HEATHER

HElium ion Acceleration for radioTHERapy

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University of HUDDERSFIELD
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Scope

Current particle therapy situation and why we should bother with helium

Helium ion acceleration with HEATHER

Conclusions

Particle therapy

- Ion and proton therapy hold advantages over conventional radiotherapy

- Physical benefits
  - Dose distribution
  - the way the particles interact with matter
  - Linear energy transfer (LET)

- Biological benefits
  - Radiobiological effectiveness (RBE)

Ion therapy

- At the moment ion therapy just means carbon ions
- Advantages of Carbon ions over protons
  - Improved Dose distribution
  - Higher LET correlating to higher RBE
- Disadvantages
  - Variable high energy RBE – difficult to model
  - Dose tail
  - Size of the required facility

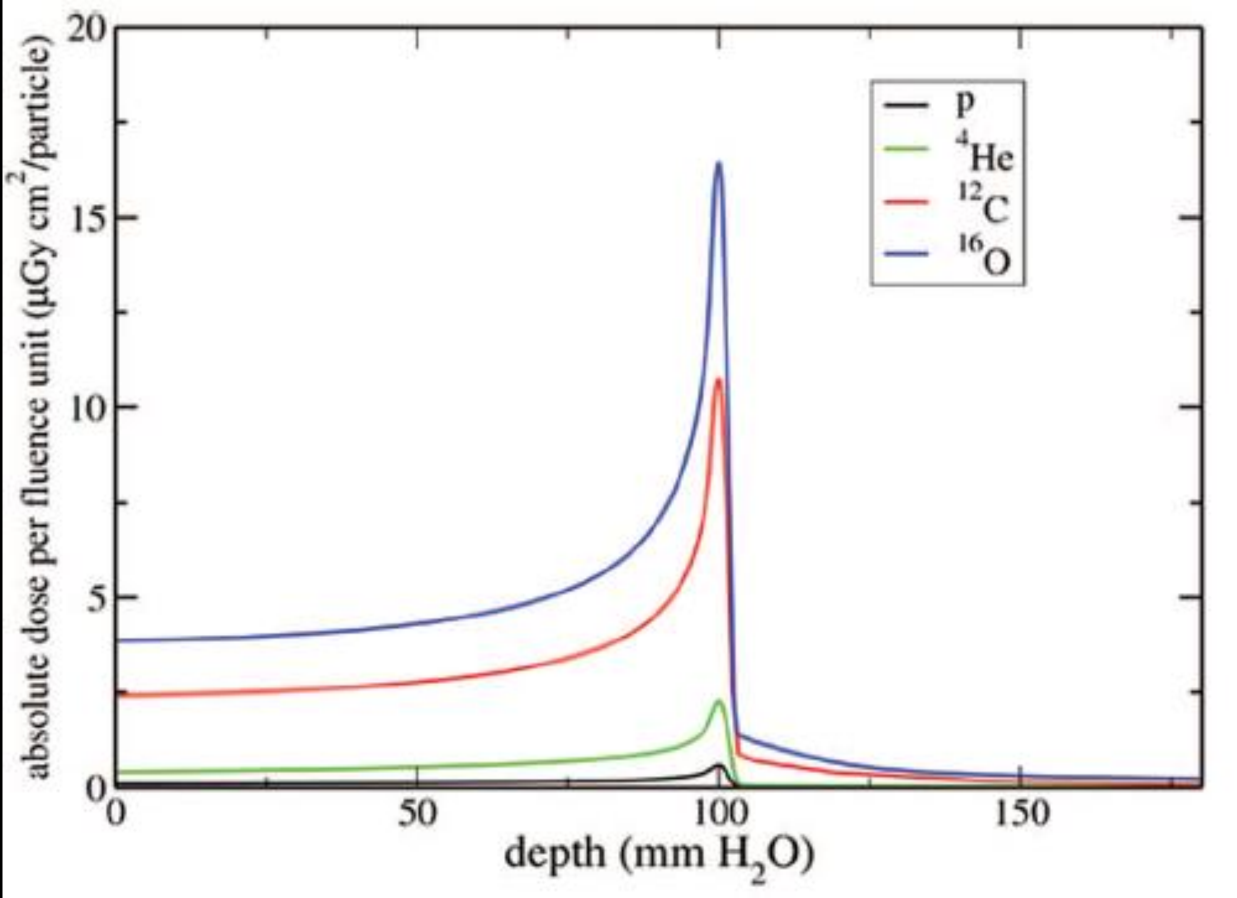

Figure 1[1]. Absolute dose per unit fluence for protons and a range of ions

Fragmentation

- Fragmentation is more prevalent in carbon ion therapy
  - secondary particles from inelastic nuclear interactions between the ion and the tissue - which adds to the total damage [1-7]
- The created low-z fragments have a longer range, creating a dose tail beyond the Bragg peak
  - problematic for organs at risk
- The use of lighter ions like helium have a reduced fragmentation tail [1-5,7]

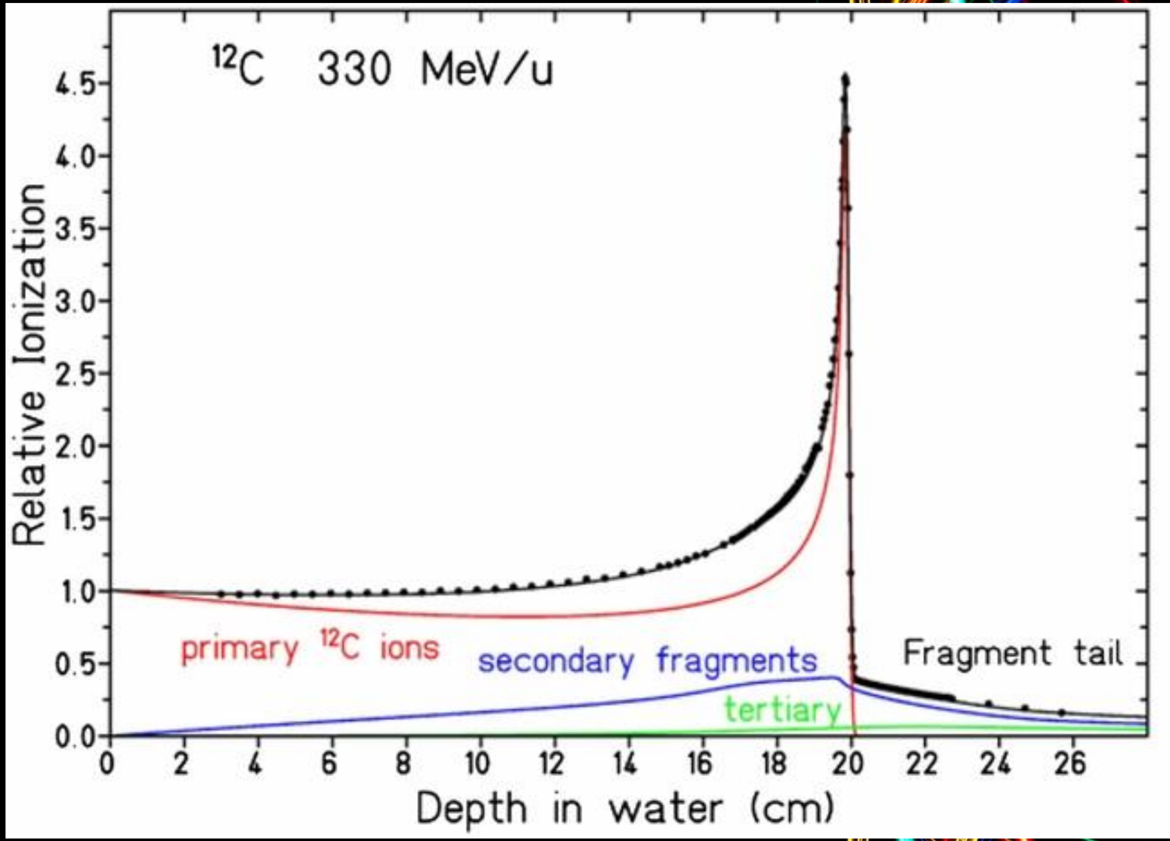

Figure 2[7]. A description of the relative ionization against depth for 330 MeV/u carbon ions, highlighting the fragmentation tail.

Acceleration

- The difficulty in accelerating carbon can be expressed via beam rigidity, as depicted by Figure 3

- Currently 10 facilities that can provide carbon ions for therapy
  - China (2) Japan (5) Europe(3)
  - All synchrotrons

- Cyclotrons are the workhorses of proton therapy

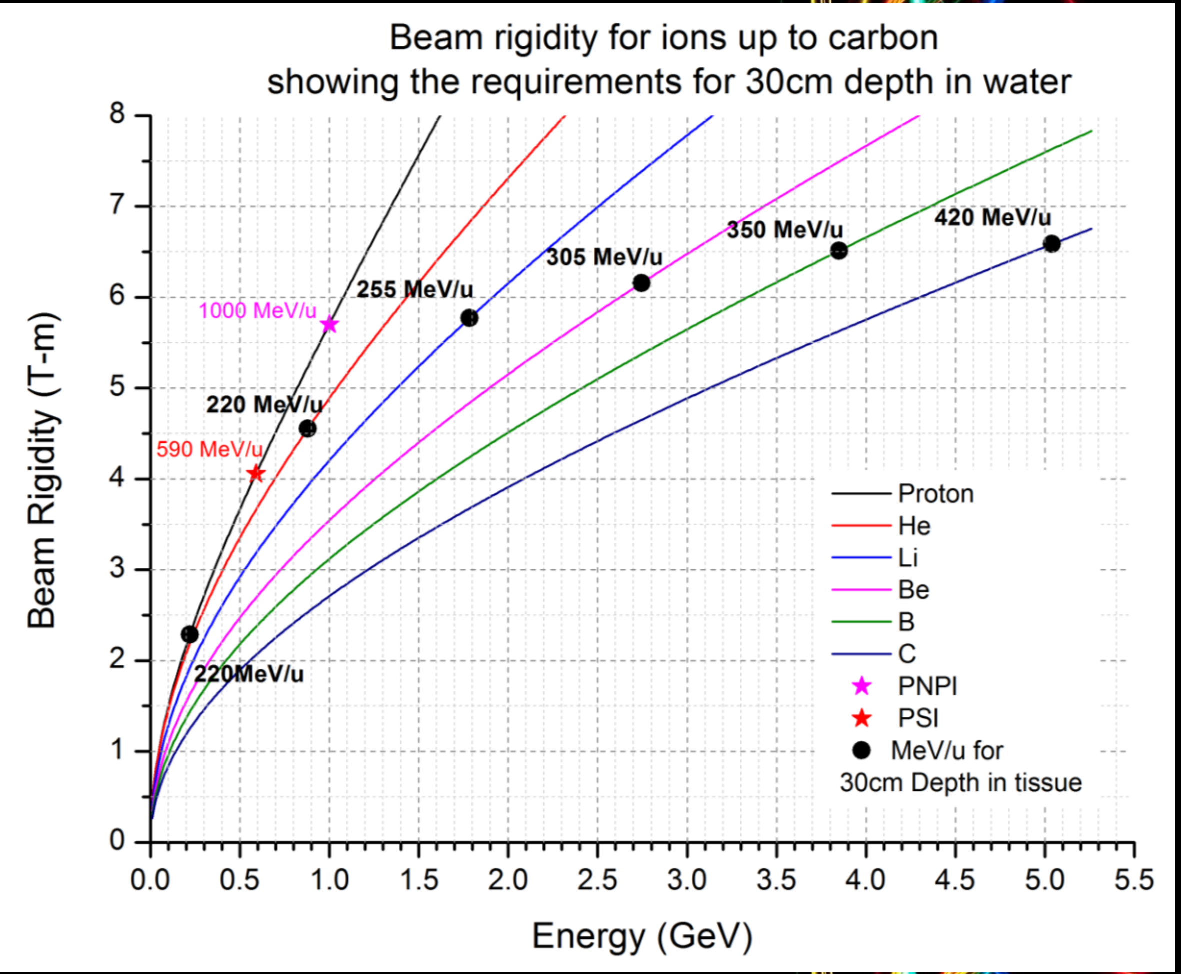

Figure 3. The bending radius necessary to bend the beam against kinetic energy for fully stripped ions up to carbon

Why Helium?

- Used before at Berkeley (57-92) [8-9]
    - 2000 patients

- Physically
    - Easiest to accelerate after protons – same MeV/u
    - Less projectile fragmentation than carbon ions
    - Half the MCS scattering and sharper Bragg peak compared to protons

- Biologically
    - Treatment plan comparison found helium RBE and conformity effects carbon and protons[3]
        - TRiP98 and LEM model
        - Mass is closer to protons - He could be easier to model with less RBE uncertainties
        - RBE values found correlate with data from Berkeley experiments

    - Revival is not unrealistic
        - Research has started in Heidelberg [10](Apr 16)
        - Interaction with matter study required as for carbon ions
        - Can only be studied at current carbon facilities

Aims

- Helium therapy feasibility study using an non scaling FFAG accelerator
  - Non scaling allows fixed frequency acceleration - ease of use
  - CW beam and ease of use like a cyclotron
  - Variable energy like a synchrotron

- isochronously accelerate He^{2+} to 900MeV (225 MeV/u)
  - 2 stage acceleration

- deliberately designed with $\frac{q}{m} = \frac{1}{2}$
  - Can accelerate C^{6+} (225/u approximately ~10cm depth)

- If we can accelerate to 330 MeV/u we can image with H_2^+
  - Possibility to treat and image with the same machine
  - Carbon range increases to ~20cm

HEATHER Stage 1

- Superconducting ring with 4 identical magnets
- 0.5 > 400 MeV
- 2.5m radius
- 600 KeV/turn
  - 2 cavities @ 300KeV
- 350 turns

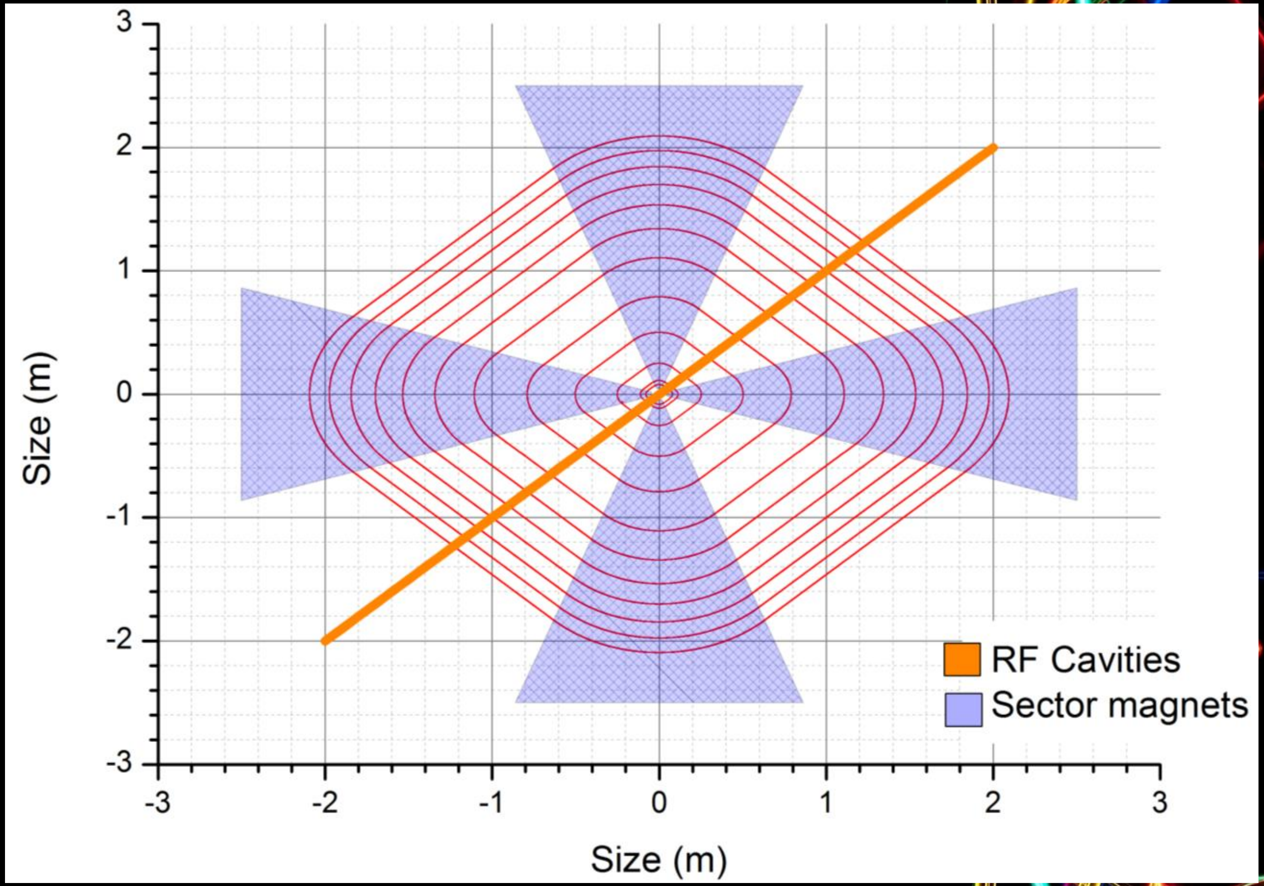

Figure 4. HEATHER stage 1 magnet layout showing stable orbits from 0.5 MeV through to 400 MeV

S1 - Isochronicity

- constant orbital frequency across all energies
- Percentage difference compared to the mean ToF over all energies using COSY and OPAL
- Isochronous enough to accelerate at fixed frequency RF
- Initial overlapping fringe fields supress TOF

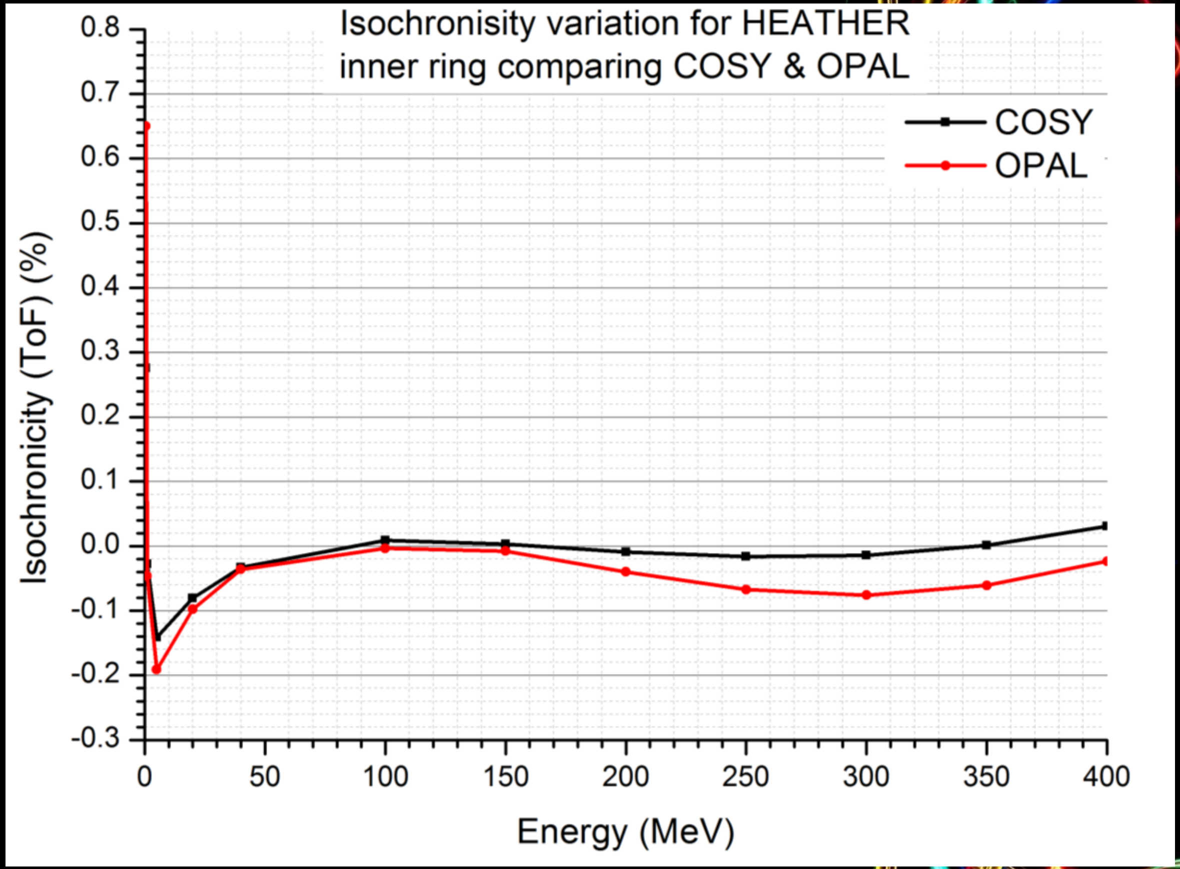

Figure 5. HEATHER stage 1 Isochronicity variation in percentage

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S1 - Tunes

- Frequency of oscillation around the ideal orbit
- Good agreement between COSY and OPAL
- Crosses the integer just after 1 MeV - OK – demonstrated by EMMA @ Daresbury
- Tune suppression caused by overlapping fringe fields

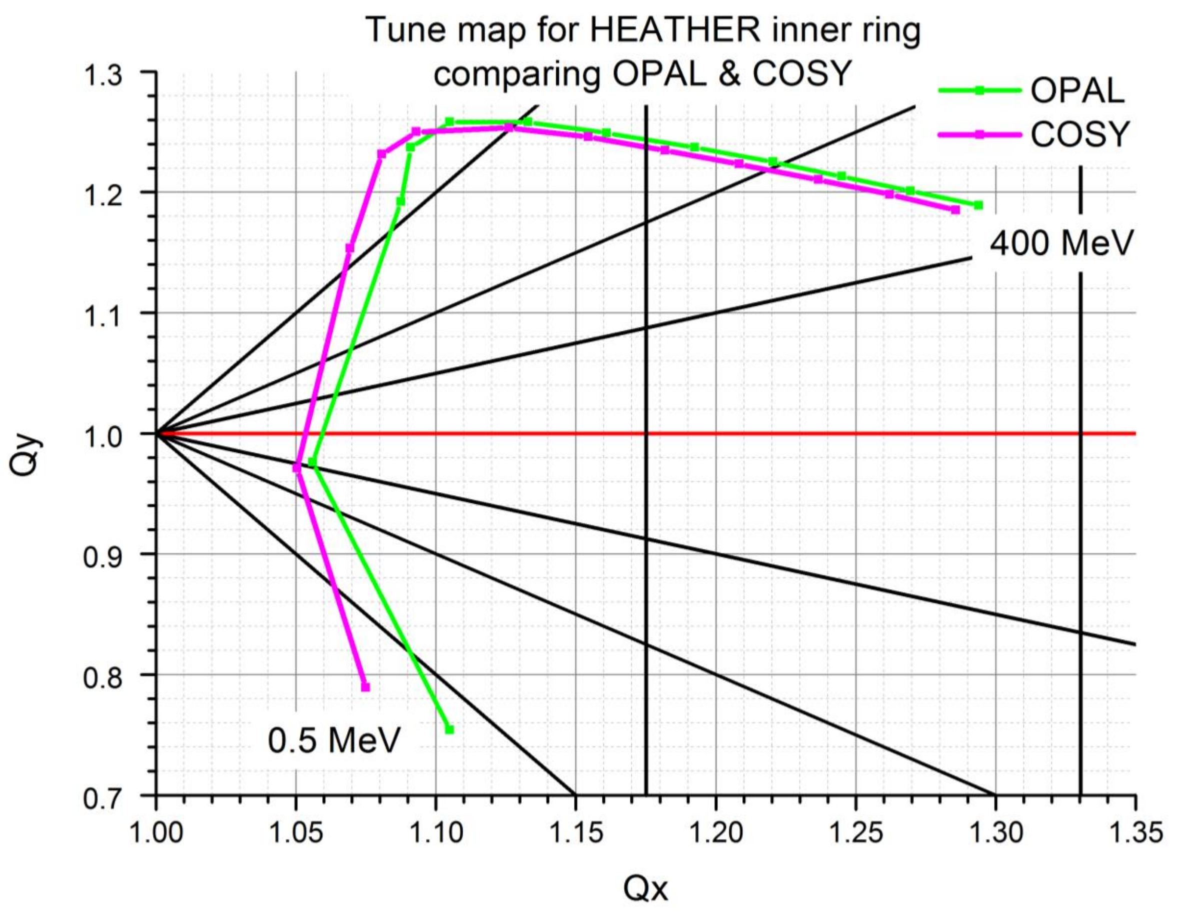

Figure 6. HEATHER Stage 1 tune map showing a comparison between COSY and OPAL

S1 - Acceleration

- Parabolic time of flight leads to Serpentine acceleration
- Fixed frequency of 10.338 MHz
- Large phase acceptance

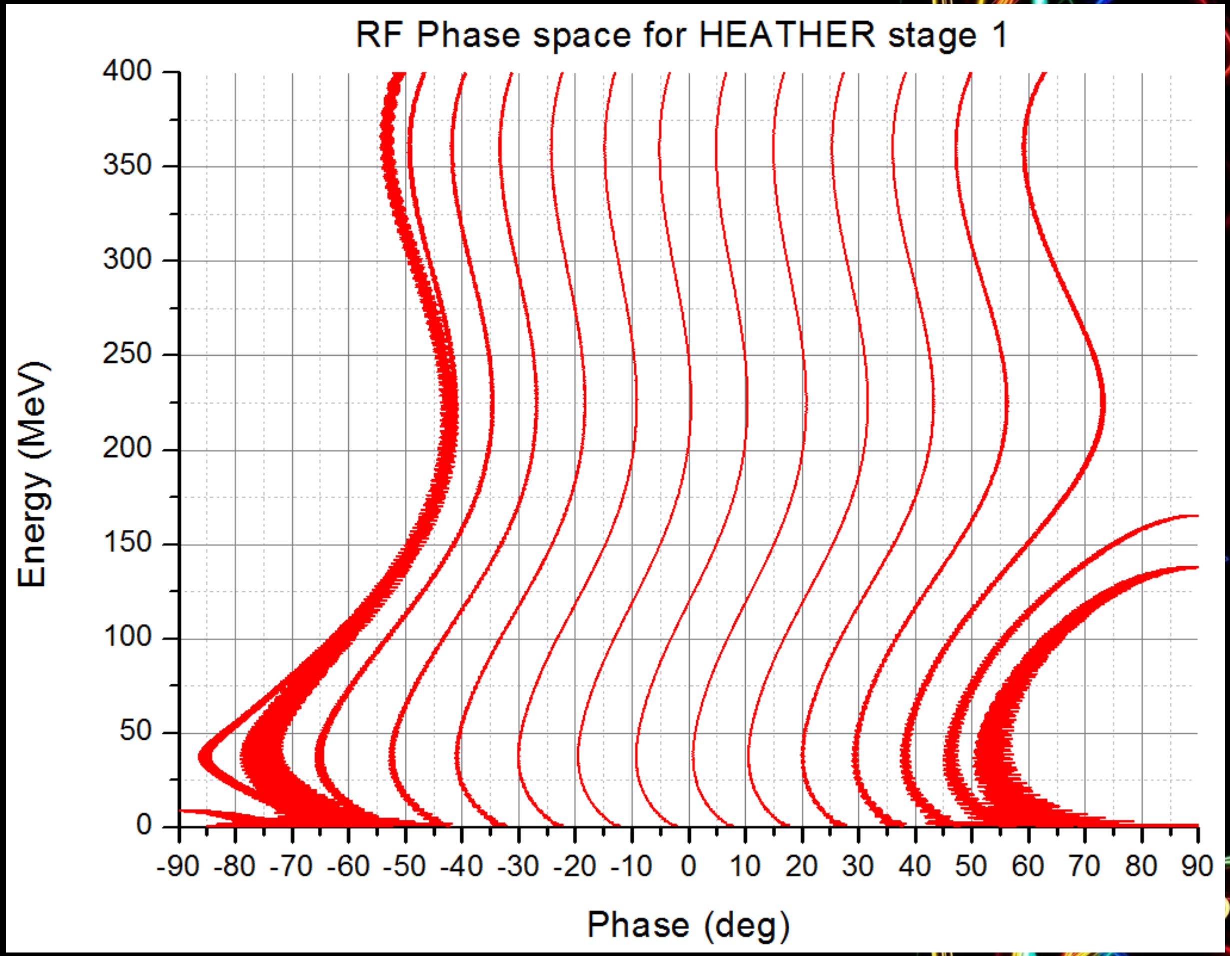

Figure 7. HEATHER Stage 1 RF Phase space plot

HEATHER Stage 2

- Superconducting racetrack
  - Straights for extra space
  - 400 > 900 MeV
- 3 x 3.5m radius
- 1 MeV/turn
  - 2 cavities @ 500KeV
- 300 Turns

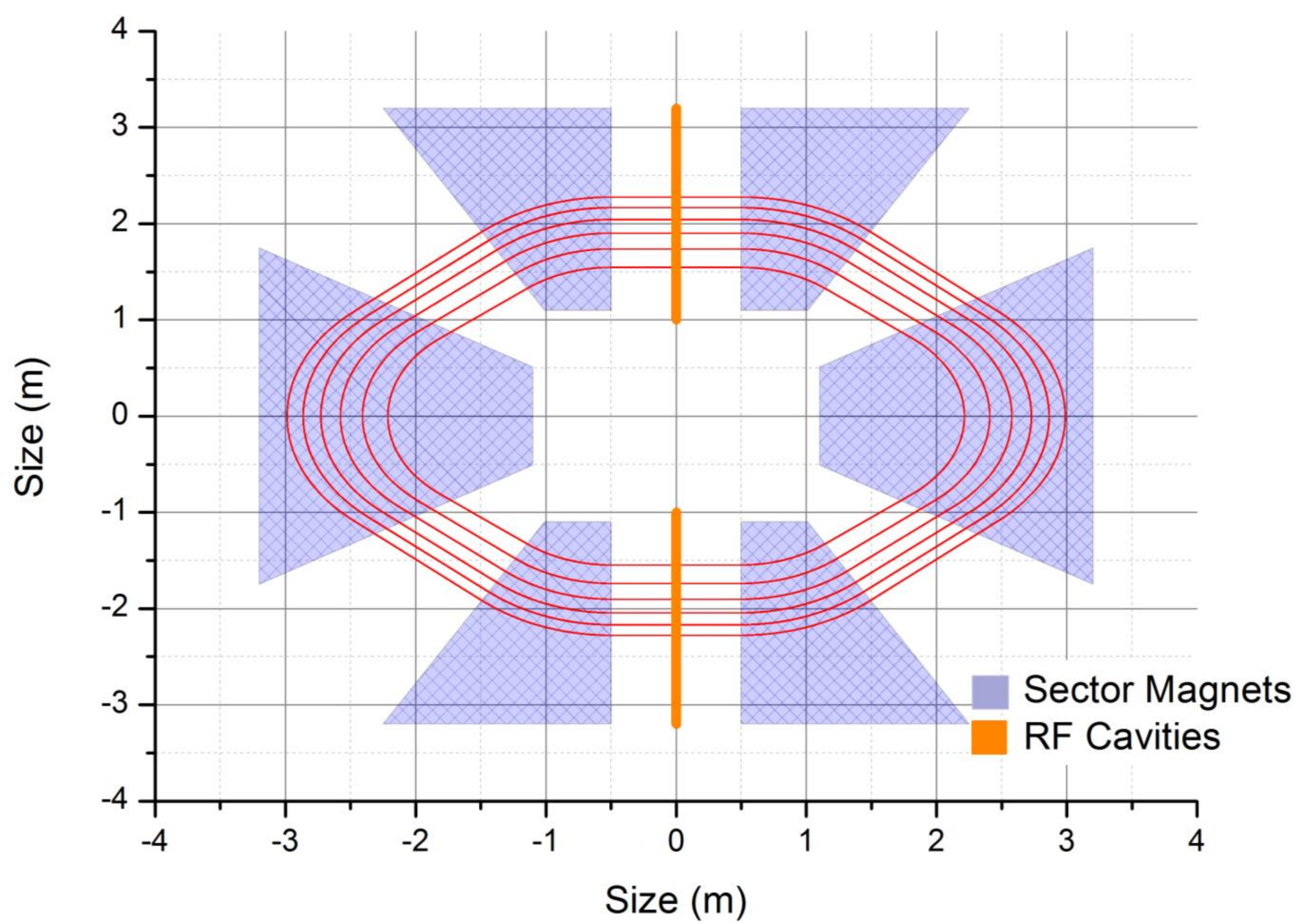

Figure 8. HEATHER stage 2 magnet layout showing stable orbits from 400 MeV through to 900 MeV

S2 - Isochronicity

- Percentage difference compared to the mean ToF over all energies using COSY and OPAL
- Good agreement between the two codes
- Isochronous enough to accelerate at fixed frequency RF

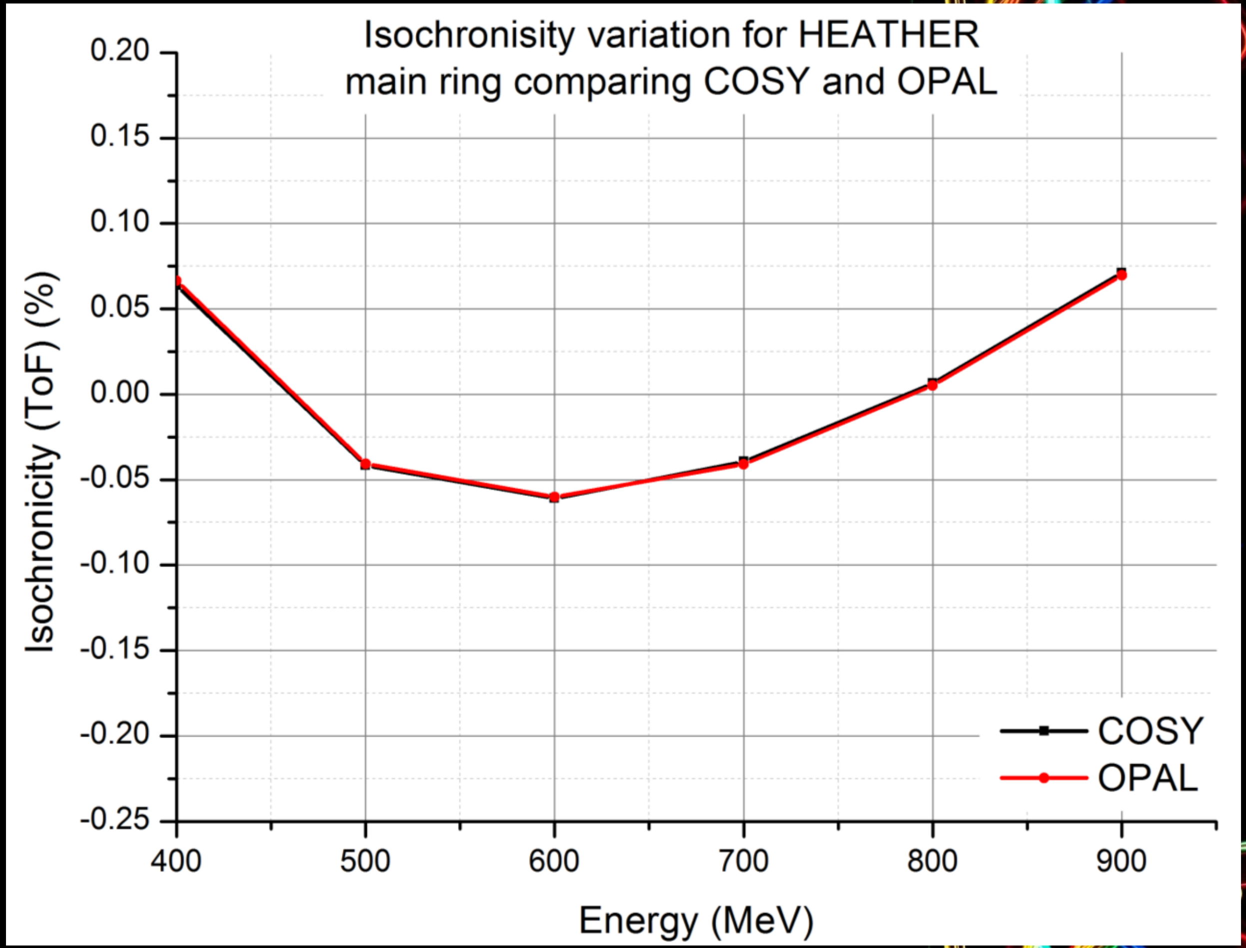

Figure 9. HEATHER stage 2 Isochronicity variation in percentage

S2 - Tunes

- Tunes are acceptable
- Crosses no integer resonances, just a 2nd order and 2 3rd order resonances

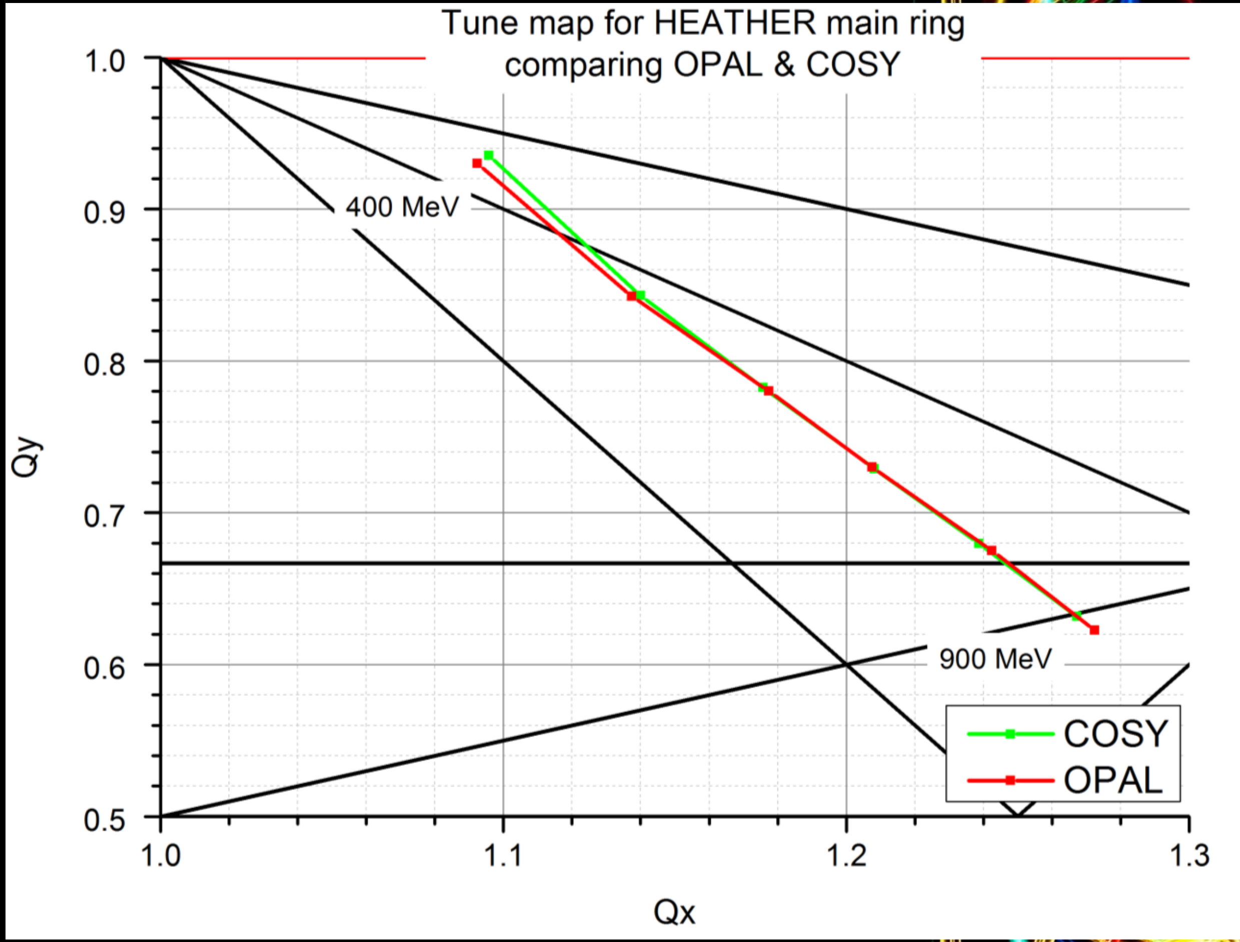

Figure 10. HEATHER stage 2 tune map showing the tune calculation from COSY.

S2 - Acceleration

- Serpentine acceleration
- Fixed frequency of 8.83 MHz
- Large phase acceptance

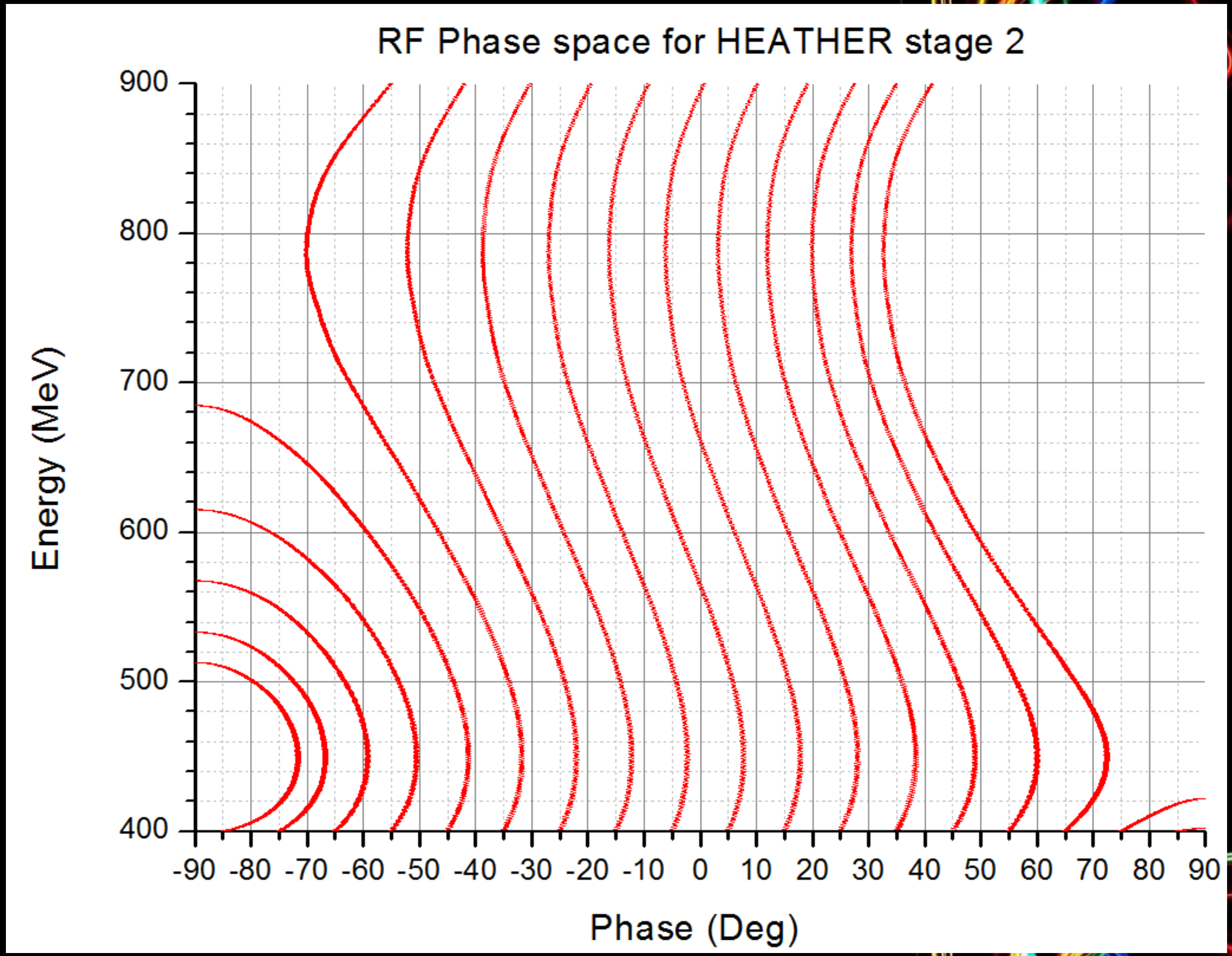

Figure 11. HEATHER Stage 2 RF Phase space plot

Next steps

- There is a lot of work to do
  - Work being done on inserting counterbend magnets
    - Improve tunes if we have issues
  - Losses and emittance studies
  - Inject a realistic beam into the accelerator
  - Injection/extraction – variable energy
    - Carol Johnstone's idea

- Reaching 900 MeV
  - It is possible (and beyond)
  - Stand alone useful machines

Conclusions

- We need to increase the availability Ion therapy
  - Helium could be the compromise
  - There is no superior Ion - therapeutic advantage

- It is definitely feasible to accelerate He^{2+} to 900MeV

Thank you

If you are interested and want to get involved please get in touch!

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