Investigations Into Particle Acceleration Towards Hadron Therapy

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Abstract

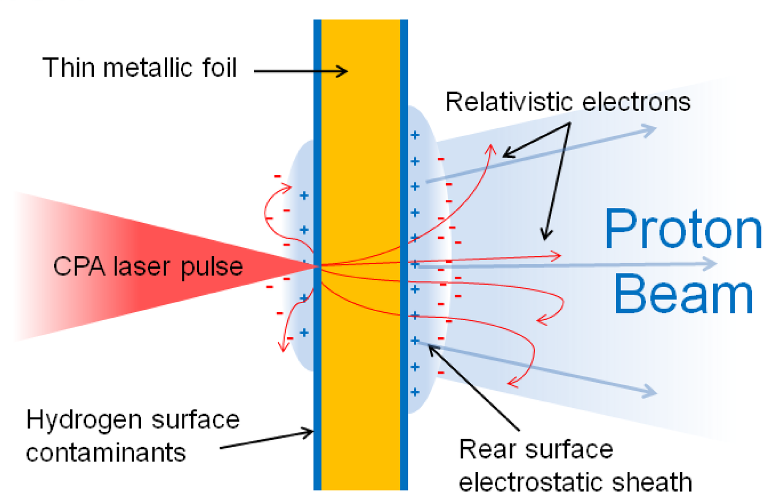
Petawatt range lasers, interacting with matter, can generate beams of accelerated protons and other ions which in turn could be used for diagnosis and therapy. Such laser-generated beams are a potentially cheaper and more compact alternative to conventional proton accelerators, but so far the beam energies attained with laser accelerators are not high enough to make them useful for this purpose. The aim of this project is to identify adequate parameter sets, target geometries, and beam shaping and control schemes to obtain proton and ion beams which could be used for nuclear radiotracers at lower energies and therapy at higher energies.

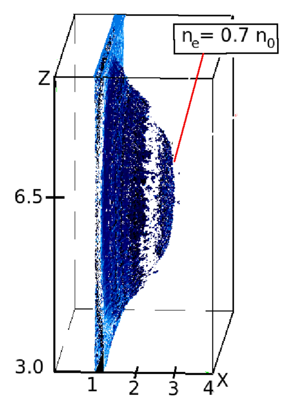
We will work in the determination, control and characterization of the optimal laser parameters for proton acceleration. We will also perform simulations of the generation of particle beams by means of plasma codes and we will design and set up the experiments of proton acceleration at lower energies to be carried out at CLPU.

Target Normal Sheath Acceleration

I ~ 10^{19} W/cm^2
Overdense plasma

- Proton acceleration up to tens of MeV
- Ultrashort proton pulses (< 1 ps)
- High number of protons per pulse (~ 10^{14})
- High beam quality





Radiation Pressure Acceleration

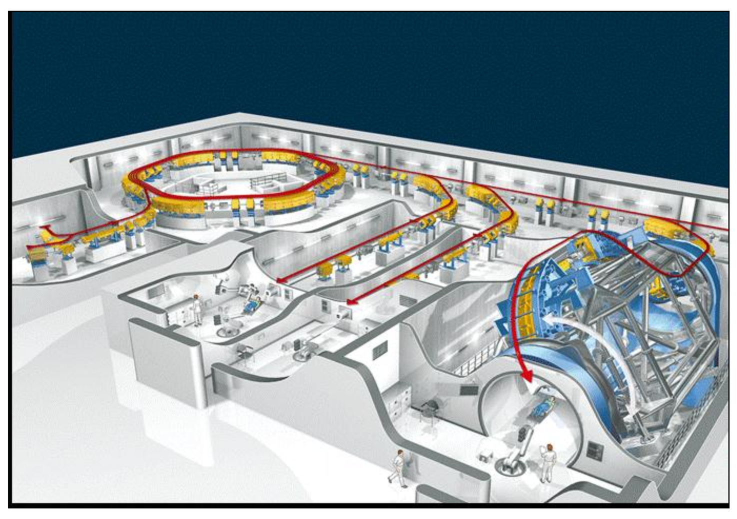
- Hole Boring (Shock acceleration)
- Light sail acceleration
  - → Cyclical re-acceleration of ions
  - → Narrow-band spectrum
  - → Fast scaling with intensity

Higher energy predicted compared to Target Normal Sheath Acceleration

C. A. J. Palmer et al., "Monoenergetic Proton Beams Accelerated by a Radiation Pressure Driven Shock", Phys. Rev. Lett. 106, 014801 (2011)

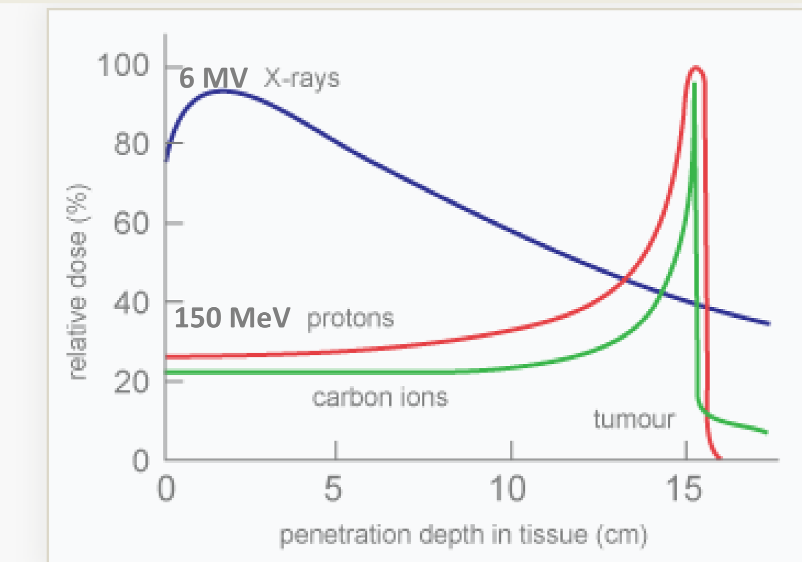
Proton Therapy

- High radiation dose with minimal damage to healthy tissue
- Tunable penetration depth according to proton energy.
- Conventional facilities are very complex and expensive.



Layout of HIT facility. HIT facility consists of two ion sources, 7 MeV/u injector, synchrotron with variable-energy operation and two horizontal fixed ports and one rotating gantry.

Fundamental features of hadron beam



- Depositing low dose as beam enters body en route to target **(plateau region)**
- Greatest amount of energy released at end of beam range **(Bragg Peak)**
- Very low dose deposited in tail region beyond the Bragg Peak

Challenges of laser acceleration for proton therapy

- Low energy (need 100's of MeV)
- Broad proton spectrum (need a monochromatic beam)
- Low repetition rate
- Higher pulse contrast required for Radiation Pressure Acceleration (RPA)

Solutions

- Unique laser facility
- High peak intensity (1 PW, 30J/30fs, adaptive mirror , tight focusing → 10^{21} W/cm^2)
- High rep rate (10 Hz at 200 TW and 1 Hz at 1 PW)
- High pulse contrast → try RPA mechanism → monochromatic proton beam

What is CLPU?

The Pulsed Laser Center (Centro de Láseres Pulsados, CLPU) is a national facility specialized in femtosecond laser pulses with peak powers at Gigawatt, Terawatt and Petawatt levels. The object of the facility is to serve the scientific community and the industry by providing access to state-of-the art high power lasers as well as advice through collaborative research. Our facilities are open to national and international users. CLPU is a member of Laserlab Europe and a regional facility of ELI (the European Extreme Light Infrastructure)

Infrastructures

Main beam line – The VEGA laser system

The main beam line is a 1 PW (30 Joule / 30 fs) Ti:Sapphire laser system (wavelength centred around 800 nm) operating at 1 Hz repetition rate. This beam line is divided in three phases of increasing power which can be used simultaneously, thus offering a ladder of laser pulses for different applications.

- Phase 1 – 20 TW (600 mJ / 30 fs), 10 Hz
- Phase 2 – 200 TW (6 J / 30 fs), 10 Hz
- Phase 3 – 1 PW (30 J / 30 fs), 1 Hz

Auxiliary beam lines

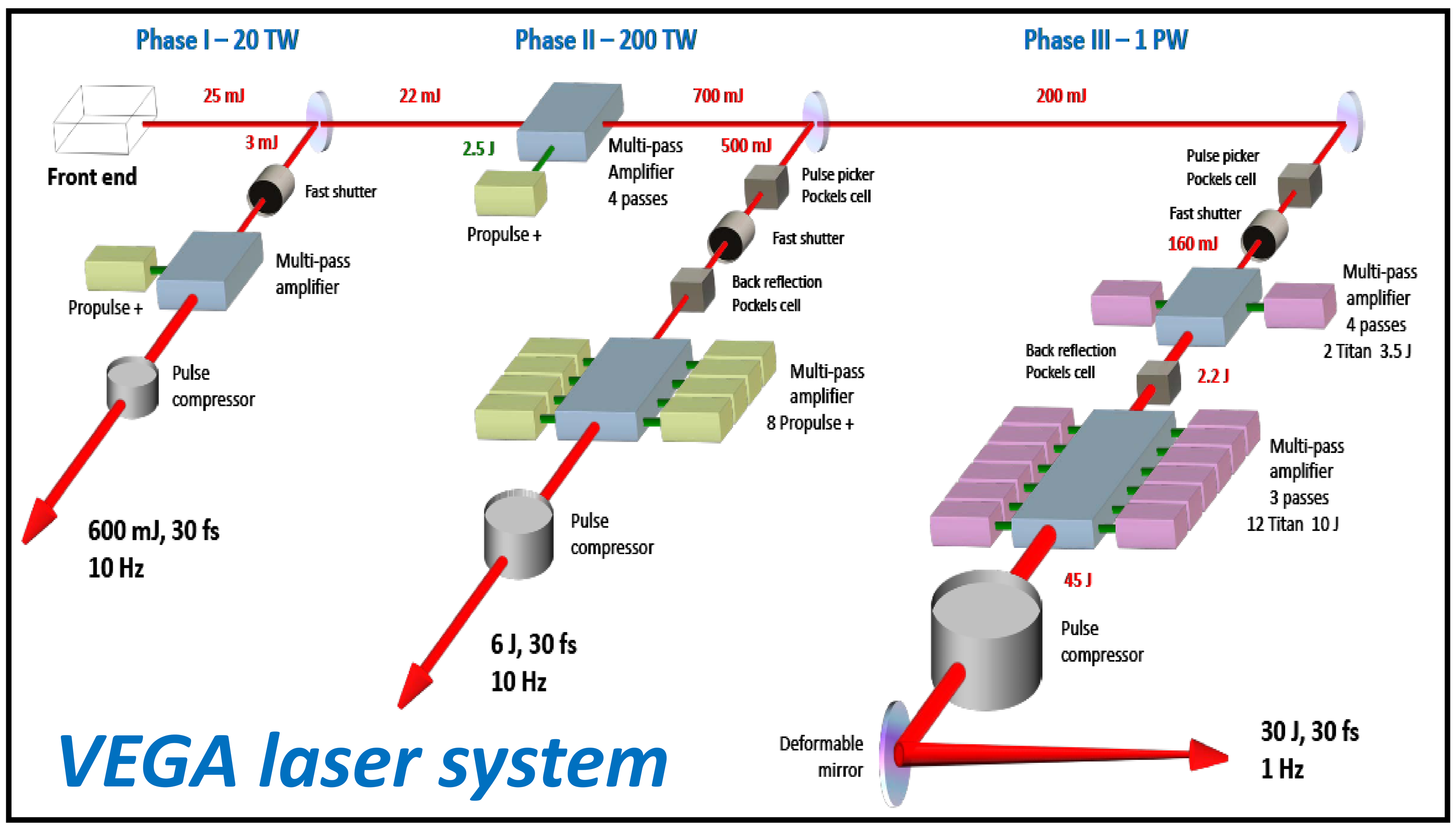
The main beam line will be complemented with the following systems:

- CEP-stabilised femtosecond laser, for attosecond science.
- High-repetition rate femtosecond laser, for microprocessing and micromachining.

Secondary sources

Additional beam lines of ultrashort X-rays and charged particles are expected to be developed from the main laser.

- Multi-mJ few –cycle laser pulses
- Pulsed coherent soft X-rays
- Attosecond XUV pulses
- IR-Vis-UV tunable femtosecond laser
- Relativistic electron beam, up to 1 GeV
- Proton beam, up to 100 MeV



Three outputs are fully synchronised - Allows pump and probe

References

P. Gibbon, "Short pulse laser interactions with matter: an introduction", Imperial College Press, London, UK, 2005

S. C. Wilks et al., "Energetic proton generation in ultra-intense laser–solid interactions", Phys. Plasmas 8, 542 (2001)

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