Capture Radiation Management

Muon Collider 2011

Telluride, Colorado

June 27–July 1, 2011
The Study 2 Target System

Neutrino Factory Study 2 Target Concept
STUDY II SOLENOID GEOMETRY

OLD GEOMETRY

IRON PLUG

RESISTIVE COILS

SHIELDING

SC#1 -120<z<57.8 cm \( R_{in} = 63.3 \text{ cm} \) \( R_{out} = 127.8 \text{ cm} \)
SC#2 67.8<z<140.7 cm \( R_{in} = 68.6 \text{ cm} \) \( R_{out} = 101.1 \text{ cm} \)
SC#6-13 632.5<z<218.7 cm \( R_{in} = 42.2 \text{ cm} \) \( R_{out} = 45.1 \rightarrow 43.4 \text{ cm} \) (TOTAL # SC=13)

Harold G. Kirk
Secondary Particle Production

Black = $p$, Green = $n$, Red/Blue = $\pi^\pm$, Orange/Turquoise = $e^\pm$, Gray = $\gamma$. 
DEPOSITED ENERGY WITH 24 GeV AND 8 GeV BEAM

N. Souchlas

MARS WITH 0.1 MeV DEFAULT NEUTRON ENERGY CUTOFF VS.

MARS+MCNP WITH $10^{-11}$ MeV NEUTRON ENERGY CUTOFF.

ENERGY DEPOSITED IN SOLENOIDS IN kW.

<table>
<thead>
<tr>
<th></th>
<th>SC#1</th>
<th>%</th>
<th>SC#2-13</th>
<th>%</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>14.28</td>
<td>–</td>
<td>14.90</td>
<td>–</td>
<td>29.18</td>
<td>–</td>
</tr>
<tr>
<td>b</td>
<td>22.06</td>
<td>+54.48</td>
<td>16.30</td>
<td>+9.40</td>
<td>38.36</td>
<td>+31.50</td>
</tr>
<tr>
<td>c</td>
<td>24.97</td>
<td>+74.86</td>
<td>11.84</td>
<td>-20.54</td>
<td>36.81</td>
<td>+26.15</td>
</tr>
<tr>
<td>d</td>
<td>37.62</td>
<td>+50.66</td>
<td>12.46</td>
<td>+5.24</td>
<td>50.08</td>
<td>+36.05</td>
</tr>
</tbody>
</table>

From 24 GeV to 8 GeV, and from a more detail treatment of low energy neutrons: from ~14 kW to ~38 kW power in SC1 and from ~29 kW to 50 kW in total power.

50 kW at 4° K $\rightarrow$ ~20 MW wall power

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Peak Energy Deposition

5.5 mW/g

ITER Limit: 1 mW/cc $\Rightarrow$ 0.15 mW/g
IDS80 GEOMETRY

SC#1-5: 2.6 kW  
TOTAL: 3.47 kW  
Peak SC5: 0.36 mW/gr

IDS80f GEOMETRY (Bob Weggel)

SC3: 4.15 kW  
TOTAL: 5.69 kW  
Peak SC3: 0.42 mW/gr
Energy Deposition Results

MARS+MCNP (NEUTRON ENERGY CUTOFF $10^{-11}$ MeV)

60% WC + 40% H$_2$O SHIELDING

STUDY II

IDS80

SC#1: 42.5 kW \rightarrow SC#1-5: 2.4 kW

SC#1-13: 58.1 kW \rightarrow SC#1-26: 3.4 kW
IDS GEOMETRIES

Energy Deposition:  Total (kW)  Peak (mW/g)

IDS90f

SC3:  2.07  
TOTAL:  2.45  
Peak SC3:  0.15  
SC10:  0.07

IDS100f

SC3:  1.01  
TOTAL:  1.41  
Peak SC3:  0.08  
SC9:  0.05  
SC10:  0.10  
SC11:  0.04

IDS110f

SC3:  0.49  
TOTAL:  1.14  
Peak SC3:  0.03  
SC5:  0.20  
SC7:  0.07  
SC14:  0.08

IDS120f

SC3:  0.26  
TOTAL:  0.97  
Peak SC3:  0.03  
SC5:  0.19  
SC12/19 : 0.09

(Bob Weggel)

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Peak Energy Depositions

FROM ITER peak DE ≤ 0.15 mW/gr

IDS90f

Peak SC3 (mW/gr)

R_{in}(cm)

0.1

0.01

0.001

10 110 120 130

80 90 100

NATIONAL LABORATORY
Total Energy Depositions

![Graph showing total energy depositions versus R_in (cm). The graph displays a downward trend with increasing values of R_in, indicating a decrease in energy depositions.]
FLUKA Simulations - John Back  2/8/2011

Typical distribution of beam power

Deposited Power (MGray/year)

MARS+MCNP
SC3: 0.26 kW
SC5: 0.19 kW
TOTAL: 0.97 kW
MARS/FLUKA Energy Depositions

<table>
<thead>
<tr>
<th></th>
<th>MARS</th>
<th>FLUKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC#1-19</td>
<td>0.97</td>
<td>0.56</td>
</tr>
<tr>
<td>SH#1-4</td>
<td>2020.06</td>
<td>2148.9</td>
</tr>
<tr>
<td>RS#1-5</td>
<td>329.55</td>
<td>405.1</td>
</tr>
<tr>
<td>BP#1-3</td>
<td>458.39</td>
<td>482.8</td>
</tr>
<tr>
<td>Hg TARG.</td>
<td>376.5</td>
<td>319</td>
</tr>
<tr>
<td>Hg POOL</td>
<td>10.16</td>
<td>4.4</td>
</tr>
<tr>
<td>Be WIND.</td>
<td>0.53</td>
<td>2.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3196.16</td>
<td>3362.86</td>
</tr>
</tbody>
</table>
Capture Systems Comparisons

IDS-120

Study 2
Latest Configuration - Bob Weggel

SC B Field: 15T  Resistive Field: 5T  Power Consumption: 11.5MW
SUMMARY

- Bulk of energy deposition in capture solenoids is due to neutrons
- Study II capture configuration had large energy deposition and hence a large dynamic heat load
- Study II configuration had peak energy depositions which exceeded ITER criteria by a factor of ~35
- New (IDS 120) configuration has reduced the dynamic heat load in the capture solenoids to ~1kW and the peak energy deposition to <0.15mW/g
- But the capture solenoids stored energy now > 3GJ
Backup Slides
Target System Exploded View

All insertion/extraction from upstream end
Locating & supporting features not shown – will require additional space
MARS Energy Deposition Studies

MARS15 study of Study 2 configuration yields 25KW energy deposition in SC1 alone.
Reconfigure SC magnets

Increase the SC ID’s. Fill released volume with shielding.

Rult: Total energy deposition in all SC’s reduced to 2.4kW.

But SC magnets around target are now extremely difficult.

Require an iterative approach
The Neutrino Factory Target Concept

Maximize Pion/Muon Production

- Soft-pion Production
- High-Z materials
- High-Magnetic Field

Palmer, PAC97

Harold G. Kirk
# Target Baseline Proton Beam Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
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<tbody>
<tr>
<td>Proton Beam Energy</td>
<td>8 GeV</td>
</tr>
<tr>
<td>Rep Rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Bunch Structure</td>
<td>3 bunches, 320 μsec total</td>
</tr>
<tr>
<td>Bunch Width</td>
<td>2 ± 1 ns</td>
</tr>
<tr>
<td>Beam Radius</td>
<td>1.2 mm (rms)</td>
</tr>
<tr>
<td>Beam $\beta^*$</td>
<td>$\geq$ 30 cm</td>
</tr>
<tr>
<td>Beam Power</td>
<td>4 MW ($3.125 \times 10^{15}$ protons/sec)</td>
</tr>
</tbody>
</table>
## Target System Baseline

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target type</td>
<td>Free mercury jet</td>
</tr>
<tr>
<td>Jet diameter</td>
<td>8 mm</td>
</tr>
<tr>
<td>Jet velocity</td>
<td>20 m/s</td>
</tr>
<tr>
<td>Jet/Solenoid Axis Angle</td>
<td>96 mrad</td>
</tr>
<tr>
<td>Proton Beam/Solenoid Axis Angle</td>
<td>96 mrad</td>
</tr>
<tr>
<td>Proton Beam/Jet Angle</td>
<td>27 mrad</td>
</tr>
<tr>
<td>Capture Solenoid Field Strength</td>
<td>20 T</td>
</tr>
</tbody>
</table>
Key Target Challenges

General Target Issues

- Thermal management (~3MW power deposited)
- Shielding (SC Solenoids required)
- Target integrity (Thermal Shock)
- Target regeneration (50Hz rep-rate)
- 20T environment

Liquid Hg specific issues

- Stable fluid flow (Nozzle performance)
- Hg handling system
The Key Parameters

Proton Driver
- 4 MW Beam Power
- 5-15 GeV KE (8GeV is currently favored)
- 50 Hz operation
- 3 Bunch structure (280μs total favored)

Target System
- 20T Solenoid Magnet
- Liquid Jet
- 20 m/s flow rate (50Hz operations)
- High-Z (Hg favored)