Beam Emittance and Energy Spectra for Hg and C Targets

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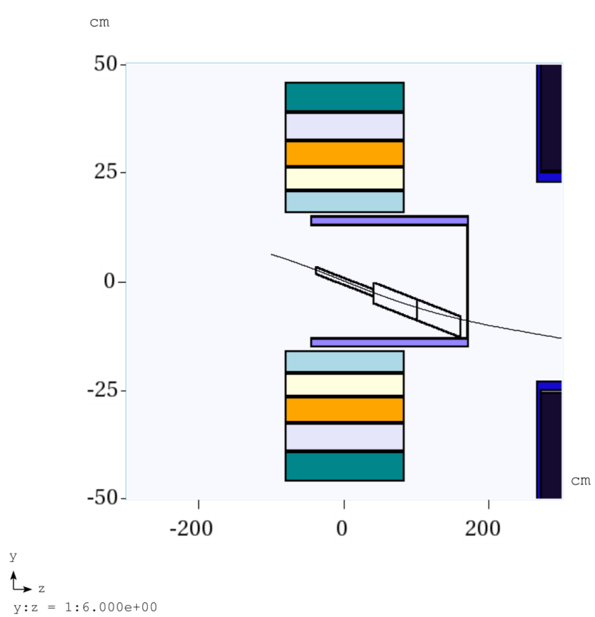
Motivation—Neuffer's Results

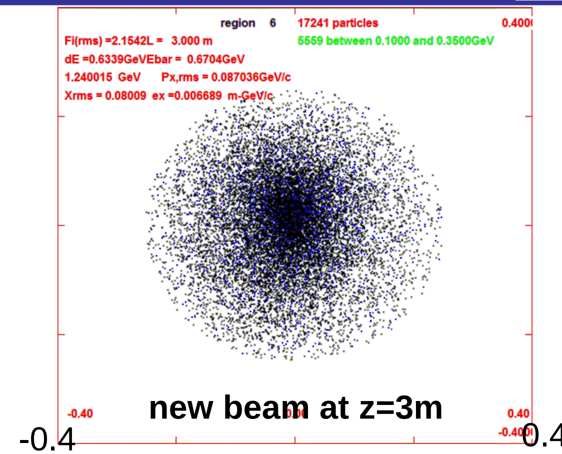
- Neuffer's talk at the MAP 2014 Winter Meeting, Dec. 4, 2014 (next 3 slides)
- Compared results from 8 GeV beam on Hg target to 6.75 GeV beam on C target
- C target had larger emittance by over a factor of 2
- Large increase in loss in first 6 m
- Performance reduction by about a factor of 2

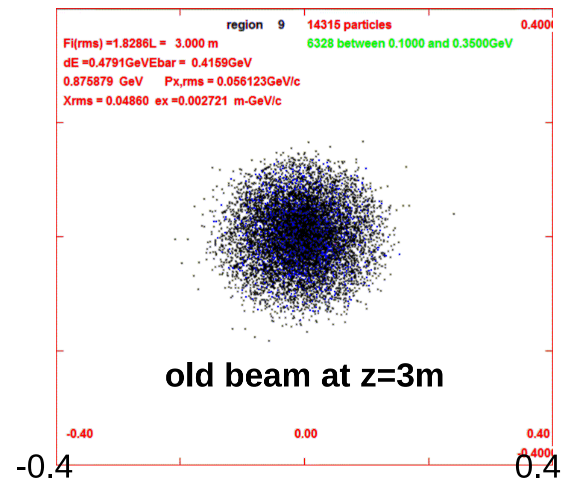
Motivation—Neuffer’s Results

Use old FE with new initial beam

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







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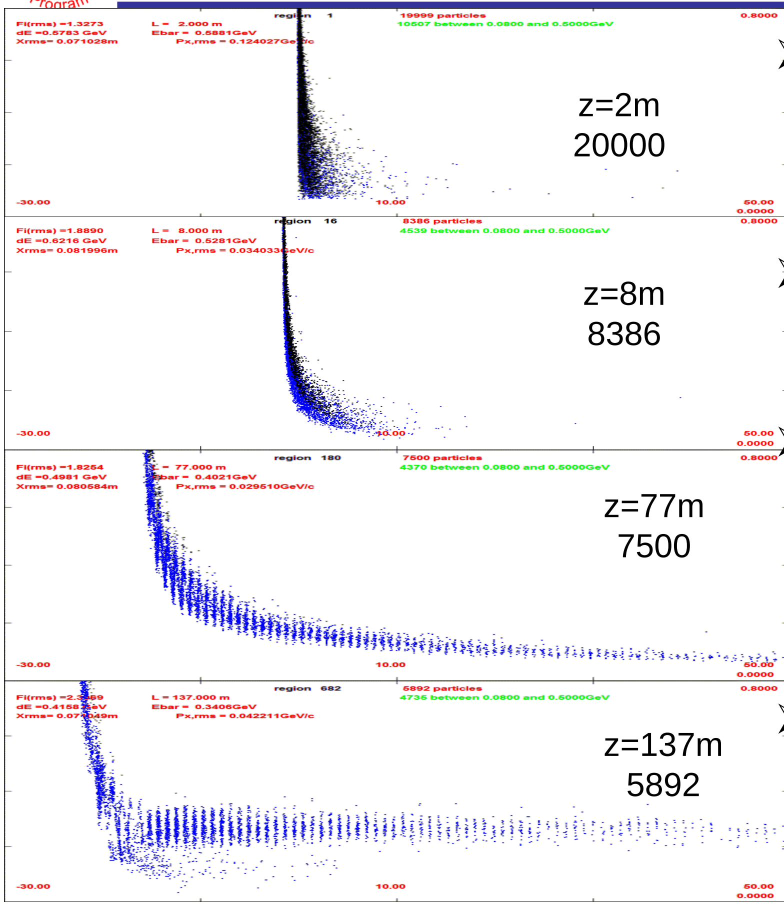
Motivation—Neuffer's Results

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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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 ..

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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
  - What we should use for "reference" distributions is beyond the scope of what I've done, and a discussion which will occur following this talk
  - In any case, I am merely analyzing distributions: X. Ding did the runs, others collaborated to make the target scenarios
  - My results will inform this process to some extent

Examine Distributions

- Every 8 GeV Hg in 20 T distribution I could find
- 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
- Propagate all distributions to 3 m downstream from field peak

Distribution 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	41.2	16.4	43.8	17.2	33.1	21.4	32.8	21.2
140206-HSayed	44.2	25.0	44.2	25.0	33.8	31.9	32.6	31.0
141215-XDing-00-d	68.1	24.9	68.3	27.2	48.9	32.7	47.8	33.7
141215-XDing-00-n	49.8	22.7	51.2	24.6	35.1	27.1	35.3	28.3
141215-XDing-65-d	58.1	21.4	60.2	23.2	43.6	26.7	43.3	27.9
141215-XDing-65-n	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

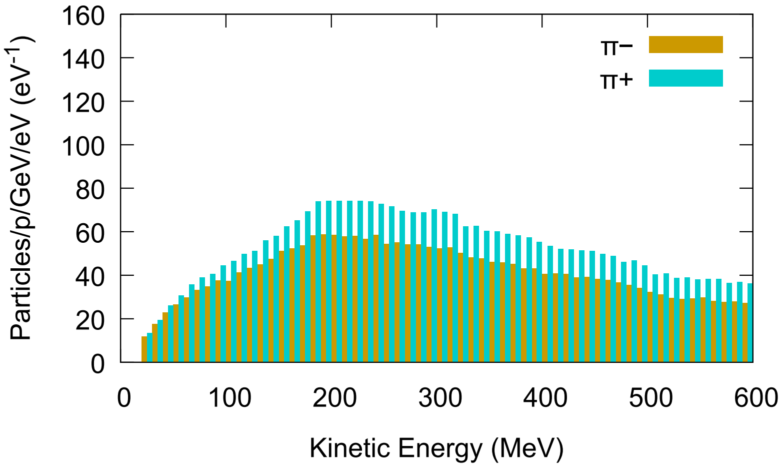
- Normalized canonical emittances in mm
- Large sign is sort of helicity
- Difference in emittances is angular momentum
- Names to left are distributions, contain date
  - Carbon: two digit angle, d for dump, n for no dump

Analysis

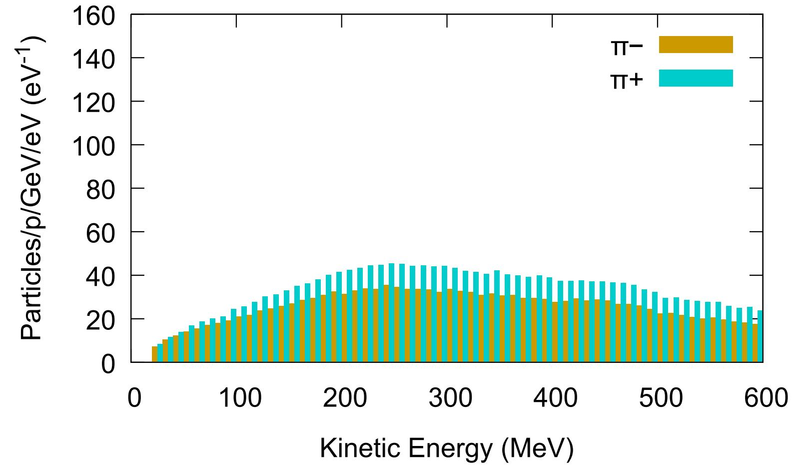
- Hg emittances all over the place
  - Energy spectra also differ
- Carbon emittances
  - Removing dump improves emittance
  - With dump, lower emittance with tilt
  - Without dump tilt makes emittance a tiny bit worse
  - Proton beam emittance didn’t matter (not shown)
  - Larger than Hg, but sometimes close

C: Pions vs. Geometry

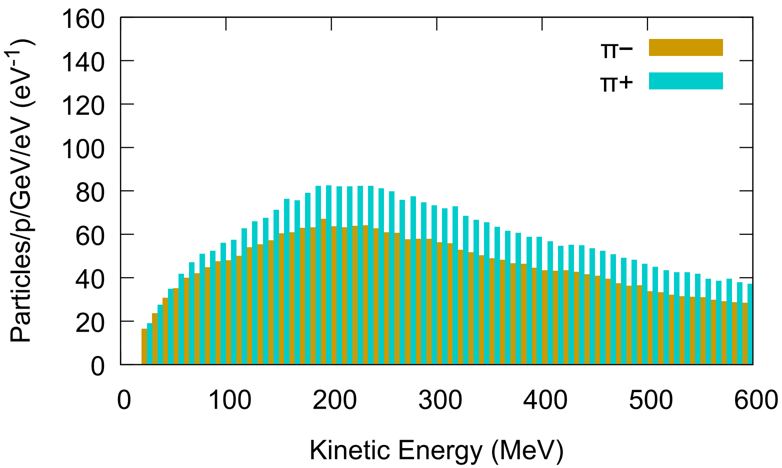
No Tilt, No Dump



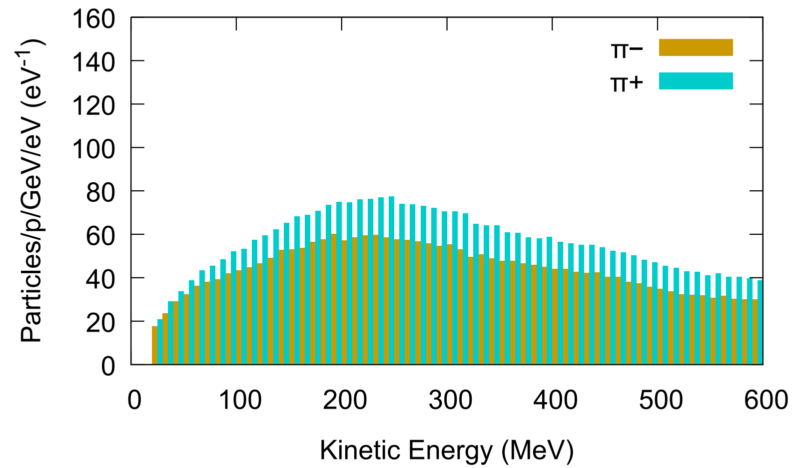
No Tilt, With Dump



With Tilt, No Dump

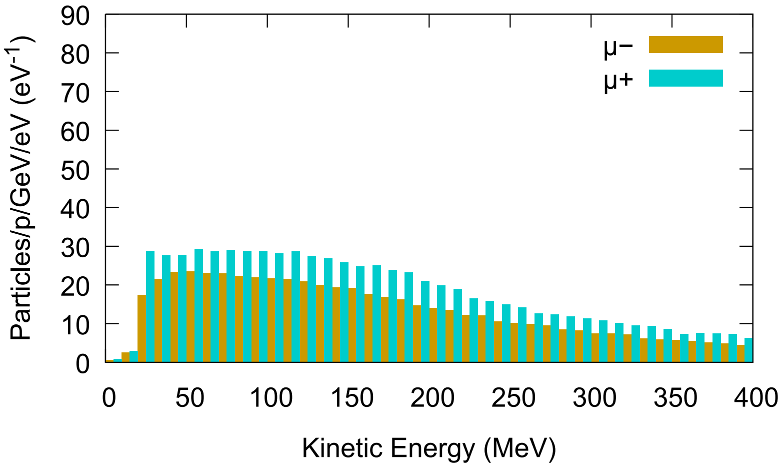


With Tilt, With Dump

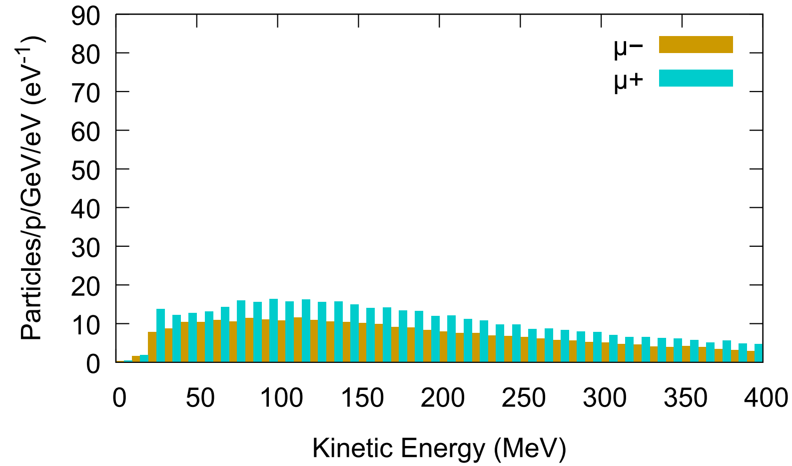


C: Muons vs. Geometry

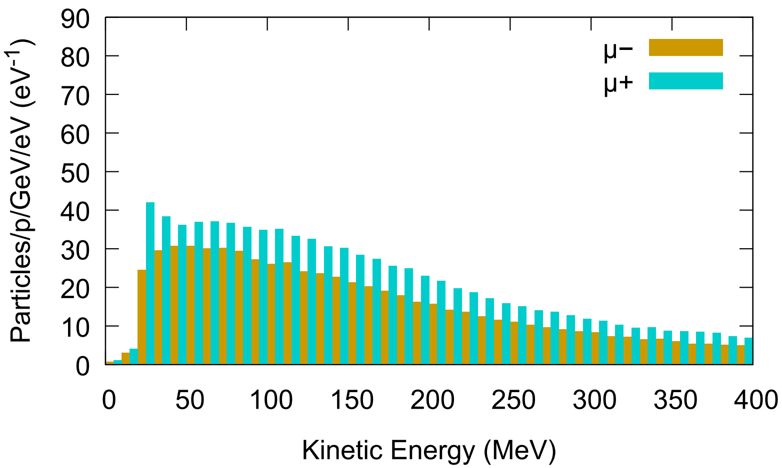
No Tilt, No Dump



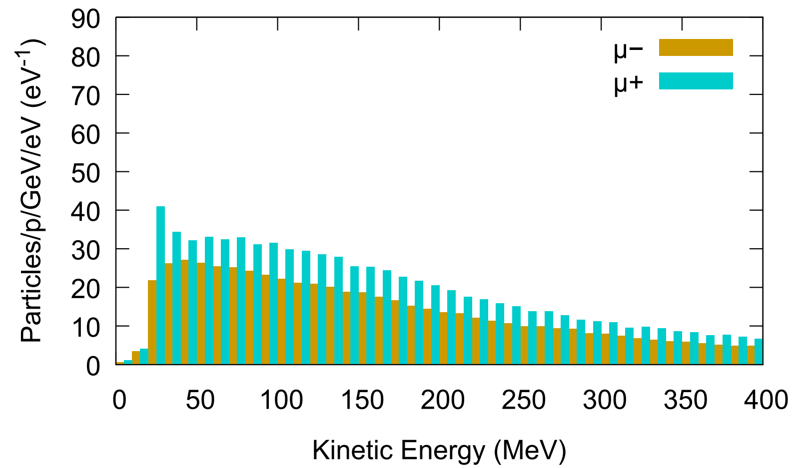
No Tilt, With Dump



With Tilt, No Dump



With Tilt, With Dump



C vs. Geometry

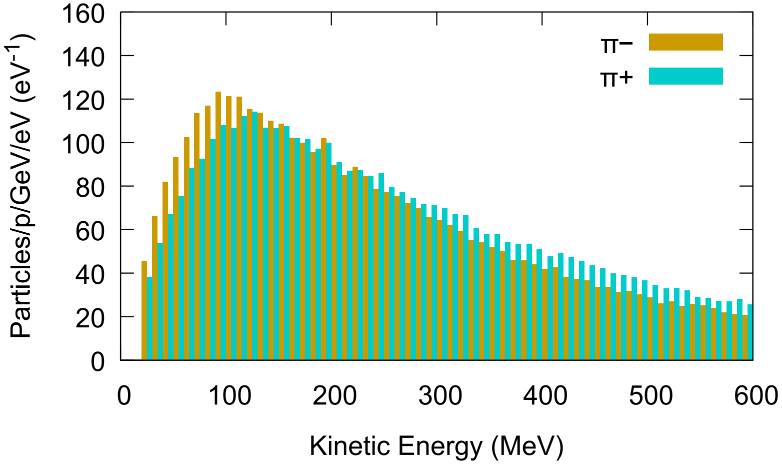
- Only major production hit is no tilt, with dump
- With tilt no dump is the best

IQGSM

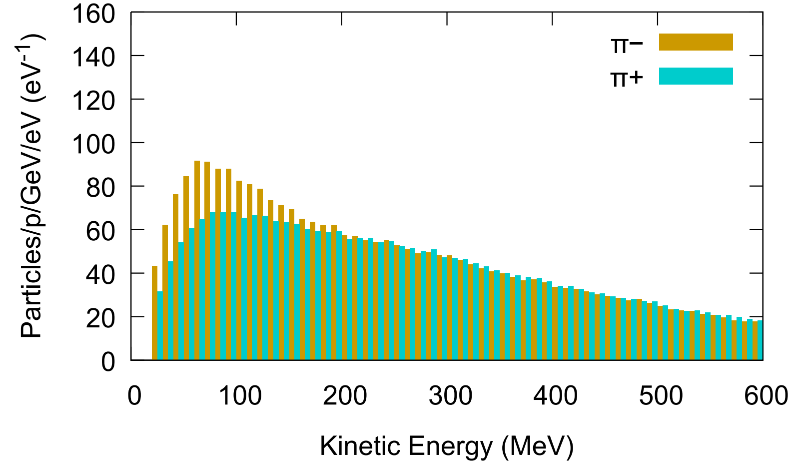
- IQGSM gives a "choice of inclusive and exclusive event generators at nuclear inelastic interactions"
- IQGSM=0: exclusive CEM (cascade exciton model?) for $E < 3$ GeV, MARS inclusive for $E > 5$ GeV, LAQGSM for some special cases. Old MARS default.
- IQGSM=1: CEM for $E < 0.3$ GeV, LAQGSM for $0.5\text{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

Distributions for Hg, IQGSM

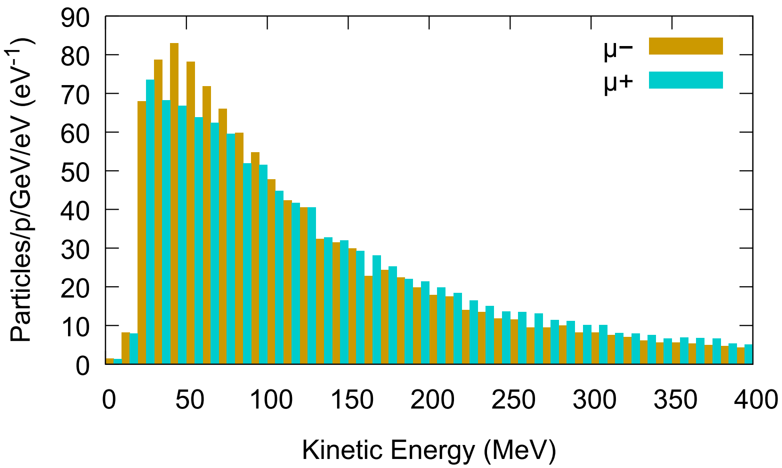
13-Jan-2015 IQGSM=0



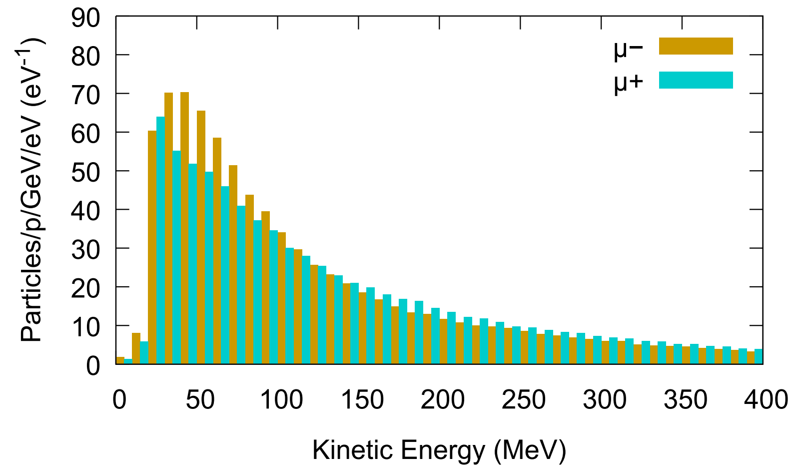
13-Jan-2015 IQGSM=1



13-Jan-2015 IQGSM=0



13-Jan-2015 IQGSM=1



IQGSM

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

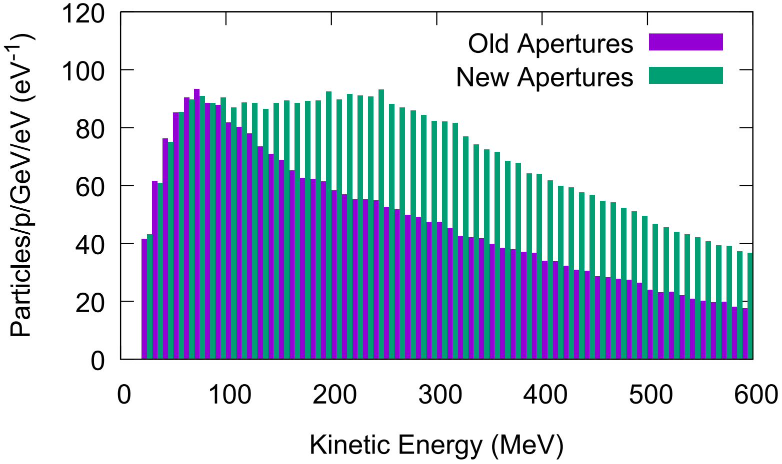
Maximal Aperture Runs

- Ran both C and Hg with
  - 13 cm inner radius to 85 cm
  - 23 cm inner radius beyond that
- Compare distributions at 3 m to results with old apertures
- Emittances are larger, and are identical for Hg and C: emittances determined by apertures!
  - Differences in C apertures based on tilt, etc: likely differences in interaction with aperture

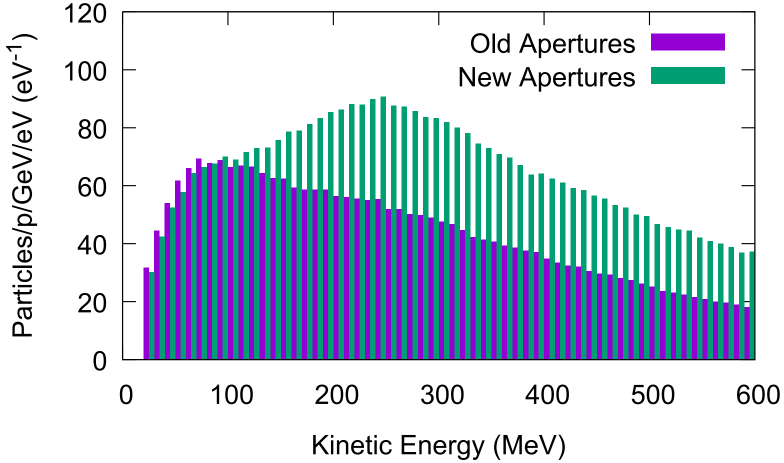
	μ^-+	μ^--	μ^++	μ^+-	π^-+	π^--	π^++	π^+-
Hg old	30.7	13.4	35.2	15.1	21.0	14.4	21.9	15.1
Hg new	60.2	17.5	66.6	18.8	62.8	14.6	64.8	14.8
C old	51.5	22.1	52.7	23.9	36.5	26.0	36.6	27.4
C new	60.7	18.5	64.5	19.4	63.8	15.4	66.1	15.6

Hg at 3 m

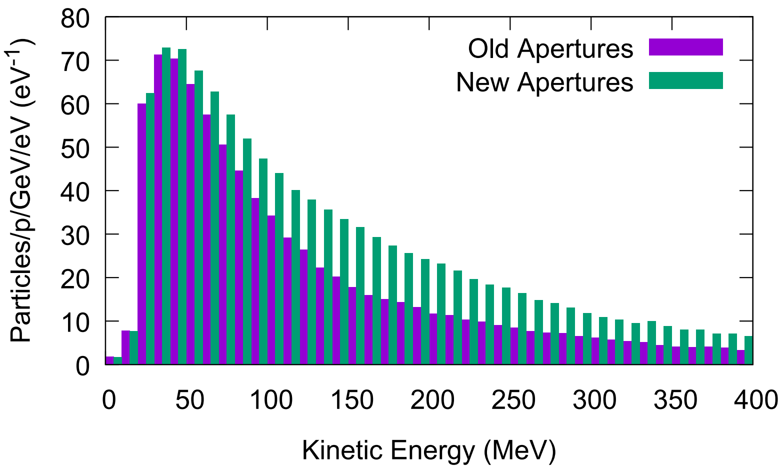
π^-



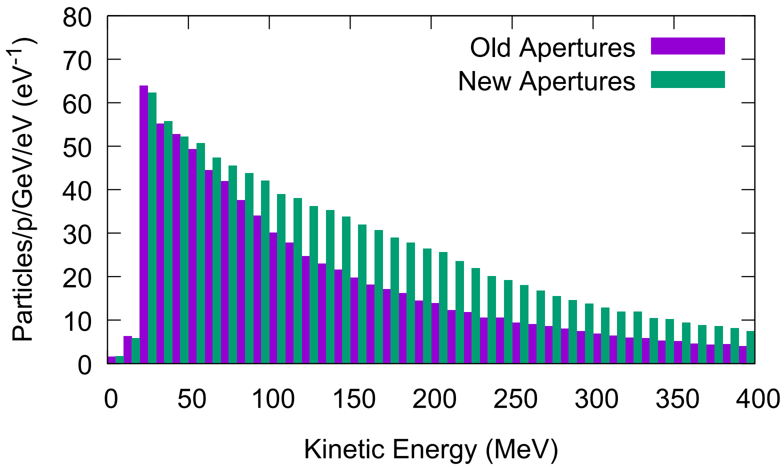
π^+



μ^-



μ^+

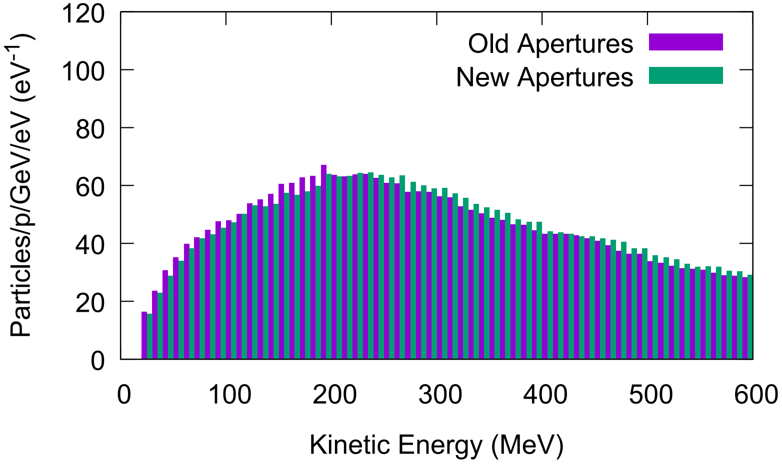


Hg at 3 m

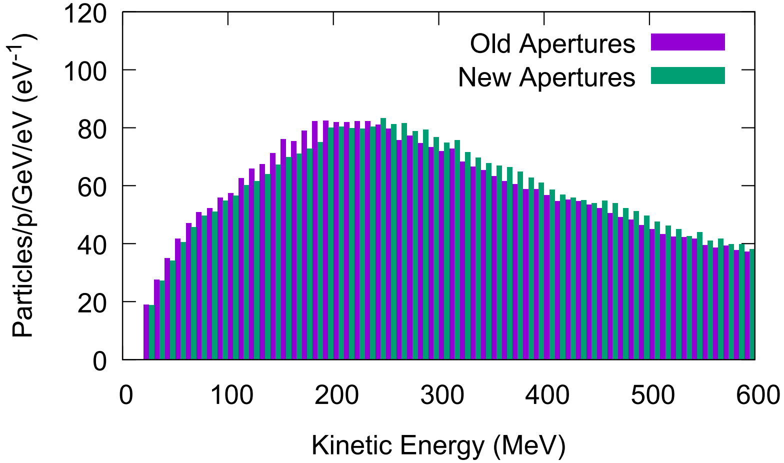
- Hg: widening apertures gives more particles at higher energy
- C: less change seen: only difference is that 13 cm portion got shorter in new version
- Some decrease in low energy pions: pions were losing energy in beampipe?

C at 3 m

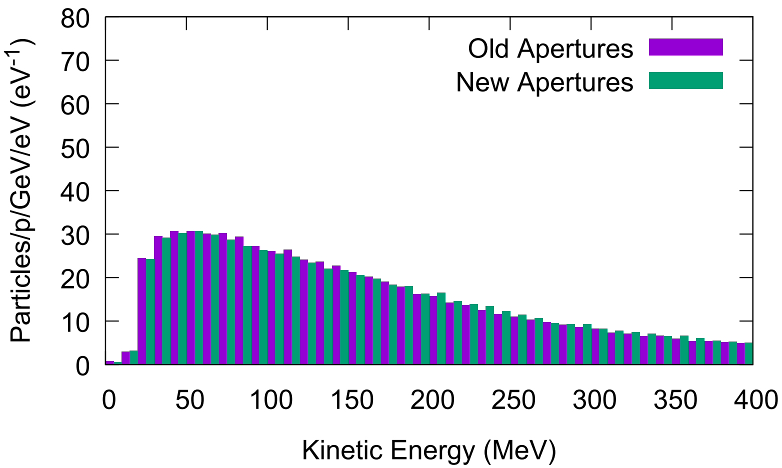
π^-



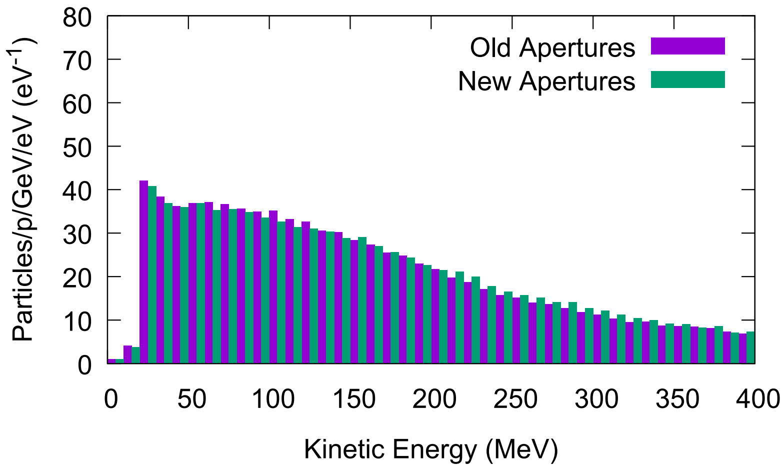
π^+



μ^-

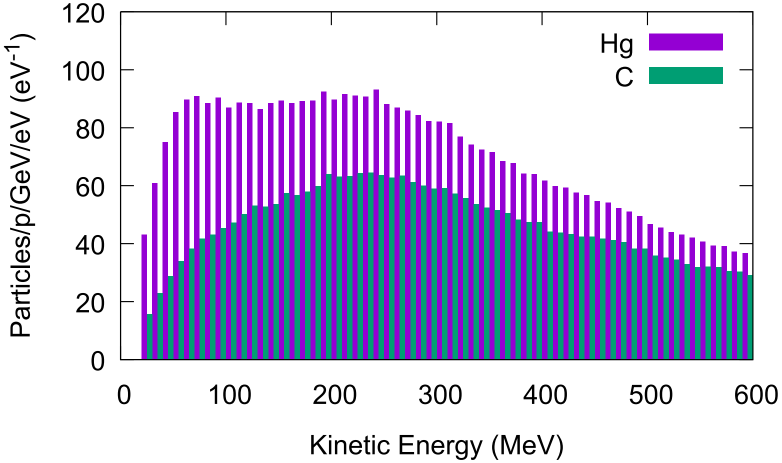


μ^+

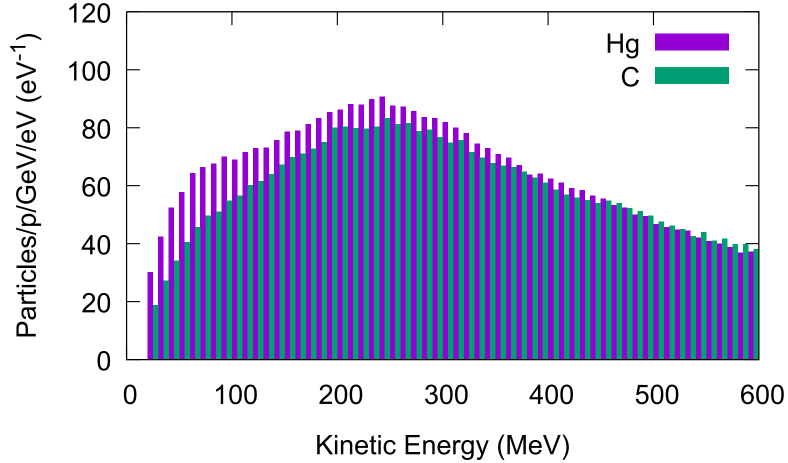


Hg vs. C at 3 m

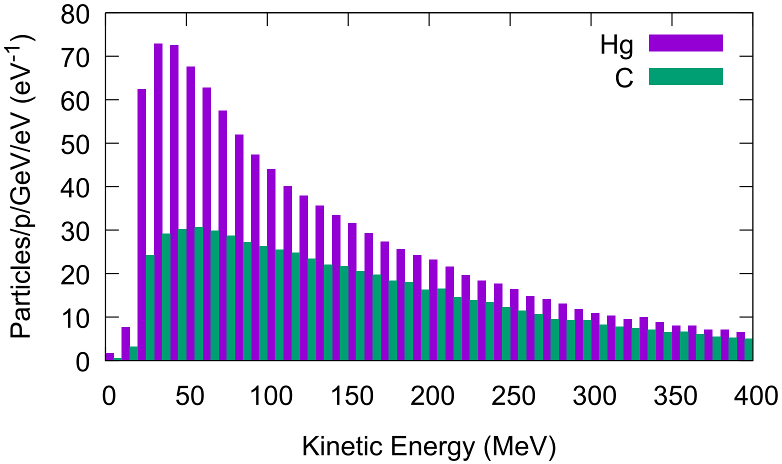
π^-



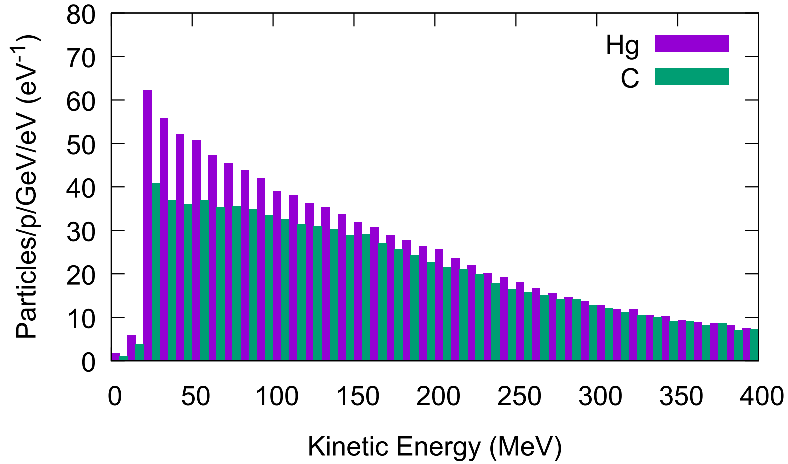
π^+



μ^-



μ^+

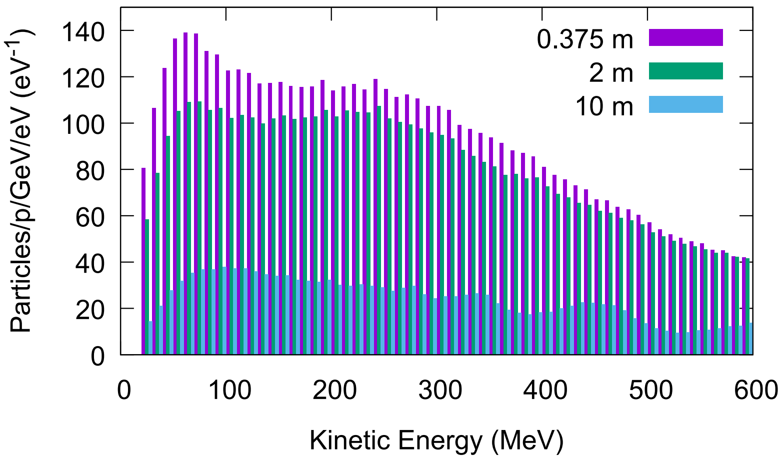


Hg vs. C at 3 m

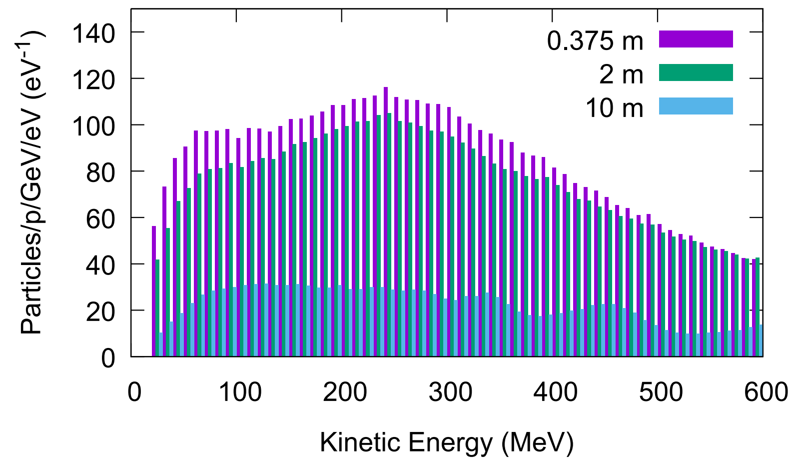
- Hg production per MW always higher than C
- Distributions (per MW!) get very similar at high energy, especially for positive charges
- Pion production peak at 250 MeV shows up in Hg as well as C
    - This peak may be related to geometry: higher fields may move this to higher energy
- C and Hg will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

Spectrum vs. Distance (Hg)

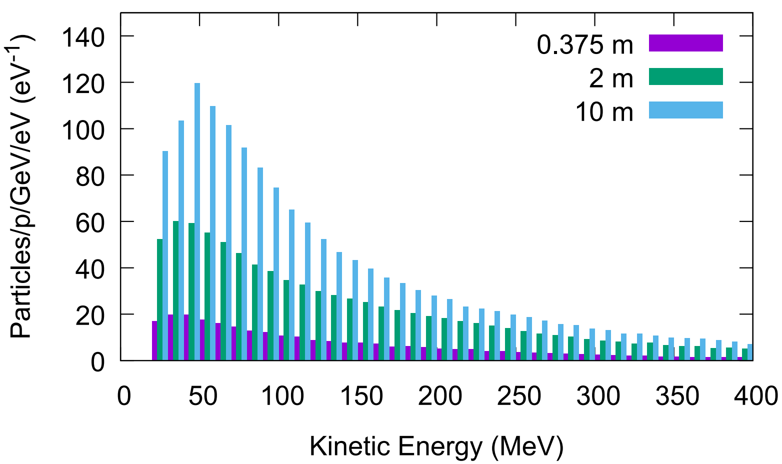
π^-



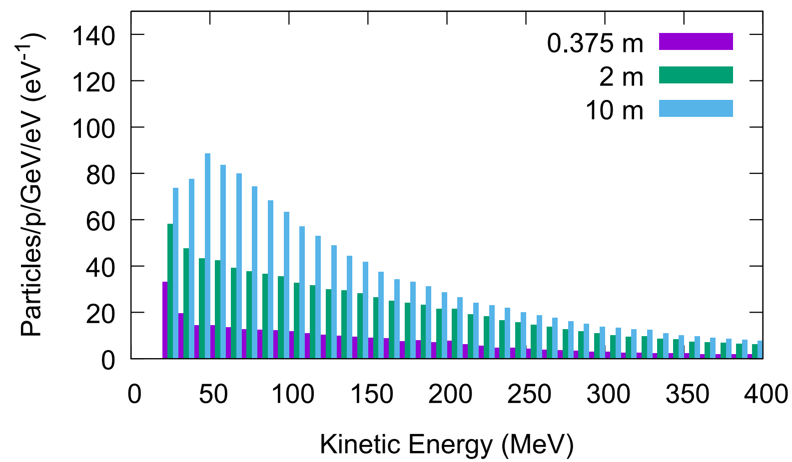
π^+



μ^-

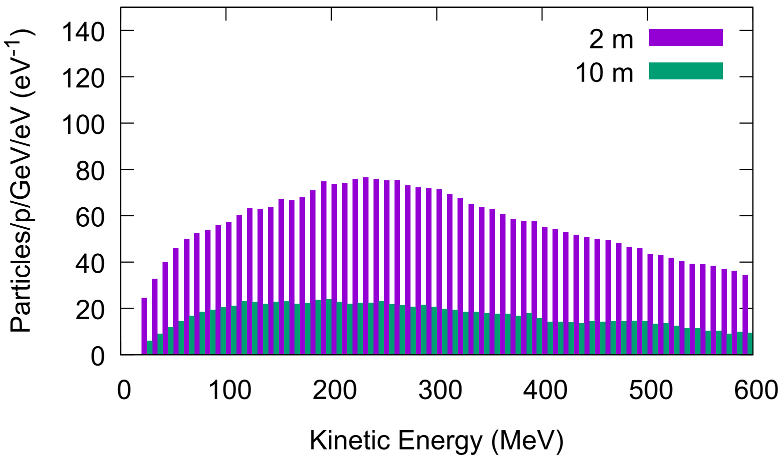


μ^+

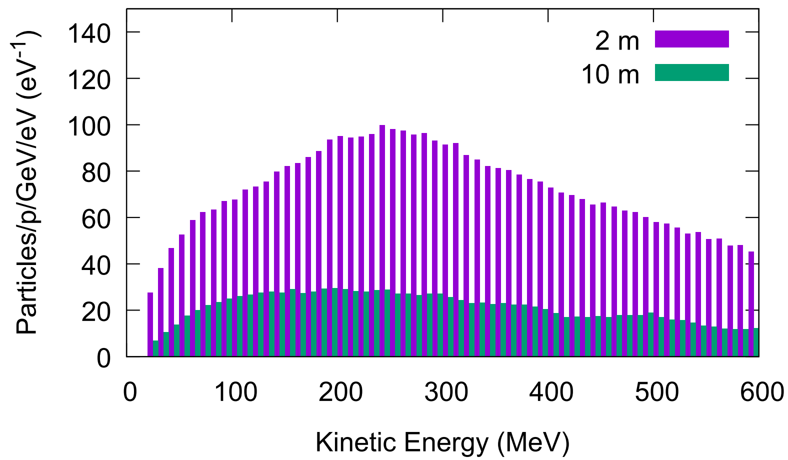


Spectrum vs. Distance (C)

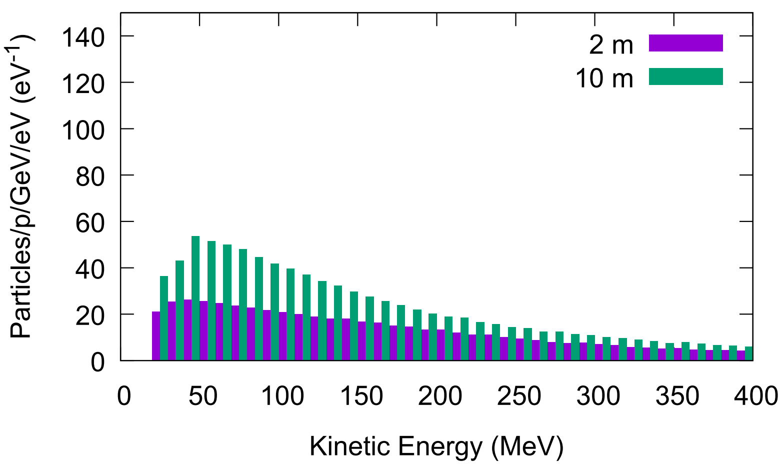
π^-



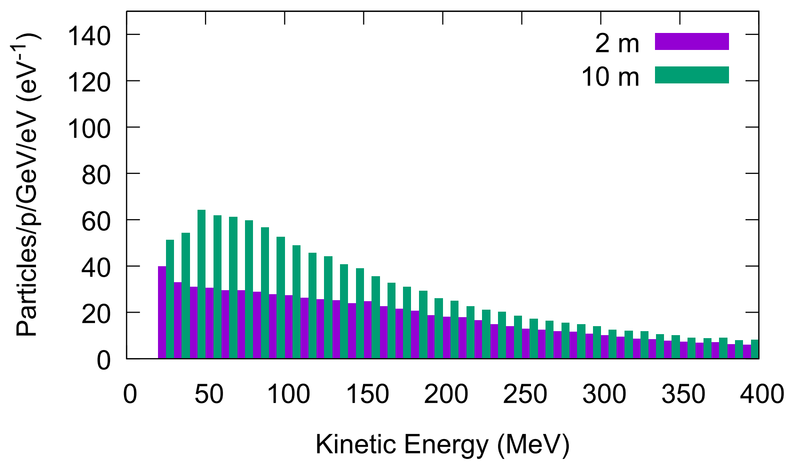
π^+



μ^-



μ^+



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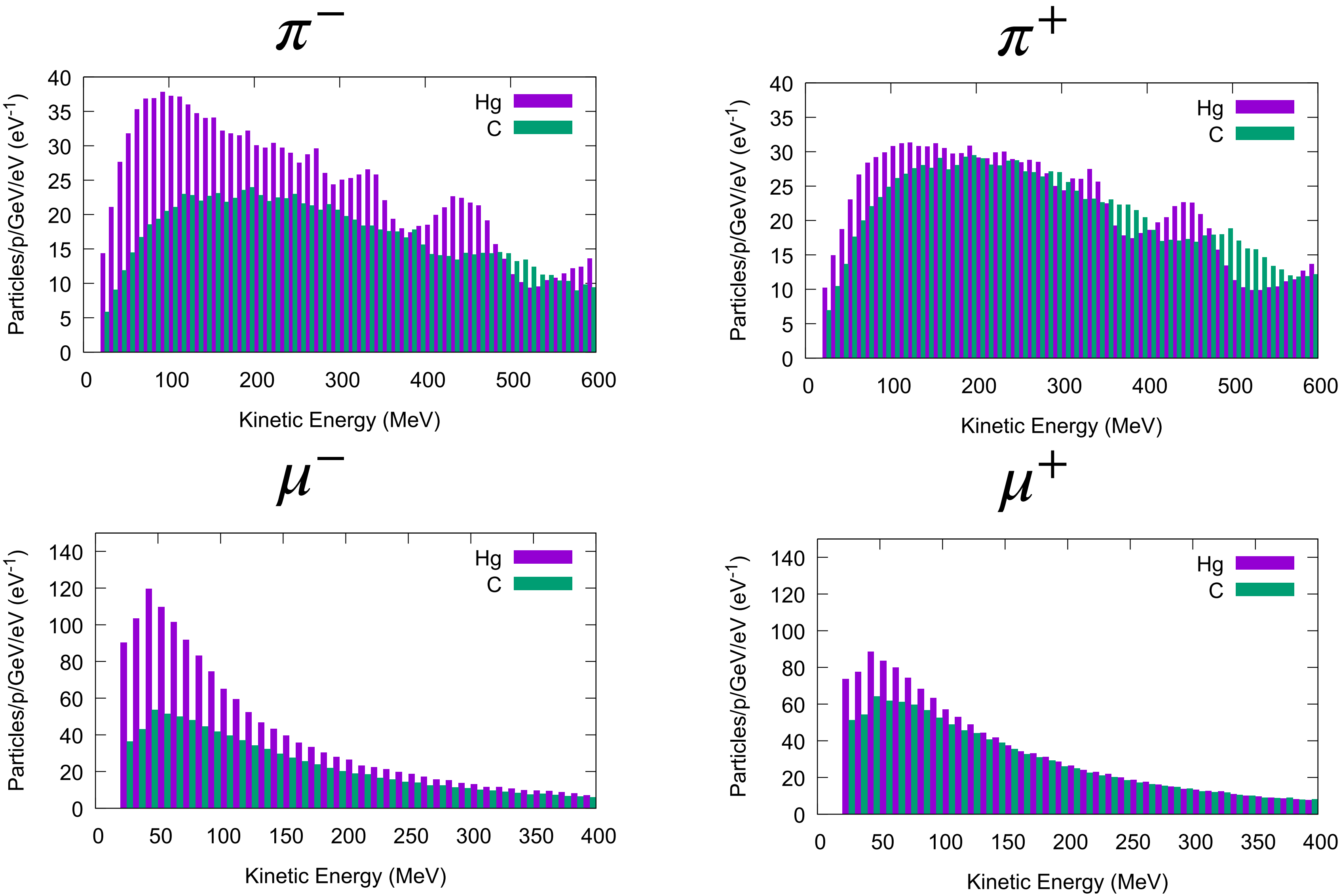
Spectrum vs. Distance

- 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
- High energy spectrum oscillates for Hg
  - Longer betatron period for high energies
  - Expect to eventually flatten out
  - Less so for C: production over larger longitudinal range?
- Transmission would be improved by higher fields
  - Consistent with Hisham's results
  - Spectrum would be weighted toward higher energy

Hg vs. C at 10 m



π^-
π^+
μ^-
μ^+
Hg
C
Particles/p/GeV/eV (eV^{-1})
Kinetic Energy (MeV)
0
100
200
300
400
500
600
5
10
15
20
25
30
35
40
50
60
80
120
140
150
250
350

Hg vs. C at 10 m

- Similar to 3 m, especially for muons
- Main difference is disappearance of pion peak at 250 MeV

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)
- C: no tilt with dump has worst performance; tilt no dump is best
- Emittances are determined primarily by apertures; Hg and C are the same
- High energy portion of spectrum clipped by apertures as well
- Spectrum shape differs for different signs

Conclusions

- Positive production similar for Hg and C
- Negative production differs significantly at low energy (< 150 MeV for μ^-)
  - Optimal NBPR will be very different for Hg and C
- Higher fields 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

Distribution Availability

- Distributions available at https://pubweb.bnl.gov/~jsberg/150201-Distributions/
- ICOOL for003.dat input, as well as raw MARS output
- At 2 m and 10 m for both Hg and C, also 0.375 m for Hg
- At 10 m, also have charged pions, kaons, and muons, plus same separated by charge signs
- MARS input files also available
- Following discussion: what distributions should we really be using?

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 ν 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?