



STAR



Higher harmonic flow of ϕ meson in STAR at RHIC

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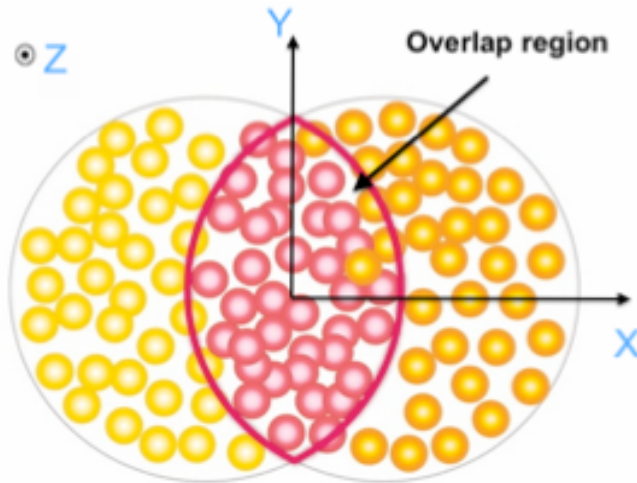
OUTLINE:

- ✓ Introduction and Motivation
- ✓ STAR Detector and Data set
- ✓ Analysis Method
- ✓ Results
- ✓ Summary



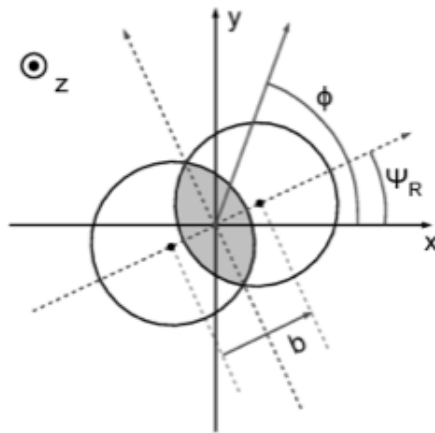
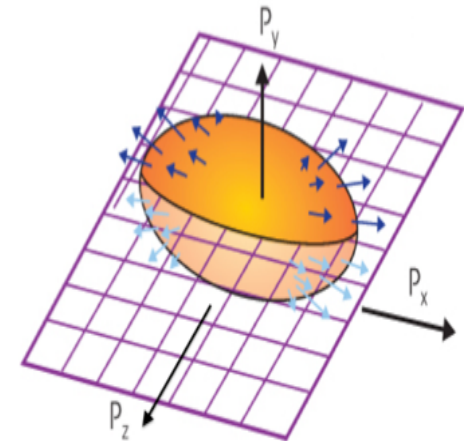
Mukesh Sharma ICPAQGP 2015

Introduction: Azimuthal anisotropy



Interactions
↓
Pressure (P)

$y > x \longrightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y}$



$$\frac{dN}{d\phi} \propto \frac{1}{2\pi} \left[1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \psi_R)) \right]$$

$$\phi = \tan^{-1} \left(\frac{P_y}{P_x} \right)$$

$$v_n = \langle \cos[n(\phi - \psi_R)] \rangle$$

- ψ_R is the azimuthal angle of the reaction plane (spanned by impact parameter and beam direction)
- v_2 , v_3 and v_4 are called elliptic, triangular and quadrangular flow

A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671(1998).



Motivation

- ϕ meson has small hadronic interaction cross section. Thus ϕ meson v_n is less affected by later stage hadronic interaction. Hence ϕ meson is a clean probe to study the medium created in the early stage of collisions.
- The ratios between various harmonics can be used to understand the properties of the system created in heavy-ion collisions.

Coalescence Model

$$\frac{v_{4,M}(2p_T)}{v_{2,M}^2(2p_T)} \approx \frac{1}{4} + \frac{1}{2} \frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}$$

Where $v_{n,q}(p_T) = kv_{2,q}^{n/2}(p_T)$

If $k=1$ $\frac{v_{4,M}(2p_T)}{v_{2,M}^2(2p_T)} \approx 0.75$

Hydro Model

$$\frac{v_4}{v_2^2} = 0.5$$

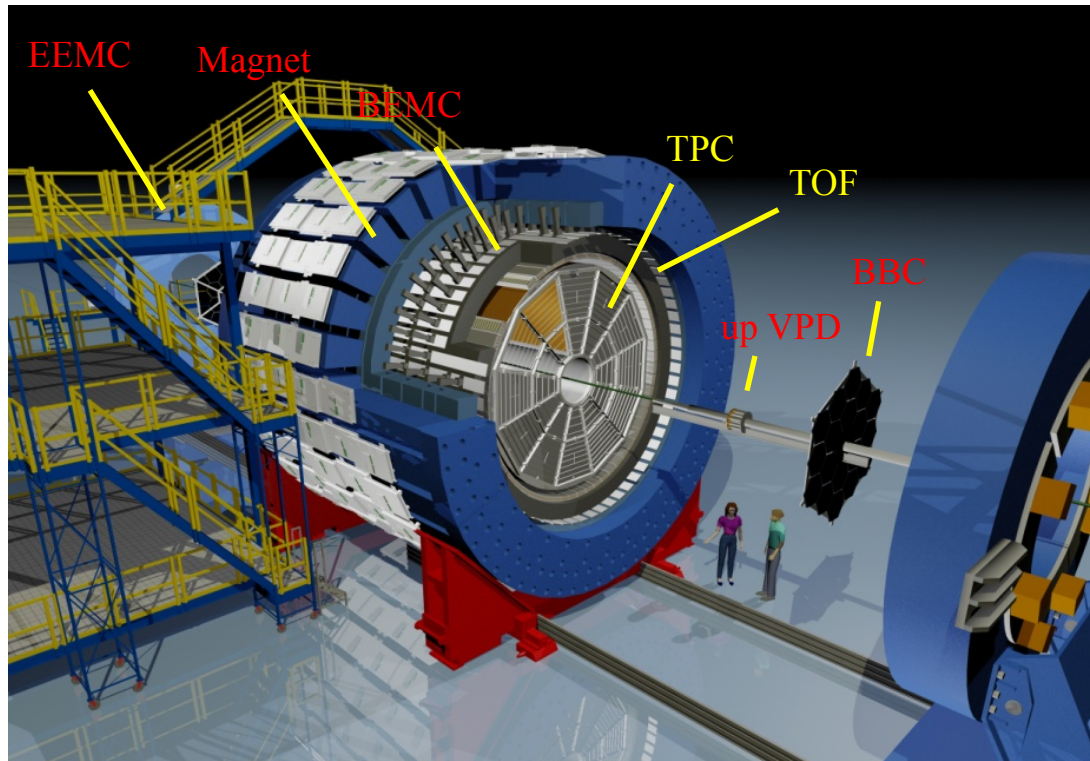
$$\frac{v_3}{v_2} = \text{Constant at high } p_T$$

L. W. Chen et al., Phys. Rev. C 73, 044903 (2006).

J. Adams et al. (STAR Collaboration), Nucl. Phys. A 757, 102 (2005).

C. Lang et al., Eur. Phys. J. C 74 (2014) 2955.





Magnetic field 0.5 Tesla
 Full azimuthal coverage
 $(0, 2\pi)$
 $|\eta| < 1.0$ for TPC and
 $|\eta| < 0.9$ for TOF

| Data Set | Vertex Cut | Trigger | No. of events |
|--------------------------|-----------------------------------|---------|---------------|
| AuAu 200 GeV (Run 11) | $ V_z < 30$ cm $ V_r < 2$ cm | MinBias | 560 Million |



Particle Identification with STAR TPC and TOF

☐ TPC

- Full azimuthal coverage ($0, 2\pi$)
- Identifies kaon up to $p = 0.65$ GeV/c
- **Bethe Bloch Formula**

$$-\left\langle \frac{dE}{dx} \right\rangle \sim A \left(1 + \frac{m^2}{p^2} \right)$$

- Particle identifies using

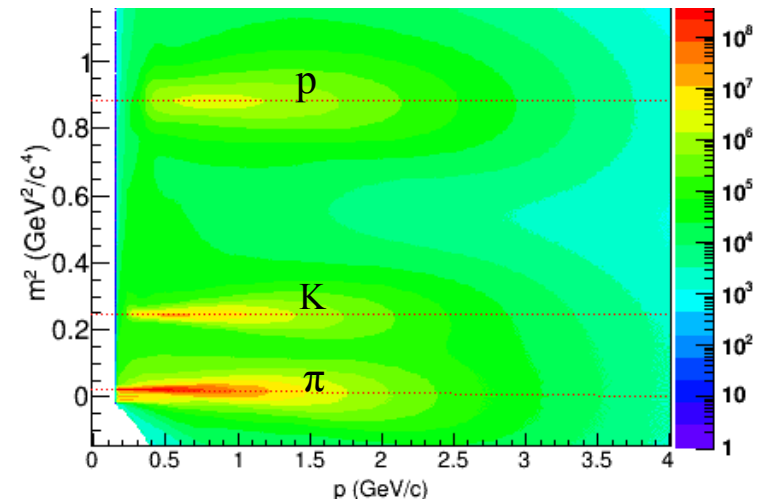
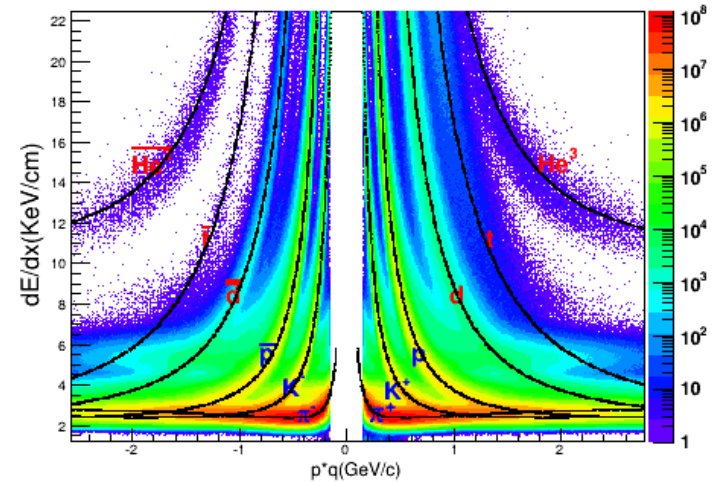
$$N\sigma = \frac{1}{R} \times \log \left(\frac{dE / dx_{measured}}{dE / dx_{theory}} \right)$$

☐ TOF

- Full azimuthal coverage ($0, 2\pi$)
- Kaons can be identified up to 1.6 GeV/c

▪ Time of Flight

$$\langle t \rangle = \frac{L}{\beta} \quad \frac{1}{\beta} = \sqrt{1 + \frac{m^2}{p^2}}$$



Hans Bichsel, NIM Phys Research A 562 (2006) 154–197.





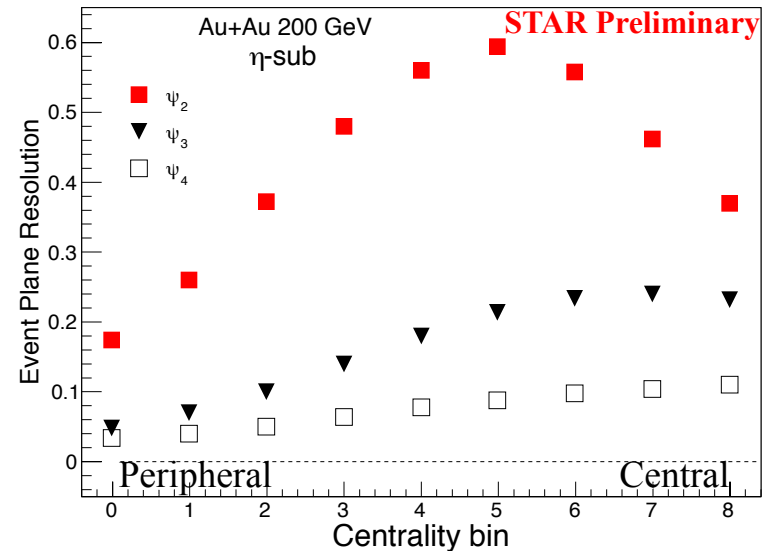
Event Plane Resolution

- Event Plane defined as:

$$\Psi_n = \left(\tan^{-1} \left[\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)} \right] \right) / n$$

- Event Plane angle calculated in two different windows ‘west’ ($\eta > 0.075$) and ‘east’ ($\eta < -0.075$)
 - η sub-event method used with η -gap = 0.15
 - Event Plane Resolution then given by:
- $$R = \sqrt{\langle \cos[n(\Psi_n^{west} - \Psi_n^{east})] \rangle}$$
- event- by- event resolution correction

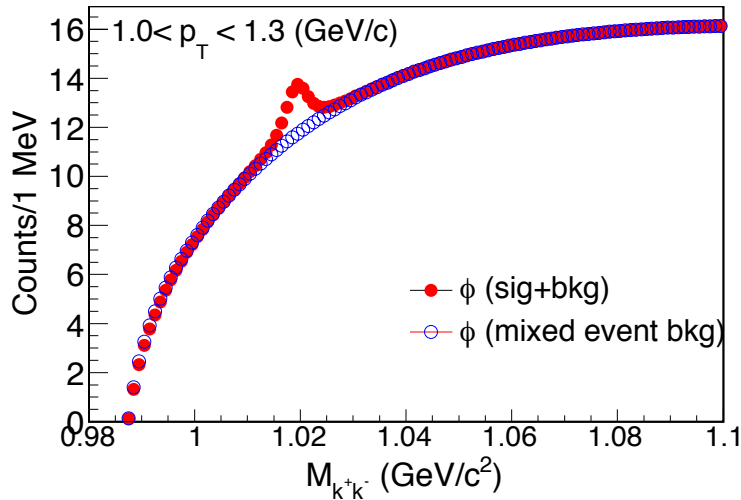
$$\langle v_n \rangle = \left\langle \frac{v_n^{obs.}}{R} \right\rangle$$



A.M. Poskanzer & Voloshin, Phys.Rev. C58 (1998).

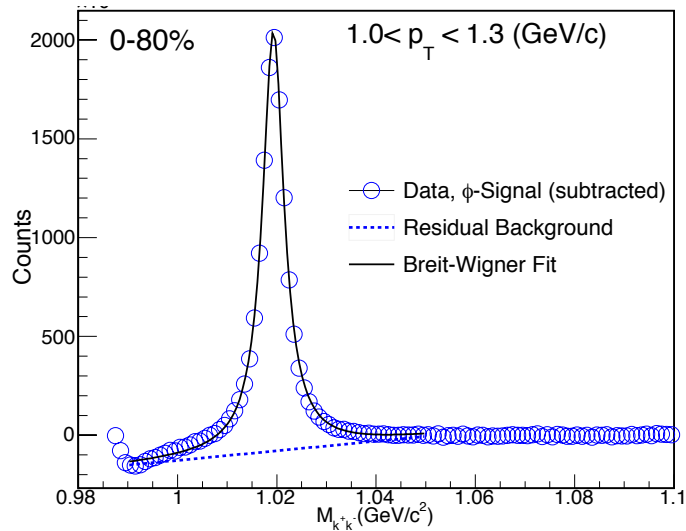
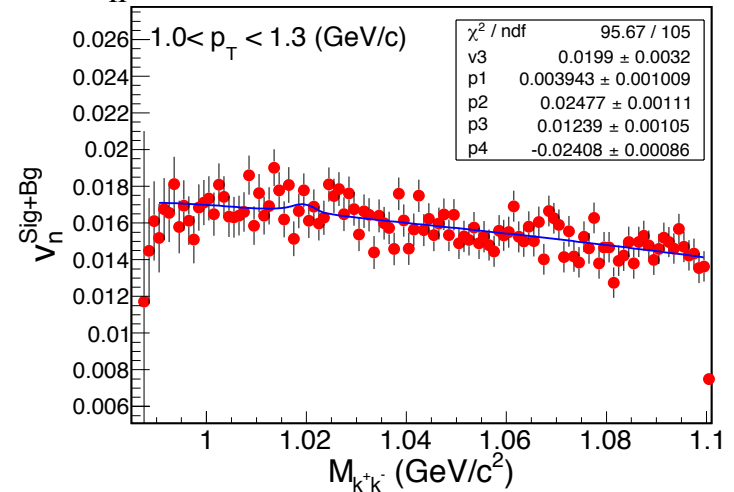


ϕ -meson signal extraction



- ϕ meson decay $\rightarrow K^+K^-$ (B.R 48.9 %)
- Background reconstructed from mixed events
- ϕ signal is fitted with BW + 1st order polynomial

V_n vs Invariant mass method

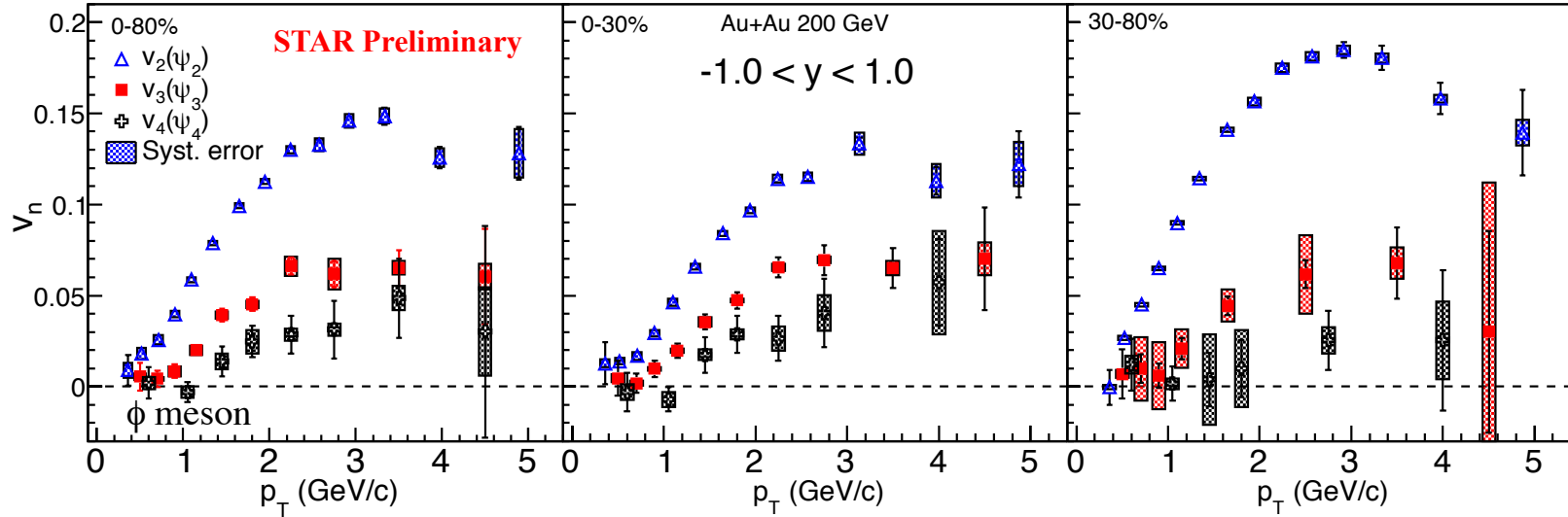


$$v_n^{\text{Sig+Bg}}(m_{\text{inv}}) = \langle \cos(n(\Phi - \Psi)) \rangle$$

$$= v_n^{\text{Sig}} \cdot \frac{\text{Sig}}{\text{Sig} + \text{Bg}}(m_{\text{inv}}) + v_n^{\text{Bg}} \cdot \frac{\text{Bg}}{\text{Sig} + \text{Bg}}(m_{\text{inv}})$$

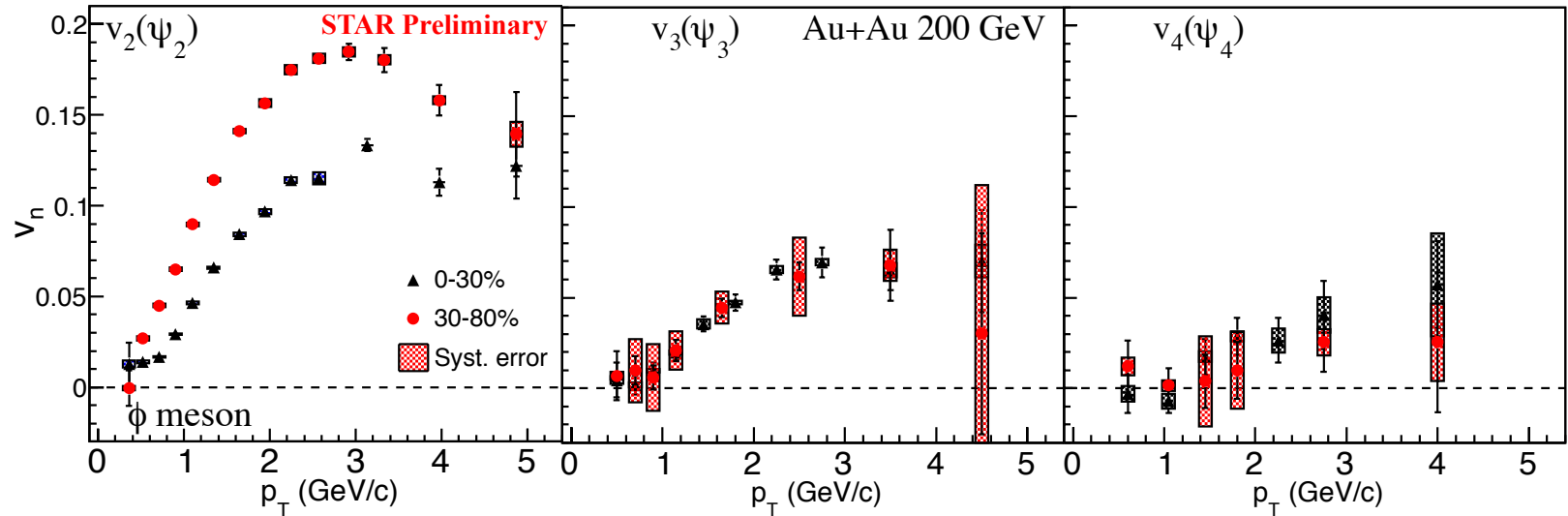
N. Borghini and J. Ollitrault Phys.Rev. C 70, 064905(2004).

v_2 , v_3 , v_4 of ϕ meson



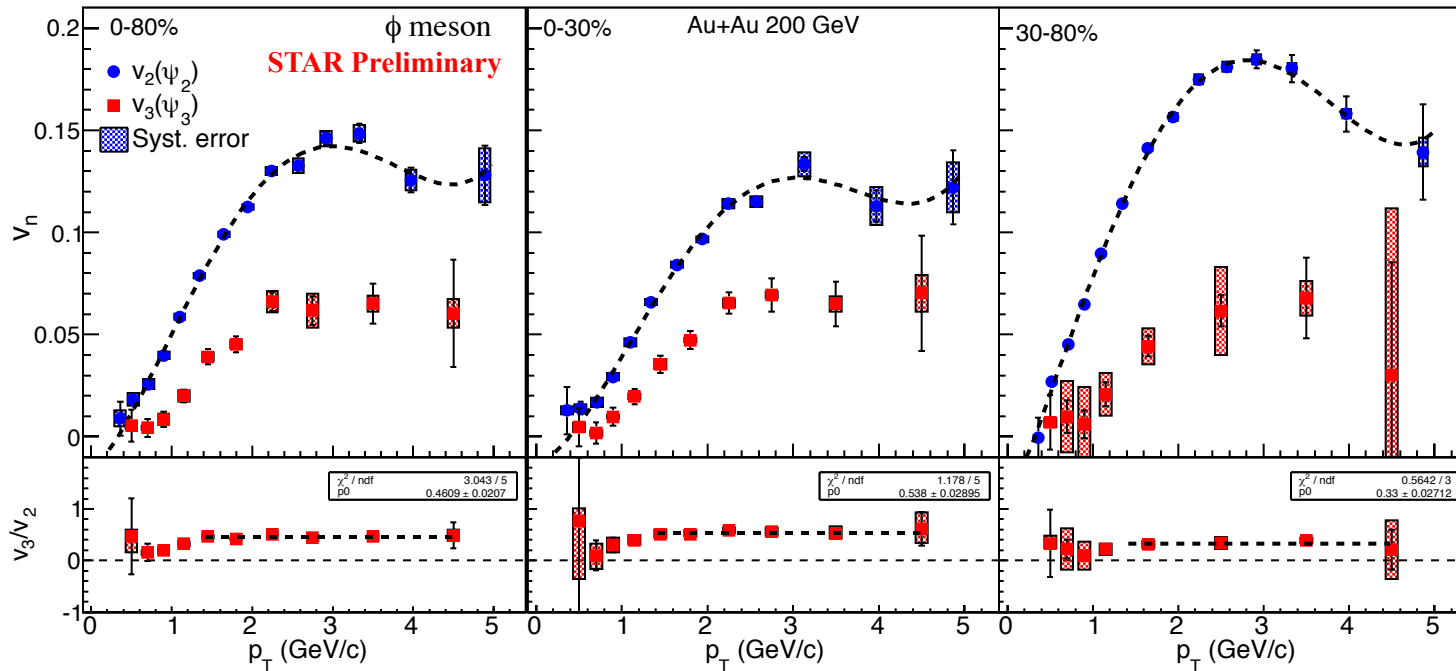
- The magnitude of $v_2(\psi_2)$ is greater than $v_3(\psi_3)$ and $v_4(\psi_4)$ for all centralities.
- v_n increases with p_T and has a maximum value at 2-3 GeV/c

v_n : Centrality dependence



- $v_2(\psi_2)$ shows strong centrality dependence
- No centrality dependence for $v_3(\psi_3)$ and $v_4(\psi_4)$ within statistical uncertainties

v_3/v_2 ratio



0-80%

$$v_3/v_2 = 0.46 \pm 0.02$$

0-30%

$$v_3/v_2 = 0.53 \pm 0.02$$

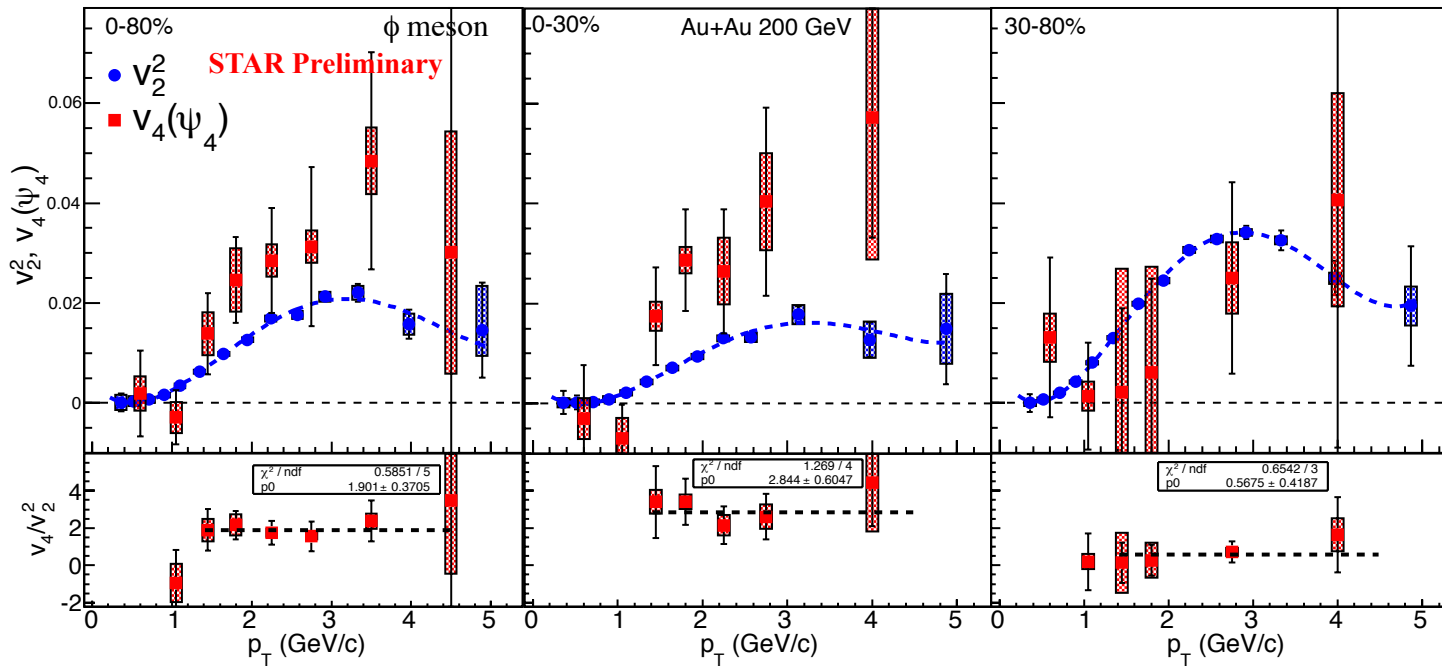
30-80%

$$v_3/v_2 = 0.33 \pm 0.02$$

These error on the ratios are statistical only

- v_3/v_2 ratio is constant for $p_T > 1.5$ GeV/c

v_4/v_2^2 vs p_T



0-80%

0-30%

30-80%

$$v_4(\psi_4)/v_2^2 = 1.90 \pm 0.37$$

$$v_4(\psi_4)/v_2^2 = 2.84 \pm 0.60$$

$$v_4(\psi_4)/v_2^2 = 0.56 \pm 0.42$$

These error on the ratios are statistical only



Summary

- We have presented $v_3(p_T)$ and $v_4(p_T)$ of ϕ meson in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV
- v_n increases with p_T and has a maximum value at 2-3 GeV/c
- No centrality dependence for $v_3(\psi_3)$ and $v_4(\psi_4)$ within uncertainties
- v_3/v_2 and $v_4(\psi_4)/v_2^2$ ratios are calculated in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV and v_3/v_2 ratio is constant for $p_T > 1.5$ GeV/c
- Ratios of v_3/v_2 and $v_4(\psi_4)/v_2^2$ show clear centrality dependence.



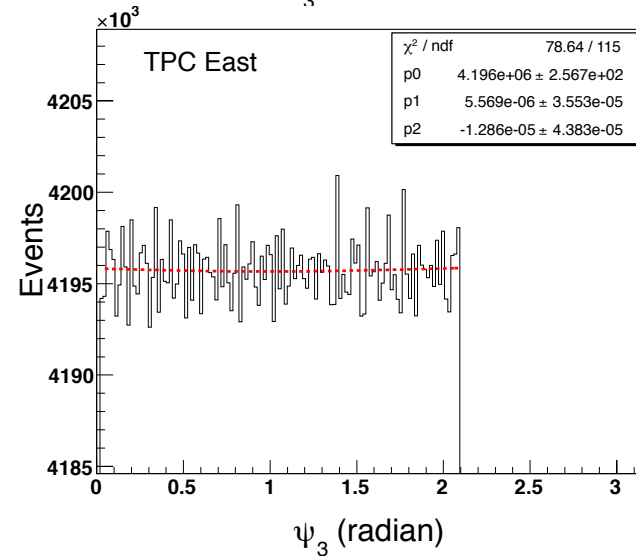
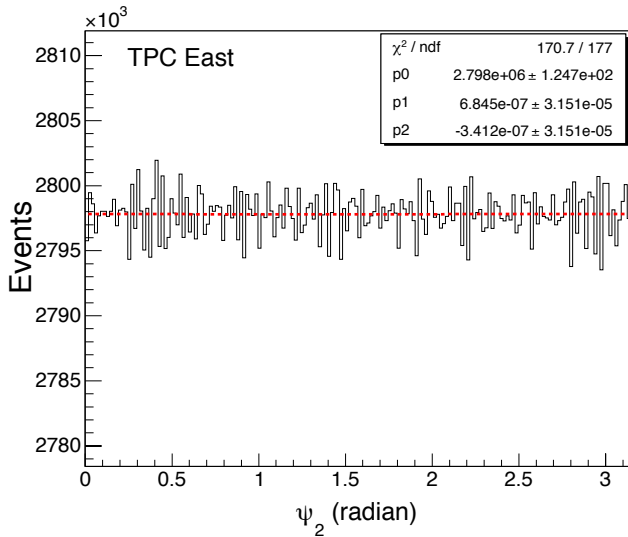
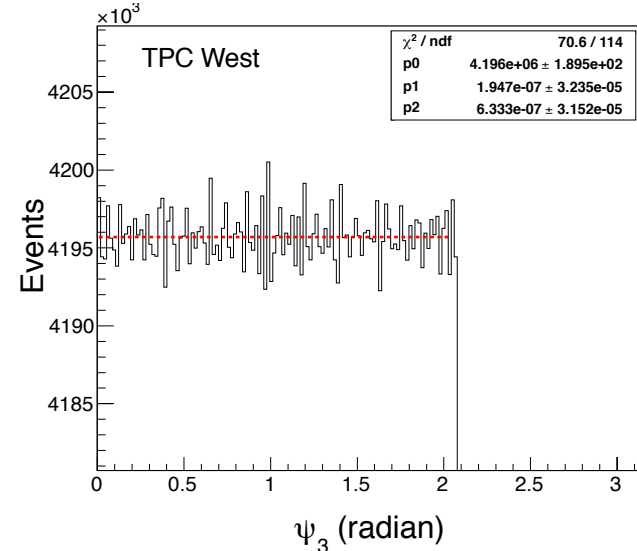
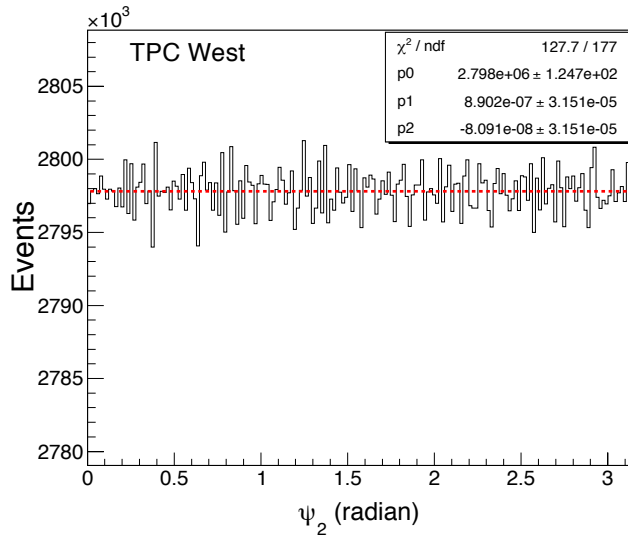


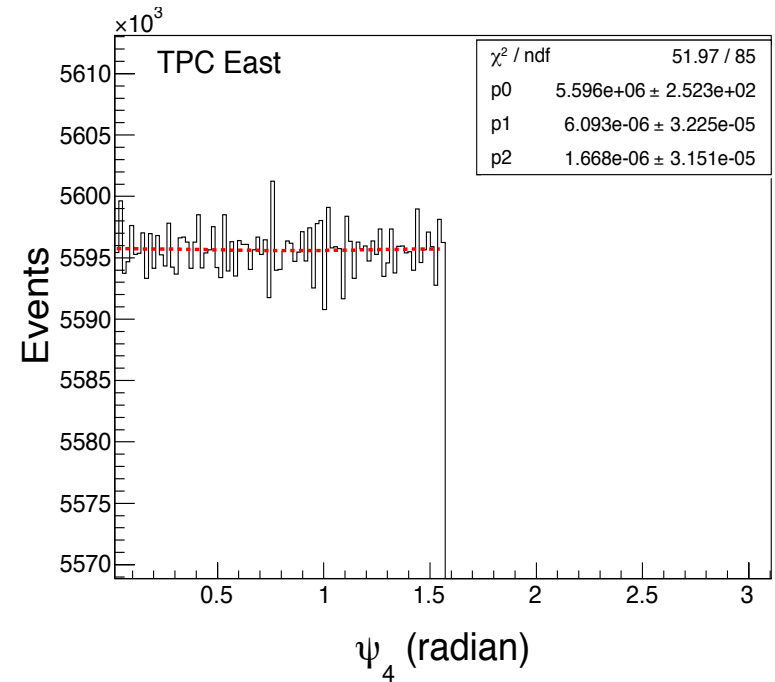
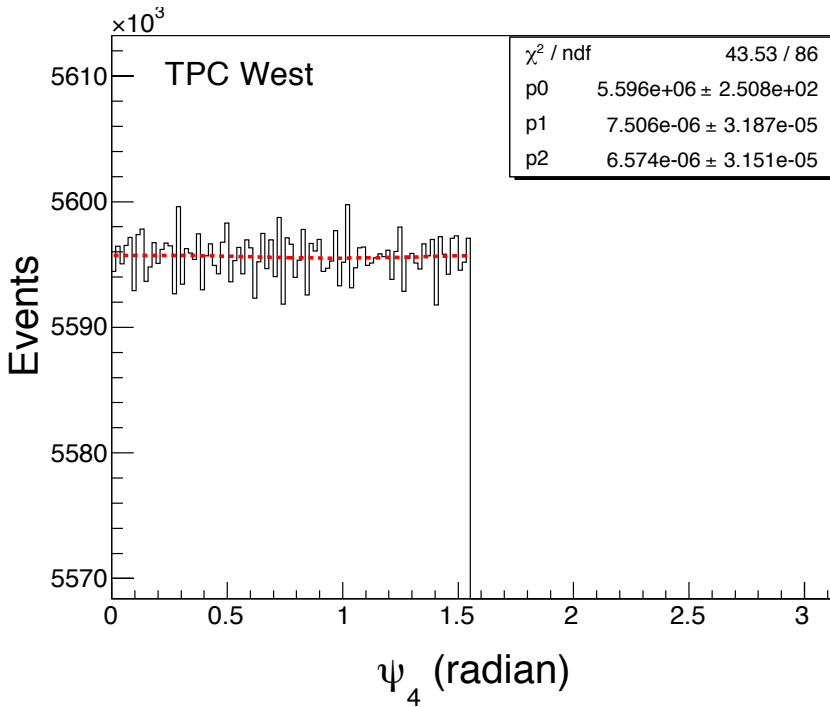
Thank you





Back up Slides





- Corrected by Recentre + Shift method
- Fitted with $p0*(1+p1*\cos[n\Psi_n] + p2*\sin[n\Psi_n])$
- η gap between east & west event plane is 0.1