Elliptic flow of electrons from heavy flavor decays

Shingo Sakai for PHENIX Collaborations
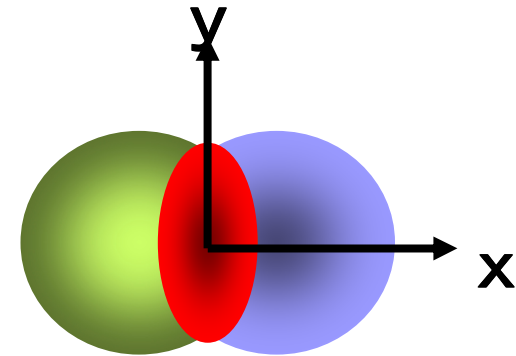
(Univ. of Tsukuba

JSPS)

Elliptic flow (v2)

- Elliptic flow

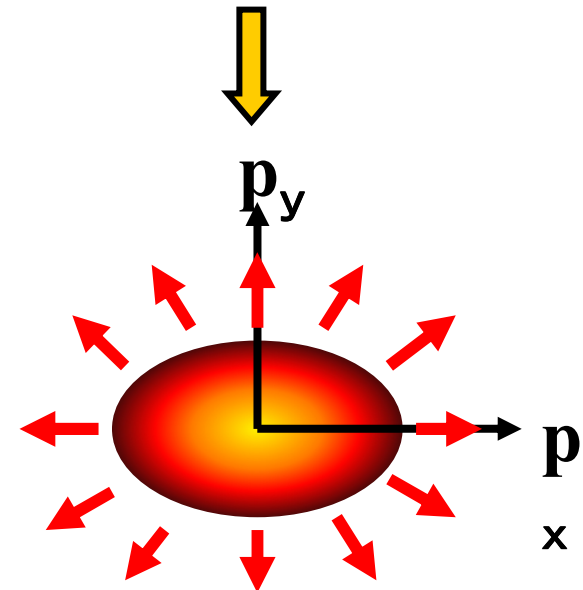$$dN/d\varphi \propto N_0(1+2v_2\cos(2\varphi))$$

- A powerful probe of the initial state of the high energy heavy ion collision

- transfer initial spatial anisotropy to momentum space anisotropy

  - macroscopic ; hydro model
    => pressure gradient
 - microscopic
    => scattering in the medium

Initial spatial anisotropy

Momentum space anisotropy

of particle emission

v_2 already developed in partonic phase ?

- identified hadrons v_2 after scaling pT and v2 number of quarks

- v2 after scaling fall on same curve

- v2 already formed in the partonic phase for hadrons made of light quarks (u,d,s)
=> partonic level v2

- charm quark also flow @ RHIC ?
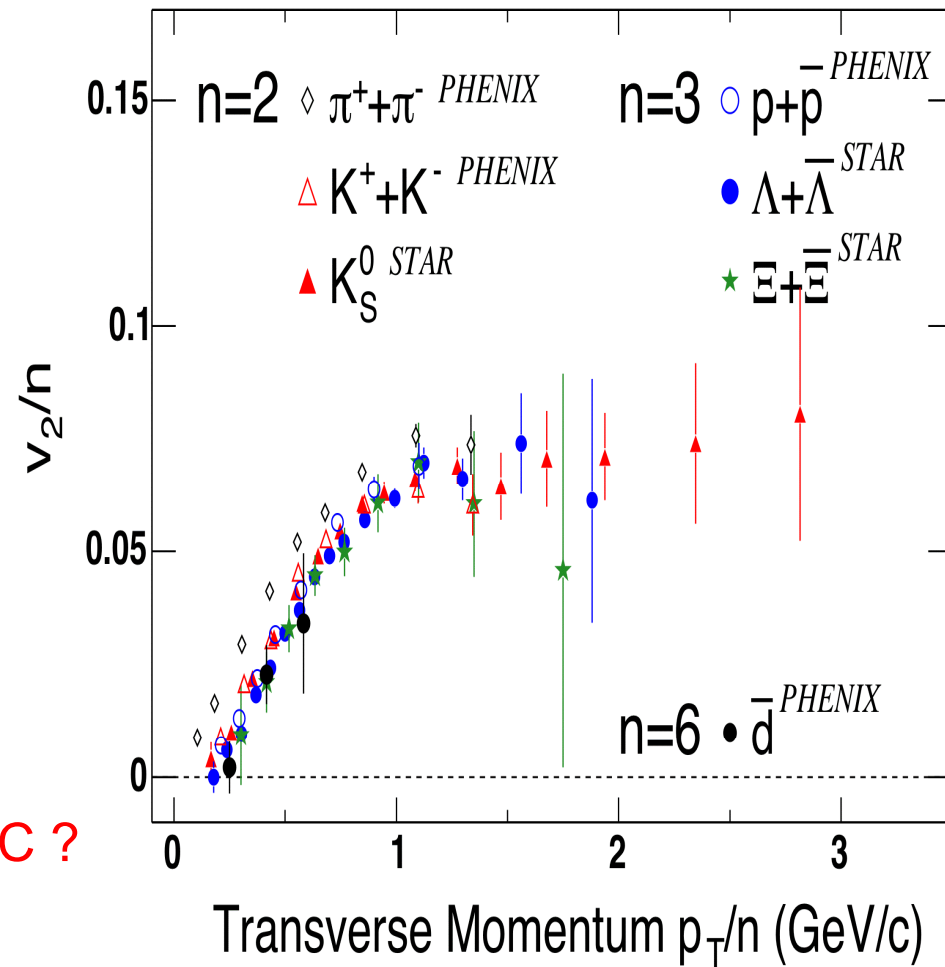
Charm quark

■ Charm is believed to be produced in
   initial collisions via gluon fusion
=> total cross-section ; binary scaling (N_{coll})

■ Charm propagates through
   medium created in the collisions
=> good probe of medium

■ initial charm v2 might be 0
   => charm quark v2 due to scattering
      in medium
   => non-zero charm v2 indicate
      very high dense medium created
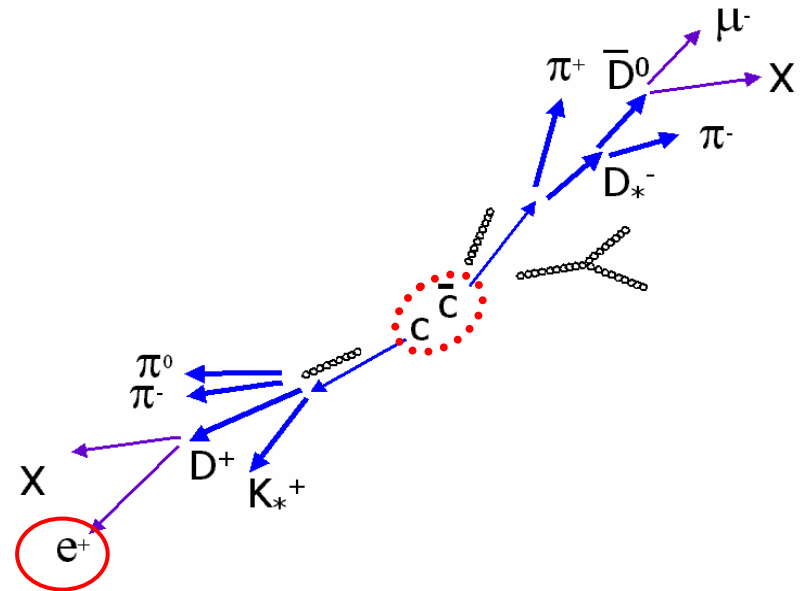   in the collision and quark level thermalization

Phys.Rev.Lett.94:082301,2005
(PHENIX)
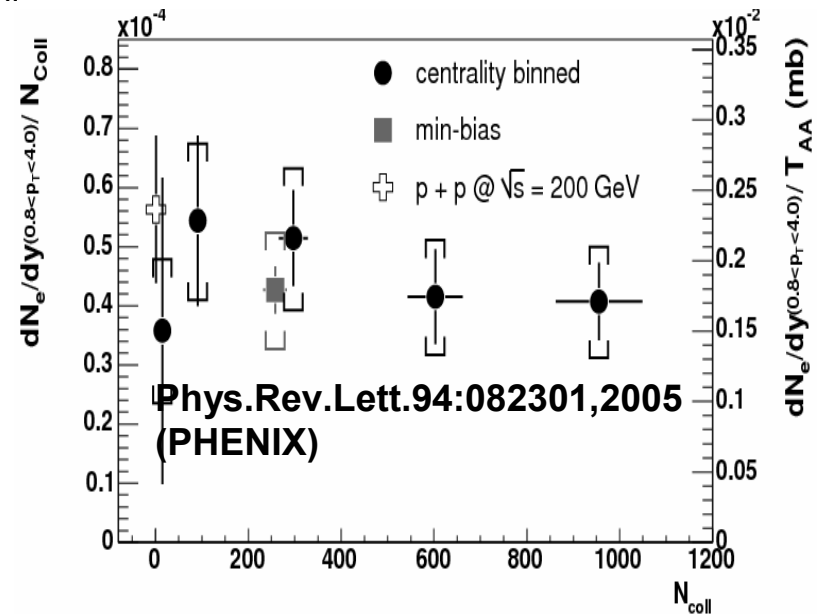
Charm quark study @ PHENIX

■ Electron sources

charm decay ⎫
beauty decay ⎬ non-photonic

Dalitz decays ⎫
Di-electron decays ⎪
Photon conversions ⎬ photonic
Kaon decays ⎪
Thermal dileptons ⎭

■ Subtract photonic electrons following methods
  □ "Cocktail subtraction" – calculation of "photonic" electron background from all known sources
  □ "Converter subtraction"– extraction of "photonic" electron background by special run with additional converter (brass, X = 1.7%)

Charm quarks interact with medium ?

- non-photonic electron R_{AA}

- clear suppression @ high pT in more central collisoion ($R_{AA} < 1.0$)

  => one of the evidence charm quarks interact with the medium

- low pT and peripheral collision (centrality > 40 %) is consistent with binary scale

- v2 measurement (pT,cent) gives us additional info. of the interaction between charm and the medium

2006/6/4
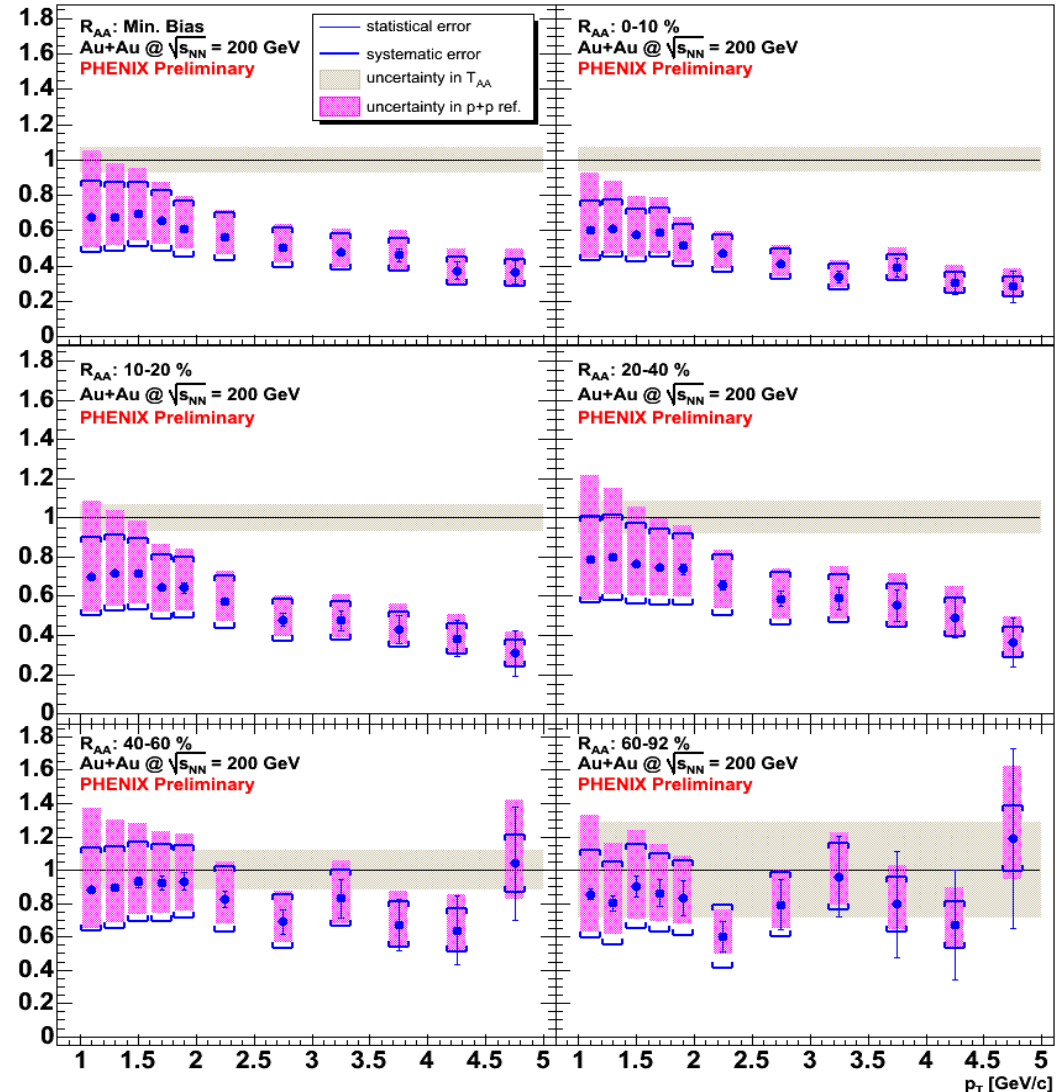
Electron v2 measurement @ PHENIX

- Electron v_2 is measured by R.P. method

$$dN/d(\phi-\Phi) = N (1 + 2v_2^{obs}\cos(2(\phi-\Phi)))$$

- R.P. --- determined with BBC
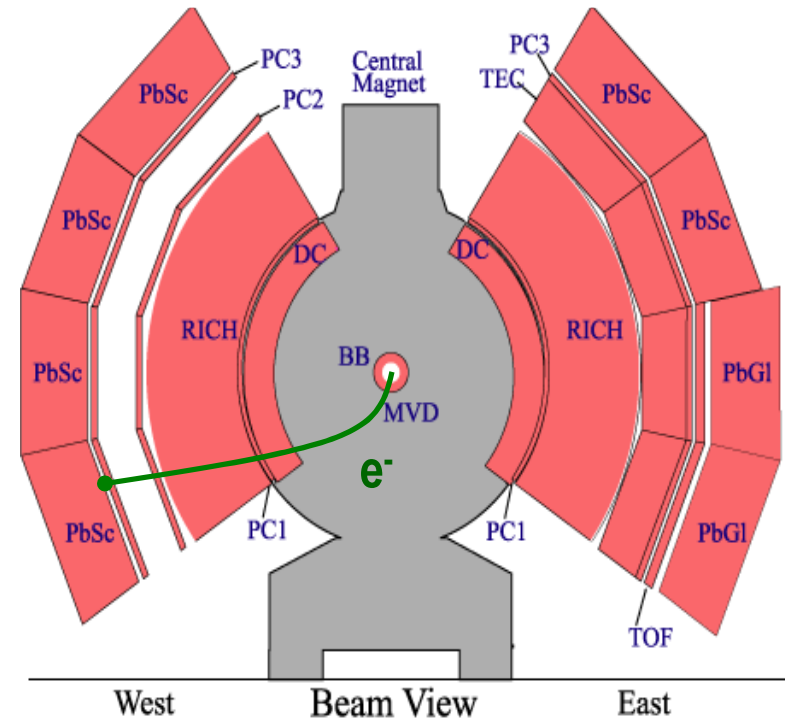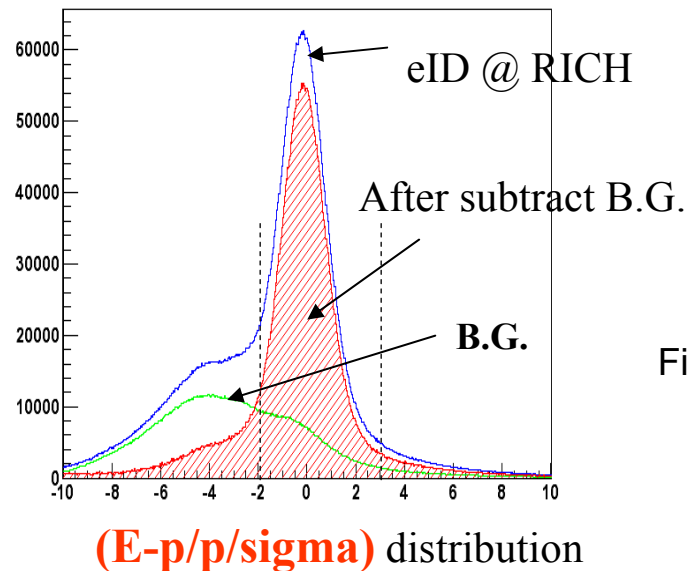- Tracking (pT, ϕ) --- DC + PC
- electron ID --- RICH & EMCal

Fig : Energy (EMcal) & momentum matching
of electrons identified by RICH.
Clear electron signals around E/p-1 = 0

(E-p/p/sigma) distribution

Non-photonic electron v2 measurement

■ Non photonic electron v2 is given as;

$$dN_e/d\Phi = dN_{pho.e}/d\Phi + dN_{non-pho.e}/d\Phi$$

$$\Rightarrow \boxed{v2^e_{non-\gamma} = \{(1+R_{NP})\, v2 - v2^e_{\gamma}\}\} / R_{NP}}$$

- ☐ v2 --- inclusive electron v2
- ☐ R_{NP} --- e (non-γ)/ e(γ)
- ☐ $v2^e_{\gamma}$ --- photonic electron v2

■ photonic electron v2 determination
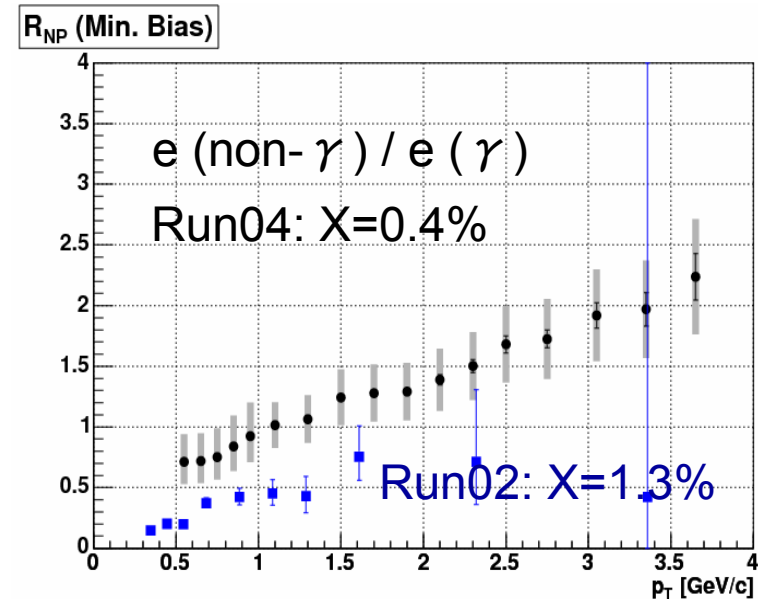 - ☐ *converter method (experiment)*
    <u>Measure inclusive electron v2
    with/without converter.</u>
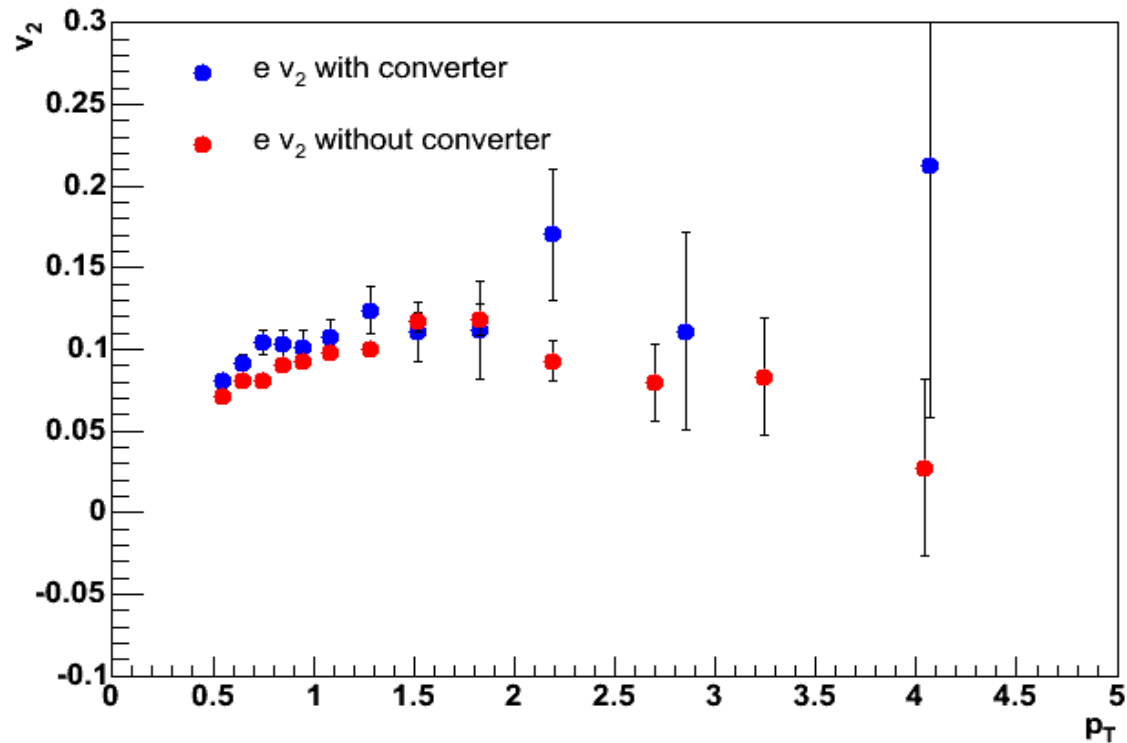   Then separate non-photonic & photonic e v2
  - ☐ *cocktail method (simulation)*
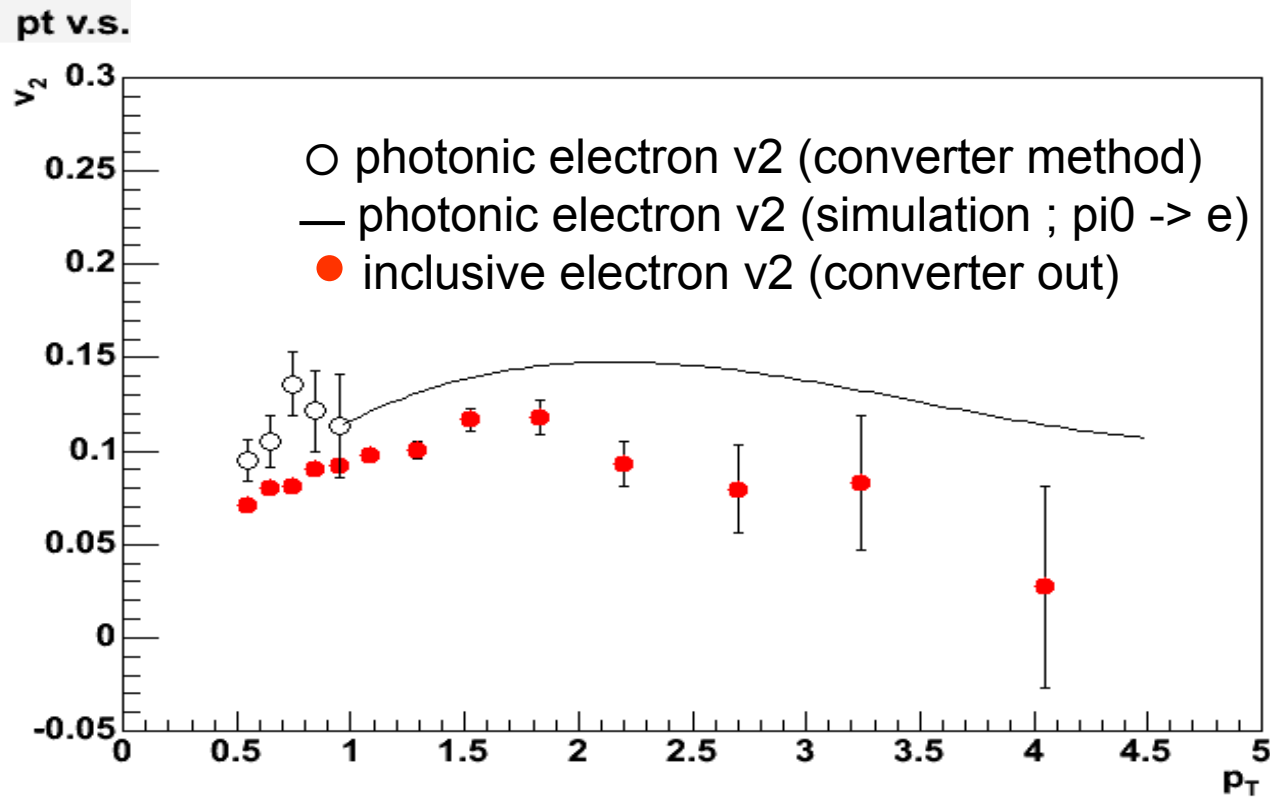   Determined <u>photonic electron v2 with simulation</u>

R_{NP} (Min. Bias)

e (non-γ) / e (γ)

Run04: X=0.4%

Run02: X=1.3%

p_T [GeV/c]

(QM05 F. Kajihara)

# *Inclusive electron v2 (in/out converter)*

- ■ inclusive electron v2 in / out converter
- ■ difference between converter in / out
  => photonic & non-photonic e v2 is different
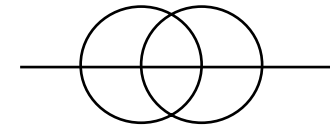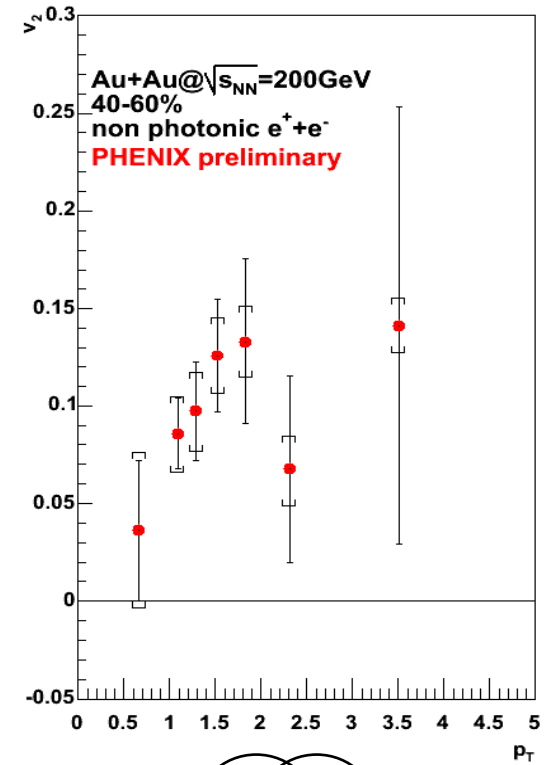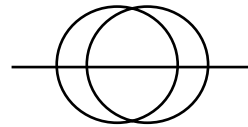
Inclusive electron & photonic electron v2

pt v.s.
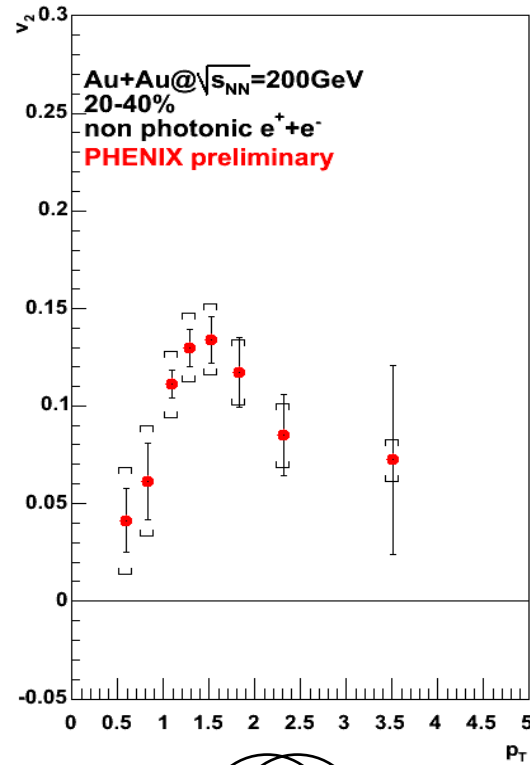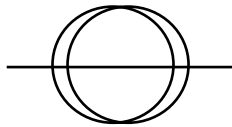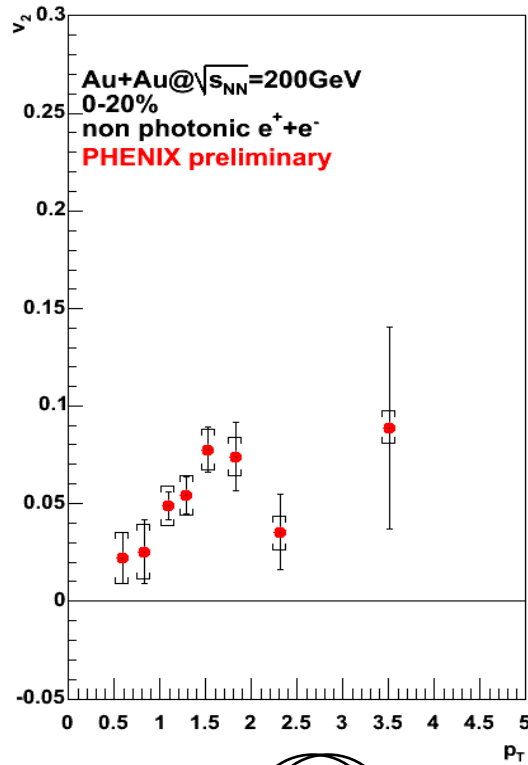

- compare with inclusive & photonic electron v2
- photonic e v2 ; pT < 1.0 (conv.) & pT > 1.0 (cock.)
- inclusive electron v2 is smaller than photonic electron v2

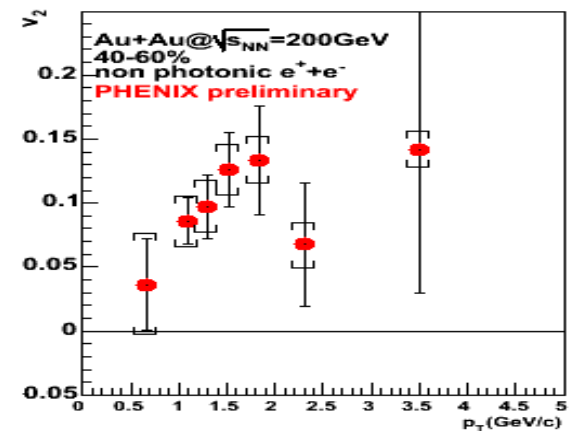# *Non-photonic electron v_2*
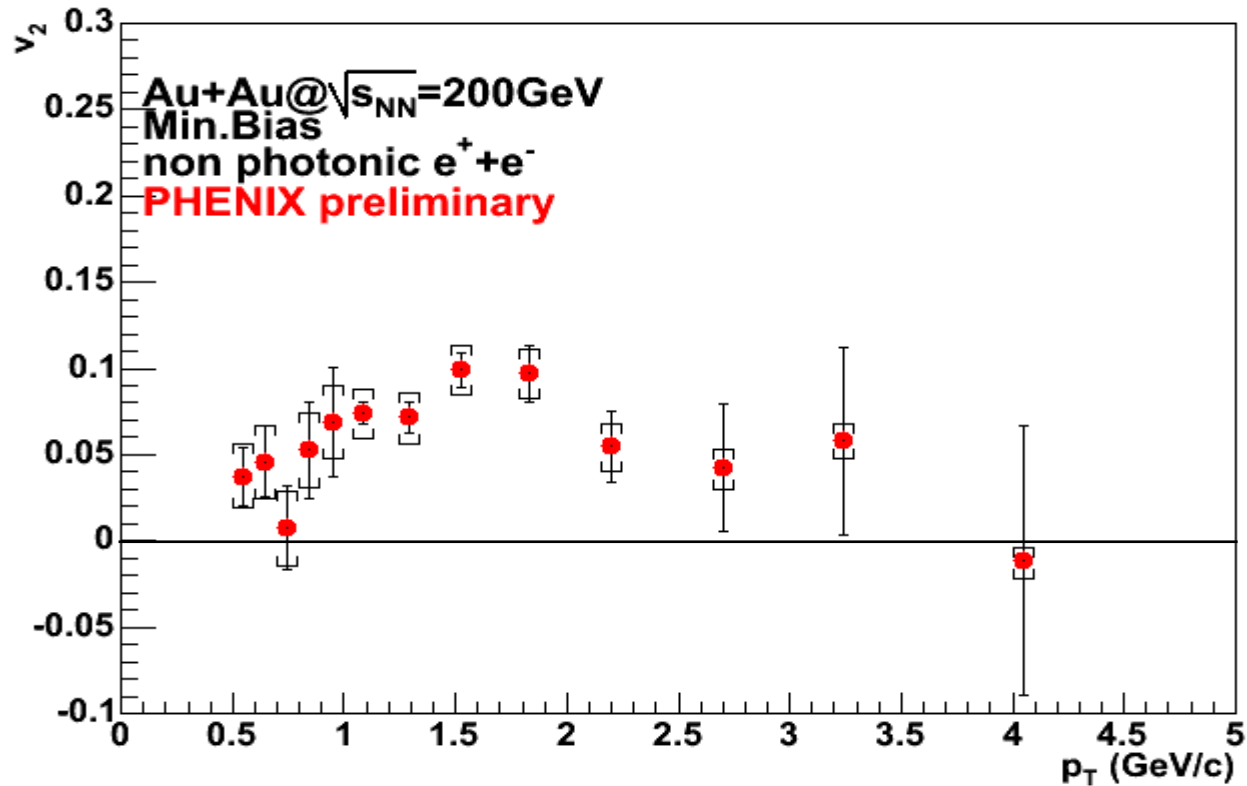
- Non-photonic electron v2 : pT < 1.0 (conv.) & pT>1.0 (cock.)
- Non-photonic electron v2 has non-zero v2

Non-photonic electron v2 (centrality dep.)

■ non-photonic electron v_2 seems like getting larger with centrality

Compare with R_{AA}
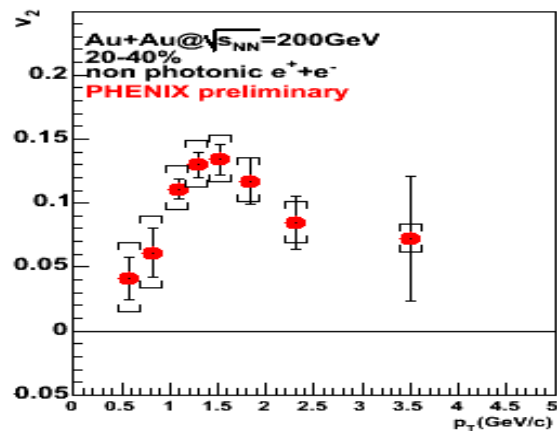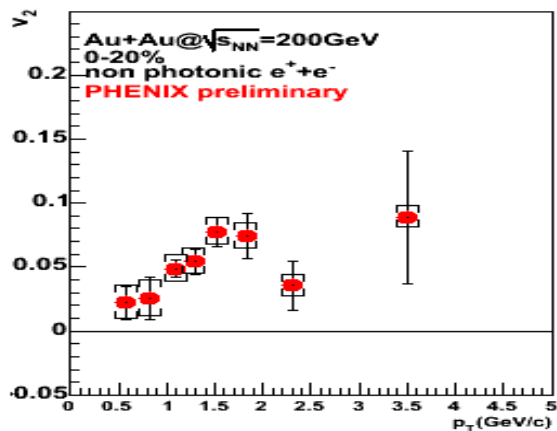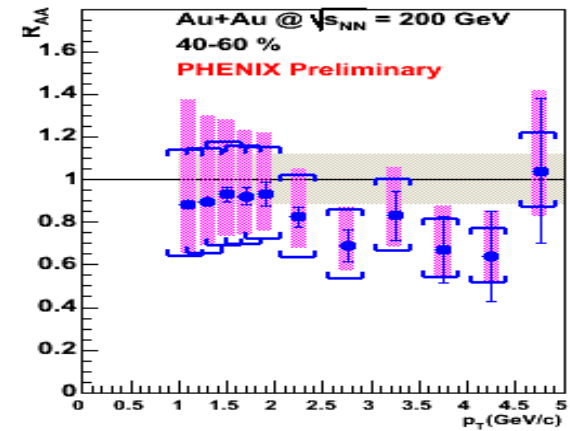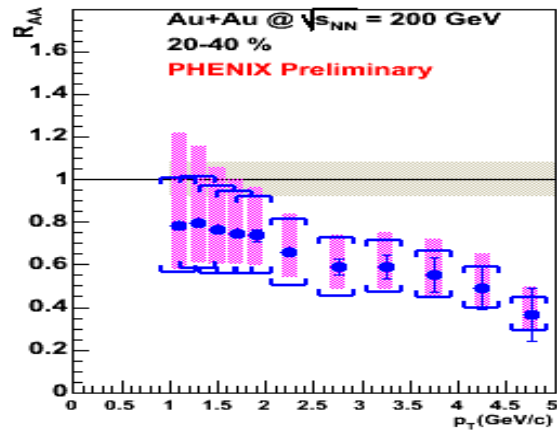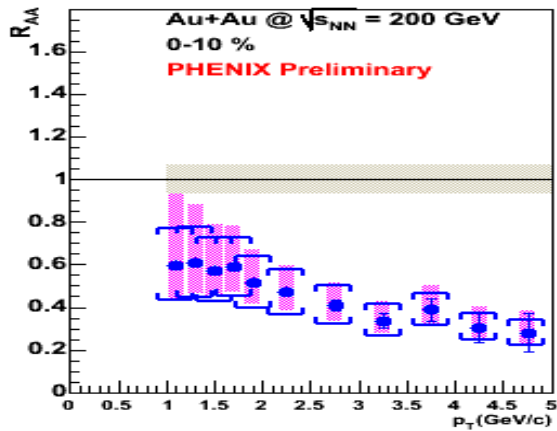
- $R_{AA} \sim 1.0$ @ peripheral collision but v_2 still non-zero
- indicate *charm quarks* interact with *medium* not only central but also peripheral

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D meson flow ?

simulation

Phys.Lett.B597:328-332,2004
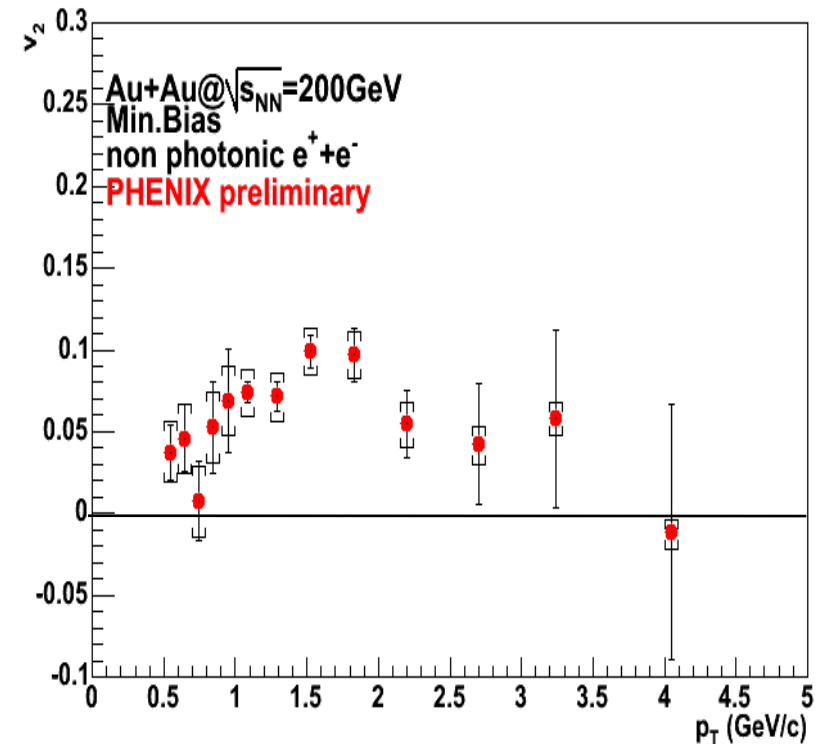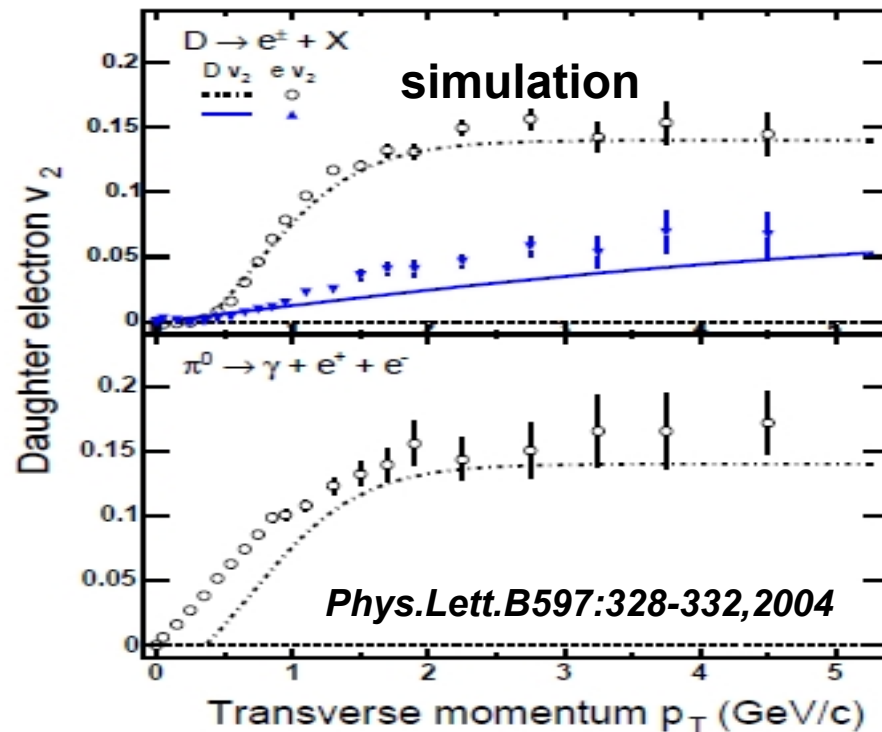
- electron v_2 from D meson decay well reflect parent v_2
- <u>non-zero</u> non-photonic electron v_2 suggest D meson also flow @ RHIC

expected D v$_2$ from non-photonic e v$_2$

- **expected D v2 from non-γ v2**
- **process**
  - **(1) D v2 = a*f(pT)**
    - **a ; free parameter**
    - **f(pT) ; pi,K,p**
  - **(2) D -> e v2**
  - **(3) Calculate χ^2**
  - **(4) Find χ^2 minimum for "a"**

D meson v_2 shape $(f(p_T))$	$a_{\chi^2 mim.}$	χ^2/ndf
$v_2(\pi)$	0.7	0.88
$v_2(K)$	0.75	0.89
$v_2(p)$	0.65	1.23

π, deuteron v2 --- PHENIX preliminary
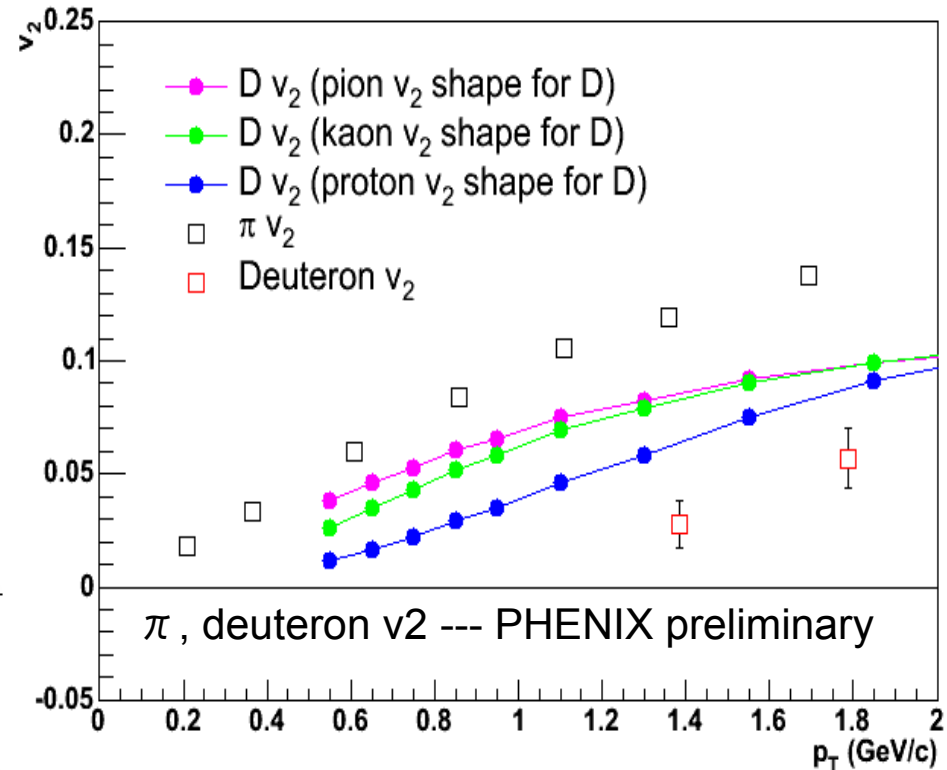
- expected D meson v2 from non-photonic electron v2
  - □ smaller than pi v2
  - □ larger than Deuteron v2 *"if D v2 shape same as pi, k, p"*
    Mass D meson~ Mass Deuteron

Charm quark flow ?

■ Compared with quark coalescence model prediction.
with/without charm quark flow
(Greco, Ko, Rapp: PLB 595 (2004) 202)
   - No Bottom contribution
   - c v2 small u v2 @ low pT
   - quark v2 flat @ high p_T

■ Below 2.0 GeV/c ;
consistent with <u>charm quark flow</u> model.
   => favor charm quark flow model

■ assume c v2 < u v2 @ low pT
   => mass effect in partonic level ?

Au+Au@$\sqrt{s_{NN}}$=200GeV
Min.Bias
non photonic e⁺+e⁻
PHENIX preliminary

---- without charm flow
—— with charm flow

pT[GeV/c]

□ h
■ π

pT[GeV/c]

B meson contribution ?

Left plot labels:
- PHENIX prel (min bias)
- Au-Au $\sqrt{s}$=200 GeV (b=7 fm)
- Hendrik, Greco, Rapp nucl-th/0508055
- c+b reso
- c+b pQCD
- c reso
- w.o. B meson (c flow)
- w. B meson (c,b flow)
- based on quark coalescence model
- c, b reso ; c,b get v2 by elastic scat. in QGP

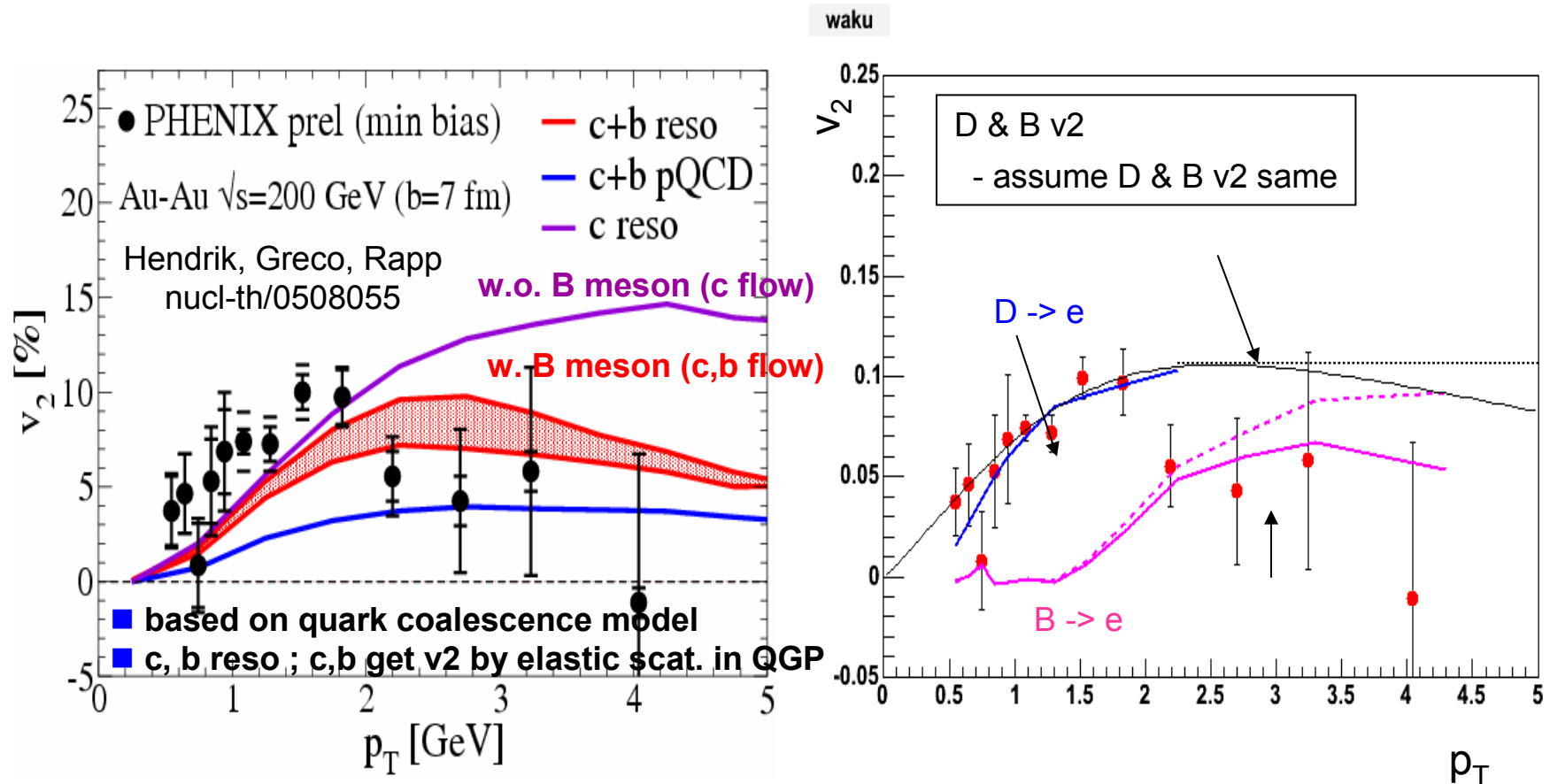Right plot labels:
- D & B v2 - assume D & B v2 same
- D -> e
- B -> e
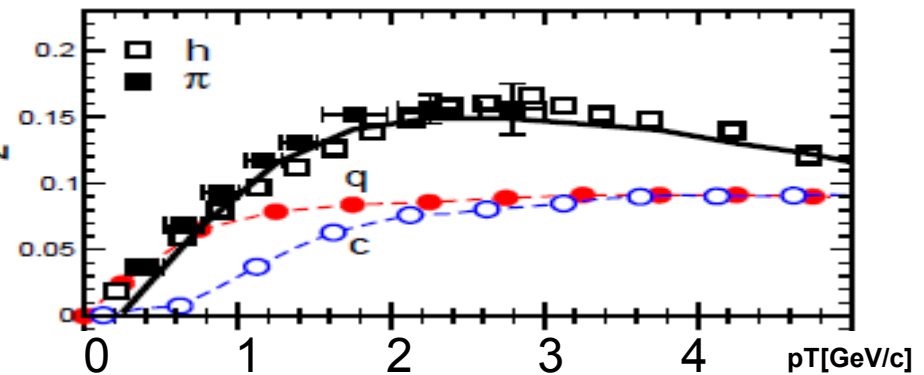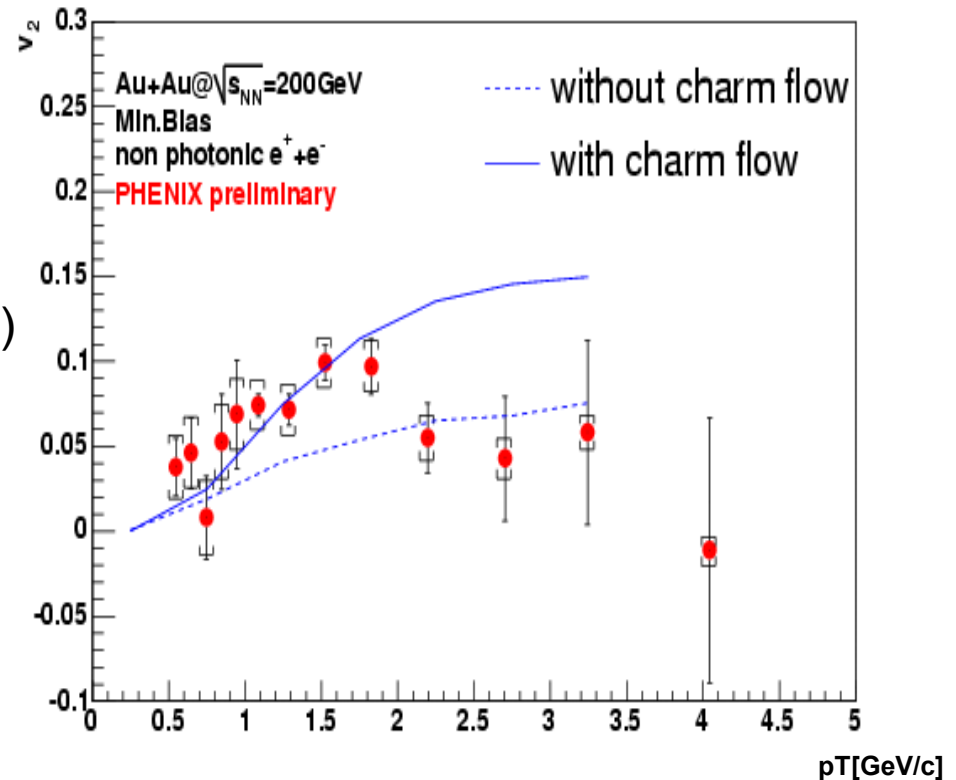
- B meson contribution is model dependent now but the contribution is getting larger at high pT.
- electron v2 from B meson is smeared due to large mass difference => high pT single electron v2 is getting smaller ?

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Near future

- **single μ v2**
- **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 v2**
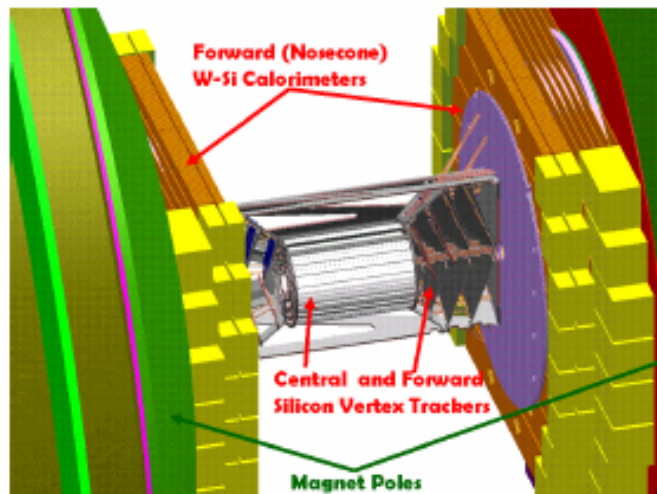

[Silicon vertex detector]
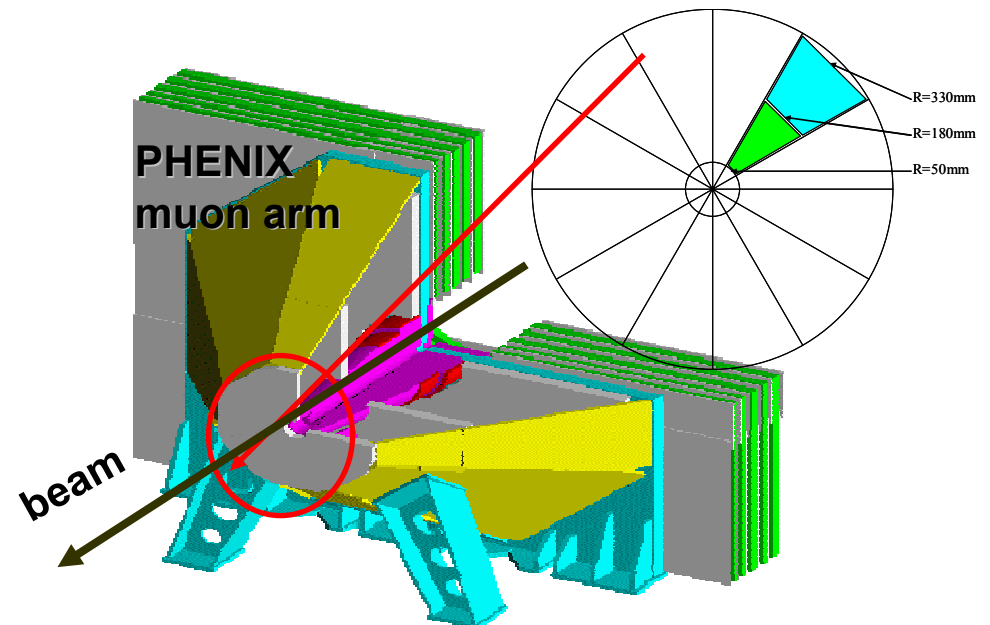
[Reaction plane detector]

Summary

- Non-photonic electron v_2 from heavy flavor decays has been measured with RHIC-PHENIX

- Non-photonic electron v2 has non-zero v2
  => indicate non-zero D meson v2

- Clear centrality dependence of non-photonic e v2

- Compare with model calculation with charm flow (c v2 < u v2)
  => **consistent with charm flow model** below 2.0 GeV/c
  => mass effect in partonic level ?

- Estimate D meson v2 from non-photonic electron v2 assuming D meson v2 shape same as pion, Kaon, proton.

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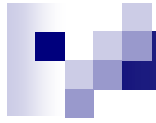
- **Backup slides**

Converter method

Separate non-photonic & photonic e v2 by using
Non-converter run & converter run

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

$(1+R_{NP})v2_{nc} = v2_{\gamma} + R_{NP}v2_{non-\gamma}$
$(R\gamma + R_{NP}) v2_c = R\gamma v2_{\gamma} + R_{NP}v2_{non-\gamma}$

$R\gamma$ --- ratio of electrons with & without converter (measured)
R_{NP} --- non-photonic/photonic ratio (measured)
$v2_{nc}$ --- inclusive e v2 measured with non-converter run (measured)
$v2_c$ --- inclusive e v2 measured with converter run (measured)

$v2_{non-\gamma}$ **(non-photonic)** & $v2_{\gamma}$ **(photonic) is
"experimentally" determined !**

Cocktail method

Determined photonic electron v2 with simulation
Then subtract it from electron v2 measured
 with non-converter run

$$dN_e/d\Phi = dN_{pho.e}/d\Phi + dN_{non-pho.e}/d\Phi$$

$\Rightarrow$ $v2_{non-\gamma} = \{(1+R_{NP})\, v2 - v2_{\gamma}\}\} / R_{NP}$ measured
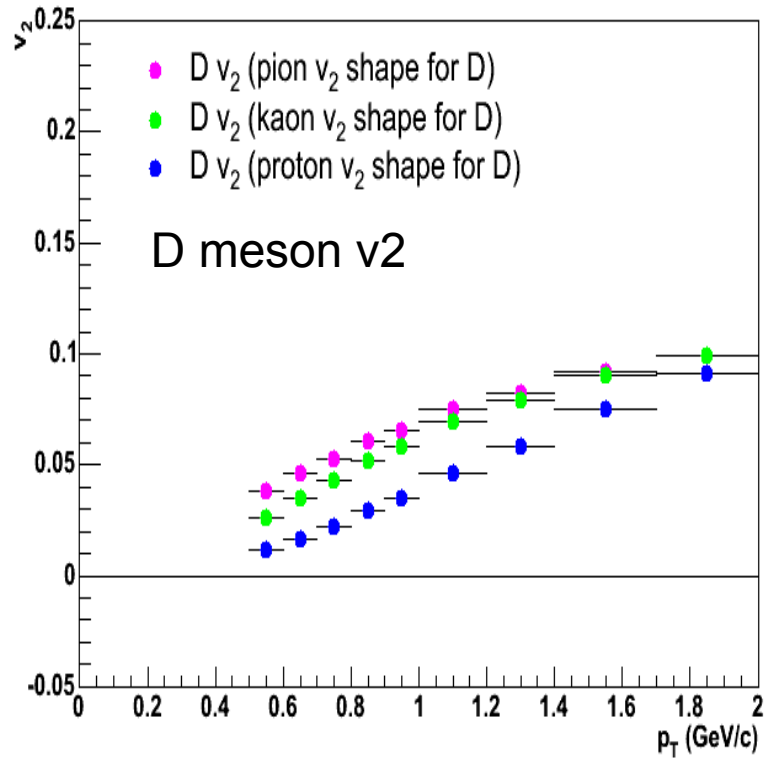
measured   calculate

R_{NP} --- non-photonic/photonic ratio
       experimentally determined
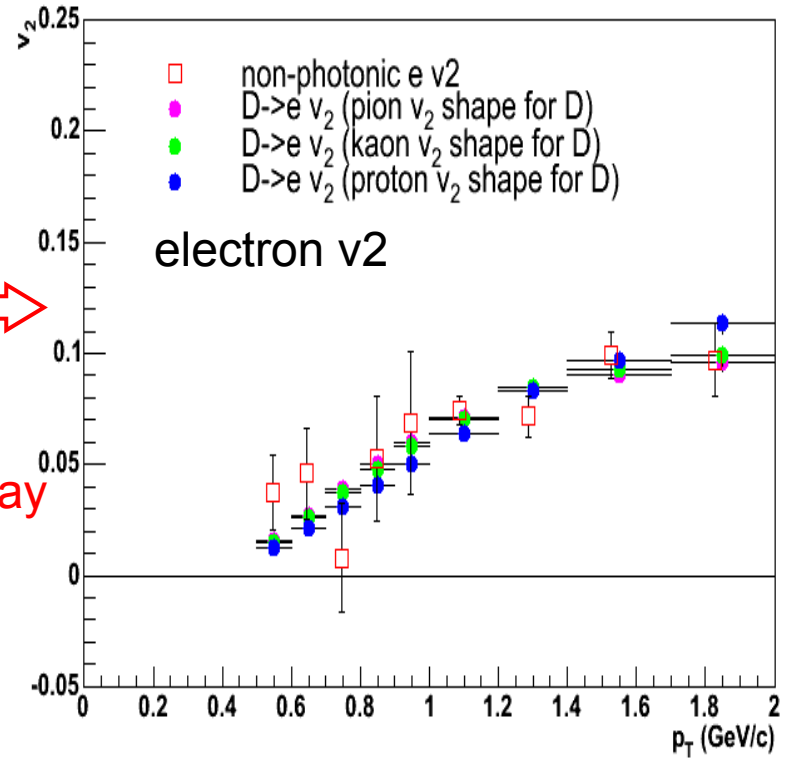v2 --- inclusive electron v2 (without converter)
$v2_{\gamma}$ --- photonic electron v2
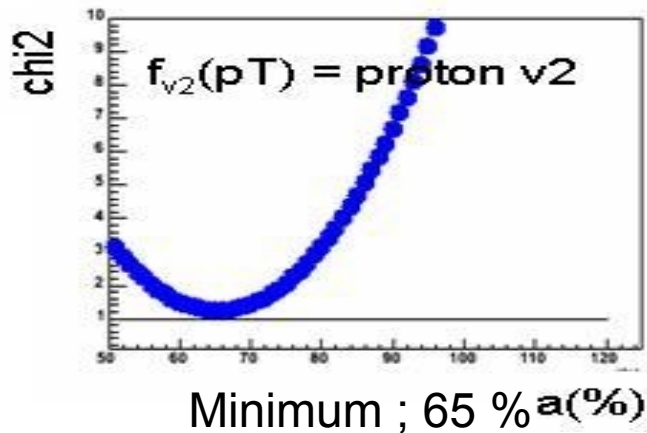   calculated from pi0 (pion) v2

D-> e v2

D meson v2

Legend (left plot):
- D v_2 (pion v_2 shape for D)
- D v_2 (kaon v_2 shape for D)
- D v_2 (proton v_2 shape for D)

Decay

electron v2

Legend (right plot):
- non-photonic e v2
- D->e v_2 (pion v_2 shape for D)
- D->e v_2 (kaon v_2 shape for D)
- D->e v_2 (proton v_2 shape for D)

D v2 estimate from non- γ e v2 (2)

$f_{v2}(pT) = \text{pi } v2$

Minimum ; 70 % a(%)

$f_{v2}(pT) = \text{kaon } v2$

Minimum ; 75 % a(%)

$f_{v2}(pT) = \text{proton } v2$

Minimum ; 65 % a(%)
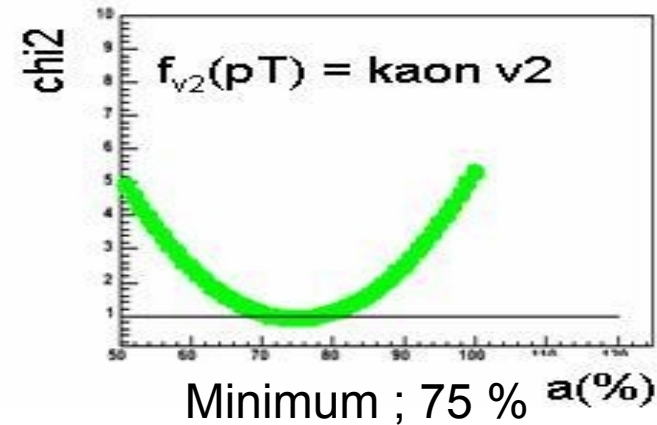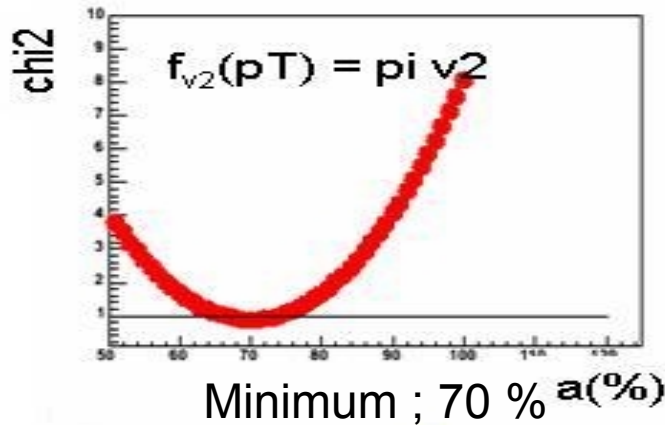
- χ^2/ndf v.s. scale factor (a)
- current result can't decide what shape is better.

New reaction plane detector

PHENIX
muon arm

R=330mm
R=180mm
R=50mm
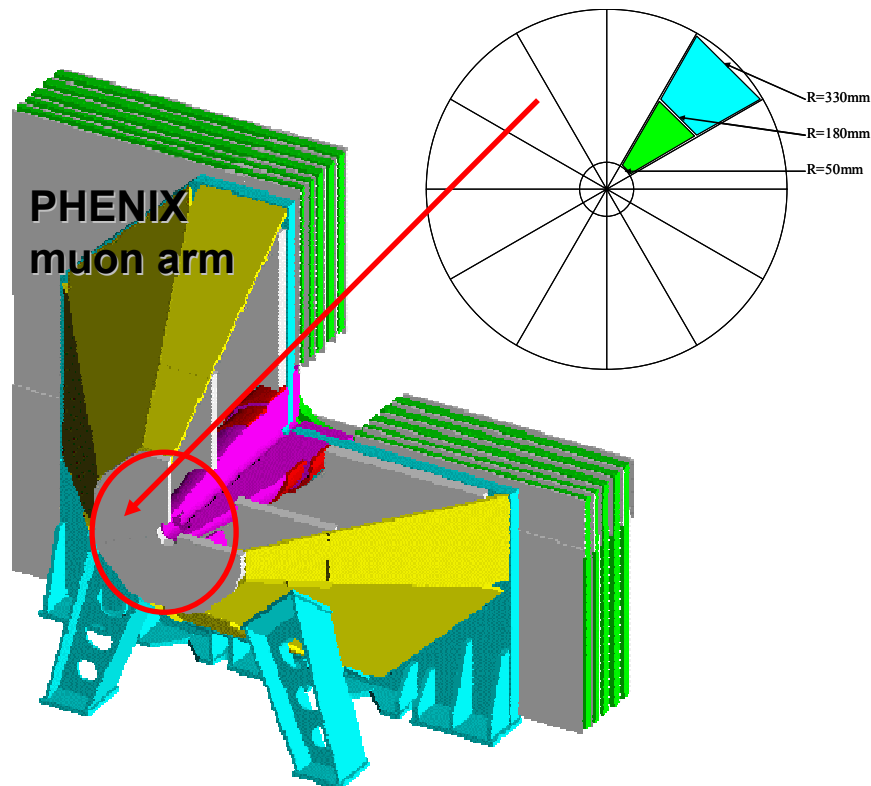
- A new reaction plane detector
- position ; $1 \sim |\eta| \sim 2.5$,
- resolution ; $\langle \cos 2\Delta\Phi \rangle \sim 0.7$
  (BBC ; $\langle \cos 2\Delta\Phi \rangle \sim 0.3$)
- materials ;
  Pb converter + scintillator