A Laser Proton Accelerator for 70th birthday

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Outline

1. Introduction
2. Compact laser plasma accelerator at Peking University
3. Experiments of generation and focusing of laser accelerated proton beams at PKU
4. Laser accelerator of 3-9 MeV proton beams with 1% energy spread
5. Summary
Application of Laser Driven Ions

Biological irradiation

Ion radiograph

WHM

Radiotherapy

In China in 2016:

✓ Cancer patients -- 4.29M and death by cancer --- 2.81M.
✓ The best way to do Cancer therapy is radiation therapy.

Highest energy ~100 MeV/u

TNSA 85 MeV Proton

RPA 93 MeV Proton

PRL 116, 205002 (2016)

POP 23, 070701 (2016)
Characteristics of Laser Driven Ion Beam

- Large energy spread ~100%
- Large diverge angle ~10°
- Small emittance ~0.1π mm.mrad
- Small initial size, spot source ~5μm
- Short pulse duration ~a few ps
- High peak current ~10^{10}-10^{13} ppp, KA

Except maximum energy, RAMI (Repeatability, Availability, Maintainability and Inspectability) is important for applications in the near future.
CLAPA at Peking University (Compact Laser Plasma Accelerator)

High Contrast 5Hz 200TW Laser System

- Pulse Energy: 5 J
- Duration: 25 fs
- Repetition: 5 Hz
- Wavelength: 800 nm +/- 10 nm
- Contrast Ratio:
  - > 10^{10}:1 @ ~ns
  - 10^{10}:1 @ 100 ps
  - 10^9:1 @ 20 ps
  - 10^6:1 @ 5 ps
  - 10^3:1 @ 1 ps
Laser Proton Accelerator with a beam line

Quadruple Triplet lens

Dipole magnet

Quadruple doublet lens

Energy : 1-44 MeV
Energy spread: 0.5~±5%
Transfer efficiency >90%
Number: $10^8-10^{10}$

Jan 25-26, 2018, UCI, USA
Beam Spot on The Irradiation Platform

44 MeV with ±1% energy spread

44 MeV with ±4% energy spread

Experiments of Laser proton acceleration

Laser parameters

Energy: 1.8 J
Duration: 30 fs
Spot: 4.5 μm × 5.3 μm
Intensity: 8.3 × 10^{19} W/cm²
Incident angle: 30 degree
Plastic targets produced proton beams with good stability and the beam cutoff energy stability better than 3%.

Stable protons were generated based on 20nm plastic target without PM.
The distance between target and quadruple triplet was 19 cm with a collection angle ±50 mrad.

Focusing with quadruple triplet lens (1)

The proton charge on MCP was significantly enhanced:

- 3.5 MeV ×7
- 4.5 MeV ×20
- 5.5 MeV ×20
Dipole magnet for energy selection (1)

Simulated distribution of proton with 3.3788 MeV central energy and ±5% energy spread on the third scintillator.

<table>
<thead>
<tr>
<th>Slit distance</th>
<th>Energy spread</th>
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<tbody>
<tr>
<td>+/-7mm</td>
<td>1%</td>
</tr>
<tr>
<td>+/-30mm</td>
<td>5%</td>
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Dipole magnet for energy selection (2)

Cutoff energy
3.38 MeV

70um Al foil
scintillator
EMCOM

Cutoff by Al foil

E=3.38 MeV

E=4.0 MeV
4.2 MeV
3.8 MeV
Quadruple doublet lens to refocus the beam

Proton propagation envelope with 5 MeV central energy and 5% energy spread.

Simulated proton distribution on MCP
Focused proton beams with different energies

3 MeV, 1%

4 MeV

5 MeV

6 MeV
Spread-out Bragg Peak using CLAPA Beamline

**Single Bragg Peak**

- Electron (21 MeV)
- Photon (22 MeV)
- Carbon (270 MeV/u)
- Proton (250 MeV)

**SOBP**

![Graph of Relative dose vs Depth for different particle types](image)

**Figure 6.** The 2D reconstruction result of the SOBP for an ideal situation with a specific tumor region.

With the development of high-rep rate PW laser technology, now we can envision a table-top proton cancer therapy machine very soon.

Table-top proton cancer therapy machine with RAMI

RAMI:
- Reliability
- Availability
- Maintainability
- Inspectability
Summary

- A compact laser plasma accelerator (CLAPA) at Peking University has been built.

- 3-15 MeV proton beams have been generated with stability better than 3% by using plastic targets.

- With the beam line, laser accelerator of 3-9 MeV proton beams with 1% energy spread and 1-20 pC has been achieved.
Happy 70th birthday!
Verification of the energy accuracy

By using the aluminum foil cut-off energy, the accuracy of the beam line has been verified,
Emittance Measurement (1)

\[ \varepsilon^2 = \gamma^2 \left( \langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2 \right) \]

The emittance of 2.8 MeV proton from CLAPA

Molybdenum, 20 × 20 array of 0.1 mm holes

The emittance of 2.8 MeV proton from CLAPA

\[ \varepsilon_m = 0.091 \, \pi \, \text{mm mrad} \]