ρ^0 vector meson elliptic flow (v_2) in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in STAR at RHIC

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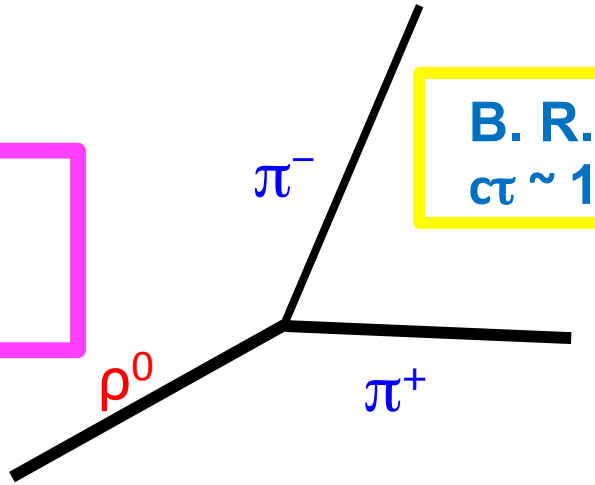
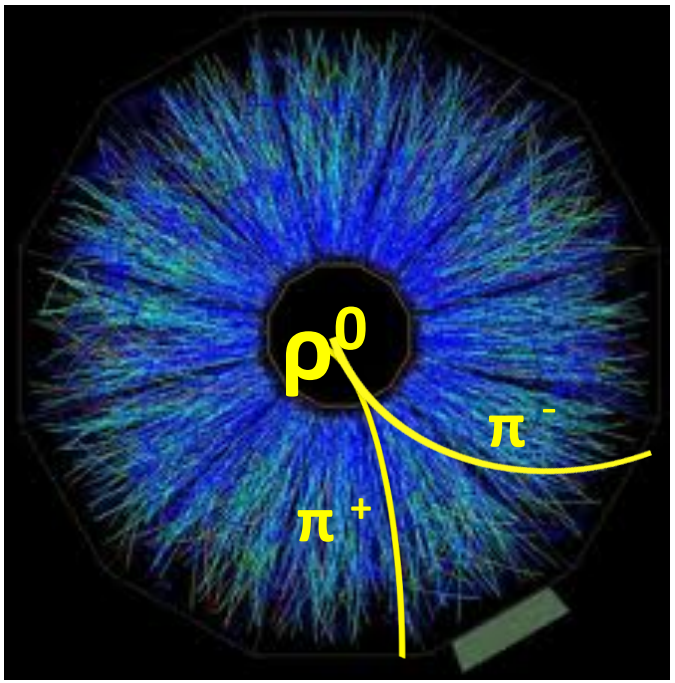


Mass : 775.5 ± 0.4 MeV
Width: 149.4 ± 1.0 MeV

B. R. ~ 99.8 %
$c\tau$ ~ 1.3 fm

Outline

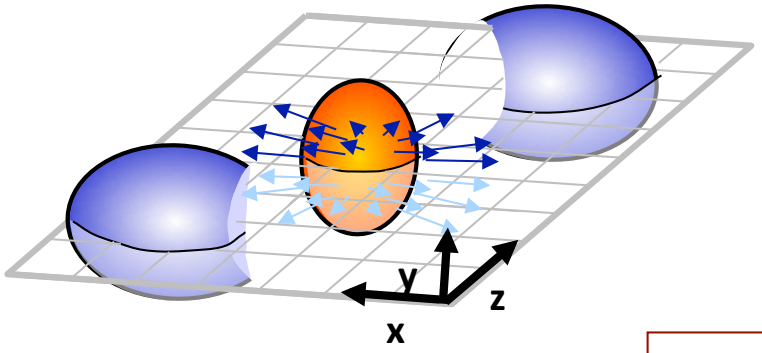
- Introduction: elliptic flow (v_2)
- Motivation: ρ^0 resonance v_2
- STAR Experiment
- Data Analysis Methods
  - ($\phi - \Psi_2$) binning method
  - Invariant mass method
- Results
- Summary and Outlook

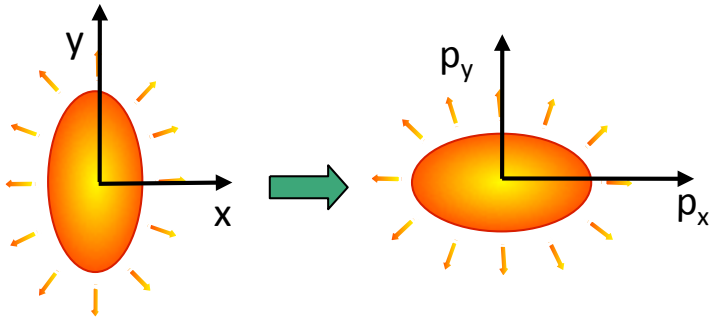


Elliptic Flow and its Origin

Flow is a phenomenon seen in nucleus-nucleus collisions, which correlates the momentum distributions of the produced particles with the **spatial eccentricity** of the overlap region.

azimuthal dependence of the pressure gradient.





Reaction plane: z-x plane

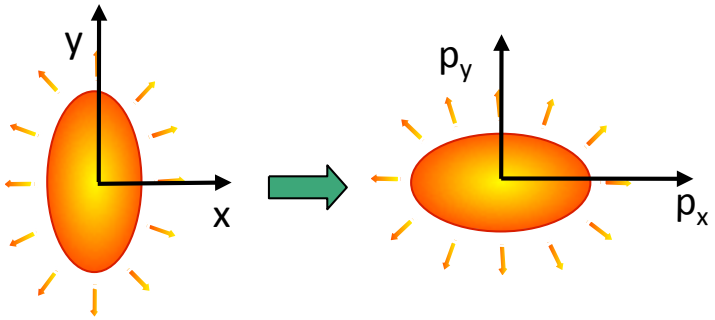
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Elliptic flow is the second coefficient of the Fourier expansion of the azimuthal particle distribution:

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{dN}{p_t dp_t dy}\left(1 + \sum_{n=1} 2v_n \cos\left(n\left[\varphi - \Psi_{RP}\right]\right)\right) \qquad v_2 = \left\langle \cos\left(2\left[\varphi - \Psi_2\right]\right)\right\rangle$$

Motivation - I

Why Elliptic Flow (v_2) ?



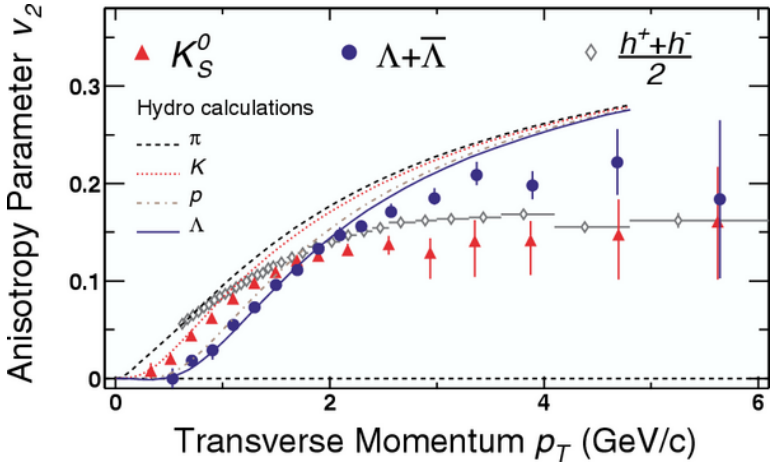
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

- Elliptic flow provides early time information on the collectivity of particles from heavy ion collisions.
  - Signal is self - quenching with time – ***EARLY TIME OBSERVABLE !***
- v_2 is a measure of the degree of thermalization of the matter produced early in the collisions.
- Hydrodynamics calculation of v_2 involves the equation of state (EoS) of QGP.

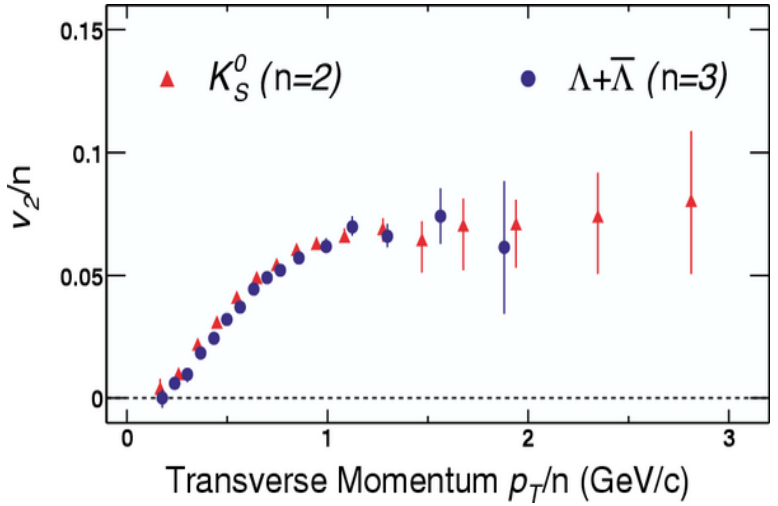
Motivation - II

Why ρ^0 Elliptic Flow ?

- Physics is different in different transverse momentum (p_T) regions.
  - Low p_T ($0 < p_T \leq 1.5$ GeV/c)
    Hydrodynamics
  - Intermediate p_T($1.5 < p_T \leq 5$ GeV/c)
    Coalescence/recombination
  - High p_T ($p_T \geq 5$ GeV/c)
    Jet fragmentation



- Number of Constituent Quark (NCQ), (2 = mesons, 3 = baryons) scaling at intermediate p_T ➡ Indication of partonic degrees of freedom.



- ρ^0 production mechanism.
  $\Rightarrow$ scale NCQ $\Rightarrow$ v_2/n
  - $\pi^+\pi^- \rightarrow \rho^0 \Rightarrow n = 4$
  - $q\bar{q} \rightarrow \rho^0 \Rightarrow n = 2$

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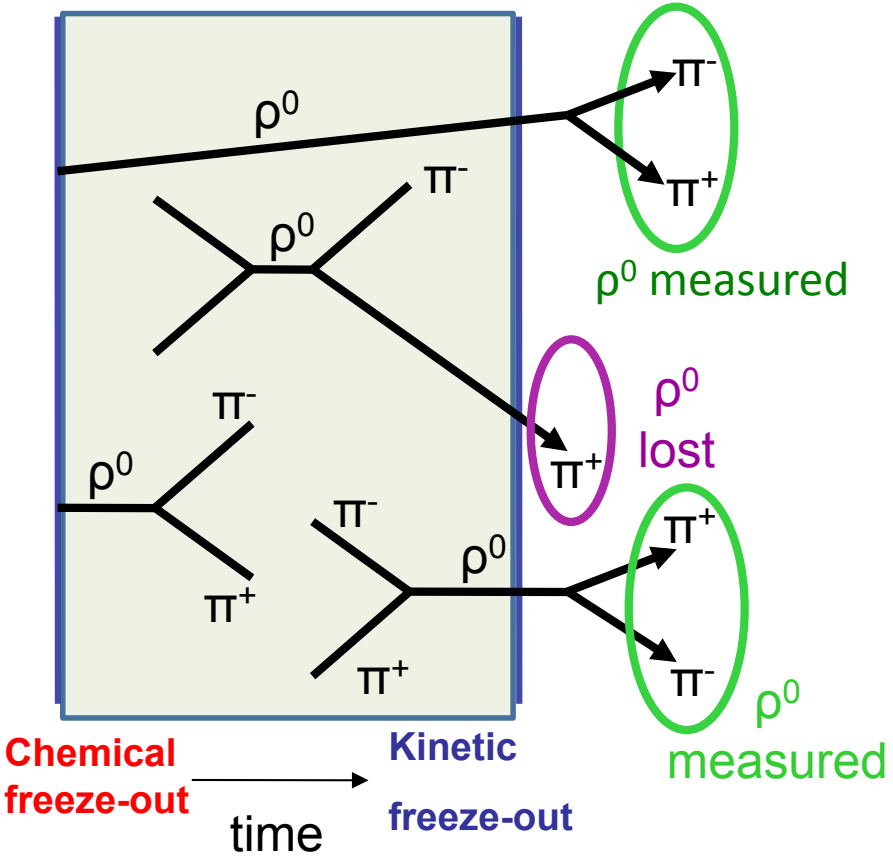
Motivation - III

Why ρ^0 Elliptic Flow ?

- Leptonic decay products are measured directly as they do not interact, but hadronic decay products are sensitive to the medium.
- Study of v_2 from $\rho^0 \rightarrow \pi^+ \pi^-$ channel may provide information of the dynamical evolution during chemical - kinetic freeze-out.



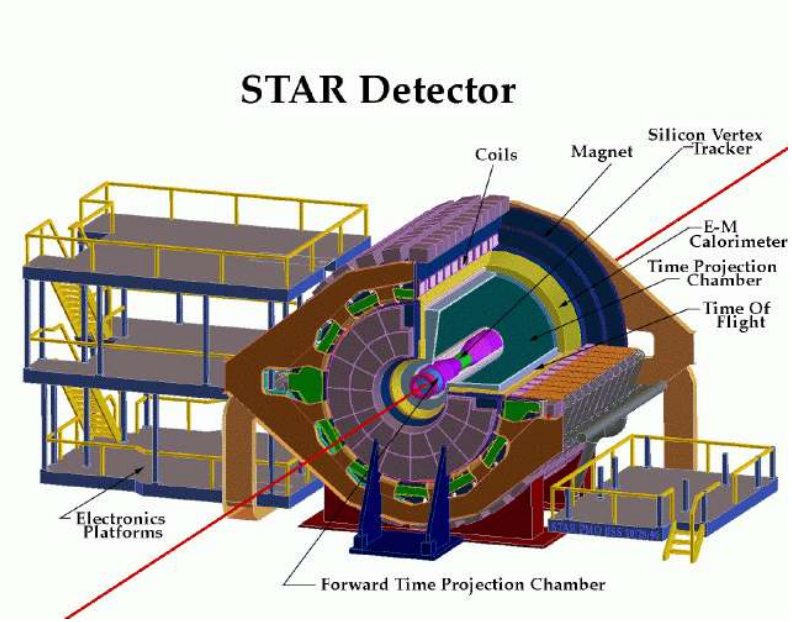
- Regeneration is a key phenomenon in resonance study.
  - ρ^0 regeneration $\Rightarrow \sigma(\pi\pi)$
- Can v_2 help to understand the hadronic daughters regeneration effects in the medium?

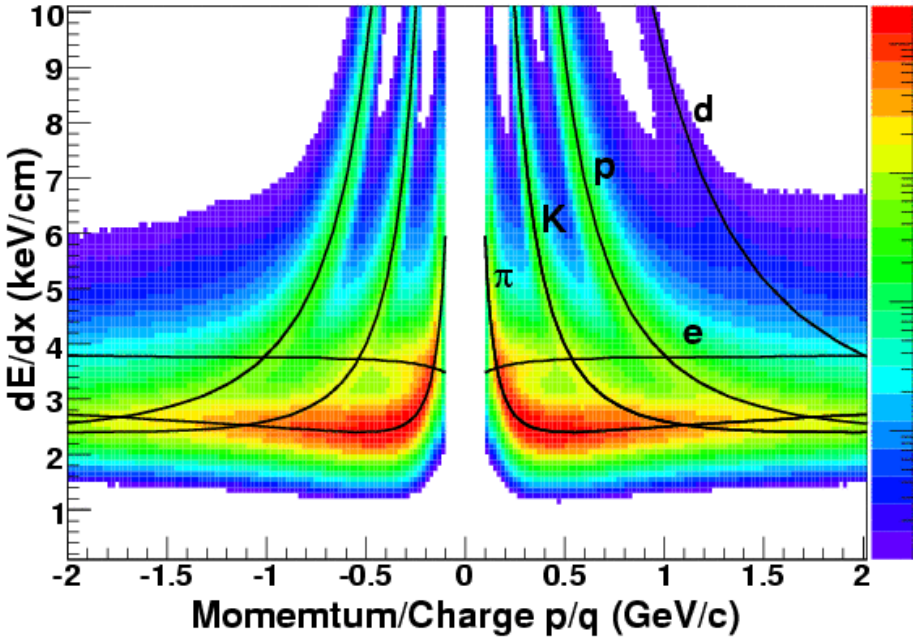
The STAR Experiment

We used the high statistics 200 GeV Au+Au data to measure the ρ^0 observables.

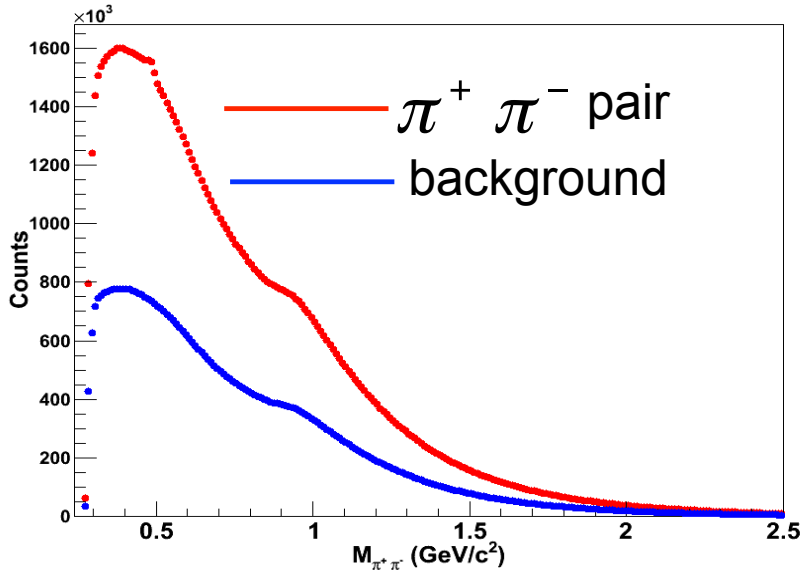
- ~ 25M peripheral (40-80% centrality) events

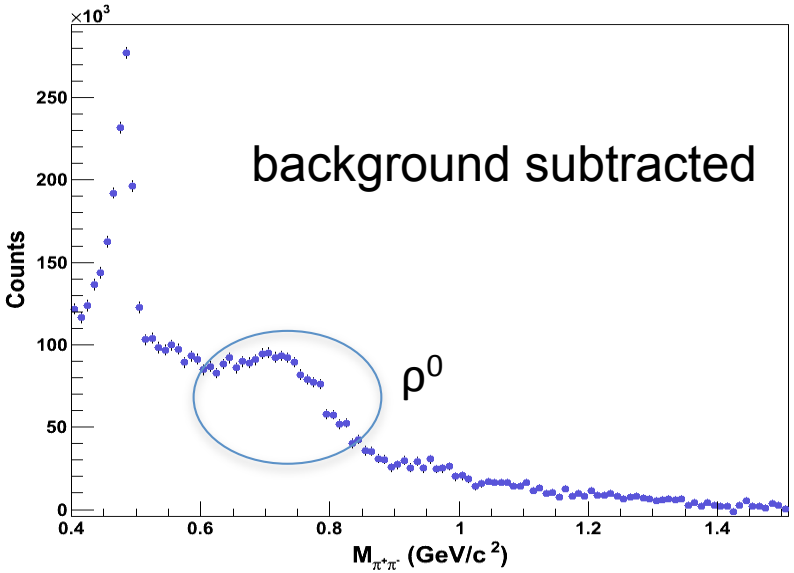
STAR TPC is used to identify pion via dE/dx in TPC gas.





Measurement – ρ^0 invariant mass reconstruction





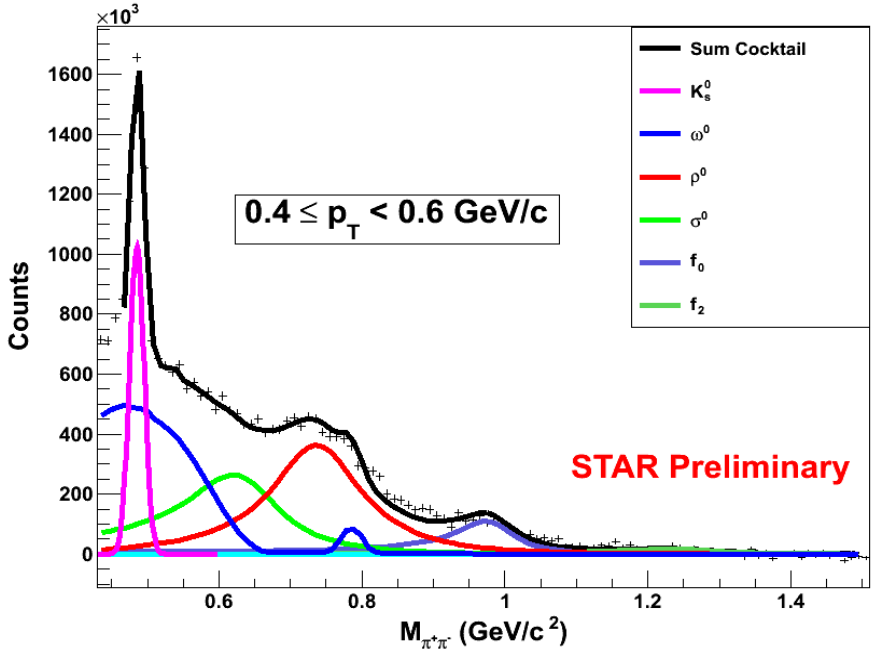
- Same event like-sign method used to estimate background from un-correlated $\pi^+\pi^+$ and $\pi^-\pi^-$ pairs.

Background = $\sqrt{\pi^+\pi^+ * \pi^-\pi^-}$

Particle	Mass	Width
ρ0	775	150.7
ω0	782	8.43
Ks0	497.67	
f0	980	40 – 100
f2	1275	185
σ0	400 – 1200	600 – 1000

Measurement – Hadronic Cocktail

- Final background subtracted $M_{\pi+\pi-}$ invariant mass distribution fitted with a cocktail function to extract the ρ^0 yield.



- **Hadronic cocktail**

✓ K_s^0 is fitted to a gaussian function.

✓ ω^0 shape obtained from HIJING event generator.

✓ ρ^0, σ^0, f_0 and f_2 are fitted with relativistic Breit-Weigner times the Boltzmann factor which takes the phase space in account.

✓ The masses of K_s^0 and ρ^0 are free parameter in the above fit.
✓ The ω^0, f_0 and f_2 masses are fixed according to PDG values .
✓ The ρ^0, f_0 and f_2 widths are fixed in the cocktail fit.
✓ The mass and width of σ^0 is fixed at 630 MeV/c^2 and 160 MeV/c^2 respectively.

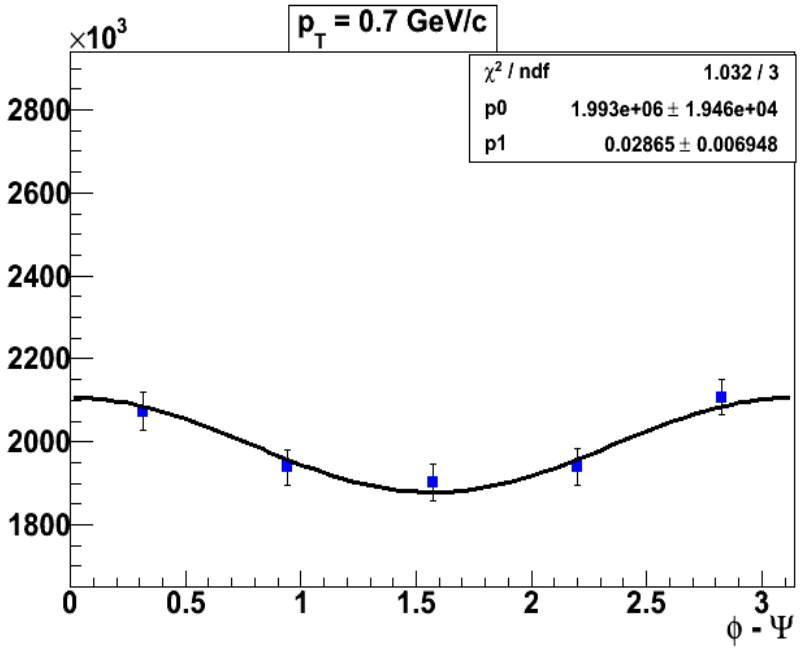
Analysis: (ϕ-Ψ_2) bin method

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos[2(\phi - \Psi_2)]$$

Elliptic flow

TPC event plane

- The ρ^0 counts as a function of ($\varphi - \psi_2$) are plotted.
- The ρ^0 counts as a function of ($\varphi - \psi_2$) are fitted to
  $A\,[1+2v_2^{obs} \cos2(\varphi - \psi_2)]$
- Final $v_2 = v_2^{obs}$ / event plane resolution



Analysis: v_2 vs M_{inv} method

- **Multi-parameter fitting function to get v_2 observed values.**

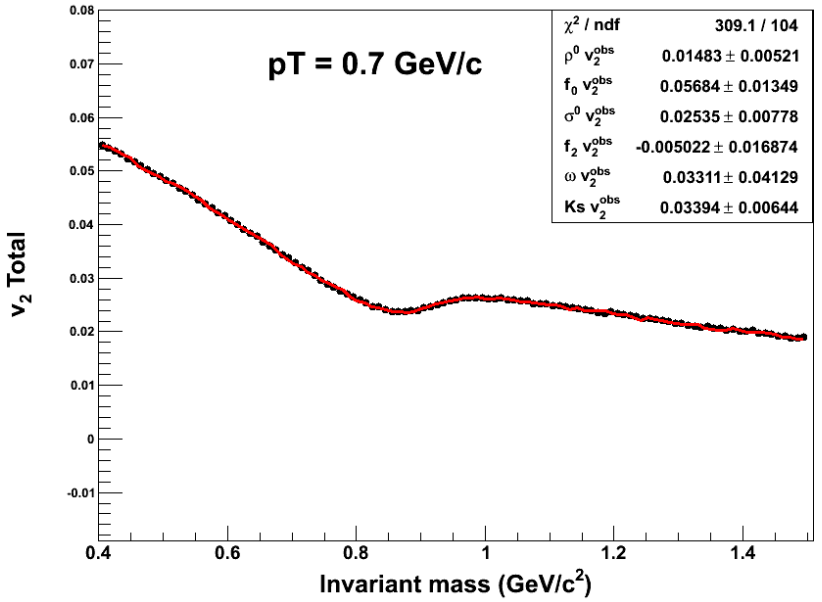
$$v_2^{Total}(M) = v_2^{\rho^0} * \frac{N\rho^0}{N_{Total}}(M) + v_2^{\sigma^0} * \frac{N\sigma^0}{N_{Total}}(M) + v_2^{\omega^0} * \frac{N\omega}{N_{Total}} + \ldots \quad + v_2^{Bkg}(M) * \frac{N_{BKG}}{N_{Total}}(M)$$

$v_2^{Bkg}(M)$ **is calculated from $\pi^+ \pi^+$ and $\pi^- \pi^-$ distributions.**

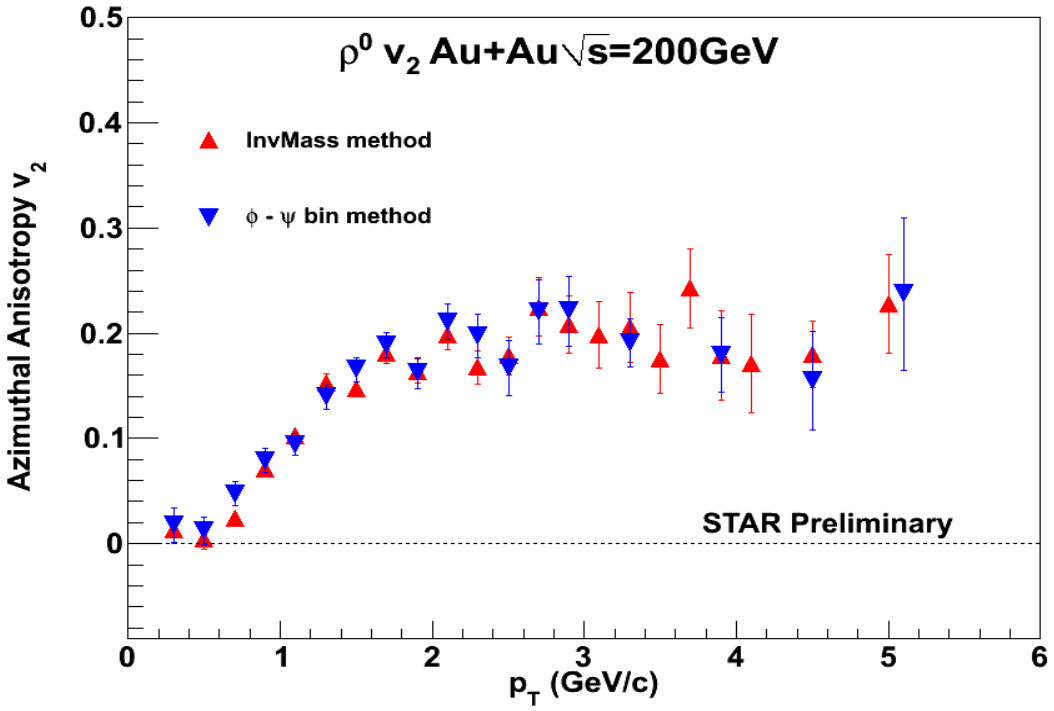
Where,

$$N_{BKG} = N_{Real\ pairs} - \left(N_{\rho^0} + N_{\sigma^0} + N_{\omega} + \ldots\right)$$

ρ^0 final v_2 = $v_2^{\rho 0}$ / event plane resolution



Analysis: Methods Comparison

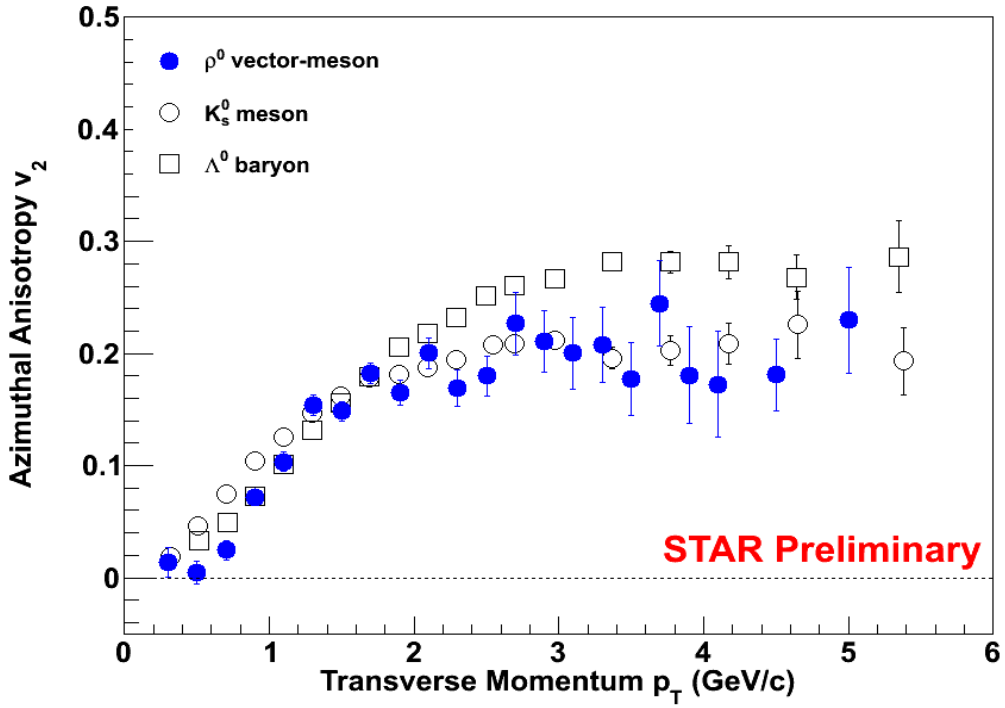


- The ρ^0 v_2 results from the above two methods consistent with each other within statistical error bars.

- Systematic error calculation is in progress.

Analysis: Results

v_2 as a function of p_T

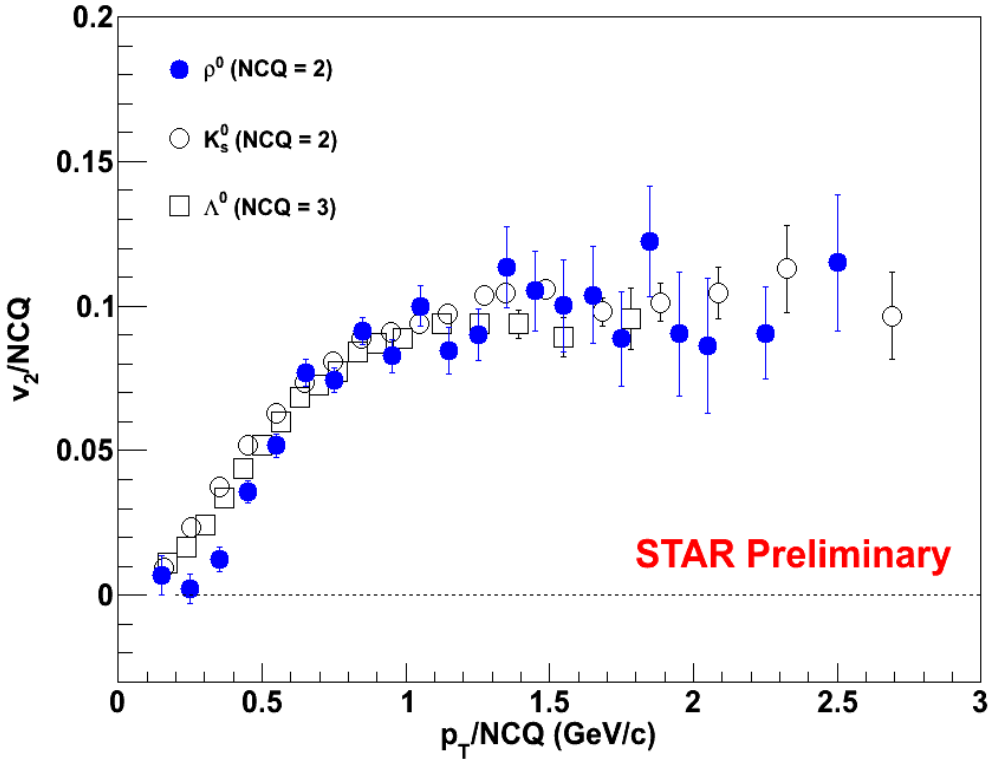


- For p_T > 1.5 GeV/c, v_2 of ρ^0 is more consistent with v_2 of K_s^0 than v_2 of Λ^0 .

K_s^0 and Λ^0 v_2 data points - Phys. Rev. C 77 (2008) 54901

Analysis: Quark Scaling of v_2

NCQ = 2 for ρ^0



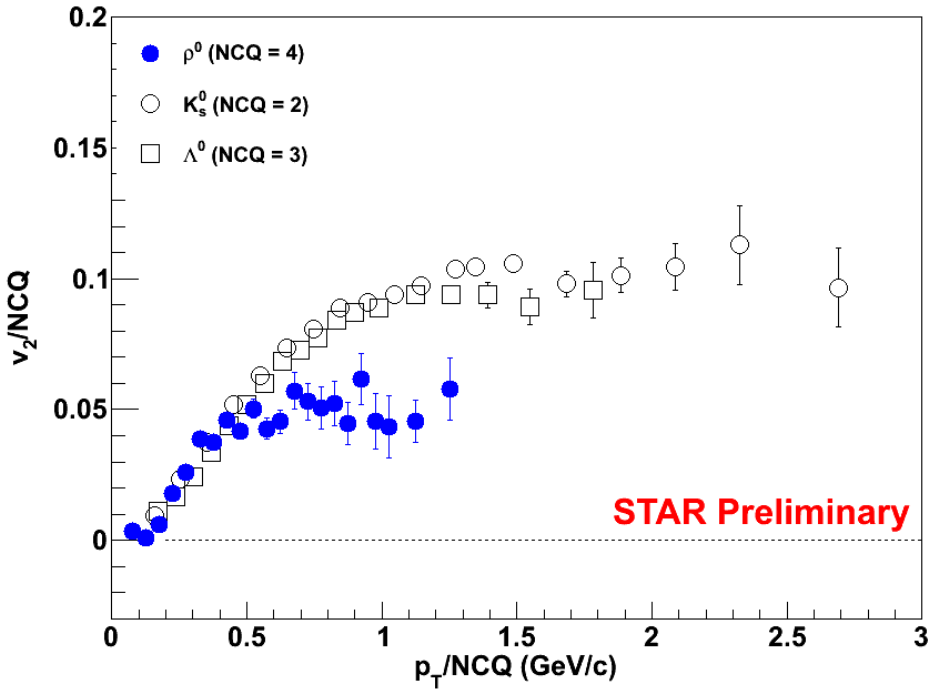
Early Time Information:

- The number of constituent quark scaling of v_2 of ρ^0 vector-meson in the intermediate p_T follows n =2.

The ρ^0 production mechanism is dominated by the early stage quark – anti-quark coalescence.

- $\pi^+ \pi^-$ regeneration might be playing an important role in the low p_T region.

Analysis: n=4 scaling of ρ^0 v_2



- n= 4 scaling of ρ^0 v_2 does not hold in the intermediate p_T.

Intermediate p_T ρ^0s are not generated from the late stage $\pi^+\pi^-$ interaction rather the ρ^0s are produced from the early stage quark coalescence.

Summary

- ✓ ρ^0 v_2 measured in Au+Au 200 GeV collisions in TPC ($\phi - \Psi_2$) bin method and invariant mass method.

- ✓ The final results obtained in the above two methods were compared and they are consistent within the statistical error bars.

- ✓ In the intermediate transverse momentum ($1.5 < p_T < 5$ GeV/c), the ρ^0 v_2 scales with n=2 quarks.

- ✓ In the low p_T, we observed the deviation of mass ordering of the ρ^0 v_2 . Study is going on to understand the mass ordering effect in the low p_T region.

Outlook

- Di-lepton measurement
- Inclusion of Time Of Flight
- Beam Energy Scan

STAR Collaborators