

# Open Heavy Flavor with PHENIX Detector

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for the PHENIX collaboration

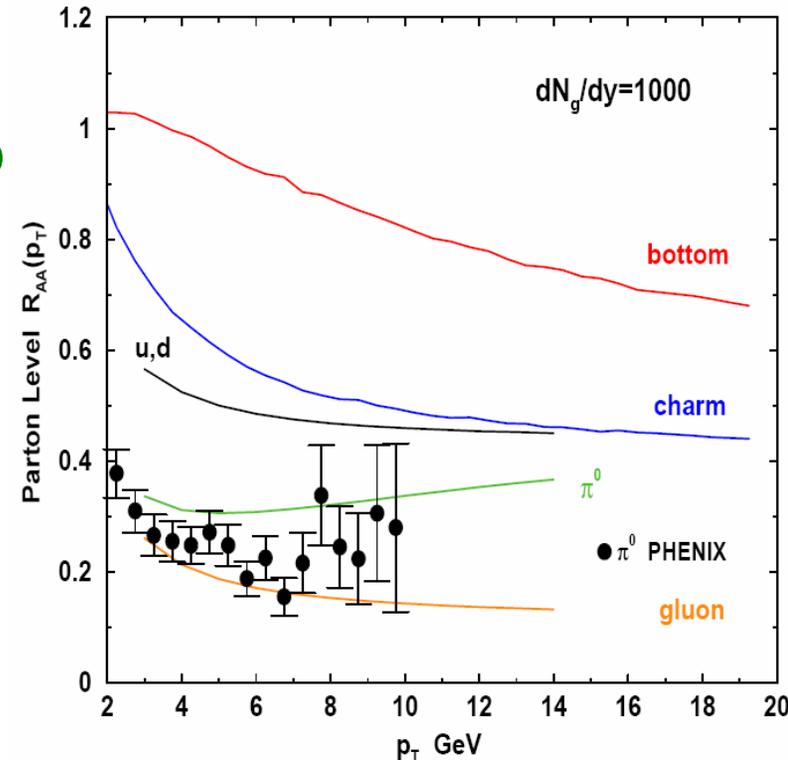
# Outline

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- ✦ Heavy Quark as a Unique QGP Probe
- ✦ PHENIX Heavy Flavor Physics Program
- ✦ Latest Results for Open Charm Measurements in PHENIX
- ✦ Future Outlook

# Heavy Quarks – Unique Probes of QGP

- ✦ Charm and bottom quarks do not exist in the nucleus → they need to be produced early in the collision
- ✦ Quark mass is large → production can be explained by pQCD
- ✦ Heavy → energy loss in the medium should be smaller than for light quarks
- ✦ Bottom quark is so heavy ( $m_b \sim 4.5 \text{ GeV}/c^2$ ) that it should be least affected by interactions with medium



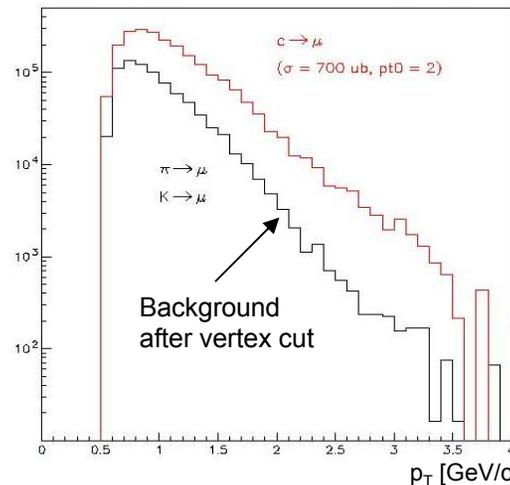
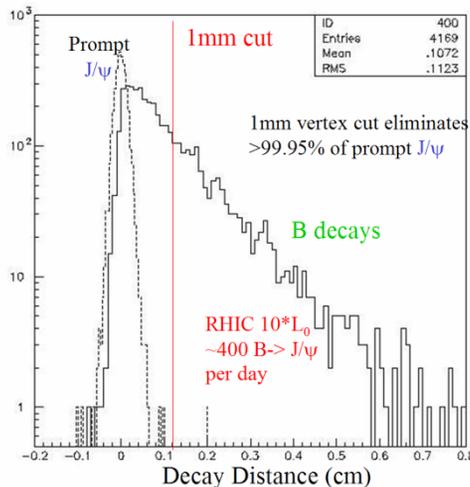
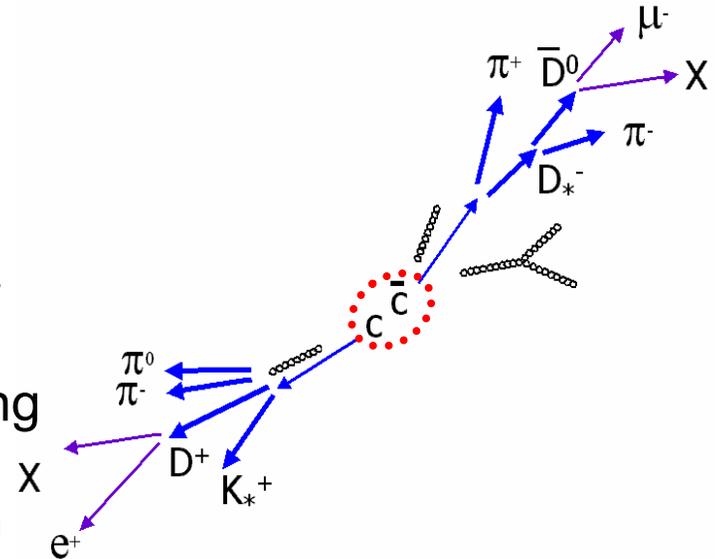
Theoretical predictions for Partonic Level  $R_{AA}$  for different quark flavor

M. Djordjevic, M. Gyulassy, R. Vogt, S. Wicks. Nucl-th/0507019

# Identification of Heavy Flavor

## ✦ Experimentally easy to observe

- Hadronic decay channels  $D \rightarrow K\pi$ ,  
 $D^0 \rightarrow K^+ \pi^- \pi^0$
- Semi-leptonic decays  $D \rightarrow e(\mu) \pi \nu_e$
- Tagging B and D meson decays away from primary vertex
- Separate bottom from charm by tagging  
 $B \rightarrow J/\psi + X$  decays



Meson	$D^\pm, D^0$
Mass	1869(1865) GeV
BR $D^0 \rightarrow K^+ \pi^-$	$3.85 \pm 0.10 \%$
BR $D^0 \rightarrow K^+ \pi^- \pi^0$	$14.1 \pm 0.10 \%$
BR $\rightarrow e^+ + X$	17.2(6.7) %
BR $\rightarrow \mu^+ + X$	6.6 %

# Heavy Flavor Program at RHIC

## ★ PHENIX

### ★ Open Charm

- Single electron, muon measurements in p+p, d+Au, Au+Au  
 $\sqrt{s_{NN}} = 130, 200, 62.4 \text{ GeV}$
- Direct D mesons decay channels in p+p and d+Au

### ★ Open Charm, Bottom

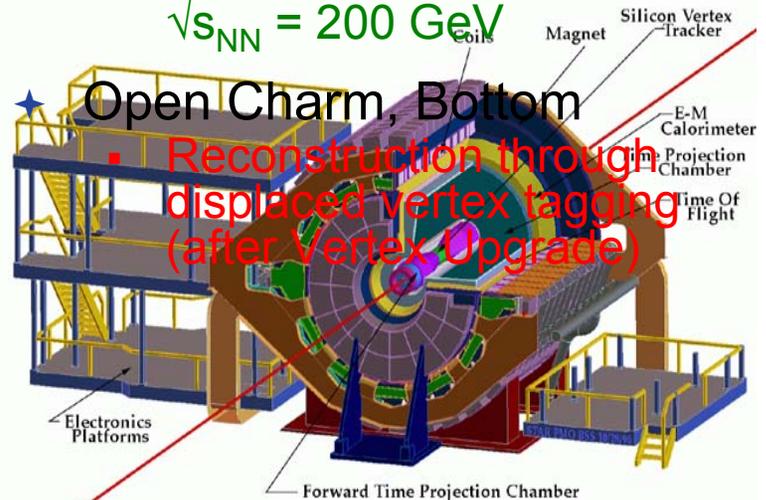
- Reconstruction through displaced vertex tagging (after Vertex Upgrade)



## ★ STAR

### ★ Open Charm

- Direct D mesons decay channels in d+Au
  - $D^0 \rightarrow K^- \pi^+$
  - $D^\pm \rightarrow K^- \pi^+ \pi^\pm$
  - $D^{*\pm} \rightarrow D^0 \pi^\pm$
- Single electron measurements in p+p, d+Au, Au+Au  
 $\sqrt{s_{NN}} = 200 \text{ GeV}$



### ★ Open Charm, Bottom

- Reconstruction through displaced vertex tagging (after Vertex Upgrade)

# PHENIX detector at RHIC

## ✦ Photon & Charged Particle Tracking

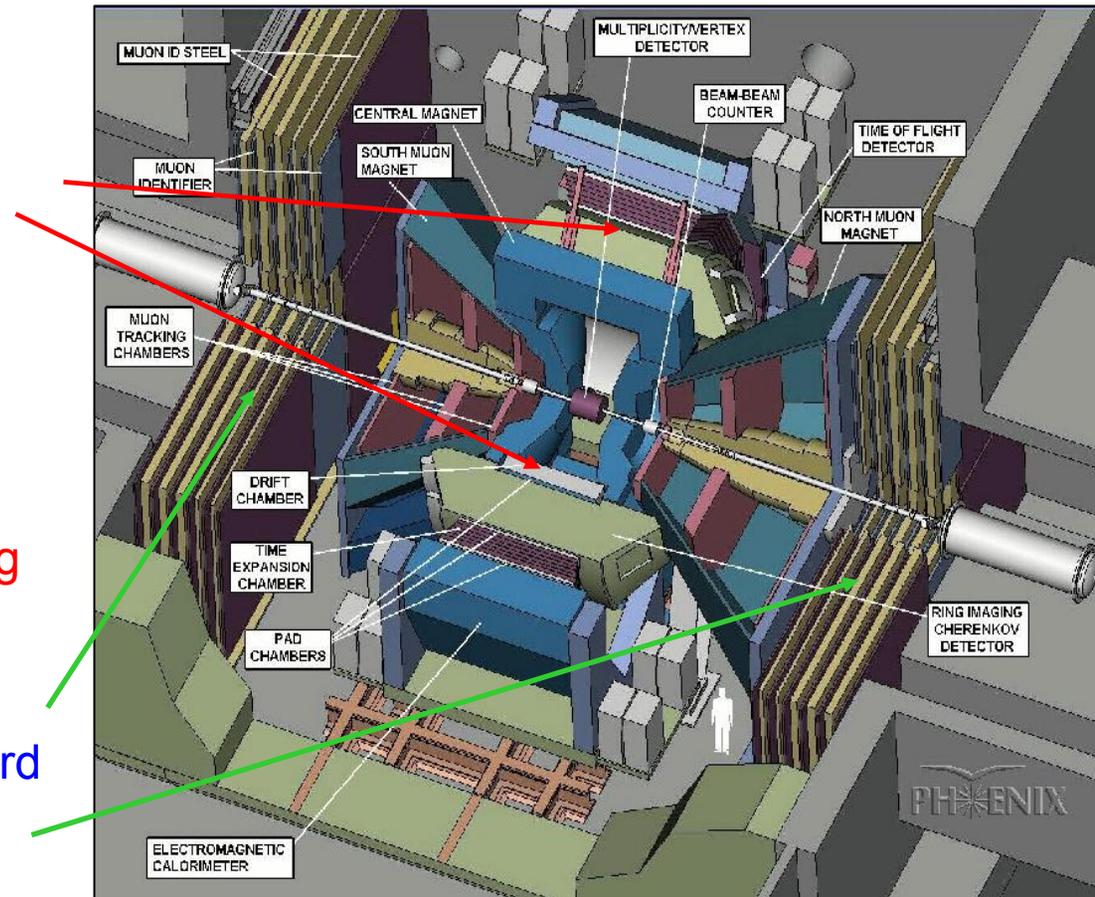
- $|\eta| < 0.35$
- Two separate arms  $90^\circ$
- $dp_T/p_T \approx 1.2\% \cdot p_T$

## ✦ Electron ID

- RICH ( $\gamma_{\text{thr}}=35$ )
- $e/\pi$  separation up to  $p_T \sim 5 \text{ GeV}/c$
- Energy/momentum matching

## ✦ Muon measurements

- $1.2 < |\eta| < 2.7$
- Two separate arms in forward and backward rapidity



# Electron ID in PHENIX

- PHENIX detector has unique electron ID capabilities
- Electron is tagged by Ring Imaging Cherenkov Detector
- Energy of the EMC cluster and momentum of the track should match each other

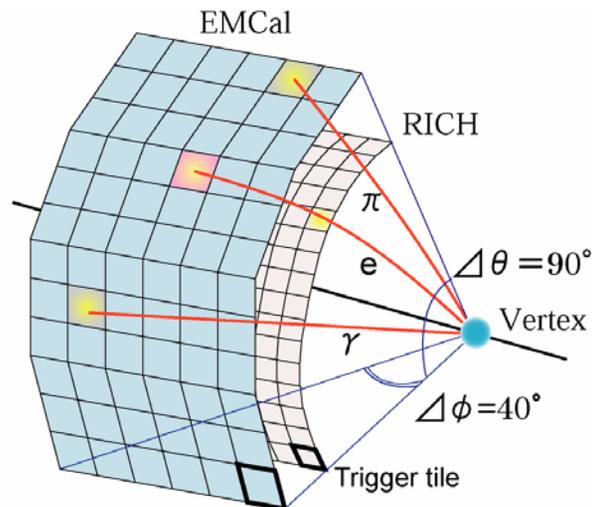
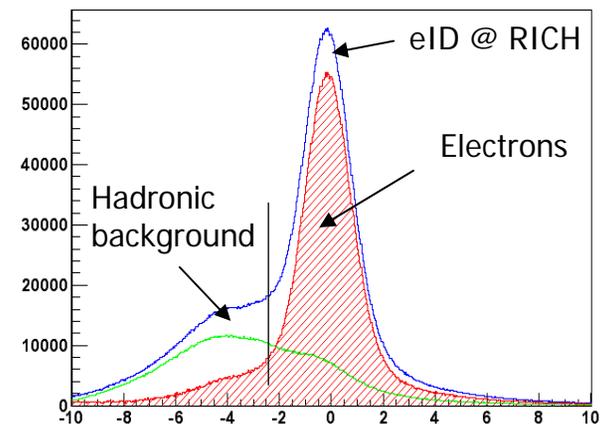
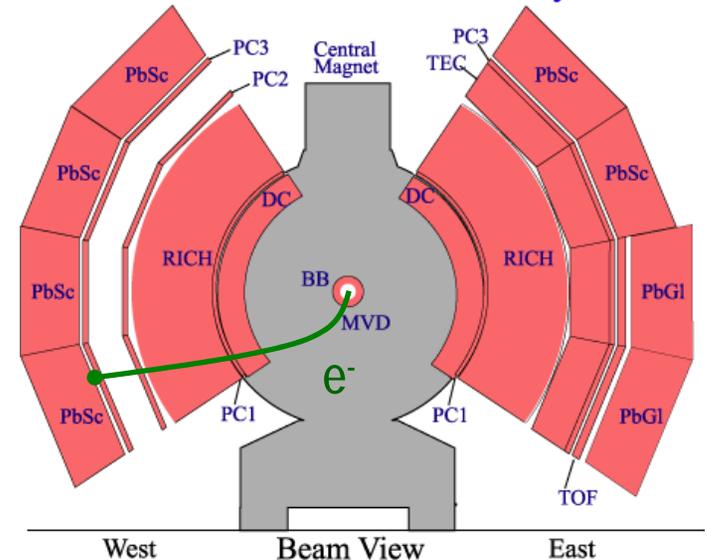


Image of electron detection (one of 2 arms)

PHENIX Detector - Second Year Physics Run



# Heavy Flavor Analysis Progress

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- ✦ Greatly improved statistical significance of p+p reference measurements using Run 5 dataset
- ✦ Increased a  $p_T$  range of single electron measurements ( $p_T > 5$  GeV/c) by using tighter RICH and EMC cut
- ✦ Finalizing of non-photon electron  $v_2$  and di-lepton continuum analyses
- ✦ First look at direct reconstruction of D meson through hadronic decay modes
- ✦ Run 7 Au+Au data set should provide a factor of  $\sim 5 \div 10$  statistics improvement to heavy flavor signal

# Charm Electrons in PHENIX

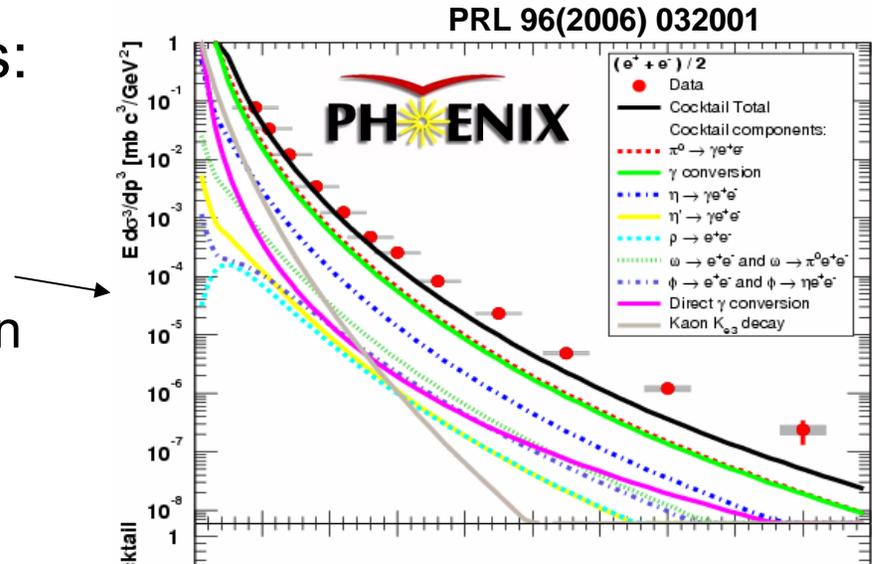
## ★ Signal extraction methods:

### ■ Cocktail subtraction

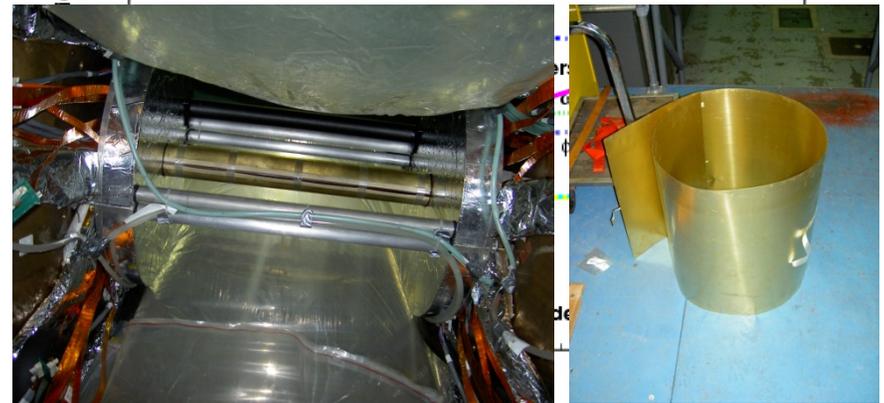
Simulate “photonic” electron background from decay of  $\pi^0$ , light mesons, photon conversion and  $K_{e3}$  decays

### ■ Converter subtraction

Extract the “photonic” component by adding conversion material of “photon converter”

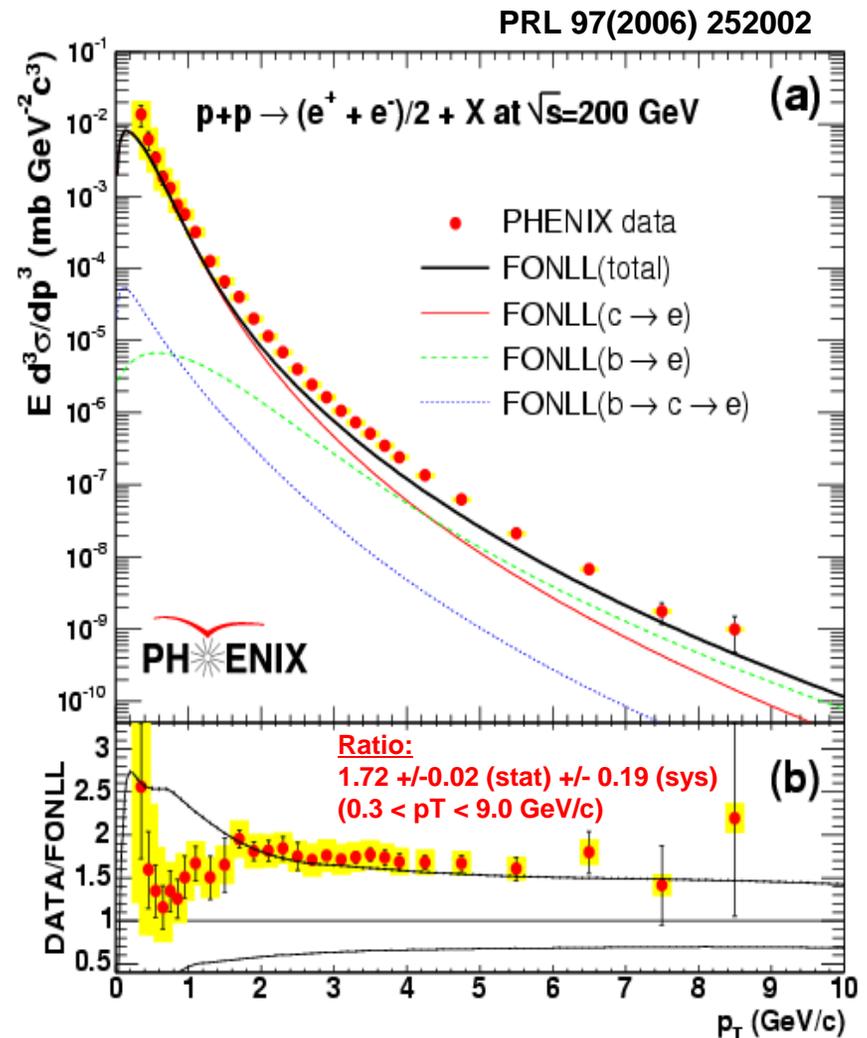
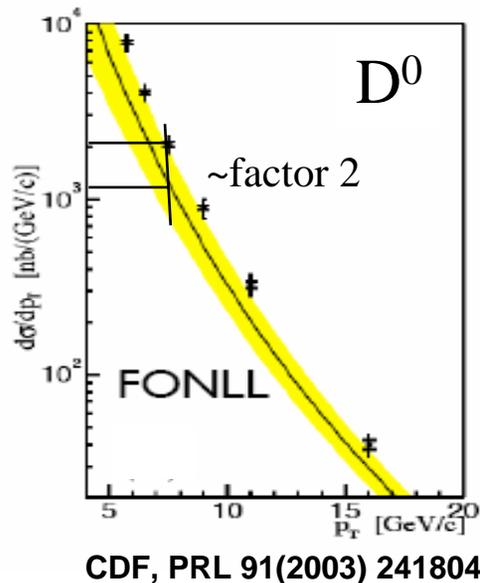


Photon Converter (Brass: 1.7%  $X_0$ )



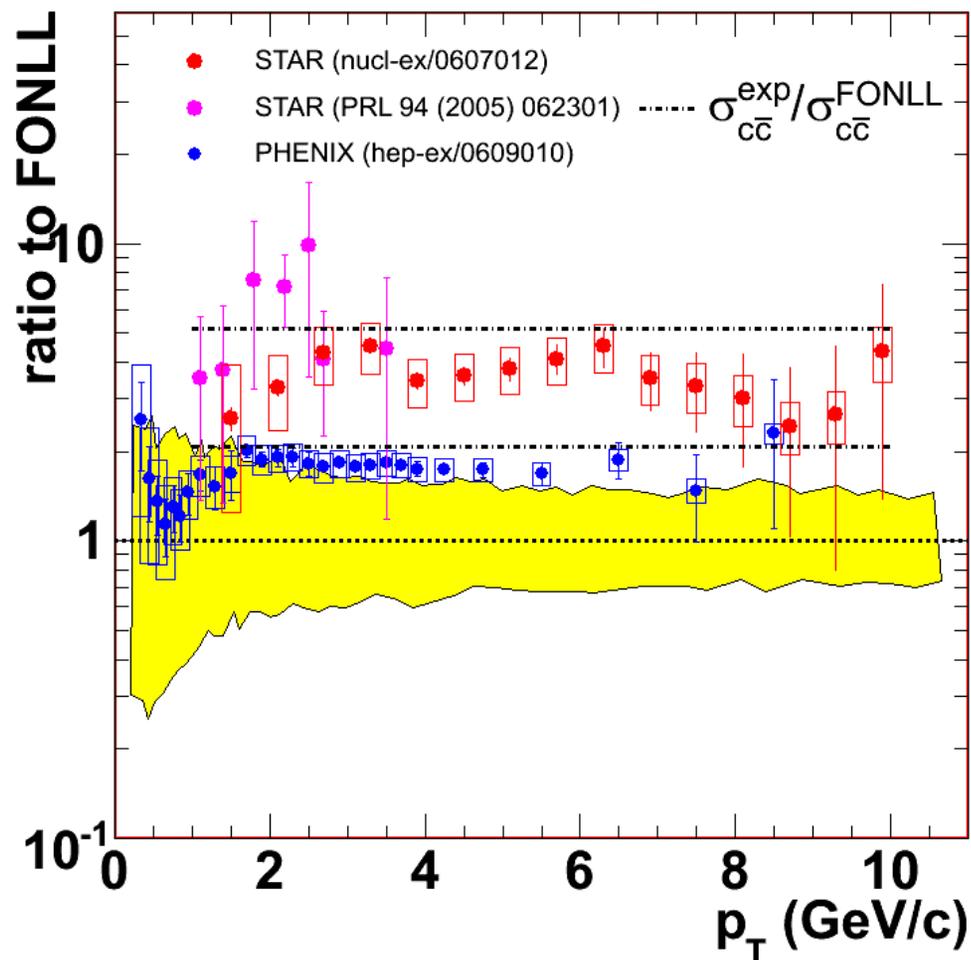
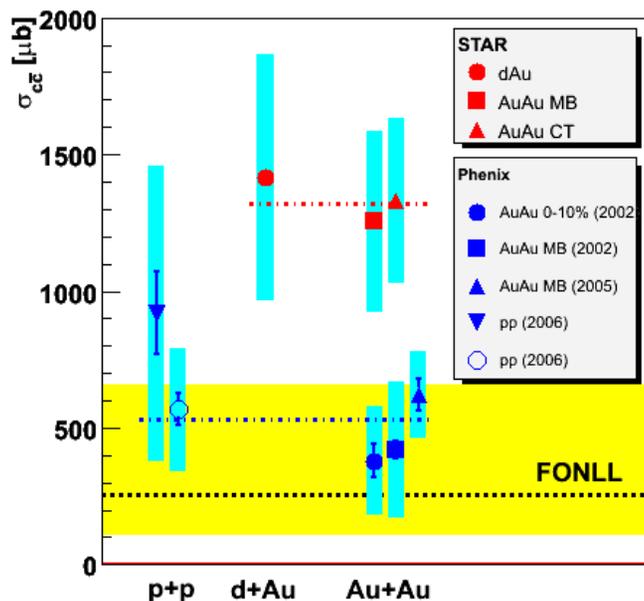
# Open Charm in p+p at $\sqrt{s}=200$ GeV

- ★  $\sigma_{cc} = 567 \pm 57(\text{stat}) \pm 224(\text{sys}) \mu\text{b}$
- ★ Central value for NLO predictions by M.Giacchiari underpredicts the data by 1.7
- ★ pQCD next order corrections usually comparable with error bars on the previous order calculations



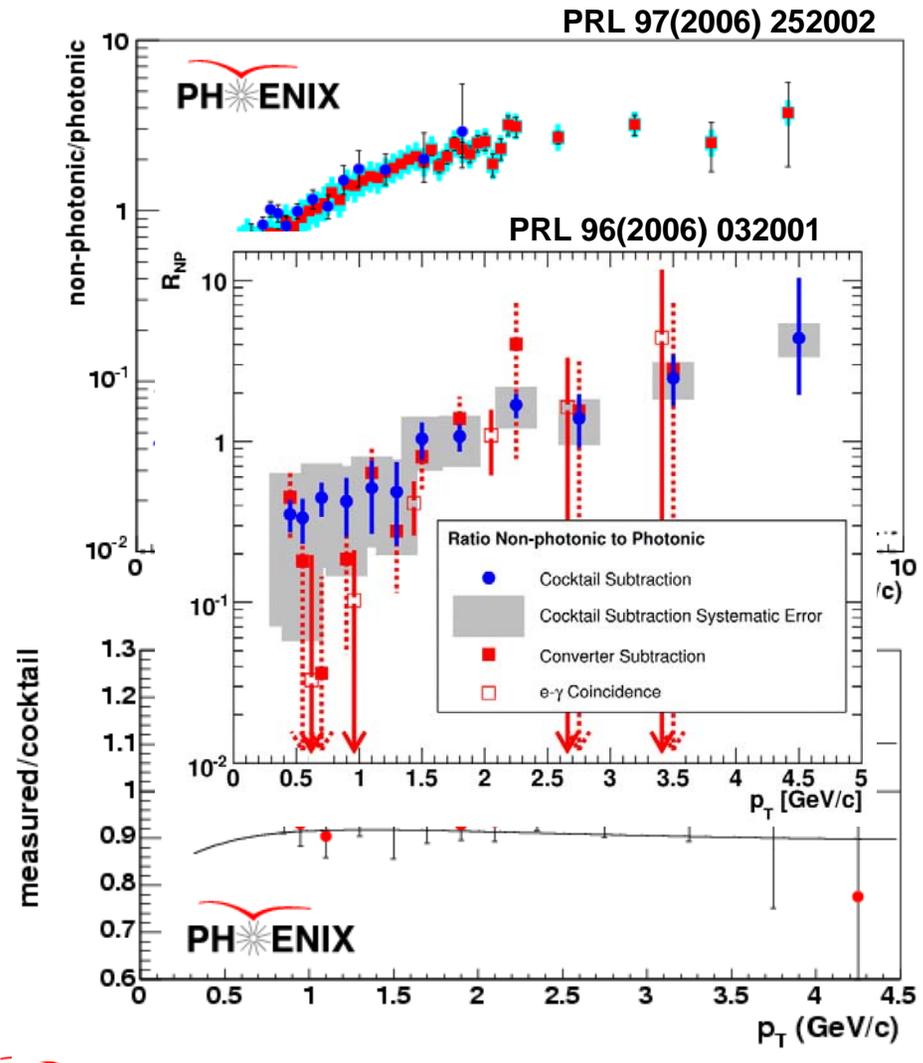
# Open Charm in p+p STAR vs. PHENIX

- ★ PHENIX & STAR electron spectra both agree in shape with FONLL theoretical prediction
- ★ Absolute scale is different by a factor of 2



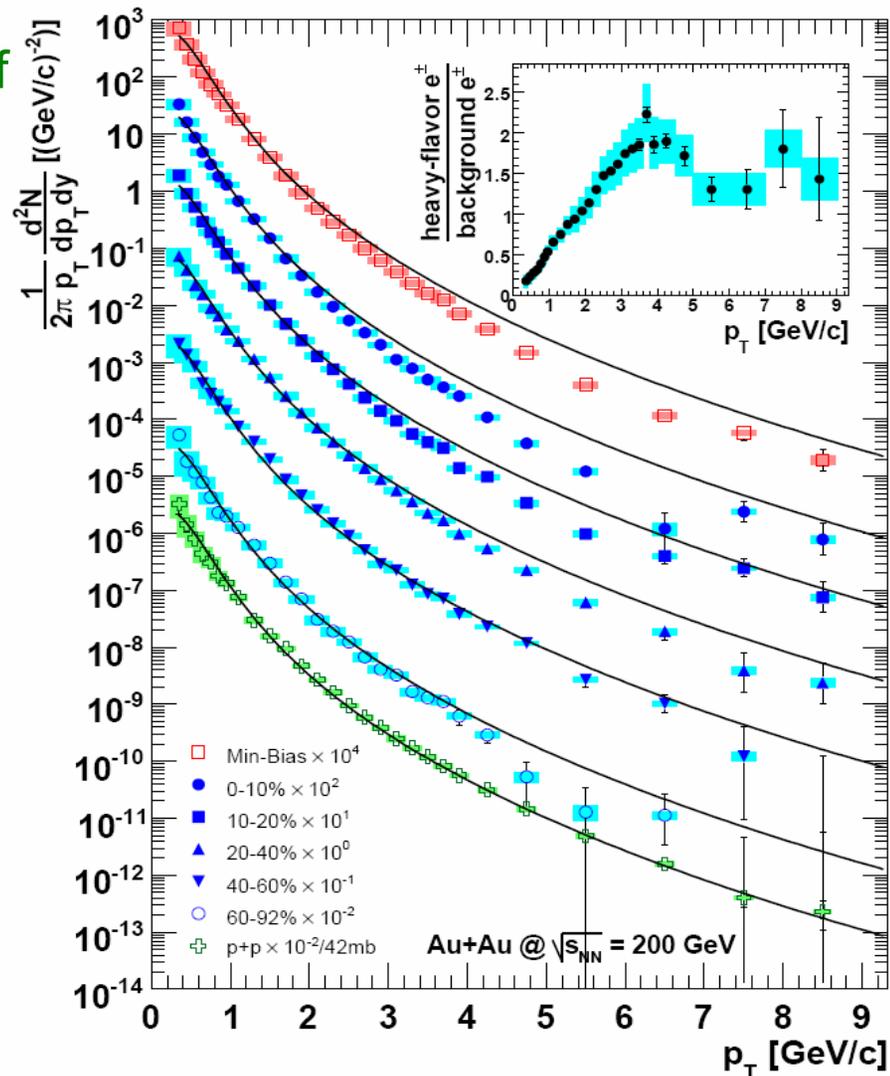
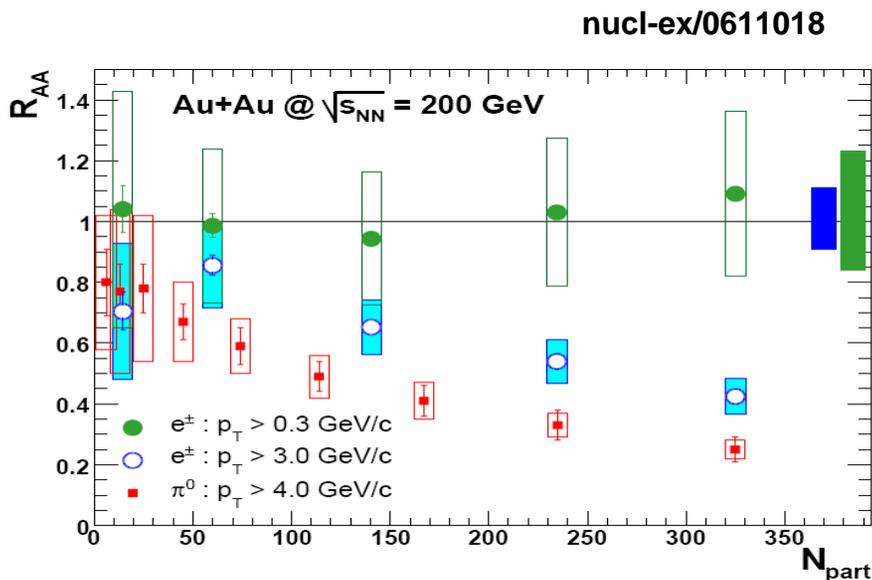
# Analysis Crosscheck

- ✦ Ratio of “non-photonic” to “photonic” electrons agrees very well between two completely independent analysis techniques
- ✦ Converter method more accurate at low  $p_T$
- ✦ Cocktail analysis more accurate at high  $p_T$
- ✦ Combination of both analysis is used for the publications



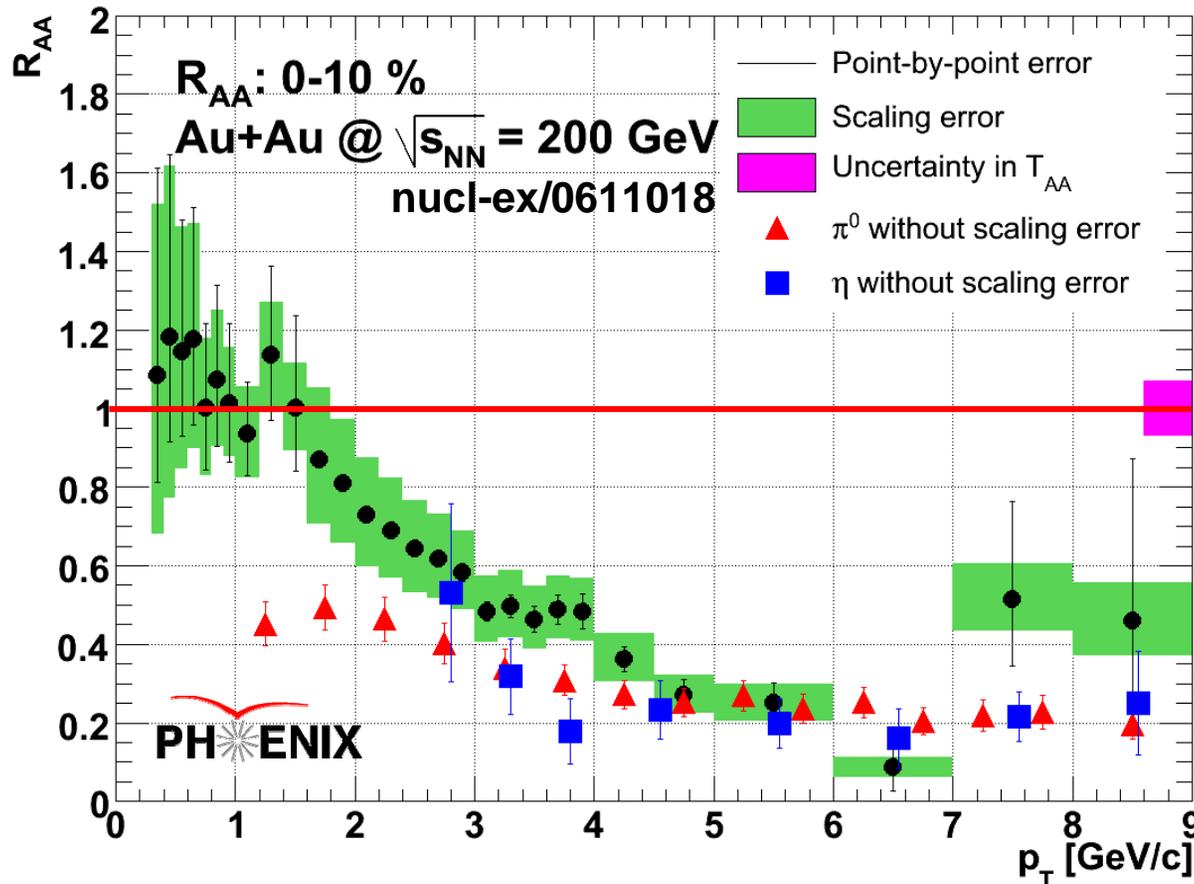
# Open Charm in Au+Au at $\sqrt{s_{NN}}=200$ GeV

- Not much higher statistics of binary collisions
- Clear indication of high  $p_T$  suppression in central collisions
- Need more statistics for precise Total yield of Open Charm still scales with  $N_{bin}$



# $R_{AA}$ for the Heavy Flavor from PHENIX

00-10 %



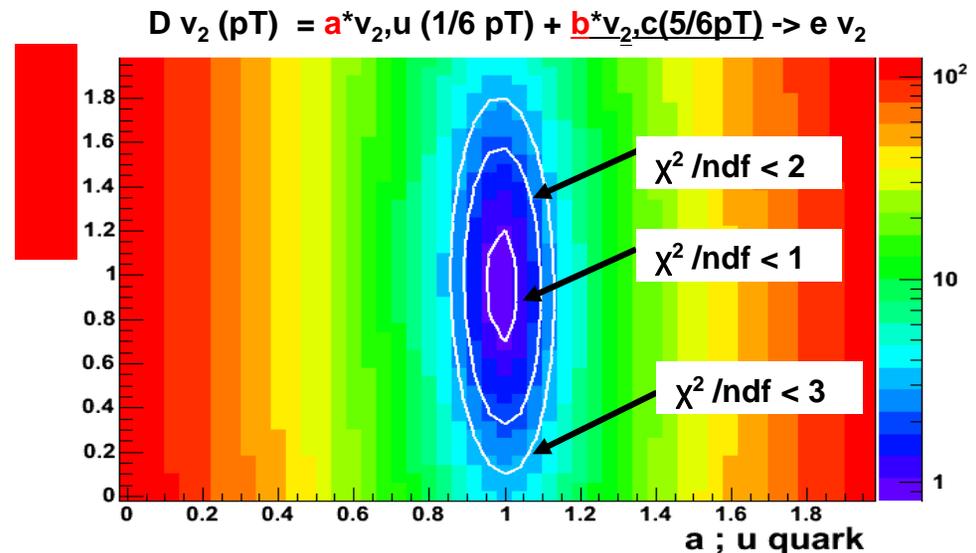
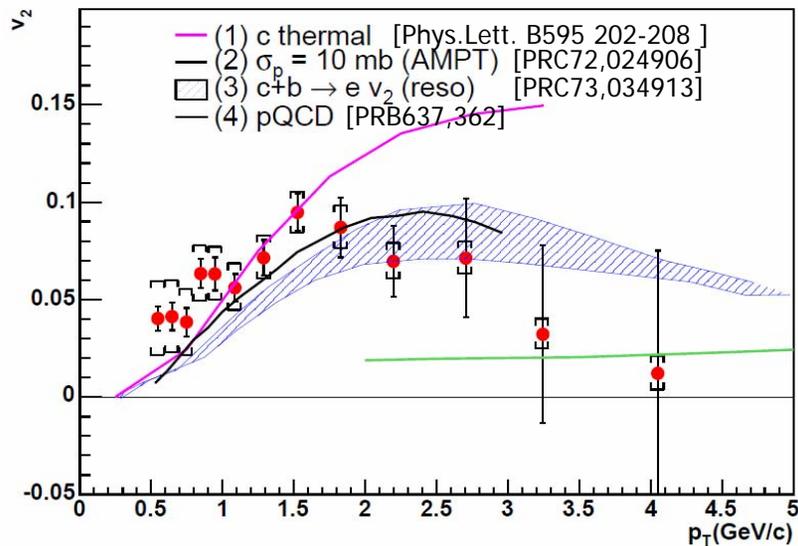
$$R_{AA} = \frac{\left( \frac{d^3 N}{dp^3} \right)_{AA}}{T_{AA} \cdot \left( \frac{d^3 \sigma}{dp^3} \right)_{pp}}$$

★ Strong modification of the spectral shape in Au+Au is observed at  $p_T > 1$  GeV/c

★ Sufficient statistics is collected to quantify  $R_{AA}$  centrality dependence

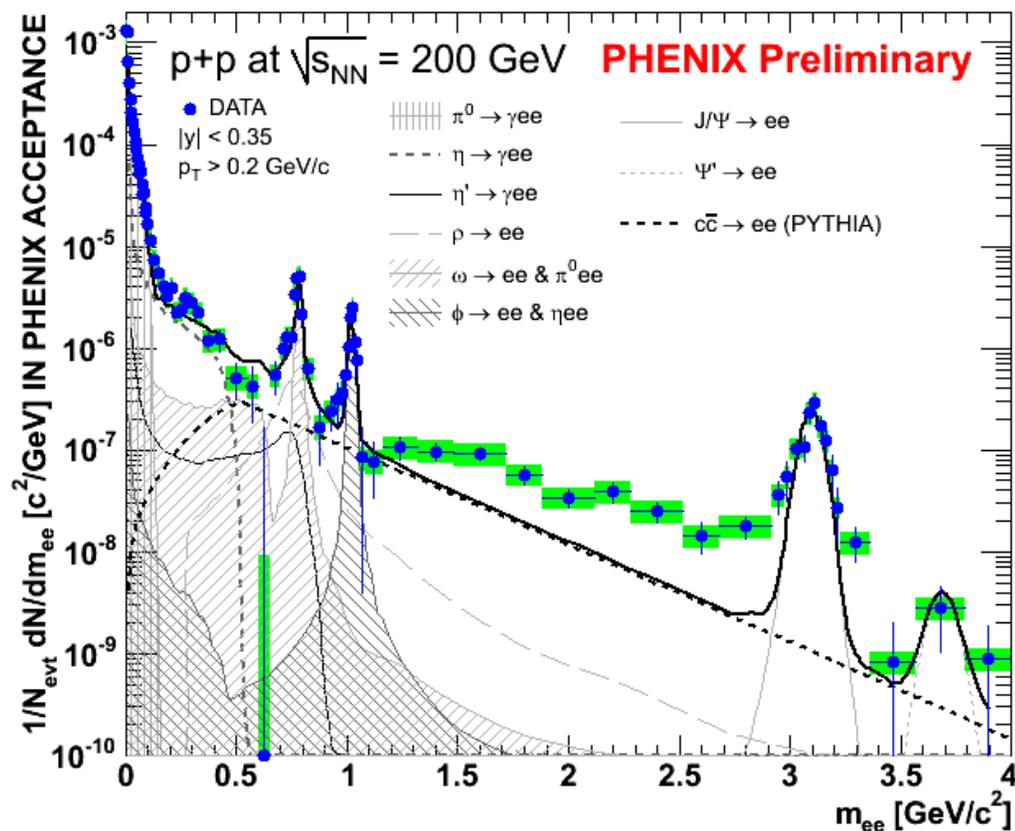
# Heavy Flavor Flow Interpretation

- ★ Indication of Quark level thermalization & strong coupling
- ★ Quark coalescence model perfectly describes  $v_2$  of D meson as a superposition of C and u quark  $v_2$  [PRC 68 044901 Zi-wei & Denes]

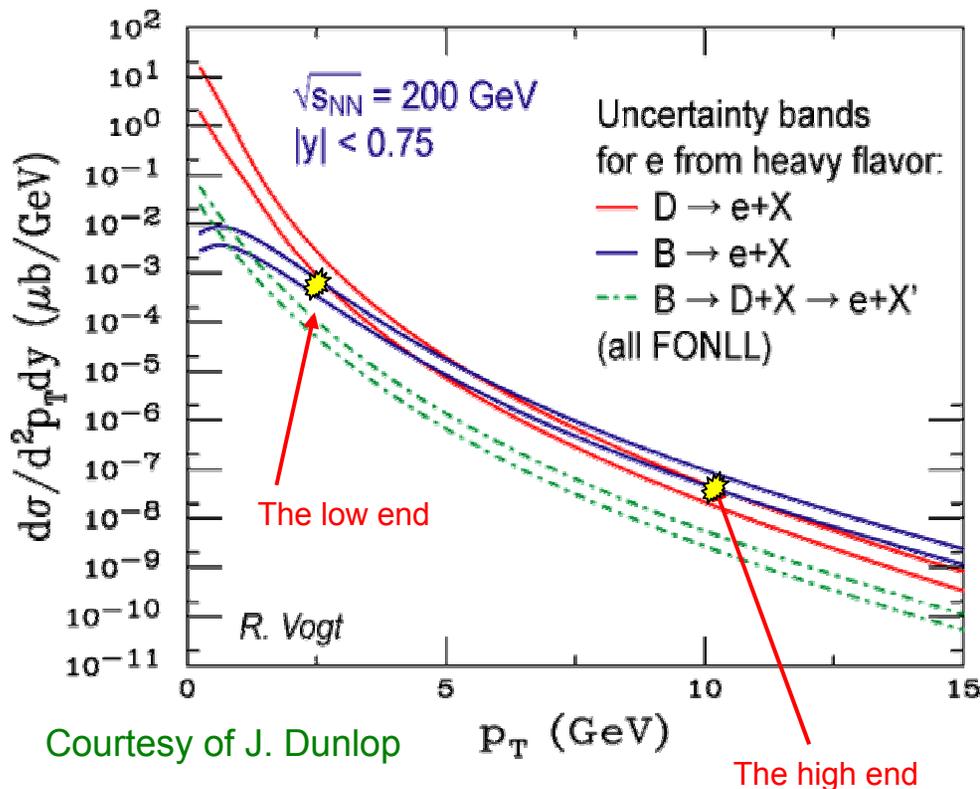


# First Look at Continuum in p+p

- ✦  $e^+e^-$  pair mass spectrum from Run 5 p+p clearly indicates a signal in the range of  $m_{ee} > 1.5 \text{ GeV}/c$  consistent with expectation from Open Charm correlated decays
- ✦ PYTHIA underpredicts the data the same way as for the single lepton cross section
- ✦ Obtained an important reference for comparison with Au+Au results



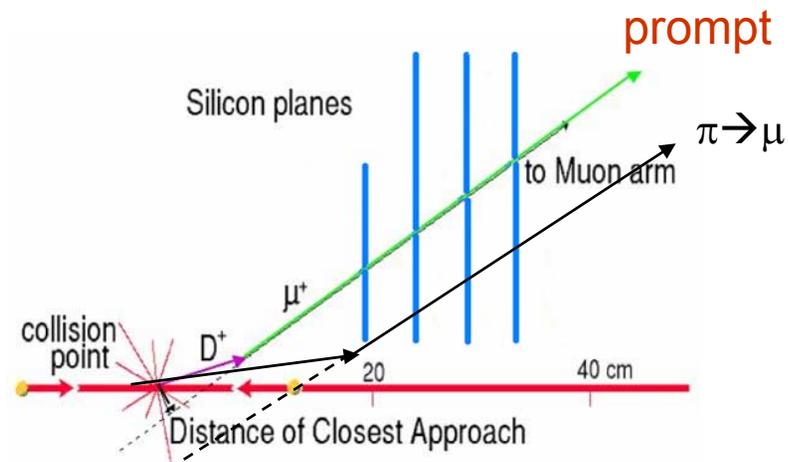
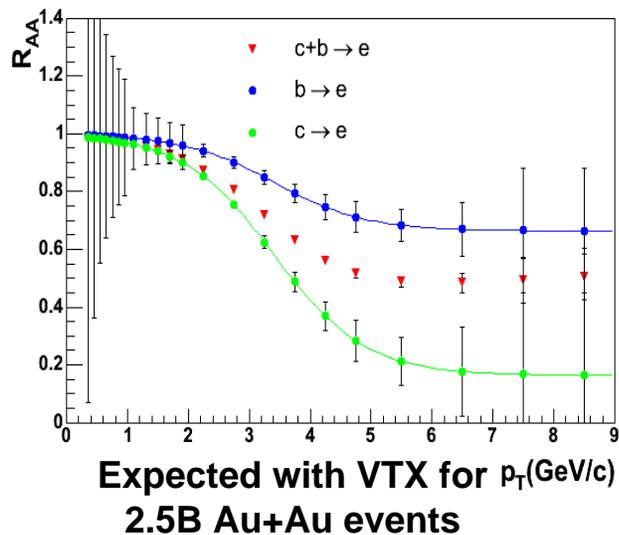
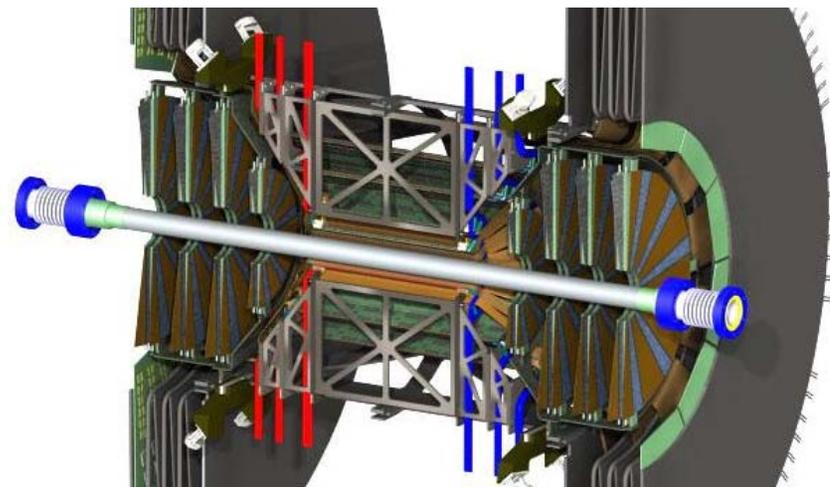
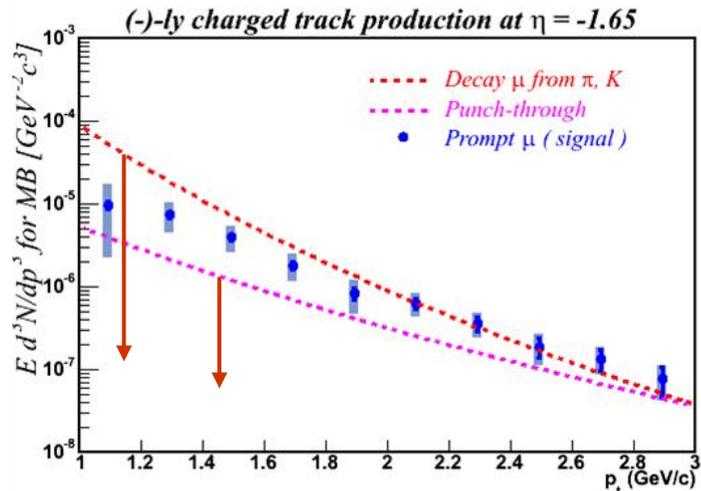
# Unanswered Question



c/b crossing point – somewhere in  
3-10 GeV/c  $p_T$  range

- ✦ Separate Charm from Bottom contribution to the lepton spectrum
- ✦ Solutions:
  - Direct measurement of Open Charm signal through hadronic D decay channels
  - Direct measurement of Open Bottom through  $J/\psi \rightarrow B+X$  decay channel

# Vertex Upgrade Plans



# Summary and Conclusions

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- ✦ PHENIX heavy flavor program significantly evolved over the last year
- ✦ Finalized and published results from:
  - Open Charm production in p+p collisions from electron channel
  - Nuclear modification of the heavy flavor production in Au+Au collisions
  - Correlated di-lepton production in Au+Au collisions
- ✦ Total cross section for Open Charm is a factor of 1.7 higher than current pQCD predictions
- ✦ Both experiments results are in good agreement with each other in spectral shape, absolute normalization need to be studied
- ✦ Binary scaling of the cross section established with high accuracy in d+Au and Au+Au collisions
- ✦ There is a clear modification of high  $p_T$  spectral shape in central Au+Au collisions

***More interesting results in near and far future ...***