THE CNAO EXPERIMENTAL LINE & FUTURE DEVELOPMENTS

Marco Pullia
Future and R&D
R&D activities

- Gating
On-line imaging

“Minimal” choice: breathing synchronisation (already applied in Chiba and HIT, planned at CNAO)

External surrogates with correlation models
X-rays
Ultrasound, MRI
Particle radiography

Interesting also for IMRT: lots of efforts and devices

(Review in Riboldi et al, Lancet Oncology 2012)
R&D activities

- Gating
- Cycle Shortening
Cycle shortening

- Reduce delays
- Long flat top (to avoid repetitions with faint spots)
- Dynamic betatron
- Chopstop/end of charge
- Smaller hysteresys cycle for protons
R&D activities

- Gating
- Cycle Shortening
- Experimental room
  - High energy beam line
  - New ion species (1 < Z < 8)
  - Medium energy beam line
Present
Experimental room
New source/new particles (1)

### Additional ion species

<table>
<thead>
<tr>
<th>Z</th>
<th>H</th>
<th>He</th>
<th>Li</th>
<th>C</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (p/s)</td>
<td>1.00E+10</td>
<td>2.50E+09</td>
<td>1.11E+09</td>
<td>2.78E+08</td>
<td>1.56E+08</td>
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<tr>
<td>K (MeV/u)</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>400</td>
<td>400</td>
</tr>
</tbody>
</table>

Higher energy He for radiography
New source/new particles (2)

## Additional ion species

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>He</th>
<th>Li</th>
<th>Be</th>
<th>B</th>
<th>C</th>
<th>N</th>
<th>O</th>
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</thead>
<tbody>
<tr>
<td>Z</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
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<tr>
<td>I (p/s)</td>
<td>1.00E+10</td>
<td>2.50E+09</td>
<td>1.11E+09</td>
<td>6.25E+08</td>
<td>4.00E+08</td>
<td>2.78E+08</td>
<td>2.04E+08</td>
<td>1.56E+08</td>
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<tr>
<td>K (MeV/u)</td>
<td>330</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
</tbody>
</table>
Further in future: 7 MeV/u beam?

30% of users is interested
Parasitic operation

To synchrotron

100 ms 100 us

3 s

To XPR
R&D activities

- Gating
- Cycle Shortening
- Experimental room
  - High energy beam line
  - New ion species (1 < Z < 8)
  - Medium energy beam line
- Gantry
Further in future: gantries

- Expansion foreseen in the design
Phase 1 (2003)
Phase 2 (2003)
SETTO DI PROTEZIONE (lavori di espansione)
Size and magnetic rigidity

Conventional RT Carbon Ion Gantry
\[ B_\rho < 6.4 \text{ Tm} \]

Proton Gantry
\[ B_\rho < 2.4 \text{ Tm} \]

Carbon Ion Gantry
\[ B_\rho < 6.4 \text{ Tm} \]
ULICE WP6 Cooperation

Istituto Nazionale di Fisica Nucleare (INFN)

<table>
<thead>
<tr>
<th>Work package number</th>
<th>Start date or starting event:</th>
<th>M1</th>
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<tbody>
<tr>
<td>Work package title</td>
<td>Carbon Ion Gantry</td>
<td></td>
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<tr>
<td>Activity Type</td>
<td>RTD</td>
<td></td>
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<tr>
<td>Participant id</td>
<td>1 CNAO, 4 CERN, 5 MEDA, 6 Etoile, 18 INFN</td>
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<tr>
<td>Person-months per beneficiary</td>
<td>117, 9, 6, 4, 18</td>
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</tbody>
</table>

**CNAO Partnership**
- Necchi Monica (100%)
- Savazzi Simone (100%)
- Viviani Claudio (100%); from the 1st September 2010 substituted by LanteValeria
- Osorio Moreno Jhonnatan (100%) – PARTNER Project WP21

Involvement of industrial partners has been pursued, other institutional and academic partners are participating, as well, **totally for free**

The ULICE project is co-funded by the European Commission under FP7 Grant Agreement Number 228436.
## Firms involved

### Schär

- They built the two protons gantry at PSI (Villigen)
- PPS and PVS for the treatment rooms at CNAO (Pavia)

- Feasibility of the mechanical structure of a mobile isocentre gantry
- Dimensions equal to 2/3 with respect to a fixed isocentre gantry
- Total structure cost 20% less than a fixed isocentre gantry

### MT Mechatronics

It is an experienced international specialist in designing and constructing turn-key precision mechatronics structures including drive control hard- and software. They built the only existing carbon ion gantry in Heidelberg: turn-key supply including development, engineering, fabrication, erection, measurement and adjustment, commissioning and test.

### Kone

They have competences in special lifts (e.g. escalators and autowalks); they set the standard for safety, reliability, visual design, space savings and environmental performance. They revolutionized the elevator industry through their sustainable, energy-efficient designs.

- Design and study for the platform and service lift system
- Cost estimate for the complete system

### IBA

IBA has pioneered proton therapy. With proven efficacy in more than 50,000 patients worldwide, more than 50% of the world’s PT clinical centres designed and equipped by IBA.

- Critical issues discussion
- Inputs useful for the treatment cabin design
- Comparison of costs for the 3 different mechanical structures
- Technical details of gantries

- Cost estimate for the complete system
- Critical issues discussion
- Inputs useful for the treatment cabin design
- Technical details of gantries
Beam line

Synchrotron
- particle Beam source
- Initial beam conditions

Match
- Adjust the beam parameters to the following elements

Phase shifter stepper
- Adjust the beam dimensions at the isocenter

Telescope
- Final Match
- Rotator
- Gantry
The ULICE gantry: mechanical structure without brackets
The ULICE gantry: mechanical structure with half brackets

Gantry mass: 350 t
Magnet misalignment effect

Isocenter displacement for random magnet alignment errors in the gantry

Isocenter displacement for structure deformation at various gantry angles
The ULICE gantry: Beam Based Alignment

Measure where the beam is and put the isocenter there...

One robot arm with two “tools”

CNAO treatment room #2: PPS and PVS
Parasitic dose to patient

- Measurement have been performed shooting four spills against water tanks simulating the preliminary beam position measurement.

- The dose measured 0.5 m on the side of the target was less than 10 uSv for both protons and carbon ions.
## The ULICE gantry: cost estimates

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Magnets (k€)</strong></td>
<td>1705</td>
</tr>
<tr>
<td><strong>Magnets PS (k€)</strong></td>
<td>975</td>
</tr>
<tr>
<td><strong>Mechanical structure &amp;\n  assembling (k€)</strong></td>
<td>5920</td>
</tr>
<tr>
<td><strong>Patient cabin &amp;\n  PPS (k€)</strong></td>
<td>3960</td>
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<tr>
<td><strong>PVS (k€)</strong></td>
<td>1360</td>
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<tr>
<td><strong>Patient handling (k€)</strong></td>
<td>225</td>
</tr>
<tr>
<td><strong>Gantry building (k€)</strong></td>
<td>1500</td>
</tr>
<tr>
<td><strong>TOTAL (k€)</strong></td>
<td><strong>15645</strong></td>
</tr>
</tbody>
</table>

+ conventional plants, cooling and ventilation, access control…
common to any solution
R&D activities

- Gating
- Cycle Shortening
- Experimental room
  - High energy beam line
  - New ion species (1 < Z < 8)
  - Medium energy beam line
- Gantry
- HeCheck
HeCheck

- Simultaneously accelerate 99.9% C and 0.1% He (in Dose)
- Real time radiography and patient thickness (range) verification
Conclusions

- R&D is fundamental in a plant like CNAO
- A dedicated facility for experimental activities is being designed
- Facility construction can be scheduled in stages (HEBT, source, MEBT, Gantries, …)
- Many possible studies possible both for improving the machine and for general advances
That's all Folks!