Long range transverse momentum correlation and radial flow in Au+Au collisions at 200 GeV

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VECC, Kolkata

Motivation:

1. Radial flow estimation:

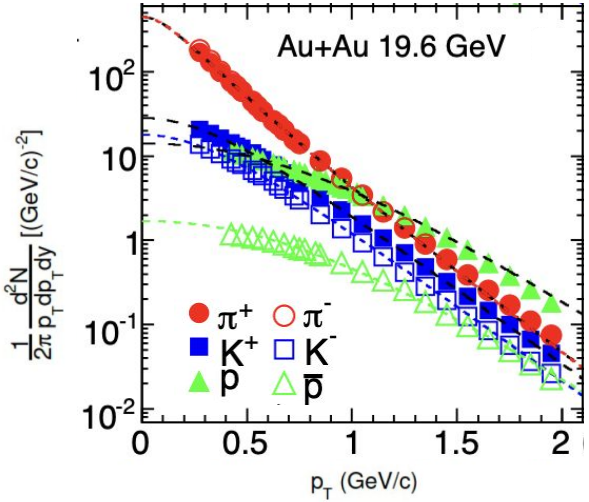
Traditionally, based on p_T integrated blast wave fit.

p_T dependence of radial flow never studied before unlike v_2,v_3 .

Why interested in p_T dependence: Mass ordering and baryon-meson splitting sensitivity if exist in radial flow.

2. **Removing non-flow effects:** v_2, v_3 study uses η-gap (subevent method).

For radial flow estimation, we don't have such method.



3. Sensitivity to viscosity:

p_T spectra and v_2 sensitive to both bulk and shear viscosity.

New observable $v_0(p_T)$ sensitive to only bulk viscosity

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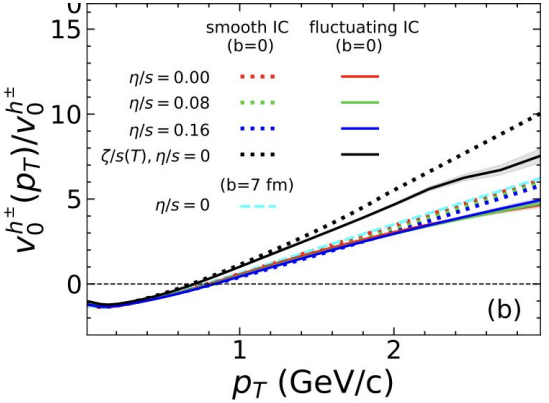
New observables $$v_0(p_T) \equiv \frac{\langle \delta N(p_T) \delta p_T \rangle}{N_0(p_T)\sigma_{p_T}}$$ PhysRevC.102.034905 (2020)



Observables:

- Observable: $v_0(p_T) \equiv \frac{\langle \delta N(p_T) \delta p_T \rangle}{N_0(p_T) \sigma_{p_T}}$

$N(p_T)$: Number of charge particles in a single event

$N_0(p_T)$: Number of charge particles in a given centrality class

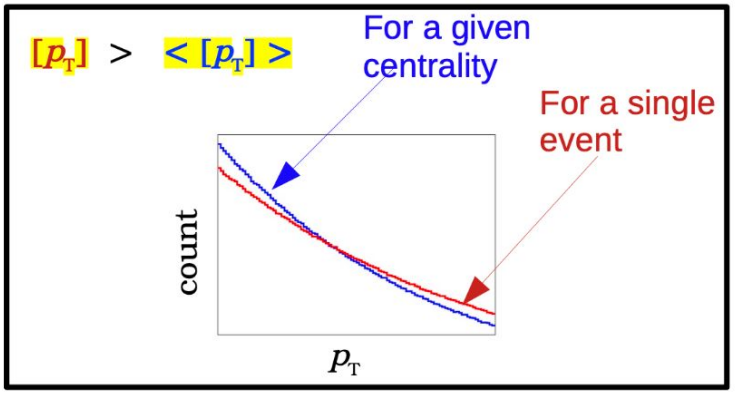
$\delta N(p_T)$: $N(p_T) - N_0(p_T)$

$[p_T]$: Mean p_T in a single event

$< [p_T] >$: Average p_T in a centrality class

δp_T : $[p_T] - <[p_T]>$

σ_{pT} :variance of $[p_T]$ distribution



$V_0(p_T)$ represents: correlation between particle yield fluctuations at a given p_T and the event-by event $[p_T]$ fluctuation .

How to calculate in experiment:

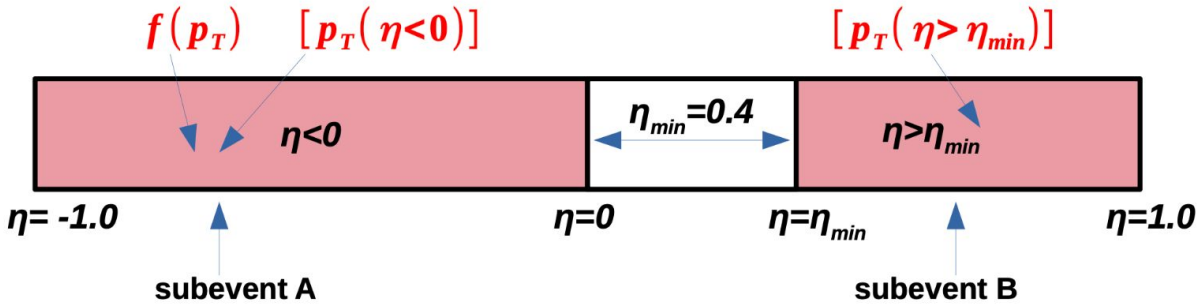
$$v_0(p_{\mathrm{T}}) = \frac{(\langle f(p_{\mathrm{T}})[p_{\mathrm{T}}(\eta > \eta_{\min})]\rangle) - \langle f(p_{\mathrm{T}})\rangle\langle[p_{\mathrm{T}}(\eta > \eta_{\min})]\rangle}{\langle f(p_{\mathrm{T}})\rangle\sqrt{\langle[p_{\mathrm{T}}(\eta < 0)][p_{\mathrm{T}}(\eta > \eta_{\min})]\rangle - \langle[p_{\mathrm{T}}(\eta < 0)]\rangle\langle[p_{\mathrm{T}}(\eta > \eta_{\min})]\rangle}}$$

$f(p_T)$: fraction of particles in a given p_T bin (with $-1 < \eta < 0$)

$[p_T(\eta<0)]$: Mean p_T of produced particles (with $-1 < \eta < 0$)

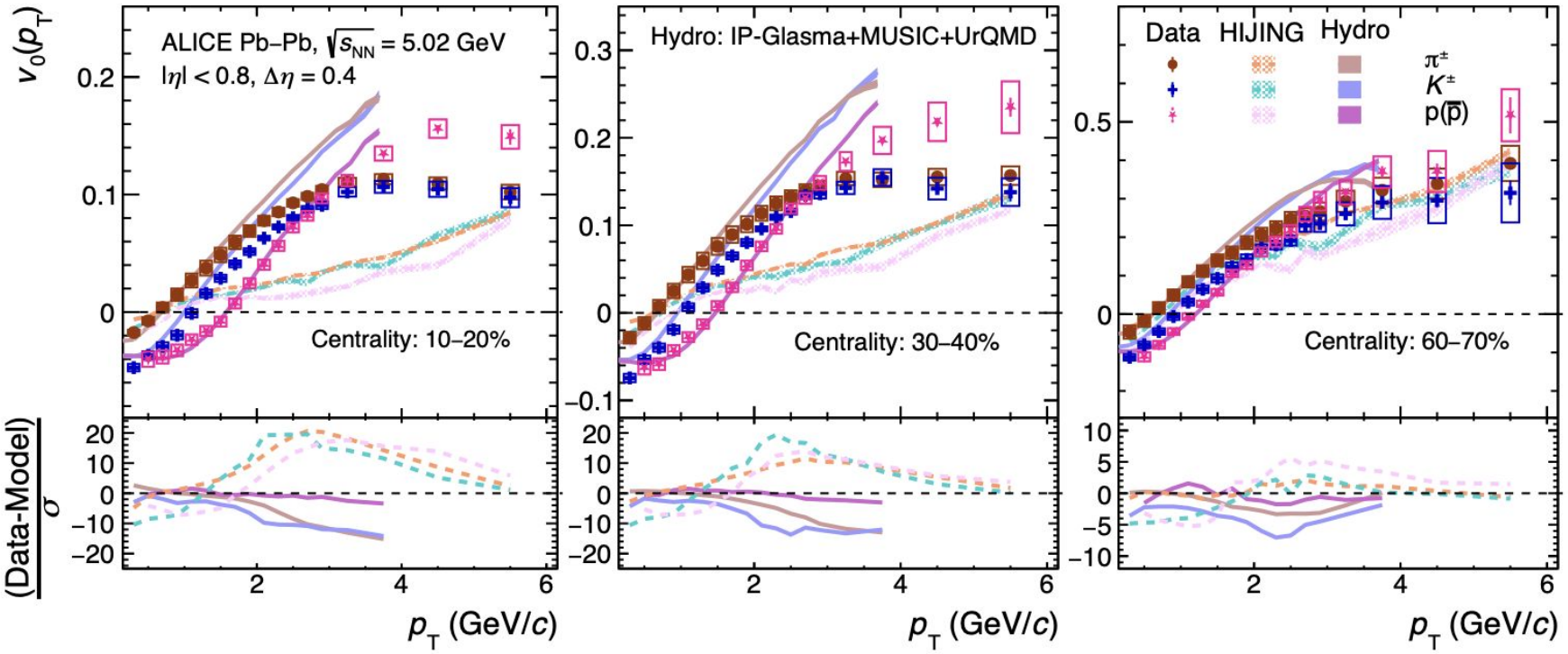
$[p_T(\eta>\eta_{min})]$: Mean p_T of produced particles (with $\eta_{min} < \eta < 1$)

- **For details:**
  Phys. Lett. B 857 (2024) 138985
- **<...> :** angle bracket denotes event averaged



Results from ALICE:

ALICE: arxiv:2504.04796

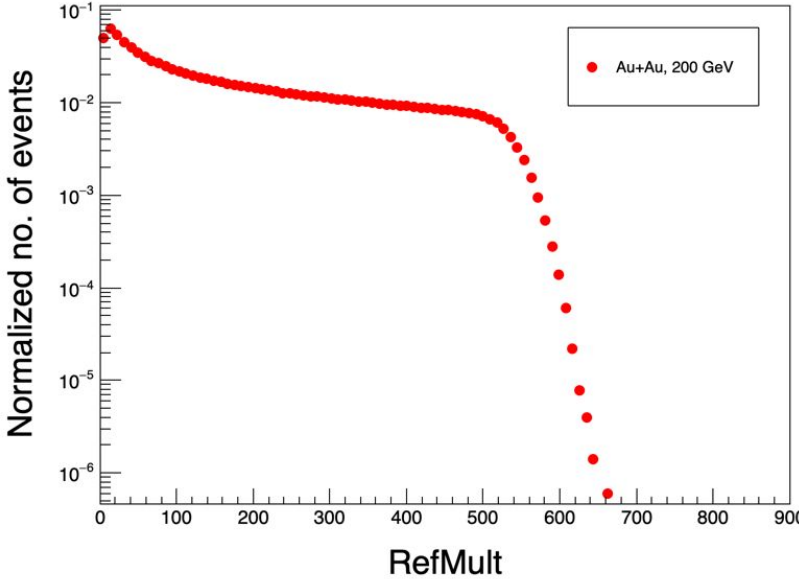


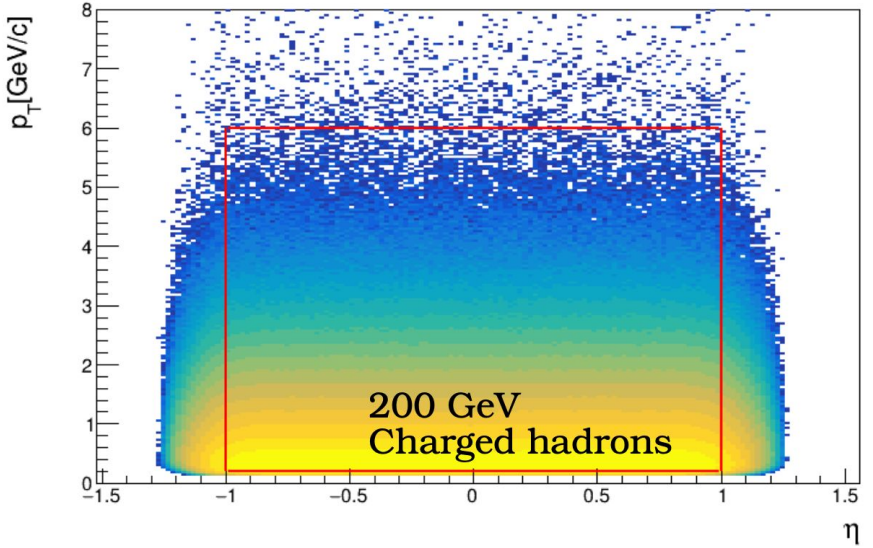
Data set details:

- Au+Au collision at 200 GeV
- Run ID: 12126079 - 12171016 (1300 runs)
- Trigger ID: 350003,350013,350023,350033,350043
- Production tag: P11id
- Number of good events: 438 M
- |Vz|< 30 cm, Vr < 2 cm, |Vz -vpdVz| < 3 cm

Bad run list used from STAR official Run QA group. Official cut used to remove bad events

Centrality and Acceptance:





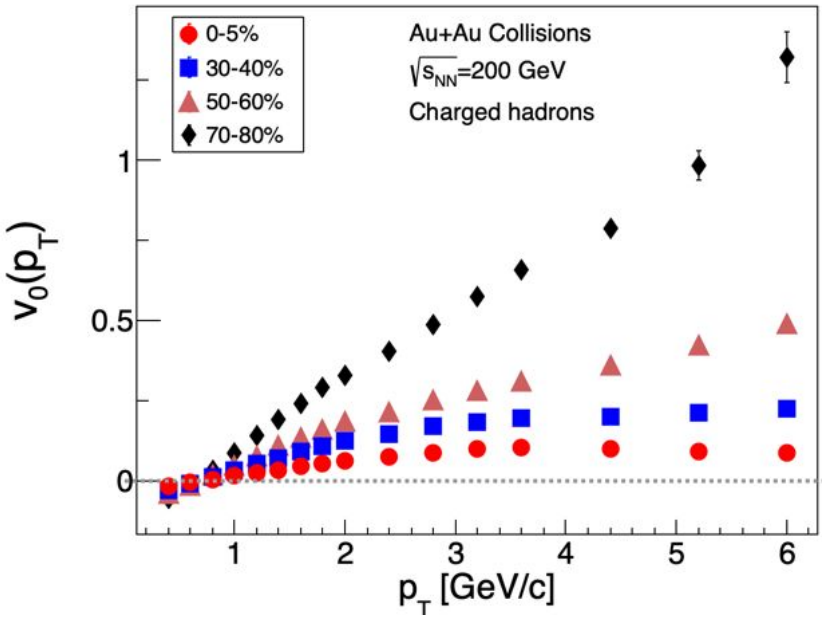
RefMult: Charged particles with |η|<0.5
STAR official centrality

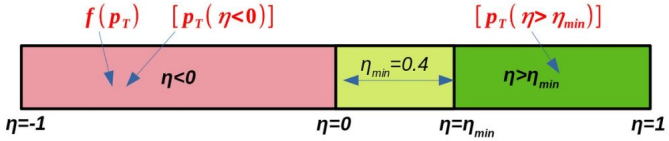
Acceptance for charged hadrons: |η|<1.0, 0.2< p_T < 6.0 GeV/c

definition	0-5%	5-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%
RefMult	466	396	281	193	125	76	43	22	10

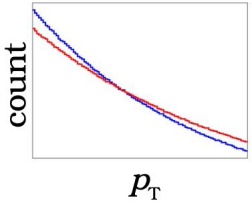
Results at 200 GeV

$v_0(p_T)$: for charged hadrons



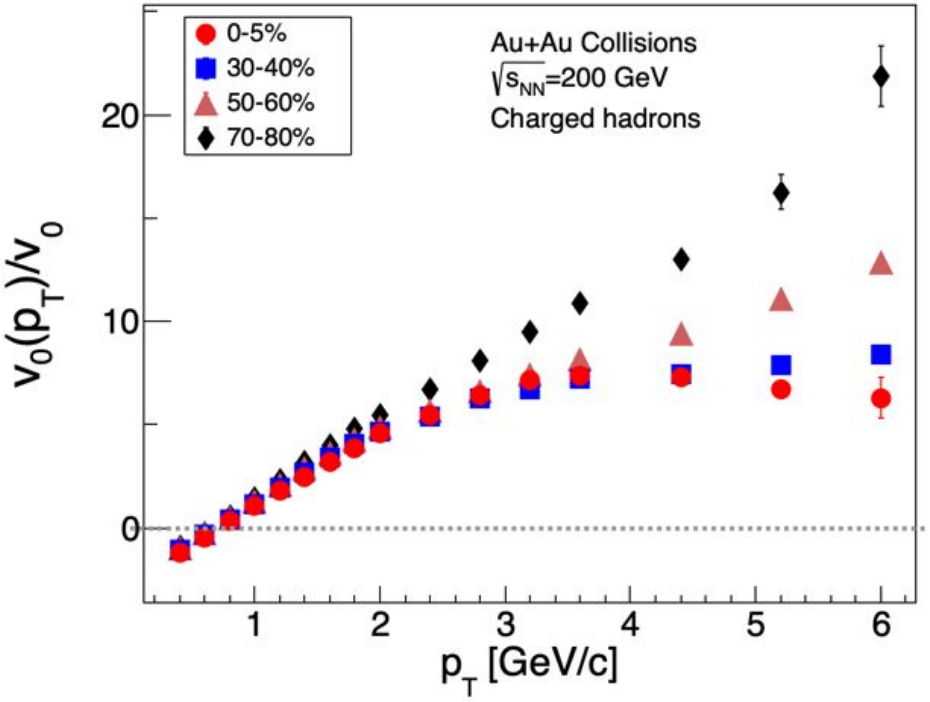


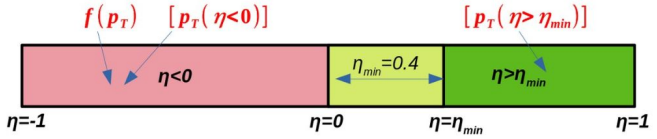
$$v_0(p_T) \equiv \frac{\langle \delta N(p_T)\, \delta p_T \rangle}{N_0(p_T)\, \sigma_{p_T}}$$



- Centrality using refmult, statistical error using bootstrap method.
- Increasing trend over p_T, goes from -ve to +ve.
- Increases as we increase centrality and then saturate.
- Larger difference at higher p_T.

$v_0(p_T)$: with scale factor





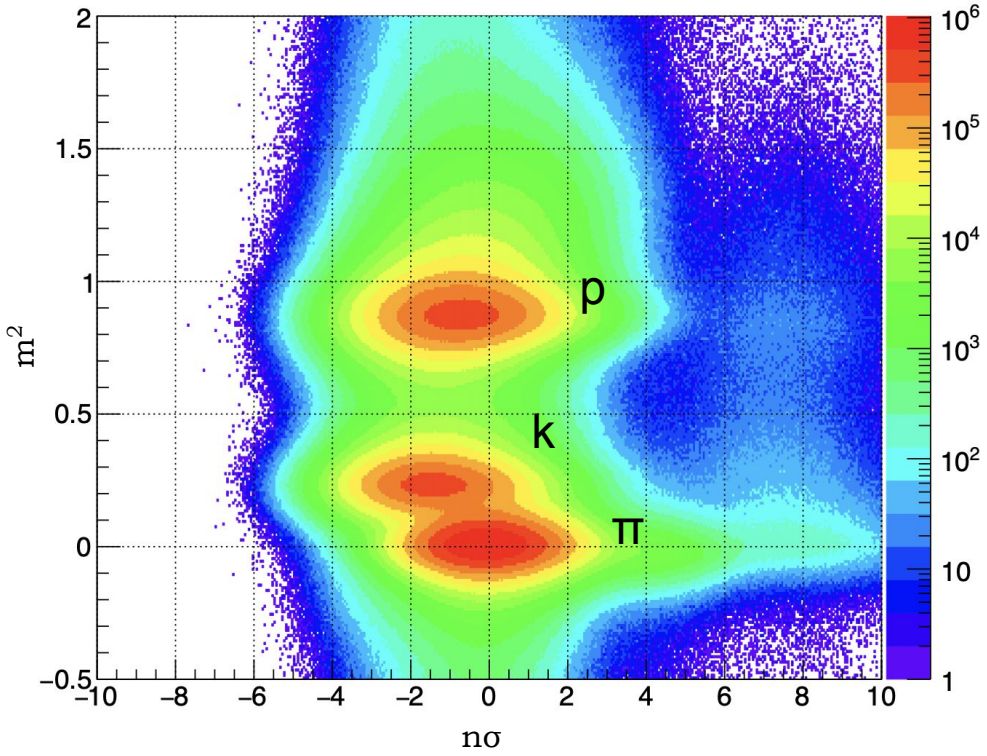
$$v_0(p_T) \equiv \frac{\langle \delta N(p_T)\, \delta p_T \rangle}{N_0(p_T)\, \sigma_{p_T}}$$

$$v_0 \equiv \frac{\sigma_{p_T}}{\langle [p_T] \rangle}$$

$$v_0(p_T) = \frac{(\langle f(p_T)[p_T(\eta > \eta_{\min})] \rangle) - \langle f(p_T) \rangle \langle [p_T(\eta > \eta_{\min})] \rangle}{\langle f(p_T) \rangle \sqrt{\langle [p_T(\eta < 0)][p_T(\eta > \eta_{\min})] \rangle - \langle [p_T(\eta < 0)] \rangle \langle [p_T(\eta > \eta_{\min})] \rangle}}$$

- Scale factor works better upto mid central collisions.
- Deviation in peripheral results with increasing pT.

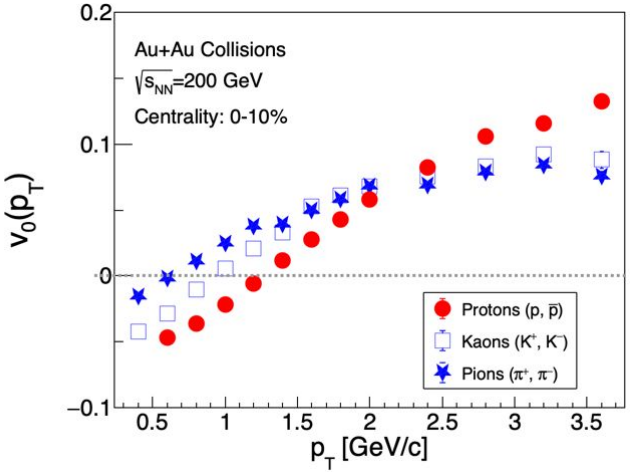
Proton, kaon, pion selection:



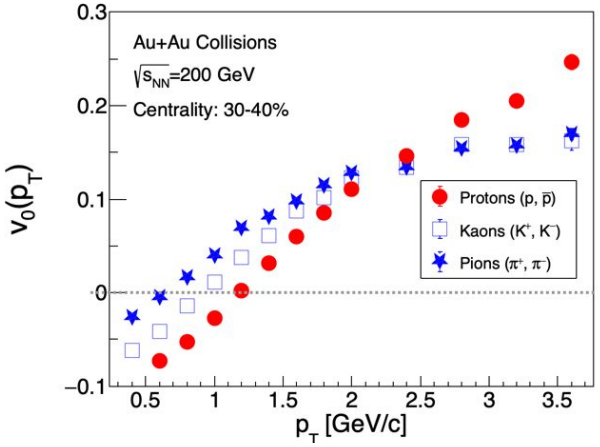
- **Proton : 0.4 < p_T < 3.6 GeV, |η| < 1.0**
  - **TPC: ($|n\sigma_p|$<2)**
  - **TOF: (0.6< m^2 < 1.2 GeV^2)**
- **Kaon: 0.2 < p_T < 3.6 GeV/c, |η| < 1.0**
  - **TPC: ($|n\sigma_k|$<2)**
  - **TOF: (0.14< m^2 < 0.4 GeV^2)**
- **Pion: 0.2< p_T < 3.6 GeV/c, |η| < 1.0**
  - **TPC: ($|n\sigma_\pi|$<2)**
  - **TOF: (-0.15< m^2 < 0.14 GeV^2)**
- **Asymmetry nσ cut used in few pT bins to improve purity**
- **Purity > 95 %**

$v_0(p_T)$: identified particles (proton, kaon, pion)

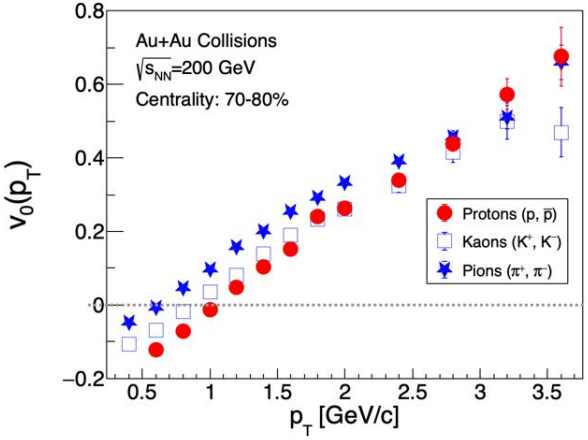
0-10%



30-40%



70-80%



- Clear mass ordering at low p_T.
- Sign change close to mean p_T.
- Baryon -meson splitting observed ~ 2.5 GeV/c .

Summary and outlook:

Summary:

1) Results for new observables $v_0(p_T)$, related to long range p_T correlation, shown at 200 GeV.
2) From central to peripheral collision: $v_0(p_T)$ increases.
3) $v_0(p_T)$ goes from negative to positive as p_T increases.
4) Mass ordering observed for proton, kaon and pions.
5) Baryon-meson splitting observed at around 2.4 GeV/c .

Outlook:

1) Systematic uncertainty to be done soon.
2) Plan to do beam energy scan of new observable $v_0(p_T)$ from 7.7 - 200 GeV

Status:

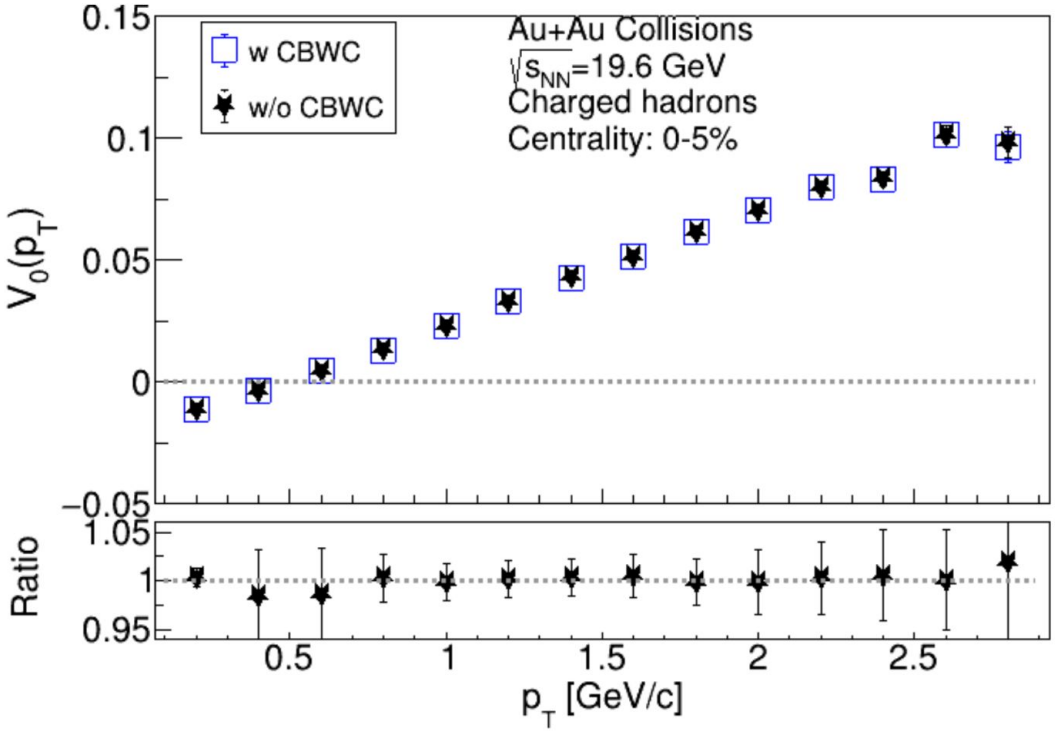
1) Paper title: Precision measurement of (Net-)proton Number Fluctuations in Au+Au Collisions at RHIC
Shown in collaboration meeting: IOP, Bhubaneswar, June, 2024. Analysis note
Status: Submitted to PRL (received positive comments from reviewers)

2) Paper title: Measurement of Fifth and Sixth Order Fluctuation of (Net-)proton Number in Au+Au Collisions from Second Phase of Beam Energy Scan Program at RHIC.
Shown in collaboration meeting: AMU, Aligarh, Nov, 2024. Analysis note.
Status: PWGC review completed, next step GPC, target journal: PRC as letter.

3) In preparation: A long paper containing all detailed results with analysis details from BES-II measurements.

Backup slides

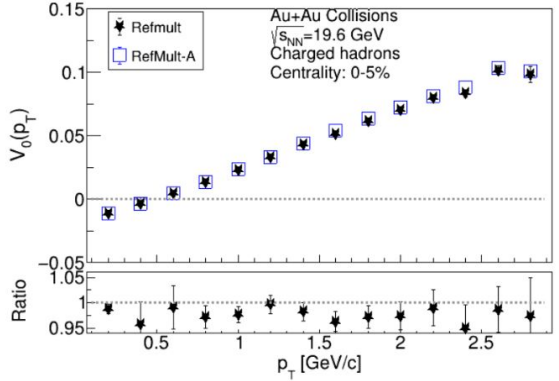
Effect of CBWC:

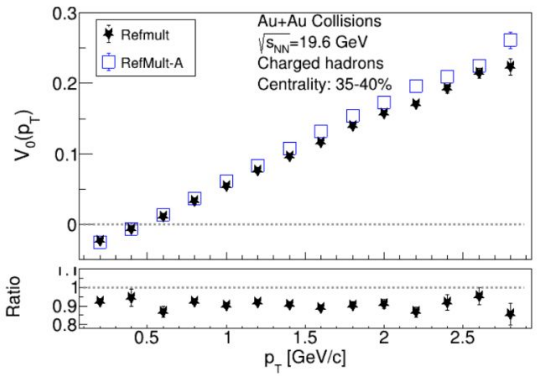


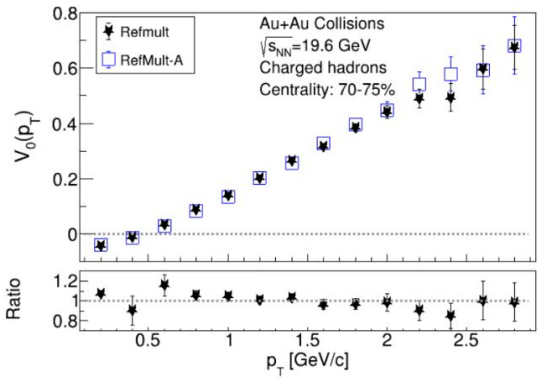
Centrality using refmult

- Effect of centrality bin width correction is very small
- Ratio taken w.r.t : sqaure marker

Effect of centrality definition:

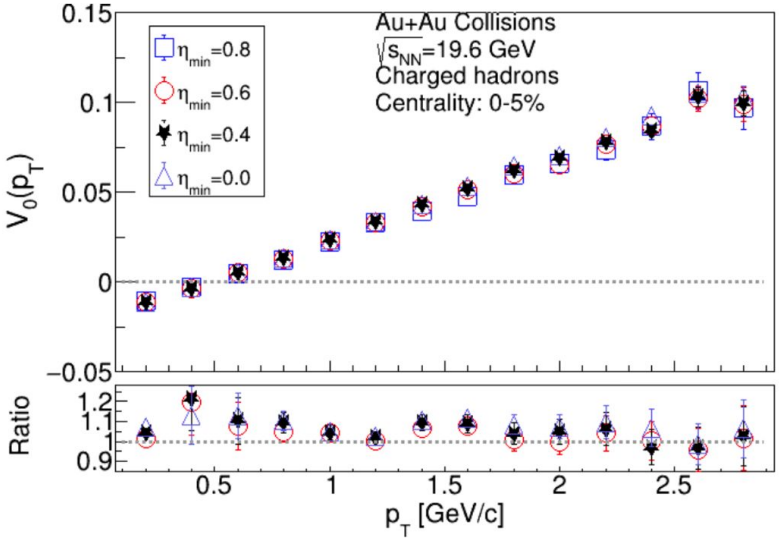


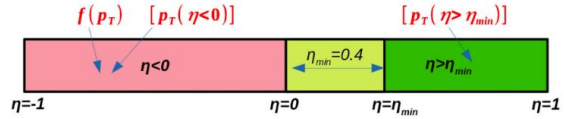


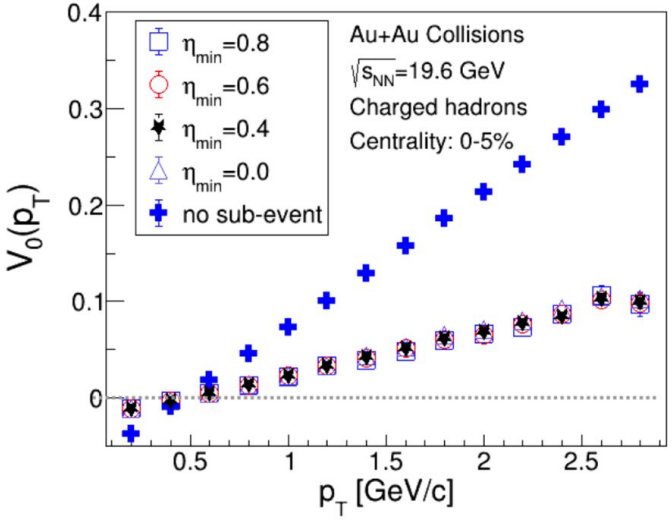


- Refmult: $|\eta| < 0.5$
- RefMult-A: $1.0 < |\eta| < 1.6$
- Effect for using different centrality definition is negligible for central collision
- Difference found in mid central collision
- Peripheral results are consistent within uncertainties
- Ratio taken w.r.t square marker

Effect of eta gap:



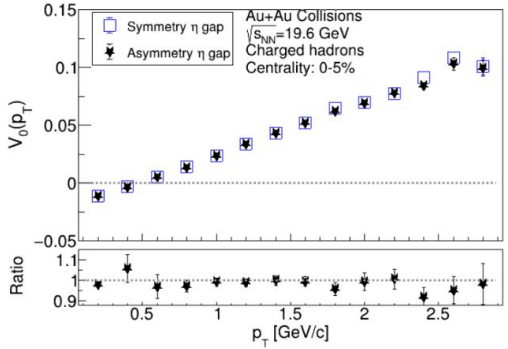


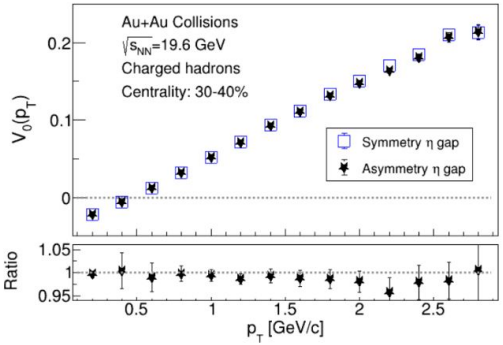


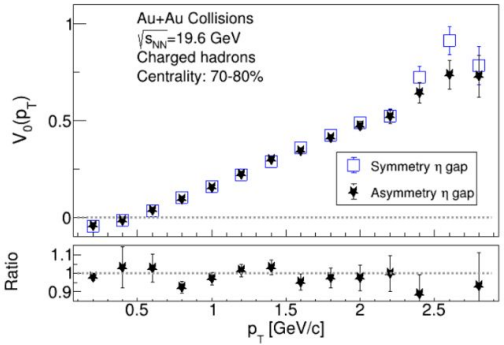
- Results consistent with changing η gap
- Ratio taken w.r.t square marker
- No sub event: large correlation found

Centrality using refmult

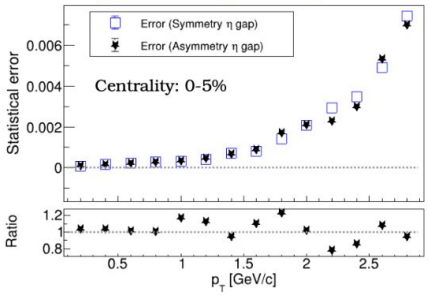
Effect of symmetric eta gap:





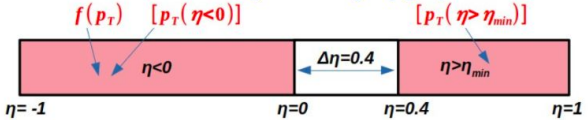


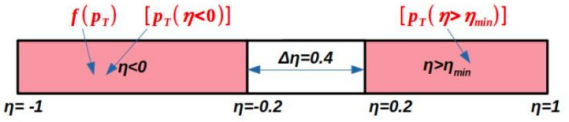
Error comparison



- Results consistent with changing η region
- Same for all centrality
- Ratio taken w.r.t square marker

Asymmetry η gap

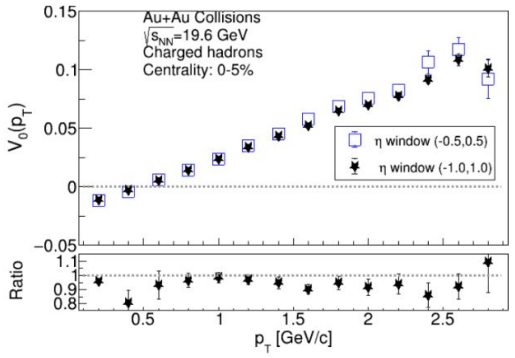


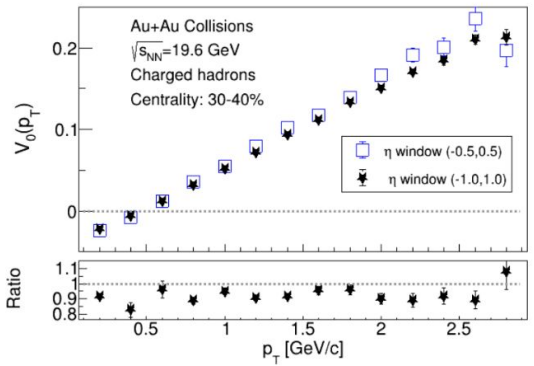


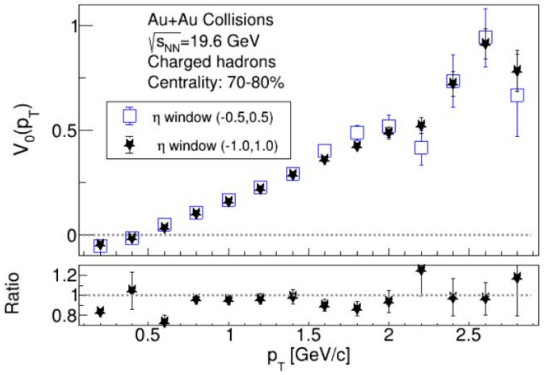
Symmetry η gap

Centrality using refmult, error from bootstrap method

Effect of reduced acceptance:

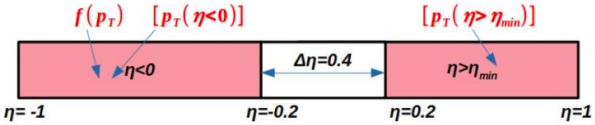


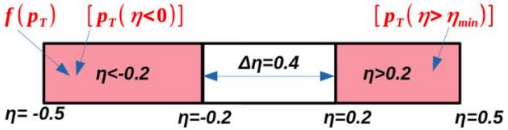




- Low p_T: results are consistent
- High p_T: larger η window gives lower $V_0(p_T)$
- Same for all centrality
- Ratio taken w.r.t square marker

Centrality using refmult





Reduced η window