Electrons and Heavy Quark at PHENIX detector

Winter Workshop on Nuclear Dynamics
La Jolla / CA, March 11-19, 2006

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PHENIX

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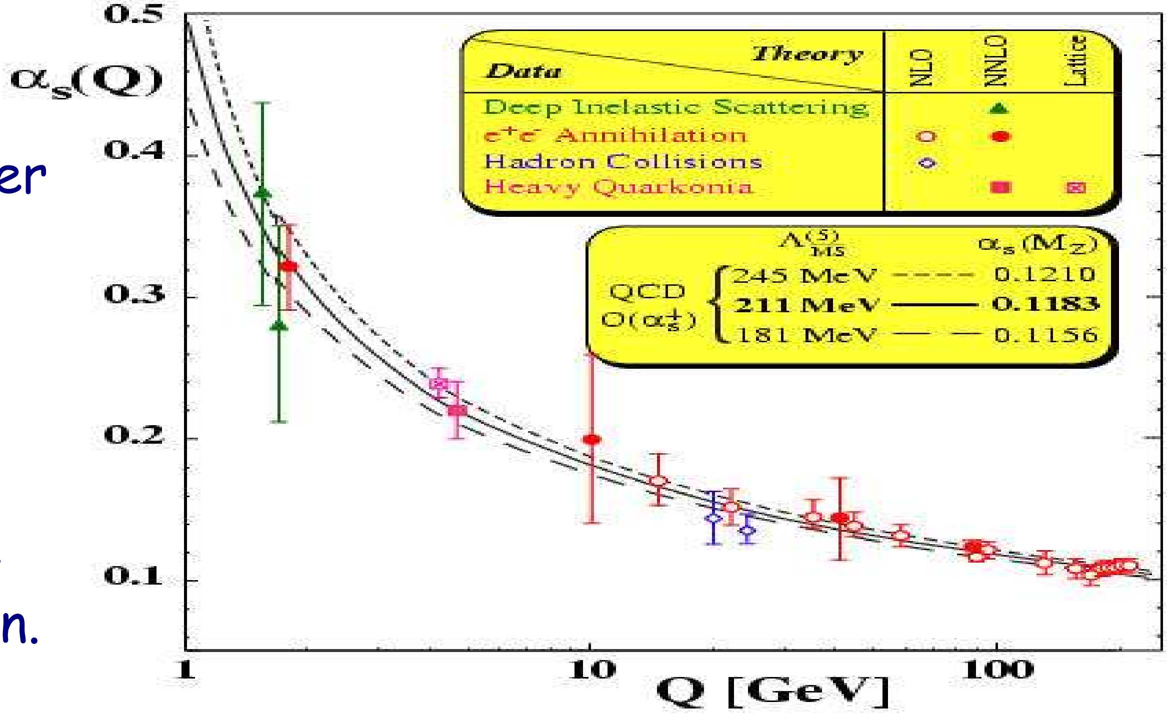
Outline

- Why Heavy Quarks are so important ?
- What can be measured ?
- PHENIX apparatus and electron identification
  - PHENIX acceptance and efficiency for electrons
- Extraction of charm and bottom from electron spectra
  - Cocktail method
  - Converter method
- Current results
  - Heavy quark yields
  - Suppression
  - Azimuthal anisotropy
- Summary and expectations

Why Heavy Quarks are so important ?

- Since heavy quark production requires large momentum transfer (Q>3 GeV) it can be treated in the pQCD framework.



- pQCD predictions can provide important information about the partonic structure of the nucleon.

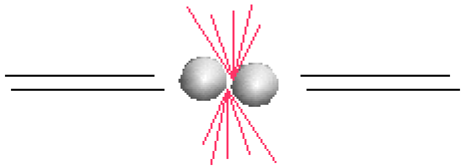
- Open charm is a reference for J/Psi measurement.

- Heavy quark suppression due to energy loss into the matter created in A+A collisions is sensitive to many environment conditions such as density, temperature, etc

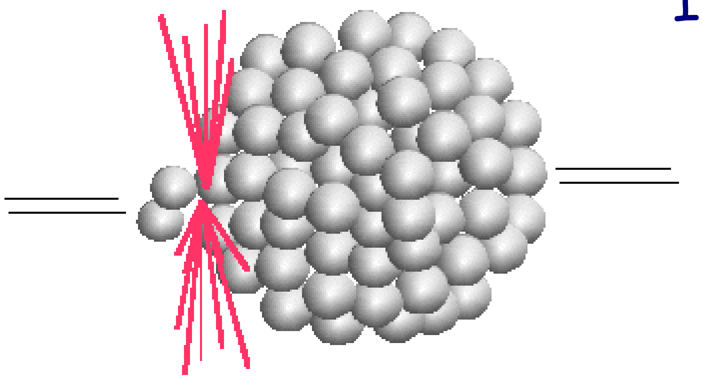
- Heavy flavor anisotropies give a valuable information about thermalization and viscosity

What can be measured about heavy quarks ?

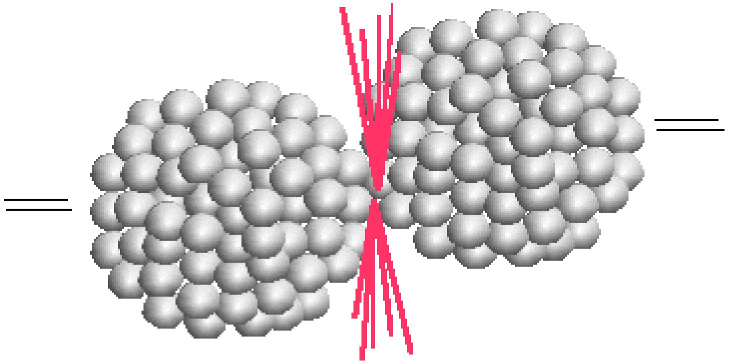
We can use different probes.



p_T spectra in p+p collision can be used to test pQCD calculations and extract the nucleon parton distribution.
It is the baseline for d+Au and Au+Au.



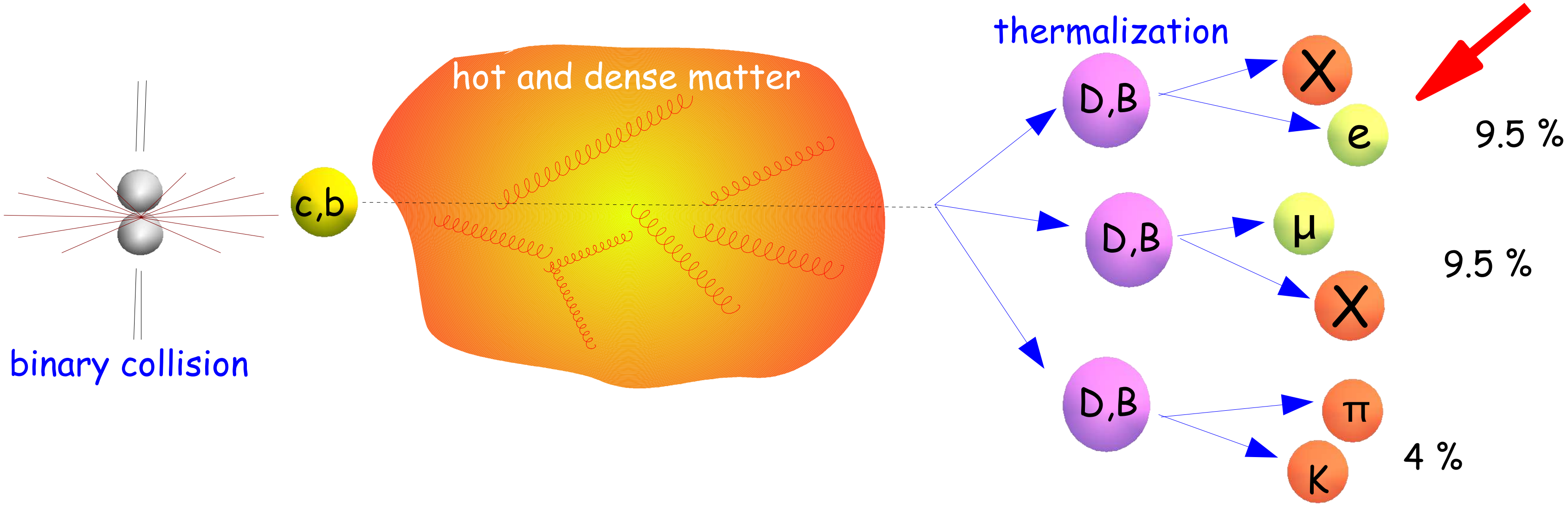
Nuclear modification factor (R_{dA}) accounts for “cold” matter effects from initial state, shadowing, Cronin effect and absorption.



R_{AA} is sensitive to energy loss in the final state matter formed. The energy loss can be used to account for thermodynamic properties of final state matter.

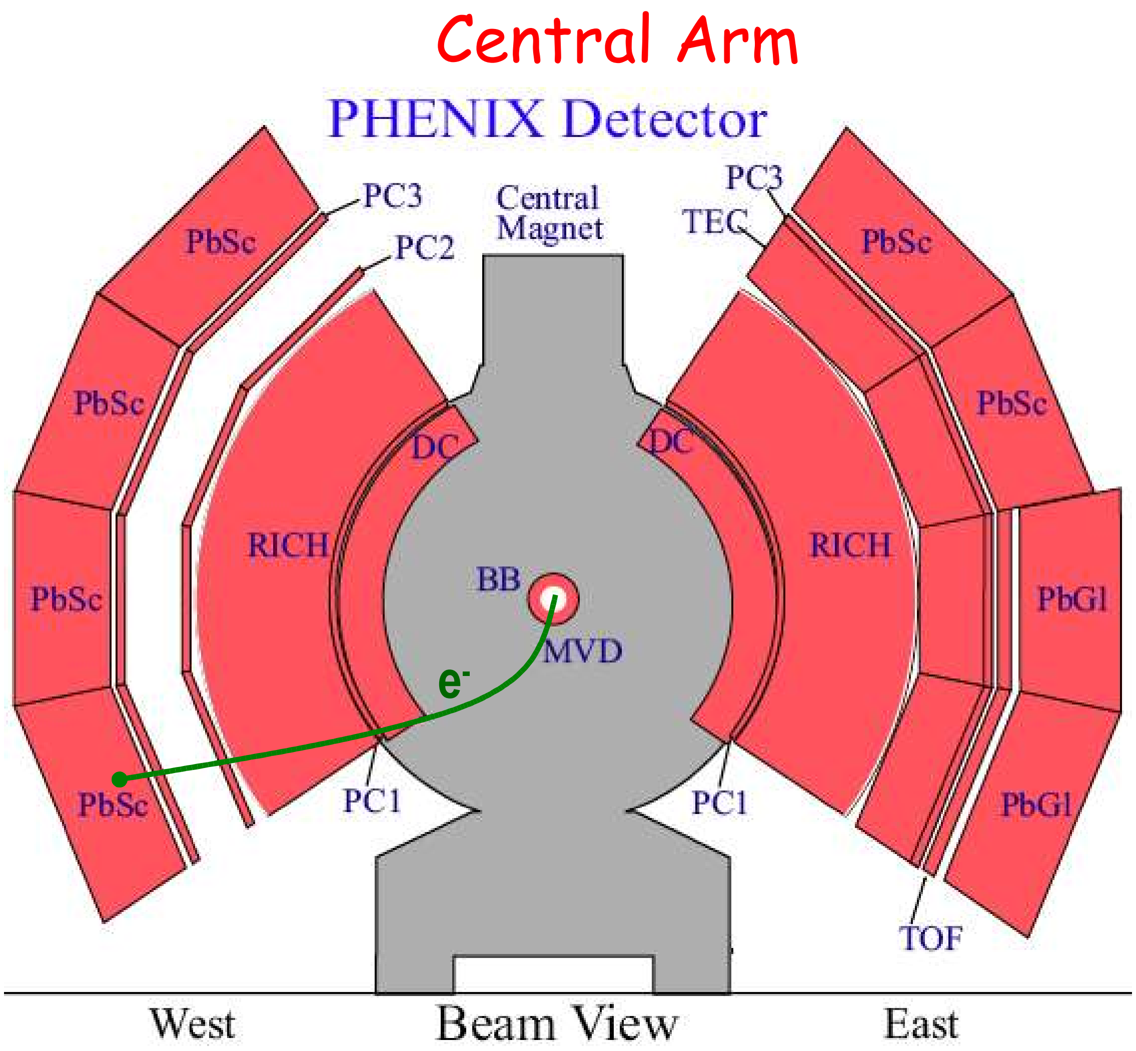
Elliptic flow is correlated to the interaction in the medium.

Heavy quark dynamics



PHENIX has measured D and B from electron and muon decays. The focus here is in the electron channel at mid-rapidity region.

PHENIX apparatus and electron identification



Central Arm :

- $|\eta|<0.35$
- $\Delta\Phi = 2 \times \pi/2$
- $\sigma p/p \sim 1\%$ (GeV/c)
- p > 0.2 GeV/c
- typical $|z_{vertex}| < 20$ cm
- radiation length = 1.1% (Run1-3)
  0.4% (Run4-)

Tracking :

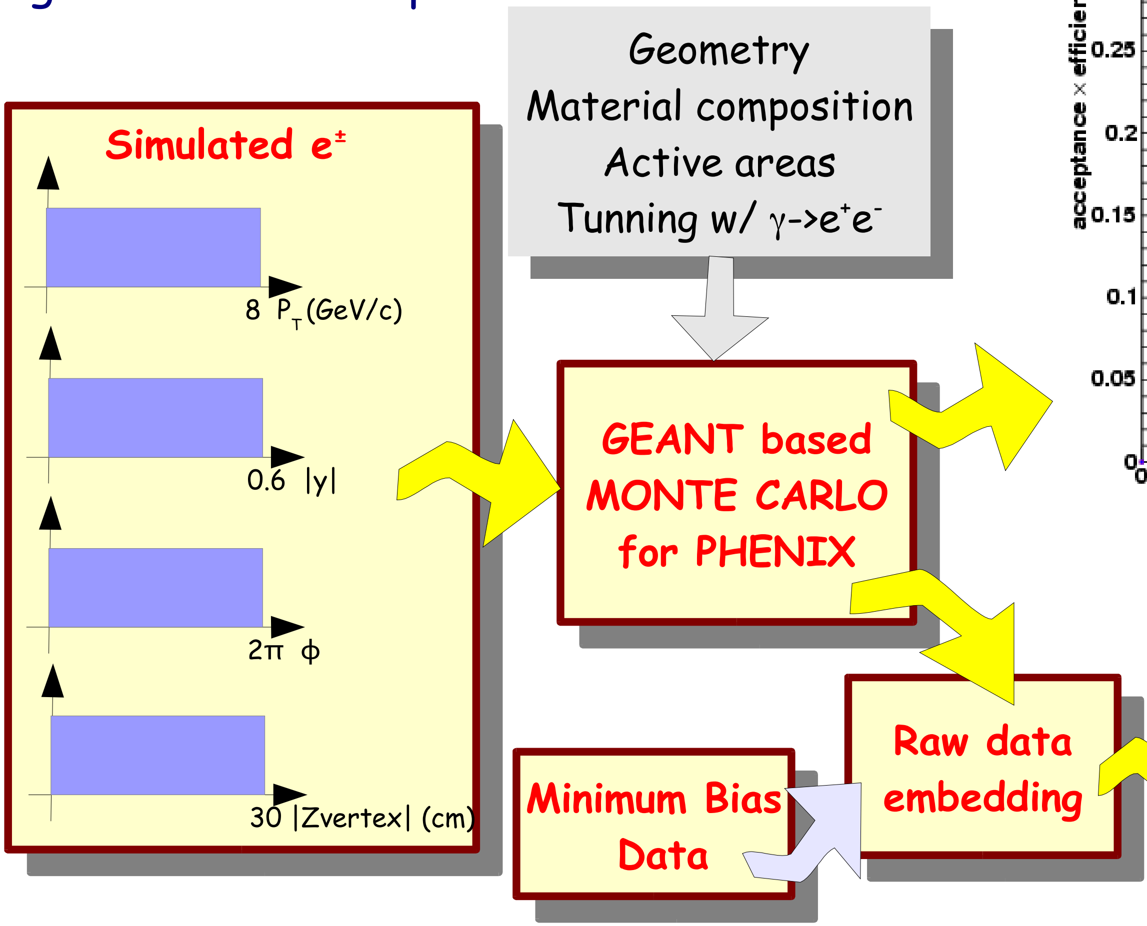
- Drift Chamber (DC)
- Pad Chamber (PC)

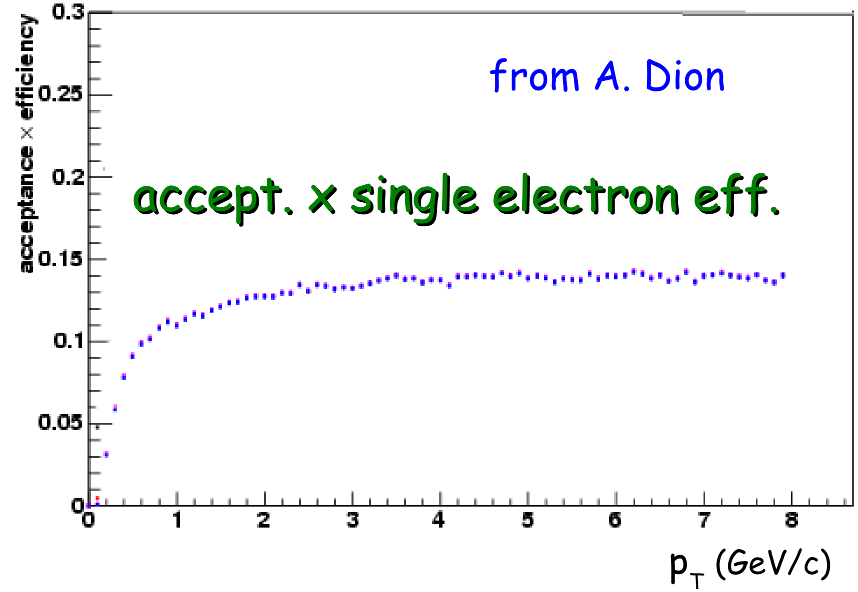
Electron Identification :

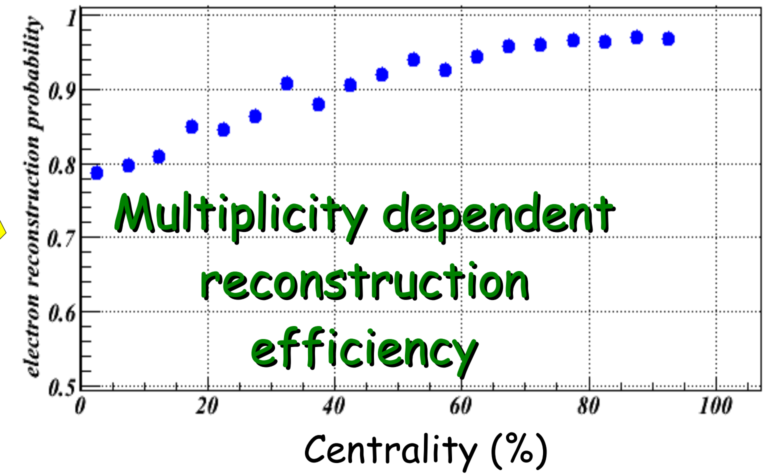
- Ring Cherenkov Detector (RICH)
- PbSc and PbGl electromagnetic calorimeters
- Transition Radiation Detector (TEC/TRD)

PHENIX Acceptance and efficiency for electrons.

geometrical acceptance : 35 %

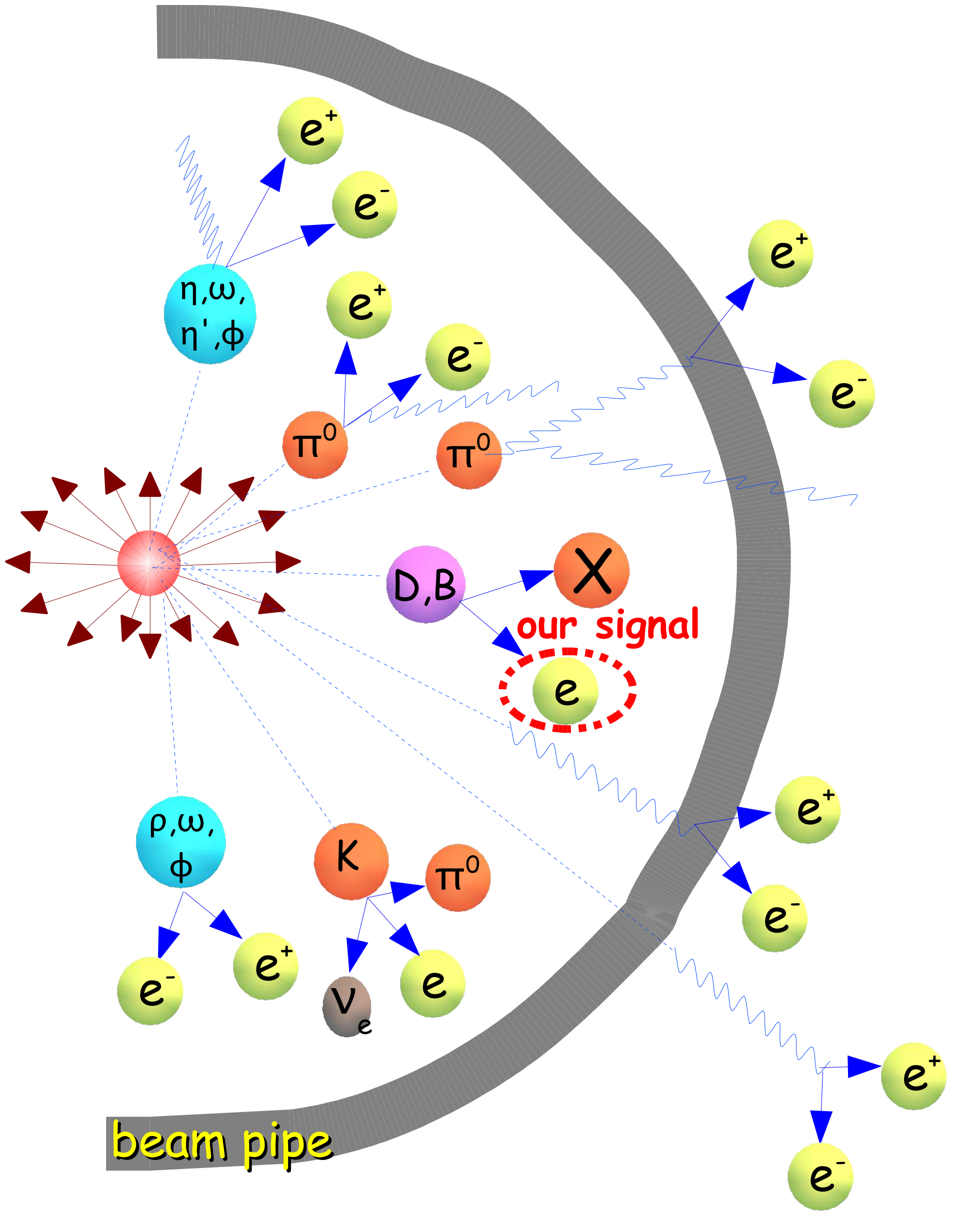






- We simulate single electrons-positrons with flat kinematics distributions (pT, y, ϕ, Zvertex)
- We use GEANT to calculate the detector acceptance and the single electron efficiency.
- The multiplicity dependent efficiency is estimated by embedding simulated single electron into the real data.

Extraction of charm and bottom from $e^{\pm}$ spectra

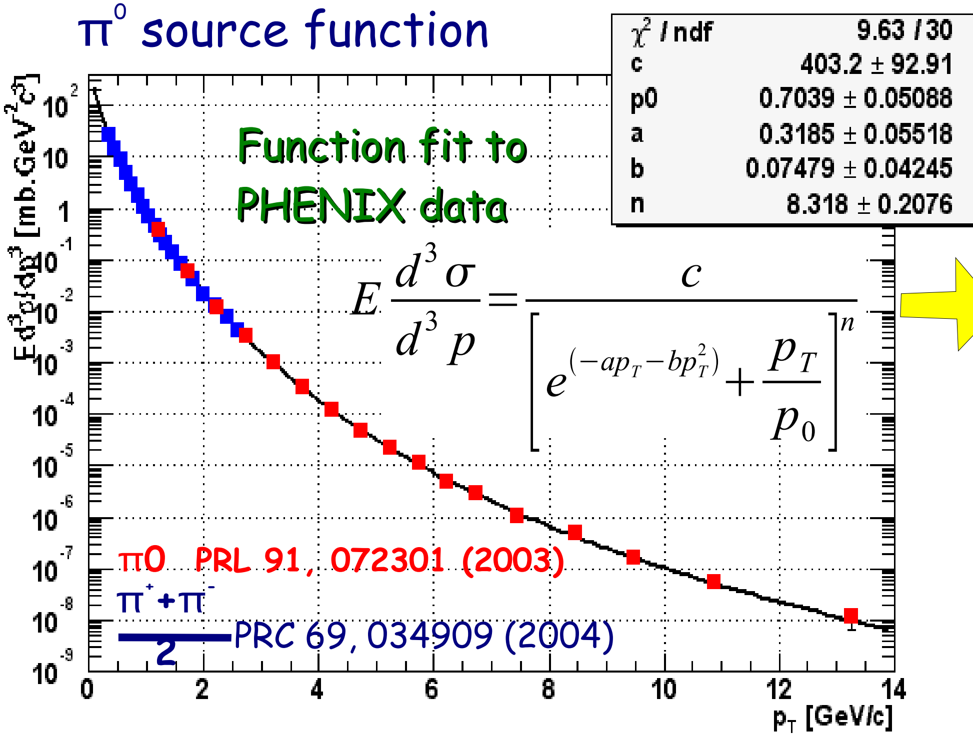


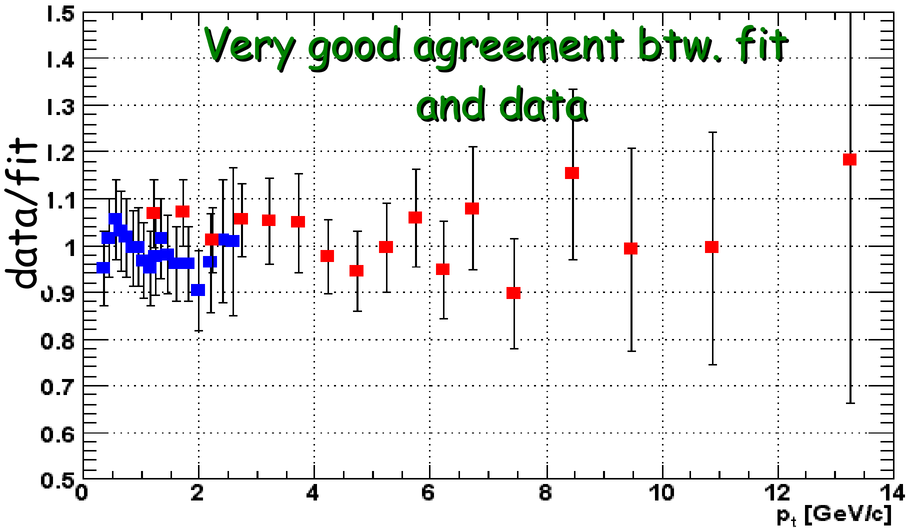
Electron source composition :

- Dalitz decay of light neutral mesons
  - $\pi^0 \rightarrow \gamma e^+ e^-$
  - $\eta, \omega, \eta', \phi \rightarrow \gamma e^+ e^-$
- conversion of photons in material
  - $\pi^0 \rightarrow \gamma\gamma \rightarrow \gamma e^+ e^-$
  - in beampipe, MVD, air: $\gamma \rightarrow e^+ e^-$
- weak kaon decays
  - K_{e3}, e.g.: $K^{\pm} \rightarrow \pi^0 e^{\pm} \nu_e$
- dielectron decays of vector mesons
  - $\rho, \omega, \phi \rightarrow e^+ e^-$
- direct radiation
  - conversion of direct photons in material
  - virtual photons: $\gamma^* \rightarrow e^+ e^-$
  - thermal radiation
- heavy flavor decays

Estimating sources : cocktail method (π^0 decays)

π^0 source function

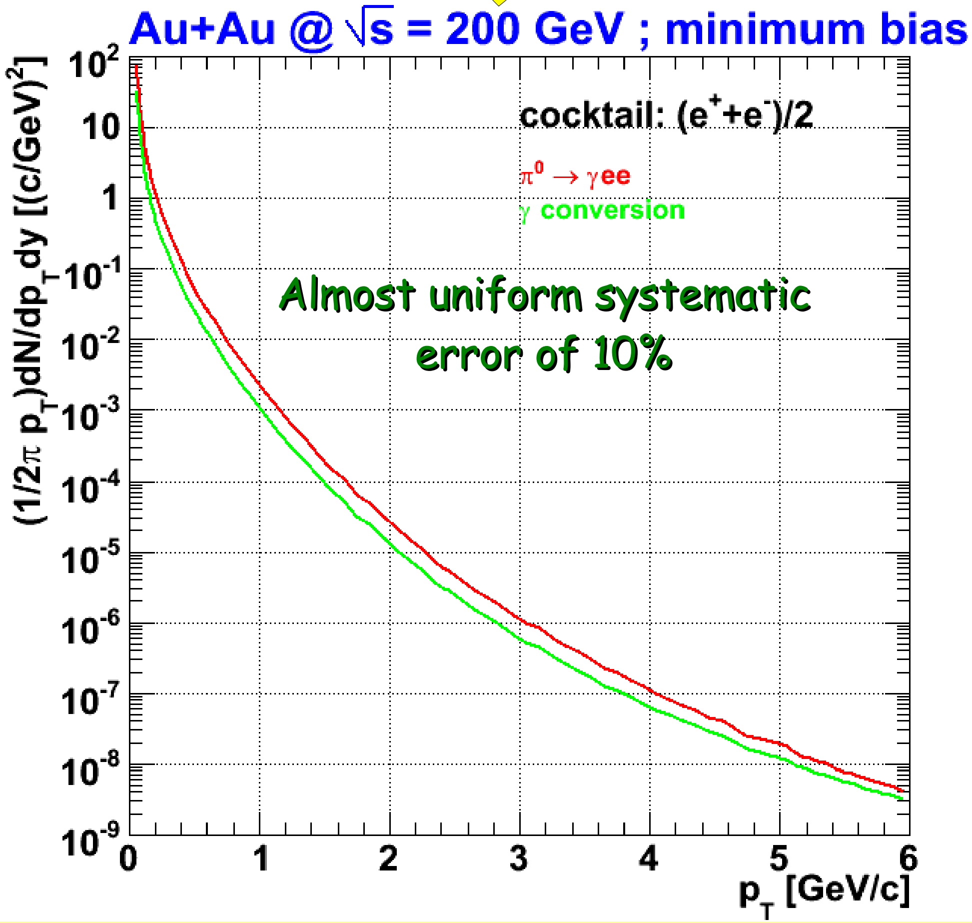




π^0 **decay generator**

GEANT based Monte Carlo for PHENIX

Electron output only



Estimating sources : cocktail method (other mesons)

π^0 source function from previous slide

By using m_T scaling and known particles ratio yields we can estimate the contribution from other mesons to electron spectra.

$p_T \rightarrow \sqrt{p_T^2 + m_\eta^2 + m_\pi^2}$
$\eta/\pi^0 = 0.45 \pm 0.10$ *

* Scaling and PHENIX measured η yield agree within 20% for all p_T

η decay generator
GEANT based Monte Carlo for PHENIX
Electron output only

$p_T \rightarrow \sqrt{p_T^2 + m_{\eta'}^2 + m_\pi^2}$
$\eta'/\pi^0 = 0.25 \pm 0.08$

η' decay generator
GEANT based Monte Carlo for PHENIX
Electron output only

$p_T \rightarrow \sqrt{p_T^2 + m_\omega^2 + m_\pi^2}$
$\omega/\pi^0 = 1.0 \pm 0.3$

ω decay generator
GEANT based Monte Carlo for PHENIX
Electron output only

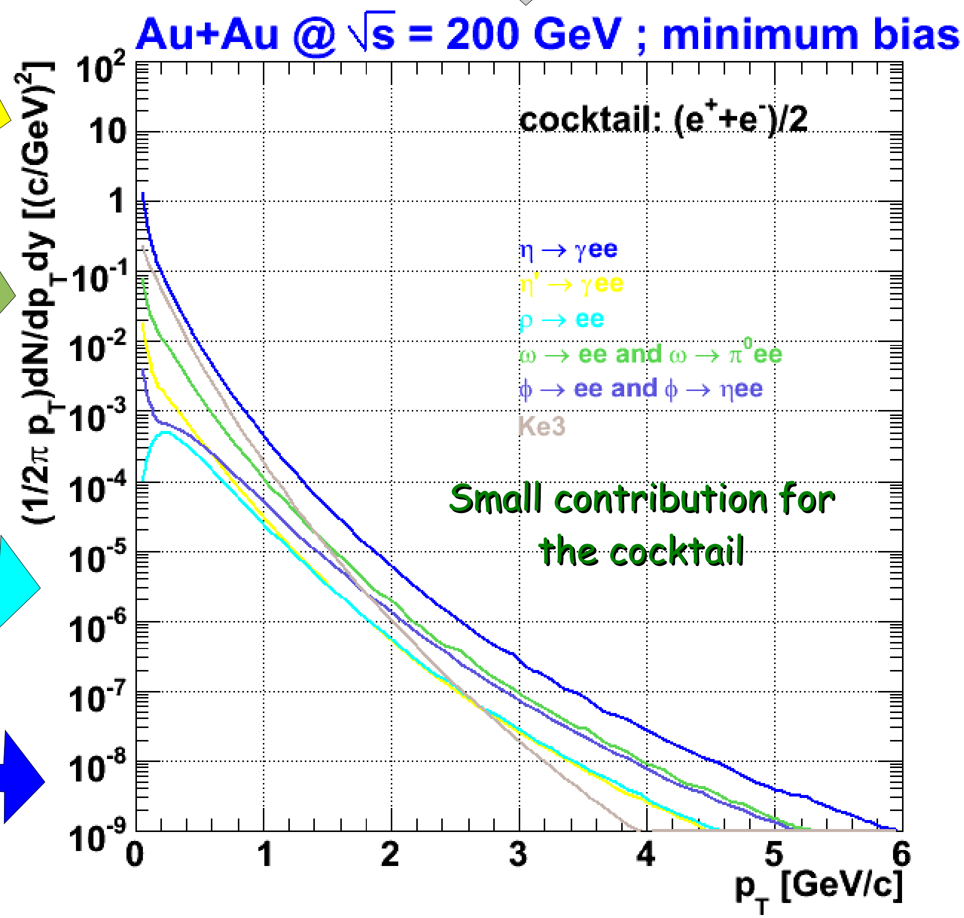
$p_T \rightarrow \sqrt{p_T^2 + m_\rho^2 + m_\pi^2}$
$\rho/\pi^0 = 1.0 \pm 0.3$

ρ decay generator
GEANT based Monte Carlo for PHENIX
Electron output only

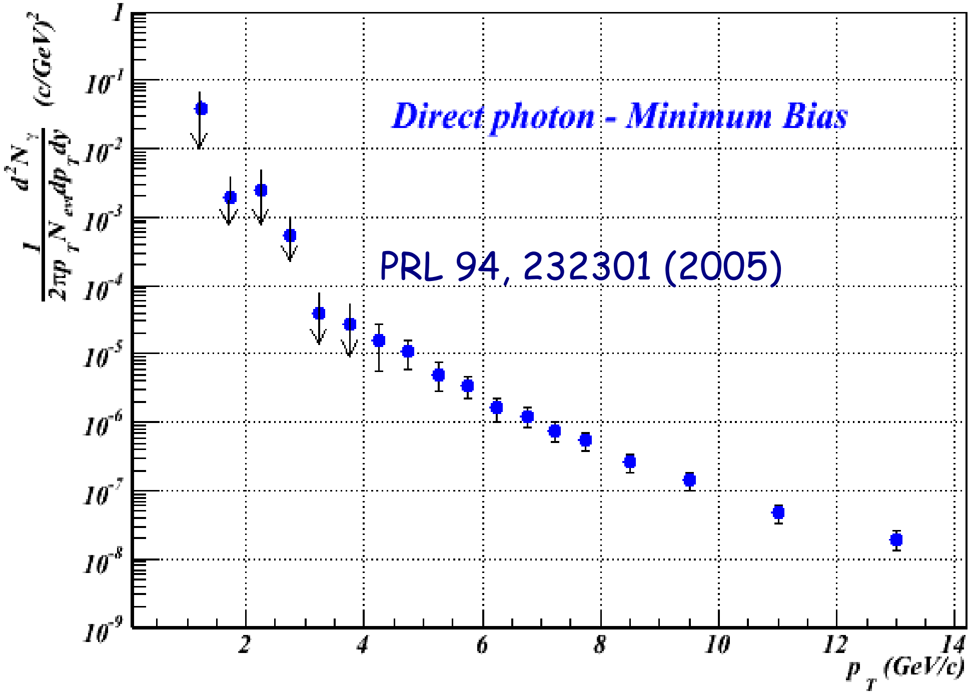
$p_T \rightarrow \sqrt{p_T^2 + m_\phi^2 + m_\pi^2}$
$\phi/\pi^0 = 0.40 \pm 0.12$

ϕ decay generator
GEANT based Monte Carlo for PHENIX
Electron output only

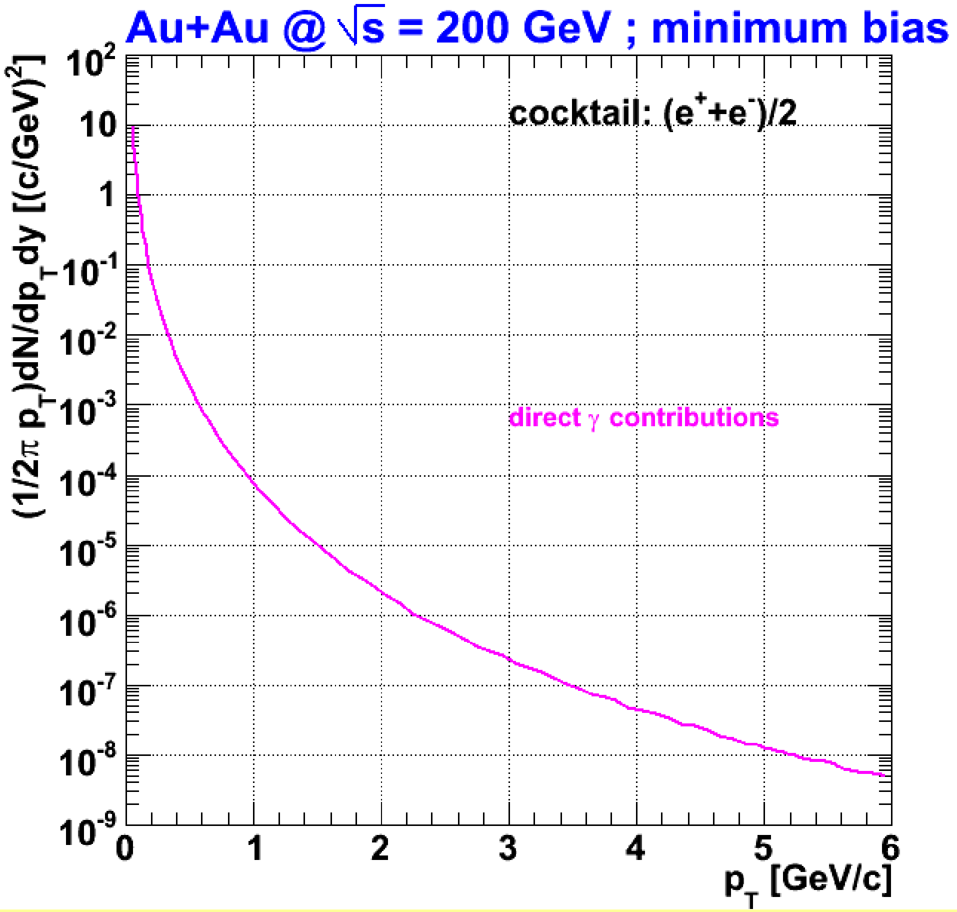
K_{e3} decay generator
by using full MC simulation based in PHENIX K measurement [PRC 69, 034909(2004)]



Estimating sources : cocktail method (direct γ)



γ decay generator
GEANT based Monte Carlo for PHENIX
Electron output only

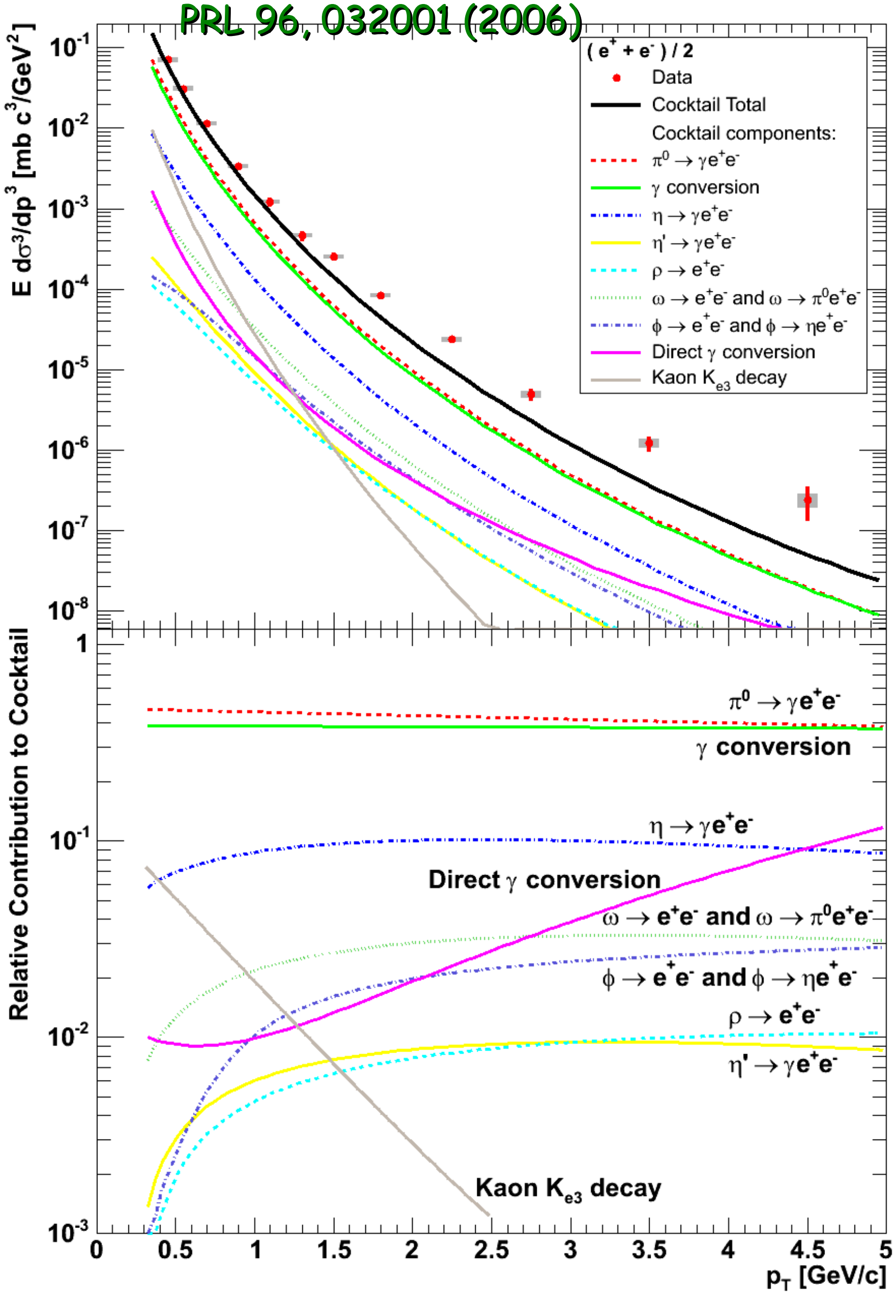


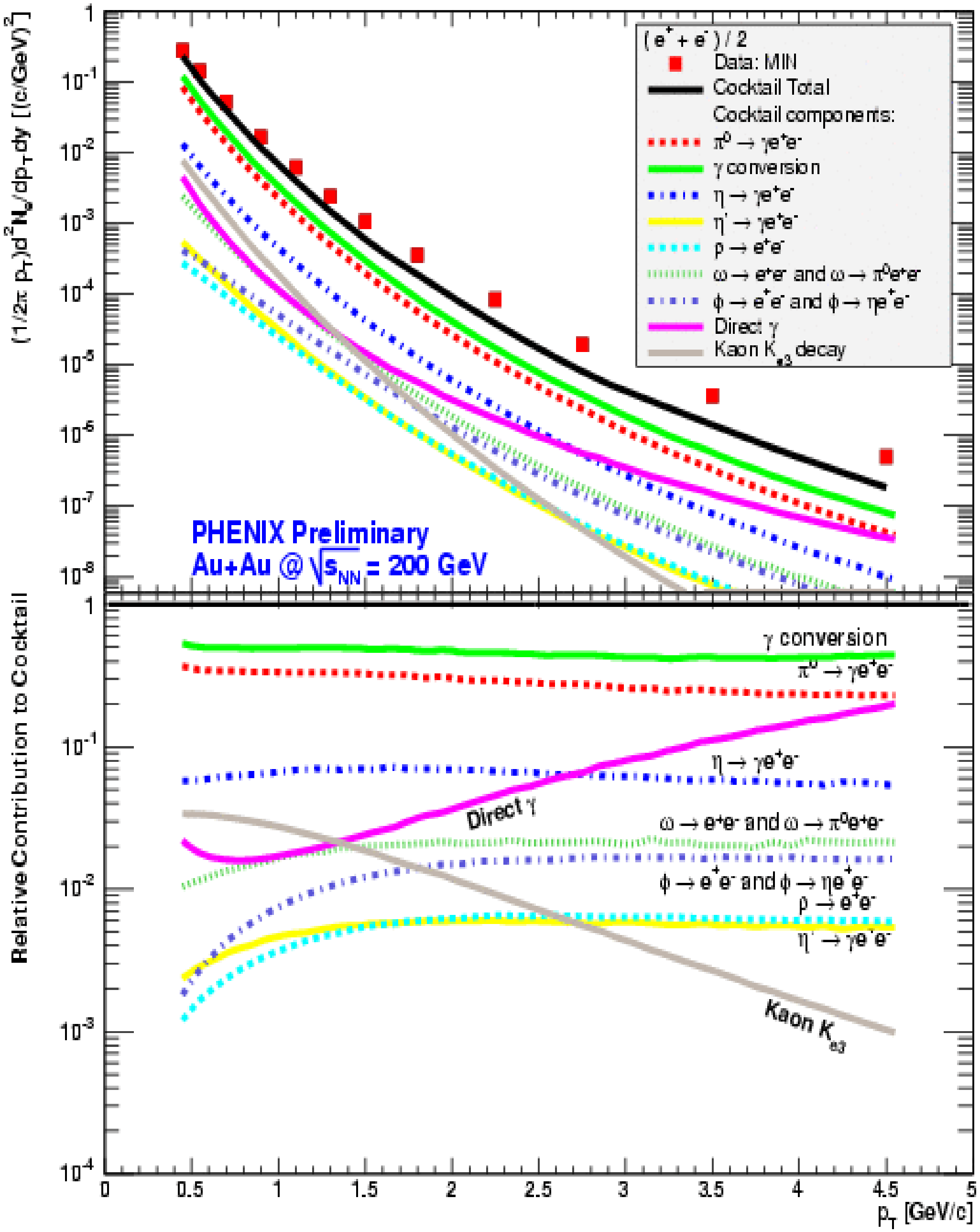
PHENIX has measured direct photon production.

We use it to estimate the contribution to the electron spectrum.

Estimating sources : Cocktail results

Run2 p+p @ √s=200GeV
PRL 96, 032001 (2006)

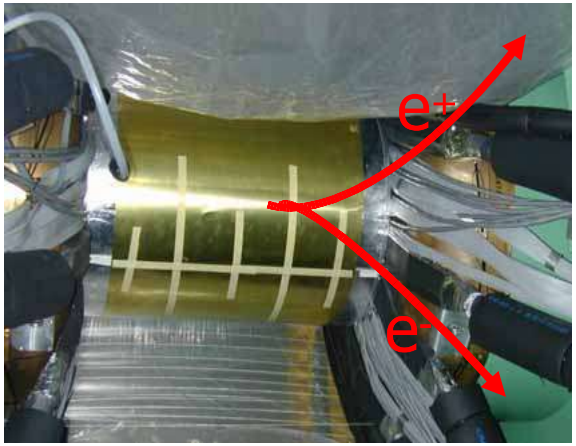




Estimating sources : Converter Method

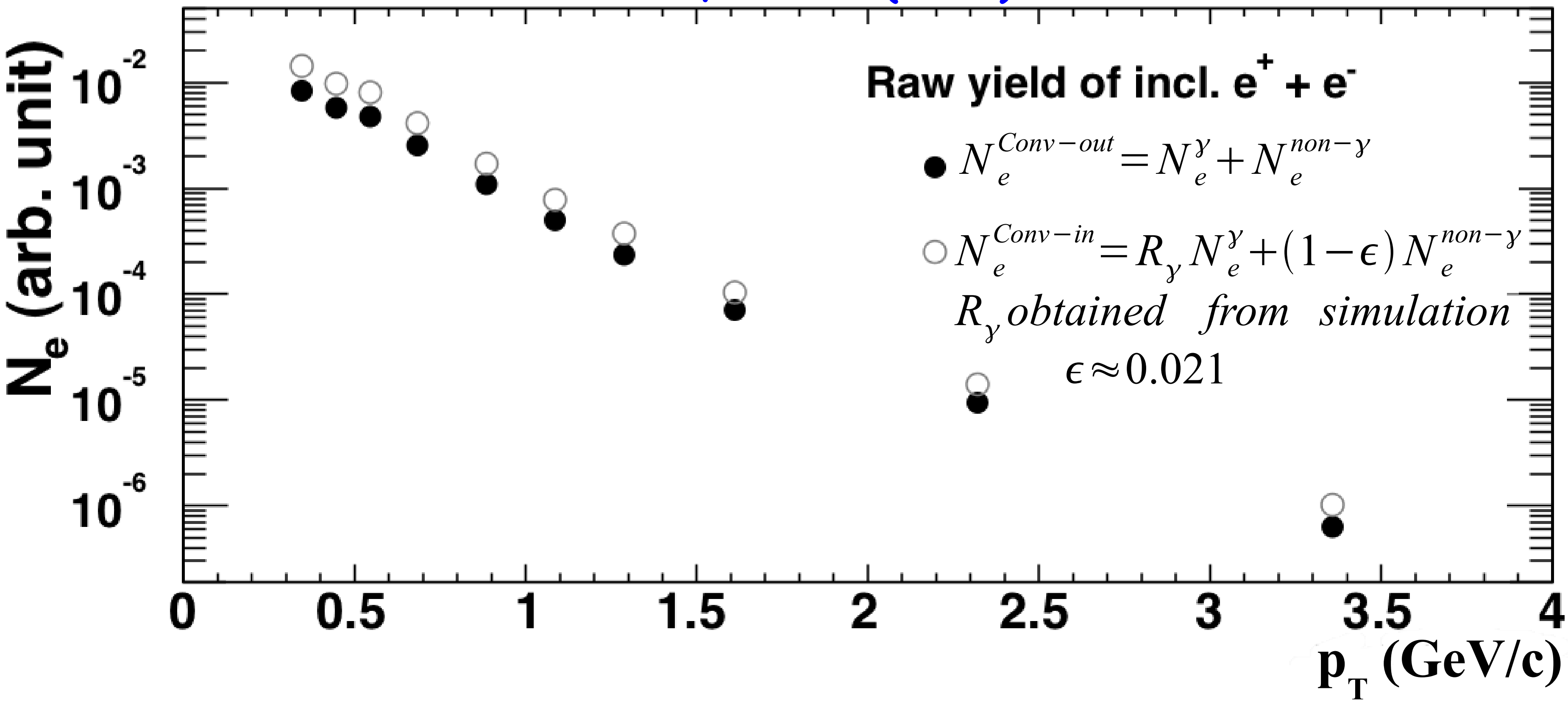
Photonic source : Decays of neutral light mesons π^0, η, η', Φ, ω, and ρ and direct γ.

Non-photonic sources : mostly from heavy quarks.

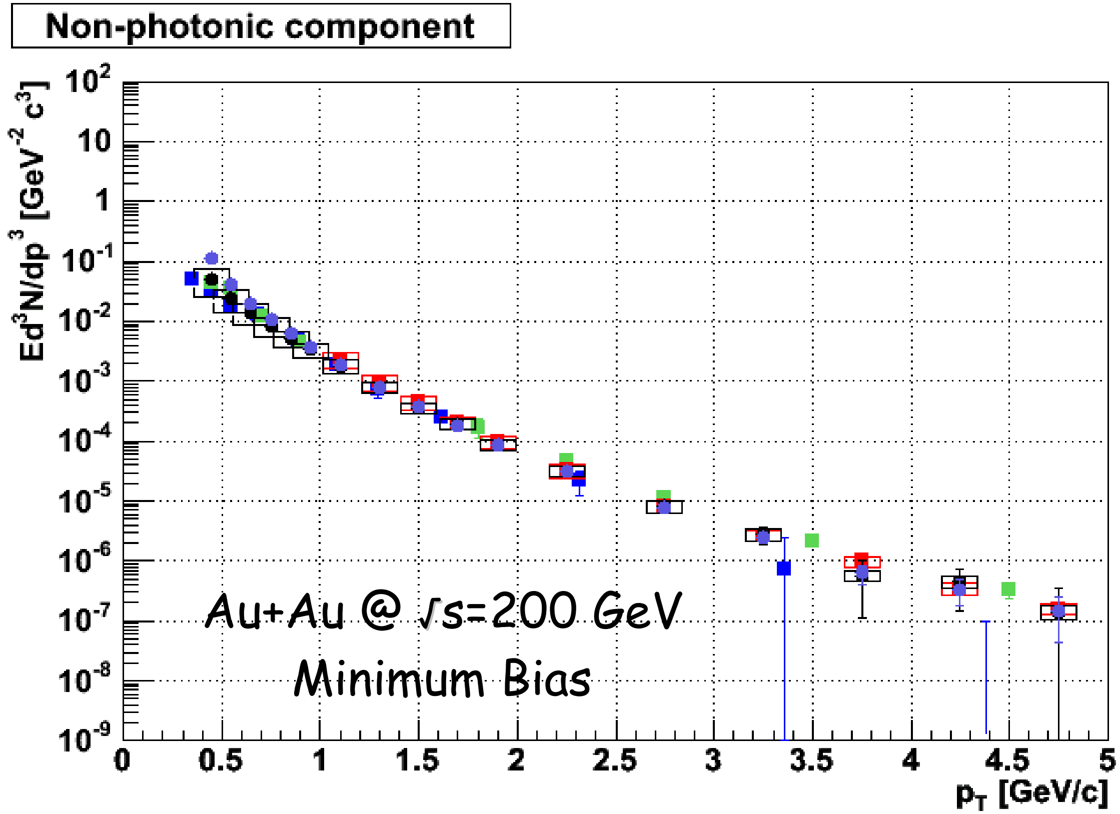


Converter : a thin brass tube (1.7% X_0) surrounding the beam pipe at 29cm.

PRL 94,082301 (2005)



Estimating sources : Cocktail-Converter comparison

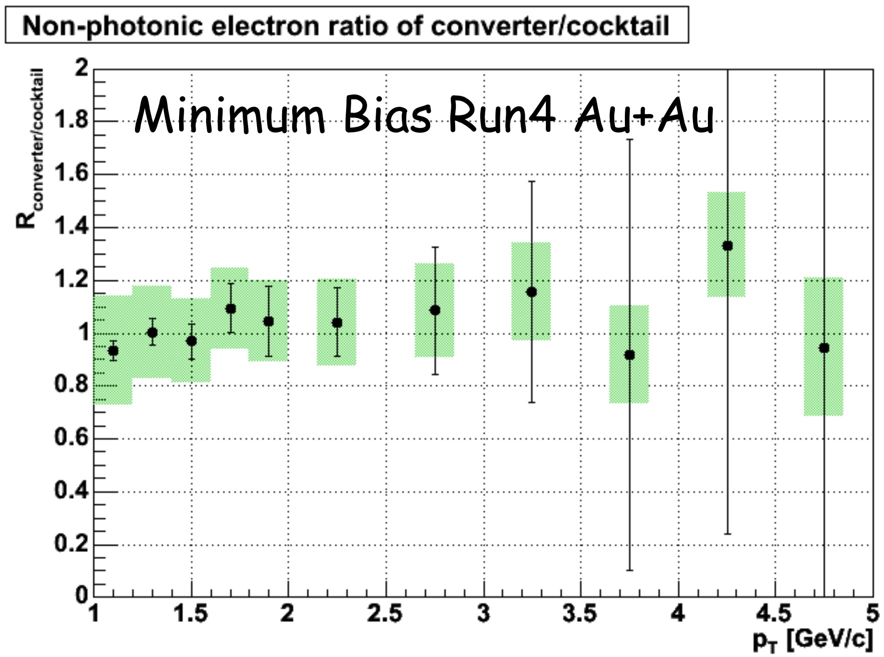


Run2 cocktail : PRL 96,032301(2006)

Run2 converter : PRL 94,082301(2005)

Run4 cocktail : QM05 PHENIX preliminary

Run4 converter : QM05 PHENIX preliminary

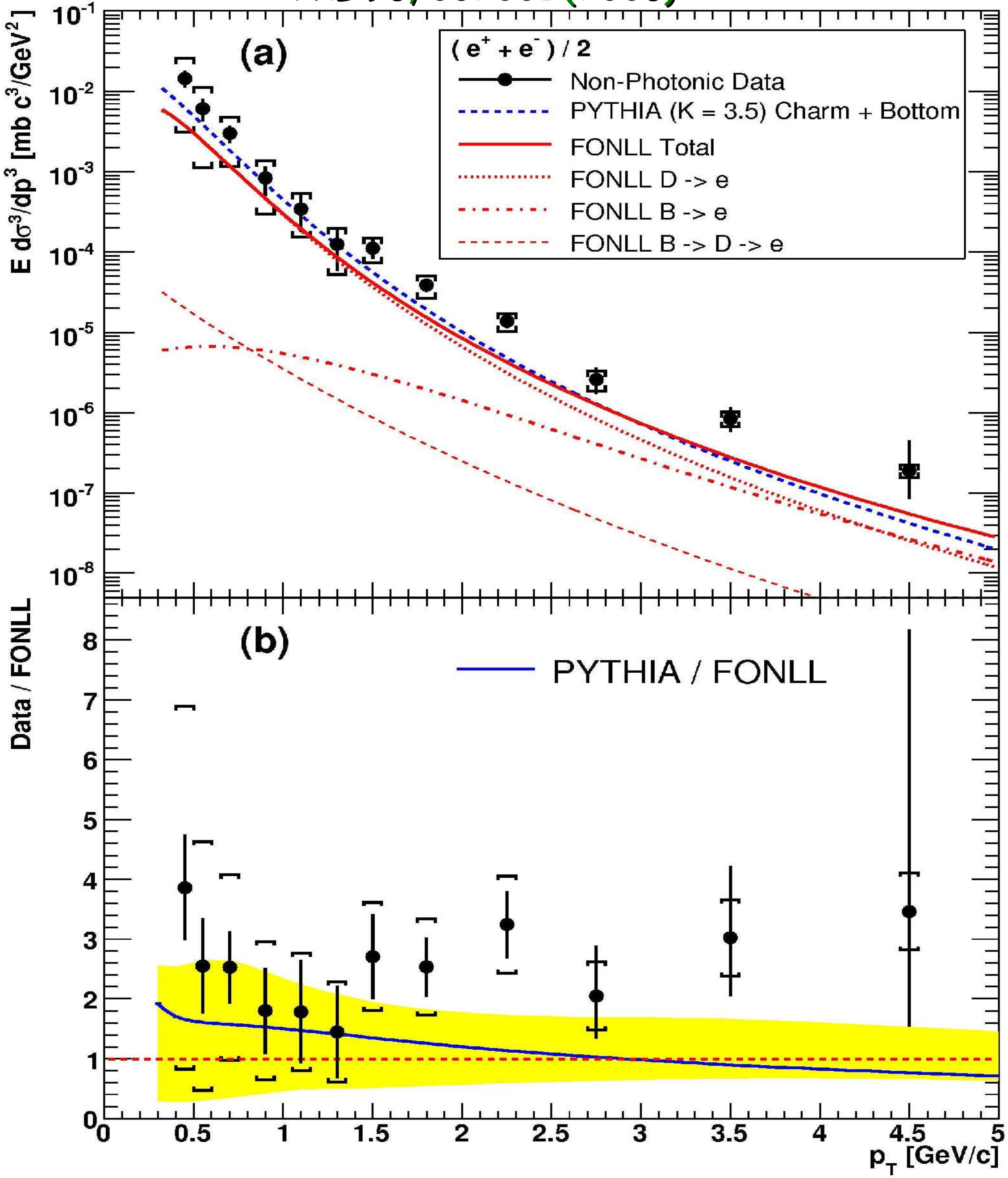


Good agreement between cocktail and converter methods.

RESULTS

p+p @ √s=200GeV

PRL 96, 032001 (2006)



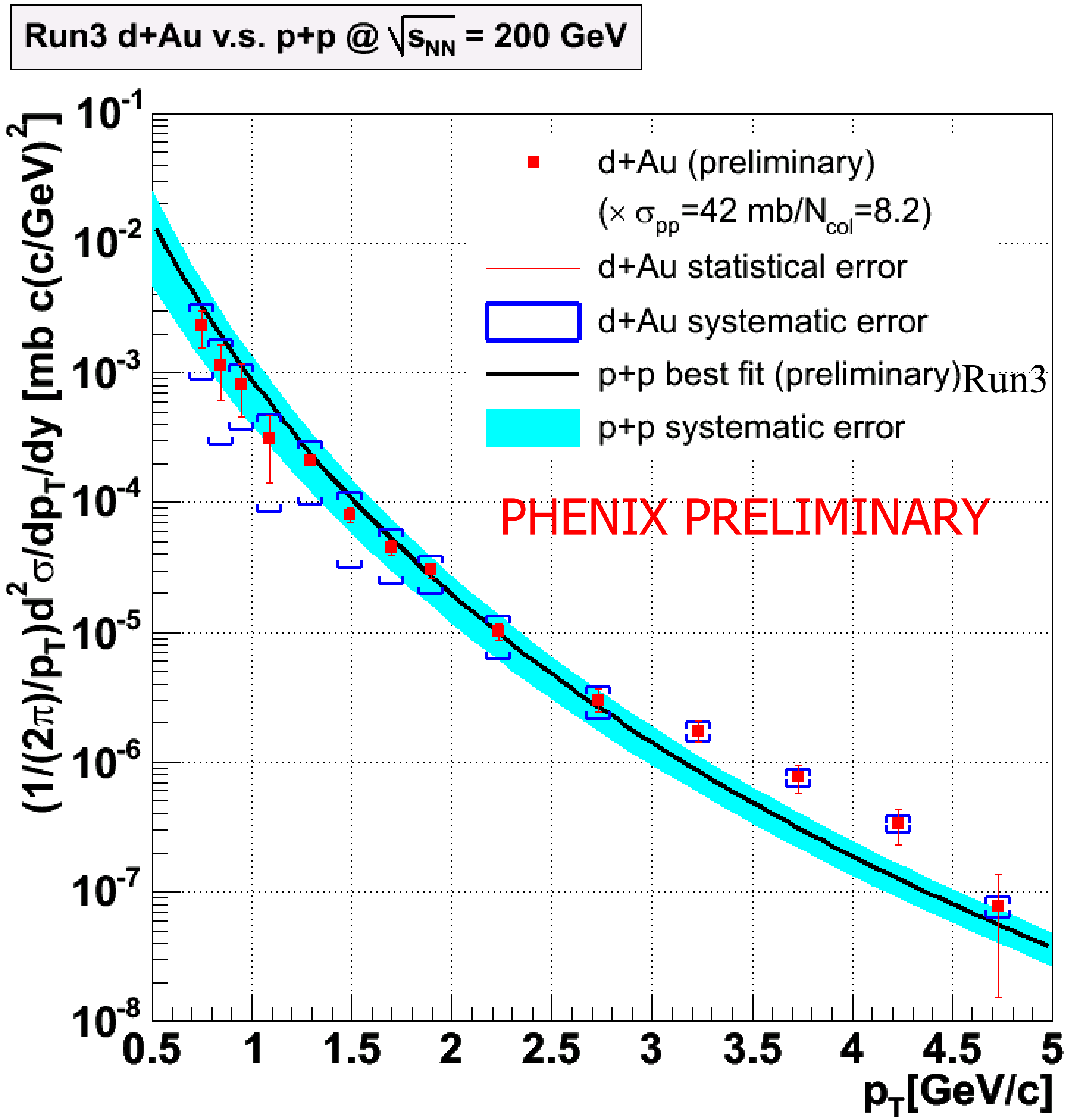
Leading Order (LO) PYTHIA was tuned with available charm and bottom hadroproduction measurements and scaled by a factor K=3.5 to accommodate neglected NLO contributions.

Above 2 GeV/c the electron spectrum suggests contributions beyond the First Order plus Next Leading Log (FONLL) pQCD calculation. (M. Cacciari, P. Nason, R. Vogt – hep-ph/0502203).

Total cross section of charm quark-antiquark pair production was estimated by using the electron spectrum shape from PYTHIA extrapolation :

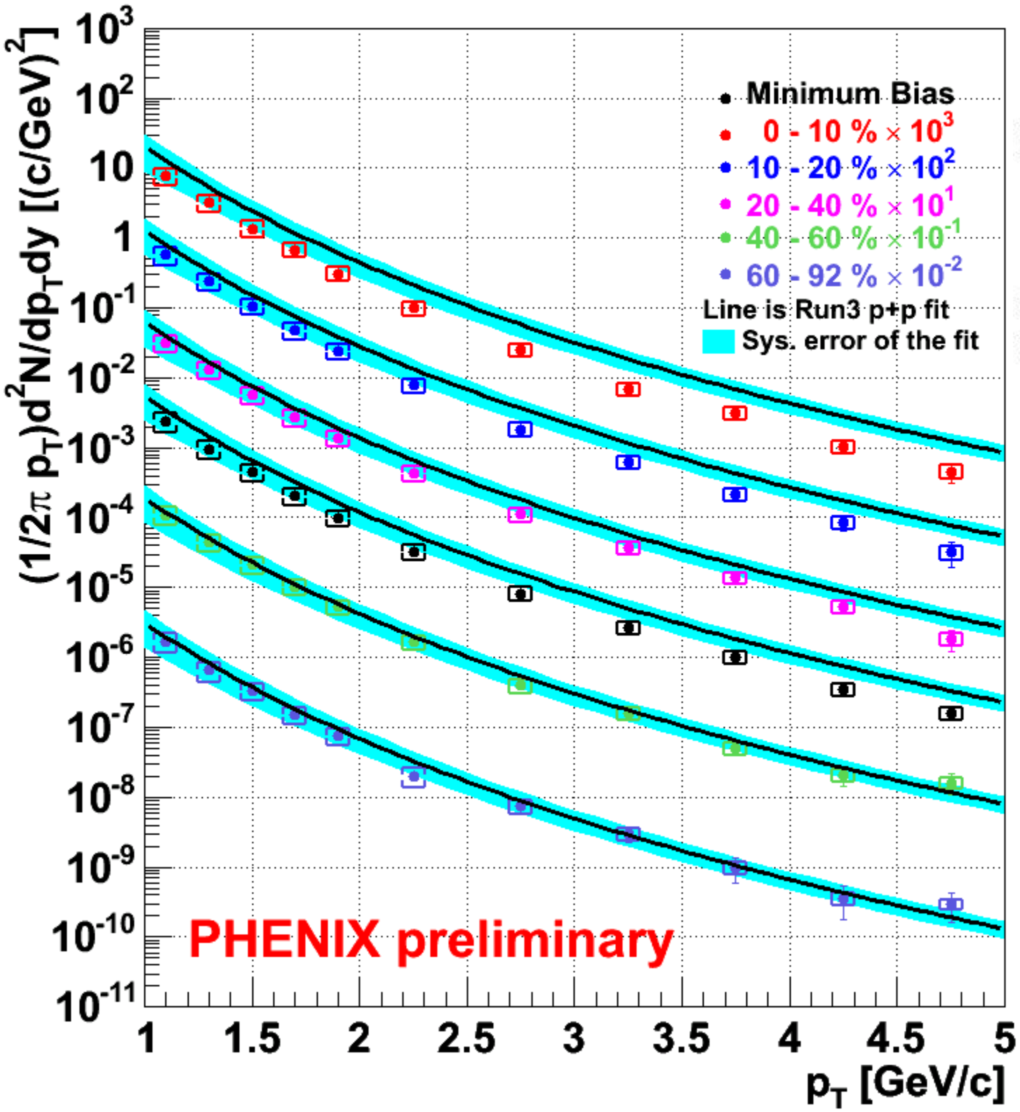
$\sigma_{c\check{c}}$ = 0.92 ± 0.15(stat.) ± 0.54(sys.) mb.

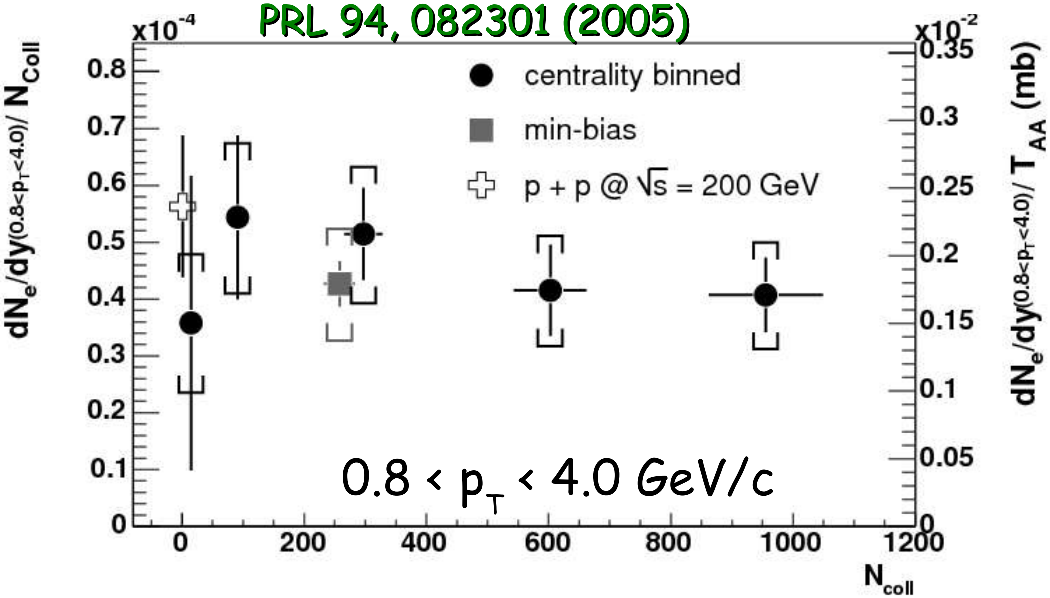
d+Au @ √s=200GeV



- Invariant cross section per binary collision for Minimum Bias data
- In d+Au data heavy quarks scales with Ncoll at low p_T.
- no apparent p_T broadening (Cronin Effect) is observed
- There is no cold nuclear matter effect in the charm p_T spectra

Au+Au @ √s=200GeV

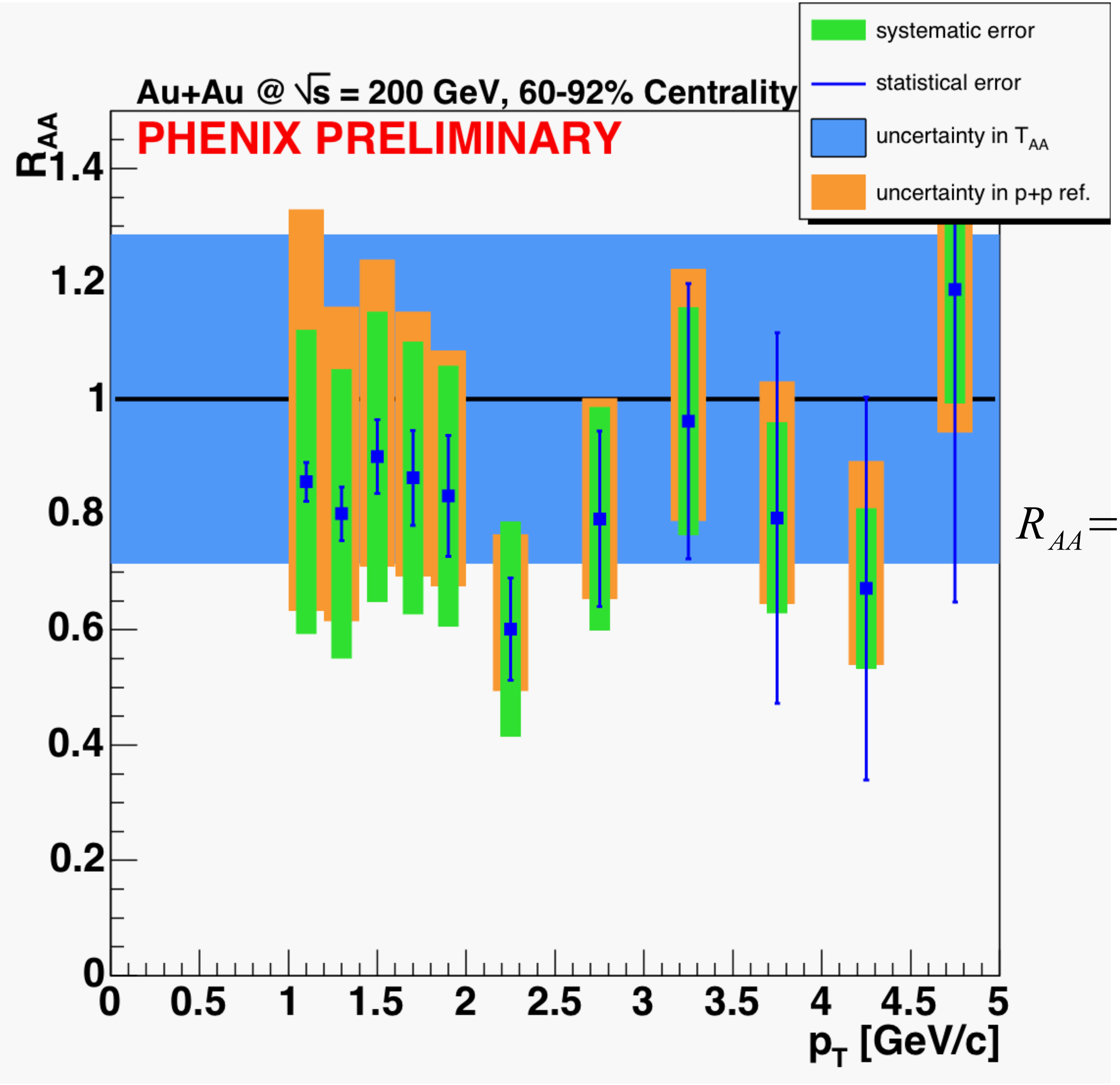




The heavy quark yield at mid-rapidity range scales with N_{coll}.

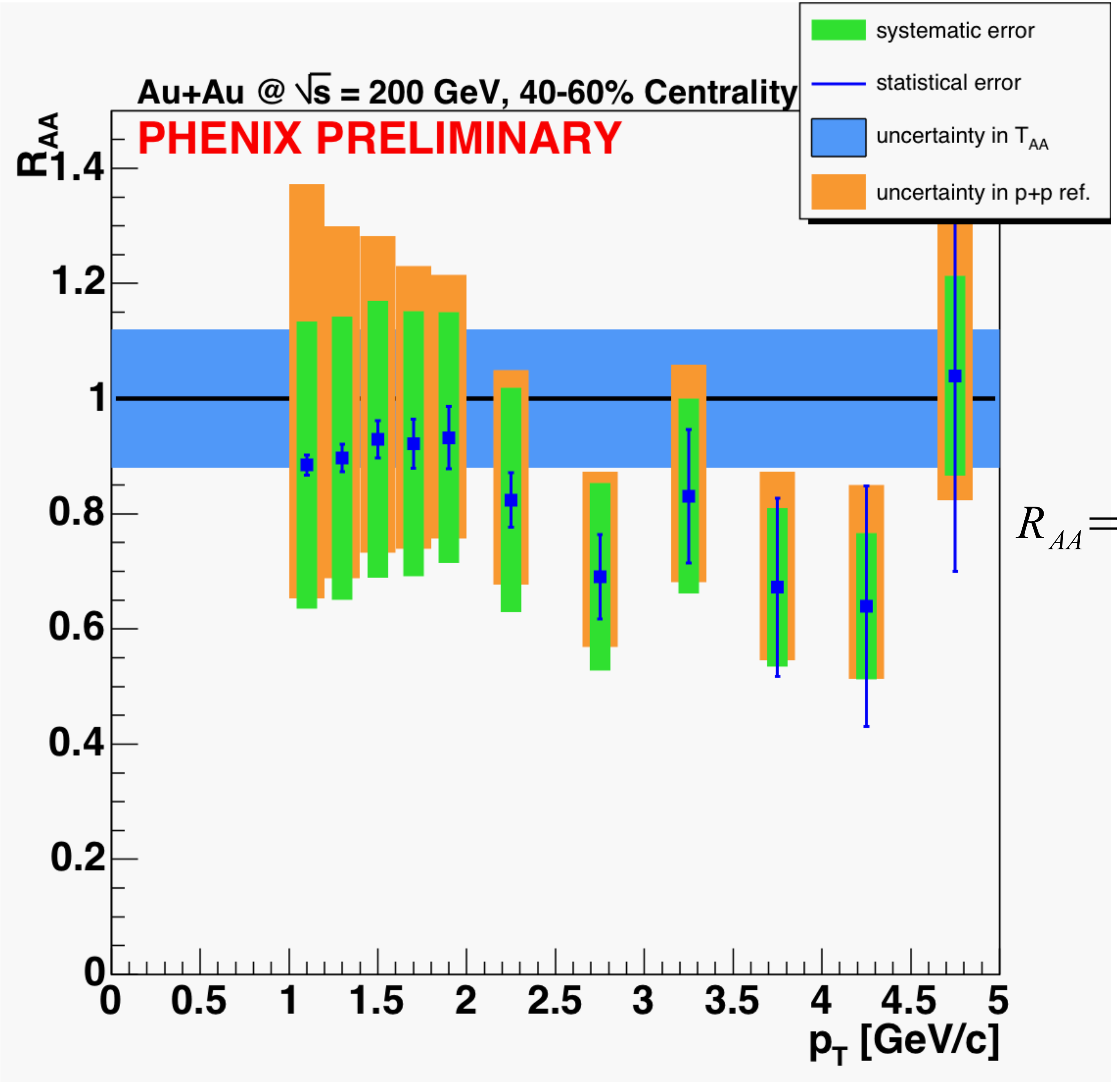
Clear suppression is observed in central events at high p_T when Au+Au data is compared to nuclear overlap integral $\langle T_{AA} \rangle$ scaled p+p data. The quantification of this effect is obtained by R_{AA} calculation.

Au+Au @ √s=200GeV



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

Au+Au @ √s=200GeV



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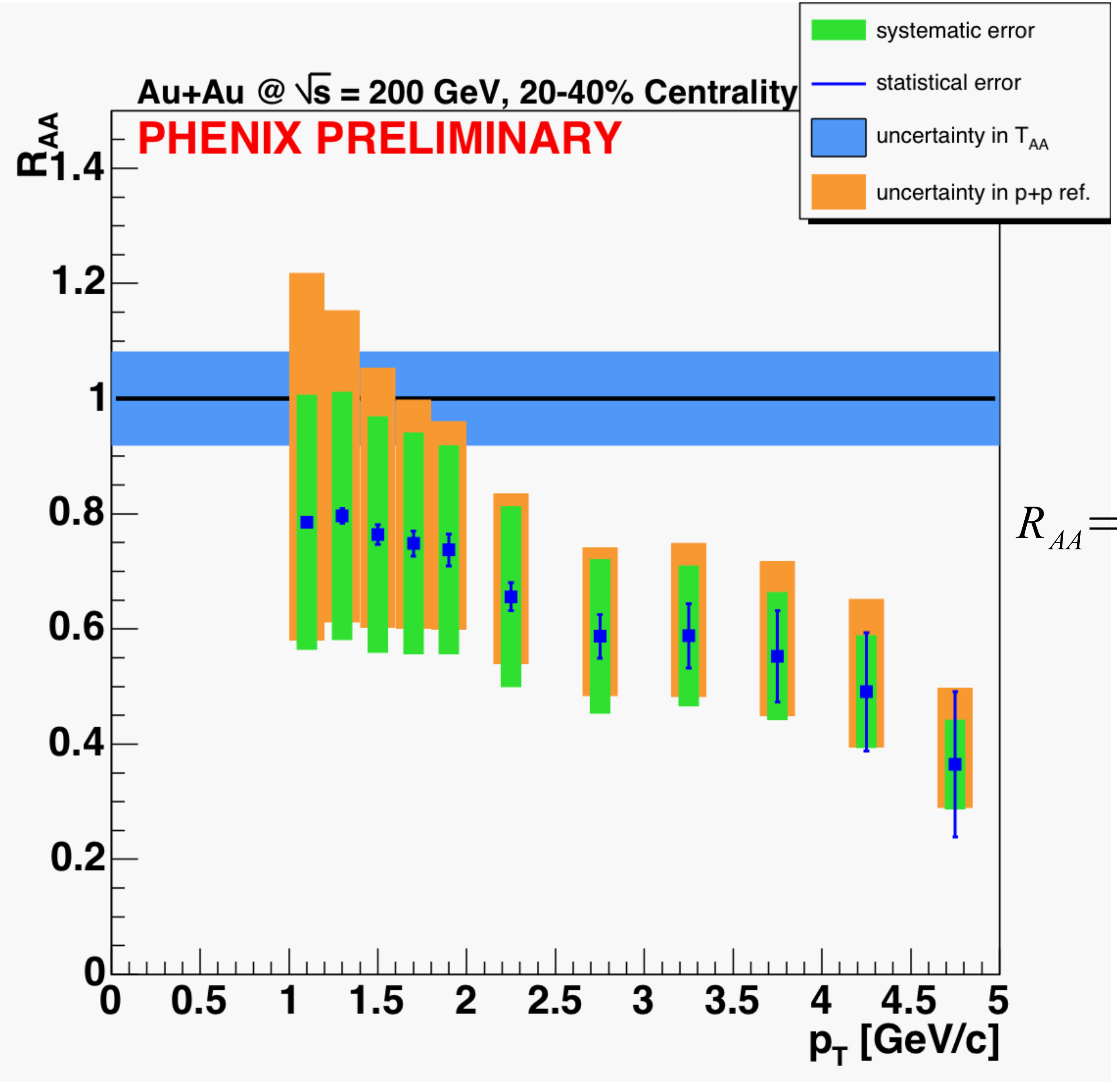
Au+Au @ √s=200GeV



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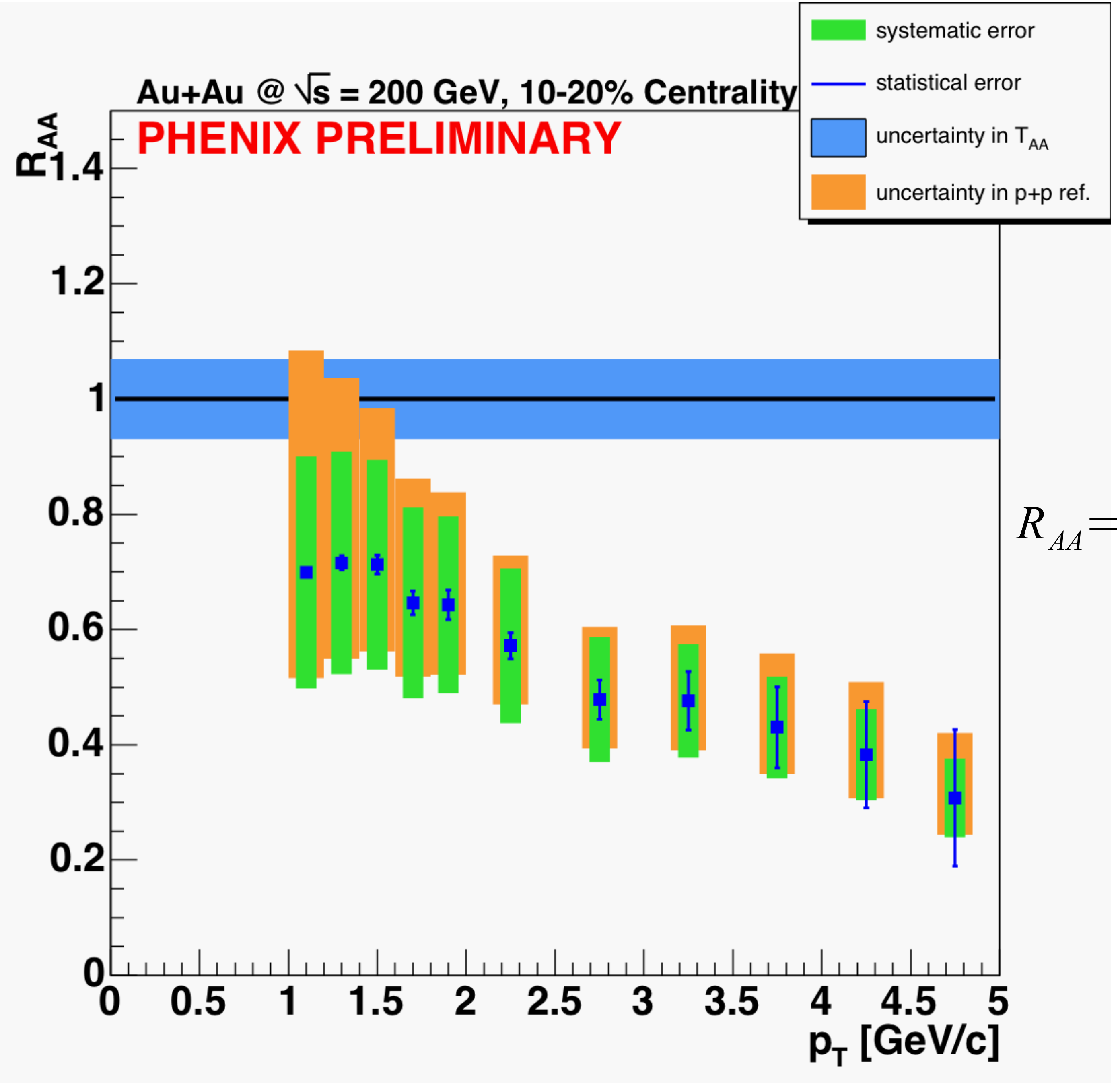
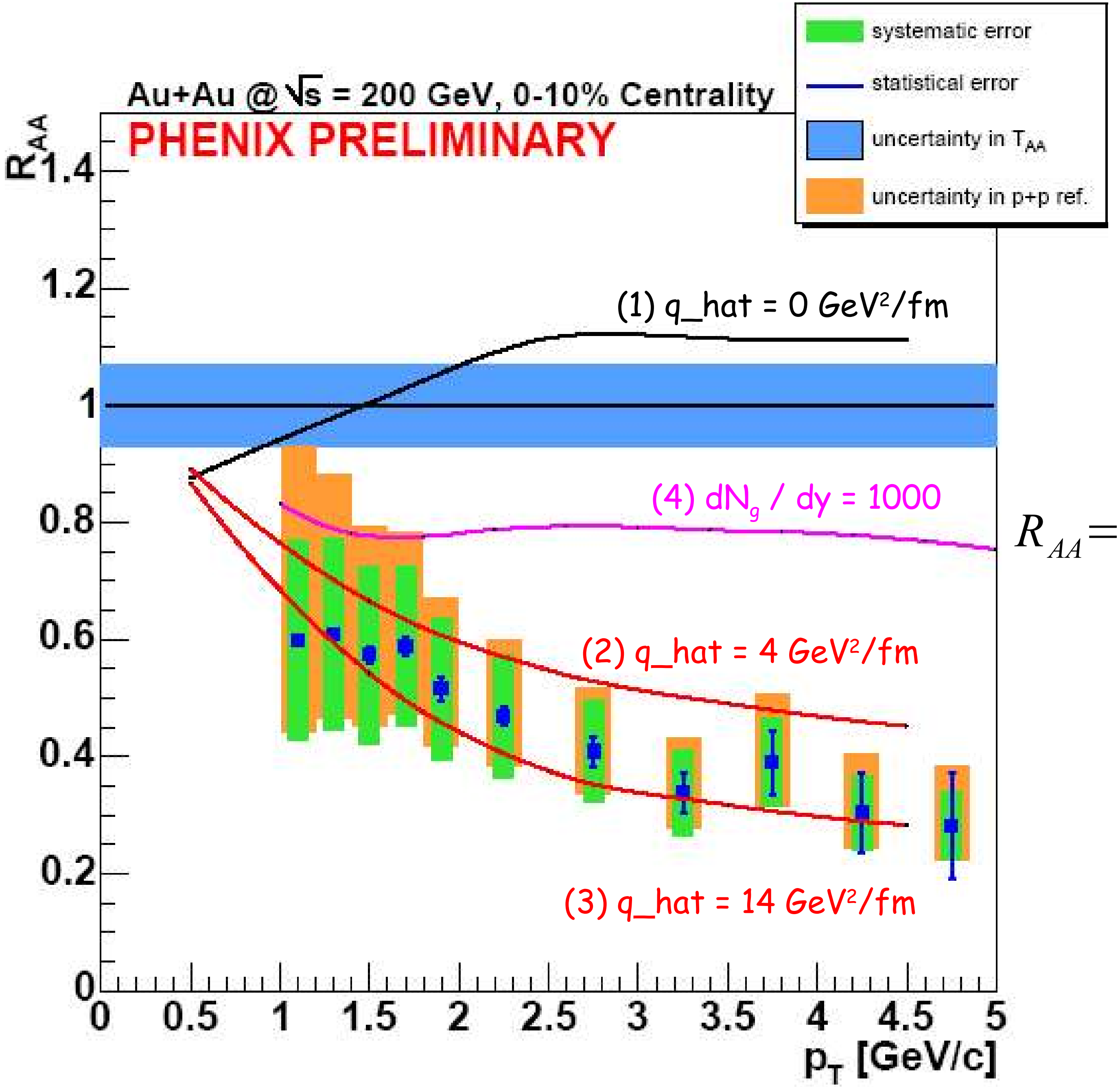
Au+Au @ √s=200GeV



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

Au+Au @ √s=200GeV



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

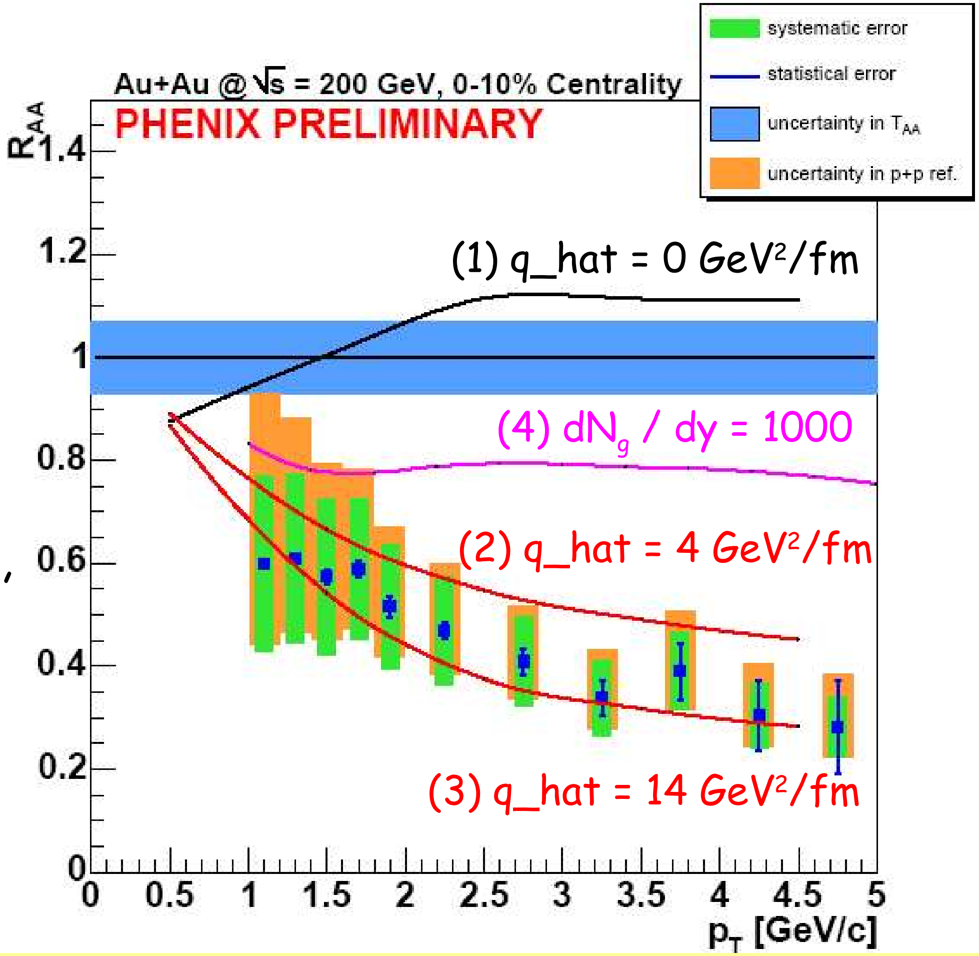
R_{AA} in Au+Au @ $\sqrt{s}$=200GeV

Results from Run4 are consistent with PHENIX published results from Run2 [PRL 94, 082301 (2005)].

The data is compared to different theoritical models and seems to be consistent with q_hat of 14 GeV^2/fm indicating a strong energy loss. For p_T>2 GeV/c the heavy quark R_{AA} is comparable to that for π^0 observed by PHENIX.

Bottom contribution might be significant at p_T>3 GeV/c, but doesn't seems to affect the R_{AA} shape from that in charm range.

Additional elastic energy loss contribution can explain the data [S. Wicks,W. Horowitz, M. Djordjevic, M. Gyulassy, nucl-th/0512076].



Theory curves

(1-3) N. Armesto, et al., PRD 71, 054027 – only charm contribution

(4) M. Djordjevic, M. Gyulassy, S.Wicks, PRL 94, 112301 – bottom included

q_hat is the transport coefficient which is proportional to the density of scattering centers in the medium.

dN_g/dy is the initial gluon density

Azimuthal anisotropy in Au+Au @ √s=200GeV

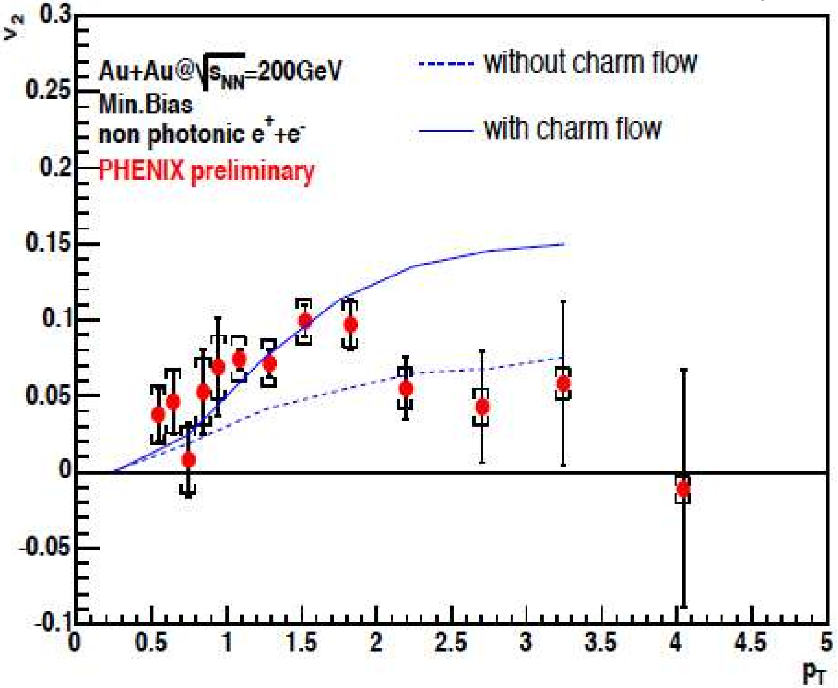
$$\frac{dN_e}{d\phi} \propto 1 + 2 v_2 \cos\left[2(\phi - \Psi_{R.P})\right] + \ldots$$

$\Psi_{R.P}$: *reaction plane*

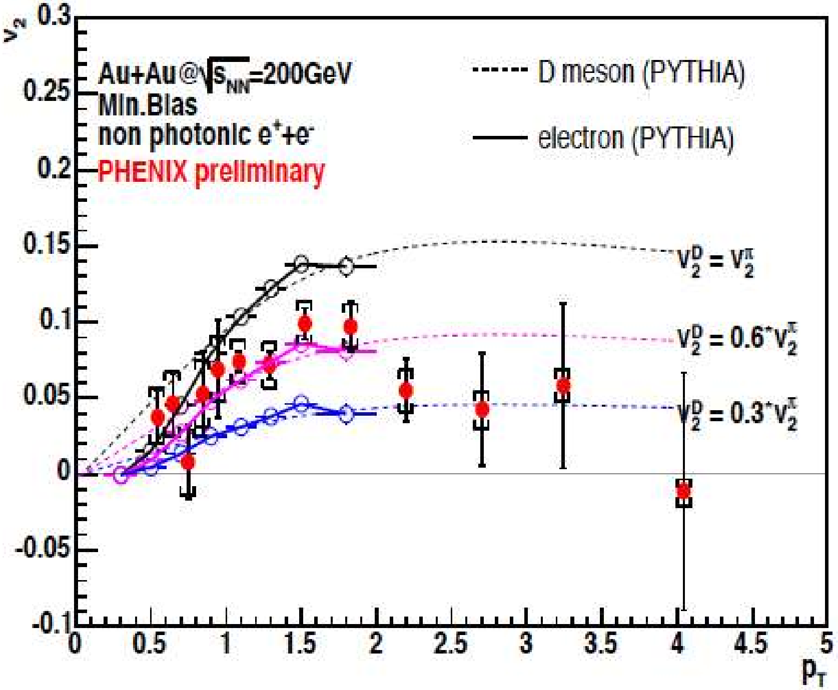
Photonic contribution :

- p_T < 1GeV/c -> converter method
- p_T > 1GeV/c -> cocktail method (based in π^0 v2 PHENIX data)

Comparison with quark coalescence model.
D. Molnar and S.A. Voloshin, PRL. 91, 092301(2003)



Comparison with different PYTHIA calculations.



In the charm p_T range collective motion is observed as for light quark mesons.

The observed charm flow is consistent with <u>partonic level thermalization</u> and <u>high density</u> of the matter formed .

Summary

- PHENIX detector measured heavy quark production for p+p, d+Au and Au+Au at mid-rapidity range for $0.8 < p_T < 5$ GeV/c by using it electron decay channel

- Photonic contribution to the electron spectra was measured with two different methods which are in good agreement

- The pQCD calculations agrees with the p+p data at low p_T and underestimates at high p_T

- Suppression at high p_T observed in R_{AA} seems to indicate an unexpected large energy loss

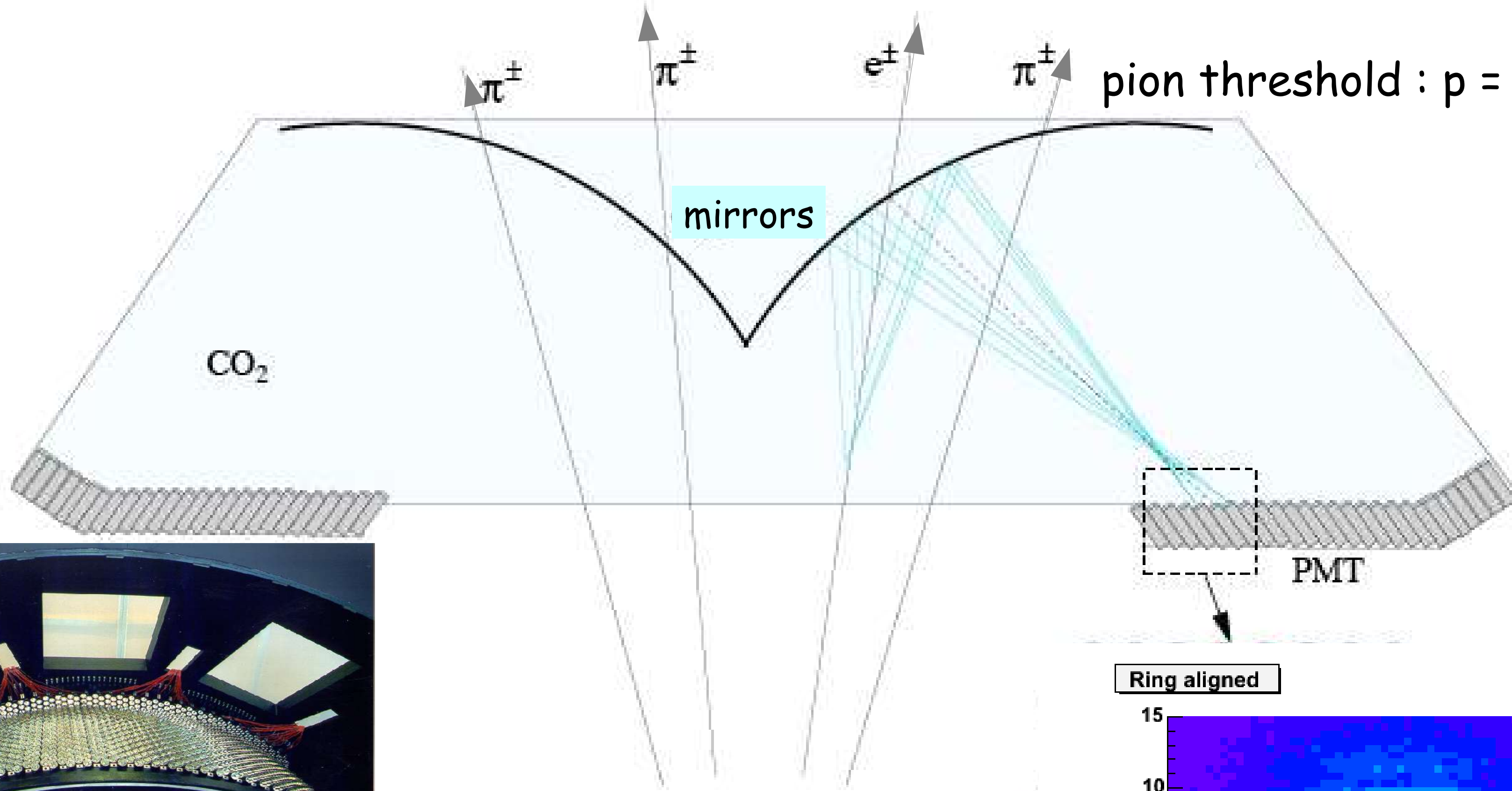
- Measurement of v2 points to a charm flow supporting a very high density in the early stages of the collisions.

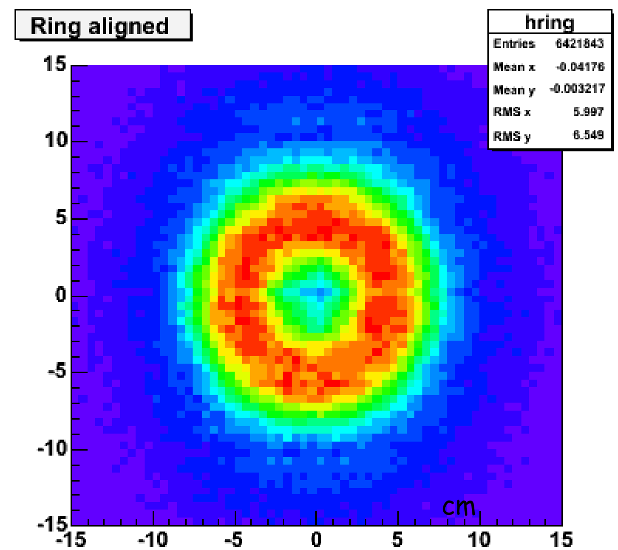
- Results will come soon from new higher statistics results providing accurate information in a extended p_T range.

BACKUP SLIDES

Electron ID : Ring Cherenkov Detector (RICH)

pion threshold : p = 4.9 GeV/c



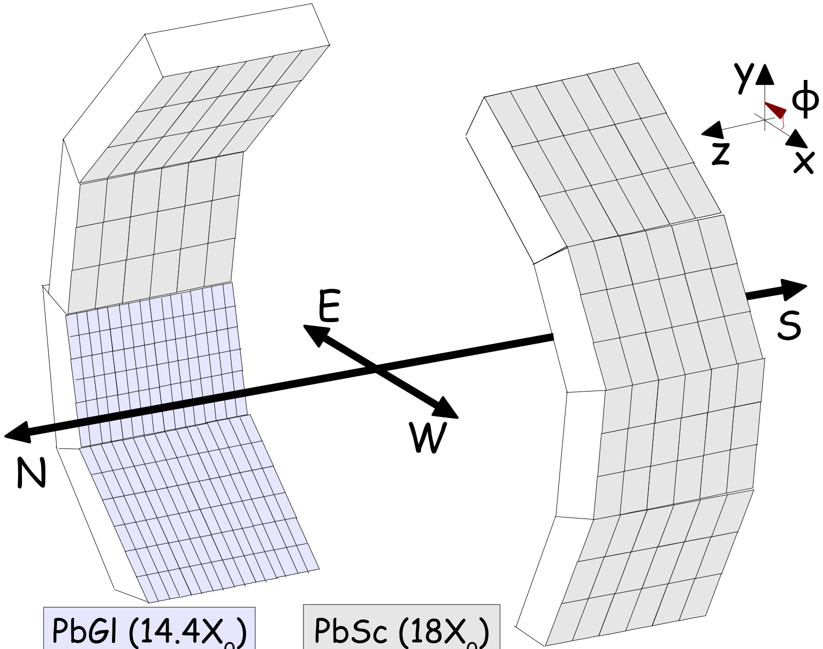


Cherenkov rings are selected if :

- more than 2 PMT are fired
- χ^2 of ring shape / total number of photoelectrons < 10
- center displacement < 5 cm

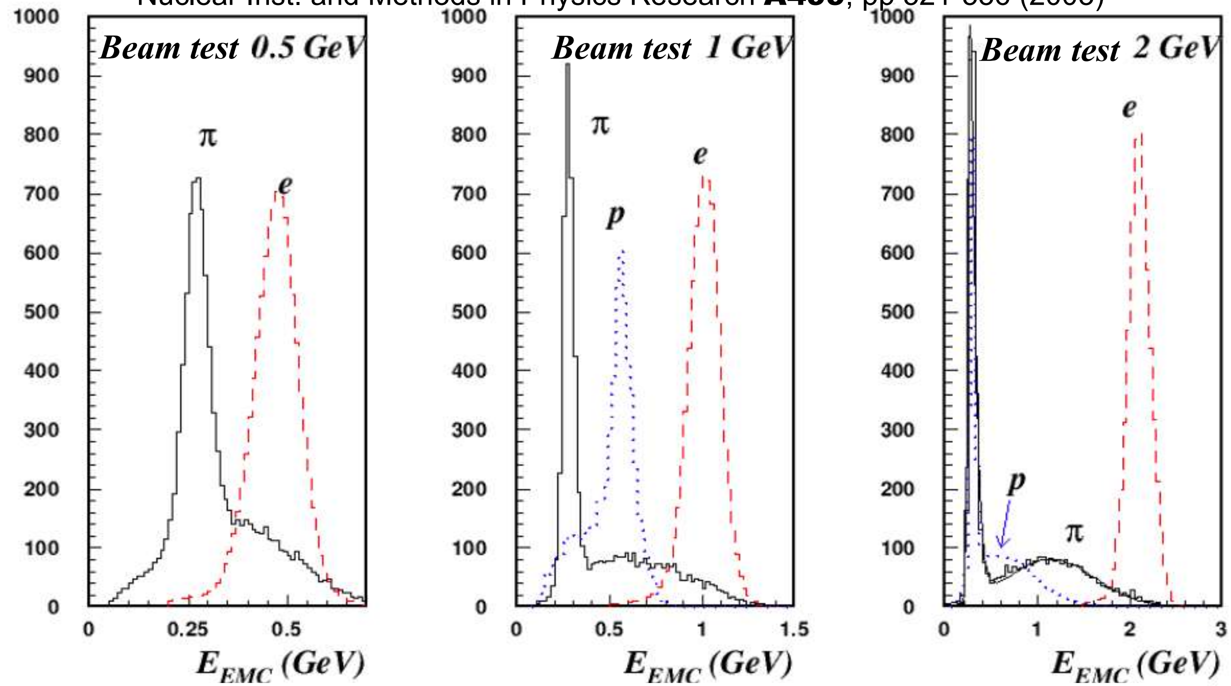
Electron efficiency after ring selection : ~ 82%

Electron ID : Electromagnetic Calorimeter (EmCal)

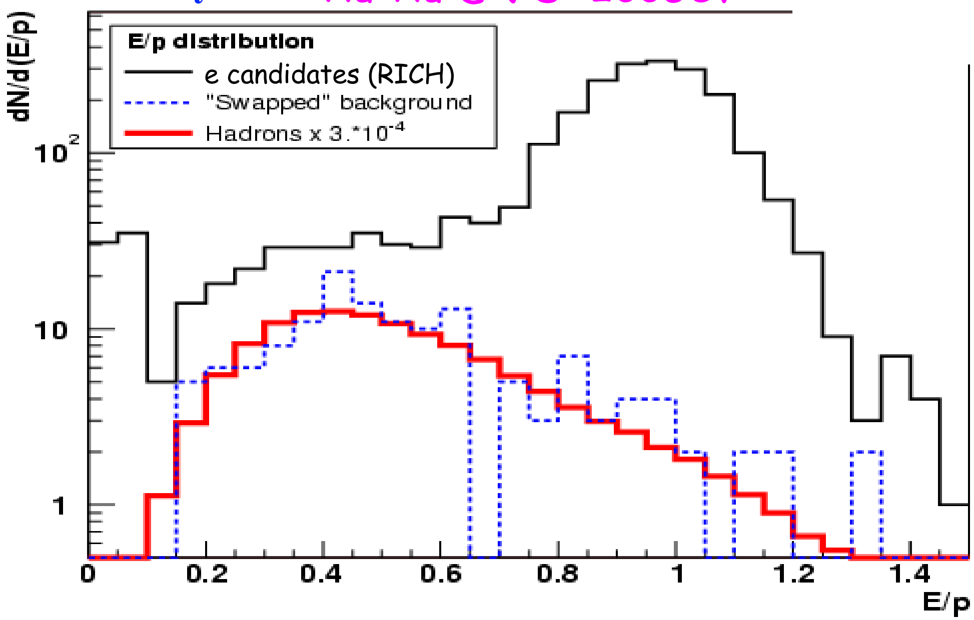


from S. Butsyk

Nuclear Inst. and Methods in Physics Research **A499**, pp 521-536 (2003)



Au+Au @ $\sqrt{s}$=200GeV



Energy/Momentum is always ~1 for electrons

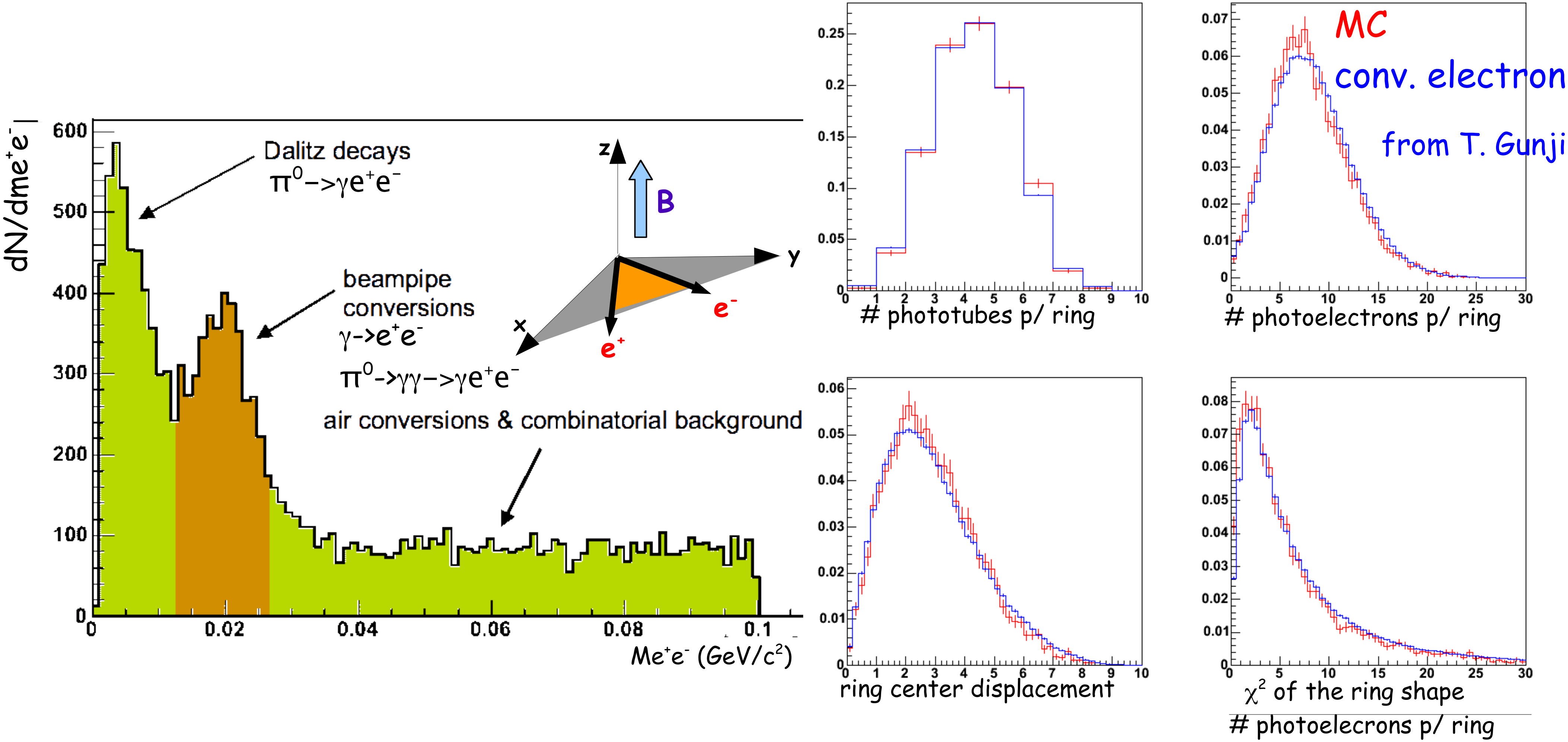
Hadrons can be identified as $e^{\pm}$ if their tracks share the same Cherenkov ring.

This Contamination is removed statistically by subtracting miscorrelated tracks in RICH ("swapped" coordinates) from E/P distribution of $e^{\pm}$ candidates.

PHENIX Acceptance and efficiency for electrons.

SIMULATION TUNNING

The GEANT based Monte Carlo is tuned with a cut unbiased $e^{\pm}$ sample from conversion e^+e^- pairs.
Conversion pairs form a peak in the invariant mass spectrum and their orientation is perpendicular to magnetic field.
One of the electron pair is selected by a tight cut. The other electron is used for MC tuning.



Estimating sources : Converter Method

Photonic source : Dalitz decays of neutral light mesons π^0, η, η', Φ, ω, and ρ and direct γ

Non-photonic sources : mostly from heavy quarks

We install for a short period a thin brass tube (1.7% X_0) surrounding the beam pipe at 29cm. This is our converter.

Number of electrons without converter

$$N_e^{Conv-out} = N_e^{\gamma} + N_e^{non-\gamma}$$

Number of electrons with converter

$$N_e^{Conv-in} = R_{\gamma} N_e^{\gamma} + (1-\epsilon) N_e^{non-\gamma} \quad , \epsilon \approx 0.021$$

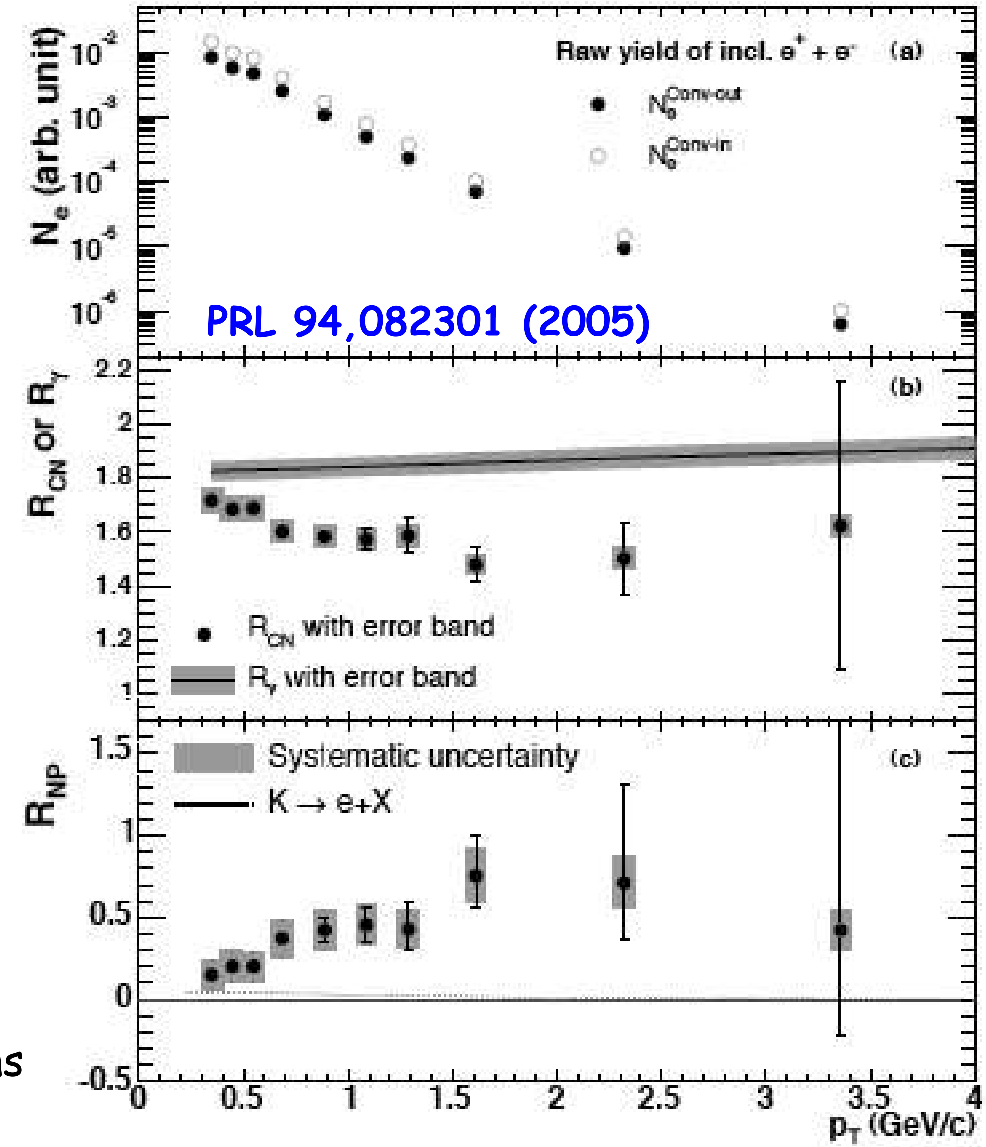
Defining,

$$R_{NP} \equiv \frac{N_e^{non-\gamma}}{N_e^{\gamma}} \qquad R_{CN} \equiv \frac{N^{Conv-in}}{N^{Conv-out}} \qquad R_{\gamma} = \frac{Y_e^{Conv-in}}{Y_e^{Conv-out}}$$

R_{γ} is obtained from full simulation w/ (w/o) converter material with ±2% of uncertainty.

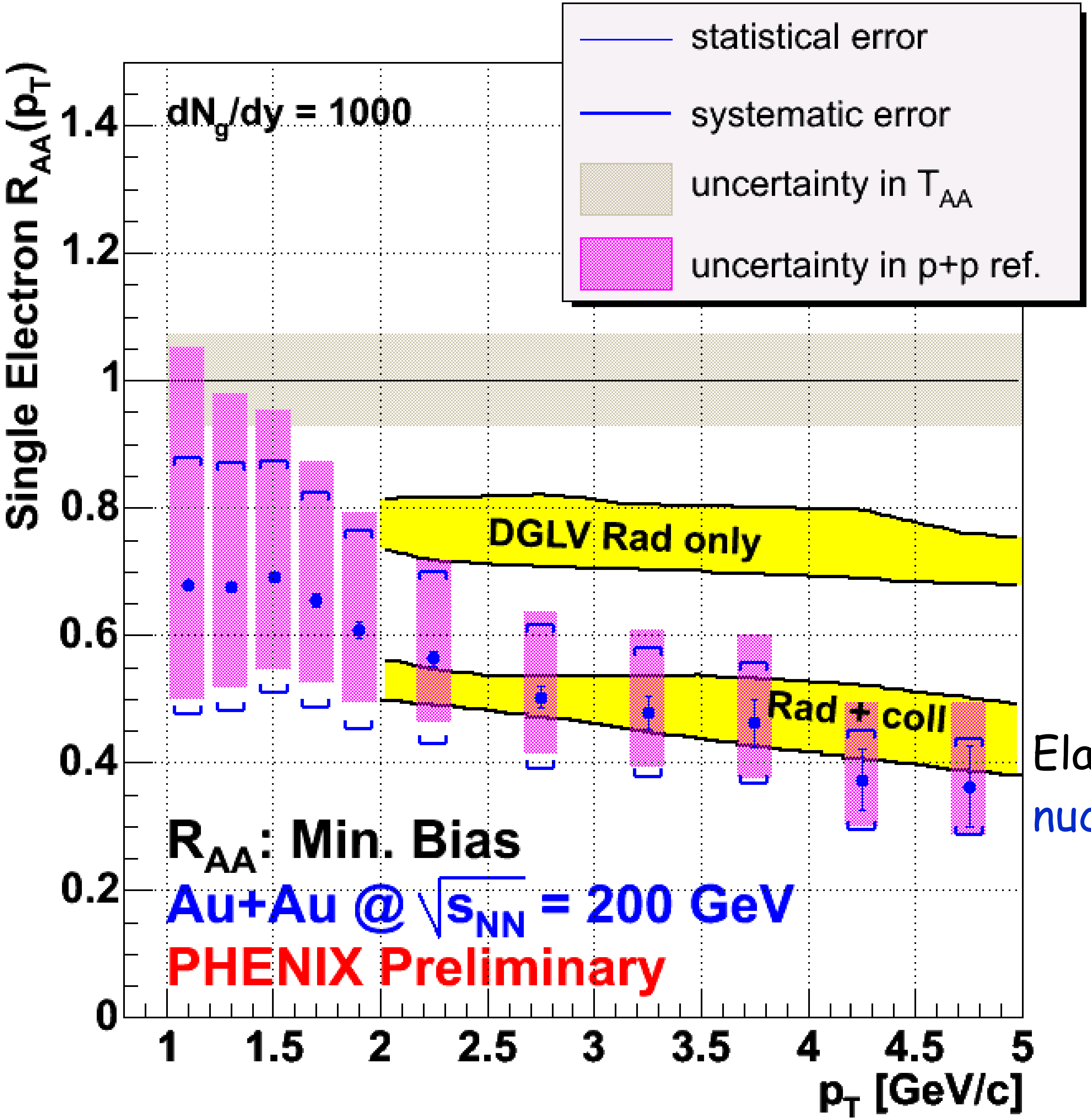
$$R_{CN} = \frac{R_{\gamma} + (1-\epsilon) R_{NP}}{1 + R_{NP}} \quad \textit{is obtained from data}$$

$$N_e^{non-\gamma} = \frac{N_e^{Conv-out}}{(1 + 1/R_{NP})}$$



Non-photonic contribution from K->πeν and di-electrons from Φ, ω, and ρ are subtracted as in cocktail method.

Au+Au @ √s=200GeV : Updated radiation model



Elastic + Radiation energy loss
nucl-th/051207