



**7° Curso de Actualización en
Protección Radiológica
para Médicos Radioterapeutas**



**“Estado actual en la Radioterapia con
Protones desde el punto de vista físico ”**

Lic. Victor Bourel

23, 24 y 25 de Octubre de 2019

AMA - Av. Santa Fe 1171 - Capital Federal

Conflicto de Intereses

Actualmente me desempeño como Consultor para Latino América de la División Protonterapia de la empresa Iba.

Breve Historia de la Protonterapia

- 1930 E. Lawrence construye el primer Ciclotron (Berkeley)
- 1946 R. Wilson propone la Protonterapia (Harvard)
- 1955 C. Tobias trata el 1^{er} paciente (Berkeley)
- 1961 R. Kjellberg comienza tratamientos (Harvard)
- 1991 Primer instalación Hospitalaria en LLUMC con SOBP
- 1994 Desarrollo PBS en el PGI (Suiza)

A partir del año 2000 aproximadamente comienza la oferta comercial de equipos de protonterapia.

Protonterapia



1930 – E. Lawrence y el primer Ciclotrón (12 cm de diámetro)

89 años de evolución



2019 – Equipo de Protonterapia con Técnica PBS y IMPT

Estado actual de la Protonterapia

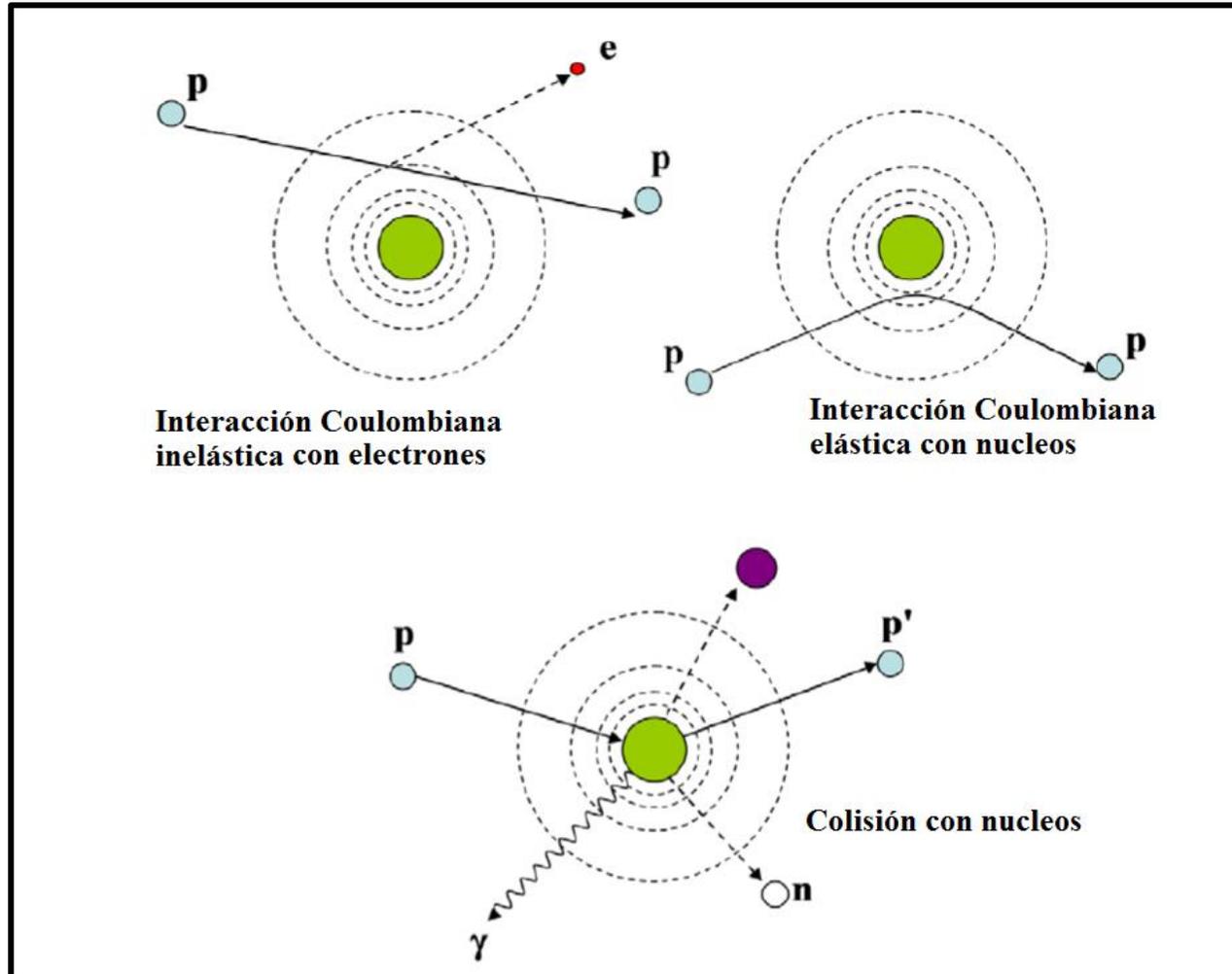
- Física de la Protonterapia
- Equipos de Protonterapia
- Técnicas de tratamiento en Protonterapia
- Ventajas dosimétricas de la Protonterapia
- Últimos desarrollos en Protonterapia

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Física de los haces de protones

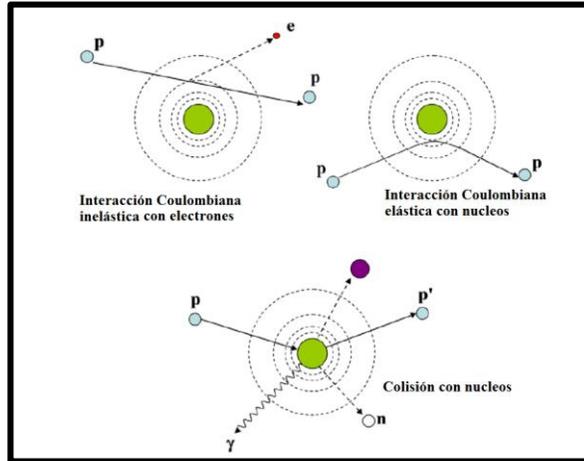
(El secreto del éxito)



Mecanismos de Interacción de los protones con el tejido

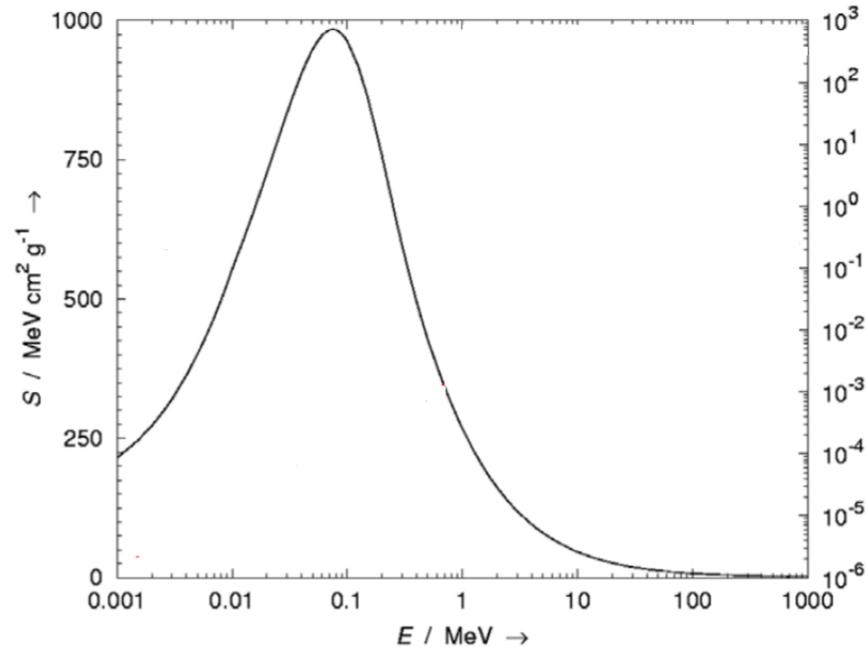
Física de los haces de protones

(El secreto del éxito)



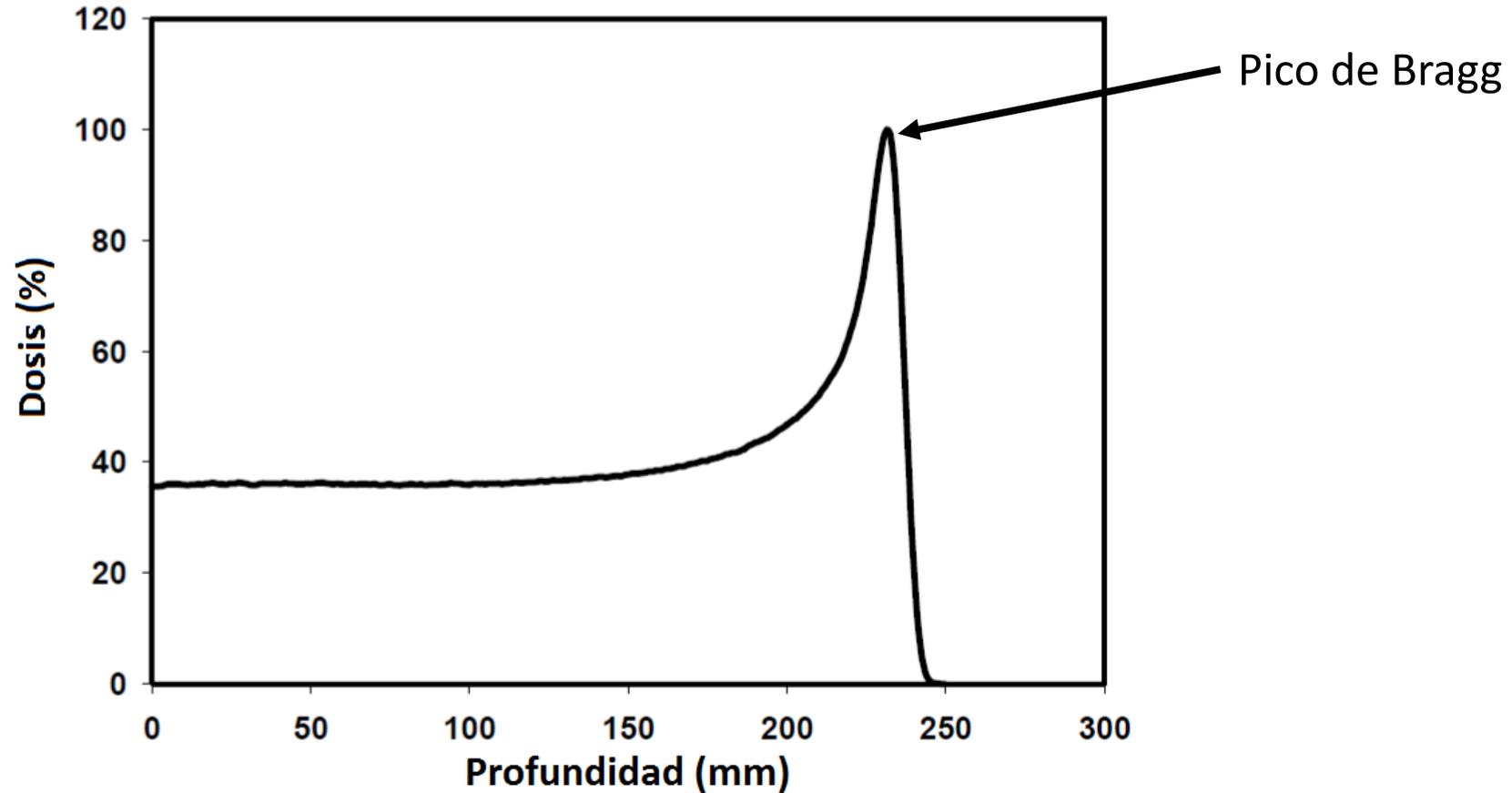
Poder másico de frenado

$$\frac{S}{\rho} = -\frac{dE}{\rho dx} = 4\pi N_A r_e^2 m_e c^2 \frac{Z}{A} \frac{z^2}{\beta^2} \left[\ln \frac{2m_e c^2 \gamma^2 \beta^2}{I} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z} \right] \propto 1/v^2$$



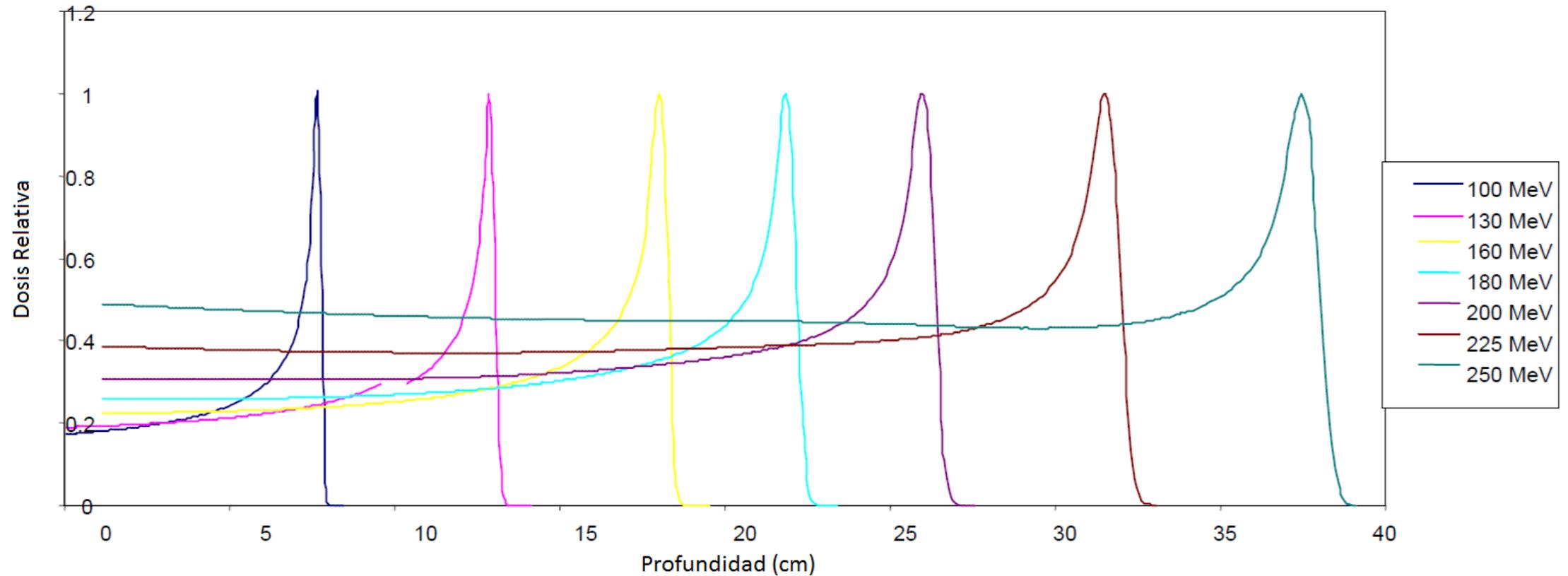
Física de los haces de protones

Deposición de la Dosis



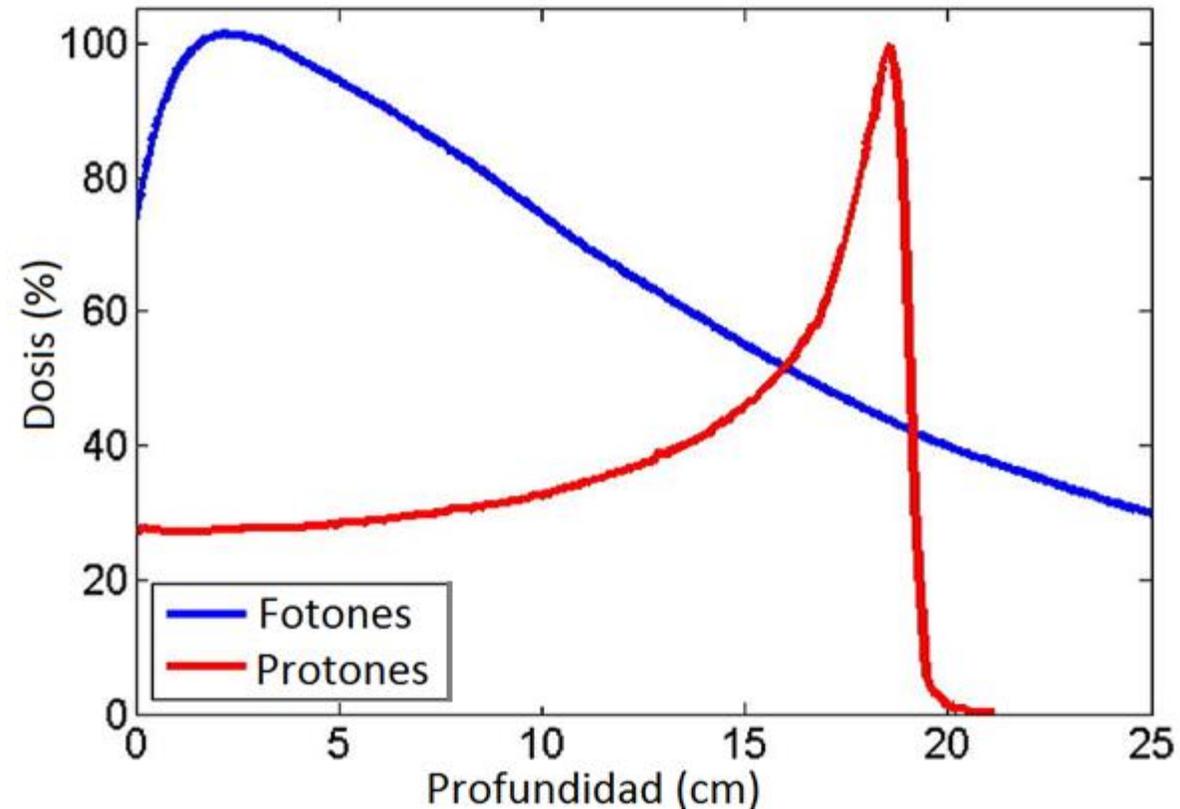
Física de los haces de protones

Deposición de la Dosis



Física de los haces de protones

Deposición de la Dosis

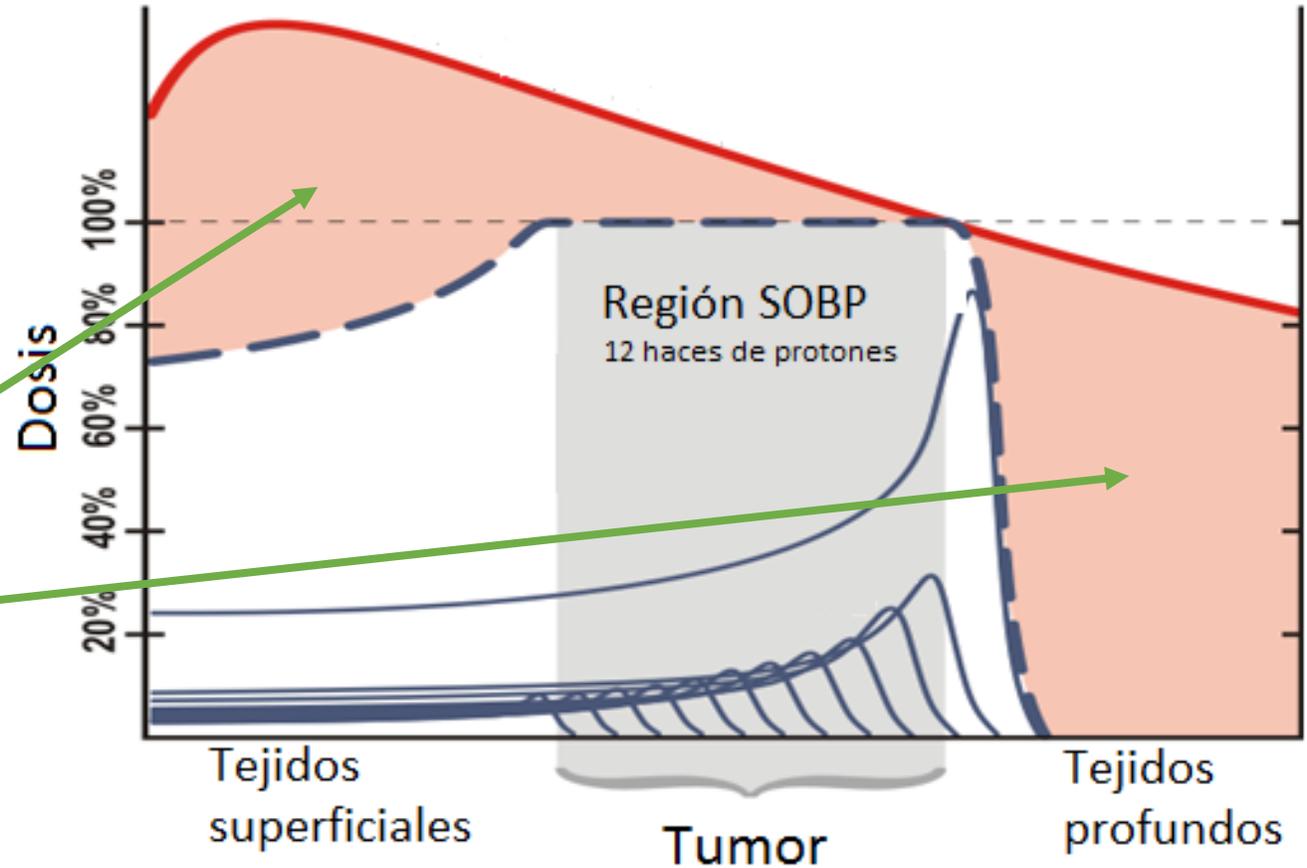


Física de los haces de protones

SOBP:

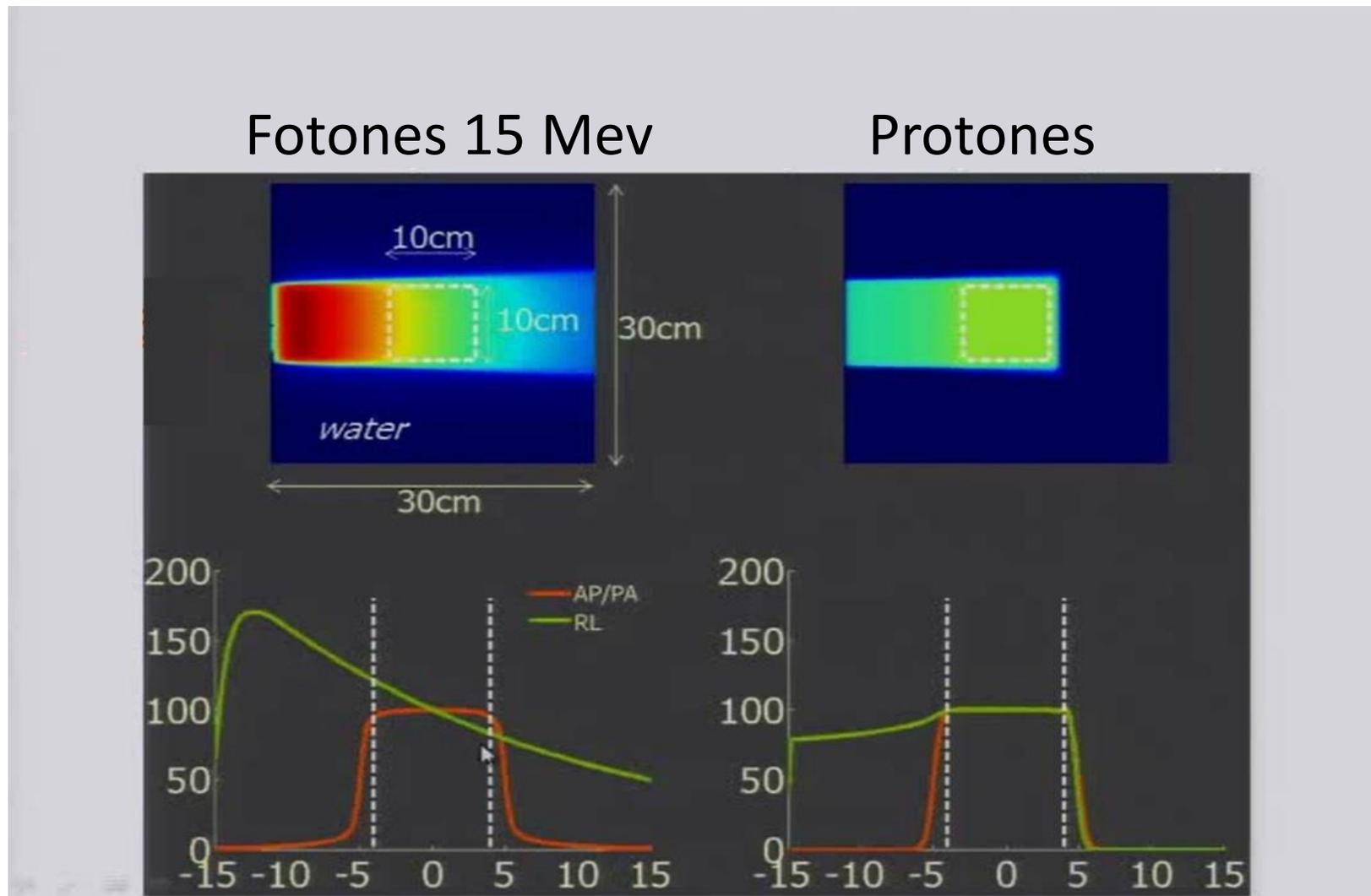
Spread Out Bragg Peak
(Pico de Bragg extendido)

Exceso de dosis
en tejidos sanos



Fotones vs. Protones

1 haz

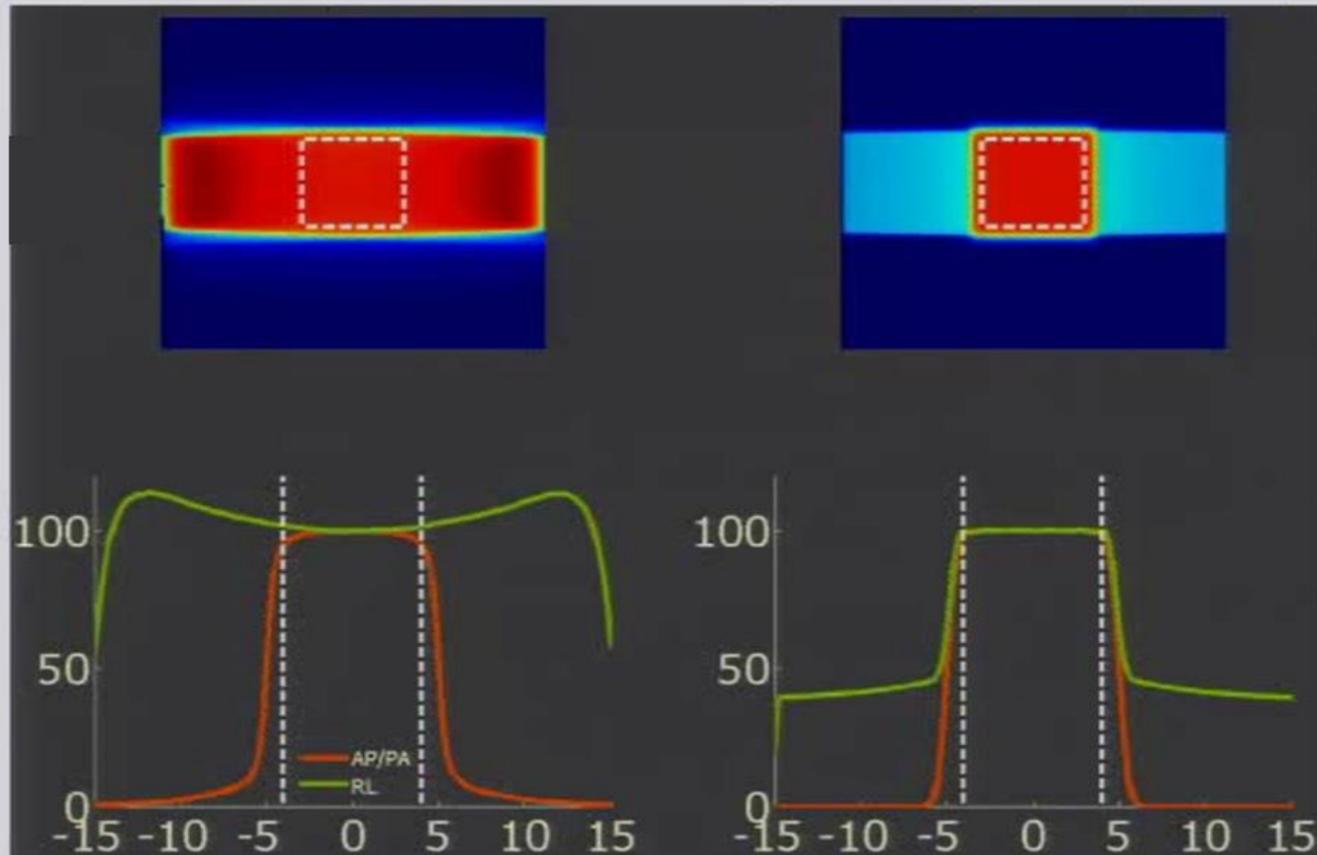


Fotones vs. Protones

2 haces

Fotones 15 Mev

Protones

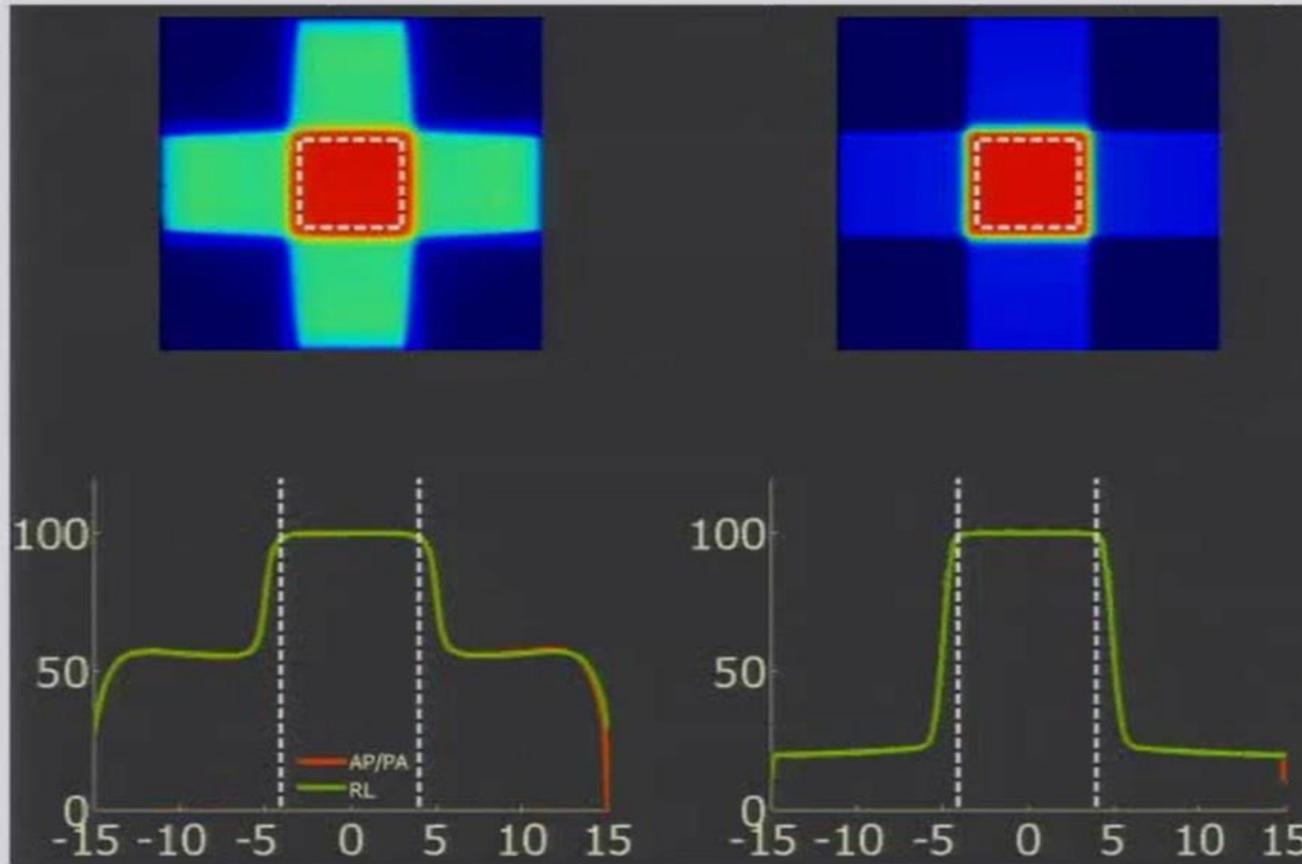


Fotones vs. Protones

4 haces

Fotones 15 Mev

Protones



Estado actual de la Protonterapia

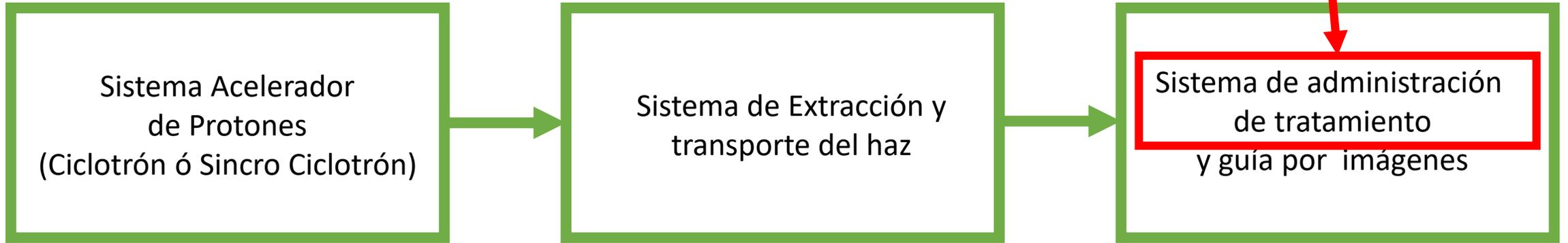
- Física de la Protonterapia
- **Equipos de Protonterapia**
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Equipos de Protonterapia



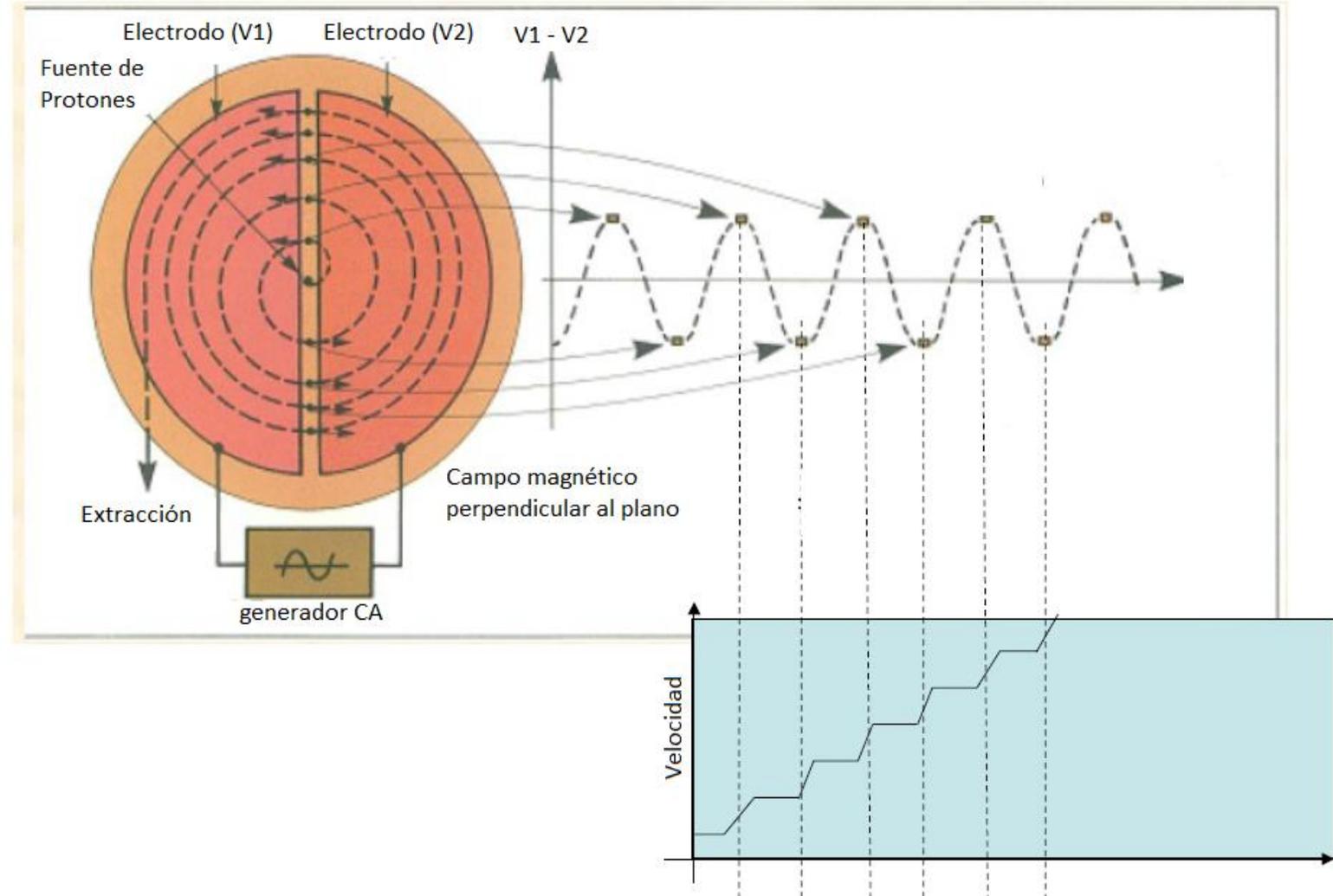
Equipos de Protonterapia

Pencil Beam Scanning: PBS
Intensity Modulated Proton Therapy: IMPT



Ciclotrones

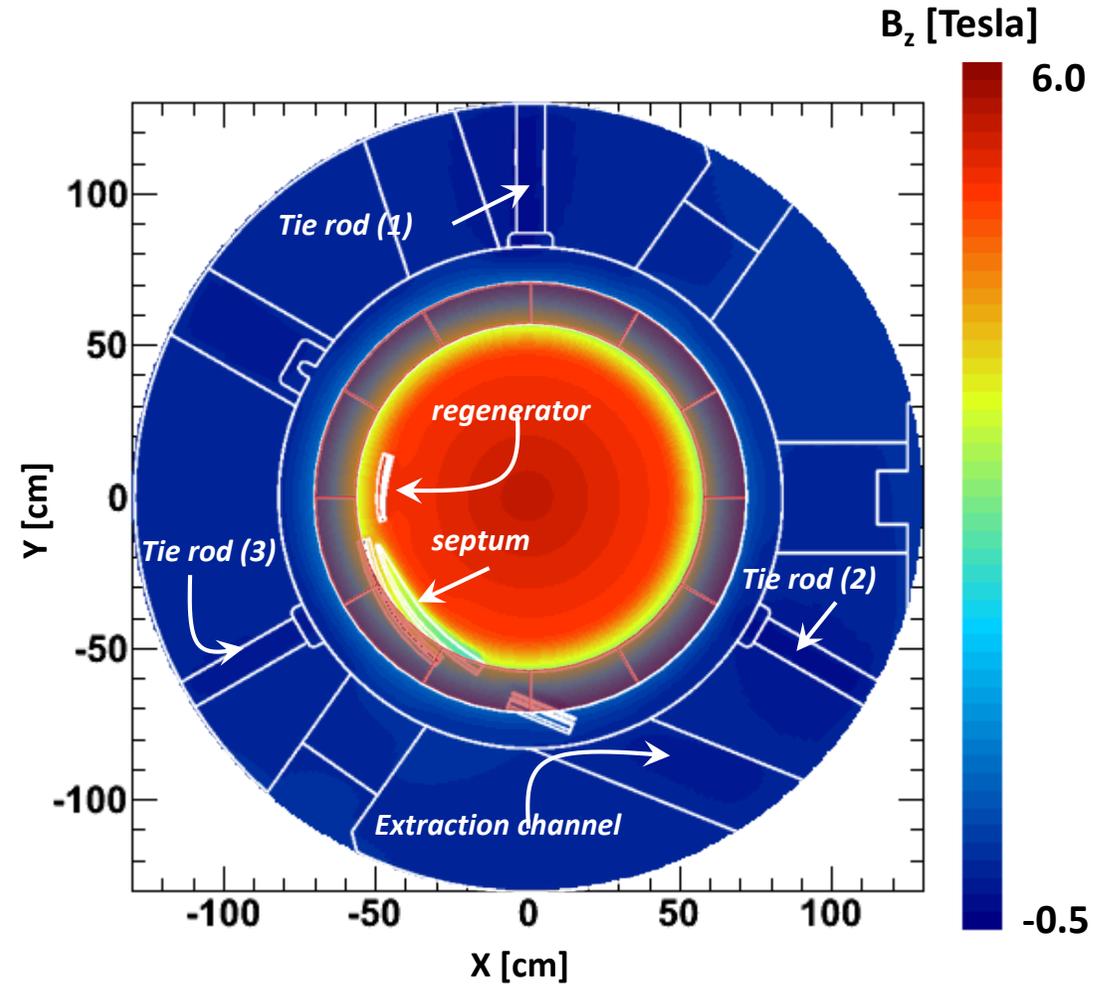
Visión simple del funcionamiento de un Ciclotrón



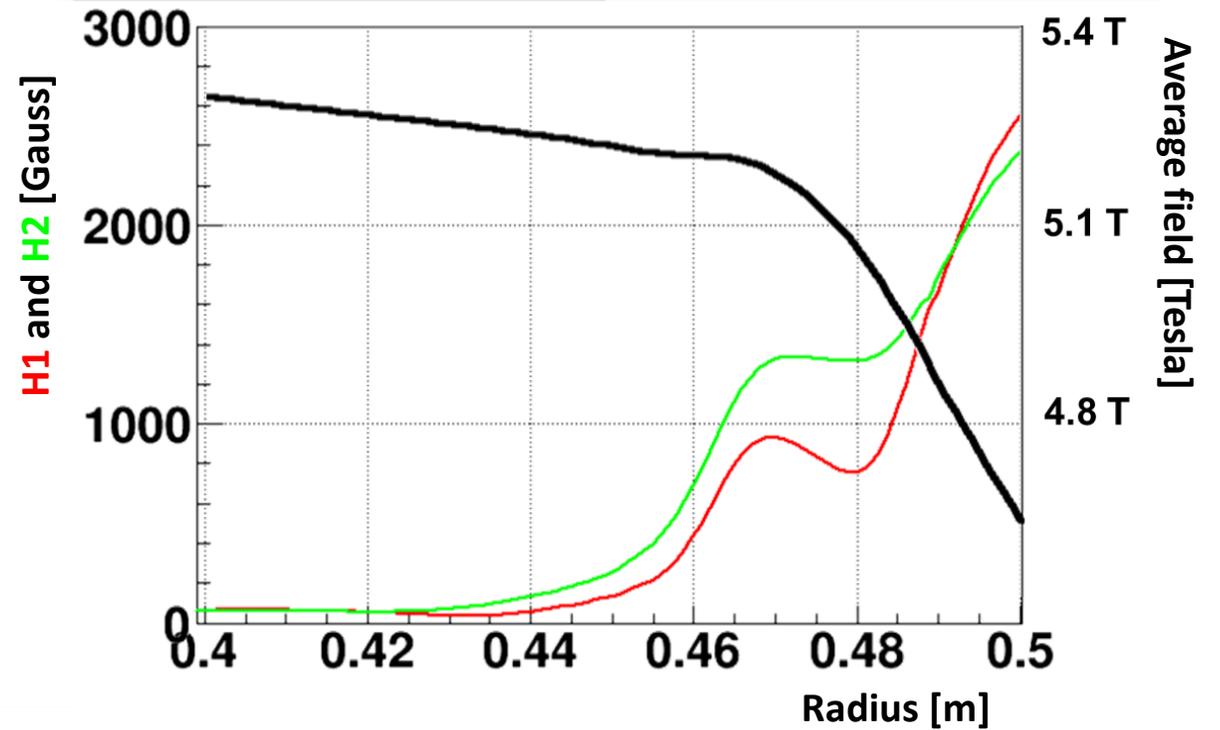
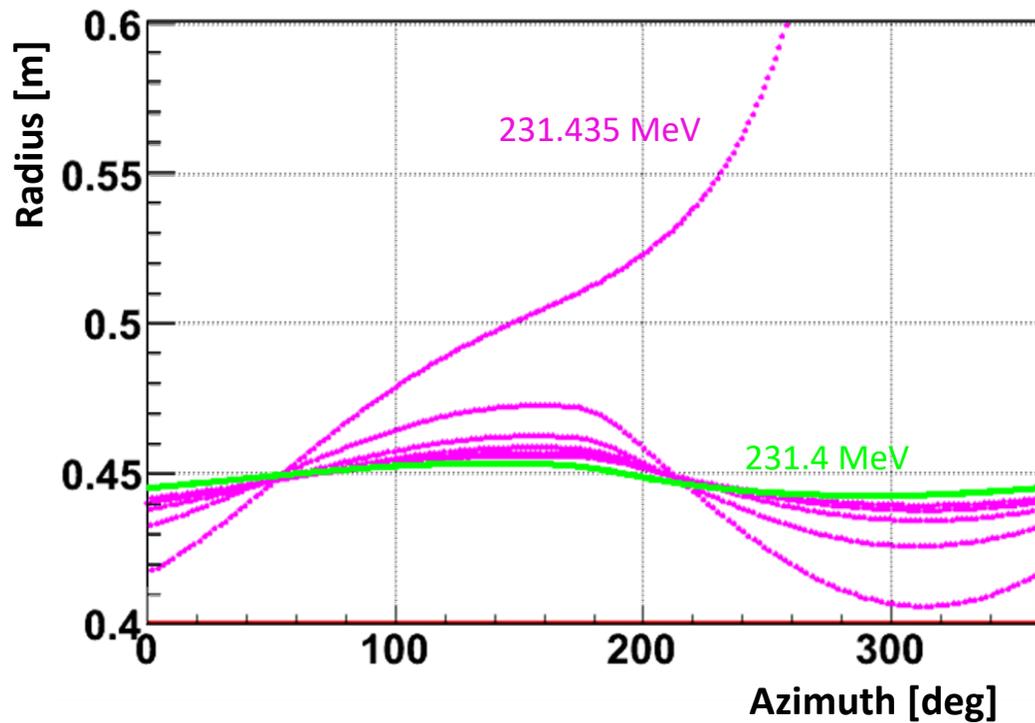
S2C2: Compacto



- ✓ Pole radius ≈ 50 cm
- ✓ Weight ≈ 50 ton
- ✓ Diameter ≈ 2.5 m



S2C2: Extracción del haz



✓ Last stable closed orbit in the S2C2 (231.4 MeV) : $v_r \rightarrow 1$

✓ $2v_r=2$ resonance : the orbit center becomes unstable

✓ ≈ 5 more turns before the proton is extracted

Equipo con Múltiples Salas



Equipo con Múltiples Salas

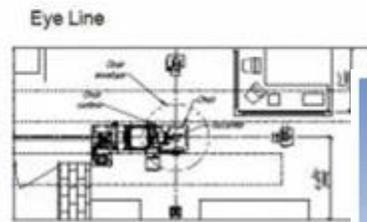
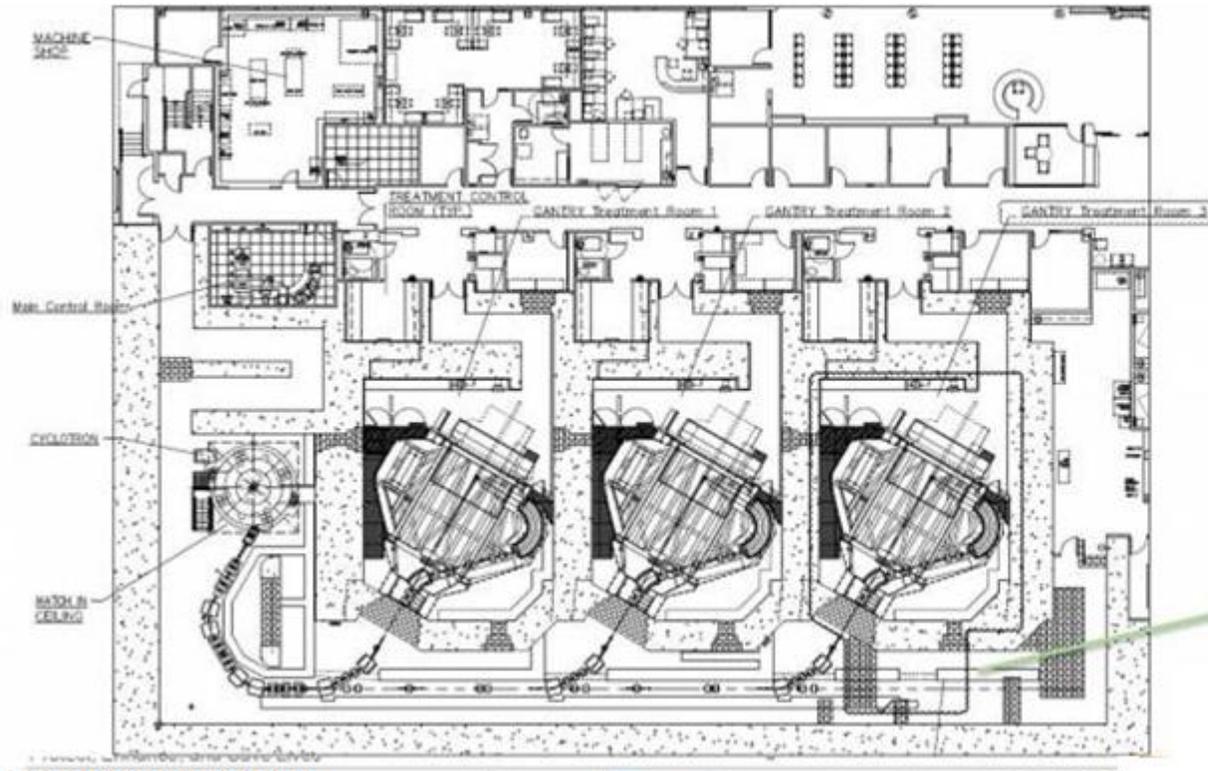


Ciclotrón Isocrónico - 230 Mev

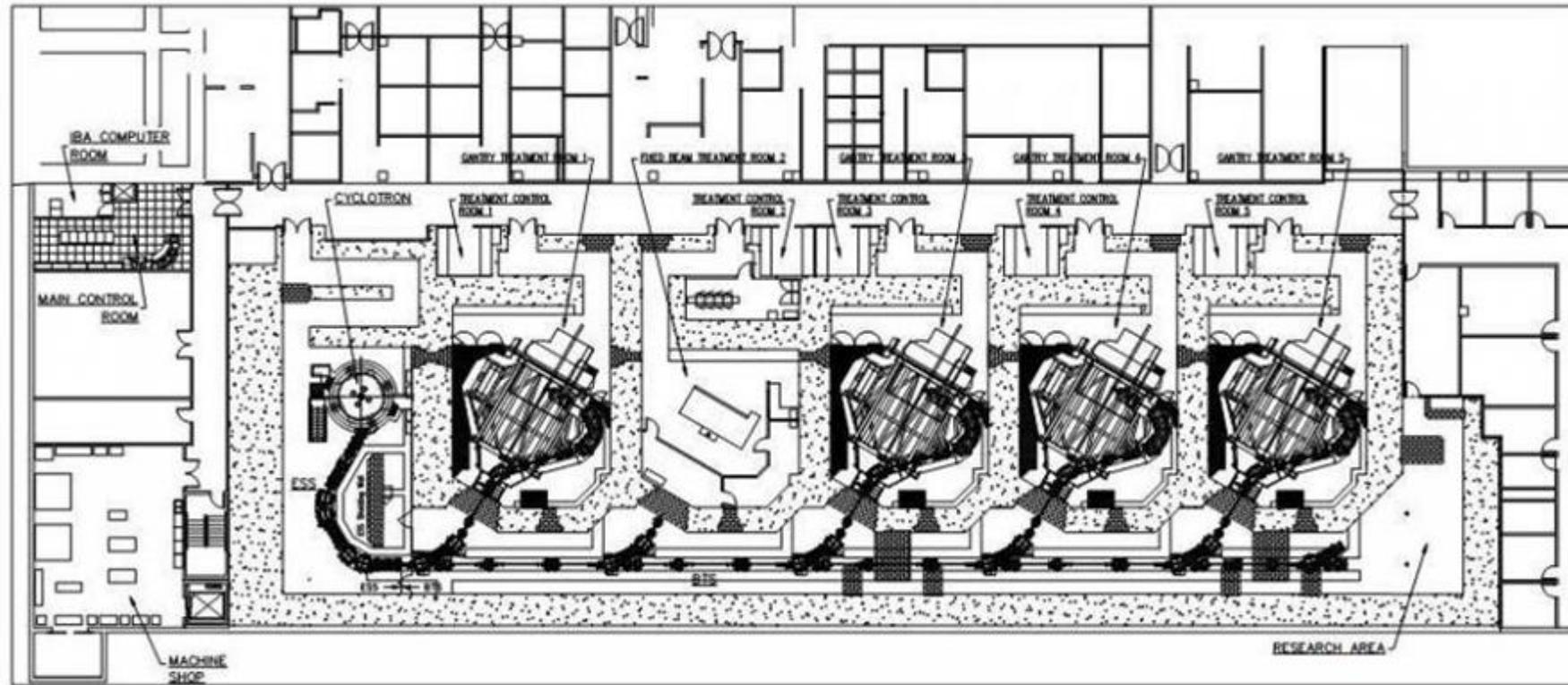


Sistema de Extracción y transporte

UFPTI – Jacksonville



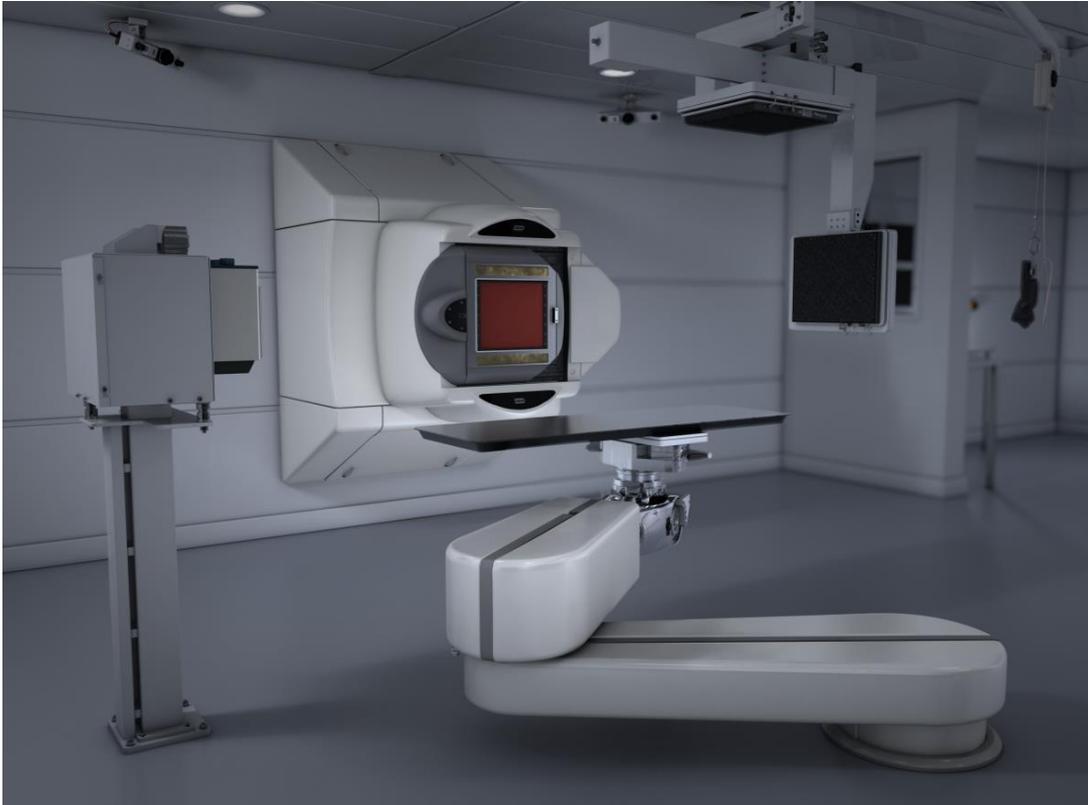
UPENN - Philadelphia



Sala de tratamiento – Gantry 360°



Salas de Tratamiento de haces fijos

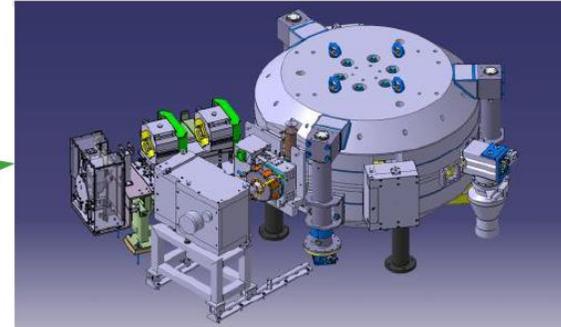
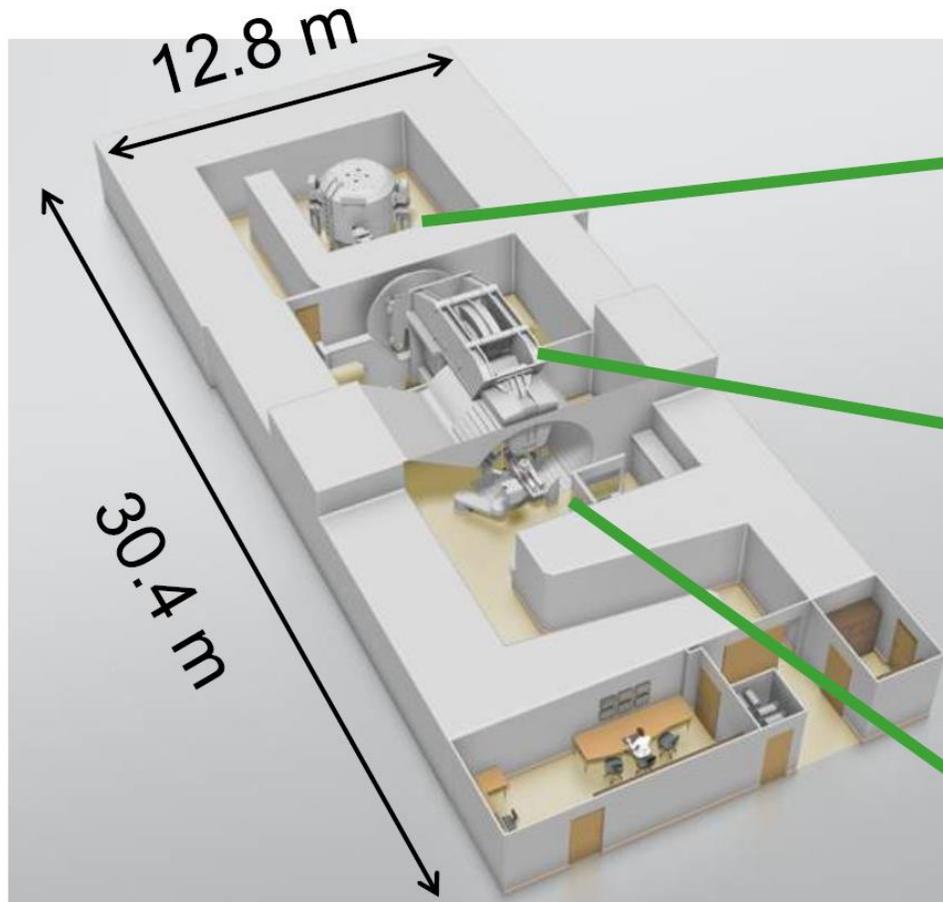


Cerebro, Cabeza & Cuello, Próstata y otro.

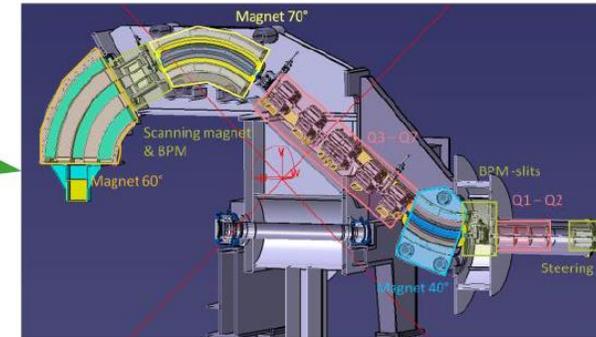


Pequeños tumores, especialmente oculares.

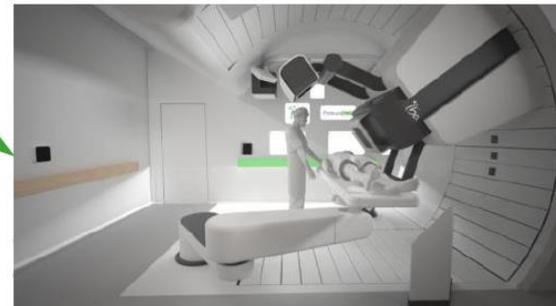
Equipo con una Sala



Sincro Ciclotrón S2C2
Energía: 230 MeV
Radio: 1.25 m



Gantry 220°

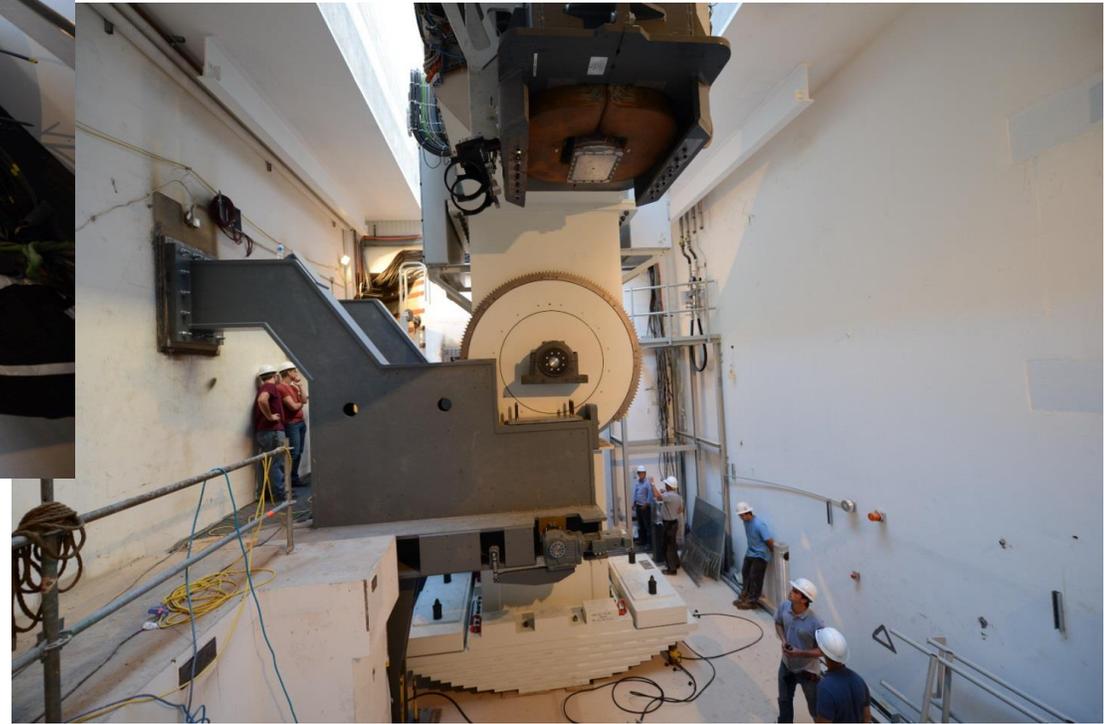
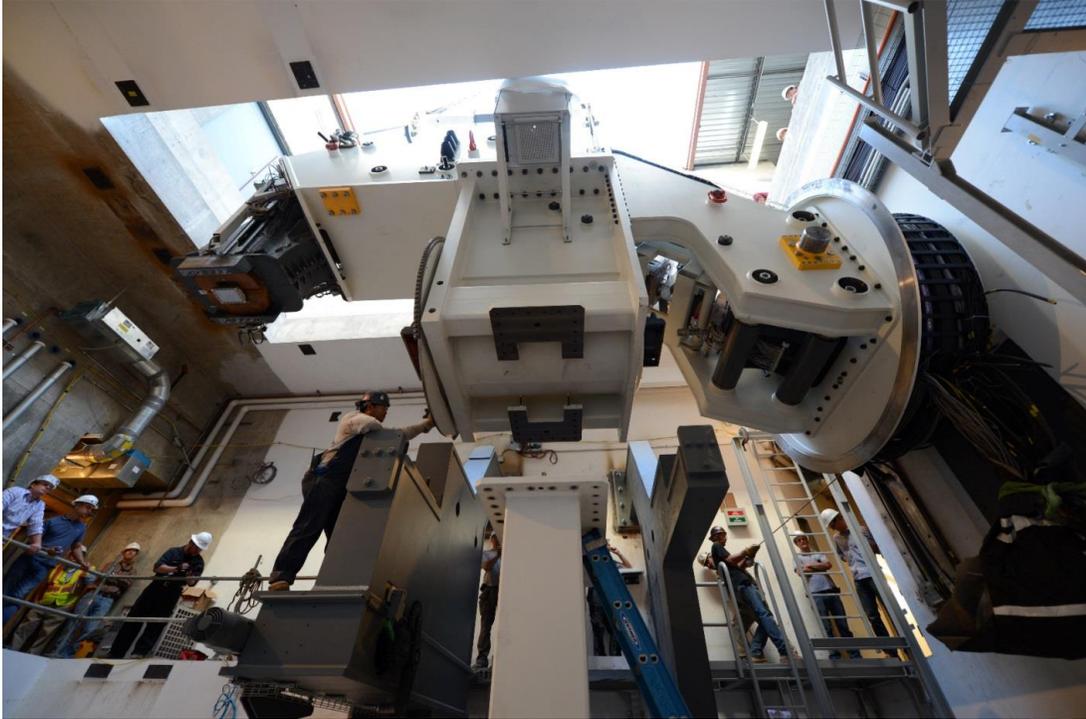


Sala de tratamiento

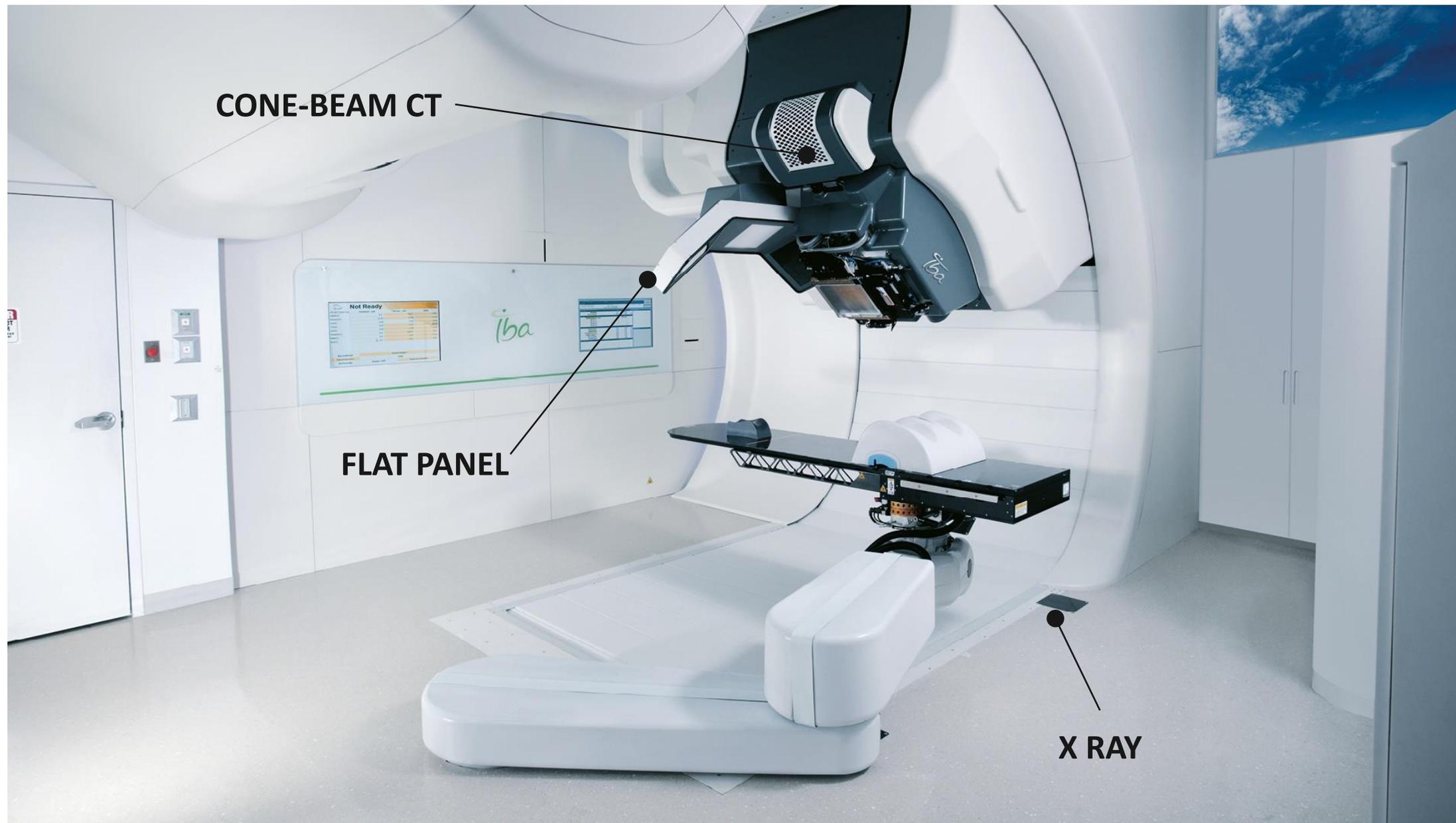
Instalación Shreveport



Instalación Shreveport

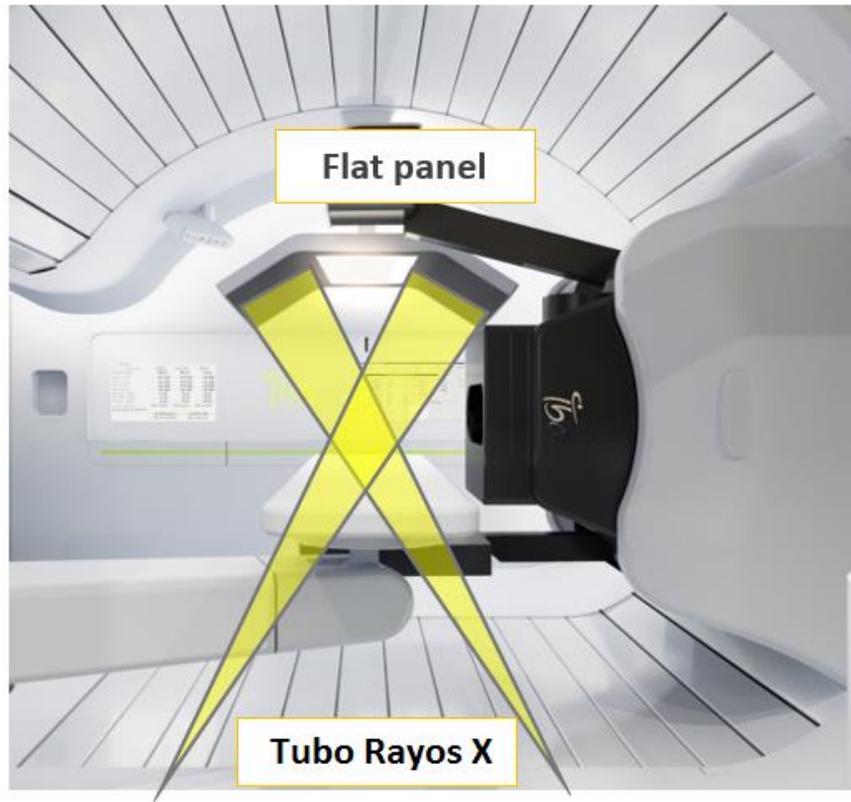


Protonterapia Guiada por Imágenes (IGPT)



Protonterapia Guiada por Imágenes (IGPT)

Estereoscopia

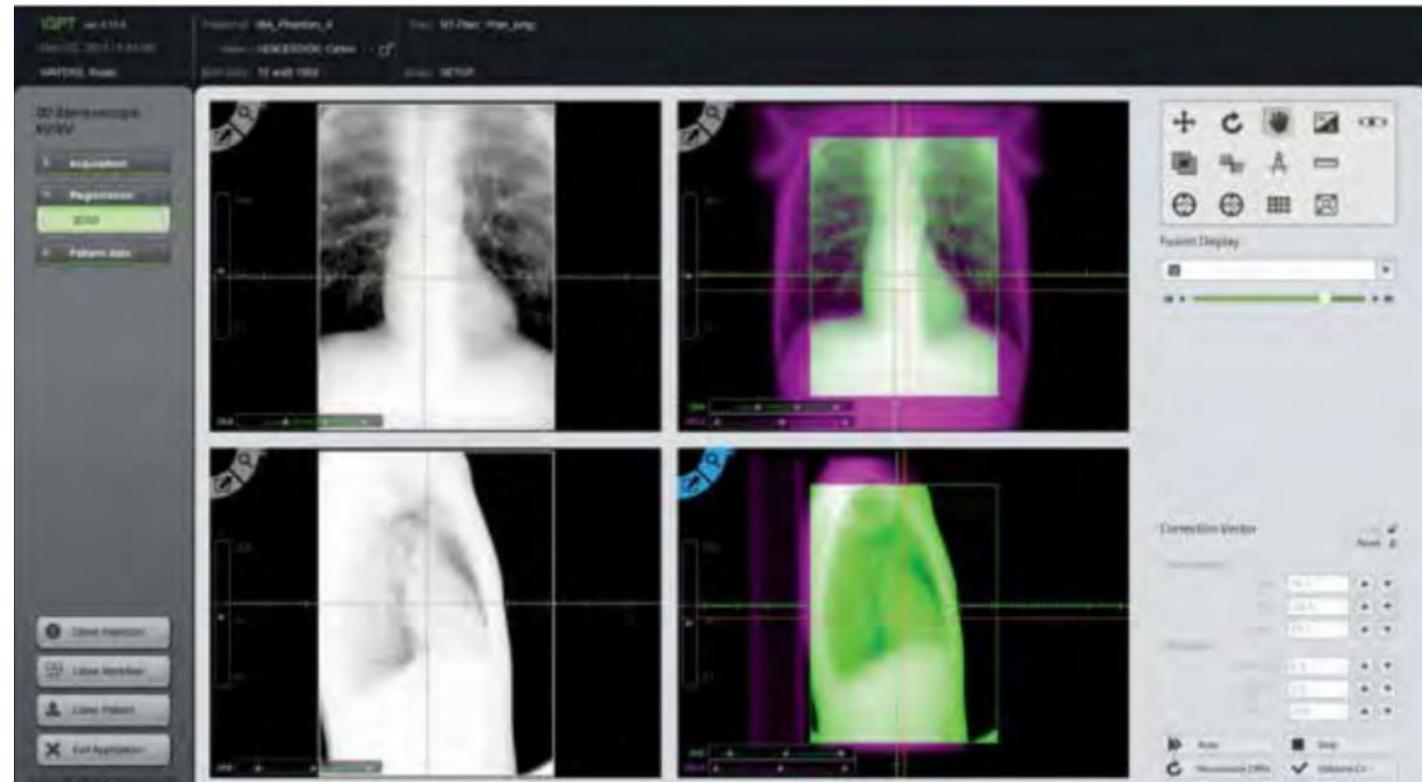
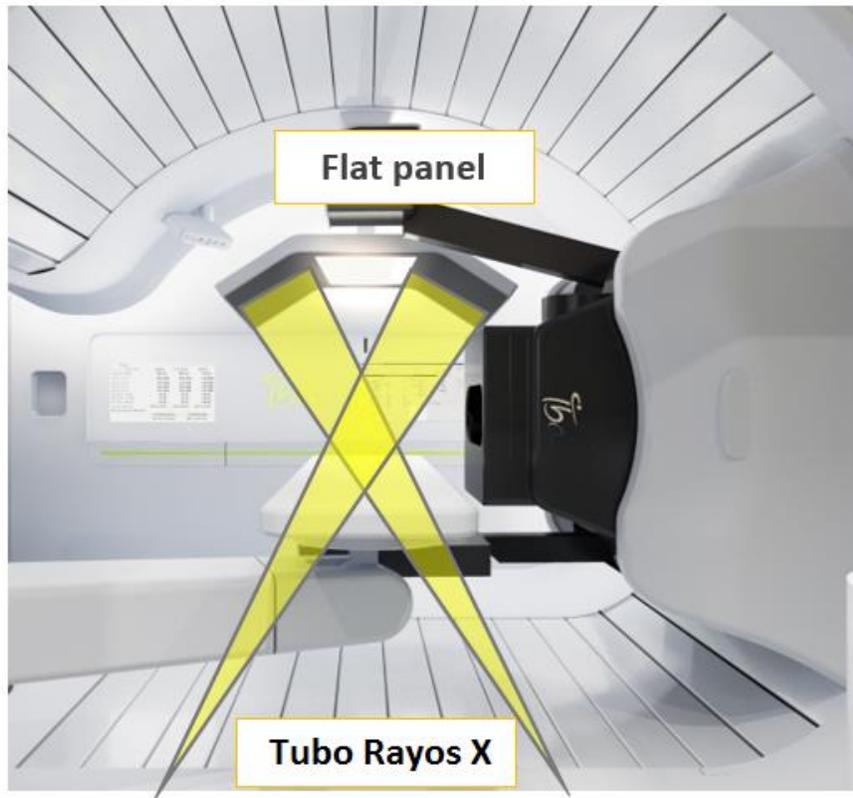


CBCT



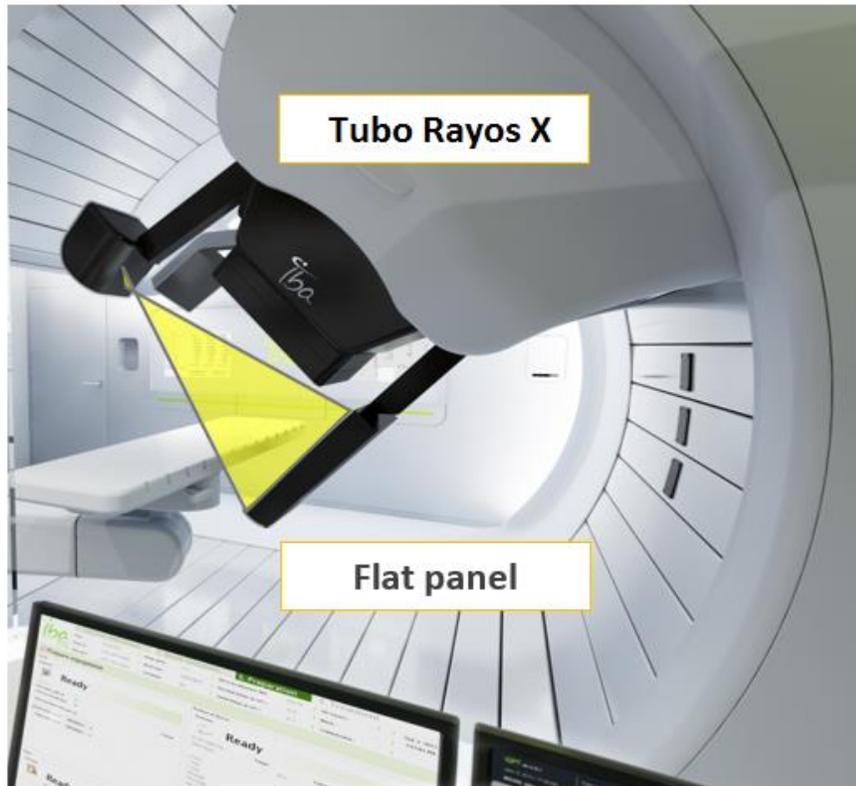
Protonterapia Guiada por Imágenes (IGPT)

Estereoscopía



Protonterapia Guiada por Imágenes (IGPT)

CBCT

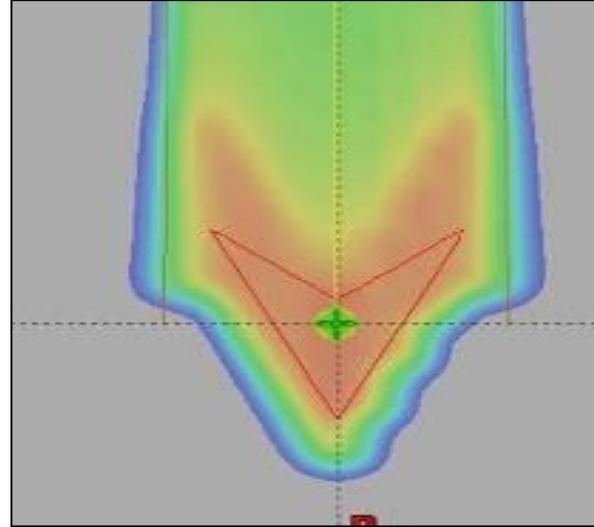
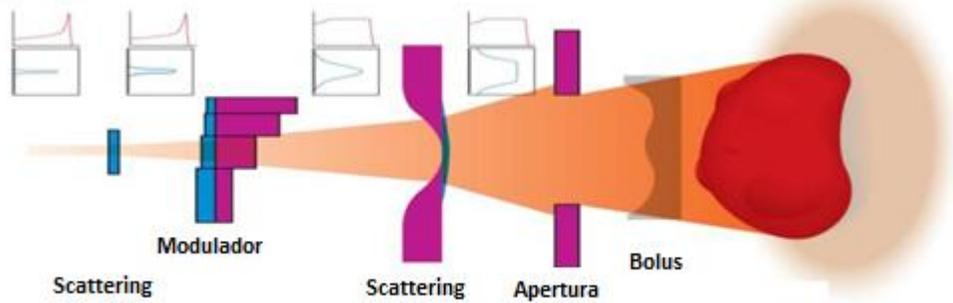


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Modos de Tratamiento

Double Scattering

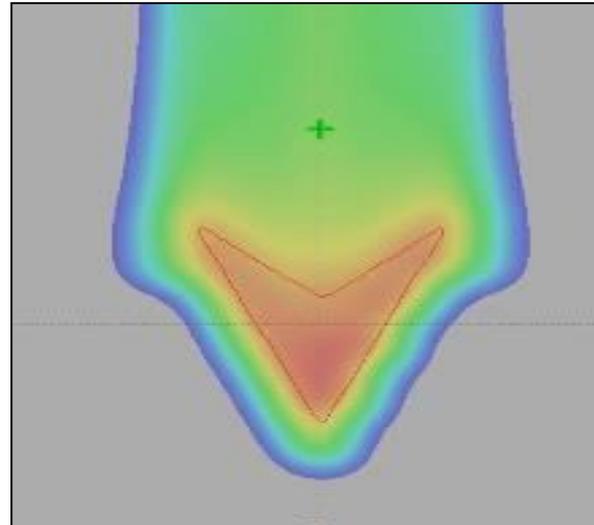
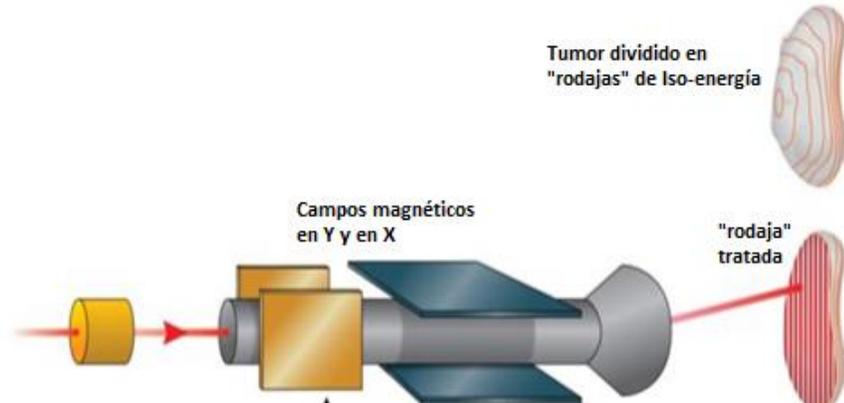


Apertura personalizada



Bolus personalizado

Pencil Beam Scanning (PBS)

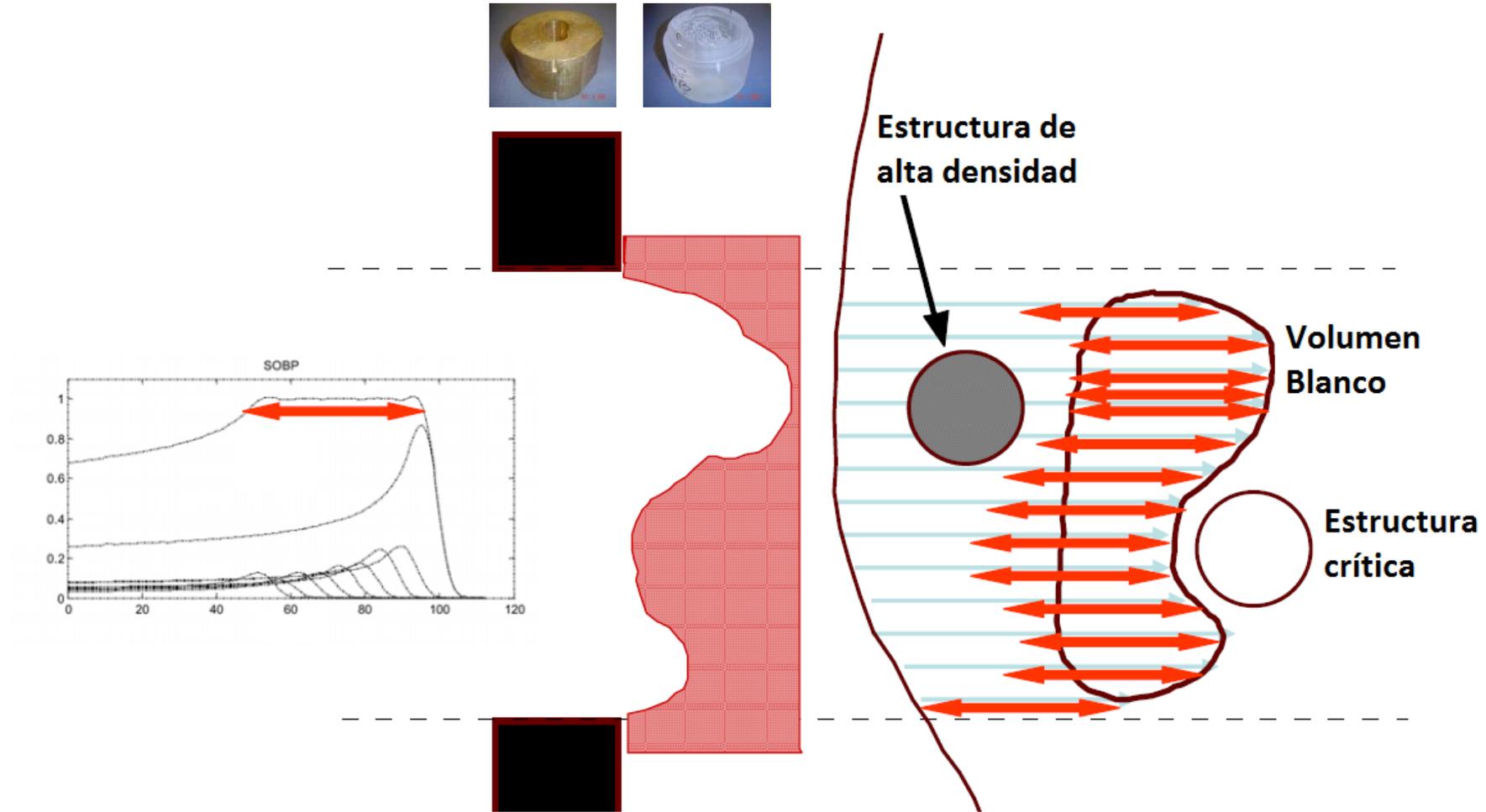


Apertura personalizada

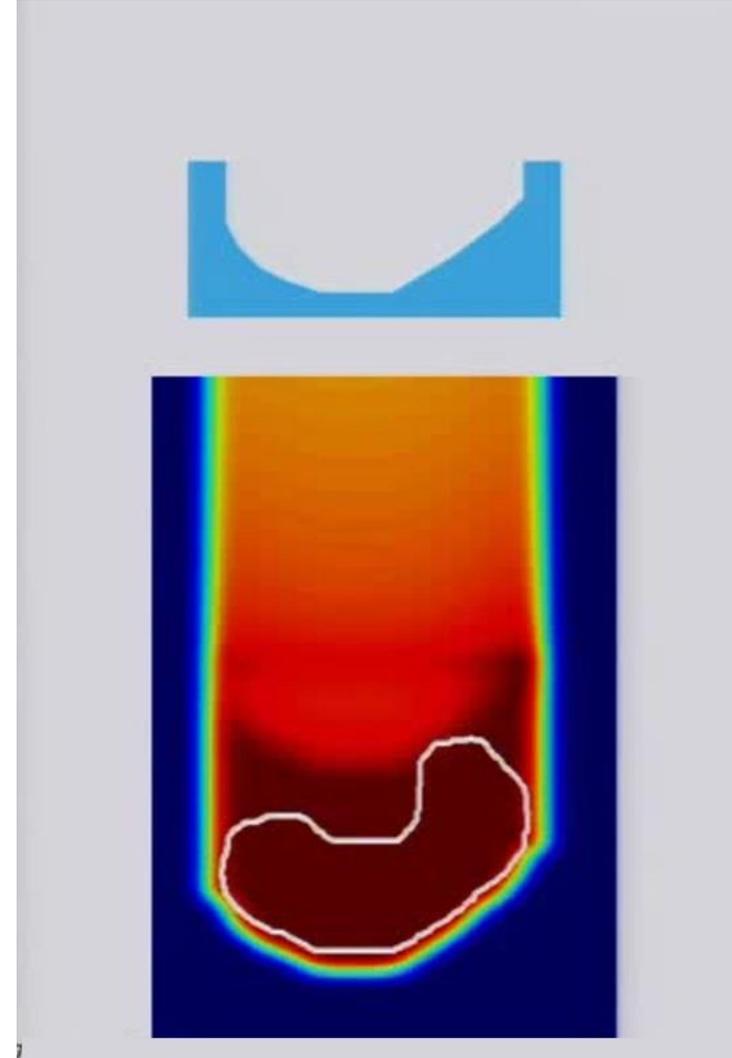
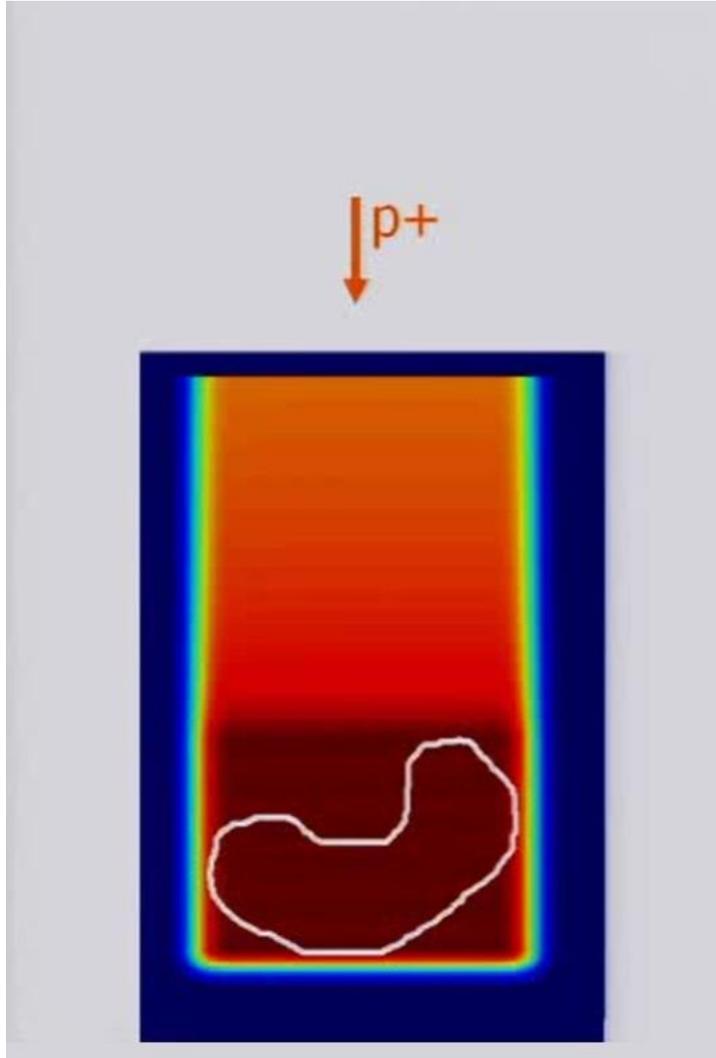


Bolus personalizado

Double Scattering



Double Scattering



The 200-MeV proton therapy project at the Paul Scherrer Institute: Conceptual design and practical realization

Eros Pedroni, Reinhard Bacher,^{a)} Hans Blattmann, Terence Böhringer, Adolf Coray, Antony Lomax, Shixiong Lin, Gudrun Munkel, Stefan Scheib, Uwe Schneider, and Alexander Tourovsky^{b)}

Department of Radiation Medicine, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

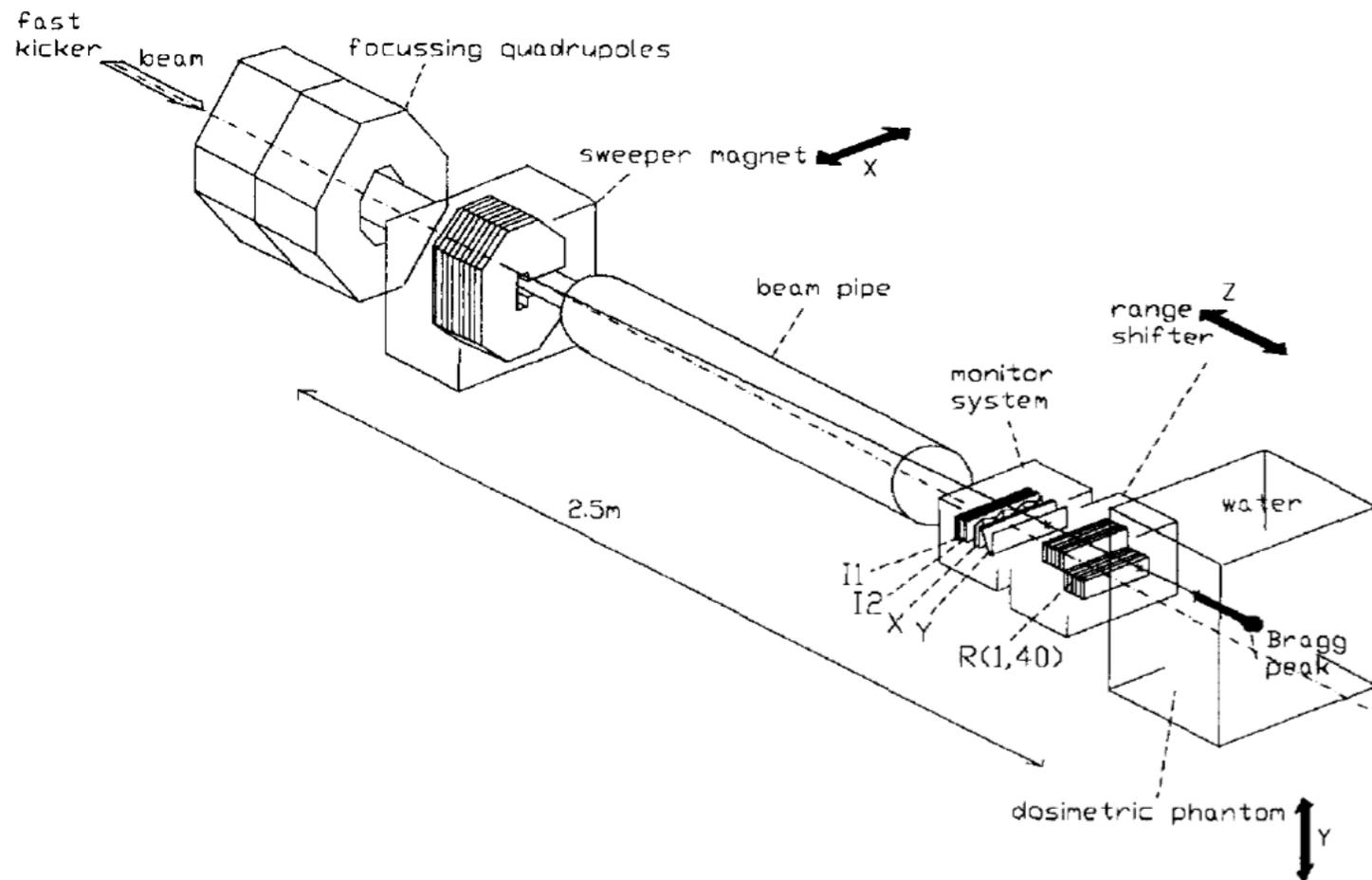
(Received 31 January 1994; accepted for publication 24 August 1994)

The new proton therapy facility is being assembled at the Paul Scherrer Institute (PSI). The beam delivered by the PSI sector cyclotron can be split and brought into a new hall where it is degraded from 590 MeV down to an energy in the range of 85–270 MeV. A new beam line following the degrader is used to clean the low-energetic beam in phase space and momentum band. The analyzed beam is then injected into a compact isocentric gantry, where it is applied to the patient using a new dynamic treatment modality, the so-called spot-scanning technique. This technique will permit full three-dimensional conformation of the dose to the target volume to be realized in a routine way without the need for individualized patient hardware like collimators and compensators. By combining the scanning of the focused pencil beam within the beam optics of the gantry and by mounting the patient table eccentrically on the gantry, the diameter of the rotating structure has been reduced to only 4 m. In the article the degrees of freedom available on the gantry to apply the beam to the patient (with two rotations for head treatments) are also discussed. The devices for the positioning of the patient on the gantry (x rays and proton radiography) and outside the treatment room (the patient transporter system and the modified mechanics of the computer tomograph unit) are briefly presented. The status of the facility and first experimental results are introduced for later reference.

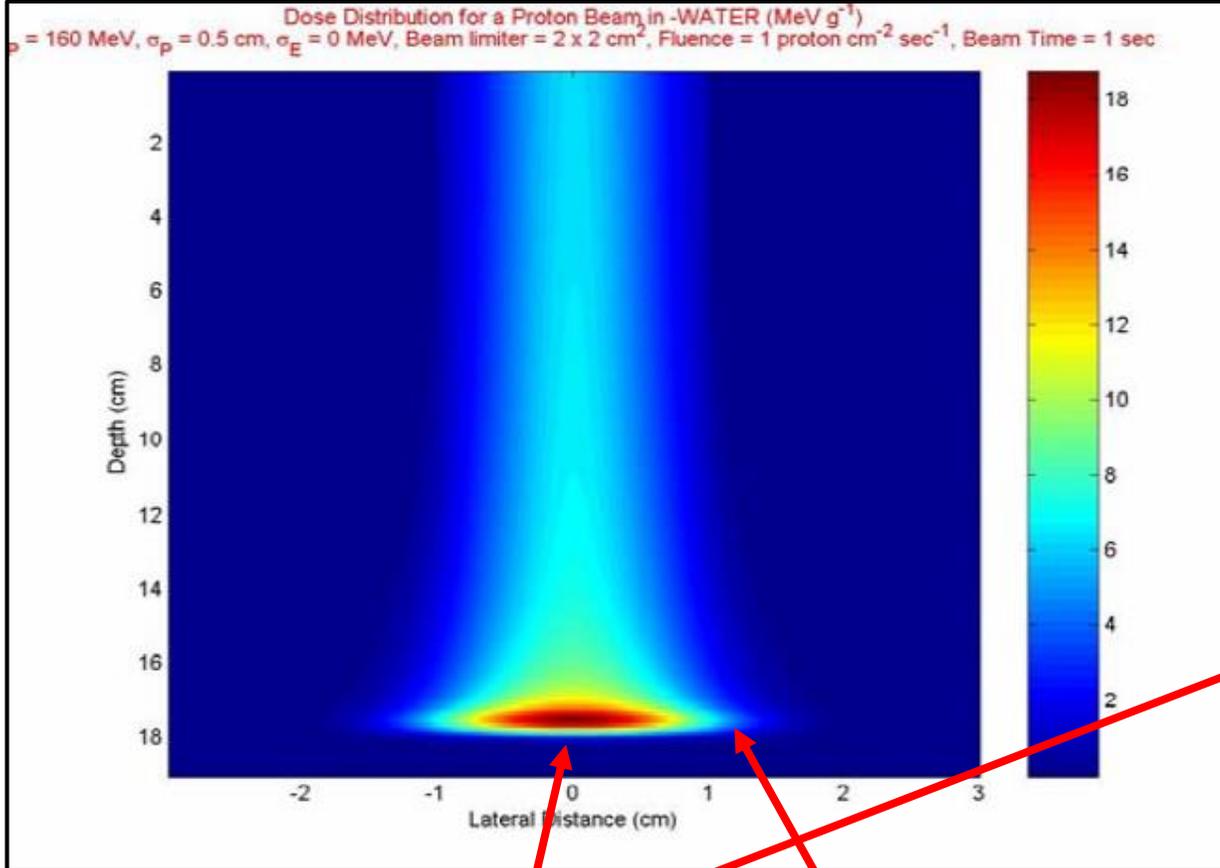
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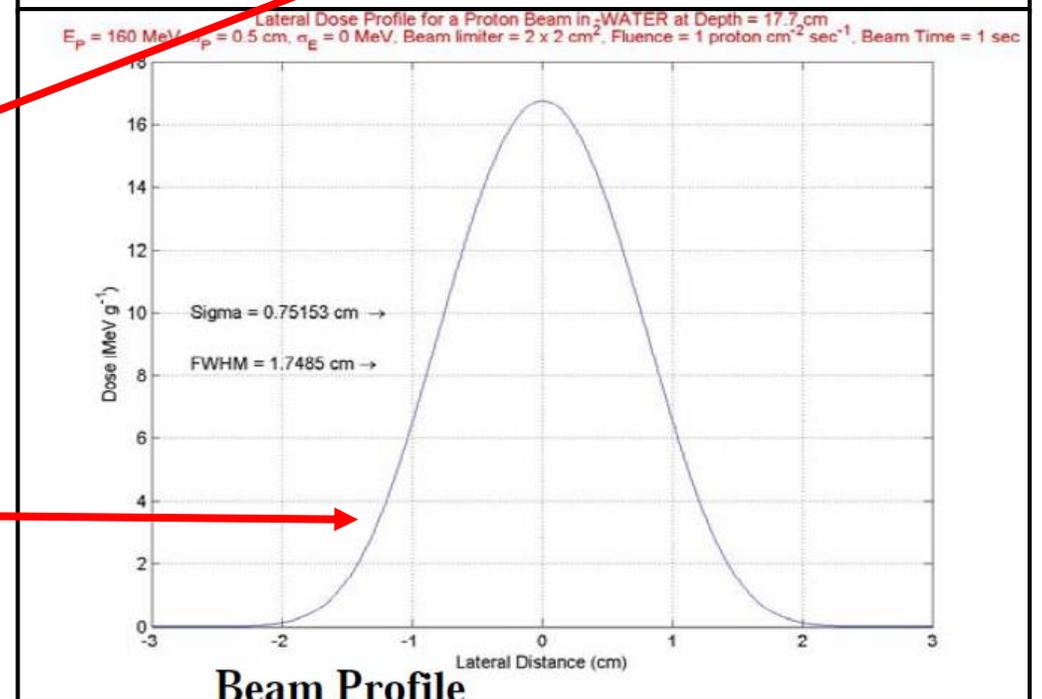
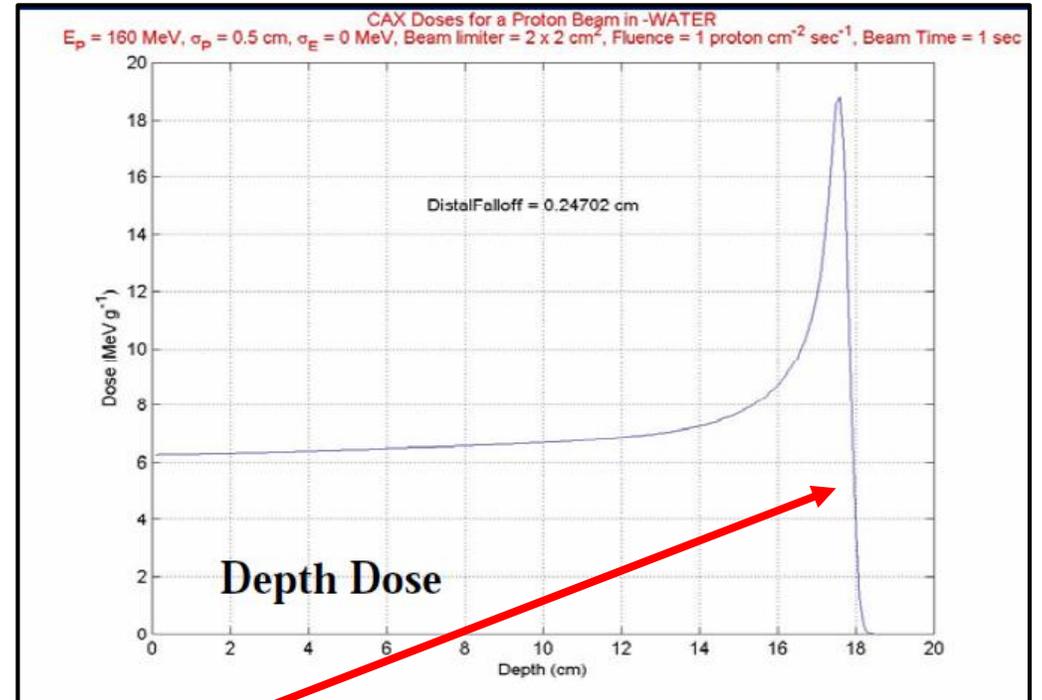
Spot de un haz de protones en agua



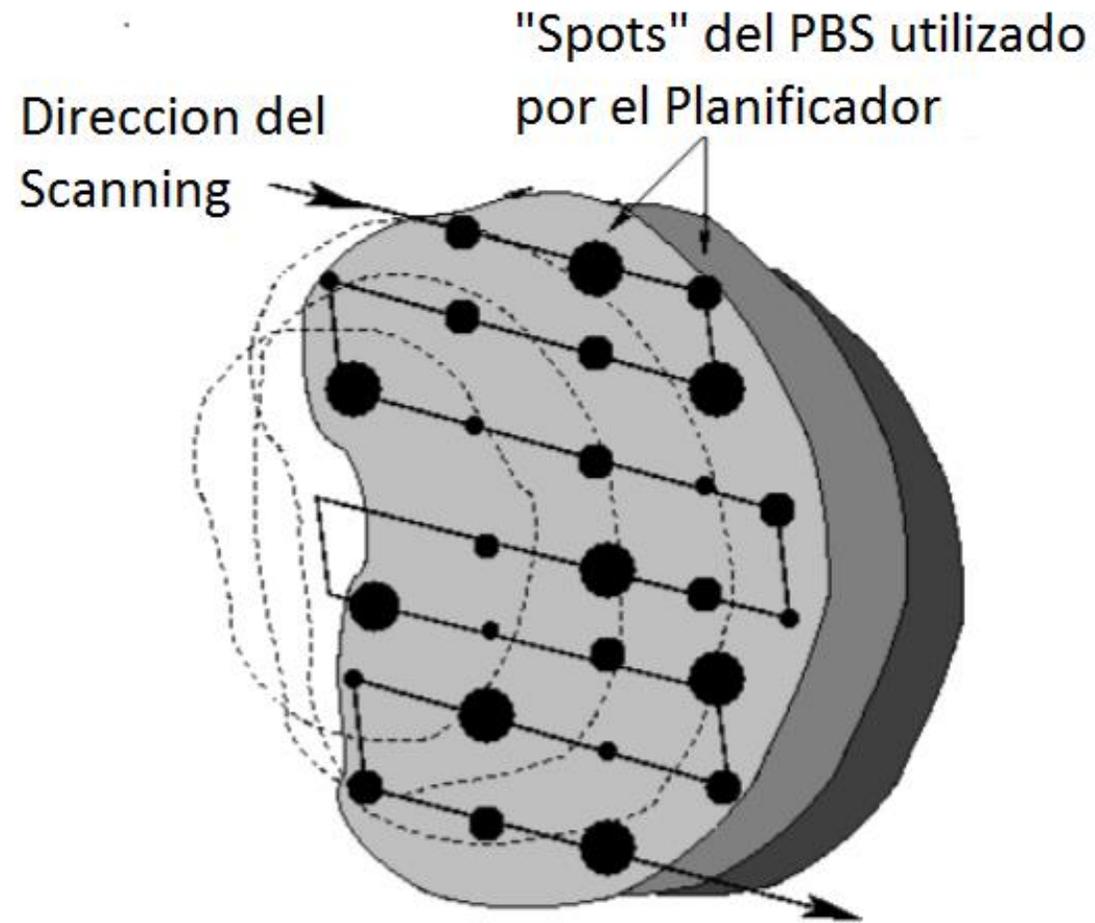
Alto gradiente de dosis
después del Pico de Bragg

Penumbra dependiente de
las características del Spot

G. Ciangaru, MDACC



Pencil Beam Scanning (PBS)



Trofimov and Bortfeld

Pencil Beam Scanning (PBS)

Dos modalidades:

1) **SFUD (Single Field Uniform Dose)**

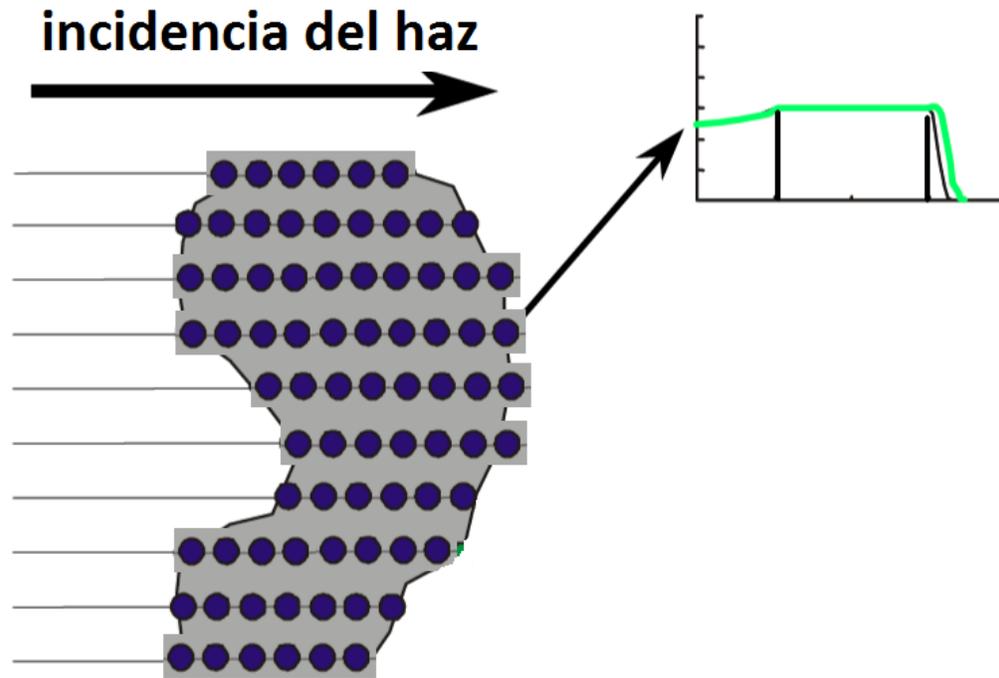
Campo Simple de Dosis Uniforme

2) **IMPT (Intensity Modulated Proton Therapy)**

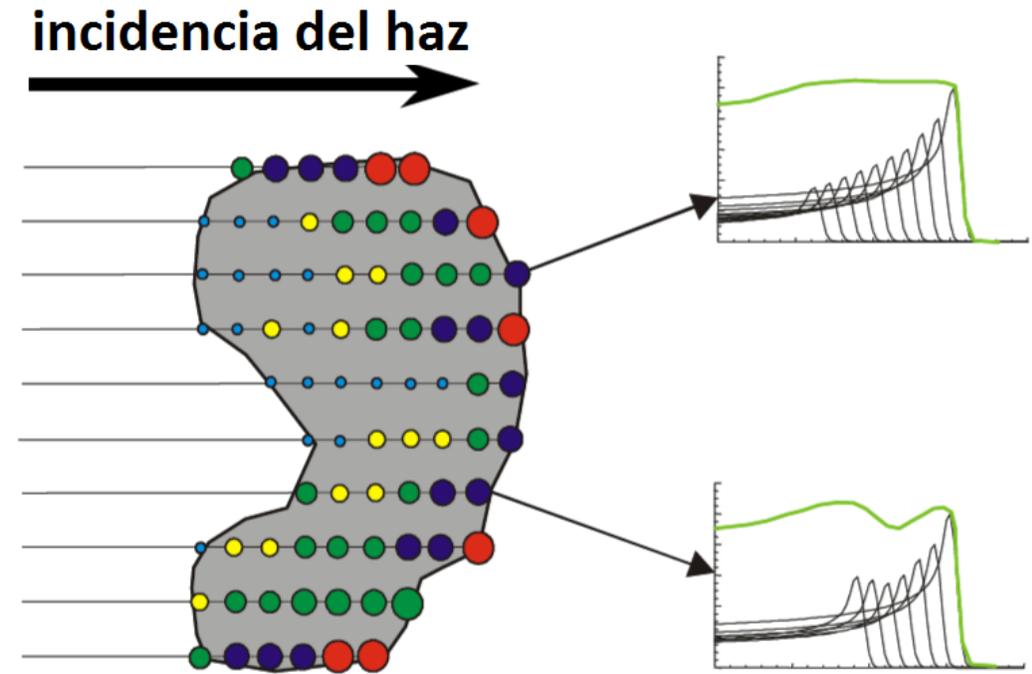
Protonterapia de Intensidad Modulada

Pencil Beam Scanning (PBS)

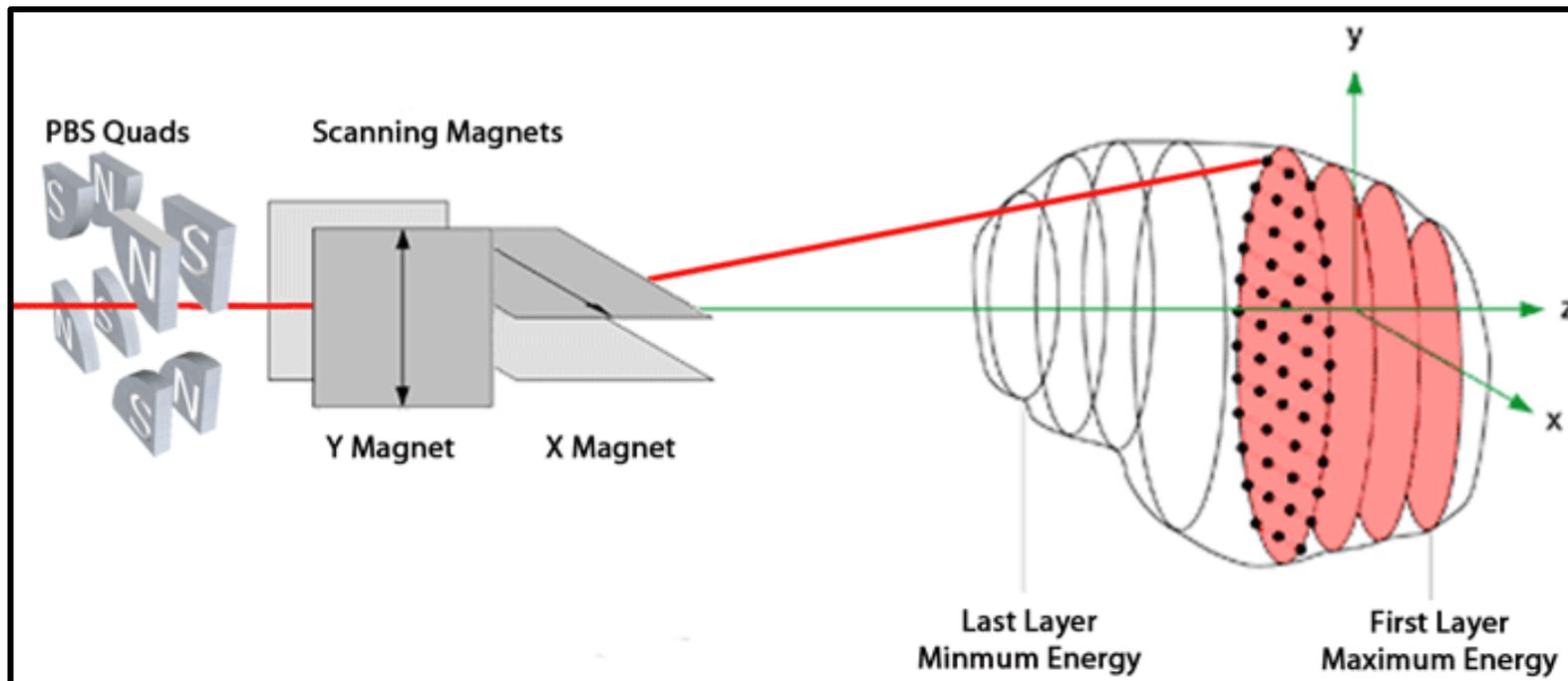
SFUD



IMPT



Pencil Beam Scanning (PBS)



Ventajas:

- Buena conformación de dosis
- Baja dosis de neutrones
- No hay necesidad de apertura y bolus

Desventajas:

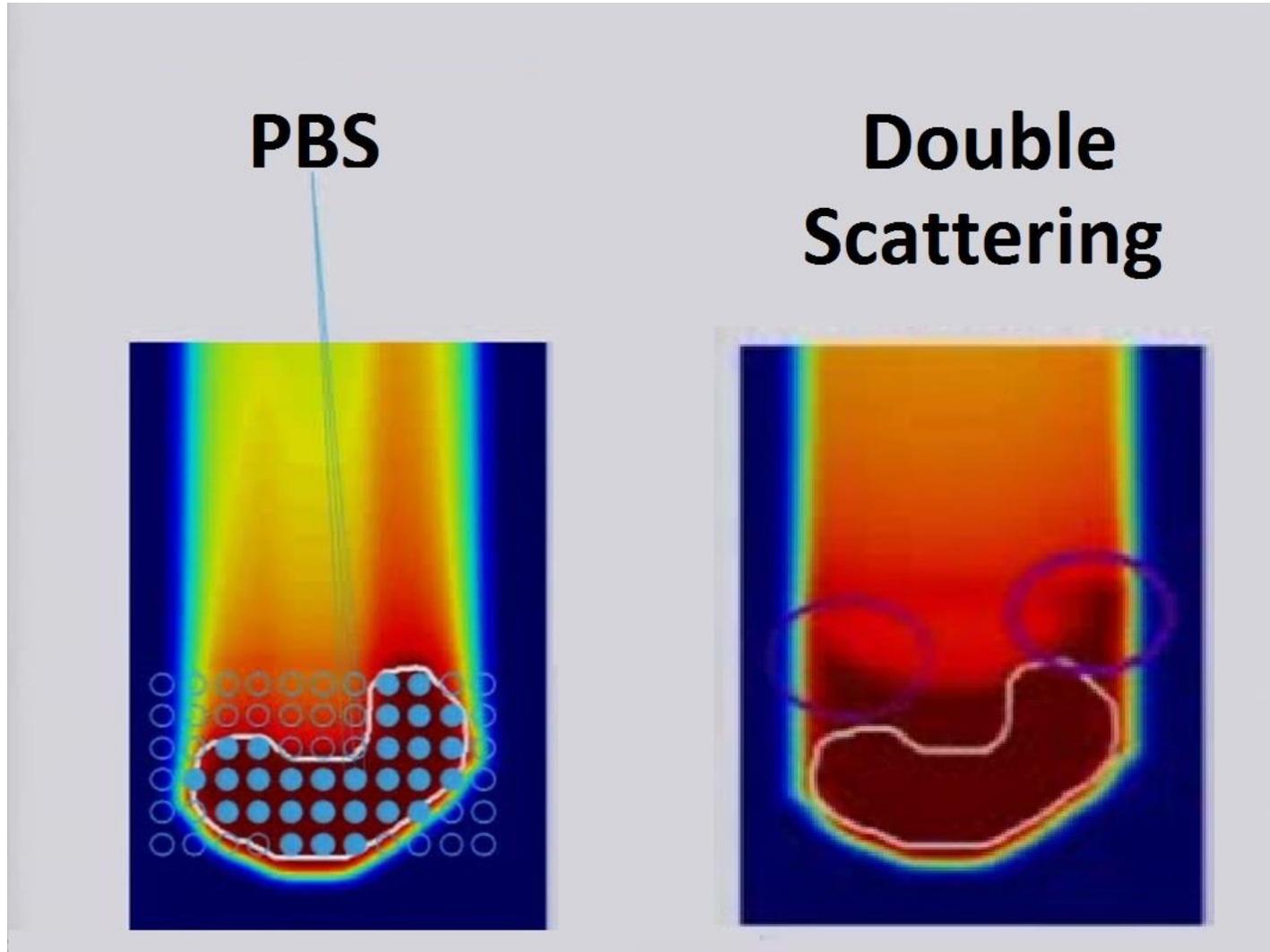
- Sistema dinámico, menos seguro que DS
- Mas lento que DS
- penumbra lateral peor que con colimación

Pencil Beam Scanning (PBS)

Basicamente cada Pencil Beam es definido por cinco parámetros:

- Energía (relacionada con la penetración en el paciente)
- Número de protones (relacionada con la dosis)
- Deflexión látero-lateral
- Deflexión superior-inferior
- Tamaño del spot (generalmente algunos milímetros)

PBS vs Double Scattering

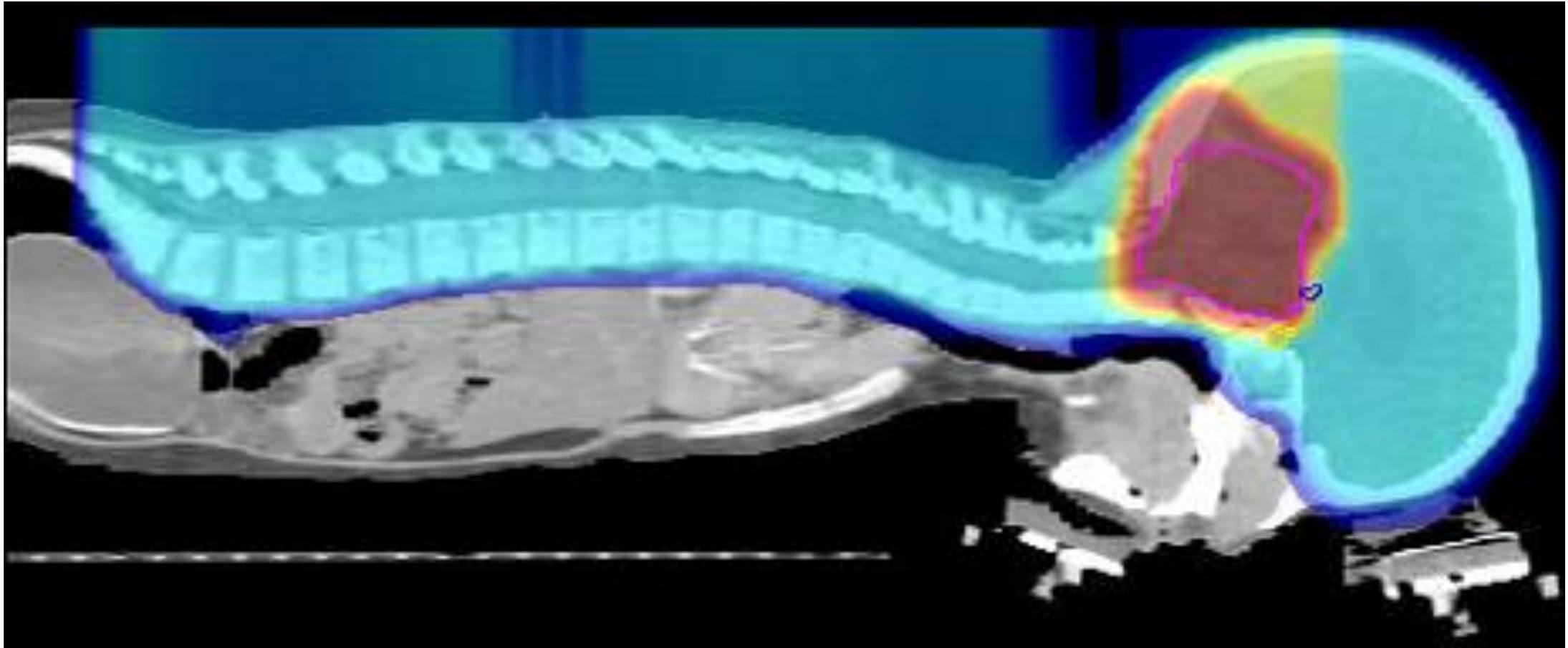


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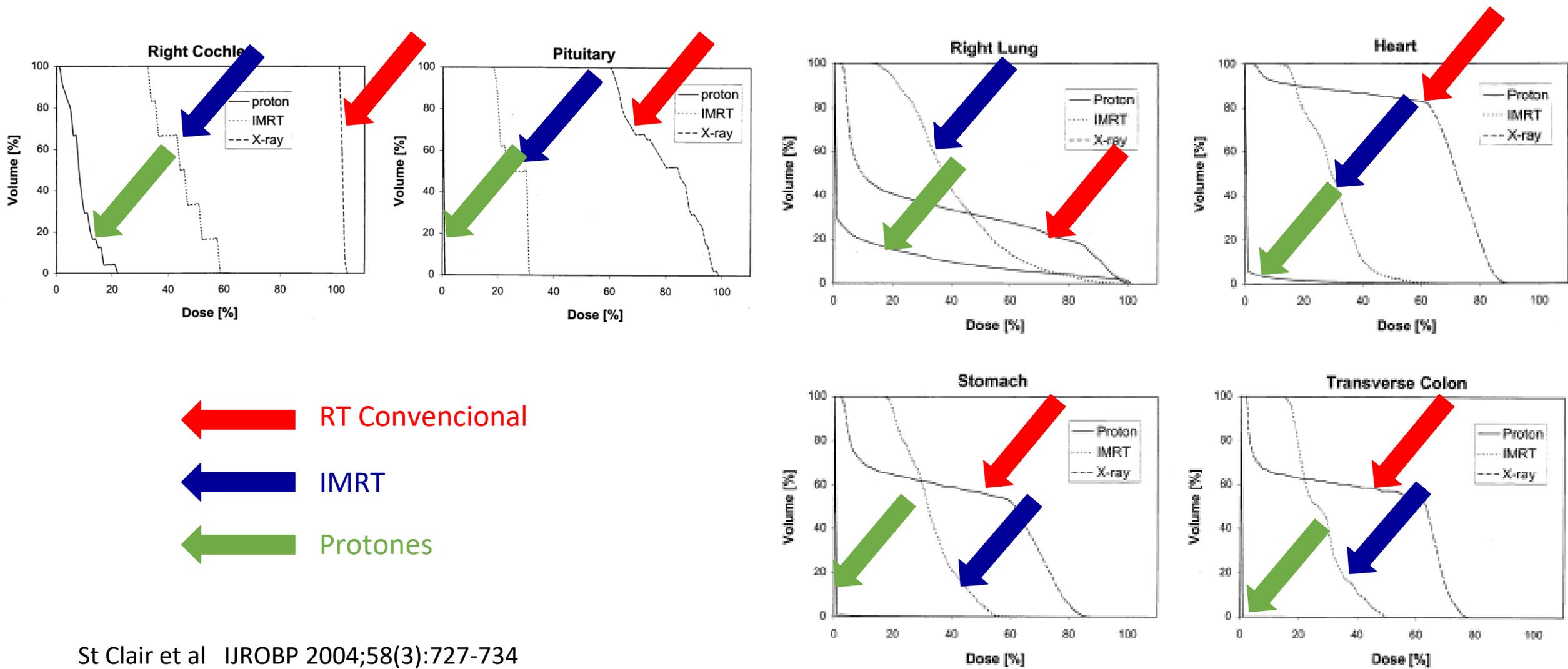
Protonterapia

MEDULOBLASTOMA PEDIATRICO



Protonterapia

MEDULOBLASTOMA PEDIATRICO



← RT Convencional
← IMRT
← Protones

Protonterapia

MEDULOBLASTOMA PEDIATRICO

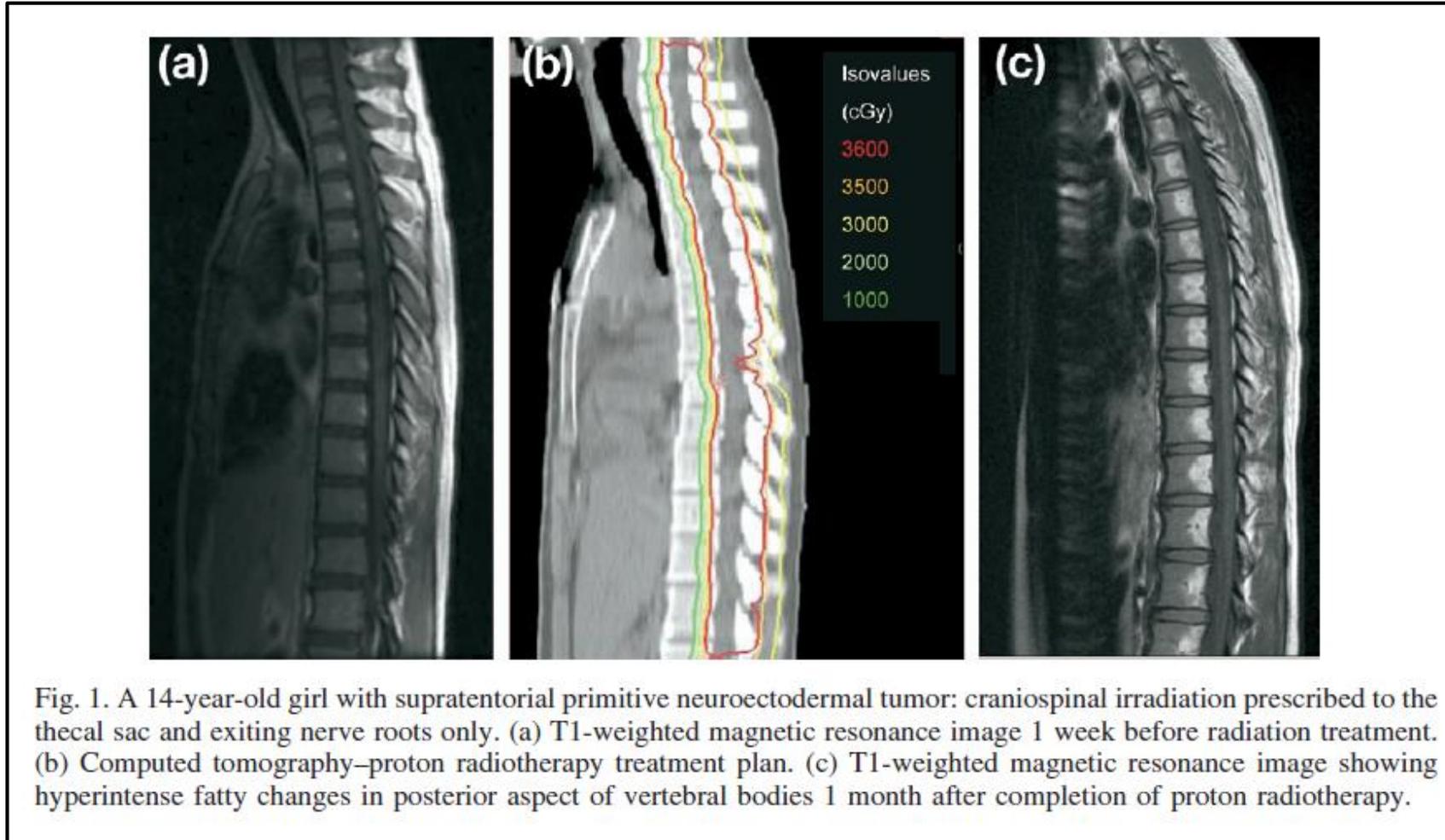
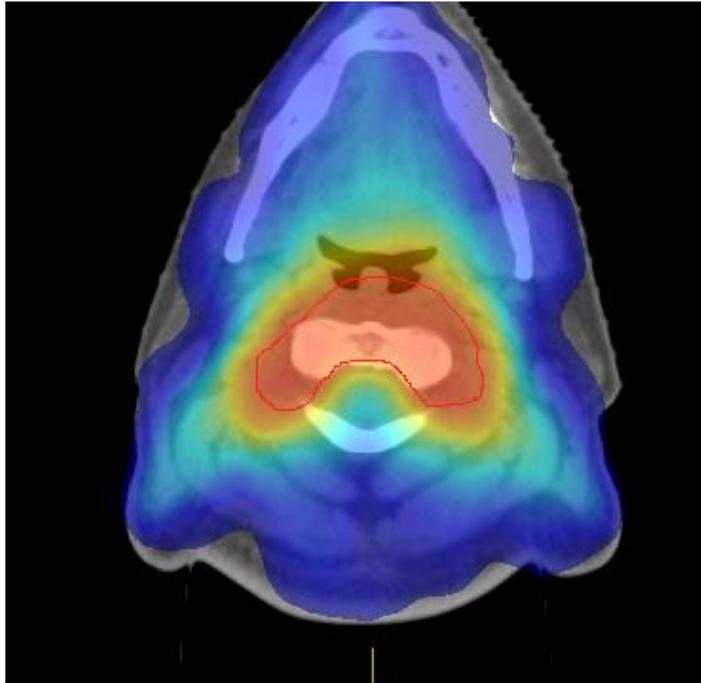


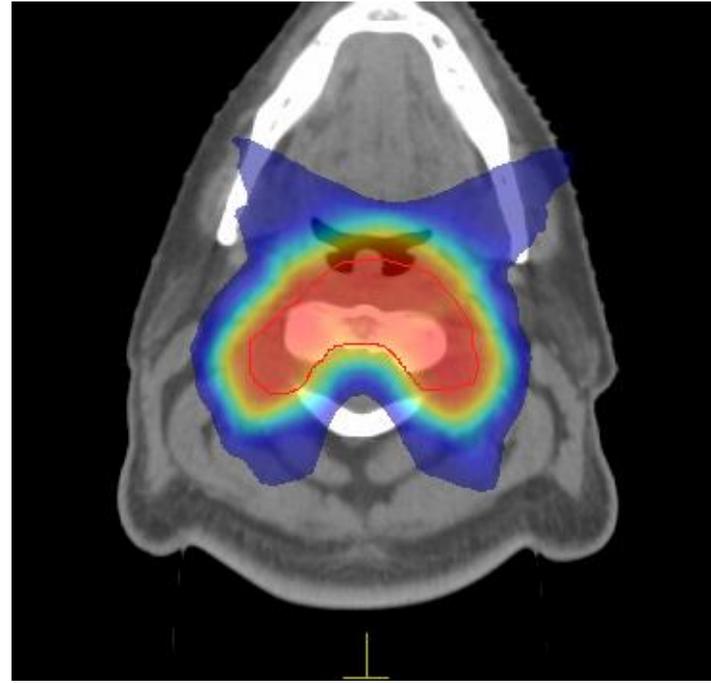
Fig. 1. A 14-year-old girl with supratentorial primitive neuroectodermal tumor: craniospinal irradiation prescribed to the thecal sac and exiting nerve roots only. (a) T1-weighted magnetic resonance image 1 week before radiation treatment. (b) Computed tomography–proton radiotherapy treatment plan. (c) T1-weighted magnetic resonance image showing hyperintense fatty changes in posterior aspect of vertebral bodies 1 month after completion of proton radiotherapy.

Terapia de Arco vs. Protonterapia DS vs. IMPT

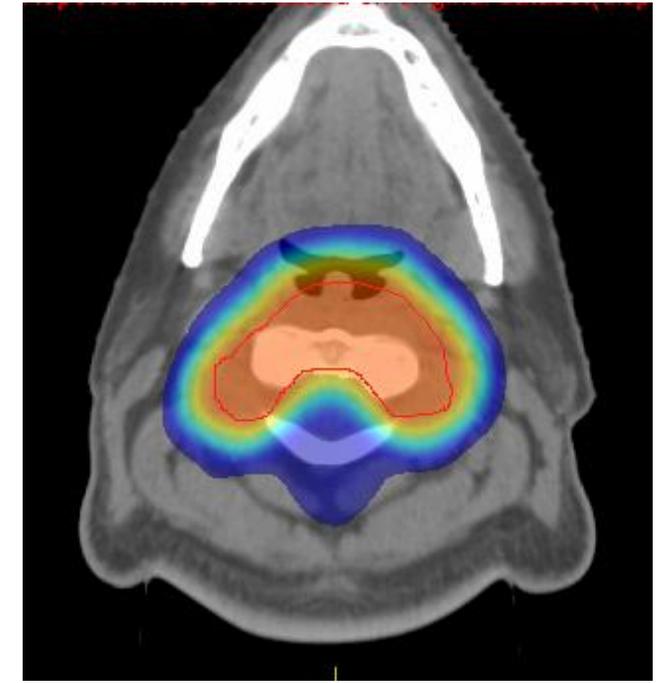
CABEZA & CUELLO



VMAT : 1 arco



Protonterapia DS: 4 campos

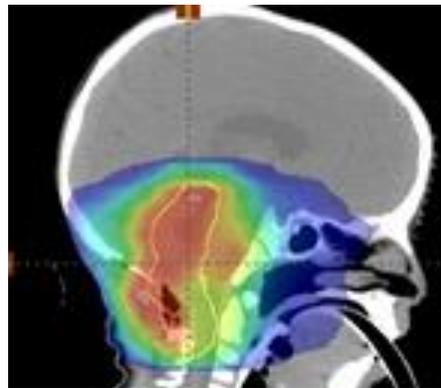
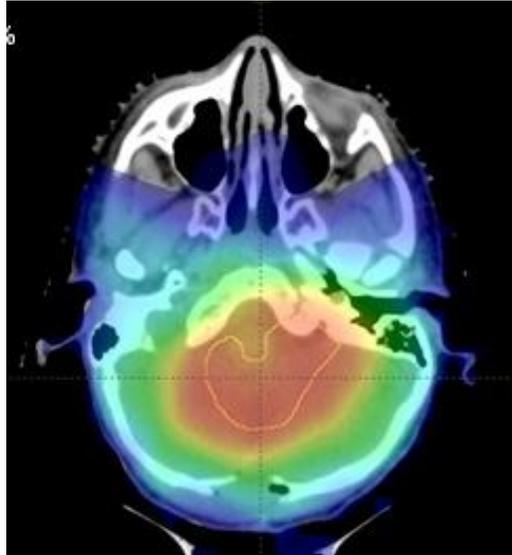


IMPT: 1 campo

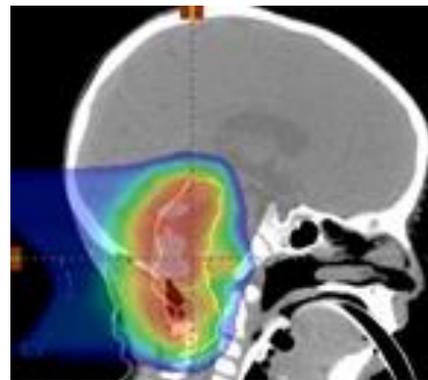
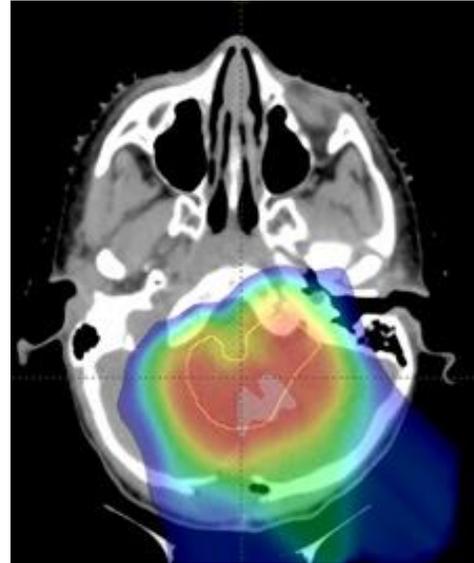
Protonterapia

EPENDIMOMA PEDIATRICO

VMAT



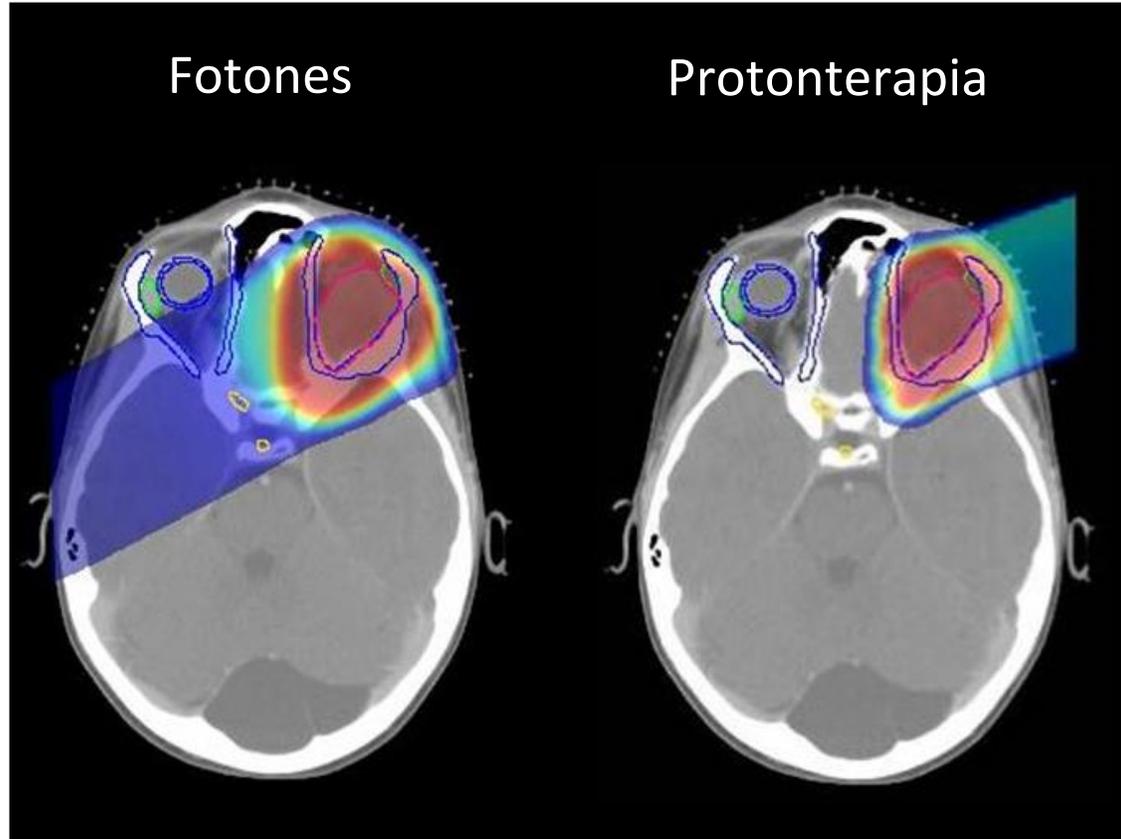
Protonterapia



Images Courtesy of Stefan Both, Ph.D. – (*) Cotter SE, et al. «Proton radiotherapy for solid tumors of childhood.» [Technol Cancer Res Treat.](#) 2012 Jun;11(3):267-78. Epub 2012 Mar 15.

Protonterapia

RABDOMIOSARCOMA PEDIATRICO

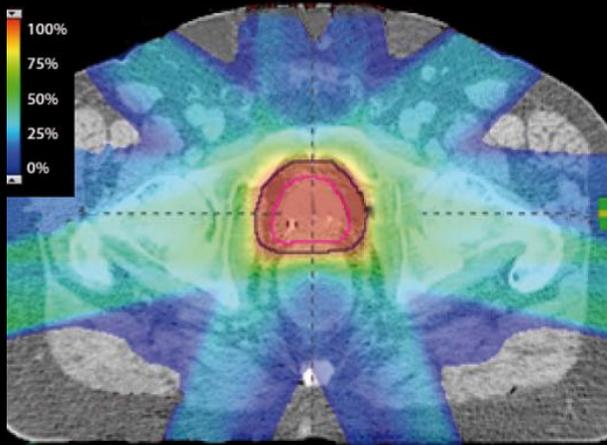


Images Courtesy Torunn I Yock, MD Burr Proton Therapy Center Boston USA – (*) Yock, T. et al; « Proton radiotherapy for orbital rhabdomyosarcoma: clinical outcome and a dosimetric comparison with photons. », [Int J Radiat Oncol Biol Phys.](#) 2005 Nov 15;63(4):1161-8. Epub 2005 Jun 13

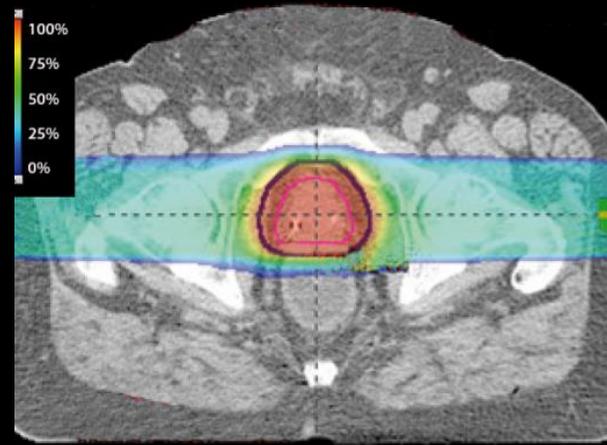
Protonterapia

PROSTATA Y GANGLIOS

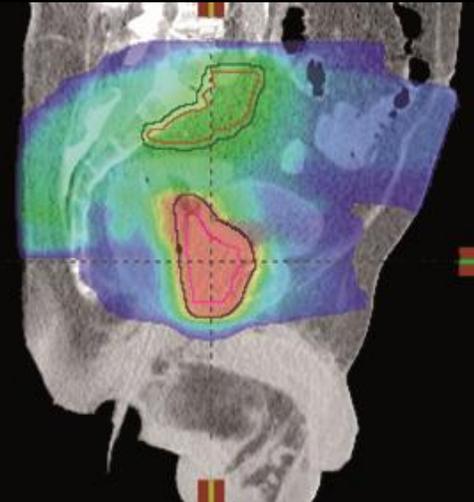
IMRT



Protonterapia



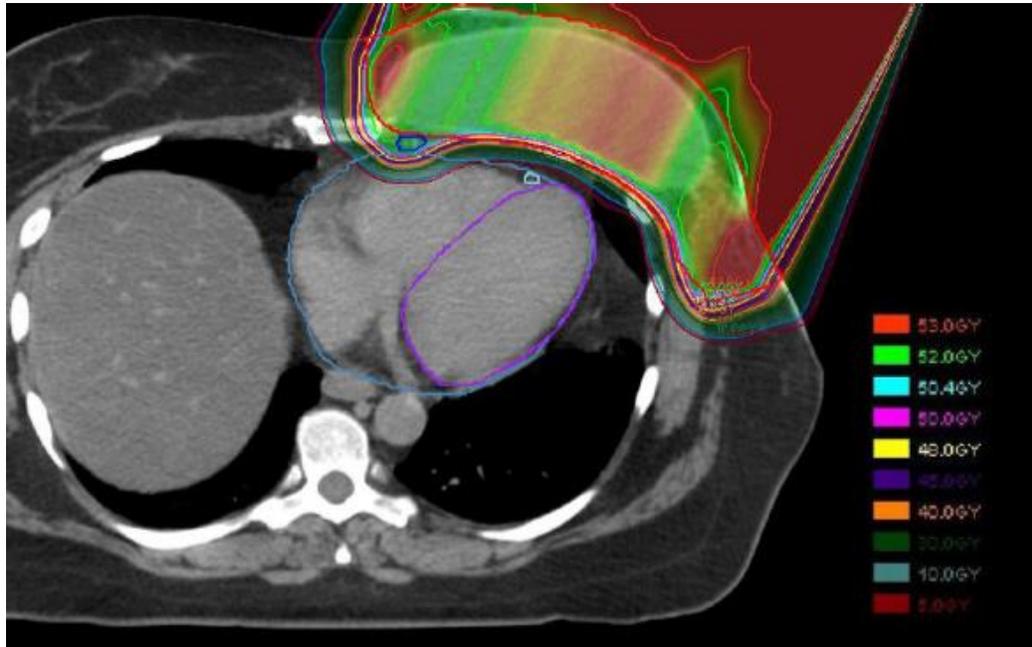
“Early outcomes with image-guided proton therapy suggest high efficacy and minimal toxicity with **only 1.9% Grade 3 GU symptoms and <0.5% Grade 3 GI toxicities**”



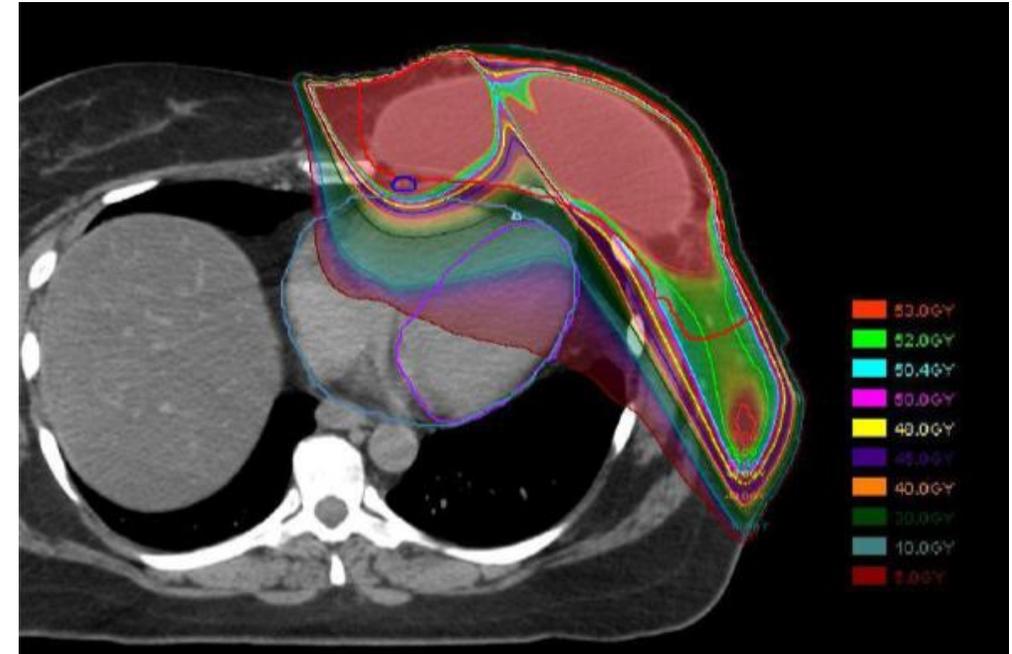
Images Courtesy of Stefan Both, Ph.D – (*) Mendenhall NP, et al. « Early outcomes from three prospective trials of image-guided proton therapy for prostate cancer” (low risk prostate trials); [Int J Radiat Oncol Biol Phys.](#) 2012 Jan 1;82(1):213-21. Epub 2010 Nov 17

Protonterapia

CANCER DE MAMA



Protones: 1 campo “Double Scattering”



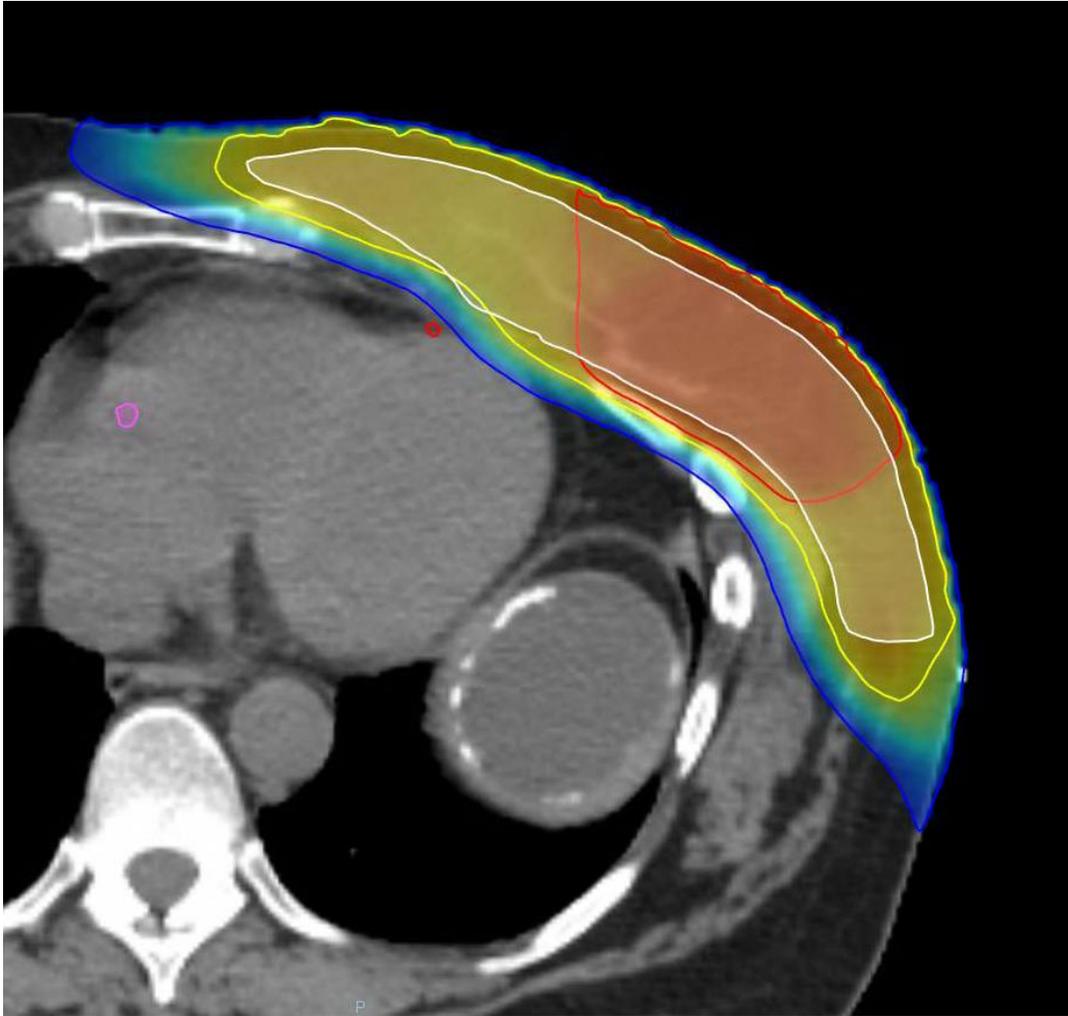
Fotones + Electrones

Int J Radiation Oncol Biol Phys
Vol. 86, No. 3, pp. 484–490, 2013

Massachusetts General Hospital
Harvard Medical School, Boston, MA

Protonterapia

CANCER DE MAMA



Pencil Beam Scanning

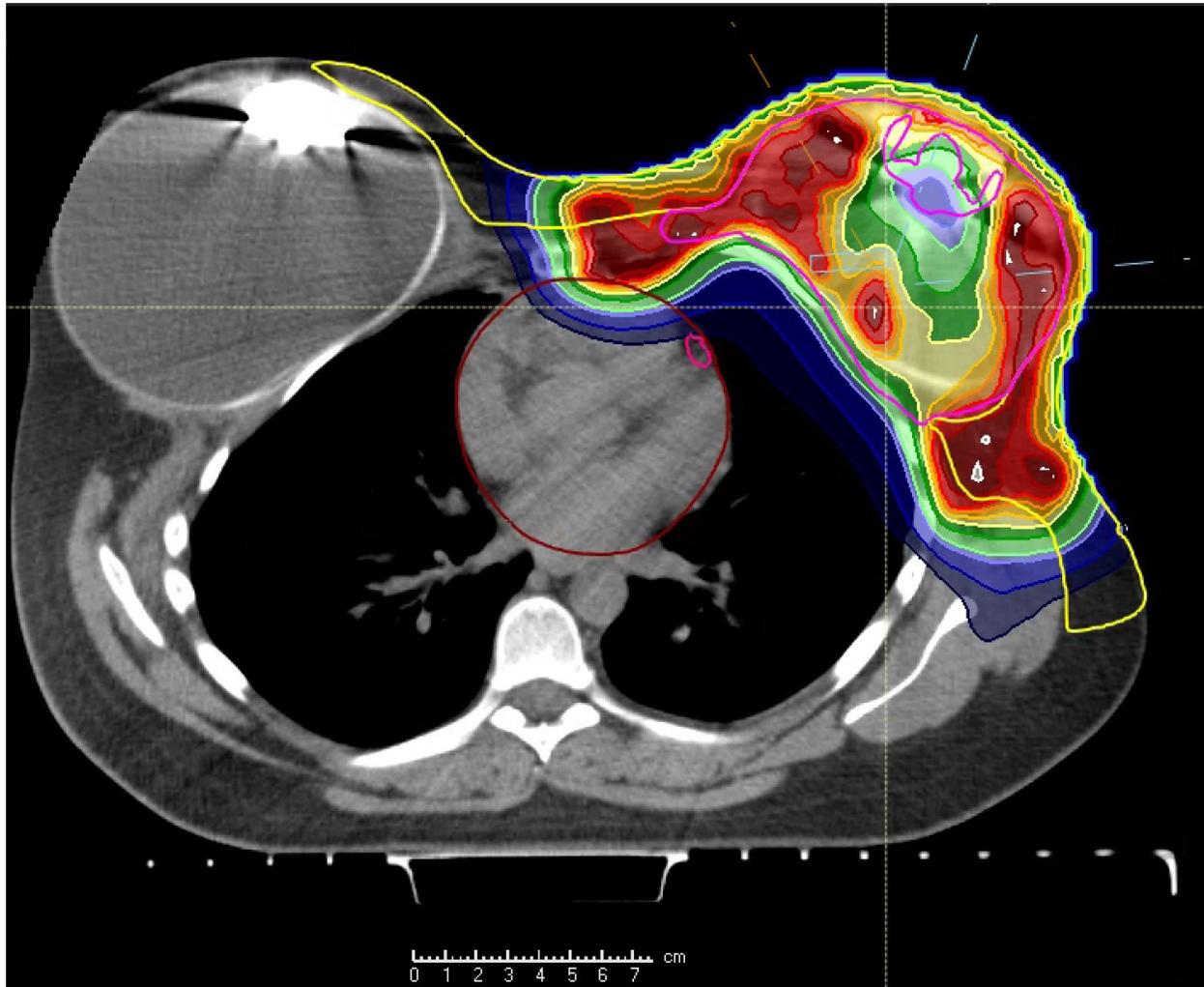
Northwestern
Medicine®
Chicago Proton Center

Material presentación 2017
Cortesía Mark Pankuch

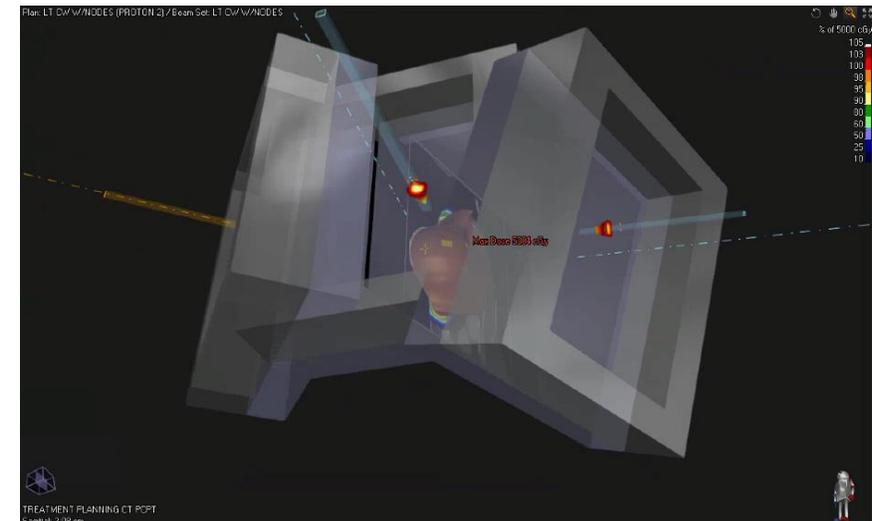
Protonterapia

CANCER DE MAMA

Mama con expansor



Material presentación 2017
Cortesía Niek Schreduer



Tres campos (uno no coplanar) con PBS

Estado actual de la Protonterapia

- Física de la Protonterapia
- Equipos de Protonterapia
- Técnicas de tratamiento en Protonterapia
- Ventajas dosimétricas de la Protonterapia
- **Últimos desarrollos en Protonterapia**

Últimos desarrollos en Protonterapia

- Terapia de Arco con Protones (SPArc)
- FLASH Protonterapia

Gracias
por su
atención