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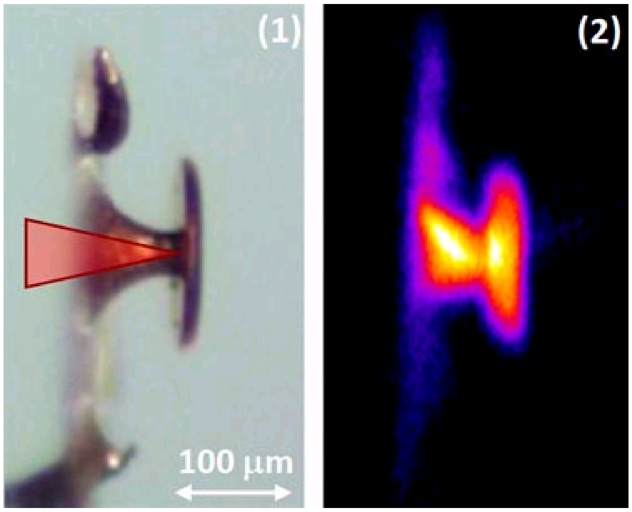
Laser creates record-breaking protons

Nov 9, 2009 14 comments



Laser proton anvil in action

An international group of physicists working at the Los Alamos Laboratory in the US has used a laser to generate 67.5 MeV protons – the highest-energy protons yet produced in this way. Their work points the way to new laser-based devices for proton therapy, which would be far smaller and cheaper than existing particle-accelerator sources.

When a high-energy proton beam travels through the human body it deposits most of its energy within a small volume, the size and location of which can be calculated to great precision. As a result, protons offer a distinct advantage over other forms of radiation used to destroy tumour cells because they cause less damage to surrounding healthy tissue. Unfortunately, the accelerators needed to generate the protons can cover thousands of square metres and cost some $100m. This has limited the number of proton-therapy facilities available and patients often have to travel considerable distances to be treated in this way.

Some physicists believe that a laser-based proton generator could be made for about one tenth of the cost of a conventional accelerator and be small enough to be contained within a classroom-sized laboratory. The idea is that ultra-powerful laser pulses knock electrons out of the atoms within a tiny target, causing the electrons to accumulate on the target's rear surface. This sets up an electric field across the target, accelerating the resultant ions and forcing them to leave the material as a very high-energy beam.

Energy is a problem

In practice, however, some of the world's most powerful petawatt (10^{15} W) lasers have only been able to generate protons with a maximum energy of about 58 megaelectronvolts (MeV). While tumours of the eye can be treated using protons of 60–70 MeV, deeper tumours require energies of about 300 MeV.

The latest breakthrough was carried out by Kirk Flippo of Los Alamos, Sandrine Gaillard of the Forschungszentrum Dresden–Rossendorf research centre (FZD) in Germany and colleagues, who used Los Alamos' Trident laser to generate 67.5 MeV protons. The work relies on a novel target design – an anvil-shaped piece of copper

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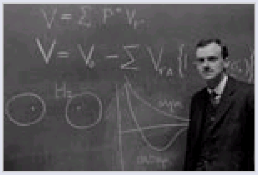

comprising a cone around 100 µm long with a 100 µm flat disc across perched on its tip. Flippo's team directed the laser beam to the inside of the cone, liberating electrons that were guided to the tip and which set up an electric field that accelerated protons away from the disc. The researchers claim that this arrangement is far more efficient than the thin films used in previous experiments – they used 80 J laser pulses, whereas the previous record of 58 MeV involved 450 J laser pulses.

Team-member Michael Bussmann of the FZD says that this significant step forward in maximum proton energy was also made possible by increasing the intensity of the main part of each pulse relative to the "pre-pulse", which precedes the main pulse and can damage the target.

Not enough protons

However, it might take a decade or more before laser-generated protons can be used to combat cancer. Another major challenge is that Trident and the other more intense lasers simply require too much energy to be able to function at the roughly 10 Hz pulse rate needed to produce enough protons for cancer therapy.

According to Bussmann, reaching the sought-after high production rates will be a matter of getting the target right. One possibility will be some kind of refinement of the anvil shape, he says. Others, however, believe that the answer lies in reducing the size of the target, allowing electrons to be heated and ejected from the target much more quickly and therefore with a more uniform energy distribution, in other words leading to fewer low-energy electrons. "We already have enough energy in our lasers, the question is how can we use it more efficiently," says Bussmann. "Nobody has the final idea right now," he said, "but we are in a position to test all these different theories and see which works best."

Looking beyond cancer therapy, Flippo believes that such proton sources could also be used to create medical isotopes and employed to generate neutrons for research in condensed-matter physics and other areas of science. They might also be used to search for nuclear materials inside cargo, given that the characteristics of a proton beam are altered in a well defined way by radioactive substances.

The research was presented at the annual meeting of the Division of Plasma Physics of the American Physical Society, held in Atlanta on 2–6 November.

About the author

Edwin Cartlidge is a science writer based in Rome

14 comments

Add your comments on this article

1 **Oliver K. Manuel**
Nov 9, 2009 5:15 PM
United States

LASER DID NOT CREATE THE PROTON

THis is an excellent story, but the laser did not create the proton.

The proton (the nucleus of the most abundant isotope of hydrogen) was simply accelerated to 67.5 MeV.

The story correctly notes that a 67.5 MeV proton does not travel very far in the human body. It produces many (+ / -) ion pairs in a short distance. This ion pairs destroy tumour cells.

This asset is also a problem if surrounding healthy tissue is traversed before the 67.5 MeV proton reaches the tumour.

With kind regards,
Oliver K. Manuel

Reply to this comment   Offensive? Unsuitable? Notify Editor

2 **michaelbussmann**
Nov 9, 2009 8:49 PM
Dresden, Germany

Bragg Peak

Dear Oliver,

you are right that the protons were not 'created' by the laser. They are the positive nuclei of hydrogen atoms which are deposited on top of the target surface. This hydrogen was ionized by the strong laser field prior to the acceleration. The hydrogen thus lost its electrons and only the nucleus, meaning the proton, was left behind.
Protons are used for cancer irradiation because almost all of their initial energy is deposited close to their final stopping position. Thus most of their energy is deposited inside the cancerous tissue while the surrounding healthy tissue remains (almost) unharmed. X-ray irradiation in comparison does harm the healthy tissue surrounding the tumor significantly.

Best regards, Michael Bussmann (FZD)

Edited by michaelbussmann on Nov 9, 2009 9:15 PM.

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3 **Oliver K. Manuel**
Nov 10, 2009 3:59 AM
United States

Quote:

> *Originally posted by* ***michaelbussmann***
> Dear Oliver,
>
> . . . . Protons are used for cancer irradiation because almost all of their initial energy is deposited close to their final stopping position. Thus most of their energy is deposited inside the cancerous tissue while the surrounding healthy tissue remains (almost) unharmed.
>
> Best regards, Michael Bussmann (FZD)

Michael,

How do you get the high energy proton "inside the cancerous tissue" without traversing any "the surrounding healthy tissue" ?

With kind regards,
Oliver K. Manuel

Reply to this comment Offensive? Unsuitable? Notify Editor

4 **michaelbussmann**
Nov 10, 2009 8:58 AM
Dresden, Germany

Killing the tumor, not the healthy tissue

Dear Oliver,

I agree with your first comment that protons (and ions) partly ionize the healthy tissue. But, as in drugs, getting the dose right is the key. Take, for example, a deep-seated brain tumor.
With x-rays a lot of healthy tissue is harmed, since x-rays loose much of their energy inside the healthy tissue surrounding the tumor before reaching the tumor. With modern diagnostics such as Positron-Emission-Tomography (PET) we find that almost as much dose is lost in the healthy part of the brain as is deposited in the tumor.

With protons (and ions), only about 20% of the dose used to kill the tumor is lost in the healthy tissue, thus the harm done to your brain is much smaller compared to x-ray cancer treatment. These values get even better when using heavier ions such as carbon (we are working on that as well).

Please follow this link to see the difference in dose distribution:

tinyurl.com…xraysvsions

Let me also point you to some fascinating research on controlling the effect of cancer treatment during the irradiation:

tinyurl.com…fzdradiotherapy

Best regards, Michael Bussmann (FZD)

Edited by michaelbussmann on Nov 10, 2009 9:12 AM.

Reply to this comment Offensive? Unsuitable? Notify Editor

5 **Oliver K. Manuel**
Nov 11, 2009 5:06 AM
United States

Quote:

> *Originally posted by* ***michaelbussmann***
> Dear Oliver,
>
> I agree with your first comment that protons (and ions) partly ionize the healthy tissue. But, as in drugs, getting the dose right is the key. Take, for example, a deep-seated brain tumor.
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> Let me also point you to some fascinating research on controlling the effect of cancer treatment during the irradiation:
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> tinyurl.com…fzdradiotherapy
>
> Best regards, Michael Bussmann (FZD)

Dear Michael,

Thanks for the information.

Could you also explain "radiosensitizers" that selectively go into tumor cells and make them more sensitive to radiation damage?

With kind regards,
Oliver K. Manuel

Reply to this comment Offensive? Unsuitable? Notify Editor

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6 **michaelbussmann**
Nov 11, 2009 10:30 AM
Dresden, Germany

I'm a physicist

Dear Oliver,

I'd love to answer your question, but you are asking the wrong person. I am a physicist and can tell you a lot about the physics involved. I am however not an expert in the biological and chemical processes which can enhance the effect of radiation damage in tumors.
I will contact our partners from Oncoray

www.oncoray.de…

and get back to you on this question.

Best regards, Michael Bussmann (FZD)

Edited by michaelbussmann on Nov 11, 2009 10:31 AM.

Reply to this comment Offensive? Unsuitable? Notify Editor

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7 **michaelbussmann**
Nov 11, 2009 11:54 AM
Dresden, Germany

Radio Sensitizers - What a physicist can tell you

Dear Oliver,

please remember that I can only try to repeat what I heard from others. I am not an expert in this. I encourage other readers of this article with a background in radio pharmacy to correct any mistakes I make.

So here is what I found out:

Radio Sensitizers are chemical substances that enhance the destruction of tumor cell DNA when subjected to radiation.

There are currently two major radio sensitizers: Optical Sensitizers and molecules with heavy element atoms inside. The optical sensitizers are activated by visble green light, so they can only work on tumor cells that can be reached by visible light, for example skin cancer cells.

The heavy element molecules are more interesting to us, because they can be activated by x-ray radiation or other high-energy radiation and thus can be applied to deeper seated tumor. After their activation the radio sensitizers send out low-energy electrons (so-called Auger electrons with an energy of about 100 eV) which cause much damage in their vicinity.

Unfortunately, the damage is very local, about 2 nanometers (1 nanometer = one billionth of a meter) around the radio sensitizer, which is roughly the diameter of the DNA. So you have to bring these radio sensitizer molecules very close to the DNA of the tumor, which is not easy to realize. The only tests I have heard of involved replacing the nucleobase Thymin by a synthetic version with additional Iodine.

Hope this help,
best regards, Michael Bussmann (FZD)

Edited by michaelbussmann on Nov 11, 2009 11:59 AM.

Reply to this comment   Offensive? Unsuitable? Notify Editor

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8 **inthend9**
Nov 9, 2009 7:47 PM
United States

There's such thing as cost-efficient

I'm all for science, but when it comes to cancer treatment, I think funding would be much better spent in the recently discovered and fruitful realms of RNA and complex biochemistry research, that can be done quite simply, compared to massive particle accelerators.

Reply to this comment   Offensive? Unsuitable? Notify Editor

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9 **michaelbussmann**
Nov 9, 2009 9:03 PM
Dresden, Germany

Lasers cost much less than accelerators

I agree with you that money for cancer treatment should be spend efficiently.
We thus work on making treatment of tumors that cannot be killed by drugs alone much more cost-efficient by trying to replace huge accelerators with much cheaper and smaller laser systems.
With the rapid development seen in modern laser system design prices have dropped considerably. It might well be possible that laser-based proton treatment will be affordable for your local clinic.

Best regards, Michael Bussmann (FZD)

Edited by michaelbussmann on Nov 9, 2009 9:35 PM.

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10 **hywelowen**
Nov 13, 2009 8:31 AM
Manchester, United Kingdom

Proton therapy

Quote:

> *Originally posted by **inthend9***
> I'm all for science, but when it comes to cancer treatment, I think funding would be much better spent in the recently discovered and fruitful realms of RNA and complex biochemistry research, that can be done quite simply, compared to massive particle accelerators.

The particle accelerators presently used for therapy are generally not massive, nor are they expensive. Most present-generation particle therapy sources are electron linacs, which are supplied commercially as part of a larger therapy instrument. the linac is mounted on a rotating gantry to illuminate a deep tumour from multiple directions whilst minimising the dose in other tissues.

Proton therapy is presently entering the mainstream. Although proton accelerators are more expensive, the therapy dose is more concentrated because of the Bragg peak for energy deposition: a much higher percentage of the particle's energy is deposited at the tumour compared to intervening tissue; the depth at which this peak occurs depends on the particle energy. Crucially though, protons have very little 'downstream' dose. This means for example that you can deliver a therapy dose to a tumour close to the spine, whilst not illuminating the spinal cord behind the tumour. This means that proton therapy is particularly useful for certain types of cancer.

Present generation proton therapy machines, which are all cyclotrons, are practically limited in energy to around 70 MeV, which limits the depth in the body that tumours can be treated. However, there are a variety of cancers which clinicians think are appropriate (and economic) to treat with protons, and there are a number of commercial companies providing both the cyclotrons and the integrated therapy instruments - there is a LOT of clever beam steering and dose manipulation in these machines.

In the USA the present focus seems to be on using protons for prostate cancer, whilst in the UK the priority is for treating particular childhood cancers. In the UK the NHS has budgeted around 50,000 UK pounds per patient, and on the basis of that intends to construct two proton therapy facilities.

Future proton therapy should deliver both higher energies, and more flexible treatment planning by being able to easily vary the proton energy and dose. Neither of these things are possible with cyclotrons. A number of options are being examined, and laser-accelerated protons are only one of them. Others are synchrotrons, new kinds of proton linacs, and FFAGs (a modified kind of cyclotron). It's fair to say that laser-accelerated protons are their infancy compared to other options, although there is potential in the long term for the laser method to end up being cheaper. It certainly isn't cheaper now.

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11 **jjeherrera**
Nov 10, 2009 5:55 PM
Ciudad Universitaria, Mexico

Question on the spectrum

The article tells us what is the maximum energy protons can achieve, but how does their spectrum look like? The advantage of accelerators is that they have an excellent resolution in the accelerated particles energy. This is certainly an interesting work, anyway.

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12 **michaelbussmann**
Nov 11, 2009 10:14 AM
Dresden, Germany

Only the high-energy protons matter

The energy spectrum of laser-accelerated ions is an issue of current research. Accelerators can deliver beams with a very sharp energy spectrum, while laser accelerated ion beams still deliver rather broad spectra with ions of various energies (as is the case for the experiment described in the article).

However, there has been much experimental improvement on controlling the energy spectrum of laser-accelerated ion beams in the last few years. New theoretical ideas promise that almost mono-energetic (=having only one energy) ion beams are in reach with present laser technology.

Furthermore, we are in the fortunate situation to get a huge amount of ions with a single laser shot, so we can 'throw away' all the low energy ions using very compact filtering devices that let pass only the high-energy ions and still have enough high energy ions left for application.

Finally, radiation therapy with ions might also be feasible using ion beams with a broad energy spectrum. Here techniques similar to those developed for x-ray radiation therapy might help.

As stated in the article, there are still many open questions we need to answer - and this is what makes this research so exciting. Accelerators have been around since the 1930s, so they had almost 80 years to mature to where they are now. Laser acceleration is still at the beginning, but progress is fast - so expect to hear more about laser acceleration in the future.

Best regards, Michael Bussmann (FZD)

Edited by michaelbussmann on Nov 11, 2009 10:16 AM.

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13 **Dus08**
Nov 13, 2009 9:32 AM

proton versus heavy ion therapy

Nice work, no doubts!
Congratulations!

However, I believe, for the sake of a 'broadness' of the discussion, you should not 'hide' the (well-known for experts) fact, that the heavy-ion therapy (like that, used at GSI, in Germany) is better than the proton therapy as far as the Bragg peak argument is concerned?
(For non-experts: at GSI they use 12C ions, read here:
cerncourier.com…2)

Anyway, good work, Michael!
Good luck!

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14 **michaelbussmann**
Nov 13, 2009 2:10 PM
Dresden, Germany

You are right on the ions

Thank you!

You are right, I just wanted to be short in my answer. There is of course a difference in dose distribution and, as I mentioned in my reply to Oliver, with heavier ions we would get better results due to the sharper Bragg-peak (although at some point the lateral extent of the secondary particle cascade becomes an issue!).
Proton/Ion therapy right now is just starting to become a tool for clinical therapy rather than a field of research. The very successful work done at GSI has paved the way for the Heidelberg HIT facility and it is indeed an exciting time for cancer radiation therapy.

Best regards, Michael Bussmann (FZD)

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