# PHENIX results on collectivity tests in high-multiplicity p+p and p+Au collisions at $\sqrt{s_{NN}}$=200 GeV

RIKEN/RBRC

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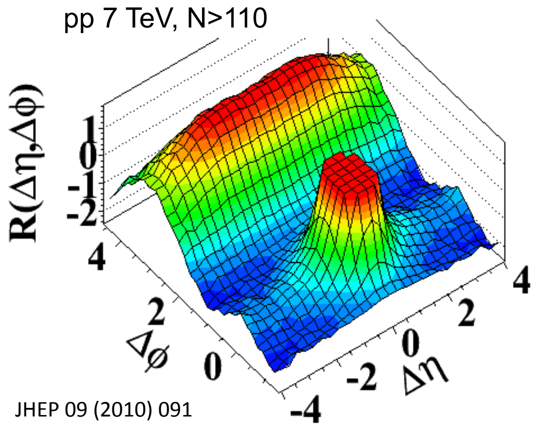
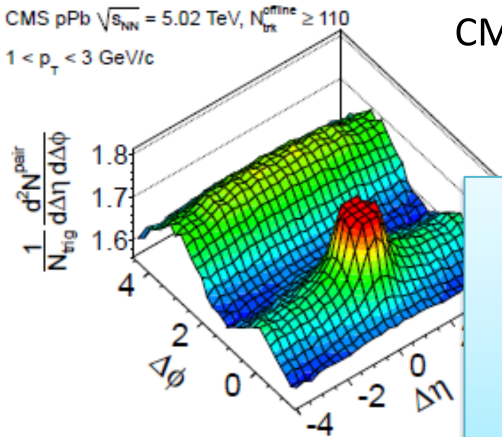
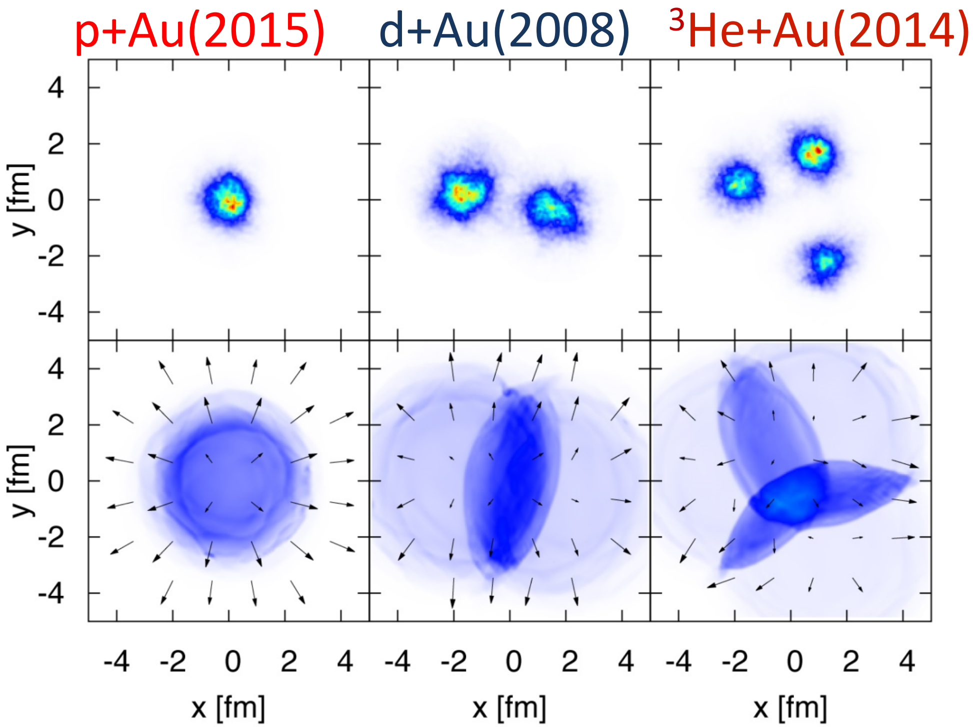
# Origin of “ridge” for Small Colliding Systems




CMS: Phys. Lett. B 7198(2013)

Different small system nuclei provide distinctive initial geometries




graphic from Bjoern Schenke

## Initial State

convolution

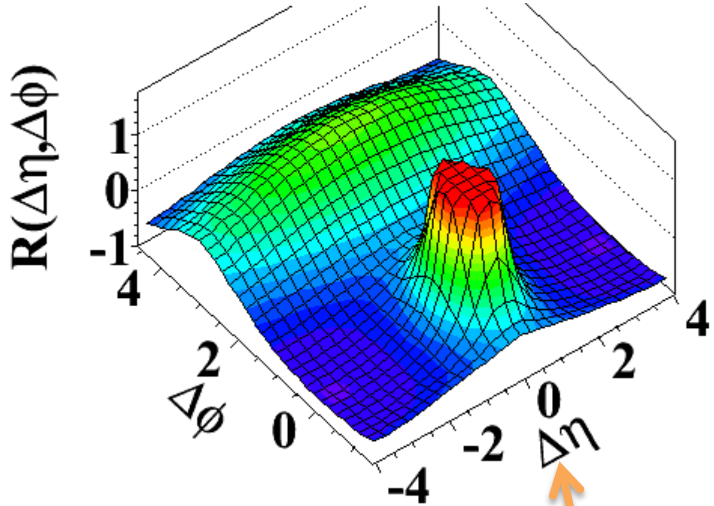
- Intrinsic eccentricity caused by initial state fluctuation
- Ground state wave function
- Initial state momentum correlation : CGC

## Final State

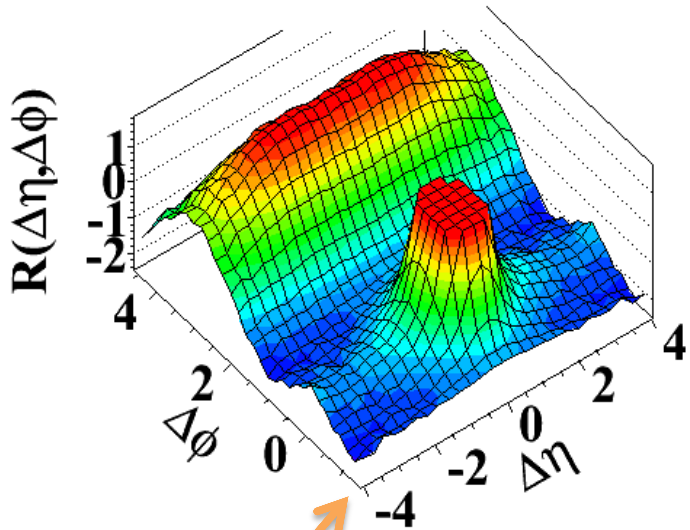
- Hydro dynamics
- Viscosity

# High Multiplicity Events is the key!

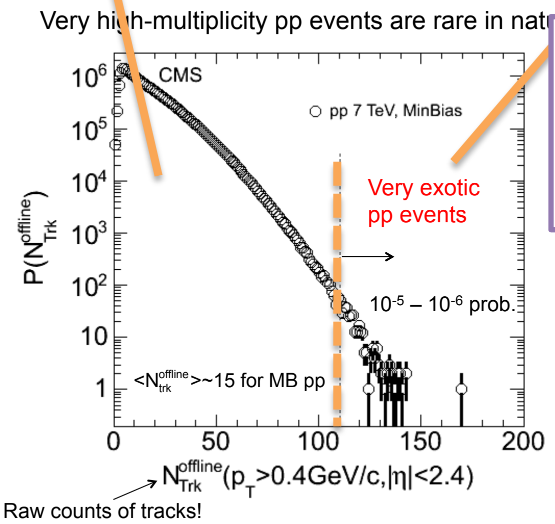
pp $<N>\sim 15$, $1<p_T<3$ GeV/c




pp $N>110$, $1<p_T<3$ GeV/c



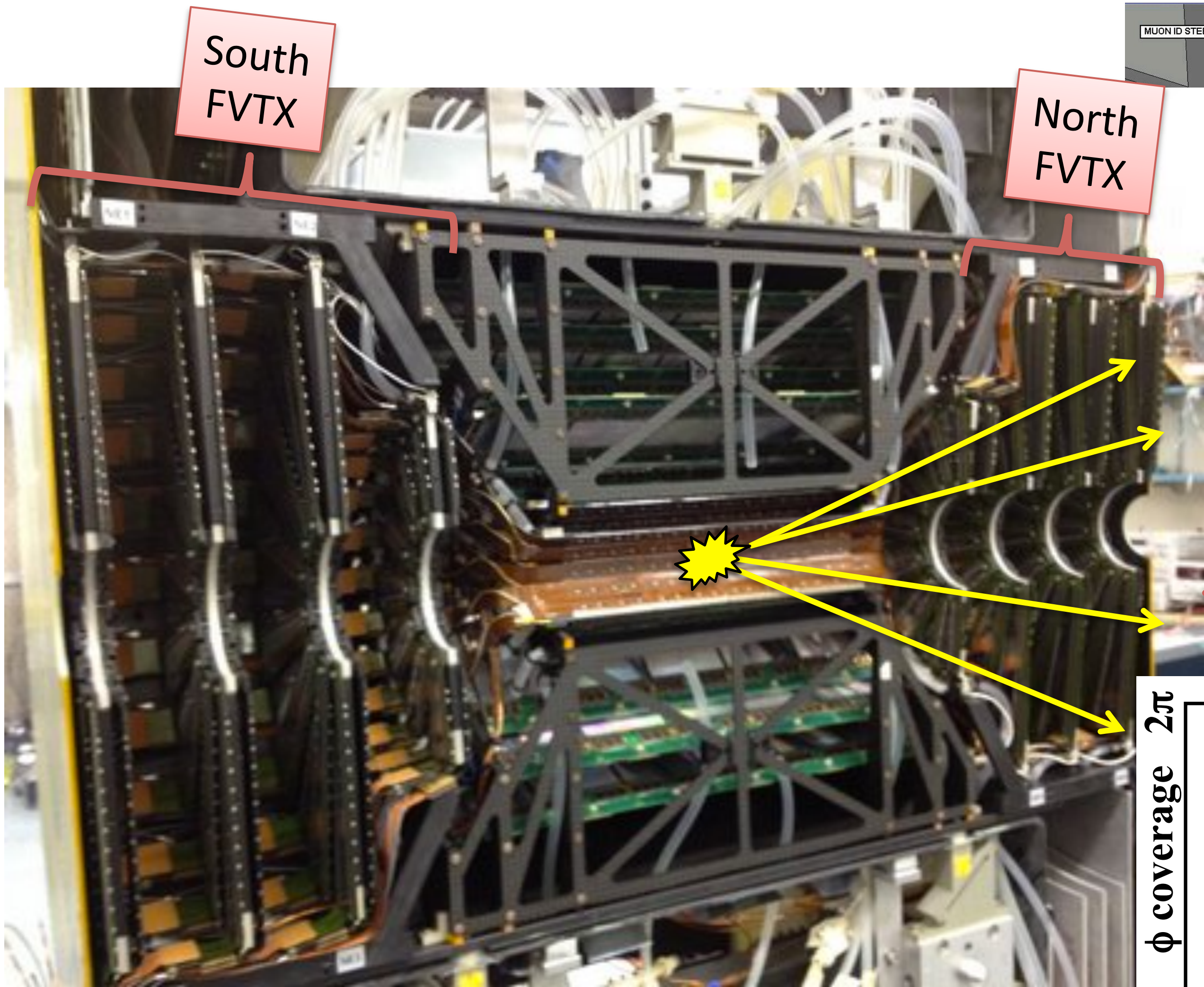

The final state #tracks>110 plays key role. The initial energy √s may not be the critical condition.

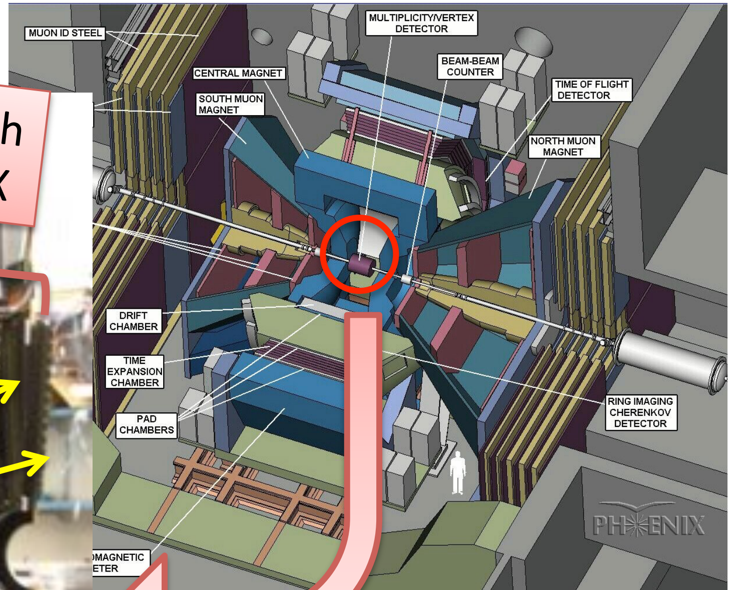



Multiplicity is lower at RHIC energy, therefore statistically challenging.

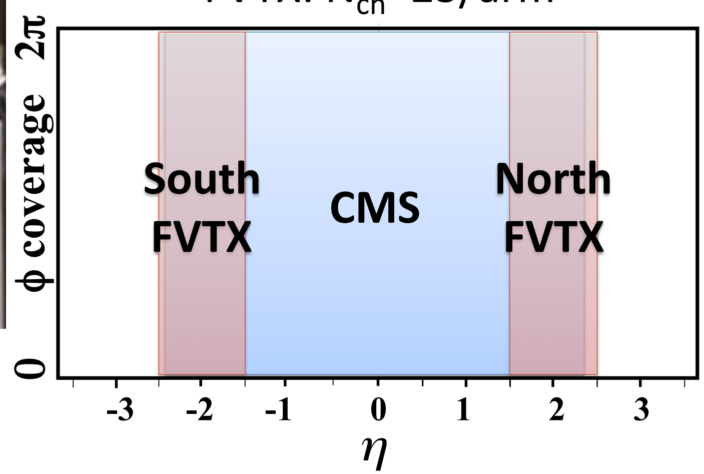
Need trigger development

# High Multiplicity Trigger for PHENIX



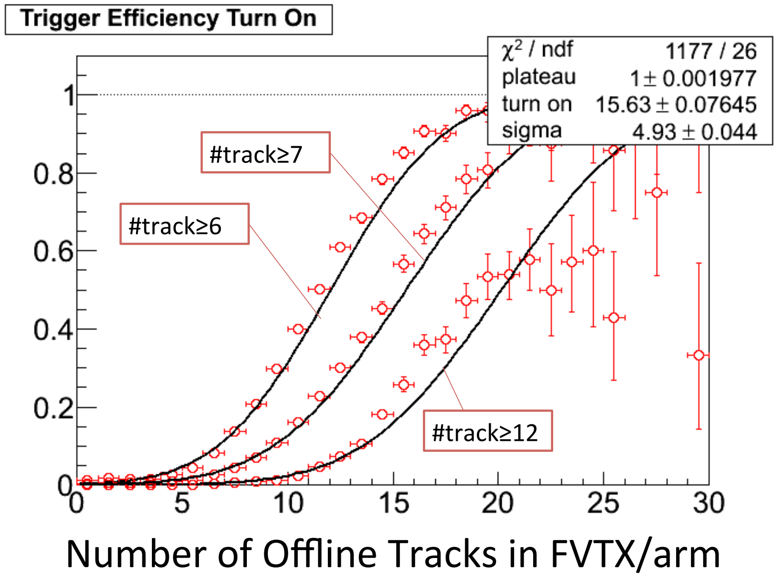



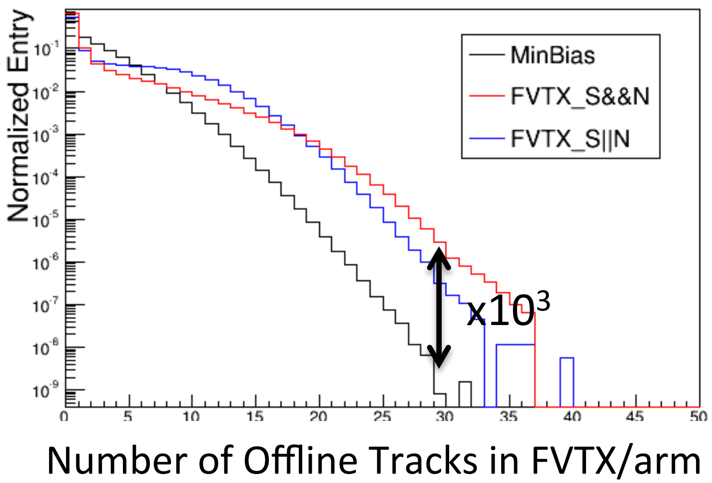

FVTX: $N_{ch}$>23/arm




Implement New High Multiplicity Trigger Capability in Existing Readout Electronics for Run15 p+p Run

# Trigger Performance for p+p

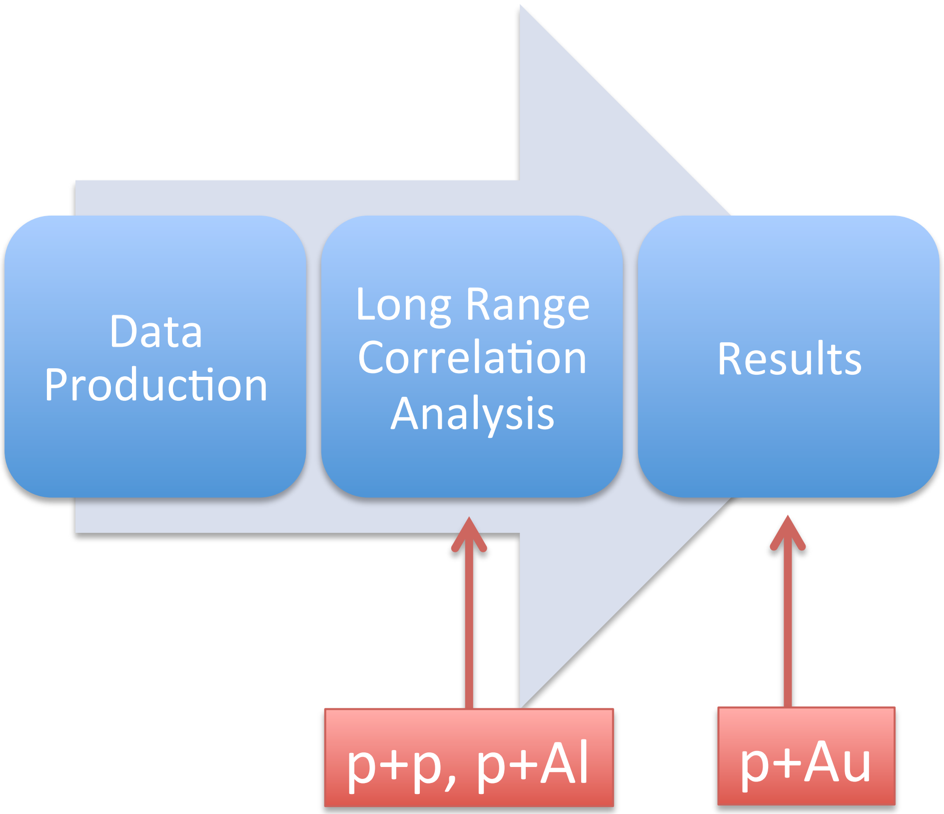



- Coarse Online Tracking
- Trigger events above multiplicity threshold
- Good turn on response is observed for different thresholds
- Up to 3 orders of magnitudes enhanced sensitivity to high multiplicity events compared to MB.
- Accumulated 500M events in p+p

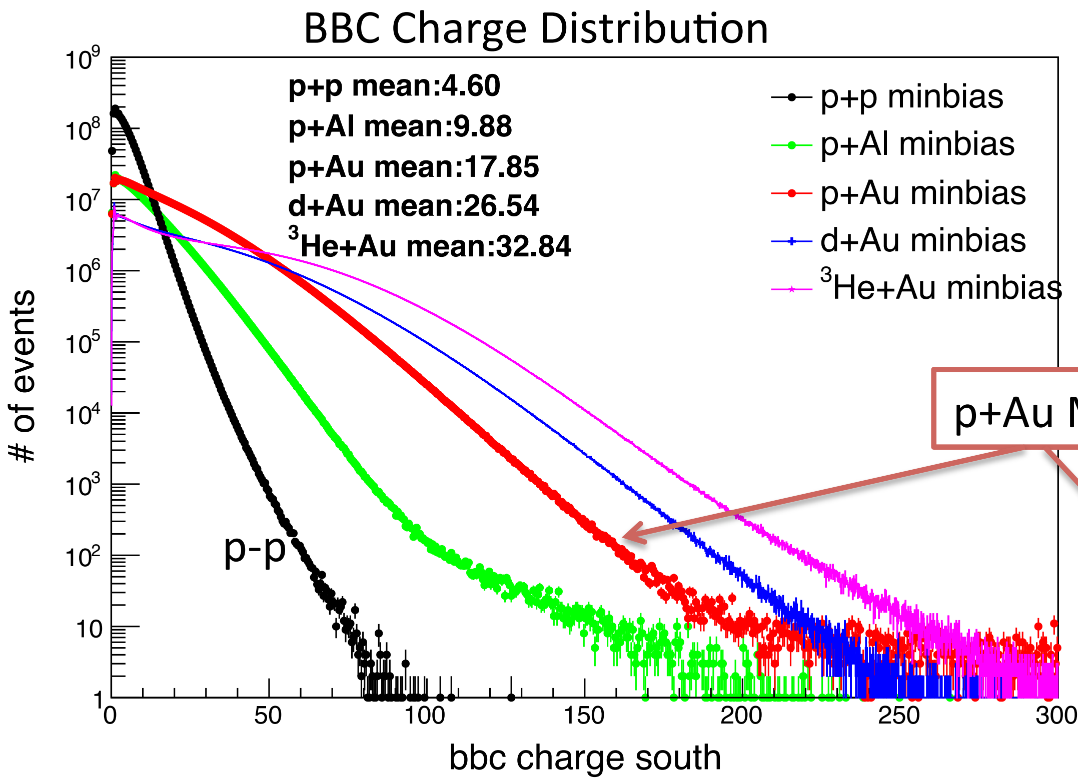
Poster presentation:
Toru Nagashima (1391), SeYoung Han (1392)

# Run15 Data Analysis Status



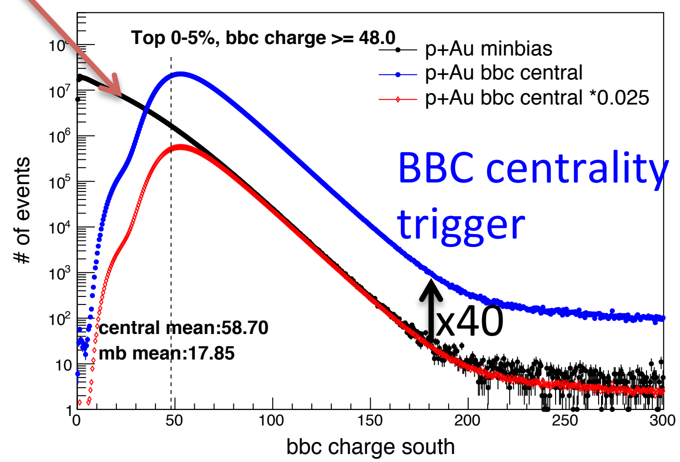

# Run15 p+Au

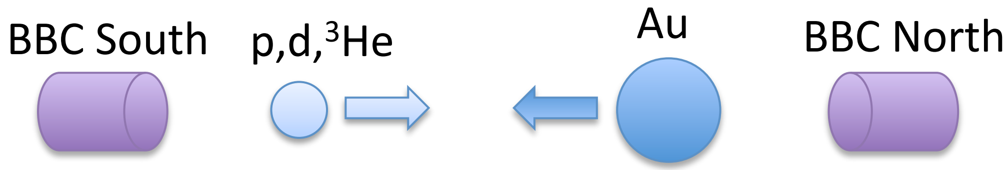
# BBC Multiplicity in Small Systems




BBC centrality trigger for Au-going direction (South) was used for p+Au analysis to enhance high multiplicity events.

p+Au MB



# Long Range Two Particle Correlation

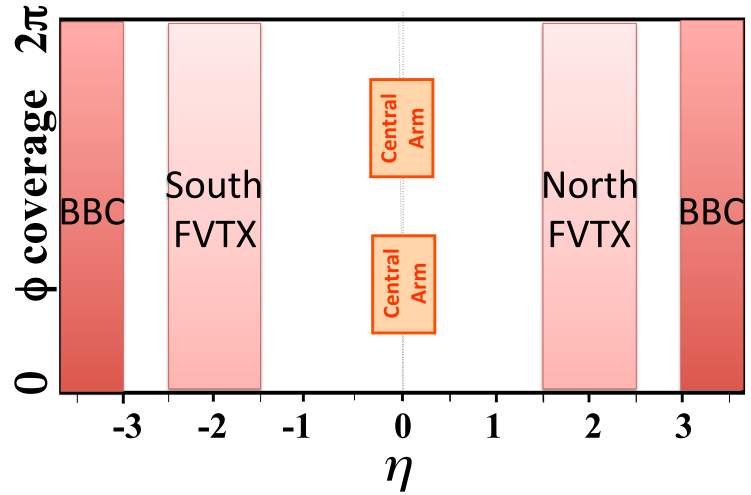
- Two Particle Correlation

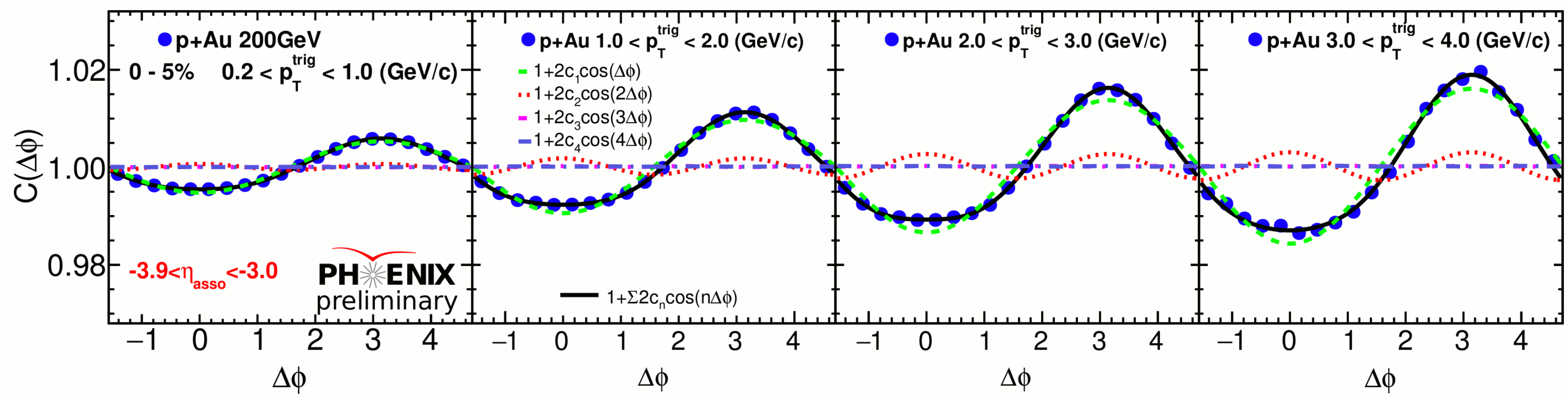
$$\Delta\varphi = \varphi_{track} - \varphi_{BBC}$$

$$S(\Delta\varphi, p_T) = \frac{d(w_{PMT} N_{same\ event}^{track(p_T)-PMT})}{d\Delta\varphi}$$

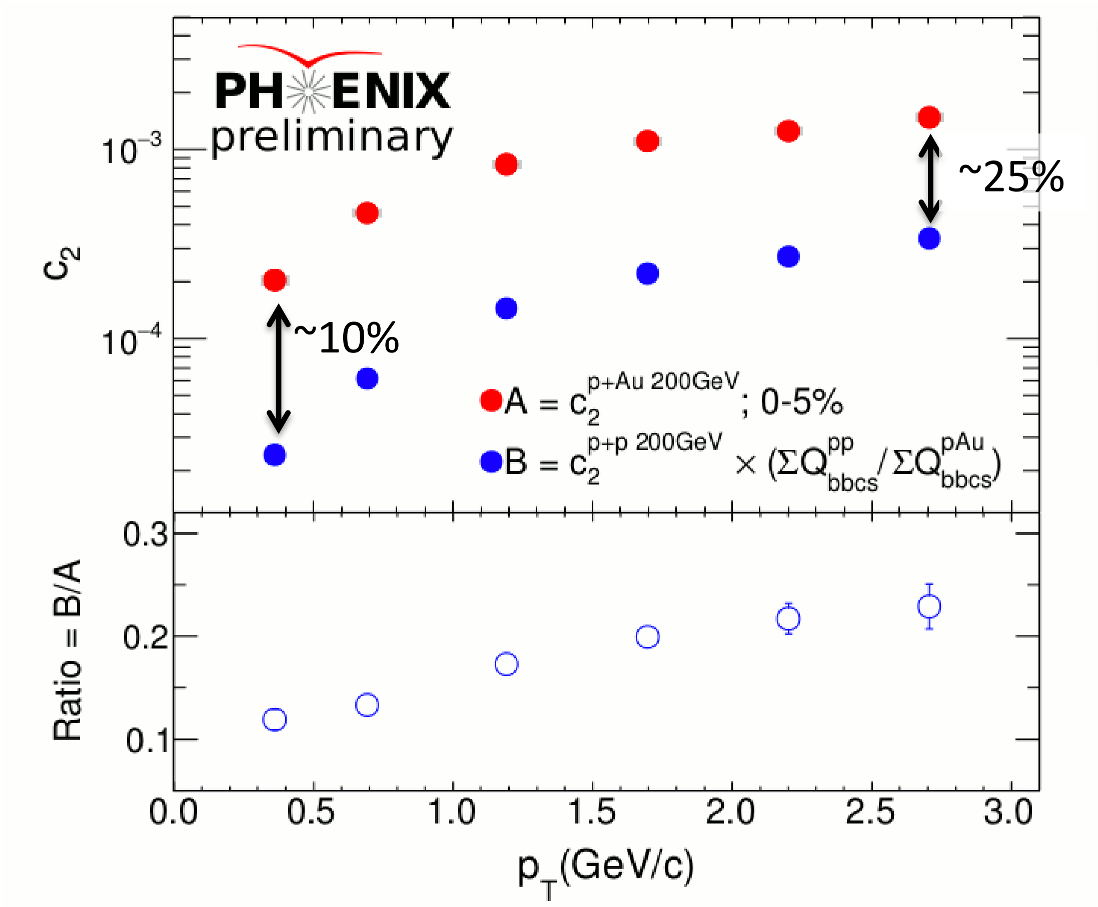
  - Event Mixing

$$C(\Delta\varphi, p_T) = \frac{S(\Delta\varphi, p_T)}{M(\Delta\varphi, p_T)} \frac{\int M(\Delta\varphi', p_T) d\Delta\varphi'}{\int S(\Delta\varphi', p_T) d\Delta\varphi'}$$



# $c_2$ and elementary process contribution




- The Fourier coefficients from 0-5% central p-Au collisions
- Non-flow effects are estimated by MB p+p scaled by dilution factor ~ 12.

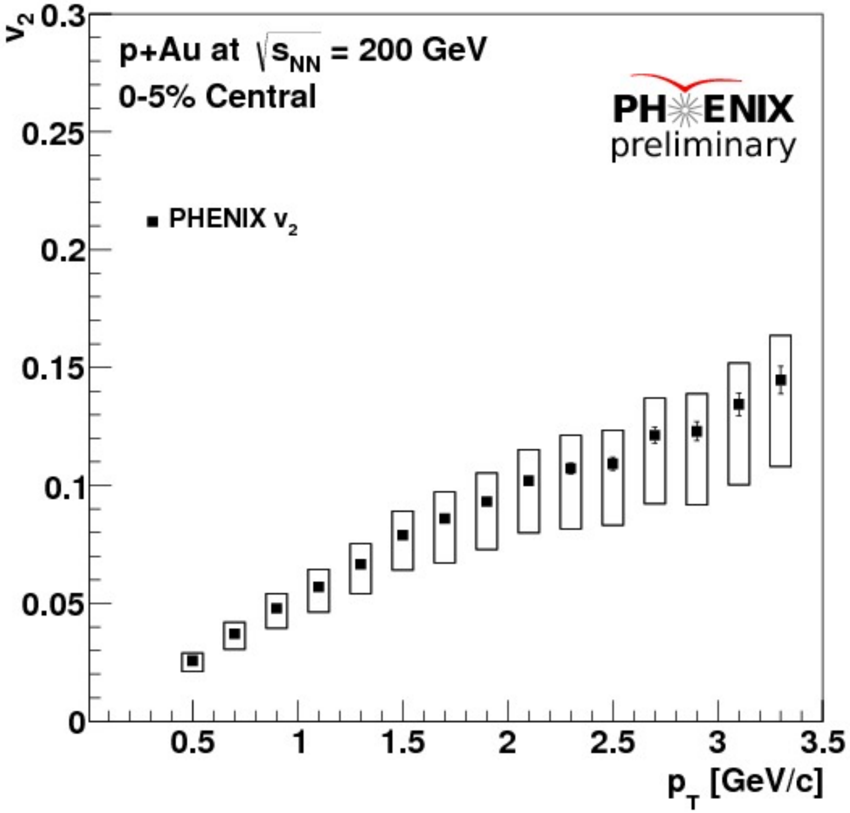
Contribution from elementary process is estimated to be 10 % at small $P_T$ and grows in higher $P_T$ region up to 25%.

Assigned as systematic uncertainty

# $v_2$ Extraction via Event Plane Method

Event plane by FVTX

$$\psi_{2,FVTXs} = arctan\left(\frac{Q_y}{Q_x}\right) = arctan\left(\frac{\sum_{i=1}^{N} w_i \sin(2\varphi_{FVTX,i})}{\sum_{i=1}^{N} w_i \cos(2\varphi_{FVTX,i})}\right)$$



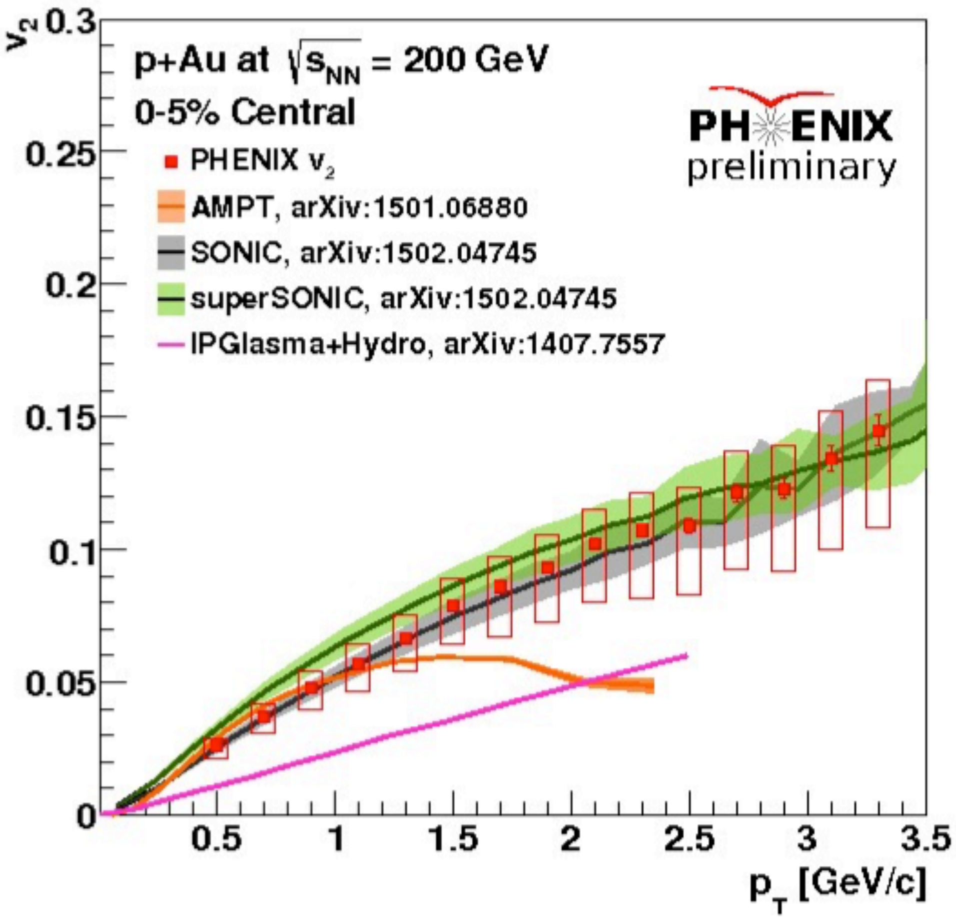

Second order anisotropic flow coefficient

$$v_2 = \frac{\cos[2(\varphi - \psi_{2,FVTXs})]}{Res(\psi_{2,FVTXs})}$$

Resolution Res($\Psi_{2,FVTXs}$) is calculated by three sub-events method using BBC-South event plane and central arm event plane based on low $P_T$ tracks.

For details see PHENIX poster (0218, QGP in small systems) by Qiao Xu

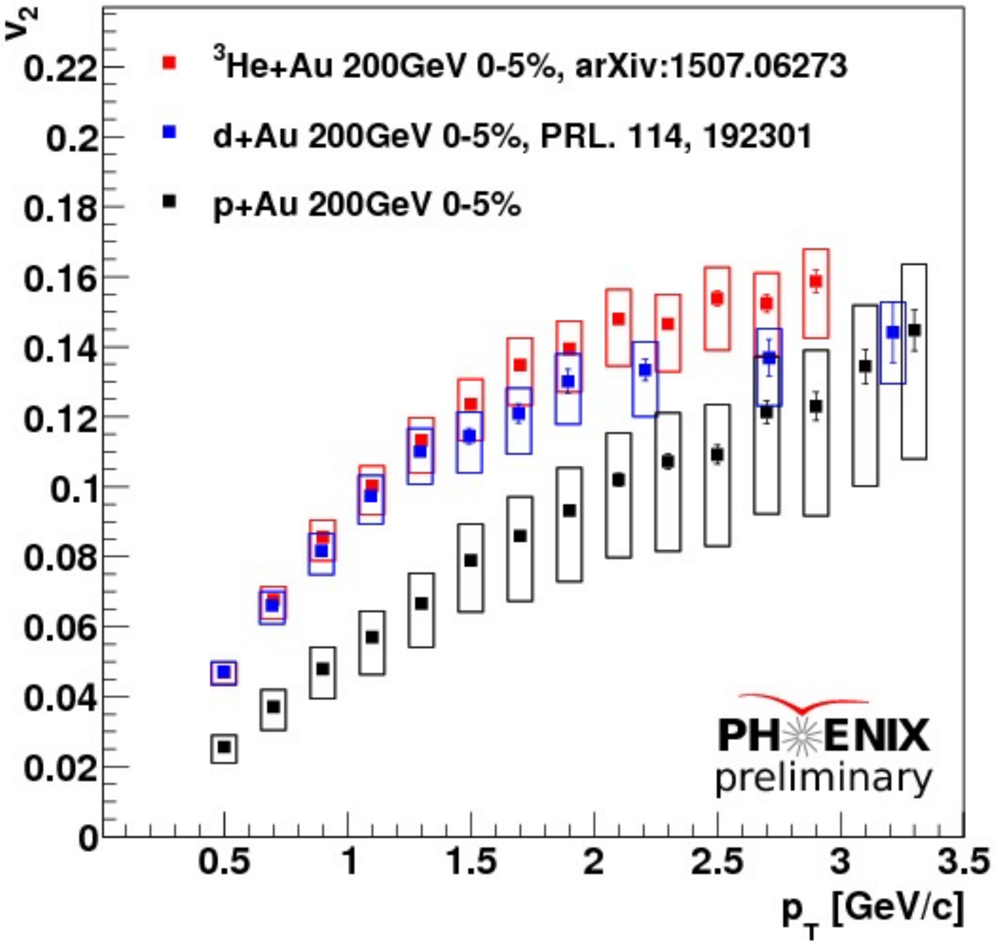
# Comparison with Model Predictions




- "SONIC and superSONIC with Glauber initial conditions agrees with data within uncertainties"
- "Hydrodynamics with IPGlasma initial conditions underpredicts v2 by x2."
- "AMPT agrees up to pT ~ 1 GeV/c, then underpredicts"

# Comparison with p+Au, d+Au, $^3$He+Au

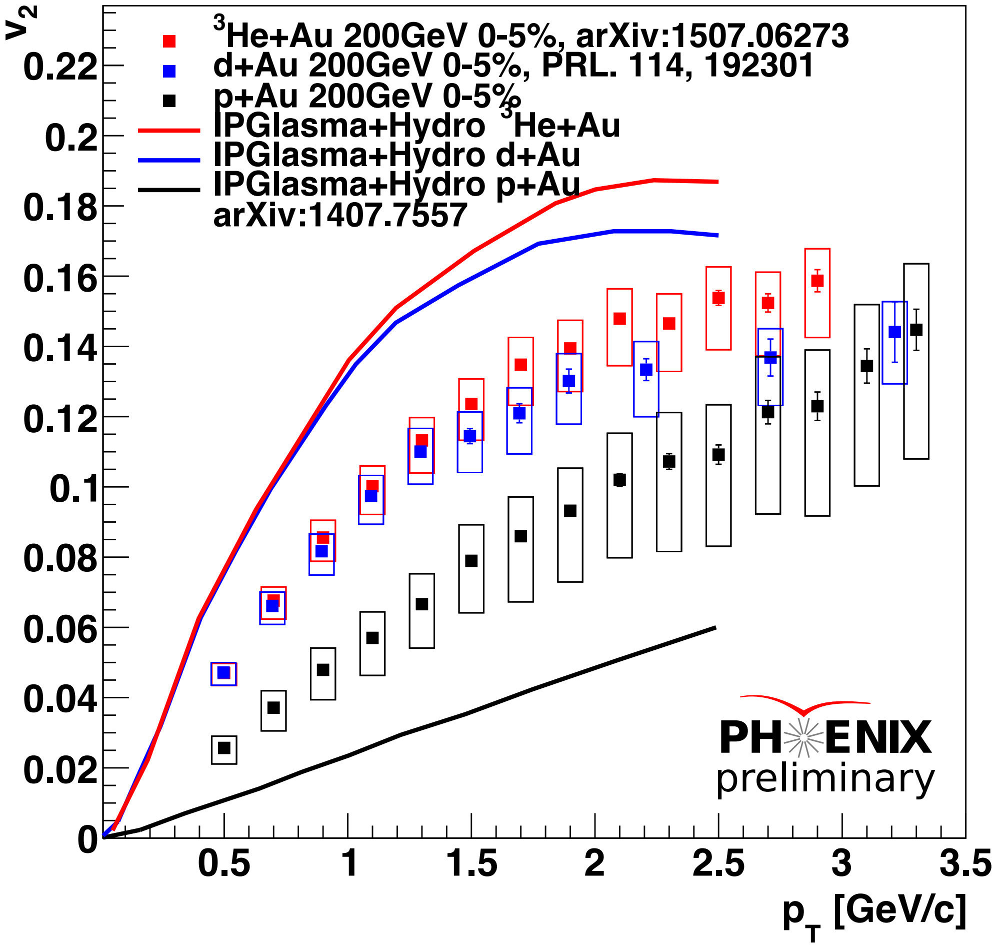
Data sets are 0-5% centrality.




$$v_2^{pAu} < v_2^{dAu} \leq v_2^{^3HeAu}$$

This ordering is expected from initial state eccentricities
-> smallest $\varepsilon_2$ in p+Au

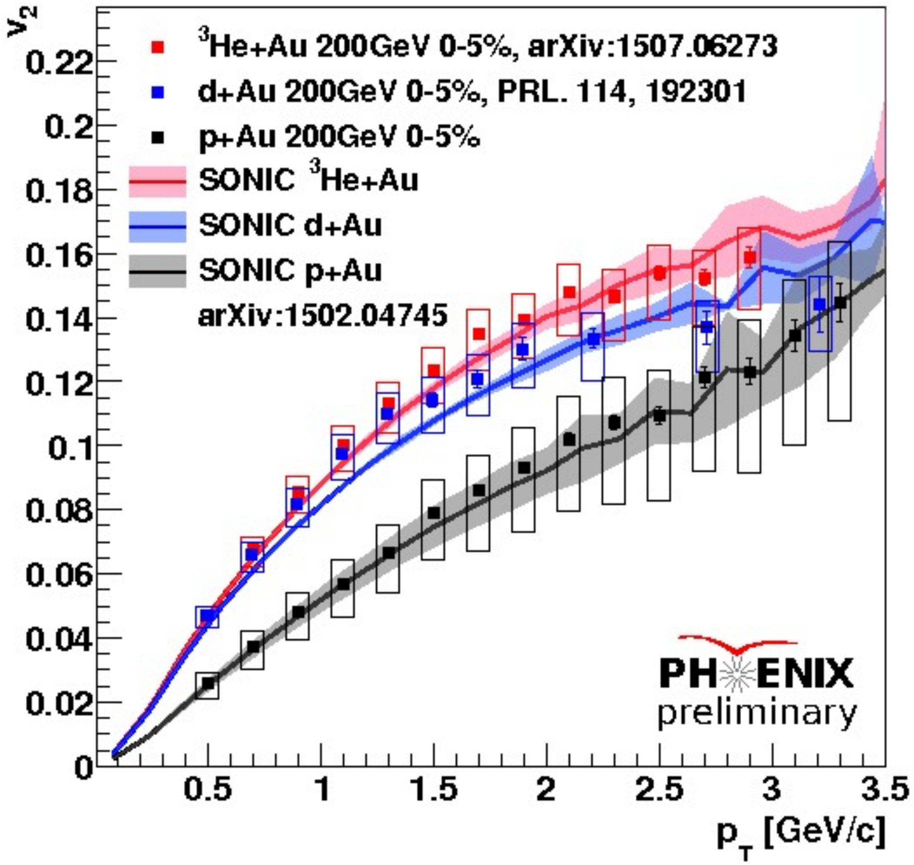
# IP-Glasma Calculations




- IP-Glasma calculations overestimate $v_2$ of d+Au and $^3$He+Au by > 5$\sigma$
- However it underestimates $v_2$ of d+Au and $^3$He+Au by ~ 2.5$\sigma$

# SONIC Calculations

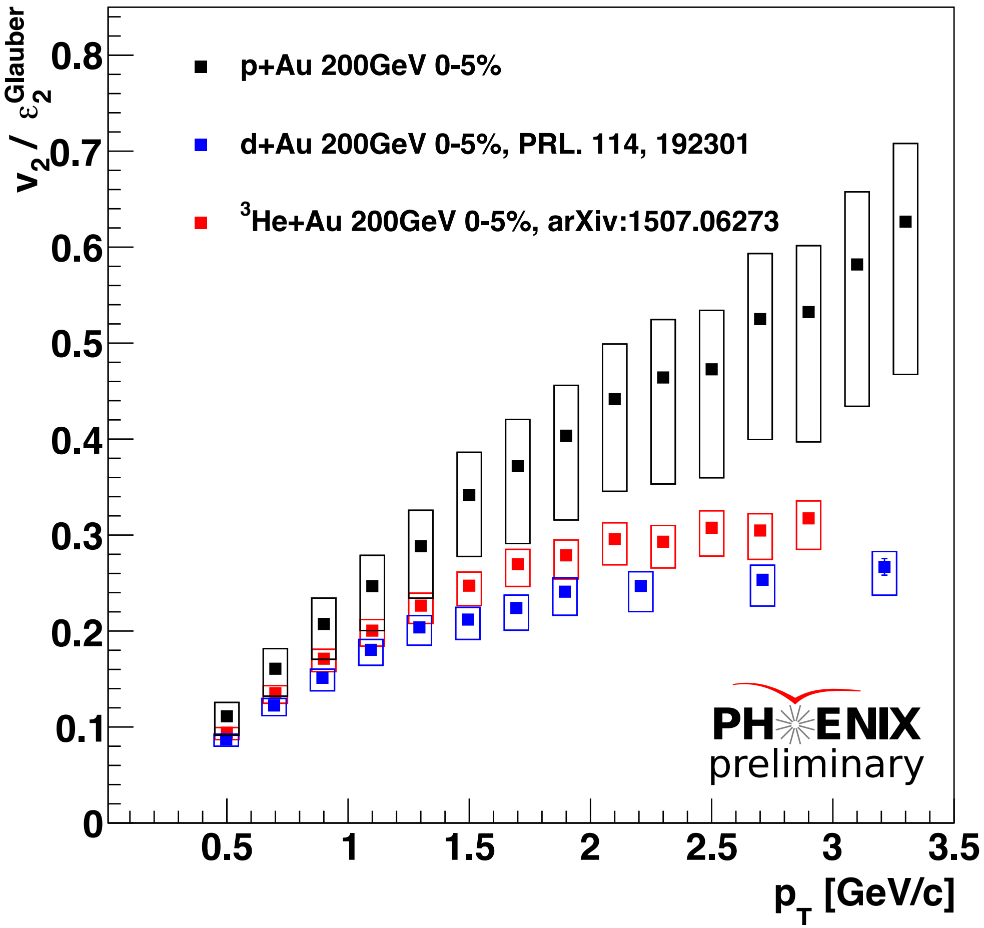
Glauber-like initial condition  hydro + hadronic cascade




- SONIC Calculations reproduce $v_2$ for p+Au, d+Au, $^3$He+Au within systematic errors.

# Eccentricity Scaling

$\varepsilon_2$ : Glouber (Round nucleon)




$$\frac{v_2^{dAu}}{\varepsilon_2^{dAu}} < \frac{v_2^{^3HeAu}}{\varepsilon_2^{^3HeAu}} < \frac{v_2^{pAu}}{\varepsilon_2^{pAu}}$$

- The ordering now changes and p+Au becomes largest due to round nucleon assumed in Glouber calculation.
- Small system with shorter lifetime would not fully reflect initial geometry information

# Summary

- Developed the FVTX high multiplicity trigger for the collective motion study in p+p,p+Au, p+Al system. The analysis is now underway.
- Long range two particle correlations are observed in central p+Au at √s=200GeV.
- v2 ordering $v_2^{pAu} < v_2^{dAu} \leq v_2^{^3HeAu}$ may make sense from initial state eccentricity
- Simultaneous theory comparisons of $v_2$ from p+Au, d+Au, $^3$He+Au :
  - SONIC predictions match data within uncertainties
  - AMPT predictions match data up to $p_T$ ~ 1 GeV/c
  - IPGlasma initial conditions + hydro underpredict p+Au $v_2$
  - Proposal of proton 3 constituent quark model version of IPGlasma needs full calculations and comparison.