The AISHa ion source for CNAO

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CNAO Syncrotron room

7-250 MeV (p)
7-400 A MeV (C)

I ~0.1-5 mA (p)
I ~ 0.03-1.5 mA (C)
PK Supernanogun ion sources

$I \sim 0.5 \text{ mA (H}_3^+\text{)}$

$I \sim 0.15 \text{ mA (C}_4^+\text{)}$
Treatment rooms

3 Treatment Rooms (2H, 1 H+V)

Protons: 60-250 MeV  \(10^{10}\) p/spill (~2nA)
Carbon: 120-400 AMeV  \(4 \times 10^8\) C/spill (~0.4nA)

More than 3500 patients treated
Carbon/Protons=60/40
Treatment rooms

3D Real-time IR Optical Tracking (OTS)
- Real time reconstruction of spherical markers
- Sub-millimeter accuracy: peak 3D errors < 0.5 mm
- 3D data flow @70 Hz

X-ray Patient Verification System (PVS)
- 2 X-ray tubes (deployable)
- 2 flat panels (deployable)
- Supporting structure rotation: ±180°
- Rotation and deployment accuracy: ± 0.15mm, ± 0.1°

Patient Positioning System (PPS)
- Automatic couch or chair docking
- Absolute accuracy: ± 0.3 mm

Courtesy of M. Pullia
Beam line for R&D activities

Unique possibility to perform activities ranging from clinical to radiobiological research. A dedicated experimental irradiation room is available in time slots not impacting on patient treatments, but specifically devoted to research purposes.
Experimental room

Easily reconfigurable!

- **Isocenter 1**: Fixed beam (single spot)
- **Isocenter 2**: Fixed beam (single spot), Beam measured and controlled
- **Isocenter 3**: 135 x 135 mm², Scanned beam
- **Isocenter 4**: 200 x 200 mm², Scanned beam

- Beam delivery system
  - On rails
- Incoming beam pipe
- Laser lines to identify Irradiation positions
- Scanning magnets can be displaced easily
Revamping of critical components in order to speed some normal machine operations:

- Revamping of critical components to increase machine reliability
- Upgrade of the radiobiology laboratory
- **AISHa source** for Helium, Lithium, Oxygen and Iron for new clinical protocols (He, O, Li) and biological/material experiments for space radiation research.
Extension of the BIANCA biophysical model up to Fe-ions and applications for space radiation research

- BIANCA simulations vs experimental data for monochromatic ion beams.

**V79 cell death**

![Graph showing V79 cell death](image1.png)

**Chromosome aberrations in lymphocytes**

![Graph showing chromosome aberrations in lymphocytes](image2.png)

Radiobiological databases predicting cell death and chromosome damage as a function of dose and energy already created from Z=1 to Z=26 (Ramos et al., submitted)

Courtesy of V. Vercesi
Evaluation of biological damage by Galactic Cosmic Rays: example of calculation using FLUKA + BIANCA

- Spherical water phantom (radius 15 cm) included in a spherical, isotropic source (radius 32 cm).
- The simulations were repeated for a source consisting of 1 GeV protons, 1 GeV/u He-ions, 1 GeV/u C-ions, or 1 GeV/u Fe-ions.

\[
\text{RBE} = \frac{\text{photon dose}}{\text{Ion dose}} \quad \text{to obtain the same biological damage}
\]

<table>
<thead>
<tr>
<th>Ion</th>
<th>( RBE_{dc} )</th>
<th>Dose(Gy)*( RBE_{dc} )</th>
<th>( RBE_{surv} )</th>
<th>Dose (Gy)*( RBE_{surv} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^1\text{H}) (0.20 Gy)</td>
<td>1.56</td>
<td>0.31</td>
<td>1.48</td>
<td>0.30</td>
</tr>
<tr>
<td>(^4\text{He}) (0.10 Gy)</td>
<td>2.56</td>
<td>0.26</td>
<td>1.40</td>
<td>0.14</td>
</tr>
<tr>
<td>(^{12}\text{C}) (0.15 Gy)</td>
<td>2.82</td>
<td>0.42</td>
<td>1.76</td>
<td>0.26</td>
</tr>
<tr>
<td>(^{56}\text{Fe}) (0.05 Gy)</td>
<td>14.52</td>
<td>0.73</td>
<td>7.37</td>
<td>0.37</td>
</tr>
</tbody>
</table>

More simulations, considering the full GCR spectrum and/or an anthropomorphic phantom, included in a shielding structure, will be object of future studies.

Courtesy of V. Vercesi
PK Supernanogun O1 ion source

PK Supernanogun O2 ion source

To RFQ
AISHa integration @ CNAO
AISHA
Advanced Ion Source for HAdrontherapy

- low space occupation and minimization of electrical consumption
- high stability and high reproducibility
- highly charged ion beams with low ripple
- low maintenance time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial field</td>
<td>1.3 T</td>
</tr>
<tr>
<td>Axial field</td>
<td>2.7 T - 0.4 T - 1.6 T</td>
</tr>
<tr>
<td>Operating frequencies</td>
<td>18 GHz – 21 GHz</td>
</tr>
<tr>
<td>Operating power</td>
<td>1.5 + 1.5 kW (max)</td>
</tr>
<tr>
<td>Extraction voltage</td>
<td>40 kW (max)</td>
</tr>
<tr>
<td>Chamber diameter / length</td>
<td>Ø 92 mm / 360 mm</td>
</tr>
<tr>
<td>LHe</td>
<td>Free</td>
</tr>
<tr>
<td>Warm bore diameter</td>
<td>274 mm</td>
</tr>
<tr>
<td>Source weight</td>
<td>1400 kg</td>
</tr>
</tbody>
</table>
AISHa performances @INFN-LNS (17.3-18.4 GHz – 1.5 kW max)

**Charge state**

<table>
<thead>
<tr>
<th>Charge state</th>
<th>Beam intensity [eμA]</th>
<th>ε_{rms,norm} [π · mm · mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16O^{6+}</td>
<td>1400</td>
<td>0.2198</td>
</tr>
<tr>
<td>16O^{7+}</td>
<td>350</td>
<td>0.247</td>
</tr>
<tr>
<td>12C^{4+}</td>
<td>650</td>
<td>0.272</td>
</tr>
<tr>
<td>12C^{5+}</td>
<td>165</td>
<td>---</td>
</tr>
<tr>
<td>40Ar^{11+}</td>
<td>155</td>
<td>0.201</td>
</tr>
<tr>
<td>40Ar^{12+}</td>
<td>140</td>
<td>0.201</td>
</tr>
<tr>
<td>He^{2+}</td>
<td>5400</td>
<td>0.418</td>
</tr>
<tr>
<td>He^{2+}</td>
<td>7000</td>
<td>0.245</td>
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</table>

**News: 21 GHz just delivered!**
Adaptation of GSI STO oven to AISHa for PANDORA to test long term production of 176Lu
Oct.21  Magnetic measurements.

Nov.21-Jan.22  Assembly of supports and ancillary equipment.

Feb.22  Test of electronics and CC debugging.

Mar.22  Source disassembly in macro-parts, transportation to CNAO, integration with the syncrotron ring.

Apr.22  Start commissioning with O, He and C beams, test acceleration through the syncrotron.

Operation planned, in the meanwhile, at the AISHa site @INFN-LNS: restart operation in the new room, new diagnostics and OES setup, double frequency operation, Fe beam development.
AISHa will permit to realize a unique possibility to perform activities ranging from clinical and radiobiological research. A dedicated experimental irradiation room is available in time slots not impacting on patient treatments, but specifically devoted to research purposes (e.g.: space radiation research).

Integration at CNAO in progress. Deployment expected for March 2022 and first beam in April 2022.

Restart of operation of AISHa in the new LNS site is expected for Jan. 22 with a program of R&D funded by INFN within the Fifth National Commission under the IONS experiment.

Fe beam development in collaboration with GSI and in the framework of PANDORA developments for the production of $^{176}$Lu.

Competitive dialogue for the construction of the fully superconducting magnetic trap just published on-line.

Prequalification phase open up to October 25th.

https://servizi-dac.dsi.infn.it/index.php/gestioneavvisi/dettaglioAvviso/2151819/0/2
Thanks for your attention!