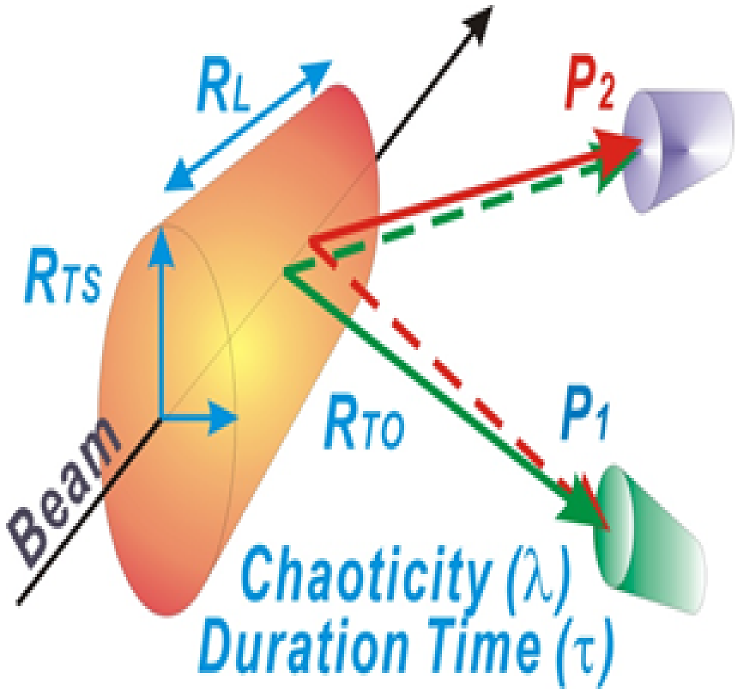
Femptoscopic measurements for event-shape selected Au+Au collisions in the BES

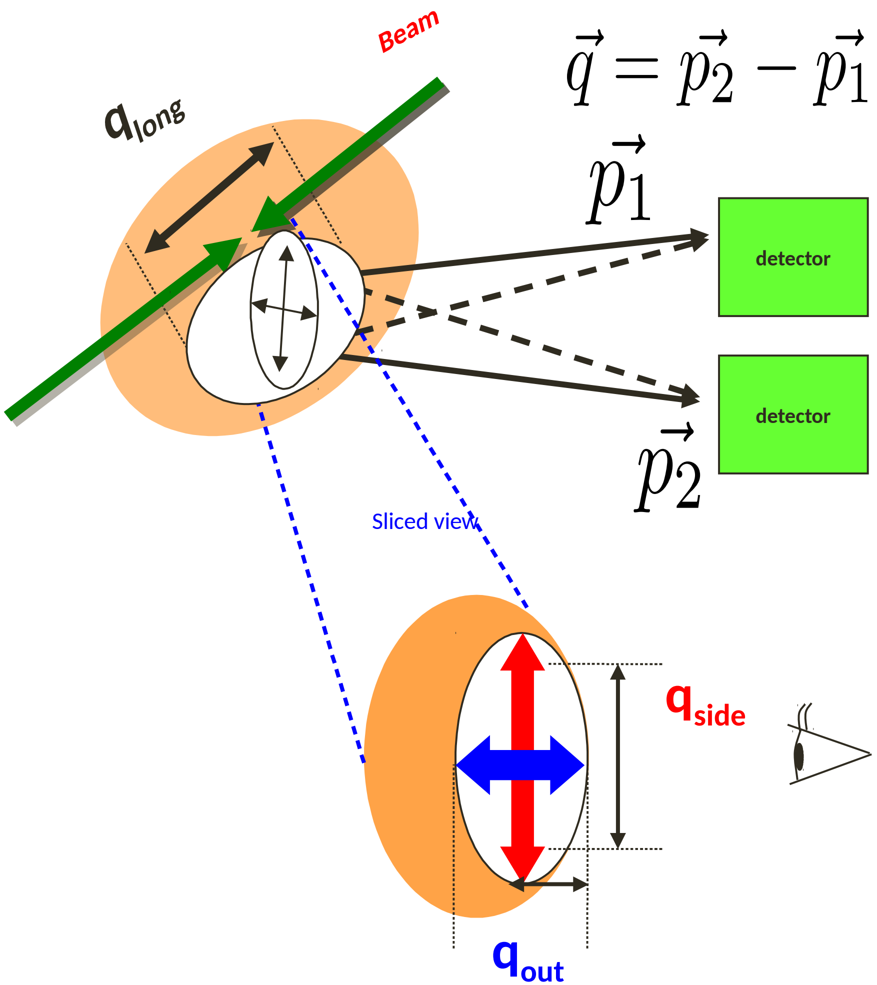
Benjamin Schweid
For the STAR Collaboration
Stony Brook University

HBT Measurements



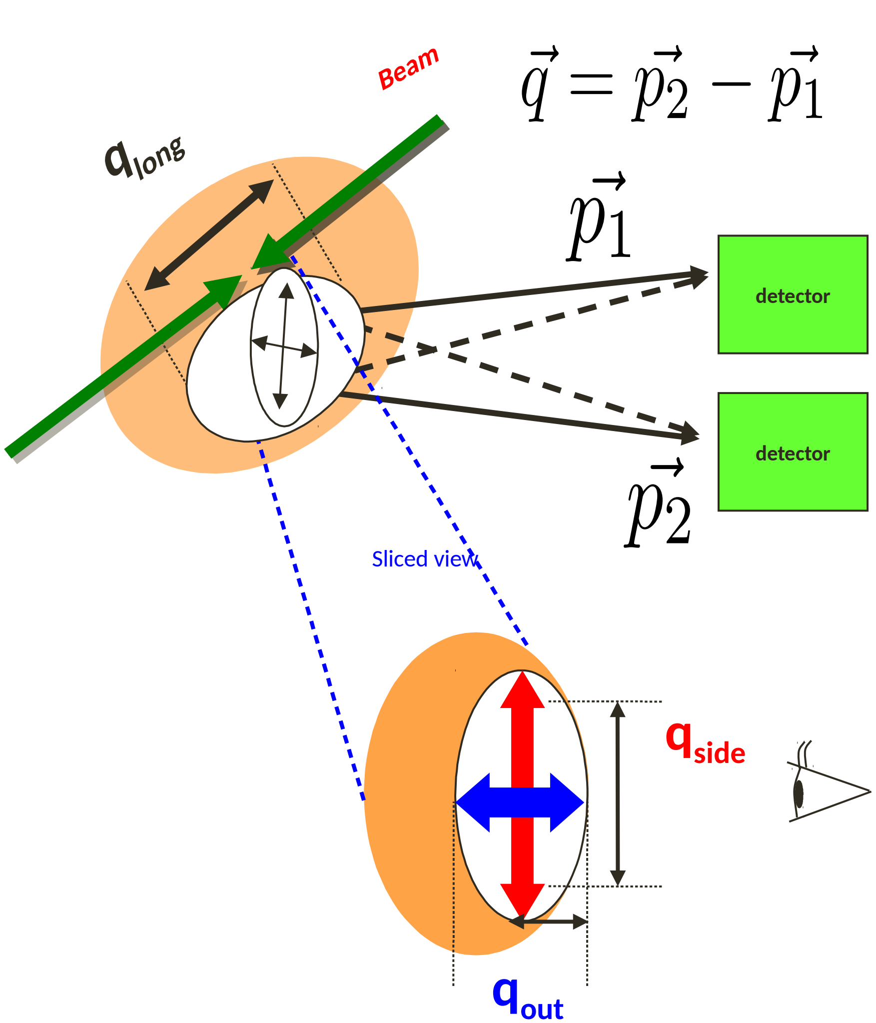
- **HBT radii characterize**
  - Size
  - Source shape & orientation
  - Lifetime & Emission Duration
- **System expansion dynamics are influenced by**
  - Transport Properties
  - Phase Transition/Critical Point
  - Initial-state Event Shape

Pion interferometry



- **Longitudinally Co-Moving System (LCMS)**
  - Pion pair velocity along beam line is zero
- **In the Bretsch Pratt parameterization of $\vec{q}$ is decomposed into:**
  - $q_{long} \rightarrow$ beam direction
  - $q_{out} \rightarrow$ direction of average transverse momentum of pair
  - $q_{side} \rightarrow$ perpendicular to both above
- **Radii R_{long}, R_{out}, R_{side}, point in these directions respectively**
- **Extracted radii measure the homogeneity lengths of the source**

Pion interferometry



$$R^2_{side} = \frac{R^2_{geo}}{1 + \frac{m_T}{T}\beta_T^2}$$

Yu. M. Sinyukov, V. M. Shapoval, and V. Yu. Naboka Nucl.Phys. A946 (2016) 227-239

$$R^2_{out} = R^2_{side} + \beta_T^2(\Delta\tau)^2 - 2\beta_T \Delta x_{out} \Delta\tau$$

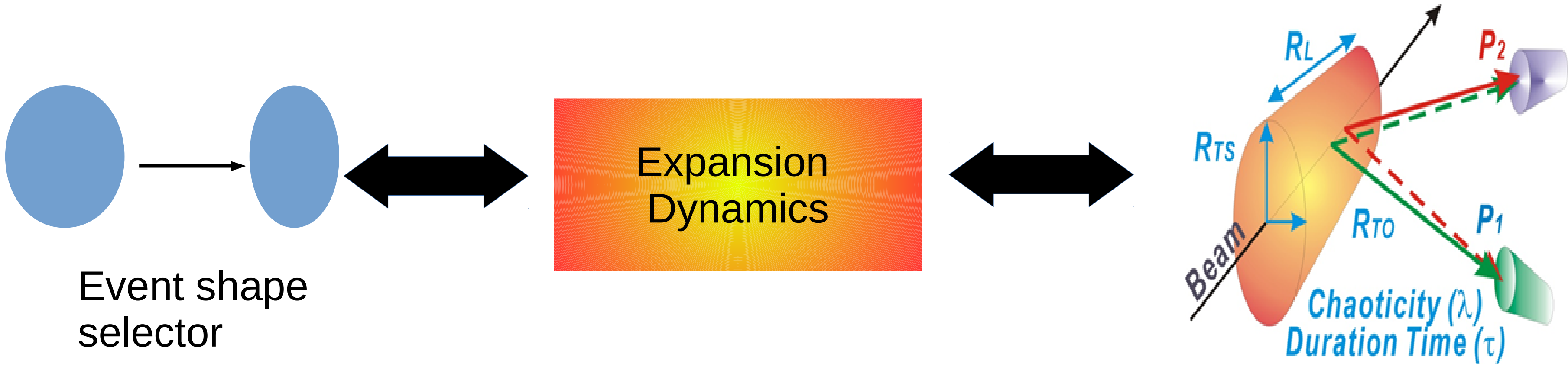
$$R^2_{long} = \lambda^2\tau^2(1 + \frac{3}{2}\lambda^2);$$

$$where \quad \lambda^2 = \frac{T}{m_T}(1 - (\beta_T^2))^{\frac{1}{2}}$$

$$If \quad m_T/T \ll 1; then \quad R^2_{long} \approx \frac{T}{m_T}\tau^2$$

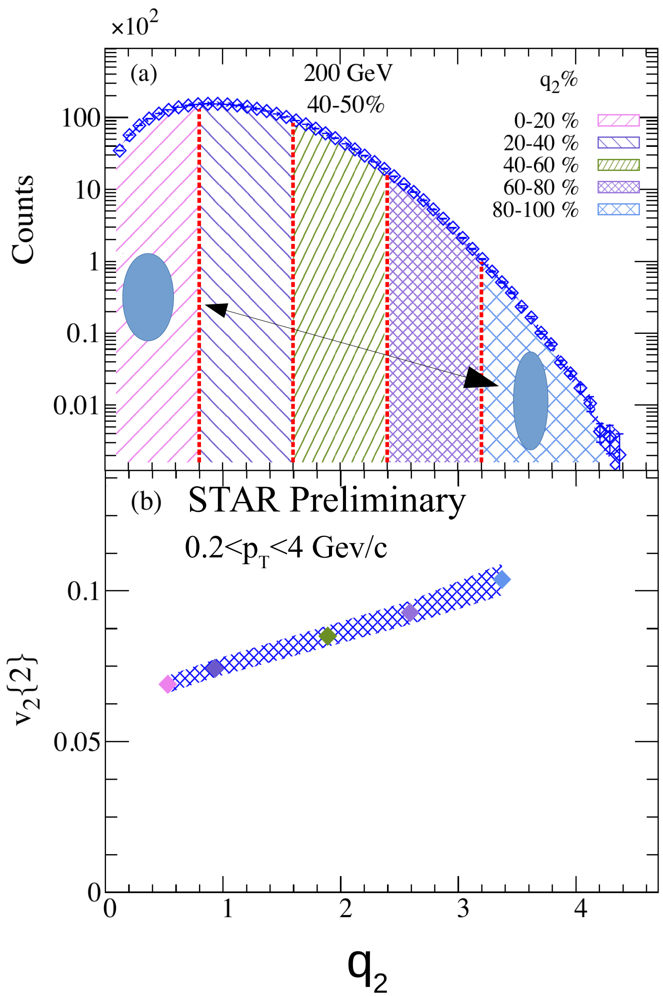
- Emission Duration $\Delta\tau$
- Lifetime τ
- Transverse geometric source size R_{geo}
- **r** vector component in Cartesian coords x_{out}
- Transverse velocity of pair β_T

Applying Event Shape Selection to HBT



- Make a selection to change initial event shape
- Which then influences expansion dynamics
- Which results in changes to measured HBT radii
  - HBT radii encode information about the expansion dynamics
- This will help to connect the initial state to the expansion dynamics

What we know: Flow, Event shape, and q_2



- Events are further subdivided into groups with different q_2 magnitudes

$$Q_{2,x} = \sum_{i=1}^{M} cos(2\phi_i) \quad Q_{2,y} = \sum_{i=1}^{M} sin(2\phi_i)$$

$$|Q_2| = \sqrt{Q_{2,x}^2 + Q_{2,y}^2}$$

$$q_2 = \frac{|Q_2|}{\sqrt{M}}$$

- $v_2\{2\}$ increases linearly with q_2
  - ✓ Demonstrates that q_2 is good event-shape selector

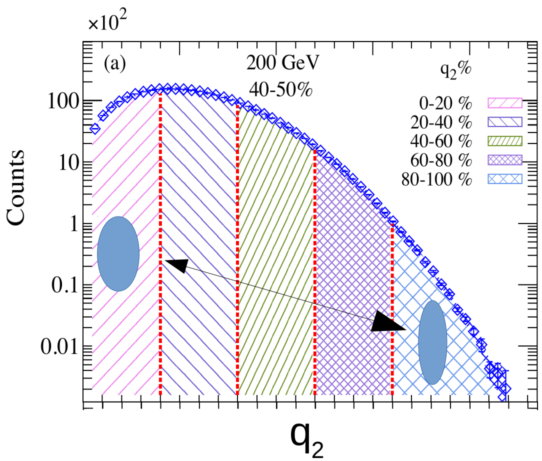
$$q_2 \rightarrow \epsilon_2 \Longrightarrow v_2$$

- q_2 selection changes ε_2
- Leads to increased pressure gradients
- This drives the expansion creating a momentum anisotropy

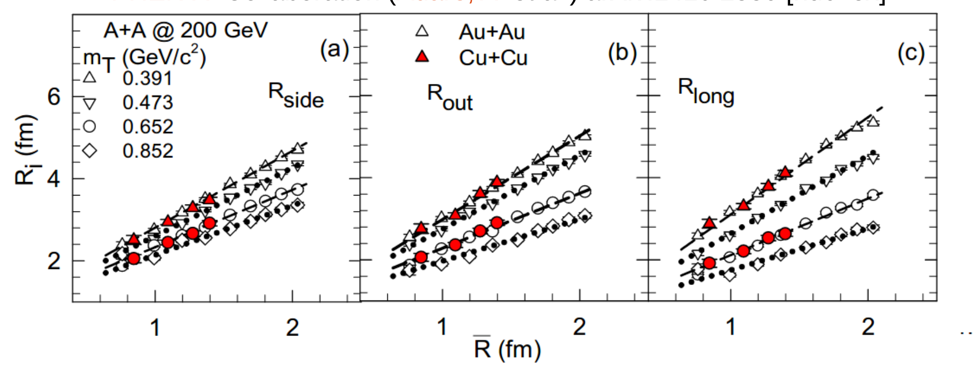
What we want to know: HBT&Event Shape

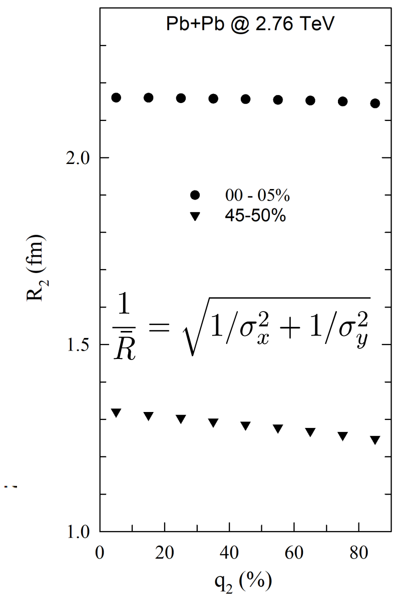
$$q_2 \rightarrow \bar{R}_2 \rightarrow ExpansionDynamics \Longrightarrow R_{side,out,long}$$

characteristic initial transverse size



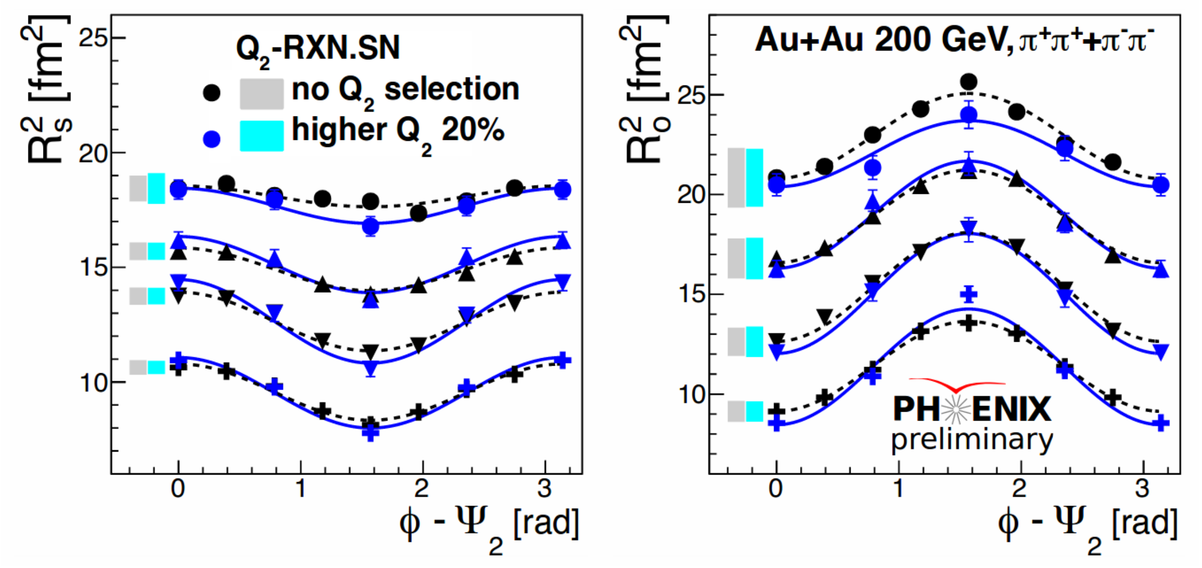
Beam-energy and system-size dependence of the space-time extent of t
pion emission source produced in heavy ion collisions
PHENIX Collaboration (Adare, A. et al.) arXiv:1410.2559 [nucl-ex]





- q_2 selection changes eccentricity and initial transverse size, $\bar{R}_2$
- All radii scale linearly with transverse source size
  - Each with different slopes
- A change in initial transverse source size influences the expansion dynamics

Indications for HBT radii sensitivity to q_2 selection

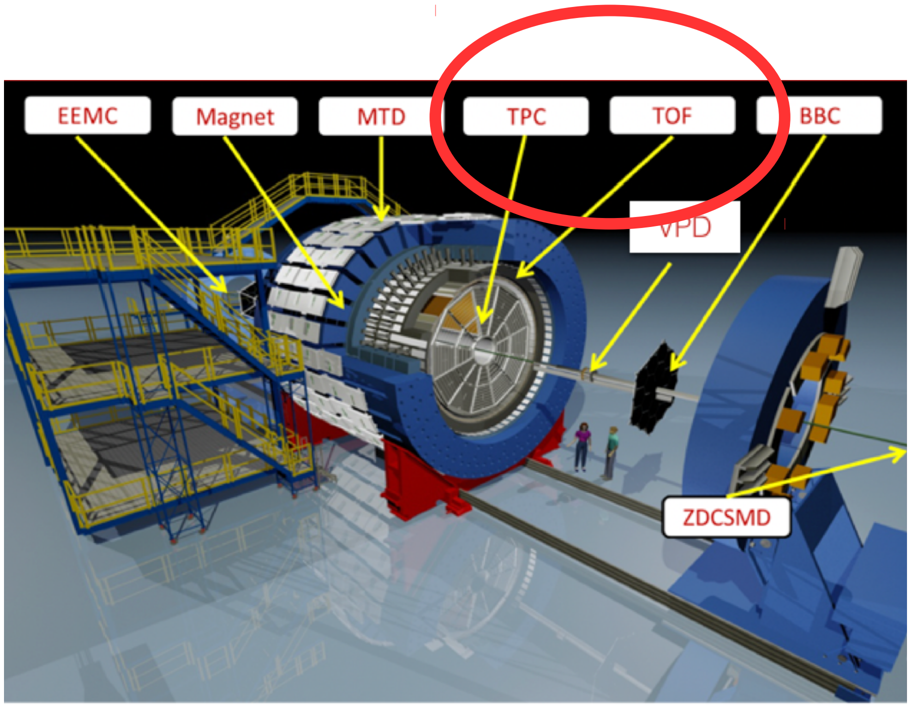


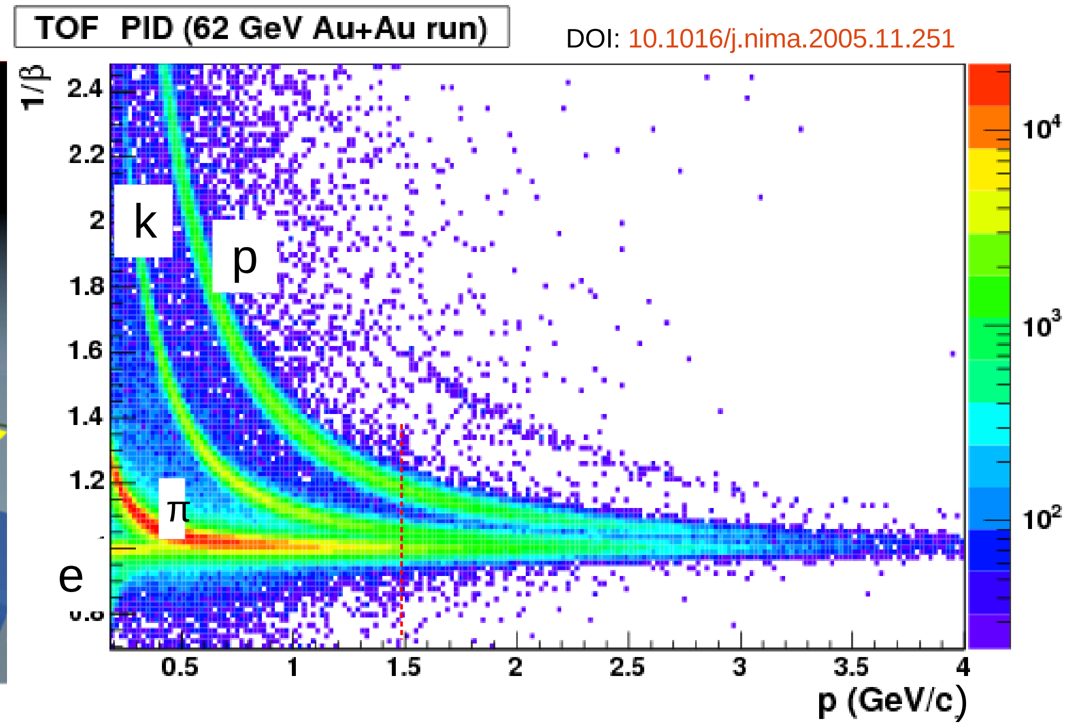
- PHENIX Results:
  - Angle dependent
  - Small differences observed in extracted radii with q_2 selection
  - Sensitive to source shape

Event geometrical anisotropy and fluctuation viewed by HBT interferometry,PHENIX Collaboration, Niida,Takafumi arXiv:1412.4068

- Current analysis:
  - Angle-integrated
  - Several k_T , centrality, and q_2 selections for the beam energy scan

The STAR Experiment





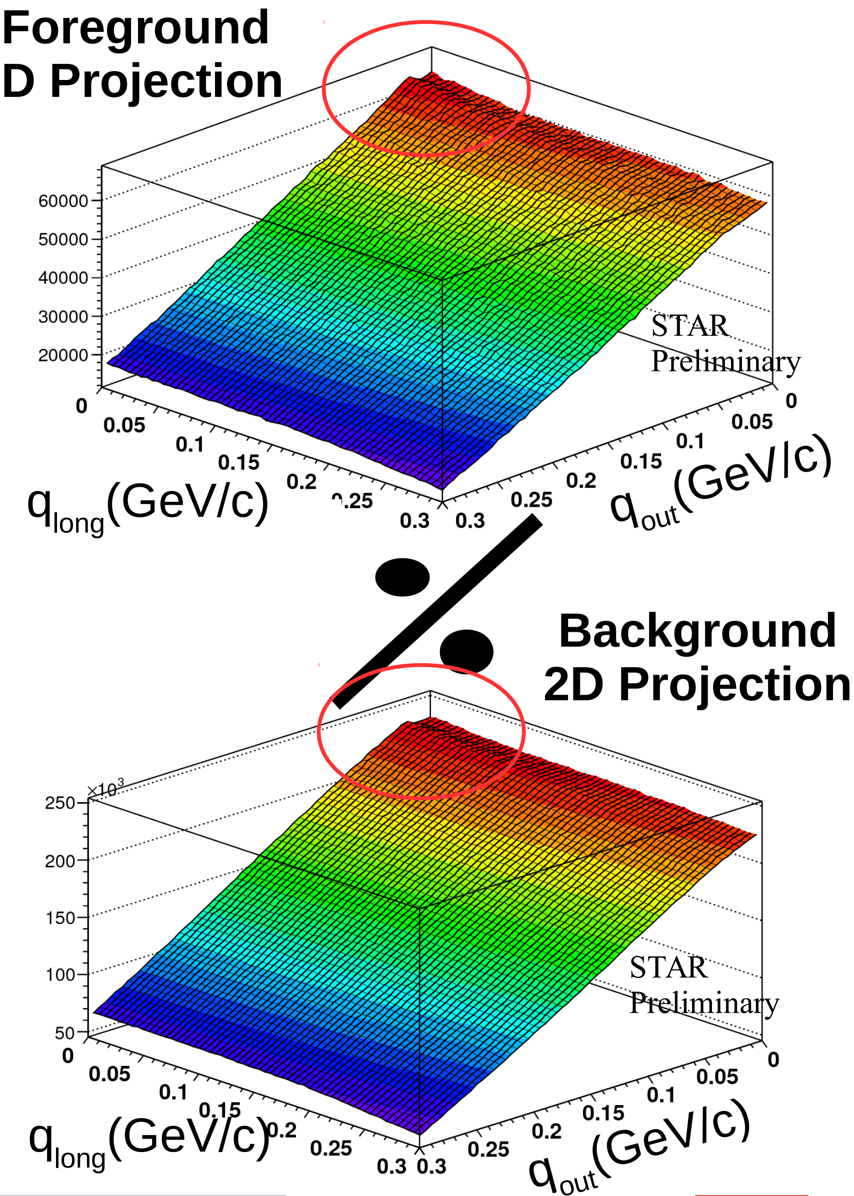
DOI: 10.1016/j.nima.2005.11.251

- TPC is used to measure momentum of charged particles

- TOF(Time Of Flight) & TPC (Time Projection Chamber) used for PID
  - ✓ TOF extends momentum range for pion identification

Correlation Function: Event Mixing Technique

$$C_2(q) = \frac{C(q_{out}, q_{side}, q_{long})_{Same}}{C(q_{out}, q_{side}, q_{long})_{Mix}}$$



$C(q)_{Same}$

- Momentum of particle pairs from the same event
  - Contains HBT correlation & other effects

$C(q)_{Mix}$

- Momentum of particle pairs from different events
  - No possible source of HBT correlation. Background correlations only.
- The pool of mixed events is chosen to be similar to the same event in the numerator (centrality, z-vertex, event shape, EP angle)

Correlation Function: Event Mixing Technique

$$C_2(q)=\frac{C(q_{out},q_{side},q_{long})_{Same}}{C(q_{out},q_{side},q_{long})_{Mix}}=\lambda[K_{coul}(q_{inv})(1+e^{-q_o^2R_o^2-q_l^2R_l^2-q_s^2R_s^2})-1]+1$$

M. G. Bowler, Phys. Lett.B270(1991) 69.
Yu. Sinyukov, R. Lednick y, S. V. Akkelin, J. Pluta and B. Erazmus, Phys.Lett.B432(1998) 248

$C(q)_{Same}$

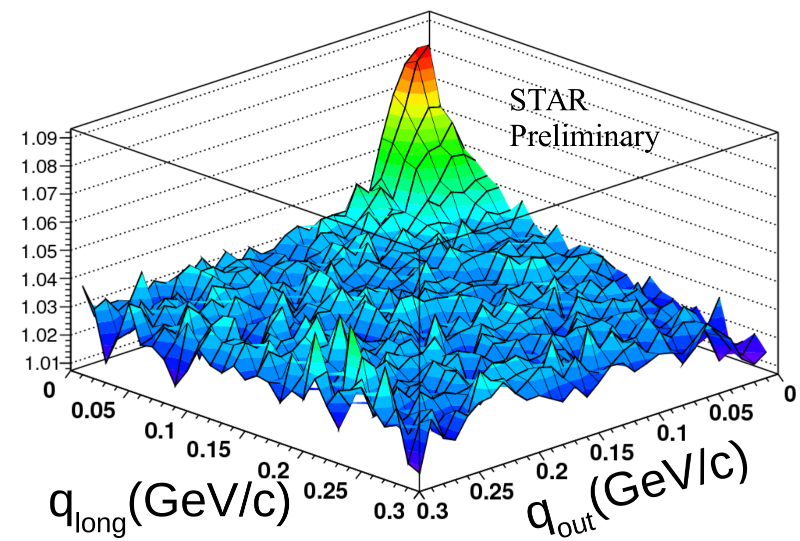
- Momentum of particle pairs from the same event
  - Contains HBT correlation & other effects

$C(q)_{Mix}$

- Momentum of particle pairs from different events
  - No possible source of HBT correlation. Background correlations only.
- The pool of mixed events is chosen to be similar to the same event in the numerator (centrality, z-vertex, event shape, EP angle)

Ratio, 2D Projection of $C_2(q)$

=

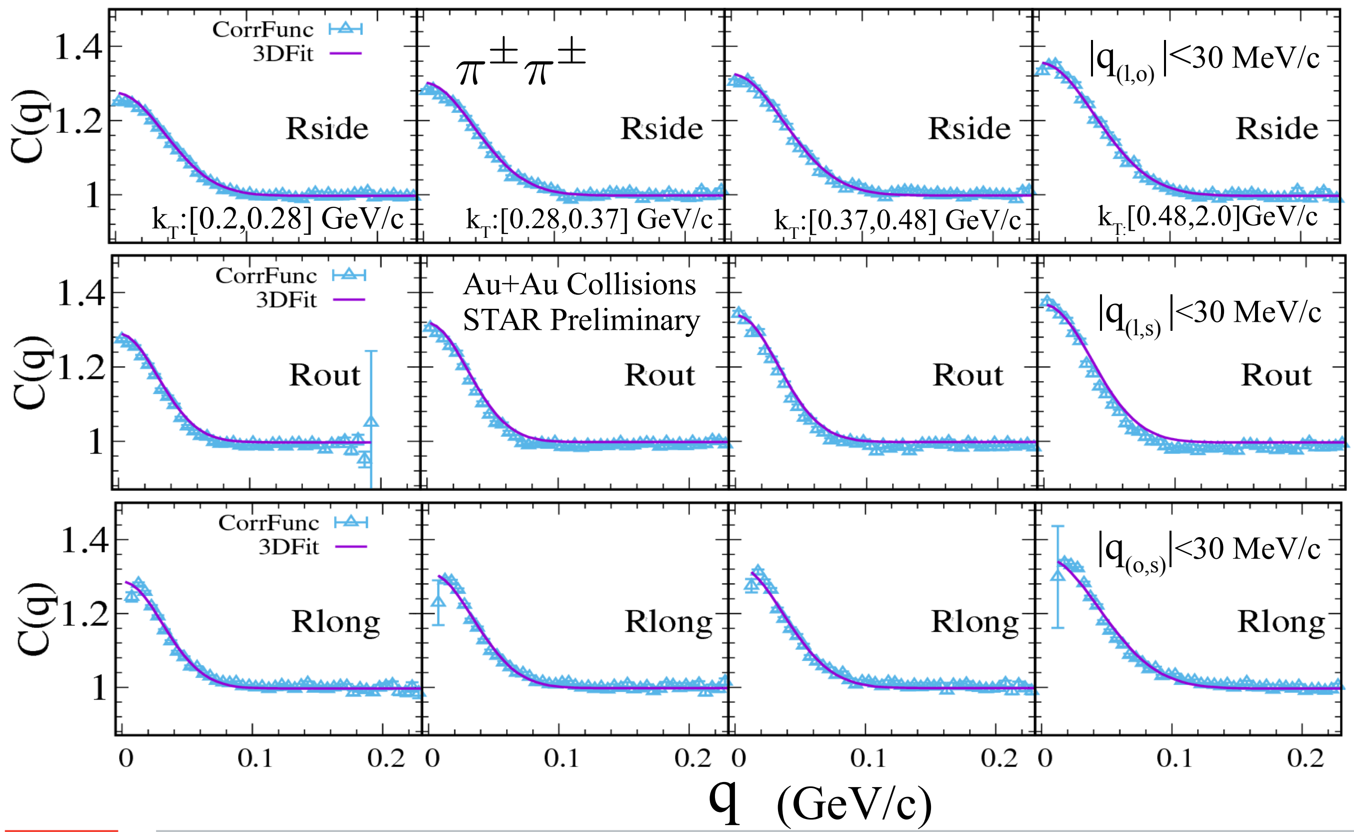


Correlation Function

$$C_2(q)=\frac{C(q_{out},q_{side},q_{long})_{Same}}{C(q_{out},q_{side},q_{long})_{Mix}}=\lambda[K_{coul}(q_{inv})(1+e^{-q_o^2R_o^2-q_l^2R_l^2-q_s^2R_s^2})-1]+1$$

M. G. Bowler, Phys. Lett.B270(1991) 69.
Yu. Sinyukov, R. Lednick y, S. V. Akkelin, J. Pluta and B. Erazmus, Phys.Lett.B432(1998) 248

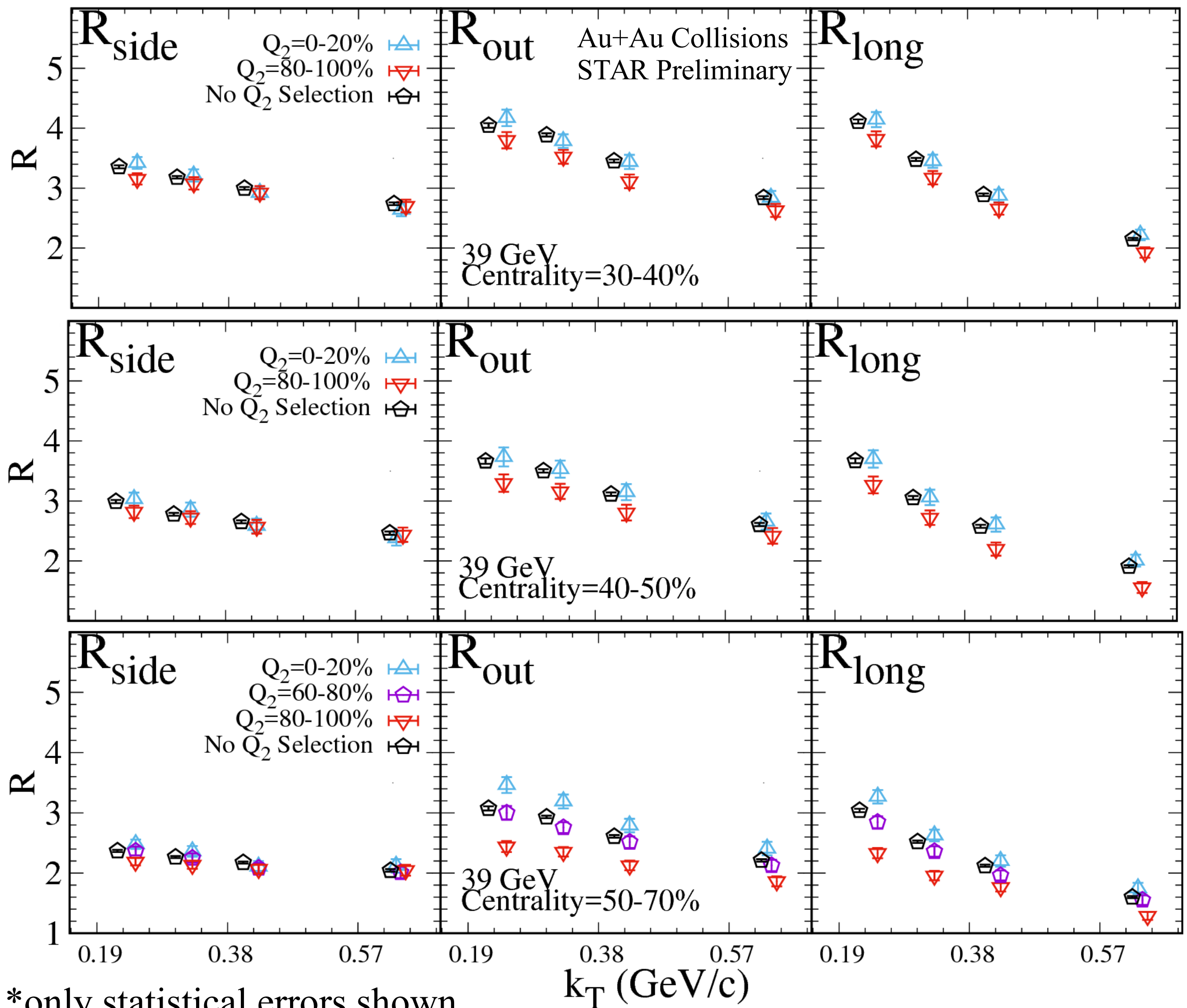
- 3D Like-sign correlation functions & fits projected for out,side, and long



- 1D projections from 3D correlation surface
- Angle-integrated
- Robust correlation functions and fits obtained
  - ✓ Here $K_{coul}(q_{inv})=1$

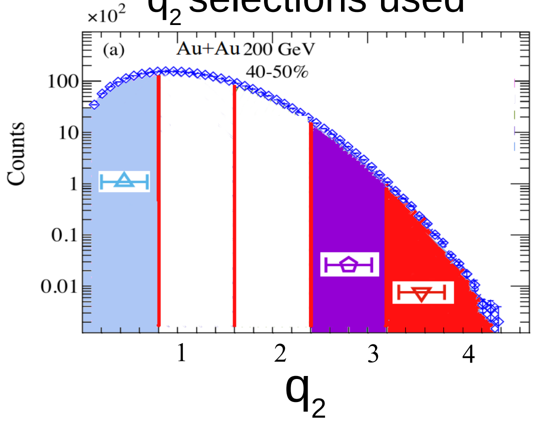
Results

Radii for different Event Shape Selections



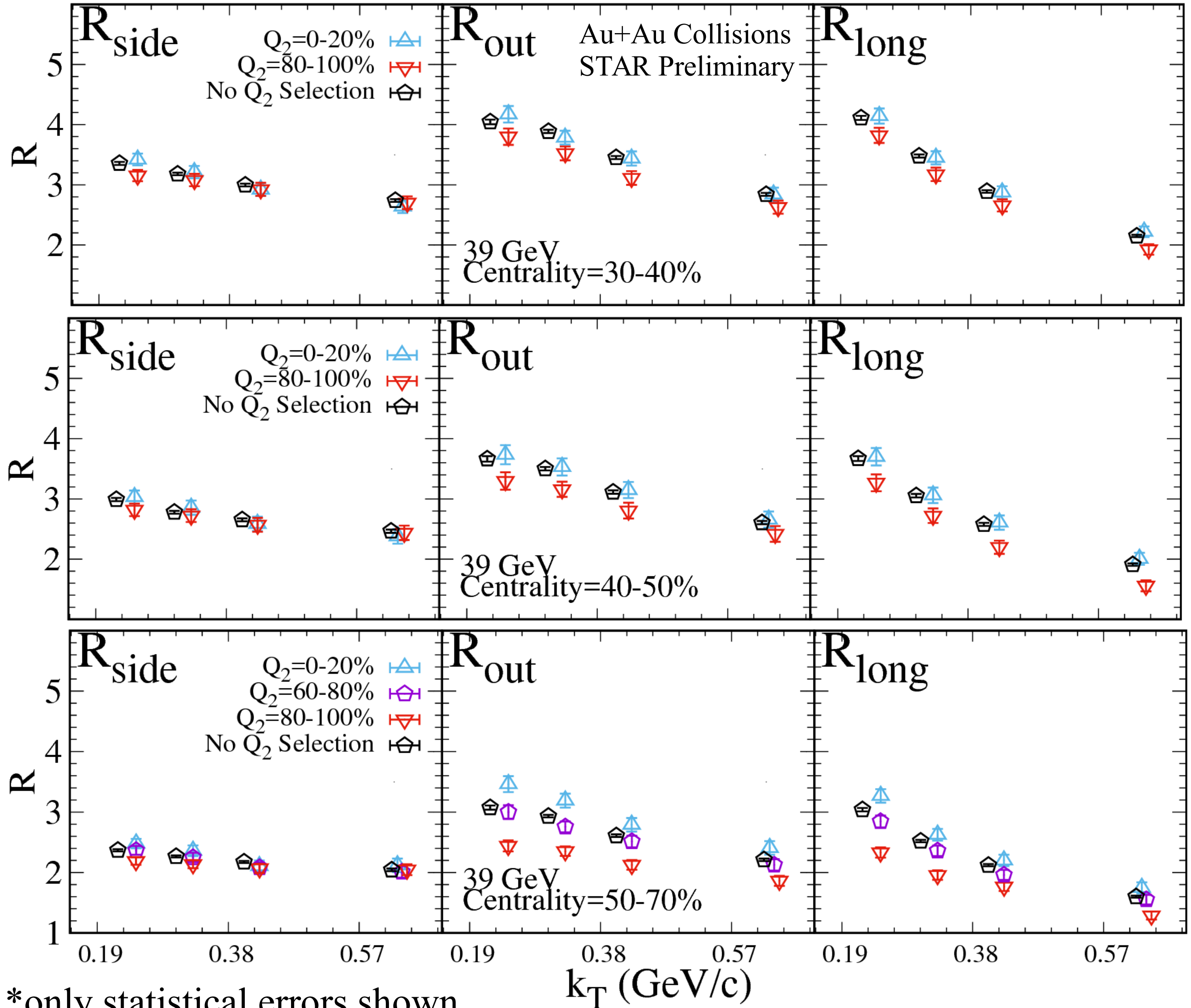
*only statistical errors shown

q_2 selections used

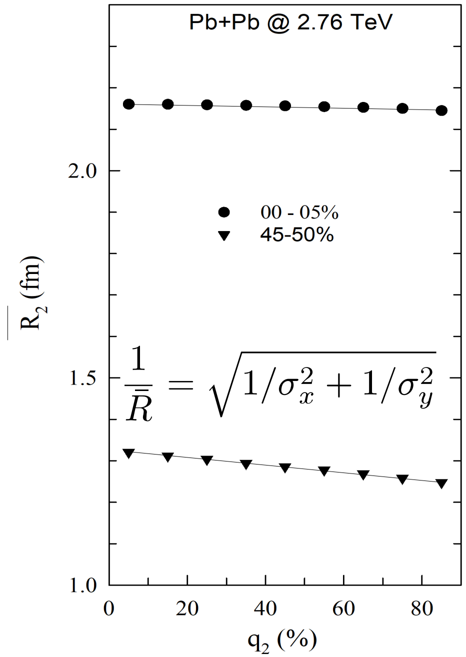


- For a given q_2 selection all radii decrease with k_T
- R_{side} shows a very weak dependence on q_2
- R_{long} and R_{out} show modest q_2 dependence which increases with centrality
  - ✔ Both contain temporal contributions

Radii for different Event Shape Selections

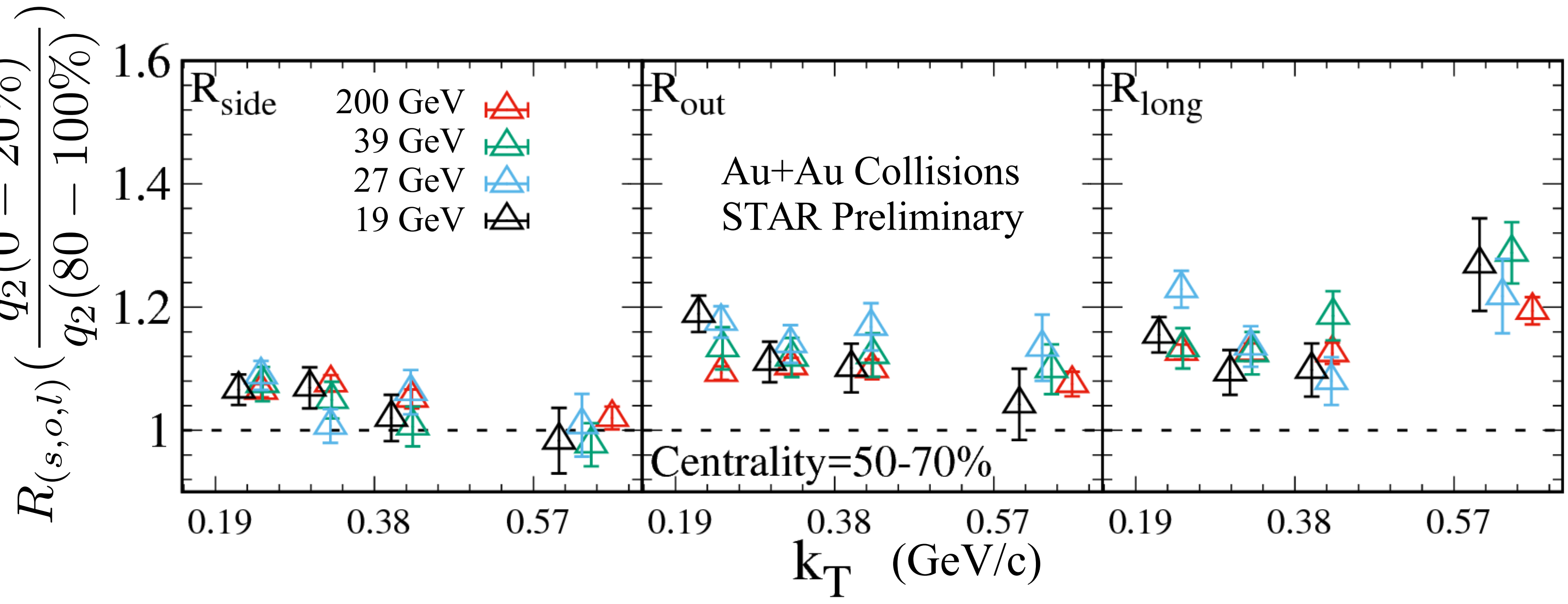


*only statistical errors shown



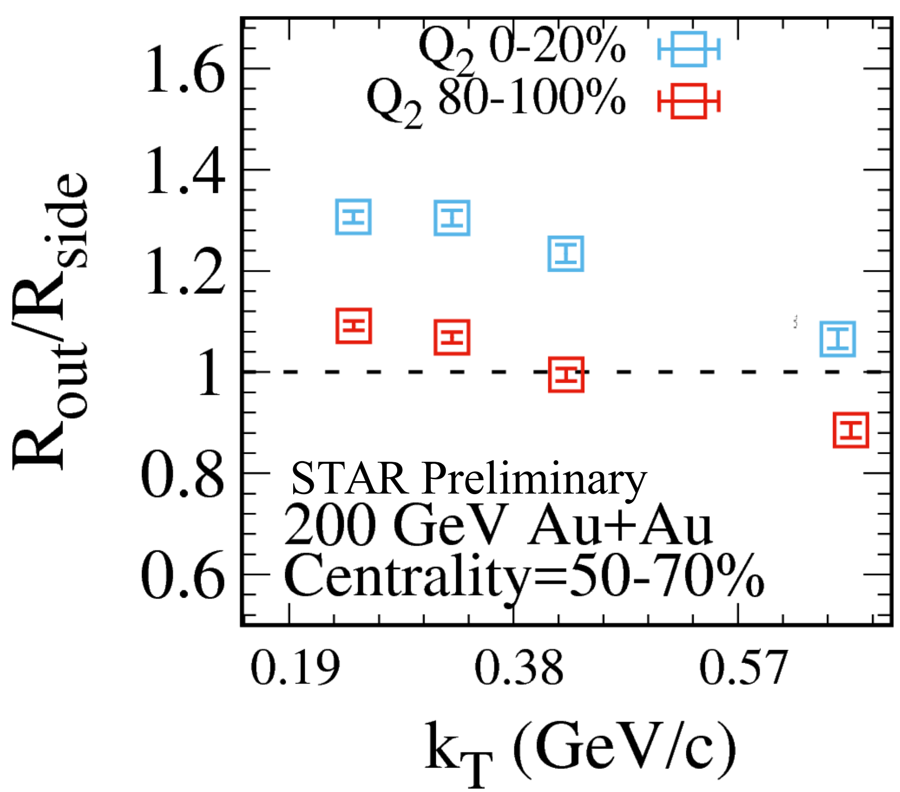
- Transverse geometric source size dependence for q_2 increases in more peripheral collisions
  - Expect stronger change in radii as centrality increases
  - R_{side} q_2 dependence suppressed due to Angle averaging

Ratio of high and low q_2 selections for each radii



- q_2 selected ratios do not indicate a strong dependence on k_T
- q_2 selected ratios do not indicate a strong dependence on beam energy.
- ✓ Ratios for R_{long} and R_{out} suggest sensitivity to q_2 selection while the ratio for R_{side} does not

R_{out}/R_{side} for different shape selections



- The ratio between R_{out}/R_{side} provides rough measure for the relative emission duration

$$R_{side}^2 = \frac{R_{geo}^2}{1 + \frac{m_T}{T}\beta_T^2}$$

$$R_{out}^2 = R_{side}^2 + \beta_T^2(\Delta\tau)^2 - 2\beta_T \Delta x_{out} \Delta\tau$$

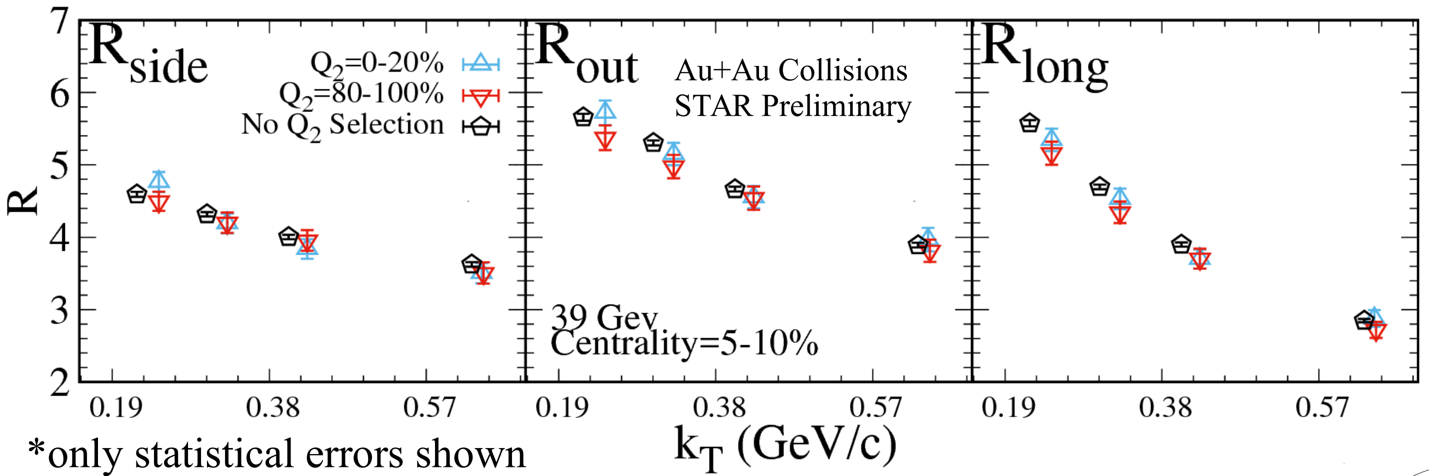
- Ratios for the two q_2 selections show the expected decrease with k_T
- The ratio decreases with q_2 selection
  - ✓ **Possible event-shape influence on emission duration?**

Conclusion

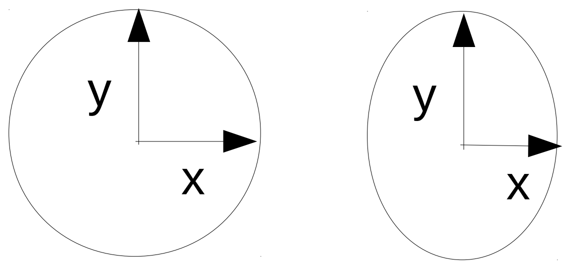
- New measurements of event-shape selected angle-averaged HBT radii for different centrality and k_T selections for several beam energies have been made
  - ✔ R_{side} is relatively insensitive to q_2 selection
  - ✔ In contrast, R_{long} & R_{out} show modest sensitivity to q_2 selection at mid-central and peripheral collisions
    - ➢ Influence from q_2 shows very weak k_T and energy dependence
  - ✔ The ratio R_{out}/R_{side} shows measurable q_2 dependence
    - ➢ May indicate emission duration has q_2 dependence
- *These results suggest that event shape selection influences the expansion dynamics which leads to measurable changes in the HBT radii*

BACKUP

Radii for different Event Shape Selections



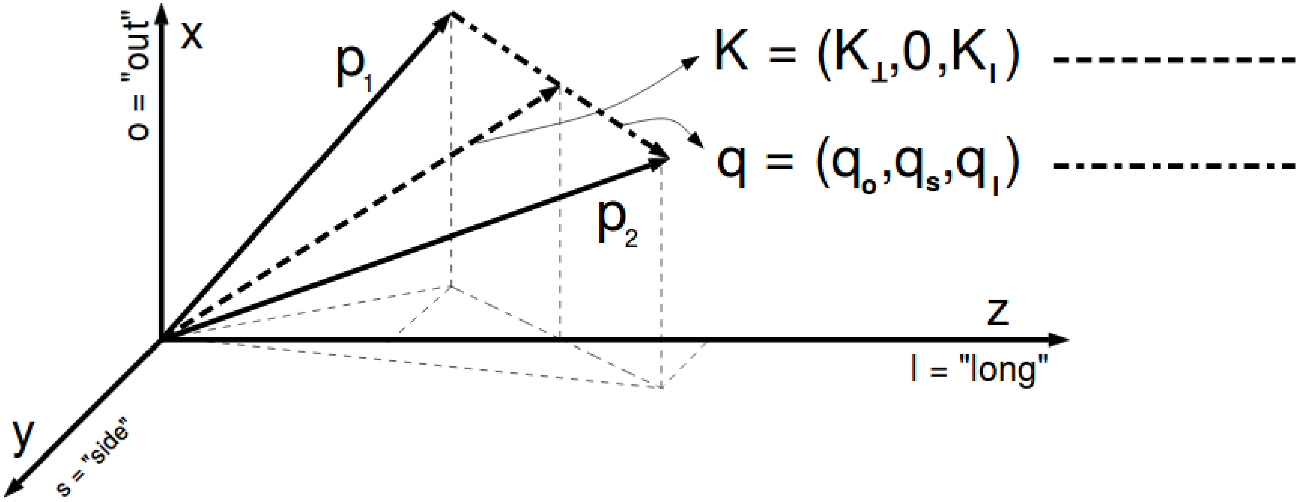
Central collisions



$$\frac{1}{\bar{R}} = \sqrt{1/\sigma_x^2 + 1/\sigma_y^2}$$

- For a given q_2 selection all radii decrease with k_T
- For central collisions, all radii show little (to no) change for q_2 selection
  - In central collisions, transverse source size is less influenced by q_2

B.P. Parameterization



Ulrich Heinz

10.1016/S0370-1573(99)00032-0

$$R_i^2(p) = \langle(\Delta r_i - v_i \Delta t)^2\rangle_p = \langle \Delta r_i^2 \rangle_p + v_i^2 \langle \Delta t^2 \rangle_p - 2v_i \langle \Delta r_i \Delta t \rangle_p, \; (i = out,\, side,\, long)$$

$$\Delta r_i = r_i - \langle r_i \rangle_p,$$

Saddle point approximation

Average value for a chosen momentum

$$R_{out}^2 = R_{side}^2 + \beta_T^2 (\Delta\tau)^2 - 2\beta_T \Delta x_{out} \Delta\tau$$

Cartesian component