Recent Results on Acceleration Mechanisms and Beam Optimization of Laser-Driven Proton Beams

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Actual characteristics

- Low emittance beam: 0.015 mm.mrad
- Laminarity: virtual source size of 4 µm
- Short bunch duration: few picoseconds

- High proton numbers: $10^{11}$-$10^{13}$ per bunch
- High energy: Up to 60 MeV
Applications

- **Warm dense matter generation**: high current and large spectra
- **Plasma field radiography**: large spectra
- **Compact accelerator system**: laminarity, emittance, cost and facility size.
Predominant mechanism:

**Target Normal Sheath Acceleration**

Electrons crossing target

Beam divergence depends on proton energy
Paths toward beam optimisation

- Increased laser intensity:
  - Improved laser parameters \(\text{limited by laser development}\)
  - Reduced focal spot \(\text{limited by diffraction and experiment geometry}\)

- Reduced electrons dilution:
  - Limited lateral size target
  - Reduced target thickness

- Increased laser absorption:
  - New interaction regimes
  - New kind of target

\(\text{Need for high contrast laser}\)
Laser intensity increase using Elliptical plasma mirror (using a 400fs laser pulse)

Reduced spot size: very short focal length

Increased contrast ratio:

plasma mirror

Reflectivity increases abruptly when Intensity is high enough:

Amplified Spontaneous Emission is reduced

100TW LULI Facility
Laser focal spot is reduced
Laser intensity is increased (~70% energy is lost on EPM)

Protons beam energy is increased

\[ I_{\text{laser}} = 1.10^{19} \text{ W.cm}^2 \quad I_{\text{laser}} = 8.10^{19} \text{ W.cm}^2 \]

• Acceleration seems to saturate:
  Plasma mirror surface gets perturbed.
• At the same intensity, small focal spot is less efficient:
  Lateral spreading likely to increase.
Electron confinement using reduced lateral size target (using a 400fs laser pulse)

Lateral expansion sheath is about 100 µm

Lateral expansion is blocked

Electron sheath is confined if target size < “natural” sheath size
When target surface is less than 0.1 mm² we increase ...

2μm thick target

... Proton energy

... Conversion rate

S. Buffechoux, submitted (2009)
Electron sheath parameters are improved

Fluid model:

\[ \frac{dN}{dE} = 1.3N_{\text{hot}}c_s [c(2E k_B T_{\text{hot}})^{1/2}] \exp\left(-\frac{2E}{k_B T_{\text{hot}}}^{1/2}\right) \]


Coupling between laser and plasma is increased
Using 25fs laser pulse duration

- High laser intensity with only few Joules
- 10 Hz repetition rate
- High contrast ratio

Time Of Flight diagnostic

With plasma mirrors:
- 220 mJ on target
- 6.5 µm target thickness

\[ \text{Energy (MeV)} \]

\[ \text{arbitrary unit} \]

- rear side

4 MeV

(ALLS- INRS facility)
Comparing with others laser facilities around the world

Using very thin target (less than 1µm), with high laser contrast:

expect to increase significantly proton
Conclusion

All the above-shown different approaches demonstrate feasible optimization paths for proton beams acceleration.

Other paths toward energy increase:

• Using coating or foam target: increase absorption.
• Using several beams: modify electrons acceleration.
• Using circular polarisation: RPA regime.

Laser driven protons acceleration becomes more and more interesting:

• laser development.
• Better understanding in proton acceleration mechanism.
Thank you for your attention

Any questions?
Time And Space Resolved Interferometry

Main beam (400 fs, 30 J)

Probe beam (40 ps, 100 m J)

parabola

Proton source target

Heated target

Beamsplitter

Mirror

Slit

Grating

CCD

Mach Zender