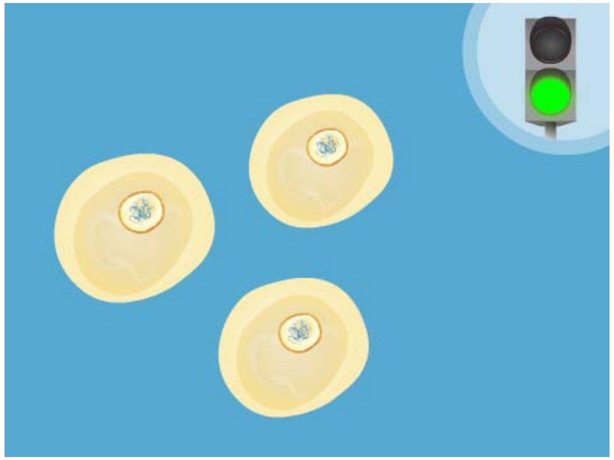
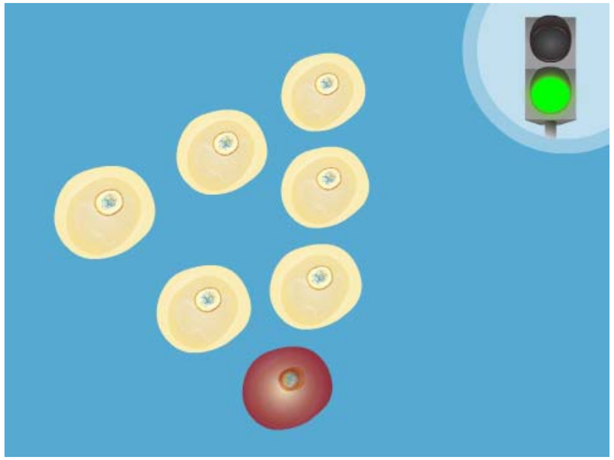
CNAO ACCELERATORS AND BEAMS

Marco Pullia

Cells multiply



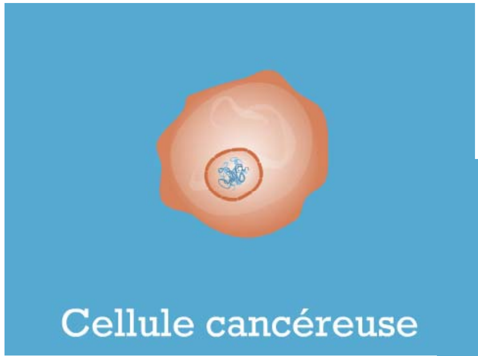


Normally cells multiply only when they are told so

If there is a mutation (DNA error)…

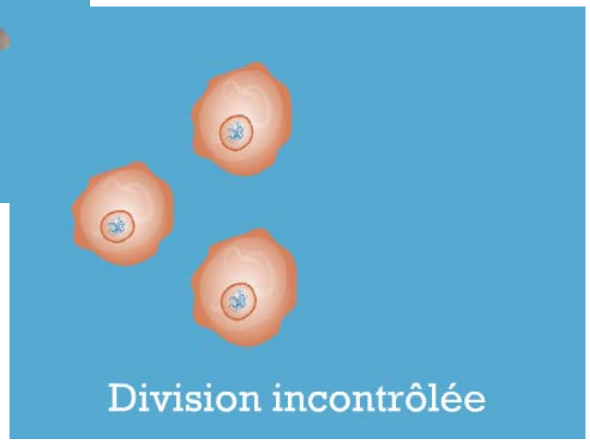
…the cell is told to suicide (apoptosis)

Tumour

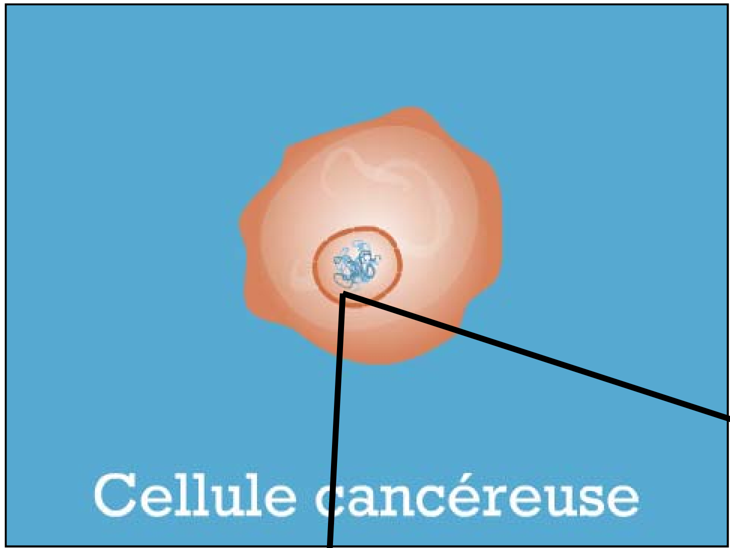


Something (else) goes wrong and the mutant cell refuses to die …

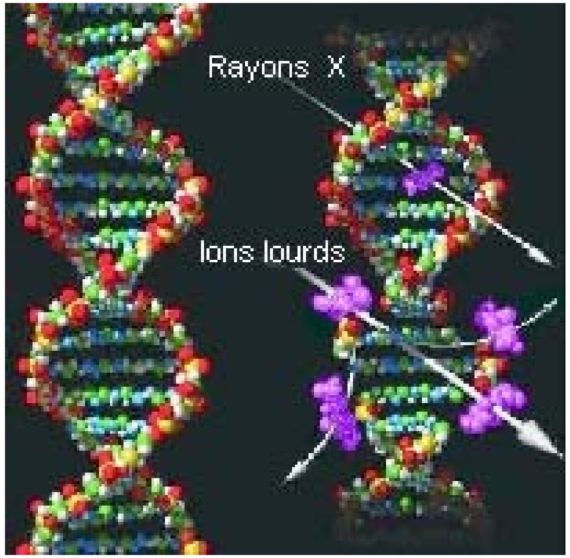
… and begins to multply in an uncontrolled way

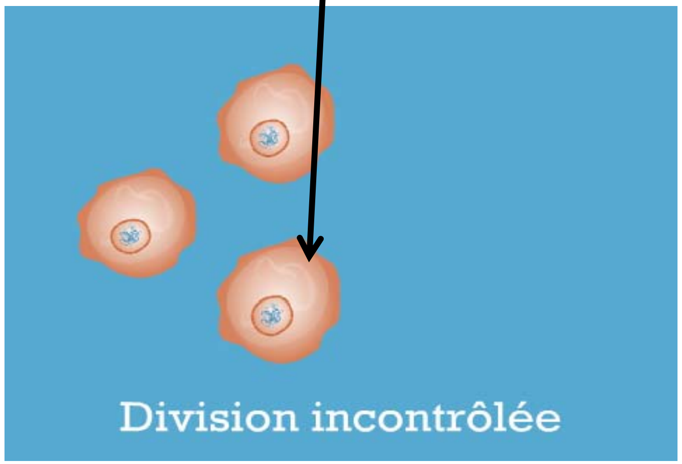


TUMOUR!



La cellula tumorale ha un DNA mutato





Le radiazioni sono in grado interagire
col DNA e bloccare la crescita incontrollata

La progenie della cellula d'origine
porta la stessa mutazione

Tumours

- They grow in an uncontrolled way
- They infiltrate the surrounding tissues and can originate metastasis (malignant)
- When metastatic, only chemotherapy is possible
- If localised, surgery or radiotherapy

Energy and Efficacy

Administered dose

1 Gy = 1 J / 1Kg

How many cells do I kill?

Potential energy (1 m fall = 10 Gy)

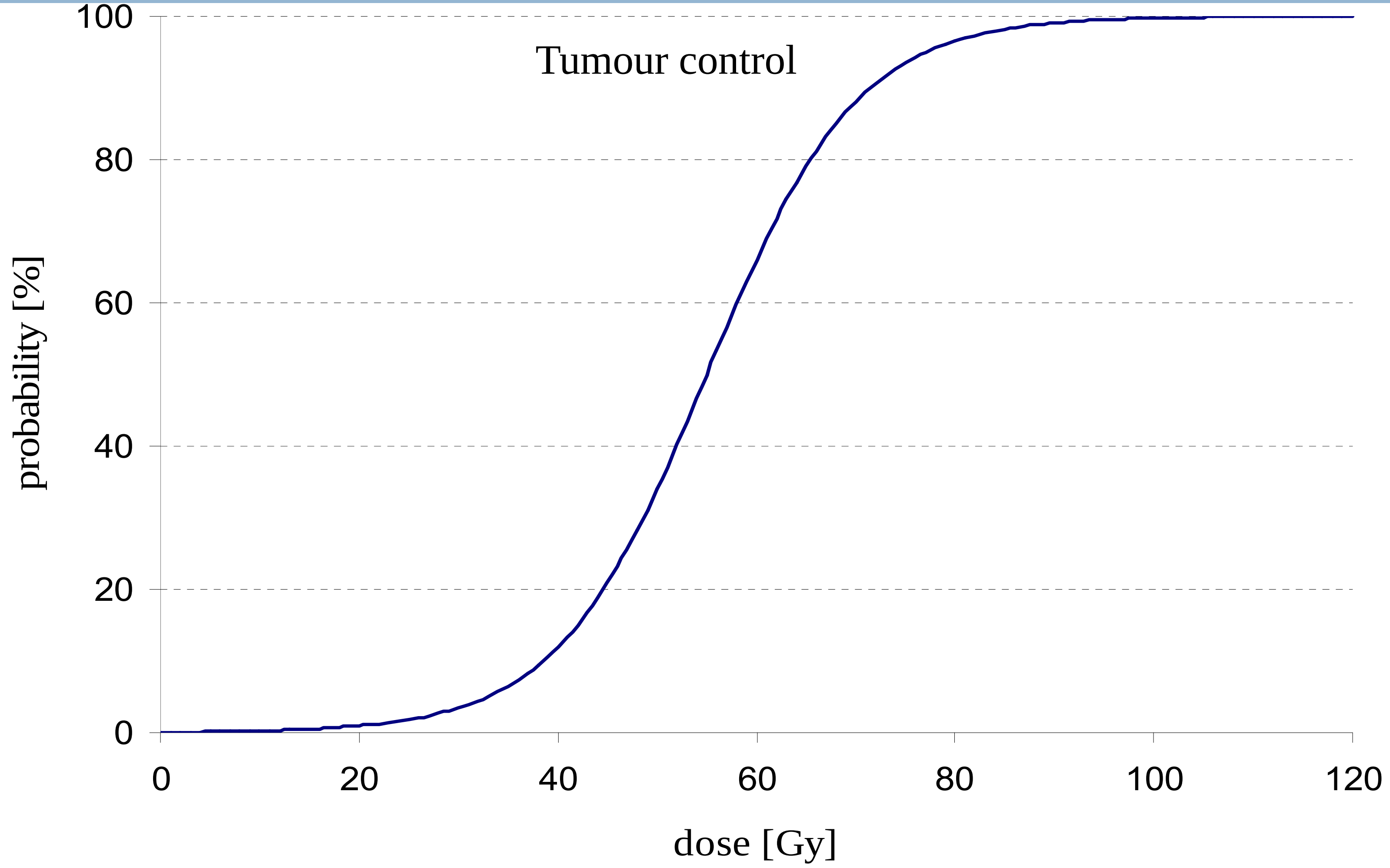
Heat (fever 38° = 4185 Gy)

Ionizing radiation (little energy, many damages)

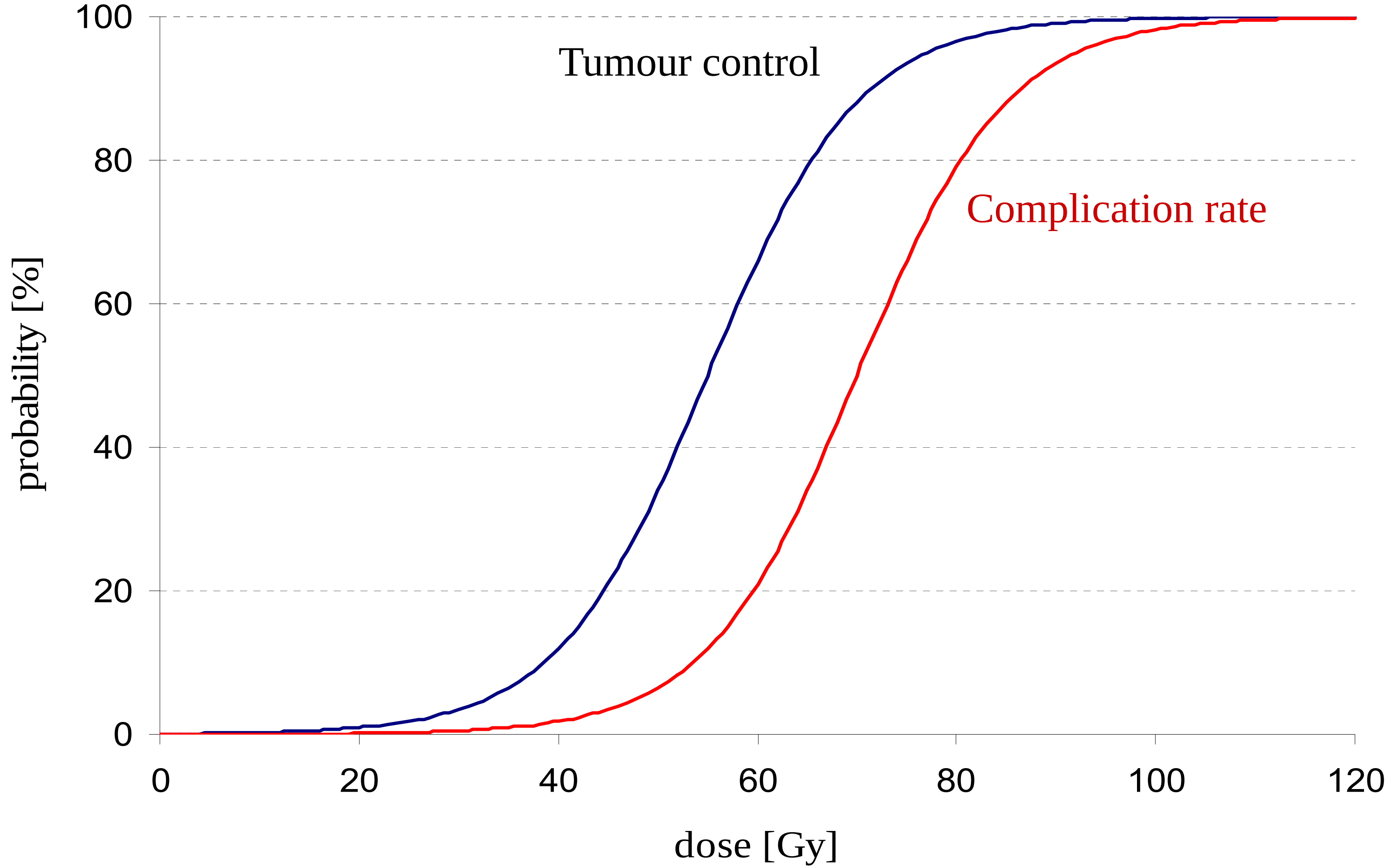
Radiation damage

- Ionization breaks chemical bonds
- Free radicals creation (mainly hydroxyl radical, OH^-, and superoxide, O_2^- . Poison for the cell!)
- The target is DNA, ionization distribution is relevant

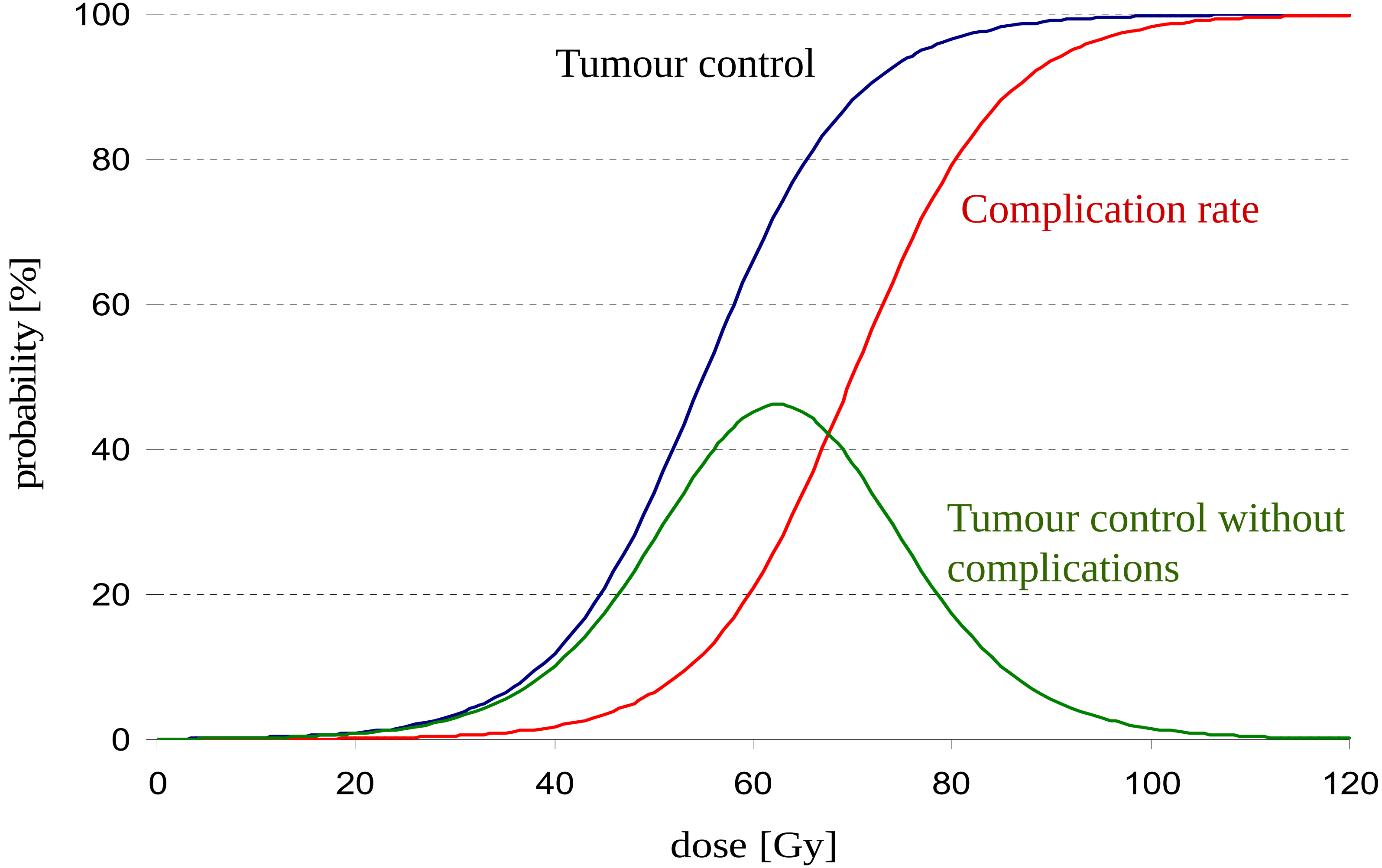
General principle of radiation therapy



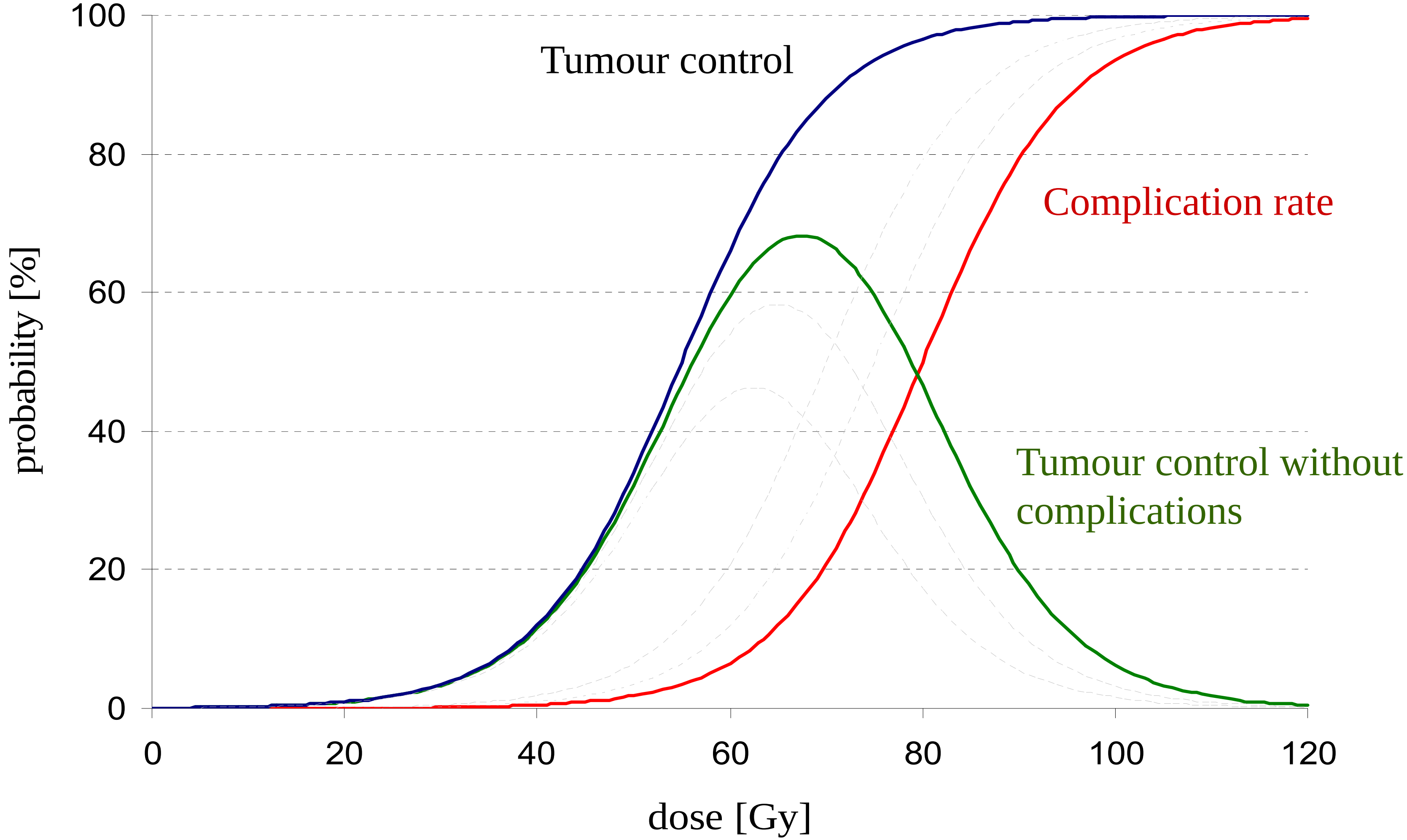
General principle of radiation therapy



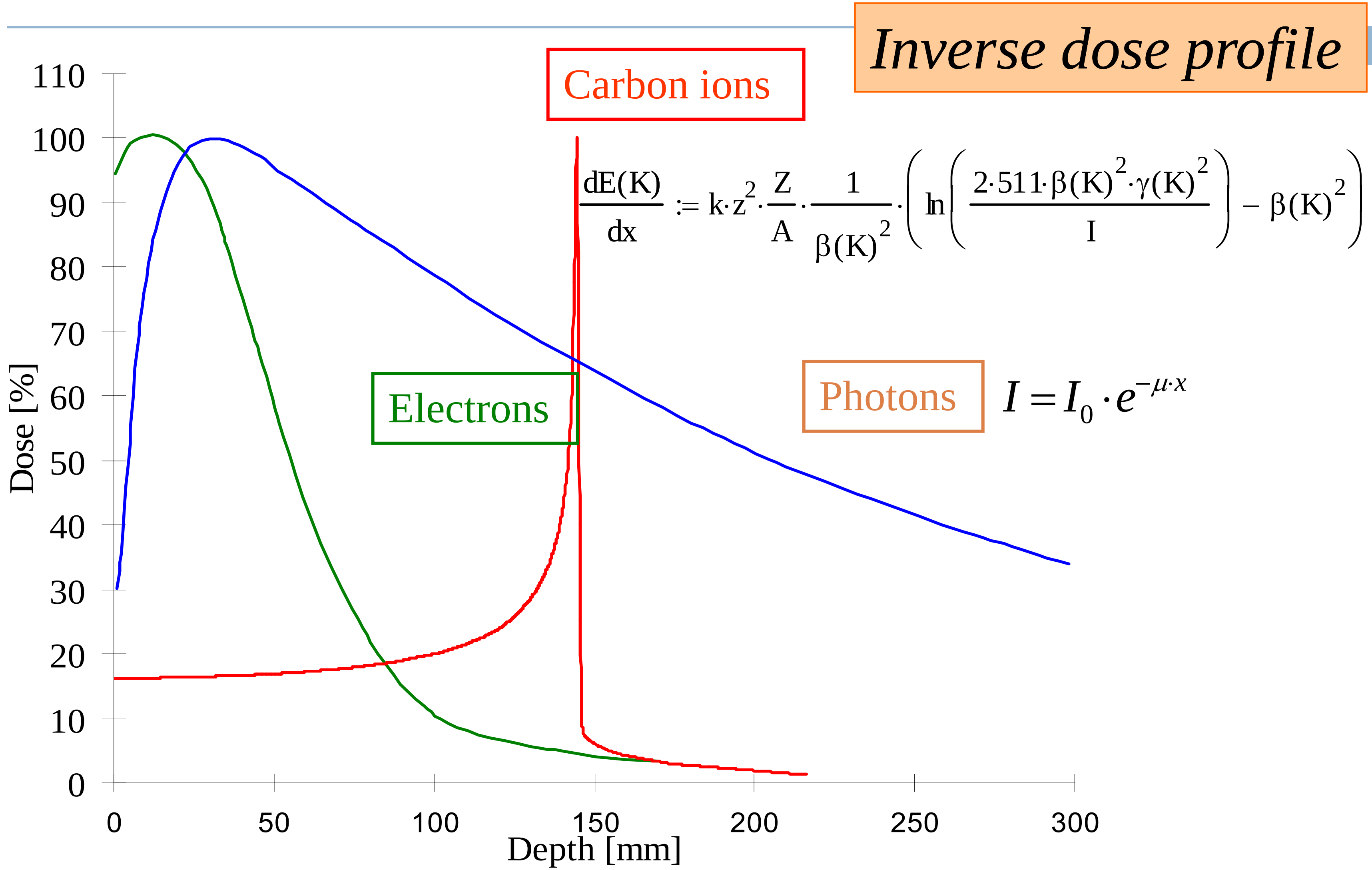
General principle of radiation therapy



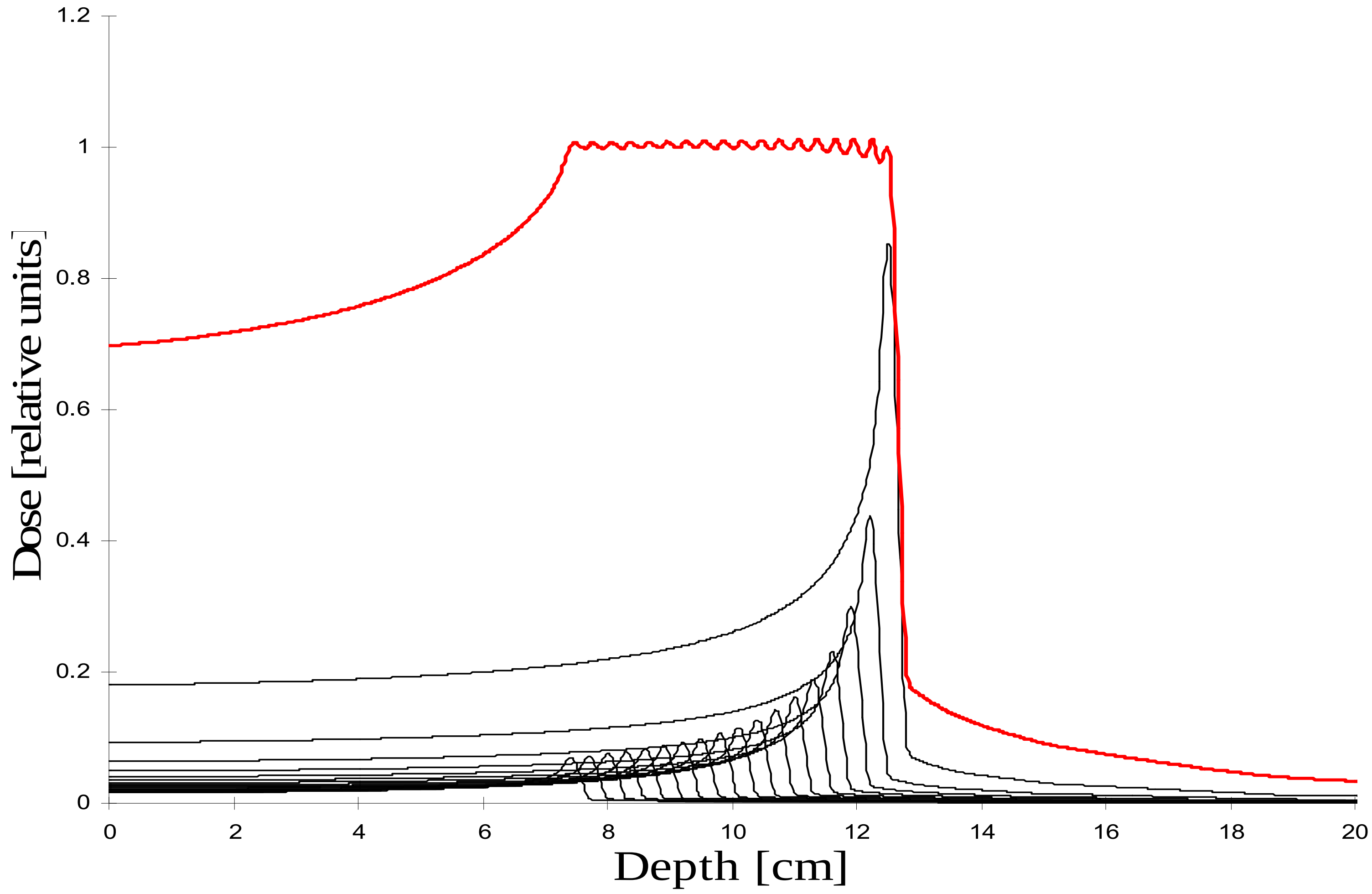
General principle of radiation therapy



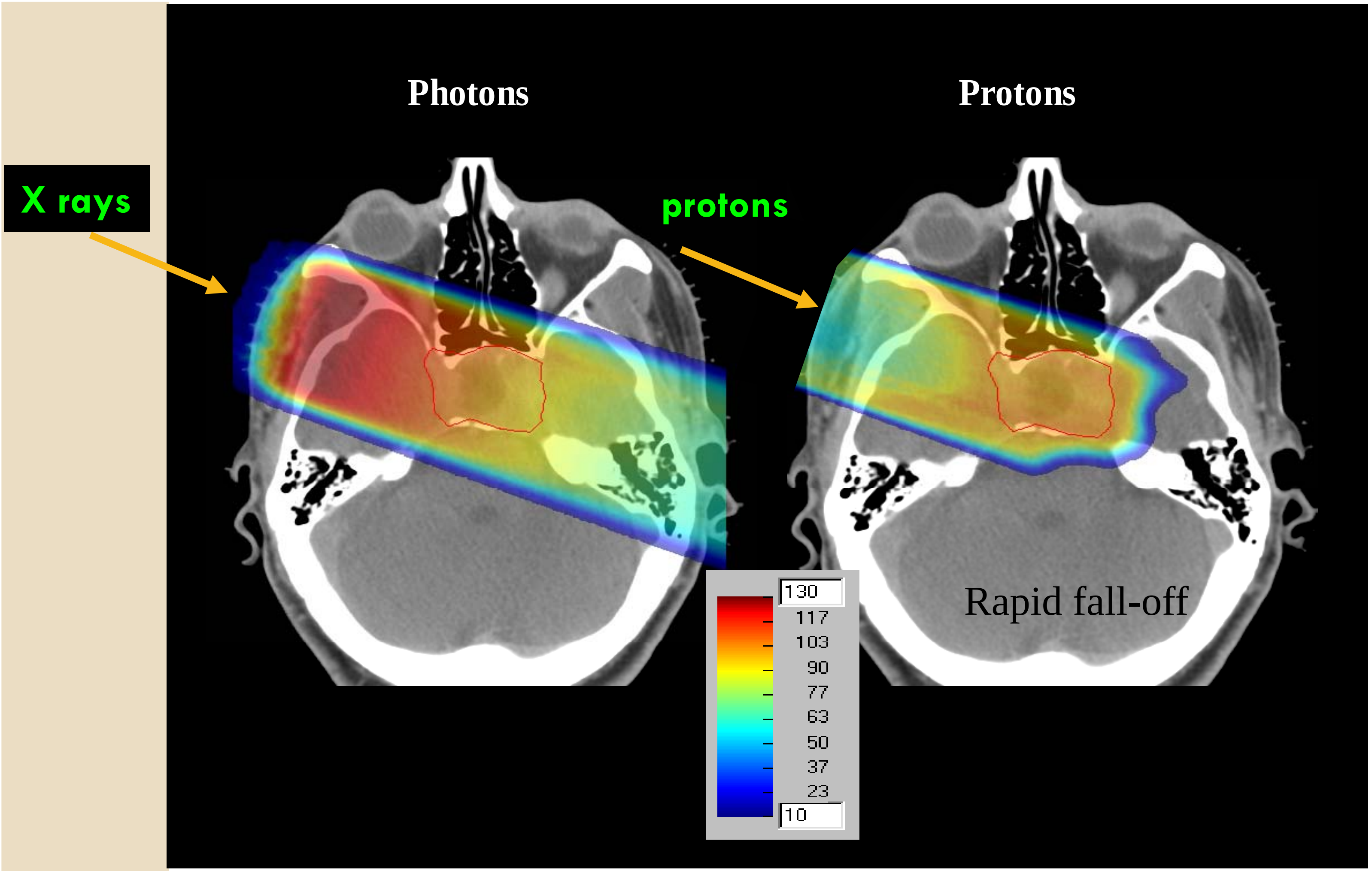
Comparison of the depth dose profiles



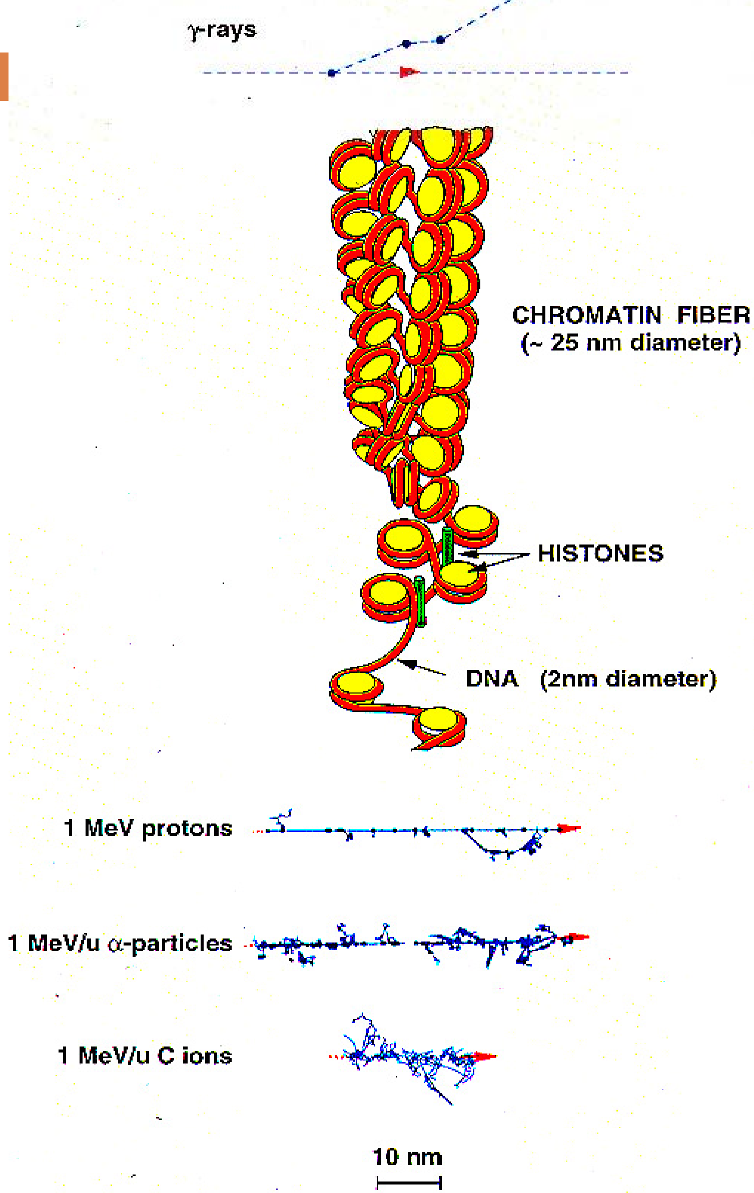
Longitudinal - Spread Out Bragg Peak

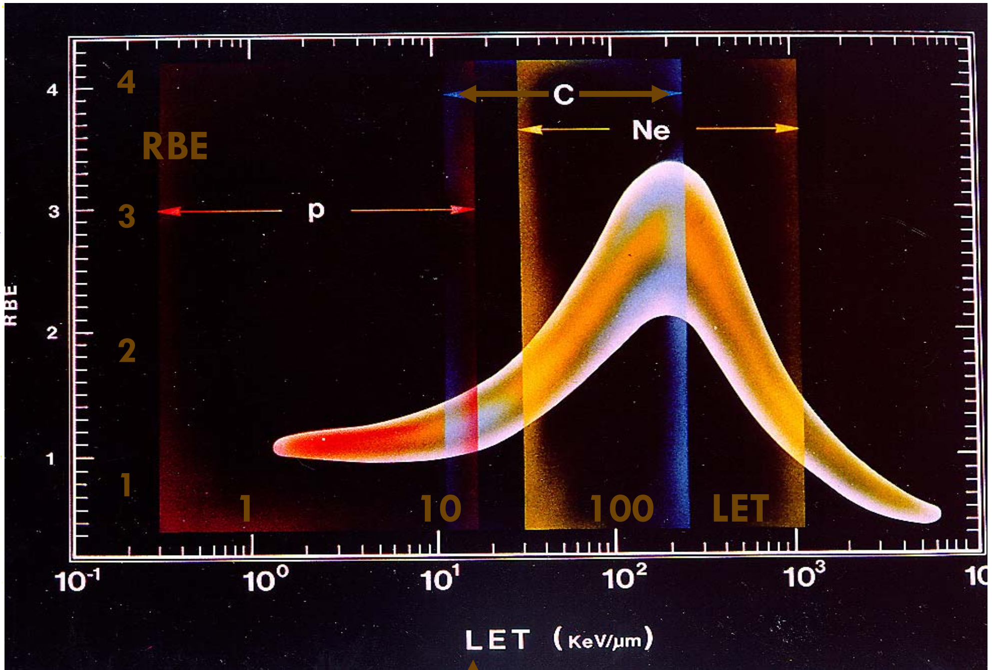


Macroscopic advantage of hadrons



Microscopic advantage of C ions

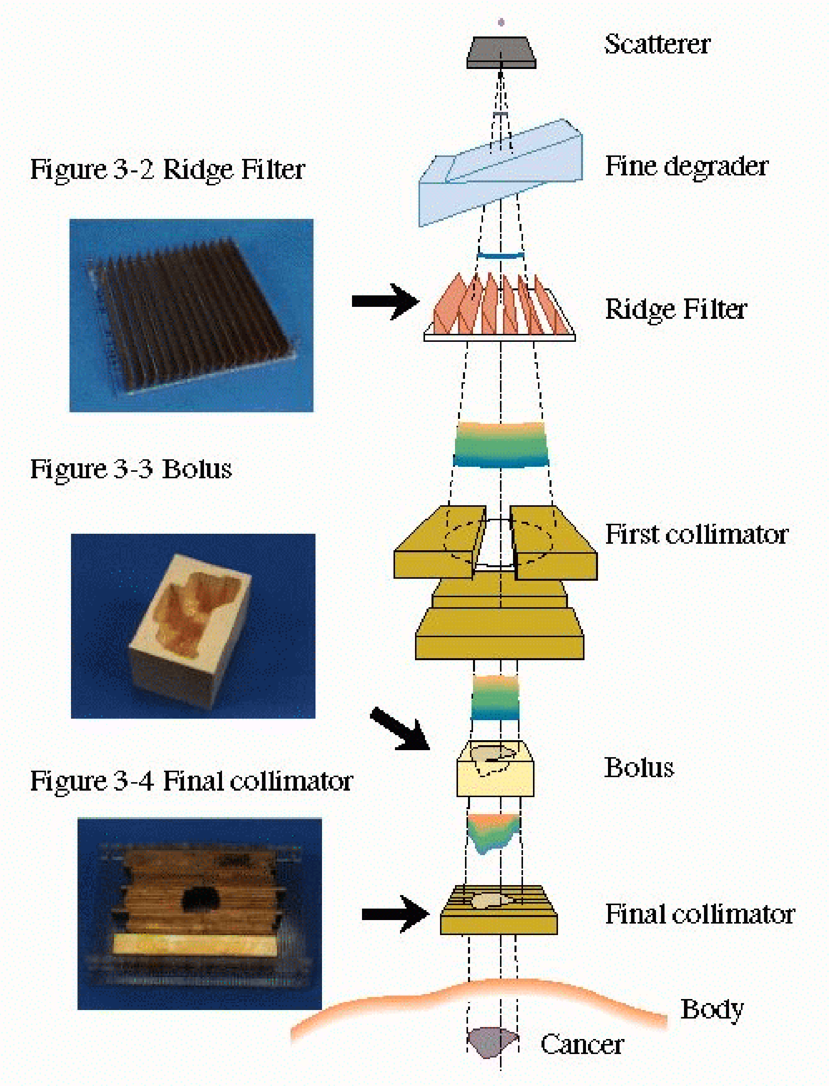


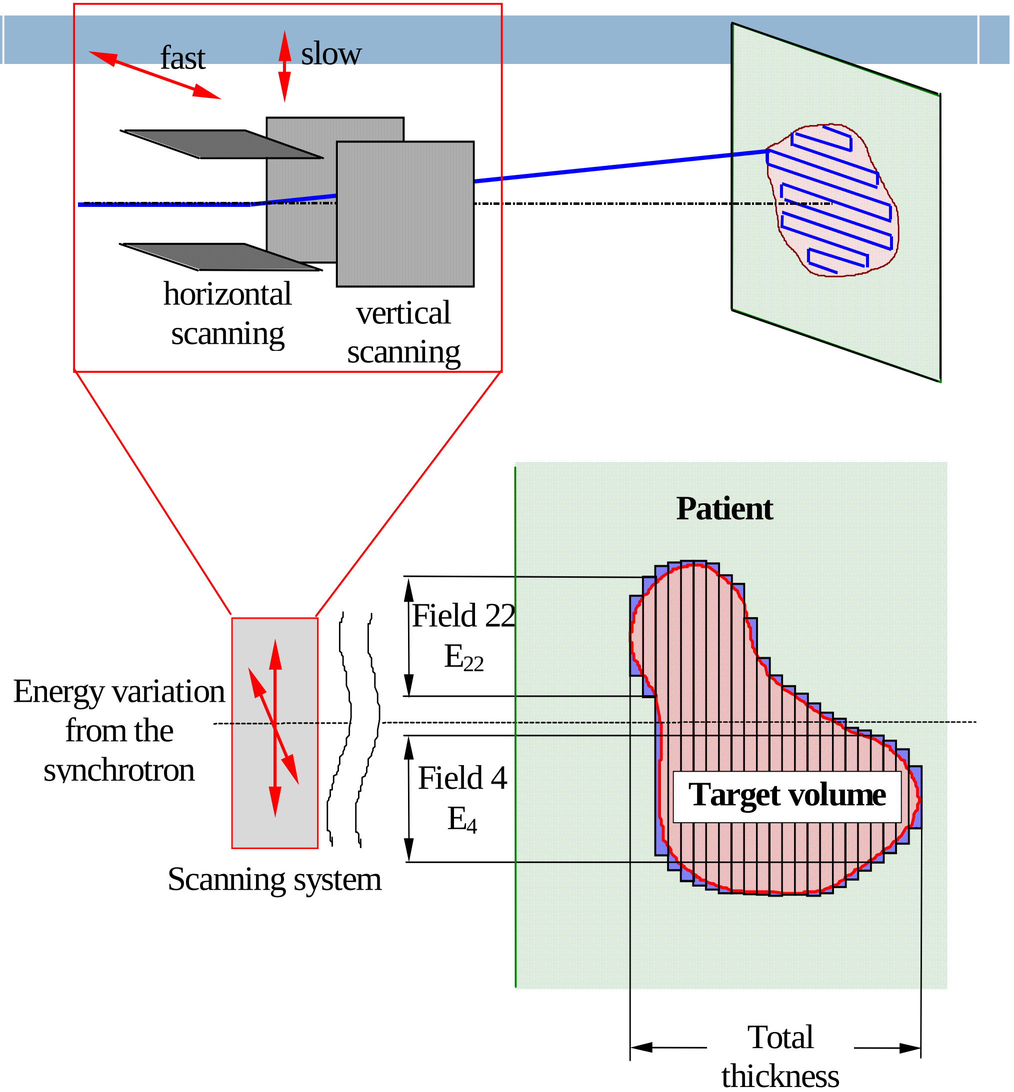


10 – 20 keV/mm = 100 – 200 MeV/cm =

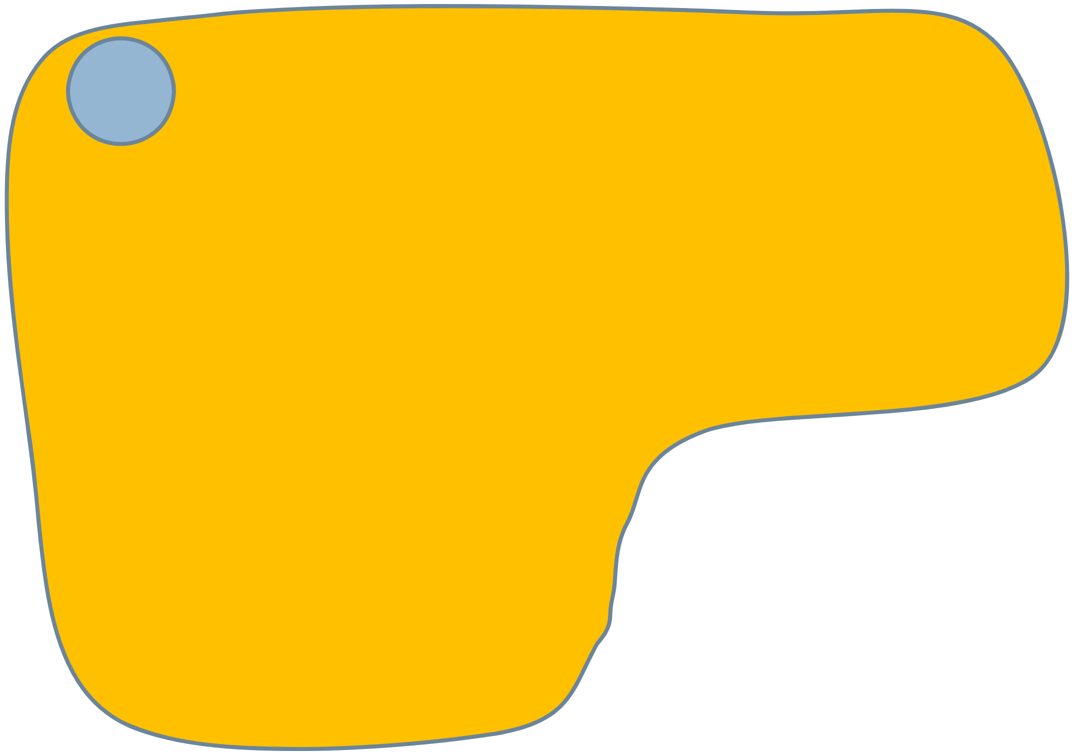
20 – 40 eV/(2 nm)

Transverse - Beam delivery



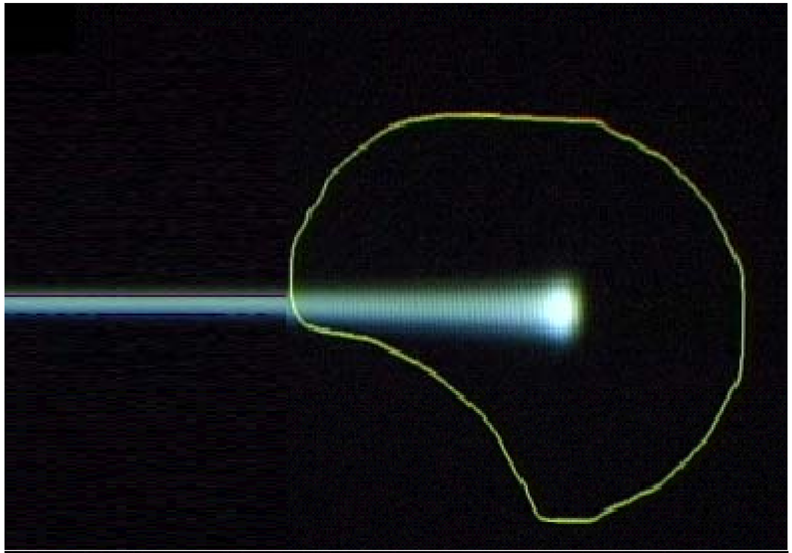


Scanning beam

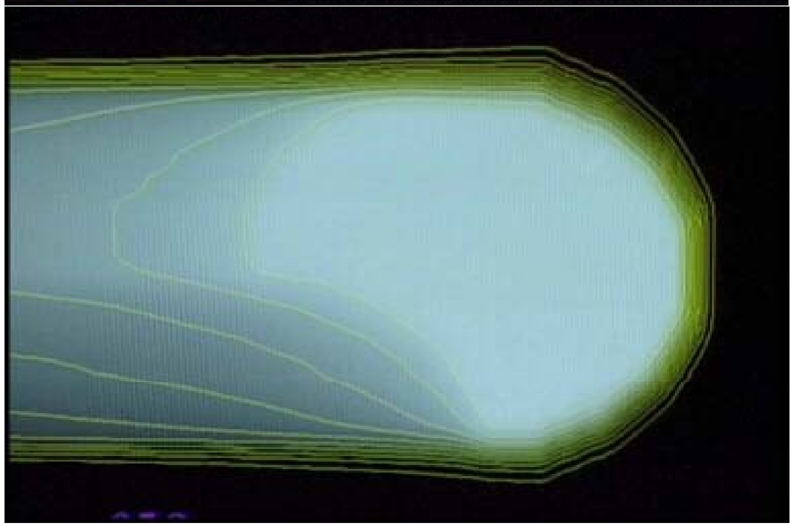


Dose conformation active vs passive

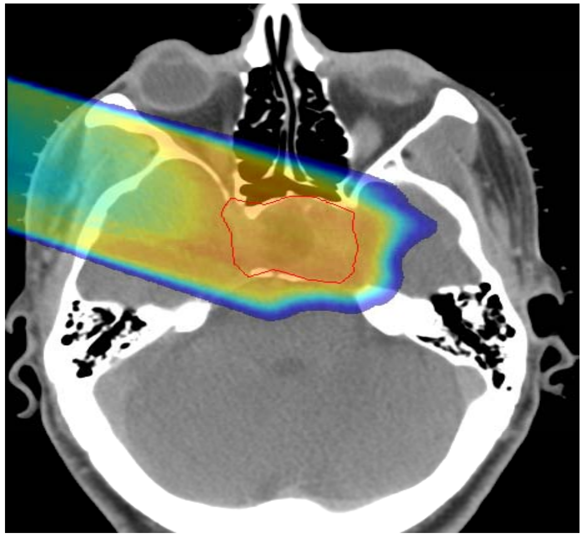
Pencil beam



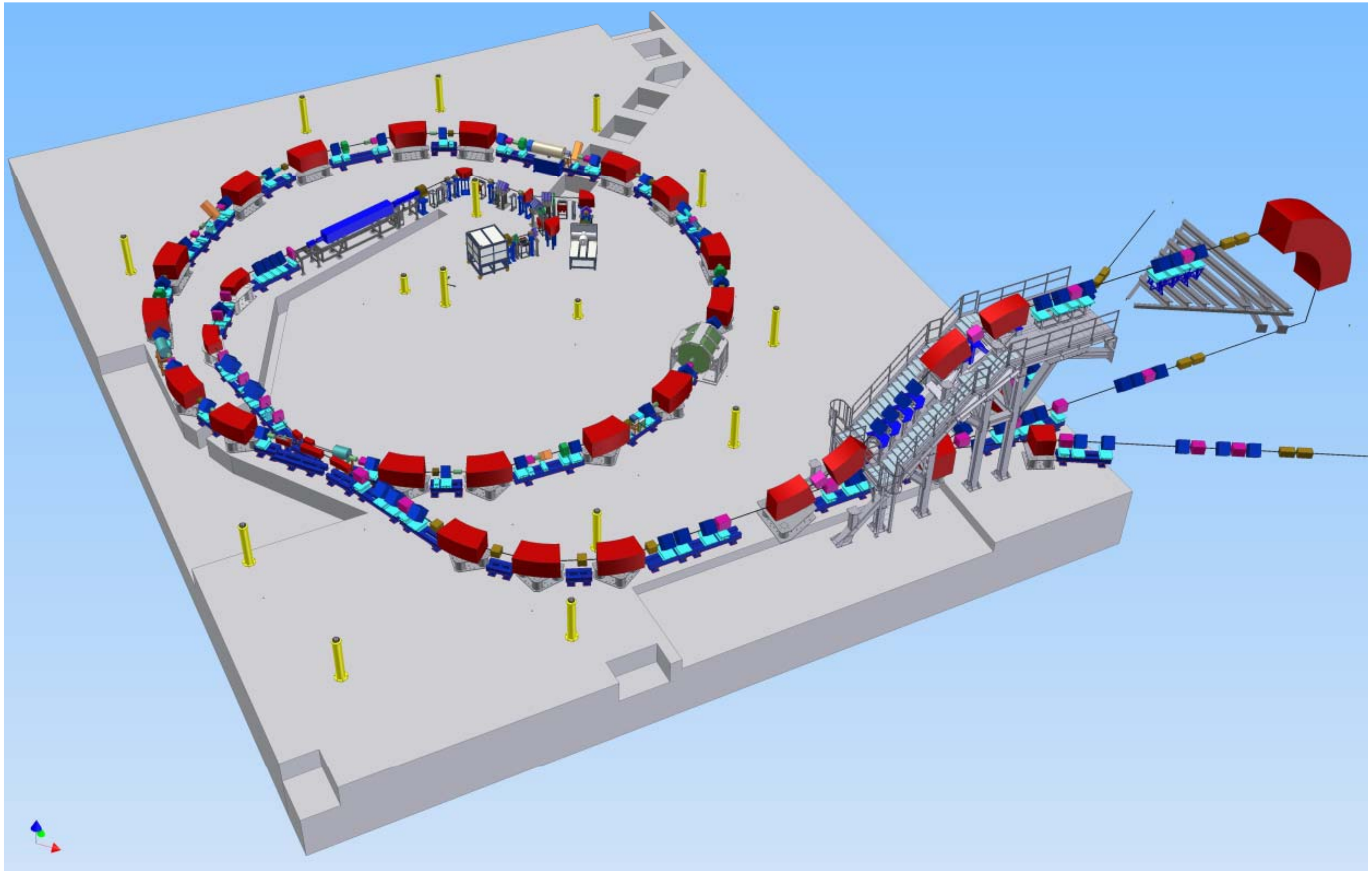
Scanned beam



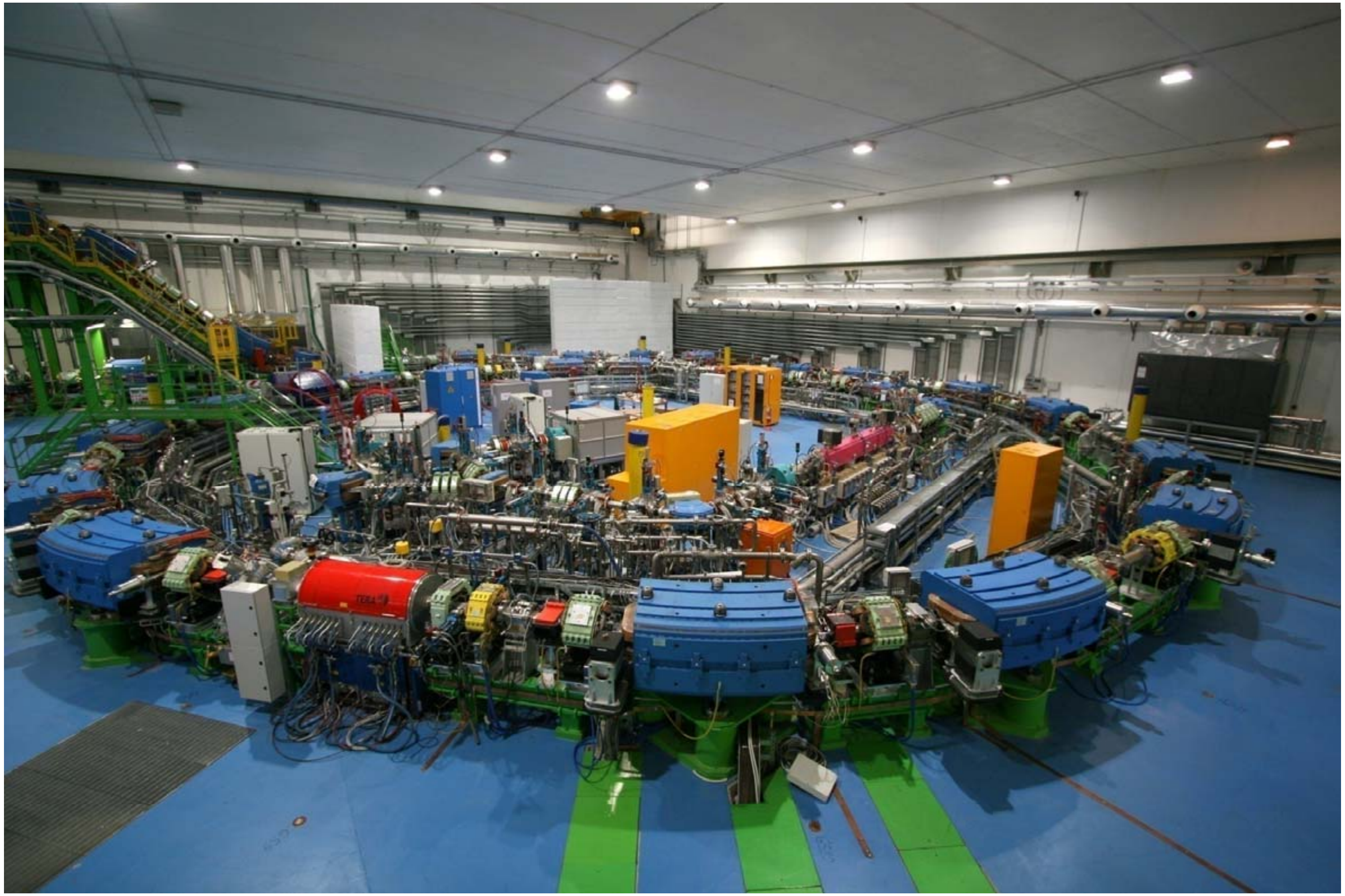
Passive system “horns” in healthy tissue



The CNAO accelerator and lines



Synchrotron with slow extraction



Range 3-27 g/cm^2

Slow extraction

Betatron core

Design Parameters I

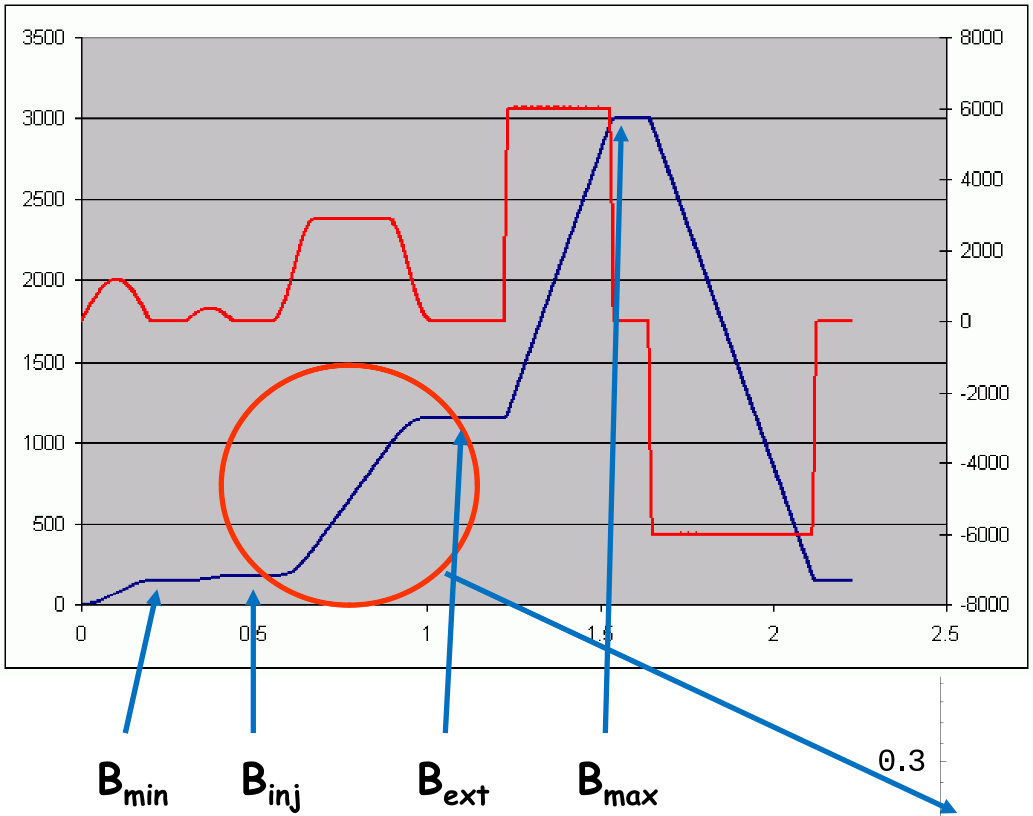
Protons (10^{10}/spill)				
	LEBT (*)	MEBT	SYNC	HEBT
Energy [MeV/u]	0.008	7	7-250	**60-250**
Imax [A]	1.3×10^{-3} (0.65, 0.45)	0.7×10^{-3}	5×10^{-3}	**7×10^{-9}**
Imin [A]	1.3×10^{-3} (0.65, 0.45)	70×10^{-6}	0.12×10^{-3}	**17×10^{-12}**
$\varepsilon_{rms,geo}$ [π mm mrad]	45	1.9	0.67-4.2	0.67-1.43(V)
$\varepsilon_{90,geo}$ [π mm mrad]	180	9.4	3.34-21.2	3.34-7.14 (V) 5.0 (H)
Magnetic rigidity [T m]	0.013 (0.026)	0.38	0.38-2.43	0.38-2.43
$(\Delta p/p)_{tot}$	±1.0‰	±(1.2-2.2)‰	±(1.2-3.4)‰	±(0.4-0.6)‰

* (H_2^+, H_3^+)

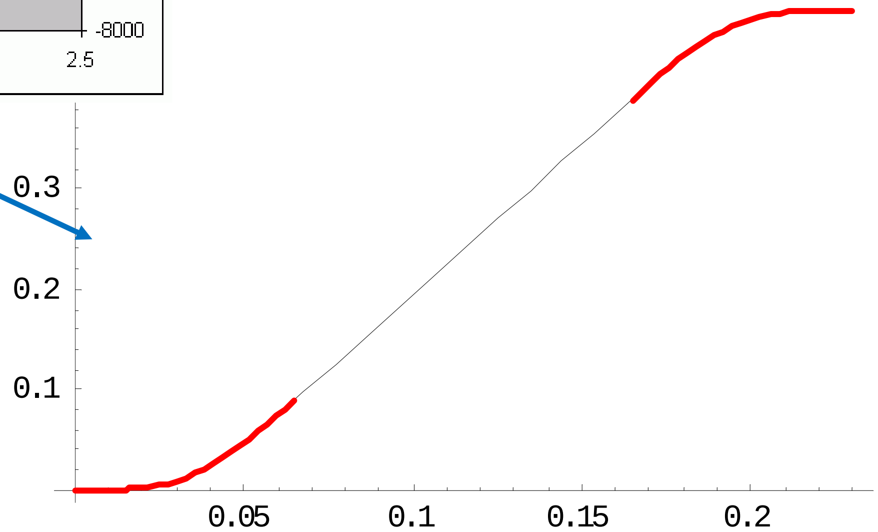
Design Parameters II

Carbon ($4\cdot10^8$ C/spill)				
	LEBT (C^{4+})	MEBT	SYNC	HEBT
Energy [MeV/u]	0.008	7	7-400	**120-400**
Imax [A]	0.15×10^{-3}	0.15×10^{-3}	1.5×10^{-3}	**2×10^{-9}**
Imin [A]	0.15×10^{-3}	15×10^{-6}	28×10^{-6}	**4×10^{-12}**
$\varepsilon_{rms,geo}$ [π mm mrad]	45	1.9	0.73-6.1	0.73-1.43(V)
$\varepsilon_{90,geo}$ [π mm mrad]	180	9.4	3.66-30.4	3.66-7.14 (V) 5.0 (H)
Magnetic rigidity [T m]	0.039	0.76	0.76-6.34	3.25-6.34
$(\Delta p/p)_{tot}$	±1.0‰	±(1.2-2.0)‰	±(1.2-2.9)‰	±(0.4-0.6)‰

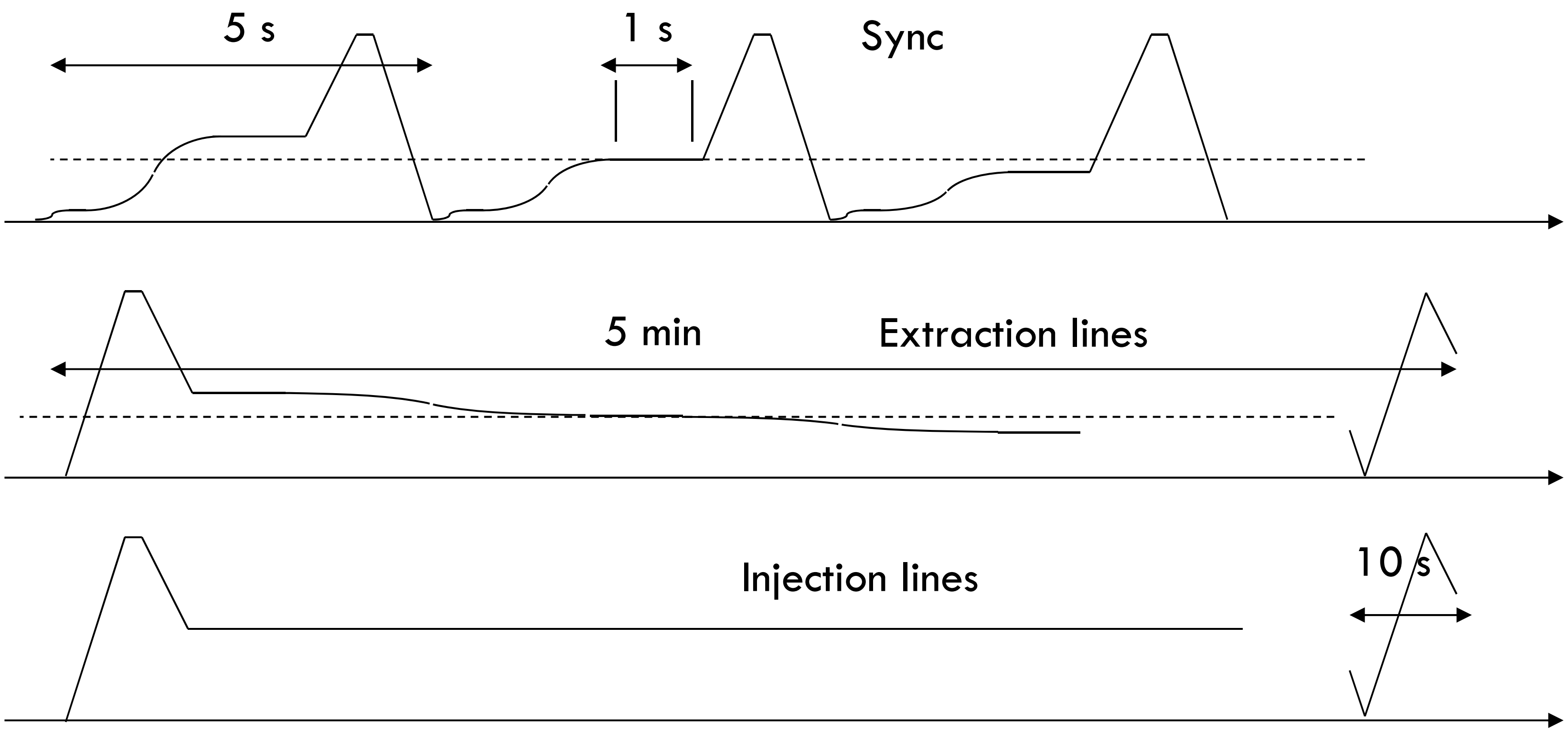
Magnets' cycle



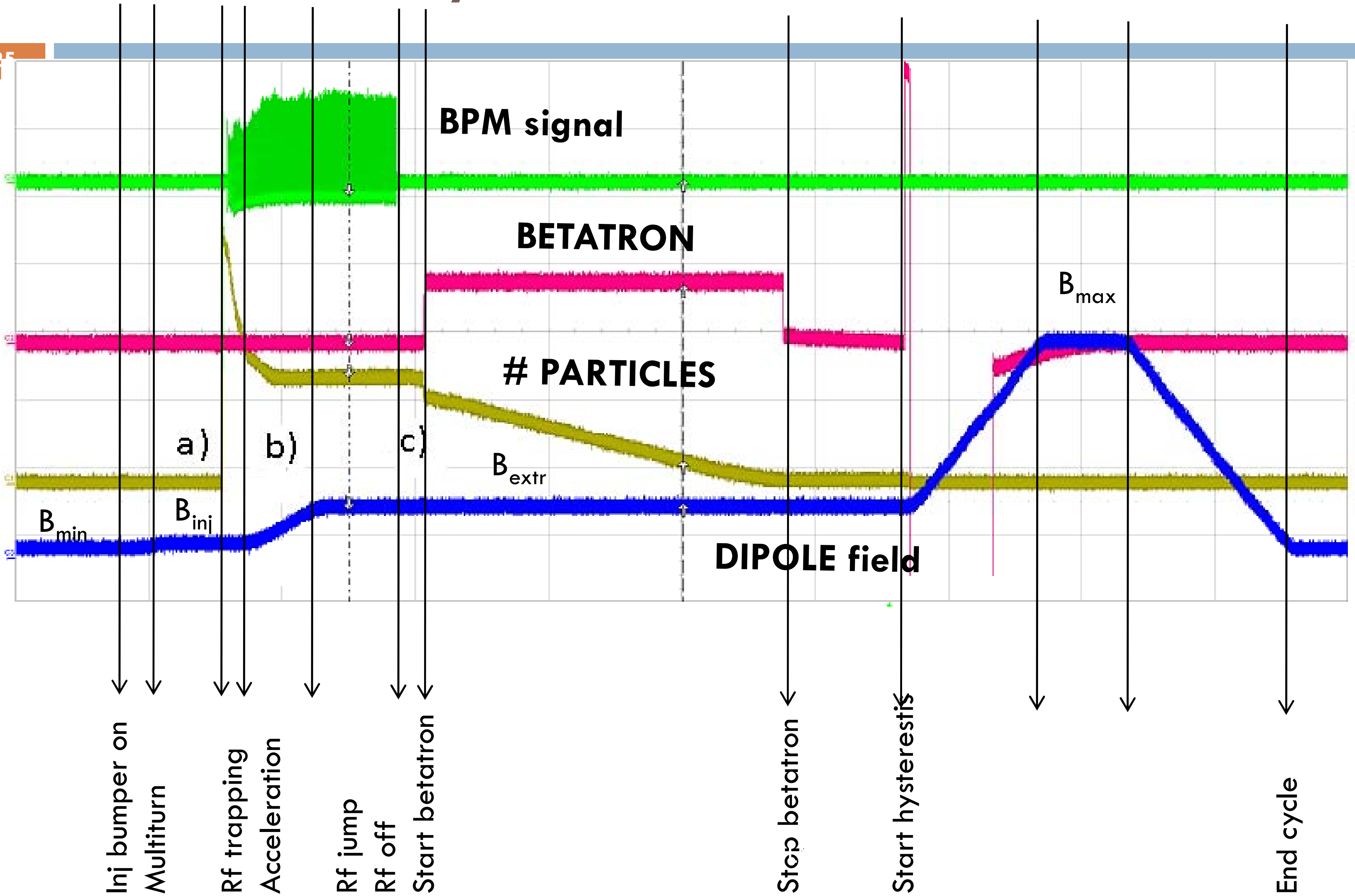
Fixed ramps connected by linear ramps



Machine cycle



Machine Cycle

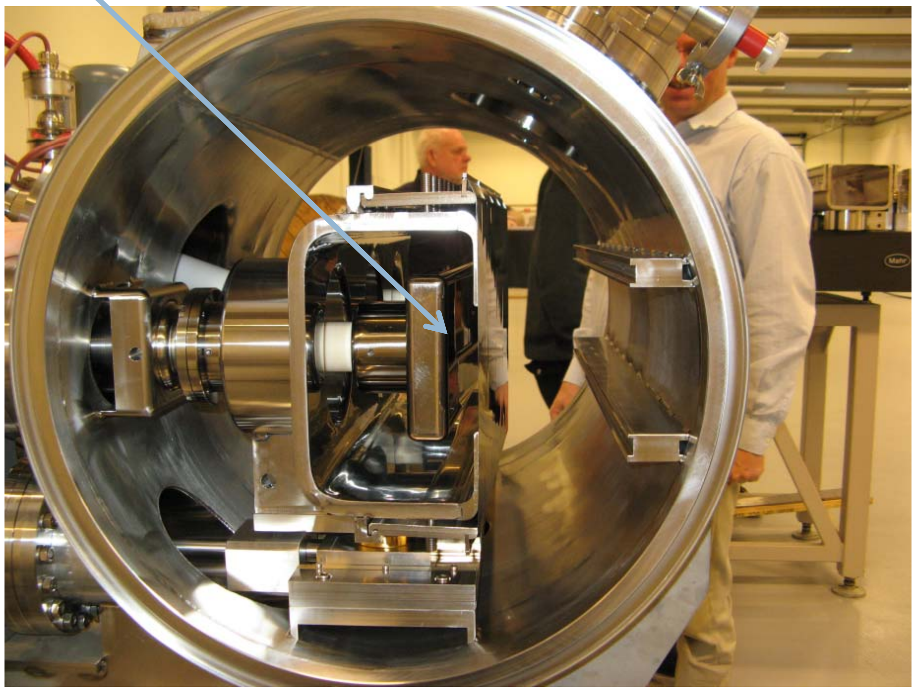


Slow extraction

- "Peeling" the beam

Beam

Electrostatic septum

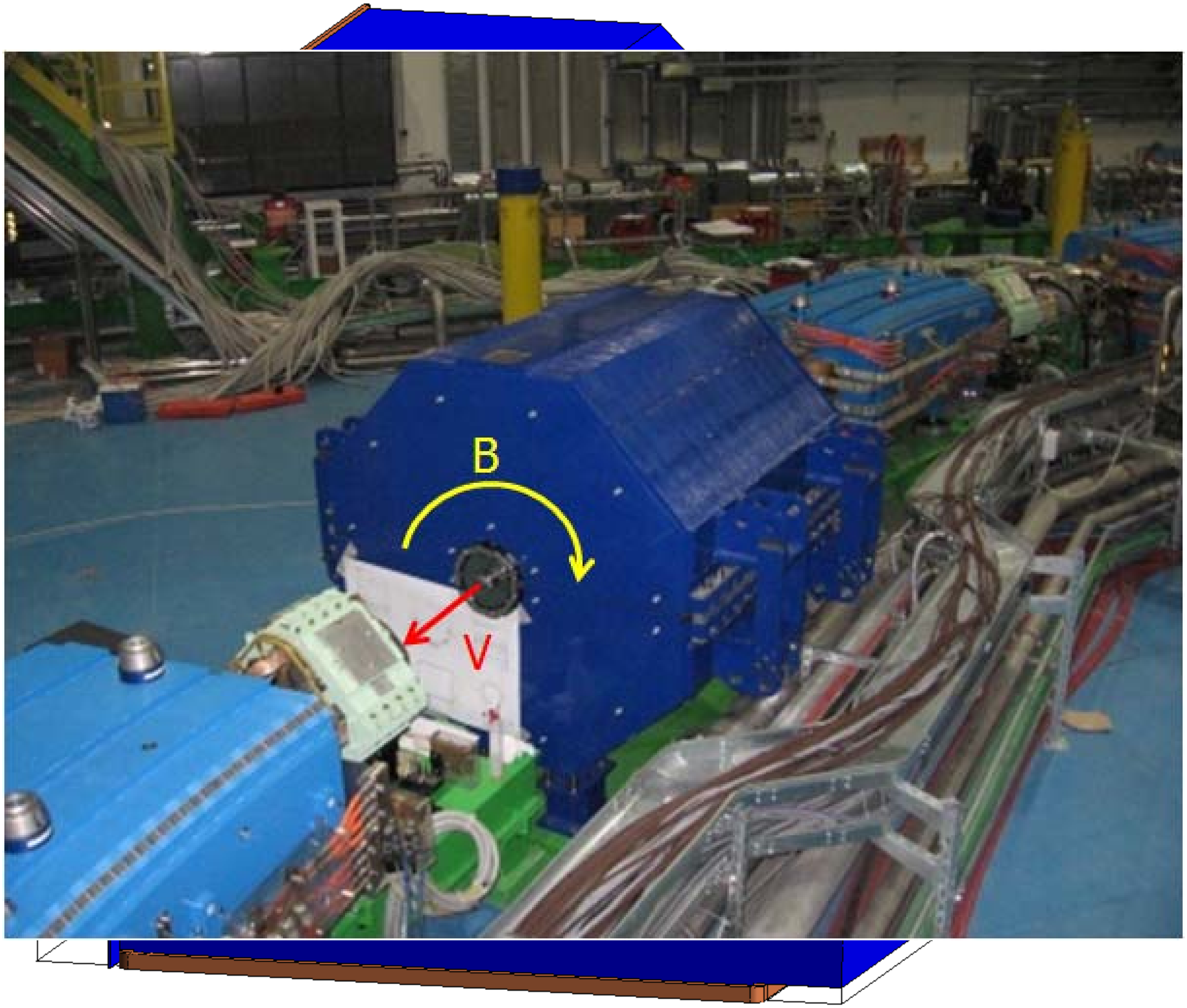


Betatron core

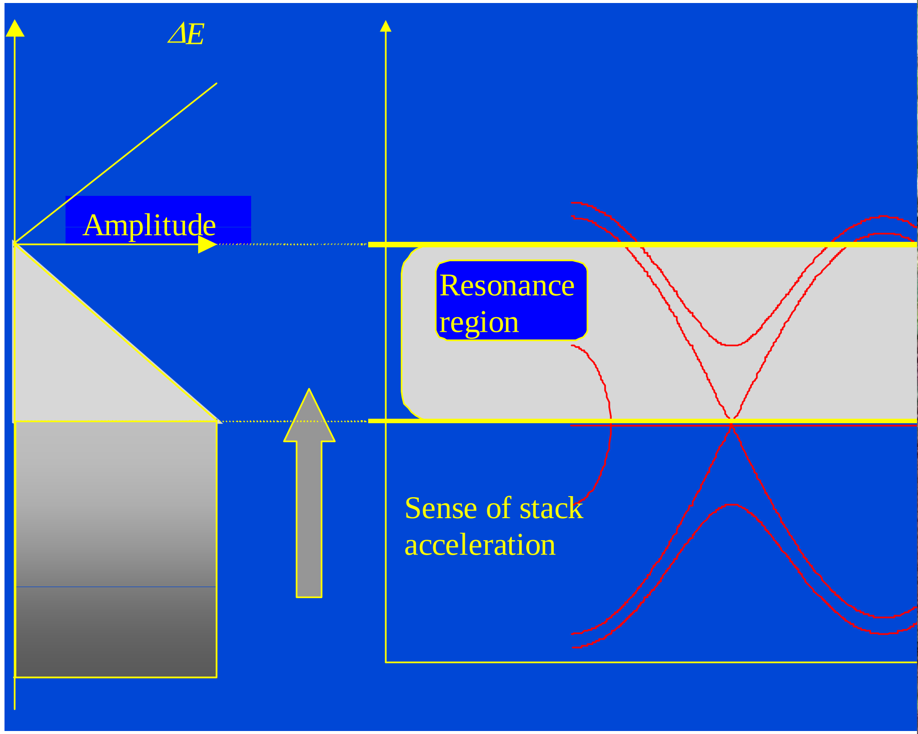
$\Delta\Phi$ = 2.46 Wb

Sensitivity to gap between halves

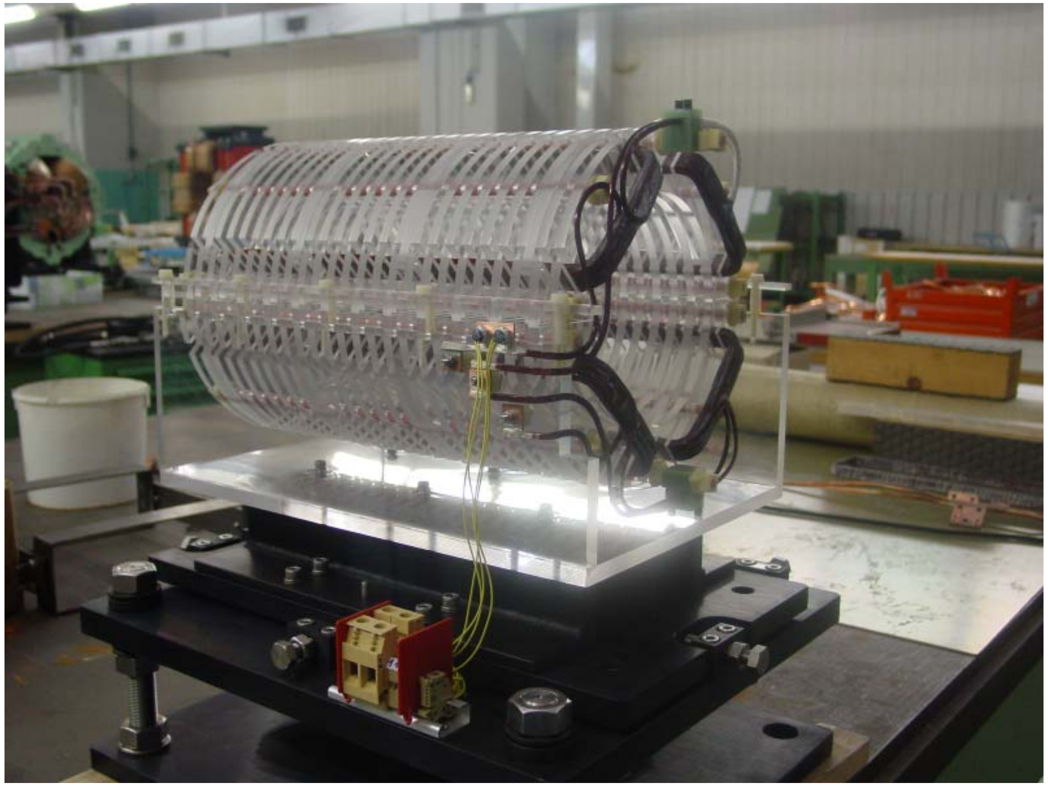
Magnetic screen needed



Empty bucket

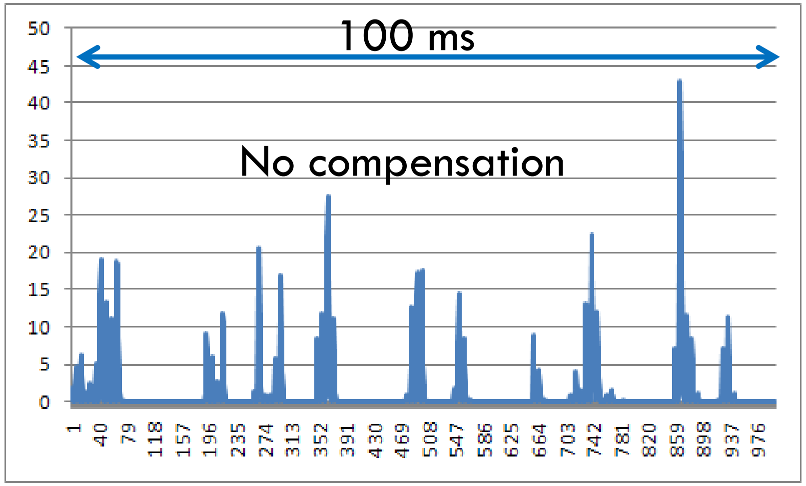


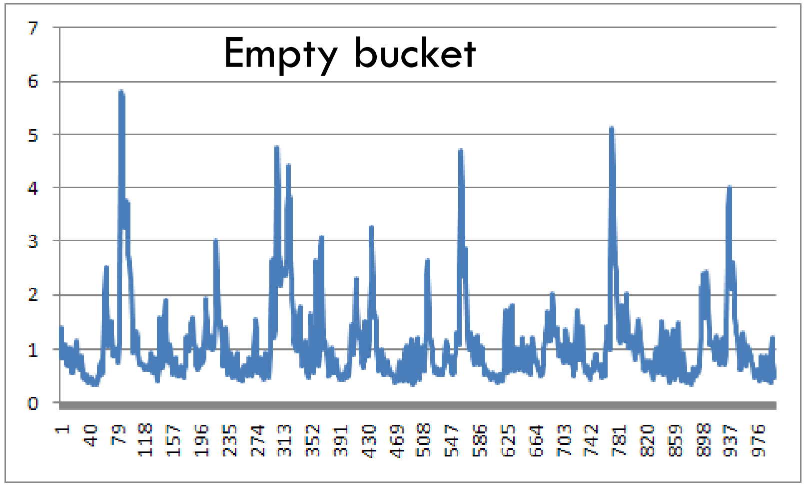
Air core quadrupole



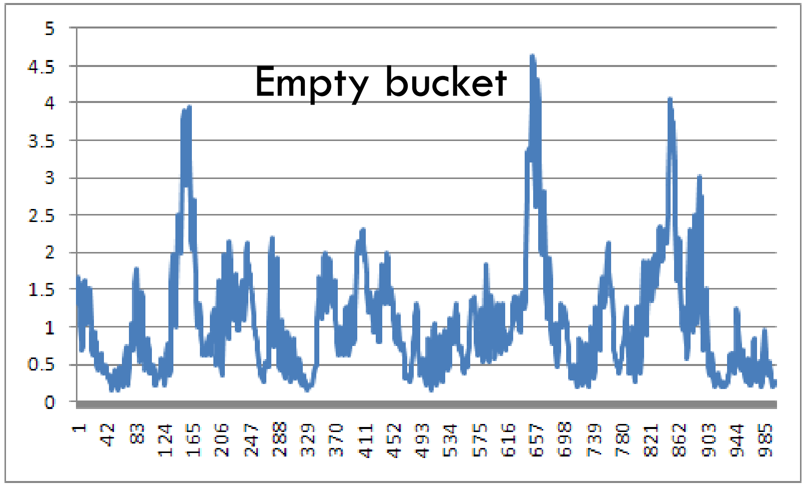
Ripple compensation

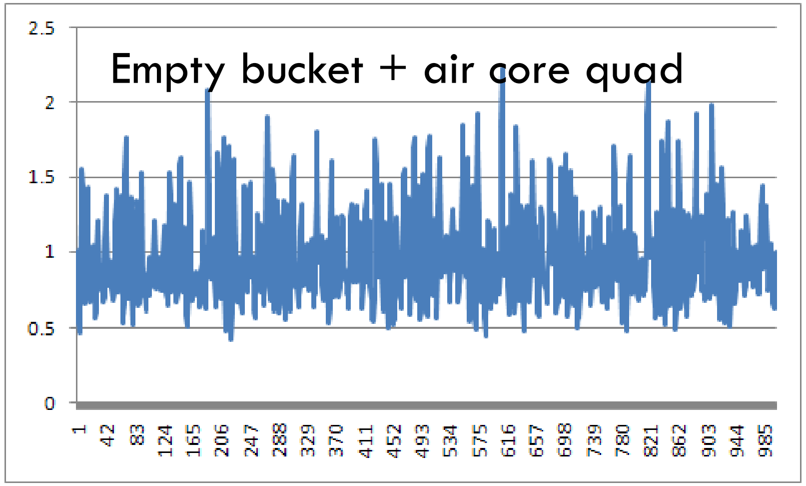
Sampling frequency 10 kHz



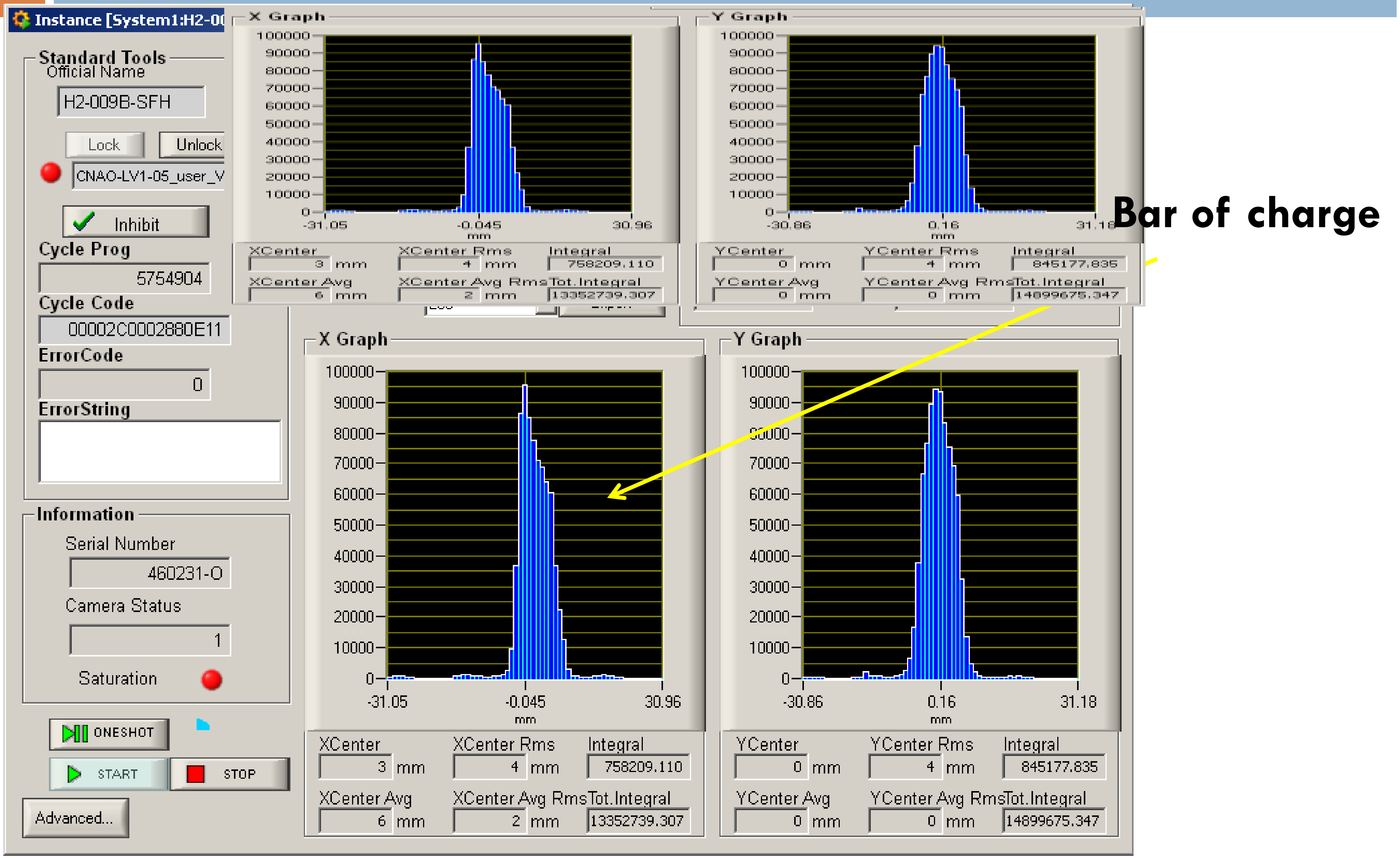


FeedBack vs FeedForward





Beam at HEBT entrance

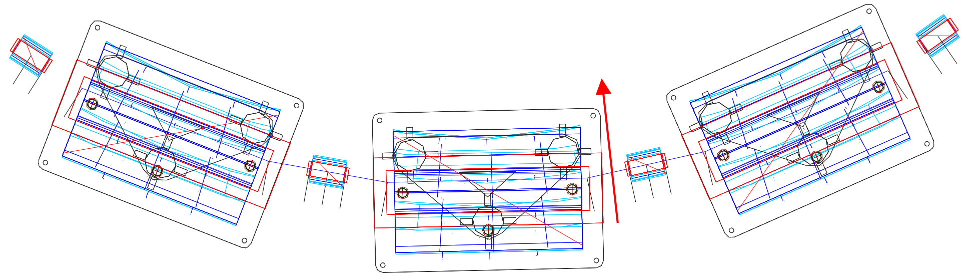


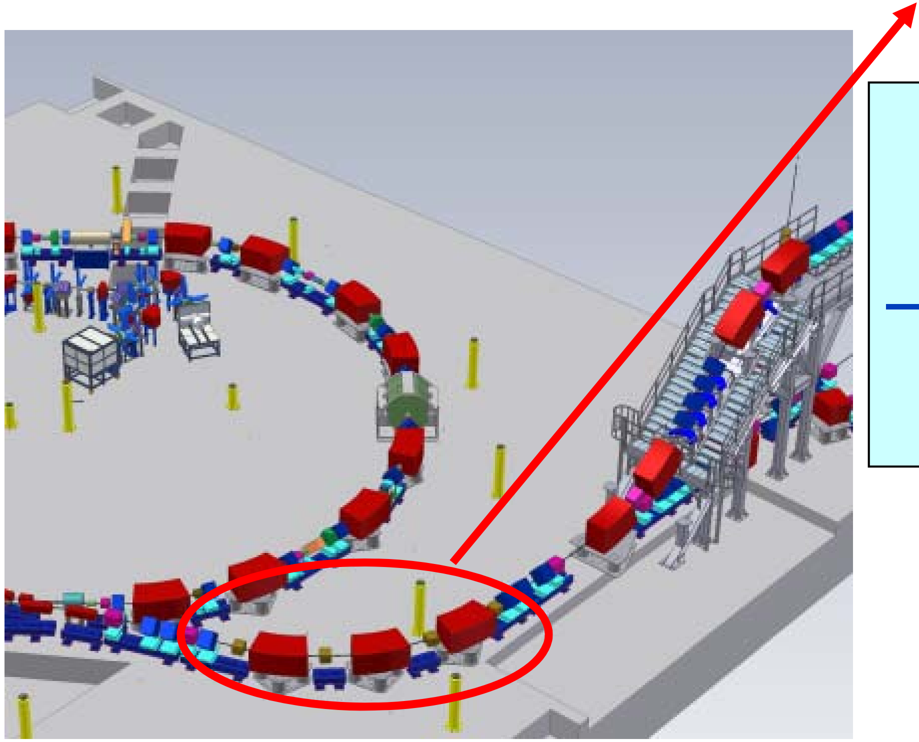
Chopper

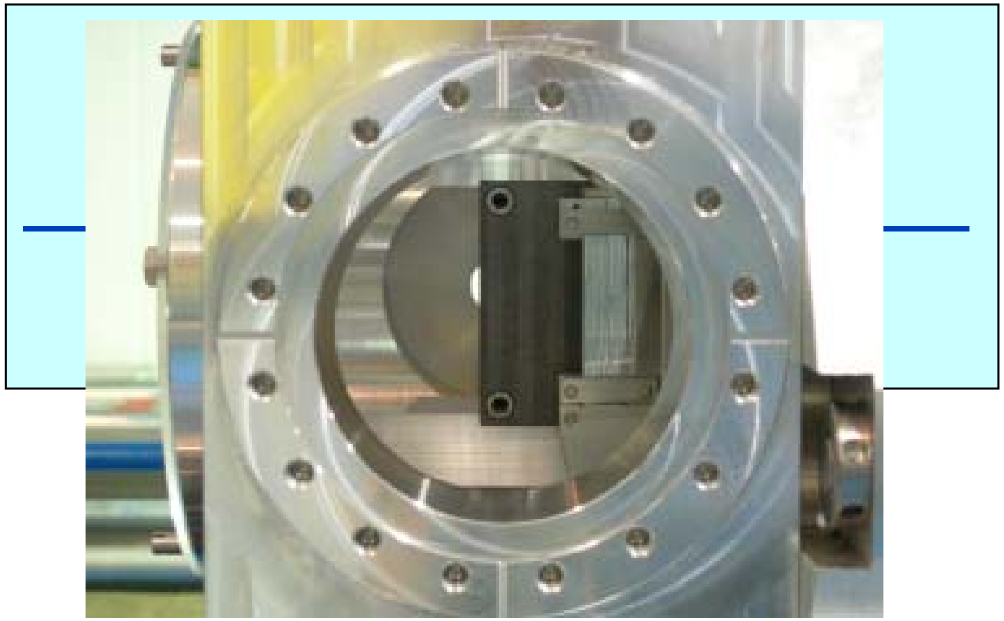
Fast turn on/off for the beam

Intrinsically safe

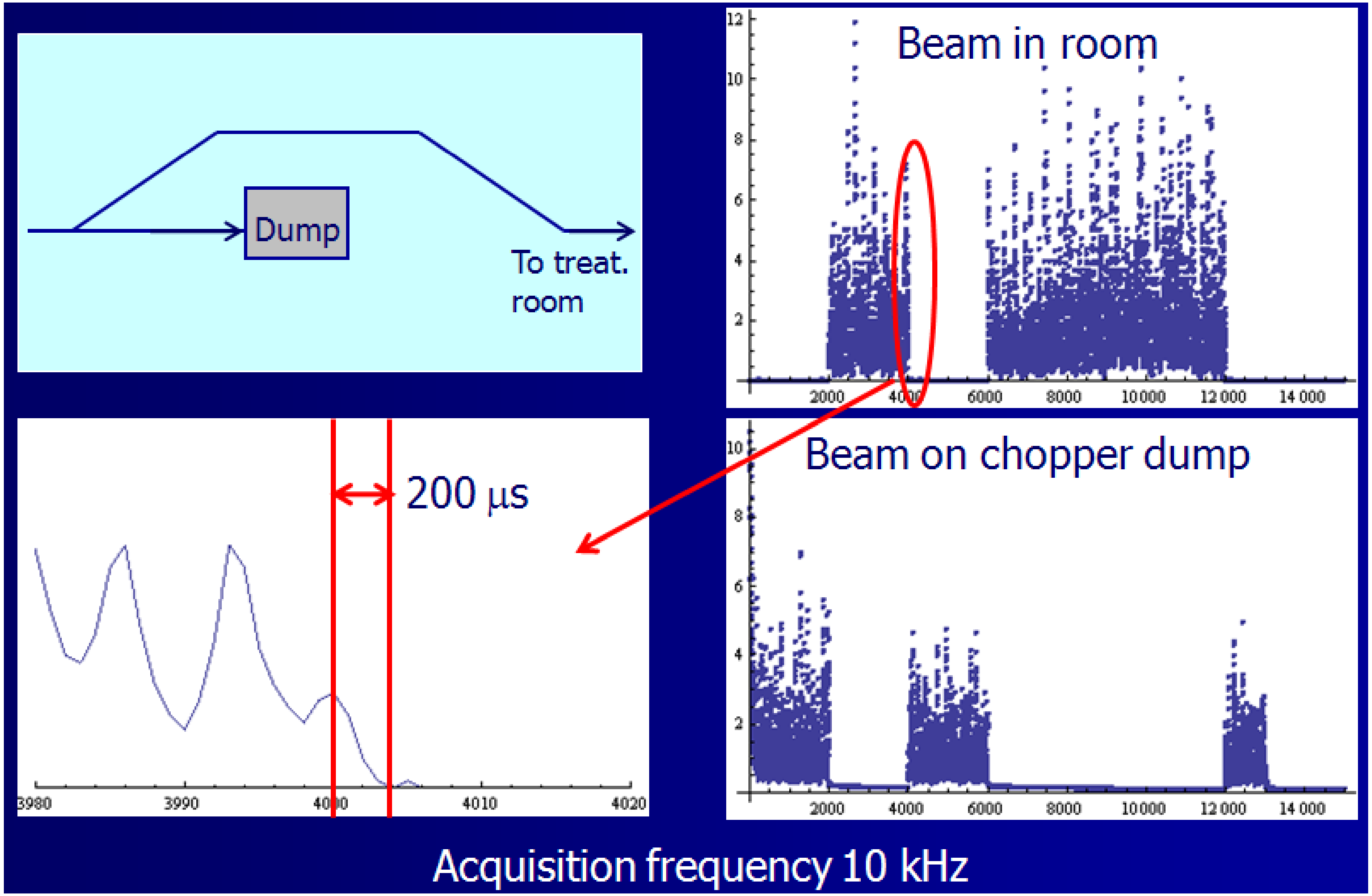
Allows beam qualification







Chopped beam

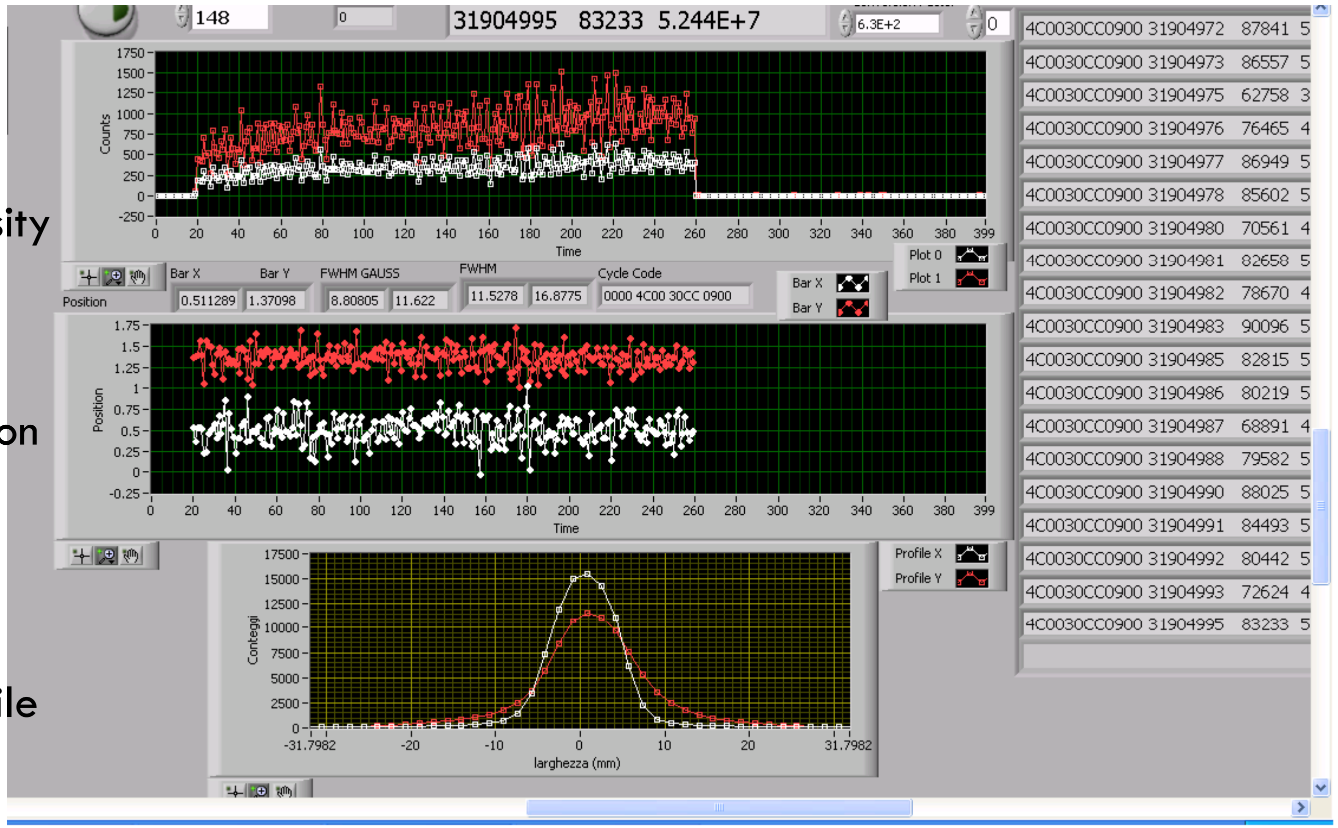


Beam measurement at isocenter

Intensity

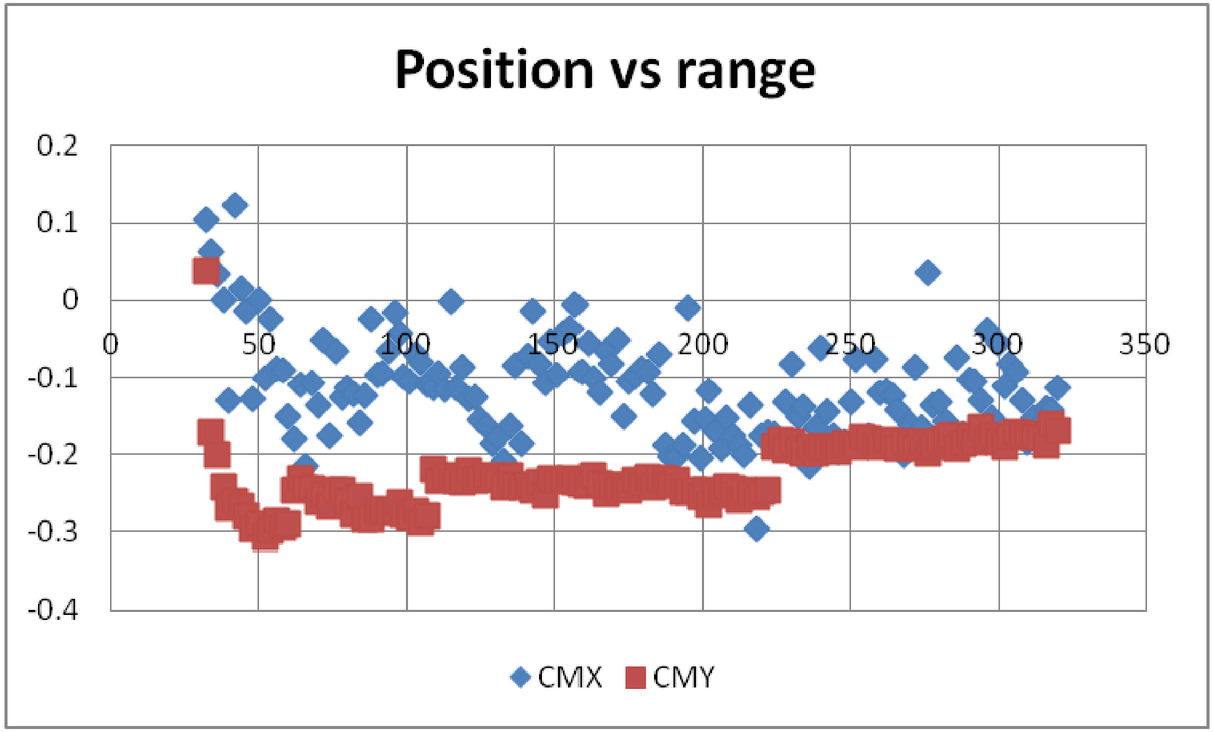
Position

Profile

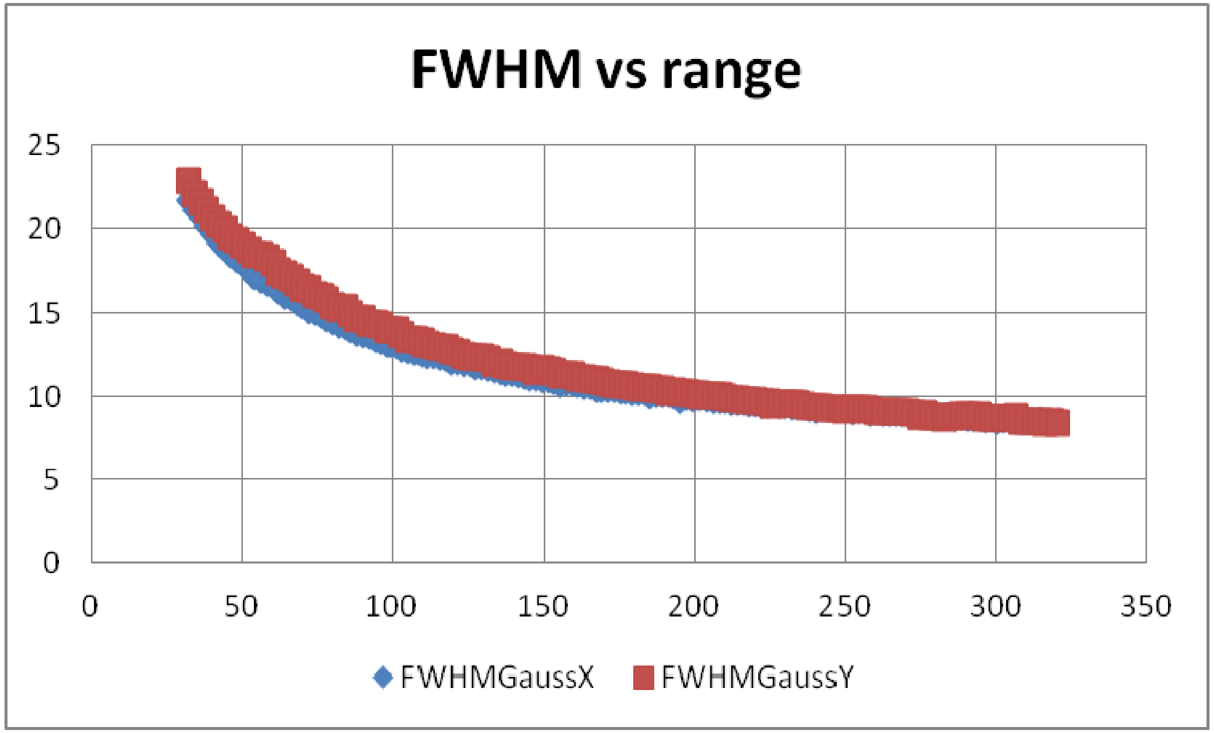


Beam position at HEBT end

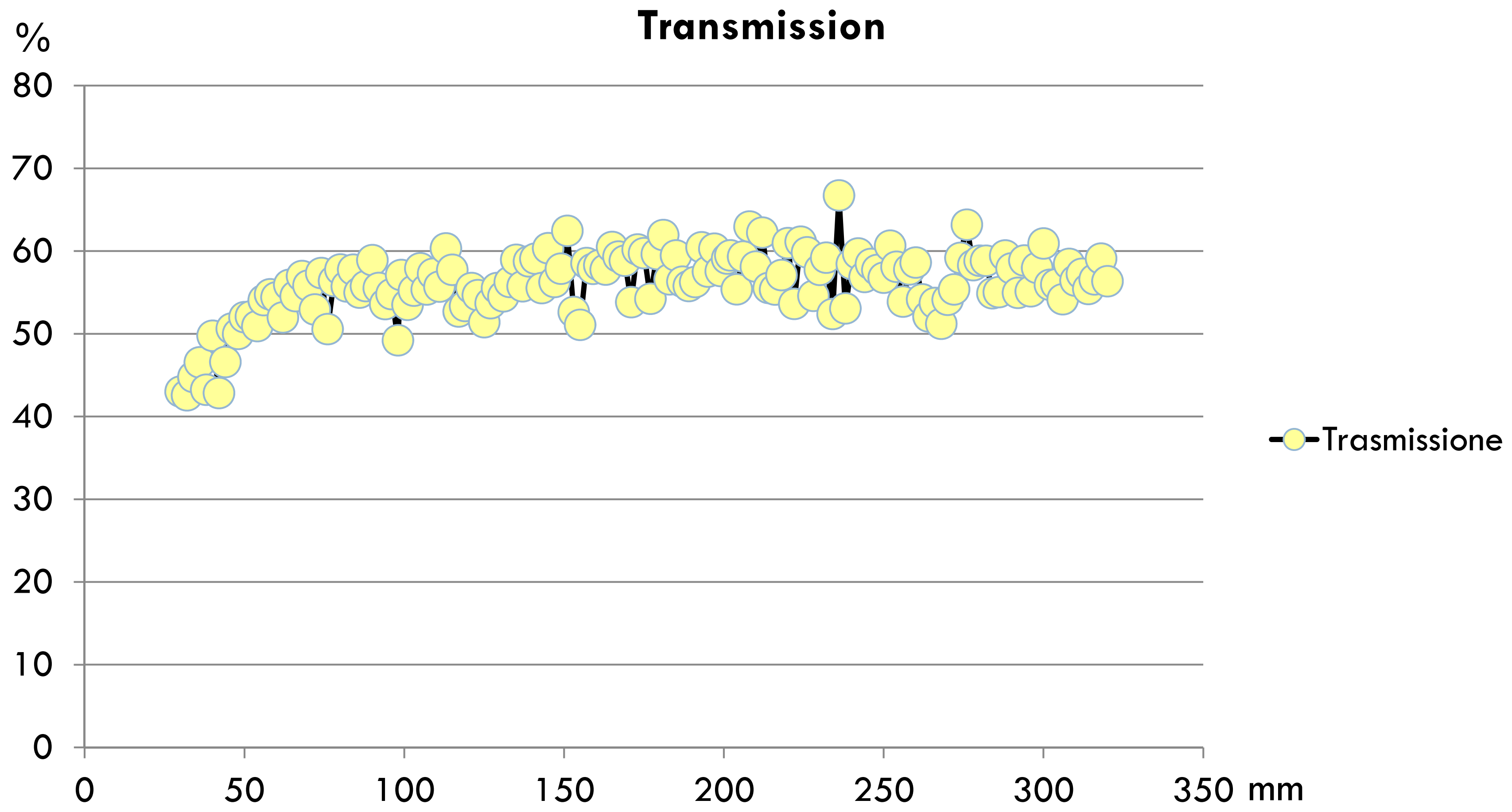
Beam position repeatability (at the same energy): 0.2 mm
Beam position precision (at different energies): 0.3 mm



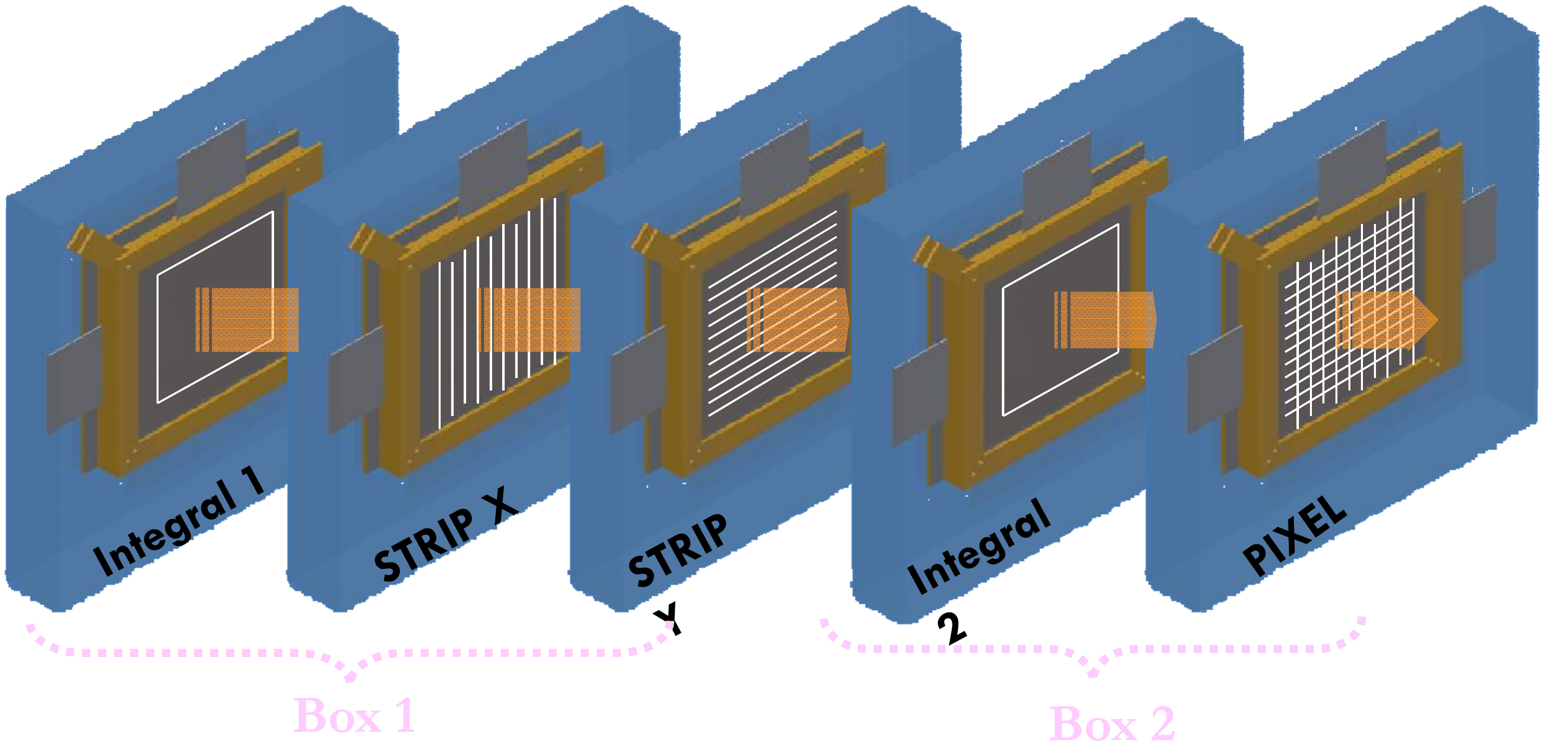
Beam size at nozzle



Accelerated / Isocenter protons



Beam delivery – scanning control



1 Integral chamber:
- Beam Intensity measure every 1 μs

2 Strip chambers (X and Y):
- Beam position measure every 100 μs, with 100 μm of precision

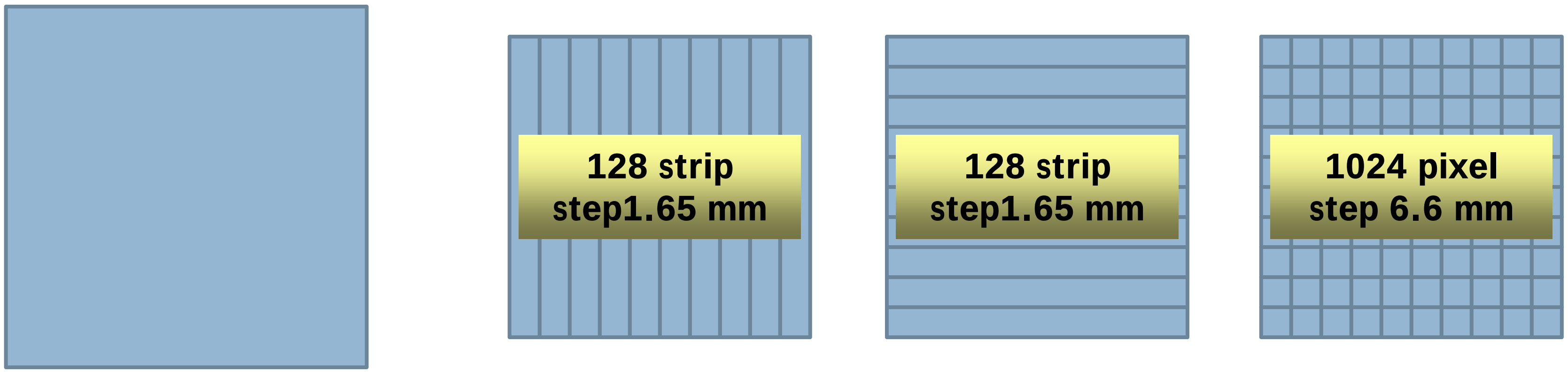
1 Integral chamber:
- Beam Intensity measure every 1 μs

1 Pixel chamber:
- Beam position and dimension measure every 100 μs/1 ms, with 200 μm of precision

Monitor dimensions

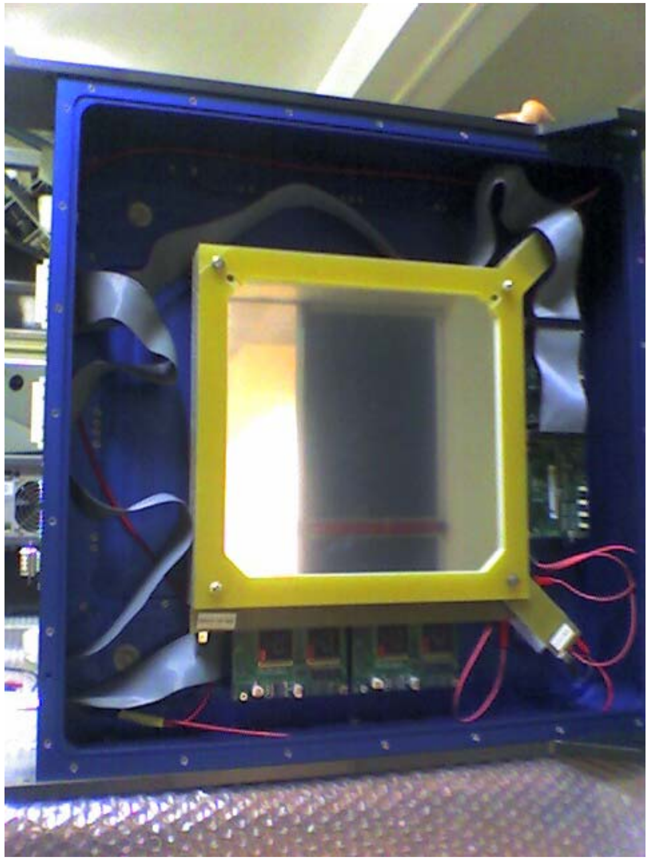
Integral chamber active area 24x24 cm^2

Strip and Pixel active area 21x21 cm^2



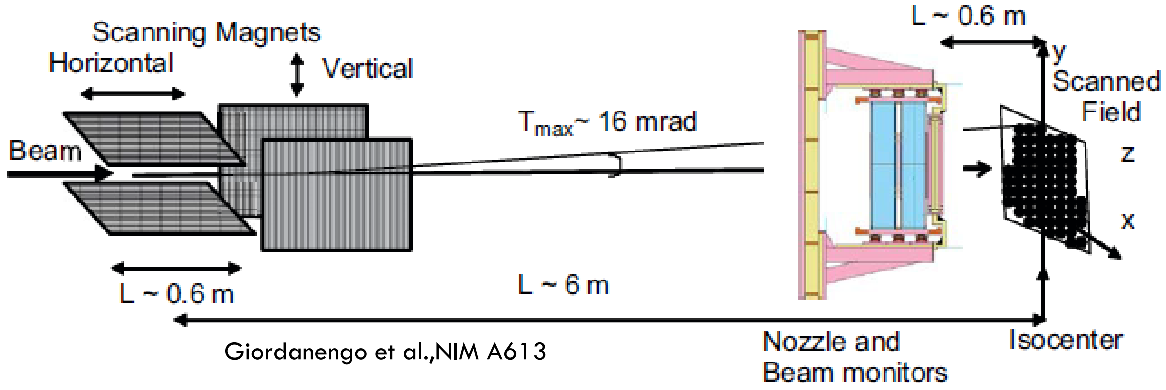
Courtesy of Marco Donetti

BOX 1 – BOX 2

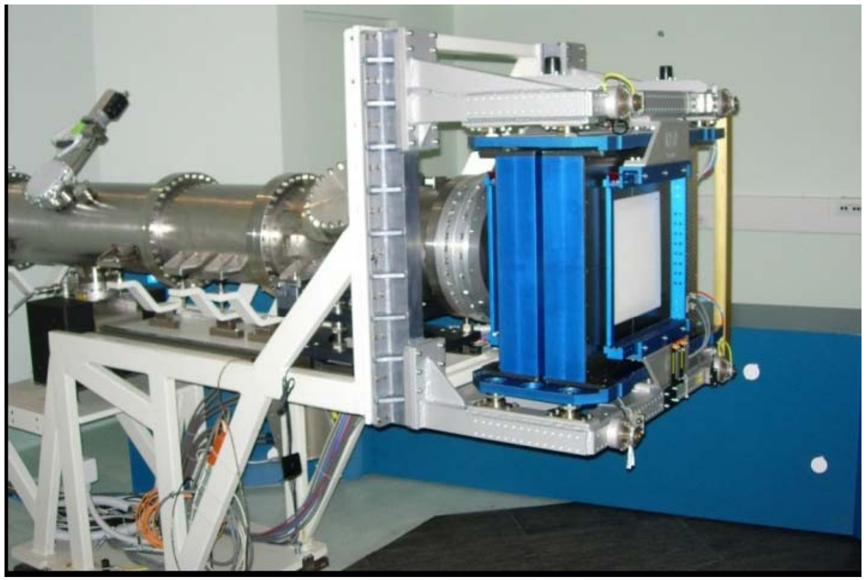


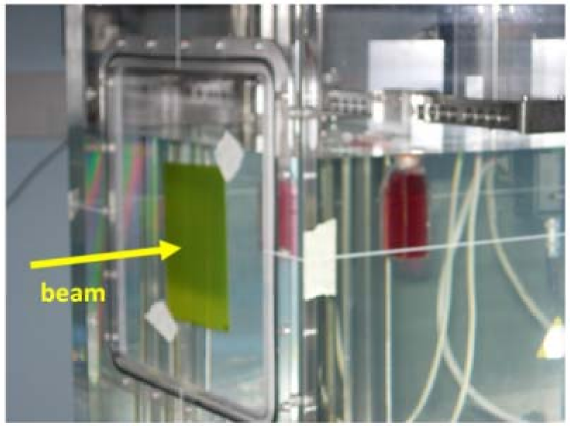
Courtesy of Marco Donetti

Dose delivery

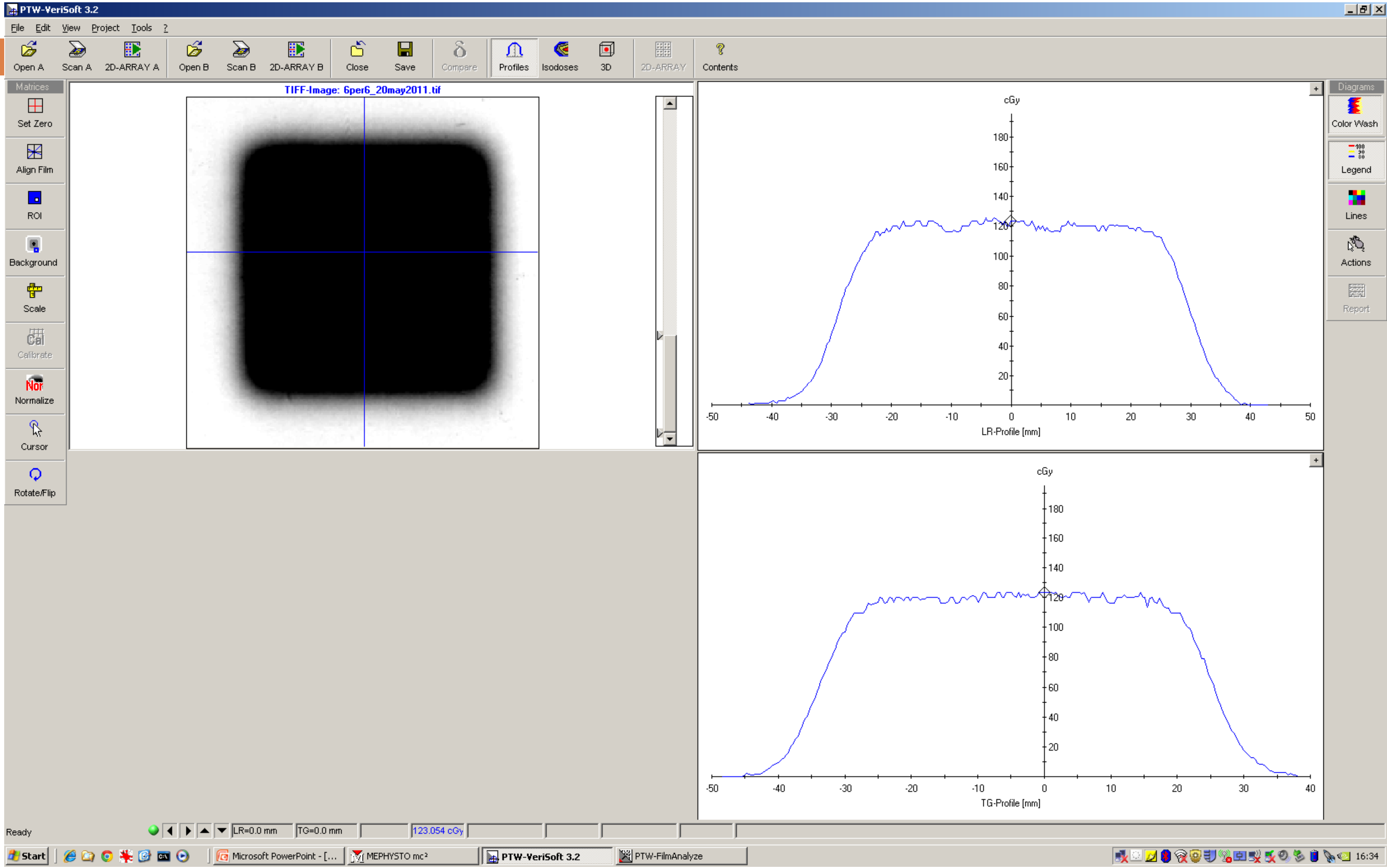


Giordanengo et al.,NIM A613



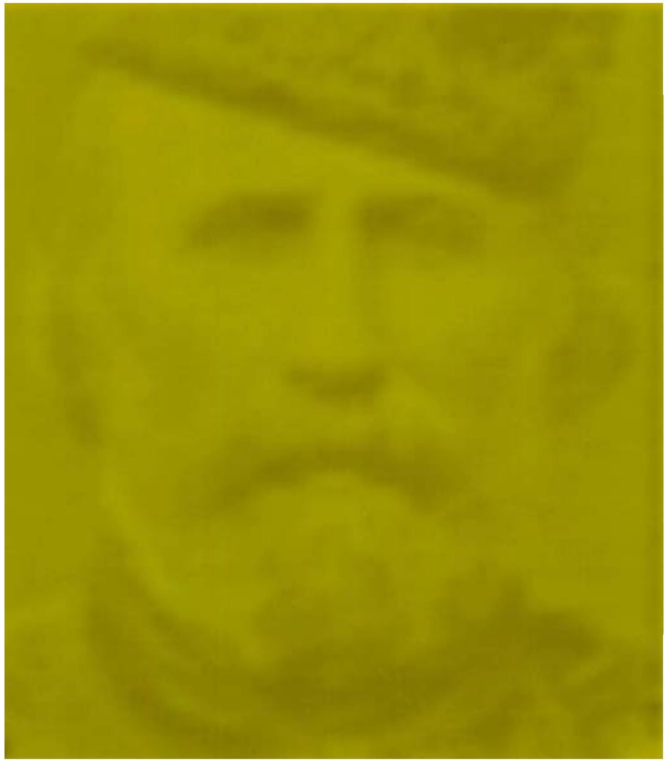


First scannings



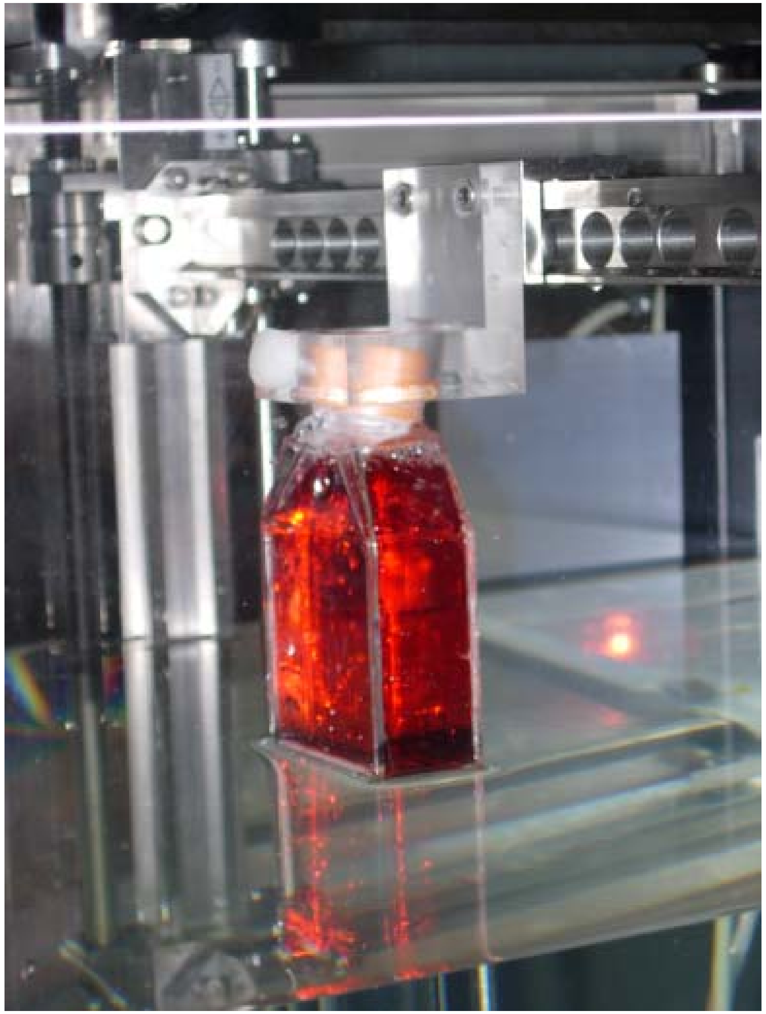
Artistic use of the beam

Radiochromic film

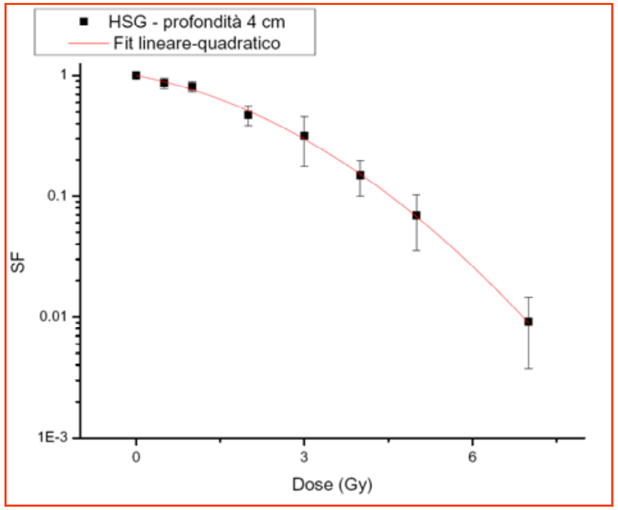


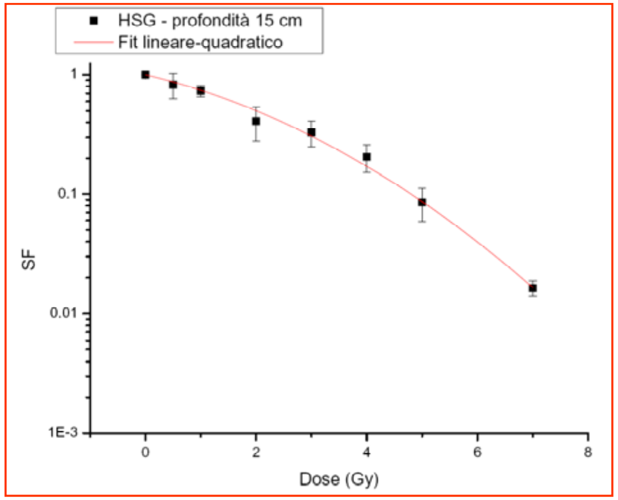
Treatment room

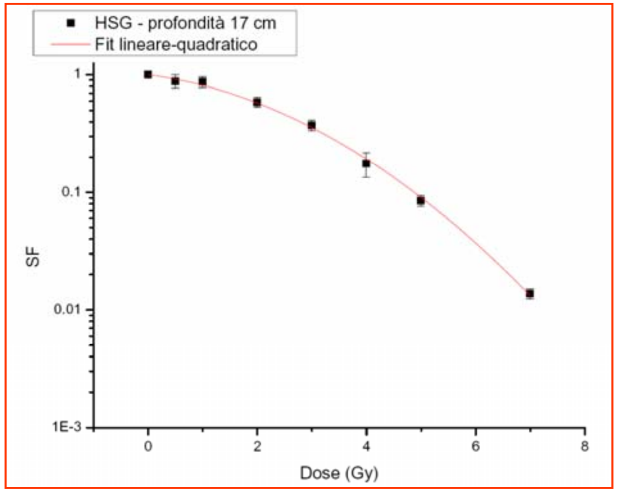
In vitro measurements



Survival curves– Proton: HSG cells





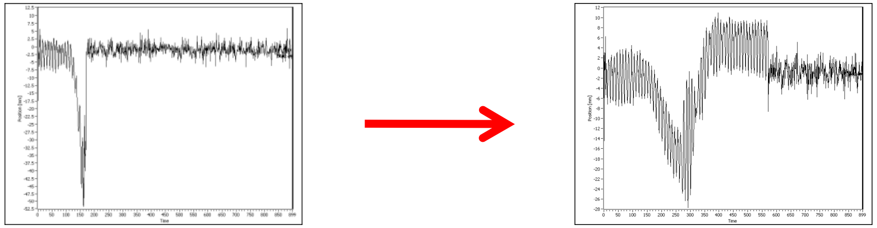


(Courtesy of Roberto Cherubini)

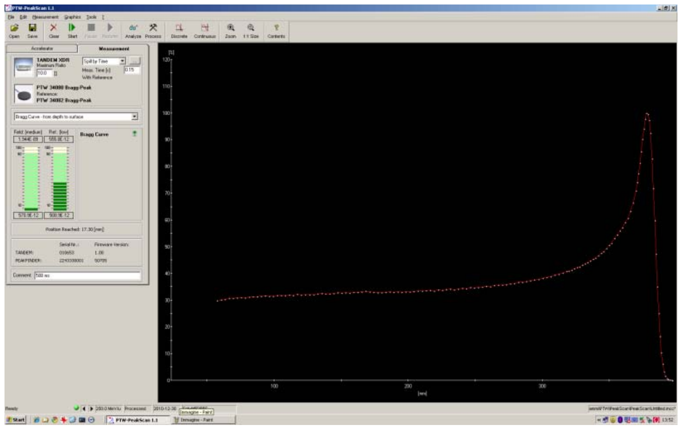
Milestones

MARCH 2005
"posa della prima pietra"

SEPTEMBER 2010
FIRST BEAM ACCELERATED
IN THE SYNCHROTRON



OCTOBER 2010
FIRST BRAGG PEAK
MEASURED IN TREATMENT
ROOM

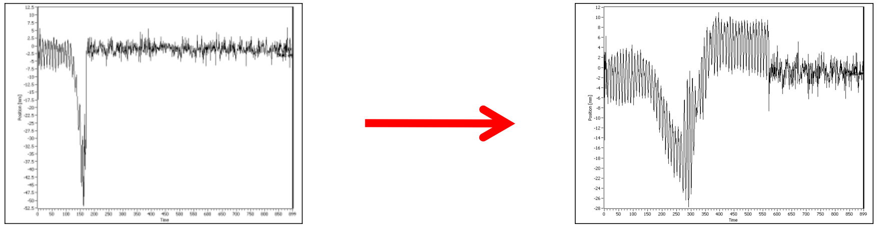


MARCH 2005

“posa della prima pietra”

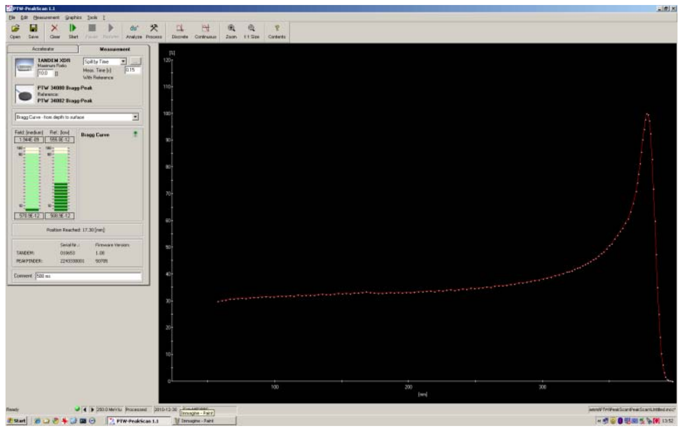
SEPTEMBER 2010

FIRST BEAM ACCELERATED IN THE SYNCHROTRON



OCTOBER 2010

FIRST BRAGG PEAK MEASURED IN TREATMENT ROOM



Start of medical activities

First patient with Proton beam
September 22, 2011)

Conclusions

- The machine construction is finished
- Treatment with protons have started
- Treatment with carbon already authorized
- There is still a lot of space to improve performances (treatment rooms, vertical line, treatment time, beam size, ...)

Thank you for your attention