Heavy Flavor and Strangeness at the PHENIX Experiment

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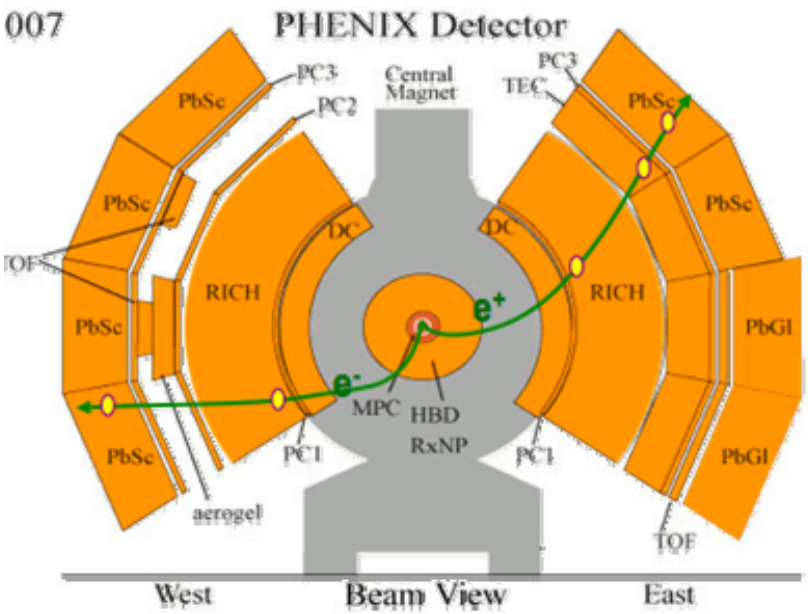
Introduction

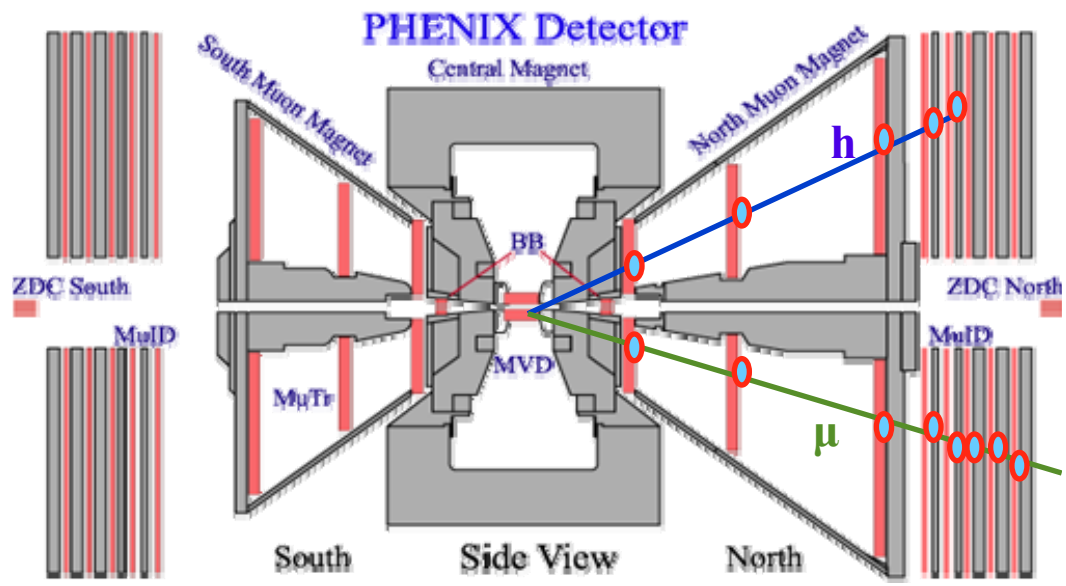
- Thermalized, hot, and dense matter is created at RHIC.
- What are the properties of this matter and how do we study them?
  - Thermalized: collective flow
  - Partonic: flow scaling with n_q
  - Dense: suppresses high P_T hadrons, heavy quarks, J/ψ
  - Strongly coupled: heavy quarks flow
- Focus today on PHENIX measurements of
  - Strangeness
  - Heavy flavor
  - Quarkonia

PHENIX Experiment

Central Arms



Forward Arms



Hadrons, electron, photons

$|\eta|<0.35$ $\Delta\Phi = 2 \times \pi/2$

Momentum resolution $\sigma_p/p \sim 1\% \oplus 1\%\ p$

Muons

$-2.2<\eta<-1.2$ $1.2<\eta<2.2$ $\Delta\Phi=2\pi$

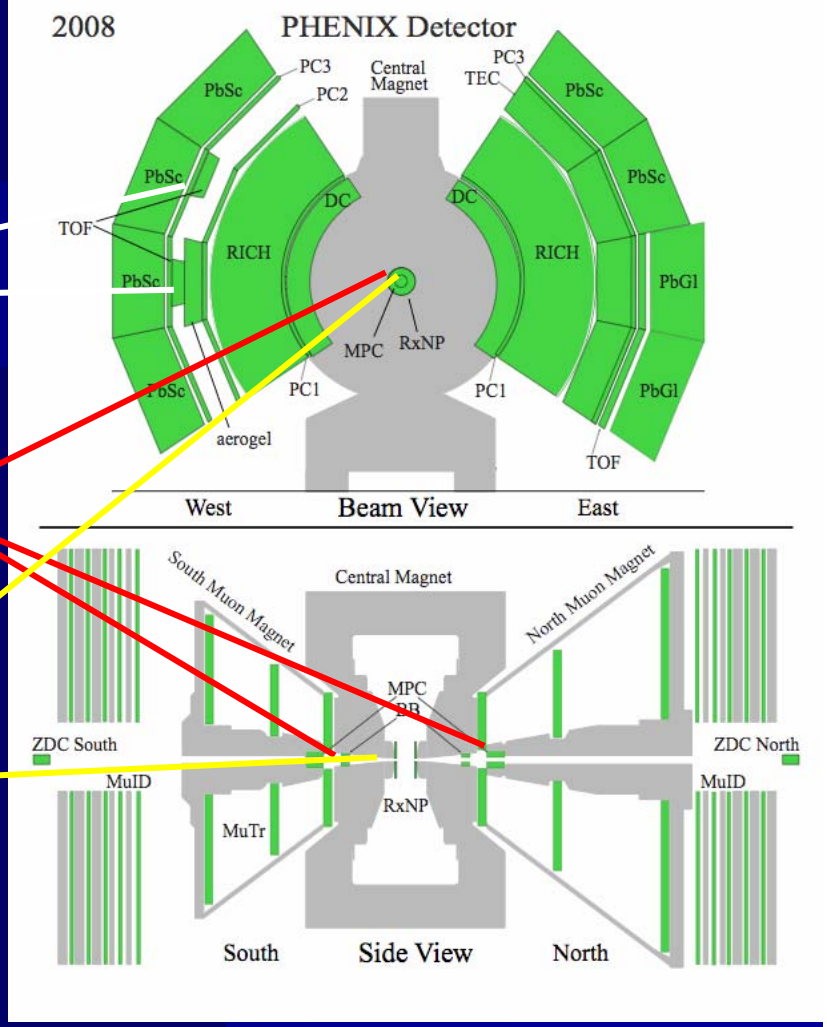
muons decays $p>2$ GeV/c

PHENIX "new" detectors & data

TOF W: PID at high pT
MultiGap RPC
TOF resolution~75ps

Muon Piston Cal: Forward physics in pp
Reaction Plane in AA
400 $PbWO_4$ crystals

RxNP: Reaction plane in AA
Trigger for low energy runs
2 rings of scintillator counters
$\eta = 1.0 \rightarrow 1.5$, $\eta = 1.5 \rightarrow 2.8$

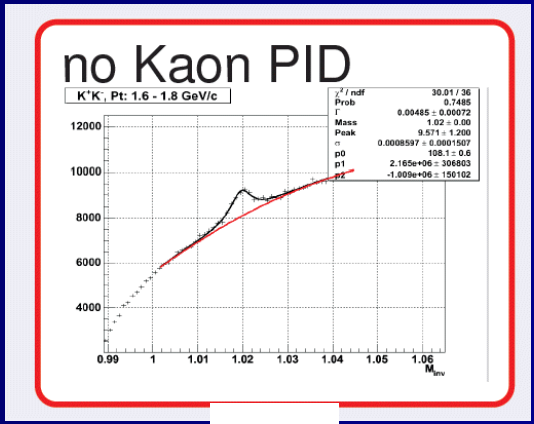


Recent DataSets:

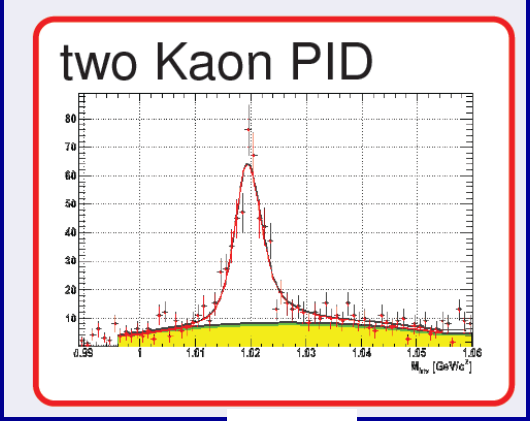
- **Run 7 Au+Au 3 times the Run4 Au+Au - some results**
- **Run8 d+Au is 30 times the Run 3 d+Au - ongoing analysis**

Strangeness Measurements

φ→K+K-

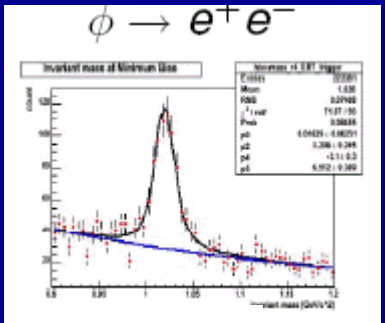


p+p



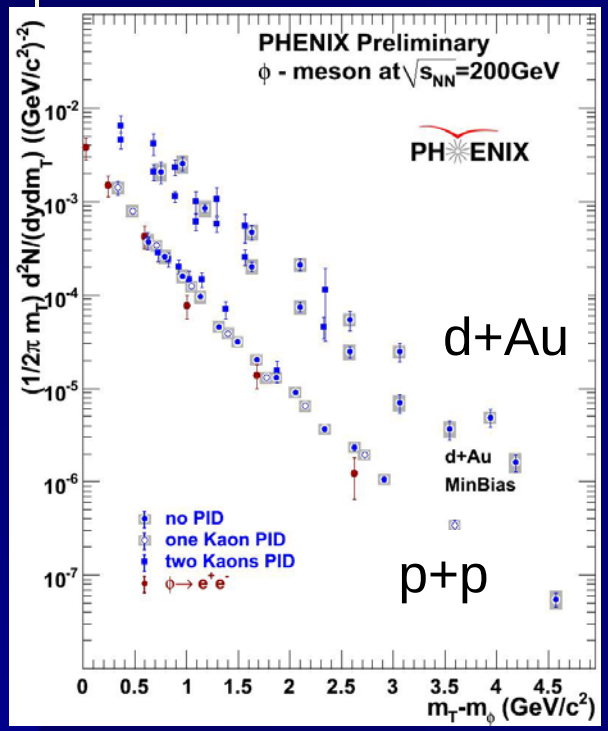
p+p

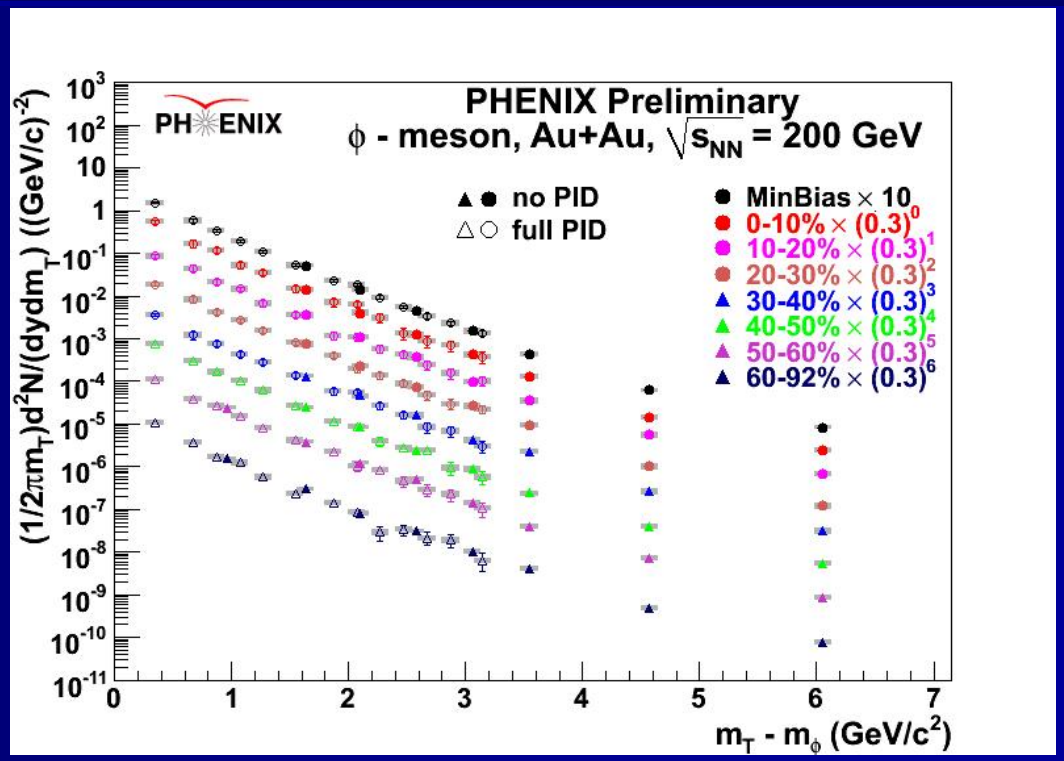
Work in progress φ→e+e-



p+p

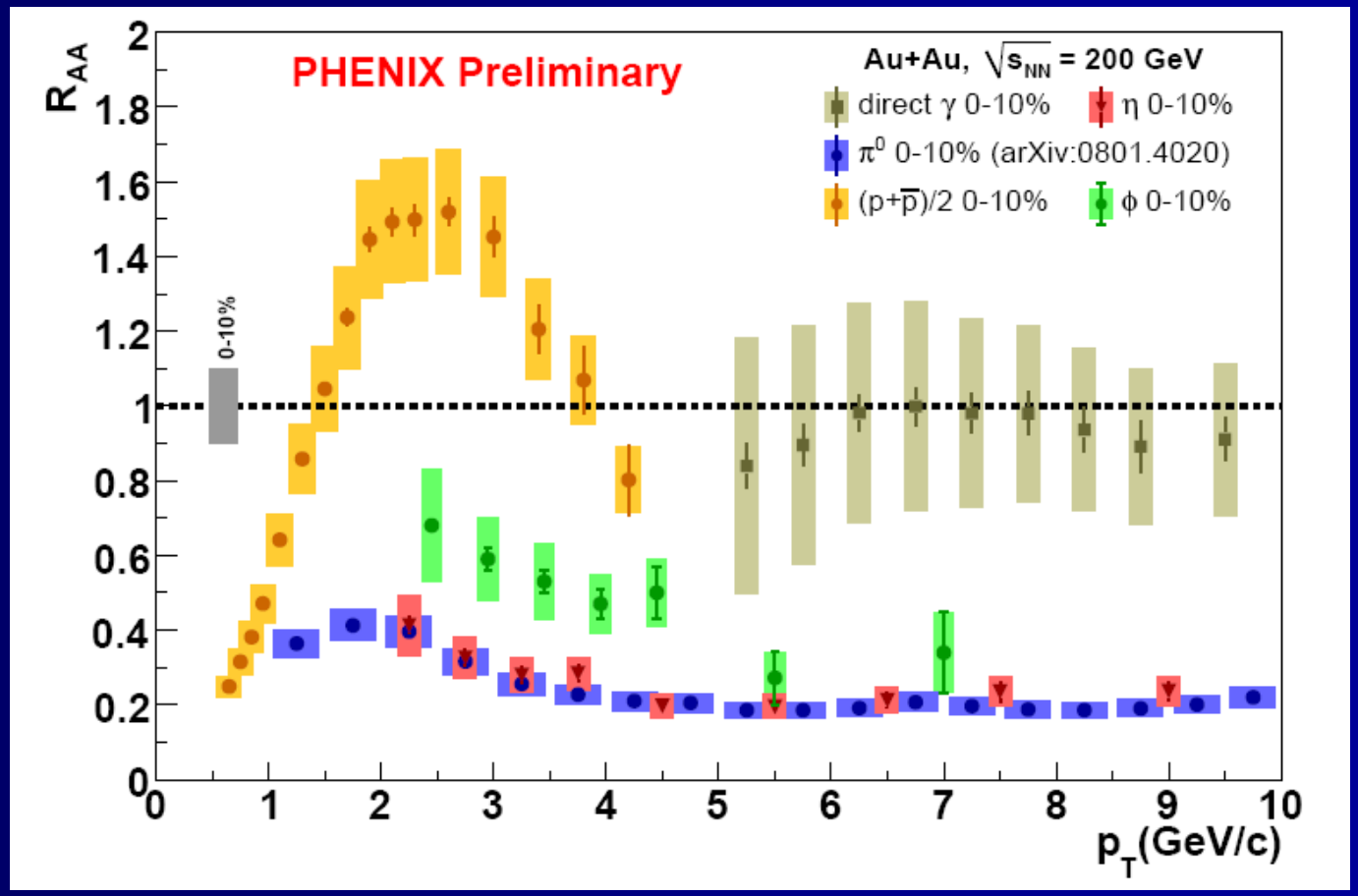
ϕ meson spectra





- **PHENIX measures clear signal of $\varphi \rightarrow K^+K^-$ in all collision systems**
- **Two independent analyses agree in Au+Au and p+p**

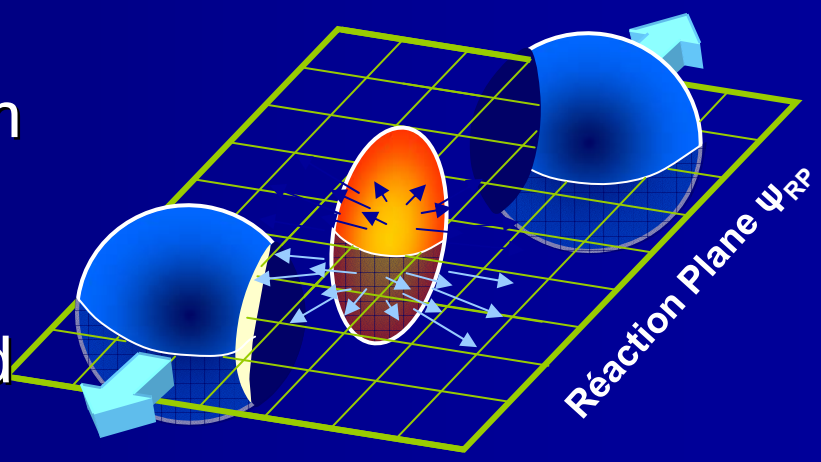
Nuclear Modification Factor



- φ suppression factor different from π^0, η, and proton

Azimuthal anysotropy

- In non central collisions, almond shaped interaction region results in a pressure gradient
- More particles are emitted 'in plane' than 'out of plane'



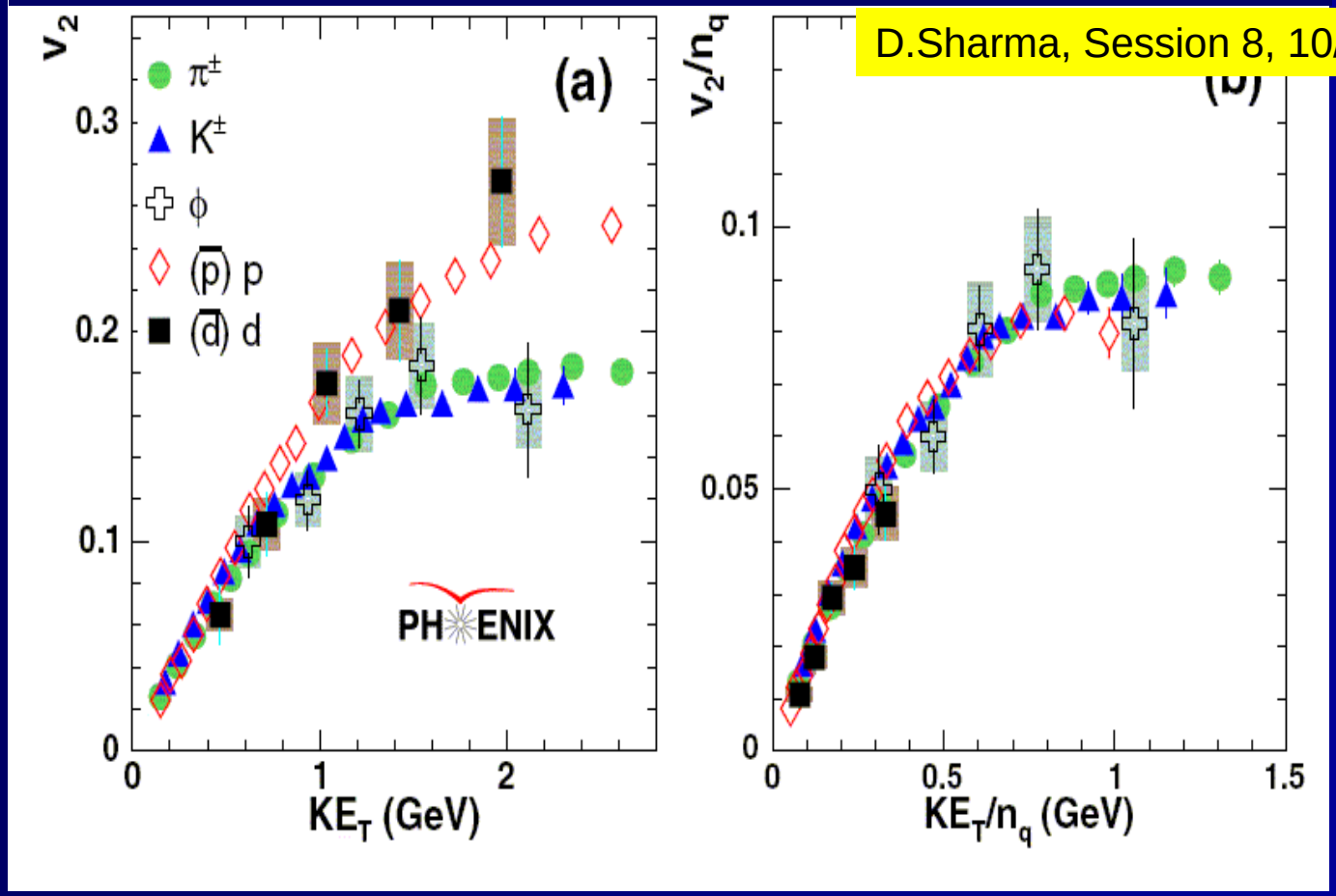
$$\frac{dN}{dp_t dy d\phi} \approx \frac{dN}{dp_t dy}\left[1 + 2v_2 \cos\left(2\left(\phi - \Psi_{RP}\right)\right)\right]$$

- The phi interaction with hadrons is suppressed by the OZI rule we expect smaller v_2 if flow is established in the hadronic phase

ϕ Elliptic Flow – v_2

Phys. Rev. Lett. 99, 052301 (2007)

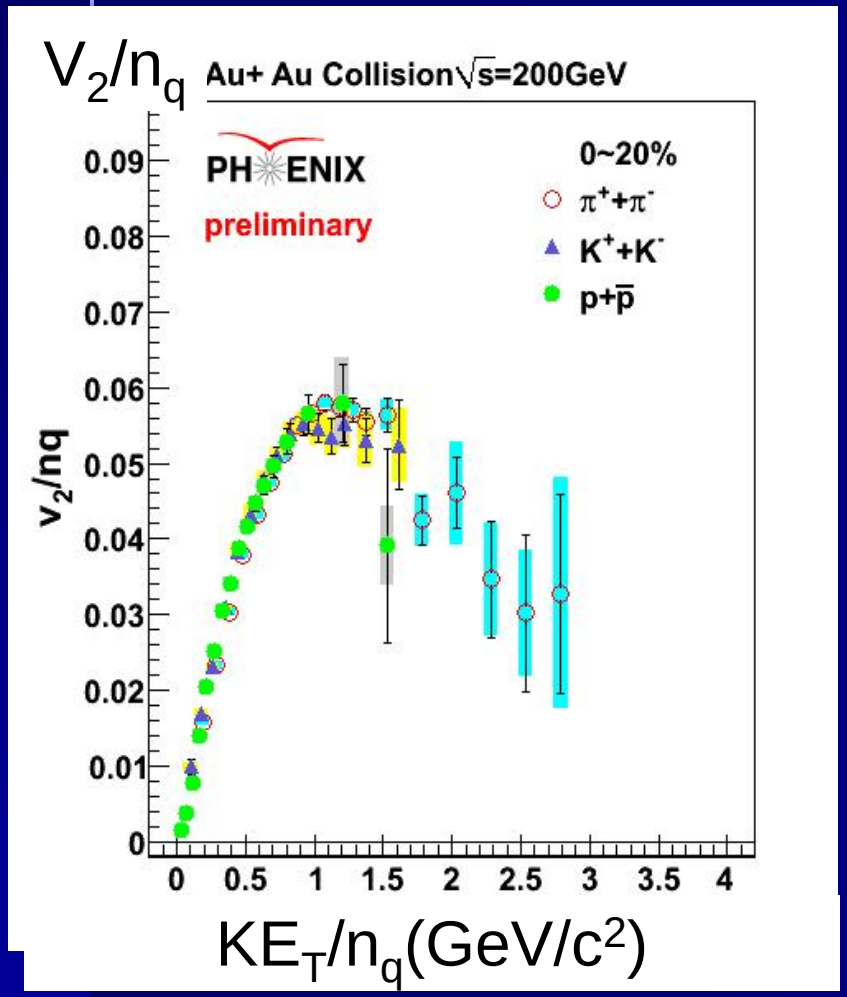
D.Sharma, Session 8, 10/07 17:15h

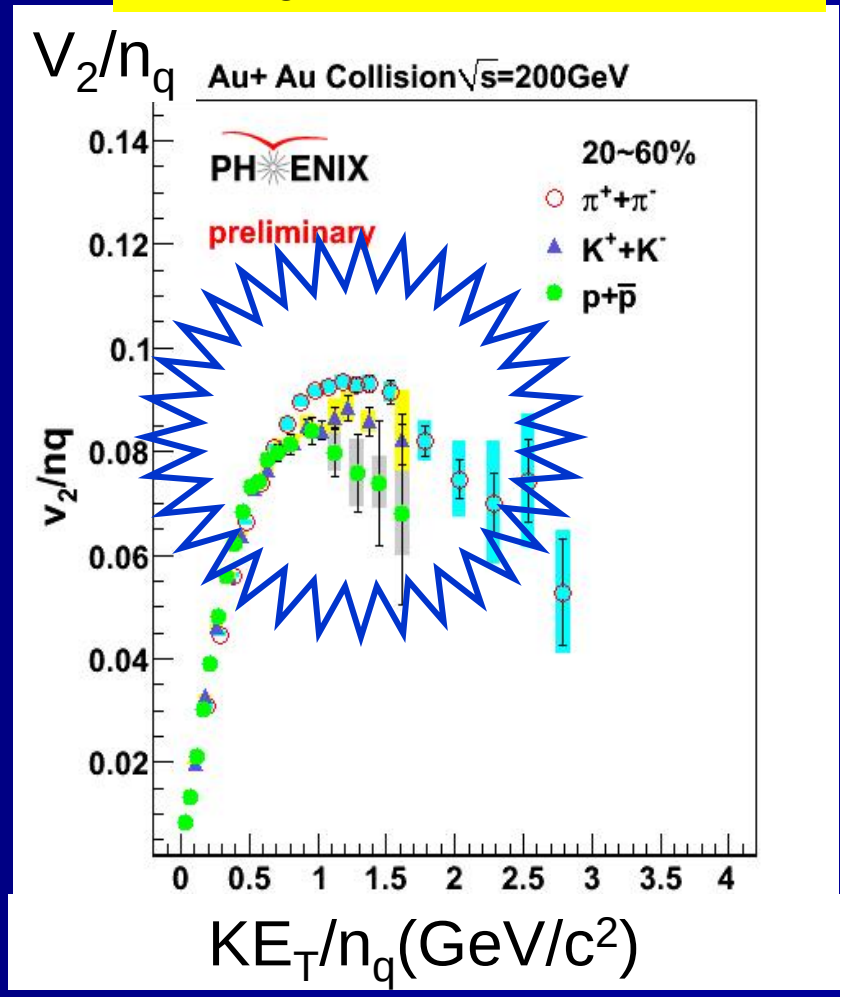


- ϕ follows universal scaling for baryons and mesons

Elliptic Flow – v_2 at high p_T

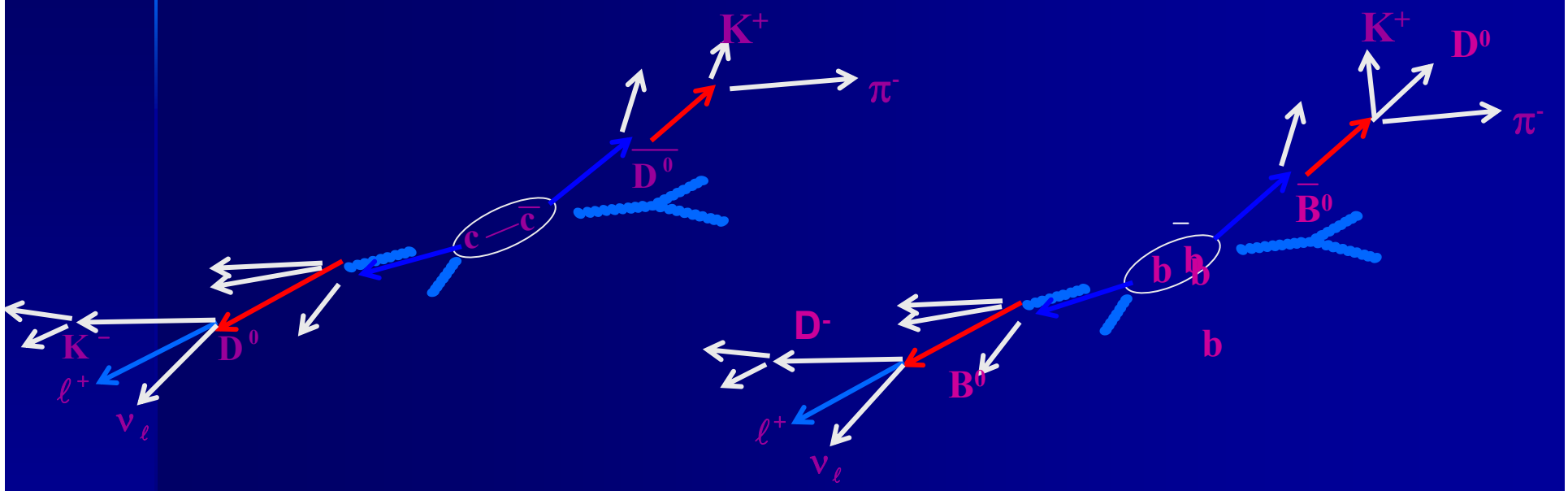
S.Huang, Session III, 10/09 14:20h





- Baryon/meson scaling breaks at about 1GeV

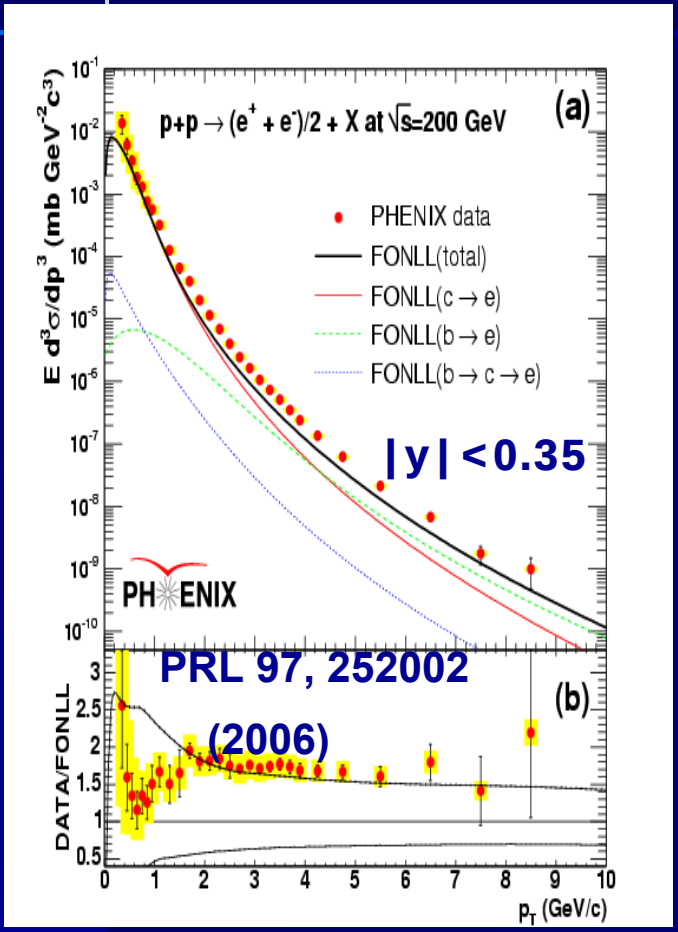
Heavy Quark Measurements

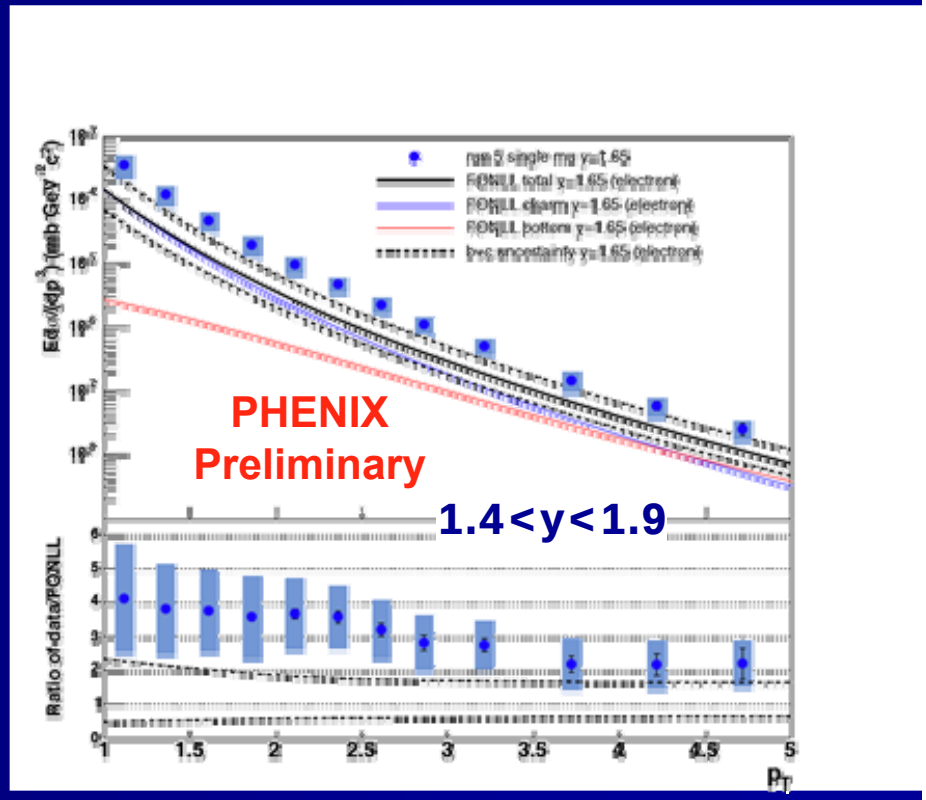


indirect measurement using semileptonic heavy-flavor decays:

Measure contribution of heavy flavor to lepton spectra and even separate charm and bottom

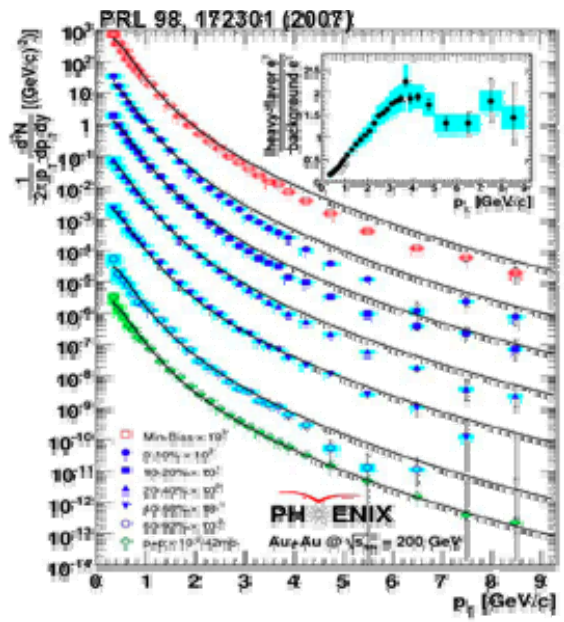
Heavy Quark in p+p Collisions



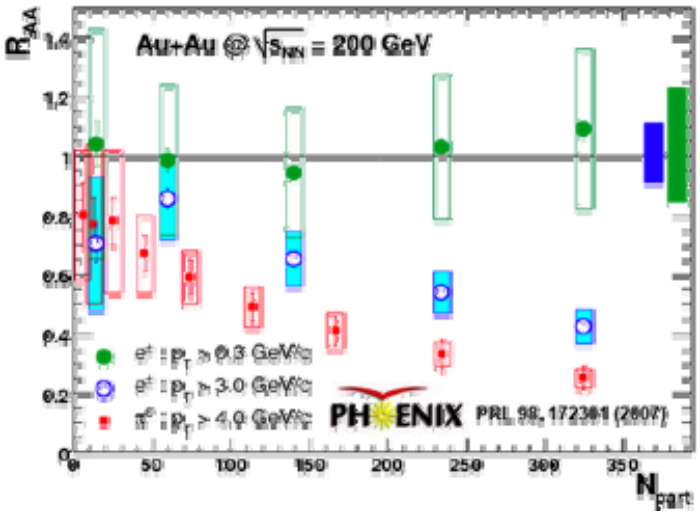


- Measurements in agreement with pQCD calculations within large theoretical uncertainty

Heavy Flavor in Au+Au

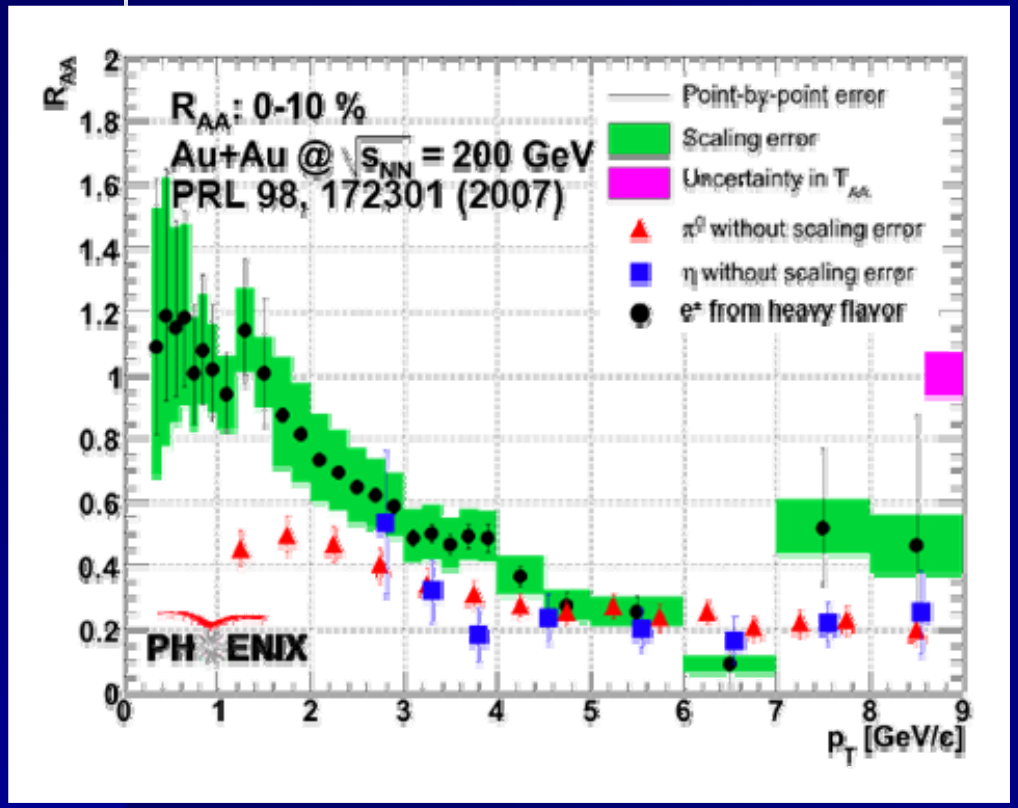


$$R_{AA} = \frac{dN_{Au+Au}}{\langle T_{AA} \rangle \times d\sigma_{p+p}}$$



- binary scaling of total $e^{\pm}$ yield from heavy-flavor decays
  - hard process production and no destruction
- high p_T $e^{\pm}$ suppression increasing with centrality
  - similar to π^0 suppression

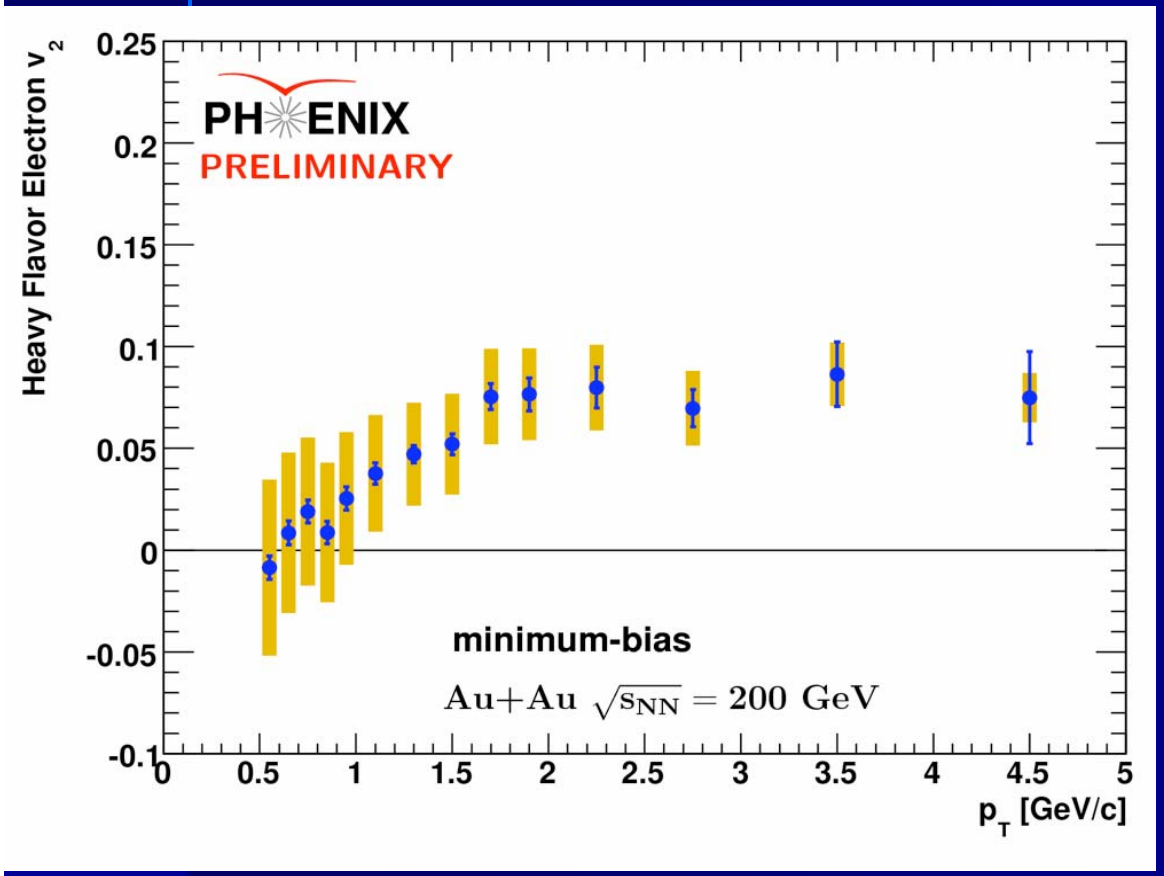
p_T dependence of R_{AA}



- intermediate p_T indication for quark mass hierarchy as expected for radiative energy loss
  Dokshitzer and Kharzeev, PLB 519(2001)199
- highest p_T
  $R_{AA}(e^\pm) \sim R_{AA}(\pi^0) \sim R_{AA}(\eta)$

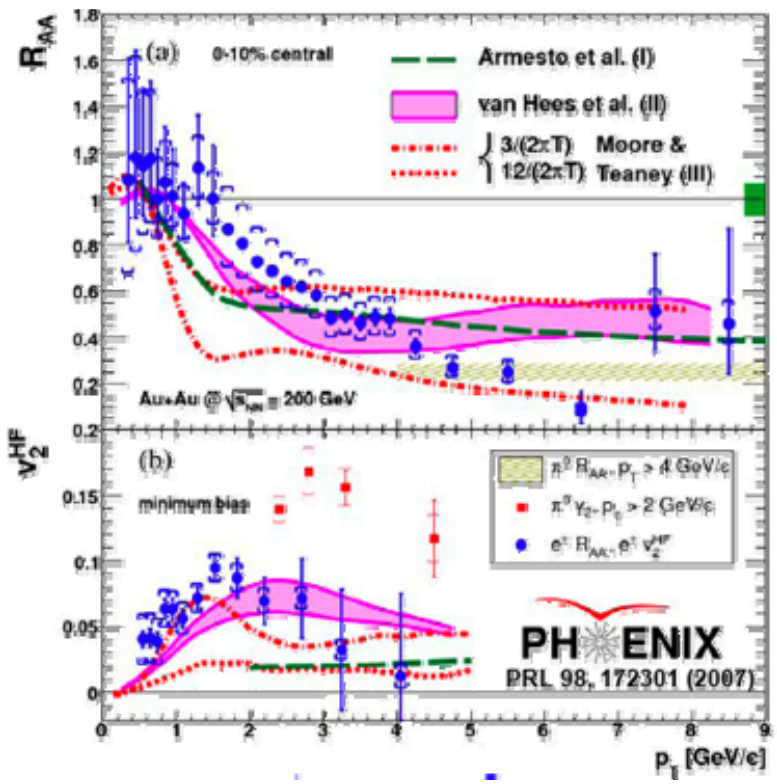
- Heavy quark nuclear modification factor similar to light hadrons

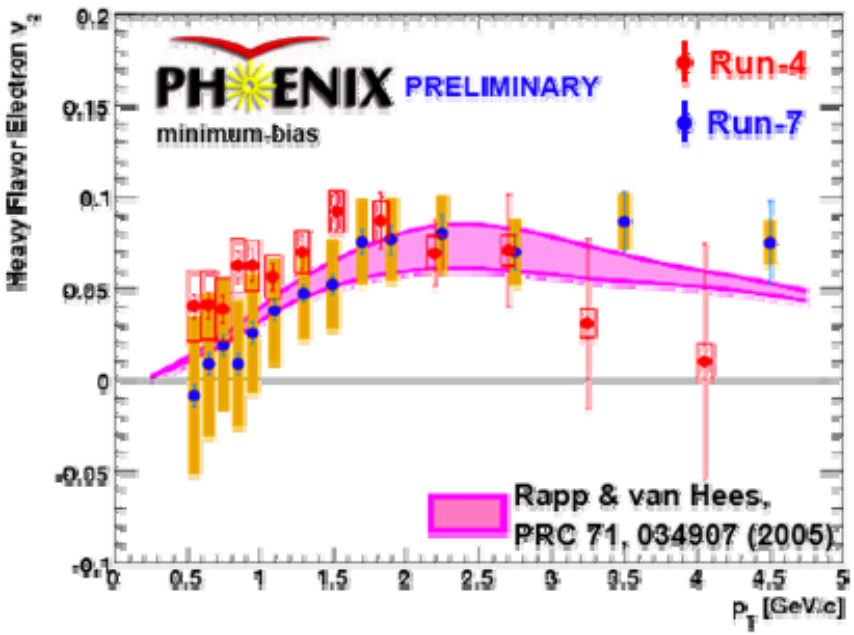
Heavy Flavor Elliptic Flow



- Significant v_2
  - high density
  - small diffusion coefficient
- Need to distinguish bottom from charm to find out if bottom flows

Heavy Flavor v_2





- good agreement with Langevin based transport calculation including resonant elastic scattering (radiative ΔE + collisional ΔE included)

Estimating η/s from heavy quarks

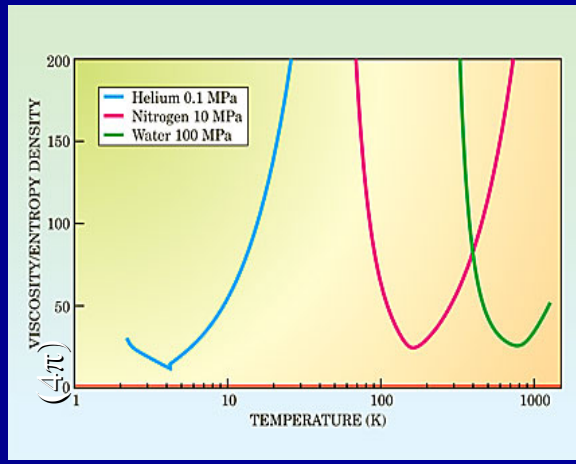
- Conjecture quantum limit motivated by AdS/CFT* and derived by P. Kovtun, D.T. Son, A.O. Starinets (PRL94,111601 - 2005) for the minimum viscosity suggest

$$\frac{\eta}{s} \geq \frac{\hbar}{4\pi}$$

- Diffusion coefficient required for simultaneous fit of R_{AA} and v_2 [Rapp & van Hees PRC 71, 034907 (2005)]

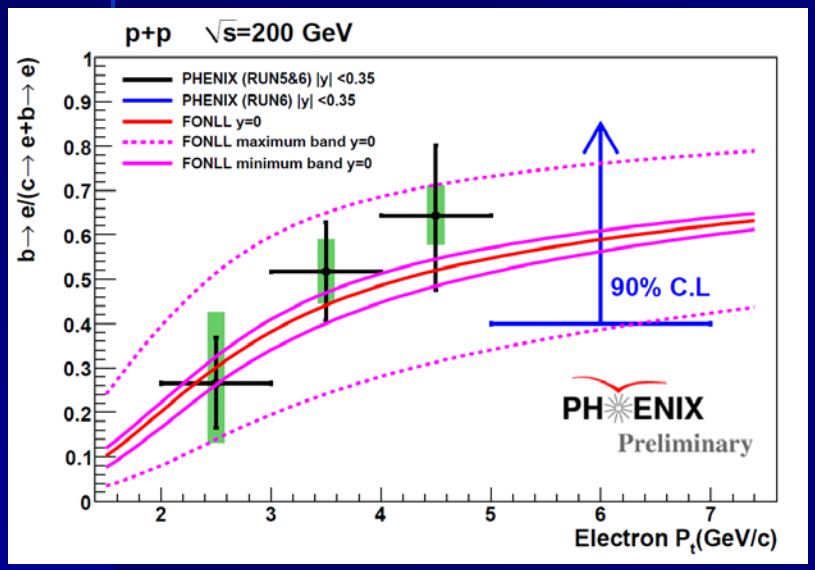
$$D_{HQ} \times 2\pi T = 4 - 6$$

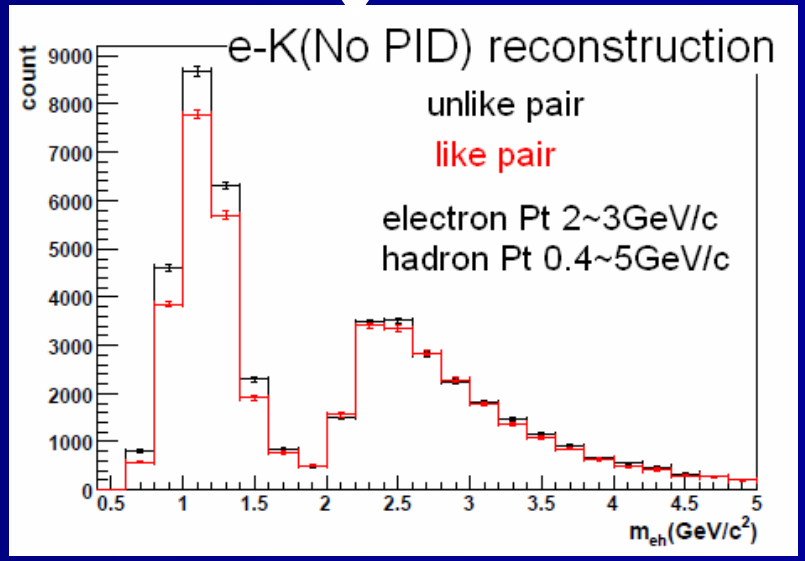
$$\frac{\eta}{s} = \frac{(1.3 - 2)}{4\pi}$$



B measurement in p+p collisions

- Measurement of invariant mass for electron-hadron pairs to select D→keν





bottom fraction in non-photonic electrons is dominant above 4GeV

Excess below 1.9 GeV is charm

Is bottom also suppressed in Au+Au above 5GeV ?

Y.Morino, Session II, 10/09 15:40h

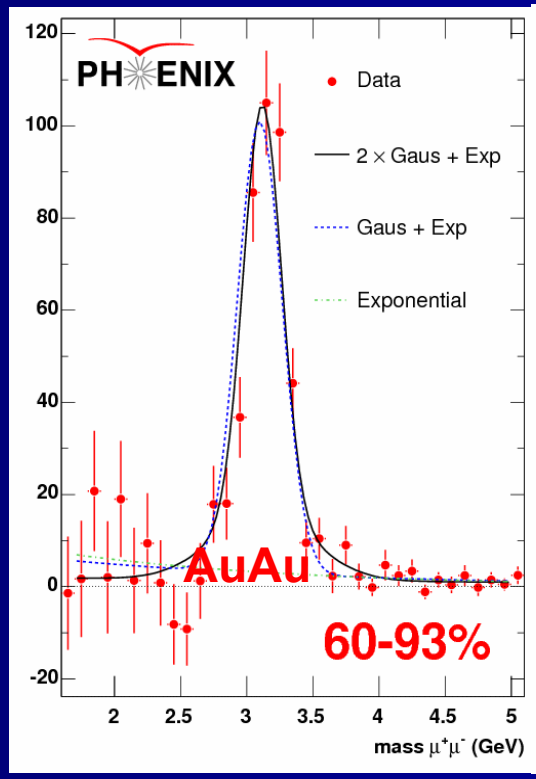
Quarkonia Measurements

PHENIX measures:

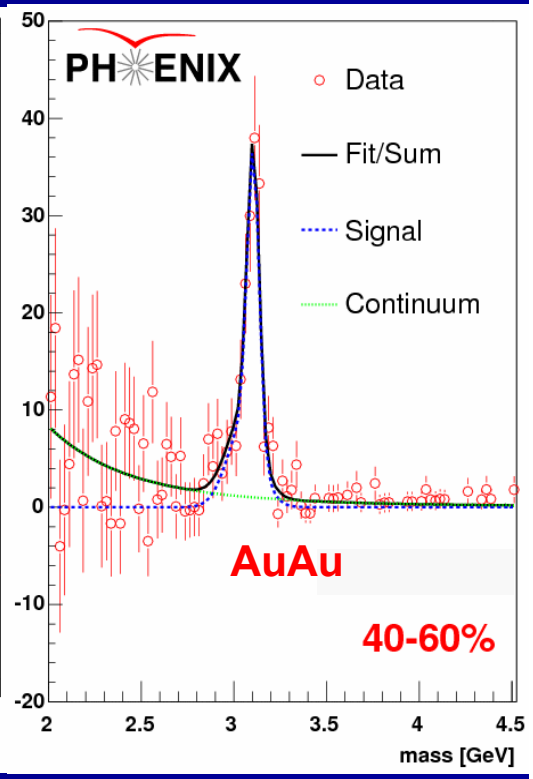
- J/ψ, ψ', $\Upsilon \rightarrow e^+e^-$, $\mu^+\mu^-$
- $\chi_c \rightarrow J/\psi + \gamma$

Di-lepton mass peaks must be separated from di-lepton physics backgrounds + combinatorial background

$J/\psi \rightarrow \mu^+\mu^-$



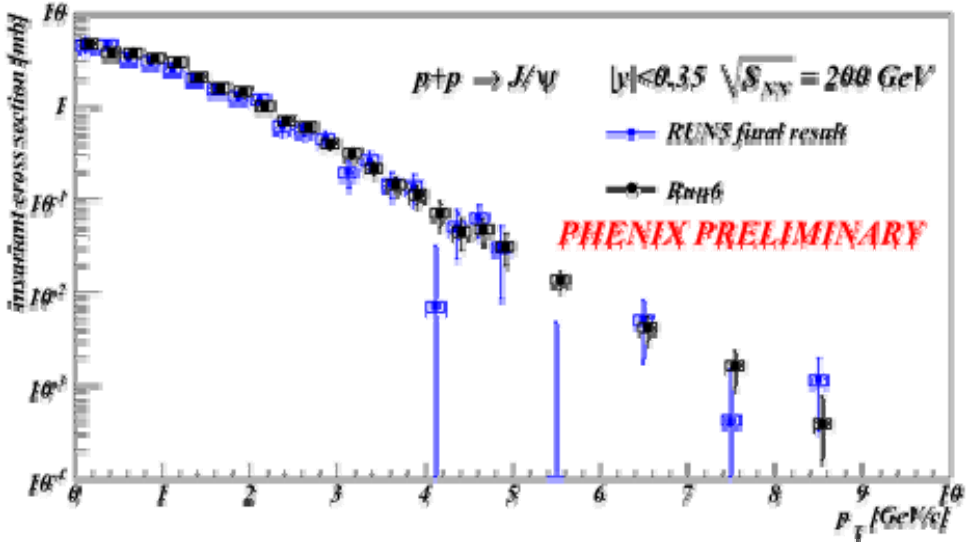
$J/\psi \rightarrow e^+e^-$

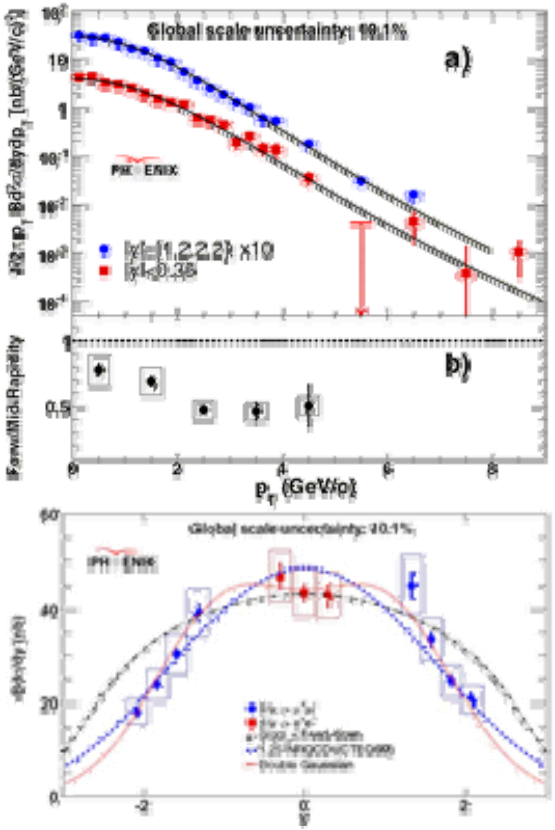


L.A. Linden Levy, Session 5, 10/07 9:30h

J/ψ in p+p collisions

PRL98, 232002 (2007)

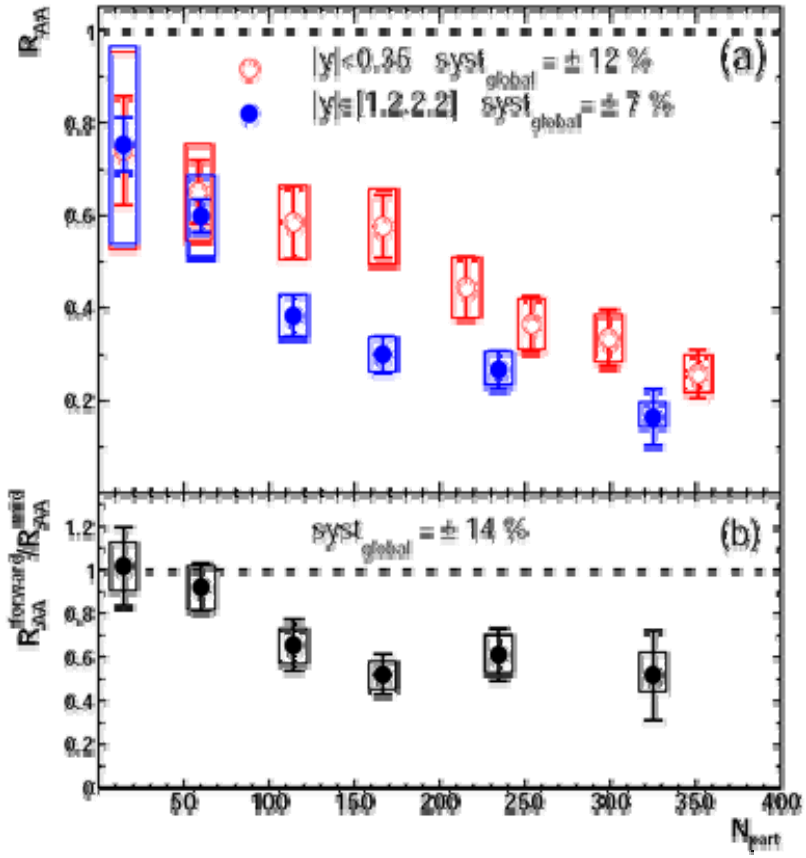




- Comparison J/ψ production mechanisms
- Wide kinematic range, good baseline to heavy ion yields

BR(J/ψ→l+l-)σ(J/ψ)=178 ± 3(stat) ± 53(syst) ± 18(norm) nb

Suppression Factor in Au+Au Collisions

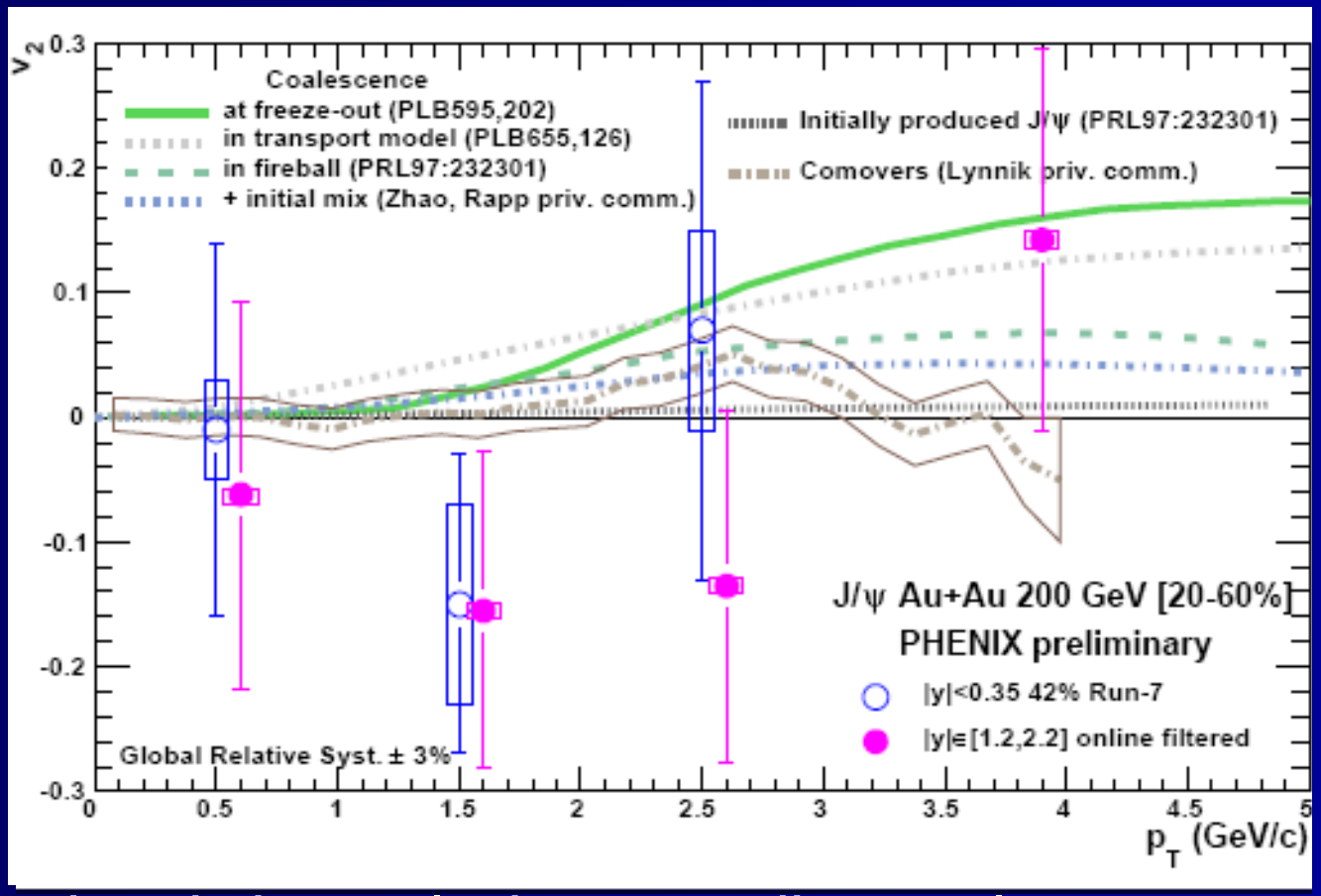


- Forward rapidity more suppressed than mid-rapidity
- Does the J/ψ show anomalous suppression? Need a precise measurement of cold nuclear matter effects

L.A. Linden Levy, Session 5, 10/07 9:30h

- Recombination: could potentially explain suppression versus centrality: measure J/ψ flow

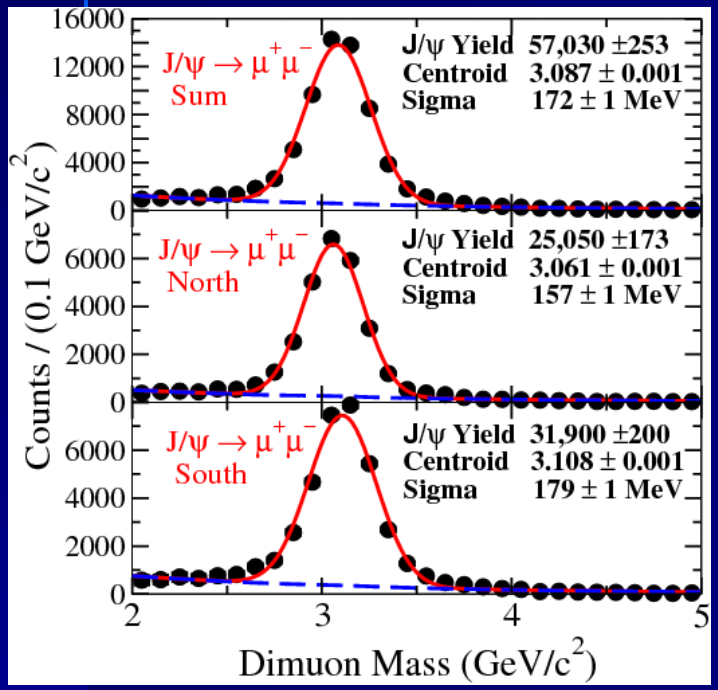
J/ψ flow measurement

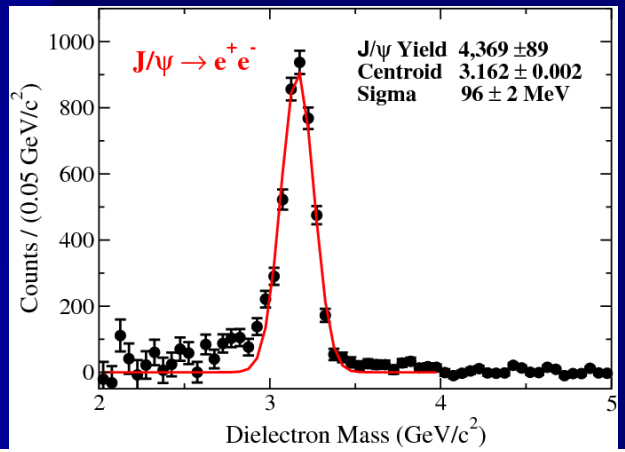


- data is inconclusive regarding coalescence
- Needs much higher statistics

Future is bright !

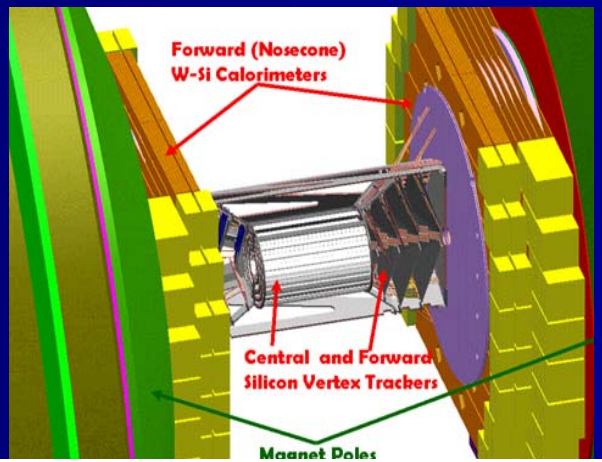
Run8 - dAu

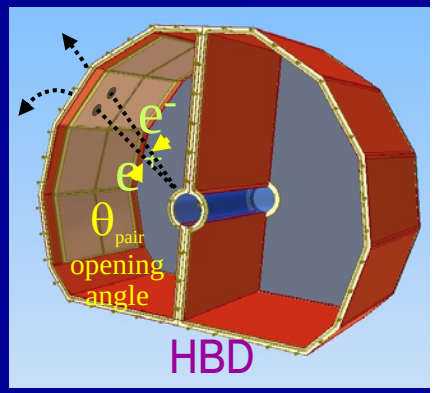




Upgrades

- Data with Hadron Blind Detector: improve low mass electron pairs
- Silicon Vertex Detector: direct open charm and bottom mid and forward rapidity
- Nosecone Calorimeter : forward rapidity photons → χ
- Forward Muon Upgrades: higher PT





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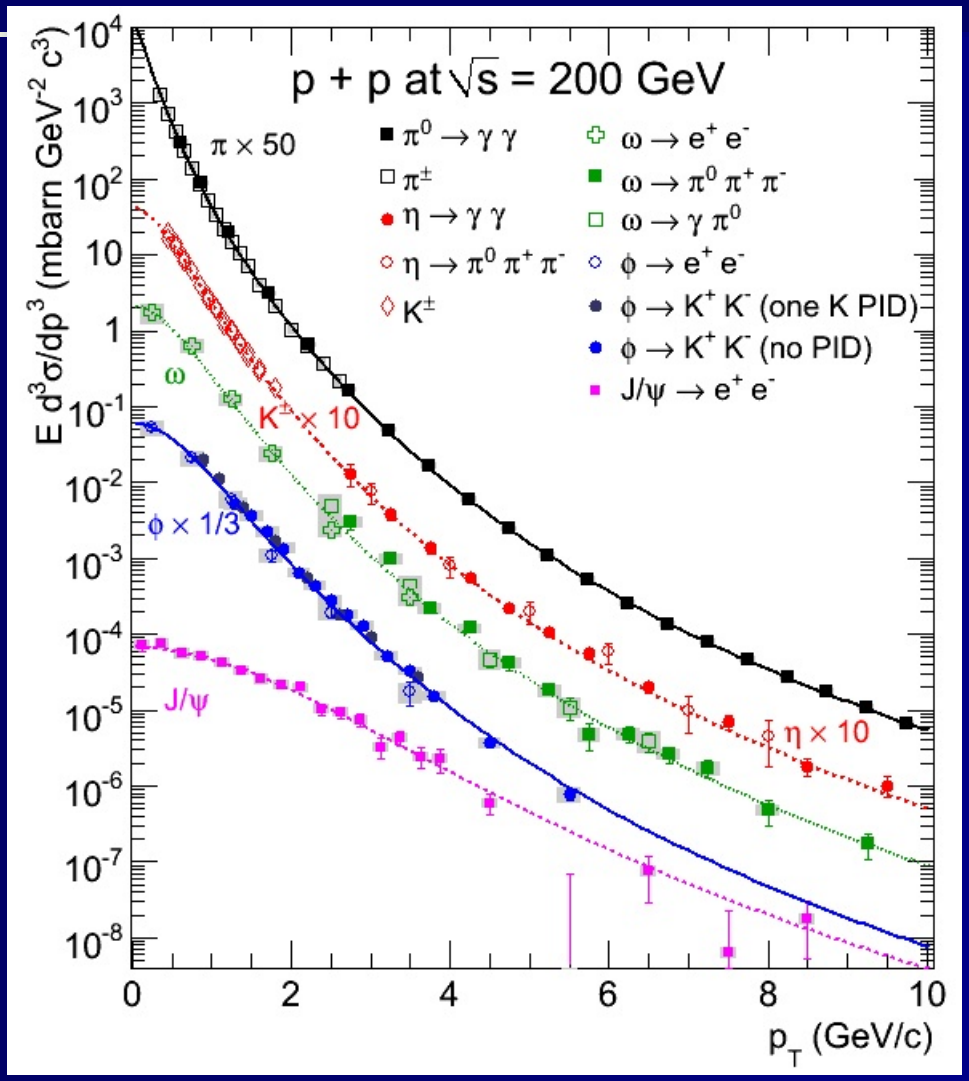
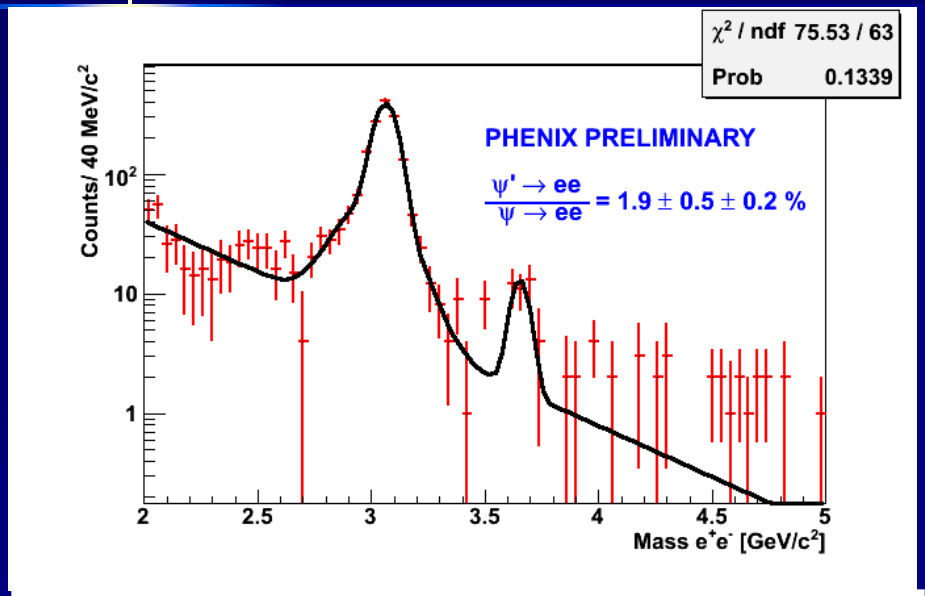
Backup Slides

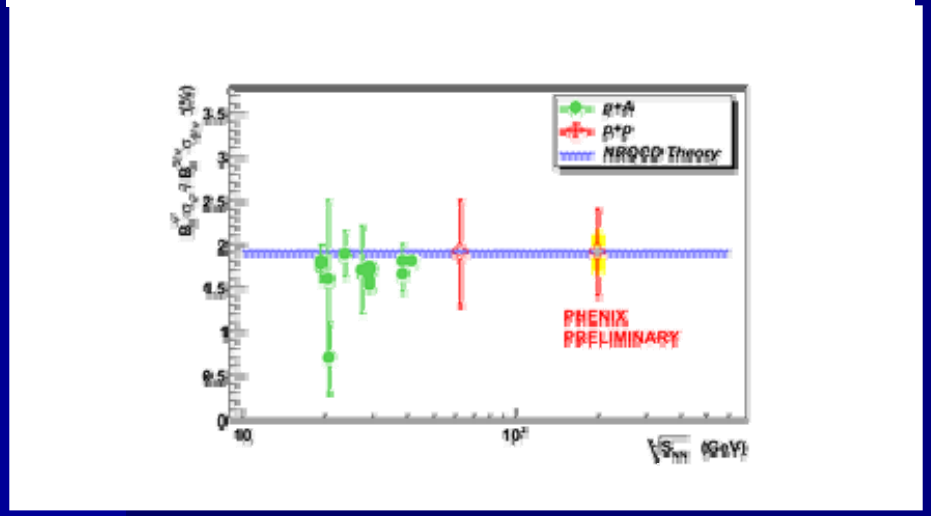
PHENIX Capabilities



In p-p collisions, all spectra can be described by fitting π^0's with modified Hagedorn function and applying m_T scaling.

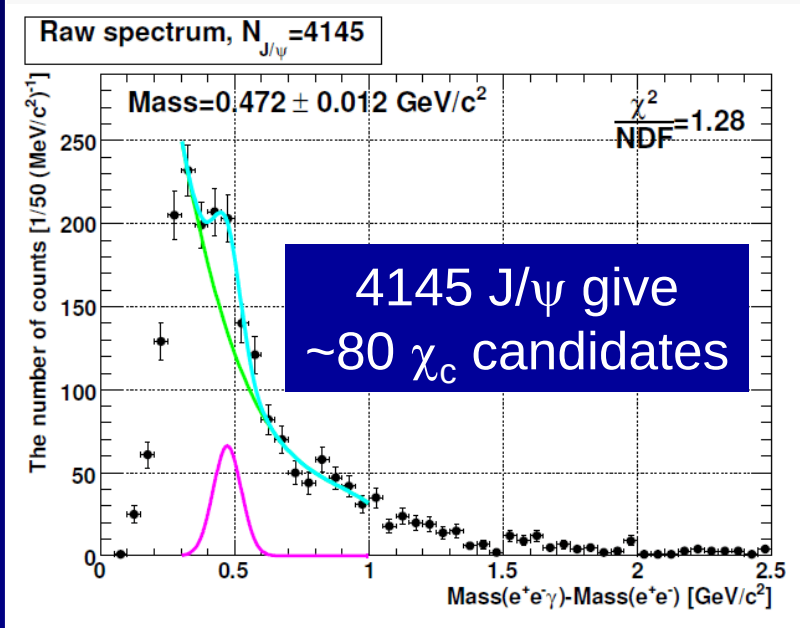
ψ' measurement

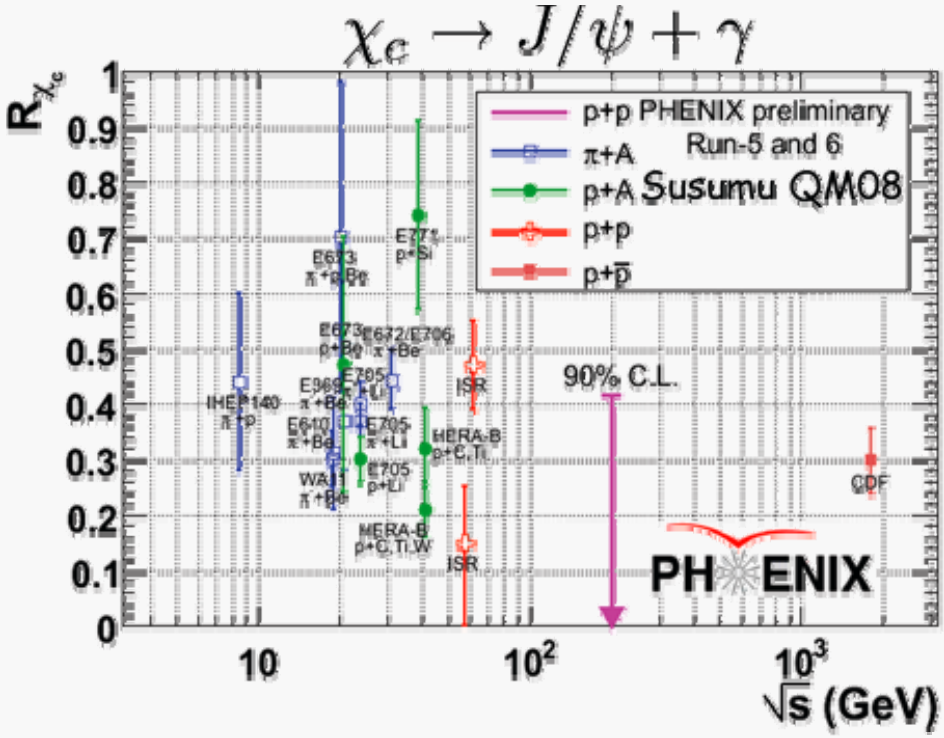




- PHENIX preliminary
  $BR(\psi' \rightarrow e^+e^-)\sigma(\psi')$ / $BR(J/\psi \rightarrow e^+e)\sigma(J/\psi)$
  $=0.019 \pm 0.005$ (stat) 0.002 (syst)
- PDG 2007 values
  - $BR(J/\psi \rightarrow e^+e^-)=5.94 \pm 0.06\%$
  - $BR(\psi' \rightarrow e^+e^-)=0.743 \pm 0.018\%$
  - $BR(\psi' \rightarrow J/\psi+X)=56.9 \pm 0.9\%$
- $\sigma(\psi')/\sigma(J/\psi)=0.15 \pm 0.04$
- Feed-down fraction of J/ψ from ψ' is **0.086 ± 0.025**.

χ measurement



$$R_{\chi_c} = \frac{1}{\sigma(J/\psi)} \sum_{J=1}^{2} \sigma(\chi_{cJ}) BR(\chi_{cJ} \to J/\psi\,\gamma)$$

< 0.42 (90% C.L., PHENIX preliminary)