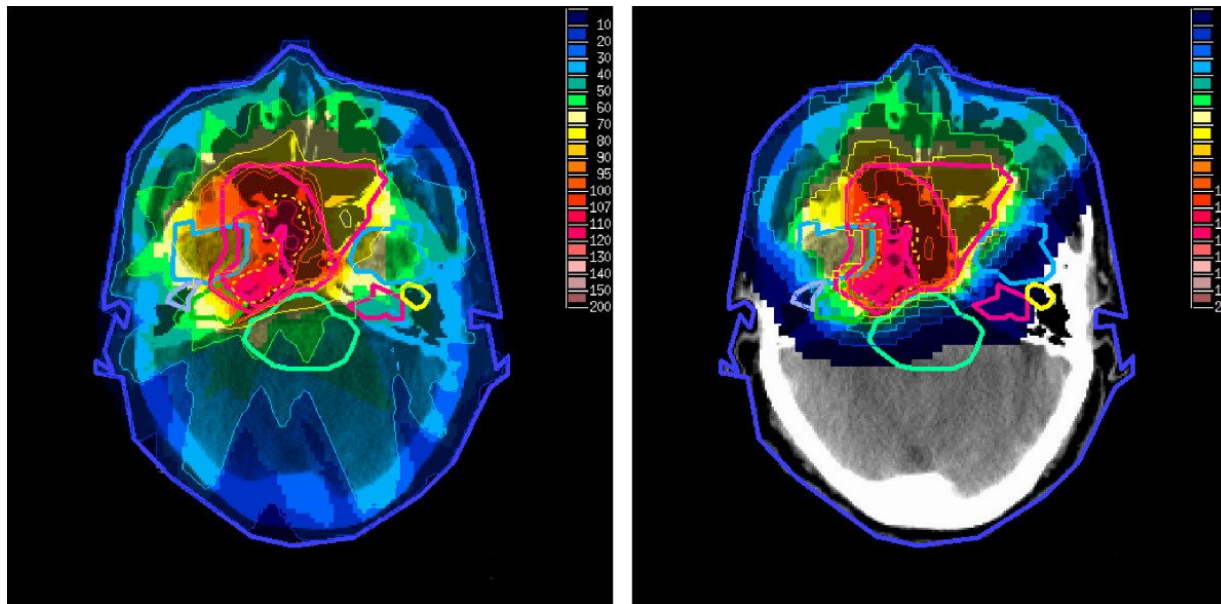
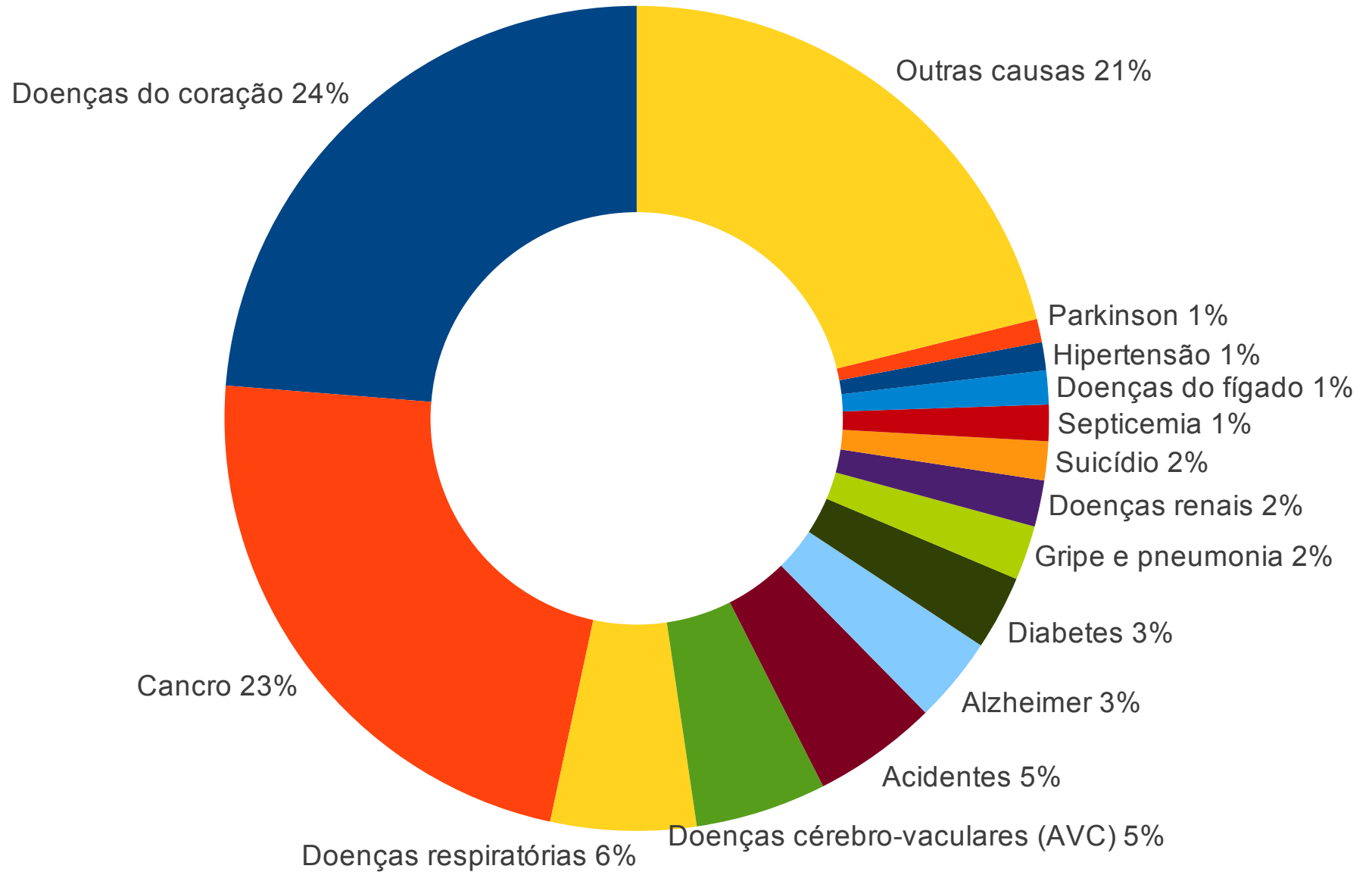


# Feixes iónicos contra o cancro

Luis Peralta



# Causas de morte USA 2010-2011

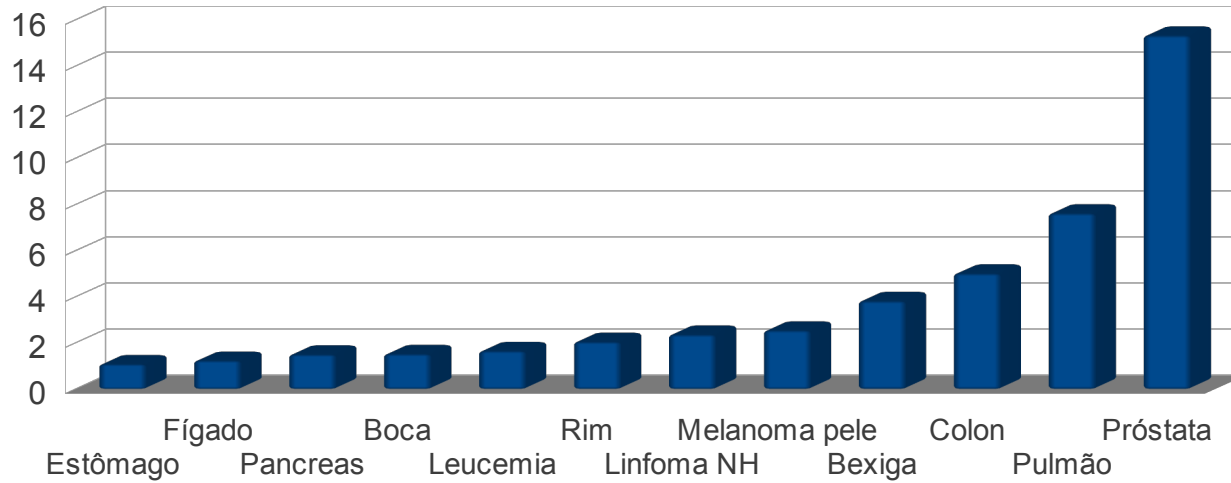


USA 2013  
Homens



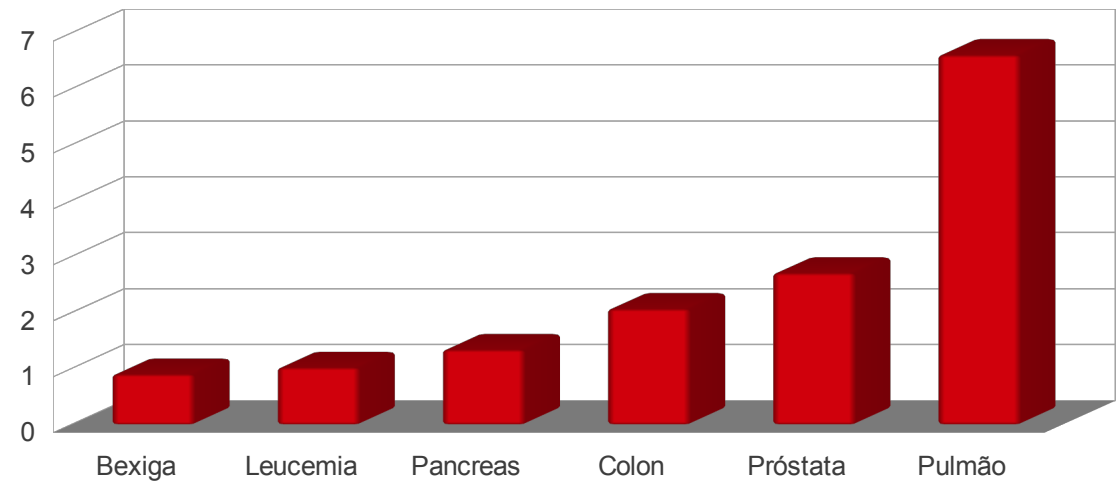
### Risco desenvolver cancro

44% todos tipos



### Risco morrer cancro

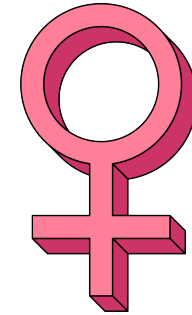
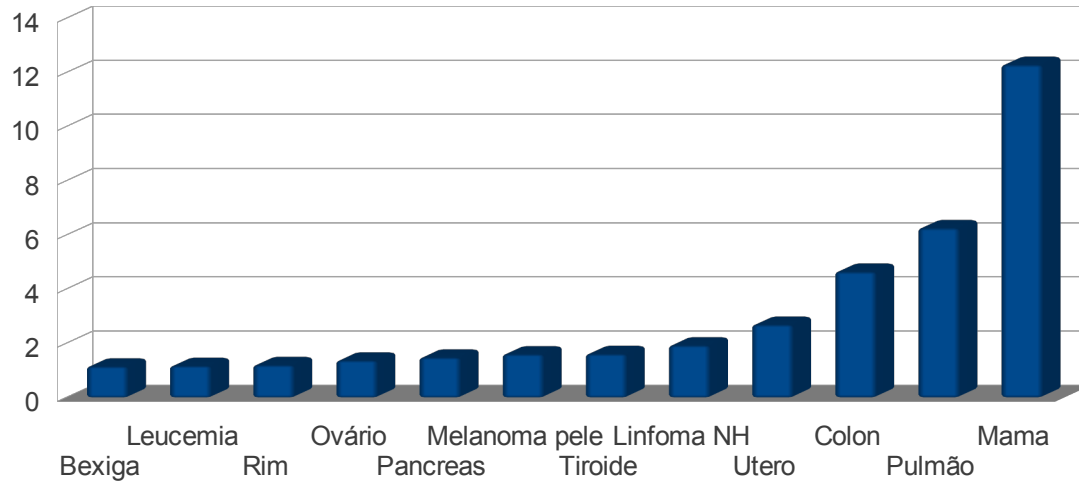
23% todos tipos



# USA 2013 Mulheres

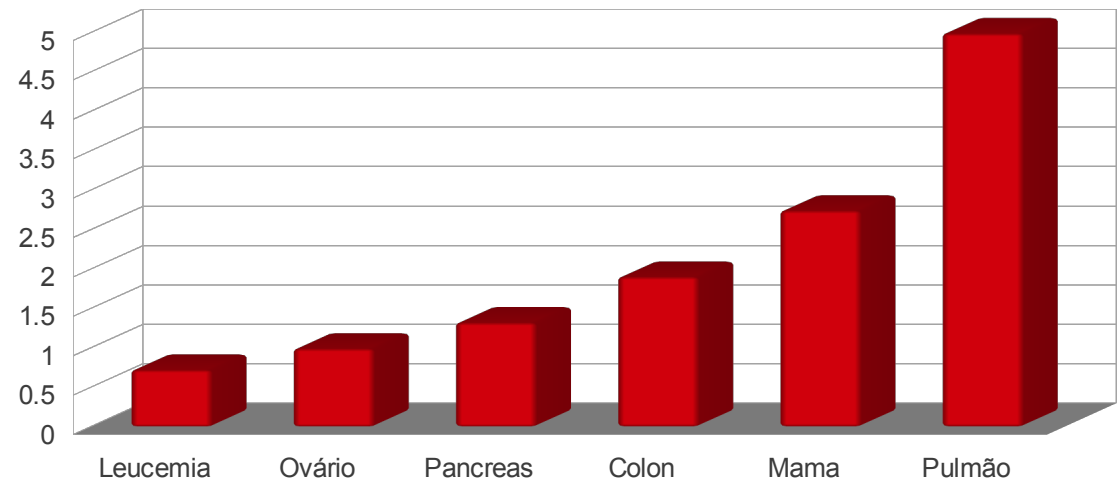
## Risco desenvolver cancro

38% todos tipos

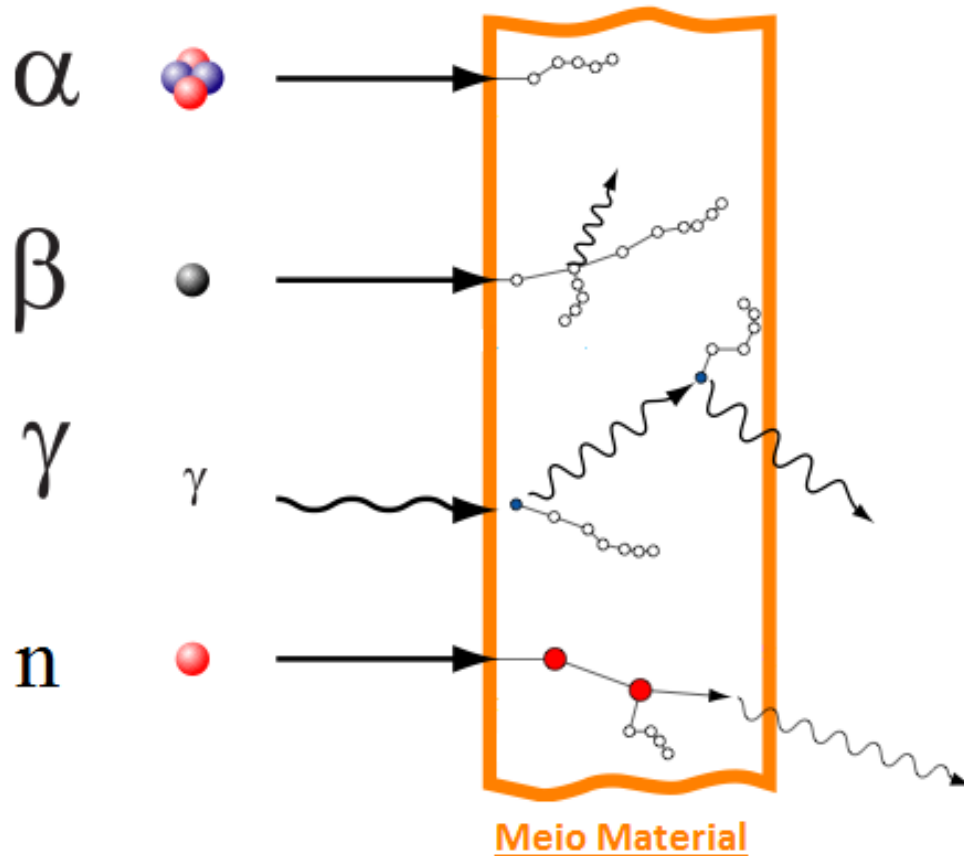


## Risco morrer cancro

19% todos tipos



# Tipos de Radiação



Menor poder de penetração



Mais energia depositada localmente

Maior poder de penetração



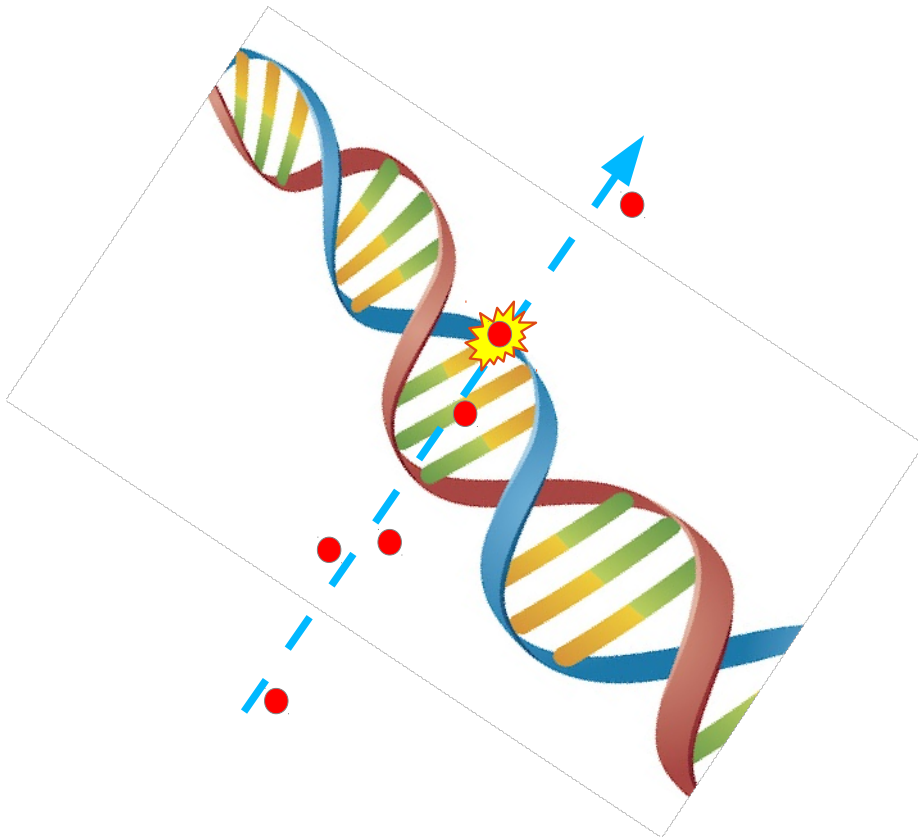
Menos energia depositada localmente

# Interação com as células

Efeito direto:

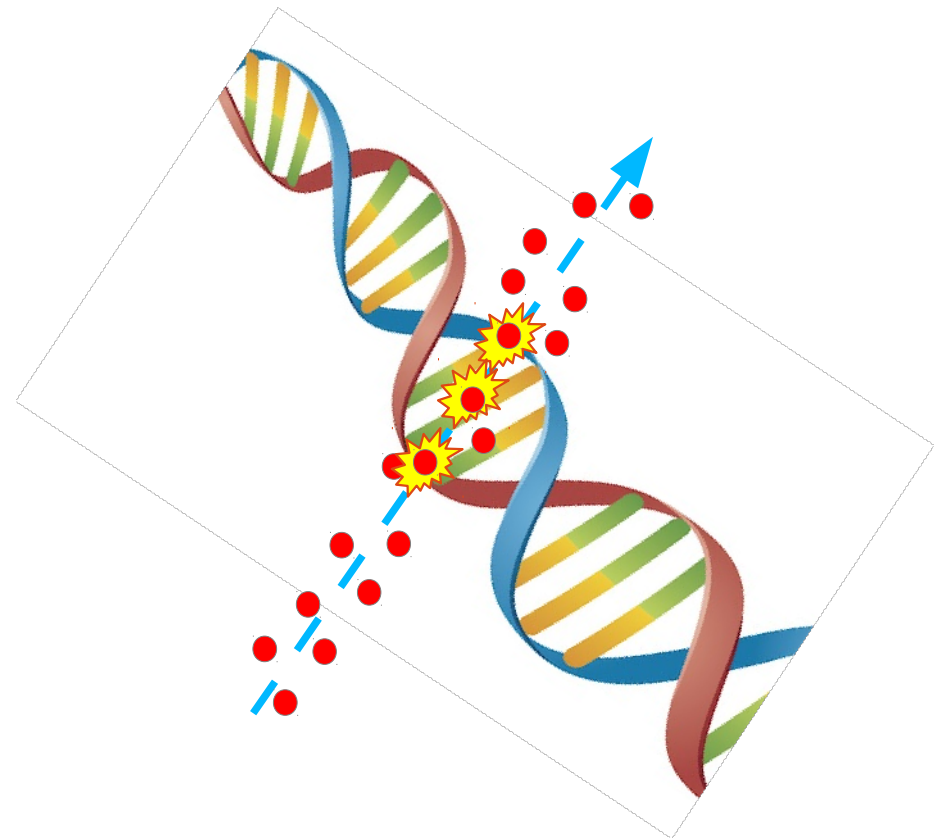
Alvo preferencial: DNA da célula

Radiação pouco ionizante



Lesões isoladas: reparação fácil

Radiação altamente ionizante

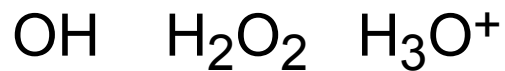


Lesões agrupadas: reparação difícil

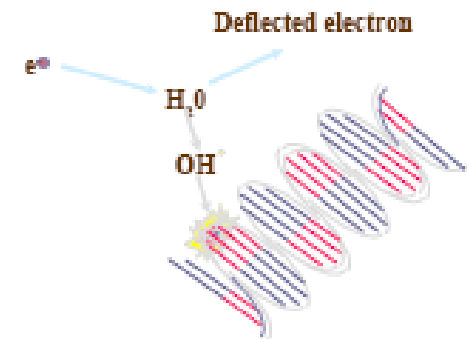
# Interação com as células

## Efeito indireto

A partir das moléculas de água existentes na célula formam-se iões ou radicais livres



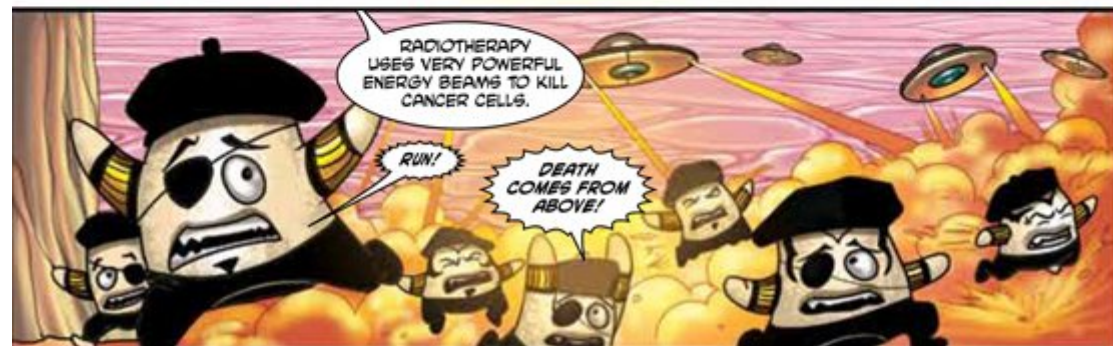
que podem reagir com outras moléculas da célula (carbohidratos, proteínas) alterando o metabolismo celular.



# Dose

As lesões celulares são correlacionadas com a energia depositada por unidade de massa

$$D = \frac{dE}{dm} \quad (1 \text{ gray} = 1 \text{ J/kg})$$

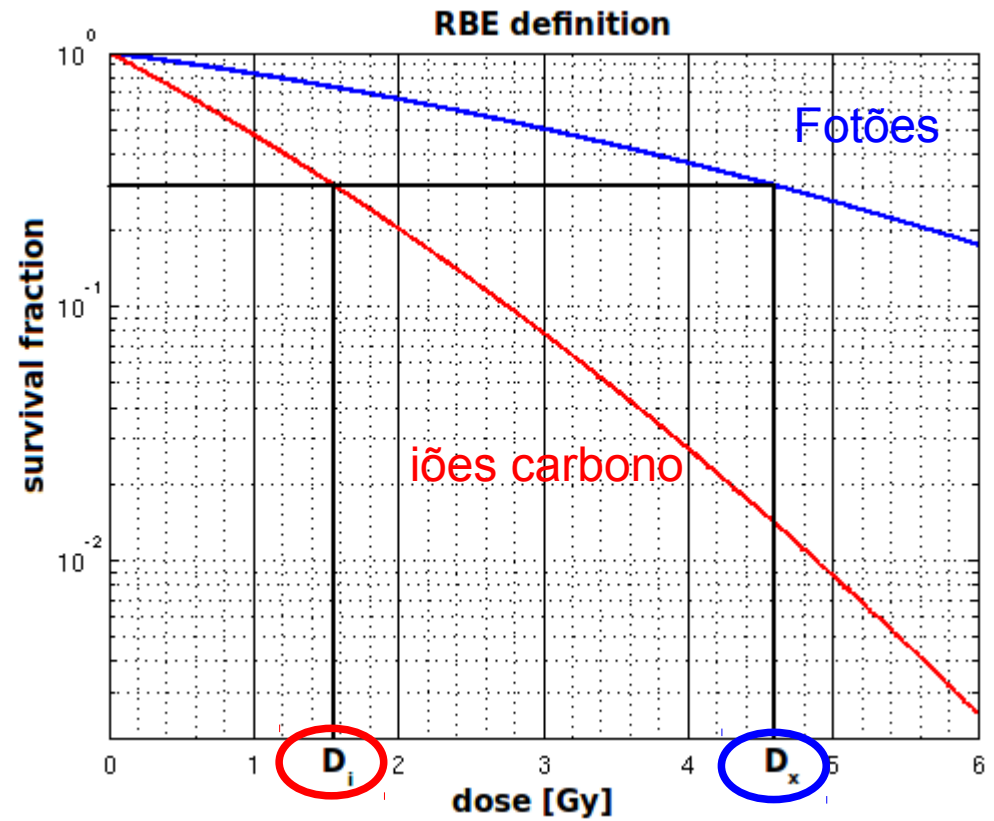






# Eficácia biológica relativa

$$\text{RBE} = \frac{\text{Dose}_x}{\text{Dose}_{\text{rad}}}$$



# Radioterapia convencional

Fonte de radiação  
exteriores



Radioterapia externa

Terapia com  
radiações

Braquiterapia

Fontes  
radioativas



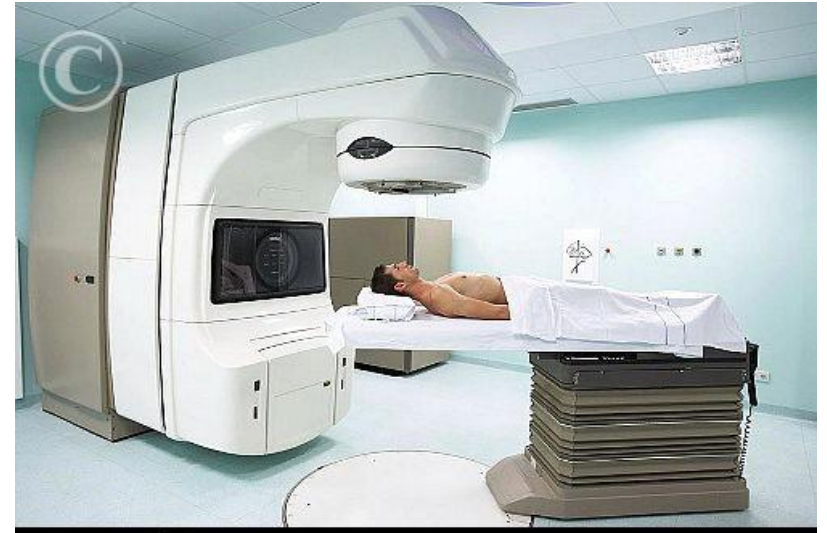
# Radioterapia externa

A radioterapia externa convencional usa feixes de fótons de energia elevada



<http://news.stanford.edu/news/2007/april18/med-accelerator-041807.html>

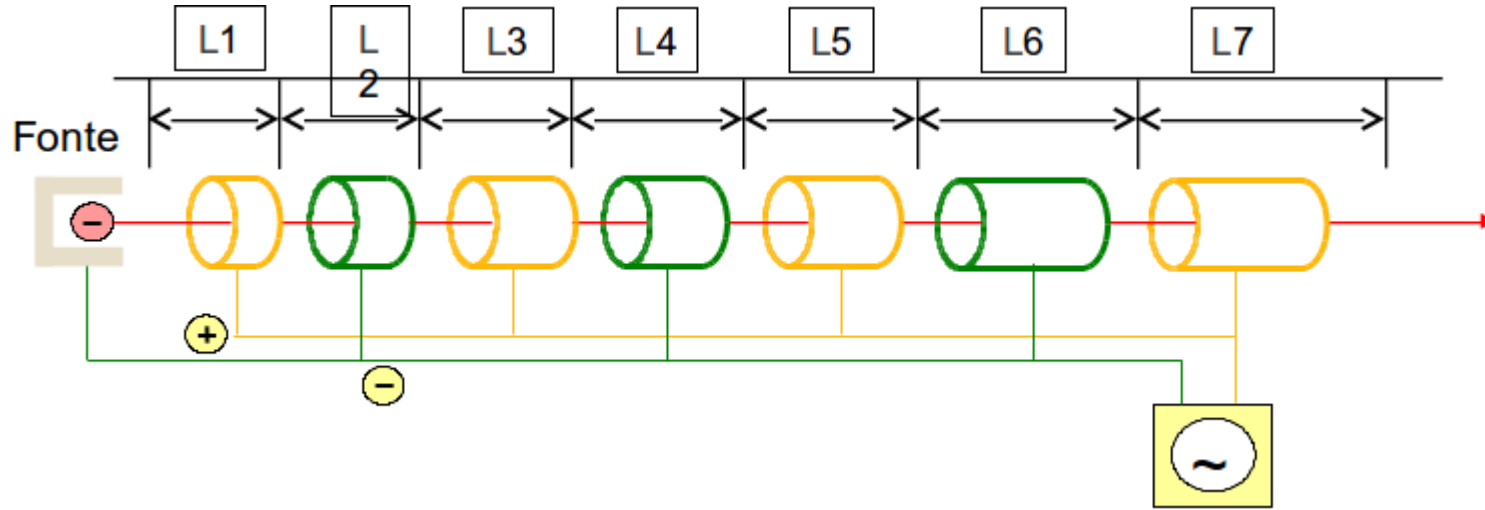
Anos 50



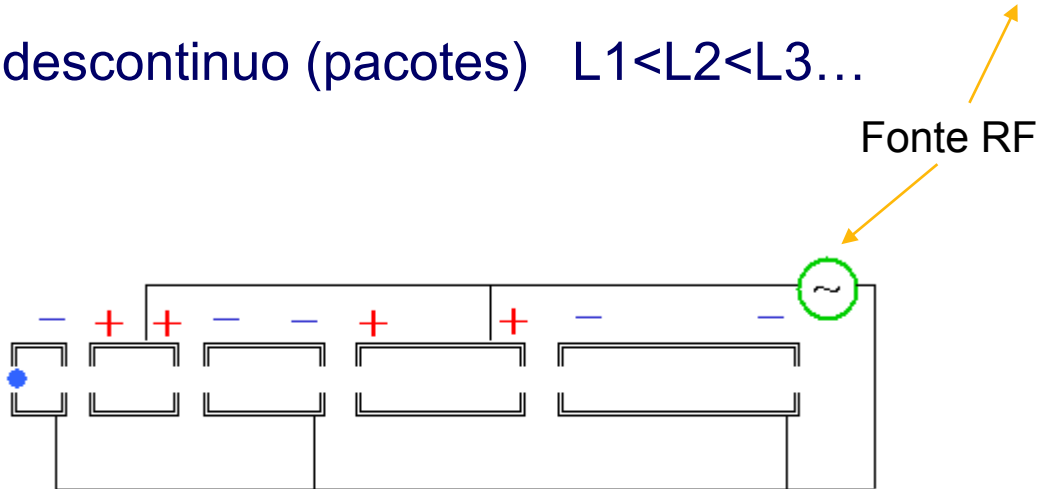
WE033891 [RF] © www.visualphotos.com

Atualidade

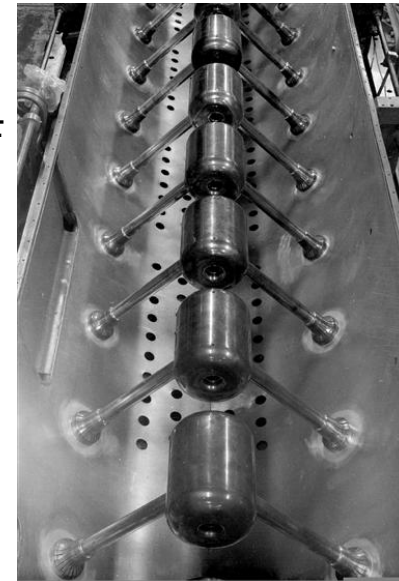
# O acelerador Linear



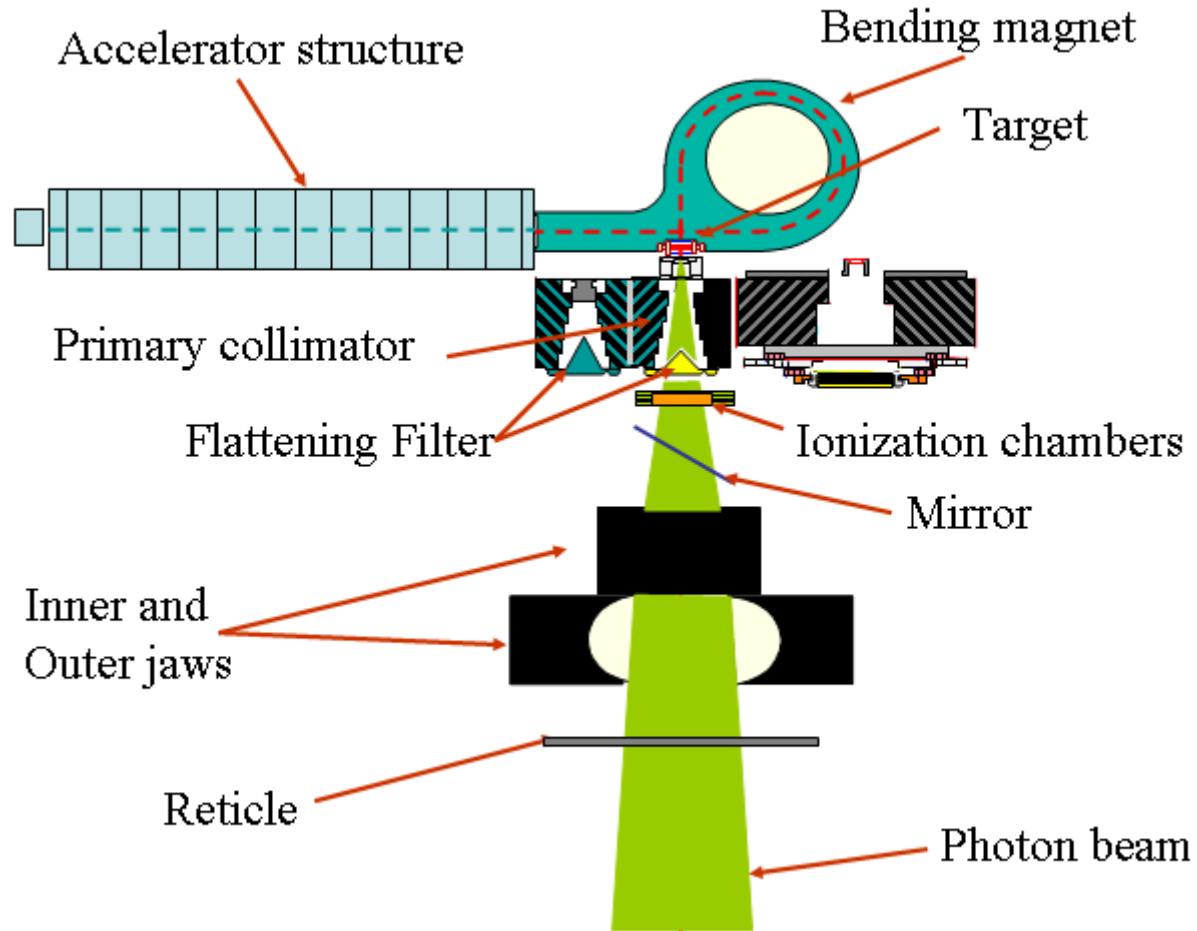
O feixe é descontínuo (pacotes)  $L1 < L2 < L3 \dots$



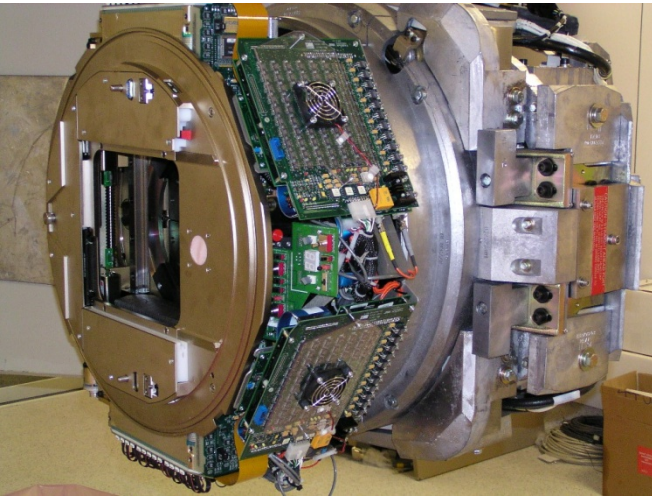
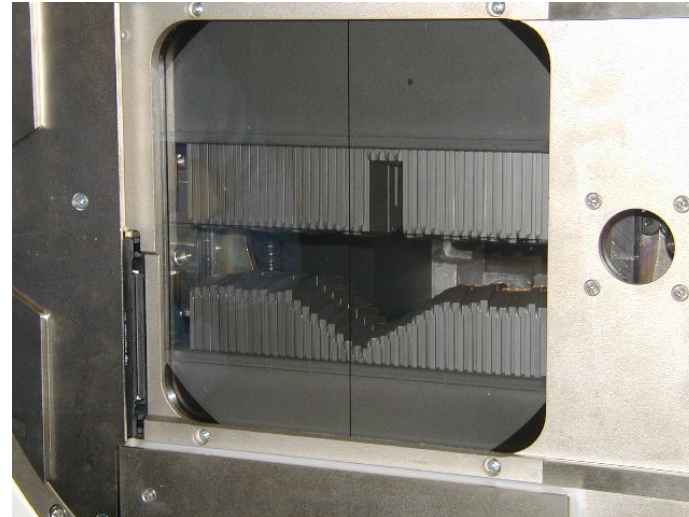
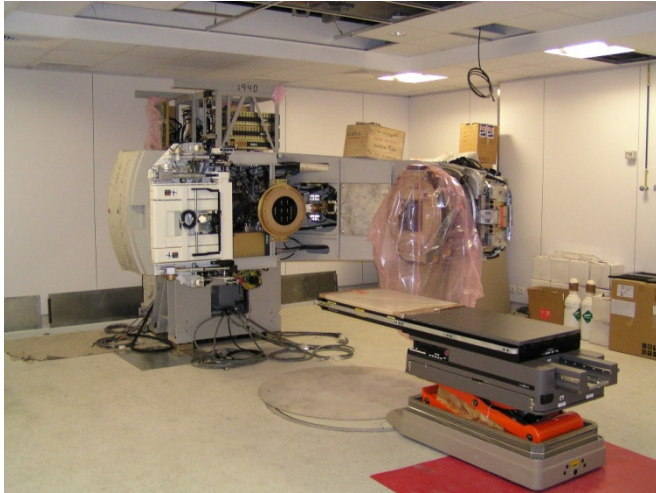
Fonte RF



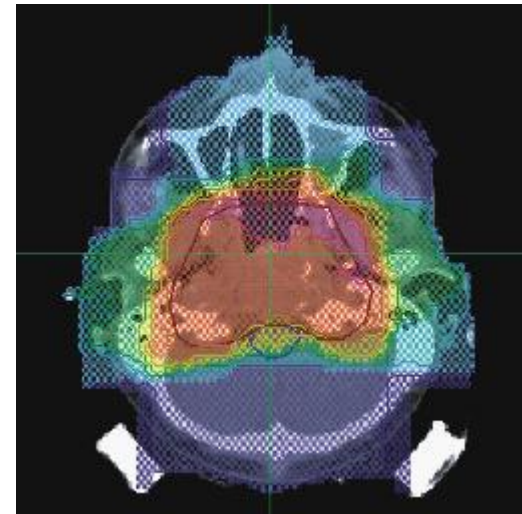
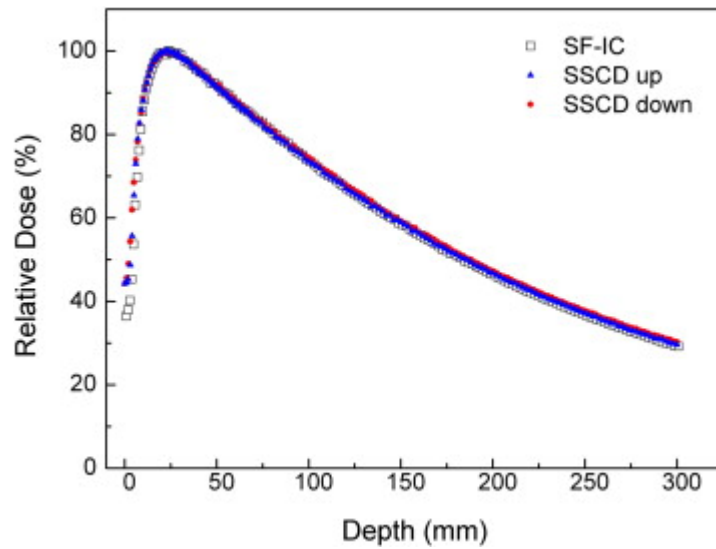
# Acelerador clínico de elétrons moderno



# Instalação de um acelerador linear



# Tratamento com um feixe de fótons

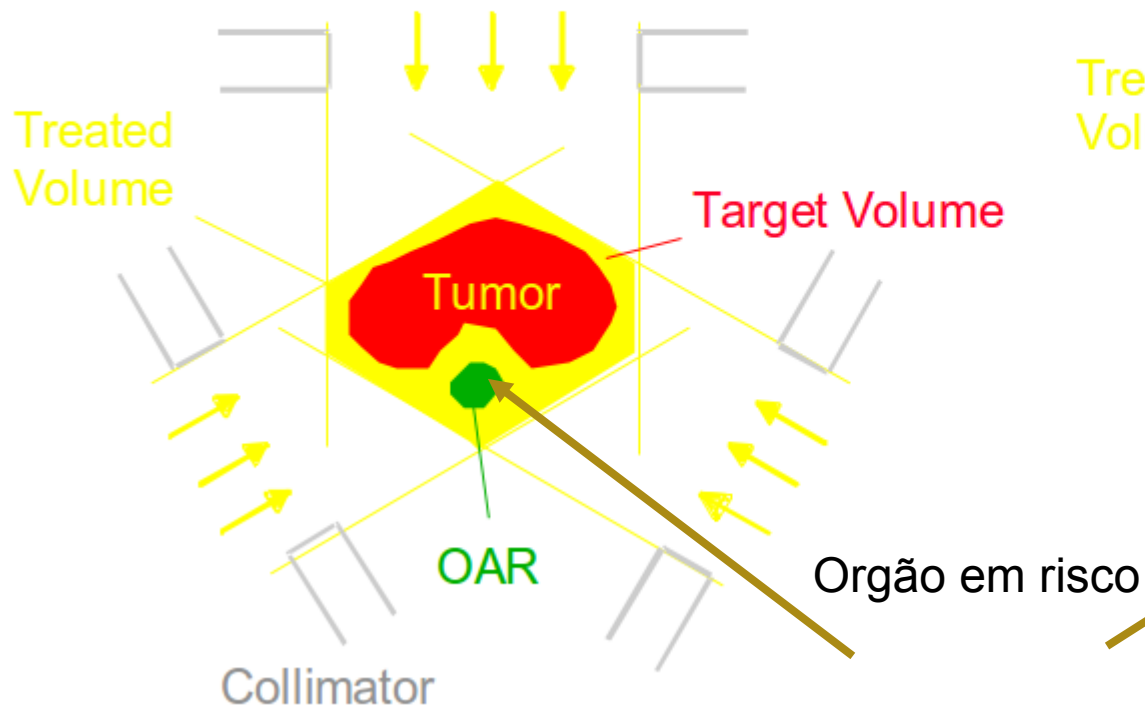


Dose varia com a profundidade

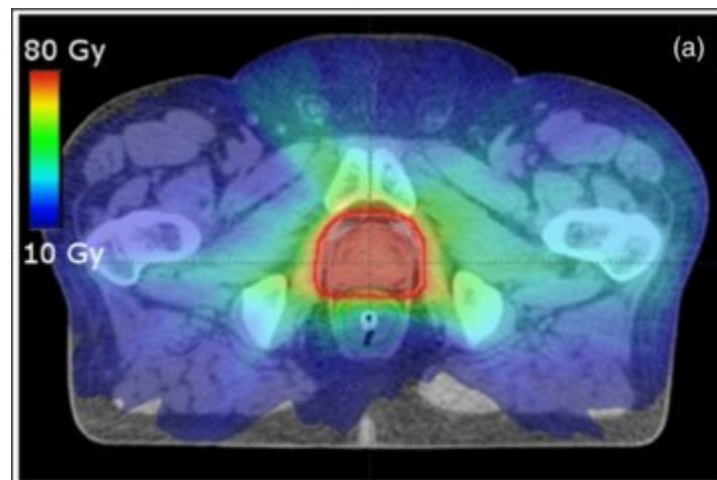
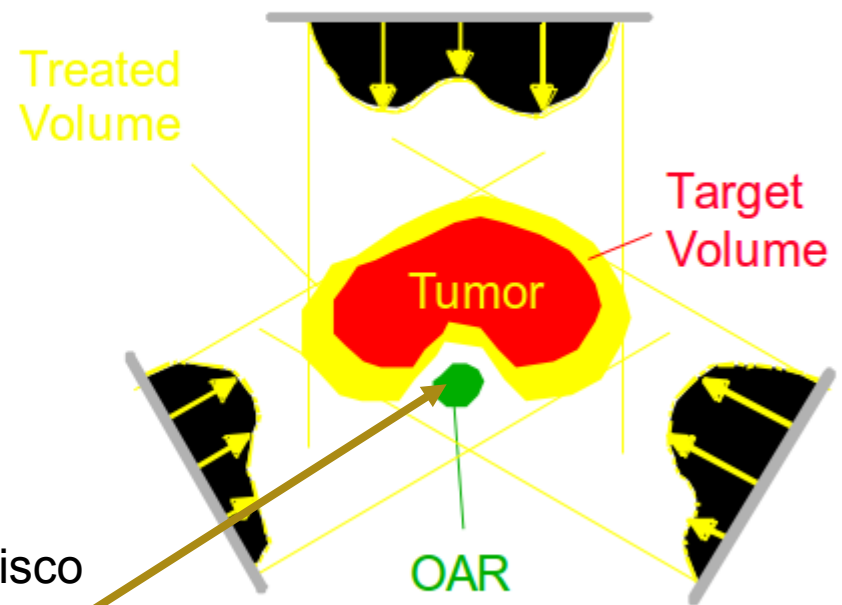


# Conformação do feixe de fótons

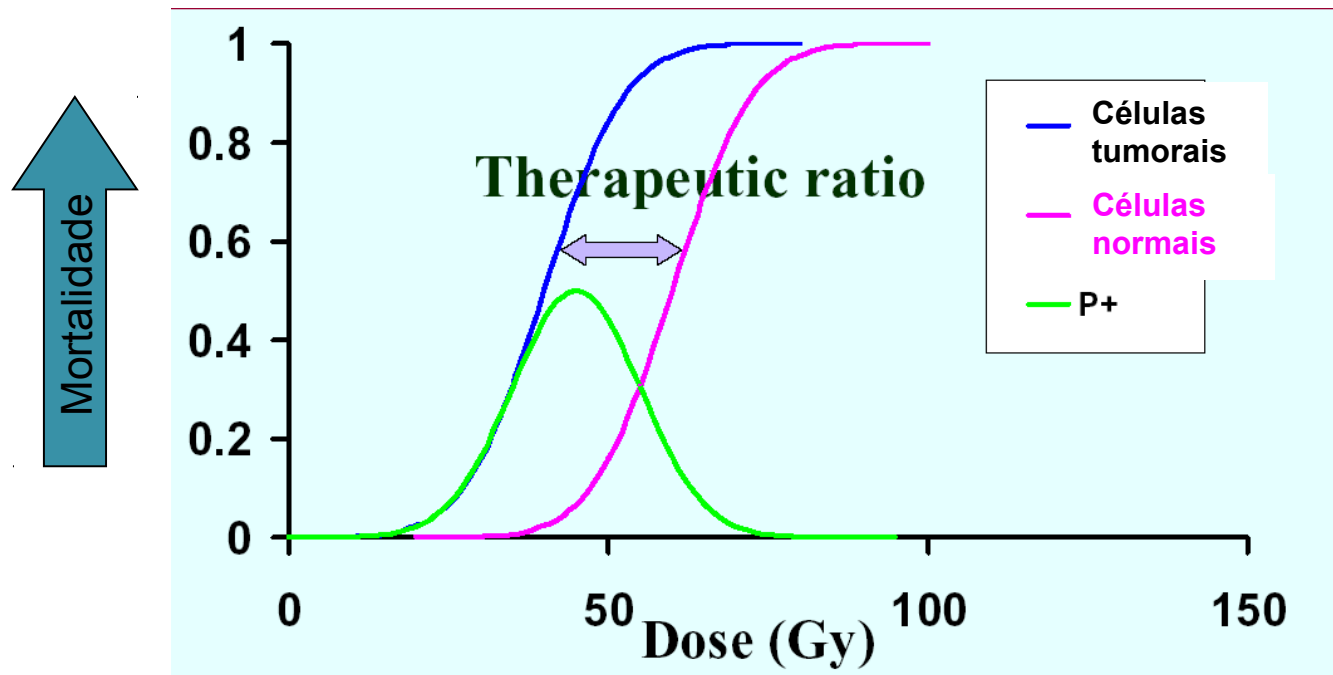
Várias incidências feixe de fótons



IMRT (RadioTerapia de Intensidade Modulada)



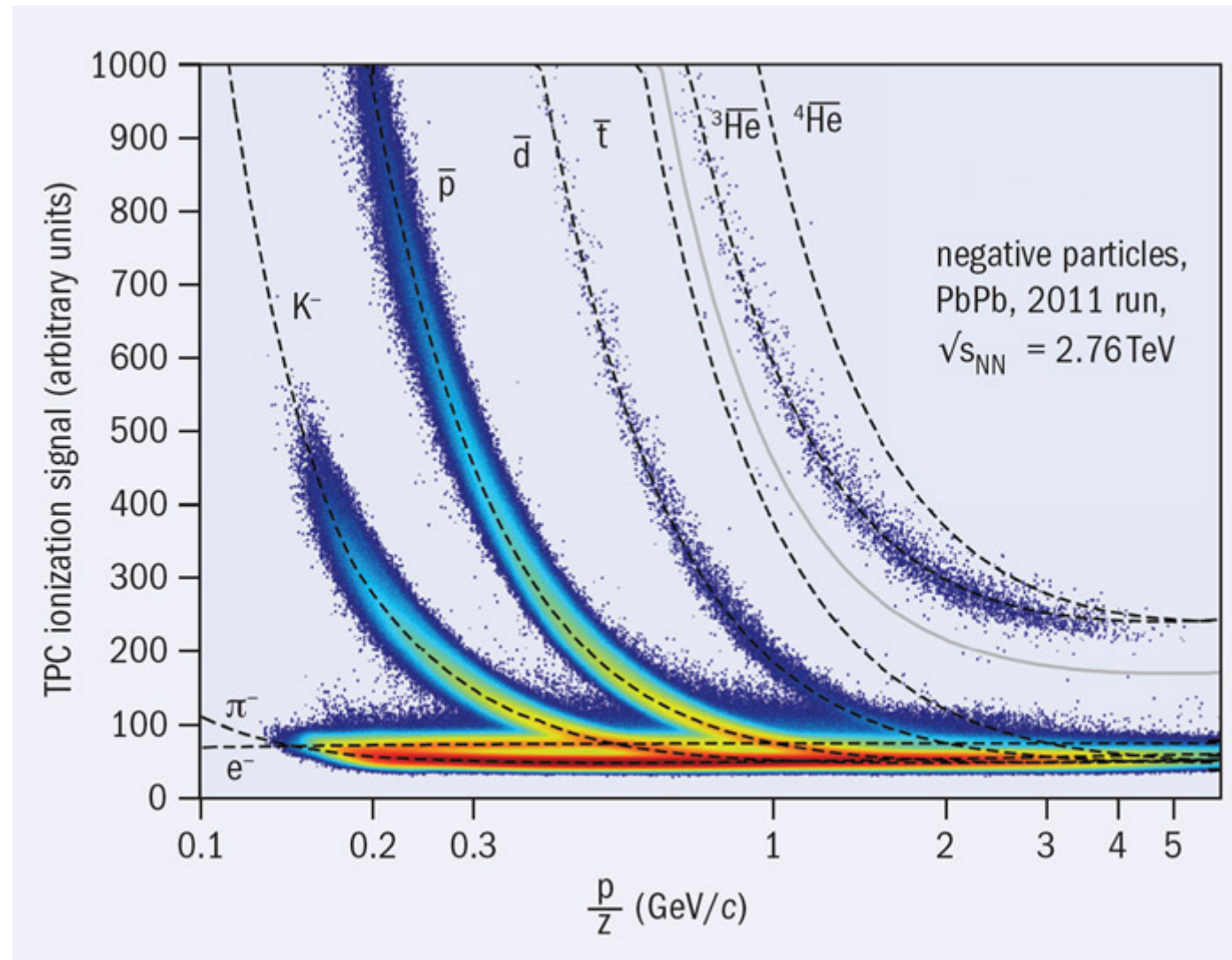
# Sobrevivência de células tumorais / normais



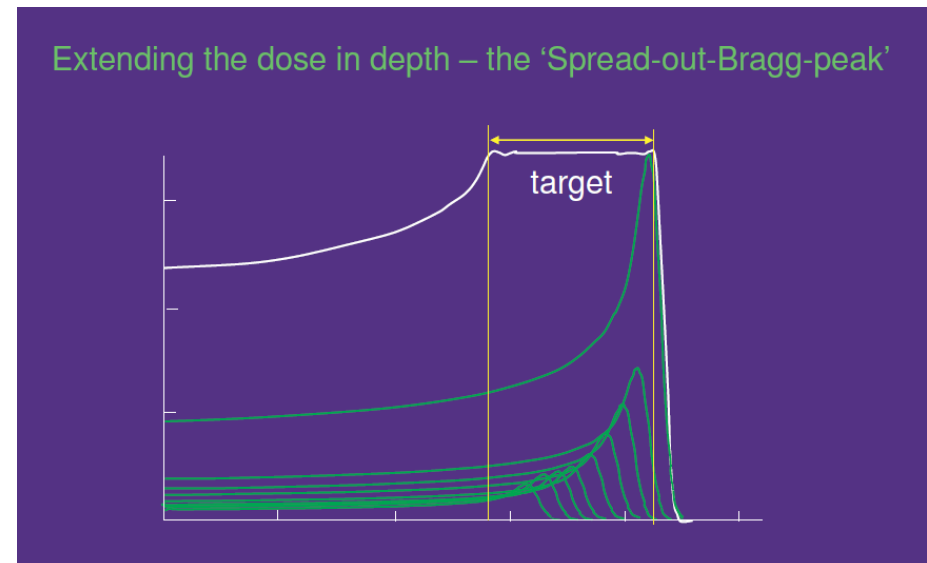
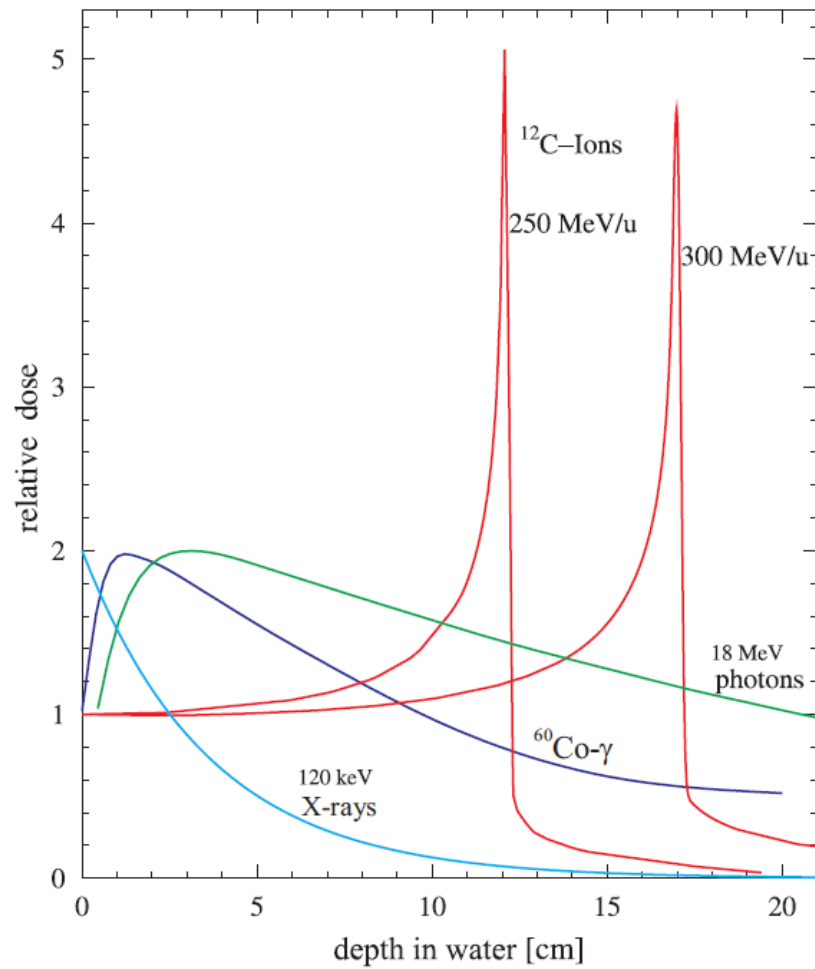
# Feixes de partículas carregadas

## Poder de paragem

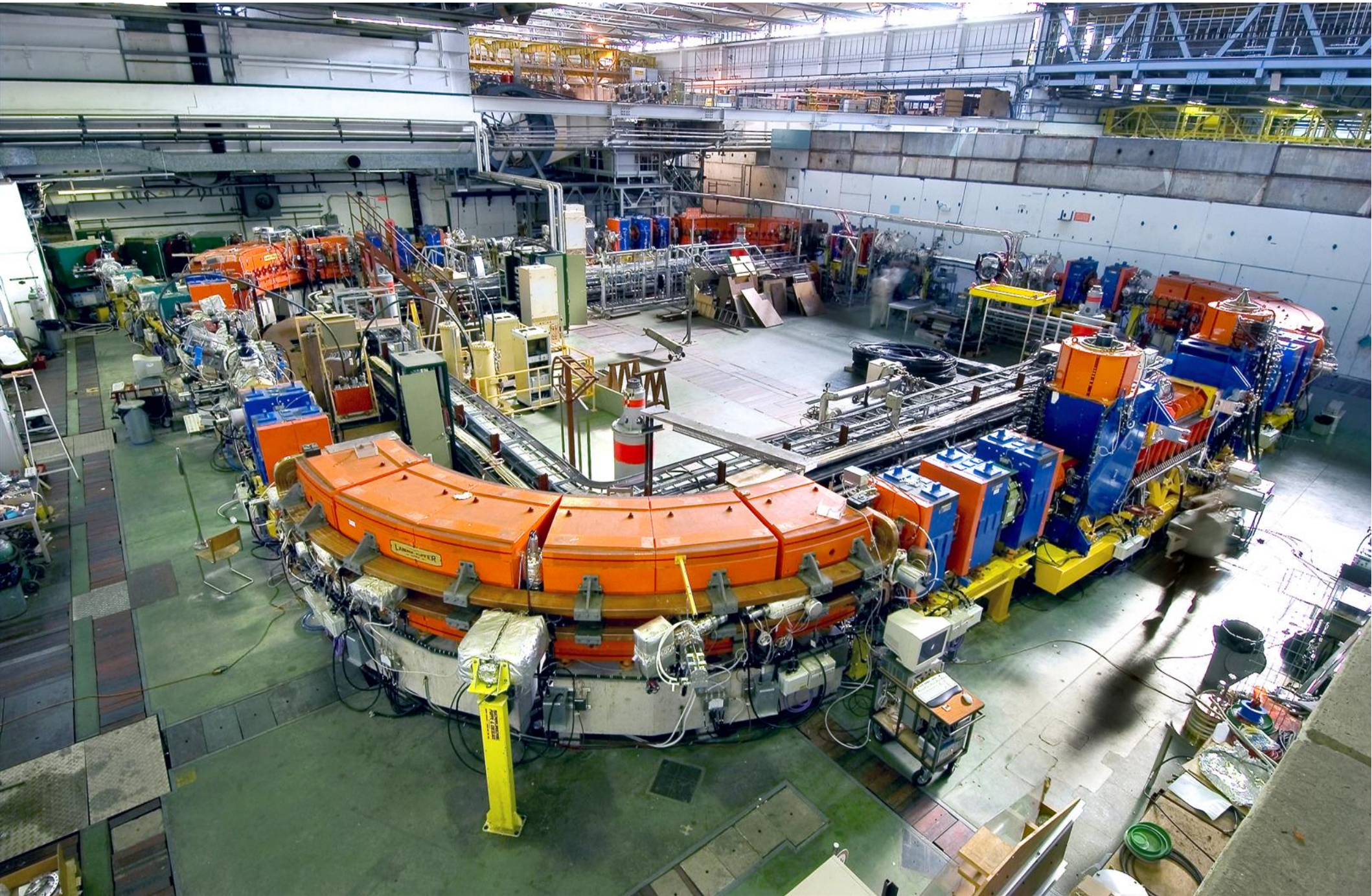
$$S = -\frac{dE}{dx}$$



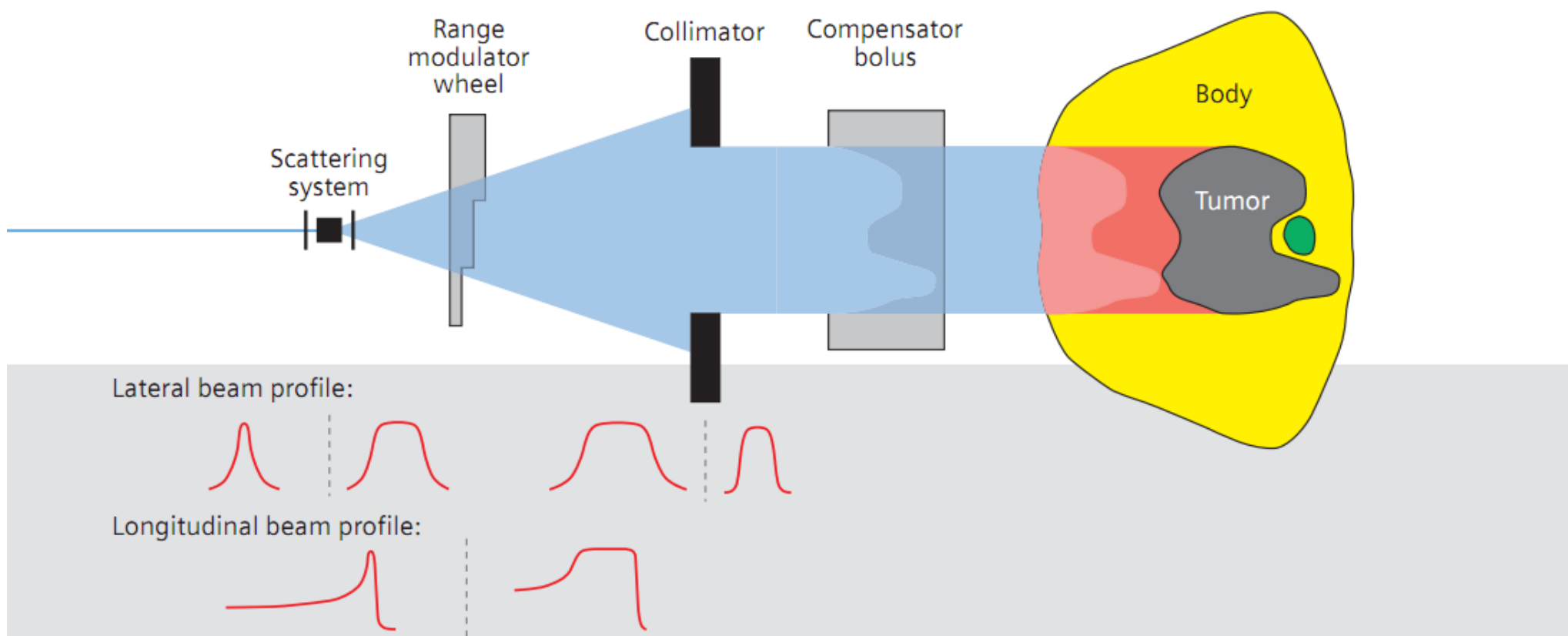
# Deposição de energia de prótons / iões



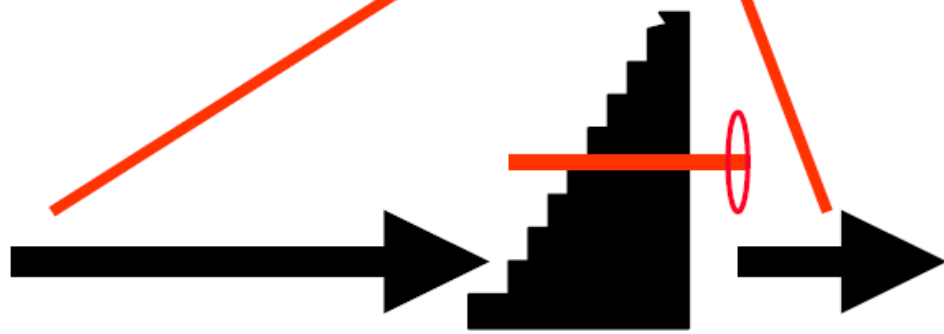
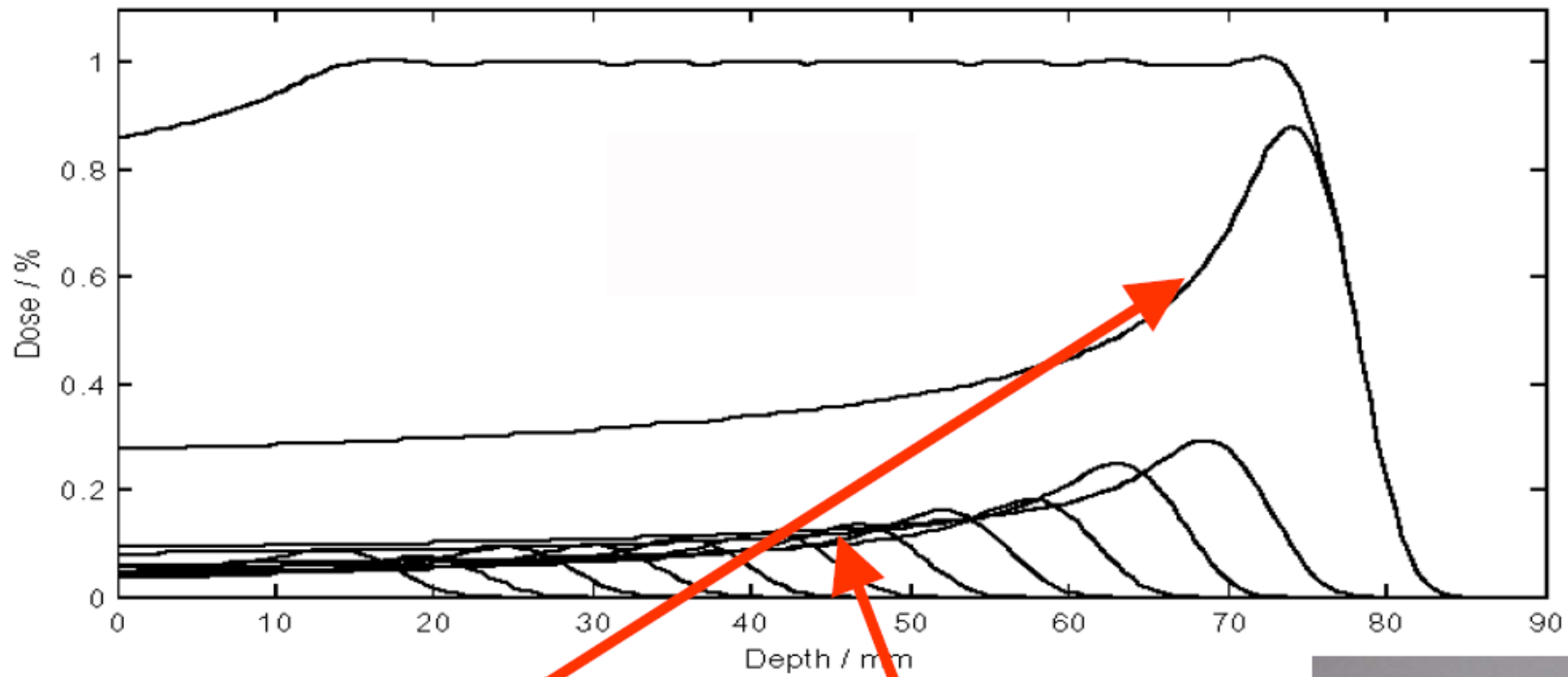
# Acelerar prótons/iões



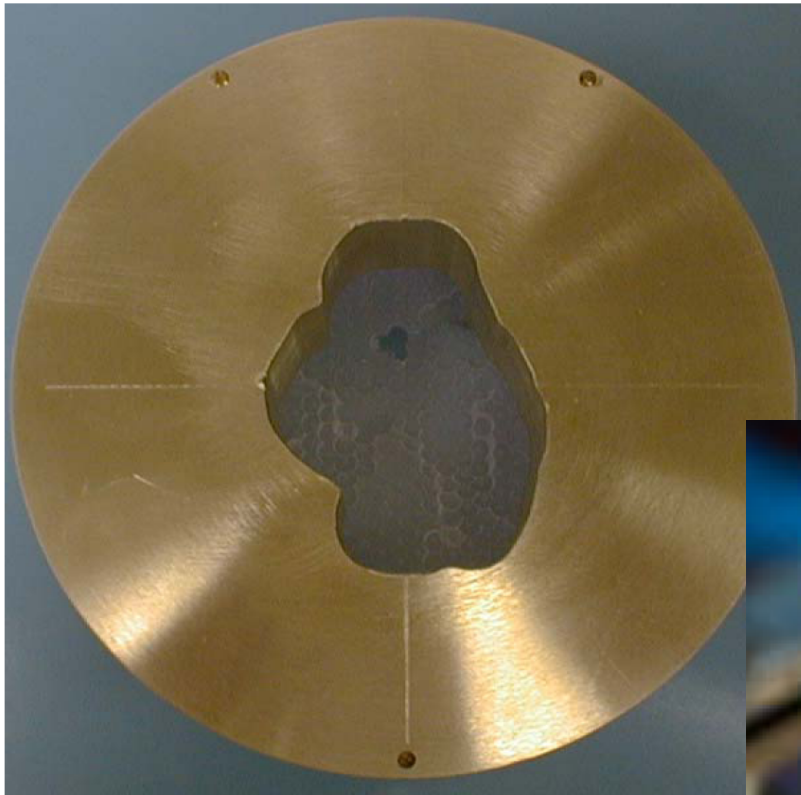
# Sistemas passivos de formatação do feixe



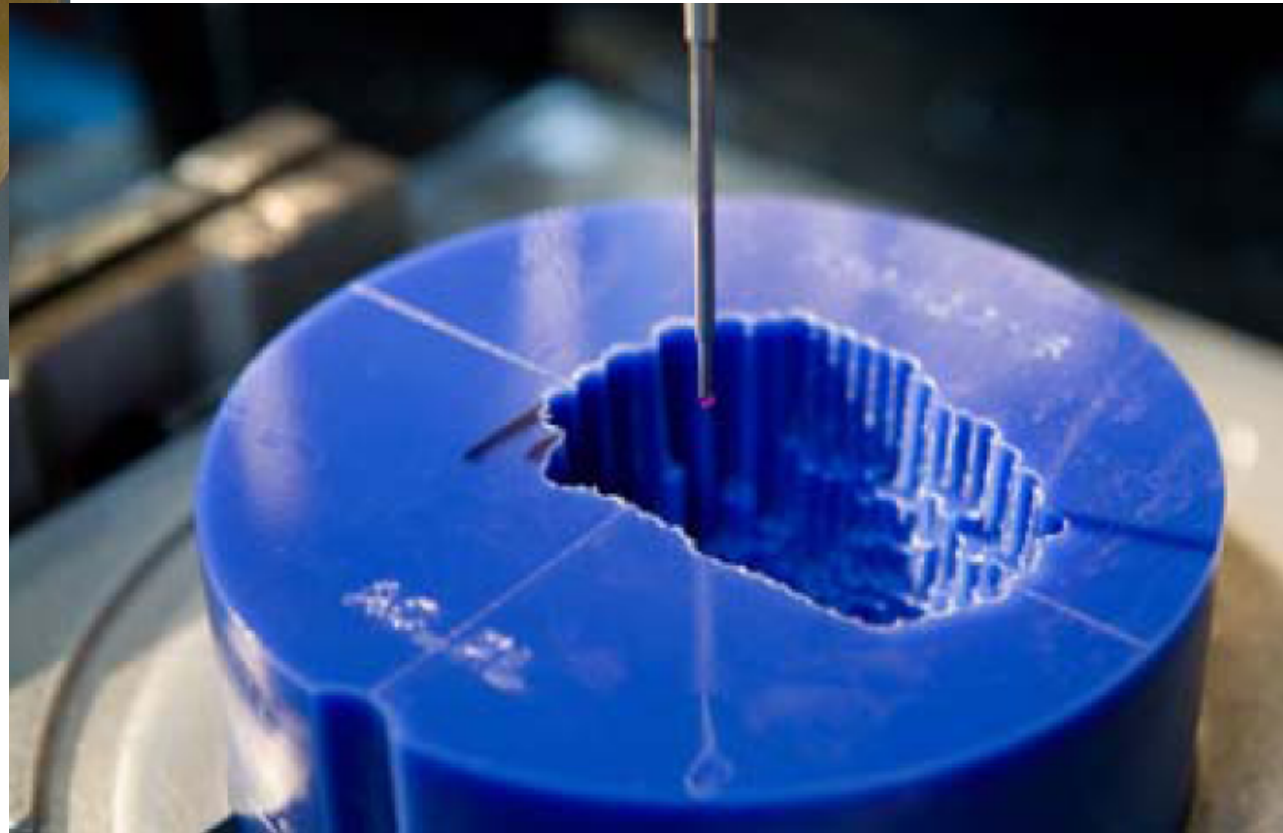
# Modulação do alcance do feixe



Colimador em bronze

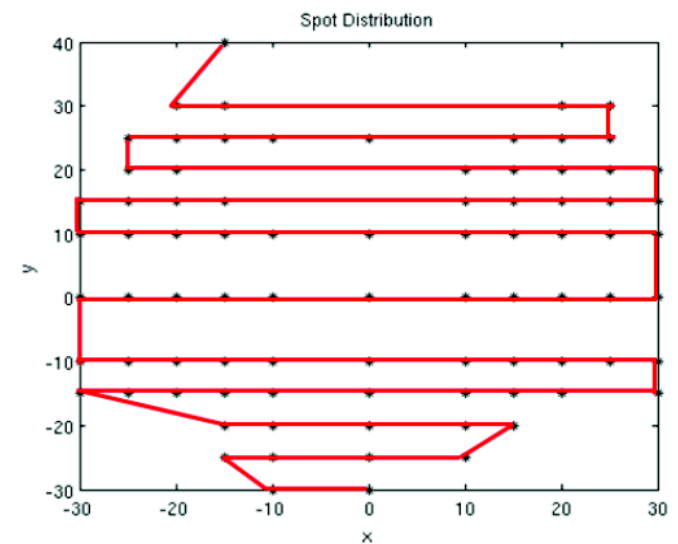
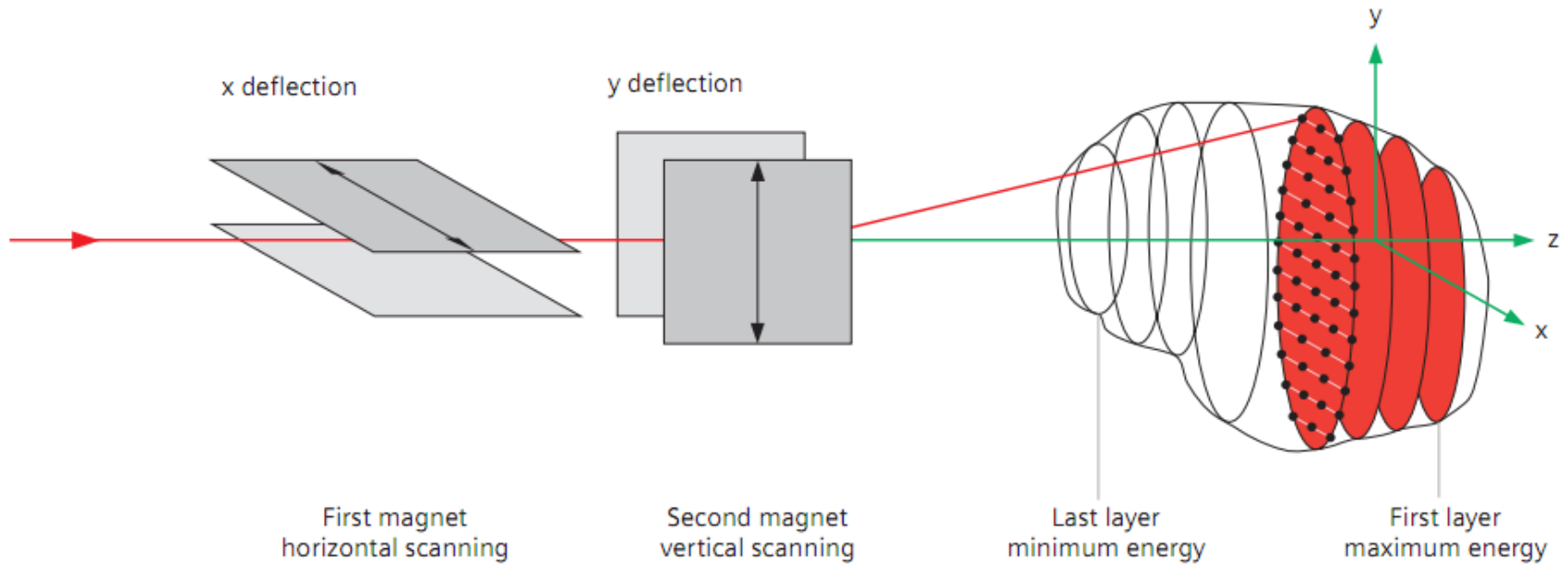


Compensador alcance

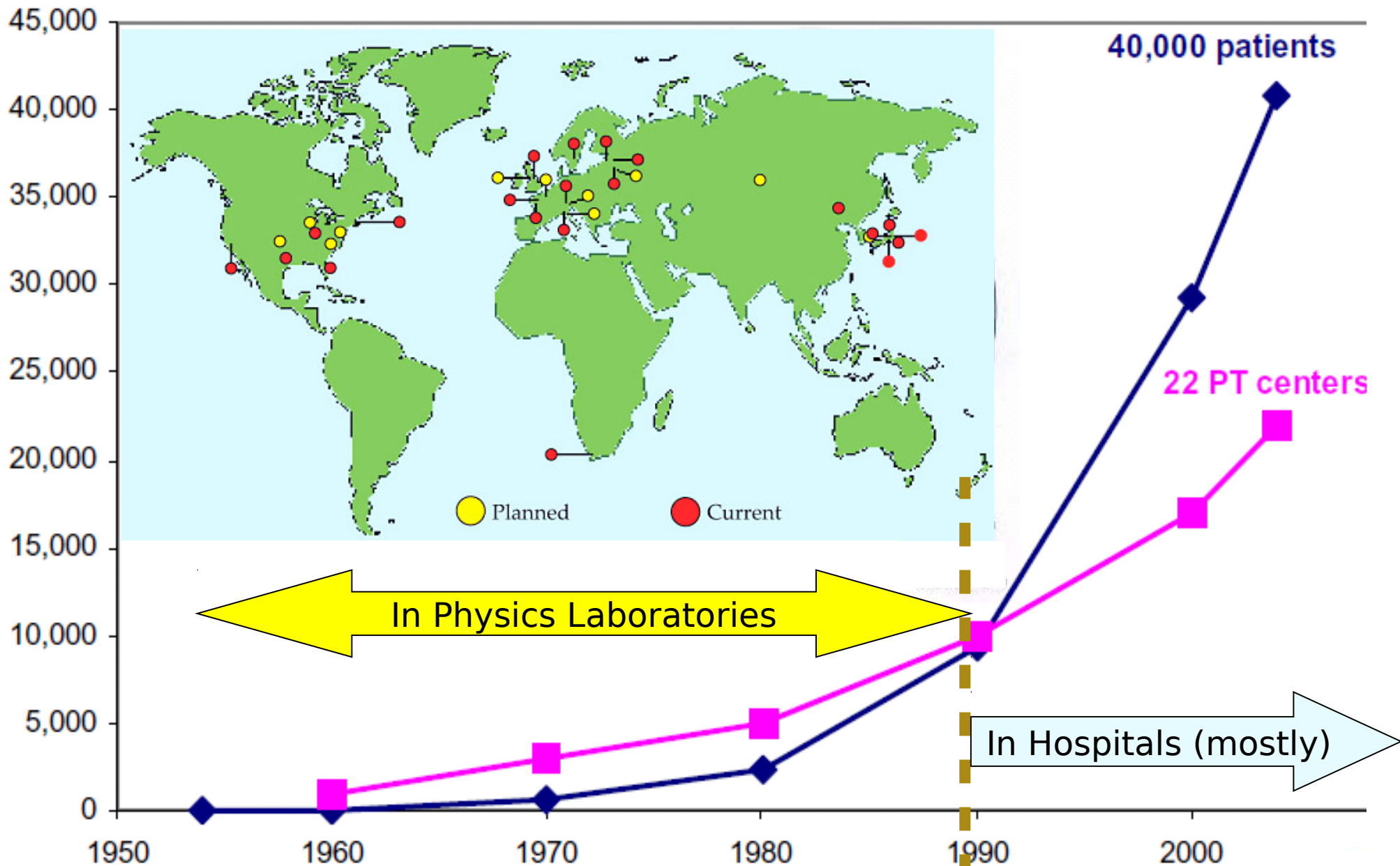




# Sistemas ativos de formatação do feixe



# Evolução temporal da terapia com prótons



Courtesy Janet Sisterson, MGH

39 centros de terapia com prótons/iões em operação no mundo

Em 2012,

108238 doentes tratados

93895 com prótons

10756 com iões de carbono

3587 outros iões (e.g. hélio e piões)

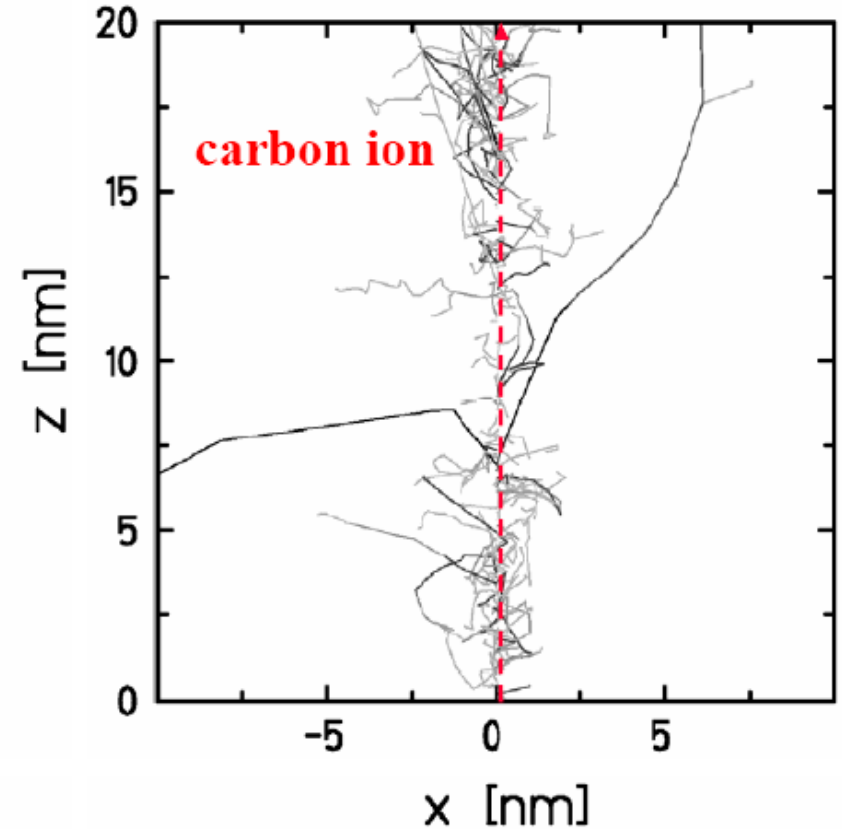
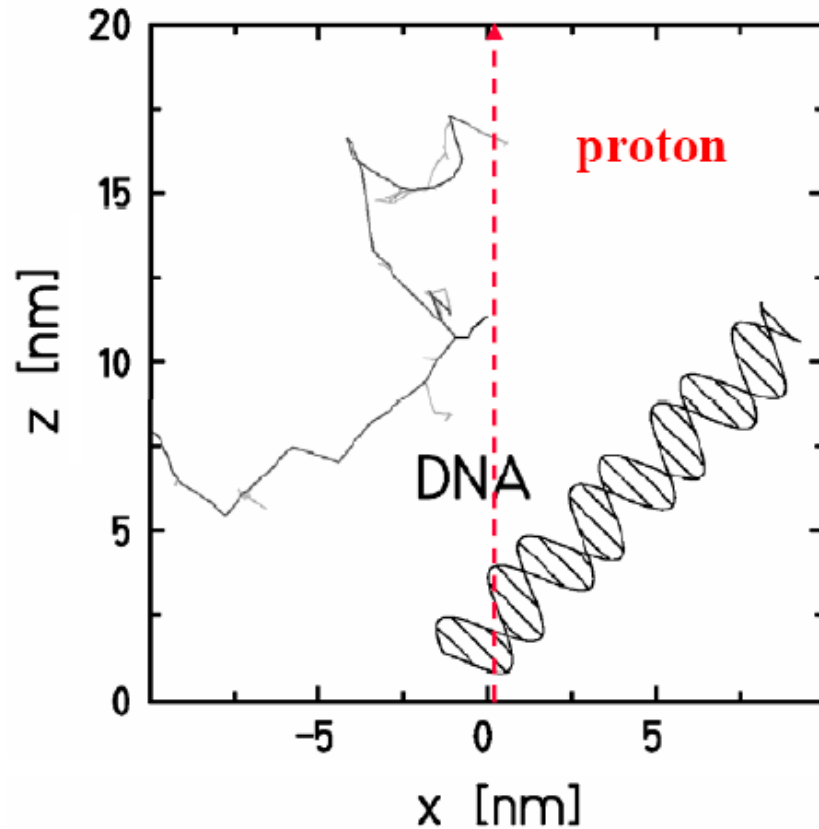
No HIT (Heidelberg) foram tratados 1232 doentes:

252 com prótons

980 com iões de carbono

Dados do Particle Therapy Co-Operative Group ([ptcog.web.psi.ch](http://ptcog.web.psi.ch))

# Porquê usar terapia com iões?

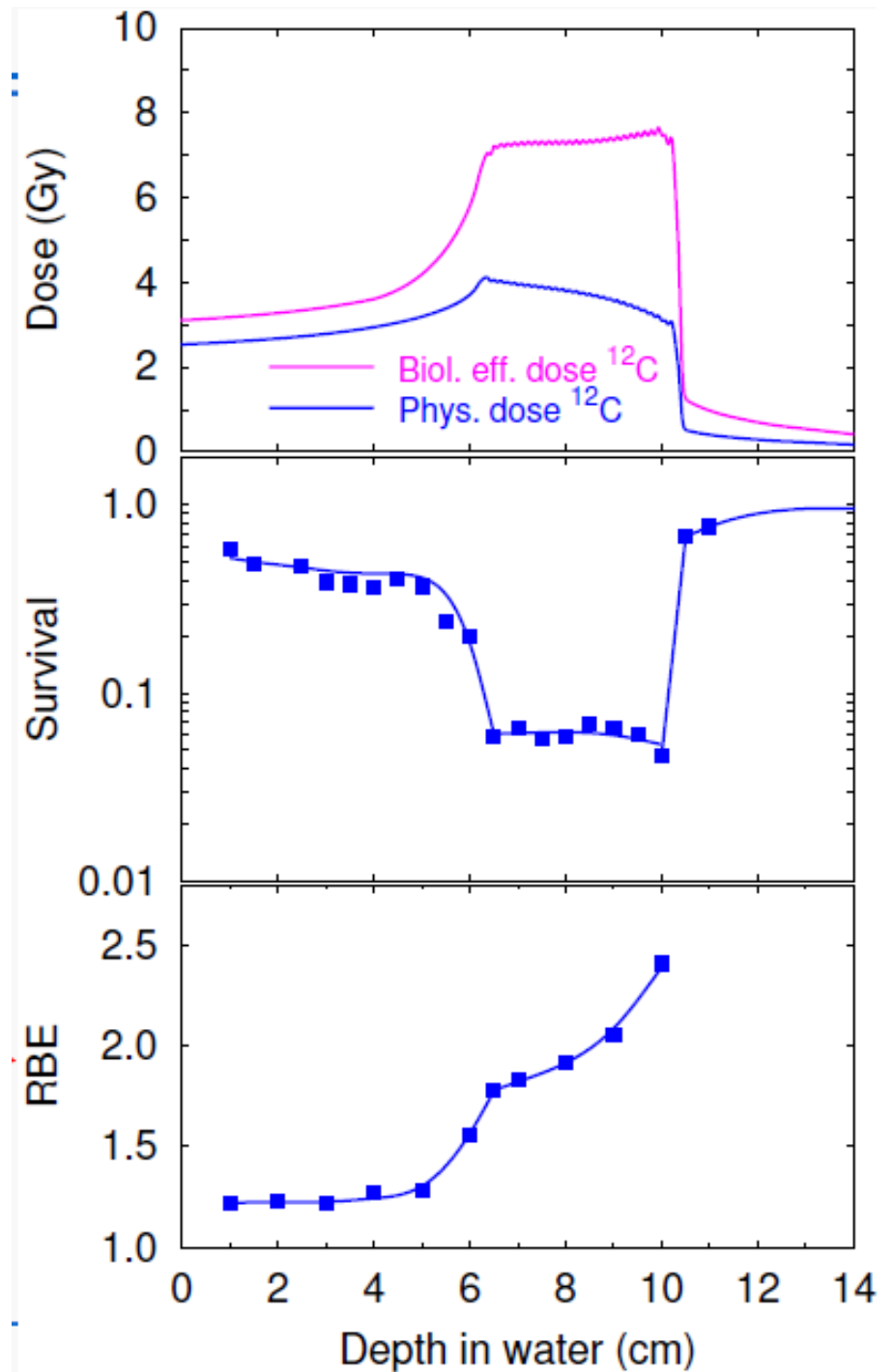


U. Amaldi & G. Kraft, Rep. Prog. Phys. **68** (2005) 1861–1882

**ões: Maior densidade de ionização ao longo percurso da partícula**

# Eficácia biológica relativa

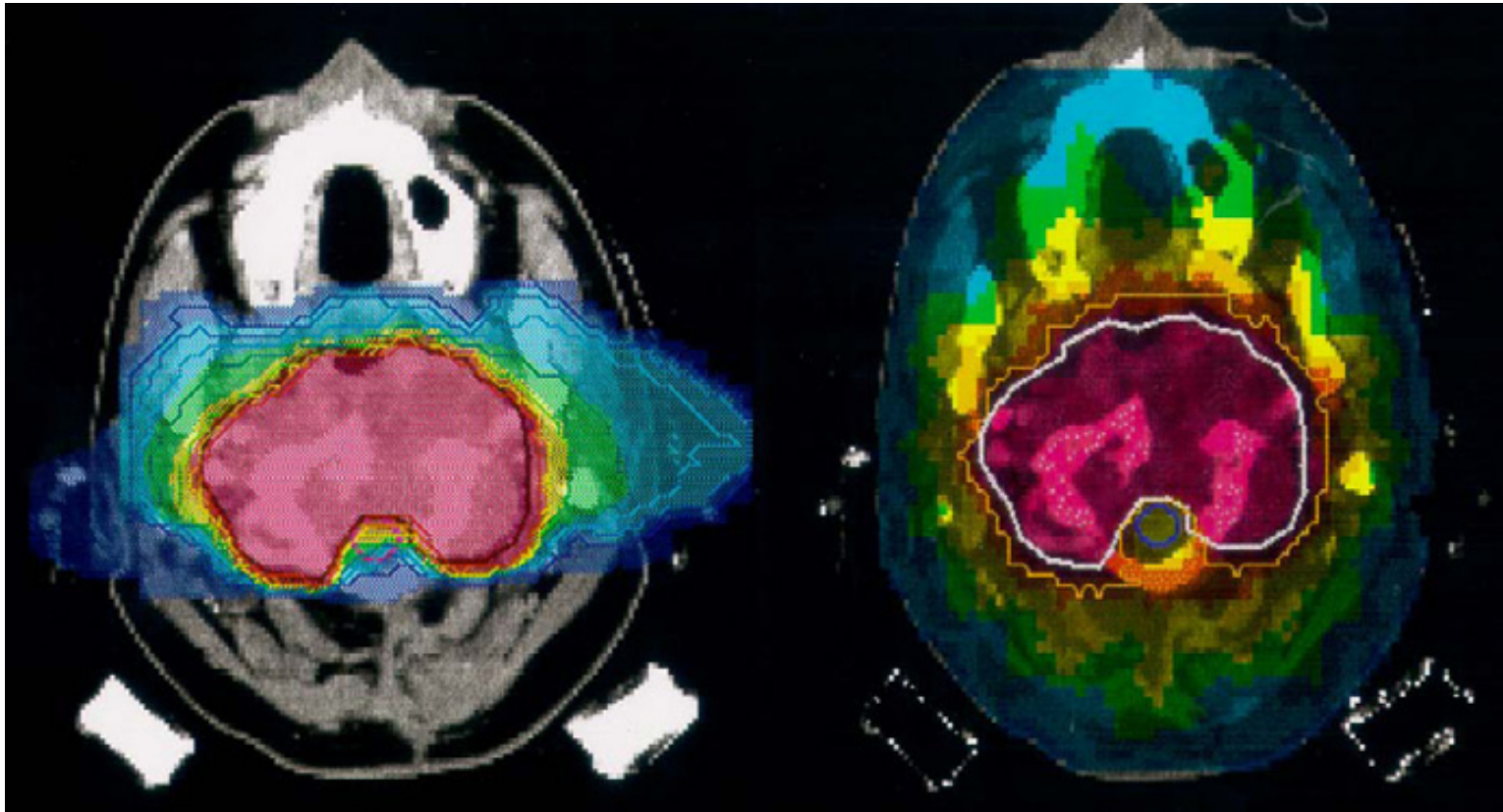
$$RBE = \frac{Dose_{raios-X}}{Dose_{C12}}$$



## Diferenças carbono / fótons

Carbono: 2 campos opostos

Fótons IMRT: 9 campos

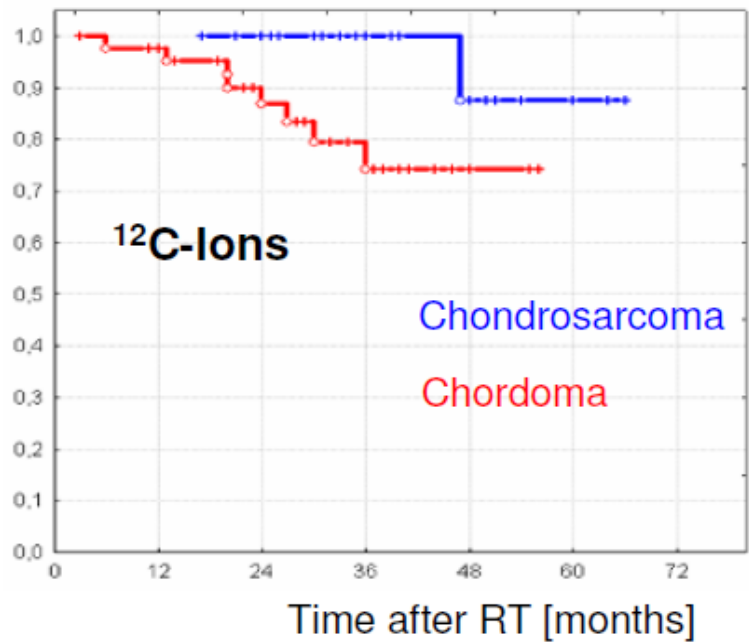


U. Amaldi & G. Kraft, Rep. Prog. Phys. **68** (2005) 1861–1882

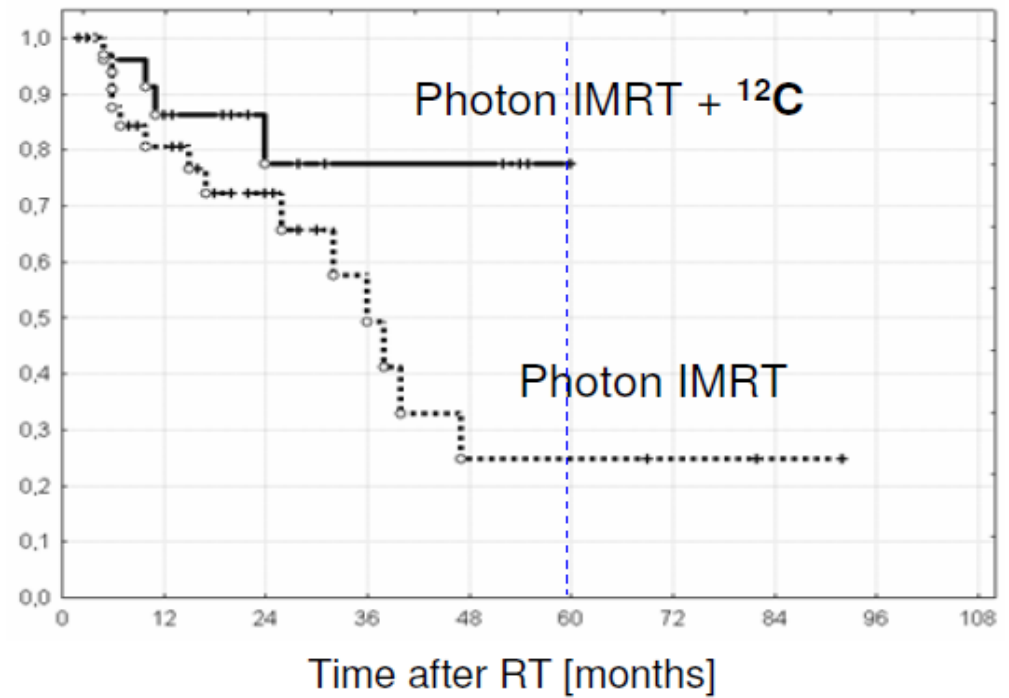
A terapia com feixes de carbono permite poupar os tecidos normais

# Melhor controlo local do tumor

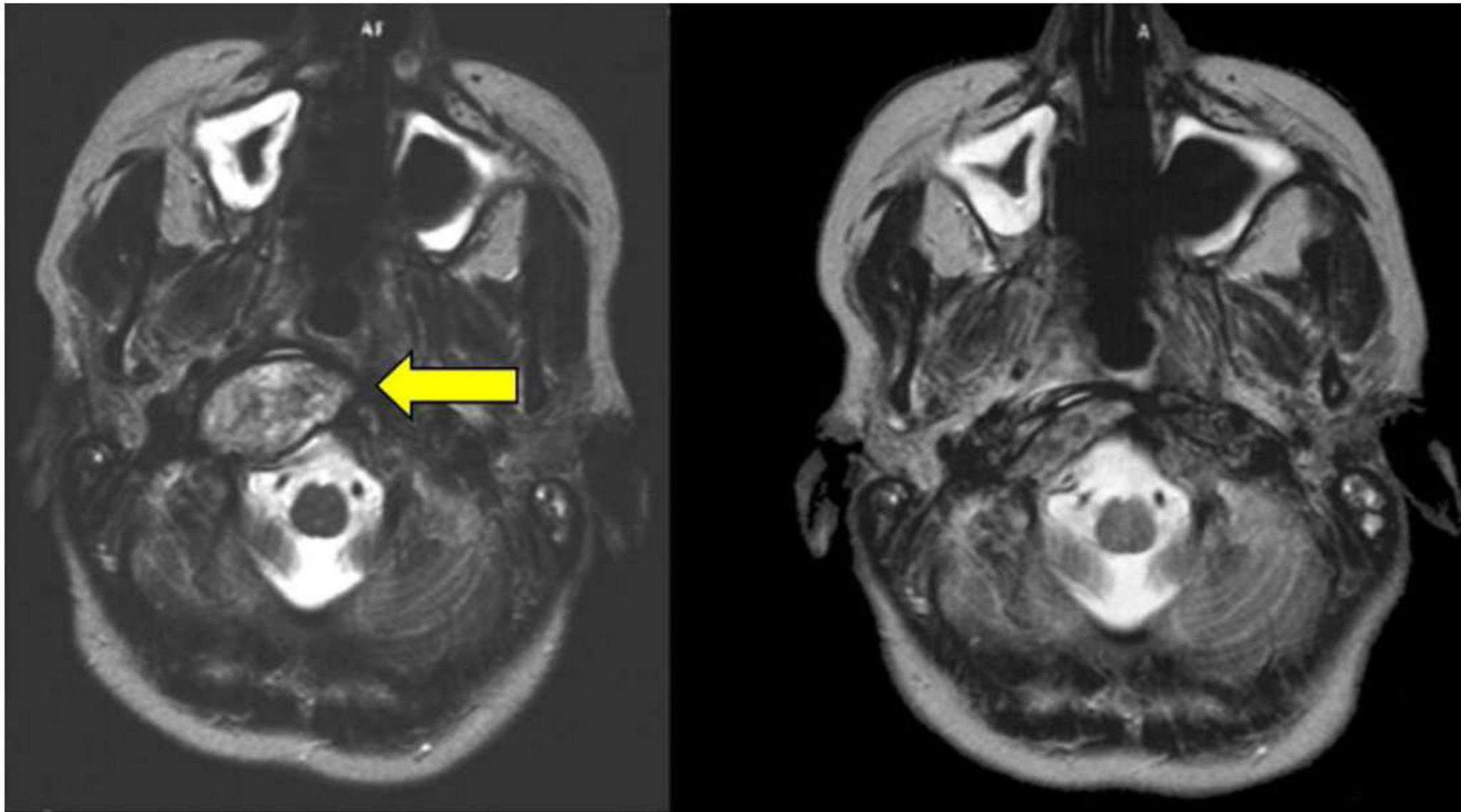
## Chordoma and Chondrosarcoma



## Adenoid-cystic carcinoma



Cordoma na base do cérebro (esquerda)  
Regressão do tumor 6 semanas após tratamento com C12 (direita)





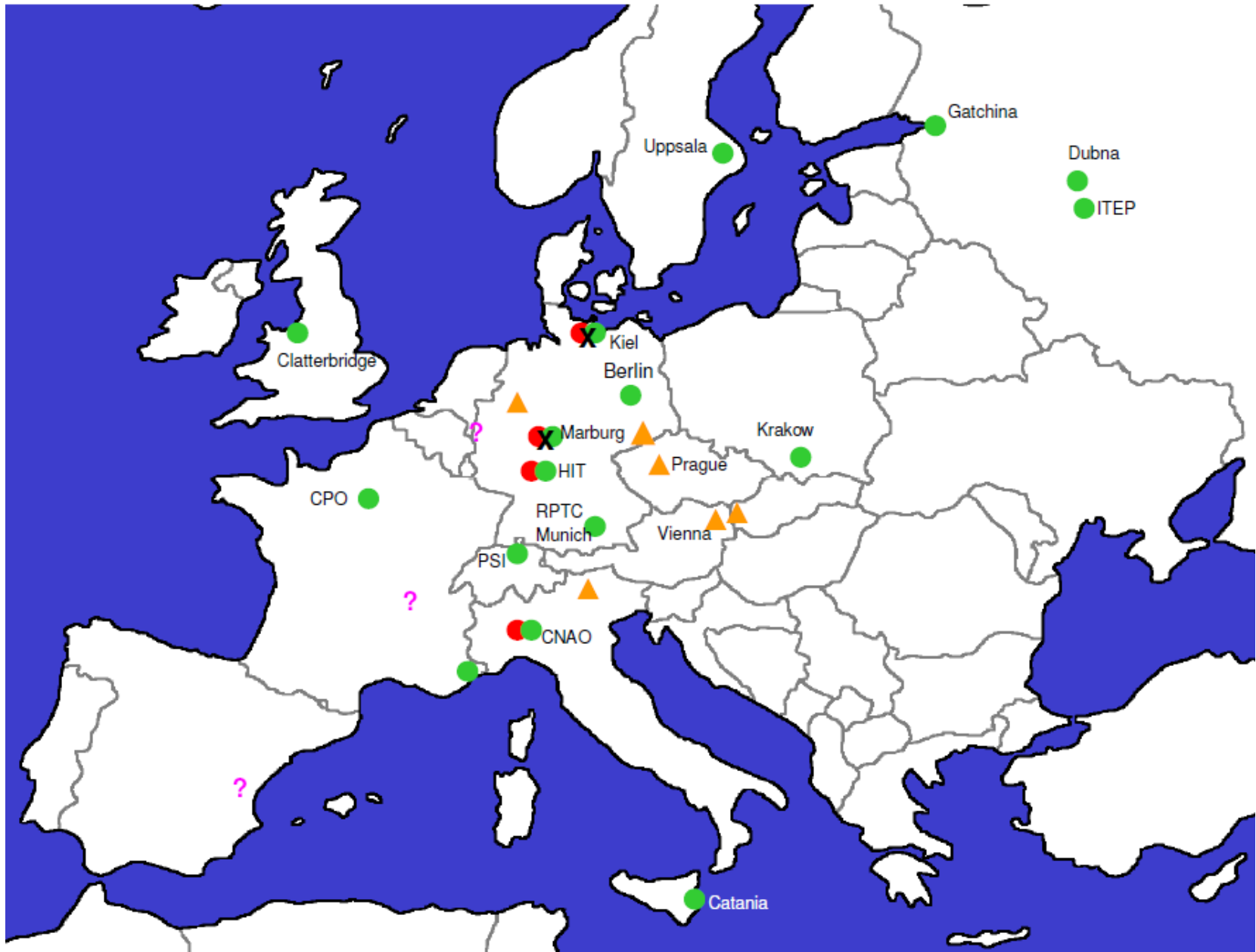
**Centers in Operation**

- Protons
- Light Ions
- X Marburg / Kiel (stopped)

**Under construction**

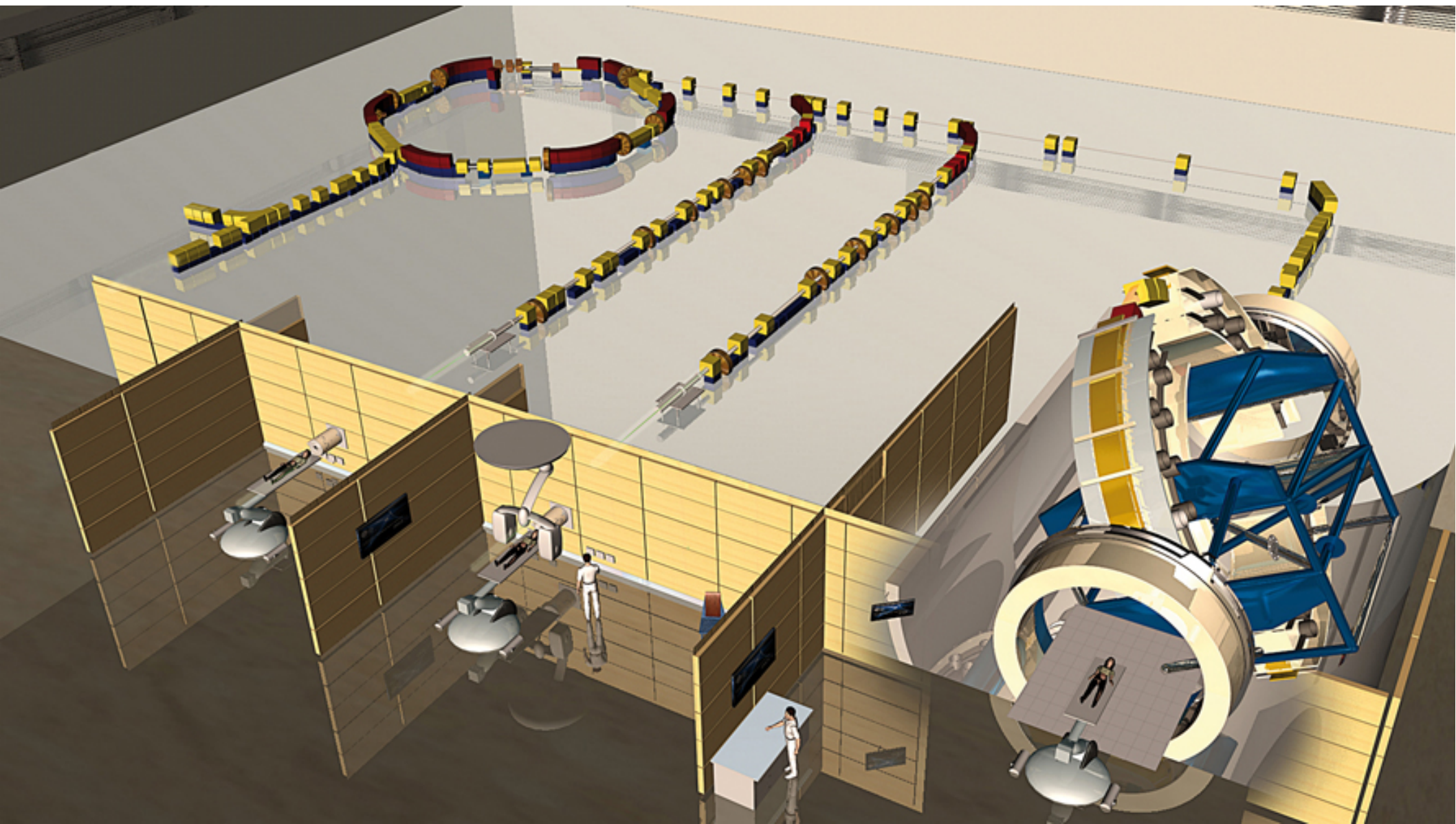


**Under discussion**



# Heidelberg Ion Beam Therapy Centre (HIT)

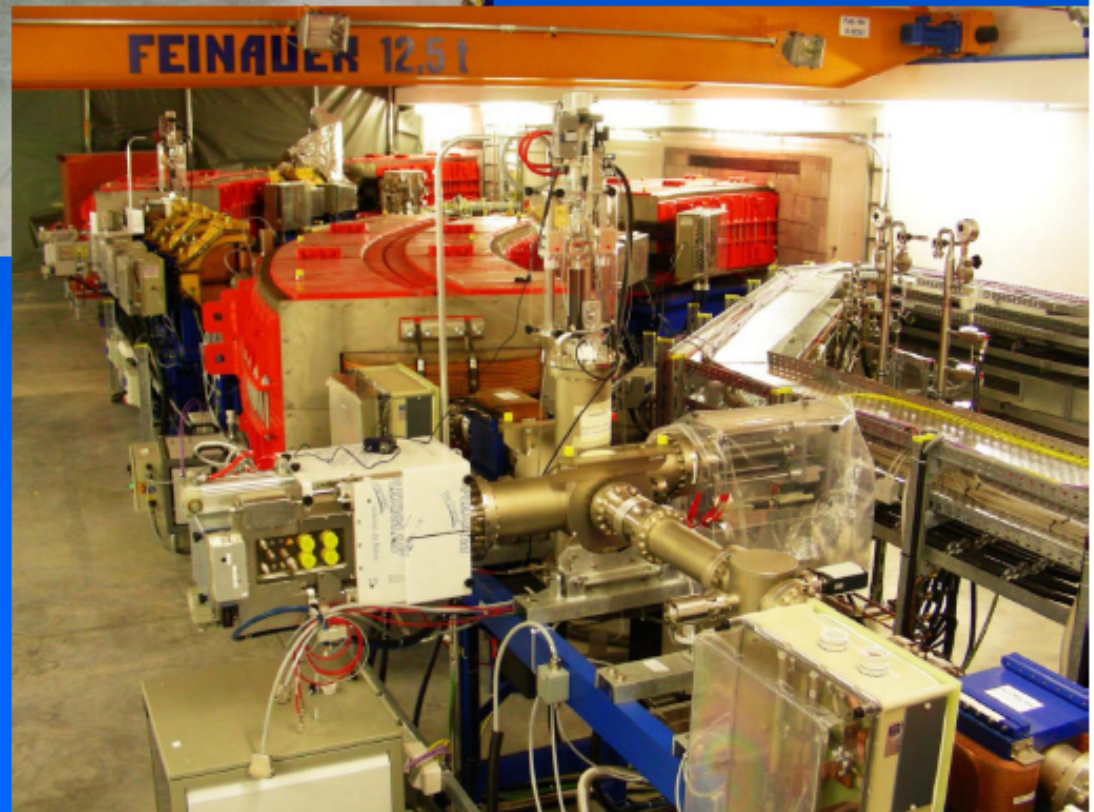






high energy  
beam transport

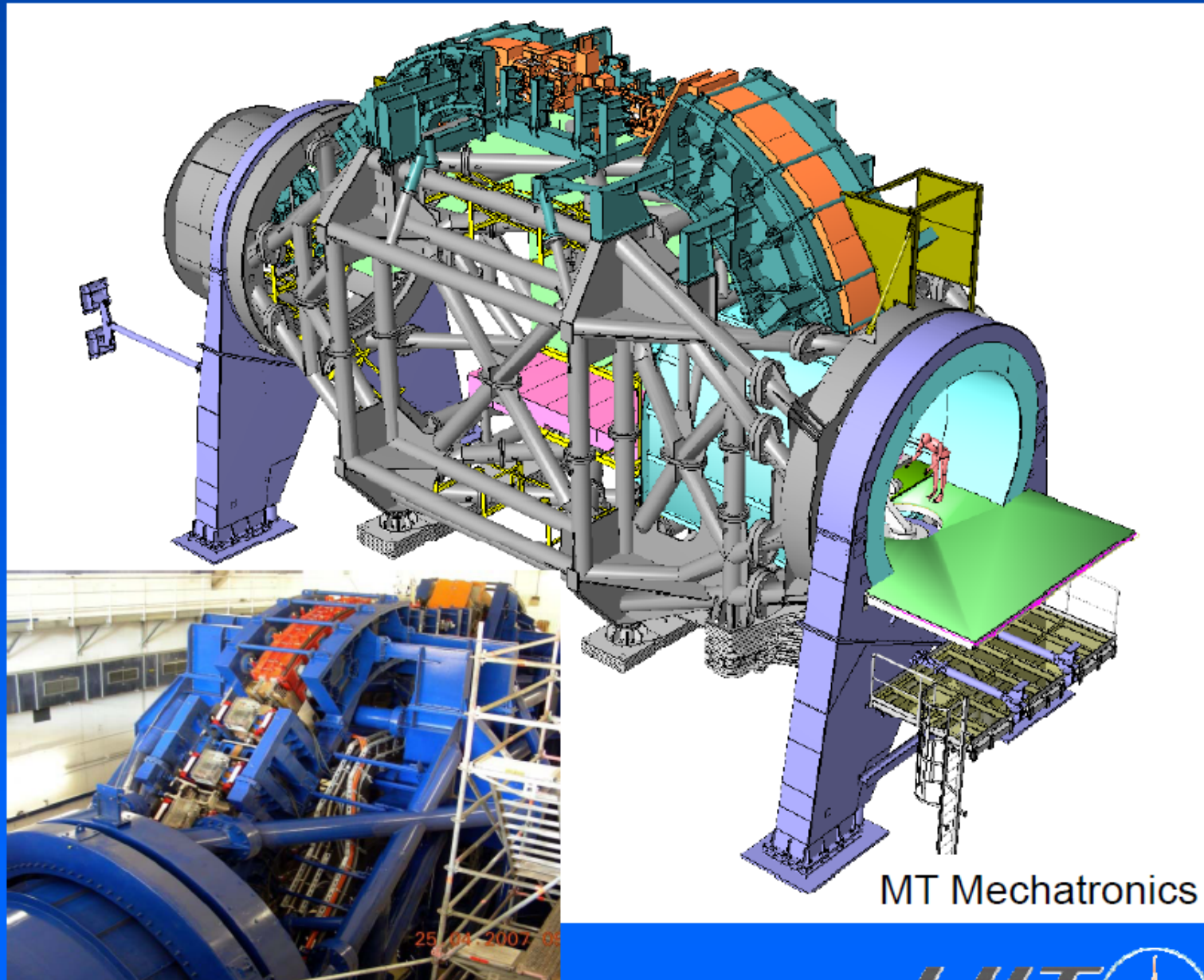
synchrotron



Th. Haberer, Heidelberg Ion Therapy Center

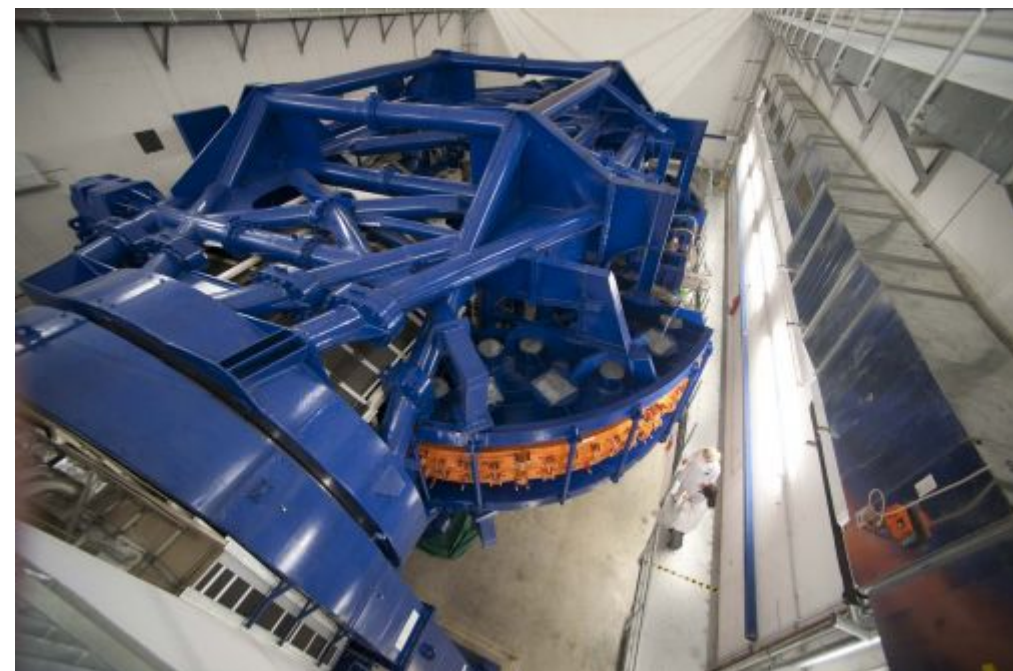
# Scanning Ion Gantry

- optimum dose application
- world-wide first ion gantry
- world-wide first integration of beam scanning
- 13m diameter  
25m length  
600to overall weight  
0,5mm max. deformation
- prototype segment tested at GSI



MT Mechatronics

# Ion Gantry



# Mesa de tratamento

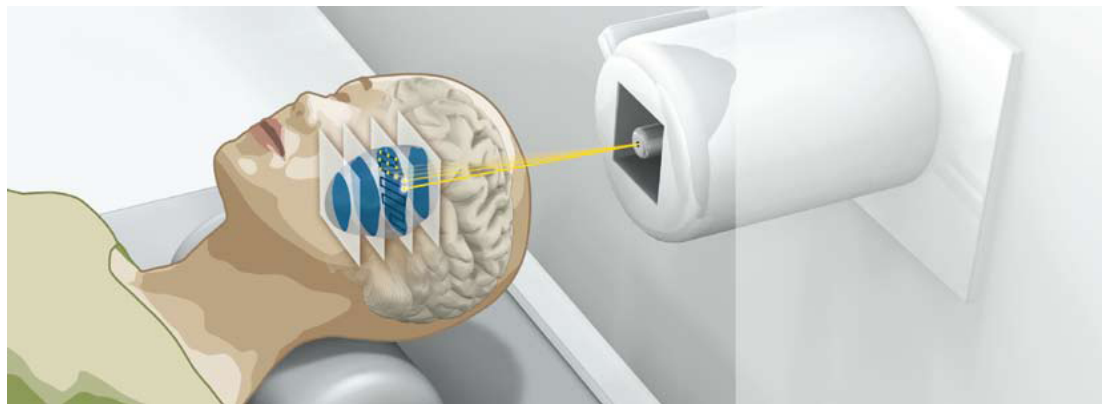


# Sala de tratamento









# Melhoramentos à terapia com prótons/iões

Um tratamento com prótons/iões começa com um planeamento feito com base numa imagem radiológica do paciente, como por exemplo um TC (Tomografia Computarizada)

## Contudo:

O TC baseia-se na medida do coeficiente de atenuação linear de fótons na matéria.

Estes valores são convertidos para unidades de Hounsfield (desvio percentual relativo a água).

Mas num tratamento com iões o importante é a espessura (alcance) equivalente em água

# Incertezas no alcance dos prótons

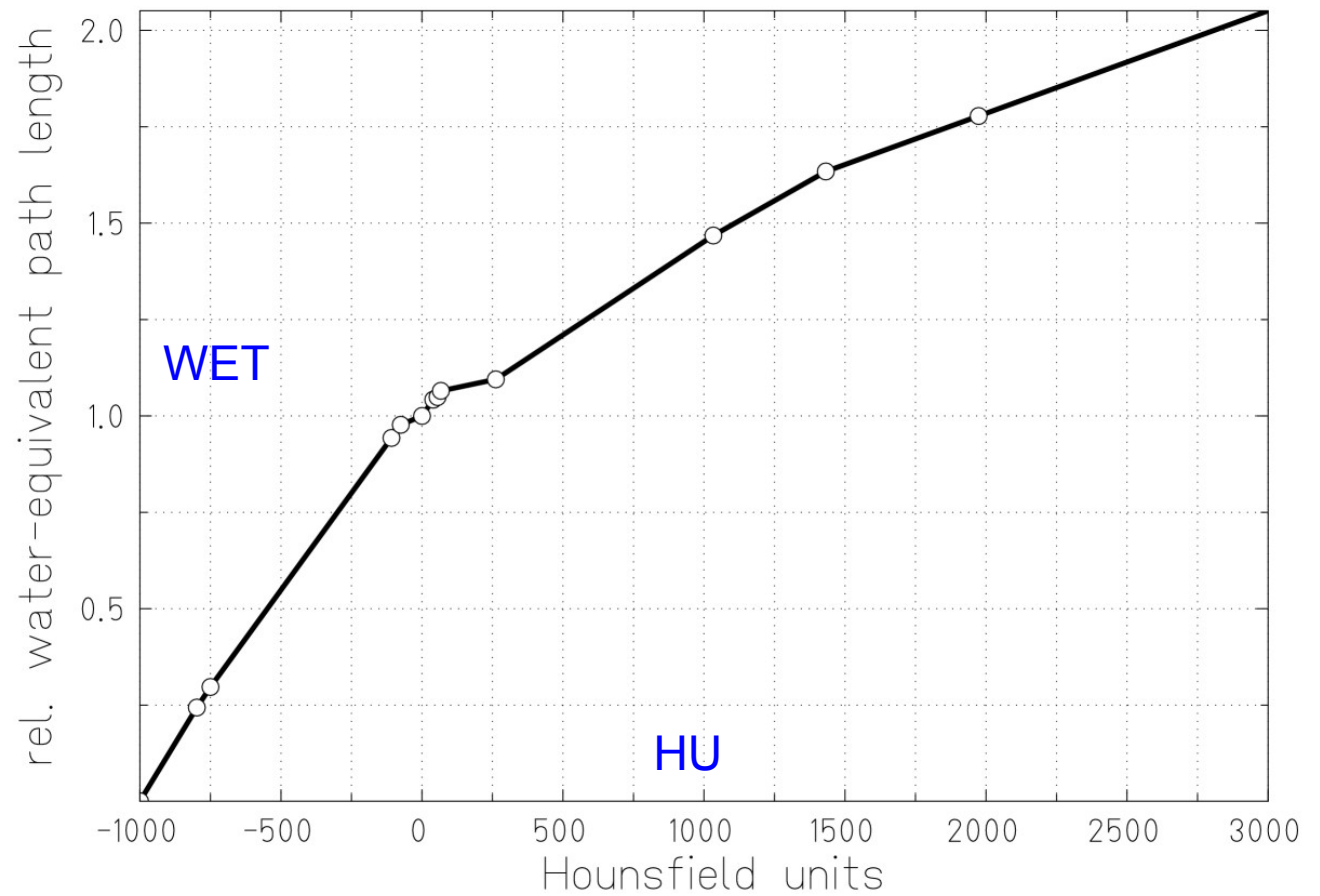
Conversão de Hounsfield Units (HU) → 1-3% incerteza  
para “water equivalent thickness” (WET)

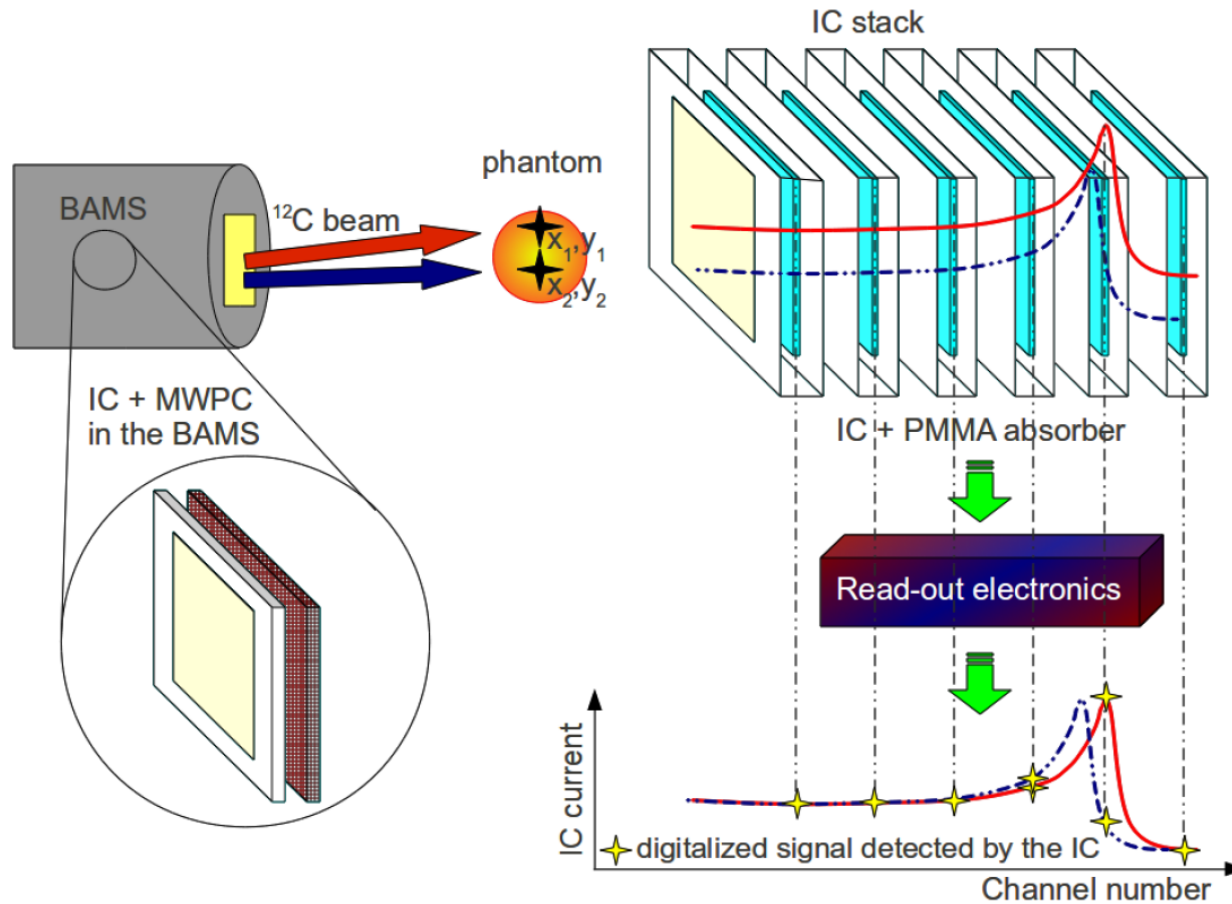
Erros intrínsecos à TC

Modificação na anatomia/posicionamento  
do doente

5-20% incerteza

Uma incerteza de 1-3% no alcance corresponde a 1-3 mm de incerteza na deposição da energia do feixe num tratamento a 10 cm de profundidade

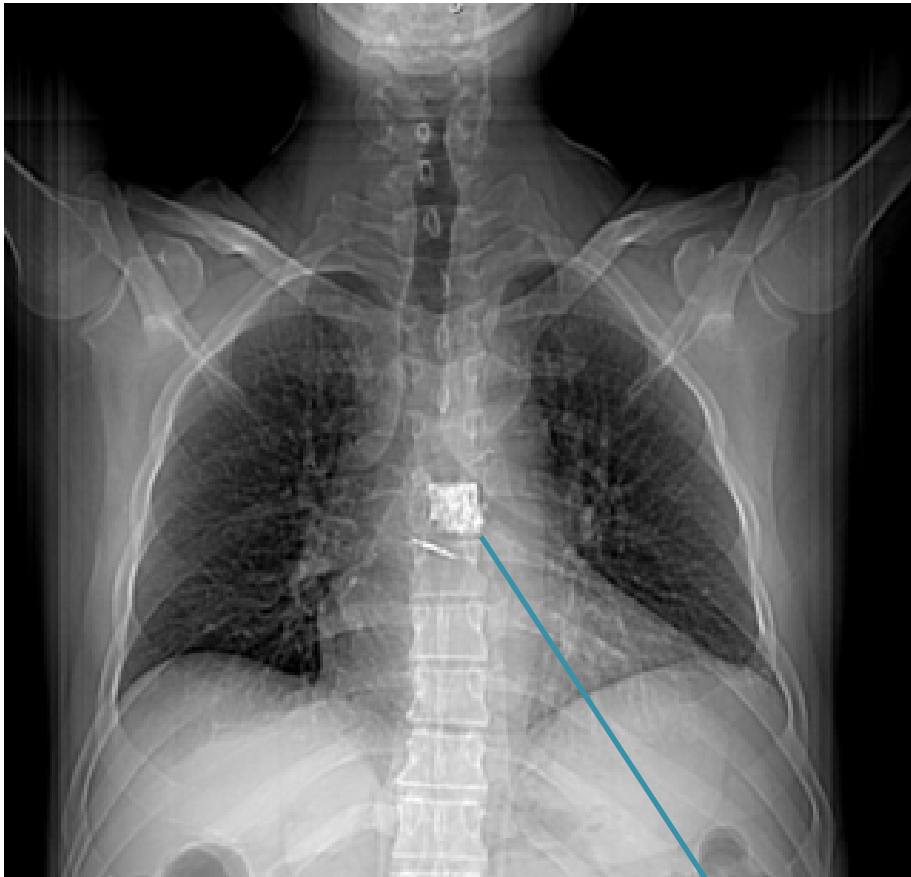




I. Rinaldi et al., Phys Med Biol. 59 (2014) 3041-57.

Estão a ser feitas medidas com feixes de carbono para determinar da forma mais rigorosa possível a relação entre as HU e WET

## Radiografia com feixe de prótons (simulação)



Raios-X

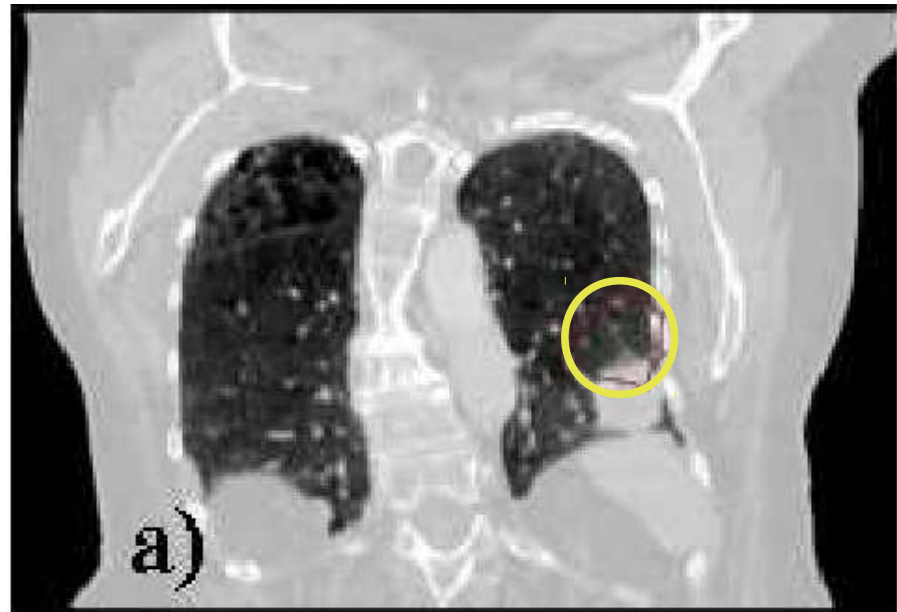
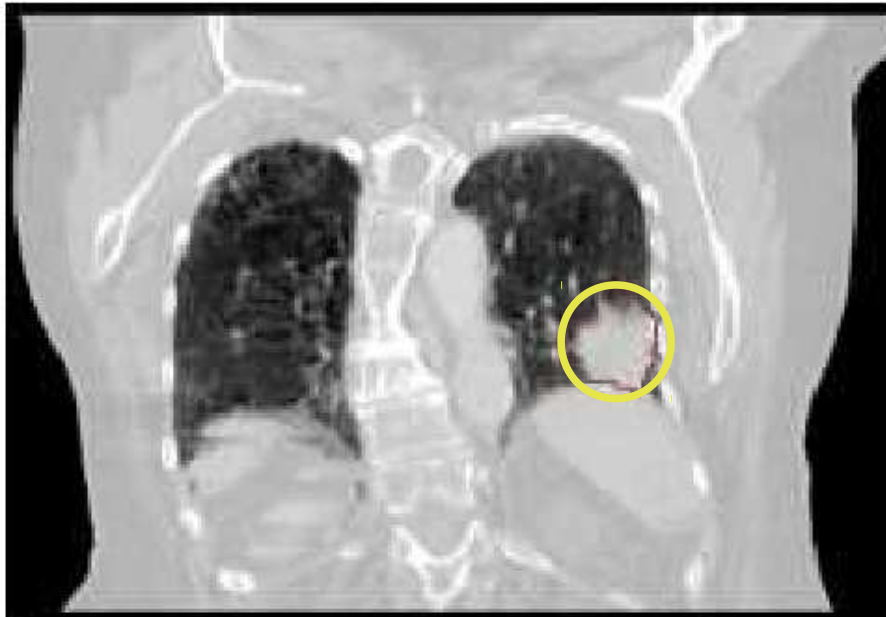
Tumor



Imagem Prótons (MC)

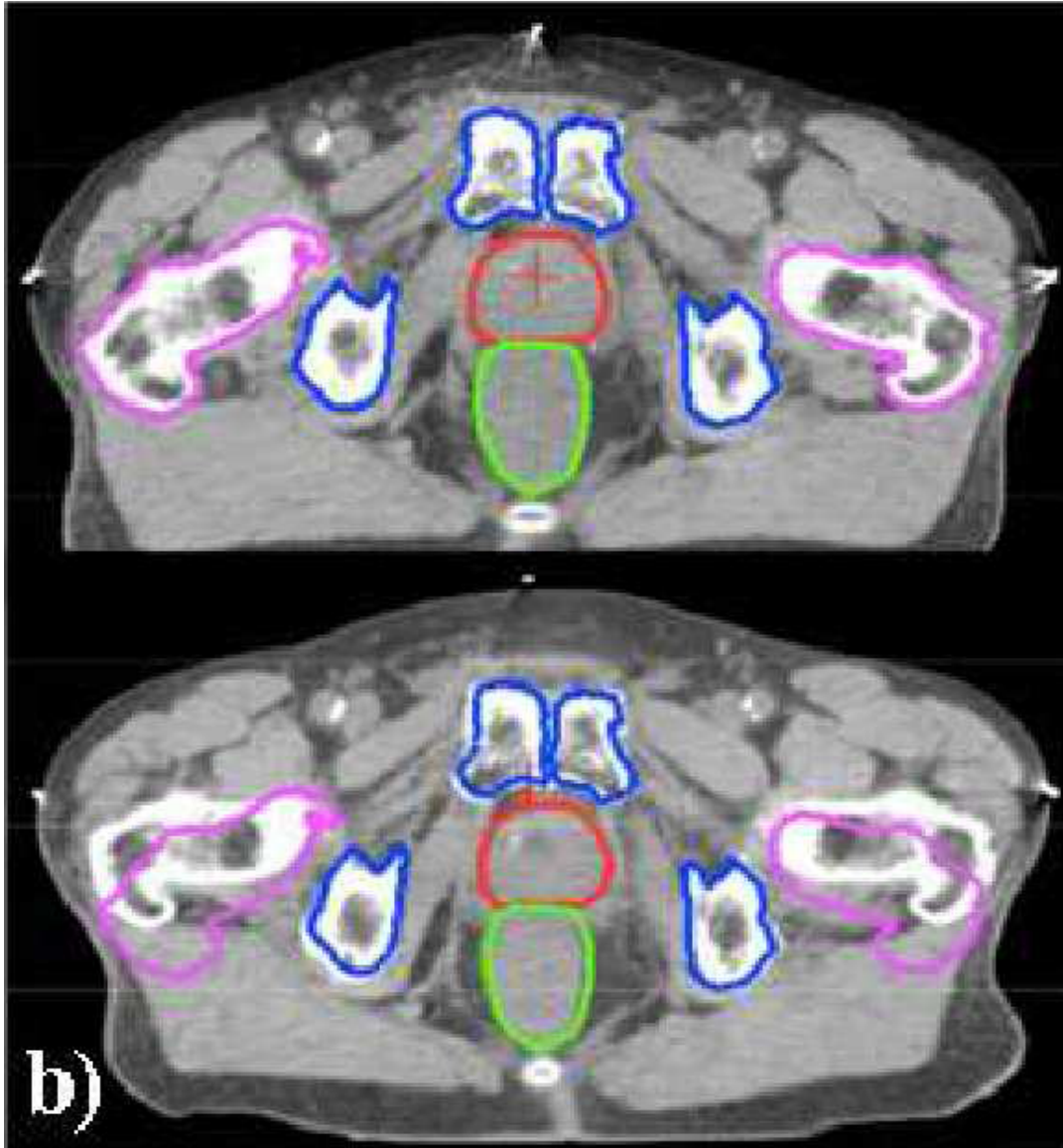
A radiografia com prótons permite ter a mesma “visão” que o feixe

## Movimentos de órgãos: desvio do tumor (respiração)

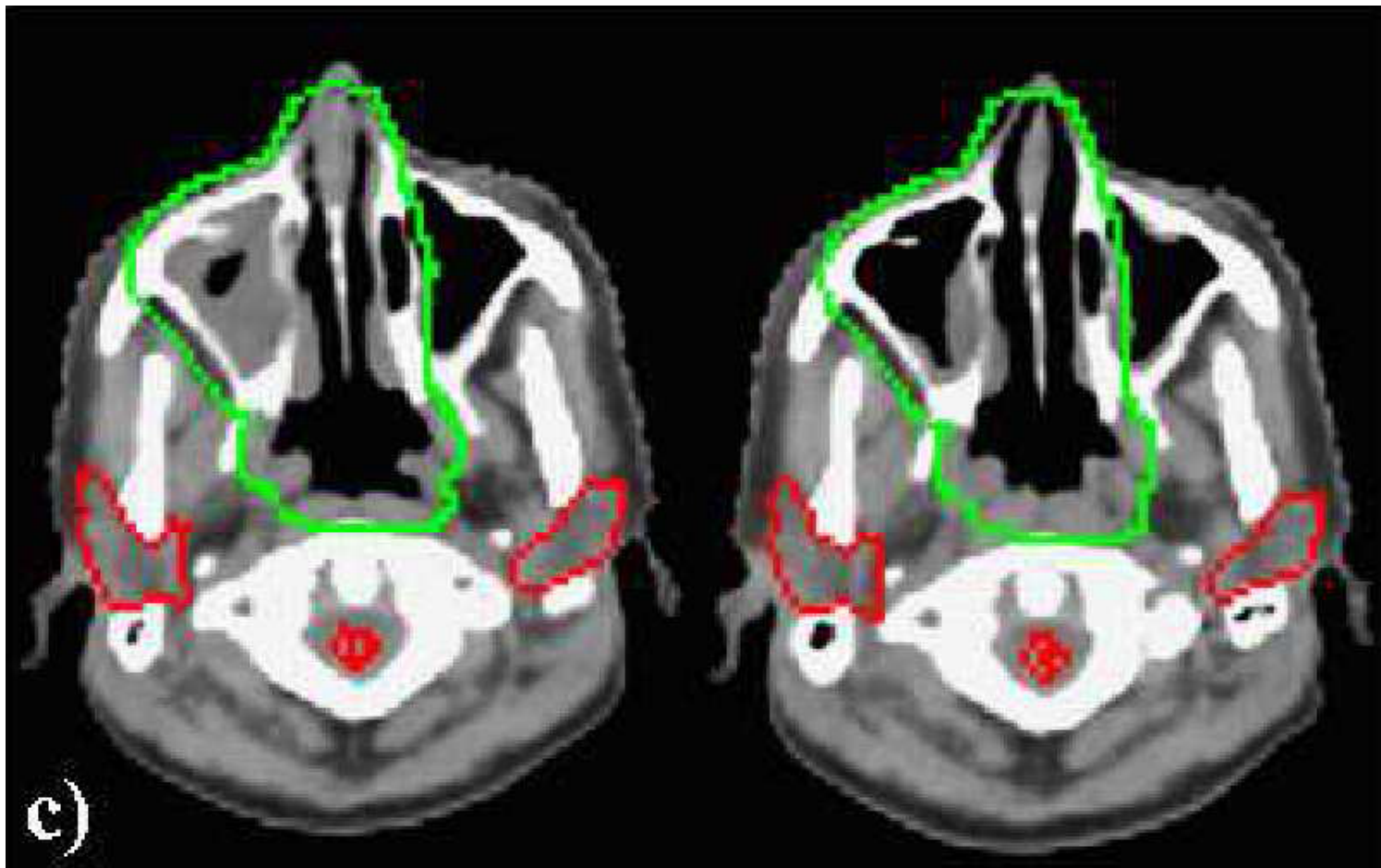




## Movimentos do alvo: deformação do paciente (mau posicionamento)



Modificação de órgãos: preenchimento de cavidades  
(variação da densidade)



## Agradecimentos

Prof. Paulo Crespo (Univ. Coimbra)

Eng<sup>a</sup> Marta Dias (Univ. Lisboa)

Tiago Marcelos (Univ. Lisboa)

FIM