Overview of Laser-Driven Multi-GeV Muon Sources and the ELI Beamlines plan

Gabriele Maria Grittani[1,*], S. V. Bulanov[1], A. Cimmino[1], D. Margarone[1], M. Nevrkla[1], J. Sisma[1], R. Versaci[1], P. Valenta[1], F. Vitha[1]

[1]ELI Beamlines Facility, The ELI ERIC, Dolni Brezany, Czech Republic
**Leader of the Electron Acceleration Group @ ELI Beamlines*

XVIII Conference on Resistive Plate Chambers and Related Detectors, UERJ Rio de Janeiro, 17th September 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

A. Pirozhkov, T. Wei, M. Kando

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

J. Williams, B. Pagano, S. Kerr

L. Labate, L. A. Gizzi

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

M. Barroso Ferreira Filho, K. Mota Amarillo, H. Nogima

B. K. Russell

A. G. R. Thomas, R. Herbst, Y. Ma

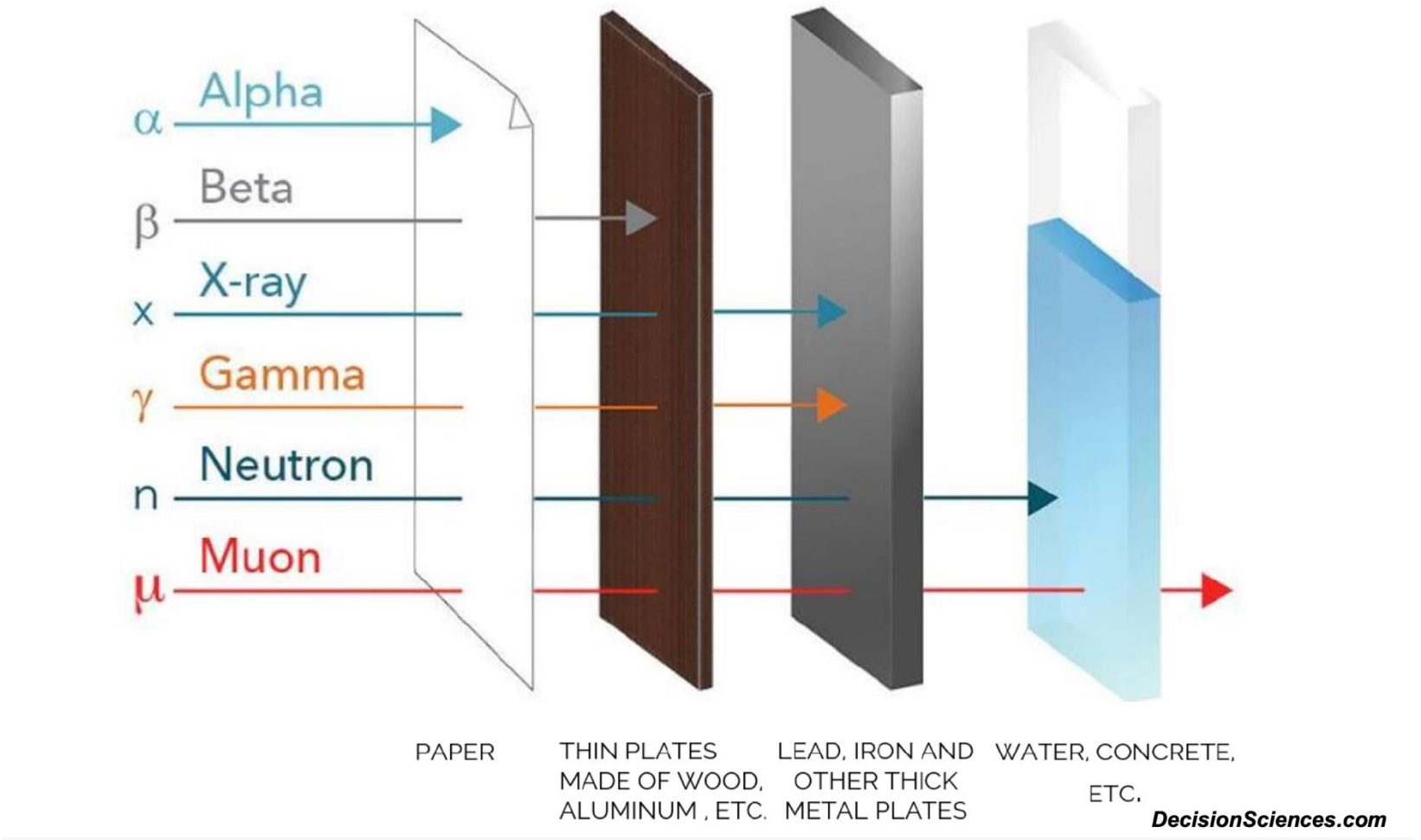
S. Buontempo, R. Pompili, F. Stocchi, M. Galletti

S. S. Bulanov

I. Bagaturia

M. Ali Shah

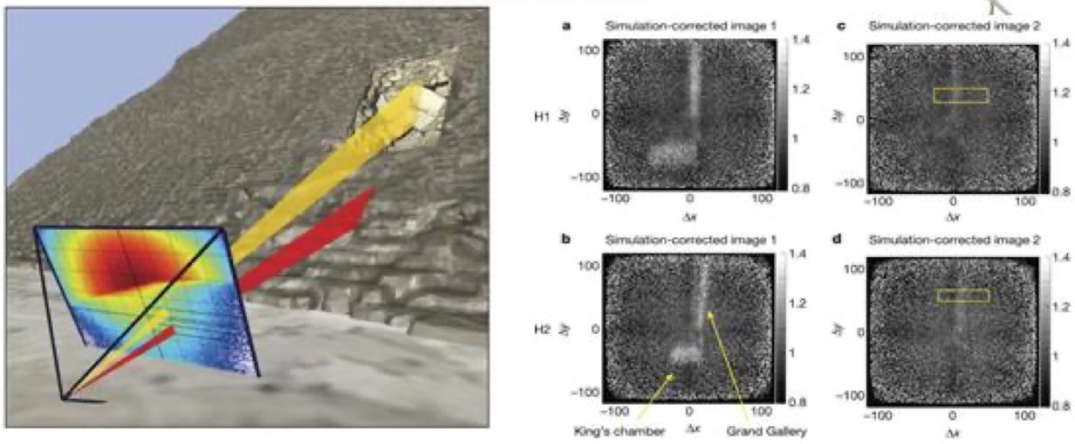
Multi-GeV muons penetrate much more than X-rays enabling unique imaging capabilities



Credits to B. Reagan

Cosmic muons have a mean energy of about 4 GeV, and are routinely used to image gigantic objects. A 4 GeV conventional accelerator has kilometer-scale size.

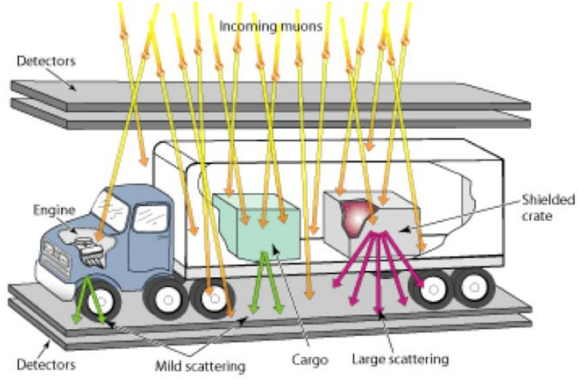
Discovery of a hidden chamber in the Great Pyramid of Giza using Cosmic-ray Muons



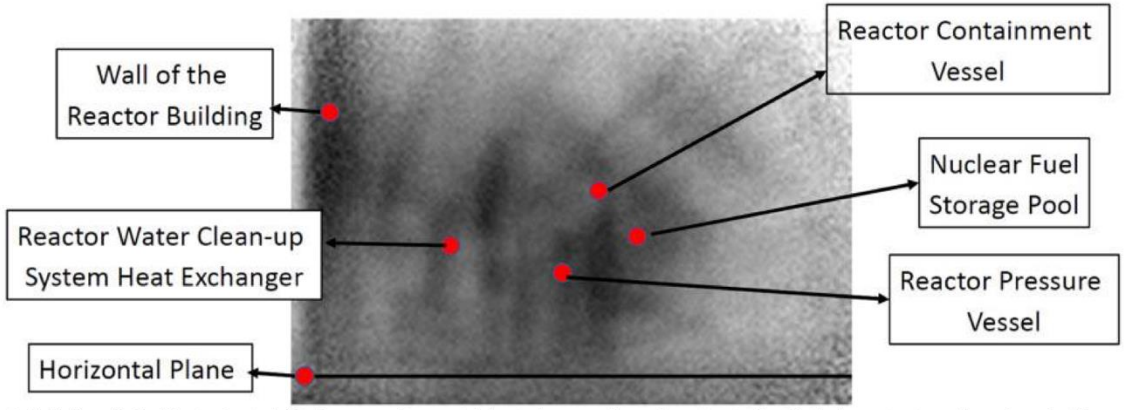
Morishima, K., Kuno, M., Nishio, A. *et al.*, "Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons," *Nature*, 552, 386–390 (2017). Link.

Inspection of cargo containers using cosmic-ray muon tomography

https://science.osti.gov/np/Benefits-of-NP/Applications-of-Nuclear-Science/Archives/Muon-Radiography-at-LANL



Inspection of the inside of the Fukushima Daiichi reactor

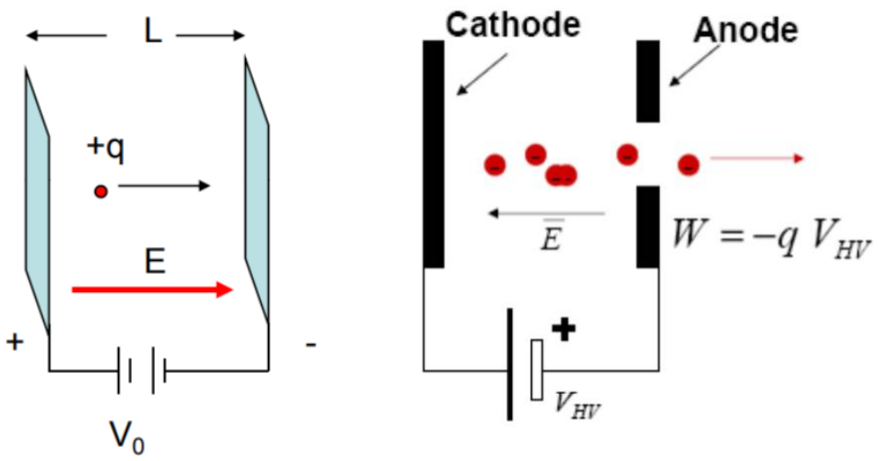


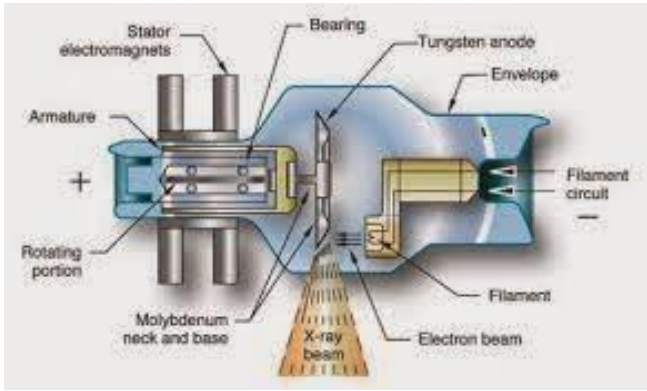
Fujii, H., Hara, K., Hashimoto, S., *et al.*, "Performance of a remotely located muon radiography system to identify the inner structure of a nuclear plant," *Prog. Theor. Exp. Phys.*, 2013, 7, 073C01 (2013). Link.

Credits to B. Reagan

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

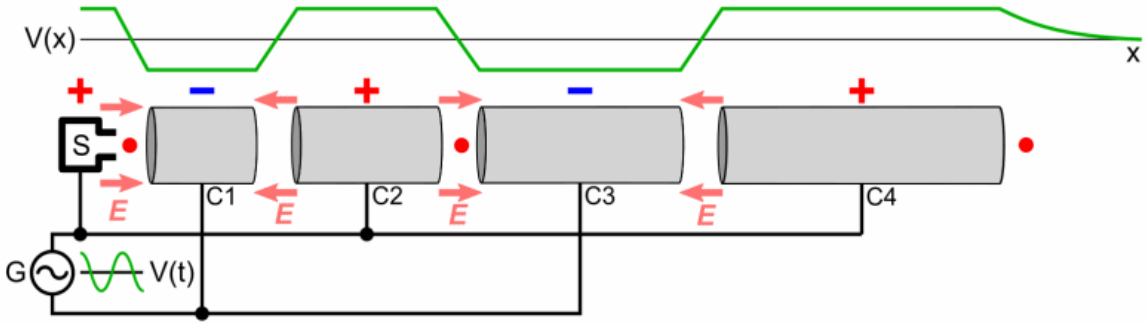
Electrostatic acceleration: *X-ray tube, up to MeV*

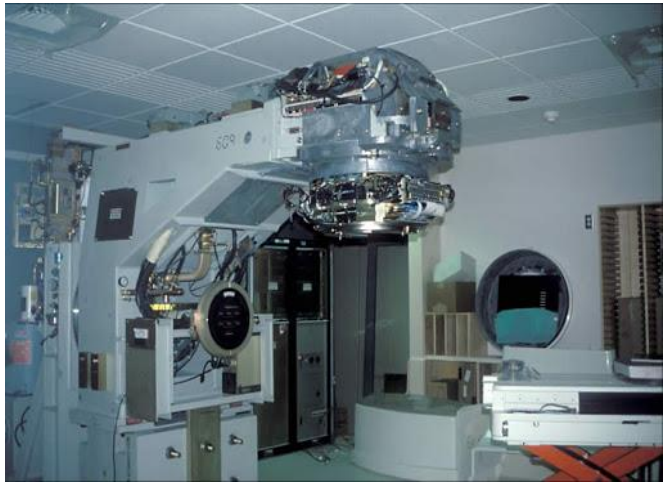




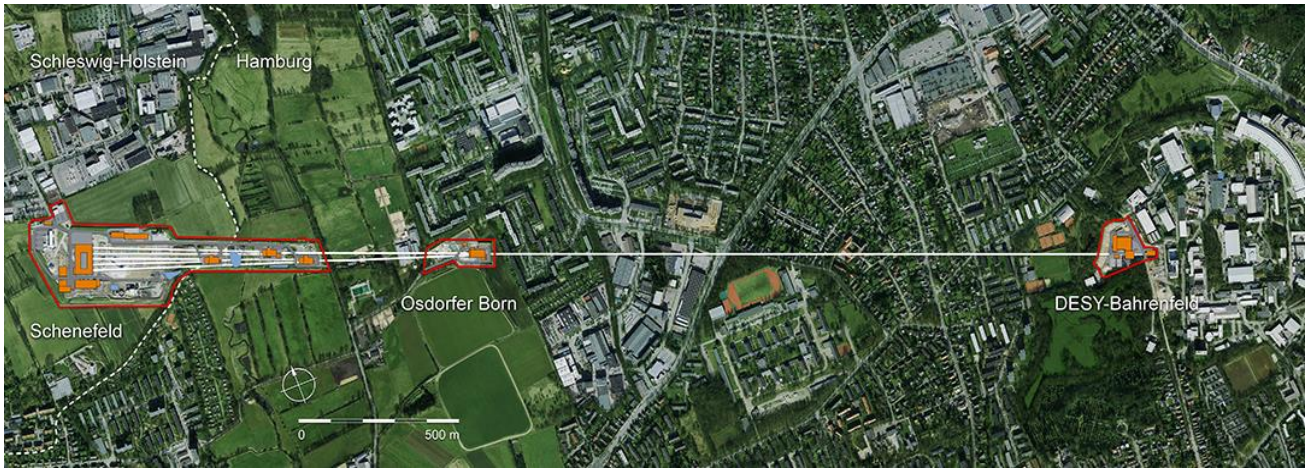


Radiofrequency acceleration: *linac, up to 300 MeV for laboratory scale facilities*

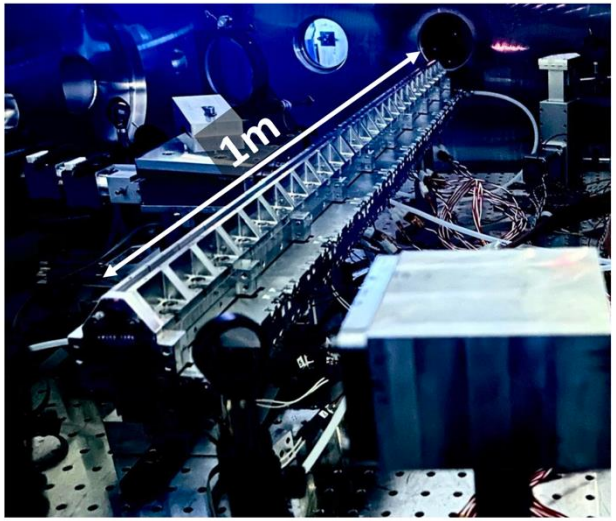


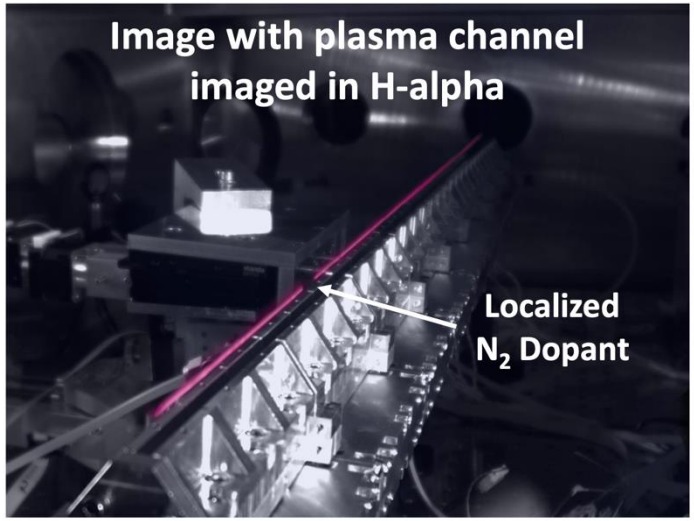


Conventional radiofrequency accelerators are almost 100-year-old technology, and their performance is extremely reliable. Their maximum accelerating gradient is 10-100 MeV/m.



European XFEL in Hamburg:
17 GeV, 3 km long



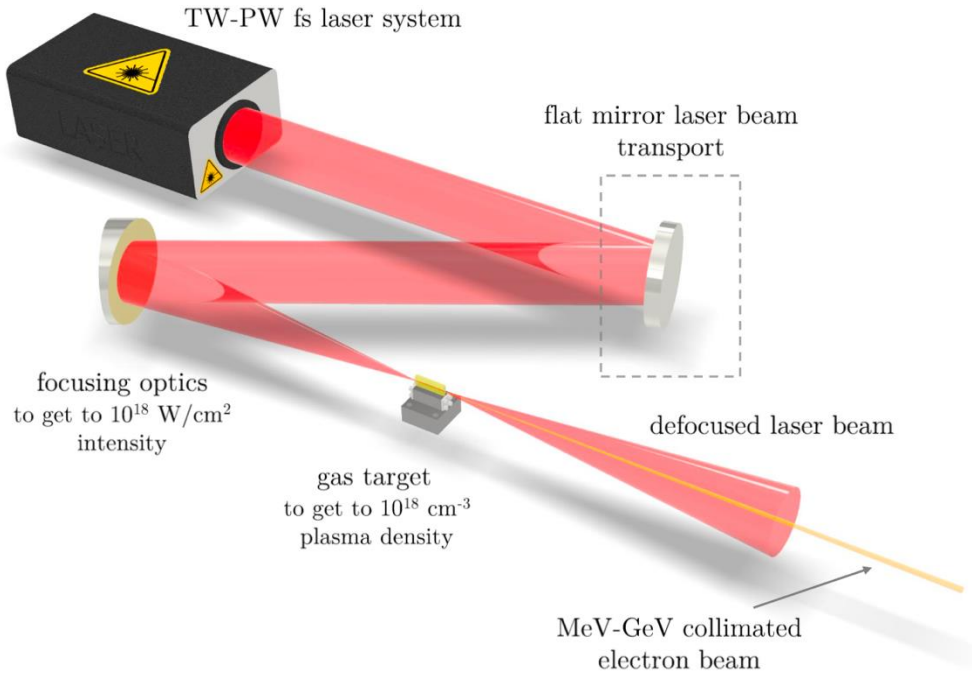


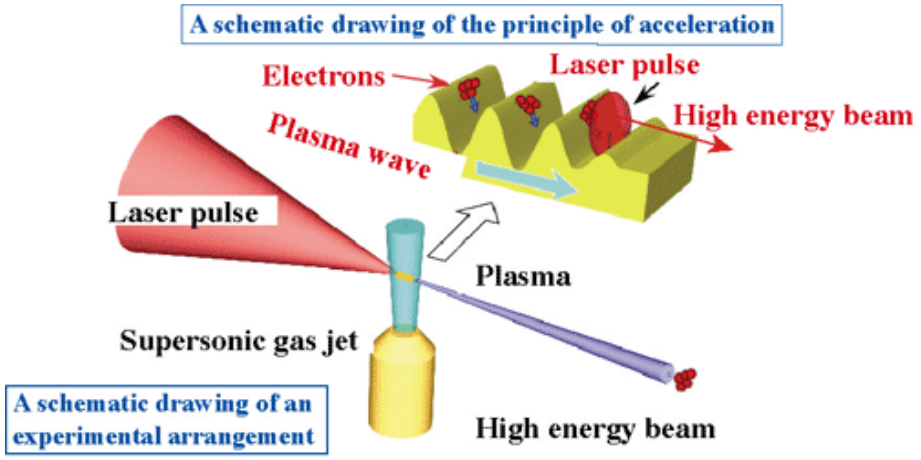
Laser Plasma Accelerator at
Colorado State University:
10 GeV, 30 cm long

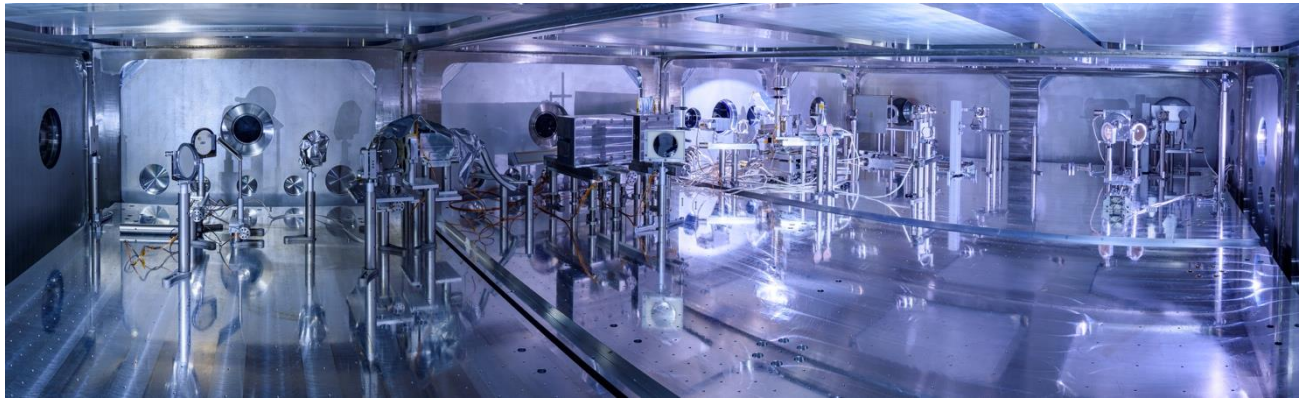
Lawrence Livermore National Laboratory · APT · University of Maryland · XUV Lasers · Berkeley Lab · eli beamlines · Colorado State University · Lockheed Martin

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

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







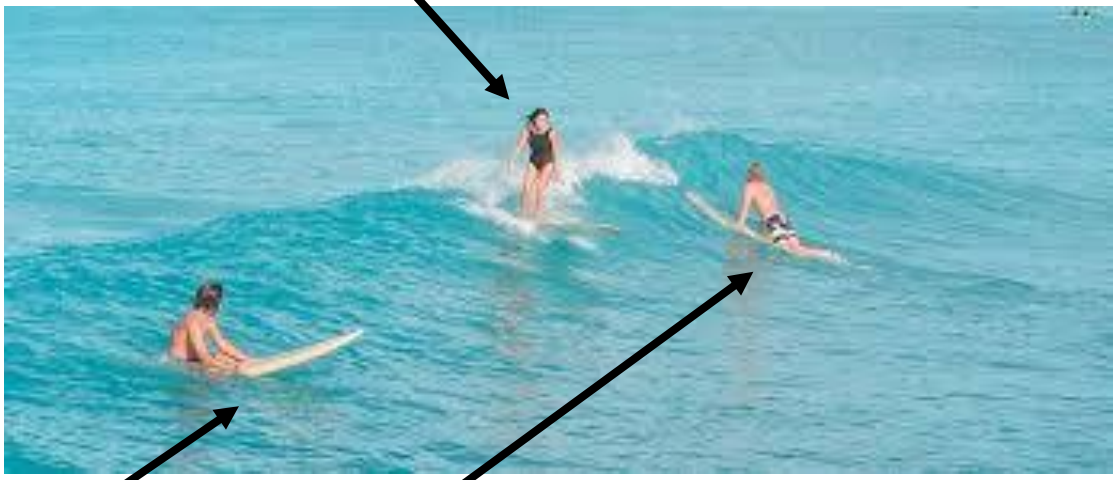


Creating the accelerating cavity is quite simple. Injecting the electrons requires pre-accelerating them close to the speed of light.

Pre-acceleration required to catch the wave



Fast enough



They will oscillate and stay in the same position

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 **E**uropean **R**esearch **I**nfrastructure **C**onsortium (a legal entity under EU law, created by EU countries and partners to develop and operate pan-European research infrastructures).

AN ESFRI LANDMARK PROJECT







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.

SZEGED, HUNGARY
SINCE 1 JANUARY 2024



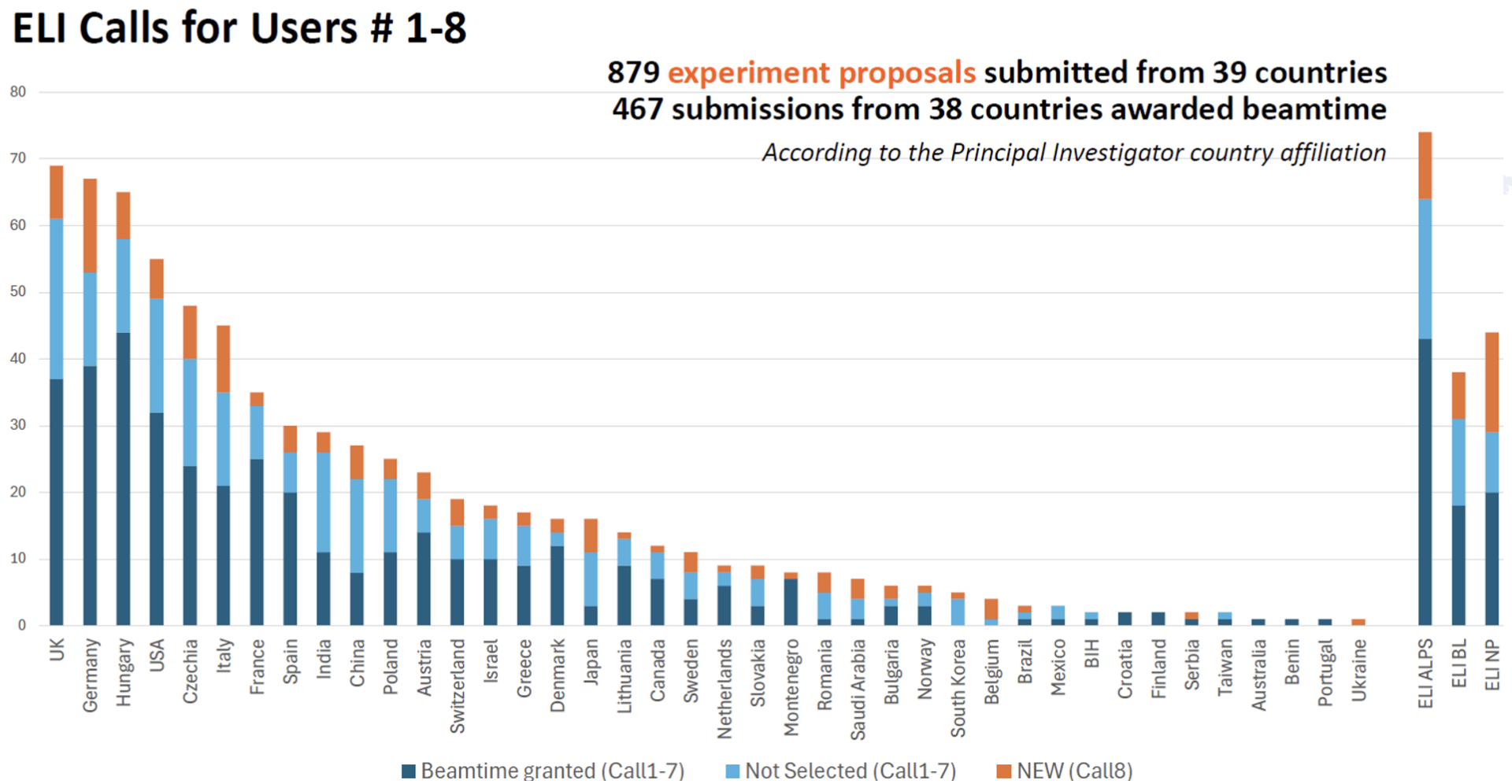
ELI Nuclear Physics Facility

Nuclear Physics facility with ultra-intense lasers and brilliant gamma beams (up to 19 MeV) to produce and explore new nuclear states or generate neutron beams.

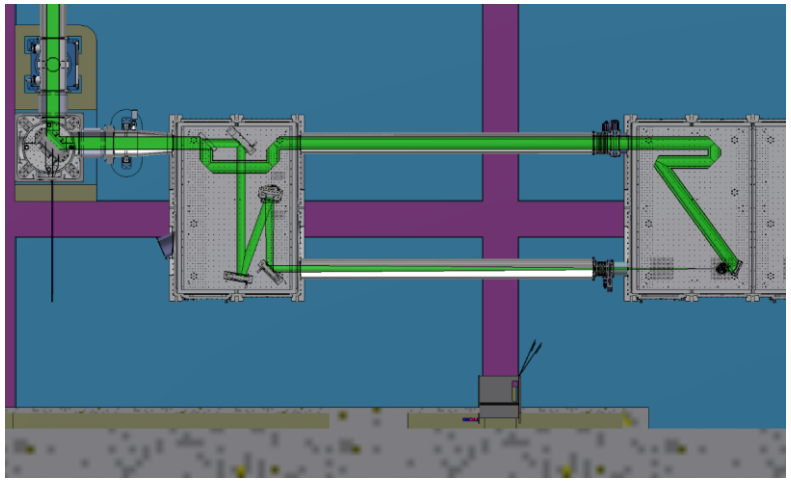
MĂGURELE, ROMANIA

A growing user community

Submitted vs Granted ***Proposals***



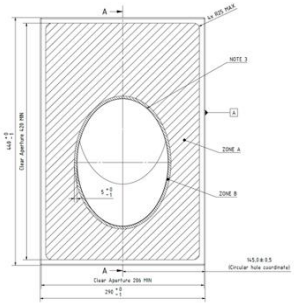
ELBA laser electron collider has been designed to approach parameters relevant for QED studies.

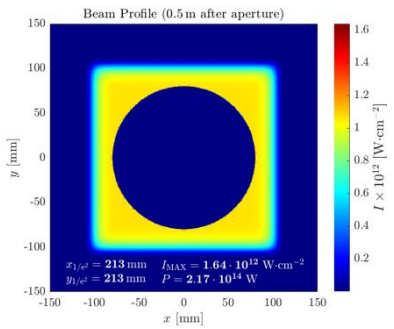


$$\chi_e \simeq 0.18\,\mathcal{E}_0[\mathrm{GeV}]\, I_0^{1/2}[10^{21}\ \mathrm{Wcm}^{-2}]$$

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

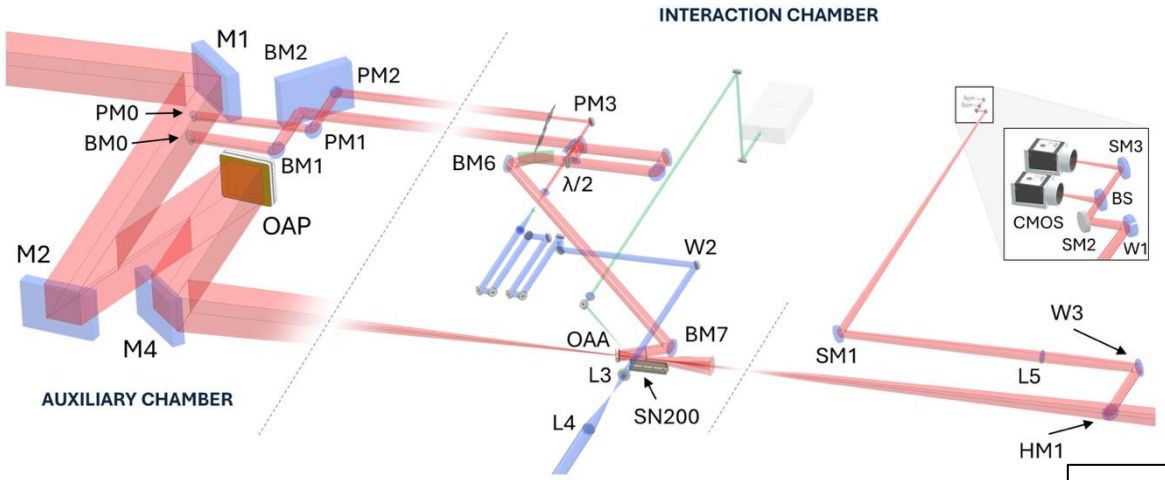
Key Technology is 50:50 Wavefront Splitting to enable high temporal synchronization of the LWFA beam and the CP laser





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

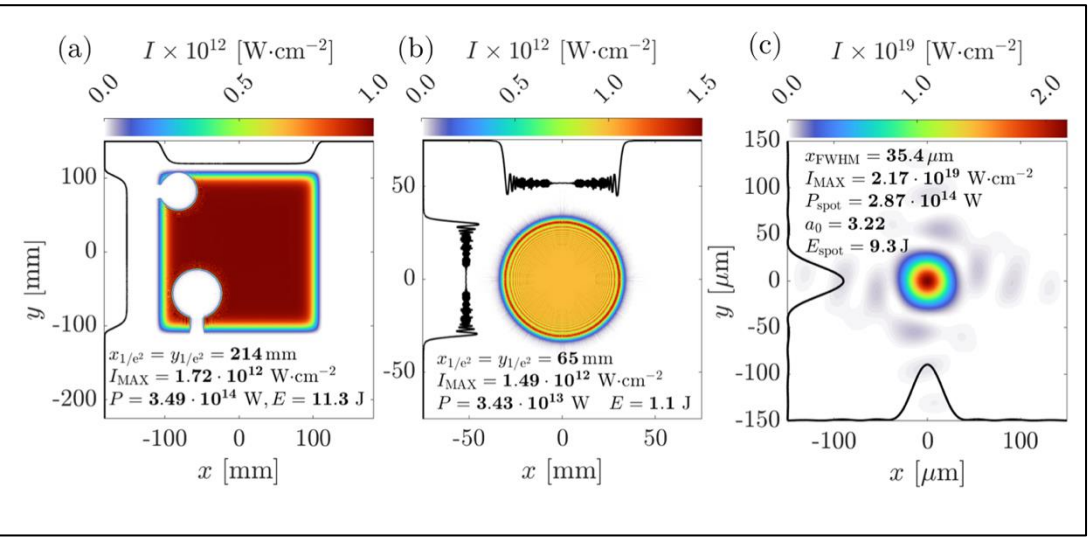
HIGH POWER LASER SCIENCE AND ENGINEERING

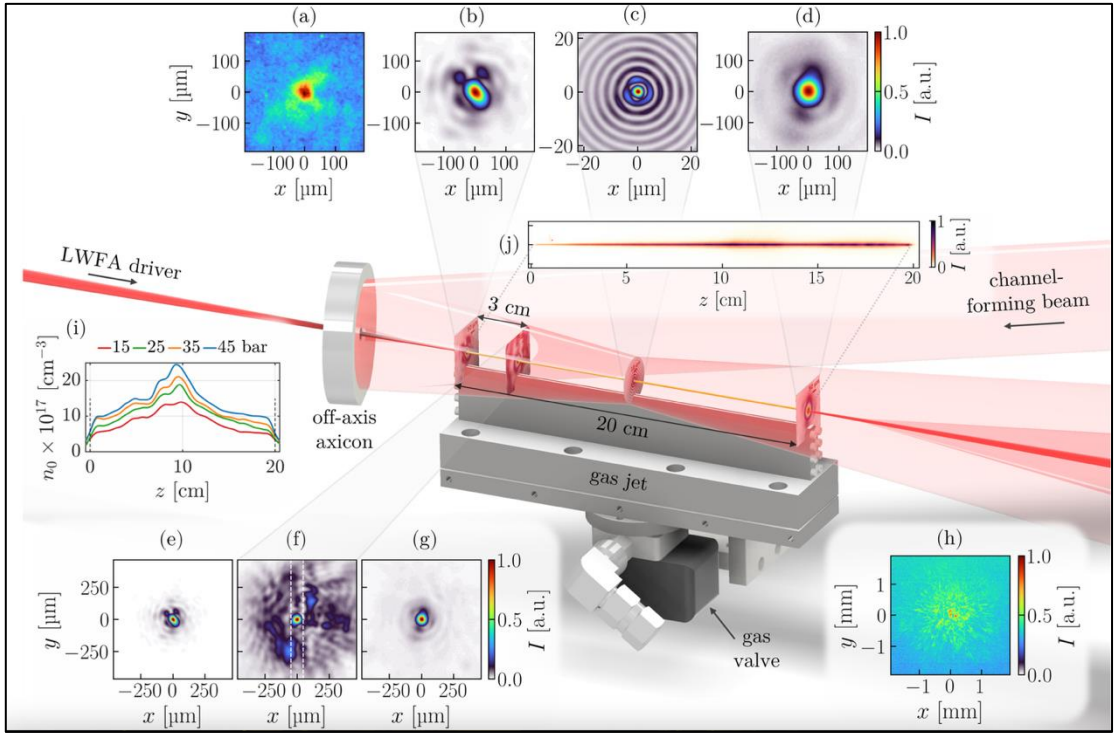
RESEARCH ARTICLE

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

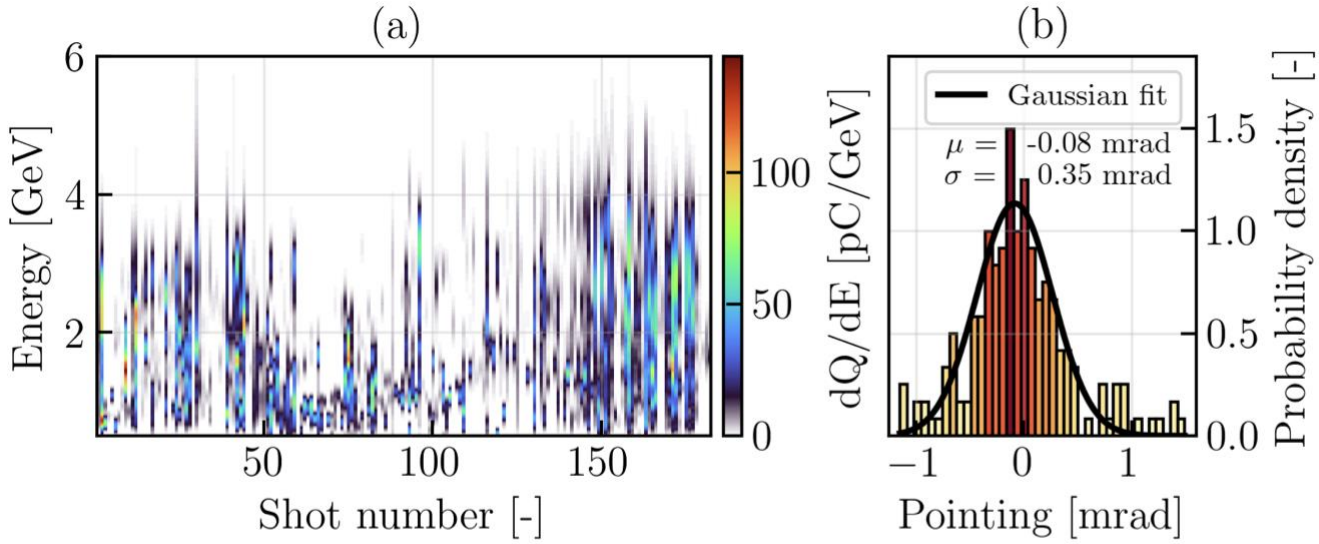
Jiří Šišma[1,2], Michal Nevrkla[1,2], Filip Vitha[1,2], Sebastian Lorenz[1], Illia Zymak[1], Alžběta Špádová[1,2], Andrea Kollárová[1,2], Matěj Jech[1,3], Alexandr Jančárek[1,2], Davorin Peceli[1], Carlo M. Lazzarini[1], Leonardo V. N. Goncalves[1], Gabriele M. Grittani[1], Sergei V. Bulanov[1], Jaron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

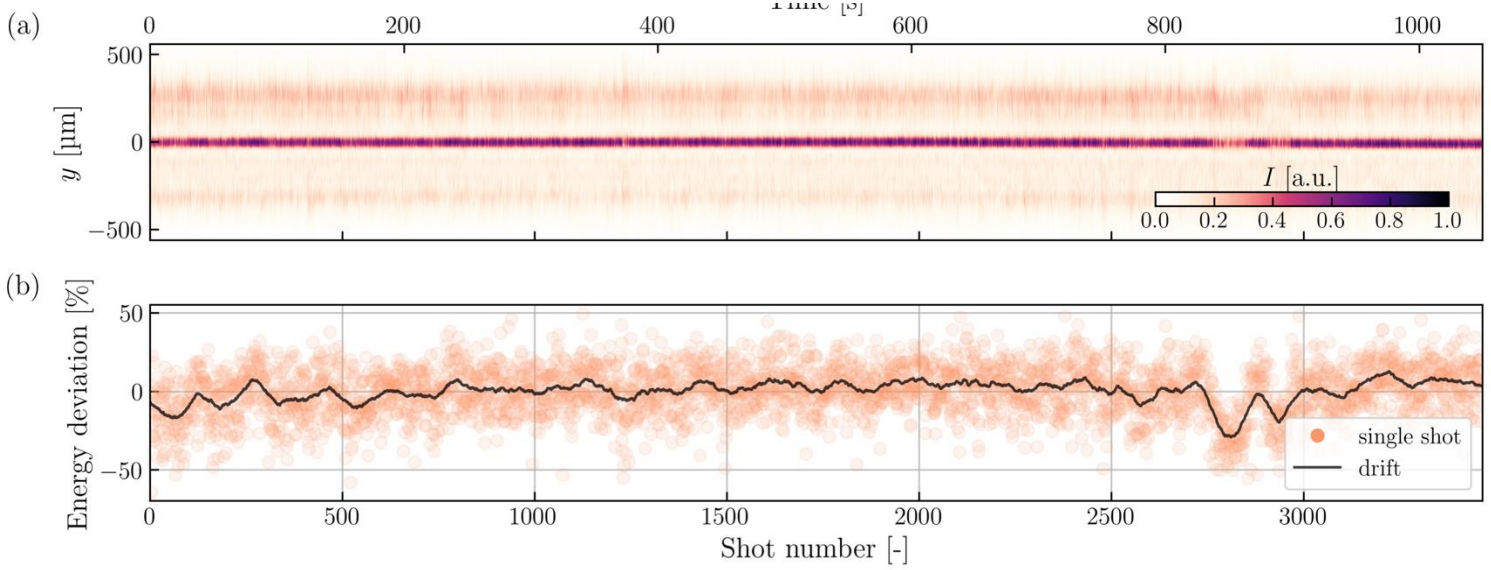
[1] *ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Dolní Břežany, Czech Republic*
[2] *Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic*
[3] *Faculty of Information Technology, Czech Technical University in Prague, Prague, 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*



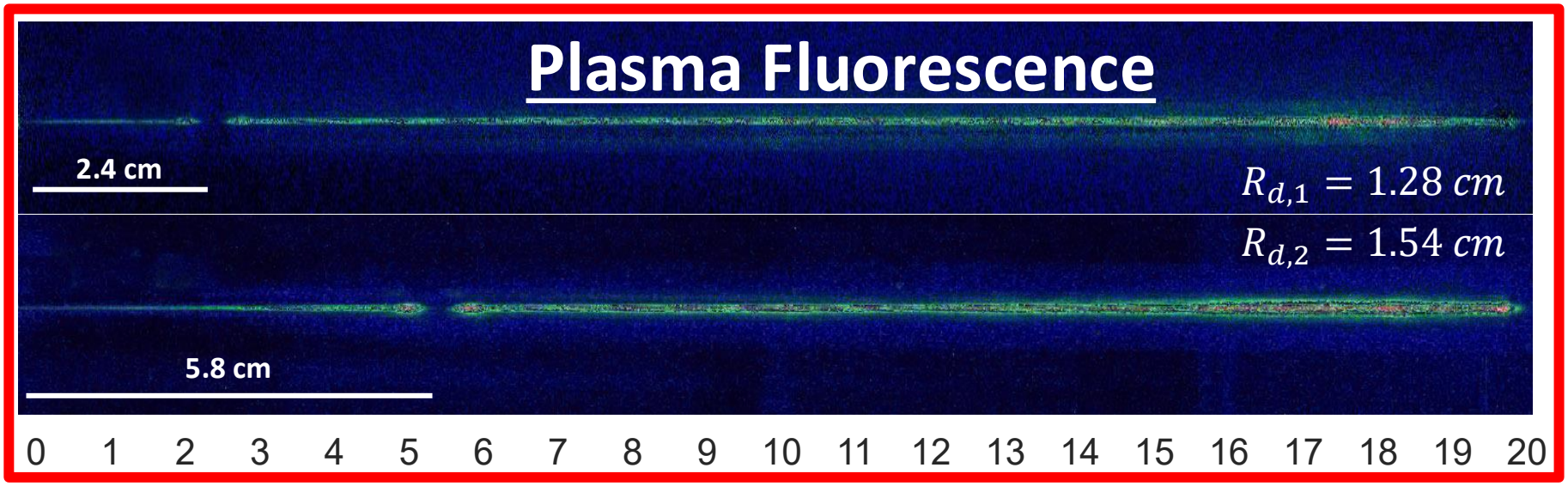


We achieved up to 6 GeV with 0.35 mrad pointing stability. The guiding scheme has been demonstrated up to 3.3 Hz. But these beams are almost not usable for QED due to spectral instability.

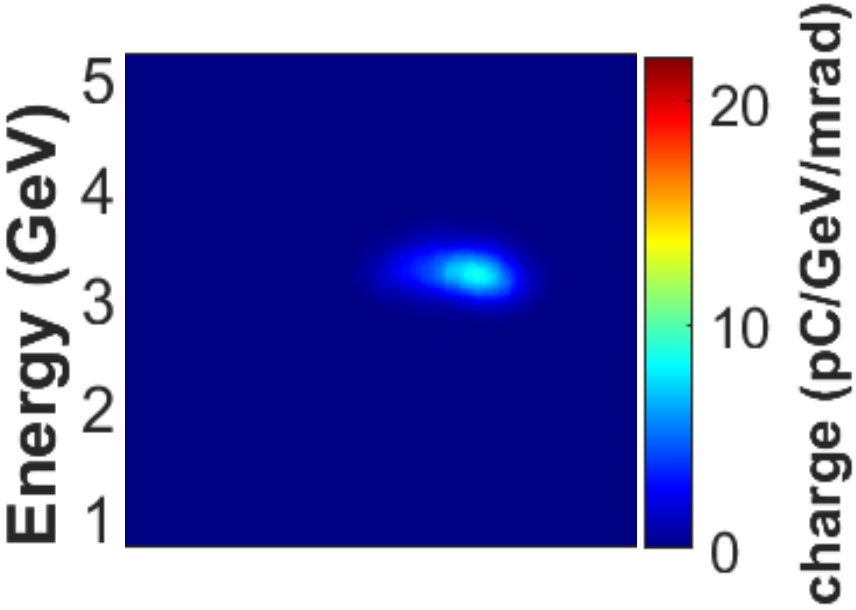


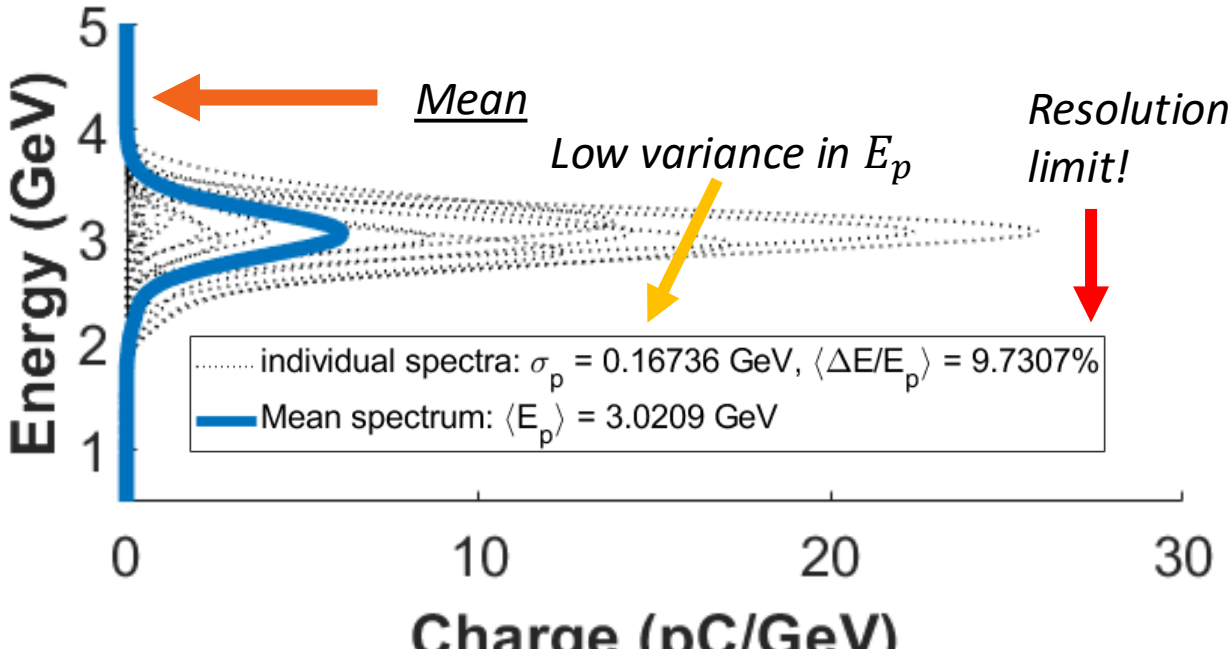


We developed two techniques that enabled high quality beams.
Pi-step enables the most monochromatic beams.

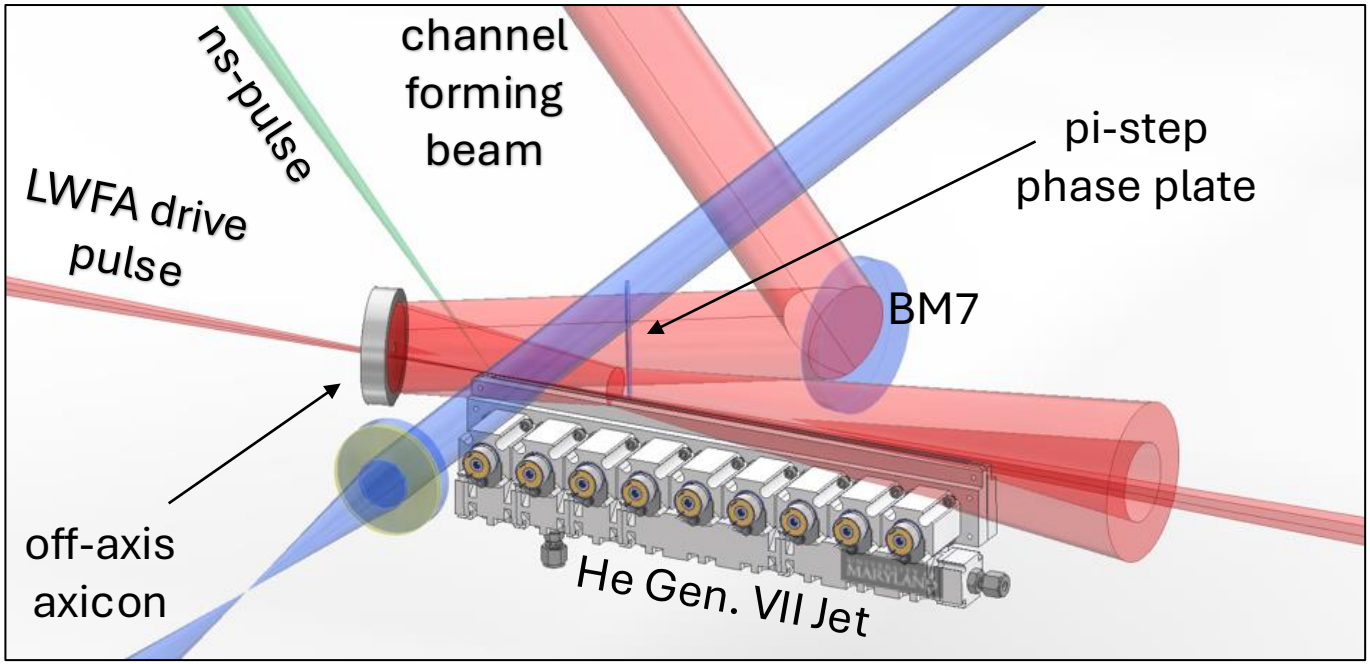


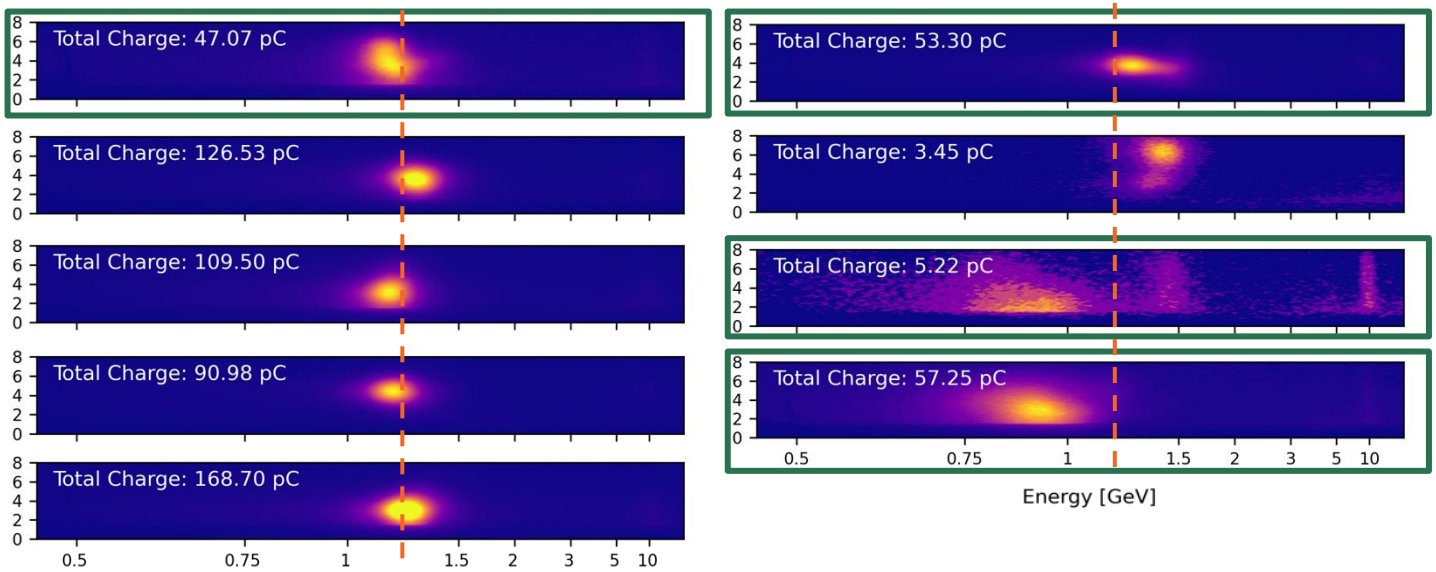
credits to
J. Shrock





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.

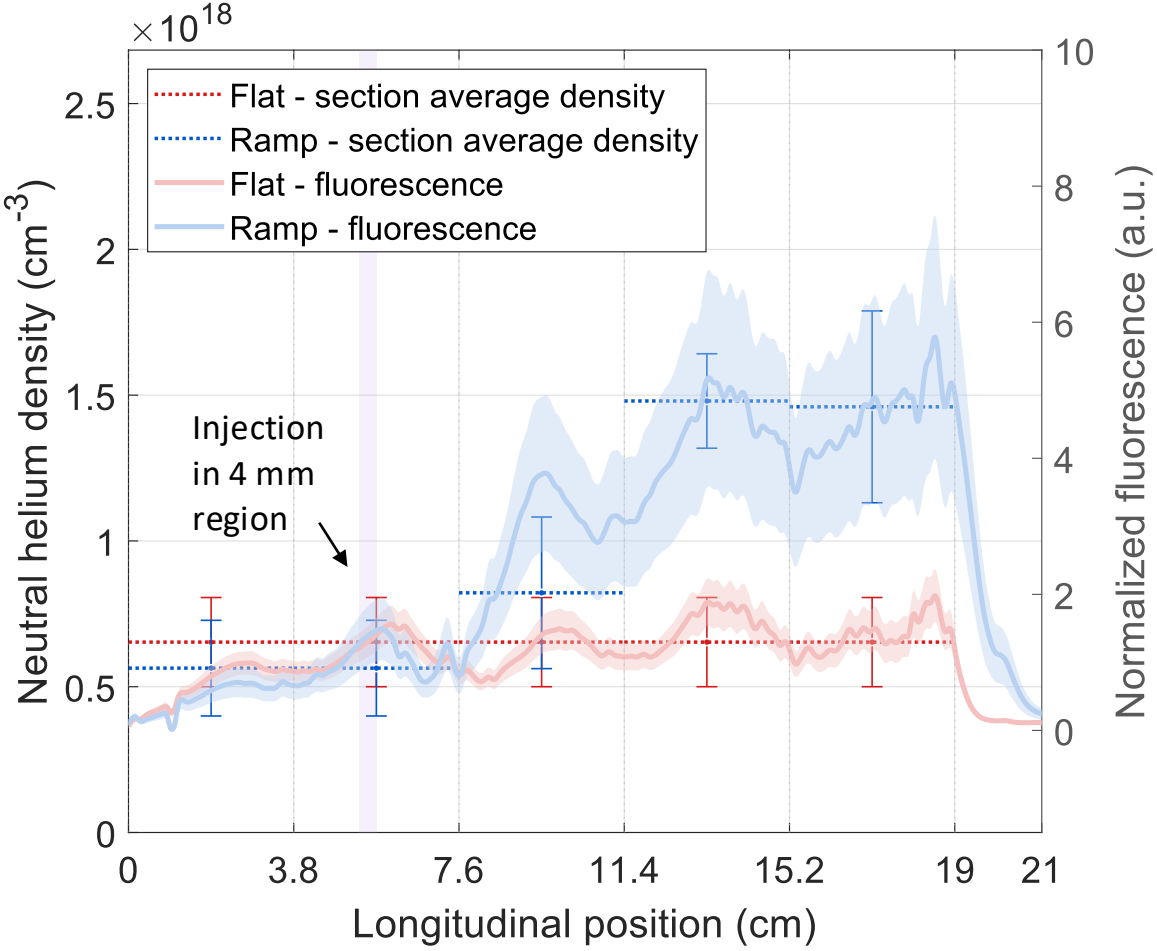
Toward controlling electron beam charge with nanoparticle-assisted laser wakefield accelerators

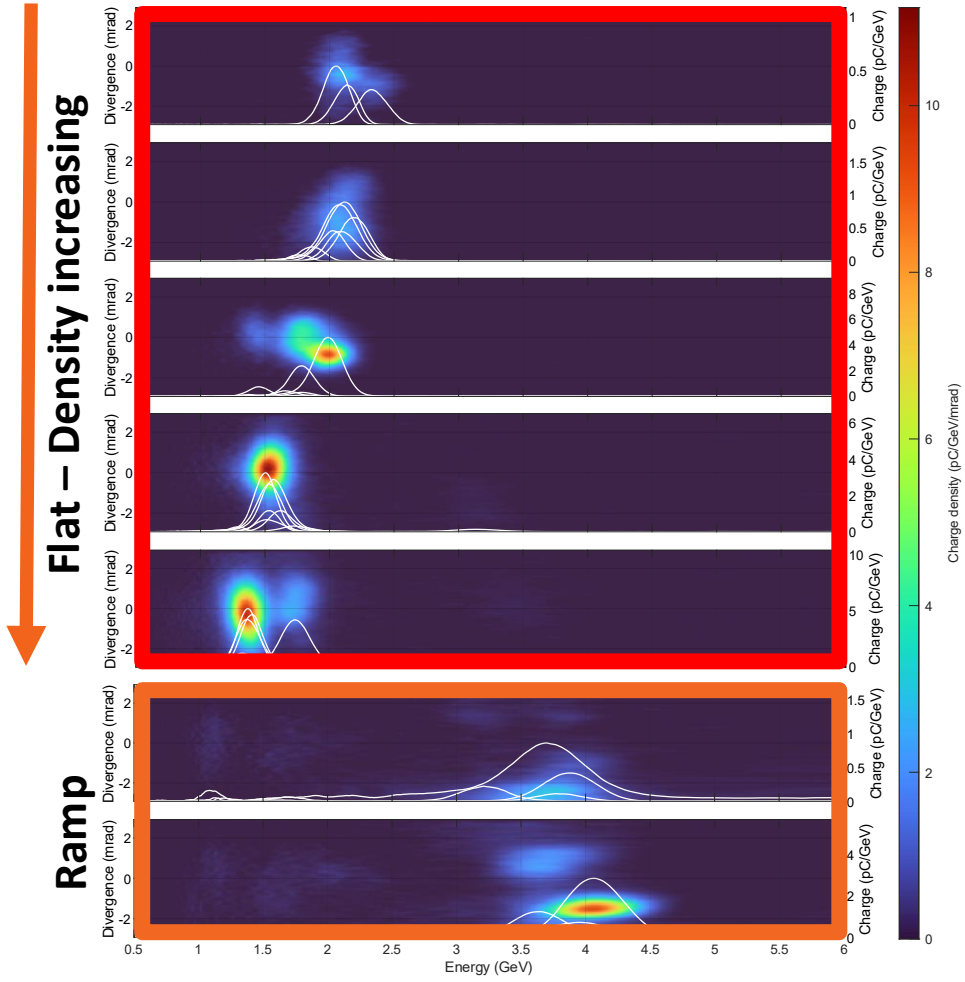
Cite as: Phys. Plasmas 32, 123104 (2025); doi: 10.1063/5.0295050
Submitted: 6 August 2025 · Accepted: 21 November 2025 ·
Published Online: 11 December 2025

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.



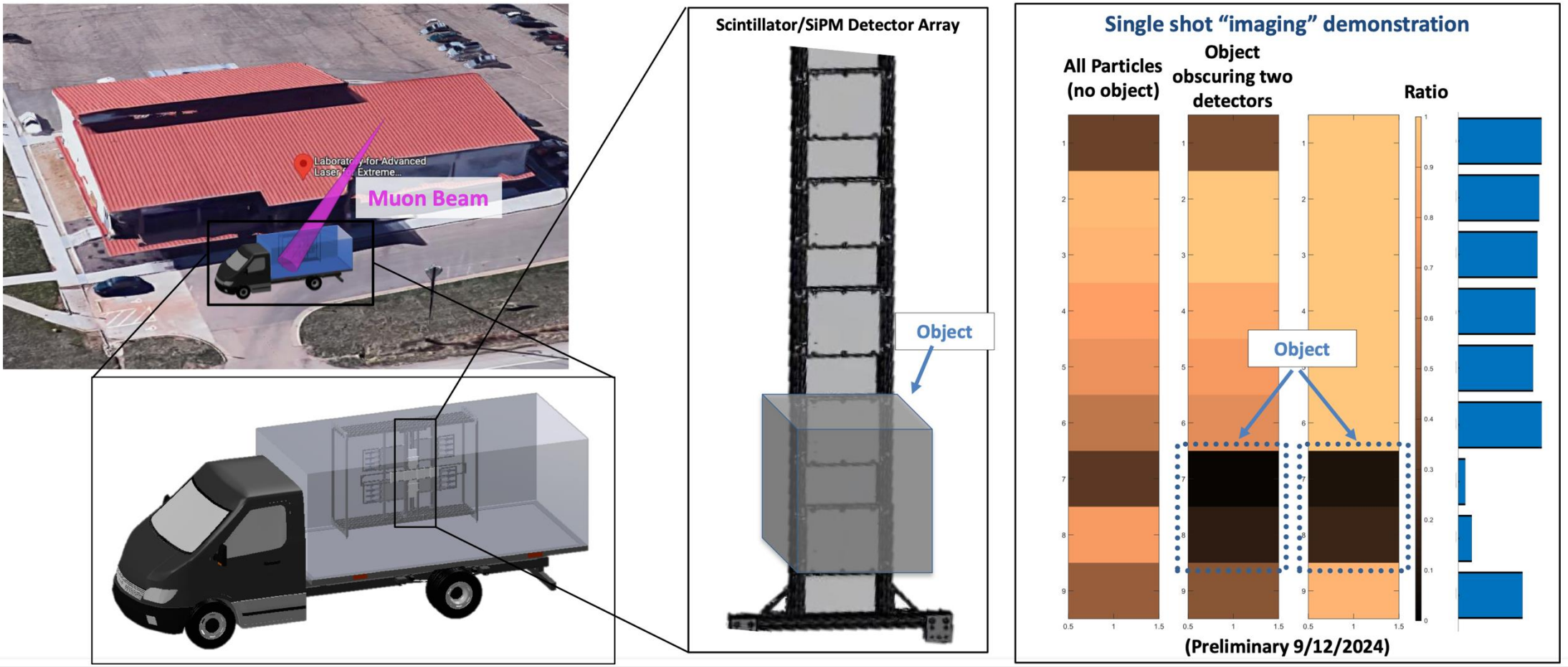


Acceleration dephasing limited. 20 cm density ramp increases energy by ~2x.

credits to E. Rockafellow

E. Rockafellow *et al., in preparation*

We demonstrated single shot (<1 ns) muon and particle imaging of thick blocks in a truck placed in the parking lot at Colorado State University.

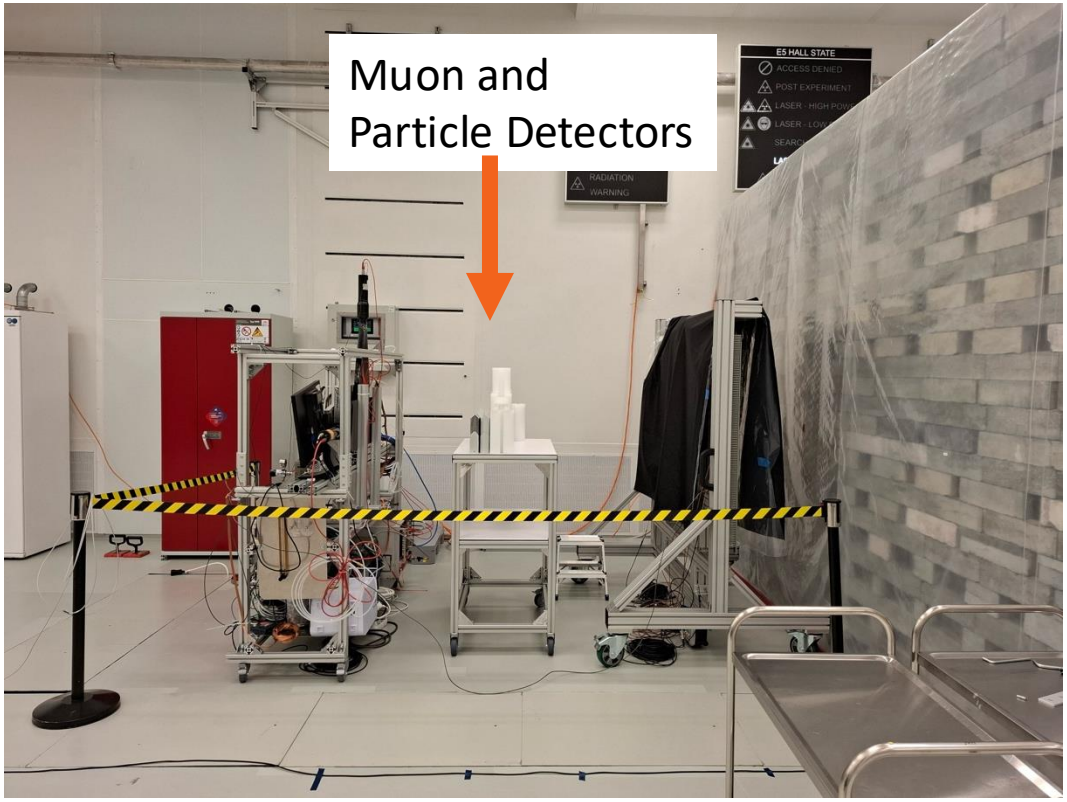


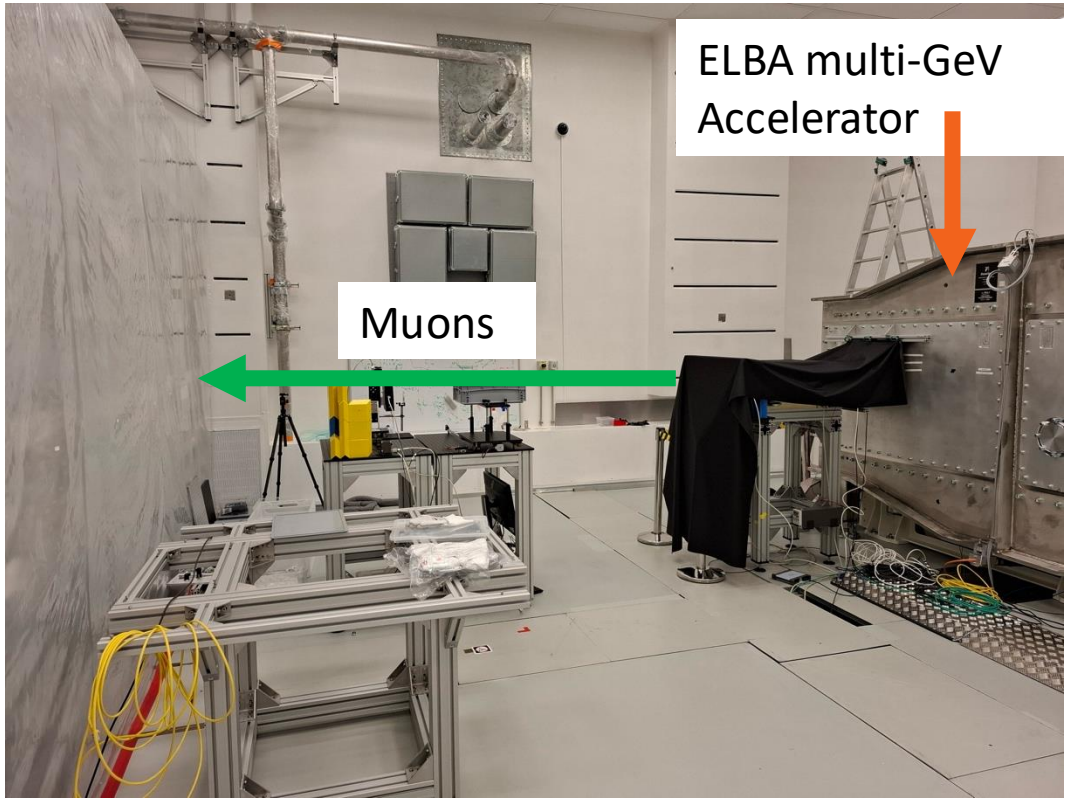
K. Zhu *et al.,* arXiv preprint arXiv:2607.12984

Credits to B. Reagan

Since 2025, we started having the first RPC and muon detectors users in ELBA at ELI Beamlines, with the initial collaborative goal of characterize this novel muon sources.

ELBA_MuLASER2 experiment (ongoing)
Principal Investigator: Salvatore Buontempo





THANK YOU FOR YOUR ATTENTION!

gabriele.grittani@eli-laser.eu