Feasibility study of a Turning Linac for Protontherapy

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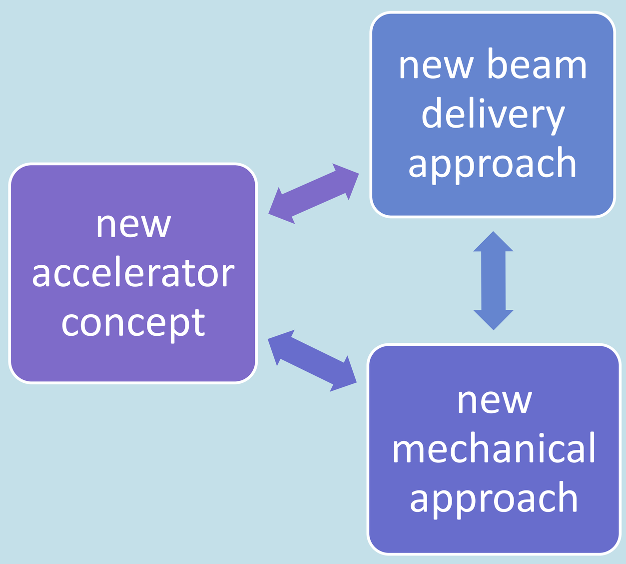
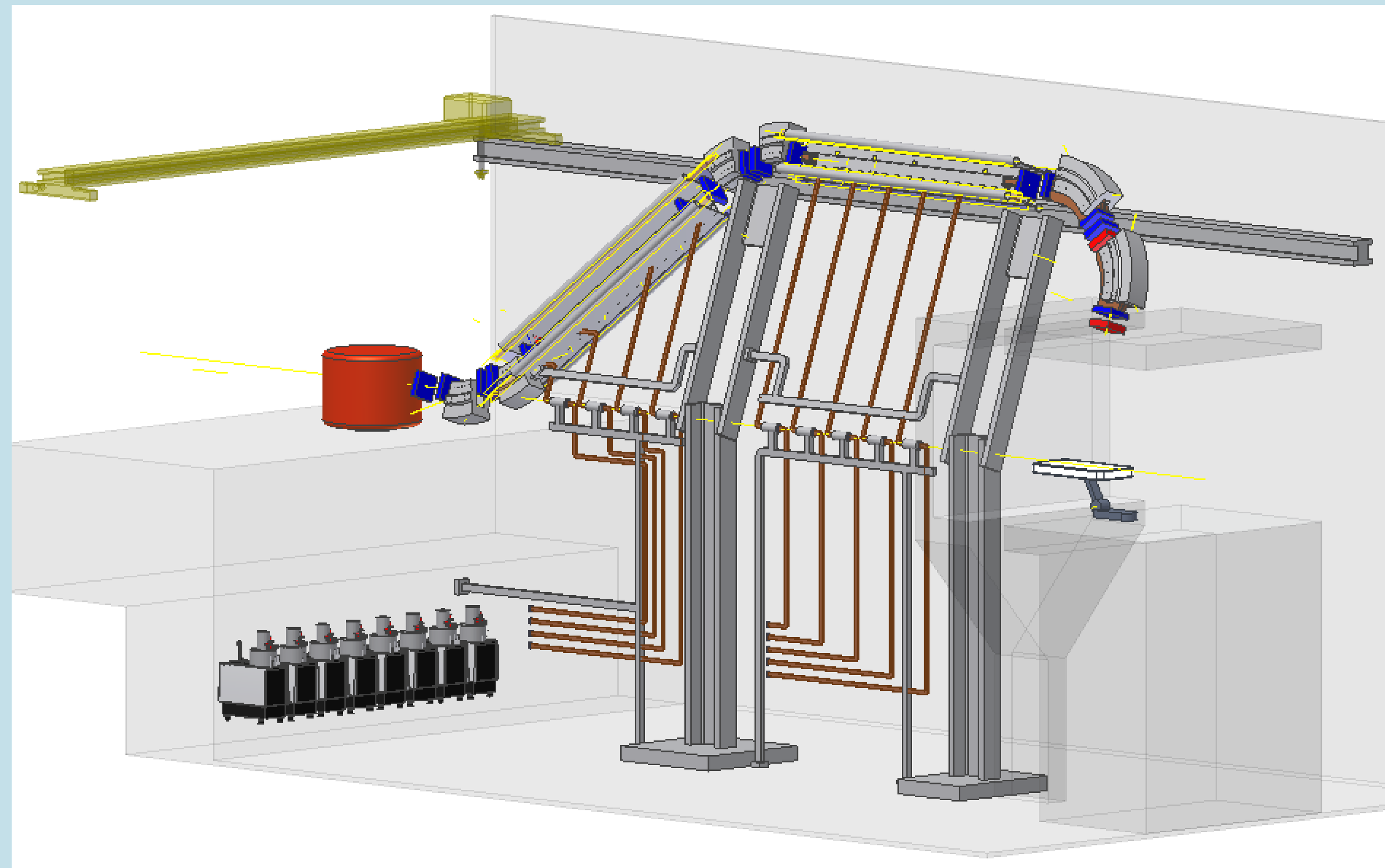
TULIP: a TUrning LInac for Protontherapy

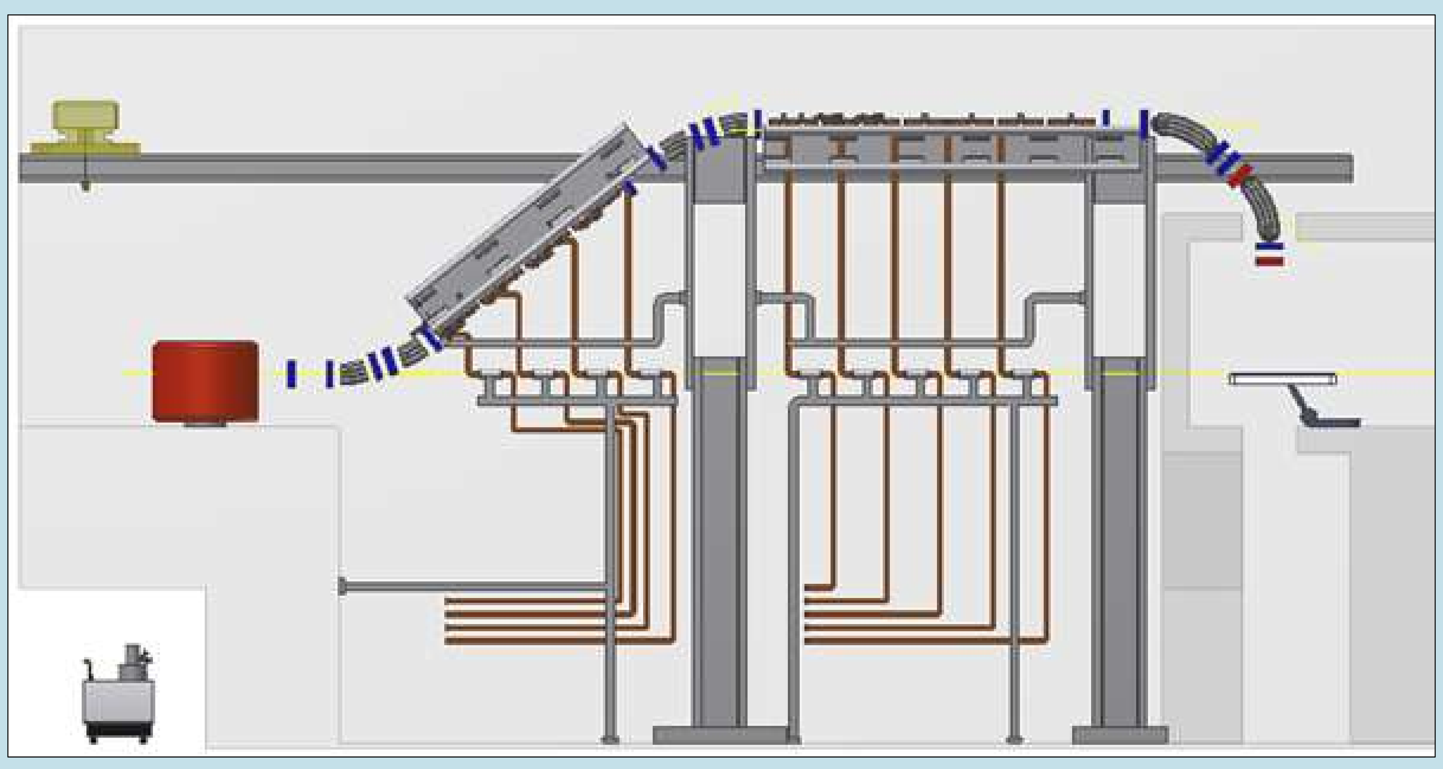
The project TULIP (TUrning LInac for Protontherapy) is an application of the **Cyclinac concept** for a **proton single room facility.**

- A fast cycling linear accelerator with active energy modulation is mounted on a light gantry which can rotate around the patient.
- The fast repetition rate (up to 200 Hz) combined with the rotation of the structure allows the study of **new dynamic beam deliveriy approaches** with protons (like Tomo-protontherapy).
- **Innovative mechanical solutions** to reduce size and weight of the machine have been studied.
- **High gradient accelerating structures** at high frequencies are needed to achieve proton acceleration in a compact structure.

The project TULIP (TUrning LInac for Protontherapy) is based on three novel concepts (acceleration, mechanics, beam delivery).
***Bottom:** Schematic section of TULIP.*

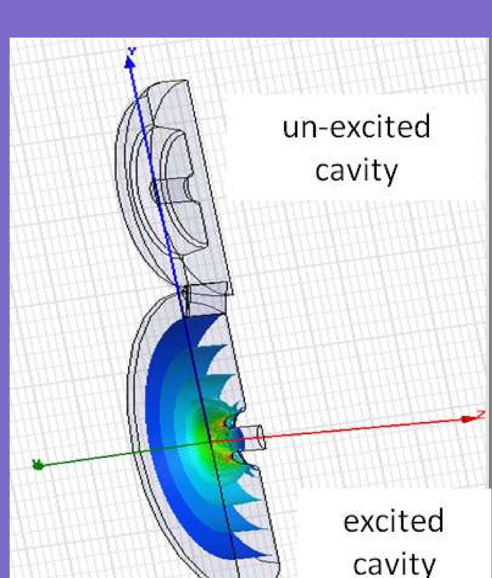






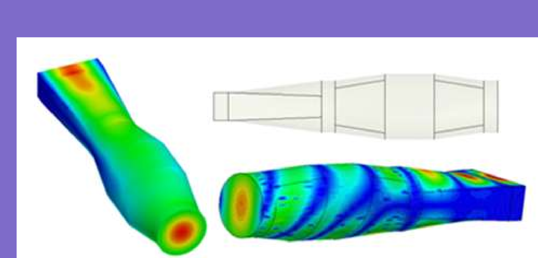
Cyclinac: Acceleration Complex for Hadrontherapy

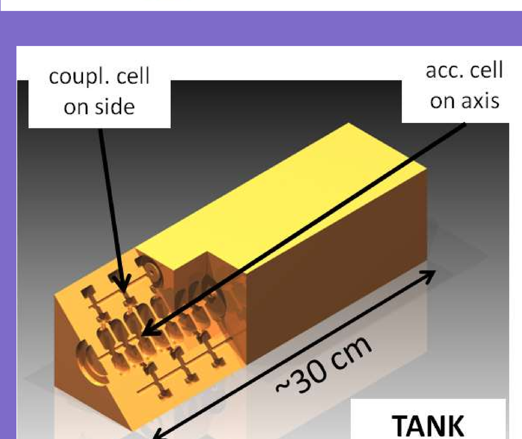
A Cyclinac is an accelerator complex which combines a high current cyclotron with a high frequency linac used as booster. The linac is a standing wave Side Coupled Linac working at a frequncy of 5.7 GHz. It is modular and is powered by independently controlled klystrons with high repetition rates (100-200 Hz). The use of high power RF rotating joints developed for the CLIC project at CERN enables the transfer of the power to the RF modules.



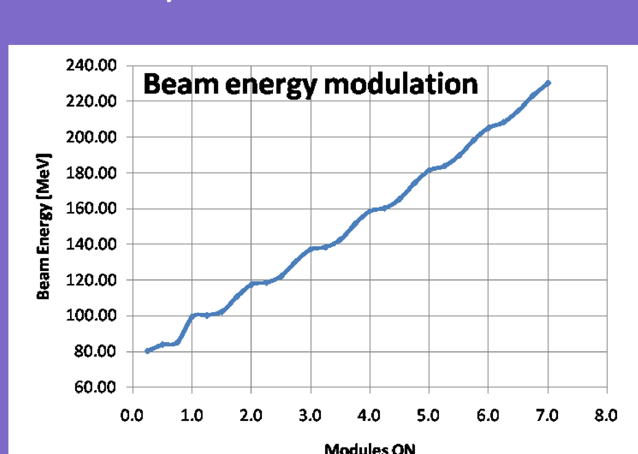
Left: RF cavities design with electric field region.

Right: (top) rotating RF joints (courtesy of I.Syratchev and A. Cappelletti), and (bottom) artistic view of a basic accelerating section called 'tank'.





This accelerator features an electronically-controlled energy variation obtained by amplitude (and/or phase) modulation of the klystrons signal, while a computer controlled source enables variations of the beam intensity every pulse.
High gradient tests on C-band cavities are under preparation to proof the reliability of the machine in terms of BreakDown Rate (10^{-6} bpp/m) [2].



Quantity [unit]	Sec.1	Sec. 2
Total length [m]	3.9	5.8
Energy [MeV]	80	**210**
Avg. Electric Field [MV/m]	20-25	32-38
Number of modules	4	7
Peak Power [MW]	25	84

NEXT STEPS:

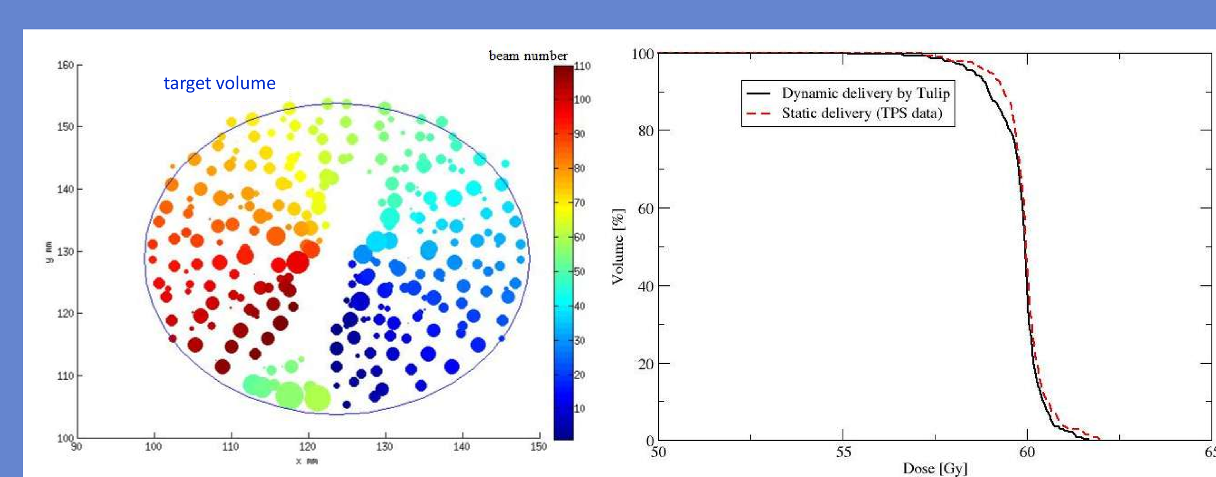
- study of the **rebunching** system between section 1 and section 2
- dynamic beam delivery study including **organs at risk** and **moving targets**
- optimization of the mechanical structure and **alignment study**

Beam delivery study

The beam delivery is simulated by a C-based computer software using patient specific treatment plan data. Based on the spot positions and the corresponding numbers of protons for a static spot-scanning delivery, the dose is calculated for a dynamic rotational delivery of protons by Tulip.

Dynamic characteristics of Tulip:
- a high variable repetition rate ⟶ very fast energy variation
- gantry rotation
- couch motion

Left: Dynamic spot distribution (spot sizes correspond to number of protons).
Right: DVH comparison.



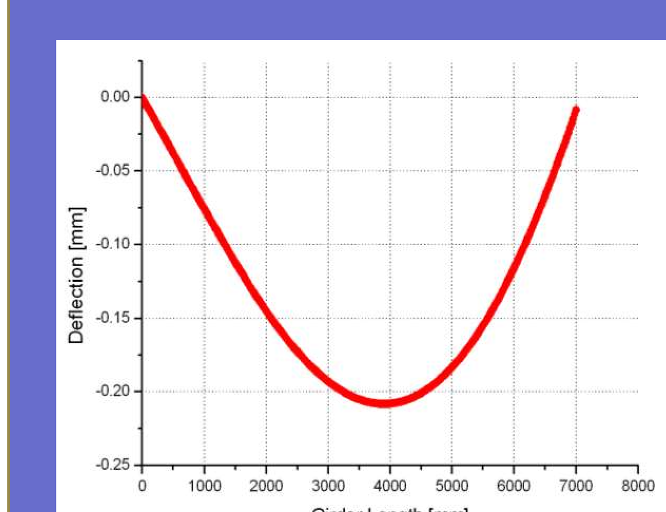
New mechanical solutions

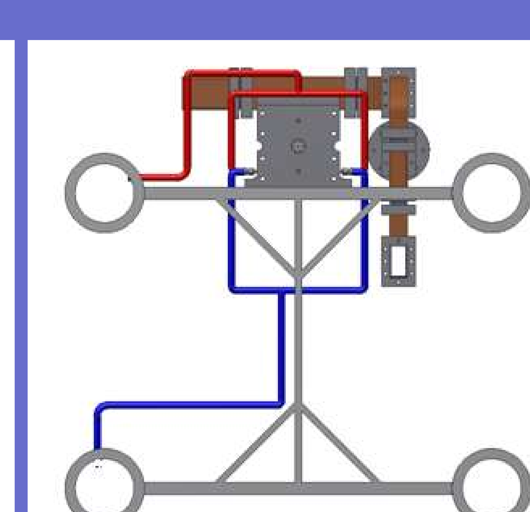
The aim is to apply ***Occam's razor*** philosophy according to which only what is needed must be present. This grants:

✓ ***Lightweight:***
The linac is directly positioned on the rotating girders → minimum number of supporting parts and lower magnets weight.
The elements of the support girders needed for resistance are also used to transport ancillaries.

✓***Modularity:***
The structure is divided into 6 modules (2 for the linac + 4 general supports) → independent assembly and prealignment of the linac can be carried out at external facilities.

✓***Accessibility:***
Tulip's case is stripped of any useless element → alignment, position control and inspection are possible at any moment.





Left: deflection of section II support girder due to flection caused by self mass and external loads.
Right: section view of girder., Linac and ancillaries.

Different cross sections are being analyzed especially for the linac support girders, in order to optimize the deflection to weight ratio. In the preliminary configuration the maximum deflection interval has been kept around 200 µm.

Mechanical features	
Estimated overall weight [t]	70
Tulip R_rotation [m]	4.6
Angular velocity [rpm]	1.5
Angular acceleration [rad/s^2]	0.5

REFERENCES:
[1] U. Amaldi et al., *Accelerators for hadrontherapy: from Lawrence cyclotrons to linacs*, NIM A 620 (2010)
[2] A. Degiovanni et al., *TERA high gradient test program of RF cavities for medical linear accelerators*, NIM A (2011), in press.