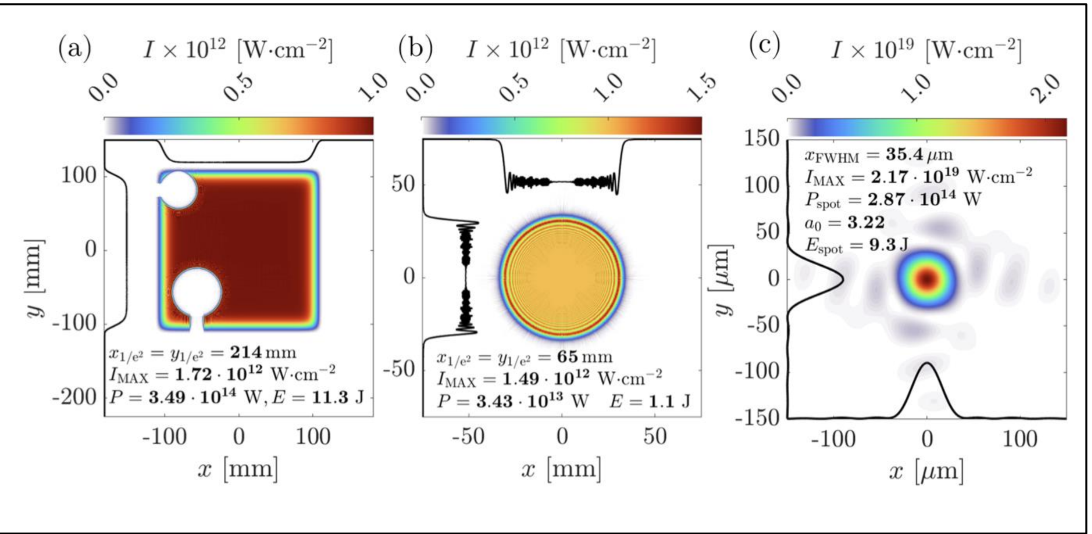
HIGH POWER LASER SCIENCE AND ENGINEERING

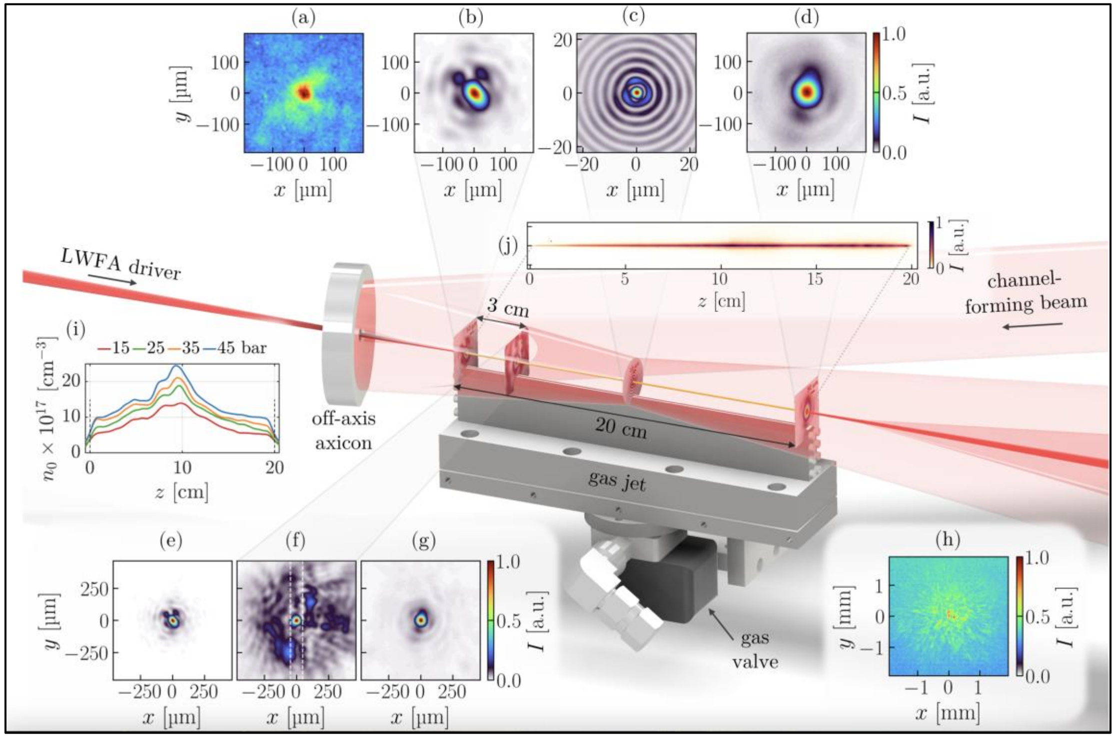
RESEARCH ARTICLE

High-repetition-rate, all-reflective optical guiding and electron acceleration in helium using an off-axis axicon

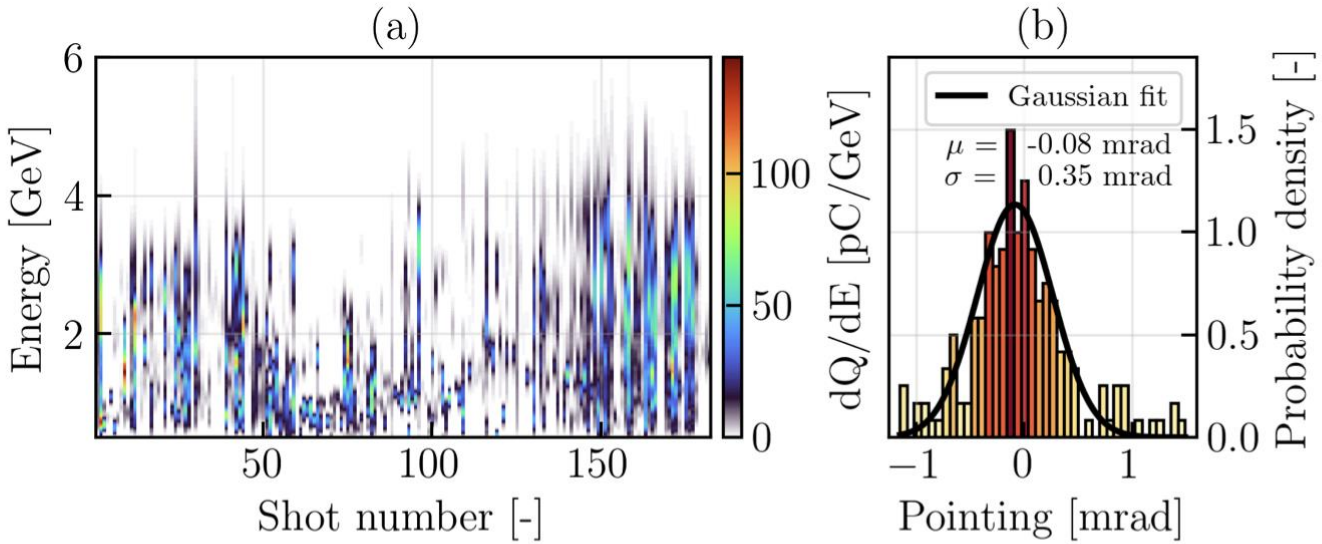
Jiří Šišma[1,2], Michal Nevrkla[1,2], Filip Vitha[1,2], Sebastian Lorenz[1], Illia Zymak[1], Alžběta Špádová[1,2], Andrea Kollárová[1,2], Matěj Jech[1,3], Alexandr Jančárek[1,2], Davorin Peceli[1], Carlo M. Lazzarini[1], Leonardo V. N. Goncalves[1], Gabriele M. Grittani[1], Sergei V. Bulanov[1], Jaron E. Shrock[4], Ela Rockafellow[4], Ari J. Sloss[4], Bo Miao[4], Scott W. Hancock[4], and Howard M. Milchberg[4,5]

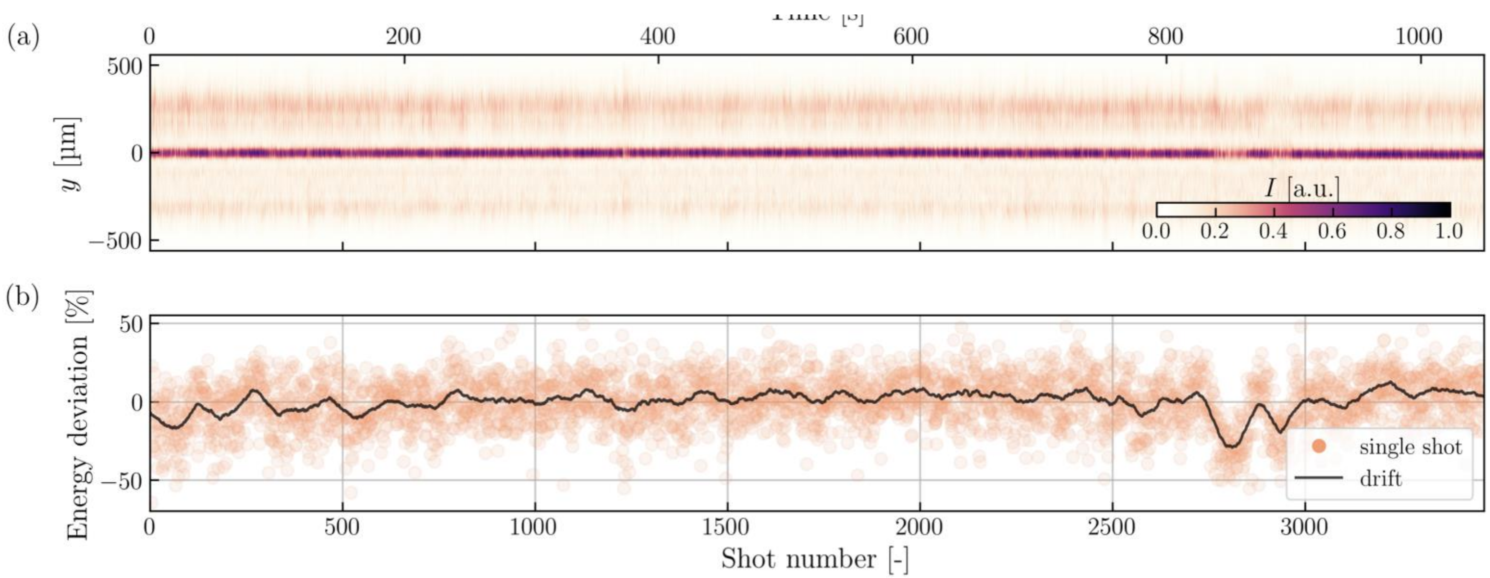
[1] *ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Dolní Břežany, Czech Republic*
[2] *Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic*
[3] *Faculty of Information Technology, Czech Technical University in Prague, Prague, Czech Republic*
[4] *Institute for Research in Electronics and Applied Physics and Department of Physics, University of Maryland, College Park, Maryland, USA*
[5] *Department of Electrical and Computer Engineering, University of Maryland, College Park, Maryland, USA*





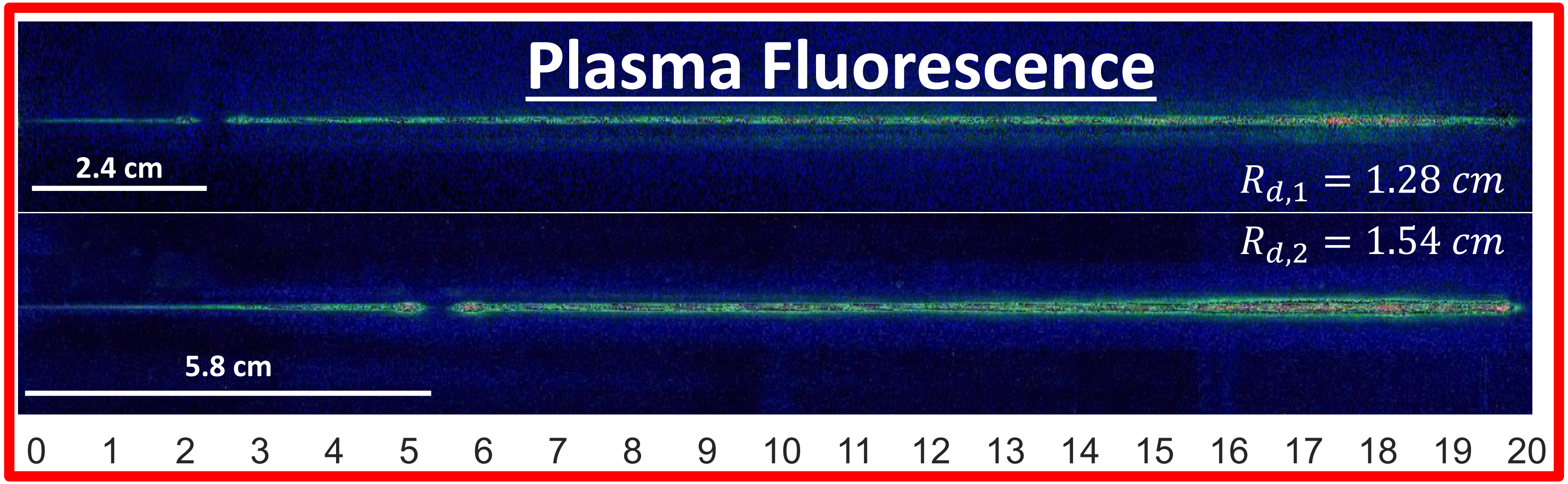
We achieved up to 6 GeV with 0.35 mrad pointing stability. The guiding scheme has been demonstrated up to 3.3 Hz. But these beams are almost not usable for QED due to spectral instability.

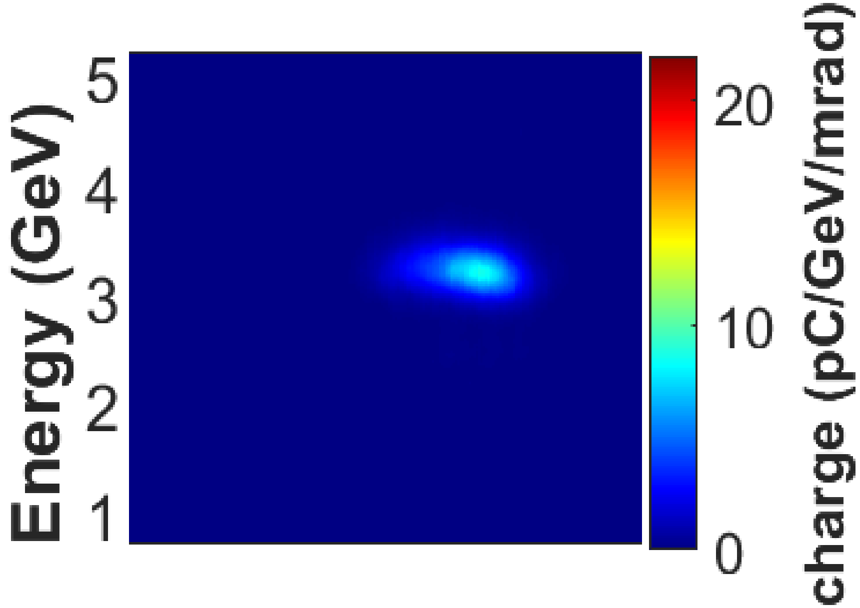


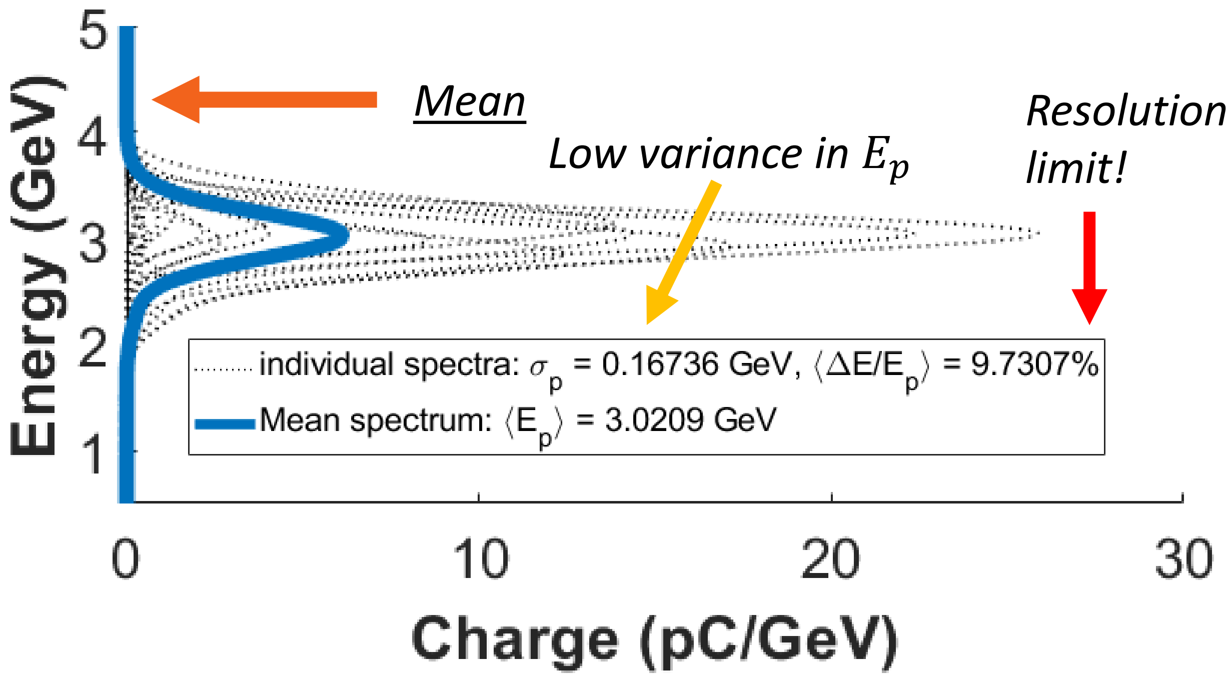


We developed two techniques that enabled high quality beams. Pi-step enables the most monochromatic beams.

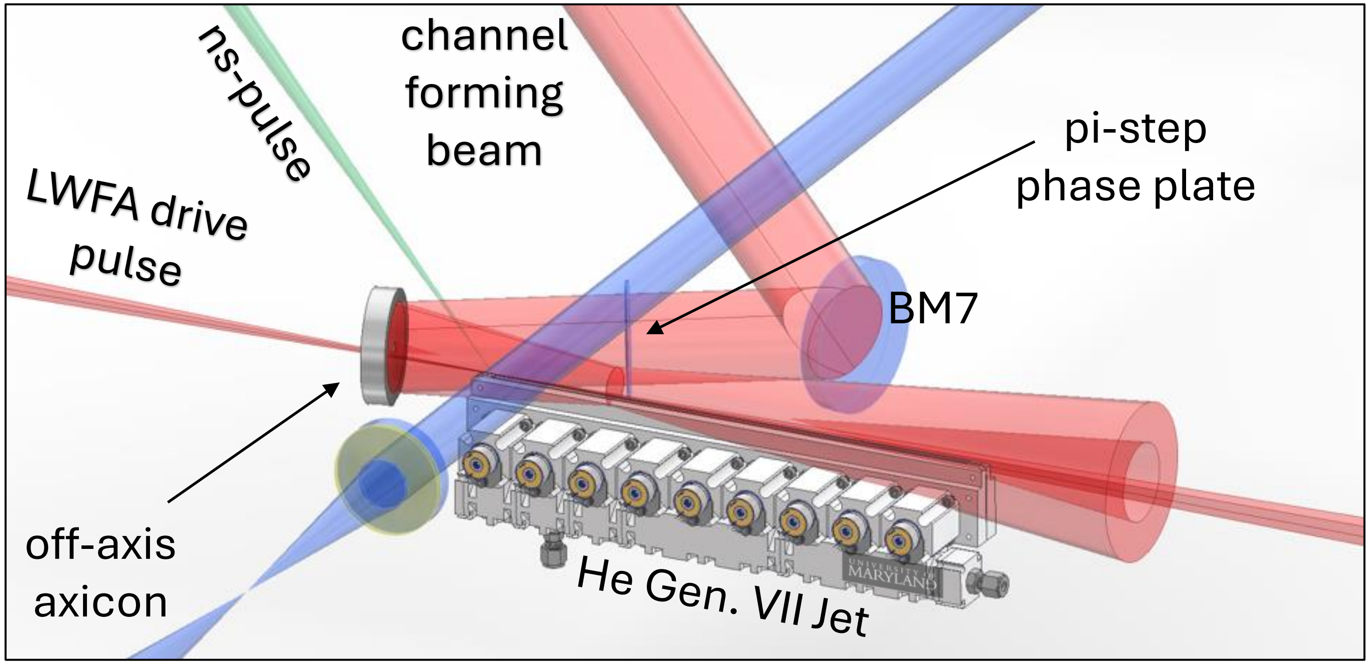
adapted from J. Shrock's talk on Monday





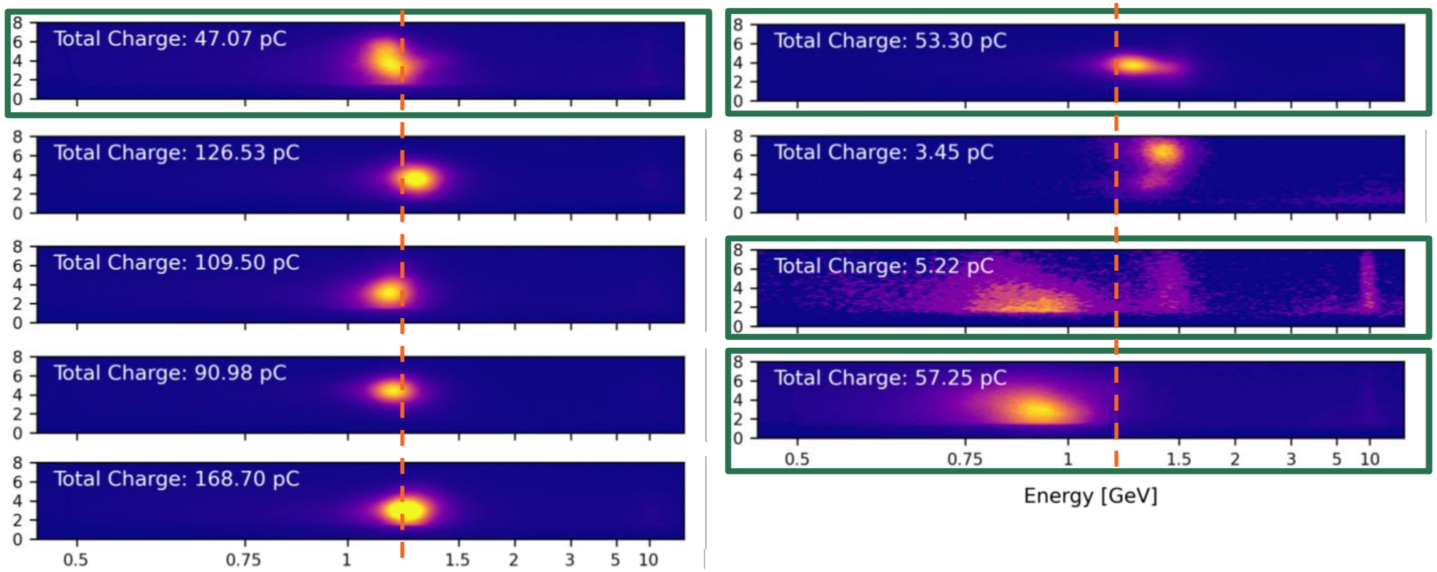


We developed two techniques that enabled high quality beams.
Localized Ablation Injection enables high charge beams.

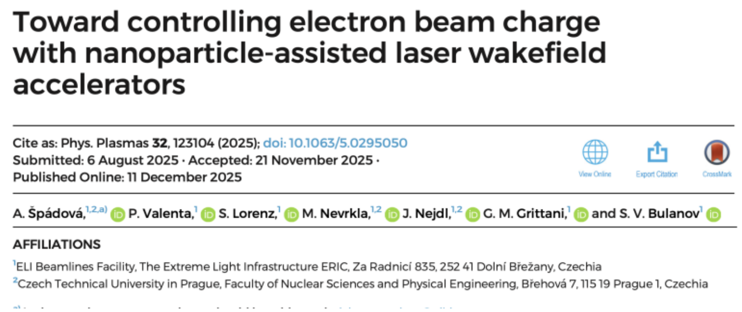


- Electron spectra for 3 bar backing pressure (UMD gas jet) and laser ablation energy 60 mJ
- Showing 9 successful shots (out of 13 consecutive)
- Green rectangle – shots not hitting the slit properly (influence on charge and energy)
- Orange dashed line – approximately @ 1.2 GeV (average energy for this data set)

Abl. laser E	Beam generation eff. [%]	Avg. energy
All beams	70% (16 beams out of 23)	1.26 ± 0.17 GeV
50 mJ	75% (3 beams out of 4)	1.13 GeV
55 mJ	71% (5 beams out of 7)	1.34 ± 0.07 GeV
60 mJ	69% (9 beams out of 13)	1.19 ± 0.03 GeV



Modeling paper published + experimental paper in prep.



Toward controlling electron beam charge with nanoparticle-assisted laser wakefield accelerators

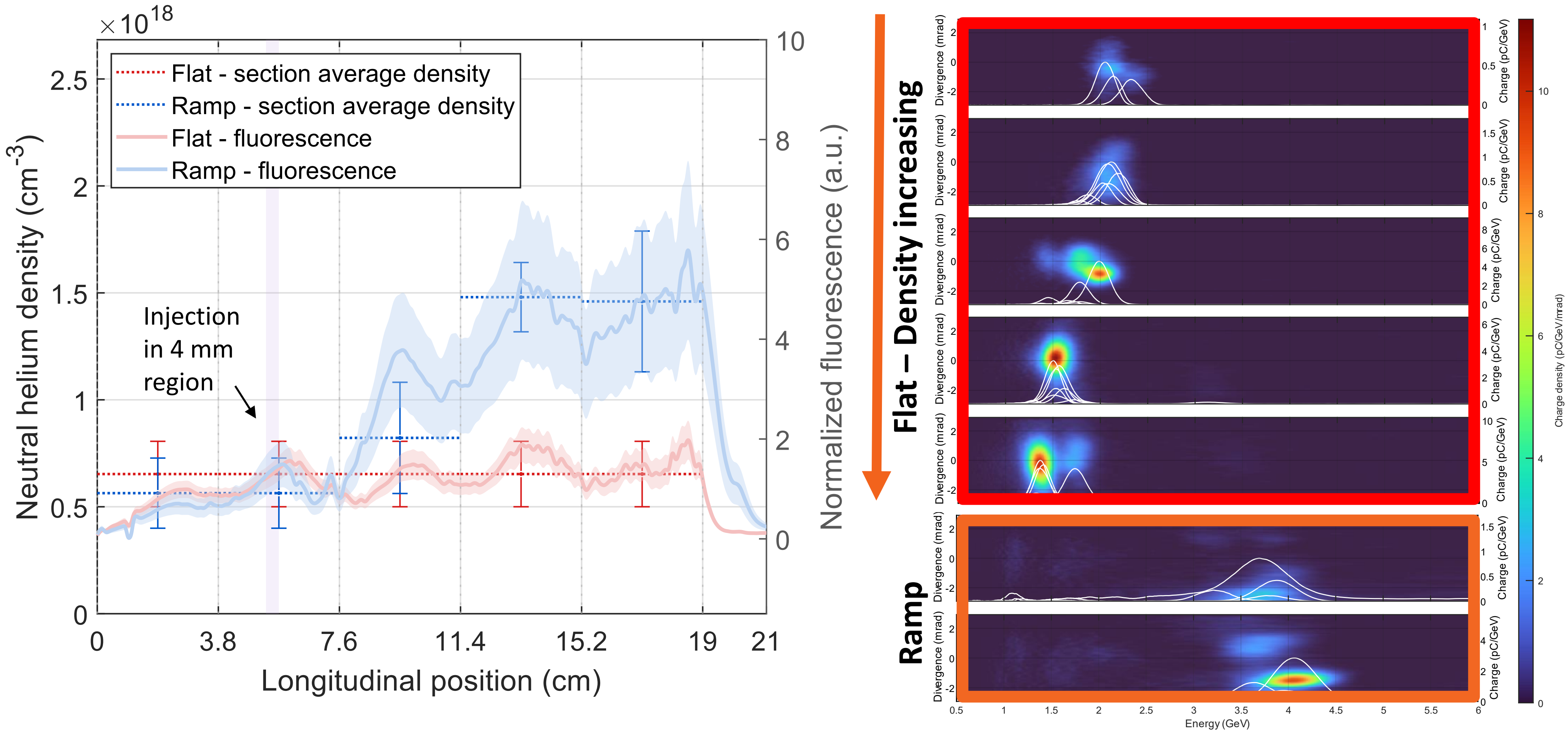
Cite as: Phys. Plasmas **32**, 123104 (2025); doi: 10.1063/5.0295050
Submitted: 6 August 2025 · Accepted: 21 November 2025 · Published Online: 11 December 2025

A. Špádová,[1,2,a)] P. Valenta,[1] S. Lorenz,[1] M. Nevrkla,[1,2] J. Nejdl,[1,2] G. M. Grittani,[1] and S. V. Bulanov[1]

AFFILIATIONS

[1]ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Za Radnicí 835, 252 41 Dolní Břežany, Czechia
[2]Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Břehová 7, 115 19 Prague 1, Czechia

Upramp enables reaching monochromatic 5 GeV beams.



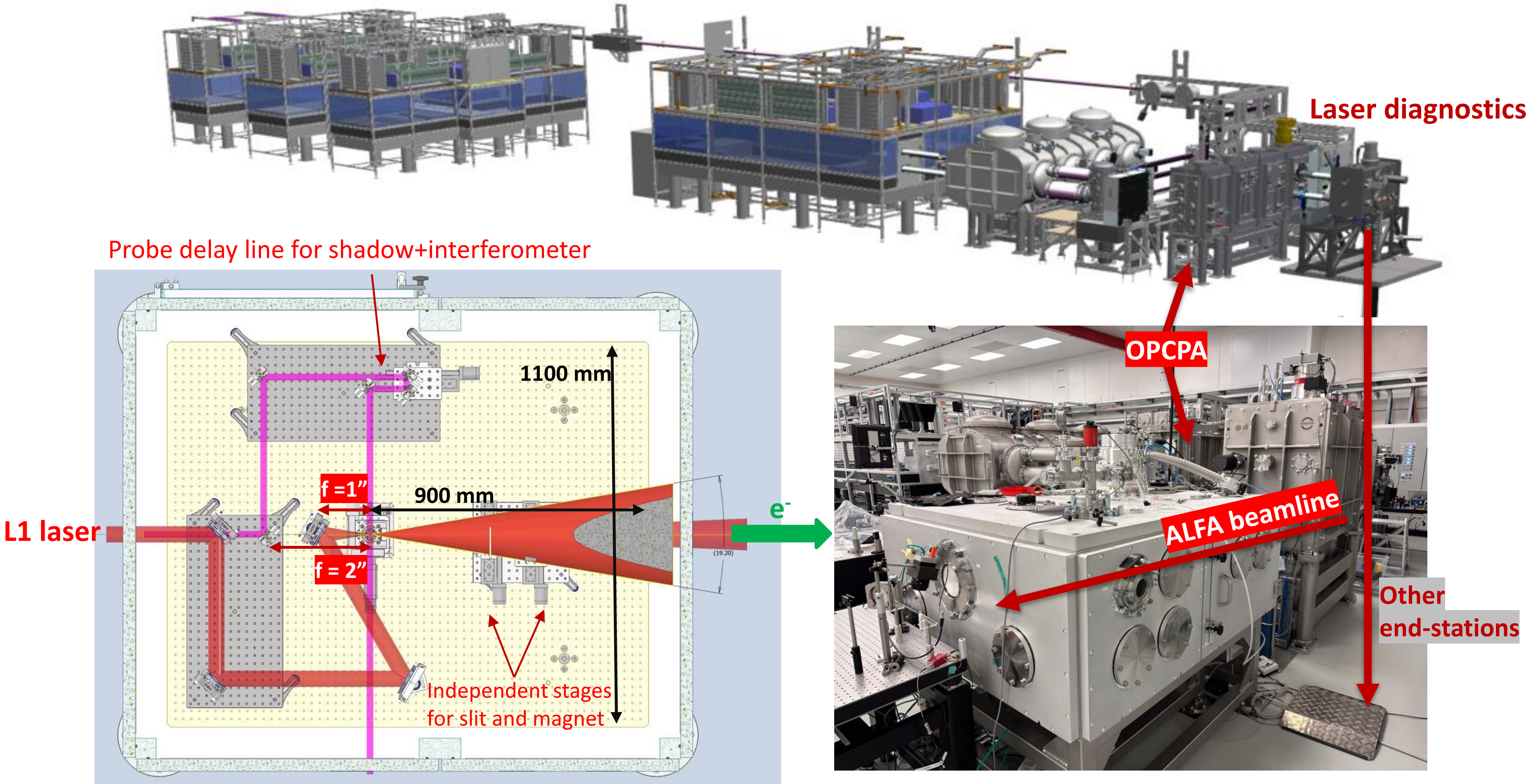
Acceleration dephasing limited. 20 cm density ramp increases energy by ~2x.

adapted from E. Rockafellow's talk on Monday

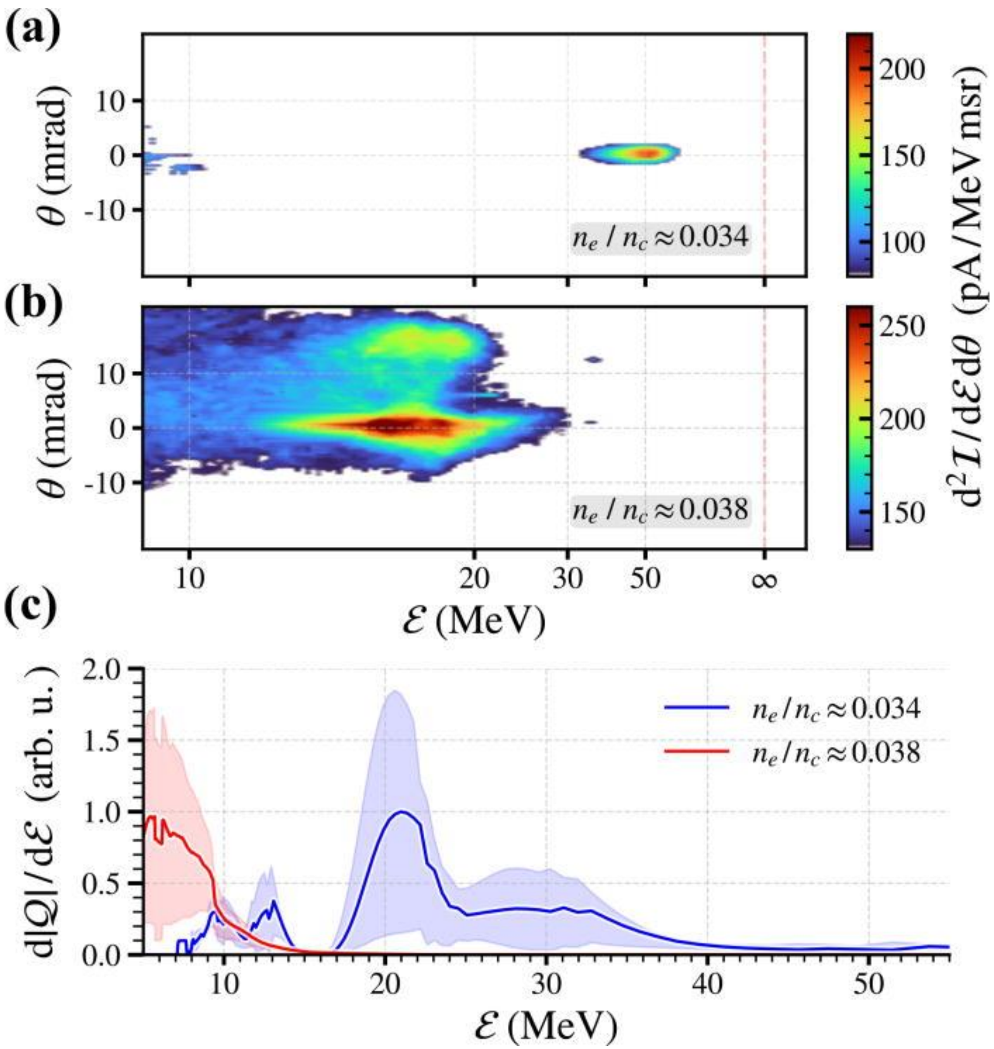
E. Rockafellow *et al., in preparation*

ALFA the first laser electron accelerator with same energy and average dose rate of a medical linear accelerator for radiotherapy. But with much higher instantaneous dose rate.

Designed: 100 mJ / 1 kHz / 15 fs & synchronised to facility clock (GPS)



By using different gases, we can tune the electron beam properties.



Feature (average over thousands pulses)	High energy mode	High power mode
Energy	32 ± 5 MeV	22 ± 2 MeV
Energy Spread (FWHM)	8 MeV (25%)	15 (68%)
Current*	12 ± 6 pA	276 ± 28 pA
Divergence* (FWHM)	2.1 ± 0.8 mrad	7.8 ± 1.2 mrad
Pointing* (std)	6.9 mrad	4.2 mrad
Electron Beam Power Output*	0.4 mW	6 mW

He/N mixture **Pure N**

Ultrarelativistic electron beams accelerated by terawatt scalable kHz laser

Cite as: Phys. Plasmas **31**, 030703 (2024); doi: 10.1063/5.0189051
Submitted: 26 November 2023 · Accepted: 28 February 2024 ·
Published Online: 28 March 2024

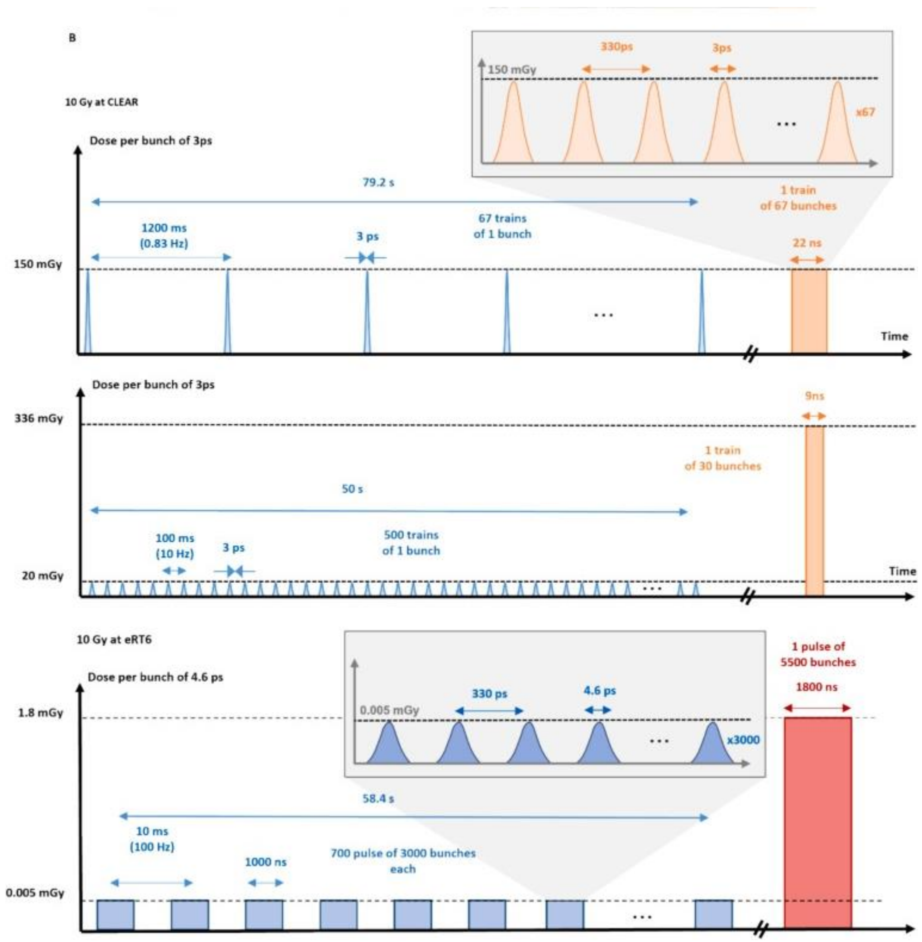
View Online Export Citation CrossMark

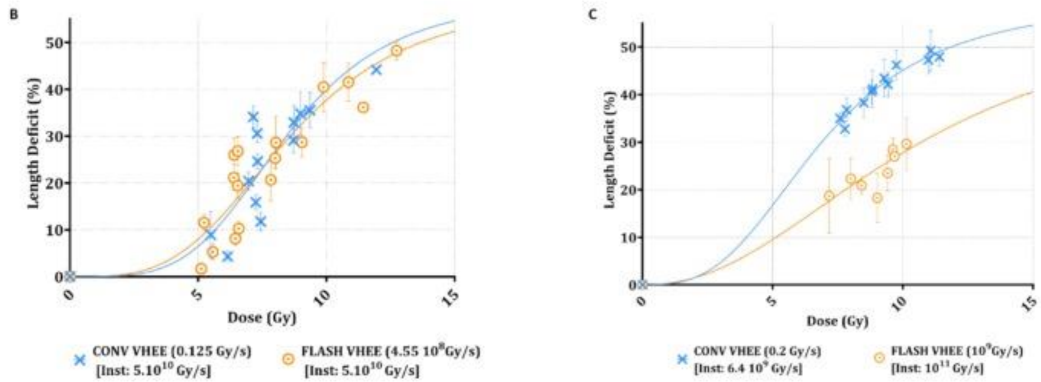
C. M. Lazzarini,[1,2,a)] G. M. Grittani,[1] P. Valenta,[1] I. Zymak,[1] R. Antipenkov,[1] U. Chaulagain,[1] L. V. N. Goncalves,[1] A. Grenfell,[1] M. Lamač,[1,3] S. Lorenz,[1,2] M. Nevrkla,[1,2] A. Špaček,[1,2] V. Šobr,[1] W. Szuba,[1] P. Bakule,[1] G. Korn,[1] and S. V. Bulanov[1,4]

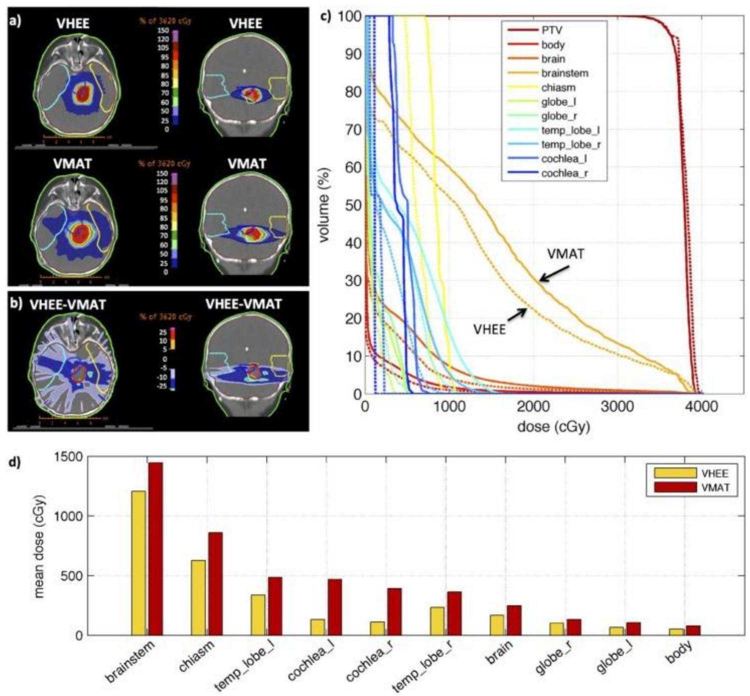
AFFILIATIONS

[1]ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Za Radnicí 835, 25241 Dolní Břežany, Czech Republic
[2]Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 11519 Prague, Czech Republic
[3]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague, Czech Republic
[4]Kansai Photon Science Institute, National Institutes for Quantum Science and Technology, 8-1-7 Umemidai, Kizugawa, Kyoto 619-0215, Japan

There is growing evidence that both ultra-high instantaneous dose rates and very high energy electrons (100-250 MeV) can have beneficial effects in cancer treatment.



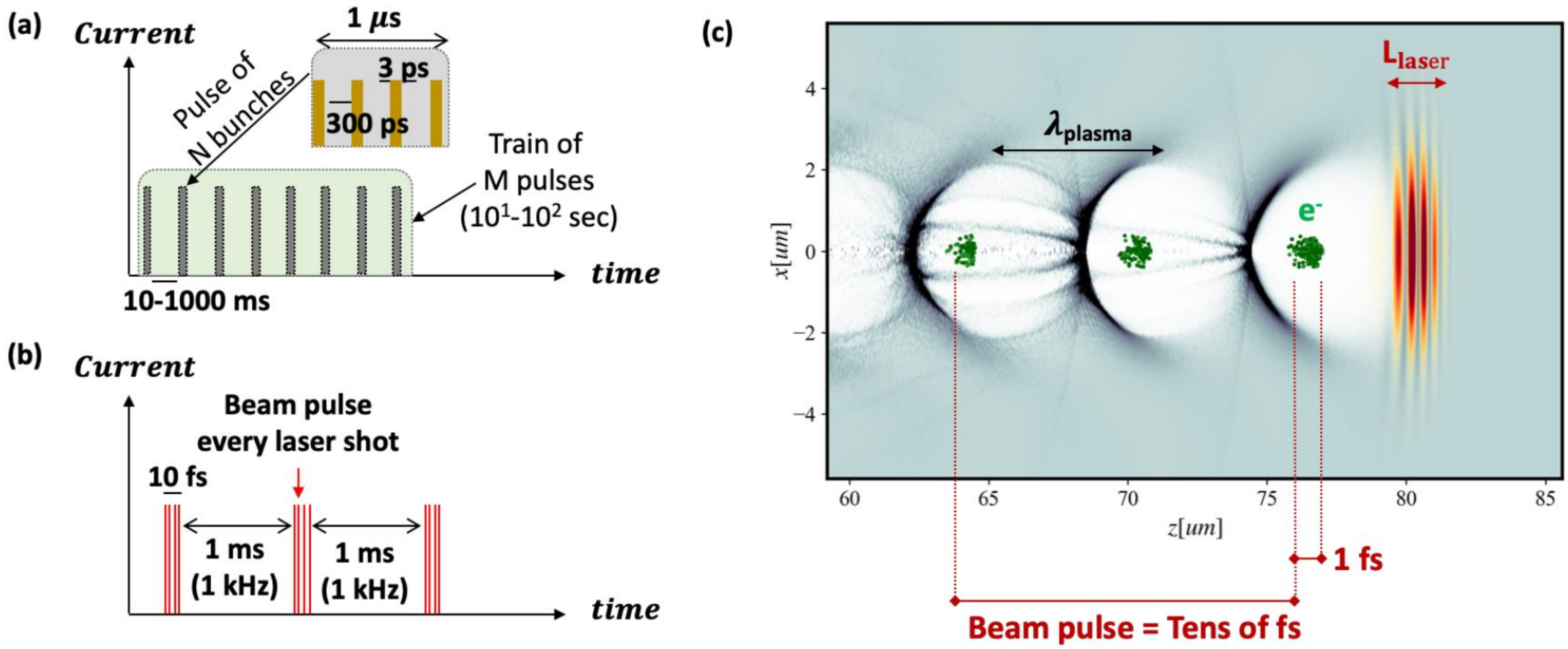




J. Wenz et al., Nature Photonics 13 (4), 263-269 (2019)

J. Bedford and U. Oelfke, Physics and Imaging in Radiation Oncology 32, 100670 (2024)

Laser wakefield accelerators can produce beams as short as 1 fs. ALFA can operate up to 1 kHz pulse repetition rate.



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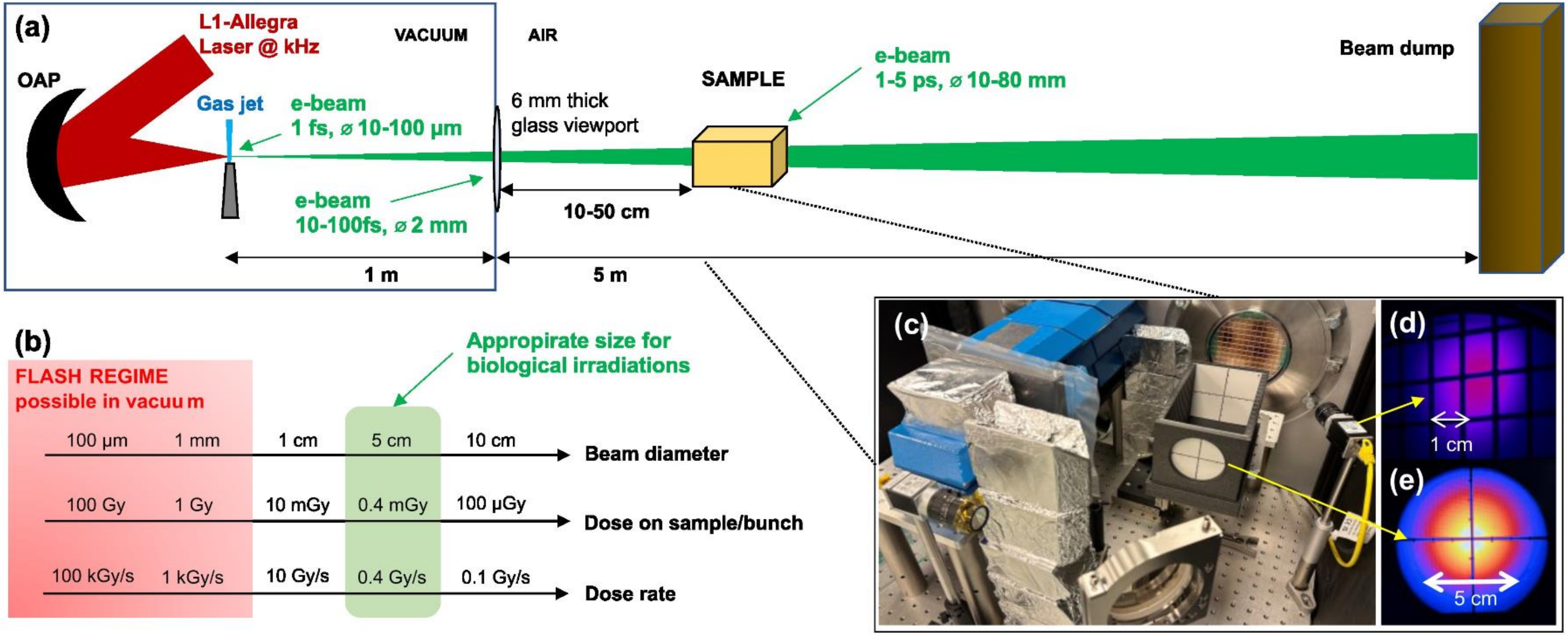
C. Lazzarini et al., manuscript under review

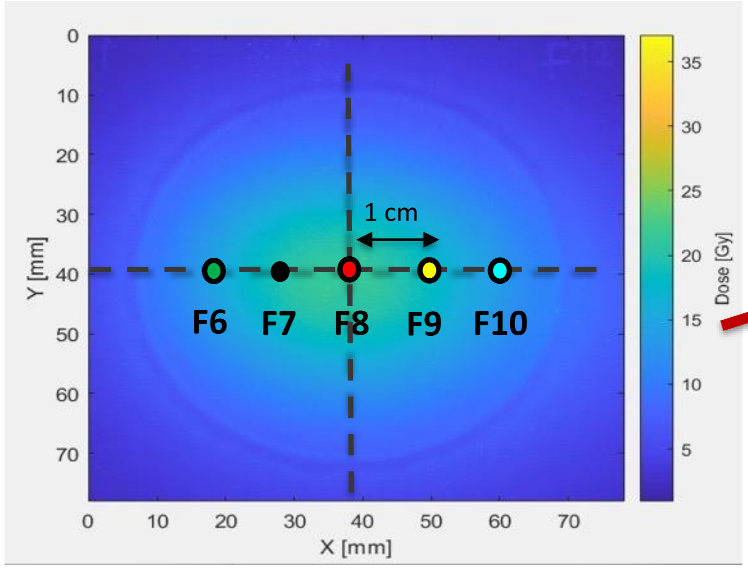
Laser wakefield accelerators produce divergent beams with dose rate tunable with the distance from the source.



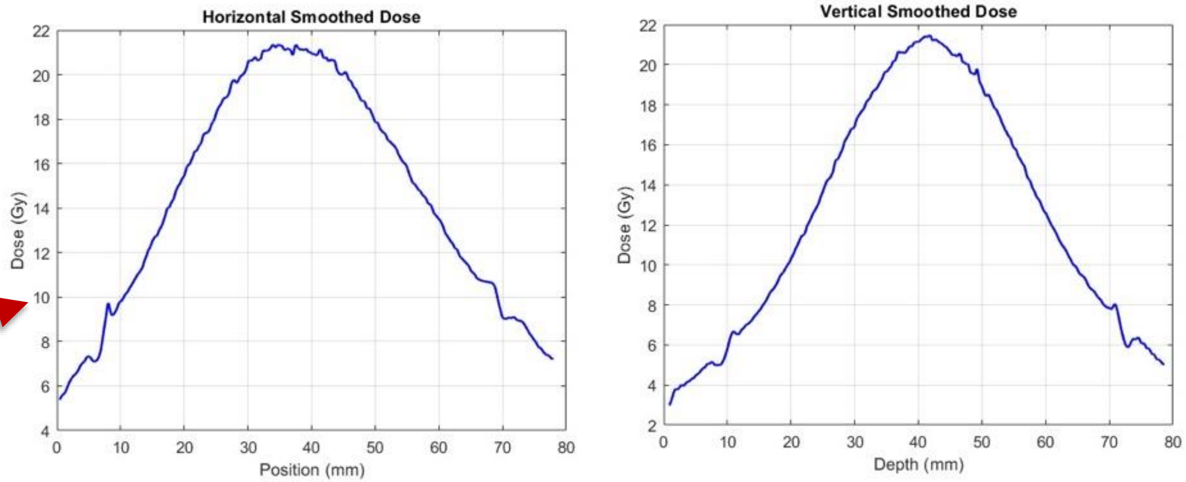
C. Lazzarini et al., manuscript under review

ALFA is over-subscribed for radiobiology experiments, since it enables a new dose delivery time profile. The main limitation is the pointing stability.

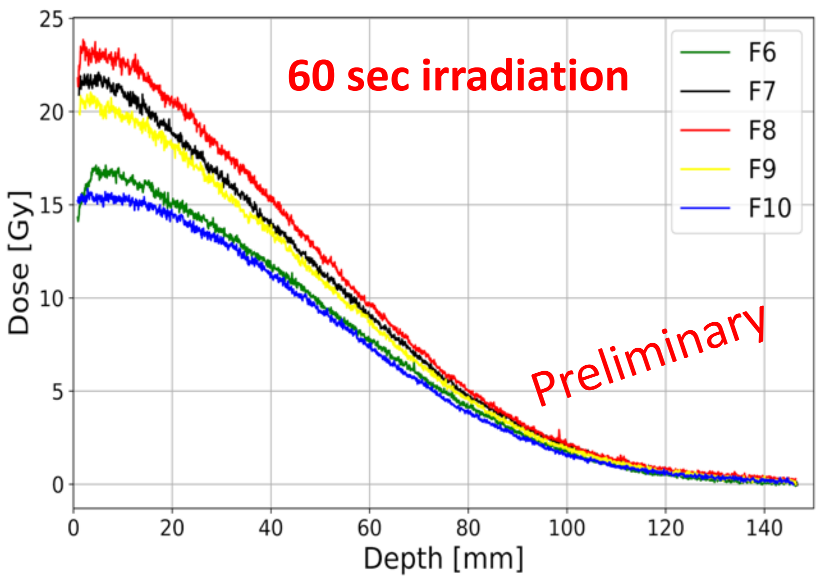
Radiochromic film at the entrance



Front film dose line plots



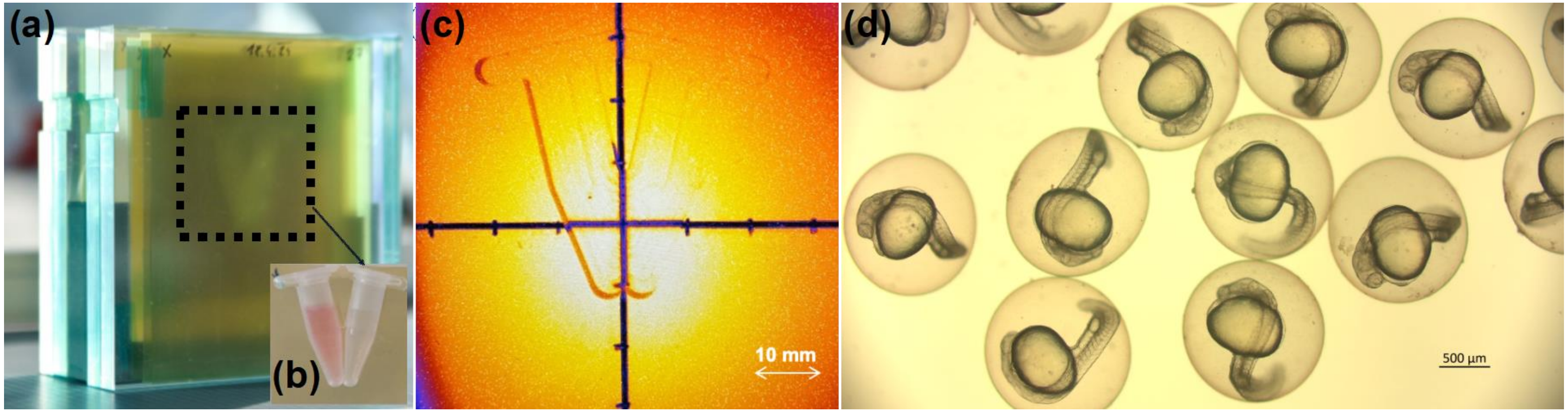
Depth dose profile in different positions



Achievements:

- ✓ Dose of ~ 30 Gy in 60 sec confirmed with Alanine
- ✓ **Max dose rate 0.5 Gy/sec over cm^2**
- ✓ **R50 at 5-6 cm**

ALFA is over-subscribed for radiobiology experiments, since it enables a new dose delivery time profile. The main limitation is the pointing stability.

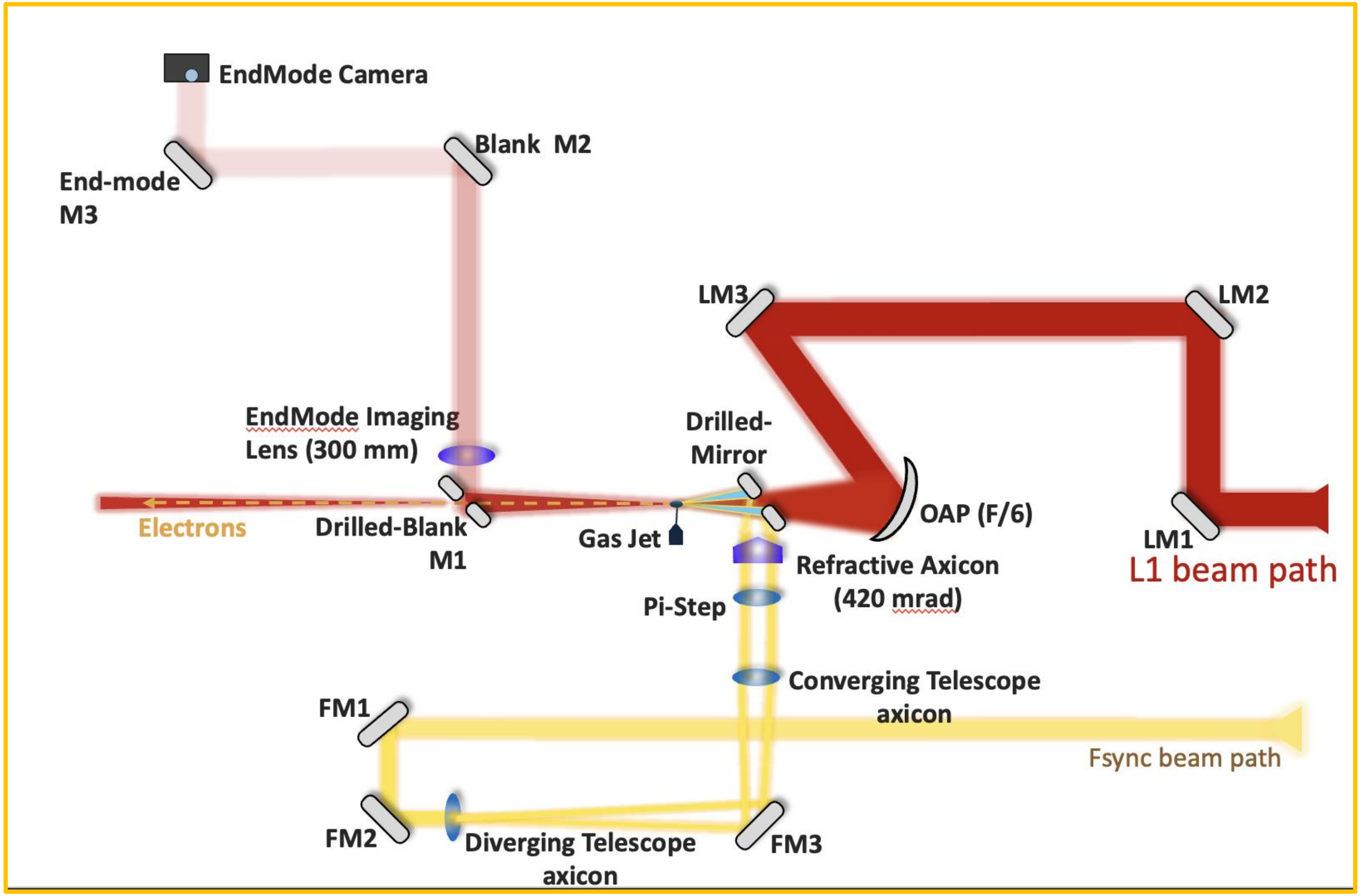


Target: zebrafish embryos in 2x2 cm target area

- **First ever on-demand in-vivo irradiation of biological sample with kHz electrons**
- **On-demand target doses (within 10%) at specific hour agreed 48 hours in advance**
- Volume **dose uniformity < 10%** at 1 cm depth, 4 cm^2

C.M. Lazzarini et al., «Controlled kHz laser-driven electron irradiations for pre-clinical applications», submitted, https://doi.org/10.48550/arXiv.2603.10058

We asked UMD team to work together to solve this problem. We developed and installed a new beamline that enabled kHz LWFA beams.

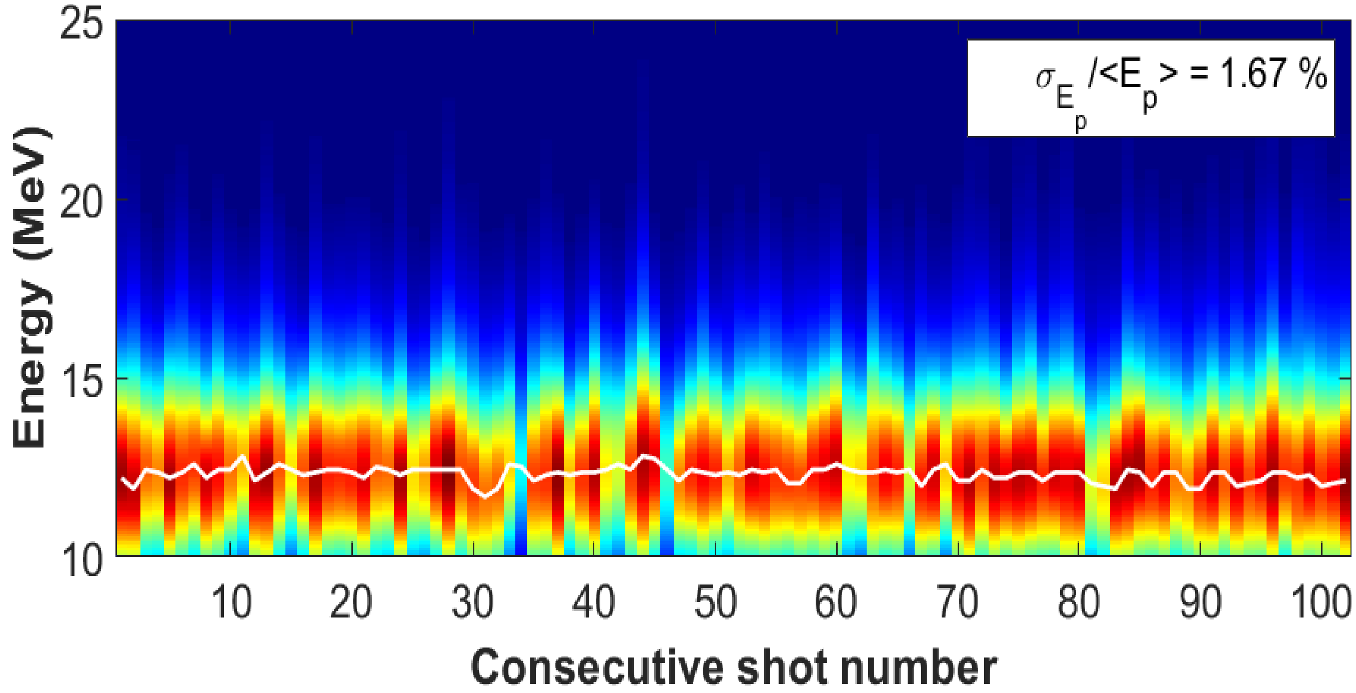


adapted from G. Brewster's talk on Monday

We demonstrated kHz LWFA beams with 10x improved pointing stability and comparable electron beam energy.

__Conditions:__

- Higher density N_2
- 2 mm channel
- Quasimonoenergetic beams likely from beam loading
- Few-mrad divergence with ~mrad pointing stability



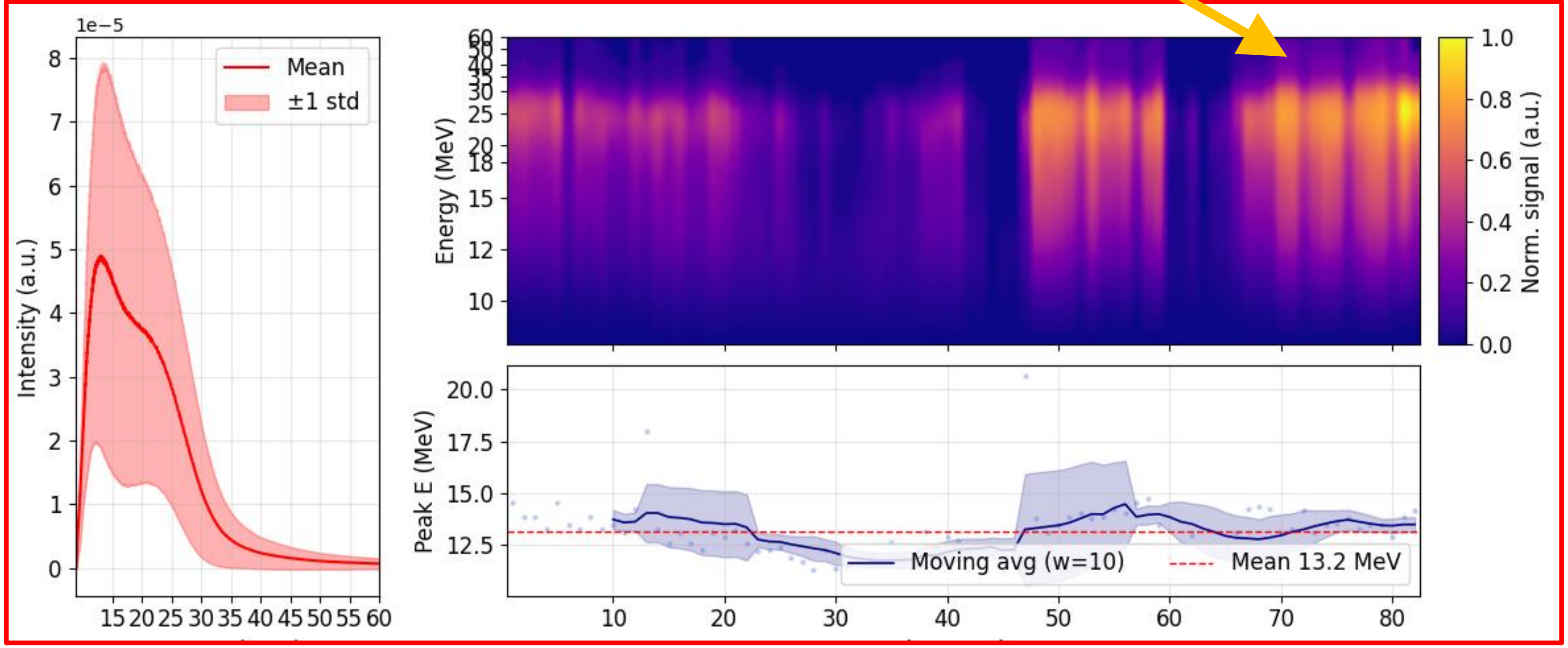
Series of 100 consecutive bursts (not single shots) with ~45 mJ on target

adapted from G. Brewster's talk on Monday

We demonstrated kHz LWFA beams with 10x improved pointing stability and comparable electron beam energy.

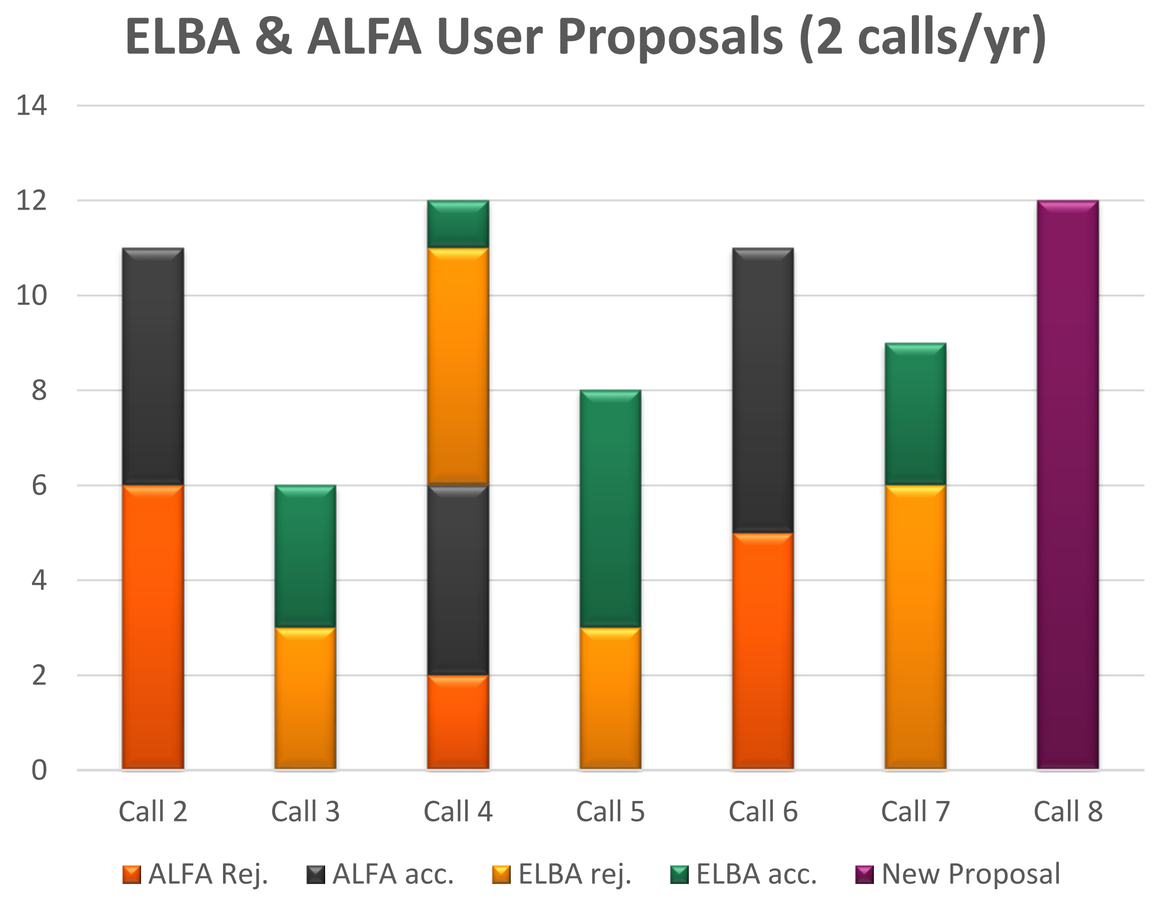
2 mm N_2 channel, high energy parameter space

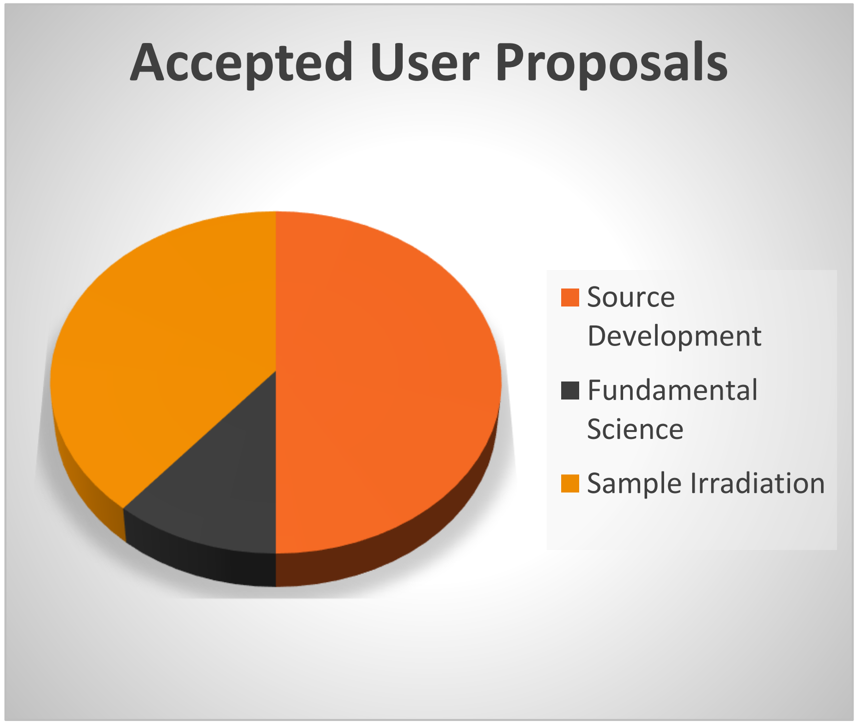
Real signal in high-energy region!



adapted from G. Brewster's talk on Monday

ELBA and ALFA received 69 user proposals so far. The acceptance rate is stabilizing around 30%-40%.



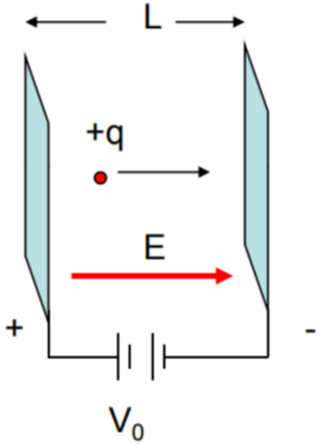


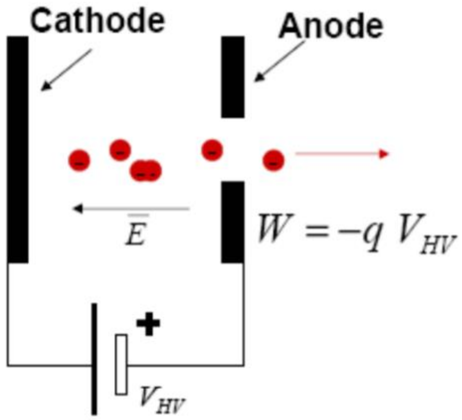
THANK YOU FOR YOUR ATTENTION!

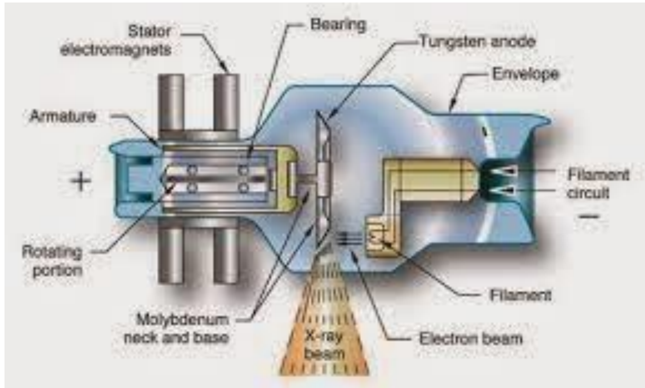
gabriele.grittani@eli-laser.eu

Conventional sources of electron beams are based on electrostatic acceleratorion (X-ray tube) or on radiofrequency acceleration (linac).

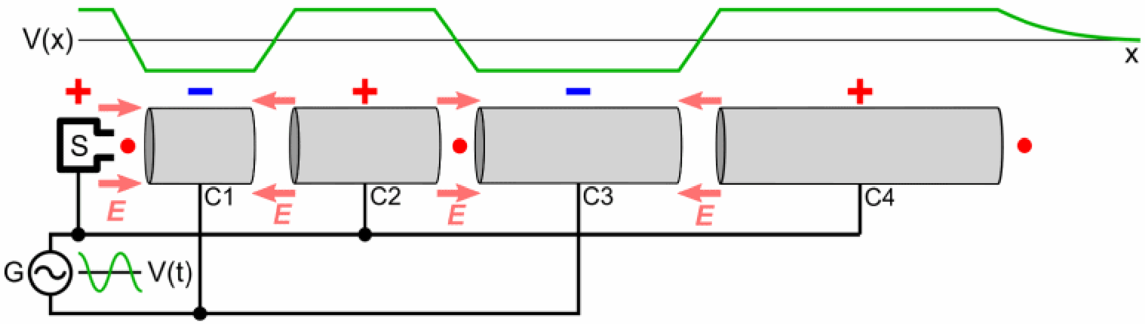
Electrostatic acceleration: *X-ray tube, up to MeV*

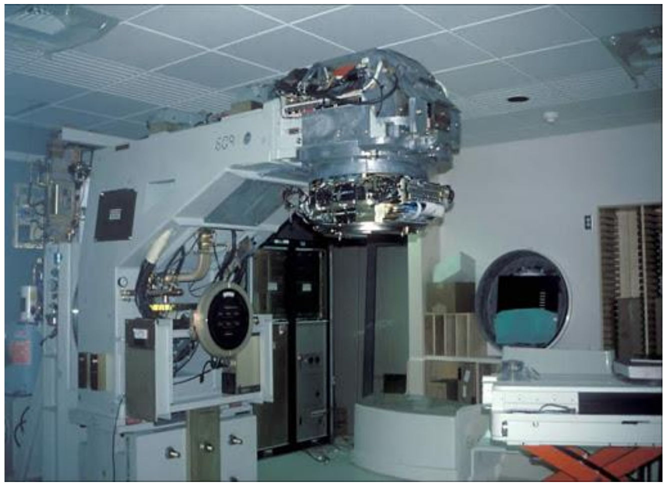






Radiofrequency acceleration: *linac, up to 300 MeV for laboratory scale facilities*





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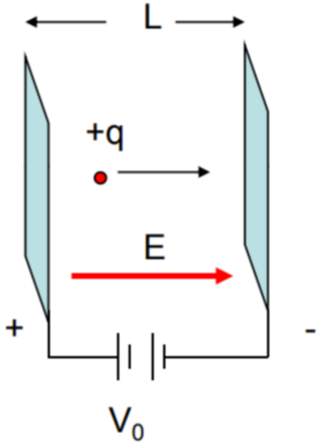

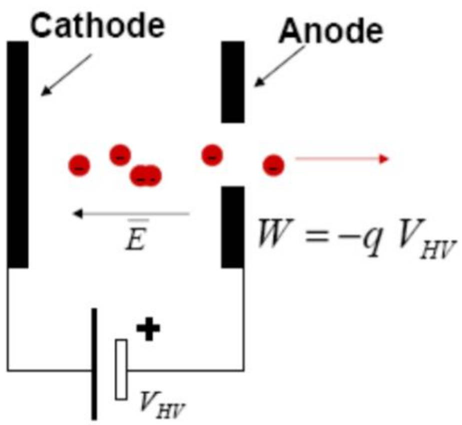

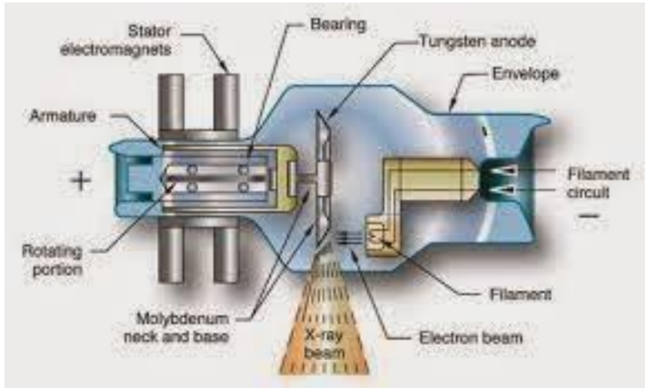

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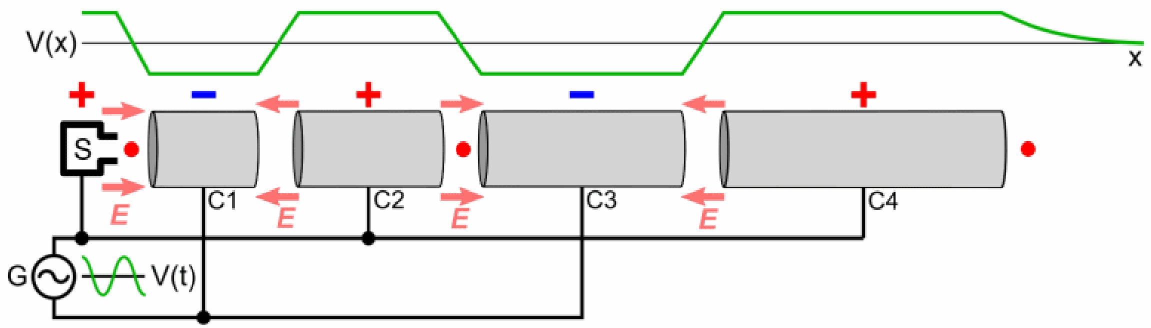

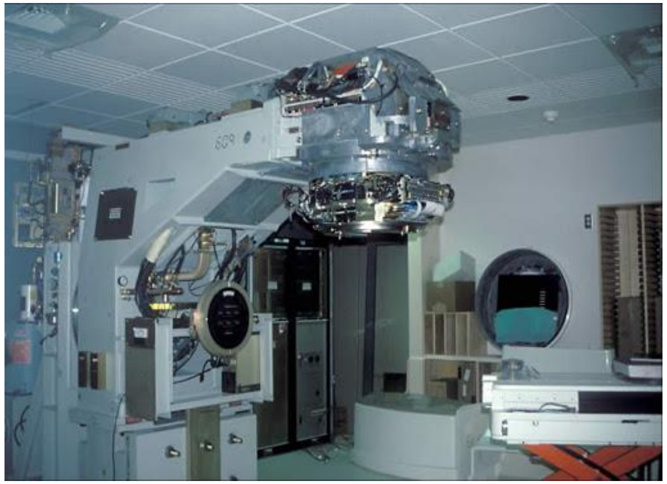

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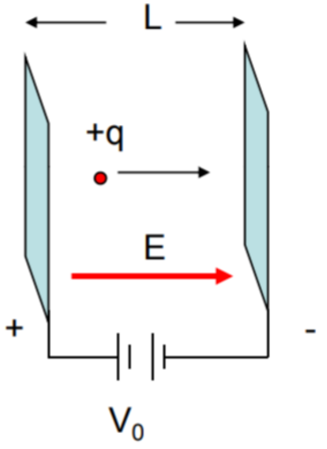
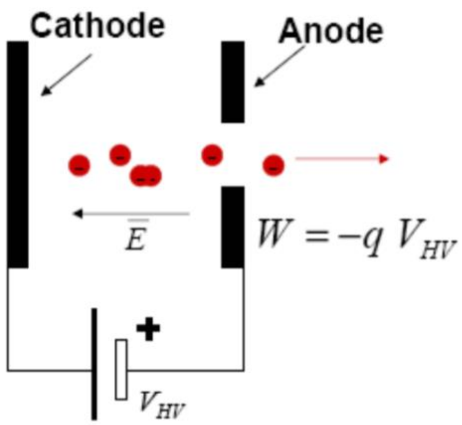
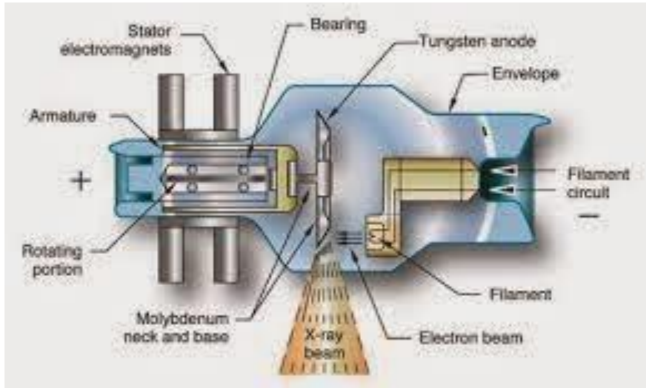
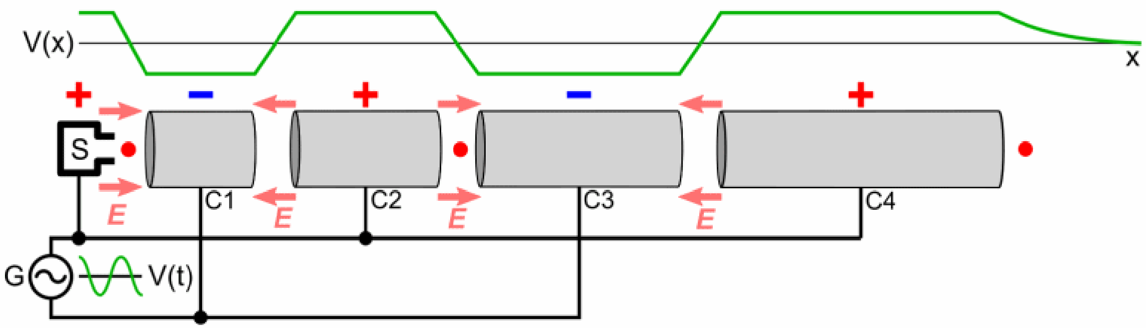
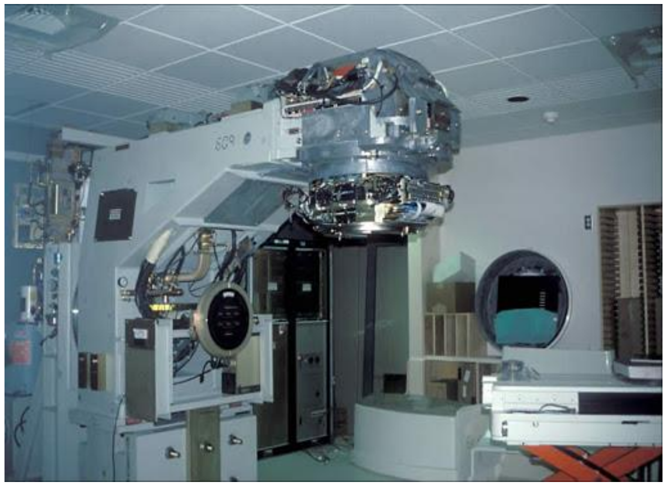






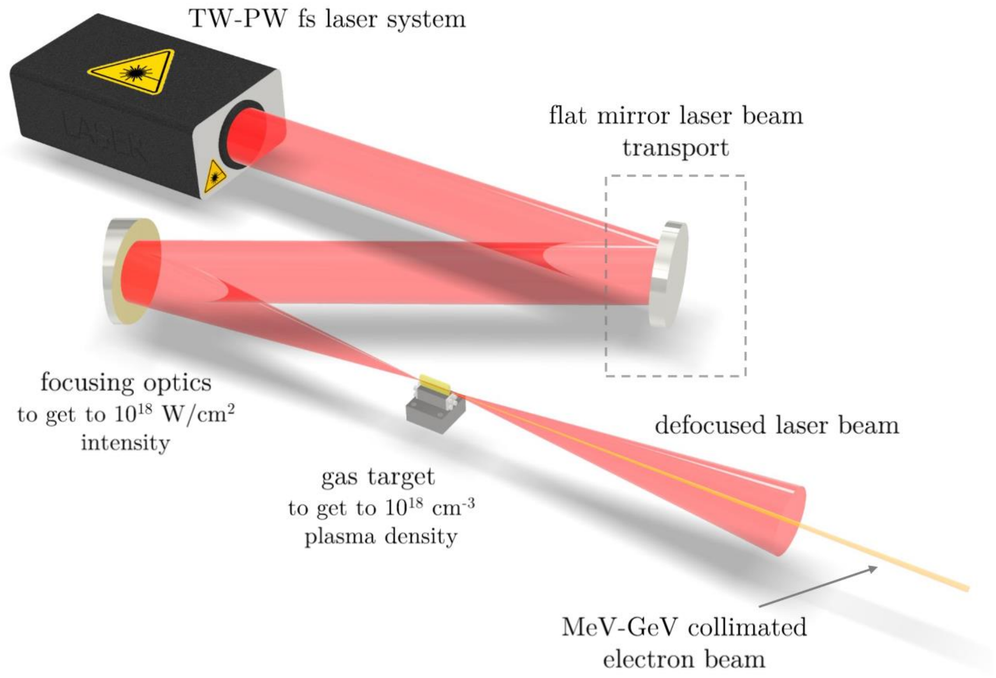
Radiofrequency acceleration: *linac, up to 300 MeV for laboratory scale facilities*

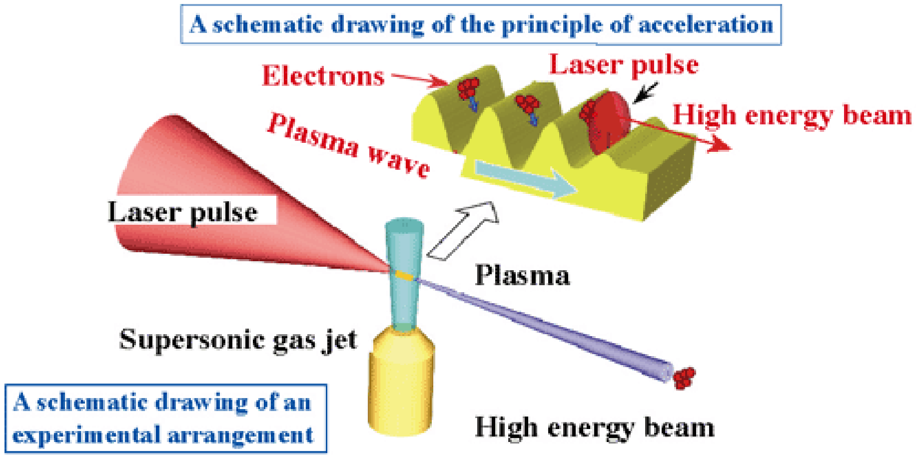




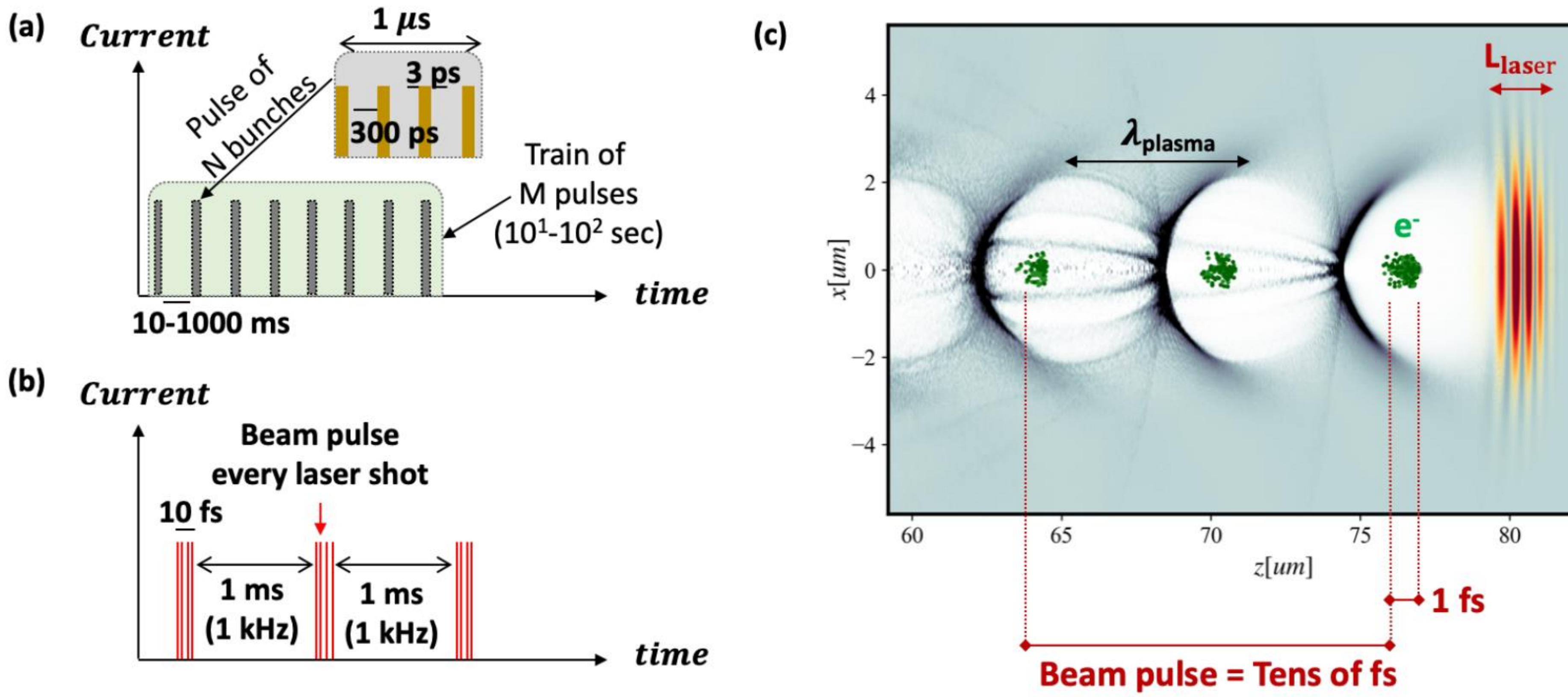
Laser wakefield electron acceleration (LWFA) is the most compact technology to produce VHEE electron beams.

Laser wakefield acceleration: *ultra-short (fs) and up to 10 GeV in laboratory scale facilities*





Laser wakefield accelerators can produce beams as short as 1 fs. They can operate up to 1 kHz pulse repetition rate.



J. Wenz et al., Nature Photonics 13 (4), 263-269 (2019)

C. Lazzarini et al., manuscript under review

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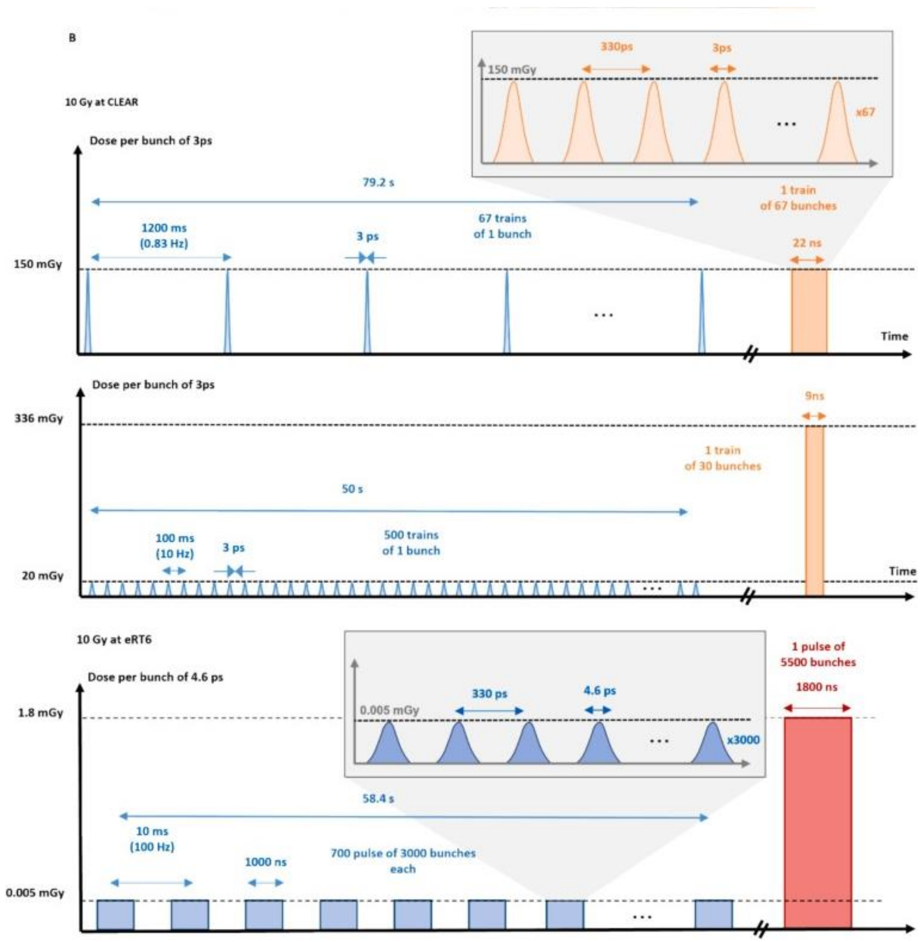

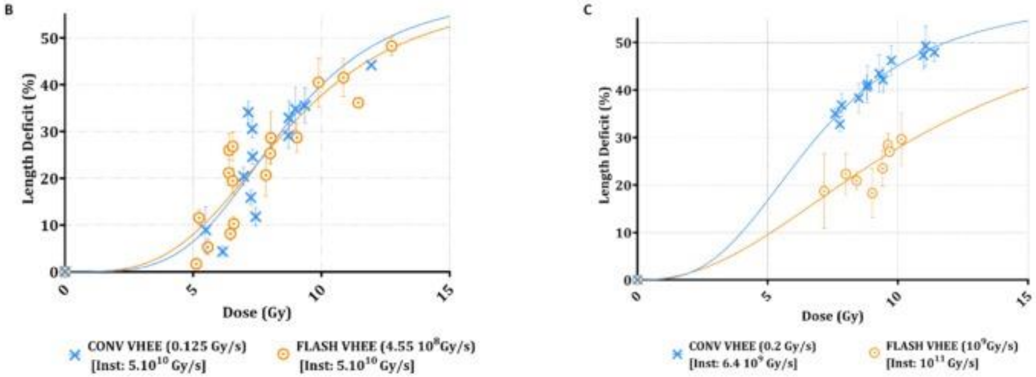

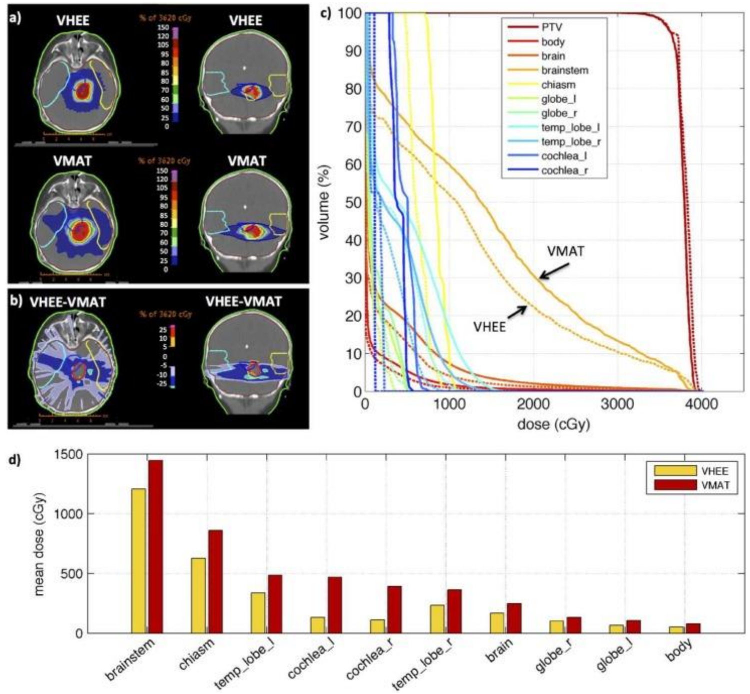

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J. Bedford and U. Oelfke, Physics and Imaging in Radiation Oncology 32, 100670 (2024)

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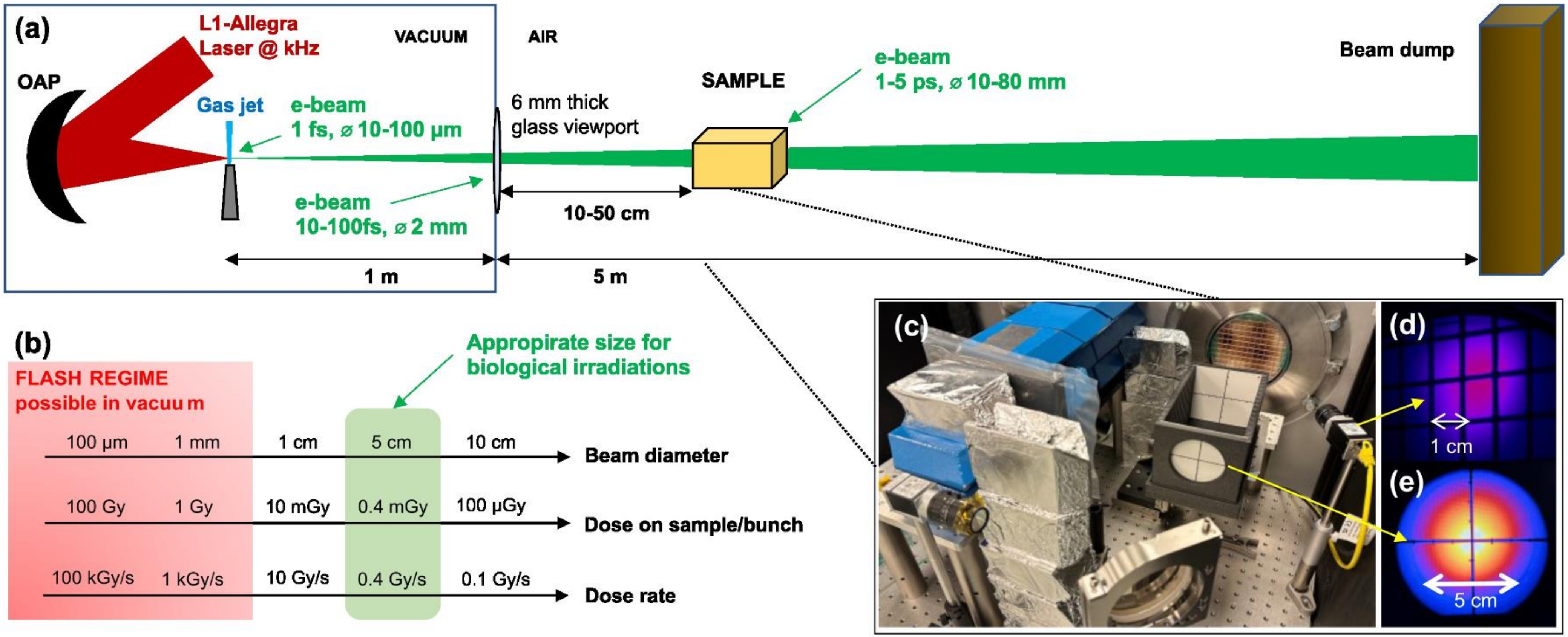


C. Lazzarini et al., manuscript under review

In order to keep the dose deposition as short as the electron beam duration, higher beam energy is required.

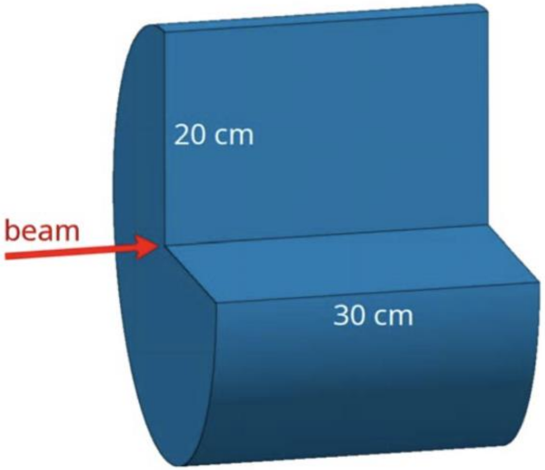
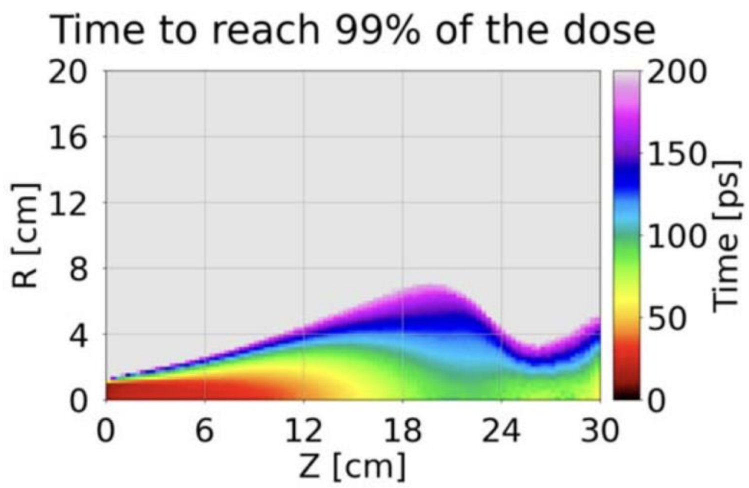
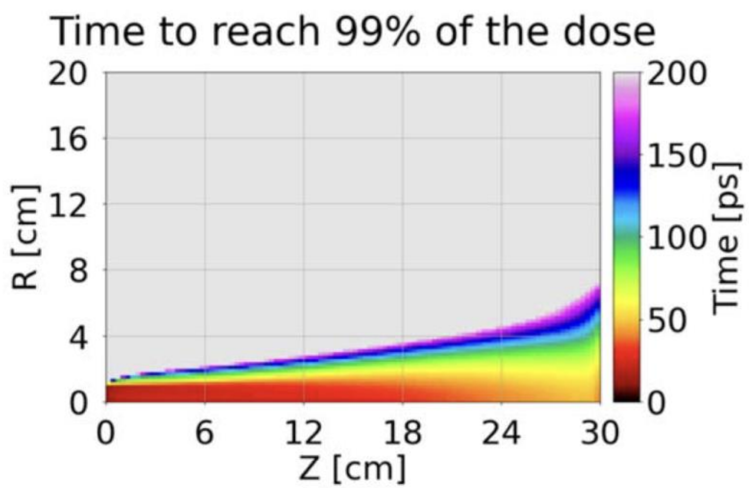


Table 2. Bunch lengths at different depths as calculated with FLUKA.

Depth [cm]	Bunch length [ps]
5	0.075
10	0.39
15	1.056
20	2.295
25	4.08
30	7.0



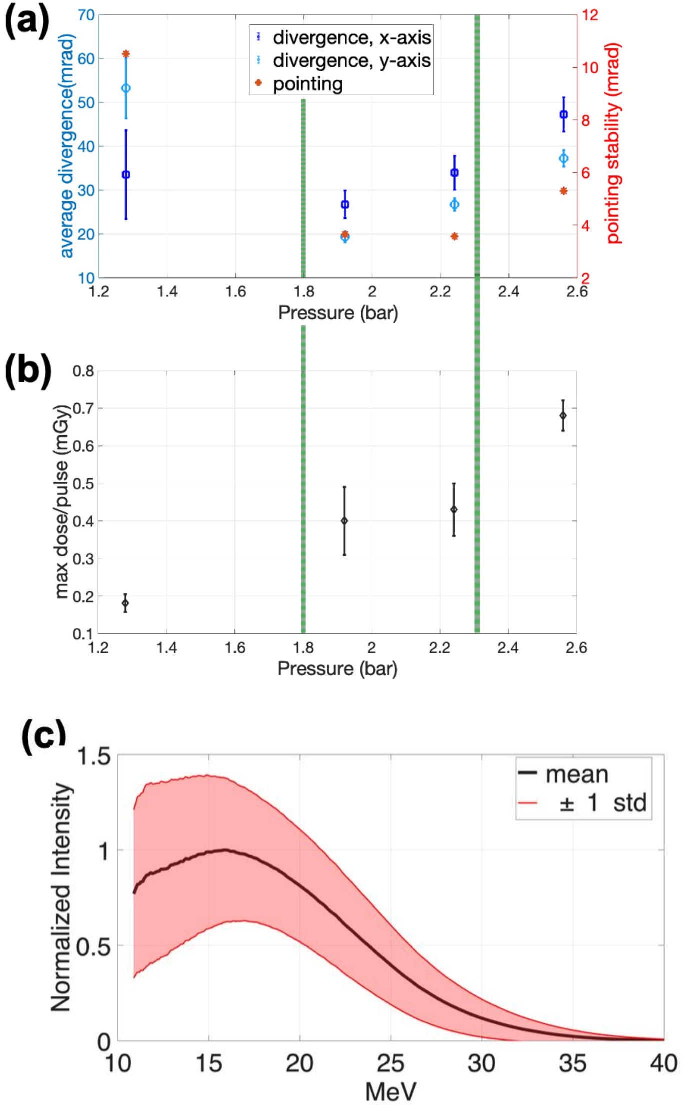
(b) $E = 50$ MeV

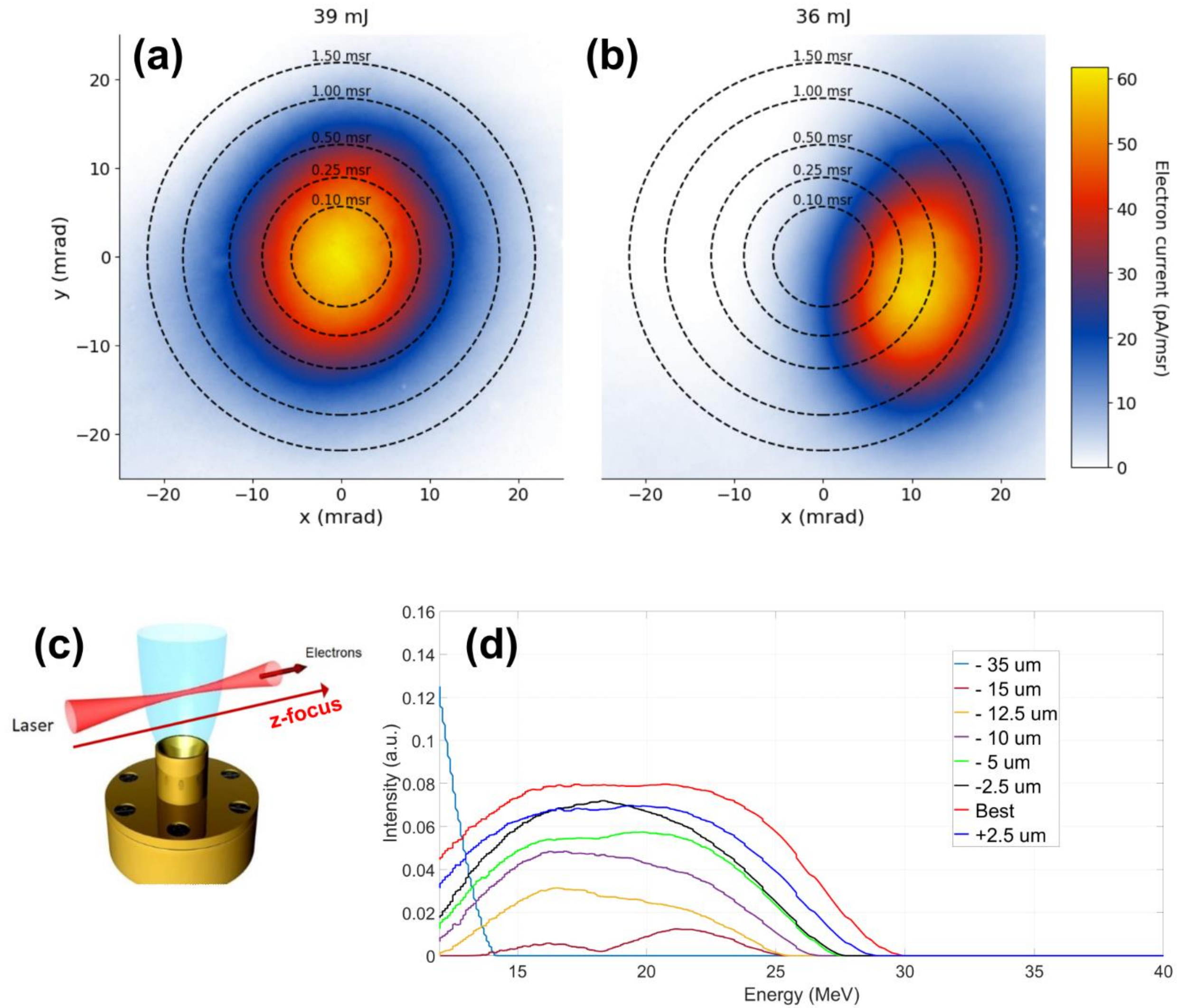


(d) $E = 150$ MeV

D. Horvath et al., Physics in Medicine and Biology 68 (22), 22NT01 (*2023*)

ELI is devoted to deliver stable and reproducible particle beams for external user experiments.



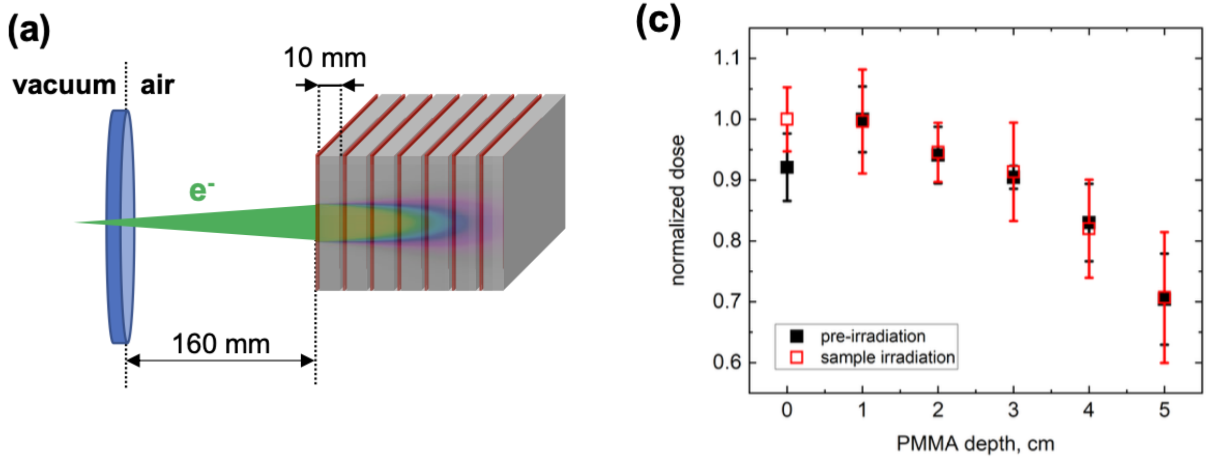


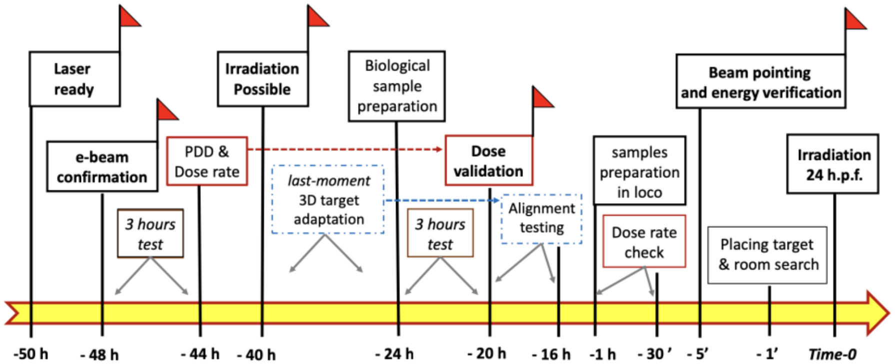
S. Lorenz et al., Accepted on High Power Laser Science Engineering

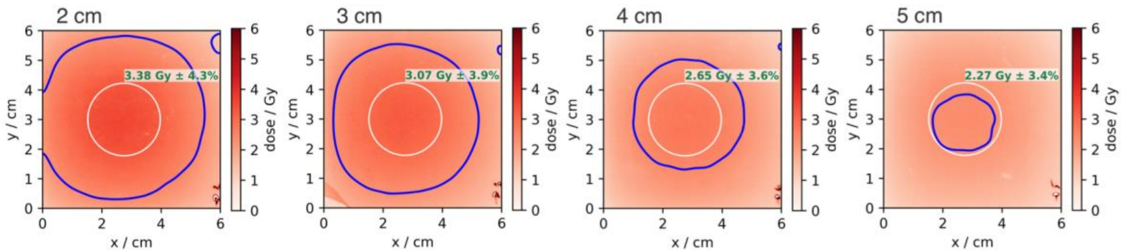
C. Lazzarini et al., manuscript under review

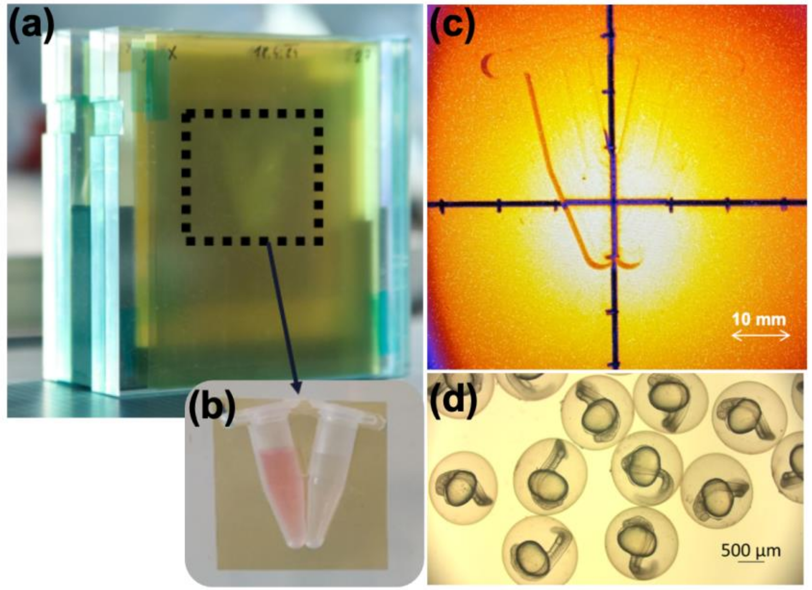
ALFA at ELI Beamlines delivers electron beam with same energy and same average dose rate of a medical linac.

Parameter	High Power Mode	High Energy Mode
Energy (MeV)	22±2	32±5
Energy Spread (MeV)	15 (68%)	8 (25%)
Average Current (pA)	276±28	12±6
Divergence (mrad)	7.8±1.2	2.1±0.8
Power (mW)	6	0.4



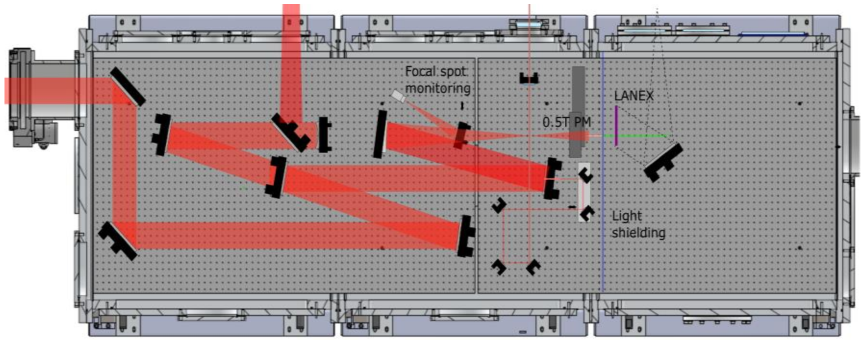






ESYLOS at ELI ALPS holds the potential to be the world's first laser-driven VHEE beamline at 1 kHz.

Available to Users since Nov 2024

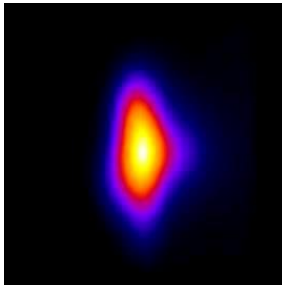


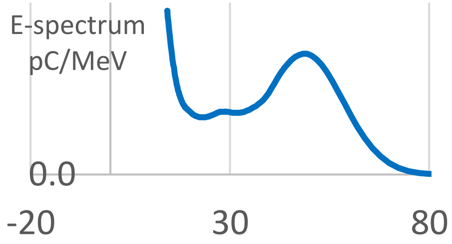
eSYLOS key features

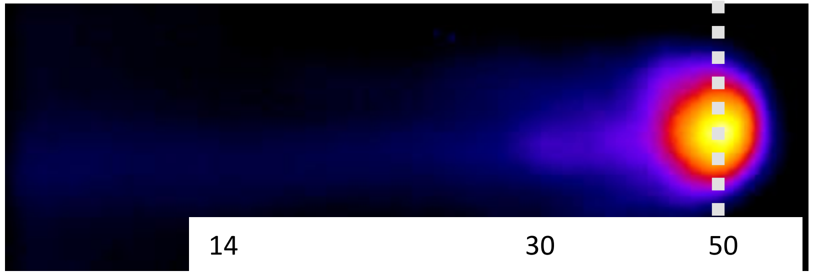
- 1 kHz shot-to-shot **data acquisition**
- **2 DMs available** (laser side and within chamber)
- **Two focusing OAPs** : 605 mm and 300 mm

Operation statistics and on-target specs

- ***>6 hours*** daily, uninterrupted e-beam delivery at ***10 Hz and/or 100 Hz***
- 1.5 ***hours*** *continuous* operation at ***1 kHz***
- **On-target energy at 8 fs :**
  - Tunable 12 - 76 mJ







Electron output (as of Dec 2025)

- 20 × 50 mrad divergence
- Pointing: ***0.5 × 0.4 mrad RMS***
- Electron energy: ***49 MeV peak***
- Electron charge: ***94±5 pC total***
  - *(60.0±3.5 pC above 30 MeV)*
- *Total e- energy :* **3.3 mJ (5% effic.)**

Applications
User experiments

At eSYLOS chamber

- Positron generation and detection at high repetition rates
- Systematic study of CEP effects
- LWFA dosimetry mapping
- Machine learning at kHz rep rates
- THz streaking

At dedicated endstation (IFIR)

- Irradiation of biological samples
  - Zebrafish embryos
  - Cell cultures

EPW at ELI ALPS delivers up to GeV electron beams. It will be available to Users from May 2026.

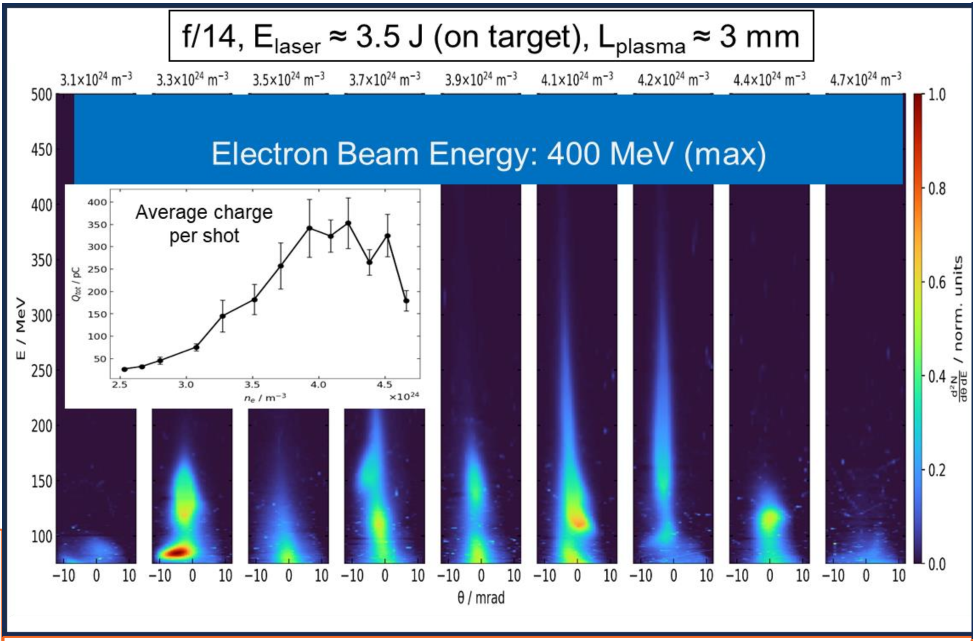
Applications / User experiments (from Apr 2026)

Fast betatron x-ray μ-tomography (μCT) //

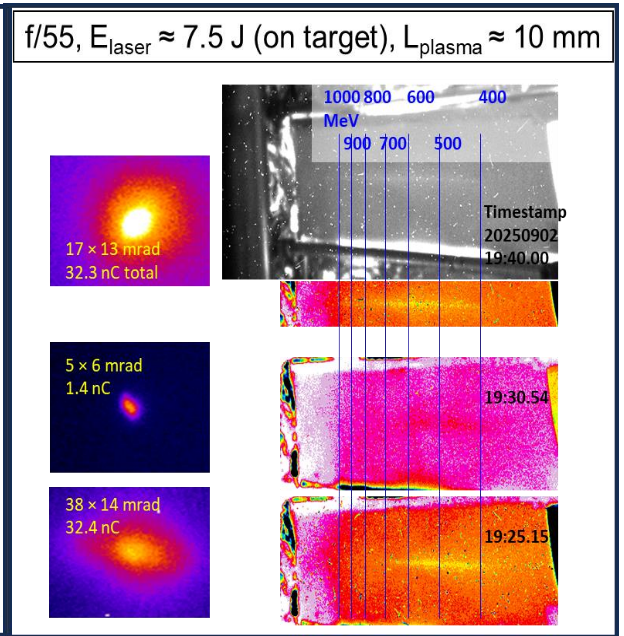
VHEE cancer therapy (200-400 MeV)

Electron/X-ray Energy Boosting schemes //

Light Sources with GeV electrons



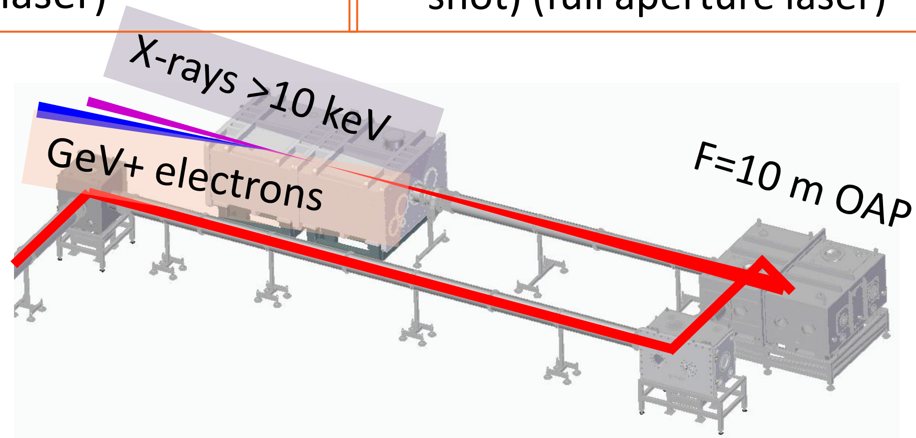
f#15: up to 400 MeV, nC-level (single-shot) (reduced aperture laser)



f#55: ~1 GeV, nC-level (single-shot) (full aperture laser)

ePW key features and operational regimes

- 2 DMs available (laser side and after final compressor)
- **Two focusing OAPs :**
  - f/15 : high charge/"low energy" ebeams (for VHEE cancer therapy)
  - f/55 : "low charge"/high energy ebeams (for betatron x-ray µ-CT

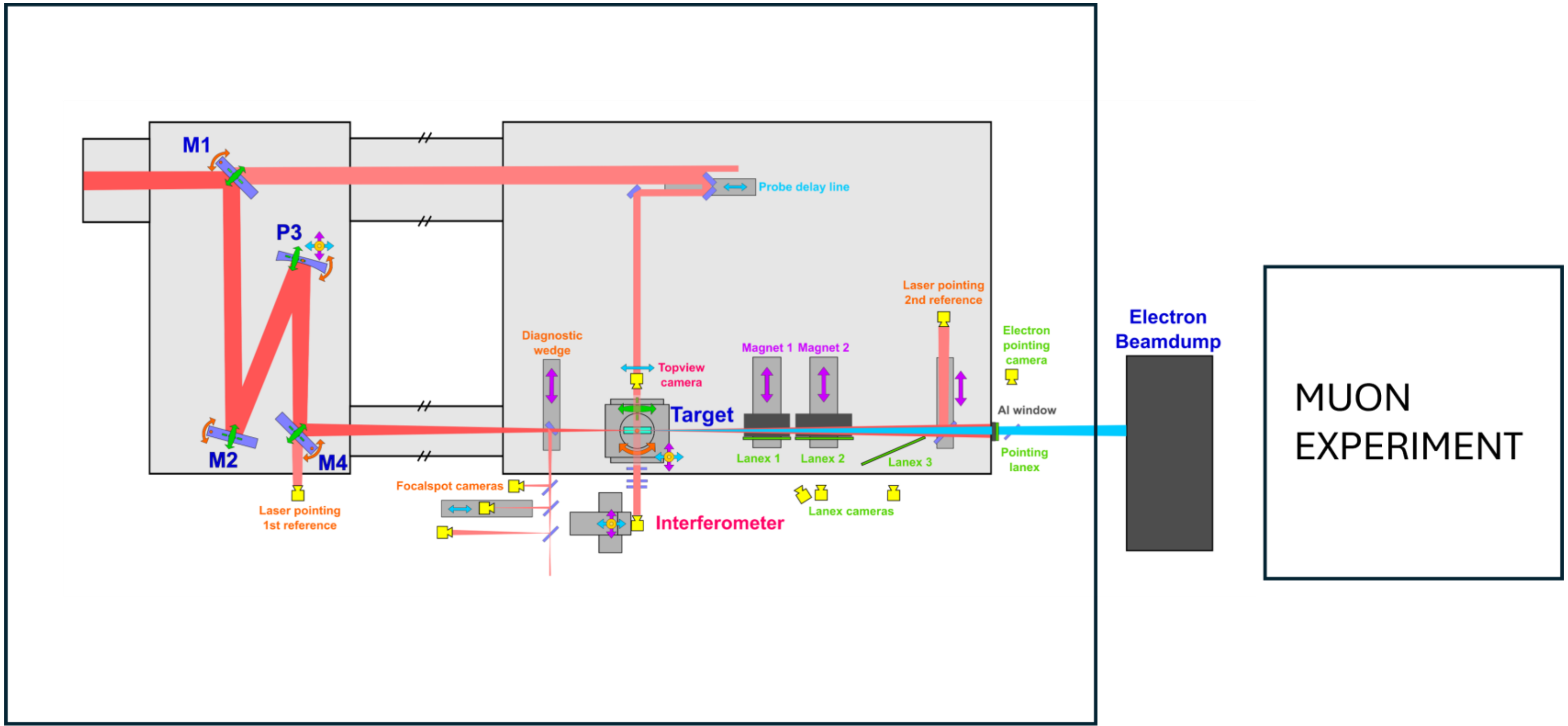


On-target laser energy @ 21 fs:

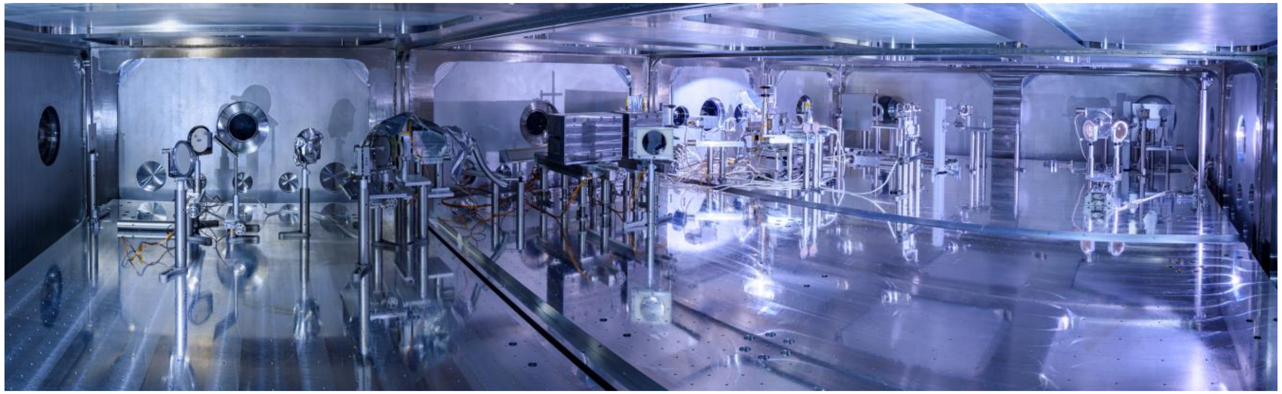
- 7.5 J (f/55 – full aperture)
- 3.5 J (f/15 – reduced aperture)

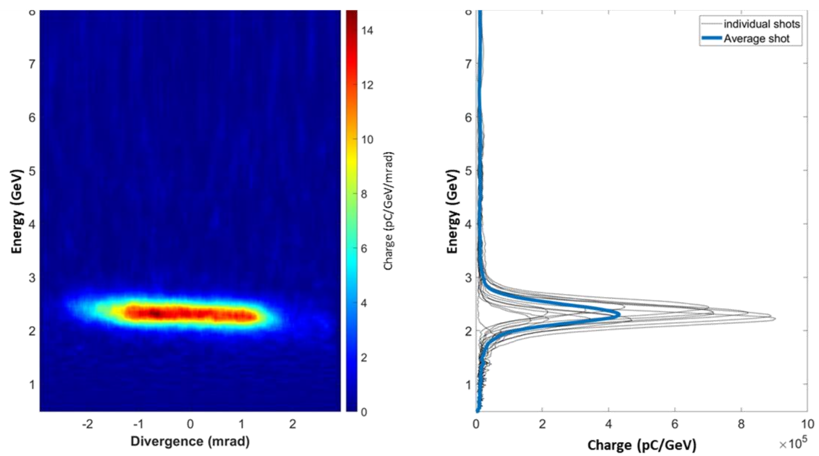
Commissioned in Sep 2025 Available to Users from May 2026

ELBA delivers stable multi-GeV laser electron accelerator for users. The size of E5 experimental hall enables future scenarios with electron-based tertiary sources (positrons, muons).

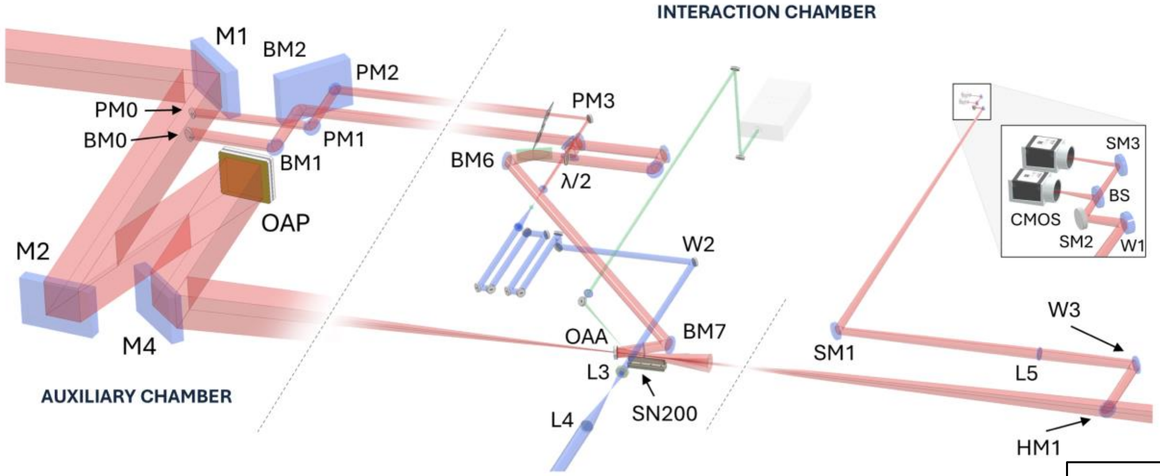


Parameter	Value
Energy (GeV)	5±0.5
Energy Spread (MeV)	0.5 (10%)
Charge per pulse (pC)	108±28
Divergence (mrad)	1.4±0.3
Power (mW)	63





ELBA offers to users all-reflective guided LWFA configuration up to 15 J and up to 3.3 Hz.



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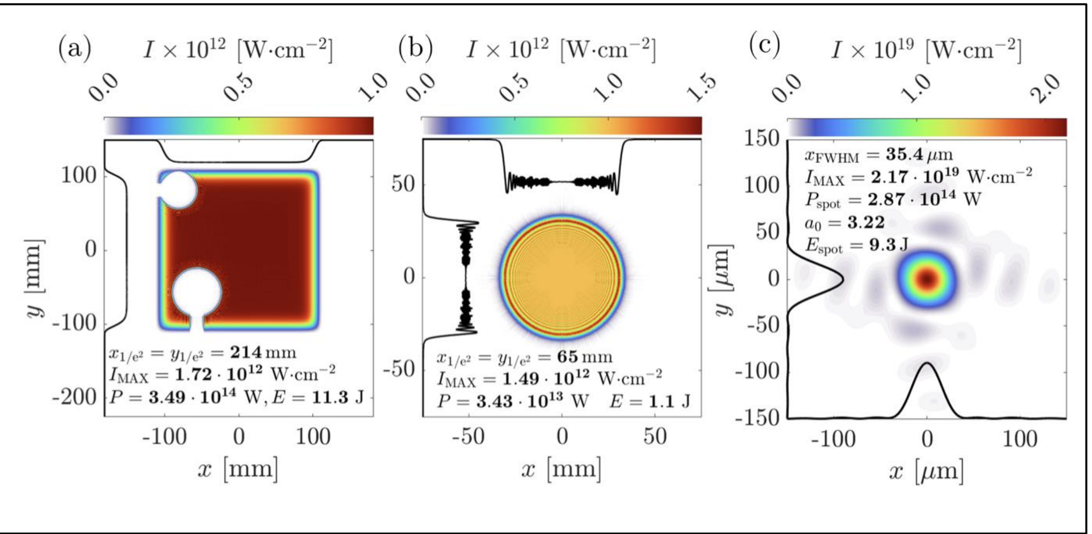

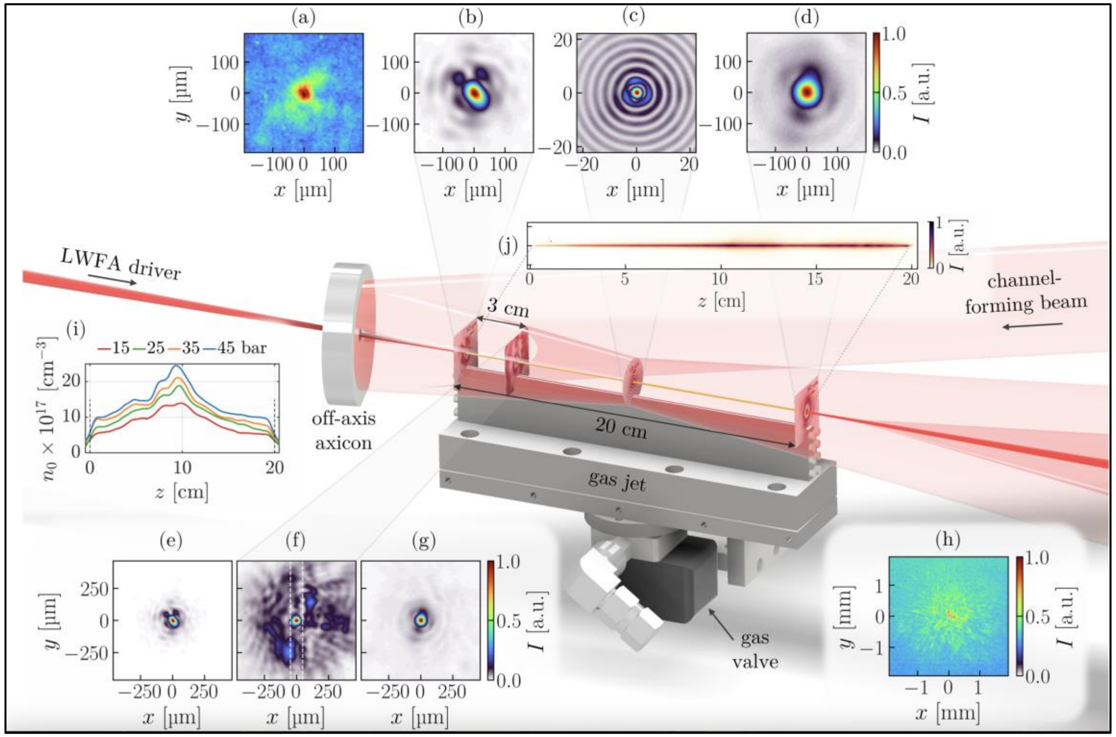

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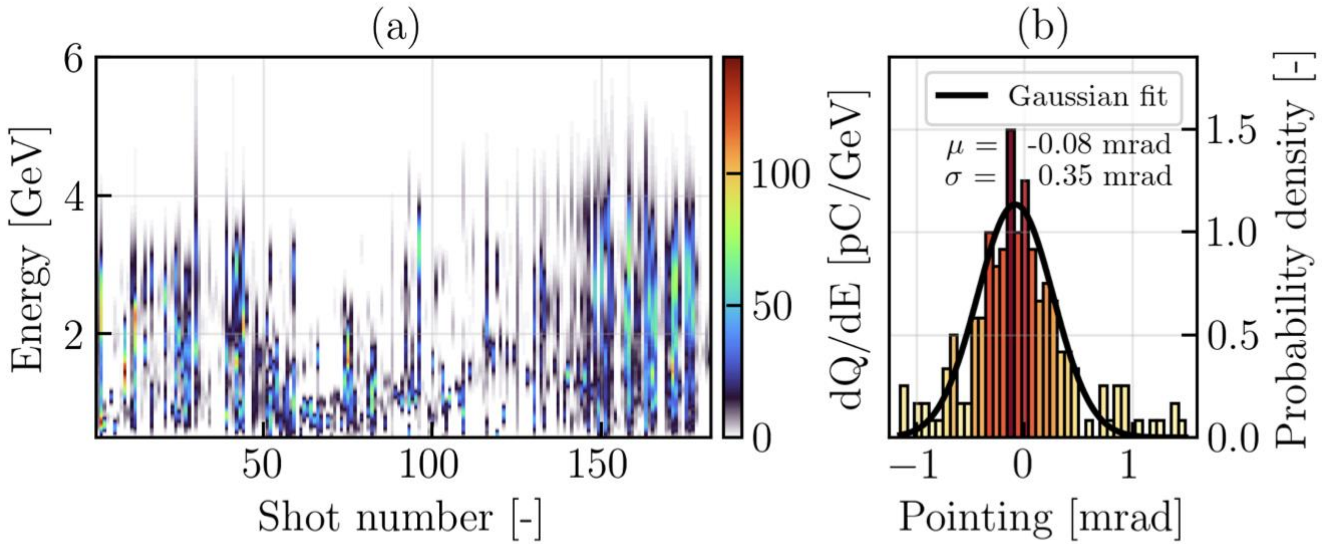

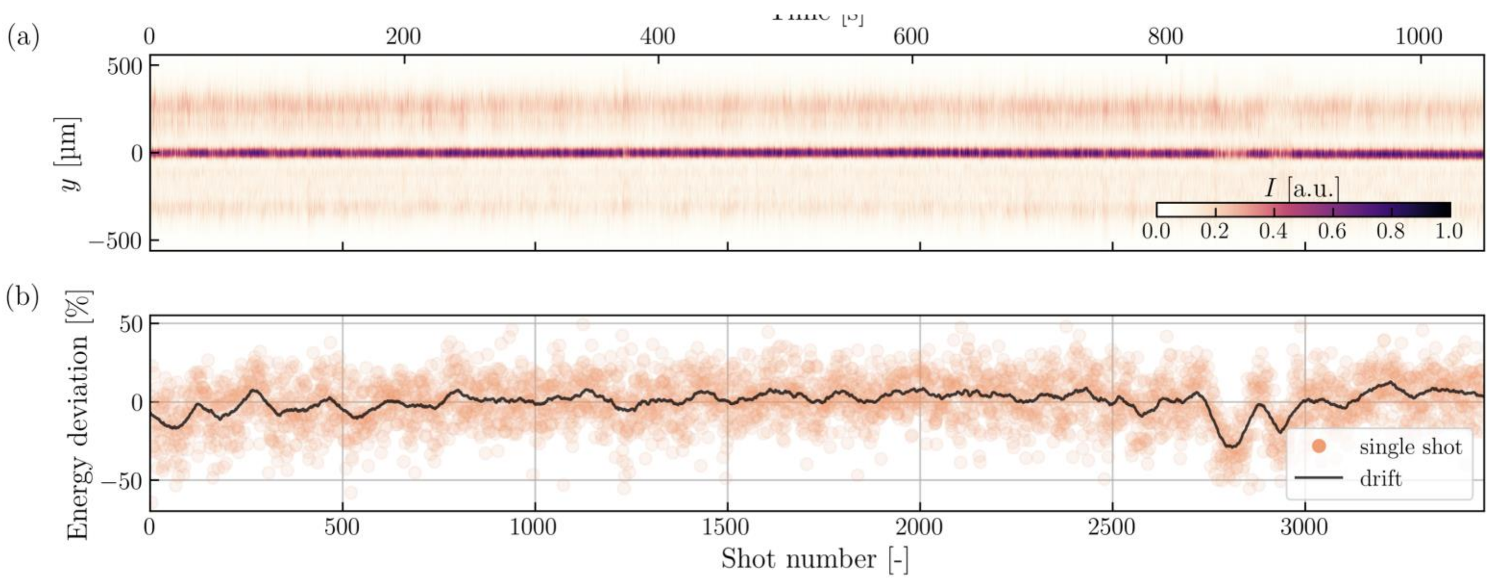

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