• Introduction
• Requirements
• Funding
• Machine design
• Hardware status
• Conclusions
• NS-FFAGs: part of baseline
• No such machine ever built:
  - resonance crossings
  - asynchronous acceleration
  - tiny momentum compaction
• Need EMMA
• Funding: generic as possible
• Study proton, carbon, etc
• Proof-of-principle NS-FFAG
• Main emphasis: still muons
• 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

• ................
UK Involvement

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

Energy Recovery Linac Prototype at DL
Funding

- **EMMA collaboration:** Adams, BNL, CCLRC, CERN, Cockcroft, Grenoble, FNAL, Rostock, TRIUMF

- **EU FP6 – too big**

- **UK Basic Technology:**
  - generic as possible
  - three WPs
    - EMMA
    - charge particle therapy
    - other applications

- **Successful!**

- **Funding starts 1\textsuperscript{st} March**

- **Work already started**

- **Total: £8.2M**

- **For EMMA construction: £5.6M**
## Funding

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost / £k</th>
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</thead>
<tbody>
<tr>
<td>RF cavity system</td>
<td>1641</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>492</td>
</tr>
<tr>
<td>Magnets</td>
<td>502</td>
</tr>
<tr>
<td>Mechanical and vacuum chamber</td>
<td>391</td>
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<tr>
<td>Vacuum equipment</td>
<td>134</td>
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<tr>
<td>Controls</td>
<td>122</td>
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<tr>
<td>Electrical</td>
<td>443</td>
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<tr>
<td>Cooling and services</td>
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<td>Civil engineering</td>
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<td><strong>Hardware sub-total</strong></td>
<td><strong>3830</strong></td>
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<td>Staff</td>
<td>1808</td>
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<td><strong>TOTAL</strong></td>
<td><strong>£5638k</strong></td>
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</table>
EMMA Design

1st attempt: July 2006 (for BT proposal)

Design Reviews:
- 30th November
- 4th-5th January: fixed some parameters
  nothing is easy!
- 26th-28th February: start of change control

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

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

Documentation at:
http://www.conform.ac.uk/documents/emma
• Main requirement: independent di- and quadrupoles
• Magnets are mainly quads
Magnets

Pipe apertures: -21.6 to 20.7
Vertical: 17.8
Shifts: 4.9 to 10.2

-6.1 to 18.8
23.4
28.7 to 48.6

3D modelling underway
Prototypes to be ordered soon
Different Lattices

Graph 1:
- Axes: $v_x$ vs. $v_y$
- Curves in different colors

Graph 2:
- Axes: Kinetic Energy (MeV) vs. Time of Flight (ps)
Requirements:

- Maximum total voltage: 5MV(!)
- Allowable max voltage: >2.5MV
- Frequency: 1300.000, variable by -4.028 to +1.554
- Aperture: ~38mm

Original solution:

- 1 cavity every 2 cells
- 7 IOTs for power, distributed by cables
- Difficult to inject or extract
- Two possibilities:
  - 1 cavity every 3 cells
  - 1 cavity every 2 cells minus 2
Studied orbit distortion

- 21 rf
- 14 rf
- 21rf №18, №21
- 21rf №17, №21
RF Cavities

- Maximising shunt impedance very important
Injection and Extraction

Requirements:

• 55ns revolution time
• Inject & extract at any energy
• Scan EMMA dynamic aperture
• 1 & 2 kicker options studied for practicality
• 1 looks difficult
Injection and Extraction

2 parameters to control at injection point:
position and angle
Angle done with kicker
Position done with upstream steerers
This allows the incoming transfer line pipe to be fixed.

Injection at 10 Mev with one kick 0.15 R
-ve kick
Injection and extraction lines being worked on.

Results soon.
## 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 4 in injection &amp; diagnostics lines</td>
<td>50µm</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 1 scope</td>
<td>2%</td>
</tr>
<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>
</tr>
<tr>
<td>Beam loss</td>
<td>Beam Loss Monitor</td>
<td>4</td>
<td>2%</td>
</tr>
<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>
</tr>
<tr>
<td>Longitudinal profile</td>
<td>Transverse deflecting cavity and screen</td>
<td>1 in diagnostics line</td>
<td>20keV and 5 degrees</td>
</tr>
</tbody>
</table>

- **Requirements agreed**
- **Hardware under study, but........**
• **EMMA operation:**
  - 1 bunch
  - 80pC
  - $\varepsilon_{n,rms} = 3\pi$ mm mrad
  - 2ps rms length

• **Linear tune shift** $\Delta Q = -0.68$ per turn!

• **Linear part can be corrected; non-linear is a problem**

**Can be corrected:**
- reduced charge
- increase pulse length
- increase emittance
- increase # of bunches

4th order resonance
Conclusions

- EMMA is a crucial R&D project for the NF
- Now funded in the UK
- Funding starts on 1st March:
  - construction complete Q3 2009
  - commissioning complete Q2 2010
- Design work already started
  - lattice done
  - magnet modelling advanced
  - RF modelling started
  - injection & extraction being designed
  - diagnostics specified
  - electrical, civil, etc investigated
- Basic design parameters complete by end February