Heavy Flavor production at STAR

Daniel Kikoła for the STAR collaboration

Purdue University

Top RHIC energy: QGP properties

→ Open heavy flavor → energy loss and flow

→ J/ψ, Upsilon → thermodynamic properties

Heavy Flavor production vs energy

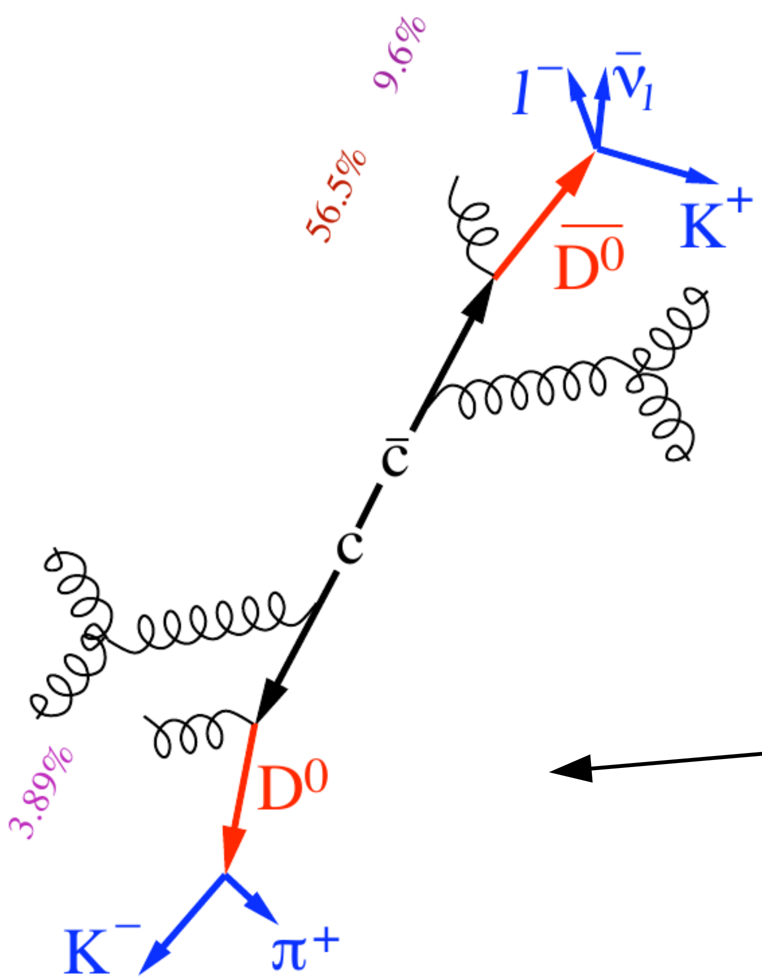
→ Is nuclear medium similar/different at 200 GeV and 62 and 39 GeV?

Open heavy flavor

Y. Zhang, 26 July, 17:30
Session: Quarkonia/Heavy Flavour

D. Tlusty, 25 July, 14:40
Session: Heavy Flavour 2

Open heavy flavor at STAR



Courtesy of David Tlusty

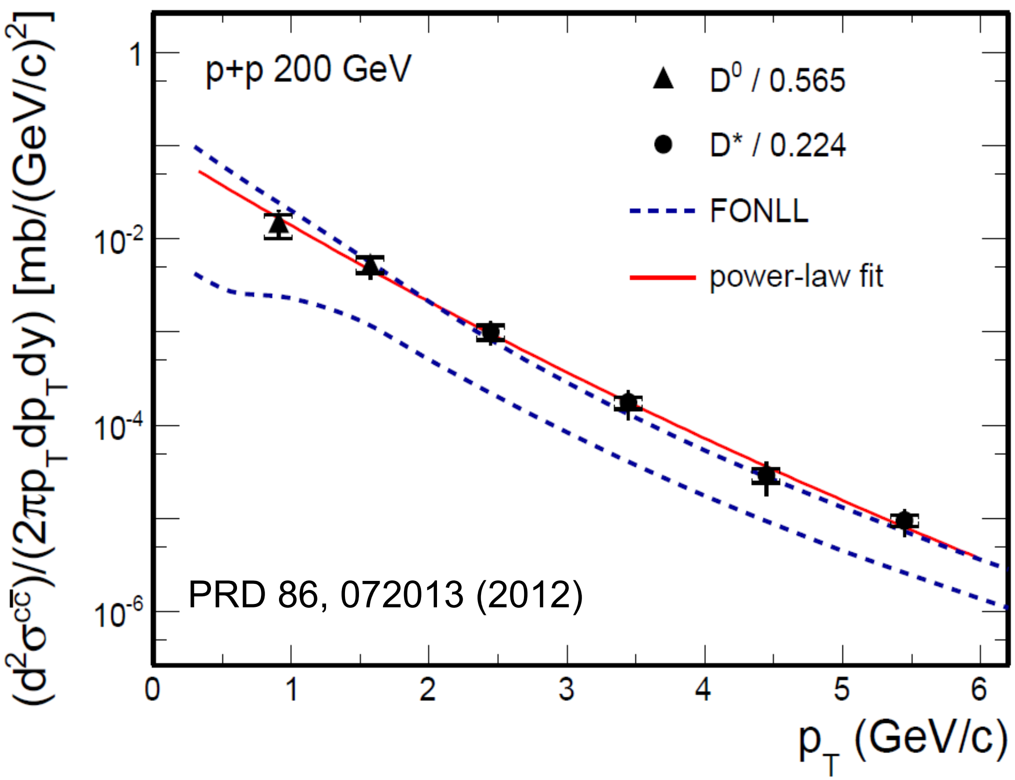
<u>Electrons from semi-leptonic heavy flavor hadrons decay (Non-photonic electrons)</u>

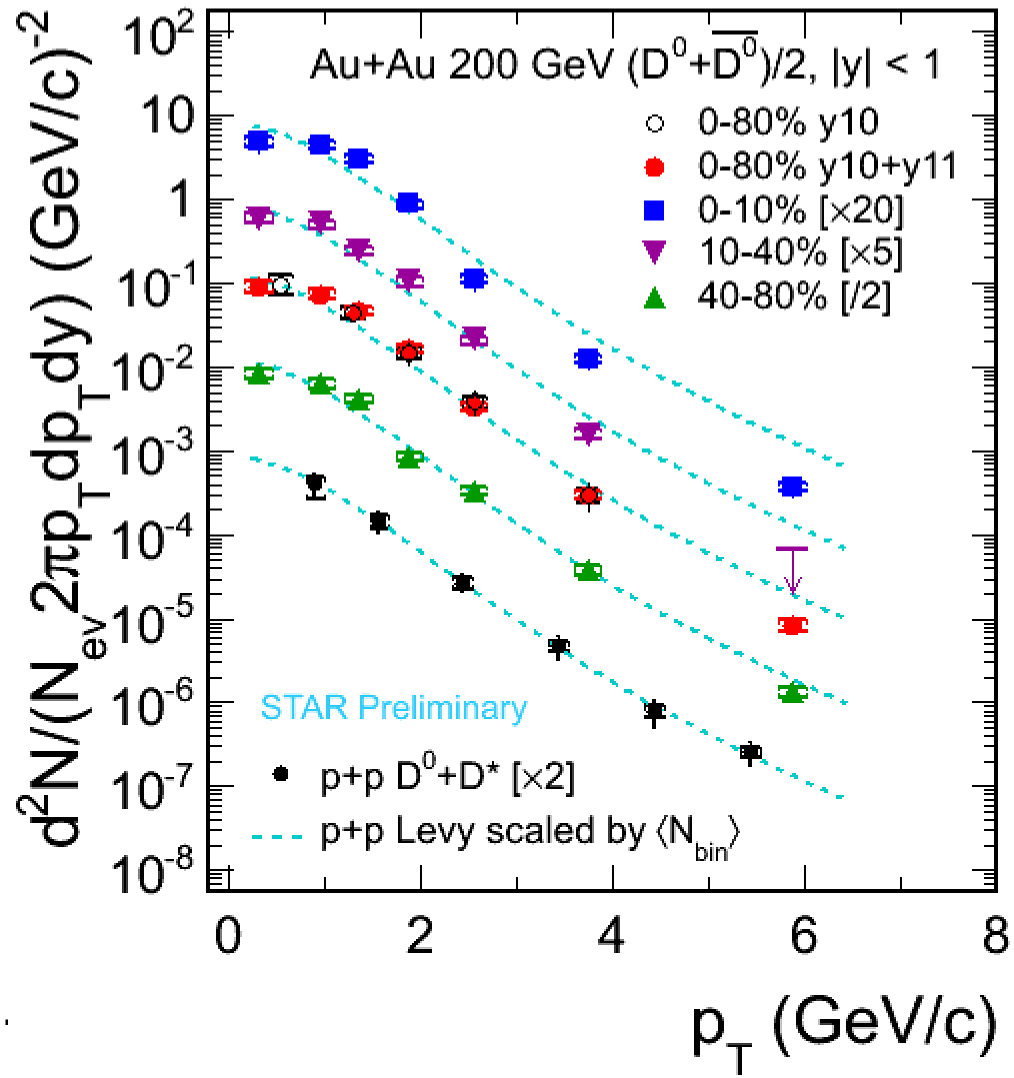
- easy to trigger
- indirect access to the heavy quark kinematics

<u>Direct open charm reconstruction</u>

- direct access to the heavy quark kinematics
- large background without vertex detector
- difficult to trigger

D^0, D* p_T spectra in p+p and Au+Au 200 GeV





p+p: Constraints for the pQCD calculations.

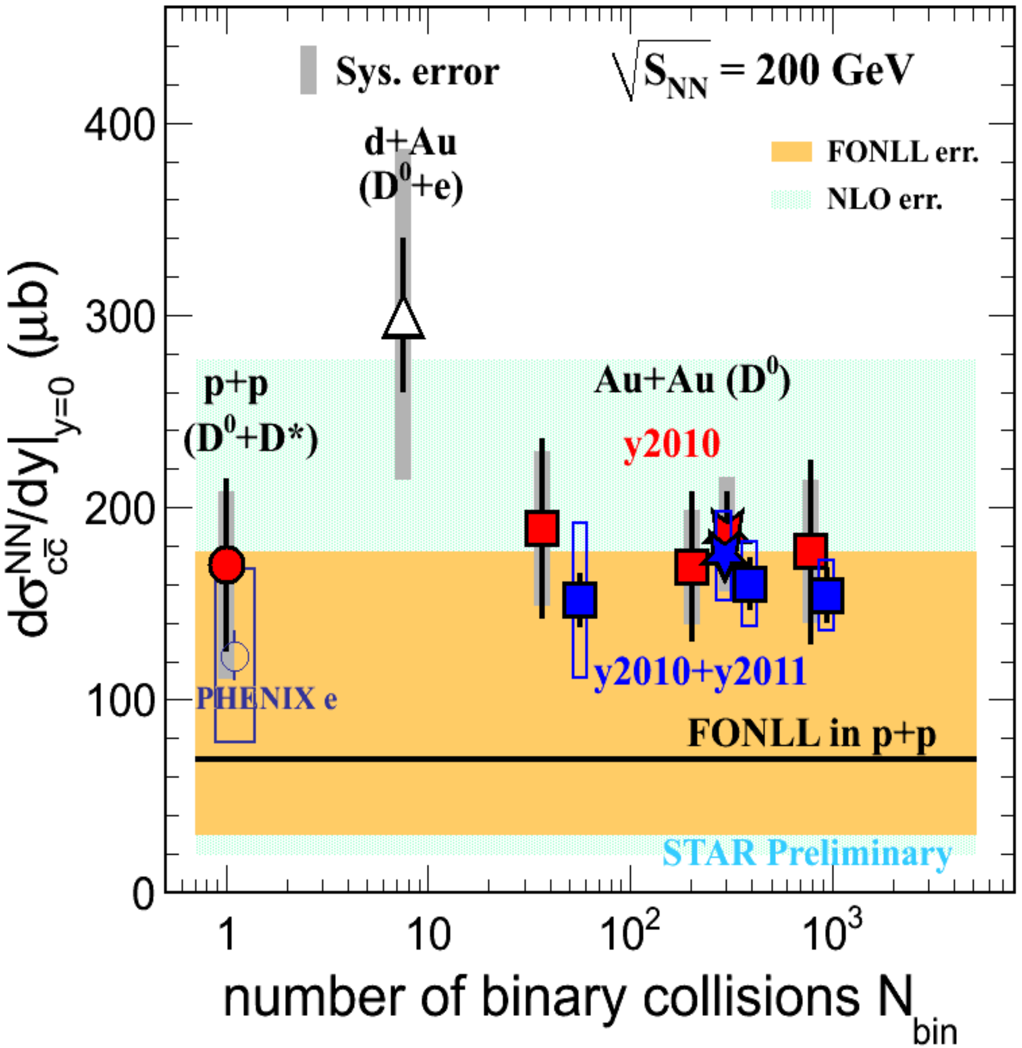
Results consistent with FONLL upper limit.

Au+Au: New data (2010 + 2011): 800 M events

Suppression at high-p_T in central collisions

(FONLL: Fixed Order plus Next-to-Leading Logarithms calculation, $\mu_F = \mu_R = m_c$, |y| < 1, *R. Nelson, R. Vogt, A. D. Frawley, arXiv: 1210.4610*)

Charm cross section at 200 GeV



Charm cross section at mid-rapidity:

$$\left.\frac{d\sigma}{dy}\right|^{pp}_{y=0} = 170 \pm 45^{+38}_{-59}\,\mu b \qquad \left.\frac{d\sigma}{dy}\right|^{AuAu}_{y=0} = 175 \pm 13 \pm 23\,\mu b$$

Total charm cross section:

$$\sigma^{pp}_{c\bar{c}} = 797 \pm 210^{+208}_{-295}\,\mu b \qquad \sigma^{AuAu}_{c\bar{c}} = 822 \pm 62 \pm 192\,\mu b$$

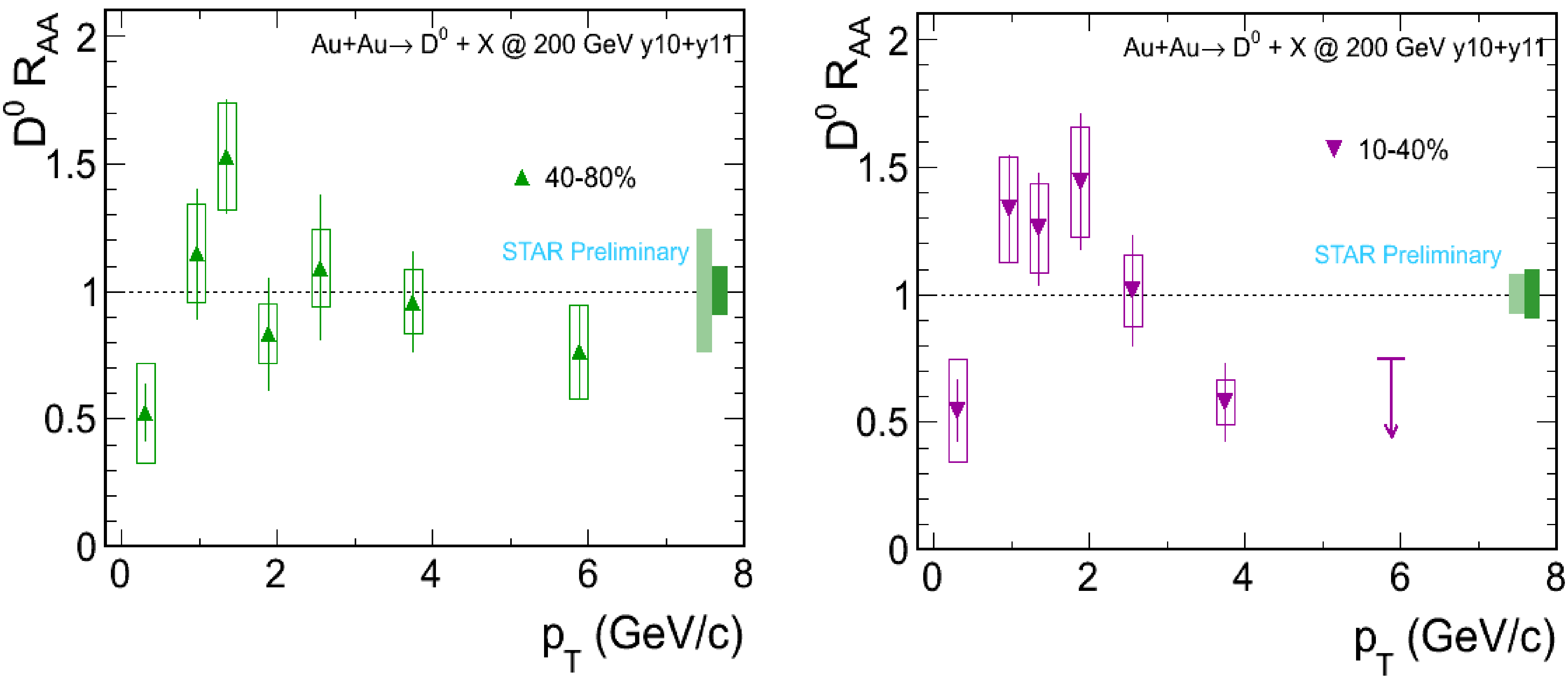
New, improved precision Au+Au data

Charm cross section follows number of binary collisions scaling

→ Charm quarks produced mostly via initial hard scatterings

[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.

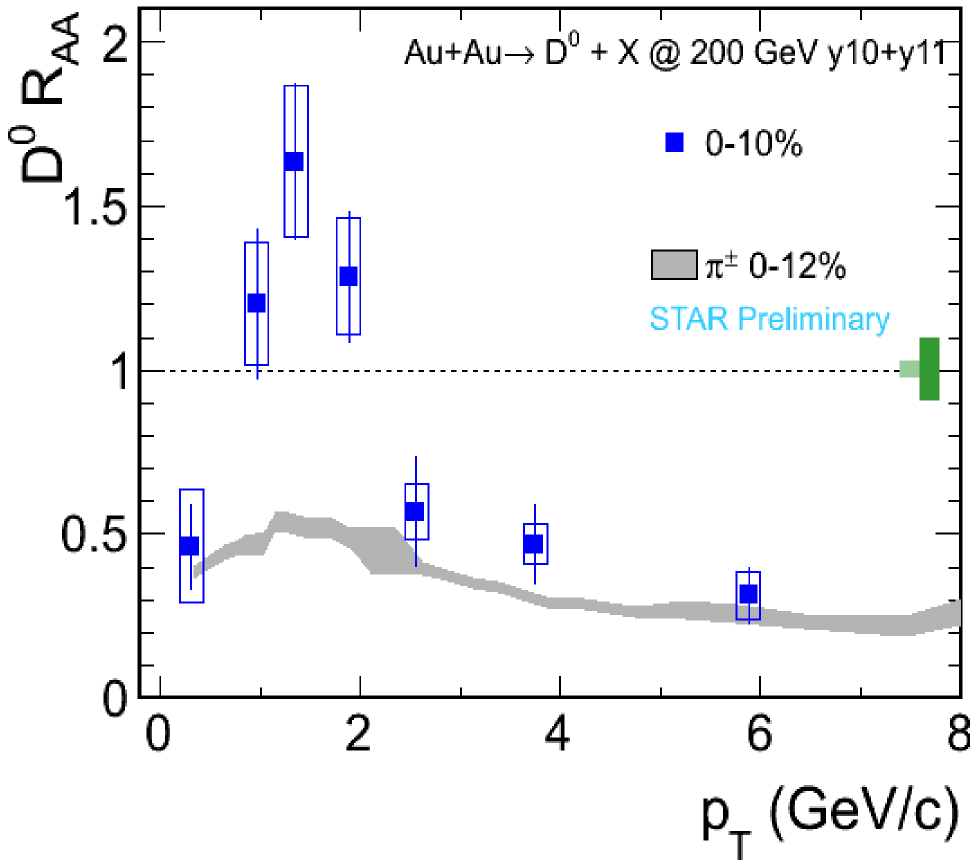
Open charm suppression

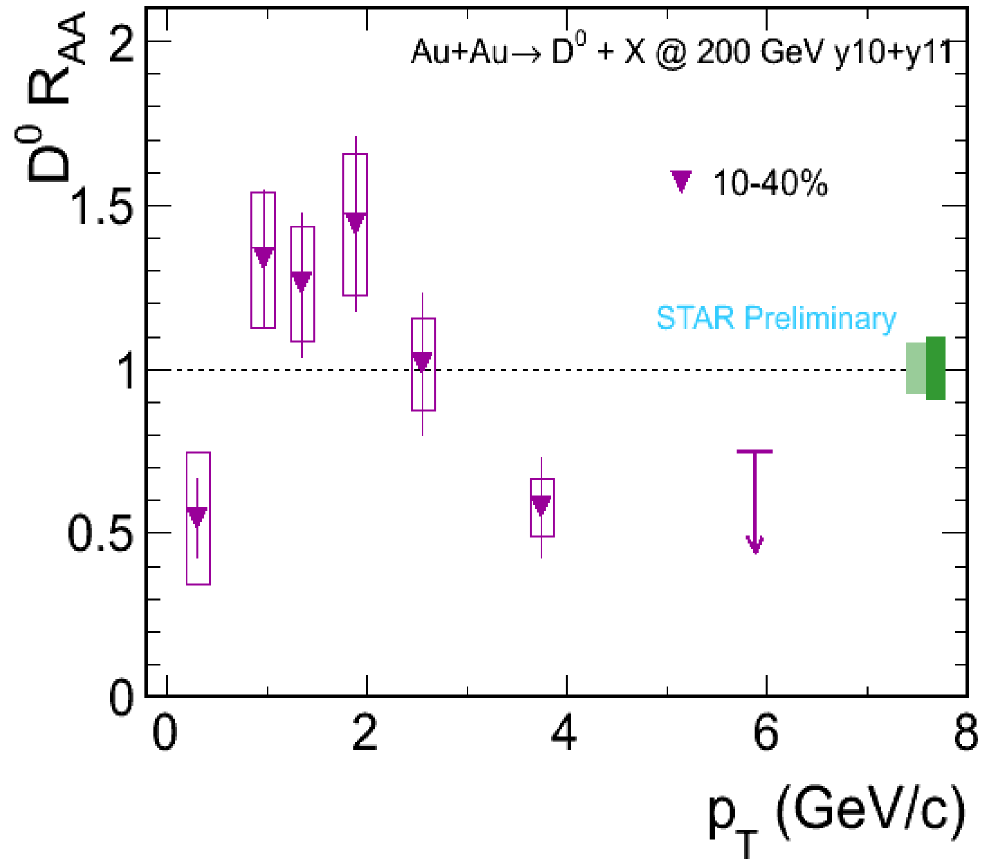


Suppression at high p_T in central and mid-central collisions.

Enhancement at intermediate p_T

Open charm suppression



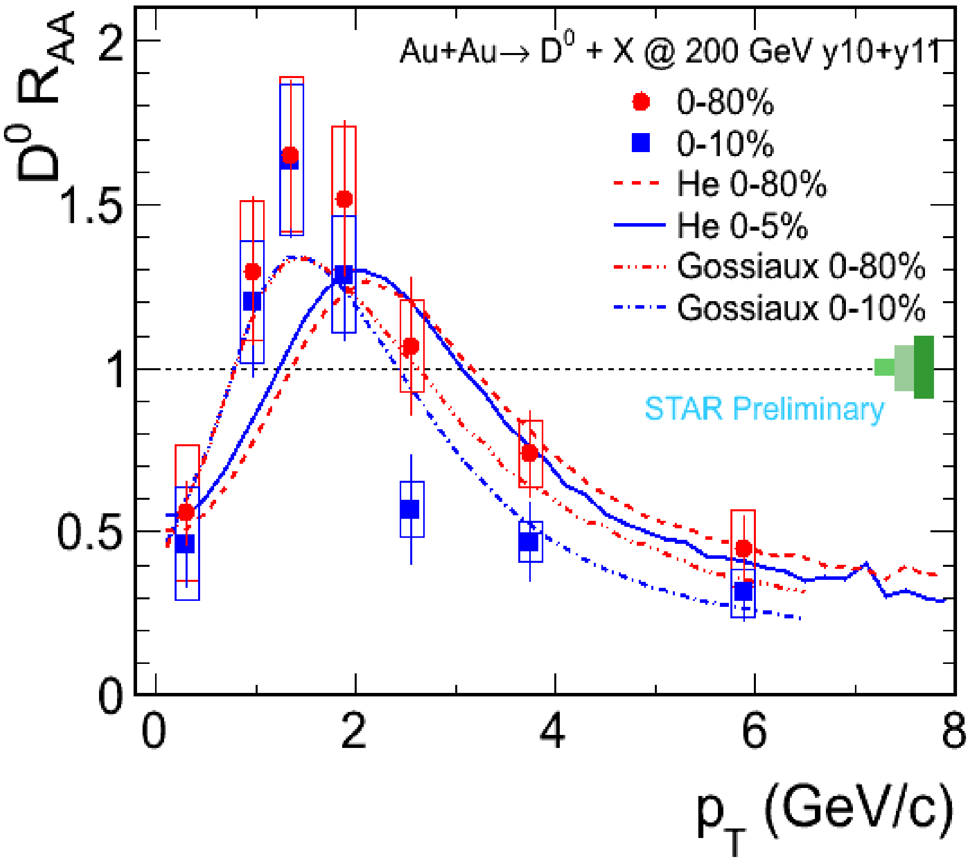


Suppression at high p_T in central and mid-central collisions

Enhancement at intermediate p_T

Suppression at high p_T in central collisions similar to light hadrons

Open charm suppression



He, Fries, Rapp: PRC86,014903;
arXiv:1204.4442; private comm.
Gossiaux: arXiv: 1207.5445

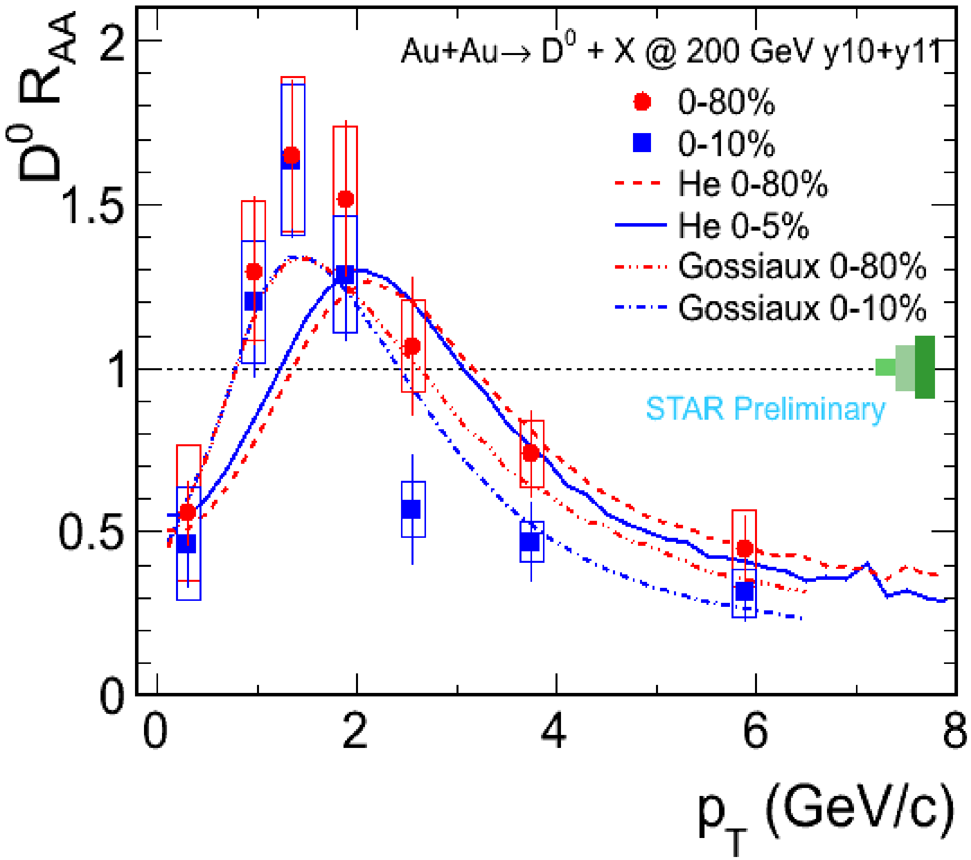
Models:

"bump" → radial flow of thermalized light quark which coalesces with charm

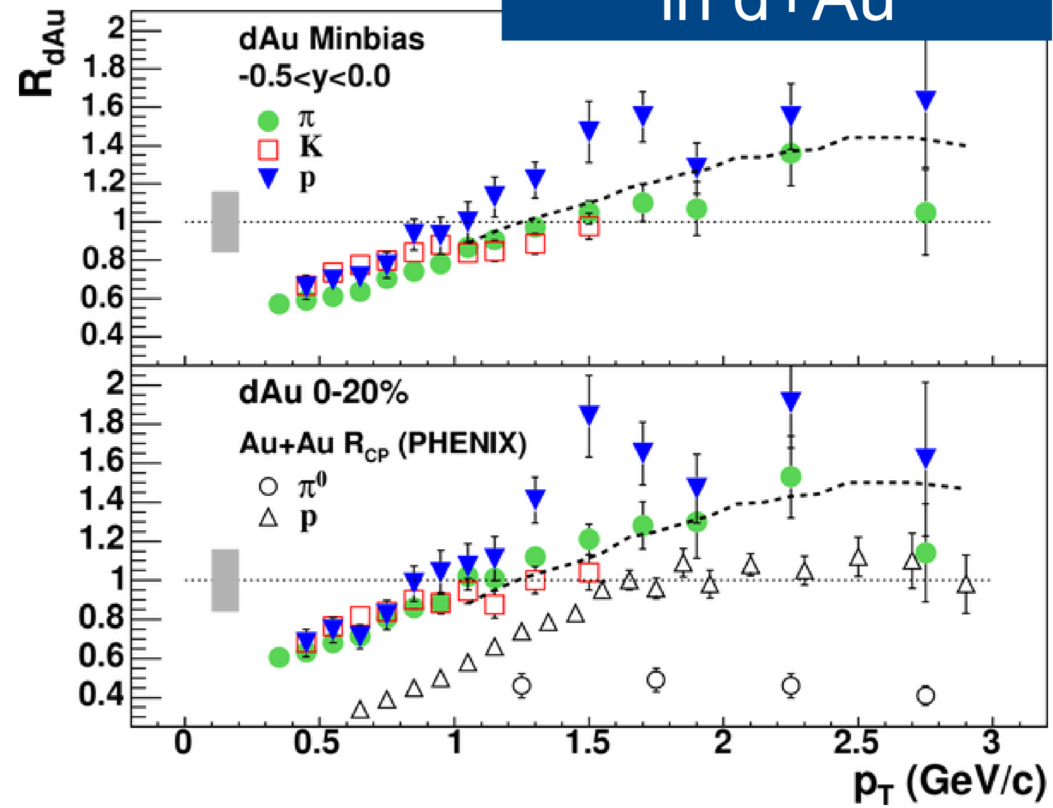
Enhancement at intermediate p_T:

→ Radial flow (?)

Open charm suppression



Cronin effect in d+Au



Phys. Lett. B 616 (2005) 8

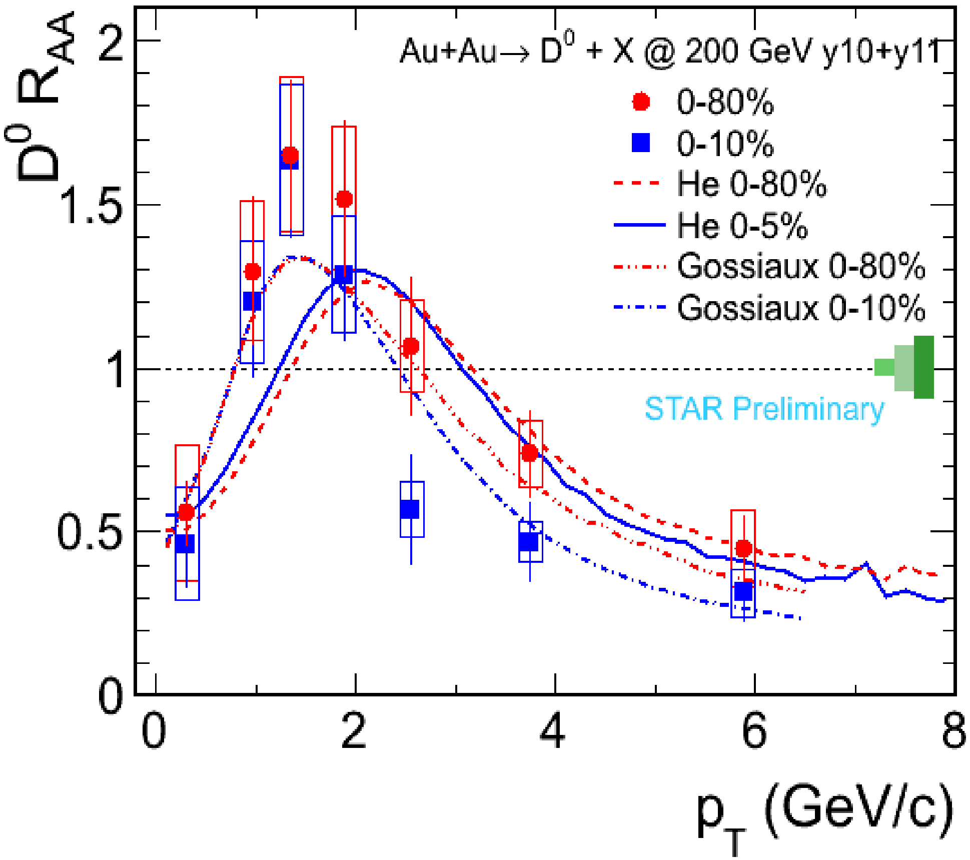
Enhancement at intermediate p_T:

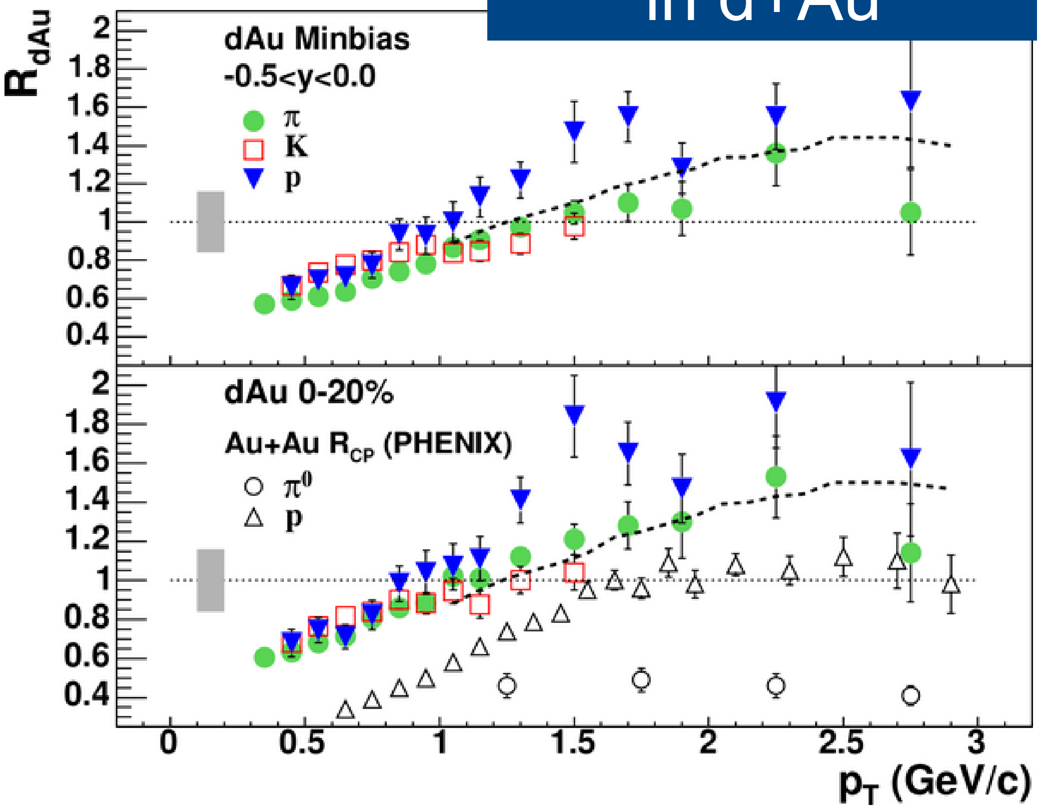
→ Radial flow (?)

→ Cronin enhancement + suppression at high p_T (?)

Open charm suppression

Cronin effect
in d+Au





Phys. Lett. B 616 (2005) 8

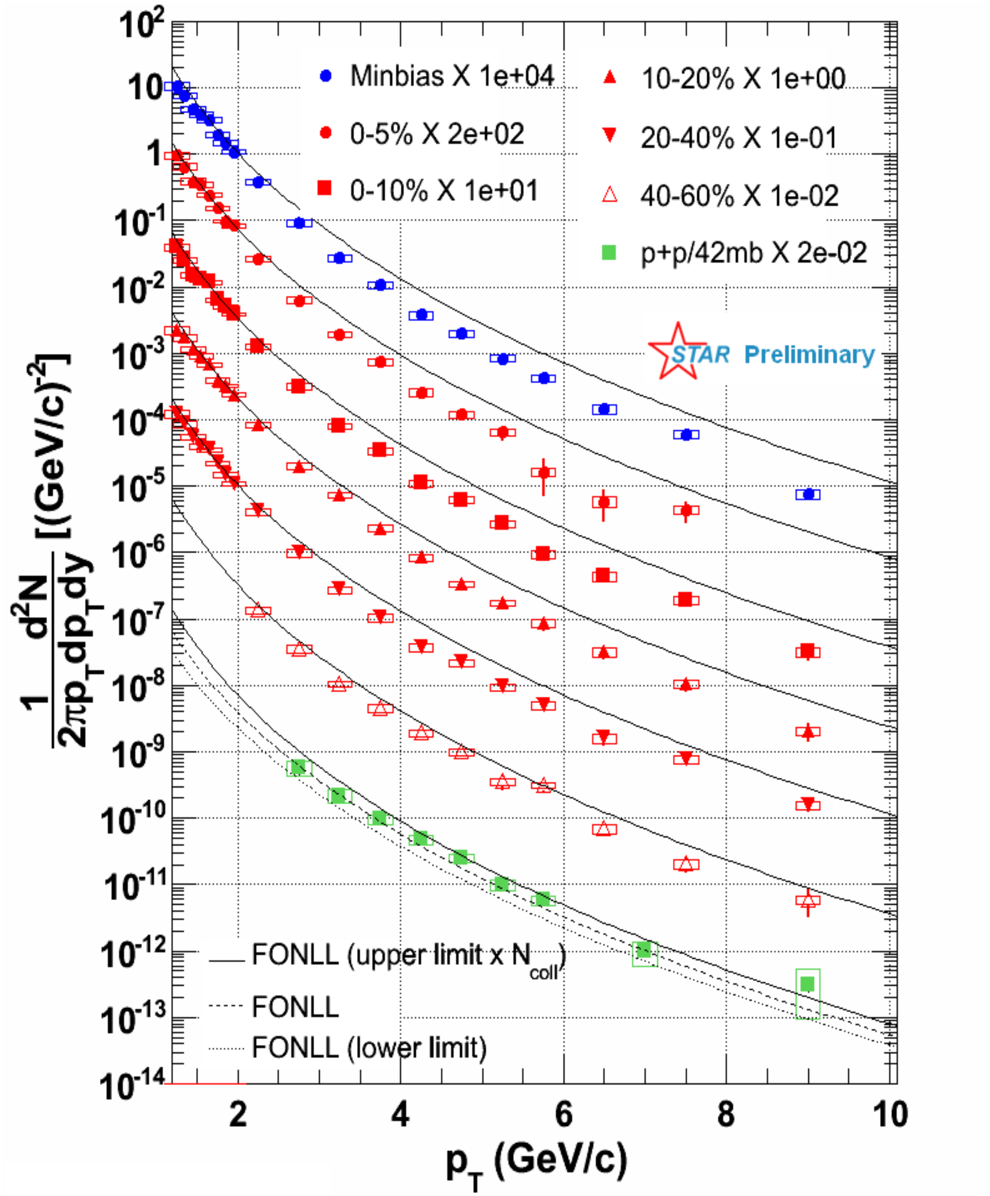
Enhancement at intermediate p_T:

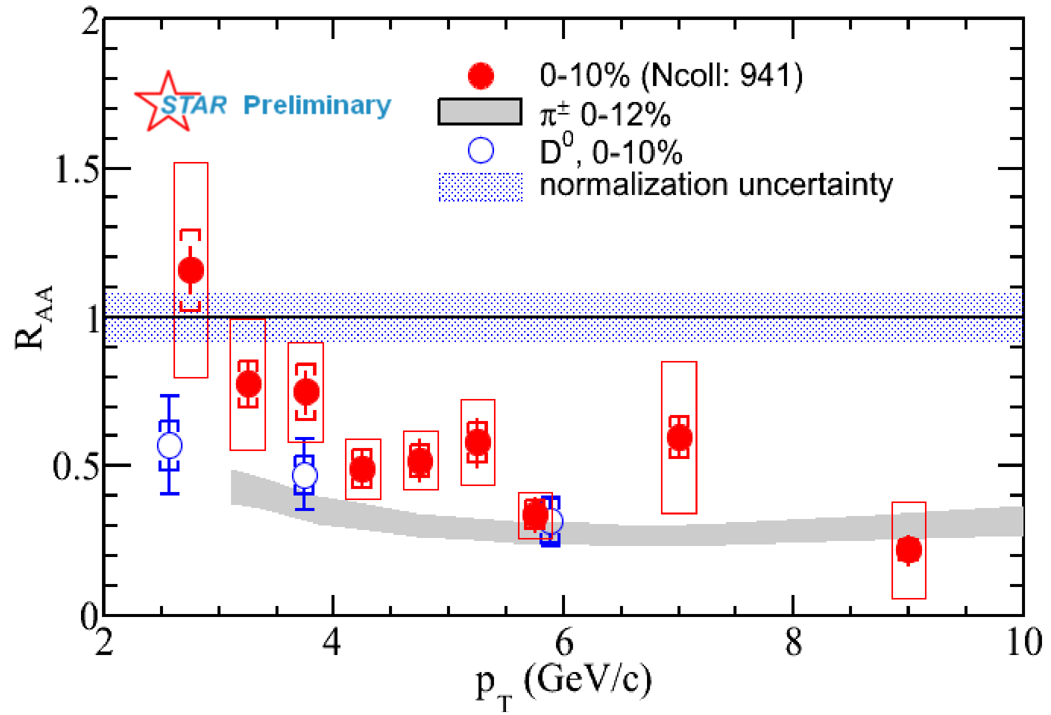
→ Radial flow (?)

→ Cronin enhancement + suppression at high p_T (?)

→ high quality d+Au data required

Non-photonic electron spectra in Au+Au 200 GeV





New high-quality data

Strong suppression at high p_T in central collisions

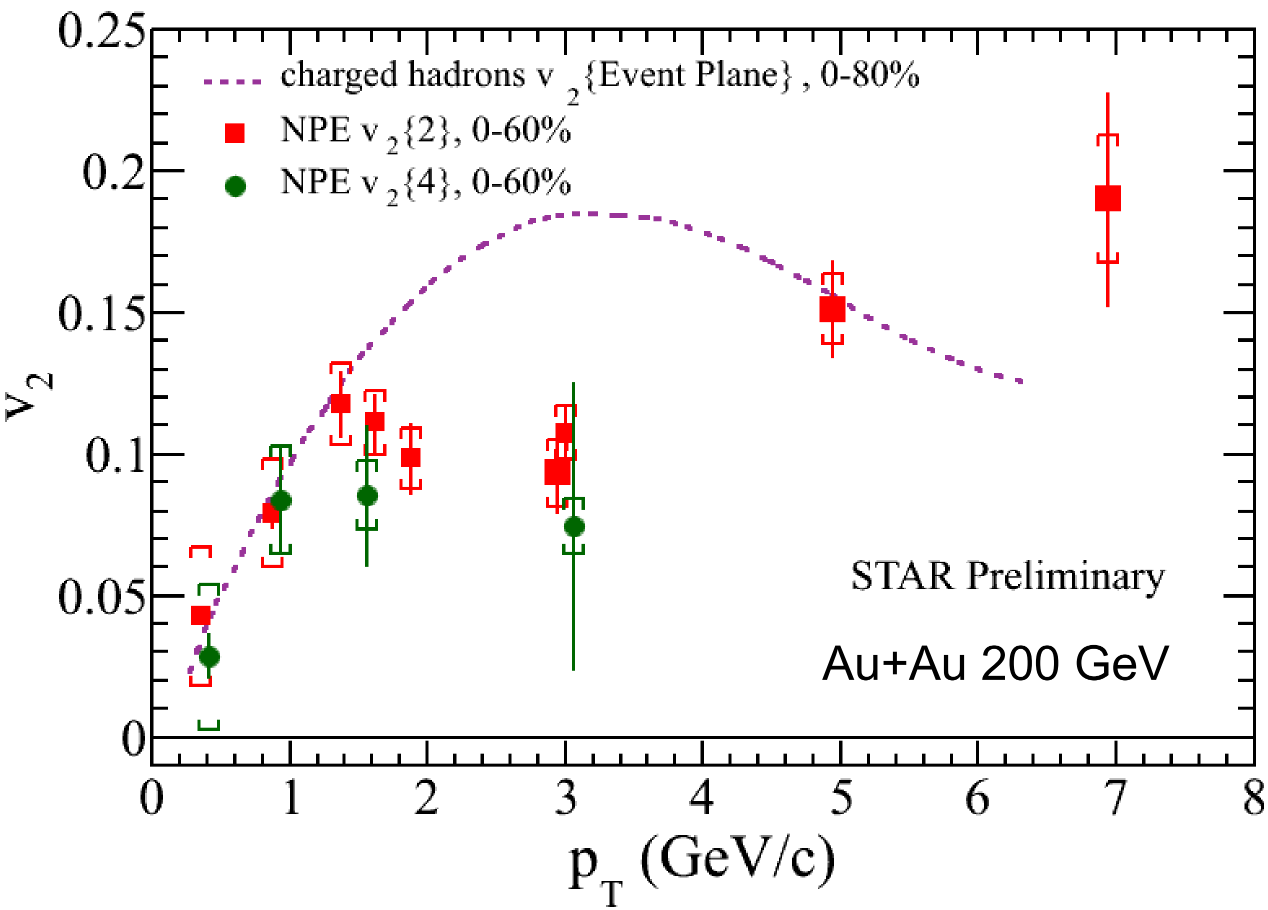
D^0 and NPE suppression are similar

NPE elliptic flow

- $v_2\{2\}$ and $v_2\{4\}$ – upper and lower limit on elliptic flow:

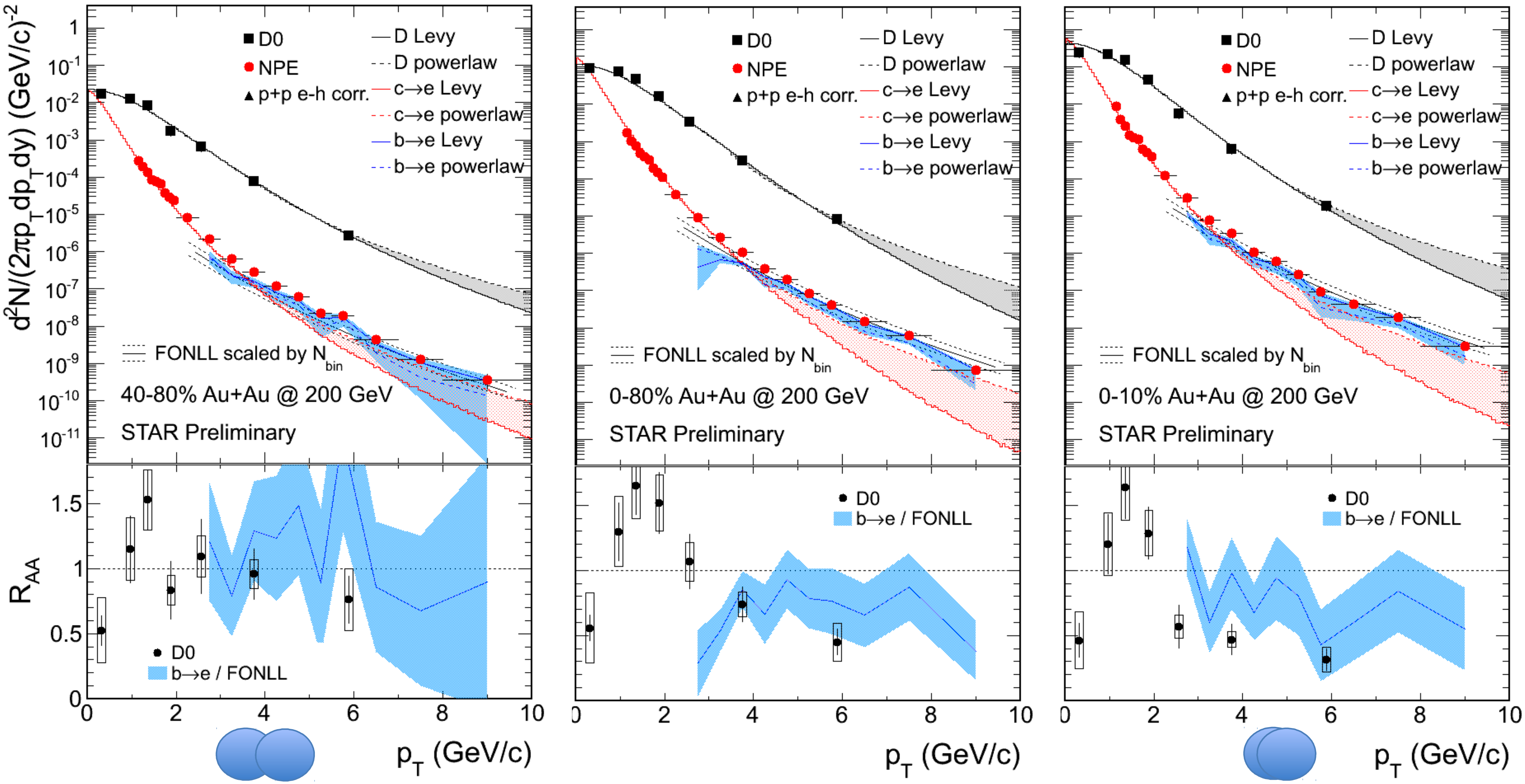
$$v_2\{2\}^2 = \langle v \rangle^2 + \sigma^2 + \delta$$
$$v_2\{4\}^2 \approx \langle v \rangle^2 - \sigma^2$$

Phys.Lett. B659, 537 (2008)



- Finite v_2 at low and intermediate p_T
- Increase of v_2 at high p_T likely due to jet-like correlation and/or path length dependance

Bottom suppression



Peripheral → consistent with no suppression.

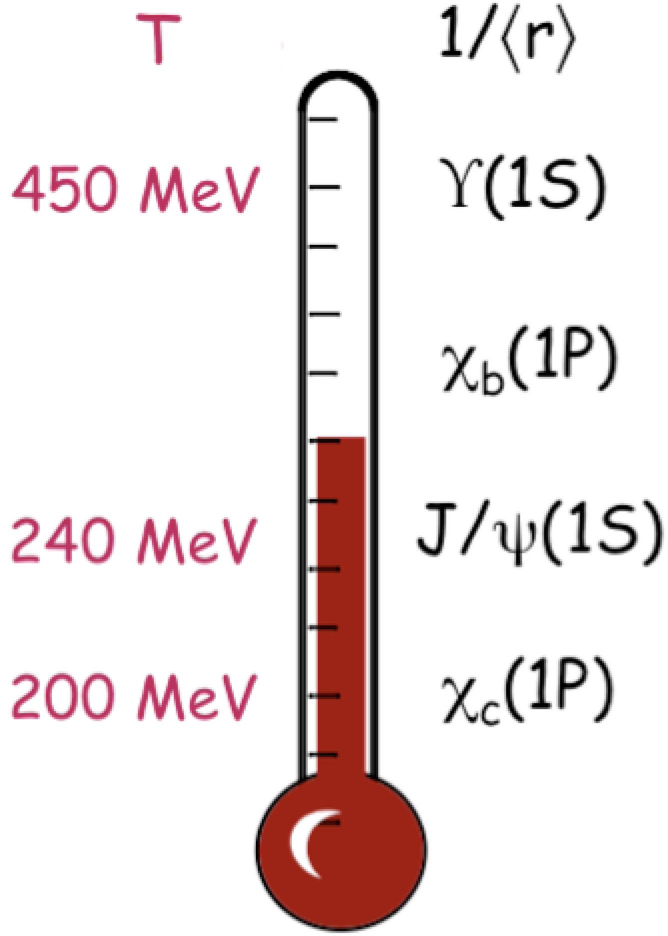
Min-bias and central → a hint of less suppression than for D^0

Quarkonia

D. Kikoła, 26 July, 14:00
Session: Quarkonia/Heavy Flavour

Quarkonia sequential melting

→ Temperature of QGP



A. Mocsy Eur.Phys.J.C61: 705-710,2009

Complications

Cold nuclear matter effects

- shadowing
- nuclear absorption

...

Effects in QGP

- secondary production via recombination
- dissociation by gluons, energy loss

…

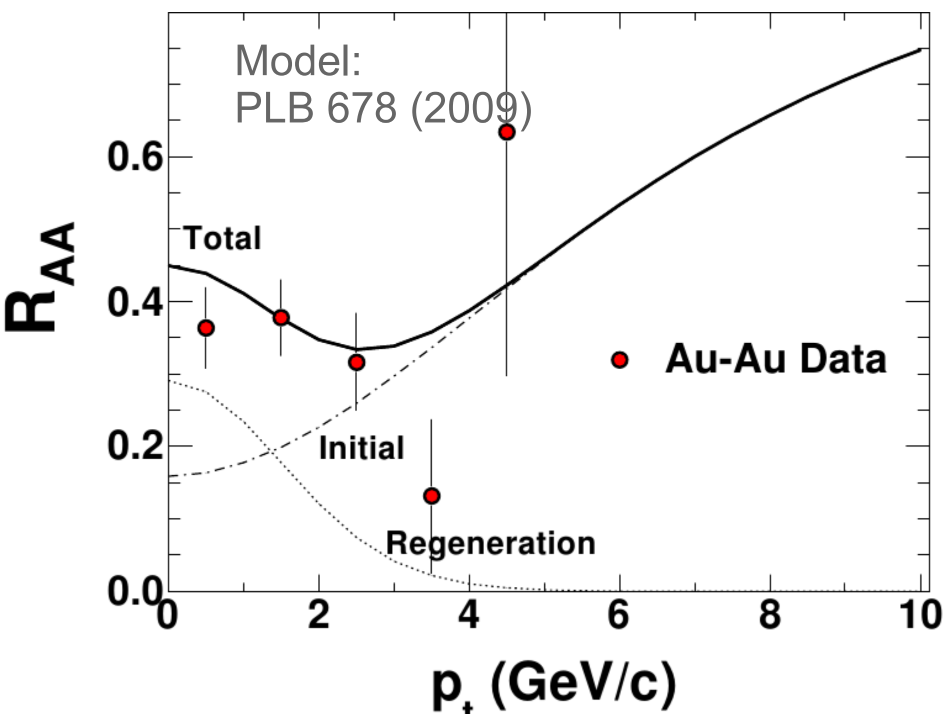
How to disentangle

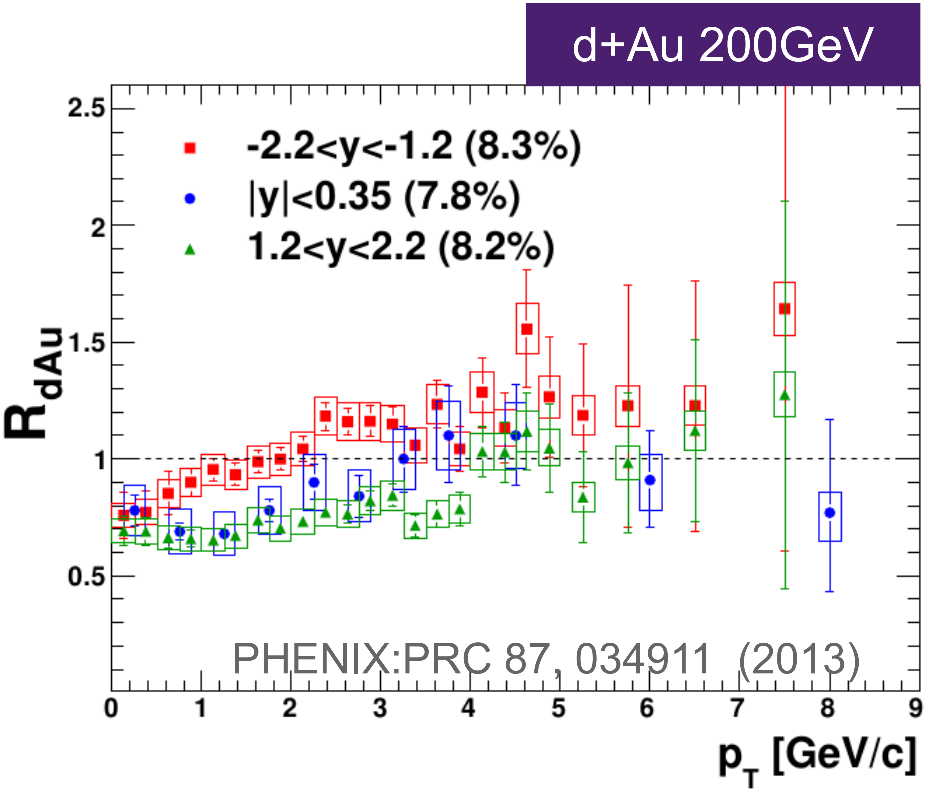
Color screening vs recombination vs CNM ?

high-p_T J/ψ

→ small recombination

→ small CNM effects





How to disentangle

Color screening vs recombination vs CNM ?

high-p_T J/ψ

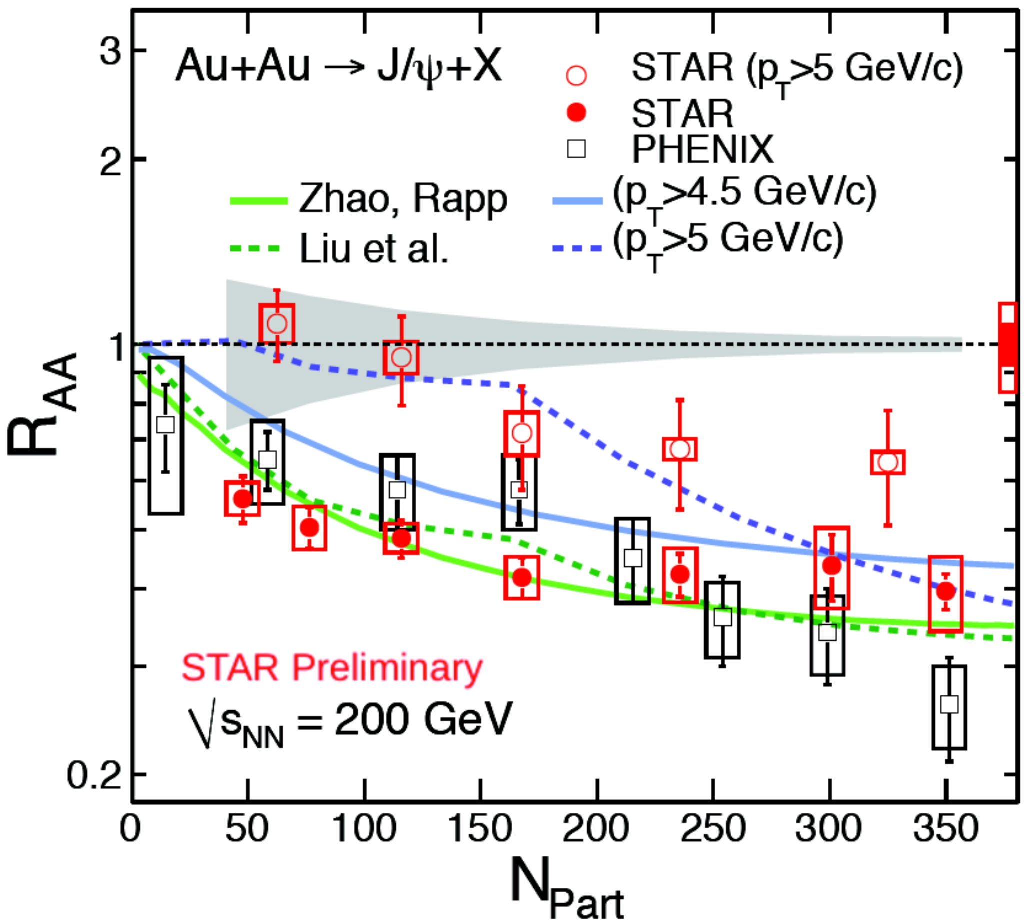
→ small recombination and CNM effects

Υ

→ negligible co-mover abs. and recombination

→ less affected by nuclear absorption and shadowing compared to J/ψ at RHIC

High-p_T J/ψ R_{AA} vs centrality



High-p_T J/ψ: Phys. Lett. B 722 (2013) 55

High-p_T J/ψ **suppressed** in central collisions

→ **clearly QGP effect**

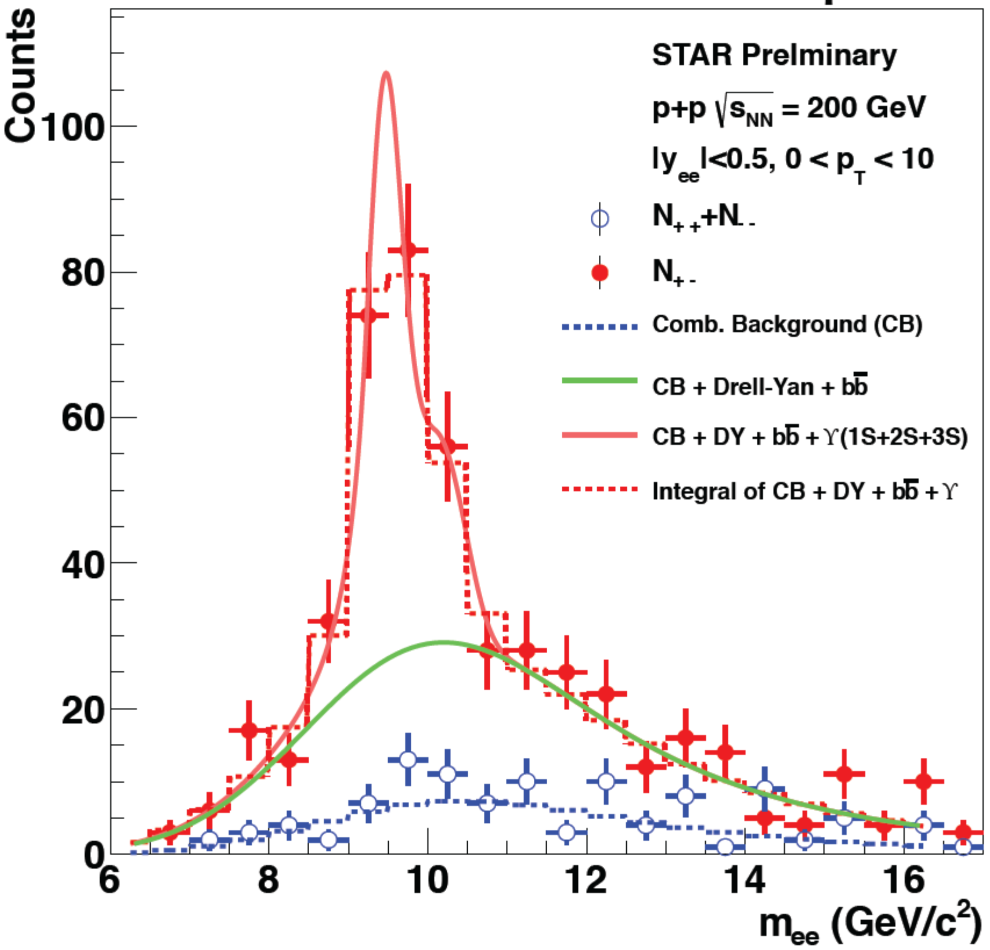
Suppression systematically **smaller at high p_T** in all centralities

Low-p_T data agrees with models including color screening and regeneration effects

Υ production in p+p 200 GeV

New, high-statistics p+p baseline for R_{AA}

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

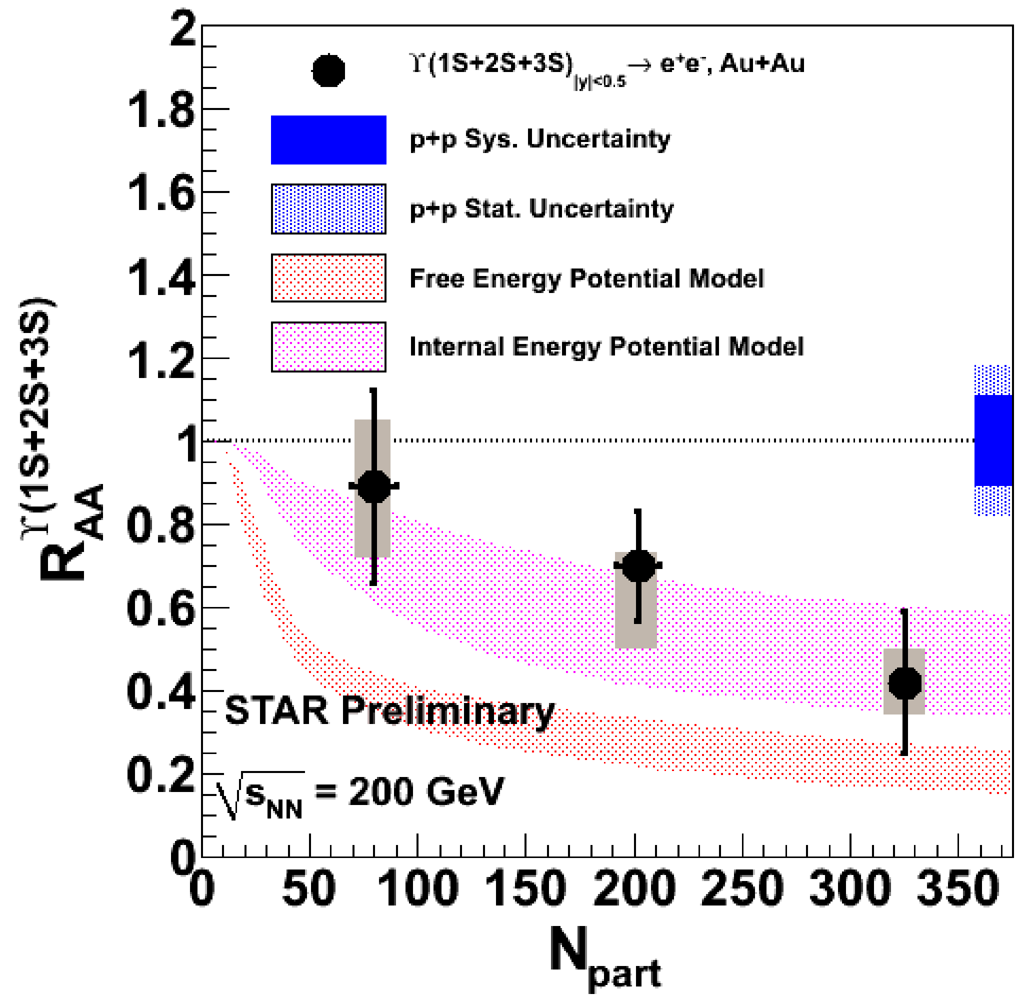


Υ(1S+2S+3S) suppression in Au+Au 200 GeV

New, high-statistics p+p baseline

Suppression getting **stronger** with **centrality**

Consistent with model assuming **complete 2S and 3S suppression**

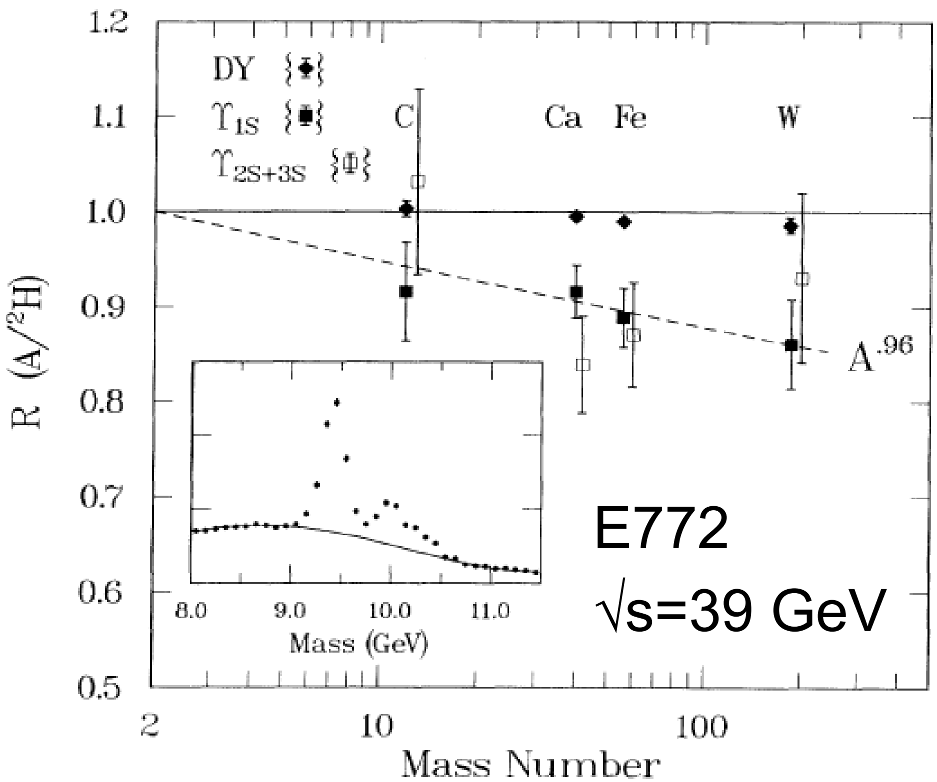


Model: Strickland et al., PRL 107, 132301 (2011).

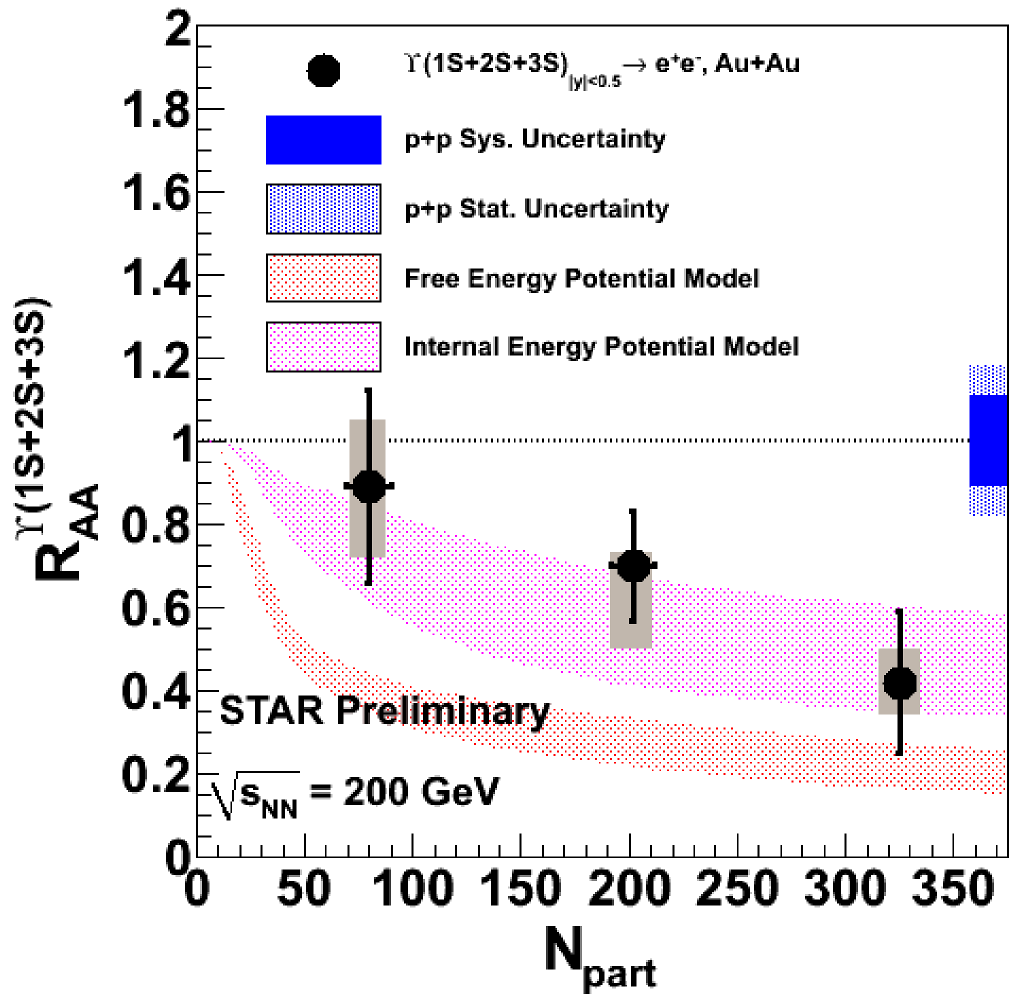
ϒ(1S+2S+3S) in Au+Au 200 GeV

Caution: cold nuclear matter effects could be significant

$\sigma_{pA} = A^{\alpha}\sigma_{pp}$



PRL 66, 2285, 1991



Model: Strickland et al., PRL 107, 132301 (2011).

Heavy Flavor production vs energy

J/ψ suppression vs energy

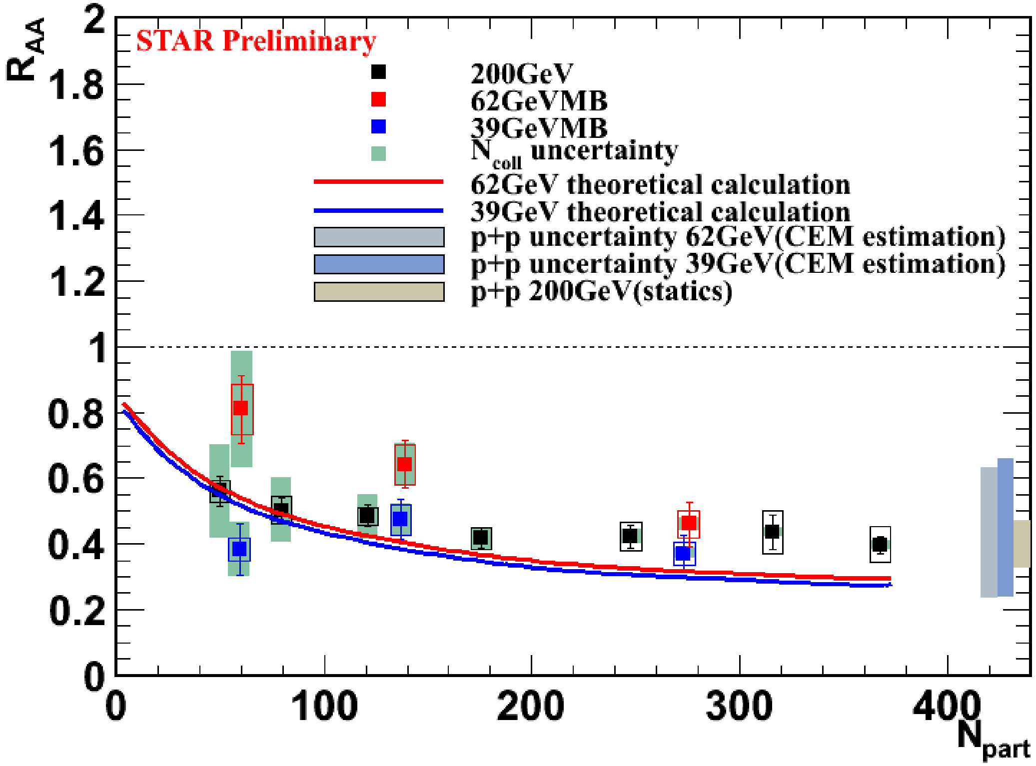
different temperature and recombination probability → test for models

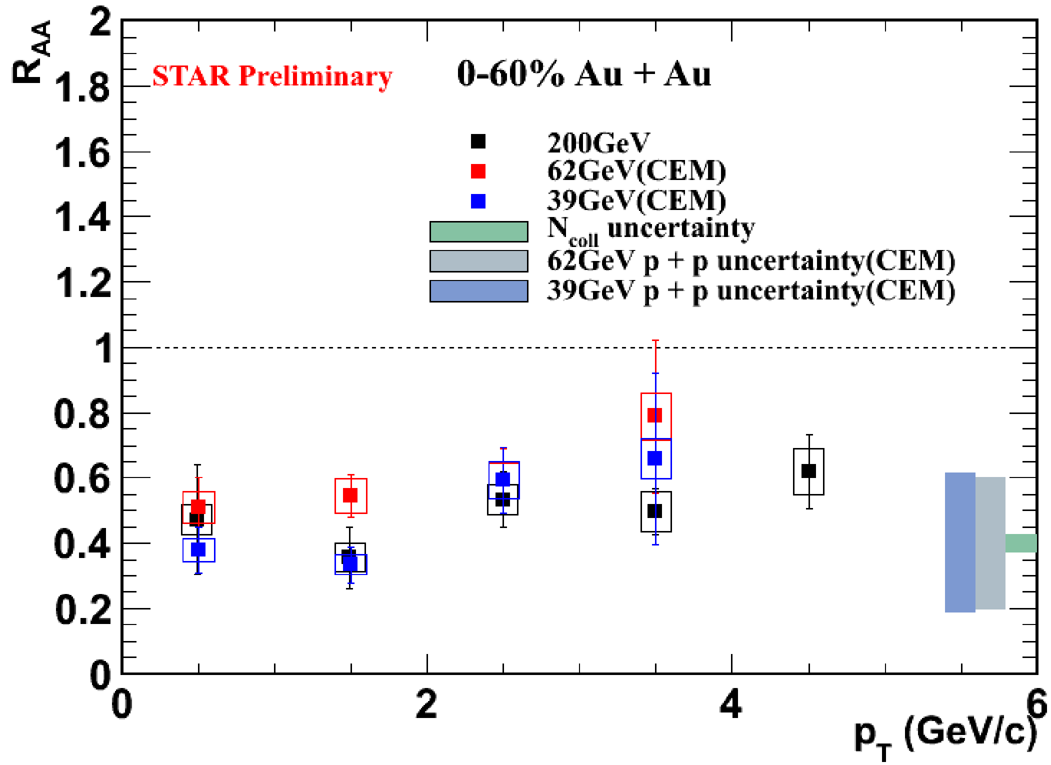
Open heavy flavor vs energy

quenching at high-p_T ?

J/ψ suppression vs centrality and p_T

Model: Zhao, Rapp Phys Rev C.82.064905



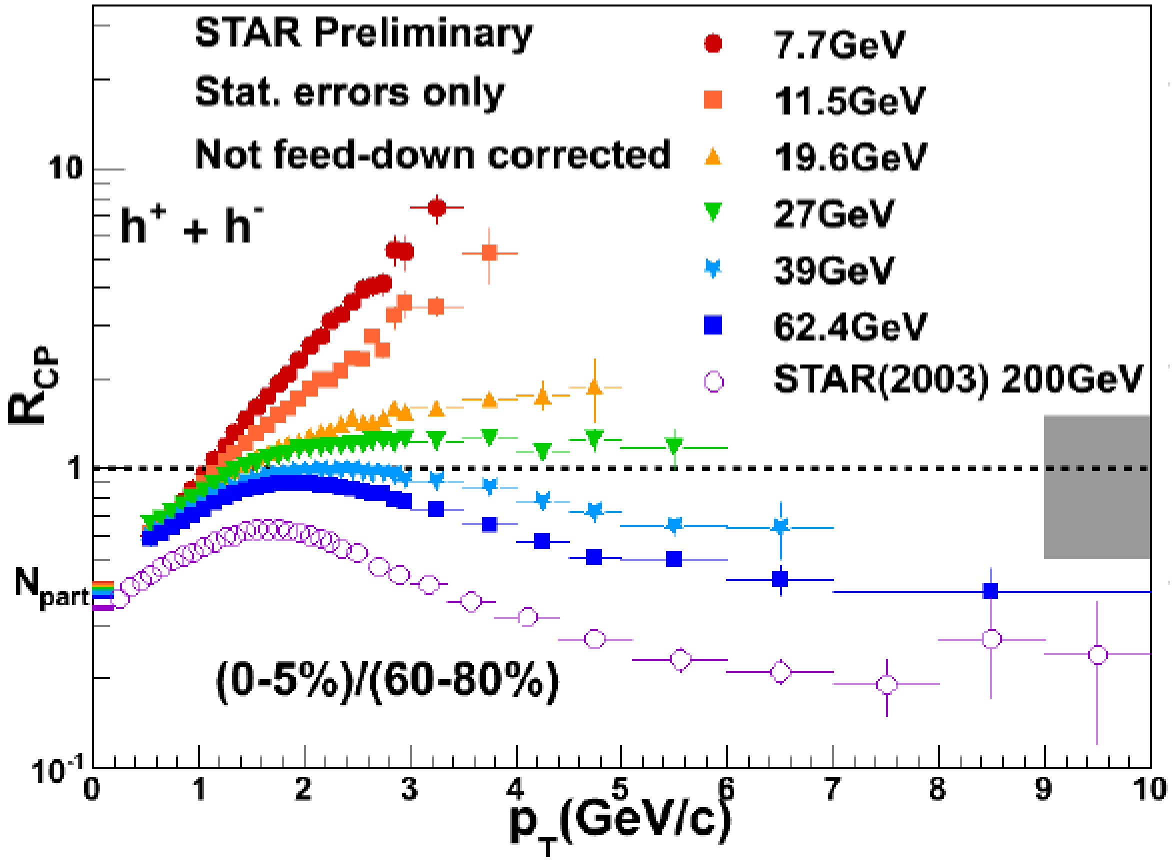


Significant suppression at 39 and 62 GeV, similar as at 200 GeV

Model with two main components (direct suppression and regeneration) consistent with data.

39 and 62 GeV p+p reference: Color Evaporation Model (CEM)

Jet quenching at RHIC

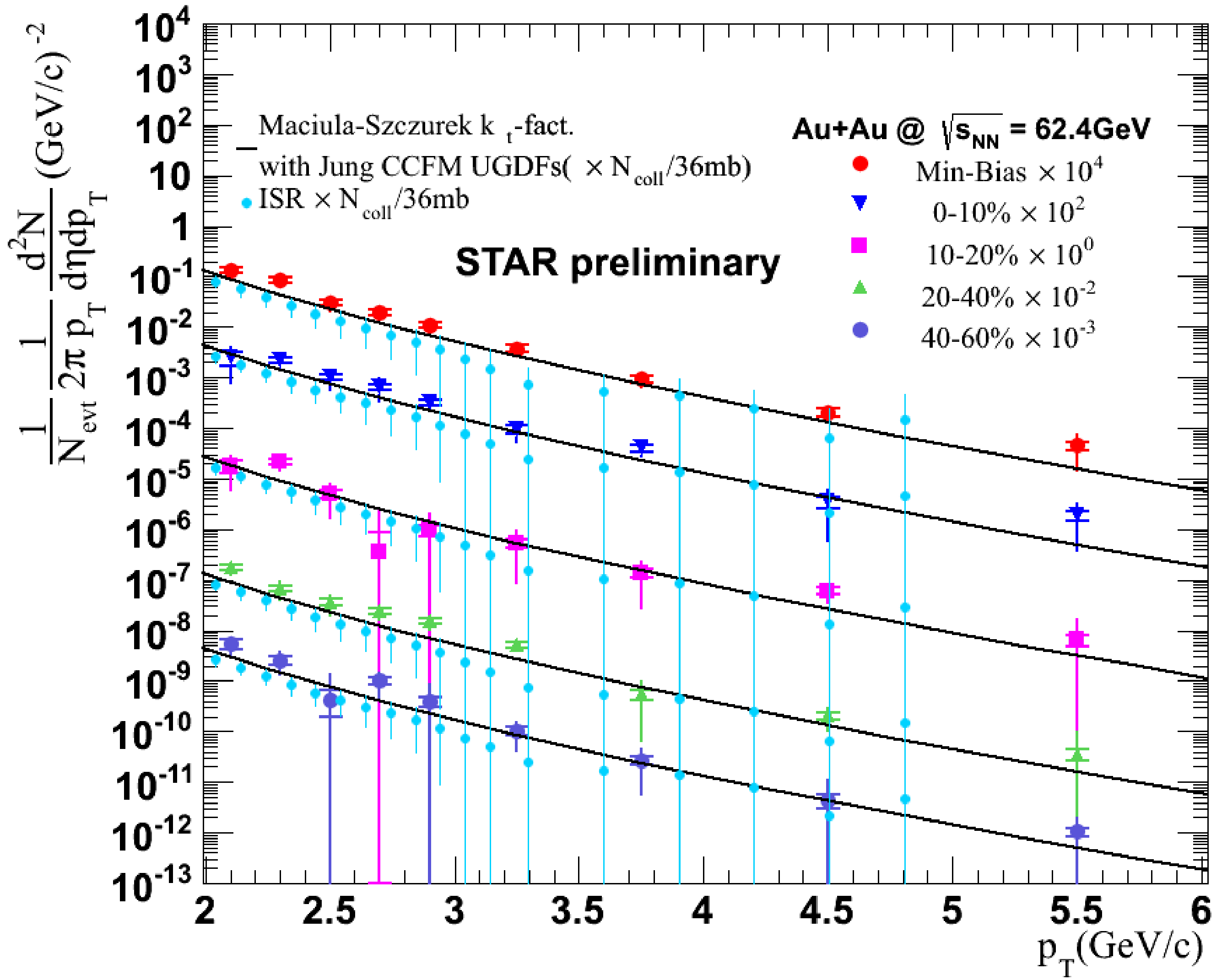


Light hadrons suppressed at high-p_T at 39 - 200 GeV

NPE spectra in Au+Au at $\sqrt{s_{NN}}$ = 62 GeV

No NPE suppression compared to pQCD calculations for $p_T < 5.5$ GeV

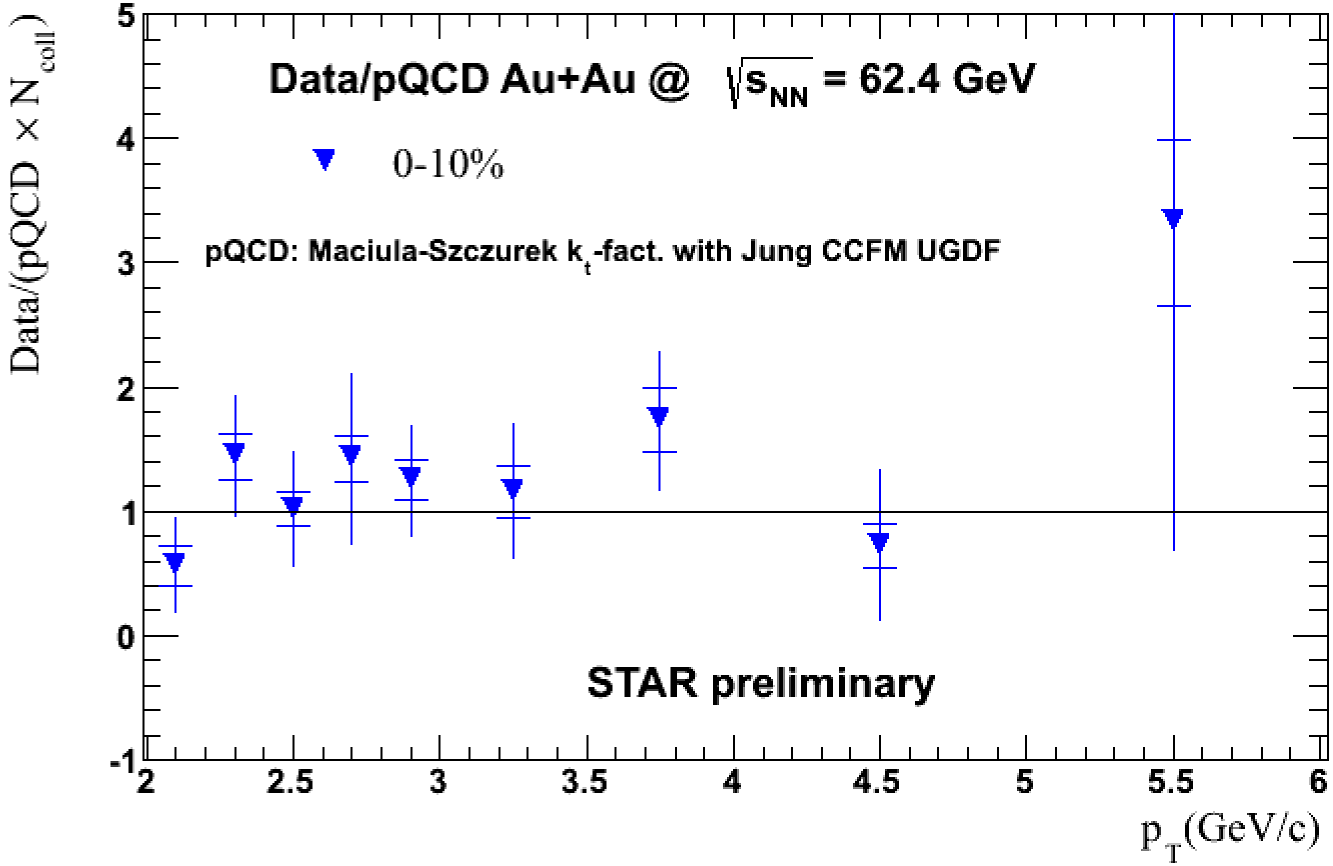
J/ψ contribution not subtracted



ISR: Il Nuovo Cimento (1981), 65A, N4, 421-456
k_T-factorization: Phys. Rev. D 79, 034009 (2009)
and private communication with R. Maciula

NPE R_{AA} at $\sqrt{s_{NN}}$ = 62 GeV

Central: 0-10%



No NPE suppression compared to pQCD calculations for p_T < 5.5 GeV

QCD medium at RHIC:

Au+Au 200 GeV

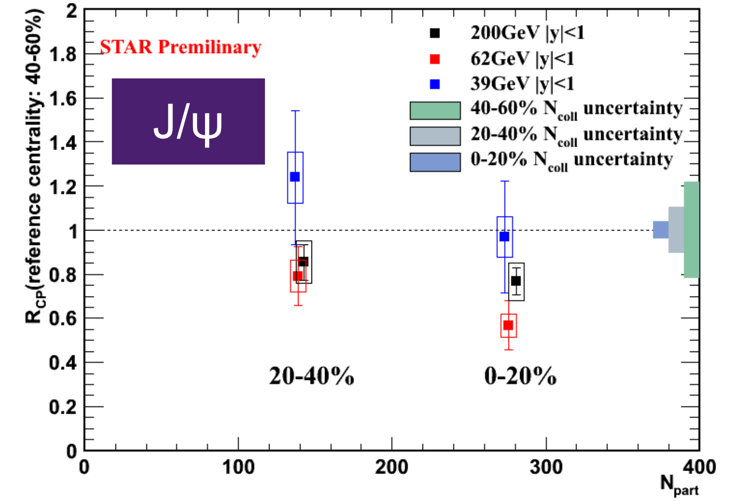
- Hot (J/ψ, Upsilon suppressed)
- Dense (D^0, NPE quenching)

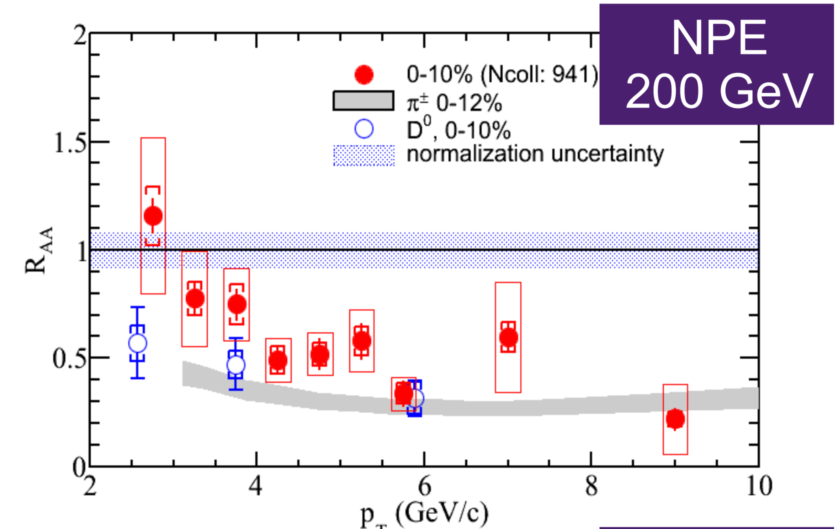
Au+Au 62.4 GeV

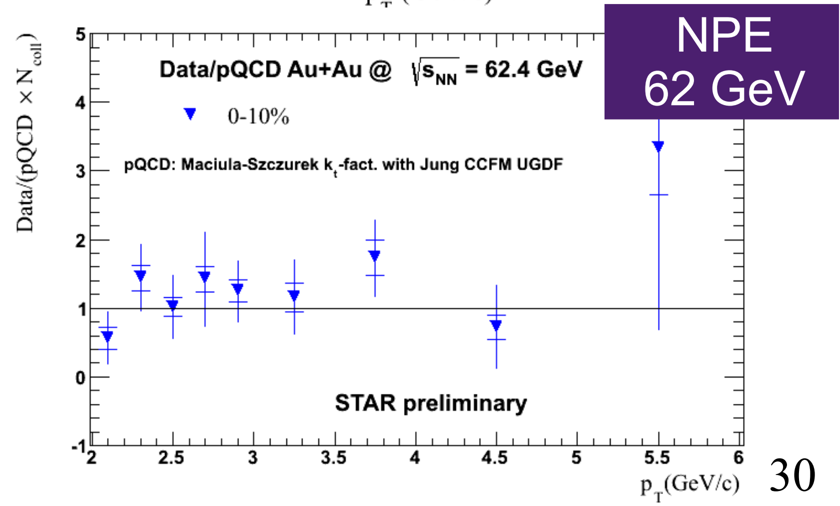
- Hot (J/ψ suppressed)
- Not so dense

→ no NPE suppression compared to pQCD for p_T < 5.5 GeV

→ jet quenching for light hadrons

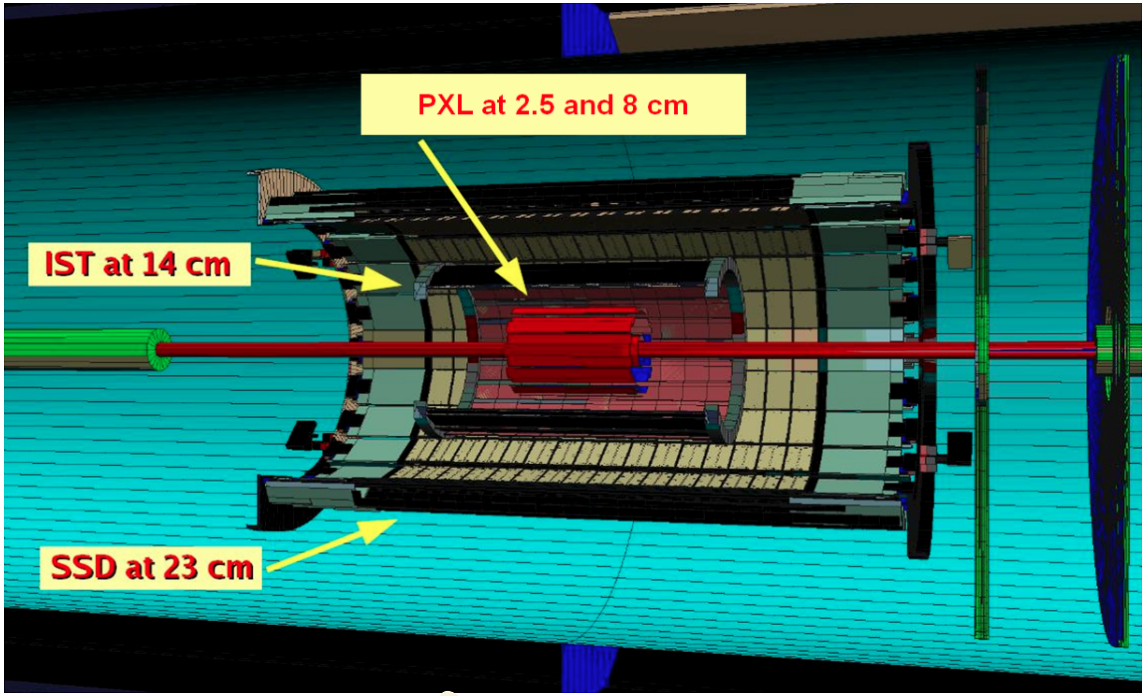


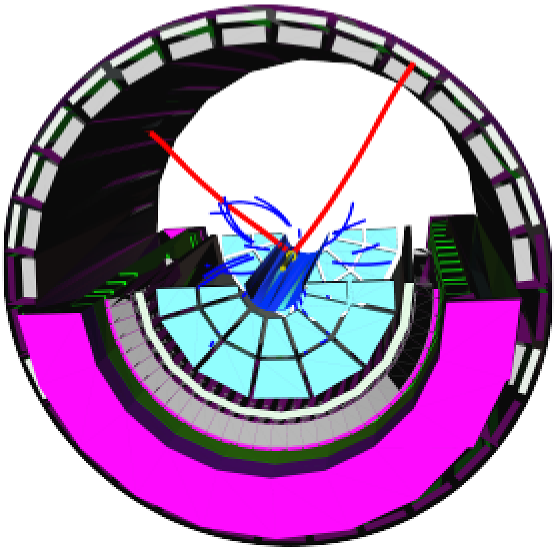




Heavy Flavor Tracker

Muon Telescope Detector





J/ψ event in p+p 500 GeV

2013: Engineering HFT run (PIXEL prototype with 3 sectors instrumented) and first data taking in STAR,

63% of MTD was installed and took data.

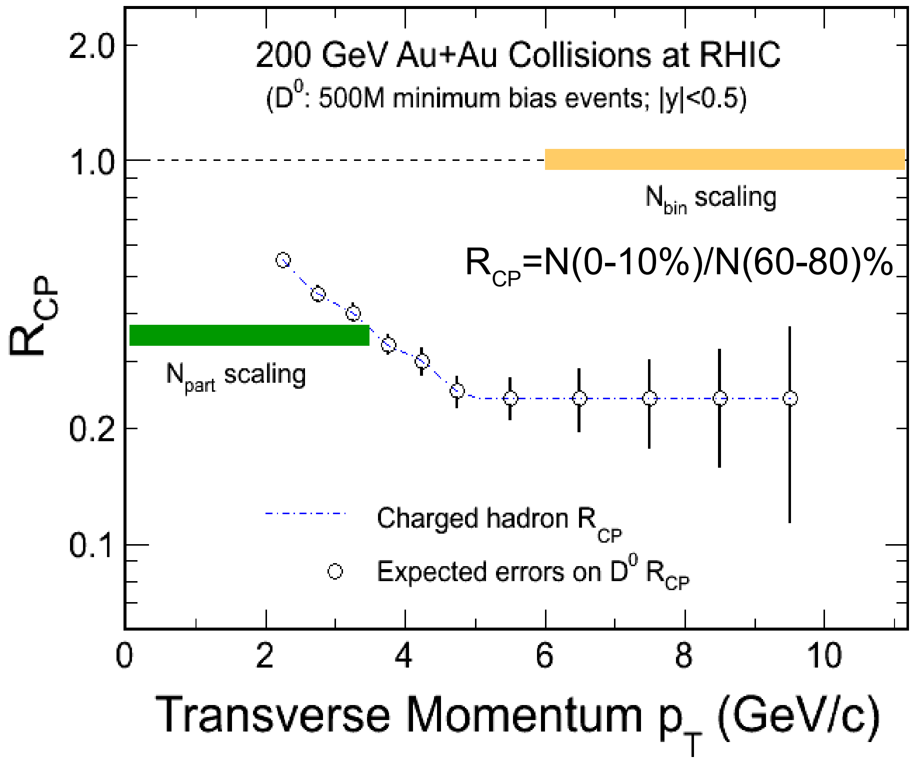
2014: The full HFT assembly (PIXEL, IST and SSD) and MTD will be available for RHIC Run-14 (a long Au-Au 200 GeV run)

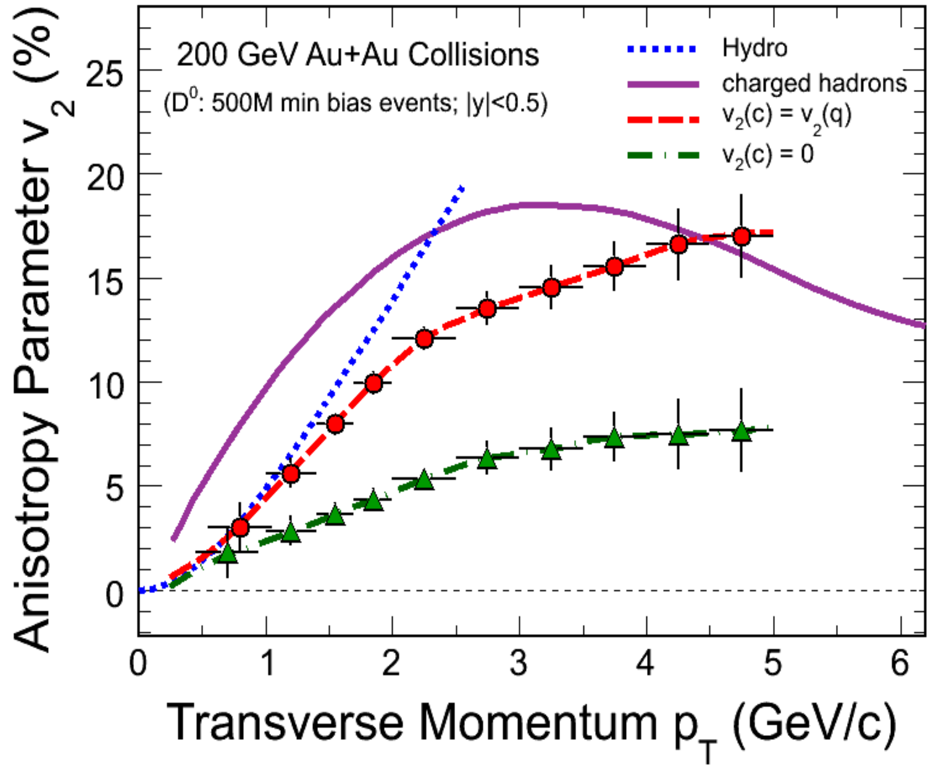
Summary

- **Strong heavy flavor (D^0, NPE) suppression** at 200 GeV
- NPE **not suppressed** compared to pQCD calculations for p_T < 5.5 GeV at **62 GeV**
- Significant J/ψ suppression at **high-p_T** → clear signal of QGP effects
- J/ψ suppression at lower energies (39 and 62 GeV) **similar as at 200 GeV**
- ϒ(1S+2S+3S) in Au+Au 200 GeV consistent with complete 2S and 3S suppression

Backup

Charm v_2 and R_{AA} – projections for 2014





Assuming D^0 v_2 distribution from quark coalescence.

Precision charm v_2 and R_{AA} measurements:

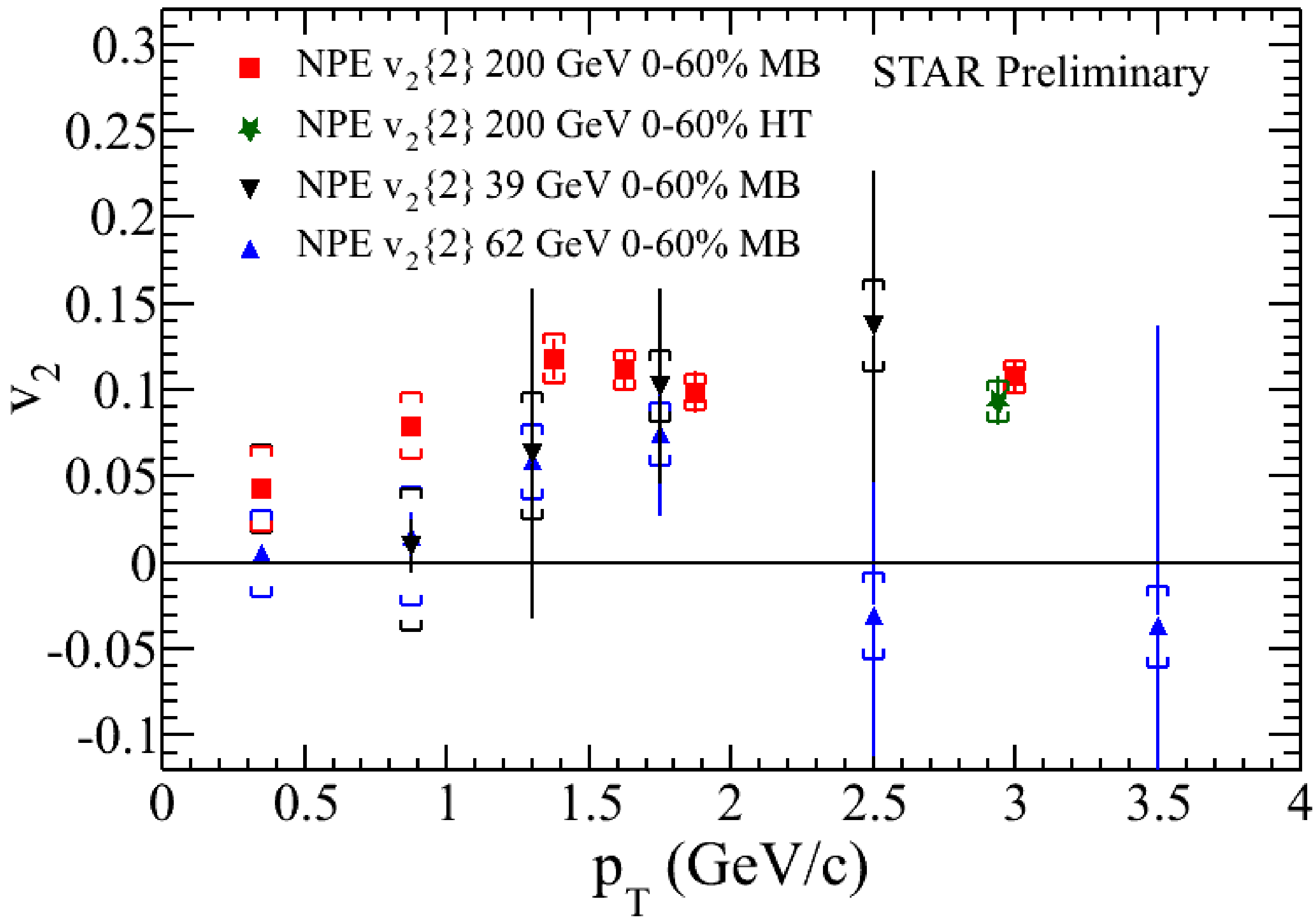
→ energy loss mechanism

→ charm interaction with the QCD matter

→ medium thermalization degree

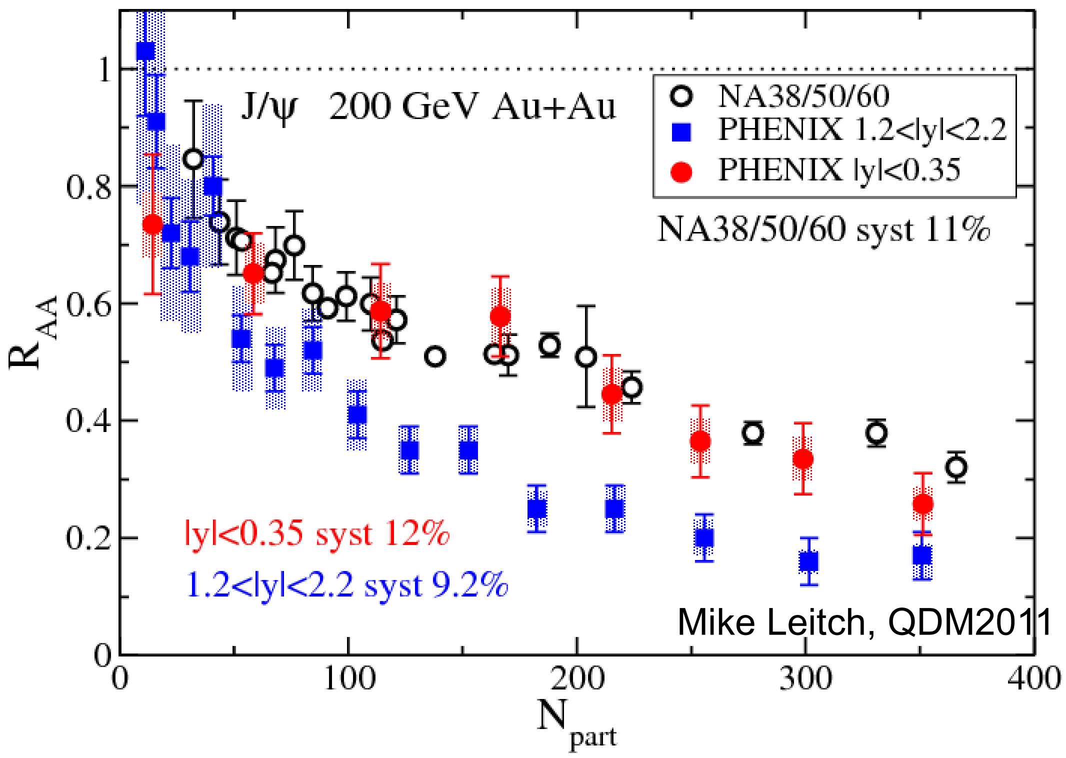
→ transport coefficients

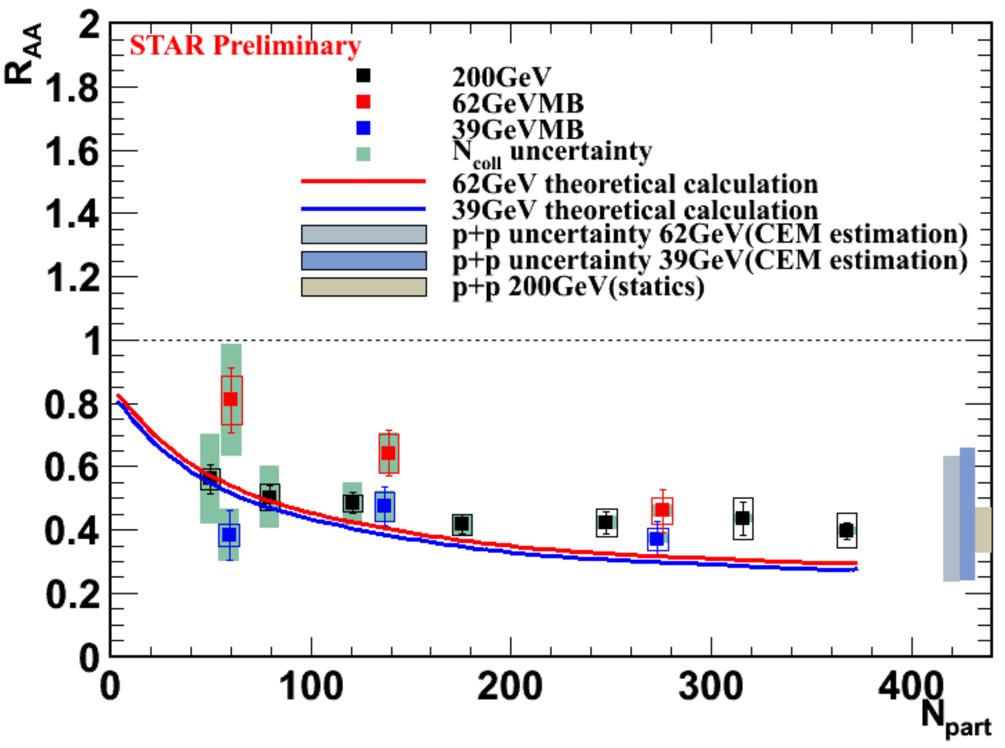
NPE v_2 62 and 39 GeV



A hint that at **low p_T** (p_T<1 GeV) v_2 at 39 and 62 GeV is lower than at 200 GeV (although systemic errors are sizable)

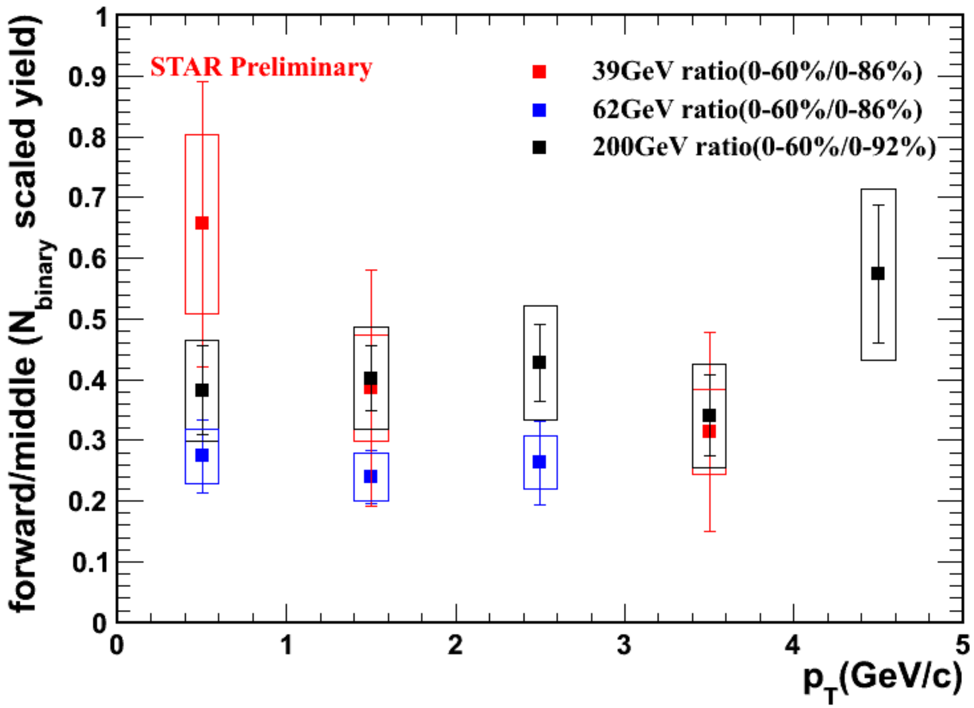
J/psi suppression: RHIC vs SPS

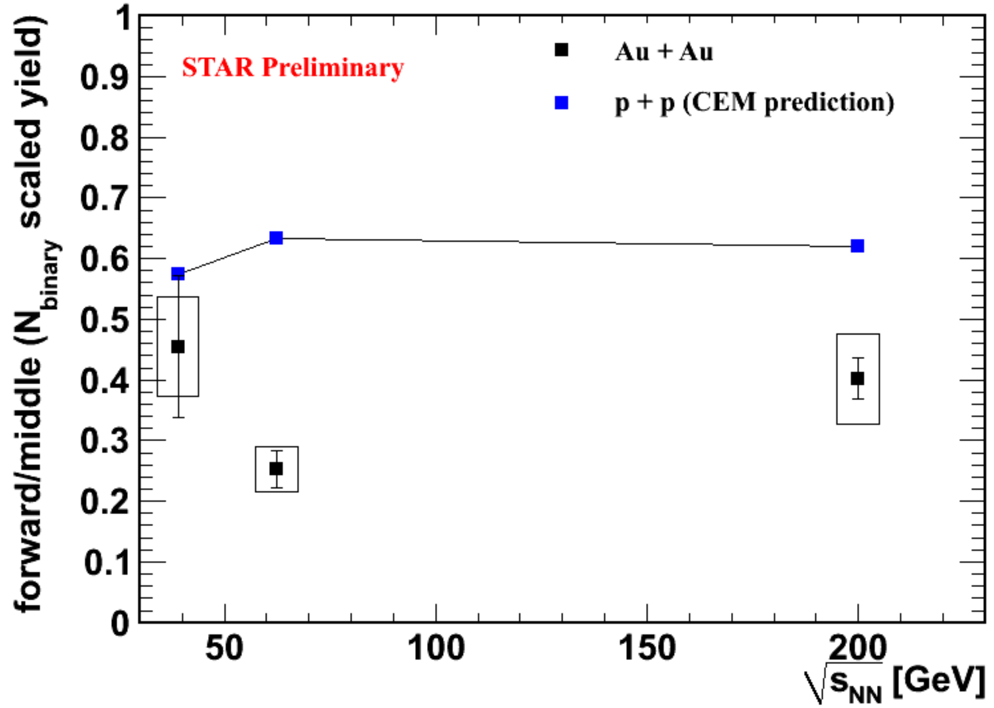




Similar J/psi suppression at SPS (17.3 GeV)
and RHIC (200, 62, 39 GeV)

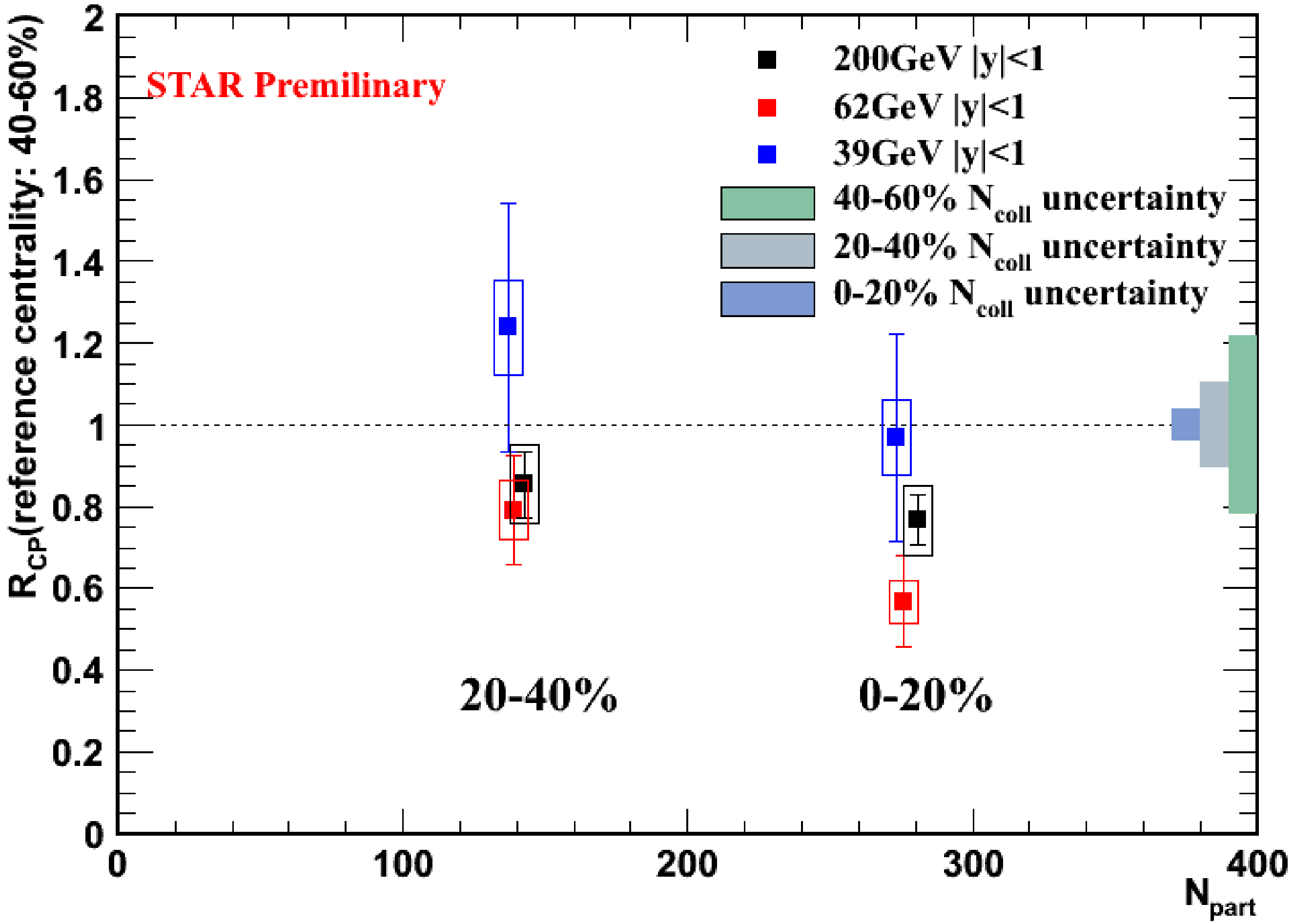
J/psi production: forward/midrapidity ratio





No significant energy and p_T dependence

J/ψ suppression vs energy (R_{cp})

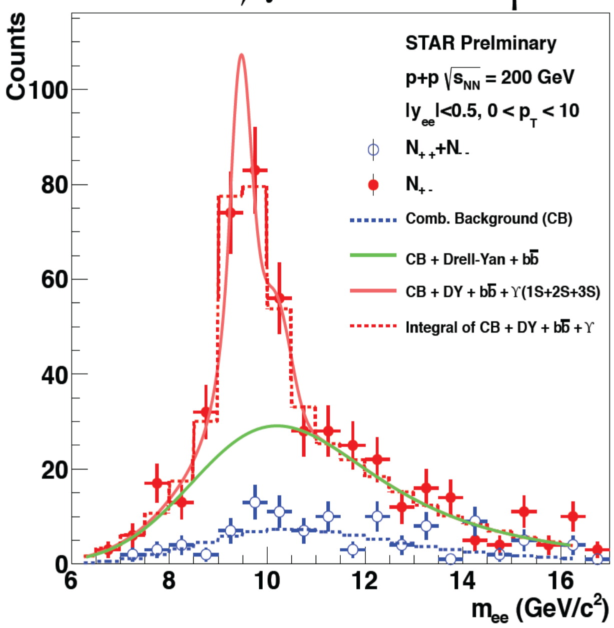


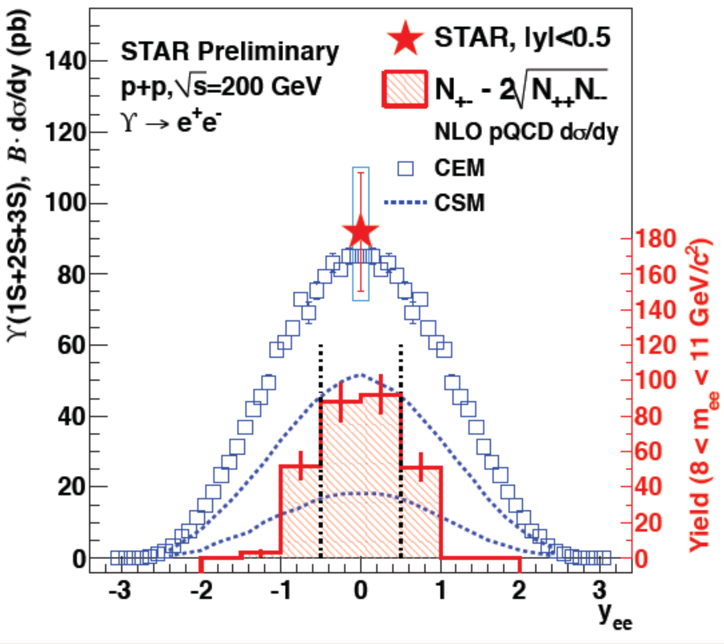
Significant suppression in central collisions at 62 GeV, similar as at 200 GeV

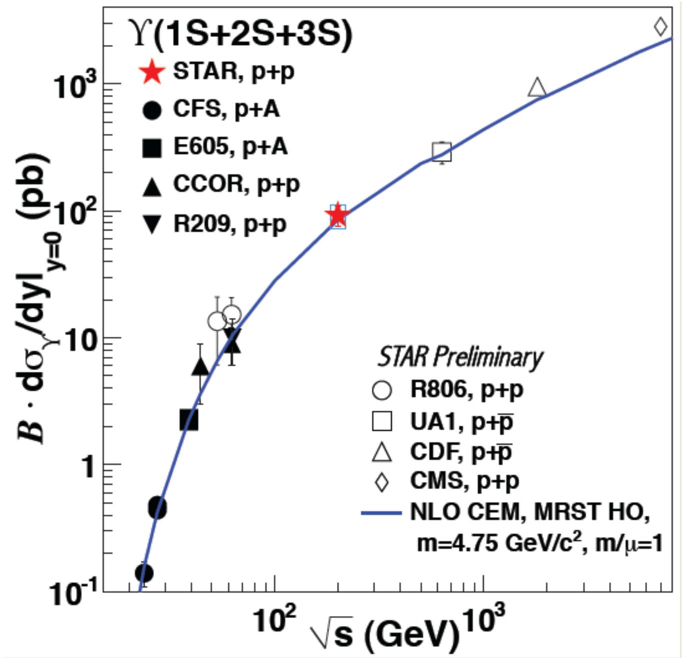
No significant energy dependence at 39-200 GeV (within errors)

Upsilon p+p reference at 200 GeV

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







Cross section: consistent with pQCD and world data trend

$\int L\,dt$ = 19.7 pb-1

Nϒ(total)= 145±26(stat.)

$$\sum_{n=1}^{3} \mathcal{B}(nS) \times \sigma(nS) = 91.8 \pm 16.6 \pm 19 \text{ pb}$$

High-p_T J/ψ in Au+Au 200 GeV

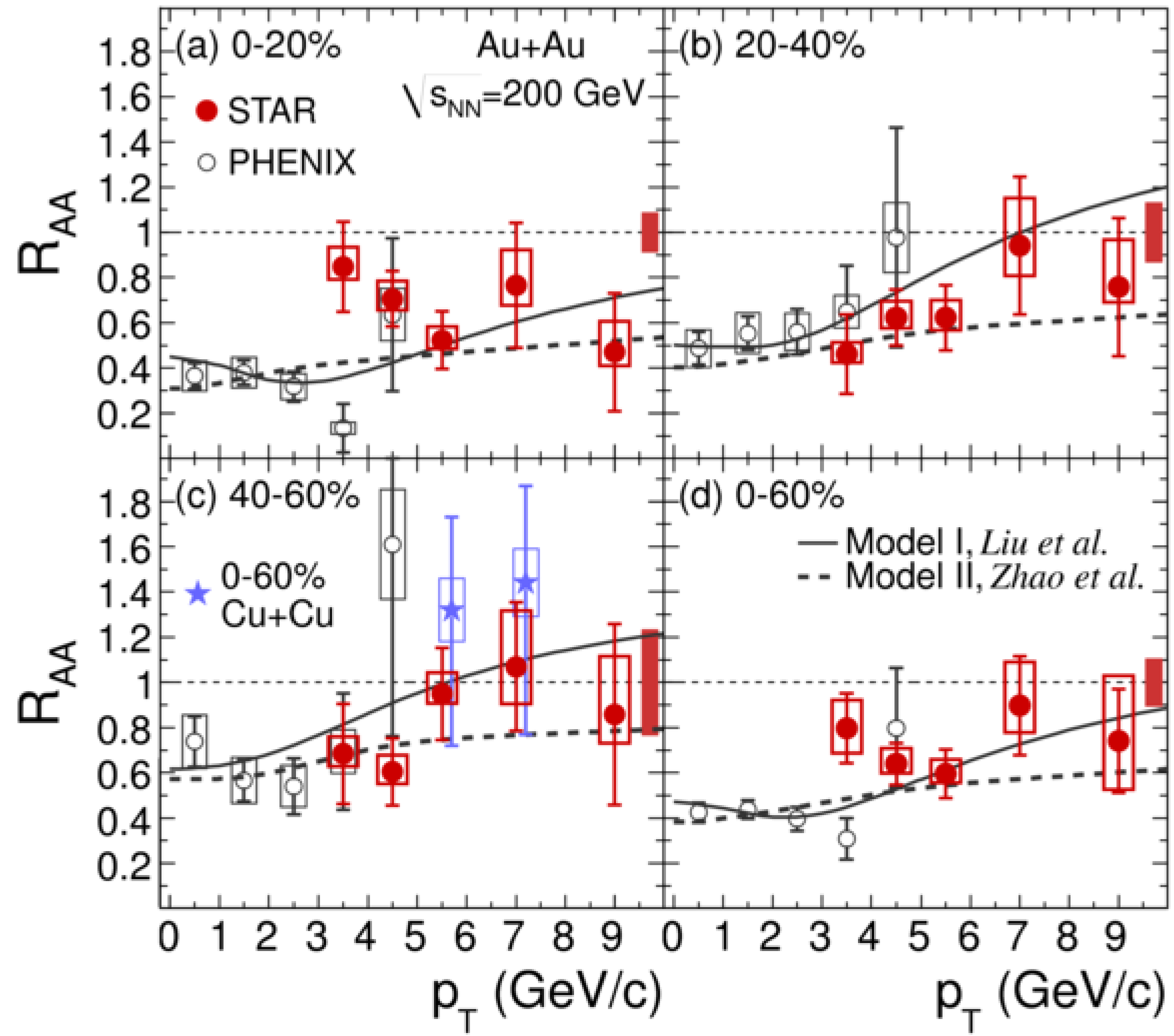
Phys. Lett. B 722 (2013) 55

Suppression decrease with p_T

R_{AA} consistent with unity at high p_T in peripheral collisions

Larger suppression in central than in peripheral collisions

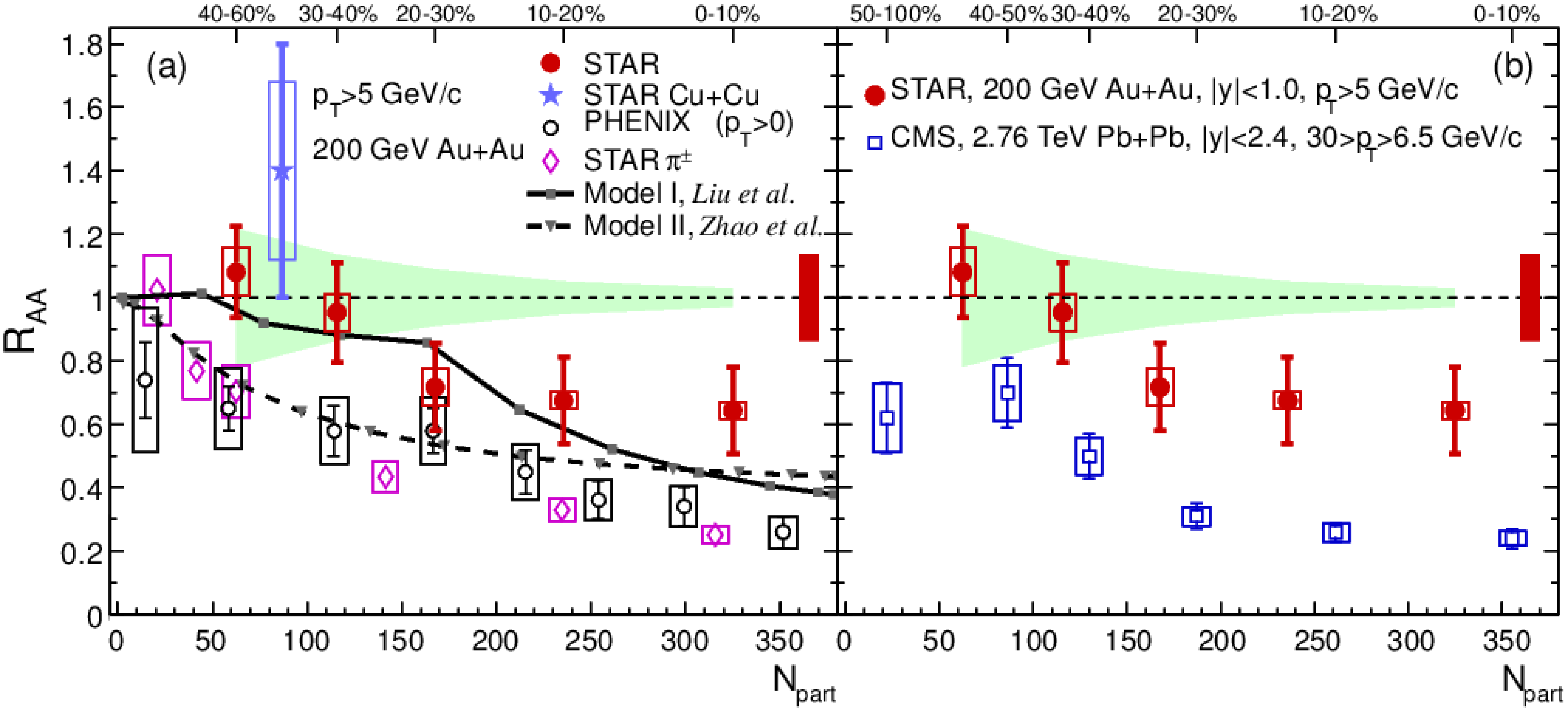
Suppression at high p_T (p_T >5 GeV) in central events



Yunpeng Liu, Zhen Qu, Nu Xu and Pengfei Zhuang, PLB 678:72 (2009) and private comminication

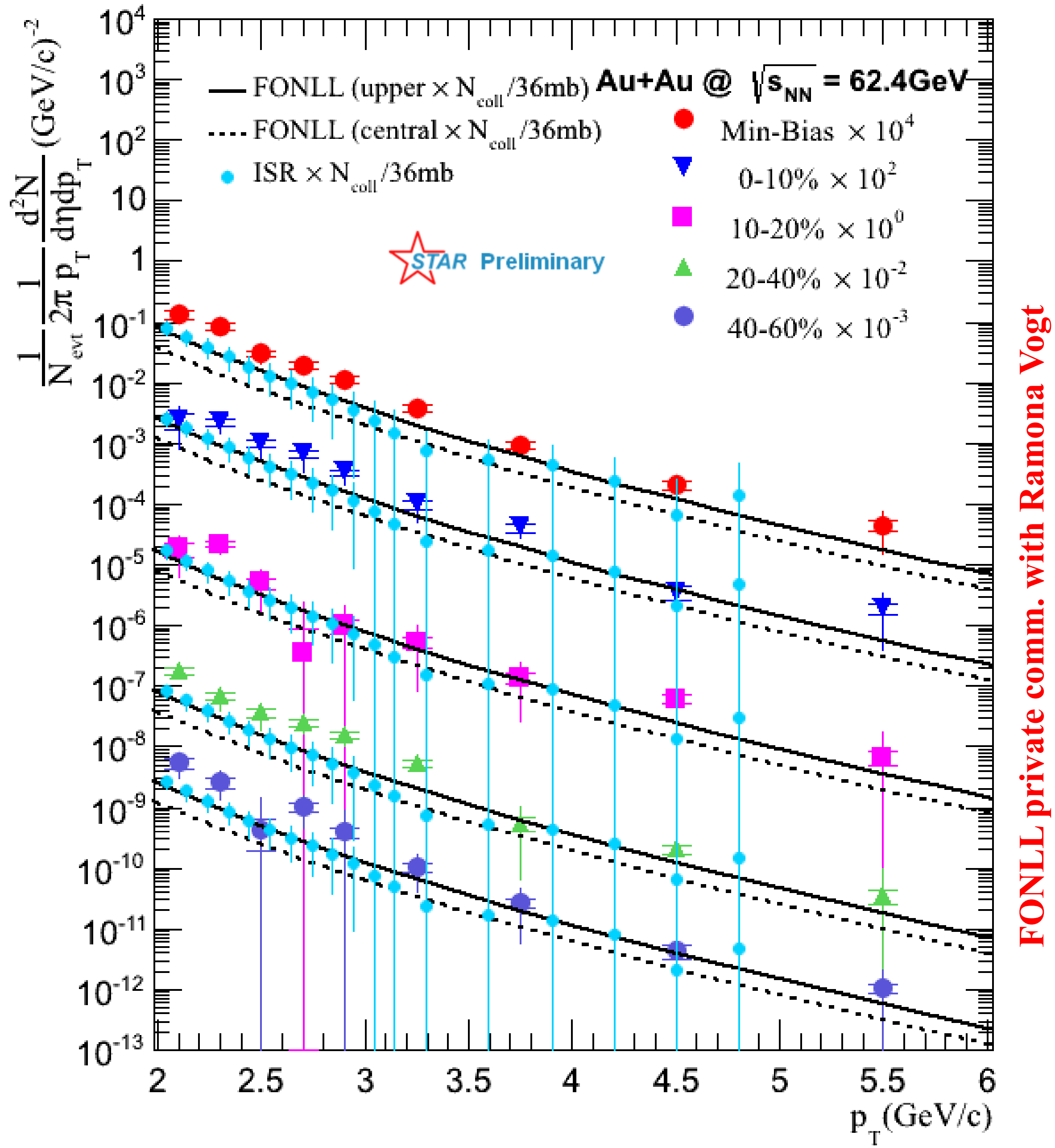
Xingbo Zhao and Ralf Rapp, PRC 82,064905(2010) and private communication

High-p_T J/ψ: RHIC vs LHC

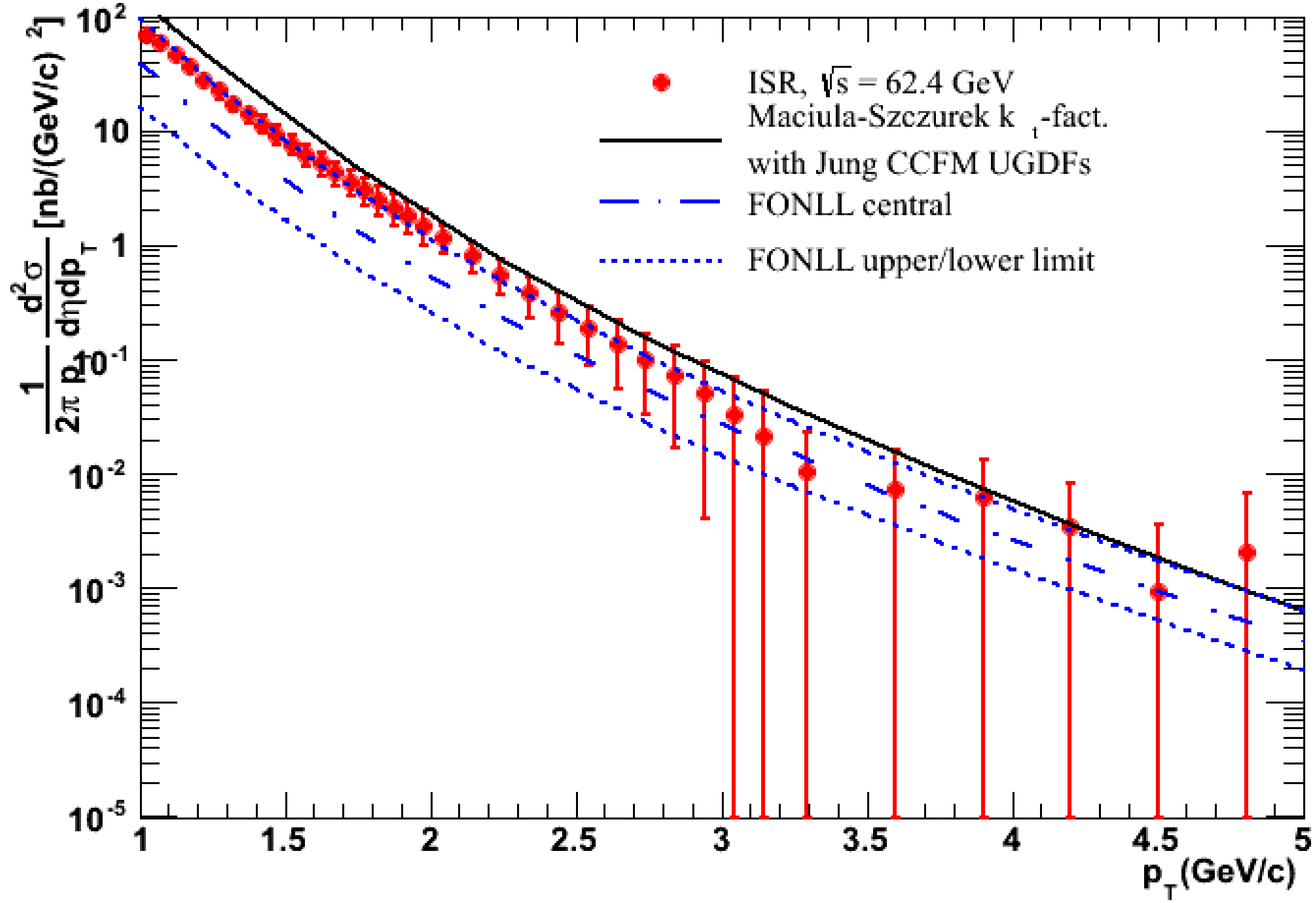


NPE spectra in Au+Au at $\sqrt{s_{NN}}$ = 62 GeV

Measurements are systematically higher then pQCD calculations (FONLL upper limit):
→ no suppression compared to FONLL predictions

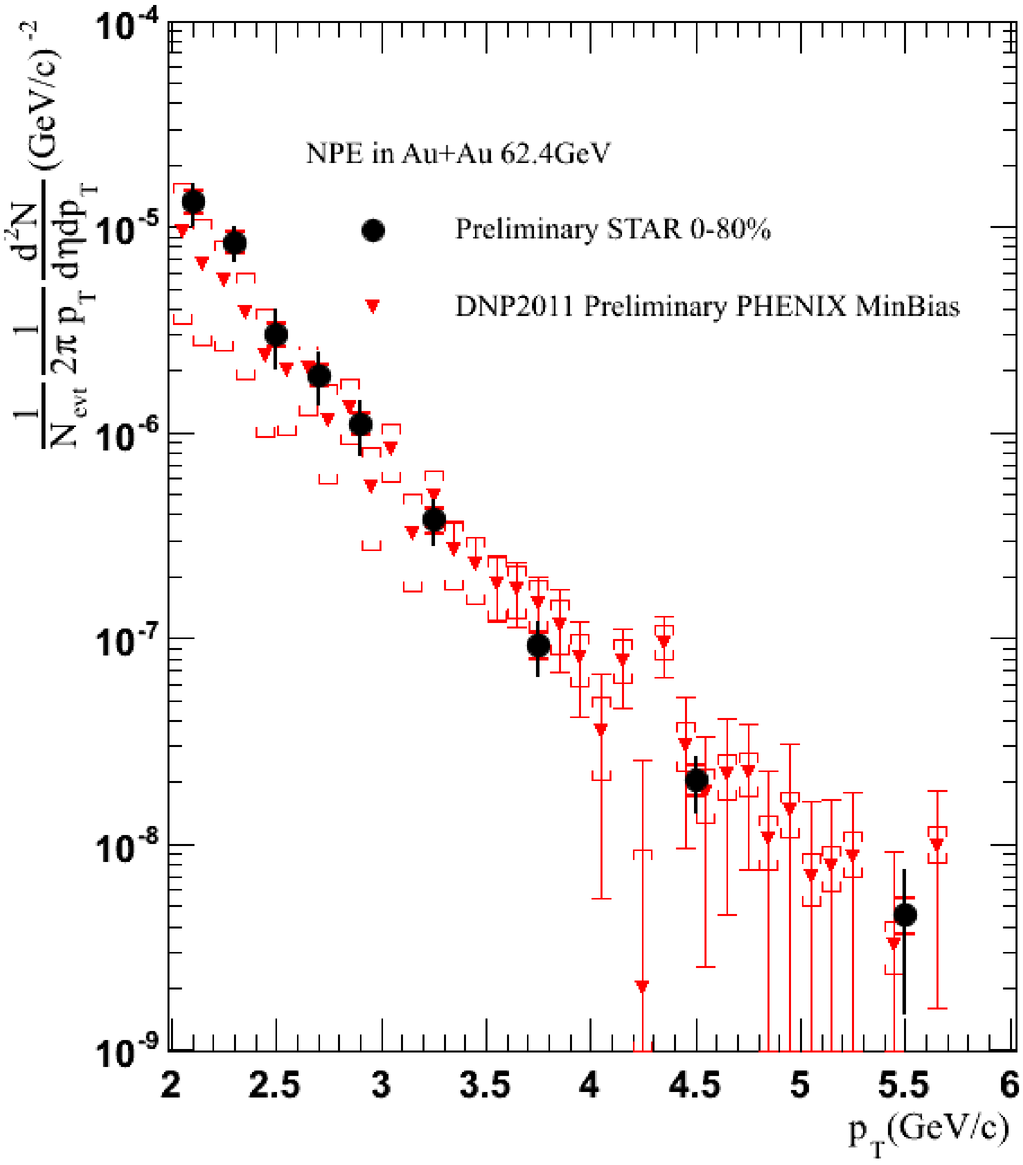


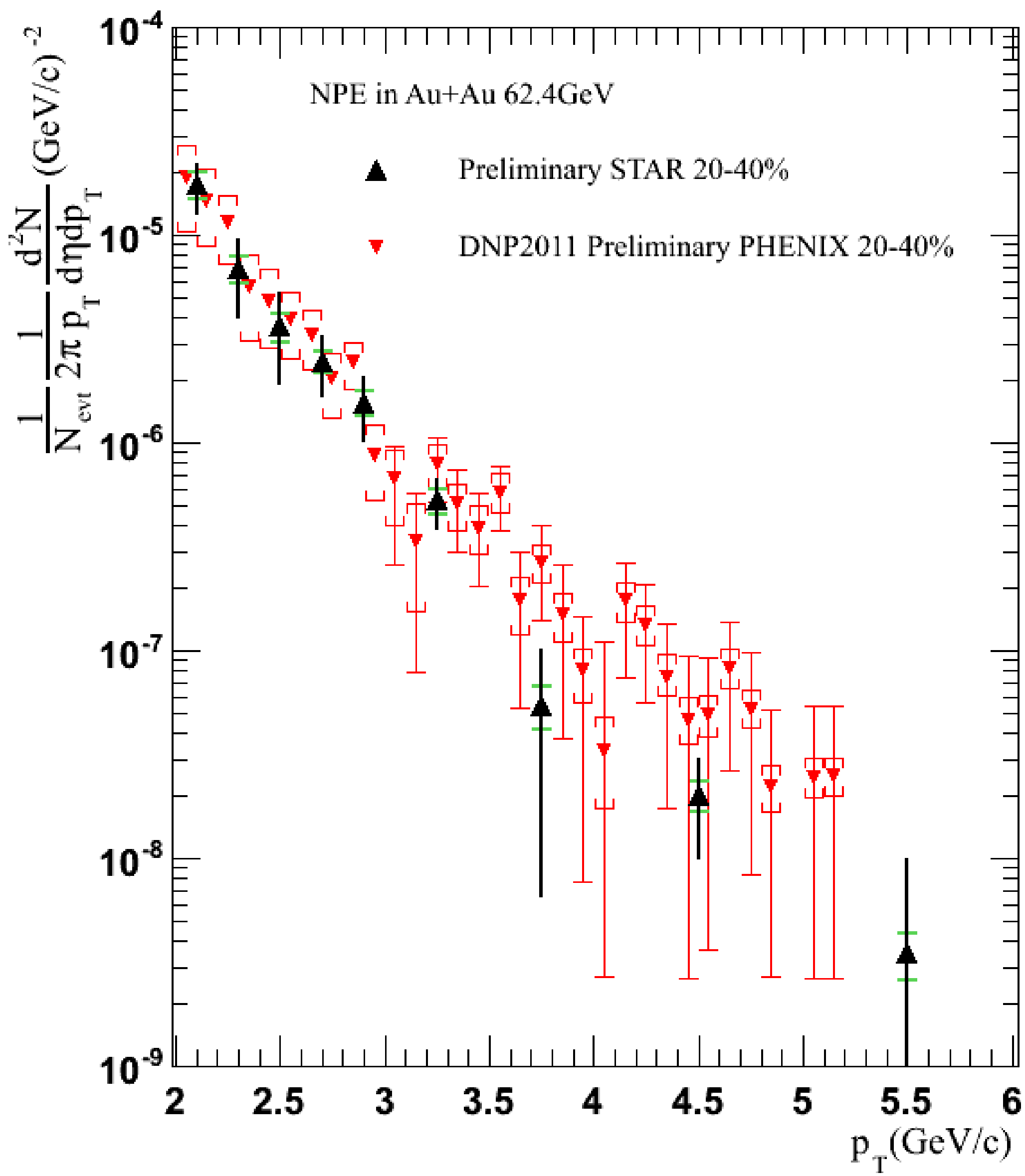
NPE in p+p 62.4 GeV



ISR: IL NUOVO CIMENTO (1981), 65A, N4, 421-456
FONLL: R. Vogt, private communication
k_T-factorization: Phys. Rev. D 79, 034009 (2009) and private communication with R. Maciula

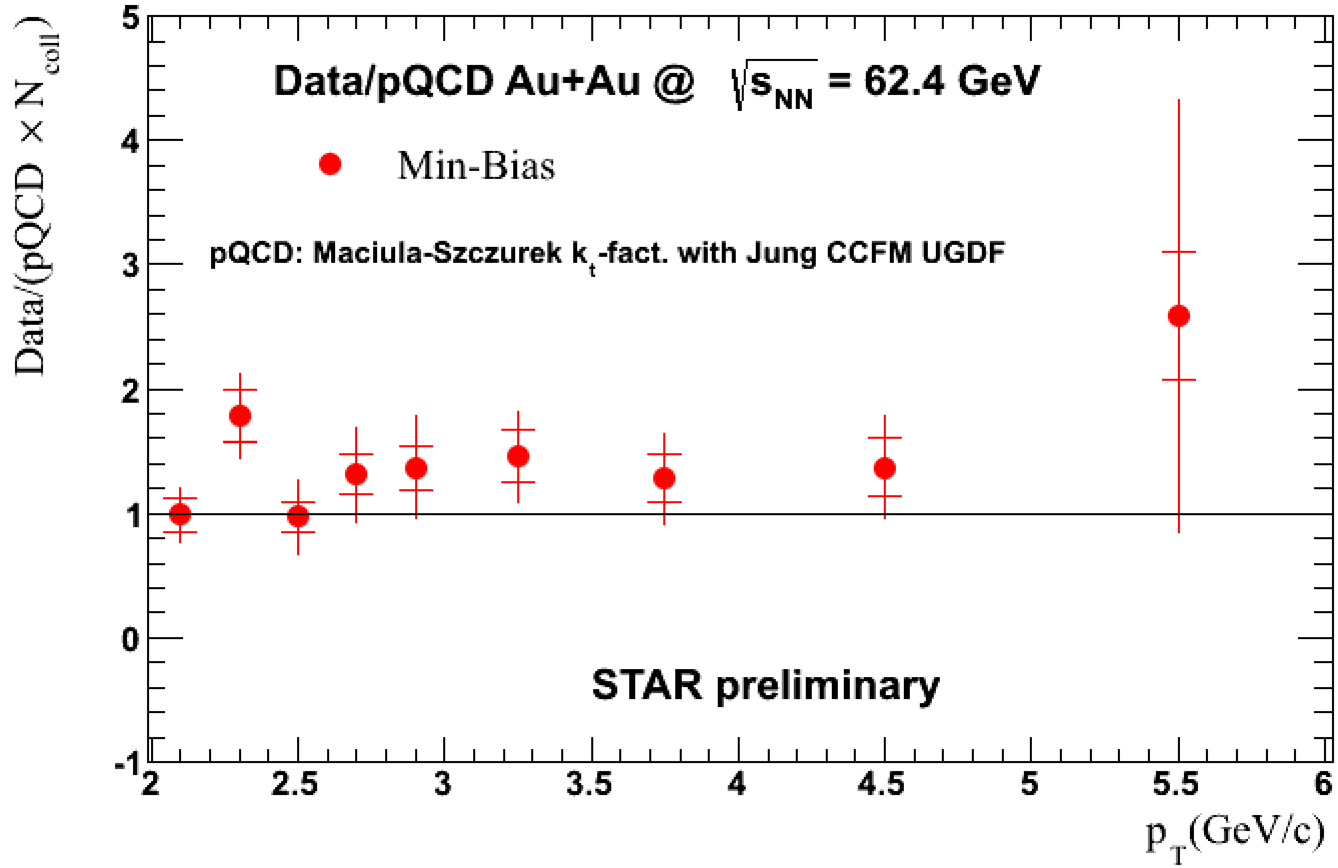
NPE spectra in Au+Au at $\sqrt{s_{NN}}$ = 62 GeV





NPE R_{AA} at $\sqrt{s_{NN}}$ = 62 GeV

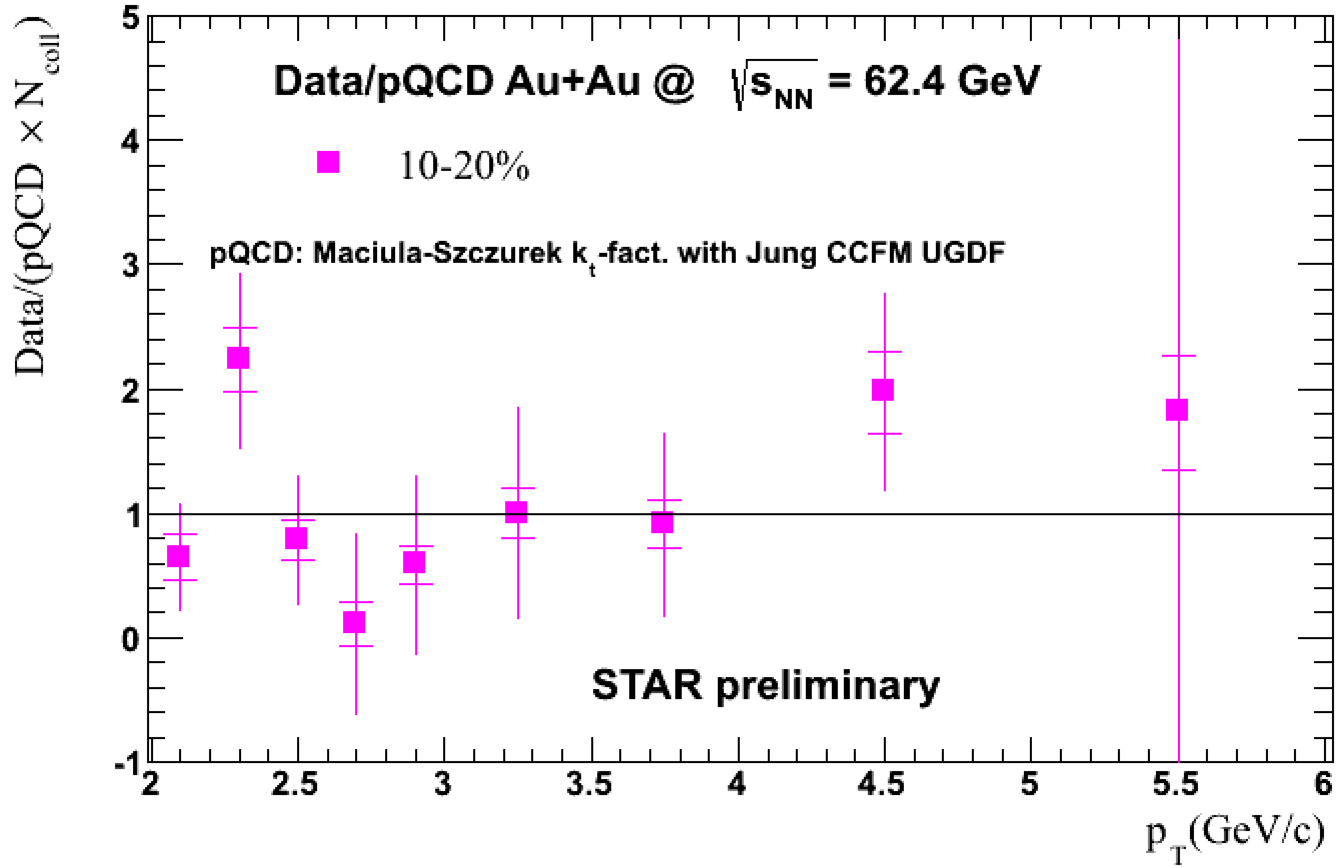
Min-Bias



No NPE suppression compared to ISR p+p data and pQCD calculations

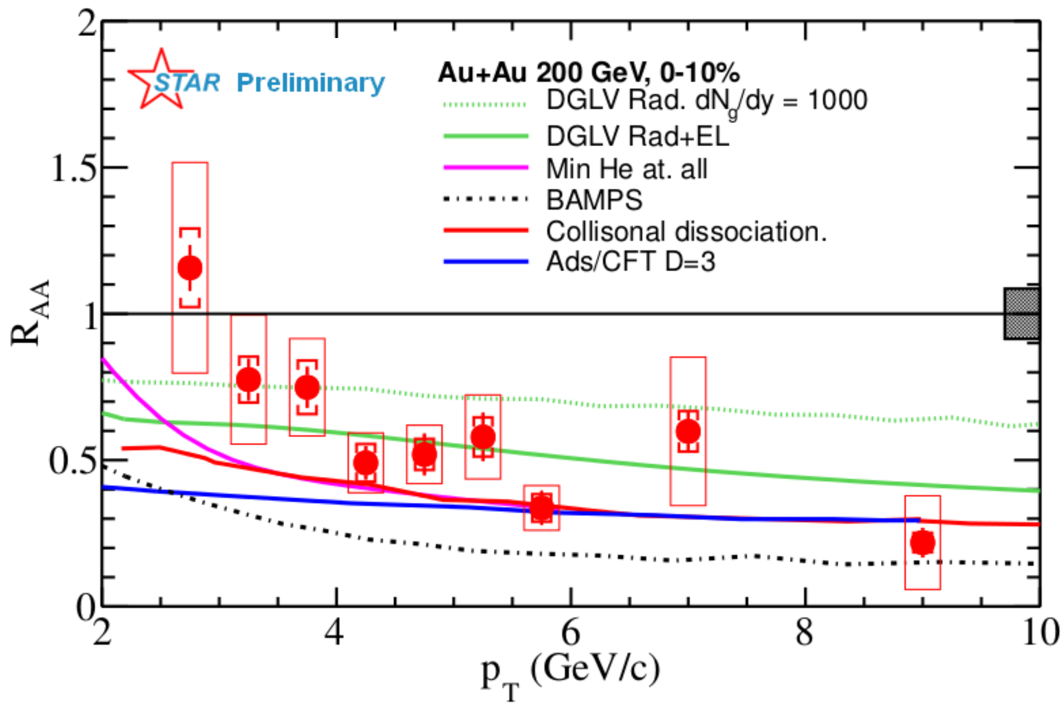
NPE R_{AA} at $\sqrt{s_{NN}}$ = 62 GeV

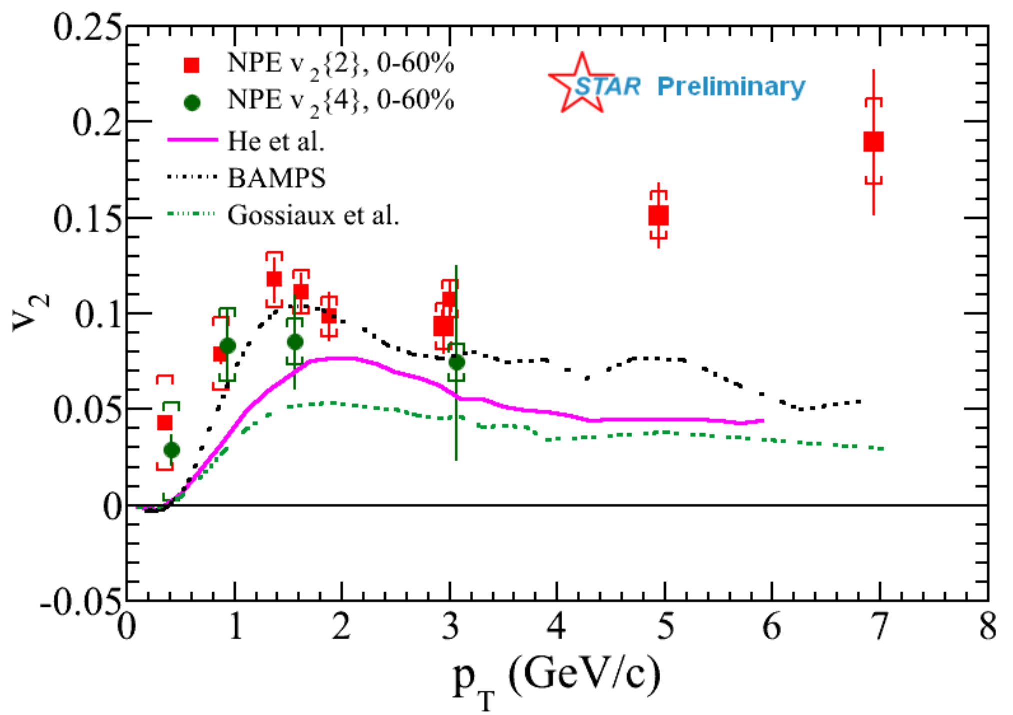
Central: 10-20%



No NPE suppression compared to ISR p+p data and pQCD calculations

NPE v_2 and R_{AA} in Au+Au 200 GeV

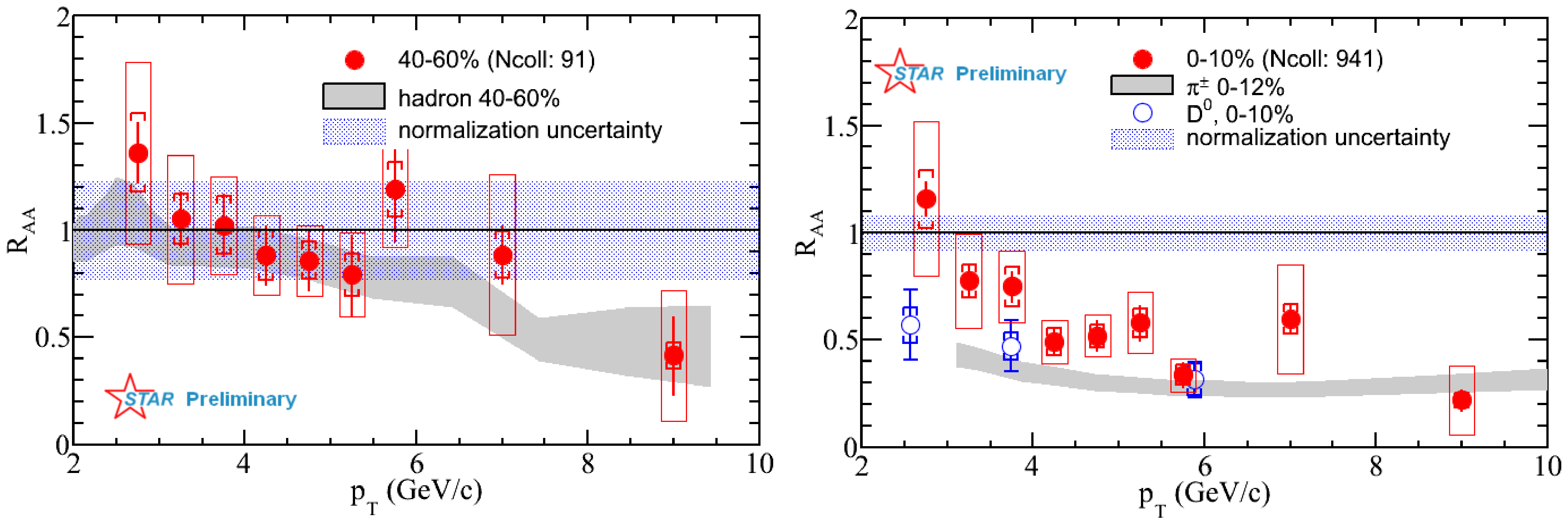




- Data disfavor radiative energy loss as the only energy loss mechanism
- Finite v_2 at low and intermediate p_T
- No model so far can describe suppression and v_2 simultaneously
- Increase of v_2 at high p_T likely due to jet-like correlation

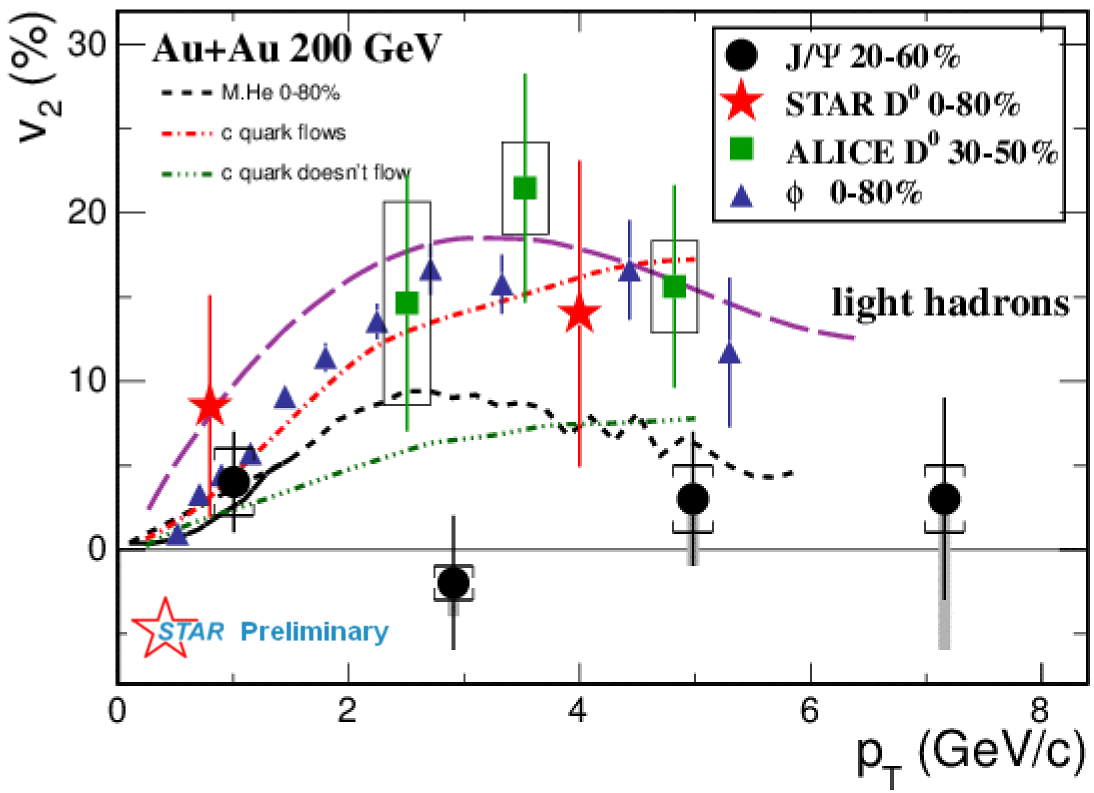
DGLV: Djordjevic, PLB632, 81 (2006), **BAMPS**: arXiv:1205.4945.
He et al.: PRC 86, 014903 (2012), **Coll. Dissoc.** R. Sharma et al., PRC 80, 054902(2009).
Ads/CFT: W. Horowitz Ph.D thesis, **Gossiaux et al.** : PRC 78, 014904 (2008)

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

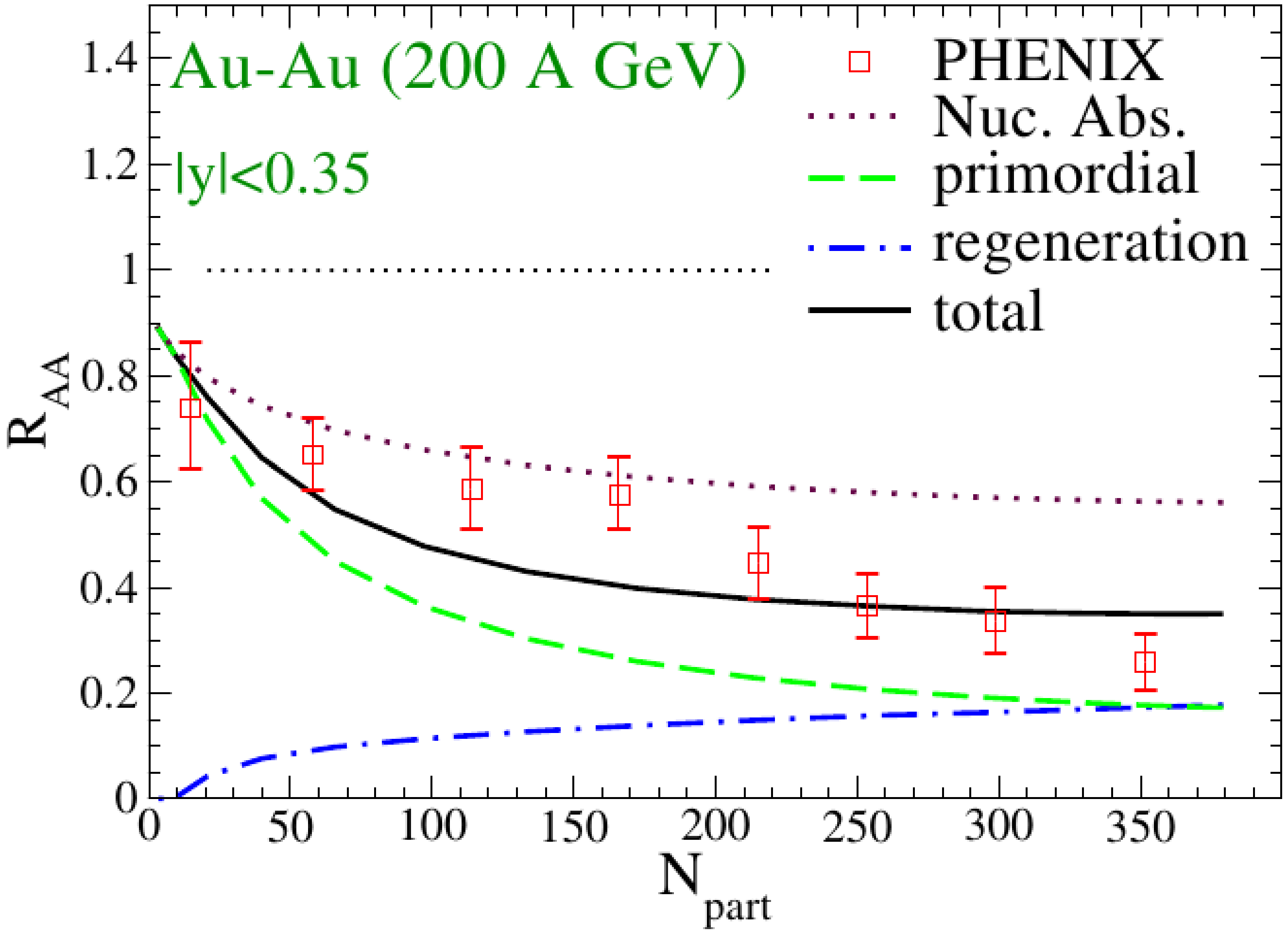


- Strong suppression at high p_T in central collisions
- D^0 and NPE suppression are similar
- Uncertainty dominated by p+p baseline

D^0 elliptic flow



J/psi secondary production via recombination (an example)



Xingbo Zhao, Ralf Rapp, Phys.Rev.C82:064905,2010