Extreme Light Infrastructure (ELI) and Hadron Therapy

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Abstract

Hadron therapy is a part of radiation therapy, which uses not only beams of high energy ions, but also π–mesons, neutrons, electron beams, X- and gamma rays to irradiate cancer tumors.

Proton therapy is an effective treatment especially against cancers located in areas which are inaccessible to surgeon's instruments or which are hard to treat by radiotherapy.

Among the advantages of proton therapy we mention: the proton beam scattering on the atomic electrons is weak and thus there is less irradiation of healthy tissues in the vicinity of the tumor; the deceleration length for a proton with given energy is fixed, which avoids undesirable irradiation of healthy tissues behind the tumor; the well localized maximum of the proton energy losses in matter (the Bragg peak) leads to a substantial increase of the radiation dose in the vicinity of the proton stopping point.

Our work will first describe the benefits of proton therapy vs. X-ray and the present status of the art of medical applications of proton beams generated by conventional accelerators of charged particles (synchrotrons, cyclotrons, linacs).

A laser-based accelerator is fairly attractive because of its compactness and of the additional possibility it offers of controlling the proton beam parameters.

For medical applications, the maximum proton energy must be in the range of 230 to 250 MeV.

The present-day laser parameters (pulse energy, pulse duration, peak intensity and focal spot size) are not yet optimized for the intended applications.

Laser proton accelerators are based on the fact that the nonlinear interaction of high-power laser radiation with matter is accompanied by the efficient conversion of laser energy into the energy of fast particles.

In the last years, energetic proton beams with high beam quality have been produced from thin metallic foils irradiated by ultraintense short laser pulses ($I > 10^{18}$ W cm^{-2}).

These proton beams have a number of unique properties, including high brightness and ultralow emittance, they are extremely laminar, collimated, with a smooth angular distribution and a duration of the order of tens of femtosecond till one picosecond.

The characteristics of targets used in laser proton accelerators are very important and the solutions to increase proton generation efficiency will be discussed.

Other applications of proton beams, such as fusion, radiotherapy, PET and spallation will be shortly presented.

The last section of the work will be dedicated to the Extreme Light Infrastructure (ELI), which will be the first pan-European large-scale facility dedicated to multidisciplinary applications.

It will be an Exawatt-class laser, approximately 1000 times more powerful than either existing laser.

This gigantic scientific machine would serve to investigate a new generation of compact accelerators delivering energetic particles and radiation beams of femtosecond (10^{-15} s) to attosecond (10^{-18} s) duration and intensities exceeding $I_L > 10^{25}$ W/cm².

In this way, it will be possible to explore for the first time the intensity territory of ultra-relativistic regime ($I_L > 10^{23}$ W/cm²), where a plethora of novel effects will be studied: X-ray generation, γ-ray generation, relativistic self focusing, high-harmonic generation, electron and proton acceleration, neutron and positron production, as well as manifestation of nonlinear QED effects.

Finally, the present situation and the future plans to increase the laser power capability at INFLPR, Bucharest, will be discussed.

RADIOTHERAPY WITH NEUTRONS, PROTONS AND CARBON IONS BEAMS

PREDEAL, ROMANIA

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Extreme Light Infrastructure (ELI) and Hadron Therapy

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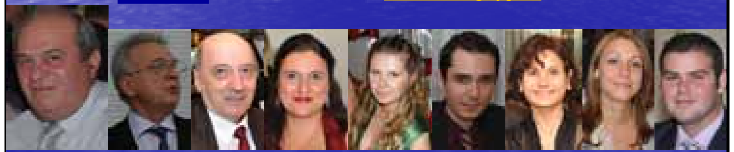

Overview

1. Introduction
2. Proton therapy vs. X-rays
3. Present status of the art
4. Laser-based particle accelerators
5. Other applications
6. Extreme Light Infrastructure (ELI) project
7. Conclusions

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Introduction

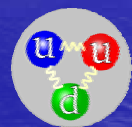
DEFINITION:

Hadron – is a bound state of quarks

- Hadrons are held together by the strong force, similarly to how atoms are held together by the electromagnetic force
- There are two subsets of hadrons: baryons and mesons
- The most well known baryons are protons and neutrons

Proton – is a subatomic particle with an electric charge of +1 elementary charge

- It is found in the nucleus of each atom but also stable by itself
- Has a second identity as the hydrogen ion, H^+
- It is composed of 3 even more fundamental particles comprising two up quarks and one down quark



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Introduction

Hadron therapy is a part of radiation therapy, which uses not only beams of high energy ions, but also π-mesons, neutrons, electron beams, X- and gamma rays to irradiate cancer tumors

Proton therapy is an effective treatment especially against cancers located in areas which are inaccessible to surgeon's instruments or which are hard to treat by radiotherapy (brain tumors, in areas close to the spinal cord, inside the eye, etc.)

Advantages of proton therapy:

- the proton beam scattering on the atomic electrons is weak and thus there is less irradiation of healthy tissues in the vicinity of the tumor
- the deceleration length for a proton with given energy is fixed, which avoids undesirable irradiation of healthy tissues behind the tumor
- the well localized maximum of the proton energy losses in matter (the Bragg peak) leads to a substantial increase of the radiation dose in the vicinity of the proton stopping point

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Proton therapy vs. X-rays

- Main difference between X-rays and particles is their different biological action and different depth dose distribution
- X-rays: the dose decreases exponentially for larger penetration depths → deep-seated tumors have to be irradiated for many parts in order to distribute the non-wanted dose in front of the tumor over a large volume when delivering a lethal dose to the tumor (up to 10 fields in Intensity Modulated Radio Therapy – IMRT)
  - main problem: induction of secondary tumors
- Particle therapy: hadron beams have an inverse dose profile that produces a greater dose to the tumor than to the healthy tissue in the entrance
  - by Intensity Modulated Particle Therapy (IMPT), hadron beam is guided according to the shape of the zone to be treated (the tumor can be delineated in all its contours with a precision of 2 – 3 mm)
  - changing the ion energy shifts in depth the position of energy deposition, allowing proton therapy of deep-seated tumors
- *Ions* are better for radio-resistant tumors while *protons* minimize the risk of appearance of secondary tumors

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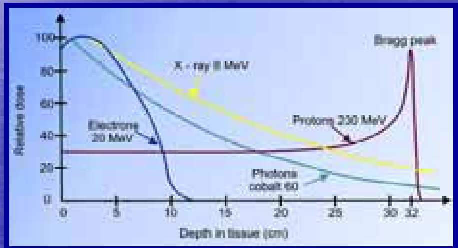
Proton therapy vs. X-rays

- One of the main challenges in radiation therapy is to deliver a substantially high and homogeneous dose to a tumor, while sparing neighboring healthy tissues
- Proton beams with high quality, i.e., with sufficiently small energy spread, $\Delta E/E$, is of fundamental importance



Relative dose deposition of different particles in human tissue

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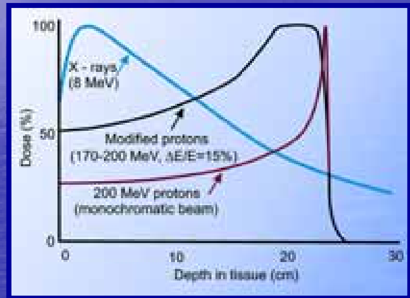
Proton therapy vs. X-rays

- If the proton beam is not completely monoenergetic, the energy deposition is modified and the dose is deposited on a longer path
- For a precision of ~ 1 mm, the energy spread needs to be ΔE < 0.3 MeV



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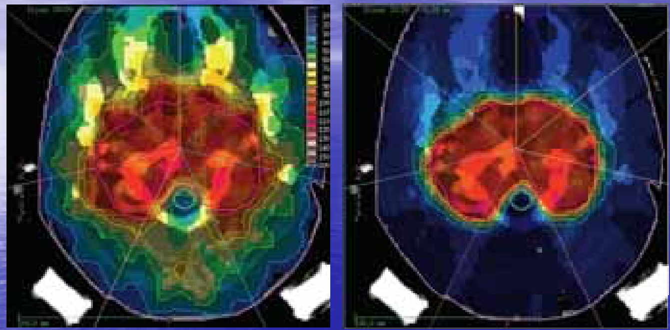
Proton therapy vs. X-rays



Left: image of the human brain superimposed with a deposited dose by an X-rays irradiation; right: same, but using protons
⇒ in proton therapy, the dose is deposited much more locally

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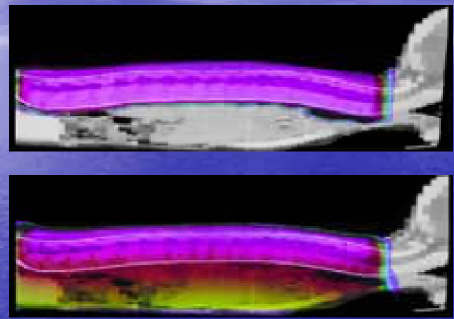
Proton therapy vs. X-rays



The importance of dose sparing to healthy tissue in preventing side effects is shown in the Proton (above) vs. X – ray (below) dose distribution for spinal treatment (*pediatric meduloblastoma*)

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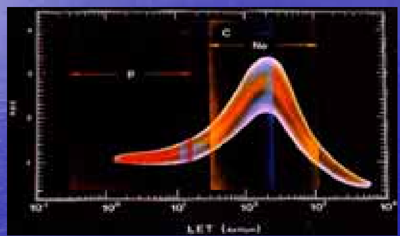
Proton therapy vs. X-rays

One of the major advantages of heavy ion tumor therapy is the increase in relative biological effectiveness (RBE) of particle beams; it depends in a complex way on different factors like e.g. ion type and energy, depth in tissue, dose level and the tissue type



Compared relative biological effectiveness (RBE) for proton, carbon and neon beams versus linear energy transfer (LET)

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Present status of art

- By now, proton beams with the required parameters have been obtained using conventional accelerators of charged particles (synchrotrons, cyclotrons, linacs)
- Both linear particle accelerators (linacs) and circular accelerators use a very low energetic thermal particle source (a few 100 keV) and then an accelerating section
- In the linac, the acceleration is done by putting succesively linear accelerating sections in a straight line; an electromagnetic field that is generated within a cavity accelerats the particles and electromagnetic magnets (quadrupoles) focus them to make sure that the particles do not diverge
- In circular accelerators, particles move in a circle and are bent by electromagnets; the ring structure has the advantage that particles can transit indefinitely

Linac accelerator used for PET

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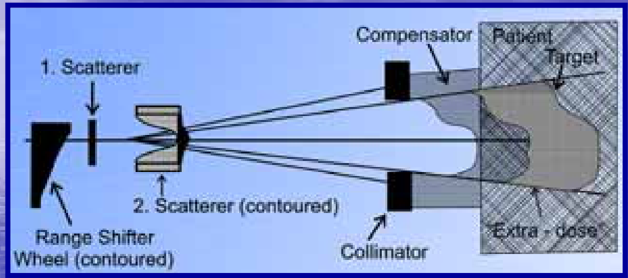
Present status of art



The basic process of the proton therapy application.
A monoenergetic proton beam is first spread in energy and in space.
Protons cross a plastic mask that helps to compensate the energy loss necessary to deposit the proton energy peak (Bragg peak) in the concerned region

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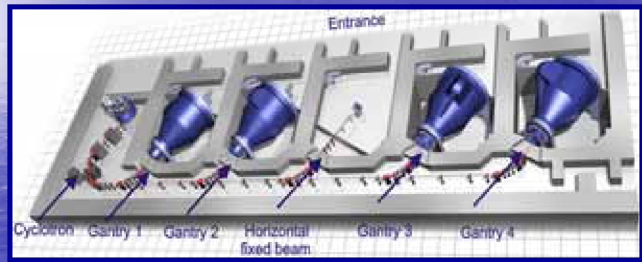
Present status of art

- GANTRY – a device that provides multi-directional irradiation of a lying patient
- Due to the size of the accelerator and mainly of the transport lines, an entire building (the size of a football field) is needed to house this equipment, which can weigh up to 900 tons



Plan of Rineker Proton Therapy Center (RPTC - München),
using one accelerator and 5 rooms for treatment. The total size is 100 x 45 m

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Present status of art

- Proton beam handling and focusing is expensive and difficult
- Eccentric or isocentric machines are used to transport proton beams from the last section of the accelerator to the tumors
- These structures are made up of heavy magnet for beam deflexion weighing from 100 to 200 t and having a diameter from 4 to 10 m
- An average cost for a specialized centre is 150 M€

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Present status of art

- LOMA LINDA (Los Angeles, USA)
  - first hospital-based proton therapy facility in the world
  - patient treatments were started in 1990
  - up to now more than 5000 patients have been treated
  - recently reached the capability to treat 1000 patients per year

The synchrotron: maximal proton energy – 250 MeV;
irradiation period – 2.2 s; diameter size – 12 m

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Present status of art

- NPTC (The Northeast Proton Therapy Center – Boston, USA) has been treating patients with proton beams since November 2001. Over 200 patients were treated in the first year of operation

- four operating beam lines
- rotating Gantries
- patient – positioning system
- deeper proton penetration

Allow a wider range of clinical applications:
- head and neck sites (ocular melanomas – 96% success; chordoma – 98% success; paranasal sinus – 80% success)
- prostate
- hepatocellular carcinoma
- lung cancer
- rectal carcinoma
- pediatric tumors

The proton cyclotron (230 MeV) produced by industry (Ion Beam Applications – IBA) (size: 4 m diameter; weight: 220 tons)

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Present status of art

For a full proton treatment:
- usually 60-71 Gy are needed that are deposited in doses of 2 Gy per session for 5 days a week
- the dose is given within ~ 1 minute
- the estimated cost (all inclusive) per treatment session is ~ 1000 €

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Present status of art

PARTICLE THERAPY CENTERS:

NORTH AMERICA, CANADA:

- Francis H. Burr Proton Therapy Center (NPTC), Boston
- Loma Linda University Proton Therapy Center, CA
- University of California, Crocker Nuclear Lab, CA
- Midwest Proton Radiotherapy Institute, Bloomington
- M.D. Anderson Proton Therapy Center, Houston, TX
- University of Florida Proton Therapy Institute, Jacksonville
- National Association for Proton Therapy
- Hampton University Proton Therapy Institute, Hampton, VIA
- Northern Illinois Proton Treatment and Research Center
- The Roberts Proton Therapy Center, Pennsylvania
- TRIUMF Proton Therapy Facility, Vancouver

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Present status of art

PARTICLE THERAPY CENTERS:

EUROPE:

- Proton Therapy Centre, Paul Scherrer Institute (PSI), Switzerland
- Centre de Protonthérapie, Orsay, France
- Centre Antoine Lacassagne, Nice, France
- Centre of Oncology, Clatterbridge, UK
- Proton Therapy, Charité/HZB (formerly HMI), Berlin, Germany
- Biophysics and Therapy Centre, GSI, Darmstadt, Germany
- Radiation and Radiobiological Research, JINR, Dubna, Russia
- Medical Physics Department, ITEP, Moscow, Russia
- Gatchina Medicine Radiation Facility, St. Petersburg, Russia
- CATANA, INFN, Catania, Sicily, Italy
- RPTC, Munich, Germany
- WPE, Essen, Germany
- Particle Therapy Center, Malburg, Germany
- Ion Beam Therapy Center, HIT, Heidelberg, Germany
- NRoCK, Kiel, Germany
- TERA Foundation, Novara, Italy
- The Svedberg Laboratory, Uppsala, Sweden
- MedAustron, Wienerneustadt, Austria

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Present status of art

PARTICLE THERAPY CENTERS:

ASIA:

- HIMAC, Chiba, Japan
- Hyogo Ion Beam Medical Centre, Japan
- PMRC, Tsukuba, Japan
- WERC, Wakasa Bay, Japan
- GHMC, Gunma University Heavy Ion Medical Center, Japan
- Wanjie Proton Therapy Center, Zibo, China

AFRICA

- iThemba Research Labs, Radiation Group, South Africa

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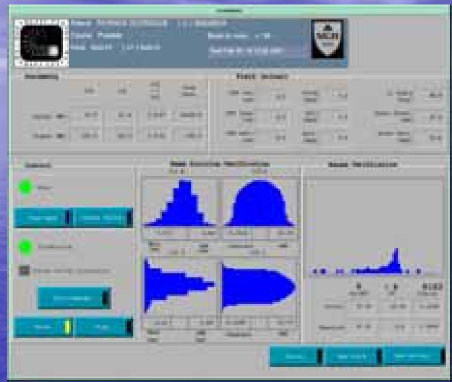
Present status of art



Example of a screen used during treatment
showing beam parameters monitored in real time

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Present status of art

The Large Hadron Collider (LHC)

LHC is a gigantic scientific machine for accelerating protons

It operates at CERN Geneva

It is located inside a circular underground tunnel of 27 km circumference (8.6 km diameter)

It will accelerate protons up to an energy of 14 TeV

The cost for the LHC machine alone is about 3 G€

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Laser-based particle accelerators

- A laser-based accelerator is fairly attractive because of its compactness and of the additional possibility it offers of controlling the proton beam parameters
- There are two possible ways of using a laser beam accelerator:
  - simply replacing the conventional proton accelerator
  - delivering the laser radiation to the target where its energy is converted into the energy of fast ions (simplifies the technical problems related to the generation and transport of the ion beam and reduces costs substantially)
- For medical applications, the proton beam intensity must be in the range 10^{10} to $5x10^{10}$ protons per second and maximum proton energy must be in the range 230 to 250 MeV
- Two conditions are the most demanding for the laser accelerator:
  - a highly monoenergetic proton beam with $\Delta E/E = 10^{-2}$
  - the system duty factor (the fraction of the time during which the proton beam can be used) must not be smaller than 0.3

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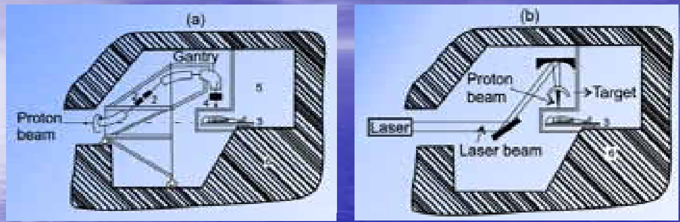
Laser-based particle accelerators



a) Conventional Gantry system: (1) deflecting magnets; (2) quadrupole lenses; (3) positioner; (4) dose delivery system and dose monitoring; (5) treatment room; (6) concrete protection

b) Laser-based proton accelerator (by using a set of mirrors, the laser beam could be relayed much closer to the patient, greatly reducing the need for large and costly beam transport lines and gantries)

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Laser-based particle accelerators

- Laser proton accelerators are based on the fact that the nonlinear interaction of high-power laser radiation with matter is accompanied by the efficient conversion of laser energy into the energy of fast particles
- Energetic proton beams with high beam quality have been produced in the last ten years from thin metallic foils (usually aluminum) irradiated by ultraintense short laser pulses ($I > 10^{18}$ W·cm^{-2})
- Protons accelerated from solids originate primarily from hydrogenated contaminant layers of water vapor and hydrocarbons on the target surface
- These proton beams have a number of unique properties, including high brightness (~10^{12} ions in subpicosecond-scale bunches) and ultralow emittance, they are extremely laminar, collimated (~15° half-angle with a divergence decreasing with the beam energy), with a smooth angular distribution and a duration at the source of the order of tens of femtosecond till one picosecond
- For the human body it is not relevant if protons arrive continuously or pulsed, since human cells do not react differently when a source is continuous or pulsed with a repetition rate higher than 10 Hz

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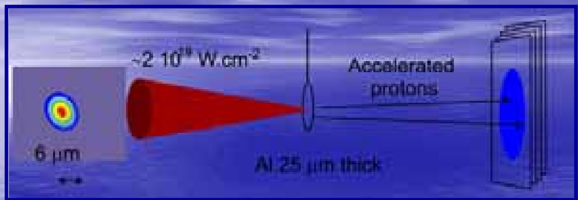
Laser-based particle accelerators



The principle of laser-based proton accelerator: the focused laser beam hits the target and protons are ejected from the rear surface

- Targets used for proton acceleration are a few centimeters in size
- The target can be placed as close as possible to the patient, which means that only small mirrors are required for laser beam transport instead of heavy and costly magnets
- Although particle selection and focusing systems will be necessary after the target, the whole equipment should be much lighter, smaller and affordable than current machines

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Laser-based particle accelerators

- MECHANISM
  - when multiterawatt laser radiation interacts with a target, matter is ionized in an interval shorter than a single optic oscillation period of the laser radiation, producing a collisionless plasma
  - under the action of the laser radiation the electrons are expelled from a region on the foil with transverse size of the focal spot
- The basic mechanism involved in the production of these proton beams is electrostatic acceleration of protons at the target rear (non-irradiated) surface. The proton acceleration is achieved by charge-separation electric fields (gradients of the order of MV µm^{-1}) induced by the laser-accelerated hot electrons produced at the front surface going through the target and emerging from the rear
- Till now, protons with energies up to 60 MeV and heavier ions with energies up to ~ 7 MeV per nucleon have been measured; efficiencies between 0.2% and 6.0% were observed
- Electron energies were measured in the range of hundreds of MeV
- The present-day laser parameters (pulse energy, pulse duration, peak intensity and focal spot size) are not yet optimized for the intended applications

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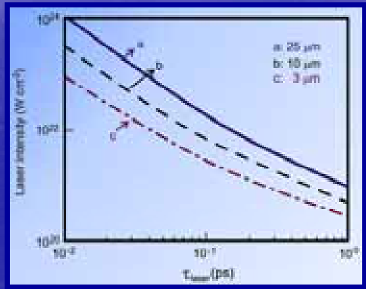
Laser-based particle accelerators

The proton energy has to be high enough to penetrate through several centimeters of tissue, that is, 60 MeV corresponding to eye tumors or to tumors in small animals for preclinical studies, and 250 MeV corresponding to the deepest zones to be treated (25 cm)

Laser intensity required to achieve 200 MeV as maximum proton energy for various laser pulse durations and target thicknesses (based on fluid model, Fuchs et al. 2005)



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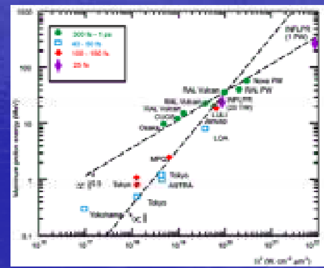
Laser-based particle accelerators

- In the case of maximum proton energy versus intensity, a general tendency can be estimated for two different intensity regimes
- For laser intensities $I\lambda^2 < 10^{19}$ W·cm^{-2} µm^2 the tendency is mostly $E_p \propto I$, while for $I\lambda^2 > 10^{19}$ W·cm^{-2} µm^2 the tendency is closer to $E_p \propto I^{0,5}$ (fluid based model, Mora 2003, Antici 2007)

- A power scaling of the form $E_{pmax} = a \cdot I^b$ with b = 0,5 ± 0,1 provides a good fit to the complete data set (individual fits for 10 µm and 25 µm targets are obtained with b = 0,5 and 0,6, respectively) (Fuchs et al. 2005, Robson et al. 2007)

- This indicates that the maximum proton energy is proportional to the fast – electron temperature, which scales as the ponderomotive potential ($\propto (I\lambda^2)^{1/2}$); the result is in very good agreement with proton energy measurements at intensities between 10^{18} W·cm^{-2} and 10^{20} W·cm^{-2} (Clark et al. 2000, Allen et al. 2003)



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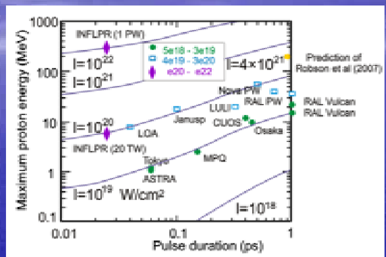
Laser-based particle accelerators

Experimental data reported by different laboratories. Lines have been calculated by Antici (2007) with rear surface acceleration (RSA) model assuming 20 µm thick targets and a 10 µm FWHM laser spot size



- Robson et al. (2007) predicts that 200 MeV protons required for oncology should be achievable with 1 ps laser pulses focused to 4x10^{21} W·cm^{-2} (with a 25 µm Al target)
- The increase of the maximum proton energy is much slower than previously thought (based on two-phases model with 3D effects)
- Even higher intensities are required to produce the number of 200 MeV protons required for oncology

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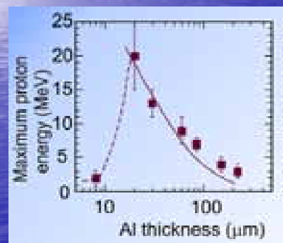
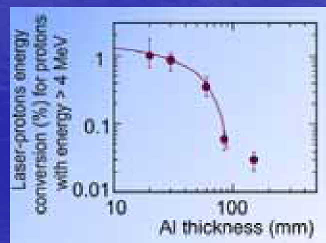
Laser-based particle accelerators

- A decrease in target thickness results in an increase in the maximum proton energy and in the energy conversion efficiency (Antici 2007)
- However, if the target is too thin (≤ 8 µm), protons are not accelerated to high energies (the rear surface is massively perturbed by the laser amplified spontaneous emission – ASE)
- ASE-induced effects have previously been shown to affect the spatial distribution and reduce the maximum energy of ions accelerated from thin targets





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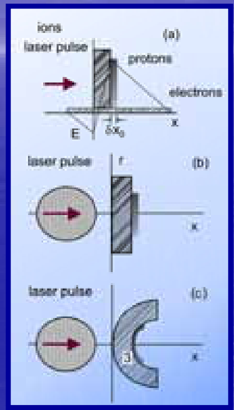
Laser-based particle accelerators

A solution to increase proton generation efficiency is to use multi-layer targets, where a thin foil is used as a target and its rear surface is coated with a thin hydrogen layer (Bulanov *et al.* 2002)

Scheme of a two-layer target
a) Density distribution of heavy ions, protons, and electrons and dependence of the electric field on the *x* coordinate
b) The form of two-layer target in the *r, x* plane
c) Shape of a curved two-layer target in the *r, x* plane



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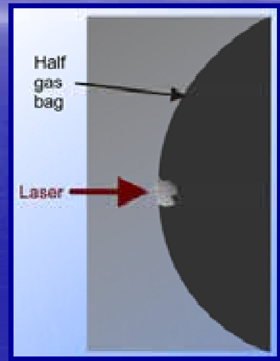
Laser-based particle accelerators

Alternative paths for proton energy increase:
- by a controllable large preplasma in front of the solid (increases the number and the temperature of the accelerated electrons)
⇒ it can be achieved by using a controlled gas (e.g. He) in front of the target ("gas bag targets")
- by the relativistically transparency regime; the laser pulse interacts with the whole volume of an ultra thin (30 – 500 nm) dense target and accelerates efficiently the whole electron population
⇒ it requires ultra-high temporal contrast pulses



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Other applications

Potential applications of a laser-based source of ions:
- proton oncology
- fast ignitor beam for laser-driven fusion
- proton imaging (radiography)
- medical isotope production (e.g., for positron emission tomography – PET)
- studies related to nuclear spallation physics
- injection into large-ion accelerators
- astrophysics
- fundamental physics

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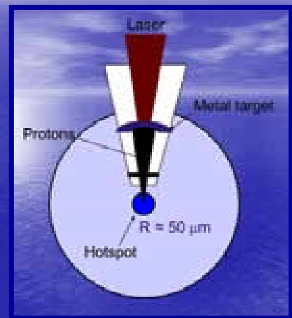
Other applications

1. FUSION – the use of protons for the fast ignition:
   - protons are used as energy transfer medium to heat the ignition region
   - protons have the advantage, compared to fast electrons, that they have a much better energy deposition and can be focused to the hotspot
   - due to their Bragg peak, they are able to deposit their energy very locally and are therefore very suitable for fast ignition
   - moreover, protons can be focused to a small spot generating a more intense proton beam on the hotspot



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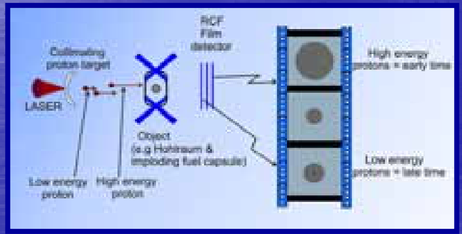
Other applications

2. RADIOGRAPHY
- an interesting application of laser-generated proton beams relies on their unique spatial properties of high laminarity or low emittance
- they can be used in radiography, producing images with high spatial resolution; since protons are sensitive to electric fields, they are therefore able to probe electric fields
- as they can penetrate deep into matter, depositing their energy very locally (Bragg-peak), they can radiograph dense objects
- using the time of flight (TOF) technique they allow detecting details of a few microns on picoseconds timescale



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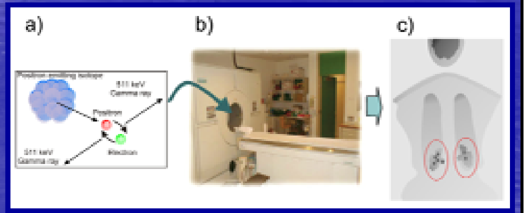
Other applications

3. PET (Positron Emission Tomography)
– a nuclear medicine technique used for medical imaging
– uses positron emitters to characterize the biochemical function of cells, organs, and body structures *in vivo*, producing a three-dimensional image or map of functional processes

- To produce intense radioisotope sources for PET (> 10^9 Bq of ^{11}C or ^{18}F are commonly used per patient dose), a large number of protons with energy ~ 10 MeV is required
- Recently, it was measured up to 10^7 Bq of ^{11}C and 10^5 Bq of ^{18}F produced by laser-accelerated protons

Operating mode of PET



Other applications

4. SPALLATION
- is the process in nuclear physics when a very high-energy proton bombards a heavy atomic nucleus and neutrons are emitted in the nuclear reaction
- at high proton energies (~ 1 GeV), for every proton striking a heavy nucleus, 20 to 30 neutrons are expelled
- there are two spallation processes using protons: the direct and the indirect spallation
  - the direct spallation is when the proton directly hits the heavy atomic target (e.g. ^{90}Sr, ^{137}Cs), generating neutrons and more stable heavy ion isotopes
  - the indirect spallation is when protons bombard a heavy atomic element and neutrons are generated that activate the transmutation process (this process is much more efficient than direct spallation, since the energy needed for transmutation is about 1/3 the energy needed for creating the isotopes)
- spallation processes are one of the main possibilities for transmutation of radioactive isotopes; transmutation is the transformation of long-lived radioactive isotopes into more stable short-life (< 30 years) isotopes
- spallation is used for the treatment of nuclear waste

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Extreme Light Infrastructure (ELI) project

- ELI would be the first infrastructure dedicated to the fundamental study of laser-matter interaction in a new and unsurpassed regime of laser intensity: the ultra-relativistic regime (I_L>10^{23} W/cm²); it would be an exawatt-class laser ~1000 times more powerful than either existing laser; ELI would attain its extreme power from the shortness of its pulses (femtosecond and attosecond)
- The infrastructure would serve to investigate a new generation of compact accelerators delivering energetic particles and radiation beams of femtosecond (10^{-15} s) to attosecond (10^{-18} s) duration; relativistic compression offers the potential of intensities exceeding I_L>10^{25} W/cm², which would challenge the vacuum critical field as well as provide a new avenue to ultrafast attosecond to zeptosecond (10^{-21} s) studies of laser-matter interaction.
- Romania is one of the 13 members of the consortium formed by European countries and a candidate to host the infrastructure
- ELI-PP (Preparatory Phase) is a contract financed by EU FP 7 Program for three years (November 2007 – October 2010) (6 M€)

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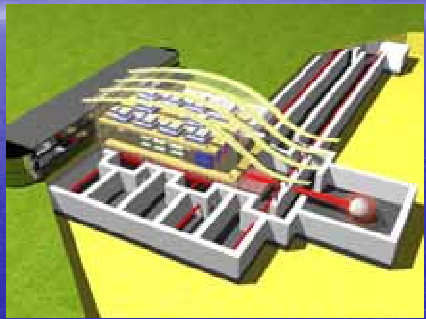
Extreme Light Infrastructure (ELI) project

ELI will be the first pan-European large-scale facility dedicated to multi-disciplinary applications



ELI would afford wide benefits to society ranging from improvement of oncology treatment, medical imaging, fast electronics and our understanding of aging nuclear reactor materials to development of new methods of nuclear waste processing.

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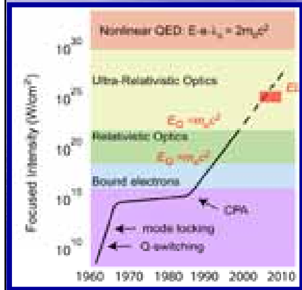
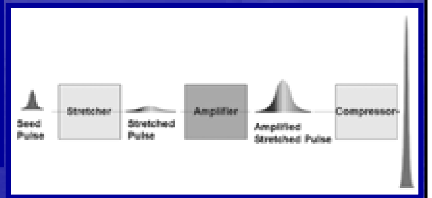
Extreme Light Infrastructure (ELI) project





Principle of CPA – Chirped Pulse Amplification (Mourou 1985)

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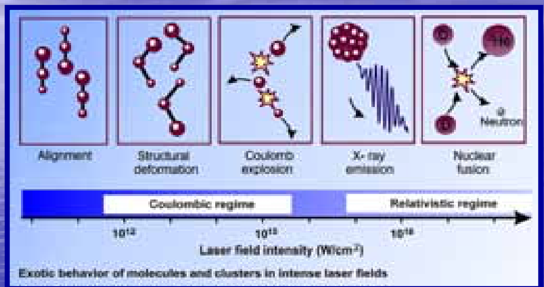
Extreme Light Infrastructure (ELI) project



The relativistic regime $I_L > 10^{18}$ W/cm² results in a plethora of novel effects: X-ray generation, γ-ray generation, relativistic self-focusing, high-harmonic generation, electron and proton acceleration, neutron and positron production, as well as the manifestation of nonlinear QED effects

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Extreme Light Infrastructure (ELI) project

Relativistic regime: $1 < a_0 < 100$, $a_0^2 = I_L\lambda_L^2/(1.37 \times 10^{18}$ Wμm²/cm²)
where a_0 is the normalized electric field amplitude,
I_L and λ_L are the laser intensity and wavelength

At $a_0 = 1$ the electron mass increases by $2^{1/2}$; the limit $a_0 \sim 100$ corresponds to the 100 TW class lasers

Ultra-relativistic regime: $I_L > 10^{23}$ W/cm² ($a_0 \sim 10^2 - 10^4$)

- in this novel regime, positrons, pions, muons and neutrinos could be produced as well as high-energy photons
- this largely unexplored intensity territory will provide access to physical effects with much higher characteristic energies and will regroup many subfields of contemporary physics: atomic physics, plasma physics, particle physics, nuclear physics, gravitational physics, nonlinear field theory, ultrahigh-pressure physics, astrophysics and cosmology)
- the ultra-relativistic regime opens possibilities of:
  - i. extreme acceleration of matter so that generation of very energetic particle beams of leptons and hadrons becomes efficient
  - ii. efficient production (~ 10%) of attosecond or even zeptosecond pulses by relativistic compression occurring at rate of $600/a_0$ [as]
  - iii. study of the field – vacuum interaction effects

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Extreme Light Infrastructure (ELI) project

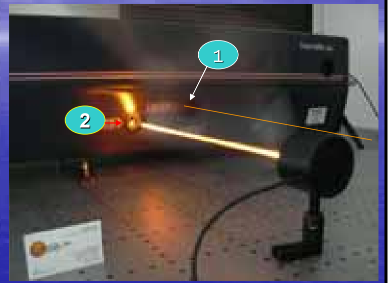
2005-2007	2008	2009	2010	2011	2012
4 GW/200 fs (0.7 mJ)					
20 TW/25 fs (400 mJ)	20 TW/25 fs (400 mJ)				
	1 PW/25 fs (25 J)	1 PW/25 fs (25 J)	1 PW/25 fs (25 J)	Proton therapy X-ray lasers Optical coherent tomography Radiation sources Accelerated particle sources	

High power fs lasers in INFLPR Bucharest 45

LASER CLARK CPA2101

SErF Fiber Oscillator:
- laser radiation at 775 nm
- pulse duration 200 fs
- repetition rate 35 MHz
- energy ~150 pJ (power ~1.5 mW)

Regenerative Amplifier :
- laser radiation at 775 nm
- pulse duration 200 fs
- repetition rate 2 kHz
- energy ~700 μJ (power ~1.5 W)



Applications:

Material Processing: micromachining, drilling, laser ablation
Optical Spectroscopy: time-resolved fluorescence
Characterisation: confocal microscopy, fluorescence microscopy

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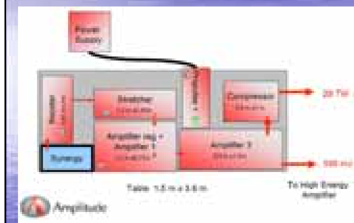
Extreme Light Infrastructure (ELI) project

2005-2007	2008	2009	2010	2011	2012
4 GW/200 fs (0.7 mJ)					
20 TW/25 fs (400 mJ)	20 TW/25 fs (400 mJ)				
	1 PW/25 fs (25 J)	1 PW/25 fs (25 J)	1 PW/25 fs (25 J)	Proton therapy X-ray lasers Optical coherent tomography Radiation sources Accelerated particle sources	

High power fs lasers in INFLPR Bucharest 47

20 TW LASER (DEC. 2008)



Extreme Light Infrastructure (ELI) project

2005-2007	2008	2009	2010	2011	2012
4 GW/200 fs (0.7 mJ)					
20 TW/25 fs (400 mJ)					
	1 PW/25 fs (25 J)			Proton therapy X-ray lasers Optical coherent tomography Radiation sources Accelerated particle sources	

High power fs lasers in INFLPR Bucharest 49

Conclusions

- The future of proton therapy requires the construction of specialized centers, equipped with modern diagnostics and medical accelerators near oncological clinics
- The construction of small centers would make it possible to provide cheaper facilities for hadrontherapy closer to the patients
  ⇒ a possible solution is to produce a specialized laser proton accelerator
- The use of multi-layer targets with different shapes and composition opens up additional opportunities for controlling the parameters of the fast proton beam, for optimizing its energy spectrum, the number of particles per bunch, the beam focusing and the size of the region where the beam deposits its energy
- To increase the duty factor we must use a system of several high-power, 1 Hz repetition rate lasers or to use a multi-stage acceleration scheme in the case of moderate power, high repetition rate (1 kHz) lasers
- The generation of fast ions becomes highly effective when the laser radiation reaches the petawatt power limit
- By optimizing the laser-target parameters, it becomes possible to accelerate protons up to energies in the several hundred MeV range

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INTERNATIONAL CONFERENCE

LEI 2009

Light at Extreme Intensities

Scientific opportunities and technological issues of the Extreme Light Infrastructure

October 16 - 21, 2009

Brasov, Romania

http://lei2009.inflpr.ro

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KEY TOPICS

* High intensity and ultrashort pulse lasers
* Exotic physics at high laser intensities
* Secondary sources of particles
* Secondary sources of X-ray
* Attosecond generation and applications
* Science and society

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IMPORTANT DATES

July 15, 2009	Summary due date
August 15, 2009	Notification of paper acceptance
August 31, 2009	Advanced Registration Fee
September 15, 2009	Accommodation deadline
September 15 , 2009	Preliminary program
September 15, 2009	Post deadline papers
October 1, 2009	Final program
October 16, 2009	Manuscript due date
October 16-21, 2009	Conference

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Thank you for your attention!

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