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General design considerations on structures, power sources and accessories

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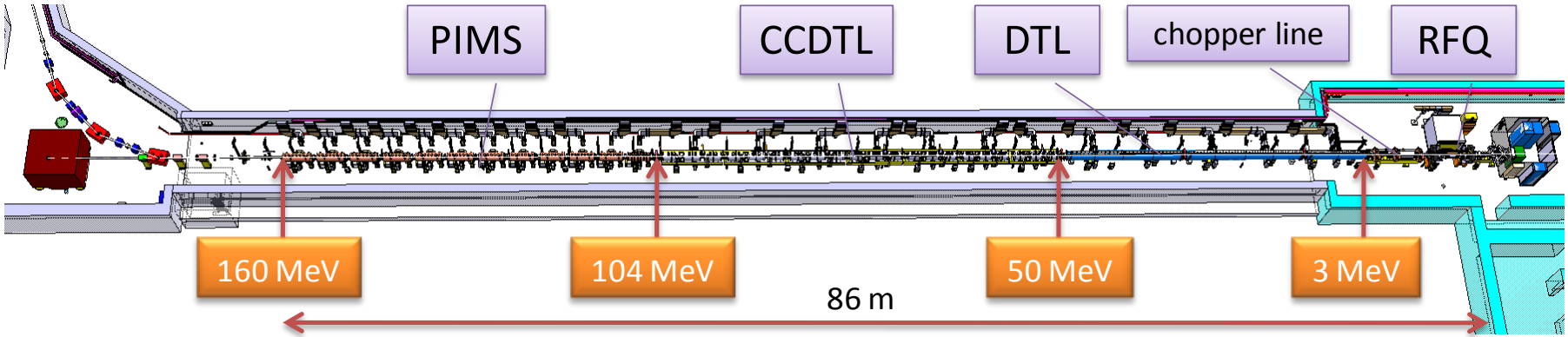
Novel Linac for Challenging Environments 7 November 2016

CERN and Linacs

- CERN has no experience in radiotherapy linacs.
- But CERN has more than 50 years of experience in building linear accelerators.
- The last achievement: Linac4, 160 MeV H-, 100 m length, final commissioning.

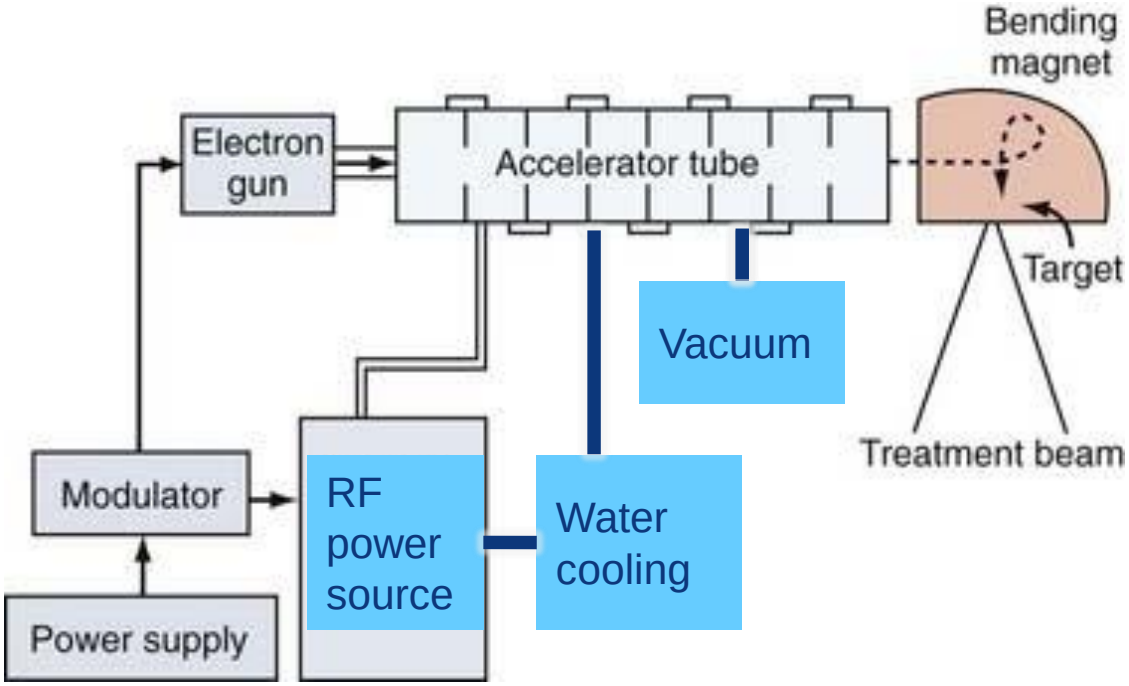


Reliability

- A key point for CERN linacs (and accelerators): reliability.
- Present Linac2 99% availability, initial goal for Linac4 95% (for a 100 m machine with thousands of components!).
- More general RAM approach (Reliability-Availability-Maintainability), including maintenance time.
- Motivations: strong pressure from users / large investment in the accelerators / large manpower cost pushing to minimize maintenance.

- **Modularity** (fast repair)
- **Stripped down** systems (few components, little electronics)
- **Low voltages**
- **Proven** industrial components

Linac block diagram



- Blocks and modules well identified.
- Must be made of plug-in units easily interchangeable.

Vacuum, cooling, and supplies

- Vacuum: needs a primary/turbo pumping system for pre-vacuum and an ion pump. Standard commercial units, can be equipped with fast mounting systems for replacement. Overall cost 10 – 20 k€.
- Water cooling: Heat exchanger/cooler-fan may be similar to a standard air-conditioning system. Fast mounting system.
- Power supply for RF source: solid design, modular, minimum electronics, replaceable.
- UPS (Uninterruptable Power Supply, battery-based) or diesel generator to keep up the vacuum pumps during electricity breaks (the rest can go down…).

RF power source

magnetron

klystron

For radiotherapy linacs:

- **Magnetrons** for low power and energy (<10 MeV).
- **Klystrons** for high power and energy (> 10 MeV).

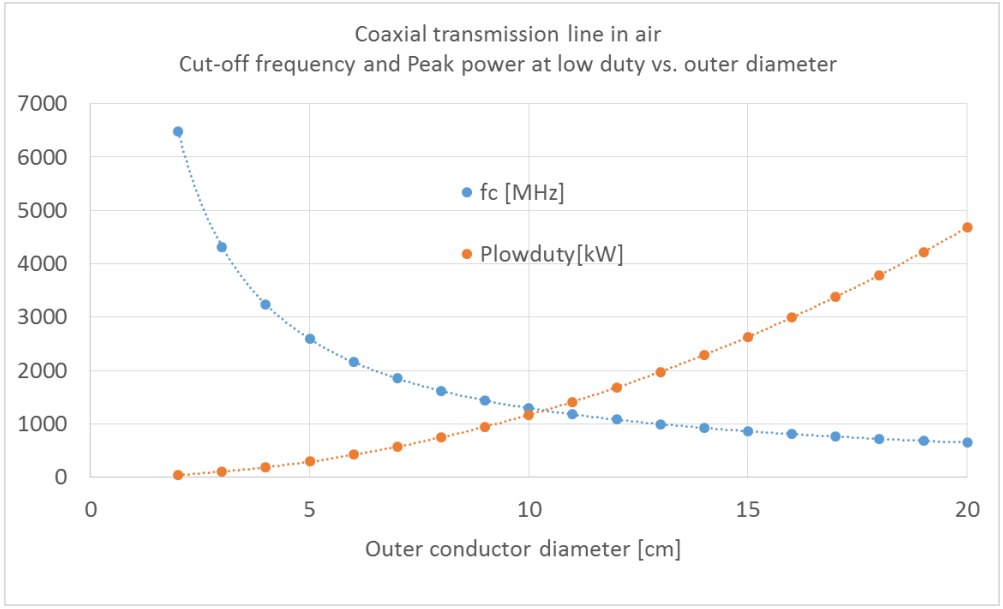
Magnetrons (invented for radars, used in every microwave oven) are simple and inexpensive; they cannot be used for scientific accelerators because not stable in phase. Scientific applications are moving towards solid state (reliable, low voltage, but still expensive ~3 €/W).

- Magnetrons are the logical choice for a new solid and compact radiotherapy design. Companies are now producing a wide range of economic magnetrons around 3 GHz (S-band).

Power range between 2 and 5.5 MW

Transmission line

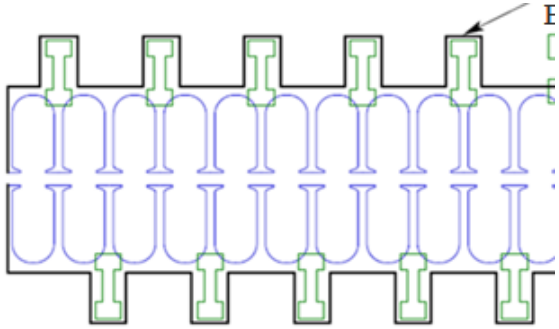
- Standard: rectangular waveguide (with rotary joint)
- Can we use a flexible coaxial to replace the joint?

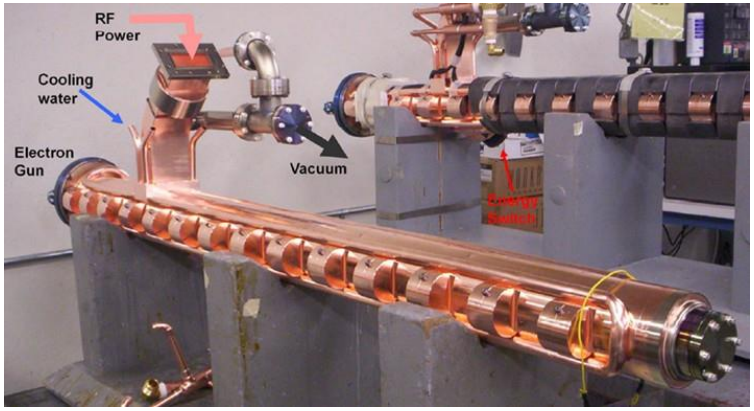


Not at high frequency
(3 GHz: max. 4.5 cm diameter, power < 200 kW)
Possible at low frequency
(1 GHz: 13 cm, 2 MW)

Alternative: flexible waveguide WR340

Accelerating structure – state of the art





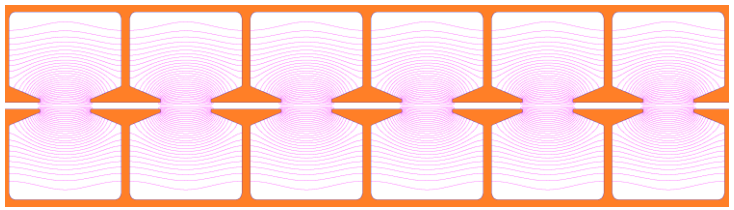
Standard RF frequency: 3 GHz

- Commonly used: Side-Coupled or On-Axis Coupled Structure.
- Invented at Los Alamos in the early 60's for long high-energy linacs. S-band version developed in the early 80's.
- Stabilised electric field, but requires complex 3D machining, vacuum brazing, high-level tuning.
- At CERN we have worked on Side-Coupled models and prototypes, but for Linac4 we moved to simpler structures!

Accelerating structure – lower frequency

- Several linac designs at higher frequency, but what about going down in frequency, to 1 GHz?
- Larger dimensions can offer some advantages: less cells, does not need stabilization – can be made of bolted copper-plated elements, no need for brazing – could use coaxial flexible cables instead of rigid waveguide.
- Main disadvantage: some magnetrons designs exist at low frequency, but not readily available commercial units – some magnetron development is needed.

Medical Pi Mode Structure
Preliminary design by R. Wegner, CERN



6 MeV design

frequency 750 MHz

diameter ~ 300 mm

length ~ 1.4 m (7 cells)

ZTT ~ 37 MΩ/m

E0 = 4 MV/m

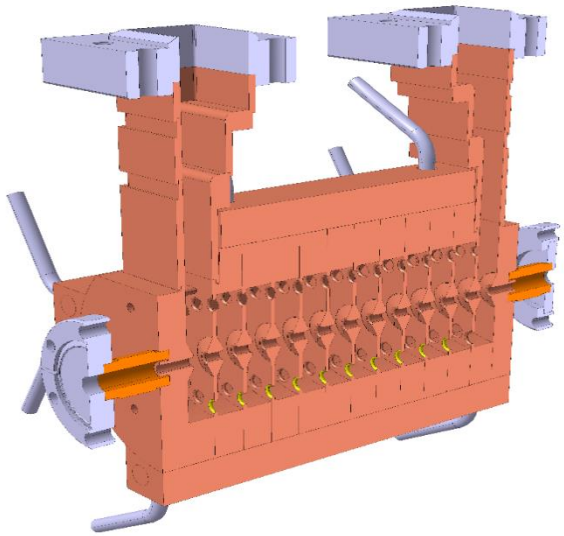
V0T = 5.6 MV

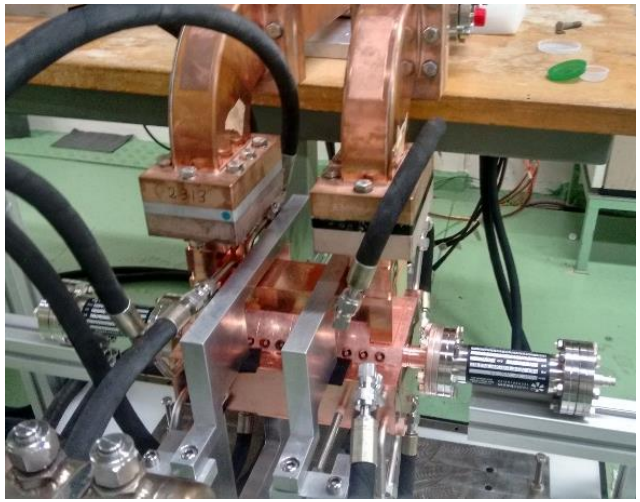
power dissipated ~ 600 kW

5-1/2" HELIFLEX® Air Dielectric Coaxial Cable

Accelerating structure – traveling wave revisited

- Initially, medical linacs used traveling wave (TW) structures, later abandoned because of higher power loss.
- Recently, CERN and TERA Foundation have developed a new high-efficiency TW at 3 GHz, the Backward TW (BTW).
- Advantages: simpler construction (diffusion bonding instead of brazing), high efficiency.

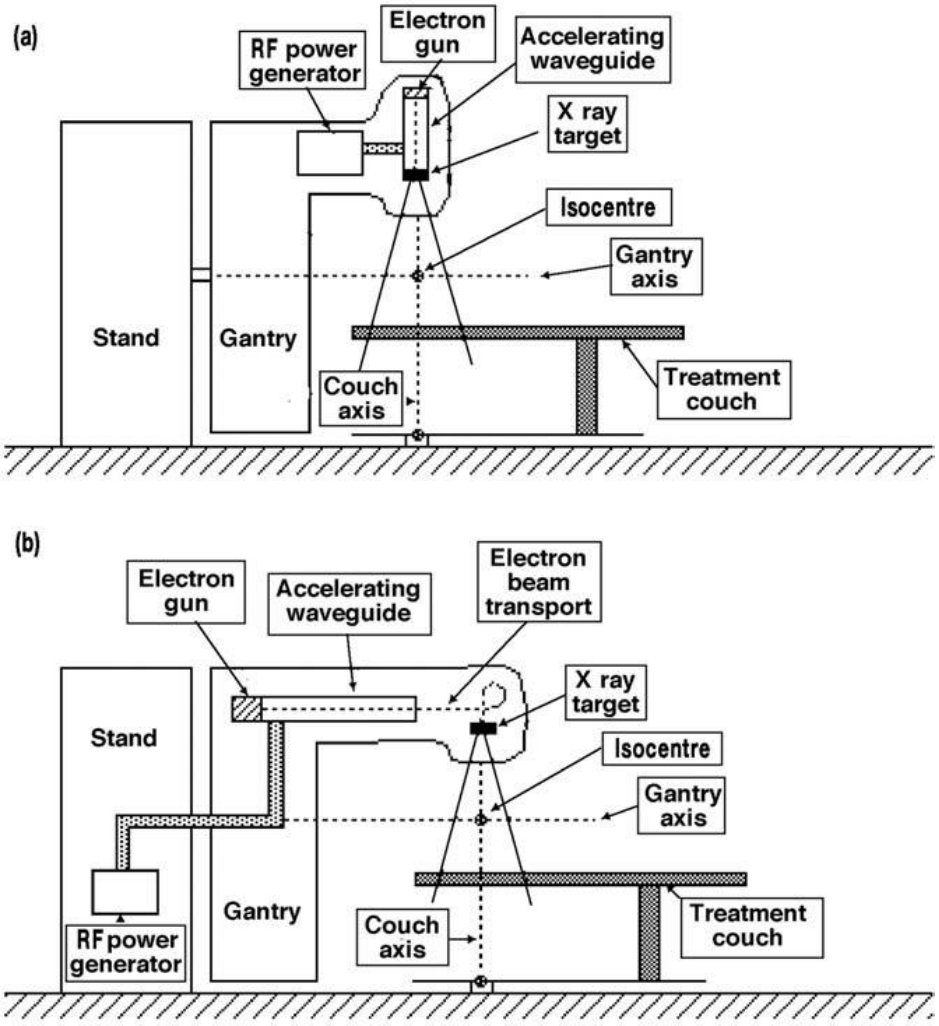




Summary	
Input-output energy	25 keV – 6 MeV
Total length	0.56 m
Number of cells	14
Avg Gradient	10 MV/m
Peak Power (0 synch.ph.)	0.56 MW

Preliminary design by S. Benedetti, CERN

Configuration



- Structure perpendicular to patient, for short structures (<8 MeV).
- Parallel to patient, for long structures (>8 MeV).
- It is essential in our case to get rid of the beam transport and of the 270deg magnet and use a simple perpendicular configuration.

Conclusions, tentative parameters

A Novel Radiotherapy Linac for challenging environments must have:

- Modular construction with exchangeable elements.
- Simple design, little electronics, low voltages.
- Backup UPS and/or diesel generator for safe stand-by during cuts.
- Perpendicular gantry with rotating structure and RF source.
- Using a low-power magnetron as RF source.
- Using a simple high-efficiency accelerating structure. Short-term: only option is **3 GHz, side-coupled or BTW**. Medium-long-term: novel frequencies or structures that require some development.
- Limited energy to respect the above requirements: **6 MeV or maximum 9 MeV** (or start with a design for 6 MeV, upgradable to 9 MeV as a second stage).

A final remark

An interesting problem, the challenge is like reinventing the car…