TUPAB030

Superb Fixed Field Permanent Magnet Proton Therapy Gantry

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ABSTRACT: We present the top-notch design of the proton therapy gantry made of permanent magnets with very strong focusing. This is a superb solution fulfilling all cancer treatment requirements for all energies without changing any parameters. The proton energy range is between 60-250 MeV. The beam arrives to the patient focused on each required treatment energy. The scanning system is place between the end of the gantry and the patient. There are multiple advantages of this design: easy operation, no significant electrical power - just for the correction system, low weight, low cost. The design is based on the recent very successful commissioning of the permanent magnet ERL 'CBETA' at Cornell University.

Background

We present a permanent magnet proton gantry with large enough momentum acceptance to cover all required treatment beam energies without having to change the magnetic fields. New *"FLASH" and "mini-beams"* developments required this type of gantry.

[The effect called *"FLASH"* is based on very high dose-rate irradiation (pulse amplitude ≥10^6 Gy/s), short beam-on times (≤100 ms) and large single doses (≥10 Gy). The second effect relies on the use of arrays of *mini-beams* (0.5–1 mm, spaced 1–3.5 mm). Both approaches have been shown to protect healthy tissues.]

A superconducting magnet gantry could be built on the same principle for use with Carbon ion beams. The gantry is:

*1. **Less massive** and **more compact beam delivery systems** capable of delivering ion beams by protons* the permanent magnets of the proposed gantry design are 1/10 the size of corresponding iron magnets and the gantry radius is smaller. **This reduces the overall gantry weight very significantly**. The same would be true for a carbon ion gantry built with constant field superconducting magnets.

2. Technology that can provide for rapid (seconds) scanning of the beam over a tumor volume in three dimensions (that is: both transversely and longitudinally)": the permanent magnets (or constant field superconducting magnets) would allow very fast patient treatment within the required energy range (protons: 65-250 MeV; carbon: 400-225 MeV/u - or 225-128 MeV/u) as there is no need for changing the magnetic field. The constant field design allows for rapid longitudinal scanning, making this gantry deign the optimum solution for fast-cycling linacs, fast cycling synchrotrons, or cyclotron-based cancer therapy systems with rapid energy scan. The gantry makes significant simplification of the patient treatment as no magnet adjustments are needed.

The permanent magnet gantry also has reduced operating costs due its very low electric power consumption. The permanent magnet design is based on the superb results [1] obtained in the recent CBETA Energy Recovery Linac (ERL) project built by a BNL-Cornell collaboration [2]. The successful behavior and agreement between the design and measured orbits in the CBETA Fixed Field Alternating Linear Gradient (FFA-LG) beam lines with momentum acceptance of -60%< Δp/p < 60% indicate that the proton gantry built on the same principle should be feasible.

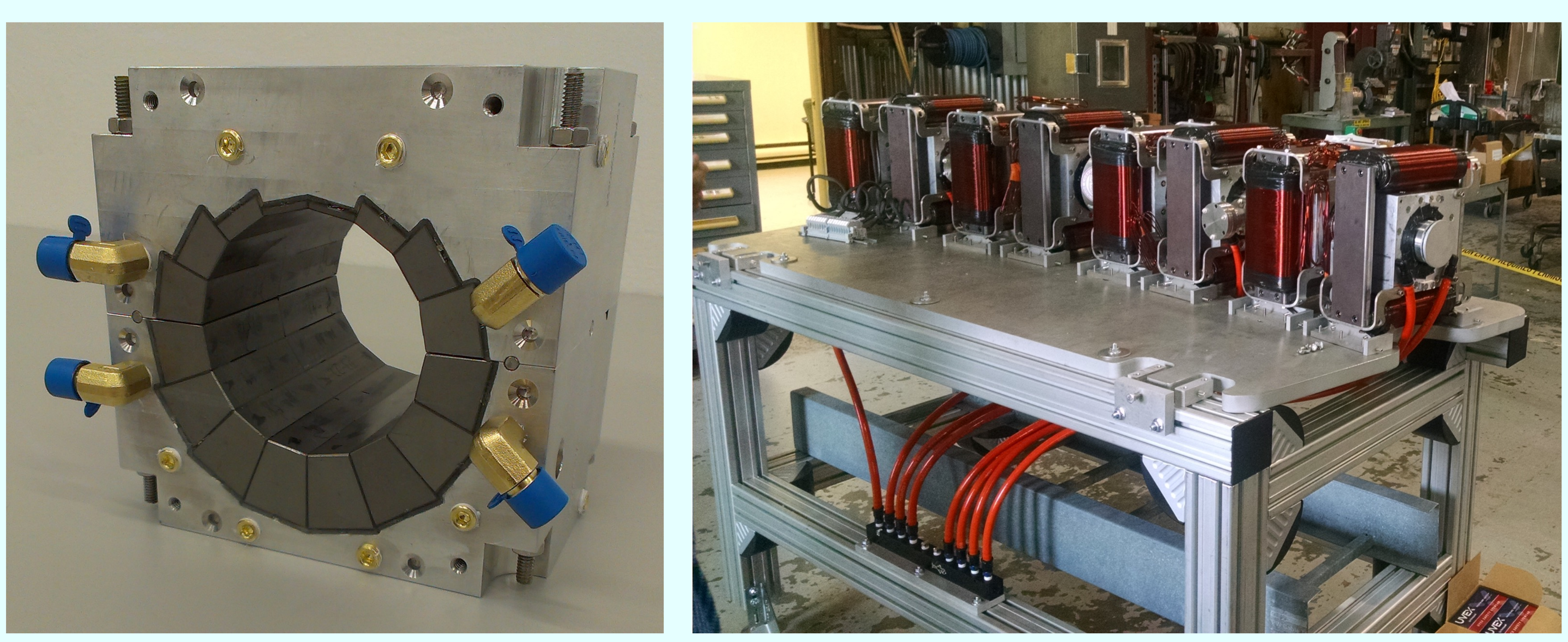

Figure 1: Combined function permanent magnet (left) and the full 8 magnet girder built and used in very successful commissioning of the ERL 'CBETA' at Cornell University. Built by *'KYMA'* and Brookhaven National Laboratory.

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Figure 2: NS-FFAG with 12-magnet girder at BNL Advanced Test Facility.

The central proton energy is E_k=150 MeV or E=1.0883 GeV within momentum range where the central momentum is equal to p_o= 551.3 MeV/c, the range is **–35.6% ≤ δp/p ≤ 32.2%.** The 12-magnet NS-FFAG girder structure has been very successfully tested for the **-66.7% ≤ δp/p ≤ 44.5%** momentum range .

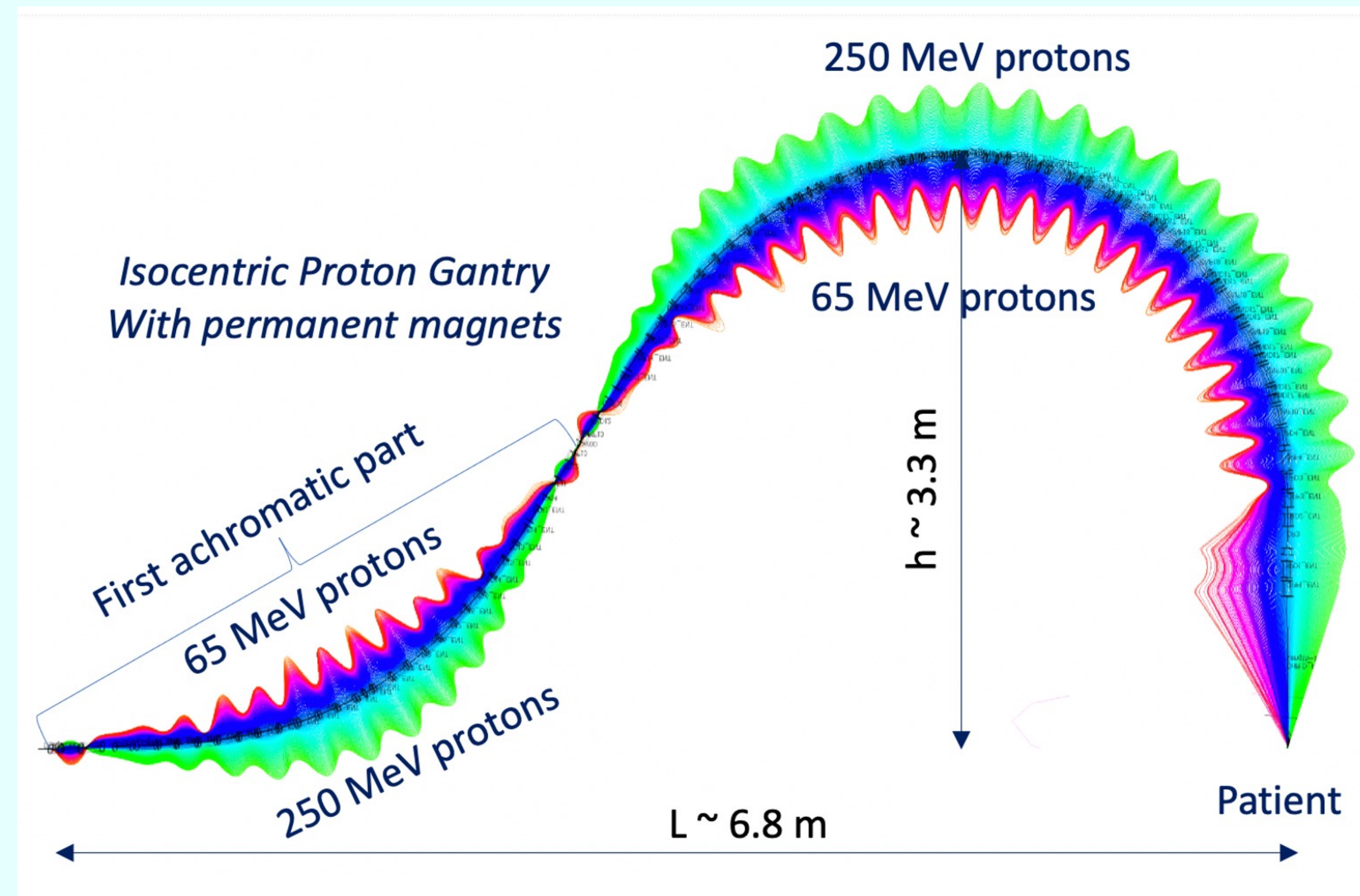

Figure 3: The proton gantry with magnified proton orbits (orbit offsets are less <10 mm) in the kinetic energies 65-250 MeV with the layout of the whole gantry

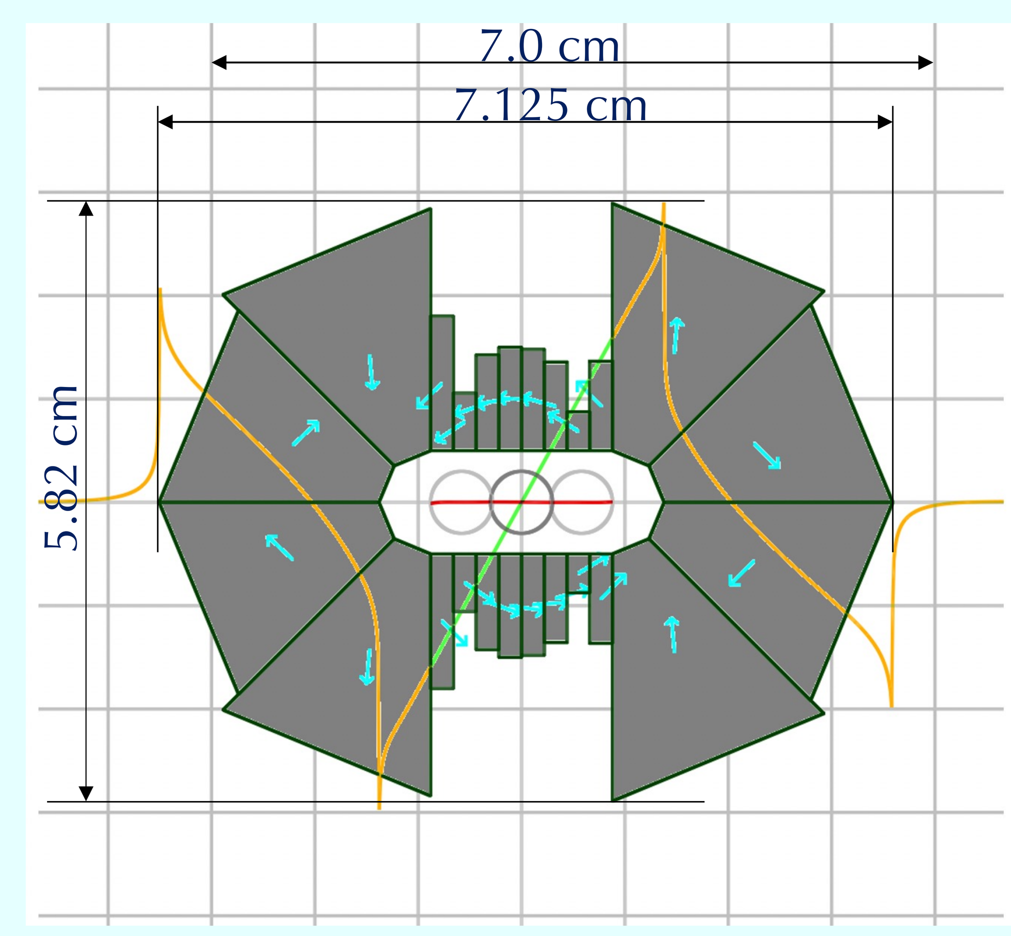

Figure 4: Permanent magnet design with a gradient of 150 T/m.

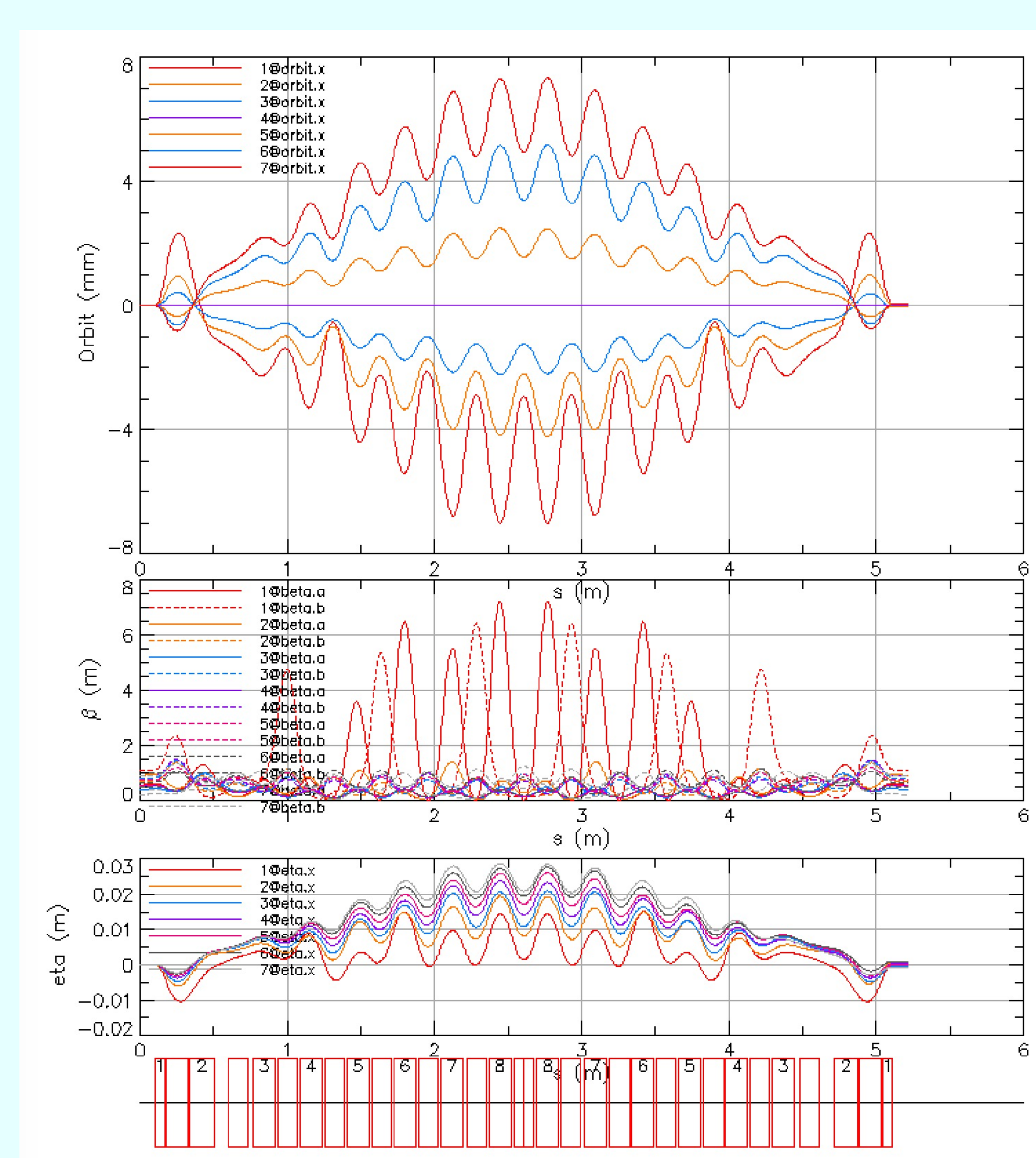

Figure 5: The first achromatic module of the permanent magnet proton gantry with betatron functions and orbit offsets.

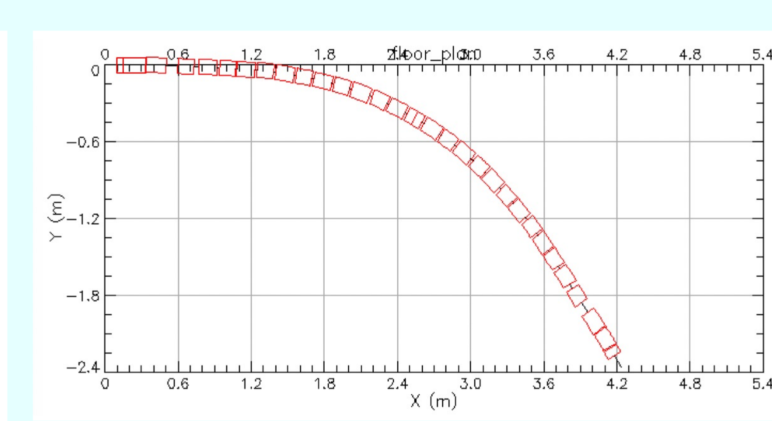

Figure 6: The layout of the first achromatic module of the permanent magnet proton gantry.

Summary:

Permanent magnet proton cancer therapy gantry represents dramatic simplification of the required therapy devices. The gantry is of the same size as the existing proton gantries, but it is of significantly smaller weight as magnet are very small as shown. Magnetic fields are fixed for all energies required for the treatment. It is the largest momentum acceptance gantry reported. The newest developments in the radiation therapy FLASH requires very fast high radiation dose delivery with very fast longitudinal scanning not possible with other types of gantries.