WP10-TA
Laser-driven particle beams at CLPU

José-Manuel Álvarez on behalf of CLPU team
RADNEXT 2nd Annual Meeting – 9-10 May 2023
https://indico.cern.ch/e/radnext-2023

CENTRO DE LÁSERES PULSADOS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008126

Outline

- Part 1: Introduction
  - High intensity laser facilities
  - Laser plasma accelerator
  - Applications - Space radiation

- Part 2: CLPU
  - Laser VEGA
  - Transnational Access – WP10
  - Conclusion

Intense Laser Labs World Wide

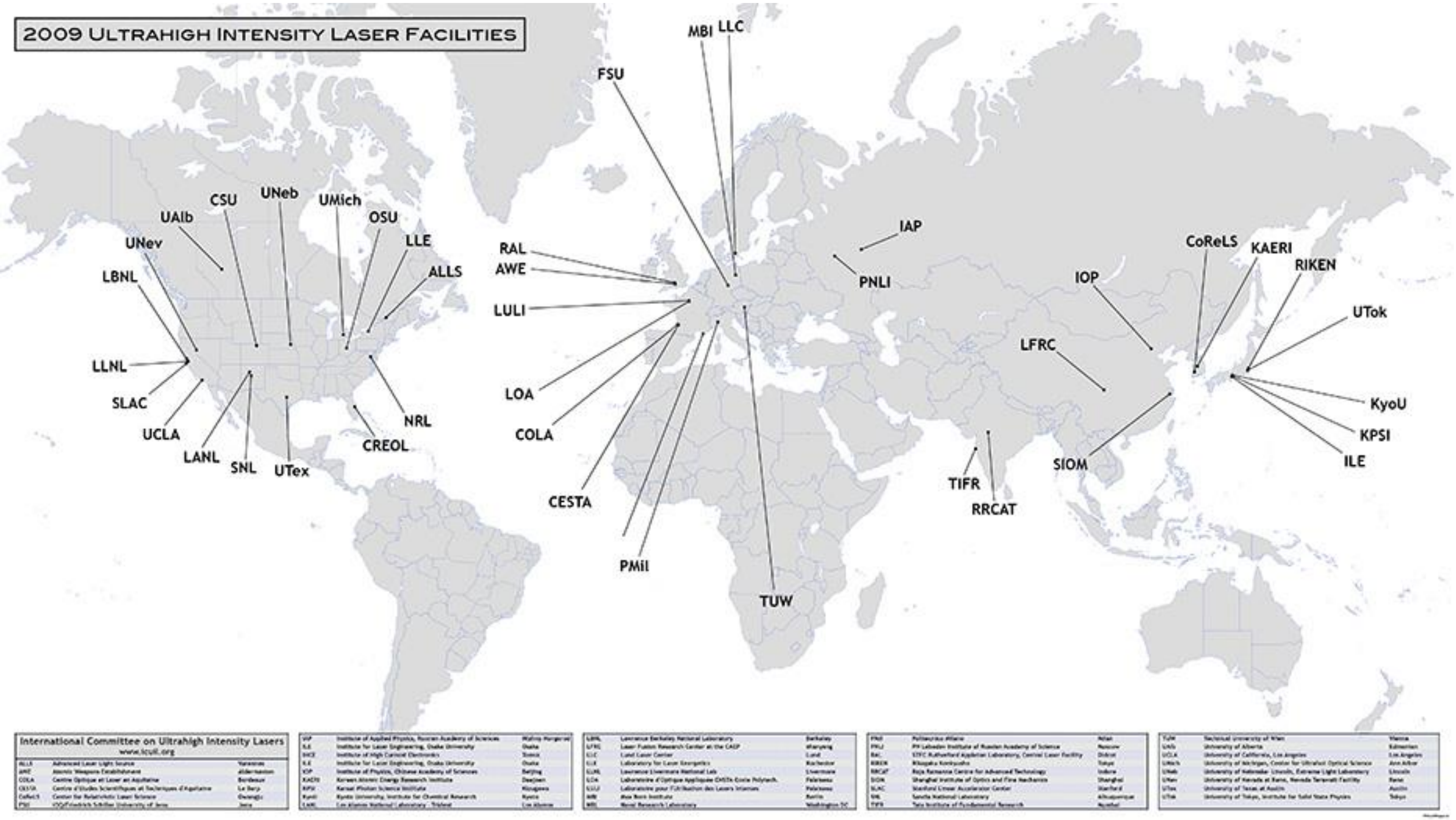
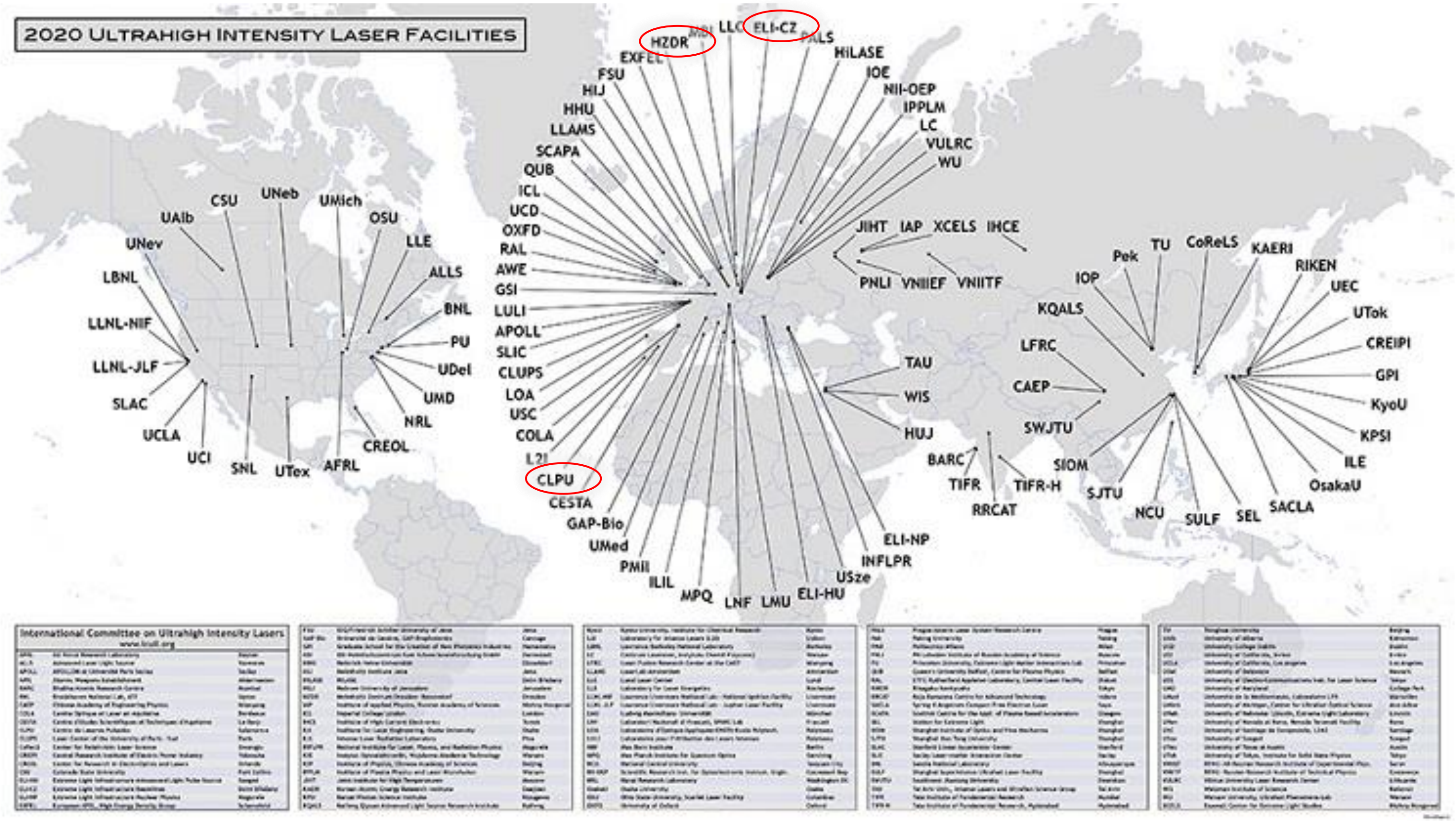


Image source “International Committee of Ultra-High Intensity Lasers” (ICUIL, www.icuil.org)

Intense Laser Labs World Wide



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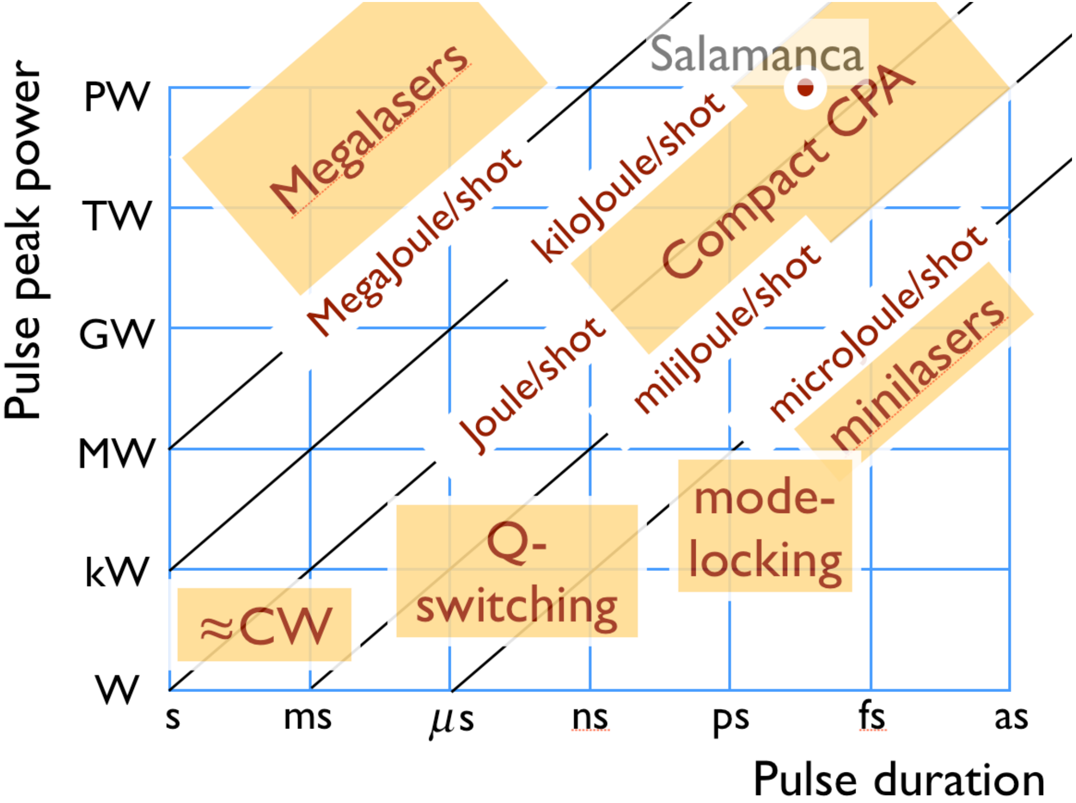
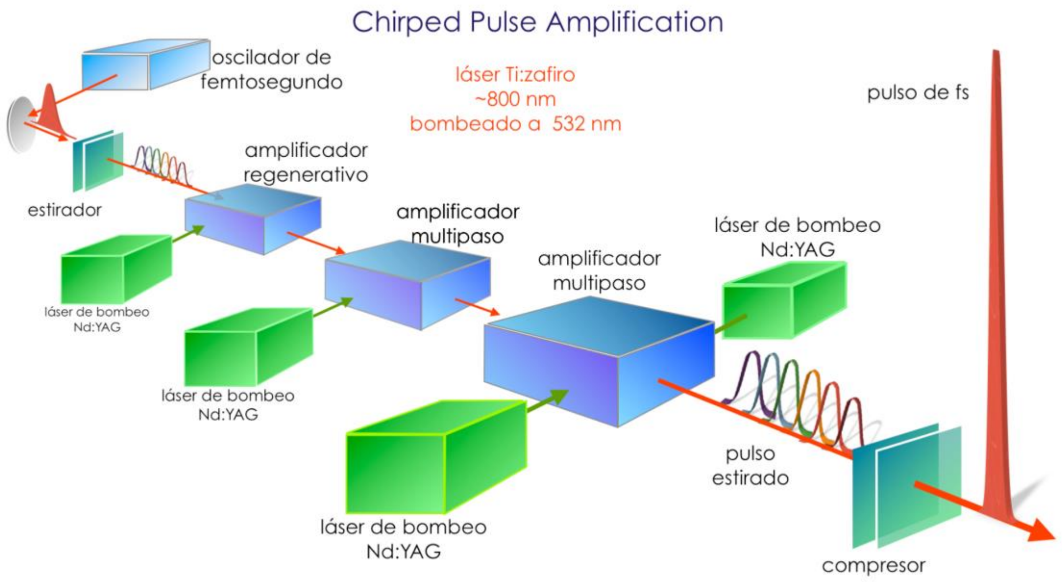
High intensity laser facilities

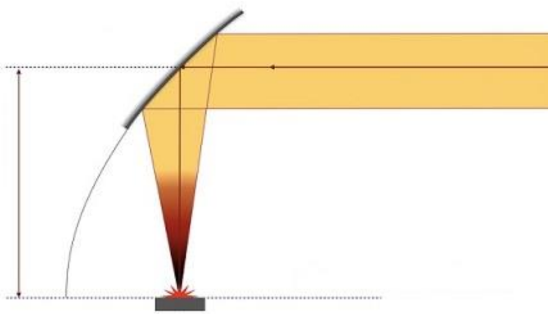


High intensity laser facilities

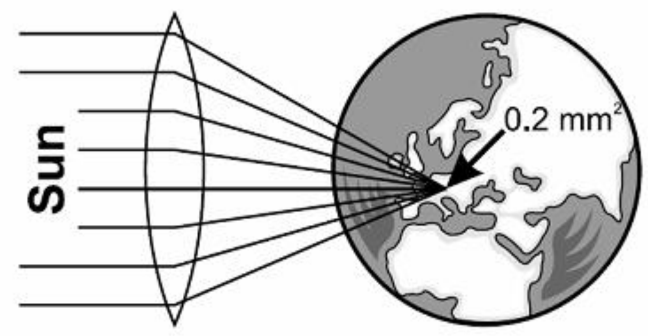
Nobel Prize in Physics (2018) to Arthur Ashkin, Donna Strickland and Gérard Mourou “for ground-breaking inventions in the field of laser physics”

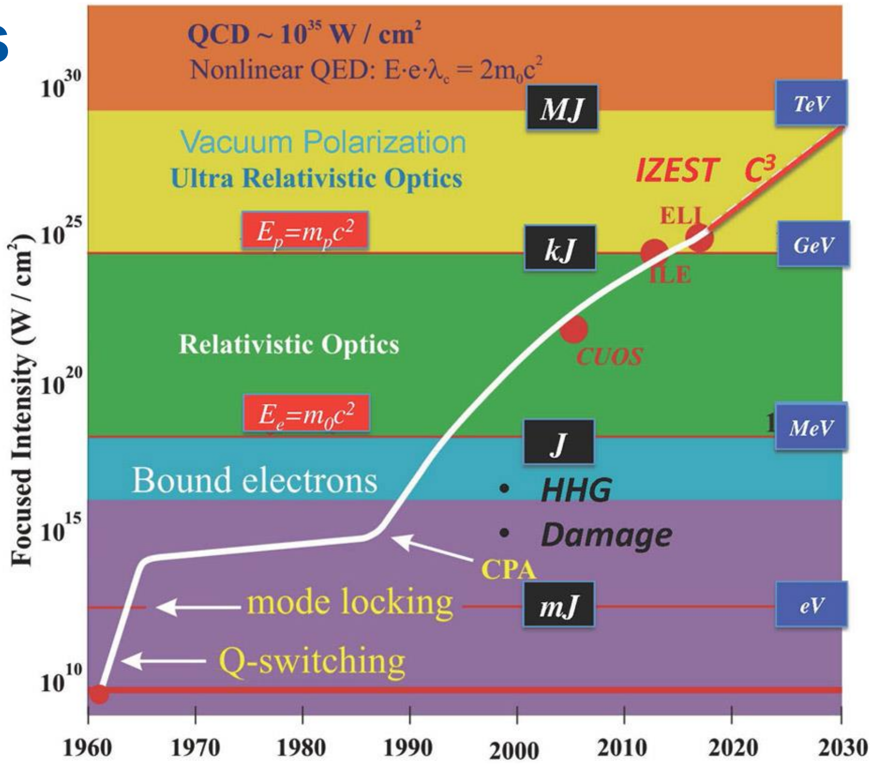


High intensity laser facilities



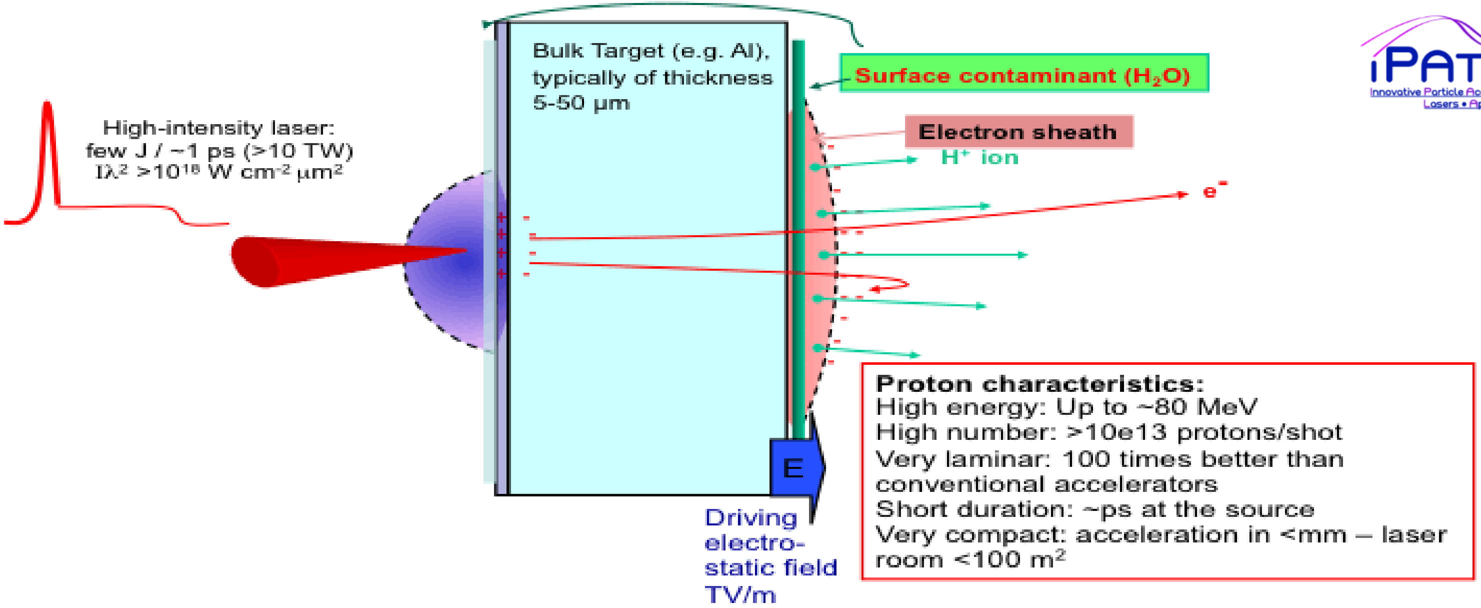
10^{20} W/cm^2





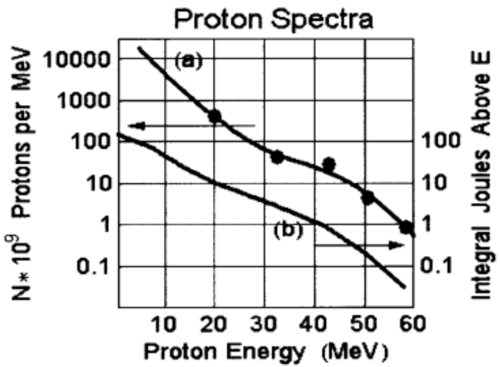
Intensity evolution since the first laser demonstration in 1960, with the different regimes of optics and electrodynamics.

Laser-driven proton/ion acceleration using TNSA mechanism



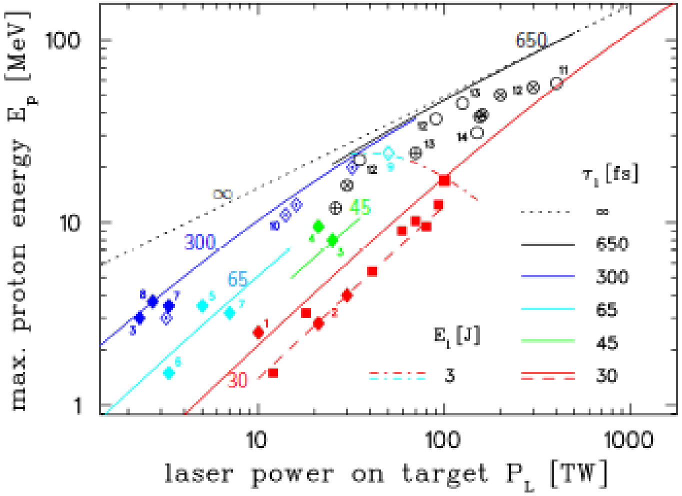
In the Target Normal Sheath Acceleration (TNSA) mechanism the accelerating electrostatic field is located at the rear target surface of a solid target.

Multi-MeV protons from solid targets



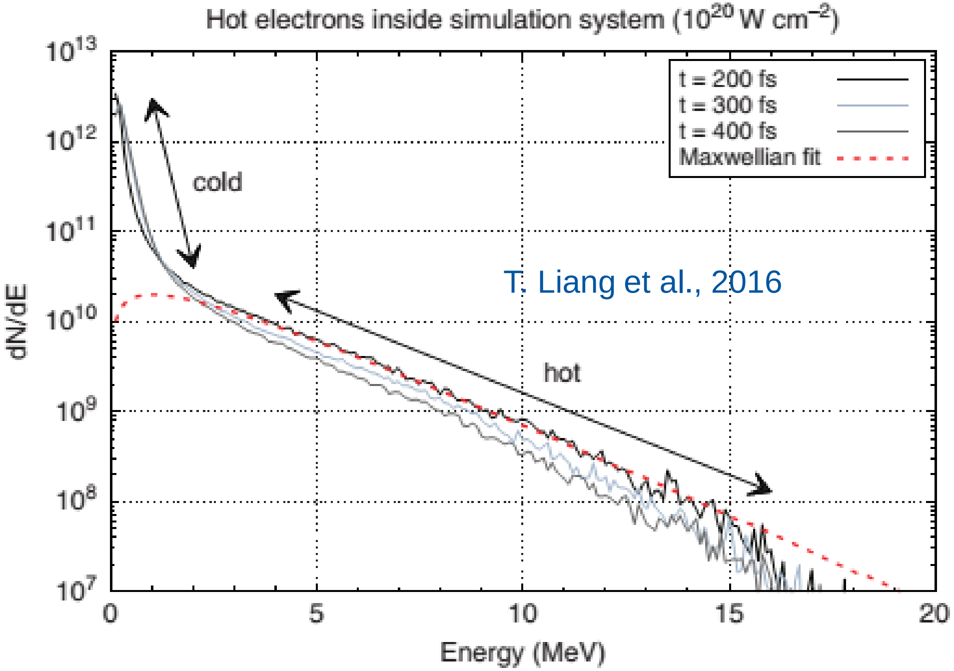
Protons have been observed and characterized in a large number of laboratories and for different laser pulse regimes. Snavely et al, PRL 85 (2000) 2945

Experimental scaling of proton energy cut-off with laser power and pulse duration from Zeil et al. (2010), New J. Phys. 12, 045015.

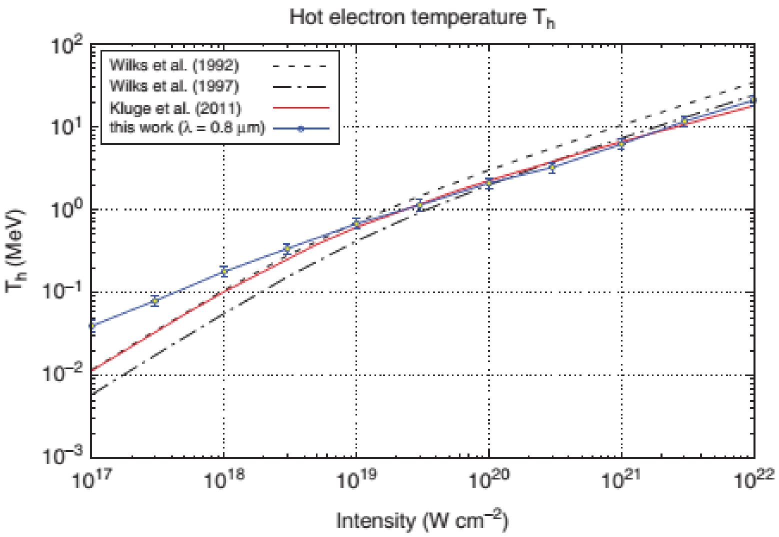


Up to 94MeV protons observed at Vulcan laser, Nat Commun 9, 724 (2018).

Electrons from solid targets

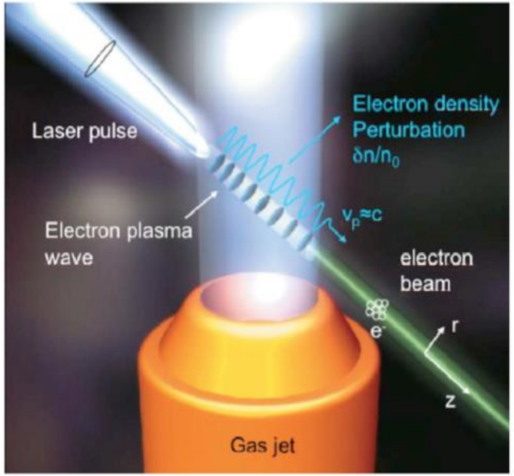


T. Liang et al., 2016



A Maxwellian fit yields a characteristic slope of T=2.1MeV

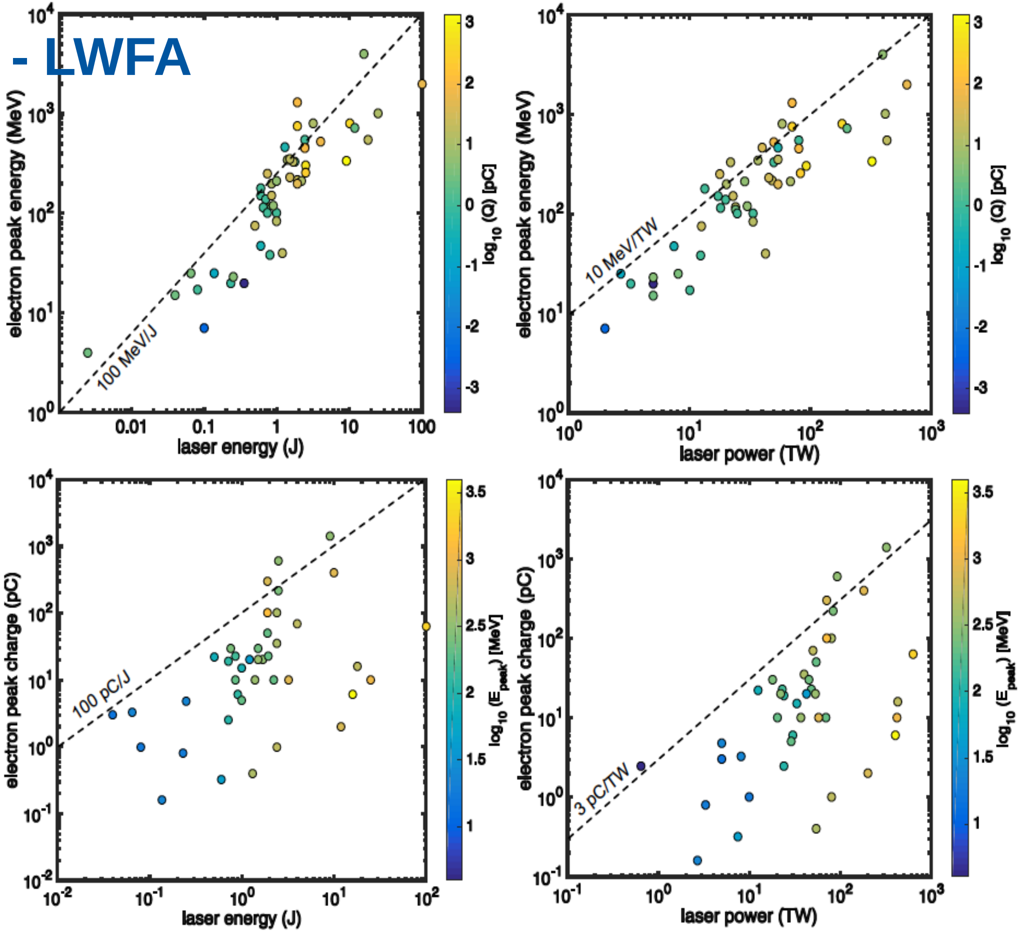
Laser Wakefield Acceleration - LWFA



Electron acceleration from a gas jet.

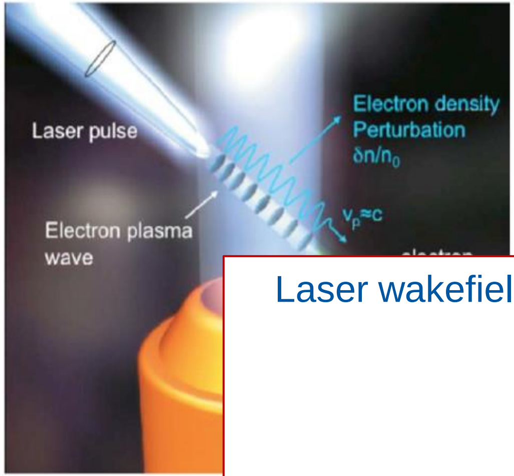
Image from Rev. in Mut. Res. 704 (1-3), 142, 2010

Data is based on 50+ publications on LWFA during the last 15-20 years from *Wenz, J., & Karsch, S. (2020). Physics of Laser-Wakefield Accelerators (LWFA). arXiv: Accelerator Physics.*



Experimental results for electron peak energy and charge.

Laser Wakefield Acceleration - LWFA



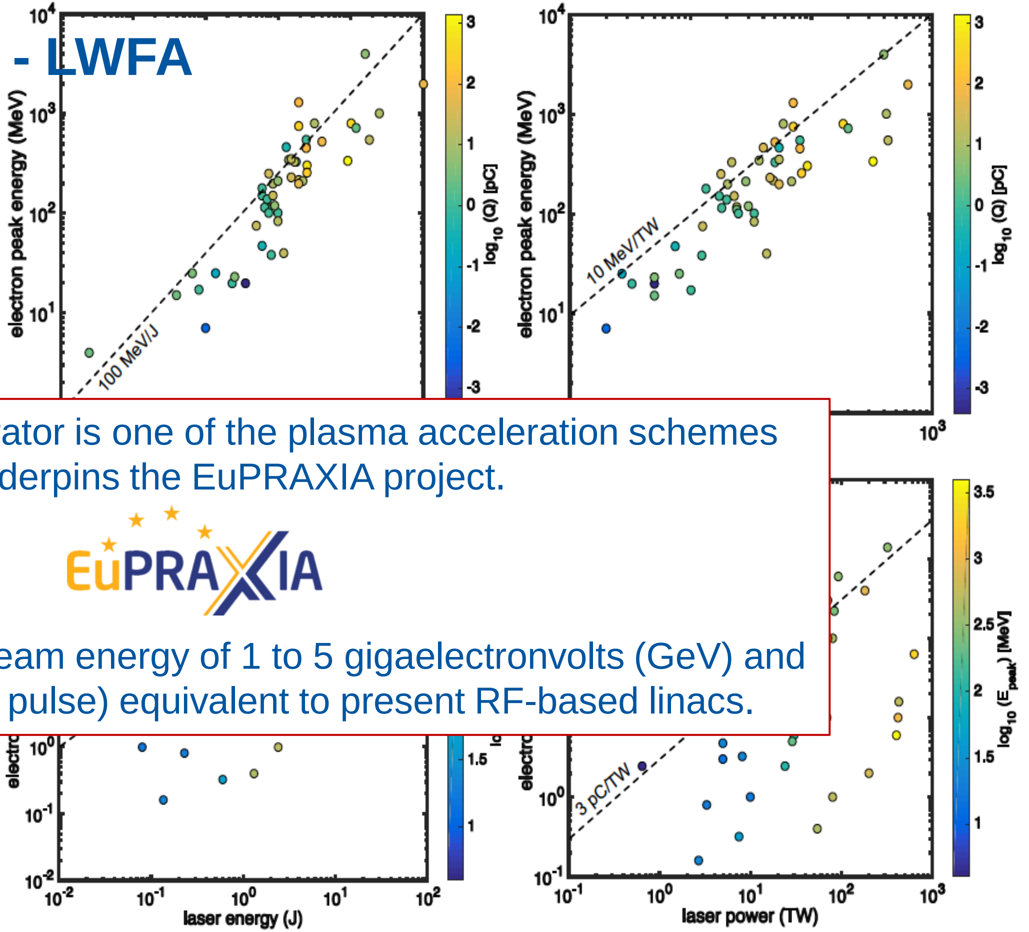
Electron acceler

Image from Rev. in Mu

Laser wakefield accelerator is one of the plasma acceleration schemes that underpins the EuPRAXIA project.

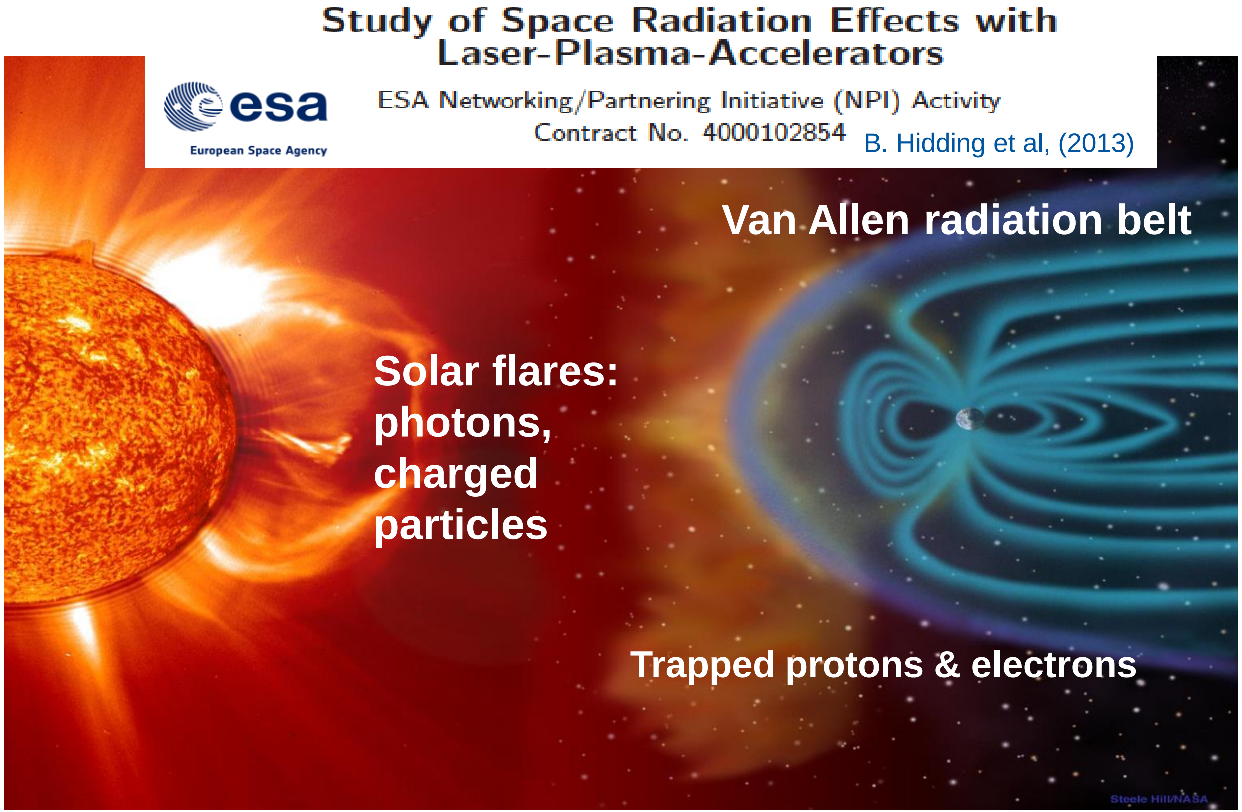
EuPRAXIA envisions a beam energy of 1 to 5 gigaelectronvolts (GeV) and a beam quality (single pulse) equivalent to present RF-based linacs.

Data is based on 50+ publications on LWFA during the last 15-20 years from *Wenz, J., & Karsch, S. (2020). Physics of Laser-Wakefield Accelerators (LWFA). arXiv: Accelerator Physics.*



Experimental results for electron peak energy and charge.

Applications - Space radiation



Applications - Space radiation

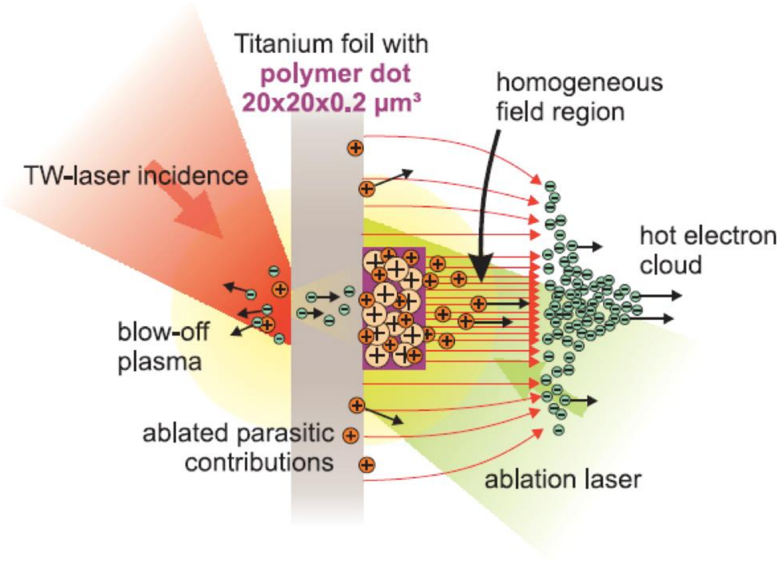
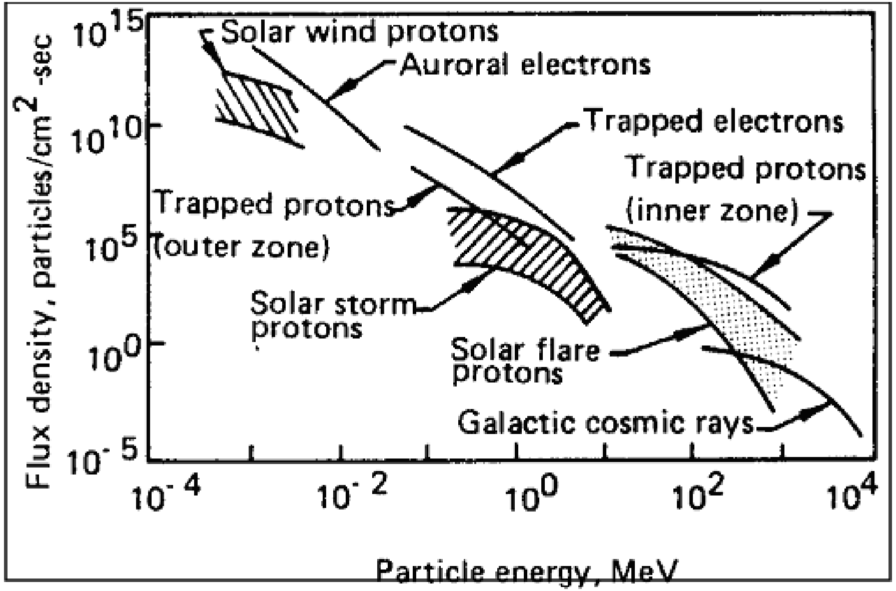


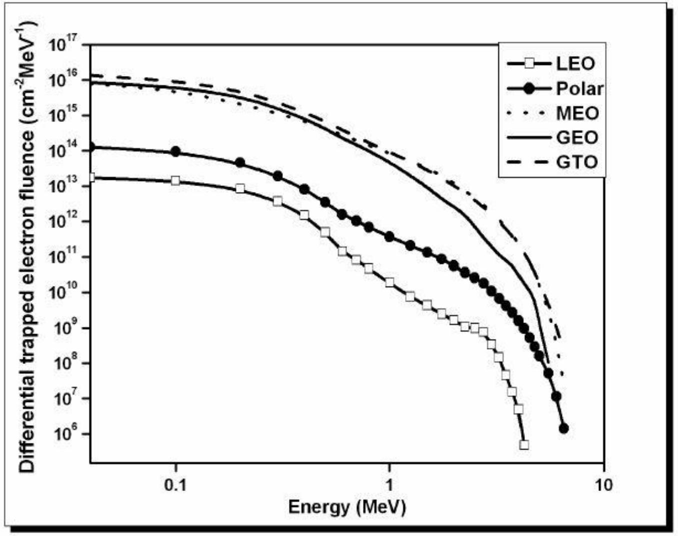
Image taken from S.M. Pfotenhauer et al, New J. Phys. (2008) 033034



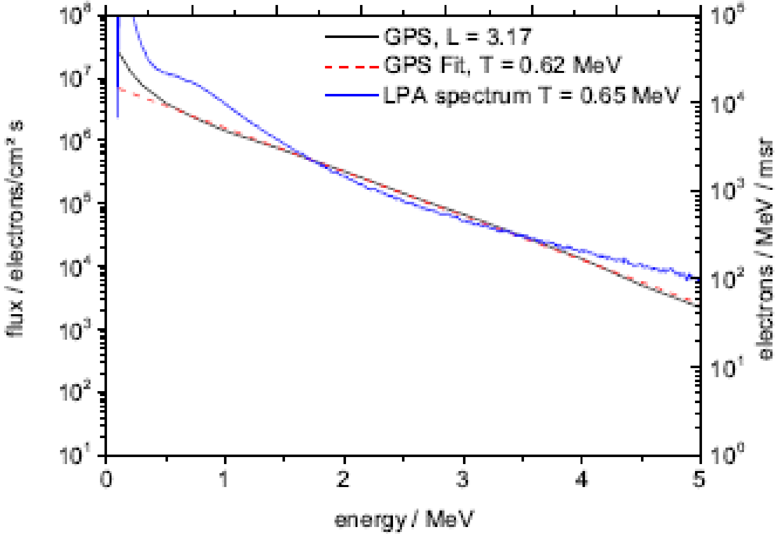
Schimmerling,.W and Curtis, S.B, NASA

Applications - Space radiation

Trapped Particles Environment : Electron



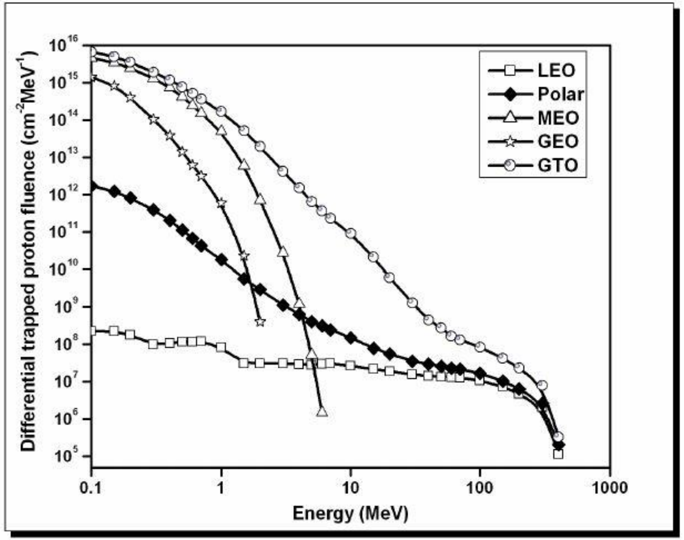
S. Samwel et al.,International Journal of Astronomy and Astrophysics 01, 2006.



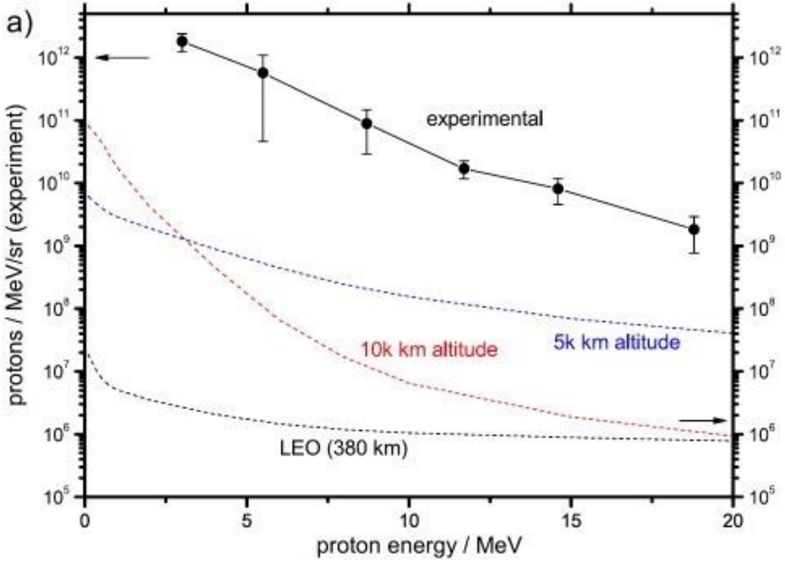
Reproduction of electron fluxes in the GPS orbit with laser-plasma-generated electron flux with T=0.65MeV. Hidding et al. (2013), ESA NPI Activity 4000102854

Applications - Space radiation

Trapped Particles Environment : Proton



S. Samwel et al.,International Journal of Astronomy and Astrophysics 01, (2006).



Hidding, B., et al. Laser-plasma-based Space Radiation Reproduction in the Laboratory. Sci Rep 7, 42354 (2017).

Outline

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Centro de Láseres Pulsados - CLPU

CLPU is:

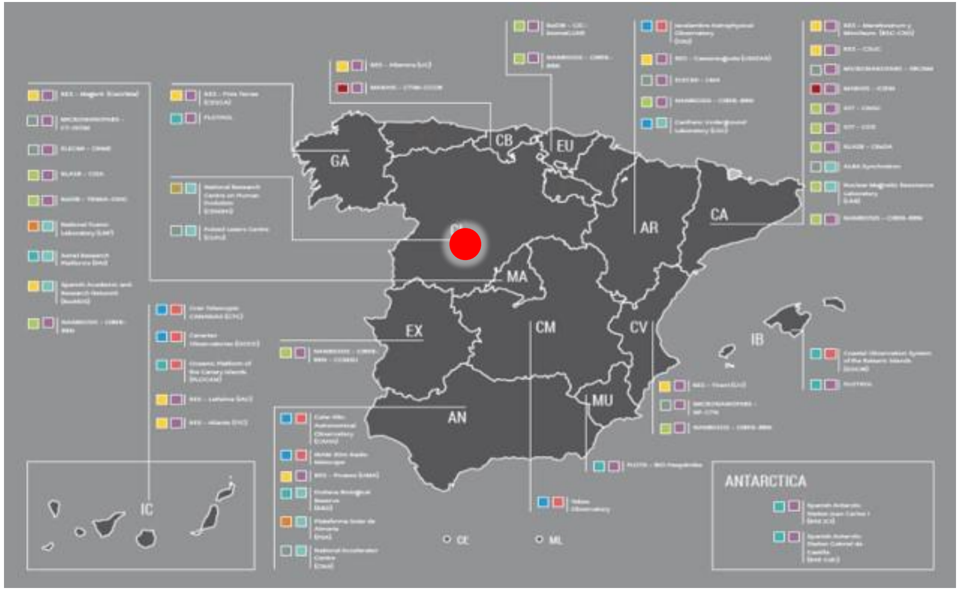
- a user facility opened to national & international users
- a ICTS Technical and Scientific unique Infrastructure
- Radiactive authorized installation IRA-3254

Funded by:

50 % Ministry of science and Innovation

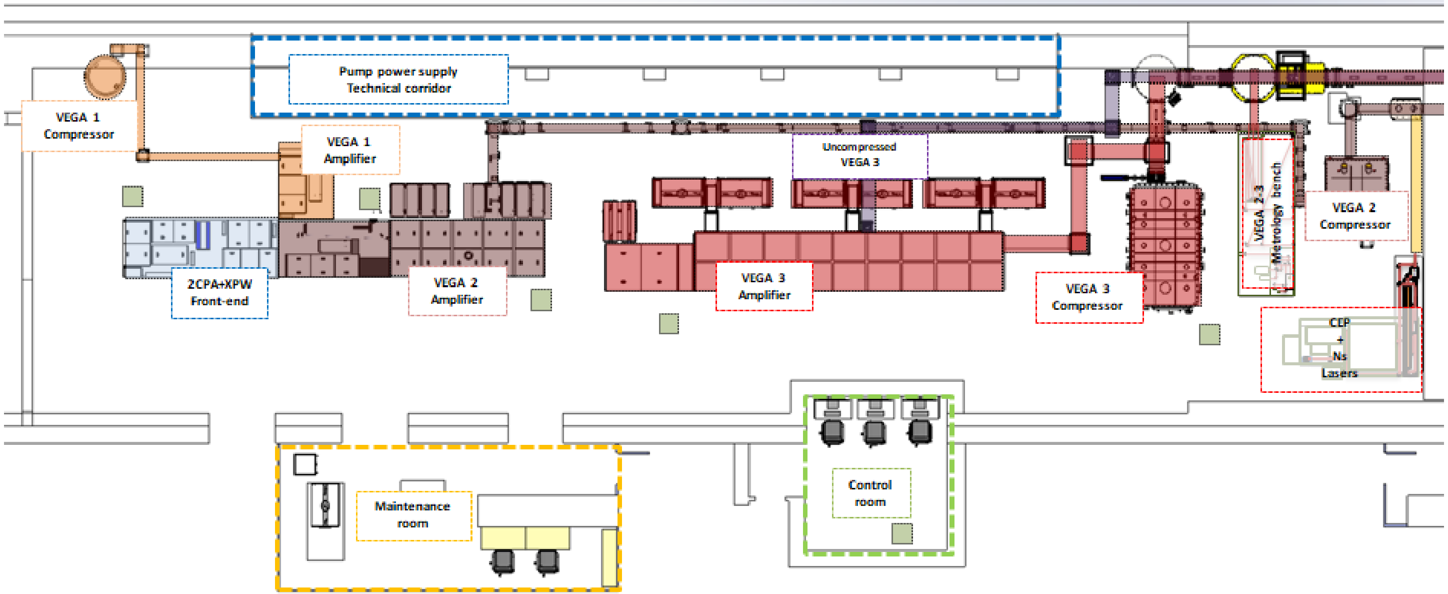
45 % region of Castilla y Leon

5 % University of Salamanca



Laser VEGA overview

Slice from Cruz Mendez



- Target Area close to compressor's output.
- Laminar flow cabinets with ISO Class 7 level.
- **Metrology bench installed between VEGA 2 and VEGA 3.**
- CEP and ns laser installed at the beginning of 2019 in the laser bay.
- Uncompressed VEGA 3 output also indicated.

VEGA 3

Energy 30 Joules

Power 1 PW

Rep rate 1 Hz

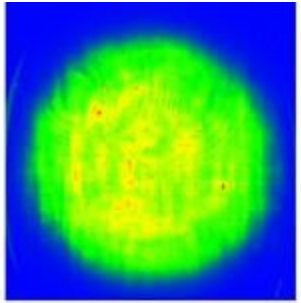
VEGA 2

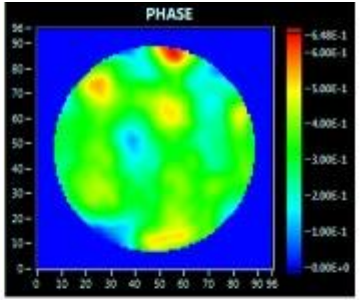
Energy 6 Joules

Power 200 TW

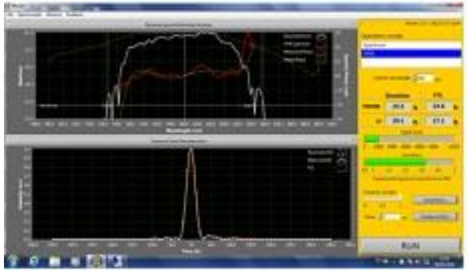
Rep rate 10 Hz

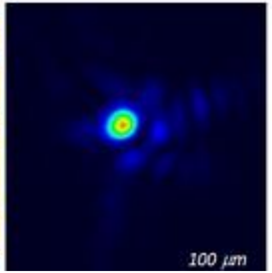
Array of data given to users from the metrology bench every day:

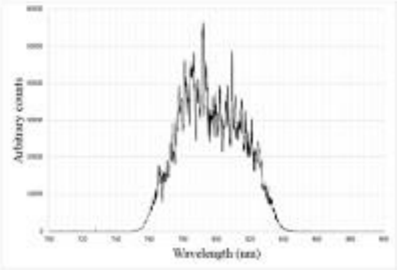




- Near field (image at compressor entrance)
- Far field (lens focal plane 2.1 m focal length)
- Wizzler temporal measurement (shape and phase)







- Sequoia temporal contrast measurement
- Wavefront+Strehl ratio measurement (Phasics)
- Output spectrum

Slice from Cruz Mendez

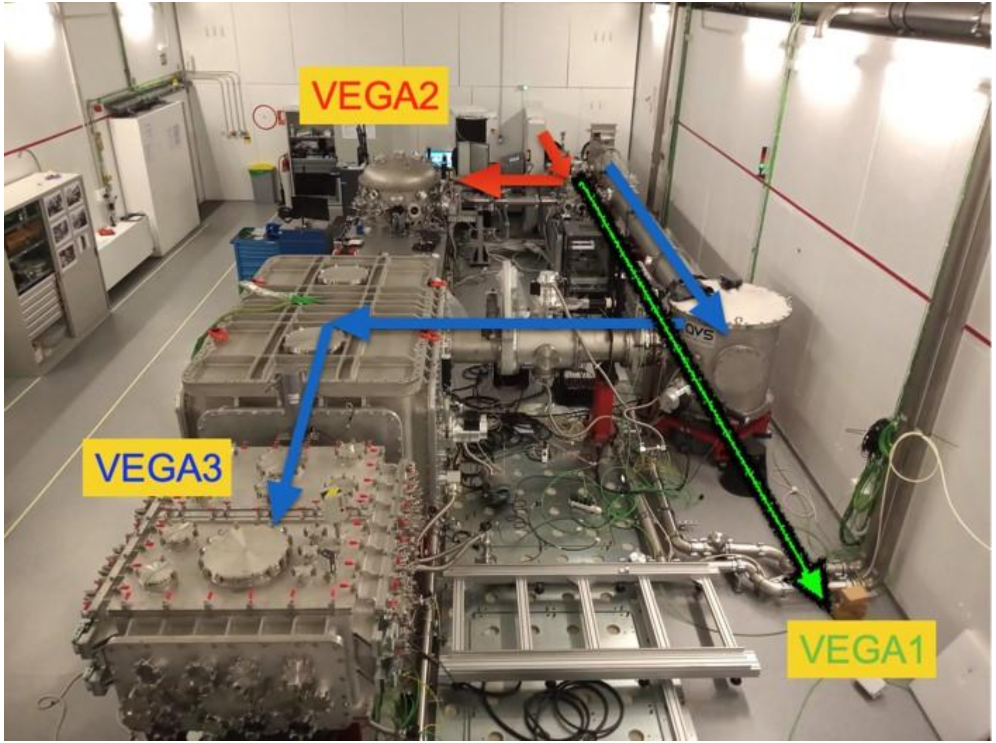
RADNEXT

Laser VEGA

Laser VEGA

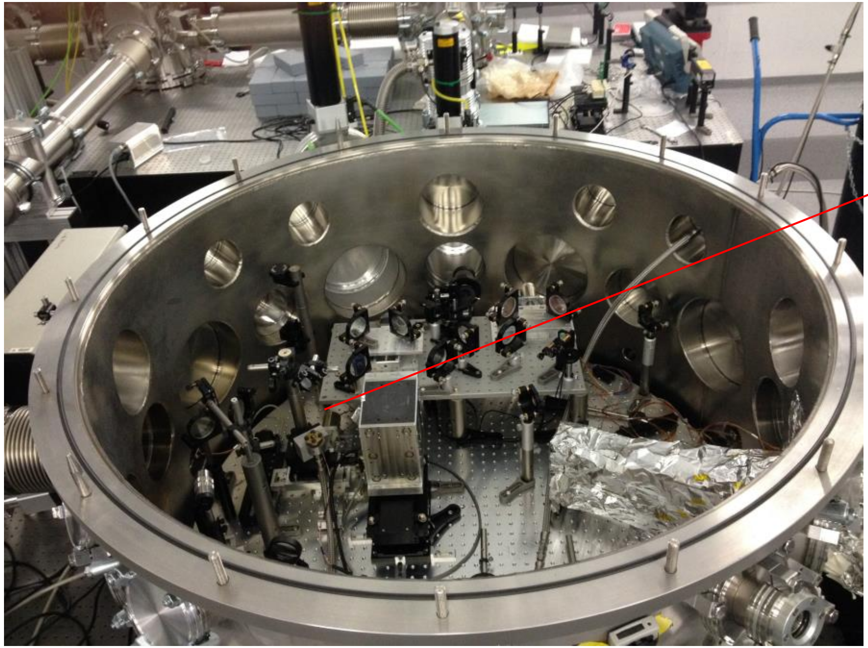
Transnational Access – WP10/TA2

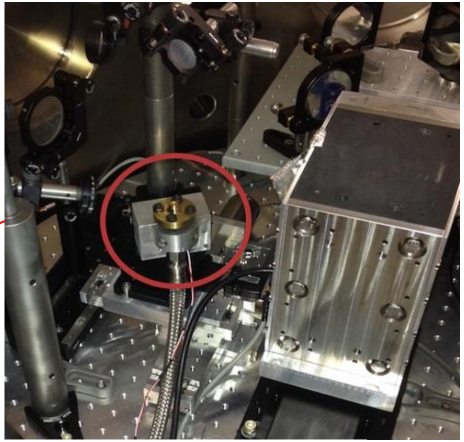
- **Offered particle beams:**
  - Proton beam
    - Energy 10-20 MeV
    - Charge ~ nC/ps
    - Divergence 0.3-0.4 rad (~ 20˚)
  - Electron beam up to
    - Energy 300-400 MeV
    - Charge ~ pC/fs
      - Divergence 10-20 mrad (~ 1˚)
- **Offered access time**
  - 150 hours
  - Number of projects ~ 3
  - Number of Users ~ 6

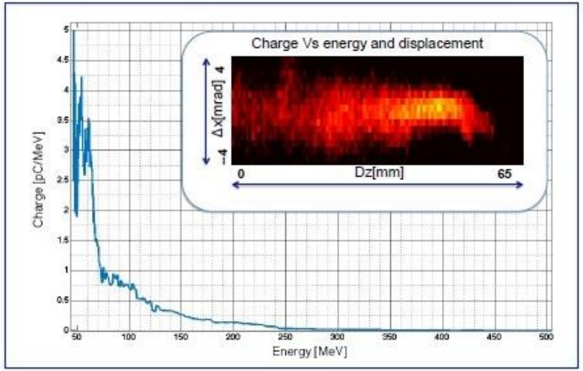


Slice from Luca Volpe

Interaction Chamber VEGA2

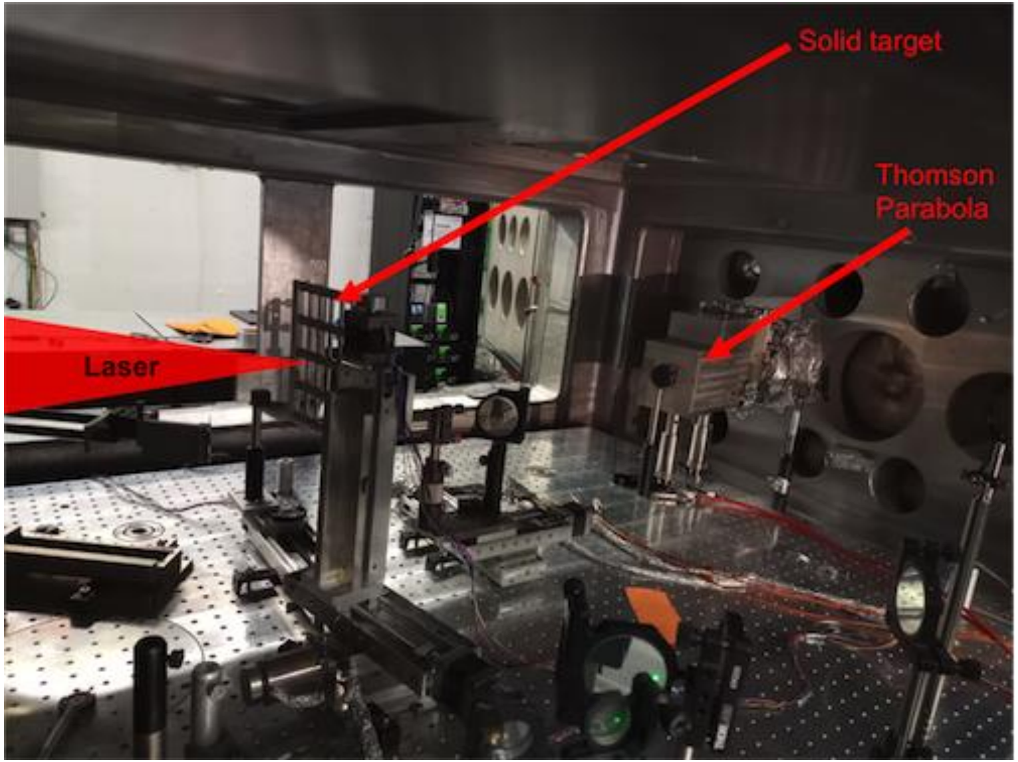


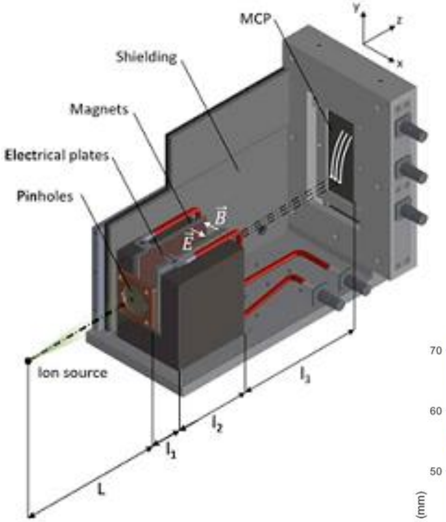


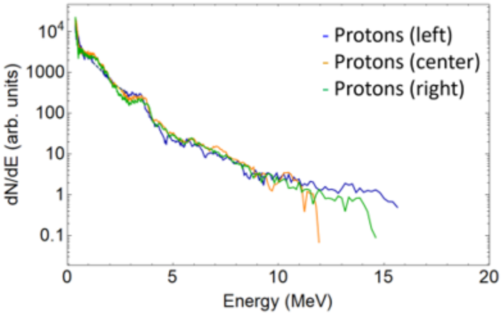


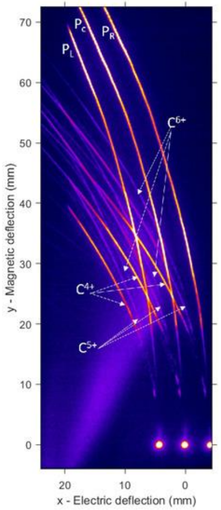
Typical non-monoenergetic electron spectrum measured with 1.2 tesla magnetic spectrometer; (in-sertion) ltered image of measured electron energy spectrum

Interaction Chamber VEGA3









Salgado-López, C. et al. Angular-Resolved Thomson Parabola Spectrometer for Laser-Driven Ion Accelerators. Sensors 2022, 22, 3239. https://doi.org/10.3390/s22093239

Some requirements on the diagnostic systems

- The proton/ions accelerated by laser-plasma typically present a broadband spectrum. The complete and accurate characterization of the whole spectrum requires to have a diagnostic system characterized by **high sensitivity** to appreciate the maximum achievable energy, but also to have a **high dynamic range**.

- When a high intensity laser interacts with matter, **intense electromagnetic waves (EMP)** in the microwave-radiofrequency range are produced. This is a serious threat for any electronic device placed near the interaction point, leading to the disabling, or even to the damaging, of the deployed diagnostic systems.

- The use of **passive detectors generally solves the problem**, but this is not a viable solution when aiming for an on-line characterization of a system working at **high repetition rates**.

Transnational Access Campaign

CLPU has hosted **one** RADNEXT Campaign

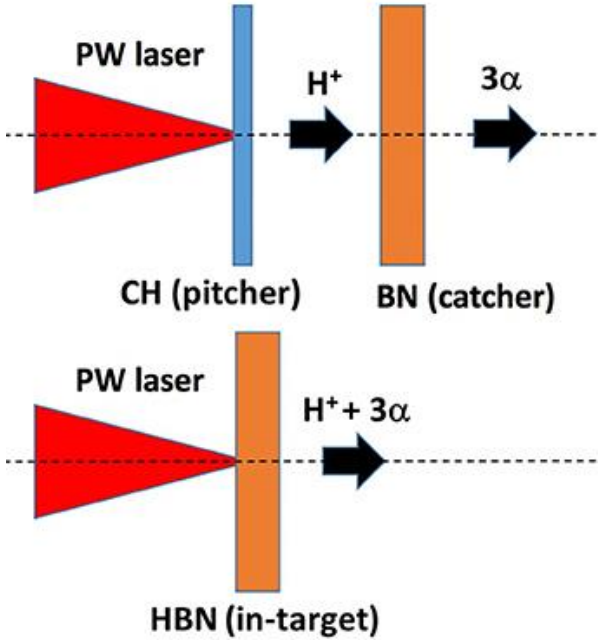
TA04-55:Laser-driven Ion Sources for Applications
(PI Dimitri Batani)

The proton-boron fusion reaction

$$p + B^{11} \rightarrow 3He^{4} + 8.7\ MeV$$

was explored to develop a high brightness laser-driven alpha-particle source

The campaign was performed in marz 2023
with VEGA-3. CLPU offered the laser ion-acceleration set up.



Different setup where proposed:
(a) Pitcher-catcher configuration: TNSA proton produced from thin aluminium foil target (Pitcher) interact on a solid thick B6Ca or B target (catcher).
(b) Directly irradiation of thick samples rich of Boron-nitride (BN) target.

Conclusion

- During the past twenty years the progresses in laser-driven acceleration mechanisms led to the proposition to use them as an alternative source of energetic particles for many different applications.

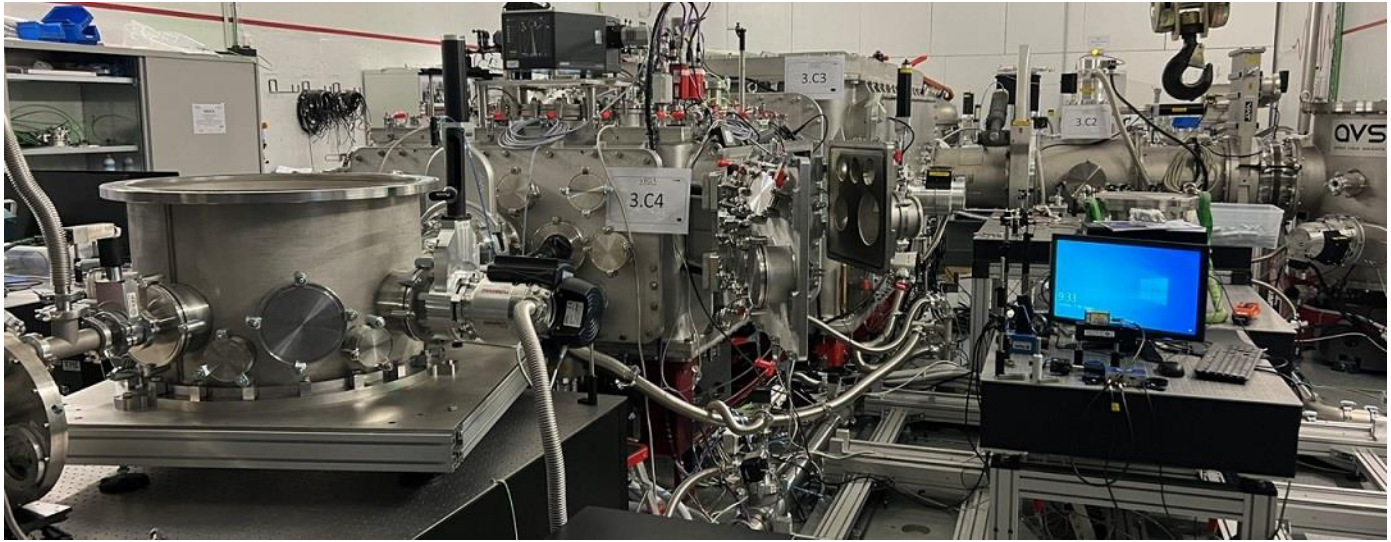
- Laser-driven source might cover the need of affordable and compact accelerators for electronics component irradiation.

- The generation of particle beams with energy and quality (single pulse) equivalent to conventional accelerator is envisions (EuPRAXIA project).

- The generation of broadband energy is much easier than the monoenergetic beams, early applications of the high intensity laser facilities for space radiation reproduction are possible.

- The Spanish Laser Center (CLPU) is a high intensity laser facility with capability to contribute in this field, together with the community.

Thanks for your attention!



CLPU
CENTRO DE LÁSERES PULSADOS