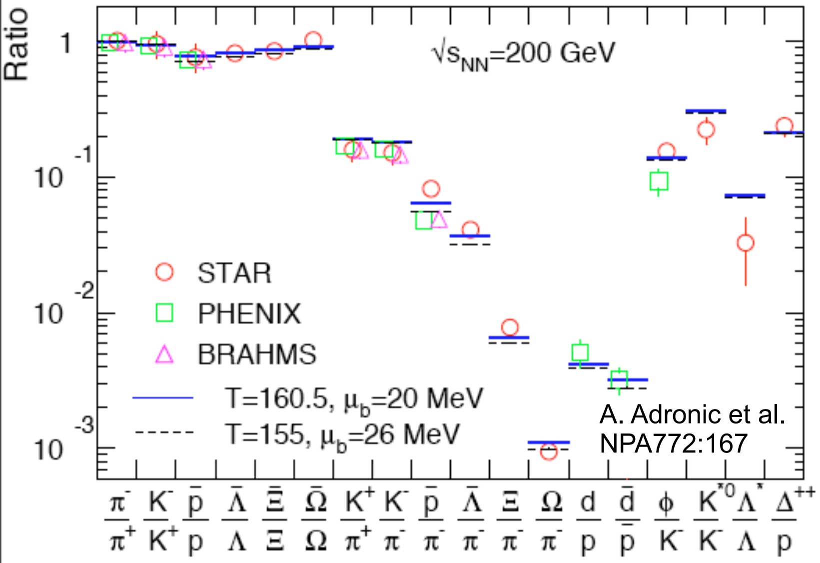
Using Identified Particles to Probe the Medium Produced at RHIC

Helen Caines - Yale

XIII Mexican School of Particles and Fields

Oct. 2008

Bulk light flavor production



- Yields are well reproduced by

statistical/thermal models

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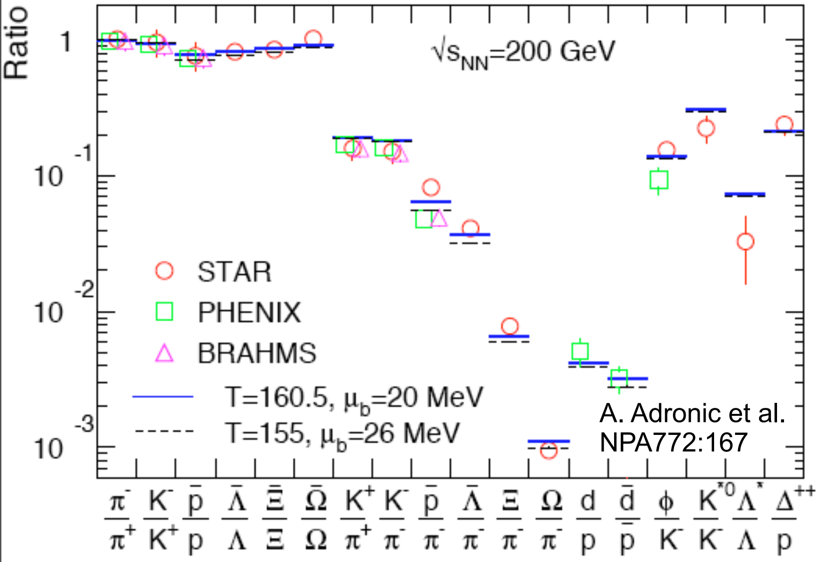


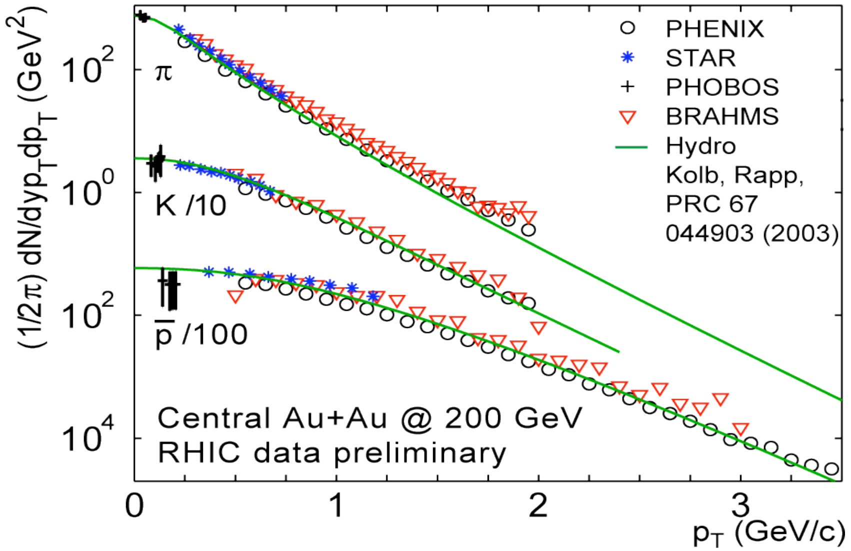
A. Adronic et al.
NPA772:167

- Yields are well reproduced by

  statistical/thermal models

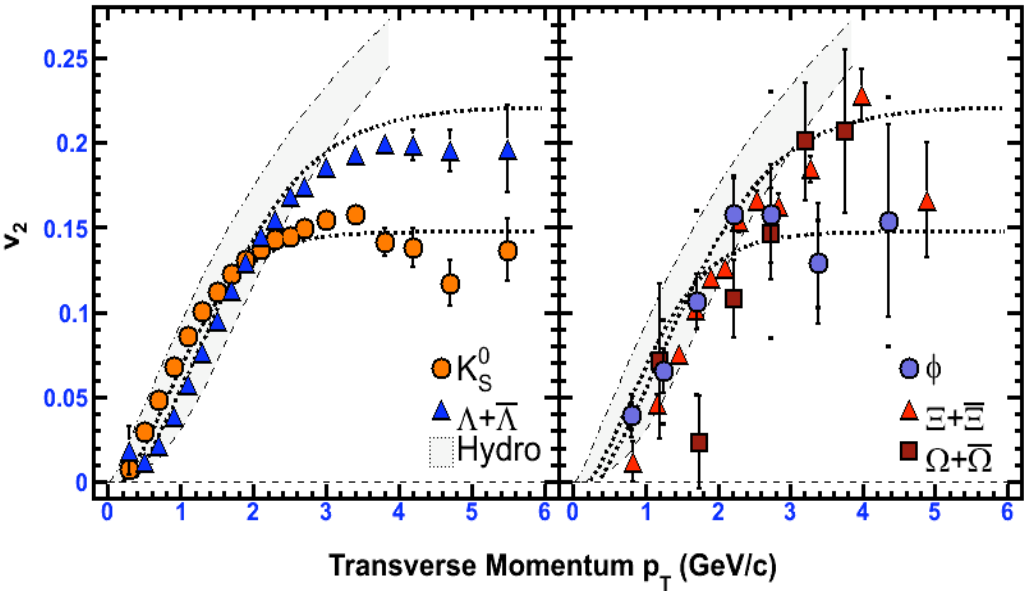
- Significant radial and elliptic flow that is well reproduced by

  hydrodynamical models



Central Au+Au @ 200 GeV
RHIC data preliminary

$\sqrt{s_{NN}}$ = 200 GeV ^{197}Au+^{197}Au Collisions at RHIC (run IV)



Constituent quark degrees of freedom

The *complicated* observed flow pattern in $v_2(p_T)$ for hadrons

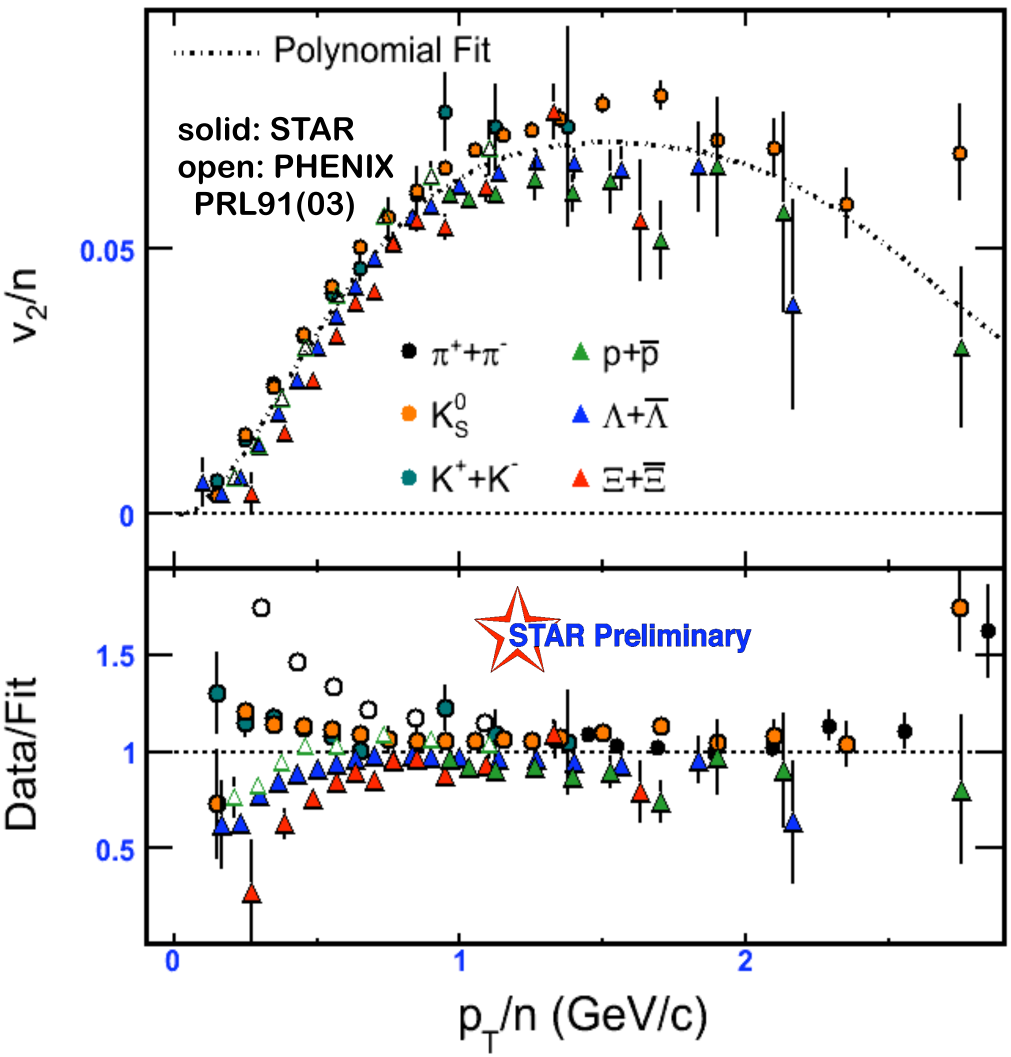
$$\frac{d^2N}{dp_T d\phi} \propto 1 + 2\, v_2(p_T)\cos(2\phi)$$

is predicted to be *simple* at the quark level

$p_T \rightarrow p_T/n$

$v_2 \rightarrow v_2 / n$,

n = (2, 3) for (meson, baryon)



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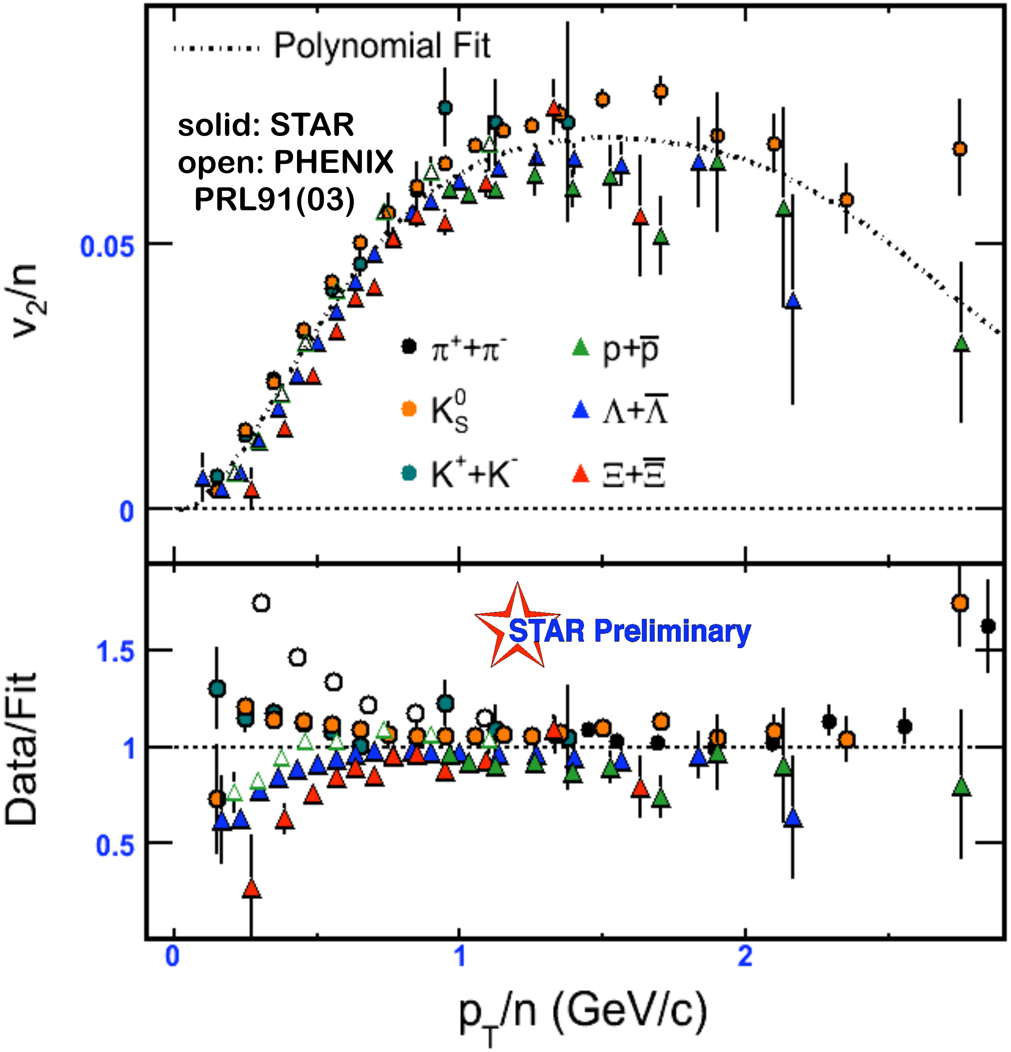
$p_T \to p_T/n$

$v_2 \to v_2/n$,

n = (2, 3) for (meson, baryon)

$v_2^s \sim v_2^{u,d} \sim 7\%$



Quarks (and gluons) are the relevant degrees of freedom

At RHIC there's a new state of matter

The QGP is the:

hottest (T=200-400 MeV ~ 2.5 10^{12} K)

densest (ε = 30-60 $\varepsilon_{\text{nuclear matter}}$)

matter ever studied in the lab.

It flows as a

(nearly) perfect fluid

with systematic patterns, consistent with

quark degree of freedom

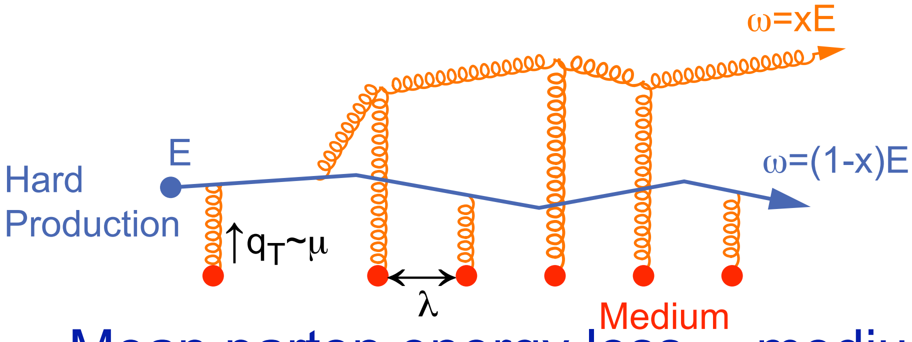
and a viscosity to entropy density ratio

lower

than any other known fluid.

Now want to learn more about properties

Calculating medium density



- Mean parton energy loss ∝ medium properties:
    - $\Delta E_{loss} \sim \rho_{gluon}$ (gluon density)
  - Coherence among radiated gluons
    - $\Delta E_{loss} \sim \Delta L^2$ (medium length)

      $\Rightarrow \sim \Delta L$ with expansion
- Characterization of medium
  - transport coefficient

  is $\langle k_T^2 \rangle$ transferred per unit path length

$$\hat{q} = \frac{\langle k_T^2 \rangle}{L} \approx \frac{\mu^2}{\lambda} \qquad \hat{q} = \hat{q}(\vec{r}, \tau)$$

  - gluon density dN_g/dy

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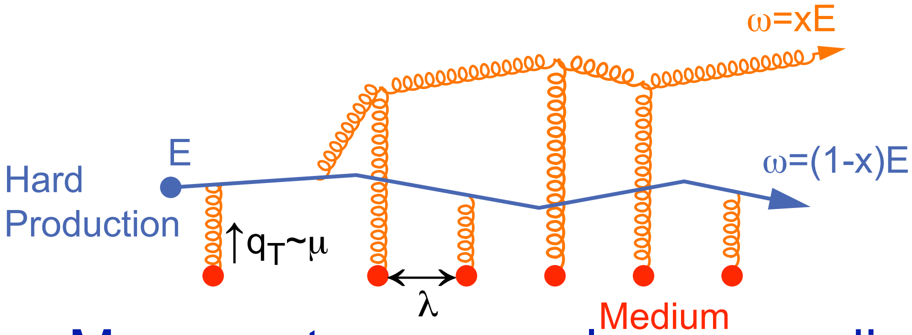

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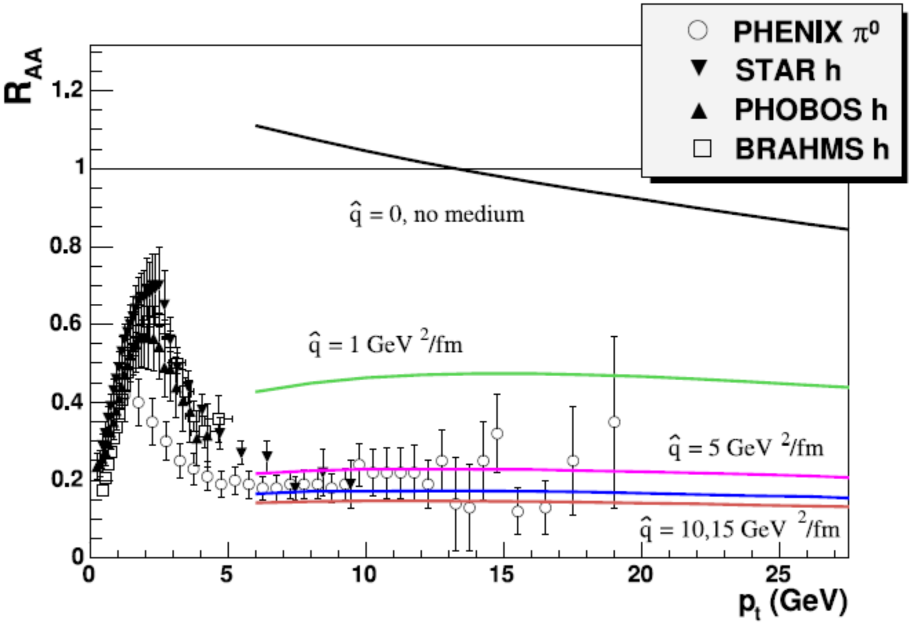


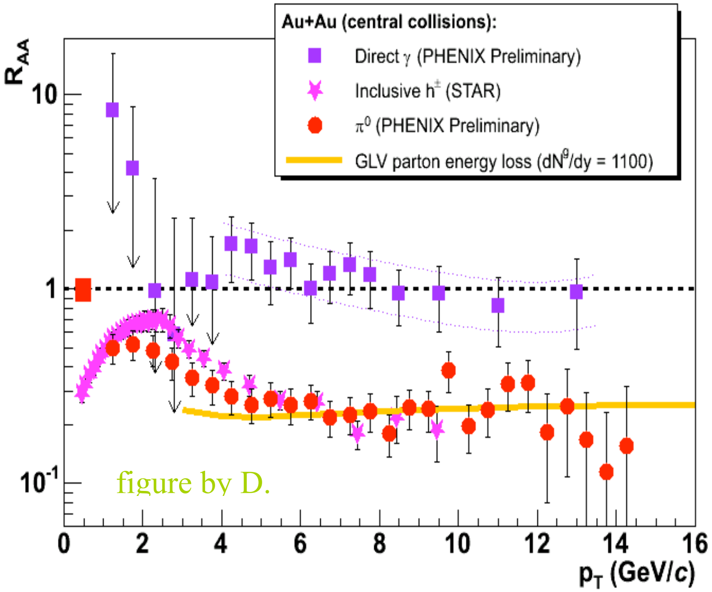
Problem: saturation of R_{AA}

Medium appears black to light hadrons

Need to increase sensitivity to medium density

Color factors: glue versus light quarks

QCD: dependence of energy loss on color charge: $\Delta E \sim \alpha_s C \hat{q} L^2$



The Color Factor Effect: $\dfrac{\Delta E_g}{\Delta E_q} = 9/4$

Higher suppression of g than q

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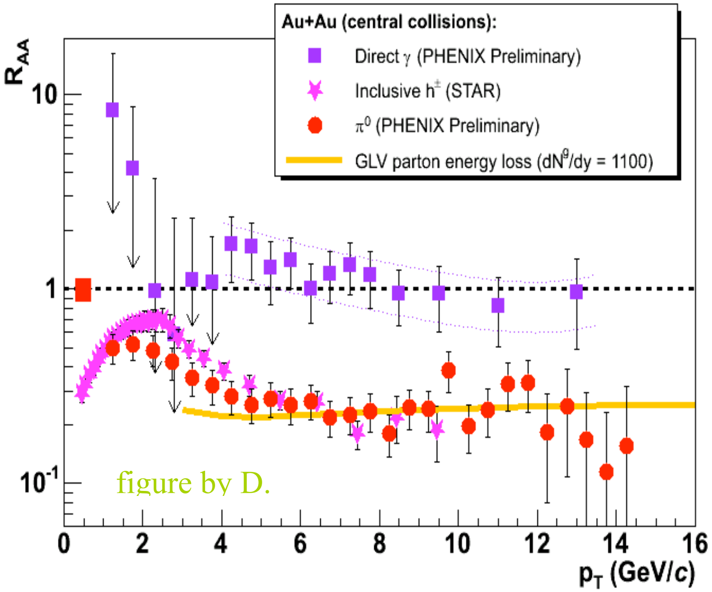

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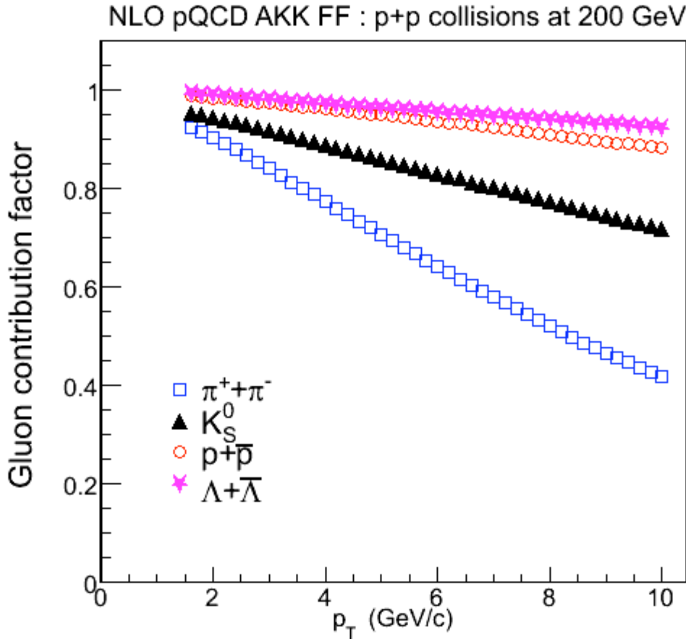
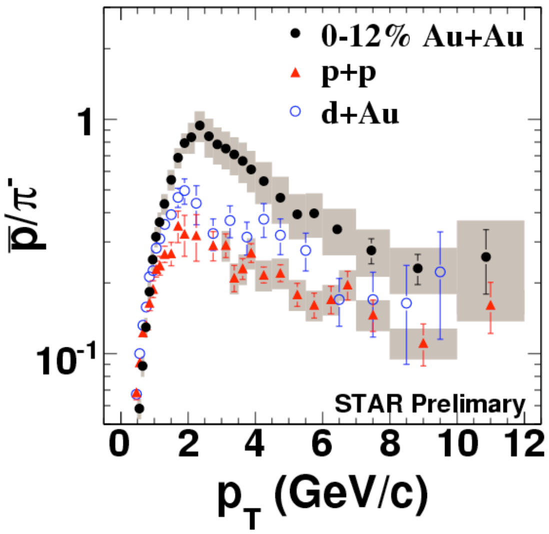


- Gluon jets have a higher probability of fragmenting into a proton
  - p come predominantly from glue at high p_T

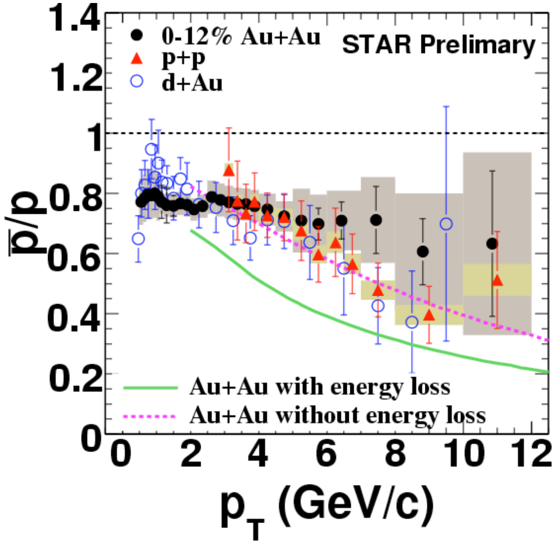
Proton R_{AA} should reflect the stronger suppression of gluons

Color factors: glue versus light quarks

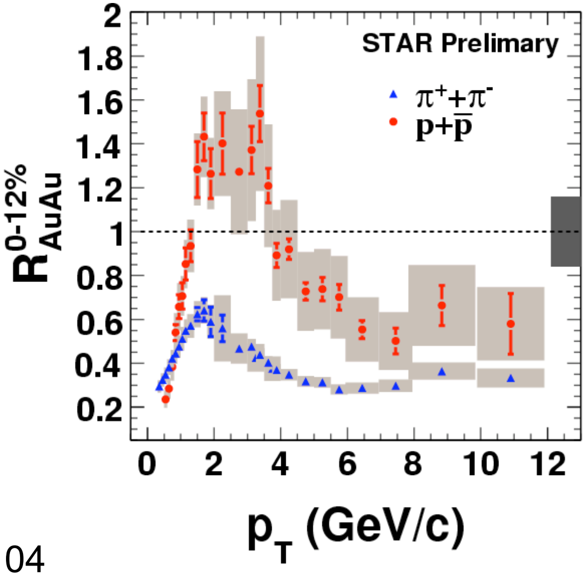
Anti-Baryon/meson



Anti-particle/particle



Baryon & meson NMF



STAR : PLB 637 (2006) 161, PRL 97 (2006) 152301, PLB 655 (2007) 104

No sign of this, in fact appears to go the wrong way
- Perhaps not sensitive?

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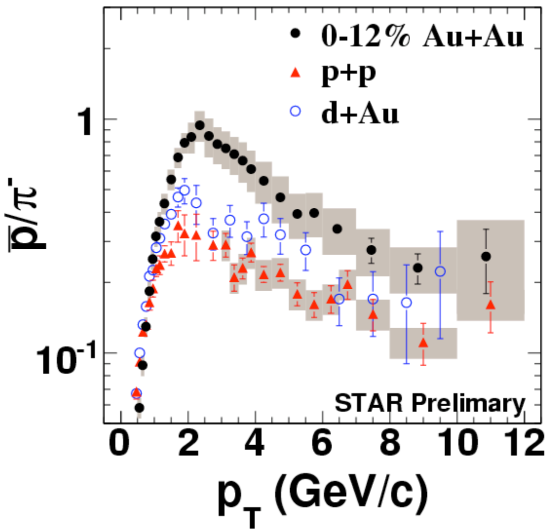

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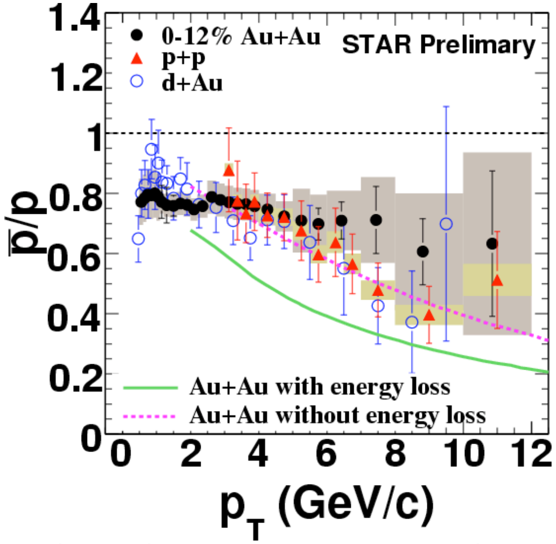

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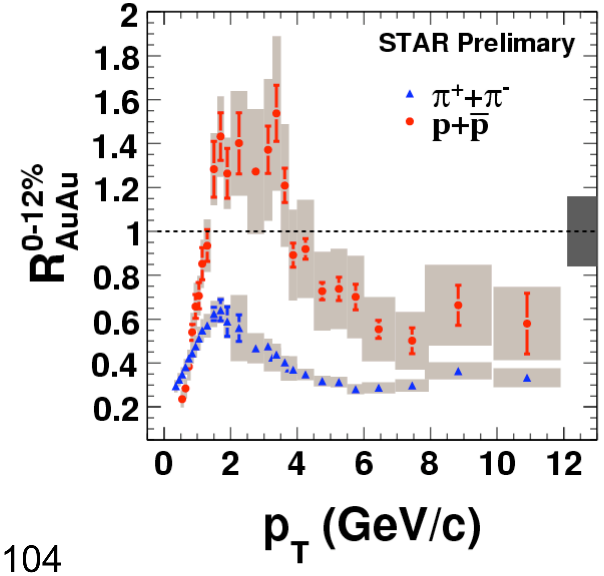

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Theory: The more realistic the calculation, the smaller effect

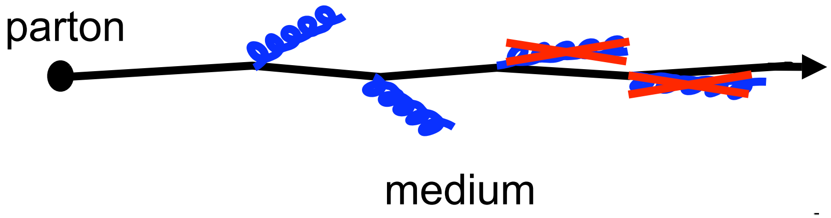
- saturation of suppression in dense regions of the medium
- hadron probes do not equal quark probes (FF?)
- conversion reaction (q → g or g → q)

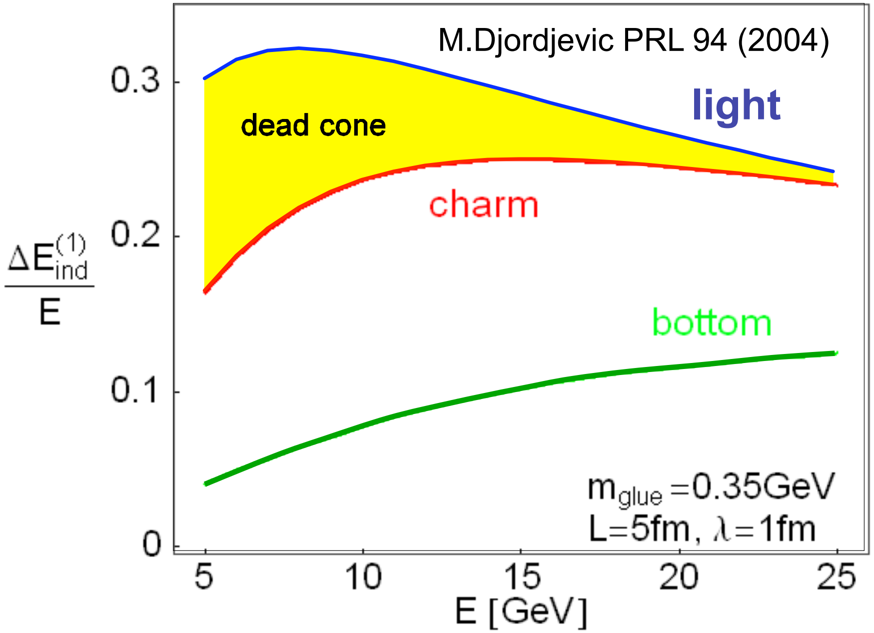
Using heavy flavor as gray probe

- Heavy quark energy loss
  - Prediction: less than light quark energy loss (dead cone effect)

$$\omega \frac{dI}{dw}\Big|_{\mathrm{HEAVY}} = \frac{\omega \frac{dI}{dw}\Big|_{\mathrm{LIGHT}}}{\left(1+\left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^2}$$

Dokshitzer and Kharzeev, PLB 519 (2001) 199.




M.Djordjevic PRL 94 (2004)

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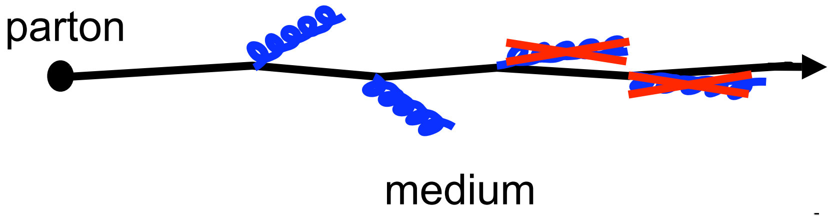

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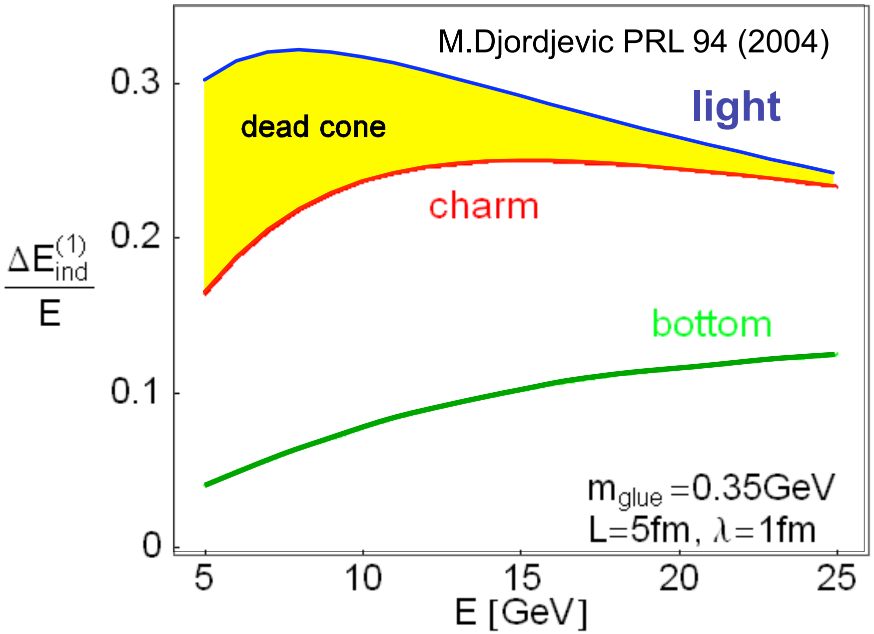
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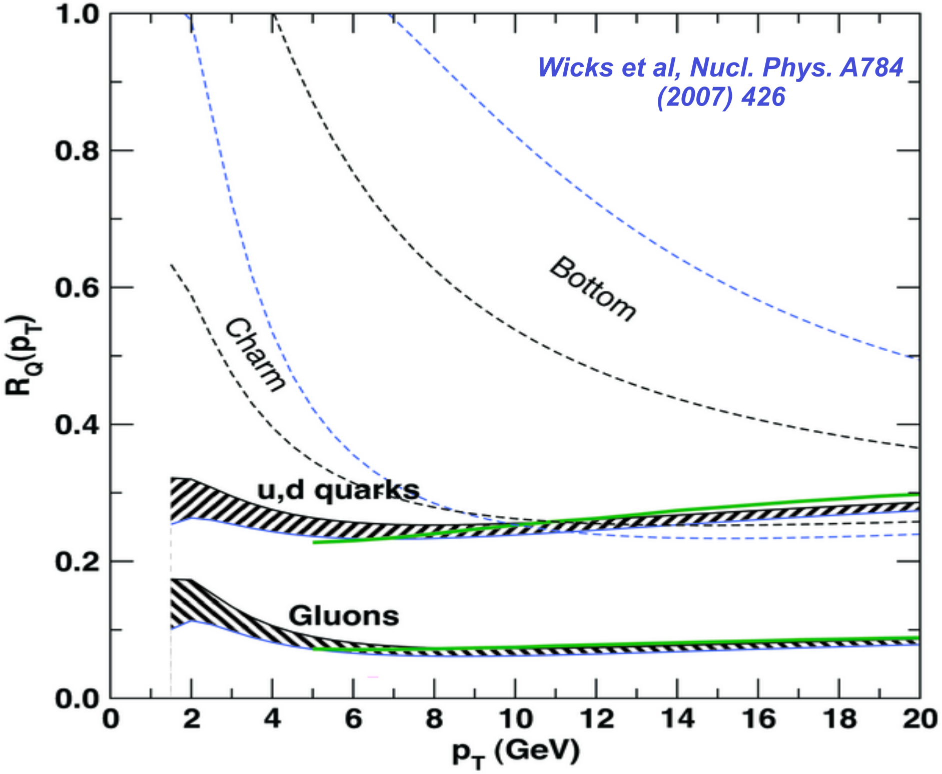
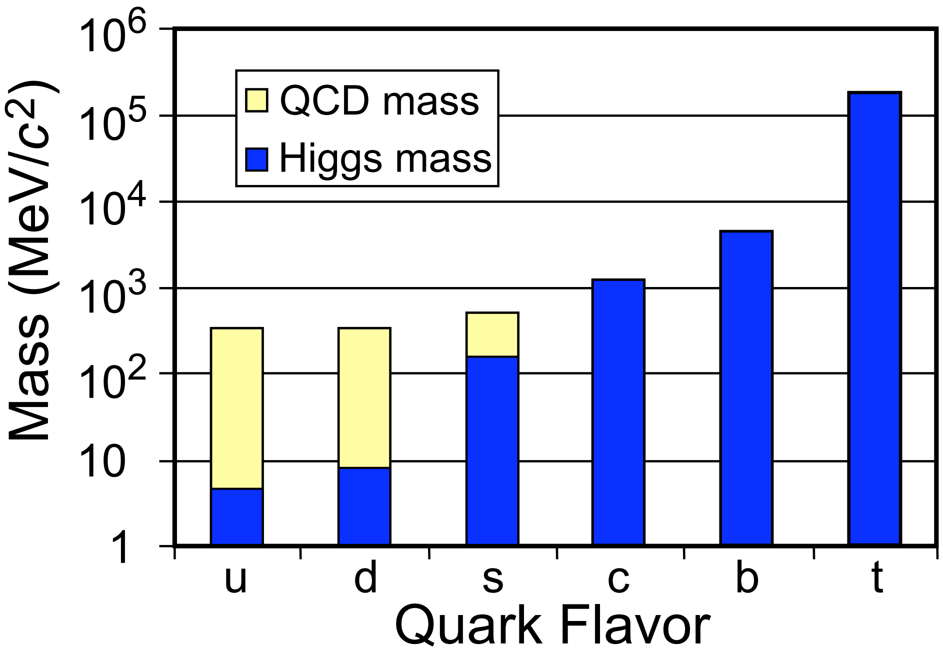

Wicks et al, Nucl. Phys. A784 (2007) 426

Suppression c,b < than u,d, glue.

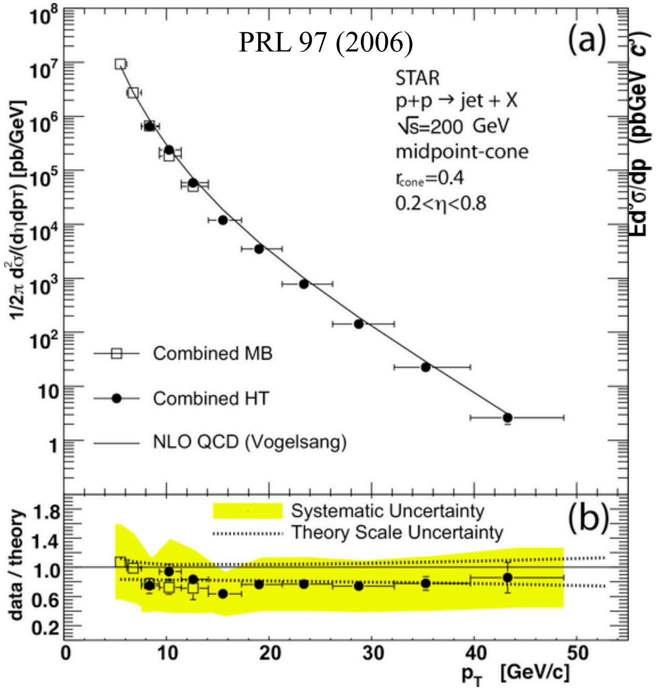
Why is heavy flavor different?

- Heavy quarks too massive to be produced in thermal bath
- Produced in initial hard scattering of partons
  - Dominant: $gg \rightarrow QQ$
  - Production rates from pQCD
  - Sensitive to initial gluon distributions
- Expect heavy flavor cross-section to scale with N_{bin}
- Must pass through medium before detection

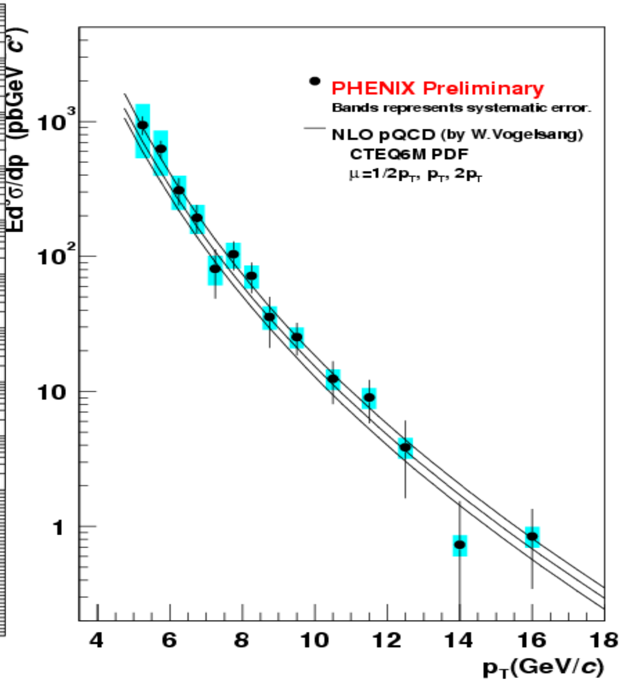


Charm and bottom good probes of produced medium

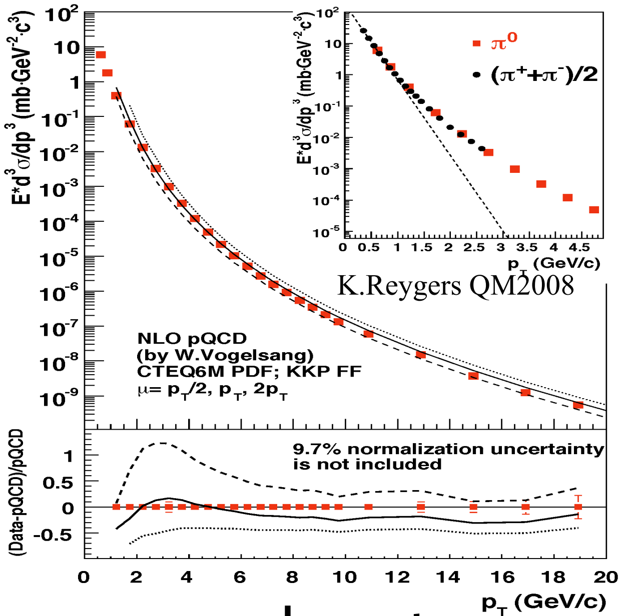
High Q^2 scatterings - calibrated probes?



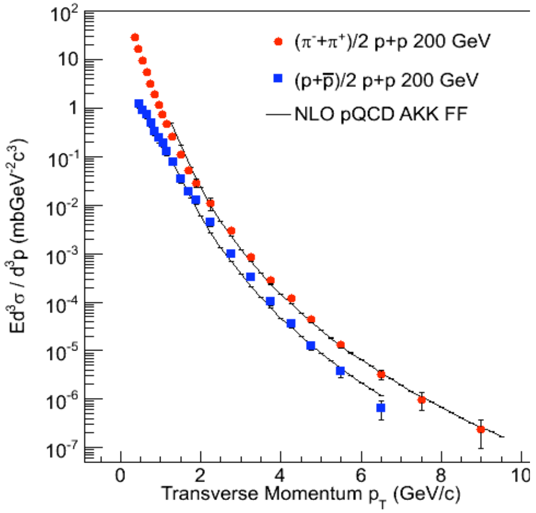
Inclusive Jets



Photon



π and proton



High Energy Probes well described in p+p reactions by NLO perturbative QCD

Measuring open heavy flavor

Hadronic decay channels

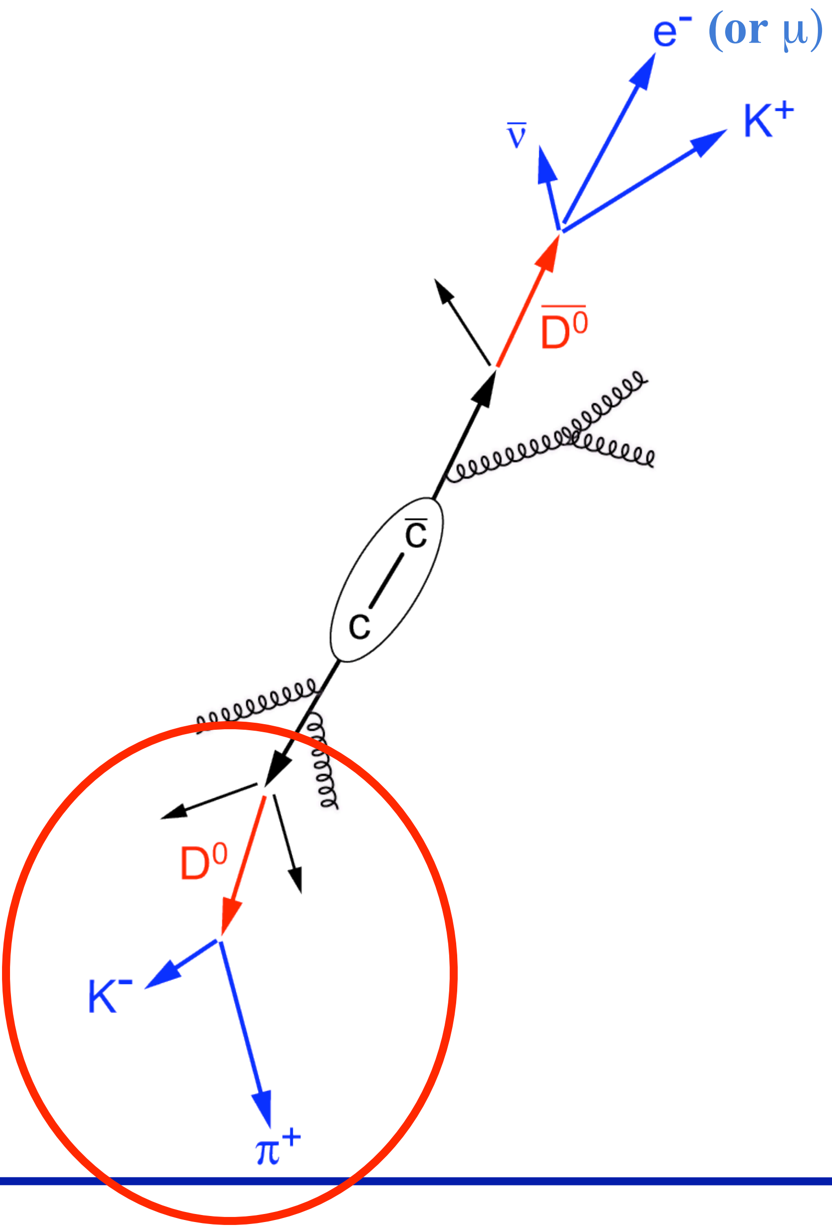
- $D^0 \rightarrow K\pi$ (B.R.: 3.8%)
- $D^\pm \rightarrow K\pi p$ (B.R.: 9.1%)
- $D^{*\pm} \rightarrow D^0\pi$ (B.R.: 68% × 3.8% ($D^0 \rightarrow K\pi$) = 2.6%)
- $\Lambda_c \rightarrow p K \pi$ (B.R.: 5%)

Pro:

- Direct clean identification (*peak*)

Cons:

- No trigger
- Large combinatorial background
- Need handle on decay vertex
  - charm $c\tau$~100-200 μm
  - bottom $c\tau$~400-500 μm
- ⇒ requires high resolution silicon vertex detectors



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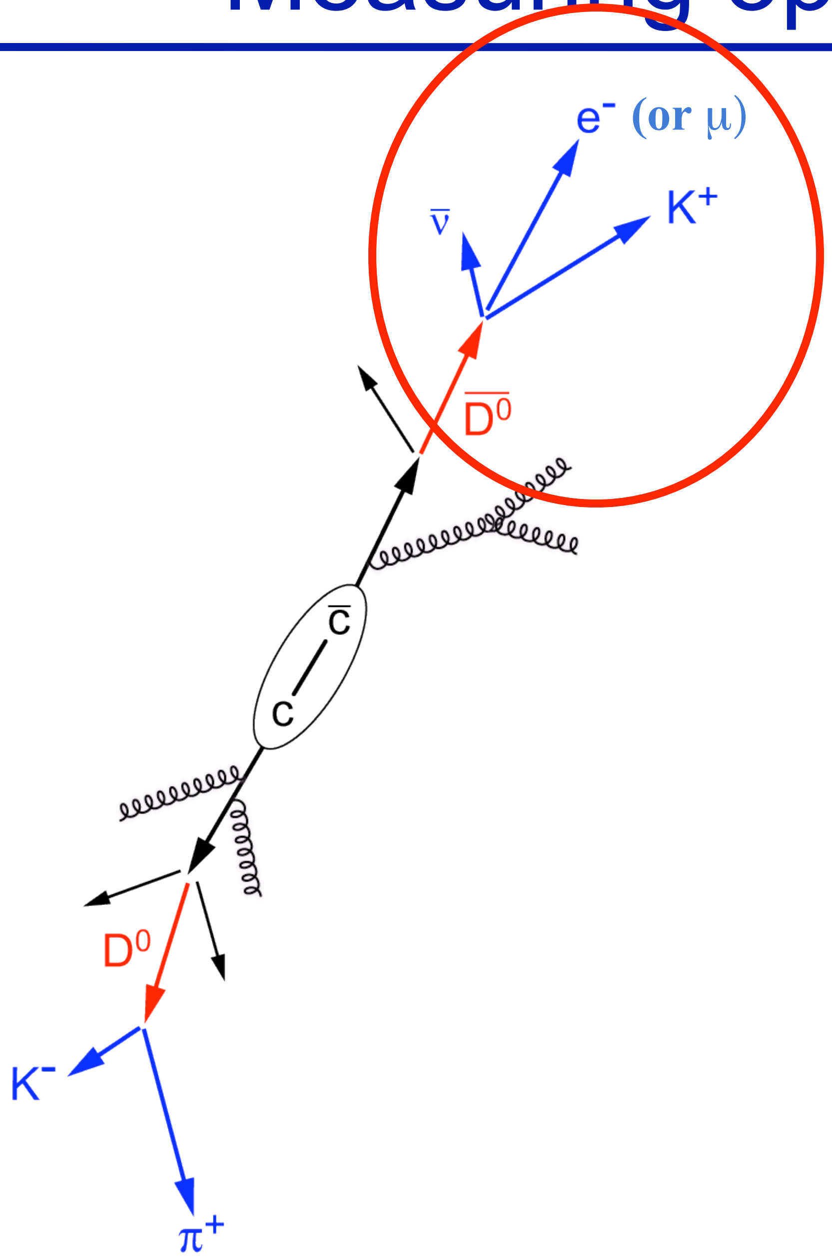

Semileptonic decay channels

- $c \rightarrow \ell^+ + \text{anything}$ (B.R.: 9.6%)
  - $D^0 \rightarrow \ell^+ + \text{anything}$ (B.R.: 6.87%)
  - $D^\pm \rightarrow \ell^\pm + \text{anything}$ (B.R.: 17.2%)
- $b \rightarrow \ell^+ + \text{anything}$ (B.R.: 10.9%)
  - $B^\pm \rightarrow \ell^\pm + \text{anything}$ (B.R.: 10.2%)

Pro:

- Can deploy (simple) trigger

Cons:

- *Continuum*: cannot disentangle bottom and charm contributions?
- "*Photonic*" Electron Background:
  - γ conversions ($\pi^0 \rightarrow \gamma\gamma$)
  - π^0, η, η' Dalitz decays
  - ρ, ϕ, … decays (small)
  - Ke3 decays (small)

Electrons from semi-leptonic decays

$c \rightarrow \ell^+ + $ anything (BR ~ 10%) - A very complex analysis!

Need to remove large e^- background contribution - mostly photonic

Both experiments start by identifying all $e^\pm$ perform PID via - dEdx, RICH, p/E in calorimeter

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- Reconstruct γ conversions and Dalitz decays: e^-e^+ pairs have low invariant mass
  - cut: $M_{inv} < 150$ MeV/c^2

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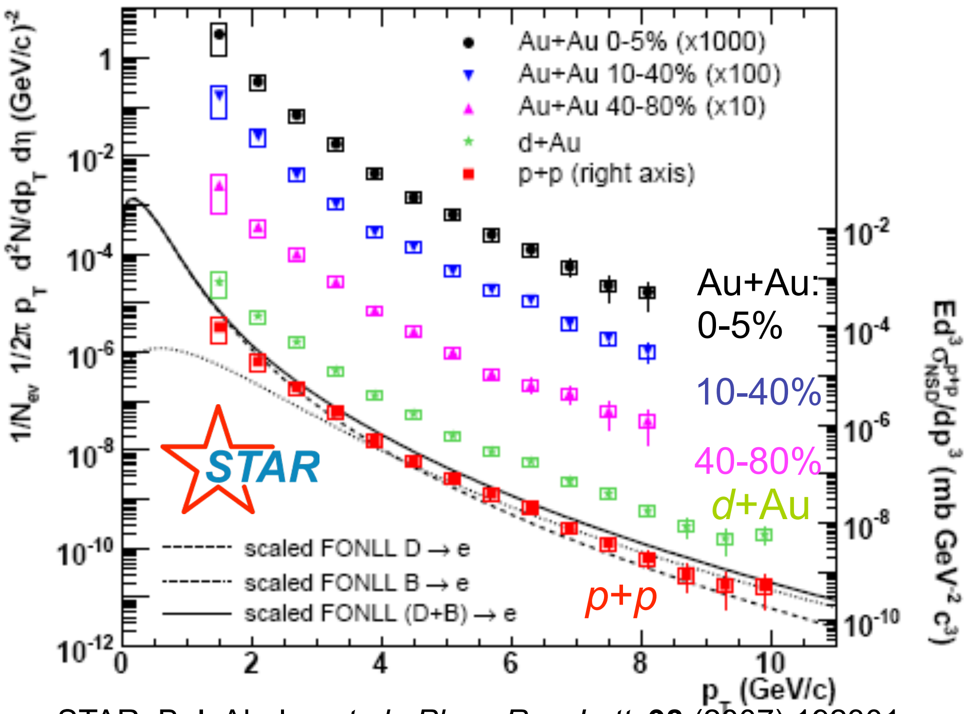
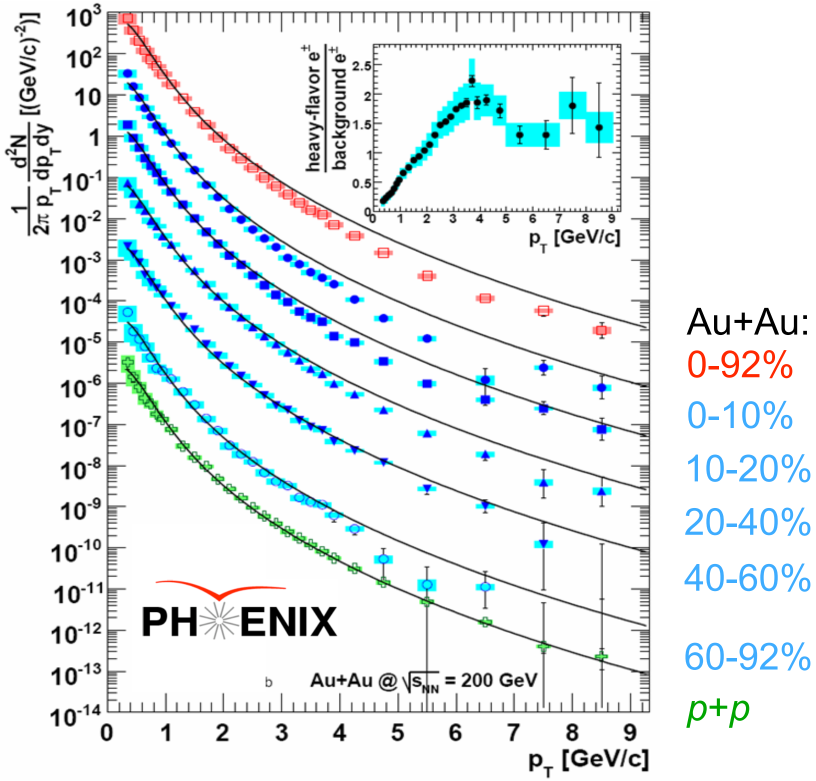
PHENIX

- Simulate background $e^\pm$ from "cocktail" of measured sources (γ,π^0,η, etc.)
- Measure $e^\pm$ with converter, extrapolate to 0 rad. length

Electrons from semi-leptonic decays





STAR: B. I. Abelev *et al.*, *Phys. Rev. Lett.* **98** (2007) 192301
PHENIX: A. Adare *et al.*, *Phys. Rev. Lett.* **98** (2007) 172301

This technique very successful - results for p+p, d+Au, Au+Au

Issues -

- leptons come from c and b
- different hadron p_T produce same $e^{\pm}$ p_T

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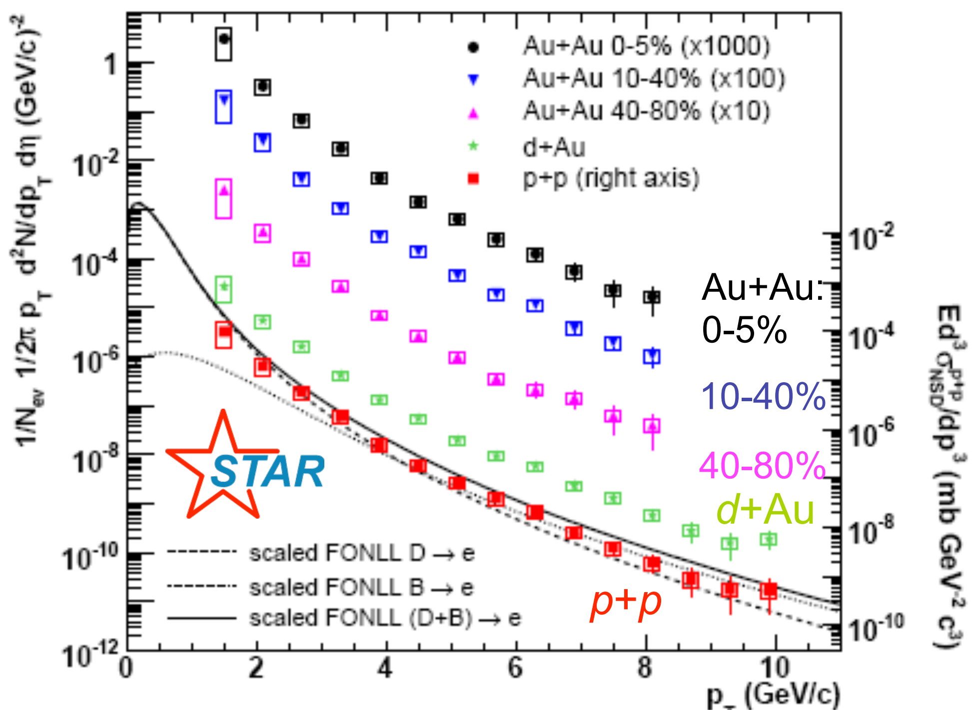

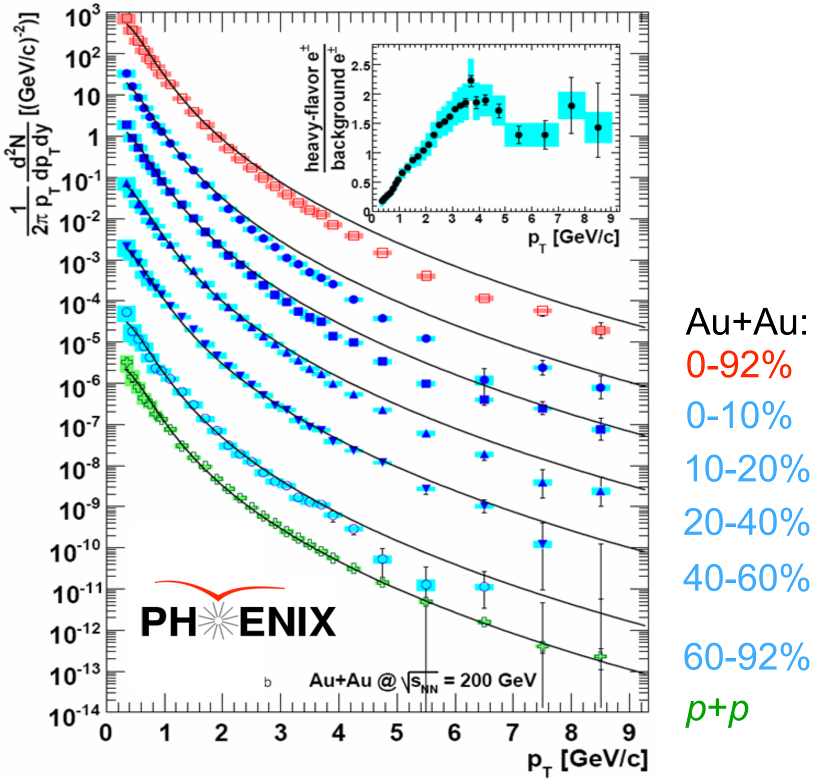

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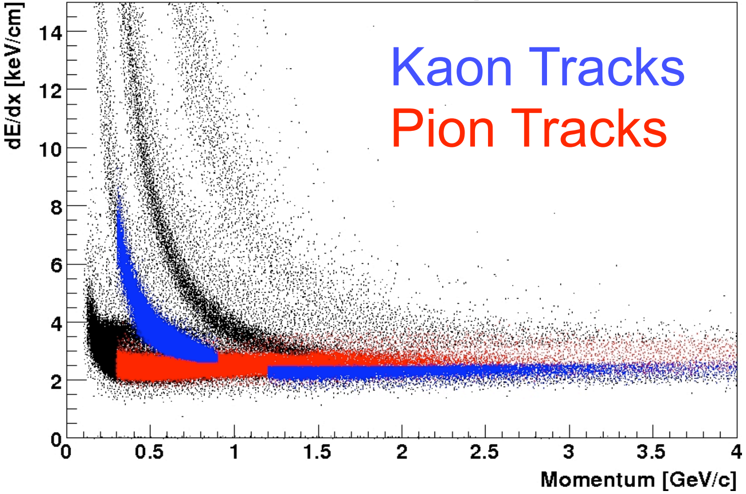
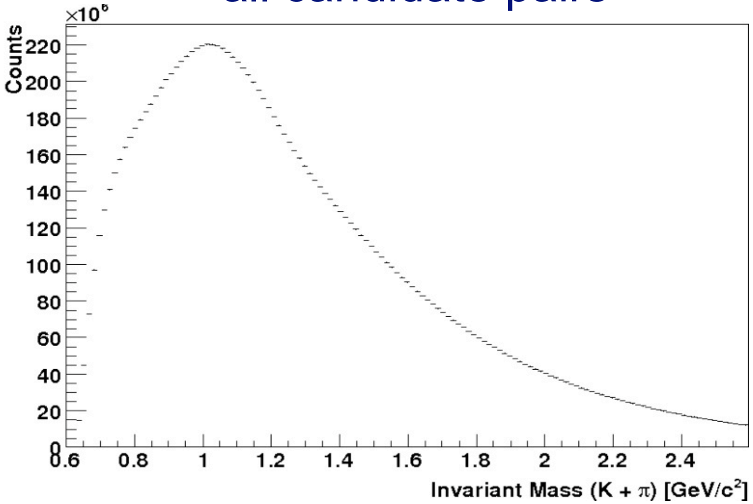
Direct charm measures would be ideal

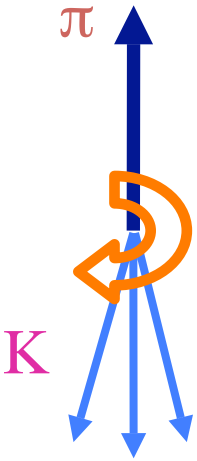
Reconstructing the $D^0 \rightarrow K\pi$

Momentum and dE/dx used to select all K and π pairs



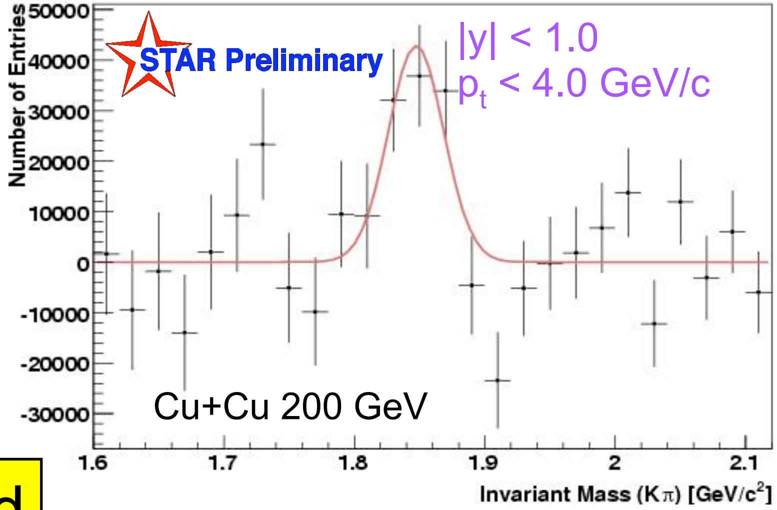
Invariant mass calculated from all candidate pairs





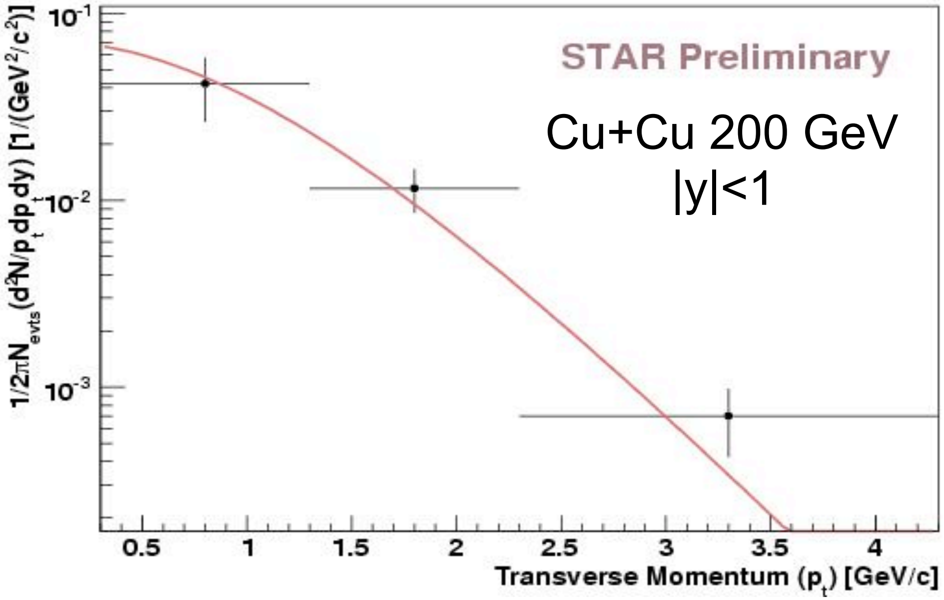
Rotational or event mixing used to calculate combinatorial background.

Often residual background remains subtracted statistically



Clear signal observed

Mid-rapidity $(D^0+\bar{D}^0)/2$ p_T spectra



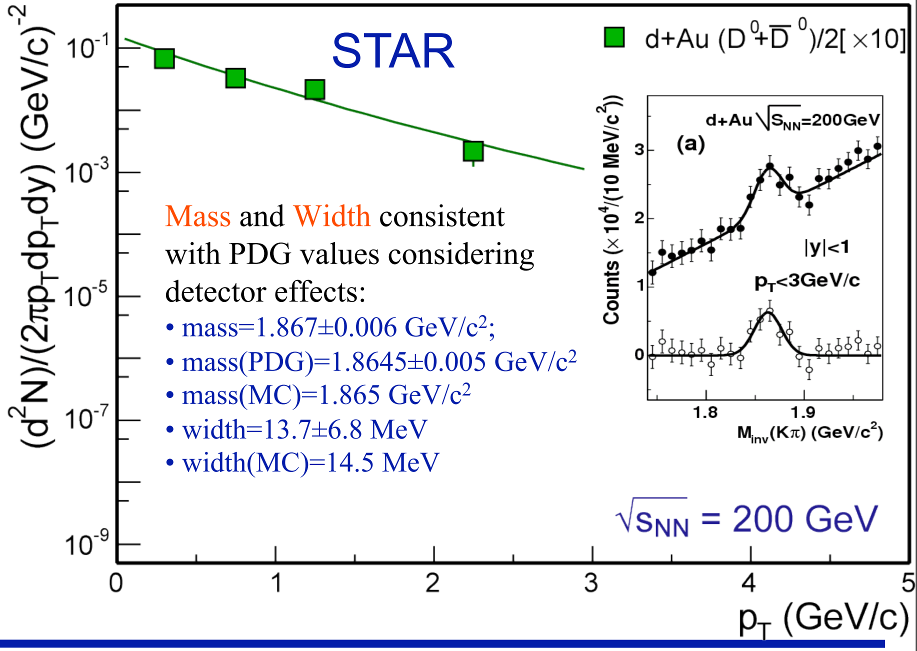
Cu+Cu 200 GeV:

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

d+Au 200 GeV:

$$dN_{D^0}/dy = 0.028 \pm 0.004 \pm 0.008$$

PRL 94, 062301 (2005)



Mass and Width consistent with PDG values considering detector effects:

- mass=1.867±0.006 GeV/c^2;
- mass(PDG)=1.8645±0.005 GeV/c^2
- mass(MC)=1.865 GeV/c^2
- width=13.7±6.8 MeV
- width(MC)=14.5 MeV

Large combinatoric background:

large systematic errors

restricted p_T range

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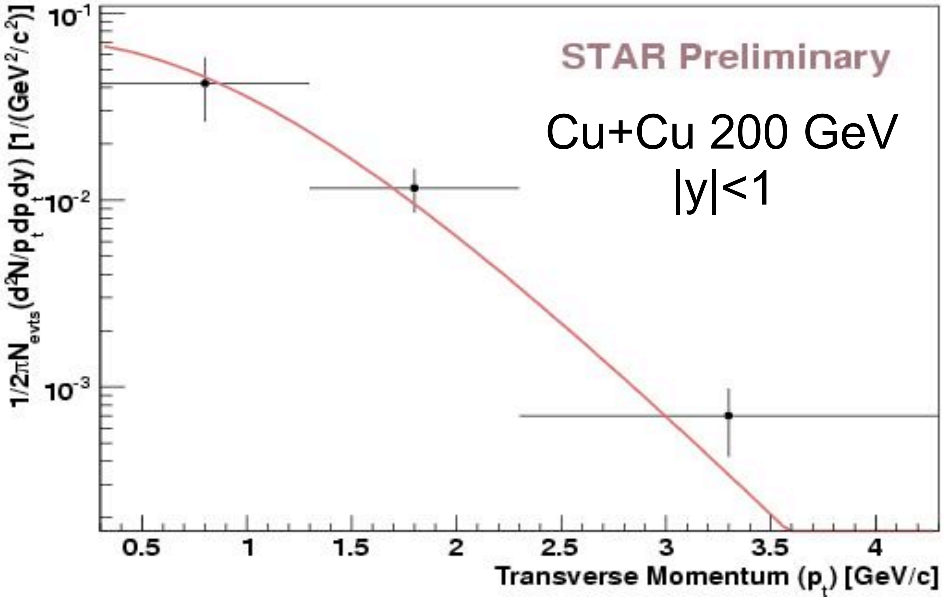

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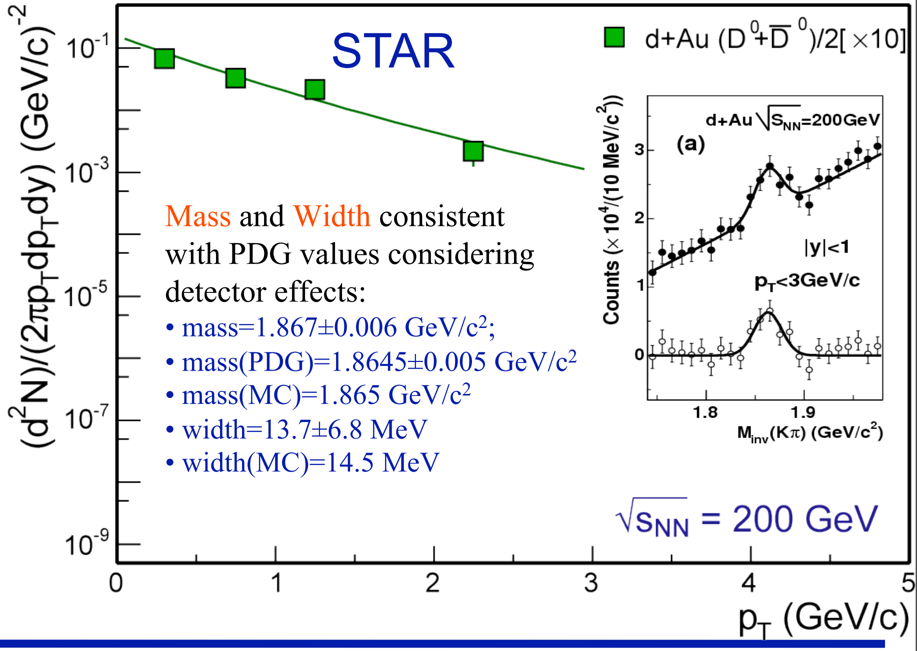

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RHIC upgrades,LHC:

accurate vertexing

cleaner signal

Conversion to total cross-section

Example from Cu+Cu D^0 measurement:

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

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

number of binary collisions $N_{binary}^{Cu+Cu} = 80.4 + 5.9 - 5.6$ 0 - 60% Centrality

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

conversion to full rapidity $f = 4.7 \pm 0.7$

(using PYTHIA simulation, ver. 6.152)

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

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

$$\mathrm{sys.\,error\,from\,dN/dy\,to\,\sigma\,conversion} = +0.17 - 0.18\,mb$$

A potential fly in the ointment

PYTHIA tells us:

$$\frac{D^+}{D^0} \approx 0.3 \qquad \frac{D_s^{\ +}}{D_s^{\ -}} \approx 1.1$$

$$\frac{D_s^{\ +}}{D^0} \approx 0.2 \qquad \frac{\Lambda_c^{\ +}}{D^0} \approx 0.16$$

Statistical recombination tells us:

$$\frac{D^+}{D^0} \approx 0.4 \qquad \frac{D_s^{\ +}}{D_s^{\ -}} \approx 1.$$

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A. Andronic et al. PLB 571 (2003)

They are different because many more strange quarks available in A+A collisions

It is NOT thermal production but thermal coalescence

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Need to measure these D's

$$D_s^+ \rightarrow \phi\,\pi^+ \ \text{(BR 3.6\%)}$$

$$\hookrightarrow K^+K^-$$

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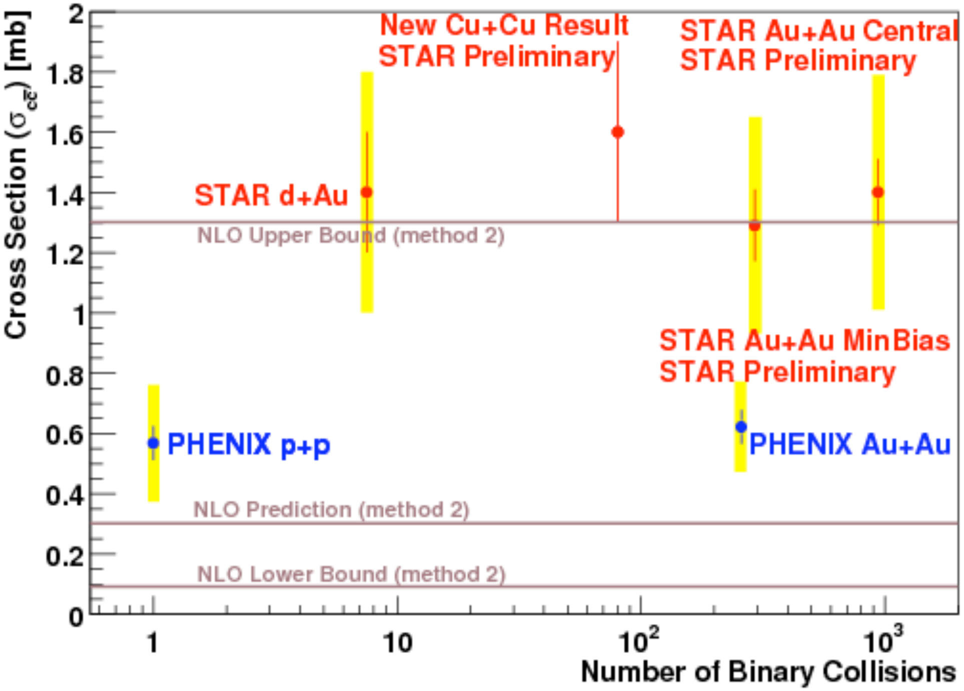
$D_s^+ \rightarrow \phi\, \pi^+$ (BR 3.6%)

$\hookrightarrow K^+K^-$

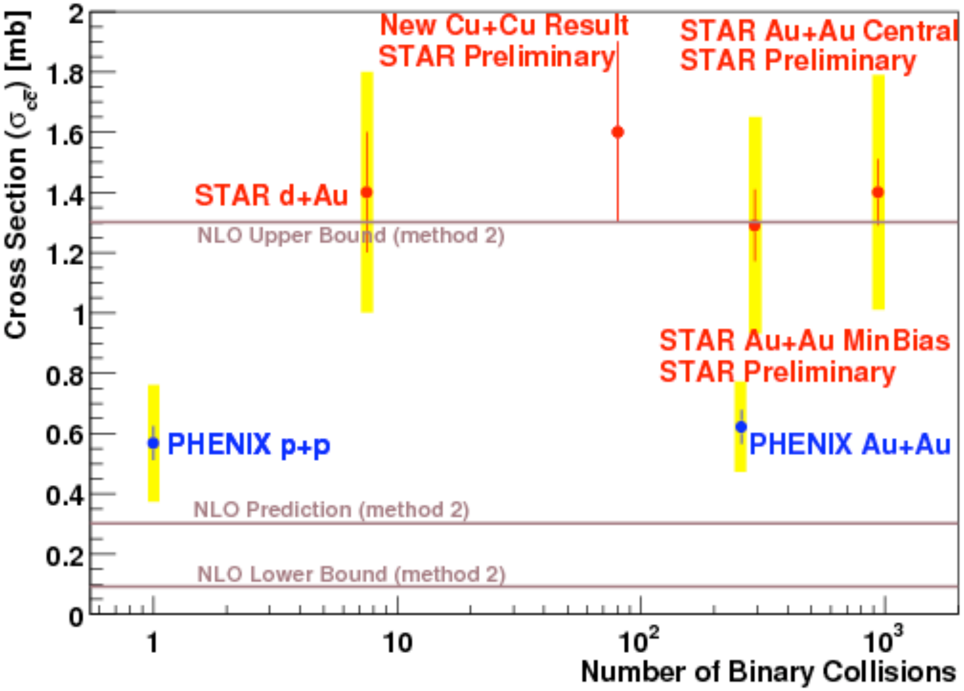
Should be feasible at LHC – more charm

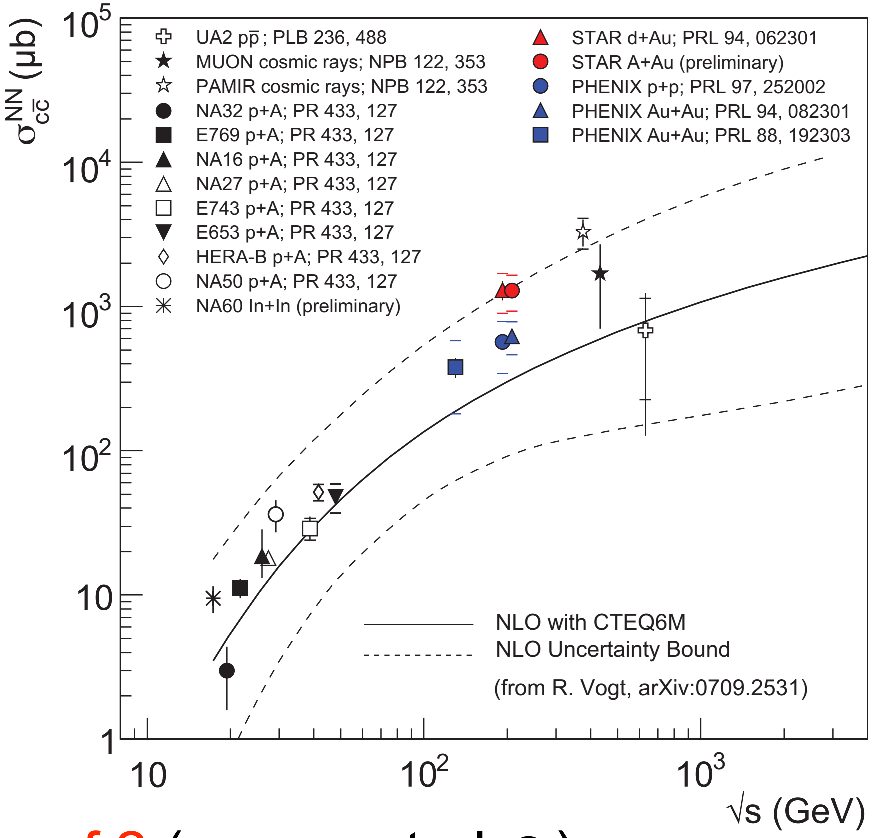
Total charm cross-section



- STAR and PHENIX differ by a factor of 2 (unexpected ☹)
- Charm cross-section is higher than NLO calculations but within errors

Total charm cross-section





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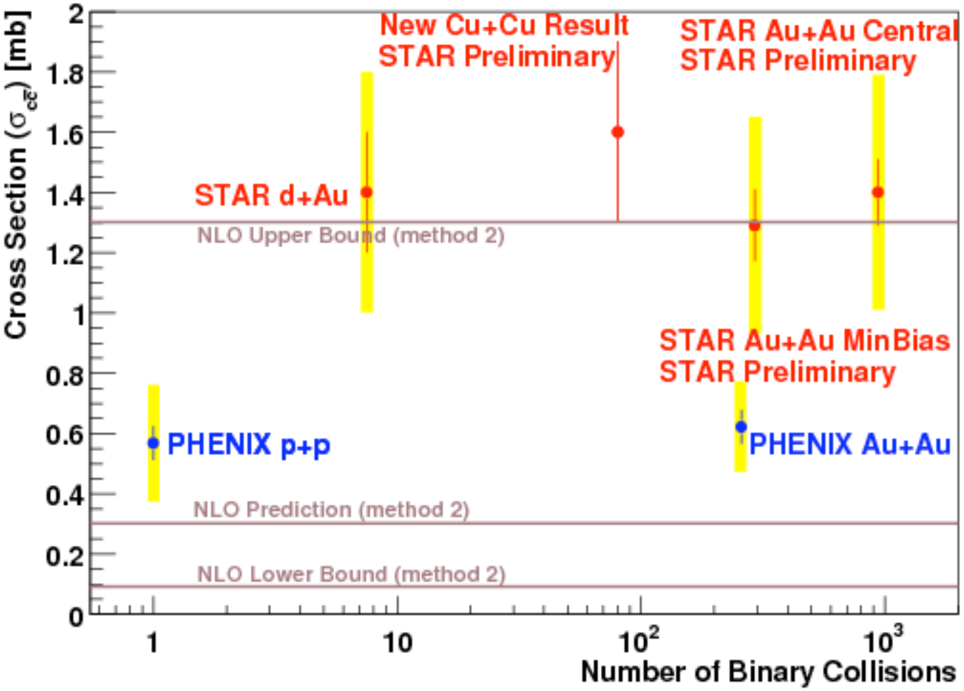
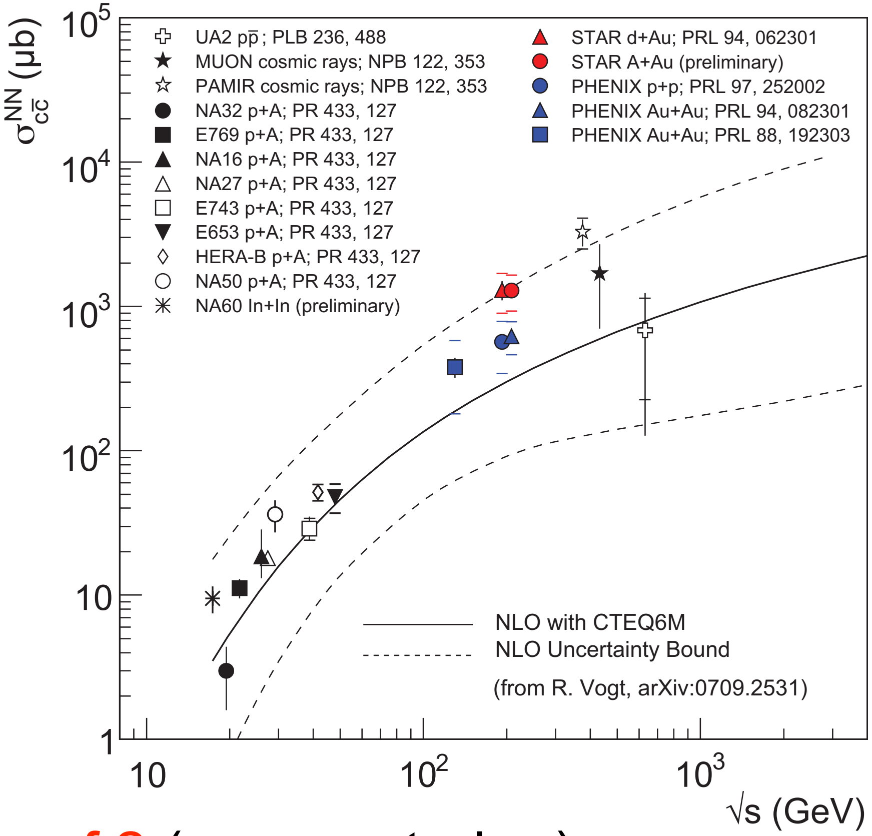




- STAR and PHENIX differ by a factor of 2 (unexpected ☹)

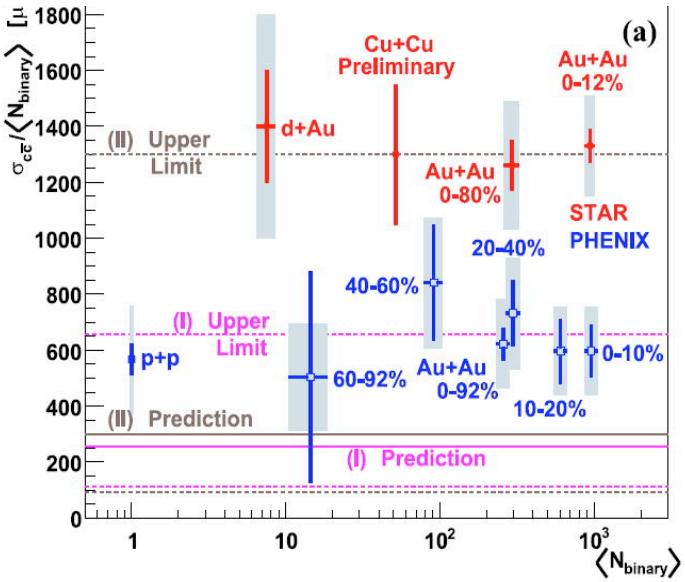
- Charm cross-section is higher than NLO calculations but within errors

Charm cross section scales with N_{bin}

Comparison of PHENIX and STAR

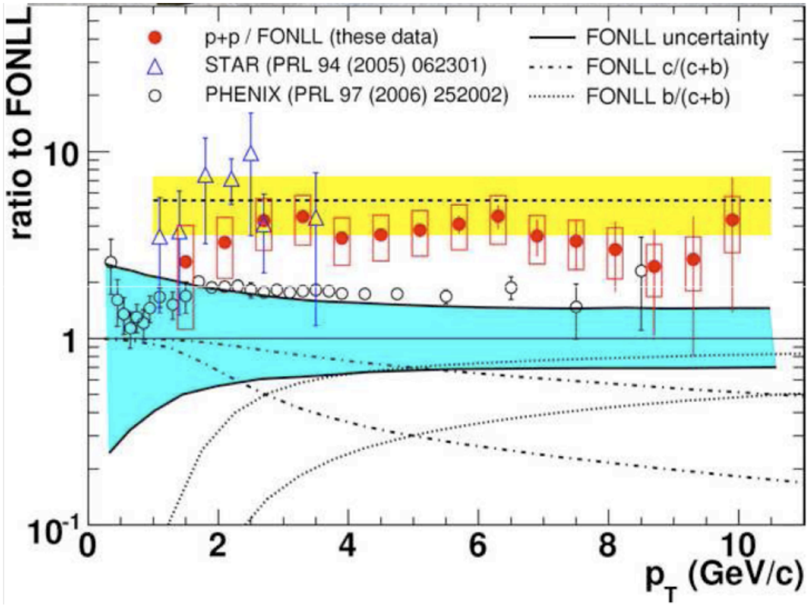
Discrepancy:

- There for all collision types
- There even when using multiple measuring techniques
- Constant as a function of p_T



What's being done to resolve issue?

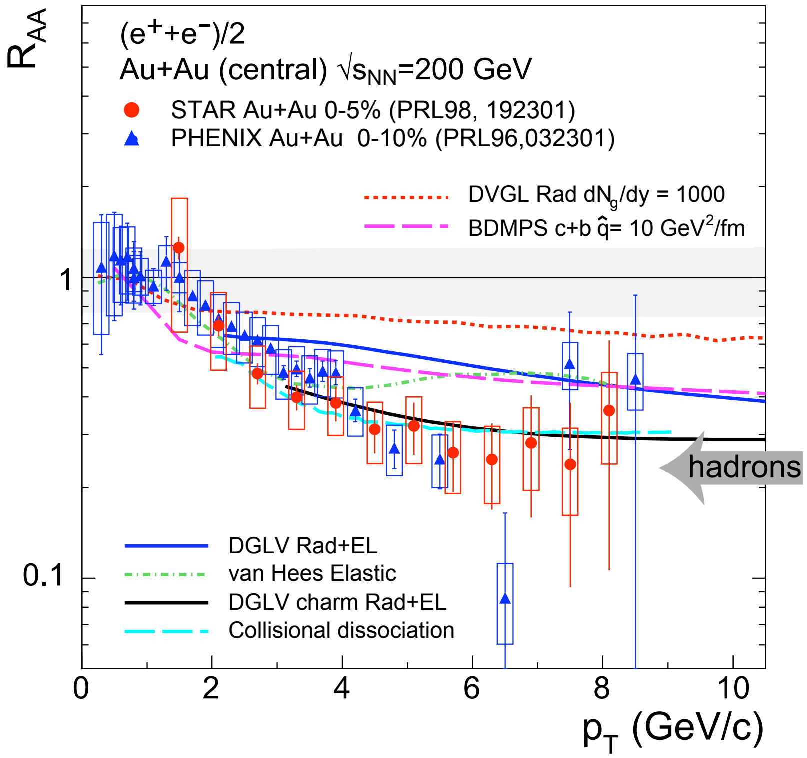
- Cross experiment meetings
- Low material 2008 run by STAR



Watch this space

Electrons equally suppressed - not gray

electrons from heavy flavor c,b→e X



- Substantial suppression on same level to that of light mesons
- Describing the suppression is difficult for models

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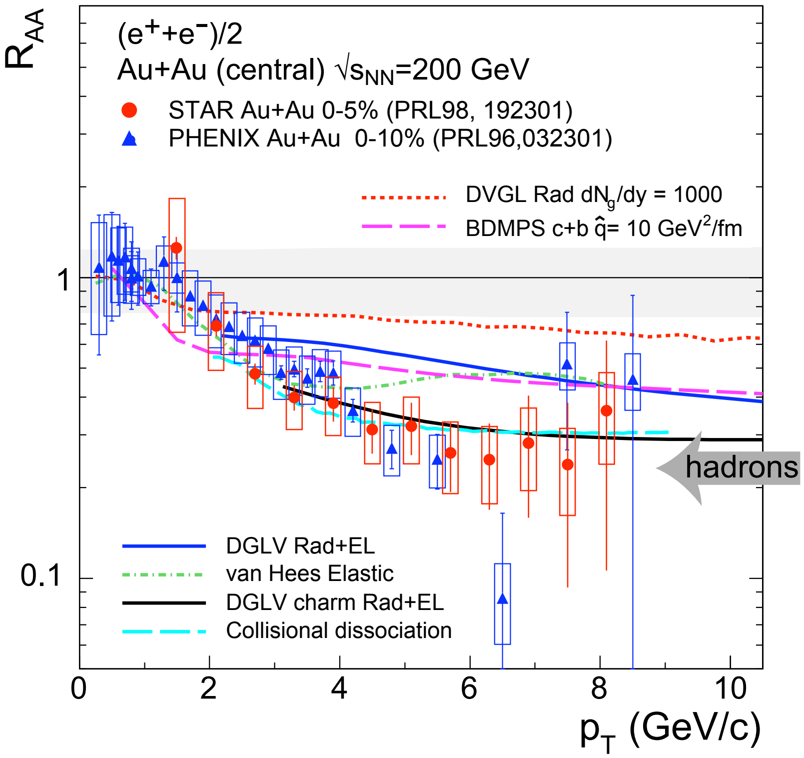


- Substantial suppression on same level to that of light mesons
- Describing the suppression is difficult for models

➡ radiative energy loss with typical gluon densities is not enough

(Djordjevic et al., PLB 632(2006)81)

➡ models involving a very opaque medium agree better

(Armesto et al., PLB 637(2006)362)

➡ collisional energy loss / resonant elastic scattering

(Wicks et al., nucl-th/0512076,
van Hees & Rapp, PRC 73(2006)034913)

➡ heavy quark fragmentation and dissociation in the medium → strong suppression for charm and bottom (Adil & Vitev, hep-ph/0611109)

➡ Radiative energy loss in a finite dynamical QCD medium

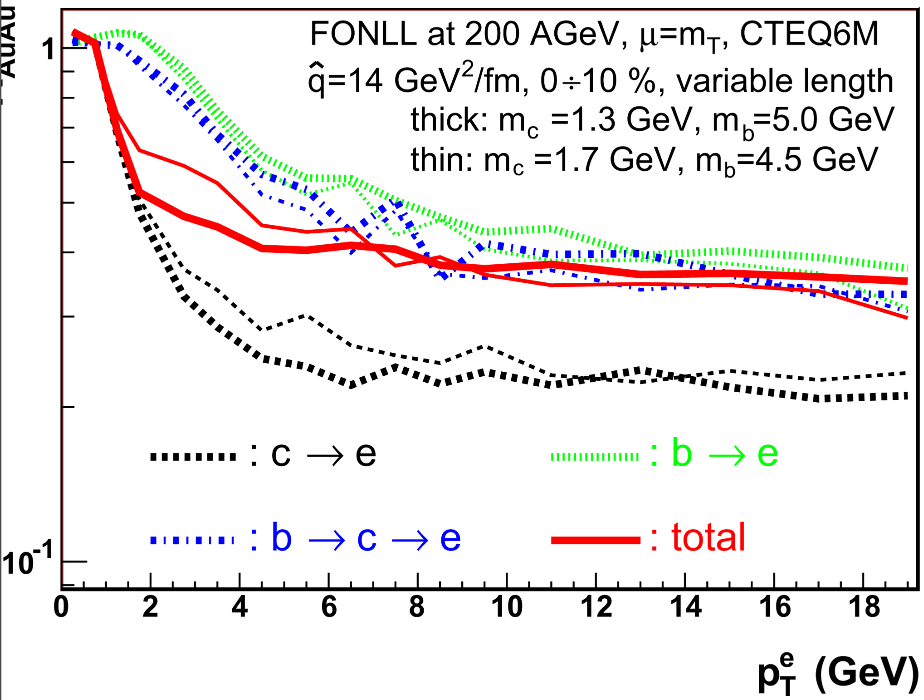
Djordjevic & Heinz, arXiv:0802.1230v1 (2008)

➡ Universal upper bound on Eloss

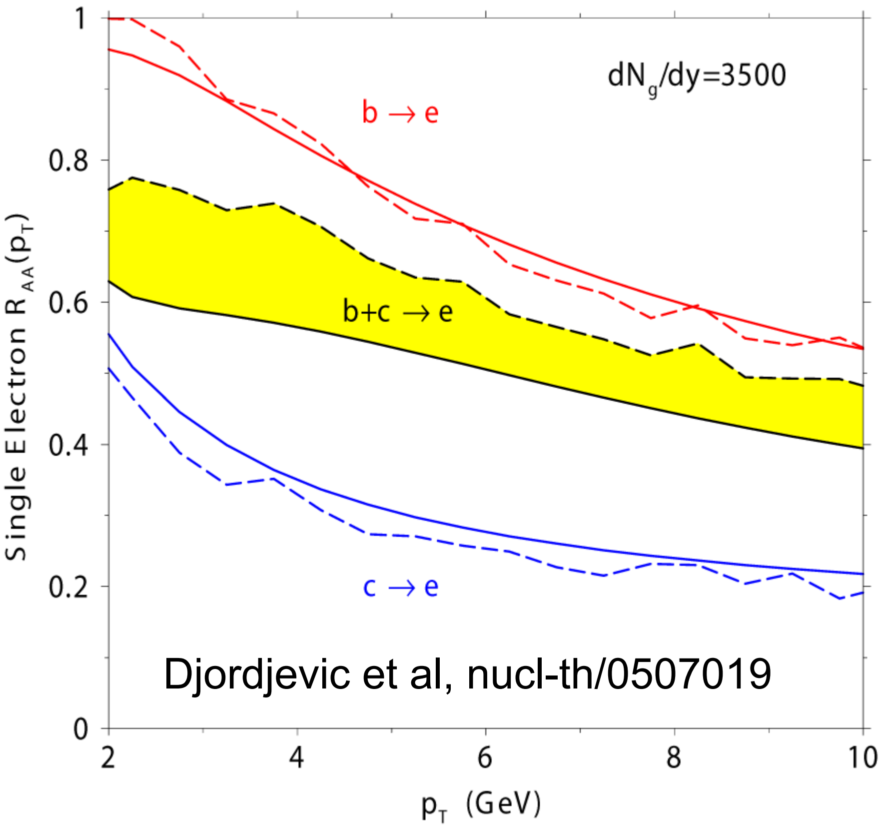
see talks by D. Kharzeev

Expectations for non-photonic $e^{\pm}$ R_{AA}

N. Armesto et al., private communication



See also Armesto et al, Phys. Rev. D71 (2005) 054027



Djordjevic et al, nucl-th/0507019

- R_{AA} combination of c and b
- Different suppression for c and b

Little suppression of heavy flavor

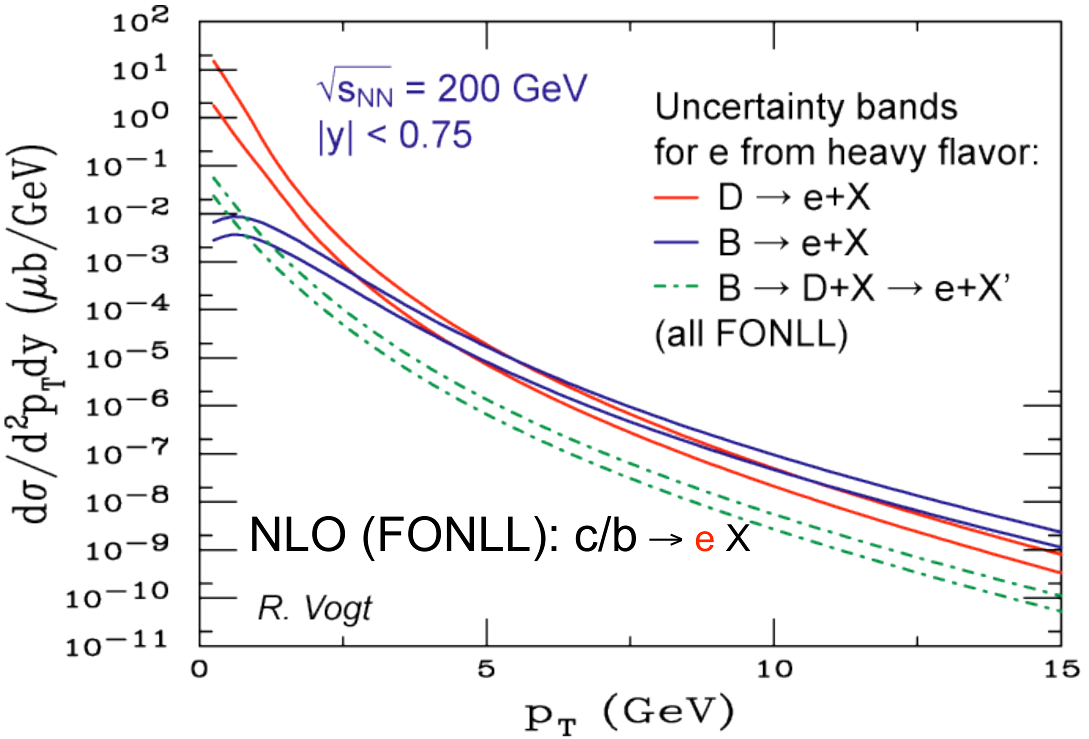
Disentangling charm and bottom

- Semileptonic decay modes:
  - $c \rightarrow e^{\pm}$ + anything (B.R.: 9.6%)
    - $D^0 \rightarrow e^{\pm}$ + anything (B.R.: 6.87%)
    - $D^{\pm} \rightarrow e^{\pm}$ + anything (B.R.: 17.2%)
  - $b \rightarrow e^{\pm}$ + anything (B.R.: 10.9%)
    - $B^{\pm} \rightarrow e^{\pm}$ + anything (B.R.: 10.2%)
  - $\mu^{\pm}$ decay modes

Theory says:

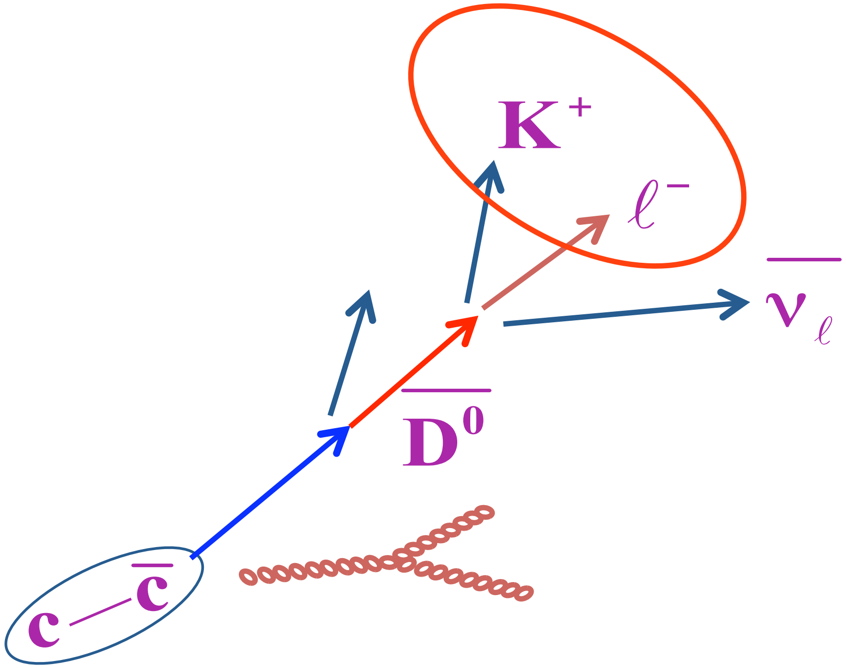
- *b* decays should dominate at high p_T
- crossover ~5 GeV/*c* but large uncertainty

Need experiments to determine for themselves



Finding c/b: method 1 - PHENIX

Separate c→e component using the charge correlation of K and e from D-meson decay.



D-mesons decay into unlike sign e-K pairs:

$$\bar{D} \rightarrow K^+ e^- X$$

$$D \rightarrow K^- e^+ X$$

B-meson decays are like sign e-K pairs (there's a small contribution from unlike pairs(1/6))

Can determine the contribution of c→e by measuring the fraction associated with opposite sign kaon, or opposite sign charged hadron

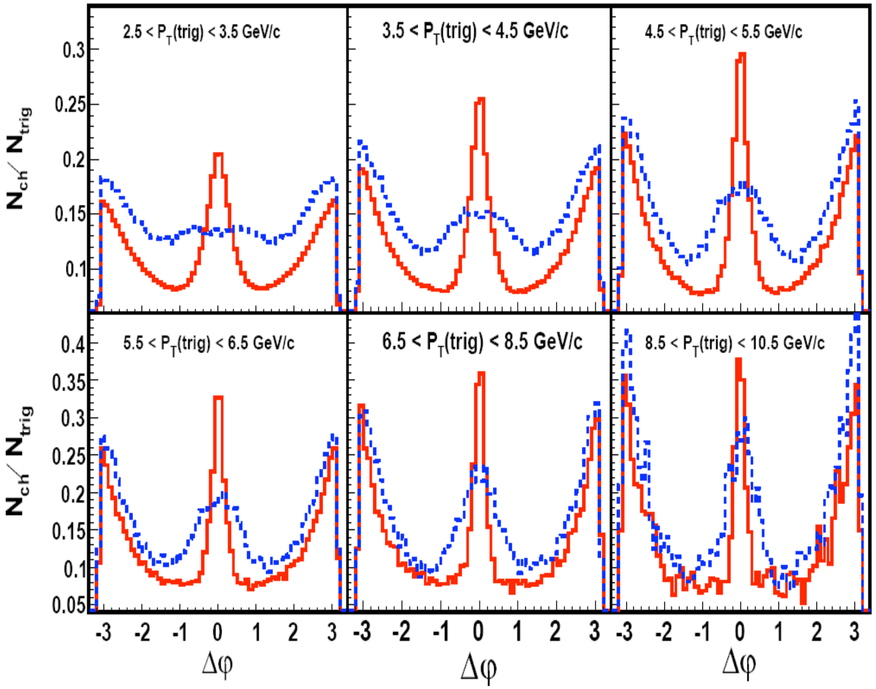
(Actual analysis is done as e-h charge (i.e. no kaon PID) correlation for higher statistic)

Finding c/b: method 2 - STAR

Azimuthal angular correlation of e-h pairs from c or b decays (small angle ⇒ from same decay as e)

- Width of near-side correlations largely due to decay kinematics.
  - B decay has larger Q value
- c, b: significant difference in the near-side correlations.

PYTHIA: blue=bottom, red=charm



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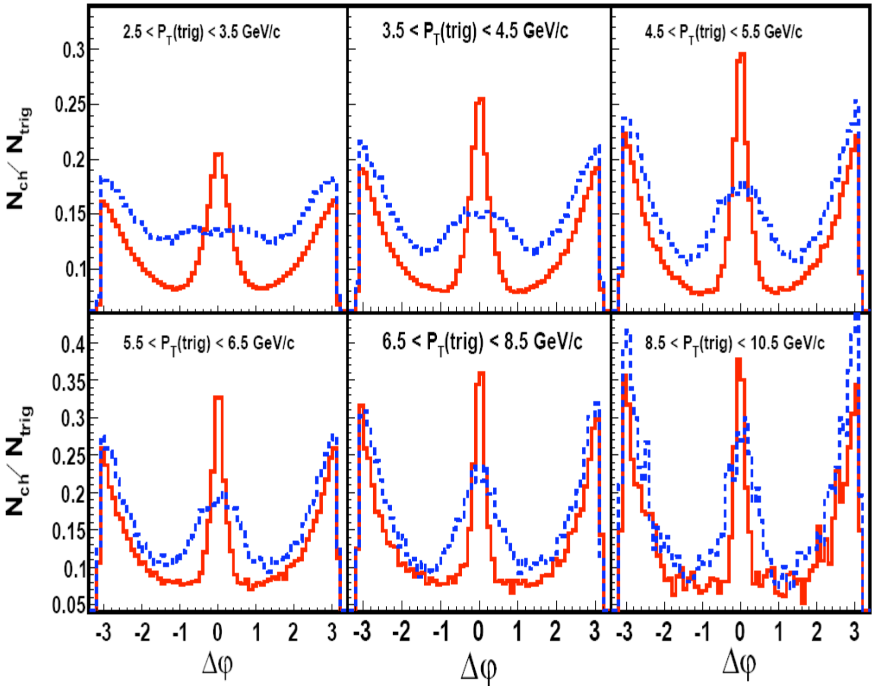
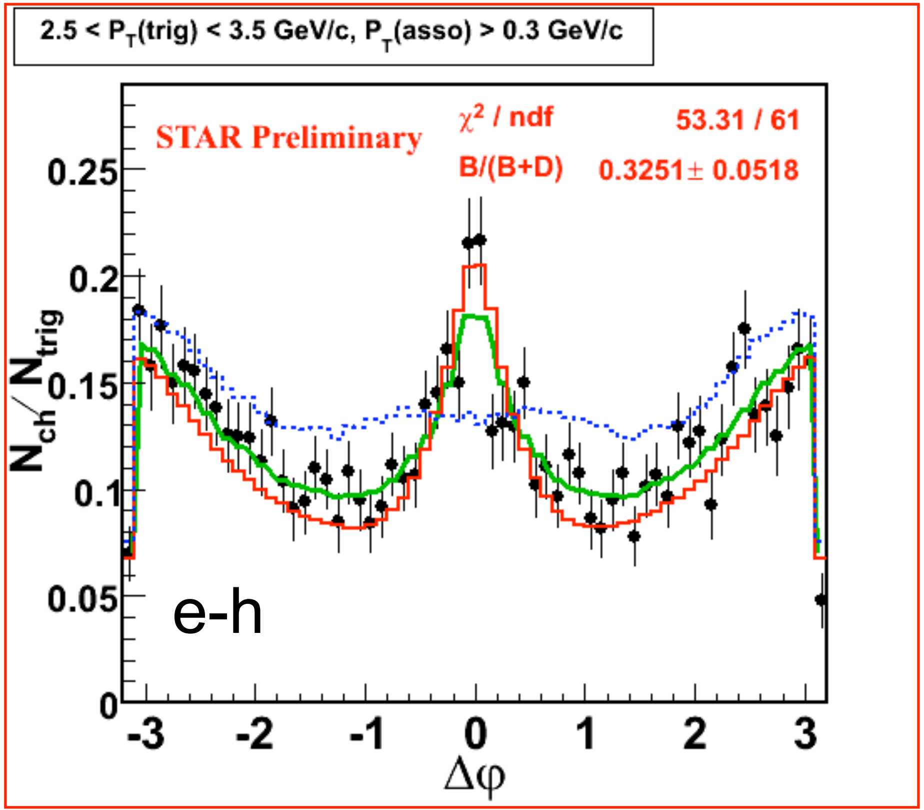


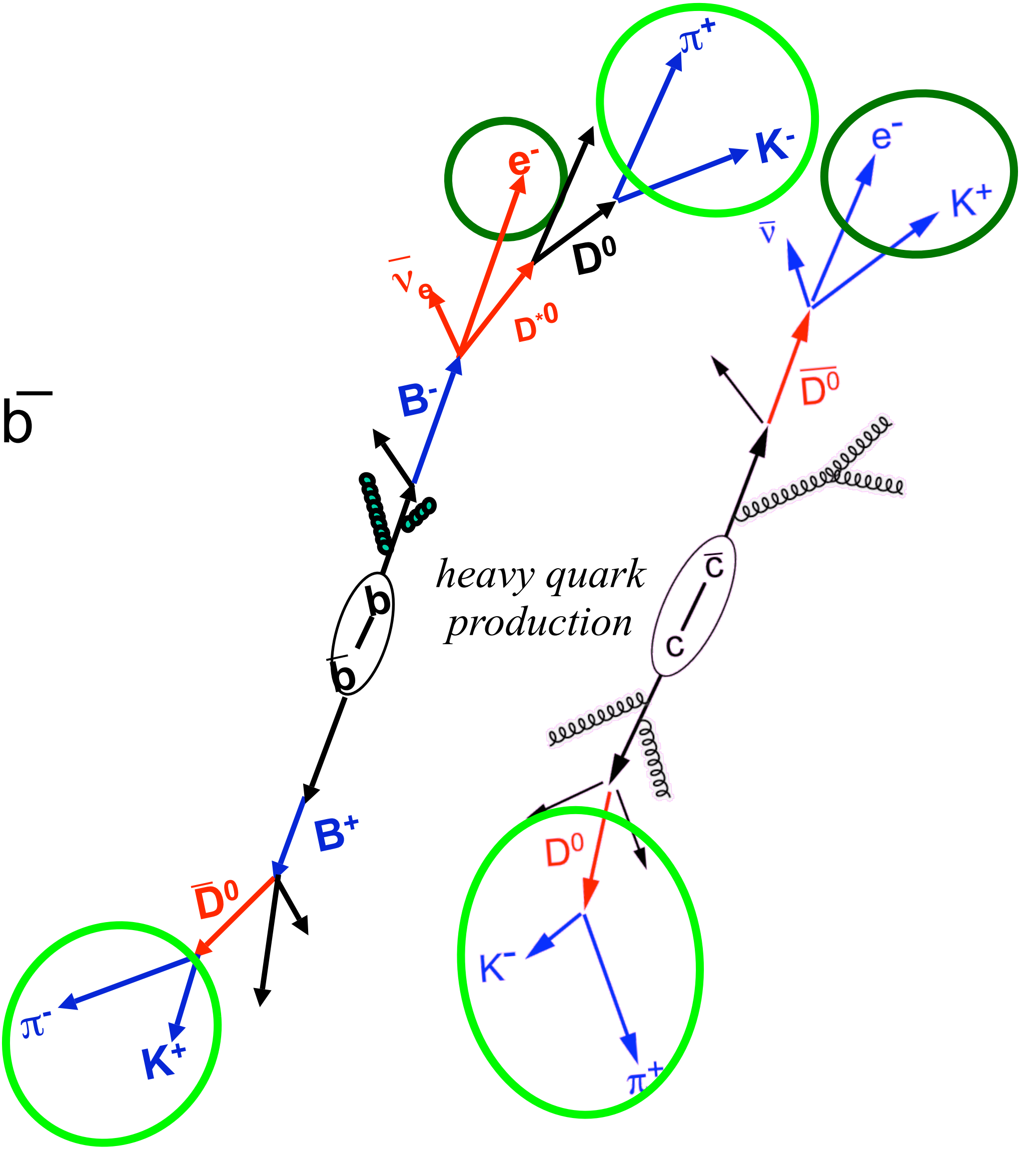


Finding c/b: method 3 - STAR

e-D^0 correlations

- non-photonic electrons from semi-leptonic charm decays are used to trigger on c-$\bar{c}$, b-$\bar{b}$ pairs

- back-2-back D^0 mesons are reconstructed via their hadronic decay channel (probe)



Finding c/b: method 3 - STAR

e-D^0 correlations

- non-photonic electrons from semi-leptonic charm decays are used to trigger on $c\text{-}\bar{c}$, $b\text{-}\bar{b}$ pairs

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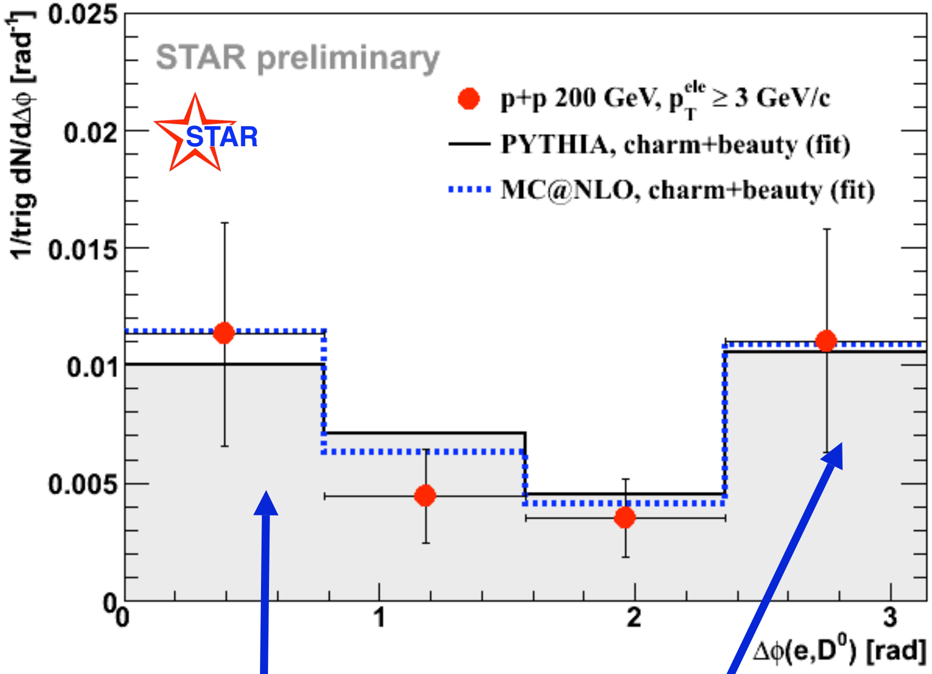
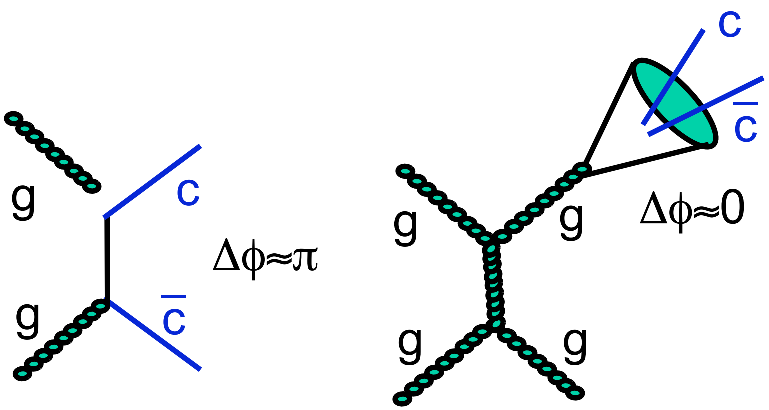


essentially from B decays only

≈75% from charm
≈25% from beauty

What about gluon splitting?

- Second charm particle could come from gluon splitting



flavor creation

gluon splitting/
fragmentation

- NLO QCD computations with a realistic parton shower model

- S. Frixione, B.R. Webber, JHEP 0206 (2002) 029
- S. Frixione, P. Nason, and B.R. Webber, JHEP 0308 (2003) 007
- private code version for charm production

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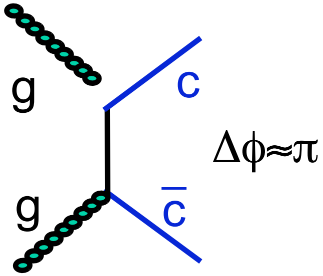
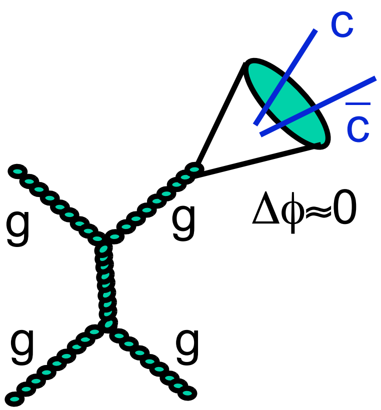


flavor creation



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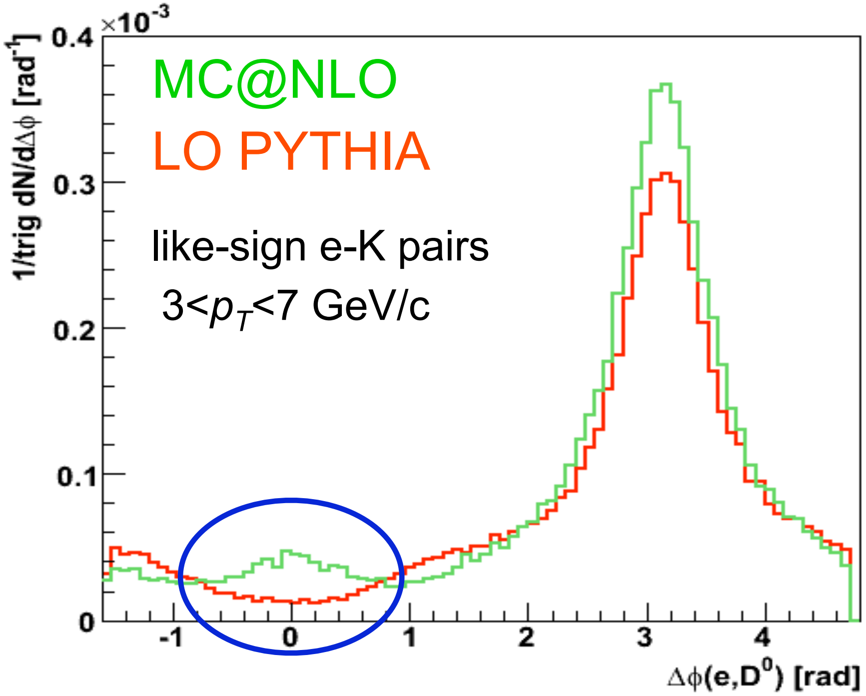
- Away-side peak shape: remarkable agreement between LO PYTHIA and MC@NLO

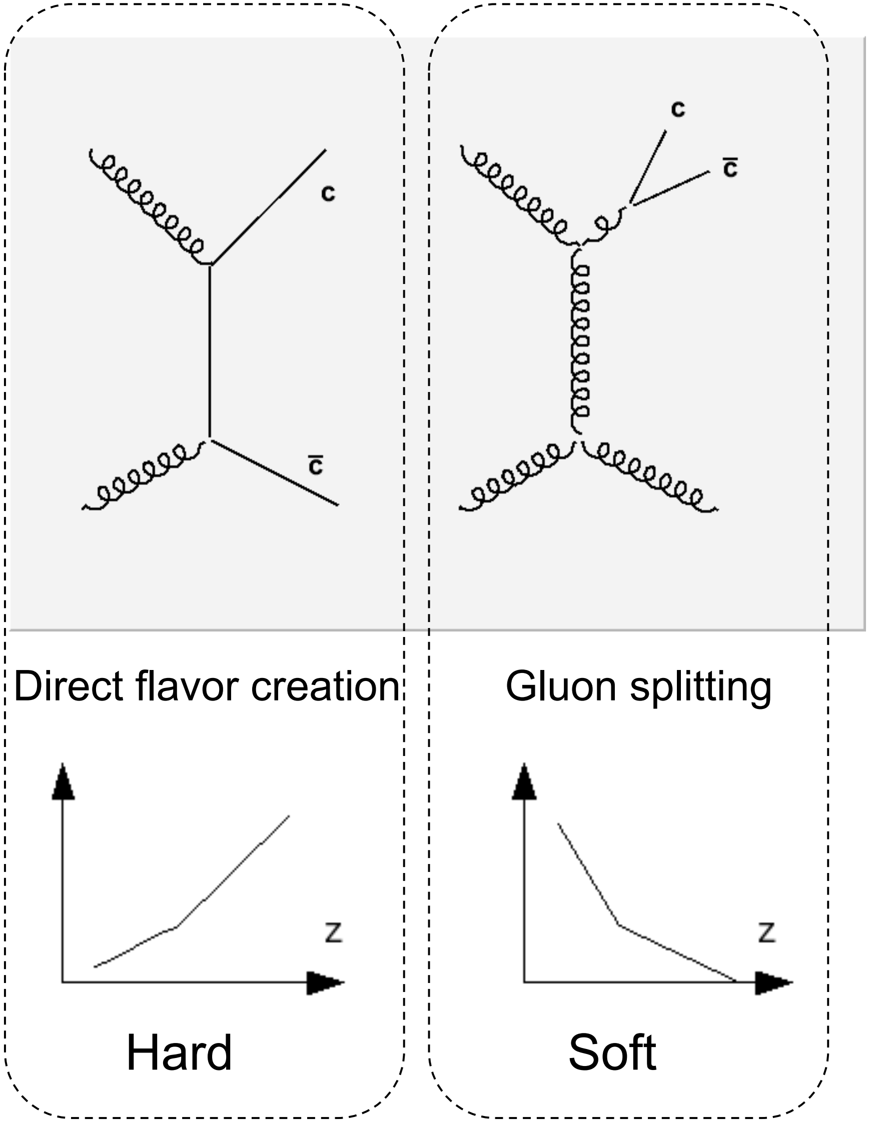


Near-side: GS/FC ≈ 5%
→ small gluon splitting contribution

Checking gluon splitting experimentally

Relies on theory

- Check QCD prediction



Direct flavor creation

Gluon splitting

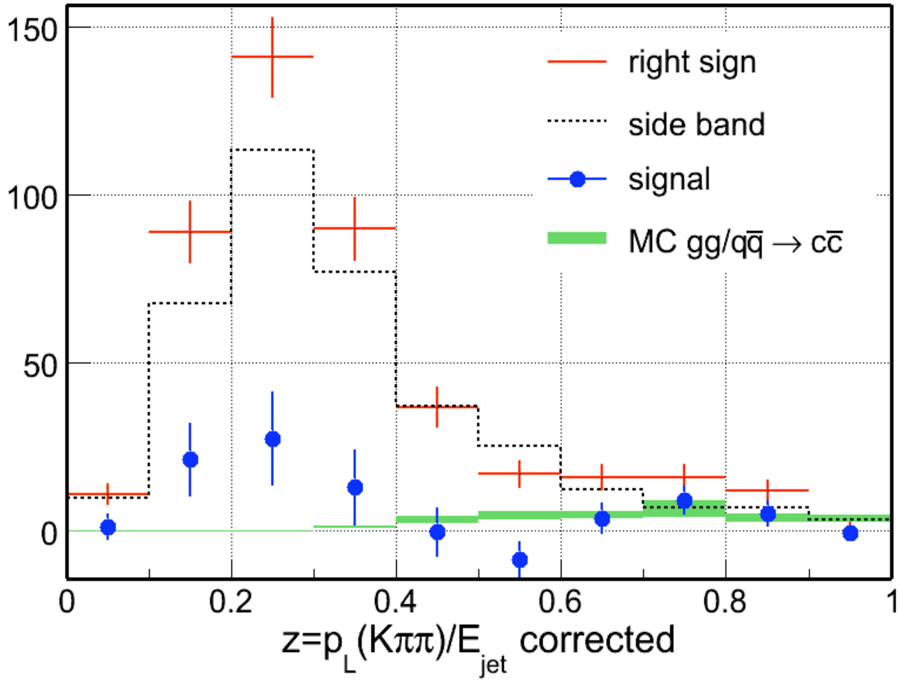
Hard

Soft

Checking gluon splitting experimentally

Relies on theory

- Check QCD prediction
- Determine STAR’s jet trigger sensitivity on z

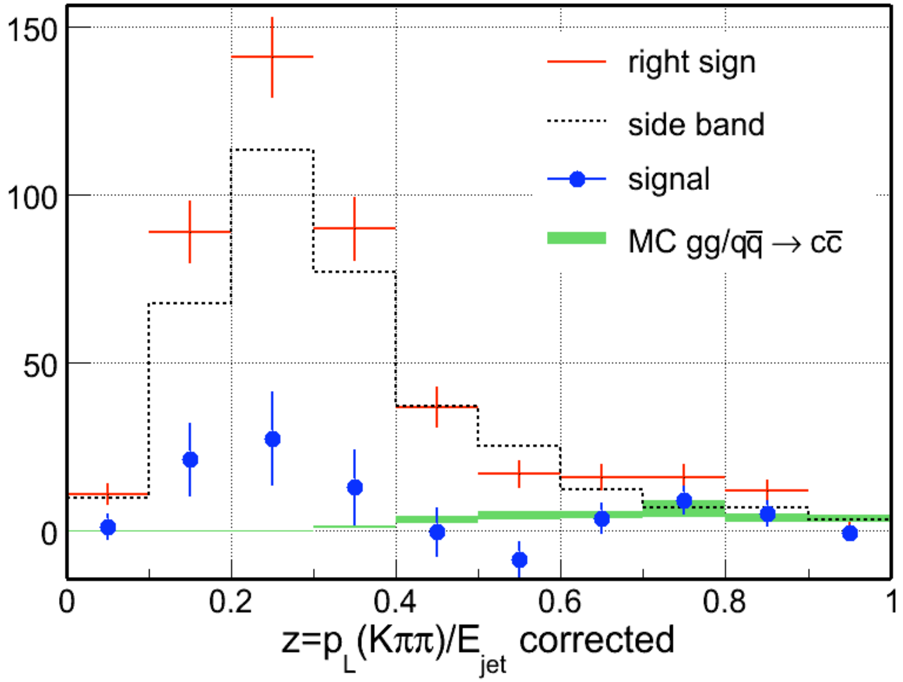


$p_L(K)$: momentum projection of K on jet axis

Checking gluon splitting experimentally

Relies on theory

- Check QCD prediction
- Determine STAR's jet trigger sensitivity on z
- Find the jets...



$p_L(K)$: momentum projection of K on jet axis

Checking gluon splitting experimentally

Relies on theory

- Check QCD prediction
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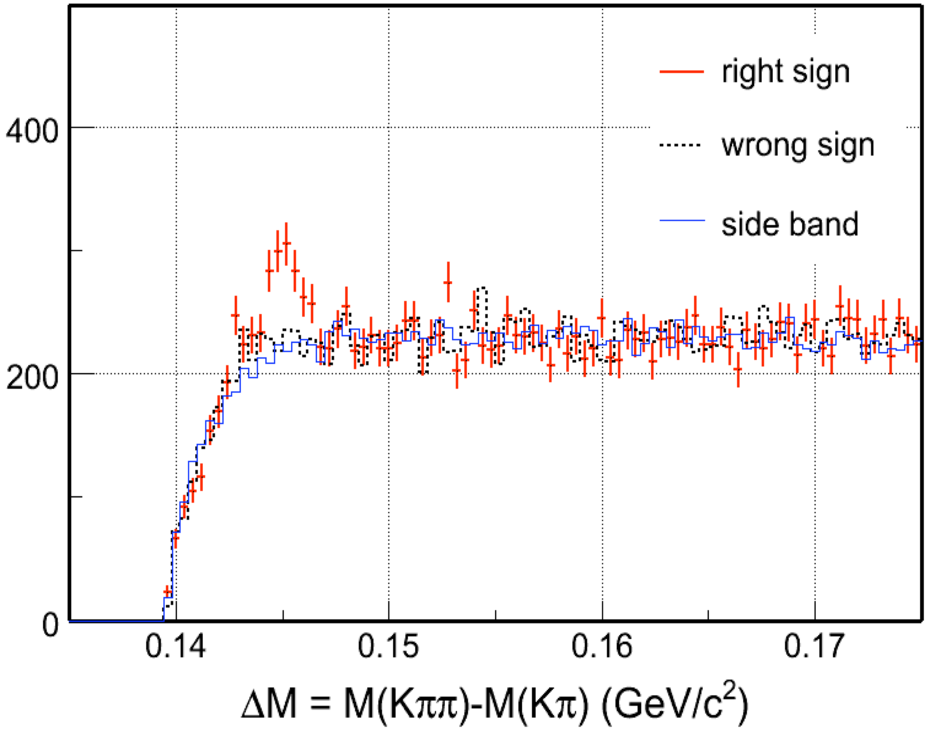
- Find the jets...
- Look for D* in the cone

$$D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$$

$$m_{D^{*+}} - m_{D^0} = 145.421 \pm 0.010 MeV$$



right sign: $K^-\pi^+\pi^+$

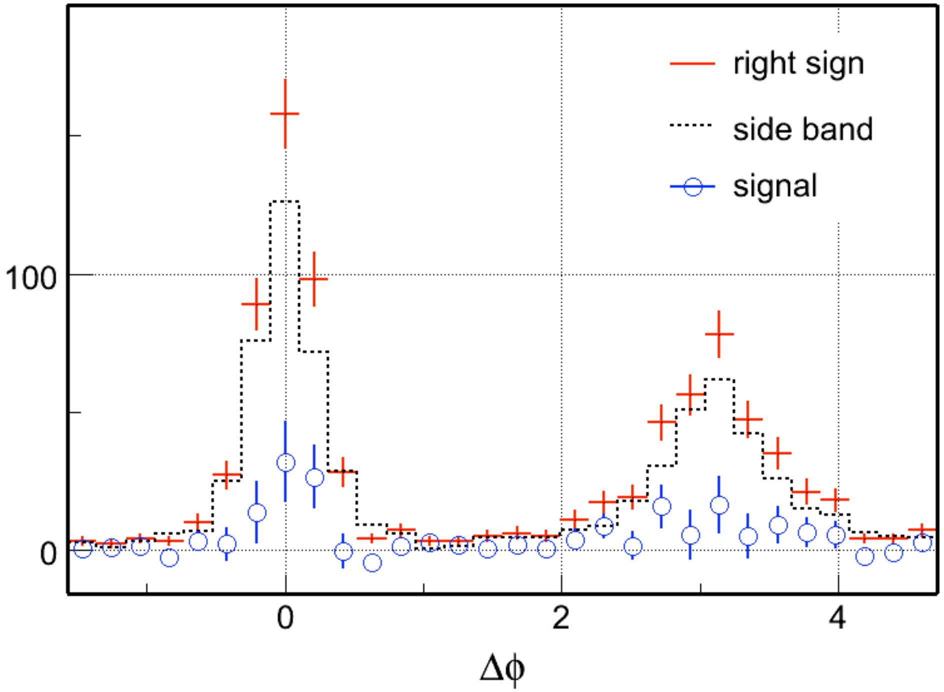
wrong sign: $K^-\pi^-\pi^+$

Checking gluon splitting experimentally

Relies on theory

- Check QCD prediction
- Determine STAR's jet trigger sensitivity on z
- Find the jets...
- Look for D* in the cone
- D*-jet azimuthal correlations

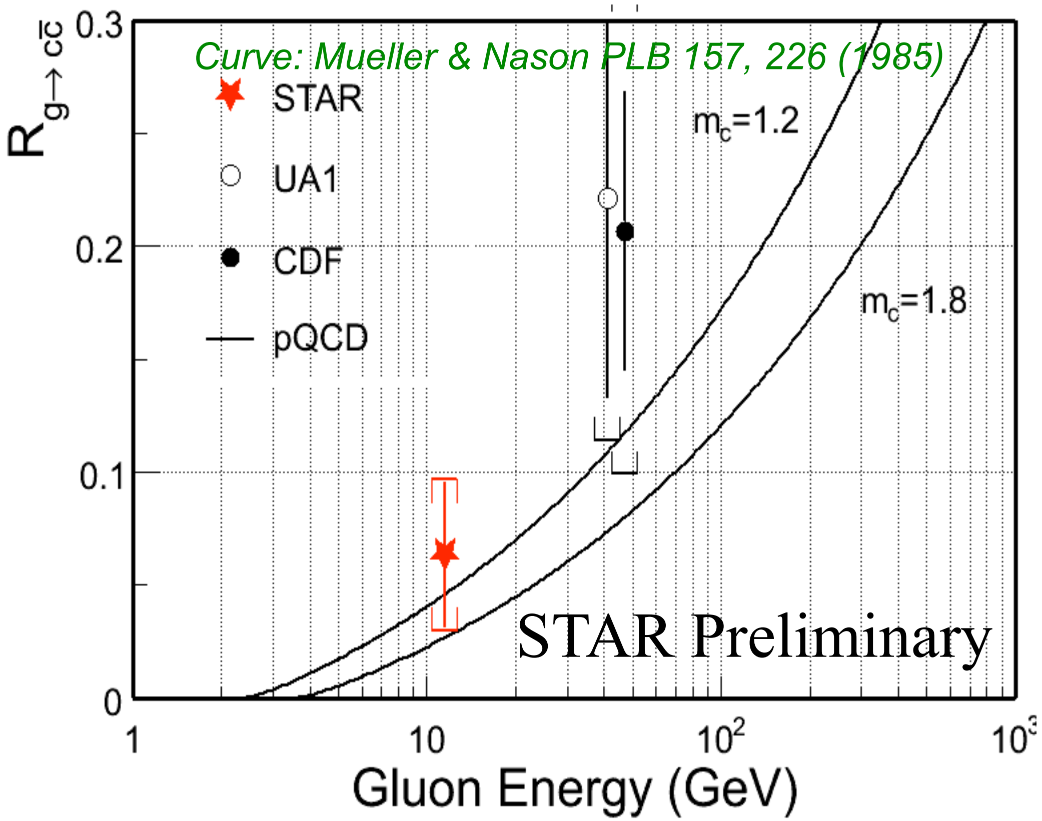
D* - jet correlation



Checking gluon splitting experimentally

Relies on theory

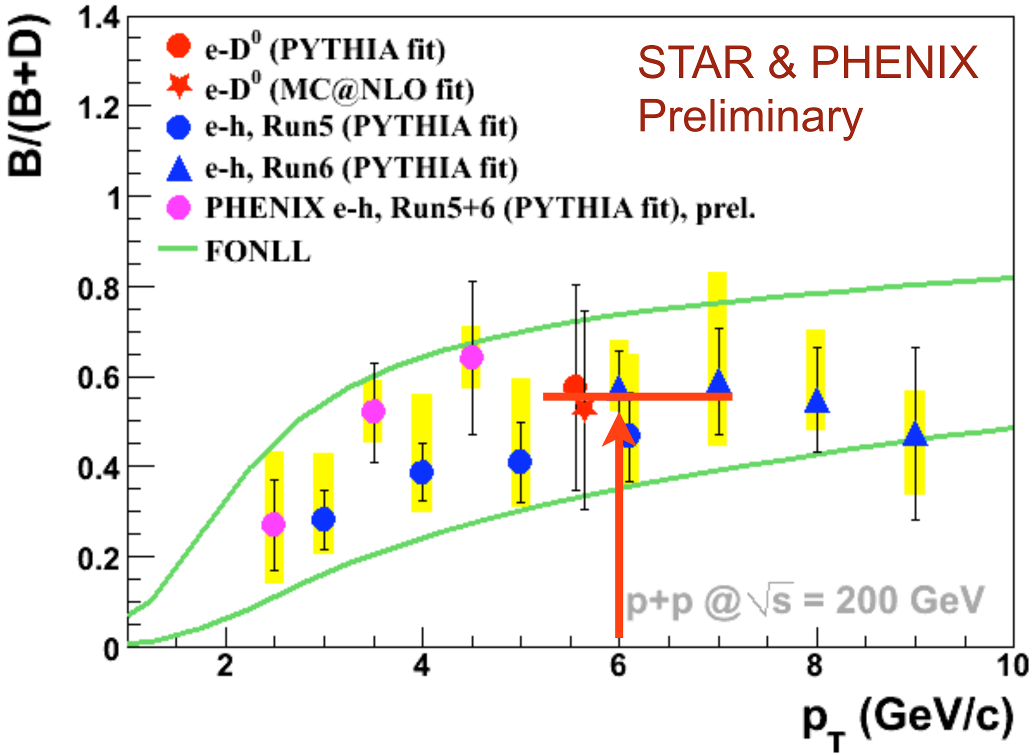
- Check QCD prediction
- Determine STAR's jet trigger sensitivity on z
- Find the jets...
- Look for D* in the cone
- D*-jet azimuthal correlations
- Contribution is very small



$$N(D^{*+}+D^{*-})/N(\text{jets}) = (1.5 \pm 0.8 \pm 0.5) \times 10^{-2}$$

$0.2<z<0.5$, $\langle E_T \rangle \sim 11$ GeV

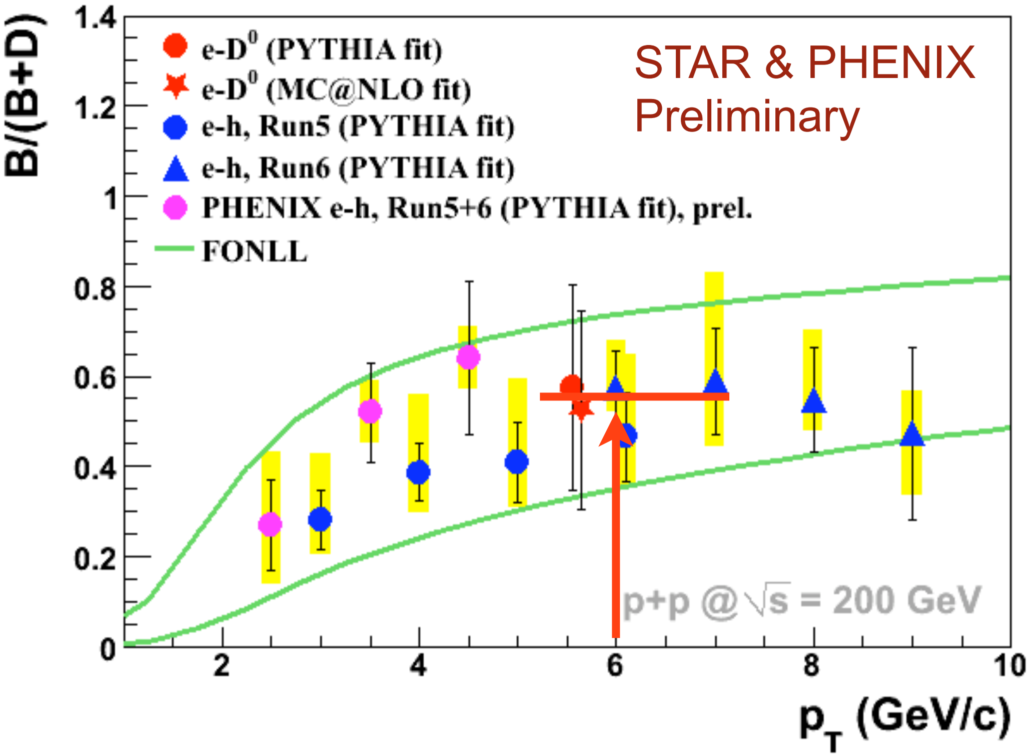
The bottom contribution

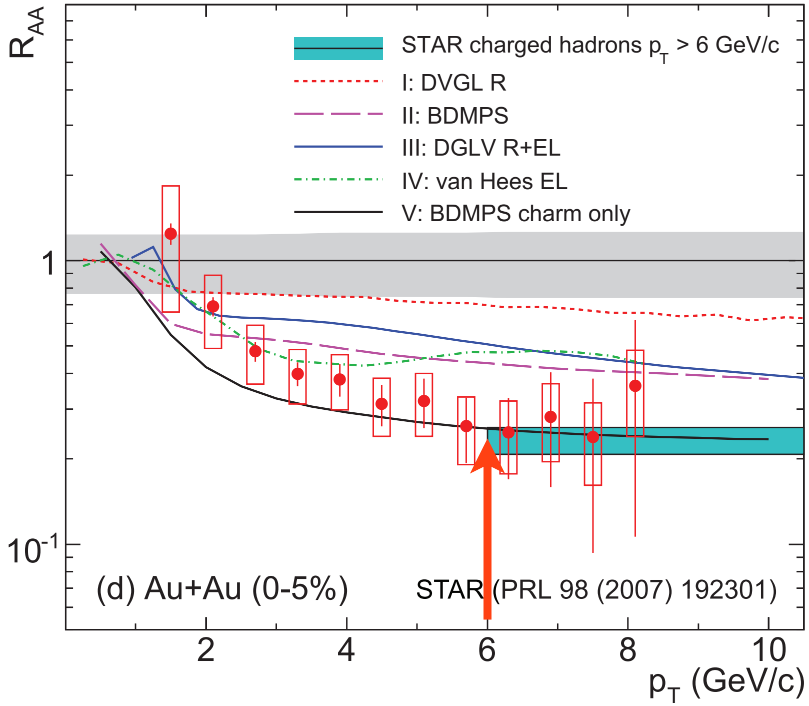


Correlation measurements in STAR and PHENIX agree and constrain beauty contribution to non-photonic electrons in p+p collisions

~55% bottom at p_T^e = 6 GeV/c

The bottom contribution





Correlation measurements in STAR and PHENIX agree and constrain beauty contribution to non-photonic electrons in p+p collisions

~55% bottom at p_T^e = 6 GeV/c

Beauty appears to be strongly suppressed

What is $R_{AA}{}^{b}$?

We measured R_{AA} (for electrons) and r (for electrons). We do not know $R_{AA}{}^{c}$ and $R_{AA}{}^{b}$ but we can look at one as the function of the other avoiding **any** model dependence.

$$R_{AA} = \frac{Y^c_{AA} + Y^b_{AA}}{\langle N_{bin} \rangle (\sigma^c_{pp} + \sigma^b_{pp})} = r R^b_{AA} + (1-r) R^c_{AA} \quad \text{where } r = \frac{\sigma^b_{pp}}{\sigma^c_{pp} + \sigma^b_{pp}}$$

$$R^b_{AA} = \frac{R_{AA} + (r-1) R^c_{AA}}{r}$$

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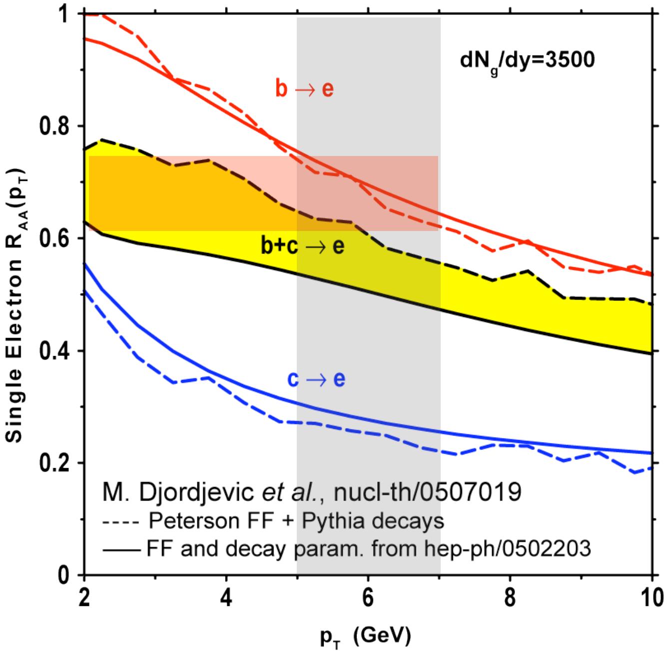
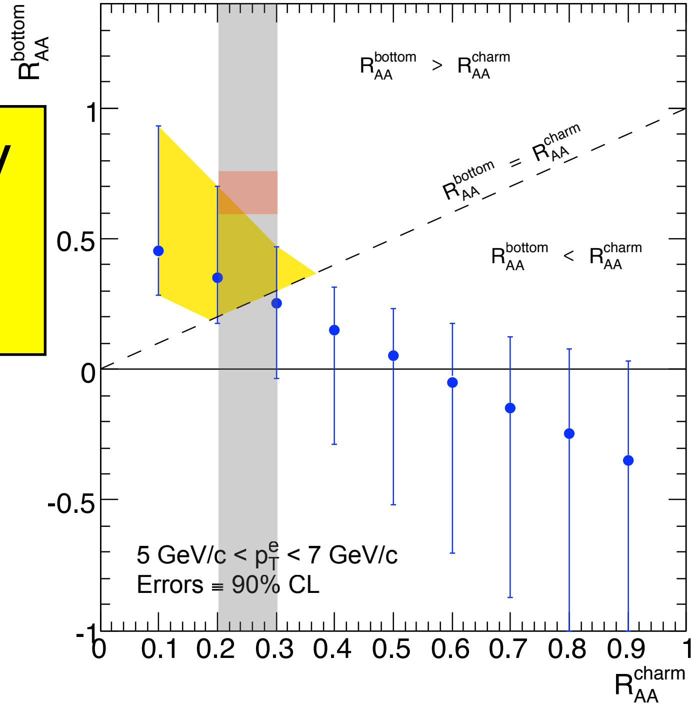


Data and theory still consistent! just!!

Urgently need independent c and b measurements

Statistical Analysis (STAR data only)



Thermalization of heavy flavor?

Recall discussion of elliptic flow:

- Observe large v_2 for light hadrons
- Large v_2 indicates *early* thermalization

Reminder when measured w.r.t. reaction plane:

$dN/d\varphi \sim 1+2\, v_2(p_T)\cos(2\varphi) + \ldots.$

v_2 measures Elliptic Flow

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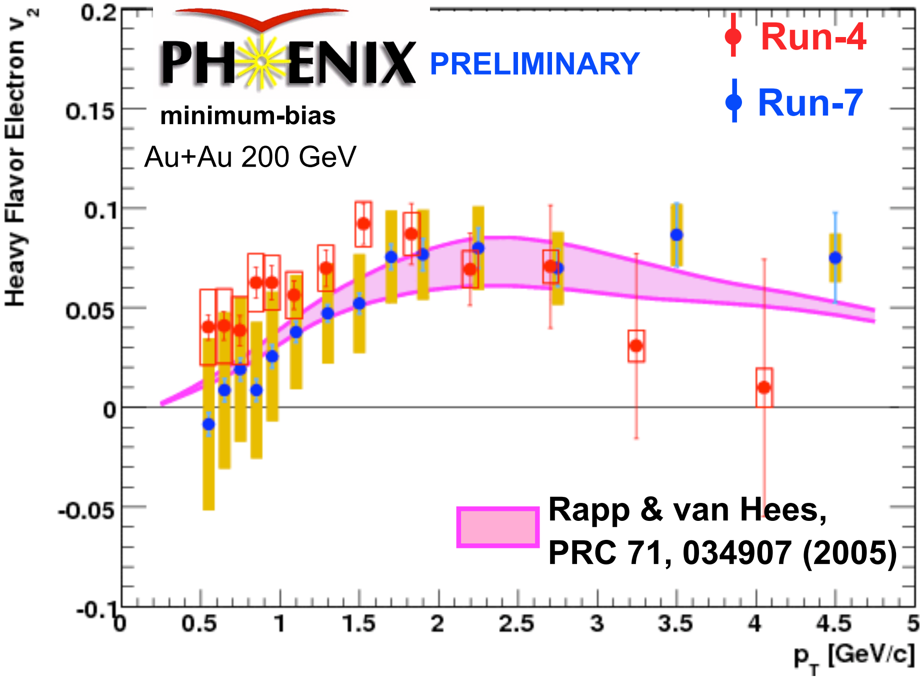
v_2 measures Elliptic Flow

If there's significant collisional energy loss is heavy flavor thermalized?

- Naïve kinematical argument: need $M_c/T \sim 7$ times more collisions to thermalize

- NPE carry v_2 of parent



There is a significant v_2 of NPE - thermalization?

Open heavy flavor summary

Binary scaling of total charm cross-section

Large cross-section compared to theory

NPE indicate strong suppression at high p_T

- similar to that of light hadrons

Significant Bottom contribution to NPE measure

Small gluon splitting contribution

Significant elliptic flow of NPE

- sufficient collisions for thermalization?

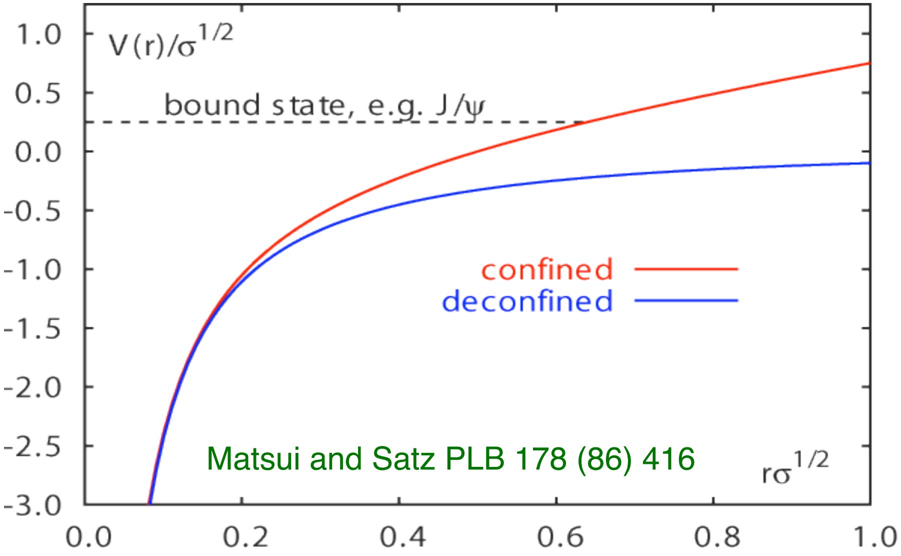
Quarkonia and deconfinement

Charmonia: J/ψ, Ψ', χ_c

Bottomonia: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

- Color screening of static potentials between heavy quarks

- Suppression of states is determined by T and their binding energy



Matsui and Satz PLB 178 (86) 416

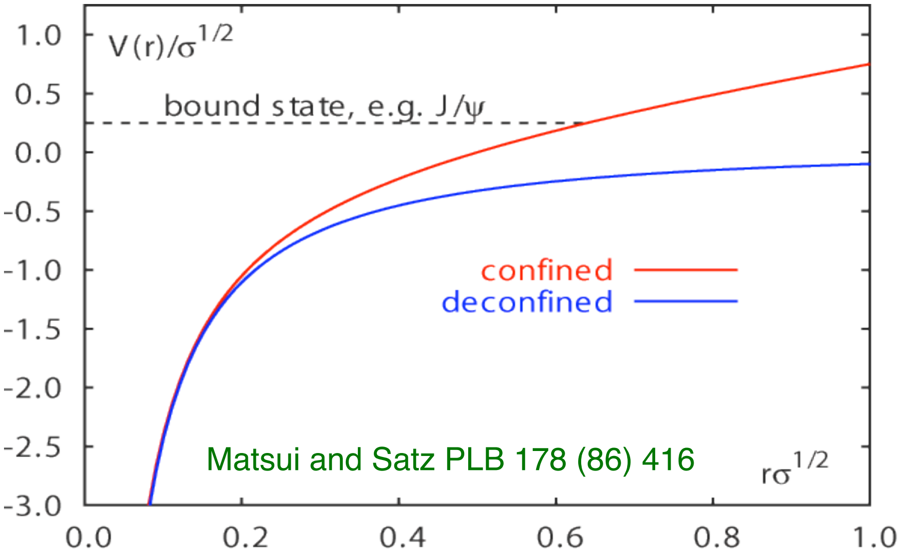
Quarkonia and deconfinement

Charmonia: J/ψ, Ψ', χ_c

Bottomonia: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

- Color screening of static potentials between heavy quarks
- Suppression of states is determined by T and their binding energy
- Sequential disappearance of states:
  - ⇒ Color screening
    - ⇒ Deconfinement
  - ⇒ QCD thermometer
    - ⇒ Properties of QGP

This is the only clear
signature of deconfinement
on the market



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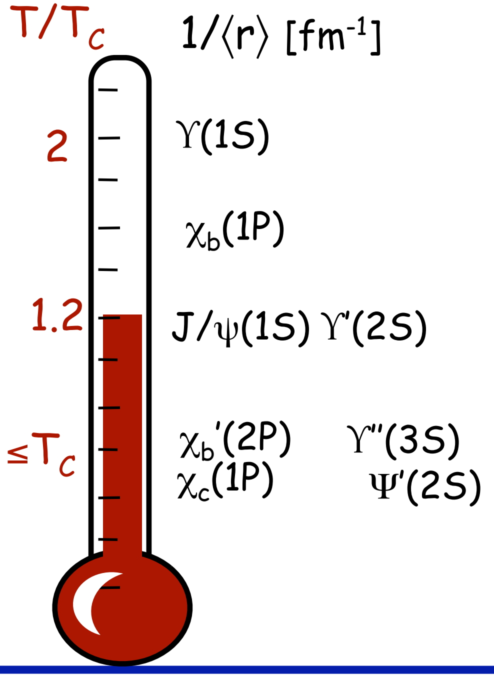


Theory ...

Spectral Functions

- Lattice
  - J/ψ melts at 1.5-2.5 T_C ?
- Potential models
  - Melting temperatures lower than lattice (but consistent)

AdS/CFT

- Hot Wind Dissociation

many, many more ....

Theory ...

Spectral Functions

- Lattice
  - J/ψ melts at 1.5-2.5 T_C ?
- Potential models
  - Melting temperatures lower than lattice (but consistent)

AdS/CFT

- Hot Wind Dissociation

many, many more ....

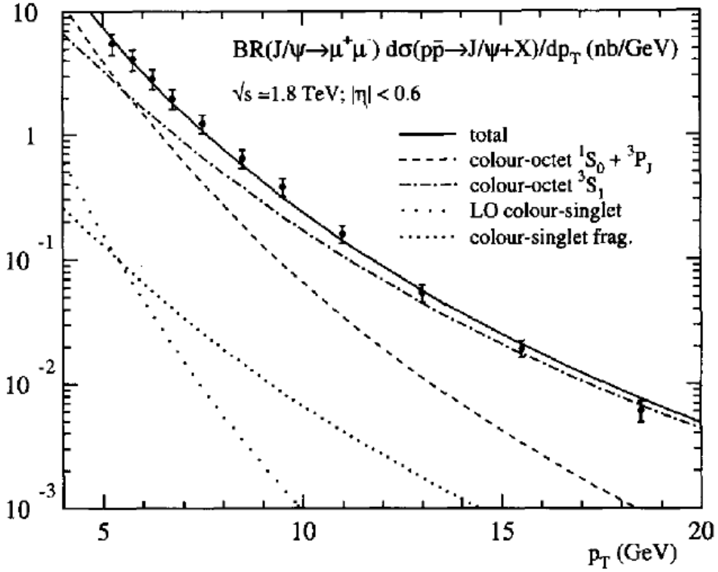
Different (lattice) calculations do not agree on what is screened at what temperature – measurements will have to tell!

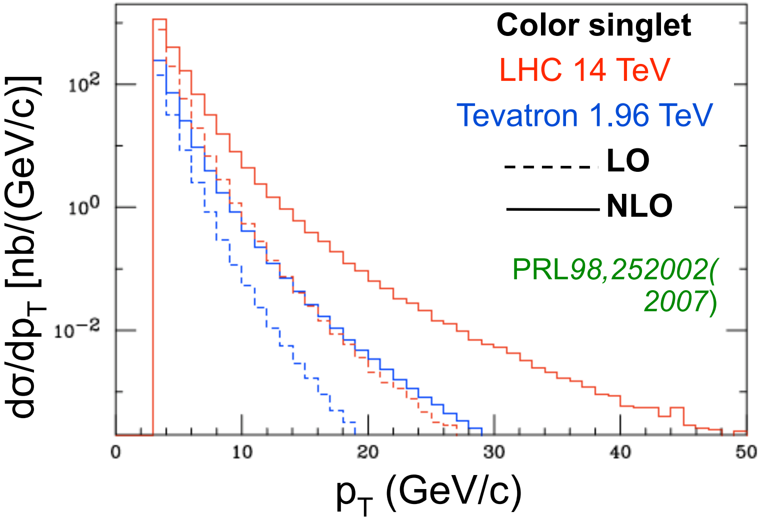
What theory appears to agree on is:

$$T_{diss}(\psi') \approx T_{diss}(\chi_c) < T_{diss}(\Upsilon(3S)) < T_{diss}(J/\psi) \approx T_{diss}(\Upsilon(2S)) < T_{diss}(\Upsilon(1S))$$

Quarkonia production

- Gluon fusion dominating process at RHIC and SPS
  - Gluon fragmentation ? [5)]
- Is J/ψ produced in a color-singlet or octet state?
  - Color singlet model (CSM) [1)] ⇒ pQCD
    - underpredicts cross-section
  - Color octet model (COM) [2)] ⇒ NRQCD
    - predict transverse polarization at large p_T - but small longitudinal polarization was seen (E866, CDF)
  - Color evaporation model (CEM) [3)]
  - Recent: new singlet model seems to get both correct [6)]





Production mechanism at SPS,RHIC,LHC?

1) R. Baier et al., PLB 102, 364 (1981)
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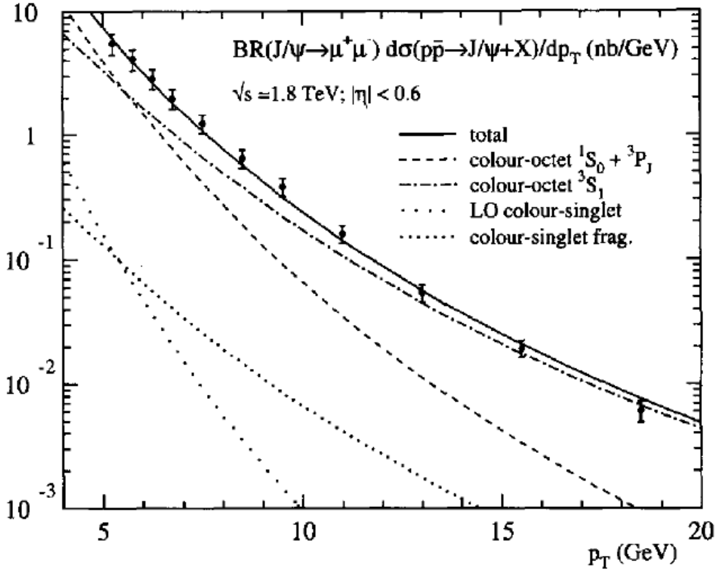

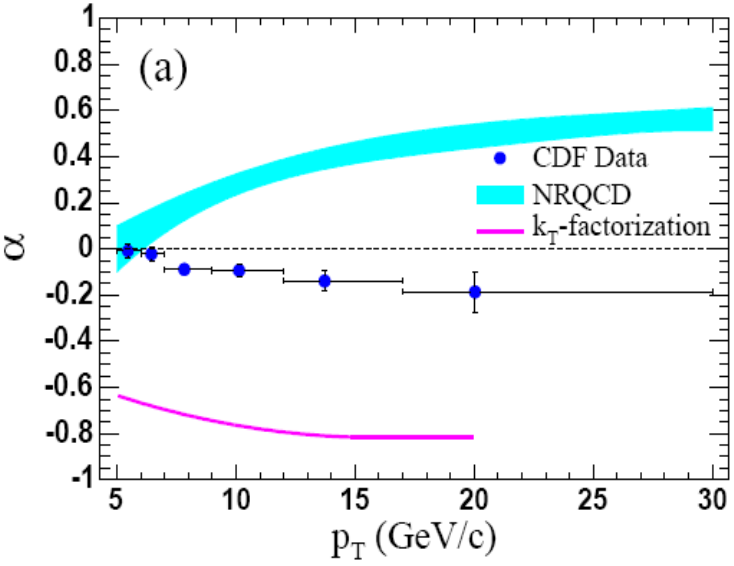

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RHIC J/ψ at a glance ...

PHENIX Au+Au data shows suppression at mid-rapidity about the same as seen at the SPS at lower energy but

- stronger suppression at forward rapidity
- Forward/Mid R_{AA} ratio looks flat above a centrality with N_{part} = 100

Several effects contribute:

Cold nuclear matter (CNM) effects

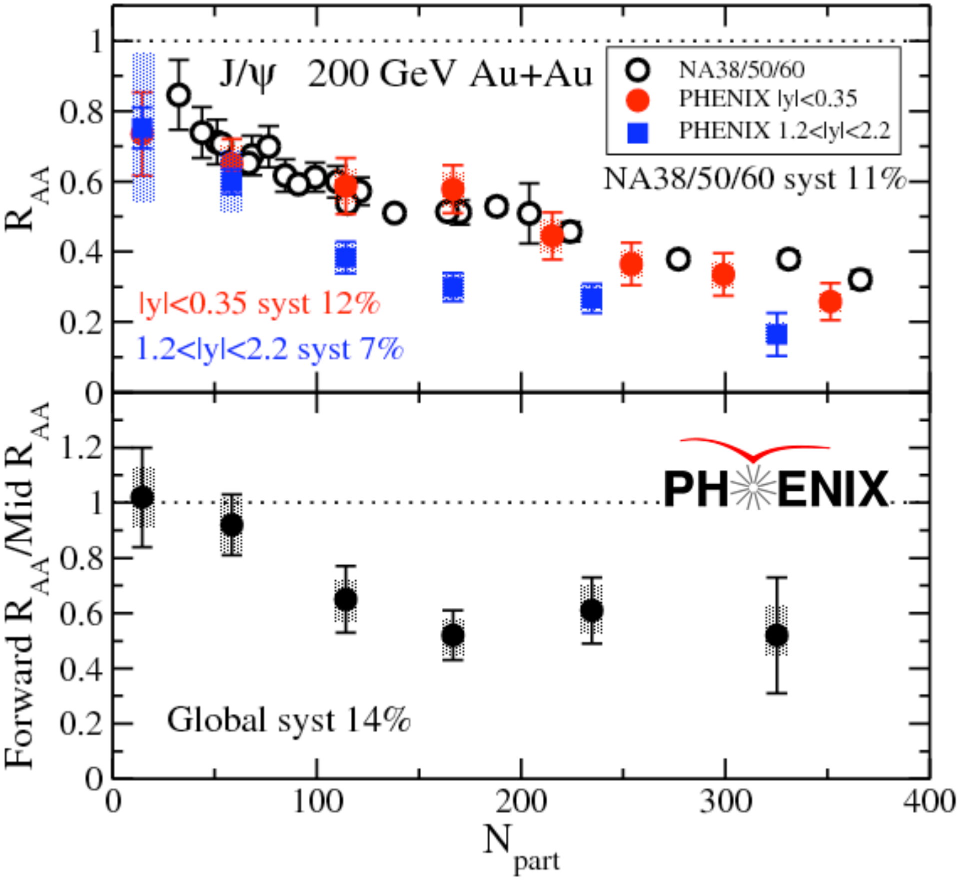
- absorption
- (anti-) shadowing

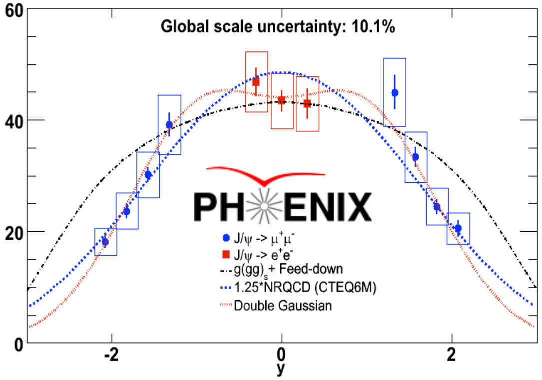
Feeddown from χ_C & ψ'

- removing their feed-down contribution to J/ψ at both SPS & RHIC

Regeneration

- gives enhancement that compensates for screening





$\mu^+\mu^-$ ⇒ forward

e^+e^- ⇒ central

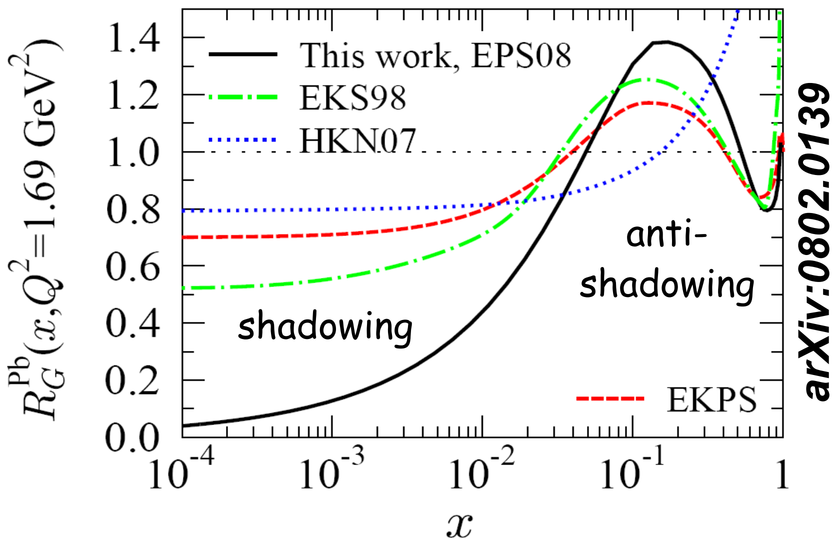
J/ψ d+Au: cold nuclear matter

Cold nuclear matter T << T_c

J/ψ modified by:

Cronin effects (p_T broadening of final state)

Nuclear PDF modification



Gluon saturation (initial state)

Breakup cross-section in nucleus

Use EKS model to evaluate CNM effects EKS Nucl. Phys. A696, 729

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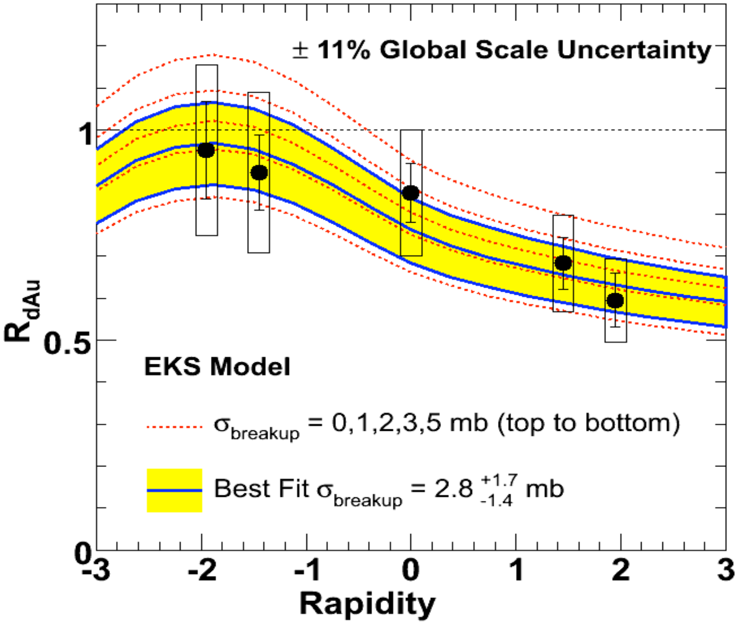
PHENIX: J/ψ R_{dAu} 200 GeV



PRC77 024912 (2008)

RHIC:

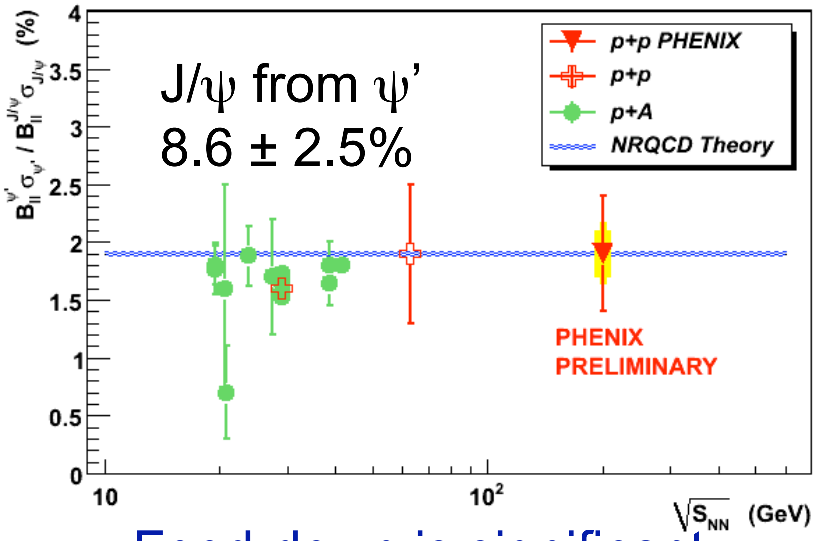
$\sigma_{Breakup}$ = 2.8+1.7-1.4 mb

Close to SPS result:

$\sigma_{Breakup}$=4.2+/-0.5mb

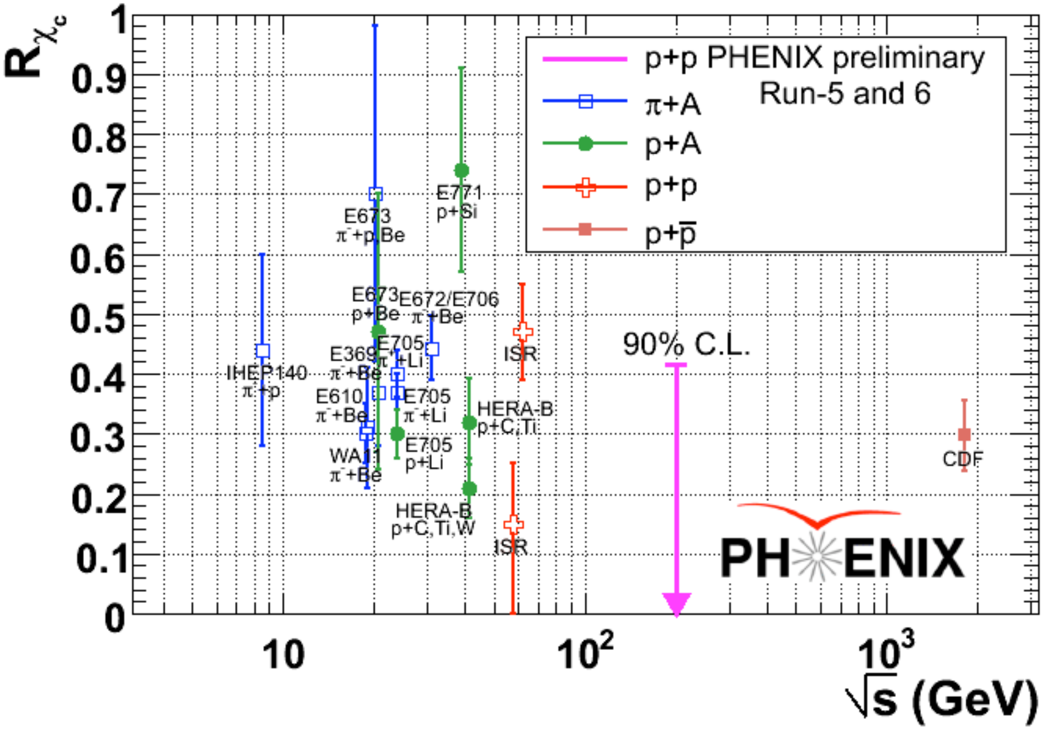
(which did not use EKS or similar)

Feed-down from higher resonances (ψ',χ_c)



J/ψ from ψ'
8.6 ± 2.5%

Feed-down is significant



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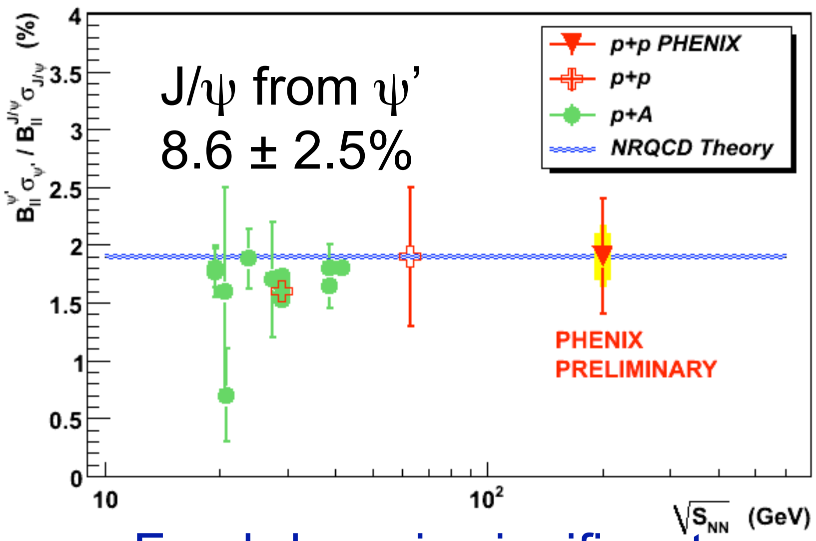

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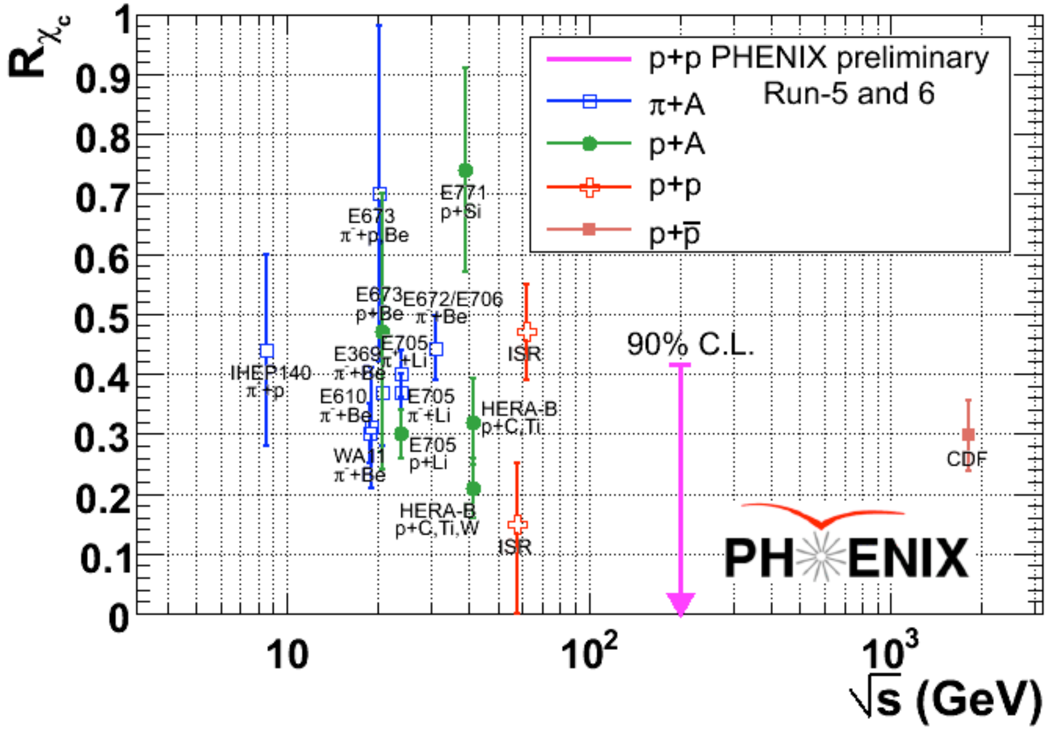
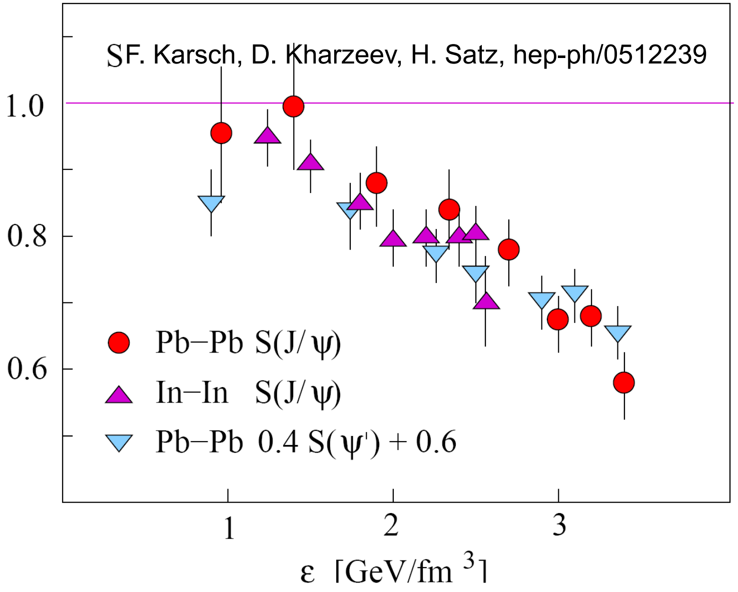




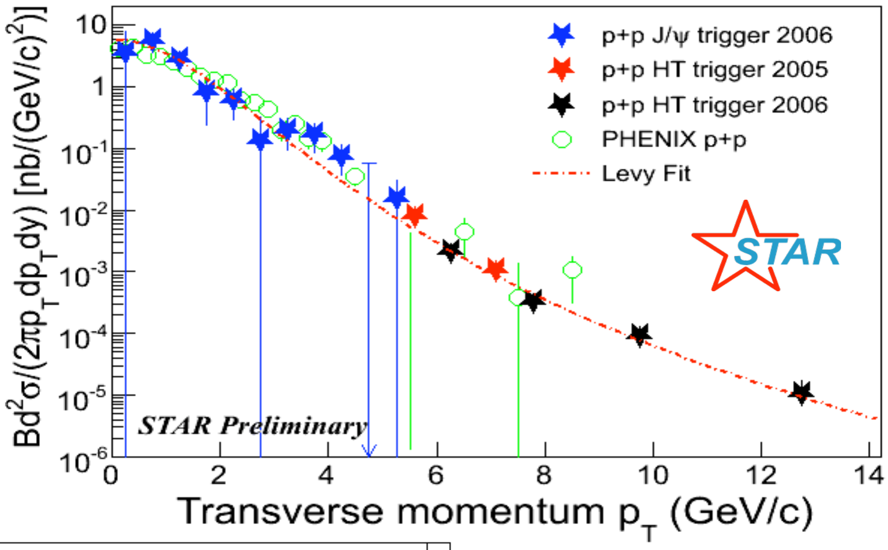
Study for SPS: Can explain J/ψ suppression with melting of ψ', χ_c and hence the absence of feed-down

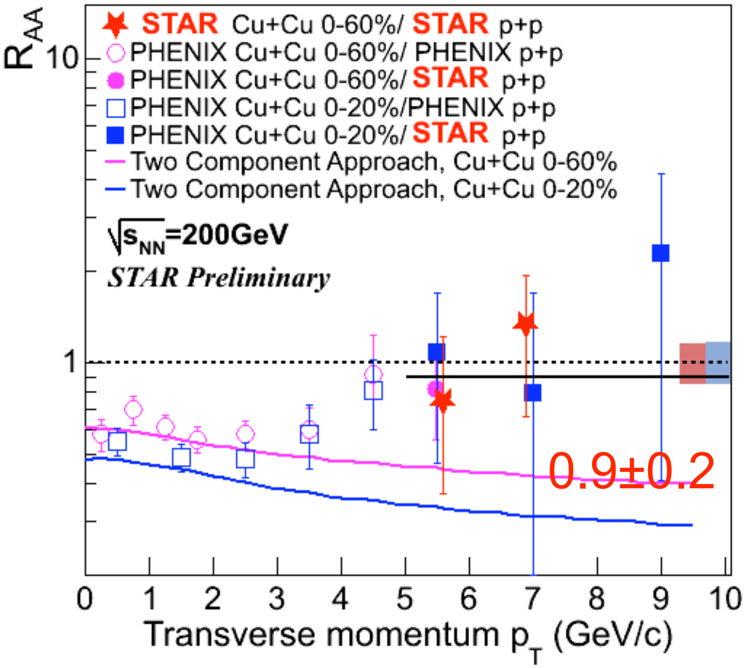
Another very challenging measurement!

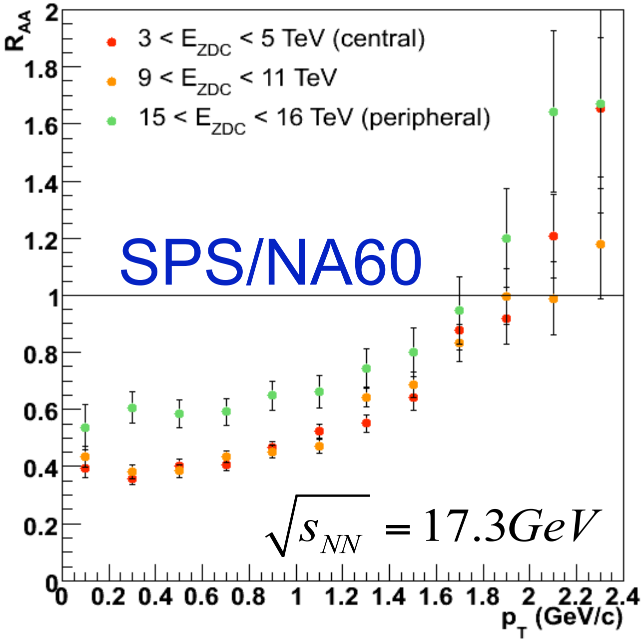
Right or wrong, it shows how important the χ_c measurement is!

No suppression at high-p_T?

- STAR beginning to measure J/ψ, especially at larger p_T
  - Consistent with PHENIX measurements
- RHIC: Cu+Cu, consistent with no suppression at $p_T > 5$ GeV







SPS: In+In, at $p_T > 1.8$ GeV consistent with no suppression

Not yet fully understood

J/ψ summary

p+p

- Agreement between PHENIX and STAR and Theory
- Significant feed-down contribution from ψ', χ_c

d+Au

- Cold nuclear matter effects are significant
- Break-up cross-section similar to SPS

A+A

- Suppression of R_{AA} at low p_T
    - similar to SPS
    - strong function of rapidity
- No suppression seen at high p_T

The future

Analysis of run 7 Au-Au data ongoing

- high statistics J/ψ and good statistics Υ

Analysis of run 8 d-Au, p+p

- better understanding of cold nuclear matter effects
- better understanding of differences between STAR/PHENIX

Next Au-Au run

- full TOF, less material and DAQ1000 for STAR
    - better statistics, less background

RHIC-II + Inner vertex detector upgrades for both PHENIX & STAR

- Reconstruction of decay vertices of open charm
    - Direct measurement D_s and Λ_c

Repeat at LHC in more detail