重粒子治療的應用與未來的發展
Application and future development of heavy ion radiotherapy

各家醫院的軍備競賽

新技術-質子放療

質子放射治療為目前特殊的
術，質子放射治療對病灶區
傷害小很多，相對地副作用

林口長庚醫院放射腫瘤科引
器，提供優質的腫瘤治療方

北醫大精緻型質子機吊裝儀式，見證北醫體系癌症治療的歷史新頁

臺北醫學大學超導精緻型質子中心，從2018年3月開始興建，經歷2年8個月工程期，於2020年12月8日舉行「超導精緻型質子機吊裝儀式」。本校張文昌董事長、林建煌校長、臺北醫學大學附設醫院陳瑞杰院長、臺北癌症中心創院院長彭汪嘉康院士、臺北癌症中心邱仲峯院長，比利時臺北辦事處文浩德處長、何邁新副處長，IBA亞太區史格瑞副總裁、承業生醫企業集團李典穎副董事長及逾30位校院內外貴賓出席，一同見證北醫體系癌症治療的歷史新頁。

張文昌董事長表示，北醫大從2013年通過校務及董事會之後，開始進行籌備及申請；在全國激烈競爭下成為2016年衛福部核准的全國7個醫療機構之一；2017年1月正式取得核准函、展開質子中心的建置。同時，因為校園廣場底下有雨水排管道，在臺北市政府工務局水利處核准下遷移，雨排的遷移工程至2018年12月完成，隨後

心醫院輻射科學暨質子治療中心20日
台大癌醫中心醫院院長楊

首家重粒子癌症治療中心明年底收治病人 北榮跑第一

2020-06-30 20:40 聯合報 / 記者楊雅棠 / 台北即時報導

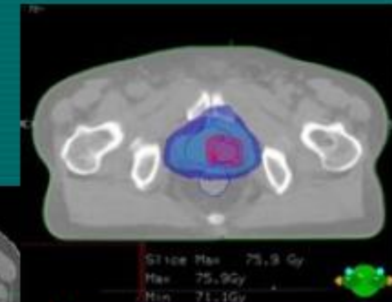
＋ 腫瘤

放射治療的演進

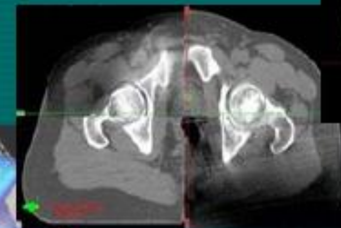
YML, VGHTPE, Taiwan

放射治療演進

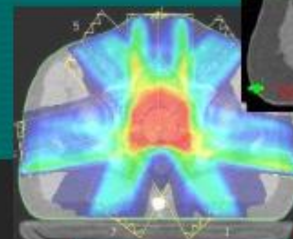
> 90 Gy ?



80 Gy



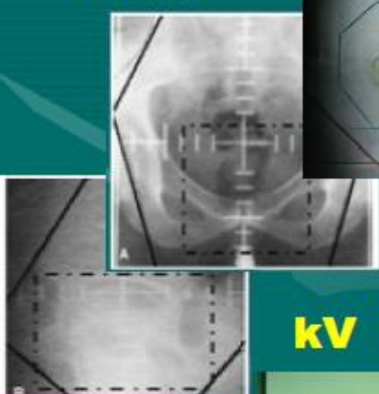
78 Gy



72 Gy

68 Gy

60 Gy



kV

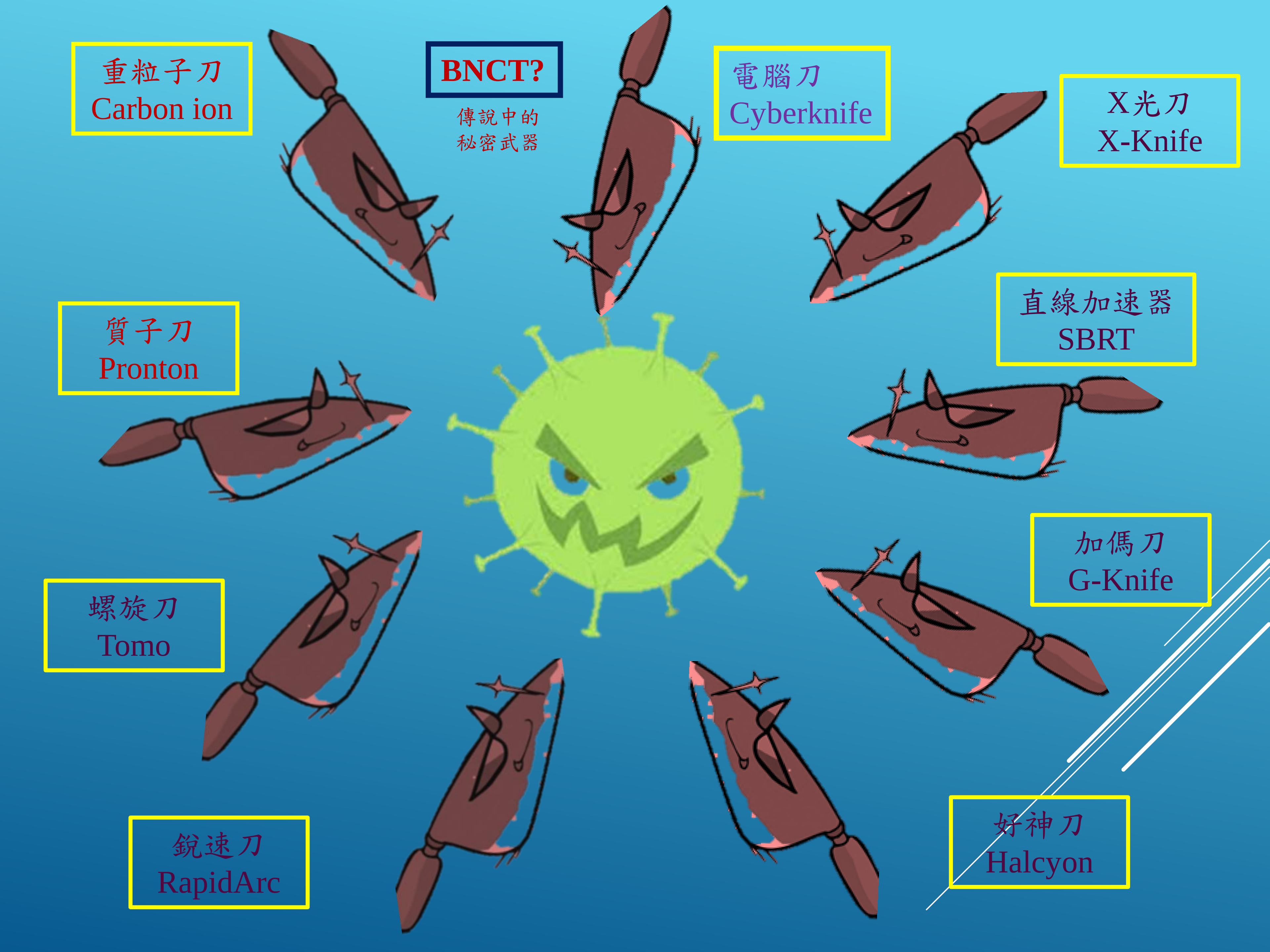
1.33 MeV

10 MeV

200 MeV

430 MeV

放射治療現況


重粒子刀
Carbon ion
BNCT?
傳說中的
秘密武器
電腦刀
Cyberknife
X光刀
X-Knife
質子刀
Pronton
直線加速器
SBRT
加馬刀
G-Knife
螺旋刀
Tomo
銳速刀
RapidArc
好神刀
Halcyon

Comparison of X-rays, Protons, and Heavy Ions

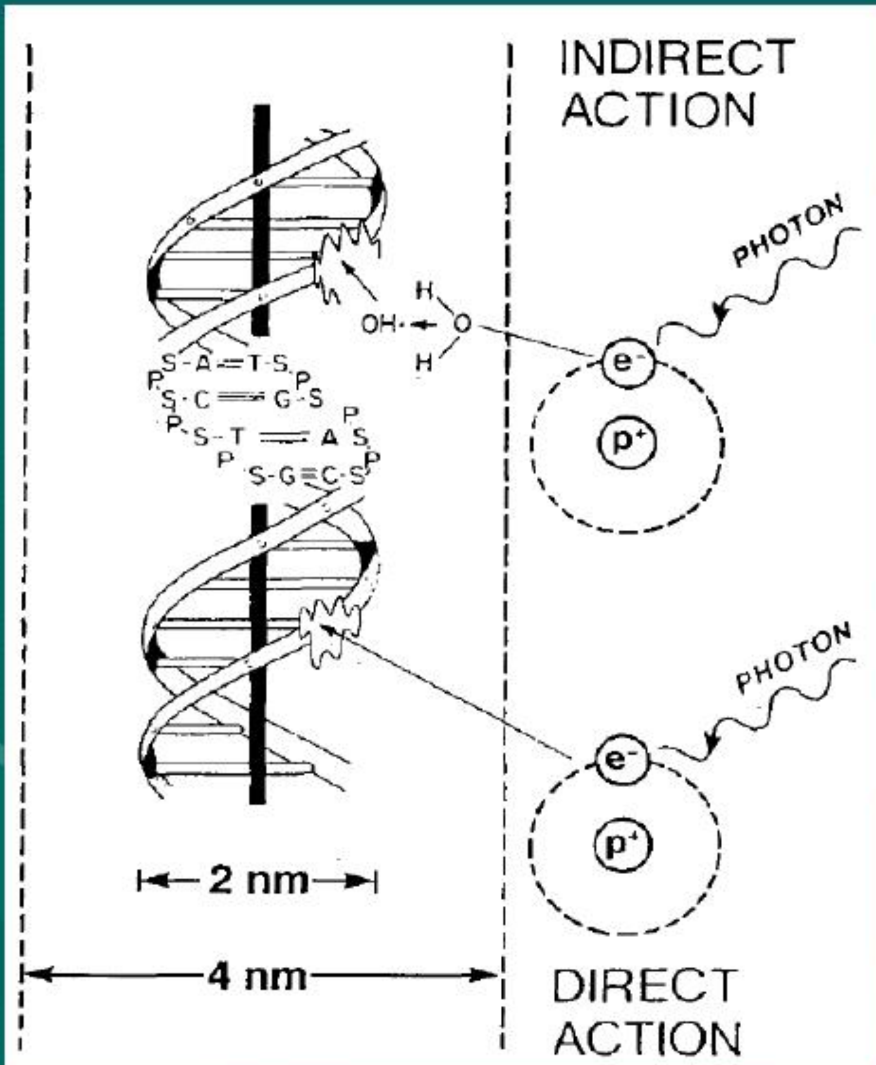
Parameter	X-rays	Protons	Carbon Ions
Volume of irradiated normal tissue	Large	Small	Smallest
Biological effectiveness			
In normal tissue	Low	Low	Low
In tumor tissue	Low	Low	High
Targeting precision	Low	High	Highest
System cost		High	Highest
Worldwide centers, No.	Thousands	Over 55	over12
Worldwide treated patients, estimate	Millions	over120 000	over15 000

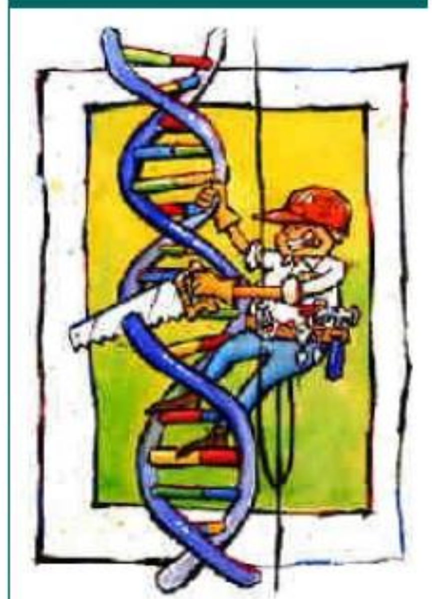
放射治療儀的比較

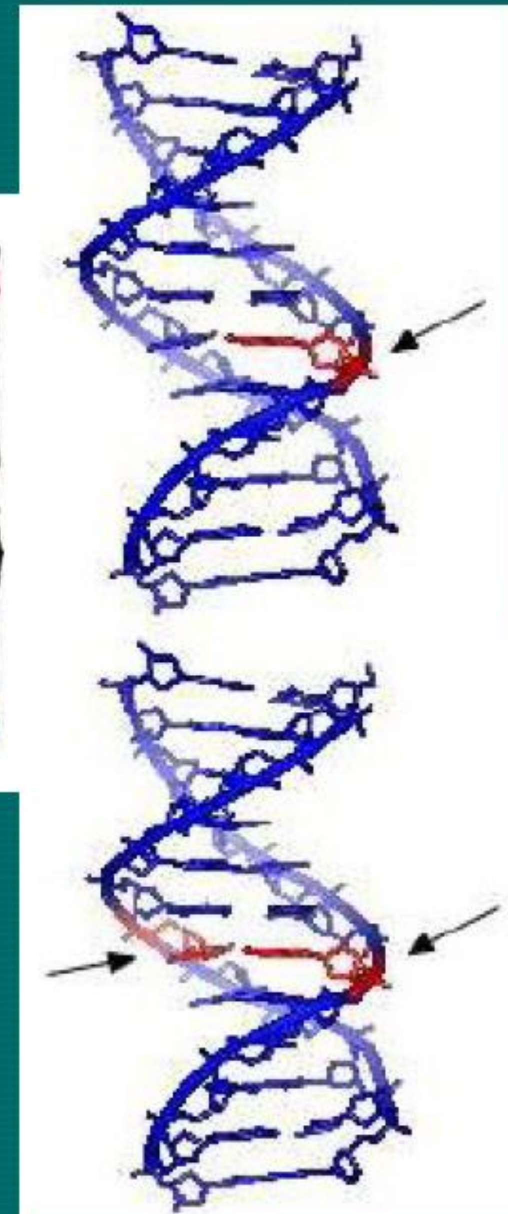
	Carbon Ion	Proton	Tomotherapy	RapidArc	Gamma Knife Cyber Knife
建購價	約50億	約30億	約 2億	1.5億	2億
臨床應用	放射治療劑量區包覆體積小 治療次數較傳統少	放射治療劑量區包覆體積大一些 傳統的治療次數	放射治療劑量區包覆體積大些 傳統的治療次數	放射治療劑量區包覆體積大些 傳統的治療次數	放射手術治療劑量區包覆體積小 可治療的病人較少
適用治療部位	全身	全身	全身	全身	Gamma knife 只可治療頭頸部
使用的射線能量種類	430MeV,C,P	250MeV,P	6MeV X-ray	6-15MeV X-ray	6MeV γ-ray,X-ray
治療平均療程及生活品質	約10次(2-3周) 佳	約15-25次(3-5周) 較佳	約35次(5-7周) 病人較辛苦	約35次(5-7周) 病人較辛苦	單次 5-10次
抑制腫瘤的能力	RBE3-5	RBE1	接近1	接近1	接近1
費用	預估50萬-80萬 參考各醫院收費標準	預估30萬-40萬 參考各醫院收費標準	20萬-30萬	20萬-30萬	20萬-25萬

為甚麼選擇粒子治療?

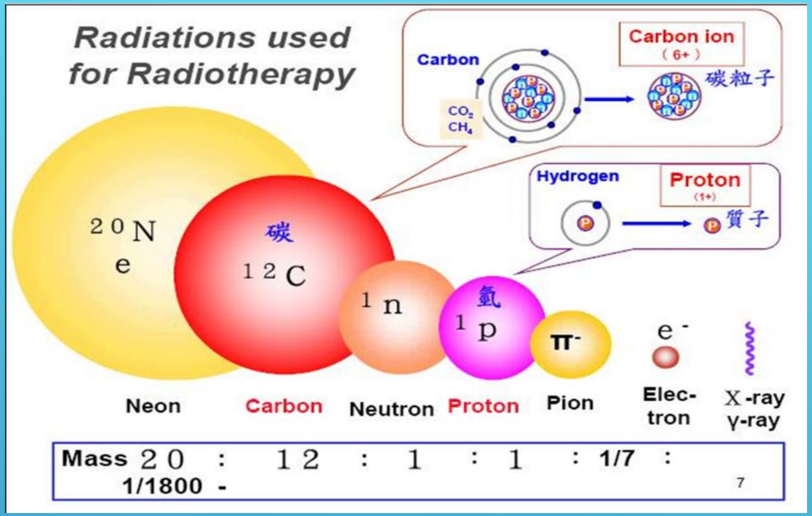
DIRECT AND INDIRECT ACTION OF RADIATION

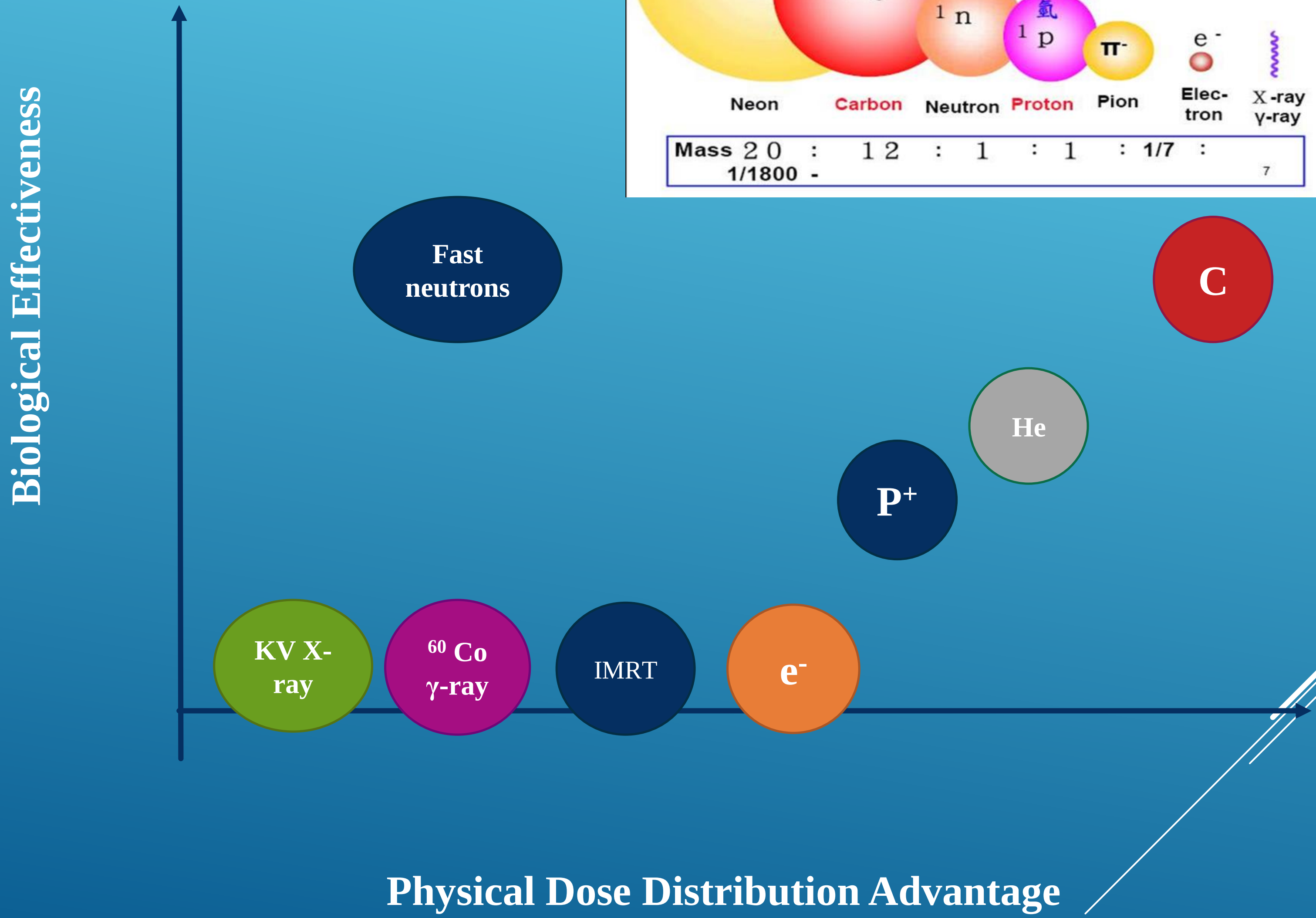


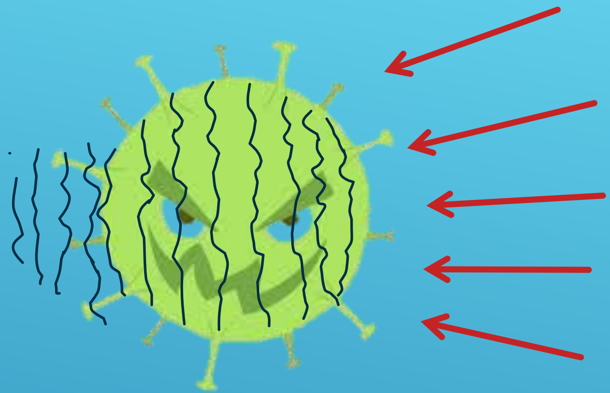




It is estimated that about **two thirds of the x-ray** **damage to DNA in mammalian** cells is caused by **<u>indirect action</u>**


Radiations used for Radiotherapy
Carbon
Carbon ion
(6+)
碳粒子
CO_2
CH_4
Hydrogen
Proton
(1+)
質子
^{20}Ne
碳
^{12}C
^{1}n
氫
^{1}p
π-
e-
Neon
Carbon
Neutron
Proton
Pion
Elec-tron
X-ray γ-ray
Mass 20 : 12 : 1 : 1 : 1/7 : 1/1800 -

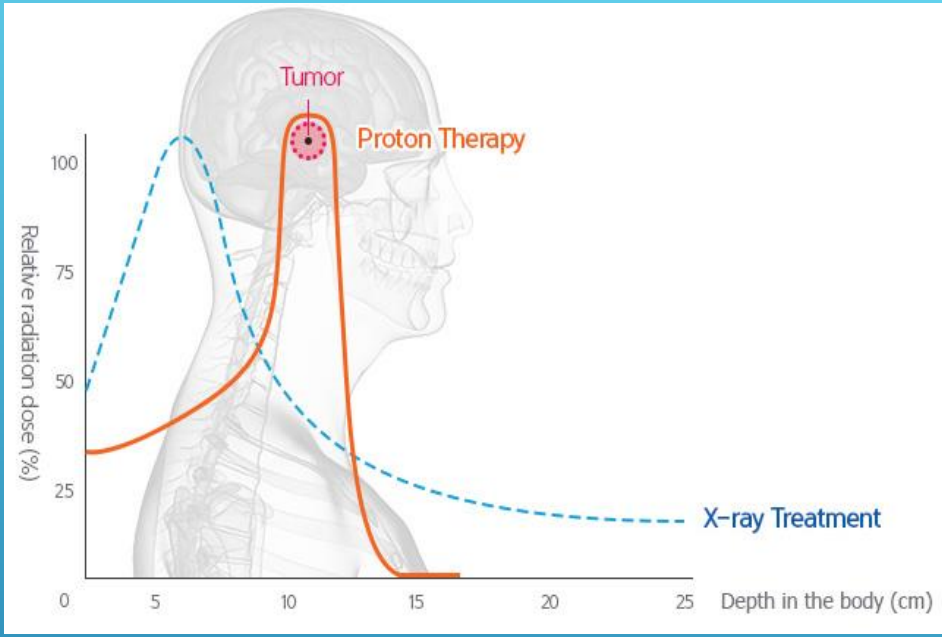

Biological Effectiveness
Fast neutrons
C
He
P+
KV X-ray
60 Co γ-ray
IMRT
e-
Physical Dose Distribution Advantage

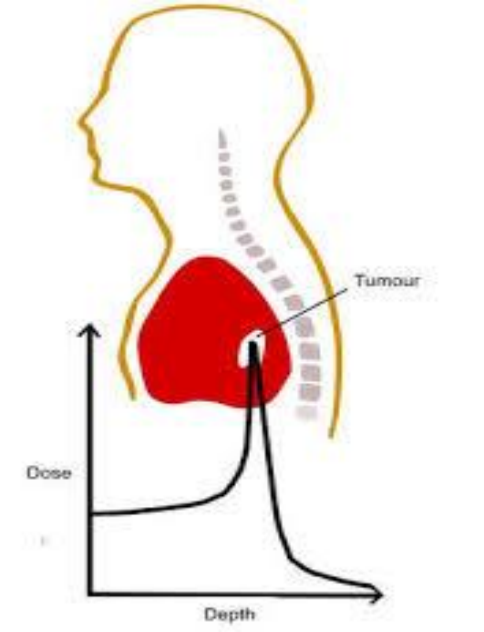


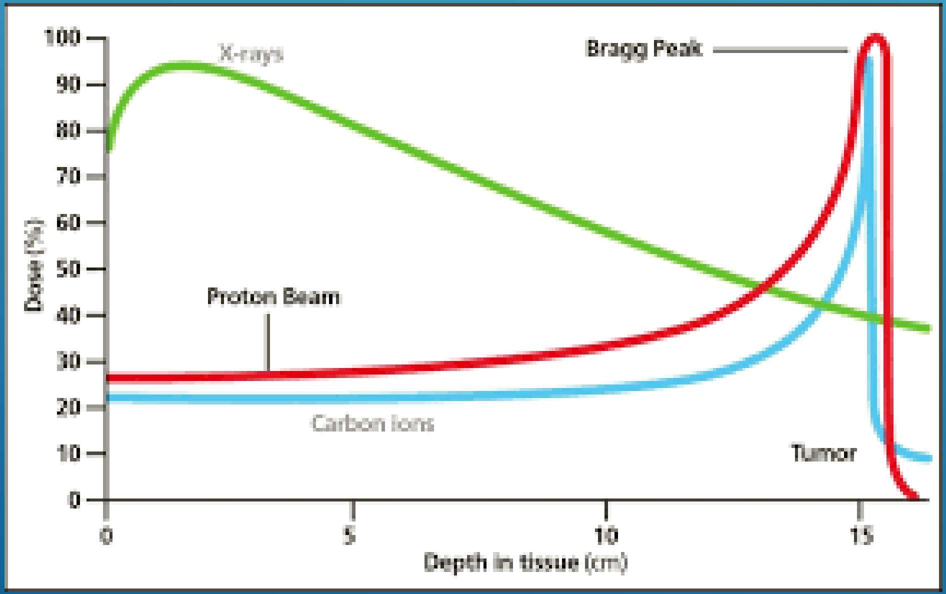
凌遲處死的光子治療

灰飛煙滅的重粒子治療

化學治療, 基因治療, 免疫療法,
熱治療……

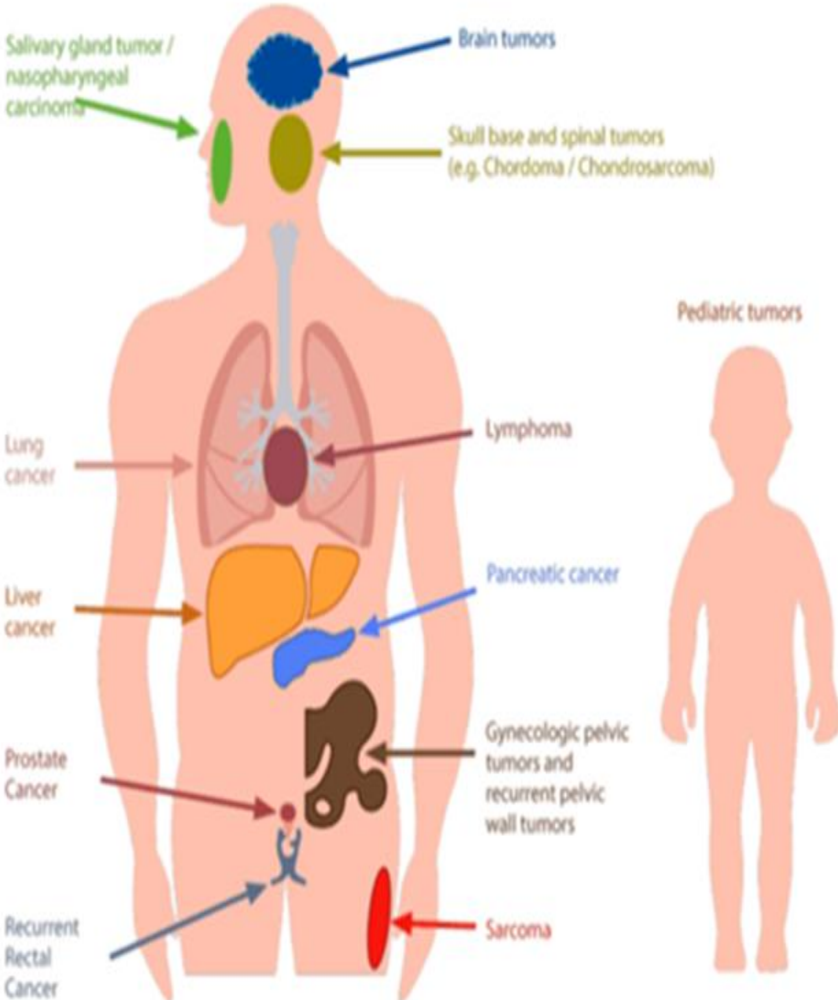

Tumor
Proton Therapy
X-ray Treatment
Relative radiation dose (%)
100
75
50
25
0
5
10
15
20
25
Depth in the body (cm)


Tumour
Dose
Depth


X-rays
Bragg Peak
Proton Beam
Carbon Ions
Tumor
Dose (%)
100
90
80
70
60
50
40
30
20
10
0
5
10
15
Depth in tissue (cm)

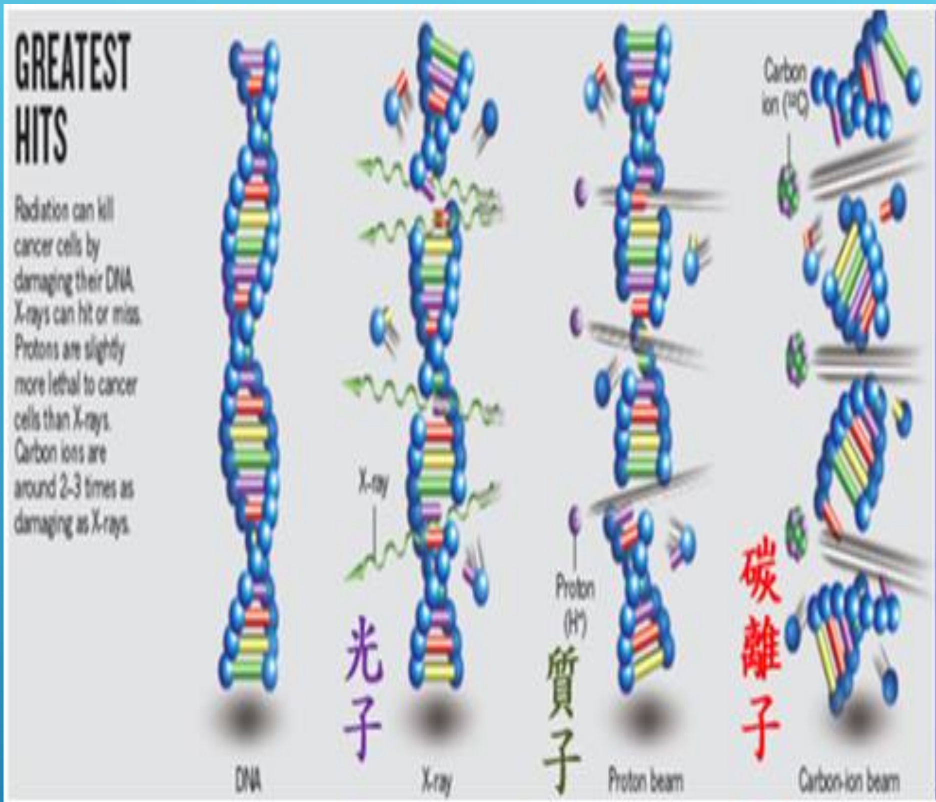
具有優勢的劑量曲線

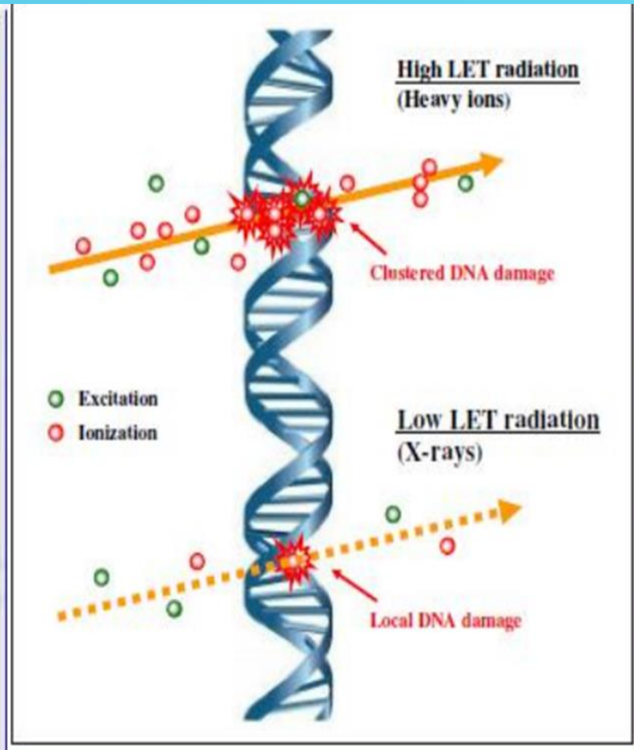
We currently treat the following cancers in children and adults:

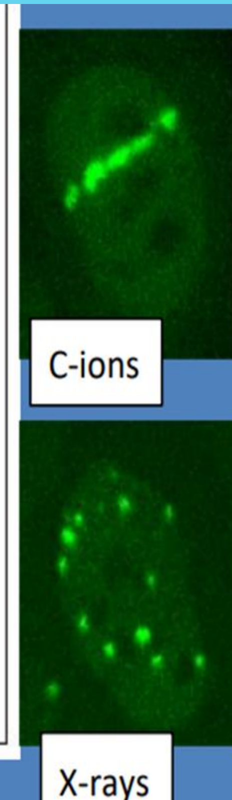


- Salivary gland cancer (e.g. adenocystic carcinoma)
- ENT tumors, e.g. paranasal carcinoma
- Chordoma / Chondrosarcoma of the base of the skull or the pelvis
- Prostate cancer
- Brain tumors, e.g. glioblastoma, glioma, meningioma, pylocytic astrocytoma
- Pancreatic cancer
- Liver cancer
- Recurrent rectal cancer
- Lung cancer
- Cancers for which ion radiation is favorable, especially deeply placed tumors that can be treated effectively or those where particular care is necessary for the surrounding tissues
- Lymphomas, e.g. malignant mediastinal lymphomas

又為甚麼選擇碳粒子治療?







質子殺死癌細胞的威力不如碳離子, 碳粒子質量是質子的12倍, 更能切斷癌細胞的DNA,且能量威力達於質子的3倍.

Source by Heavy Ions in therapy and Space: Benefits and Risks, Health phys 2012,103,532-539

Advantages of carbon ion beams

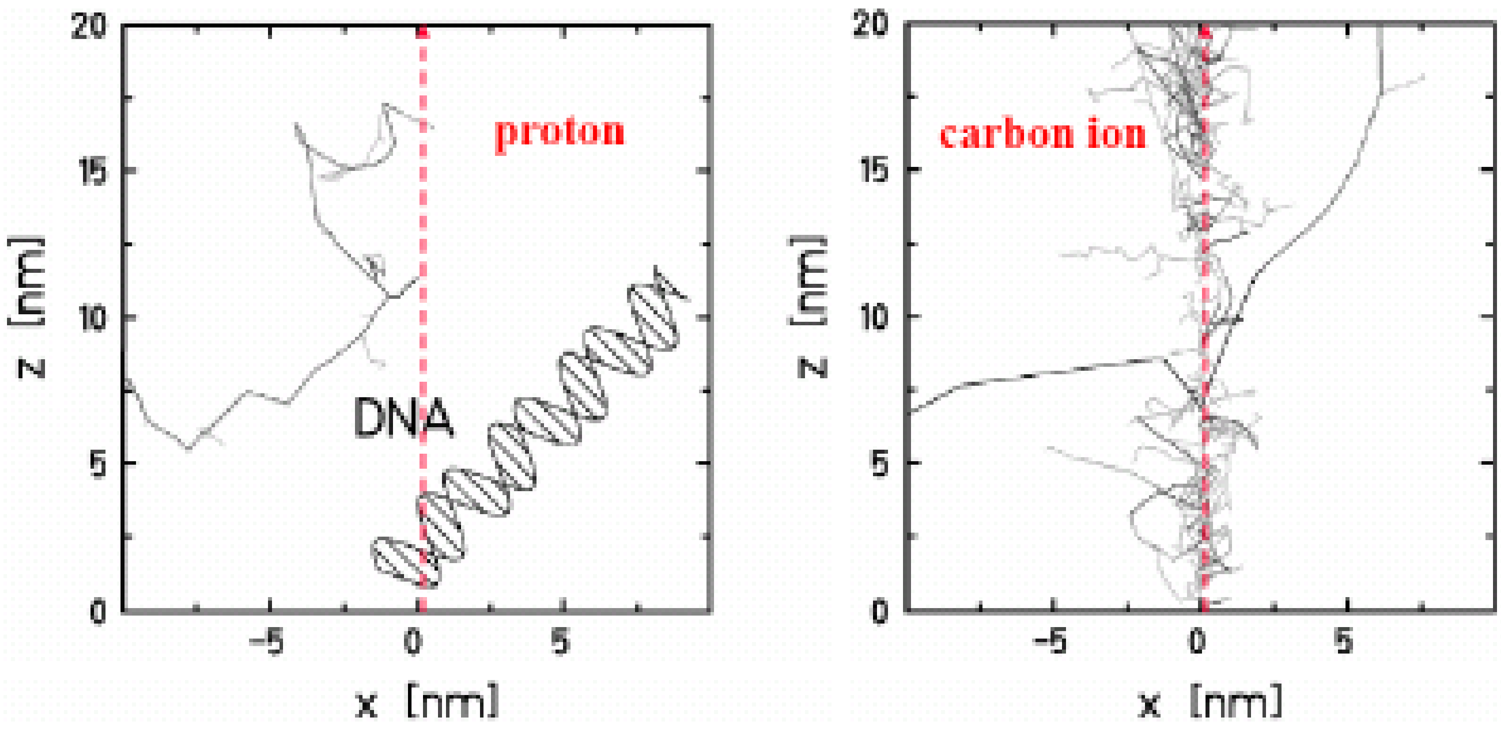


Figure 2. The structure of a proton and a carbon track in nanometre resolution are compared with a schematic representation of a DNA molecule. The higher density of the secondary electrons, produced by carbon ions, creates a large amount of clustered DNA damage.

- **It has been shown, for carbon beams, that the location of elevated RBE coincides with the Bragg maximum. In particular, for many cells and many biological reactions, the RBE becomes definitely larger than 1**

Advantages of carbon ion beams

Table 2. The energies of column 2 correspond to a range of 26.2 cm in water. The other columns give LET values at different residual ranges.

Charged particle ${}^{M}N^{Z}$	E (MeV u^{-1}) Range = 262 mm	LET (keV μm^{-1}) at various residual ranges in water (mm)				
		262	150	70	30	1
${}^{1}H^{+1}$	200.0	0.5	0.6	0.8	1.1	4.8
${}^{4}He^{+2}$	202.0	1.8	2.2	3.1	4.4	20.0
${}^{7}Li^{+3}$	234.3	3.7	4.6	6.2	8.9	40.0
${}^{11}B^{+5}$	329.5	8.5	10.0	13.5	19.0	87.5
${}^{12}C^{+6}$	390.7	11.0	13.5	17.5	24.5	112.0
${}^{14}N^{+7}$	430.5	14.5	17.5	22.5	31.5	142.0
${}^{12}O^{+8}$	468.0	18.0	21.5	28.0	39.0	175.0

- **One can see that the LET of carbon ions is larger than 20 keVμm−1 in the last 40mm of their range in water, while for helium this only happens in the last millimetre.**
- **For protons, the range of elevated effectiveness is restricted to a few micrometres at the end of the range—too small to have a significant clinical impact. For ions heavier than carbon the range of elevated RBE starts too early and extends to the normal tissues located before the tumour.**

Advantages of carbon ion beams

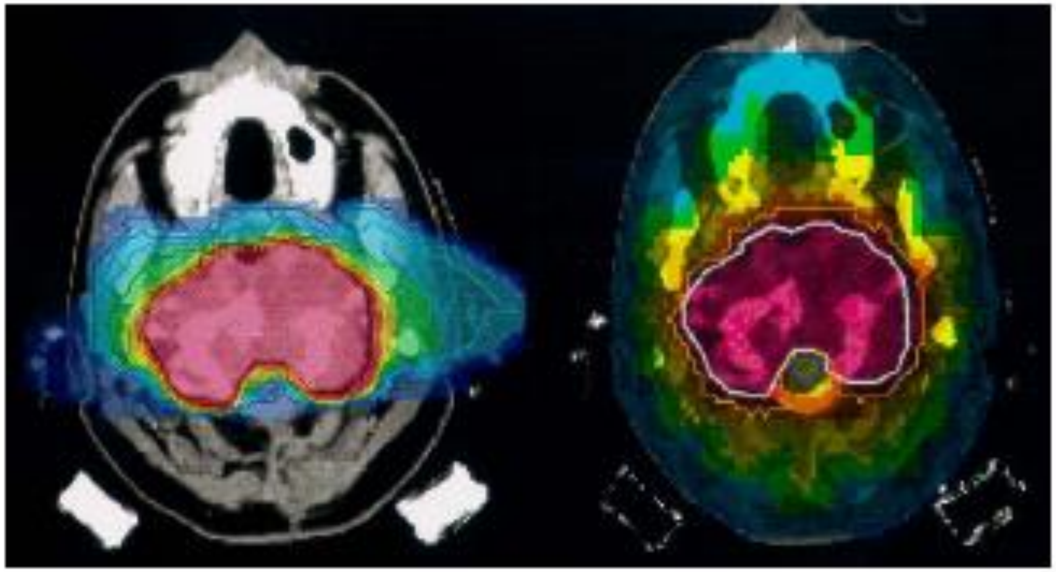


Figure 4. Comparison of treatment plans with 2 fields of carbon ion (IMPT—left panel) and with 9 fields of x-rays (IMRT—right panel) [23]. In both cases the conformity to the target volume is good but for carbon ions the dose to the normal tissues is much smaller.

- **This applies also to protons, yet carbon ions are more effective for radio-resistant tumors.**
- **These types of tumors are thus the elective targets in a carbon ion facility, while protontherapy is well adapted to other cases in which a tumor is close to the organs at risk that cannot be irradiated.**

重粒子治療與質子治療優缺點比較

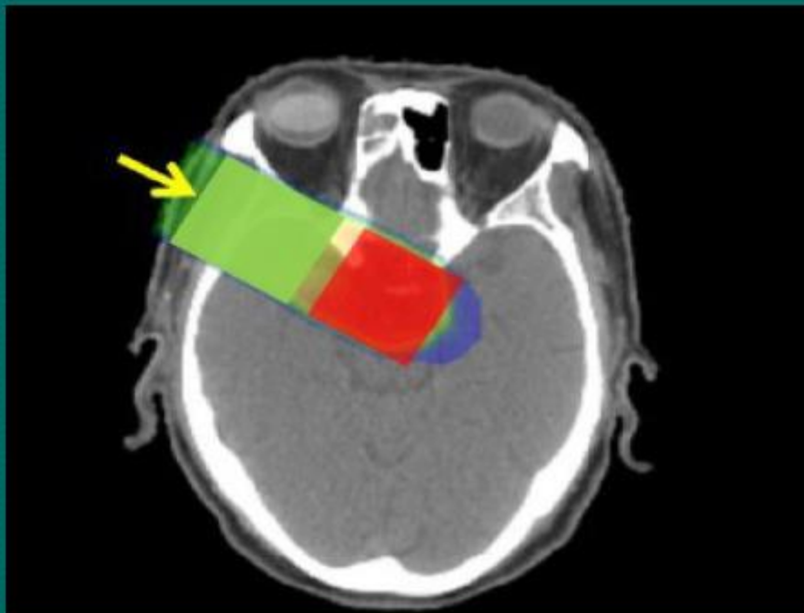
特性比較	重粒子（碳離子）治療	質子治療
1.物理劑量分布特性	縱向具布拉格峰（Bragg Peak）物理特性。	縱向具布拉格峰（Bragg Peak）物理特性。
2. 相對生物效應（RBE）	較高的相對生物效應優於質子治療。	相對生物效應：質子與一般X光相當，不具優勢。
3.氧加強反應率（OER）	低氧加強反應率（OER）不需要依賴氧氣以達到摧毀癌細胞。為重粒子勝過質子的最顯著優勢。	高氧加強反應率（OER），缺氧環境下癌細胞具有抗輻射，治療效果減弱。
4. 治療次數	每人平均治療次數明顯低於光子或質子治療。以攝護腺癌療程為例，目前通常以十二次重粒子照射，治療療程短，病患無須住院。	以攝護腺癌療程為例，光子或質子治療通常需要三十五次照射。
5. 副作用	副作用小。碳粒子射束在進入人體組織釋放的能量極低，達到腫瘤處才將能量完全釋放，避免鄰近組織受到不必要的輻射傷害。	副作用小
6. 治療部位與適應症	適用於全身不同部位之腫瘤，特別對於難治、手術困難及使用傳統放射治療無效的腫瘤，重粒子是種有效的治療方式。例如：惡性肉瘤、胰臟癌與口腔黏膜黑色素瘤等等。	適用於全身不同部位之腫瘤，較不適用於病患有多處轉移性腫瘤。
7. 對病患生活品質的影響	對病患生活品質的影響相對較小。	對病患生活品質影響較大。

Sources by台北榮民總醫院腫瘤醫學部

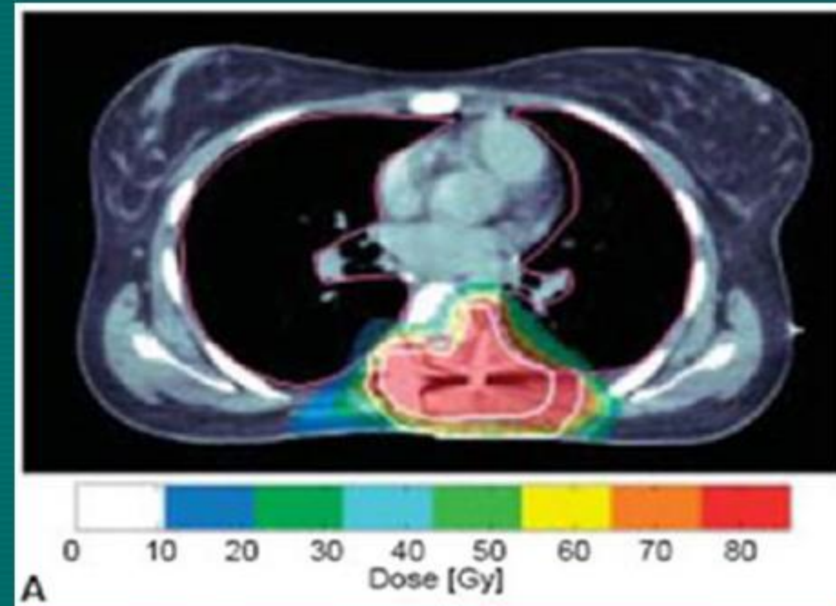
YML, VGHTPE, Taiwan

碳離子放射治療劑量分佈優勢

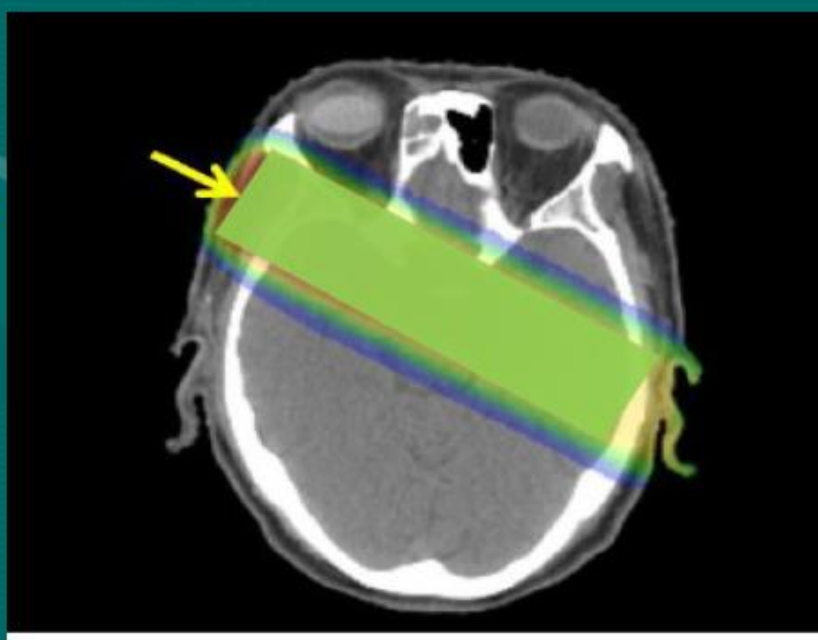
碳離子



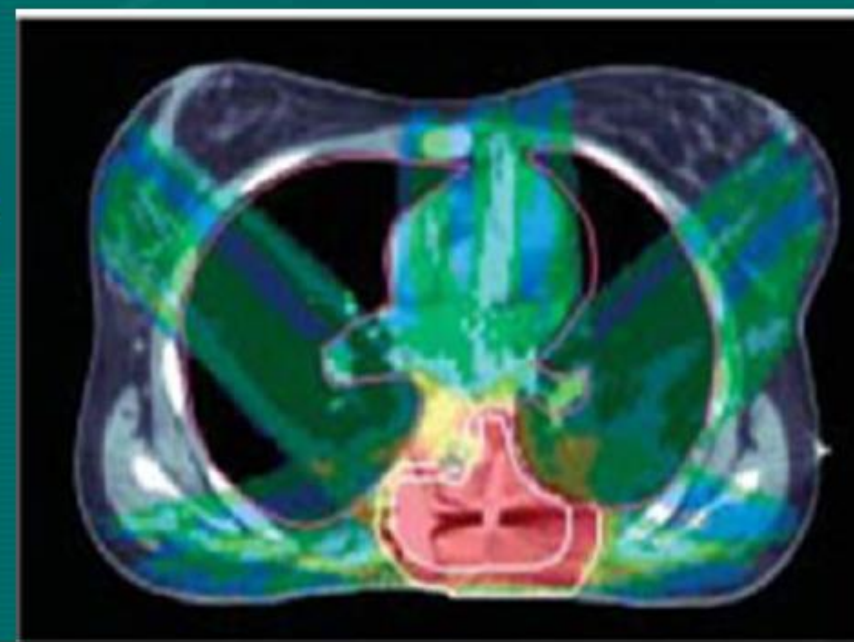
碳離子



光子

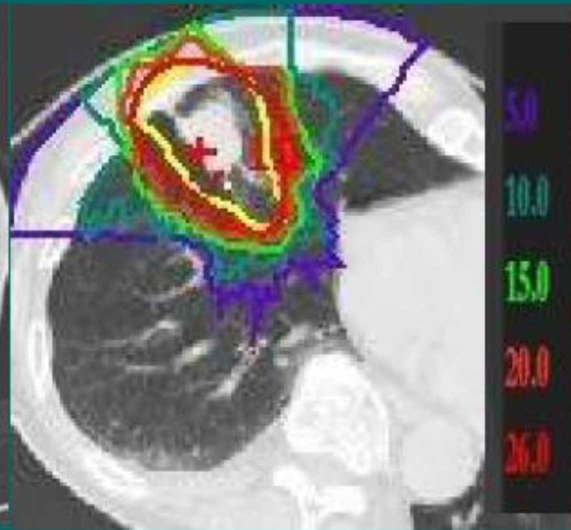


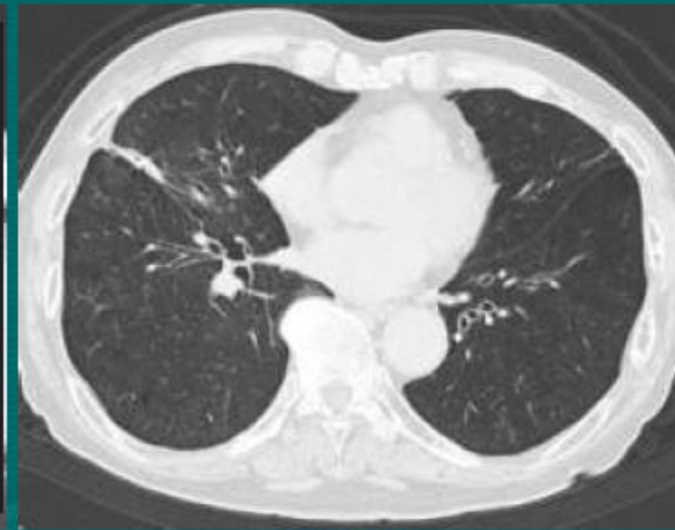
光子



肺腺癌療效優良
T2N0M0 stage IB

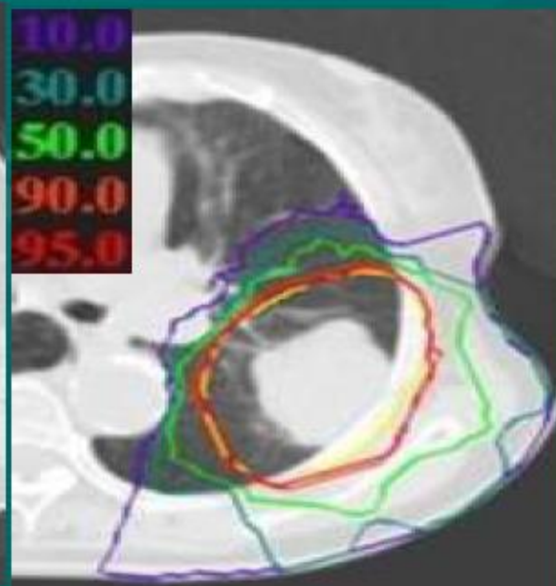
Single fraction C-ion RT
肺腺癌單次照射治療前後之比較



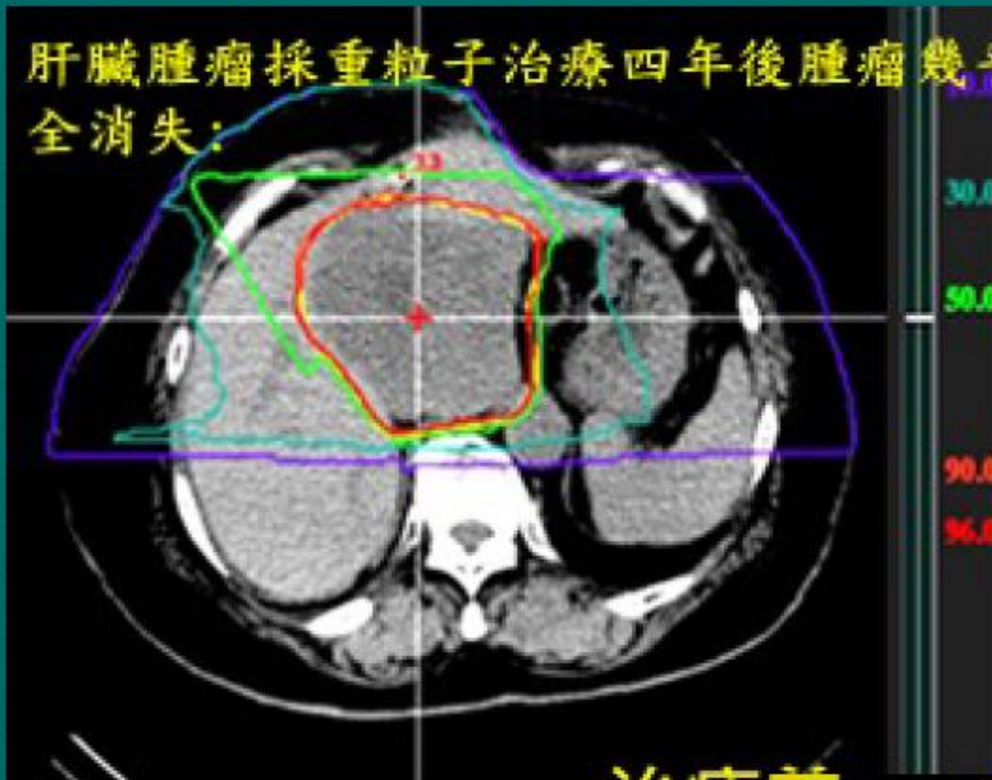


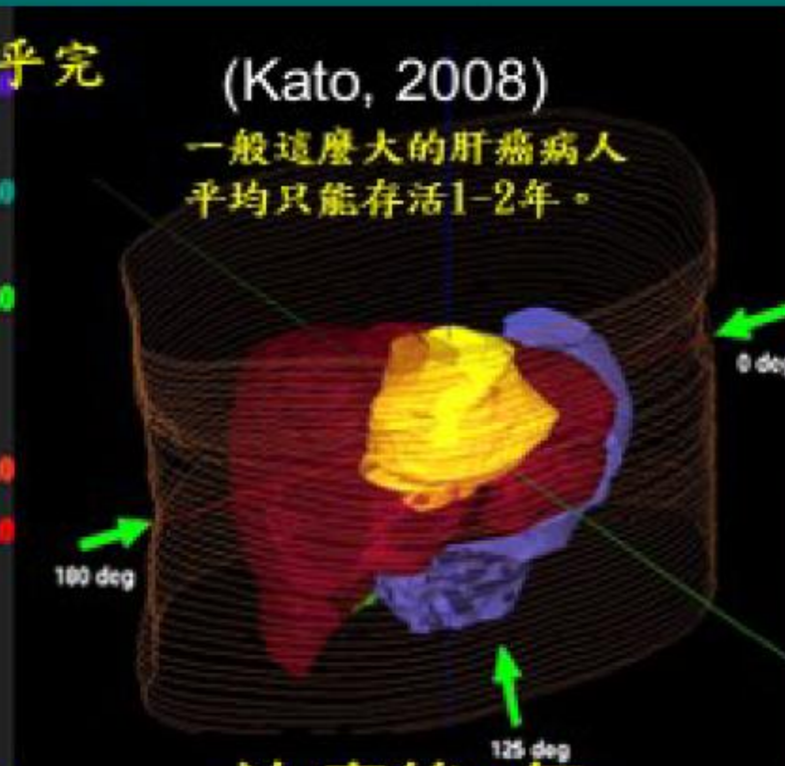
治療前

治療後



臨床案例

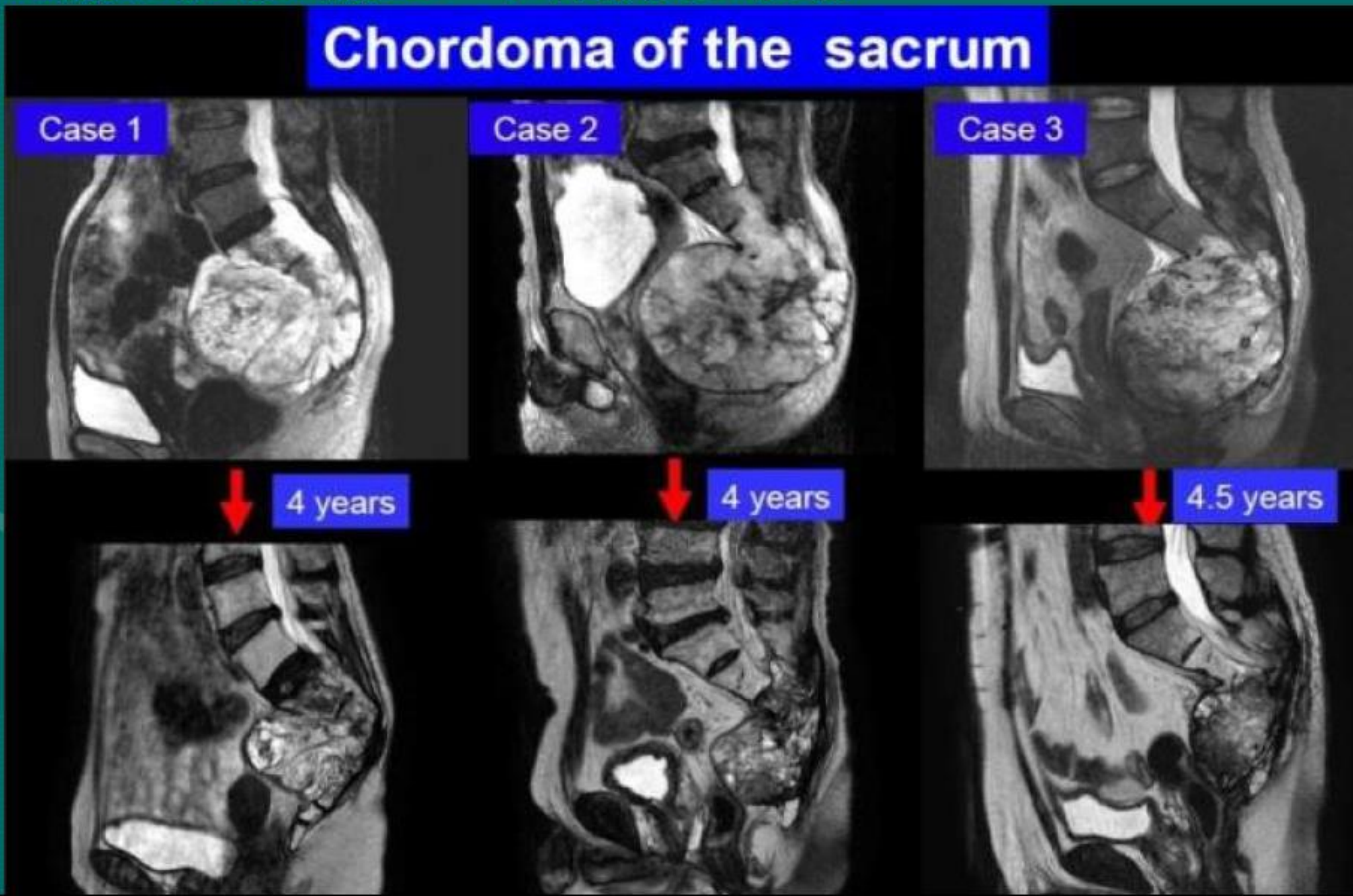




Yellow : PTV
Red : 96% Dose
Orange: 90% Dose
Green : 50% Dose
Blue : 30% Dose
Purple : 10% Dose

臨床案例

脊索瘤（薦骨處）採重粒子治療後腫瘤顯著縮小，光子及質子治療不易達此療效，手術易產生復發



Postoperaand Nasopharyngeal Spacetive Chordoma in the Clivus 顱底及鼻咽脊索瘤 (不易治療)

Carbon ion dose: 60.8 GyE/16 frs.

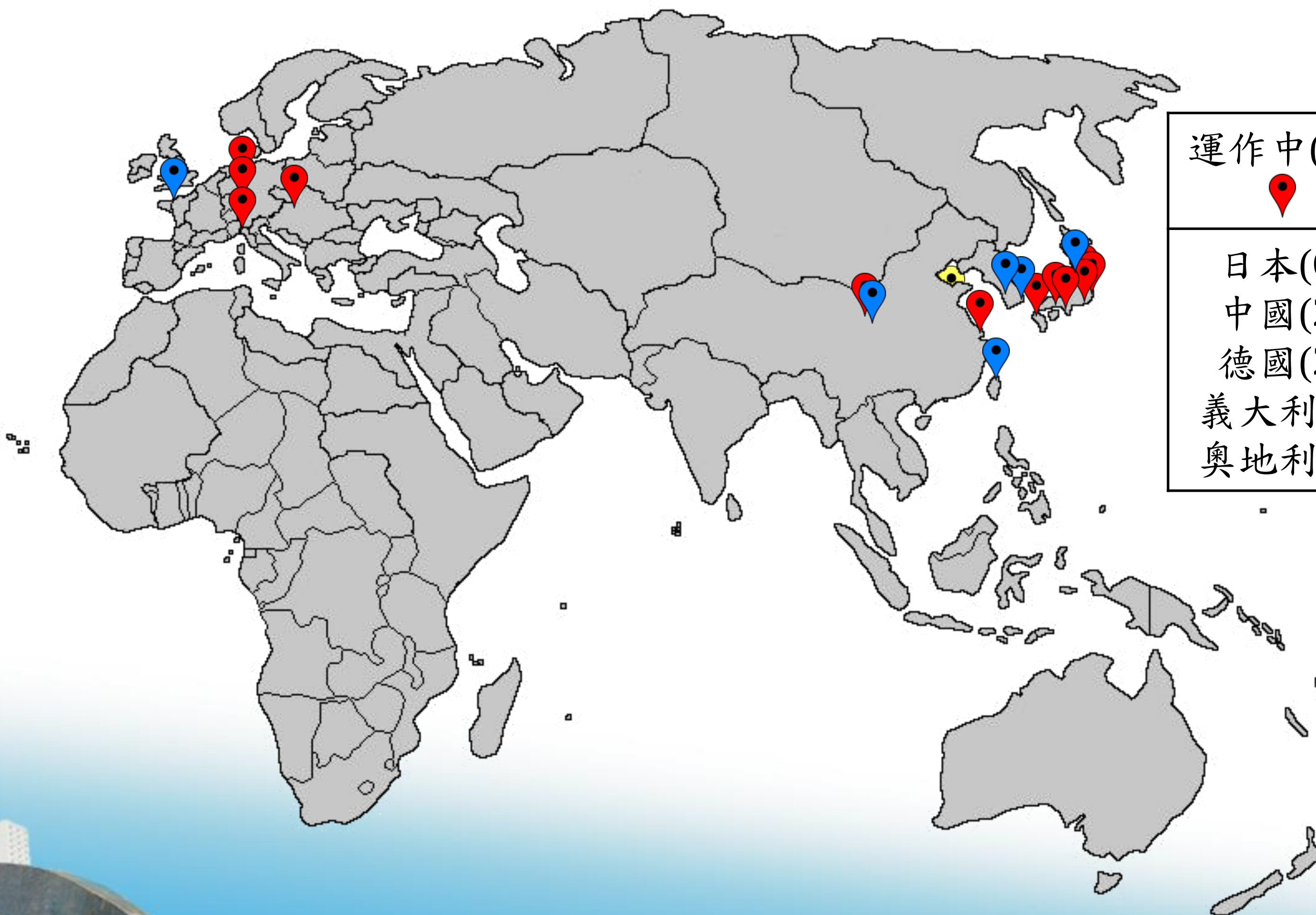
Pre c-ion RT

Dose distribution

Post 67 months

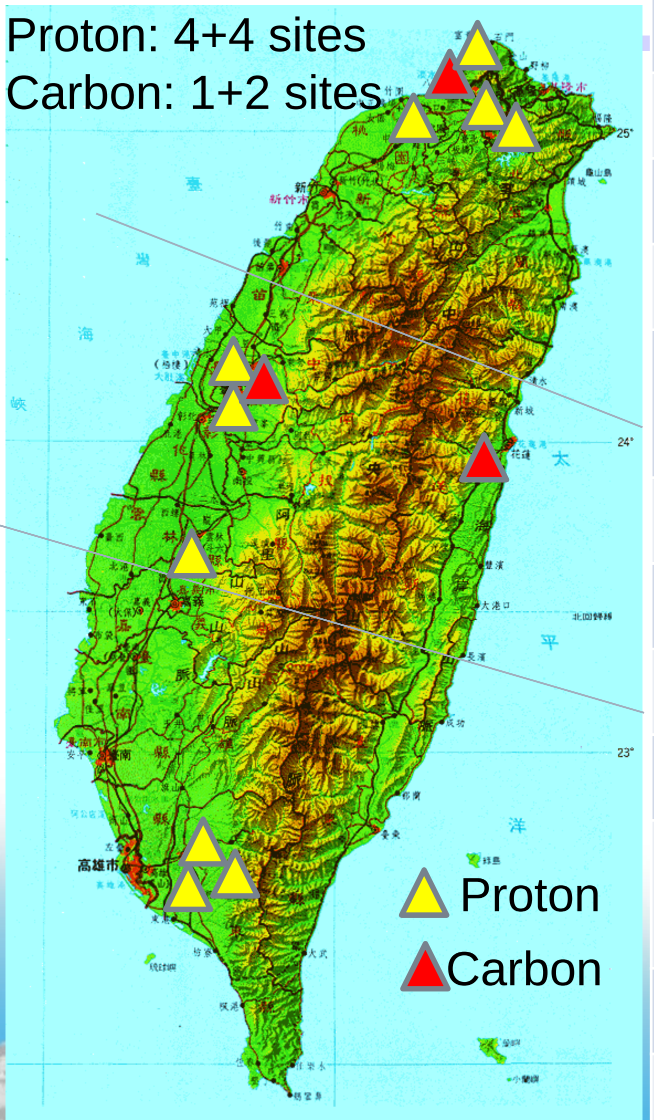
世界重粒子設施現況

資料來源：PTCOG (國際粒子治療合作組織)



運作中(12)	建設中(6)
日本(6) 中國(2) 德國(2) 義大利(1) 奧地利(1)	南韓(2) 日本(1) 中國(1) 臺灣(1) 法國(1)

臺灣粒子治療設備設置審核現況

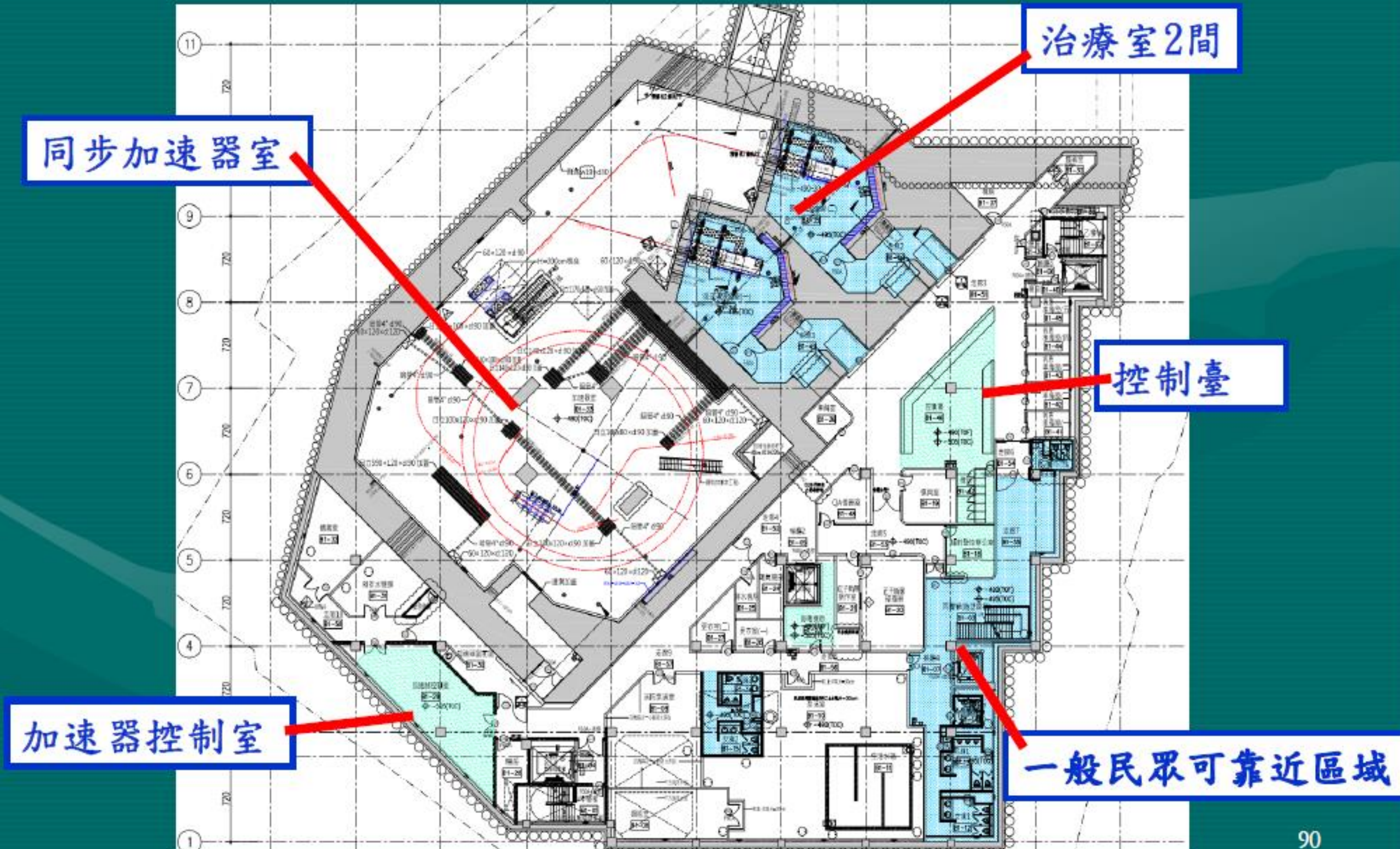


醫院名稱	粒子	治療室	衛福部	狀態
臺北榮民總醫院	C	2(3)	已核准	裝機中
台大癌醫中心醫院	P	3	已核准	興建中
台北醫學大學附設醫院	P	1	已核准	裝機中
馬偕紀念醫院	P	1	已核准	規劃中
林口長庚醫院	P	4	已核准	營運中 2015/11
中國醫藥大學附設醫院	P+C	1+3	已核准	規劃中
彰化基督教醫院	P	1	已核准	規劃中
花蓮慈濟醫院	C	3?	已核准	規劃中
大林慈濟醫院	P	1	規劃中	
高雄長庚醫院	P	3	已核准	營運中 2018/10
高雄醫學大學附設醫院	P	1	已核准	規劃中
義大醫院	P	1	規劃中	

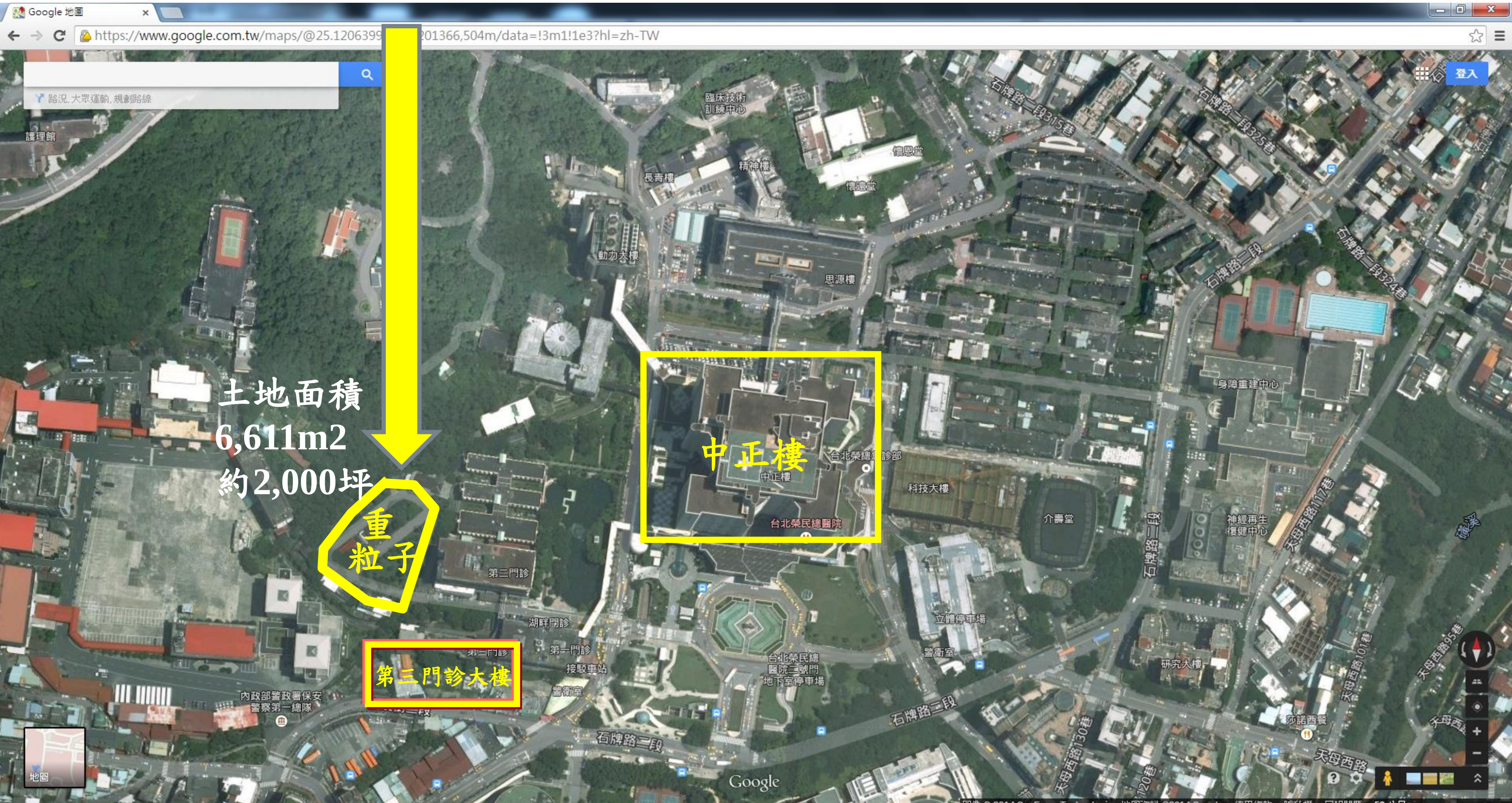
重粒子癌症治療中心
-地上四層地下一層

正面

重粒子癌症治療中心設施簡介 (B1F)



重粒子癌症治療中心位置



YML, VGHTPE,
Taiwan

建築空拍圖

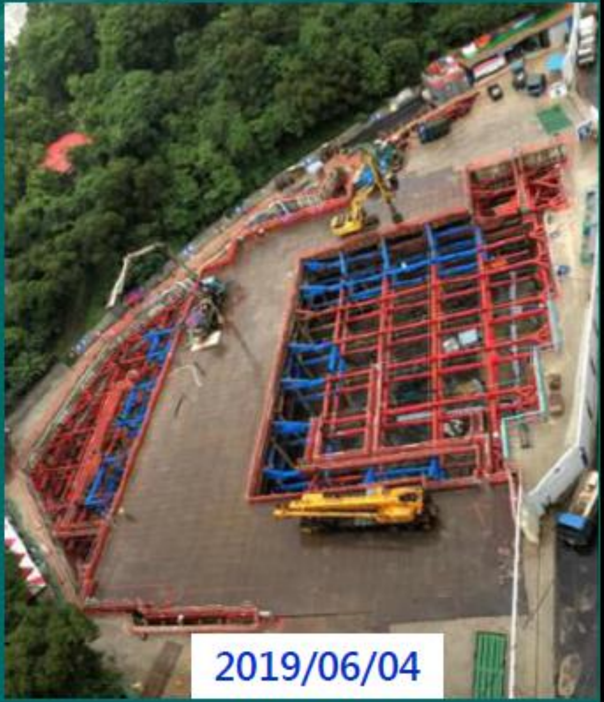
2019/01/25

2019/02/15

2019/03/19

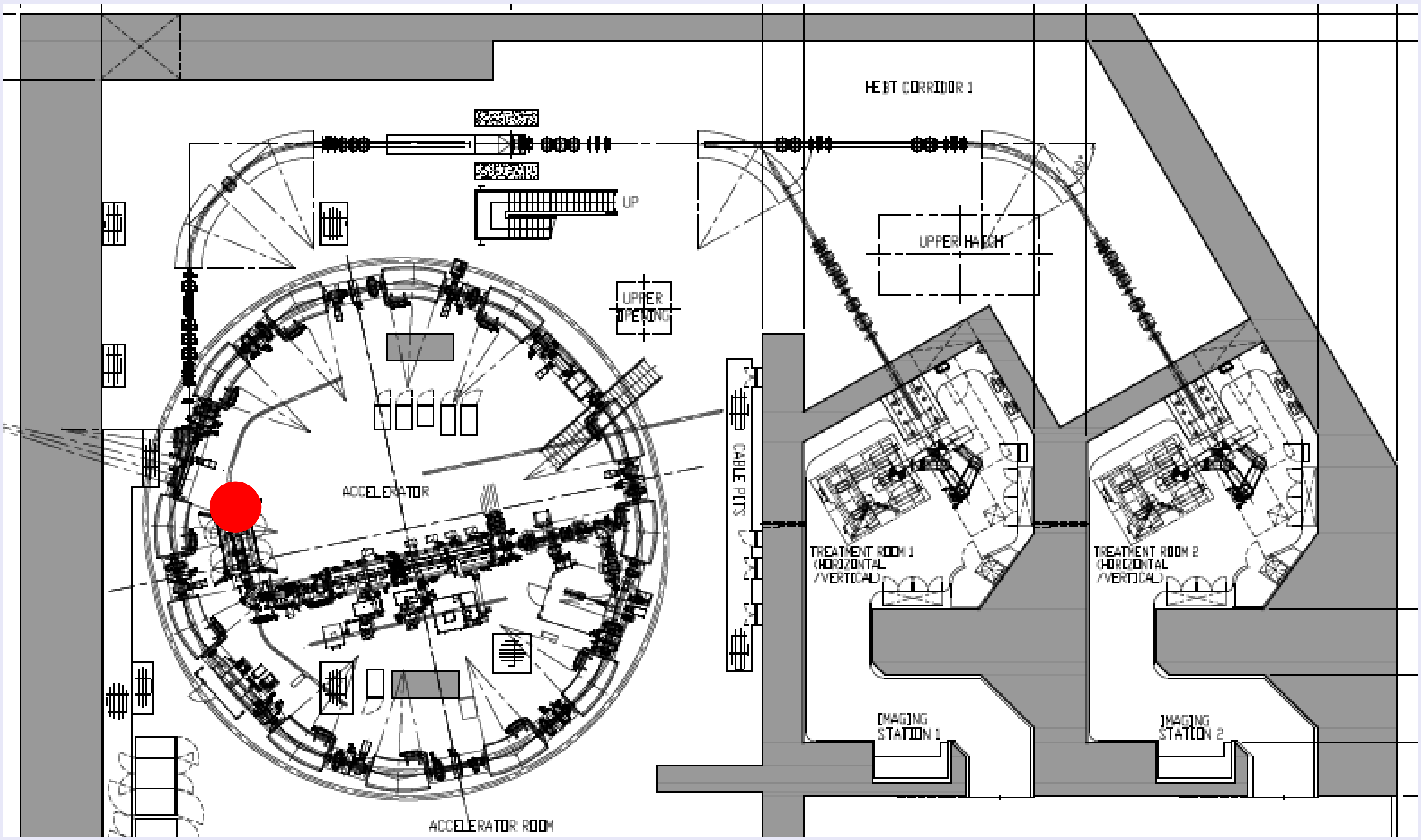
2019/04/23

2019/05/06



2019/06/04

日立公司重粒子治療系統



NIRS HIMAC

Specification of the Compact Carbon-Therapy Facility

1. Ion species: high LET (100keV/μm) charged particle - Carbon
2. Range: Max. 25cm in water
3. Maximum irradiation area: 20cm square
4. Dose rate: 5Gy/min/l $\longrightarrow$ 1.2×10^9pps (C ions)
5. Irradiation direction : horizontal, vertical
6. Treatment rooms: 3 (H&V, H, V)
7. Irradiation technique: gating & layer stacking irradiation

Optimized for Carbon beams

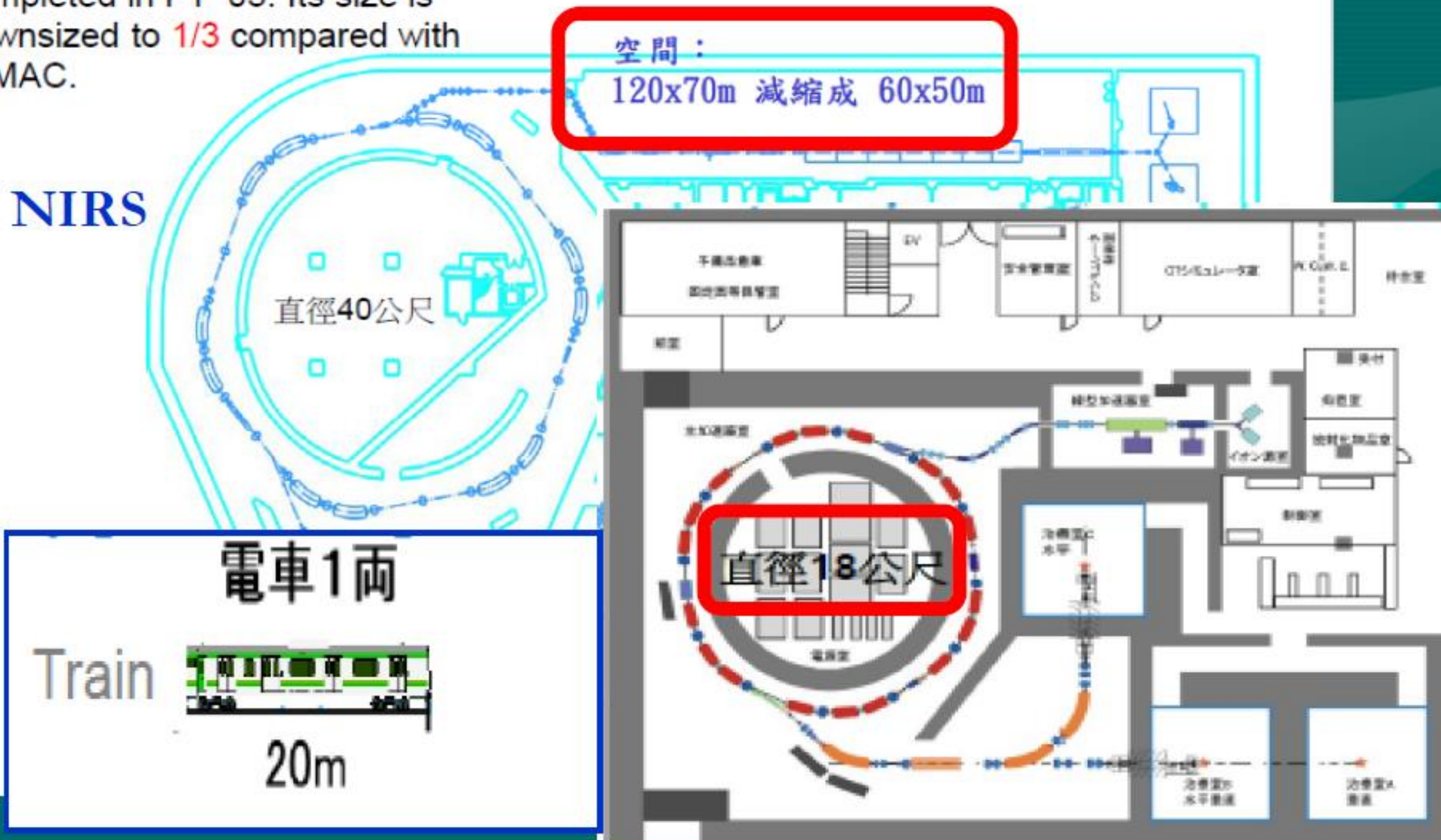
1. Accelerator systems and Irradiation systems :
   High reliability, stability, reproducibility, easy operation, easy maintenance and absolute safety
2. The other requirements :
   - Precise beam delivering
   - Easy beam tuning in a short time within a few minutes
   - Accurate dose measurement and control
   - Fail-safe system

Furthermore how can we reduce the size?

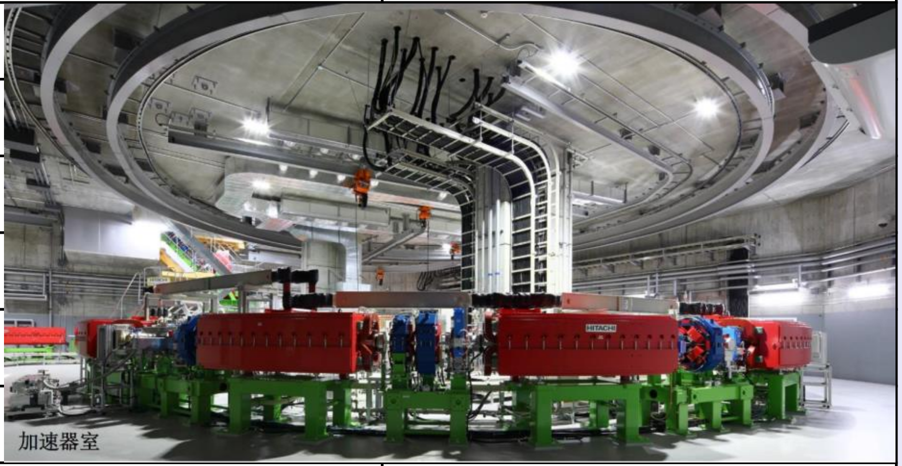
重粒子系統空間規劃

緊緻型同步加速器

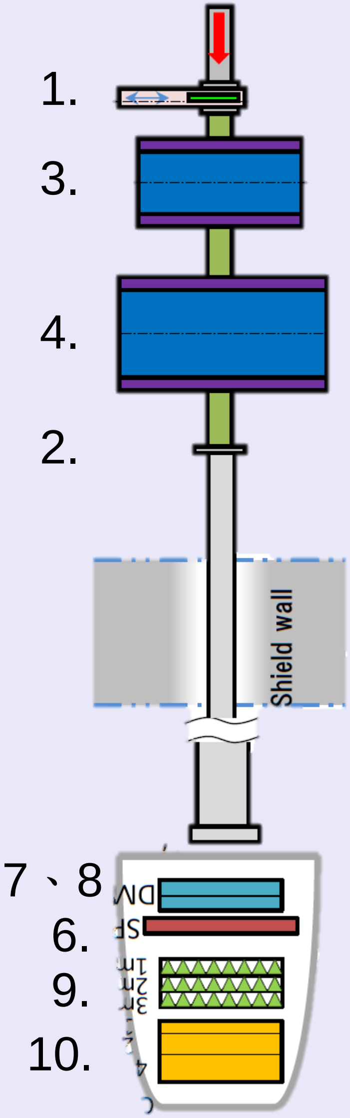
Detailed design and R&D was completed in FY '05. Its size is downsized to 1/3 compared with HIMAC.



日立公司重粒子治療系統: 同步加速器

編號	項目	規格	備註和選項
1	加速器類型	同步加速器	
2	注射器類型	RFQ 和 APF-IH	
3	離子源	$^{12}C^{4+}$	
4	注射器束流能量	4.0 MeV / u	
5	加速束流能量範圍	140 - 430 MeV / u	
6	能級的初始設定值	100能級	
7	能級的最大設定值	300能級	
8	束流提取方法	射頻擴散引出 (Radiofrequency Diffusion Extraction)	
9	**束流關閉**	少於200微秒	**使用高速轉向磁鐵**
		≤300毫秒	**使用Fast Faraday Cup**

治療室噴嘴系統規格

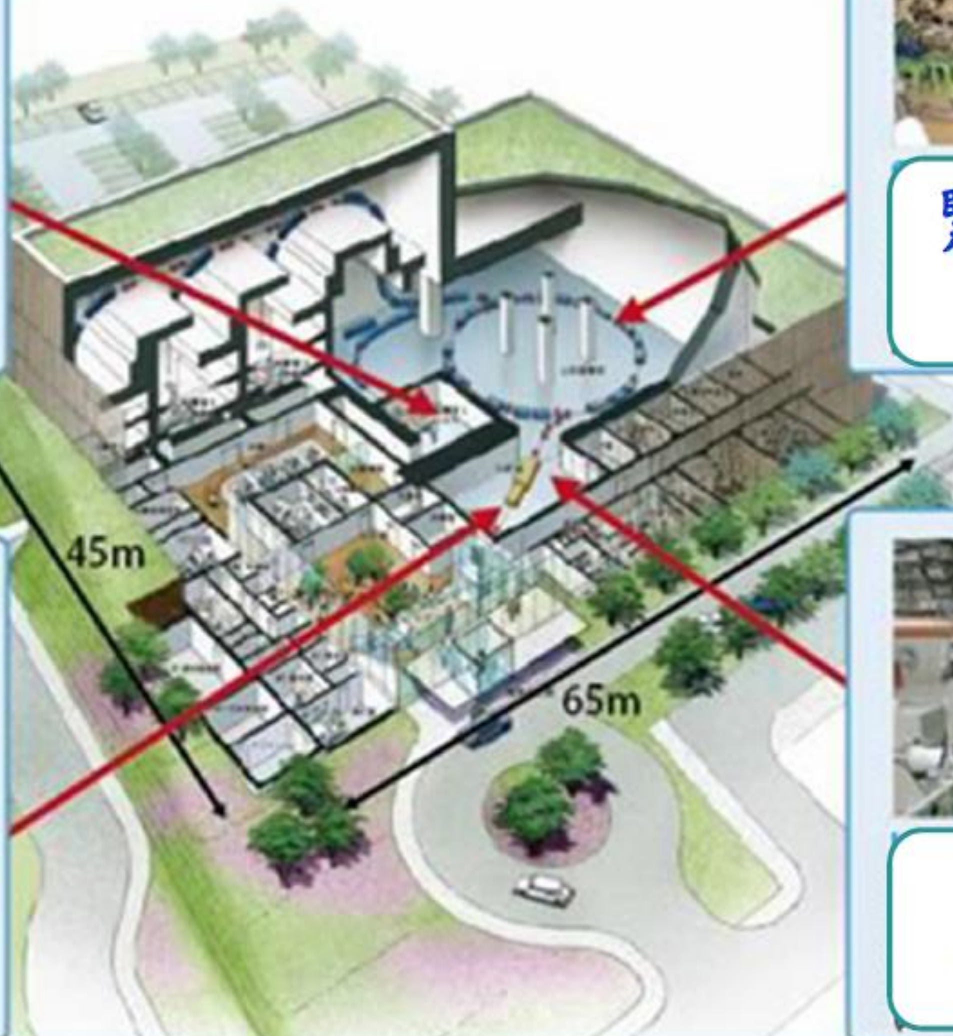


編號	項目	規格	備註
1	Profile Monitor (PRM) 射束輪廓監視器	Multi-wired proportional counter 網狀比例計數器	
2	真空腔類型	帶薄金屬窗的真空腔	
3	第一掃描磁鐵	Y方向掃描：IC　±10公分	
4	第二掃描磁鐵	X方向掃描：IC　±10公分	
5	掃描速度	Y方向100公尺/秒 X方向50公尺/秒	
6	束流斑點位置監視器	Multi-wired proportional counter 網狀比例計數器	
7	主劑量監視器	Parallel plate ionization chamber 平行板游離腔	
8	次劑量監視器	Parallel plate ionization chamber 平行板游離腔	
9	山形濾片	1 毫米，2 毫米和3毫米 （可自動更換）	
10	減能器	40 毫米, 1 毫米和2 毫米 （可自動更換）	通過疊加1毫米和2毫米可實現3毫米厚度

重粒子癌症治療中心

治療室

緊緻型同步加速器

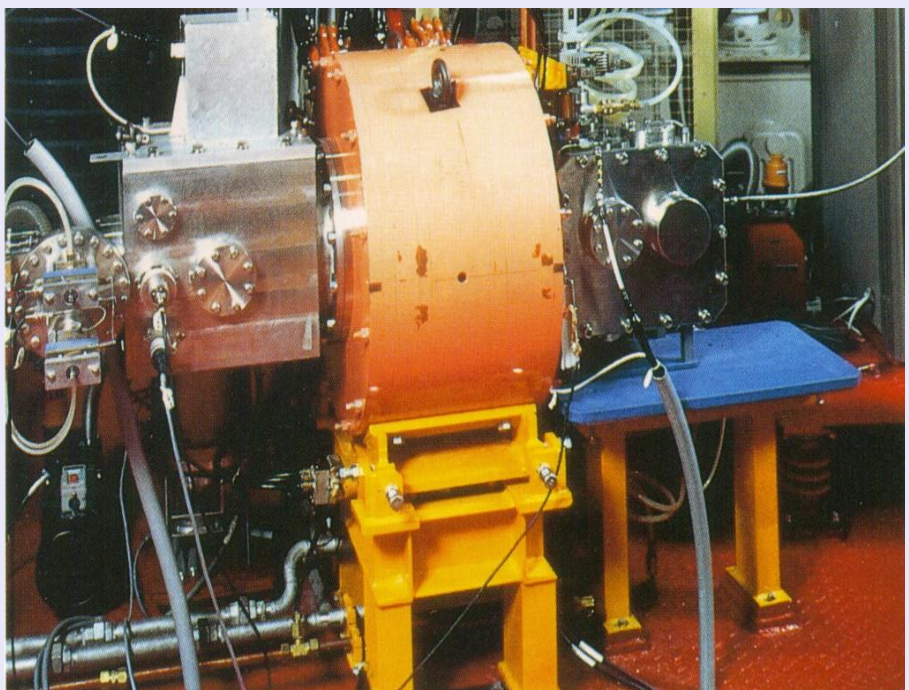


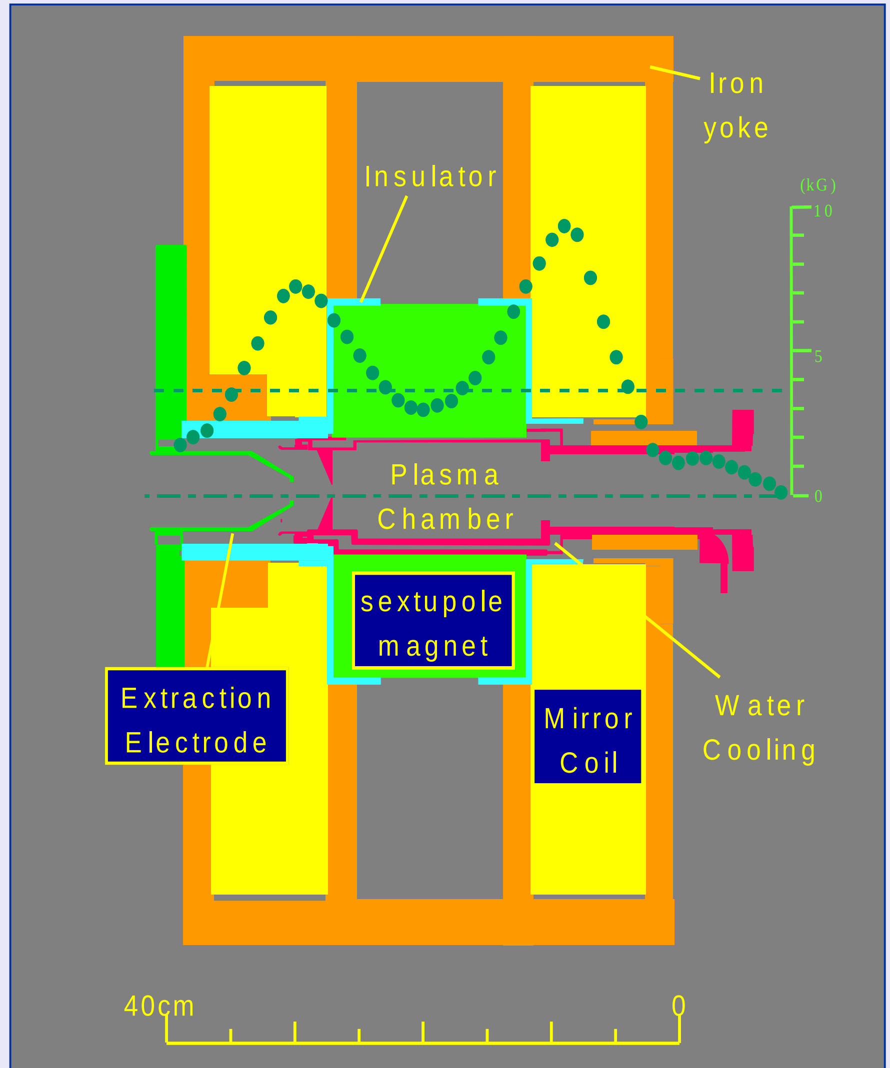
離子源

加速裝置

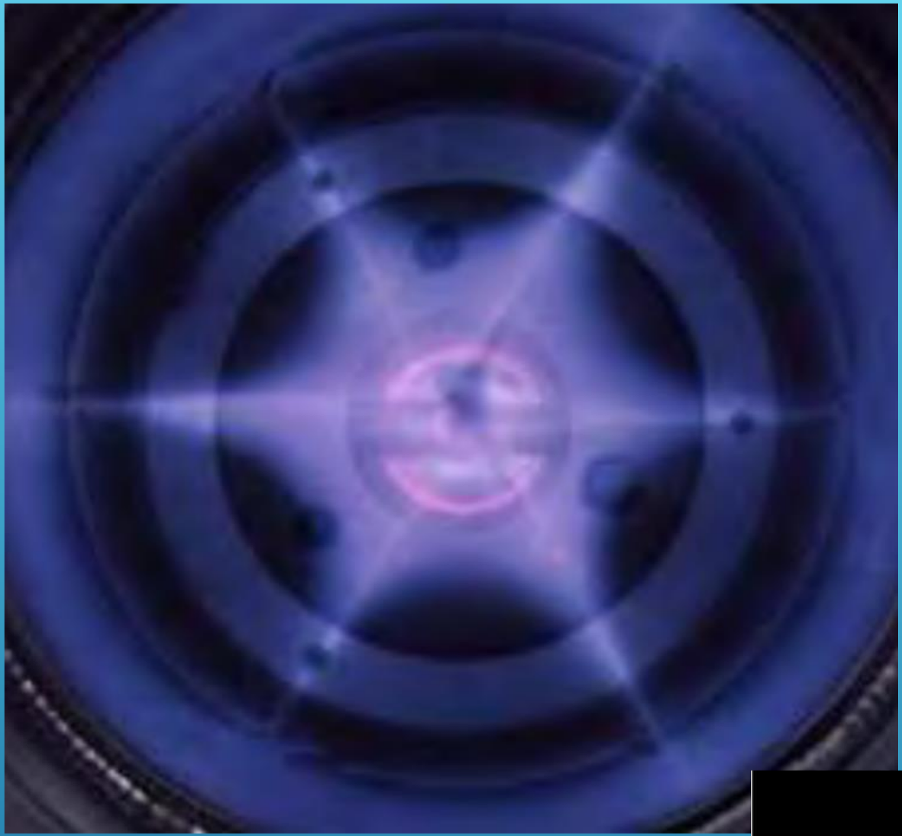
ECR Ion Source(electron cyclotron resonance)

- 10 GHz microwave(ECR at 3.6 kG)
- Simple minimum B structure
  - Mirror field: 9.3 kG / 7.6 kG
  - Axial field: 8.0 kG
- Extraction voltage: 25kV max.

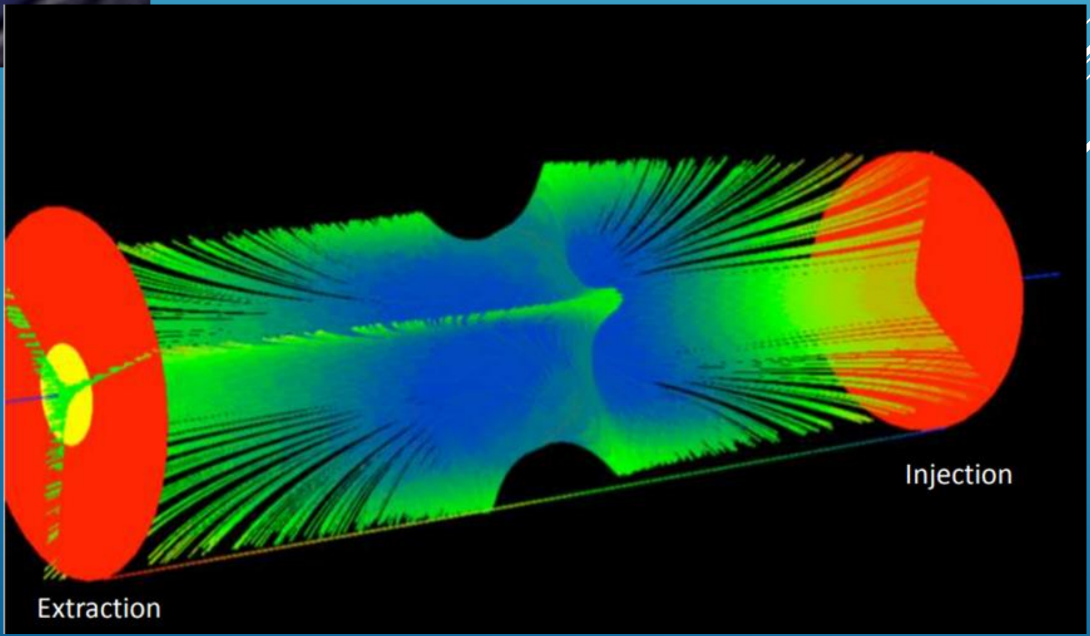




ECR Ion Source



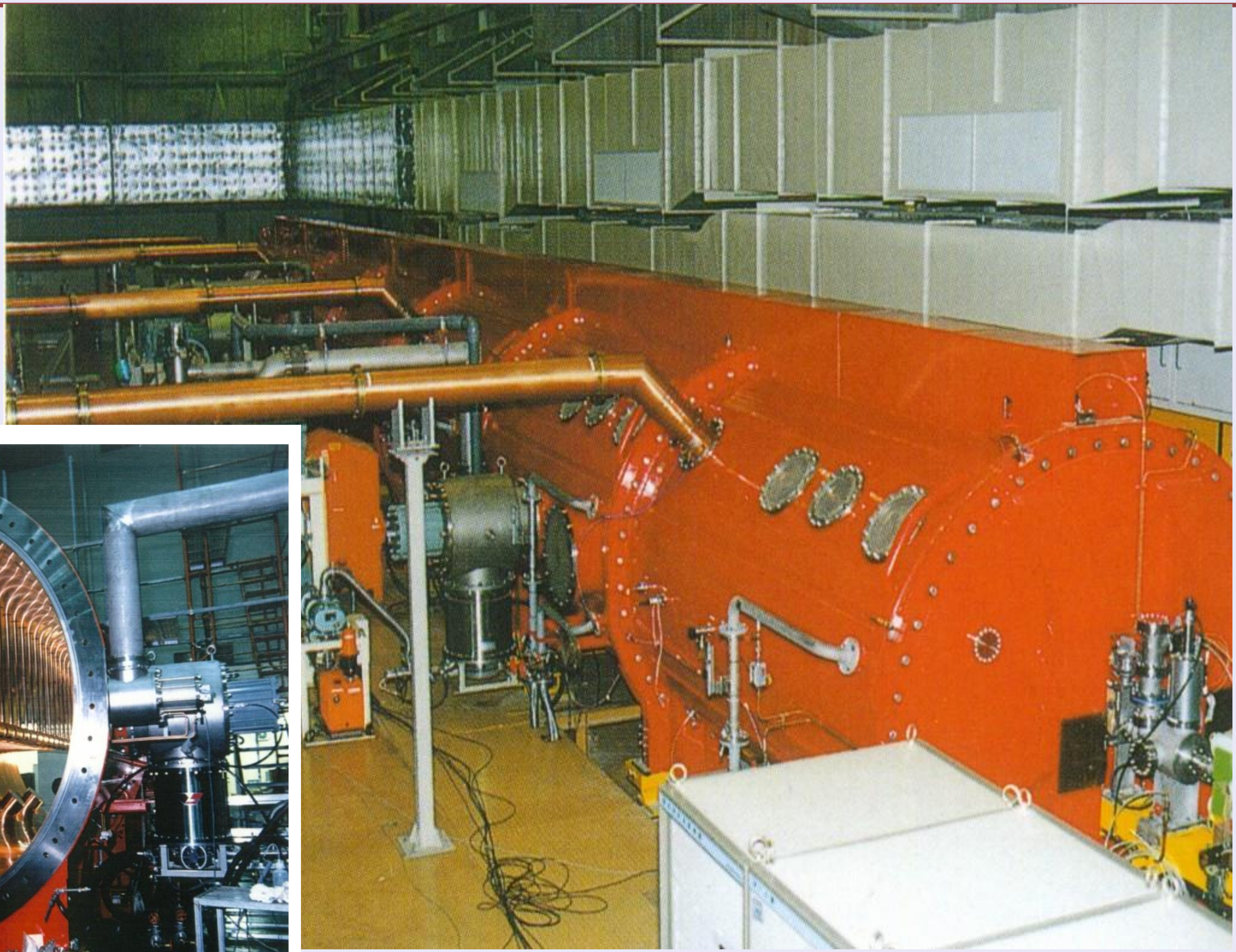
ECR plasma

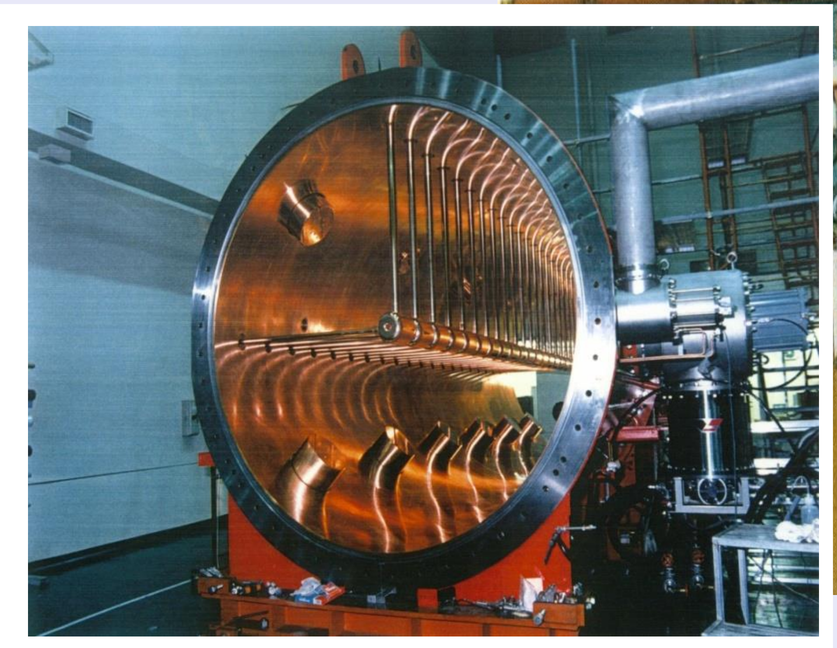


Source by 2014/04/14 Columbia University Claude Lyneis LBNL

Alvarez (Drift Tube) Linac

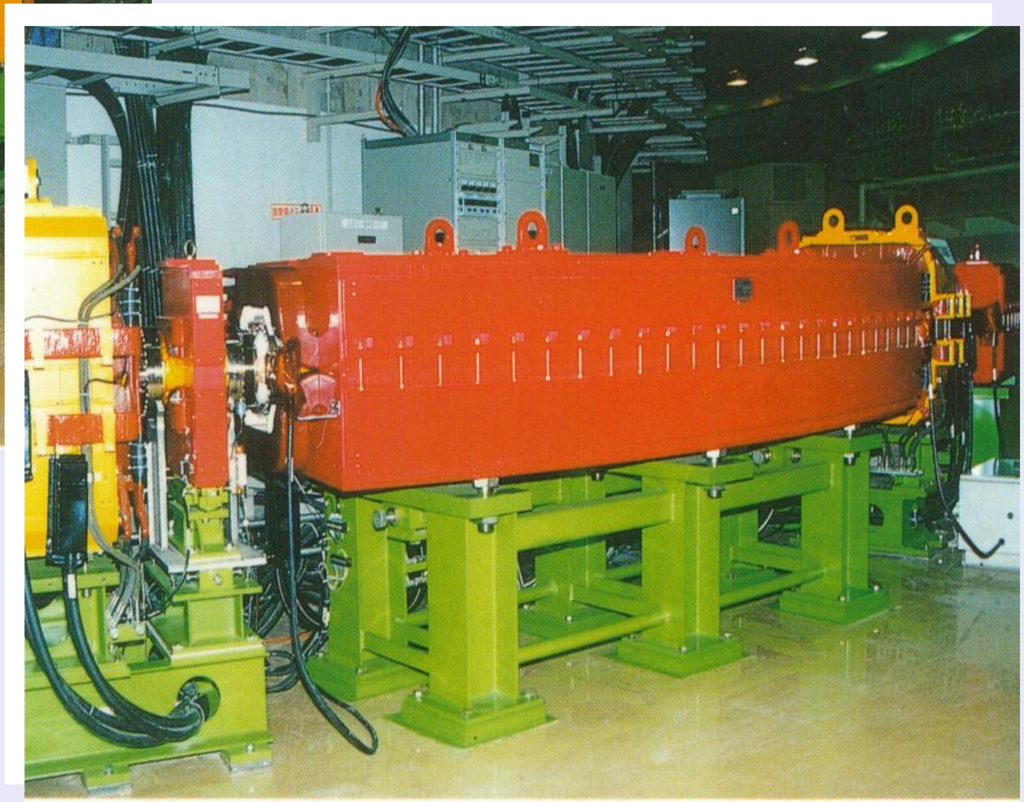
- Energy: 6MeV/u (q/m<1/7)
- No. of cavity : 3
- Peak power : 1.4MW/cavity
- Frequency: 100MHz





Synchrotron

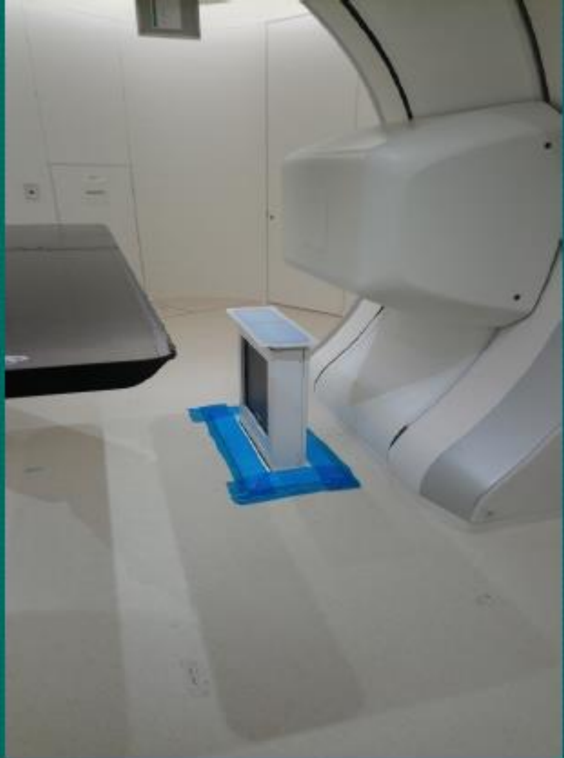
- Maximum energy: 430MeV/u (q/m=1/2)
- Repetition rate: 0.5Hz max.



RF cavity
acceleration voltage: <9kV
frequency: 1 - 8MHz

Bending Magnet
rigidity:9.7Tm



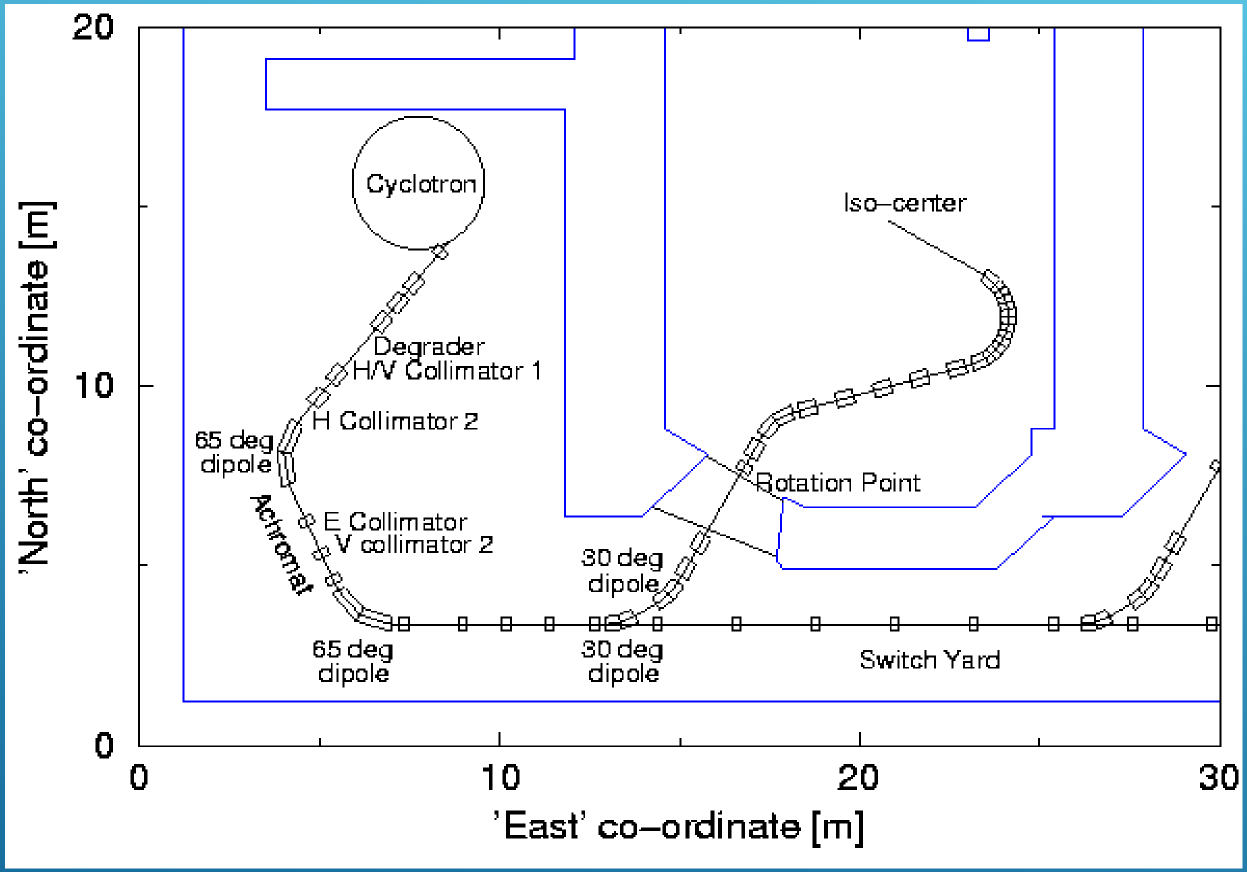



治療室配置

粒子的治療原理

CYCLOTRON VS SYNCHROTRON: CYCLOTRON

(ACCEL superconducting cyclotron for RPTC, Munich)

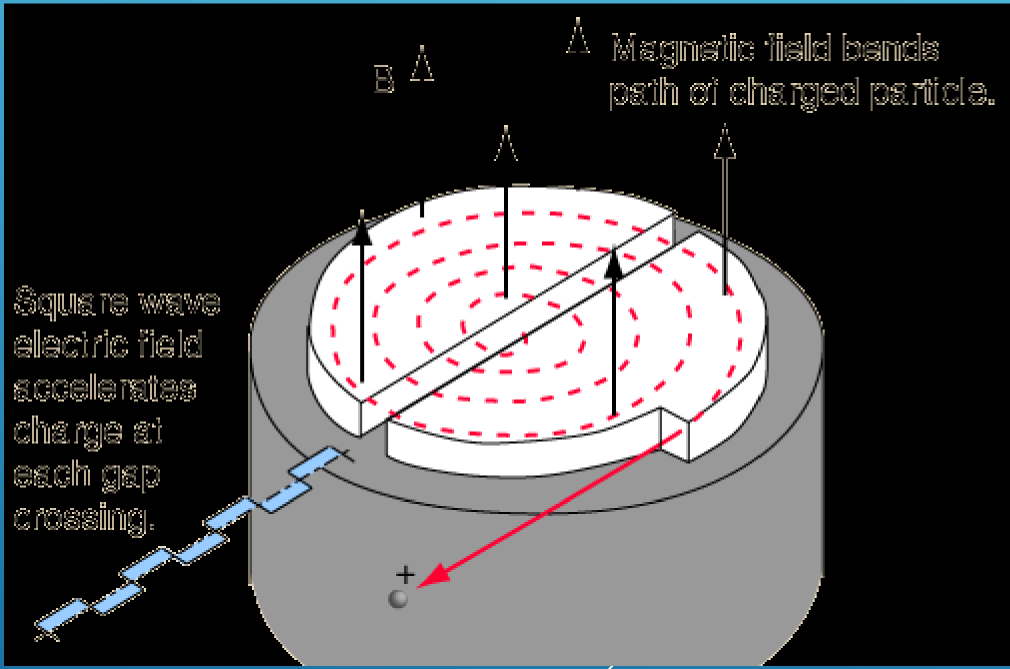


- Fixed energy output at constant current
- Energy degrader reduces beam energy
- Collimators scrape beam to size
- Large intrinsic beam size in all three dimensions

PARTICLE BEAM PRODUCTION: CYCLOTRON

Principle

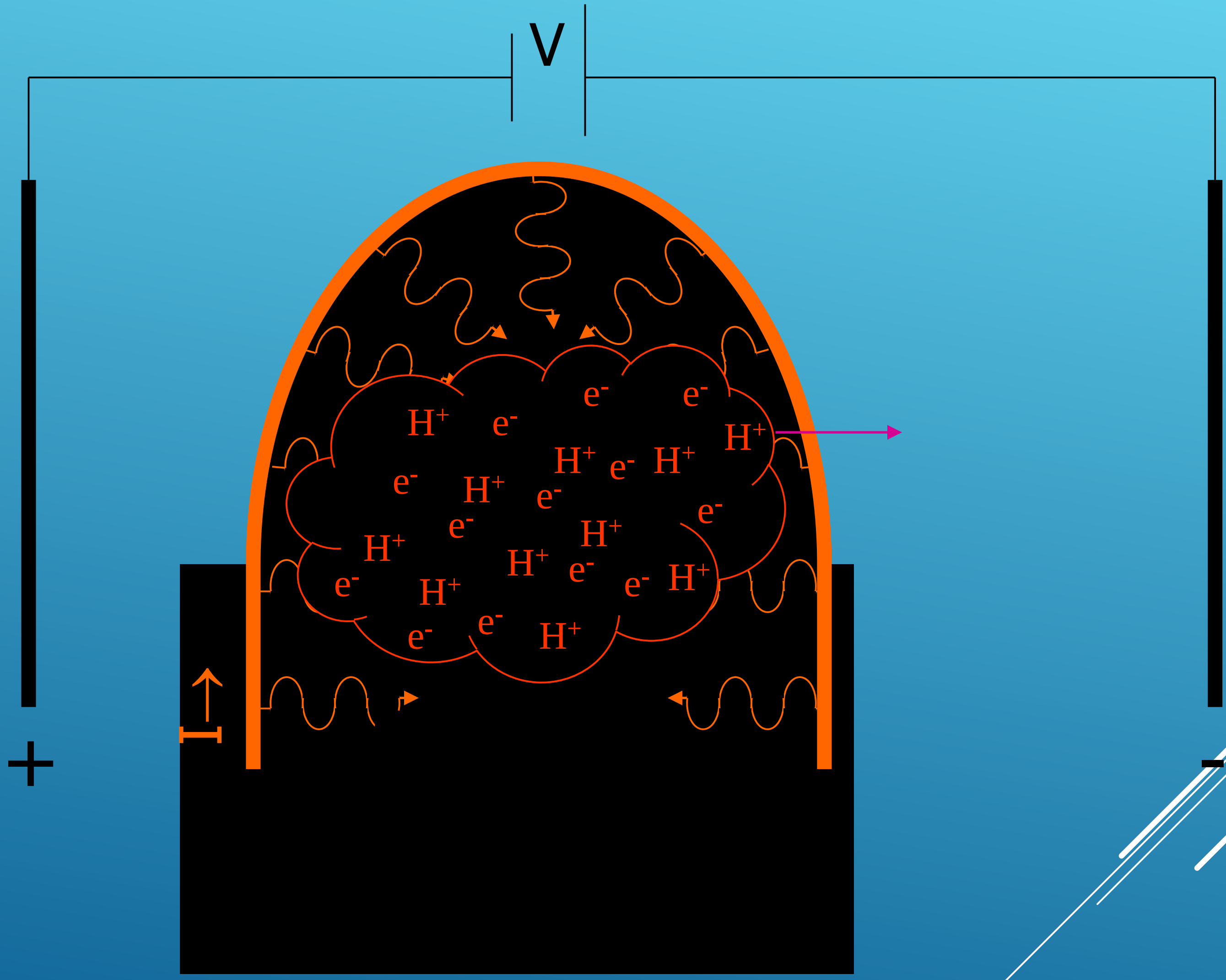
- electric field accelerates protons RF
- magnetic field bends protons Lorentz: radius proportional to momentum
- fixed energy at exit defined by size cyclo



Our cyclotron

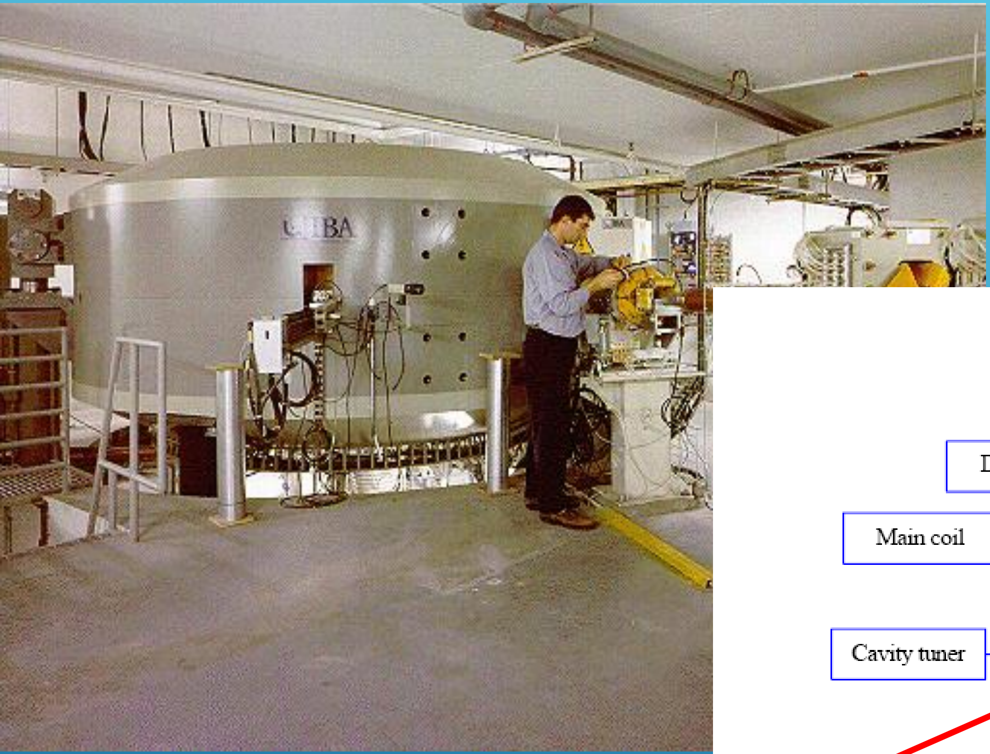
- 230 MeV penetration depth of 33 cm in water
- 4 accelerating gaps
- proton extraction: electro-static deflector

CYCLOTRON ION SOURCE

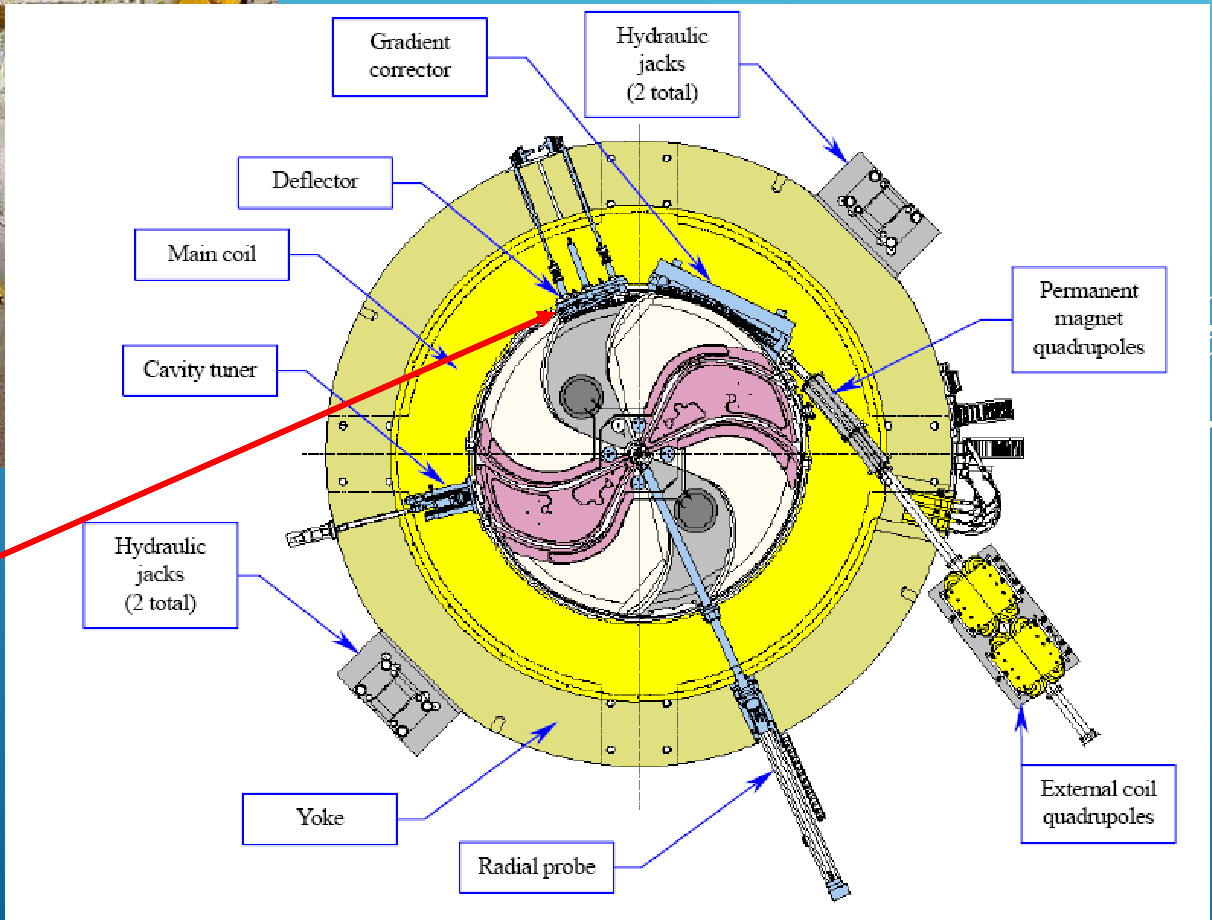


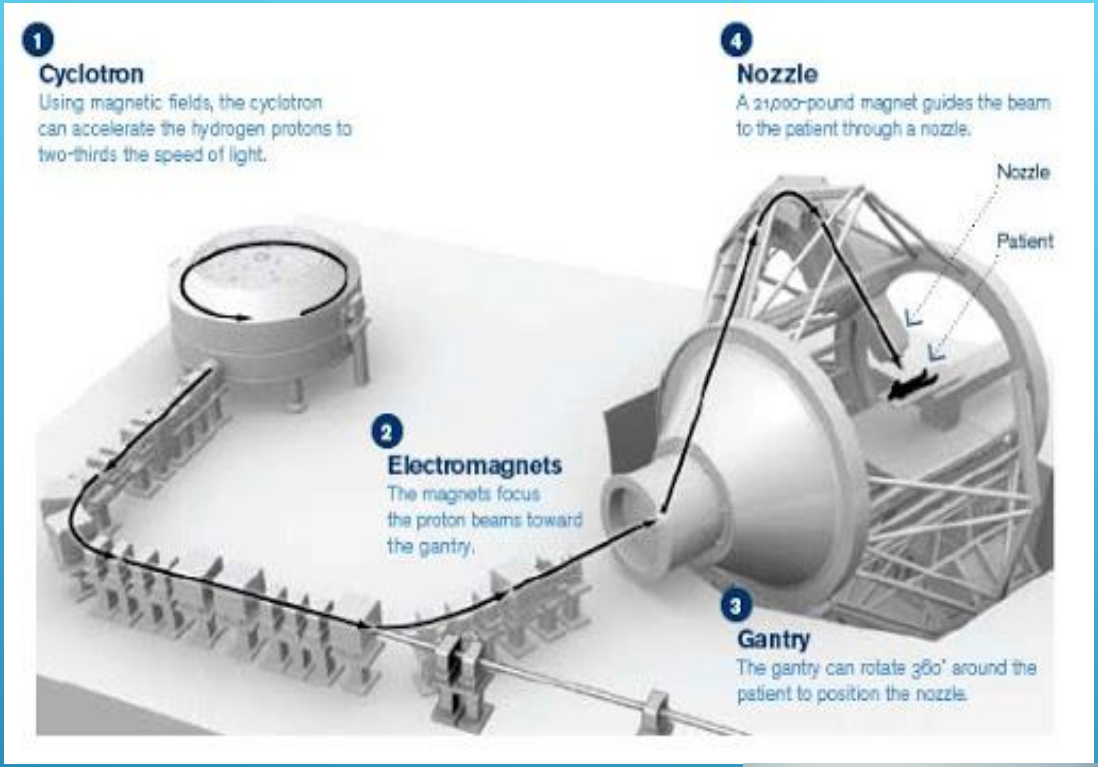
hydrogen gas + heat → plasma + electrostatic force → free proton (H^+)

THE IBA ISOCHRONOUS CYCLOTRON



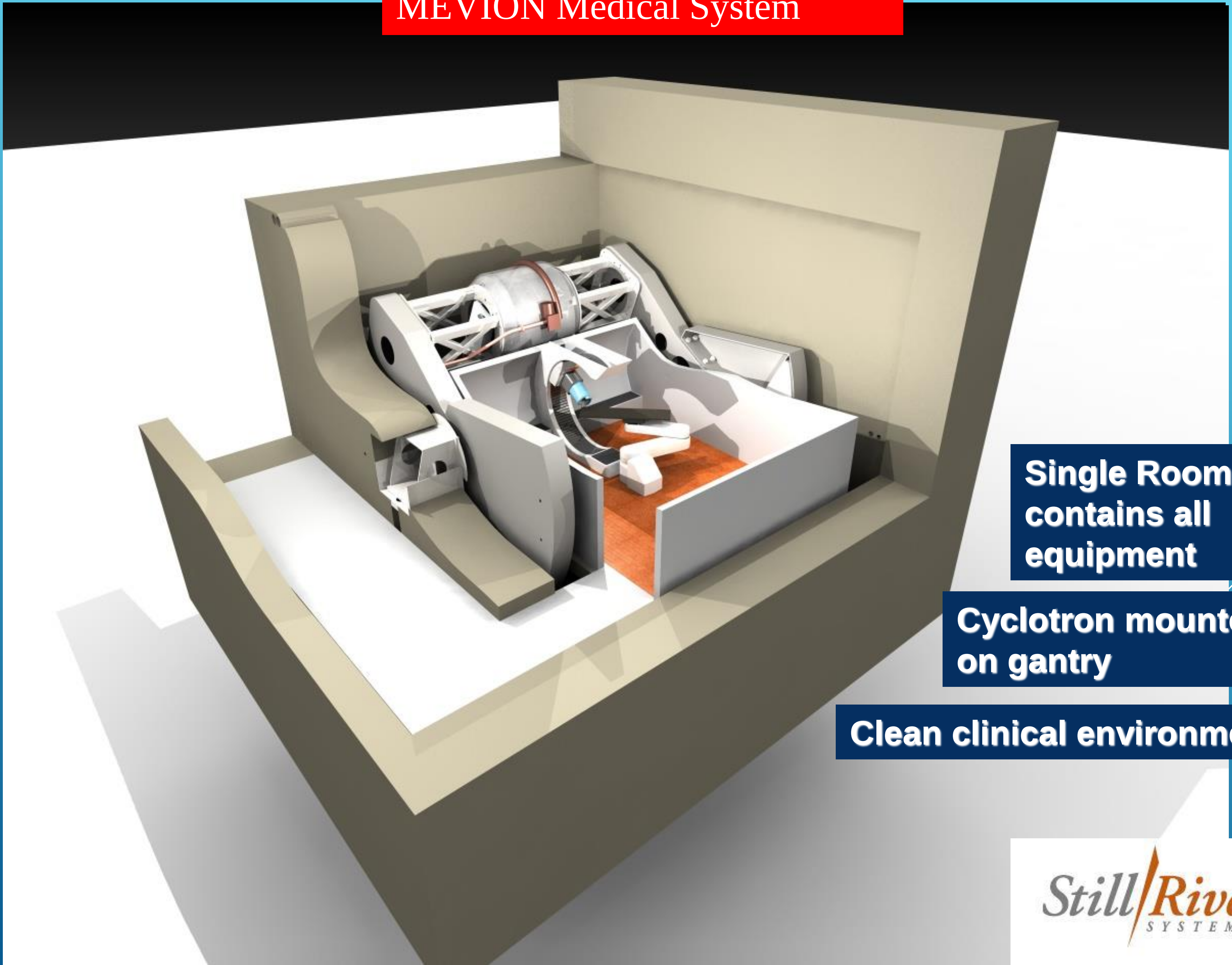
Diameter = 4 m
235 MeV





IBA proton 230MeV

MEVION Medical System



Single Room contains all equipment

Cyclotron mounted on gantry

Clean clinical environment

Still River
SYSTEMS

MEVION

Varian proton therapy

1.Fully integrated image-guided IMPT

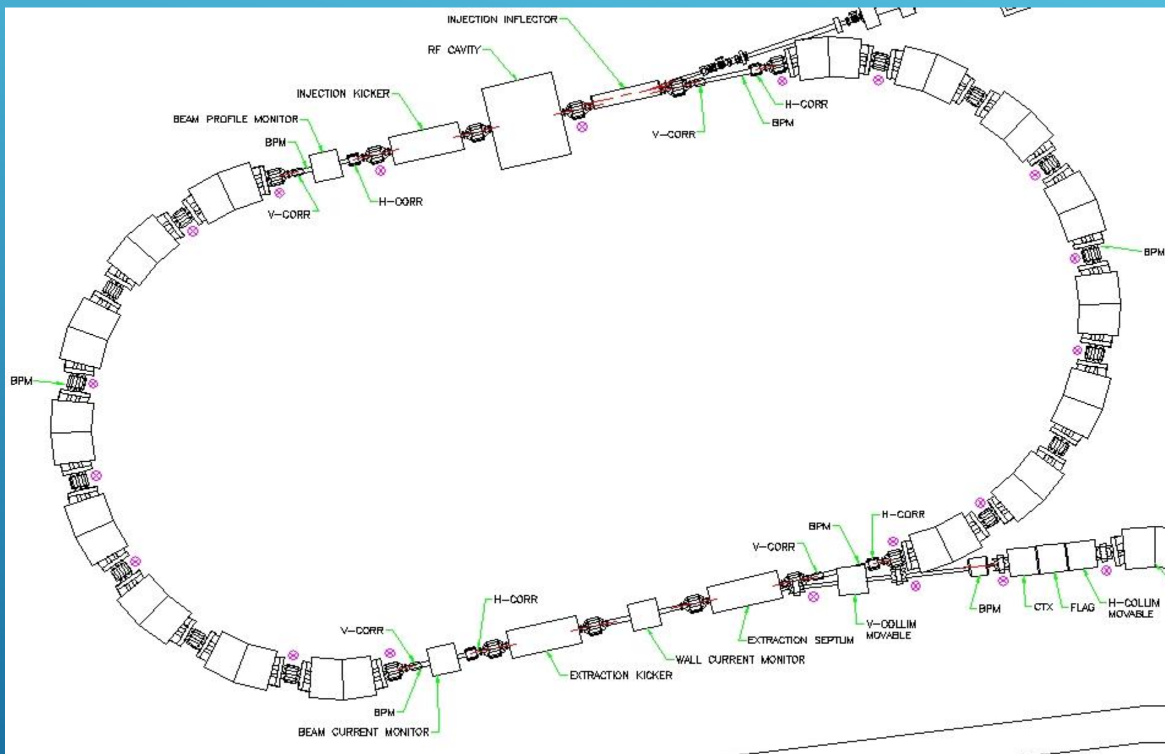
2.A newly designed SRPT with proton beam energies ranging from 70 to 220 MeV was commissioned in late 2019.(13 August2000,https//doi.org/10.1002/acm2 .12984)

Pronova Proton Therapy

1. 360˚ superconducting gantry
2. Independent energy selection system
3. Pencil beam scanning

CYCLOTRON VS SYNCHROTRON: SYNCHROTRON

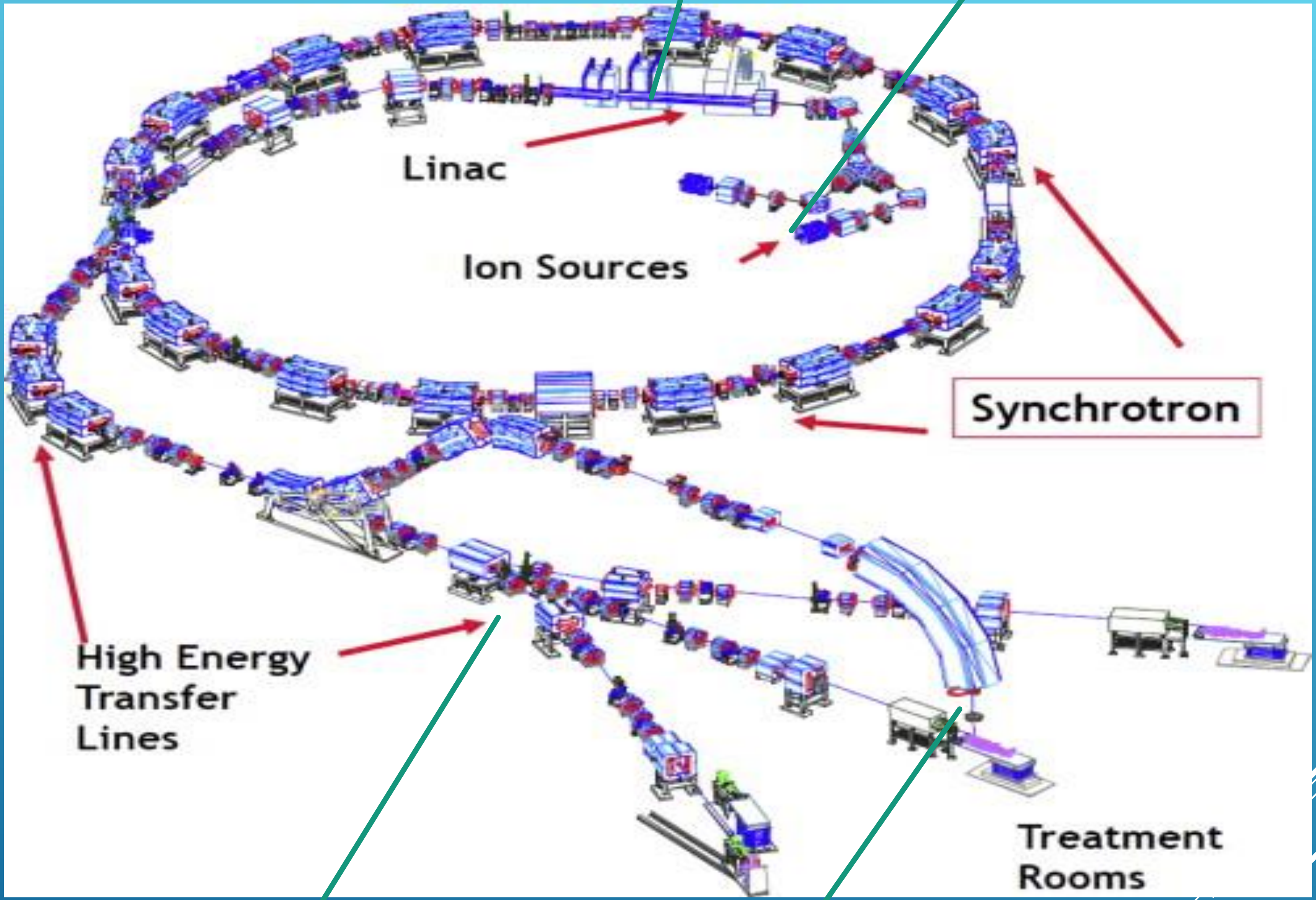
(Rapid Cycling Medical Synchrotron, RCMS)



- **Accelerate variable beam intensity to variable energy**
  - **50-430 MeV**
  - **No energy degrader**
  - **Smaller beam sizes**
- **Accelerate either**
  - **Small beam intensity rapidly (30-60 Hz), extract in one turn**
  - **Large beam intensity slowly, extract in many turns**

The protons are injected into the cyclotron where they are accelerated

Hydrogen atoms are separated into electrons and protons



These high power protons are sent through an energy selection system and a degrader that adjust their energy

The proton beam arrives in the treatment room via a gantry

High Performance Hadron Therapy Centers with Carbon and Proton Beams

- Heidelberg ion therapy (Germany)
- Marburg (Germany):2015
- CNAO (Pavia, Italy)
- MedAustron (Wiener Neustadt,Austria):2016
- Shanghai
- Hyogo ion beam Medical Centre
- HIMAC (Japan,Chiba)
- Gunma University heavy Ion Medical Centre :2010

REQUIREMENTS FOR THE THERAPY AT HIMAC

- **Ion species: high LET (100keV/mm) charged particles**
- **⇒ He, C, Ne, Si**
- **Range: 30cm in soft tissue ⇒ 430MeV/u (C)**

  800MeV/u(Si)
- **Maximum irradiation area: ⇒ 22cm in diameter**
- **Dose rate: 5GyE/min ⇒ 2×10^9pps**
- **Beam direction: horizontal, vertical, etc...**

-> "large accelerator" used for physics experiments

HISTORY OF CONSTRUCTING HIMAC

- Heavy Ion Medical Accelerator in Chiba (HIMAC)

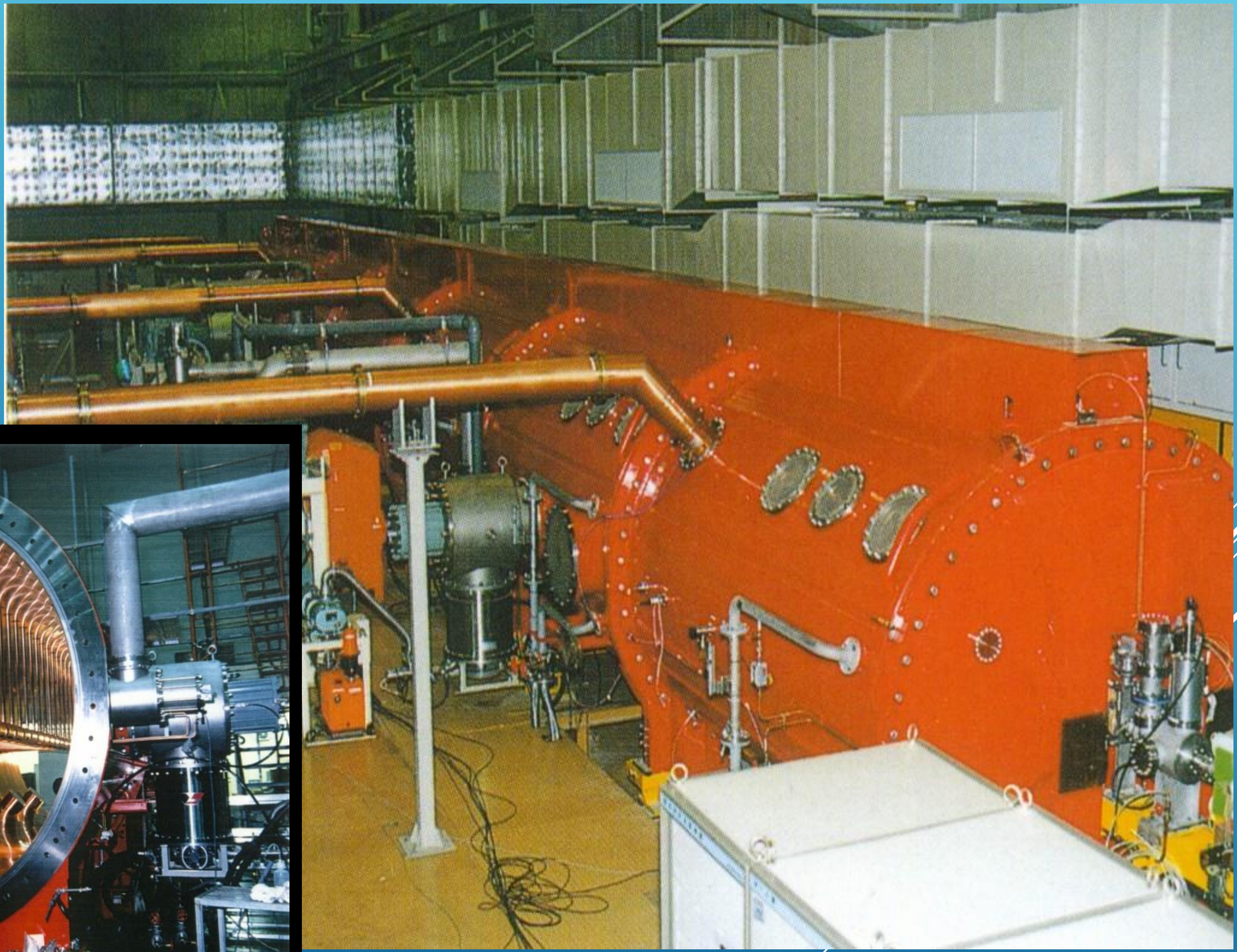
- 1984: 10 years strategy for confronting the cancer
- 1986: International Workshop on Heavy Ion Treatment Facility
- 1989: Start of the construction
- 1993: Commissioning ended, beams were successfully accelerated.
- 1994: Clinical Trials began.
- 2003: Advanced Medical Therapy (AMT).
- - Jul. 2009: 4,818 patients were treated. (AMT 2,284)

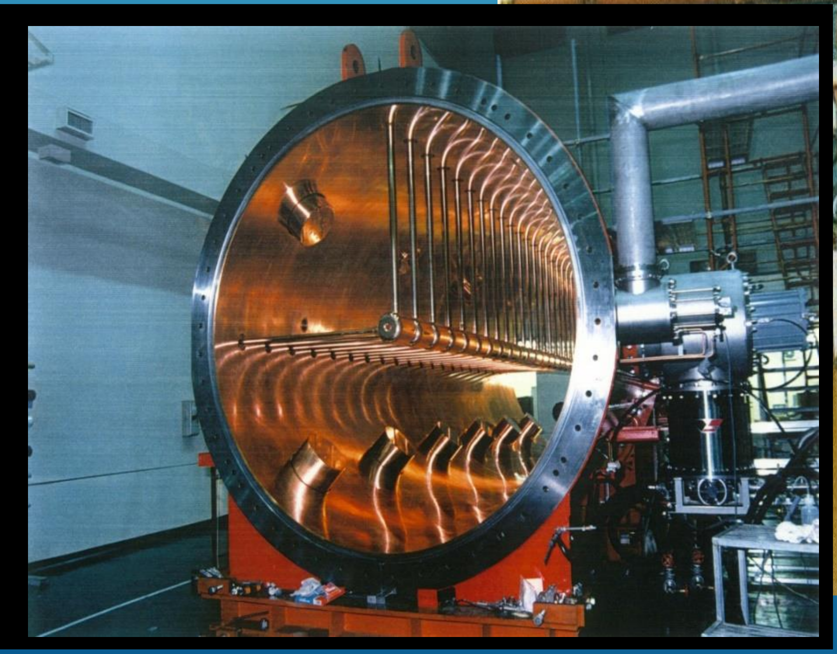
CUT-AWAY VIEW OF HIMAC

- **HIMAC: (Heavy Ion Medical Accelerator in Chiba)**

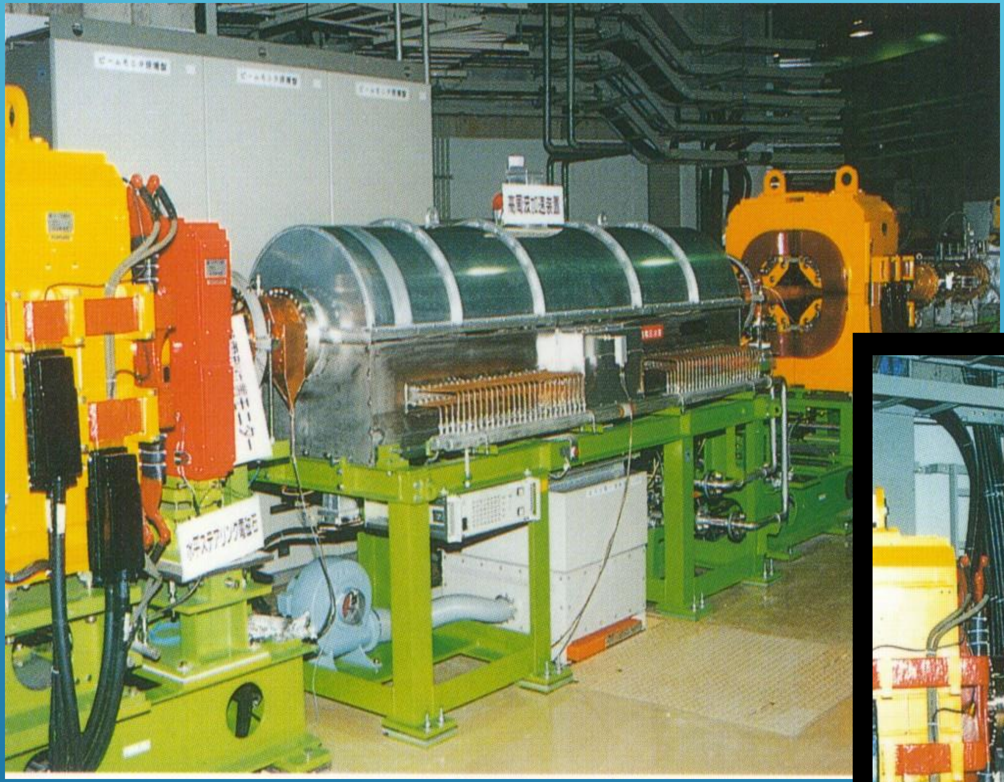
ALVAREZ (DRIFT TUBE) LINAC

- Energy: 6MeV/u (q/m<1/7)
- No. of cavity: 3
- Peak power: 1.4MW/cavity
- Frequency: 100MHz
- Diameter: 2.2m
- Length: 24m





SYNCHROTRON



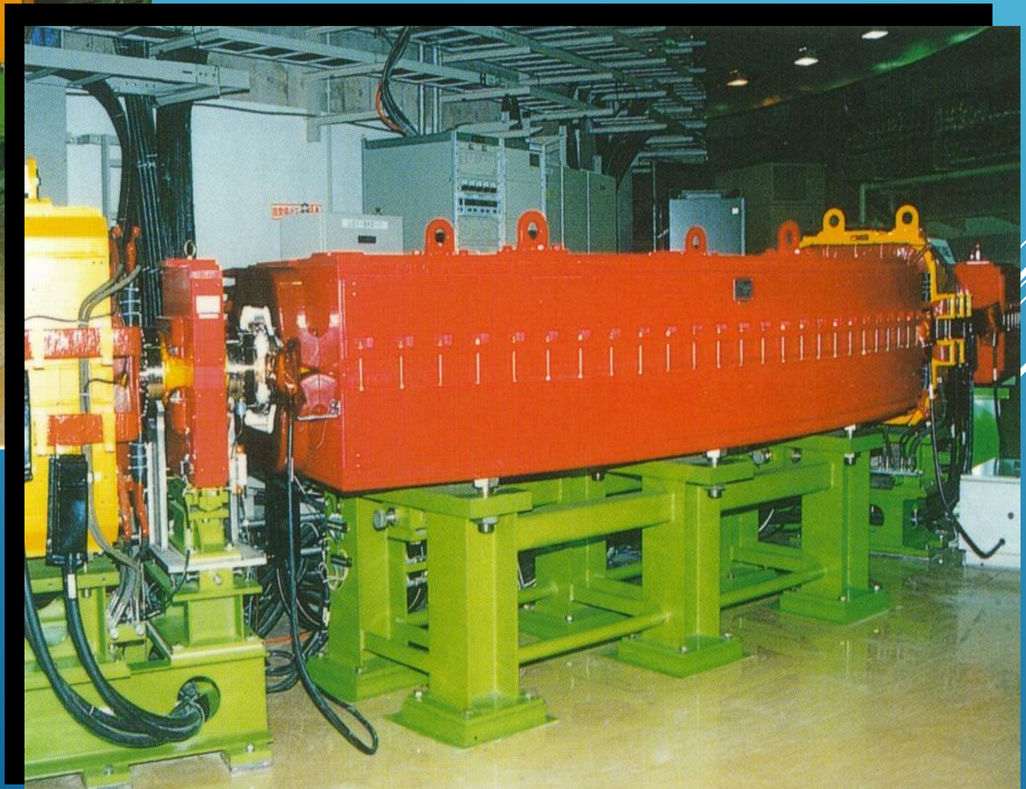
- Maximum energy: 800MeV/u (q/m=1/2)
- Repetition rate: 0.5Hz max.

RF cavity

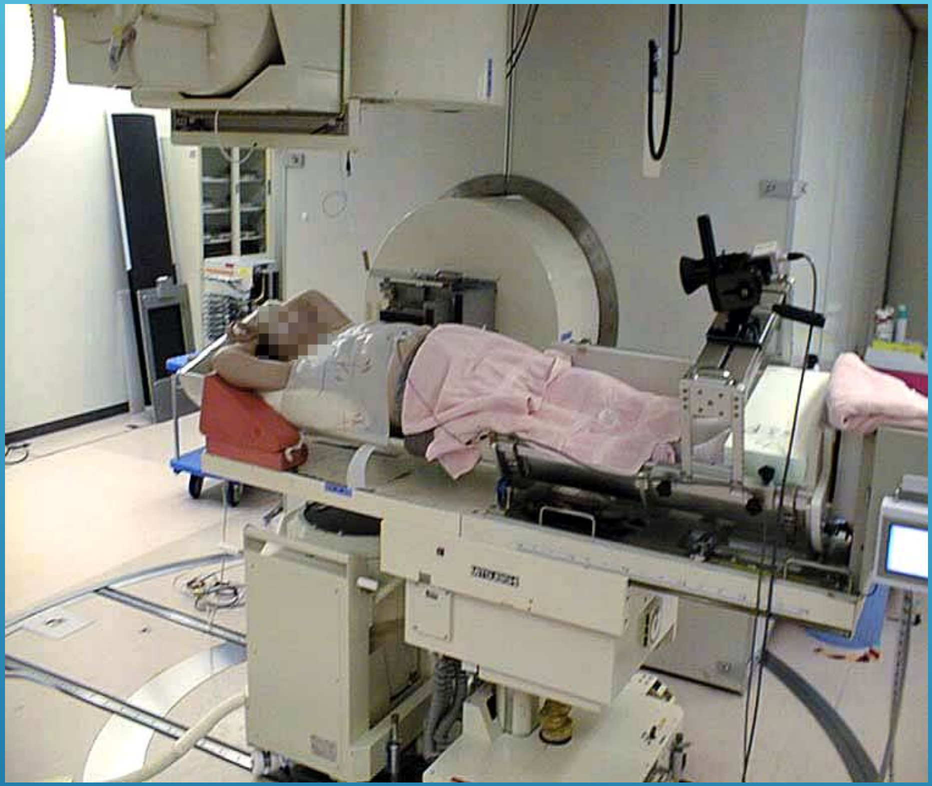
acceleration voltage: <9kV
frequency: 1 - 8MHz

Bending Magnet

rigidity:9.7Tm



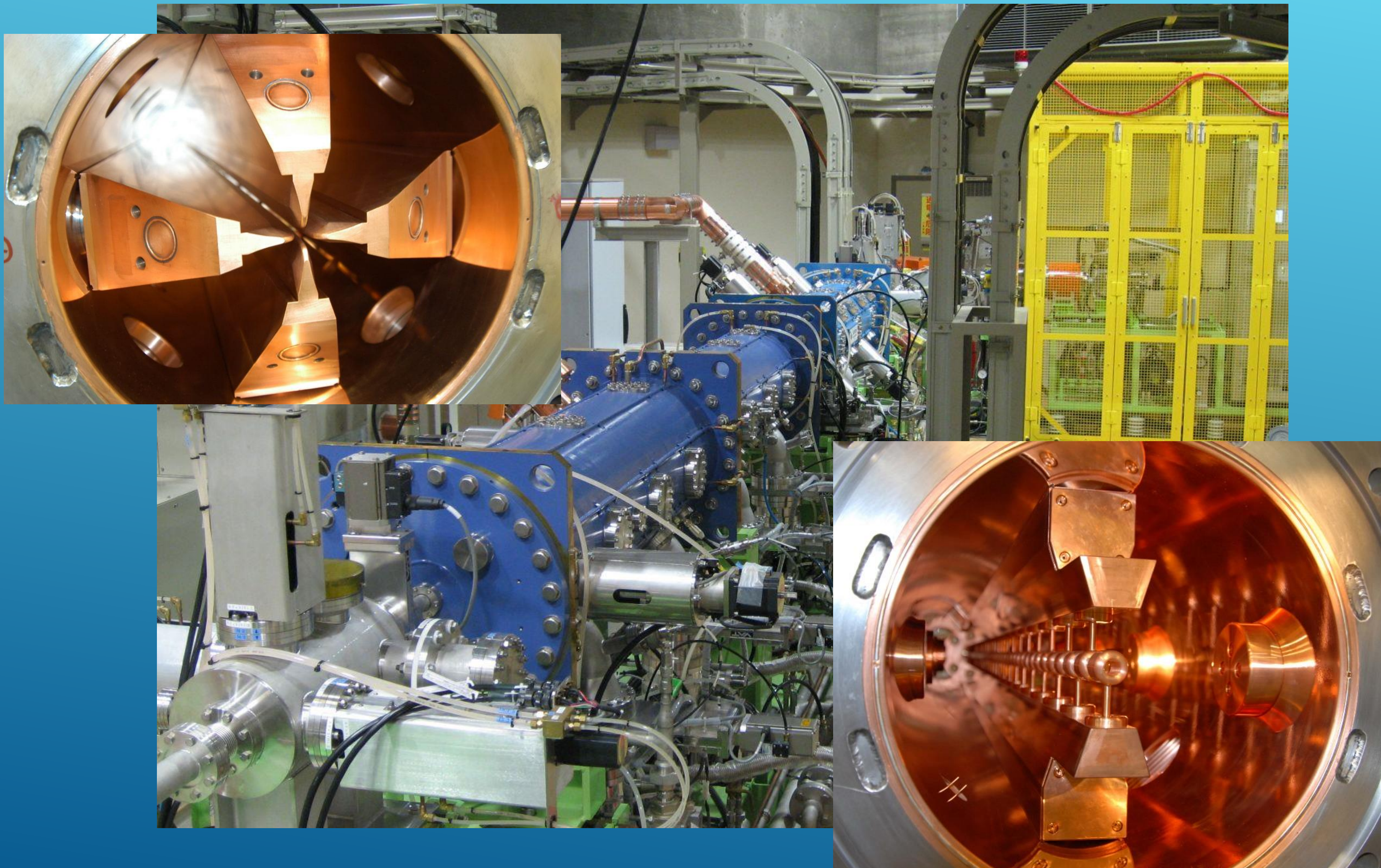
TREATMENT ROOM



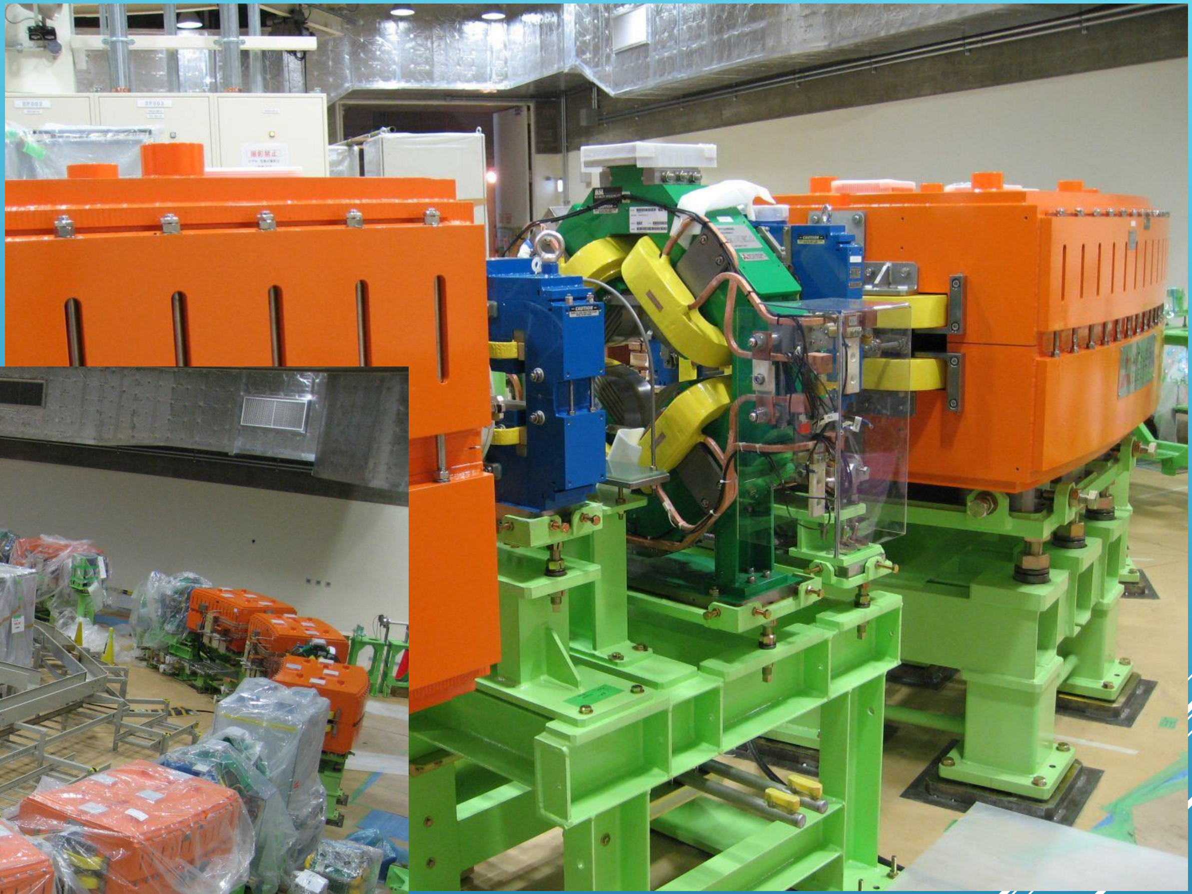
Horizontal beam port

Vertical beam port

GUNMA INJECTOR LINAC AND ECR SOURCE



GUNMA SYNCHROTRON



GUNMA TREATMENT ROOM A, HORIZONTAL LINE

Carbon ion facilities under construction (HIT)

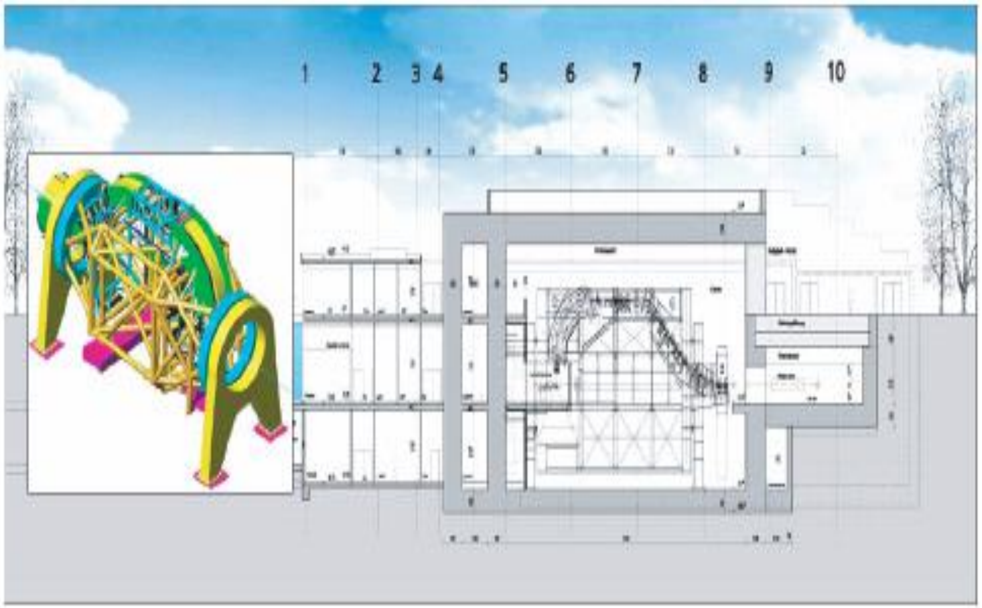
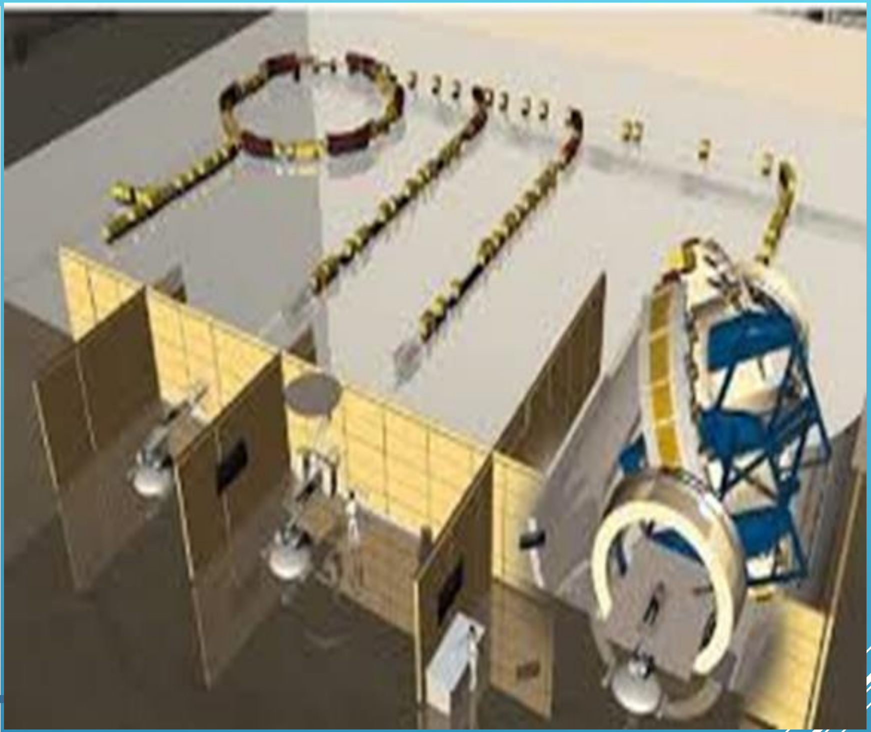


Figure 8. The GSI isocentric gantry for carbon ions. It is about 25 m long and vertically occupies three floors.



- HIT is a very ambitious project that applies all the techniques and methods developed in the framework of the pilot project and features the first carbon ion gantry, which weighs about 600 tons (figure 8).
- HIT is a joint project of the Heidelberg Clinics and GSI in the sense that the responsibility for accelerator is given to GSI. The irradiation system and the medical equipment will be supplied by Siemens Medical Solutions. The construction of the buildings and the operation is with the Heidelberg Clinics.

HIT Treatment room H1

(HIT)

At a glance

1.Targeted and gentle treatment against certain cancer types

2.700 patients per year

3.Extensive expertience in treating children and adolescents

4.ver 95% of patients are treated as outpatieents

5.Treatment duration per session: several minutes up to maximum 60 minutes

6.HIT facility is located 45 minutes from Frankfurt airport

Carbon ion facilities

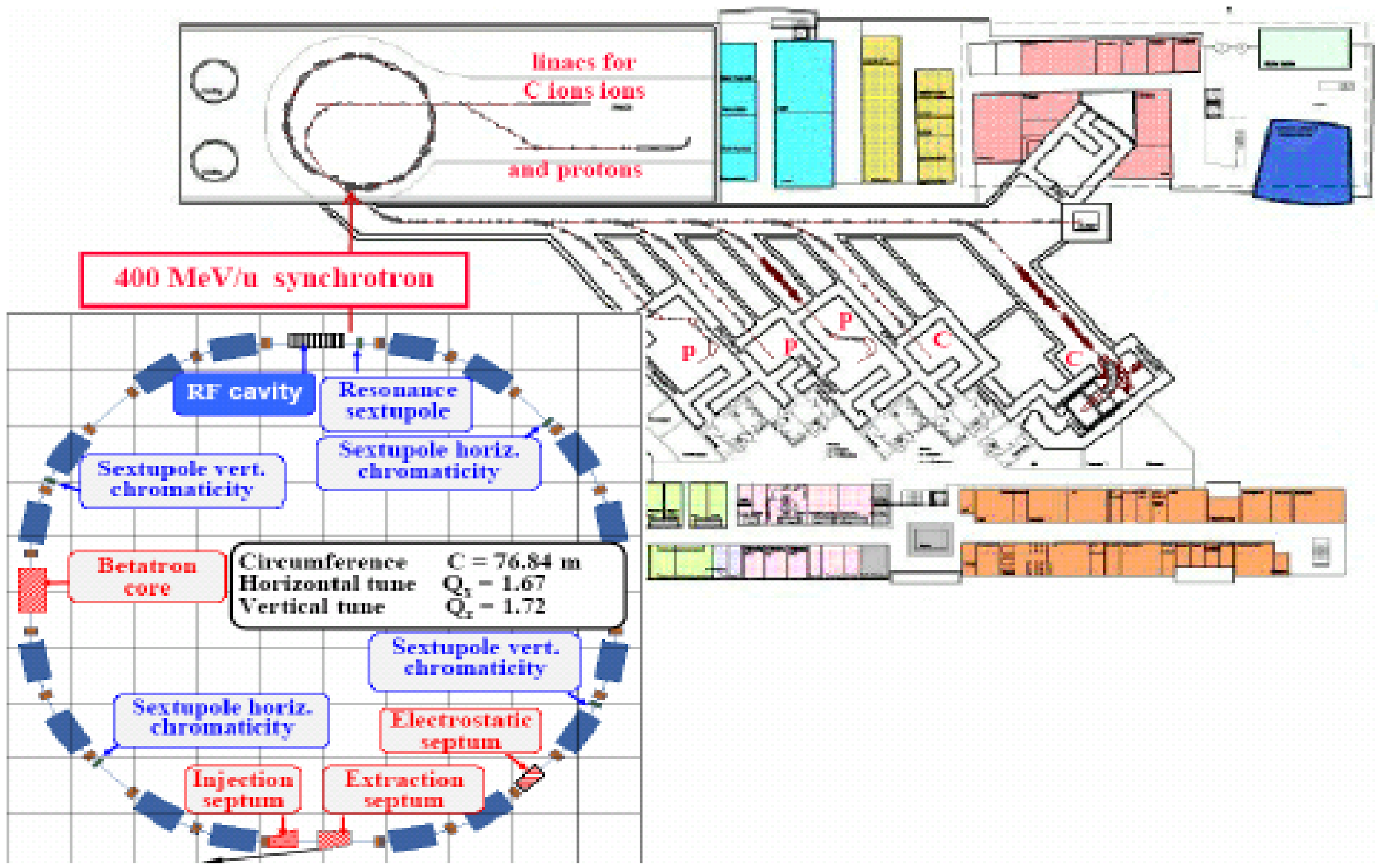
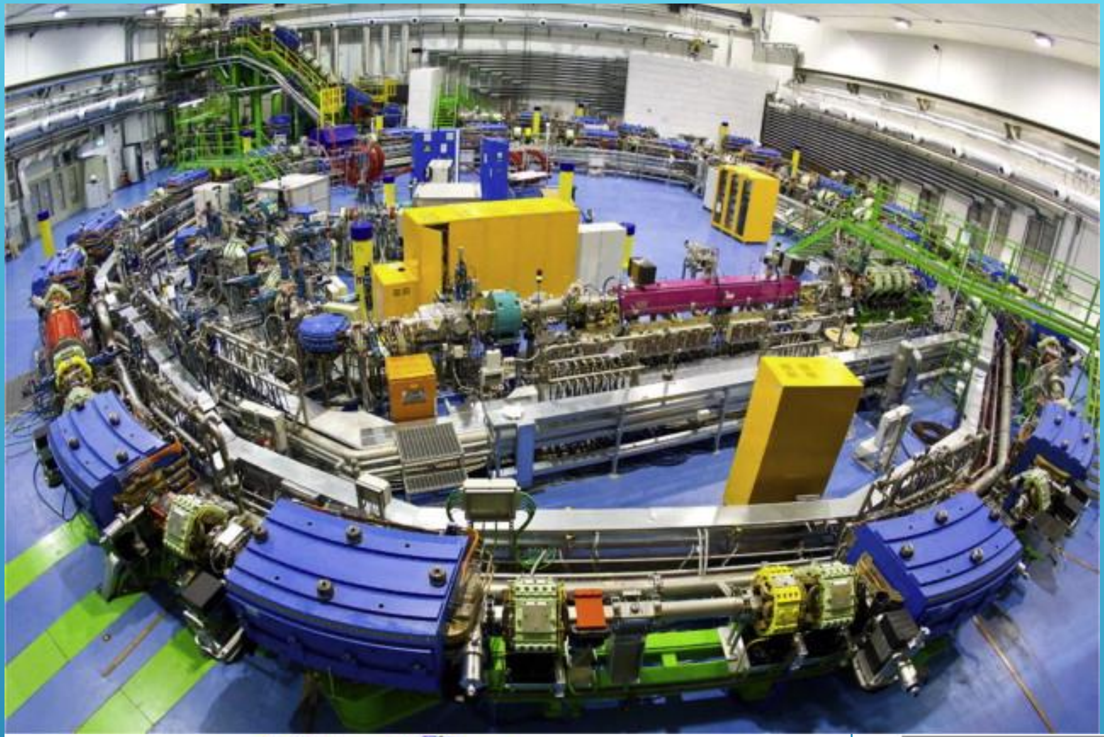


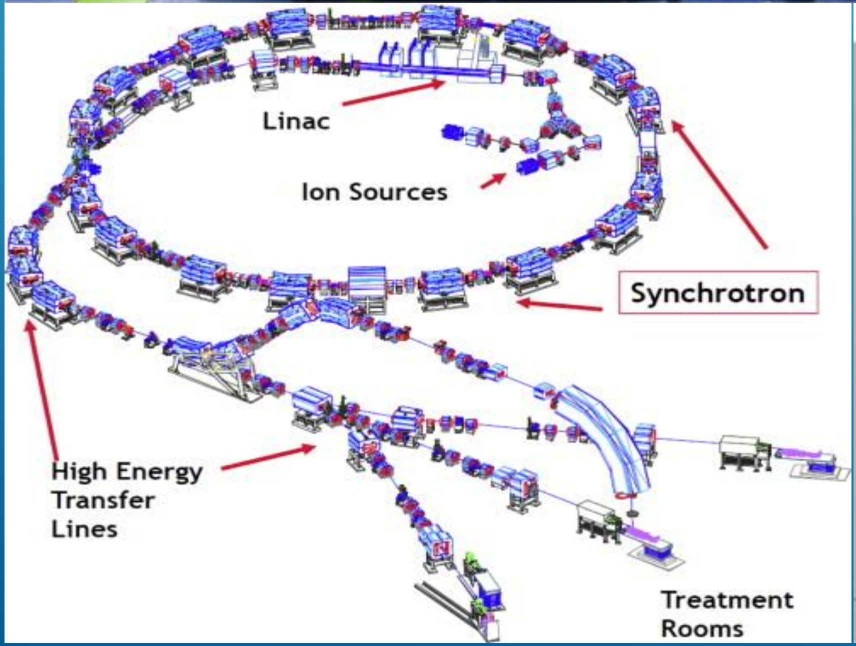
Figure 9. The general layout of the facility designed in the PIMMS [35]. The beam distribution line is long as it has the special feature that various functions are performed by different modules. The covered area is 15 000 m^2.

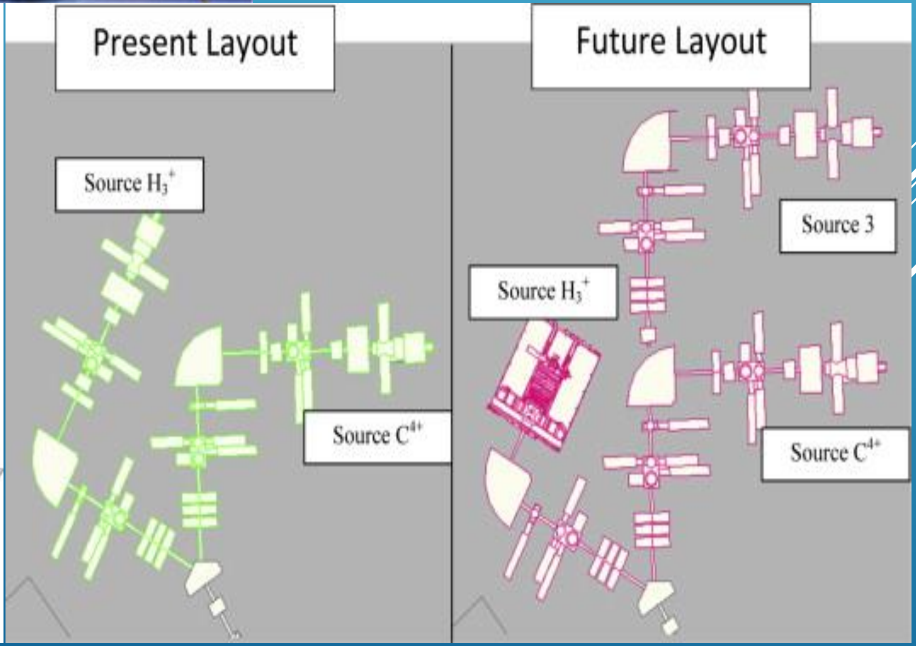
PIMMS: Proton ion Medical Machine Study



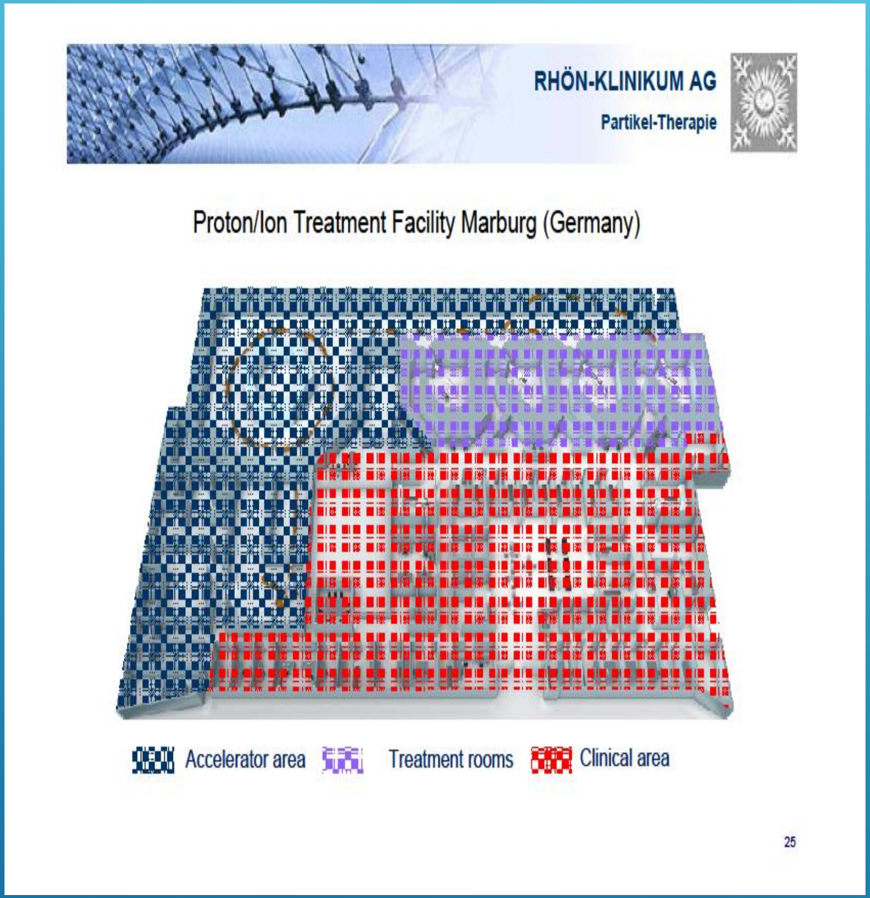
CNAO:Nazionale di Adroterapia Oncologica

Beam particle species: P, He^{2+} ,Li^{3+} ,Be^{4+} ,B^{5+} ,C^{6+} (O^{8+})



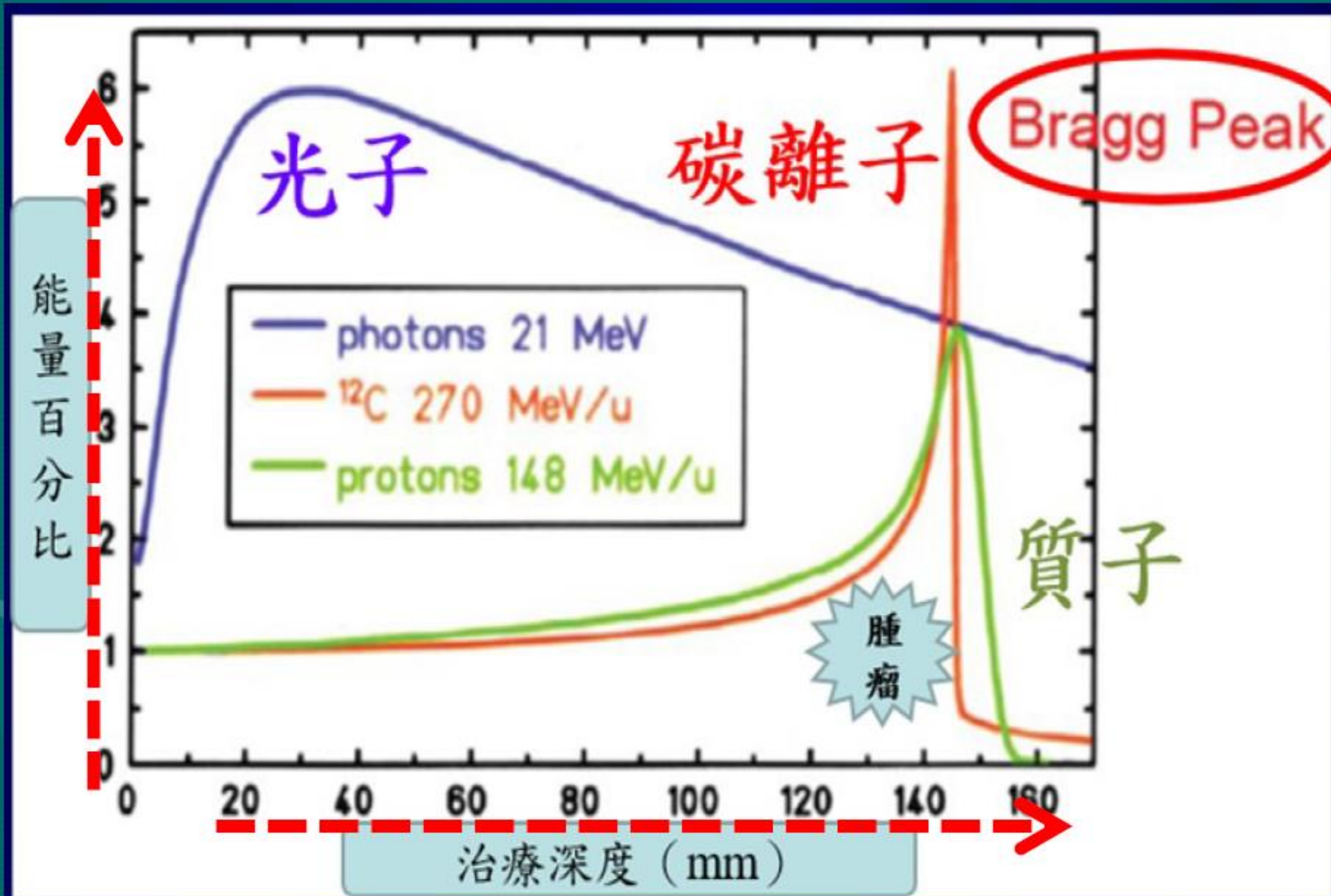


Marburg particle therapy center

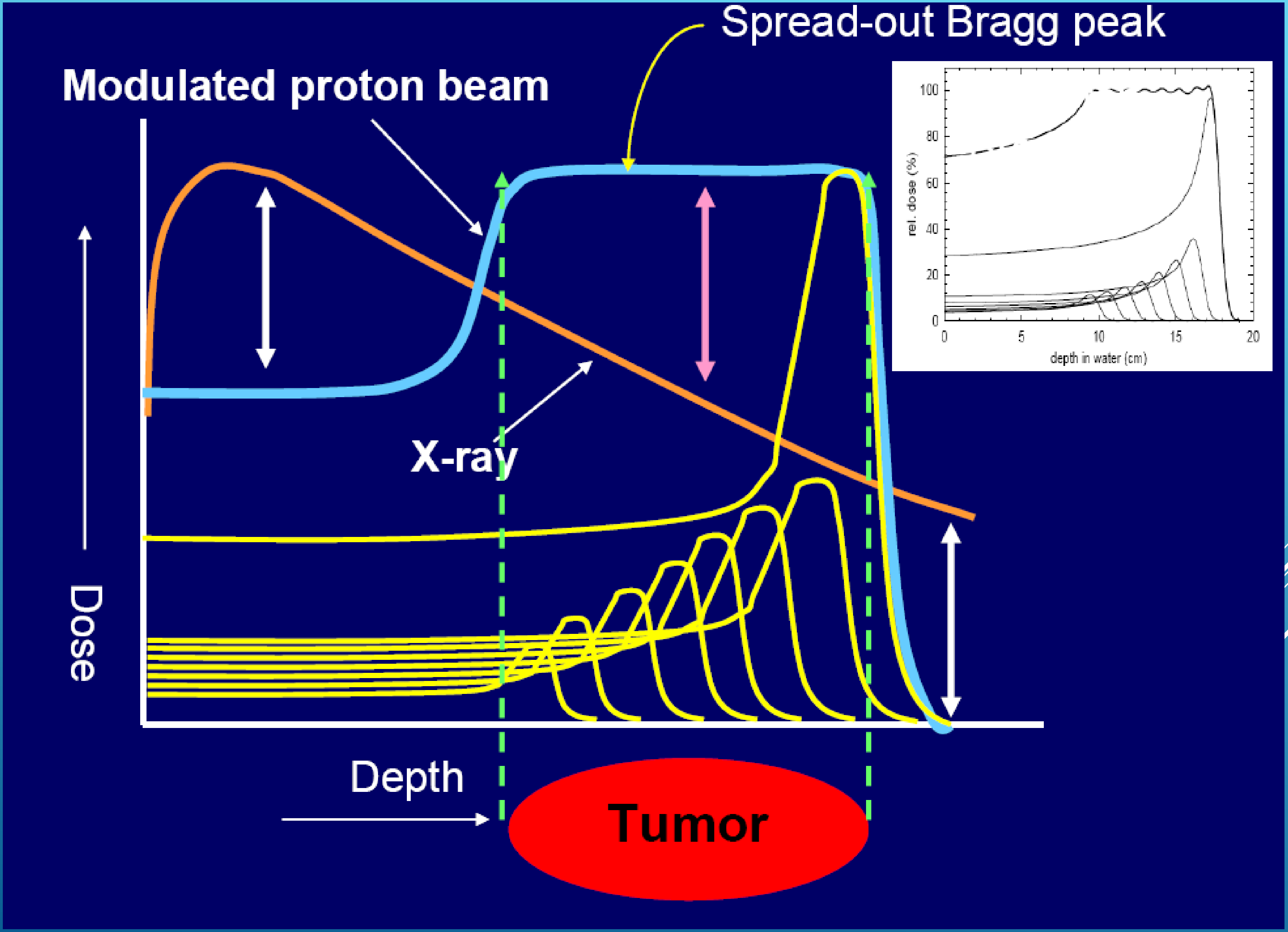


Treatment rooms

碳離子放射治療優勢



參考資料來源 http://www.bestcyclotron.com/particletherapy/

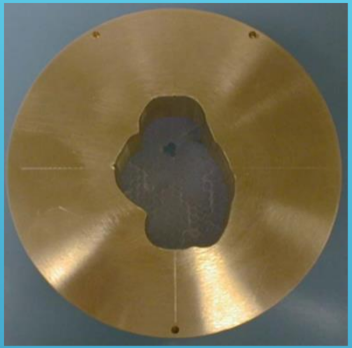


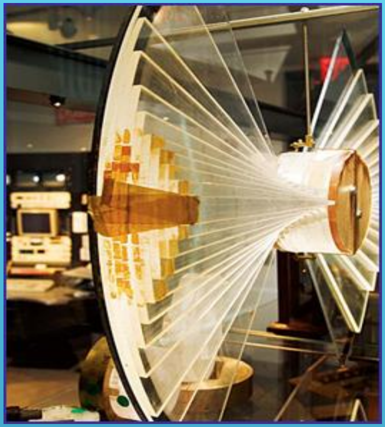
Spread-out Bragg peak
Modulated proton beam
X-ray
Dose
Depth
Tumor
100
80
60
40
20
0
rel. dose (%)
0
5
10
15
20
depth in water (cm)

Particle therapy –beam delivery system

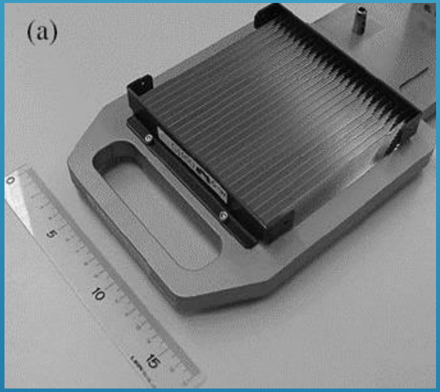
Broad Beam(Passive Scattering)
a.1Wobbling or scattering
a2.RangeModulator/Ridge filter
a3.Aperture and Compensator

b.Scanning
Various modes of particles scanning techniques
1.Discrete spot scanning
2.Raster scanning
3.Dynamin spot scanning



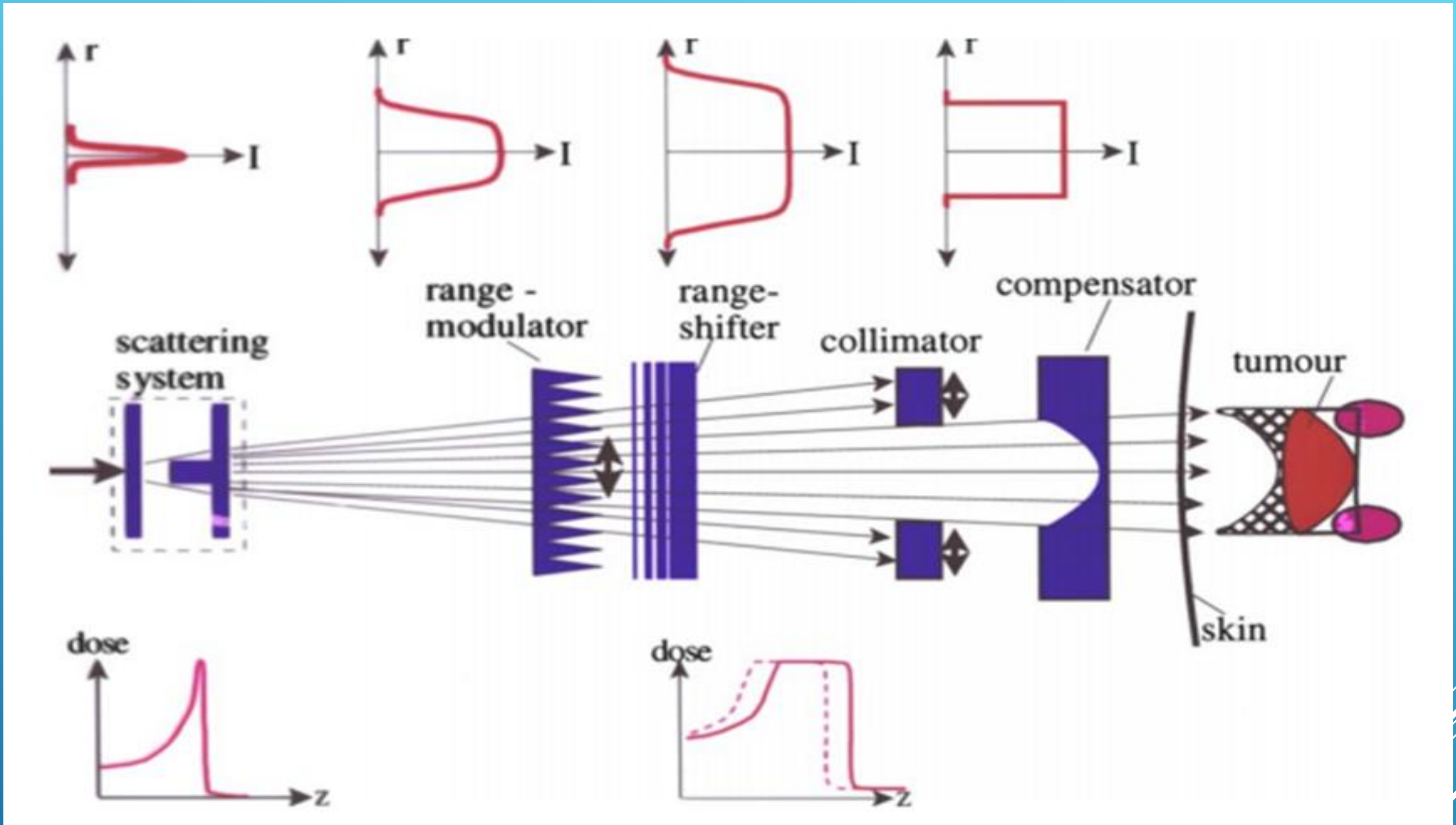


Range modulator wheel



Ridge filter

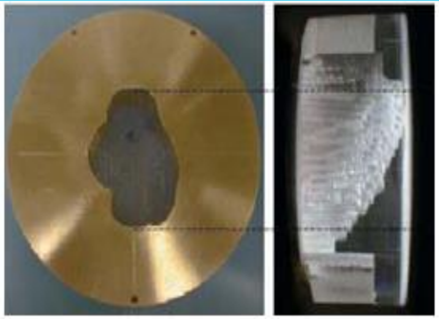
a wheel with 3 different tracks used for different modulation widths

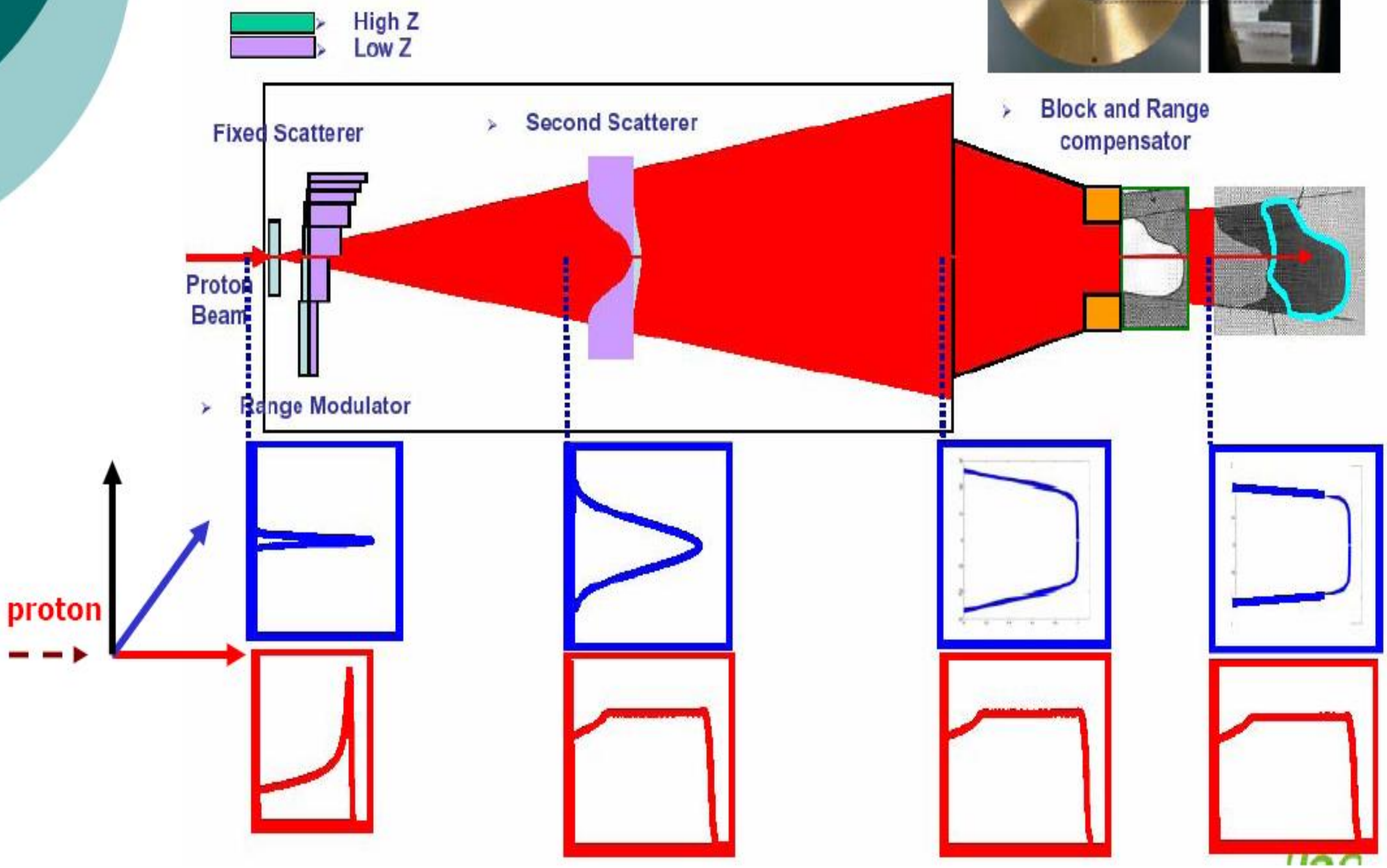


By Daniela Schulz-Ertner Markus-Krankenhaus, MVZ Radiologisches Institut, D-60431 Frankfurt/M., Germany Published 19 February 2010

雙散射系統

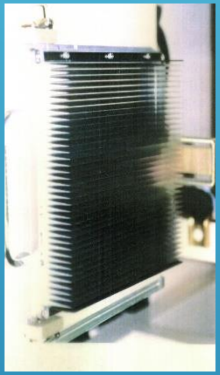
Double scattering





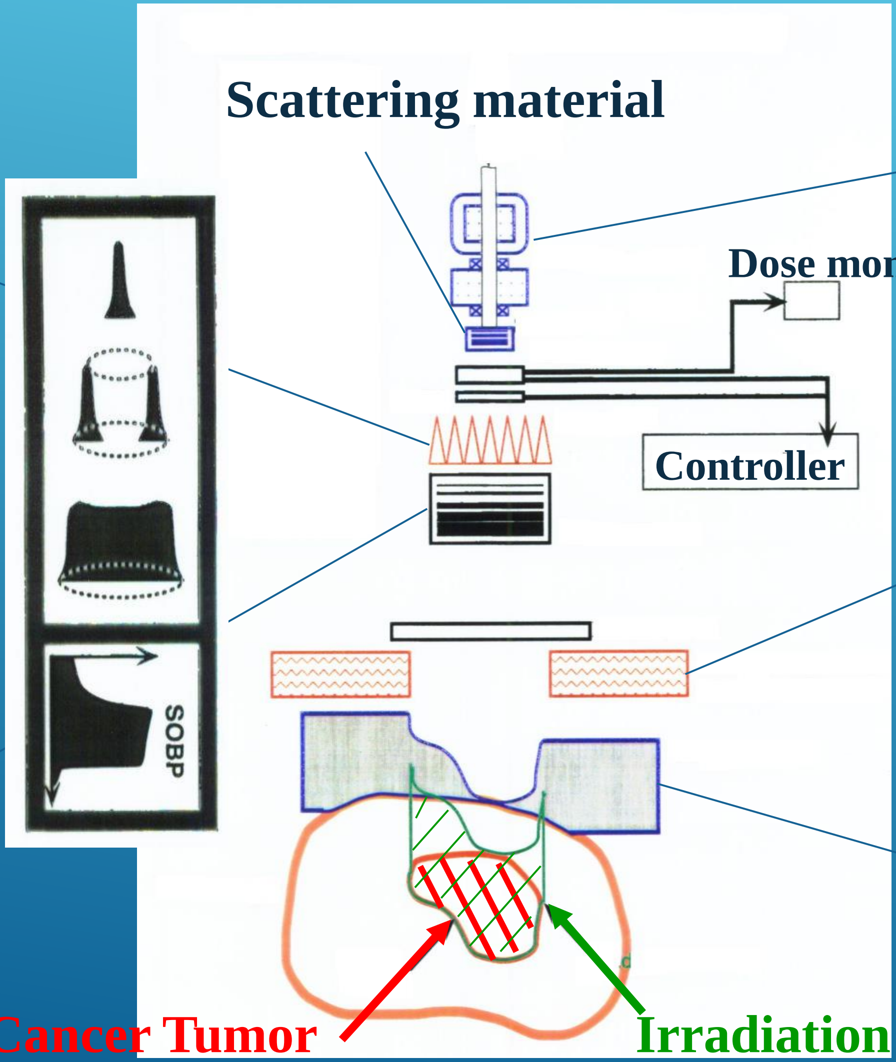
BEAM DELIVERY SYSTEM

- Making of Spread Out Bragg Peak

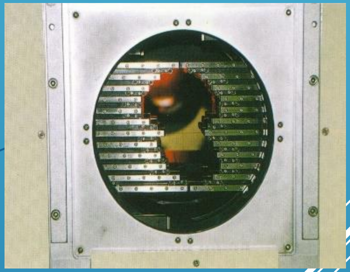


Ridge Filter

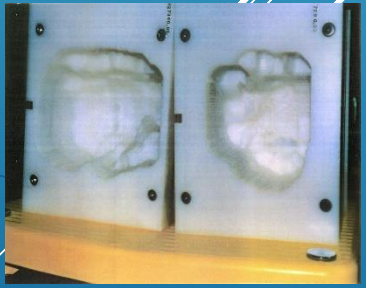
Range Shifter



Wobbling Magnet



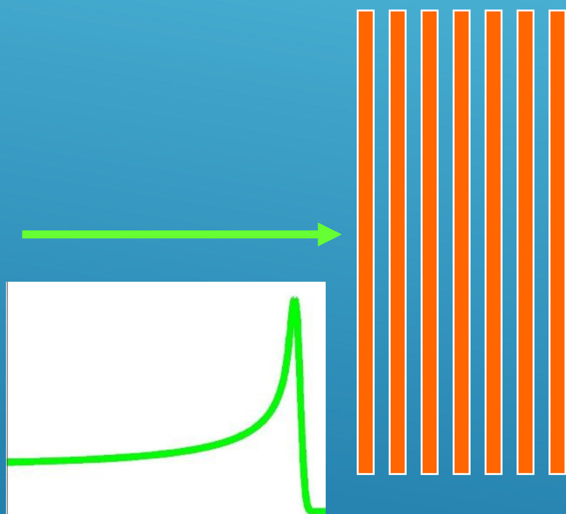
Multi Leaf Collimator

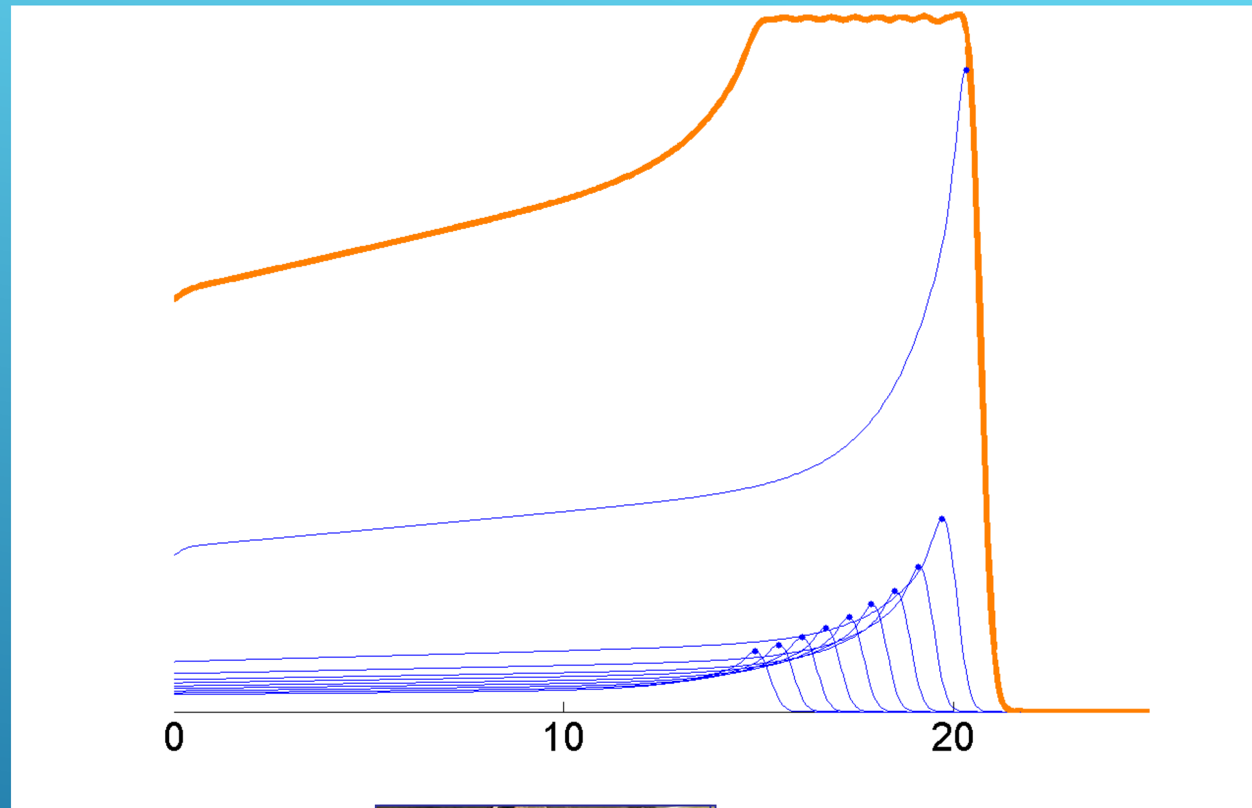


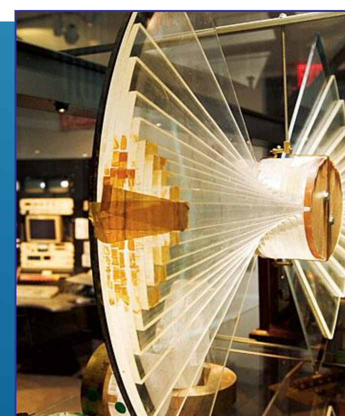
Bolus Collimator

FORMATION OF SOBP

Absorbers of pre-determined thicknesses added successively into beam to “pull back” individual pristine peaks







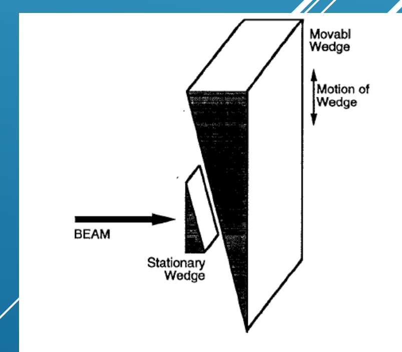
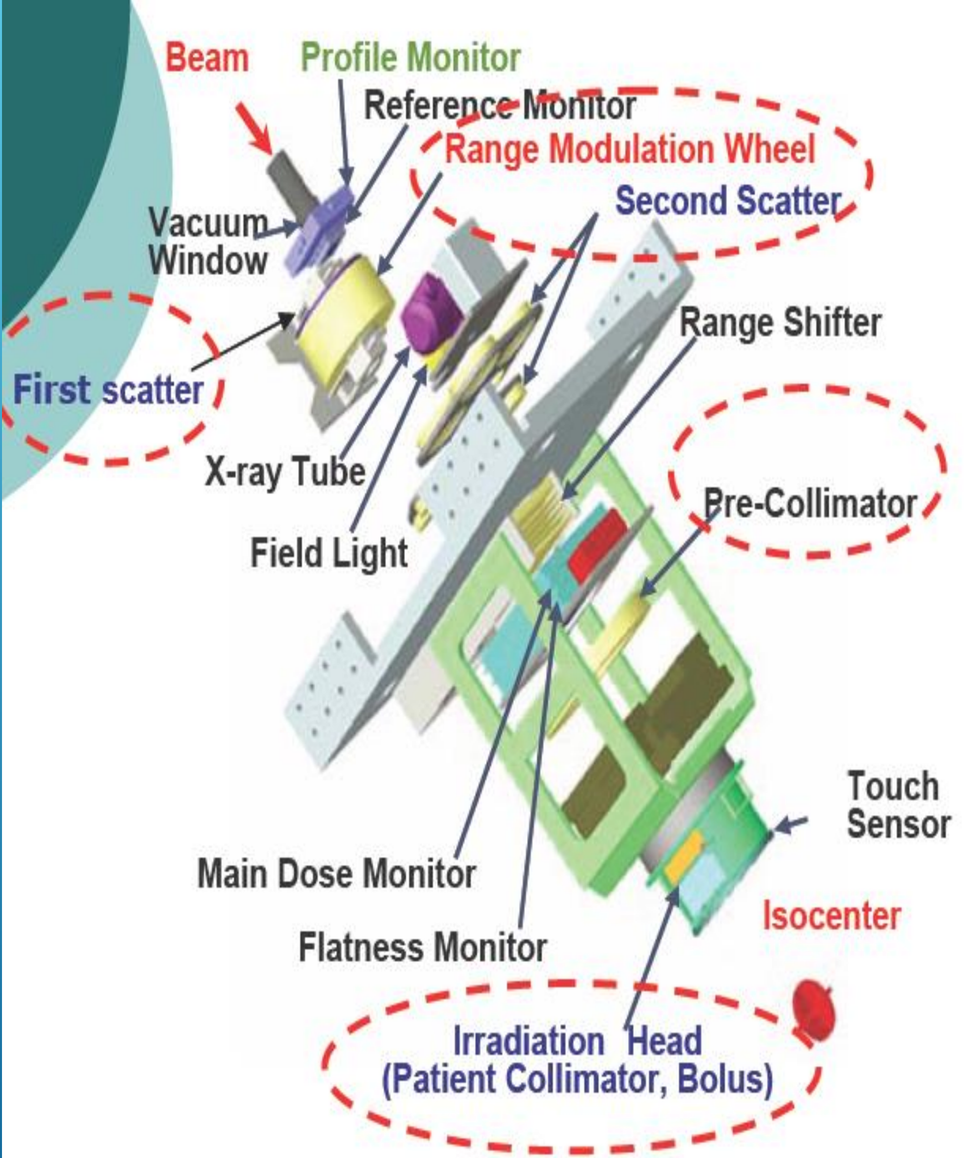
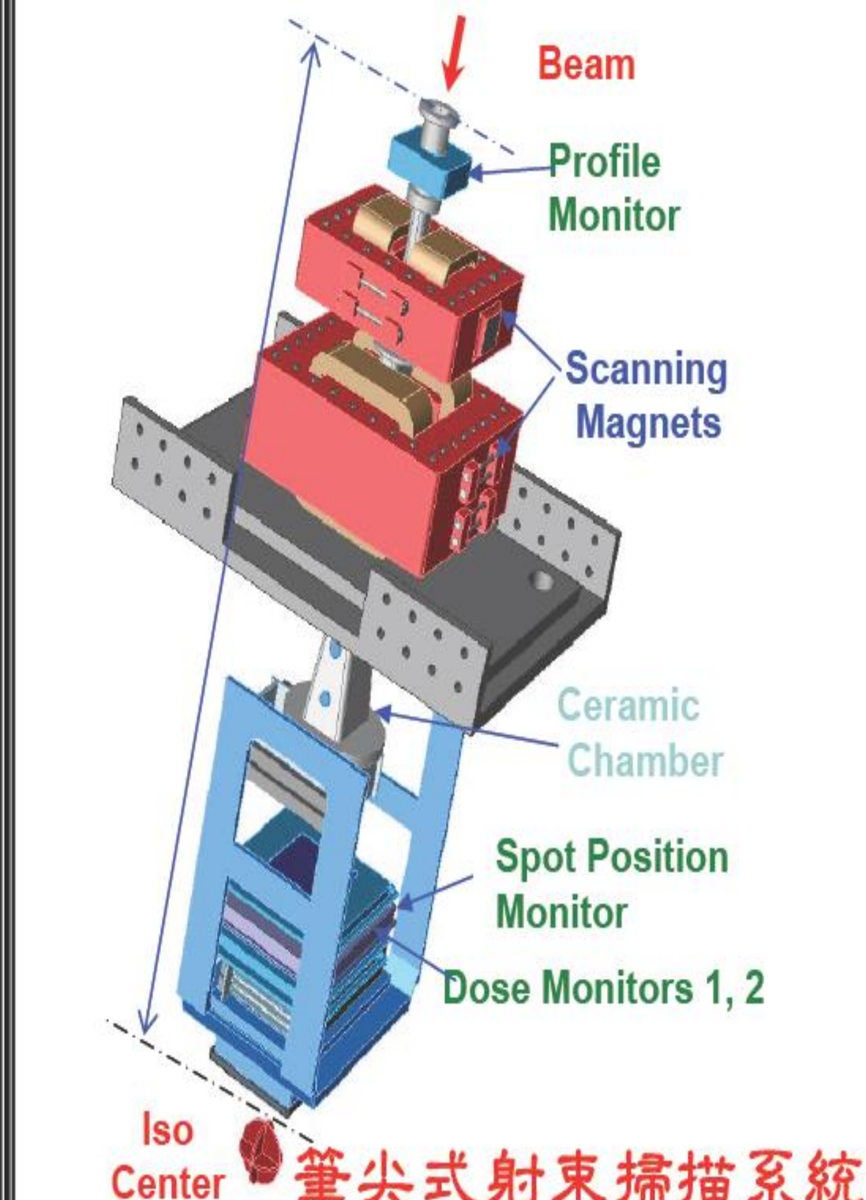


FIG. 18. Schematics of a double wedge system which is used to shift the range of the beam.



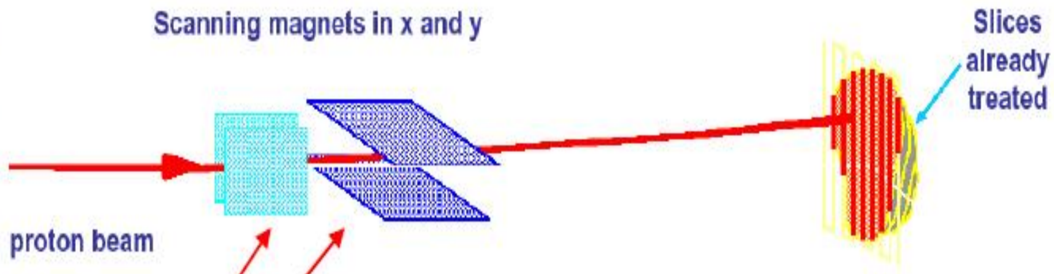
被動式散射系統

Passive beam scattering



筆尖式射束掃描系統

Pencil beam scanning

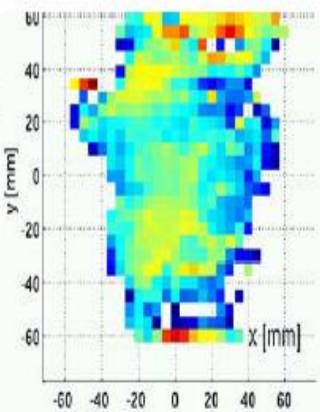


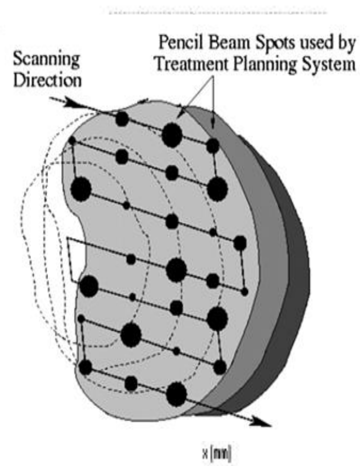
目 的:利用X,Y軸方向磁鐵及

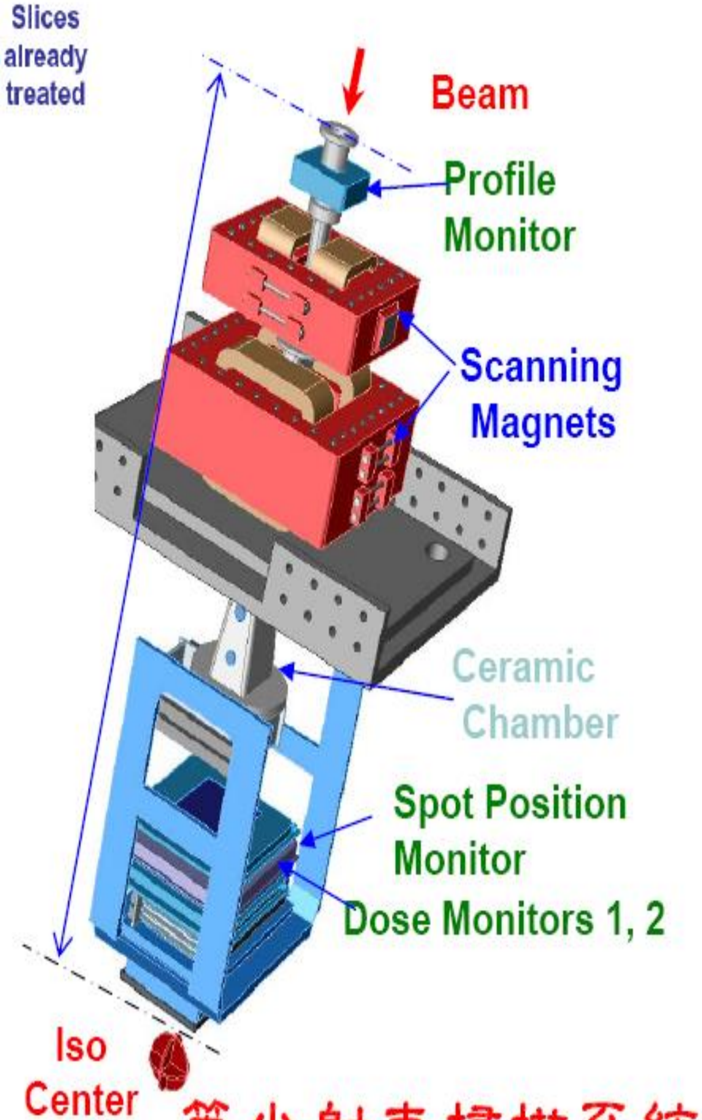
最佳化劑量強度調控技術使得

腫瘤得到均勻的質子射線劑量

(IMPT技術)



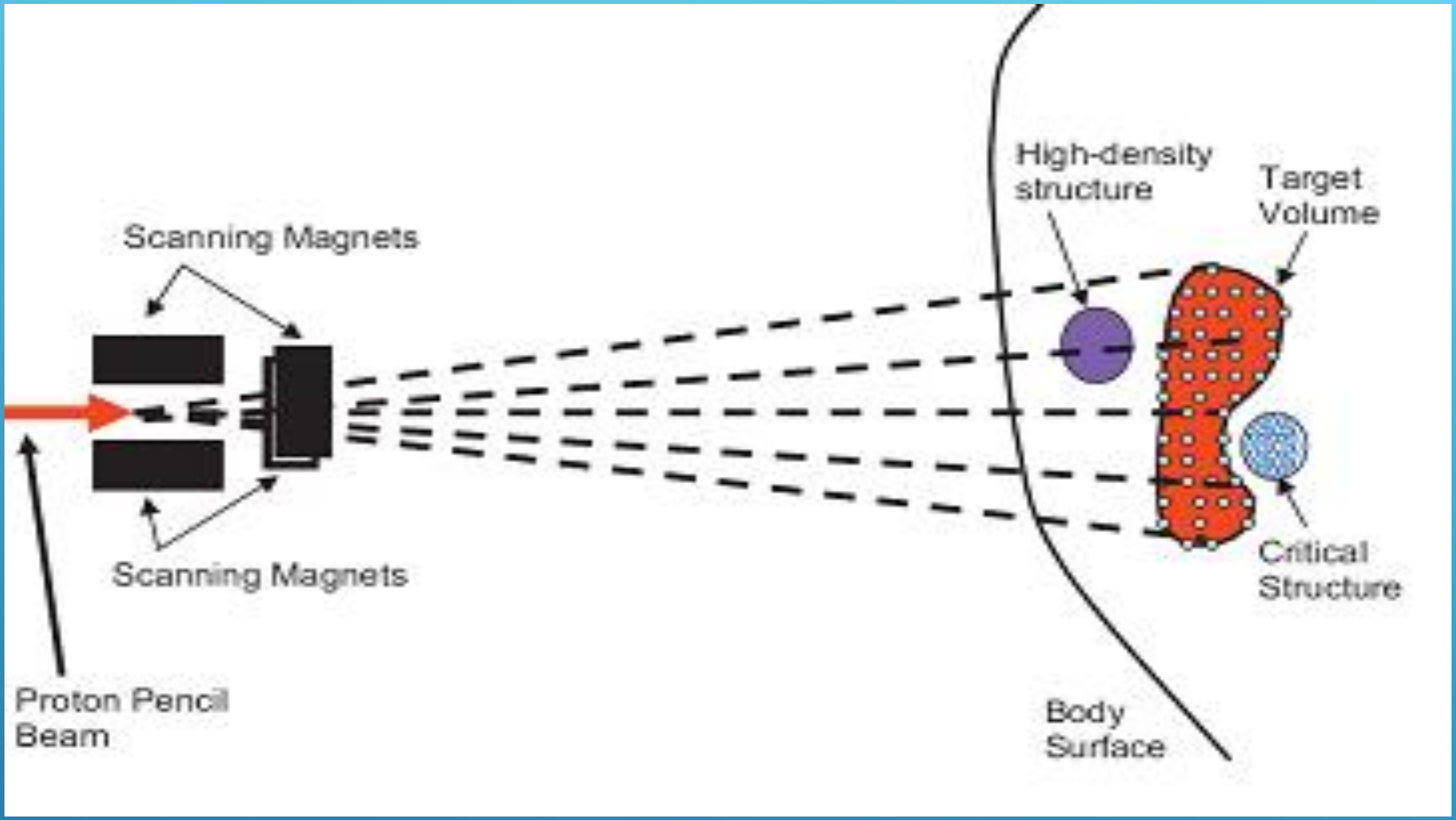




筆尖射束掃描系統

Pencil beam scanning

Pencil Beam Scanning



Powerful scanning magnets direct thousands of ultra fine proton beams, one by one, toward a patient's tumor. Intricate treatment planning allows for the protons to deposit their potent dose of radiation to the exact dimensions of the tumor, leaving nearby healthy tissue and critical structures untouched.

結論與期許

1. 精緻型的質子治療機可能會越來越多
2. 碳離子造價高
3. Pencil beam 為主流
4.雙離子射源或多樣離子的研究性高
5.可以控制及治癒各種困難的癌症

Thank you!