MODIFICATIONS OF A CLINICAL LINAC FOR USE IN NUCLEAR PHYSICS RESEARCH

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Akdeniz Üniversitesi
Nükleer Bilimler Uygulama ve Araştırma Merkezi
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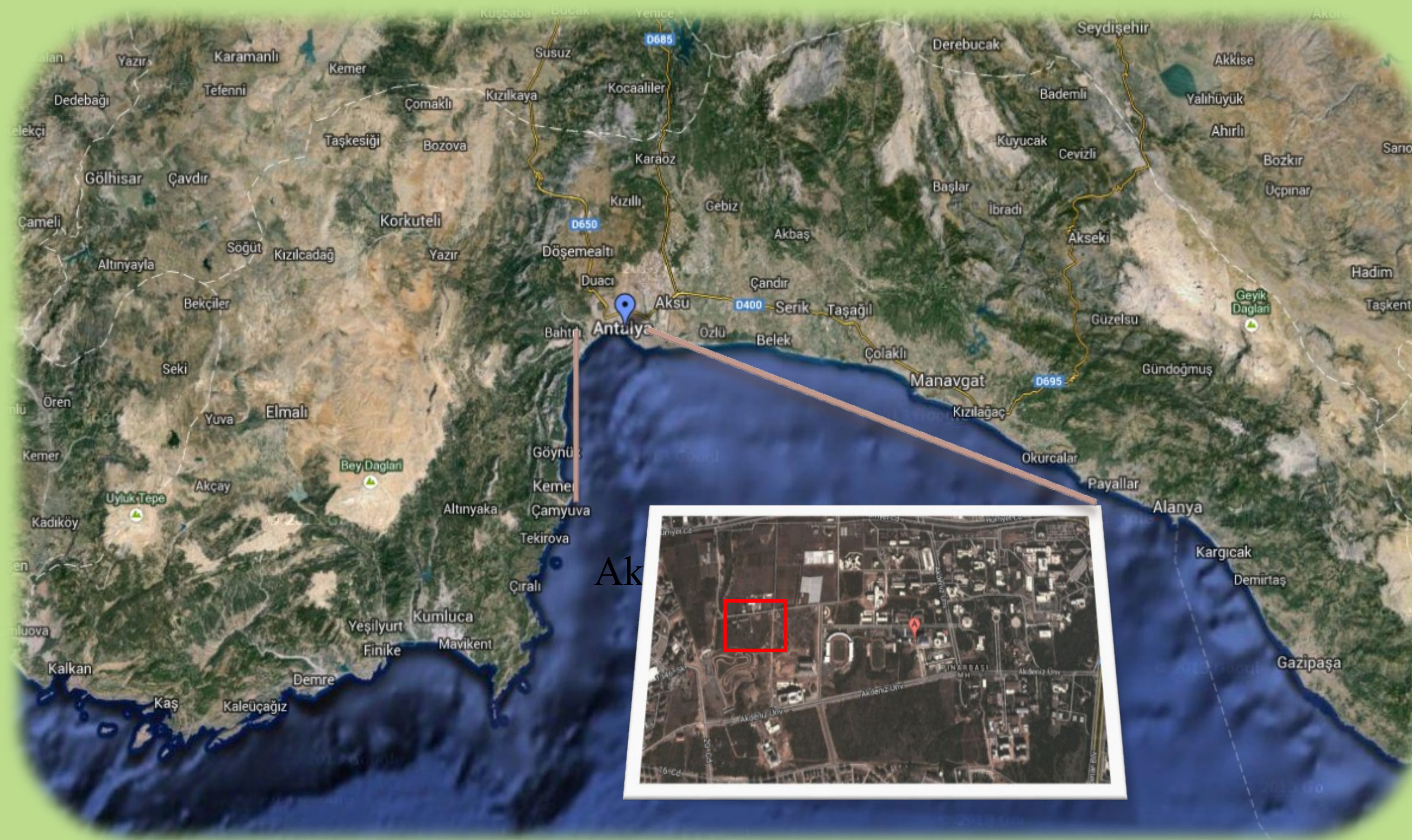

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Outline

- Introduction
- ELEKTA SLI-25 Medical linac status
- Modifications and measurements:
  - Dose/flux increase
  - Energy change
  - Neutron flux measurement
- Conclusion and Summary
- Outlook

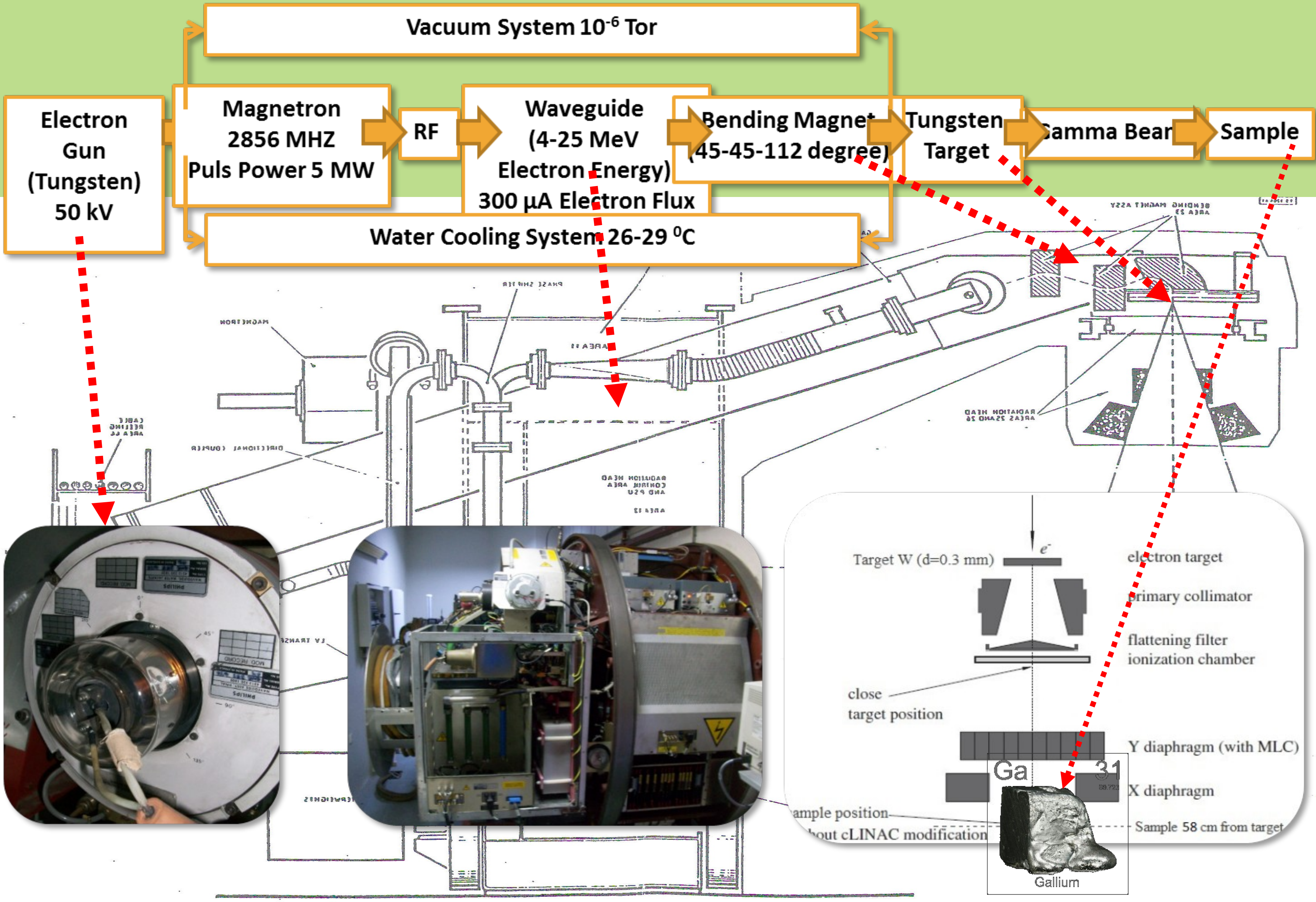
Introduction and history

- Medical linacs are designed to use electrons or photons in radiation therapy, mostly to cure various cancers
- most clinical linacs(cLINAC) have a tilted horizontal waveguide and a bending magnet at the end to turn the vertically towards the patient
- they mostly use electron beams between 4 and 25 MeV
- cLINAC produces a reliable and accurate radiation beam(better than Co60)
- Linac-based radiation therapy for cancer therapy began in 1953 in London at Hammersmith Hospital
- by 1955 several machines were being used in USA
- in 1962, Varian introduced the first fully rotational isocentric 6-MeV bent beam linac.
- in 1970 Varian introduced standing wave accelerators to medical use
- today there are a great deal of medical linac all around the world
- in Turkey there are about 200, in EU there should be thousands and world wide tens of thousands

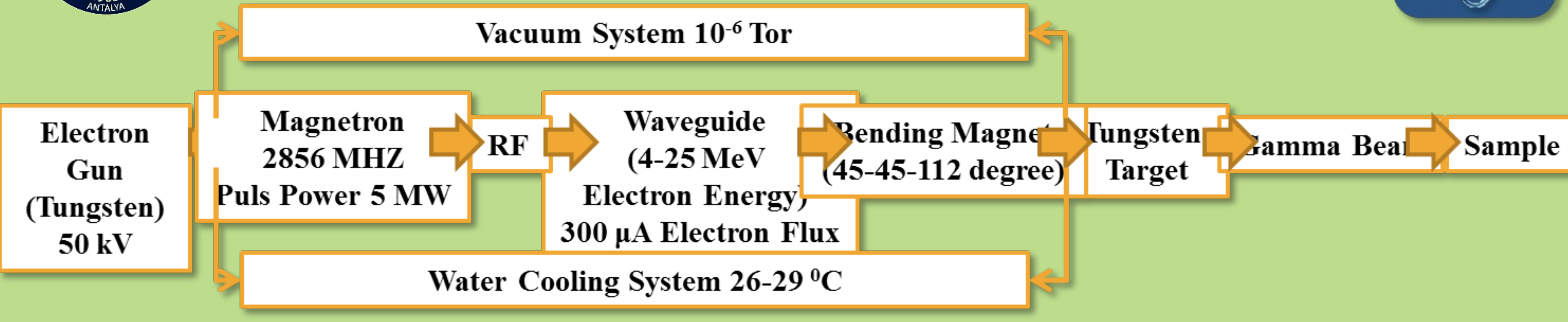
Basic description

- the electrons are boiled out of a hot cathode and accelerated up to 50 keV by static electric field
- they are formed into a pencil beam by a convergent electric field between the gun electrodes
- The rf electric field at the beginning of the accelerating structure forms the electron stream into bunches
- the bunched electrons are accelerated by the rf accelerating electric field oscillating at 3000 MHz(S-wave)

Medical Electron Linear Accelerator



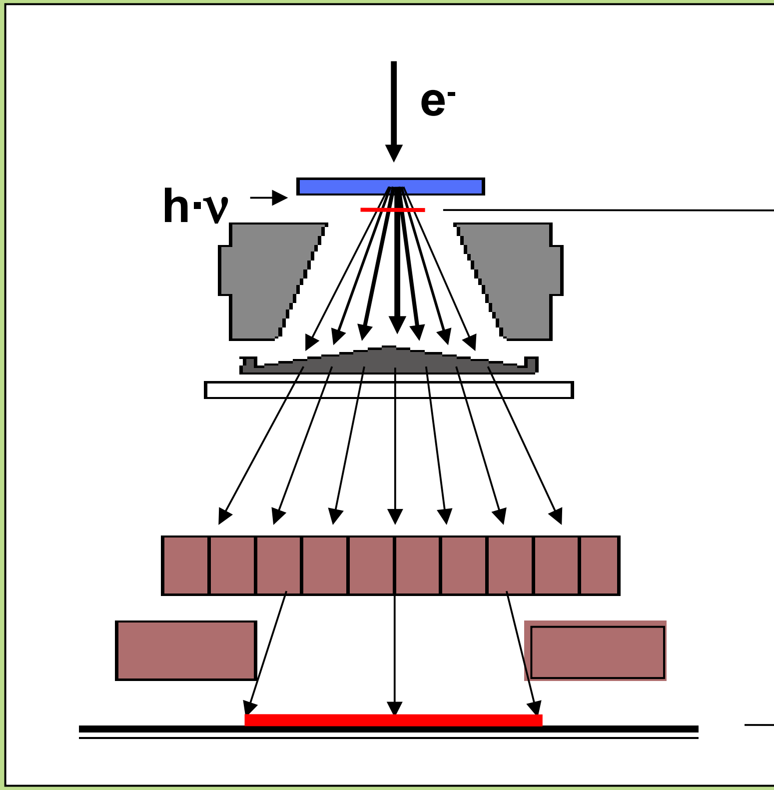
THE GALLIUM EXPERİMENT: ACCELERATOR

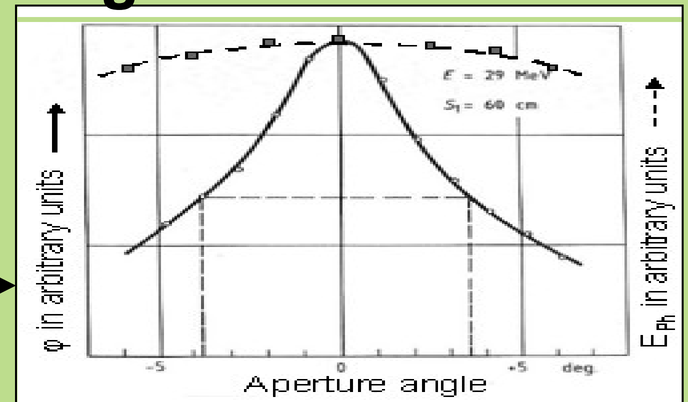


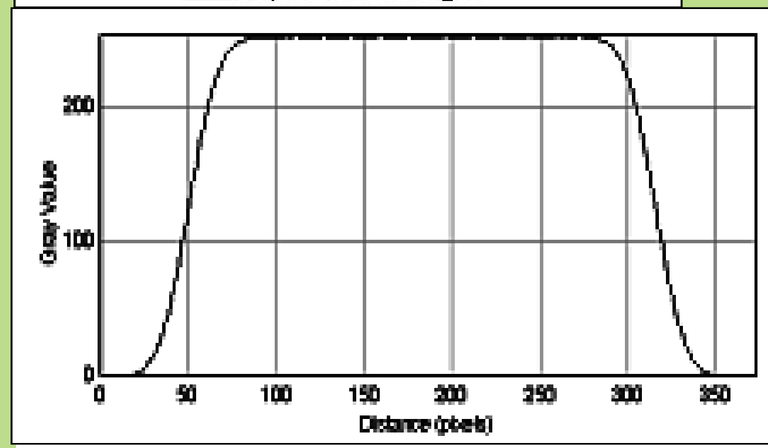
Primary electron beam is generated by an electron gun with 50 keV electrons.

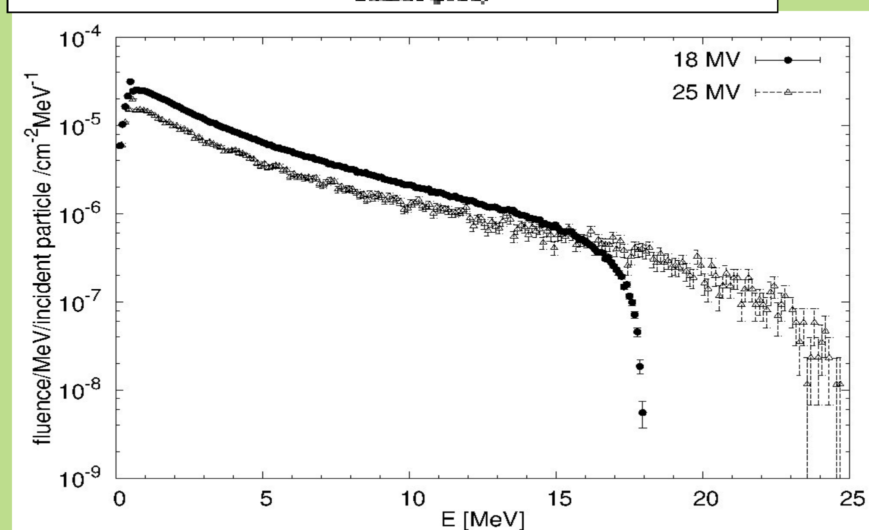
- Then the beam accelerated in a copper cavity by a 3 GHz (2856MHz to be exact) radio-frequency with peak power of about 5 MW.
- The typical average electron current is about 30 μA for an electron energy of about 18 MeV,
- The SLi-25 is a pulsed linear accelerator with 400 pulses per second and a pulse length of 3 micro seconds.
- The steering and focusing of the beam is achieved by standard magnetic and electrostatic devices.

The bremsstrahlung field

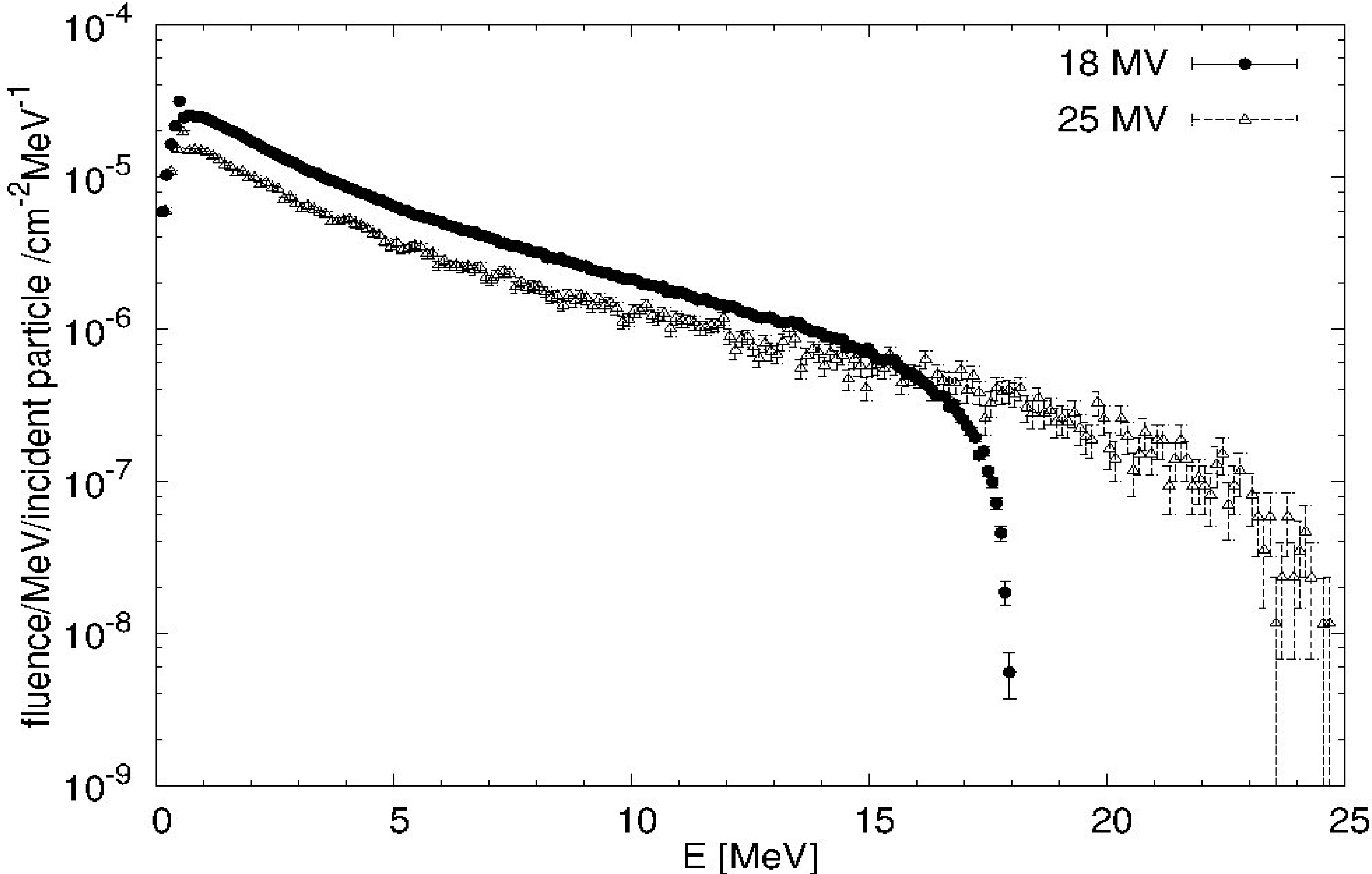








Bremsstrahlung spectrum at 100 cm from radiator



cLINAC dose rate/flux

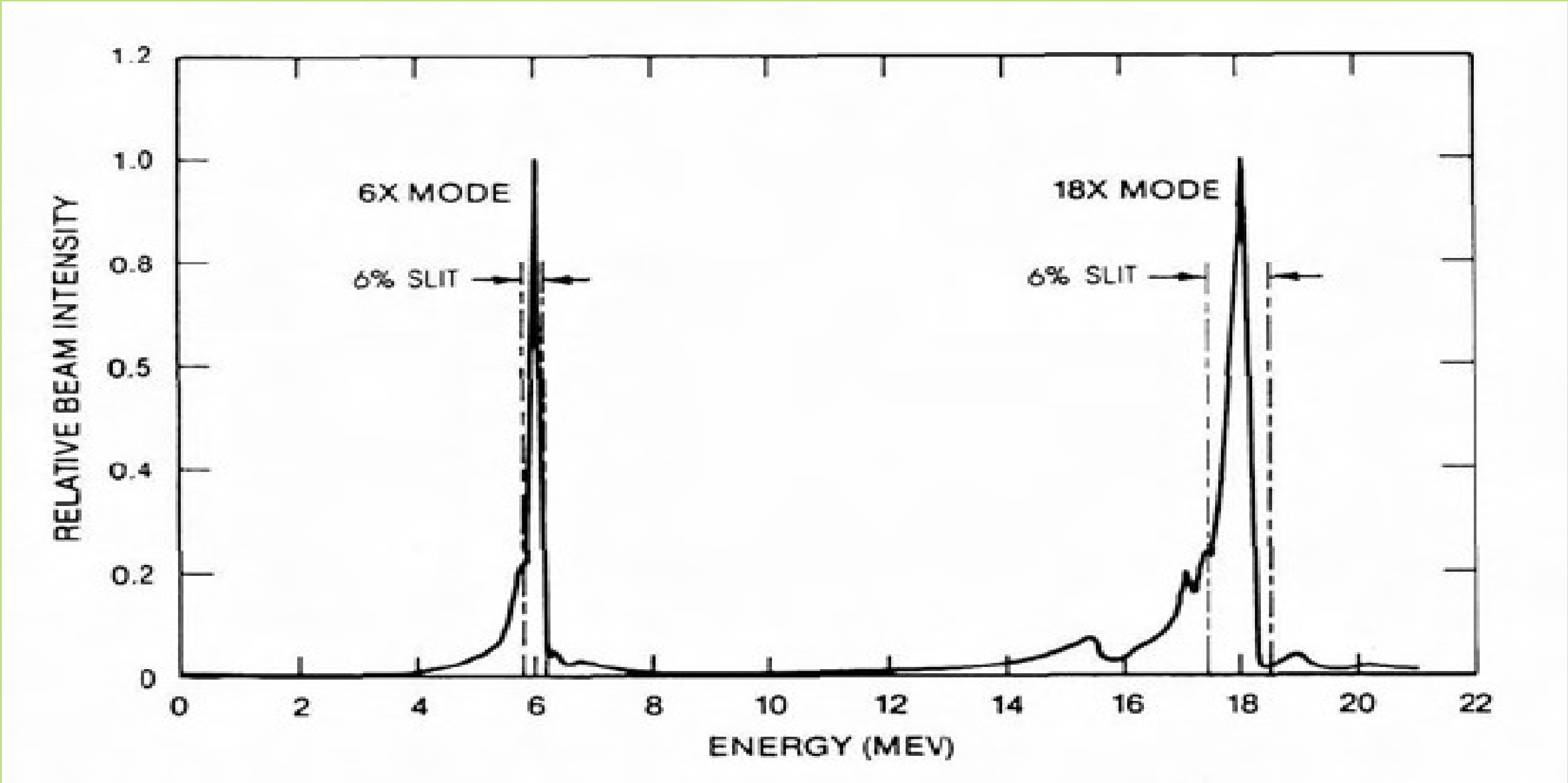
X-rays[a]				Electrons[a]			
Energy, (MV)	Average beam current in µA	Filter trans. (%)	Dose Rate (cGy/m/1m)	Energy (MeV)	Average beam current in nA	Scatter Foil (mil)	Dose rate, (cGy/m/1m)
4	200	45	200[b]				
6	100	35	400[b]	6	100	3 Ta	500
10	70	30	500[c]	9	97	{ 8 Pb	500
15	50	25	500[c]	12	67	+	500
18	30	18	500[c]	16	42	7 Al	500
						button }	
25	20	10	500[c]	20	30		500

@18 MeV electron current is 30 µA which implies ~2×10^{14} e/s

for bremsstrahlung photons we would have about 10^8 photons/s @6 MeV

Note that in electron mode beam current is **42 nA,** nearly **1000** times less than for X-ray mode, because the requirement that the dose delivered is 500 cGy/min at 100 cm

Energy stability



Typical electron energy distribution in an medical linac

The allowed deviation of the mean of the energy spectrum transmitted by the energy slit is limited to ΔE/E=1%

this is achieved by accelerating with broad electron spectrum (ΔE/E=20 %) and selecting the narrow energy window by the steering magnets

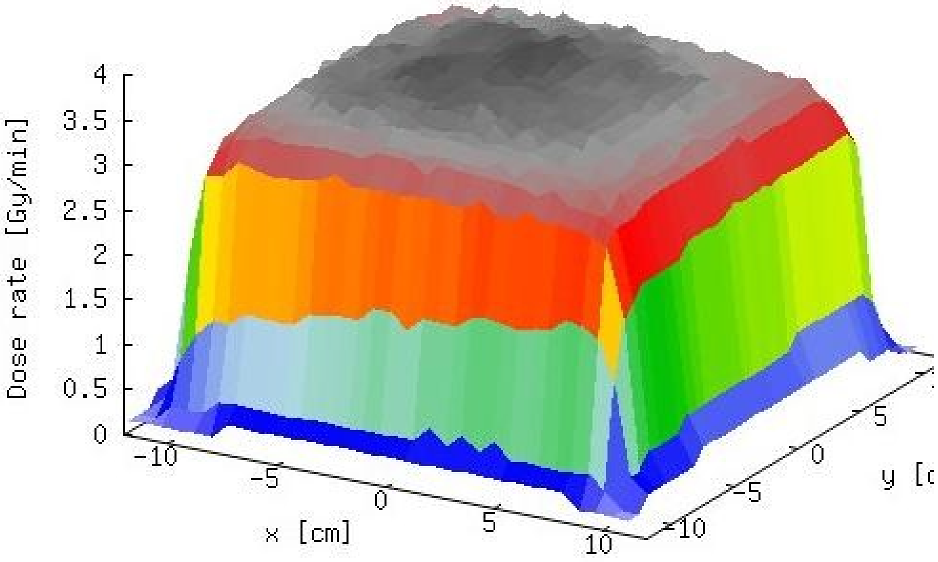
Dose measurements with matrix

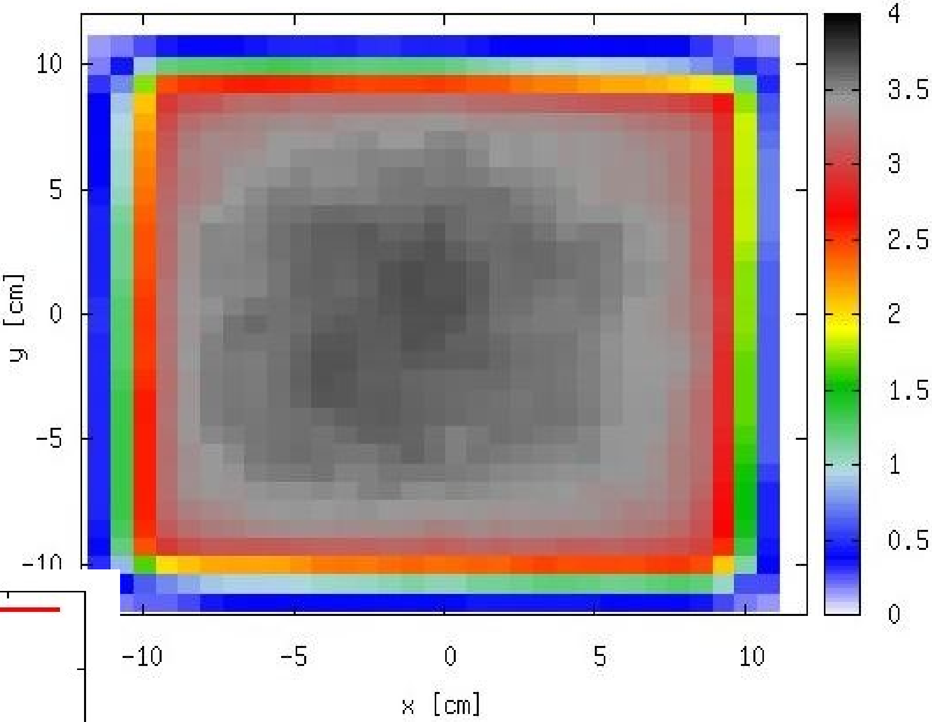
Spatial beam uniformity:

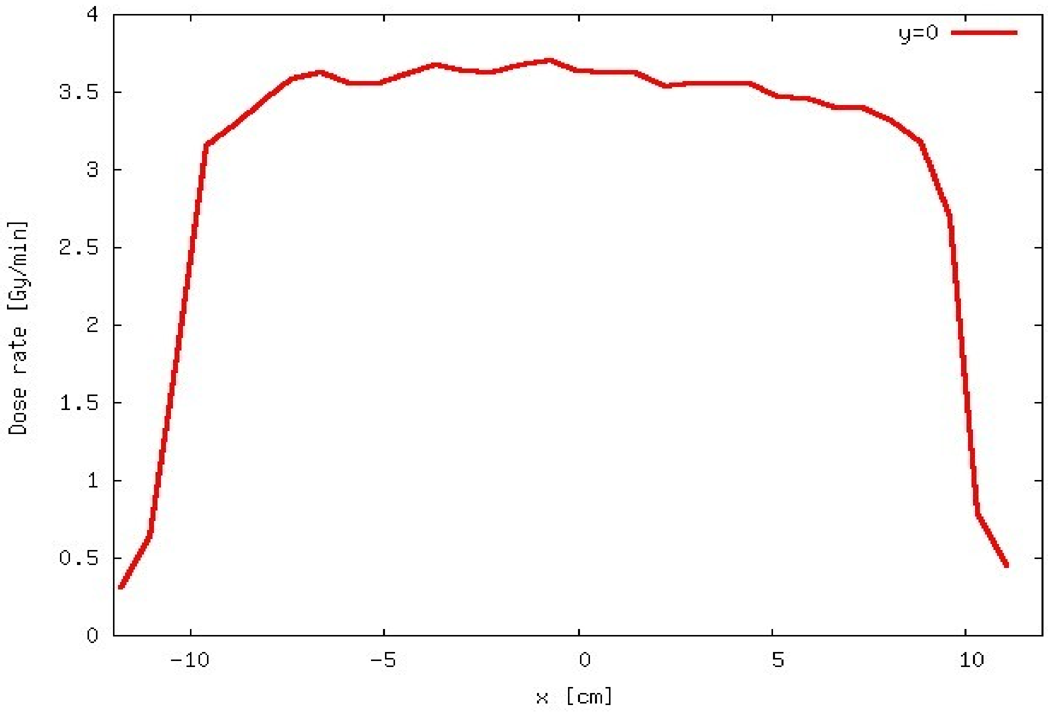
Measurement performed with a matrix of 32x32 ion chambers for 2 s.

Longer measurement times reduce the variations.

Standard dose rate



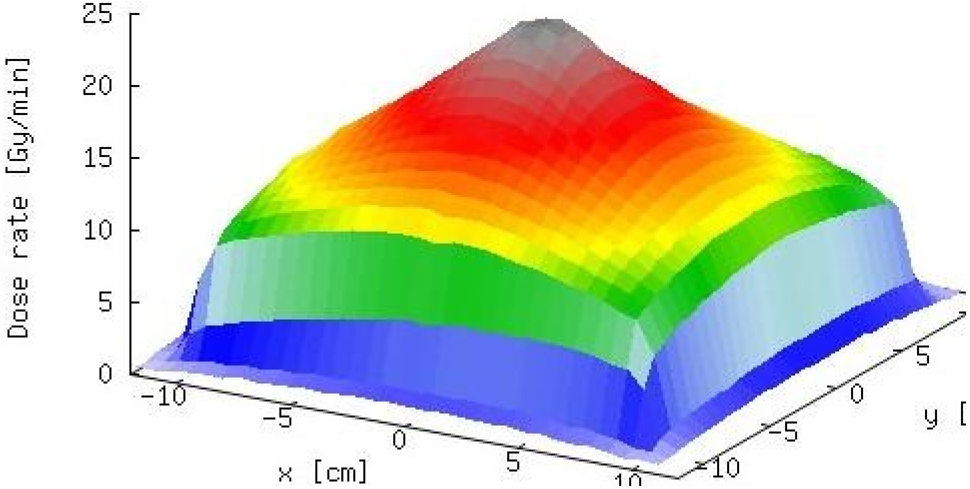


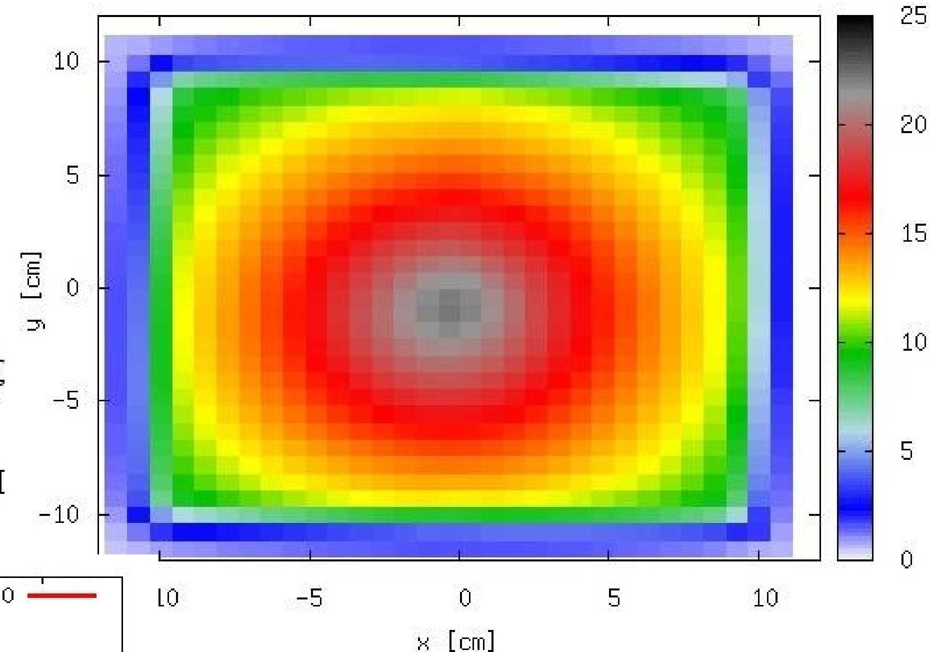


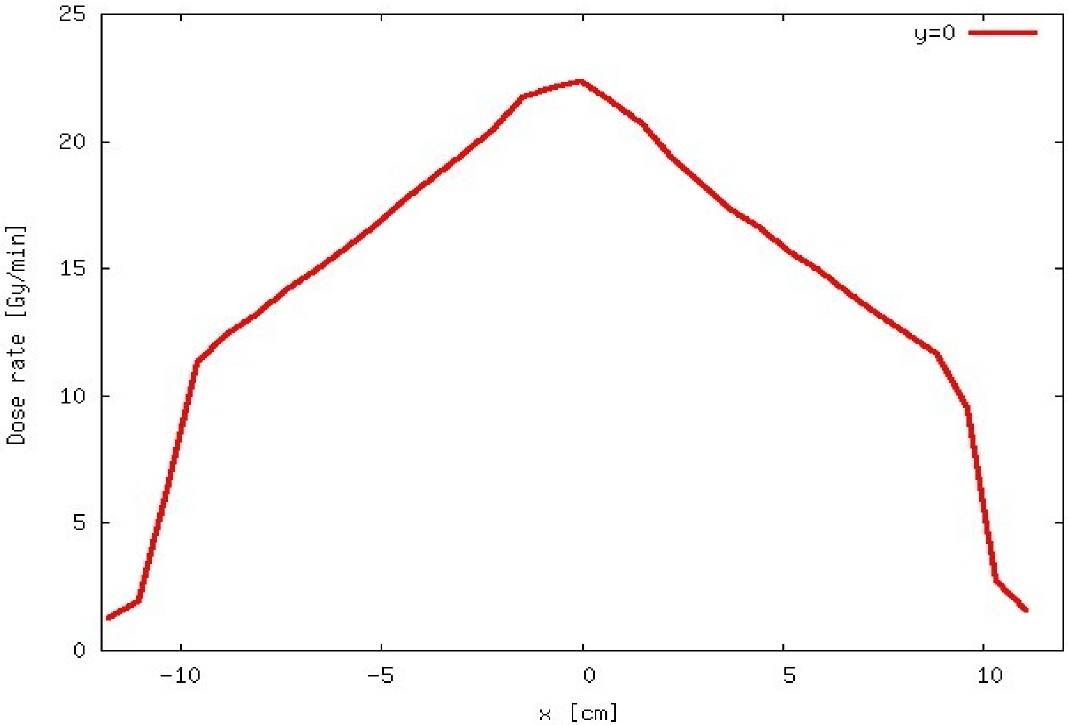
Matrix is used to measure only beam uniformity and asymmetry of dose.

Our field uniformity would be unacceptable in medicine.

Increased dose rate (no flattening filter)





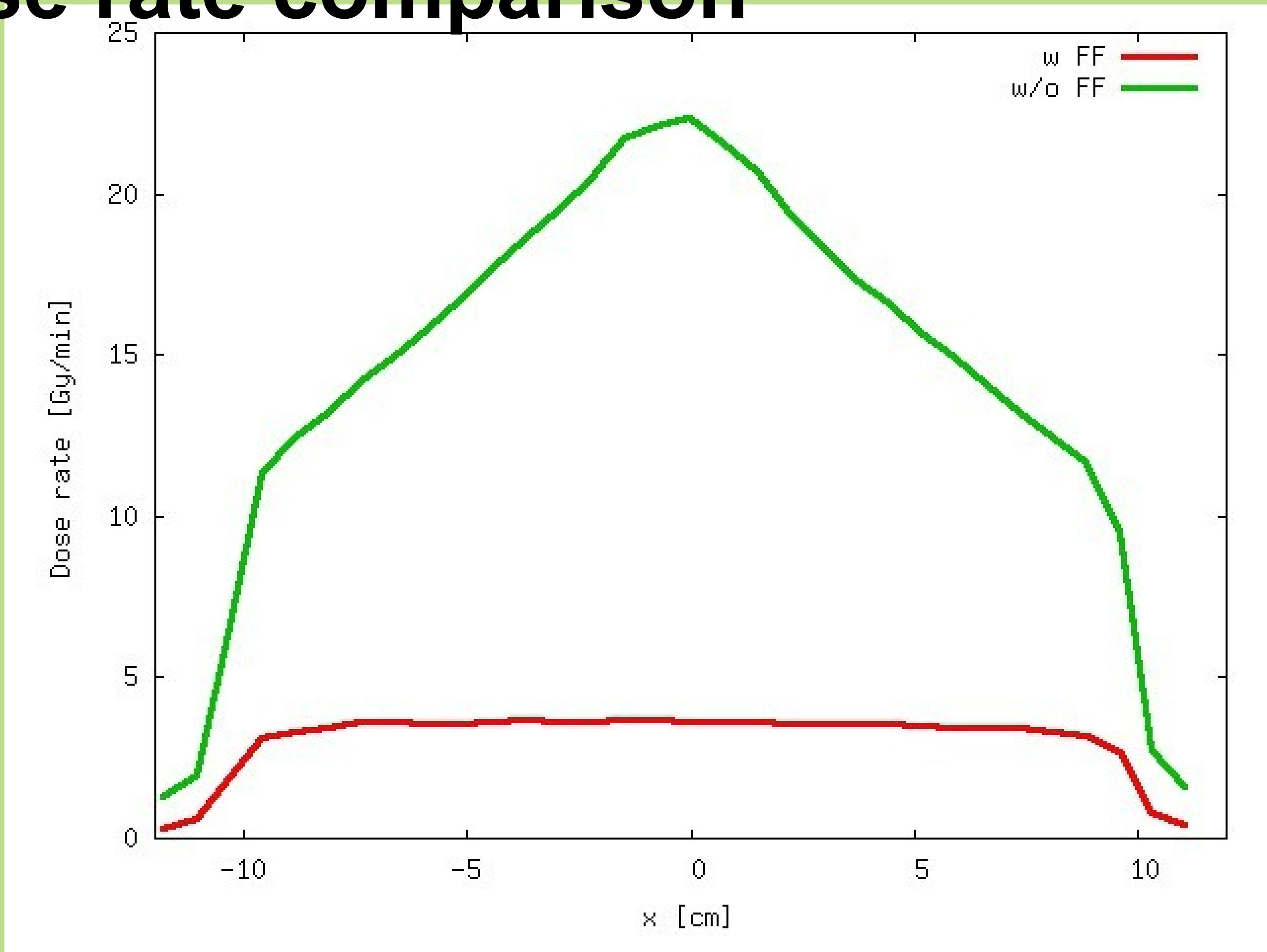


- Ion chamber used for absolute dose measurement In combination with matrix it gives dose rate information for the whole field.

Dose rate comparison

w FF dose rate is **3.69 Gy/min**

w/o FF dose rate is **22.10 Gy/min** a **~6 fold** increase



The system (internal ion chambers) measures the dose rate at the edges, only ~3 fold increase

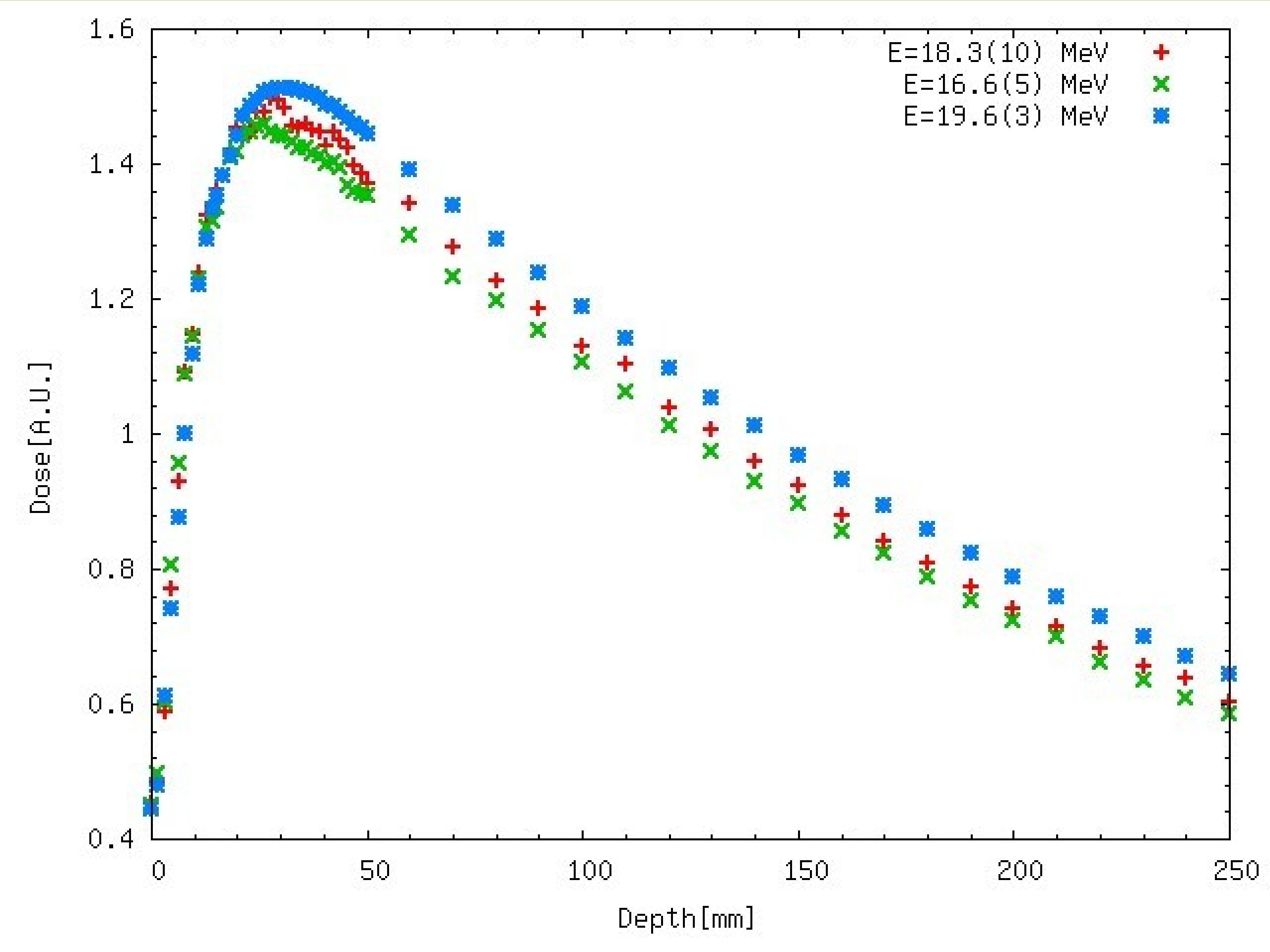
We can achieve ~8 fold increase, but the system sees ~4 fold and stops the beam after ~1 min

Water phantom

Water phantom is a tank of water with an ion chamber whose position can be changed in x-y-z coordinates

water phantom is designed for relative dose measurements in radiation beams with vertical beam incidence.

Dose depth measurements



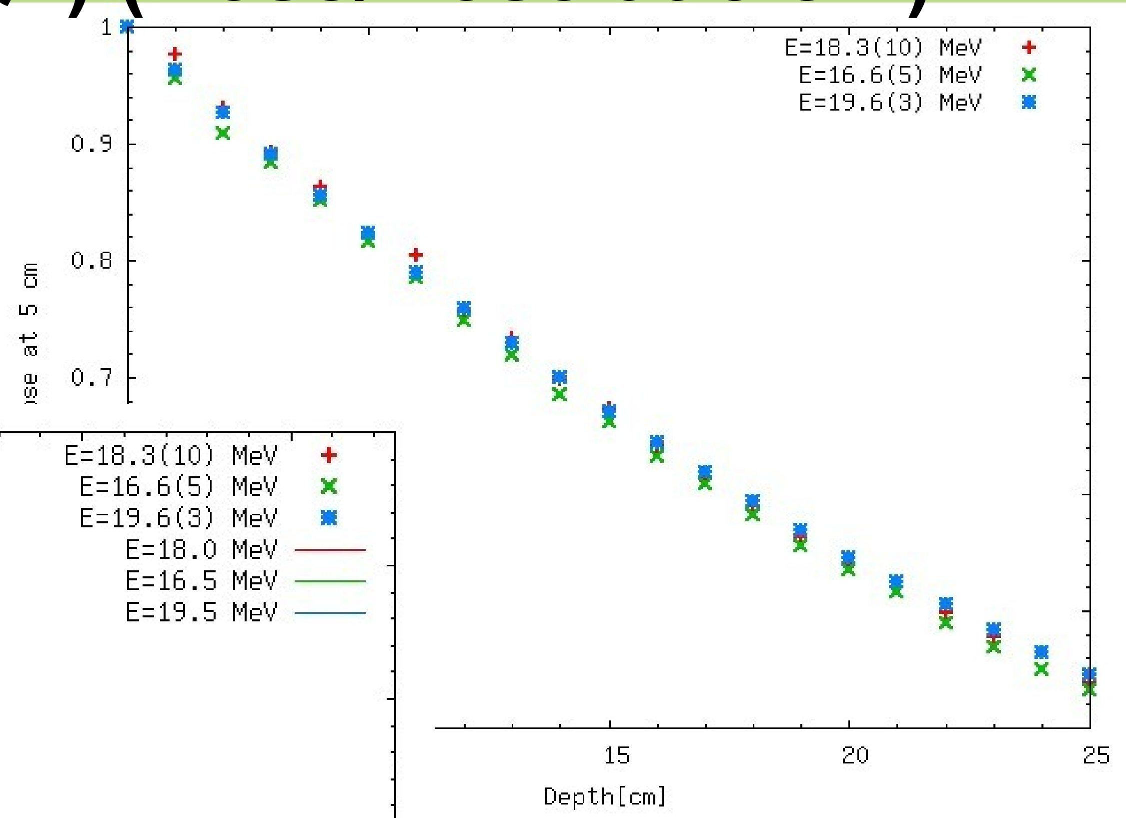
Dose-depth measurements of beams with different energies

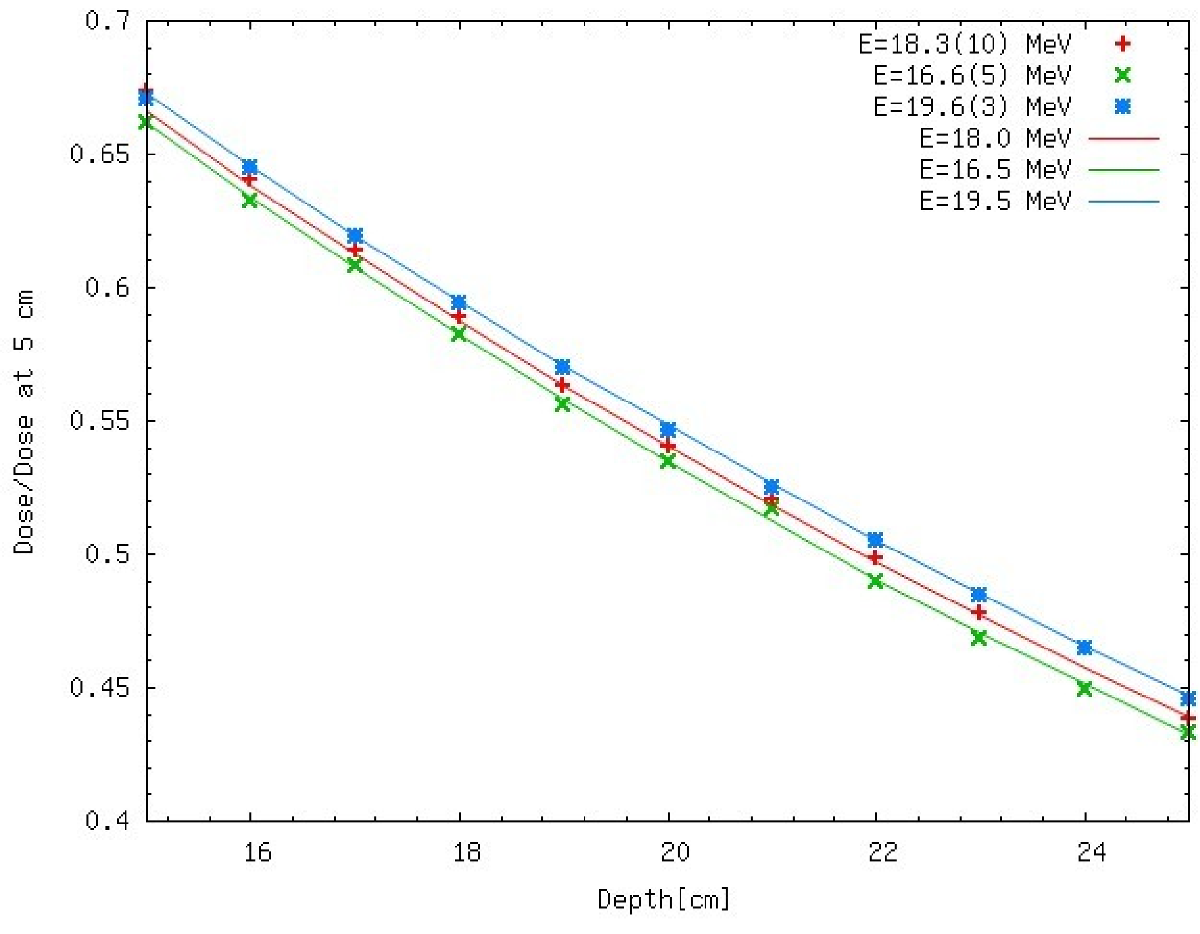
The penetration of each bremsstrahlung beam depends primarily on its energy. So the energy can be measured by measuring the penetration properties of a beam.

Quality factor(QF) (Dose/Dose at 5 cm)

To remove geometry effects a ratio of doses is used.

Quality factor(med.)



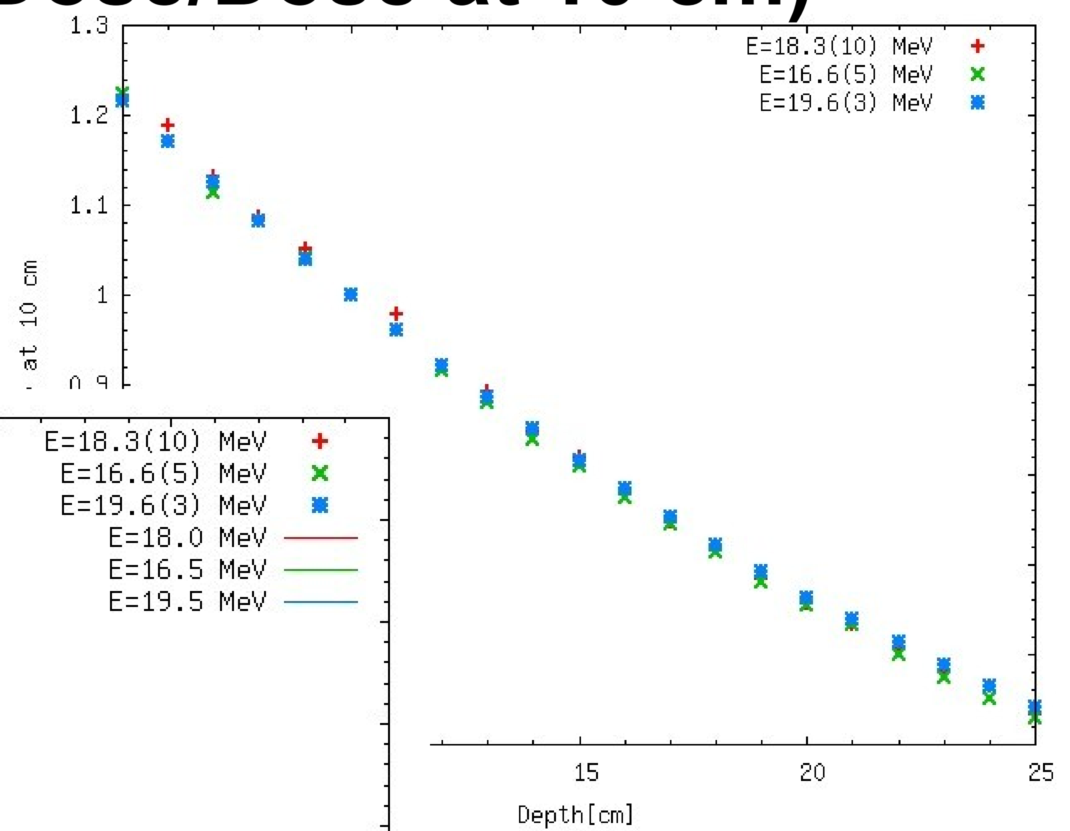


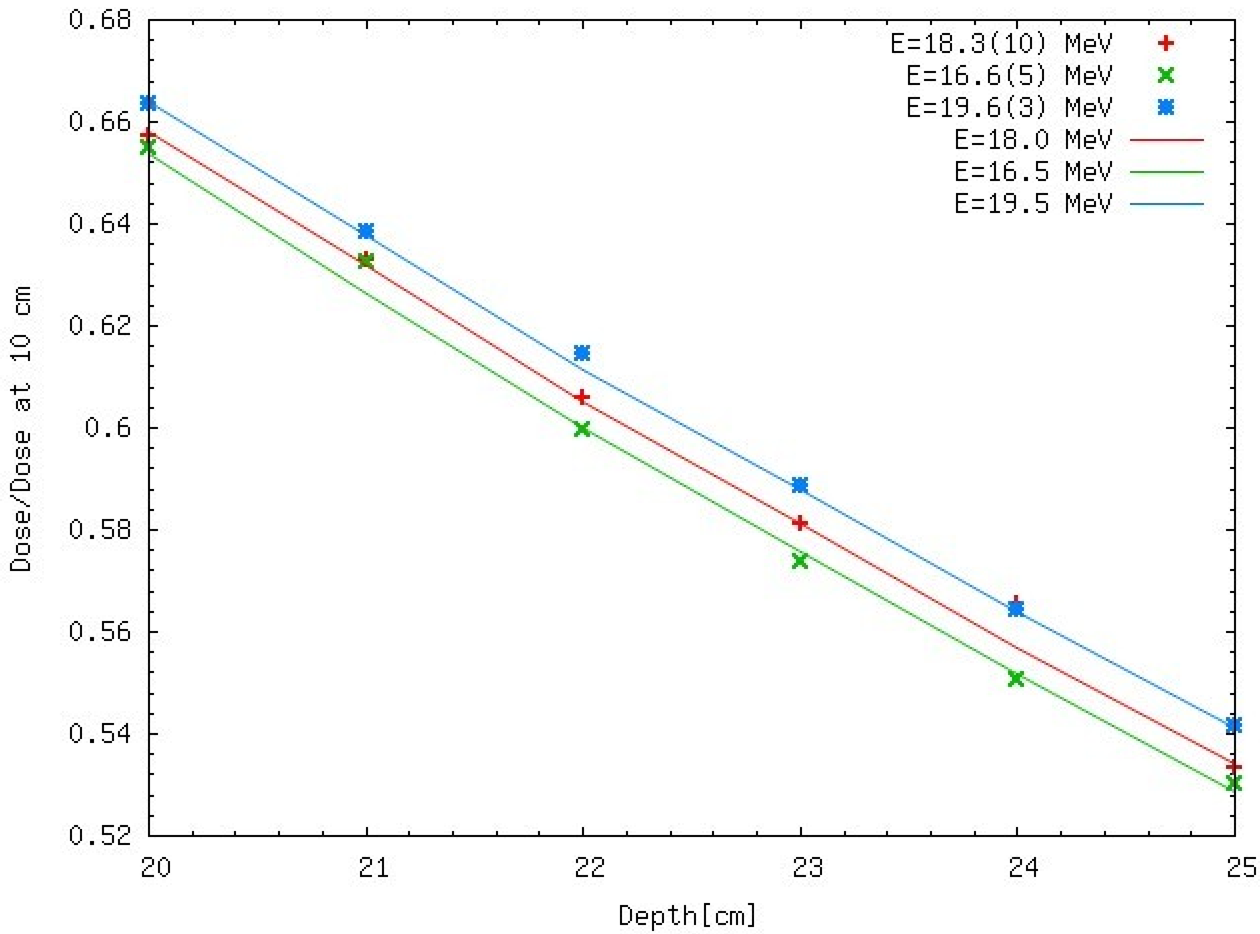
Measured QF is compared to literature values.

Only two QF factors are used, at 20/5 cm and 20/10 cm

Quality factor (Dose/Dose at 10 cm)

We used all points from 15 to 25 for 5 cm and 20 to 25 at 10 cm and interpolated



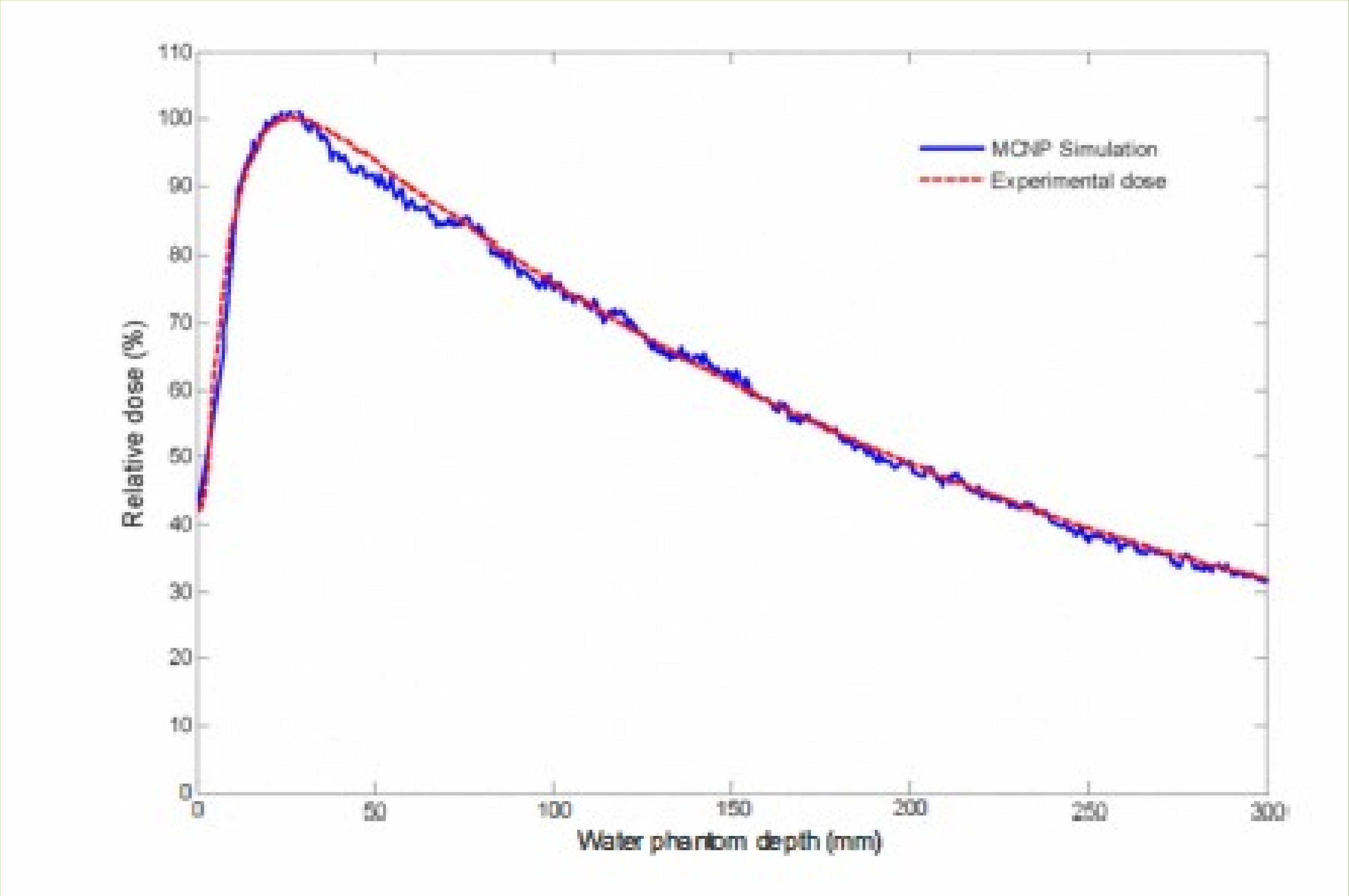


The difference in results was used as standard deviation. Systematic errors still remain.

Energy results

- data for dose depth curves is taken from BJR-25 1996 Central axis depth dose data for use in radiotherapy: 1996 Br. J. Radiol. (suppl 25)
- this data is fitted to the data obtained in our measurement for several depths
- variation in energy determination is used as statistical errors
- we were able to measure the energy for three steps
- low: 16.6(5) MeV, nominal:18.3(10) MeV and high 19.6(3) MeV
- control of energy, to obtain a stable and clean beam is a lengthy process of trial and error

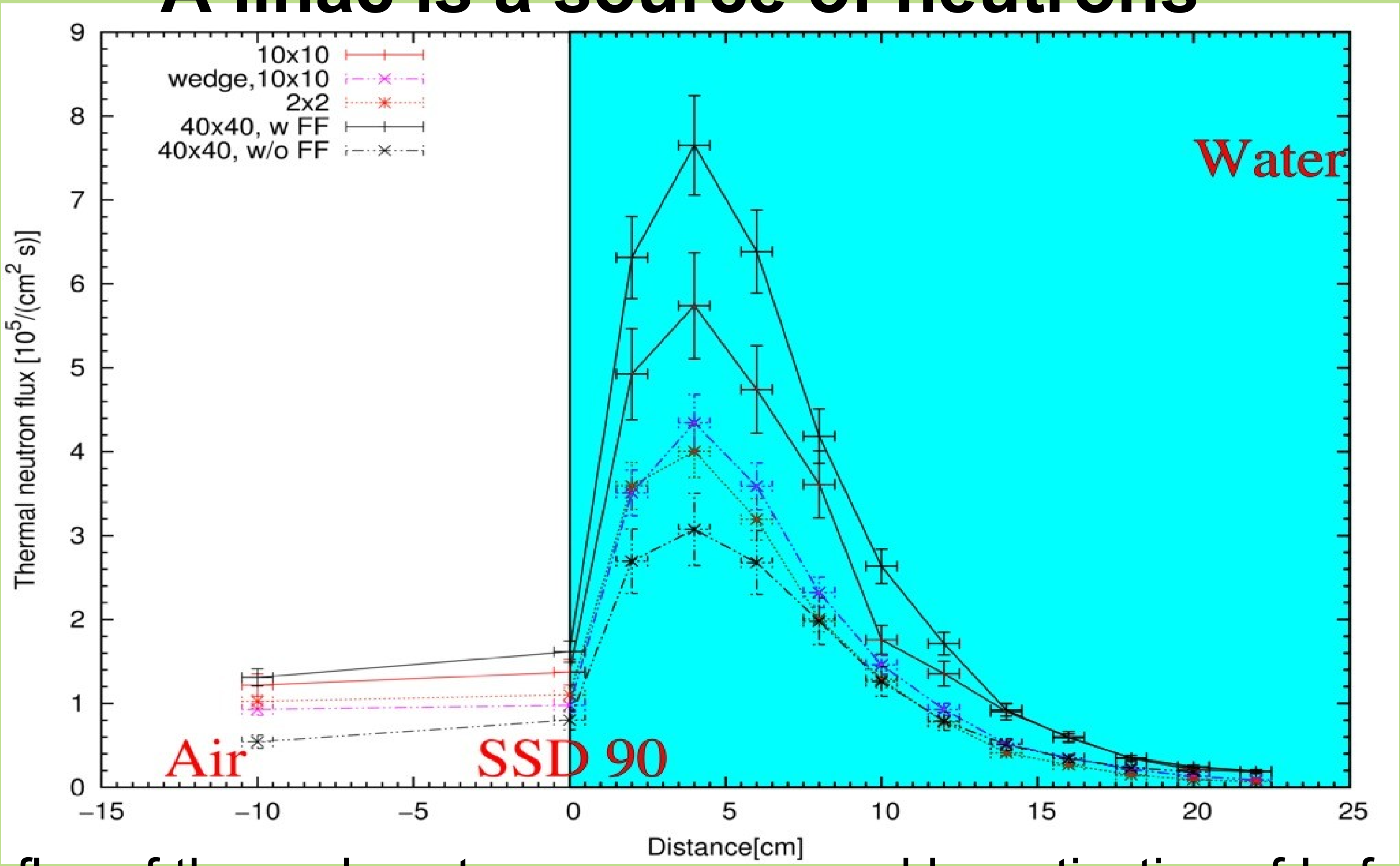
Dose depth simulation and energy determination



First simulation results

Other Monte Carlo simulation are currently ongoing.

A linac is a source of neutrons



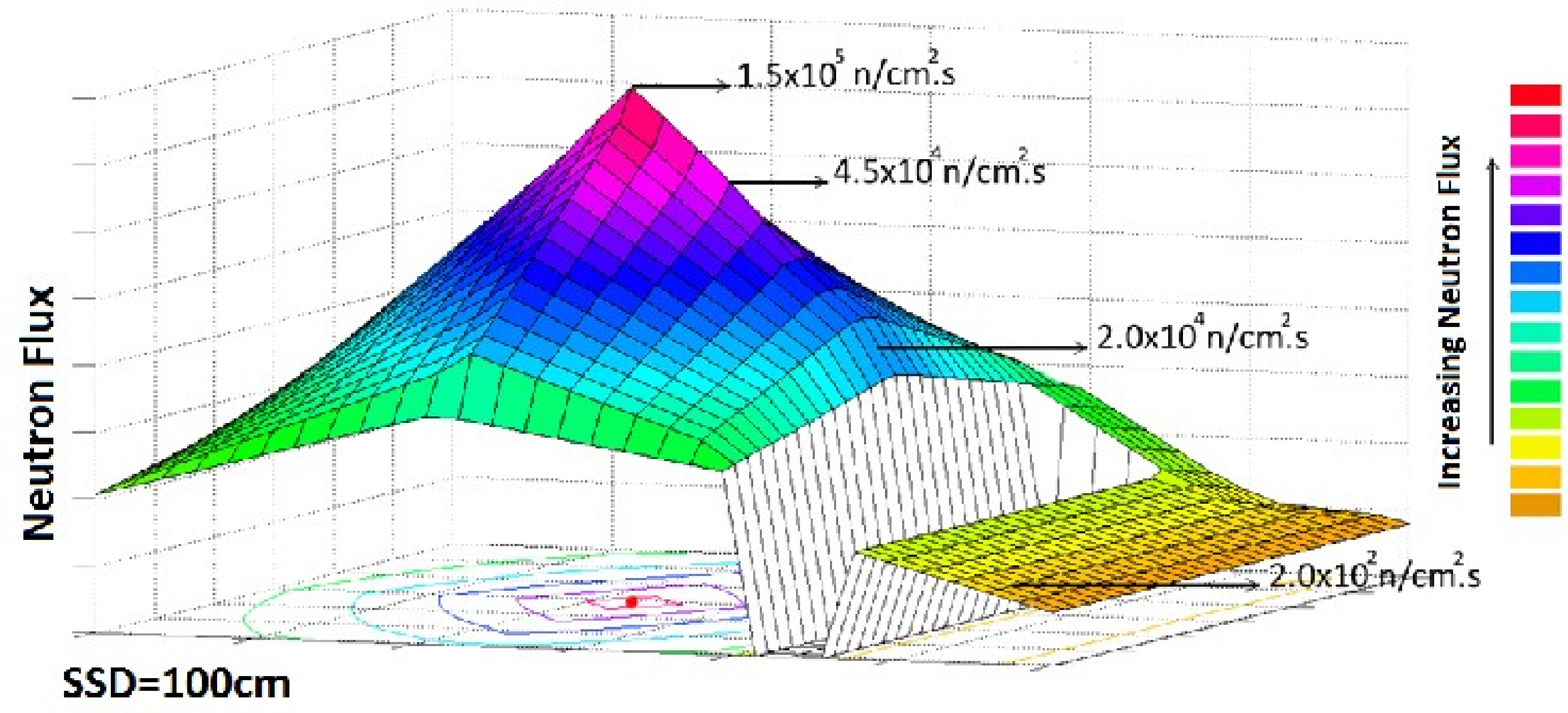
The flux of thermal neutron was measured by activation of In foils

Most neutrons come from the radiator and the FF

In air measured flux is 1.5×10^5 /cm^{2}s in water up to 8×10^5/cm^{2}s

At source ~10^{11} /s, if anisotropic

Measurement, in air, of 3d distribution of thermal neutrons



CCD cameras in treatment rooms have a half-life of 6-12 months primarily due to neutron damage.

Mapping the neutron distribution can help shield the cameras to a degree and extend their half-life

Conclusions and Summary

- cLINAC, designed for radiotherapy, is a good and versatile source of photons for nuclear physics applications
- however the primary design philosophy of delivering and maintaining a safe dose to a patient is an obstacle
- simplest of obstacles, the flattening filter, can be easily removed and a significant flux increase is achieved (~6-8 fold)
- Measuring and controlling the bremsstrahlung photons energy is a daunting task (many control mechanisms)
- First attempts at energy control yielded good results, we managed to obtain results within 0.5 MeV accuracy
- A linac is a good source of neutrons as well; $8 \times 10^5/cm^2s$ at 90 cm and $\sim 10^{11}$ /s at source

Outlook

- many more simulations, with different energies and different radiators
- repeating the measurements of energy; mapping a greater range of usable energies and achieving a better measurement accuracy
- using other methods to measure the bremsstrahlung spectrum and endpoint energy
- further modifying the linac for higher flux delivery; getting closet to the radiator; using the electrons;
- using different materials as radiators; optimizing for a harder beam; or optimizing for more neutrons, etc.

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Thank you!

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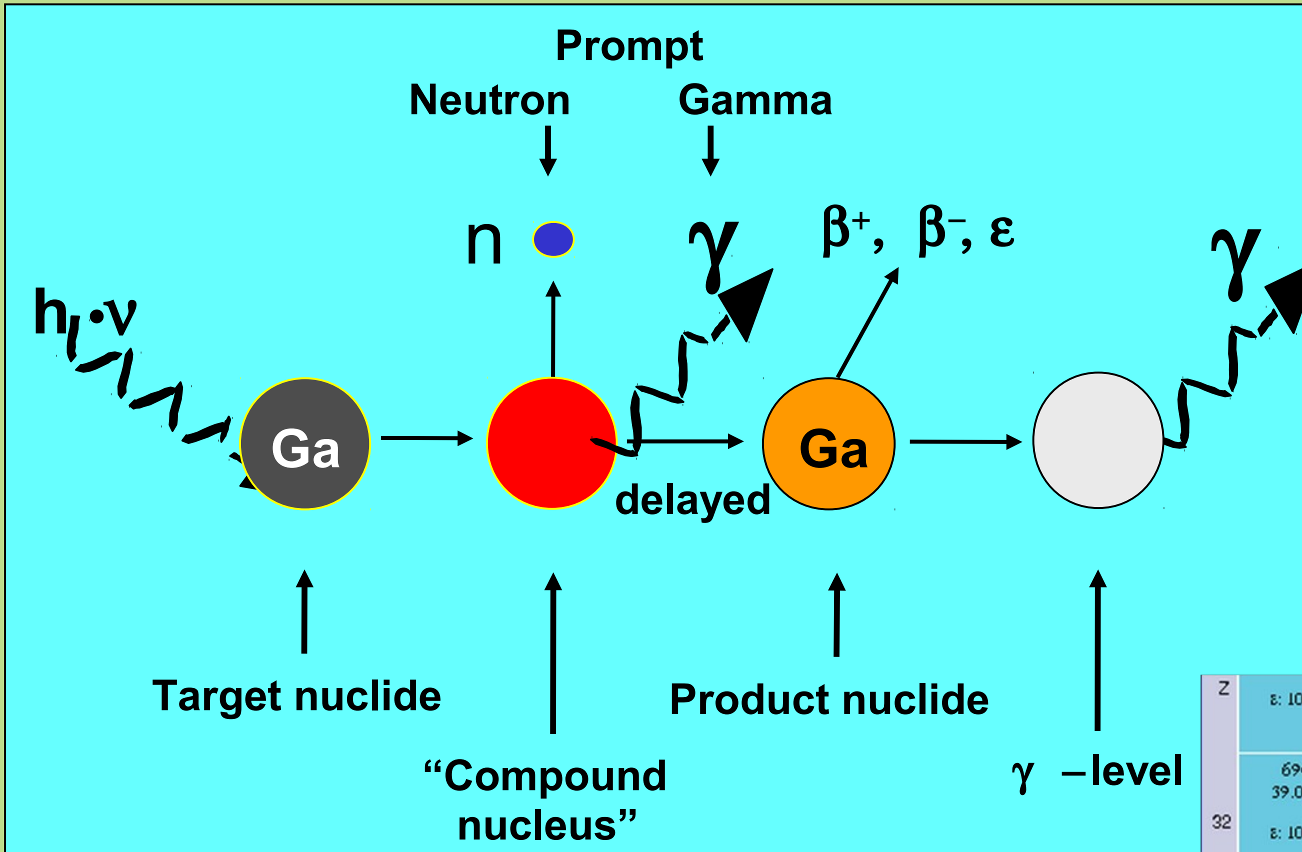
PHOTONUCLEAR REACTİONS & PHOTOACTİVATİON

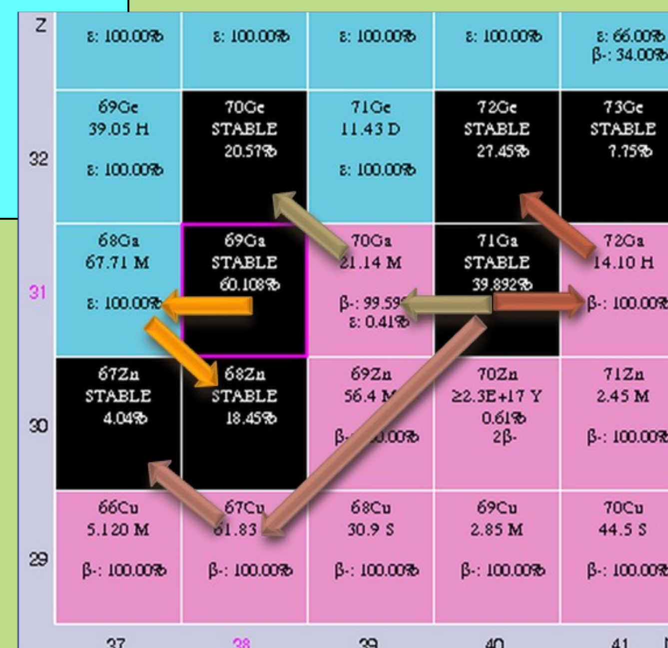


Generic neutron and β^+

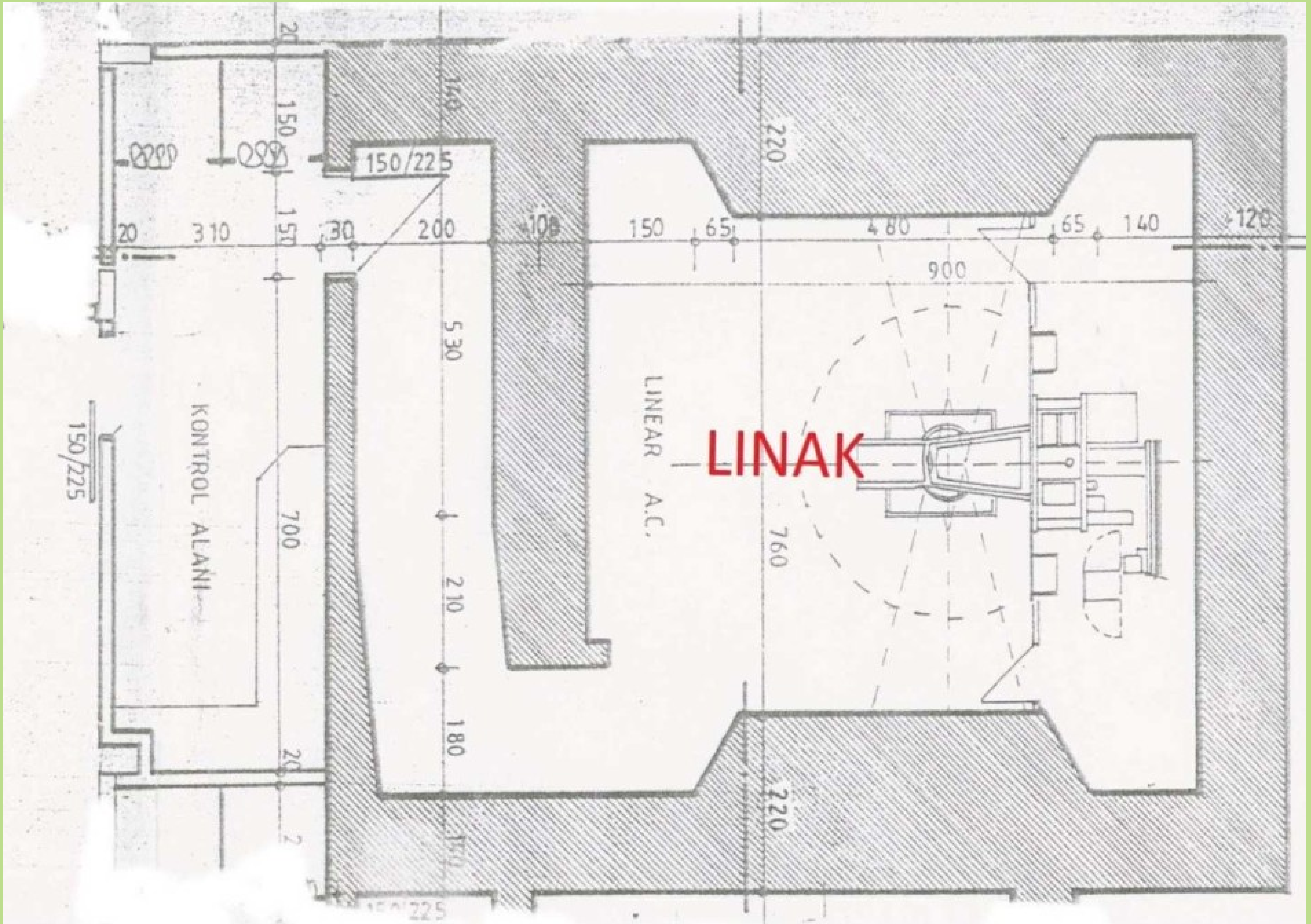
$$\gamma + {}^{A}X_N \rightarrow {}^{A-1}Y_{N-1} + n$$

$$^{A-1}Y_{N-1} \rightarrow {}^{A-1}Z^*_N + e^+ + \nu$$

$$^{A-1}Z^*_N \rightarrow {}^{A-1}Z_N + \gamma$$



Linac room


LINAK
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