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• Introduction
• Beam requirements - the cooling experiment
• Single particle muon beams
• High intensity proton beams ~ the “blast” test
• Comparison
• Conclusions
Charge to the IWG

(1) Survey existing muon beams
(2) Determine the requirements for muon beams
(3) Check if existing beams satisfy these
(4) If not, find plans for new beams
(5) Submit a report by NuFACT’01

There has been a lot of progress on (2) \(\Rightarrow\) Cooling experiment

Thus, (1), (3) and (4) have been combined and will be compared against (2).
A Cooling Experiment

Aims:

- 10% reduction in (large) 6-d emittance using prototype components
- Measure the (small) equilibrium transverse emittance
- Measure evolution of angular momentum
Requirements for the beam

• Muons with a range of parameters for emittance studies:
  – Emittance: \(1\pi\) mm.rad to \(50\pi\) mm.rad
  – Momentum: 200 to 450 MeV/c
  – Momentum spread: “zero” to 20%
• Beam diagnostics of \(x\), \(P_x\), \(y\), \(P_y\), \(z\) or \(t\), \(P_z\)

\(\Rightarrow\) Single particle muon beam
  – To measure a 10% change, need \(~1\%\) precision \(\Rightarrow\) \(~10k\) muons
• Test cooling components under high radiation
  \(\Rightarrow\) Blast test with protons
• Some advantage to doing single particle and blast test in the same place
Infrastructure Requirements

Experiment is:

- ~ 30 m long by 3 m across
- Pulsed at 50 Hz with 100 μs per pulse

Pulsed rf ⇒ Beam should be pulsed

- Ex: Pulsed at 50 Hz with 100 μs per pulse

Power amplifiers for rf require:

- 1-2 MW of power
- 50-100 m³/hr of cooling water
- ~ 28 by 19 m² of space
• Beam exists, but rarely used
• Designed for 300 MeV/c pions
• Currently limited to 184 MeV/c muons by final dipole
• Space limited < 5 m (unless D4 line removed)
• Either slow spill, or 12 fast bunches
• $\mu/p \sim 10^{-6}$
TT1 at CERN (for LHC beam)

- 72 bunches, each 1 ns long, separated by 25 ns; each bunch makes 5-10 turns
- Assume 1 µ / turn (on average) ⇒ 720 µ / 25 µs, every 14.4 s
- Pion/muon production using a target in TT1 line; experiment also in TT1
  ⇒ transverse space limited
- Blast test possible
- Limited space for rf
- Doesn’t exist:
  Cost: 4MCHF
East Hall at CERN

• For East Hall, use slow extraction: 4 bunches, making >10000 turns
• $1 \mu/$ bunch / turn $\Rightarrow >40000/14.4\,\text{s}$, separated by 450ns
• Plenty of space (in principle), including for rf power

High intensity blast test may also be possible, e.g. DIRAC

Cost: Unknown
Linac Test Facility at FNAL

- At the end of the FNAL linac
- Produces 400 MeV H⁻ ions
- 15kW beam power
- Pulses 50µs long with bunches 0.2ns long
- 1.6x10⁹ particles/bunch
- Designed for “blast” test of cooling components
- Construction expected to start spring 2002
μE1 at PSI

- CW operation, 600 MeV
- Pulse length < 1ns
- Time between pulses ~ 20ns
- Beam currently limited to 195 MeV/c
- Modifications required for 300 MeV/c and more for > 300 MeV/c
- $\mu/s$ (300 MeV/c) $> 10^6$
- Space available for experiment
- Blast test impossible

Cost: Unknown
ISIS at RAL
HEP Test Beam

- ISIS: 50Hz, >100µs at maximum energy, 800 MeV
  ⇒ CW for experiment
- Two bunches, 100ns long
- Separated by 230ns
- Simulations suggest 1µ/pass; currently being measured
  ⇒ 20000 µ/s
- Space for experiment exists
  Cost: small
- Blast test also possible:
  Cost: possibly large!

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Monday, 28th May 2001
TRIUMF

- CW: 1.9ns beam pulse, every 43 ns
- M11 has momentum range 100-420 MeV/c, but limited space
- M20 can have 12 m of space, but only 20-180 MeV/c
- Not clear if it is possible to increase this
- Intensity: $10^6 \mu/s$
- Space could be made available for rf power supplies
- Blast test not possible
# Comparison between beams

## Single particle muon beams:

<table>
<thead>
<tr>
<th>Beam</th>
<th>Momentum (MeV/c)</th>
<th>ΔP Δ(%)</th>
<th>Muon Intensity (during 1 s)</th>
<th>Area (m²)</th>
<th>Exists</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNL D2</td>
<td>100 - 250</td>
<td>10</td>
<td>50,000 / 5 ms</td>
<td>5 x 3</td>
<td>Yes</td>
</tr>
<tr>
<td>CERN – TT1</td>
<td>200 - 450</td>
<td>?</td>
<td>720 / 0.1 ms</td>
<td>&gt; 30 x 4</td>
<td>No</td>
</tr>
<tr>
<td>CERN – East Hall</td>
<td>200 - 450</td>
<td>?</td>
<td>1,000 / 0.5 ms</td>
<td>30 x 5</td>
<td>No</td>
</tr>
<tr>
<td>PSI – µE1</td>
<td>85 - 310</td>
<td>1 (?)</td>
<td>&gt; 50,000 / 5 ms</td>
<td>30 x 5</td>
<td>Yes</td>
</tr>
<tr>
<td>RAL - ISIS</td>
<td>100 - 500</td>
<td>~ 2</td>
<td>20,000 / 5 ms</td>
<td>30 x 5</td>
<td>Yes</td>
</tr>
<tr>
<td>TRIUMF – M20</td>
<td>20 - 180</td>
<td>5</td>
<td>5,000 / 5 ms</td>
<td>12 x 4</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Comparison between beams

Blast test beams:

<table>
<thead>
<tr>
<th>Beam</th>
<th>Type</th>
<th>Energy (GeV)</th>
<th>Beam Power (kW)</th>
<th>P/bunch x10^{11}</th>
<th>Bunch length (ns)</th>
<th>Beam width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN - TT1</td>
<td>p</td>
<td>26</td>
<td>83.2*</td>
<td>50</td>
<td>14</td>
<td>1.8</td>
</tr>
<tr>
<td>FNAL – linac</td>
<td>H^-</td>
<td>0.402</td>
<td>15.7*</td>
<td>0.016</td>
<td>0.2</td>
<td>9</td>
</tr>
<tr>
<td>RAL - ISIS</td>
<td>p</td>
<td>0.8</td>
<td>32</td>
<td>100</td>
<td>7</td>
<td>15</td>
</tr>
</tbody>
</table>

*Total beam power: fraction available for tests is unclear
Summary

Six candidate beams satisfy some/all single particle requirements:

1. BNL D2 - Area needs extending, cost ?
2. CERN TT1 - Not yet built, cost > 4 MCHF
3. CERN East Hall - Not yet built, cost ?
4. PSI µE1 - Area needs extending, cost ?
5. RAL ISIS - Rates low, cost small
6. TRIUMF M20 - Space limited, energy low

There are three candidates for the blast test:

1. CERN TT1 - As above
2. FNAL linac - Construction in 2002, cost ?
3. RAL ISIS - Extraction line required, cost large!

Only two labs can do both!

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Conclusions

• There are candidate beams that satisfy the cooling requirements
• All require at least some work!
• The requirements have to be more clearly defined
• Once this is done, the work to be done can be costed
• The best beam(s) can then be selected
Appendix: Cooling Experiment

Instrumentation

Position, angle and momentum from four detectors in solenoids:

Muon describes a circle. Emittance Resolution depends on detector positions on path.

With $B = 5T$, $R = 15\text{cm}$, $d = 40\text{cm}$ optimal for $p_z = 290\text{ MeV}$
Detectors

For solenoids: scintillating fibres

- Three planes of fibres
- Diameter - 0.5 to 1.0mm
- Resolution:

<table>
<thead>
<tr>
<th></th>
<th>Actual</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>150-290µm</td>
<td>5mm</td>
</tr>
<tr>
<td>Angle</td>
<td>&lt;1mrad</td>
<td>5mrad</td>
</tr>
<tr>
<td>Time</td>
<td>~500ps</td>
<td>200ps</td>
</tr>
</tbody>
</table>

- Time resolution may not be good enough ⇒ tof detectors required resolution ~ 70-200ps
Emittance Resolution

![Graph showing 6D resolution vs. Solenoid length (m)]

![Graph showing 4D resolution vs. Solenoid length (m)]

![Graph showing 6D bias vs. Solenoid length (m)]

![Graph showing 4D bias vs. Solenoid length (m)]

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Emittance Resolution

Decays:

- $\mu \rightarrow e : 0.2\%$ contamination of $e \Rightarrow 5$ times worse Resolution and Bias
  $\Rightarrow$ electron-id required

- Pion decays: similar problems
  $\Rightarrow$ must be rejected (e.g by TOF)
• Recent simulations use solenoid field maps and E-fields for the cavities

• Looking for a loss-less channel with B < 4T

• “Matching” is crucial

• Simulated $E_{\text{kin}} = 200$ MeV muons
Cavity Design

- Asymmetric 88MHz cavity design by Frank Gerigk
- 90cm long with 3.6MeV energy gain per structure
- 16 cavities ⇒ 160cm of liquid hydrogen
Solenoid Design

- Cavity design leaves 45 x 20cm of space. Can use 40 x 17cm
- First rudimentary design done
- Should not exceed B = 4T
Performance

• Simulations show:

  - full transmission
  - emittance decrease from 651cm mrad to 578cm mrad
    \( \Rightarrow 10\% \) reduction required

• Still to be done:

  - new geometry
  - better field maps
  - beam with an energy spread
  - higher energy
  - etc.....
Cost and Schedule

Cost:

Schedule:  
- TDR: Summer 2001?  
- Approval: 2002?  
- Construction done: 2004?  
- Experiment complete: 2005
Conclusions

• It is essential to demonstrate a cooling channel can be built
• A cooling experiment is being developed that will do this
• This has three components:
  • Single particle muon beam \(\rightarrow\) three candidates in Europe
  • Instrumentation \(\rightarrow\) SciFi in solenoids + TOF
  • Cooling box \(\rightarrow\) Section of 88MHz channel
• Current simulations show a 10% cooling and sufficient precision
• Setup will also allow an investigation of the cooling parameters
• Still much work to be done