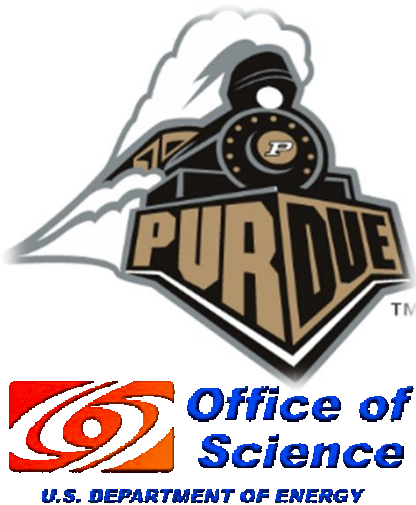


Heavy Flavor Results from STAR

Wei Xie for STAR Collaboration
(PURDUE University, West Lafayette)

- Motivation
- Open Heavy Flavor Production
 - D meson direct measurement
 - Non-photonic electron
- Heavy Quarkonia Production
 - J/ψ
 - Upsilon
- Heavy Flavor v_2
- Summary and future perspective



Motivation for Studying Heavy Quarks

- ❑ **Sensitive to initial gluon density and gluon distribution at RHIC.**
 - produced mostly from gluon fusion

- ❑ **Involve different interaction mechanisms from light quarks with the medium**
 - gluon bremsstrahlung radiation
 - collisional energy loss
 - collision dissociation
 - Ads/CFT

- ❑ **Heavy quarkonia production reveals critical features of the medium.**
 - suppression from color screening or gluon scattering
 - enhancement from coalescence

- ❑ **Cold Nuclear effect.**
 - Gluon shadowing , Color glass condensate, Initial state Energy loss, etc

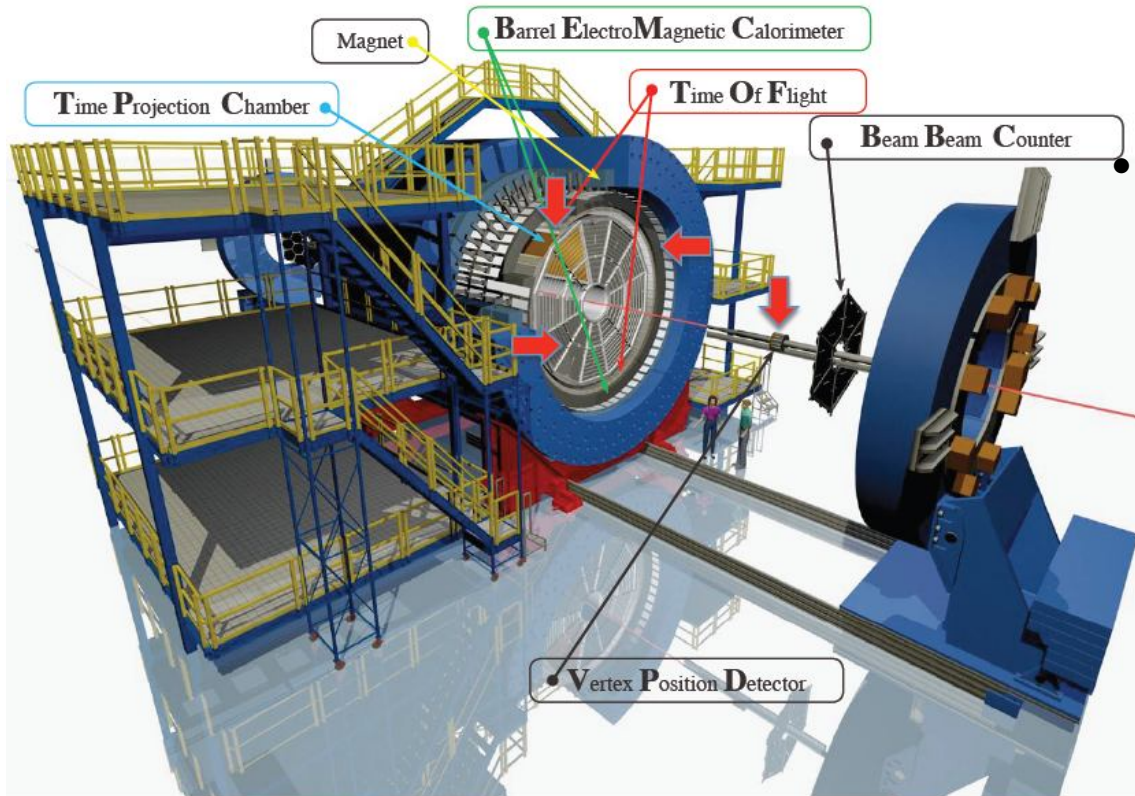
The (major) STAR Detector for Heavy Flavor Measurements

Time Projection Chamber:

- $|\eta| \leq 1.0$, full azimuth
- Tracking.
- PID through dE/dx

Barrel Electromagnetic Calorimeter

- $|\eta| \leq 1.0$, full azimuth
- **BTOW:**
 - Tower: $\Delta\phi \times \Delta\eta = 0.05 \times 0.05$
 - p/E for electron ID
 - Fast online trigger



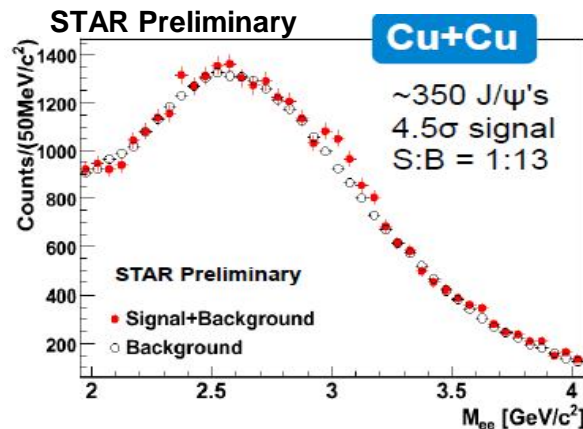
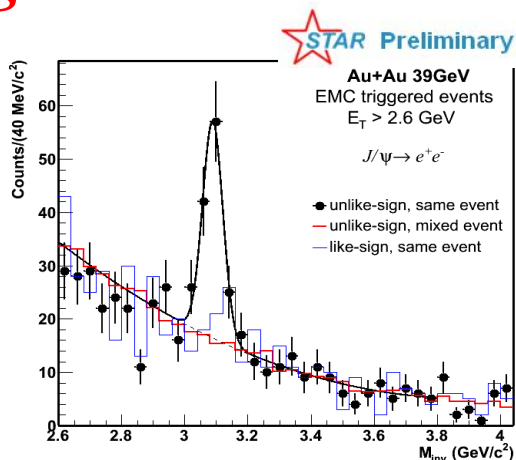
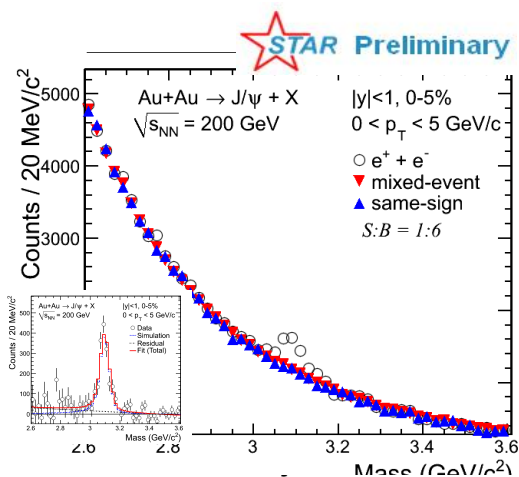
BSMD:

- Double layer High spatial resolution MWPC.
 - $\Delta\phi \times \Delta\eta = 0.0064 \times 0.1$
 - $\Delta\phi \times \Delta\eta = 0.1 \times 0.0064$
- e/h separation.

Time of Flight:

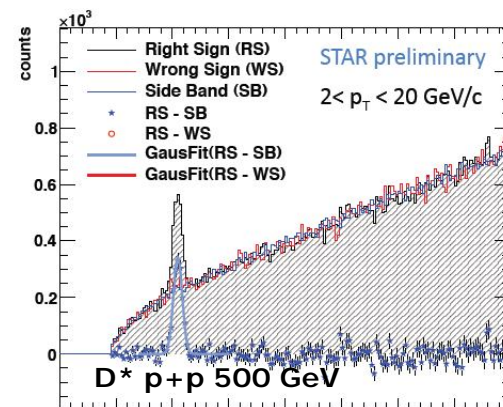
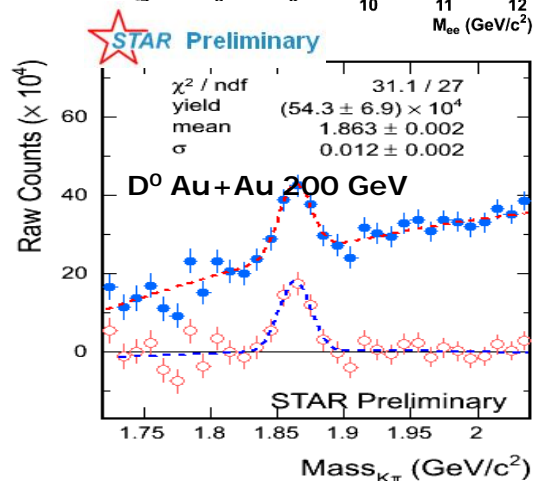
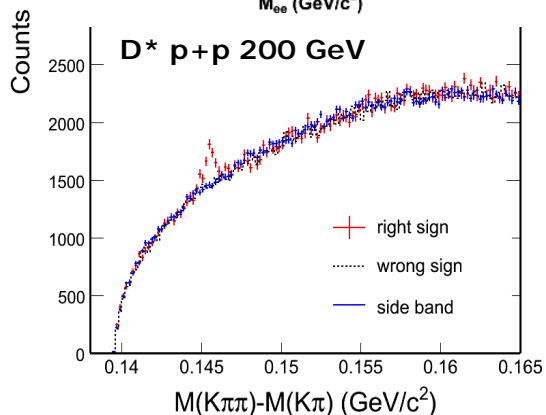
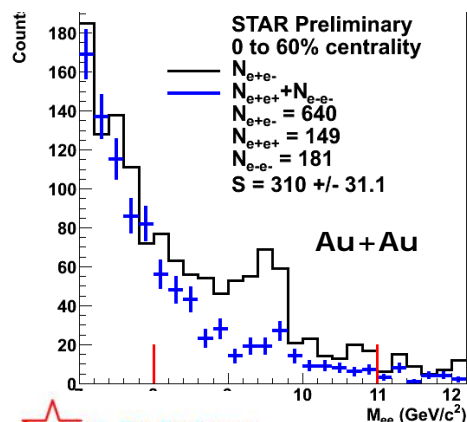
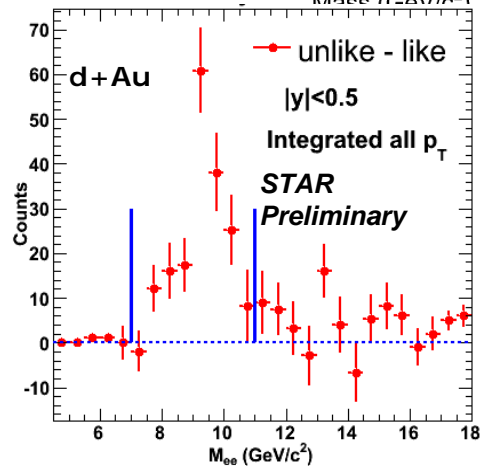
- $|\eta| \leq 0.9$, full azimuth .
- PID through TOF
- Timing resolution: ~ 85 ps.

Signals Observed in STAR

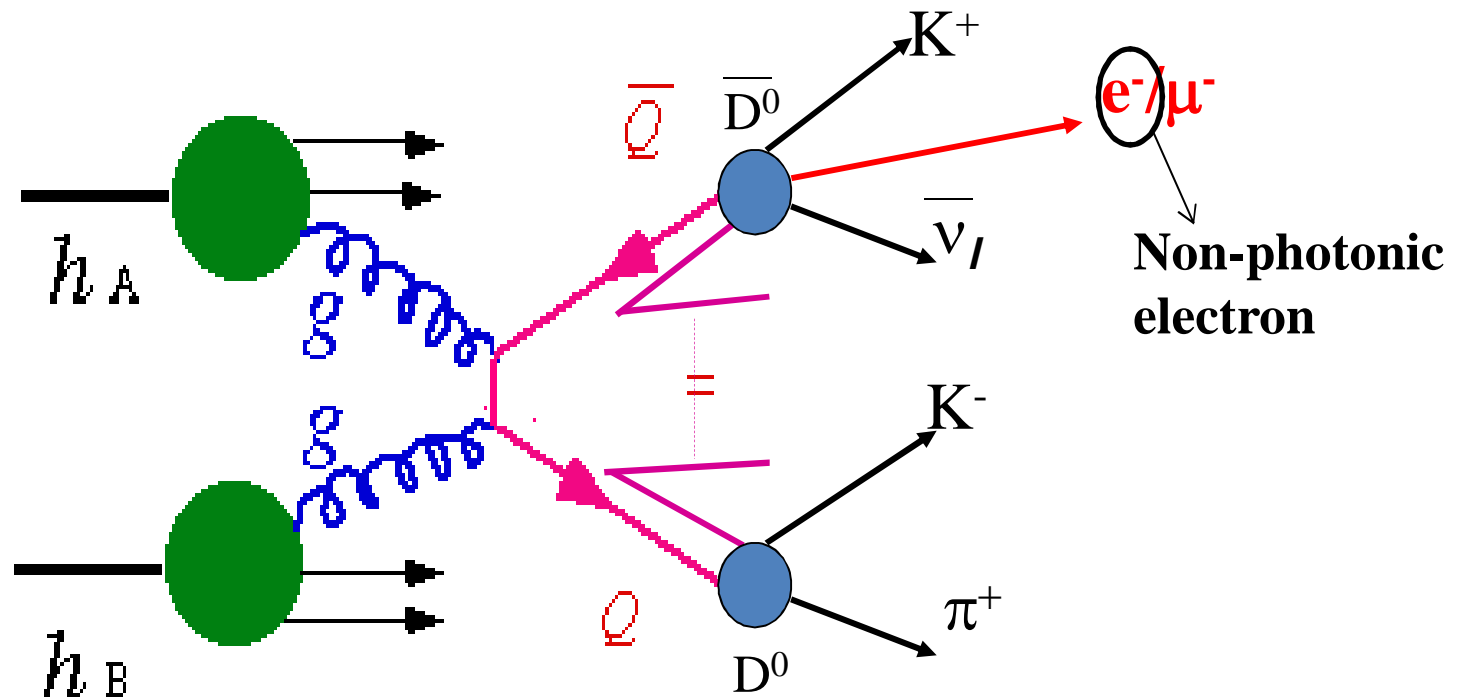


STAR can measure heavy flavor

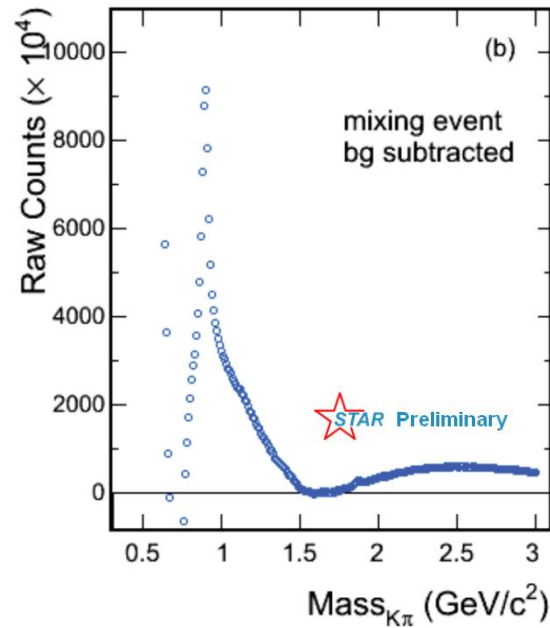
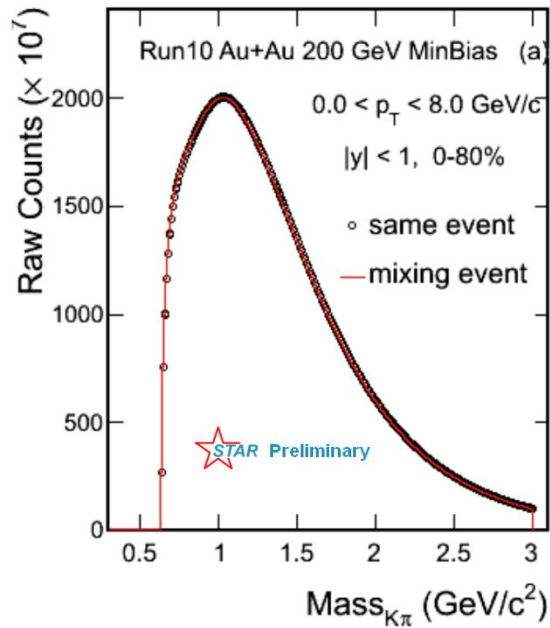
- of all different kind
 - (J/ψ , D^0 , D^* , electron ...)
- in broad p_T range.
- in all collision species.



Open Heavy Flavor Production



D⁰ Signal in Au+Au 200 GeV



□ Combining data from Run2010 & 2011.

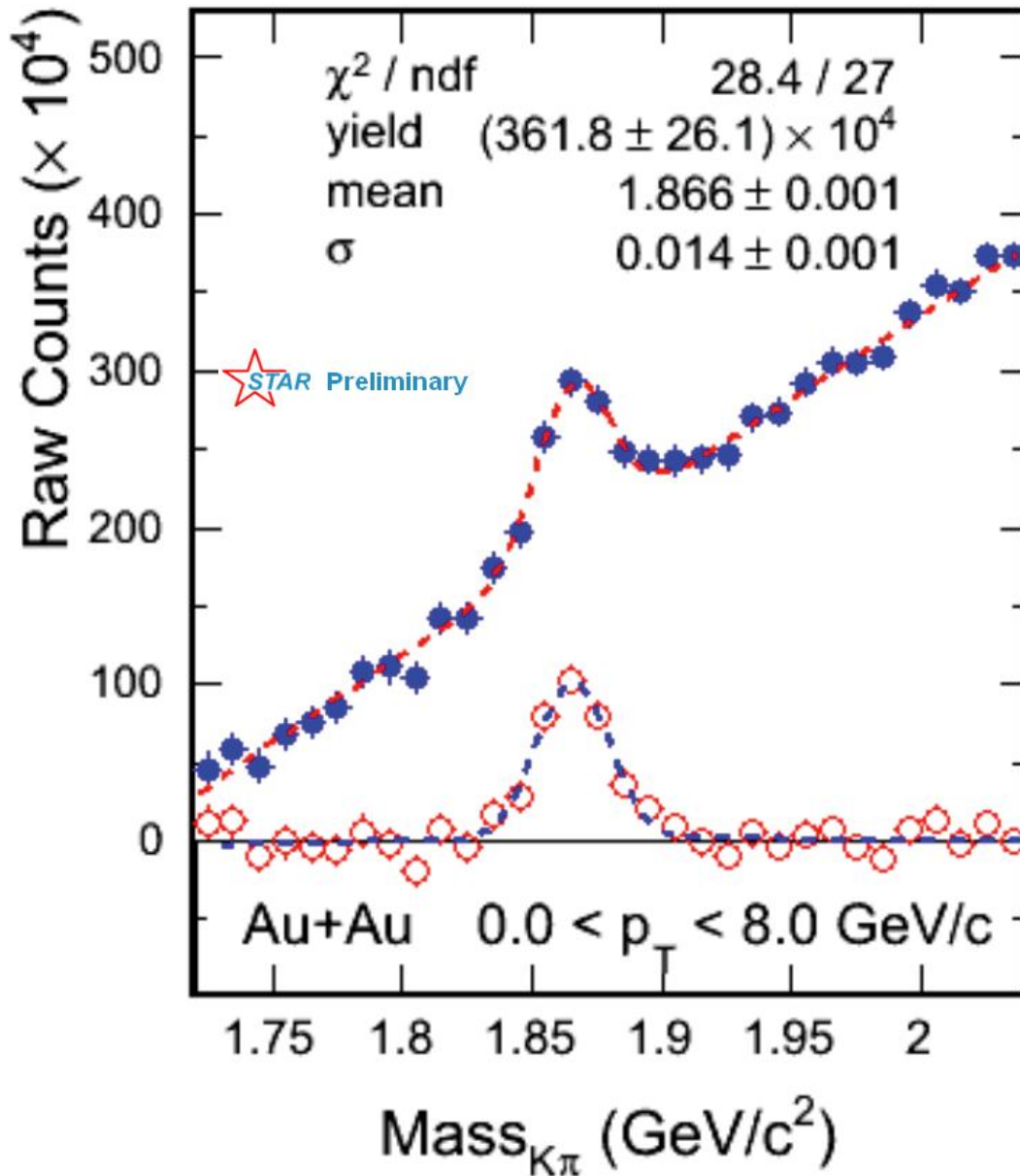
□ Total: ~800 M Min.Bias events

□ Significant signals are observed

□ In collisions of all centralities

D. Tlusty: Parallel 6A

D⁰ Signal in Au+Au 200 GeV



□ Combining data from Run2010 & 2011.

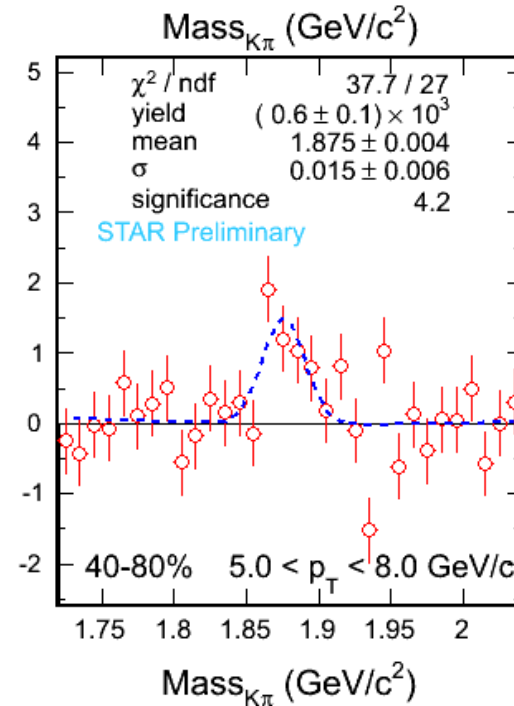
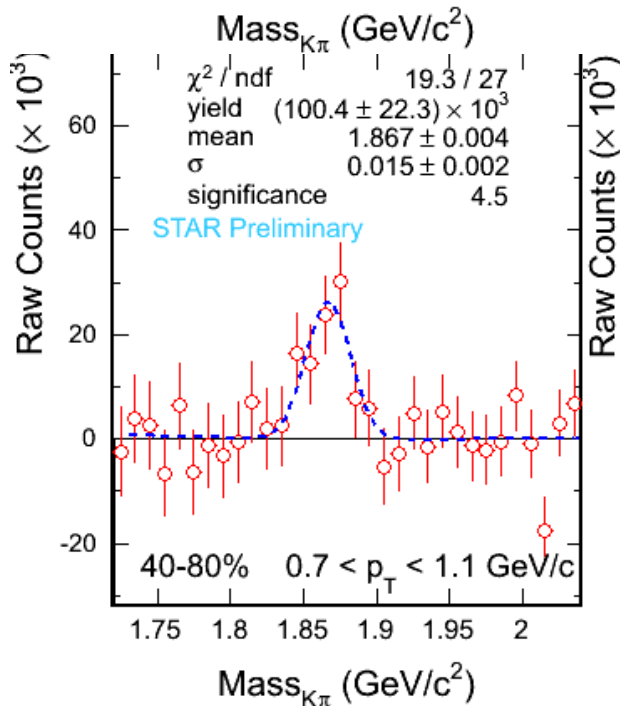
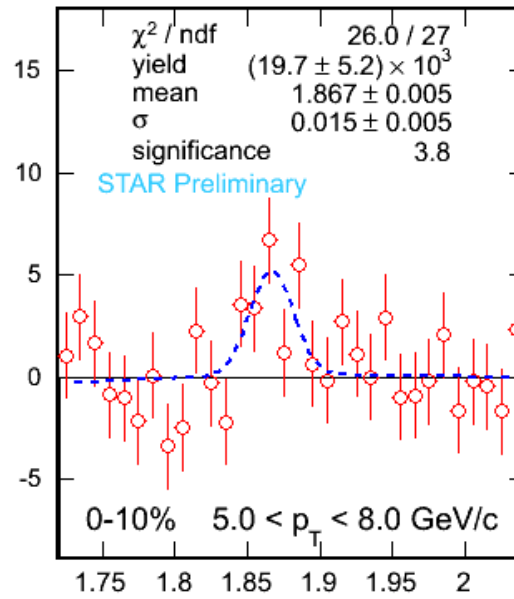
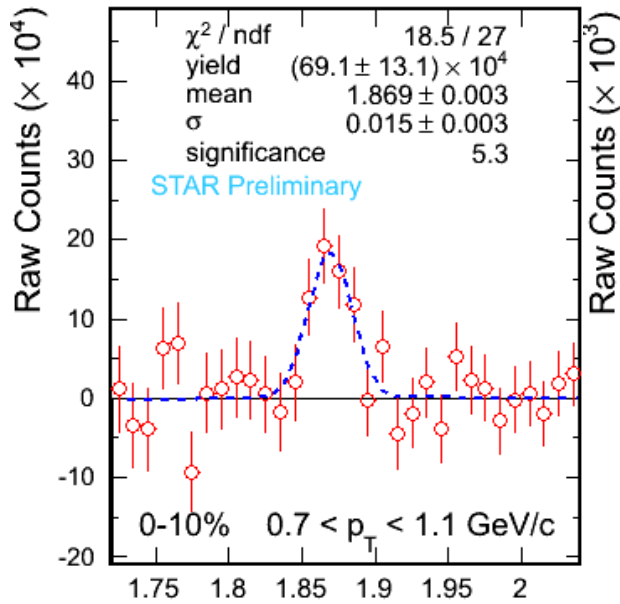
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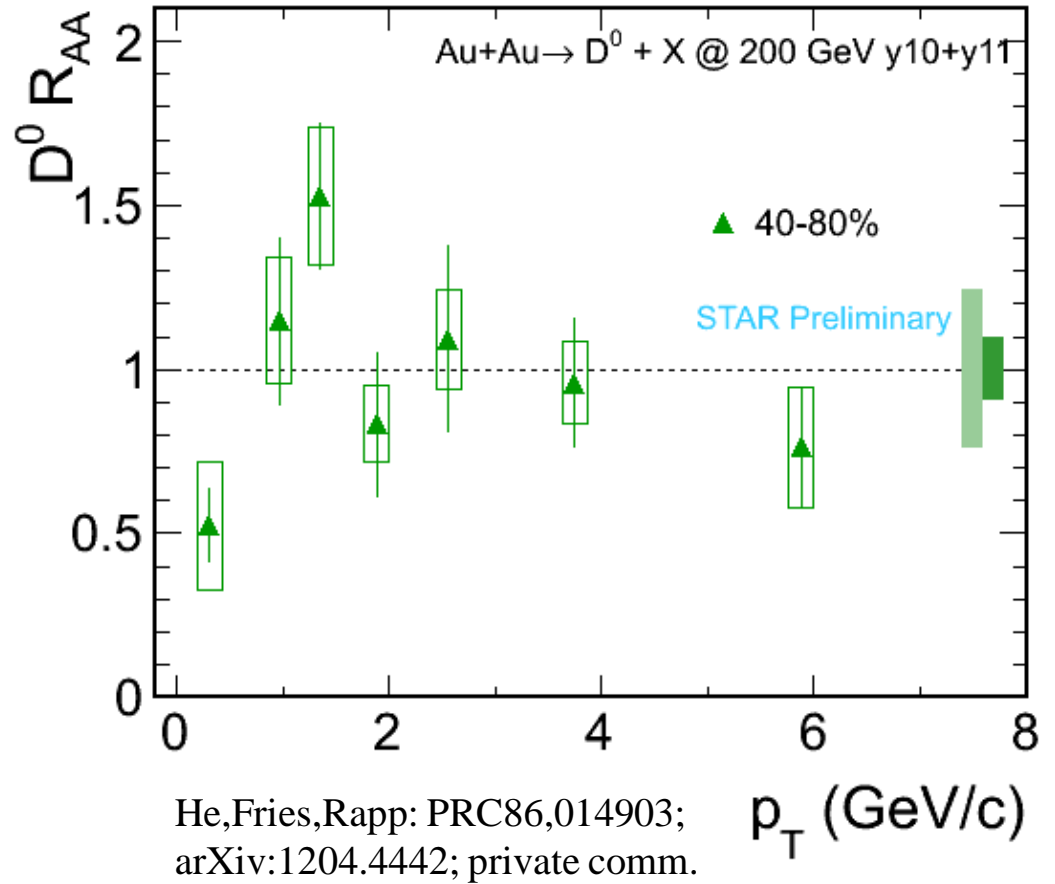
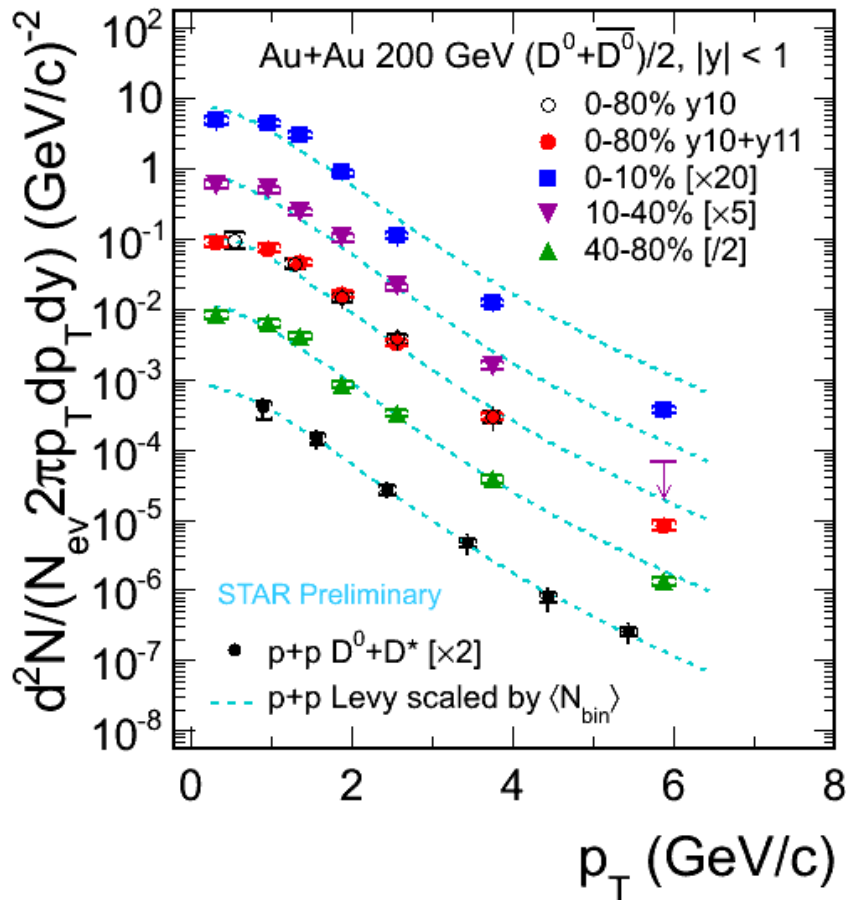
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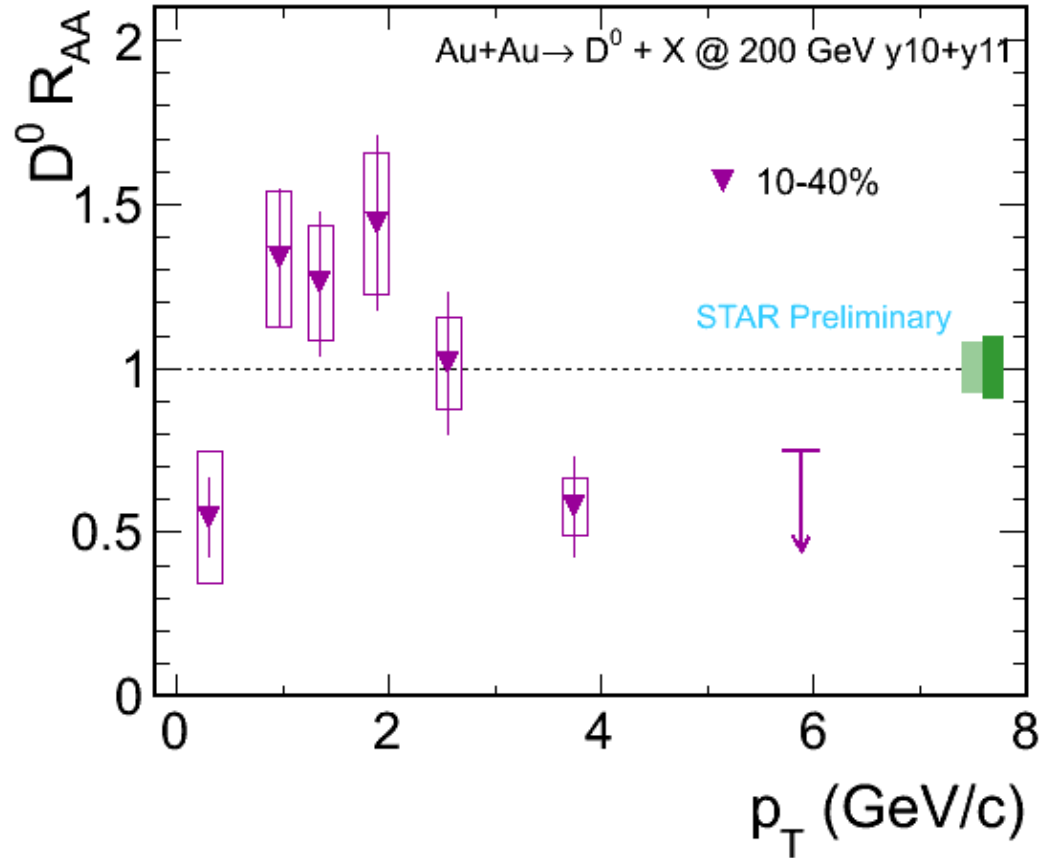
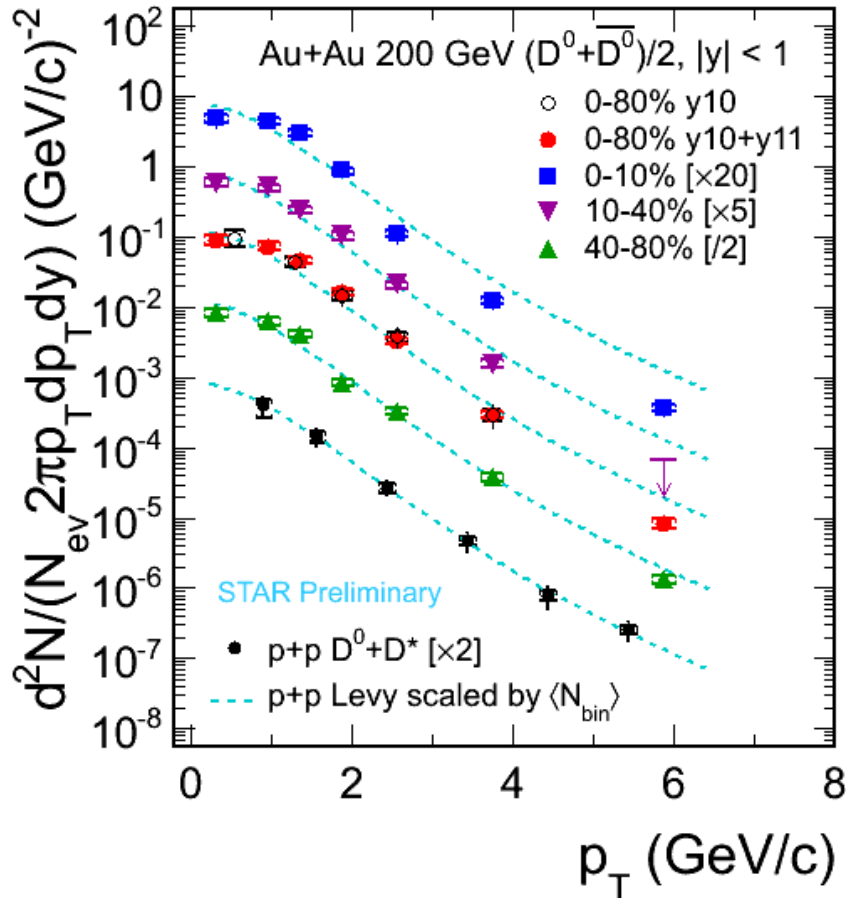
D. Tlusty: Parallel 6A

D⁰ Spectra in Au+Au 200 GeV



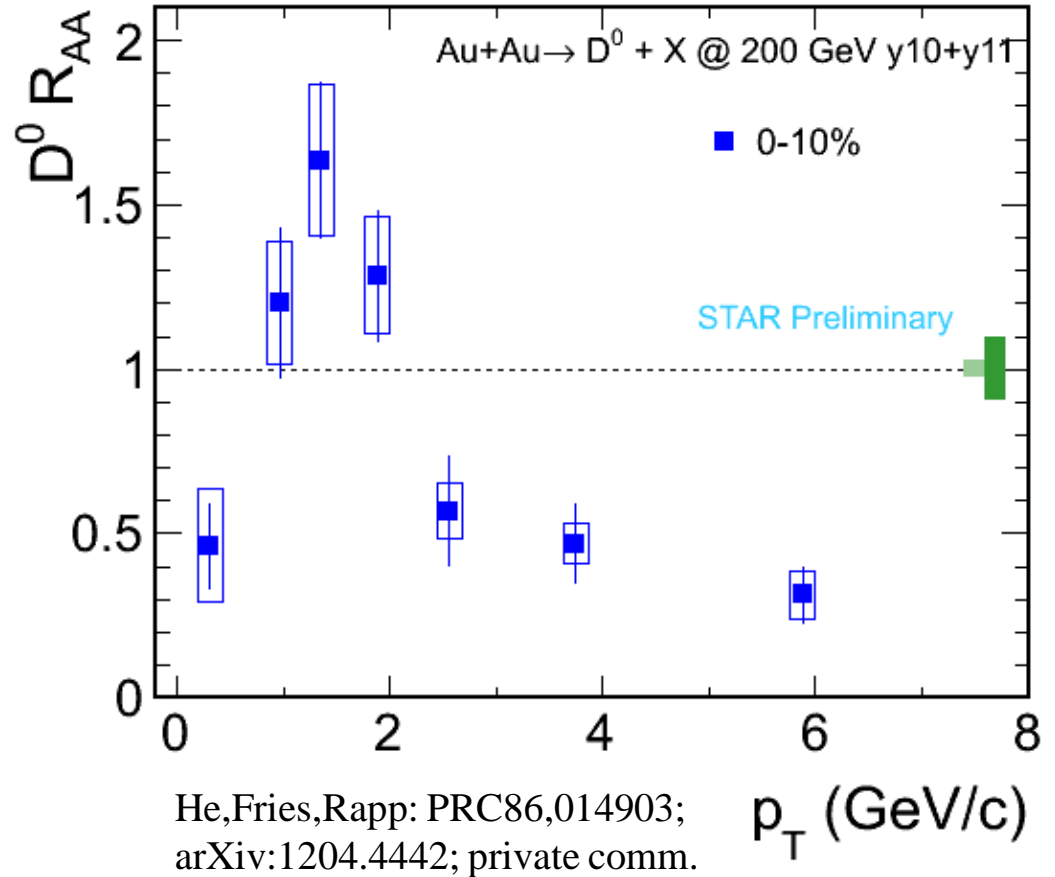
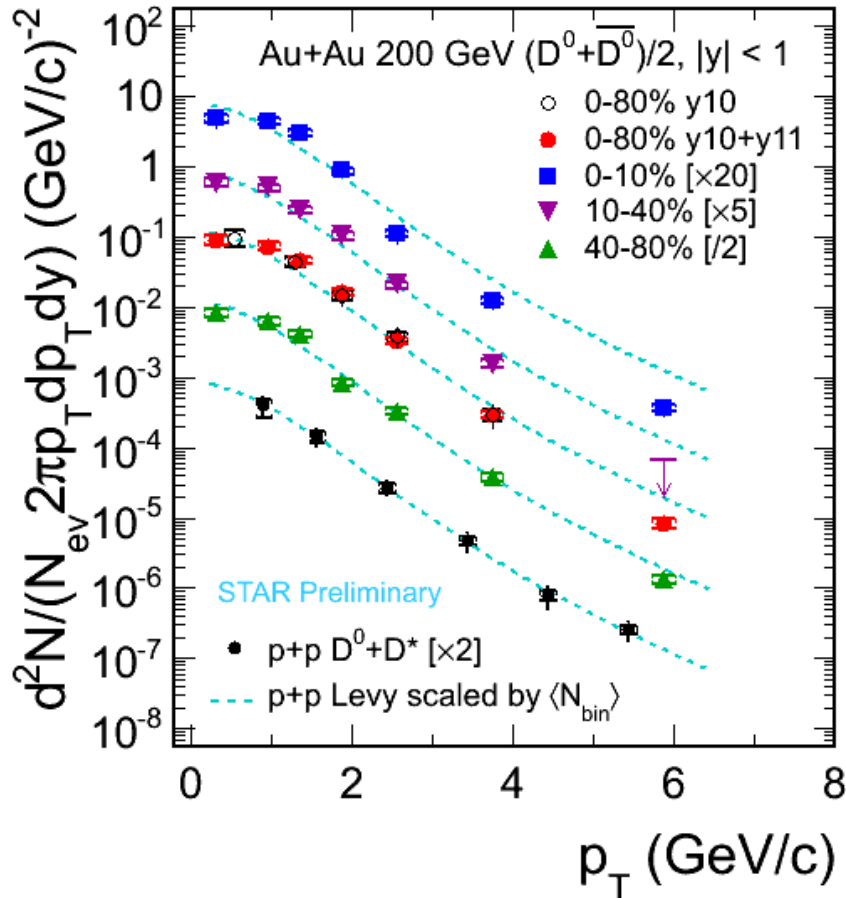
- ❑ Suppression at high p_T in central and mid-central collisions
- ❑ Enhancement at intermediate p_T .
- ❑ **D0 freeze out earlier than light hadron and/or**
- ❑ **D0 does not have much radial flow as light quarks**

D⁰ Spectra in Au+Au 200 GeV



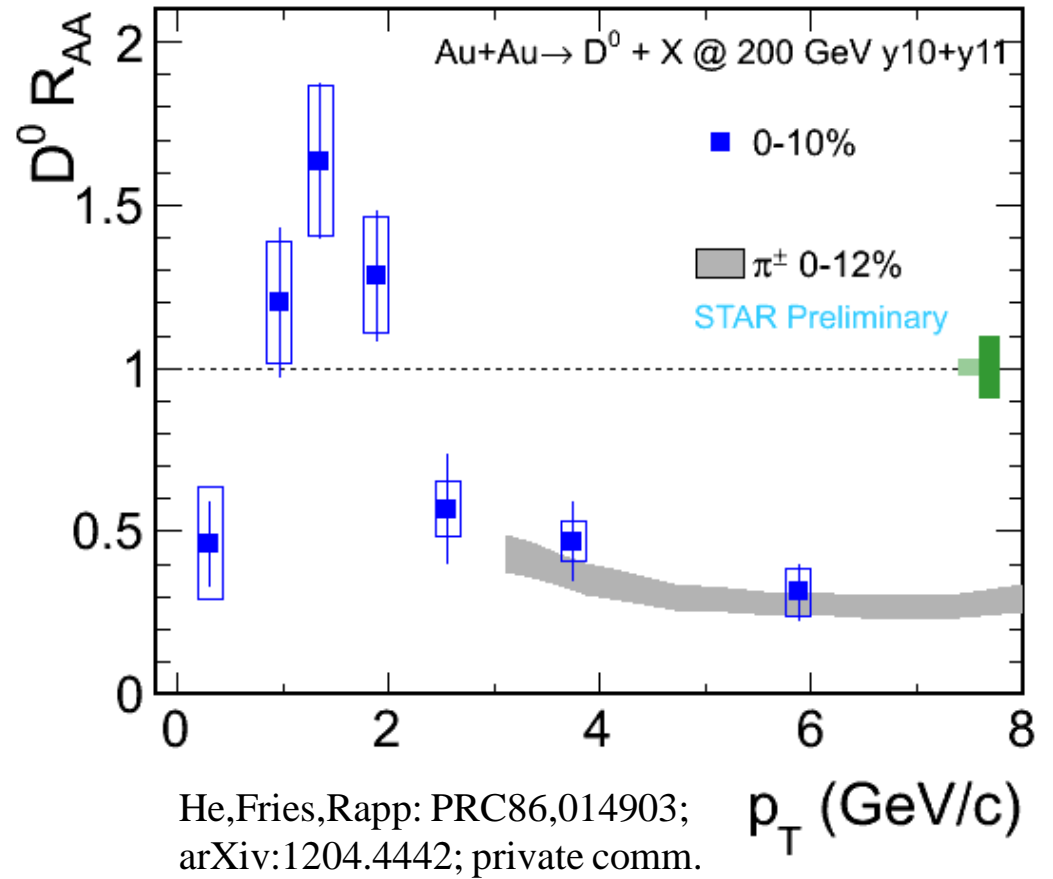
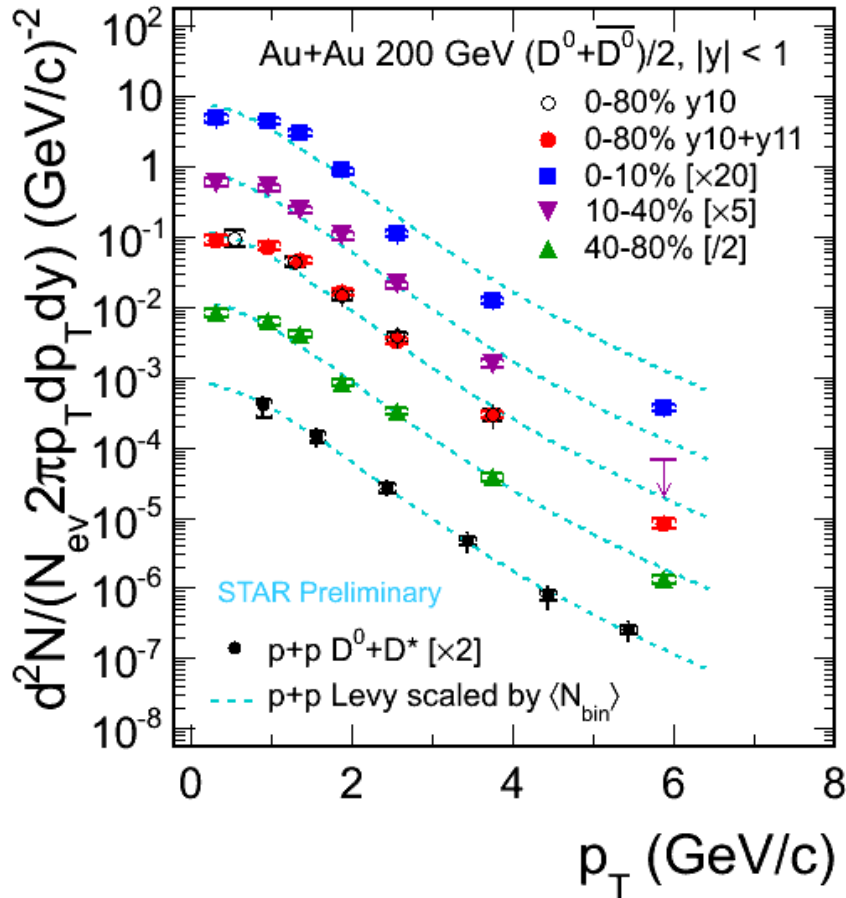
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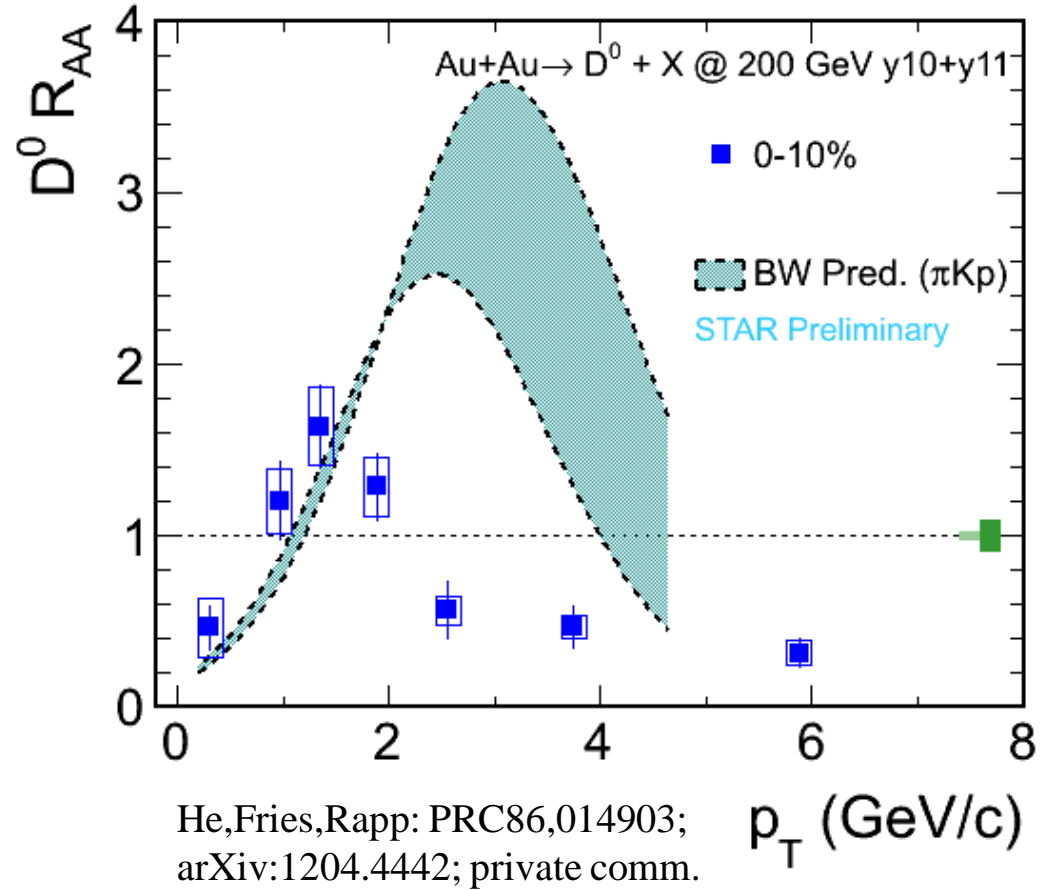
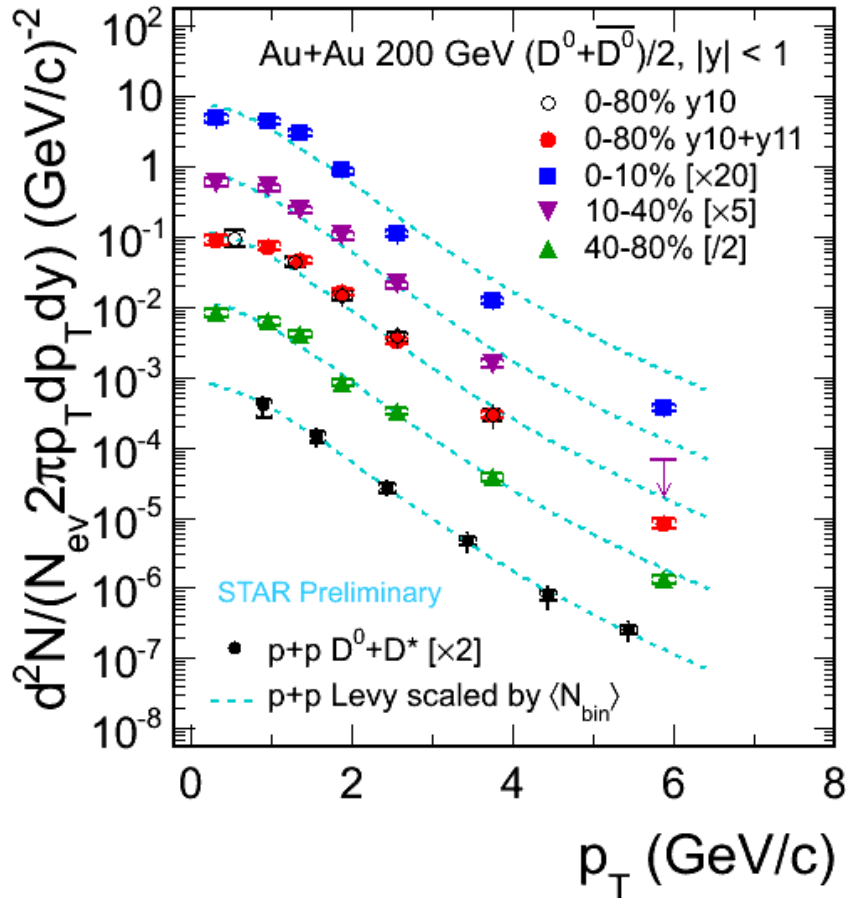
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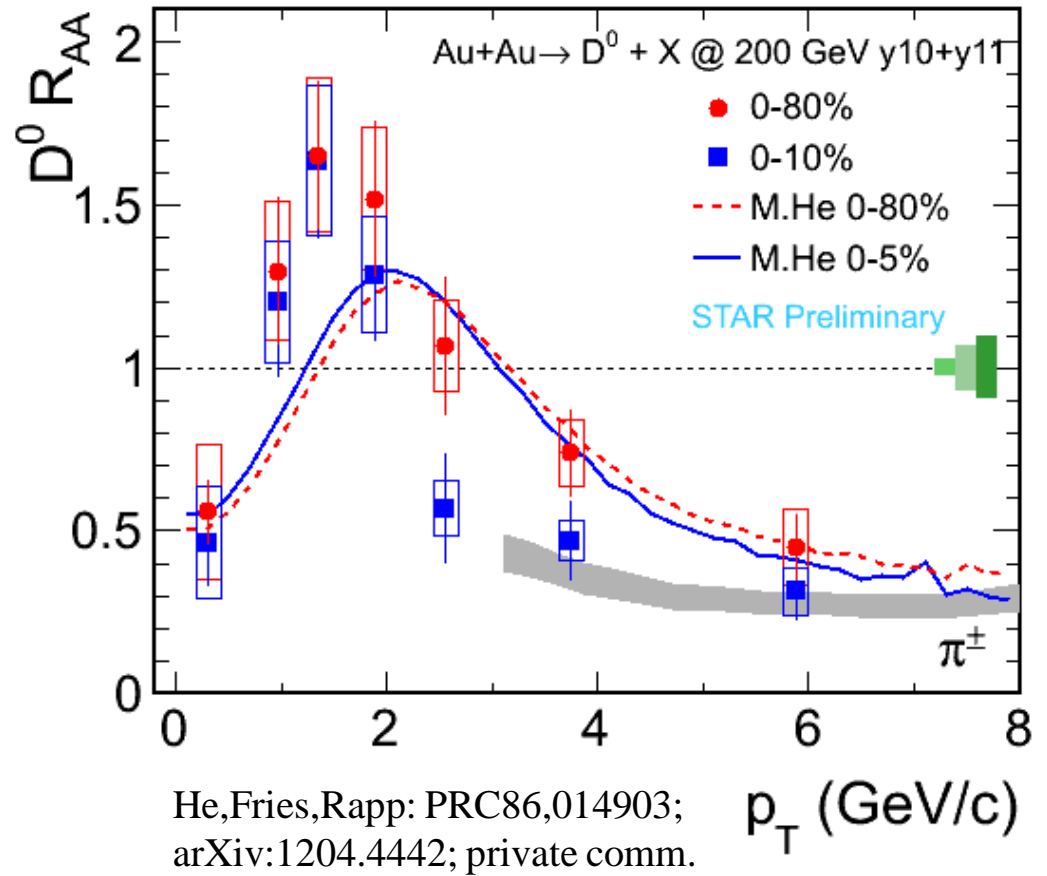
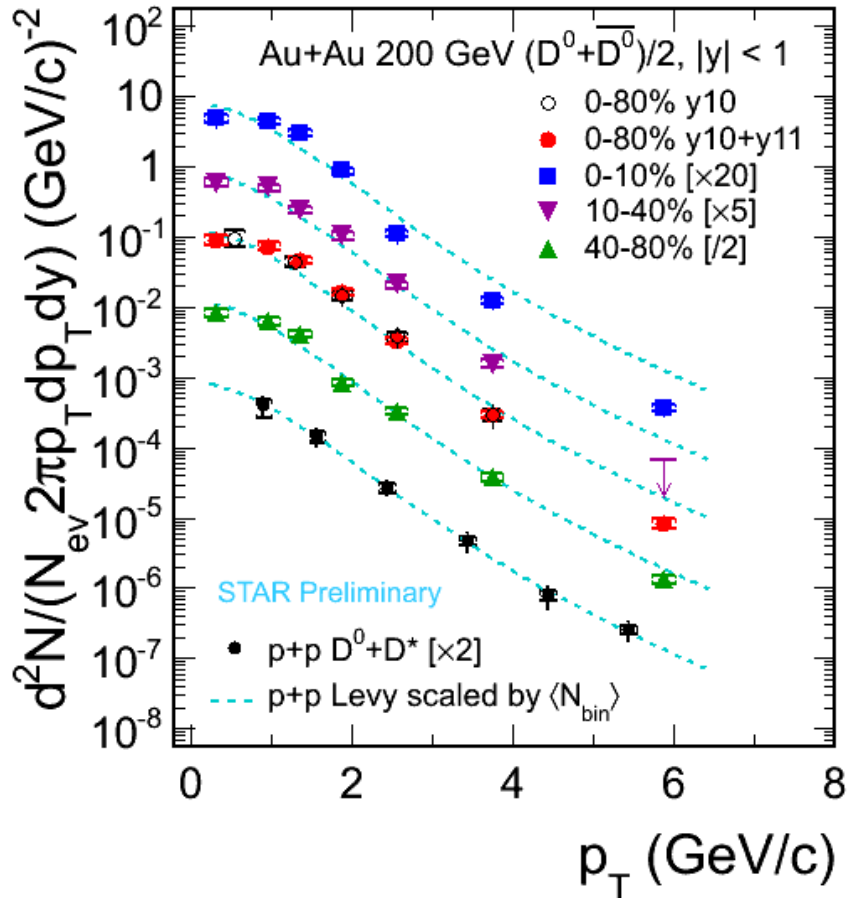
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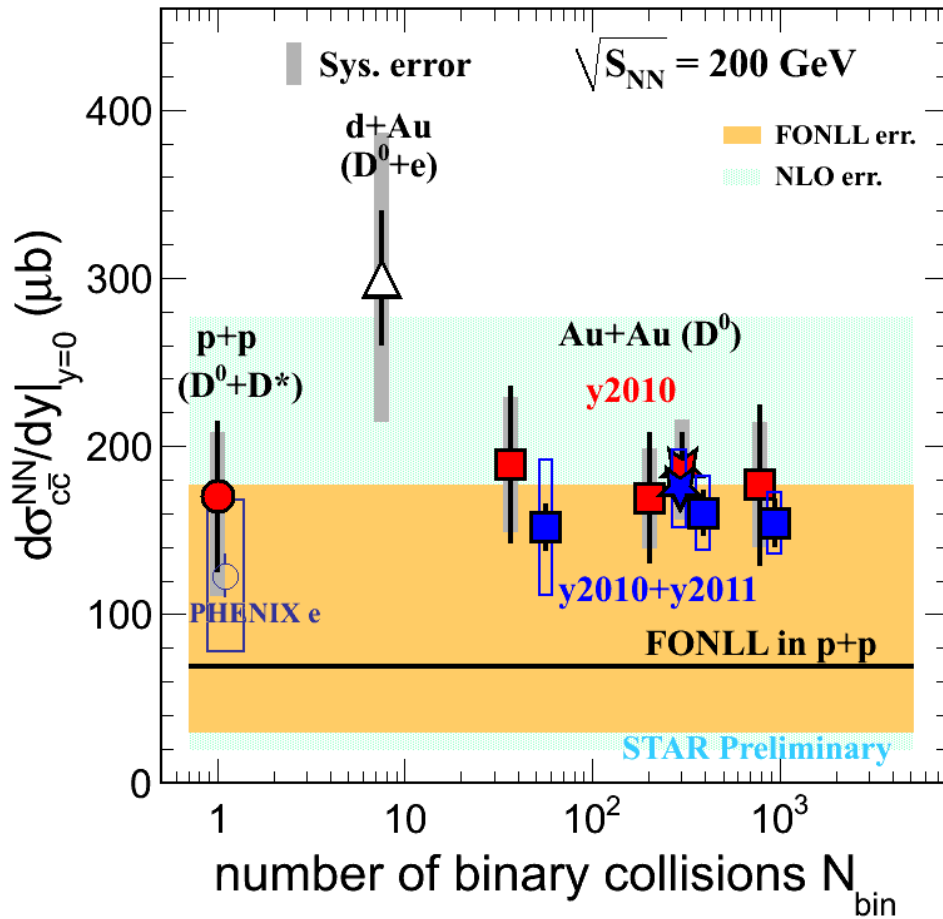
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Charm cross section vs N_{coll} in Au+Au 200 GeV



- [1] STAR d+Au: J. Adams, et al., PRL 94 (2005) 62301
- [2] FONLL: M. Cacciari, PRL 95 (2005) 122001.
- [3] NLO: R. Vogt, Eur.Phys.J.ST 155 (2008) 213
- [4] PHENIX e: A. Adare, et al., PRL 97 (2006) 252002.

- Run2003 d+Au : $D^0 + e$
- Run2009 p+p : $D^0 + D^*$
- Run 2010 & 2011 Au+Au: D^0
- Assuming $N_{D^0}/N_{cc} = 0.56$ does not change for total cross sections.

□ The charm cross section at mid-rapidity:

$$\frac{d\sigma}{dy}\bigg|_{y=0}^{c\bar{c}}(p+p) = 170 \pm 45 (stat.)_{-59}^{+38} (sys.) \mu b$$

$$\frac{d\sigma}{dy}\bigg|_{y=0}^{c\bar{c}}(AuAu) = 175 \pm 13 (stat.) \pm 23 (sys) \mu b$$

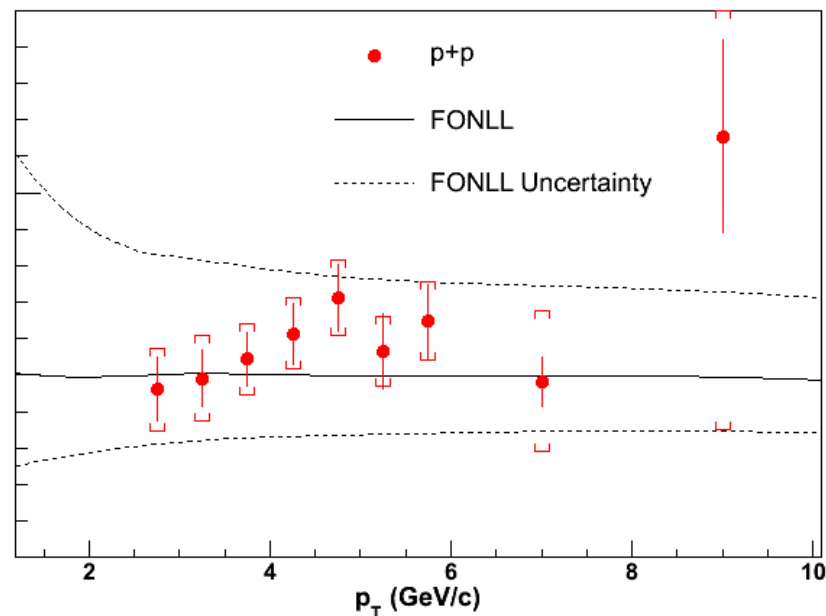
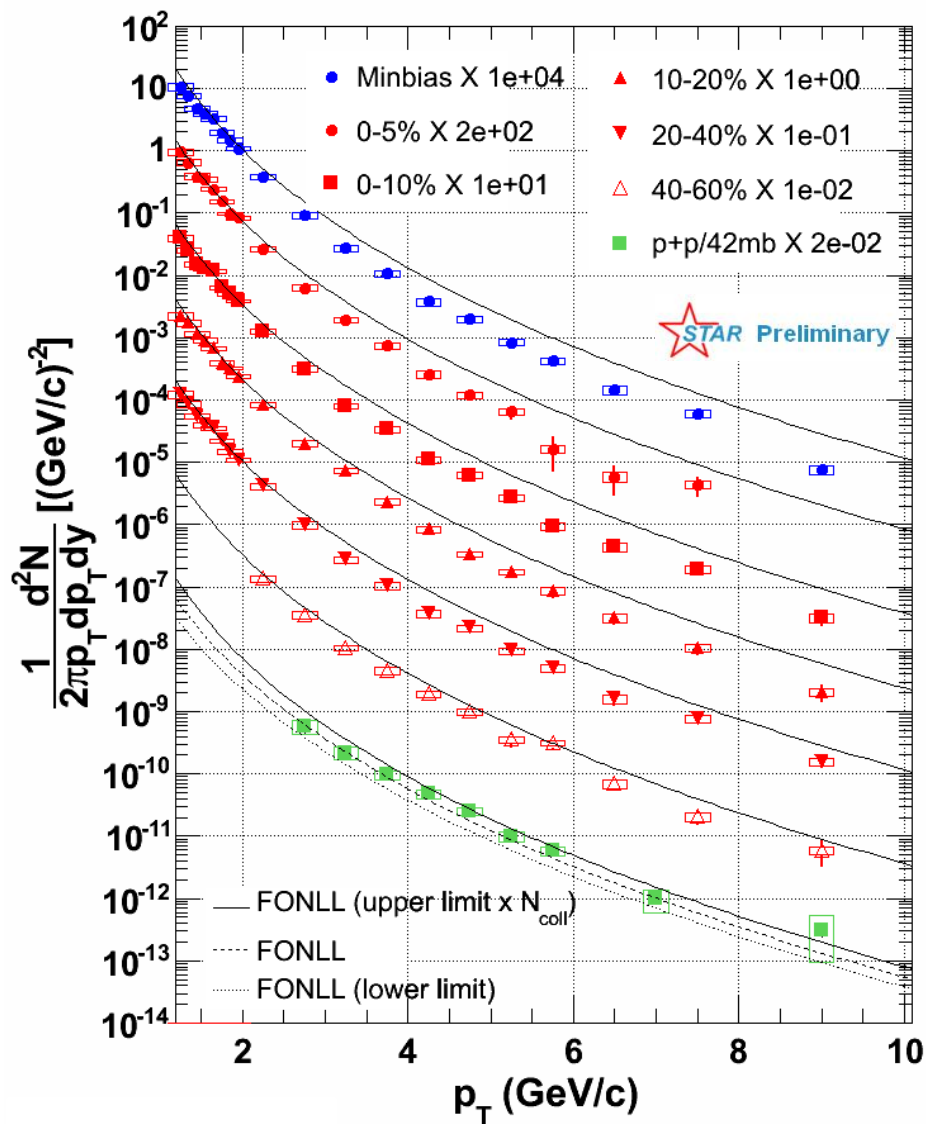
□ The charm total cross section :

$$\sigma_{c\bar{c}}(p+p) = 797 \pm 210 (stat.)_{-295}^{+208} (sys) \mu b$$

$$\sigma_{c\bar{c}}(AuAu) = 822 \pm 62 (stat.) \pm 192 \mu b$$

- Charm quarks are mostly produced via initial hard scatterings.
- Quantify other sources of production via high luminosity and upgrade.

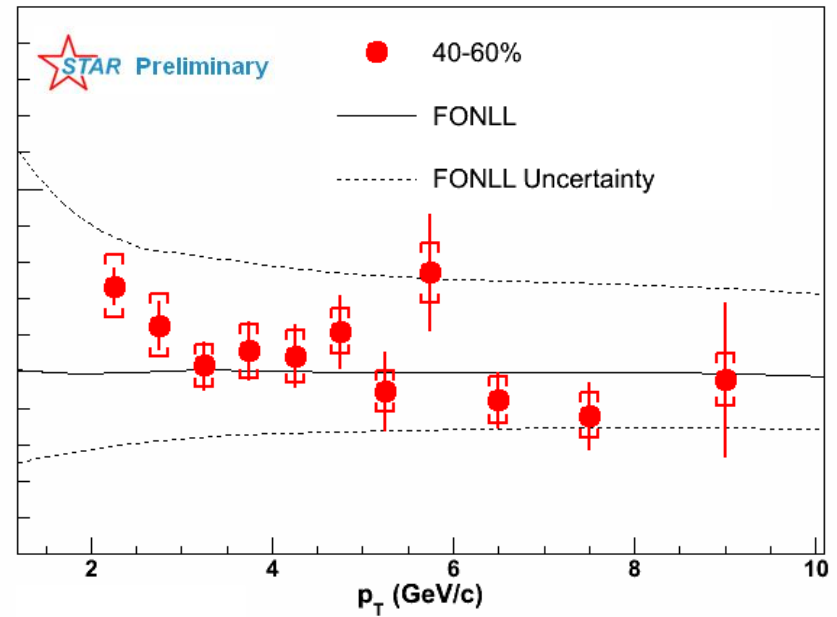
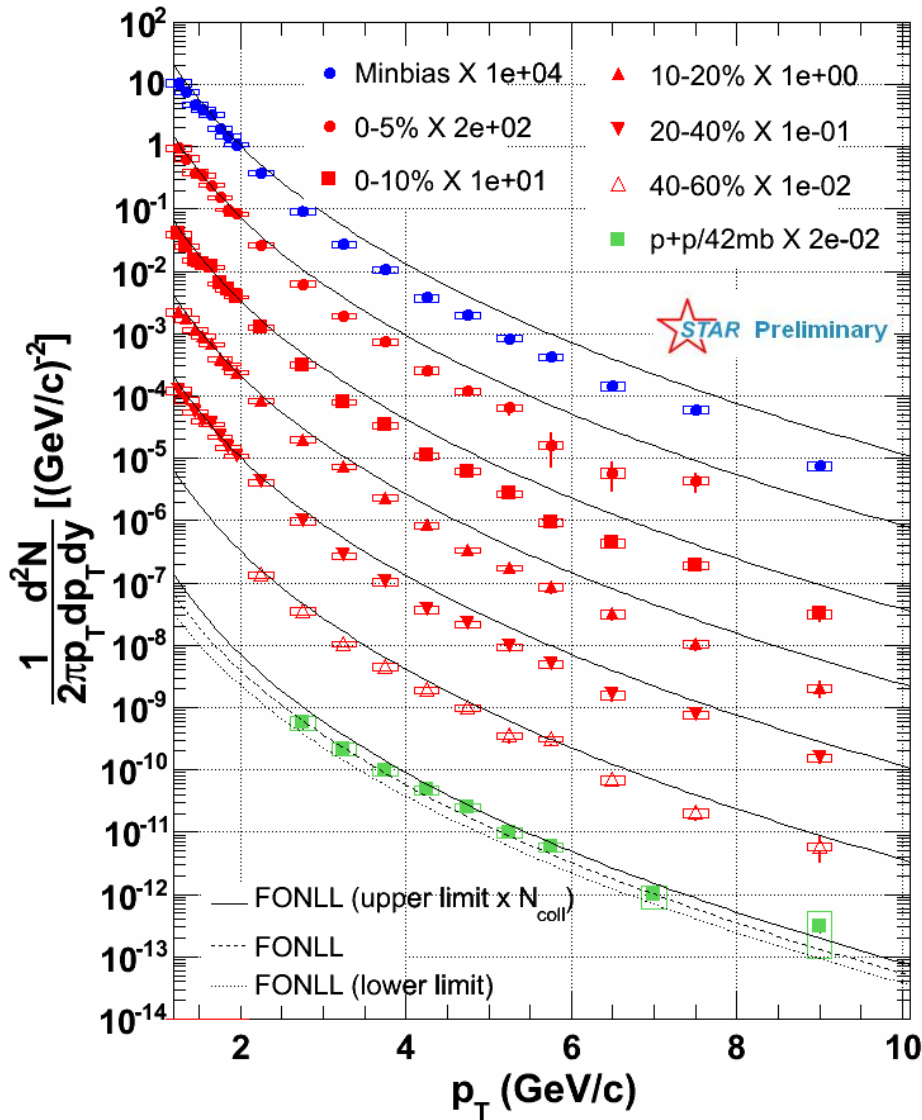
Non-photonic Electron Spectra in Au+Au 200 GeV



- $\sim 1 \text{ nb}^{-1}$ sampled luminosity in Run2010 Au+Au collisions.
- $\sim 6 \text{ pb}^{-1}$ sampled luminosity in Run2005 and Run2008 p+p collisions.

M. Mustafa: Parallel 7A

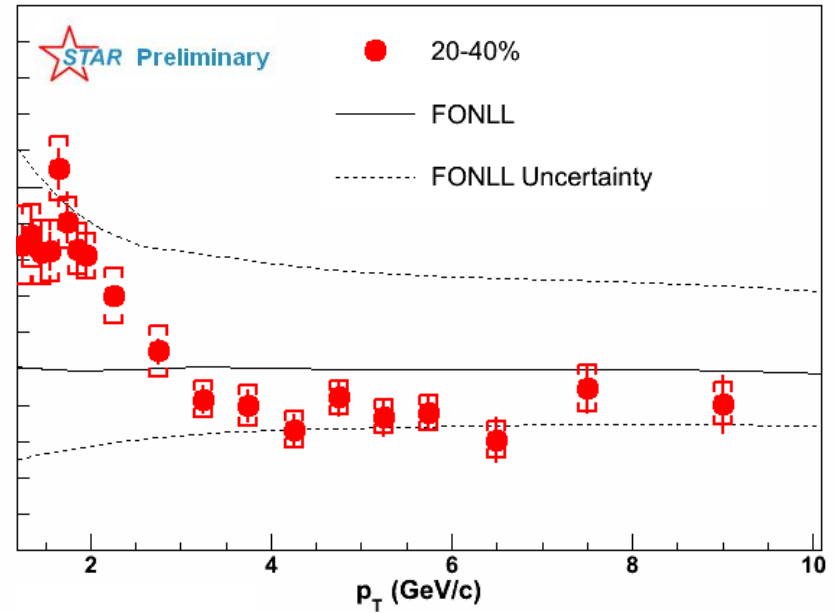
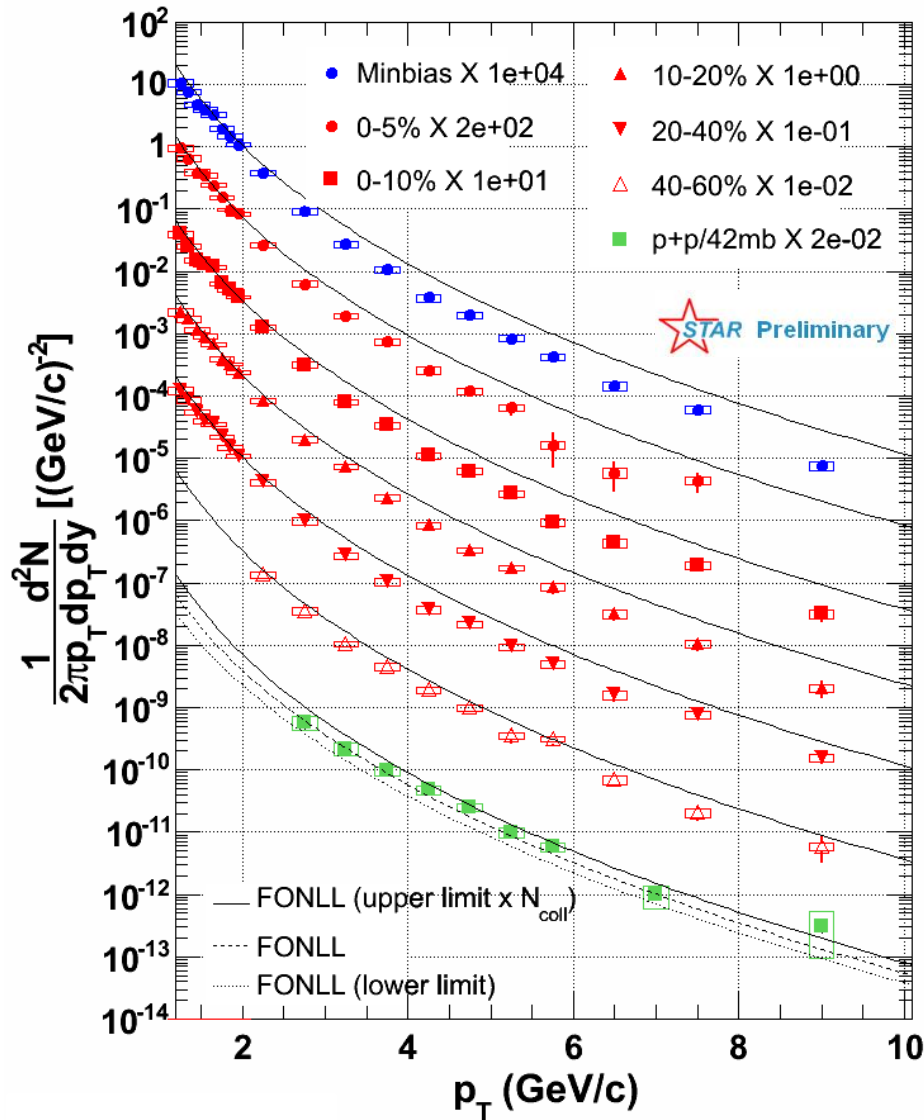
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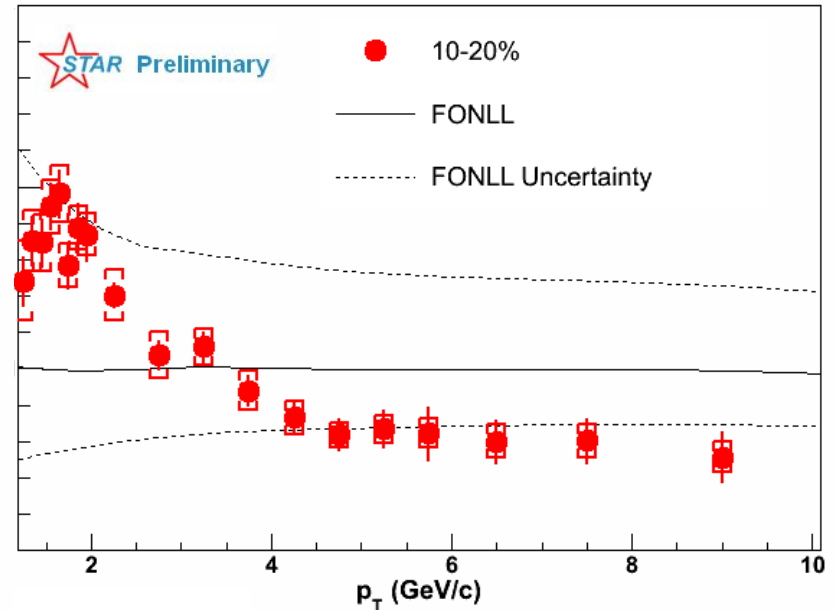
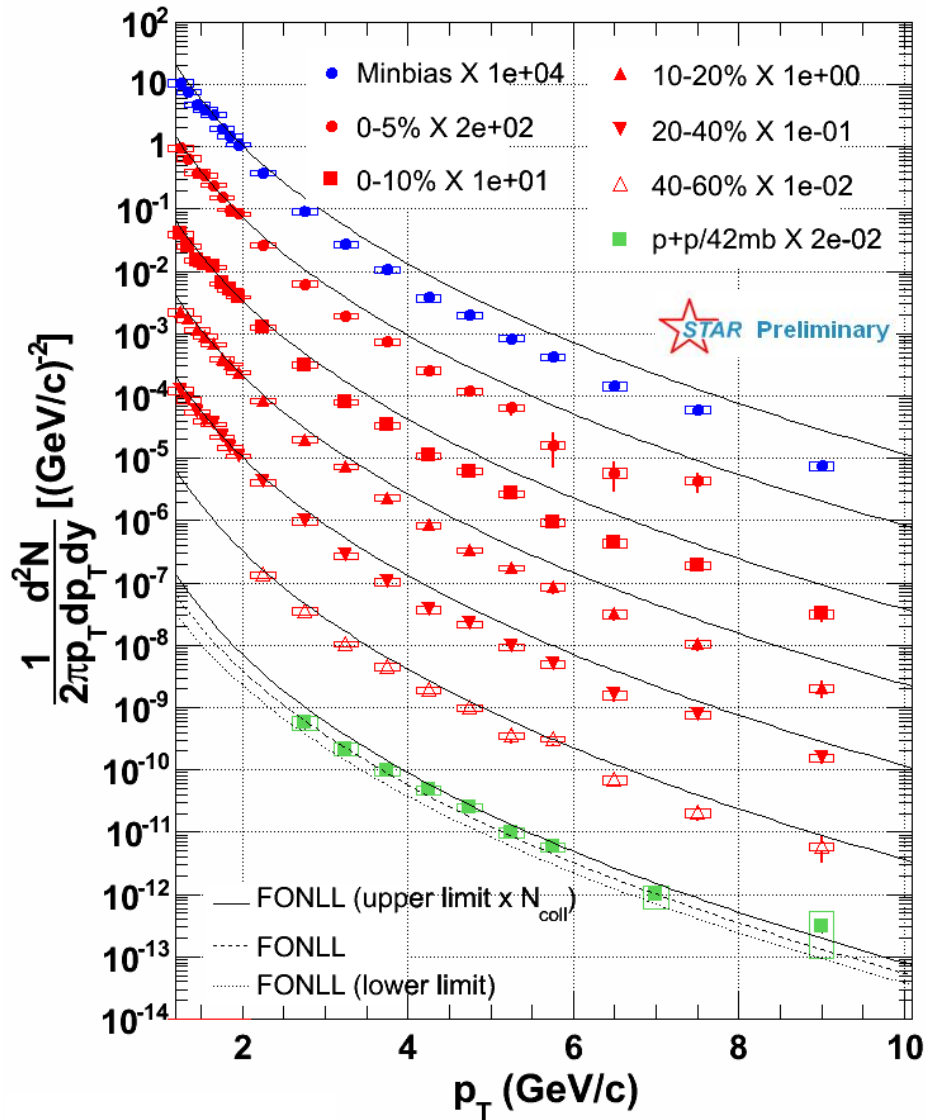
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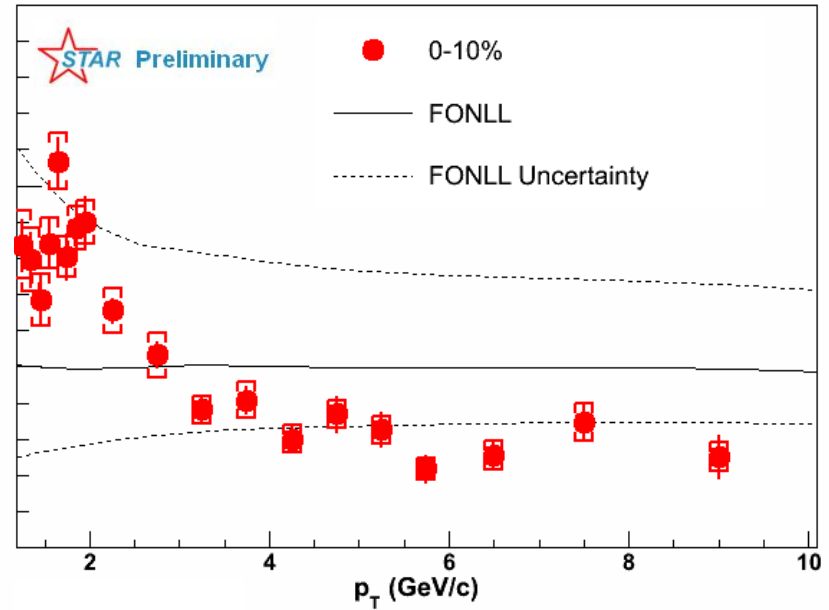
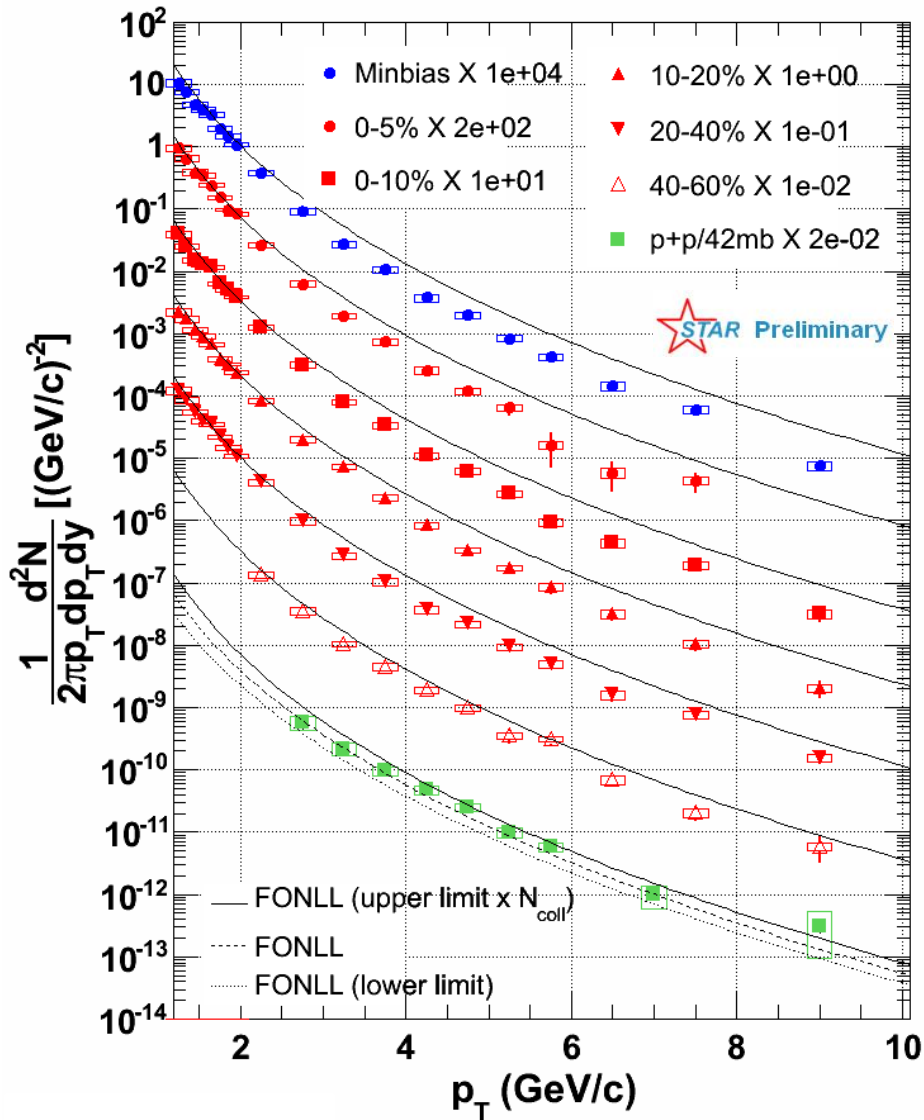
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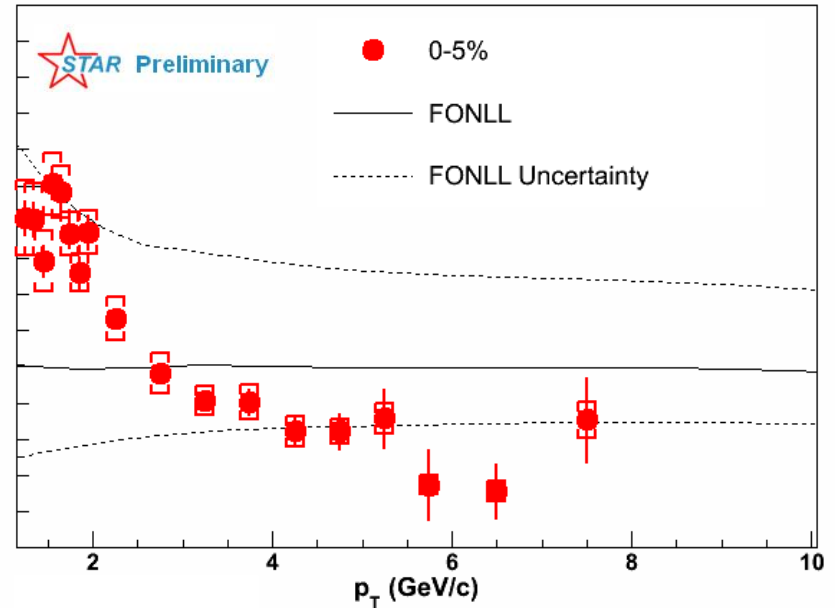
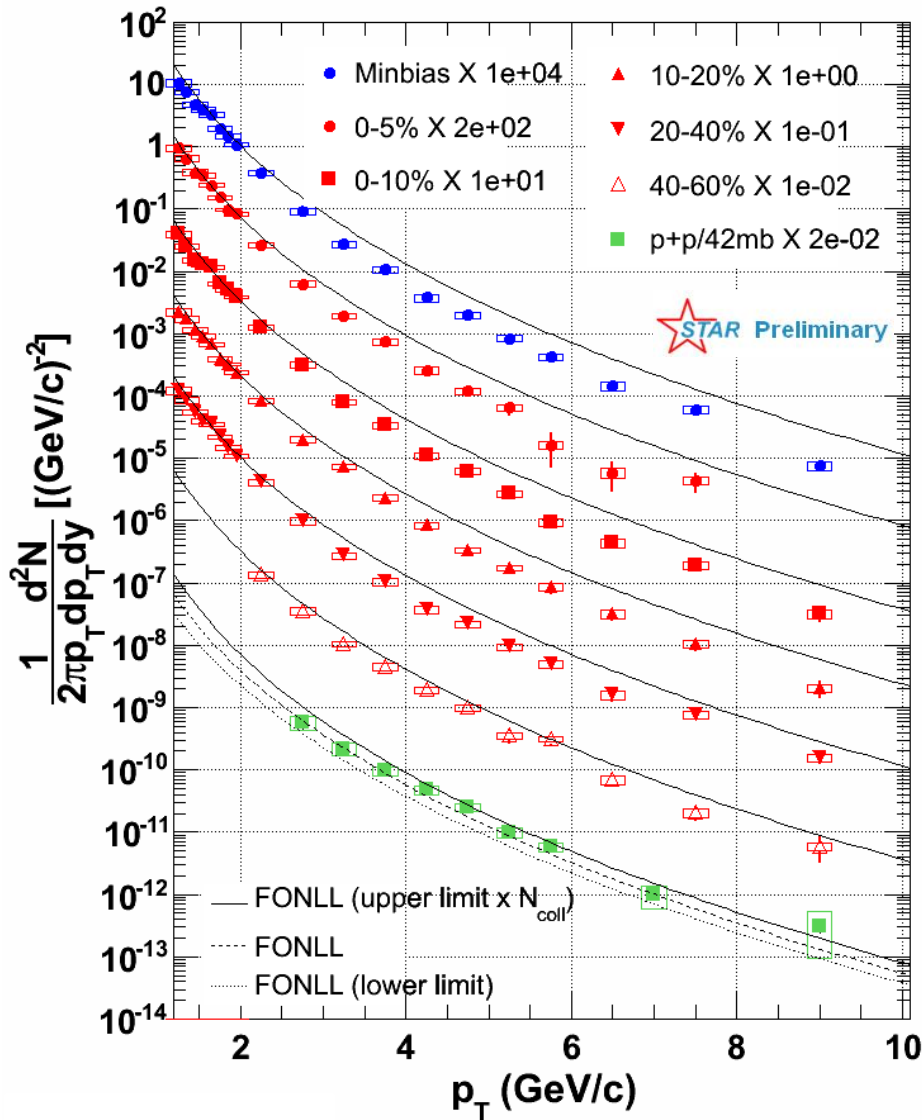
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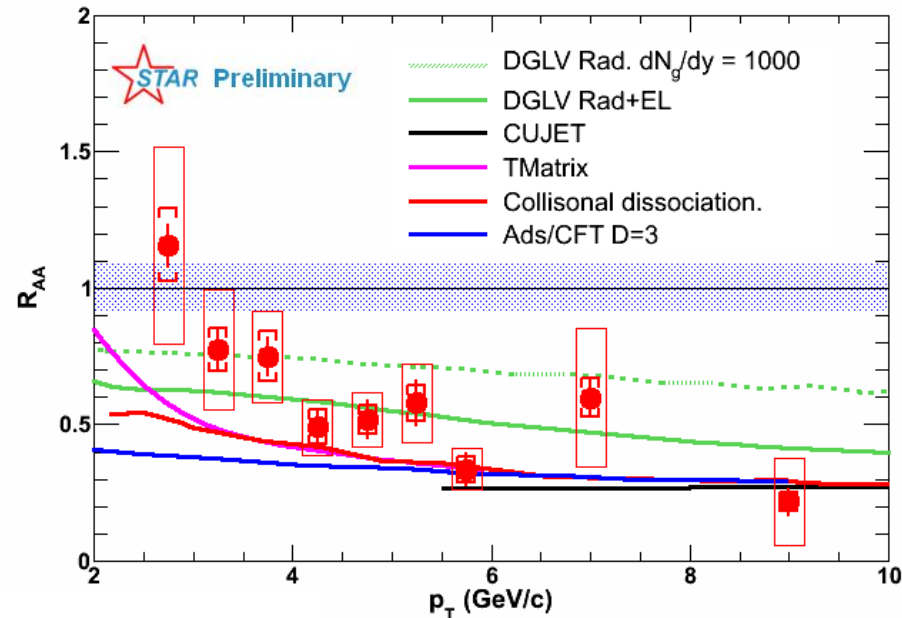
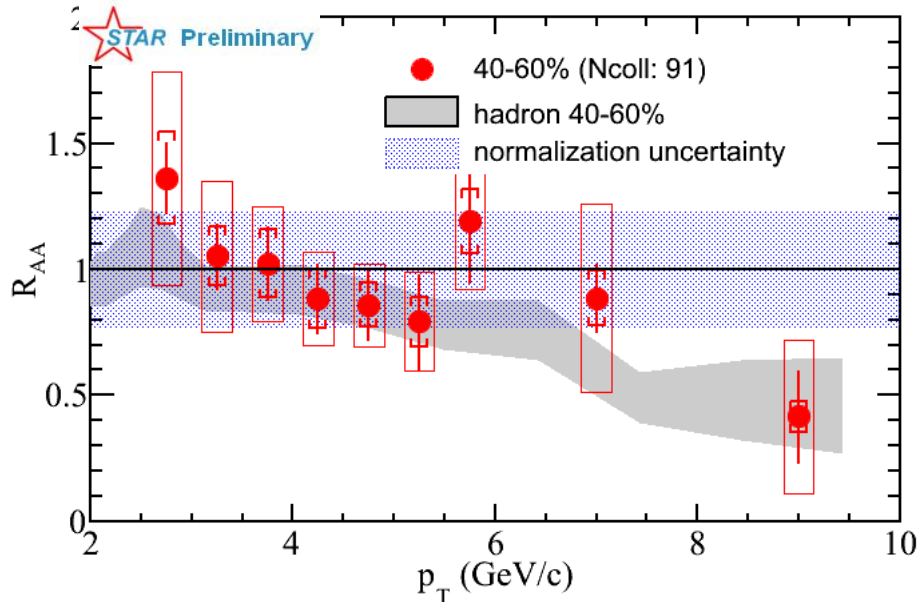
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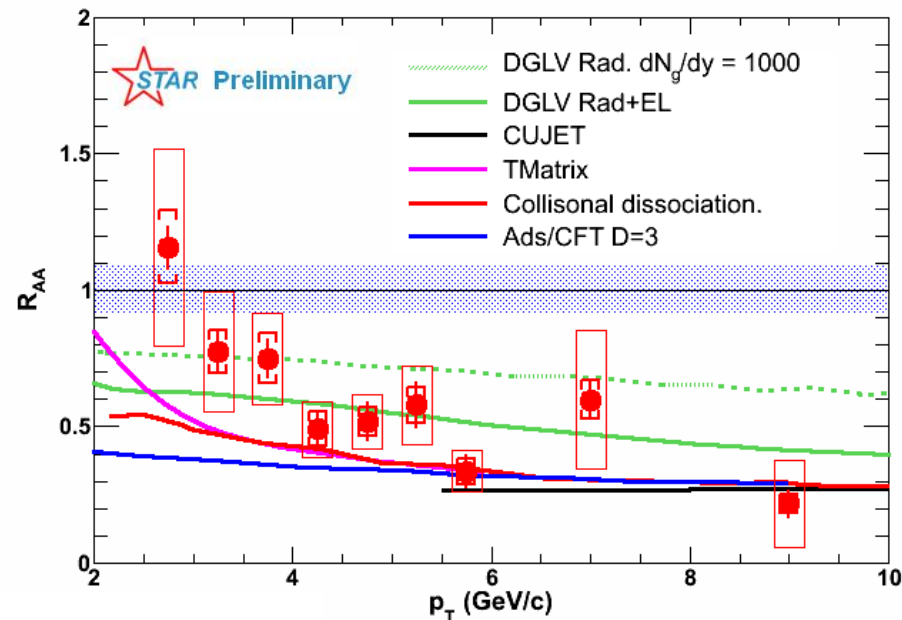
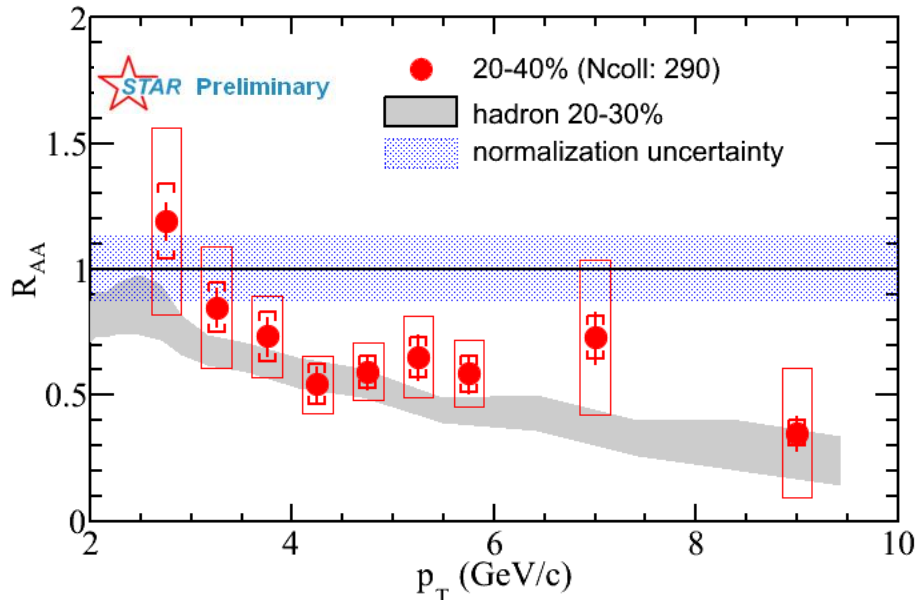
Non-photonic Electron R_{AA} in Au+Au 200 GeV



- Strong suppression at high p_T in central collisions
- D0, NPE results seems to be consistent \rightarrow kinematics smearing & charm/bottom mixing
- Models with radiative energy loss alone underestimate the suppression
- Uncertainty dominated by p+p result.
- Compare with Au+Au spectra directly, if possible.
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DGLV: Djordjevic, PLB632, 81 (2006)
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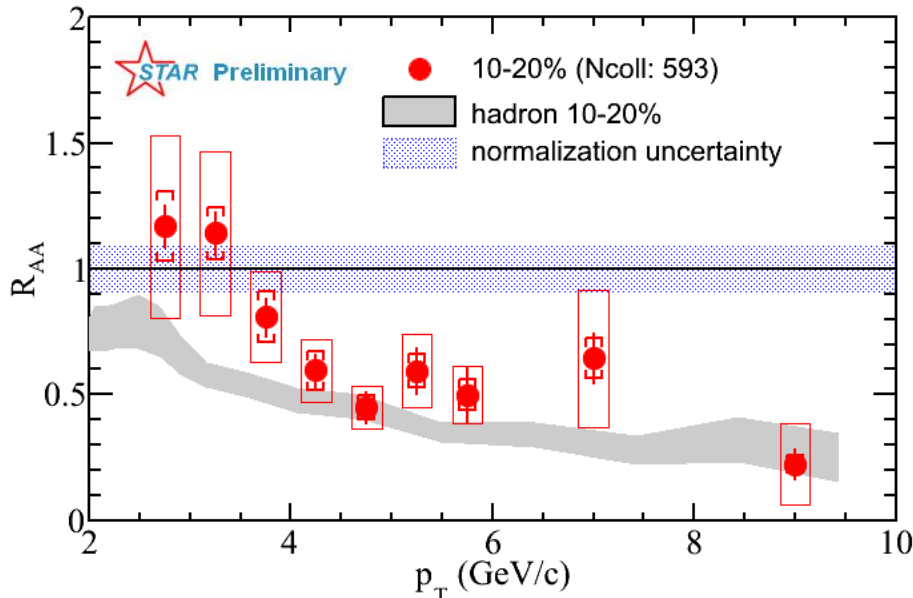
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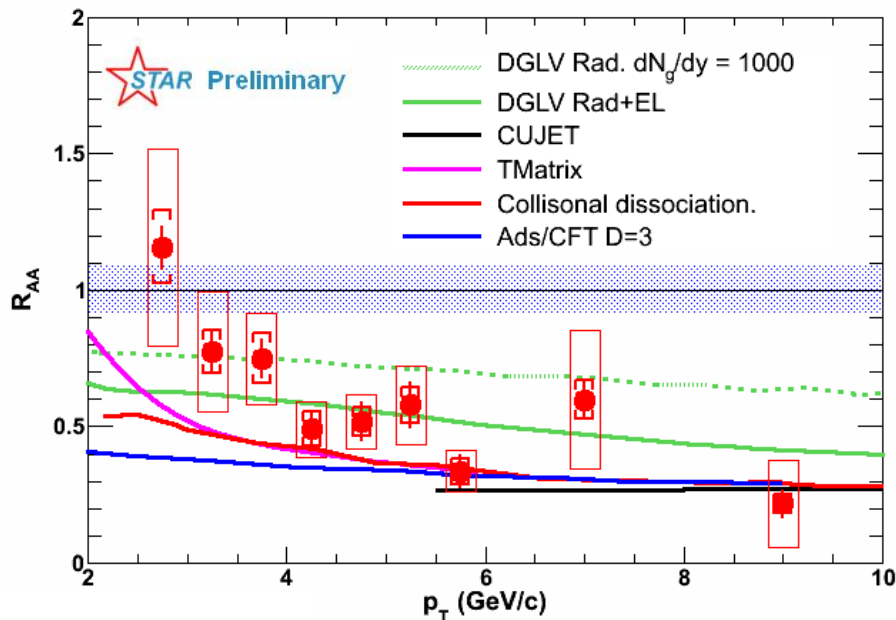
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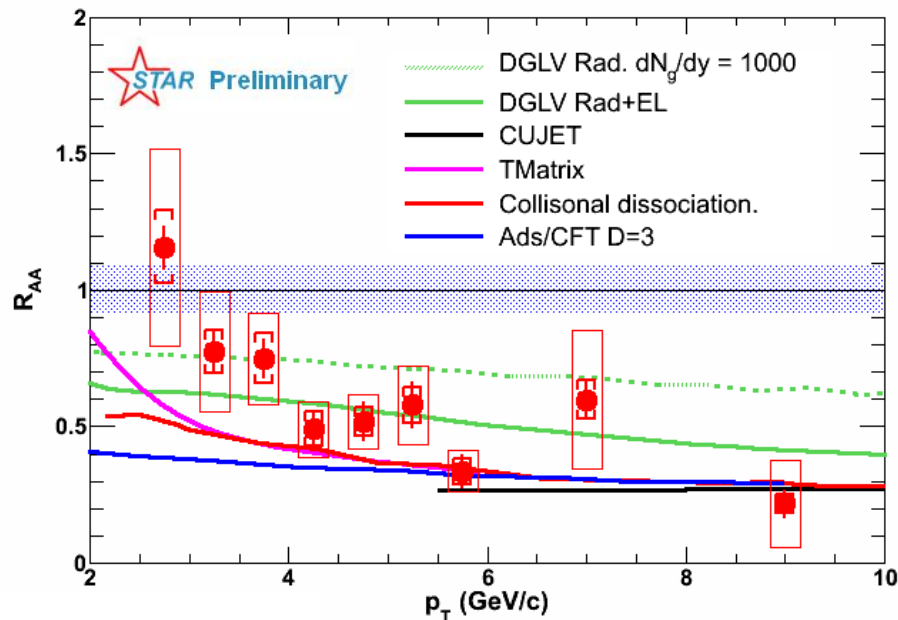
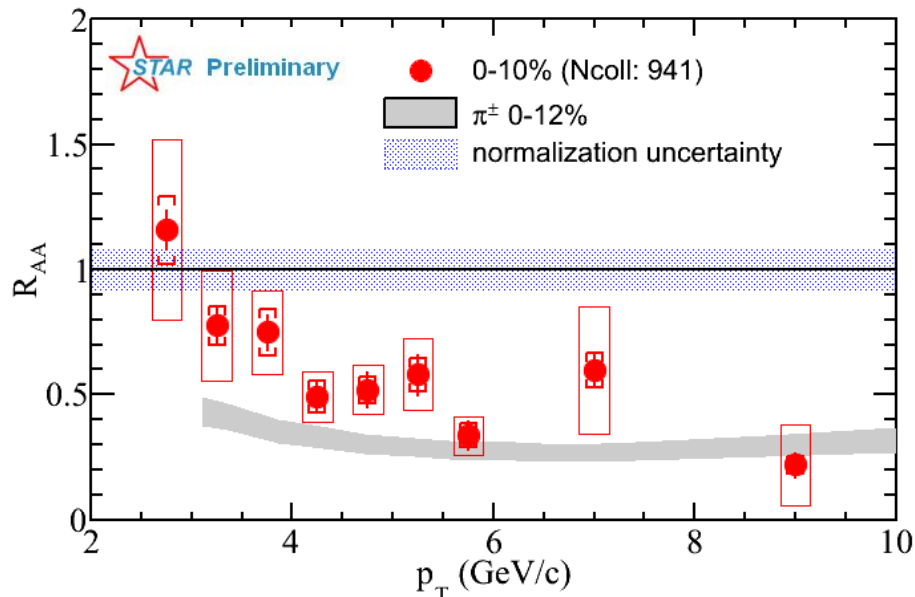


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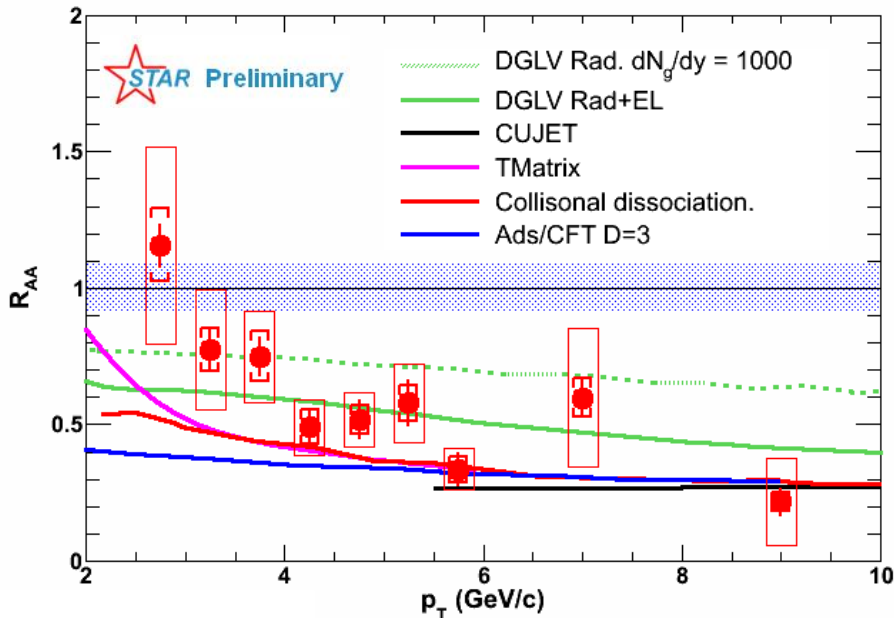
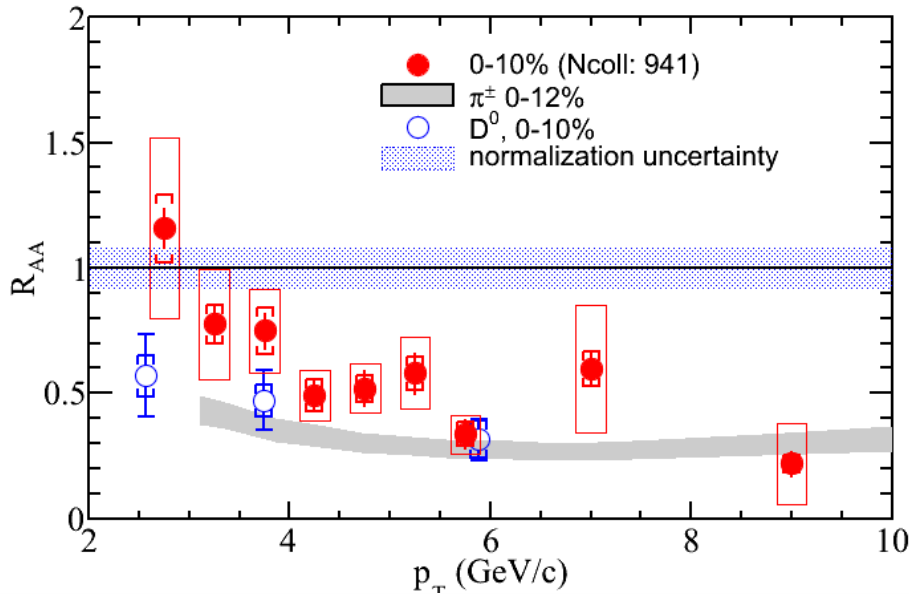
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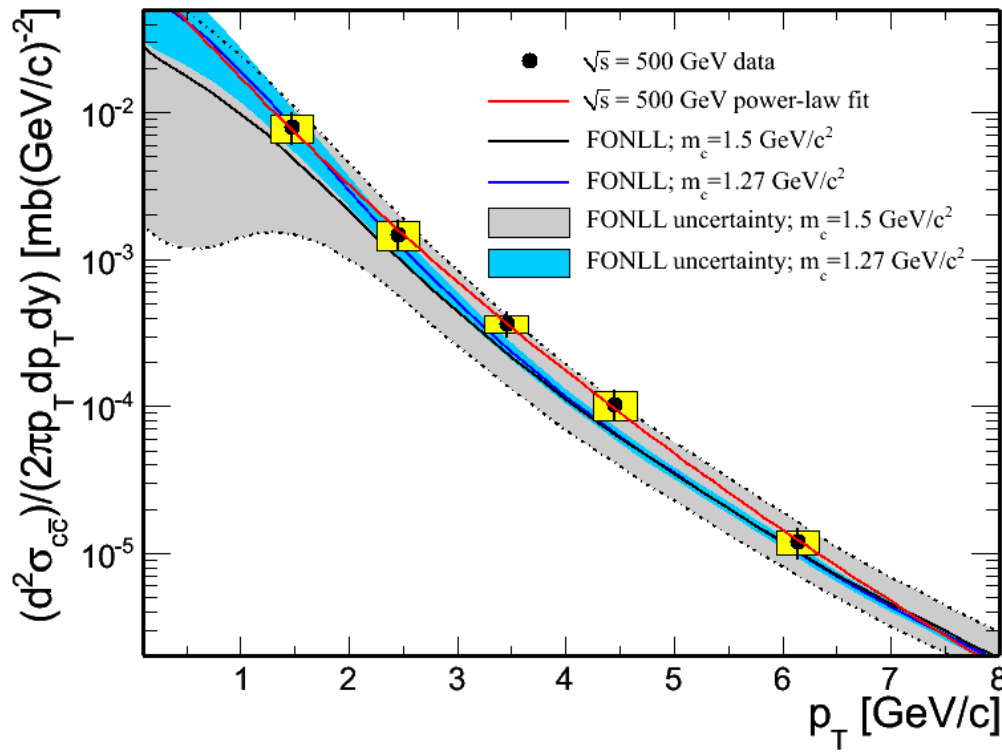
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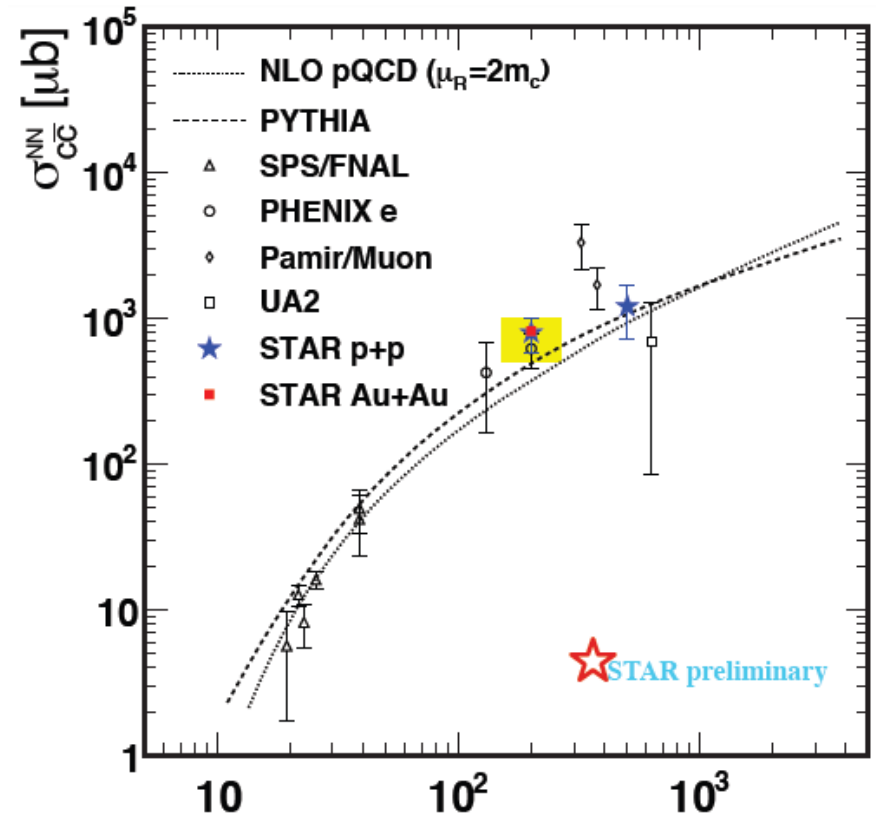
Coll. Dissoc. R. Sharma et al., PRC 80, 054902(2009).

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D mesons in 500 GeV p+p Collisions

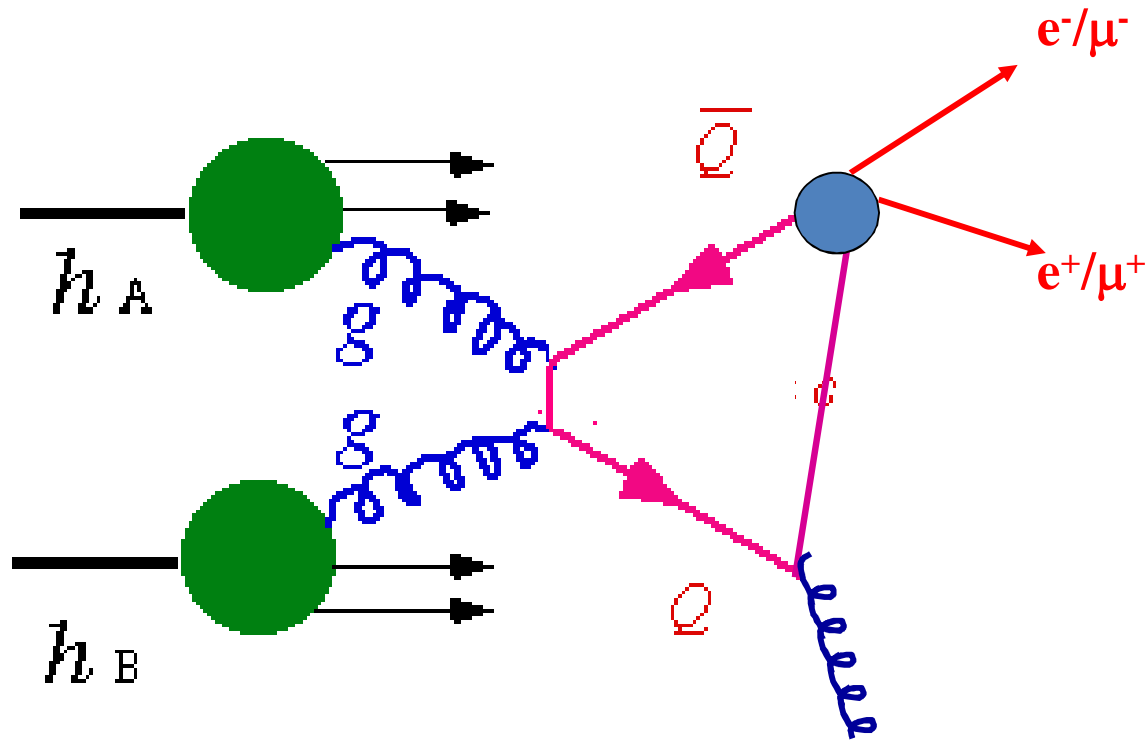


FONLL: R. Vogt, private communication

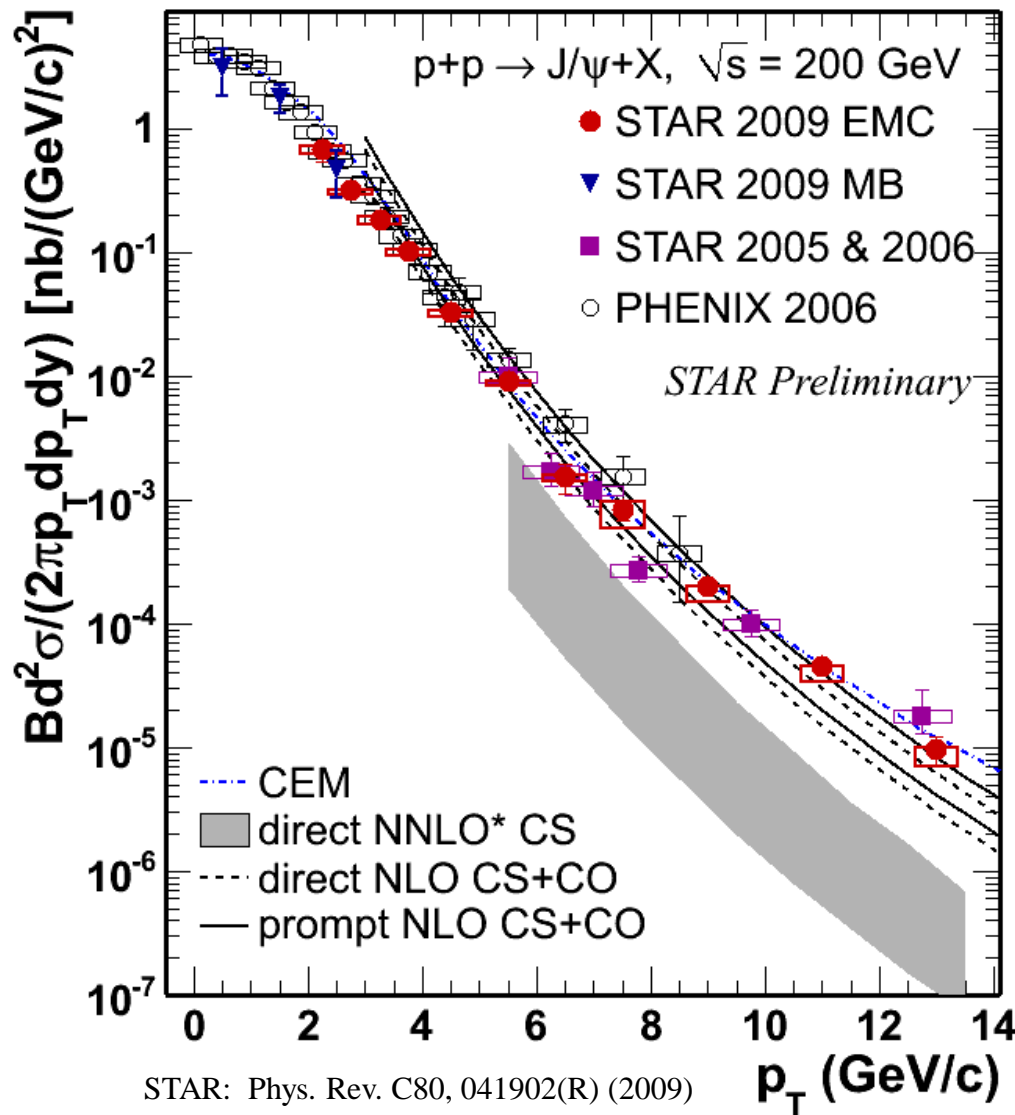


□ Data are consistent with FONLL prediction within uncertainties.

Heavy Quarkonia Production



J/ψ Production in 200GeV p+p Collisions



STAR: Phys. Rev. C80, 041902(R) (2009)
 STAR: JPG 38, 124107 (2011)
 PHENIX: Phys. Rev. D 82, 012001 (2010)

Color singlet model (NNLO*CS):

- P. Artoisenet et al., PRL. 101, 152001 (2008), and J.P. Lansberg private communication.
- Include no feeddown from higher mass state.

LO CS+ color octet (CO):

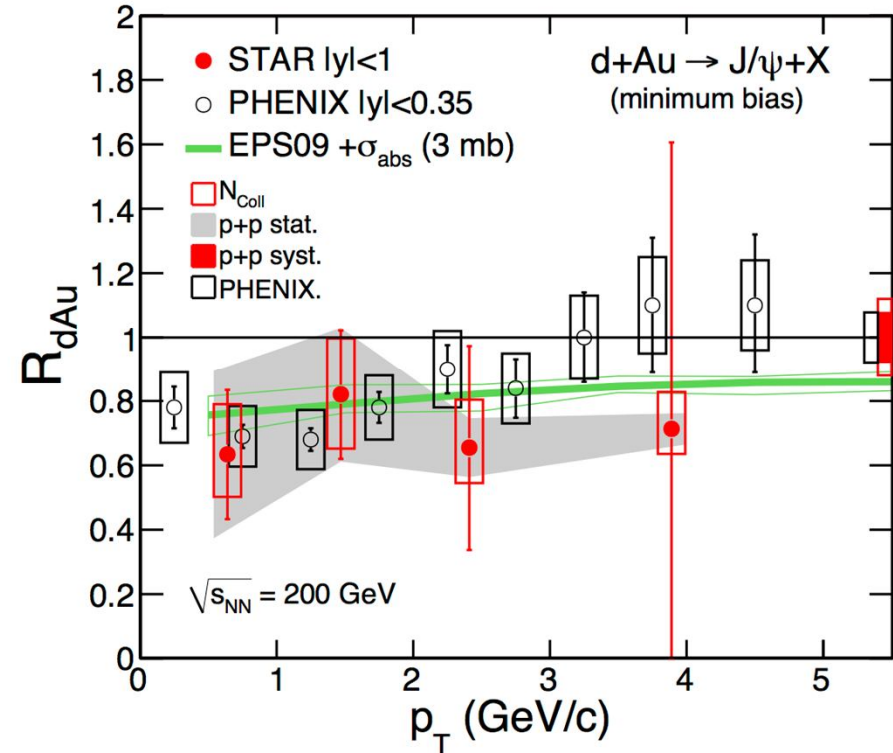
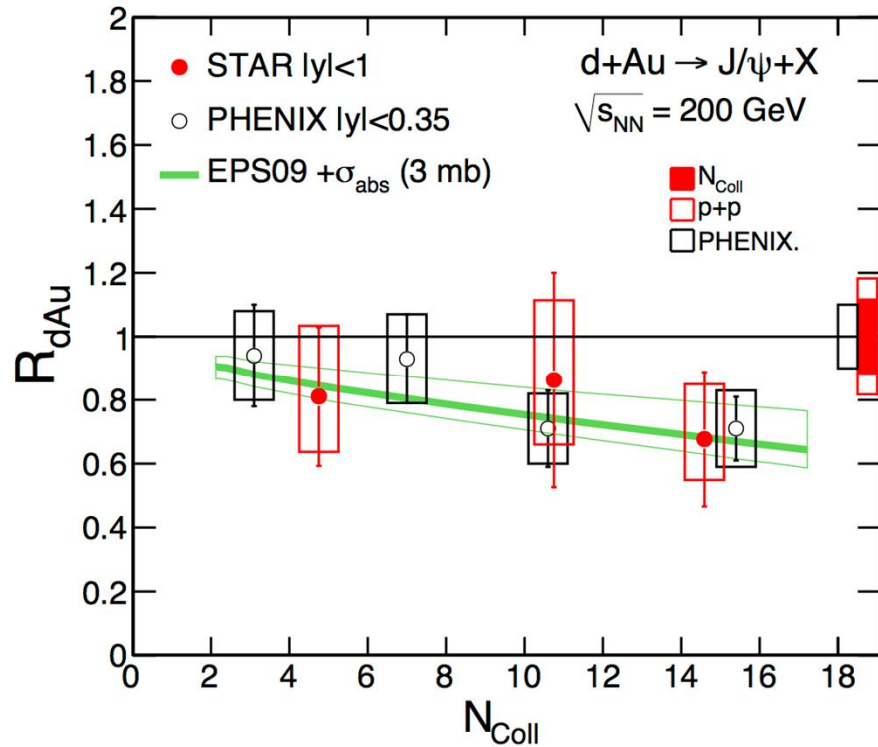
- Y.-Q. Ma, K. Wang, and K.-T. Chao, Phys. Rev. D84, 51 114001 (2011), and private communication
- Agree with the data

Color Evaporation Model:

- M. Bedjidian et al., hep-ph/0311048; R. Vogt private communication
- Include feeddown from X_c and ψ'
- Agree with the data

B. Trzeciak: Parallel 1D

J/ψ R_{AA} in 200GeV d+Au Collisions

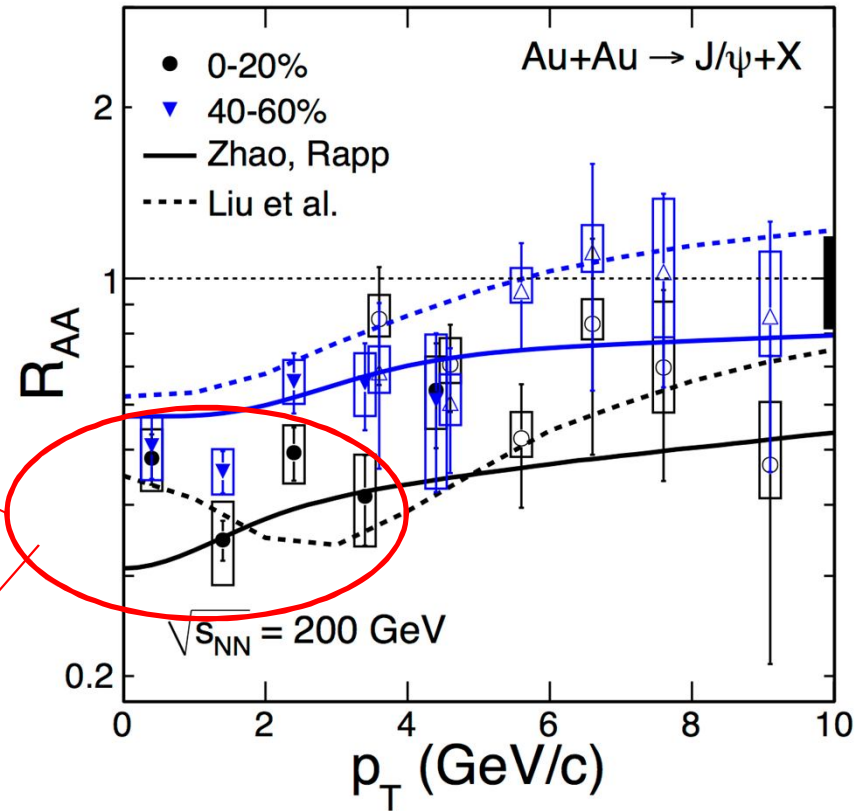
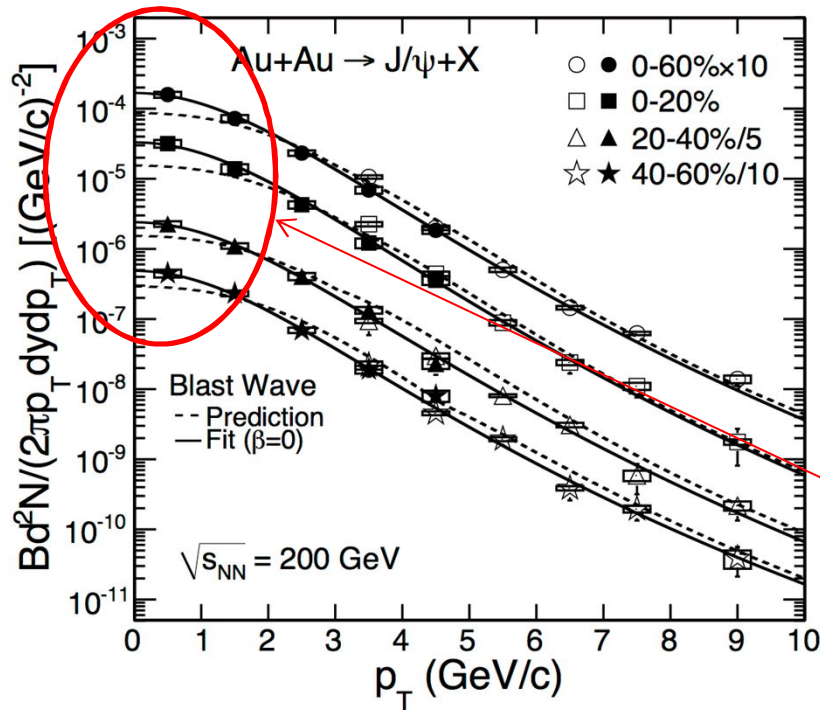


☐ STAR and PHENIX results are consistent with each other

☐ Nuclear absorption cross section $\sigma_{abs}^{J/\psi} = 4.0_{-2.7}^{+3.7} (stat.)_{-3.6}^{+4.4} (syst.)_{-1.1}^{+1.9} (EPS.sys.) mb$

- Based on model predictions using EPS09 nPDF parametrization.

J/ψ spectra in 200GeV Au+Au collisions

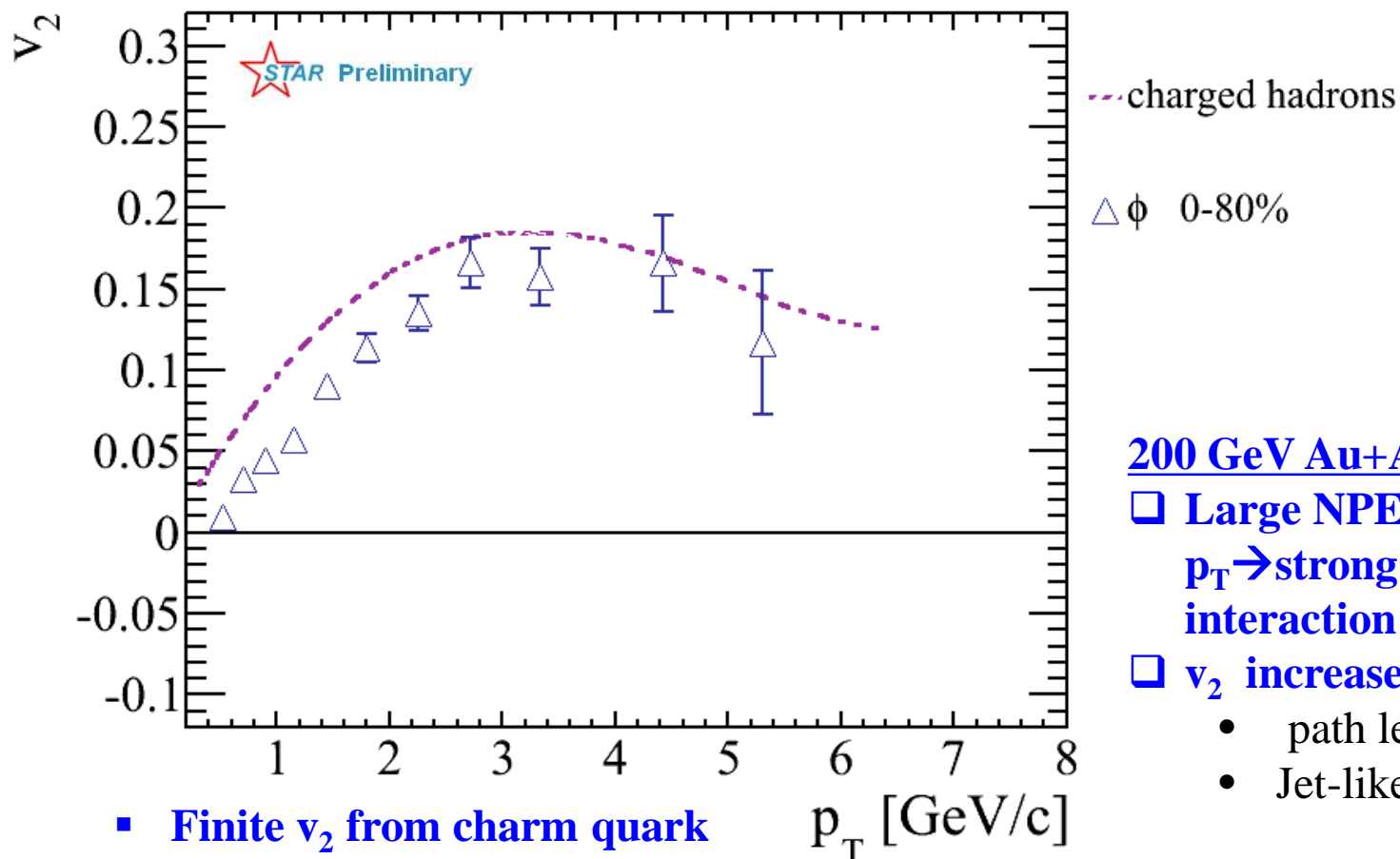


- ❑ Broad p_T coverage from 0 to 10 GeV/c
- ❑ J/ψ spectra significantly softer than light hadrons
- **Much smaller radial flow?**
- **Regeneration at low p_T ?**

- ❑ Systematically higher at high p_T in all centralities
- ❑ Suppression in central collisions at high p_T
- **formation time effect?**
- **Cronin effect?**

Tsallis Blast-Wave model: ZBT *et al.*, arXiv:1101.1912
 Yunpeng Liu *et al.*, PLB 678:72 (2009) and private communication
 Xingbo Zhao *et al.*, PRC 82,064905(2010) and private communication

v_2 Measurements from NPE, D0 and J/ ψ



- **Finite v_2 from charm quark coalescence ?**
- **Further inputs from Run2011 data.**
- **disfavors** the case that J/ Ψ with $p_T > 2\text{GeV}/c$ is produced **dominantly by coalescence** from thermalized charm and anti-charm quarks.

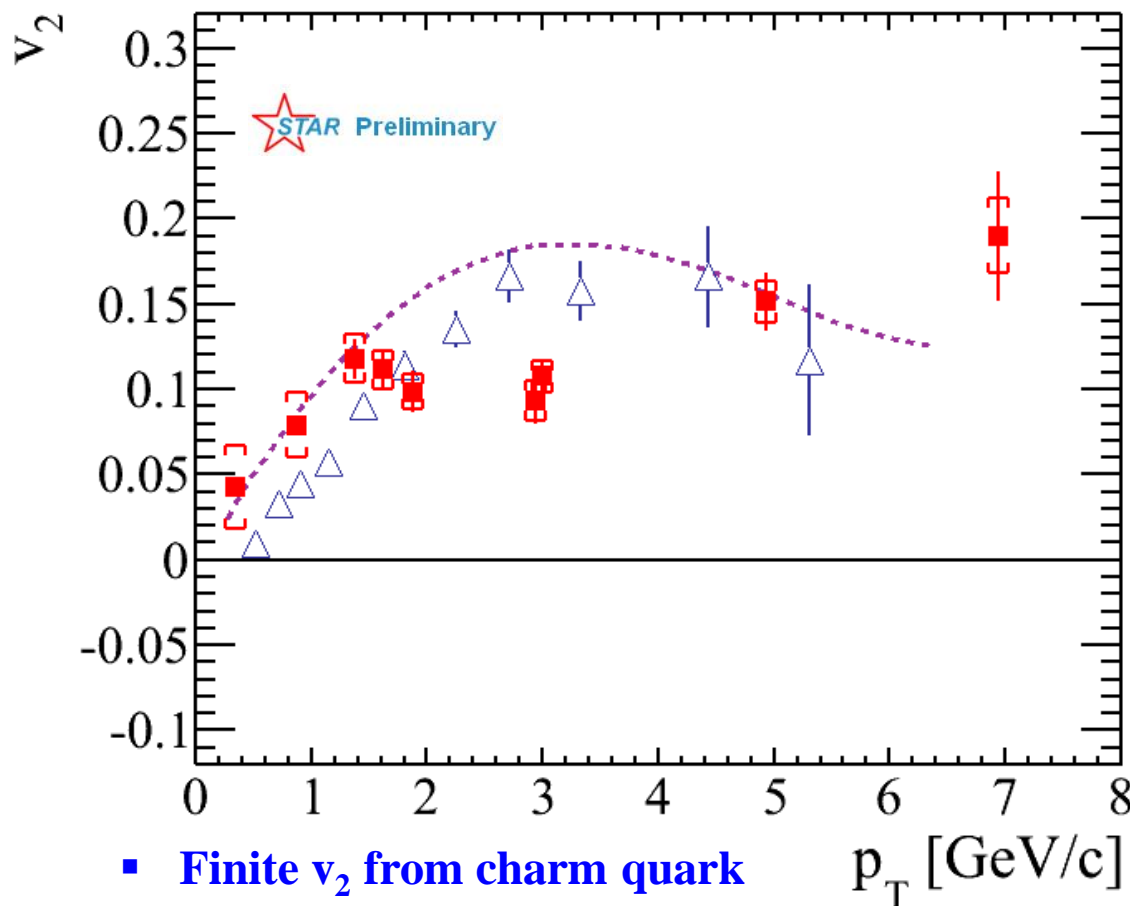
200 GeV Au+Au:

- **Large NPE v_2 observed at low $p_T \rightarrow$ strong charm-medium interaction**
- **v_2 increase at $p_T > 3\text{ GeV}/c$**
 - path length of energy loss
 - Jet-like correlation.

39 and 62.4 GeV Au+Au:

- **v_2 consistent with zero**
- **Might suggest charm –medium interaction is not as strong as in 200 GeV**

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- charged hadrons
- \triangle ϕ 0-80%
- NPE $v_2\{2\}$ 0-60%

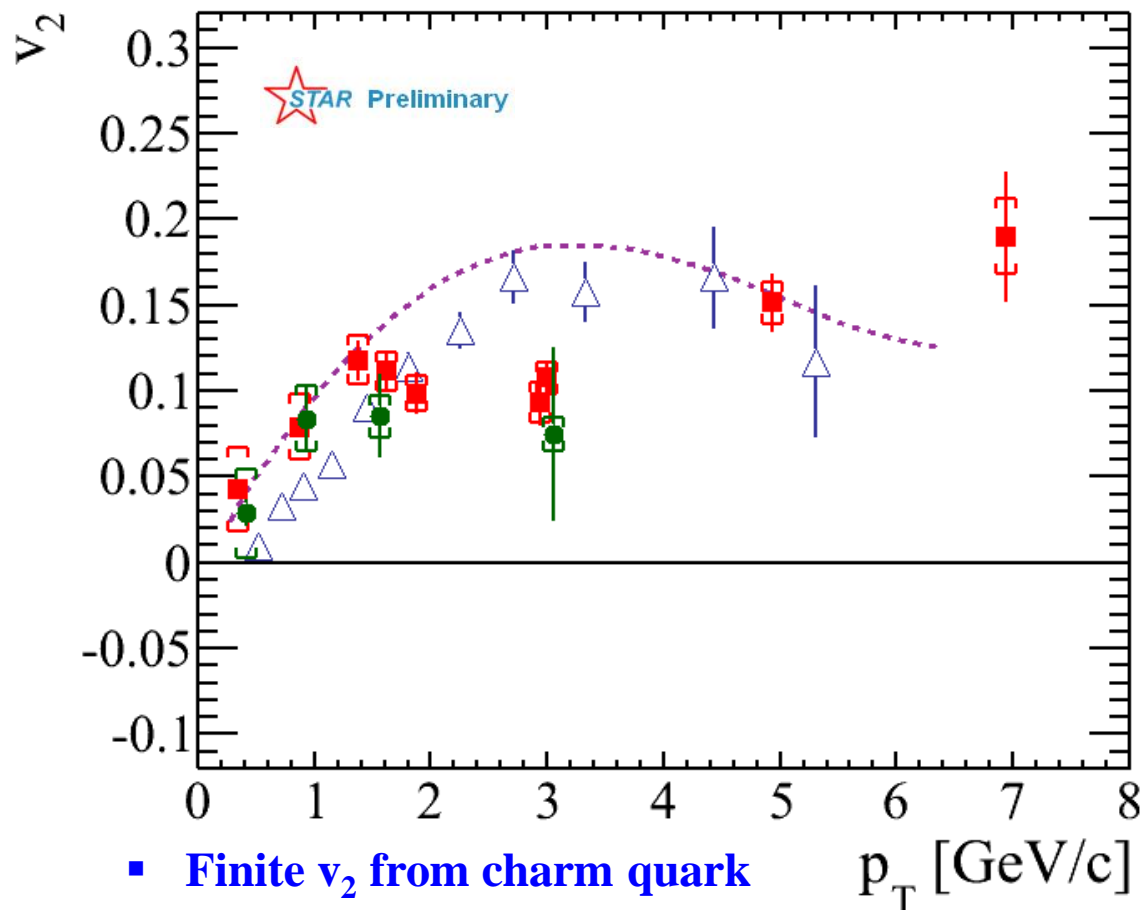
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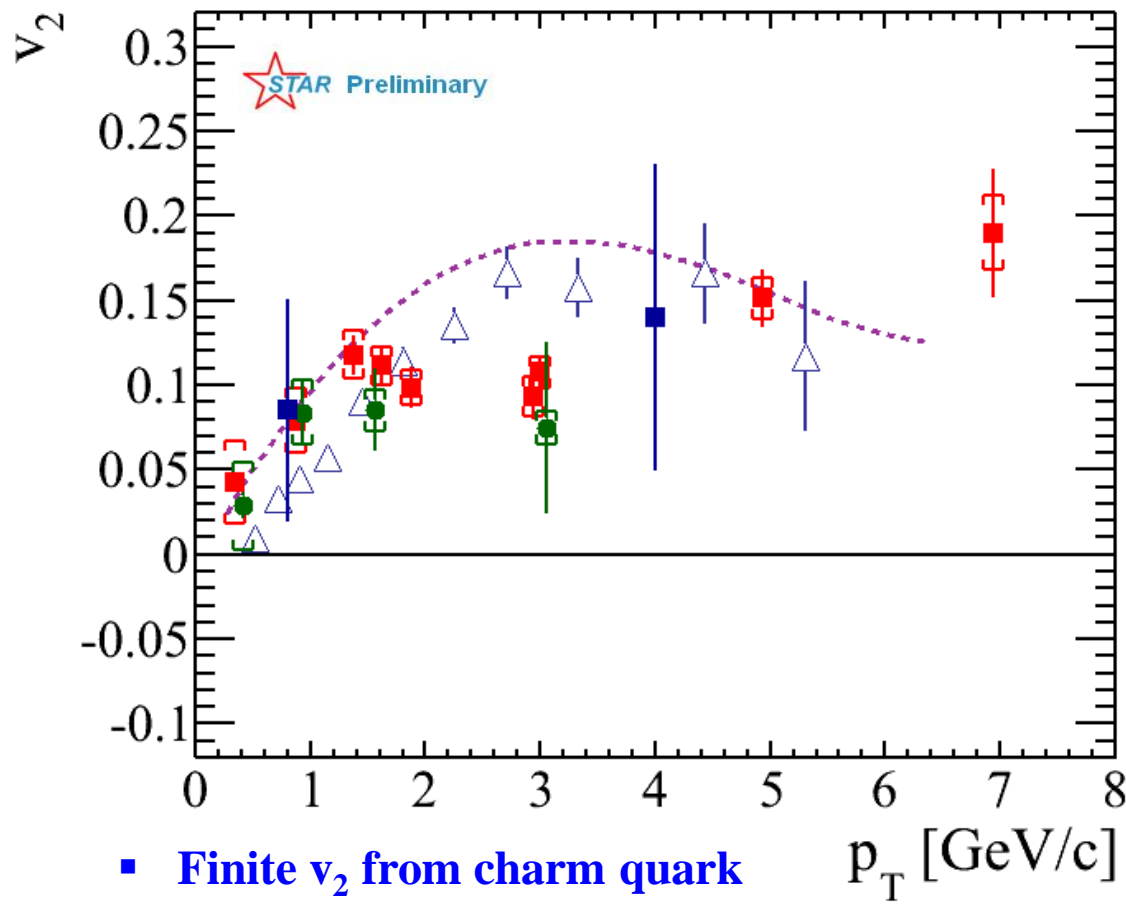
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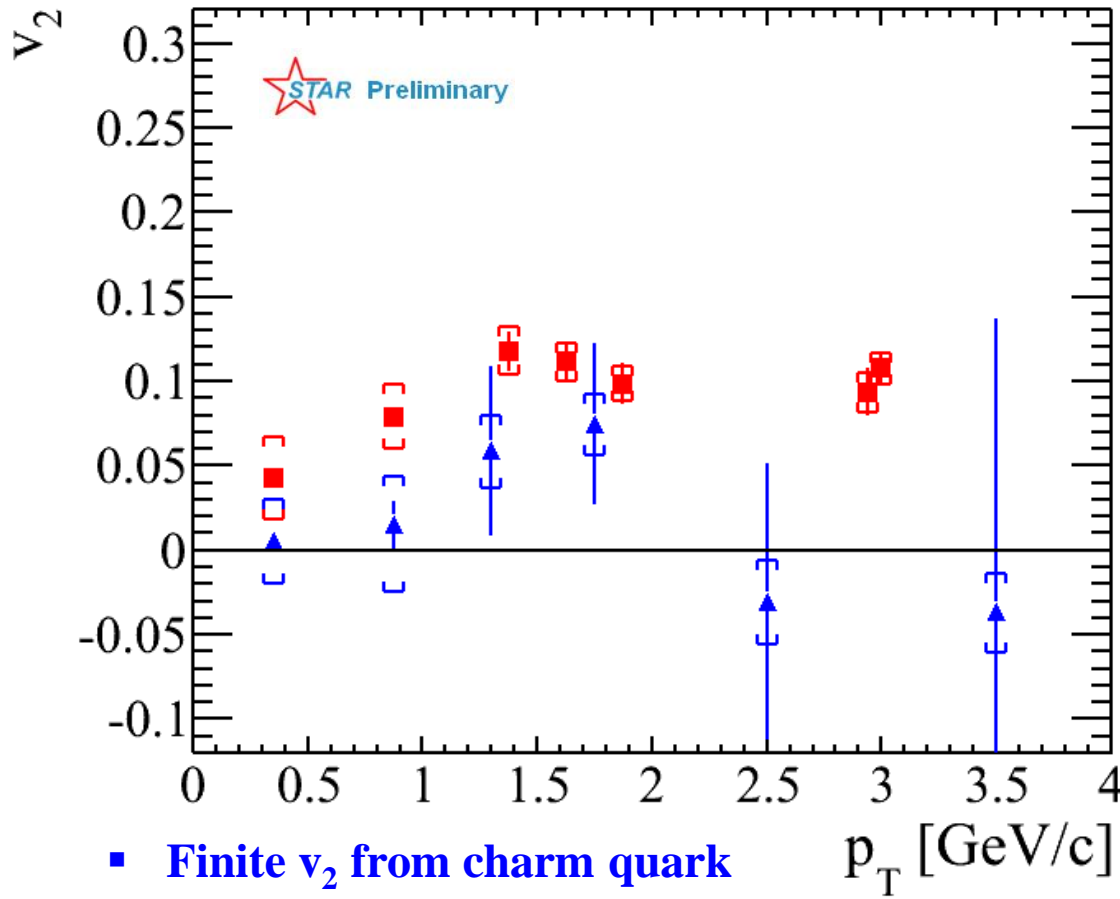
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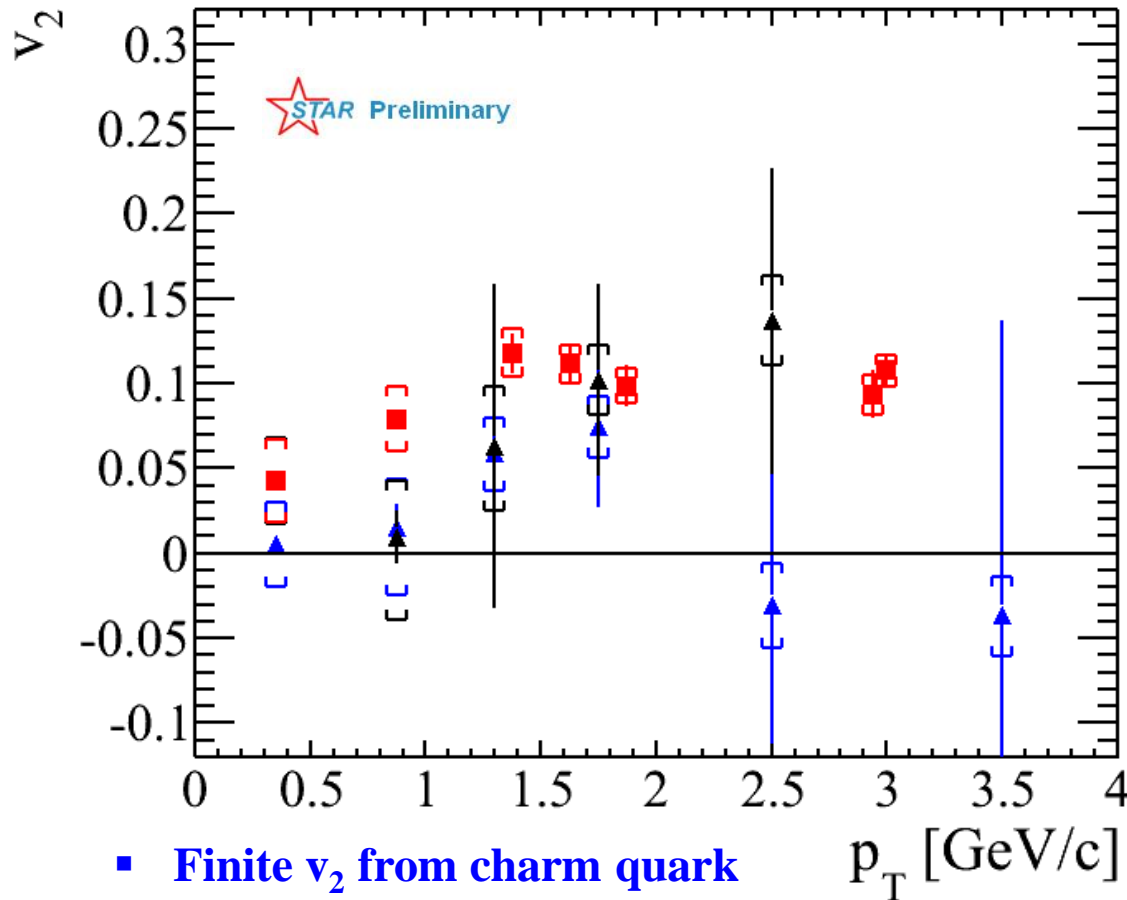
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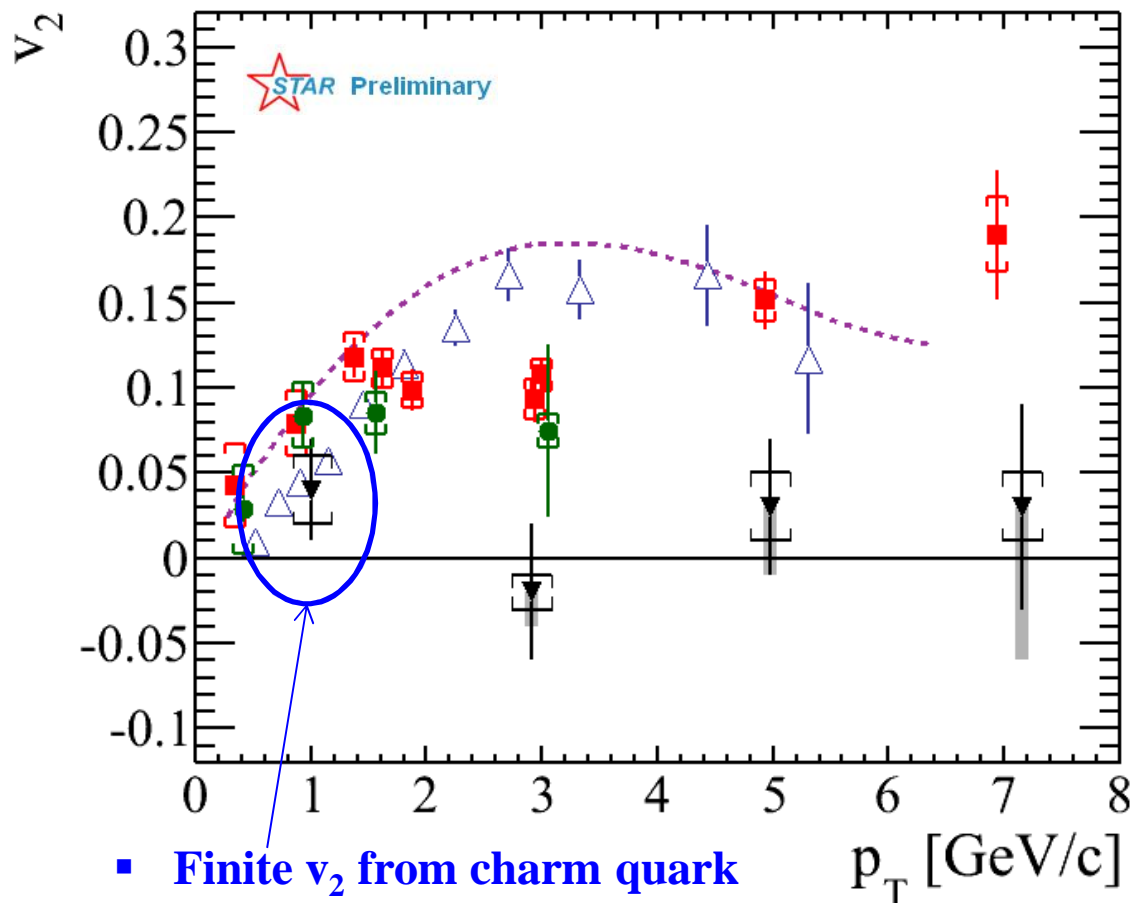
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-- charged hadrons

▼ J/ ψ 20-60%

△ ϕ 0-80%

■ NPE $v_2\{2\}$ 0-60%

● NPE $v_2\{4\}$ 0-60%

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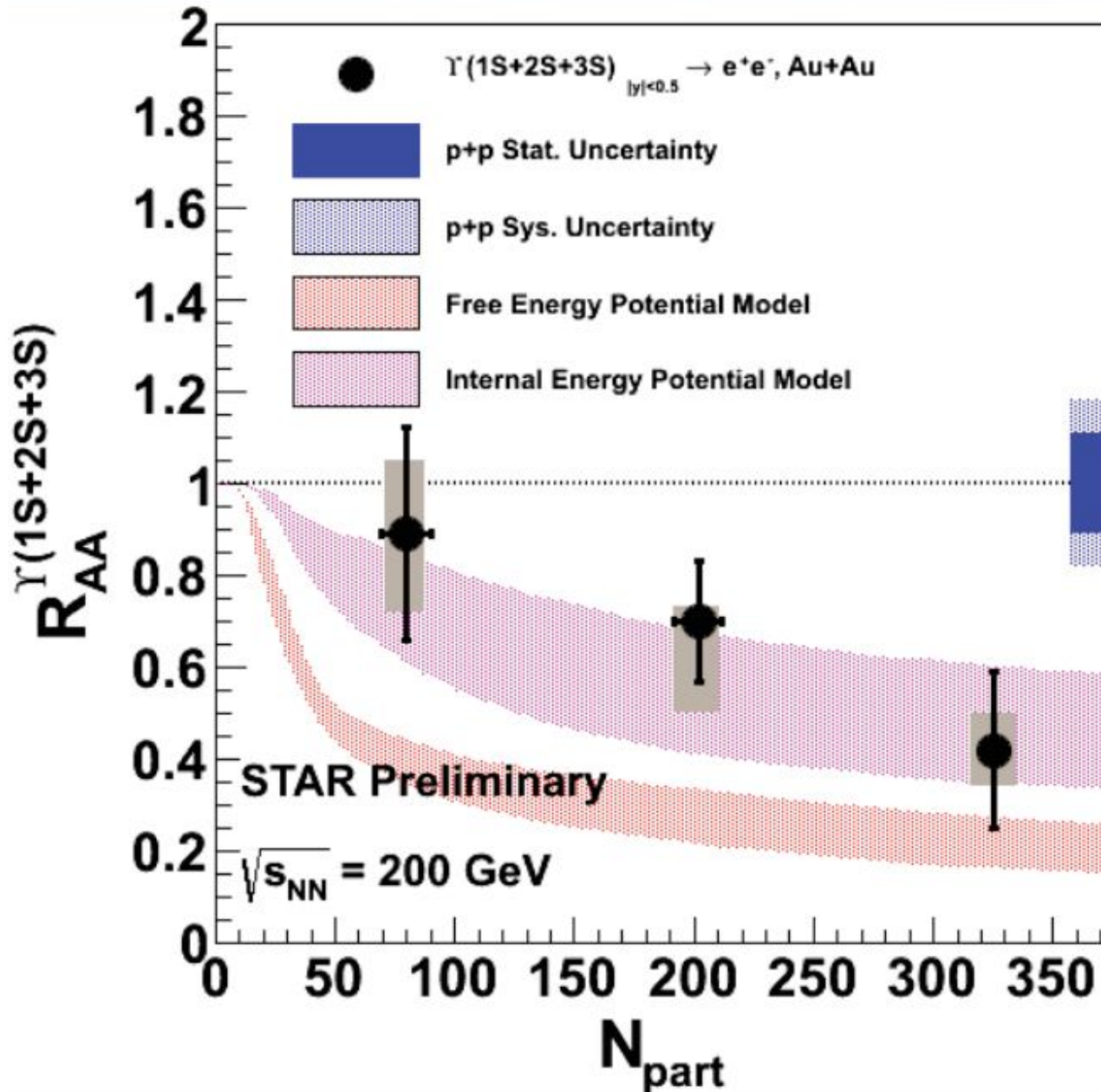
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Upsilon: a Cleaner Probe

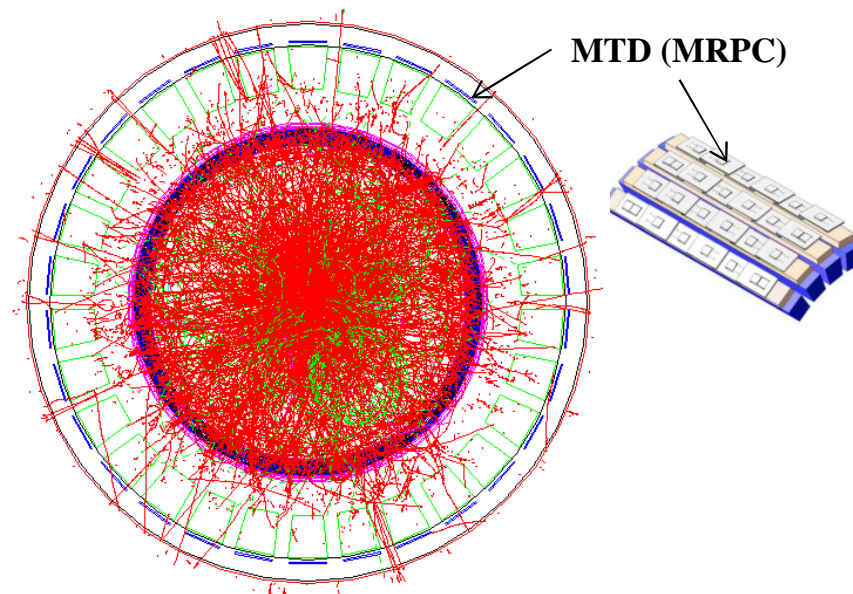
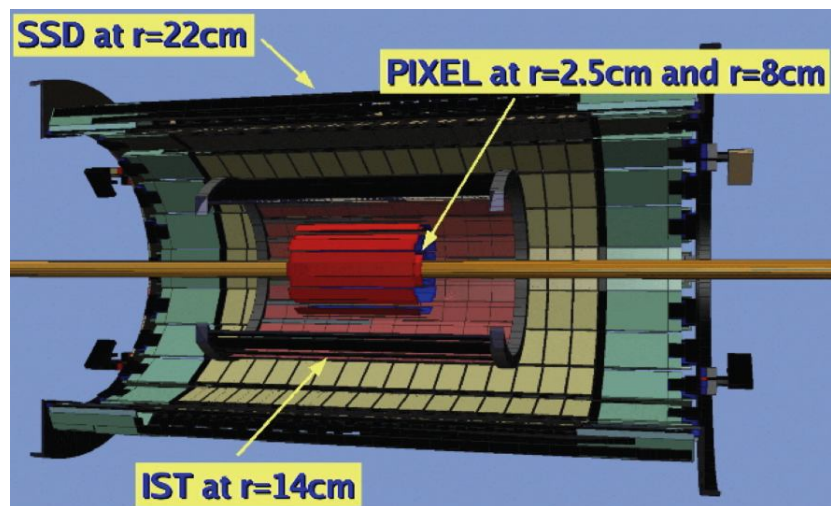


Model: M.Strickland and D. Baxow, arXiv: 1112.2761v4

Compared to J/ψ

- recombination can be neglected at RHIC
- Final state co-mover absorption is small.
- Significantly improved p+p measurements w/ ~2.5x more lum.
- More suppression in more central collisions
- Consistent with prediction from a model requiring strong 2S and complete 3S suppression.

Future of Heavy Flavor Measurement at STAR



PIXEL:

- high hit resolution: $18.4\mu\text{m} \times 18.4\mu\text{m}$ pitch
- low thickness: $0.37\% X_0$
- significantly enhance STAR capability on measuring heavy flavor production at RHIC, e.g.
 - Direct reconstruction of D mesons at both low p_T and high p_T
 - $B \rightarrow J/\psi \rightarrow \mu\mu + X$, disentangle upilon 1S/2S/3S.
- Study QGP thermal dilepton radiation
 - Understanding background through e-muon correlation.

See details in

- Huan Huang: parallel 6C
- Frank Geurt: plenary IVA

Summary

- ❑ Observe large suppression of heavy quark production through NPE and D^0 meson measurements in 200 GeV Au+Au collisions
- ❑ Observe larger NPE v_2 in 200 GeV than in 39 and 62.4 GeV Au+Au collisions, indicating the strength of charm-medium interaction increase with energy.
- ❑ J/ψ v_2 measurements disfavor the case that coalescence dominate the production at $p_T > 2$ GeV/c.
- ❑ Observe Upsilon suppression, consistent with prediction from a model requiring strong 2S and complete 3S suppression
- ❑ STAR HFT and MTD upgrades together with existing subsystems and RHIC II luminosities will provide STAR with the unprecedented opportunity to study heavy quark production at RHIC.

List of Heavy Flavor Talks and Posters

1. [“STAR Upgrade Plan for the Coming Decade”](#), H. Huan for Collaboration, parallel 6C
2. [“Measurements of Non-photonic Electrons Production and Elliptic Flow in 39, 62.4 and 200 GeV Au+Au Collisions from STAR at RHIC”](#), M. Mustafa for STAR Collaboration, parallel 7A
3. [“Quarkonia production in the STAR experiment”](#), B. Trzeciak for STAR Collaboration, parallel 1D
4. [“Open charm hadron production in p+p and Au+Au collisions at STAR”](#), D. Tlusty for Collaboration, parallel 6A
5. [“Heavy Flavour Electron azimuthal anisotropy \$v_2\$ from 2- and 4-particle correlations in Au+Au collisions at \$\sqrt{s_{NN}} = 200, 62\$ and \$39\$ GeV at STAR”](#), D. Kikola for STAR Collaboration, poster session
6. [“ \$J/\psi\$ production in \$\sqrt{s_{NN}} = 39\$ GeV and \$62.4\$ GeV Au+Au collisions from STAR”](#), Wangmei Zha for STAR Collaboration, poster session.