Identified Particle v_1 and v_2 in $\sqrt{s_{NN}}$ = 3 GeV Au+Au Collisions at RHIC-STAR

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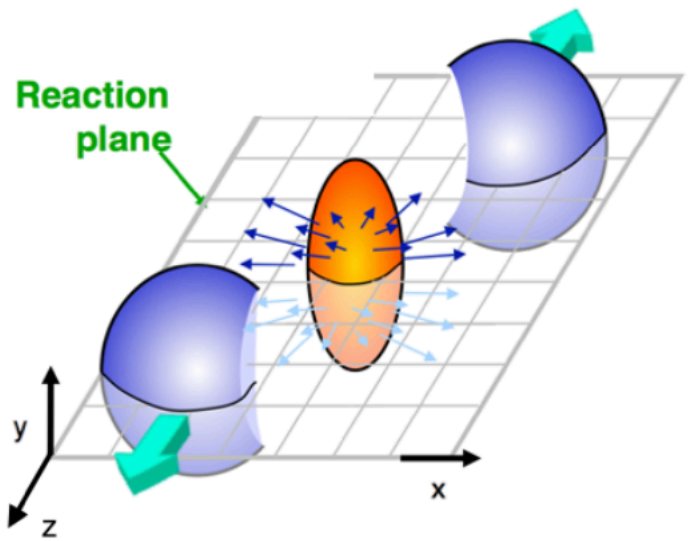
Support in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

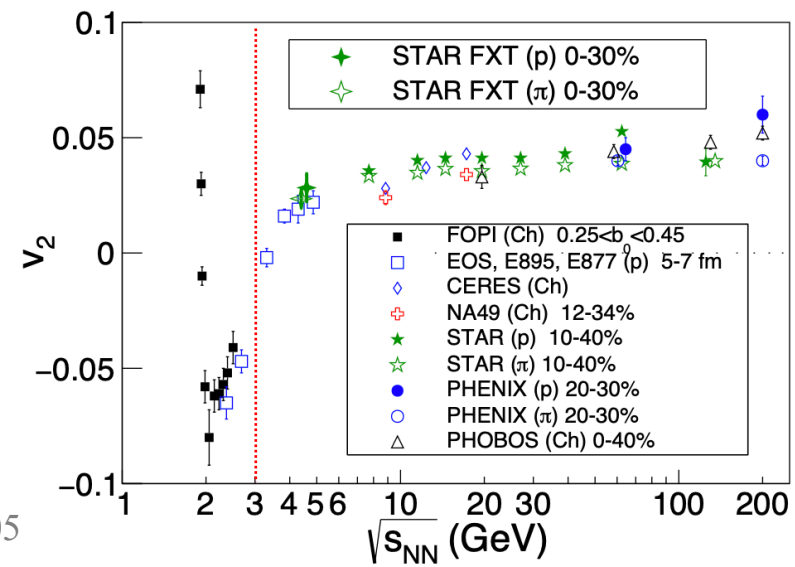
Outline

- Motivation
- Analysis method
- Results of PID v_1 and v_2
- Summary

Motivation: Flow at High Baryon Density

- Partonic Collectivity:
  - Dominant at higher energies, where the passage time t of nuclei is small
  - Passage time t ~ 2R/(γv)
- Shadowing effect by spectators:
  - Important at low energies.
  - Shadowing leads to negative elliptic flow
- Nuclear mean-field potentials and EoS
  - At collision energies <~ 5 GeV, the nuclear mean-field treatments are used to describe the flow harmonics and reaction dynamics



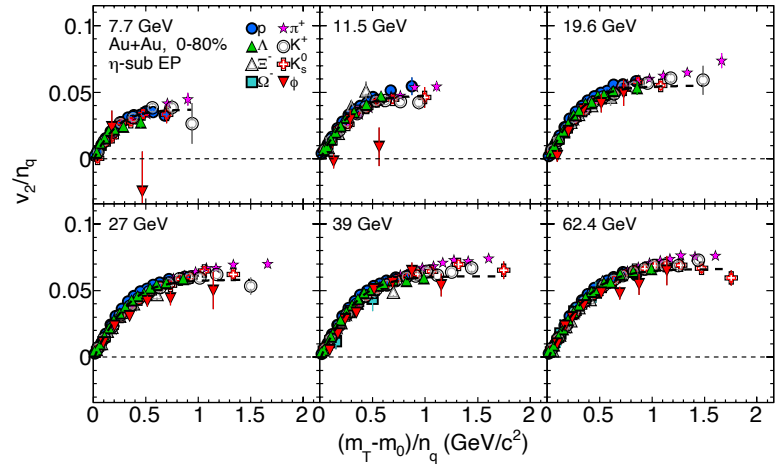


Phys. Rep. **512** (2012) 1
Phys. Rev. C. **97** (2018) 064913

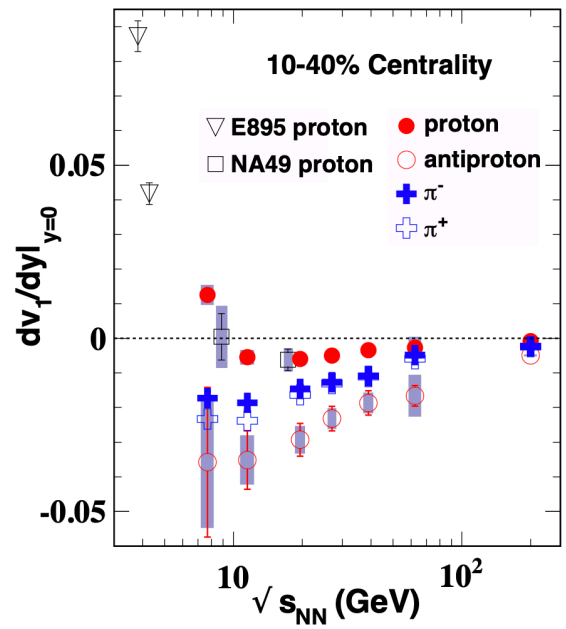
STAR: arXiv: 2007.14005

Motivation: Directed and Elliptic Flow

- Hadrons obey NCQ scaling down to collision energy of 7.7 GeV within 10%
  - Shows the interaction generating flow are partonic in nature



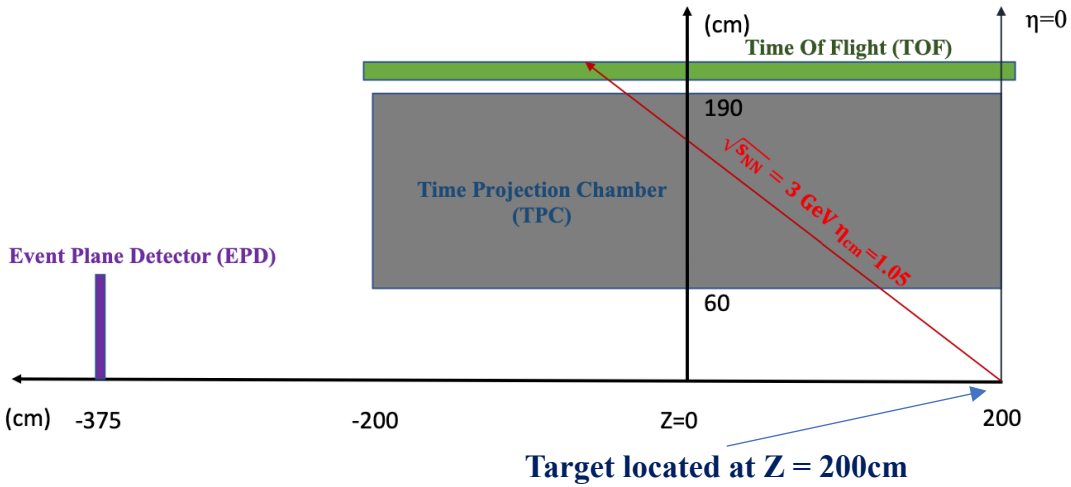
- At low energy, the repulsive nuclear mean-field potential leads to positive v_1 slope for protons and Λ



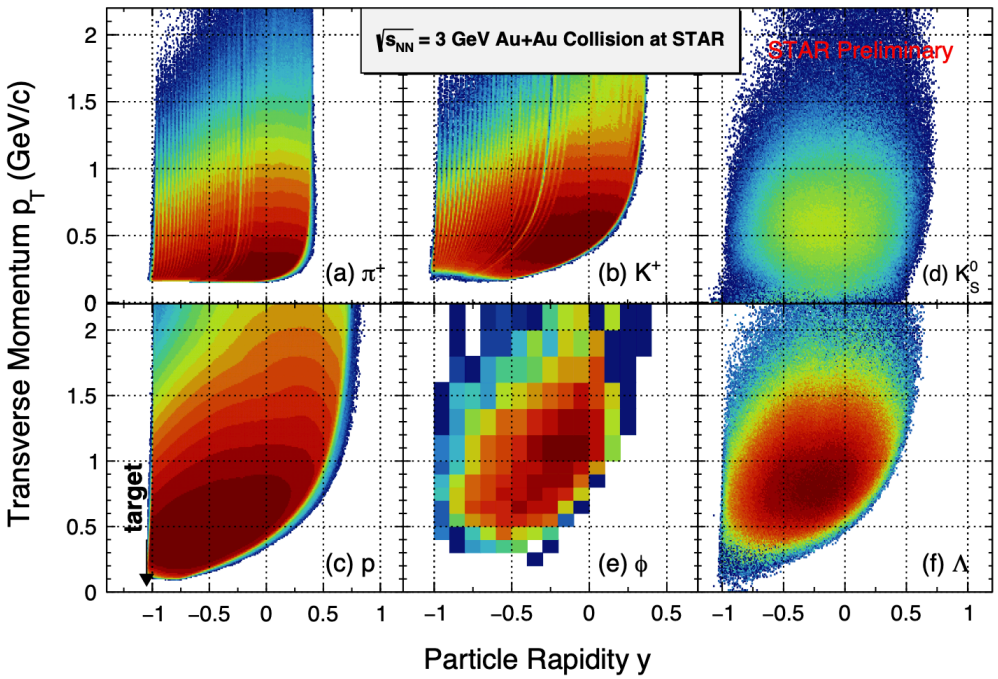
- Additional measurements in this energy region will provide important constraints on EoS at high baryon density region

STAR: Phys. Rev. C **88** (2013) 14902
STAR: Phys. Rev. Lett. **112** (2014) 162301

Dataset and Acceptance



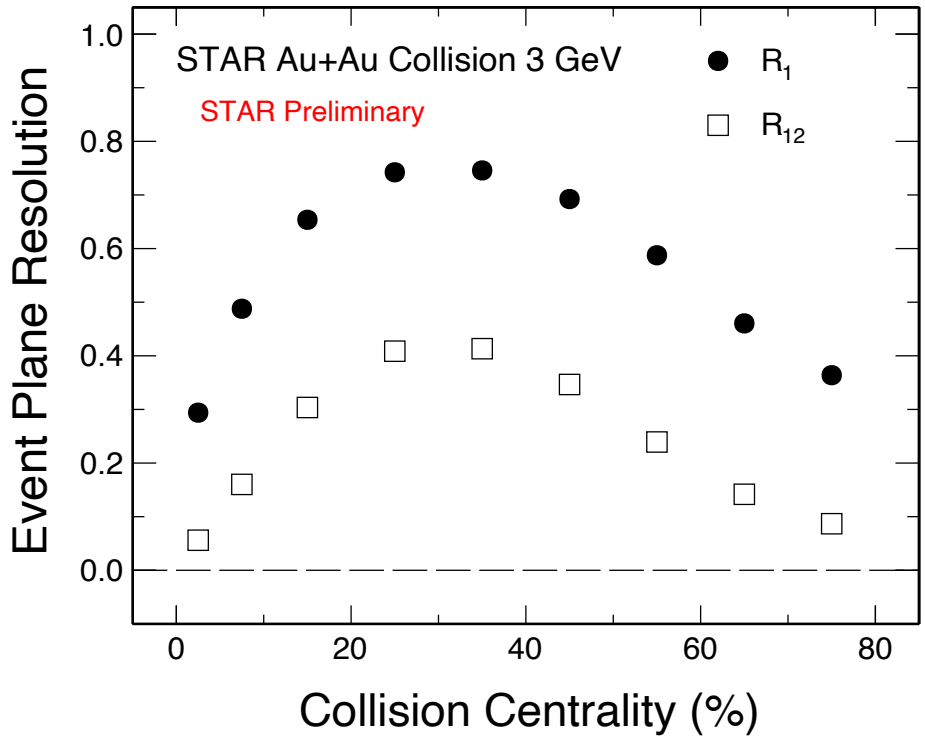
- **Dataset:**
  - Fixed target Au+Au collisions
  - Beam energy: 3.85 GeV
  - $\sqrt{s_{NN}}$ = 3 GeV
  - Number of MB events: 258M
  - Midrapidity is y = 1.05



- The acceptance cover midrapidity region for all hadrons

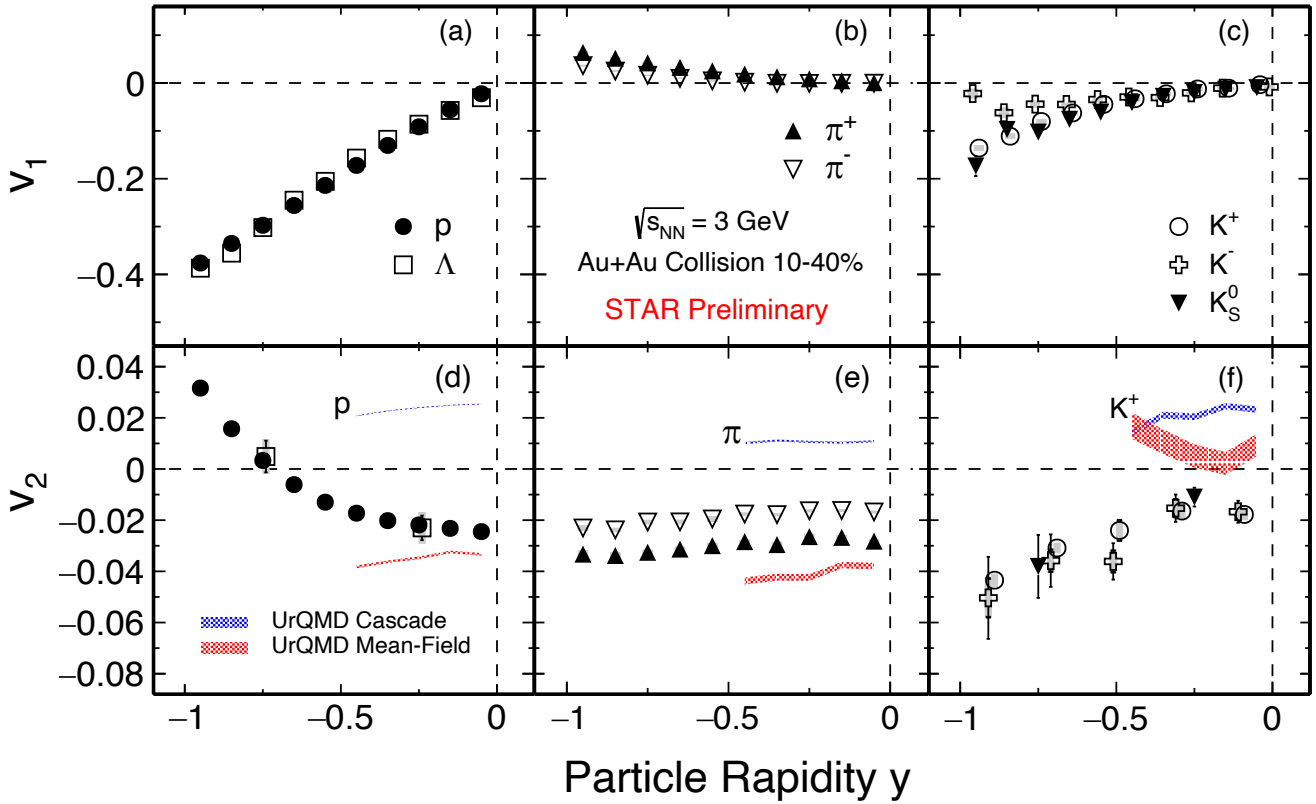
Event Plane Resolution

Phys. Rev. C **58** (1998) 1671



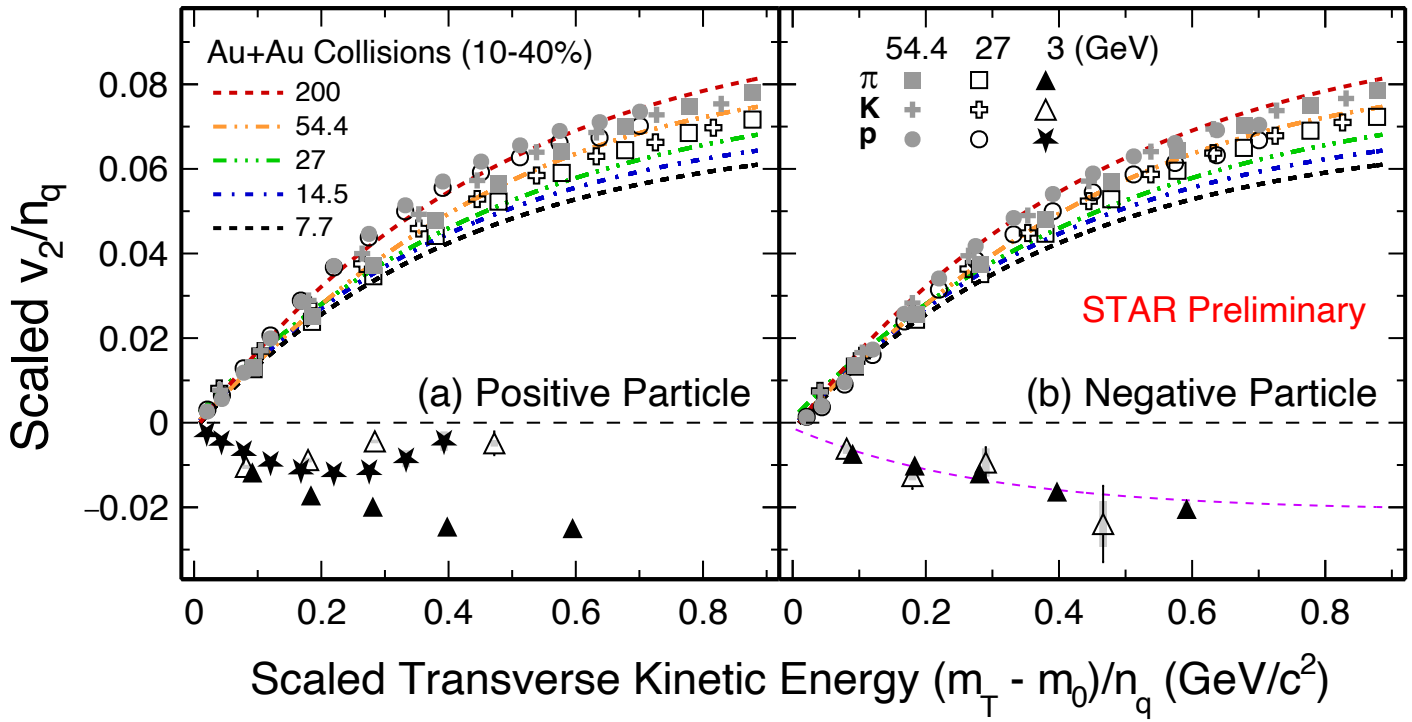
- The event plane resolution as a function of collision centrality from Event Plane Detector (EPD $-5.1<\eta<-2.1$)
- Large first order event plane resolution (up to 77%)
- R_1: First-order event plane resolution
- R_{12}: Second-order event plane resolution estimated by the first-order event plane

Rapidity Dependence



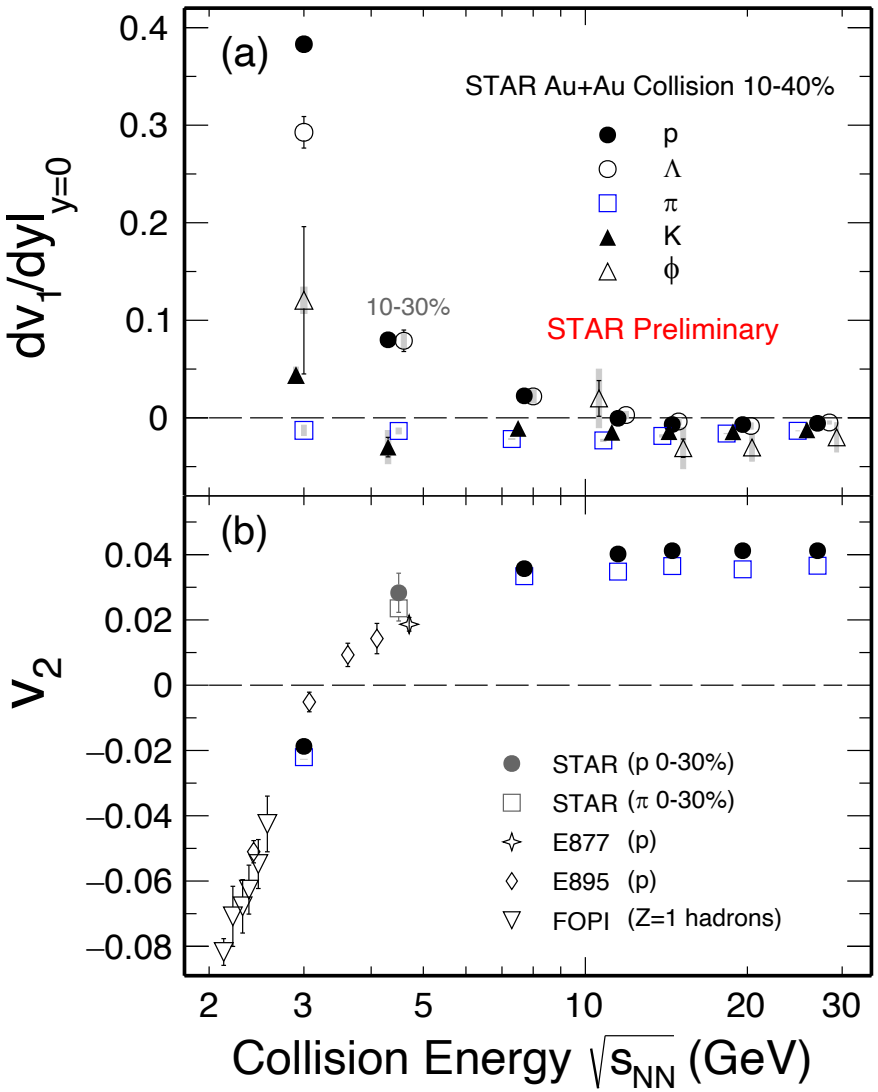
- Rapidity dependence of v_1 and v_2 for pions, kaons, proton and Λ
- v_2 at midrapidity for all hadrons are negative
- UrQMD results (include Mean-Field effects):
  - Mean-Field model can reproduce negative v_2 for pions and proton, however not for kaons
  - Cascade model fail to reproduce the negative v_2 of hadrons

Scaling Behavior



- At high energy, the number of constituent quark (NCQ) scaling holds, consistent with partonic collectivity
- At 3 GeV, the measured v_2 for all particles are negative and the NCQ scaling is absent, especially for positive charged particles
- Different color dash line indicates the strength of scaled v_2

Energy Dependence



- The v_1 slope ($dv_1/dy|_{y=0}$) of proton and Λ at 3 GeV are positive => **transport quark and repulsive nuclear mean-field effect**
- For the first time, kaon and ϕ v_1 slope is found to be positive at 3 GeV **consistent with a change of EoS**
- Pion and proton v_2 at 3 GeV are negative, they agree with world data **=> shadowing effect by spectators**

Summary

- We report v_1 and v_2 measurements for identified hadrons ($\pi, K, p, \phi, K_S^0, \Lambda$) from Au+Au collisions at $\sqrt{s_{NN}}$ = 3 GeV
- The midrapidity elliptic flow v_2 for all hadrons are negative, and the NCQ scaling is absent
- The directed flow v_1 slope ($dv_1/dy|_{y=0}$) at midrapidity for proton and strange hadrons are positive, these results are also compared to STAR high energy results
- Since the NCQ scaling is argued for the formation of a QGP phase with partonic degrees of freedom. These results imply new medium properties at 3 GeV (high baryon density) that are different from the partonic matter created in high energy collisions

Thank you!

Backup

Event Plane Method

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- **Event Plane determination:**

$$\Psi_1 = tan^{-1}\left(\frac{Q_y}{Q_x}\right) = tan^{-1}\left(\frac{\sum_i w_i sin(\phi_i)}{\sum_i w_i cos(\phi_i)}\right)$$

- **Resolution determination:**

$$R_1 = \langle cos(\Psi_1 - \Psi_r)\rangle = \frac{\sqrt{\pi}}{2\sqrt{2}}\chi_1 exp(-\chi_1^2/4)\left[I_0(\chi_1^2/4) + I_1(\chi_1^2/4)\right]$$

$$R_{12} = \langle cos(2(\Psi_1 - \Psi_r))\rangle = \frac{\sqrt{\pi}}{2\sqrt{2}}\chi_1 exp(-\chi_1^2/4)\left[I_{1/2}(\chi_1^2/4) + I_{3/2}(\chi_1^2/4)\right]$$

- **v_1 , v_2 calculation:**

$$v_1 = \frac{\langle cos(\phi - \Psi_1)\rangle}{\langle cos(\Psi_1 - \Psi_r)\rangle} = \frac{v_1^{obs}}{R_1} \qquad v_2 = \frac{\langle cos(2(\phi - \Psi_1))\rangle}{\langle cos(2(\Psi_1 - \Psi_r))\rangle} = \frac{v_2^{obs}}{R_{12}}$$