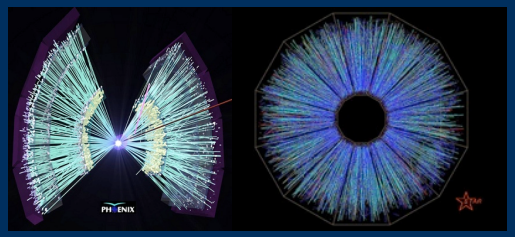
Heavy Flavor Production at RHIC



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XLIII International Symposium on Multiparticle Dynamics

ANL&IIT, Chicago, 9/15-9/20, 2013

HuaZhong Normal University

Office of Science
U.S. DEPARTMENT OF ENERGY

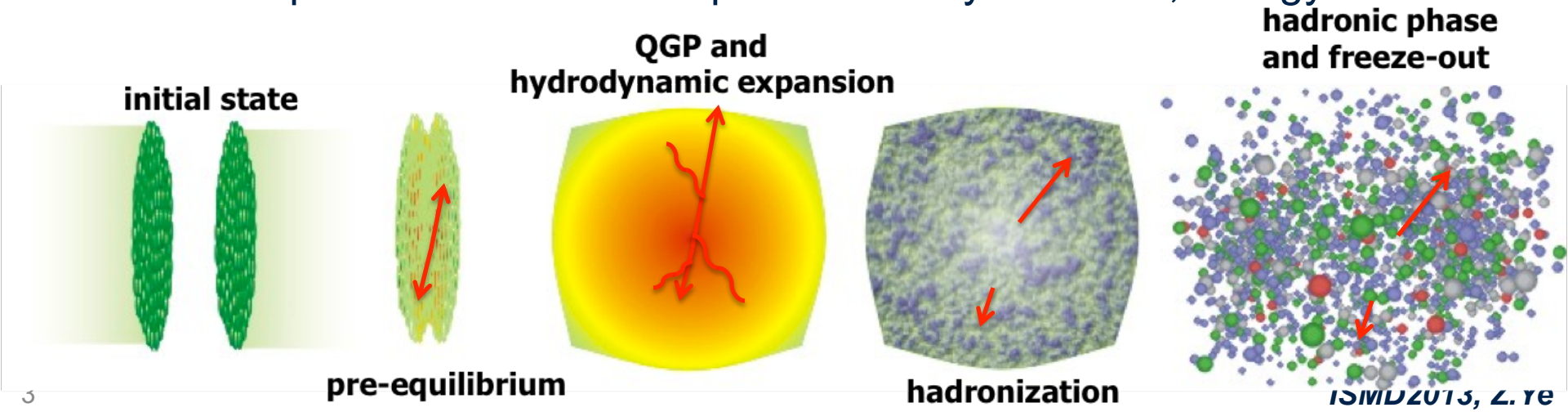
UIC UNIVERSITY OF ILLINOIS AT CHICAGO

Outline

- Introduction
- Recent HF Results from RHIC
  - Open Heavy Flavor
  - Quarkonia
- Looking into the **HF** Future at RHIC
- Conclusion

Why Heavy Flavor?

- HF quarks are produced primarily in initial hard scattering, and are exposed to the evolution of the hot nuclear matter created at RHIC.
- **Au+Au, Cu+Cu, U+U, …**
  - How does a parton lose its energy in the medium?
    radiative and/or elastic scattering? $\Delta E_g > \Delta E_q > \Delta E_c > \Delta E_b$?
  - How does the QGP thermalize?
    HF elliptic flow at low p_T
  - Properties of the QGP dependent on system size, energy



Why Heavy Flavor?

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- **Au+Au, Cu+Cu, U+U, …**
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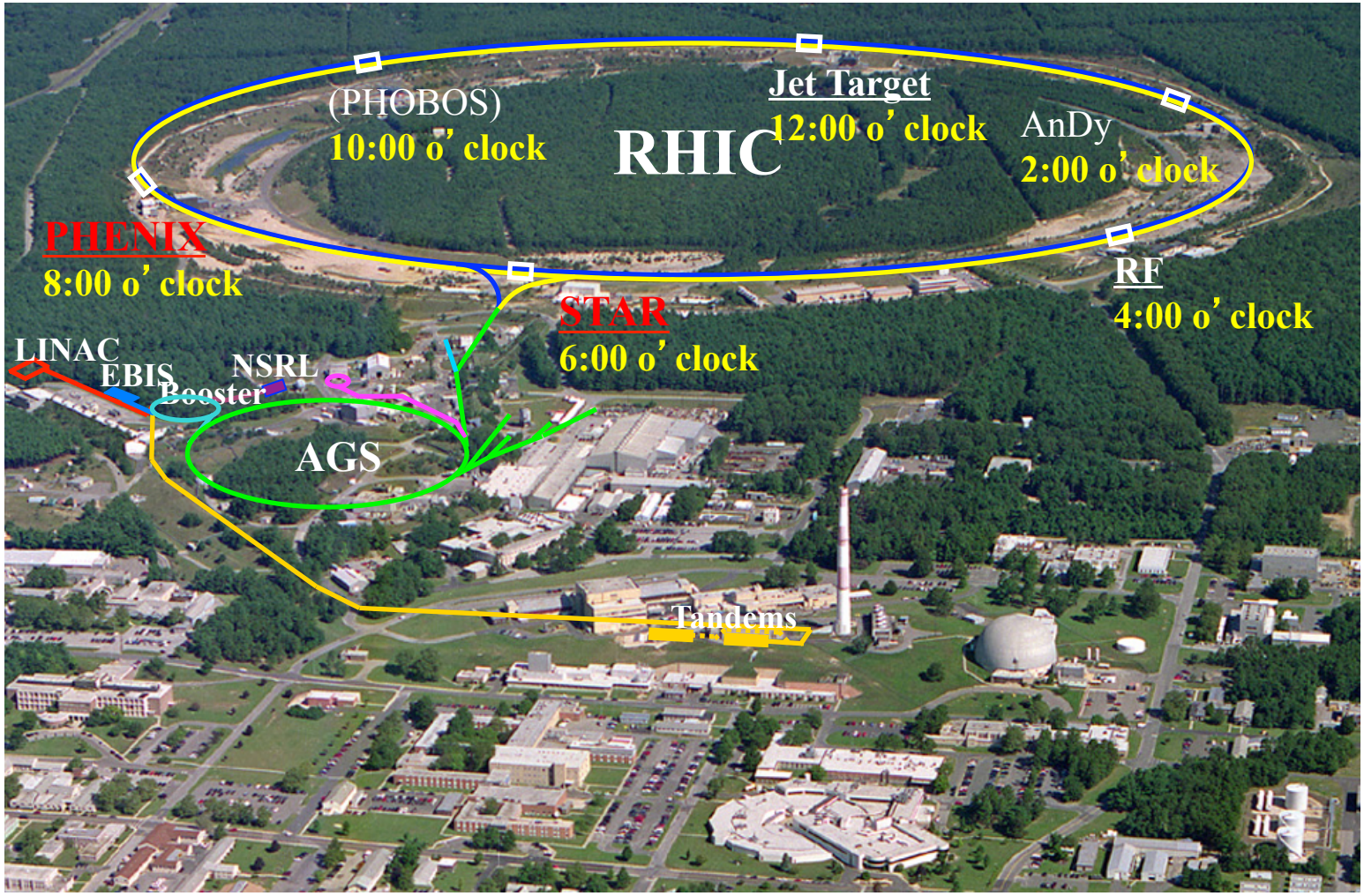
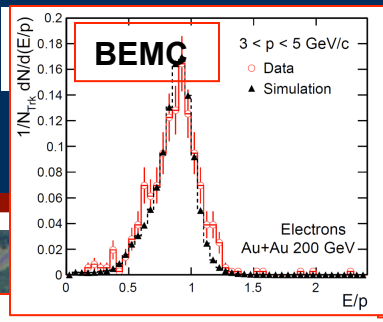
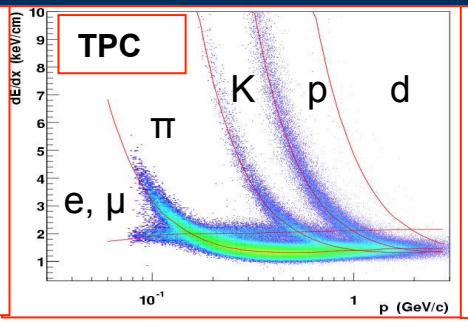
  - How does the QGP thermalize?
    HF elliptic flow at low p_T
  - Properties of the QGP dependent on system size, energy
- **p+p**
  - Test of pQCD and reference for studies of the QGP
- **p+Au, d+Au**
  - Cold Nuclear Matter effects (shadowing, CGC, Cronin effect, …)

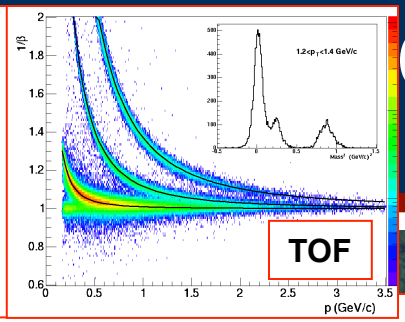
Relativistic Heavy Ion Collider

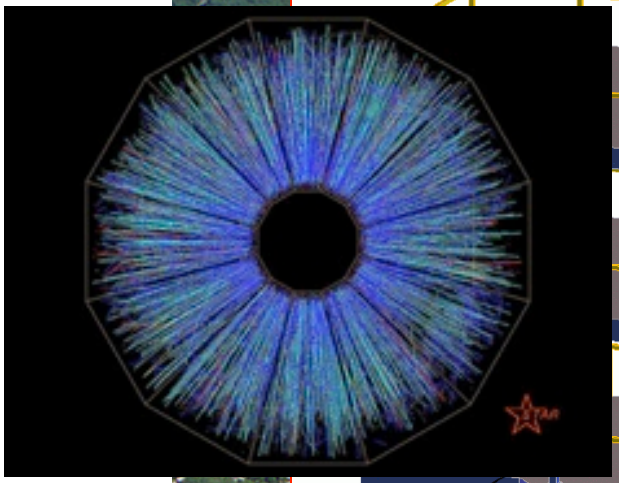


Re der


BEMC
3 < p < 5 GeV/c
Data
Simulation
Electrons
Au+Au 200 GeV
E/p

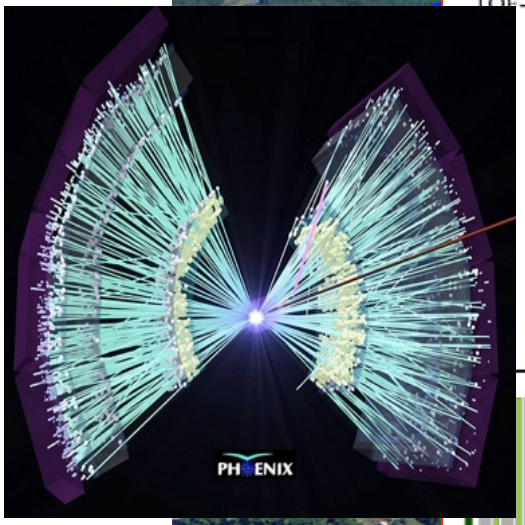

TPC
K
p
d
π
e, μ
p (GeV/c)

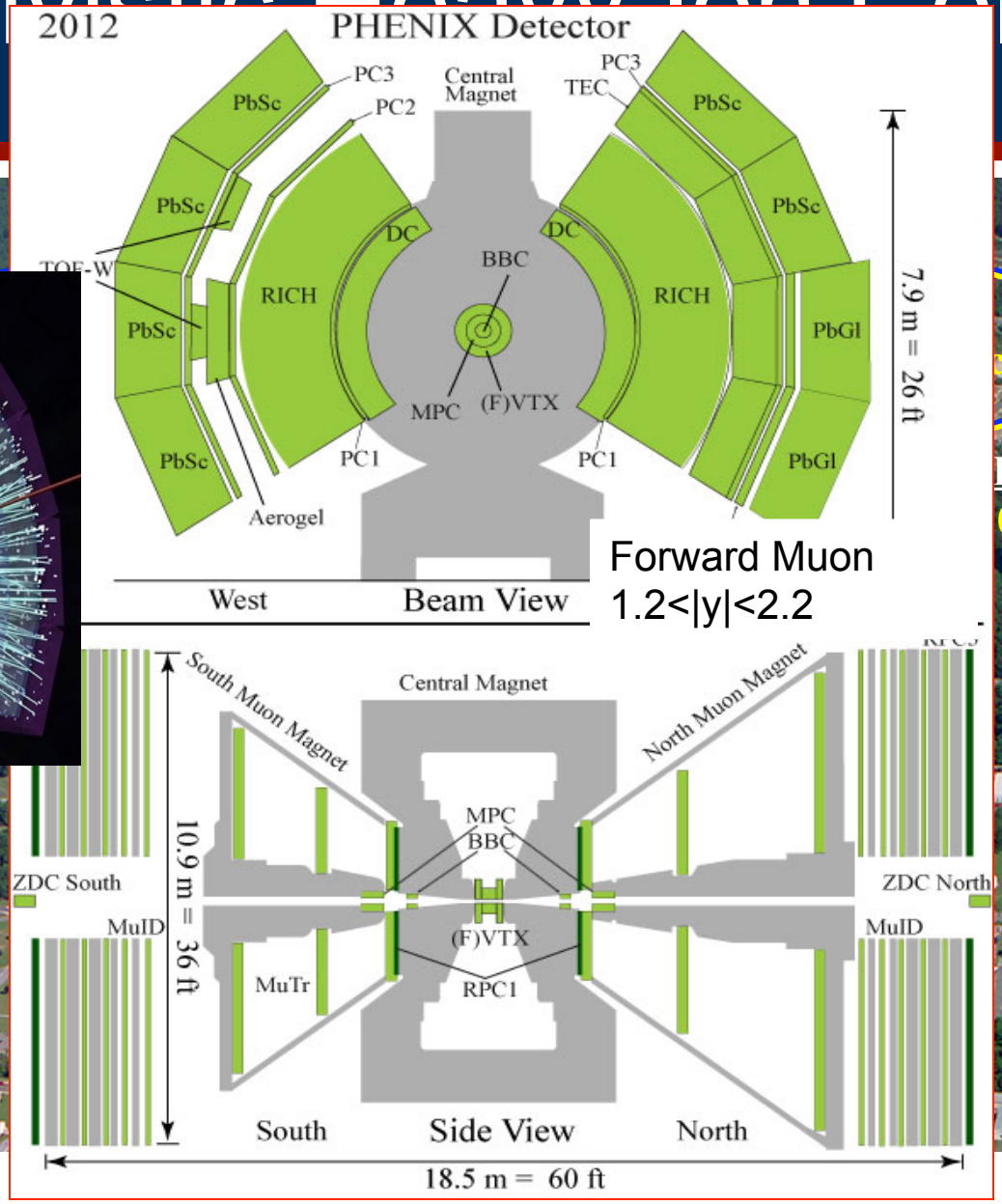

TOF
p (GeV/c)



STAR Detector 2000
Coils
Magnet
Silicon Vertex Tracker
E-M Calorimeter
Time Projection Chamber
Time Of Flight
Electronics Platforms
Forward Time Projection Chamber
STAR PMO BSS 10/28/96

Relativistic Heavy Ion Collider





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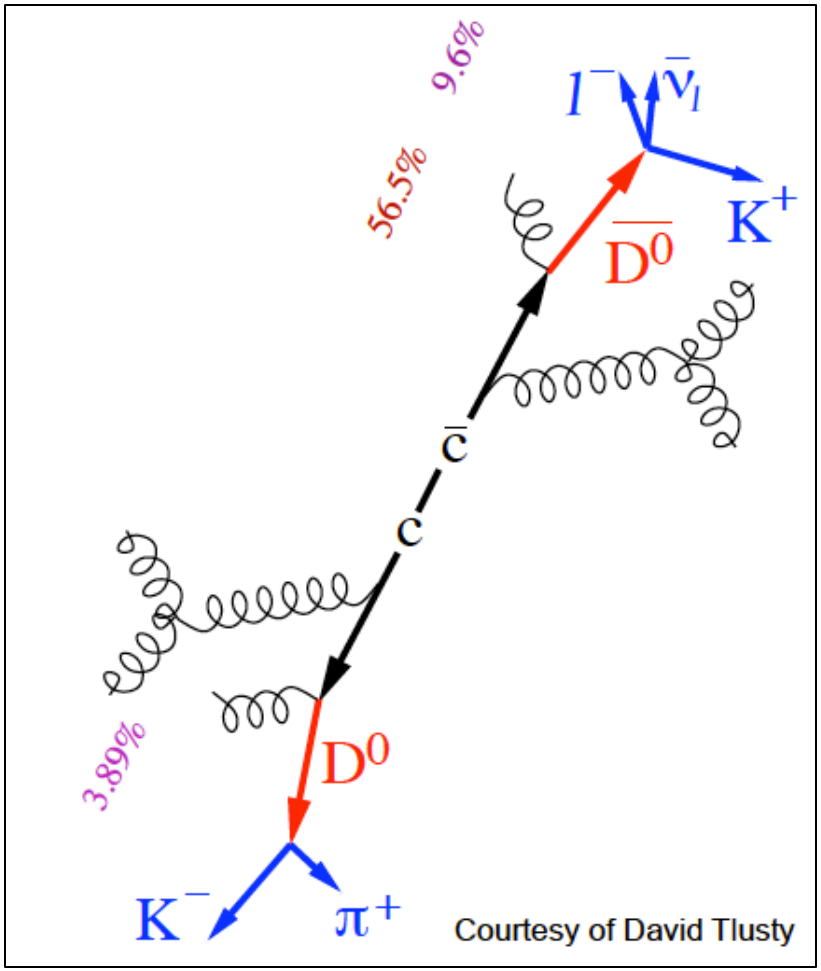
Open Heavy Flavor Production



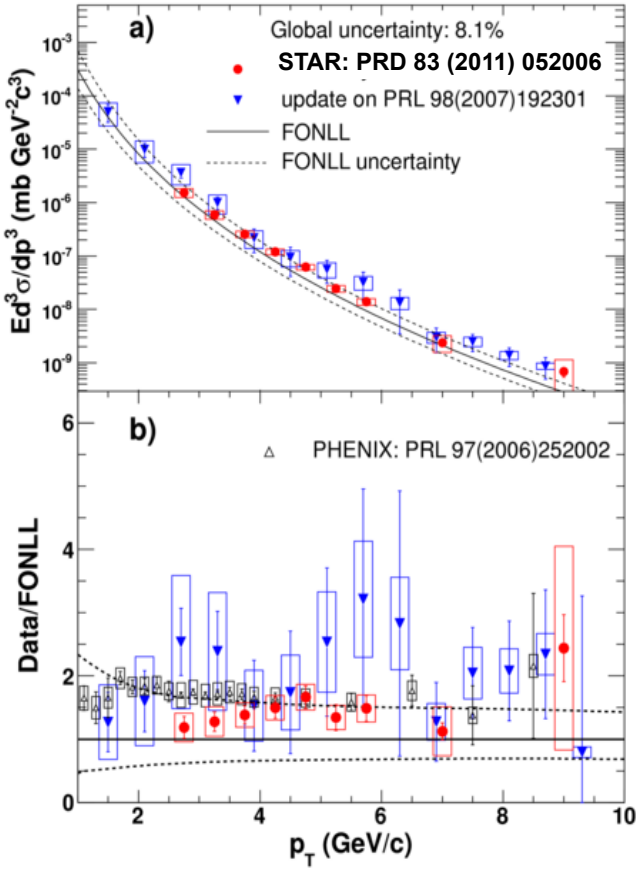
Semi-leptonic channel:

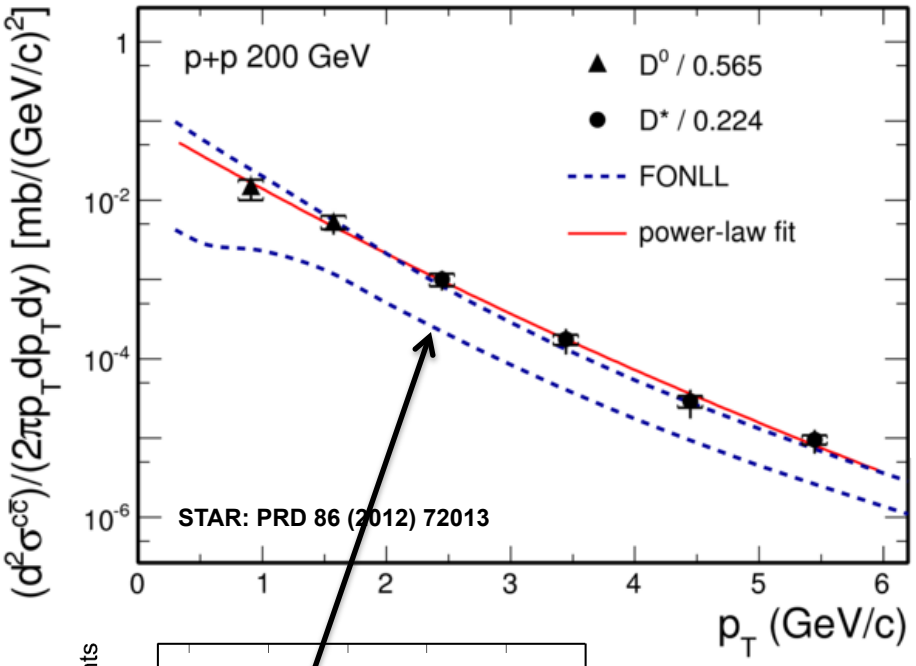
- Single $e^{\pm}$, $\mu^{\pm}$ with background subtraction estimated from MC+data
- Larger branching ratio; can trigger online on high p_T charged leptons
- No direct access to the kinematics of the original charm hadrons; Contribution from both charm and bottom

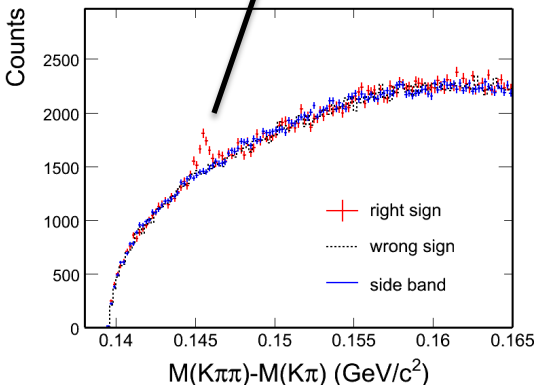
Hadronic channel:

- Fully reconstructed charm hadrons with background estimated from data
- Smaller branching ratio; no direct trigger online; large background contribution w/o good vertex measurement
- Direct reconstruction of kinematics of original charm hadrons

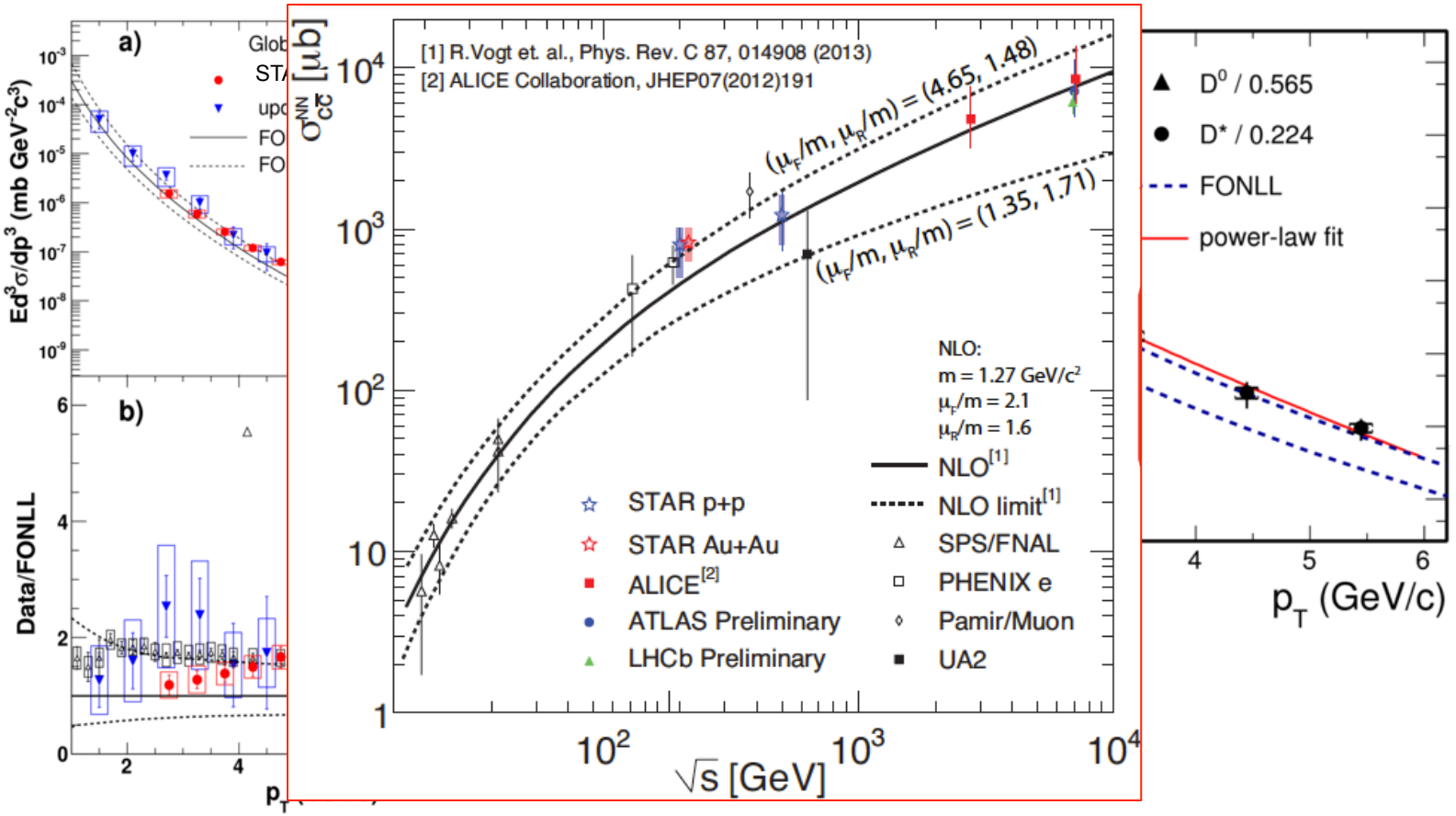
Open Charm Production - pp





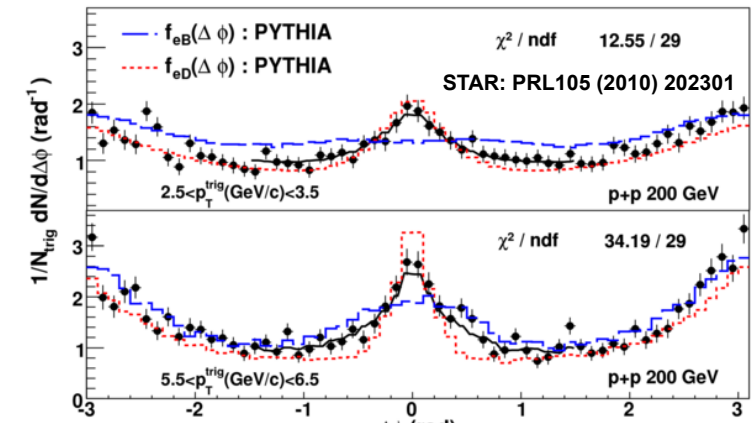


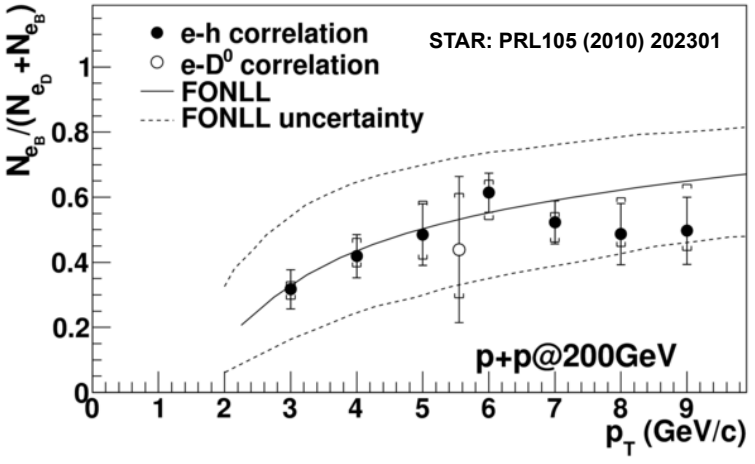
Open Charm Production - pp

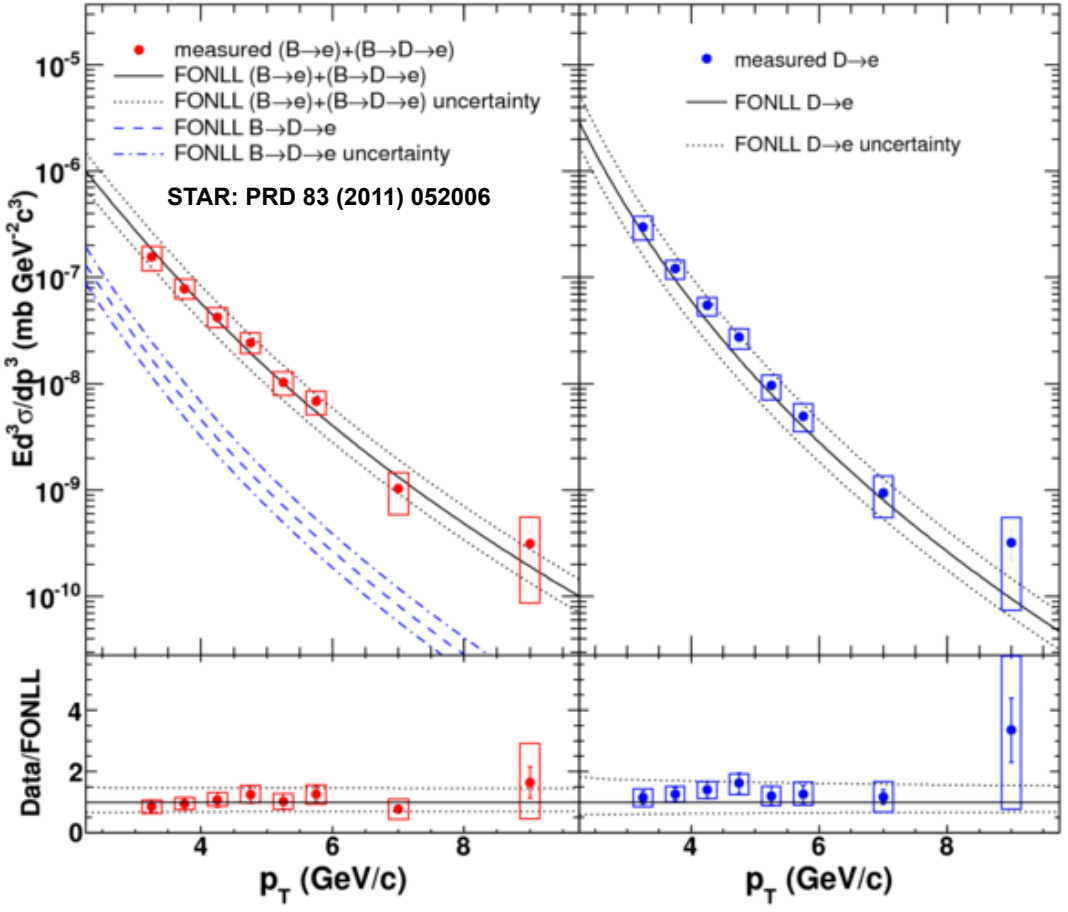


Measurements of inclusive charm production cross-section from STAR and PHENIX consistent with NLO-NLL calculation within uncertainties.

Open Bottom Production - pp

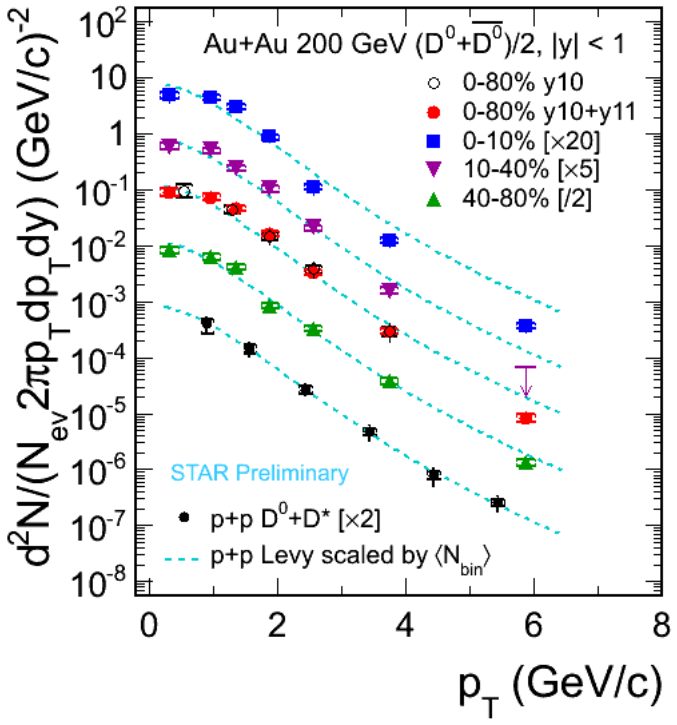


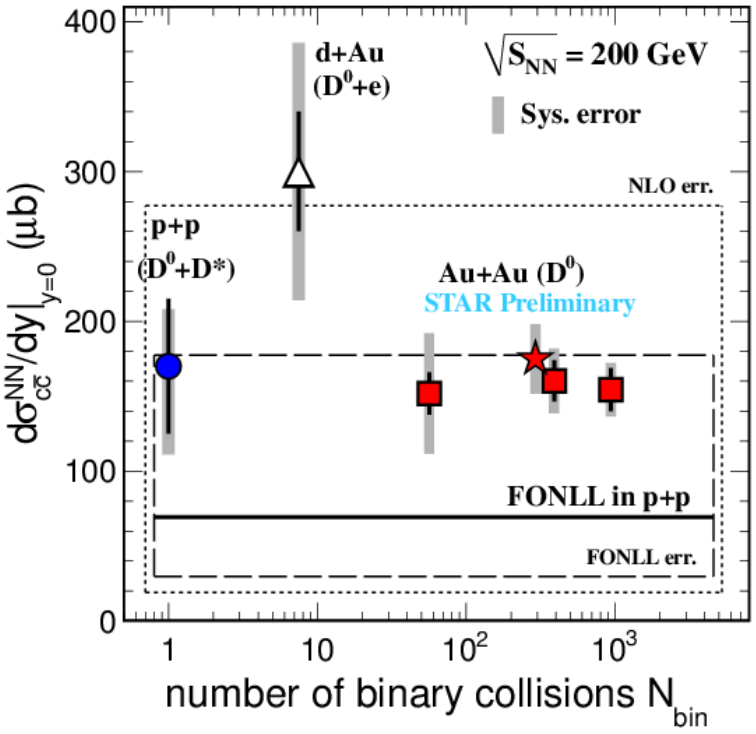




B->e and D->e extracted from e-h correlation and consistent with FONLL.

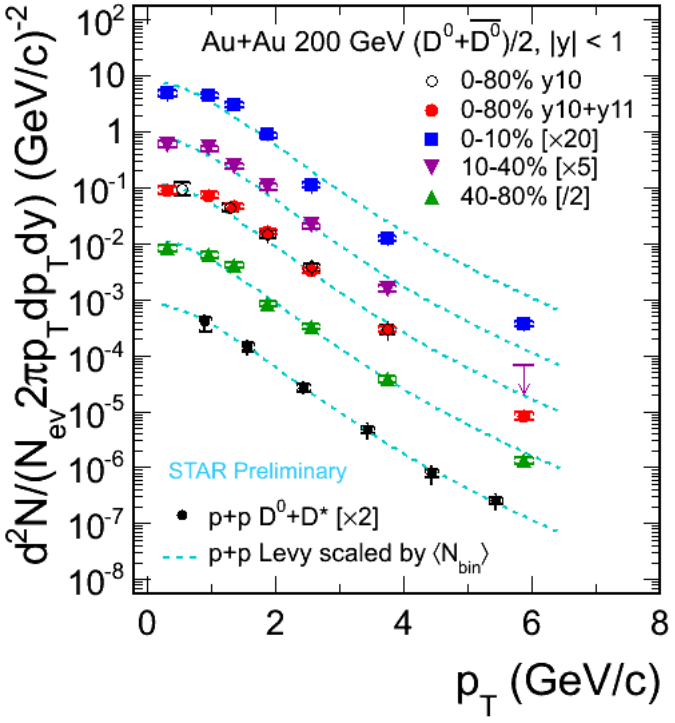
Open Charm Production - AuAu

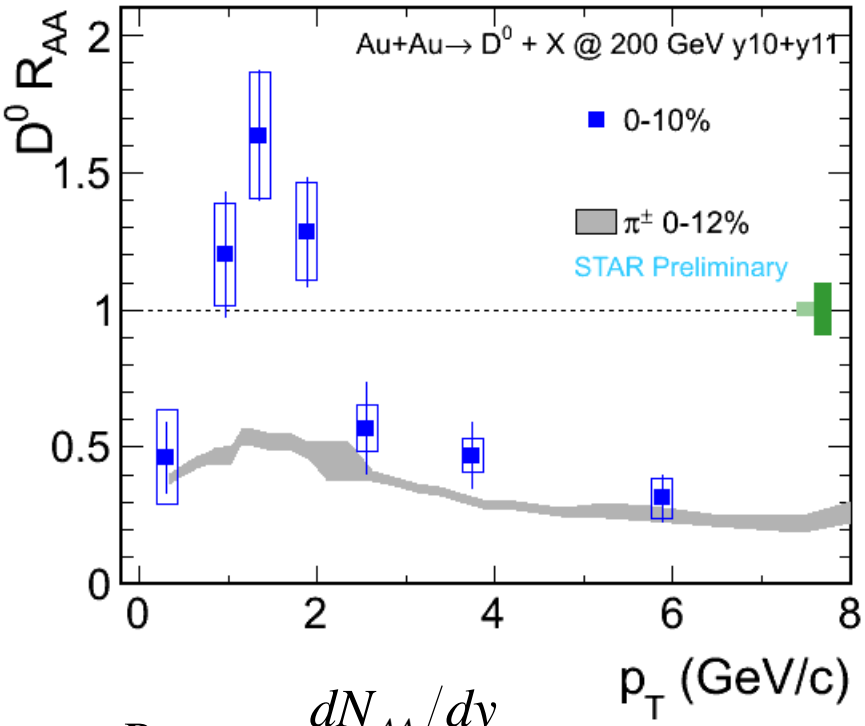




Total charm production scales with the number of binary collisions at RHIC

Open Charm Production - AuAu

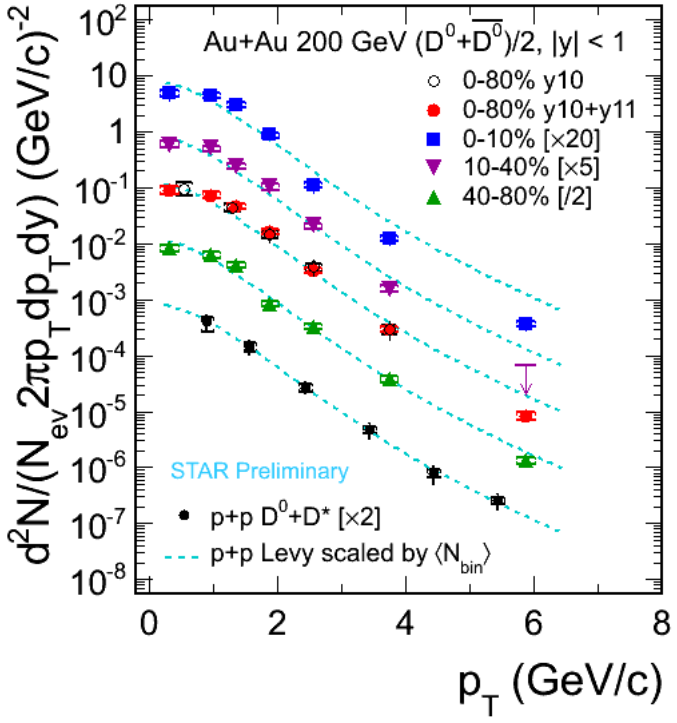


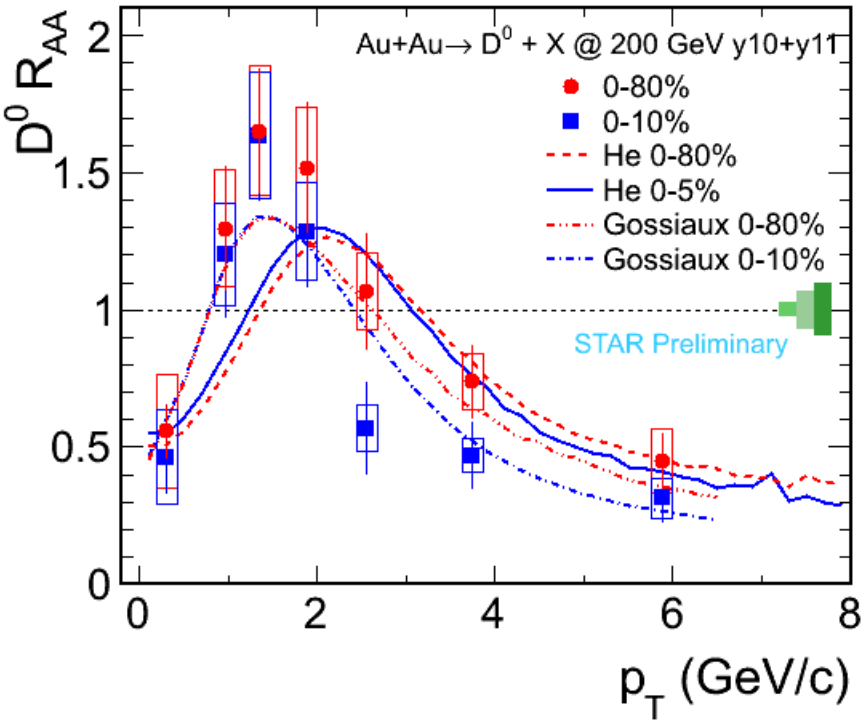


$$R_{AA} = \frac{dN_{AA}/dy}{N_{coll} \cdot dN_{pp}/dy}$$

Suppression at high p_T in central collisions is similar to that of pions.

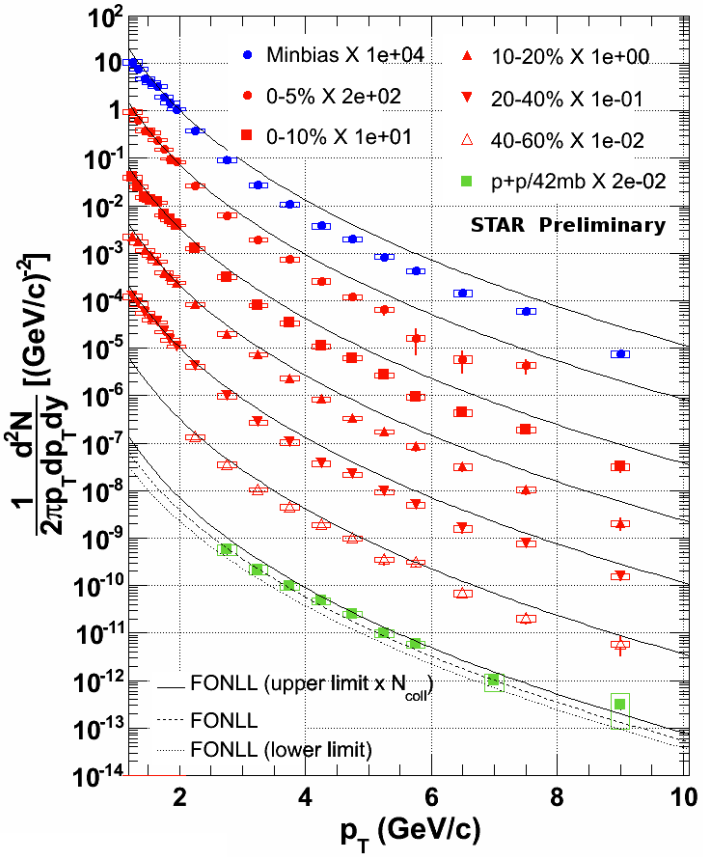
Open Charm Production - AuAu

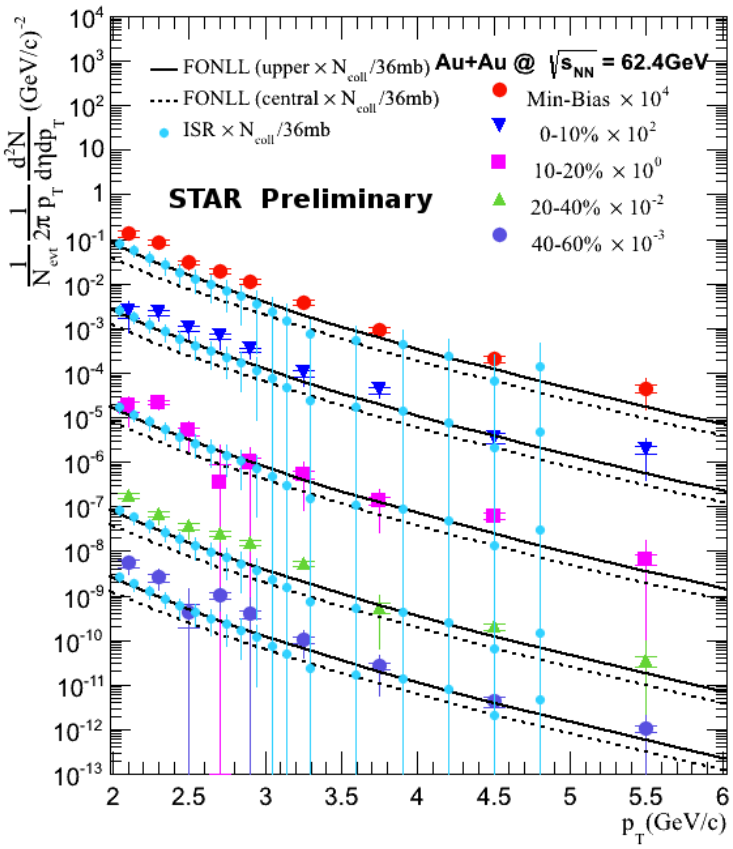




Models with light quarks coalescence with charm describe low pT bump.
But could it be due to Cronin effect + suppression at high pT?

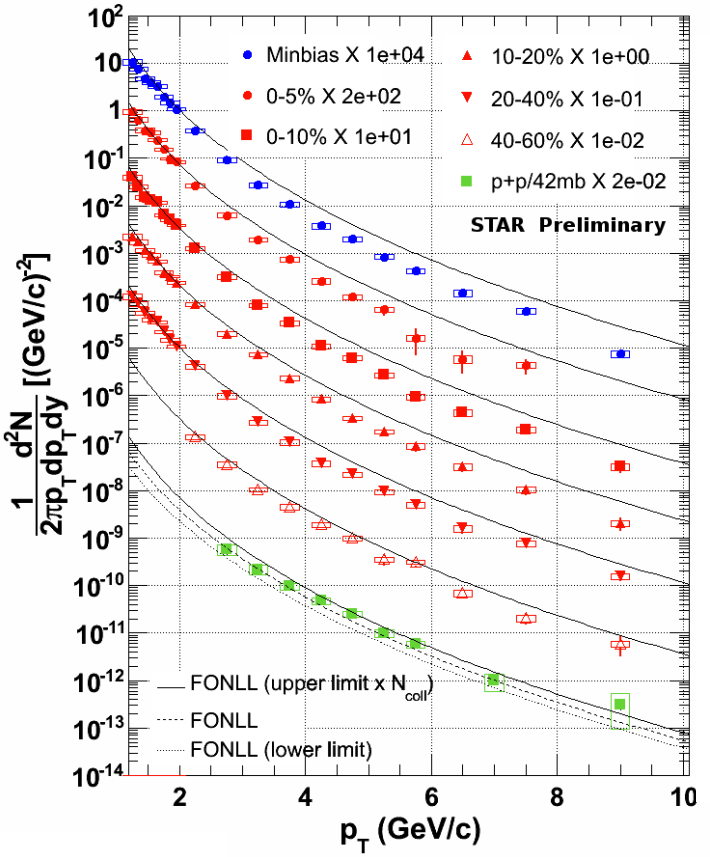
Open Charm Production - AuAu

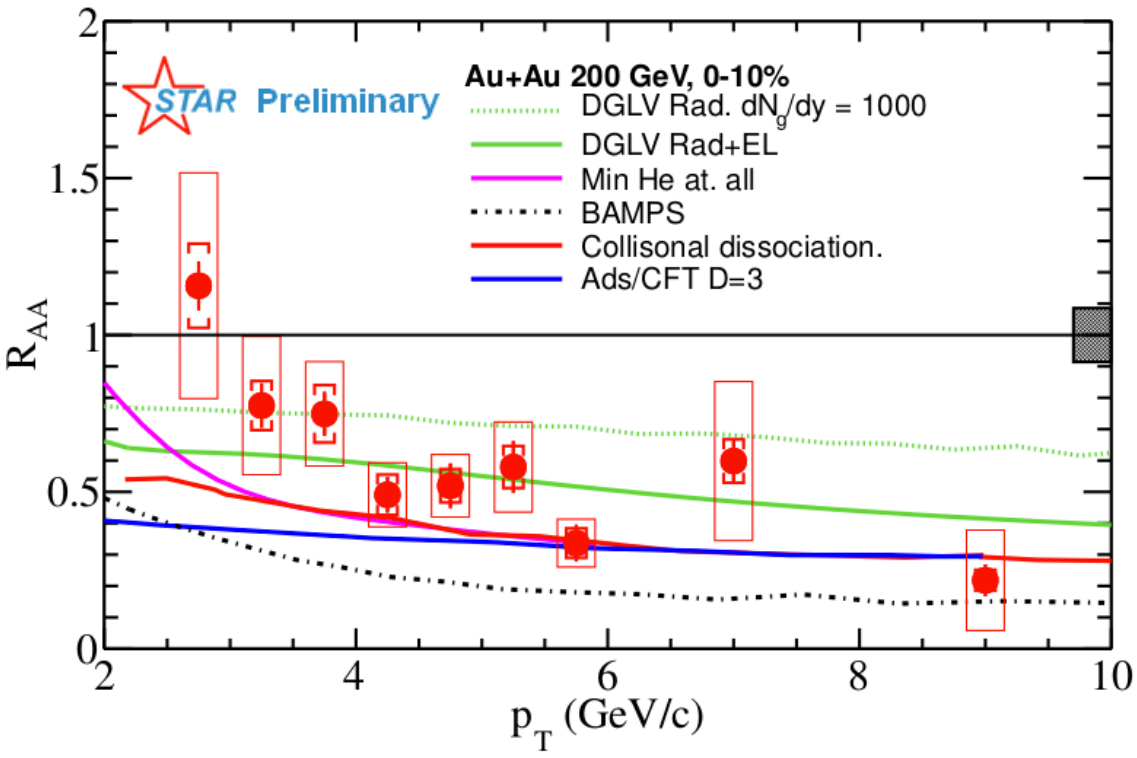




Strong suppression of NPE at 200 GeV, but no suppression at 62 GeV (results not corrected for J/Psi contribution, could be ~20% at high pT).

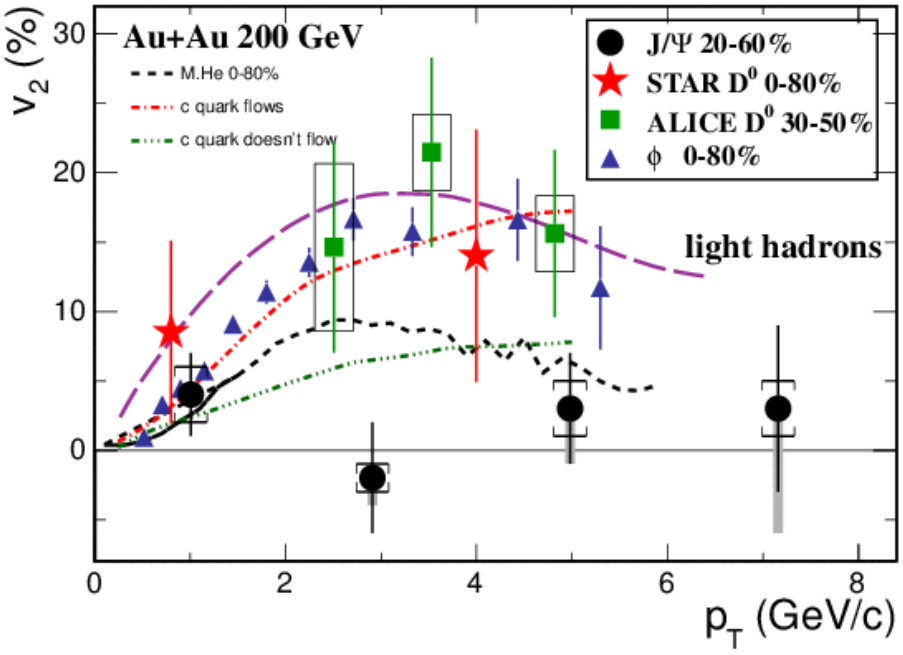
Open Charm Production - AuAu

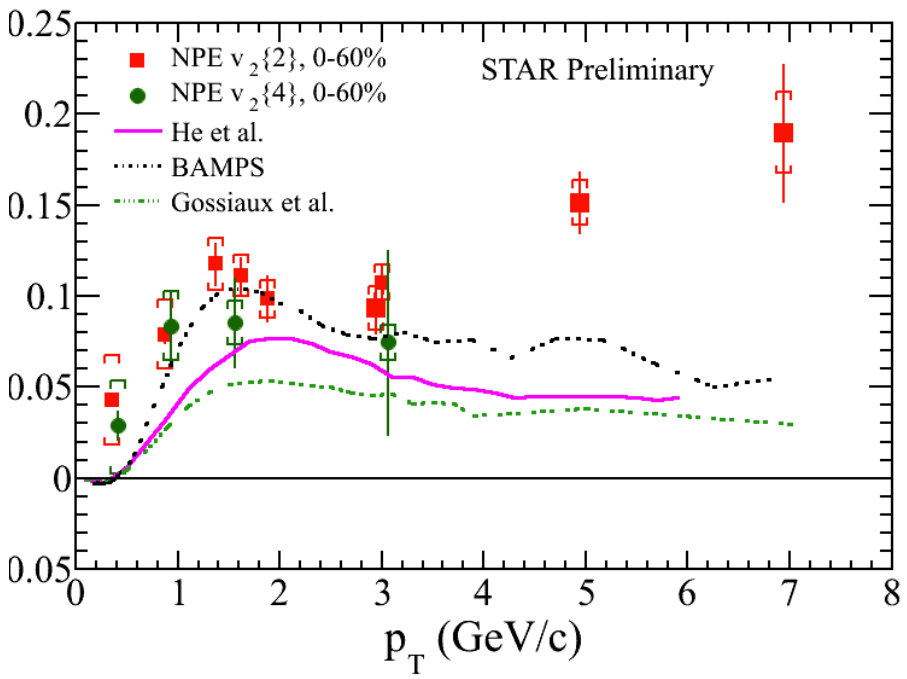




Model with Rad+EL agrees the best with observed NPE R_{AA}.
Need better precision measurements to further constrain models.

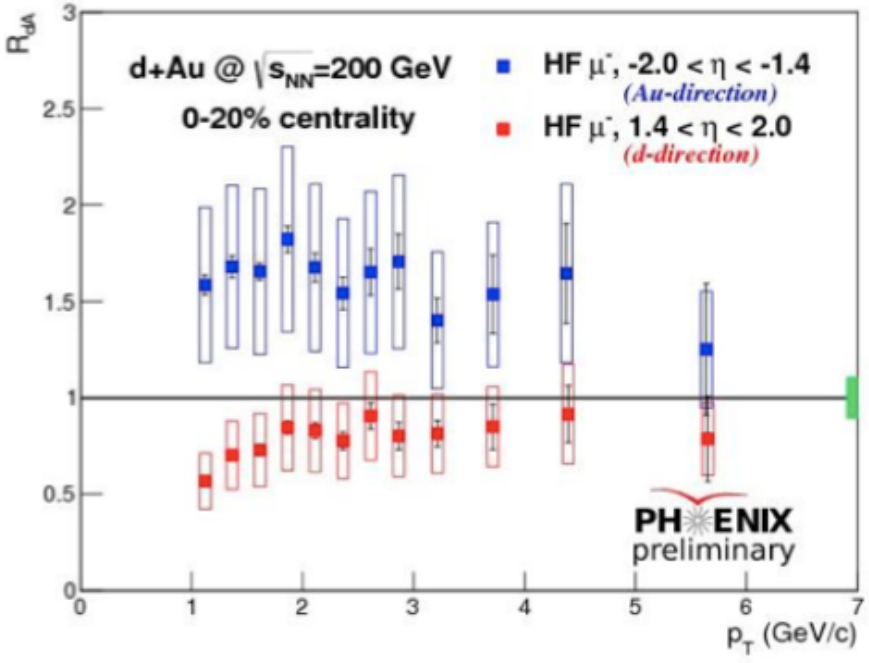
Open Charm Production - AuAu

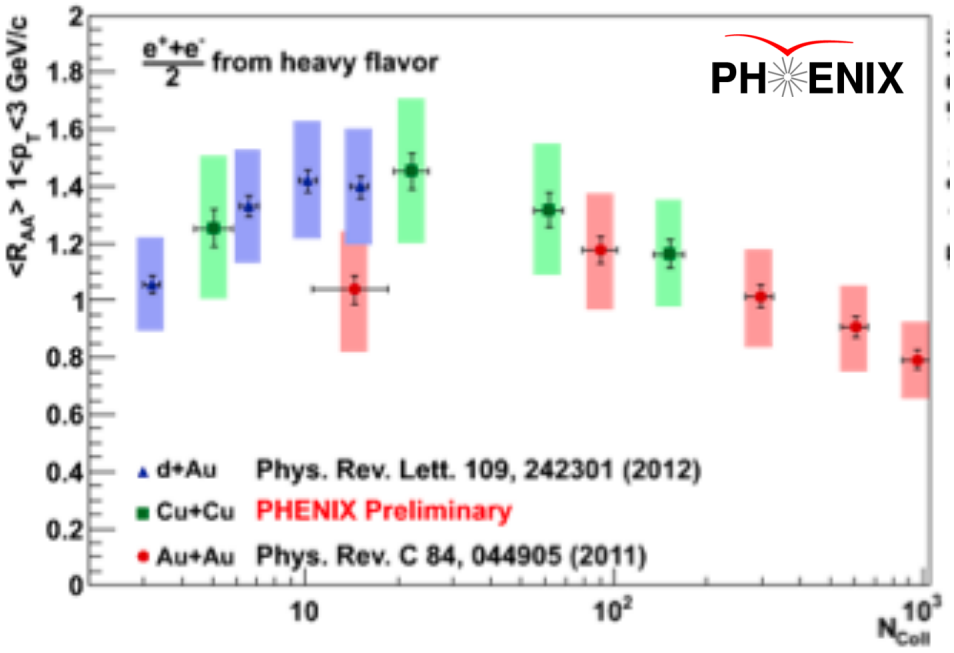




Significant non-zero NPE v2 at low pT: is it from charm quark flow and/or coalescence with light quark? Precise D^0 v2 measurements will help.

Open Charm Production - dAu





Enhancement at Au-direction – antishadowing + Cronin effects?
Indication of a global trend of R_{AA} vs N_{coll} – underlying physics mechanism?

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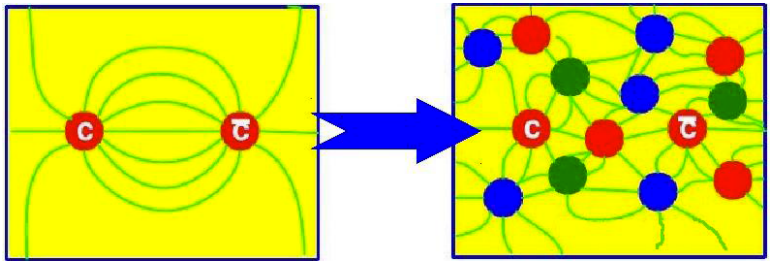
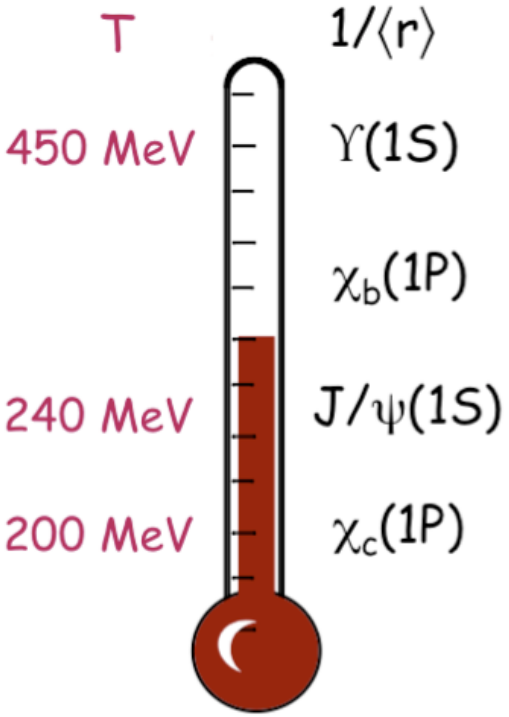
Quarkonia

Quarkonia can be used as a thermometer for the QGP:

- color screening as a function of QGP temperature

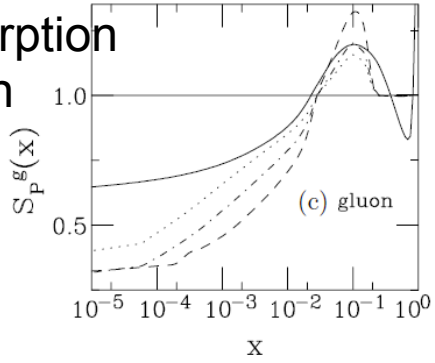




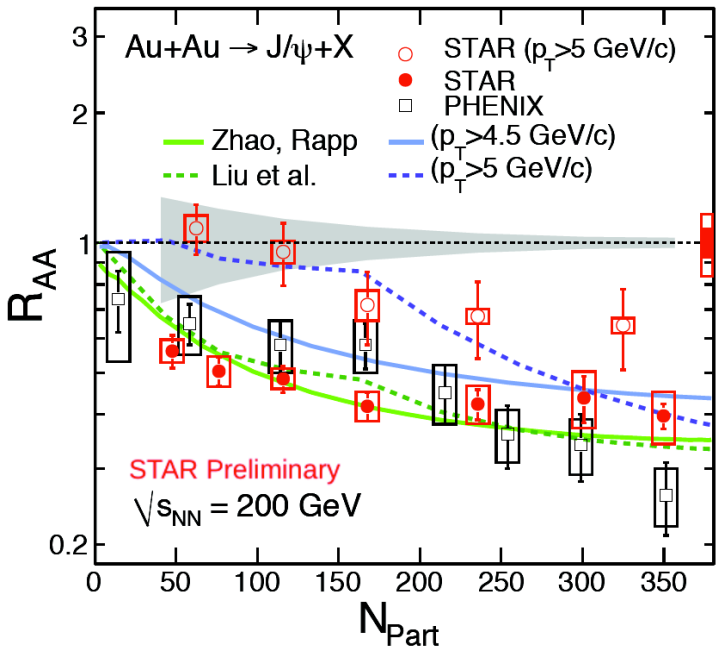
A. Mocsy,EPJC 61 (2009) 705

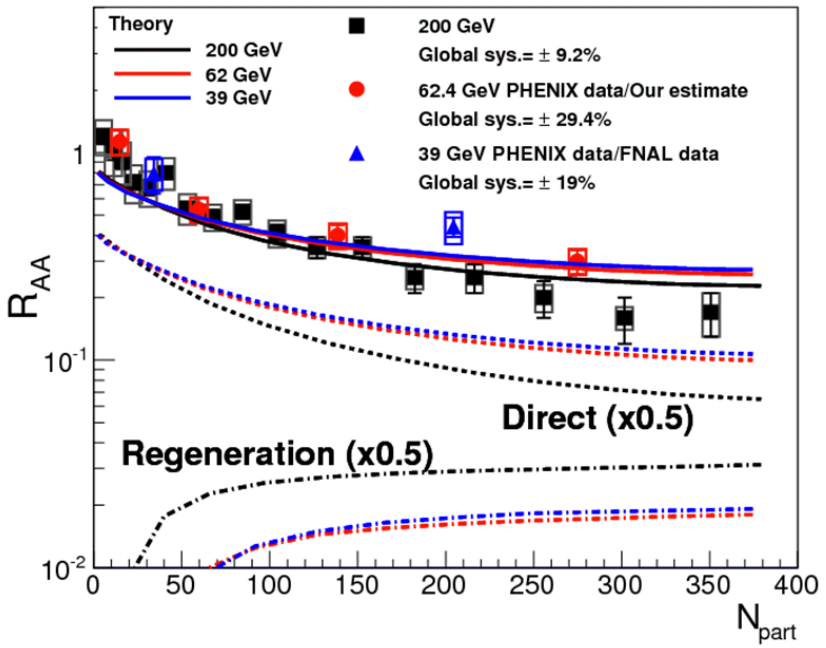
but there are other effects as well:

- Feed-down from other states;
- CNM: shadowing, nuclear absorption
- HNM: regeneration, dissociation



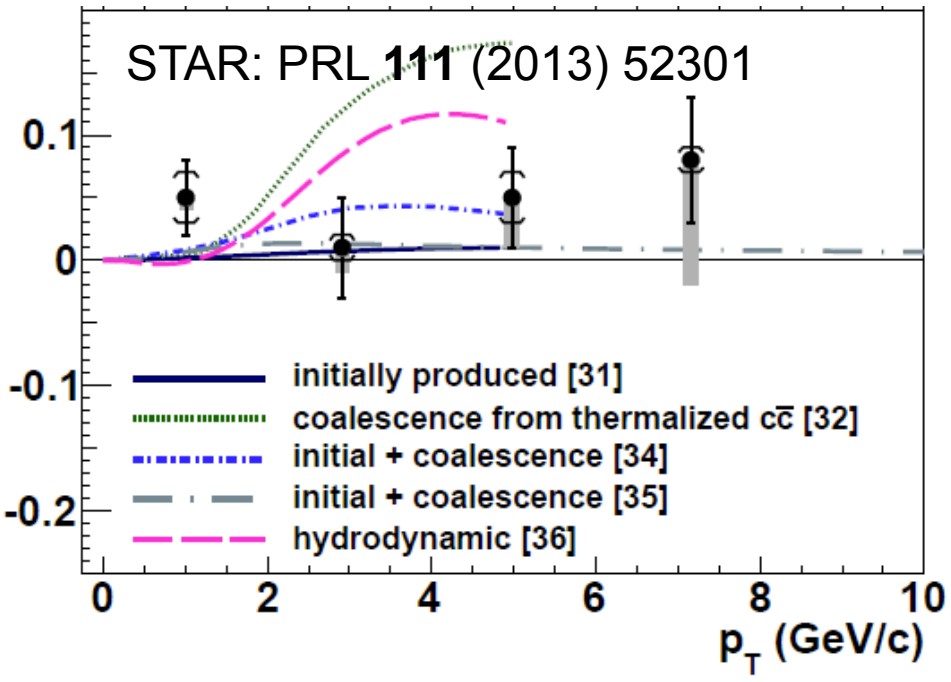
Charmonium – J/ψ





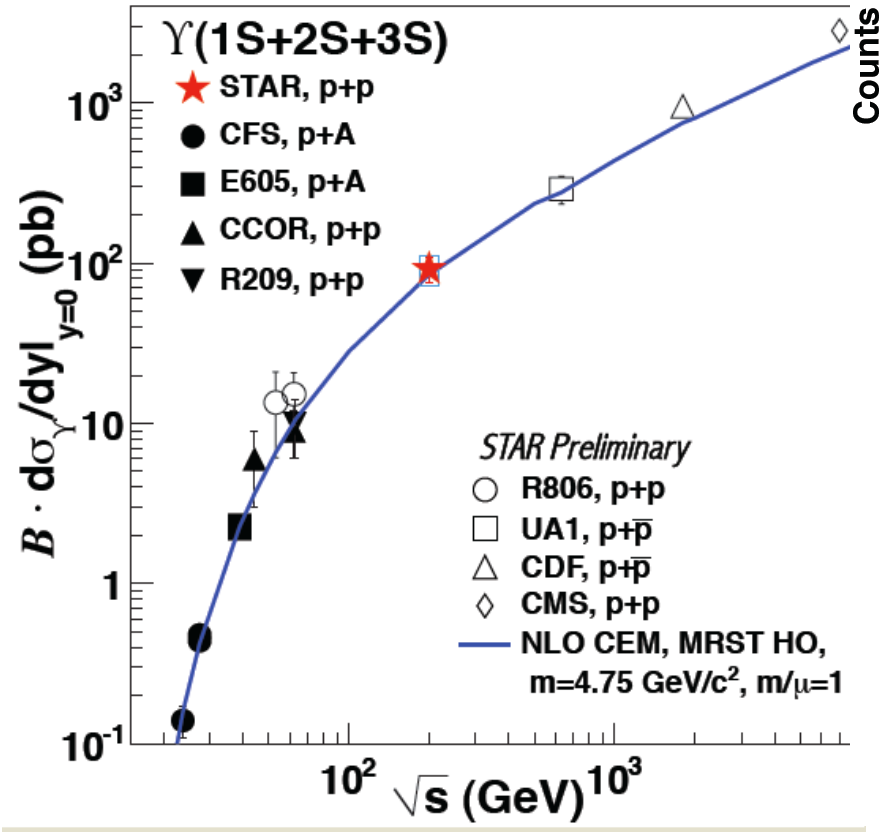
Models including color screening and regeneration are consistent with data. The energy dependences of the two effects largely cancel out.

Charmonium – J/ψ

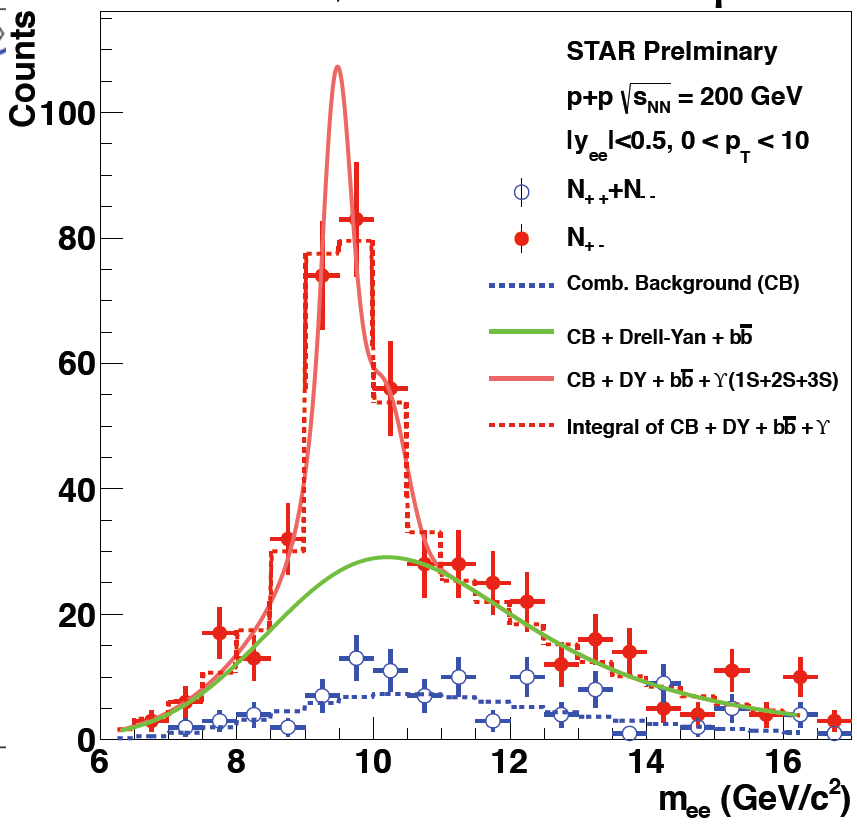


J/ψ v2 consistent with 0 at pT>2 GeV
→ J/ψ is not dominantly produced by coalescence from thermalized c and cbar quarks

Bottomium – Υ(1S+2S+3S)



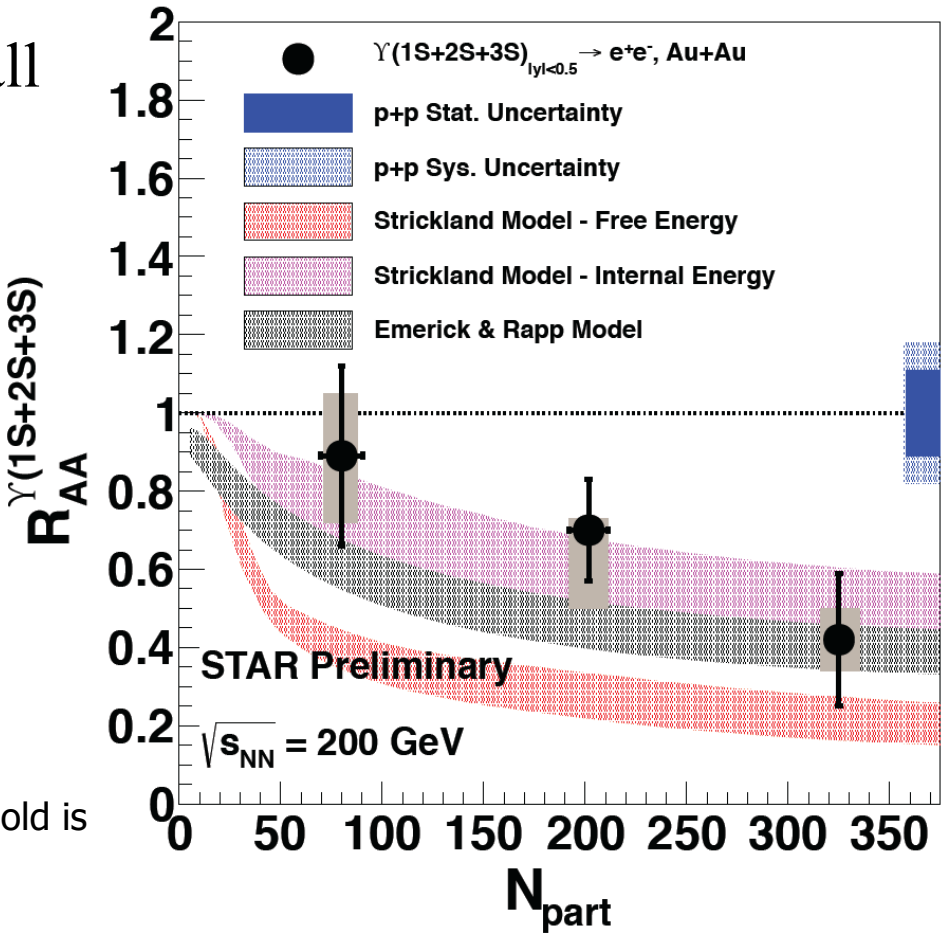
2009, $\int L\,dt = 19.7\ pb^{-1}$



New p+p reference results.

Bottomium – Y(1S+2S+3S)

- Hint of suppression vs N_{part}
- Dynamical models with fireball expansion and feed-down
  - Strickland et al., NP A 879 (2012) 25
    - anisotropic Hydrodynamics
    - Assumes:
      - T_0 range 428 – 442 MeV
      - $1/4\pi < \eta/S < 3/4\pi$
  - Rapp et al., EPJ A 48 (2012) 72
    - Kinetic theory + fireball.
    - T_0 = 330 MeV
    - "Weak Binding" (shown)
      - Binding energy changes with T
      - Bound state mass : constant
      - In-medium open-bottom threshold is reduced
      - Motivated by Lattice QCD



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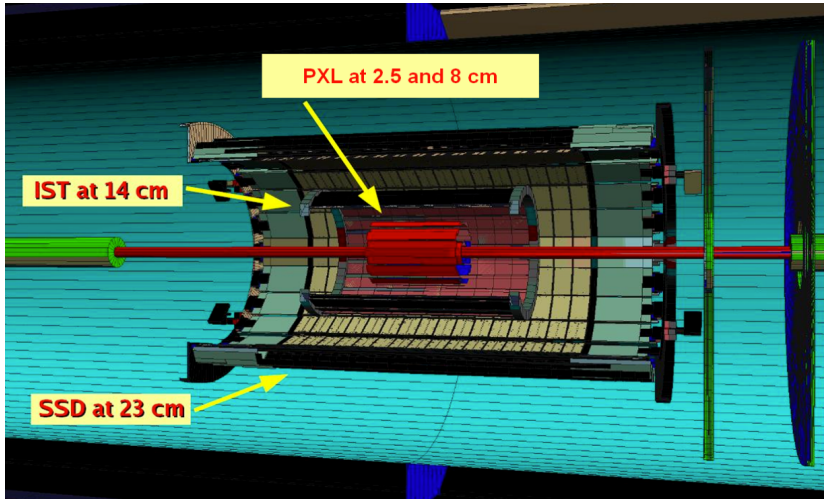
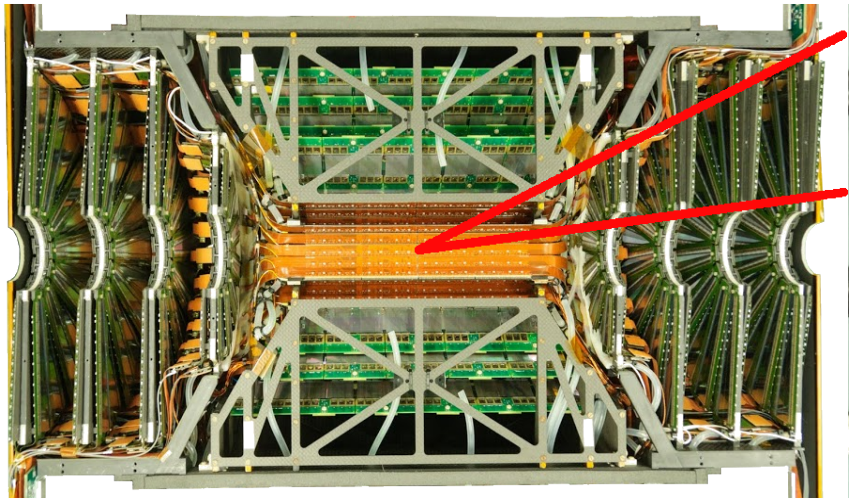
Looking into the Future

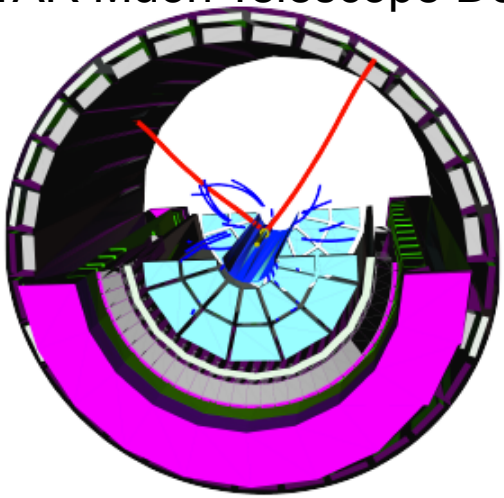
STAR Heavy Flavor Tracker



PHENIX VTX and FVTX

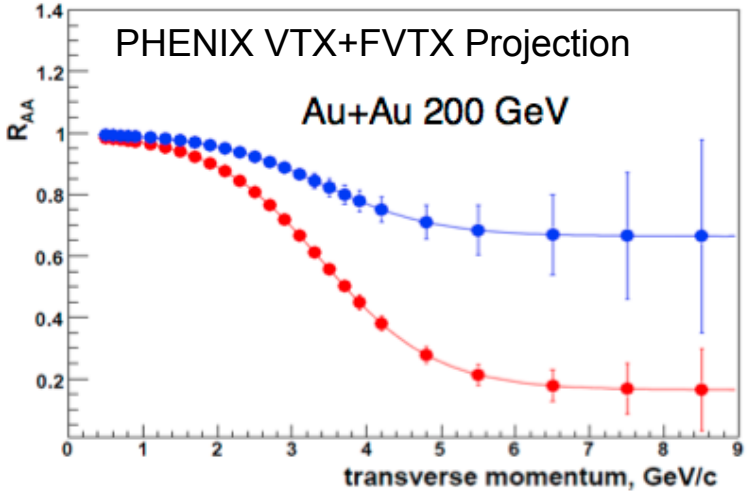


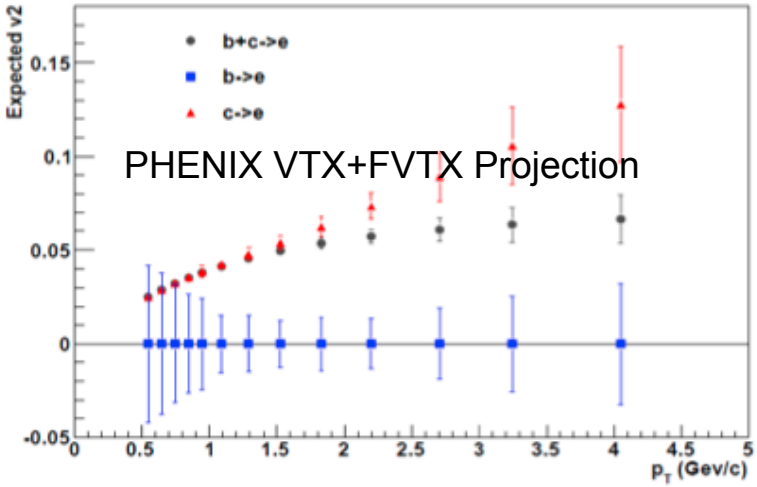
STAR Muon Telescope Detector

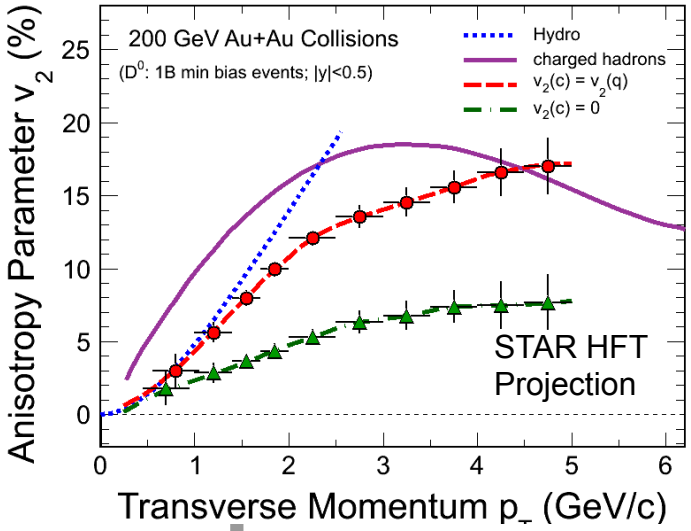


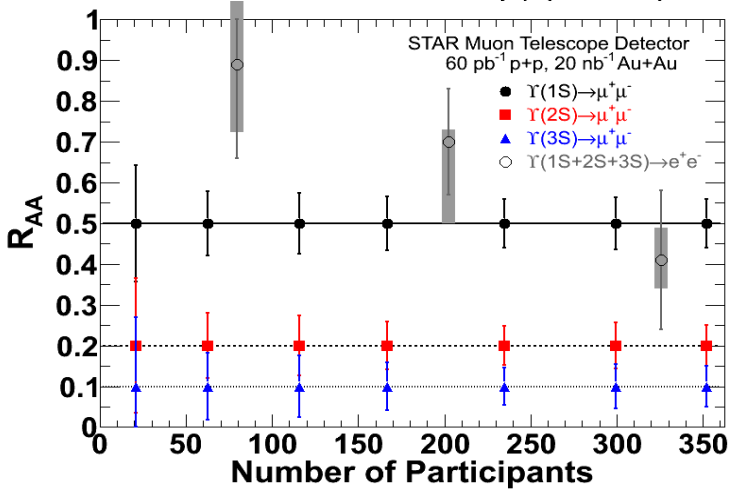
An extended AuAu run in 2014 with
PHENIX VTX and FVTX
STAR HFT and MTD
taking data for heavy flavor physics

Looking into the Future









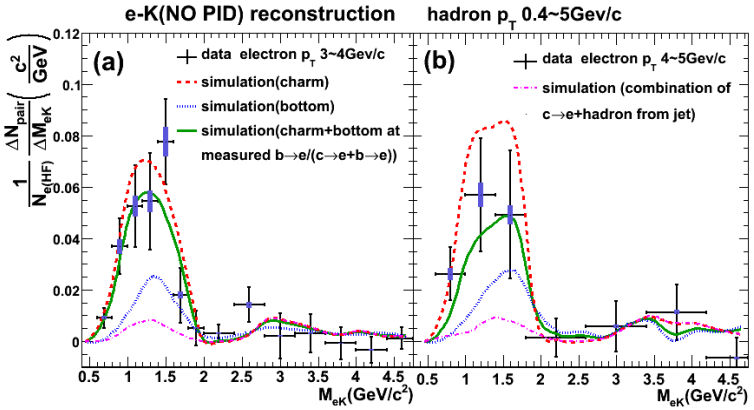
Conclusion

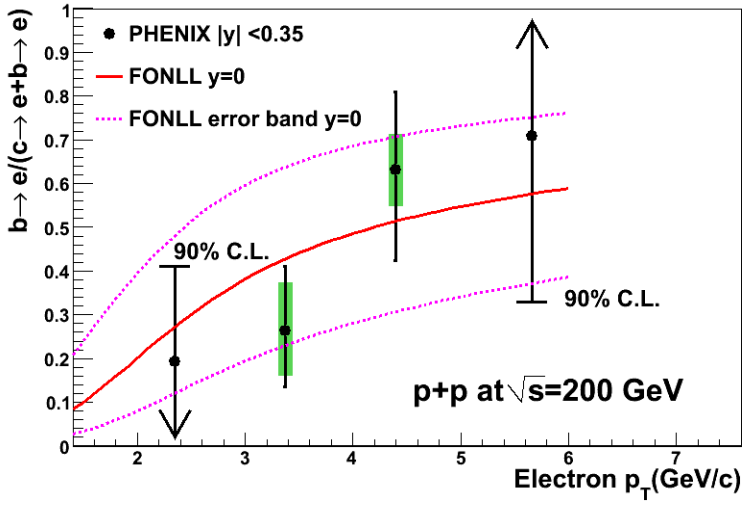
- Strong suppression observed for D_0 and NPE in 200 GeV AuAu collisions but not for NPE at 62 GeV.
- Significant v2 observed for NPE in 200 GeV AuAu collisions.

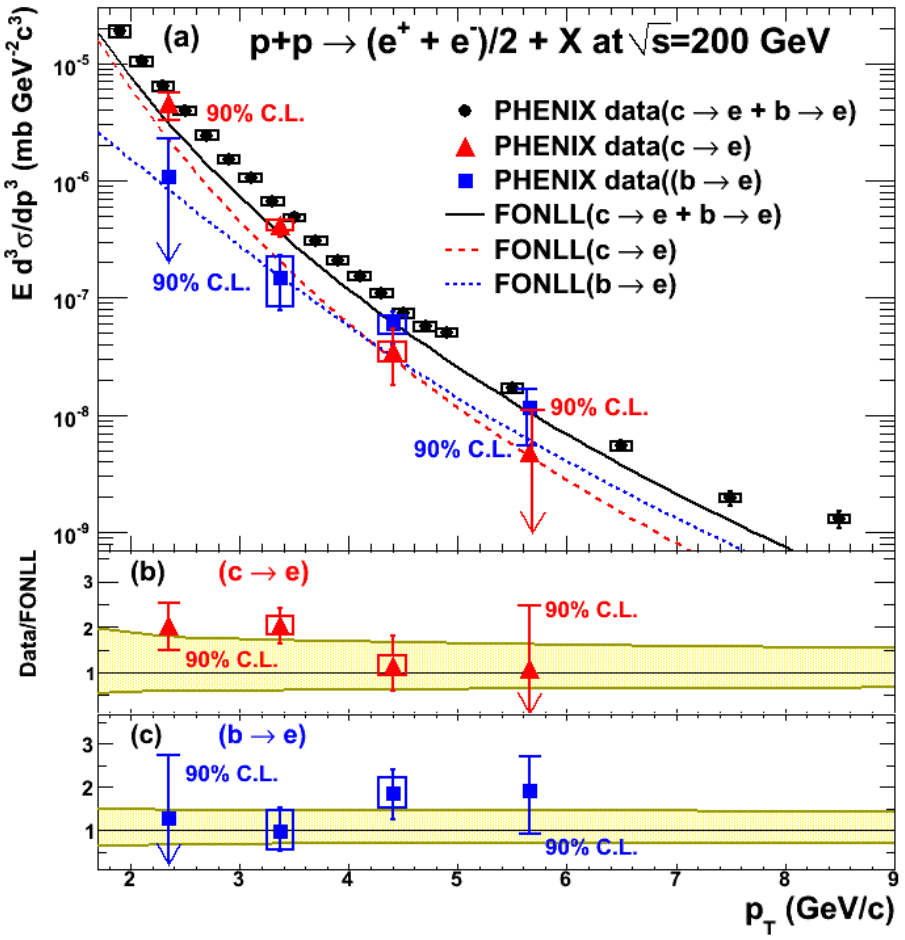
- Weak dependence of J/psi suppression on beam energy can be attributed to cancellation of suppression and regeneration effects.
- Y suppression in 200 GeV AuAu collisions consistent with models with complete Y(2S) and Y(3S) suppression.

- Both STAR and PHENIX will have new detectors take data starting in 2014 for HF physics: precise HF measurements with more definitive information to address how heavy flavor quarks interact with the hot nuclear medium, and the medium properties.

Open Bottom Production - pp

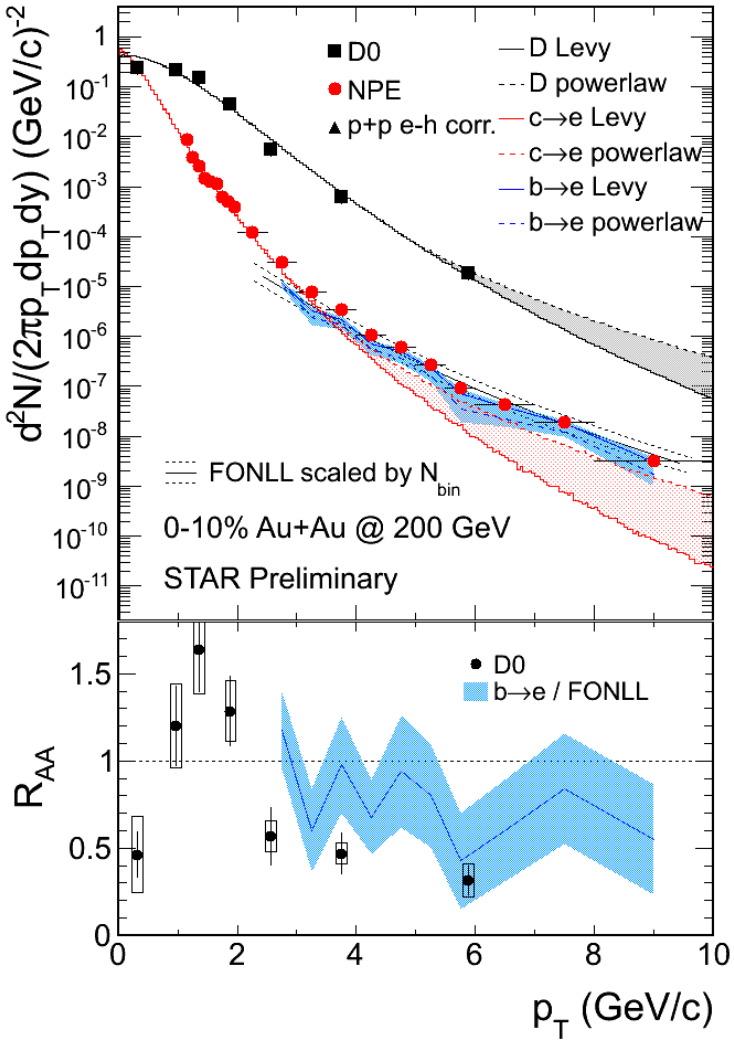


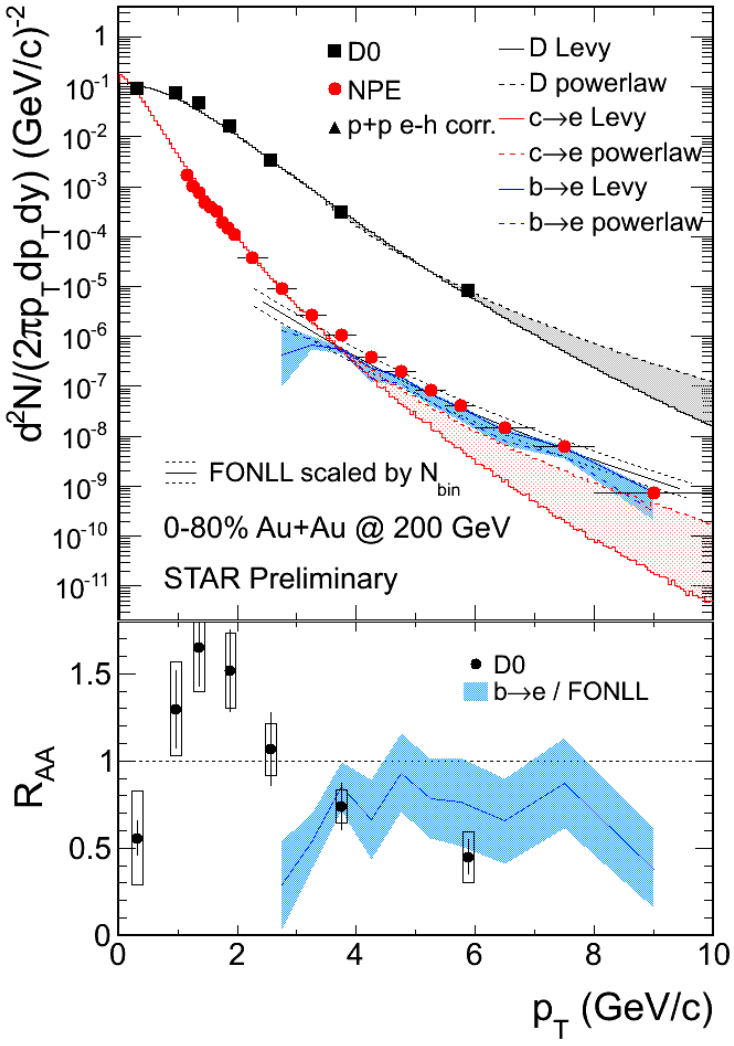


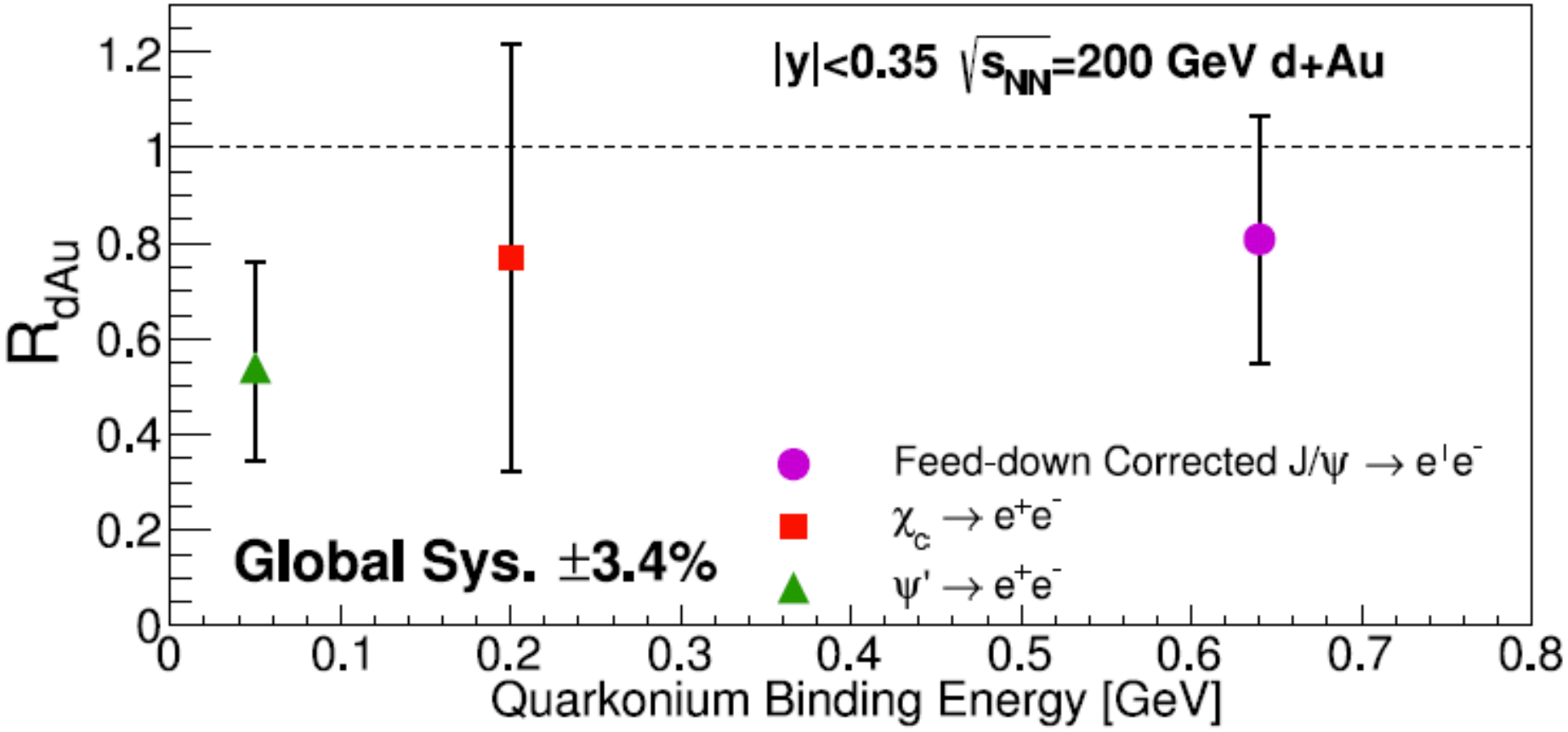


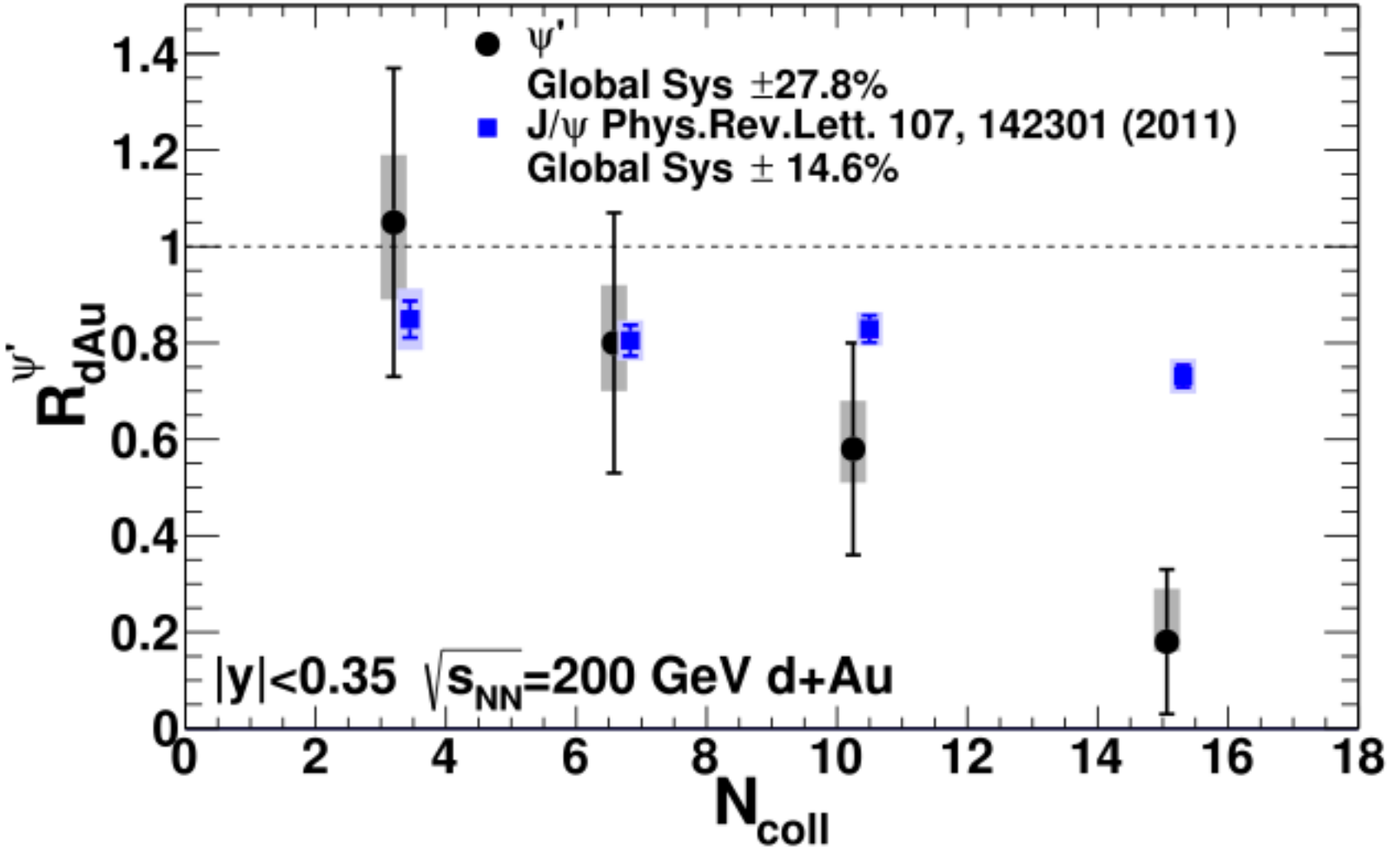
B->e and D->e extracted from e-h correlation and consistent with FONLL.

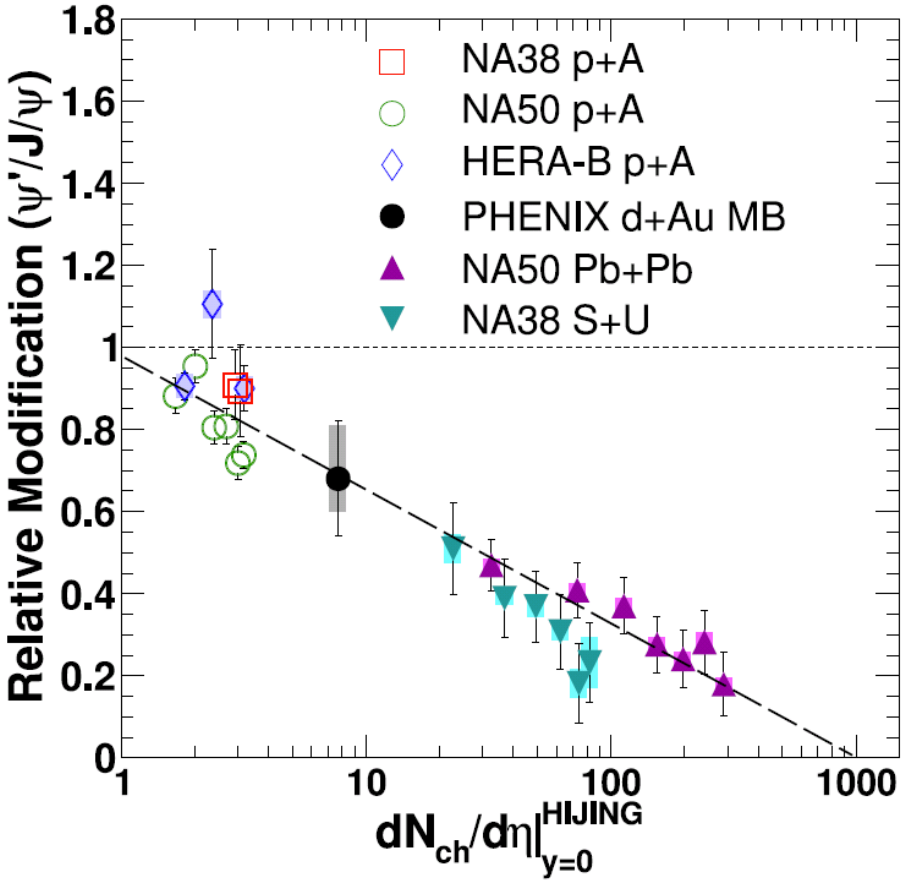
Open Bottom Production - AuAu






|y|<0.35 $\sqrt{s_{NN}}$=200 GeV d+Au
R_{dAu}
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Quarkonium Binding Energy [GeV]
Global Sys. ±3.4%
Feed-down Corrected J/ψ → e+e-
$\chi_c \rightarrow e^+e^-$
$\psi' \rightarrow e^+e^-$


ψ'
Global Sys ±27.8%
J/ψ Phys.Rev.Lett. 107, 142301 (2011)
Global Sys ± 14.6%
|y|<0.35 √s_NN=200 GeV d+Au
R_dAu ψ'
N_coll
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
2
4
6
8
10
12
14
16
18


NA38 p+A
NA50 p+A
HERA-B p+A
PHENIX d+Au MB
NA50 Pb+Pb
NA38 S+U
Relative Modification (ψ'/J/ψ)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
100
1000
dN_ch/dη|^HIJING_y=0