Electron Inversion into Charm D Meson

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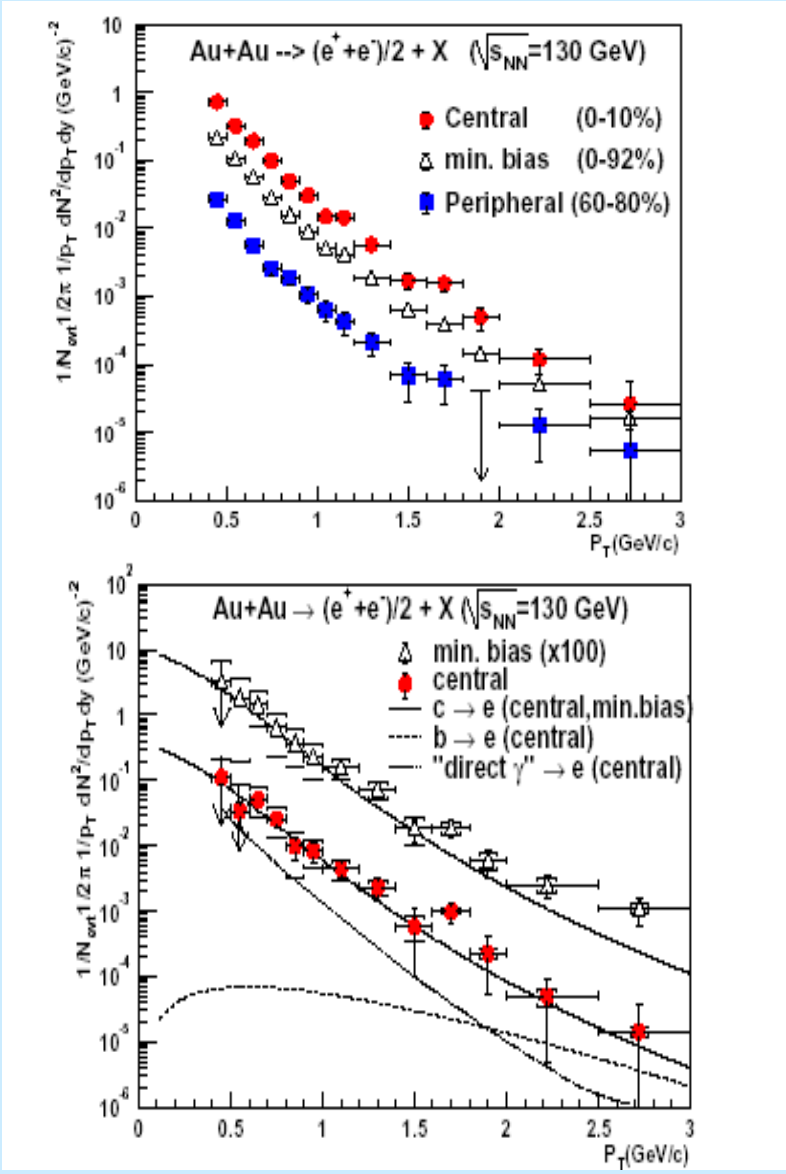
Electron spectra at PHENIX

e^+e^- p_T spectra at midrapidity for Au-Au collisions, at $\sqrt{s}$ =130GeV
(Phys.Rev.Lett.88:192303,2002)

Sources:
1. Dalitz decays
2. Di-electron decays
3. Photon conversions
4. Kaon decays
5. $c \rightarrow D \rightarrow eX$
6. $b \rightarrow B \rightarrow eX$
7. Thermal dileptons

1-4 background subtracted

Decays of D mesons dominant remaining contribution to the e-spectra

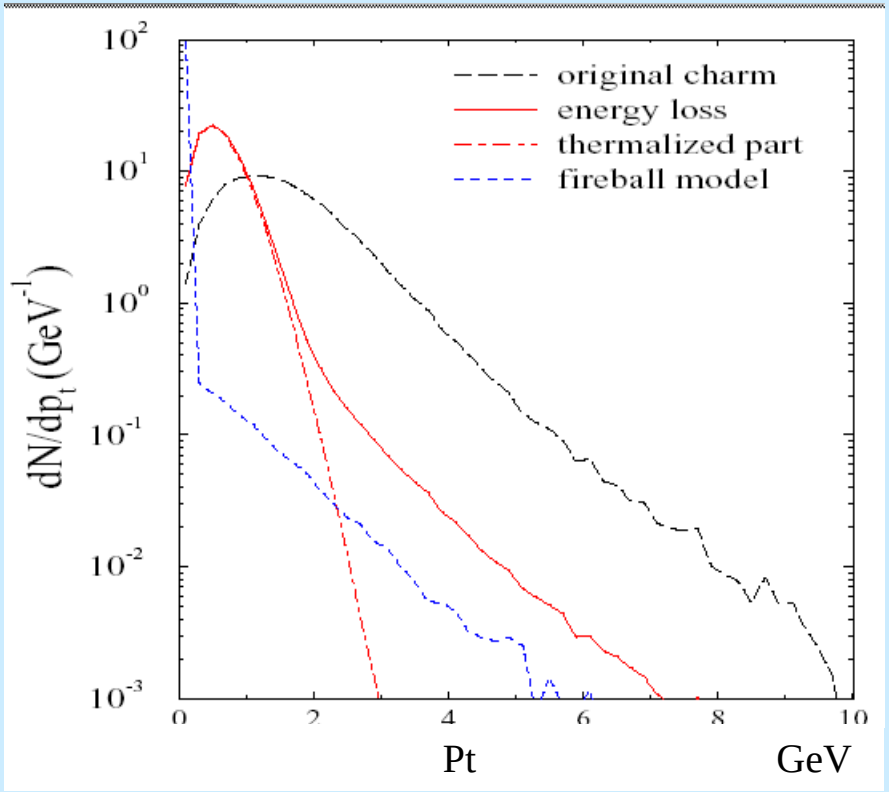


Electron Inversion into Charm D Meson

The extraction of the D meson spectrum from the electron spectrum
→study of the strongly interacting initial system.

- Heavy Quark energy loss dE/dx in medium

1. Radiative + elastic dE/dx of fast parton in medium with longitudinal expansion and partial thermalization independent of quark mass
   → suppression of large pt charm mesons
   (Z. W. Lin et al. **Phys.Rev.C 57:899,1992.**
   Z. W. Lin et al. **Nucl.Phys.B 544:339,1999**)



2. Gluon radiation from a fast parton is suppressed at angles < Mq/Eq ("*dead cone*" effect) → the suppression of heavy hadron pt distribution is smaller for heavy than light hadrons → D/π enhancement (depending on density of color charges in medium)
   (D. Kharzeev et al. **Phys.Lett.B 519:1999,2001)**

D formation time

However what if the c-quark is not fast enough to escape the medium before it fragments into D meson…

- Fusion: $gg \to c\bar{c}$ $q\bar{q} \to c\bar{c}$ and c–$\bar{c}$ pairs fragment into D mesons

Peterson fragmentation function:

$$f(z) = c \cdot \frac{1}{z \cdot \left(1 - \frac{1}{z} - \frac{e_c}{1-z}\right)^2}$$

gives $\langle z \rangle \approx 0.8$

- D with $pt \approx 4GeV$

comes from a c-quark with $\boxed{\langle p_t \rangle \approx 4/0.8 \approx 5GeV}$

D formation time

- Q.M. time t_c^D to build up a hadronic wave function and distance L_c^D traveled by c before it fragments into a D

$$\Rightarrow t_c^D = \gamma \cdot \left(\frac{R}{c} \right) \qquad \text{R (compton wavelength)} \approx \frac{\hbar}{m_c} \approx \frac{1}{1.3}\, fm = 0.8\, fm$$

$$\Rightarrow L_c^D = \gamma \cdot \beta \cdot R = \frac{p_t}{m_c} \cdot R = 3\ fm \qquad \text{for} \quad \langle p_t \rangle \approx 5 GeV$$

- The expanding fireball has a transverse size:

$$L_{fire} = 7\, fm + \frac{1}{2} ct$$

t the proper time of expanding system

It could be that $\Rightarrow c \rightarrow D$ inside the fireball?

D thermalization ?

- Low and medium p_t (0-4 GeV) D may be formed inside fireball and rescattering with surrounding particles may lead to collective behavior.
  Interactions with other hadrons are relatively weak $\sigma(\pi D)$~10 mb
  (Ziwei Lin, C. M. Ko, Bin Zhang, Phys. Rev. C 61, 024904 (2000).
  Ziwei Lin, C. M. Ko, Bin Zhang, preprint [nucl-th/9905007])
  However there is an abundance of π (for T~170MeV

or

Charm quarks undergo significant scattering in partonic medium and participate in hydrodynamic type expansion then either fragment into D mesons or coalesce with commoving spectators of low relative momentum to form D mesons.

$\Rightarrow$Thermalization, hydrodynamic flow of D?

Hydrodynamic model

Thermal model with longitudinal and transverse flow

(U. Heinz et al., Phys. Rev. C 48, 2462 (1993).

- Transverse velocity distribution:

$$\beta_r(r) = \beta_s \left(\frac{r}{R} \right)^n$$

β_s the max surface velocity, n=1

R the max radius of expanding source

- Each fluid element is locally thermalized and boosted with angle :

$$\rho = \tanh^{-1}(\beta_r)$$

- Instantaneous freeze-out in radial direction leads to model independence of freeze out hypersurface (points of last interaction). Only as normalization factor.
- Examine only the dynamics of the collision zone at freeze-out (shape of spectra). D is not assumed to have reached chemical equilibrium .

$e^{-\frac{\mu}{T}}$ enters also as a normalization factor

Hydrodynamic model

- Resulting spectrum is a superposition of the individual thermal components

$$\frac{dN}{m_t dm_t} = A \cdot \int_0^R r dr m_t I_0\left(\frac{p_t \sinh\rho}{T}\right) K_1\left(\frac{m_t \sinh\rho}{T}\right)$$

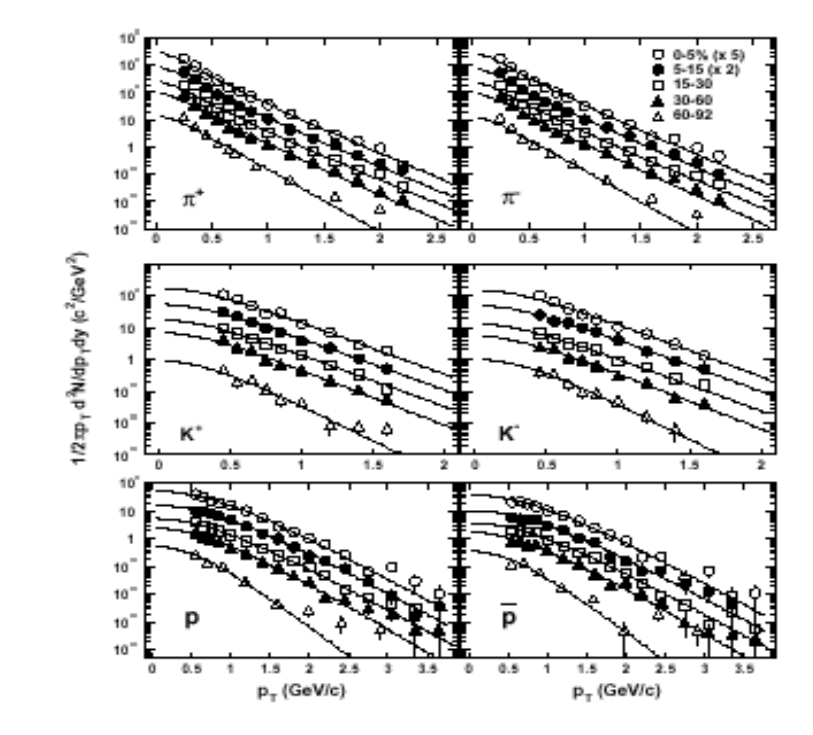
- Azimuthal symmetry - $I_0(z) = (2\pi)^{-1}\int_0^{2\pi} e^{z\cos\varphi} d\phi$
- Integrate over fireball rapidity - $K_1(z) = \int_0^{\infty} \cosh y e^{-z\cosh y} dy$

PHOBOS: charged particle flat over 2 units of η and integrand $\rightarrow 0$ for $|y| > 2$ (PHOBOS Collaboration, Phys.Rev.Lett.87:102303,2001.)

- T the freeze-out temperature

Hydro-model application to PHENIX data

PHENIX Collaboration, Single Inclusive Hadron Spectra from $\sqrt{s_{NN}}$ =130 GeV Au+Au Collisions at RHIC, in preparation.



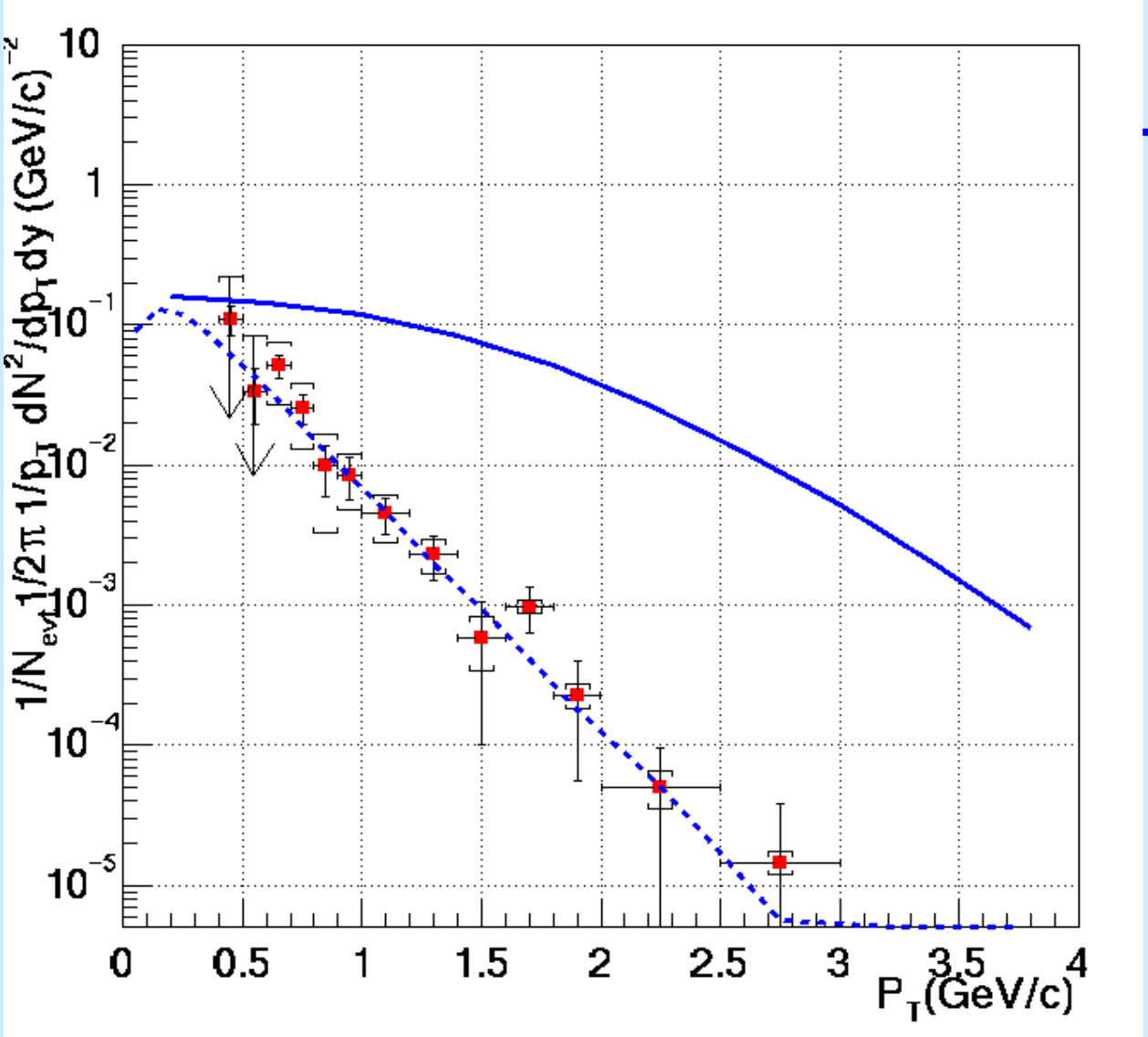
All particles decouple kinematically at same freeze-out T on the freeze-out hypersurface + Heinz hydrodynamic model

$\Rightarrow$ Simultaneous fit to the p_t spectra of $\pi^{+/-}$, $K^{+/-}$, p, $\bar{p}$ to extract T and β_s

Min. $\chi^2 = 34$ for dof=40

$$\Rightarrow T = 121 \pm 4 MeV, \beta_s = 0.70 \pm 0.01$$

Hydro-model for D meson

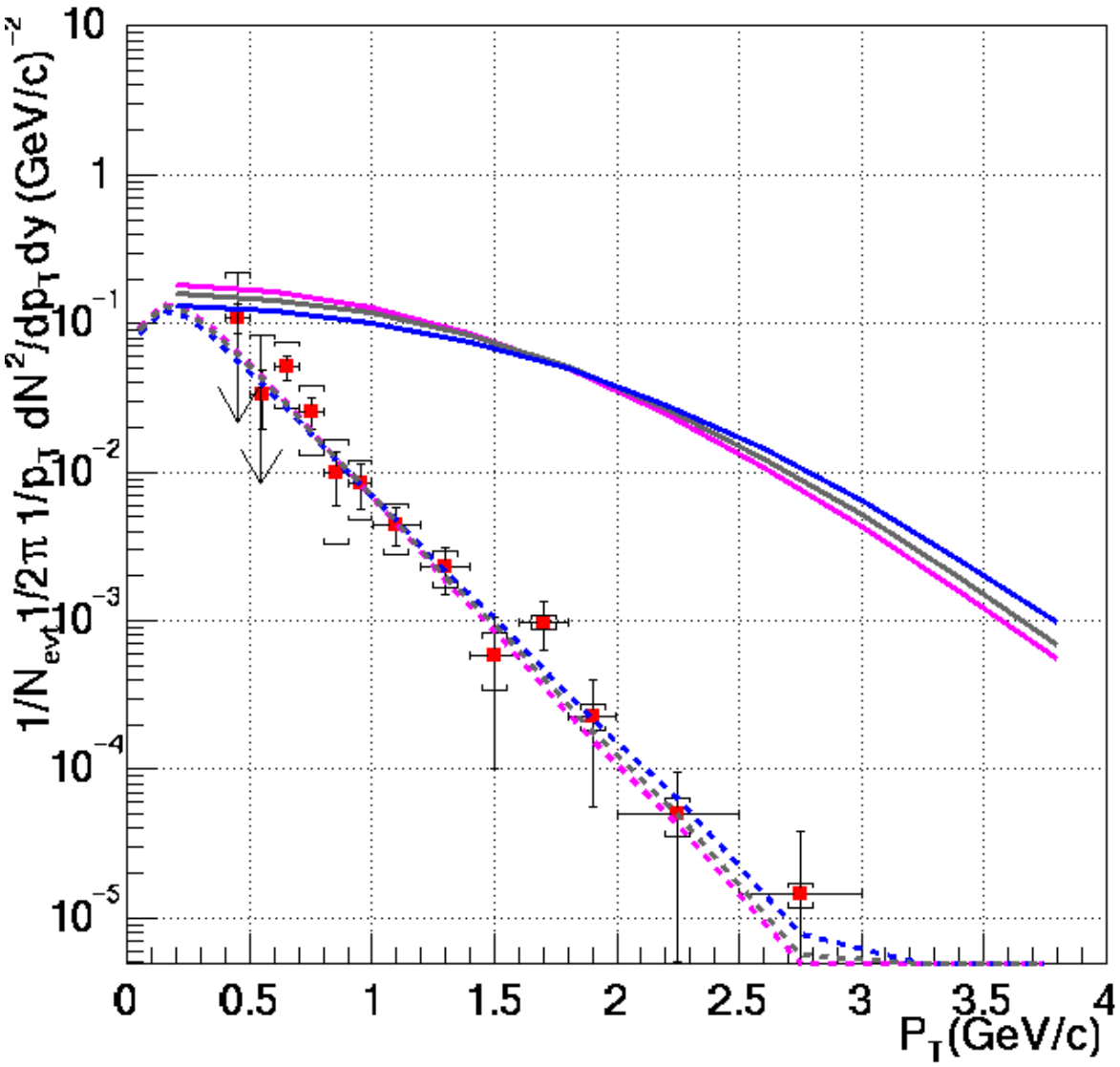


shape of D from Hydro-model normalized so that the e spectrum (---) best matches the data

$$T = 121 \pm 4 MeV$$

$$\beta_s = 0.70 \pm 0.01$$

Hydro-model for D meson



— min χ^2 flow parameters

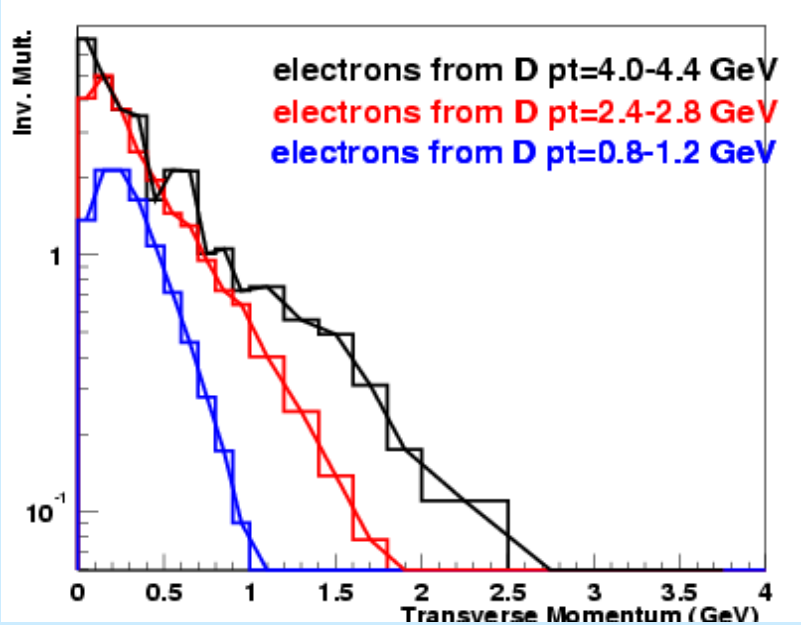
$$T = 121 \pm 4\,MeV$$
$$\beta_s = 0.70 \pm 0.01$$

2σ χ^2 contours

$$T = 111,\ \beta_s = 0.74$$
$$T = 135,\ \beta_s = 0.66$$

Not very sensitive to values of T and β_s due to statistics

Electron Inversion into Charm D Meson (1)



- PYTHIA 6.152 as decay generator $c \to D \to eX$
- Average Branching Ratio for all the D states $\left(D^0 D^+ D_s^+\right)$ that contribute to the e spectrum estimated 11% from PDG (different from PYTHIA 9.7%)
- For each D meson p_T bin $\rightarrow$ electron p_T spectrum (per D invariant multiplicity) for $y_e < 0.3$

Electron Inversion into Charm D Meson (1)

Assume functional form for D p_T spectrum

1. Power Law Parameterization

$$\frac{1}{2\pi p_T}\cdot\frac{d^2N_D}{dydp_T} = A\times\frac{1}{(1+p_T/p_0)^n}$$

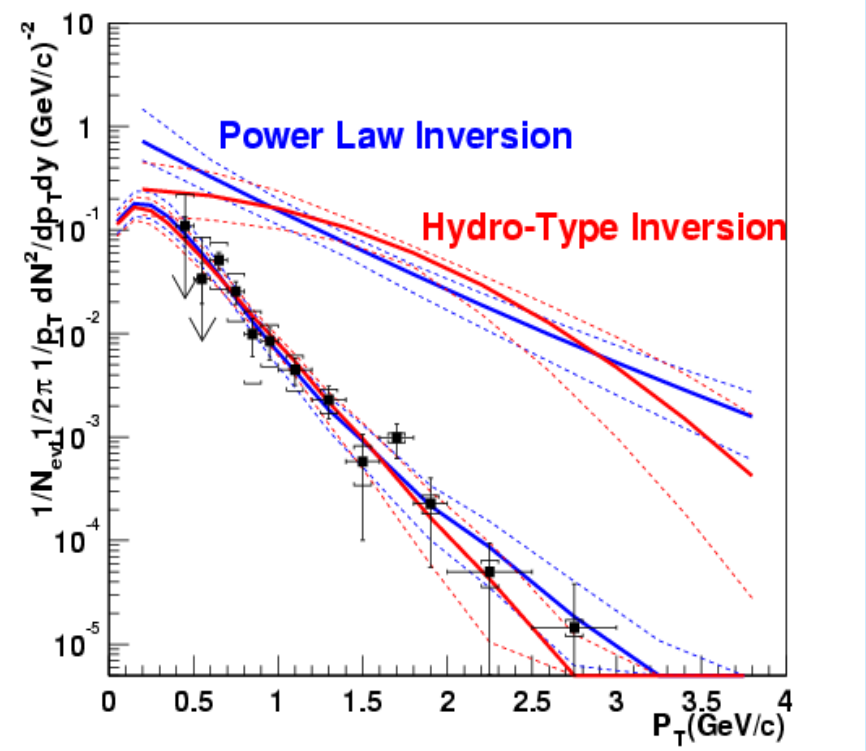
2. Gauss Parameterization (Hydrodynamic model inspired)

$$\frac{1}{2\pi p_T}\cdot\frac{d^2N_D}{dydp_T} = A\times\exp\left(-\frac{p_T^2}{2\sigma^2}\right)$$

Iterate over set of free parameters, perform D→e mapping and obtain the parameters corresponding to best fit to the electron data.

The Gaussian and Power Law parameterization match the data equally well

10% most central electron data

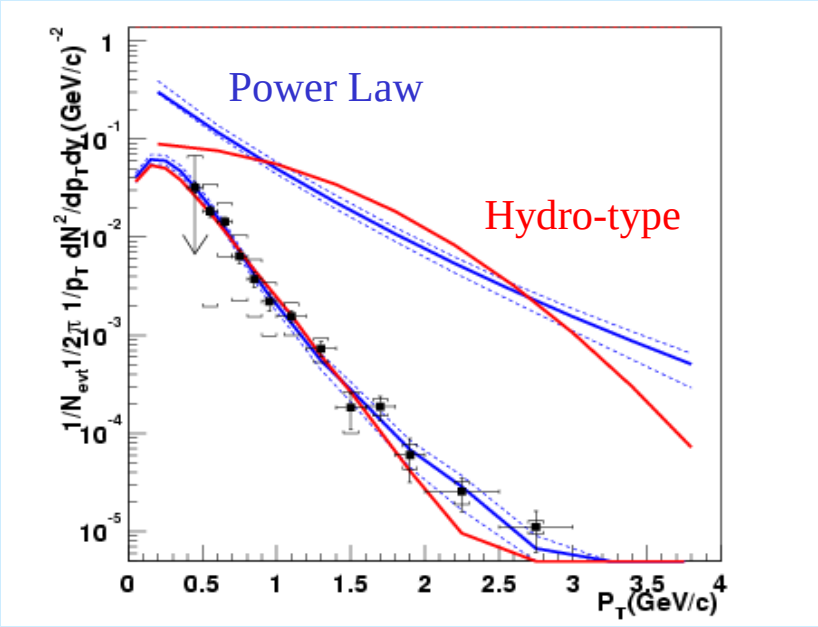


- Best inversion fit for the two models
- Resultant electron spectra

  90% statistical confidence limits

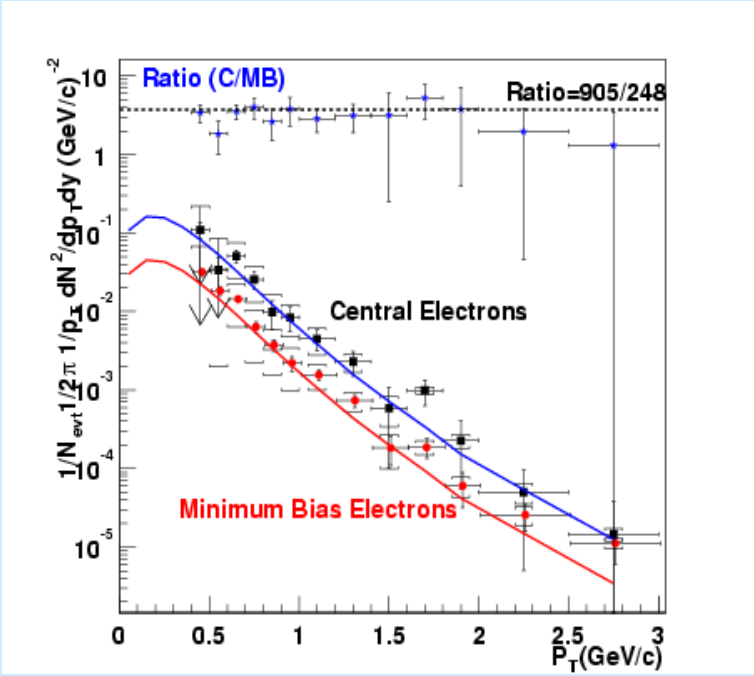
Electron Inversion into Charm D Meson (1)

Minimum bias 0-92% electron data



Gaussian parameterization does not match Data as well as Power Law

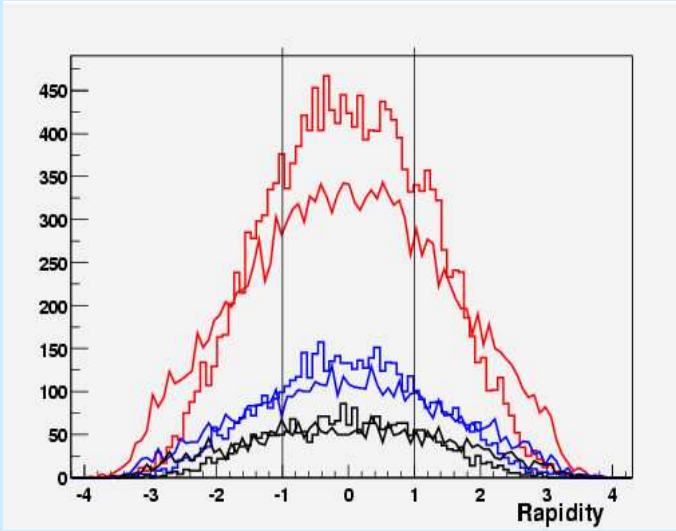
But
B meson contribution could be important for high pt



- The ratio of central to minimum bias electron data indicates that their shapes are quite similar → disagreement could be obvious because of better statistics

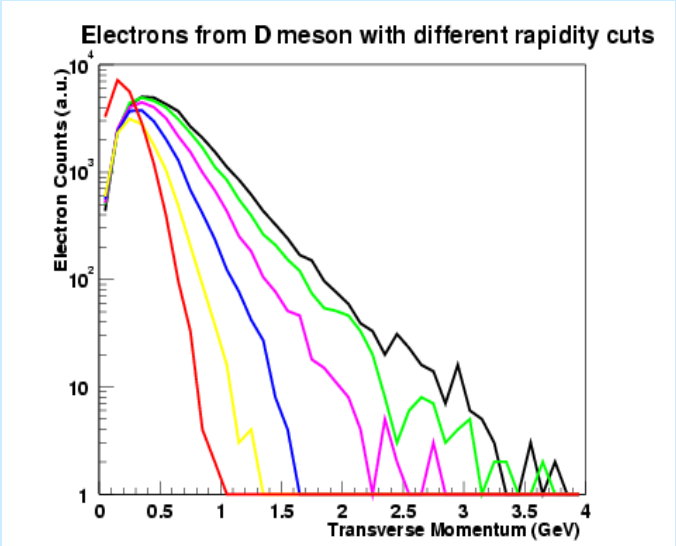
•Single electrons with energies greater than ~1.5GeV could be mainly from energetic heavy quarks that escape after energy loss
•Single electrons with smaller energies could be from thermalized charm quarks and therefore exhibit a hydrodynamic type behavior

Dependence of the electron pt spectrum on input D PYTHIA model?



- PYTHIA D rapidity distribution ~flat for $y_D < 1$
- 5% change in the electron PHENIX acceptance $(y_e < 0.3)$ if y_D is forced to be flat in the range [-1,1]

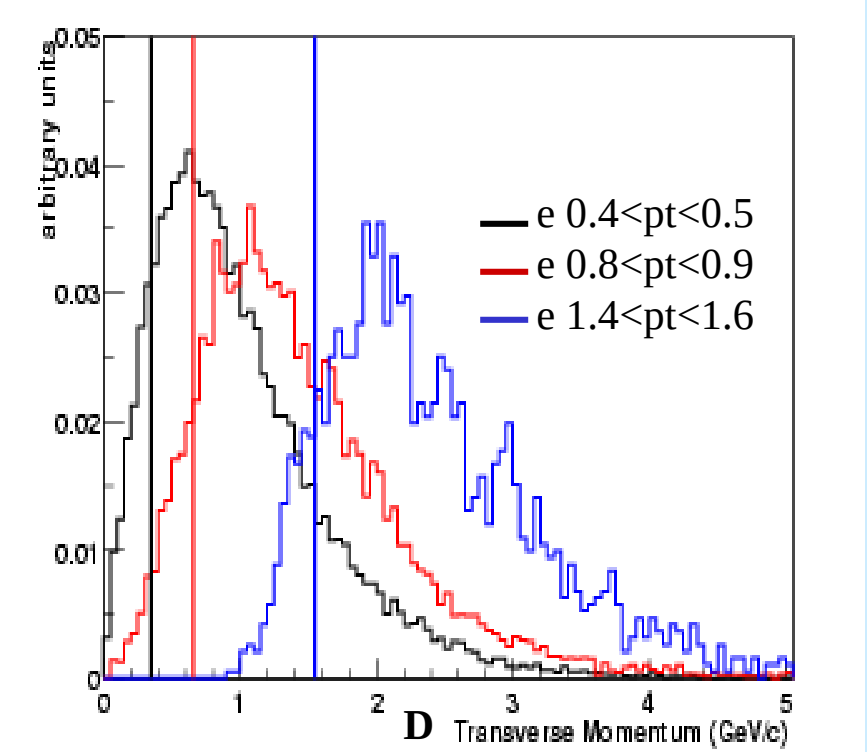
D^0, D^+ D_s^+



- y>1 contribution mostly to electrons with $p_T < 0.5\,GeV$ -outside the measured range

$|y_D|>1$, $1>|y_D|>0.8$, $0.8>|y_D|>0.6$, $0.6>|y_D|>0.4$, $0.4>y_D|>0.2$, $0.2>|y_D|>0.0$,

Electron Inversion into Charm D Meson (2)



UA1 – CDF method for inverting single lepton, dilepton spectra into D and B mesons

(Albajar et al., Phys. Lett. B 186, 237 (1987),
C. Albajar et al., ZPC 37, 487 (1987),
C. Albajar et al, Phys. Lett. B 213, 405 (1988),
C. Albajar et al., Phys. Lett. B 256, 121 (1991),
C. Albajar et al., ZPC 369, 46 (1996),
CDF, Phys. Rev. Lett. 71, 500 (1993),
CDF, Phys. Rev. Lett. 71, 2396 (1993).)

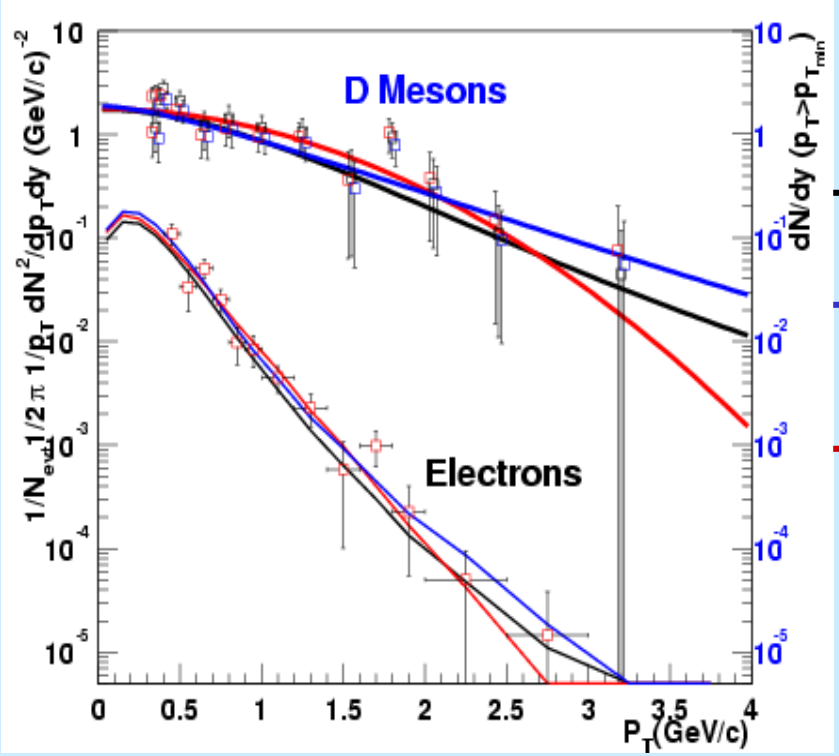
Every electron p_T point contains mostly information about the integrated D meson with $p_{TD} > p_{Te}$. For each electron $p_T \rightarrow$ D p_{Tmin} where 90% of the contribution to electrons are above that value.

Using a model $\rightarrow$ map from each electron point to an integrated dN/dy D meson point:

$$\left(\frac{dN_D / dy(p_T > p_T(\min))}{\text{electron level}} \right)_{MC}$$

Electron Inversion into Charm D Meson (2)

10% most central electron data

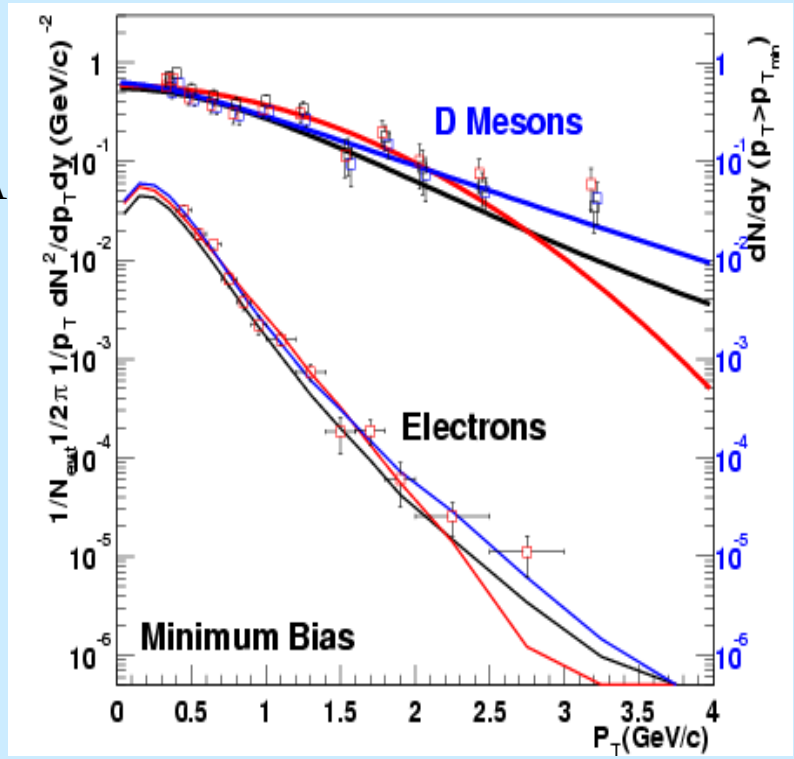


PYTHIA

Power Law

Gauss

Minimum bias 0-92% electron data

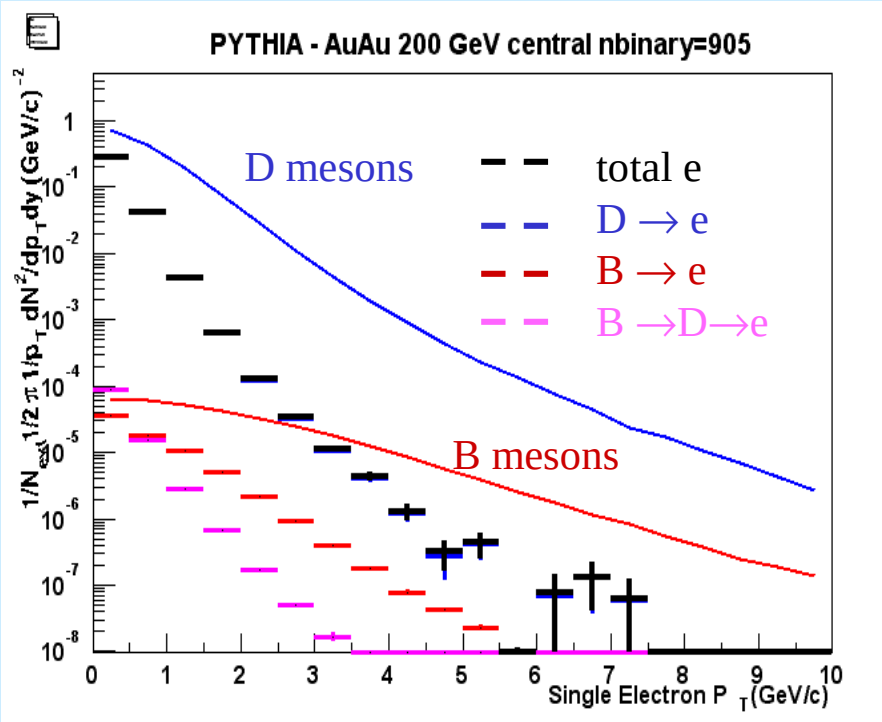


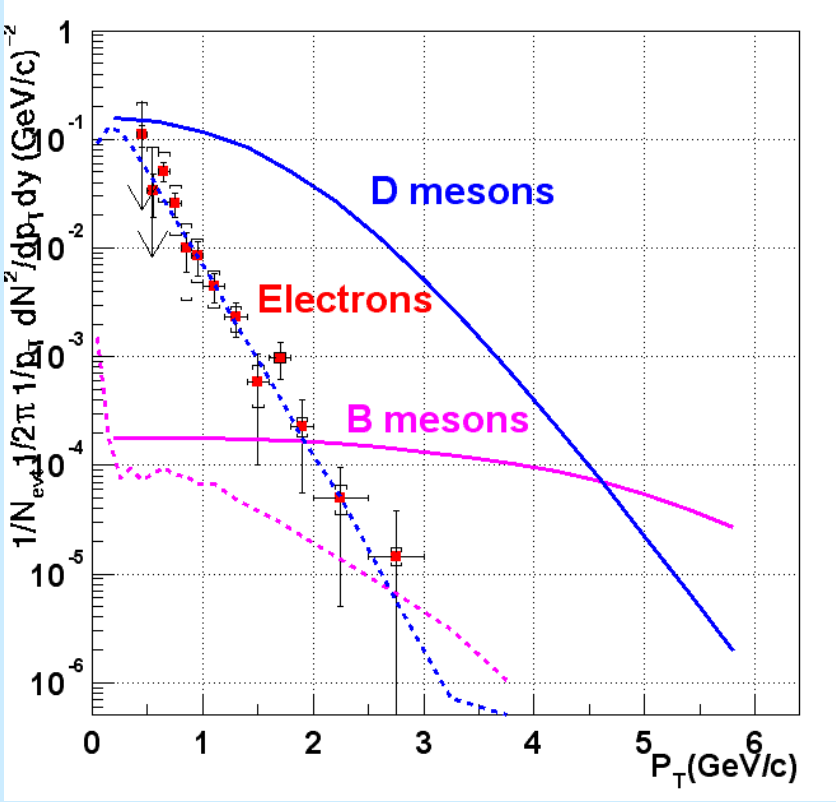
Upper points: inverted (using method 2) dN/dy (p_T>p_T(min)) integrated D meson points.
Lower points: PHENIX electron invariant multiplicity data
Inputs: PYTHIA (black), best fit power law (blue), best fit Gaussian (red).
The calculted D meson and electron distributions are shown as curves.

- 10% most central data → all models agree within statistical errors with both the electrons and D mesons.
- minimum bias data → PYTHIA and Gaussian distribution disagree with the data

B meson contribution to electron spectra

Z. W. Lin et al. **Phys.Rev.C 57:899,1992** predict that with energy loss, the electron yield from charm decays is close to that from bottom at E>2GeV.





Hydro: B mesons scaled with respect to D mesons as their total cross sections
the B contribution becomes important above 2 Gev

PYTHIA: B meson contribution becomes important at higher pt