MUON TARGET STUDIES: TAPERED CAPTURE SOLENOID

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OVERVIEW

- Target layout
- Current baseline parameters
- Solenoid Taper field calculations
- MARS simulation setup
- Tracking through FE with ICOOL
- Muon count
- Transverse position & Momentum distribution
- Conclusion
- Production of $10^{14} \mu/s$ from $10^{15} p/s \approx 4$ MW proton beam
- Low-energy $\pi$'s collected from side of long, thin cylindrical target
- Solenoid coils can be some distance from proton beam.
  - $\geq 10$-year life against radiation damage at 4 MW.
- Proton beam readily tilted with respect to magnetic axis.
  - $\Rightarrow$ Beam dump (mercury pool) out of the way of secondary $\pi$'s and $\mu$'s.
- Shielding of the superconducting magnets from radiation is a major issue.
  - Magnet stored energy $\sim 3$ GJ

5-T copper magnet insert; 10-T Nb3Sn coil + 5-T NbTi outsert. Desirable to eliminate the copper magnet (or replace by a 20-T HTS insert).
**TARGET PARTICLE PRODUCTION WITH 15 T PEAK SOLENOID FIELD**

- Particle-capture requirement ($P_t \leq 0.225$ GeV/c)
  - $B \times r = 20 \times 7.5 \text{ cm} = 150 \text{ T-cm}$
  - $B \times r = 15 \times 10 \text{ cm} = 150 \text{ T-cm}$
- Fixed-flux requirement (Aperture requirement)
  - $B \times r^2 = 20 \times 7.5^2 = 1125 \text{ T-cm}^2$
  - $B \times r^2 = 15 \times 10^2 = 1500 \text{ T-cm}^2$
- MARS simulations with 15-T peak field & new aperture settings (taper radius $r = 30 \text{ cm}$ at all $z$)

![Diagram with labels: $R_{\text{ini}} = 7.5 \text{ cm}$, $B_i = 20 \text{ T}$, $r_f = 30 \text{ cm}$](image)

Particle loss due to scrapping with beam pipe!
CURRENT TARGET OPTIMIZED PARAMETERS

(X. Ding et al.)

➤ Hg Target
   ➤ $\theta_{\text{Target}} = 0.137$ rad
   ➤ $R_{\text{Target}} = 0.404$ cm

➤ Proton Beam
   ➤ $E = 8$ GeV
   ➤ $\theta_{\text{Beam}} = 0.117$ rad
   ➤ $\sigma_x = \sigma_y = 0.1212$ cm (Gaussian Distribution)

➤ Solenoid Field
   ➤ IDS120h $\rightarrow$ 20 T peak field at target position ($Z = 0$)
   ➤ Aperture at Target $R = 7.5$ cm - End aperture $R = 30$ cm
   ➤ Fixed Field $Z = 1862.0 \rightarrow B_z = 1.5$ T

➤ Production: Muons within energy KE cut 40-180 MeV
   ➤ $3.27 \times 10^4$ ($N_{\text{init}} = 10^5$)
**Analytic Form for Tapered Solenoid**

Inverse-Cubic Taper

\[
B_z(0, z_i < z < z_f) = \frac{B_1}{[1 + a_1(z - z_1) + a_2(z - z_1)^2 + a_3(z - z_1)^3]^p}
\]

Field at R=0

\[
a_1 = -\frac{B_1}{pB_1} \quad \quad a_2 = 3\left(\frac{B_1}{B_2}\right)^{\frac{1}{p} - 1} - \frac{2a_1}{z_2 - z_1}
\]

\[
a_3 = -2\left(\frac{B_1}{B_2}\right)^{\frac{1}{p} - 1} + \frac{a_1}{(z_2 - z_1)^2}
\]

Off-axis field approximation

\[
B_z(r, z) = \sum_{n} (-1)^n \frac{a_0^{(2n)}(z)}{(n!)^2} \frac{r}{2}^{2n}
\]

\[
B_r(r, z) = \sum_{n} (-1)^{n+1} \frac{a_0^{(2n+1)}(z)}{(n+1)(n!)^2} \frac{r}{2}^{2n+1}
\]

\[
a_0^{(n)} = \frac{d^n a_0}{dz^n} = \frac{d^n B_z(0, z)}{dz^n}
\]
- Beam Pipe with constant $R=30 \text{ cm}$ (eliminate particle loss due to scrapping)
- Beam Pipe material changed to balckhole to speed calculations
- Added subroutine to m1510.f (FIELD K. McDonald) to calculate the field using inverse cubic equations
- $N_{\text{proton}}=5 \times 10^5$
- Store particles information at $z=0$
- Select $(\mu^+ - k^+ - \pi^+)$

$B_z(z=0,r=0) = 15 \text{ T}$
1- Taper solenoid field with different settings

- $B_z(r=0)$ 20 → 1.5 T  Taper Length 8→43 m
- $B_z(r=0)$ 15 → 1.5 T  Taper Length 8→43 m
- $B_z(r=0)$ 15 → 1.8 T  Taper Length 8→43 m
- $B_z(r=0)$ 15 → 2.0 T  Taper Length 8→43 m

2- ICOOL applied aperture for decay region $R_{aperture}= 0.4$ m & 0.3 m to end

3- Good particles are those who satisfy the following conditions/cuts
   1- Survived the phase rotator and cooling sections
   2- Fall within required acceleration acceptance cuts
      - $0.1 < P_z < 0.3$ GeV
      - Transverse cut $R < 0.3$ m
      - Longitudinal cut 0.15 m
MARS SIMULATION RESULTS

Tapered field using inverse-cubic field ($P = 1$)

Mesons count at $z=50$ m with K.E. 40-180 MeV

Present baseline:
$B_i = 20$ T, $B_f = 1.5$ T, $z_{end} = 15$ m.

%6 increase $zend$ 8-40 m
%8 decrease $B_i$ 20$\rightarrow$15 T
Muons within required acceleration acceptance cuts after cooling section
- $0.1 < P_z < 0.3 \text{ GeV}$
- Transverse cut $R < 0.3 \text{ m}$
- Longitudinal cut $0.15 \text{ m}$

**Solenoid Field along z-axis**

**Shorter taper better survive buncher**
- phase rotator & cooling
TRANSMISSION THROUGH FRONT END

**Pz & Σ cut**

**Trans, Pz, & Σ cut**

- Aperture: 0.4 → 0.3 m
- µons (no transvers cut n0)
- µons (w transvers cut n1)
1- Taper solenoid field: 20 → 1.5 T over 15 m
2- ICOOL applied aperture for decay region $R_{aperture} = 0.4$ m & 0.3 afterwords
3- Good particles are those who satisfy the following conditions/cuts
   1- Survived the phase rotator and cooling sections
   2- Fall within required acceleration acceptance cuts
      - $0.1 < p_z < 0.3$ GeV
      - Transverse cut $R < 0.3$ m
      - Longitudinal cut 0.15 m
DISTRIBUTIONS OF PARTICLES SURVIVED THE FRONT END AND ACCELERATION CUTS

Particle distribution Taper Length =15 m
CONCLUSION

- Mesons count at 50 m increases with longer taper
- Bz=15 $\rightarrow$ 1.8T produces as much mesons counted at 50 m as Bz=20 $\rightarrow$ 1.5T
- 15 T peak field case has ~ 7% less yield at end of cooling though it produces about the same number of muons at the target.
- No clear mismatch in the lattice that shows huge particle loss
- Particle radii extends from 0.1 at z=0 to 0.3 m at z=15 m
- Particles transverse momenta extends from 0.3 at z=0 to 0.1 m at z=15 m

<table>
<thead>
<tr>
<th>Taper Length</th>
<th>End of Decay Channel z=50 m No cuts</th>
<th>End of FE z=265 m Eclac acceleration acceptance cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td></td>
<td>Better</td>
</tr>
<tr>
<td>Long</td>
<td></td>
<td>Better</td>
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