Particle Distribution of Graphite Target Generated for the Front-End Optimization

X. Ding

Intense Muon Source Meeting
Oct 28, 2014
Carbon Target Setting

• Simulation Code: MARS15(2014) with ICEM 4 = 1 (default) and Energy Card Setting at ENRG 1 = 6.75, 2 = 0.02, 3 = 0.3, 4 = 0.01, 5 = 0.05, 6 = 0.01, 7 = 0.01;

• Carbon target Configuration(20to2T5m4PDL): Graphite density = 1.8 g/cm$^3$, Fieldmap (20T→2T) with taper length of 5m;

• Proton beam: 6.75 GeV (KE), BR/TR=1/4 (ratio of beam radius to target radius), waist at z= 0 m, varied geometric emittance and launched at z = -100 cm;

• Production Collection: (50 m downstream, 40 MeV < KE < 180 MeV).

• Particle distribution generated at z = 2 m for Front-End.
Carbon Target Geometry

Proton beam tube

Upstream proton beam window

5 T copper-coil insert. Water-cooled, MgO insulated

15 T superconducting coil outsert, Stored energy ~ 3 GJ, ~ 100 tons

Stainless-steel target vessel (double-walled with intramural He-gas flow for cooling) with graphite target and beam dump, and downstream Be window.

This vessel would be replaced every few weeks at 1 MW beam power.

He-gas cooled W-bead shielding (~ 100 tons)

Fieldmap along SC axis
(Magnet 20to2T5m120cm)
Counting of Carbon Target at $z = 5$ m

1MW beam ($9.26 \times 10^{14}$ protons with KE of 6.75 GeV)
beam angle = 0 mrad, target radius = 0.64 cm

<table>
<thead>
<tr>
<th>$L_{\text{dump}}$ (cm)</th>
<th>$R_{\text{dump}} / R_{\text{target}}$</th>
<th>Total KE (protons) ($r &lt; 23$ cm) [Watts]</th>
<th>Total KE (non-protons) [Watts]</th>
<th>Protons KE &gt; 6 GeV ($\times 9.26 \times 10^{10}$)</th>
<th>Yield at $z = 50$ m ($\times 9.26 \times 10^{10}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>265270</td>
<td>88258</td>
<td>2078</td>
<td>1063.4</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>221590</td>
<td>92222</td>
<td>1543</td>
<td>987</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>202506</td>
<td>90564</td>
<td>1419</td>
<td>927</td>
</tr>
<tr>
<td>120</td>
<td>1</td>
<td>210141</td>
<td>87216</td>
<td>1452</td>
<td>868.8</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>183241</td>
<td>90205</td>
<td>1213</td>
<td>938</td>
</tr>
<tr>
<td>80</td>
<td>2</td>
<td>155798</td>
<td>85367</td>
<td>909</td>
<td>780.3</td>
</tr>
<tr>
<td>120</td>
<td>2</td>
<td>149733</td>
<td>86754</td>
<td>870</td>
<td>743</td>
</tr>
<tr>
<td>40</td>
<td>3</td>
<td>158241</td>
<td>91585</td>
<td>1044</td>
<td>852.7</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>119851</td>
<td>85385</td>
<td>607</td>
<td>680.2</td>
</tr>
<tr>
<td>120</td>
<td>3</td>
<td>114139</td>
<td>81006</td>
<td>542</td>
<td>590</td>
</tr>
</tbody>
</table>
Coordinates of beam and dump
(carbon target and dump)

Target length: 80 cm (z = -40 cm to z = 40 cm)
Target radius: 0.80 cm
Beam angle: 65 mrad   Co-linear target and beam
TR/BR = 4
Beam dump rod: triple of the target radius
  (z = 40 cm to z = 100 cm, horizontal tilt: 31.1 mrad, vertical tilt: 56.27 mrad)
  (z = 100 cm to z = 160 cm, horizontal tilt: 44.9 mrad, vertical tilt: 44.17 mrad)
Counting of Carbon Target at \( z = 5 \) m

1MW beam (9.26 \( \times \) 10\(^{14}\) protons with KE of 6.75 GeV)
beam angle = 65 mrad, target radius = 0.8 cm

<table>
<thead>
<tr>
<th>( L_{\text{dump}} ) (cm)</th>
<th>( R_{\text{dump}}/R_{\text{target}} )</th>
<th>Total KE (protons) ((r &lt; 23 \text{ cm})) [Watts]</th>
<th>Total KE (non-protons) [Watts]</th>
<th>Protons KE &gt; 6 GeV ( (\times 9.26 \times 10^{10}) )</th>
<th>Yield at ( z = 50 ) m ( (\times 9.26 \times 10^{10}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>88359</td>
<td>105454</td>
<td>301</td>
<td>1240.7</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>85504</td>
<td>105007</td>
<td>270</td>
<td>1268</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
<td>88318</td>
<td>102577</td>
<td>318</td>
<td>1256.2</td>
</tr>
<tr>
<td>120</td>
<td>1</td>
<td>85932</td>
<td>100030</td>
<td>299</td>
<td>1230.1</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>77262</td>
<td>101664</td>
<td>207</td>
<td>1246.2</td>
</tr>
<tr>
<td>80</td>
<td>2</td>
<td>75493</td>
<td>97715</td>
<td>206</td>
<td>1196</td>
</tr>
<tr>
<td>120</td>
<td>2</td>
<td>78364</td>
<td>96967</td>
<td>204</td>
<td>1170.5</td>
</tr>
<tr>
<td>40</td>
<td>3</td>
<td>72615</td>
<td>101494</td>
<td>176</td>
<td>1084.5</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>64610</td>
<td>97569</td>
<td>112</td>
<td>1142.4</td>
</tr>
<tr>
<td>120</td>
<td>3</td>
<td>66430</td>
<td>94936</td>
<td>130</td>
<td>1134.6</td>
</tr>
</tbody>
</table>
Yield Comparison
(no-tilt vs. tilt proton beam, carbon target)

Collinear target and beam. TR/BR = 4.
~ 13% advantage to tilting the beam/target
**Setting of Be Windows**

The C vessel window is two Be discs with 0.2 cm thickness EACH while all other windows downstream have two Be discs of 0.5 cm thickness EACH. Each window has a 1.0 cm He gap between them. The zi below is the beginning of each Be window.

<table>
<thead>
<tr>
<th>BeWind#</th>
<th>zi (cm)</th>
<th>OR (cm)</th>
<th>Thickness EACH DISC (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeWind#1</td>
<td>168.8</td>
<td>13.0</td>
<td>0.2</td>
</tr>
<tr>
<td>BeWind#2</td>
<td>430.0</td>
<td>23.0</td>
<td>0.5</td>
</tr>
<tr>
<td>BeWind#3</td>
<td>993.0</td>
<td>23.0</td>
<td>0.5</td>
</tr>
<tr>
<td>BeWind#4</td>
<td>1005.0</td>
<td>23.0</td>
<td>0.5</td>
</tr>
<tr>
<td>BeWind#5</td>
<td>1005.0</td>
<td>23.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Generated Particle Distributions for Front-End  
(Scenario of No-tilt Proton Beam)

See the files at https://pubweb.bnl.gov/~xding/frontend/

(1) C-G6.75GeV-RTG1cm-RB0.25cm-BA0mrad-CA0mrad-Z2m-nodump-emittance5micron-fort.83.gz
(2) C-G6.75GeV-RTG1cm-RB0.25cm-BA0mrad-CA0mrad-Z2m-nodump-emittance20micron-fort.83.gz
(3) C-G6.75GeV-RTG1cm-RB0.25cm-BA0mrad-CA0mrad-Z2m-nodump-emittance20micron-ROOT-fort.83.gz

Symbol of the name for above files:

C: Carbon target (length of 80 cm, center at z=0 m)

G6.75GeV: proton beam with KE at 6.75 GeV

10/28/14
Generated Particle Distributions for Front-End (Scenario of No-tilt Proton Beam) (cont’d)

**RTG1cm**: carbon target radius at 1 cm

**RB0.25cm**: proton beam radius at 0.25 cm

**BA0mrad**: proton beam angle to SC axis at 0 mrad.

**CA0mrad**: Crossing angle at 0 mrad (collinear target and the beam)

**Z2m**: particle distribution at z = 2 m

**nodump**: without dump

**emittance5micron**: beam emittance is 5 micron

**emittance20micron**: beam emittance is 20 micron

**ROOT**: Geometry setting with ROOT
Generated Particle Distributions for Front-End (Scenario of Tilt Proton Beam)

See the files at https://pubweb.bnl.gov/~xding/frontend/

(1) C-G6.75GeV-RTG1cm-RB0.25cm-BA65mrad-CA0mrad-Z2m-dump120cm-3RTG-emittance5micron-fort.83.gz

(2) C-G6.75GeV-RTG1cm-RB0.25cm-BA65mrad-CA0mrad-Z2m-dump120cm-3RTG-emittance20micron-fort.83.gz

Symbol of the name for above files:

C: Carbon target (length of 80 cm, center at z=0 m)

G6.75GeV: proton beam with KE at 6.75 GeV

RTG1cm: carbon target radius at 1 cm

RB0.25cm: proton beam radius at 0.25 cm
Generated Particle Distributions for Front-End (Scenario of Tilt Proton Beam) (cont’d)

**BA65mrad**: proton beam angle to SC axis at 65 mrad.

**CA0mrad**: Crossing angle at 0 mrad (collinear target and the beam)

**Z2m**: particle distribution at $z = 2$ m

**emittance5micron**: beam emittance is 5 micron

**emittance20micron**: beam emittance is 20 micron

**dump120cm-3RTG**: the carbon dump length is 120 cm and dump rod radius is triple of the radius of carbon target
Generated Particle Distributions for Front-End (Scenario of Tilt Proton Beam) (cont’d)

Setting of Beam dump rod: triple of the target radius:

(z = 40 cm to z = 100 cm, horizontal tilt: 31.1 mrad, vertical tilt: 56.27 mrad)

(z = 100 cm to z = 160 cm, horizontal tilt: 44.9 mrad, vertical tilt: 44.17 mrad)
Backup
Yield for target without tilt
(Non-standard setting for geometry)

We prefer target radius \( \geq 8 \text{ mm} \) (beam radius \( \geq 2 \text{ mm} \)) for viable radiation cooling of the target.

For \( r_{\text{target}} = 8 \text{ mm} \), same yield for any emittance \( \leq 20 \mu\text{m} \).
Yield for target with tilt
(65 mrad to SC axis)
(Non-standard setting for geometry)

Yield for 50 μm emittance and target radius of 1.2 cm is only 10% less than that for the nominal case of 5 μm emittance and 0.8 cm target radius.
GEOMETRY SETTING with ROOT
Yield for target with tilt
(65 mrad to SC axis) (ROOT setting for geometry)

Yield for 50 \( \mu \text{m} \) emittance and target radius of 1.2 cm is only 10% less than that for the nominal case of 5 \( \mu \text{m} \) emittance an 0.8 cm target radius.