Beam Emittance and Energy Spectra for Hg and C Targets

J. Scott Berg
Brookhaven National Laboratory
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Motivation—Neuffer’s Results

- Neuffer’s talk at the MAP 2014 Winter Meeting, Dec. 4, 2014 (next 3 slides)
- Compared results from 8 GeV beam on Hg target to 6.75 GeV beam on C target
- C target had larger emittance by over a factor of 2
- Large increase in loss in first 6 m
- Performance reduction by about a factor of 2
Motivation—Neuffer’s Results

Use old FE with new initial beam

- New beam has too large initial size and divergence
  - initial transverse emittance >2X larger
    - 0.0027 → 0.0067 m-GeV/c
  - ~half of initial beam lost in <6m
First simulations results

- ~60% of initial particles are lost in first 6m
  - previous front end lost ~20%

- Beam starts out very large
  - previous much smaller in front end simulations

- $\mu/p$ reduced by factor ~ 2
  - $\rightarrow$ ~0.0545 $\mu^+/p$
  - ~0.042 $\mu^-/p$
  - $\mu^-$ less than $\mu^+$

- Not fully reoptimized for new initial beam
Motivation—Neuffer’s Results

6.75 GeV p/ C target – First Look

- Much worse than previous 8 GeV p / Hg target
  - 6.75 (~25% less), Hg → C …
    - but initial beam has very large phase space
- Causes for early losses ???
  - Long C target not a good match to short taper ?
    - target should be within lens center …
  - “Beam dump” after target blows up π beam ??
- Bugs, errors?
  - Changes in Mars production code ??
  - normalization error ??
  - initialization errors
    - starts from $z=2m$ rather than $z=0$
- After initial factor of 2 loss, very similar to old front end case
  - not yet reoptimized
- To investigate/debug/reoptimize ..
Examine Distributions

- Dug up every 8 GeV Hg in 20 T distribution I could find
    - From “P11” direction
    - Used by Neuffer
  - 23-Mar-2013, from X. Ding
    - Target angle 137.6 mrad, radius 0.404 cm.
    - RMS beam size 0.1212 cm
    - MARS15(2012)
    - Apertures: 7.5 cm radius to 37.5 cm, then square root taper to 30 cm at 19 m
06-Feb-2014, from H. Sayed
  • No apertures at all
Above all 0.375 m from field peak
13-Jan-2015, from X. Ding
  • Re-run of 23-Mar-2013, but with new MARS
  • Distribution handoff at 2 m
Carbon distributions from X. Ding, 15-Dec-2014
- 6.75 GeV, target 1 cm radius, beam 0.25 cm RMS, no crossing angle
- Tilted 65 mrad, or not
- 1.2 m dump, radius 3 cm, or not
- Proton beam emittance 5 or 20 μm
- Distributions 2 m from field peak
- Apertures: 13 cm radius to 1.7 m, then no aperture until far downstream
Propagate Distributions

- Propagate all distributions to 3 m downstream from field peak
- Use field map from Weggel, 09-May-2014
  - Carbon distributions used this to 2 m
  - Field very close to 20 T at 0.375 m; little impact of profile difference for Hg runs
- Compute vector potential at 3 m to compute canonical emittances
- Compute emittances
  - \( \pi \) KE 60–600 MeV, \( \mu \) KE 60–400 MeV; energy range at target in which 99% of ultimately captured particles lie
  - 4\( \sigma \) iterative cut
### Emittances

<table>
<thead>
<tr>
<th></th>
<th>$\mu^-$</th>
<th>$\mu^+$</th>
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<th>$\mu^+$</th>
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<td>14.0</td>
<td>20.5</td>
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- Normalized canonical emittances in mm
- Large sign is sort of helicity (actually eigenemittance)
- Difference in emittances is angular momentum
- Names to left are distributions, contain date
  - Carbon: two digit angle, d for dump, n for no dump
Analysis

• Hg distributions
  ○ 2010 emittances significantly smaller than later runs
  ○ 2014 run has tiny pion angular momentum
    • Small beam; beam/target interact over small region?
    • Also shows up in muon angular momentum
  ○ 2015 run back to 2010 emittances??? Turns out it’s a lie, as we’ll see in a bit…

• Carbon emittances
  ○ Removing dump improves emittance
  ○ With dump, lower emittance with tilt
  ○ Without dump tilt makes emittance a tiny bit worse
  ○ Proton beam emittance didn’t matter (not shown)
  ○ Larger than Hg, but sometimes close
Energy Distributions

• In Hg, similar for most runs, but don’t agree in detail
• The 06-Feb-2014 run is an outlier
Pion Distributions for Hg

28-Oct-2010

23-Mar-2013

06-Feb-2014

13-Jan-2015 IQGSM=0
Muon Distributions for Hg

28-Oct-2010

![Graph of muon distributions for Hg on 28-Oct-2010.](image)

23-Mar-2013

![Graph of muon distributions for Hg on 23-Mar-2013.](image)

06-Feb-2014

![Graph of muon distributions for Hg on 06-Feb-2014.](image)

13-Jan-2015 IQGSM=0

![Graph of muon distributions for Hg on 13-Jan-2015 IQGSM=0.](image)
IQGSM

- IQGSM gives a “choice of inclusive and exclusive event generators at nuclear inelastic interactions”
- IQGSM=0: exclusive CEM (cascade excitation model?) for $E < 3$ GeV, MARS inclusive for $E > 5$ GeV, LAQGSM for some special cases. Old MARS default.
- IQGSM=1: CEM for $E < 0.3$ GeV, LAQGSM for $0.5$ GeV $< E < 8$ GeV, MARS inclusive for $E > 10$ GeV. New MARS default.
Distributions for Hg, IQGSM

13-Jan-2015 IQGSM=0

13-Jan-2015 IQGSM=1

13-Jan-2015 IQGSM=0

13-Jan-2015 IQGSM=1
• Significant performance hit for IQGSM = 1
• Energy spectrum also changes
• Emittance doesn’t change
• C runs were all with IQGSM=1, earlier Hg were IQGSM=0
C: Pions vs. Geometry

No Tilt, No Dump

With Tilt, No Dump

No Tilt, With Dump

With Tilt, With Dump
C: Muons vs. Geometry

No Tilt, No Dump

No Tilt, With Dump

With Tilt, No Dump

With Tilt, With Dump
C vs. Geometry

- Only major production hit is no tilt, no dump
- With tilt, no dump is the best
C vs. Hg, IQGSM = 1
C vs. Hg

- Similar total number of particles for Hg and C (need to check more carefully)
- Spectrum of C weighted to higher energy than Hg
- Should use very different NBPR to capture C than for Hg
- Entire system likely longer for C than Hg
- All of this will become less true (but still true) in a bit…
With current Hg target configuration, examine emittances at 3 m in two ways
- Receive from MARS at 0.375 m, propagate in ICOOL to 3 m
- Receive from MARS at 2.0 m, propagate in ICOOL to 3 m

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<td>21.0</td>
<td>14.4</td>
<td>21.9</td>
<td>15.1</td>
</tr>
</tbody>
</table>
• Next, do ICOOL propagations without pion decays, and look at pion emittances of pions common to both runs

\[
\begin{array}{ccccc}
\pi^- & \pi^- & \pi^+ & \pi^+ & \\
0.375 & 19.3 & 14.4 & 19.4 & 15.0 \\
2.000 & 18.9 & 13.4 & 19.1 & 14.4 \\
\end{array}
\]

• Results similar to propagation from 2 m

• Conclusion: particles lost on object in MARS

• Further analysis: square root taper aperture, starting at a radius of 7.5 cm at \( z = 0.375 \) m, growing to 30 cm at \( z \approx 19 \) m
Distributions vs. Handoff Point

- Energy spectra have differences as well
- Pions weighted to higher energies
  - Still not to the degree that carbon is
- More low energy muons, presumably from low energy pions that have already decayed
Conclusions

- I believe we more or less understand what David saw
- Differences in emittances are primarily caused by the beam pipe aperture, which is often unnecessarily small
- There were production differences due to differences in the nuclear inelastic model used (IQGSM)
- The energy spectrum for C is weighted to higher energy than that of Hg
  - Optimal NBPR will be very different for the two cases
- C no tilt with dump is horrible; tilt no dump is best
Next Steps; Credits

- Next: run both Hg and C (tilt no dump) with the following apertures (runs are complete, awaiting analysis)
  - 13 cm inner radius to 85 cm
  - 23 cm inner radius beyond that
- These apertures enclose all solenoids
- Use these as our reference distributions for now
- Finally: thanks to X. Ding for lots and lots of “ok, now run this configuration” MARS runs, which he completed very efficiently