Open Heavy Flavor Production at Forward Angles in PHENIX

Ken Read
Oak Ridge National Laboratory/
University of Tennessee
on behalf of the PHENIX Collaboration

Hard Probes 2012, Cagliari, Italy

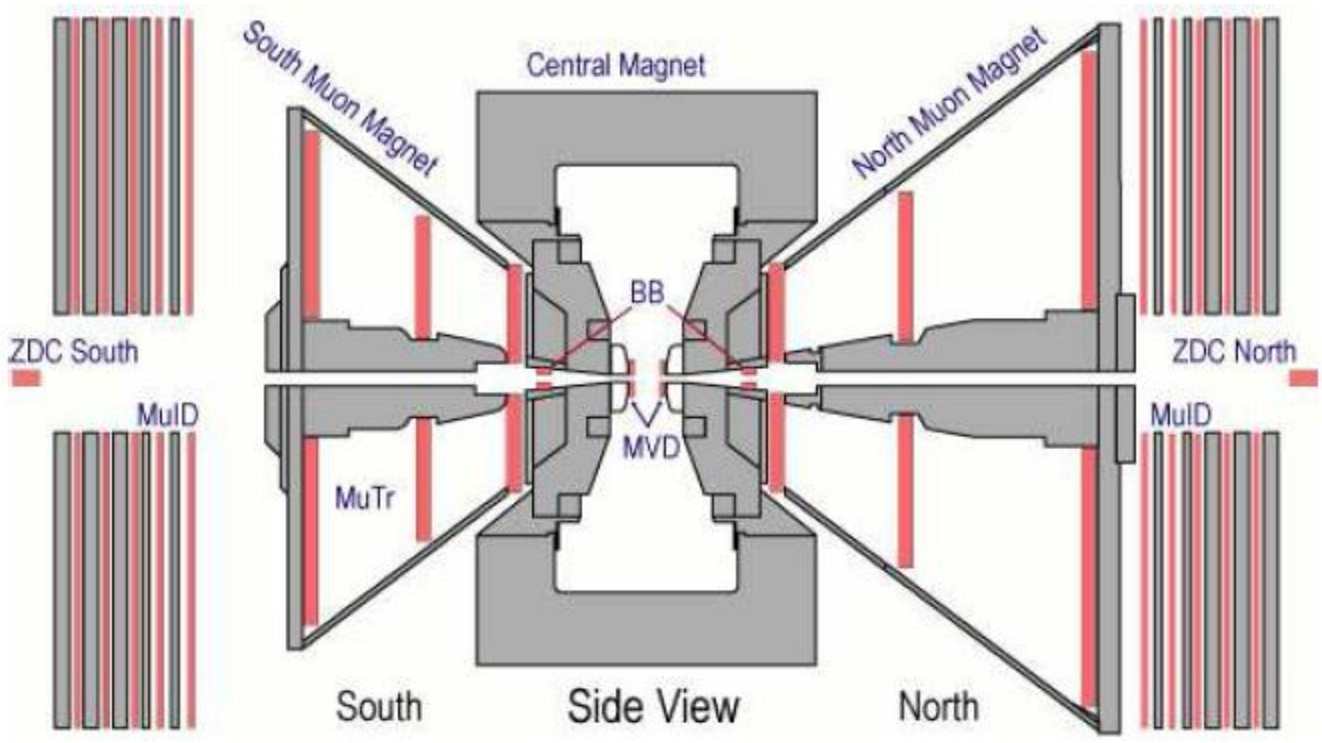
29 May 2012

Research supported by the Office of Nuclear Physics, US Department of Energy

Heavy Flavor Production

- For p+p collisions, measurement of heavy flavor production tests pQCD calculations.
- For heavy ion collisions, measurement of heavy flavor production explores hot and cold nuclear matter effects. Heavy quarks are produced in the early stages of collisions.
- Tests/constrains parton energy loss model predictions for heavy quarks which is presently a very active area of investigation.
- New measurement presented for nuclear modification factor for open heavy flavor production at forward angles in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.

PHENIX



- Measures muons from $-1.2 < \eta < -2.2$ and $1.2 < \eta < 2.4$.
- Muon Tracker: cathode strip chambers in a magnetic field
- Muon Identifier: transverse layers of Iarocci tubes with interleaved layers of iron absorber. 8 to 11 interaction lengths of iron.
- Pion rejection fraction $\sim 2.5 \times 10^{-4}$

p+p Analysis Method

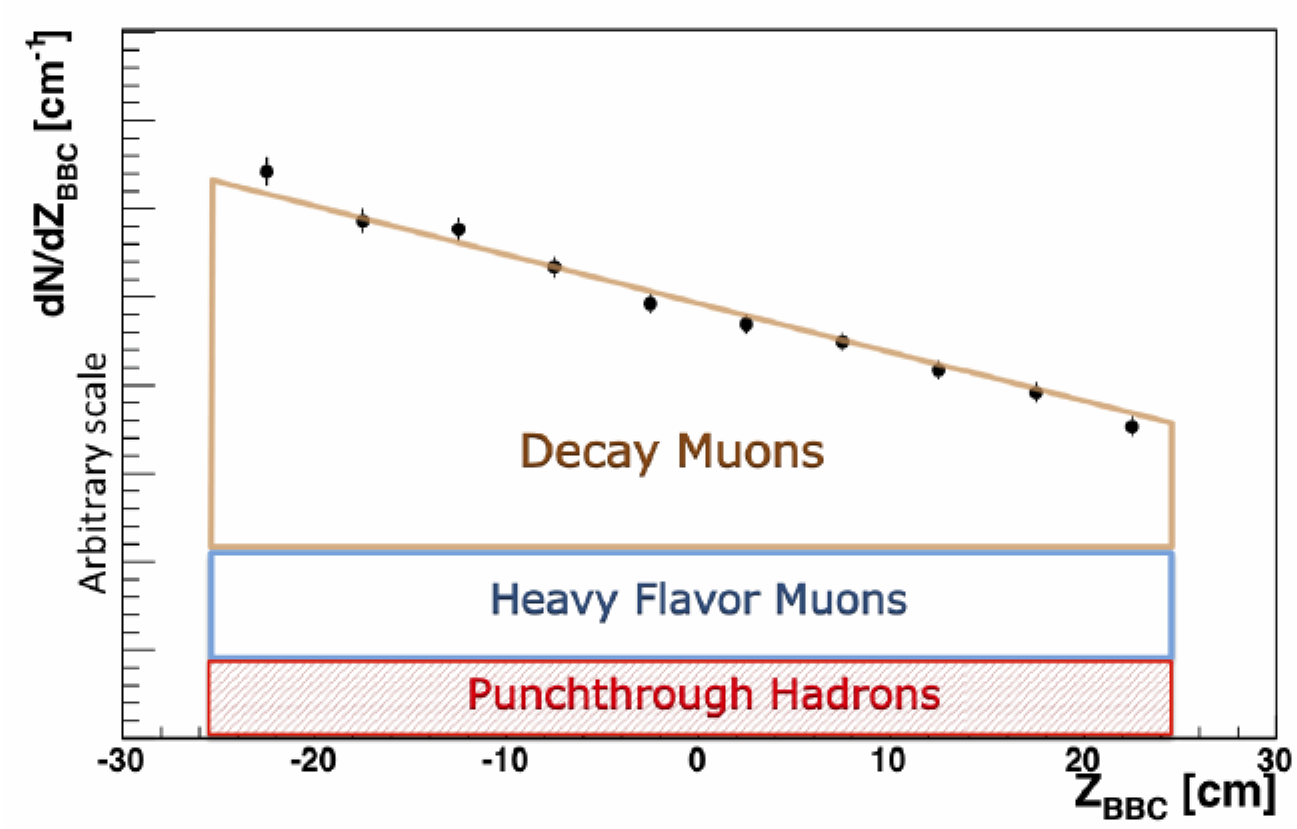
- Analyze p+p collisions at $\sqrt{s} = 200$ GeV
- Data sets obtained using muon enriched triggers requiring hits in the Muon Identifier in coincidence with the BBCs
- Integrated luminosity sampled by triggers for this analysis: 44.3 nb^{-1} (48.7 nb^{-1}) for the south (north) muon arms, respectively.
- Invariant muon yield:

$$\frac{d^2 N_\mu}{2\pi d p_T d\eta} = \frac{1}{2\pi p_T \Delta p_T \Delta\eta} \frac{N_I - N_C - N_F}{N_{evt} \epsilon_{BBC}{}^{cc\to\mu} A\epsilon}$$

- N_I is number of muon candidates in the bin. Require track quality cuts and penetration to last layer of the Muon Identifier.
- N_C is estimated irreducible background in the bin based on a cocktail simulation (described below).
- N_F is number of misreconstructed tracks in the bin (very small).

Background Subtraction

- Illustration of signal and background components versus the *z* position of the track vertex



Background Subtraction

- "Hadron Cocktail" is a data-driven simulation of the irreducible background
  - Consists of a weighted collection of simulated, individual pions and kaons appropriately distributed over p_T and y which are decayed and then propagated using GEANT3.
  - The cocktail K/π ratio is based on measured STAR and PHENIX data.
  - The cocktail momentum and rapidity distributions are based on PHENIX and BRAHMS data and NLO pQCD calculations.

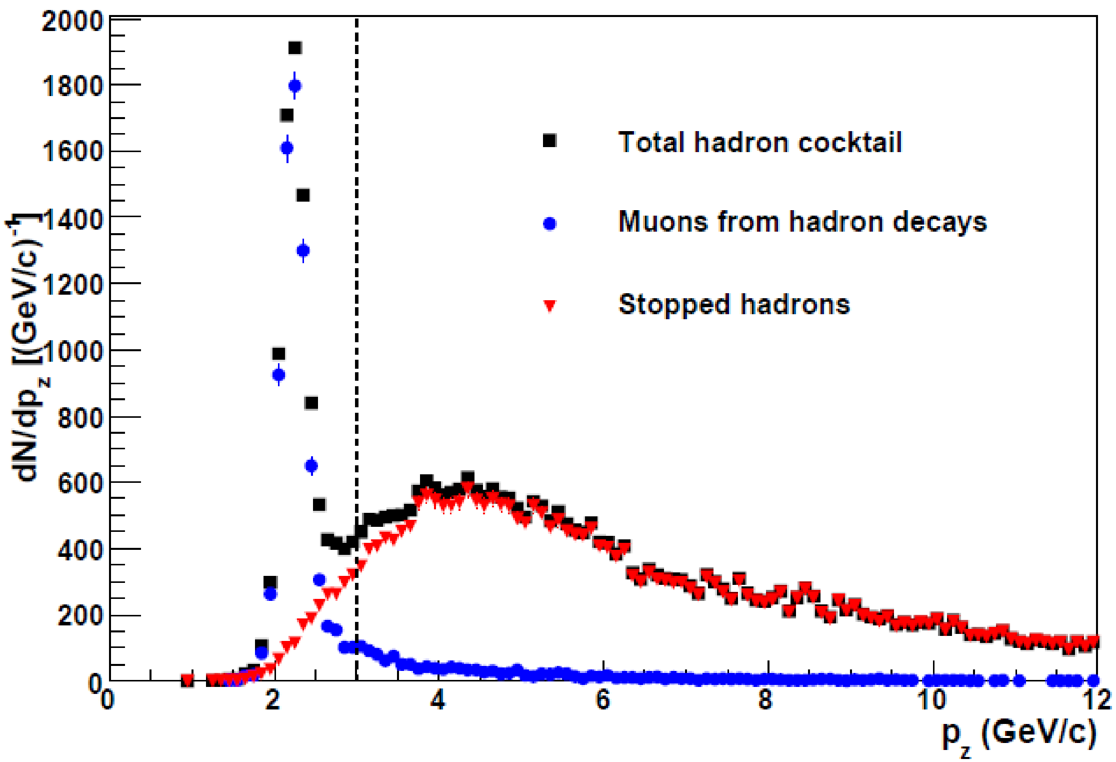
Cocktail Weighting

- Sensitivity to initial cocktail weights is significantly reduced by adjusting weights so that the simulated backgrounds conform to measurements of *hadrons* in the PHENIX muon arms.

- Next pages explain how the *last 3 gaps* of the Muon Identifier provide 3 different measurement concerning *hadrons*.

Stopped Hadrons

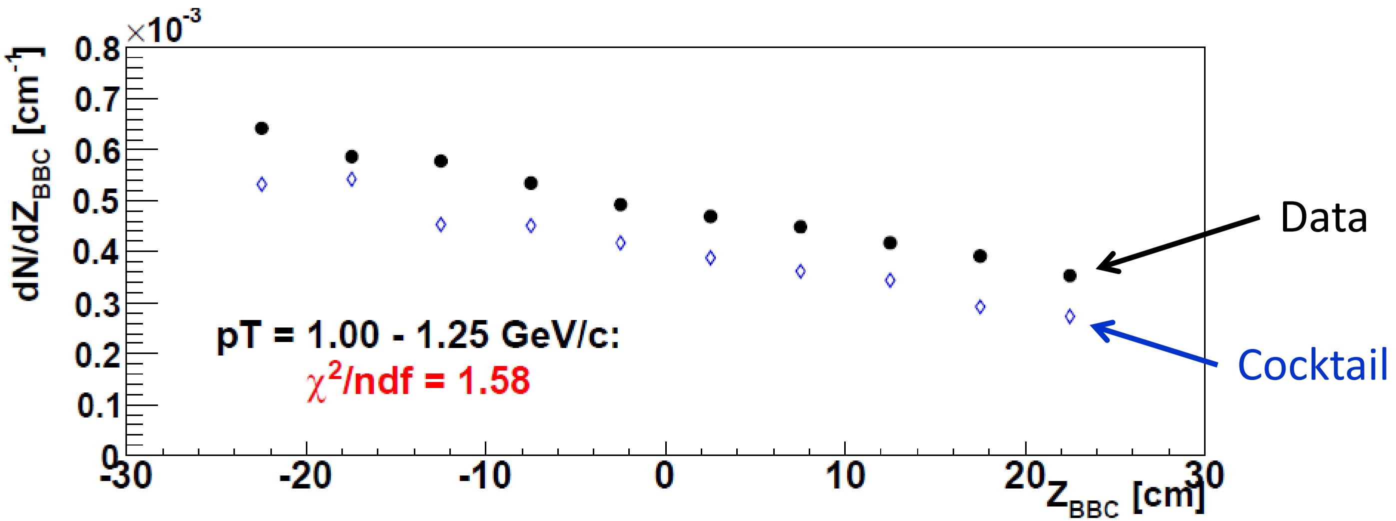
- Measure longitudinal momentum distribution of tracks in real data that stop in the *next to the last gap* (i.e., Gap 3) of the Muon Identifier.
- After reconstruction of the cocktail tracks, readjust p_T dependent weights of initial hadrons to match the observed rates for stopped hadrons in Gaps 2 and 3 in the same real data set.



Longitudinal momentum distribution of tracks stopping in next to last gap of the Muon Identifier.

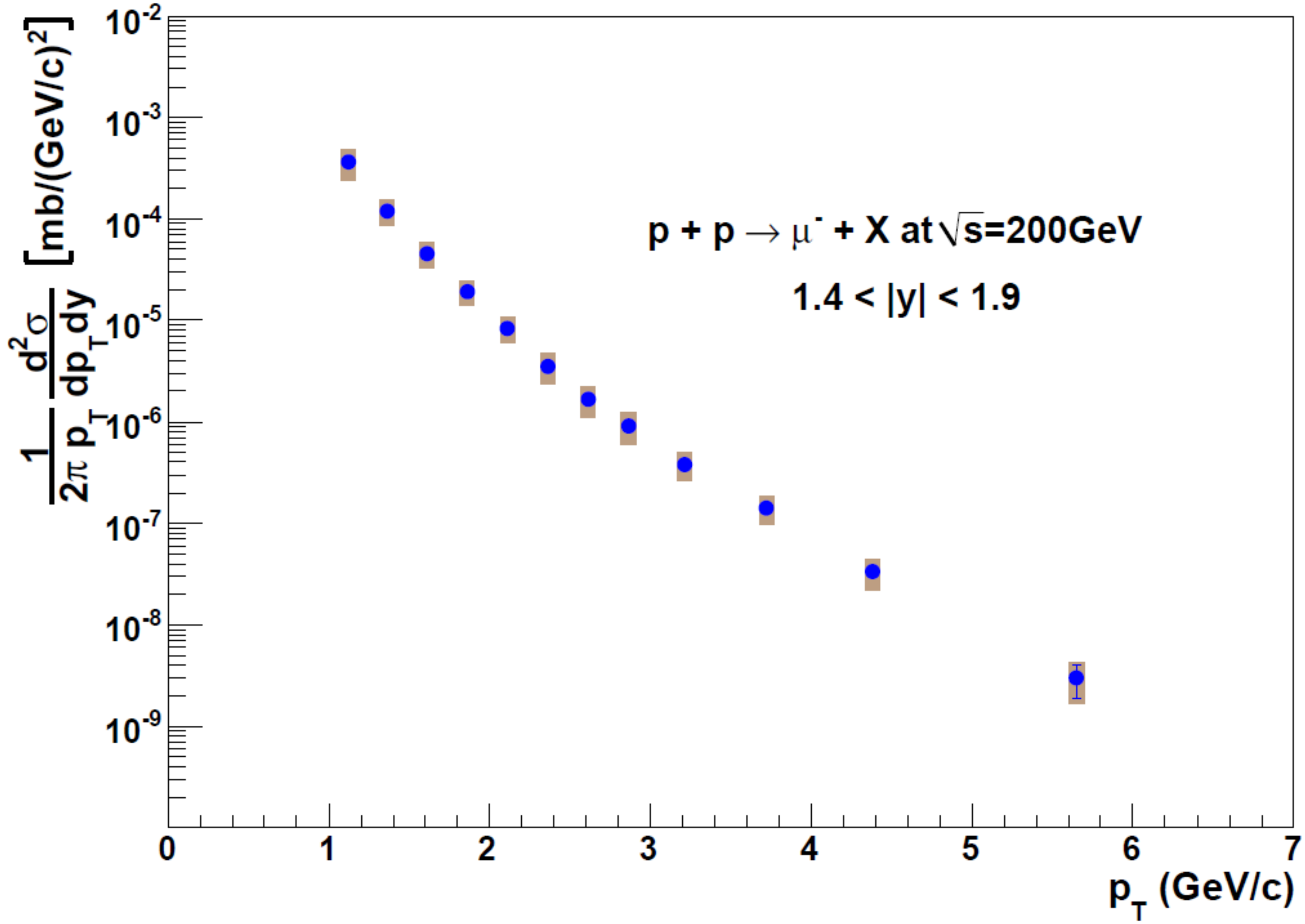
Vertex z Distribution

- z coordinate of track vertex for tracks reaching last gap of Muon Identifier (north arm shown)
- Further adjust cocktail weights to minimize χ^2 for differences in slopes between data and cocktail for different p_T intervals.
- The vertical offset below is due to the (flat in z) heavy flavor contribution.



Differential Cross Section

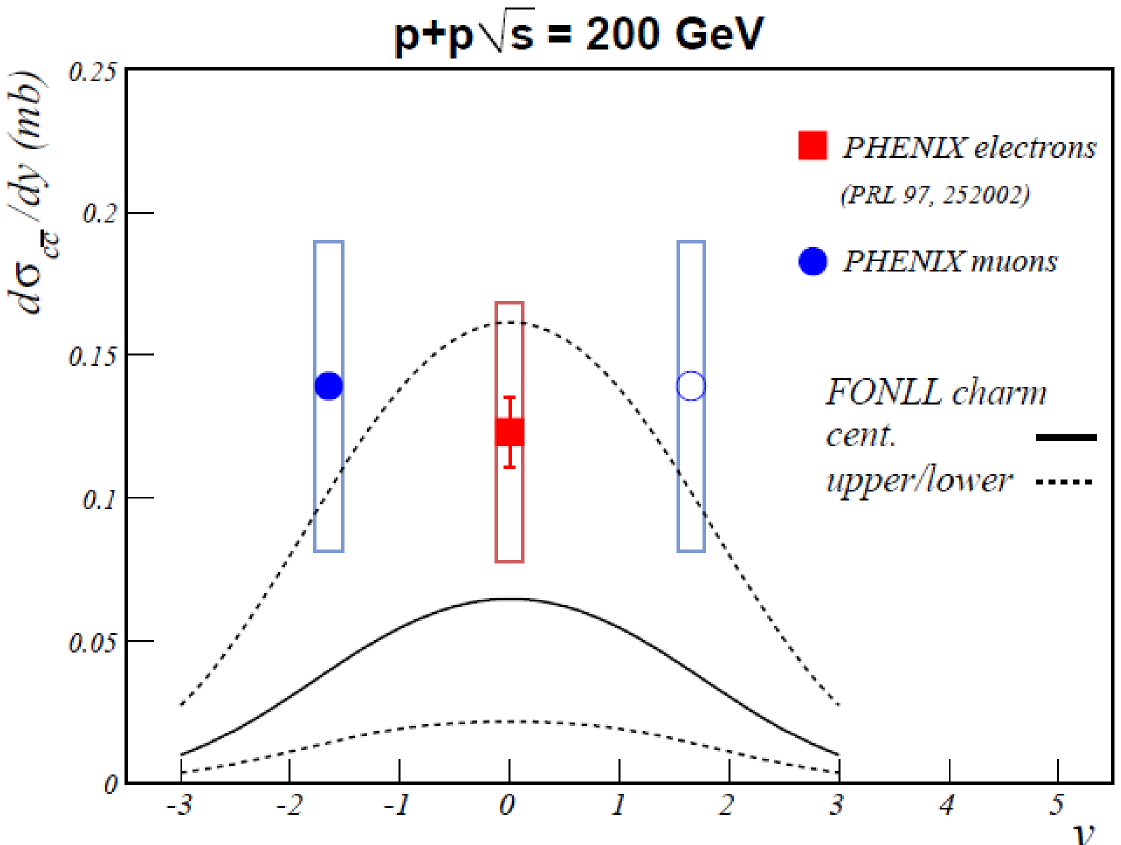
- Production cross section for muons from semileptonic decays of heavy flavor mesons for p+p collisions at $\sqrt{s} = 200$ GeV.
- Gray bars indicate systematic uncertainty.



Differential Cross Section

- Comparison of measured $c\bar{c}$ cross section for p+p collisions at $\sqrt{s} = 200$ GeV using muons (blue) and electrons (red). Extrapolation to $p_T < 1$ for muons based on FONLL.

$$\frac{d\sigma_{cc}}{dy} = 0.139 \pm 0.029\,(\text{stat})\ {}^{+0.051}_{-0.058}\,(\text{syst})\ \text{mb}$$



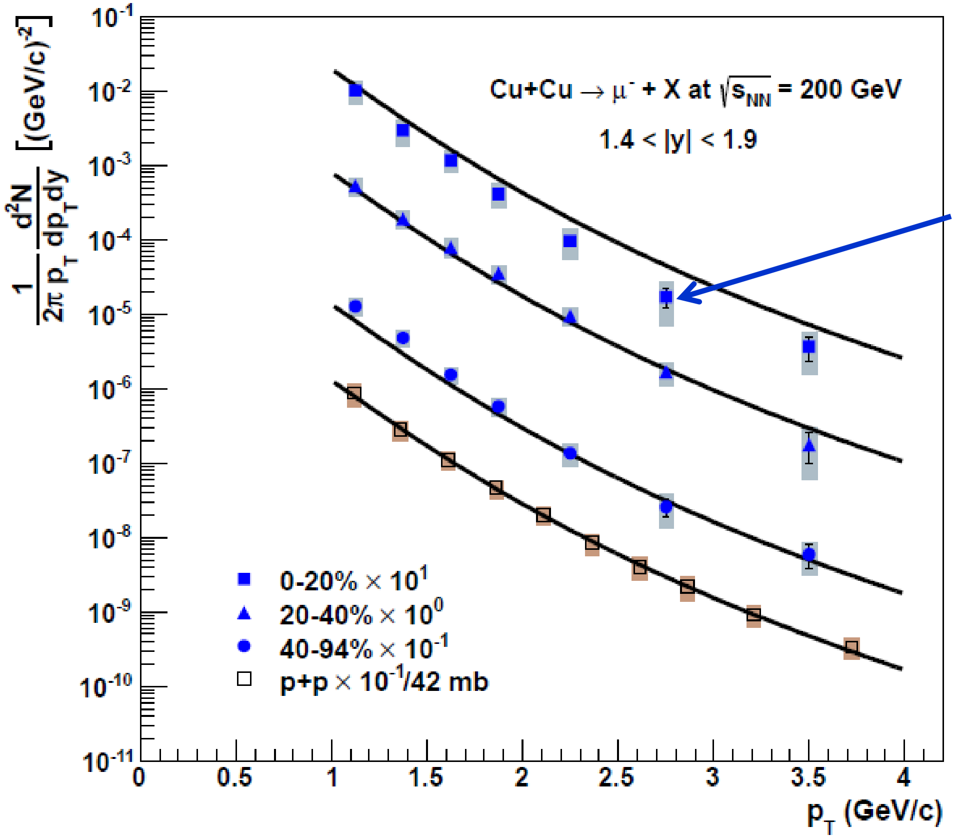
Cu+Cu Analysis Method

- Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.
- Minimum bias trigger sampled 0.13 nb^{-1} integrated luminosity.
- Use cocktail background subtraction analogous to that for p+p analysis. However, embed simulated hadrons in real Cu+Cu events before reconstruction to account for affect of higher hit multiplicity on reconstructed track quality.
- Nuclear Modification Factor for muon production from semileptonic decay of heavy flavor mesons

$$R_{AA} = \frac{1}{N_{coll}} \frac{d^2N_{Cu+Cu}/dp_T d\eta}{d^2N_{p+p}/dp_T d\eta}$$

Invariant Yield for Cu+Cu Collisions

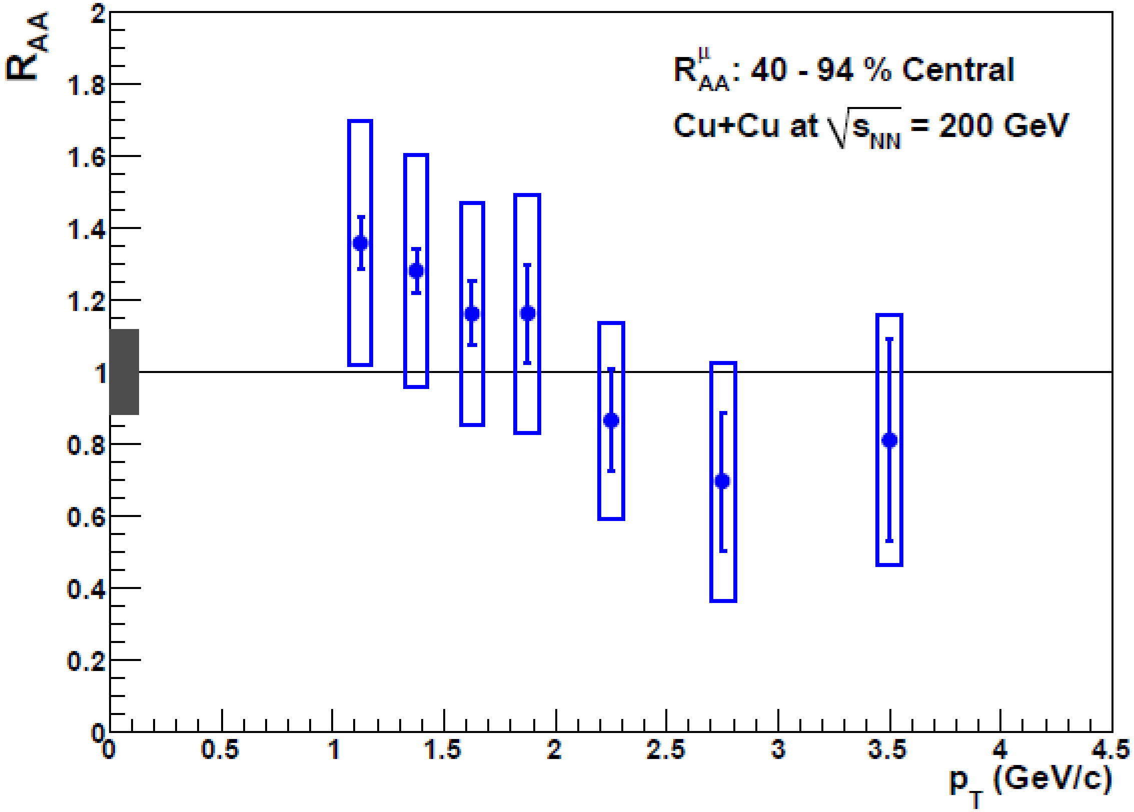
- Invariant production yields of muons from heavy flavor mesons for three different centrality bins of Cu+Cu collisions (blue).
- p+p data yield shown again (brown).
- The curves are a fit to p+p data, scaled by appropriate value of N_{coll} (and scaled by powers of 10 for purposes of comparison).



Note suppression

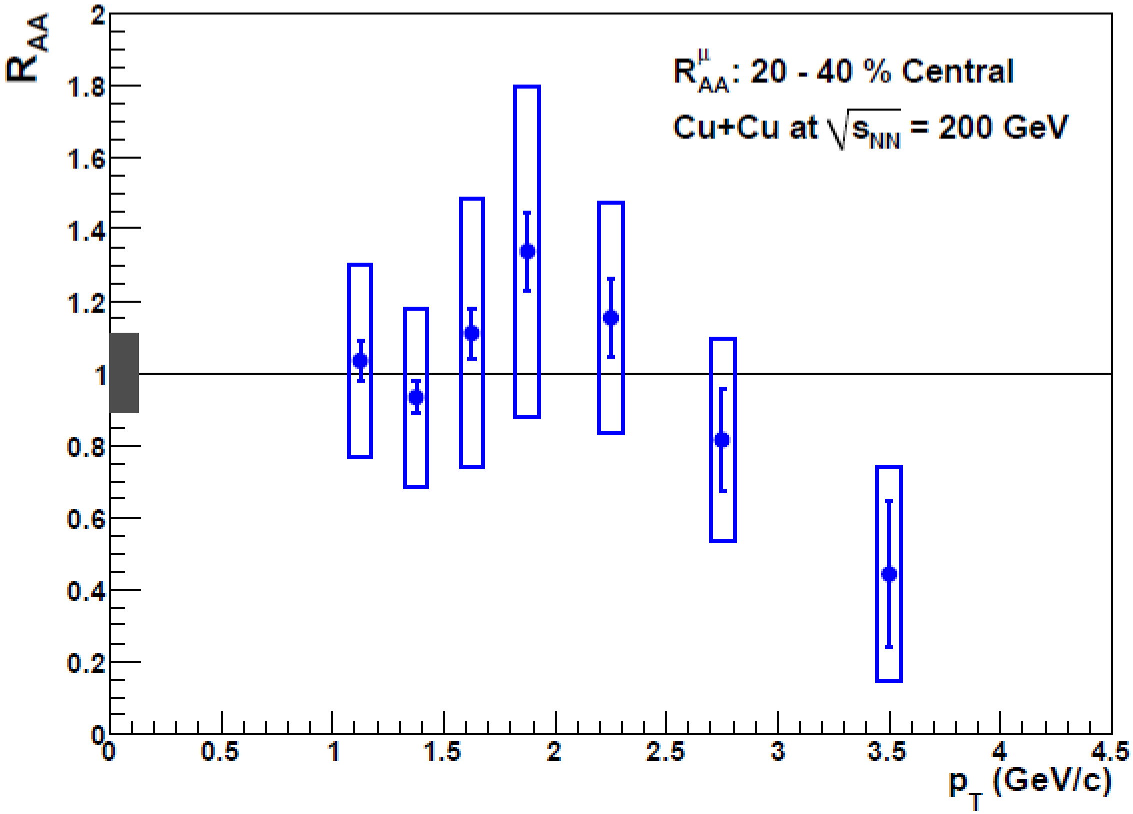
Centrality Dependence

- Nuclear modification factor for muons from heavy flavor meson decay for 40 – 94% centrality (i.e., peripheral) Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.



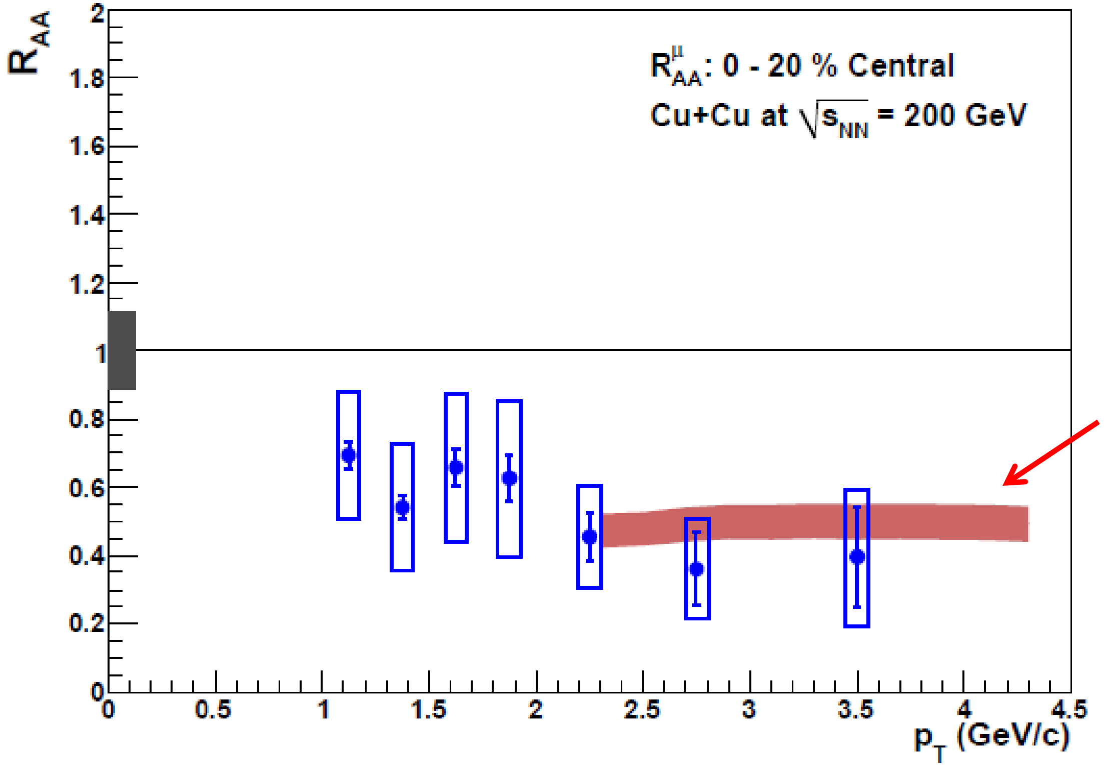
Centrality Dependence

- Nuclear modification factor for muons from heavy flavor meson decay for 20 – 40% centrality Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.



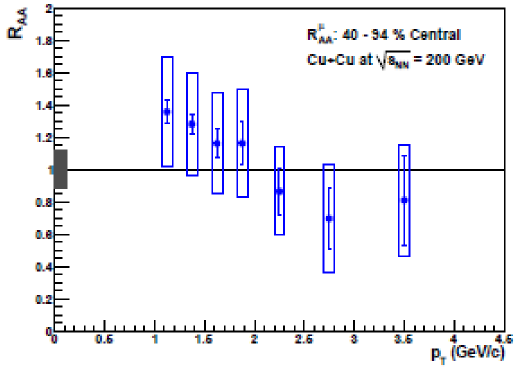
Centrality Dependence

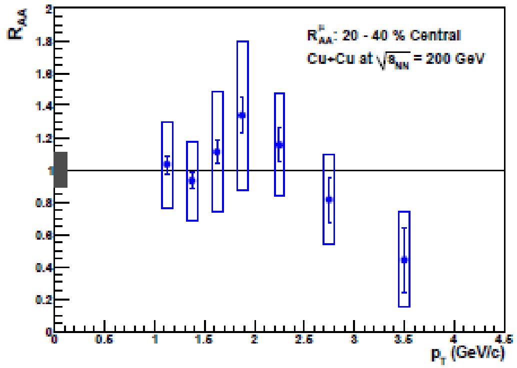
- Nuclear modification factor for muons from heavy flavor for 0 – 20% centrality Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.
- Recent theoretical prediction (red band) for muon production at $y = 1.65$ and $p_T > 2.5$. Includes elastic and inelastic heavy-quark energy loss and in-medium heavy meson disassociation. Includes cold nuclear matter effects such as shadowing and initial state energy loss of incoming partons due to multiple scattering.

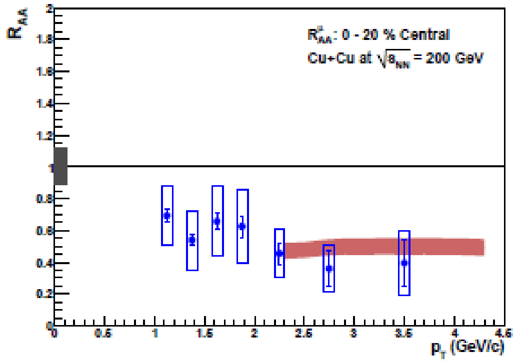


Theoretical prediction: R. Sharma, I. Vitev, B.-W. Zhang, Phys. Rev. C 80, 054902(2009).

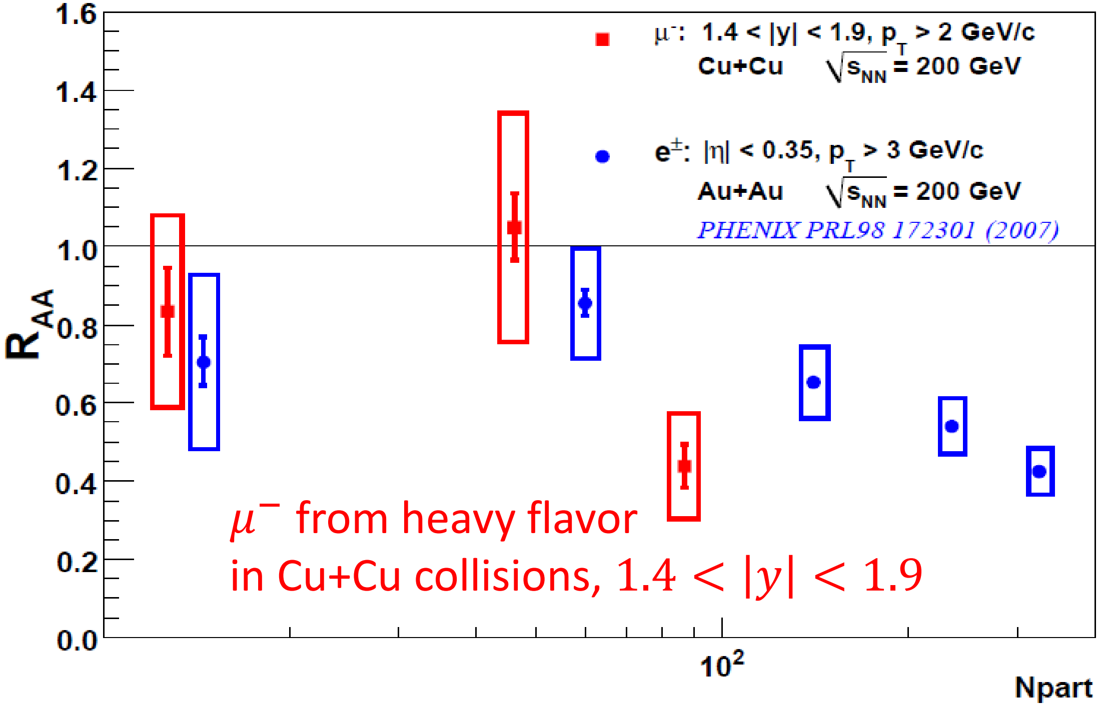
Centrality Dependence





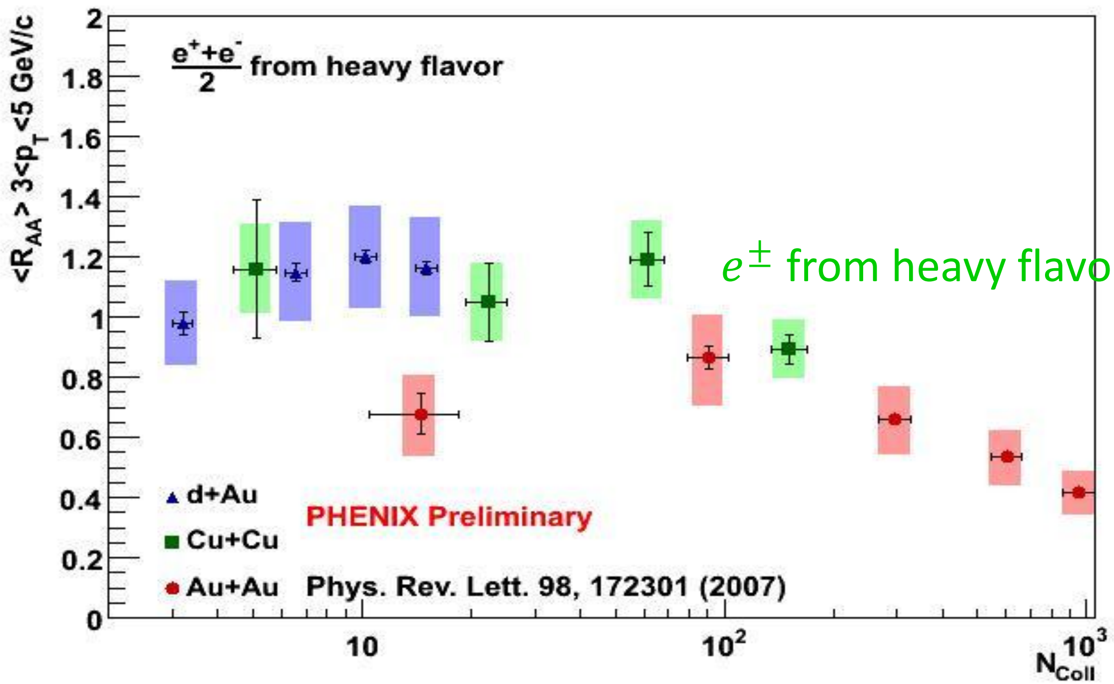


Suppression increases significantly with increasing centrality.



μ^- from heavy flavor in Cu+Cu collisions, $1.4 < |y| < 1.9$

$e^\pm$ from heavy flavor in Au+Au collisions, $|\eta| < 0.35$



$e^\pm$ from heavy flavor in Cu+Cu collisions, $|\eta| < 0.35$

$e^\pm$ from heavy flavor in Au+Au collisions, $|\eta| < 0.35$, shown in blue in top panel

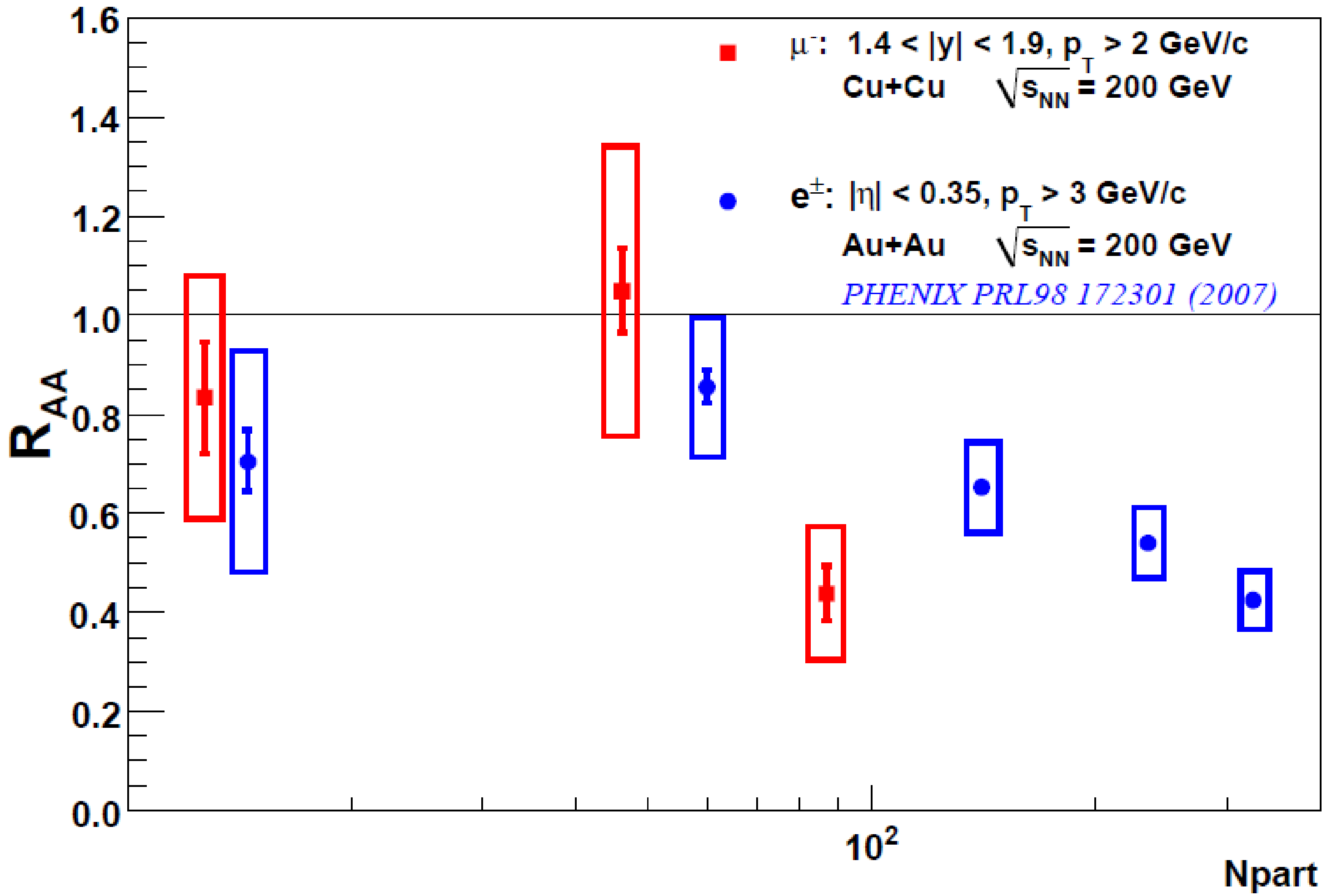
Conclusions

- Measurement of charm production cross section for p+p collisions at $\sqrt{s} = 200$ GeV over rapidity range $1.4 < y < 1.9$, with comparison to FONLL predictions.
- Measurement of nuclear modification factor for muons from heavy flavor meson decay in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV for 3 centrality intervals, indicating significant suppression for central collisions, with comparison to recent prediction.
- New PHENIX inner silicon vertex detectors will significantly reduce systematic errors associated with such measurements and permit separation of charm and bottom contributions.
- For more information see www.phenix.bnl.gov and the recently submitted http://arxiv.org/abs/1204.0754 .

Backup

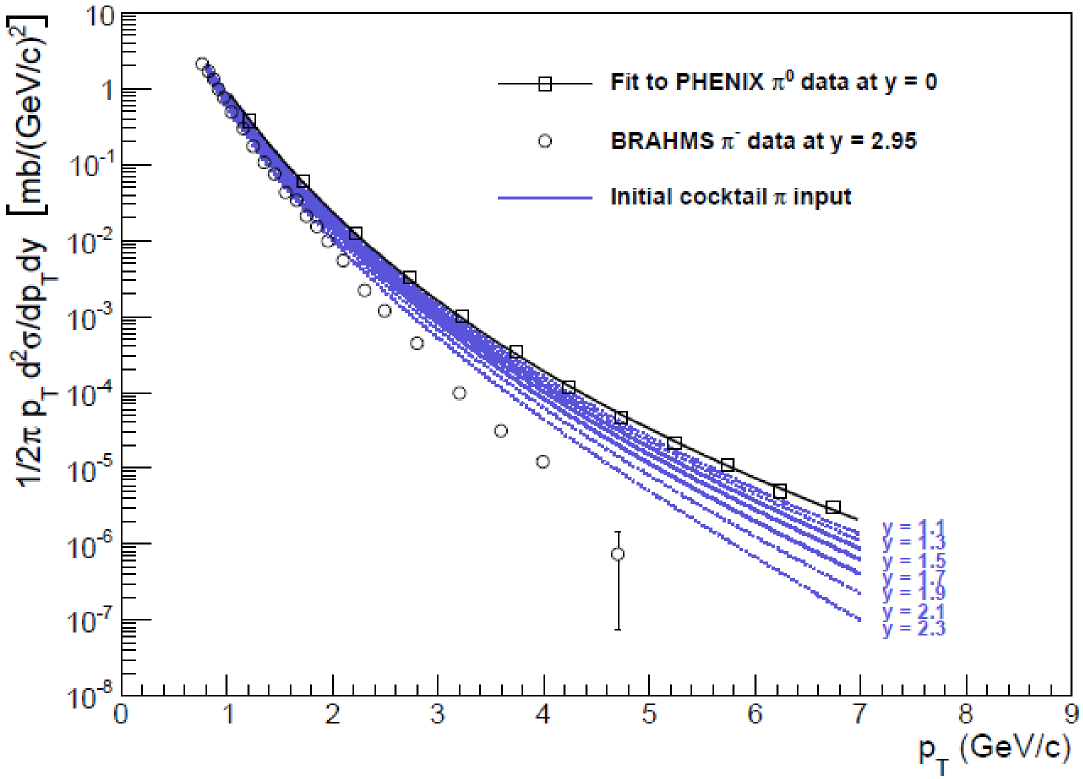
Comparison

- Comparison of these measurements to nuclear modification factor for electrons from heavy meson decay in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of N_{part}.



Cocktail Input

- Measured pion cross sections from PHENIX (squares) and BRAHMS (circles).
- Extrapolate PHENIX y=0 data to y=1.65 using a Gaussian parameterization of BRAHMS data.
- Extrapolate to other rapidities (blue curves) from y=1.65 using NLO calculation.



Hadronic Interaction Packages

- Dispersion for N_C predicted by FLUKA and GEISHA hadronic interaction packages, with a range of adjusted hadron-iron cross sections.
- This dispersion quantifies one contribution to final systematic error.