Beam Emittance and Energy Spectra for Hg and C Targets

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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
    - \(0.0027 \rightarrow 0.0067\) m-GeV/c
  - \(\approx\) half of initial beam lost in <6m

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Motivation—Neuffer’s Results

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 ..
Scope of my Studies

- Determine reasons for the behavior that Neuffer saw
- Better understand behavior in front end
- Produce distributions, equivalent in some sense to what Neuffer worked with, that address any problems in the originals
- Parameters for optimized (X. Ding) target designs
  - Target in 20 T field, tapering down to 2 T in just under 5 m
  - Hg: 8 GeV beam
  - C: 6.5 GeV beam, 65 mrad tilt, no dump
Effect of Apertures

• Old target apertures
  ◦ Mercury: square root taper aperture, starting at 7.5 cm at \( z = 0.375 \) m, growing to 30 cm at \( z \approx 19 \) m
  ◦ Carbon: 13 cm aperture to \( z = 1.7 \) m, then 23 cm downstream

• Compare: maximum possible apertures near target for 20 T: 13 cm to \( z = 85 \) cm, then 23 cm downstream

• Compare distributions at 3 m to results with old apertures
Effect of Apertures

- Emittances are larger, and are identical for Hg and C: emittances determined by apertures!
  - Normalized canonical emittances in mm
  - Large sign is sort of helicity
  - Difference in emittances is angular momentum

<table>
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<th>$\mu^-$</th>
<th>$\mu^+$</th>
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<td>13.4</td>
<td>35.2</td>
<td>15.1</td>
<td>21.0</td>
<td>14.4</td>
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<td>60.2</td>
<td>17.5</td>
<td>66.6</td>
<td>18.8</td>
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<td>14.6</td>
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<tr>
<td>C old</td>
<td>51.5</td>
<td>22.1</td>
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</tr>
</tbody>
</table>

- Spectrum: widening apertures gives more particles at higher energy
Hg at 3 m

- **π⁻**
  - Particles/p/GeV/eV (eV⁻¹)
  - Kinetic Energy (MeV)
  - Old Apertures
  - New Apertures

- **π⁺**
  - Particles/p/GeV/eV (eV⁻¹)
  - Kinetic Energy (MeV)
  - Old Apertures
  - New Apertures

- **µ⁻**
  - Particles/p/GeV/eV (eV⁻¹)
  - Kinetic Energy (MeV)
  - Old Apertures
  - New Apertures

- **µ⁺**
  - Particles/p/GeV/eV (eV⁻¹)
  - Kinetic Energy (MeV)
  - Old Apertures
  - New Apertures
Hg vs. C at 3 m

$\pi^-$

$\mu^-$

$\pi^+$

$\mu^+$

Particles/p/GeV/eV (eV$^{-1}$)
Kinetic Energy (MeV)

Particles/p/GeV/eV (eV$^{-1}$)
Kinetic Energy (MeV)
Hg vs. C at 3 m

- Hg production per MW always higher than C
- Distributions (per MW!) get very similar at high energy, especially for positive charges
- Pion production peak at 250 MeV shows up in Hg as well as C
  - This peak may be related to geometry: higher fields may move this to higher energy
- C and Hg will require different NBPR
  - Note that NBPR will function differently for both signs (moreso in Hg): must be a compromise, designed simultaneously for both signs
Spectrum vs. Distance (C)

\[ \pi^- \]

\[ \pi^+ \]

\[ \mu^- \]

\[ \mu^+ \]
Spectrum vs. Distance

- Going down to 10 m, many more pions lost than muons created
- Peak at 250 MeV goes away
- Conclusion: many pions (and maybe some decay muons) lost on apertures
- Transmission would be improved by higher fields downstream
  - Consistent with Hisham’s results
  - Spectrum would be weighted toward higher energy
IQGSM

- IQGSM gives a “choice of inclusive and exclusive event generators at nuclear inelastic interactions”
- IQGSM=0: exclusive CEM (cascade exciton 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

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• Significant performance hit for IQGSM=1 vs. IQGSM=0
• Energy spectrum also changes
• Emittance doesn’t change
• C runs were all with IQGSM=1, earlier Hg were IQGSM=0
Conclusions

- I believe we more or less understand why David saw what he saw
- There were production differences due to differences in the nuclear inelastic model used (IQGSM)
- Emittances are determined primarily by apertures; Hg and C are the same
- High energy portion of spectrum clipped by apertures
- Spectrum shape differs for different signs
Conclusions

- Positive production similar for Hg and C
- Negative production differs significantly at low energy (< 150 MeV for $\mu^-$)
  - Optimal NBPR will be different for Hg and C
- Higher fields downstream would increase number of captured particles, but likely raise energy of spectrum
- Hints that some early absorber may be beneficial, increasing lower-energy flux
  - In old days we had a “pre-cooler”
  - These results hint at a benefit from an “absorber horn”
Conclusions

• Finally: thanks to X. Ding for lots and lots of “ok, now run this configuration” MARS runs, which he completed very efficiently
Next Steps

- What does NBPR optimized for these distributions look like?
  - What portion of the distribution does it use?
  - What is the best compromise for both signs?
    - Is this different for collider and \( \nu \) factory optimization?
  - Is there a significant difference for C and Hg?

- How does chicane change things?
- How does raising the field change things?
- Would an early absorber help?