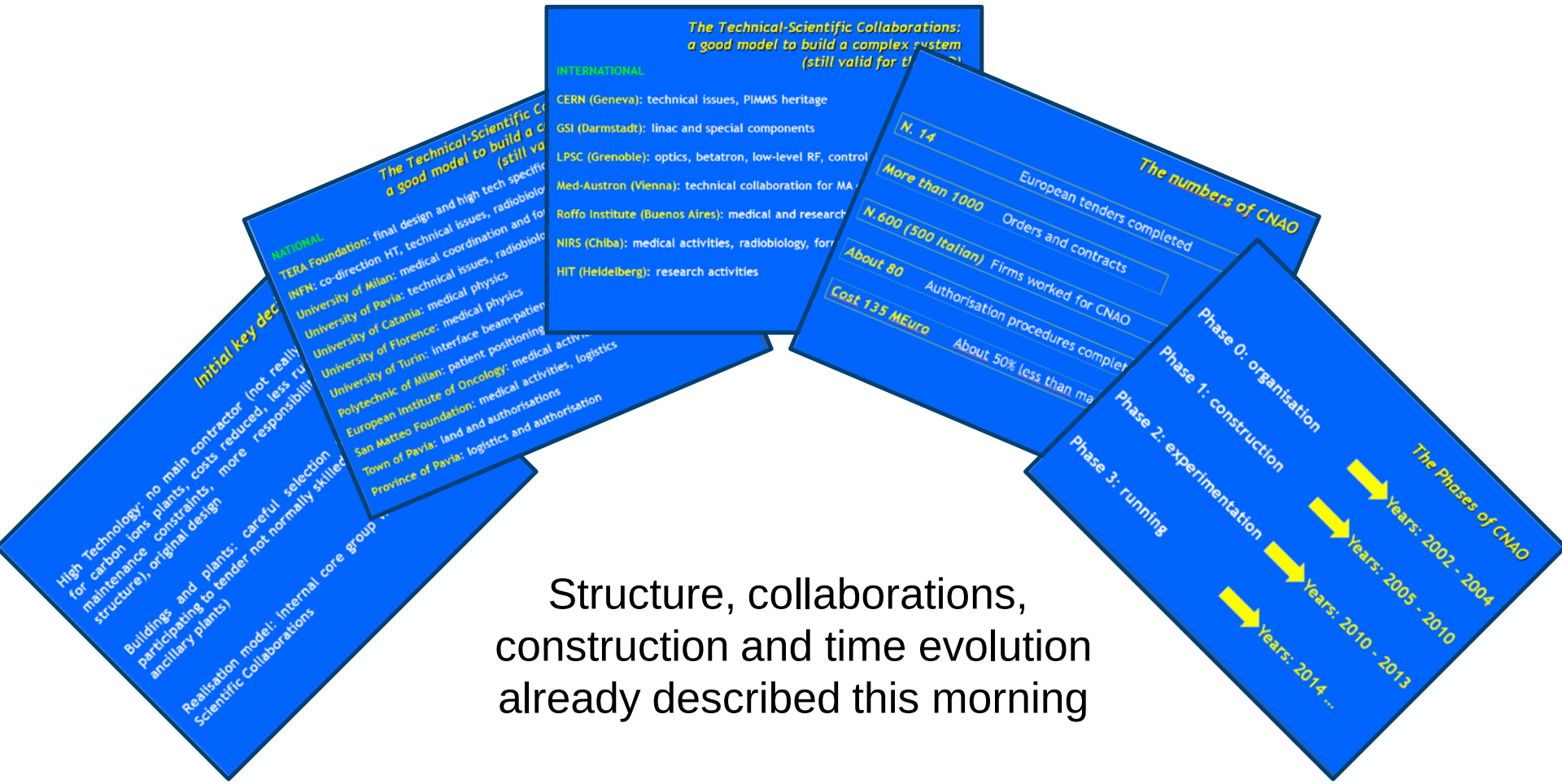
Obtaining a therapeutic beam at CNAO

M. Pullia

International Workshop on Particle Therapy Research, Nov. 13-14, 2014

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica



Structure, collaborations, construction and time evolution already described this morning

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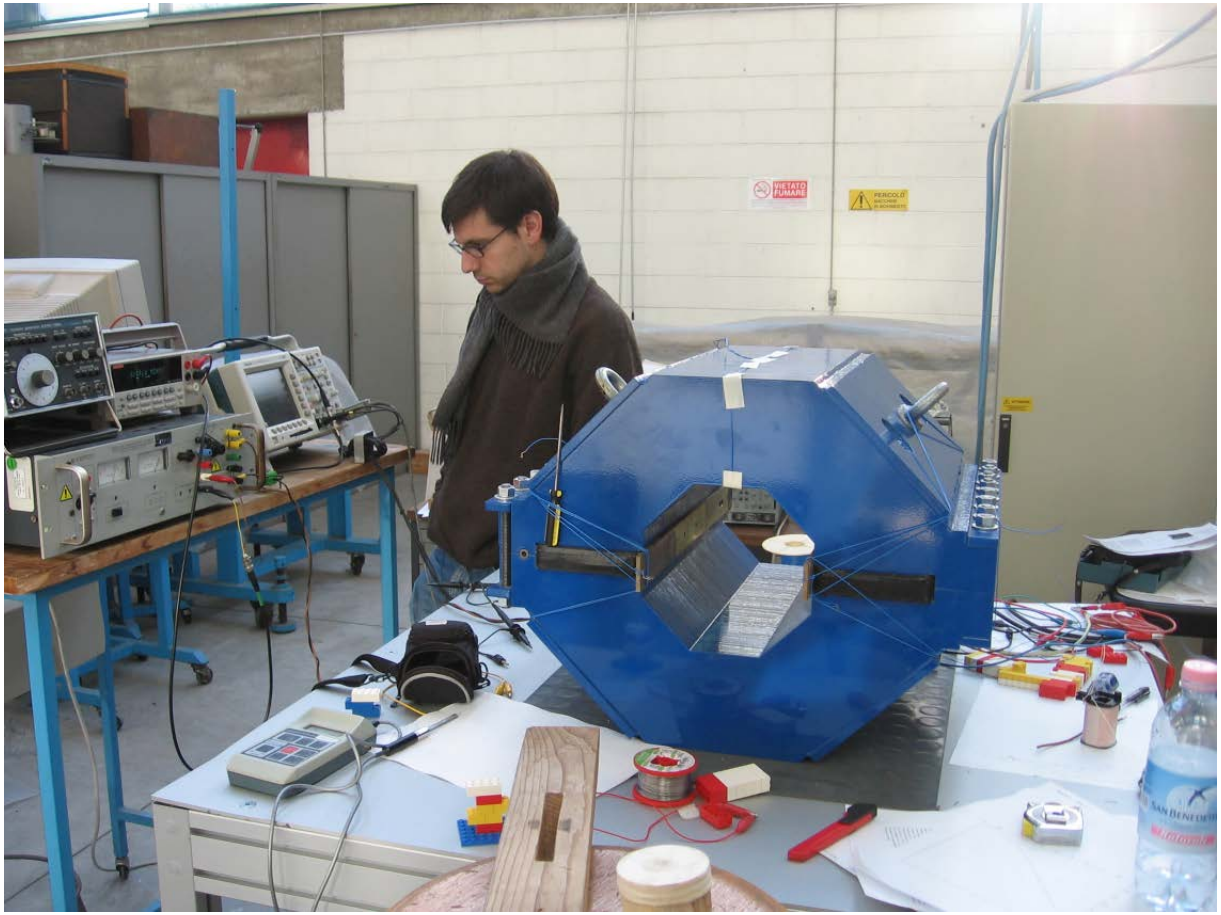
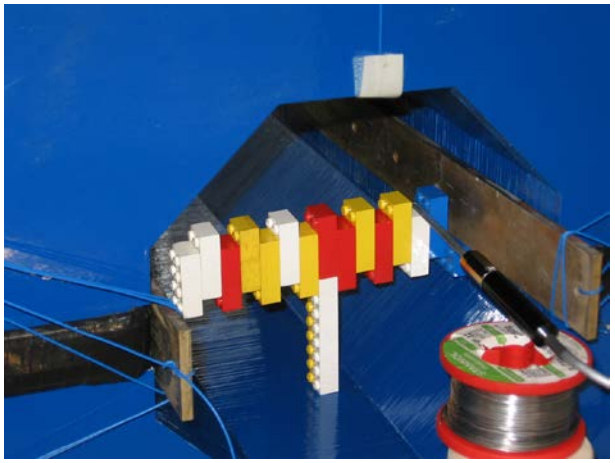
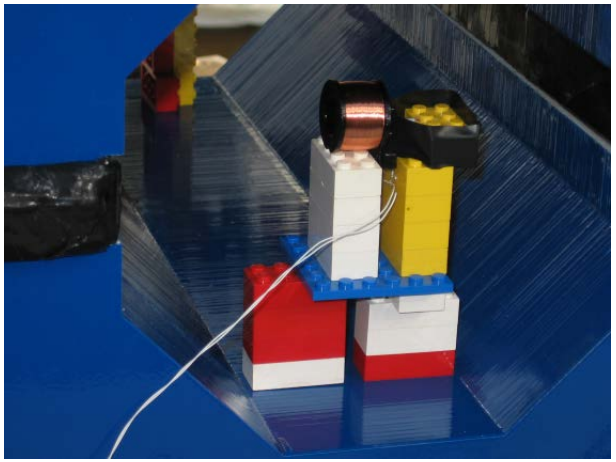
fondazione CNAO Centro Nazionale di Adroterapia Oncologica

Experience at CNAO with obtaining therapeutic ion beam at a multi-vendor “Lego” system







Prototype of the betatron core

Aim of the center

AIM OF THE PROJECT

To treat deep tumours :

- **With ion beams in the range $1 \leq Z \leq 6$**
- **With active scanning**
- **In approximately 3 min/field**

Synchrotron with slow extraction!

Everything safe, proven and/or redundant

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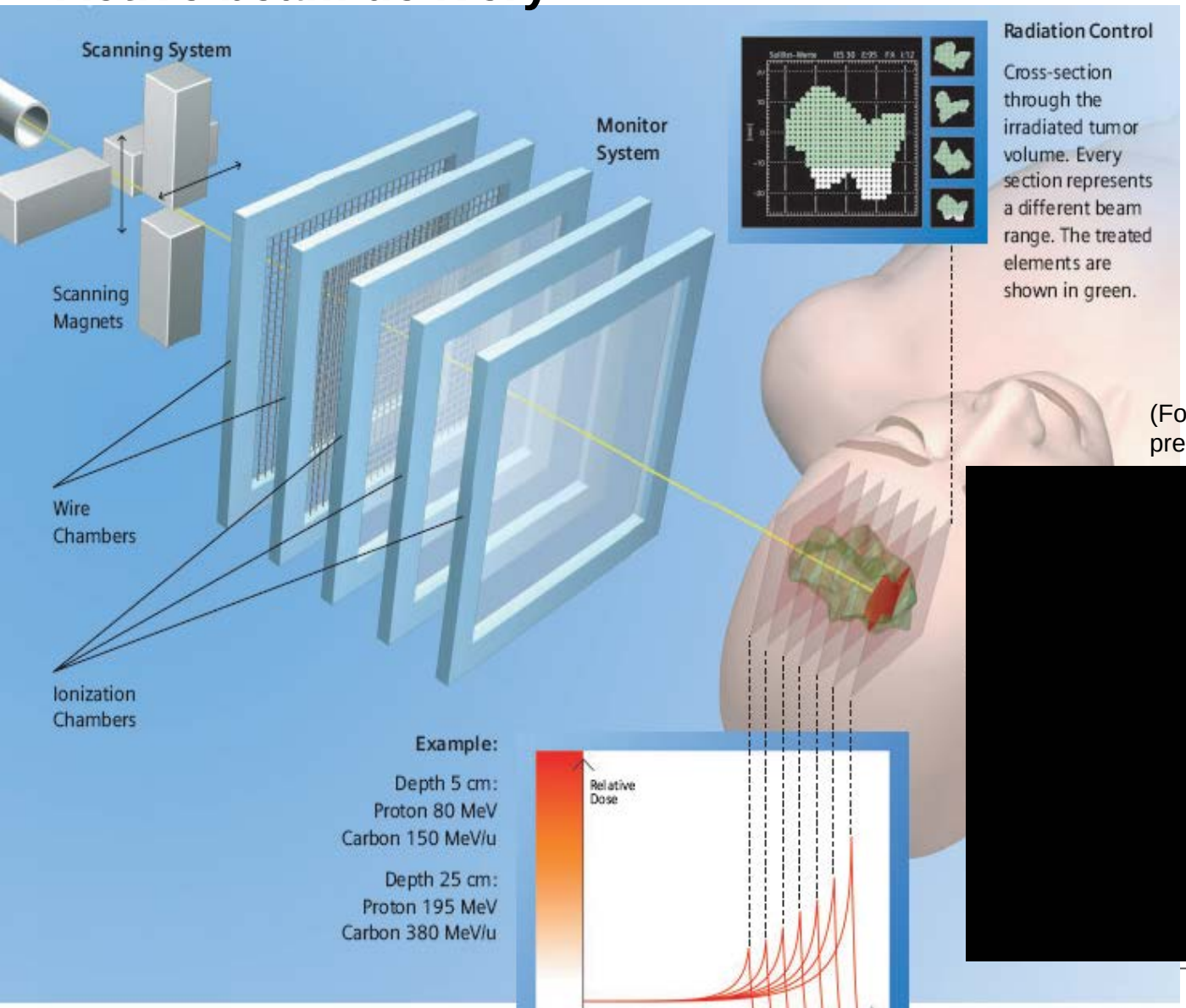
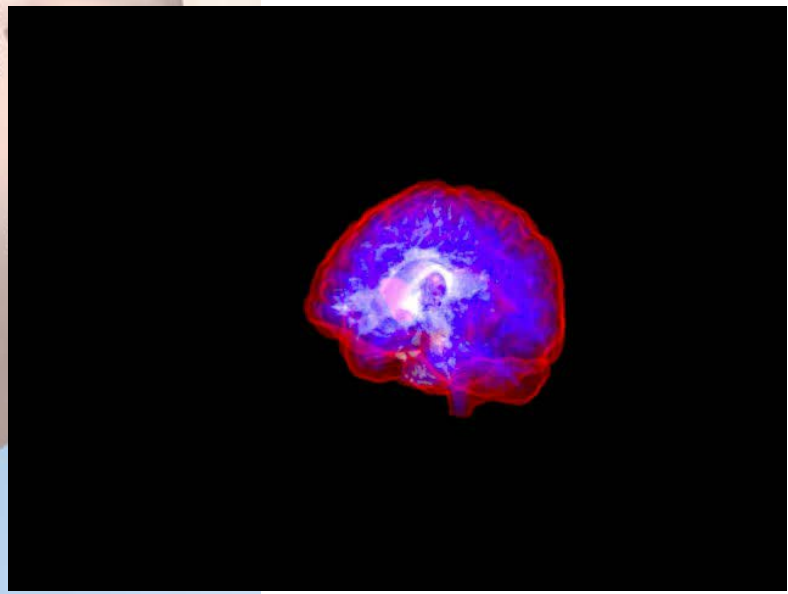
Active beam delivery



(Courtesy of Siemens Medical)

(Found on the web, forgot where, sorry... presumably Siemens or HIT)



Starting from the patient

Basic specs

1	Beam particle species	p, He^{2+}, Li^{3+}, Be^{4+}, B^{5+}, C^{6+}, O^{8+}
2	Beam particle switching time	≤ 10 min
3	Beam range	1.0 g/cm^2 to 27 g/cm^2 in one treatment room 3.1 g/cm^2 to 27 g/cm^2 in two treatment rooms Up to 20 g/cm^2 for O^{8+} ions
4	Bragg peak modulation steps	0.1 g/cm^2
5	Range adjustment	0.1 g/cm^2
6	Adjustment/modulation accuracy	≤± 0.025 g/cm^2
7	Average dose rate	2 Gy/min (for treatment volumes of 1000 cm^3)
8	Delivery dose precision	≤± 2.5%
9	Beam axis height (above floor)	150 cm (head and neck beam line) 120 cm (elsewhere)
10	Beam size[1]	4 to 10 mm FWHM for each direction independently
11	Beam size step[1]	1 mm
12	Beam size accuracy[1]	≤± 0.25 mm
13	Beam position step[1]	0.8 mm
14	Beam position accuracy[1]	≤± 0.2 mm
15	Field size[1]	5 mm to 34 mm (diameter for ocular treatments) 2×2 cm^2 to 20×20 cm^2 (for H and V fixed beams)
16	Field position accuracy[1]	≤± 0.5 mm
17	Field dimensions step[1]	1 mm
18	Field size accuracy[1]	≤± 0.5 mm

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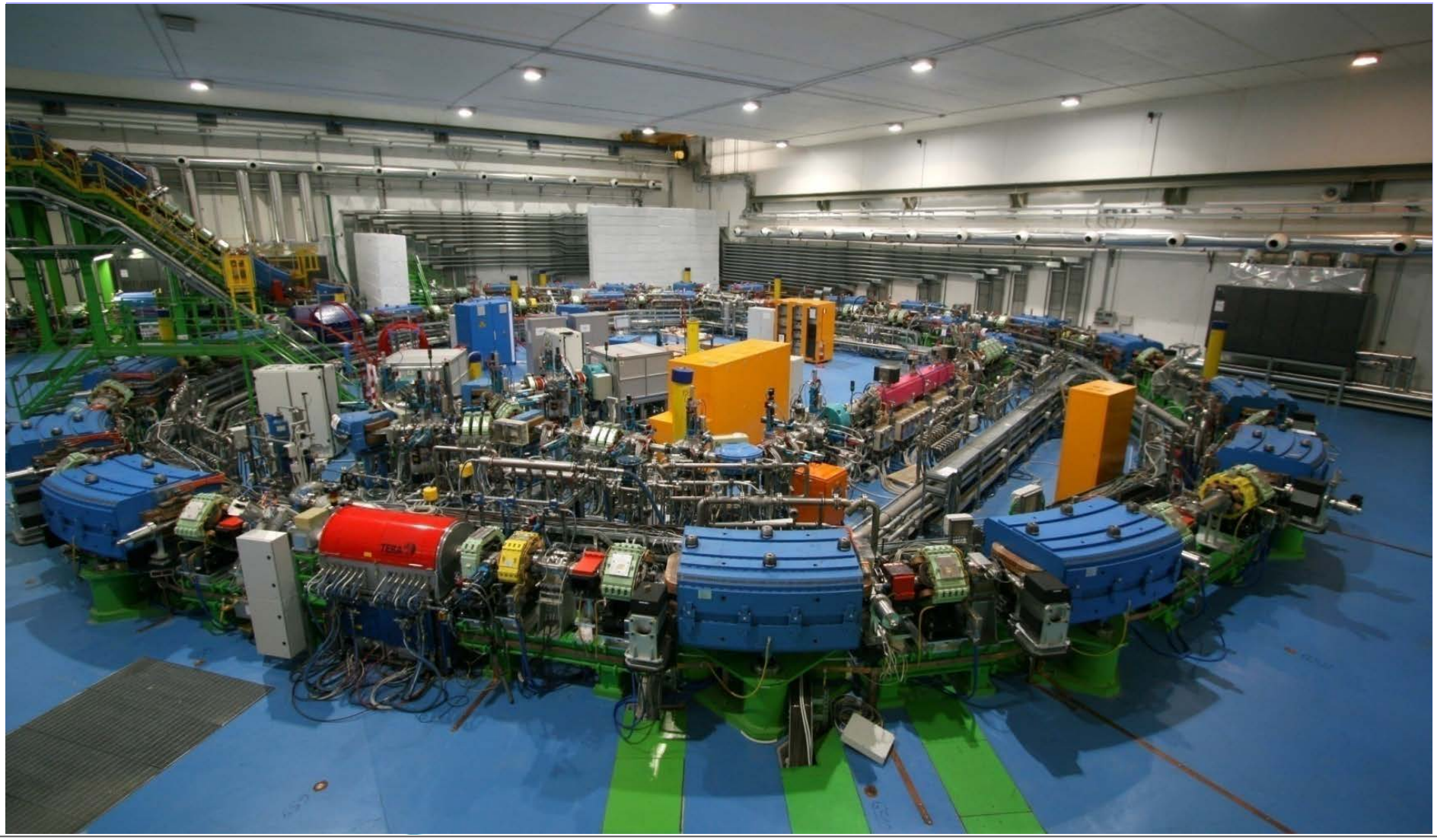
The CNAO accelerator and lines



Design Parameters I

Protons (10^{10}/spill)				
	LEBT (*)	MEBT	SYNC	HEBT
Energy [MeV/u]	0.008	7	7-250	**60-250**
Imax [A]	1.3×10^{-3} (0.65, 0.45)	0.7×10^{-3}	5×10^{-3}	**7×10^{-9}**
Imin [A]	1.3×10^{-3} (0.65, 0.45)	70×10^{-6}	0.12×10^{-3}	17×10^{-12}
$\varepsilon_{rms,geo}$ [π mm mrad]	45	1.9	0.67-4.2	0.67-1.43(V)
$\varepsilon_{90,geo}$ [π mm mrad]	180	9.4	3.34-21.2	3.34-7.14 (V) 5.0 (H)
Magnetic rigidity [T m]	0.013 (0.026, 0.039)	0.38	0.38-2.43	0.38-2.43
$(\Delta p/p)_{tot}$	$\pm$1.0‰	$\pm$(1.2-2.2)‰	$\pm$(1.2-3.4)‰	$\pm$(0.4-0.6)‰

* (H_2^+, H_3^+)

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Design Parameters II

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

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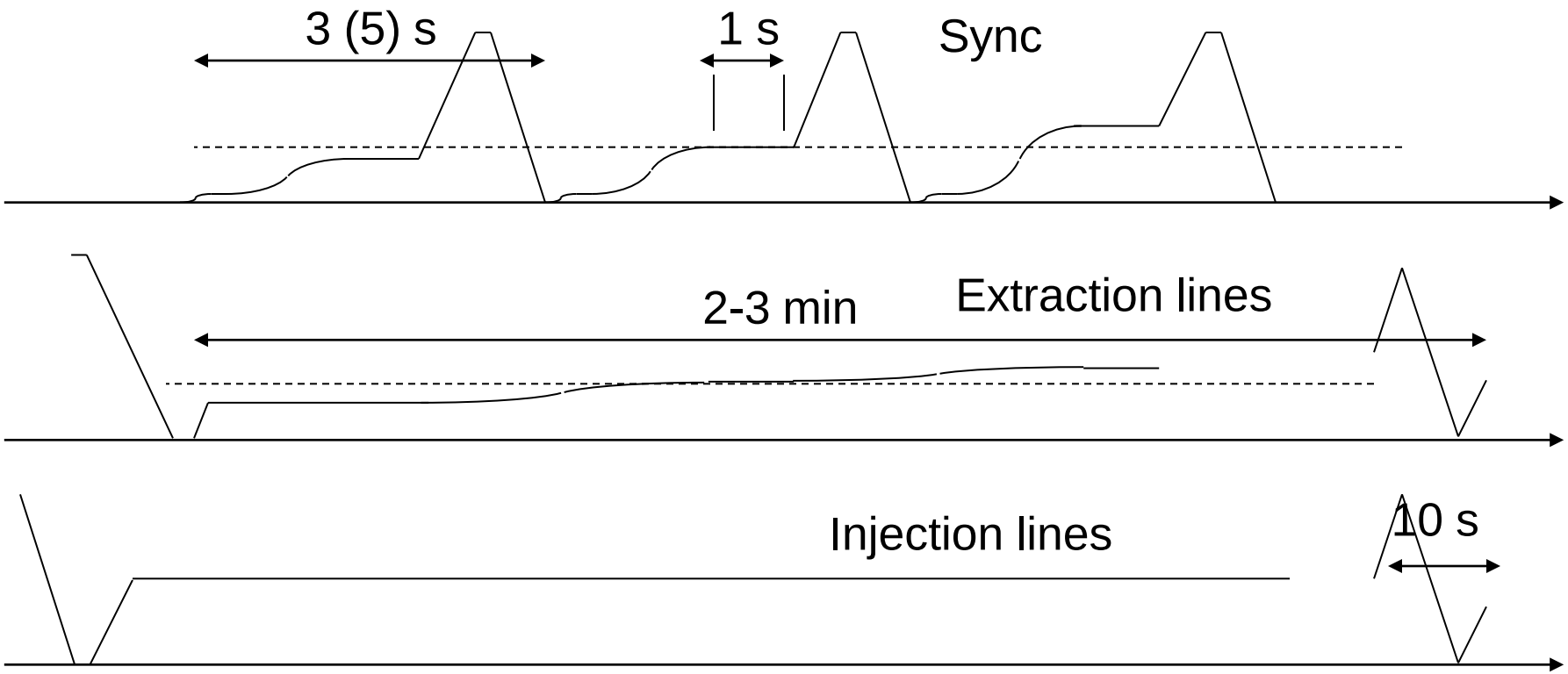
Machine cycle



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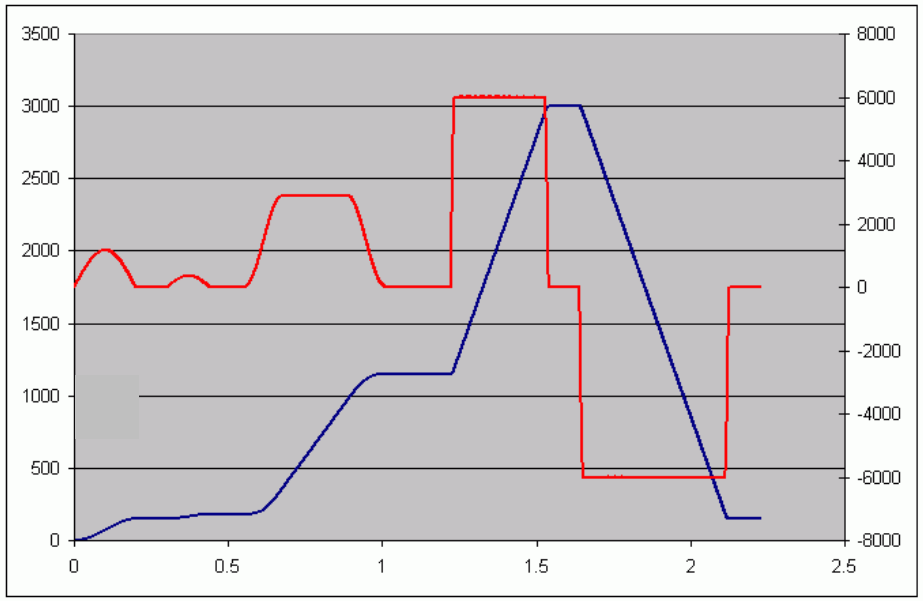
Control system

Energy changes every 5s …maybe…

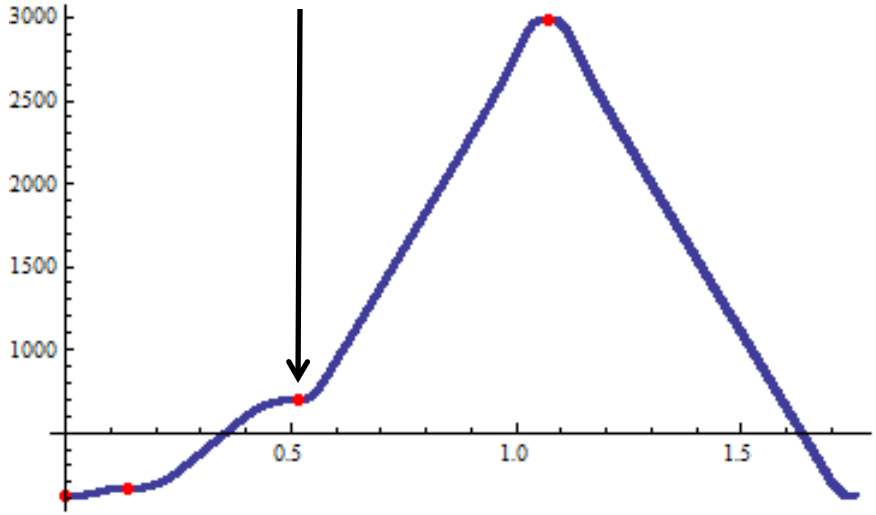
Unpredictable sequence of cycles

Unpredictable cycle duration (breath synchronization)

Event driven ramps



Arbitrary flat top



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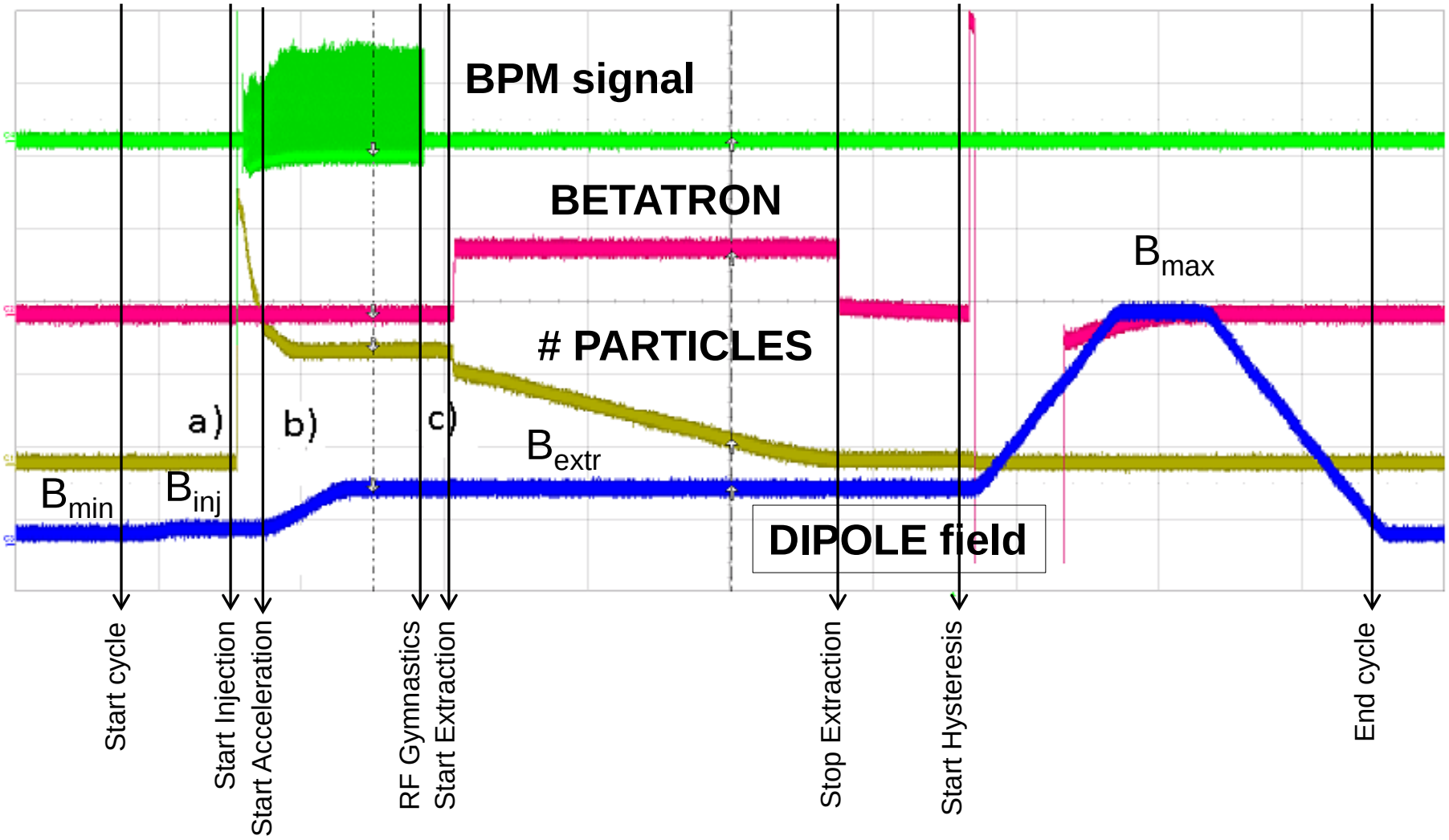
Control system

Distributed intelligence

Machine Cycle



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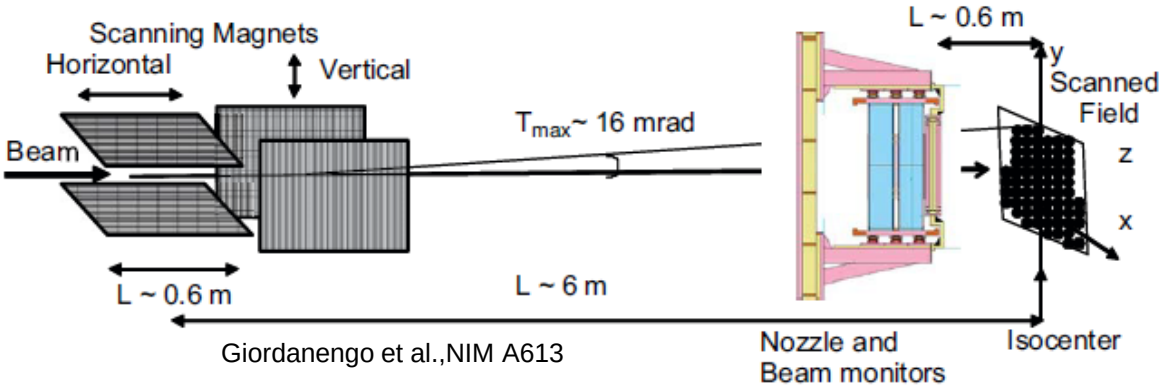
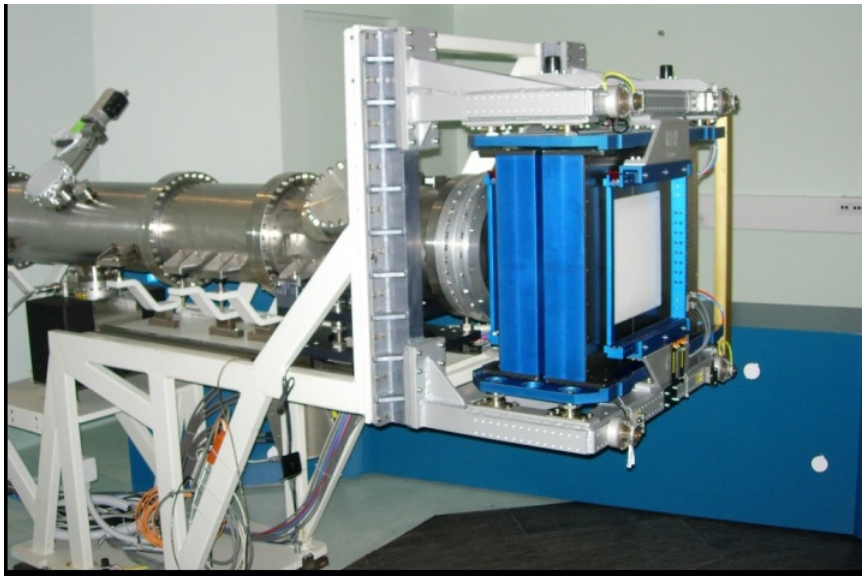
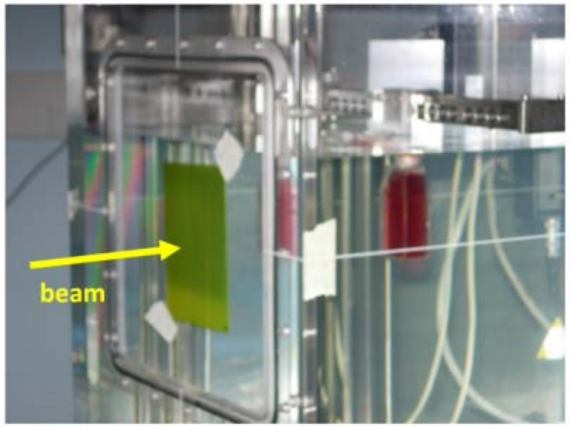
Dose delivery



Giordanengo et al.,NIM A613





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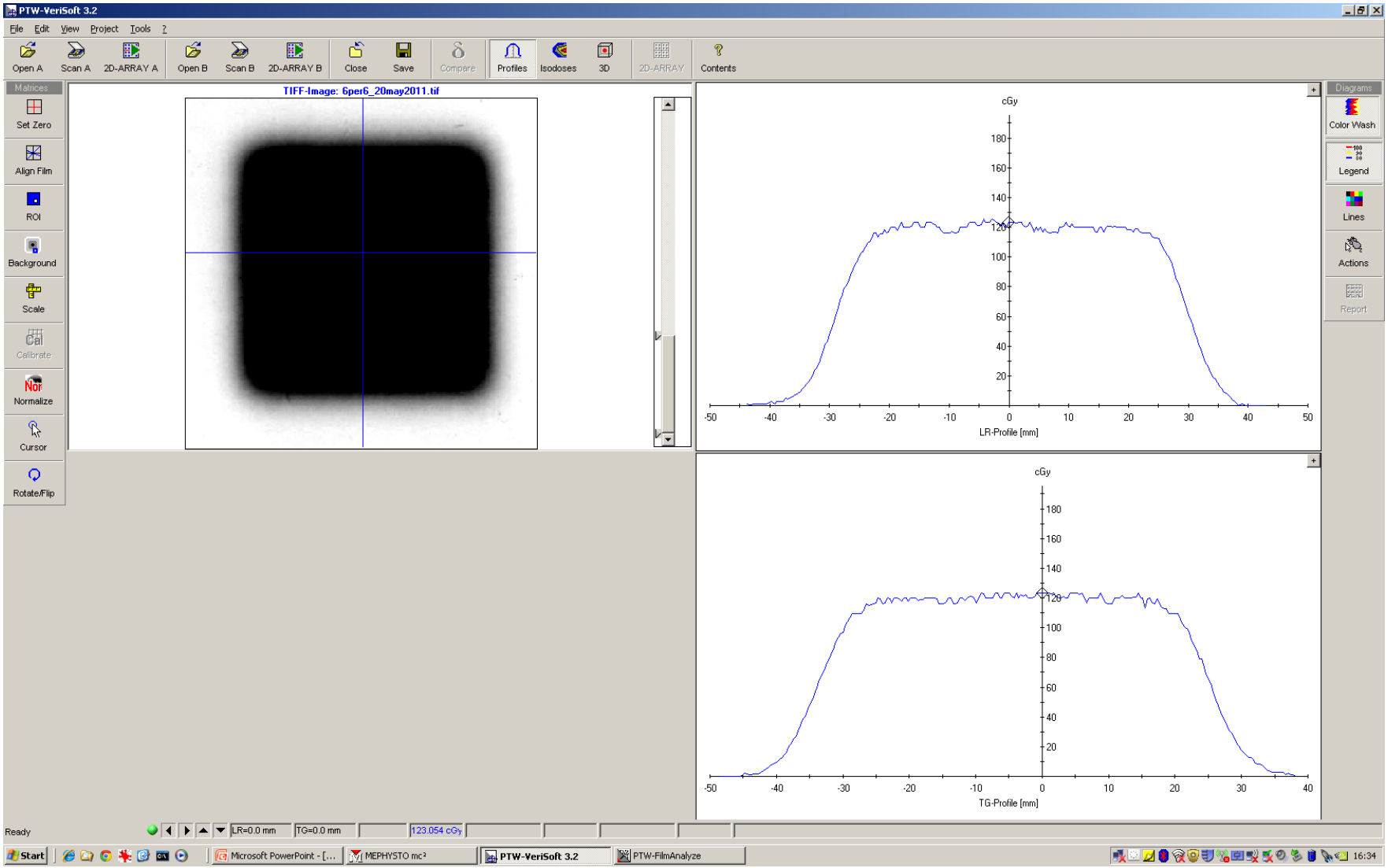
Centro Nazionale di Adroterapia Oncologica

First scannings



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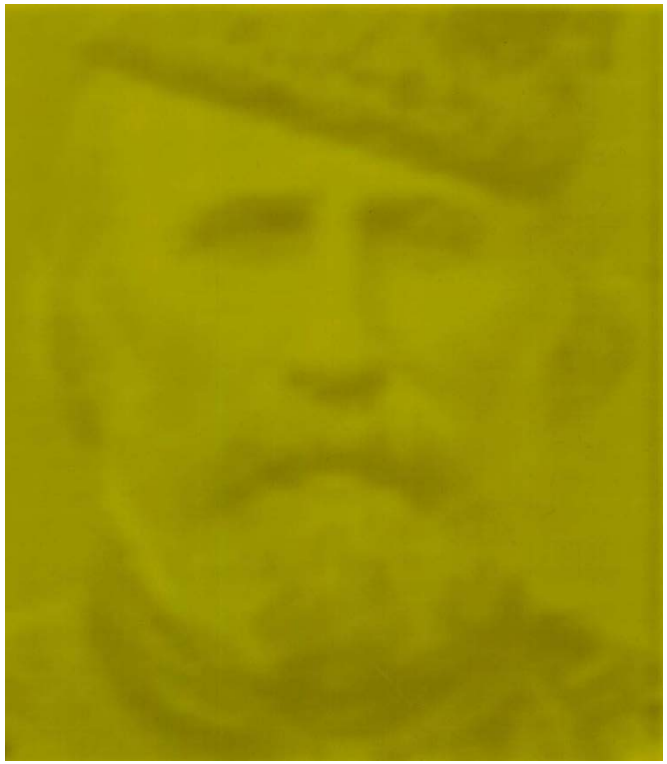
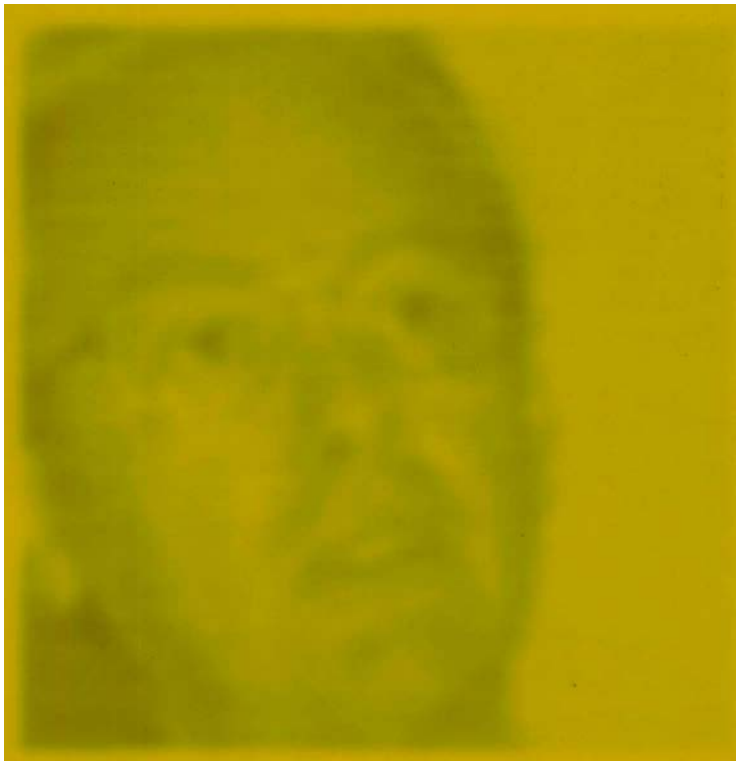
Artistic use of the beam

Radiochromic film





May 2011

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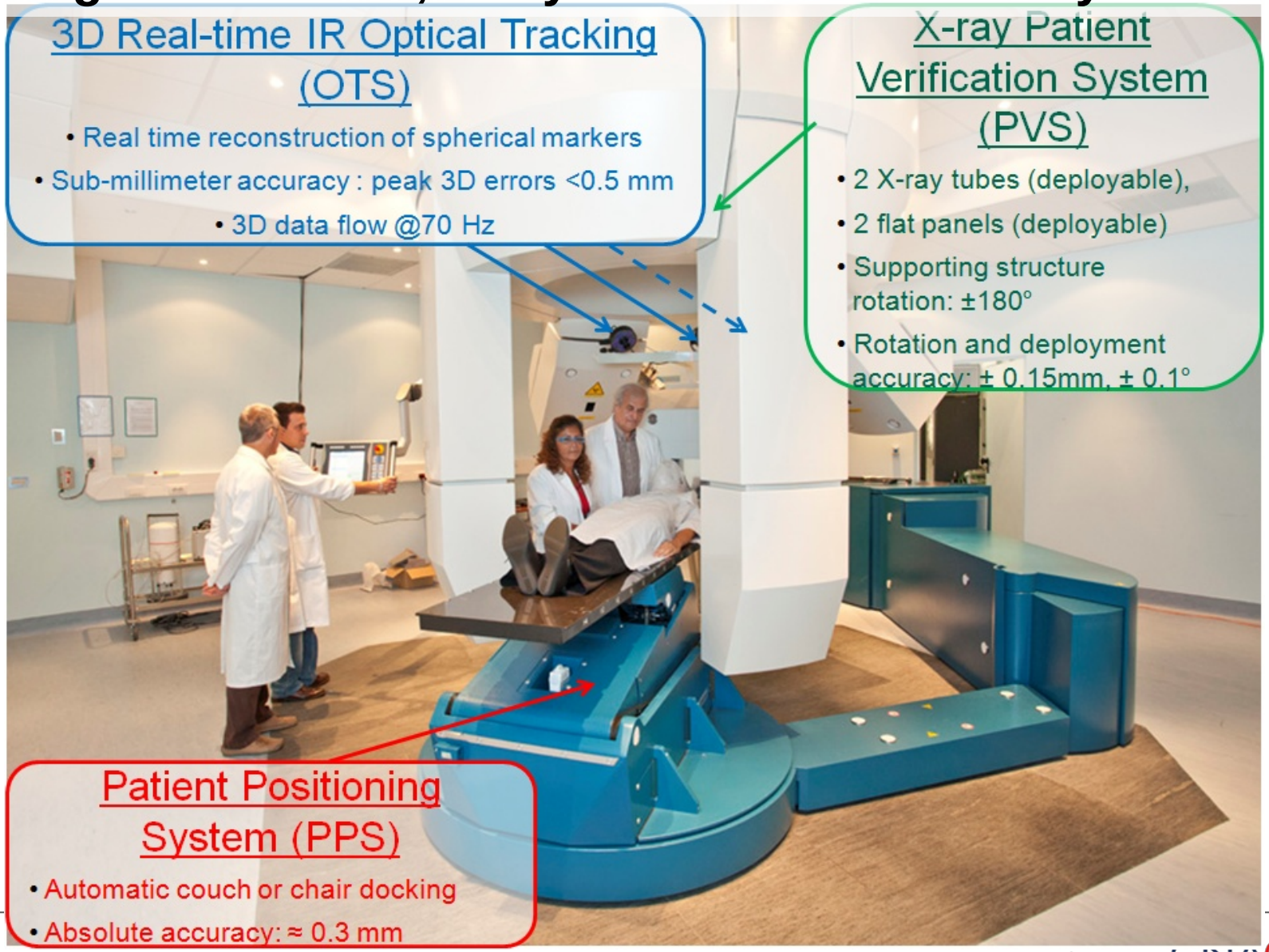
Patient Positioning and Verification strategy at CNAO
Integrated robotic, X-ray and IR localization system



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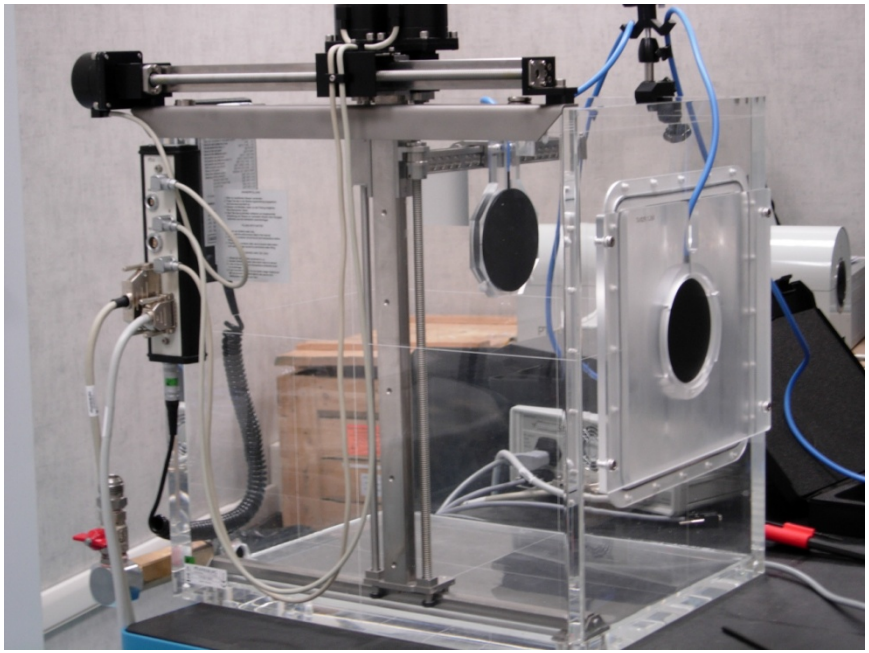
Beam measurements

Depth Dose Distributions (mono-en. pencil beams)

Peakfinder water column



3-D motorized water ph.

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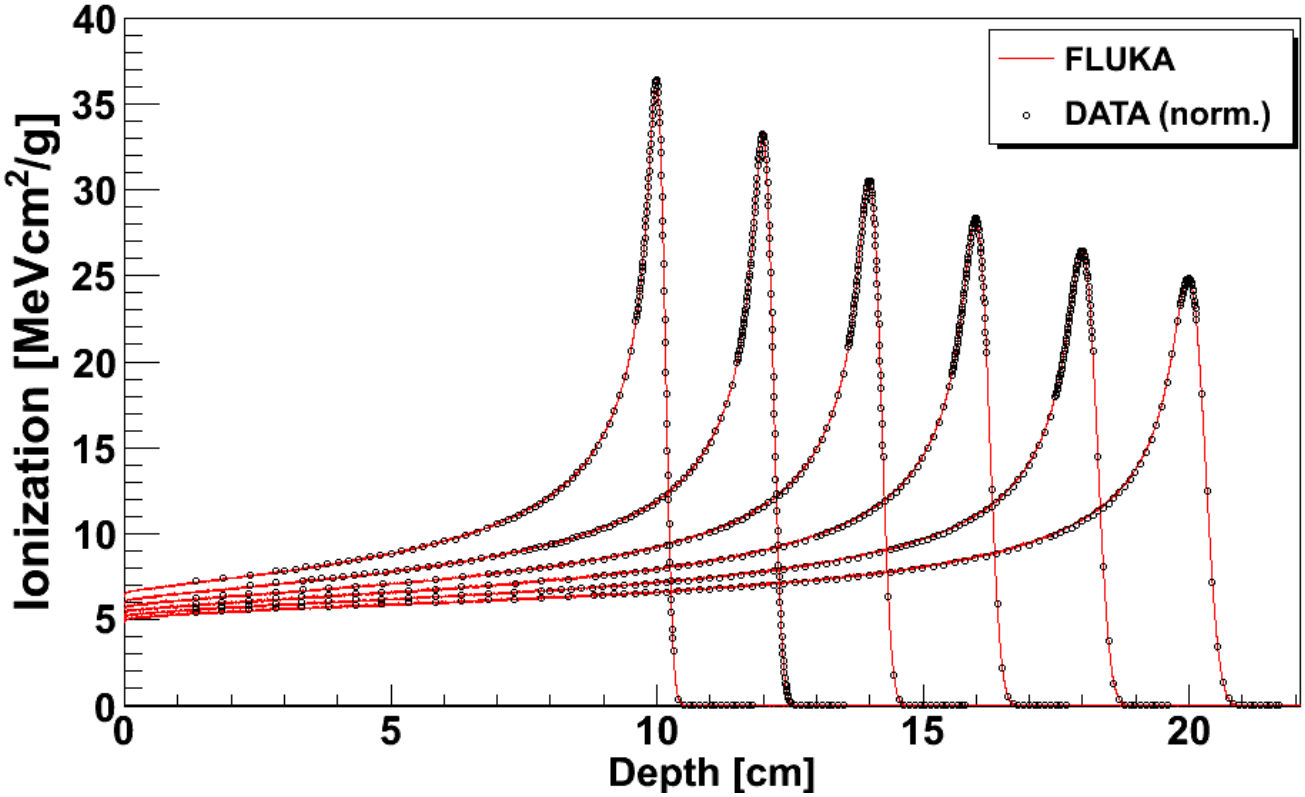
Measured Bragg Peaks



I_{pot} = 77 eV

$|BP_{meas.} - BP_{FLUKA}| \sim 0.1$ mm

147 proton energies, 62.3-226.9 MeV/u (3-32 cm BP depth), 2 mm energy step

Courtesy of M. Ciocca

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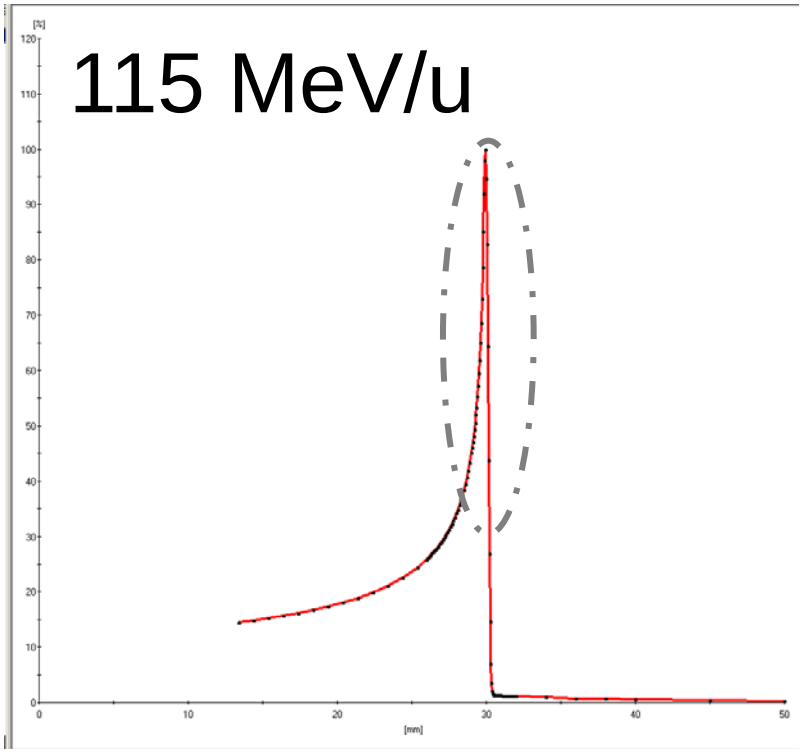
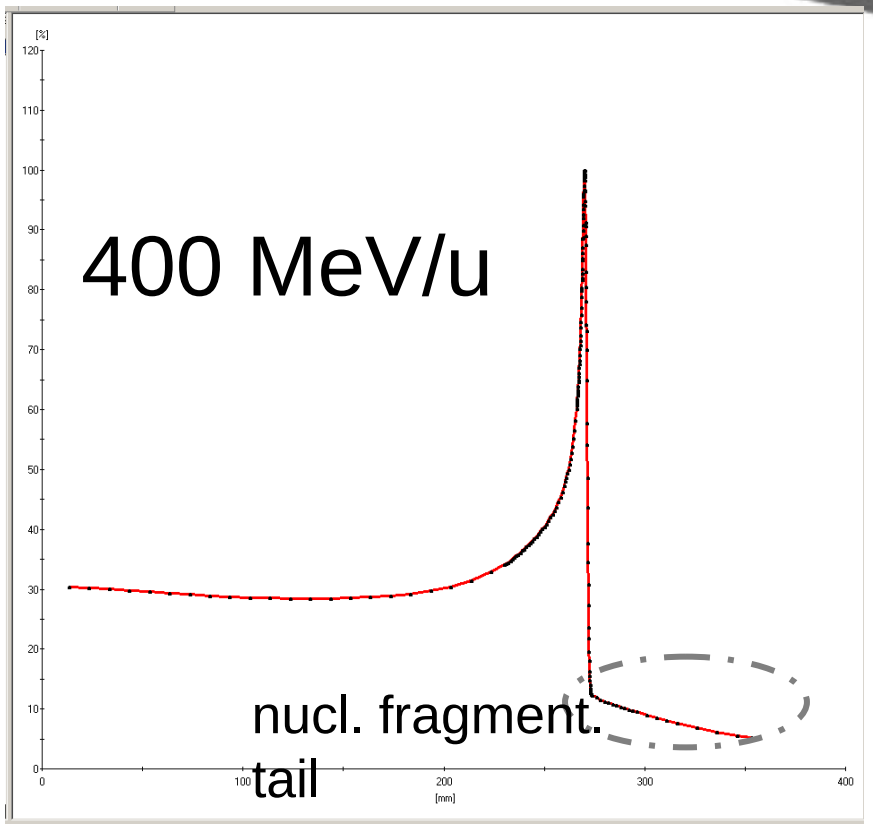
Measured Bragg Peaks





- 121 **carbon ion** energies, 115-400 MeV/u (3-27 cm), step 2 mm
- 4 intensities: $5*10^6$ – $5*10^7$ p/spill
- spill duration: 1 s
- 2 FWHM (at isocenter): 6-10 mm

Courtesy of M. Ciocca

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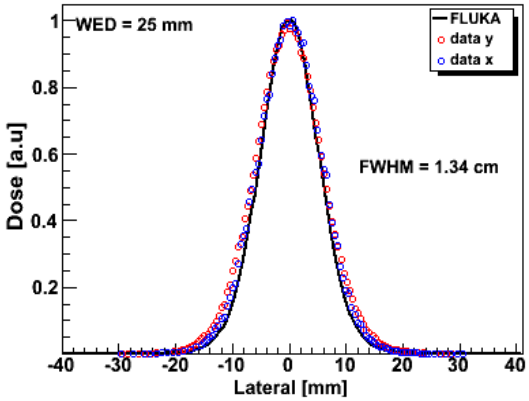
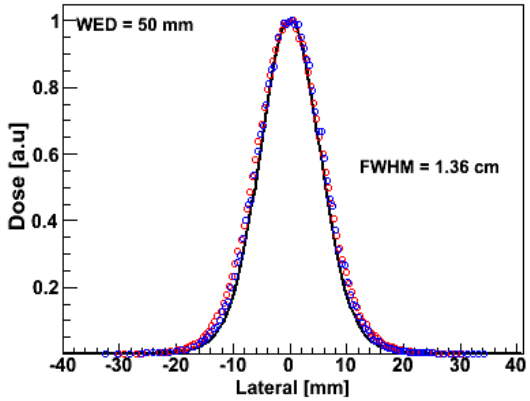
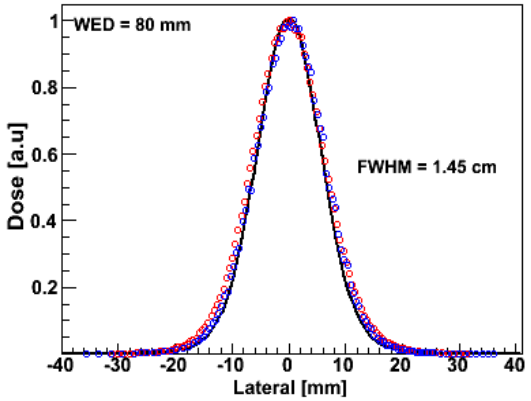
Transversal dose profiles in the water phantom

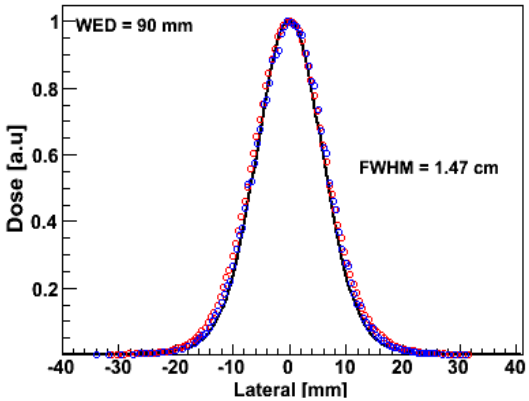
Pin-point IC (PTW 31014, 2-mm diameter)

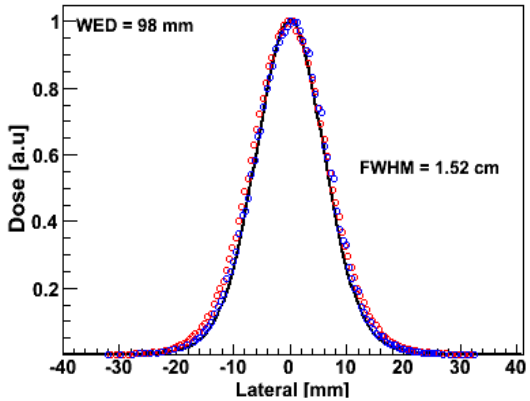
Courtesy of M. Ciocca

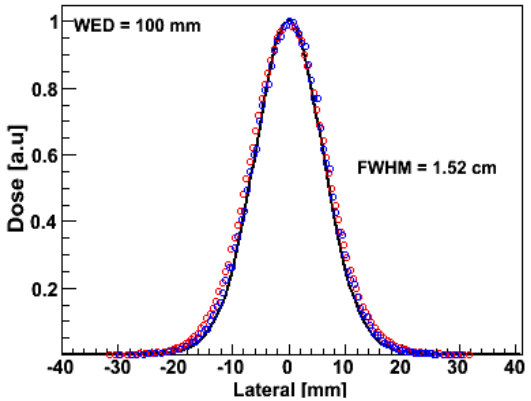












E = 117.54 MeV/u (100 mm BP)

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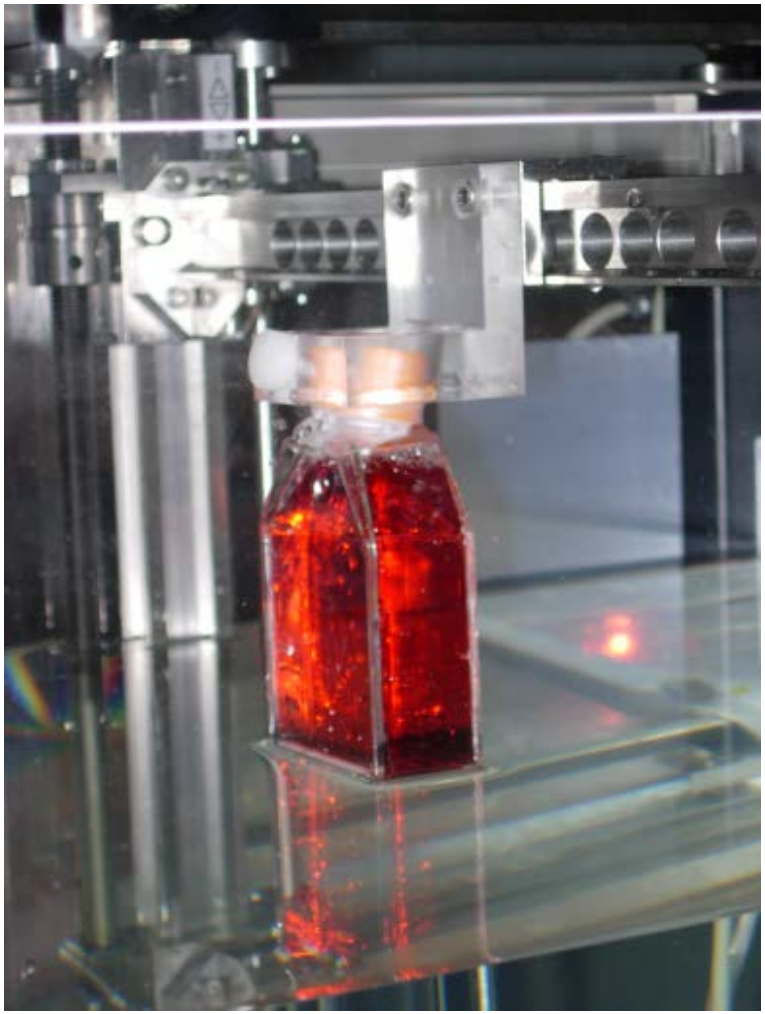
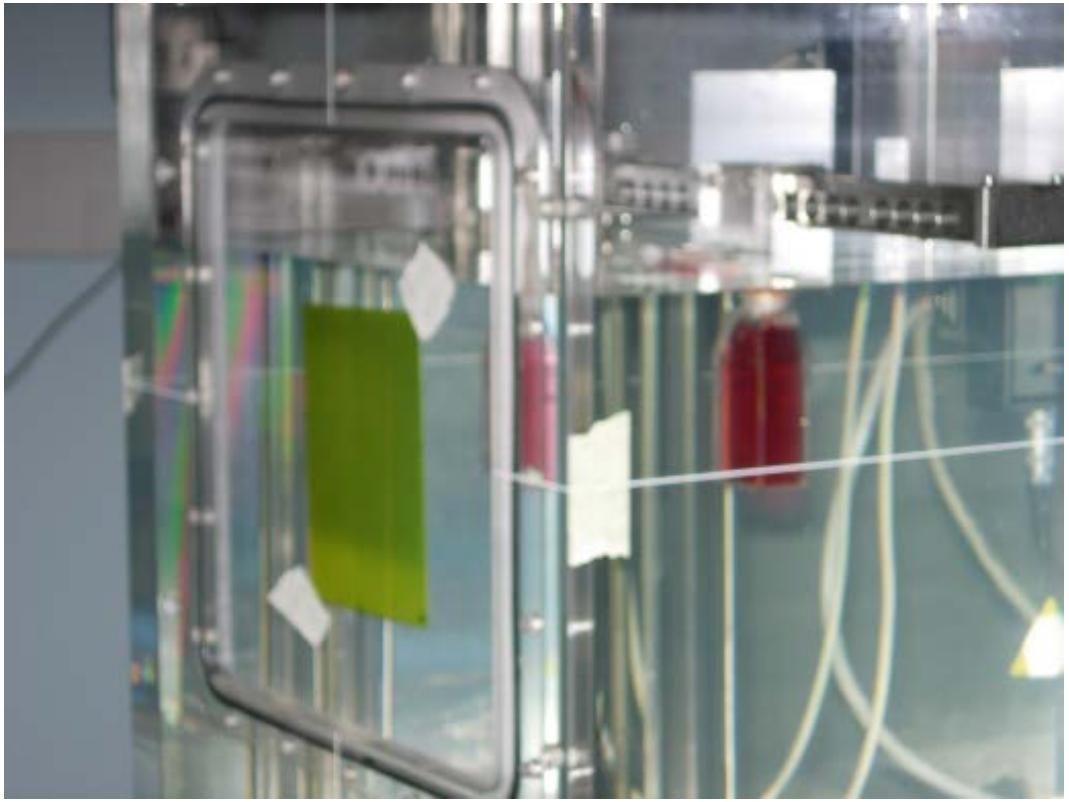
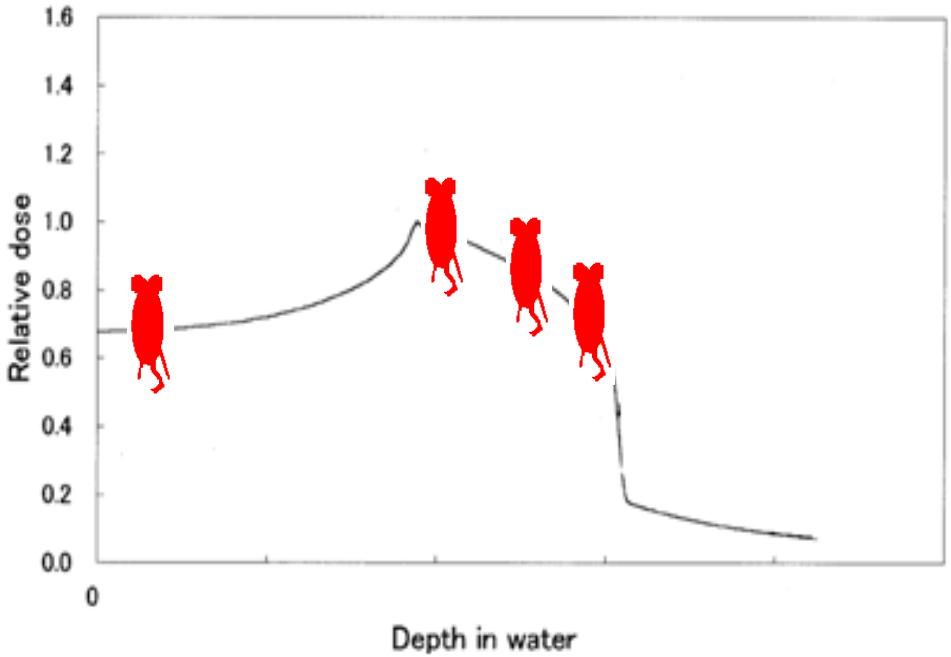
In vitro measurements





Mice Crypt survival assay



Nov. 2010

- 2 beam time sessions
- 3 points in the SOBP
- 6 dose levels, 4 mice per position

(Courtesy of B. Vischioni)

Start of clinical activities

Certification of protocols
(20-30 patients each)

First patient with Proton beam (September 2011)

First patient with Carbon beam (November 2012)

CE Label

Mod. 2200 - ISS

Istituto Superiore di Sanità

Organismo Notificato N° 0373
Sez. presso il Dipartimento di Tecnologie e Salute
Notified Body N° 0373 – Unit relating to Department Technology and Health

Roma, 13 DIC 2013

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TELEFAX: 06 49387138
http://www.iss.it

CERTIFICAZIONE CE

Secondo l'allegato III della Direttiva Europea 93/42/CEE e successive modifiche
Attuate con DLgs. 37 del 25.01.2010

EC CERTIFICATION

According to Annex III of Directive 93/42/EEC and subsequent modifications
Transposed by DLgs. 37 of 25.01.2010

Certificato n° 20131213 036 3303 CT
Certificate n°

L'Istituto Superiore di Sanità, Organismo Notificato n° 0373, certifica che il prodotto sotto menzionato soddisfa i requisiti essenziali di cui all'allegato I della Direttiva 93/42/CEE e successive modifiche verificati in accordo all'allegato III della stessa Direttiva.

The Italian National Institute of Health, as Notified Body n° 0373, certifies that the product hereinbelow described satisfies the essential requirements set out in Annex I and verified in compliance with Annex III of Directive 93/42/EEC and subsequent modifications.

Tipo e modello: Type and model:	Acceleratore per adroterapia Accelerator for hadrontherapy
Descrizione: Description:	[34469] ACCELERATORE DI PARTICELLE, RADIOTERAPIA [34469] PARTICLE ACCELERATOR, RADIOTHERAPY
Destinazione d'uso: Intended use:	Vedi allegato di 3 pagine See annex of 3 pages
Numero di serie: Serial number:	**0001/2012**
Fabbricante: Manufacturer:	**Fondazione CNAO (Centro Nazionale Adroterapia Oncologica)** **Sede Legale:** Via Caminadella,16 – 20133 Milano **Sede Operativa:** Strada Campeggi, 53 – 27100 Pavia

Rapporto di conformità n° Conformity report n°	2013 003 33 003	**del** of	13/12/2013 dd/mm/yyyy
Il presente certificato è valido dal This certificate is valid from	13/12/2013 dd/mm/yyyy	**al** until	08/07/2018 dd/mm/yyyy

Il Direttore del Dipartimento Tecnologie e Salute F.F.
The Acting Director of Department Technology and Health
(Ing. Pietro Bartolini)

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica

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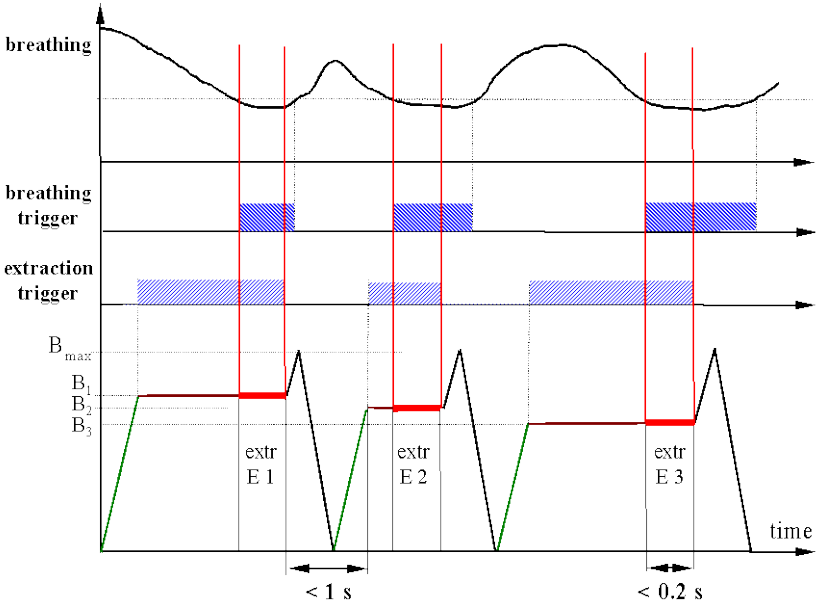
CE
0373

ACCELERATORE PER ADROTERAPIA
SN 0001/2012

Advances: breath synchronization

"Minimal" choice: breath synchronisation (already applied in Chiba, HIT and CNAO)

5 rescanning applied at CNAO



Interesting also for IMRT: lots of efforts and devices

(Review in Riboldi et al, Lancet Oncology 2012)

External surrogates with correlation models

X-rays

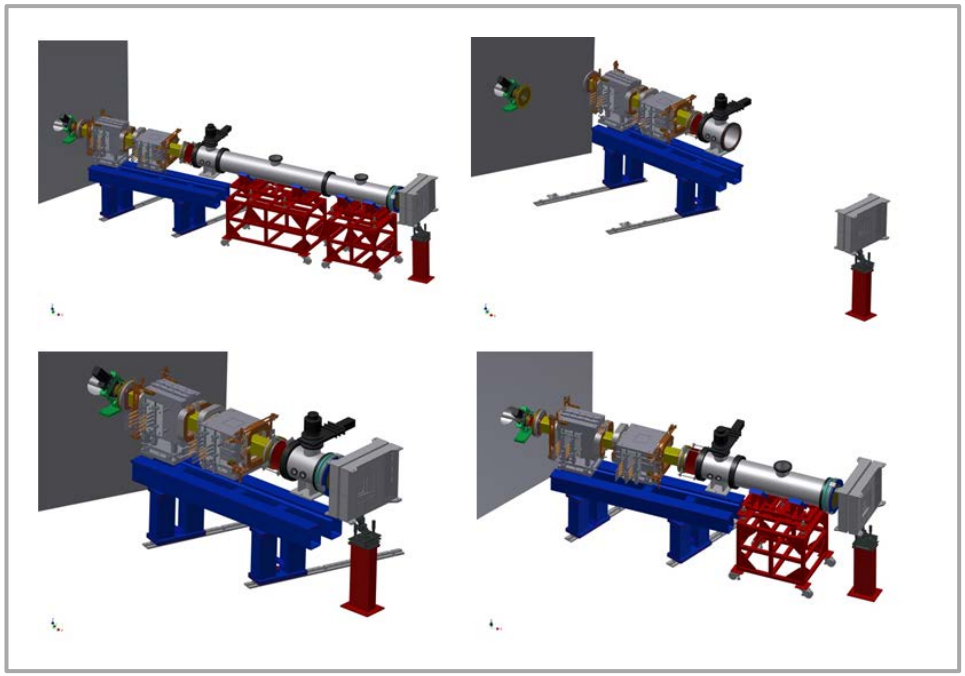
Ultrasound, MRI

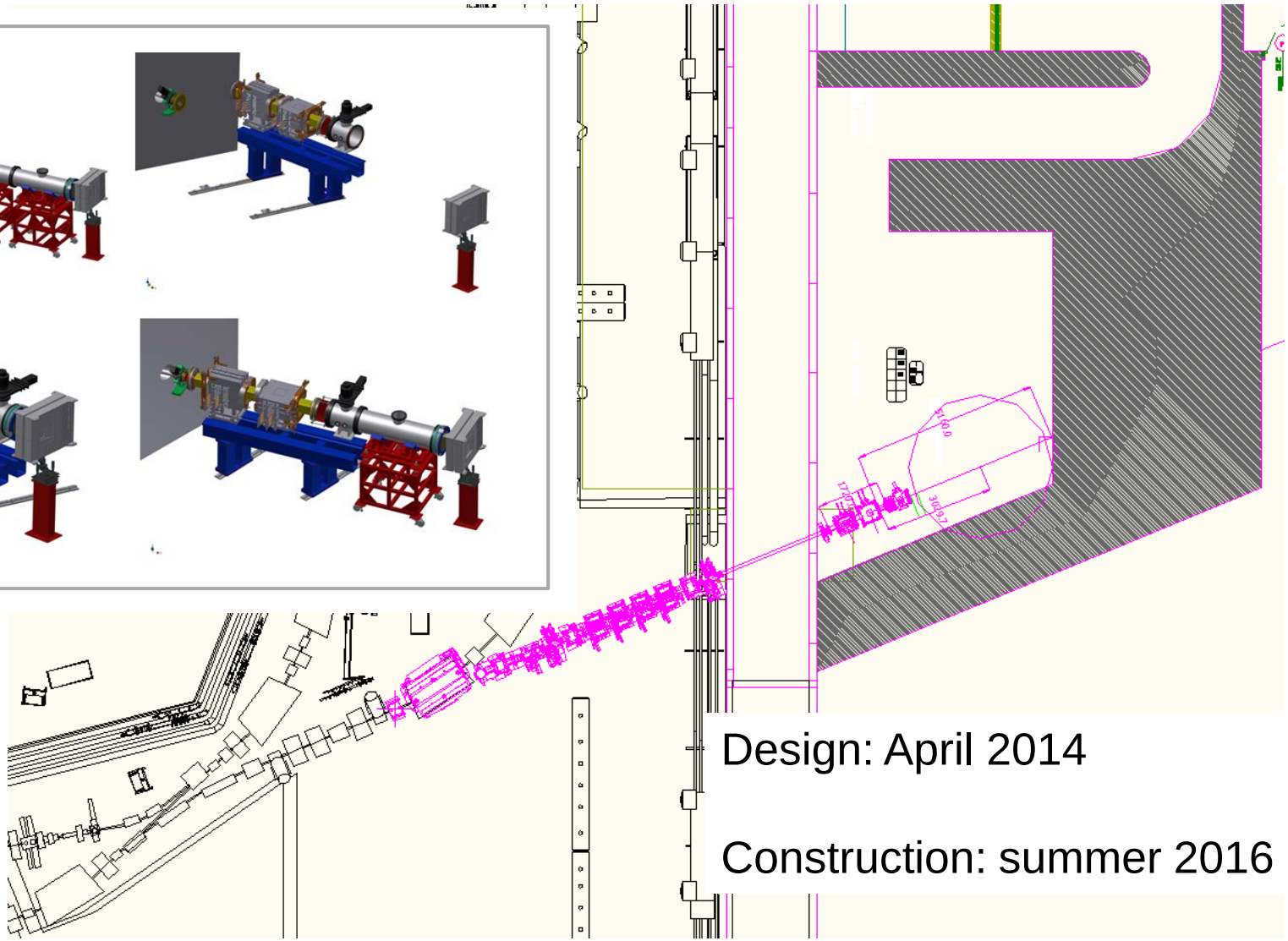
Particle radiography

(Courtesy of Medical Intelligence)

Future and R&D

Experimental room



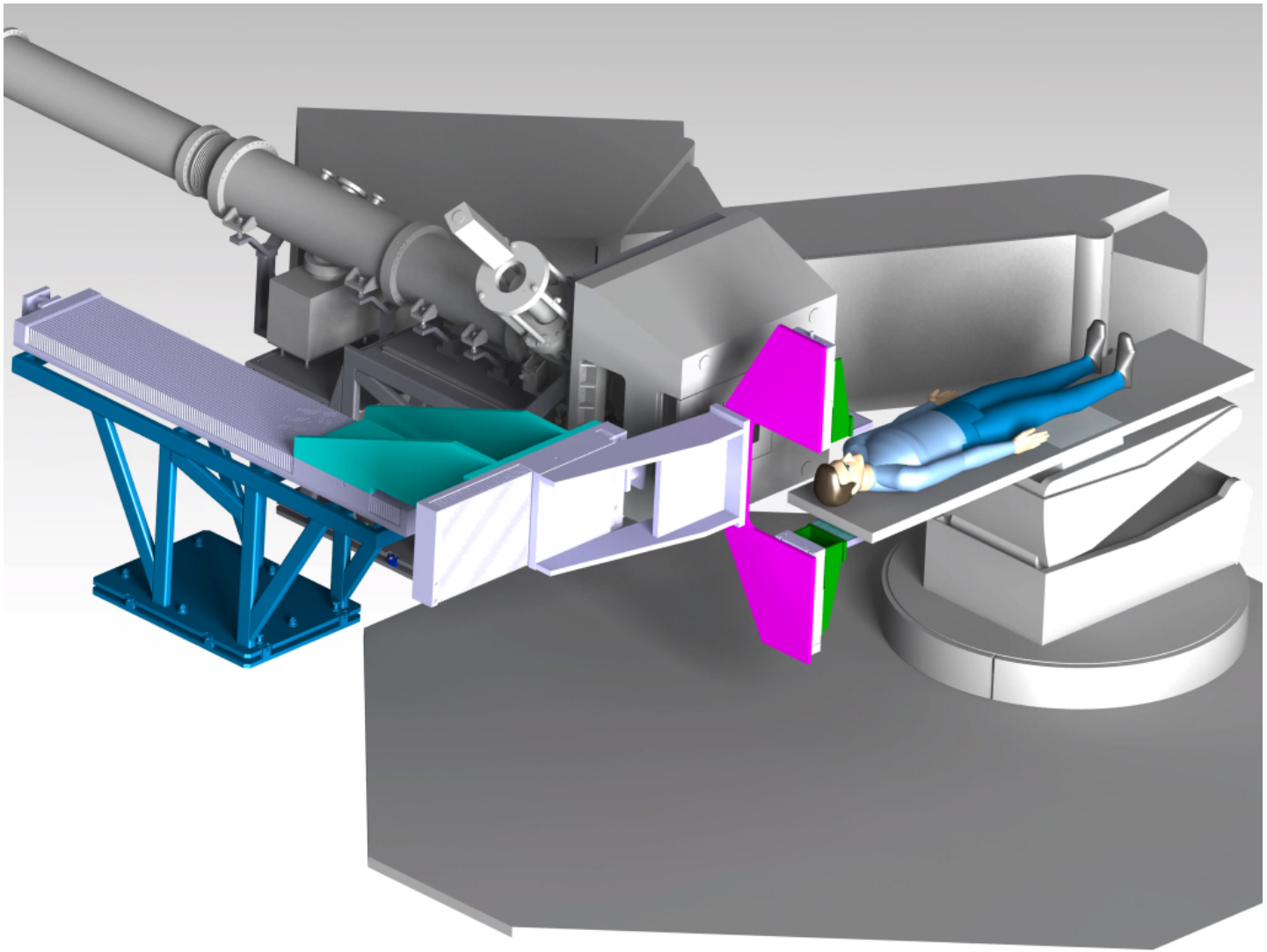


Design: April 2014

Construction: summer 2016

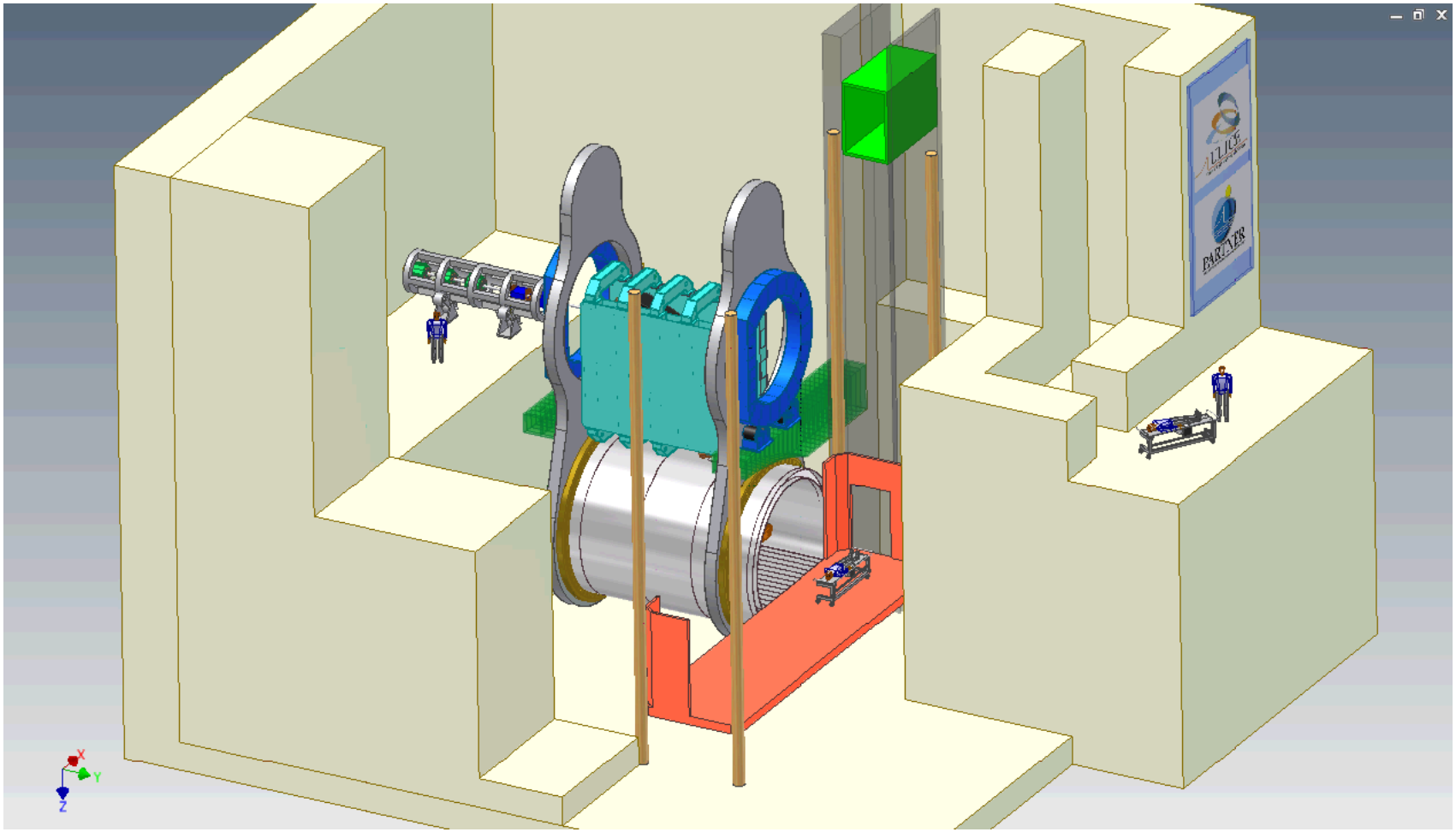
INFN Istituto Nazionale di Fisica Nucleare
Sistema Sanitario Regione Lombardia
fondazione CNAO Centro Nazionale di Adroterapia Oncologica

In beam PET



Courtesy of G. Battistoni

Gantry



Conclusions

- To get to treatments
  - Accelerator commissioning
  - Beam delivery commissioning
  - Physical characterization of the beam
  - Radiobiological characterization in vitro and in vivo
  - Clinical protocols to demonstrate validity
- Non commercial, **build it yourself**
- Collaborations fundamental
- Keep knowledge in house
- R&D is mandatory

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Thank you for your attention

“Physics is like sex: sure, it may give some practical results, but that's not why we do it. ”

R. Feynmann

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