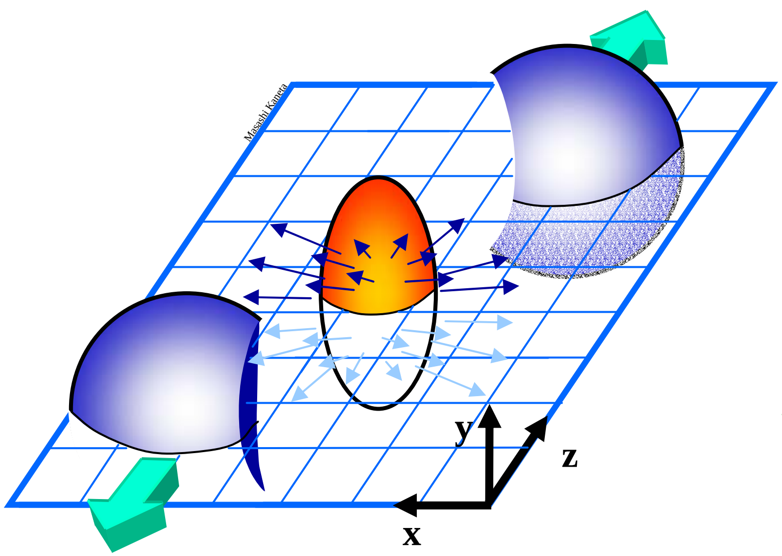
Quark Matter 2004

Oakland – January 11-17

Event anisotropy of identified π^0, γ and e compared to charged π, K, p, and d in $\sqrt{s_{NN}}$=200 GeV Au+Au at PHENIX



Masashi Kaneta

for the PHENIX collaboration

RIKEN BNL
Research Center

PHENIX

12 Countries; 58 Institutions; 480 Participants*

Brazil University of São Paulo, São Paulo

China Academia Sinica, Taipei, Taiwan
China Institute of Atomic Energy, Beijing
Peking University, Beijing

France LPC, University de Clermont-Ferrand, Clermont-Ferrand
Dapnia, CEA Saclay, Gif-sur-Yvette
IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
SUBATECH, Ecòle des Mines at Nantes, Nantes

Germany University of Münster, Münster

Hungary Central Research Institute for Physics (KFKI), Budapest
Debrecen University, Debrecen
Eötvös Loránd University (ELTE), Budapest

India Banaras Hindu University, Banaras
Bhabha Atomic Research Centre, Bombay

Israel Weizmann Institute, Rehovot

Japan Center for Nuclear Study, University of Tokyo, Tokyo
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KEK, Institute for High Energy Physics, Tsukuba
Kyoto University, Kyoto
Nagasaki Institute of Applied Science, Nagasaki
RIKEN, Institute for Physical and Chemical Research, Wako
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Rikkyo University, Tokyo
Tokyo Institute of Technology, Tokyo
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Korea University, Seoul
Myong Ji University, Yongin City
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Columbia University, Nevis Laboratories, Irvington, NY
Florida State University, Tallahassee, FL
Florida Technical University, Melbourne, FL
Georgia State University, Atlanta, GA
University of Illinois Urbana Champaign, Urbana-Champaign, IL
Iowa State University and Ames Laboratory, Ames, IA
Los Alamos National Laboratory, Los Alamos, NM
Lawrence Livermore National Laboratory, Livermore, Ca
University of New Mexico, Albuquerque, NM
New Mexico State University, Las Cruces, NM
Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
Oak Ridge National Laboratory, Oak Ridge, TN
University of Tennessee, Knoxville, TN
Vanderbilt University, Nashville, TN

*as of January 2004

Announcement

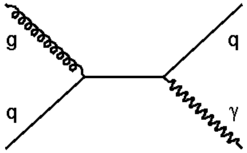
- The flow and event anisotropy from the PHENIX collaborators in the poster session
  - Shingo Sakai*
    - Azimuthal anisotropy of electrons/positrons in 200 GeV Au+Au collisions at RHIC-PHENIX
  - Andrey Kazantsev*
    - Elliptic flow of inclusive photons in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV from the PHENIX experiment at RHIC
  - Hiroshi Masui*
    - Measurement of directed flow in $\sqrt{s_{NN}}=200$ GeV Au+Au, d+Au, *p*+*p* collisions at RHIC-PHENIX
  - Akio Kiyomichi
    - Radial flow study from identified hadron spectra in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV (at PHENIX)
  - Michael Issah*
    - Azimuthal anisotropy measurements in PHENIX via cummulants of Multiparticle azimuthal correlations
  - Debsankar Mukhopadhyay
    - Elliptic flow of ϕ mesons in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV (at PHENIX)
  - ShinIchi Esumi
    - Analysis of event anisotropy and azimuthal pair correlation

**** Students***

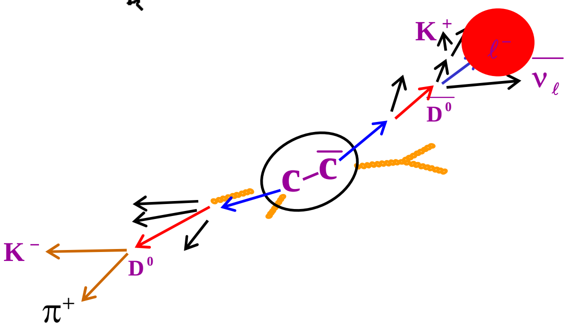
Motivation

- Event anisotropy
  - Sensitive to the initial state
    - Collectivity of hadron/parton $\rightarrow$ thermalization / recombination
    - Energy loss by Jet quenching $\rightarrow$ dense matter

- π^0
  - Large p_T coverage as an identified hadron
  - Large contribution of the decay to the following inclusive measurements
- Photon
  - Radiation / Compton from hot gas
  - Photon flow?

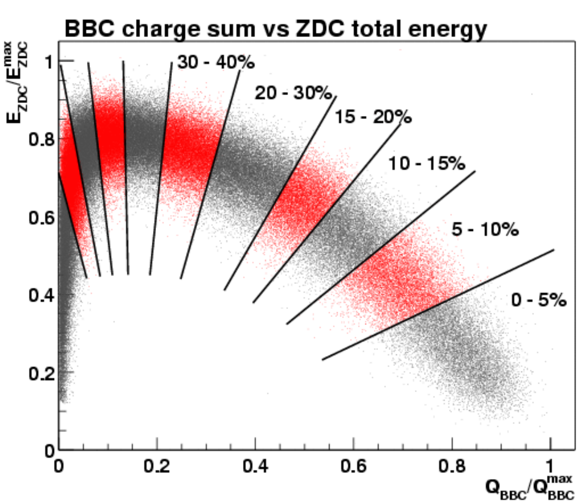


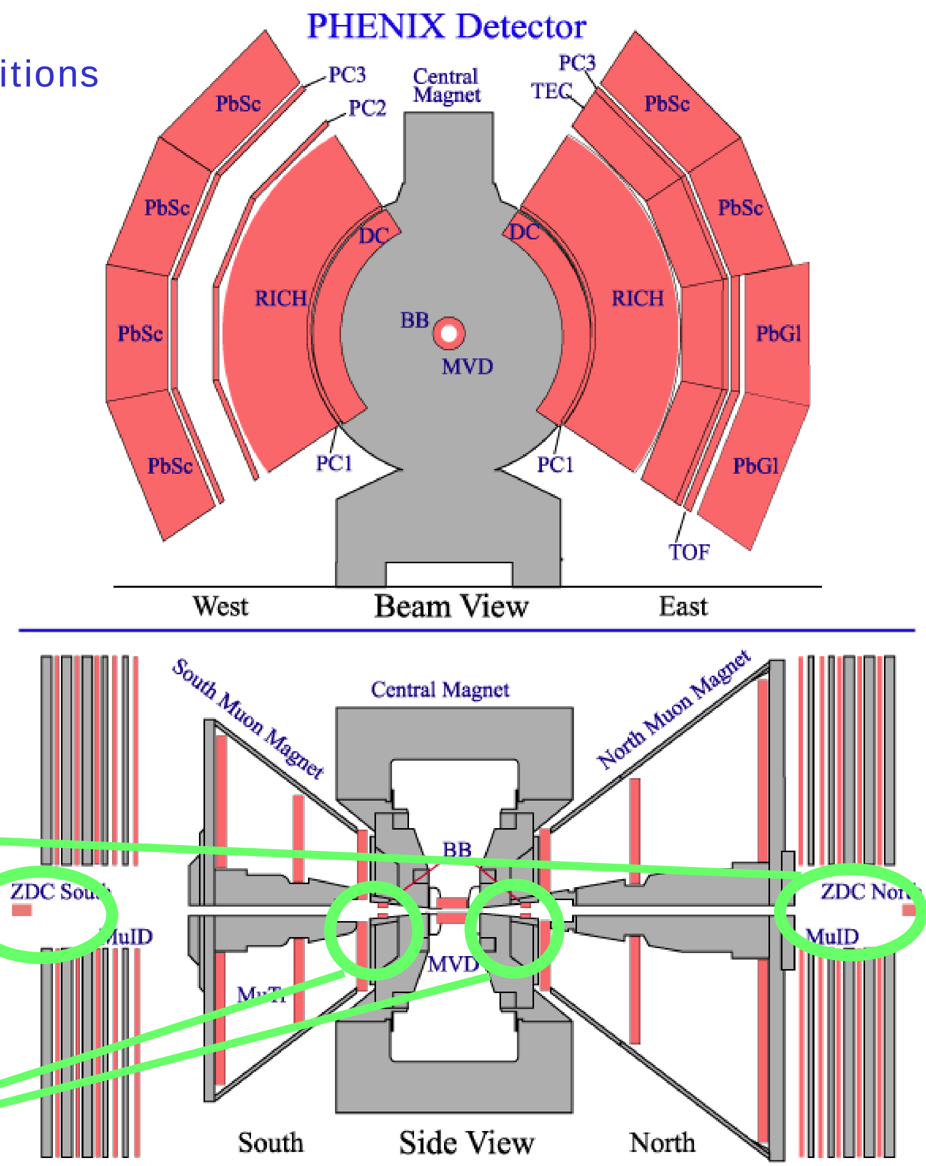
- Electron/positron
  - Open charm and bottom
  - Flow and energy loss of heavy flavors?



The PHENIX experiment at RHIC

- Photons/π^0
  - Tracking : vertex be BBC to EMC hit positions
  - PID : EMCal
- Electrons
  - Tracking
    - DC, PC hits, vertex by BBC
  - PID
    - RICH (p_T<4.9 GeV/c)
    - Energy/momentum cut by EMCal
- Event centrality
  - BBC and ZDC



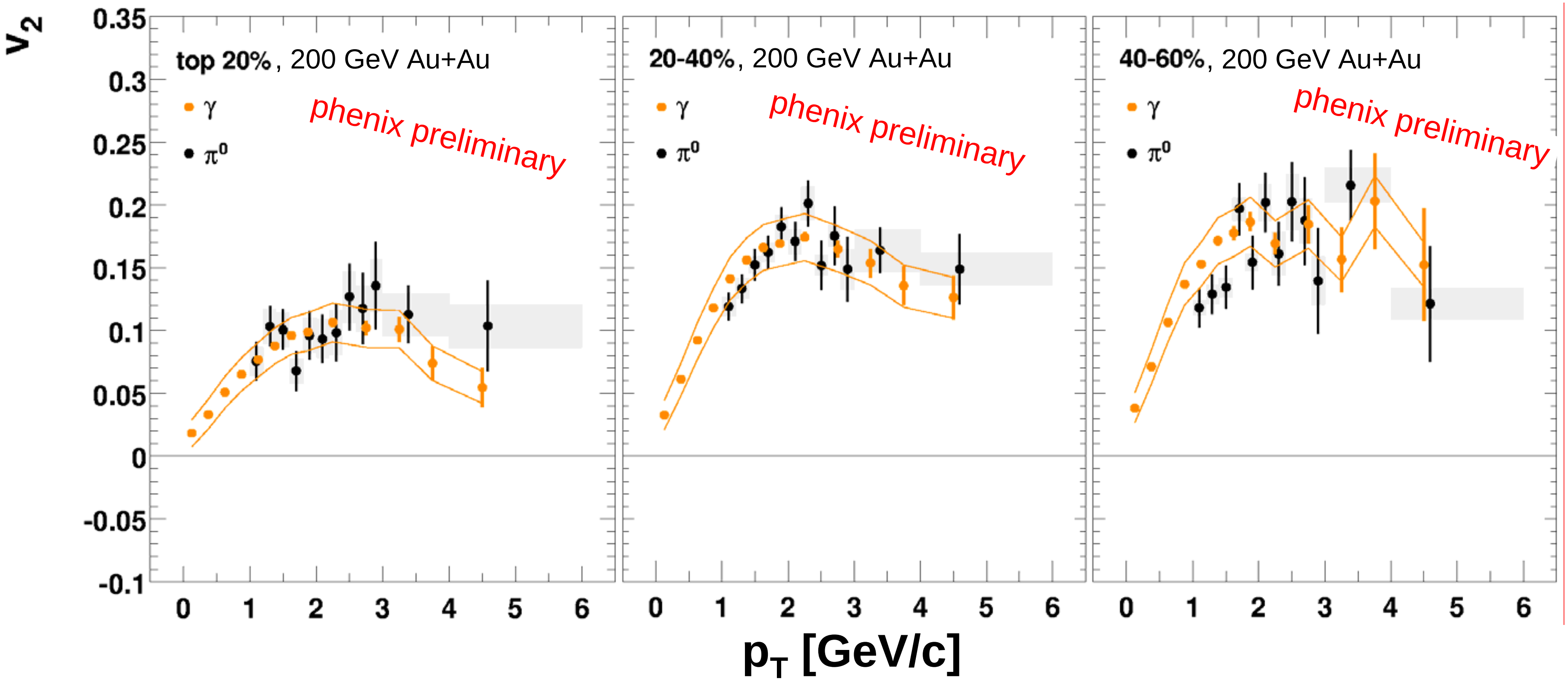


γ & π^0 v_2

Inclusive photon v_2 and π^0 v_2 in 200 GeV Au+Au

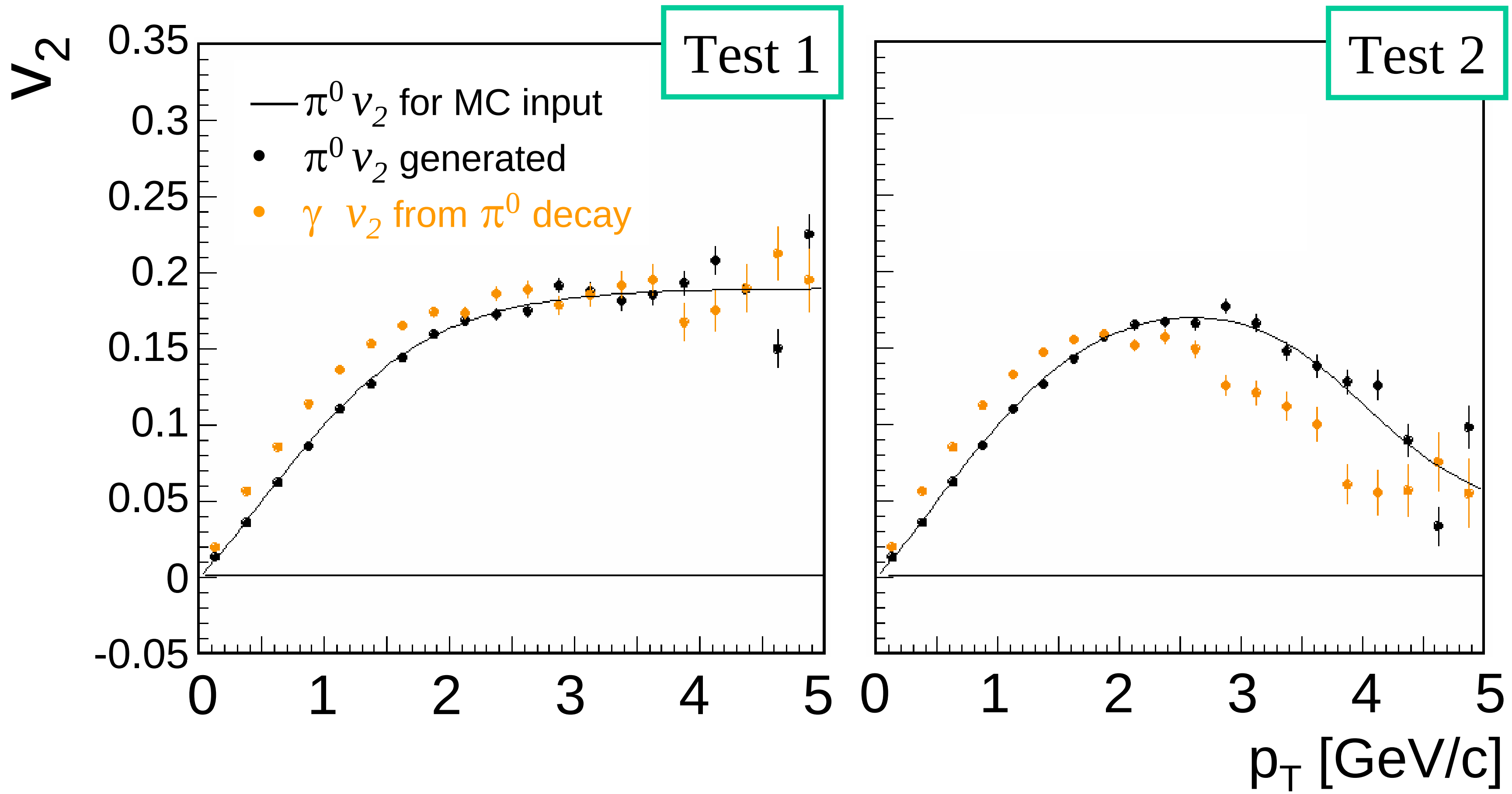
Note :
Inclusive photon = including all of the decay effect from hadrons

vertical bar : stat. error
curves, gray box : sys. error



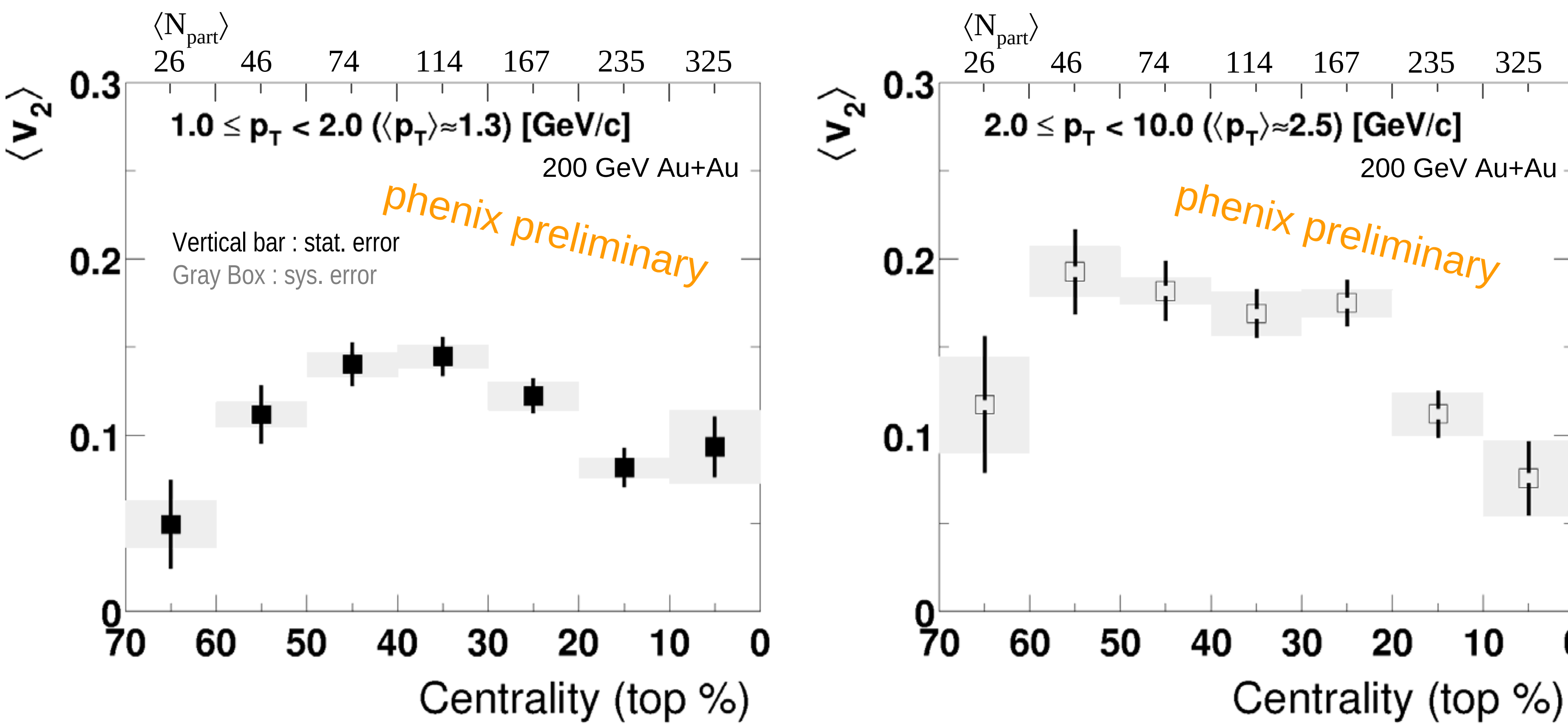
- Inclusive photon v_2 shows similar tendency with π^0
  - Need more statistics to see photon v_2 after π^0 (and also η) decay effect subtraction

π^0 decay effect for photon v_2 (MC)



- Tool is ready for the decay effect in photons

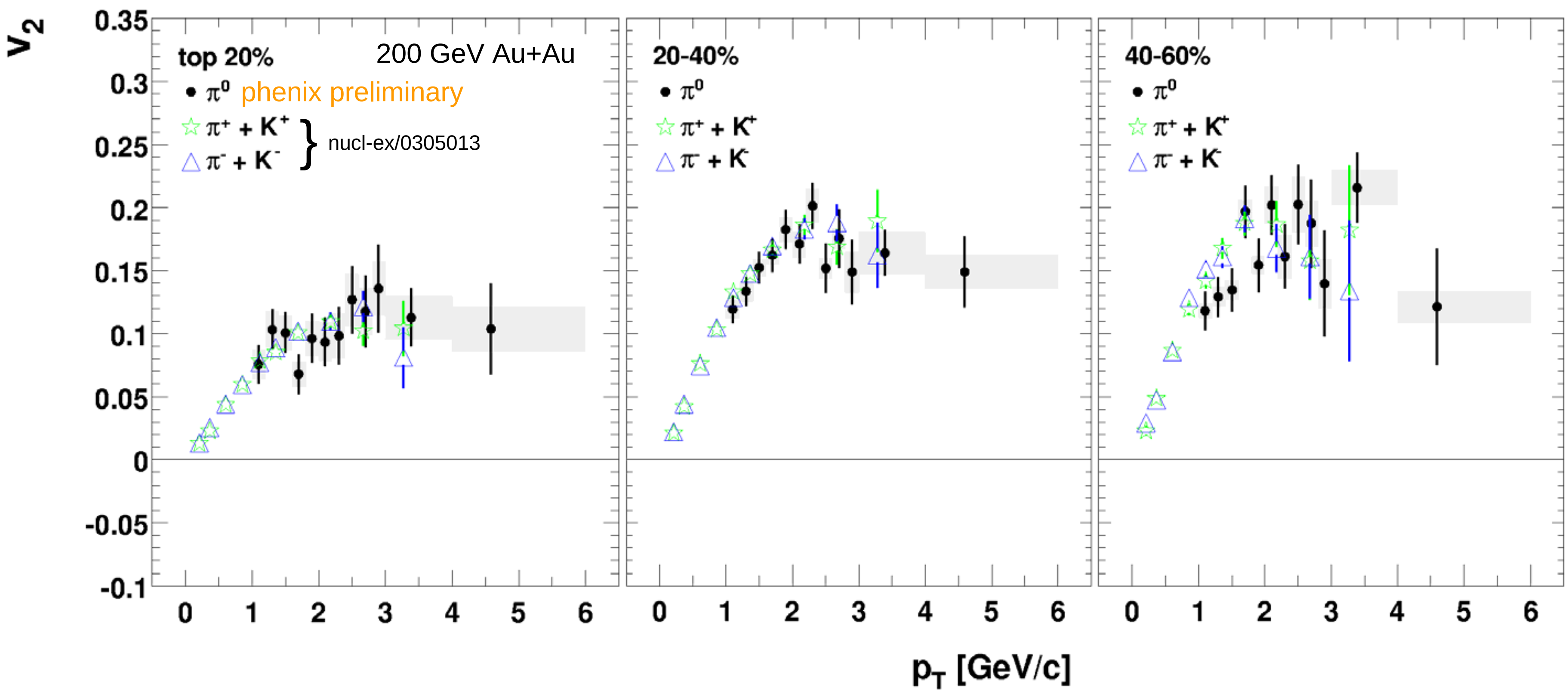
$\langle v_2 \rangle$ vs. centrality from 200GeV Au+Au



v_2 vs. p_T vs. centrality from 200GeV Au+Au

Statistical error is shown by error bar
Systematic error from π^0 count method and reaction plane determination is shown by horizontal bar
The data point stays at $\langle p_T \rangle$ in the bin and horizontal bar shows the bin range

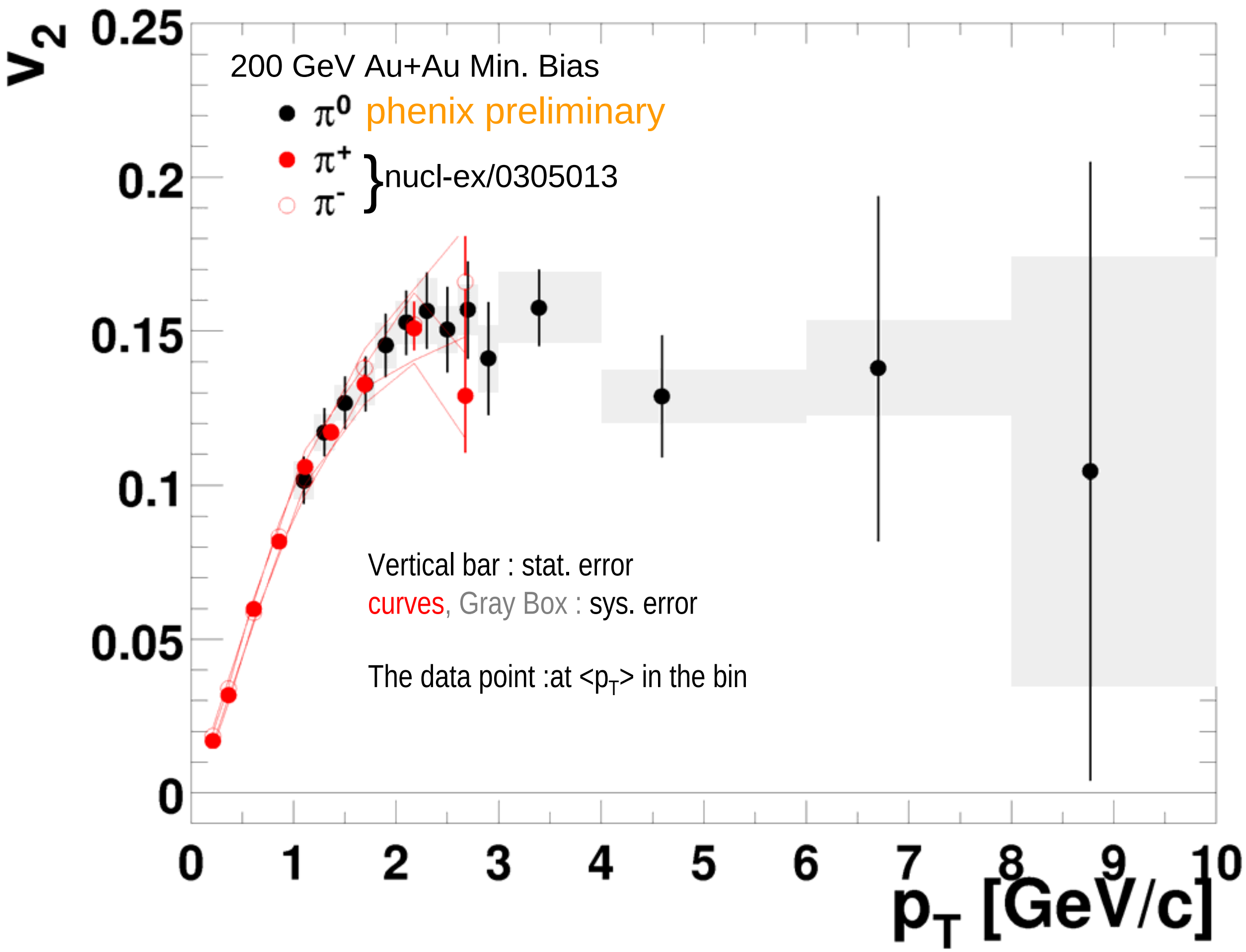
The charged π and K v_2 are shown only with statistical errors



- Charged meson v_2 consistent with π^0 v_2 in p_T<4 GeV/c

v_2 vs. p_T (Minimum Bias) from 200GeV Au+Au

- Identified particle v_2 up to p_T=10 GeV/c



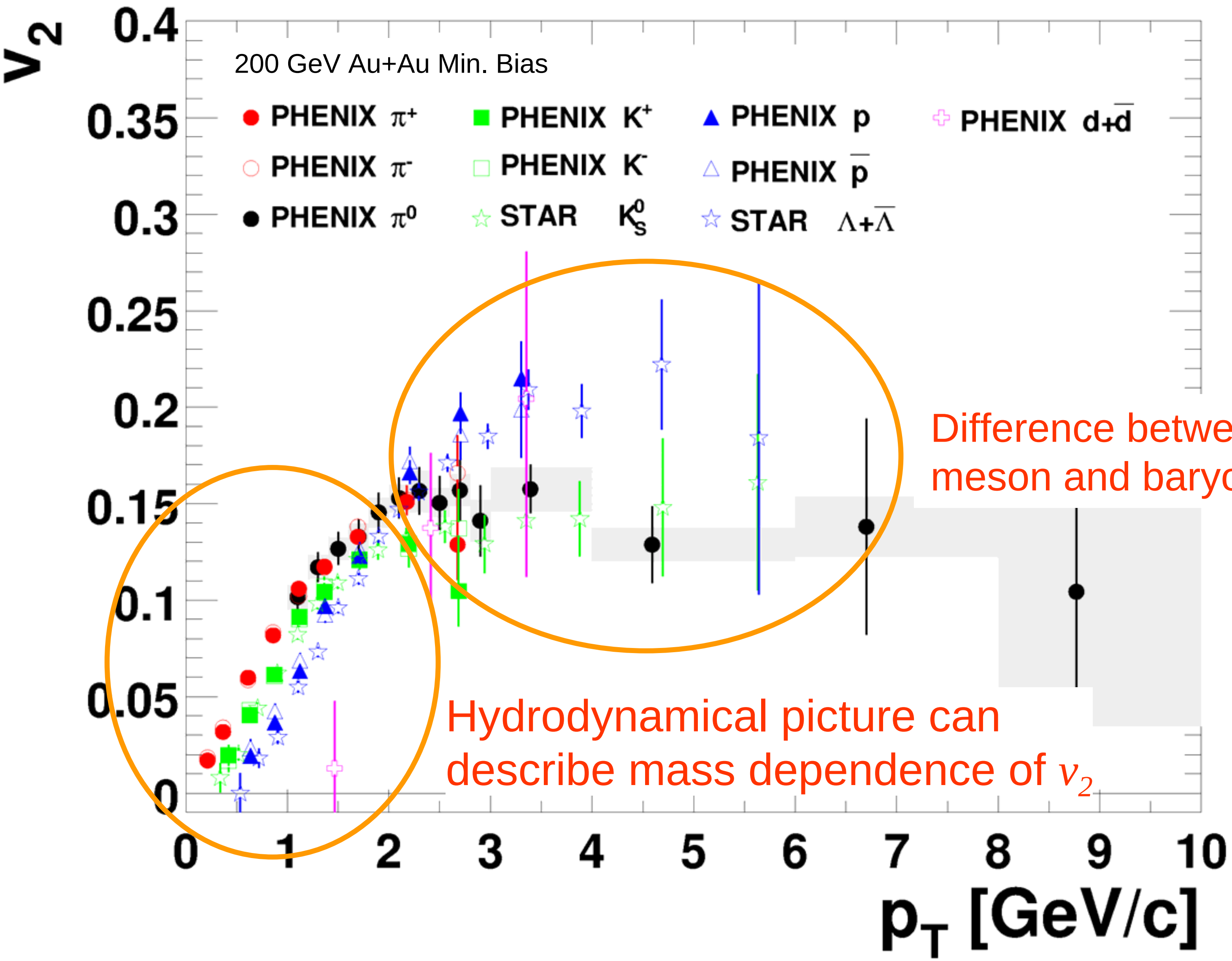
36.3×10^6 [events] = $5.3^{+0.5}_{-0.4}$ [$(\mu b)^{-1}$]

Consistent with charged pions

Also

- Similar p_T dependence with charged hadron v_2
- Low p_T : consistent with hydrodynamical calculation
- High p_T : interesting to compare to a jet quenching calculation/ fragmentation-recombination model

v_2 : identified hadrons at mid-rapidity



PHENIX π, K, p in nucl-ex/0305013

PHENIX π^0, $d+\bar{d}$ preliminary data

STAR $K^0{}_S$, $\Lambda+\bar{\Lambda}$ in nucl-ex/0306007

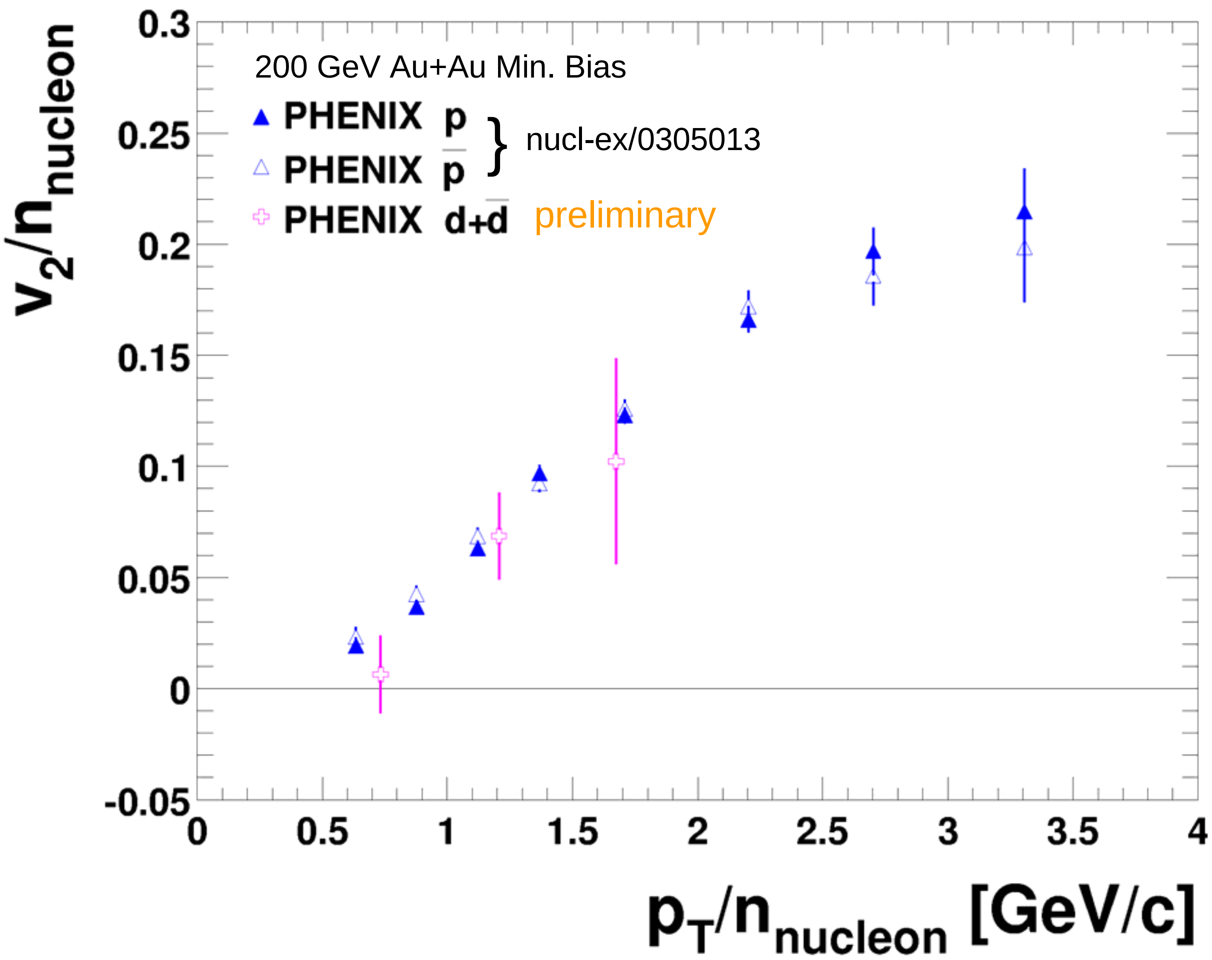
Coalescence picture

- It is established for the nuclei cross section

$$E\frac{d^3N_A}{d^3P} = B_A\left(E\frac{d^3N_N}{d^3p}\right)^A$$

A : nuclear number
P : momentum
$p = P/A$
B_A : coalescence parameter

$$v_{2,A}(P) = Av_{2,proton}(p)$$

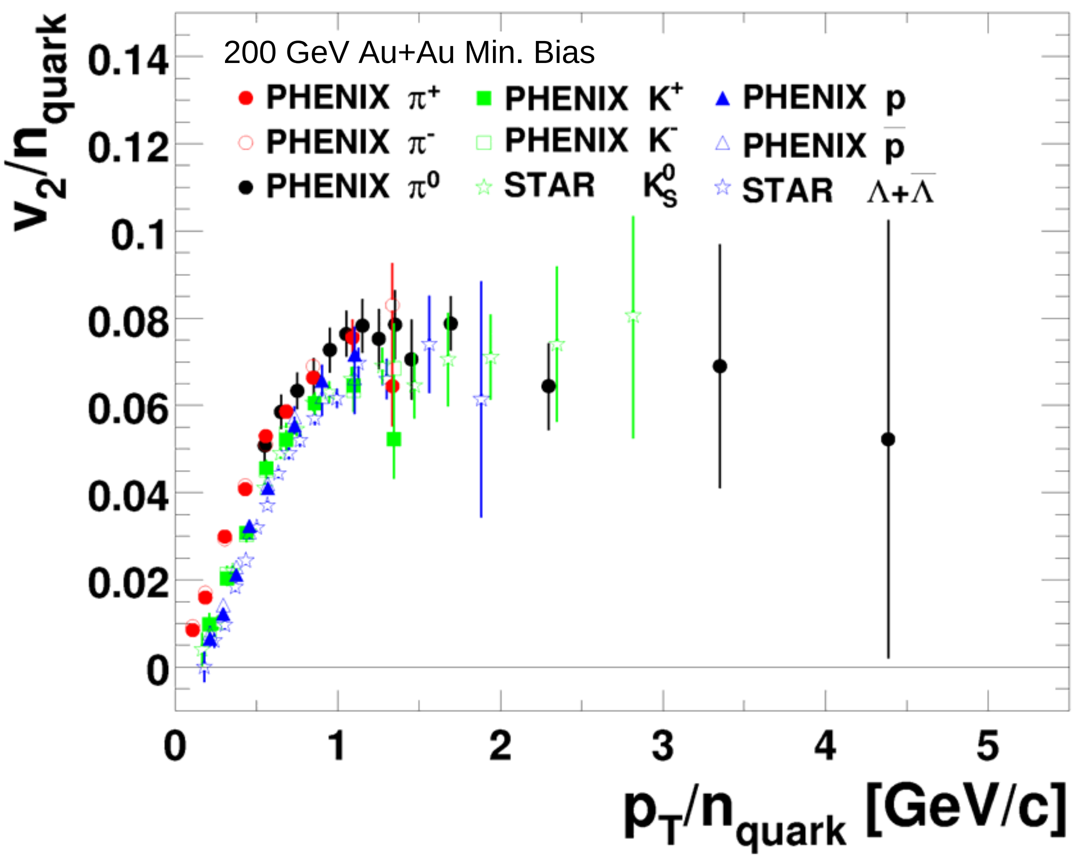


Quark coalescence?

- Phys. Rev. Lett. 91 (2003) 092301, D. Molnar and S.A. Voloshin
- $q\bar{q} \rightarrow$ meson, $qqq(\bar{q}\bar{q}\bar{q}) \rightarrow$ Baryon

$$v_{2,M}(p_\perp) \approx 2v_{2,q}\left(\frac{p_\perp}{2}\right), \qquad v_{2,B}(p_\perp) \approx 3v_{2,q}\left(\frac{p_\perp}{3}\right),$$

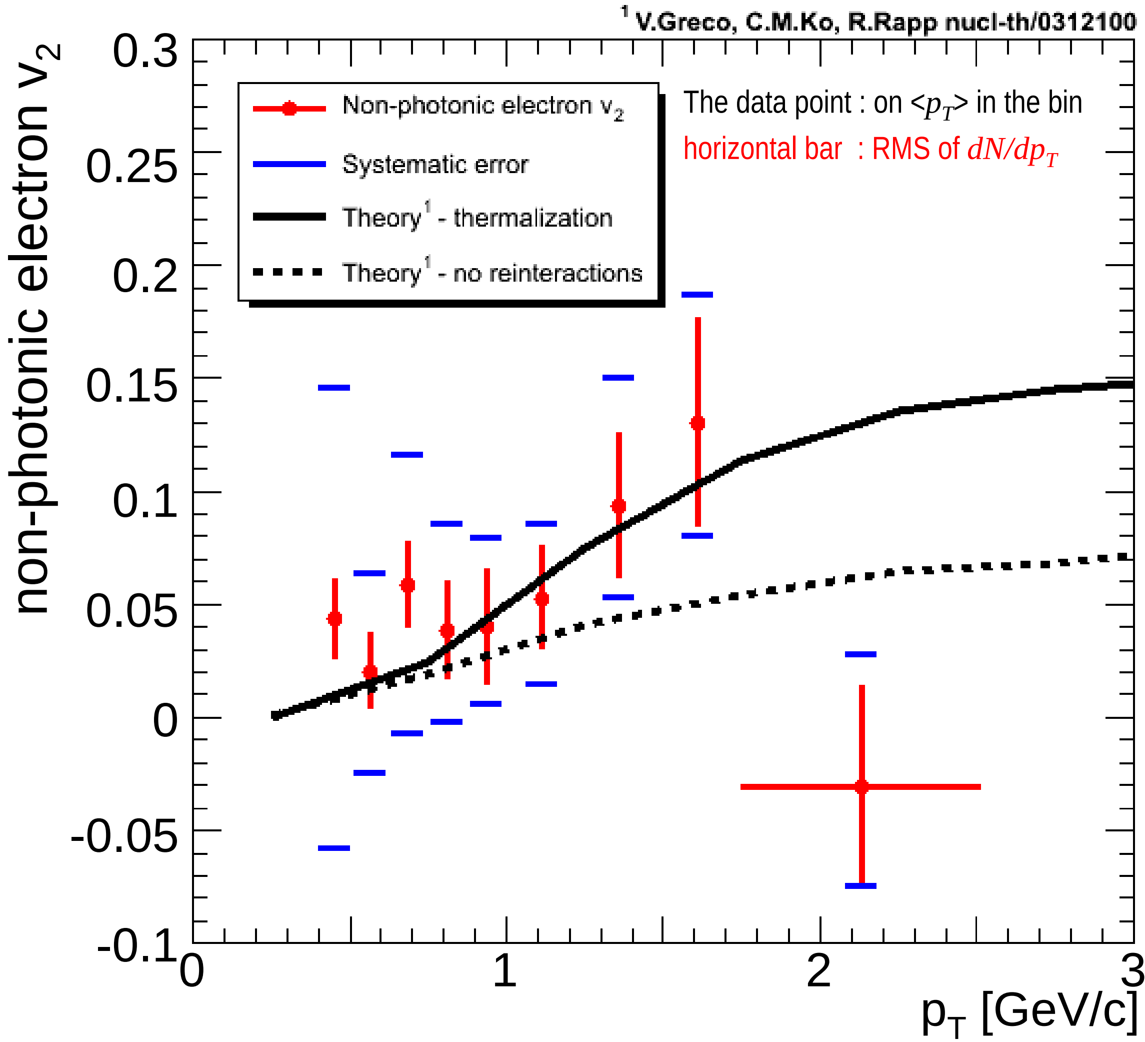
- What data looks like?
- Non-strange and strange mesons and baryons seem to be merged around $p_T/n_{quark} \approx 1\text{-}3$ GeV/c
- But we need more statistics to conclude it



$$e^{\pm}\ v_2$$

Non-photonic $e^{\pm}$ v_2

- Non-photonic electron (sorry for jargon) means
  - Measured electron minus background:
    - hadron decay
    - γ conversion
  - that is, charmed (+bottomed) electron we think
- Two scenarios in nucl-th/0312100
  - thermalized charm + transverse flow
  - no re-interaction
- Data is consistent with both scenarios



Non-photonic $e^{\pm}$ v_2

–Have a look of the poster for detail discussion

–Shingo Sakai

- Azimuthal Anisotropy of electrons/positrons in 200 GeV Au+Au Collisions at RHIC-PHENIX

–Takashi Hachiya

- Single Electrons From Semi-leptonic Decays of Heavy Flavor in Au+Au Collisions at $\sqrt{s_{NN}}=200$ GeV

金田雅司

Summary

- First measurement of π^0, γ, $e^{\pm}$ v_2 at RHIC
- π^0 v_2
  - Minimum bias data (p_T=1-10 GeV/c)
    - v_2 at the highest p_T from the identified particle analysis
    - Non-zero π^0 v_2 up to p_T~8 GeV/c
  - Charged π v_2 consistent with π^0 v_2 in p_T =1-3 GeV/c
  - Quark coalescence picture seems to work
    - from combining various hadron v_2's at RHIC
- γ v_2
  - Centrality (top 20, 20-40, 40-60%) and p_T dependence (in p_T <5 GeV/c) are consistent wit π^0
  - With more statistics from run4, we hope to reject the decay effect
- $e^{\pm}$ v_2
  - Minimum bias data (p_T =0.4-3.0 GeV/c)
  - Non-photonic e v_2 is consistent with both model
    - charm flow and no-charm flow
  - We need much more statistics to conclude

Backup

Method of π^0 and Photon v_2 Measurement

$$E\frac{dN^3}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,dy}\left(1+\sum_{n=1}^{\infty}2\,v_n^{measured}\cos[n(\phi-\Phi_r)]\right) \quad \text{where } n = 1,2,3,\ldots.$$

event anisotropy parameter measured

reaction plane angle

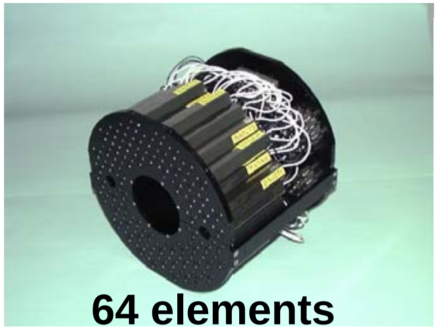
azimuthal angle of the particle

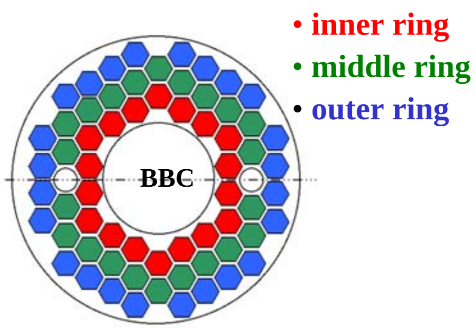
$v_n^{\text{real}} = v_n^{measured}$/ (reaction plane resolution)$_n$

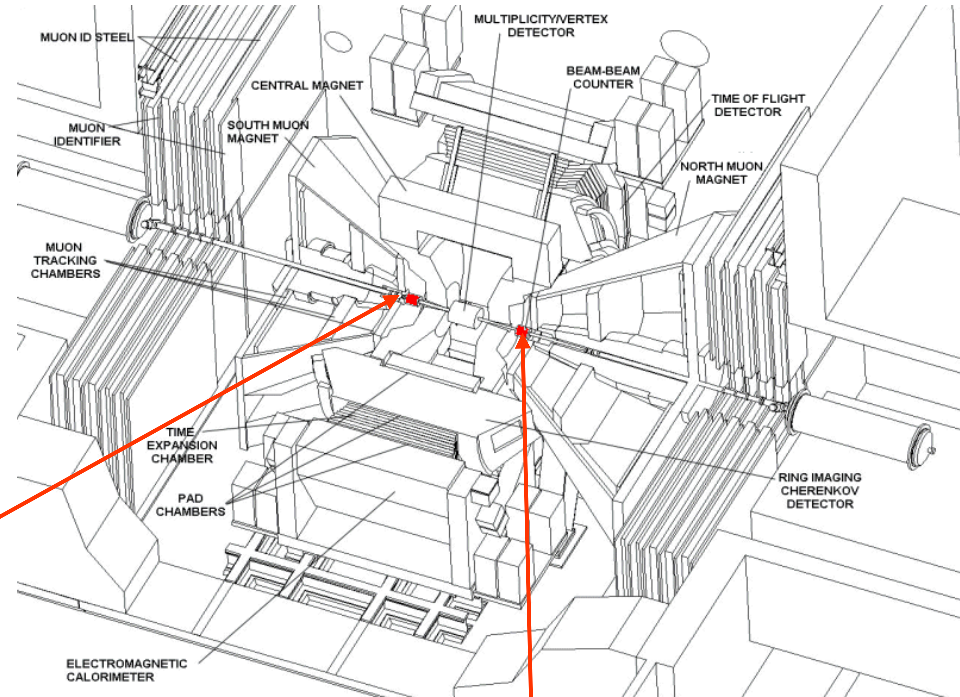
Note: the detail of reaction plane definition will be found in **nucl-ex/0305013**

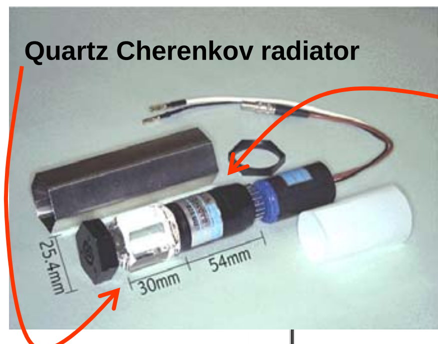
- Define reaction plane by charged multiplicity on Beam-Beam Counters
- Photons
  - Obtained the second harmonic coefficient v_2 from <cos[2(ϕ-Φ_r)]>
- π^0
  - π^0 reconstruction and background subtract (combinatorial and the others)
    - For each p_T, azimuthal angle, centrality
  - Combine both information
    - Counting number of π^0 as a function of ϕ-Φ_r and fit by the formula
- Electrons
  - Both methods are used

Reaction plane definition

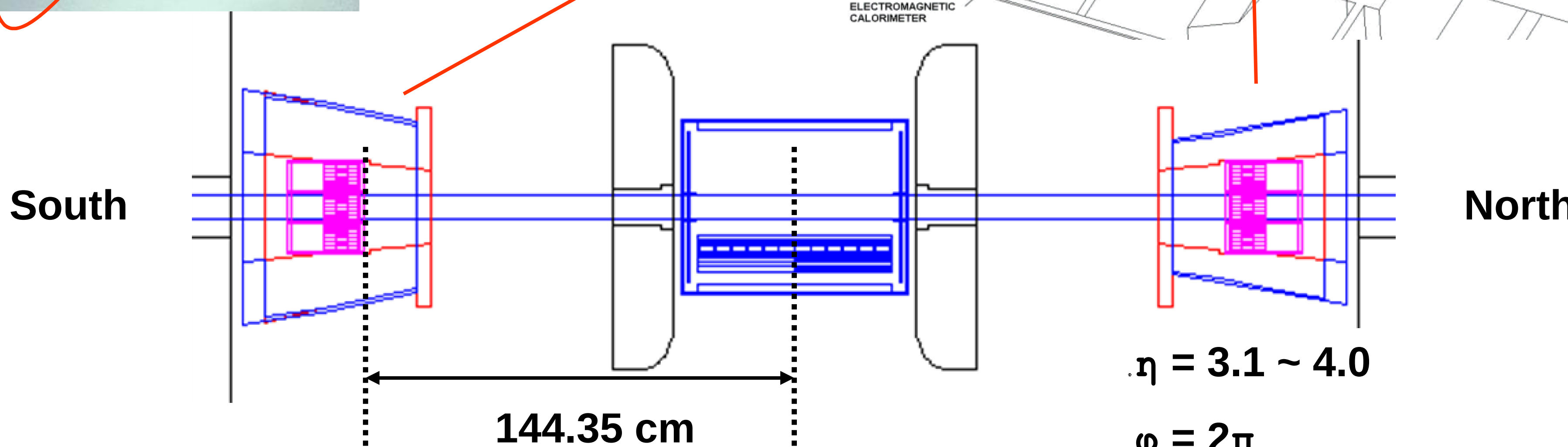








meshed dynode PMT



$\eta = 3.1 \sim 4.0$

$\varphi = 2\pi$

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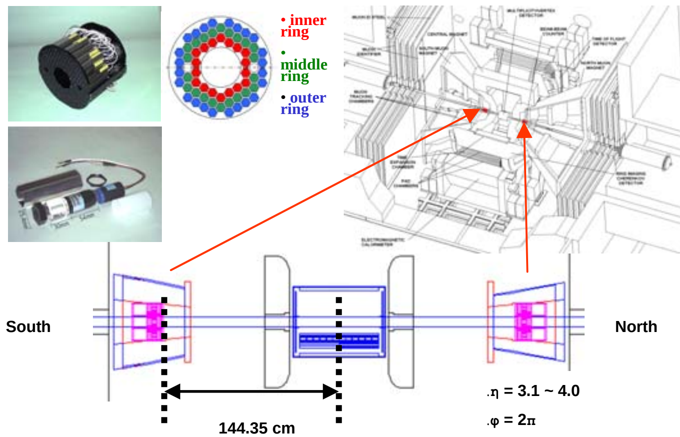
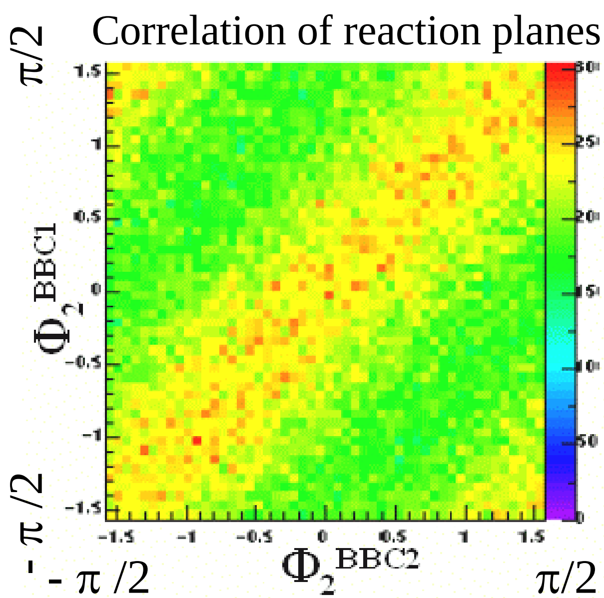
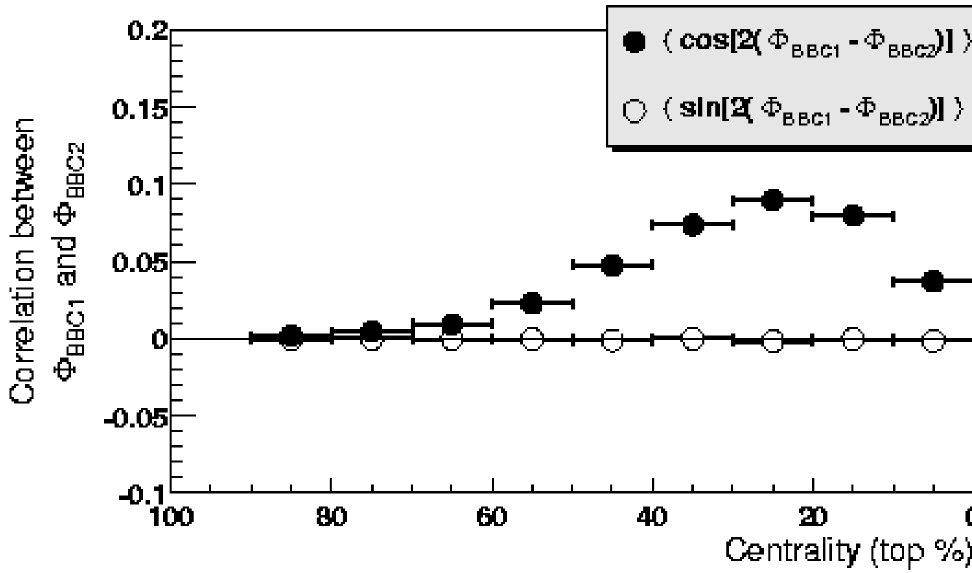
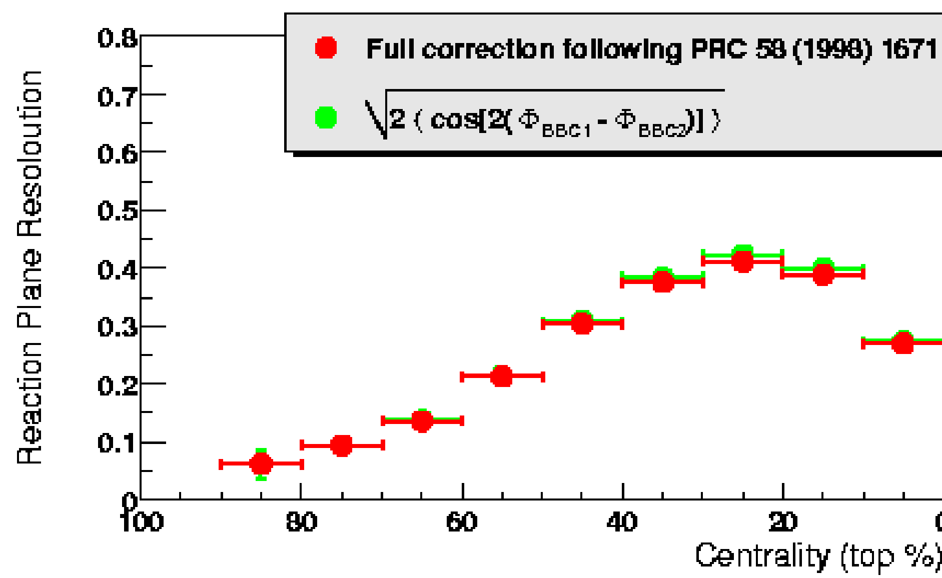
Reaction plane definition



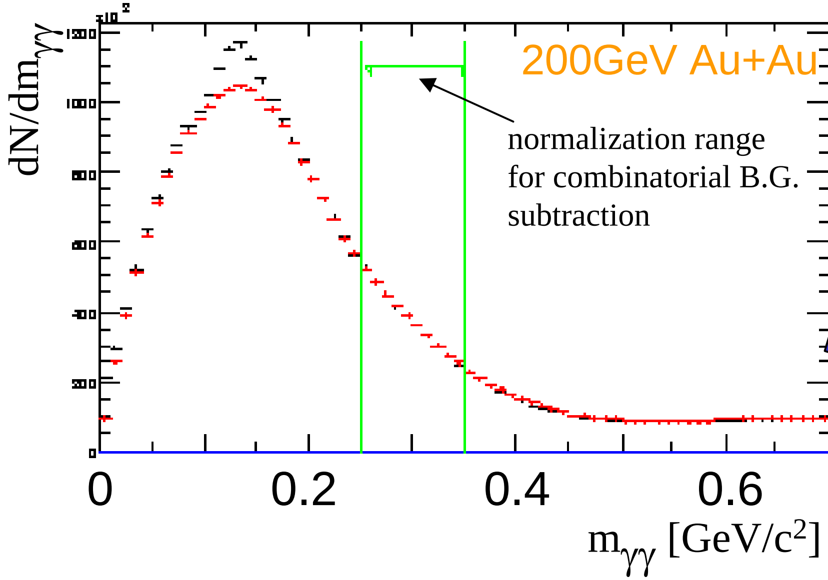




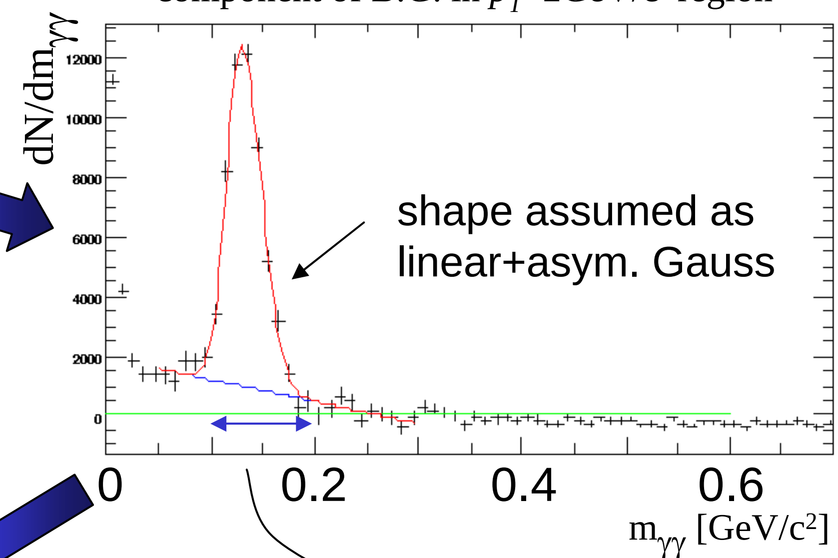


Example plots from the π^0 v_2 analysis procedures

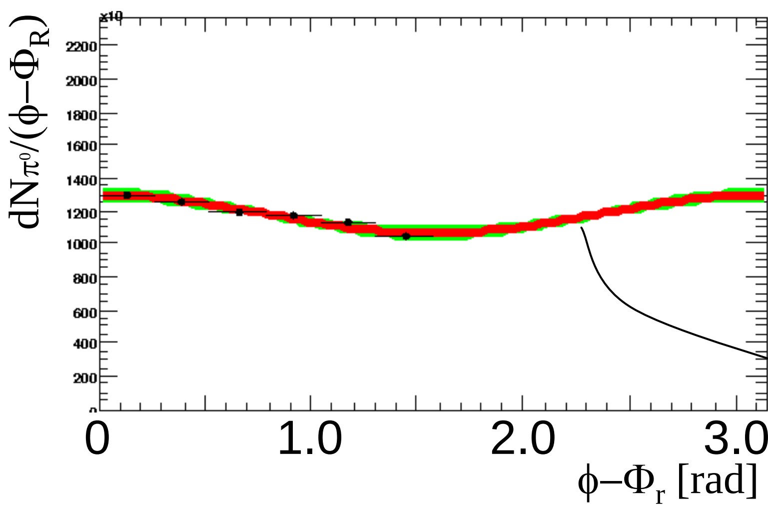
Invariant mass of $\gamma\gamma$ from same event and mixed event (classed by reaction plane, centrality, vertex position)



After the subtraction, there is 2nd component of B.G. in p_T<2GeV/c region



count number of π^0 in a range after 2nd B.G. subtraction (not used the fit function)



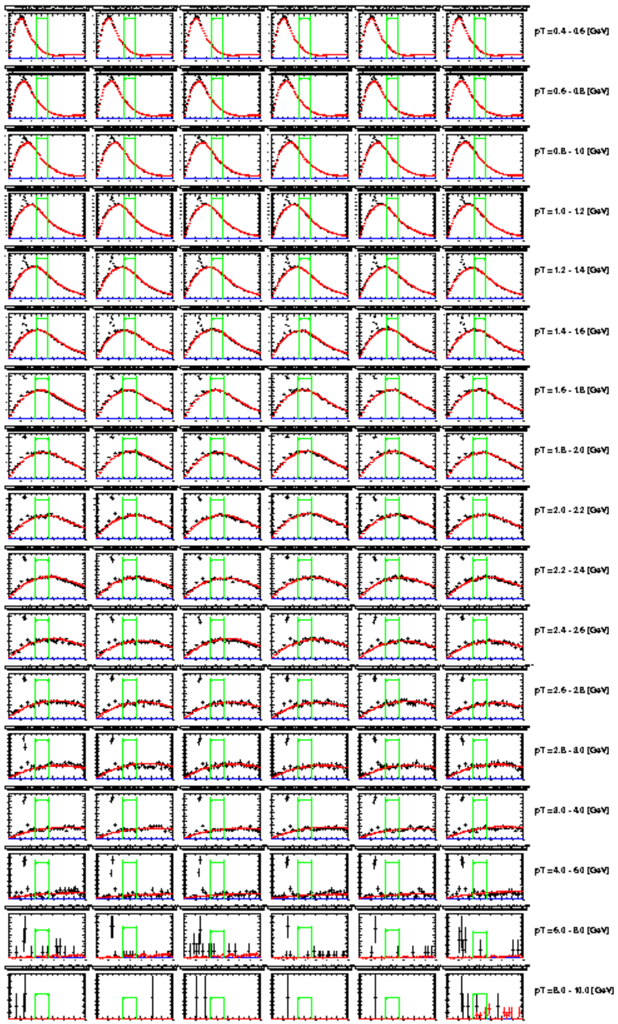
Fit function:
(average of π^0 count) × (1 + 2 v_2 cos[2(ϕ - Φ_R)])
Green lines : deviation by error of v_2

all histograms are checked by eyes!!

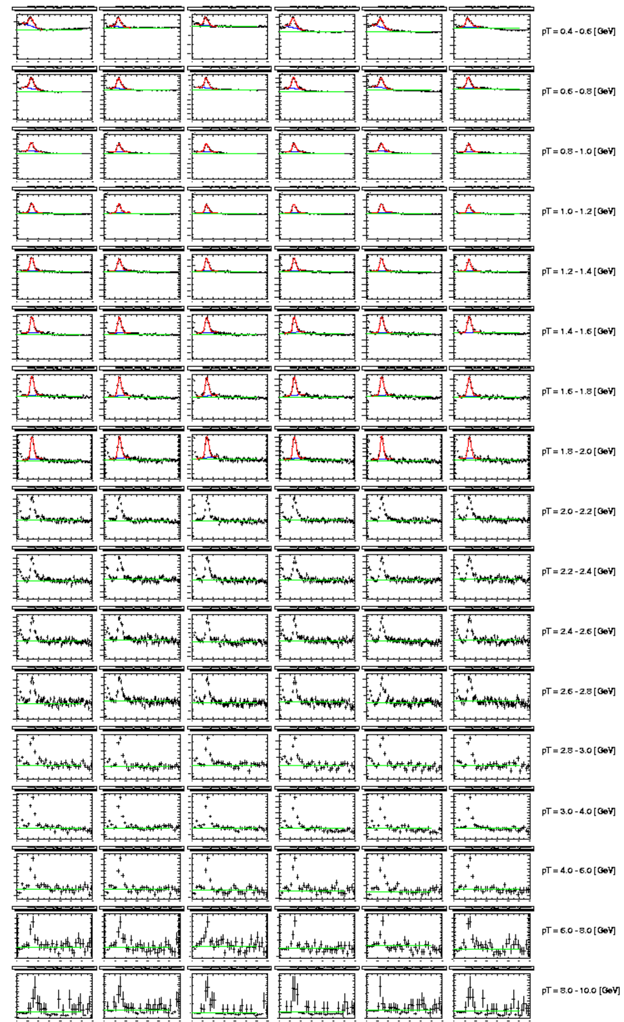
Tooooooooooooo many histograms checked

Example of invariant mass distributions for each p_T, ϕ-Φ_R in a centrality bin

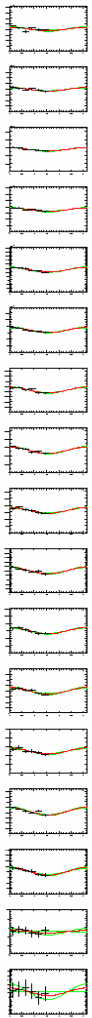
Before combinatorial background subtraction



After combinatorial background subtraction



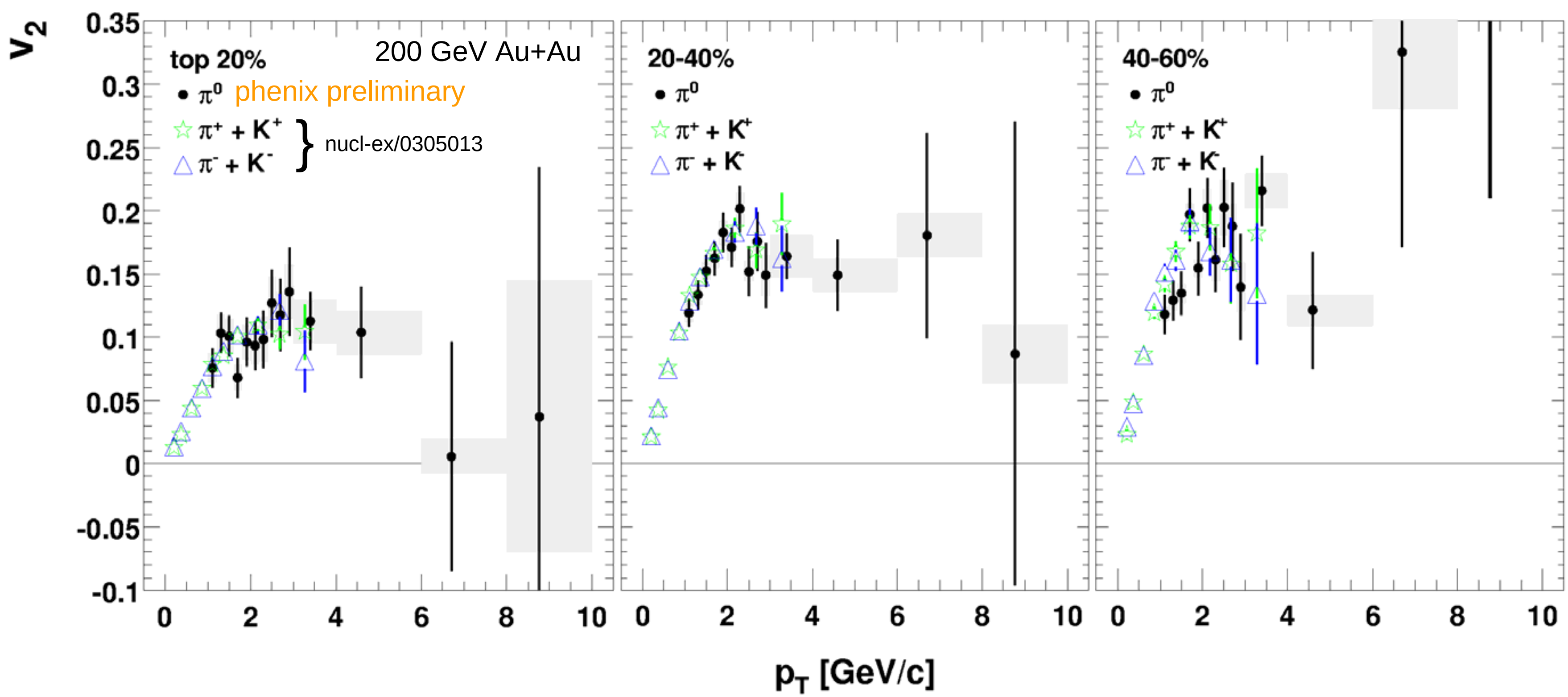
π^0 as a function of $\phi-\Phi_{Rb}$



v_2 vs. p_T vs. centrality from 200GeV Au+Au

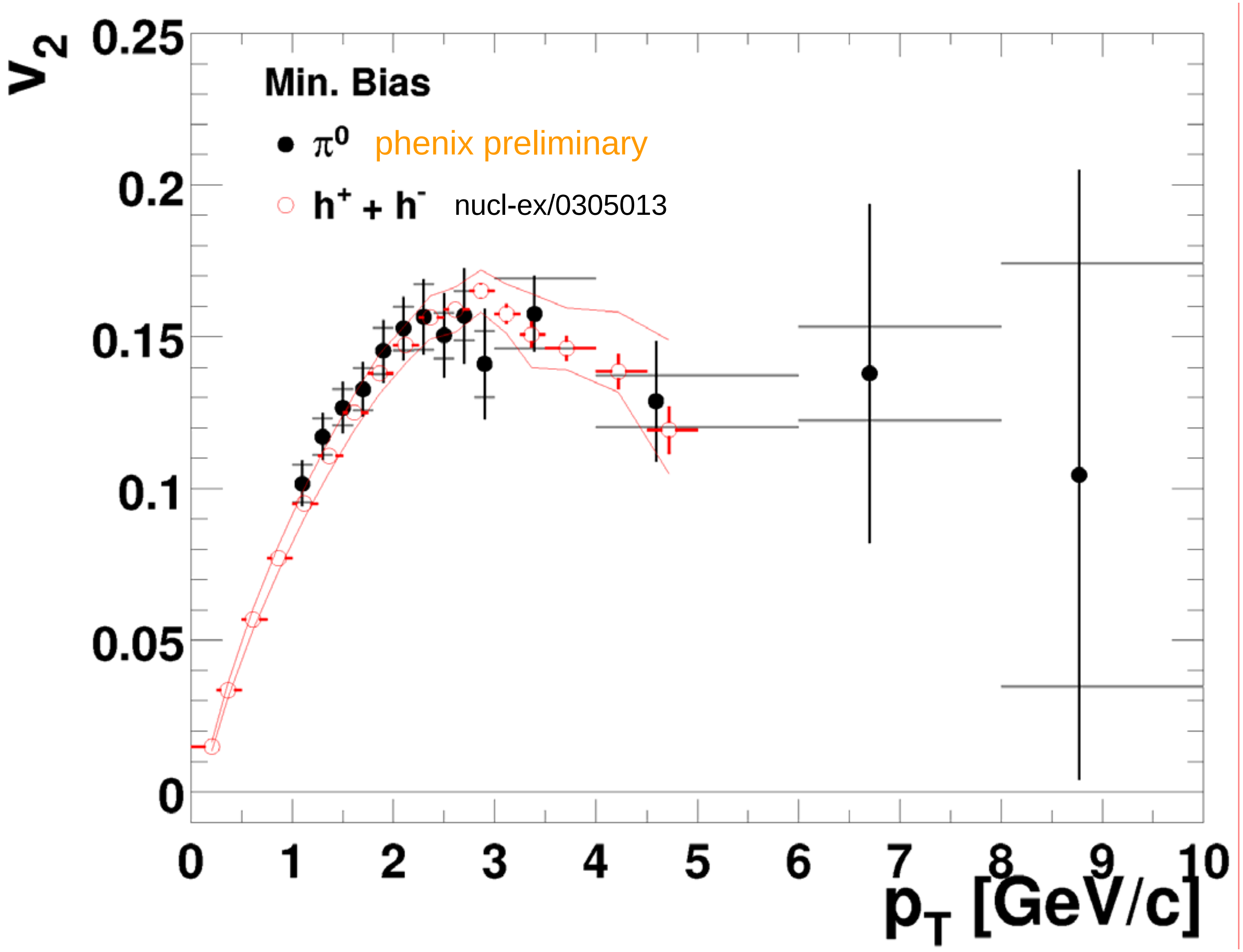
Statistical error is shown by error bar
Systematic error from π^0 count method and reaction plane determination is shown by horizontal bar
The data point stays at <p_T> in the bin and horizontal bar shows the bin range

The charged π and K v_2 are shown only with statistical errors



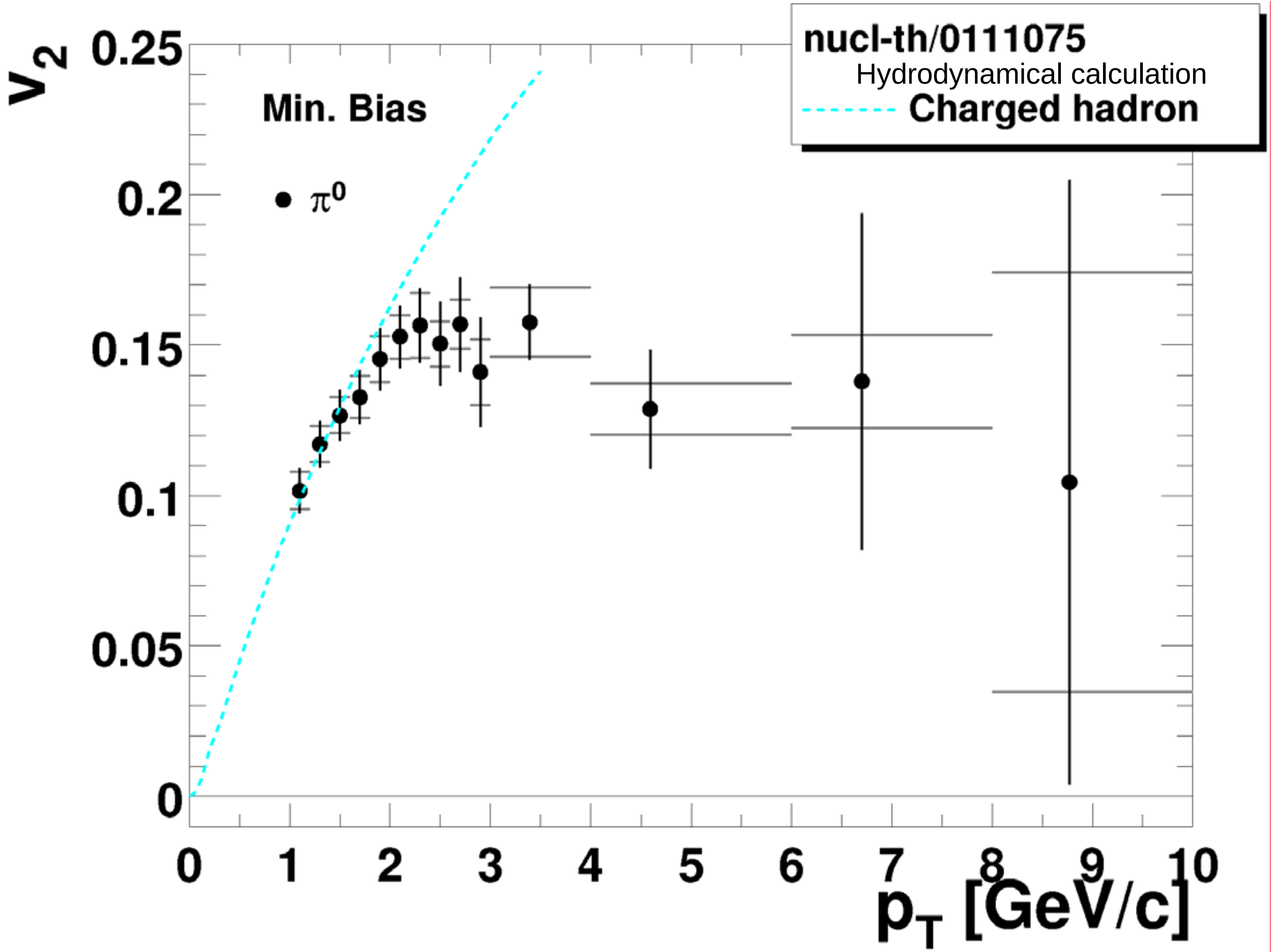
- Charged meson v_2 consistent with π^0 v_2 in p_T<4 GeV/c

v_2 vs. p_T (Minimum Bias) from 200GeV Au+Au



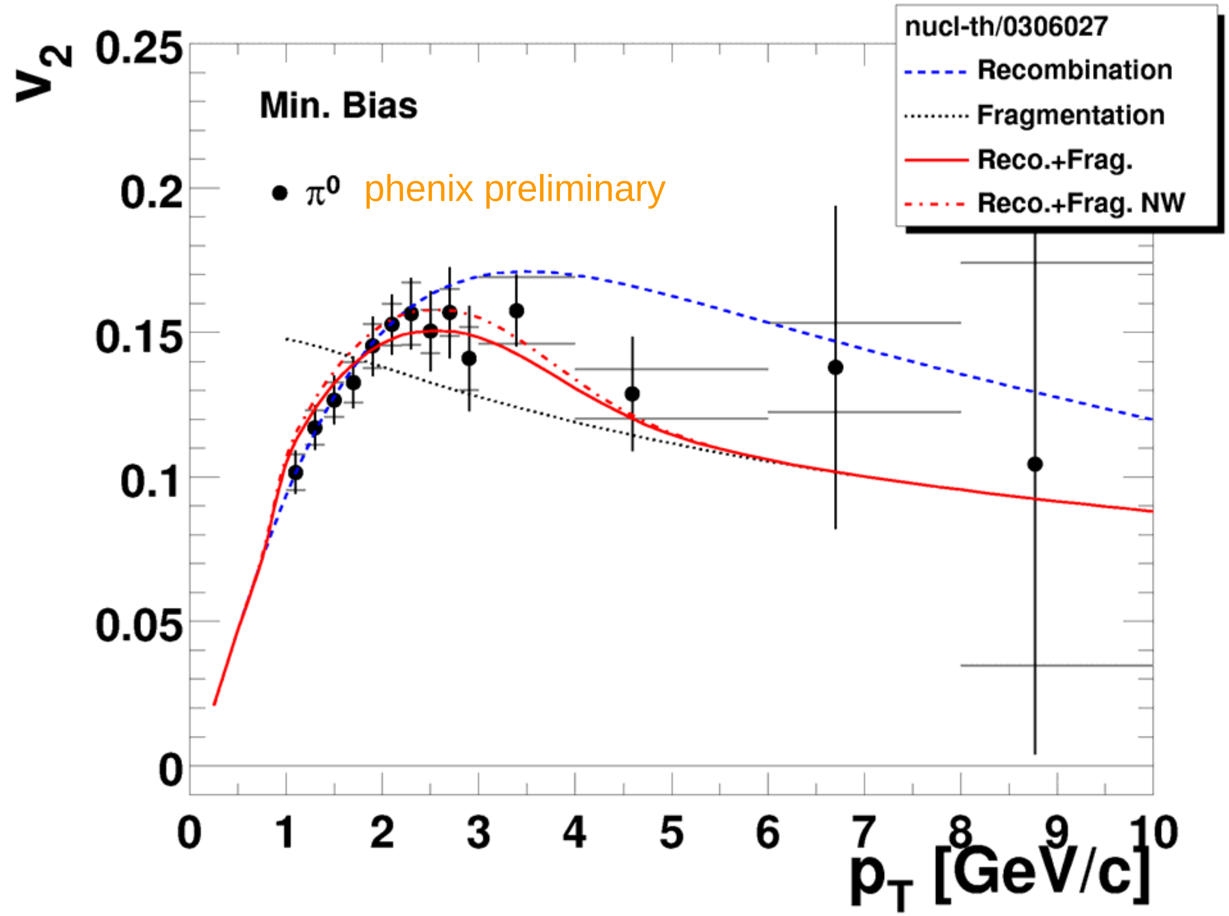
36.3×10^6 [events] = $5.3^{+0.5}_{-0.4}$ [$(\mu b)^{-1}$]

Comparison with a model



Hydrodynamical calculation agreed in p_T~<2 GeV/c
After that, it is deviated

Comparison with a model



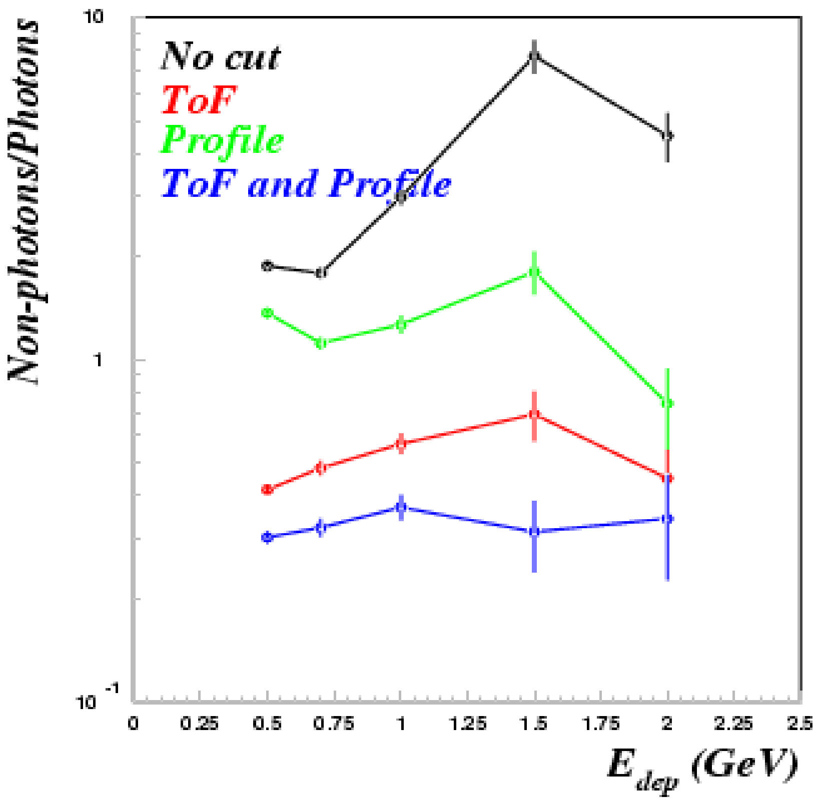
Special thanks to C. Nonaka (one of authors) of nucl-th/0306027 for data of model calculation

Comparison with a model which is described in nucl-th/0306027. Here we don't want to discuss which model can describe the data. To conclude which model can describe the data, we need much more statistics in high p_T region.

Photon purity with cuts

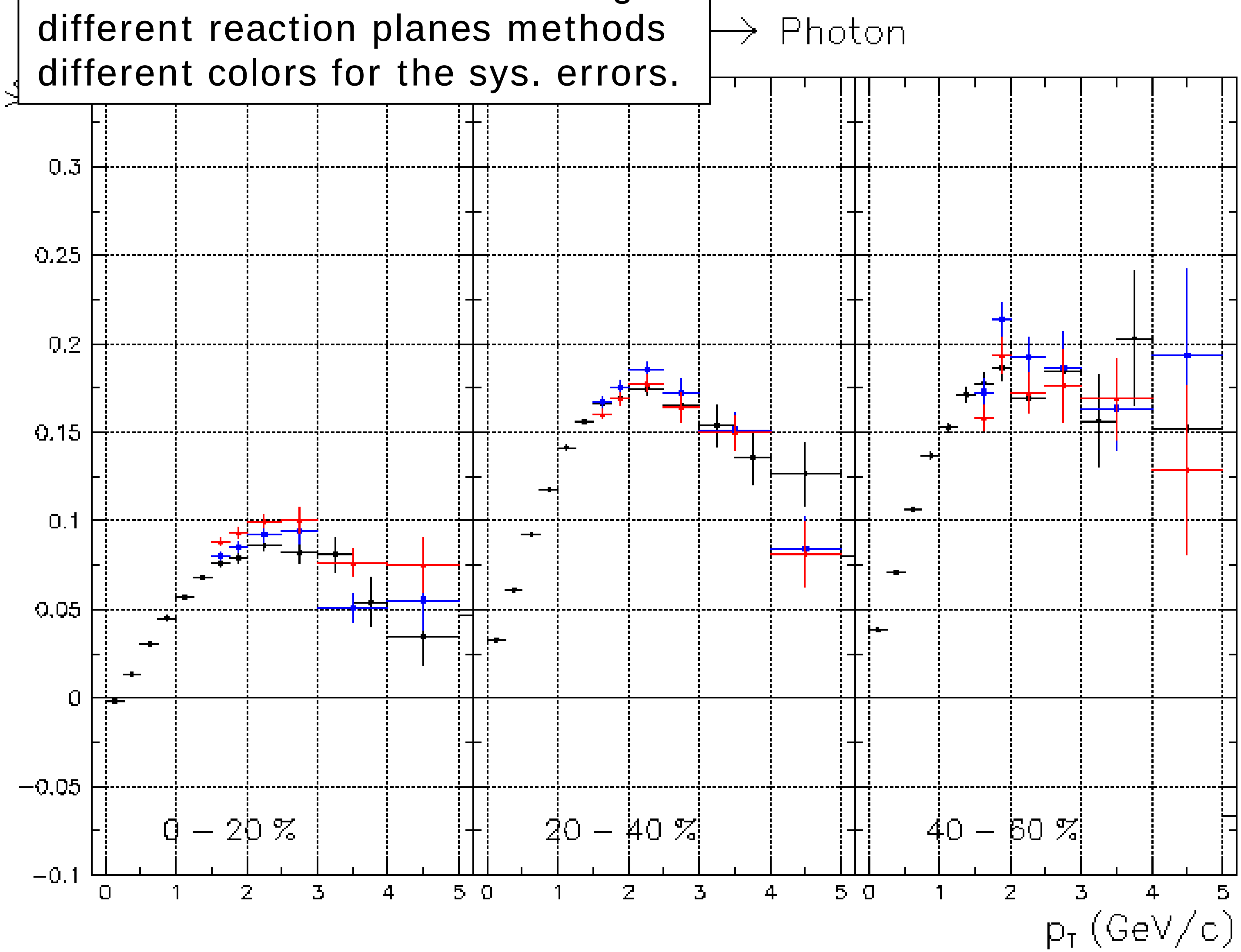
DNP99, October 1999

Central HIJING Events:
ToF and Shower Profile cut performance

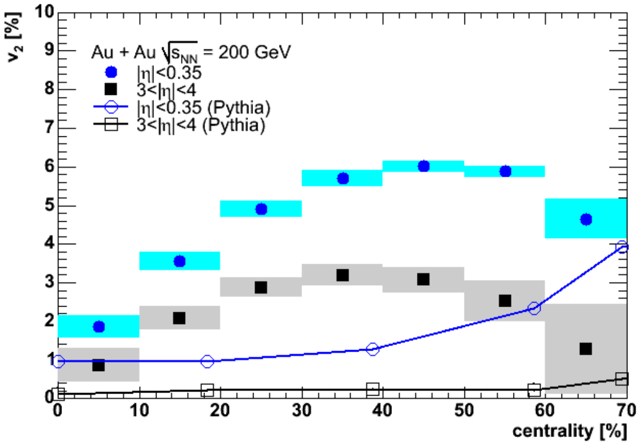


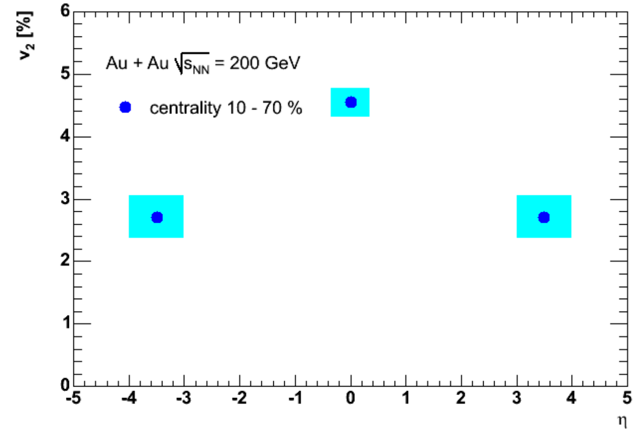
Systematic errors

different methods for extracting v2
different reaction planes methods
different colors for the sys. errors.

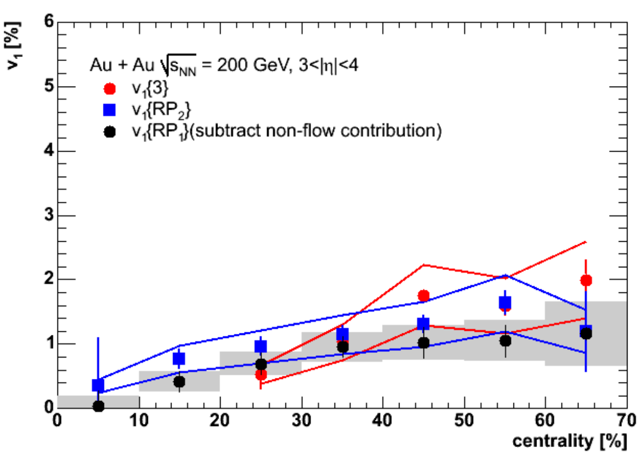


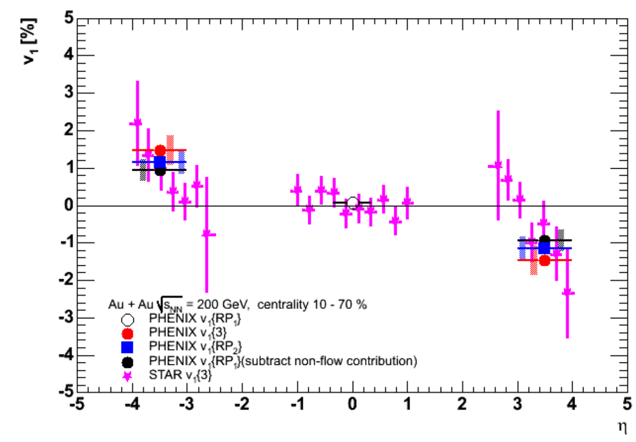
New results of charged hadron v_n





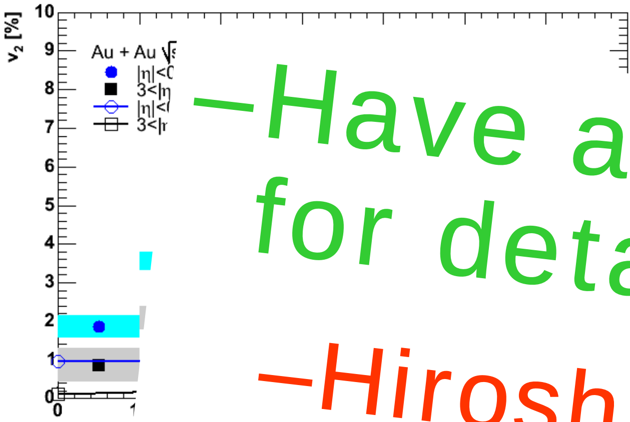
Elliptic Flow

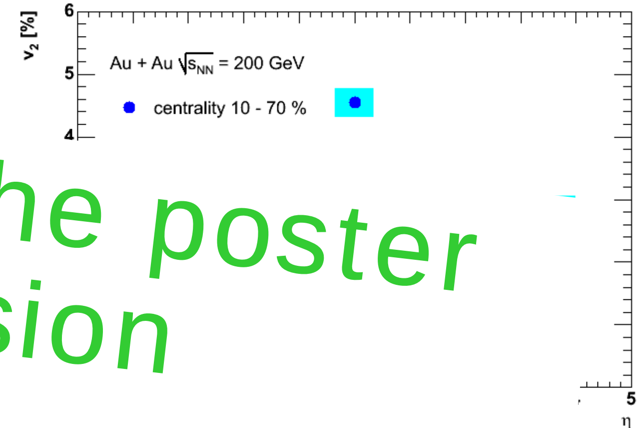




Directed Flow

New results of charged hadron v_n

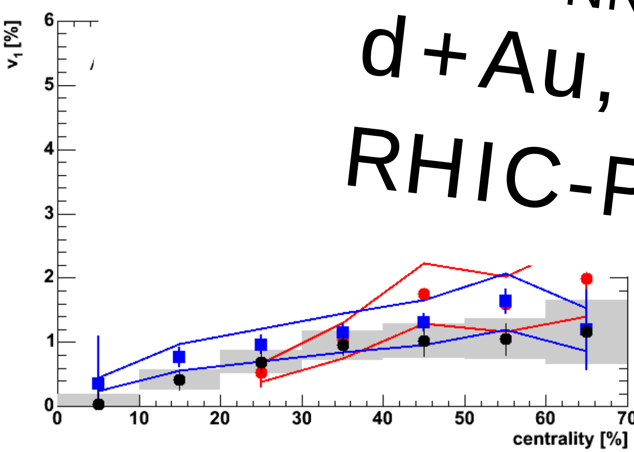


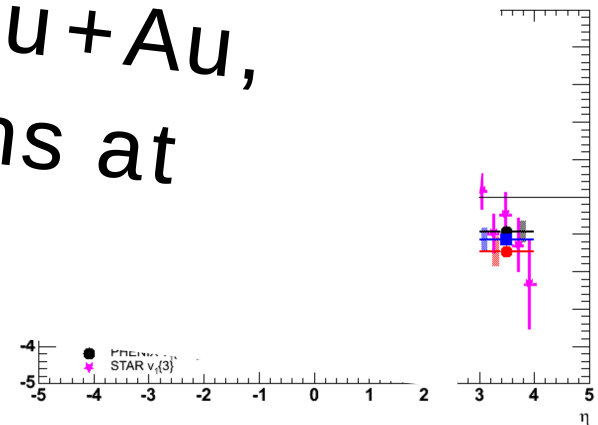


– Have a look of the poster for detail discussion

– Hiroshi Masui

- Measurement of directed flow in $\sqrt{s_{NN}}$=200 GeV Au+Au, d+Au, p+p collisions at RHIC-PHENIX



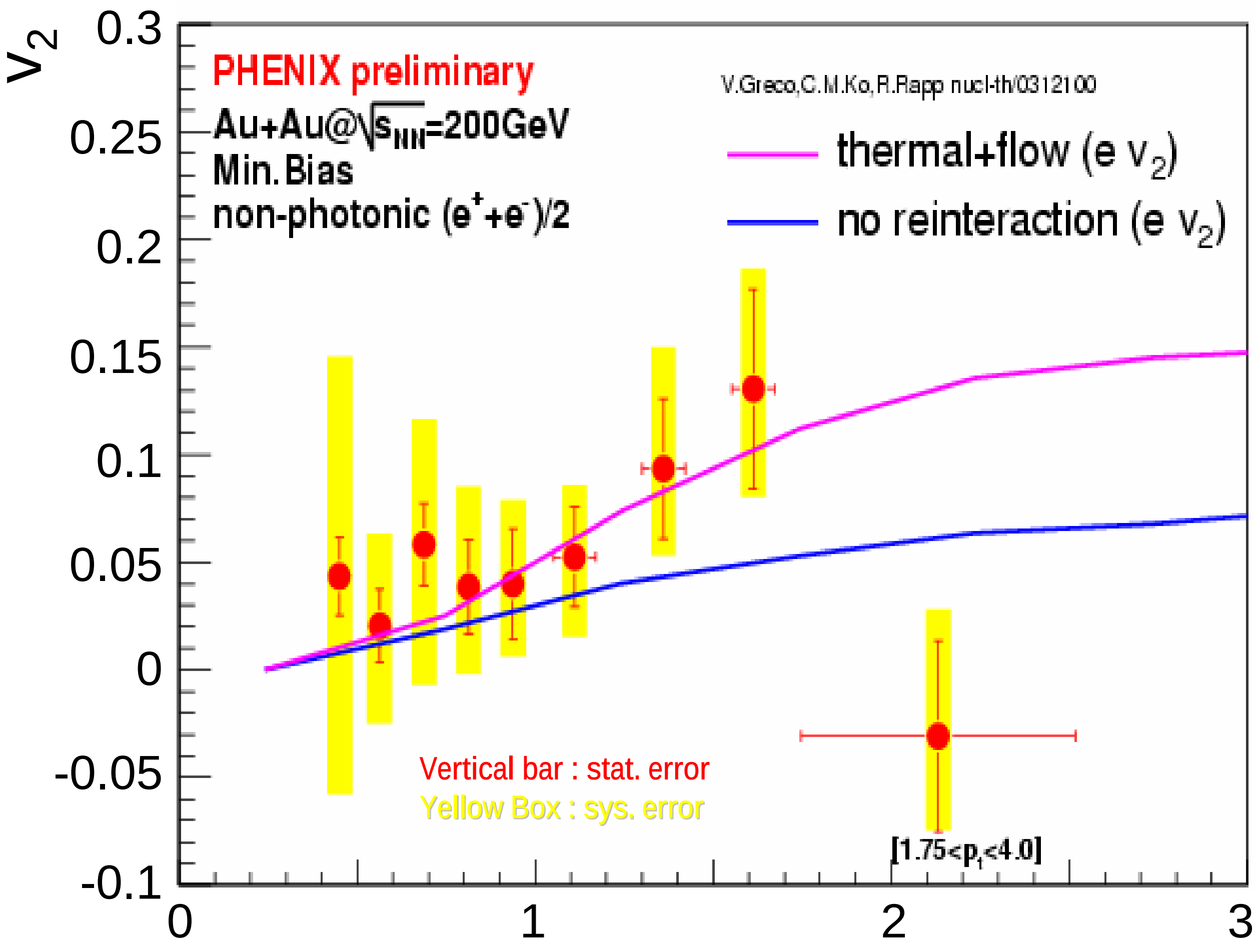


Particle identifications

- Requirement for photon
  - Dead and noisy EMC towers are removed for the analysis
  - PID cuts: $\chi^2<3$ for photon probability to shower shape
  - |TOF| cut to reject hadron
  - No charged track hit within cluster isolation window
- For π^0
  - Photon ID, plus
  - Asymmetry cut: $|E_1-E_2| / (E_1+E_2) < 0.8$
  - Combinatorial background is estimated by event mixing
    - Classes categorized for event mixing
      - Centrality : every 10%
      - BBC Z Vertex : every 10cm in ±30cm
      - Reaction plane direction in PHENIX detector : 24 bins in $\pm\pi$
- Electrons

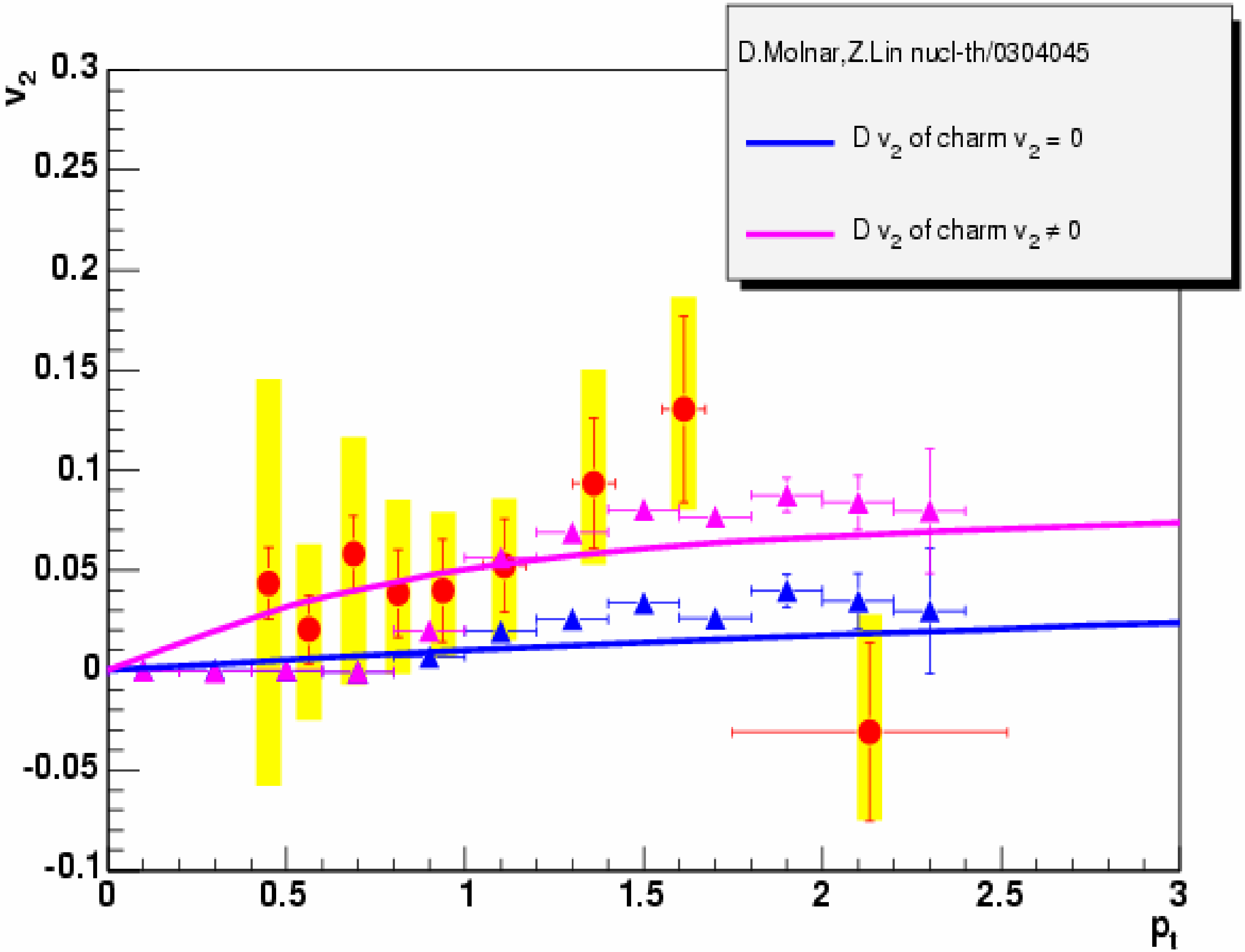
Non-photonic $e^{\pm}$ v_2

- Non-photonic electron (sorry for jargon) means
  - Measured electron minus background:
    - hadron decay
    - γ conversion
  - that is, charmed (+bottomed) electron we think
- Two scenario in nucl-th/0312100
  - (1) thermalized charm + transverse flow
  - (2) no re-interaction (PHYTHIA spectra)
- Data is consistent with both scenario



The data point : on $\langle p_T \rangle$ in the bin
horizontal bar : RMS of dN/dp_T

Charmed electron v_2



Future plan of event anisotropy analysis in PHENIX

- Trying v_2 for all of possible particles with large statistics
  - Already tried
    - charged π,K,p, deuteron, π^0, $e^{+(-)}$ (inclusive), gamma (inclusive)
  - On going but need much more statistics
    - eta
    - direct gamma
      - inclusive gamma – [contribution from π^0, eta (dominantly)]
    - charm and bottom meson
      - inclusive $e^{+(-)}$ – [contribution from π^0 and eta dalitz decay (dominantly)]
  - Seems to be hard work, but...
    - K^0_s
    - Lambda
    - resonances
    - penta-quark
- v_1 on SMD (stay around beam rapidity)
- Correlation method for v_n
- Cross section and HBT radii in-plane and out-plane