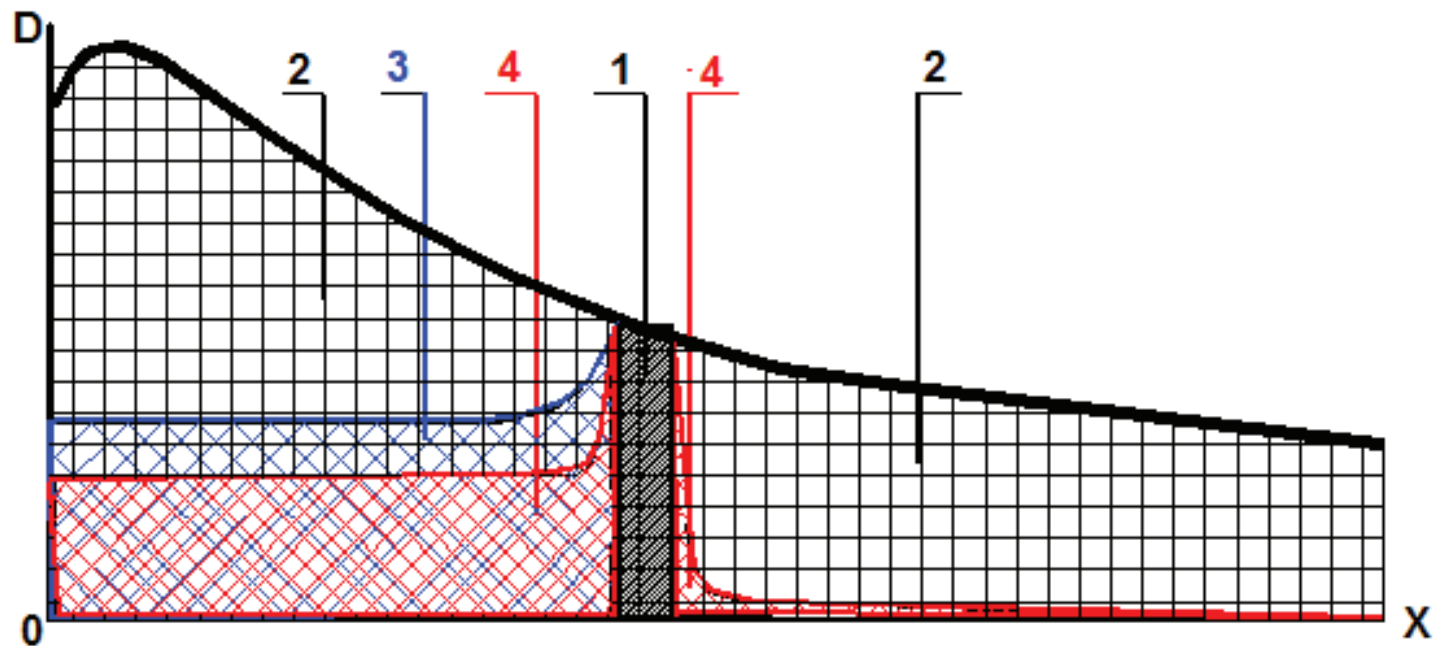


Gantry free transport line for proton/ion therapy

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1 –target. 2 –gamma. 3 – protons 4 – ions.

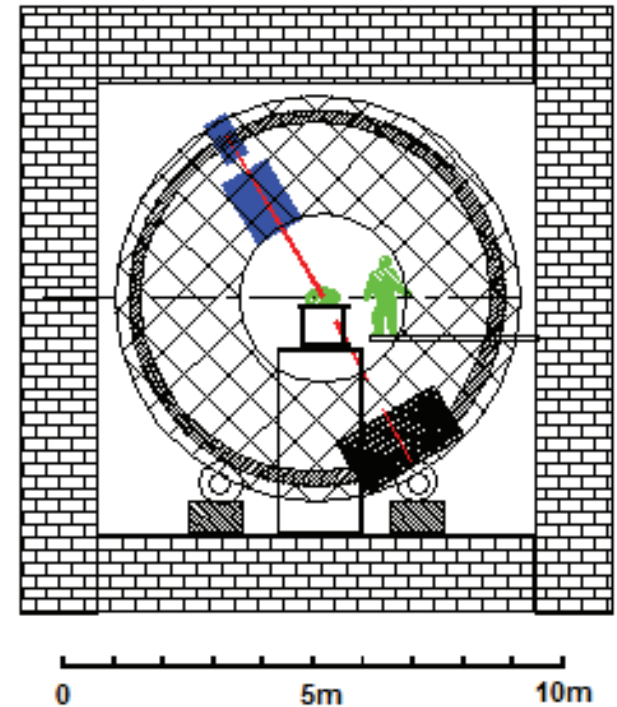
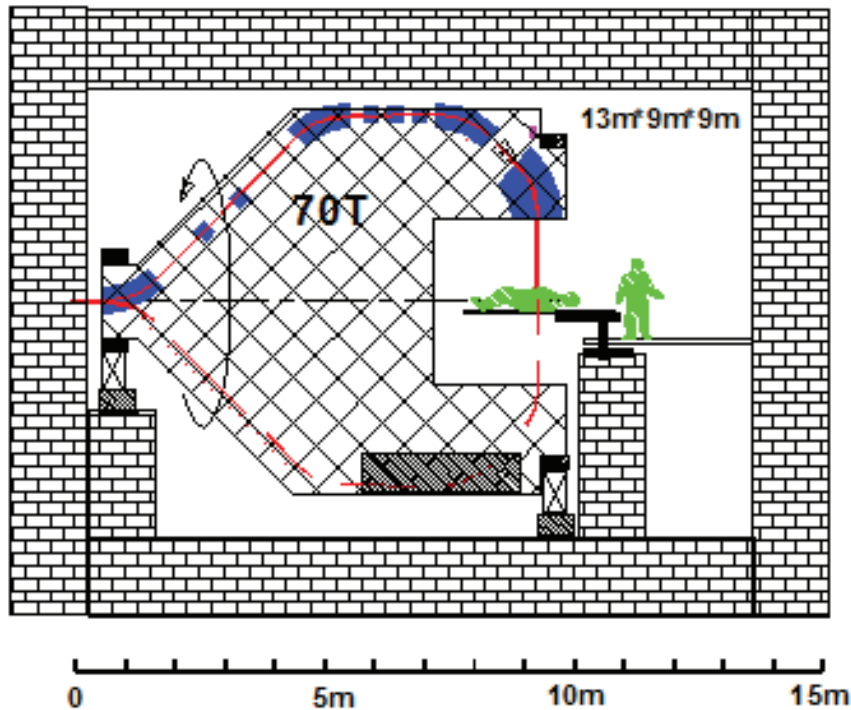


Only 1% of cancer patients can be treated by proton or ion in 2018

- The treatment by proton and ion beams is significantly more expensive today in a comparison with the treatment by gamma rays. In USA insurance companies pay now for the use of this treatment only for certain cancer locations, which need particularly important accuracy dose distribution (e.g., eyes), or for children treatment in order to prevent (on many years) reactions on small doses in healthy parts of the body.
- In the world specialists are searching for more compact and less expensive equipment for proton and ion therapy. Compact and easy to use accelerators with superconducting magnets have been proposed.
- **But beam transportation systems to the patient from different directions stay still bulky and expensive.**

- Why a choice of directions of irradiation is necessary? In order not to irradiate those parts of body that must not be irradiated, and to spread the inevitable release of the energy in healthy parts of the body in a large volume, to different organs, in order to remain them at a relatively safe level.
- Many years ago doctors formulated requirements for such equipment: the patient lies horizontally, motionless, the beam is transported from any direction of the plane perpendicular to the longitudinal axis of the patient. Systems that implement these requirements are generally called as a gantry.
- Those requirements are more strong, then it can be useful.
- The gantry is expensive and bulky equipment because conventional electromagnets can rotate a beam of protons with a radius of about 1.5m and a beam of ions with a radius of about 4m. As a result, the standard gantry for proton's has a size of about 10m^3 and the weight of the equipment rotated precisely in this volume is about 100t. Similar parameters of the HIT gantry for ion beam transport is $13\text{m} \times 13\text{m} \times 18\text{m}$ and 660t.

An optimal scheme for the proton's gantry



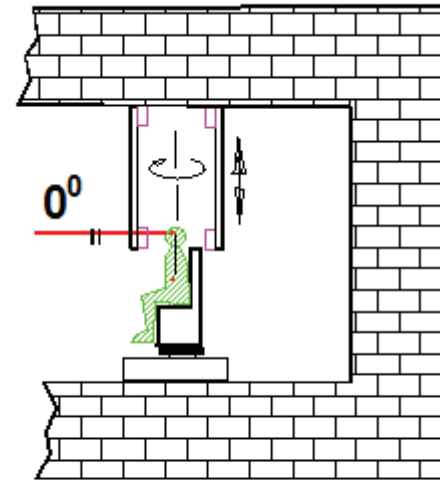
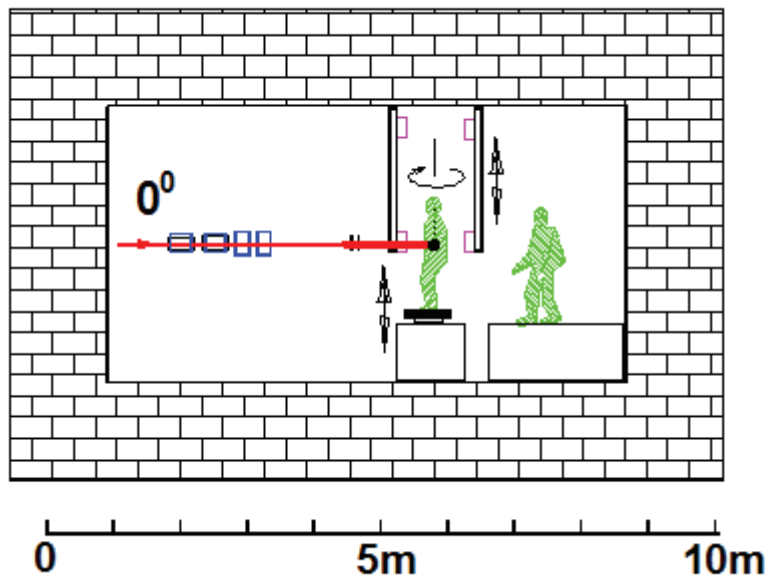
Similar scheme was used in a gantry PROTEUS ONE (IBA),
but with ESS system into gantry and with limits in directions of irradiation

- A significant part of the cost of a treatment is associated today with gantry systems (up to 70% for centers with four gantries). Attempts to develop a simple **low-cost compact gantry** based on superconductivity had not real success so far.
- A special conference of experts of this topic took place in the autumn of 2015 in Switzerland. The problem is the necessity of fast enough distribution of the beam energy for the target volume ("scanning").
- It were proposed in the form of compact "one room's" complexes by IBA, VARIAN, MEVION firms during recent years. But these complexes with one accelerator and one treatment room can work only with beams of protons, have a limited annual productivity and can not significantly reduce the price of the treatment.

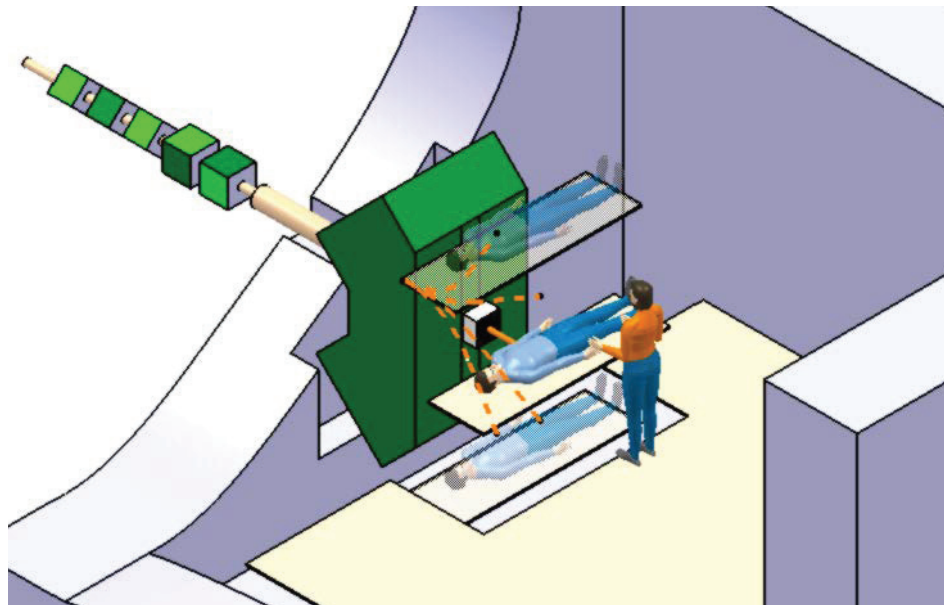
- Does a therapy by proton and ion beams have a real future in a competition with a gamma therapy?
- Yes, if its treatment cost by protons will be comparable to the cost of treatment by gamma rays. Much less expensive and more compact equipment is necessary instead of the gantry.

Previous solutions without gantry

V.E.Balakin proposed a compact and simple system with a fixed horizontal beam, which is directed to the standing or sitting patient. An initial horizontal beam is focused by quadrupole lenses and deflected by scanning magnets. The patient turns around a vertical axis in this system to change the direction of irradiation. A CT scanner with vertical displacement was proposed to control the shape of the body and of the target.



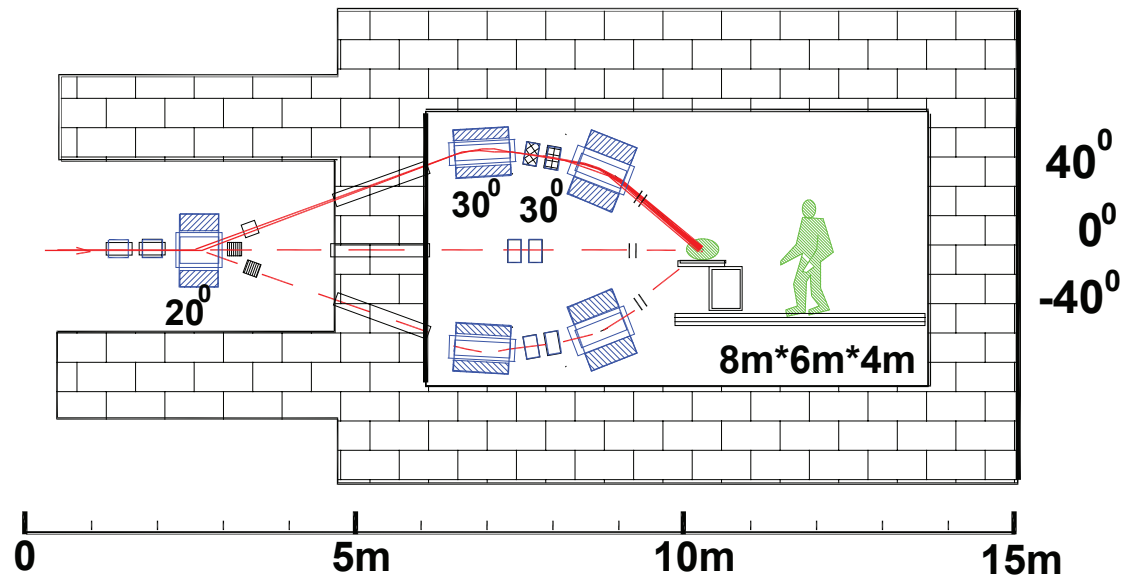
In 2002 we proposed a "Simple Planar System" - "SPS (F)". Initial horizontal beam is focused by quadrupole lenses and deflected by scanning magnets. A fixed magnet with increased gap is used to bend the beam in a vertical plane at an angle of less than F . A treatment table (with the patient fixed on it) is shifted in the vertical plane so as the rotated beam hits the target. It is compact system with a possibility to change direction of the irradiation in the interval $(-F < f < +F)$. A CT scanner shifted vertically together with the treatment table was proposed to control the shape of the body and the target. The scanner has additional possibilities of horizontal displacements.



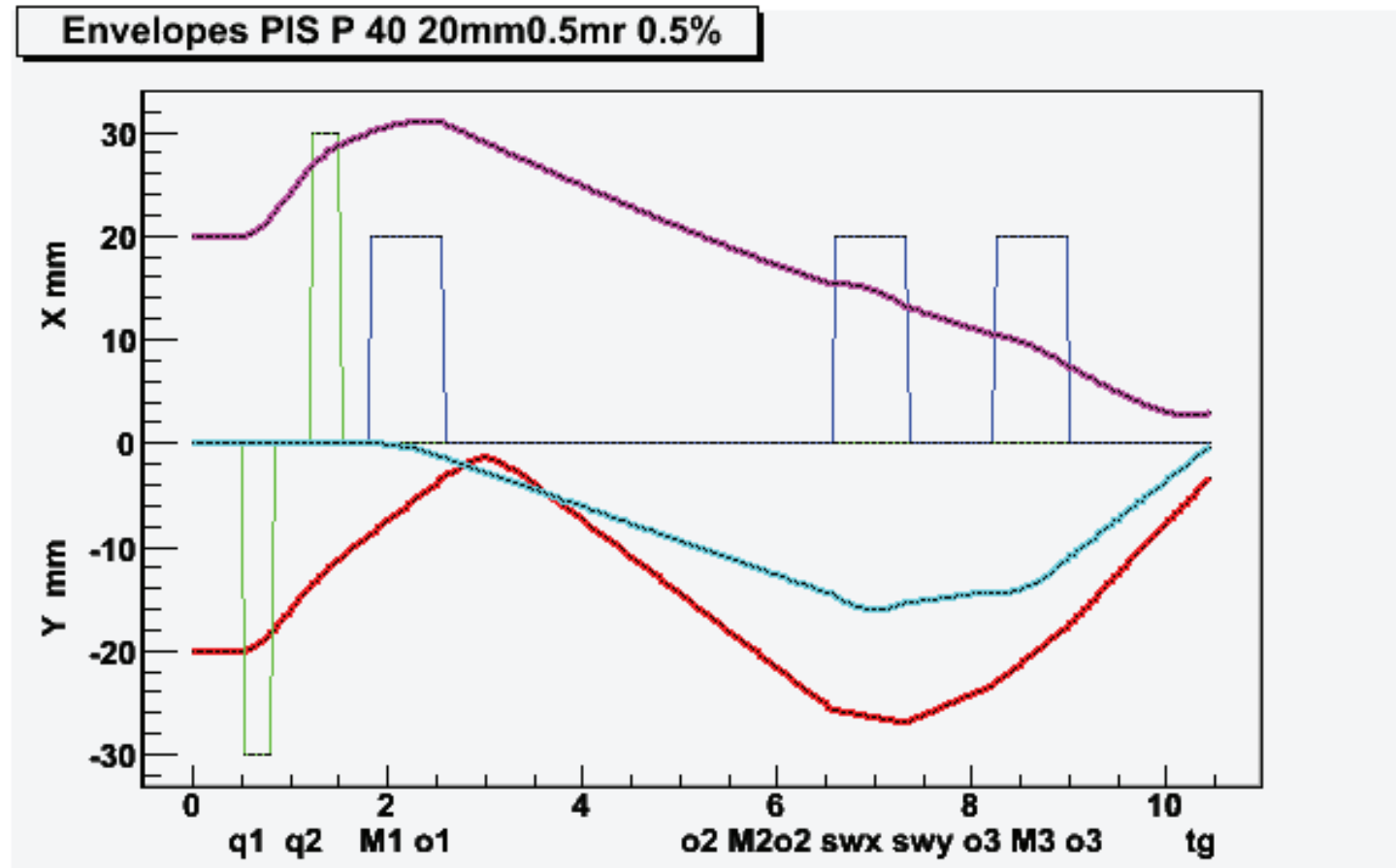
- **New requirements and a new solution**

- In 2016, the doctors of MGH (Boston) analyzing the experience of a treatment of 4300 patients with different cancer localization, take thought about the appropriateness of the cumbersome and expensive gantry and its replacement by a new equipment with the following requirements to it:
 - 1. Motionless irradiation center.
 2. An active dose distribution in the target volume (scanning).
 3. The admissibility of various positions of the patient in different fractions (the patient lying with limited ($<\pm 15^\circ$) turns of the table relative to the horizontal longitudinal axis of the patient or if the patient is sitting under rotations around of the vertical axis).
 4. The use of a CT scanner in the place of irradiation after each change of the position of the patient.
 5. The use of beam direction changes in a small interval (like $<\pm 10^\circ$).

In addition to the new doctor's requirements we proposed in 2016 the use of a "Planar Iso-centric System" with a fixed irradiation center and with three significantly different fixed beam directions in the vertical plane ("PIS"). The patient in this system can be irradiated both in lying and sitting positions. Each additional magnetic channel has small immovable magnets and a simple optic. The patient can be irradiated from its second side in the next fraction. (About 20 fractions are in treatment process). A lot of designs versions are possible.

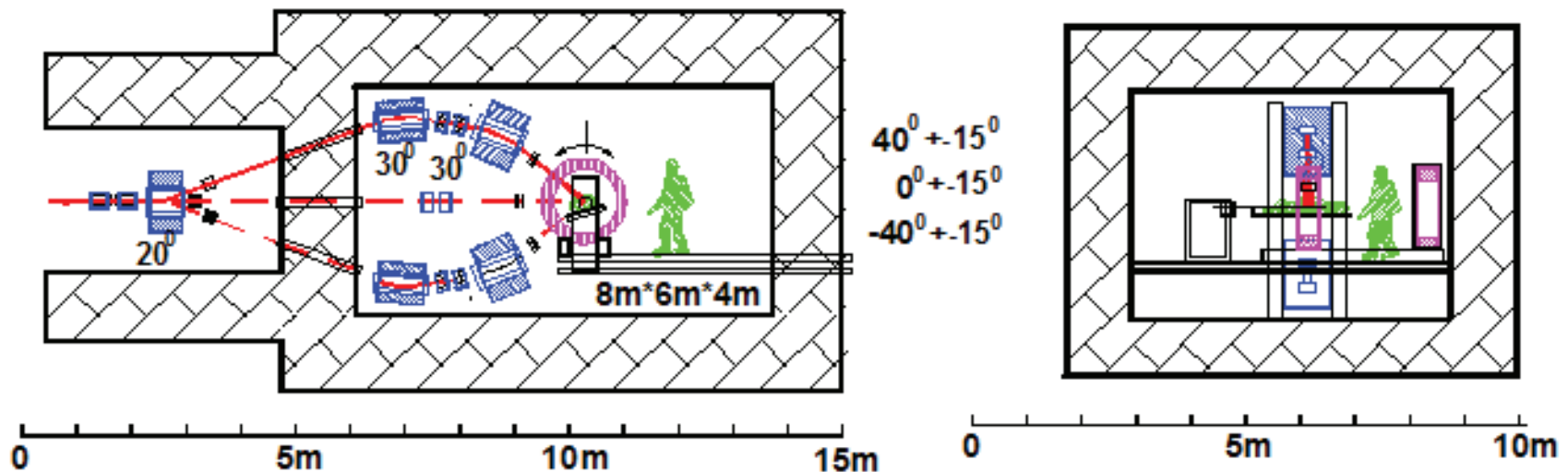


An example of optical scheme of PIS system

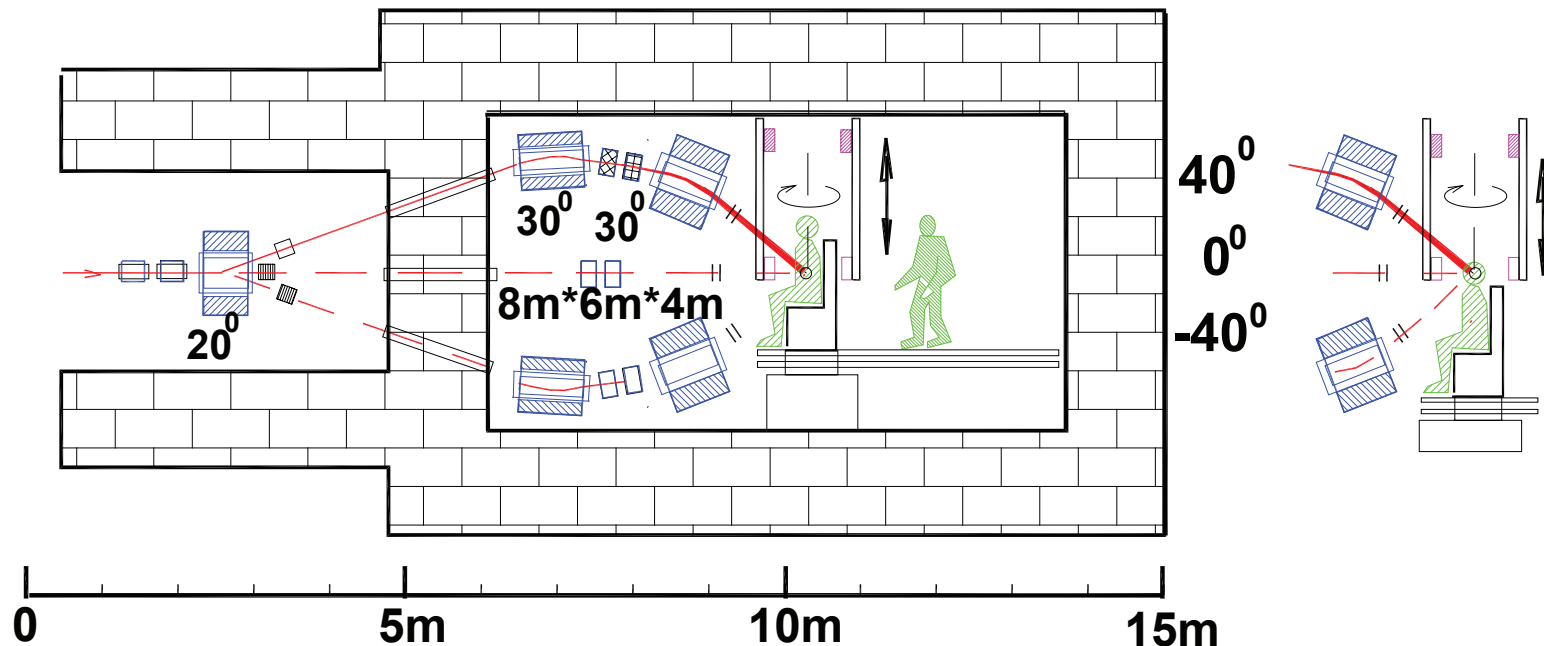


- Compared with the conventional gantry system in PIS at the beam direction of $\pm 40^\circ$ the beam rotation into PIS is decreased from 180° to 80° .
- There is no complex and expensive mechanical system for precision turns of heavy magnets in a large volume and no complex magnetic focusing of a beam.
- There is no practically power consumption at the irradiation in a horizontal direction.
- The position of the scanning magnets allows reduce the weight, power and cost of the last magnet at saving scanning distance of about 3m. This limits the weight, power and cost of the entire PIS system.
- Dimensions of a treatment rooms with the PIS system are mainly determined by the patient's comfort transportation and installation to the working position. They are 5-10 times smaller than the dimensions of the room for the gantry.

Small rotations (like $\leq \pm 15^\circ$, without discomfort to the patient) of the treatment table around a horizontal axis with the fixed lying patient can be used for the expansion of choices of the irradiation direction in addition to three fixed directions under the control of a body shape and a target by sliding horizontally the CT scanner



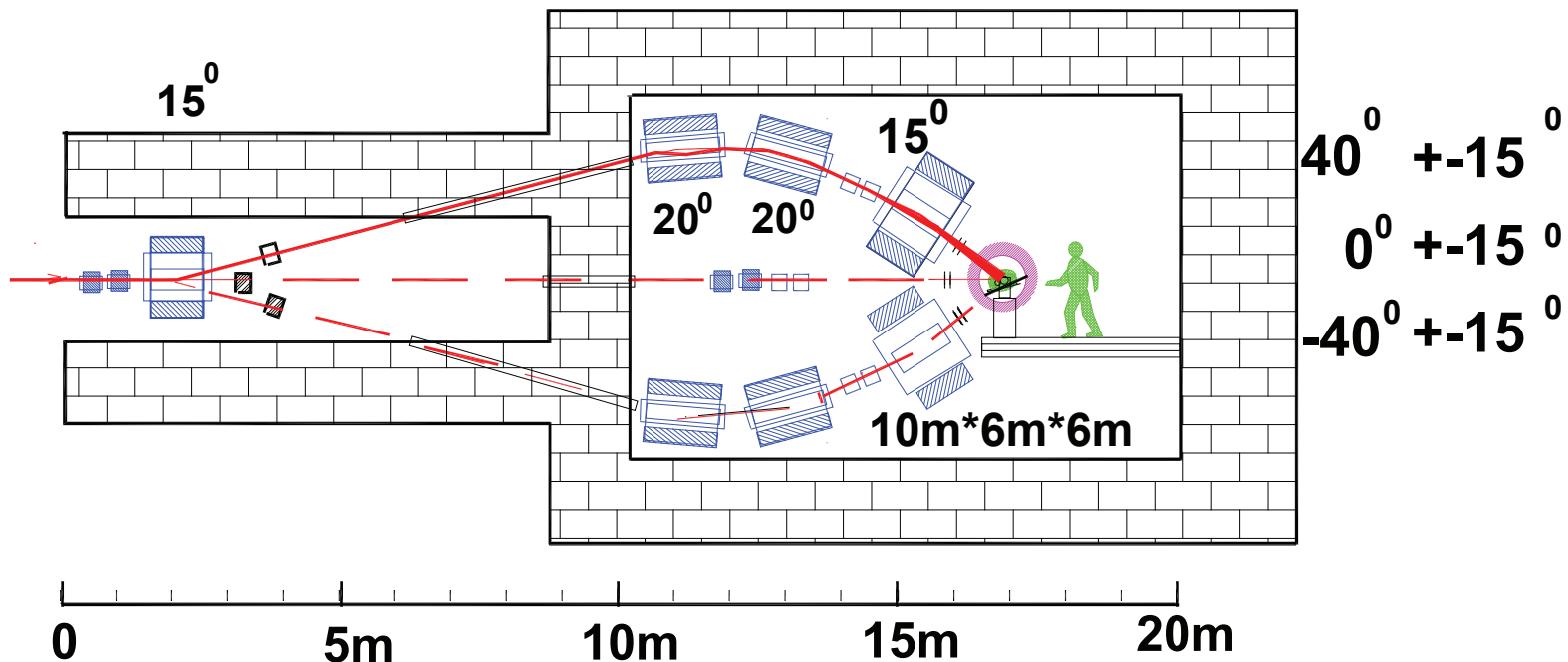
A treatment armchair with sitting fixed patient can be rotated around a vertical axis under the control of the body shape and the target with shifted vertically CT scanner for the expansion of choices of the irradiation direction in addition to three fixed directions.



- Using the PIS allows for any selected fixed position of the patient after one application of a CT scanner to clarify irradiation plans for all three possible directions of the irradiation.
- The proposed system allows to choose different directions of the irradiation in different fractions in a rather wide spread for the treatment of any cancer sites.

- **PIS system for ion transport.**

- The same system can be easily realized by using more long warm magnets for the transport of ion beams. It has low cost, small size and low power consumption compared with all versions of a gantry even in comparison with HIMAC gantry based on superconductive magnets.



The comparison of the main parameters gantry HIT, gantry HIMAC and PIS

•	HIT	HIMAC	PIS
• Directions	0-360	0-360	2*(-55<f<55)
• Max field	1.8Tl	2.9Tl !	1.6Tl
• Room sizes	25m*14m*14m	17m*13m*13m	15m*6m*6m
•	4900m**3	2900m**3	540m**3
• Weight	660t	300t	<80t
• Movement	rotation	rotation	immovable
• Power consumption	800kW	300kW	100kW

Conclusions

- The main progress in the radiation treatment in the future can be produced by a wide use of a proton therapy instead of a gamma therapy.
- For this purpose it is necessary to design compact and not expensive systems for the beam transportation to a patient by many spatial directions, to reach the price for a treatment by a proton beam comparable with the price of a treatment by a gamma equipment.
- Construction of a new gantry is not useful for this aim.

- New solution of a transport system (PIS) was suggested here instead of a gantry according of a new medical requirements.
- It used three beam directions in vertical plane with fixed center of irradiation at scanning the target volume.
- It used different positions of the patient in different fractions under the CT scanner control.
- For additional change directions of irradiation at sitting position of a patient the treatment chair can be rotated around of the vertical axis. For additional change directions of irradiation at a lying position of a patient the treatment table can be rotated on limited angels around of the horizontal axis.
- Three independent directions of irradiation are possible in any fraction at any fixed patient position.
- All magnets in PIS system are immovable, small and simple.
- PIS ideas can be used to design more compact systems for ion transport by usual magnets.

- An future equipment for low cost cancer therapy by proton beam can be designed on base of one simple accelerator with transport of its slowly extracted beam to many (4-6) treatment rooms equipped by PIS systems.
- The center of proton therapy with similar equipment is necessary in Moscow now.

Thank you for attention!

