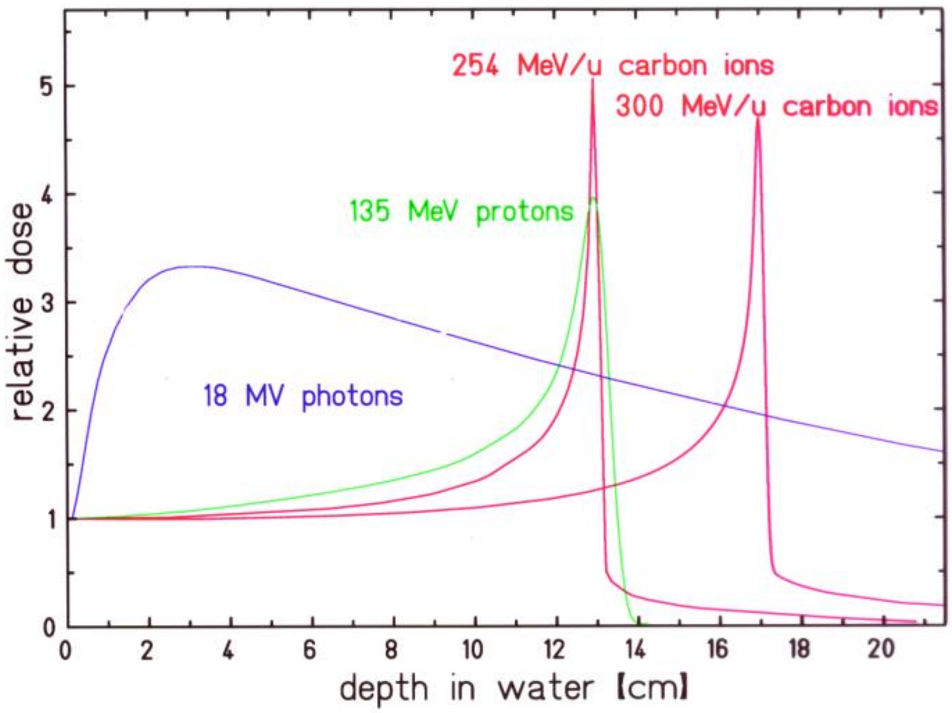
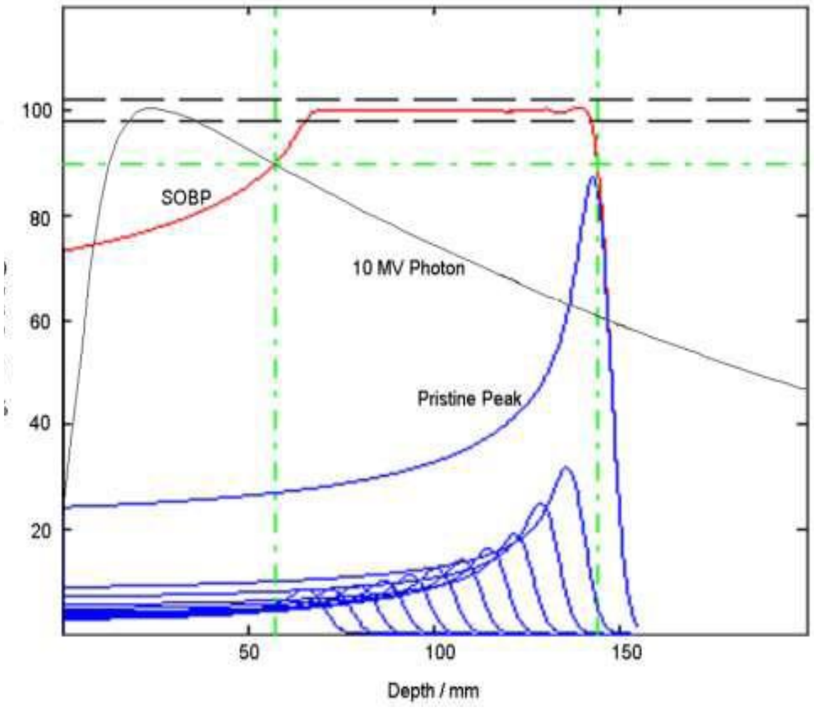
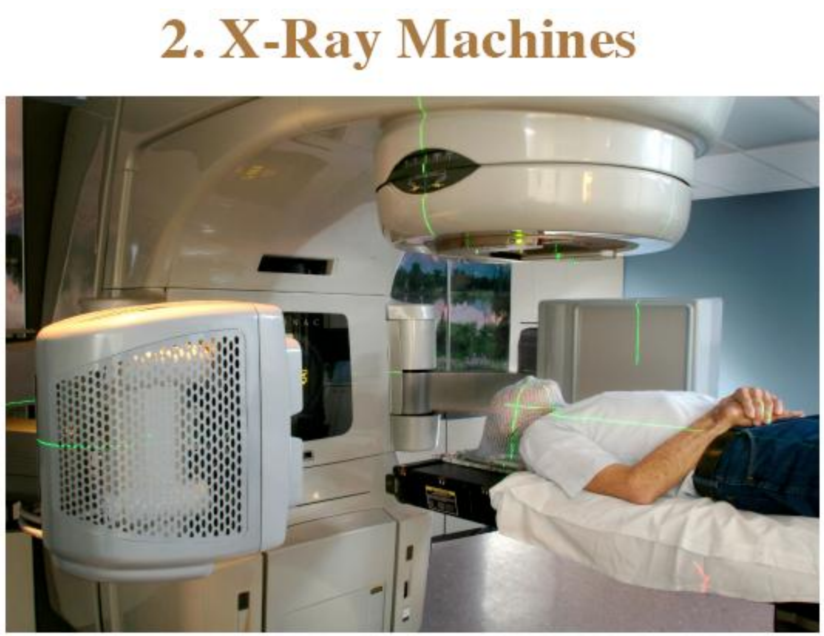
Radiation Therapy – Physics: X-ray *vs.* Proton *vs.* Carbon





Radiation Therapy – X-ray

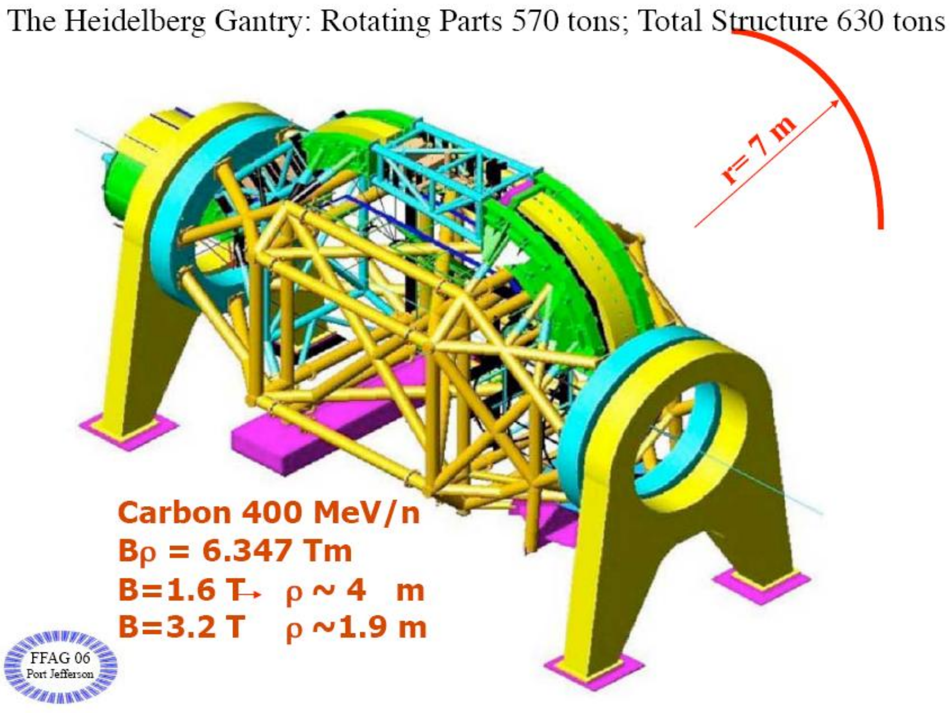
- Today’s mainstream, very successful.
- Varian Co. alone, shipping 2-3 new units per day. More than 5,000 units installed in hospitals around the world,
- Treating several millions patients every year.



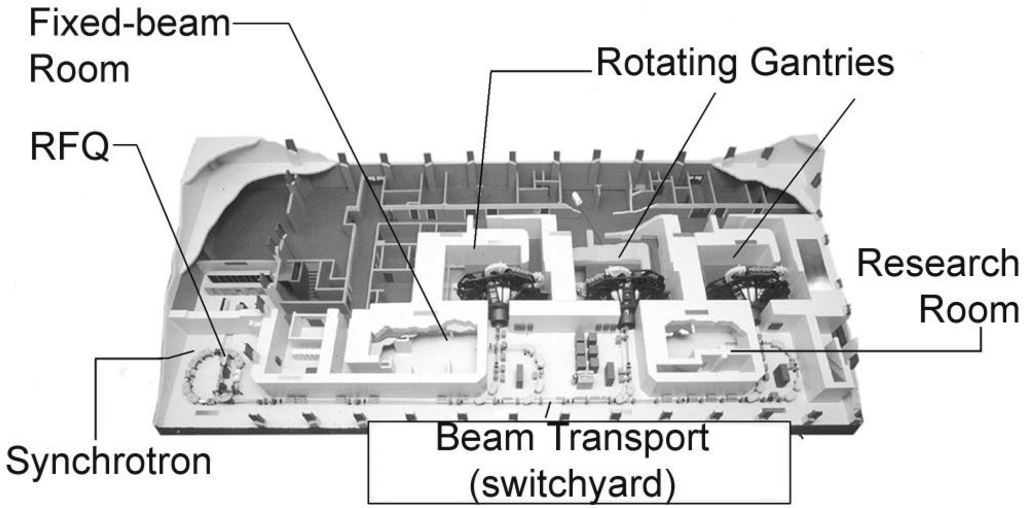
Radiation Therapy – Hadrons

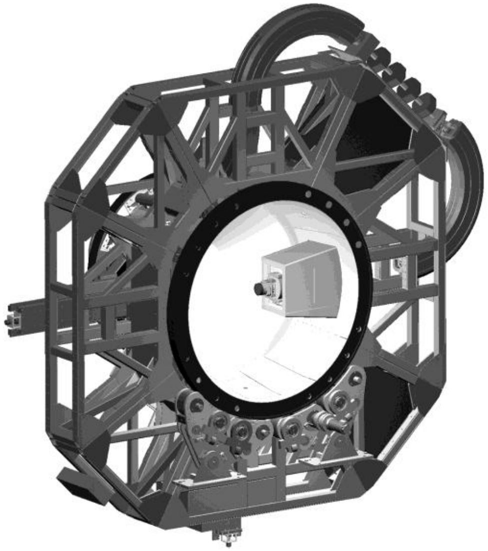
- Robert Wilson's seminal paper in 1946 created this field.
- There are about two dozen hadron therapy centers around the world today.
- Have treated a total of ~50,000 patients in the past decades.

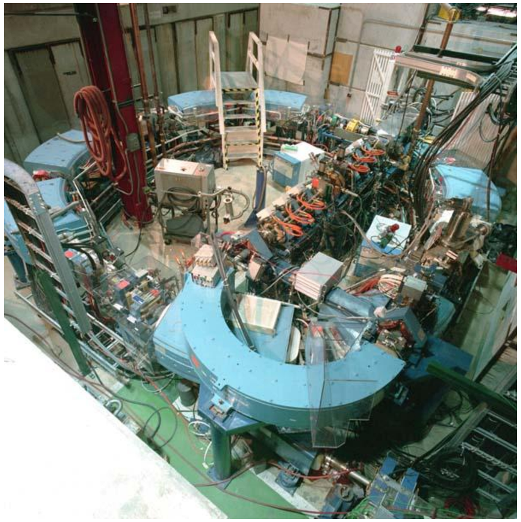
Heidelberg (HIT)



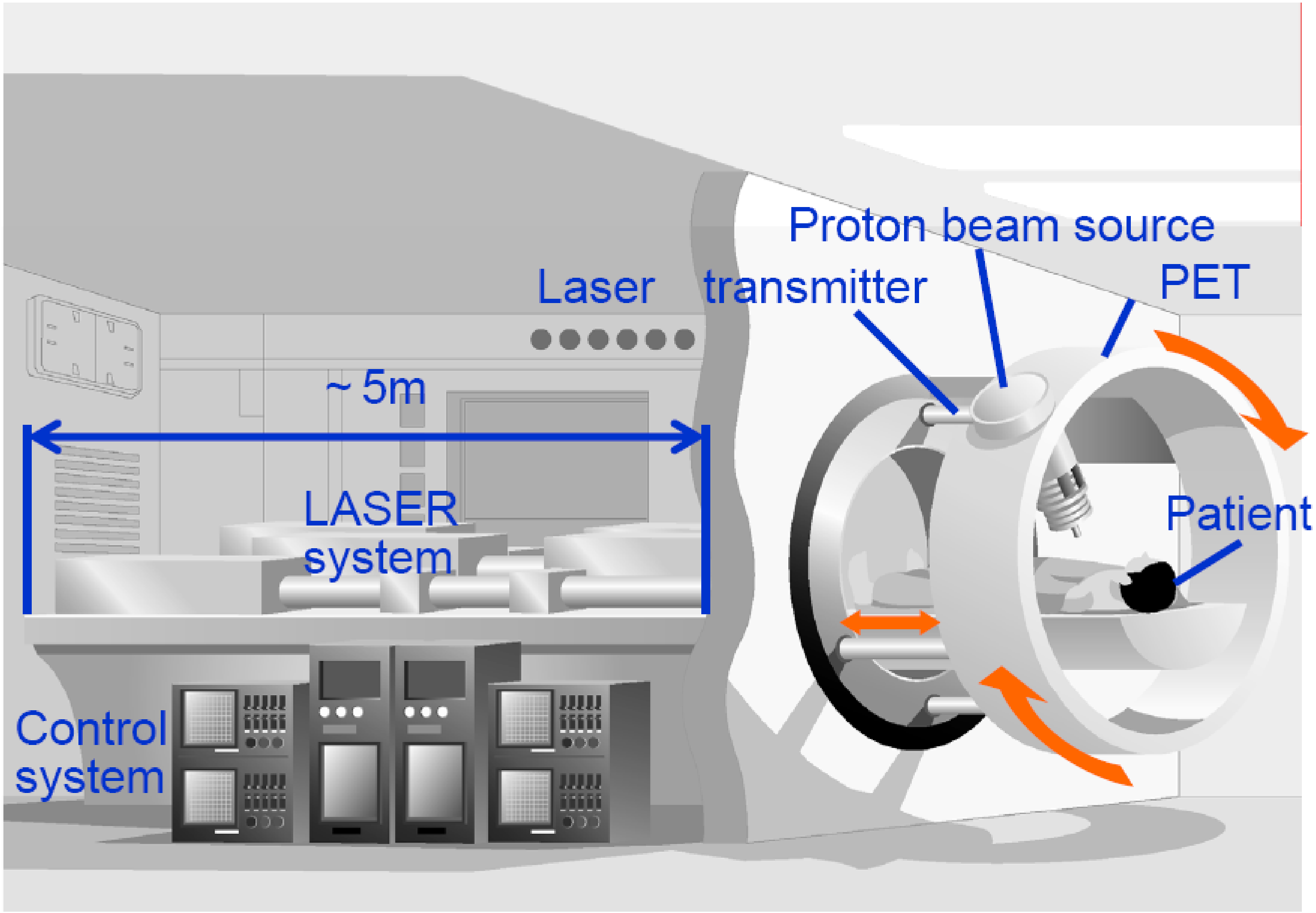
Loma Linda – First Hospital-based Hadron Therapy Center







Can Laser be used for Proton Acceleration?



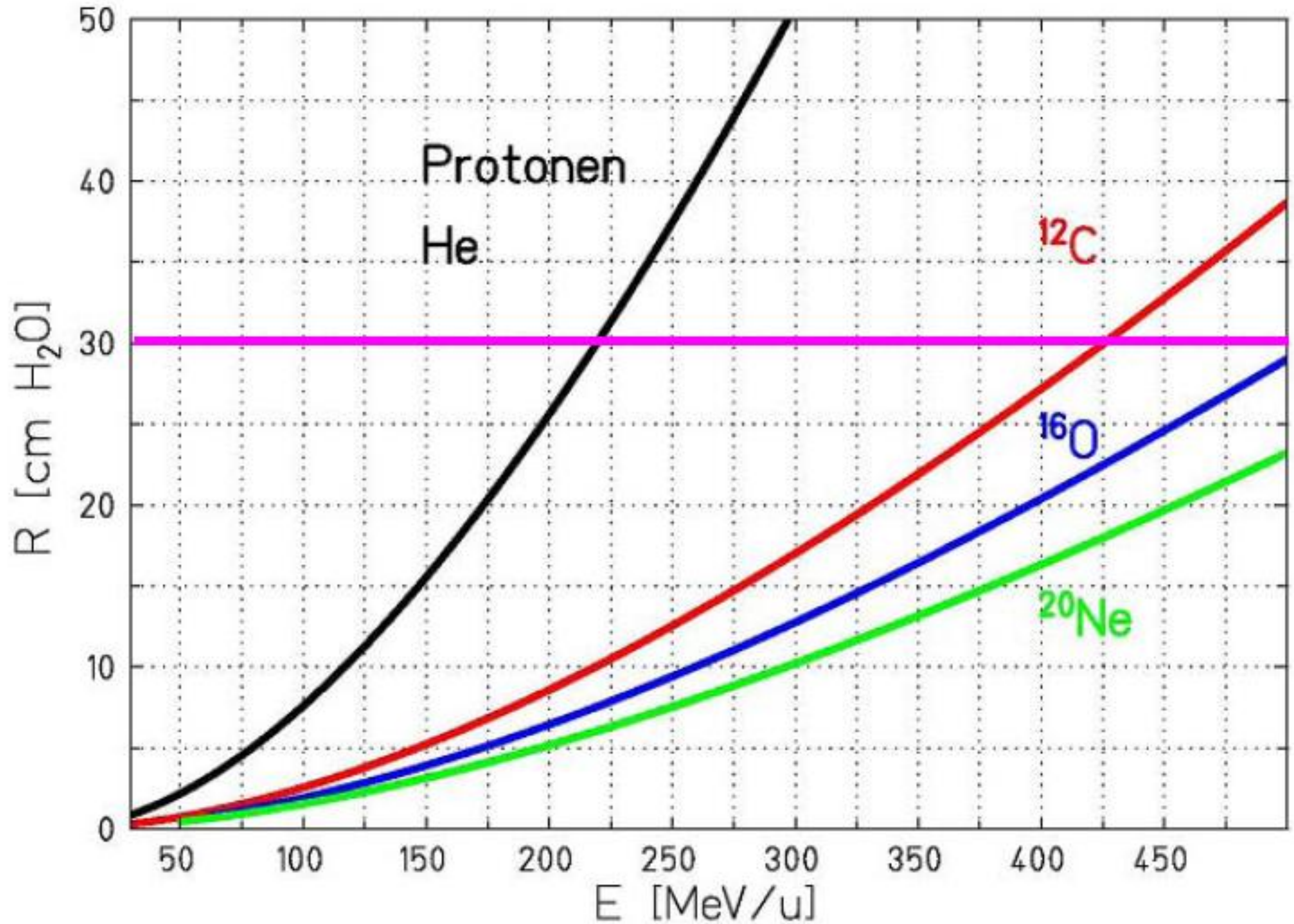
Implications on the beam energy

Range of different beams in water

30 cm range define the end energy for the accelerator design:

p → 220 MeV

C → 430 MeV/u



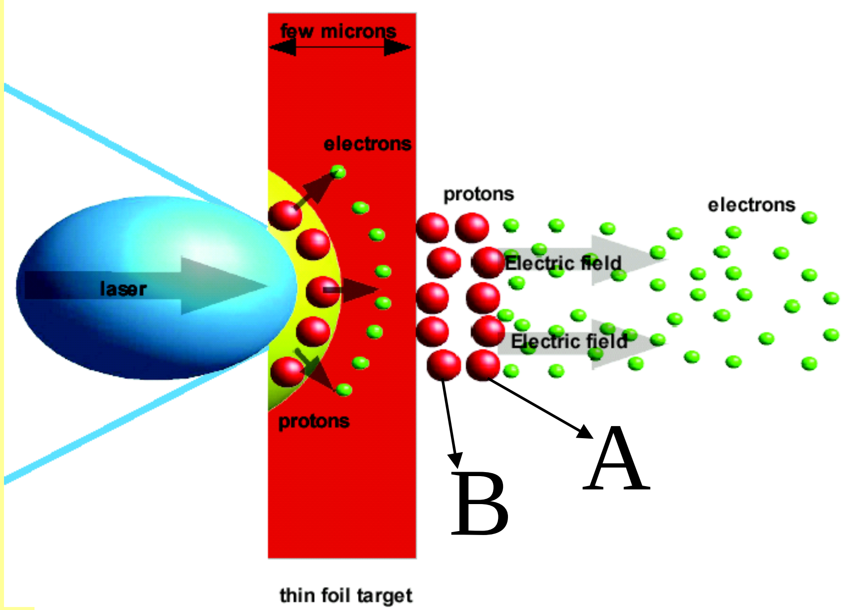
Beam Requirement for Therapy

- Total dose for killing a cancer: 70 Gy (0.07 J for 1 g tissue)
- Assuming 35 fractions: 2 Gy per fraction (0.002 J for 1 g tissue)
- Energy of a 100 MeV proton: $100 \times 1.6 \times 10^{-13} = 1.6 \times 10^{-11}$ J
- Number of protons per treatment: $\sim 10^{8}$
- Assuming 100 seconds irradiation at 10 Hz: $\sim 10^{5}$ protons per pulse
- Assuming an efficiency of 10^{-4} and a cancer of 1 kg: $\sim 10^{12}$ protons per pulse
- Energy spread: $\Delta E/E \leq 2\%$
- Beam transverse size: 50 – 200 μm
- Note: According to a physician (Richard Levy, Loma Linda), the only thing that matters is the dose. Either CW beam or pulsed beam of the same dose give the same clinical results.

Target Normal Sheath Acceleration

- Linear polarized laser irradiates the high density foil, plasma was heating efficiently.

- **Hot electrons go away quickly, acceleration length is short** (～1μm).
- **The Maximum energy got in experiment is about 60 MeV.**
- **100% energy spread**



Intense High-Energy Proton Beams from Petawatt-Laser Irradiation of Solids

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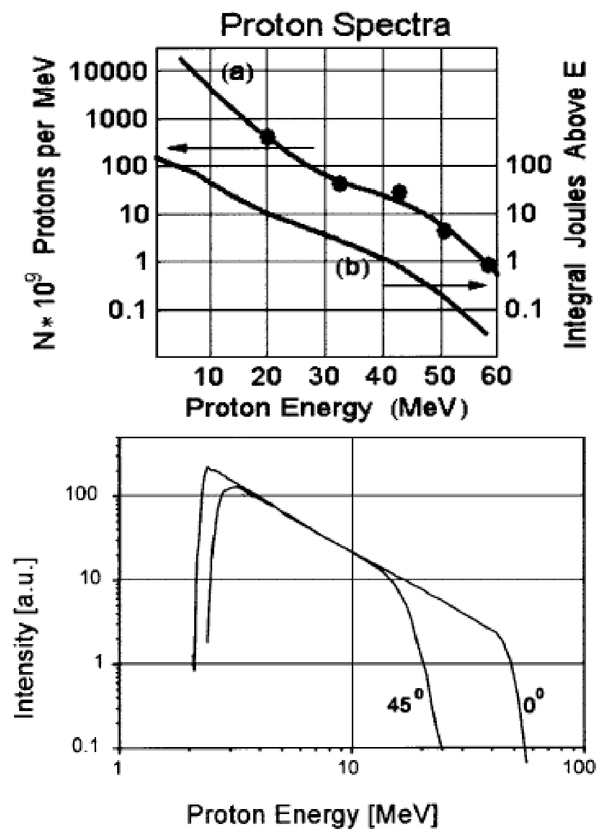
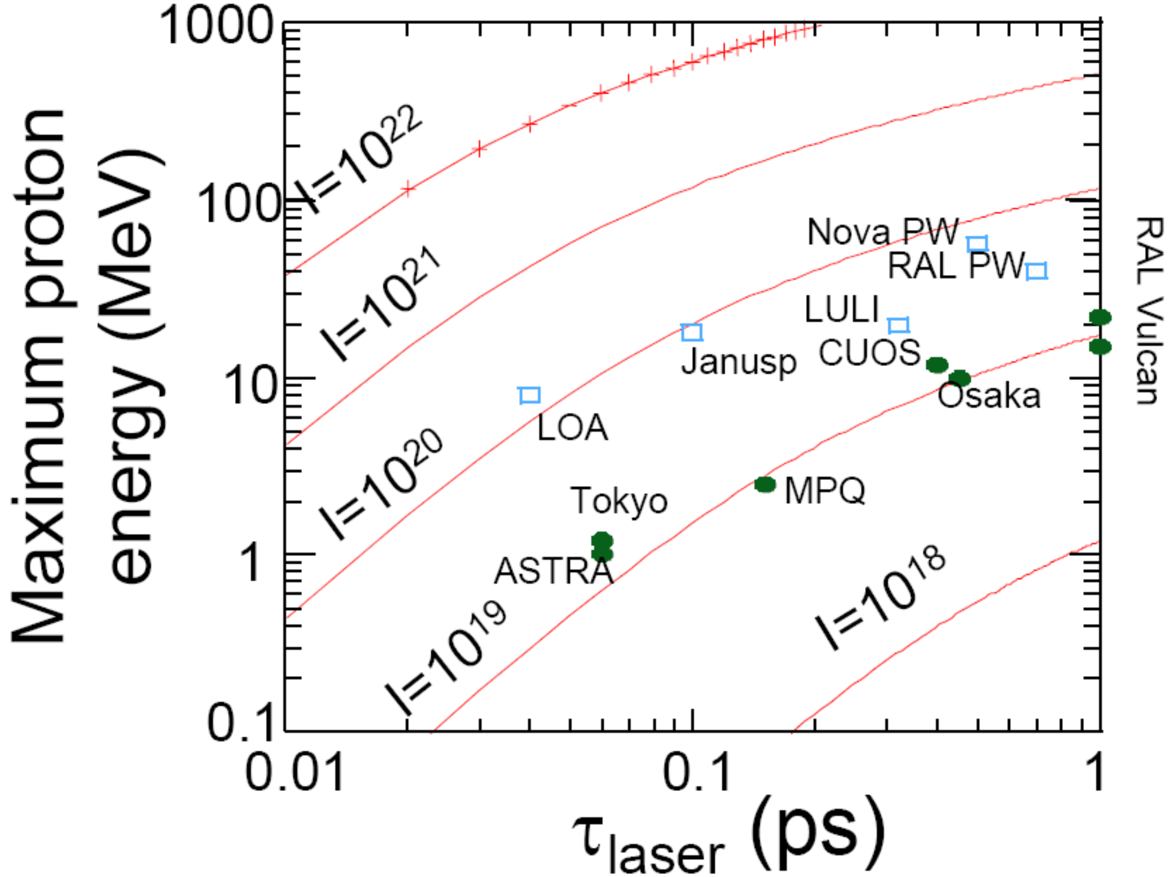


FIG. 3. (top) Proton energy spectrum deduced from radiochromic film images for a 423 J shot at normal incidence on 100 μm CH. (bottom) Spectrum of proton energy recorded on film with a magnetic deflection spectrometer. Plots show the spectrum on axis and from another shot at 45°. The detector is saturated above the cutoff region.

Present-day status of laser-accelerated protons maximum energy



targets 5-20 µm Al

Model hyp. →
20 µm thick targets/
10 µm focal spot

Challenges

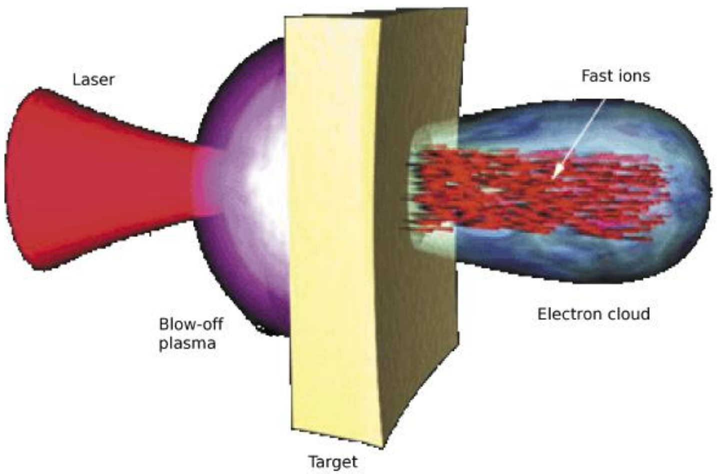
- Low efficiency. Need super laser peak power.
- Limited maximum beam energy.
- Large beam energy spread.

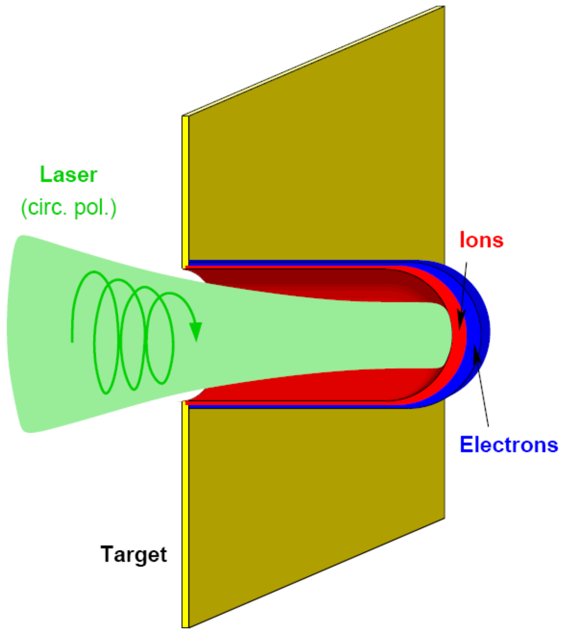
Possible Solutions / Ideas

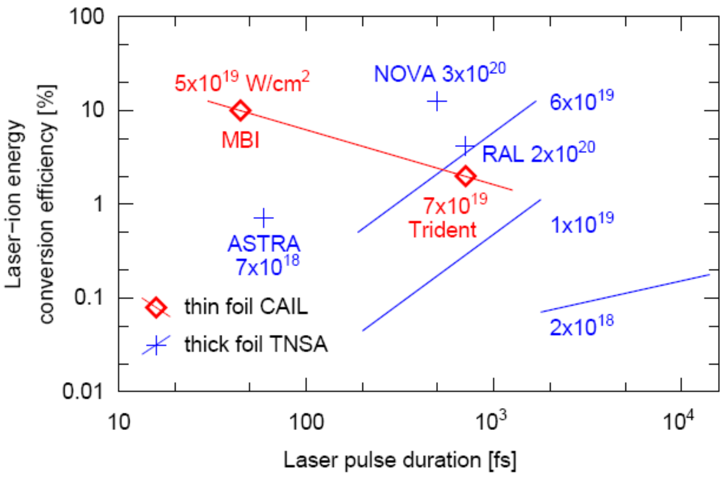
- Use thin target.
- Use circularly polarized laser.
- Use specially fabricated target.
- Use water droplet.
- Use gas jet.
- **Get smart people to work on it.**

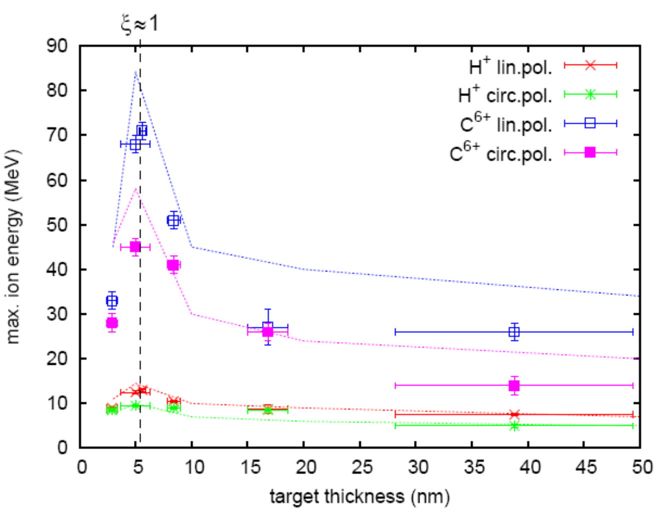
Thick Target (TNSA)

Thin Target (CAIL)









Energy Increase in Multi-MeV Ion Acceleration in the Interaction of a Short Pulse Laser with a Cluster-Gas Target

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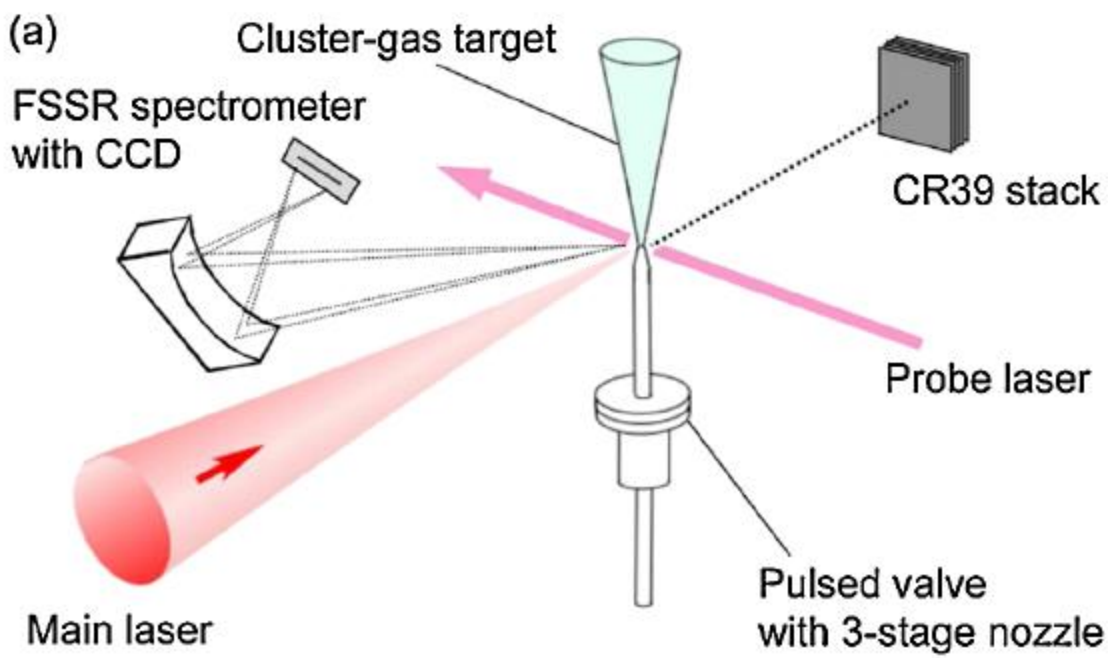

Experiment Setup

- Need a high peak power laser
- Need a moving target
- Need detector

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Enhanced Laser-Driven Ion Acceleration in the Relativistic Transparency Regime

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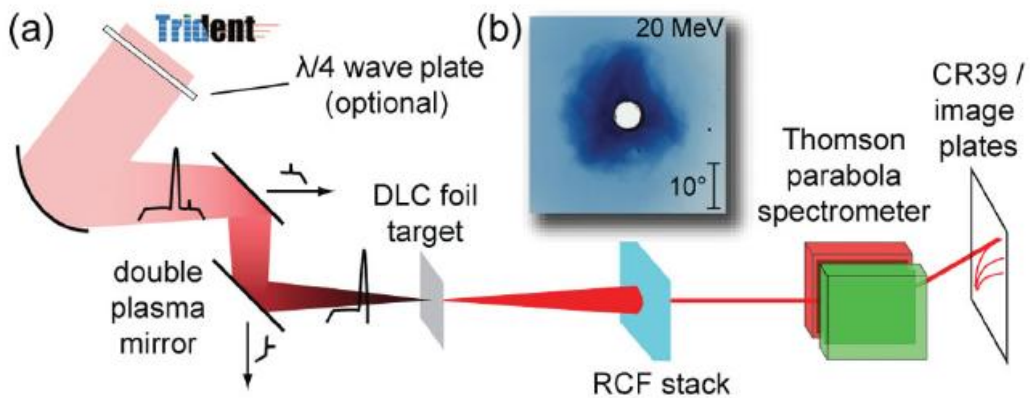

FIG. 1 (color). Experimental setup at TRIDENT (a) and a characteristic image of the proton beam profile at 20 MeV energy as obtained from a 50 nm DLC target (b).

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Ion spectrometer composed of time-of-flight and Thomson parabola spectrometers for simultaneous characterization of laser-driven ions

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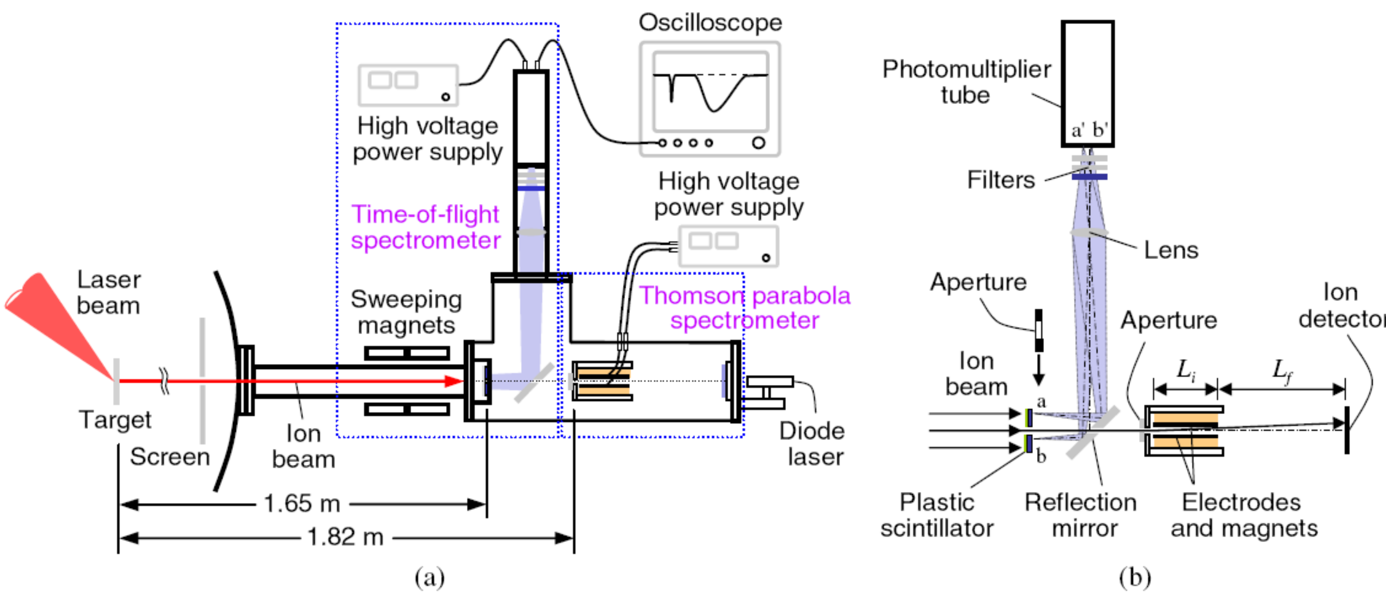

FIG. 1. (Color online) (a) Schematic diagram of the composite ion spectrometer composed of a TOFS and a TPS. (b) Detailed configuration of the TOFS and the TPS. Emission intensities at "a" and "b" on the plastic scintillator are imaged by a lens into "a'" and "b'" on the PMT, respectively.

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Thin tape target driver for laser ion accelerator

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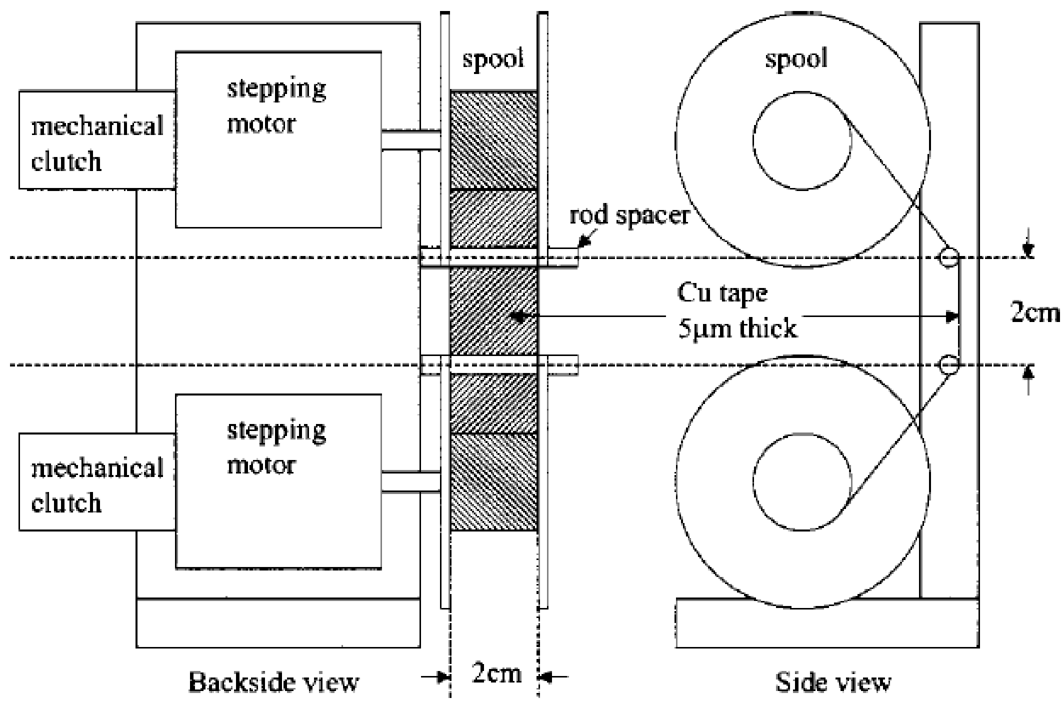

FIG. 1. Schematic diagram of thin tape driver.

ICFA-ICUIL Joint Task Force For Laser Acceleration

- ICFA = *International Committee for Future Accelerators*
- ICUIL = *International Committee for Ultra Intense Lasers*
- August 19, 2009 ICFA meeting approved the formation of a joint task force
- Mission:

  "*To promote and encourage international collaboration between accelerator and laser communities for future applications of particle acceleration*."

- Applications under consideration:
  - Laser acceleration of electrons for future TeV colliders (e.g. BELLA at LBL, FACET at SLAC)
  - Laser acceleration of protons and ions for future radiation therapy
  - Other applications