Beam-target survey of US Study 2a and CERN neutrino factory front-ends

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Introduction

• one of the ISS machine group front-end tasks is to compare the performance of existing NF front-end designs

• use similar approximations and level of detail for all designs
• use same simulation code
• use same initial beam distributions
• FOM is number of muons inside accelerator acceptance per incident proton per GeV of incident beam power
Survey

- presently considering 4 schemes
  KEK
  CERN with horn
  CERN with solenoid (not baseline)
  US Study 2a

- using 5 beam/target combinations to sample phase space
  4 GeV – C  40 GeV – C  10 GeV - Ta
  4 GeV – Hg  40 GeV – Hg

- making relative comparison now
- validate absolute values with HARP/MIPP later
Reference production files

• prepared by Stephen Brooks using MARS15
• proton bunch length is 1 ns
  (performance decreases 10% going from 1 -> 3 ns)
• target lengths
  Ta  20 cm
  Hg  25 cm
  C   66 cm
• radius = 1 cm
• aligned with solenoid axis
• re-interactions included
• no B on target
Transverse momentum at production

**Table 1: Transverse momentum on target surface**

<table>
<thead>
<tr>
<th></th>
<th>positive</th>
<th>negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>4</td>
<td>305</td>
</tr>
<tr>
<td>Hg</td>
<td>4</td>
<td>333</td>
</tr>
<tr>
<td>Ta</td>
<td>10</td>
<td>409</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>385</td>
</tr>
<tr>
<td>Hg</td>
<td>40</td>
<td>372</td>
</tr>
</tbody>
</table>
ICOOL input

• ICOOL needs beam distribution at z-plane at end of the target
• wrote code MARS2IC to
  track particles from target cylinder to end of target
  convert variables to ICOOL format

  tantalum   tapered solenoid
  carbon     constant solenoid
  mercury    tapered solenoid
             CERN horn

• tapered solenoid used US Study 2 profile around target
US Study 2a

- Accelerator normalized acceptance
  - 30 mm transverse
  - 150 mm longitudinal
  - $100 < p < 300$ MeV/c
- Reference FOM is $0.17 / 24 = 0.007$

p distribution at end of channel
Table 2: ST2a positive beam-target survey.

<table>
<thead>
<tr>
<th>$E_b$ [GeV]</th>
<th>target</th>
<th>$L$ [cm]</th>
<th>$\mu / \pi$</th>
<th>$\mu_A / \pi$</th>
<th>$\mu_A / p$</th>
<th>$\mu_A / p$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>C</td>
<td>66</td>
<td>0.256</td>
<td>0.133</td>
<td>0.045</td>
<td>0.0114</td>
</tr>
<tr>
<td>4</td>
<td>Hg</td>
<td>25</td>
<td>0.221</td>
<td>0.131</td>
<td>0.027</td>
<td>0.0066</td>
</tr>
<tr>
<td>10</td>
<td>Ta</td>
<td>20</td>
<td>0.187</td>
<td>0.097</td>
<td>0.087</td>
<td>0.0087</td>
</tr>
<tr>
<td>40</td>
<td>C</td>
<td>66</td>
<td>0.190</td>
<td>0.065</td>
<td>0.171</td>
<td>0.0043</td>
</tr>
<tr>
<td>40</td>
<td>Hg</td>
<td>25</td>
<td>0.156</td>
<td>0.071</td>
<td>0.271</td>
<td>0.0068</td>
</tr>
</tbody>
</table>
US Study 2a – negative particles

Table 3: ST2a negative beam-target survey.

<table>
<thead>
<tr>
<th>$E_b$ [GeV]</th>
<th>target</th>
<th>$L$ [cm]</th>
<th>$\mu / \pi$</th>
<th>$\mu_A / \pi$</th>
<th>$\mu_A / p$</th>
<th>$\mu_A / p$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>C</td>
<td>66</td>
<td>0.267</td>
<td>0.151</td>
<td>0.045</td>
<td>0.0113</td>
</tr>
<tr>
<td>4</td>
<td>Hg</td>
<td>25</td>
<td>0.244</td>
<td>0.157</td>
<td>0.039</td>
<td>0.0098</td>
</tr>
<tr>
<td>10</td>
<td>Ta</td>
<td>20</td>
<td>0.199</td>
<td>0.113</td>
<td>0.107</td>
<td>0.0108</td>
</tr>
<tr>
<td>40</td>
<td>C</td>
<td>66</td>
<td>0.197</td>
<td>0.081</td>
<td>0.184</td>
<td>0.0046</td>
</tr>
<tr>
<td>40</td>
<td>Hg</td>
<td>25</td>
<td>0.171</td>
<td>0.085</td>
<td>0.330</td>
<td>0.0083</td>
</tr>
</tbody>
</table>
CERN neutrino factory

- many variations, not all documented!
  horn or solenoid capture
  44/88 MHz or all-88 MHz front end
  2.2 or 3.5 GeV beam energy
  constant channel solenoid or NF-087 field or ???
- Accelerator normalized acceptance
  30 mm transverse
  300 mm longitudinal
  100 < p < 500 MeV/c
CERN 44/88 MHz front-end

- horn was designed for 2 GeV (very compact)
- needs missing matching optics to solenoid channel
- needs all new design for higher energies
- 44/88 MHz design is complicated
  - B: 1.8 -> 5 T
  - $p_{\text{REF}}$: 200 -> 300 MeV
    - 2 cooling stages with accelerator in between
- had to increase acceleration length by 10 m to get 200 -> 280 MeV/c

- horn radius = 1 m
- channel radius = 0.3 m
- want 0.5 m no-field gap

(Simon Gilardoni)
### CERN 44/88 MHz front-end

<table>
<thead>
<tr>
<th>$E_b$ [GeV]</th>
<th>target</th>
<th>$L$ [cm]</th>
<th>collection</th>
<th>$\mu / \pi$</th>
<th>$\mu_A / \pi$</th>
<th>$\mu_A / p$</th>
<th>$\mu_A / p$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Ta</td>
<td>20</td>
<td>solenoid</td>
<td>0.129</td>
<td>0.011</td>
<td>0.010</td>
<td>0.0010</td>
</tr>
<tr>
<td>4</td>
<td>Hg</td>
<td>25</td>
<td>horn</td>
<td>0.007</td>
<td>0.001</td>
<td>0.0002</td>
<td>0.00004</td>
</tr>
</tbody>
</table>
CERN – focusing in all-88 MHz channel

- last CERN front-end design
  - simpler design
  - shorter
- design of 0.5 m “matching” regions in cooling cell is not clear
- NF-087 design gives large (68%) modulation of on-axis solenoid field
- set up low (7%) modulation periodic channel for comparison

(note NF-087)
### CERN – focusing in all-88 MHz channel

<table>
<thead>
<tr>
<th>design</th>
<th>$\mu / \pi$</th>
<th>$\mu_A / \pi$</th>
<th>$\mu_A / p$</th>
<th>$\mu_A / p \text{ GeV}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>continuous</td>
<td>0.236</td>
<td>0.015</td>
<td>0.013</td>
<td>0.0013</td>
</tr>
<tr>
<td>NF-087</td>
<td>0.098</td>
<td>0.008</td>
<td>0.008</td>
<td>0.0008</td>
</tr>
<tr>
<td>low modulation</td>
<td>0.226</td>
<td>0.016</td>
<td>0.014</td>
<td>0.0014</td>
</tr>
</tbody>
</table>

- low modulation channel gives same performance as continuous channel
Table 3: CERN all-88 MHz beam-target survey.

<table>
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<tr>
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<tbody>
<tr>
<td>4</td>
<td>C</td>
<td>66</td>
<td>0.286</td>
<td>0.018</td>
<td>0.006</td>
<td>0.0015</td>
</tr>
<tr>
<td>4</td>
<td>Hg</td>
<td>25</td>
<td>0.210</td>
<td>0.017</td>
<td>0.003</td>
<td>0.0009</td>
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<tr>
<td>10</td>
<td>Ta</td>
<td>20</td>
<td>0.226</td>
<td>0.016</td>
<td>0.014</td>
<td>0.0014</td>
</tr>
<tr>
<td>40</td>
<td>C</td>
<td>66</td>
<td>0.271</td>
<td>0.010</td>
<td>0.026</td>
<td>0.0007</td>
</tr>
<tr>
<td>40</td>
<td>Hg</td>
<td>25</td>
<td>0.206</td>
<td>0.011</td>
<td>0.043</td>
<td>0.0011</td>
</tr>
</tbody>
</table>
CERN – end of all-88 MHz channel

momentum:
long high energy tail

time:
spilling into 2\textsuperscript{nd} bunch
CERN – all-88 MHz performance vs z

normalized transverse emittance hasn’t reached equilibrium

muons in accelerator acceptance are still increasing
Conclusions

• US2a results for $T_a$ better than reference value
• negative $T_a$ about 20% higher than positive
• US2a shows higher FOM than CERN
• still have uncertainties about CERN design
• CERN 88 MHz front end better than the 44/88 MHz
• CERN could use longer cooling channel