Neutrino Factory Target Yield Considerations

Click to view with less target stuff

Stephen Brooks
Scoping Study meeting, April 2006
Intermediate Z Element Needed

- Previously, results for Ta, Hg and C
- C behaviour was very different from others
- C is in P2, the others are in P6

<table>
<thead>
<tr>
<th>C</th>
<th>Ta</th>
<th>Hg</th>
</tr>
</thead>
</table>

Stephen Brooks
Scoping Study meeting, April 2006
Compare: HARP Elements

- P3: Al
- P4: Cu
- P5: Sn

- Want to compare with data
- Sensible target element
  - High melting point, density
Period 2 Elements

- Carbon clearly wins
- Boron and beryllium not so bad
- HARP has Be and C
- None of these densities are very high: require long targets
Period 3 Elements

- Silicon looks best
- Everything else has a useless melting point
- HARP has aluminium
- Densities no higher than before
- I think P3 is a non-starter
Period 4 Elements

- Transition metal melting points and densities are better
- HARP’s Cu has high density and moderate melting point
- Also about half-way (logarithmically) between C and Ta/Hg
Period 5 Elements

- Melting points and densities continue to increase
- HARP’s tin is not good for our target!
- Plenty of workable choices in transition block, if needed

Stephen Brooks
Scoping Study meeting, April 2006
Period 6 Elements

- Transition metals here have the highest values in the table
- Hence the choice of Ta in the first place
- Hg is obviously a special case
Period 7 Elements

- Thorium → uranium are OK for very-high-Z if needed
- Most of the rest are radioactive
Intermediate Z Element Needed

- Previously, results for Ta, Hg and C
- C behaviour was very different from others
- Copper was chosen to represent P4
Intermediate Z Element Needed

- Previously, results for Ta, Hg and C
- C behaviour was very different from others
- Copper was chosen to represent P4
Scaling of Cylinder Length

- Proportional to hadronic interaction length

<table>
<thead>
<tr>
<th>Element</th>
<th>Interaction length (cm)</th>
<th>Equivalent to 20cm Ta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>11.18</td>
<td>20cm</td>
</tr>
<tr>
<td>Hg</td>
<td>13.95</td>
<td>25cm</td>
</tr>
<tr>
<td>C</td>
<td>36.92</td>
<td>66cm</td>
</tr>
<tr>
<td>Cu</td>
<td>15.16</td>
<td>27cm</td>
</tr>
<tr>
<td>W</td>
<td>9.54</td>
<td>17cm</td>
</tr>
</tbody>
</table>

Harold Kirk found ~60cm is optimal

Summary Statistics ($\pi^\pm/p.\text{GeV}$)

- "Total Pion Yield" = all pions (of one sign) emitted from the rod surface
- "Captured Yield" = these weighted by survival probability in ($p_L,p_T$) space
  - Survival end of (UK) phase rotation into energy band $180\pm23\text{MeV}$ of cooling ring
  - No accounting for finite rod size (e.g. $\varepsilon_{\text{long}}$)
  - No accounting for reabsorption effects (later)
Decay modes of K$^+$ from PDG

• For E>3GeV, kaons add to the production
  – “A kaon is equivalent to ~1.06 pions”

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fraction</th>
<th>(error)</th>
<th>$\pi^\pm$ and $\mu^\pm$</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu^+\nu_\mu$</td>
<td>63.39%</td>
<td>0.18%</td>
<td>1</td>
<td>0.6339</td>
</tr>
<tr>
<td>$\pi^0 e^+\nu_e$</td>
<td>4.93%</td>
<td>0.07%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\pi^0 \mu^+\nu_\mu$</td>
<td>3.30%</td>
<td>0.06%</td>
<td>1</td>
<td>0.033</td>
</tr>
<tr>
<td>$\pi^+\pi^0$</td>
<td>21.03%</td>
<td>0.13%</td>
<td>1</td>
<td>0.2103</td>
</tr>
<tr>
<td>$\pi^+\pi^0\pi^0$</td>
<td>1.76%</td>
<td>0.02%</td>
<td>1</td>
<td>0.01757</td>
</tr>
<tr>
<td>$\pi^+\pi^+\pi^-$</td>
<td>5.59%</td>
<td>0.05%</td>
<td>3</td>
<td>0.1677</td>
</tr>
</tbody>
</table>

Mean eventual muons: 1.06247
Results: Total Pion Yield

Copper behaviour is somewhere between the high- and low-Z elements, as expected.
Results: Captured Yield

Copper beats everything at 10GeV!

Hg and Ta almost indistinguishable
Results: Captured Yield

Carbon low energy behaviour is interesting, so let’s extend the scale…
Results: Captured Yield

Stephen Brooks
Scoping Study meeting, April 2006
Observations

• The carbon peak at 1GeV is huge, but can you build a proton driver at that energy?

• Low energy behaviour is increasingly asymmetrical in sign for low Z
  – Proton charge manifests excess of $\pi^+$

• Carbon at 5GeV still apparently beats everything else
  – But ignoring the increased cylinder length, reabsorption and longitudinal emittance
Comparison with FS2, ICOOL

Harold Kirk’s results for carbon

Stephen Brooks
Scoping Study meeting, April 2006
Comparison with FS2, ICOOL

Harold Kirk’s results for carbon...are a similar shape to my results, with a scaling due to using more efficient RF capture.

Stephen Brooks
Scoping Study meeting, April 2006
Figure of Merit: $\mu^+\mu^- \text{ or } \mu^+\times\mu^-$?

• For the muon collider they should multiply
• For the neutrino factory, it depends on the physics goals
  – Experiments that test matter-antimatter asymmetry would require both signs
  – Detectors may be more sensitive to one sign than the other, giving an asymmetric function
• I will graph both + and $\times$ cases for interest
Captured Yield Sum

Optima at 5GeV for low and intermediate Z; flatter ones at 8GeV for high Z. Hg winning very slightly over Ta.

Stephen Brooks
Scoping Study meeting, April 2006
This is topologically the same apart from that the 5GeV carbon peak is now nearly as high as the 1GeV one.
Pion Reabsorption (future work)

• It might be worth re-running MARS with a 20T field in the solenoid bore and collecting the pions at the endplane, to include this effect
• Could be significant in long, low-Z targets
• A rough model for manual tracking can also be obtained by extracting an “absorption length” for pions in material
Absorption Length Estimate

- MARS15 was run for pions entering a block of tantalum, surviving particles logged at various Z-planes and an exponential decay fit to the data.

<table>
<thead>
<tr>
<th>Energy</th>
<th>$\pi^+$ length</th>
<th>$\pi^-$ length</th>
</tr>
</thead>
<tbody>
<tr>
<td>100MeV</td>
<td>82mm</td>
<td>65mm</td>
</tr>
<tr>
<td>300MeV</td>
<td>107mm</td>
<td>106mm</td>
</tr>
<tr>
<td>1GeV</td>
<td>139mm</td>
<td>159mm</td>
</tr>
</tbody>
</table>
Feasibility of “1ns” Bunches

Stephen Brooks
Scoping Study meeting, April 2006
Higher Energies than 10GeV

- Going from 10GeV to 30GeV
  - Loses 10-12% yield with a high-Z target
  - Assuming fixed power (unrealistic?)
  - Re-optimising the front end for another energy tends to give small gains of order 3%

- Going from 10GeV to 50GeV
  - Loses 25-30% yield
  - This cannot be ignored so easily
Summary Statistics ($\pi^\pm/p$.GeV)

- “Total Pion Yield” = all pions (of one sign) emitted from the rod surface
- “Captured Yield” = these weighted by survival probability in ($p_L,p_T$) space
  - Survival end of (UK) phase rotation into energy band 180±23MeV of cooling ring
  - No accounting for finite rod size (e.g. $\varepsilon_{\text{long}}$)
  - No accounting for reabsorption effects (later)
Results: Total Pion Yield

Copper behaviour is somewhere between the high- and low-Z elements, as expected.
Results: Captured Yield

Copper beats everything at 10GeV!

Hg and Ta almost indistinguishable

Stephen Brooks
Scoping Study meeting, April 2006
Results: Captured Yield

Carbon low energy behaviour is interesting, so let’s extend the scale…
Results: Captured Yield

Stephen Brooks
Scoping Study meeting, April 2006
Observations

• The carbon peak at 1GeV is huge, but can you build a proton driver at that energy?
• Low energy behaviour is increasingly asymmetrical in sign for low Z
  – Proton charge manifests excess of $\pi^+$
• Carbon at 5GeV still apparently beats everything else
  – But ignoring the increased cylinder length, reabsorption and longitudinal emittance
Figure of Merit: $\mu^+ + \mu^- \text{ or } \mu^+ \times \mu^-$?

- For the muon collider they should multiply
- For the neutrino factory, it depends on the physics goals
  - Experiments that test matter-antimatter asymmetry would require both signs
  - Detectors may be more sensitive to one sign than the other, giving an asymmetric function
- I will graph both $+$ and $\times$ cases for interest
Captured Yield Sum

Optima at 5GeV for low and intermediate Z; flatter ones at 8GeV for high Z. Hg winning very slightly over Ta.
This is topologically the same apart from that the 5GeV carbon peak is now nearly as high as the 1GeV one.
Feasibility of “1ns” Bunches

Stephen Brooks
Scoping Study meeting, April 2006
Higher Energies than 10GeV

• Going from 10GeV to 30GeV
  – Loses 10-12% yield with a high-Z target
  – Assuming fixed power (unrealistic?)
  – Re-optimising the front end for another energy tends to give small gains of order 3%

• Going from 10GeV to 50GeV
  – Loses 25-30% yield
  – This cannot be ignored so easily