Developments in proton and light-ion therapy

Sandro Rossi

Fondazione CNAO

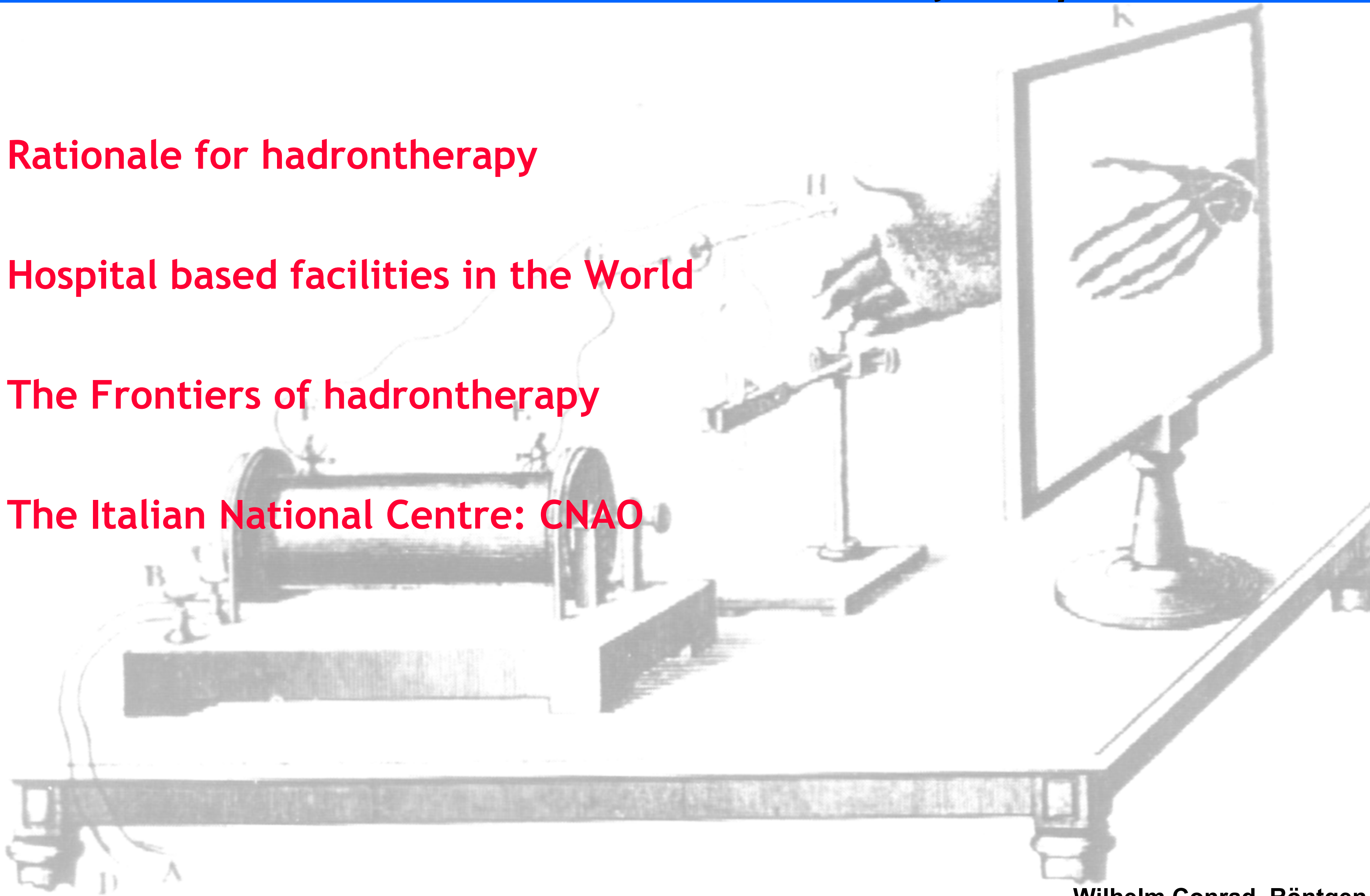
Outline of the presentation

Rationale for hadrontherapy

Hospital based facilities in the World

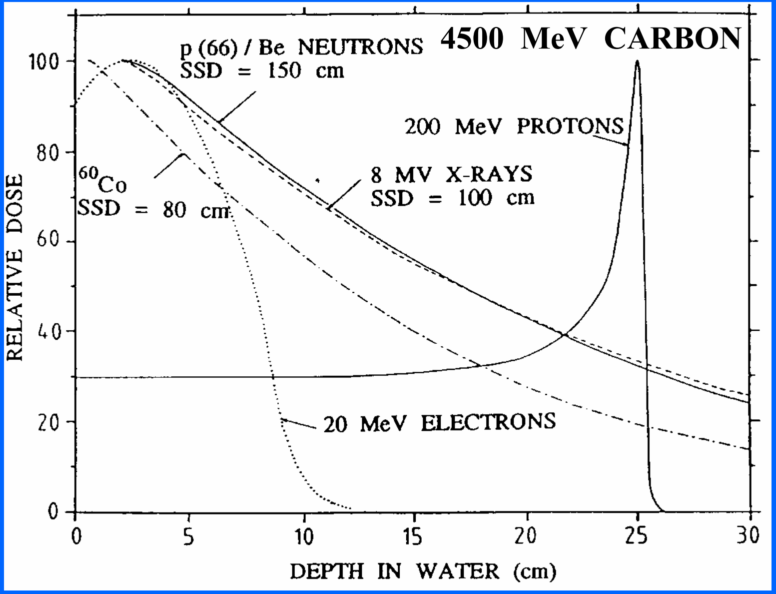
The Frontiers of hadrontherapy

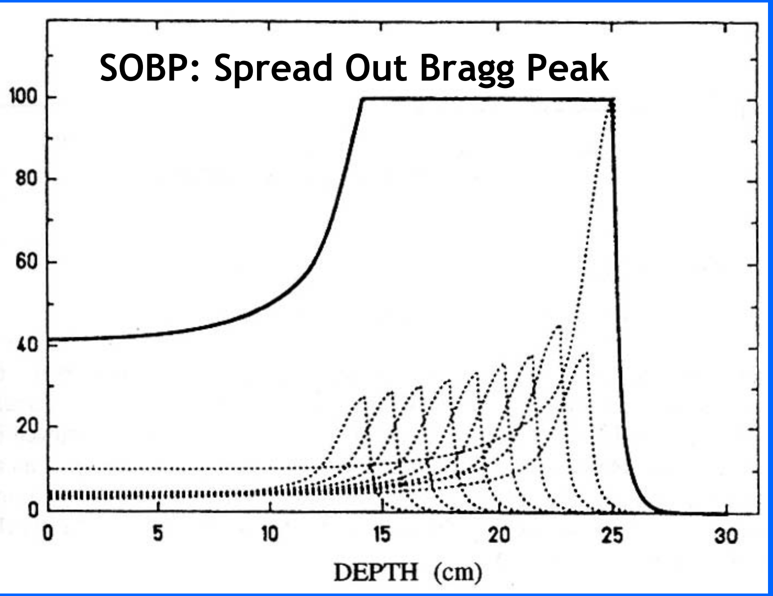
The Italian National Centre: CNAO



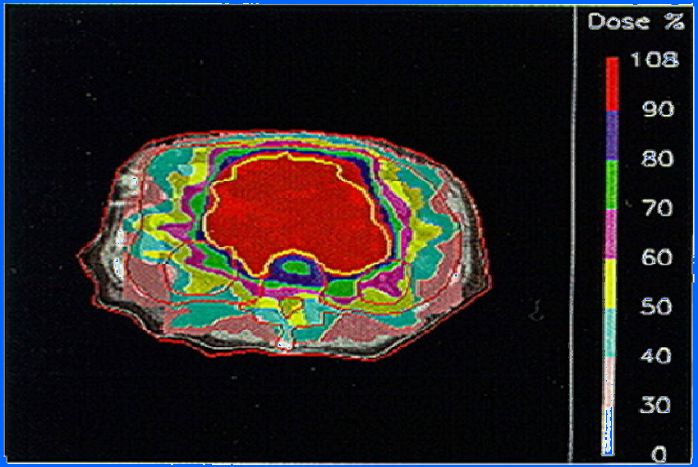
Wilhelm Conrad Röntgen
1895 discovery of X rays

Hadrons: conformal dose irradiation

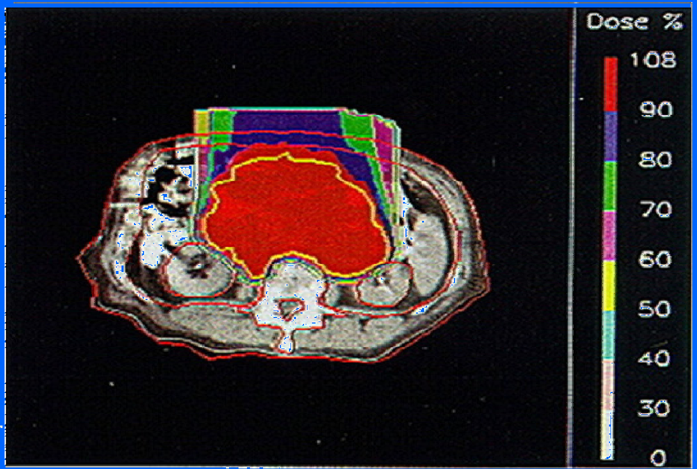




Abdomen



X-ray (IMRT) – 9 fields



Protons – 1 field

Results with protons

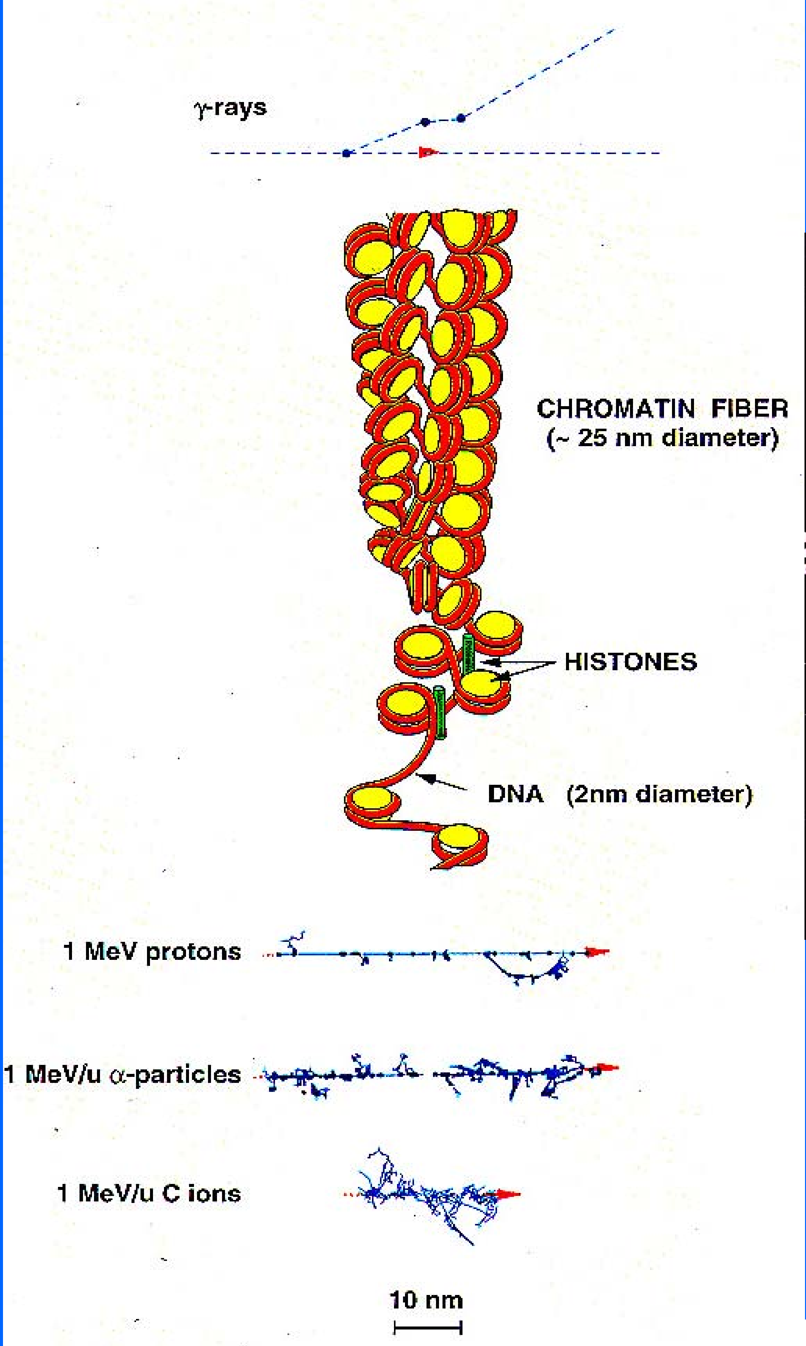
CHORDOMAS OF THE BASE OF THE SKULL		Number of Patients	OS 5 years	OS 10 years	PFS 5 years	PFS 10 years
X-rays	U. Michigan 1986	21	50 %	20 %	-	-
	R. Marsden 1988	25	44 %	17 %	33 %	20 %
	Mallinckrodt 1991	21	74 %	46 %	30 %	-
	Mayo Clinic 1993	51	51 %	35 %	33 %	24 %
	Princess Margaret 1996	13	-	-	15 %	-
Protons	MGH/HCL 1996	169	80 %	54 %	64 %	42 %

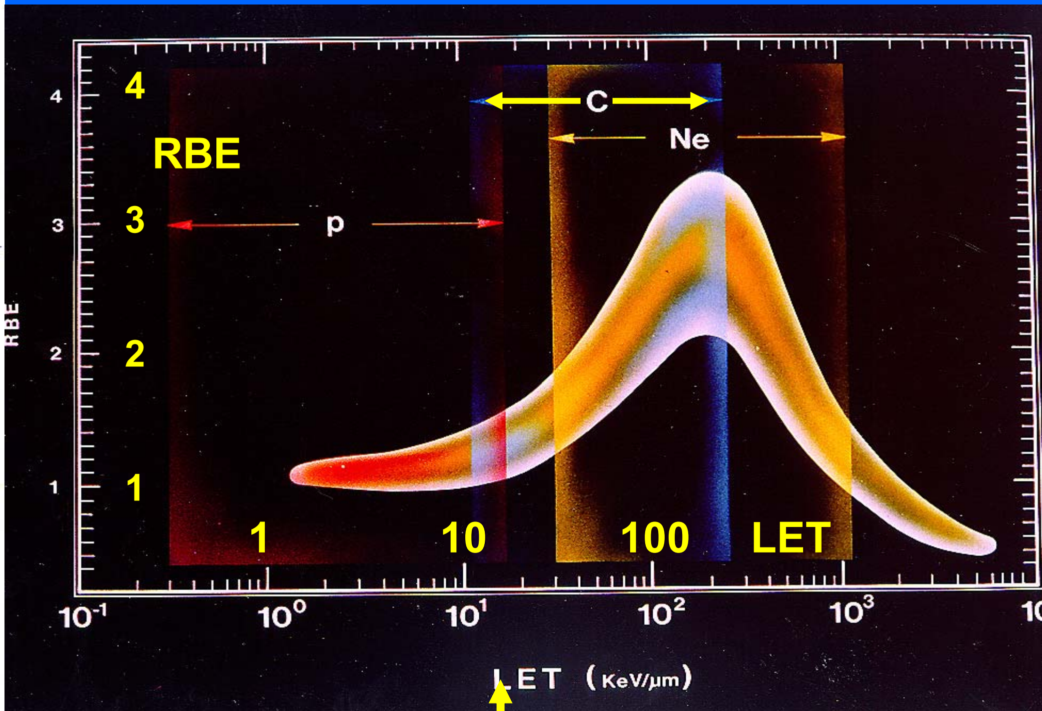
Indications for protontherapy

every 10 M EU citizens

12% of X-ray patients **2'400 pts/year**

Carbon Ions: biological efficacy





10 – 20 keV/mm = 100 – 200 MeV/cm =

20 – 40 eV/(2 nm)

Reduced effect dependence from Oxygen content

Results with carbon ions (Chiba)

NSCLC = Non Small Cell Lung Cancer
182 patients treated with carbon ions

Comment:

The results with CIRT in early stage NSCLC are impressive with a local control rate ranging from 62% to 100% and a 3 year survival between 65 and 88%. Two Japanese studies with modern photon beam radiotherapy in early stage NSCLC can be mentioned in comparison. In the study reported in 1997 by Morita *et al*, 149 patients with stage I were treated with a total dose of 64.7 Gy in 32 fractions. The local control rate was 56% and 3 year survival 34.2%. In the study reported in 1999 by Hayakawa *et al*, 36 patients received 60-81 Gy in 2 Gy fractions. The local control rate was 80.6% and 3 year survival 42%.

Indications for carbontherapy

every 10 M EU citizens

3% of X-ray patients **600 pts/year**

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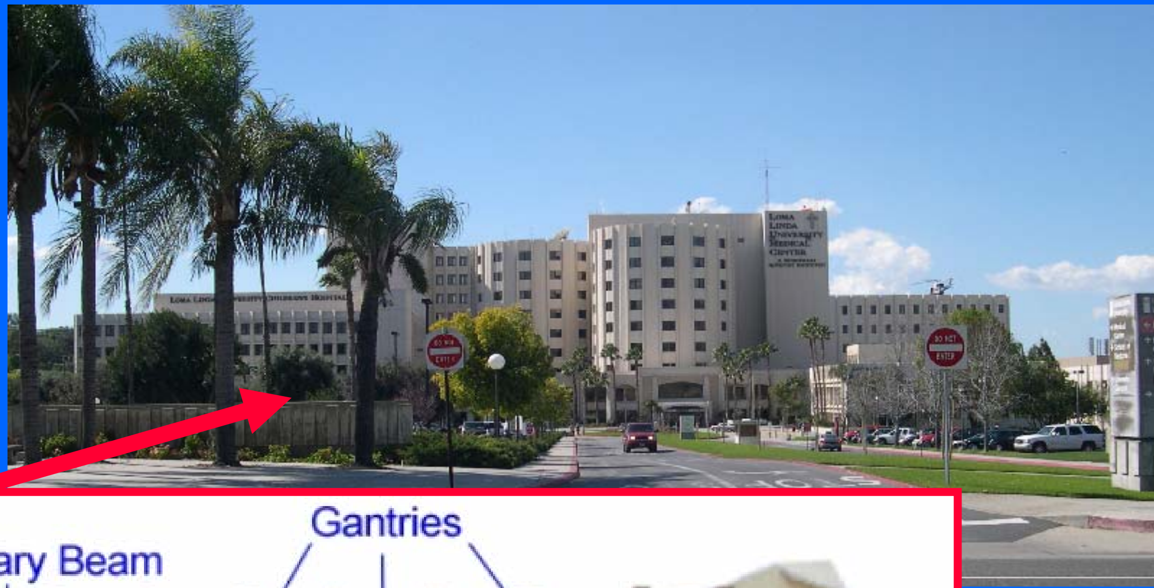
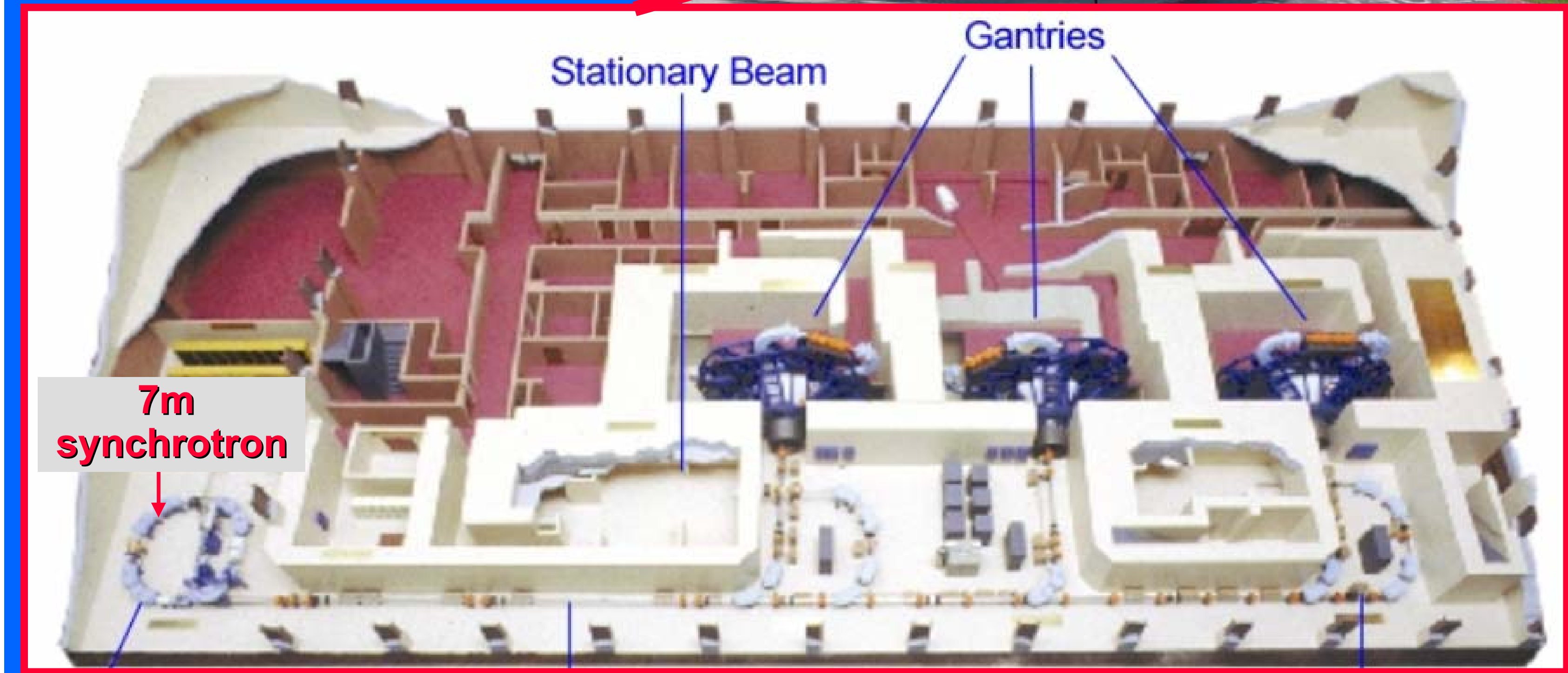
Wilhelm Conrad Röntgen
1895 discovery of X rays

Loma Linda University Medical Center: first patient 1992

- **First hospital-based proton-therapy centre**
- **2005:160 sessions/day**





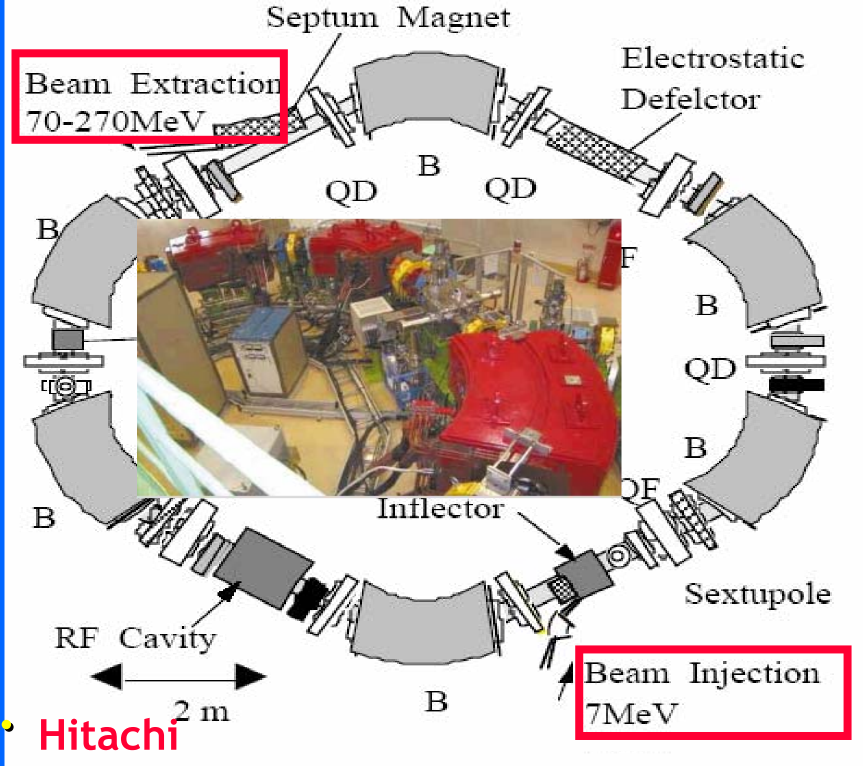
Protons: ten years of tenders

Year	Customer	Provider
1995	MGH, Boston MA, USA	IBA
1996	NCC, Kashiwa, Japan	SHI-IBA
1996-99	Tsukuba University	Hitachi
	Wakasa Wan Energy Research Center	Hitachi
	Shizuoka Prefecture	Mitsubishi
2001	PSI – Villigen, Switzerland	ACCEL
	Wanjie Tumor Hospital – Zibo, China	IBA
	Chang An PMC – Beijing, China	IBA
2002	Rinecker PTC – Munchen, Germany	ACCEL
	Korean NCC - Seoul	IBA
	IUCF (MPRI), Bloomington IN, USA	IBA
	M.D. Anderson CC, Houston TX, USA	Hitachi
2004	University of Florida, Jacksonville FL, USA	IBA

Hospital centres for deep protontherapy (>500 pts/year)

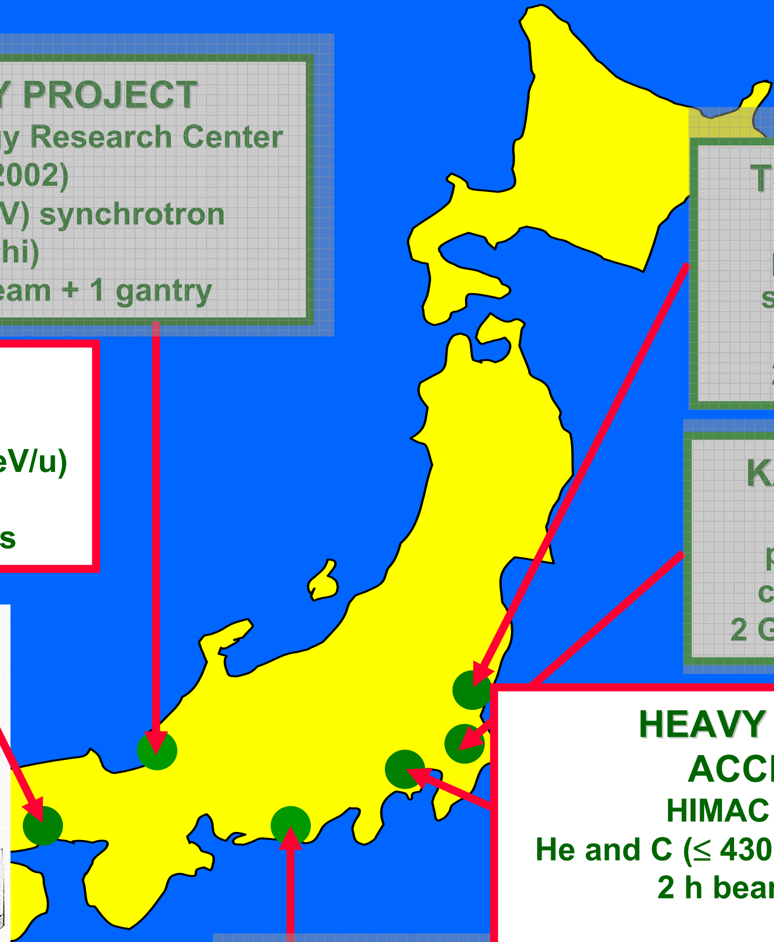
5 in USA, 4 in Japan, 2 in China, 1 in Korea, 1 in Switzerland, 1 in Germany, 1 in France and 1 in Italy

(running or financed)



Protontherapy: a mature market…

Carbon Ions: Japan 2+ centres



WAKASA BAY PROJECT
by Wakasa-Bay Energy Research Center
Fukui (2002)
protons (≤ 200 MeV) synchrotron
(Hitachi)
1 h beam + 1 v beam + 1 gantry

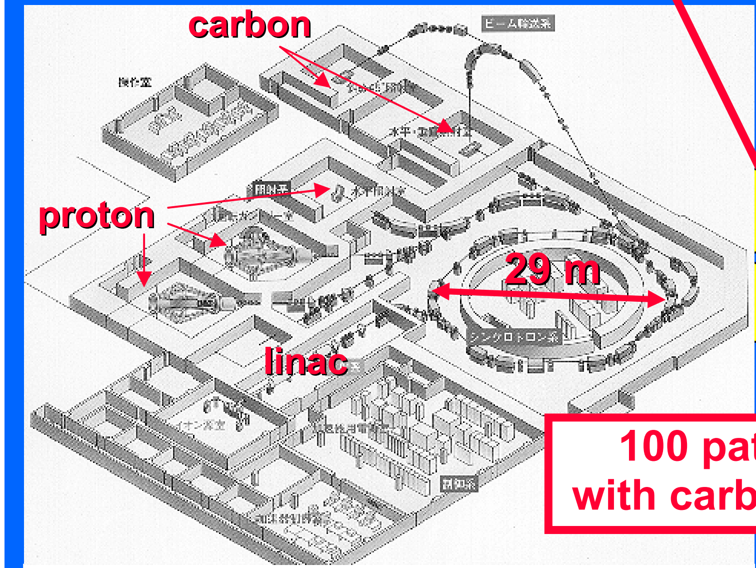
TSUKUBA CENTRE
Ibaraki (2001)
protons (≤ 270 MeV)
synchrotron (Hitachi)
2 gantries
2 beam for research

HYOGO MED CENTRE
Hyogo (2001)
protons (≤ 230 MeV) - He and C ions (≤ 320 MeV/u)
Mitsubishi synchrotron
2 p gantries + 2 fixed p beam + 2 ion rooms

KASHIWA CENTER
Chiba (1998)
protons (≤ 235 MeV)
cyclotron (IBA – SHI)
2 Gantries + 1 hor. beam

HEAVY ION MEDICAL ACCELERATOR
HIMAC of NIRS (1995)
He and C (≤ 430 MeV/u) 2 synchrotrons
2 h beams + 2 v beams

+ GUNMA UNIVERSITY



100 patients with carbon ions

SHIZUO
Shizuoka (2002)
Proton synchrotron
2 gantries + 1 h beam

2300 patients with carbon ions

Mitsubishi: turn-key system

EUROPE: GSI pilot project and Enlight

More then 200 patients treated with carbon ions, active scanning + In beam PET

Approved projects (with ions): HIT (D)-CNAO (I)-MedAustron (A)-ETOILE (F)

Many projects around Europe…

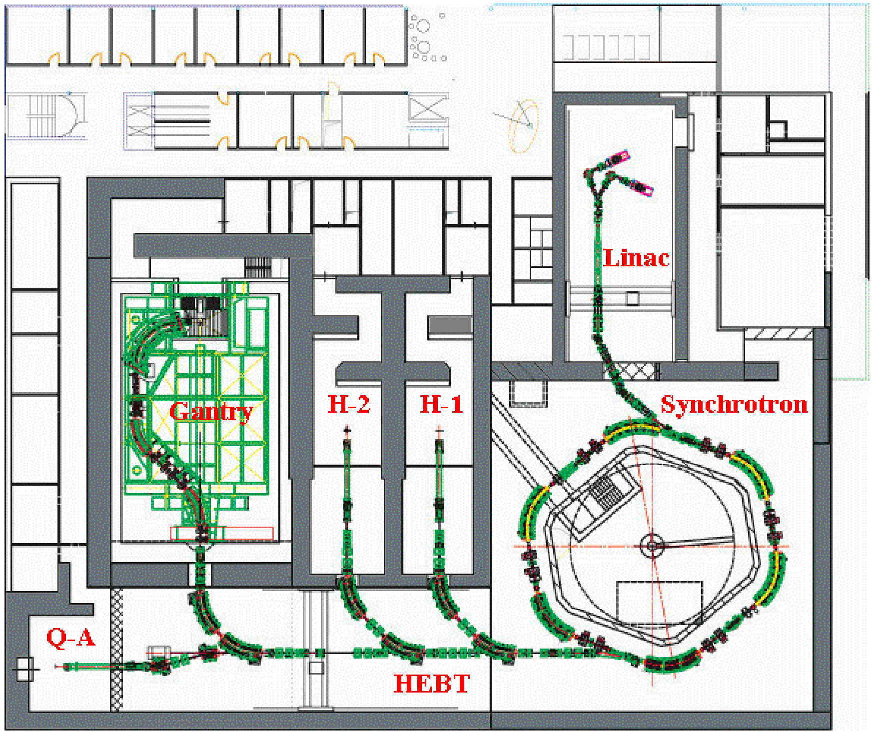
Coordination networks ENLIGHT (5 FP) and ENLIGHT++ (7 FP) :
European Network for LIGht-ion Hadron Therapy ++

HIT
The Heidelberg Ion Therapy Center

First patient: end of 2007

- compact design
- rasterscanning only
- low-LET modality: Protons (later He)
- high-LET modality: Carbon (Oxygen)
- > 1000 patients/year

  > 15.000 fractions/year



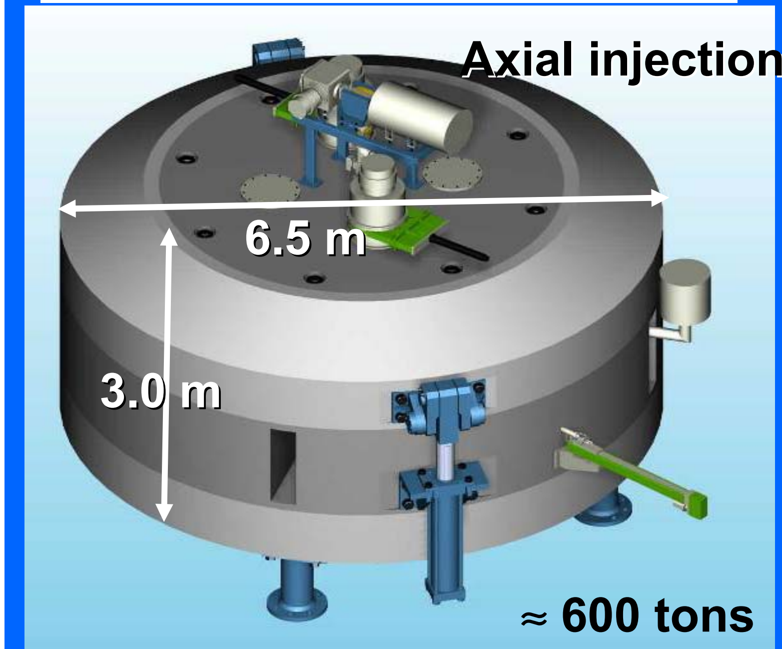
(Pictures courtesy of T. Haberer)

EU firms are interested, but “experts” support is still needed

Other firms:

ACCEL

IBA (400 MeV/U SC cyclotron)



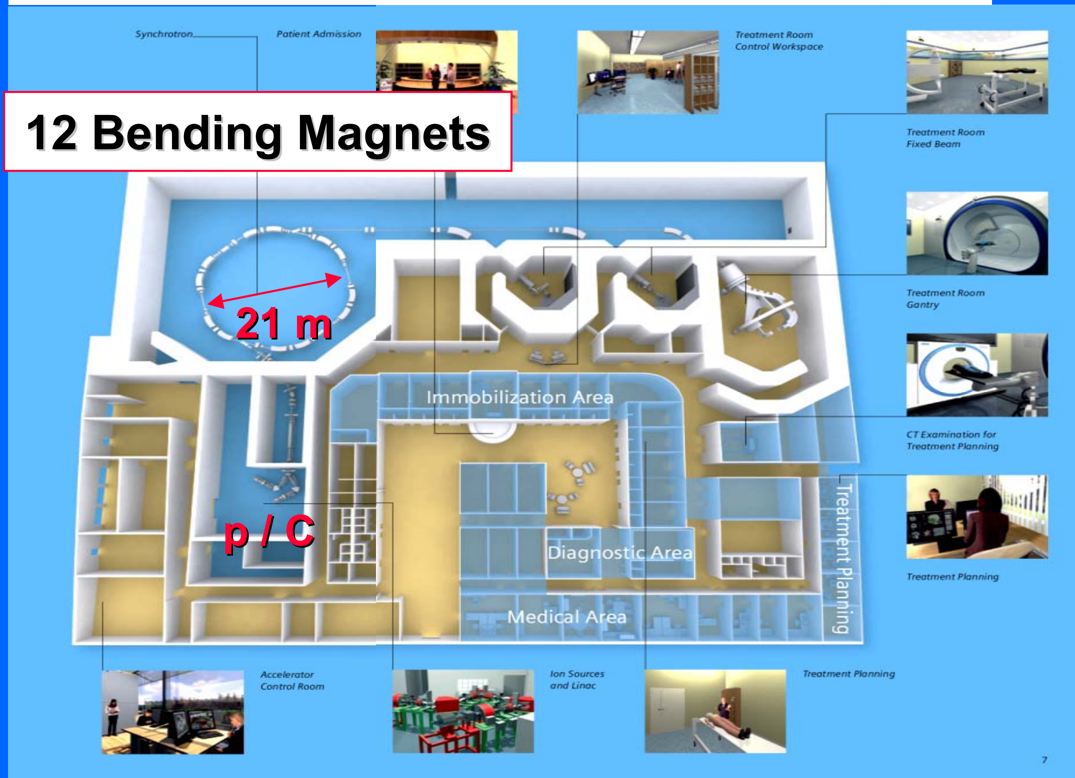
(Picture courtesy of IBA/Y. Jongen)

GSI SIEMENS

Darmstadt, October 8, 2003

A decisive milestone in the battle against cancer

Siemens and GSI signed a contract for a new method irradiating tumors that also provides a larger patient cohort with access to this method.



(Picture courtesy of Siemens Medical)

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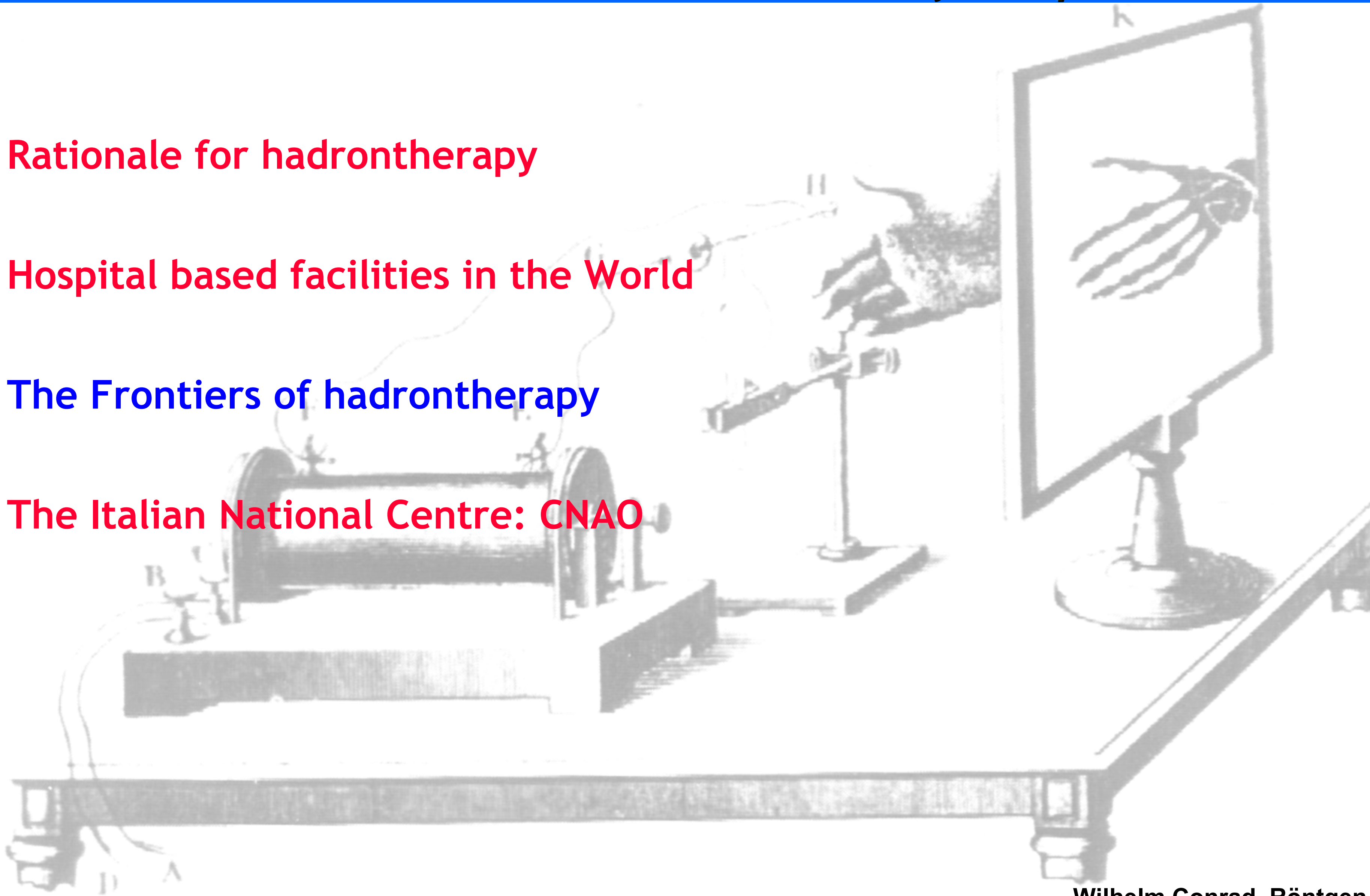
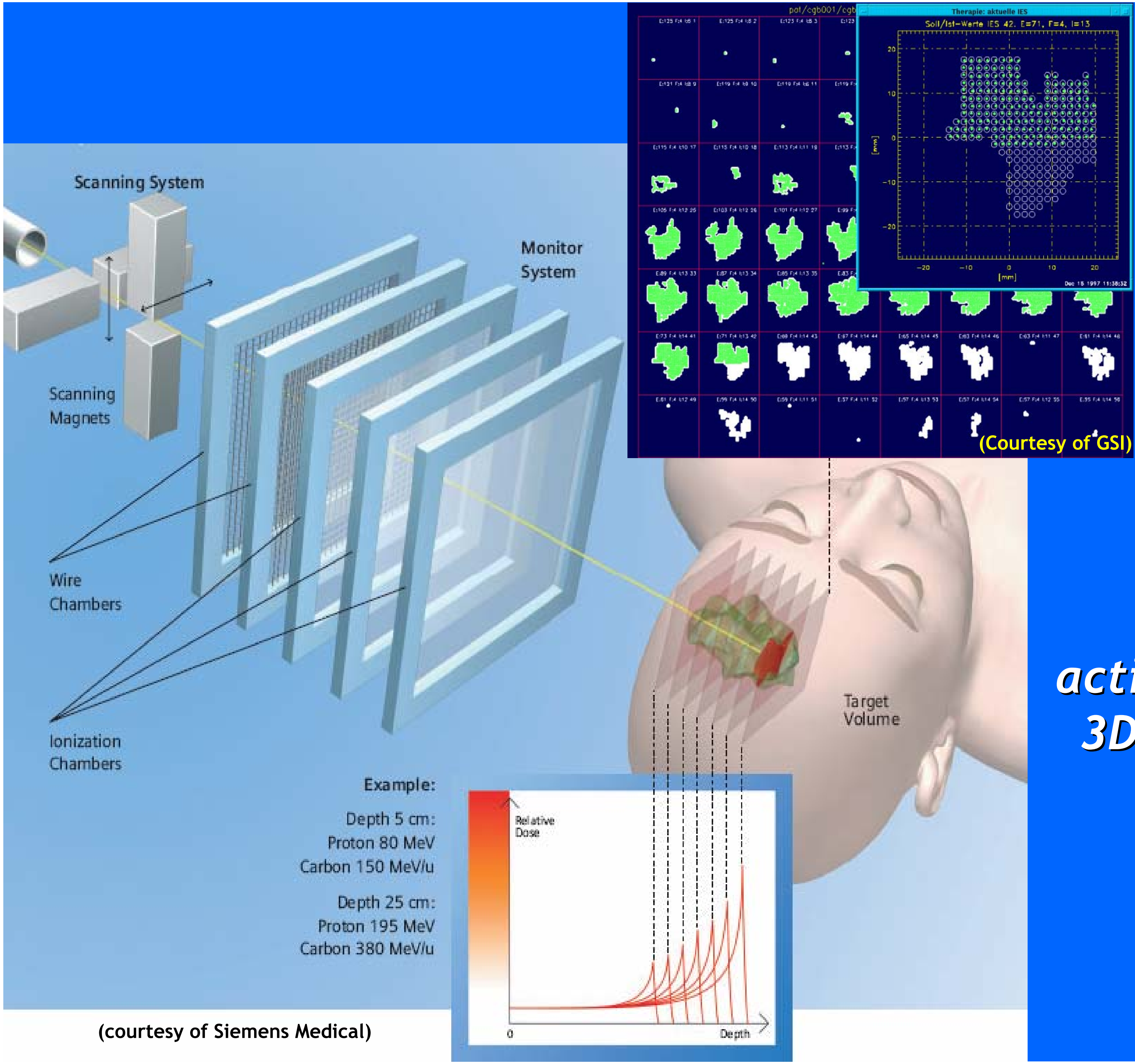


Wilhelm Conrad Röntgen
1895 discovery of X rays



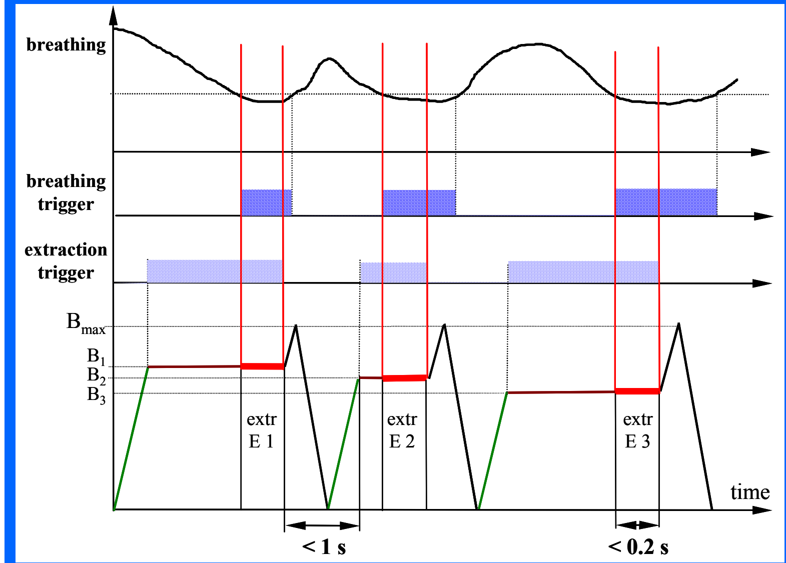
(courtesy of Siemens Medical)

Irradiation technique: active scanning 3D adaptation

Tracking Optimisation (Time coordinate)

Already applied in Chiba:

breathing synchronisation

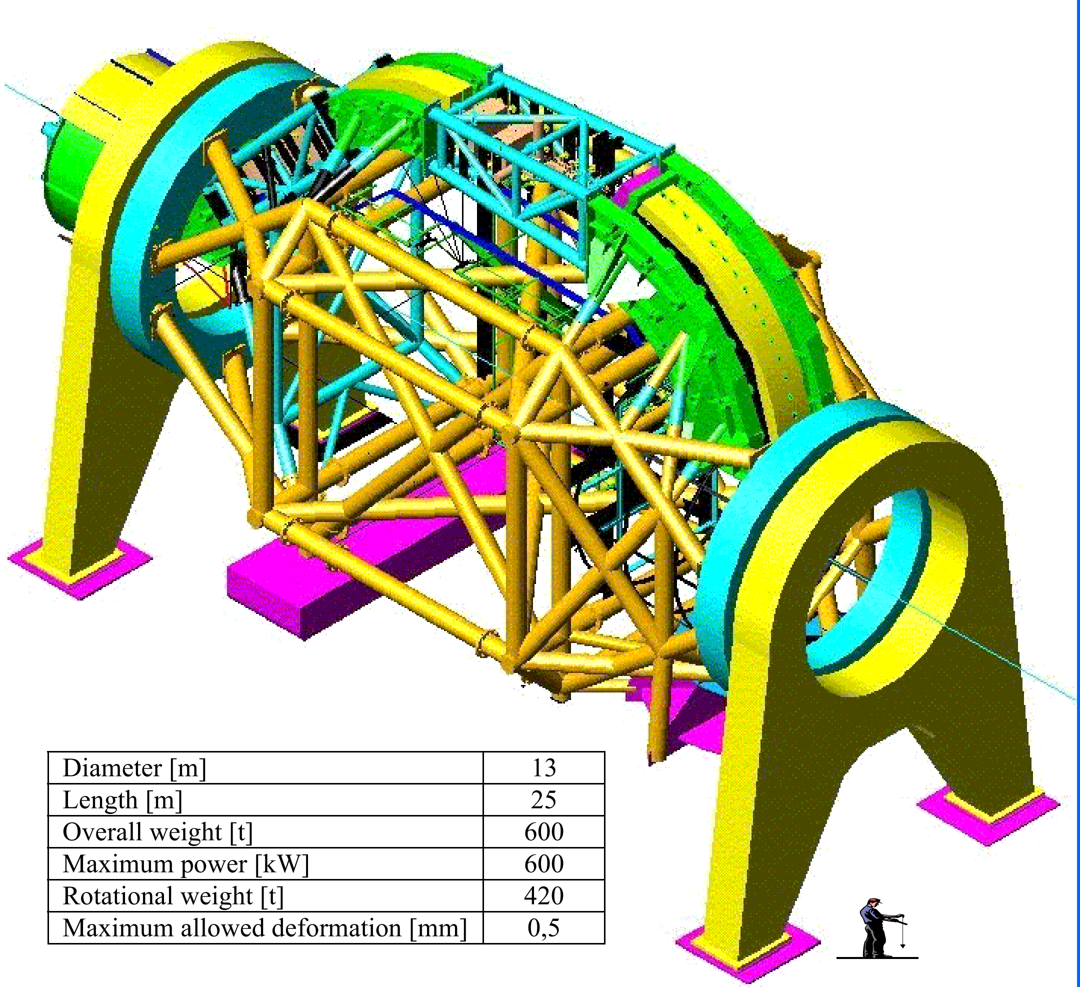


Interesting also for IMRT:
lots of efforts and devices

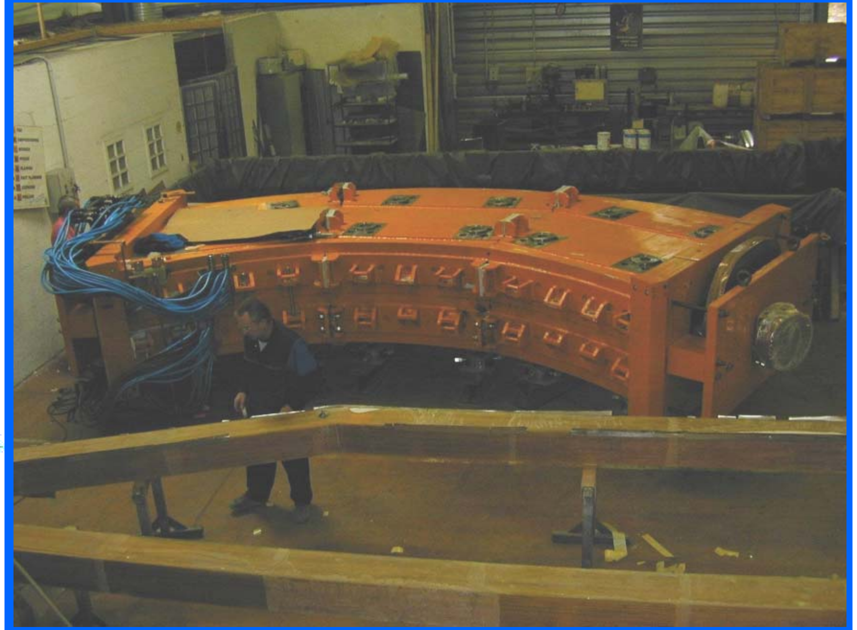
(Courtesy of Medical Intelligence)

GSI Gantry – In construction for Heidelberg

Adaptive radiotherapy:
Gantry Optimisation



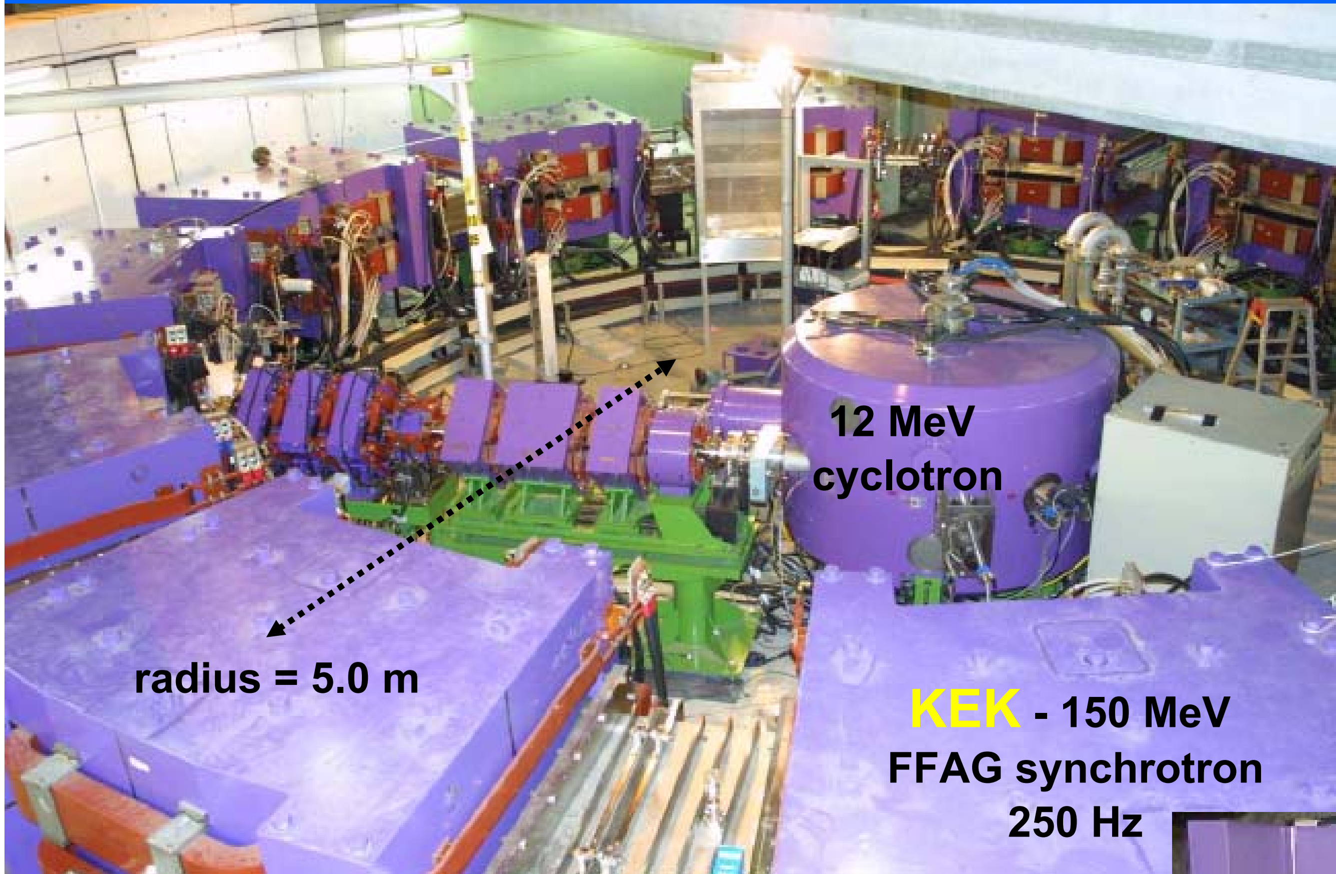
Diameter [m]	13
Length [m]	25
Overall weight [t]	600
Maximum power [kW]	600
Rotational weight [t]	420
Maximum allowed deformation [mm]	0,5



Superconductivity – FFAG magnets - … ?

Integrated system: optics, technology, scanning, patient positioning

“Novel” accelerator concepts: *FFAG synchrotron*



Typical dFd dipole triplet

Return-yoke free magnet

easy injection+extraction

Aim: compact, high rep.rate (scanning),

cost-effective accelerators for hadrontherapy ?

IDRA = Istituto per la Diagnostica e la Radioterapia Avanzate
TERA - patent pending

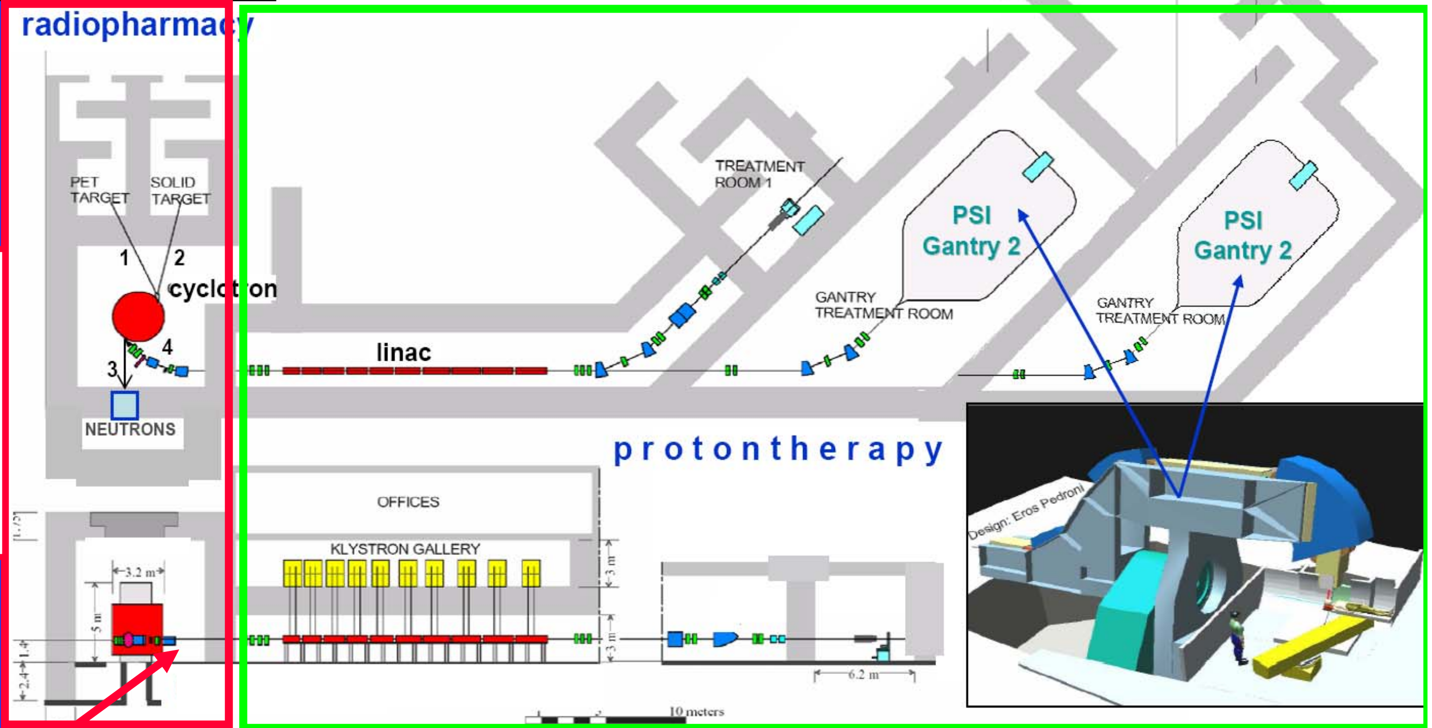
Novel accelerator concepts: IDRA (cyclinac)

Radioisotopes etc.

Production

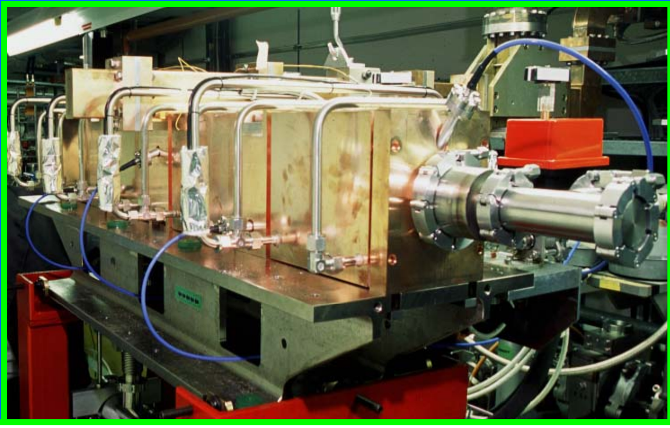
(PET, SPECT, BNCT…

Commercial product



30 MeV

100 μA – 1 mA



Protontherapy

Prototype successful

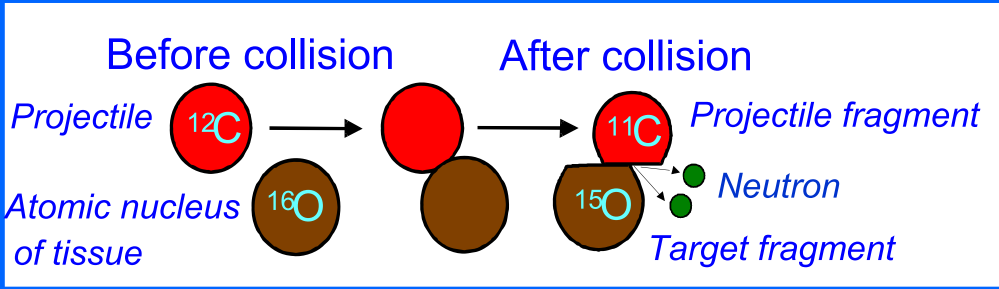
< 210 MeV
< 8 nA

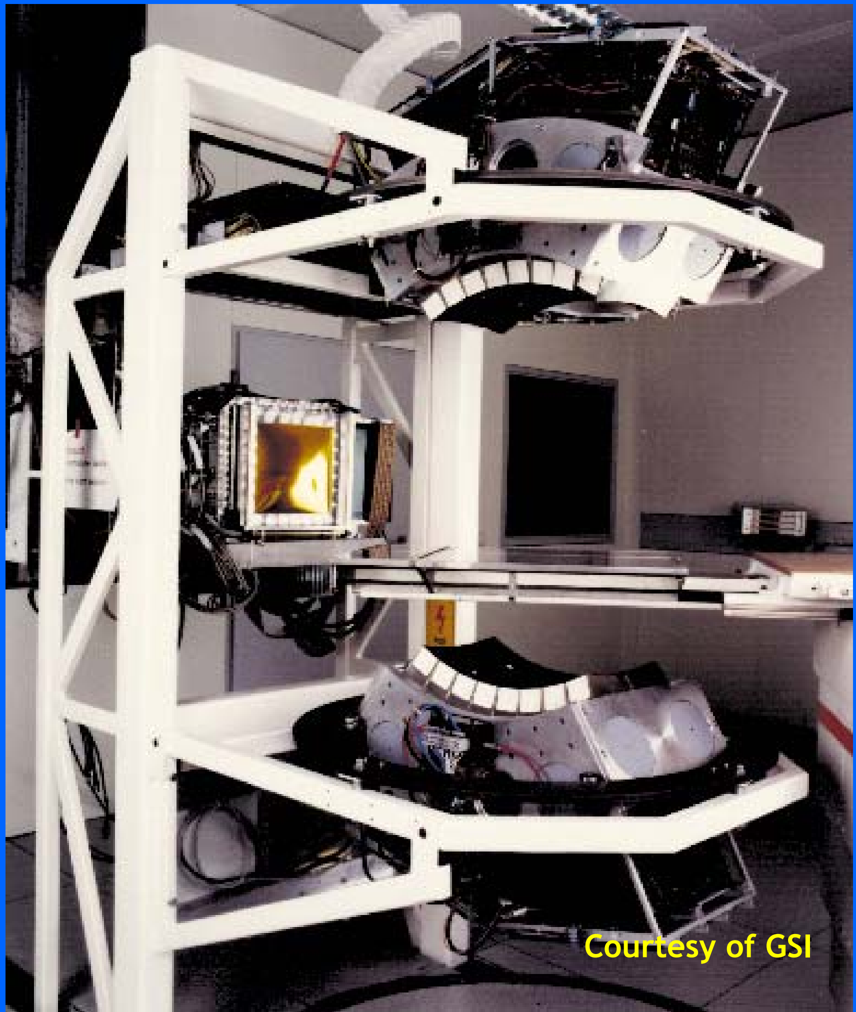
(Pictures courtesy of U. Amaldi)

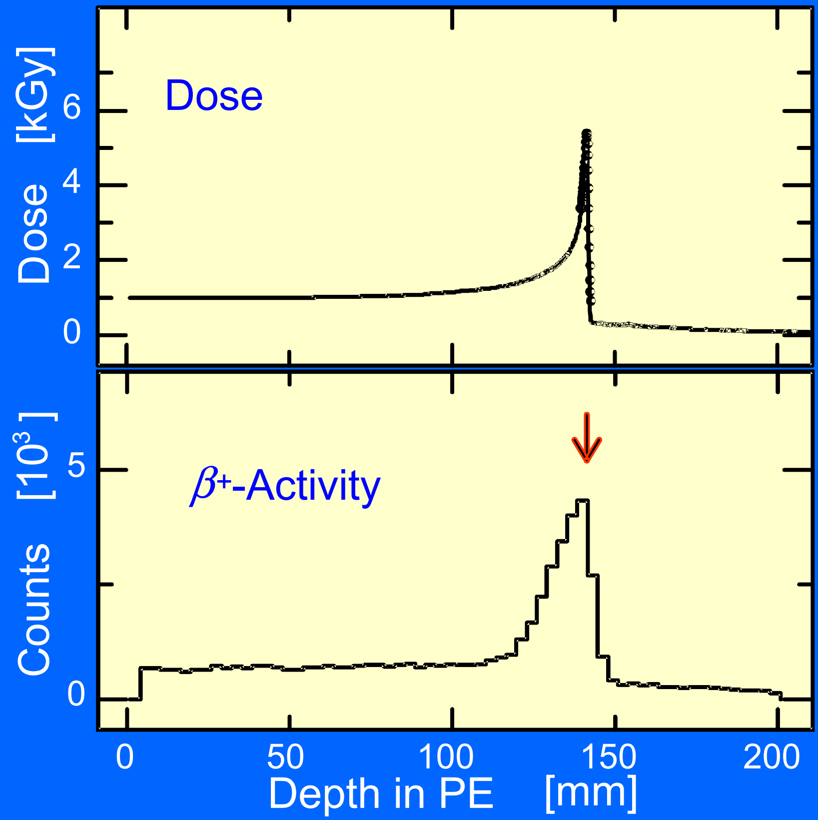
Linac Booster = LIBO (3 GHz) lenght = 16.4 m

CABOTO
for carbon

Imaging: quality assurance - In beam PET



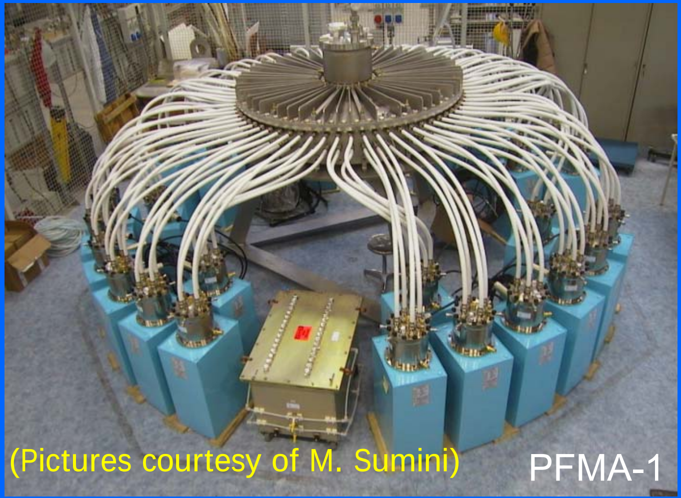




R&D Topics:

Increase efficiency, solid angle coverage, new detectors (gas), quantitative measurements of the dose

Long (?) range perspectives



PFMA-1

Plasma Focus for Medical Applications

Aim: device for 18-F production,

150 kJ (350 μF @ 30 kV)

1 Hz repetition frequency

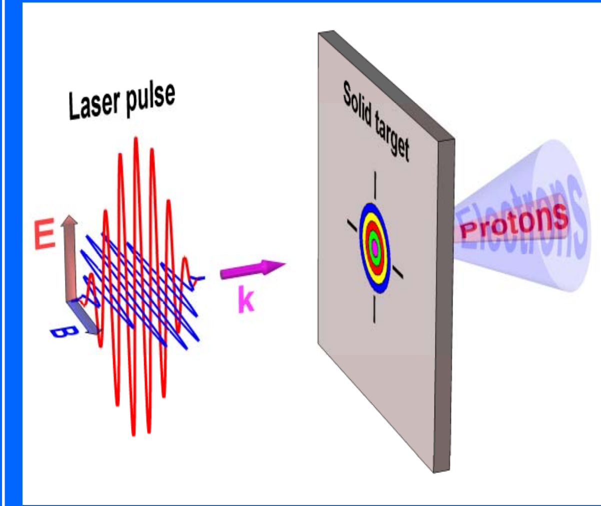
To breed ~ 1 Ci of F^{18} in 2 hours.

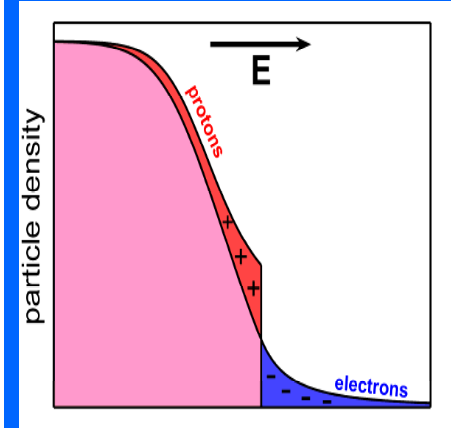
UNIVERSITY OF BOLOGNA

azienda Ulss 12 veneziana

ABO PROJECT 2010

UNIVERSITY OF FERRARA





The spectrum

- ~ 10^{13} protons **measured**
- Proton energy: 58 MeV (LLNL)

SIMULATIONS

- Laser: 50 fs, 50 J (Petawatt!)
- I = 10^{21} W/cm^2
- >10^{11} protons up to 300 MeV

+ mirrors transport and target close to patients

- broad spectrum, max. energy (C ?), rep. rate

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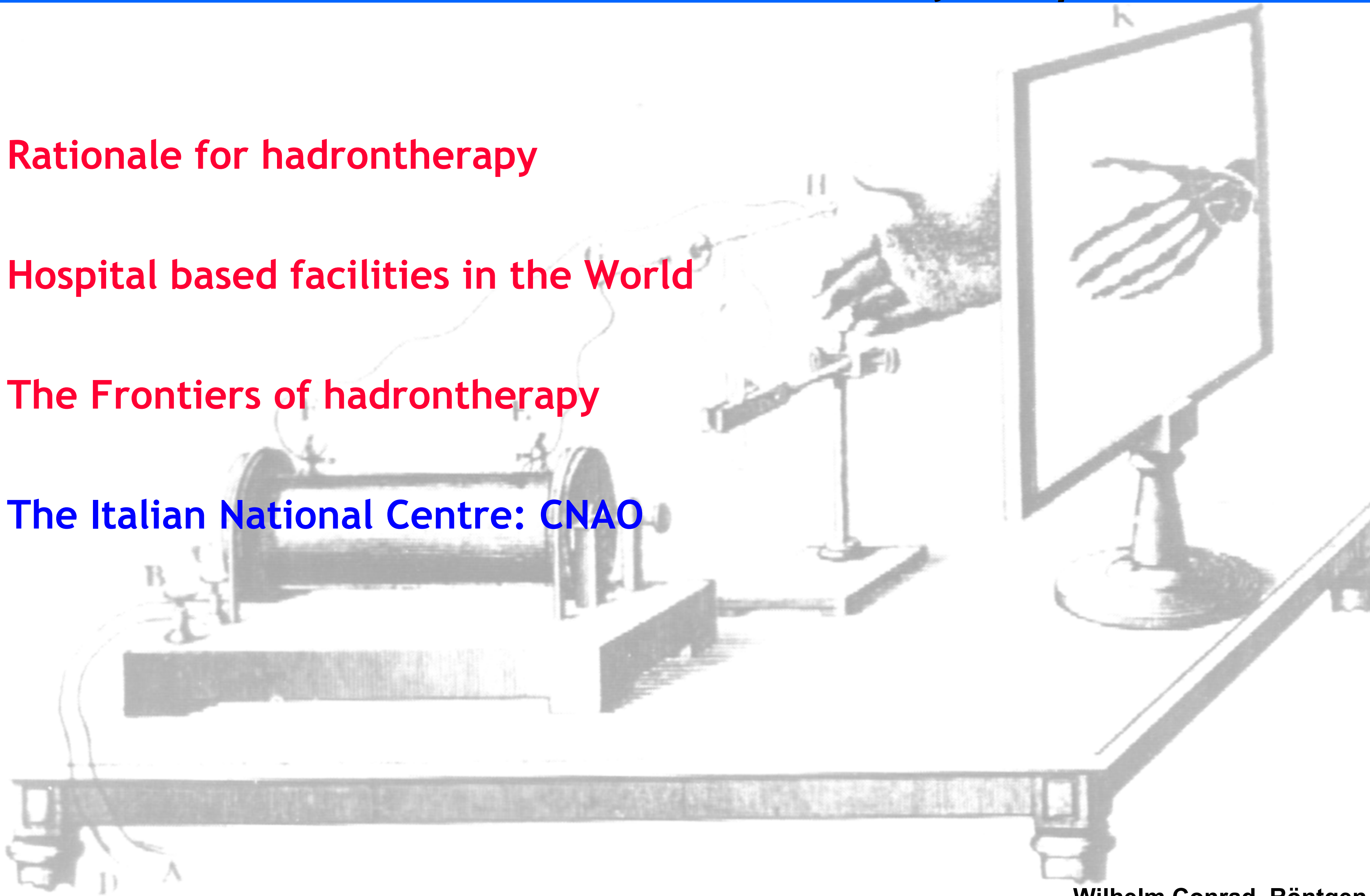


Wilhelm Conrad Röntgen
1895 discovery of X rays

COLLABORATIONS TO BUILD THE CNAO

CNAO (almost 40 fte personnel) is coordinating the effort of many Institutions

NATIONAL

INFN: co-direction, involvment/responsibility in many technical issues (15), formation

Town of Pavia: land and authorisations

University of Milan: medical coordination and formation

Polytechnic of Milan: patient positioning, radioprotection and authorisations

University of Pavia: electrical plants, special power supplies and betatron, safety,formation

Province of Pavia: logistics and authorisation

INTERNATIONAL

CERN: special magnets, dipole measurements and diagnostics (+ PIMMS heritage)

GSI: linac and special components

LPSC: optics, betatron, low-level RF, control system

Overall: about 65 fte equivalent working for CNAO

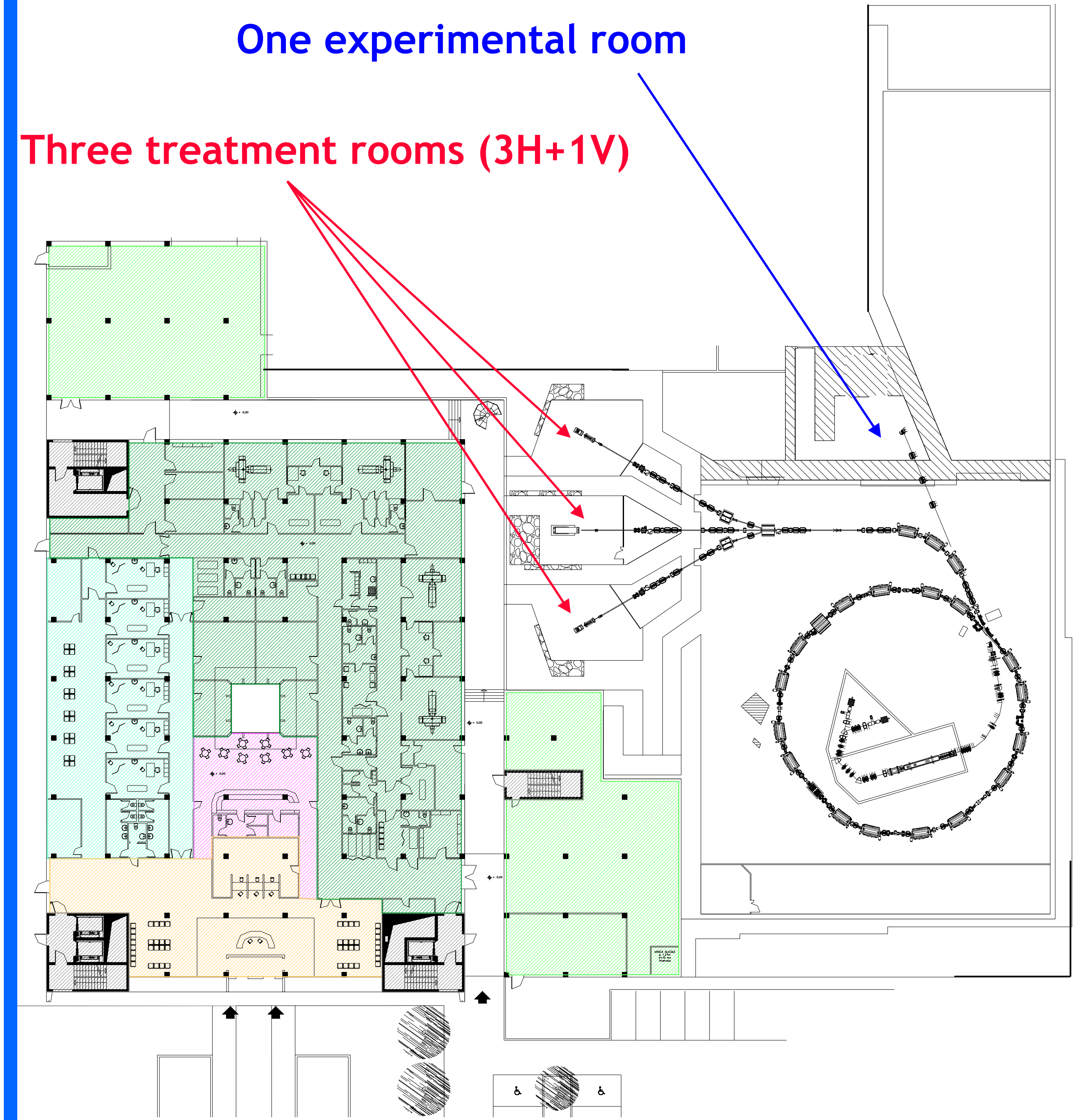
82 firms working for CNAO


Hospital Building
Completion May 2007
High Technology Bld.
Delivery - October 2006
In construction in Pave
30 km south-west of Milan
northern part of Italy

CNAO

One experimental room

Three treatment rooms (3H+1V)



LEGENDA

AREE FUNZIONALI

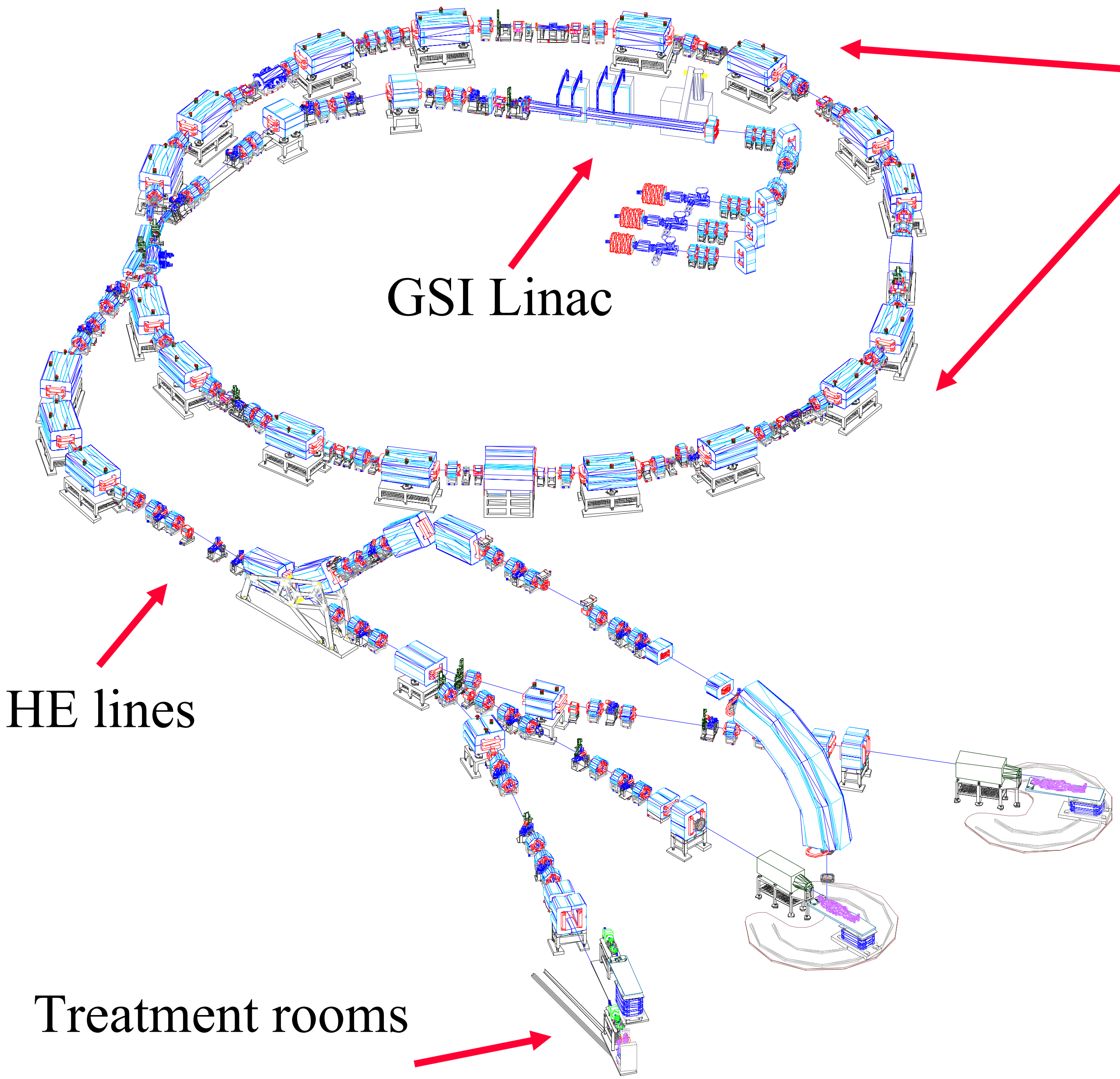
- Ambulatori mq 453
- Area immagini mq 1146
- Ingresso accettazione mq 337
- Bar mq 144
- Centrali tecnologiche mq 736
- Collegamenti verticali mq 227


CNAO SITE
May 17th, 2006
DINI
DINI
AUTOGRU


CNAO
May 17th, 2006


CNAO
June 27th, 2006

The heart of CNAO



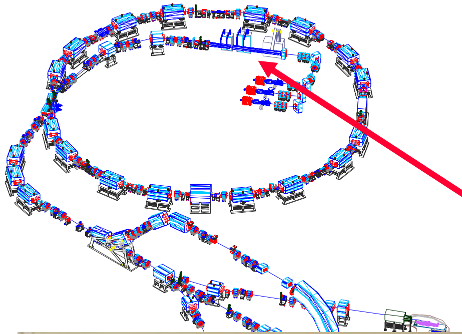
SYNCHROTRON

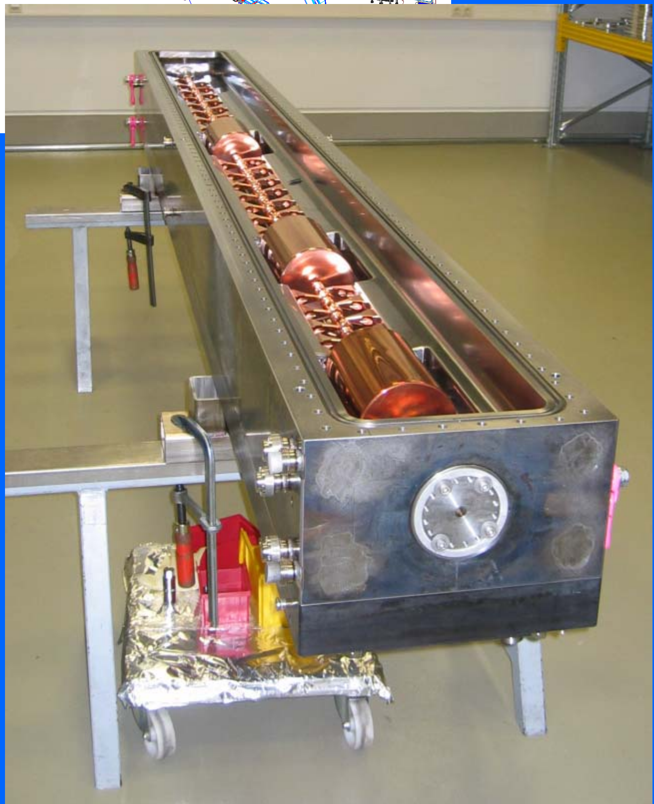
OPTIMIZED
for an hospital based facility (all Ion-therapy centres existing in the World adopt it):
- Safety
- Efficiency
- Reliability
- Maintainability

MODULAR and UPGRADABLE system:
Up-to-date for 20-30 years

CNAO Tour - RFQ + IH-LINAC

Just after the RFQ there is a second linear accelerator, the IH-linac, that increases the energy till 7 MeV/u





Contract signed 15th July 2004

Sub-contracts with firms:
Thales
Pink
Danfysik
Sigmaphy
Jaeger
NTG
Eckelmann

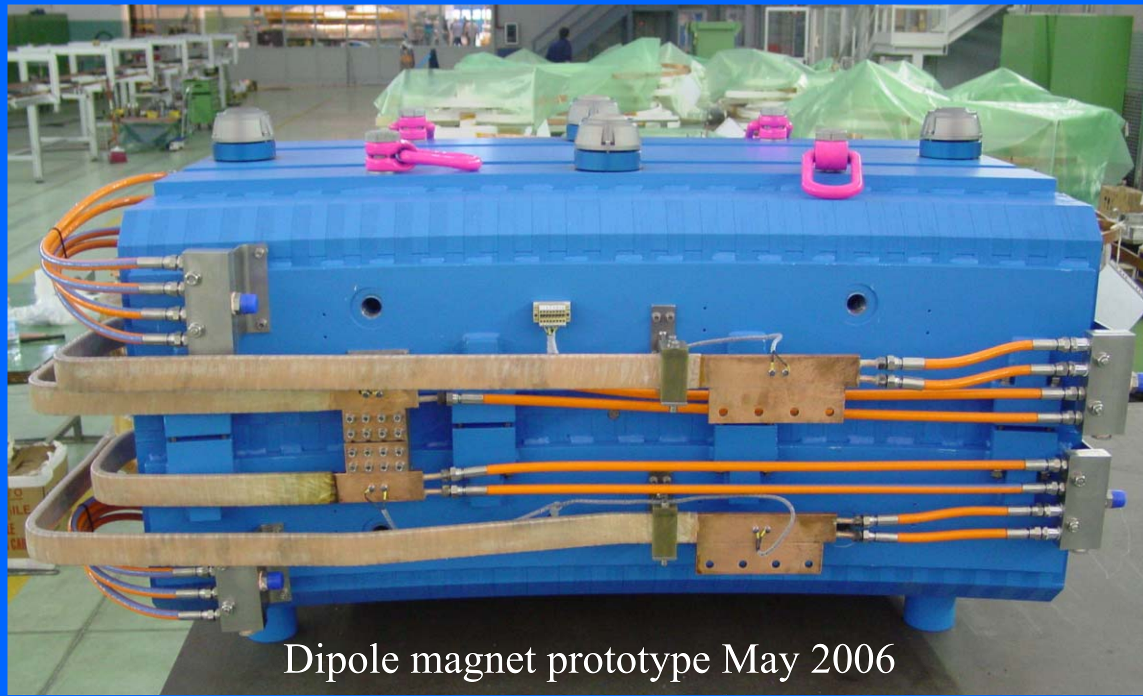
In collaboration with:

RFQ completed and presently at GSI – IH: mechanics completed, copperlating at GSI
Installation in Pavia: Feb – April 2007

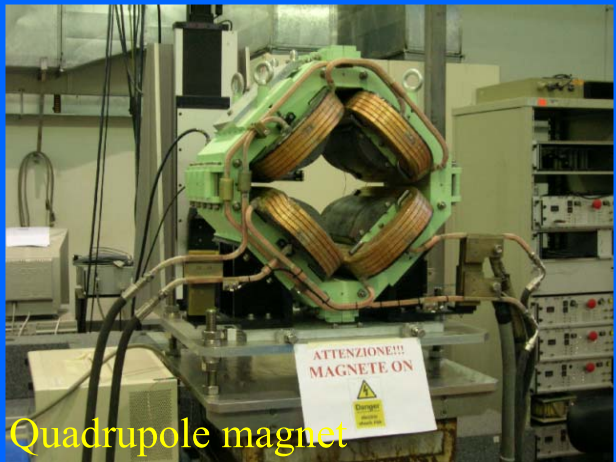
CNAO Tour - Conventional Magnets

For a total of 180 magnets:
N. 32 Bending Dipoles
N. 85 Quadrupoles
N. 7 Sextupoles
N. 56 Correctors

ANSALDO ASG
SIGMAPHI SA
End of production Spring 07



Dipole magnet prototype May 2006



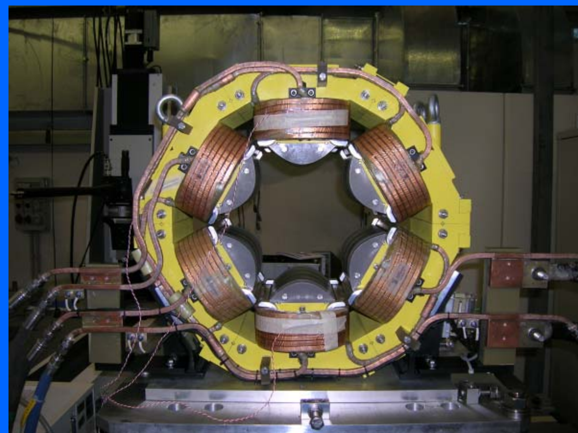
Quadrupole magnet
Prototype November 2005

In collaboration with:

INFN LNF

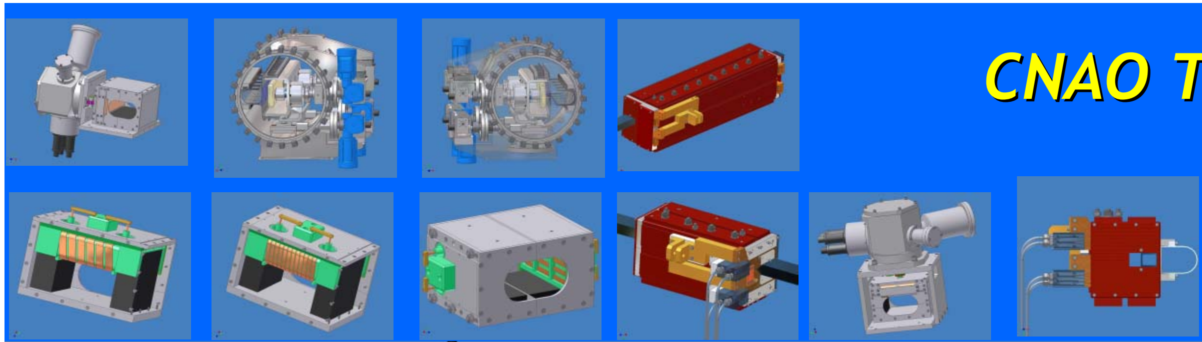
CERN

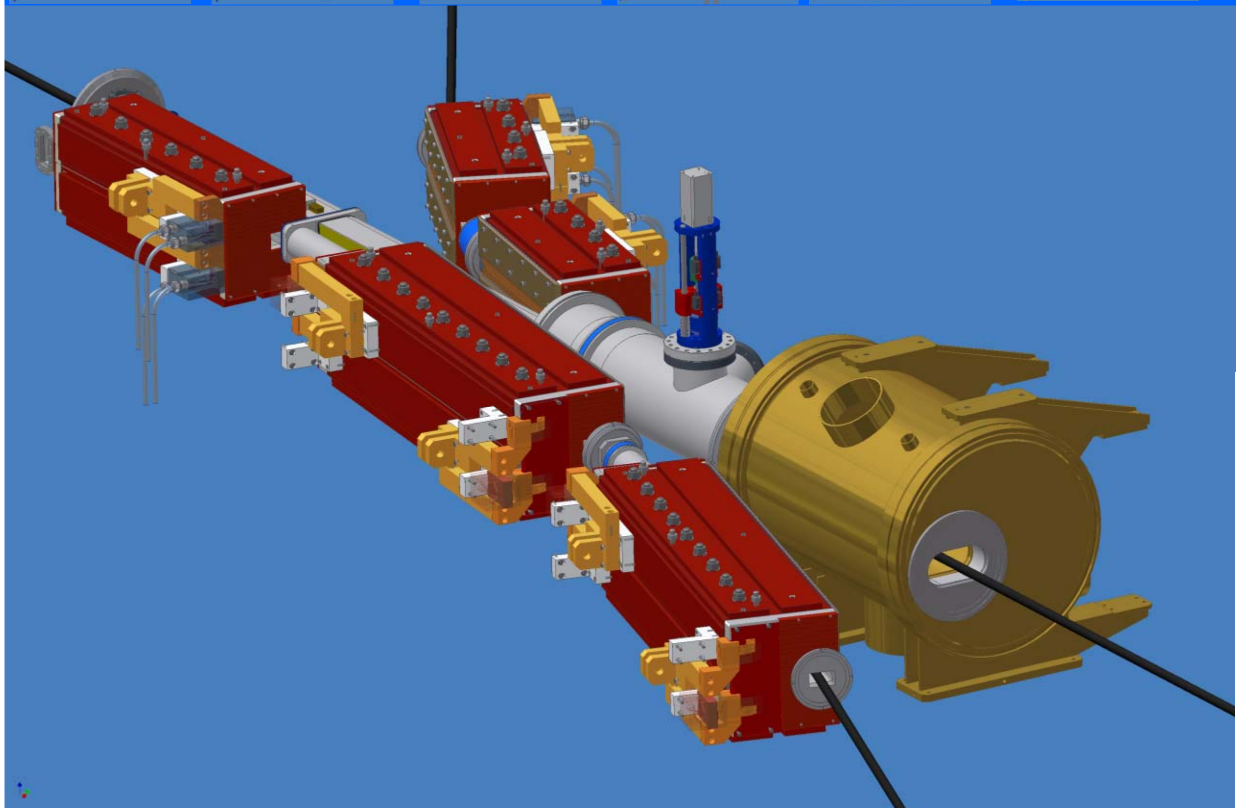
Corrector magnets
Production completed
October 2005.

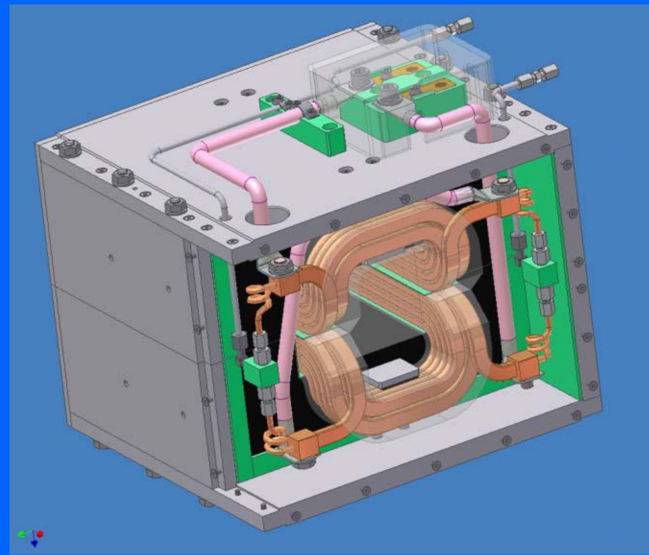


Sextupole magnet prototype
December 2005

CNAO Tour - Special Magnets







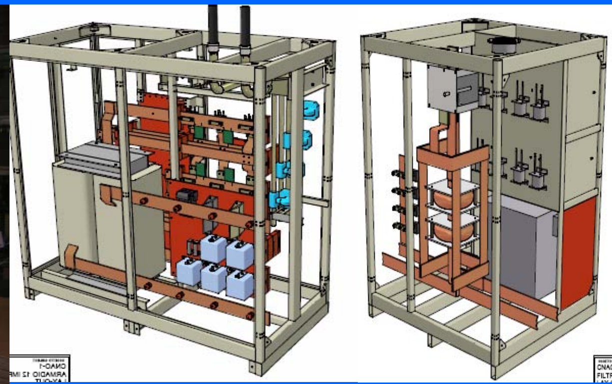
- 1 Dump Bumper magnet
- 1 Dump Bumper magnet
- 2 Injection Bumper magnets
- 4 Chopper dipoles
- 1 Horizontal Tune kicker
- 1 Vertical Tune kicker
- 2 Injection Septa
- 1 Thin Extraction Septum
- 2 Thick Extraction Septa
- 1 Electrostatic Extraction Septum
- 1 Electrostatic Injection Septum

Under construction by Danfysik
End of production October 2006

In collaboration with:
CERN
UniPv

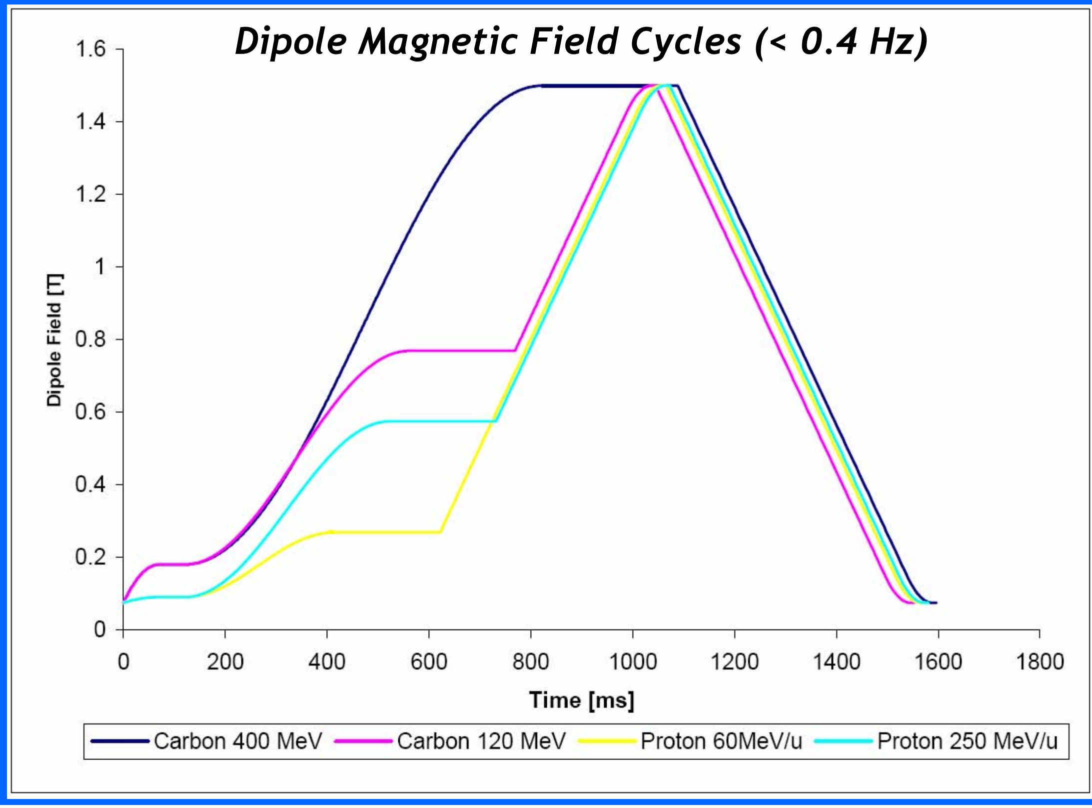
CNAO Tour - Power Supplies

Synchrotron Dipole Power Supply



Current range 30 to 3000 A
Power range 0.9 to 5000 kW
Current stability $\pm 5*10^{-6}$ to $\pm 5*10^{-4}$
Current reproducibility $\pm 2.5*10^{-6}$ to $\pm 2.5*10^{-4}$

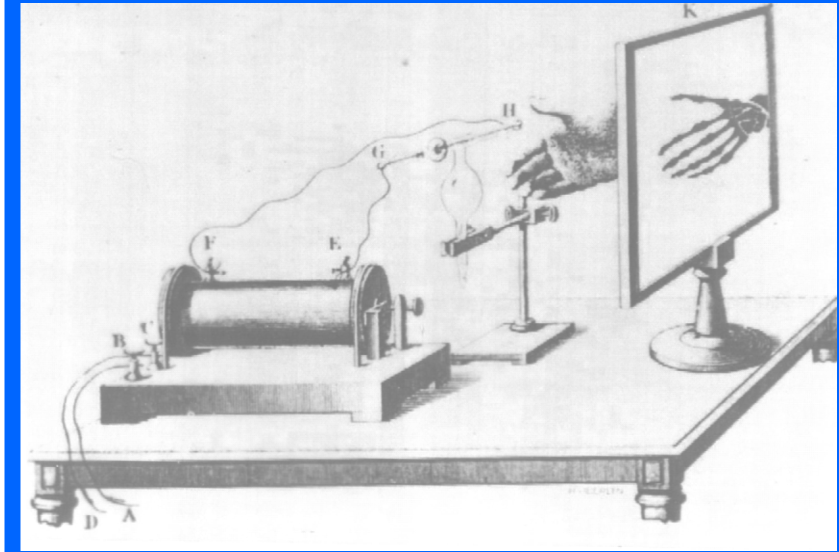
Power Supplies Total n. 187
N. 177 under construction
(OCEM - EEI)
N. 10 still to be ordered
Last delivery March 2007



In collaboration with:

INFN LNF

Conclusion



Discovery of X-rays
1895

First patient
at HIT and CNAO
fall 2007 - start 2008

… a long way through

hadrontherapy is a further step,
with good results and
very promising developments,
in radiotherapy evolution