XX International Workshop on Deep-Inelastic Scattering and Related Subjects

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Recent measurements of open heavy flavor production by PHENIX

Irakli Garishvili, Lawrence Livermore National Laboratory
PHENIX collaboration

- Heavy quarks in p+p and heavy ion collisions
- Heavy flavor measurements with PHENIX (p+p, Au+Au, Cu+Cu, d+Au data)
- Discussion & Outlook

Why open heavy flavor

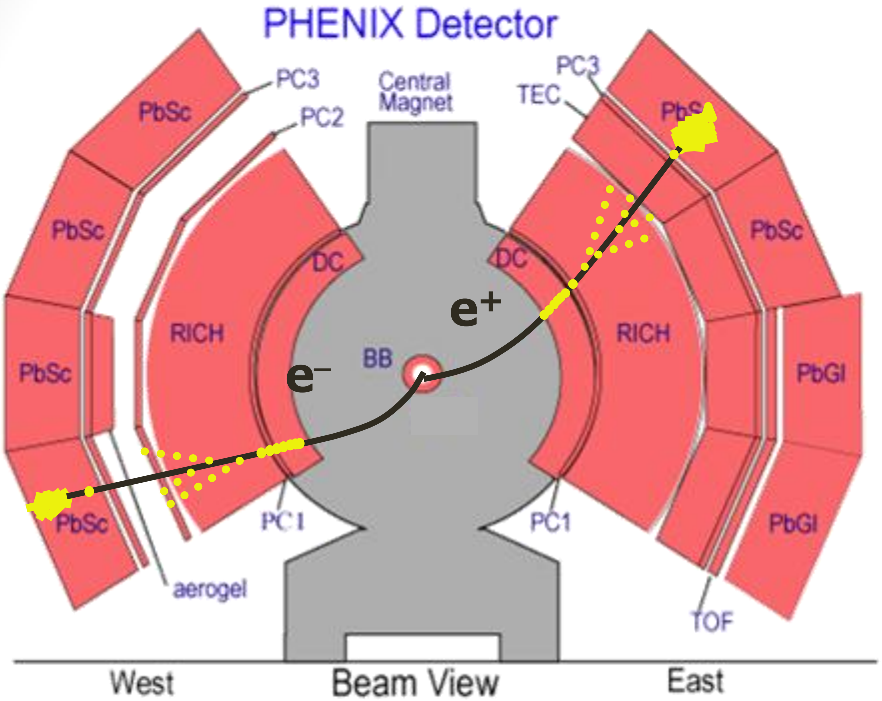
- In p+p collisions:
  (a) testing ground for pQCD
  (b) necessary baseline for heavy ion collisions

- In heavy ion collisions (Au+Au, Cu+Cu):
  (a) heavy quarks serving as a probe of strongly interacting deconfined medium
  (b) important for understanding mechanisms related to J/ψ production

- In d+Au collisions serving as a control measurement for quantifying "cold nuclear matter effects"

How we measure it in Central arms

Circa 2008



- ✧ Kinematic coverage:
  - $|\eta|<0.35$, $\Delta\phi = 2\times 90^o$
  - $p_T > 0.35$ GeV/c
- ✧ Measuring first inclusive electron spectrum
- ✧ Clean electron identification with RICH & EMCal detectors
- ✧ For p_T above 2.5 GeV/c S/N > 1. spectra for all relevant background sources (a) π and η Dalitz decay, (b) γ conversion (c) ω, φ, direct γ, etc. measured and simulated using ***Cocktail***

- ✧ At lower p_T heavy flavor electrons are measured using data with ***Converter method***, when known amount of converter material is installed for short period to see how is spectrum changed.

- ✧ Converter measurement is also used to normalize cocktail.

3/27/12

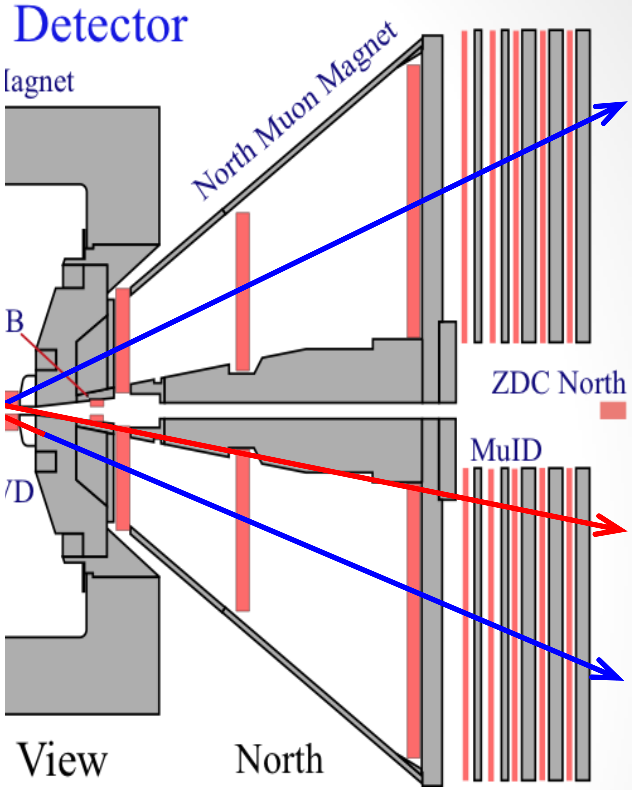
How we measure it: Forward(muon) arms

- Kinematic coverage:

(1) $1.2 < |\eta| < 2.2$ (2) $\Delta\phi = 360^{o}$ (3) $p_T > 1.0$ GeV/c

- Muon candidate has to travel through MuTR, and all layers of MuID. Total of 10 λ absorber material.

- Background sources: (1) decay muons - light vector mesons decaying in muons before nosecone absorber (largest) (2) punch-through hadrons.
- S/N ~ 0.4-0.5

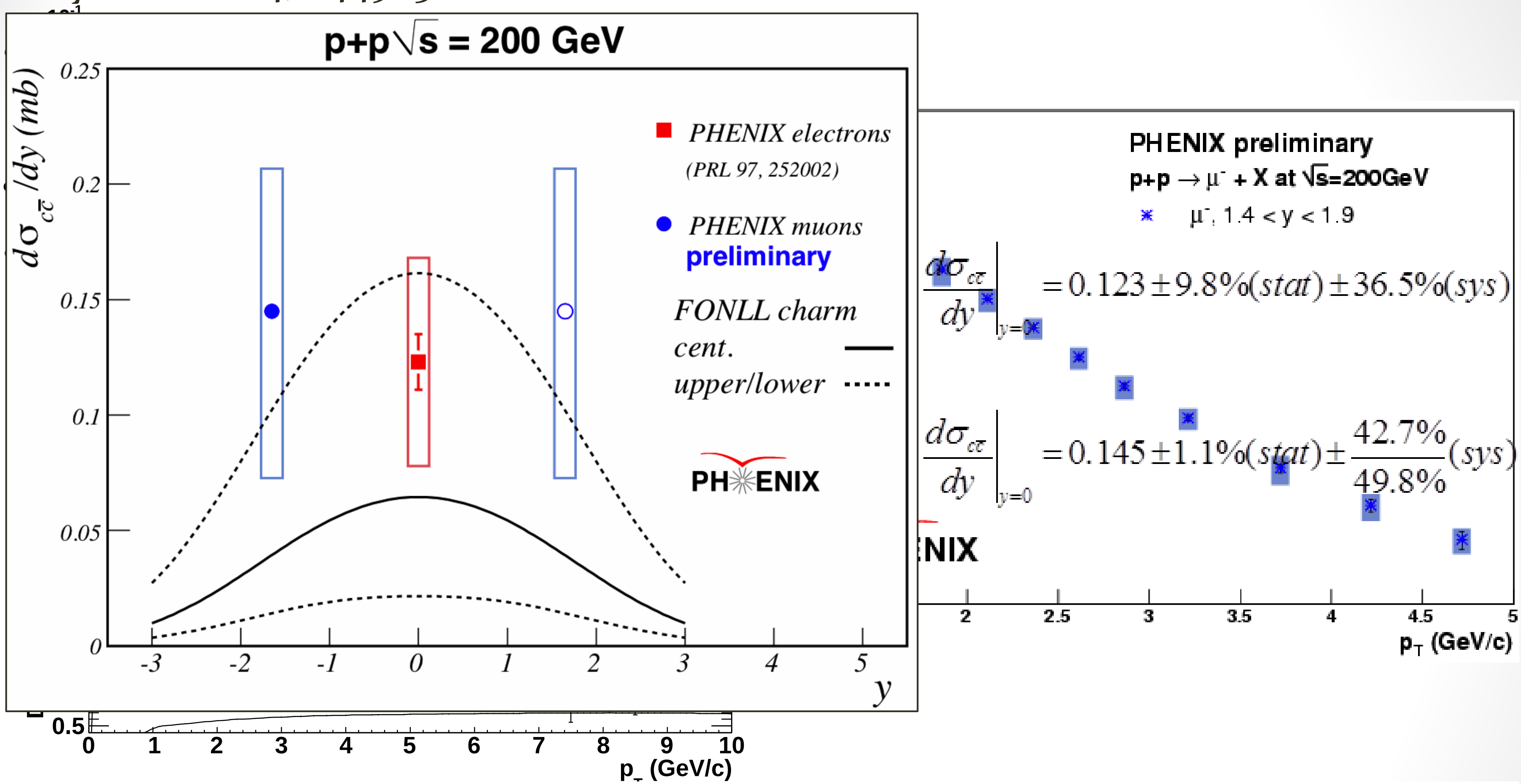


- Fully data-driven MC simulations of hadron cocktail used. Cocktail input is tuned to match data distributions: (a) z-vertex dependence of decay muons due to decay-in-flight, (b) “stopped” hadron spectra

- Finally, independent measurements in North and South arms combined for final results reducing uncertainties

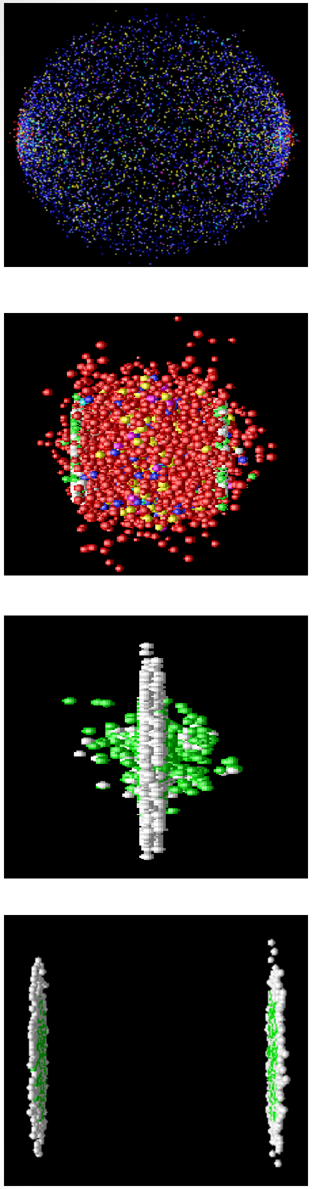
Measurements in p+p collisions

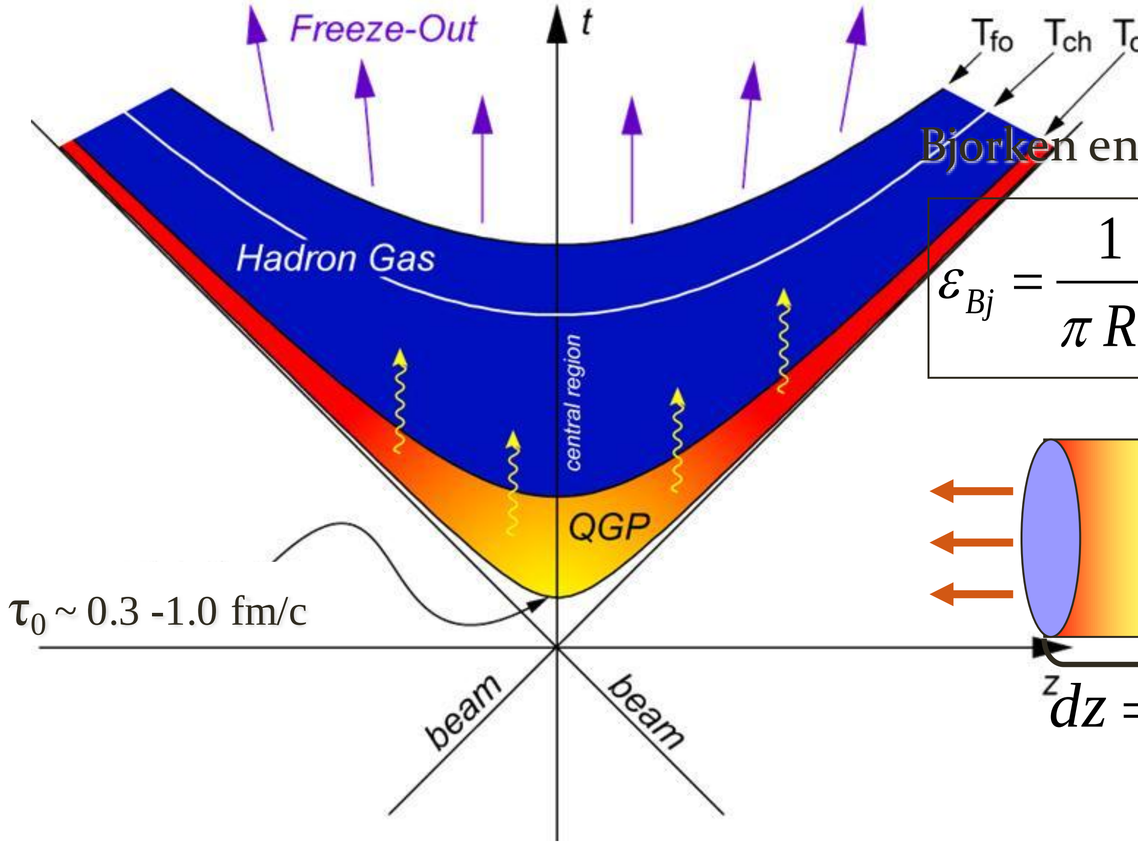
Phys. Rev. C 84, 044905



- ✧ Low pT HF lepton spectra is dominated by charm. So we simply extrapolate to p_T=0 GeV/c using FONLL to get charm cross section
- ✧ Agreement with FONLL within uncertainties.

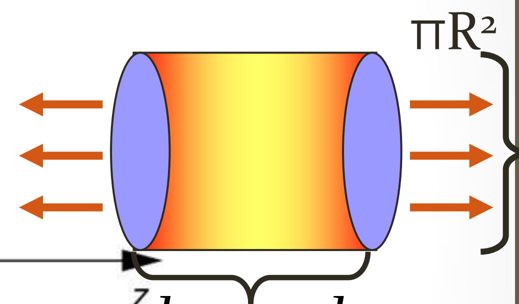
Heavy ion collisions





Bjorken energy density

$$\varepsilon_{Bj} = \frac{1}{\pi R^2} \frac{1}{\tau_0} \frac{dE_T}{dy}$$



$$dz = \tau_0 dy$$

Impossible directly accessing strongly interacting deconfined medium, originally dubbed Quark Gluon Plasma (QGP), produced at the early stages of Heavy ion collisions. Instead Bjorken energy density is estimated.

Due to large mass heavy quarks expected to be produced at even earlier stages and serving as a probe of the medium

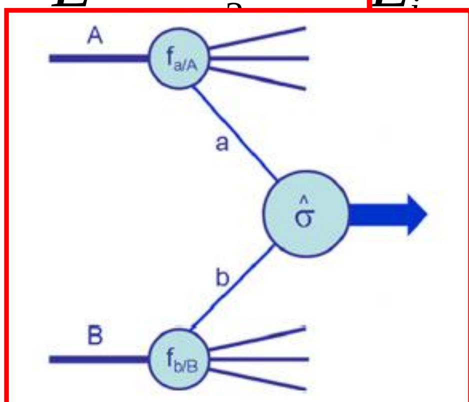
Quantifying medium effects

<u>Nuclear modification factor</u>

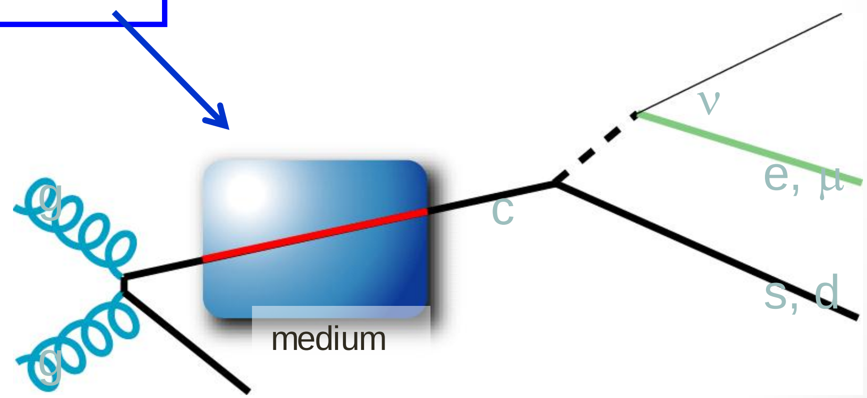
$$R_{AA} = \frac{dN_{AA}}{\langle N_{coll} \rangle \times dN_{pp}} = \frac{\text{What is measured in A+A}}{\text{Naïve scaling of QCD}}$$

$R_{AA} = 1 \rightarrow$ no overall effect
$R_{AA} < 1 \rightarrow$ suppression
$R_{AA} > 1 \rightarrow$ enhancement

$$E\frac{d^3\sigma_l^{A+A}}{dp^3} = E_i\frac{d^3\sigma_Q}{dp_Q^3} \otimes P(E_i \rightarrow E_f) \otimes D(Q \rightarrow H_Q) \otimes f(H_Q \rightarrow l)$$

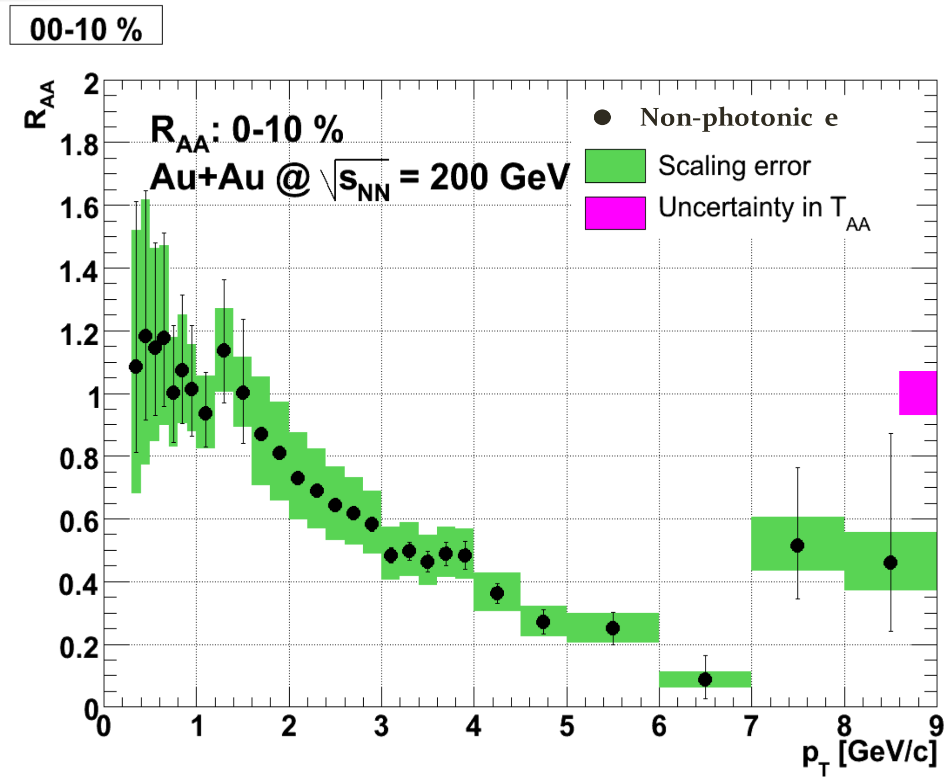


Production can be affected by initial state or Cold nuclear matter (CNM) effects, such as, modification of parton distribution functions, momentum broadening due to parton rescattering inside nucleus, etc.



Final state energy loss, $\Delta E = E_i - E_f$, depends nn the medium properties.
Could have several different energy loss mechanisms

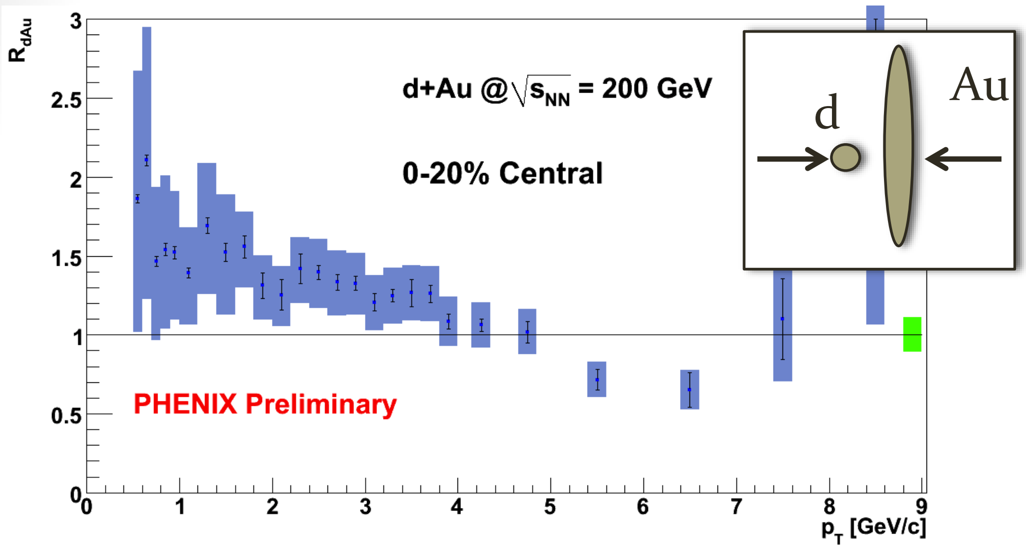
Nuclear modification factor in Au+Au

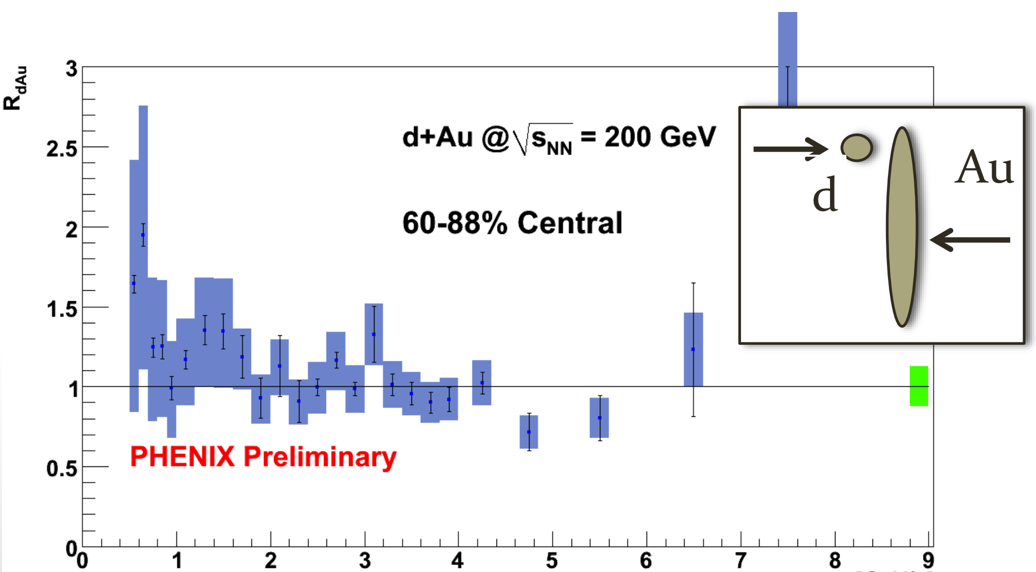


- ✧ Very large suppression in central Au+Au collisions
- ✧ HF electron suppression as large as suppression for light vector mesons at p_T above 4 GeV/c
- ✧ At time this falsified models that assumed only inelastic (radiative) in-medium energy loss, which predicted that R_{AA}(HQ) > R_{AA}(light quark) due to "dead cone effect".

- ✧ Caused consideration of other in-medium energy loss mechanisms: energy loss due to elastic scattering, dissociation, diffusion, etc.
- ✧ Separating D and B meson contributions key for establishing mass hierarchy in understanding energy loss.

Non-photonic electrons in d+Au

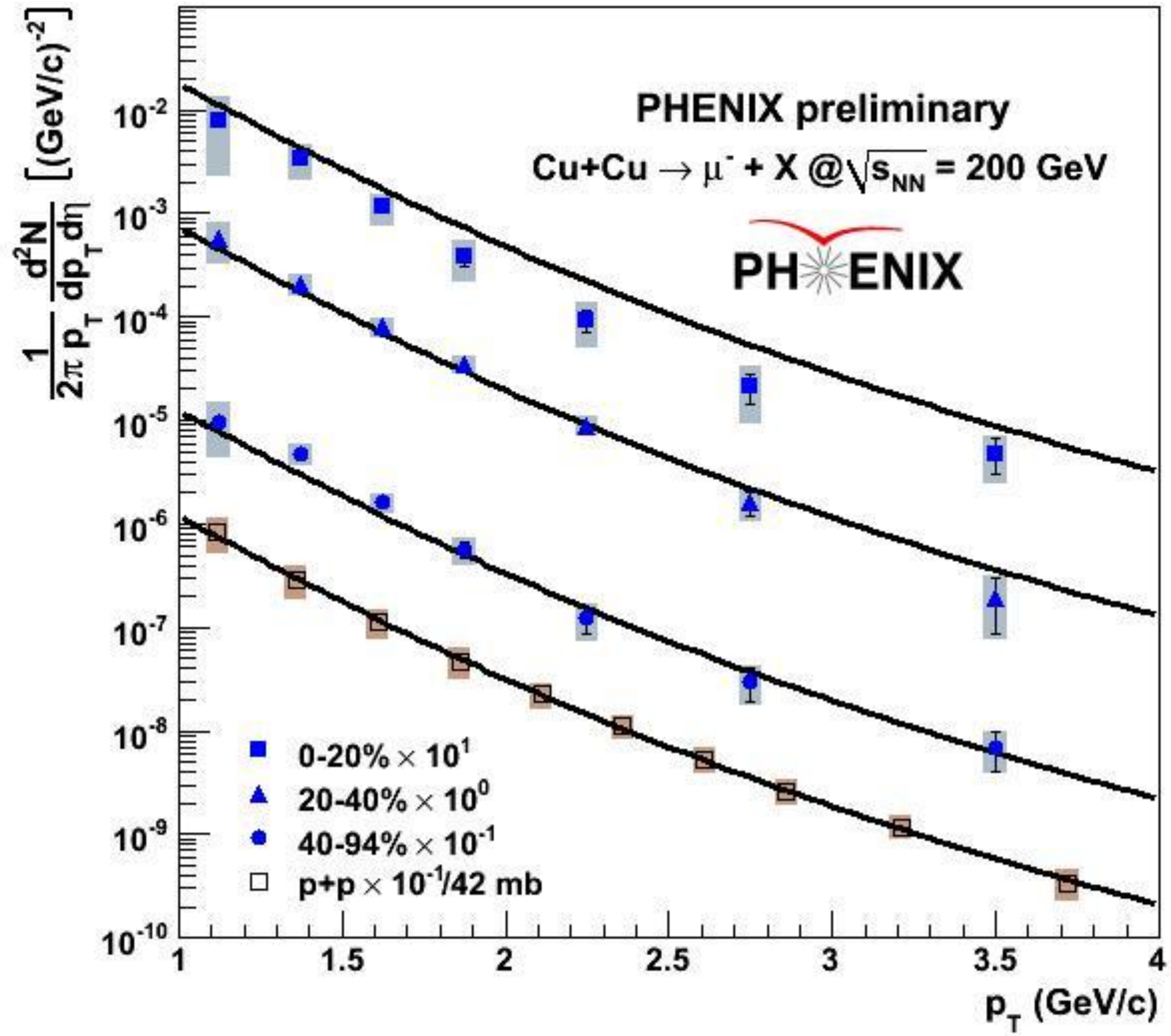


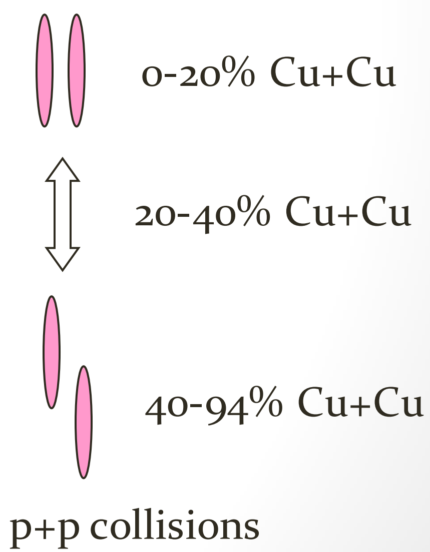


Nearing final results and publication

- d+Au collisions are not expected to produce strongly interacting dense medium.
- In peripheral (60-88%) d+Au collisions production expected to be similar to p+p. Consistent with unity within uncertainties
- Central d+Au (0-20%) indicates slight enhancement, similar to Cronin effect in hadron production
- Large HF suppression observed in Au+Au collisions can safely be attributed only to final state (hot nuclear matter) effects

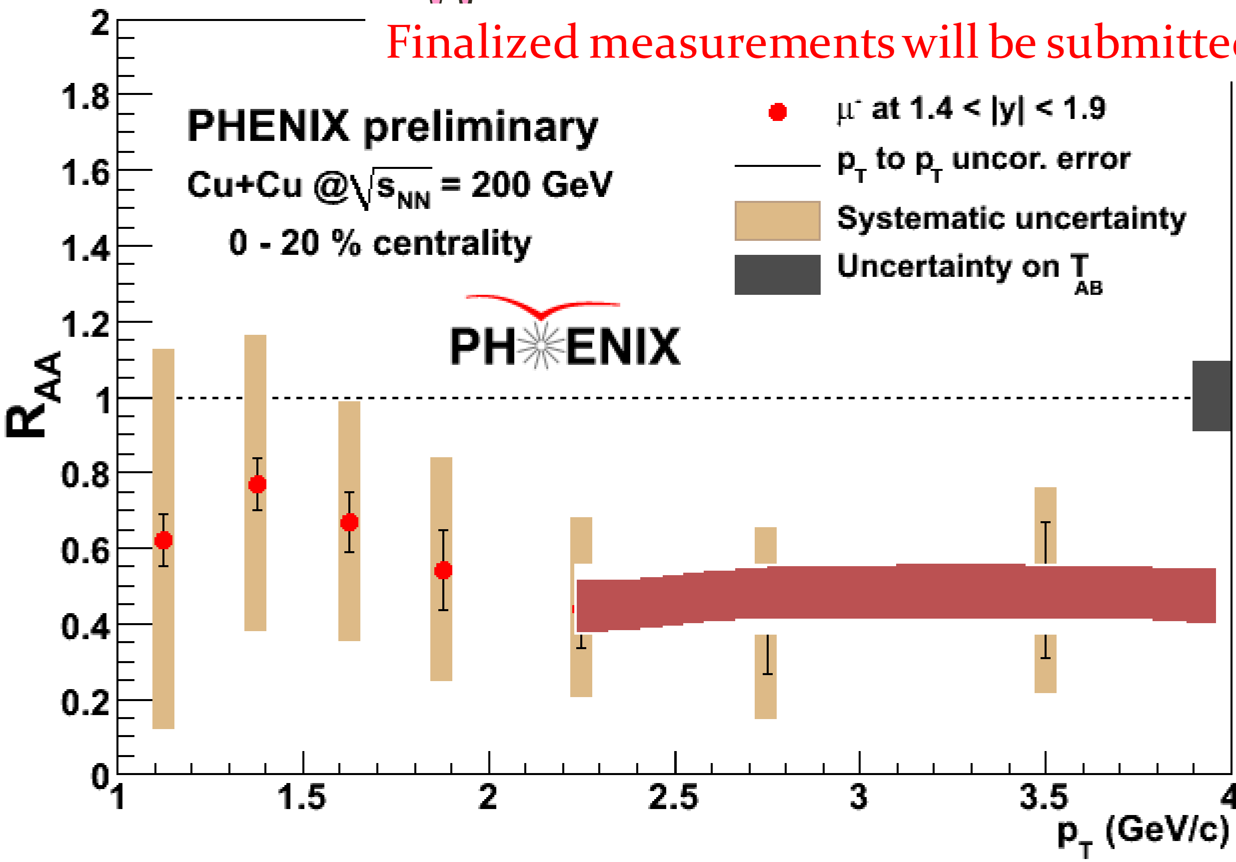
heavy flavor muon spectra in Cu+Cu





Nuclear modification factor in Cu+Cu

Finalized measurements will be submitted to PRC & arXiv next week



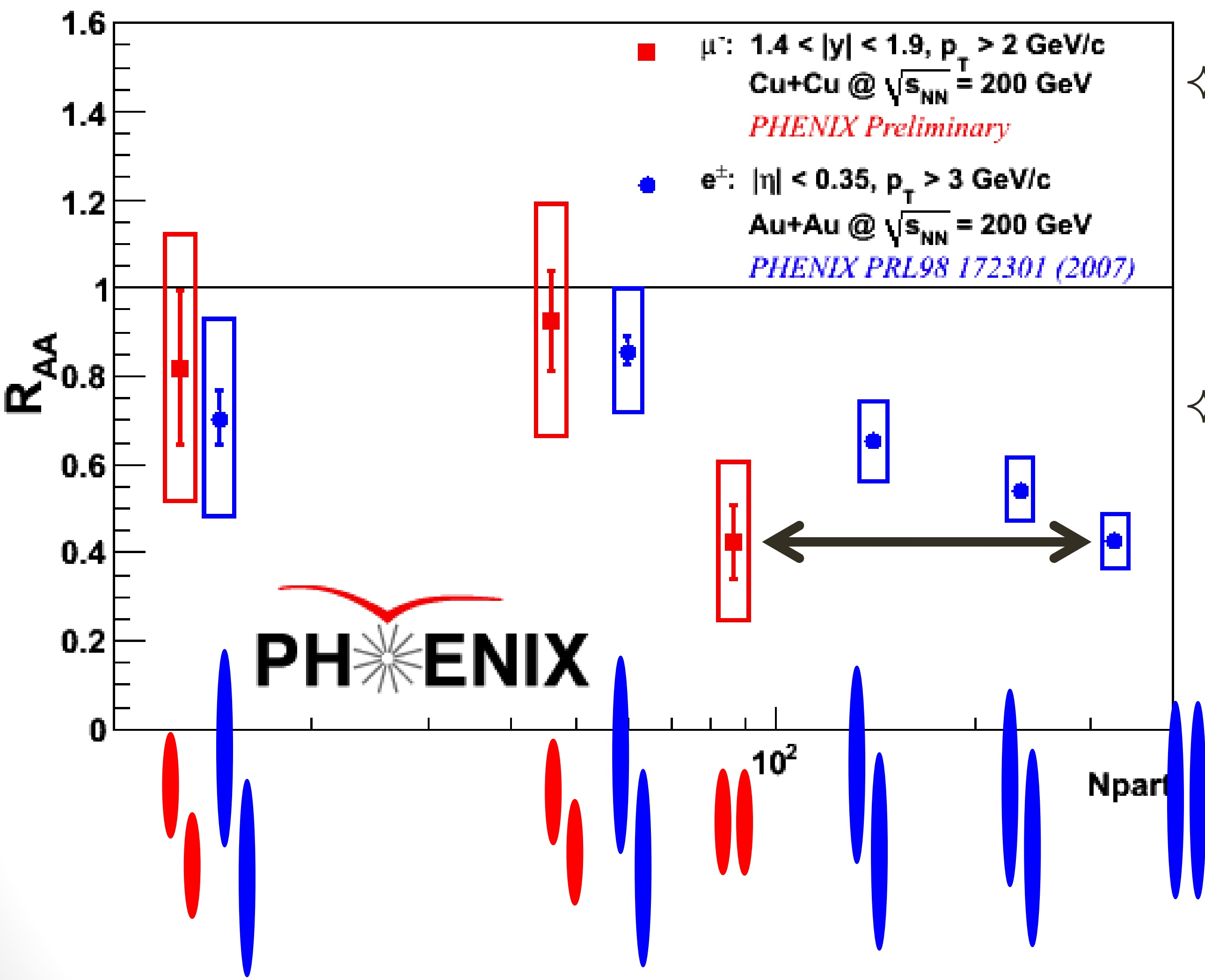
peripheral or mid-central consistent with no suppression

✧ HF muons suppressed in central Cu+Cu collisions at p_T above 2 GeV/c

✧ Data in agreement with I. Vitev's prediction that accounts for:

(1) for final state energy loss effects with his dissociation model (2) cold nuclear matter effects, such as nuclear shadowing and parton multiple scattering

Bigger picture: HF muons vs. electrons



- ✧ WARNING! Not apples to apples comparison: Cu+Cu vs. Au+Au & forward vs. mid-rapidity
- ✧ HF muons suppressed in <u>central Cu+Cu</u> collisions at p_T above 2 GeV/c as much as HF electrons in <u>central Au+Au</u> collisions.
- ✧ But Bjorken energy density in central Au+Au collisions is easily 2 times larger then that of in central Cu+Cu collisions. Thus the large HF muon suppression has to come from CNM effects.

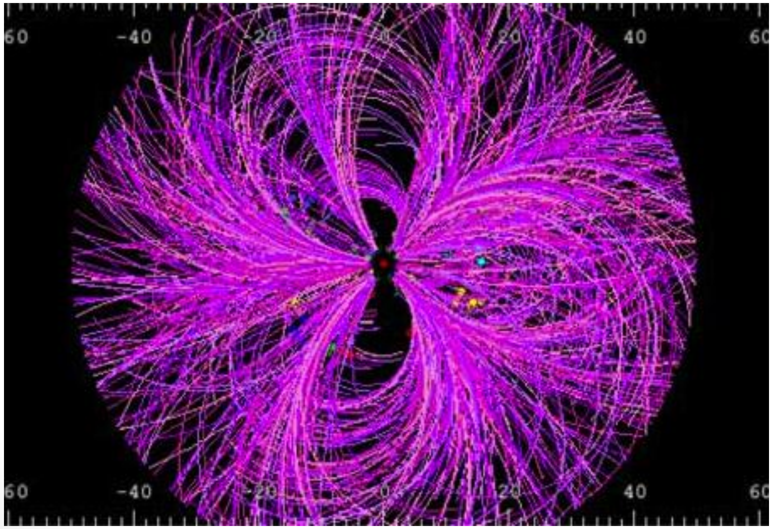
Summary

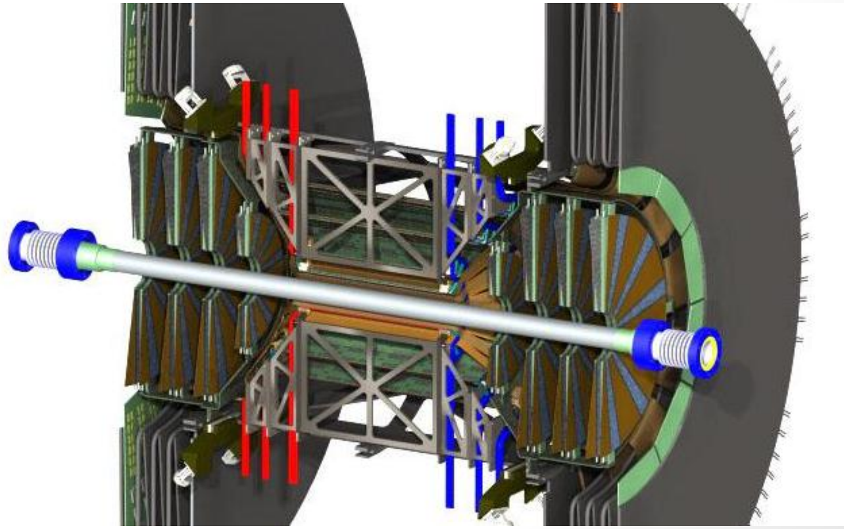
- PHENIX delivered open heavy flavor measurements (different colliding systems, kinematic regions)
- Earlier measurements indicate that large final state effects consistent with creation of a very dense and strongly interacting deconfined medium
- Recent Cu+Cu and d+Au measurements indicate additional sizable cold nuclear matter effects in different kinematic regions.
- New results on HF muon production in Cu+Cu & p+p will be submitted to PRC next week. HF electron measurements in d+Au being finalized as well.

Outlook

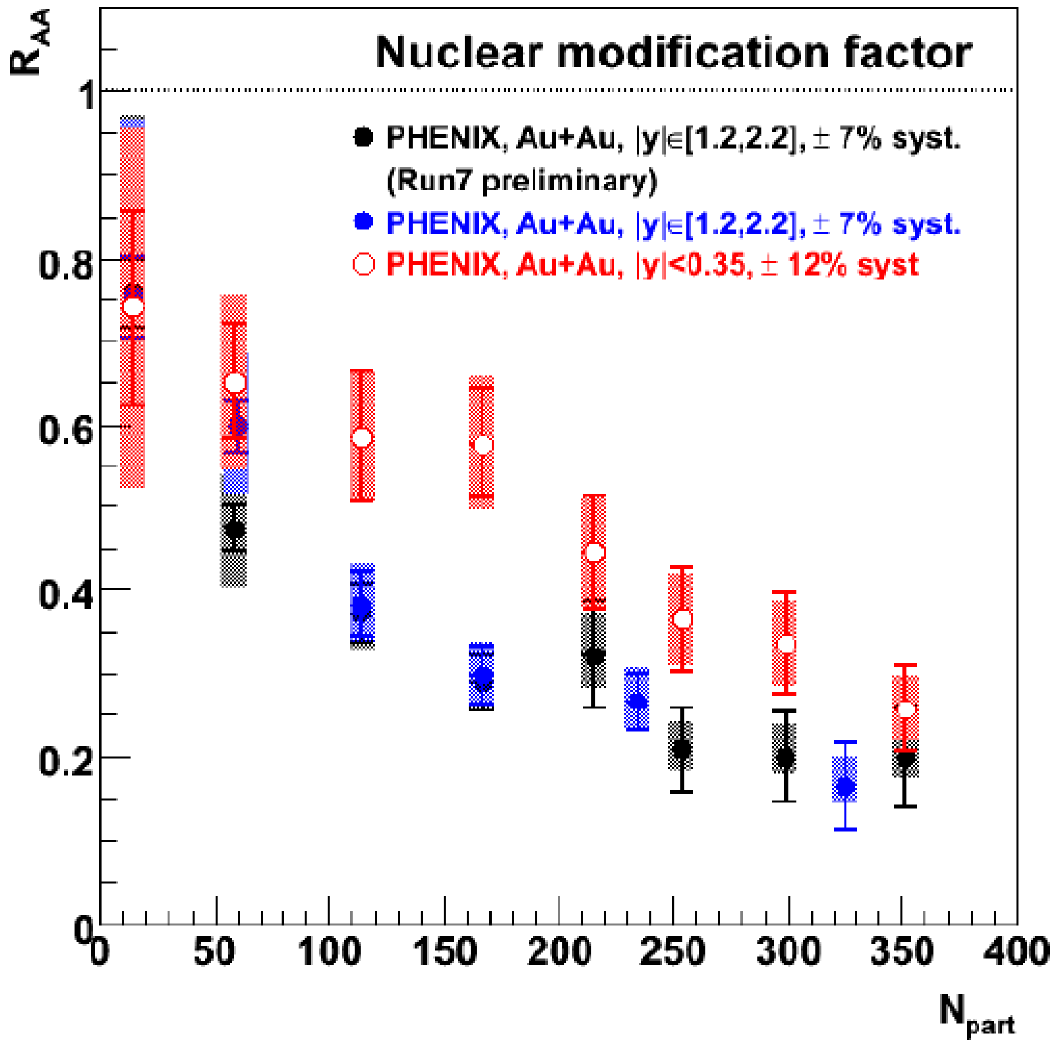
"New heavy flavor era" started with installation of VTX and FVTX detectors. Already taking data with new detectors.

Greatly enhanced heavy flavor detection capabilities: (a) smaller uncertainties (b) Very clean D and B meson separation.





Backup slides


Nuclear modification factor
R_AA
N_part
PHENIX, Au+Au, |y|∈[1.2,2.2], ± 7% syst.
(Run7 preliminary)
PHENIX, Au+Au, |y|∈[1.2,2.2], ± 7% syst.
PHENIX, Au+Au, |y|<0.35, ± 12% syst
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400