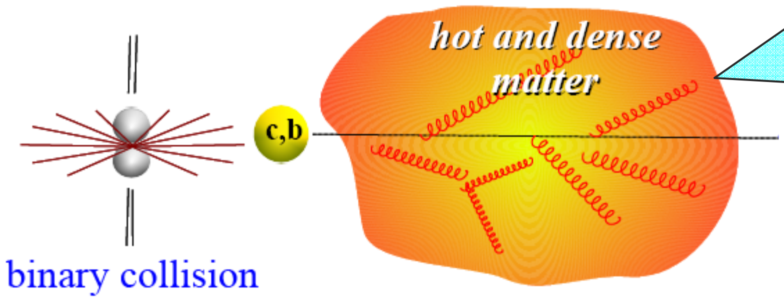
Elliptic flow of electron from heavy flavor decay by the PHENIX

Shingo Sakai
for PHENIX collaboration
(Univ. of Tsukuba & JPSP)

Outline

- Physics motivation
- Method
- Result
- Compare with models
- Summary

Motivation

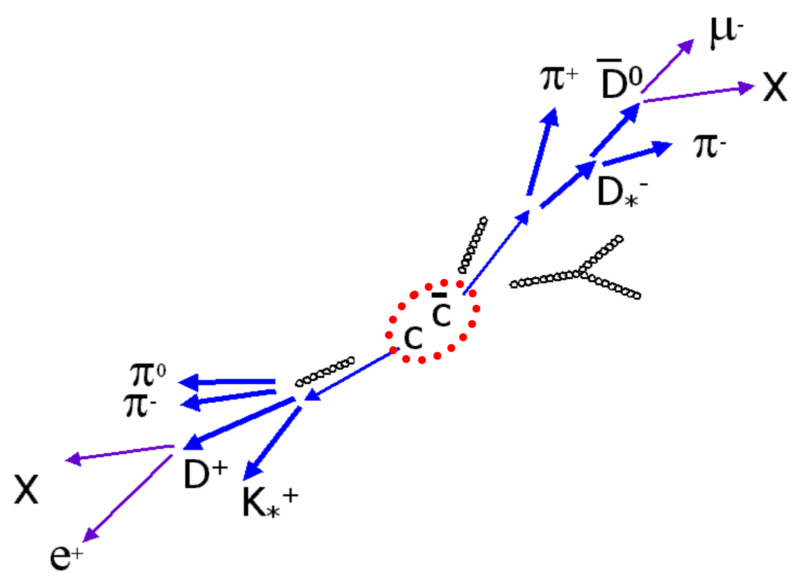


- flow & energy loss ?
- insight into the property of the medium

- Charm is produced in initial collisions via gluon fusion and propagates through medium
  => good probe for studying property of the medium
- v_2 and R_{AA} measurement are useful analysis method
- Large energy loss has been observed. => talked by F. kajihara
- How about charm flow ?
  => indicate strongly coupling & quark level thermalization
- v_2 & R_{AA} are related to the diffusion coefficient D and η/s
  $D \propto \eta/(sT)$

Charm via electron measurement

- Electron is one of the good probe of charm
- Electron sources
  - photonic
    - photon conversion
    - Dalitz decay (π^0, η , ω ---)
  - non-photonic
    - Ke3 decay
    - primarily semi-leptonic decay of mesons containing c & b



- We have two independent method for photonic electron subtraction.

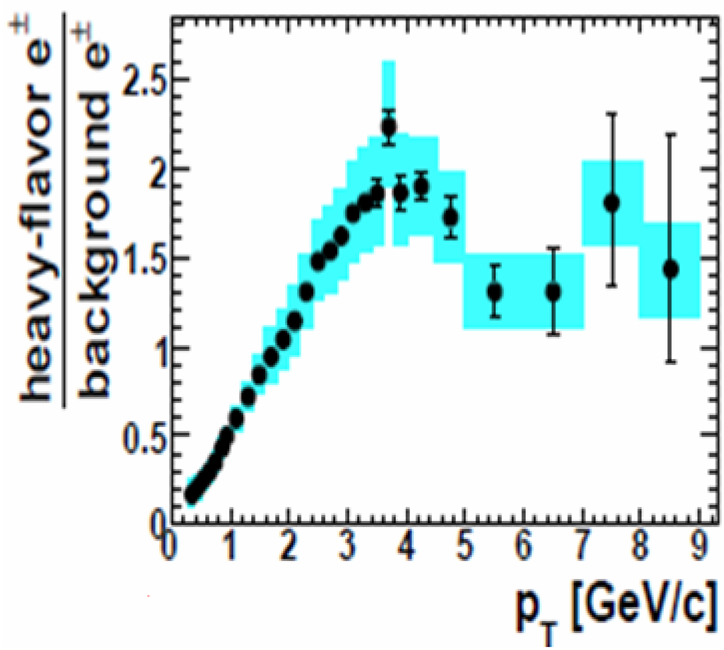
Photonic electron subtraction

- Cocktail subtraction

  photonic electrons are calculated as cocktail of each sources. [PRL 88, 192303 (2002)]

- Converter subtraction

  Photonic electrons are extracted experimentally by special run with additional converter (X = 0.4 + 1.7%) [PRL 94, 082301 (2005)]



- 50 % of e come from non-γ @ high pT (>1.5 GeV/c)

* **Details about spectra analysis ; F. Kajihara's talk**

Non-photonic electron v_2 measurement

- Non photonic electron v_2 is given as;

$$\frac{dN^{e}}{d\Phi} = \frac{dN^{\gamma.e}}{d\Phi} + \frac{dN^{non-\gamma.e}}{d\Phi} \quad (1)$$

$$v_2^{non-\gamma.e} = \frac{(1+R_{NP})v_2^{e} - v_2^{\gamma.e}}{R_{NP}} \quad (2)$$

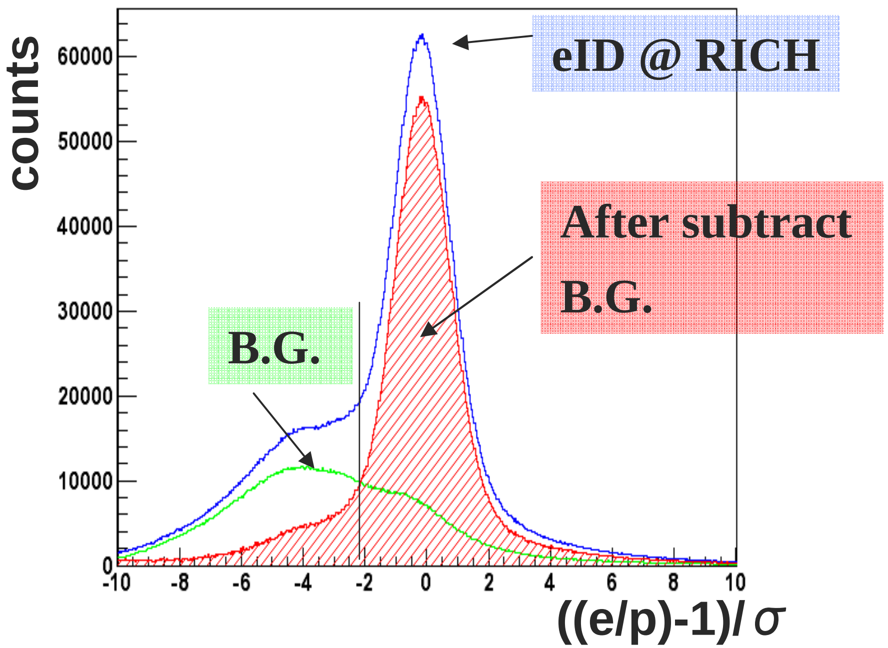
v_2^e ; Inclusive electron v_2
=> Measure

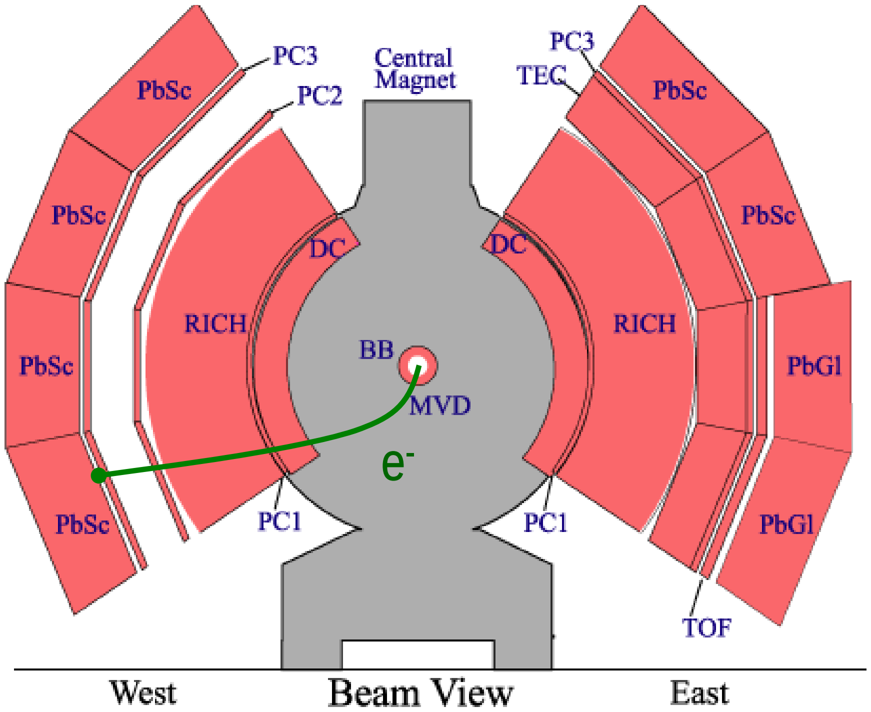
R_{NP} = (Non-γ e) / (γ e)
=> Measure

v_2 $^{\gamma.e}$; Photonic electron v_2
$\Rightarrow$ Cocktail method (simulation) stat. advantage
$\Rightarrow$ Converter method (experimentally)

Electron ID @ PHENIX

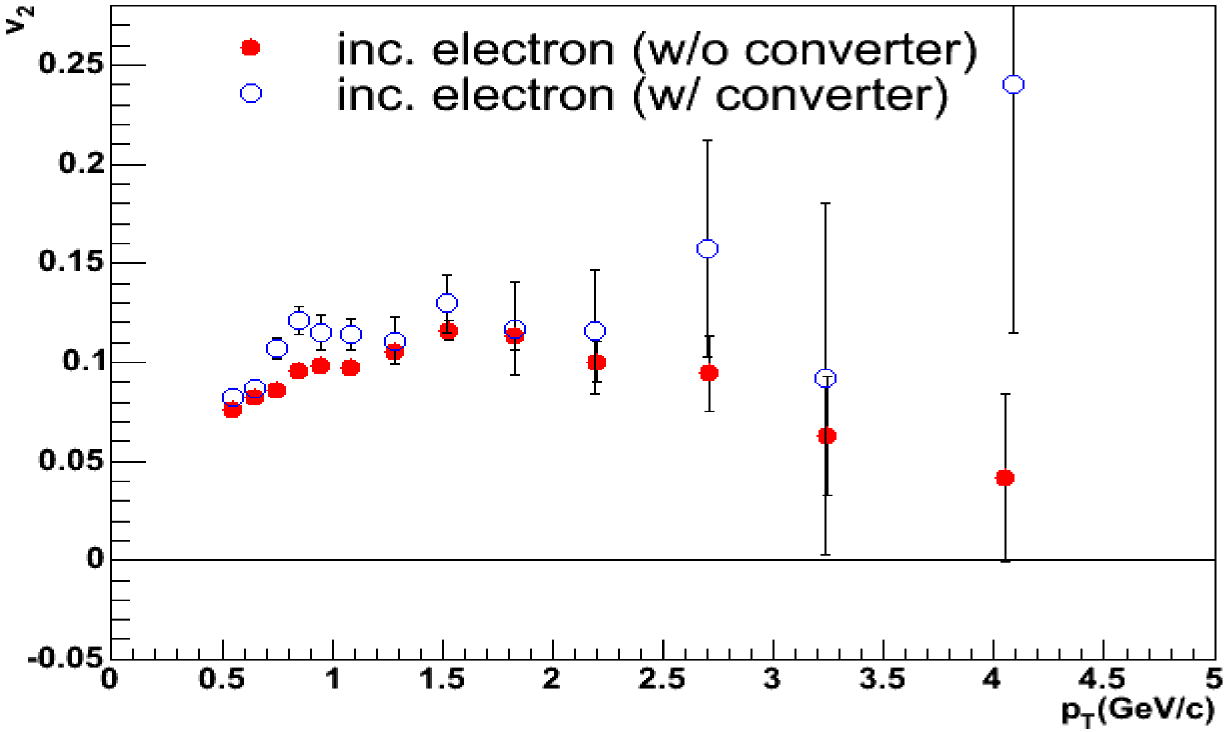
- Electron ID
  - RICH ; electron ID
  - EMC ; measure E
  - request E/p matching





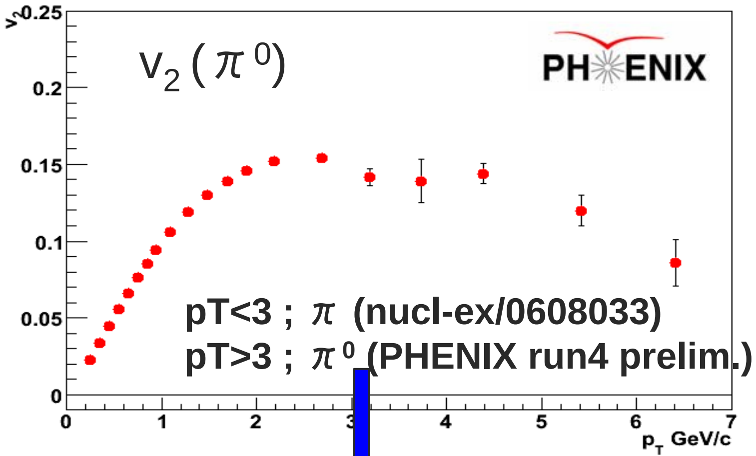
- Radiation length < 0.4 %

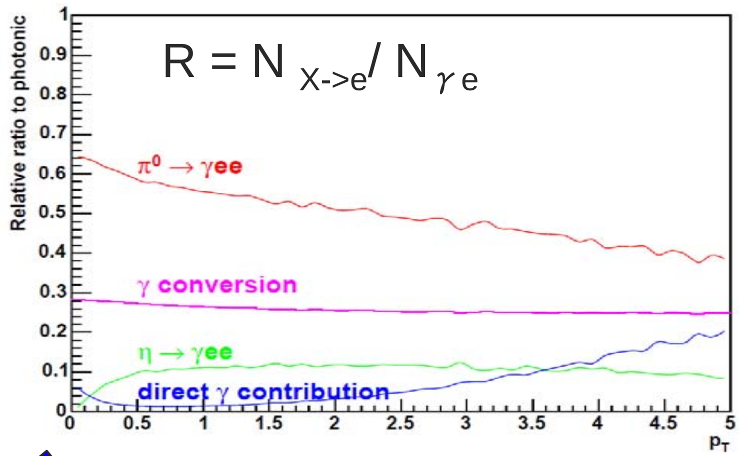
Inclusive electron v_2



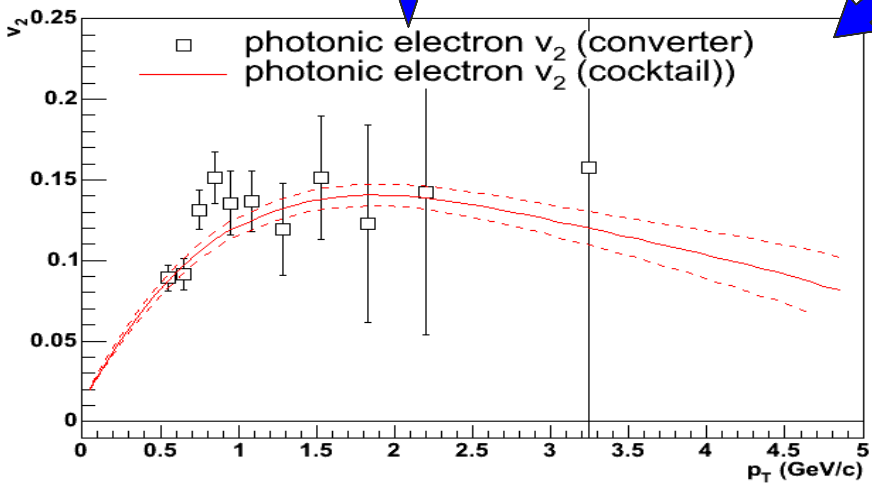
- inclusive electron v_2 measured w.r.t reaction plane
- converter --- increase photonic electron
- photonic & non-photonic e v_2 is different

Photonic e v_2 determination





decay

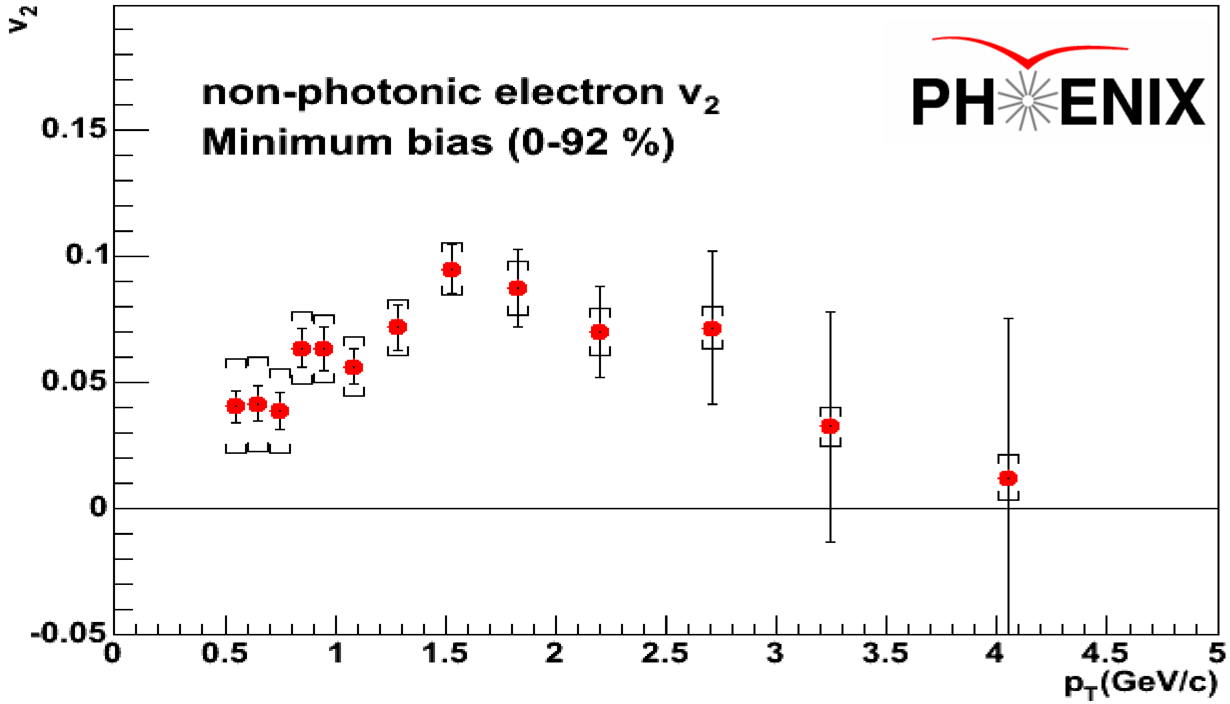


- photonic electron v_2
  => cocktail of photonic e v_2

$$v_2^{\gamma.e} = \sum R \times v_2^{decay}$$

- good agreement
  converter method
  (experimentally determined)

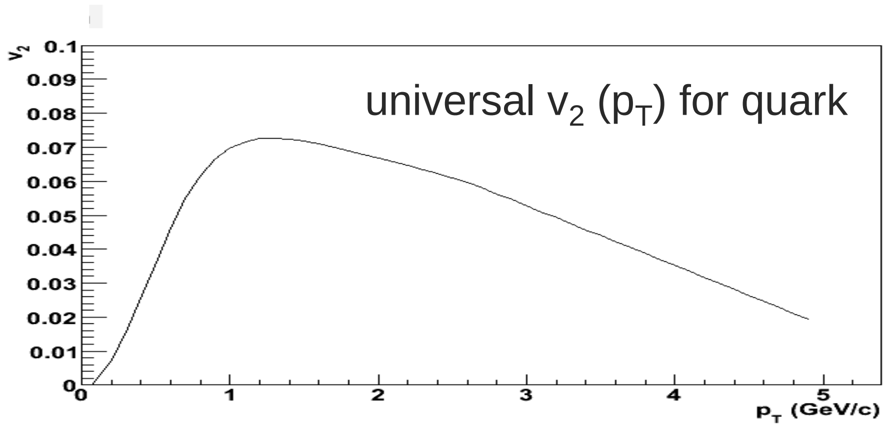
Non-photonic electron v_2



- Strong elliptic flow for non-photonic electron
- Main source is D meson -> indicate non-zero D v_2
- Charm v_2 also non-zero ?

Non-zero charm v_2 ? (1)

- Apply recombination model
- Assume universal v_2 (p_T) for quark



Shape is determined with measured identified particle v_2

[PRC 68 044901 Zi-wei & Denes]

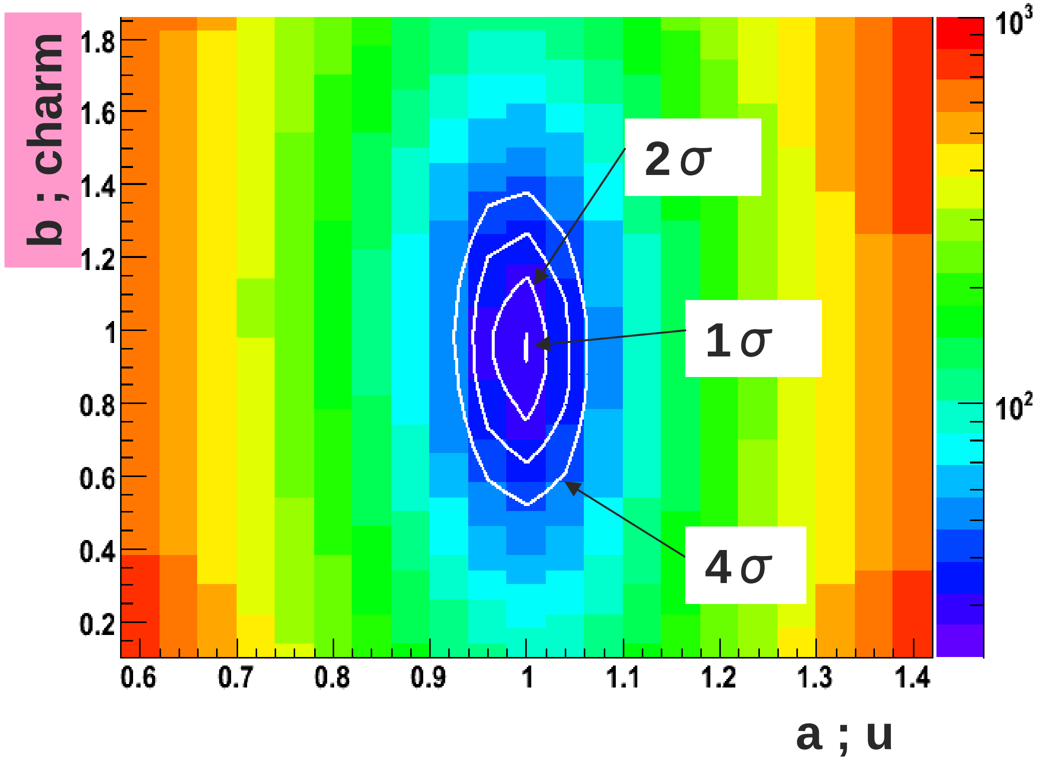
charm

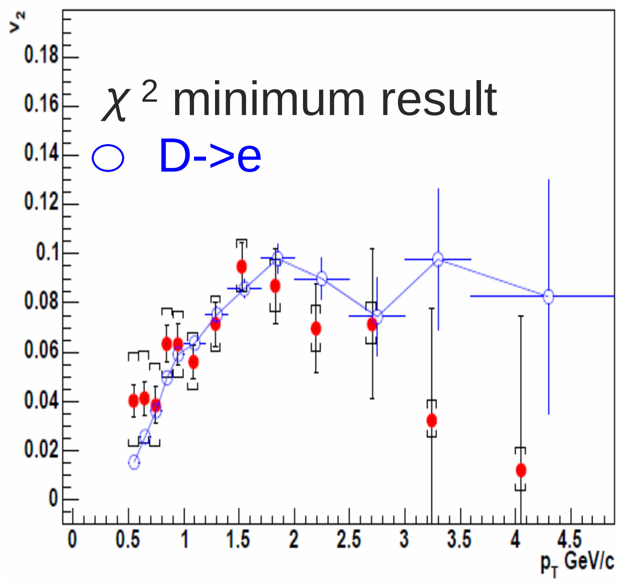
$$v_2^D(p_T) = a v_2^q\left(\frac{m_u}{m_D} p_T\right) + b v_2^q\left(\frac{m_c}{m_D} p_T\right) \rightarrow v_2^e$$

a,b ; fitting parameters

- simultaneous fit to $\mathbf{v_2}^{\pi}$, $\mathbf{v_2}^{\mathbf{K}}$ and $\mathbf{v_2}^{\text{non-}\gamma\,\mathbf{e}}$

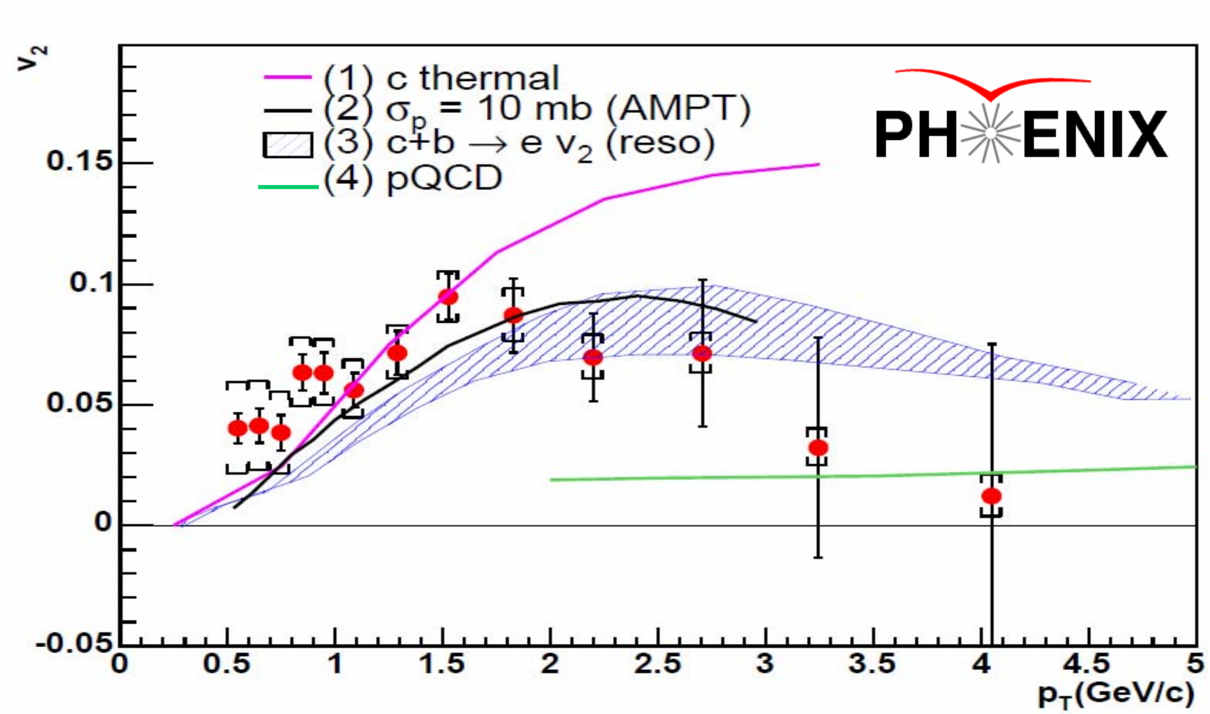
Non-zero charm v_2 ? (2)





- χ^2 minimum ; a = 1, b = 0.96 (χ^2/ndf = 21.85/27)
- Based on this recombination model, the data suggest non-zero v_2 of charm quark.

Compare with models



(1) Charm quark thermal + flow [Phys.Lett. B595 202-208]

(2) large cross section ; ~10 mb [PRC72,024906] **work**

(3) Resonance state of D & B in sQGP [PRC73,034913]

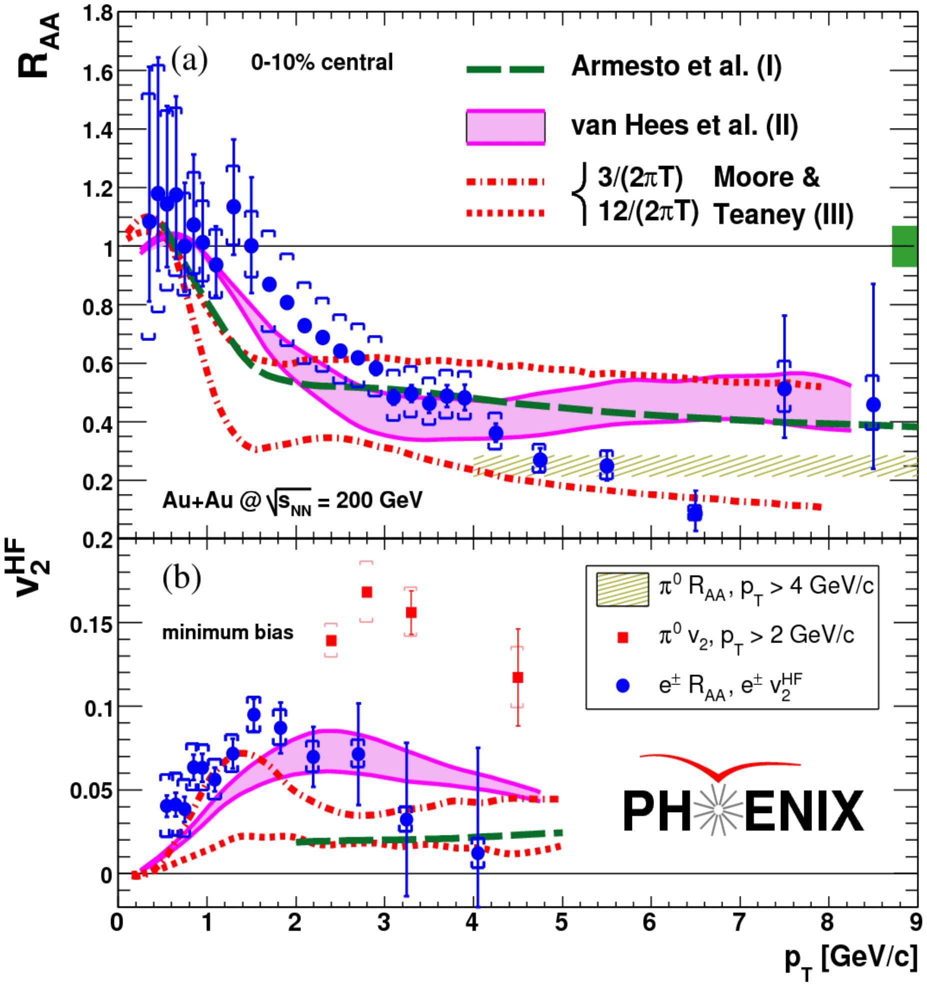
(4) pQCD [PRB637,362] **--- fail**

=> Charm quark strongly coupled to the matter

Comparison with models; R_{AA} & v_2

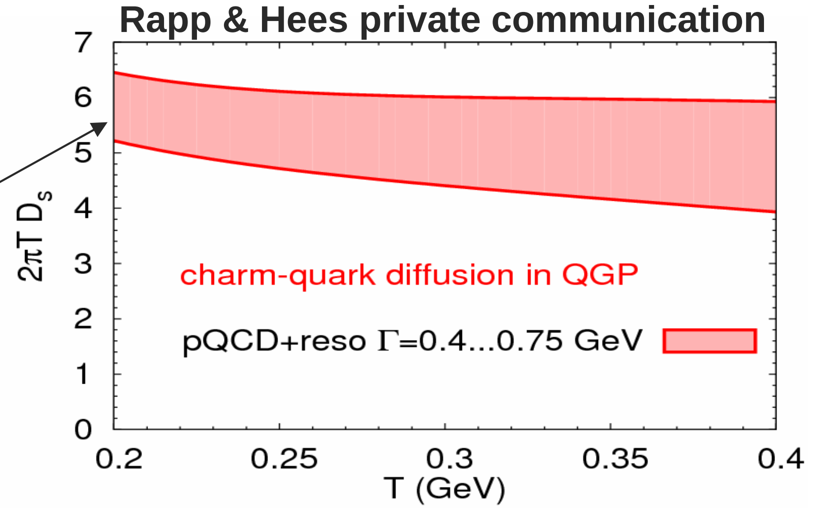
Nucl-ex/0611018

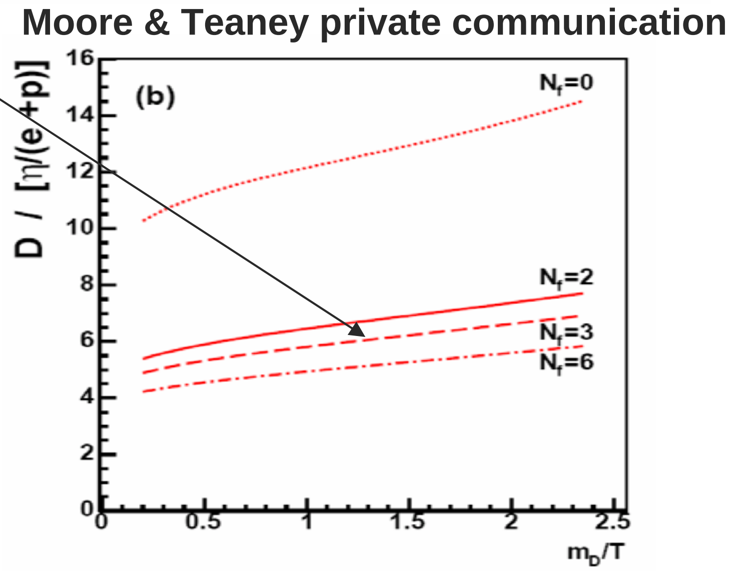
- Two models describes strong suppression and large v_2
  - Rapp and Van Hees
    - ✓ Elastic scattering -> small τ
    - ✓ $D_{HQ} \times 2\pi T \sim 4 - 6$
  - Moore and Teaney
    - ✓ $D_{HQ} \times 2\pi T = 3\sim12$
- These calculations suggest that small τ and/or D_{HQ} are required to reproduce the data.



Constraining η/s with PHENIX data

- Rapp and van Hees Phys.Rev.C71:034907,2005
  - Simultaneously describe PHENIX $R_{AA}(E)$ and $v_2(e)$ with diffusion coefficient in range $D_{HQ} \times 2\pi T \sim 4\text{-}6$
- Moore and Teaney Phys.Rev.C71:064904,2005
  - Find $D_{HQ}/(\eta/(\varepsilon+p)) \sim 6$ for $N_f=3$
  - Calculate perturbatively, argue result also plausible non-perturbatively
- Combining
  - Recall $\varepsilon+p = T\,s$ at $\mu_B=0$
  - This then gives **$\eta/s \sim (1.5\text{-}3)/4\pi$**
  - That is, within factor of 2 of conjectured bound





Summary

- Non-photonic electron v_2 mainly from charm decay was measured @ $\sqrt{s}$ = 200 GeV in Au+Au collisions at RHIC-PHENIX & non-zero v_2 is observed
- The data suggest non-zero v_2 of charm quark.
- Charm quark strongly coupled to the matter
- Model comparison suggests
  - small τ and/or D_{HQ} are required
  - η /s is very small, near quantum bound.

Thanks!

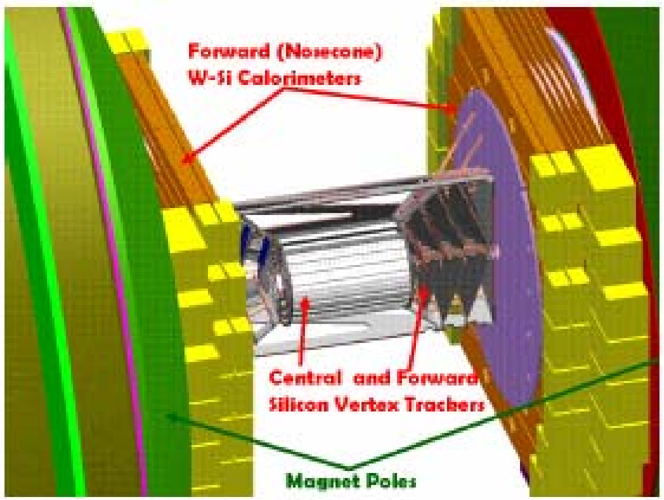
BackUp

Additional Remarks

- What does $D_{HQ}/(\eta/(\varepsilon+p)) \sim 6$ mean?
  - Denominator:
    - D_{HQ} is diffusion length ~ heavy quark diffusion length λ_{HQ}
  - Numerator:
    - Note that viscosity $\eta \sim n \langle p \rangle \lambda$
      - n = number density
      - $\langle p \rangle$ = mean (thermal) momentum
      - λ = mean free path
    - "Enthalpy" $\varepsilon + P \sim n \langle p \rangle$
      - Here P is pressure
    - So $\eta/(\varepsilon+P) = (n \langle p \rangle \lambda) / (n \langle p \rangle) \sim \lambda$
    - Note this λ is for the ***medium***, i.e., light quarks
  - Combining gives $D_{HQ}/(\eta/(\varepsilon+p)) \sim \lambda_{HQ} / \lambda$
    - Not implausible this should be of order 6
- Notes
  - Above simple estimates in Boltzmann limit of well-defined (quasi)-particles, densities and mfp's
  - The "transport coefficient" $\eta/(\varepsilon+p)$ is preferred by theorists because it remains well-defined in cases where Boltzmann limit does not apply (sQGP?)

Outlook for heavy flavor v_2 study @ PHENIX

- new reaction plane detector
  - good resolution => reduce error from R.P.
  - J/ψ v_2 & high pT non-photonic electron v_2
- silicon vertex detector
  - direct measurement D meson v_2

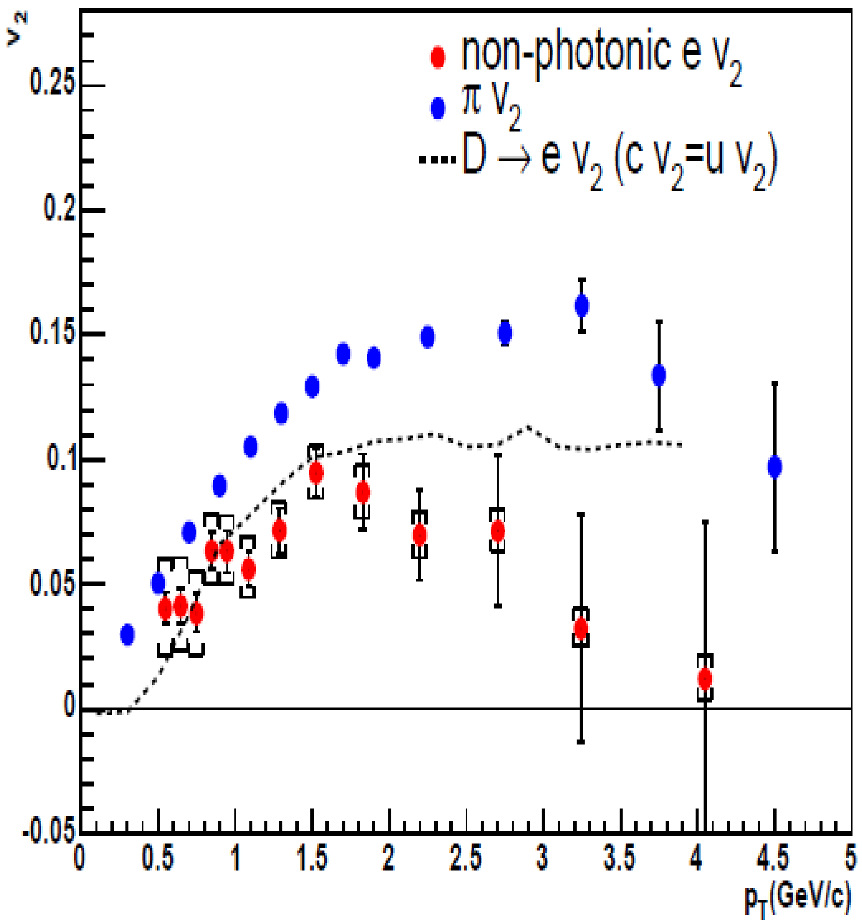


[Silicon vertex detector]

[Reaction plane detector]

- Line on the figure ; D->e v2
  - v2,u (pT) = v2,c (pT)
  - v2,D (pT)
    = v2,u(1/6pT) + v2,c(5/6 pT)

- If charm & u has same v2, the maximum v2 = 0.1
  => Non-photonic electron v2 is smaller than pi (pi0) v2

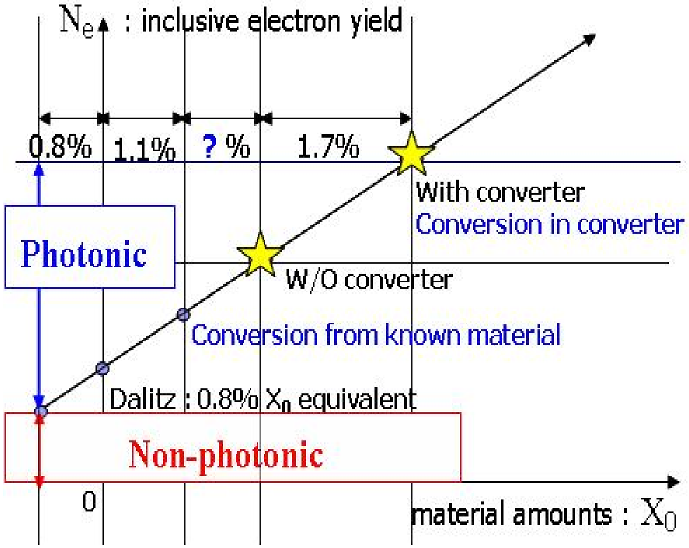


Converter method

- install “photon converter ” (brass ;X_0 = 1.7 %) around beam pipe
- increase photonic electron yield
- Compare electron yield with & without converter
- experimentally separate

Non-converter ; $N_{nc} = N_{\gamma} + N_{non-\gamma}$

Converter ; $N_c = R\gamma * N_{\gamma} + N_{non-\gamma}$



Cocktail method

- estimate background electron with simulation

- sum up all background electrons

- Input
  - π^0 (dominant source)
    use measured pT @ PHENIX
  - other source
    assume mt scale of pi

- clear enhancement of inclusive electron w.r.t photonic electron