Heavy Flavor Correlations @ PHENIX

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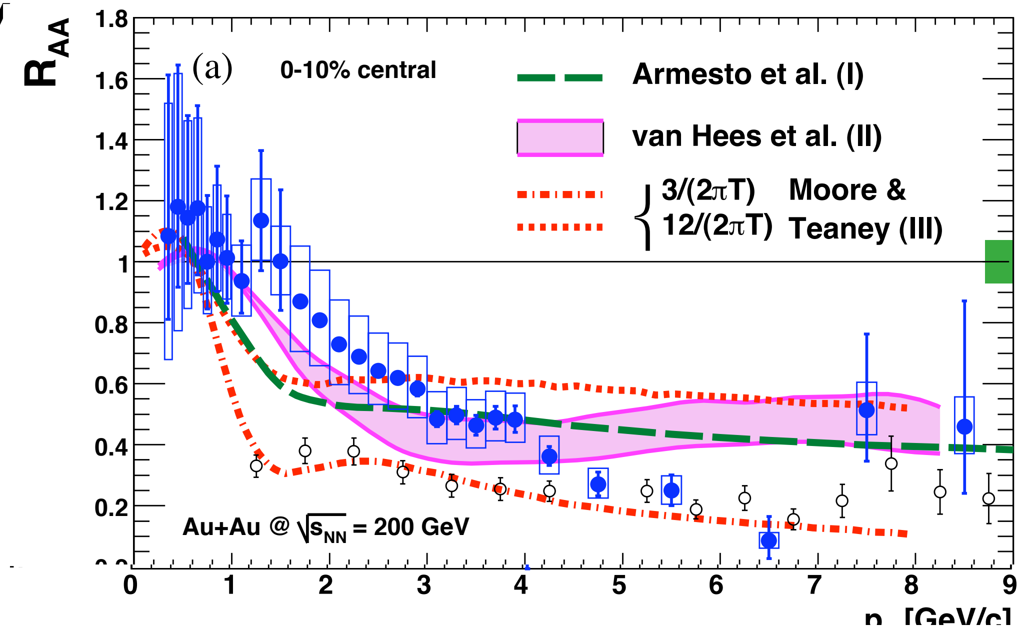
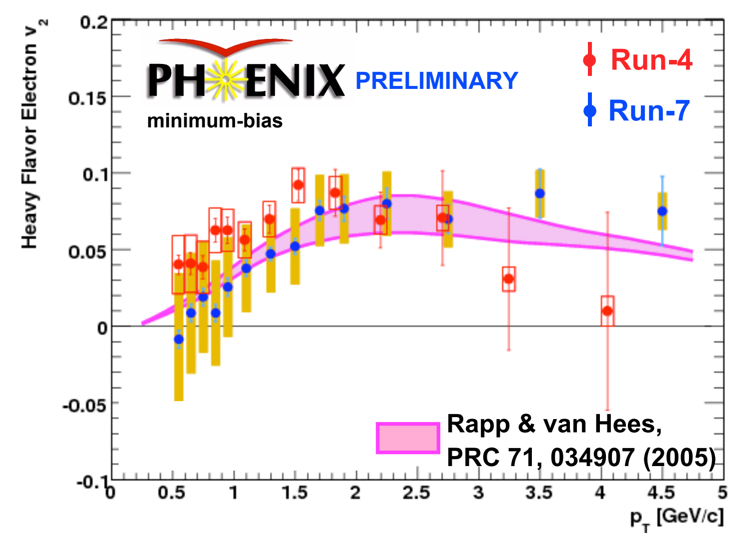
PHENIX

Why Heavy Flavor?

- electrons from decay of heavy mesons are modified by the matter in heavy ion collisions
  - yields are suppressed
  - $v_2^{HF} > 0$
- heavy quarks interact with the matter (almost as much as light quarks)

PHENIX, PRL 98 172301 (2007)





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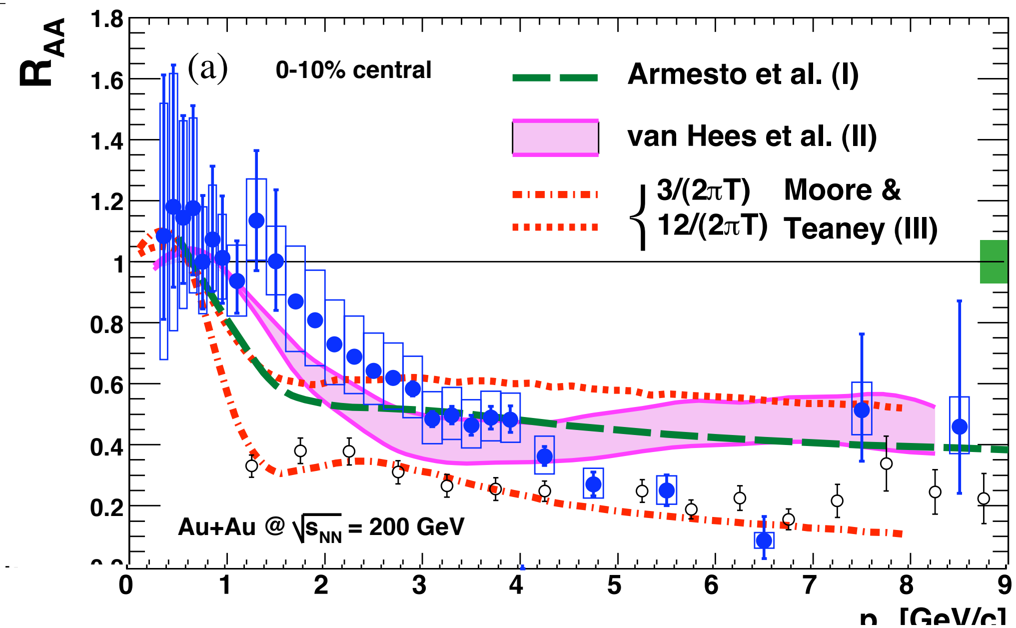
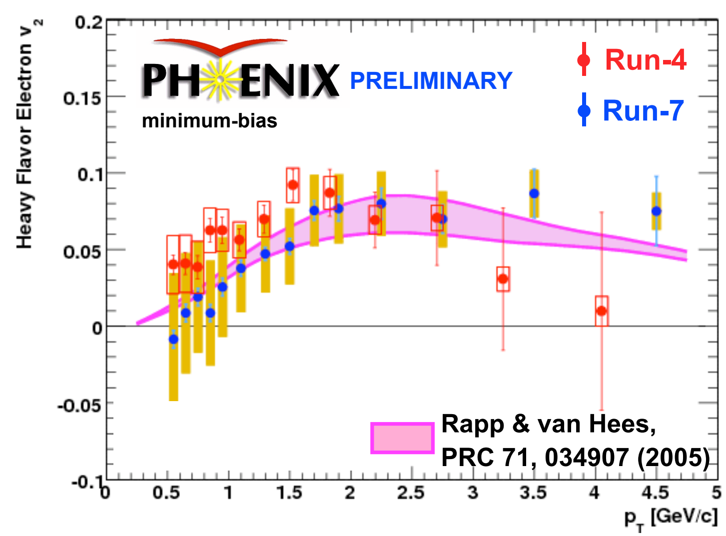
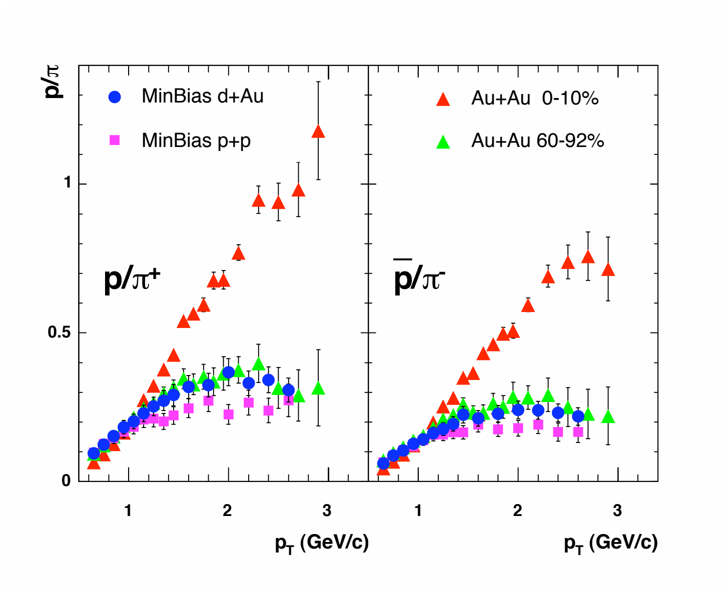
two particle correlations can provide information about how the heavy quarks interact with the matter!

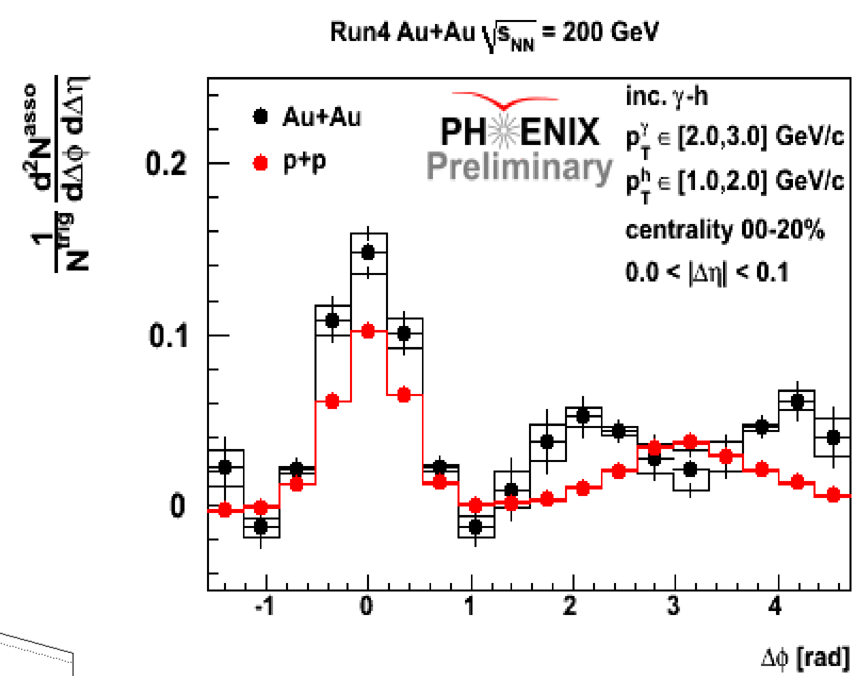
PHENIX, PRL 98 172301 (2007)

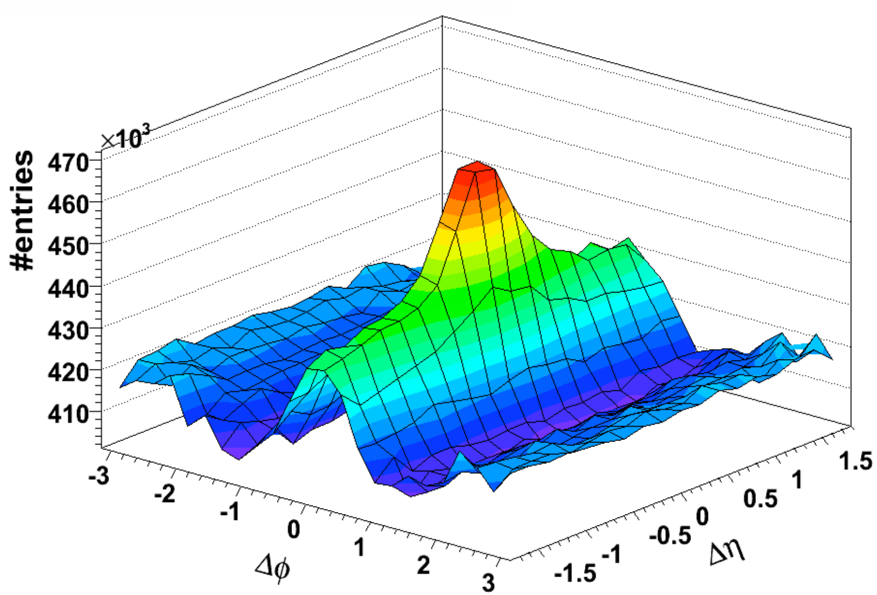




Light Jet Modifications





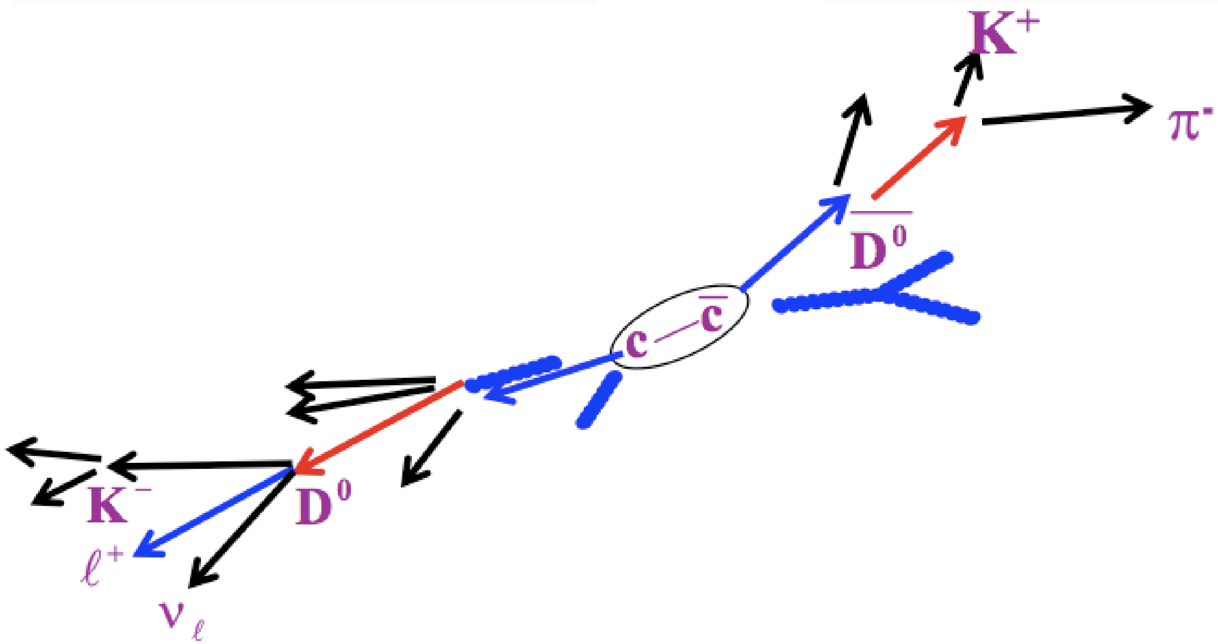


PHENIX, PRC 74 024904 (2006),
J. Chen Hard Probes 2008,
STAR Preliminary

Heavy Flavor Correlations

- energy loss (where does the lost energy go?)
  - light quarks/gluons, charm, & bottom
- recombination/coalescence (Oh et al 0901.1382)
  - evidence for significant light baryons & meson production via recombination
- in medium formation/dissociation (Adil & Vitev PLB 649 139 (2007))
- jet medium interactions: ridge, shoulder
  - heavy flavor correlations offer a good test of ridge & shoulder models

Heavy Flavor via Semi-leptonic decays



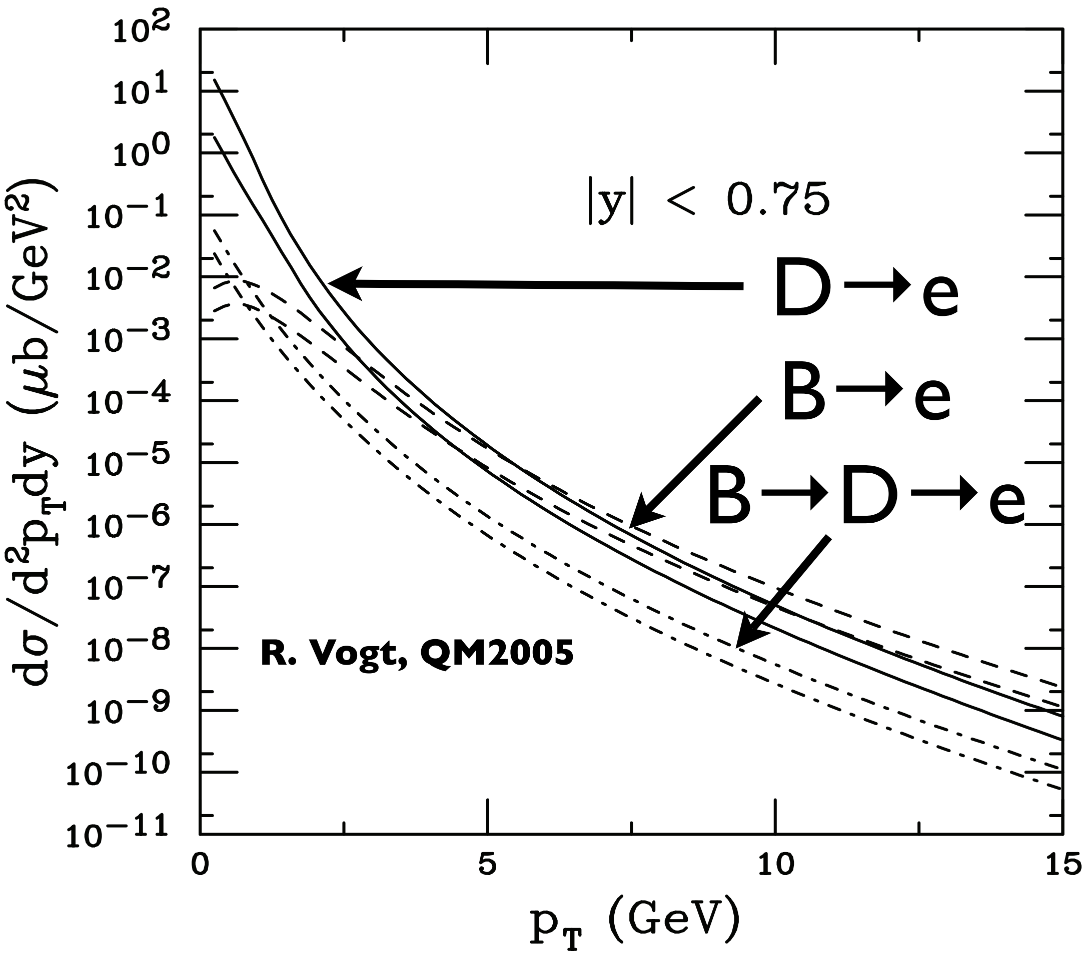
Decay	Branching Ratio
$D^{\pm} \rightarrow e+X$	16.0%
$D^{0} \rightarrow e+X$	6.5%

- single particles: measure $e^{\pm}$ from D, B decay
- hadronic decays: large backgrounds

problem: how do you know if $e^{\pm}$ came from charm or bottom?

charm & bottom: theory

Single electrons from heavy flavor



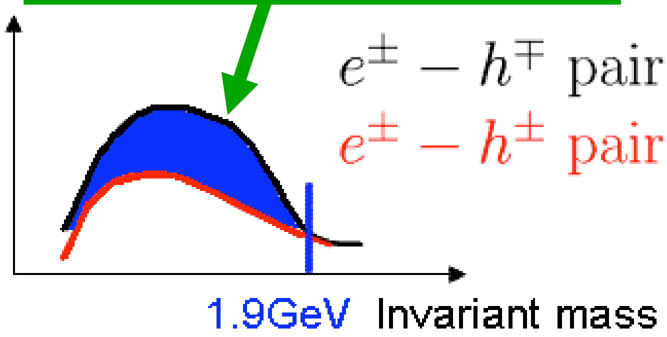
bands show theoretical uncertainty (FONLL) in components

knowledge of relative c/b contributions crucial for understanding HF modifications in Au+Au collisions

what can experiment say?

idea: D→eKν, reconstruct eK invariant mass

- heavy meson decay: e & K have opposite signs
- like sign pairs approximate the background
- use simulations to get tagging efficiency for c & b



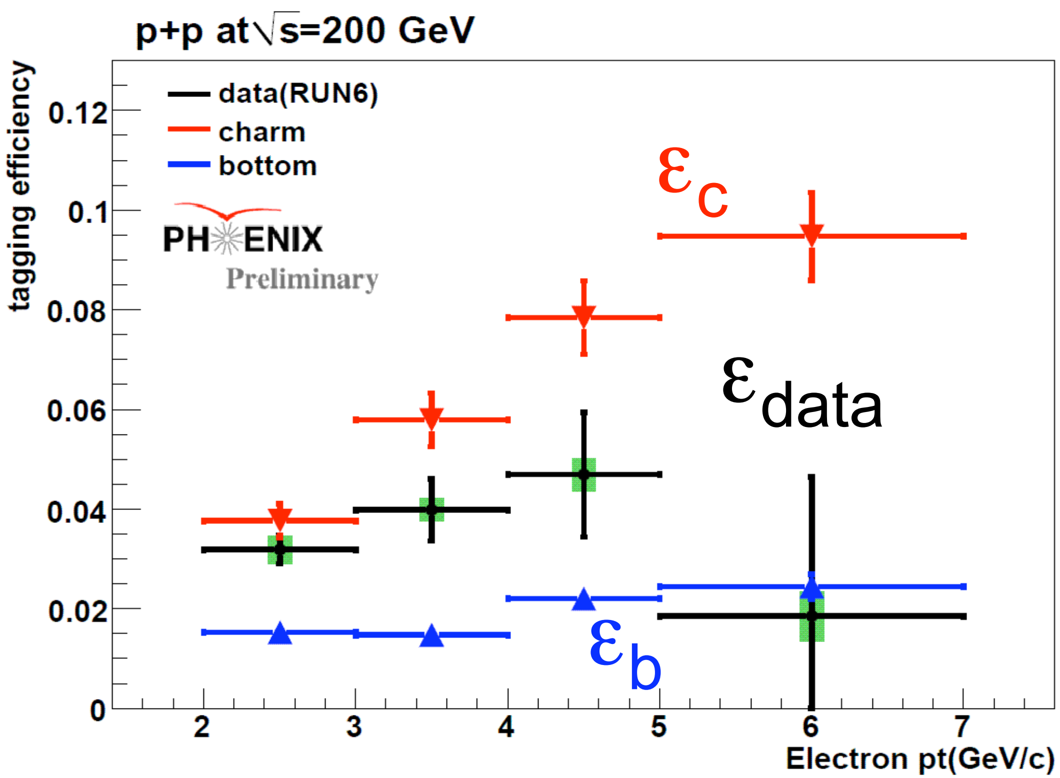
$$\epsilon_{data} \equiv \frac{N_{tag}}{N_{e(non-photonic)}} = \frac{N_{c\to tag} + N_{b\to tag}}{N_{c\to e} + N_{b\to e}}$$

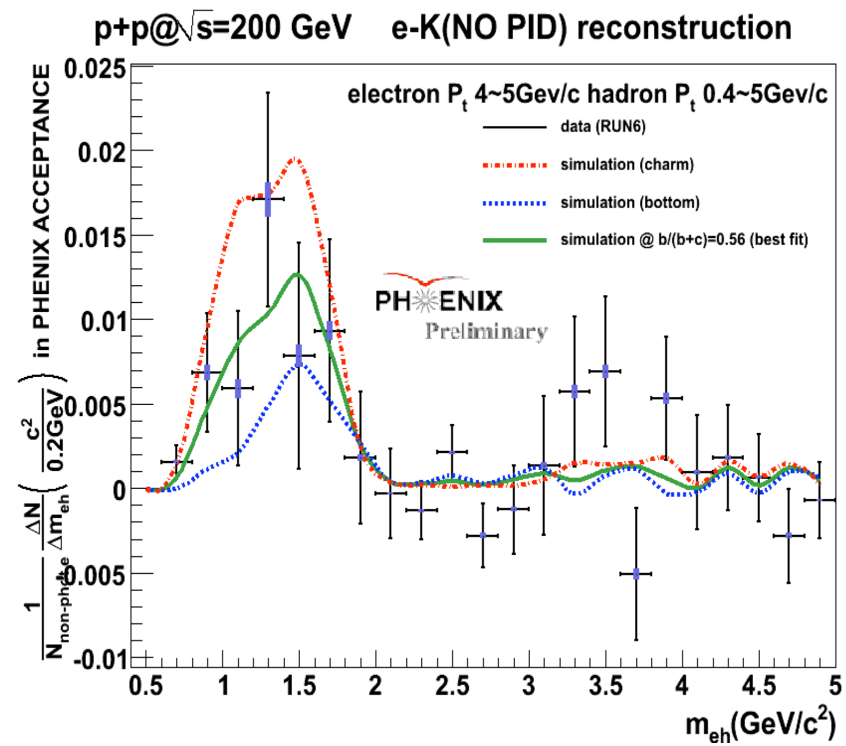
$$\epsilon_c \equiv \frac{N_{c\to tag}}{N_{c\to e}}, \epsilon_b \equiv \frac{N_{b\to tag}}{N_{b\to e}}$$

$$\frac{N_{b\to e}}{N_{c\to e} + N_{b\to e}} = \frac{\epsilon_c - \epsilon_{data}}{\epsilon_c - \epsilon_b}$$

Y. Morino QM08

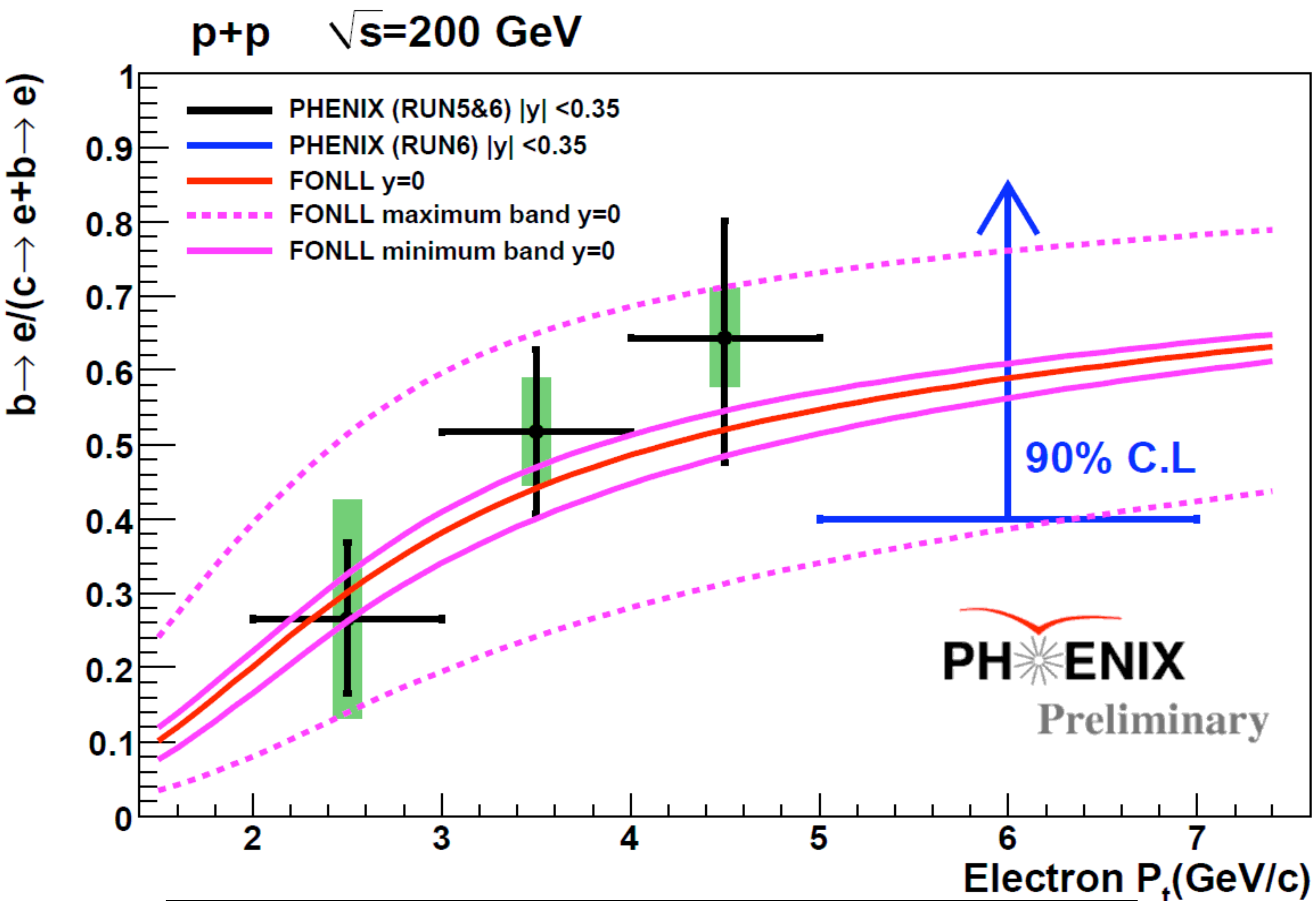
tagging efficiency





compare data to simulation, extract bottom contribution
main uncertainty: production ratios (D^+/D^0, etc)

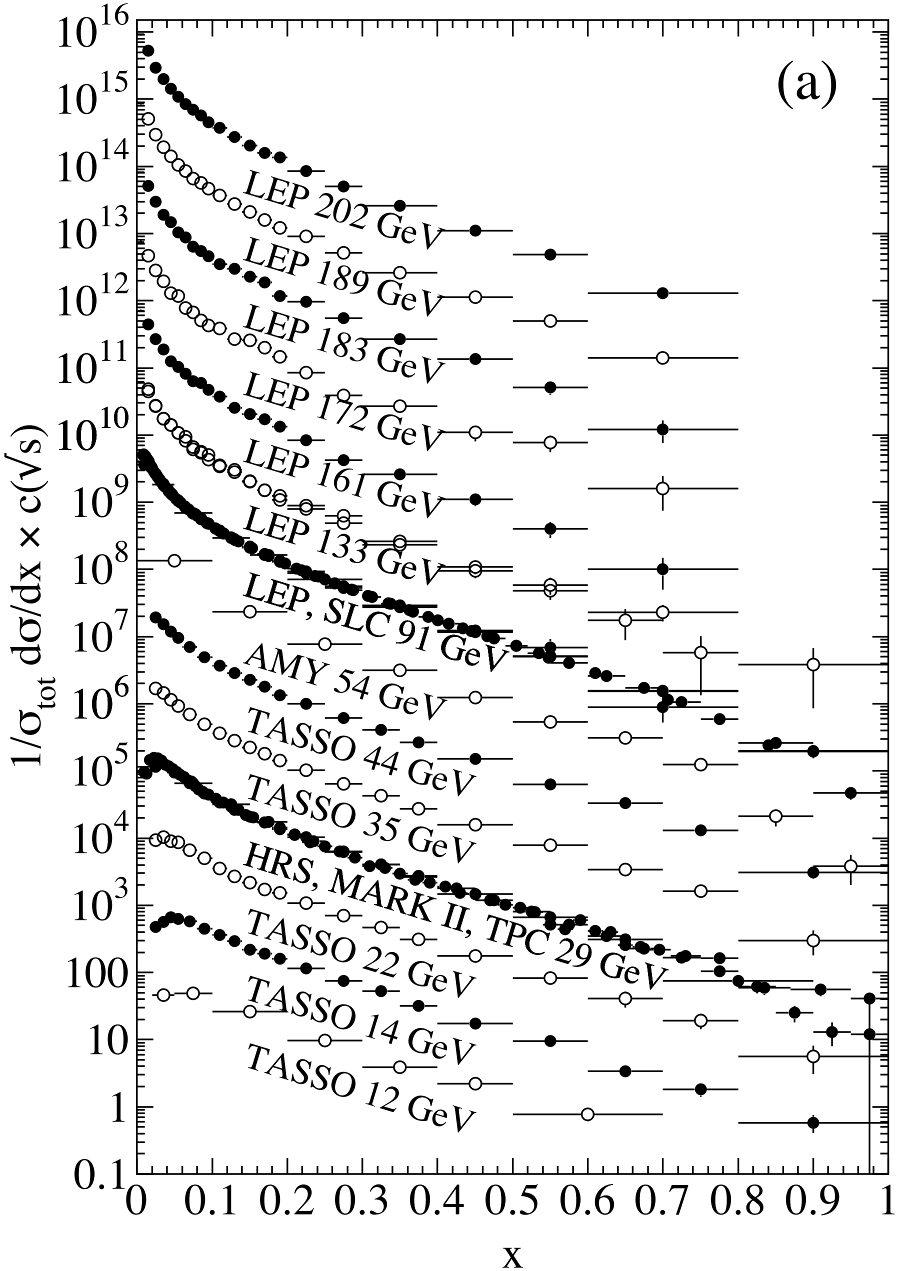
relative b→e contribution vs $p_{T,e}$



significant bottom contributions
good agreement with FONLL

Heavy Quark Fragmentation

Light Quark Fragmentation

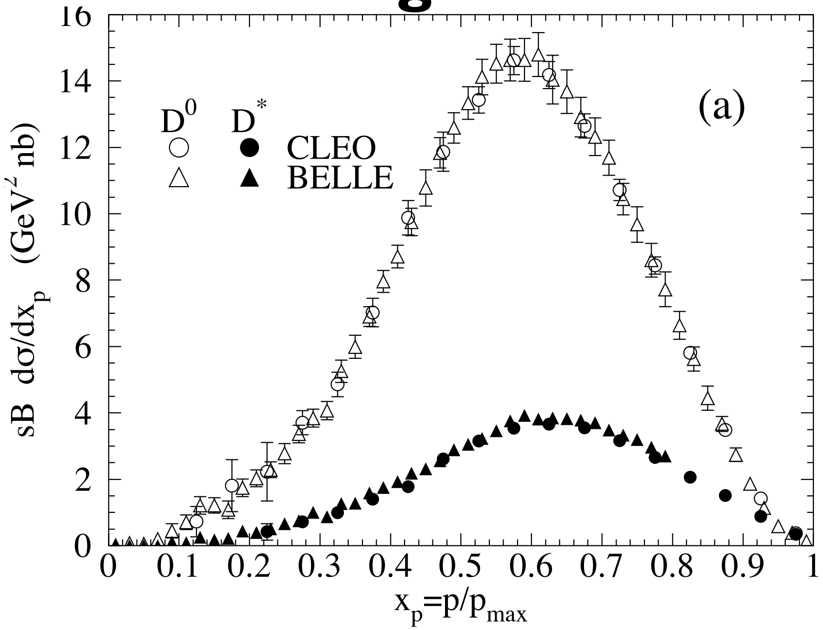


- fragmentation functions from e^+e^- collisions
- most particles carry small fraction of jet energy

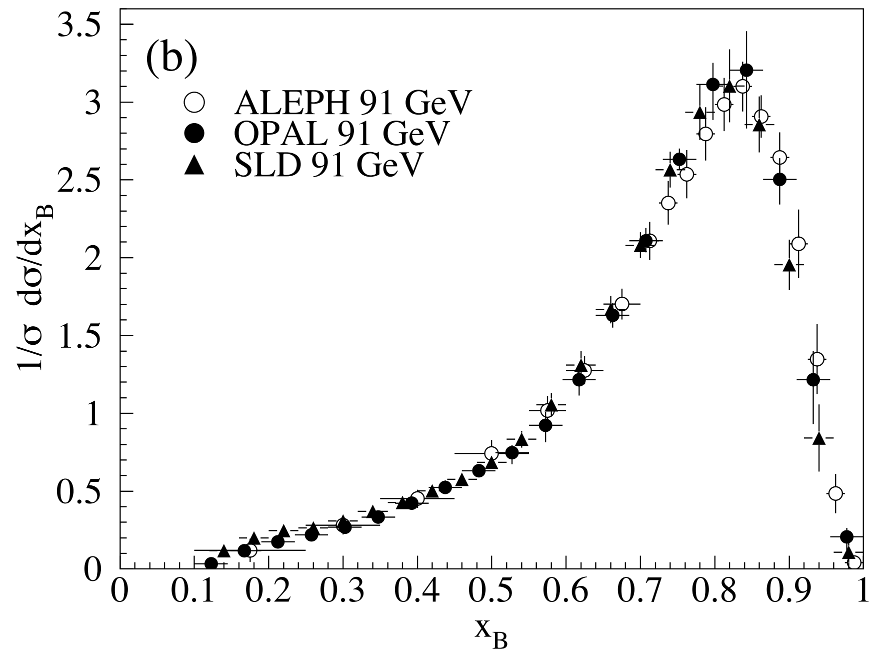
Particle Data Book

what about heavy quark jets?

c→D fragmentation



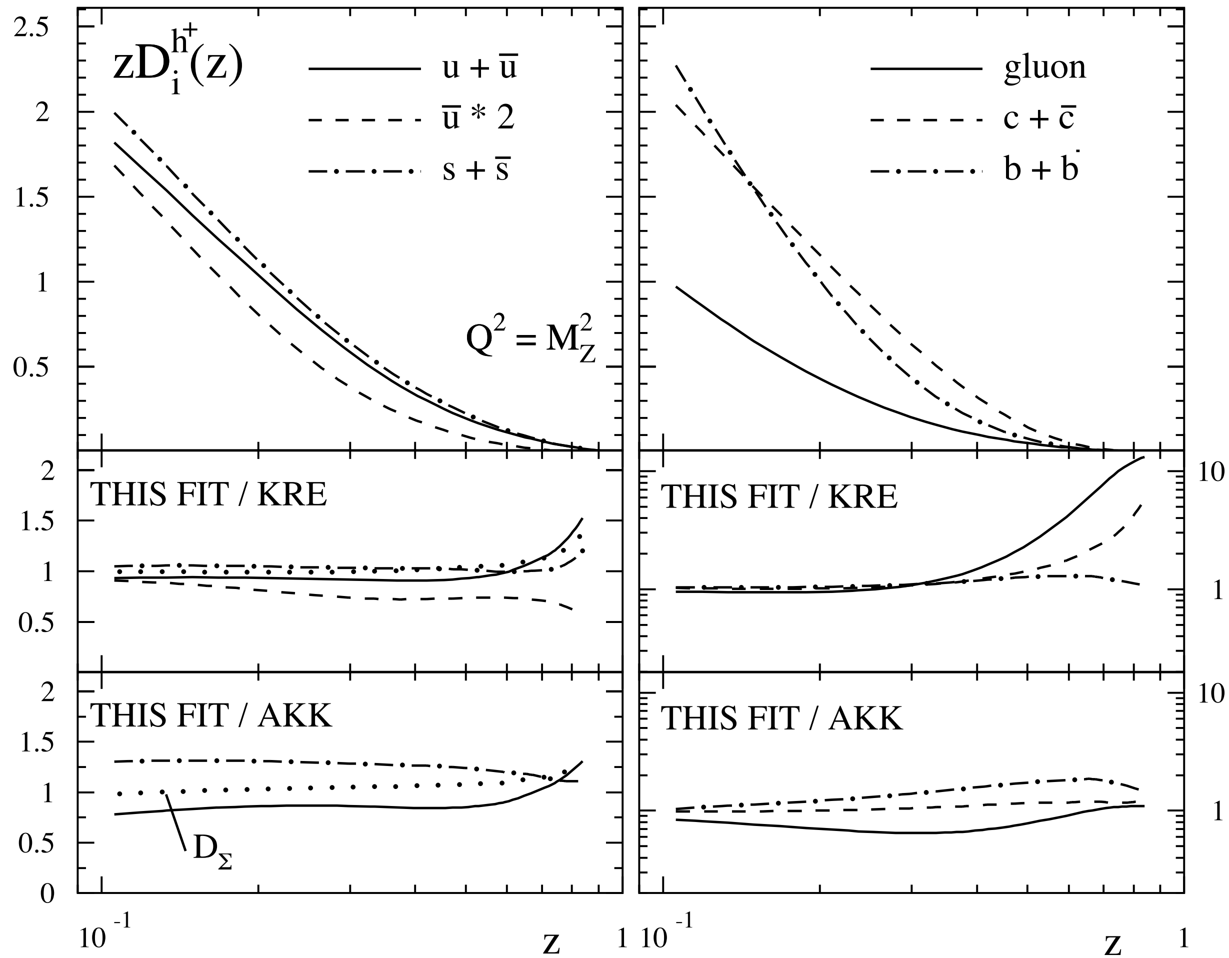
b→B fragmentation



- c→D fragmentation hard
- b→B fragmentation harder

Particle Data Book

...and the rest of jet energy?



c,b → hadrons softer than q, g jets

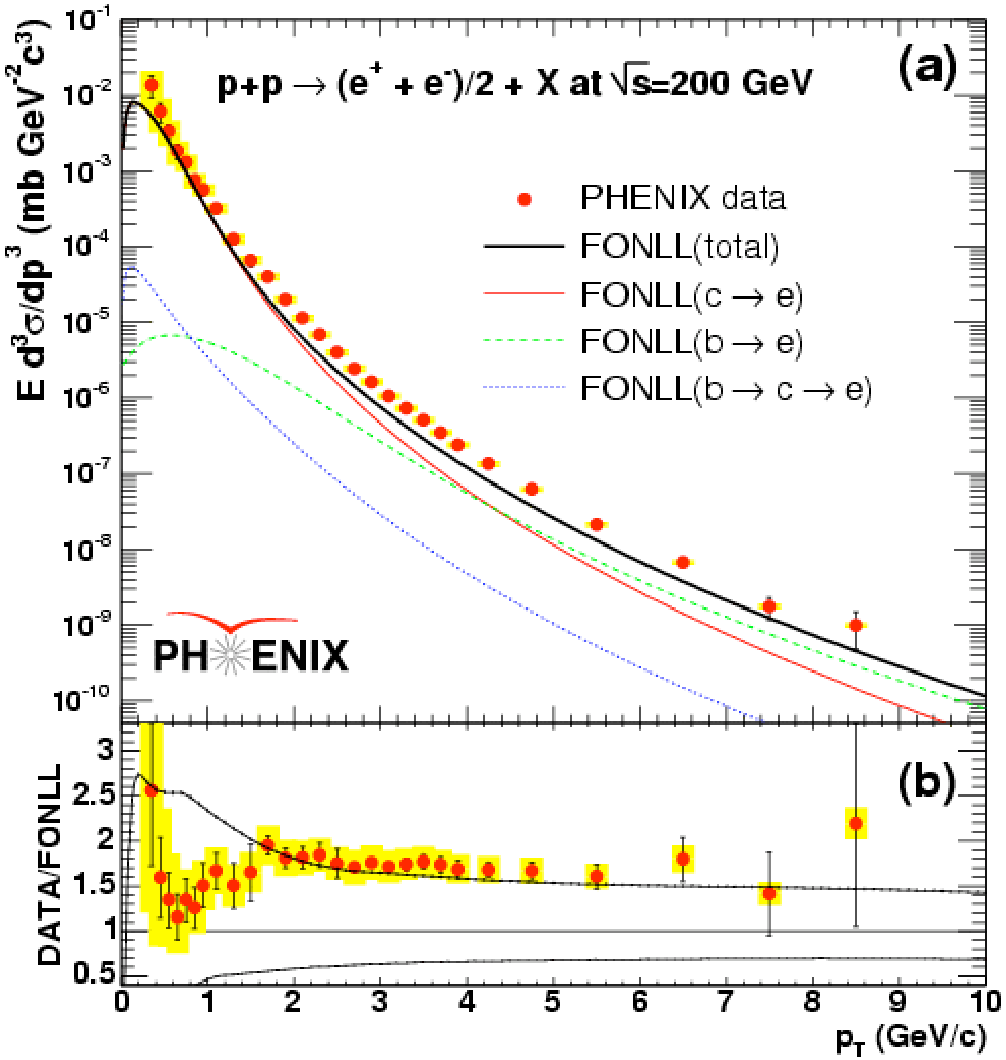
de Florian et al PRD 76 074033 (2007)

big question: is HF fragmentation modified in HI?

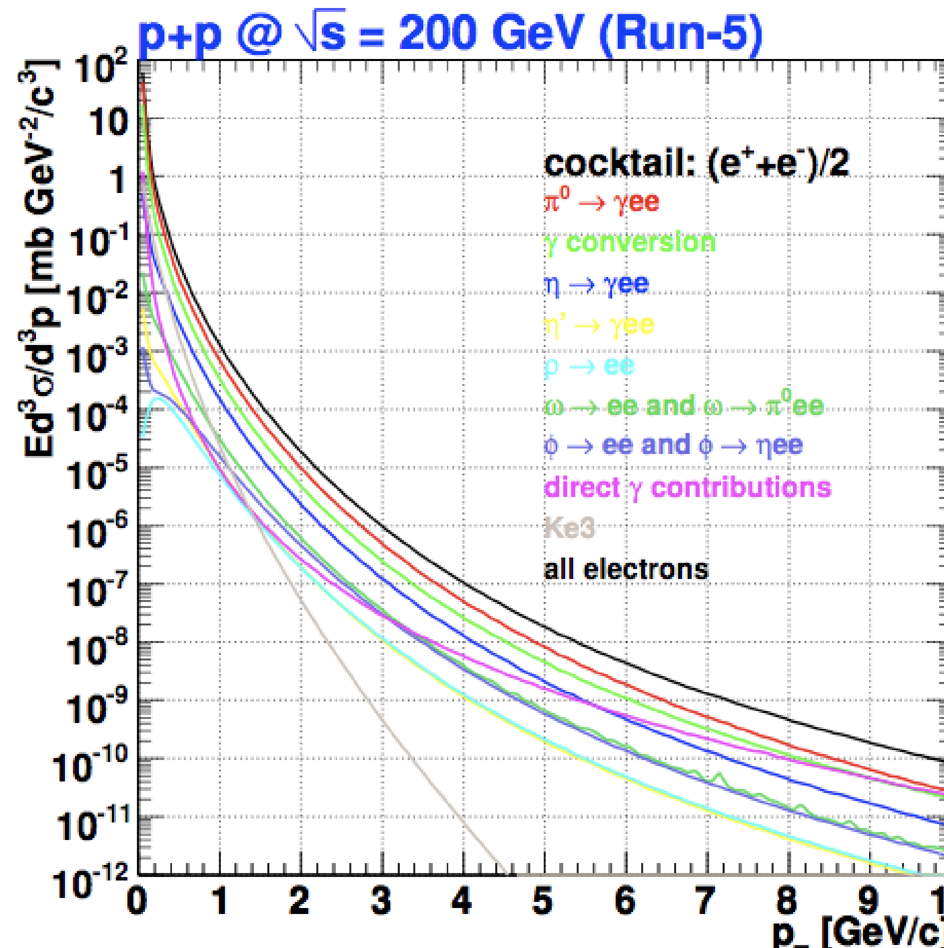
- in Au+Au we want to study how heavy quark jets are modified by the matter
  - near side: extra momentum from energy loss? the ridge?
  - away side: shoulder structure? energy loss (& how does that compare to γ_{dir}-h and π^0-h?)
- observable: e_{HF}-h correlations as a function of $p_{T,e}$ & $p_{T,h}$
- expectations: p+p measurements are an essential baseline

two types of electrons

Heavy Flavor



Photonic Electrons

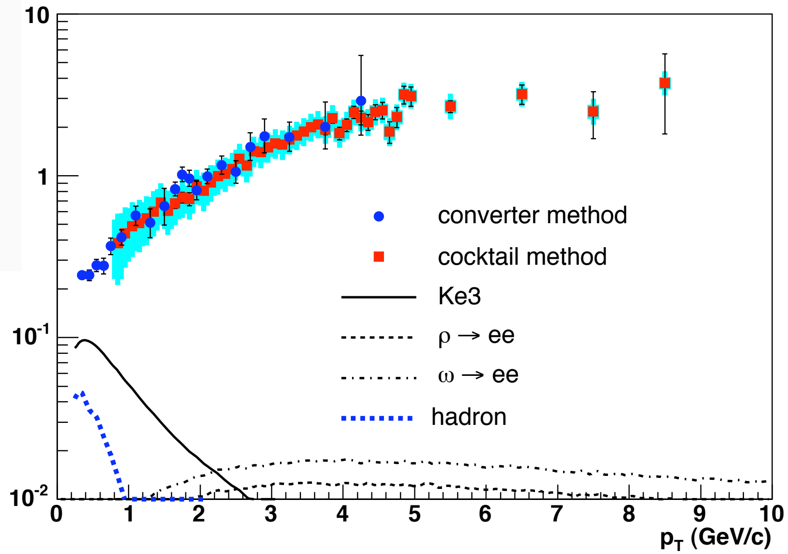


PHENIX, PRL 97 252002 (2006)

separating the correlations

$$Y_{e_{incl}-h} = \frac{N_{e_{HF}} Y_{e_{HF}-h} + N_{e_{phot}} Y_{e_{phot}-h}}{N_{e_{HF}} + N_{e_{phot}}}$$

$$R_{HF} = \frac{N_{e_{HF}}}{N_{e_{phot}}}$$



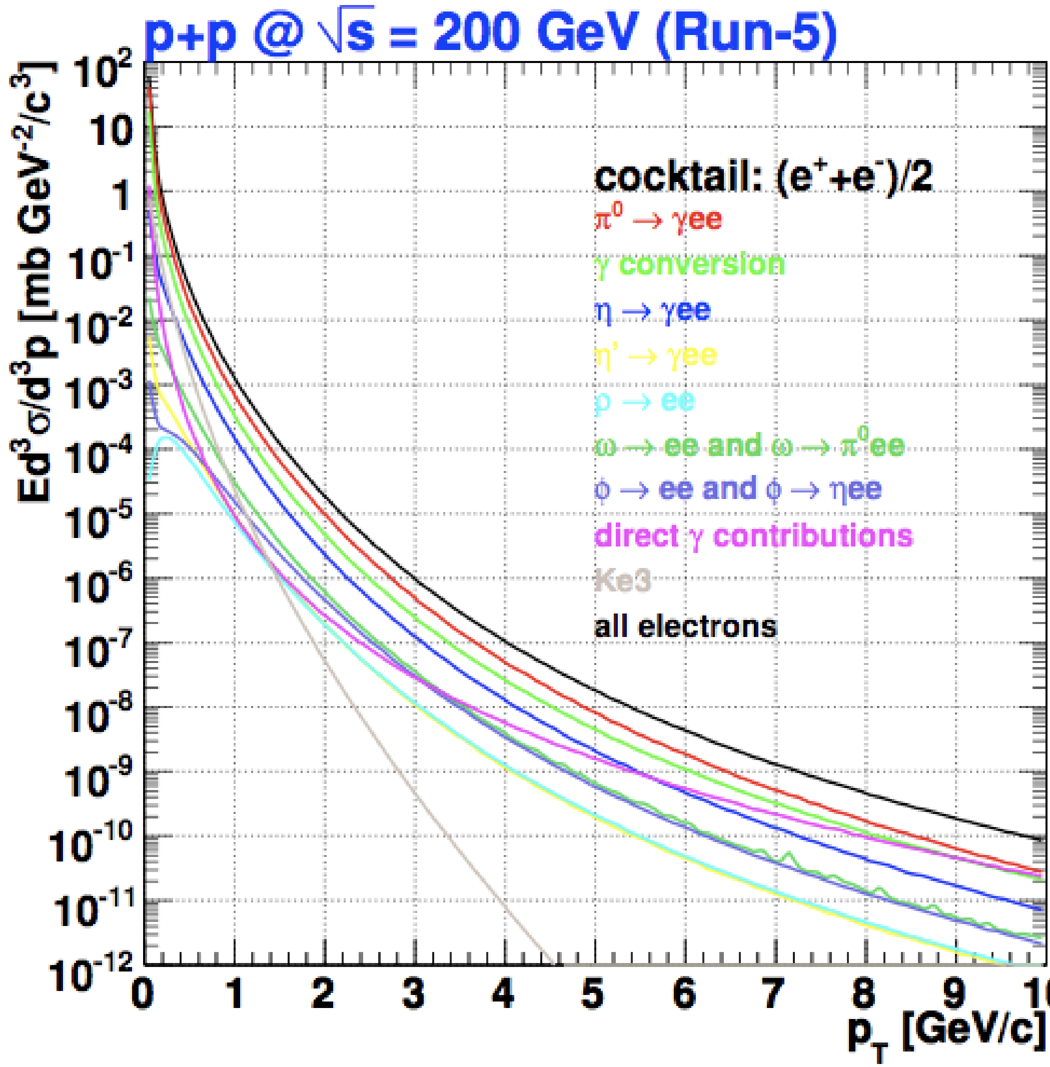
$$Y_{e_{HF}-h} = \frac{(R_{HF}+1) Y_{e_{incl}-h} - Y_{e_{phot}-h}}{R_{HF}}$$

PHENIX, PRL 97 252002 (2006)

e_{phot}-h correlations

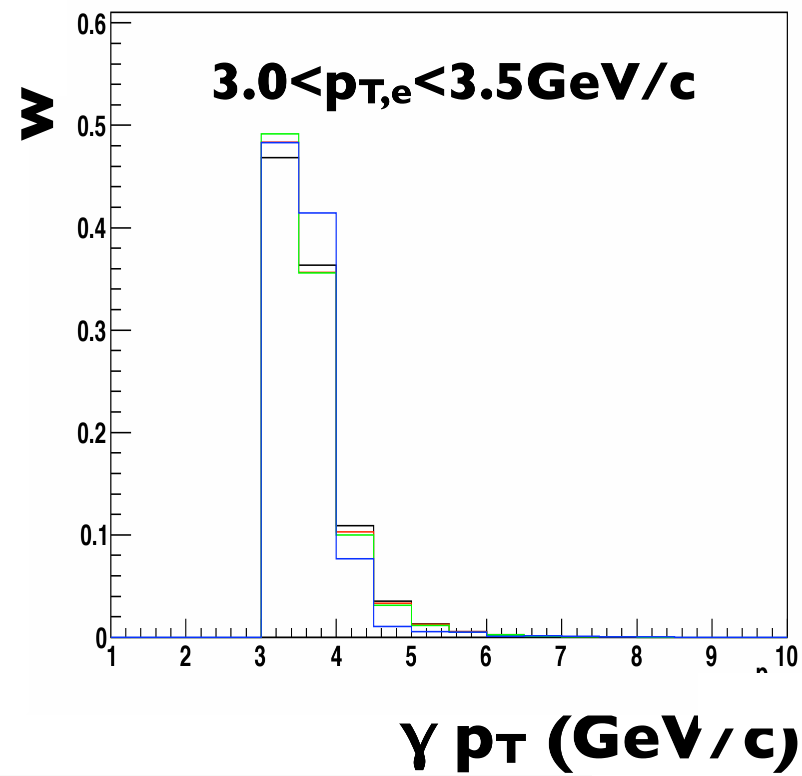
$$Y_{e_{HF}-h} = \frac{(R_{HF}+1)Y_{e_{incl}-h} - Y_{e_{phot}-h}}{R_{HF}}$$

- photonic electrons: Dalitz decays and γ conversions
  - both from light mesons
- measure γ_{inc}-h correlations
  - use MC to map between $e_{phot}(p_T)$ & $\gamma_{inc}(p_T)$



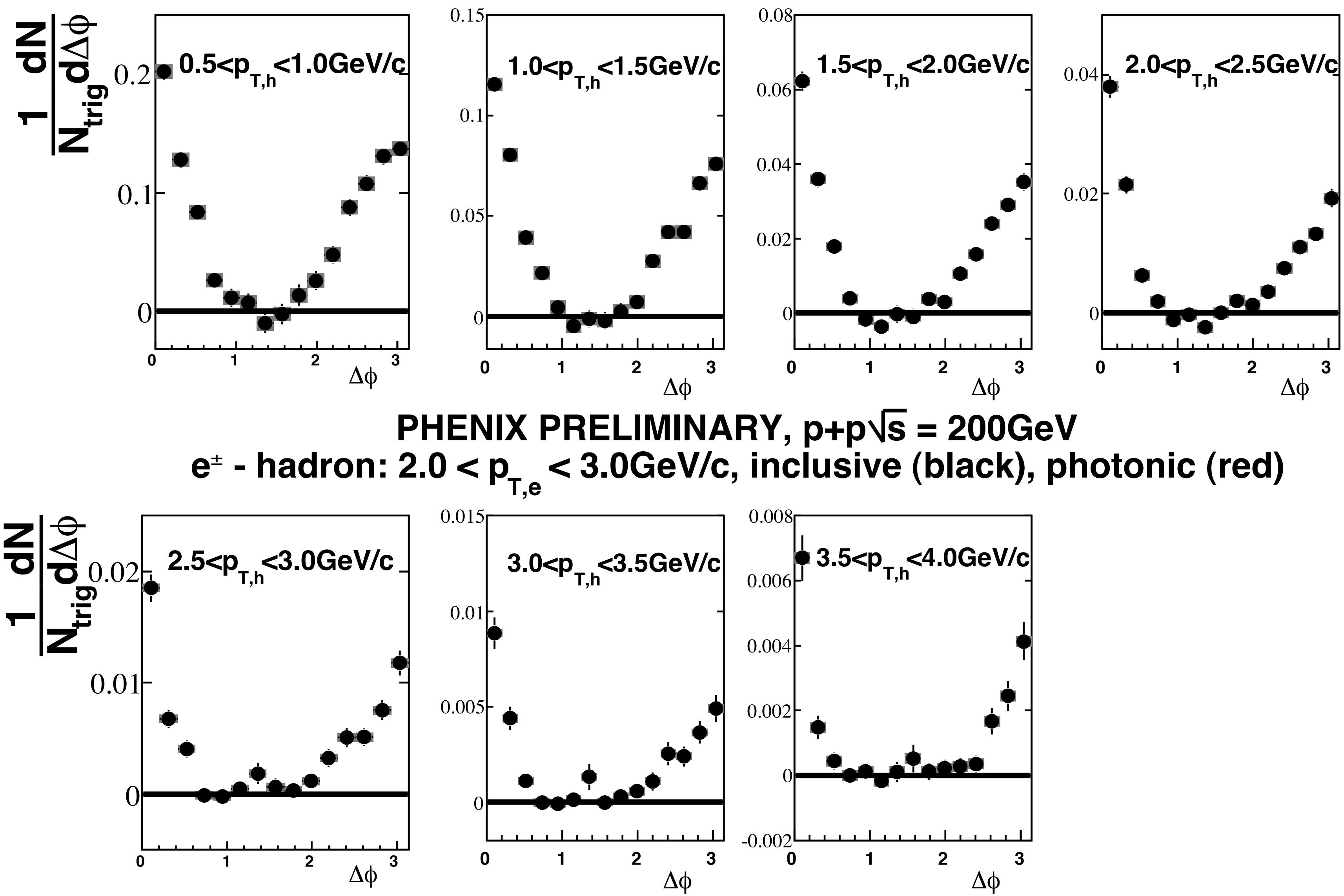
e_{phot}-h correlations (II)

- map between $e_{phot}(p_T)$ & $\gamma_{inc}(p_T)$
  - conversions: use measured γ spectra & PHENIX GEANT implementation w/ real data cuts
  - Dalitz decays: use π^0 spectra & get $\gamma^*(p_T)$ from e^+e^- in decay
- both methods give similar results: dominated by $e_{phot}(p_T) \sim \gamma_{inc}(p_T)$
  - π^0 & γ spectra fall very steeply

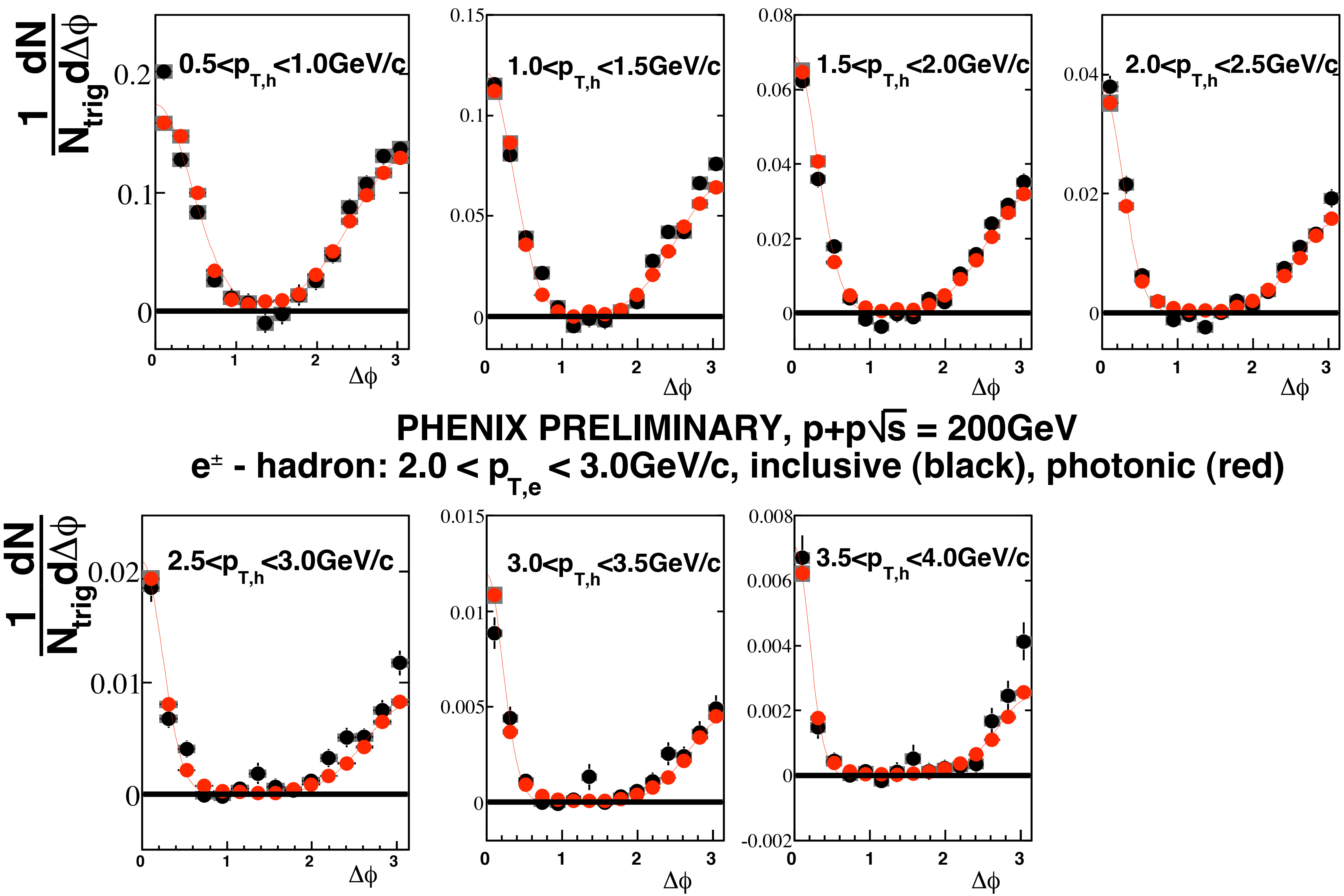


$$Y_{e_{phot}-h}(p_{T,i}) = \sum_j w_i(p_{T,j})\, Y_{\gamma-h}(p_{T,j})$$

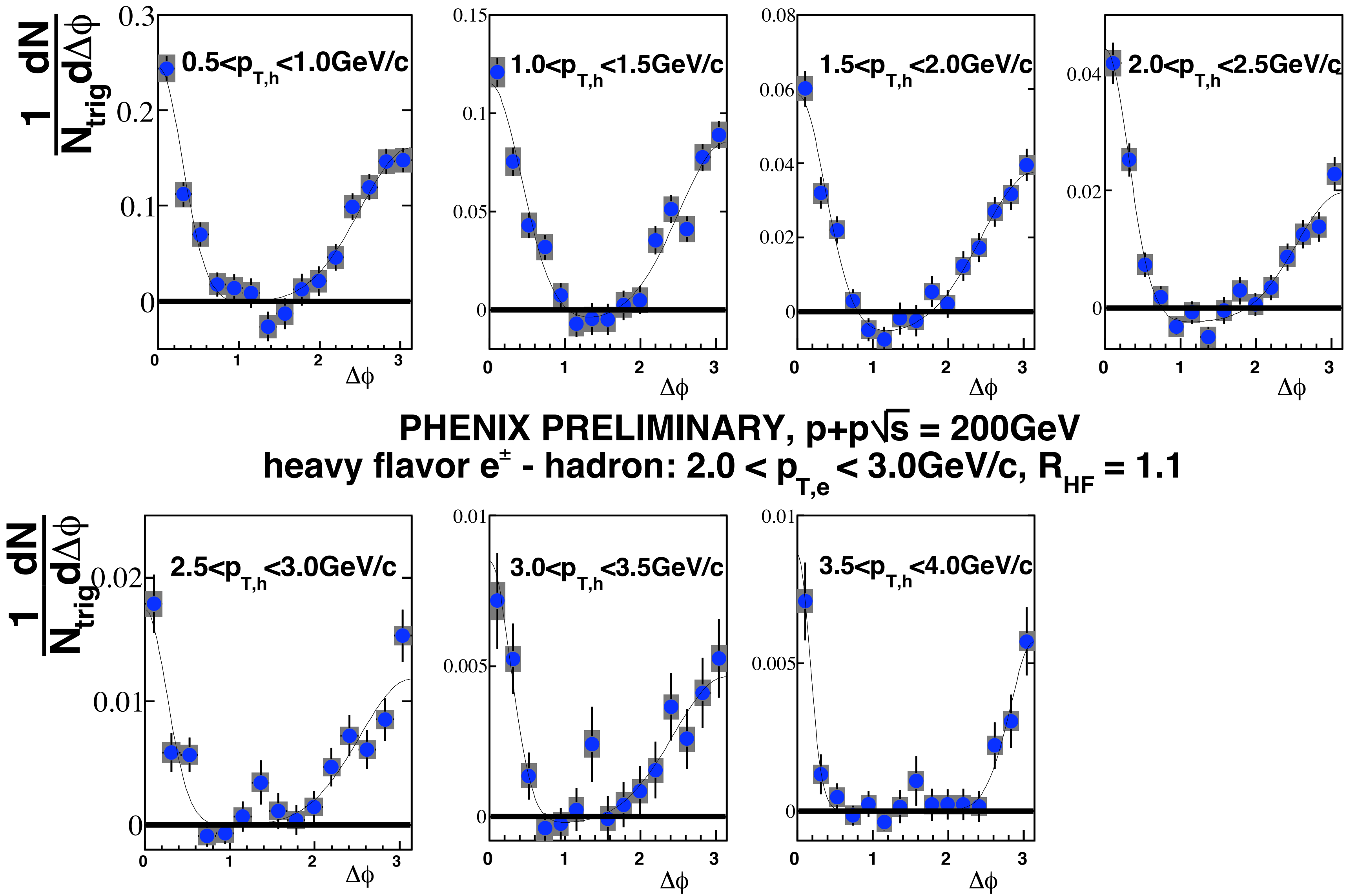
e_{inc}-h correlations



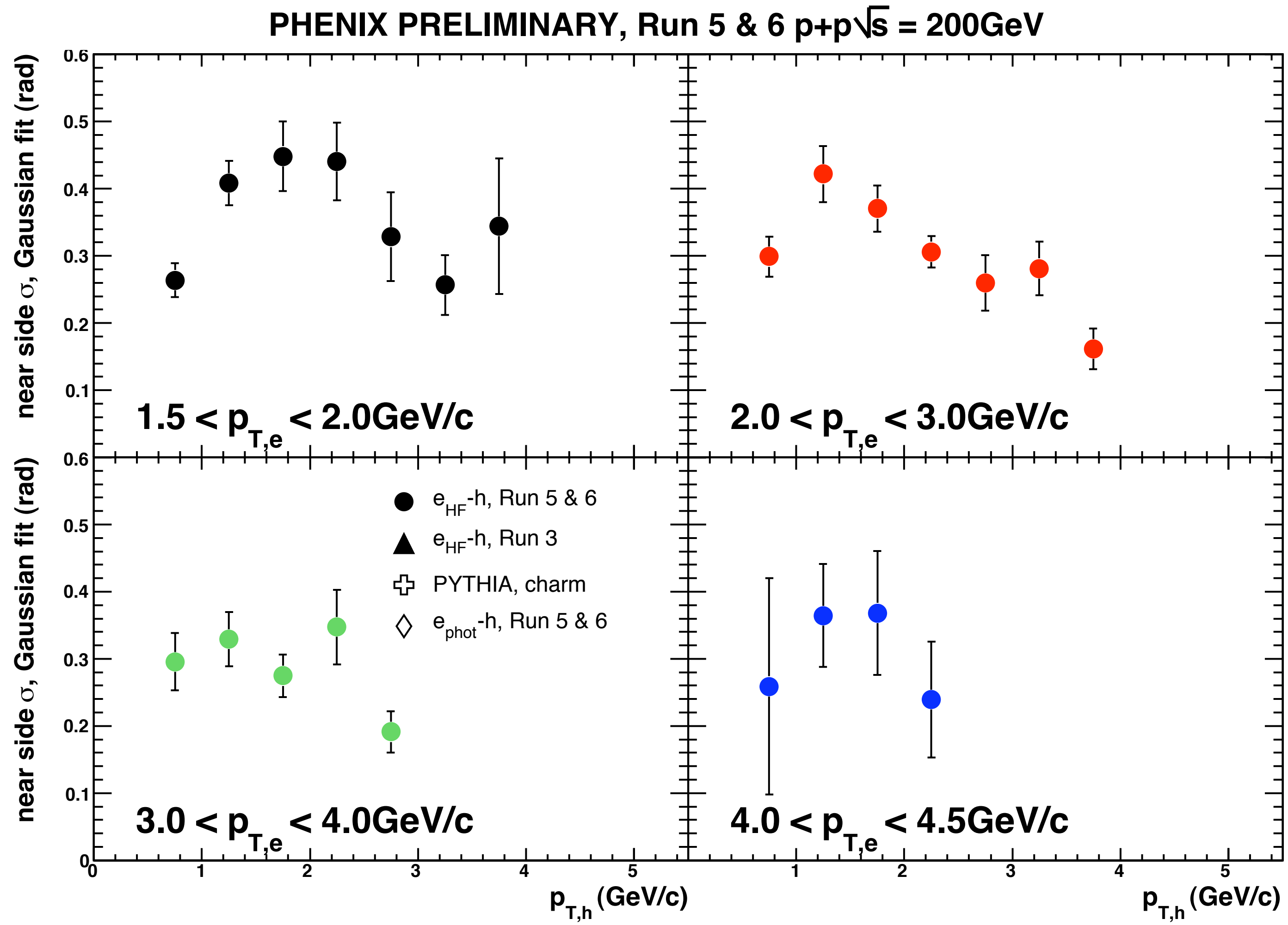
adding e_{phot}-h ...



heavy flavor correlations



near side widths



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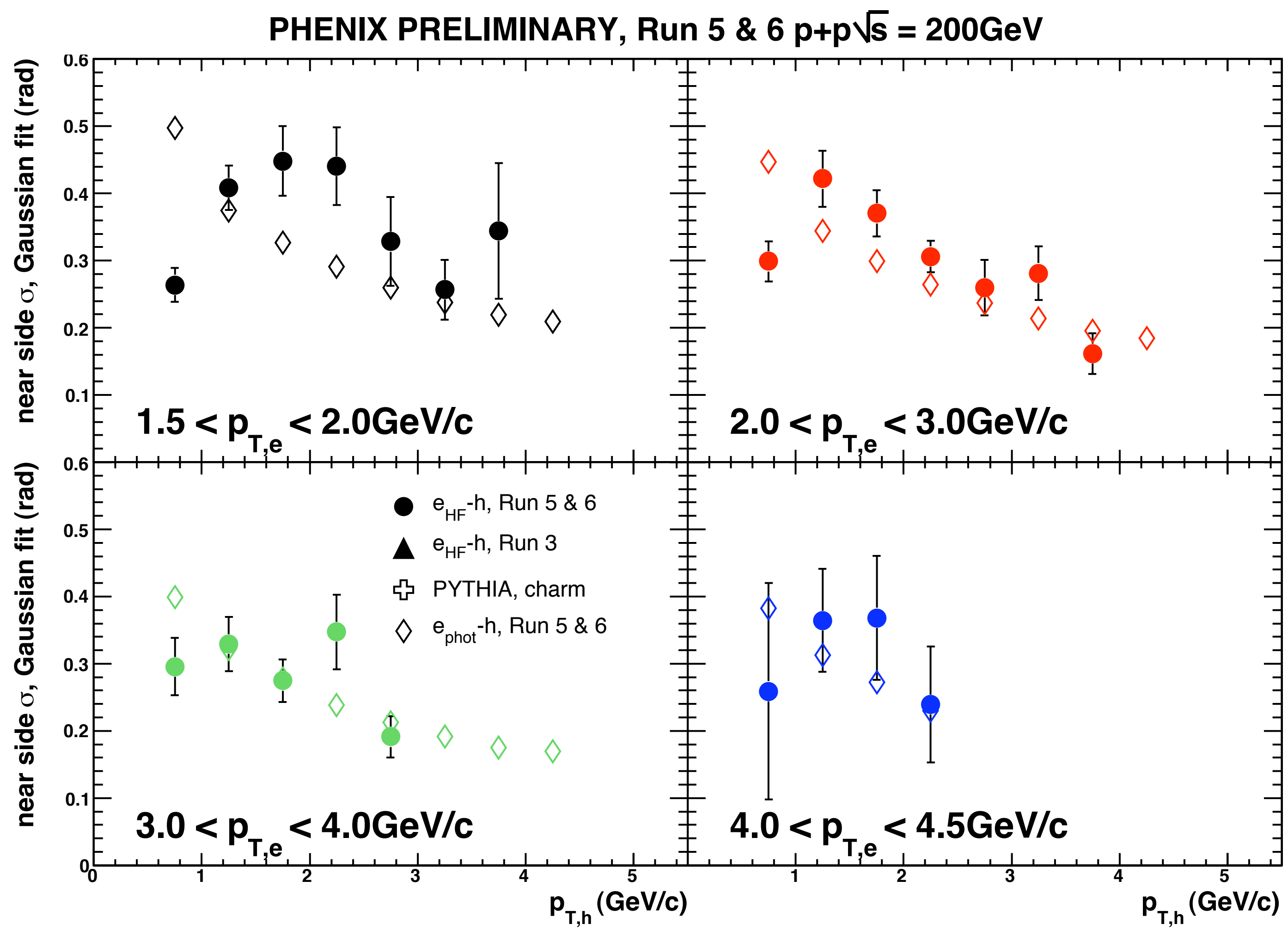
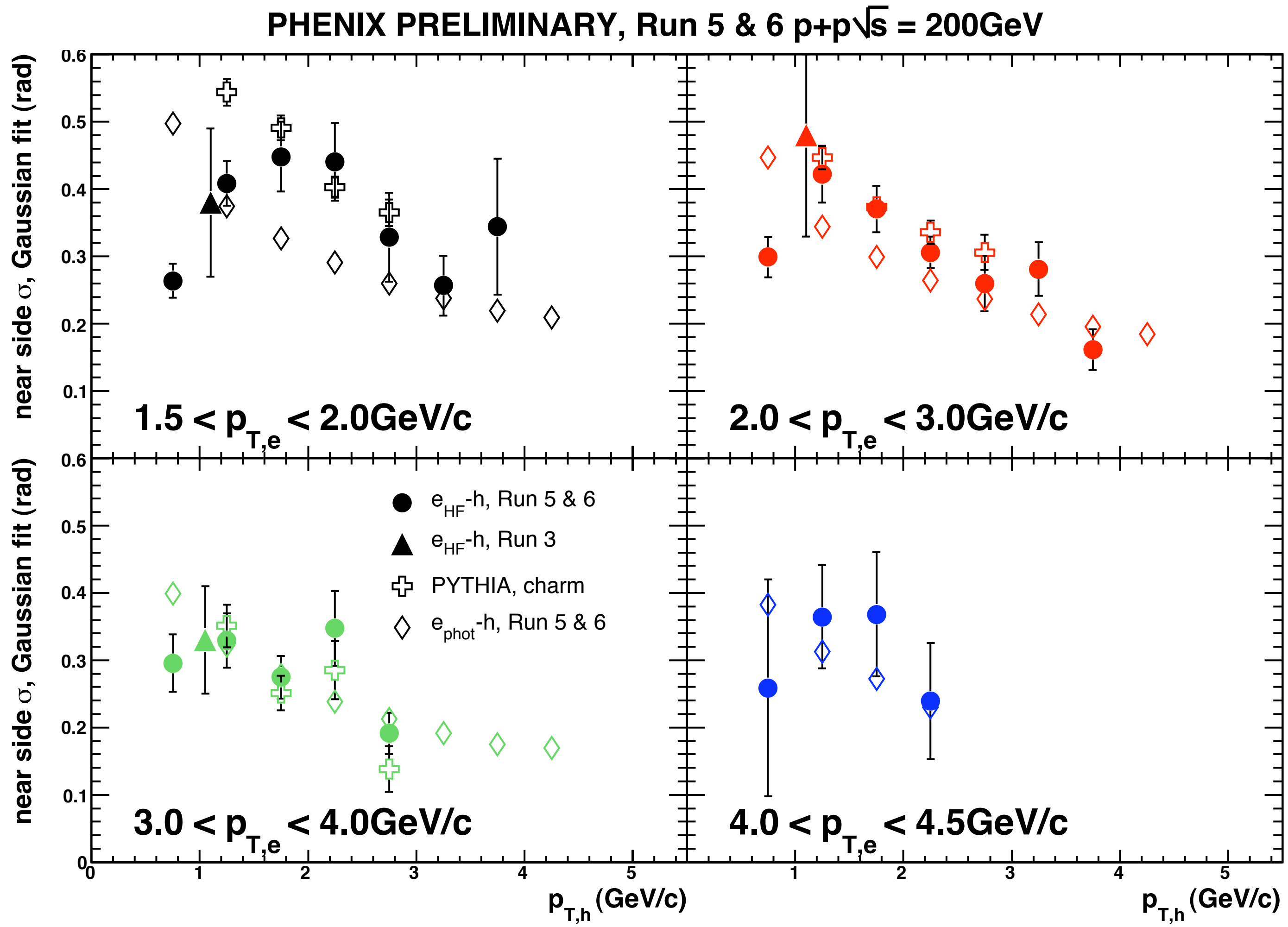


$\sigma_{HF} > \sigma_{phot}$: D/B decay kinematics

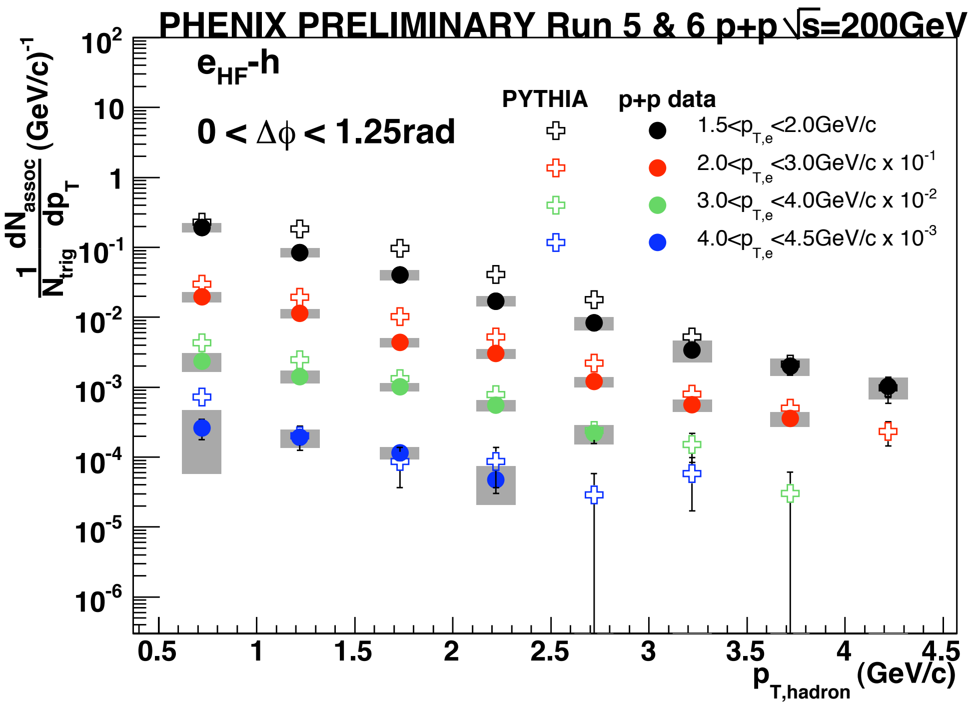
near side widths

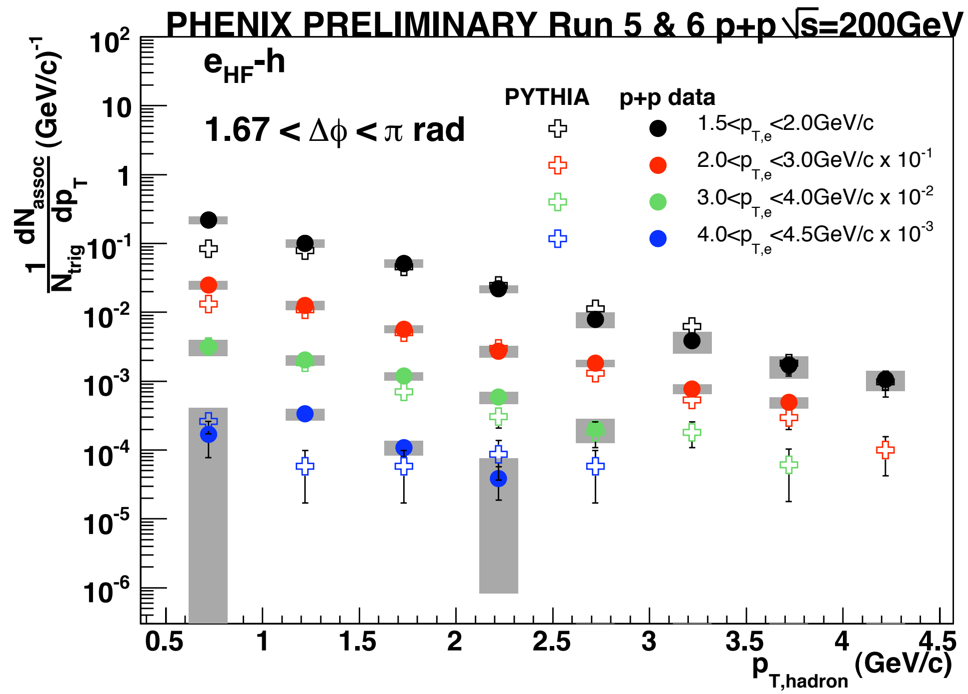


$\sigma_{HF} > \sigma_{phot}$: D/B decay kinematics

good agreement with PYTHIA (charm production)

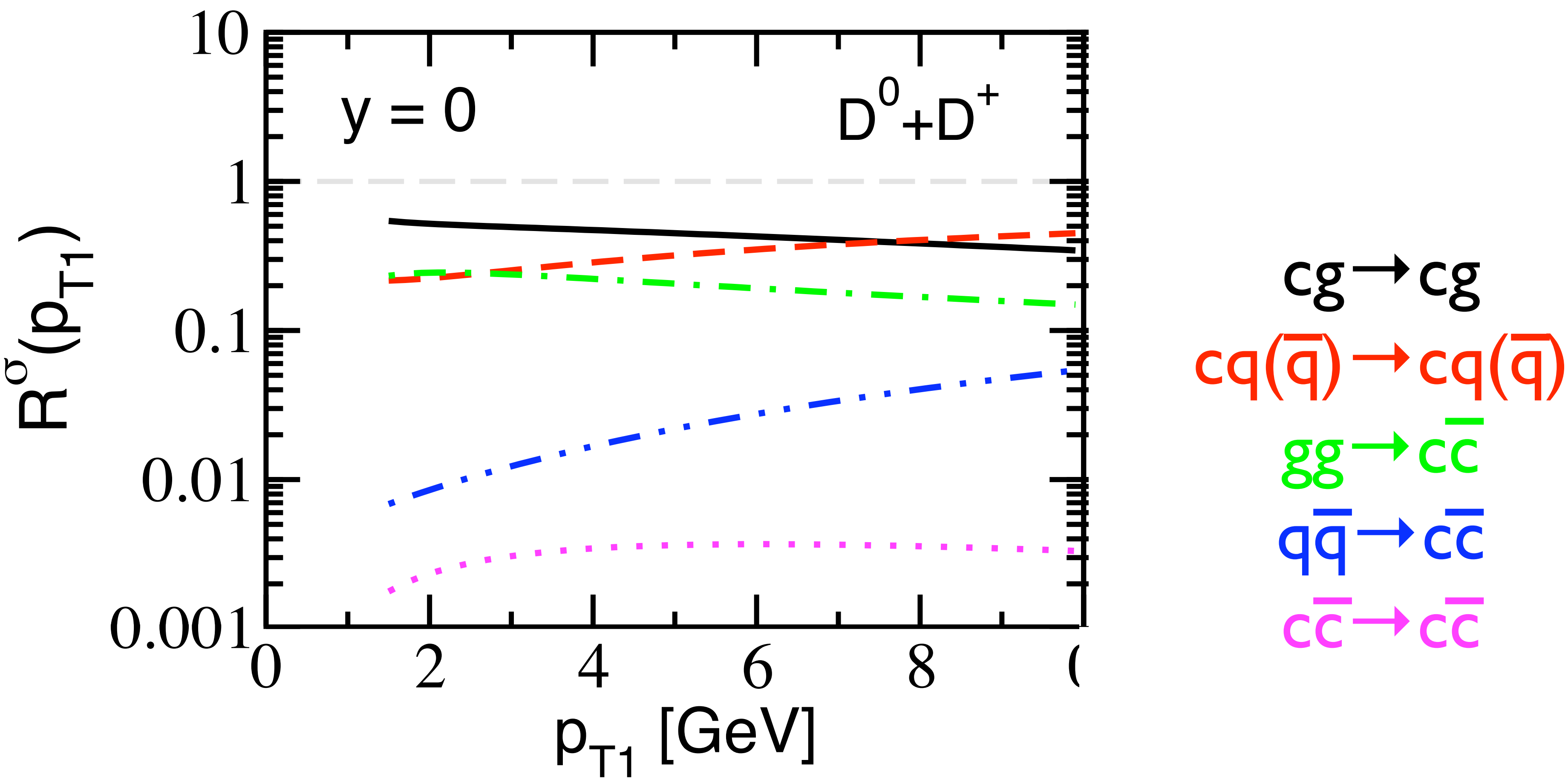
conditional yields





- near side: dominated by decays
- away side: fragmentation and decays
- reasonable agreement with PYTHIA

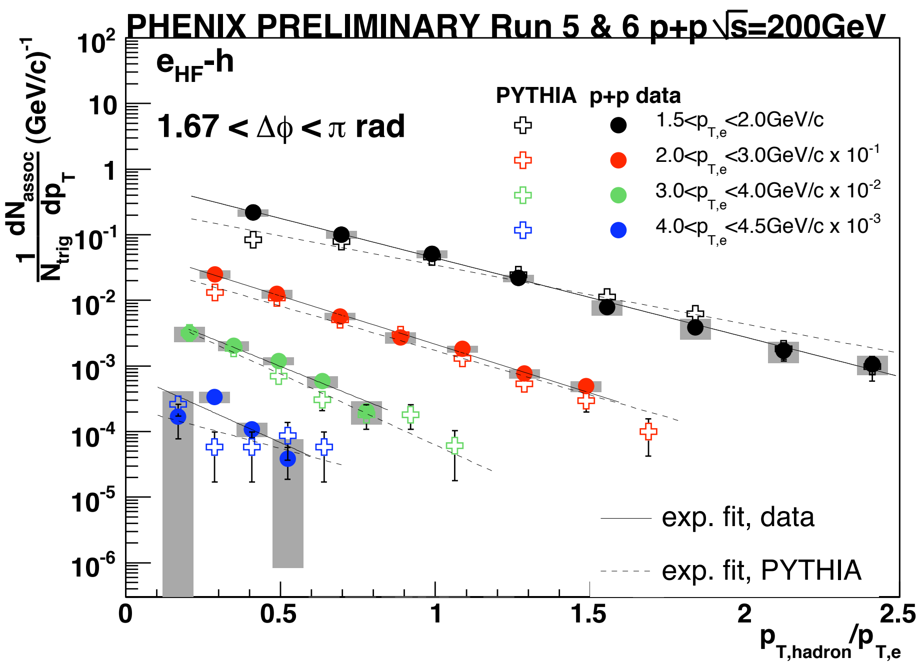
charm production subprocesses

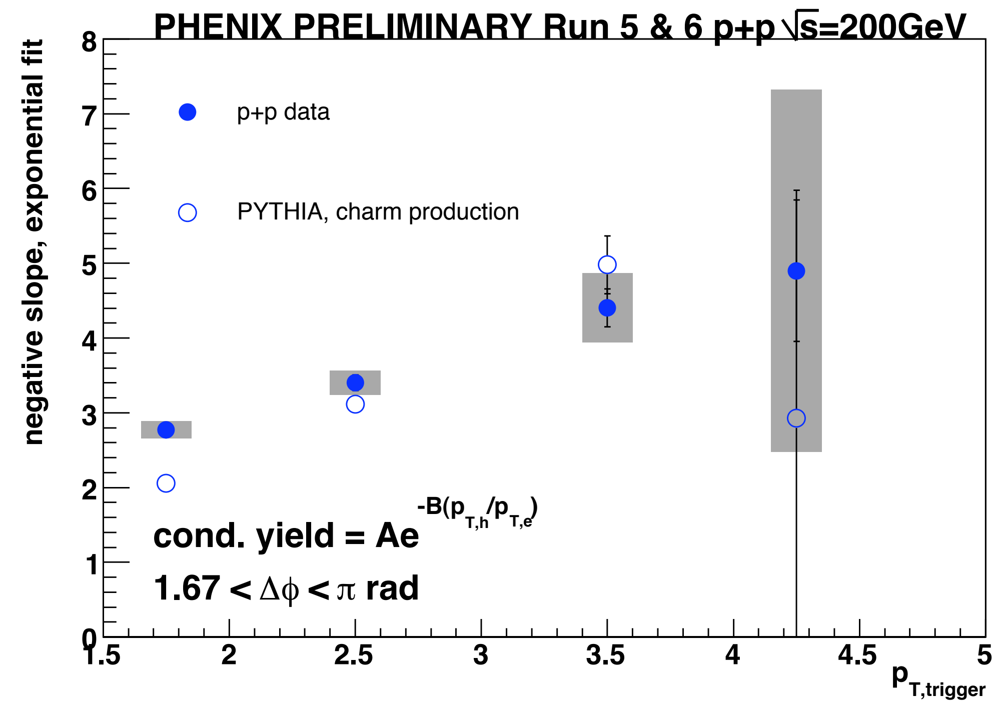


most of the time a D is not balanced by a mid-rapidity $\overline{D}$

Vitev et al PRD 74 054010 (2006)

comparison to light jets





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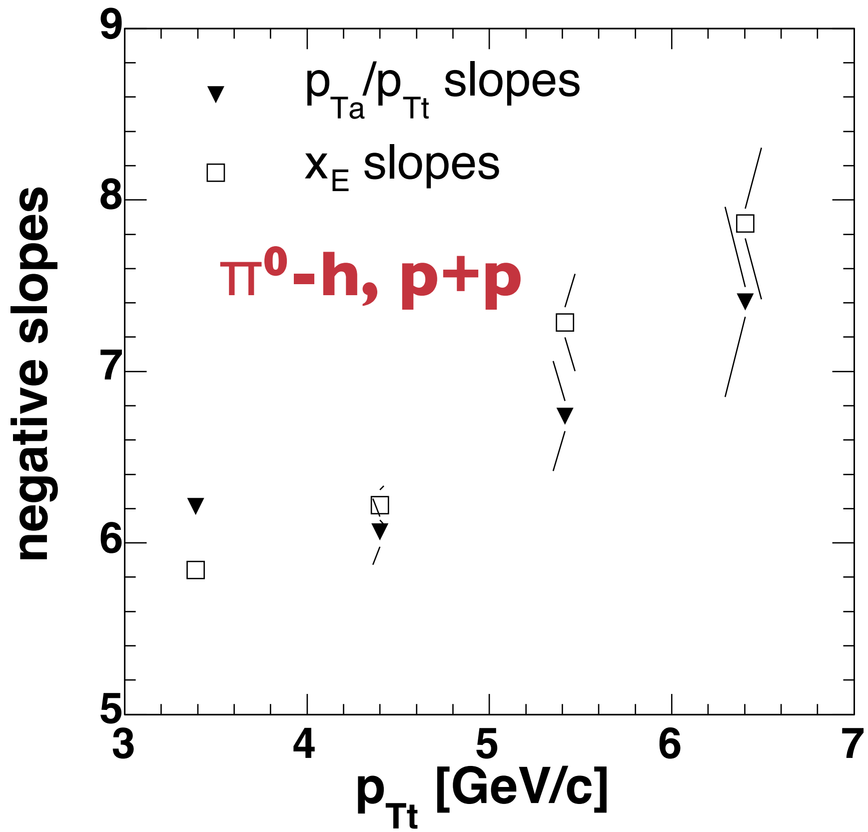

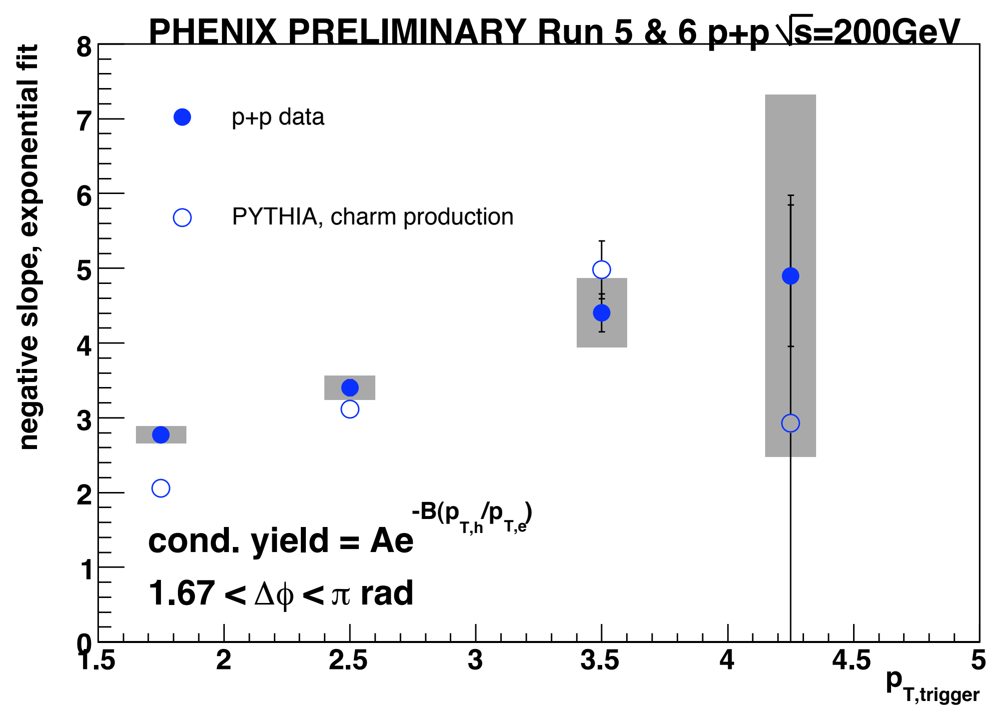

PHENIX PRD 74 072002 (2006)

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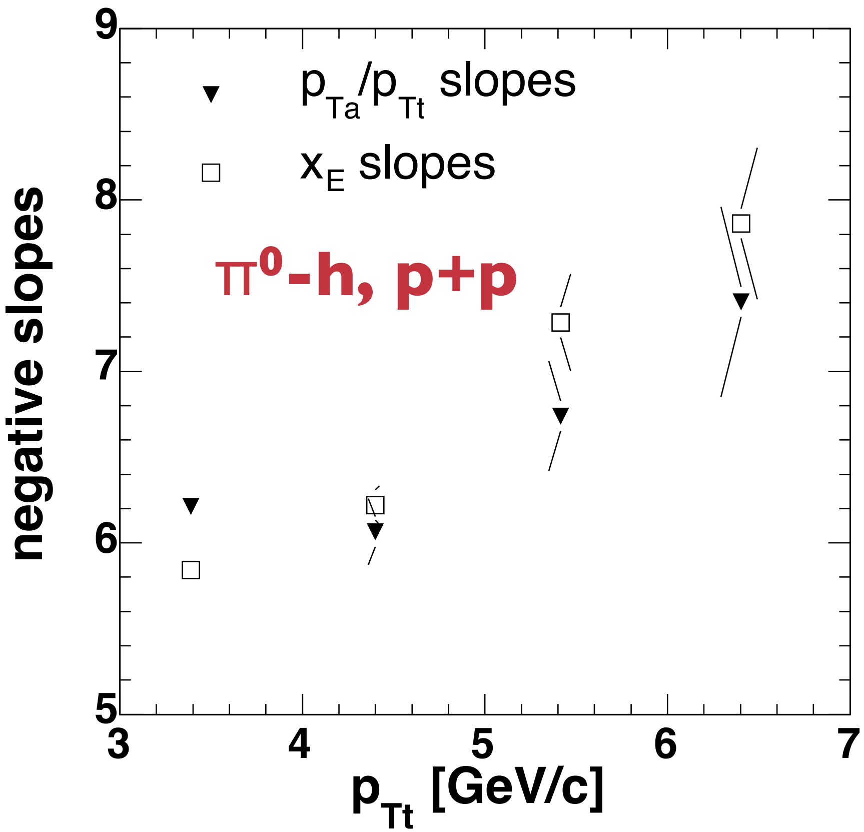
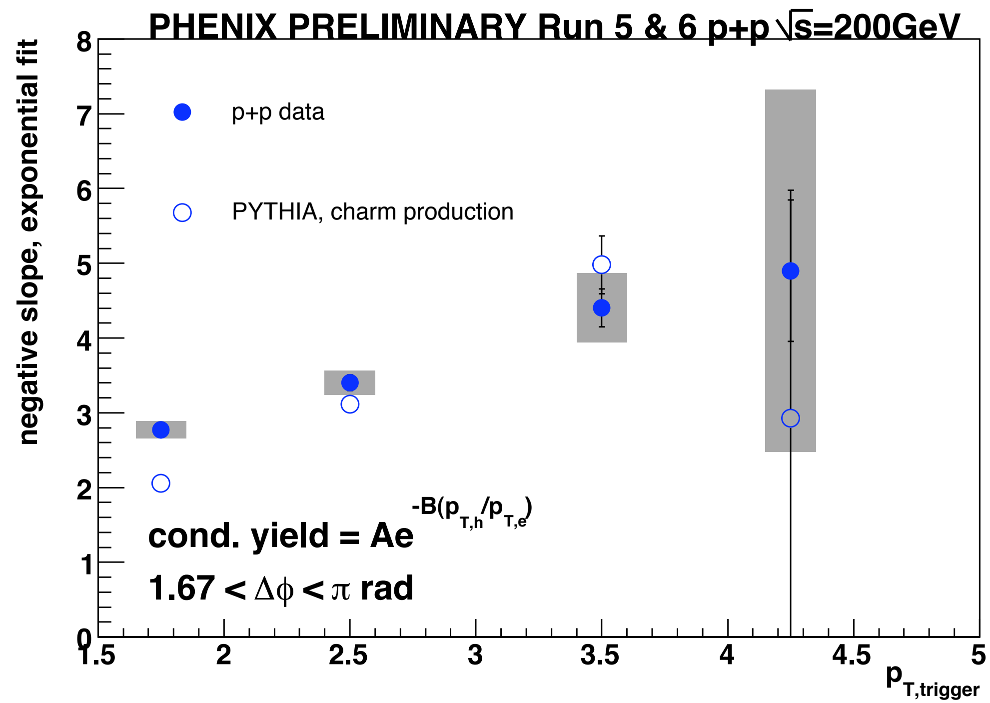




PHENIX PRD 74 072002 (2006)

e_{HF}-h harder @ same $p_{T,trig}$ ($\neq p_{T,parton}$)

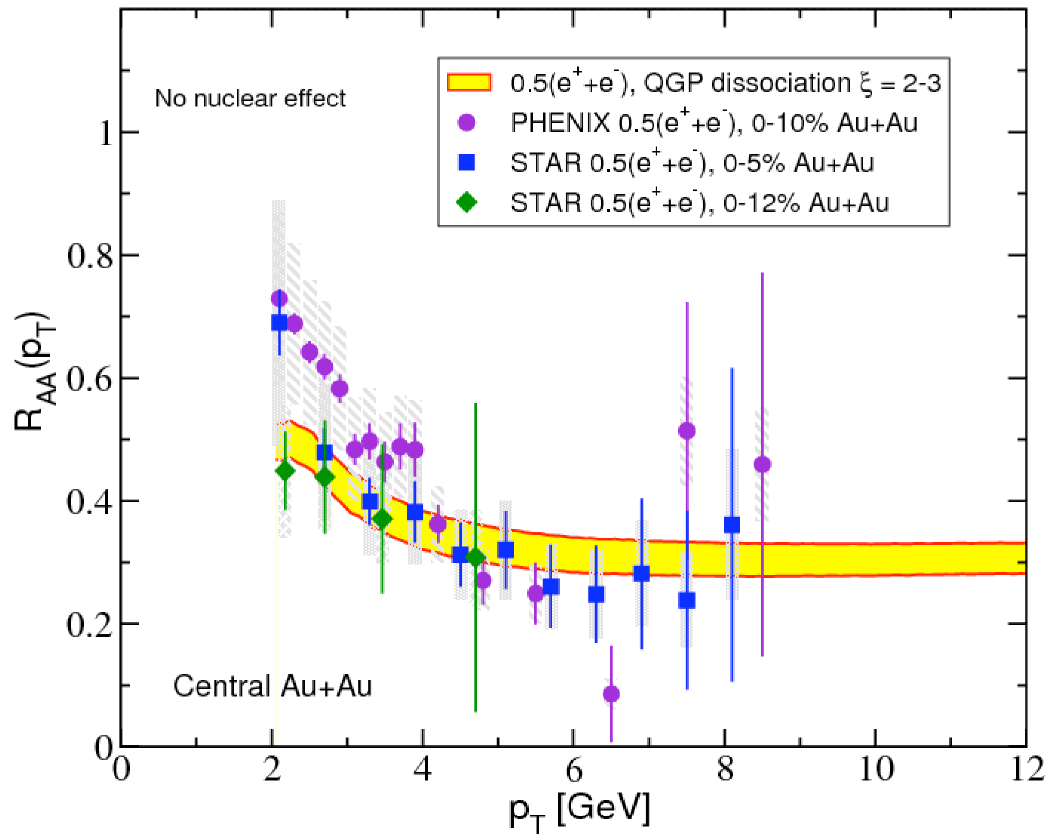
conclusions & outlook

HF correlations provide a new tool to study passage of fast parton through matter

- c/b ratio in p+p consistent with FONLL
    - this ratio crucial to understanding e± results in Au+Au
- e_{HF}-h conditional yields in p+p measured
    - method established to extract HF correlations
    - useful for testing charm fragmentation into hadrons
    - baseline for Au+Au results, being analyzed now

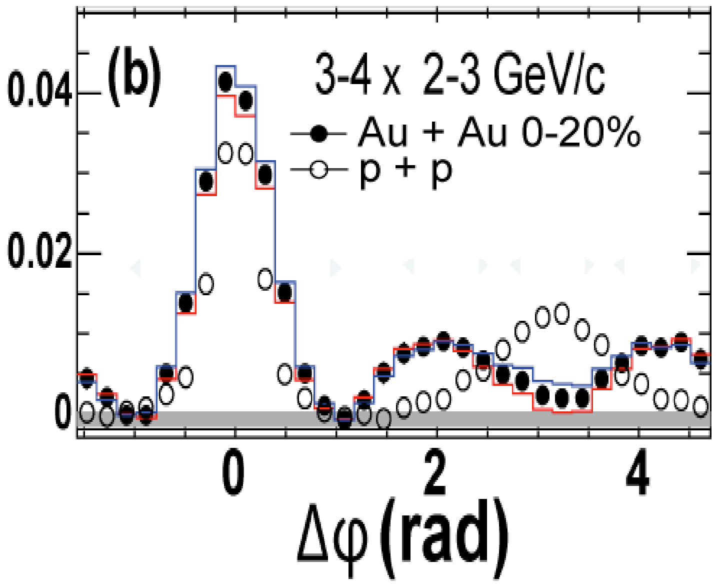
D/B in medium formation

- D/B form & dissociate in the matter:
  - $\tau_{form} \propto p_T$
  - $\tau_{formD}(10GeV/c)=1.6fm/c$
  - $\tau_{formB}(10GeV/c)=0.4fm/c$
- expect to see extra hadrons on the near side from the D & B energy loss



Adil & Vitev PLB649 139 (2007)

Double Peak Structure



PHENIX, PRC 78 014901 (2008), Noronha et al. arXiv:0807.1038, Neufeld arXiv:0807.2996

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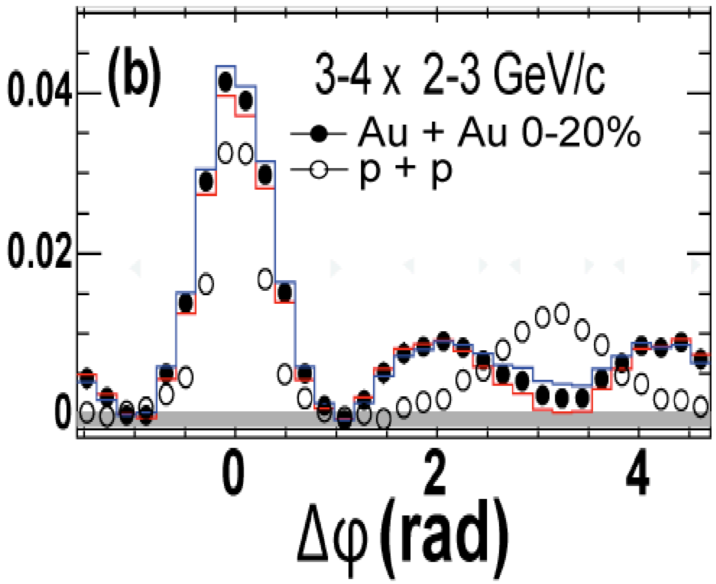

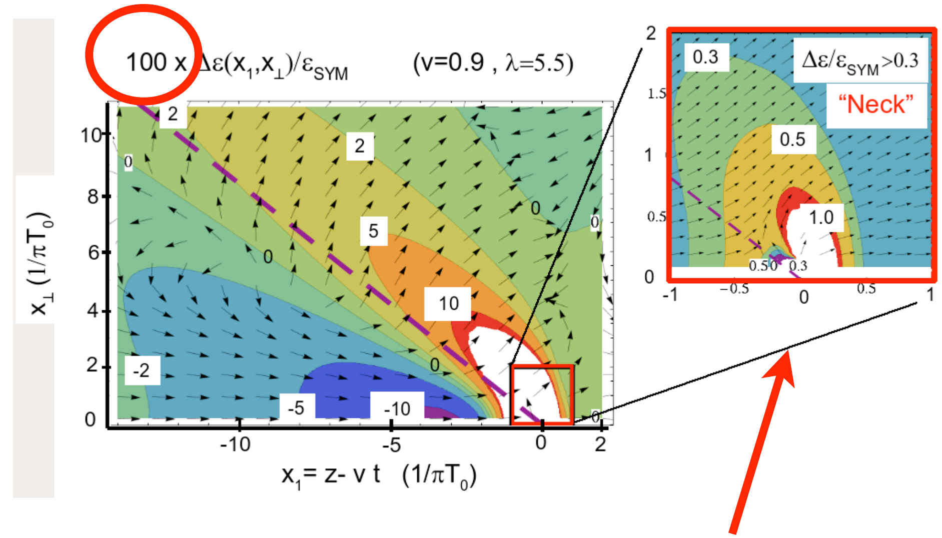

AdS/CFT: Correlations from Neck region

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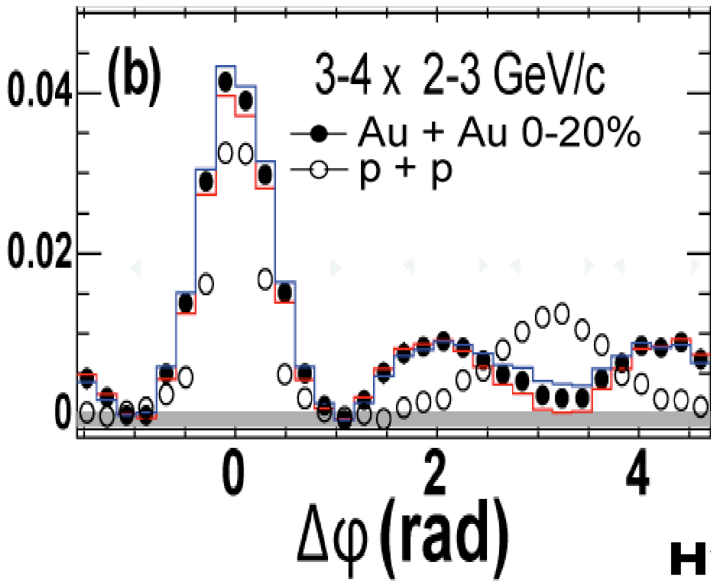
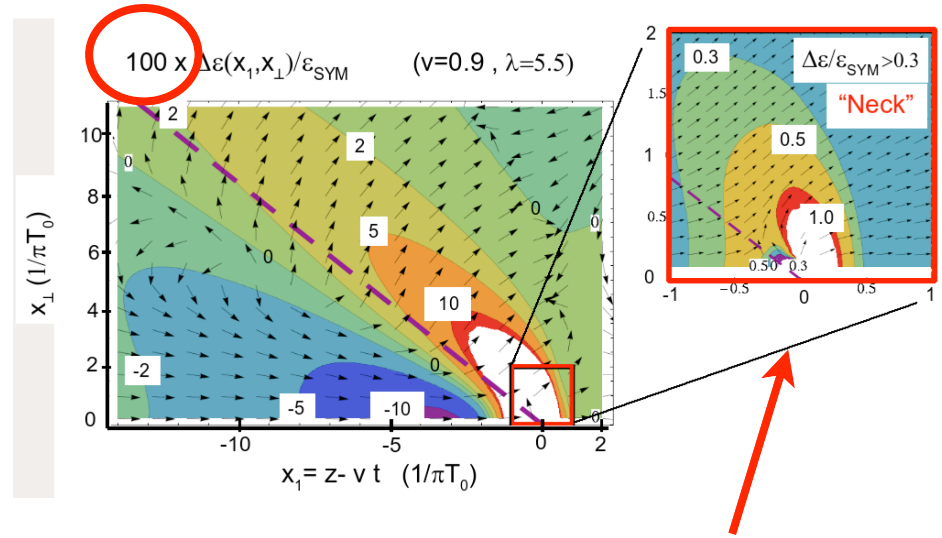
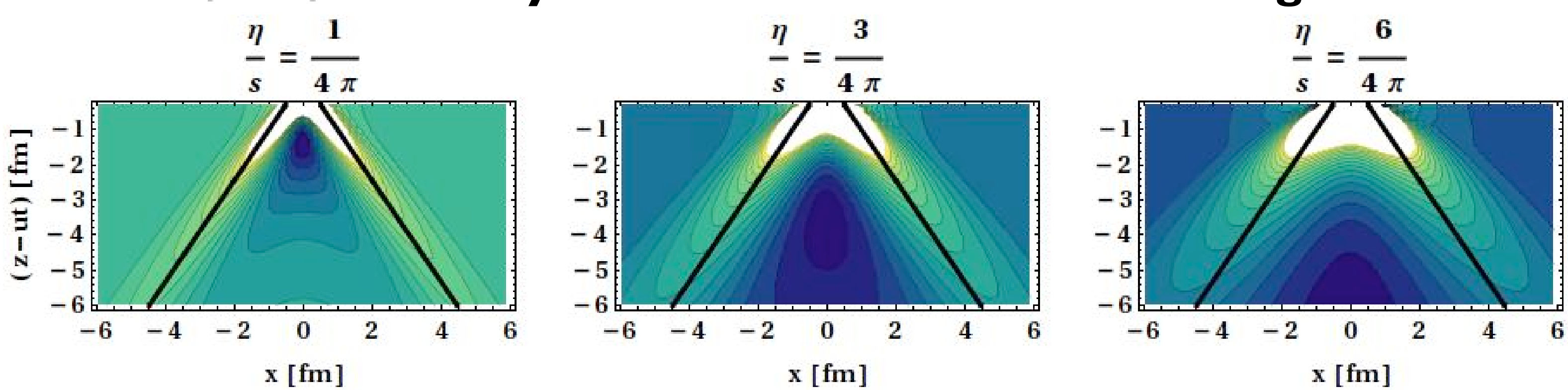




AdS/CFT: Correlations from Neck region

Hydro: Mach Cone width & strength sensitive to η/s



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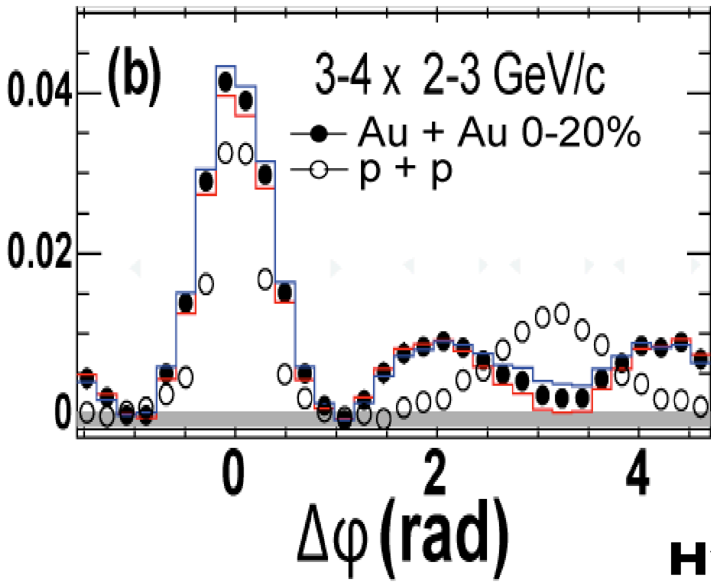

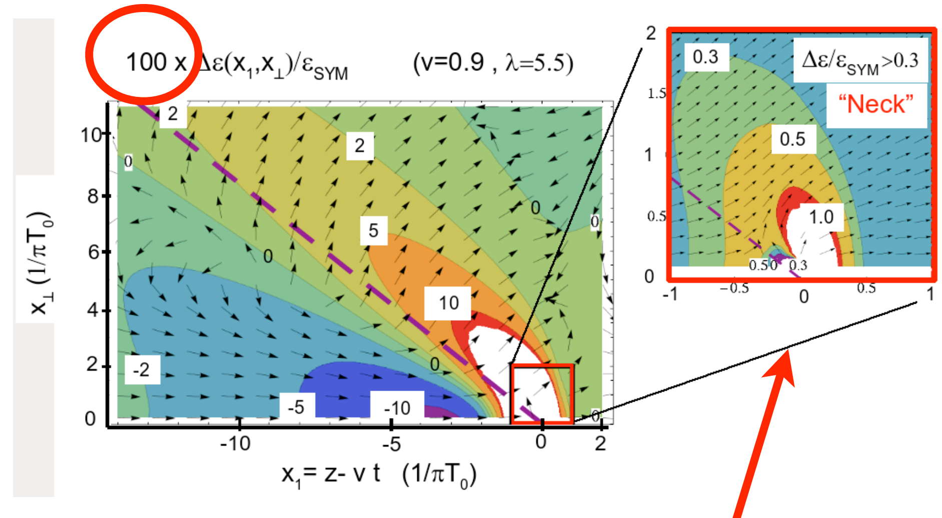

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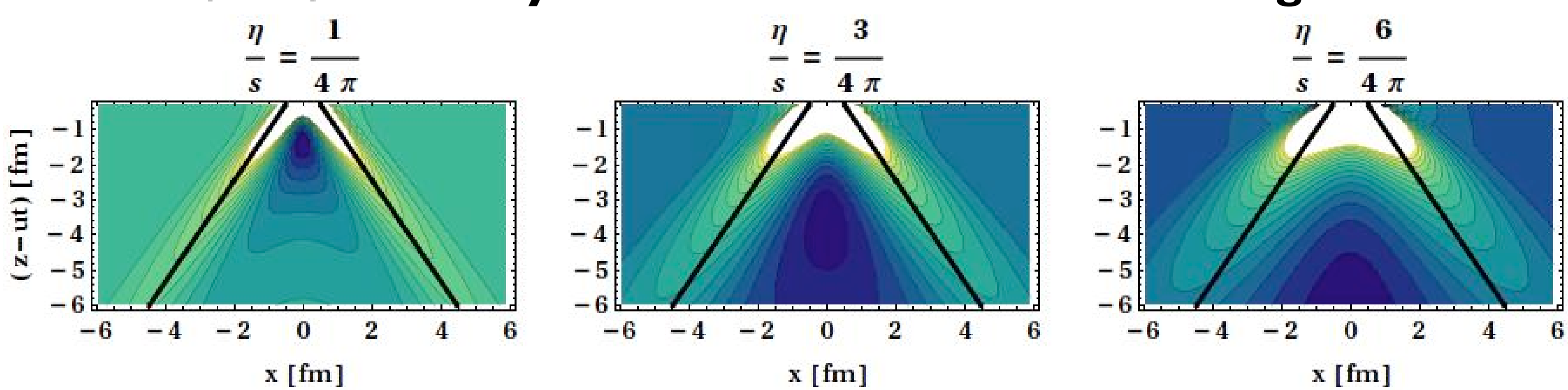
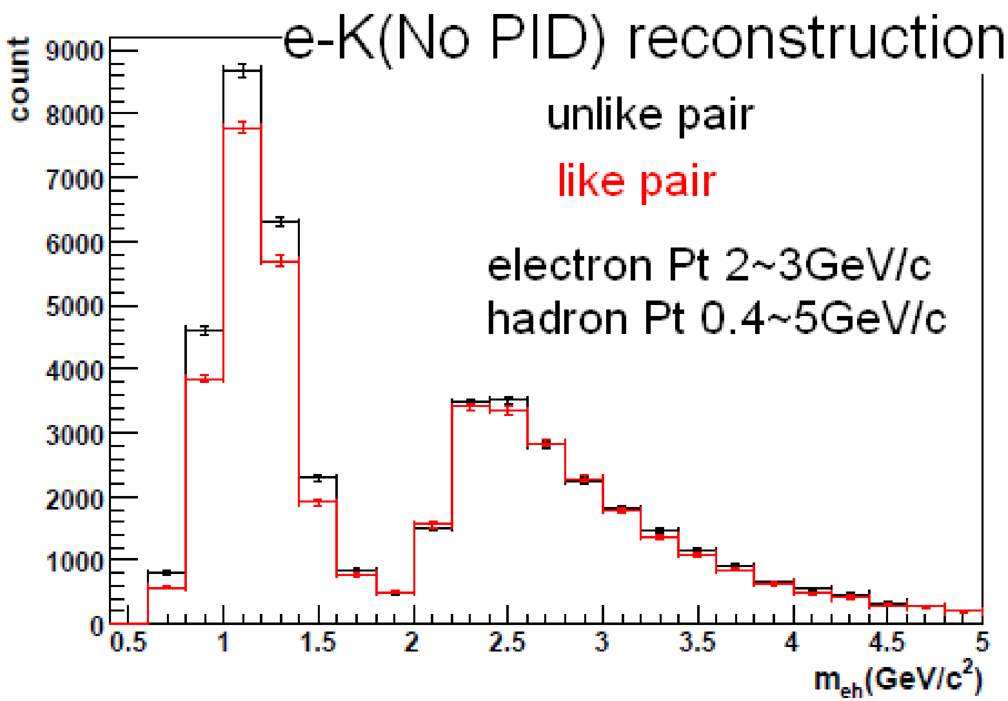


Heavy quark correlations should help discriminate!

PHENIX, PRC 78 014901 (2008), Noronha et al. arXiv:0807.1038, Neufeld arXiv:0807.2996


e-K(No PID) reconstruction
unlike pair
like pair
electron Pt 2~3GeV/c
hadron Pt 0.4~5GeV/c
count
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$m_{eh}(GeV/c^2)$