Optimized Target Parameters and Meson Production by IDS120h with Focused Gaussian Beam and Fixed Emittance (Update)

X. Ding, UCLA

AAG Meeting

June 13, 2013
**Optimized Target Parameters and Meson Productions at 8 GeV (Non-Focused Gaussian beam, Zero emittance )**

<table>
<thead>
<tr>
<th></th>
<th>HG</th>
<th>GA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Jet</td>
<td>HG</td>
<td>GA</td>
</tr>
<tr>
<td>Emittance/ ( \mu \text{m} )</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beam radius/cm</td>
<td>0.404</td>
<td>0.44</td>
</tr>
<tr>
<td>Target radius/cm (Fixed at 30% of beam radius)</td>
<td>0.1212</td>
<td>0.132</td>
</tr>
<tr>
<td>Crossing angle between beam and Jet at ( z=-37.5 \text{ cm/mrad} )</td>
<td>20.6</td>
<td>13</td>
</tr>
<tr>
<td>Beam angle at ( z=-37.5 \text{ cm/mrad} )</td>
<td>117</td>
<td>88</td>
</tr>
<tr>
<td>Jet angle at ( z=-37.5 \text{ cm/mrad} )</td>
<td>137.6</td>
<td>101</td>
</tr>
<tr>
<td>Meson Production (400000 protons)</td>
<td>130254</td>
<td>113297</td>
</tr>
</tbody>
</table>
Focused Incident Proton Beam at 8 GeV
(Beam radius is fixed at 0.12 cm at z=-37.5 cm)

Relative normalized meson production is 0.84 of max at $\beta^*$ of 0.3 m for $\varepsilon_x = \varepsilon_y = 5 \mu$m.

For low $\beta^*$ (tight focus) the beam is large at the beginning and end of the interaction region, and becomes larger than the target there.

$\sigma_x^* = \sqrt{\varepsilon_x \beta^*}$

$\sigma_x(z) = \sigma_x^* \sqrt{1 + \frac{(z - z^*)^2}{\beta^{*2}}}$
Focused Incident Proton Beam at 8 GeV (Cont’d)
(Beam radius is fixed at 0.12 cm at z=-37.5 cm)

Non-Linear Fit
(Growth/sigmoidal, Hill)

\[ Y = \frac{N}{1 + K^2/\beta^2} \]
\[ N = 1.018 \]
\[ \sqrt{K^2} = 0.1368 \]

Linear emittance is \( 5 \) \( \mu \) m with beam radius of 0.1212 cm and \( \beta^* \) of 0.3 m.
Gaussian distribution
(Probability density)

• In two dimensional phase space \((u,v)\):

\[
w(u,v) = \frac{1}{2\pi \sigma^2} \exp\left(-\frac{u^2 + v^2}{2\sigma^2}\right)
\]

where \(u\)-transverse coordinate (either \(x\) or \(y\)),
\(v = \alpha \ u + \beta \ u'\)

\(\alpha\), \(\beta\) are the Courant-Snyder parameters at the given point along the reference trajectory.

In polar coordinates \((r, \theta)\):
\[u = r \cos \theta \quad v = r \sin \theta\]
\[u' = (v - \alpha \ u)/\beta = (r \sin \theta - \alpha \ u)/\beta\]
Distribution function method

\[ \theta = 2\pi \xi_1, \quad \theta \in [0, 2\pi] \]

\[ r = \sqrt{-2\sigma^2 \ln \xi_2}, \quad r \in [0, \infty] \]

Random number generator:

\[ \Theta = 2\pi \times \text{rndm}(-1) \]
\[ R = \sqrt{-2 \times \log(\text{rndm}(-1))} \times \sigma \]
Setting with focused beam trajectories

- Modeled by the user subroutine BEG1 in m1512.f of MARS code

\[ x_v \] or \( x_h \) (transverse coordinate: \( u \));
\[ x'_v \] or \( x'_h \) (deflection angle: \( u' \))

\[ \begin{align*}
XINI &= x_0 + x_h \\
DXIN &= dcx_0 + x'_h \\
YINI &= y_0 + x_v \\
DYIN &= dcy_0 + x'_v \\
ZINI &= z_0 \\
DZIN &= \sqrt{1-\text{DXIN}^2-\text{DYIN}^2}
\end{align*} \]
Twiss parameters based on Formulae (old method)

- Intersection point \((z=-37.5 \text{ cm})\):
  \[
  \alpha^* = 0, \quad \beta^*, \quad \sigma^*
  \]

- Launching point \((z=-200 \text{ cm})\):
  \[
  L = 200 - 37.5 = 162.5 \text{ cm}
  \]
  \[
  \alpha = L/\beta^*
  \]
  \[
  \beta = \beta^* + L^2/\beta^*
  \]
  \[
  \sigma = \sigma^* \sqrt{1 + L^2/\beta^*^2}
  \]

These relations strictly true only for zero magnetic field.
Courant-Snyder Invariant
**Emittance (rms) and Twiss Parameters**

\[
\varepsilon_{\text{rms},x} = \sqrt{\langle x^2 \rangle \langle x^\prime 2 \rangle - \langle xx' \rangle^2}
\]

\[
\alpha_x = -\frac{\langle xx' \rangle}{\varepsilon_{\text{rms},x}}
\]

\[
\beta_x = \frac{\langle x^2 \rangle}{\varepsilon_{\text{rms},x}}
\]

\[
\gamma_x = \frac{\langle x^\prime 2 \rangle}{\varepsilon_{\text{rms},x}}
\]

\[
\beta_x \gamma_x - \alpha_x^2 = 1
\]
Twiss parameters based on backtrack (new method)

• Effect of Solenoid Field
  1. Backtrack particles from $z = -37.5$ cm to $z = -200$ cm.
  2. Using the particle coordinates and momentums at $Z=-200$ cm to calculate the $\alpha$, $\beta$, $\sigma$ at $z = -200$ cm.
Optimization Procedures
(Focused Beam and Fixed Beam Emittance)

Optimization method in each cycle
(1) Vary beam radius $\sigma^*$, while vary the $\beta^*$ at the same time to fix the beam emittance;
(2) Very target radius;
(3) Vary beam/jet crossing angle;
(4) Rotate beam and jet at the same time to keep the crossing angle same.
## Optimized Target Parameters and Meson Productions at 8 GeV and Different Emittance (HG Jet Case)

<table>
<thead>
<tr>
<th></th>
<th>Emittance/μm</th>
<th>2.5 (old method)</th>
<th>2.5 (new method) (1st Run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam radius/cm</td>
<td>0.135</td>
<td>0.148</td>
<td></td>
</tr>
<tr>
<td>Target radius/cm</td>
<td>0.47</td>
<td>0.494</td>
<td></td>
</tr>
<tr>
<td>Crossing Angle/mrad</td>
<td>23</td>
<td>25.2</td>
<td></td>
</tr>
<tr>
<td>Beam angle/mrad</td>
<td>118</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td>Jet angle/mrad</td>
<td>141</td>
<td>143.2</td>
<td></td>
</tr>
<tr>
<td>Meson production (400000 protons)</td>
<td>125991</td>
<td>124255</td>
<td></td>
</tr>
</tbody>
</table>
## Optimized Target Parameters and Meson Productions at 8 GeV and Different Emittance (HG Jet Case)

<table>
<thead>
<tr>
<th>Emittance/ $\mu$ m</th>
<th>5 (old method)</th>
<th>5 (new method) (1st Run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam radius/cm</td>
<td>0.15</td>
<td>0.195</td>
</tr>
<tr>
<td>Target radius/cm</td>
<td>0.548</td>
<td>0.605</td>
</tr>
<tr>
<td>Crossing Angle/mrad</td>
<td>26.5</td>
<td>30.6</td>
</tr>
<tr>
<td>Beam angle/mrad</td>
<td>127</td>
<td>127</td>
</tr>
<tr>
<td>Jet angle/mrad</td>
<td>153.5</td>
<td>157.6</td>
</tr>
<tr>
<td>Meson production (400000 protons)</td>
<td>121696</td>
<td>116523</td>
</tr>
</tbody>
</table>
## Optimized Target Parameters and Meson Productions at 8 GeV and Different Emittance (HG Jet Case)

<table>
<thead>
<tr>
<th>Emittance/ $\mu$ m:q</th>
<th>7.5 (old method)</th>
<th>7.5 (new method) (1\textsuperscript{st} Run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam radius/cm</td>
<td>0.2025</td>
<td>0.2424</td>
</tr>
<tr>
<td>Target radius/cm</td>
<td>0.60</td>
<td>0.66</td>
</tr>
<tr>
<td>Crossing Angle/mrad</td>
<td>29.3</td>
<td>34.1</td>
</tr>
<tr>
<td>Beam angle/mrad</td>
<td>131</td>
<td>126</td>
</tr>
<tr>
<td>Jet angle/mrad</td>
<td>160.3</td>
<td>160.1</td>
</tr>
<tr>
<td>Meson production (400000 protons)</td>
<td>115760</td>
<td>109916</td>
</tr>
</tbody>
</table>
## Optimized Target Parameters and Meson Productions at 8 GeV and Different Emittance (HG Jet Case)

<table>
<thead>
<tr>
<th>Emittance/μm</th>
<th>10 (old method)</th>
<th>10 (new method) (1st Run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam radius/cm</td>
<td>0.2325</td>
<td>0.274</td>
</tr>
<tr>
<td>Target radius/cm</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>Crossing Angle/mrad</td>
<td>32</td>
<td>37.3</td>
</tr>
<tr>
<td>Beam angle/mrad</td>
<td>135</td>
<td>127</td>
</tr>
<tr>
<td>Jet angle/mrad</td>
<td>167</td>
<td>164.3</td>
</tr>
<tr>
<td>Meson production (400000 protons)</td>
<td>113020</td>
<td>105730</td>
</tr>
</tbody>
</table>