EMMA – The World’s First Non-Scaling FFAG

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for the EMMA Collaboration*

*BNL, CERN, CI, FNAL, JAI, LPSC Grenoble, STFC, TRIUMF
• Introduction
• Aims of the EMMA project
• Lattice studies and tracking
• Hardware status
• Time schedule
• Conclusions
Introduction

- **NS-FFAGs:**
  - originally invented for muon acceleration
  - since then: high power proton driver
    proton/carbon therapy

- **No such machine ever built:**
  - resonance crossings
  - asynchronous acceleration
  - tiny momentum compaction

- **Proof-of-principle NS-FFAG:**
  - prove NS optics work!
  - study features in detail

- **Funding:** generic as possible

- **Simplicity:** model muon machines

Electron Model of Muon Acceleration
Many Applications
• Demonstrate that non-scaling optics work

• Study resonances in detail:
  - emittance growth vs acceleration rate
  - “ “ vs tune variation
  - “ “ vs parabola shape
  - effect of errors
  - detailed probe using injector

• Study longitudinal dynamics in detail:
  - transmission vs parameter values
  - emittance growth vs parameter values
  - tof behaviour; effect of non-parabolic nature
  - effect of moving parabola
  - effect of errors

• Check effect of transverse dynamics

• Compare with predictions

• ..................
- **Needs a flexible injector:**
  - injection at any energy
  - small emittance
  - sufficient intensity in a single bunch

Energy Recovery Linac Prototype at DL
- ERLP has been built
- Is currently being commissioned
• Consortium called CONFORM created

• Proposal to UK Basic Technology Fund:
  - for studies of basic technology
  - generic as possible
  - three WPs
    EMMA
    charged particle therapy
    other applications

• Successful!

• Funding started 1st April

• Work already started

• Total: £8.2M

• For EMMA construction: £5.6M
EMMA Lattices

- **Basic lattice:**
  - 10-20 MeV (scaling)
  - Doublet (cost)
  - 42 cells (number of cell.turns)
  - 1.3GHz RF (scaling + ERLP)
  - 19 cavities (inj. & ext.)
  - 394.481mm cell length
  - 16.57m circumference

- **EMMA operation mode:**
  - 10-20Hz
  - 1 bunch
  - 80pC
  - $\varepsilon_{n,rms} = 3\pi$ mm mrad
  - 2ps rms length
  - scan aperture

- **Documentation at:**
  - http://www.conform.ac.uk/documents/emma
Different Lattices

Requires:
- indep. dipole & quadrupole fields
- sufficient magnet aperture
- RF frequency: -4.0 to 1.5MHz
- RF gain: ~20kV to 180kV/cavity
• Started with ELBE cavity: $\Omega_s = 1.4M\Omega$

• Evolved to toroidal design: $\Omega_s = 4.3M\Omega$

• Various power options under consideration
# Diagnostics

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Device</th>
<th>Number</th>
<th>Required resolution</th>
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<tbody>
<tr>
<td>Beam position</td>
<td>4 button BPM</td>
<td>2/plane/cell in ring</td>
<td>50µm</td>
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<tr>
<td></td>
<td></td>
<td>4 in injection &amp; diagnostics lines</td>
<td></td>
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<tr>
<td>Beam profile</td>
<td>OTR screens</td>
<td>3 in ring, 1 in injection and diagnostics lines</td>
<td>100µm pixel size</td>
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<td></td>
<td>Wire scanners</td>
<td>≥4</td>
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<tr>
<td>Beam current</td>
<td>Resistive wall monitor</td>
<td>4 RWMs</td>
<td>2%</td>
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<tr>
<td></td>
<td></td>
<td>1 scope</td>
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<tr>
<td>Phase</td>
<td>Resistive wall monitor</td>
<td>As above</td>
<td>10 degrees</td>
</tr>
<tr>
<td>Transmission</td>
<td>Resistive wall monitor</td>
<td>As above</td>
<td>2%</td>
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<tr>
<td></td>
<td>Faraday cup</td>
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<td></td>
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<tr>
<td>Beam loss</td>
<td>Beam Loss Monitor</td>
<td>4</td>
<td>2%</td>
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<tr>
<td>Momentum</td>
<td>BPMs and TOF from RWMs</td>
<td></td>
<td>100keV</td>
</tr>
<tr>
<td>Emittance</td>
<td>Screens</td>
<td>3 in diagnostics line</td>
<td>10%</td>
</tr>
<tr>
<td>Extracted momentum</td>
<td>Spectrometer</td>
<td>1 in diagnostics line</td>
<td>1%</td>
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<td>Longitudinal profile</td>
<td>Transverse deflecting cavity and screen</td>
<td>1 in diagnostics line</td>
<td>20keV and 5 degrees</td>
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</table>

- **Requirements agreed**
- **Hardware under study**
**Simulations:**
- lattice design complete
- tracked in 2 codes
- preliminary injection/extraction scheme
- injection/extraction lines being designed

**Magnets:**
- 3D modelling on-going
- prototypes ordered
- PSU design underway

**RF:**
- 3D modelling complete
- thermal and structural analysis underway
- power system design advanced

**Diagnostics:**
- BPM solution found
- screens/wires on-going
- others under study

**Others:**
- engineering/services/controls advancing
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<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
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</table>
Conclusions

• EMMA will
  - prove the principle of NS-FFAGs
  - investigate dynamics for future designs

• Now funded as part of the CONFORM project

• Designed by international collaboration

• Machine design is well-advanced

• Prototypes have/are being ordered

• Construction complete & commissioning started ~2 years

• For more details, see the posters!