Recent Developments in Proton Accelerators

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C230 cyclotron for proton therapy
C230 key specifications

- Compact isochronous cyclotron
- 235 MeV proton energy
- 300 nA beam current, quasi-continuous
- Typical efficiency: 55 %

- Approx. weight: 220 T
- Diameter: 4.3 m

- Conventional magnet coil: 1.7 - 2.2 T
- RF Frequency: 106 MHz
- Dee voltage: 55 to 150 kV peak
A quite popular solution...

20 facilities including IBA equipment, 64 treatment rooms in total
Evolution...
... also for cyclotrons!

... just changing the logo?
Quite robust design

- Design not changing
- Improving tools and technical details for
  - Increased reproducibility
  - Easier maintenance
  - Faster commissioning
Personalized PT treatments
Proteus 235 is not just a cyclo
Treatment rooms
What lies inside the nice covers...

<table>
<thead>
<tr>
<th>TUMOR CHARACTERISTICS</th>
<th>EXAMPLE: LUNG</th>
<th>EXAMPLE: MEDULOBLASTOMA</th>
<th>EXAMPLE: EYE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DOUBLE</td>
<td>UNIFORM</td>
<td>PENCIL BEAM</td>
</tr>
<tr>
<td>Scattering</td>
<td>SCATTERING</td>
<td>SCANNING</td>
<td>SCANNING</td>
</tr>
<tr>
<td>Moving Target</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tumor Size</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Treatment Speed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Neutron Dose</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wing Shape Effect</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lateral Penumbra</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Good 🟢  Better 🟢  Best 🟢
## Improvements on PBS

<table>
<thead>
<tr>
<th>Feature</th>
<th>PBS V1 (UN)</th>
<th>PBS V6 (DN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigma @ 230 MeV</td>
<td>10 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>Minimal Energy</td>
<td>140 MeV</td>
<td>100 MeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>or 60 MeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Optionaly)</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>+/- 2 mm</td>
<td>+/- 1 mm</td>
</tr>
<tr>
<td>Commissioned Angle</td>
<td>0°, 360°</td>
<td>All angles</td>
</tr>
<tr>
<td>Treatment Time</td>
<td>Above 5 min</td>
<td>1 min 36 sec</td>
</tr>
<tr>
<td>Switching Time</td>
<td>2 min</td>
<td>15 s</td>
</tr>
</tbody>
</table>

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1st patient treated in Boston, Dec. 2008
Challenges are in the software!
PBS Quality Assurance challenges

- A number of parameters to control and validate
  - Spot Size (sigma, skewness)
  - Spot Position
  - Complex shape size analysis
  - Dose/Intensity analysis
  - Range analysis
IBA’s Solution : QA test pattern

Transversal 2D measurements performed using Lynx scintillator from IBA Dosimetry
Data acquisition and processing managed by OmniPro software from IBA Dosimetry
PBS Pattern (Polygone Area)

226 MeV
PBS Pattern (spot analysis)

- **226 MeV**
PBS Pattern *(Beam size analysis)*

**226 MeV**

![Image of beam size analysis](image-url)
PBS Performances

- **Gantry angle dependency**
  - Spec beam reproducibility $\leq \pm 5\%$

![Graph showing Beam sigma in air at isocenter vs Gantry angles]

Beam Spot for energy of 230 MeV in air @ Isocenter for various gantry angle
PBS performances

- **Range Accuracy**
  Spec ± 0.1 g/cm²

Better than +/- 0.2 mm
Timing performances
Reducing irradiation time: PBS-10s

- **Objective:** treat a 1-liter tumor with PBS in 10 sec.

- **Idea:** use patient-specific micro ridge filter
Making PT more accessible
Towards a novel, low-cost PT accelerator

- Lower cost & standardized Proton Therapy System
- Compact treatment room and small footprint
- Shorter installation time on site
- Operator less
- Reduced maintenance

Proteus One : low cost, smaller footprint
Smaller cyclo, integrated ESS

Beam Line shortening ➔ Smaller structure ➔ Smaller system
Towards a more compact cyclotron

- Compact machine requires higher magnetic field
  - Superconducting magnet

- To conserve isochronism one has to compensate relativistic mass increase
  - Magnetic must increase with the radius

- Increasing magnetic field is naturally defocusing
  - Restore focusing by alternating field gradients in hills and valleys
  - Further increase focusing by spiralling the poles

- … but once the pole iron is saturated, there is a limit on the field gradient between hills and valleys (flutter)
- … and there is also a limit in spiral designs
S2C2 rationale

- The only solution to increase the magnetic field while conserving the beam focusing inside the machine is to use weak focusing
  - No field gradients between hills and valleys
  - Decreasing field with radius

- With such design isochronism cannot be maintained
  - Changing RF
  - Pulsed beam at machine exit

By definition such machine is a SynchroCyclotron
Which in our case will be Super - Conducting

S2C2
Introducing IBA’s S2C2
S2C2 Specifications

- **Compact system**: diameter 2.5 m, height 2 m, weight <50 T
- **Reliability**: NbTi cryogen free coil, passive magnetostatic extraction...
- **Repeatability**: Standard high quality laminated steel
- **Operability**: Operator-free system, remote diagnostics

- 20 nA average beam current at 230 MeV for PBS; 150 nA feasible if required
- Extraction efficiency >50% at 230 MeV
- 1 kHz beam pulse repetition rate for PBS
- Still possible to reach 250 MeV (with some additional work)
Overall view

Size and weight within specs

Easy accessibility on sub-systems

Yoke shape compromise: sustainable stray field for ancillary equipments
...and the S2C2 is not just pretty CAD drawings!

Yoke return ring
...and the S2C2 is not just pretty CAD drawings!

Pole pieces
…and the S2C2 is not just pretty CAD drawings!

Magnet plate
…and the S2C2 is not just pretty CAD drawings!

Oscillator power supply
…and the S2C2 is not just pretty CAD drawings!

Dummy vacuum chamber
...and the S2C2 is not just pretty CAD drawings!

Water conditioner
…and the S2C2 is not just pretty CAD drawings!

Ion Source test bench
General presentation

Compact Gantry and Rolling Floor

Treatment Room

NZL CBCT

S2C2
Making PT more accessible

Approx. the size of two linacs

27.3 m – 89.5 ft
19 m – 62.3 ft
7.3 m – 24 ft
12.8 m – 42 ft
Patient Centric Treatment Room Design
Proteus®ONE 220 Degree Gantry
Proteus ONE* Timing

Projected Product Introduction Timeline

2011  Design Freeze Subsystems Procurement

2012  Prototype Testing

2013  FDA Filing

2014  Patient Treatments

*Subject to review by Competent Authorities (FDA, European Notified Bodies, et al.) before being put on the market.
Thank you!