π^0 and photon v_2 study in $\sqrt{s_{NN}} = 200$GeV Au+Au collisions

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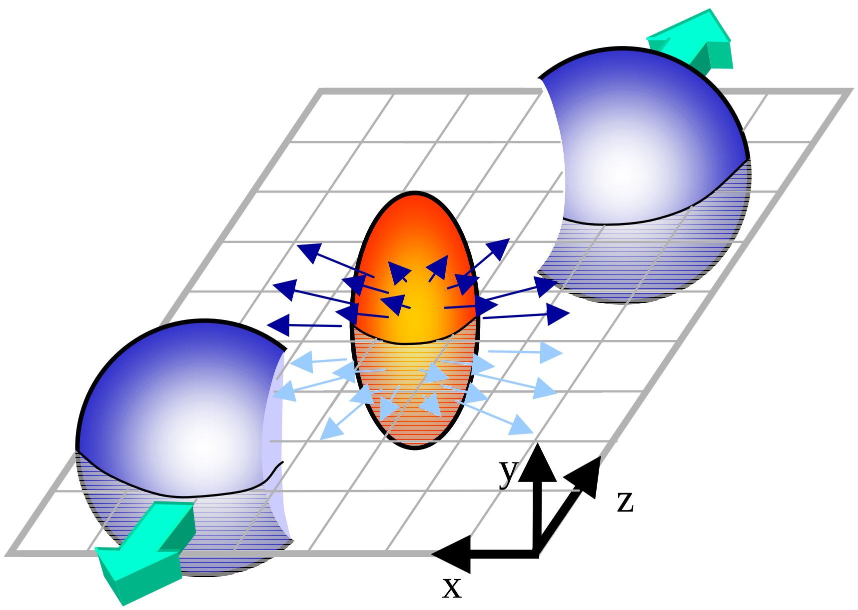
Why Event Anisotropy?

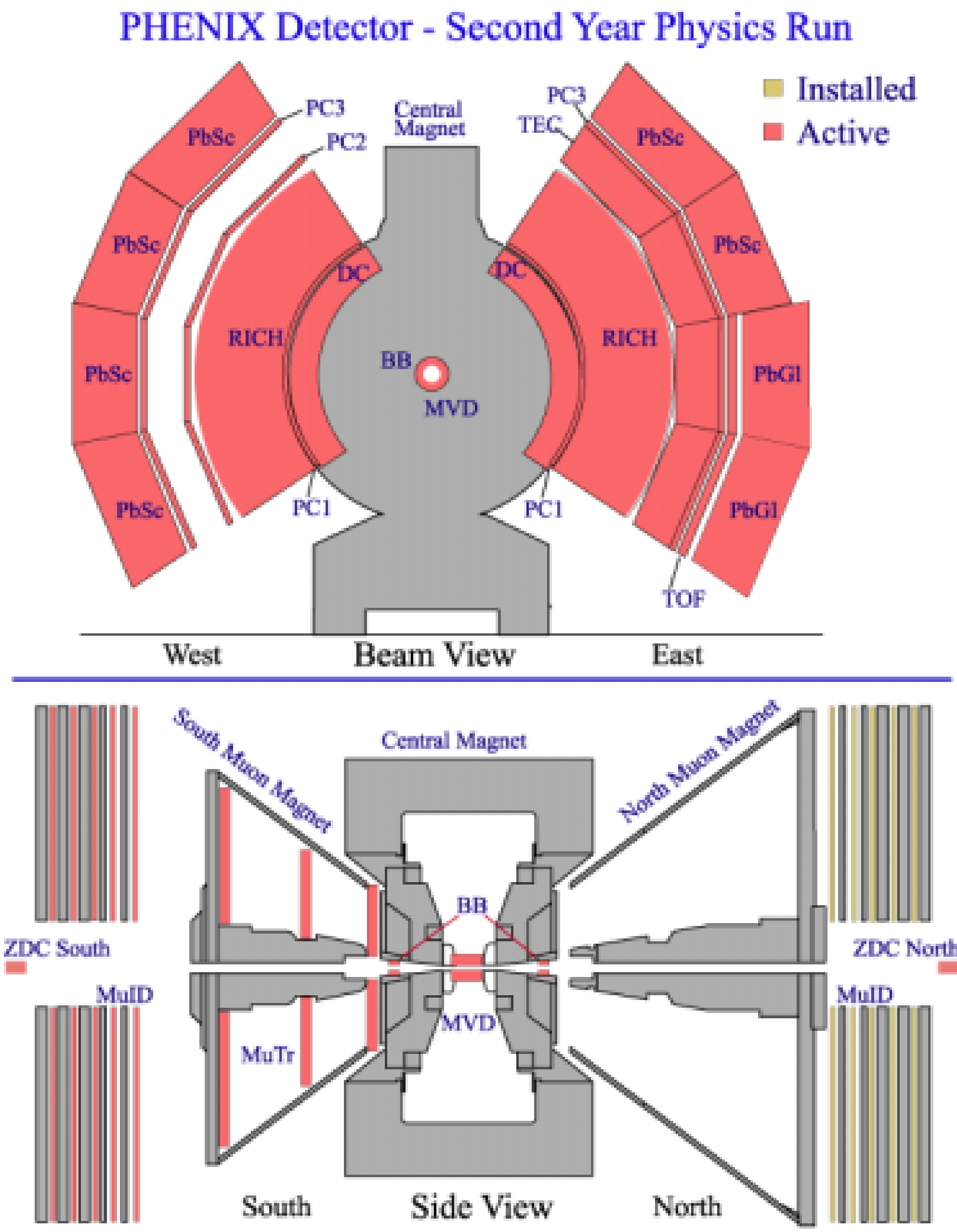
- Because of sensitive to collision geometry
  - In low p_T (~<2 GeV/c)
    - Pressure gradient of early stage
    - Hydrodynamical picture is established
  - In high p_T (>~2 GeV/c)
    - Energy loss in dense medium (Jet Quenching)
    - Partonic flow(?)

Here we focus on ellipticity of azimuthal momentum distribution, v_2 (second Fourier coefficient)



PHENIX Experiment

- Lead Scintillator and Lead Glass EMCs
  - Gamma measurement ($\pi^0 \rightarrow \gamma\gamma$)
- BBCs and ZDCs
  - Collision centrality determination
- BBCs
  - Reaction plane determination and
  - Its resolution correction



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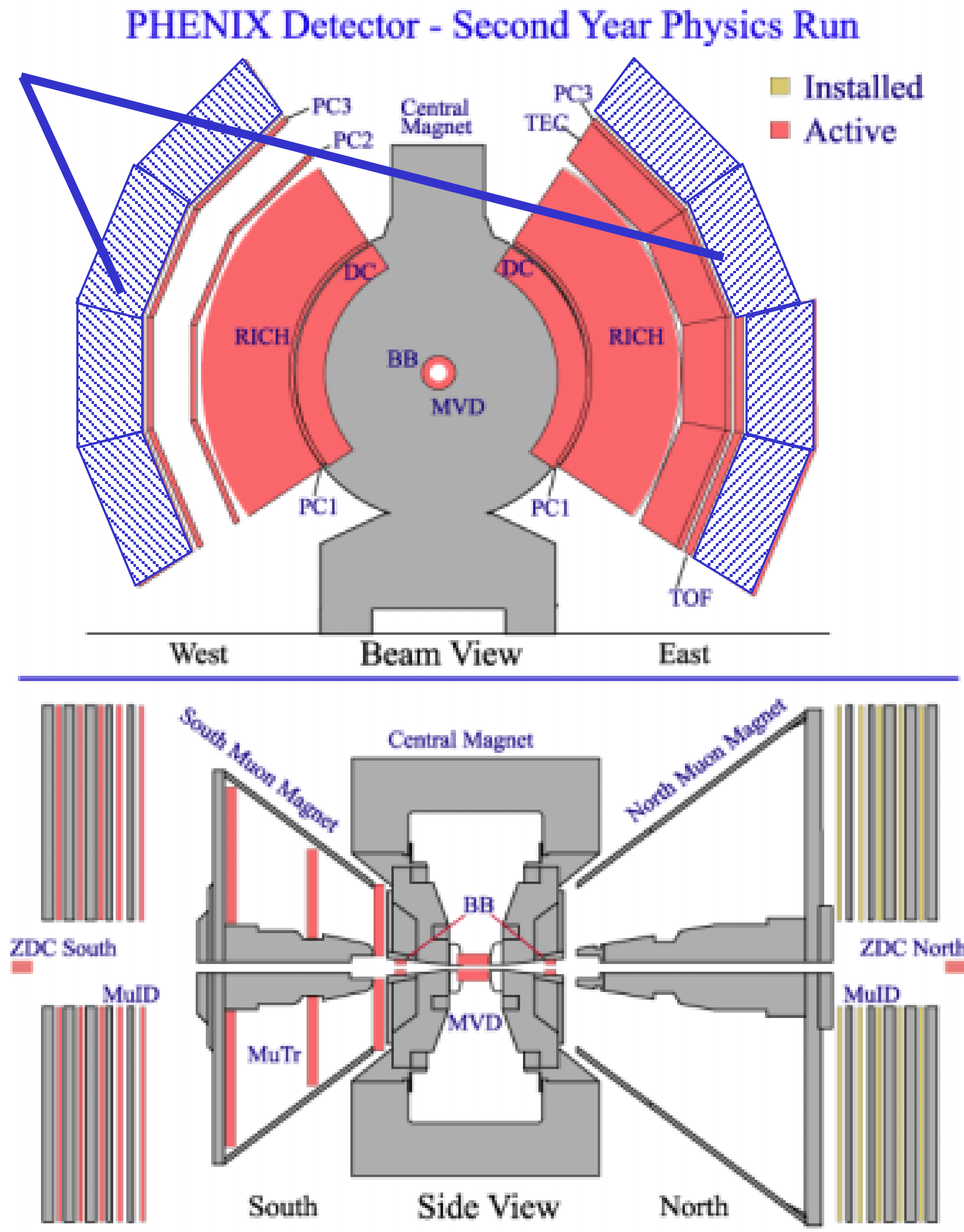

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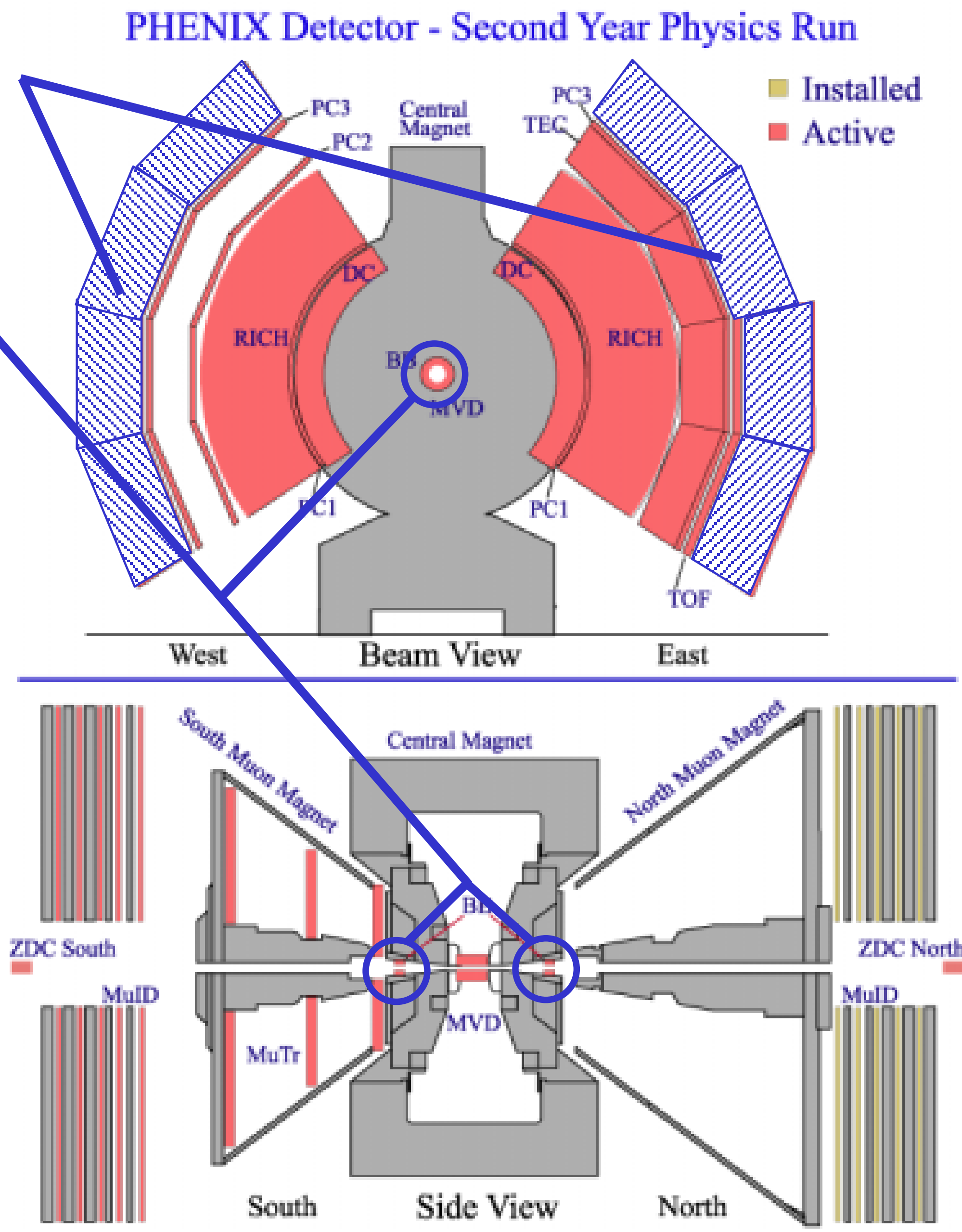

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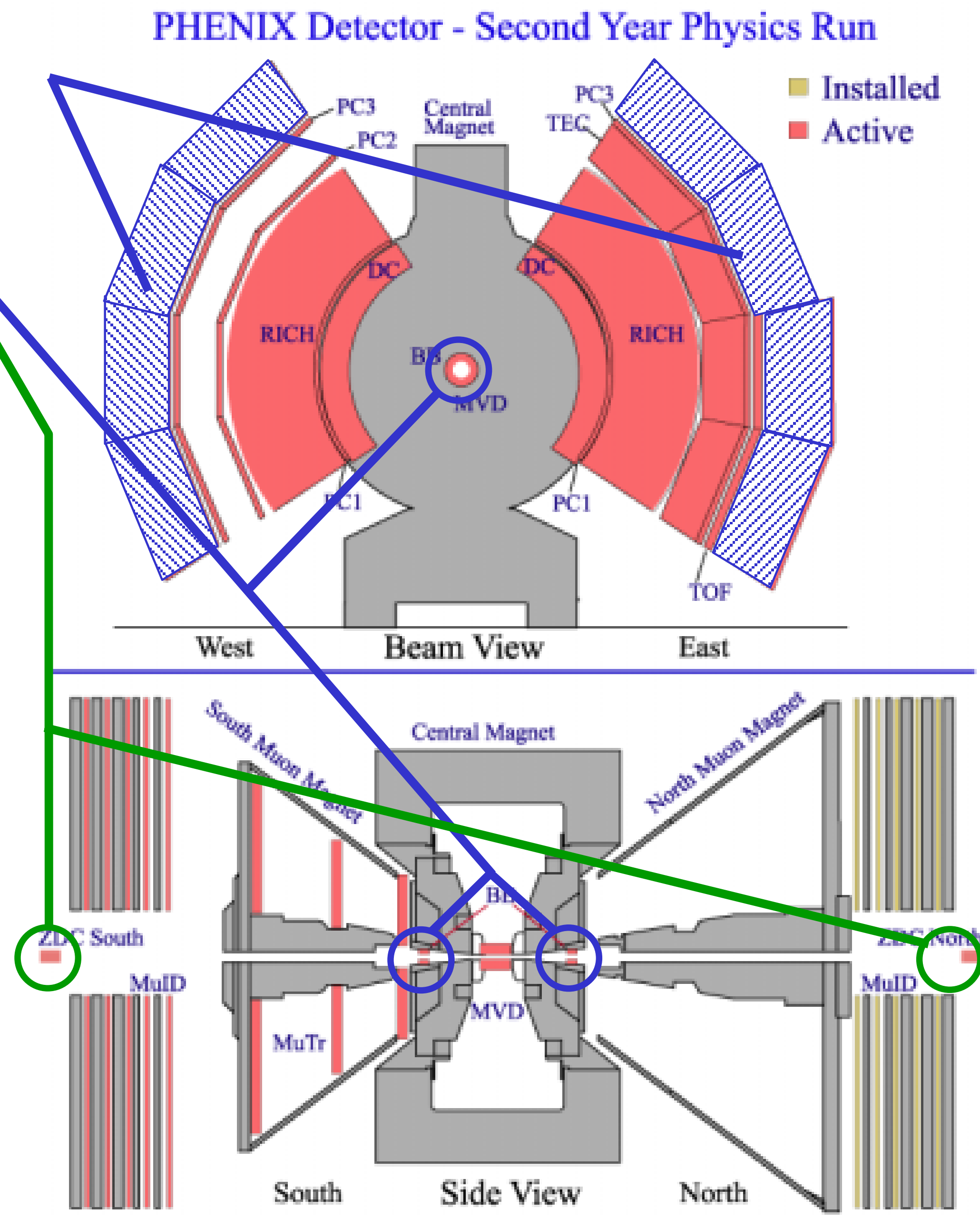
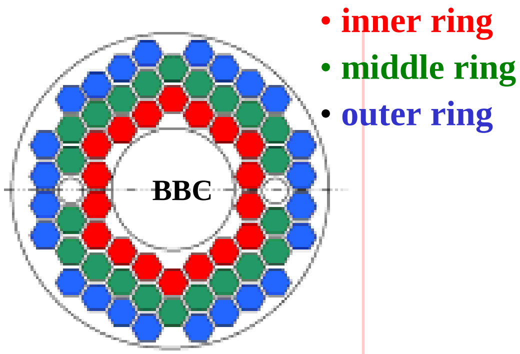
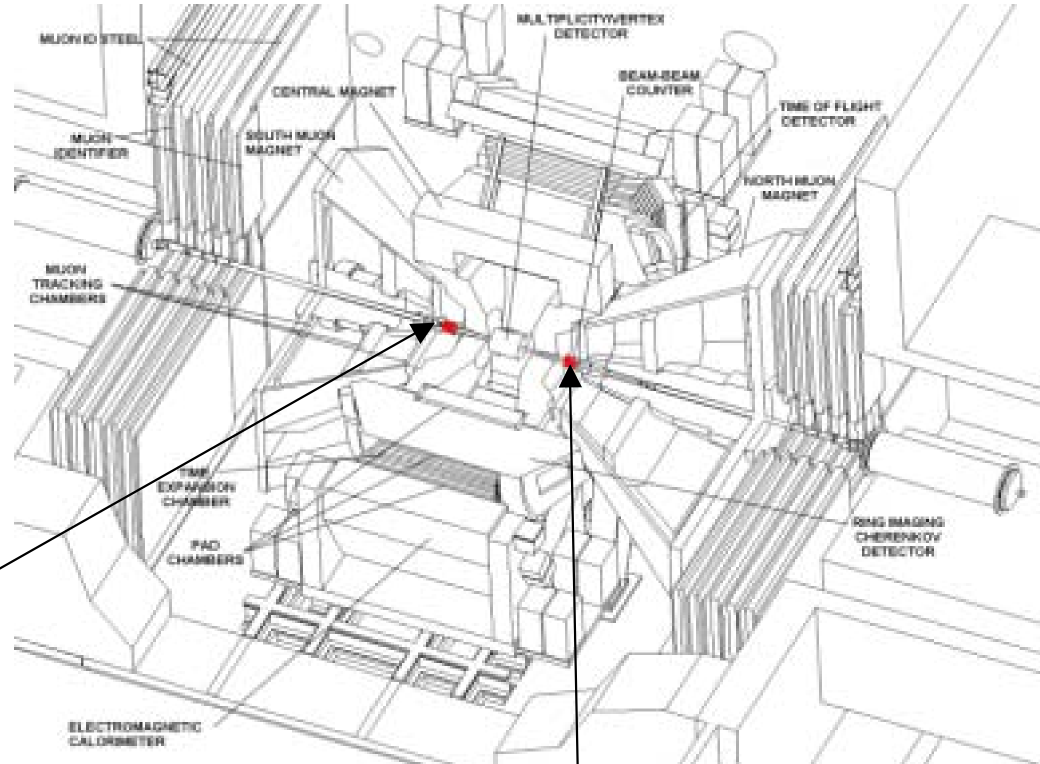
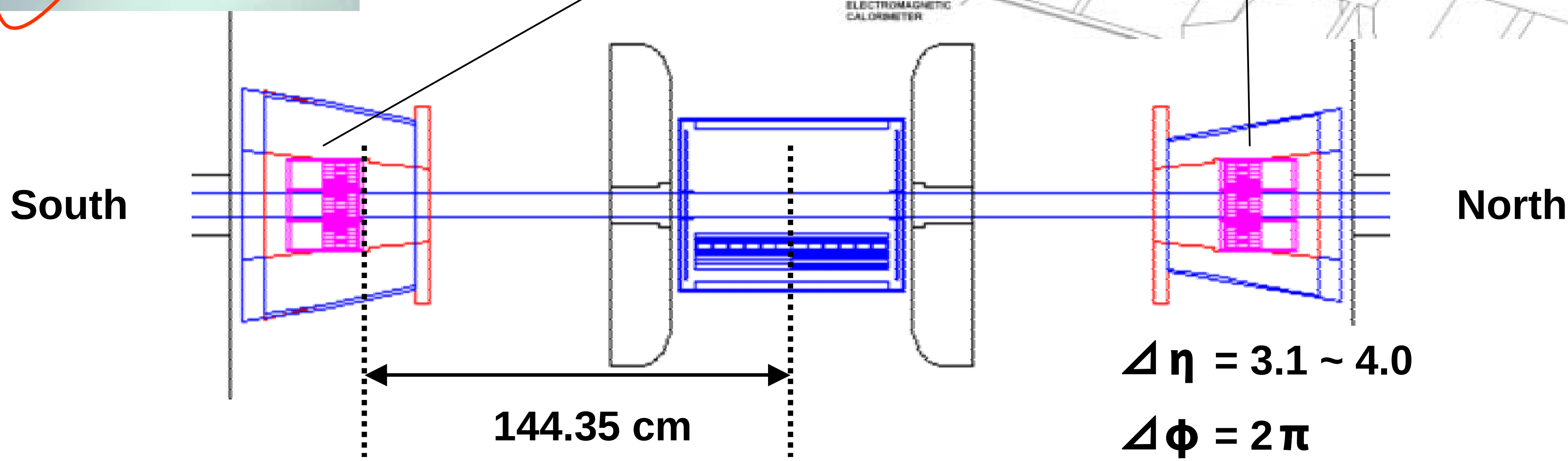


BBC in PHENIX



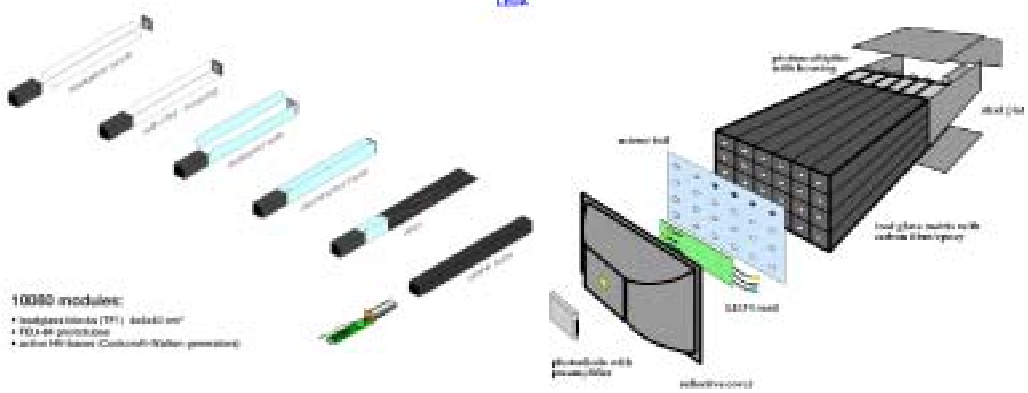


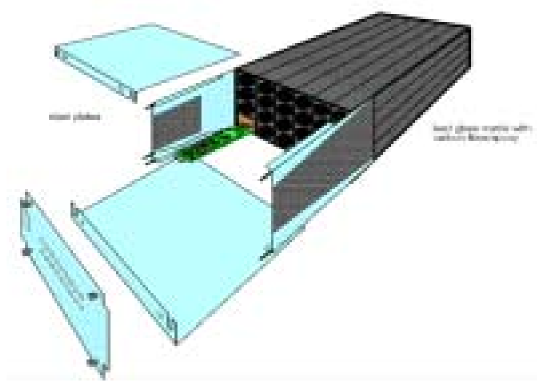


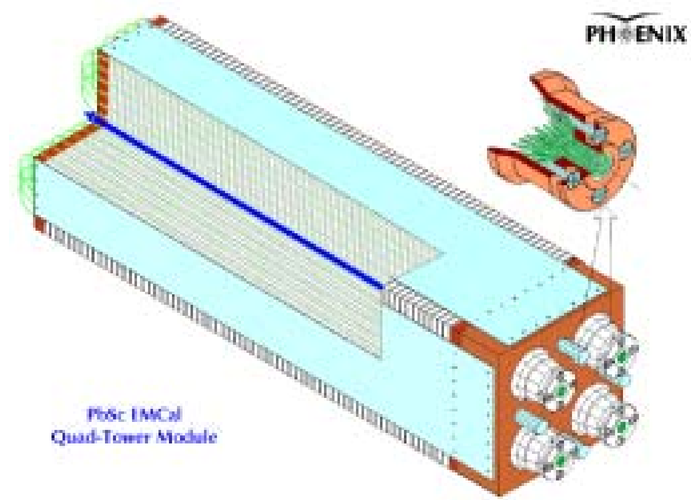
$\Delta\eta = 3.1 \sim 4.0$

$\Delta\phi = 2\pi$

PbGl and PbSc EMC's







- 1 Sector = 6x3 Supermodules (SM)
- 1 PbSc SM = 12x12 towers
- PbSc towers: 5.52 x 5.52 x 33 cm^3 (18 X_0)
- 15552 blocks total

1 PbSc tower:
- 66 sampling cells
- 1.5 mm Pb, 4 mm Sc
- Ganged together by penetrating wavelength shifting fibers for light collection
- Readout: FEU115M phototubes

- 2 Sectors PbGl
- 1 PbGl Sector
  - 16x12 supermodules (SM)
- 1 PbGl SM
  - 6x4 towers
  - Separate reference system
- 1 FEM
  - Reads out 2x3 supermodules or 12x12 towers

Method of π^0 and Photon v_2 Measurement

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

event anisotropy parameter measured

reaction plane angle

azimuthal angle of the particle

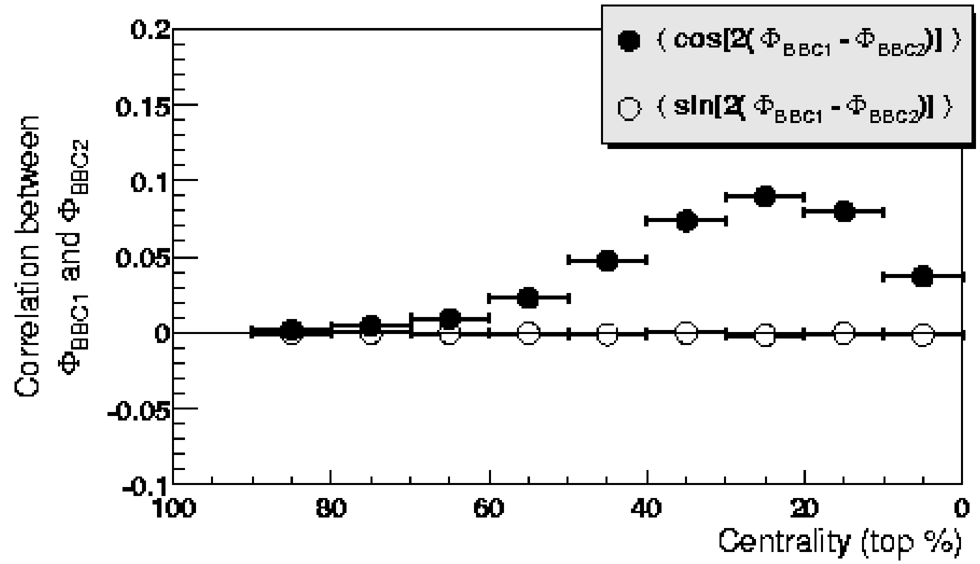
$$v_n^{real} = v_n^{measured} / (\text{reaction plane resolution})_n$$

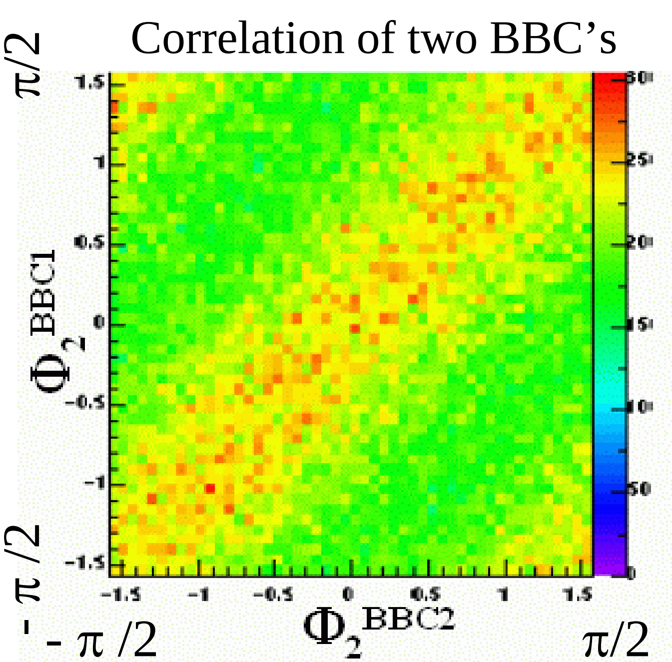
Note: the detail of reaction plane definition will be found in **nucl-ex/0305013**

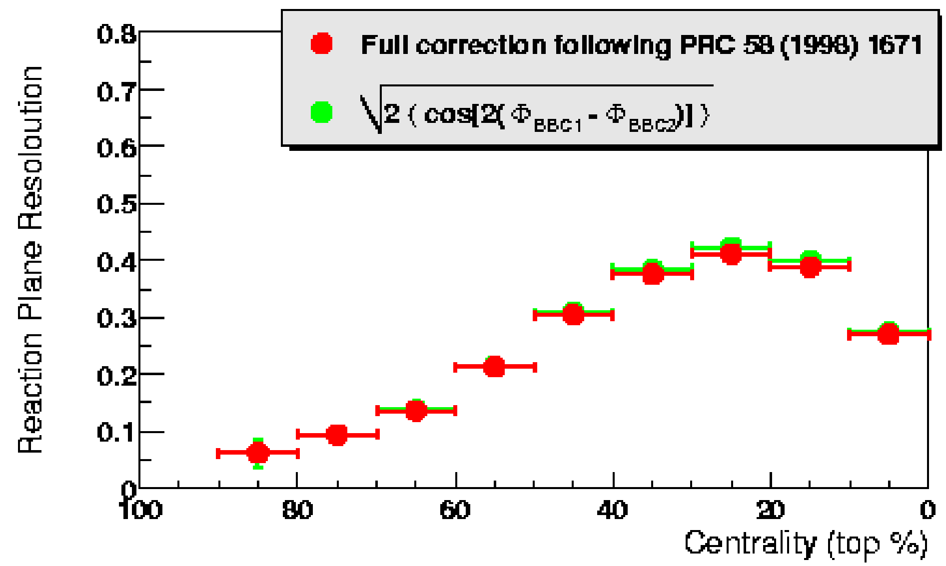
- Define reaction plane by charged multiplicity on Beam-Beam Counters
- Photon
  - Obtained second harmonic coefficient from <cos[2(ϕ-Φ_r)]>
- π^0
  - π^0 reconstruction and subtract background (combinatorial and the others)
    - For each p_T, azimuthal angle, centrality
  - Commbine both information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

Reaction Plane Defined by BBC's

- BBC north and south (η=3.1-4.0) are used
- Resolution calculation
  - Two sub-events are selected
  - North and south





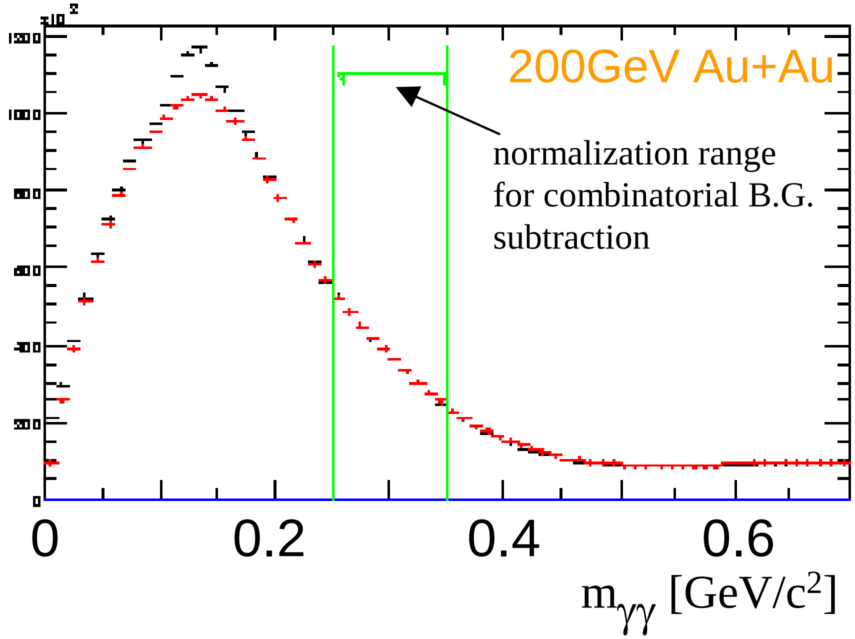


Photon and π^0 Identification

- 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 +
  - 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 $\pm\pi$

Example Plots from the π^0 v_2 Analysis Procedure

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



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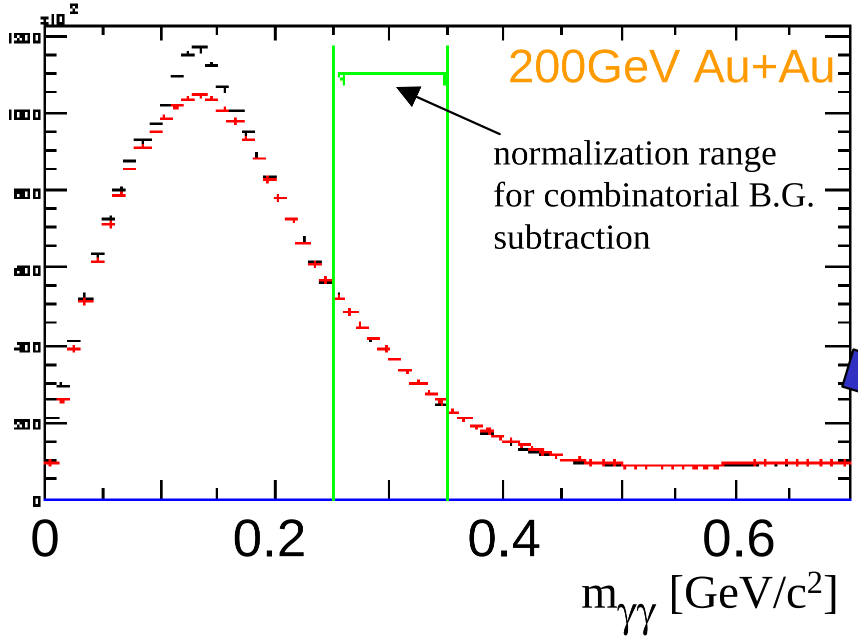
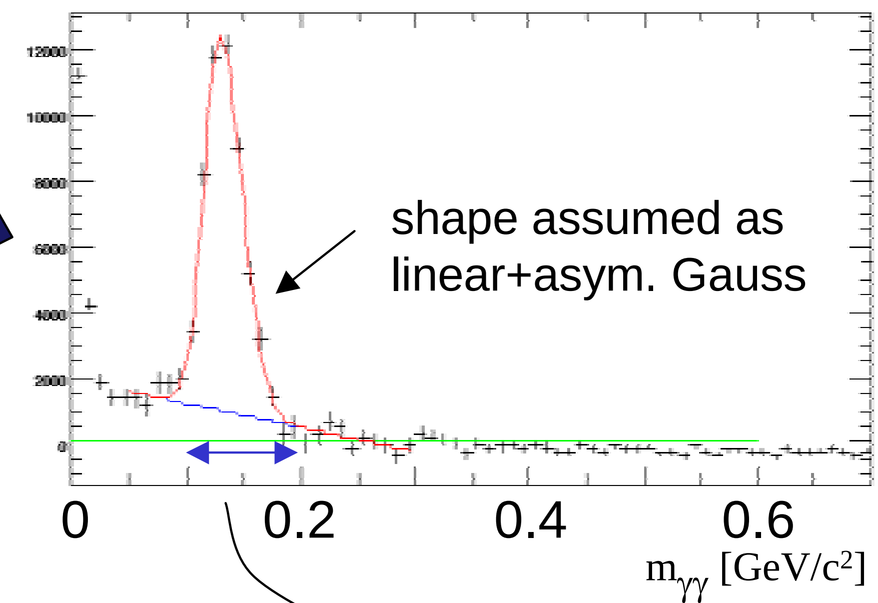


After subtraction, there is 2nd component of B.G. in p_T<2GeV/c region



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

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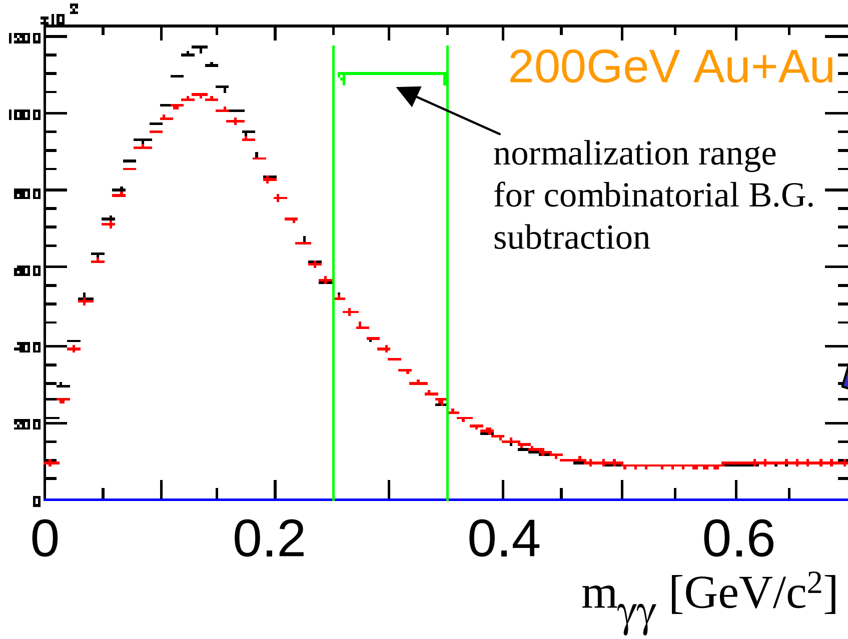

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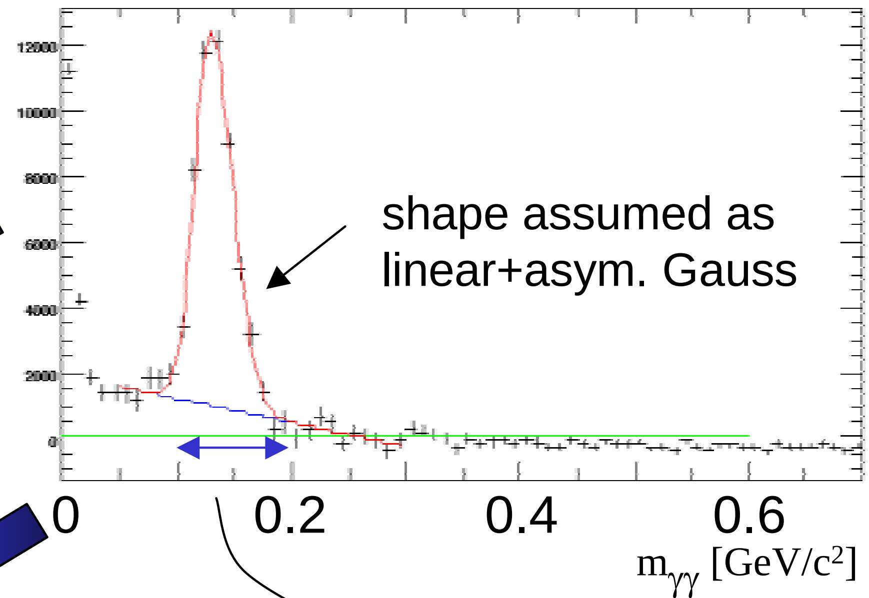

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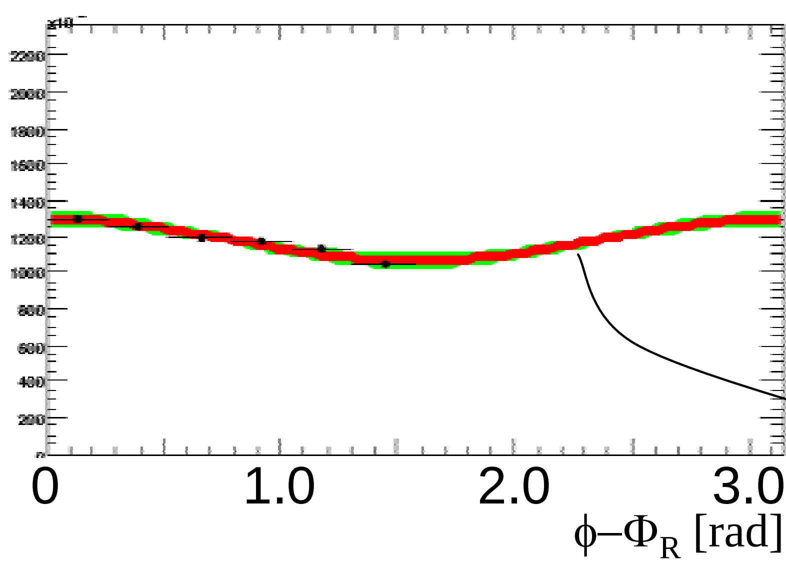


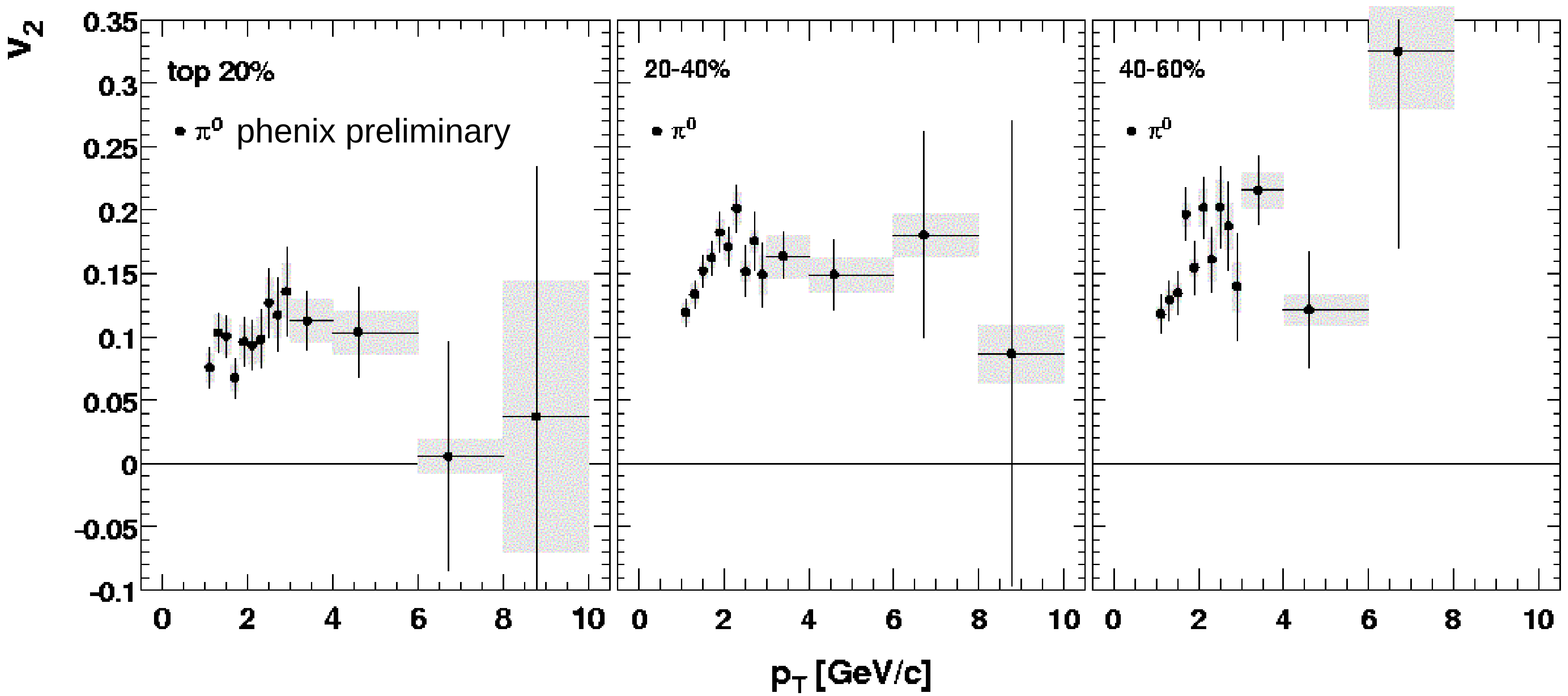
Fit function:

(average of π^0 count) $\times$ (1 + 2 v_2 $\cos[2(\phi - \Phi_R)]$)

Green lines : deviation by error of v_2

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 gray box



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

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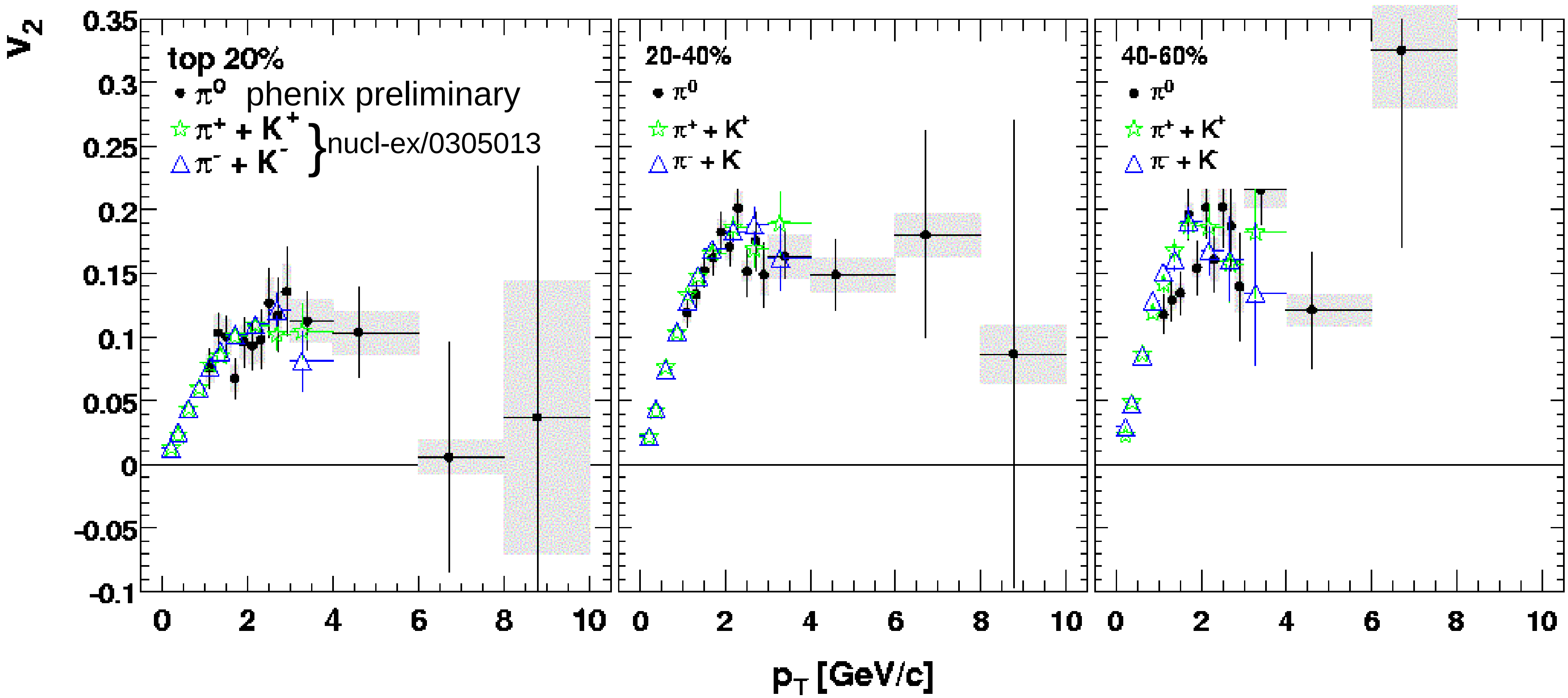
The charged π and K v_2 are shown only with statistical errors



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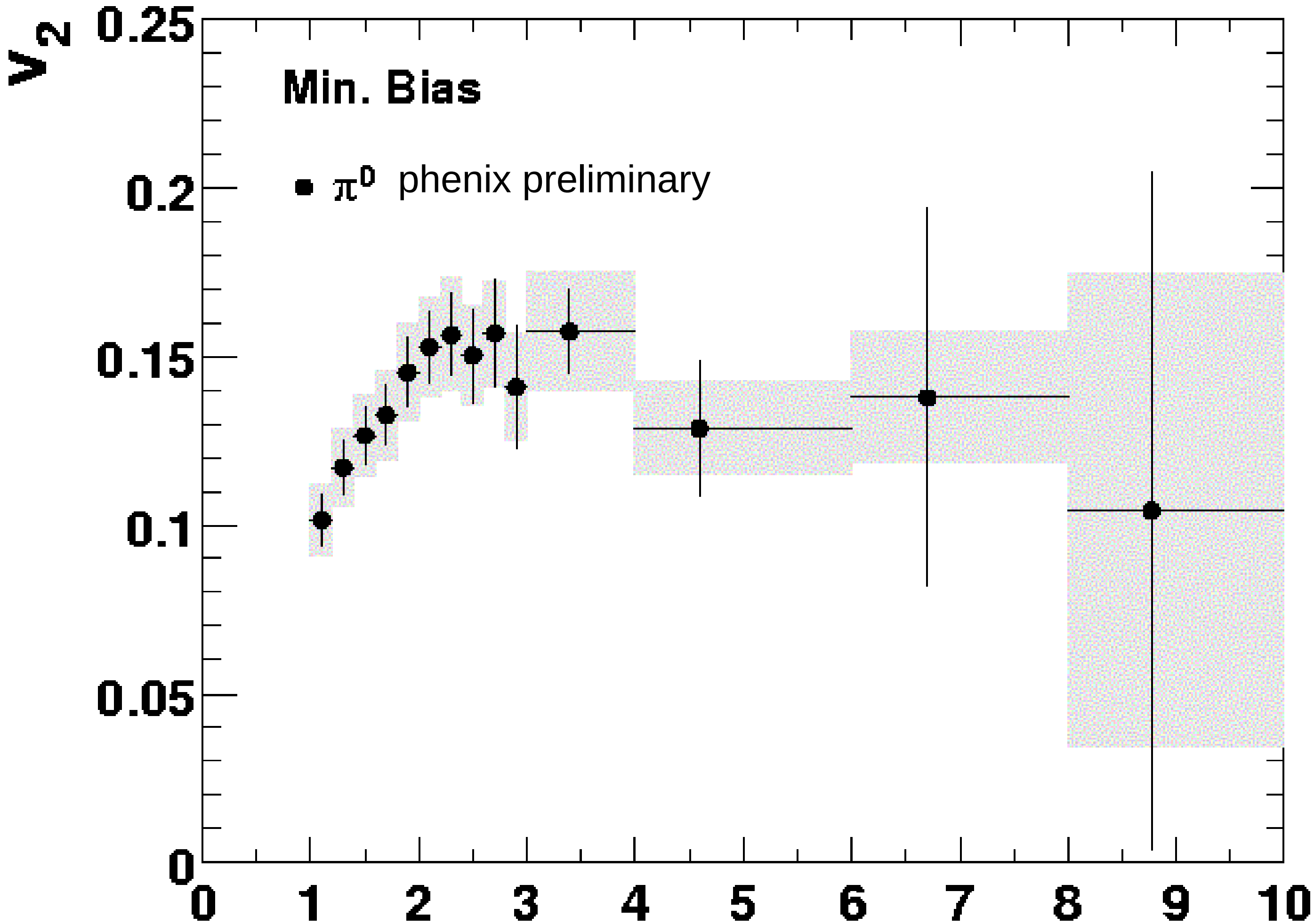
v_2 vs. p_T (Minimum Bias) from 200GeV Au+Au

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



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

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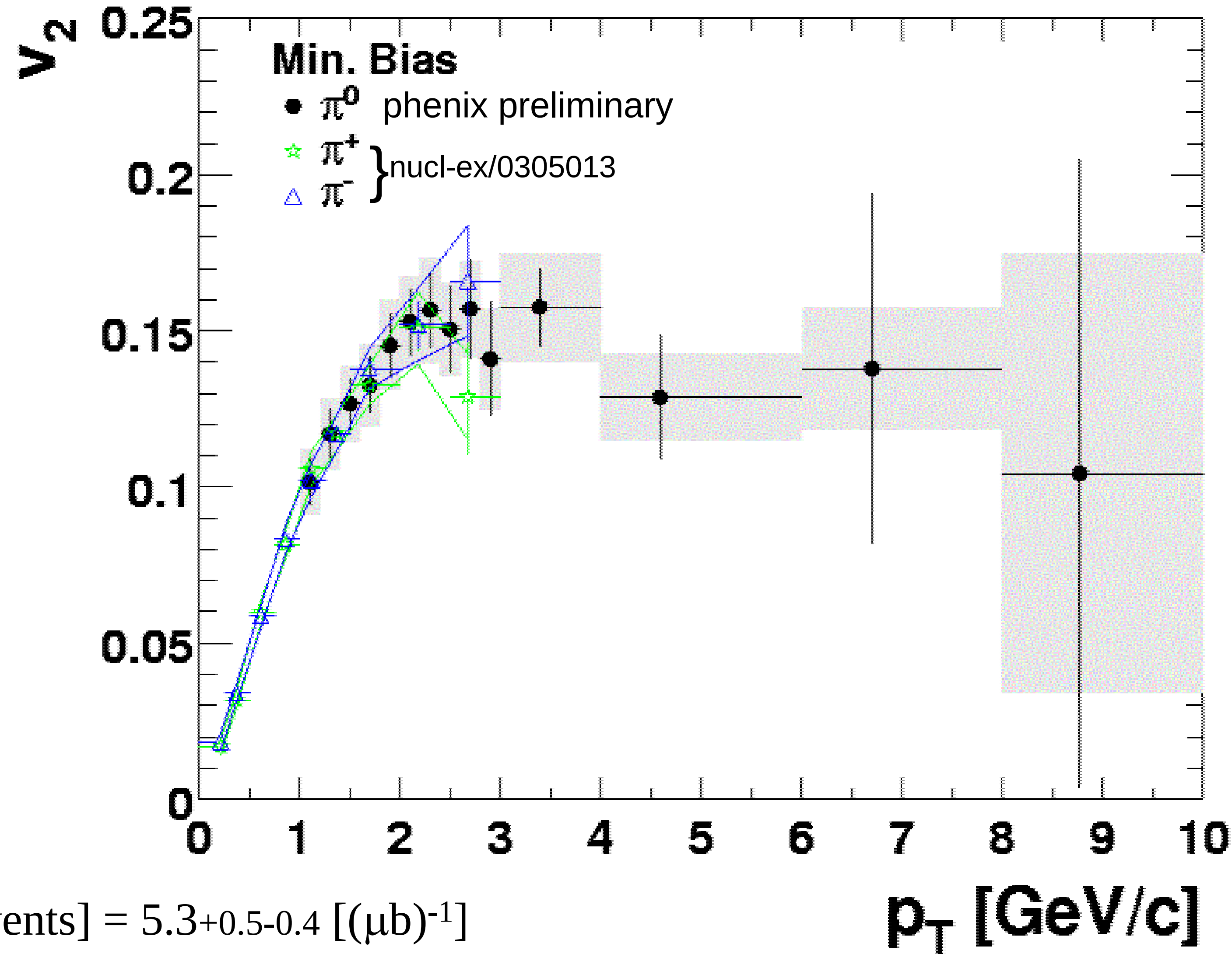

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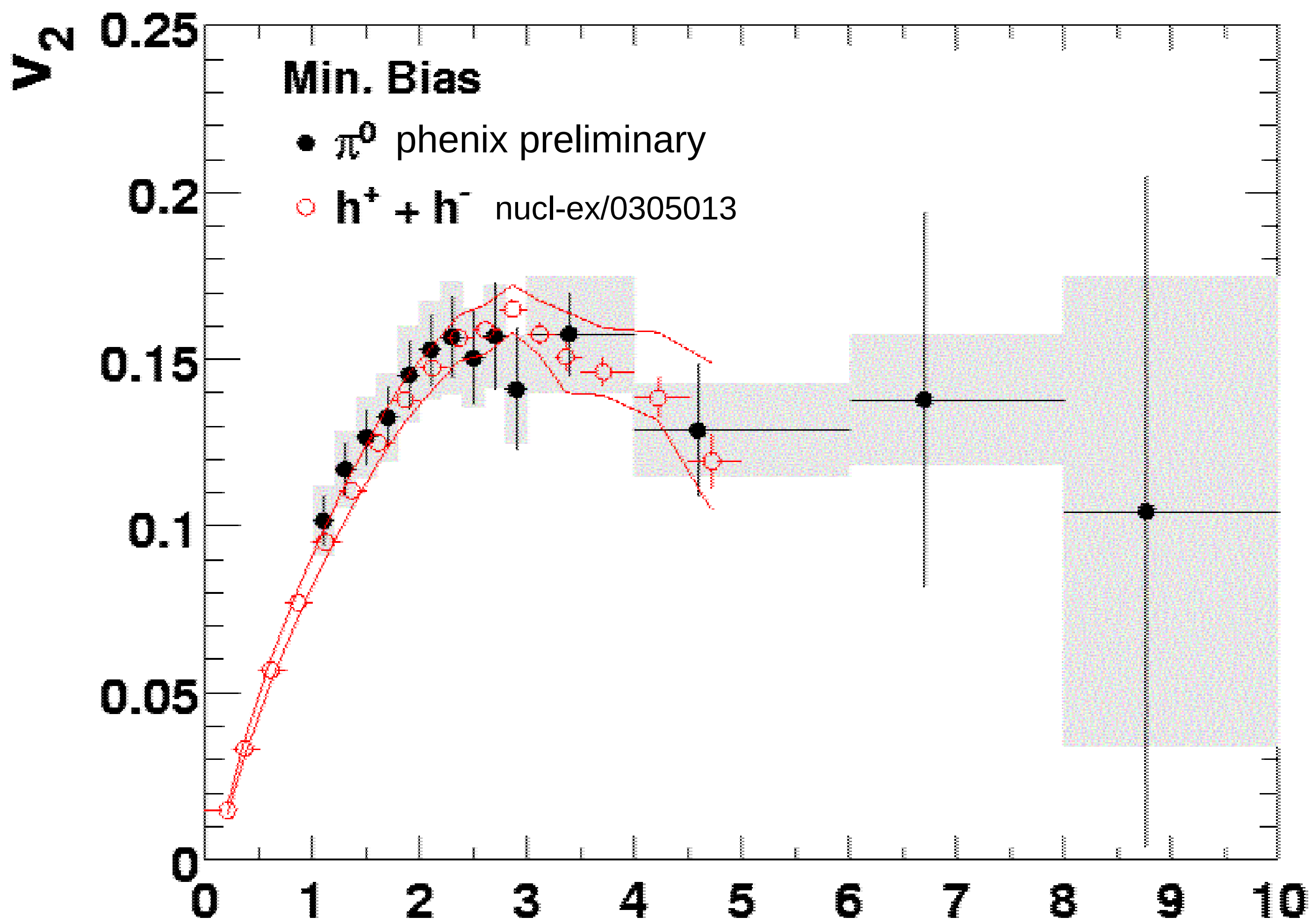

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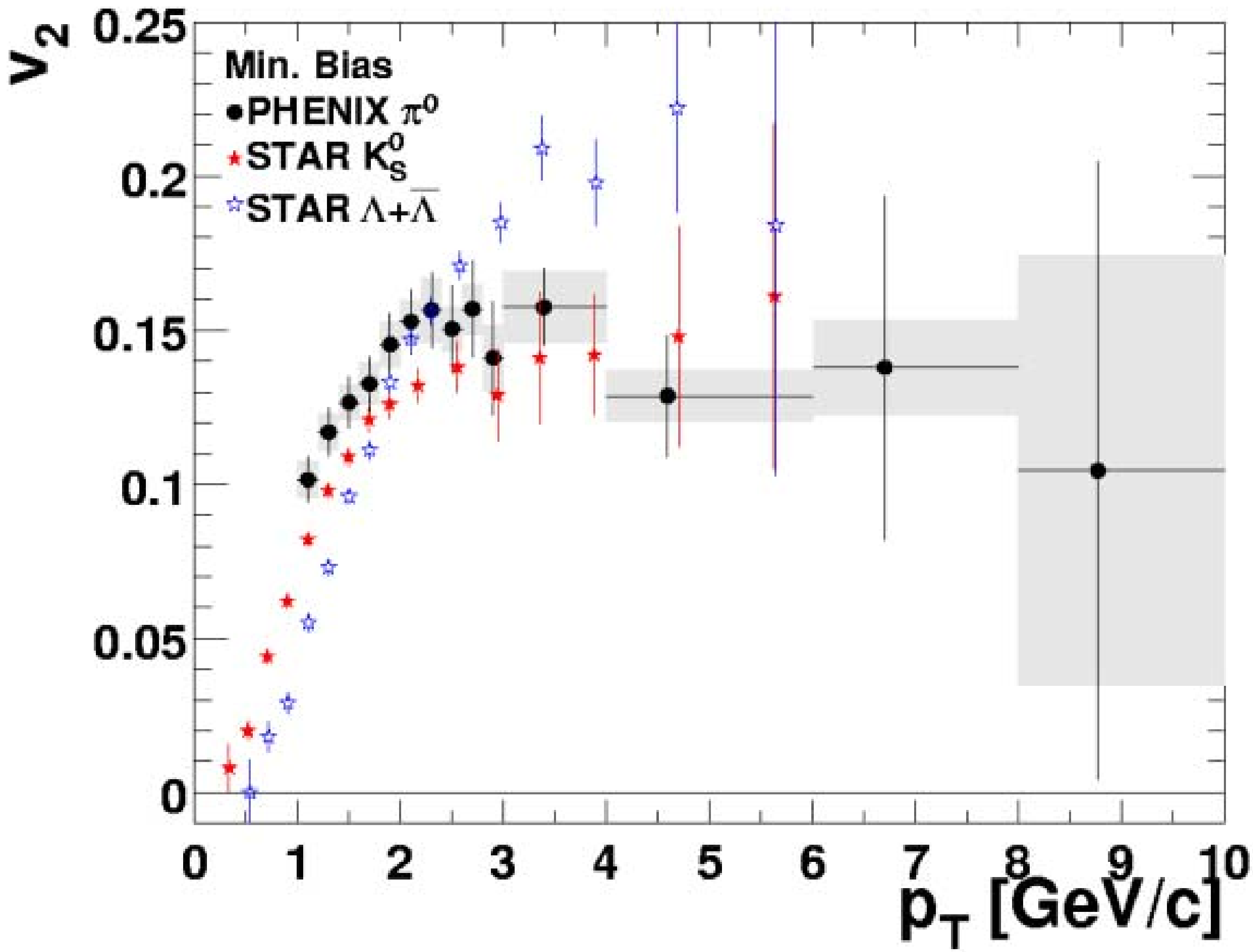
Comparison with K^0_S and Λ (STAR)



STAR data from nucl-ex/0306008

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

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

- How data looks like?
- Non-strange and strange meson and baryon seems to be merged around $p_T/n_{quark} \approx$1-3GeV/c
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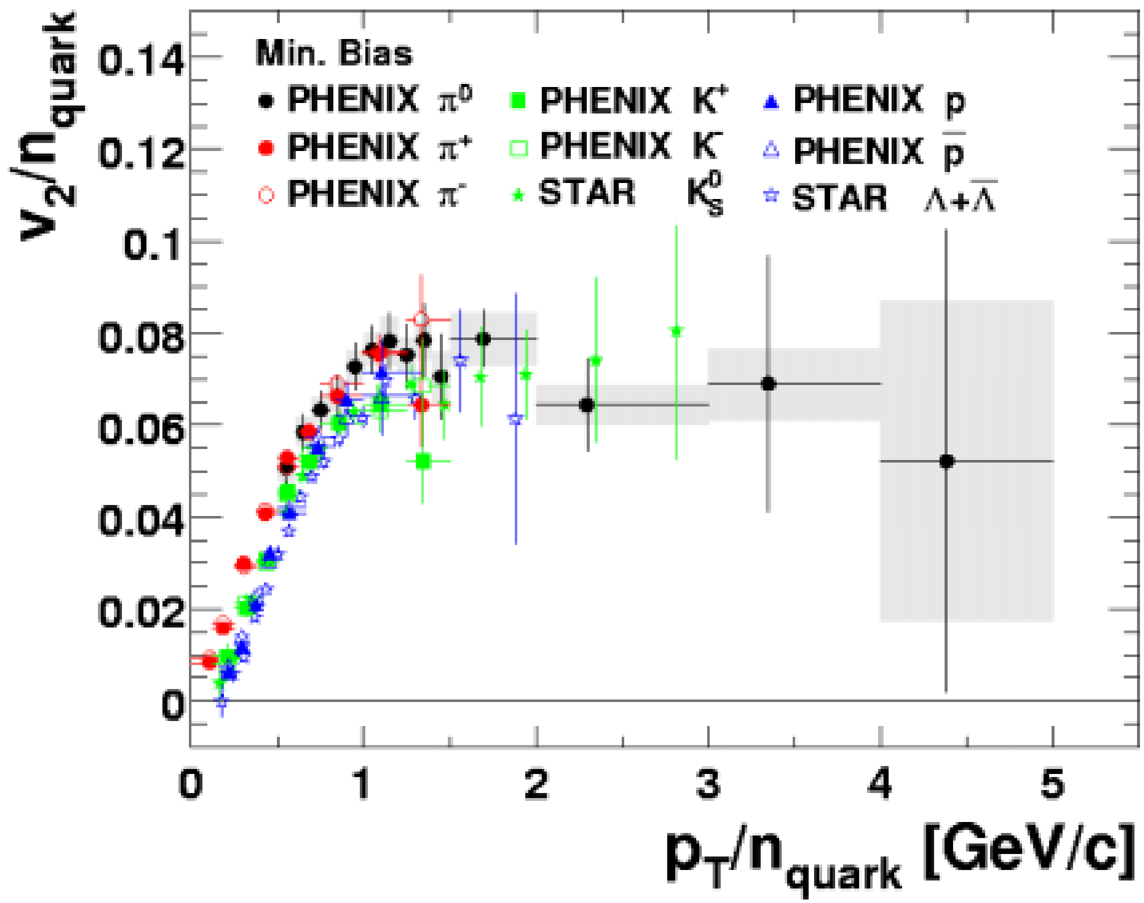
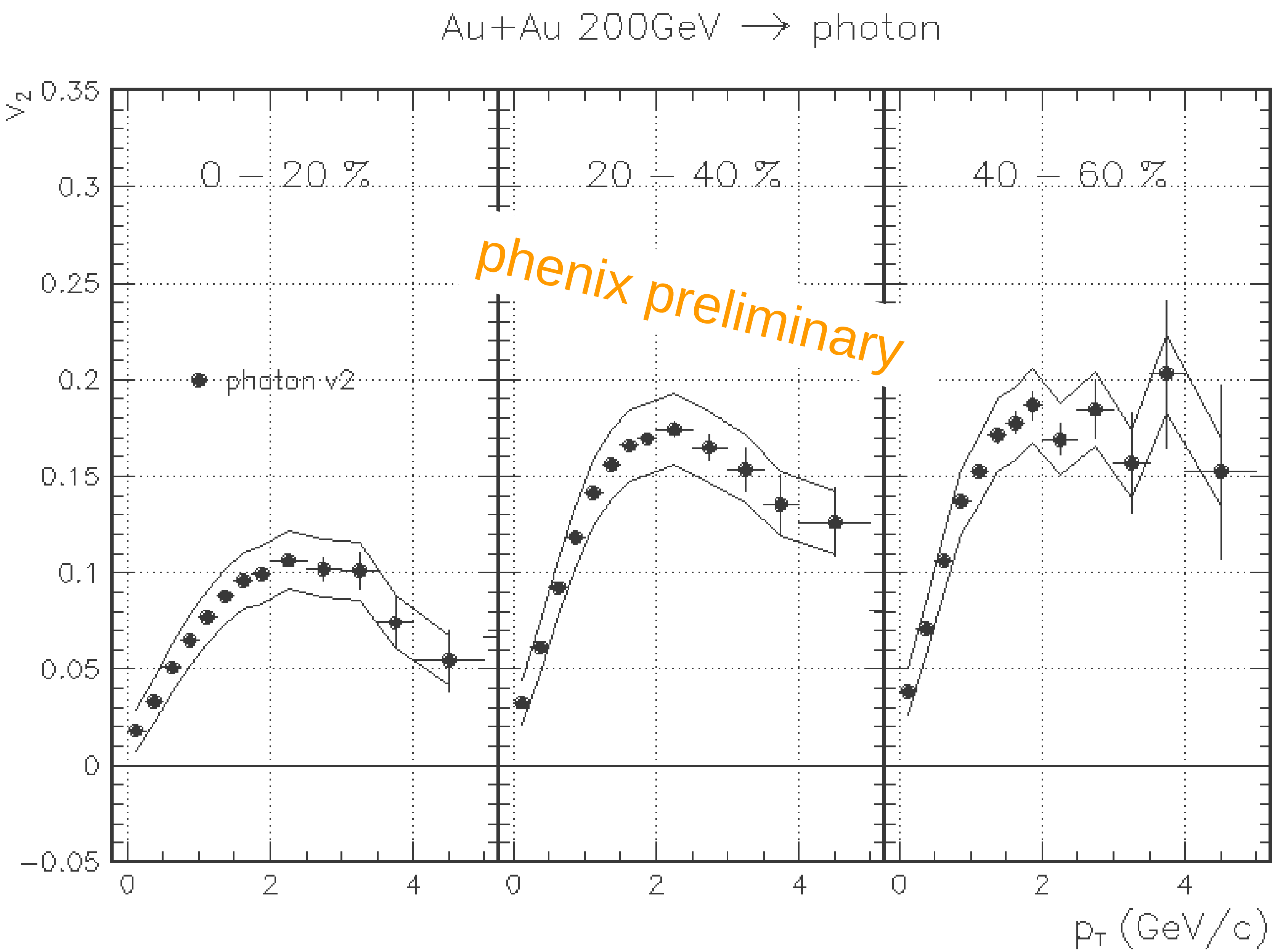
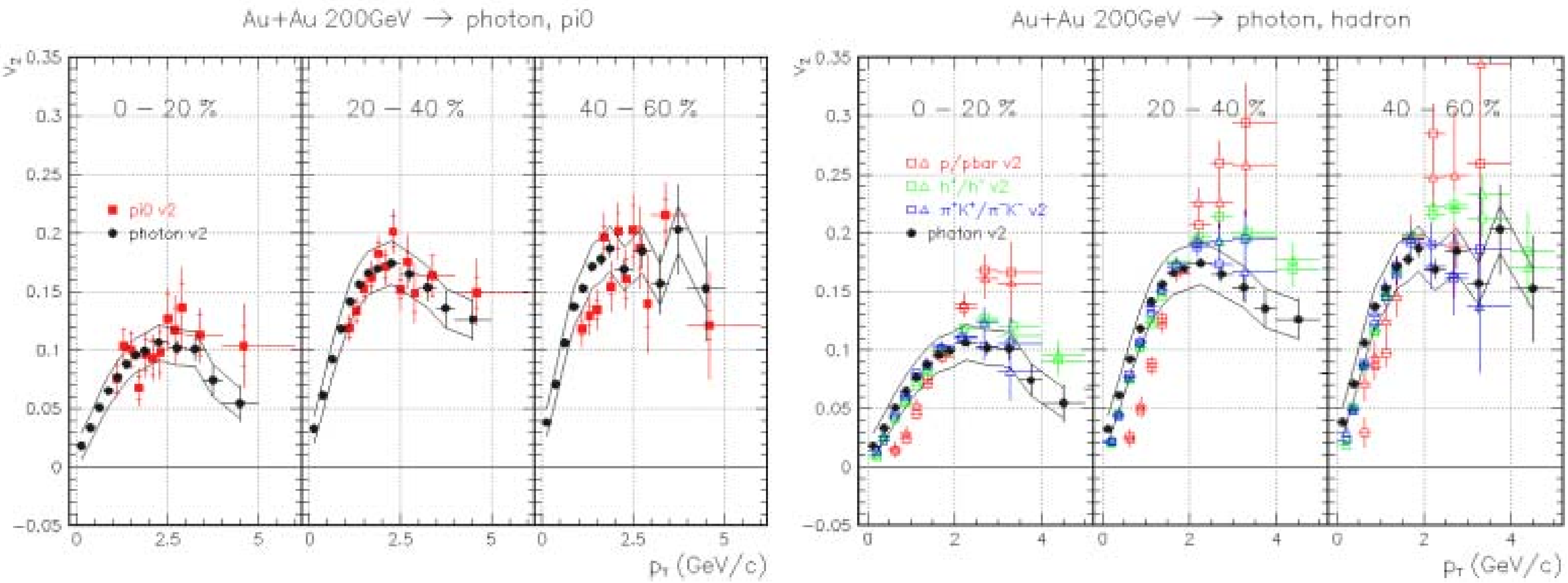


Photon v_2 from 200 GeV Au+Au

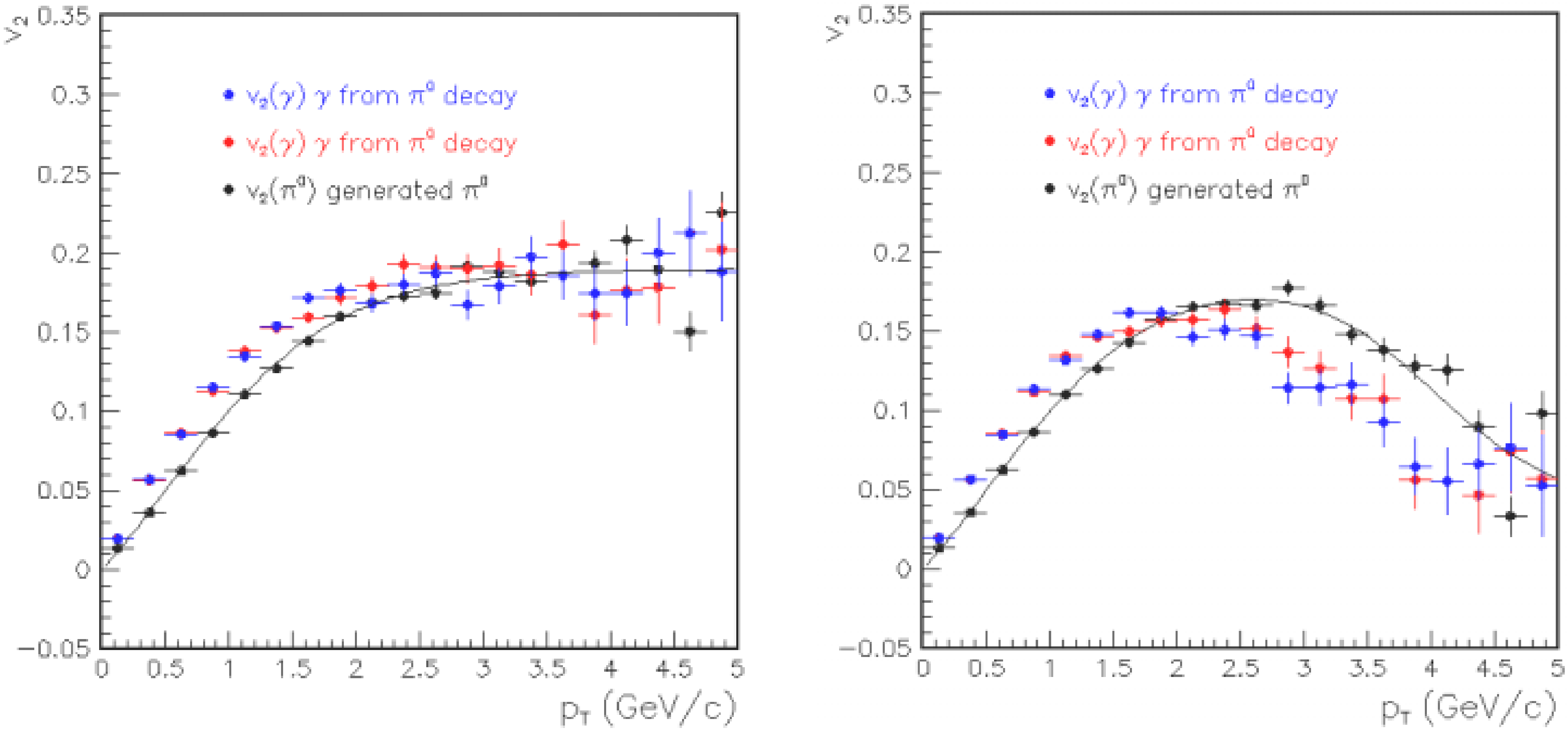


Photon v_2 and Hadron v_2



- 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

π^0 Decay Effect for Photon v_2



- Tool is ready, however..
  - We need more statistics to fix π^0 v_2 distribution as a function of p_T and also centrality

Summary

- π^0 v_2 at RHIC
  - First measurement
    - In p_T=1-10 GeV/c
    - v_2 of the highest p_T from identified particle
  - Charged π v_2 consistent with π^0 v_2
    - In p_T=1-3GeV/c
  - Minimum bias data shows finite π^0 v_2
    - Up to p_T~8 GeV/c
- Photon v_2
  - increasing with *pT* up to ~2GeV/c
  - and saturated then decreasing(?)
  - We hope to see photon v_2 after decay effect subtraction with more data

Outlook

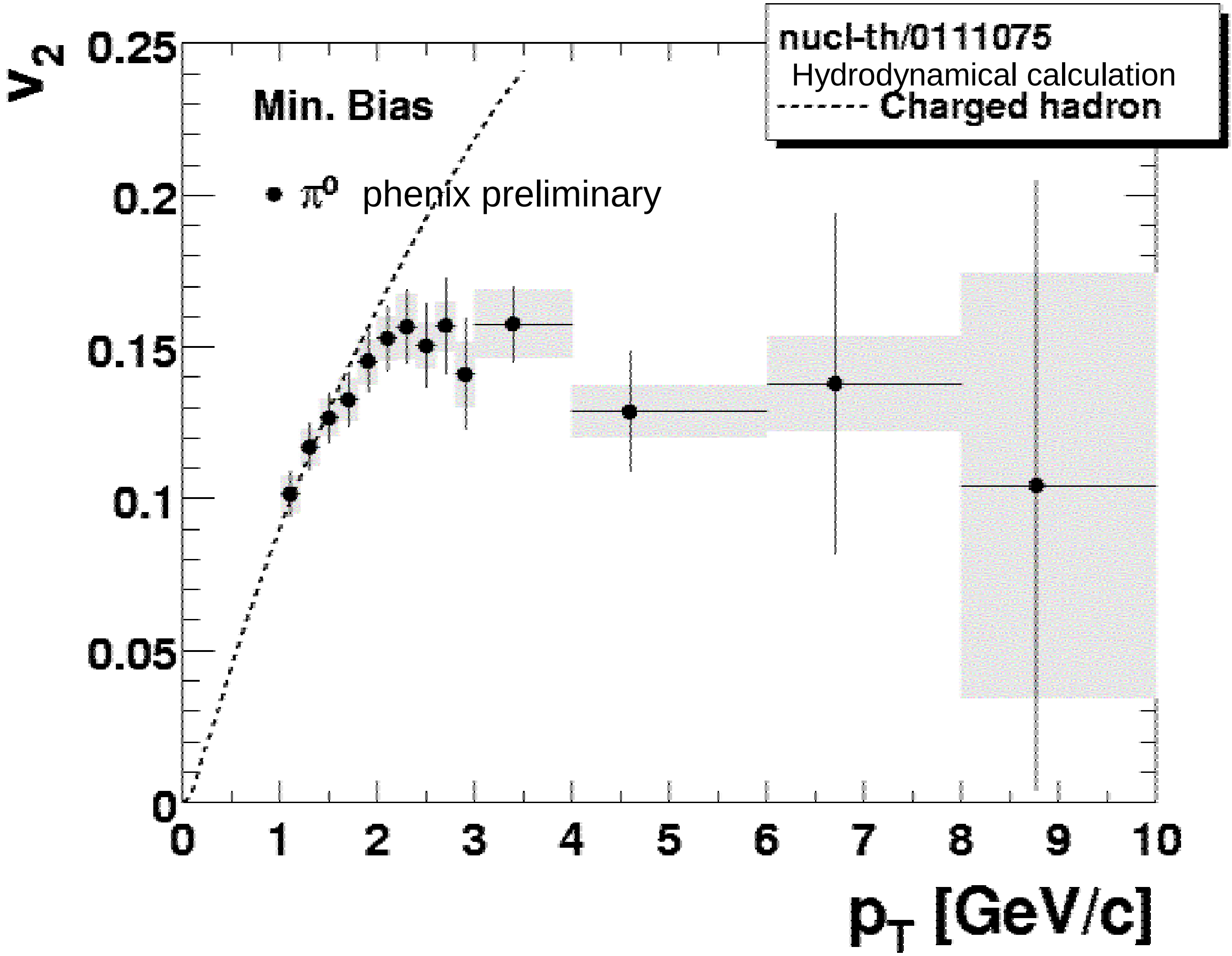
- Feature plan of analysis
  - Using high p_T gamma trigger in run2 Au+Au data
    - We will have about twice statistics in high p_T
    - need to study trigger bias
      - therefore, present analysis results are from minimum bias trigger events
  - η v_2 will be also available by same method
  - PHENIX has photon v_2 also
  - Photon v_2 after hadron decay effect, especially low p_T!
- RHIC run4 Au+Au, it will be
  - Much more statistics
    - Detail study of v_2 shape around p_T=2-4GeV/c
  - Much higher p_T
    - We want to know where is the end of finite v_2 in very high p_T
  - Also capability of photon measurement in low p_T by conversion finding

Backup

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 BBC (η=3-4)
- Correlation method for v_n
- Cross section and HBT radii in-plane and out-plane

Comparison with a model



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

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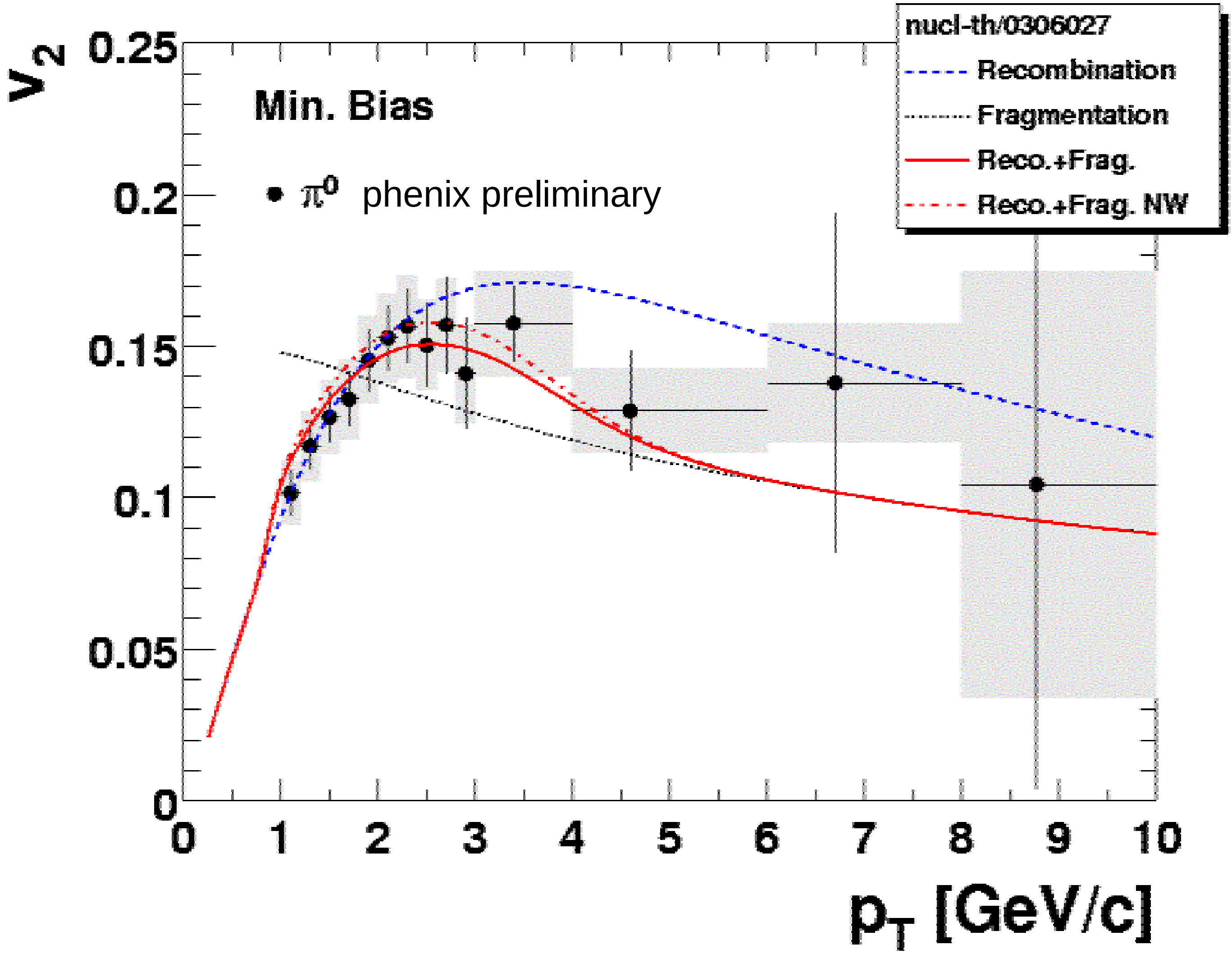


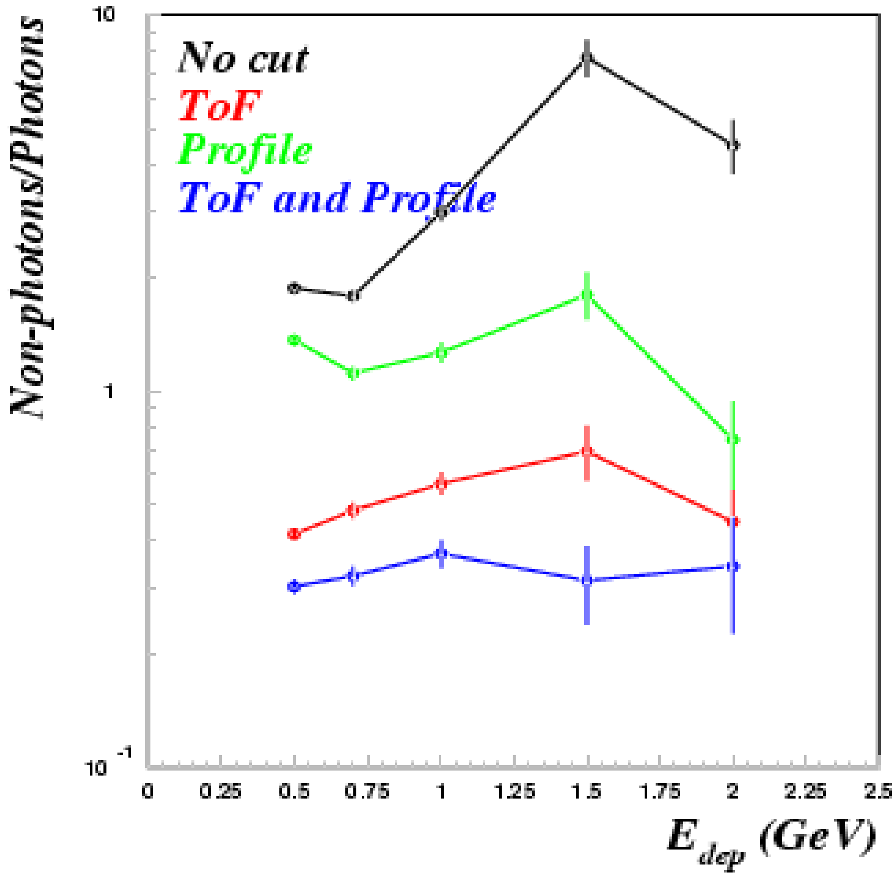
Special thanks to
C. Nonaka (one of authors)
of nucl-th/0306027 for
data of model calculation

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.