Towards a compact proton irradiator for in-vitro radiobiological studies

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Outline

1. The bigger picture: Proton Therapy
2. Laser Plasma Acceleration of Protons
3. First published beam experiments: *in-vivo* radiobiology
4. Our proposed (long-term) fully scalable experiment
5. Our experiment zero at the Imperial College
6. Advanced energy manipulation
Why use laser-plasma accelerated protons for therapy?

**Compact source** – Laser-Plasma interactions can produce high energy ion beams over short distances

**Cheaper facilities** – The source can be moved into the gantry, reducing the beam bending and radiation shielding requirements.

**Versatile** – Each laser shot can be adjusted to modify the proton beam properties during the treatment time, allowing a more modular form of treatment.

**Cost estimates**
£150 M spent on each of the new two facilities based on conventional proton accelerators in England
£5 M for a laser based facility (same price as a conventional MV photon source)

Laser-plasma interactions generate ion beams from compact sources

Ion beams can be created by using a high intensity laser pulse onto a target

Produces diverging, multi-energetic ion beams

Keeping the same set up you can accelerate other ions by changing target

Has been shown to produce $^{99m}Tc$ shooting the accelerated protons onto a $^{100}Mo$ target [1]

Energies yet to exceed 80 MeV [2]

In sheath acceleration (SA), charge separation generates an electric field which in turn accelerates ions [3].
Recent applications of laser accelerated protons: *In-vitro* radiobiological experiments


D. Doria et al., Belfast (2012) [5]

How are these experiments done?

Cells are irradiated using multiple pulses of protons to reach the desired dose. Cells are placed vertically in the line of the beam inside an ionization chamber.

*J. Bin et al., Munich (2012) [4]*

*K. Zeil et al., Dresden (2012) [7]*
What results have been found?

Standards assays

Laser-driven ions were initially shown to cause DNA double-strand breaks, indicated by orange/pink colour [Kraft, 2010]

Survival Curves

Since proving cell irradiation, survival curves have been produced for specific cell lines showing the expected dose-survival fraction relation [Hanton, 2013]
Progression from *in-vitro* experiments is to move to *in-vivo*, which need at least a 50 MeV proton beam

*K. Zeil et al., Dresden (2012) [7]*
Proposed Complete Experiment, Imperial College

High repetition laser

Ion beam

Target area

Gabor lens 1

Gabor lens 2

Iris

Gabor lens 3

Cell irradiation area

Beam bend

Scalable to 250 MeV
A Gabor lens is a space-charge lens that is able to focus ion beams. This concept of focusing beams of energetic charged particles was first proposed in 1947 [8]. Previous experiments successes for focusing lower ion energies have been limited and through fortune [9].

\[ B_{GPL} = B_{sol} \times \sqrt{\frac{m_e}{m_{ion}}} z \]  

[10]
Gabor lens simulations

4 to 30 MeV for RBE experiments are being investigated using the particle distribution obtained from various experiments. Particle tracking for two Gabor lens system for the experiment have produced good results [10].
GPL lattice for beam formation and energy selection medical application hadron therapy – “long term”

Three lenses – one aperture
First step towards the realization of a radiobiological facility

Chapter 4

Proposed Experimental Set Up

4.0.9 Experiment design

Following optimisation of the system the set up shown in 4.1 was proposed. To demonstrate focusing and energy selection: Gabor lens of length 0.50m with an anode diameter of 0.035m will be positioned 0.15m behind a targetry system. All will remain under vacuum. An aperture will be aligned 2.00m behind the target's rear surface with a diameter and depth of 0.002m.

Figure 4.1: Gabor lens experiment - focusing and energy selection: Gabor lens of length 0.50m with an anode diameter of 0.035m will be positioned 0.15m behind a targetry system. All will remain under vacuum. An aperture will be aligned 2.00m behind the target's rear surface with a diameter and depth of 0.002m. A diagnostics chamber containing a stack of the same composition as in the original experiment will be position 2.40m behind the target.

Focusing and energy selection of a wide energy spread laser-accelerated proton beam
Cerberus* Laser-plasma chamber (Blackett Lab)

* Imperial Laser Consortium
Prof R. Smith
Advanced energy manipulation - treatment

4 cavities – 928 MHz – solid state direct drive
(e.g. Siemens)

@ 80 MeV
1% Energy Spread
5% Energy Variation

@ 250 MeV

± 2 MeV

@ 250 MeV

1% Energy Spread
5% Energy Variation
Advanced energy manipulation – $^{99m}$Tc production
Thank you