Charm Production at RHIC
-- signature of thermal equilibrium

//Nxu/tex3/TALK/2004/05PD

Nu Xu -- LBNL

(1) Introduction
(2) Results from RHIC (selected)
(3) Partonic Collectivity
(4) Partonic Equilibrium
   - light-flavor equilibration and heavy-flavor spectra / v_2

Many Thanks to: **Organizers**
X. Dong, H. Huang, H. Ritter, K. Schweda, P. Sorensen, **A. Tai**, Z. Xu
L. Grandchamp, J. Raufeisen, **R. Vogt**

High-energy nuclear collisions

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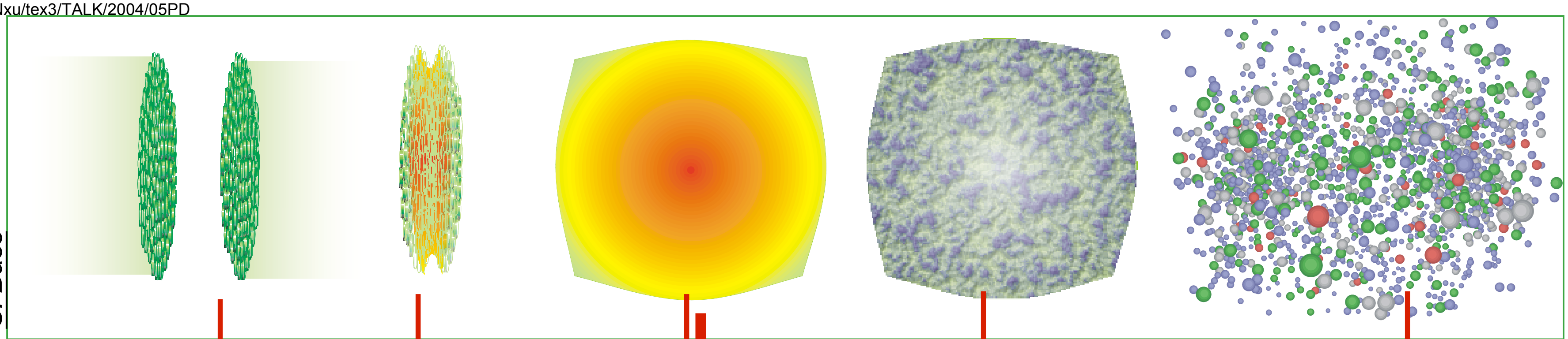

S. Bass

Initial conditions

Initial high Q^2 interactions

Parton matter - QGP - The hot-QCD

Hadronization and Freeze-out

Experime

- Energy
- Elliptic
- Charm - productions plus the combination (1) and (2)

(1) Hard scattering production - QCD prediction
(2) Interactions with medium - deconfinement/thermalization
(3) Initial parton density

(1) Initial condition in high-energy nuclear collisions
(2) The cold-QCD-matter, small-x, high-parton density
- parton structures in nucleon / nucleus

QCD Energy Scale

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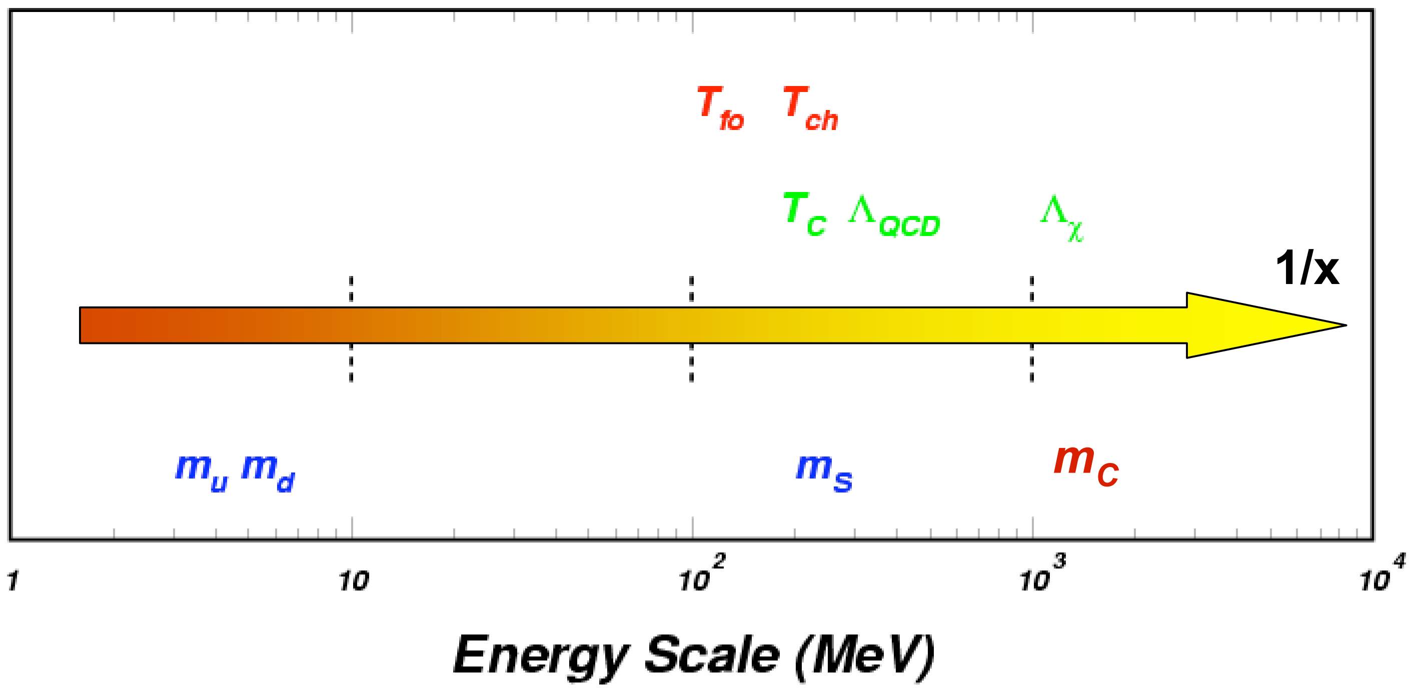

s-quark mass ~ 0.2 GeV, similar to values of

T_C	critical temperature
Λ_{QCD}	QCD scale parameter
T_{CH}	chemical freeze-out temperature
$\Lambda_\chi = 4\pi f_\pi$	chiral breaking scale

c-quark mass ~ 1.2 - 1.5 GeV >> Λ_{QCD}

-- pQCD production - parton density at small-x

-- QCD interaction - medium properties

R_{cc} ~ $1/m_C$ => color screening

J/ψ => deconfinement and thermalization

u-, d-, s-quarks: ***light-flavors*** || c-, b-quarks: ***heavy-flavors***

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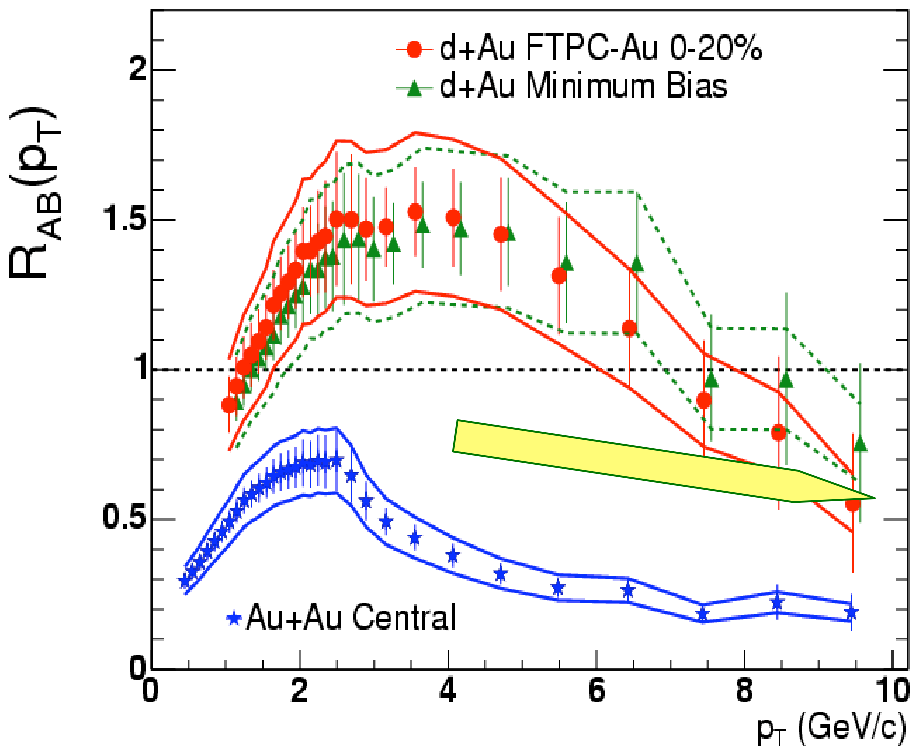
Energy Loss, Dead-cone Effect



Energy Loss:

1) Heavy quark gluon radiation is reduced in the colored medium
2) Less energy loss for charm-hadrons -> less suppressions
3) Test partonic energy loss assumption
4) Implication on both open- and close-charm hadrons spectra!

M. Djordjevic and M. Gyulassy, nucl-th/0404006
Yu. Dokshitzer and D. Kharzeev, Phys. Lett. ***B519****, 199(2001)*

Early Freeze-out

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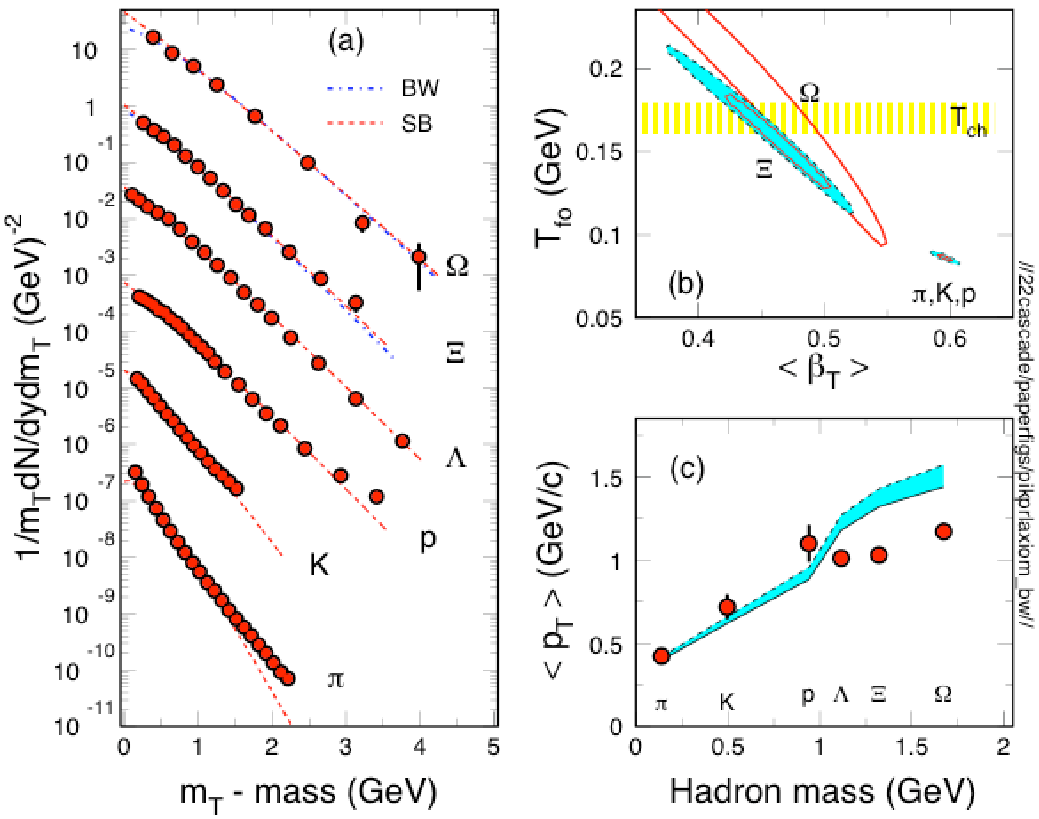
Central Au+Au collisions at RHIC



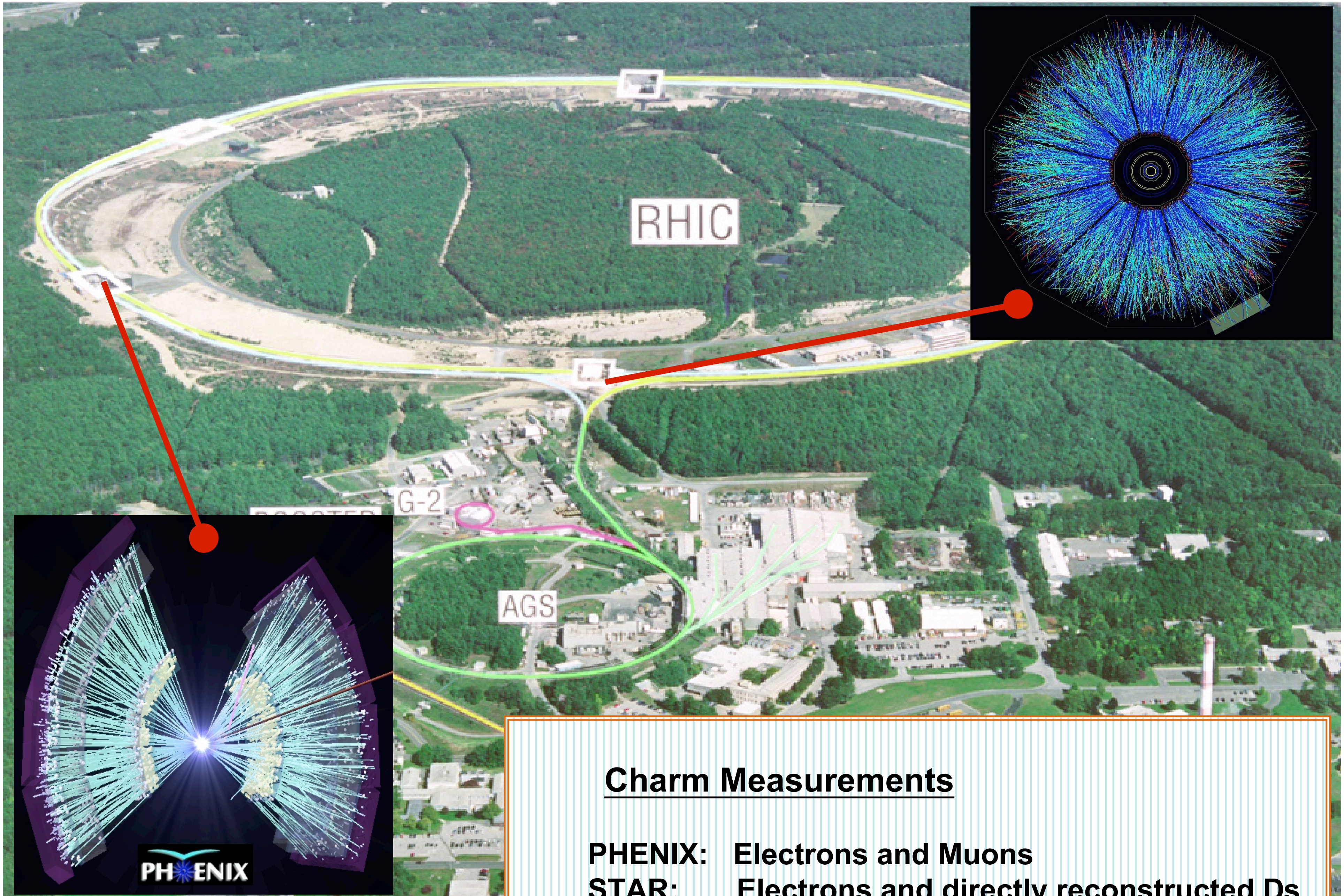
1) Multi-strange hadrons seem to freeze out earlier than others ➪ sensitive probe for early dynamics

2) Charm-hadrons should be better. A possible complication is the pQCD hard spectrum.

3) J/ψ coalescence/melting: a tool for early dynamics CGC, deconfinement, and thermal equilibrium

*PHENIX: Phys. Rev. **C69** 034909 (04).*
*STAR: Phys. Rev. Lett. **92**, 112301(04); Phys. Rev. Lett. **92**, 182301(04).*
*A. Andronic et al., NP**A715**, 529(03).*
*P. Kolb et al., Phys. Rev. **C67** 044903(03)*

<u>Chemical Freeze-out:</u> inelastic interactions stop
<u>Kinetic Freeze-out:</u> elastic interactions stop



Charm Measurements

PHENIX: Electrons and Muons

STAR: Electrons and directly reconstructed Ds

PHENIX: Ability to Study Charm

-- electron and muon measurement

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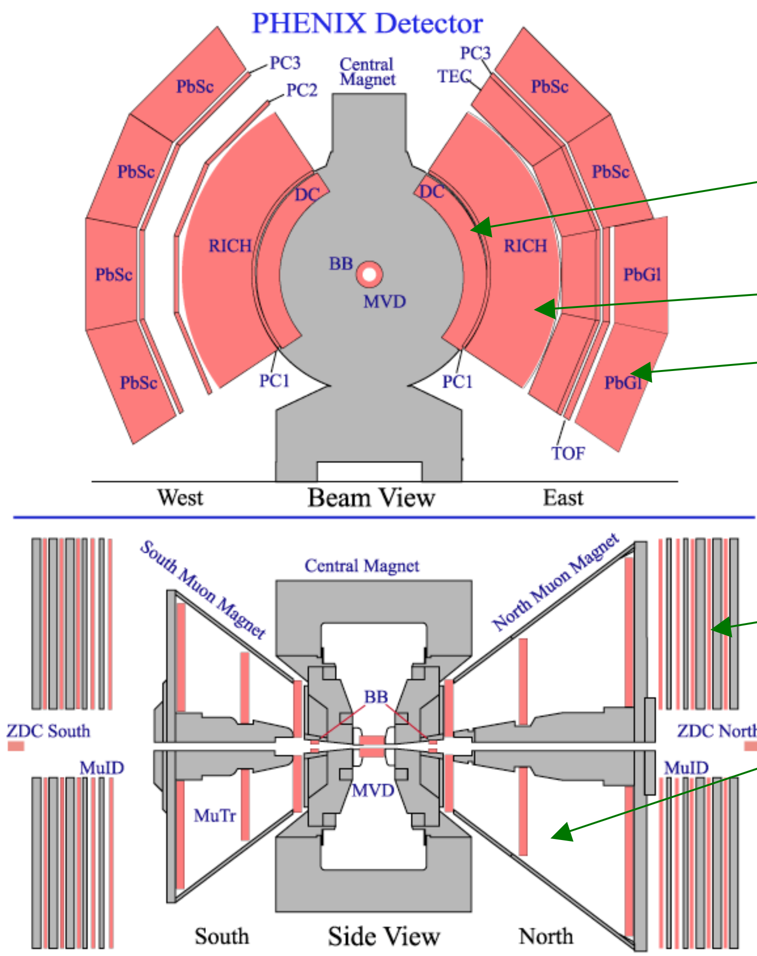

1) High resolution tracking and momentum measurement from: **Drift** chamber

2) Electron identification from:
RICH
EMCal

3) Good momentum resolution and muon identification from: **mID** and **mTrk**.

** High rate capability

PHENIX: Non-Photonic Single Electron Spectra
d-Au $\sqrt{s}$ = 200 GeV

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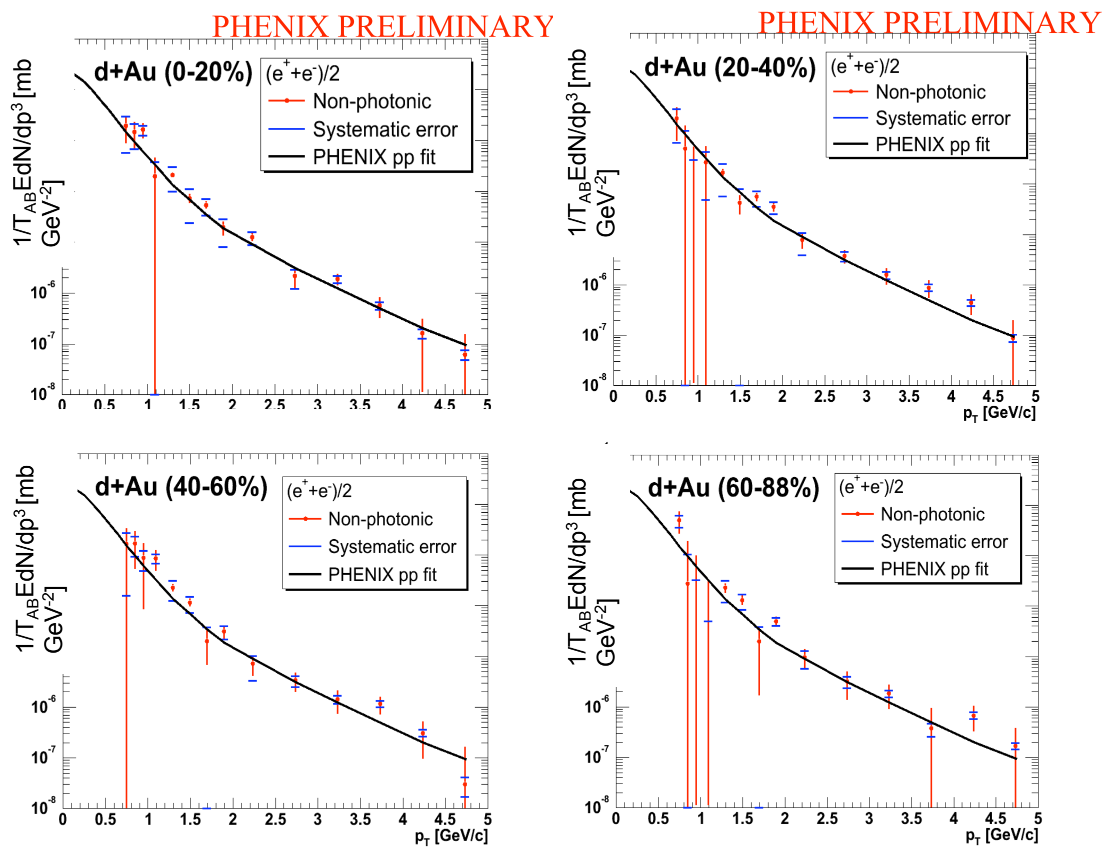


1) seems to scale with number of collision in d-Au collision

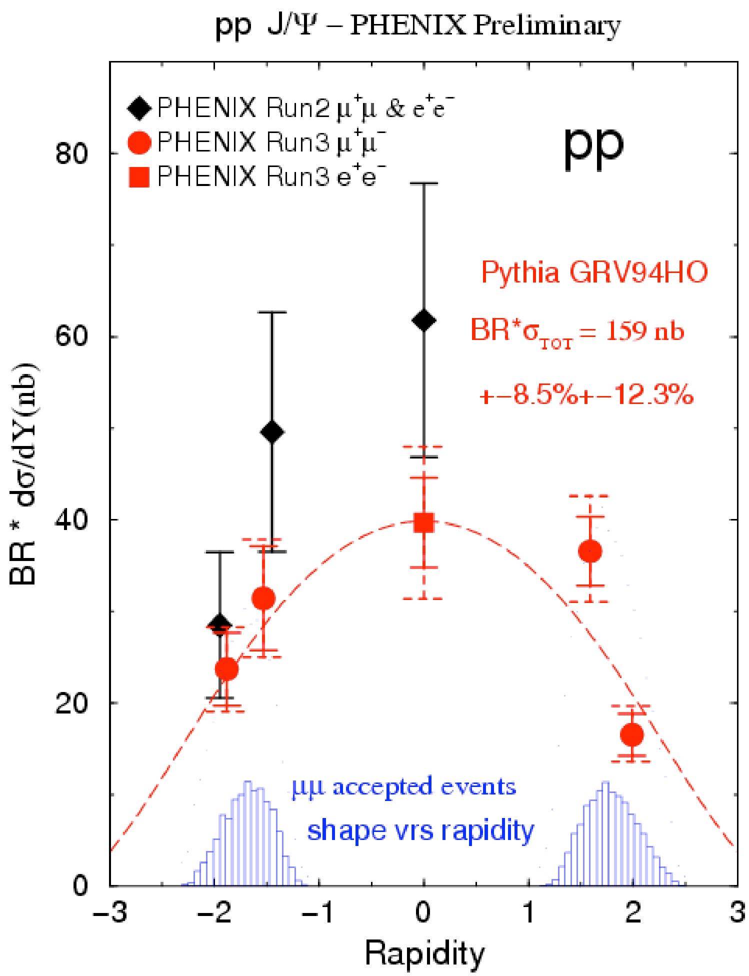
2) no indication of shadowing effect at mid-rapidity

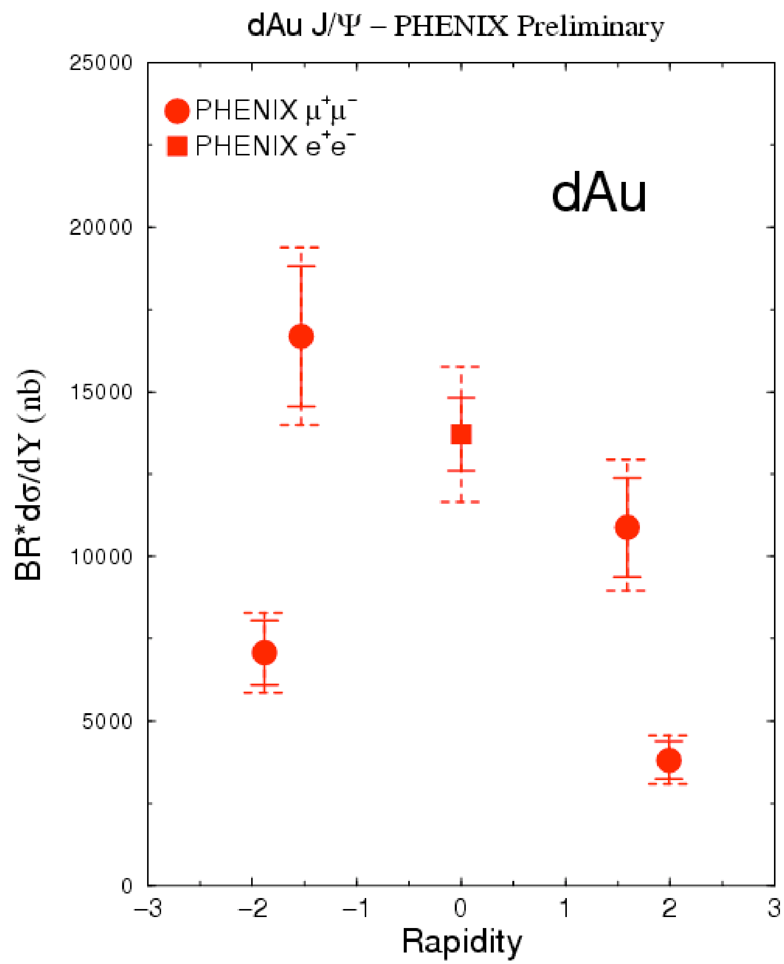
Wei Xie, AGS/RHIC User's meeting, 04

$$\sigma_{c\bar{c}}^{total} = 709 \pm 85(stat.)^{+332}_{-281}(syst.)(\mu b)$$

PHENIX: J/Ψ y-distribution

RUN3: ~300nb^{-1} p-p and ~3nb^{-1} d-Au collisions.





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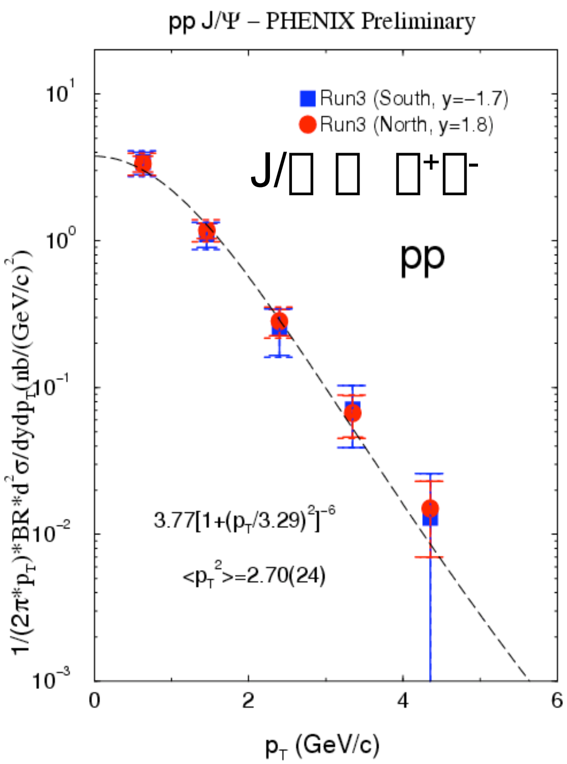
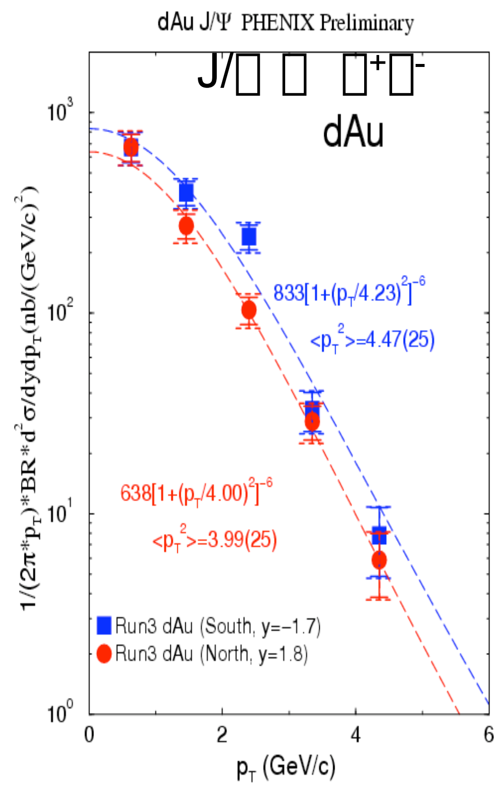
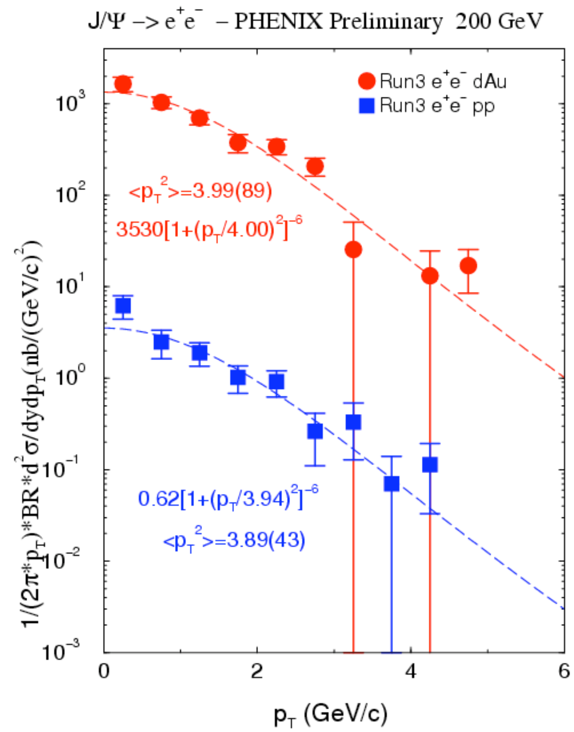
PHENIX: J/ψ p_T-distributions







1) At SPS (17 GeV), $\langle p_T^2 \rangle \sim 1\ (\mathrm{GeV}/c)^2$
2) At RHIC (200GeV), $\langle p_T^2 \rangle \sim 4\ (\mathrm{GeV}/c)^2$

STAR: TPC & MRPC-TOF

A new technology - Multi-gap Resistive Plate Chamber (MRPC), adopted from CERN-Alice

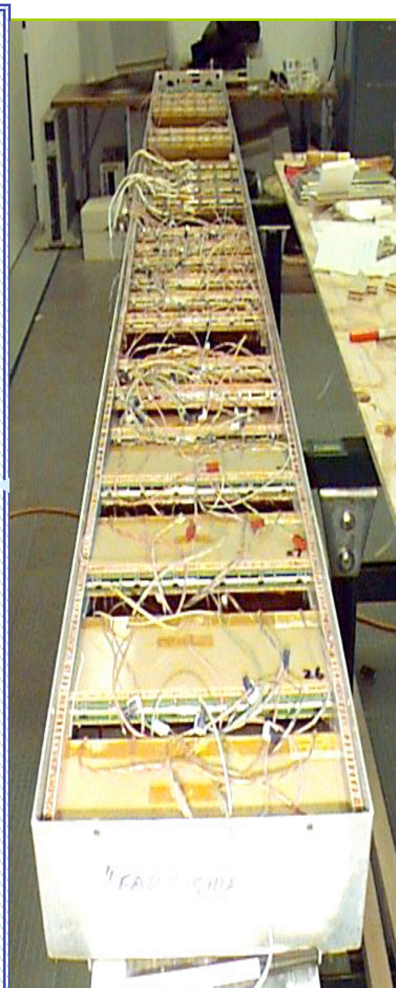
- A prototype detector of time-of-flight (**TOFr**) was installed in Run3
- One tray: ~ 0.3% of TPC coverage
- Intrinsic timing resolution: ~ 85 ps

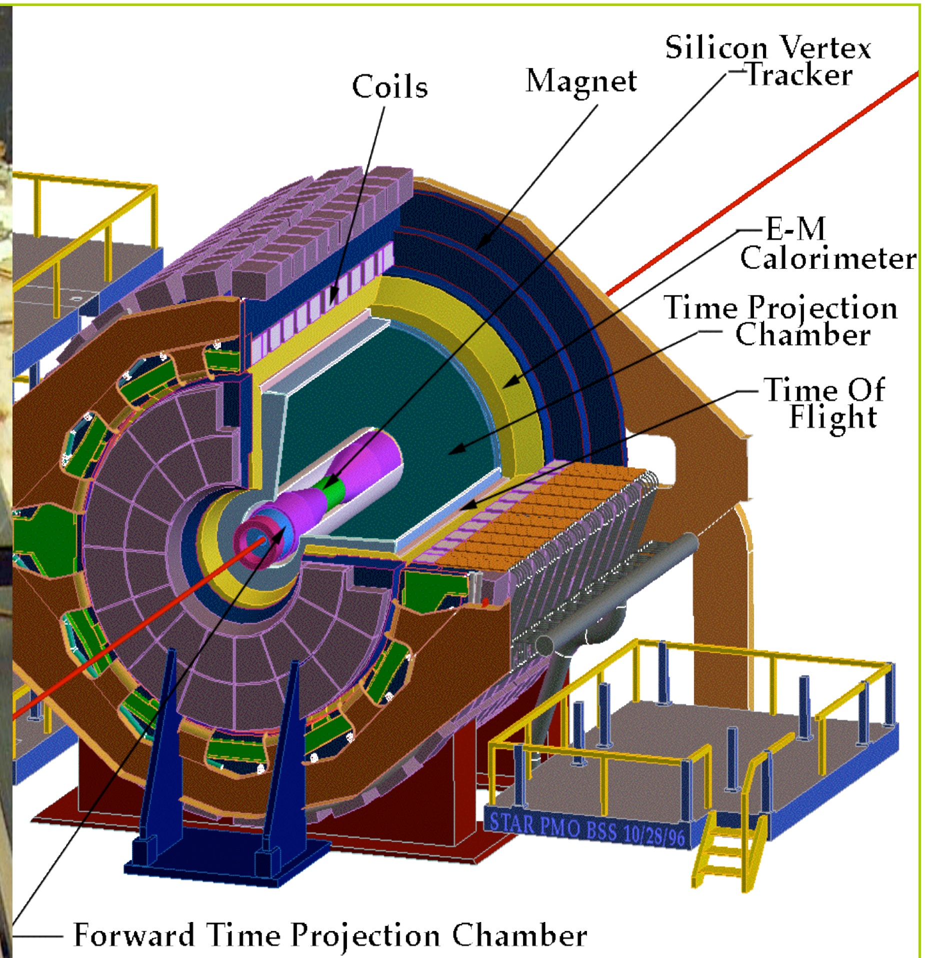
pion/kaon ID:

p_T ~ 1.7 GeV/c

proton ID:

p_T ~ 3 GeV/c





TPC dE/dx PID:
pion/kaon: p_T ~ 0.6 GeV/c; proton p_T ~ 1.2 GeV/c

Electron background

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Single Electrons Spectra:

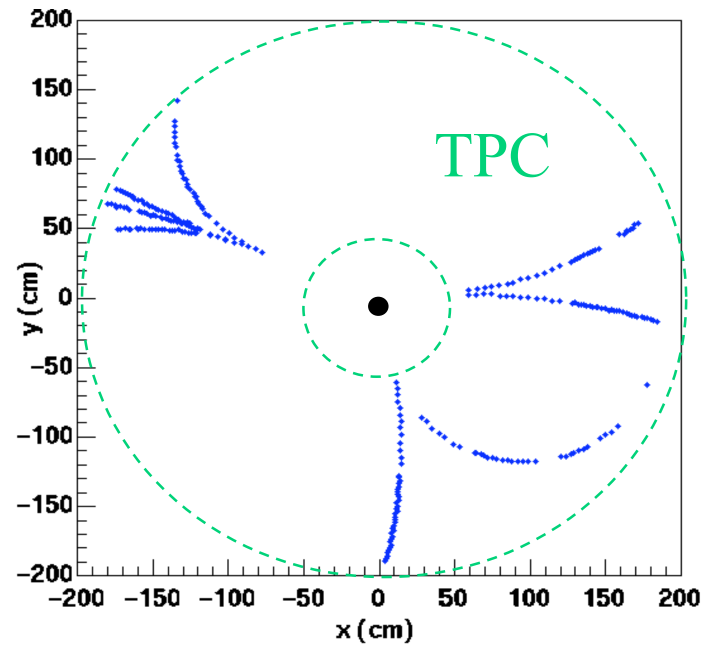
□-conversion
□^{0} , □-Dalitz decays
Kaon decays
□, □, □ vector meson decays
} B

heavy quark semi-leptonic decays
others like direct/thermal photons
} S

At low p_T, □-conversion and □^{0} Dalitz decays are dominant sources. These are obtained from data.

Background Topology:

1) TOFr tagged e^+/e^-
2) Large TPC acceptance
3) High efficiency



Electron spectra

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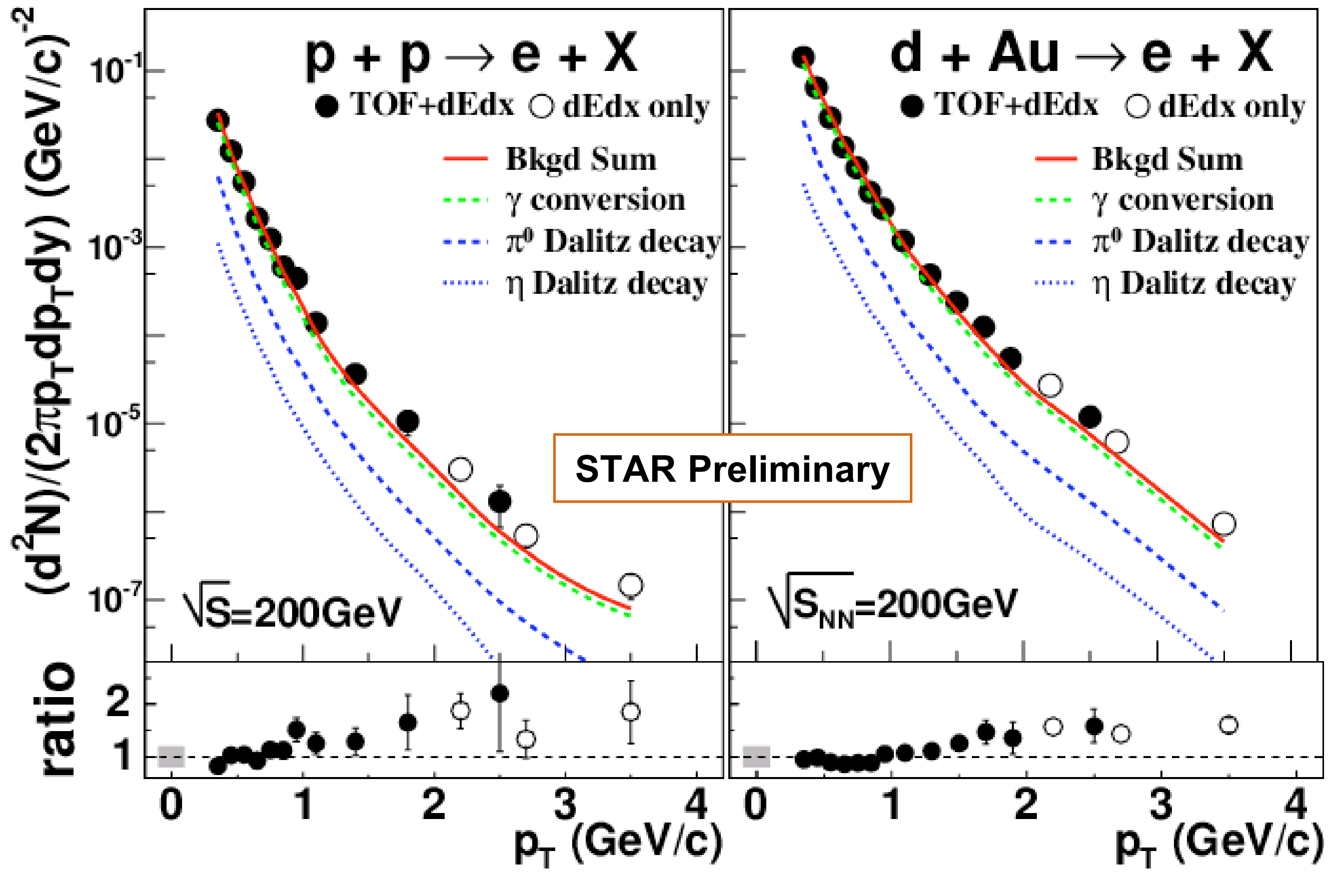

An increasing excess found at higher p_T region, p_T > 1.0 GeV/c,
→ Expected contribution of semi-leptonic decays from heavy flavor hadrons

Consistent in D measurements

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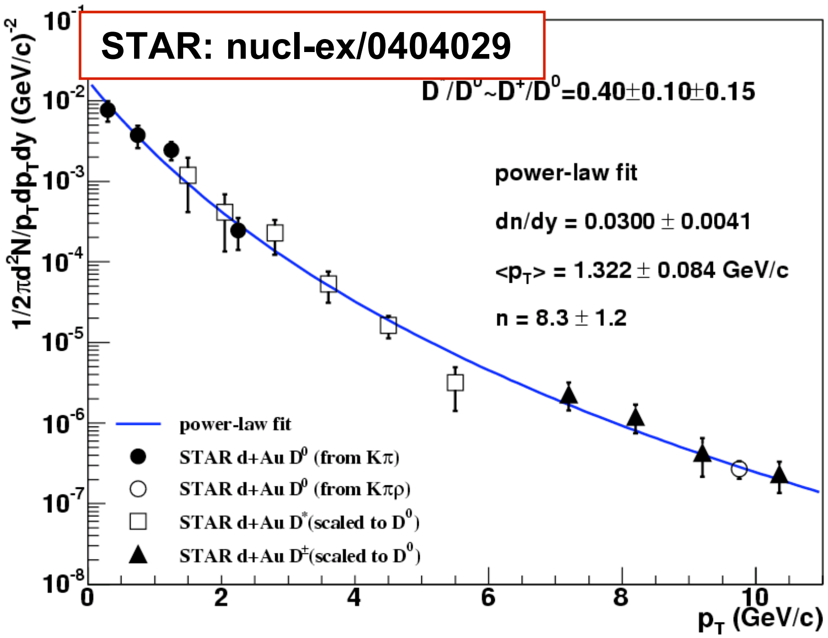

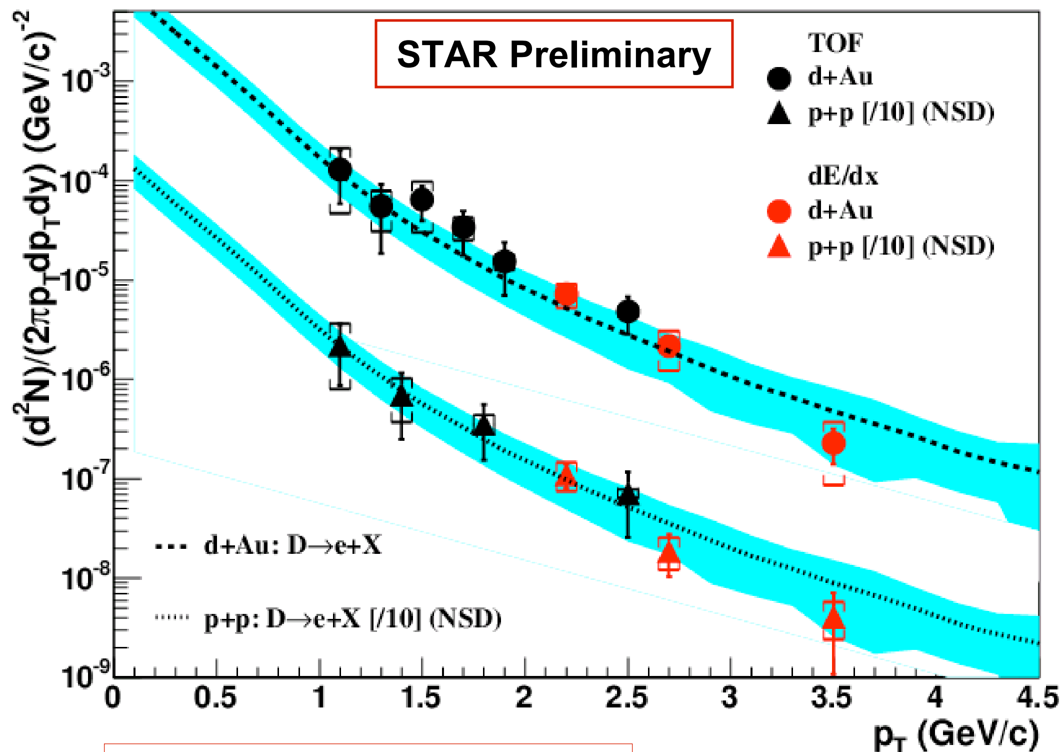

Directly reconstructed D mesons

Electrons from D decay

D and electron spectra are consistent!

Open charm production at RHIC

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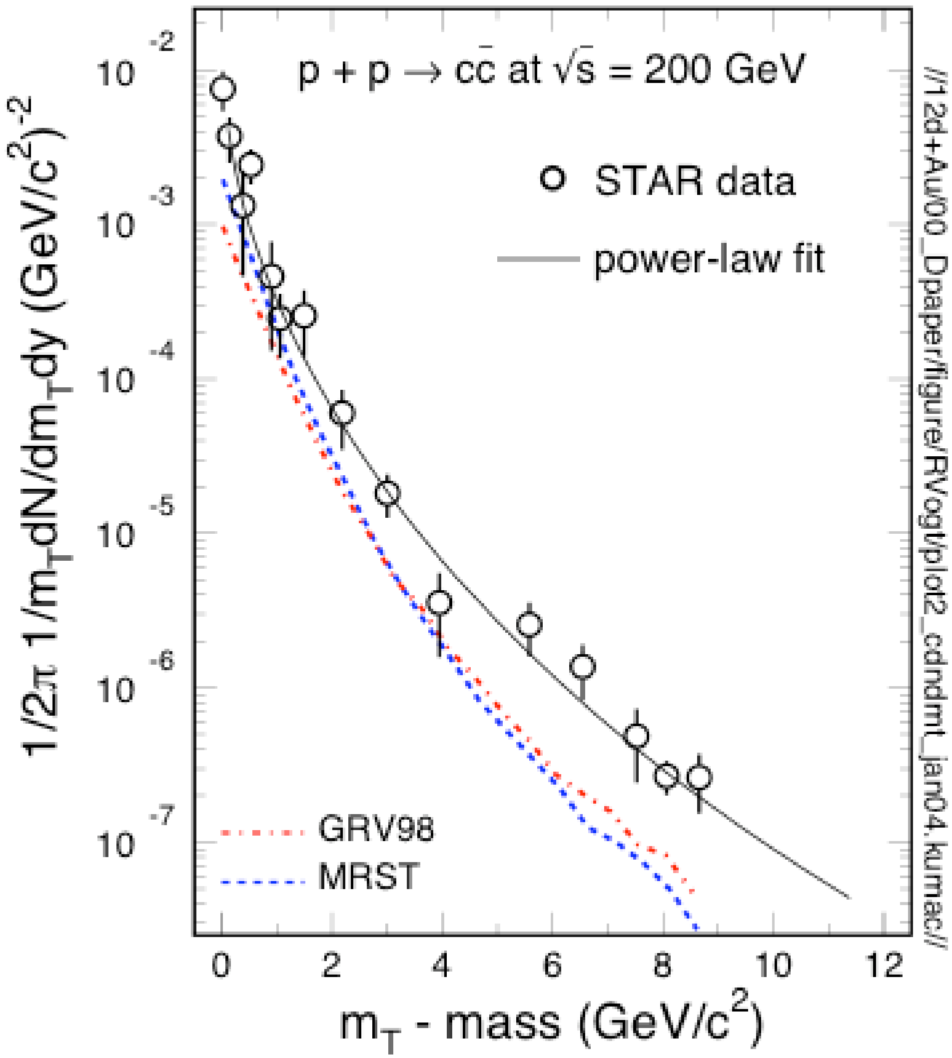

- pQCD distributions are steeper

-

- Fragmentation with delta function has harder spectrum

-Total cross sections are lower, a factor of 3-5

-

\- *R. Vogt, 2004*

Open charm spectrum is hard

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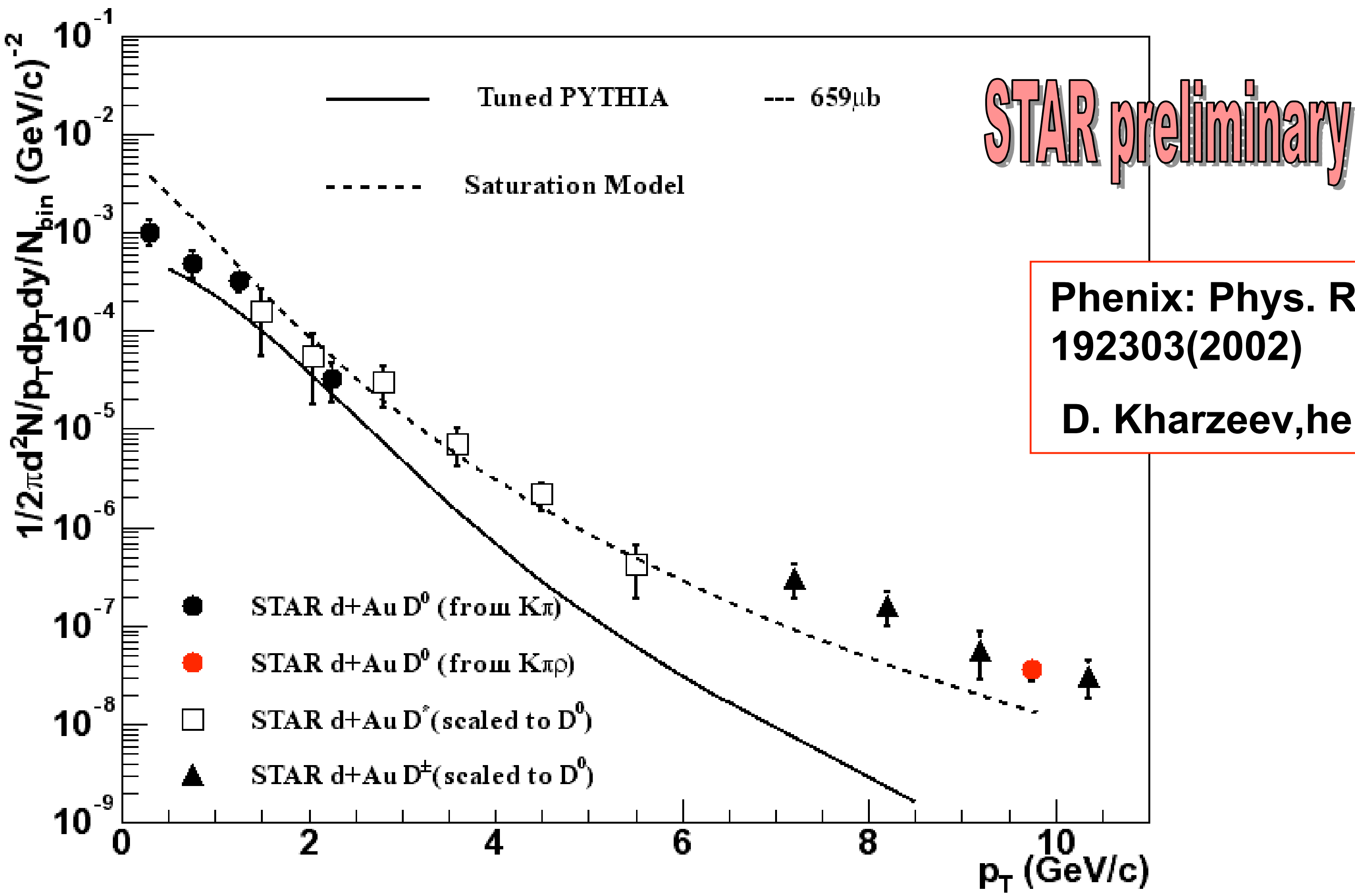

Phenix: Phys. Rev. Lett. 88, 192303(2002)

D. Kharzeev,hep-ph/0310358

Open charm production at RHIC

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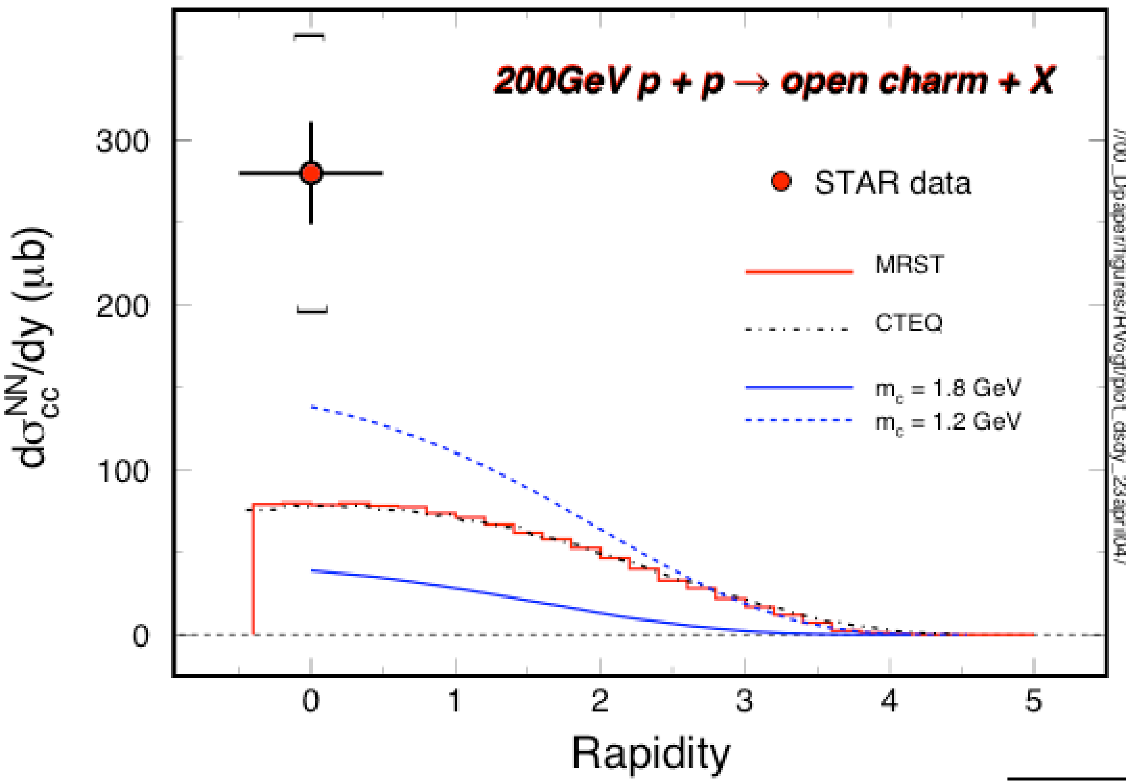
*J. Raufeisen and J. Peng, Phys.Rev. **D67**, 054008(2003)*



1) d□/dy ⇨ □: a factor from model like Pythia. At 200 GeV, the factor 4.7 was used at STAR.

2) A strong dependent on the method of fragmentation in charm p_T spectra observed, but not on rapidity distributions.

	$dN(D^0)/dy\|_{y=0}$ (10^{-2})	$d\sigma_{c\bar{c}}^{NN}/dy\|_{y=0}$ (mb)
D^0	$2.8\pm0.4\pm0.8$	$0.29\pm0.04\pm0.08$
$D^0+e^{\pm}$	$2.9\pm0.4\pm0.8$	$0.30\pm0.04\pm0.09$
$D\ +e^{\pm}$	$2.7\pm0.3\pm0.7$	$0.28\pm0.03\pm0.08$

Charm production cross-section

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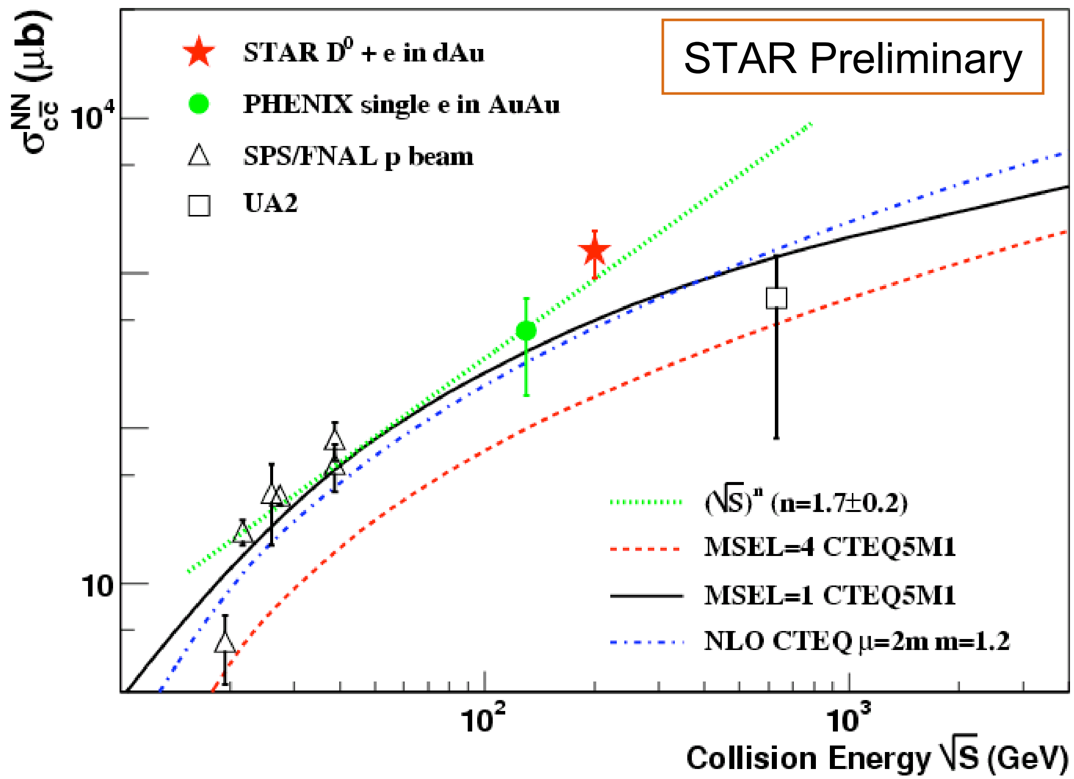
1) NLO pQCD calculations under-predict the ccbar production cross section at RHIC

2) Power law for ccbar production cross section from SPS to RHIC:
n ~ 2
(n~0.5 for charged hadrons)

3) Large uncertainties in total cross section due to rapidity width, model dependent(?).



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Charm Summary

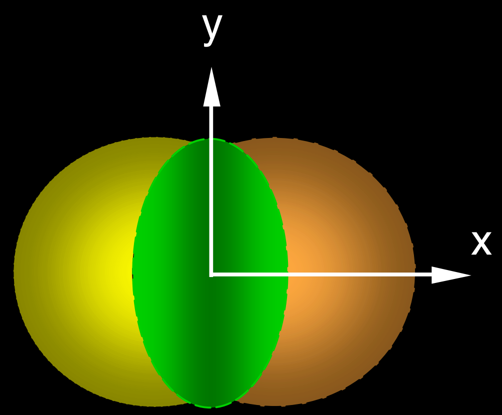
1) First J/ψ data at RHIC, high statistic data are coming
2) Open charm yields measured in both 200GeV p+p and d+Au collisions. No evidence of deviation from binary collision scaling in d+Au collisions

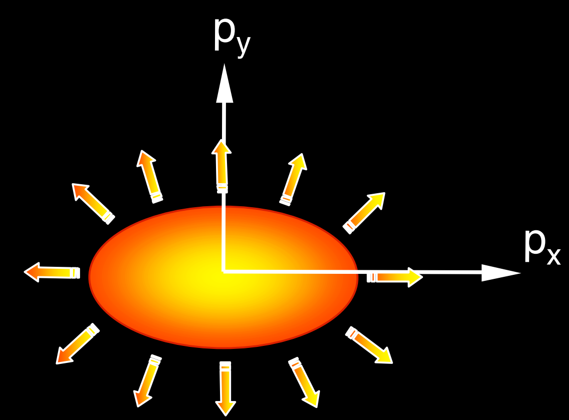
$$\sigma_{c\bar{c}}^{total} = 700 \sim 1200 (\mu b)$$

3) Perturbative calculations under predicted both yields and spectrum shape. Hadronization process not under control.

Anisotropy parameter v_2

coordinate-space-anisotropy ⇒ momentum-space-anisotropy





$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

Partonic collectivity at RHIC

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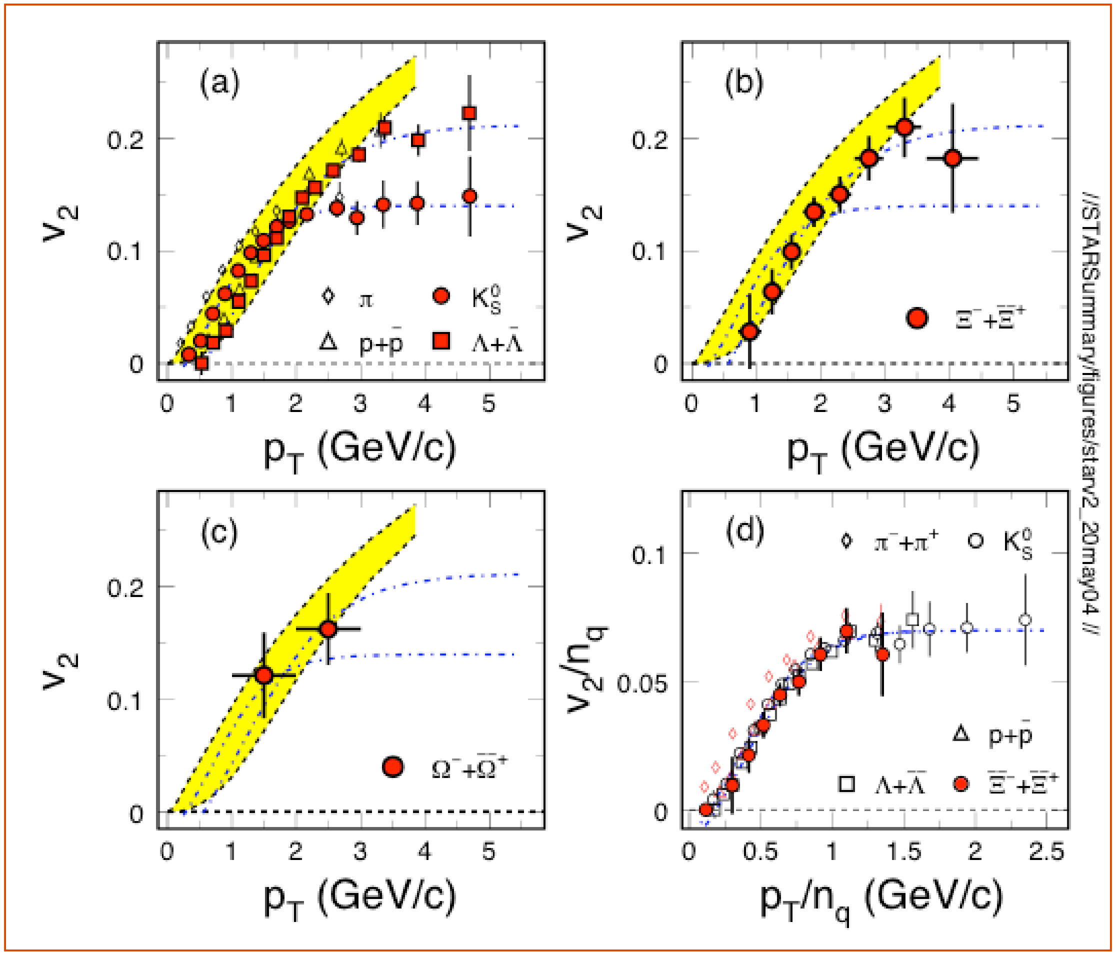
PHENIX: PRL91, 182301(03) *STAR: PRL92, 052302(04)*



With the v_2 and spectra of multi-strange hadrons and the scaling of the number of constituent quarks

➪ both deconfinement and partonic collectivity have been attained at RHIC!

Next question is the thermalization of light flavors at RHIC:

- v_2 of charm hadrons

- J/ψ distributions !!

Thermal Equilibrium at RHIC

At RHIC, yields of open charm is high:

1) The rescattering will lead to **collectivity motion** and thermalization among partons. Since $m_C >> T_0$ and $m_{u,d,s}$ thermal equilibrium is first reachable among light flavors.

2) Coalescence of charm quarks will lead to the **enhancement of J/ψ production** and **thermal-like** spectra in central nucleus-nucleus collisions.

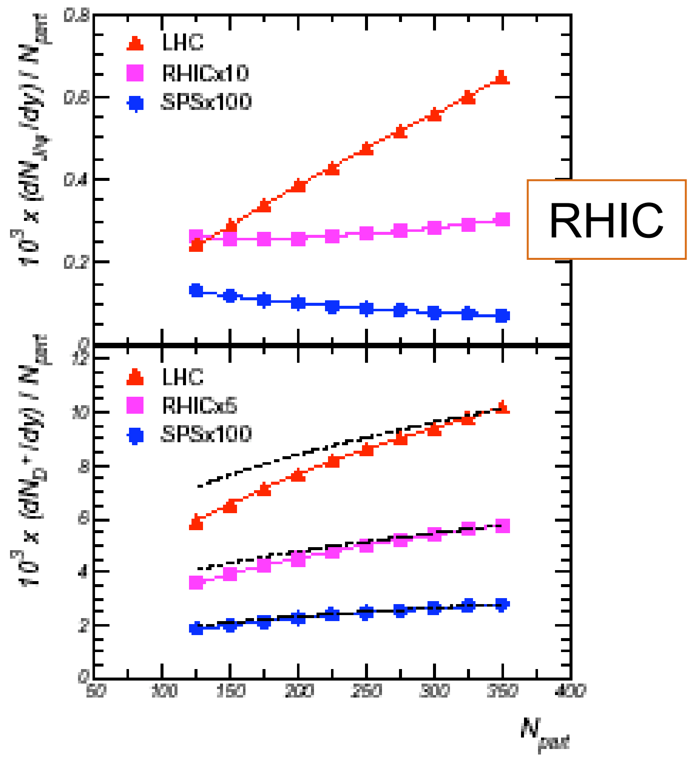
⇨ **Study open charm and J/ψ spectra and v_2**
⇨ **Study J/ψ yields versus collision centrality**

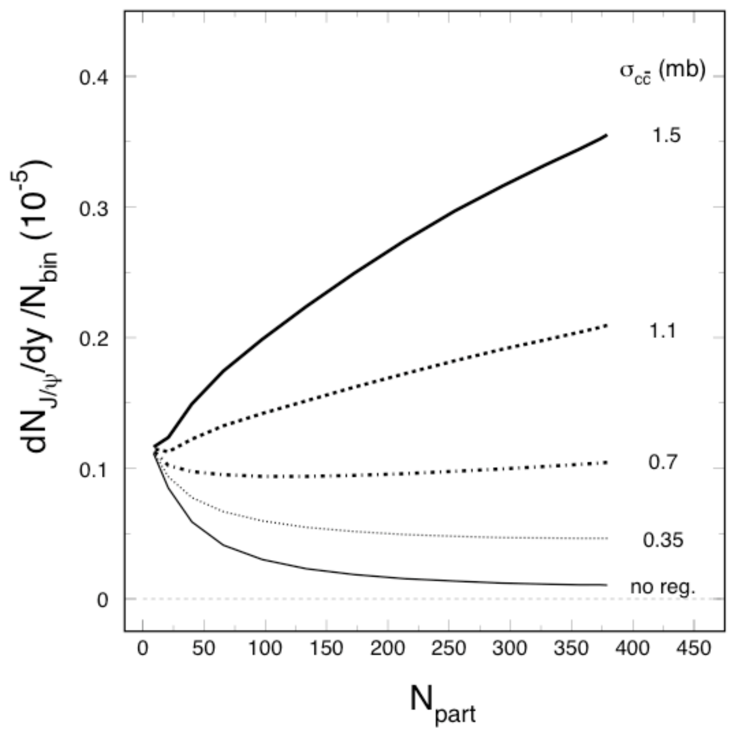
Centrality dependence

//Nx

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Phys.Lett. **B571** , 36(03).

L. Grandchamp and R. Rapp, Phys. Lett. **B523** , 60(01).





(1) open charm cross;
(2) direct pQCD production;
(3) medium effects (properties);
(4) absorption (color screening)

Model results are different, centrality dependence measurements are important!

J/ψ via coalescence

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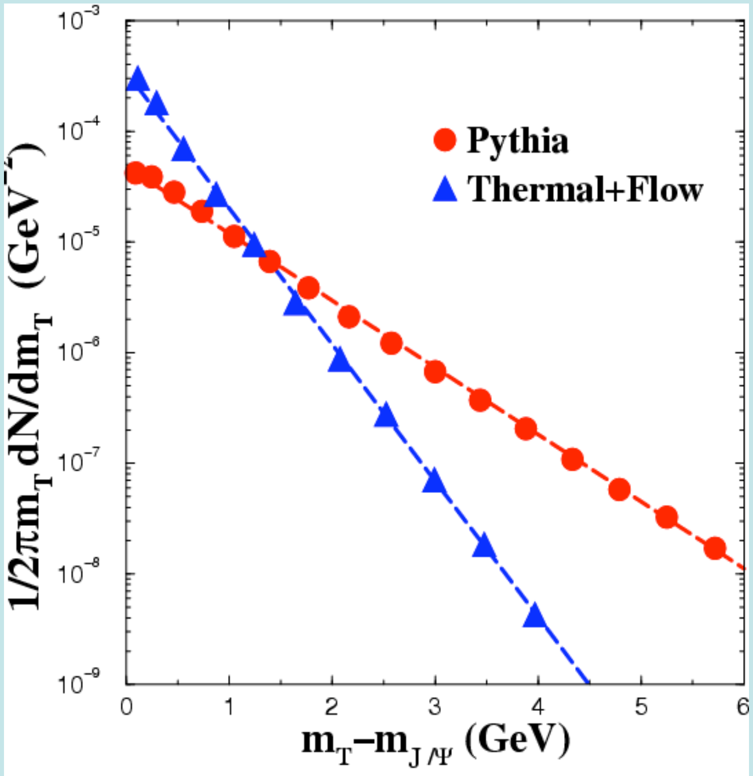
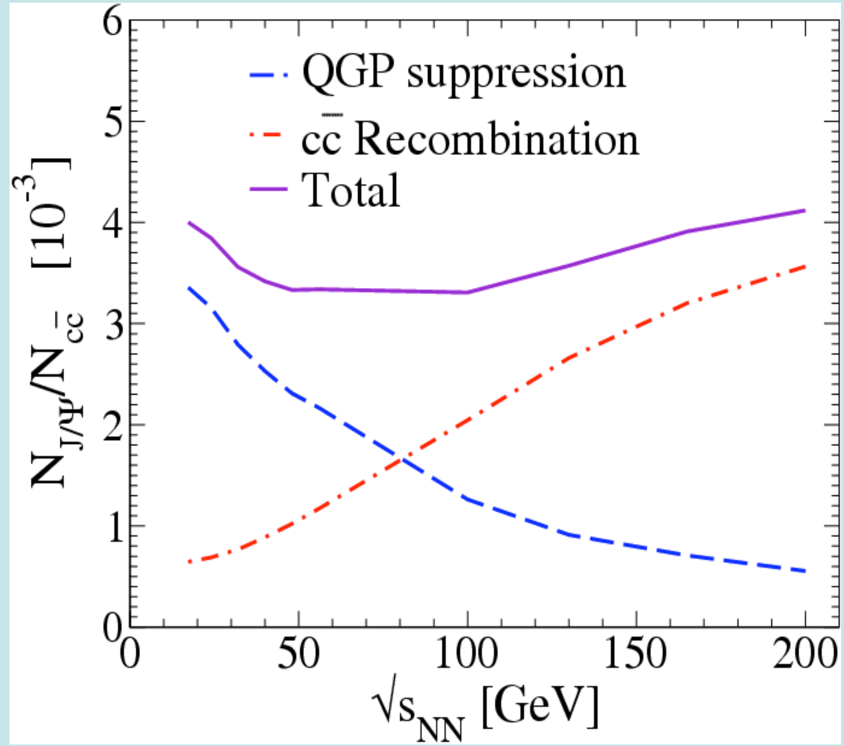




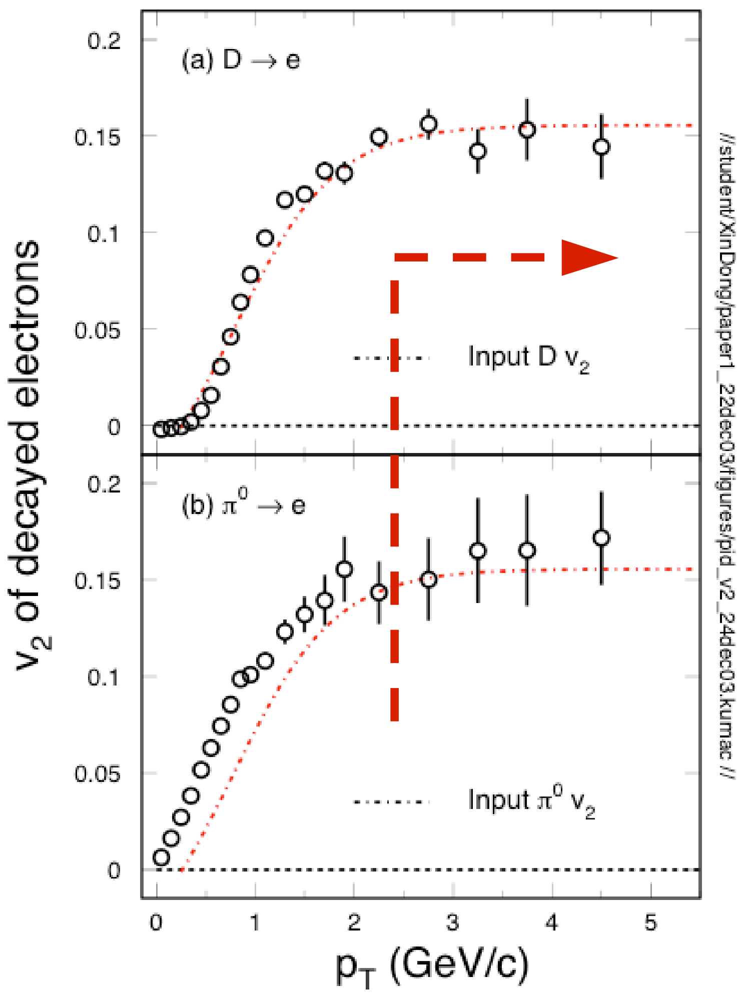
L. Grandchamp and R. Rapp, hep-ph/0209141(02)

J/ψ: in central AA collisions, due to interaction with light flavors, values of mean p_T decrease and yields increase

➪ ***deconfinement and thermalization for light flavors***

Open charm v_2

X. Dong, S. Esumi, *et al. Nucl-th/0403030*



At p_T > 2.5 GeV/c:

1) D-meson spectrum is 'hard', yields of pion will be small, measure D-decayed electron to infer the open charm v_2

2) D-meson flow ➪ indication of light flavor thermal equilibrium.

Summary

1) First J/ψ data at RHIC, much more statistics needed.
2) Open charm yields measured in both 200GeV p+p and d+Au collisions. No evidence of deviation from binary collision scaling in d+Au collisions

$$\sigma_{c\bar{c}}^{total} = 700 \sim 1200 (\mu b)$$

3) Perturbative calculations under predicted both yields and spectrum shape. Hadronization process not under control
4) Study open charm v_2 and J/ψ yields to address thermalization issues at RHIC. The run-IV data will just do that.