Acceleration and Measurement of $\alpha$-Particles and Hydrogen Molecular Ions with the HZB Cyclotron
Motivation

• more than 4000 patients treated with protons since 1998
• accompanying R & D:
  – beam delivery
  – dosimetry
  – investigations for FLASH irradiations
• “Cocktail beams”
  – same charge to mass ratio
  – same velocity
  – cyclotron operates as mass separator
  – only slight changes in cyclotron RF necessary to switch beams
• our cocktail: 45 MeV H$_2^+$ and 90 MeV He$^{2+}$
• charge to mass ratio 1:2
• nearly same velocity
  (22.34 MeV/u and 22.49 MeV/u respectively)
• fast switching of beams possible
  (less than 0.5 hours)
Accelerator Complex

- $k = 130$ isochronous sector cyclotron
  - 10 – 20 MHz

- two injectors:
  - 2 MV Tandetron™
  - 6 MV Van-de-Graaff, with 5 GHz ECR Source

- three target stations:
  - treatment room
  - experimental station ($I_{\text{max}}(\text{DC}) = 10 \text{ nA}$)
  - beam line end for tests in cyclotron vault
Experiments

- verification that vacuum window (75 µm Kapton) completely strips H$_2^+$ beam using dipole magnet and stripper foil of 50 µm Kapton:
  - beam intensity doubles directly after the stripping foil
  - no beam intensity measured at dipole setting for 45 MeV H$_2^+$
- comparing the radiation fields of both fields created with 50 µm Kapton for 45 MeV H$_2^+$ and 130 µm Kapton for 90 MeV He$_{2+}$:
  - foil induced angle of 2.45 mrad (calculated with lookup-code)
Transverse Profiles

- measured using a CCD camera, data evaluation with image pro plus

<table>
<thead>
<tr>
<th>Ion</th>
<th>Uniformity = average level in flat-top region</th>
<th>Penumbra = lateral fall-off from 90% to 10%</th>
<th>Symmetry = difference between lateral edges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stripped H$_2^+$</td>
<td>15%</td>
<td>2.1 mm</td>
<td>2%</td>
</tr>
<tr>
<td>He$^{2+}$</td>
<td>7%</td>
<td>1.2 mm</td>
<td>2%</td>
</tr>
</tbody>
</table>

![Graph showing normalized intensity vs. vertical plane (mm) for Stripped H$_2^+$ and He$^{2+}$ ions.](image)
• Bragg-Peak measured in water
  - Measurement starts at 2.6 mm due to thickness of tank and detector cover
  - Range of \( \text{He}^{2+} \) beam 0.1 mm smaller due to thicker scattering foil
  - Distal fall-off (90% to 10% of dose):
    0.16 mm for \( \text{H}_2^+ \) and 0.1 mm for \( \text{He}^{2+} \) beam
  - \( \text{He}^{2+} \) beam: better peak-to-plateau ratio
Conclusion and Outlook

- HZB cyclotron provides similar radiation fields using the same nozzle (scattering foil for He$^{2+}$ beam thicker)
- rapid changes between ion species
- He$^{2+}$ beam: sharper penumbra, better peak-to-plateau ratio
- Outlook:
  - biological experiments using both ion species
  - evaluate FLASH effect for both ion species
- dedicated clinical cyclotron can provide both ion species

Thank you for your attention!