Beam Emittance and Energy Spectra for Hg and C Targets

J. Scott Berg
Brookhaven National Laboratory

Intense Muon Beams Meeting

February 2, 2015

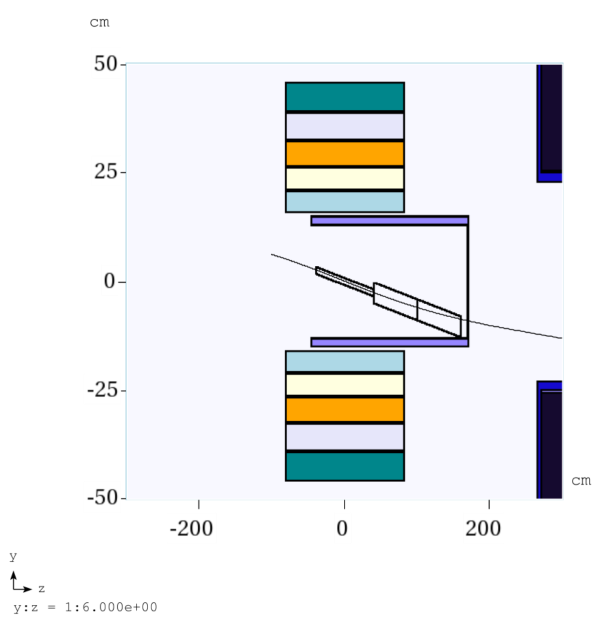
Motivation—Neuffer's Results

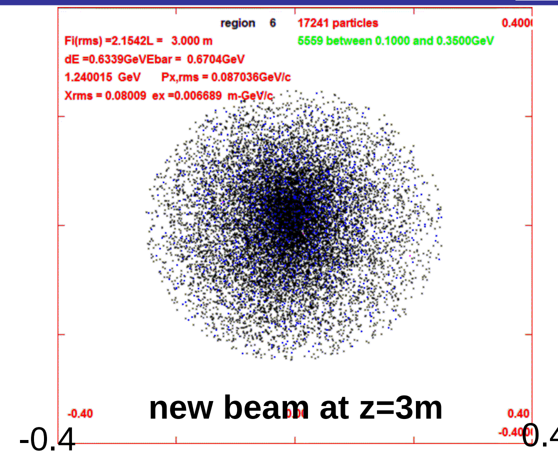
- Neuffer's talk at the MAP 2014 Winter Meeting, Dec. 4, 2014 (next 3 slides)
- Compared results from 8 GeV beam on Hg target to 6.75 GeV beam on C target
- C target had larger emittance by over a factor of 2
- Large increase in loss in first 6 m
- Performance reduction by about a factor of 2

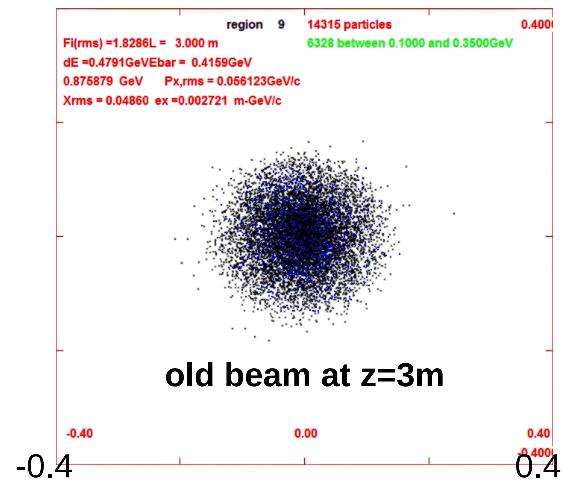
Motivation—Neuffer's Results

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







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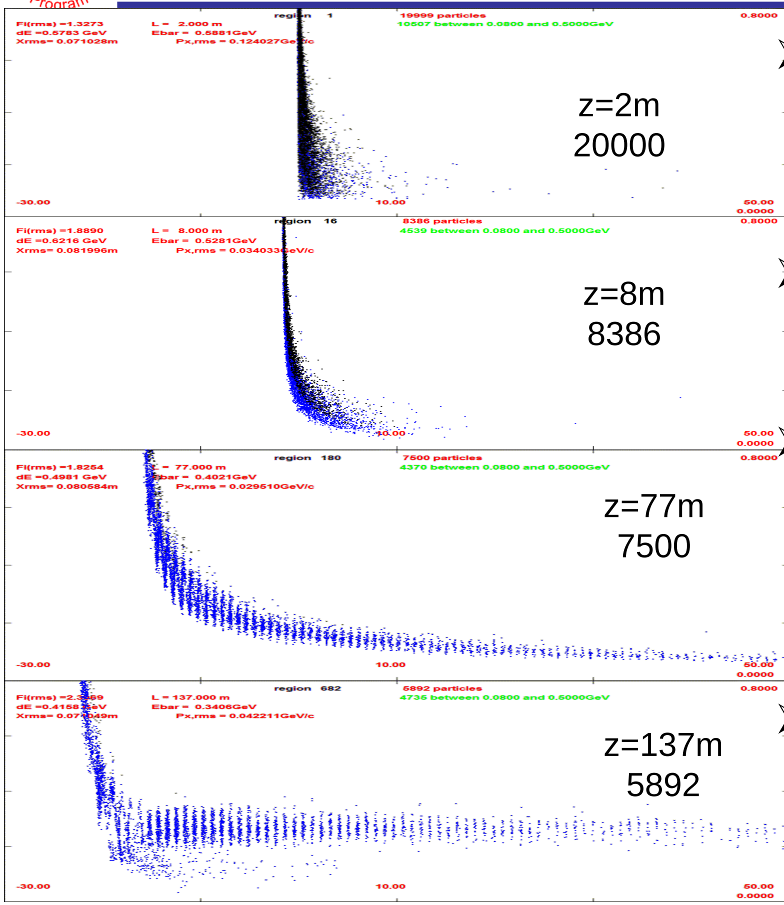
Motivation—Neuffer's Results

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
- μ/p reduced by factor ~ 2
  - → ~0.0545 μ^+/p
  - ~0.042 μ^-/p
    - μ^- less than μ^+
- Not fully reoptimized for new initial beam

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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 ..

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Examine Distributions

- Dug up every 8 GeV Hg in 20 T distribution I could find
  - 28-Oct-2010 https://pubweb.bnl.gov/~kirk/Target_Studies/Icool_for003_decks/
    - 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

Examine Distributions

- 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

Examine Distributions

- 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
  - π KE 60–600 MeV, μ KE 60–400 MeV; energy range at target in which 99% of ultimately captured particles lie
  - 4σ iterative cut

Emittances

	μ^-+	μ^--	μ^++	μ^+-	π^-+	π^--	π^++	π^+-
101028	31.8	13.1	35.6	13.7	23.1	14.9	26.0	15.0
130323-XDing 1	41.2	16.4	43.8	17.2	33.1	21.4	32.8	21.2
40206-HSayed	44.2	25.0	44.2	25.0	33.8	31.9	32.6	31.0
141215-XDing-00-dump	68.1	24.9	68.3	27.2	48.9	32.7	47.8	33.7
141215-XDing-00-nodump	49.8	22.7	51.2	24.6	35.1	27.1	35.3	28.3
141215-XDing-65-dump	58.1	21.4	60.2	23.2	43.6	26.7	43.3	27.9
141215-XDing-65-nodump	51.5	22.1	52.7	23.9	36.5	26.0	36.6	27.4
150113-XDing-Hg-IQGSM0	29.5	13.7	31.8	14.0	20.5	15.1	20.7	14.8

• 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

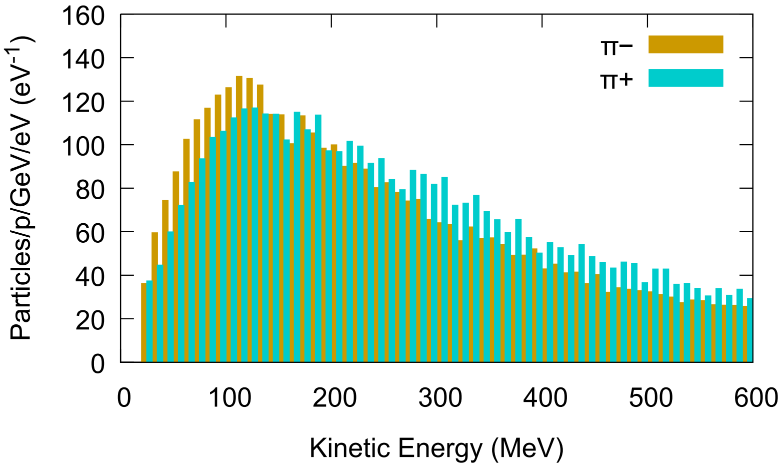
- Hg distributions
  - 2010 emittances significantly smaller than later runs
  - 2014 run has tiny pion angular momentum
    - Small beam; beam/target interact over small region?
    - Also shows up in muon angular momentum
  - 2015 run back to 2010 emittances??? Turns out it's a lie, as we'll see in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

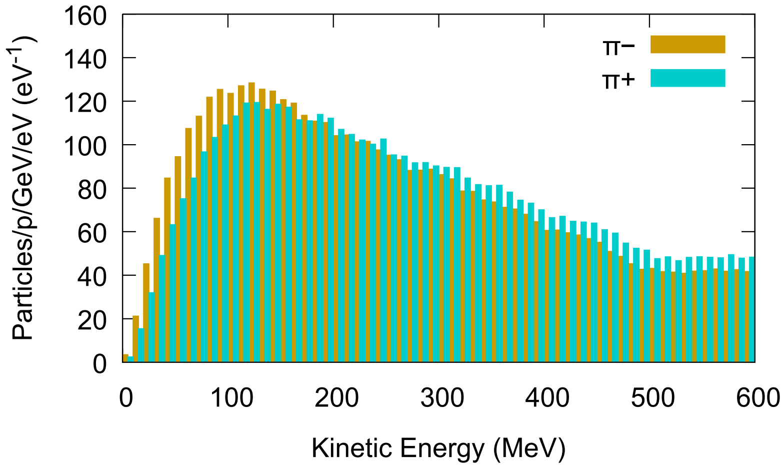
- In Hg, similar for most runs, but don't agree in detail
- The 06-Feb-2014 run is an outlier

Pion Distributions for Hg

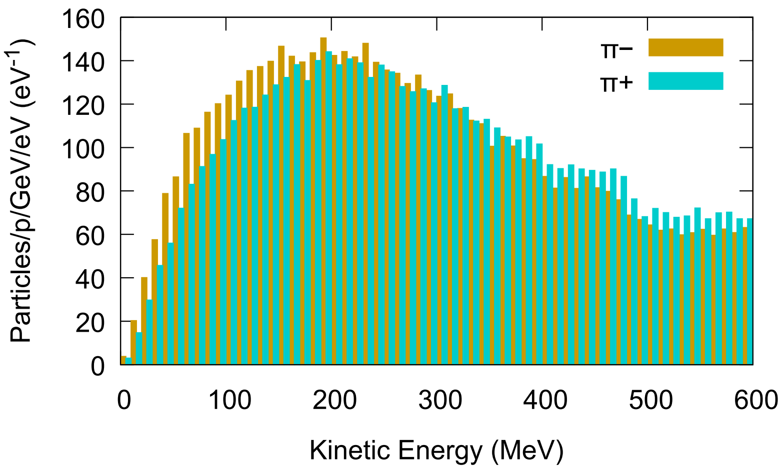
28-Oct-2010



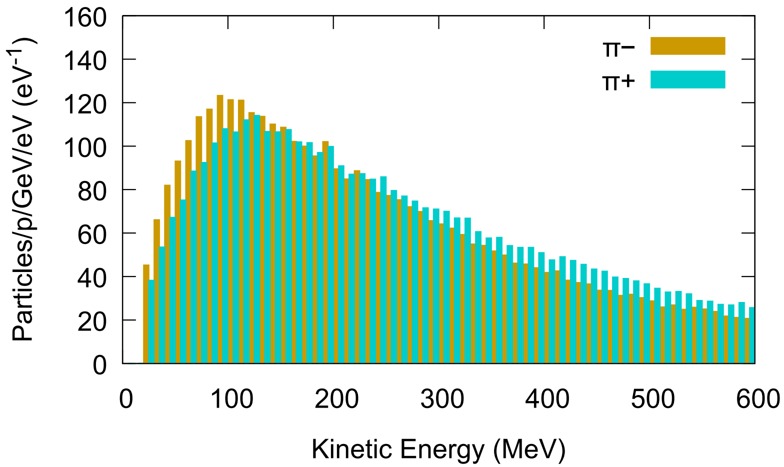
23-Mar-2013



06-Feb-2014

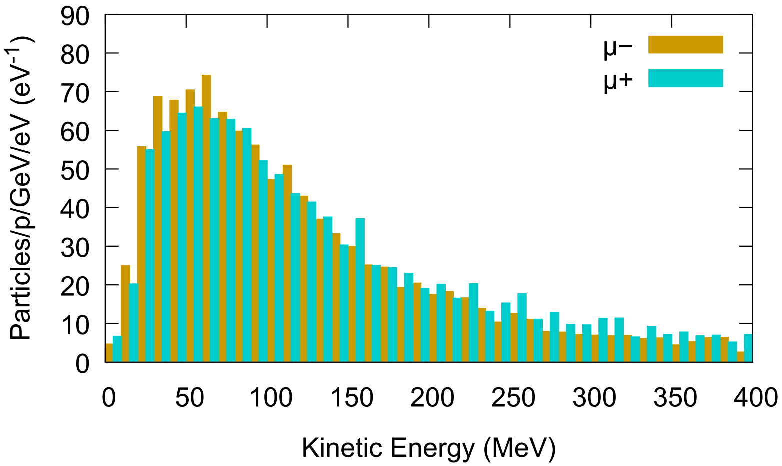


13-Jan-2015 IQGSM=0

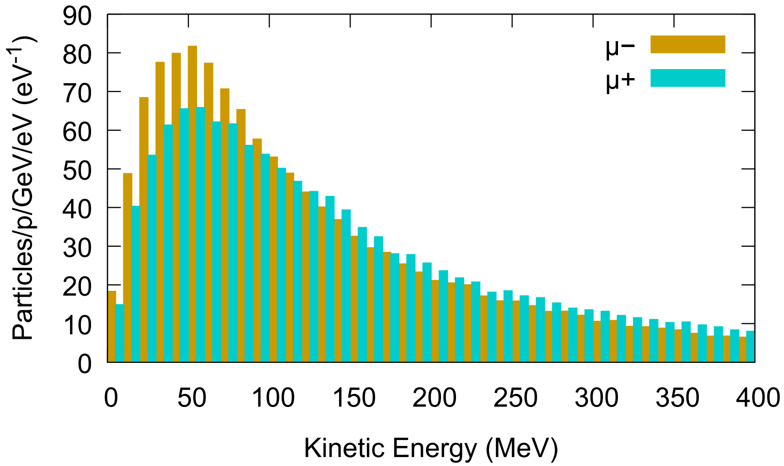


Muon Distributions for Hg

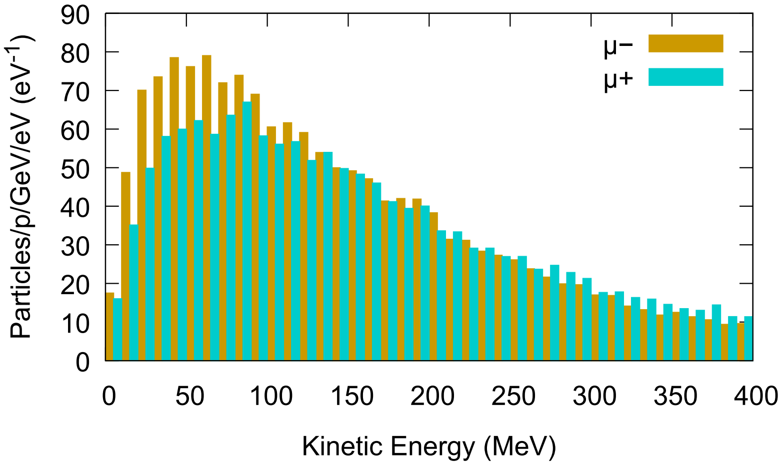
28-Oct-2010



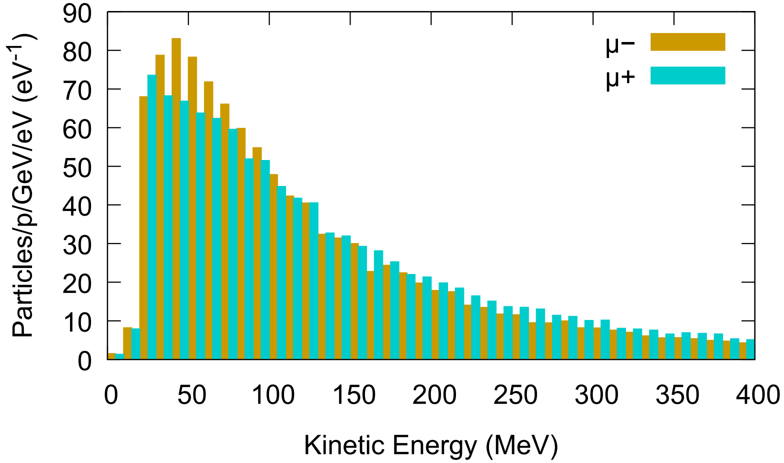
23-Mar-2013



06-Feb-2014



13-Jan-2015 IQGSM=0

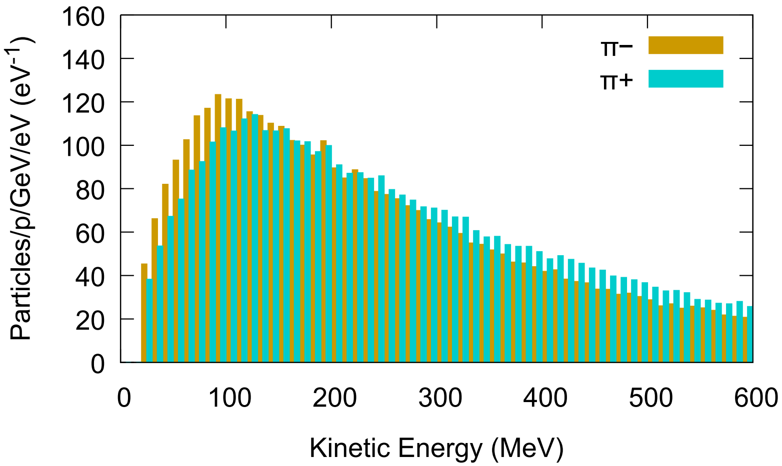


IQGSM

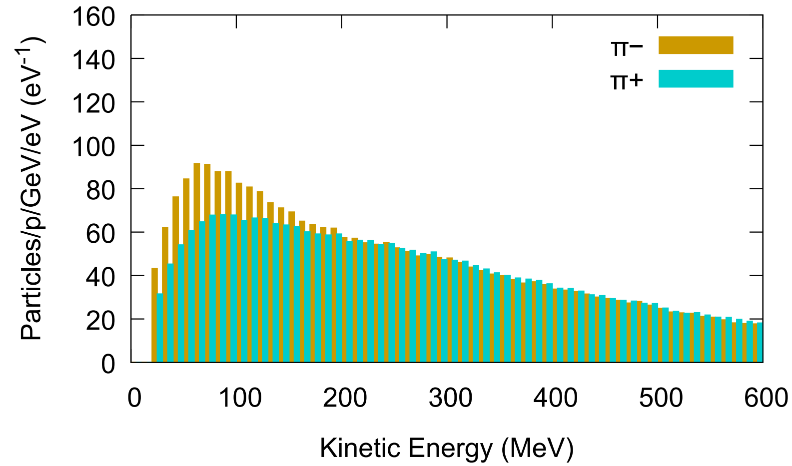
- IQGSM gives a "choice of inclusive and exclusive event generators at nuclear inelastic interactions"
- IQGSM=0: exclusive CEM (cascade excitation model?) for $E < 3$ GeV, MARS inclusive for $E > 5$ GeV, LAQGSM for some special cases. Old MARS default.
- IQGSM=1: CEM for $E < 0.3$ GeV, LAQGSM for $0.5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

Distributions for Hg, IQGSM

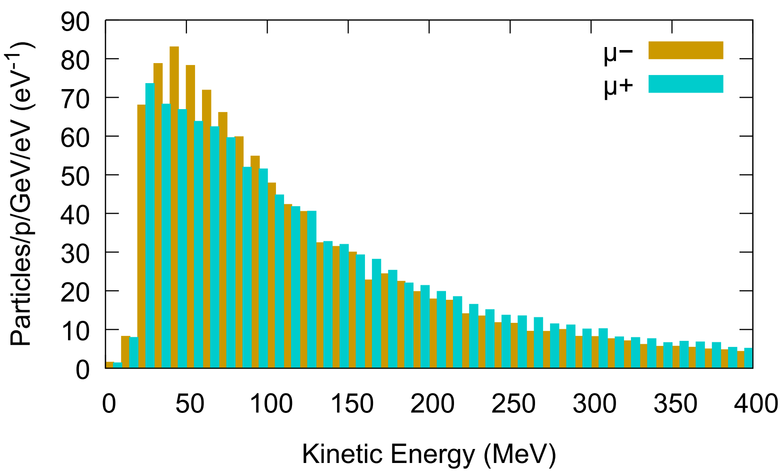
13-Jan-2015 IQGSM=0



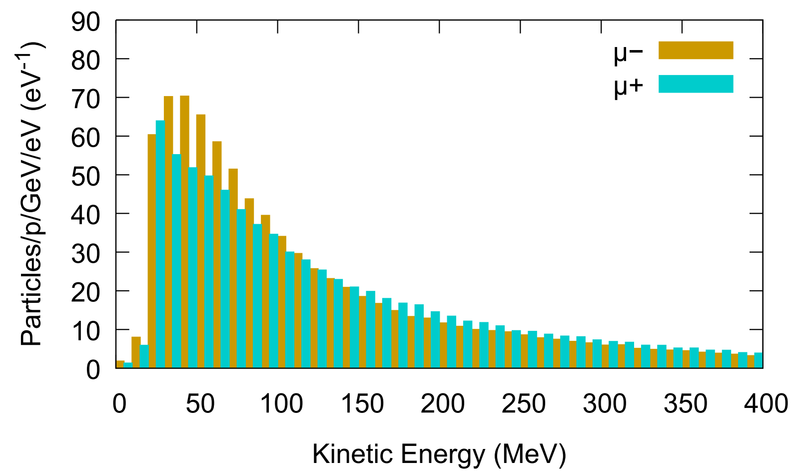
13-Jan-2015 IQGSM=1



13-Jan-2015 IQGSM=0



13-Jan-2015 IQGSM=1

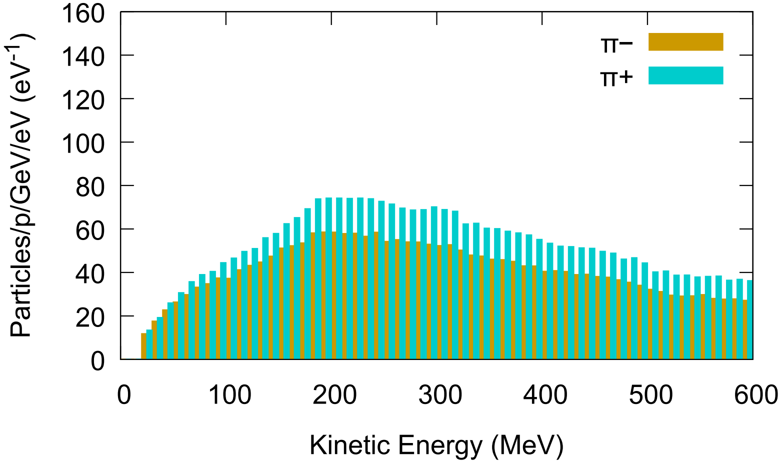


IQGSM

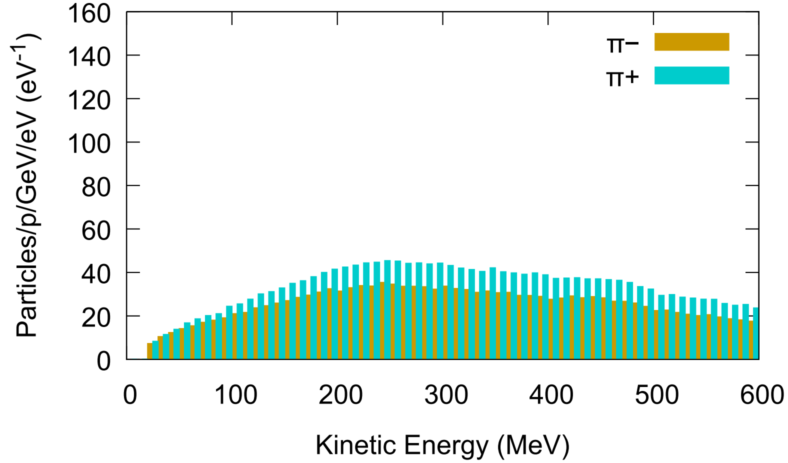
- Significant performance hit for IQGSM = 1
- Energy spectrum also changes
- Emittance doesn't change
- C runs were all with IQGSM=1, earlier Hg were IQGSM=0

C: Pions vs. Geometry

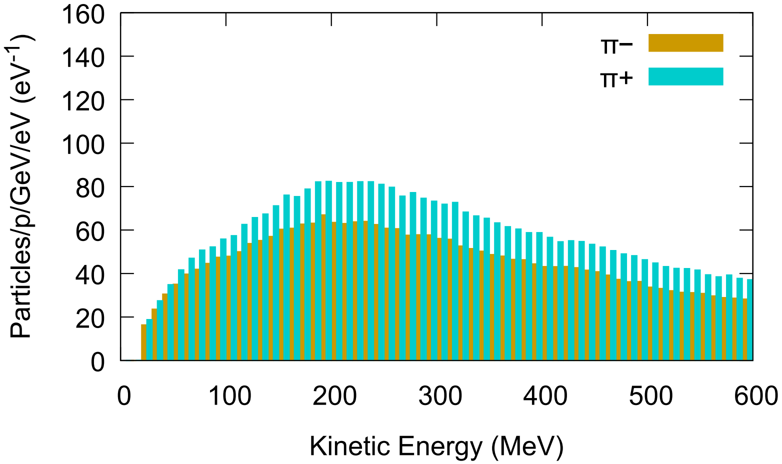
No Tilt, No Dump



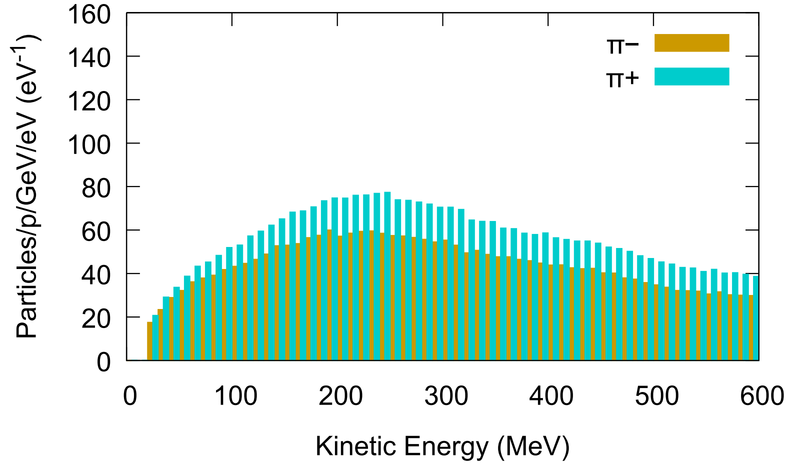
No Tilt, With Dump



With Tilt, No Dump

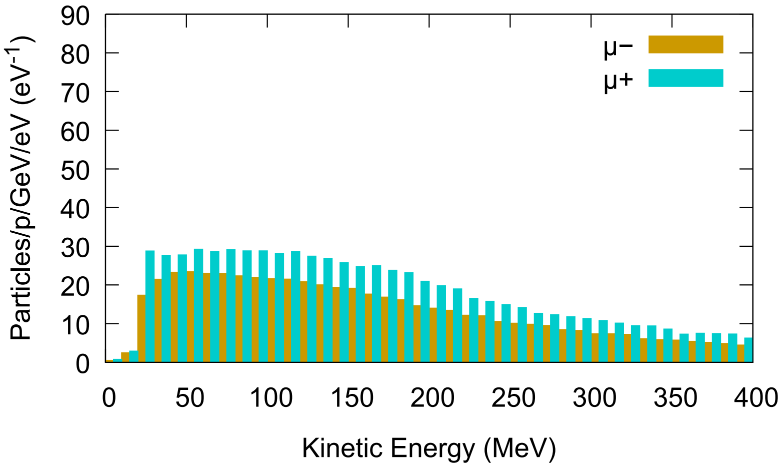


With Tilt, With Dump

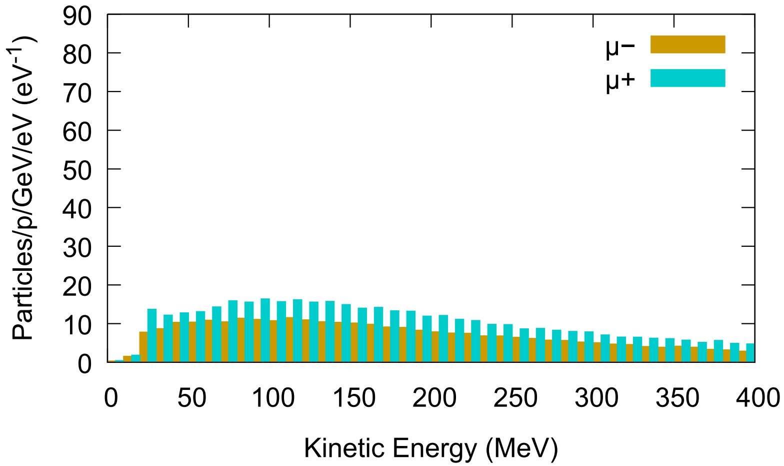


C: Muons vs. Geometry

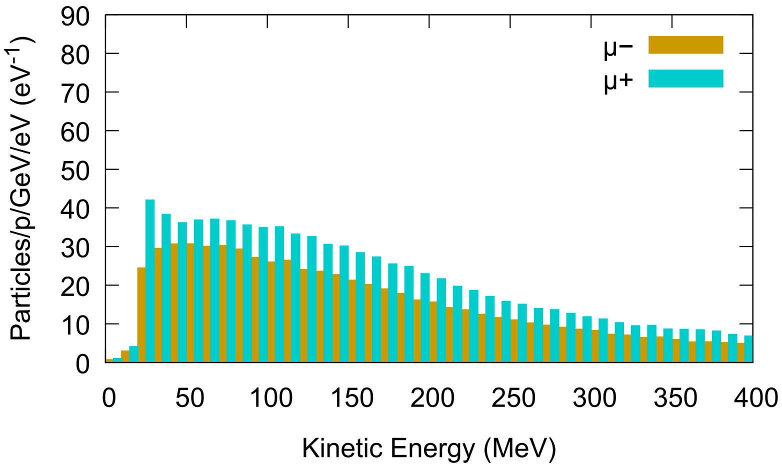
No Tilt, No Dump



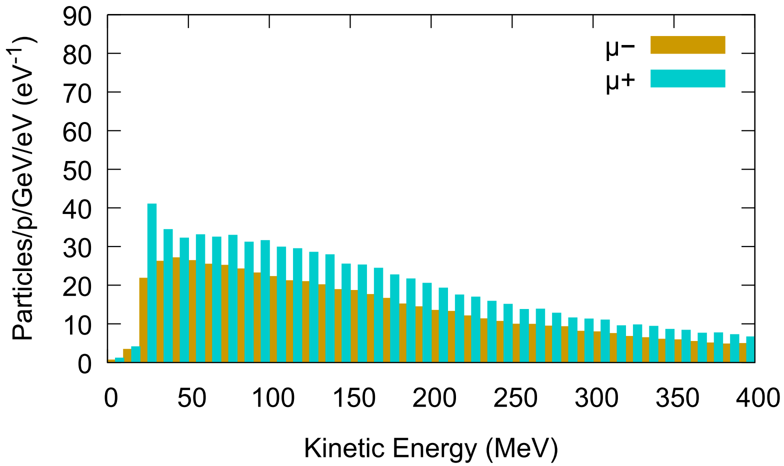
No Tilt, With Dump



With Tilt, No Dump



With Tilt, With Dump

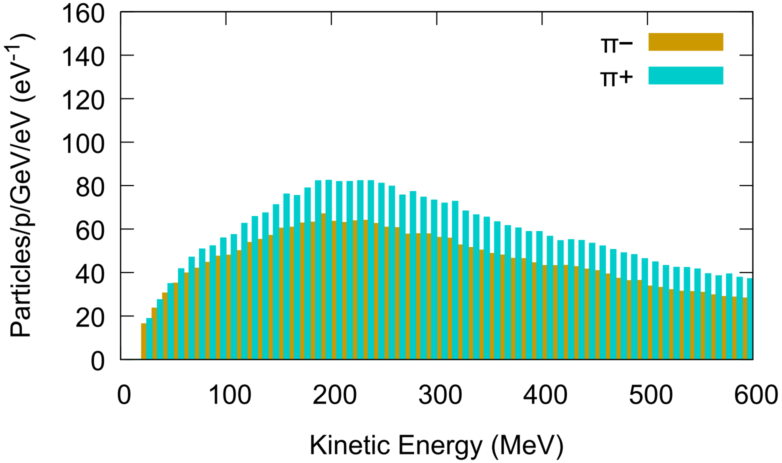


C vs. Geometry

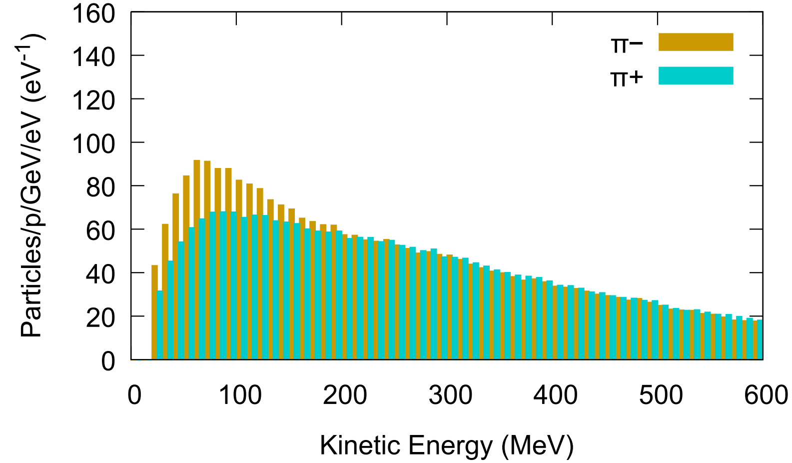
- Only major production hit is no tilt, no dump
- With tilt, no dump is the best

C vs. Hg, IQGSM = 1

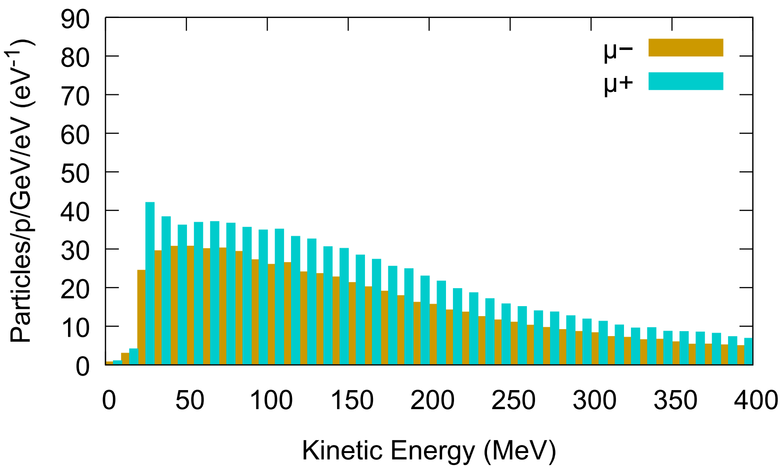
C



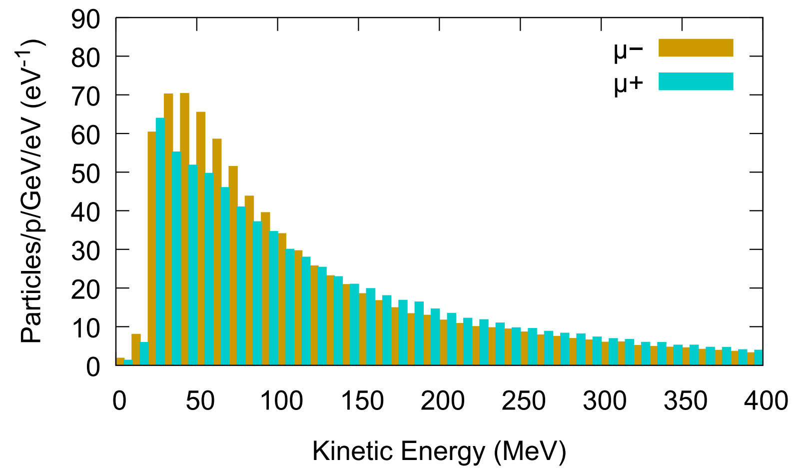
Hg



C



Hg



C vs. Hg

- Similar total number of particles for Hg and C (need to check more carefully)
- Spectrum of C wieghted 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…

Propagation in MARS vs. ICOOL

- 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

	μ^-+	μ^--	μ^++	μ^+-	π^-+	π^--	π^++	π^+-
0.375	45.4	16.8	51.1	19.7	35.5	21.5	36.4	22.8
2.000	30.7	13.4	35.2	15.1	21.0	14.4	21.9	15.1

Propagation in MARS vs. ICOOL

- Next, do ICOOL propagations without pion decays, and look at pion emittances of pions common to both runs

	π^-+	π^--	π^++	π^+-
0.375	19.3	14.4	19.4	15.0
2.000	18.9	13.4	19.1	14.4

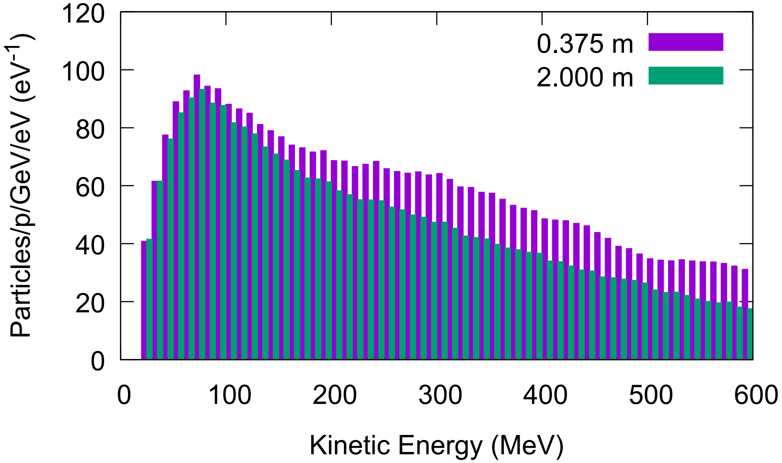
- Results similar to propagation from 2 m
- Conclusion: particles lost on object in MARS
- Further analysis: square root taper aperture, starting at a radius of 7.5 cm at $z = 0.375$ m, growing to 30 cm at $z \approx 19$ m

Distributions vs. Handoff Point

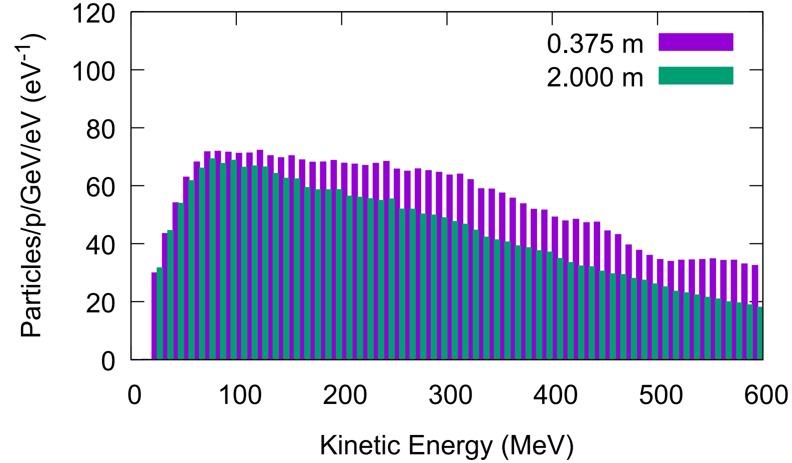
- Energy spectra have differences as well
- Pions weighted to higher energies
  - Still not to the degree that carbon is
- More low energy muons, presumably from low energy pions that have already decayed

Distributions vs. Handoff Point

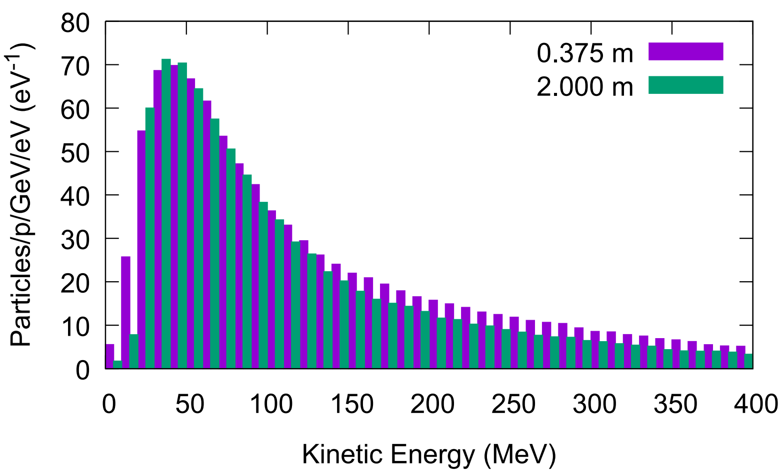
π^-



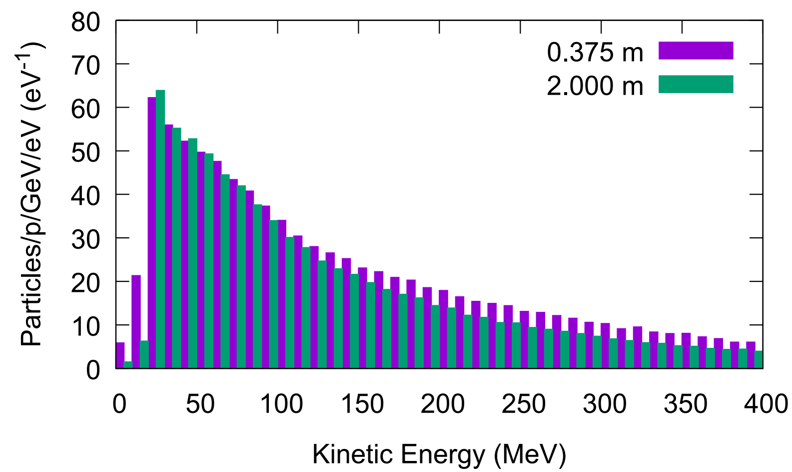
π^+



μ^-



μ^+



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