



Studying Heavy Flavor Production at RHIC via Open Charm Measurements at STAR



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Outline

- Theoretical Motivation
- Detecting Open Charm
- Hadronic Reconstruction of D^0
- Semi-leptonic Measurement in Cu+Cu
- Reconstruction of the D_s in Cu+Cu
- Conclusions and Outlook



Open Charm Production

- Prediction of Charm Cross-Section in p+p from perturbative Quantum Chromodynamics (pQCD) (NLO/FONLL)

Ref: M. Cacciari, P. Nason, R. Vogt, Phys. Rev. Lett. 95, 122001 (2005)

- Charm produced during initial gluon fusion.
 - We expect the cross-section to scale with the number of binary collisions
 - Charm produced before thermalization.
 - Charm is a good probe of the medium.



Prediction of Charm Cross-Section

Method 1:

- use dp_t slices, then integrate final result
- treat charm as active flavor
- FONLL Calculation

Charm Cross Section Predicted for 200 GeV Collisions:

$$\sigma_{c\bar{c}}^{\text{NLO}_{\text{nlf}+1}} = 244^{+381}_{-134} \mu\text{b}$$

$$\sigma_{c\bar{c}}^{\text{FONLL}_{\text{nlf}+1}} = 256^{+400}_{-146} \mu\text{b}$$

Method 2:

- calculate on full p_t range in one step
- treat charm as NOT an active flavor (heavy quark considered massive)
- NLO Calculation

Charm Cross Section Predicted for 200 GeV Collisions:

$$\sigma_{c\bar{c}}^{\text{NLO}_{\text{nlf}}} = 301^{+1000}_{-210} \mu\text{b}$$

Ref: R. Vogt, arXiv:0709.2531v1 [hep-ph]



Medium Effects

- Nuclear modification factor:

$$R_{AA} = \frac{d\sigma_{AA}(p_t)}{N_{binary} d\sigma_{pp}(p_t)}$$

- Suppression for heavy quarks was predicted to be not as large as that for light quarks (dead cone effect).

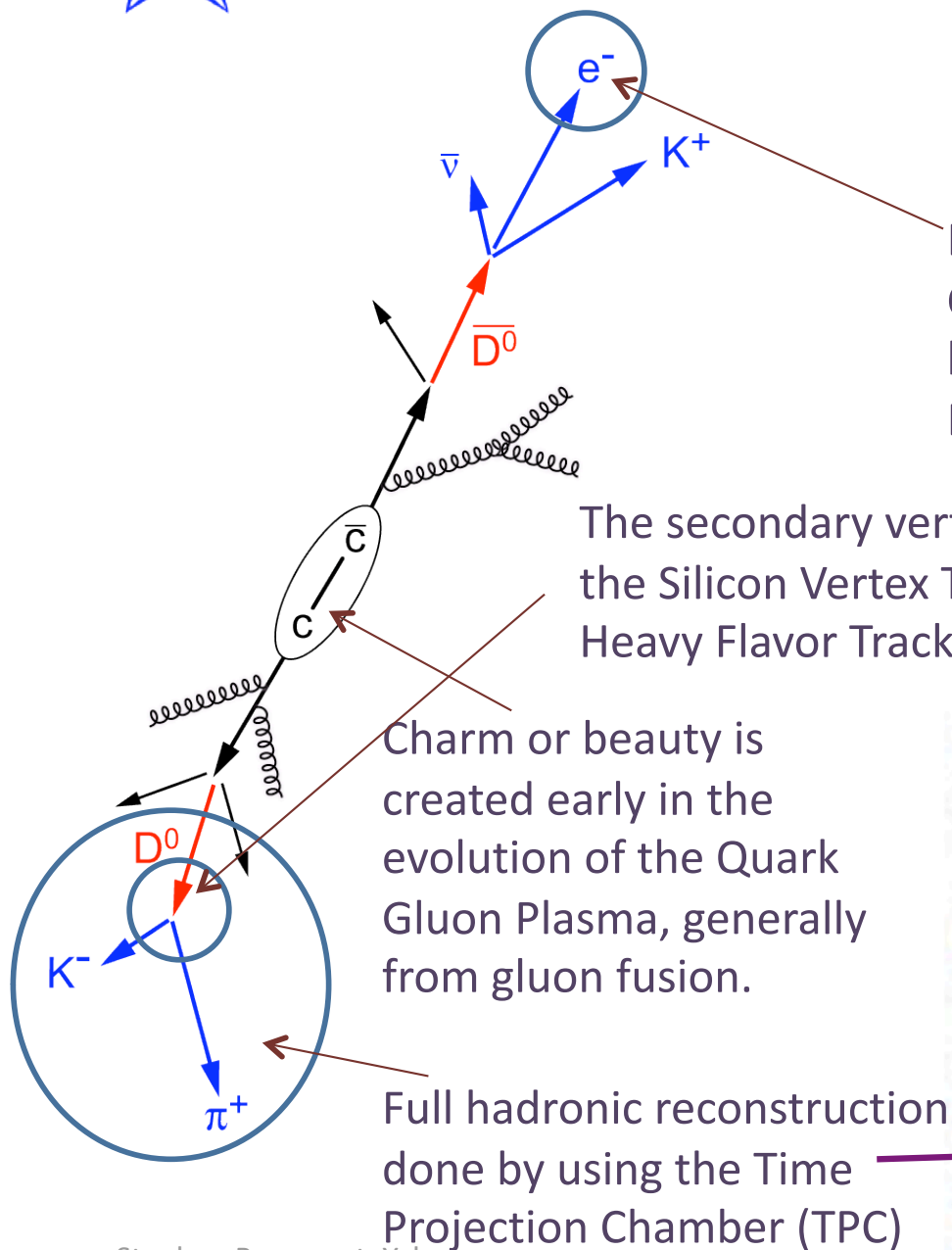
Ref.: Yu. L Dokshitzer and D.E. Kharzeev, Phys. Lett. B **519** 199-206 (2001)

- But suppression was measured to be the SAME for both light and heavy flavors.

Ref.: B. I. Abelev *et al.* (STAR), Phys. Rev. Lett. **98** 192301 (2007)



Measuring Heavy Flavor

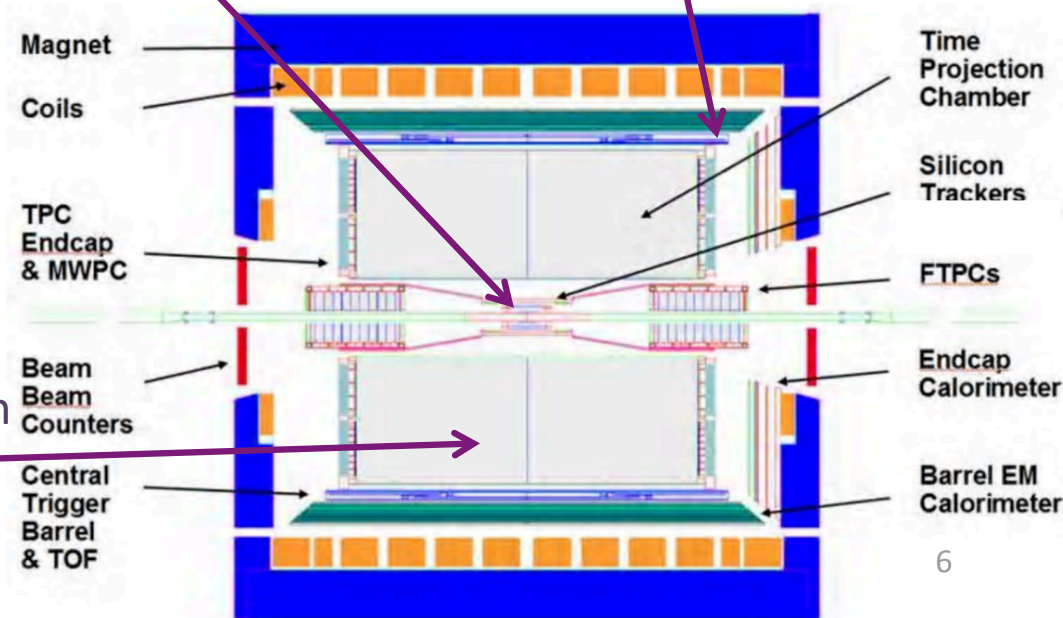


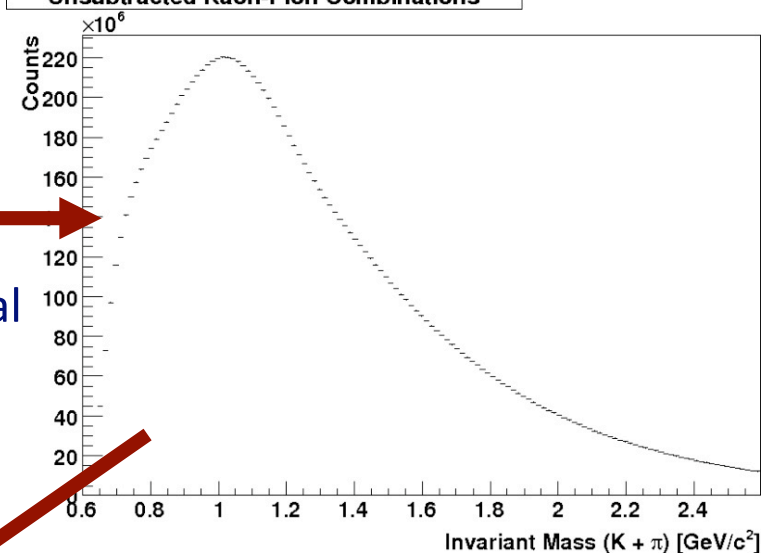
Electrons detected in the Time Projection Chamber (TPC) can be identified and triggered on by using their energy deposited in the Barrel Electromagnetic Calorimeter (BEMC).

The secondary vertex can be located by using the Silicon Vertex Tracker (SVT) or the future Heavy Flavor Tracker (HFT).

Charm or beauty is created early in the evolution of the Quark Gluon Plasma, generally from gluon fusion.

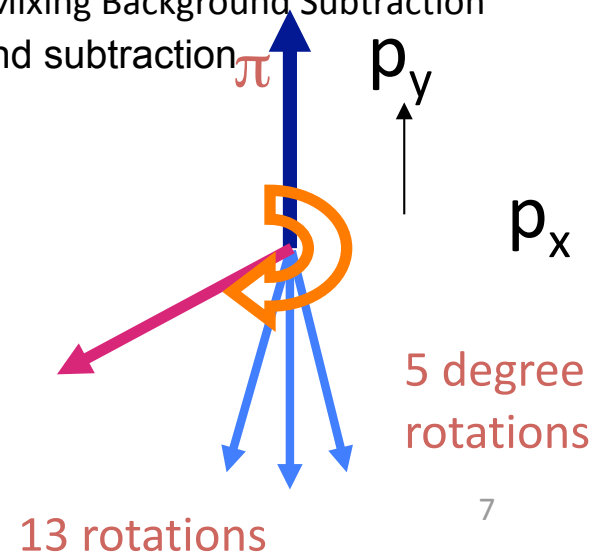
Full hadronic reconstruction done by using the Time Projection Chamber (TPC)





Rotational Background Subtraction or Event Mixing Background Subtraction

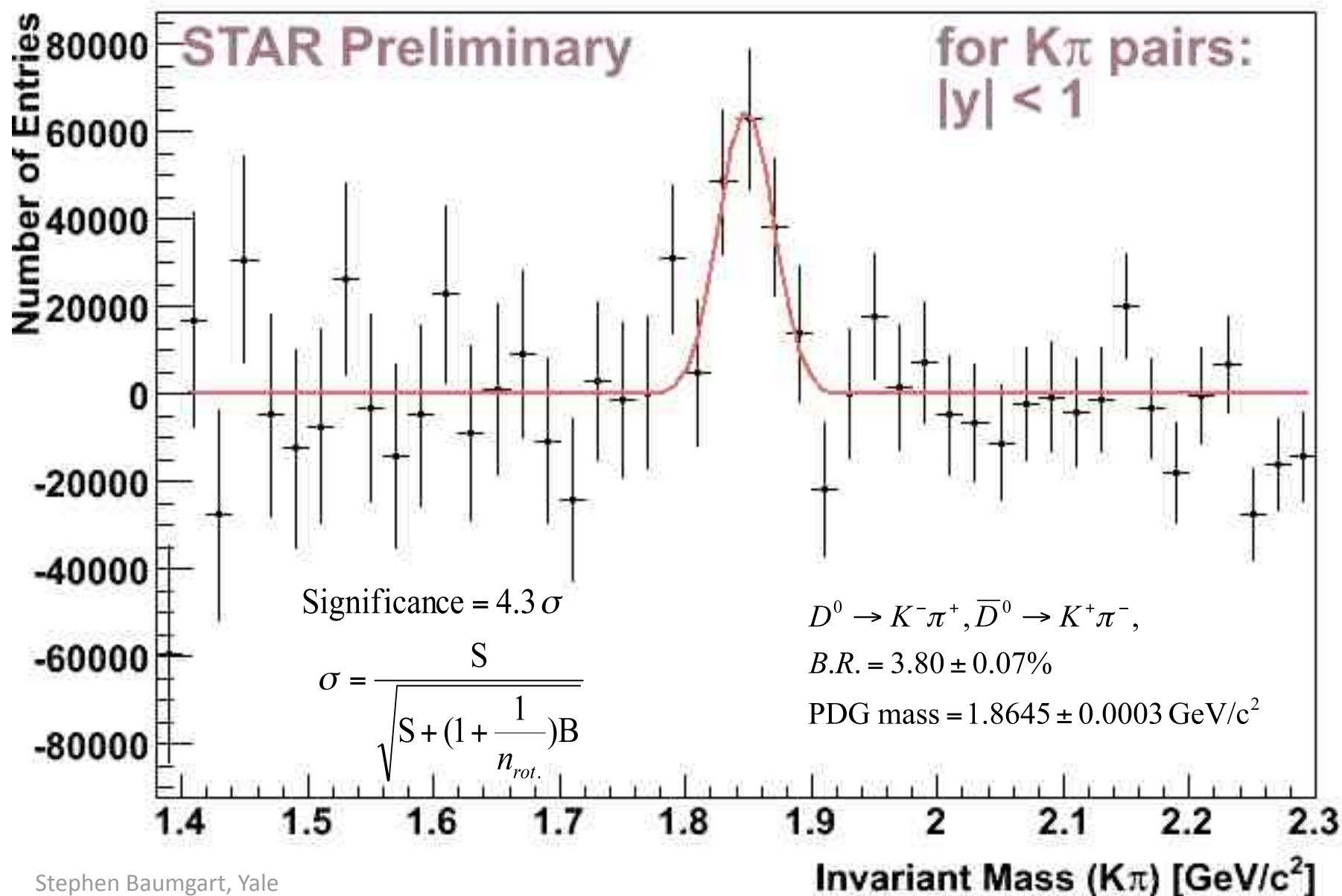
→ residual background subtraction.



Momentum and dE/dx
cuts used

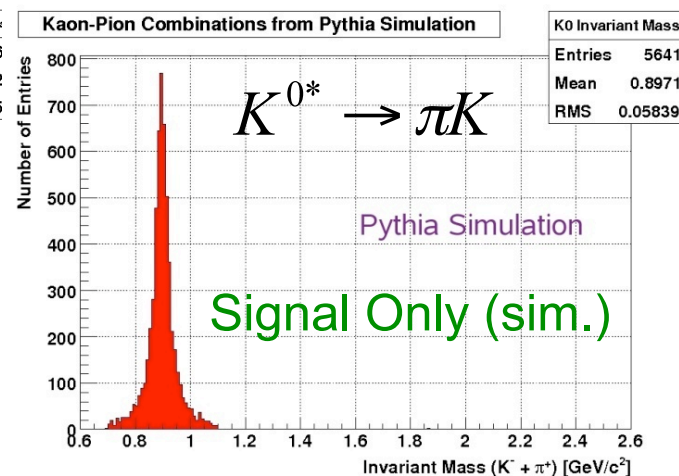
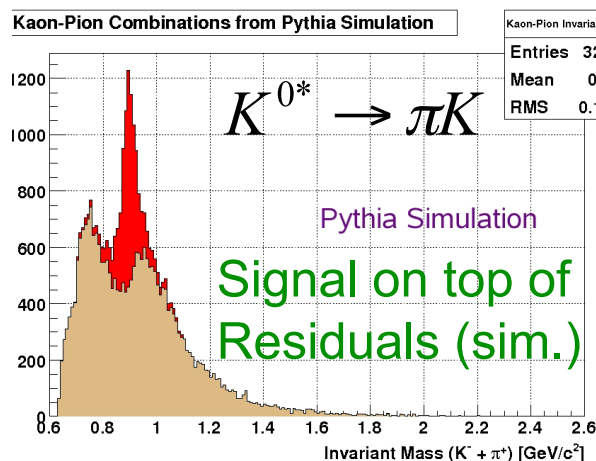
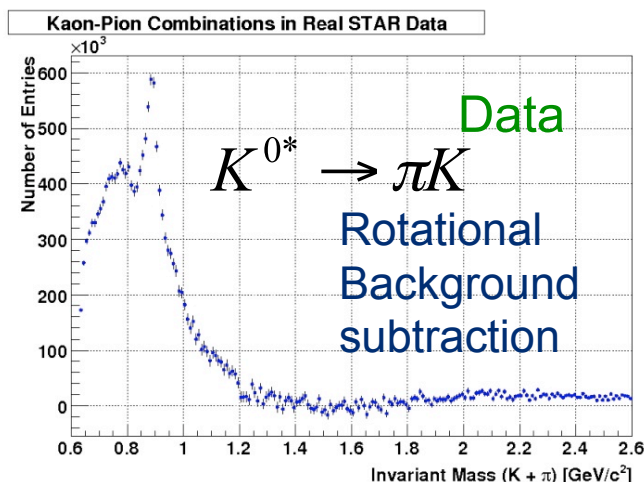


D^0 in 200 GeV Cu+Cu Collisions





Residual Background



Possible Causes:

- Misidentified Resonances (shown in plot)
- Collective Flow
- Jets
- Non-conservation of energy/momentum



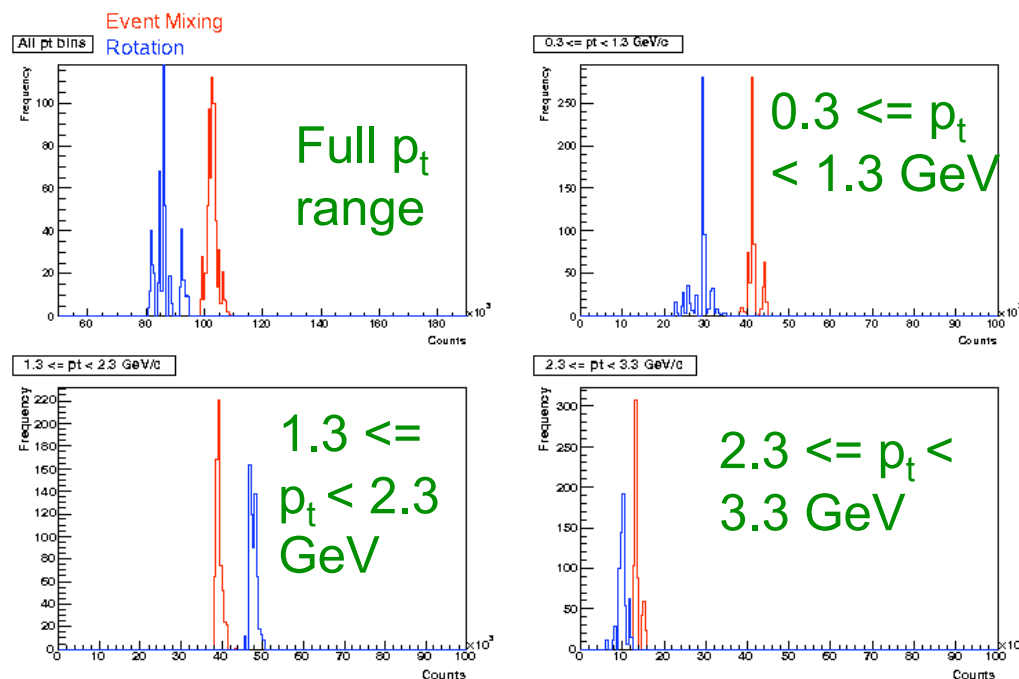
Signal (K^{0*})



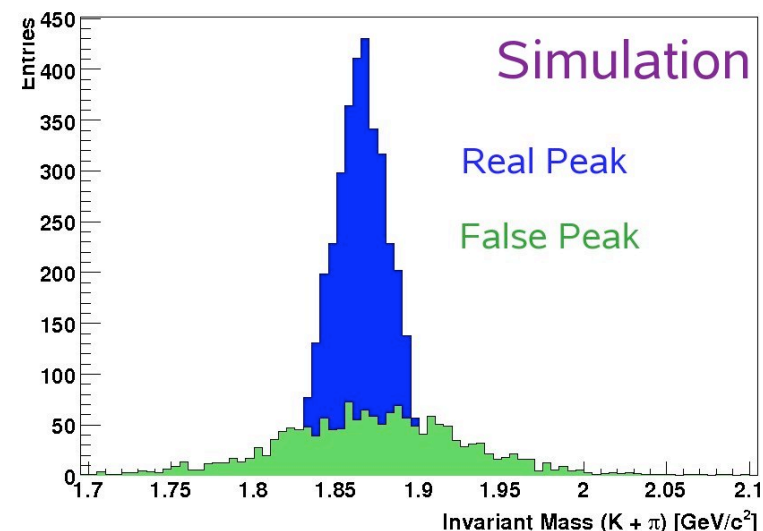
Residual Background from mis-IDed resonance



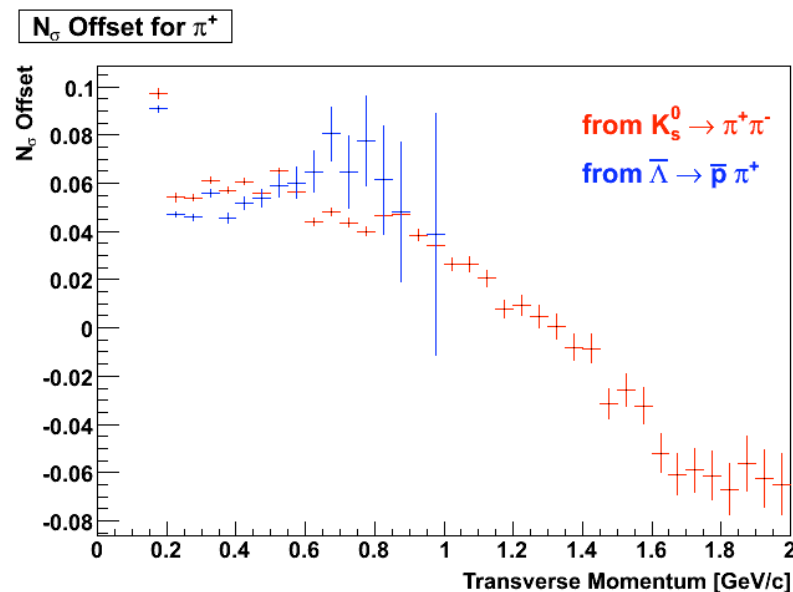
Sources of Systematic Error



- Background Subtraction Method (Rotation vs. **Mixing**)
- Differing Fit Limits (Shown by width of peaks in above plots)



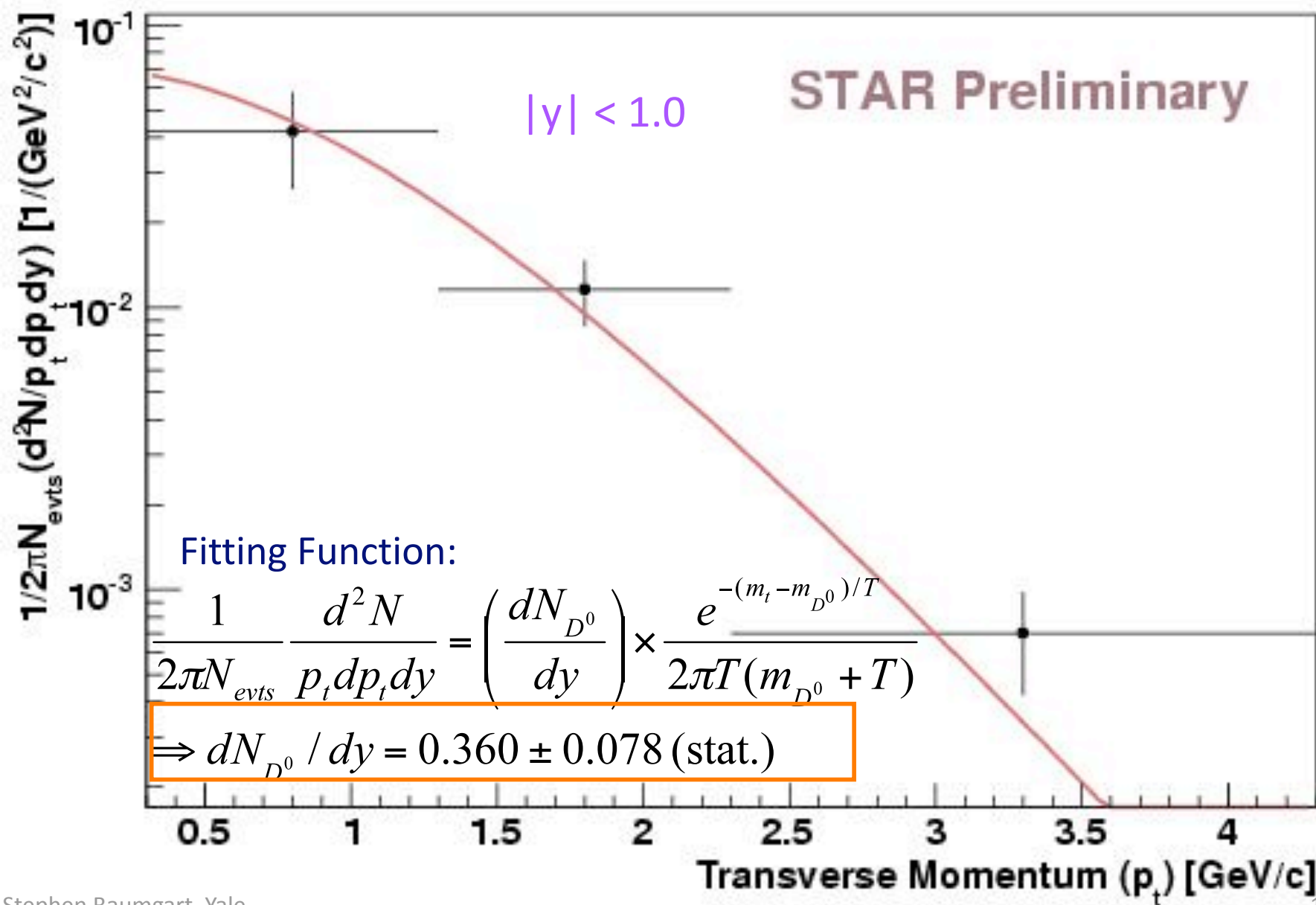
- Double counting



- dE/dx Calibration Error



D⁰ + $\overline{D}^0$ Spectra in 200 GeV Cu+Cu Collisions





Charm Cross-Section

$$\sigma_{c\bar{c}}^{NN} = dN_{D^0}^{Cu+Cu} / dy \times \sigma_{inel}^{pp} / N_{bin}^{Cu+Cu} \times f / R$$

$$dN_{D^0} / dy = 0.360 \pm 0.078 \text{ (stat.)}$$

number of binary collisions $N_{binary}^{Cu+Cu} = 80.4 + 5.9 - 5.6 \text{ (0 to 60 \% cen.)}$

p+p inelastic cross section $\sigma_{inel}^{pp} = 42 \text{ mb}$

conversion to full rapidity
(using PYTHIA simulation, ver. 6.152) $f = 4.7 \pm 0.7$

ratio from e^+e^- collider data $R = N_{D^0} / N_{c\bar{c}} = 0.54 \pm 0.05$

$$\Rightarrow \sigma_{c\bar{c}}^{NN} = 1.64 \pm 0.36 \text{ (stat.) mb}$$

sys. error from dN/dy to σ conversion = $+0.17 - 0.18 \text{ mb}$

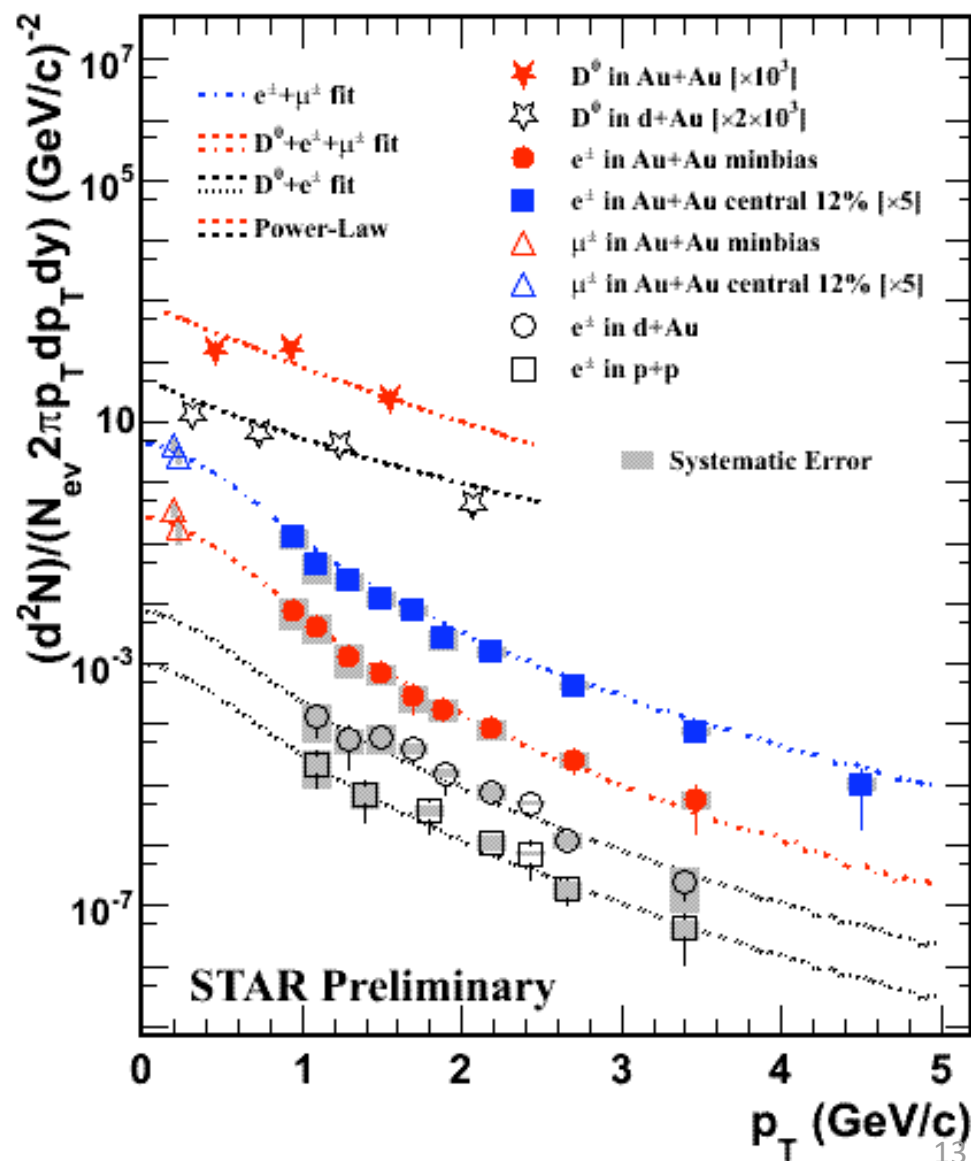
*Systematic error evaluation for dN/dy in progress.



Checking Binary Scaling

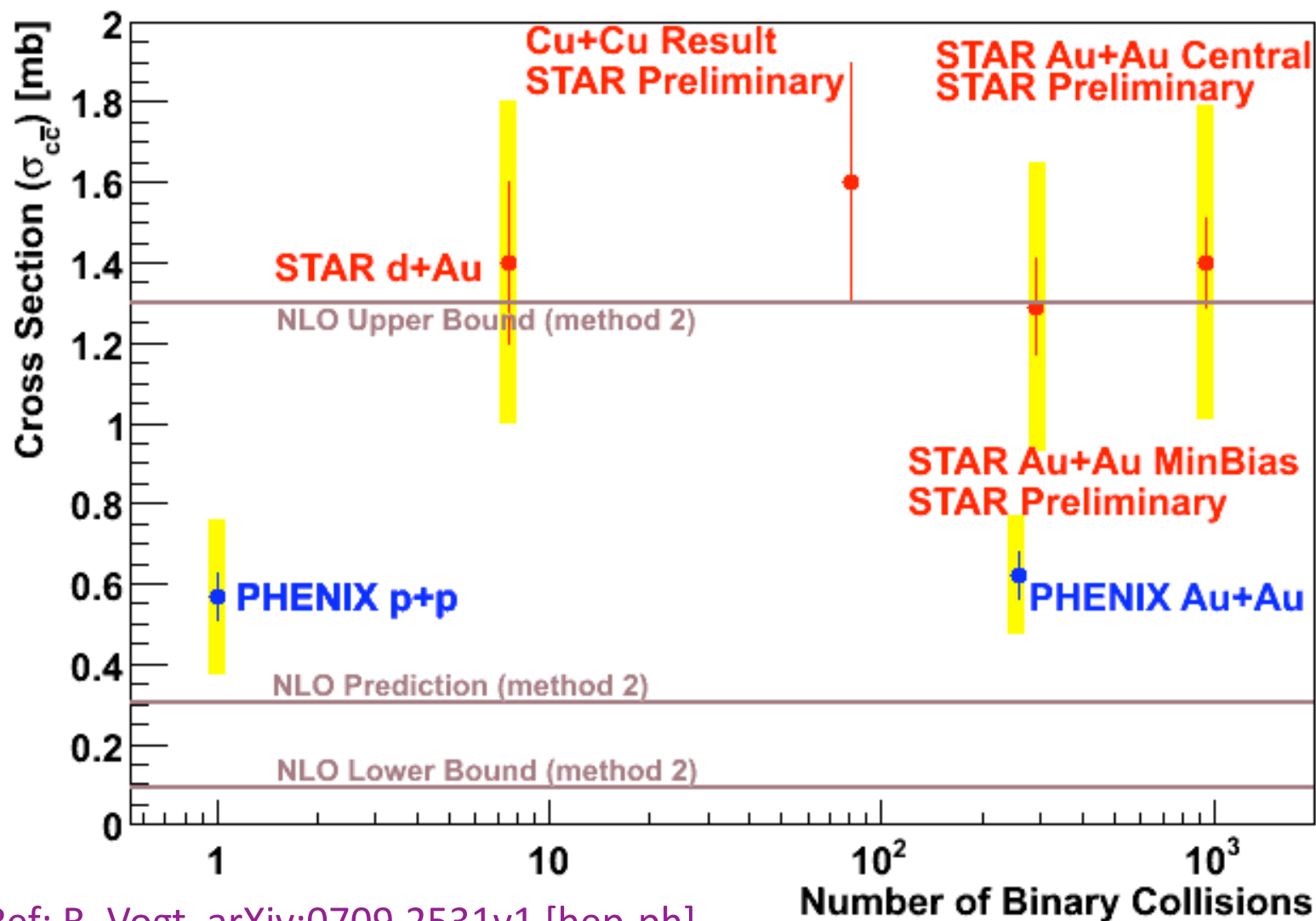
- By comparing all systems (d+Au, Cu+Cu, and Au+Au), we check for binary scaling.

- New data may allow us to improve on these measurements.





Binary Scaling of Cross-Section



NLO Ref: R. Vogt, arXiv:0709.2531v1 [hep-ph]

*Systematic error evaluation for STAR Cu+Cu in progress.

PHENIX:
S. Adler, et al. Phys. Rev. Lett. 94 082301 (2005)
S. Adler, et al. Phys. Rev. Lett. 97 252002 (2006)

Stephen Baumgart, Yale

STAR:
J. Adams et al. Phys. Rev. Lett 94, 062301 (2005)
S. Baumgart, arXiv:nucl-ex/0709.4223
[B. I. Abelev](#), et al., arXiv:nucl-ex/0805.0364

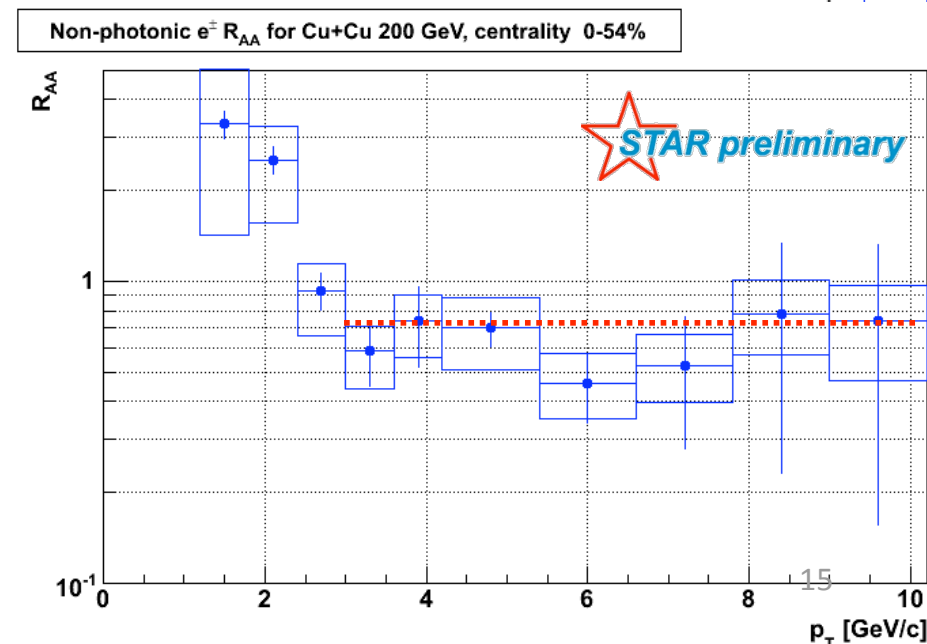
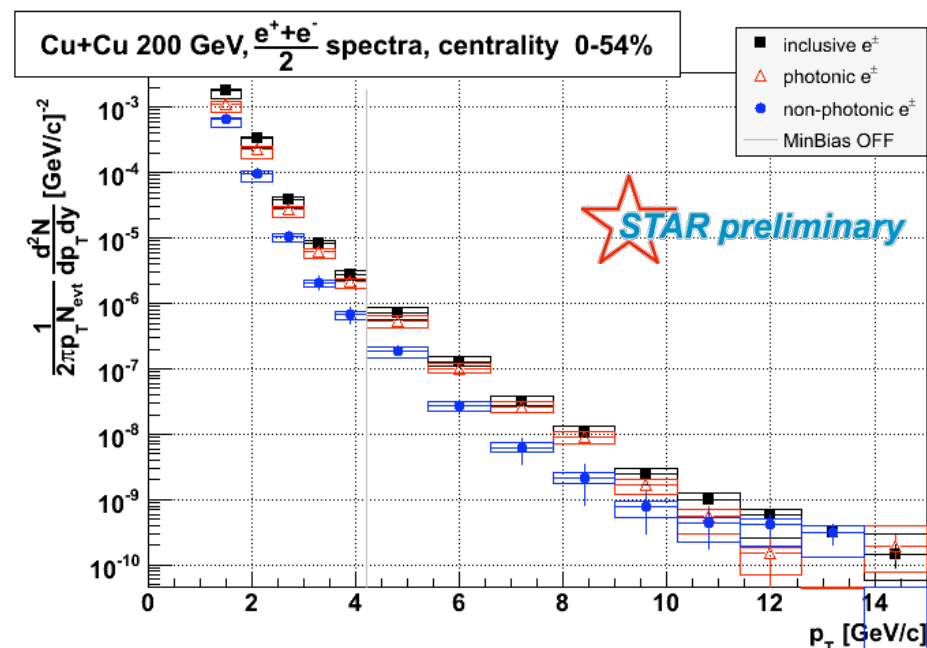


Non-photonic Electrons in Cu+Cu

- STAR can also measure heavy flavor through its semi-leptonic decays channels.
- Photonic electrons are cut out via invariant mass cuts.
- The vast majority of high- p_t non-photonic electrons are the product of charm and beauty decays.
- The resultant electron spectra can be used to find R_{AA} .

$$R_{AA} = \frac{d\sigma_{AA}(p_t)}{N_{binary} d\sigma_{pp}(p_t)}$$

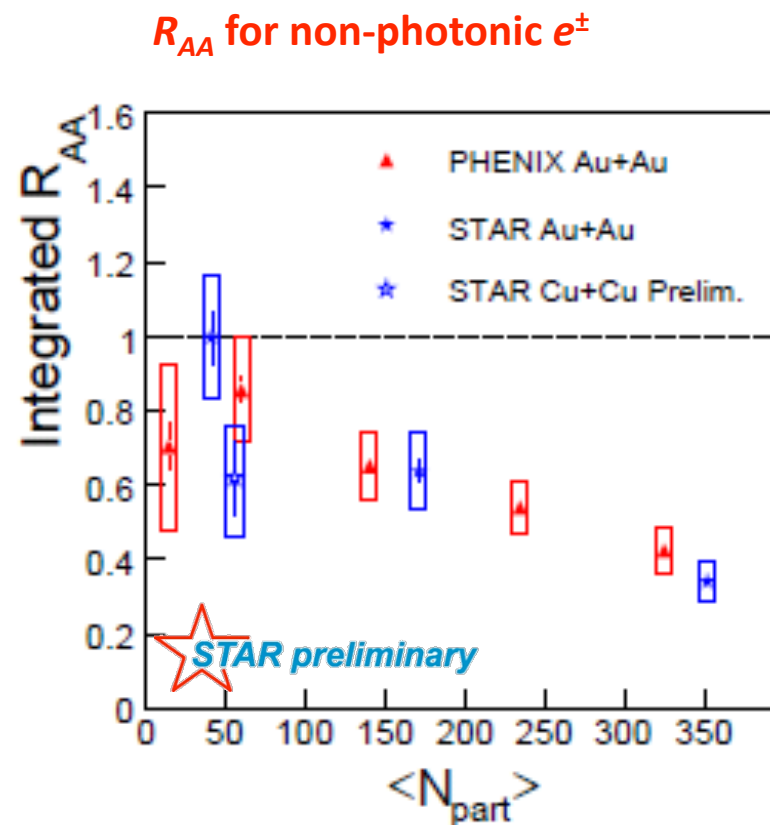
Stephen Baumgart, Yale





Open Charm R_{AA} in Cu+Cu

- The preliminary single electron R_{AA} measurement in STAR's Cu+Cu data set is consistent with previous STAR and PHENIX measurements at similar multiplicities.
- This shows that heavy flavor is suppressed like light flavor in 200 GeV Cu+Cu Collisions.



STAR: PRL 98 (2007) 192301

PHENIX: PRL 98 (2007) 172301

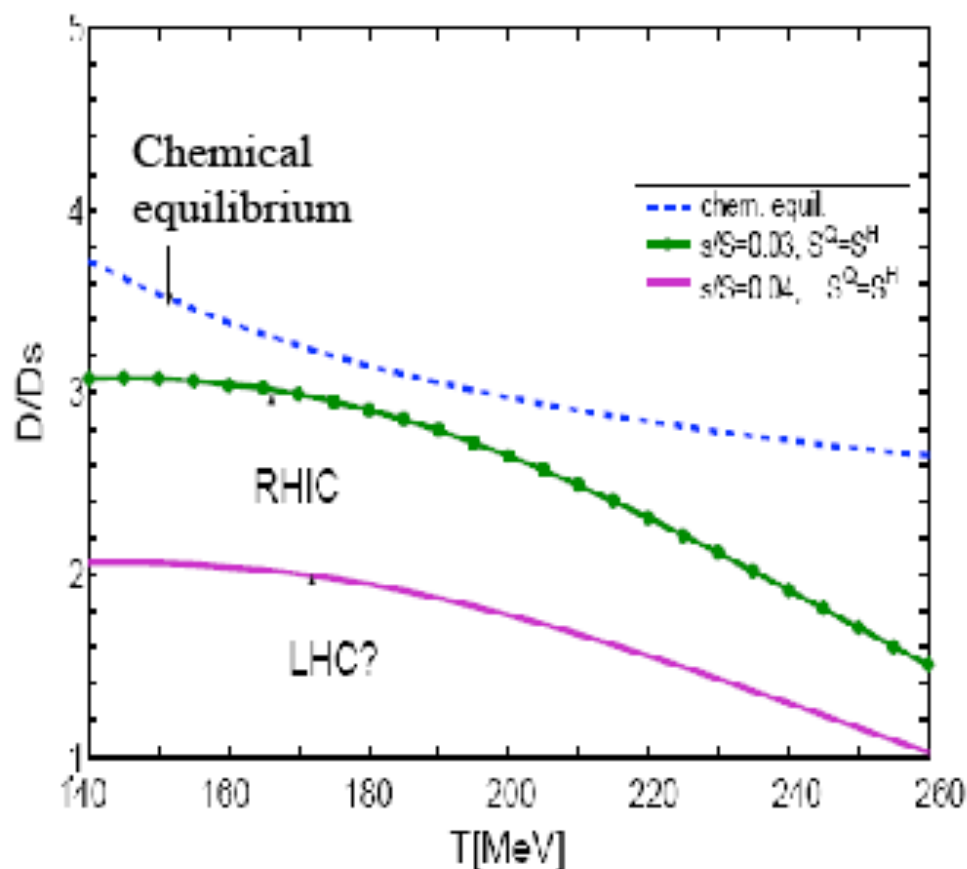


D_s Search Motivation

- D/D_s ratio predicted by stat. hadronization model. This can be tested by STAR.

Ref.: I. Kuznetsova and J. Rafelski,
Eur. Phys. J. C **51**, 113-133 (2007)

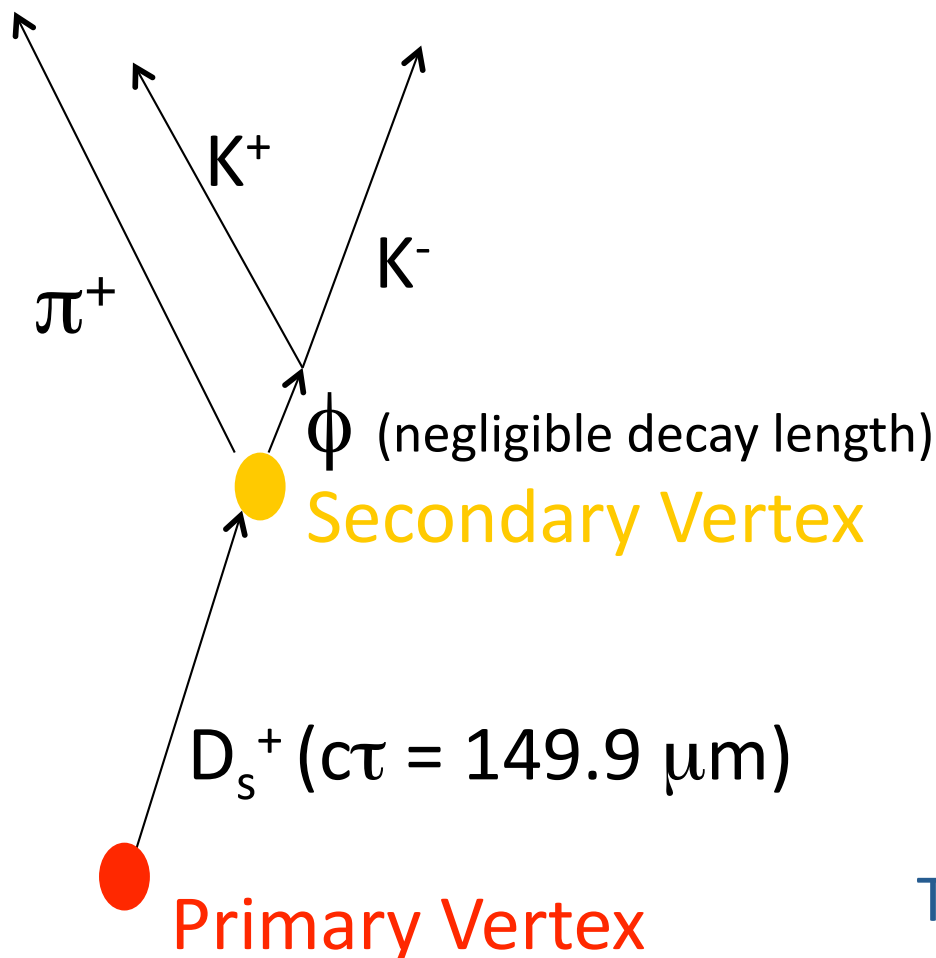
- The D_s also contributes to the total charm cross-section.





D_s Reconstruction Technique

To Detectors



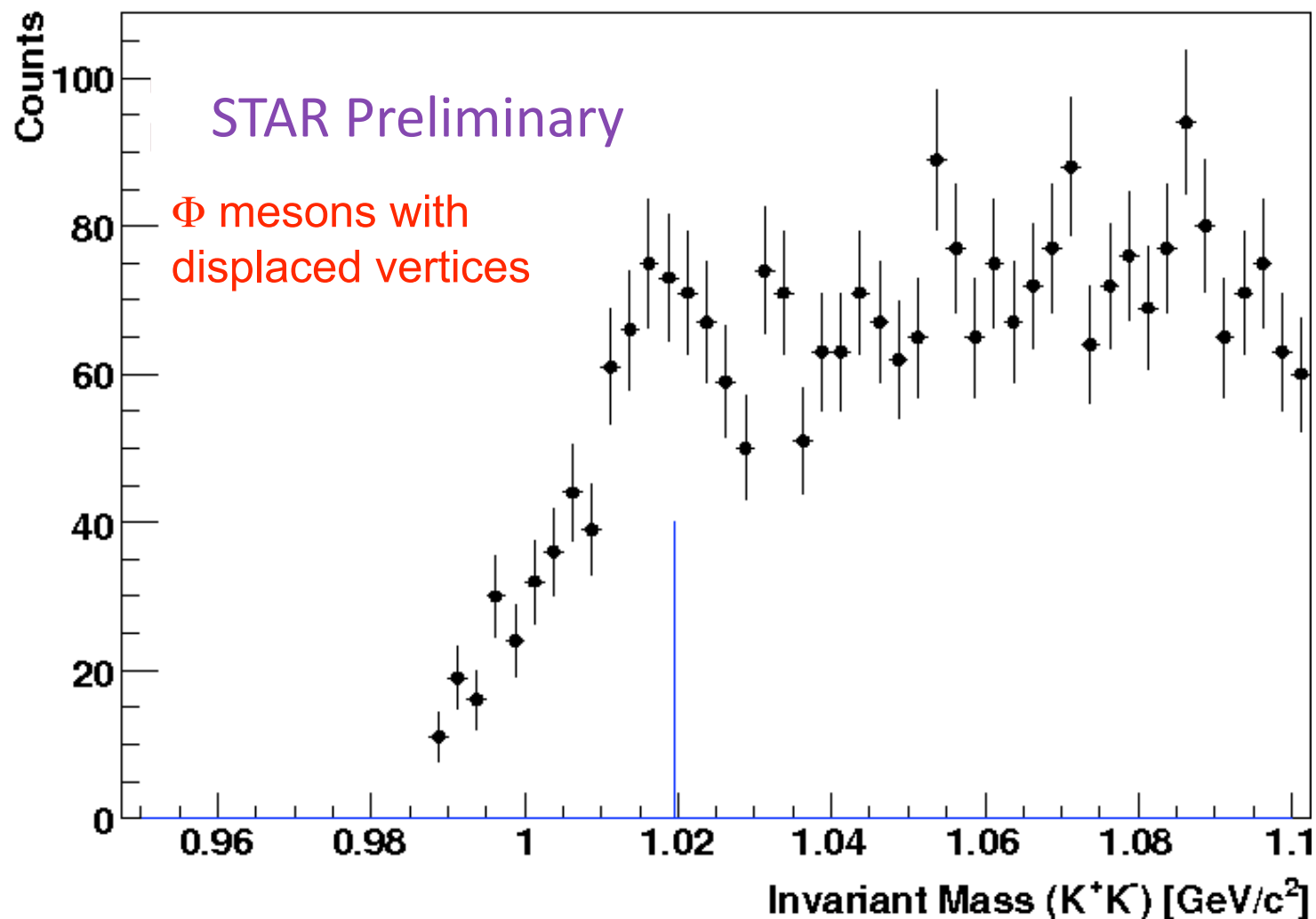
Finding the secondary vertex using the Silicon Vertex Tracker (SVT) allows one to use geometric cuts to identify particles with decay lengths from $\sim 100 \mu\text{m}$ to 10s of centimeters.

To find D_s mesons, I take only decays with decay lengths between 100 and $400 \mu\text{m}$.



Phi Reconstruction

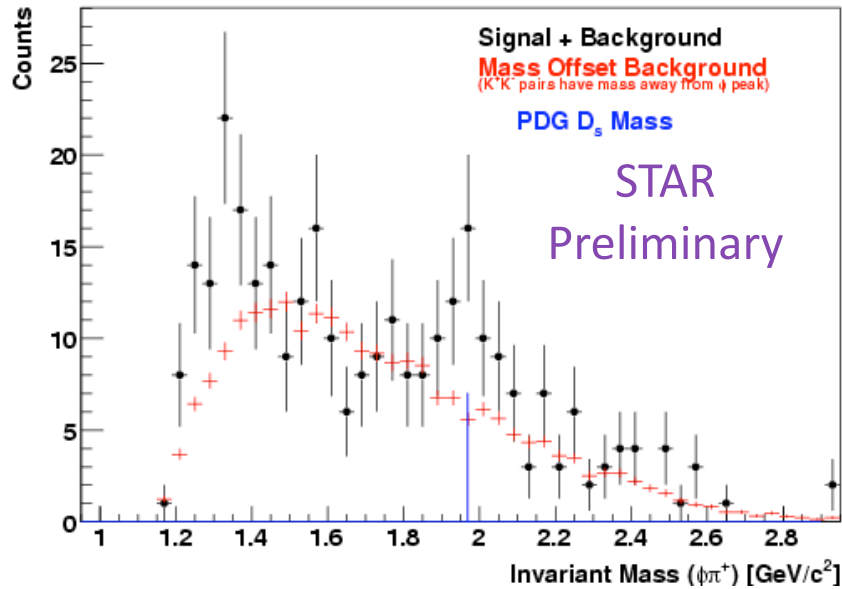
K⁺K⁻ Combinations





D_s in Cu+Cu

$\phi\pi^+$ Combinations

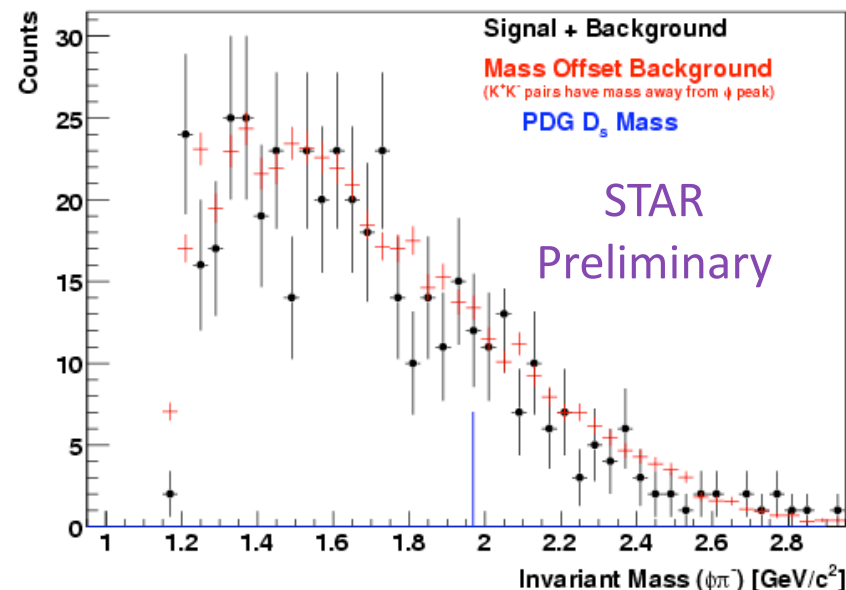


Weak ~ 3 sigma D_s^+ peak found
from reconstruction of $D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^- \pi^+$

No D_s^- found.

Pythia prediction: $\frac{D_s^-}{D_s^+} \approx 0.9$

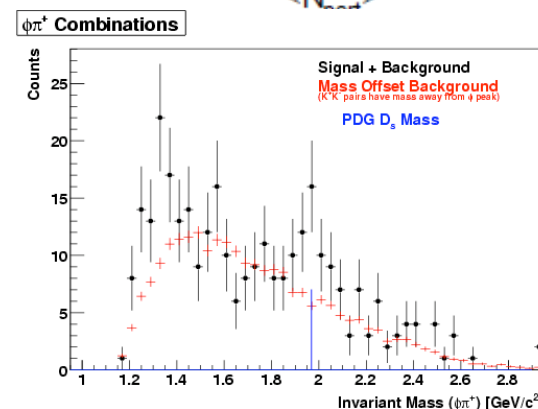
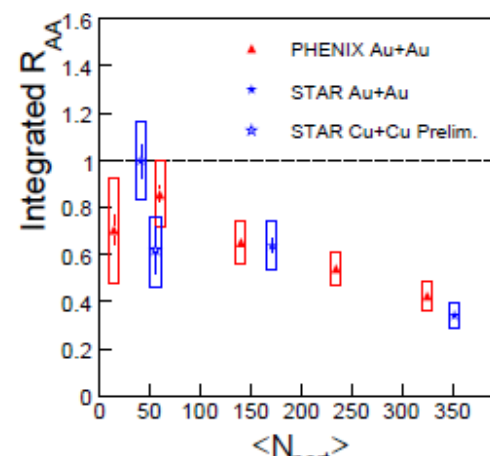
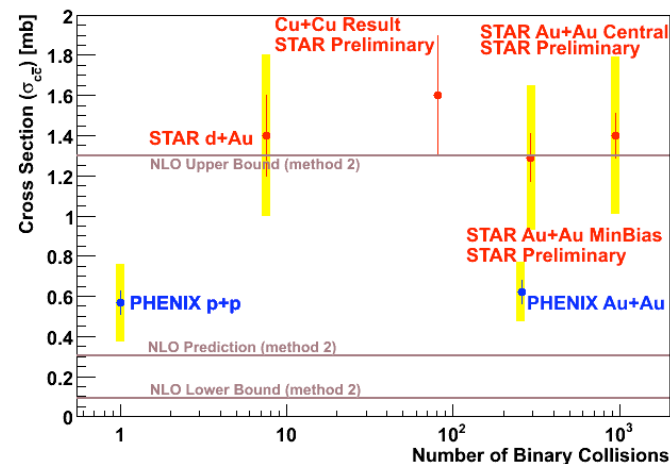
$\phi\pi^-$ Combinations





Conclusions

- STAR's open charm cross-sections are consistent with binary scaling.
- STAR's cross-sections sit near the upper limit of pQCD predictions.
- The non-photonic electron R_{AA} in Cu+Cu collisions shows the same amount of suppression that is seen in Au+Au collisions of similar N_{part} .
- There are hints of a charge asymmetry for D_s mesons; however, more data is needed.





Outlook

- D^0 searches (with and w/o SVT) in progress in Run 7 Au+Au and in Run 8 d+Au (low material budget run).
- Active D_s searches in Run 7 Au+Au as well as Run 8 d+Au.
- Further work will be done with using the SVT to study D^0 and D_s spectra.