Observation of the Electromagnetic Effect & System Size dependence via charge-dependent directed flow in U+U Collisions at 193 GeV

Muhammad Farhan Taseer

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

University of Chinese Academy of Sciences

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Outline

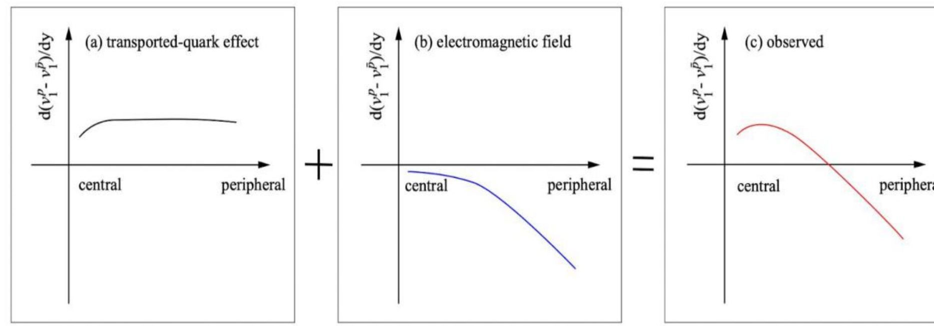
- Physics Motivations
- Analysis Procedure
- Datasets: Events, Tracks, PID & Bad Runs Selection
- Systematic Uncertainties of v_1
- v_1 and Δv_1 Results for U+U collisions
- v_1 and Δv_1 Comparison with Au+Au & Isobar
- Δa_1 study (cross check)
- Summary

Physics Motivation

Directed Flow (v_1) describes the collective sideward motion of the produced particles and nuclear fragments, and carries information from the early stages.

1- Electromagnetic Effects on v_1

- In heavy Ion Collisions, an Ultra strong magnetic filed (10^{18} gauss) is produced at very early stages
- Lorentz force results in an electric current along x-axis, referred to Hall effect
- As "B" decreases, a current induced in the opposite direction referred to Faradays Effect
- Net electric current (sum of Hall & Faraday effects) results in a charge dependent flow "v_1"

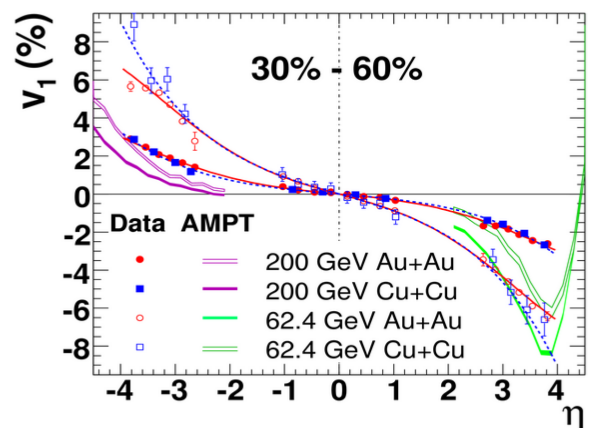


https://arxiv.org/pdf/2304.03430.pdf

2- System Size Dependence on v_1

The measurement of directed flow for the inclusive charged particles presented in this paper reported that "v_1" only depends on the incident energy but not on the size of the colliding system at a given centrality

In the present studies, U-U collision data can be used to probe system size dependence as well as electromagnetic effects



https://arxiv.org/pdf/0807.1518.pdf

Analysis Procedure

- For this analysis, v_1 is computed using Event Plane Method in which we estimate the reaction plane, called the event plane, from the observed event plane angle determined from the anisotropic flow itself.

$$v_1 = \frac{\langle \cos(\phi - \Psi_1^{EP}) \rangle}{R_1}$$

Where , Ψ_1^{EP} is reconstructed using ZDC and the event plane is flatten by applying Shift correction

- Analysis is carried out in four steps:

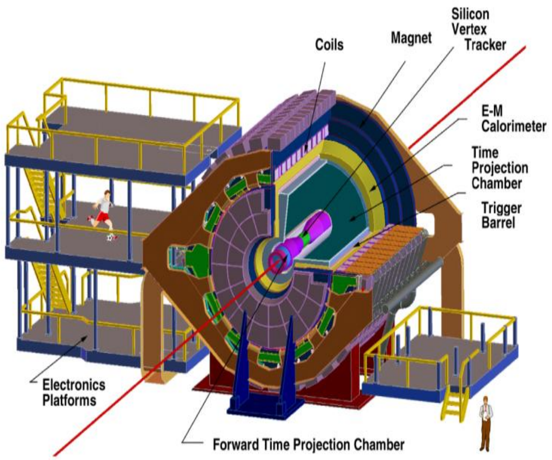
  1- Datasets and Events Selection

  2- Event Plane reconstruction

  3- Particle Identification:

     a. π, k, p ---- TPC & TOF cuts

  4- Directed Flow (v_1) extraction using the above mentioned relation:



- Finally, systematic Study is done by varying the Event, Track and PID selection

Datasets (Event, Track, PID & Bad Runs)

Collision System: (U+U)

Collision Energy	Production id	Run Numbers	Trigger id	No. of Events
193 GeV (2012)	P12id	13114025-13136015 (783)	400005, 400015, 400025, 400035	≈ 250 M

Event Cuts

$\lvert V_z \rvert < 50$ cm	$\lvert V_r \rvert < 2$ cm

Track Cuts

$\lvert \eta \rvert < 1.0$	DCA < 3 cm	nHits Fits >= 15

PID Selection

Pion:	$\lvert N\sigma \rvert < 2.0$	$-0.01 < m^2 < 0.10\ (GeV/c^2)^2$	$p < 1.6$ GeV/c && $p_t > 0.2$ GeV/c
Kaon:	$\lvert N\sigma \rvert < 2.0$	$0.20 < m^2 < 0.35\ (GeV/c^2)^2$	$p < 1.6$ GeV/c && $p_t > 0.2$ GeV/c
Proton:	$\lvert N\sigma \rvert < 2.0$	$0.8 < m^2 < 1.0\ (GeV/c^2)^2$	$p < 2.0$ GeV/c && $p_t > 0.4$ GeV/c

Bad Runs [19]

13117026, 13117027, 13117028, 3117029, 13117030, 13117031, 13117032, 13117033, 13117034, 13117035, 13117036, 13118009, 13118034, 13118035, 13119016, 13119017, 13129047, 13129048, 13132047

Systematic Uncertainties of v_1

- **The sources of systematic uncertainties:**

Default	Systematic
$-50 < V_z^{TPC} < 50$ cm	$-50 < V_z^{TPC} < 0$ cm
$N_{fits} > 15$ cm	$N_{fits} > 20$ cm
$-1.0 < y < 1.0$ cm	$-0.8 < y < 0.0$ cm & $0.0 < y < 0.8$ cm
DCA < 3 cm	DCA < 1.0 cm & DCA < 1.5 cm
$-2.0 < n\sigma^{TPC} < 2.0$ cm	$-1.0 < n\sigma^{TPC} < 1.0$ cm & $-1.5 < n\sigma^{TPC} < 1.5$ cm
$Mass^2$ (pi) = -0.01 – 0.10 $Mass^2$ (k) = 0.20 – 0.35 $Mass^2$ (p) = 0.80 – 1.0	$Mass^2$ (pi) = -0.009 – 0.09 $Mass^2$ (k) = 0.21 – 0.34 $Mass^2$ (p) = 0.82 – 0.98 & $Mass^2$ (p) = 0.84 – 0.96

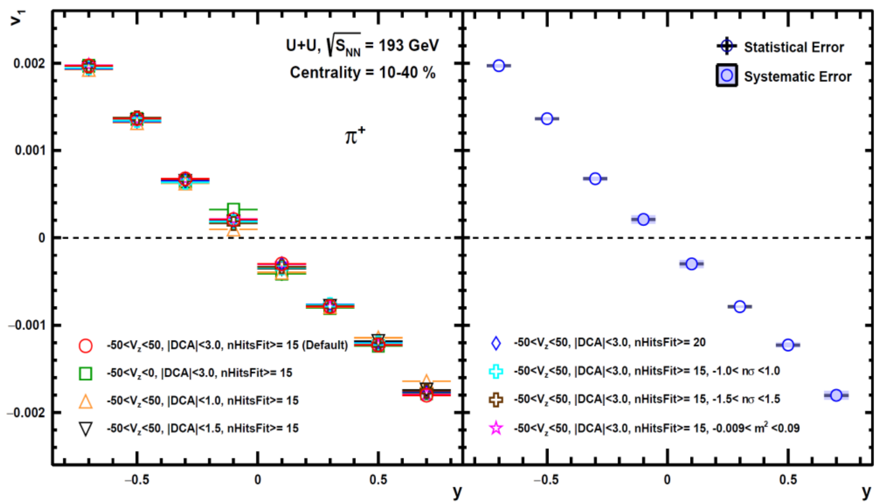
- **The systematic uncertainties of v_1 are calculated using the formula:**

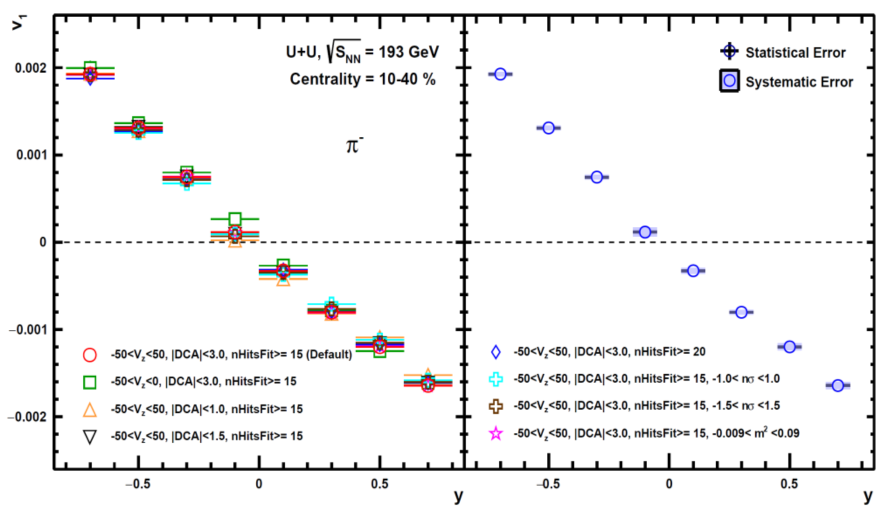
$$\sigma_i = |Y_i - Y_d|/\sqrt{12},$$
$$\sigma = \sqrt{\sum \sigma_i^2},$$

Where,
Y_i = variation result
Y_d = default result
σ = final systematic uncertainty

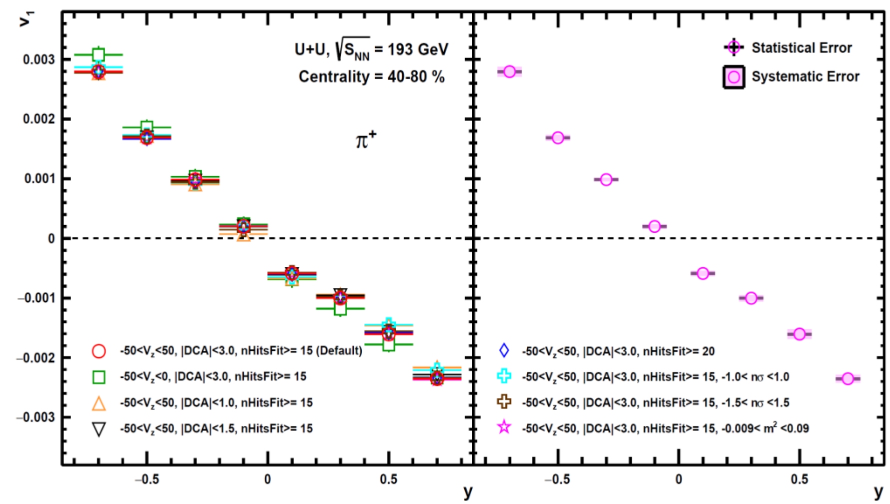
Rapidity dependent v_1 (Pion)

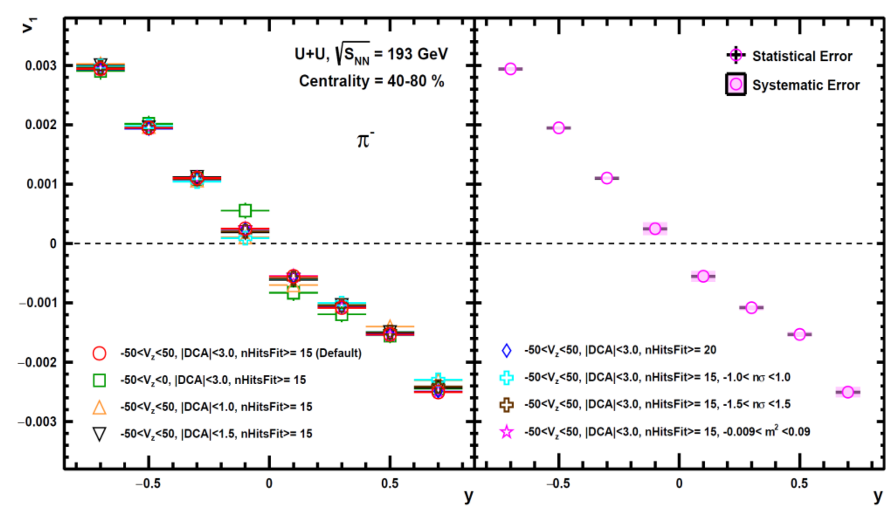
Mid Central (10 - 40)%





Peripheral (40 - 80)%

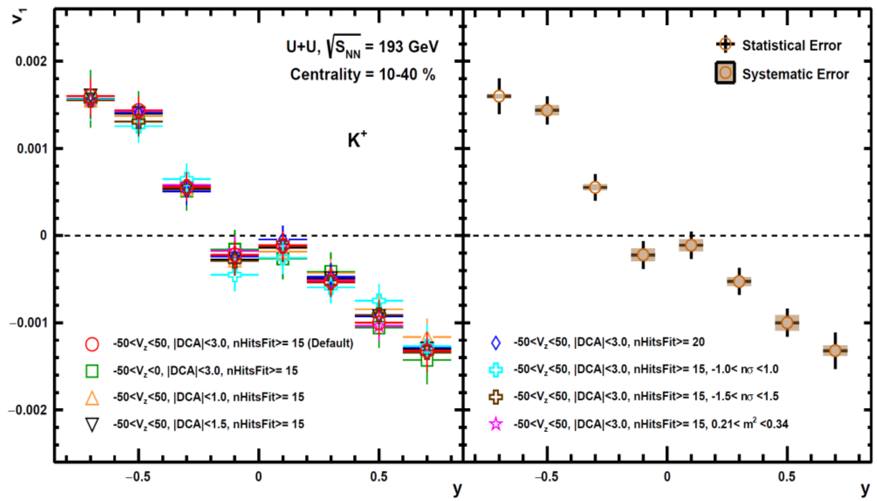


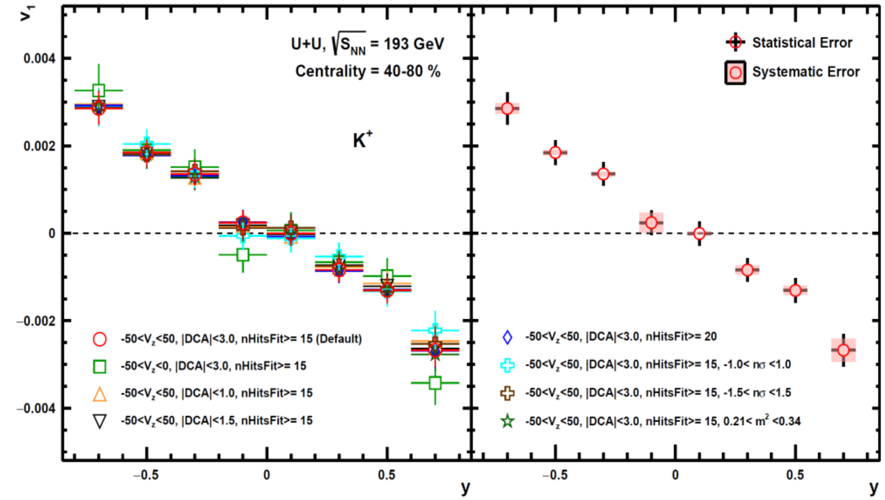


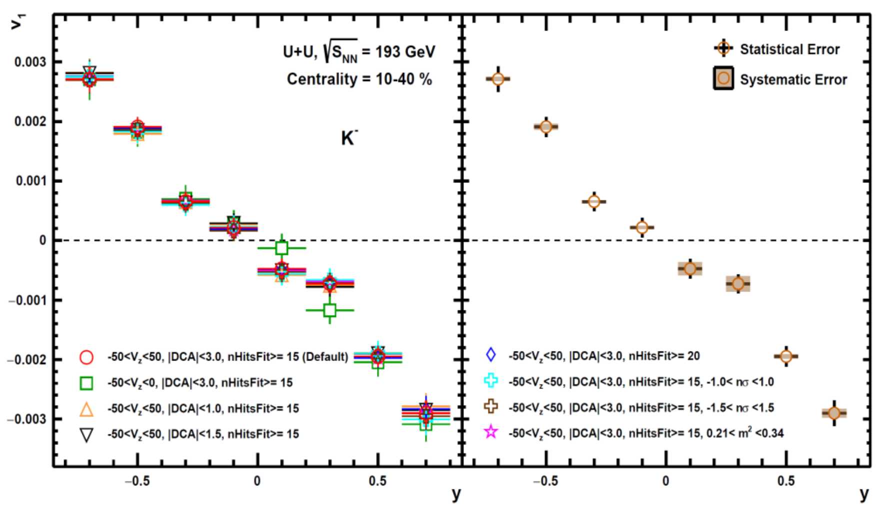
Rapidity dependent v_1 (Kaon)

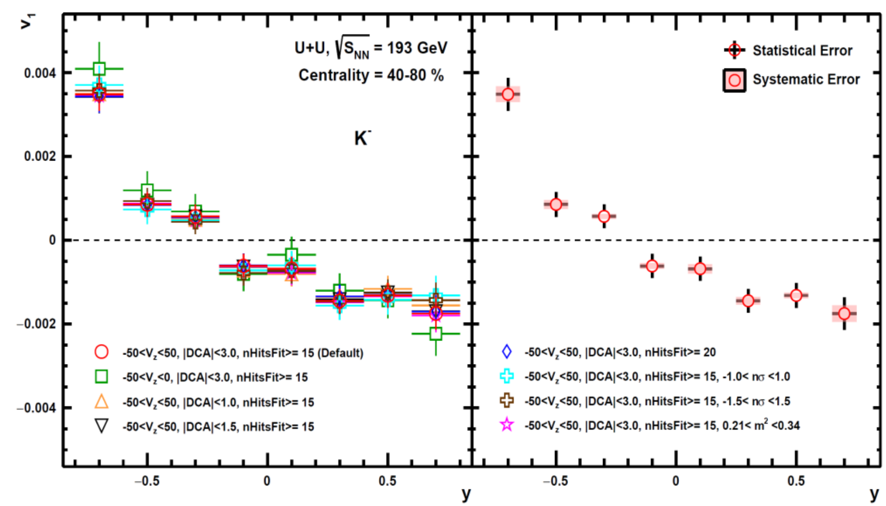
Mid Central (10 -40)%

Peripheral (40 - 80)%



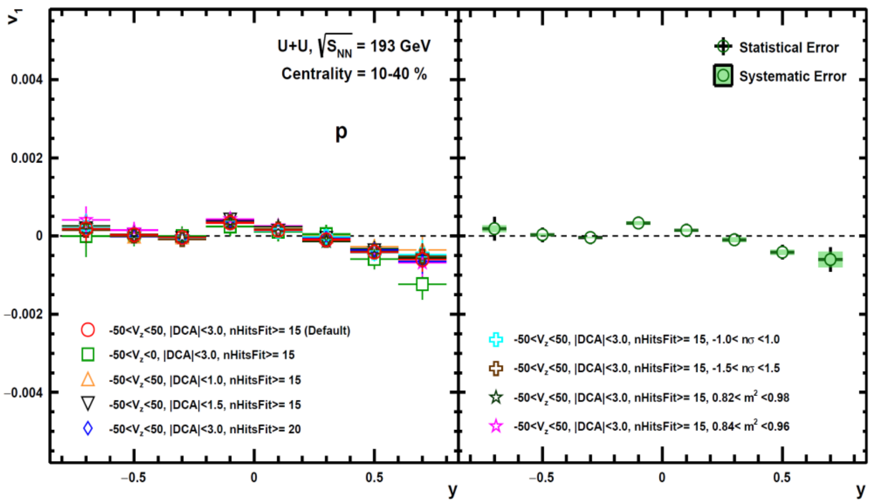




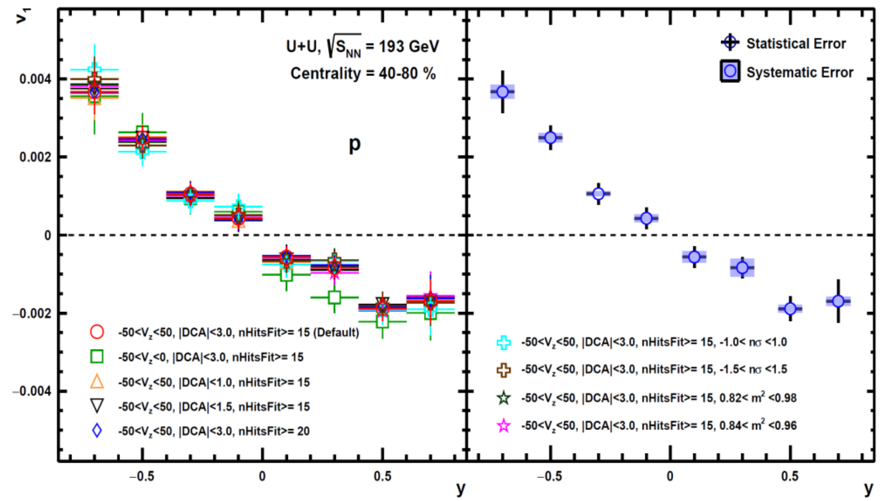


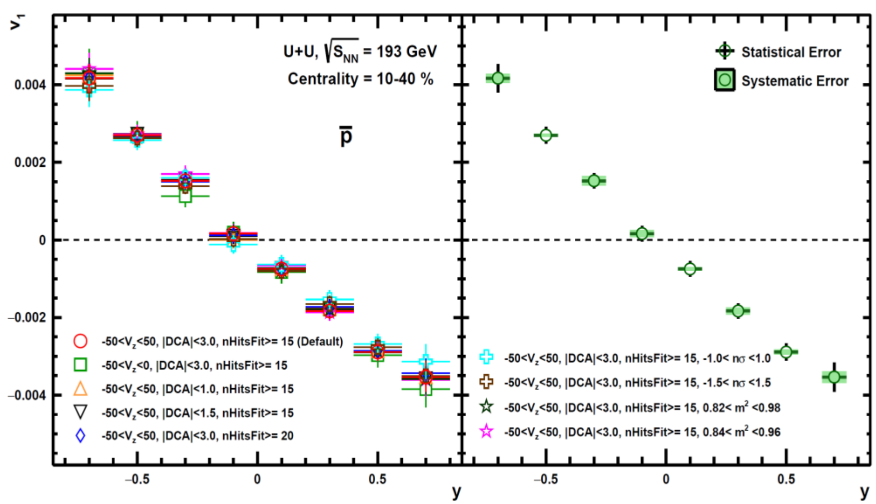
Rapidity dependent v_1 (Proton)

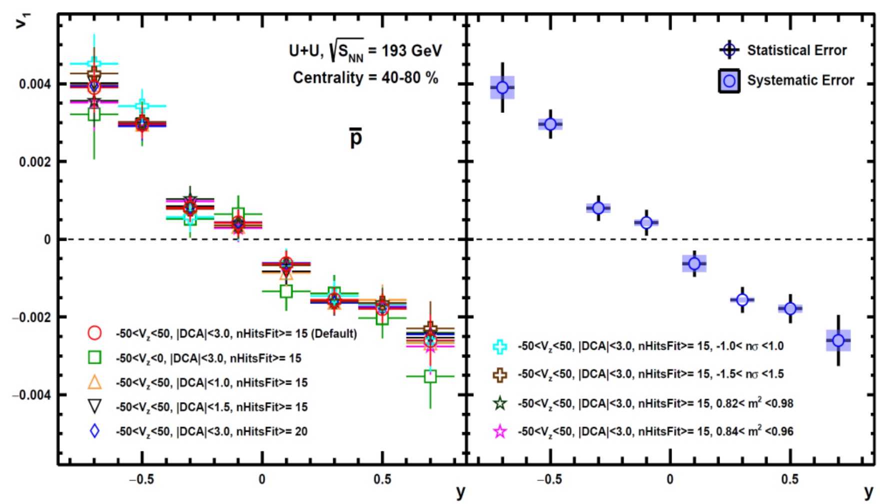
Mid Central (10 -40)%



Peripheral (40 - 80)%



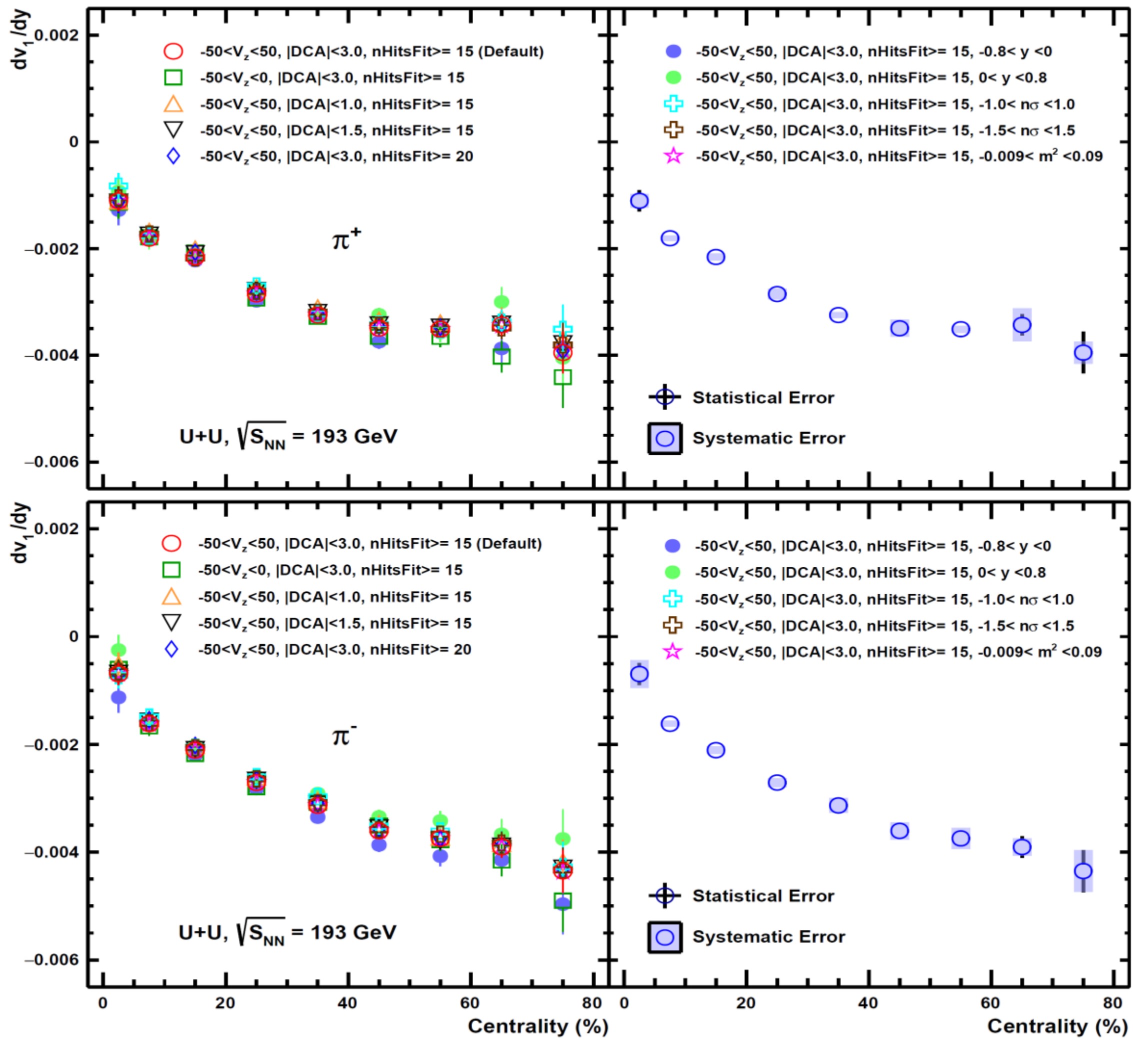




Centrality Dependent Slope (dv_1/dy) of Pion

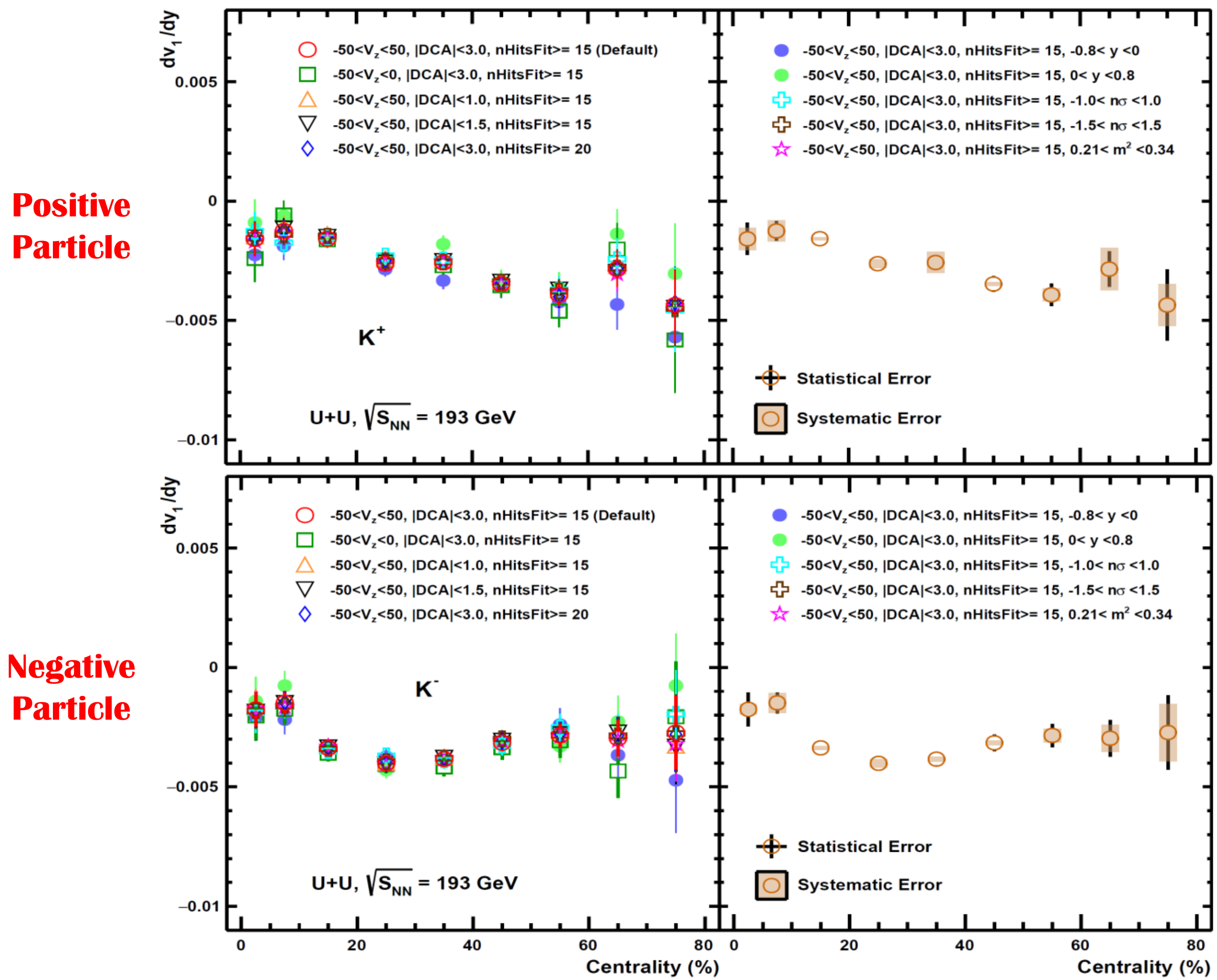
Positive Particle

Negative Particle



- A linear function "y = mx" is used to get slope (dv_1/dy) within rapidity range (-0.8, 0.8)

Centrality Dependent Slope (dv_1/dy) of Kaon

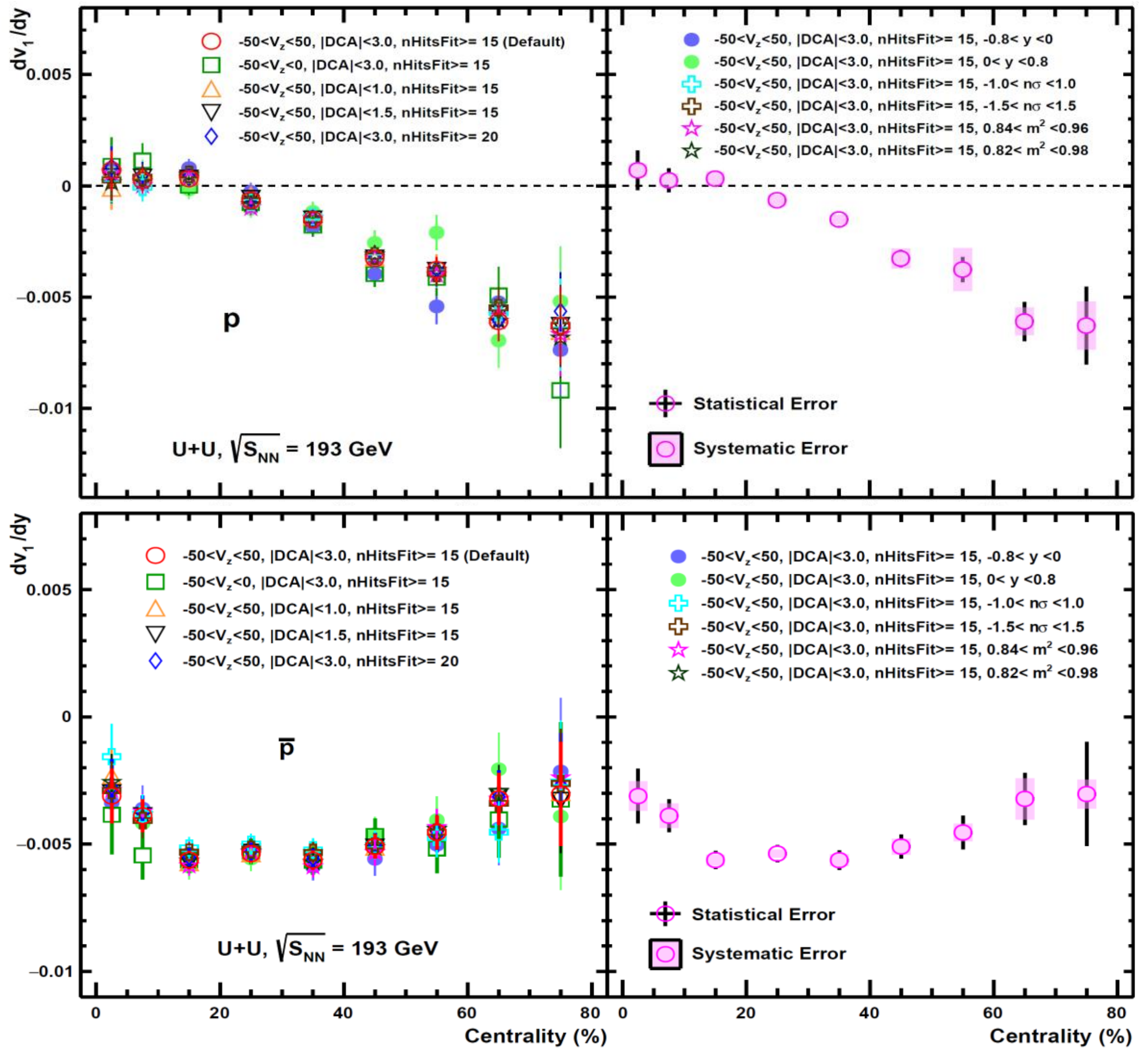


- A linear function "y = mx" is used to get slope (dv_1/dy) within rapidity range (-0.8, 0.8)

Centrality Dependent Slope (dv_1/dy) of Proton

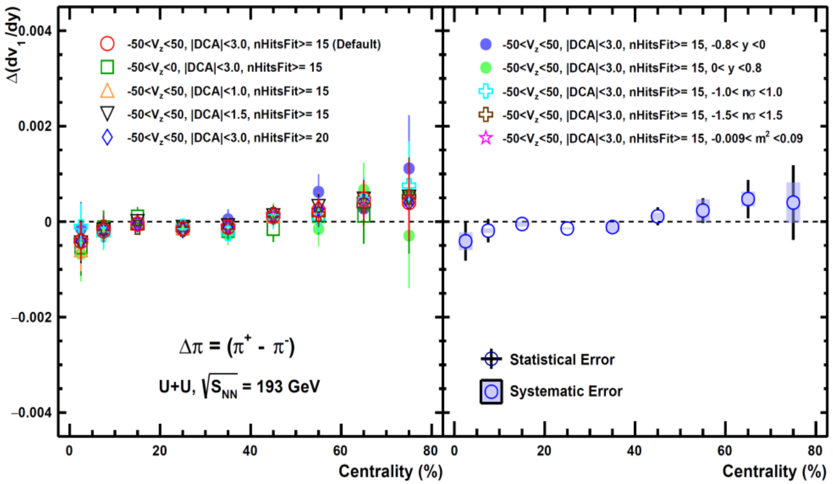
Positive Particle

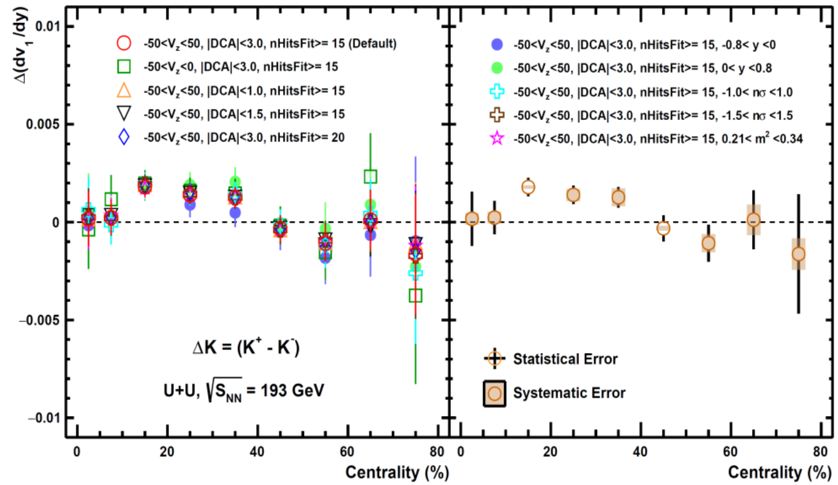
Negative Particle

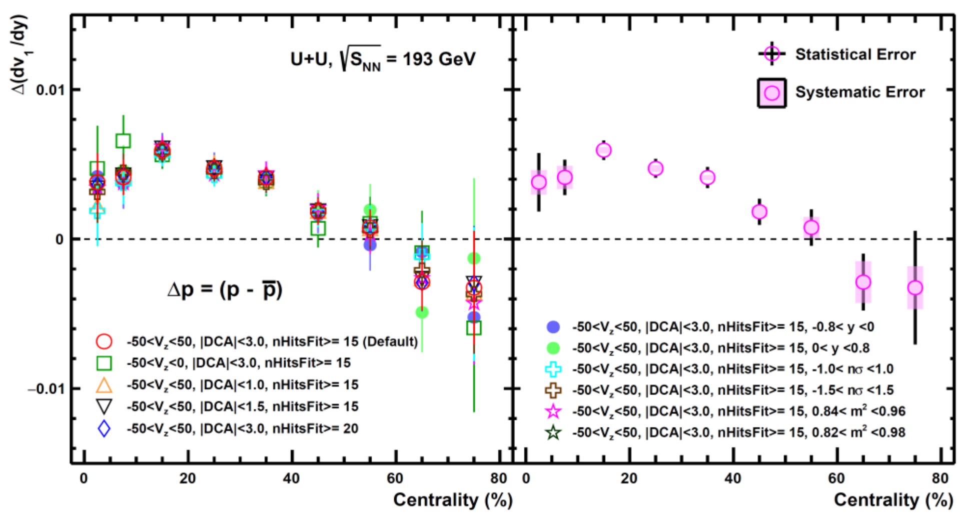


- A linear function "y = mx" is used to get slope (dv_1/dy) within rapidity range (-0.8, 0.8)
- For Proton, sign change is observed in mid central collisions (10 – 20 % centrality)

Centrality Dependent $\Delta(dv_1/dy)$ of pi, k, p





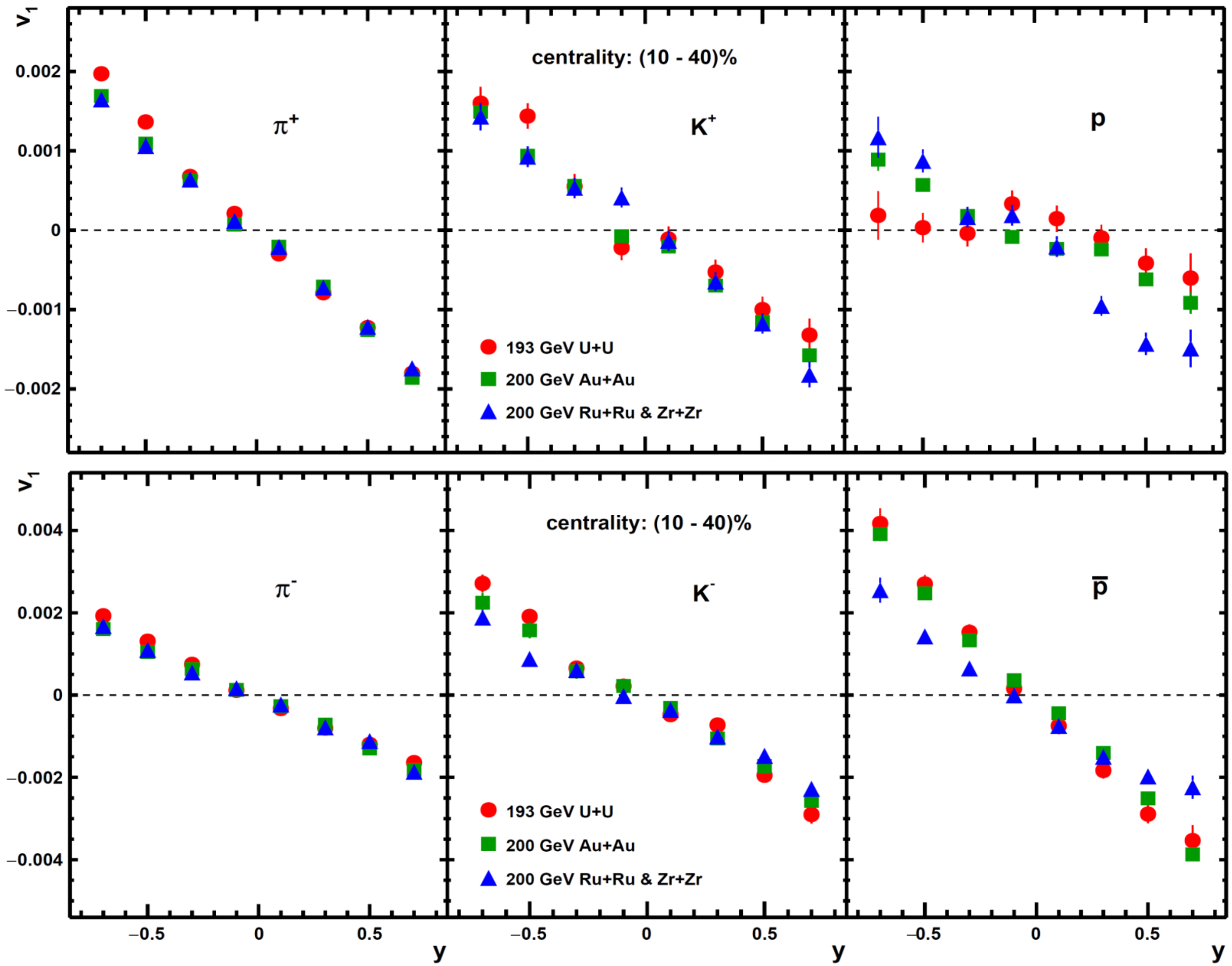


- **$\Delta(dv_1/dy)$ is obtained using: $\Delta(dv_1/dy) = [dv_1^{+}/dy - dv_1^{-}/dy]$**

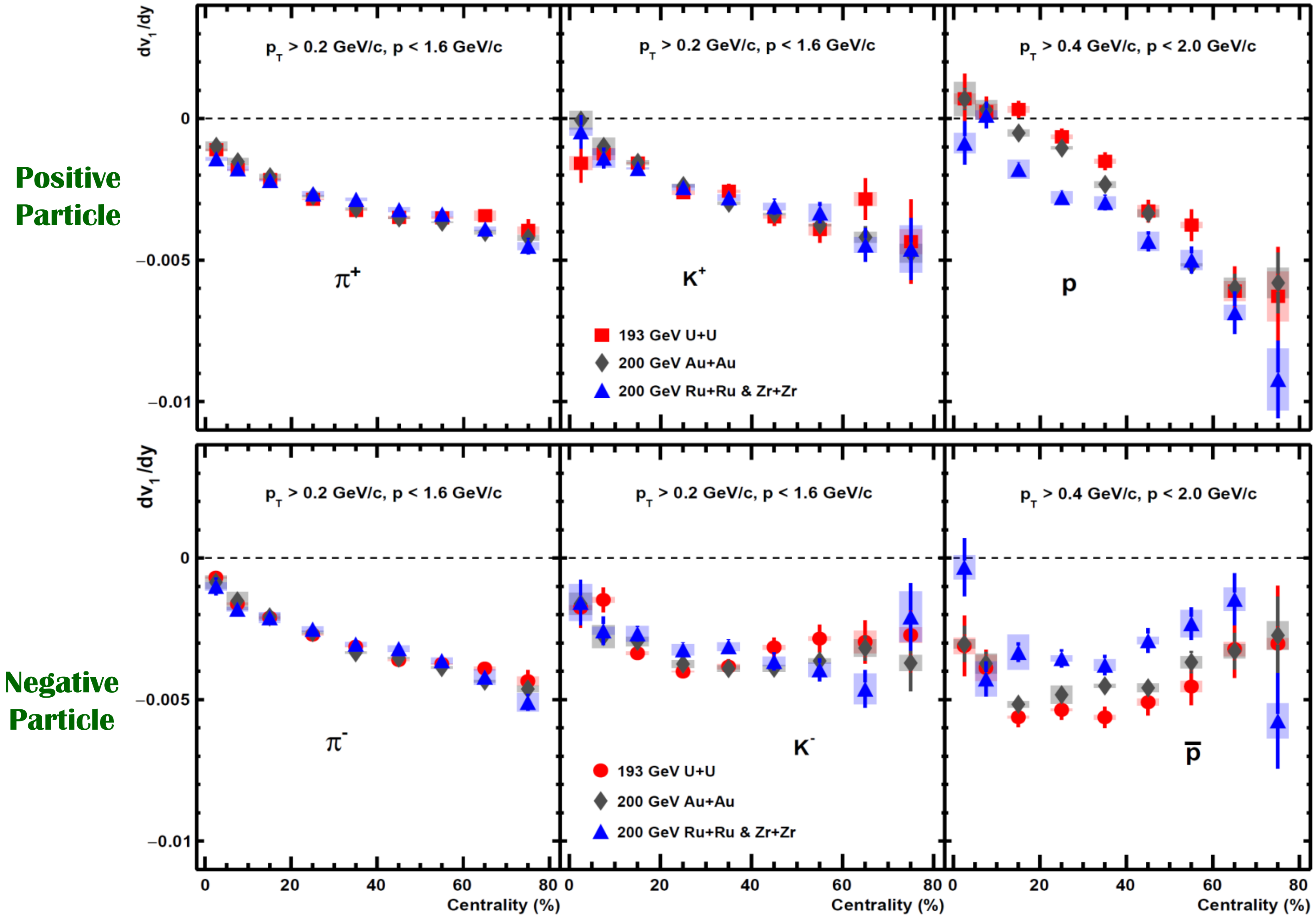
Rapidity dependent v_1 for Different Collision Systems

Positive Particle

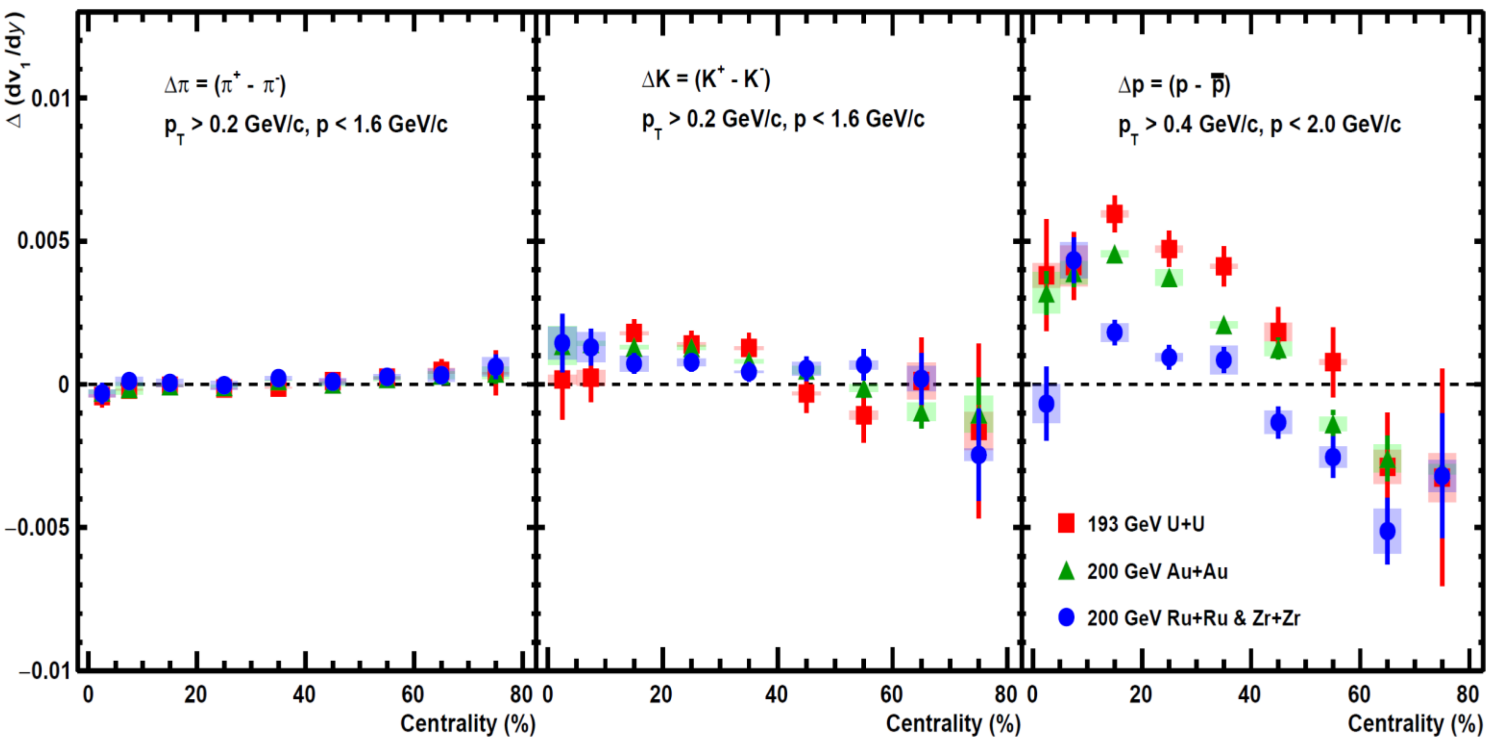
Negative Particle



Centrality dependent Slope (dv_1/dy) for Different Collision Systems



Centrality dependent $\Delta(dv_1/dy)$ for Different Collision Systems

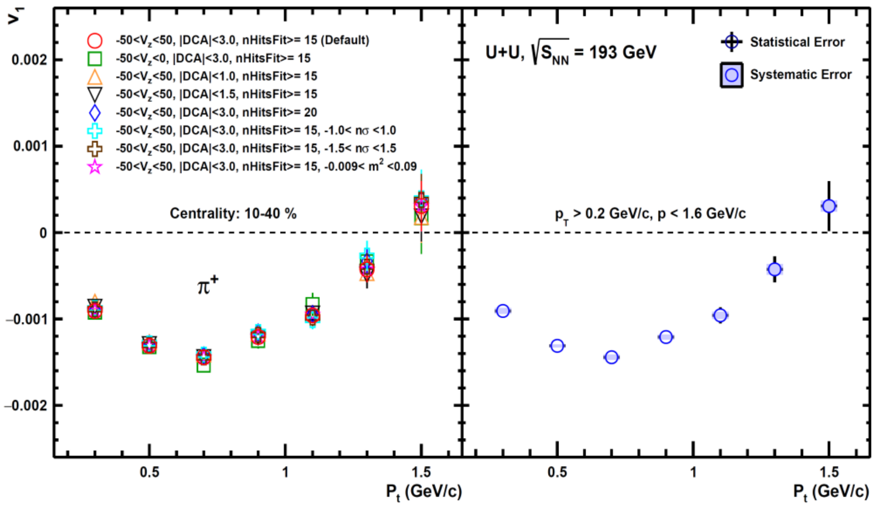


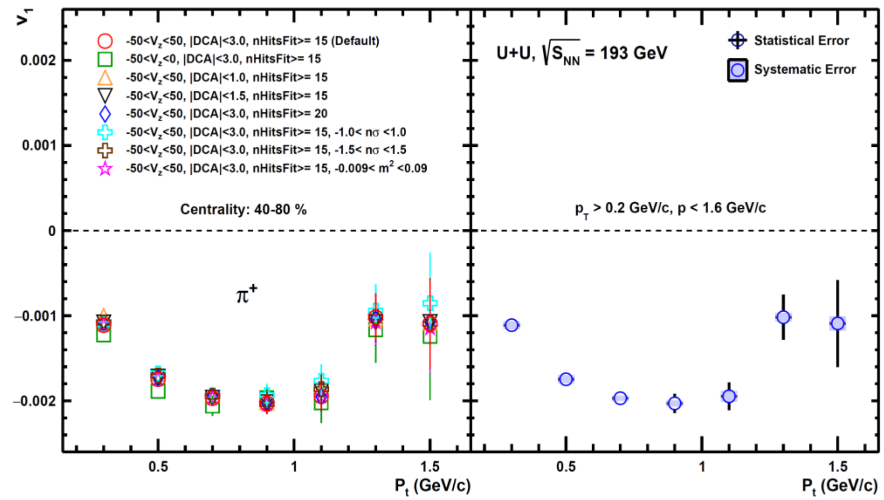
- Slope is fitted using a linear function "y = mx" within rapidity range (-0.8, 0.8)
- For Mid-central collisions, Proton shows a clear system size dependence among the three different collision systems at the same collision energy (~ 200 GeV)
- For proton in Peripheral Collisions, uncertainties are not sufficient to distinguish data among the three different collision systems

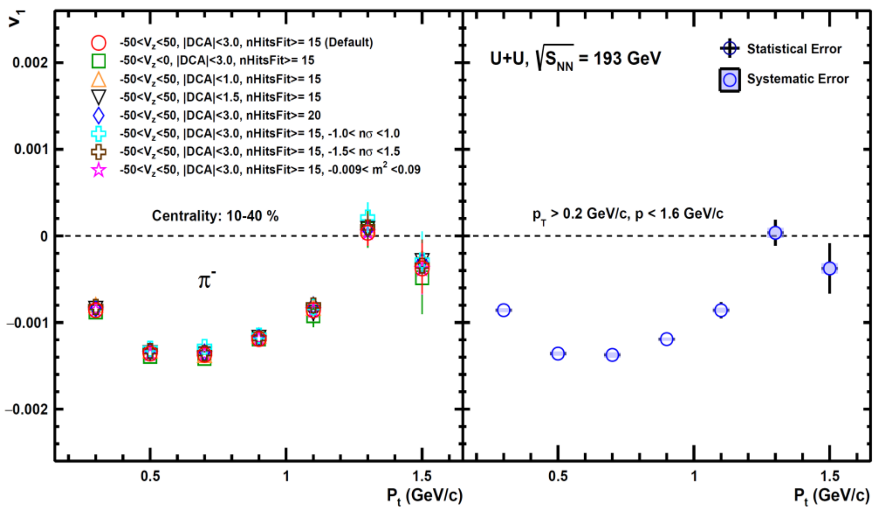
p_t dependent v_1 (Pion)

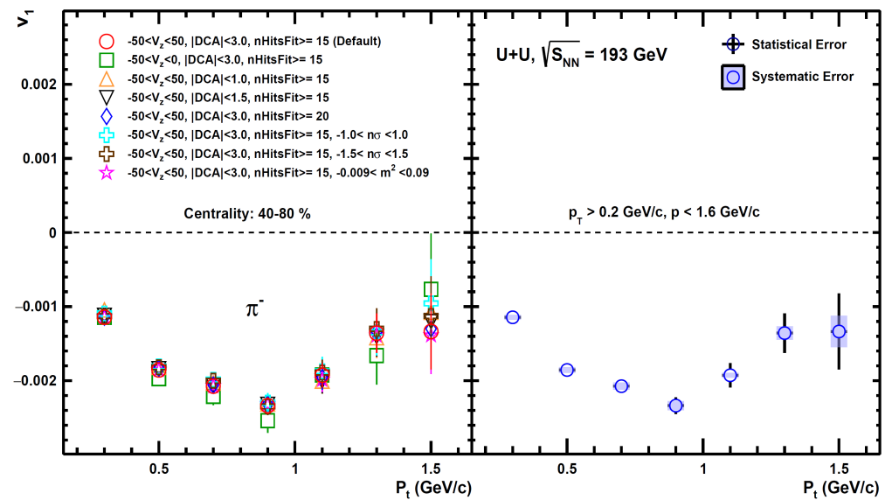
Mid Central (10 - 40)%

Peripheral (40 - 80)%





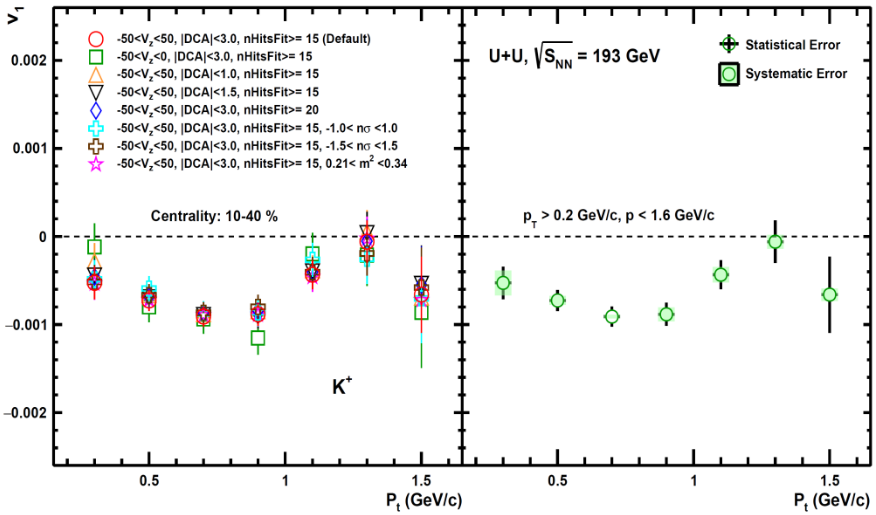


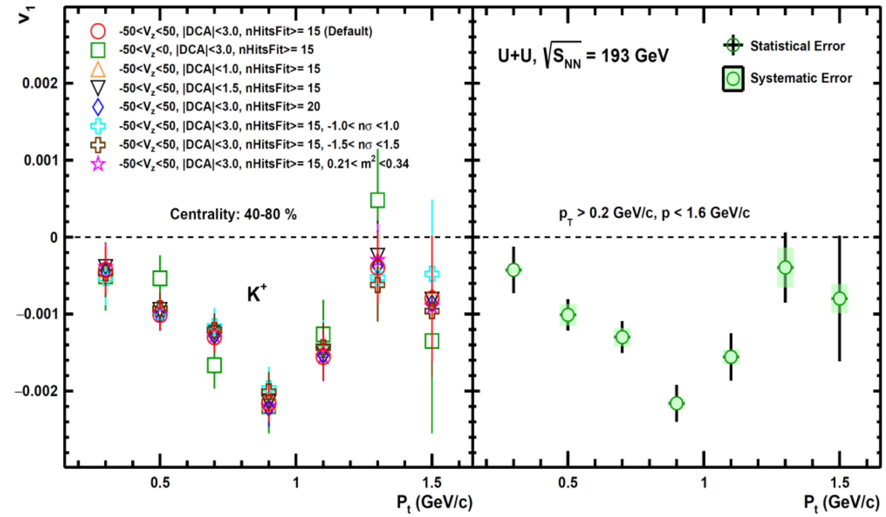


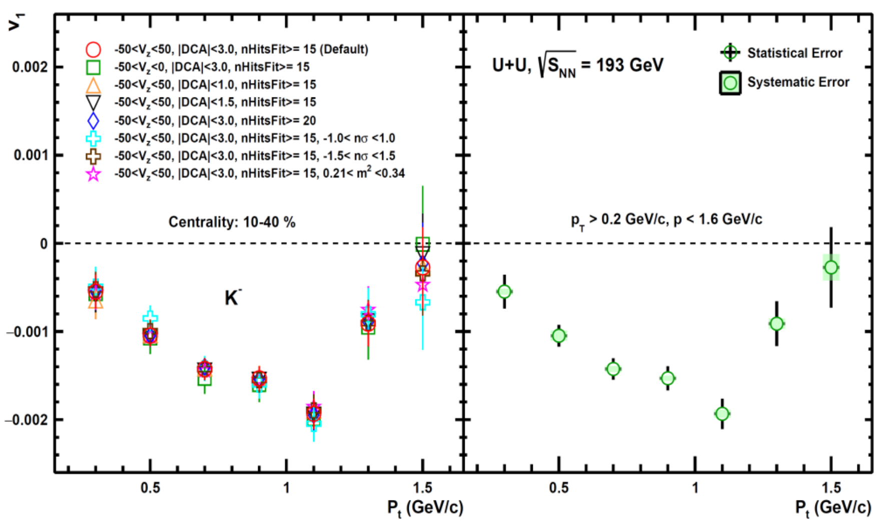
p_t dependent v_1 (Kaon)

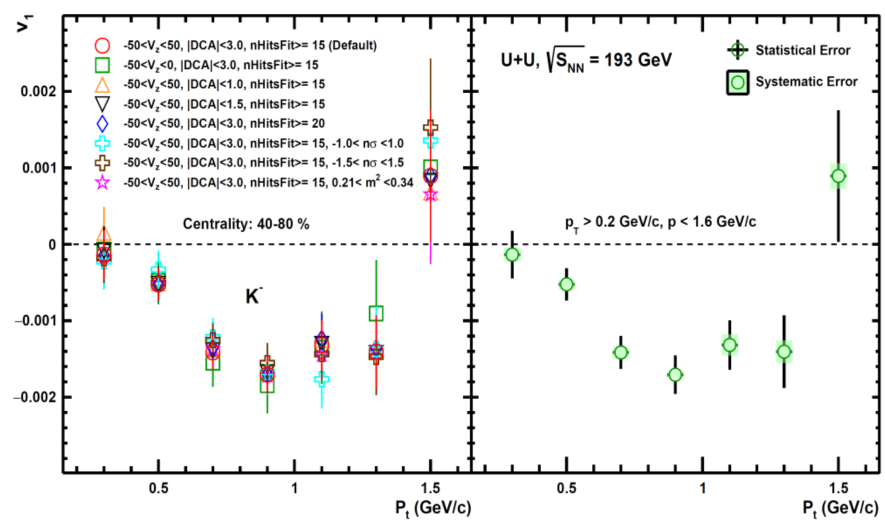
Mid Central (10 -40)%

Peripheral (40 - 80)%



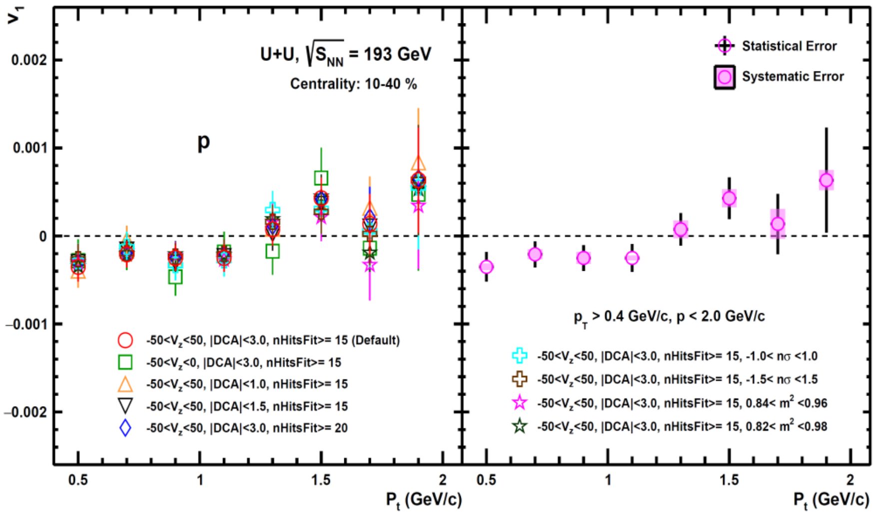


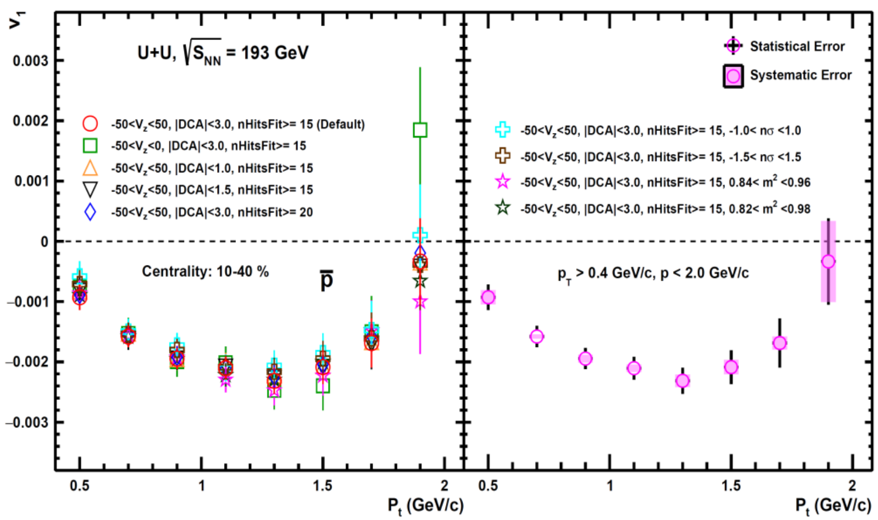




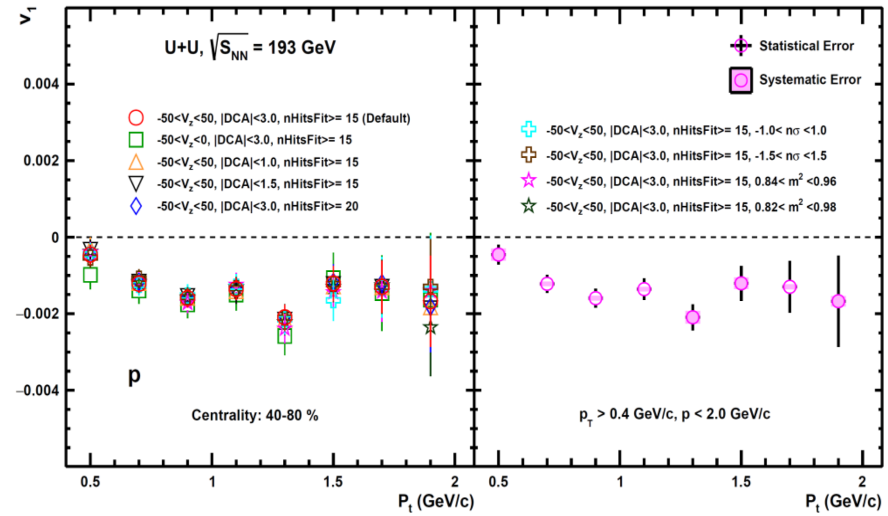
p_t dependent v_1 (Proton)

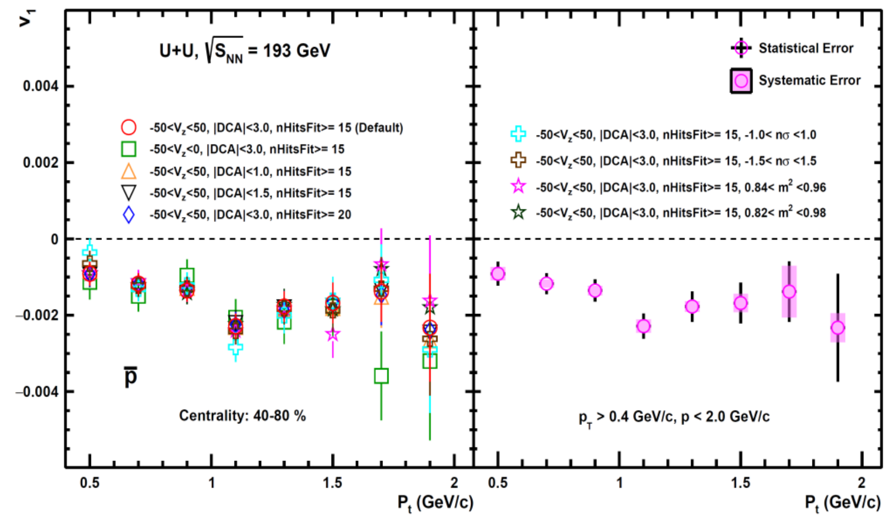
Mid Central (10 -40)%



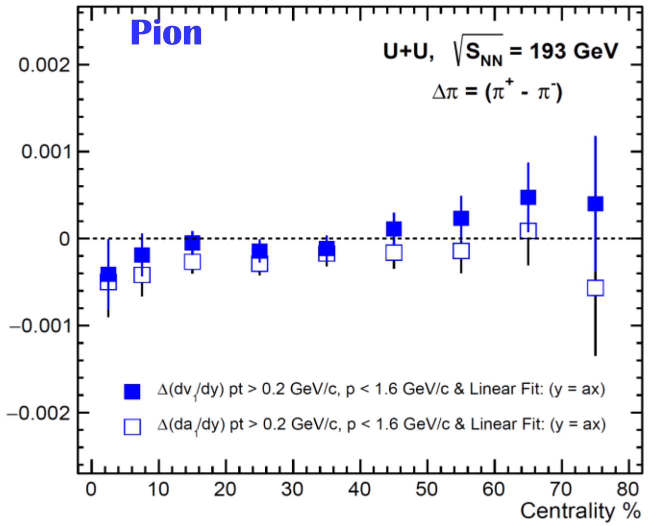


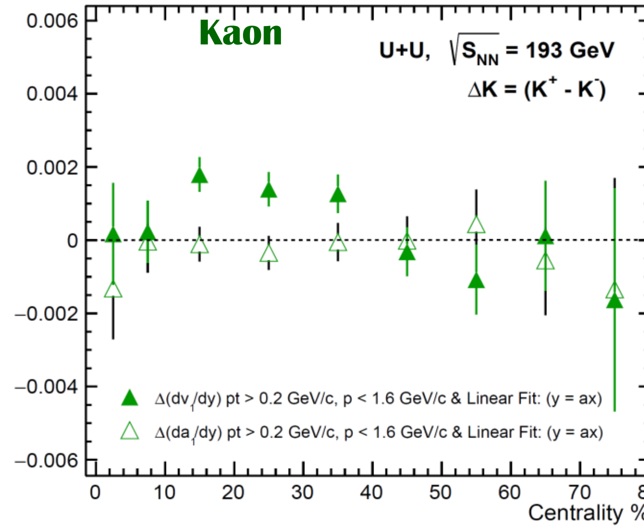
Peripheral (40 - 80)%

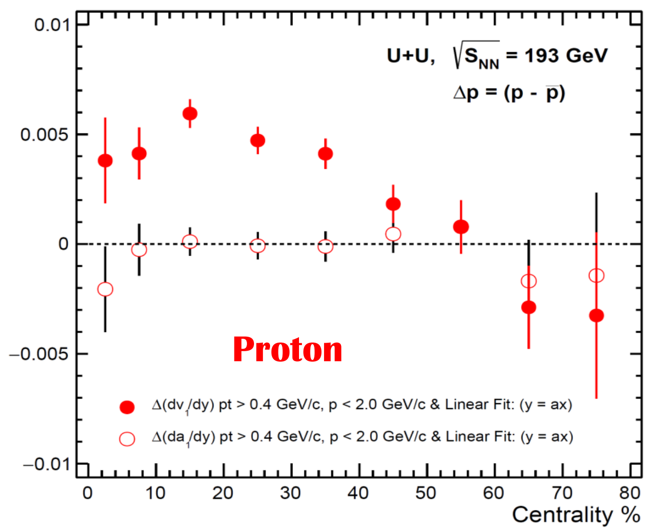




$\Delta(da_1/dy)$ as a function of centrality







$a_1 = \langle \sin(\phi - \psi) \rangle$

- $\Delta(dv_1/dy)$ shows centrality dependence while $\Delta(da_1/dy)$ slope is negligible and seems independent in all centrality bins

Summary

- We observe a significant difference in proton Δv_1 among three different colliding systems

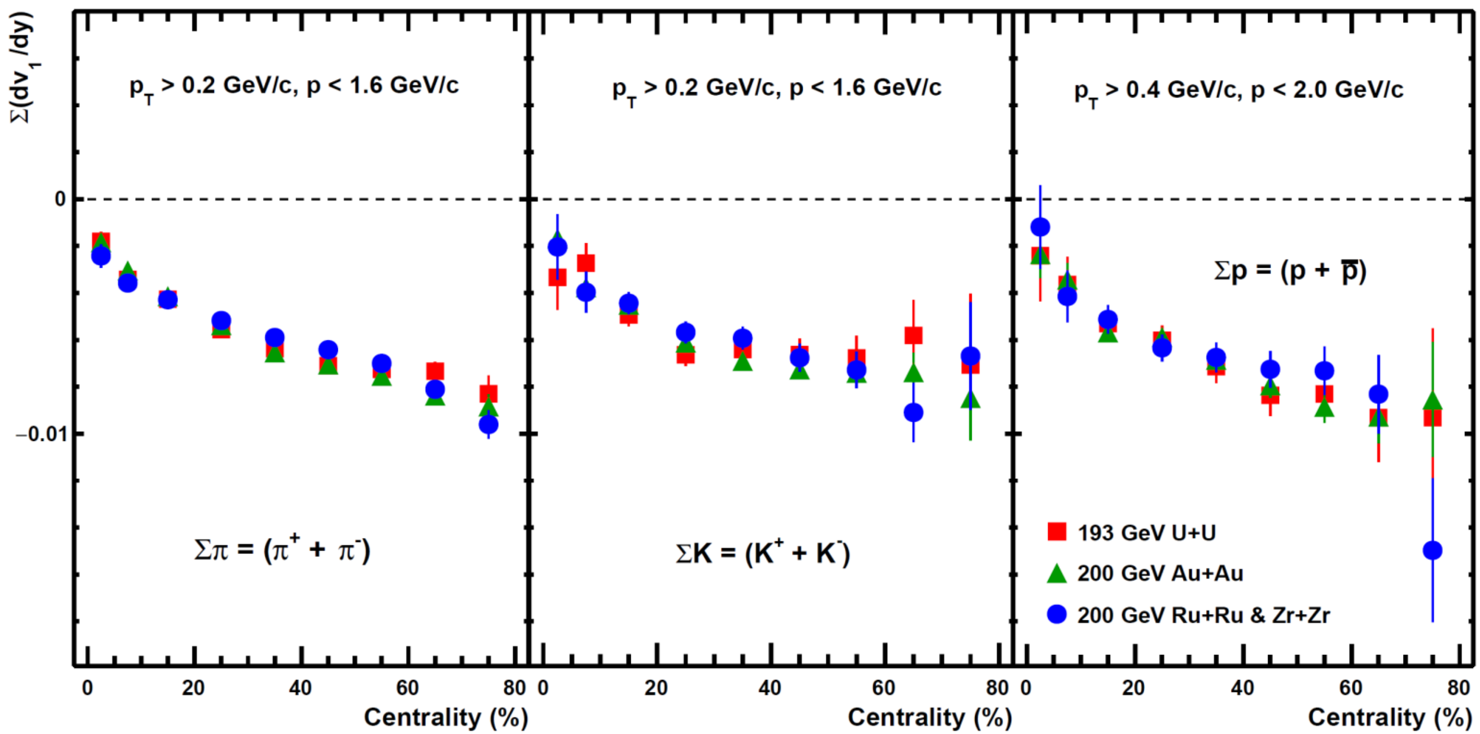
Proton Δv_1: U+U > Au+Au > Isobar

- For Proton, Δv_1 changes sign in peripheral collisions as observed in previous Au+Au and isobar data
- For pion and kaon all data points are consistent among three different collision systems at same collision energy

Thank You

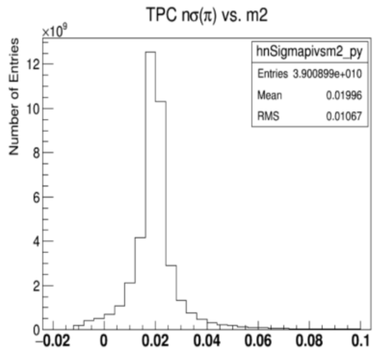
Backup Slides

Centrality dependent $\sum(dv_1/dy)$ for Different Collision Systems

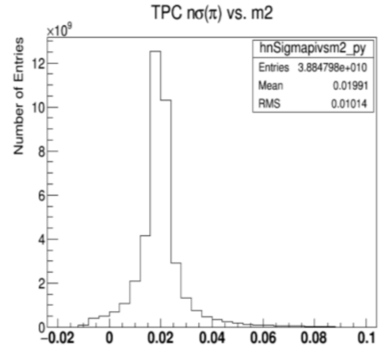


TOF Mass Square Distribution

Pion

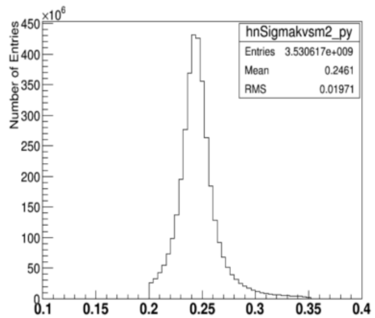


Default: -0.01 – 0.10

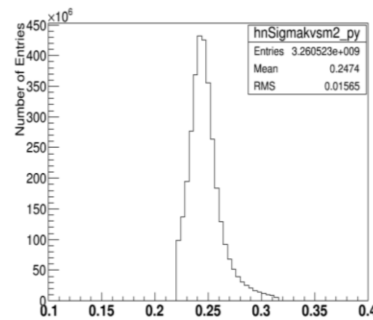


Systematics: -0.009 – 0.09

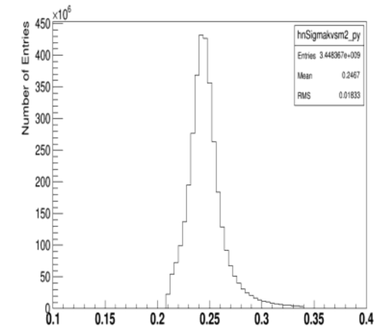
Kaon



Default: 0.20 – 0.35

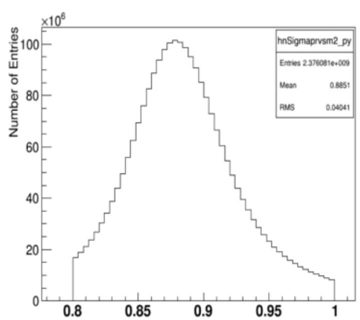


Systematics: 0.22 – 0.315

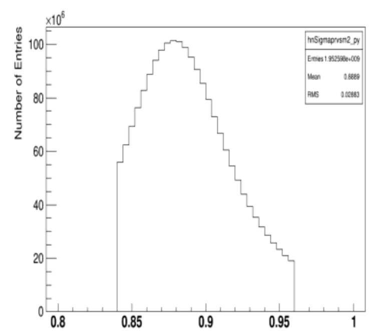


Systematics: 0.21 – 0.34

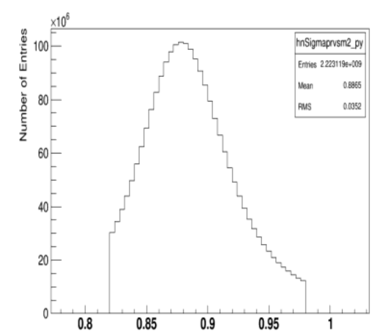
Proton



Default: 0.80 – 1.00

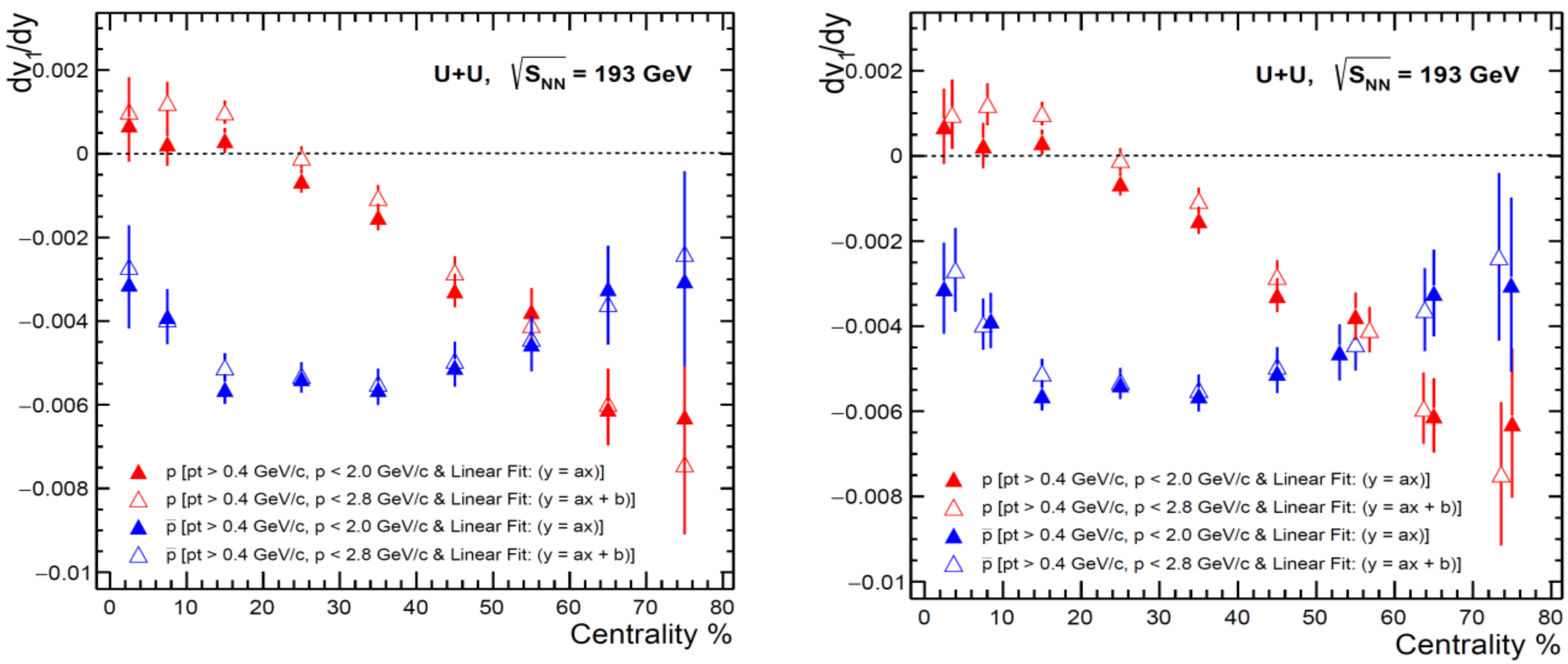


Systematics: 0.84 – 0.96

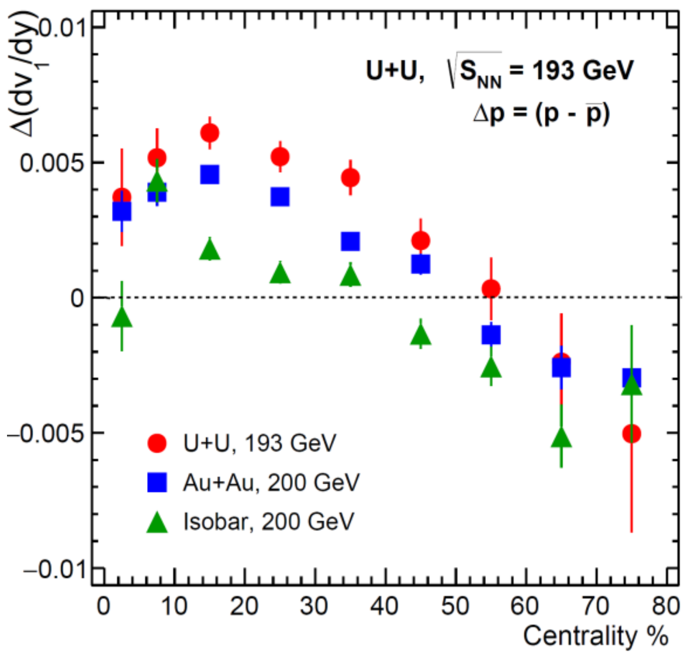


Systematics: 0.82 – 0.98

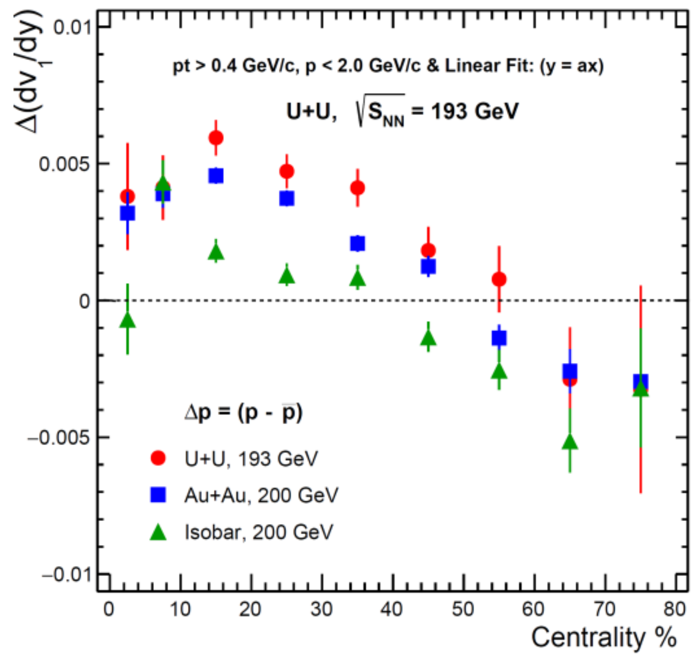
dv_1/dy and $\Delta(dv_1/dy)$ as a function of centrality



Δ(dv_1/dy) using different "p" and linear fit



pt > 0.4 GeV/c, p < 2.8 GeV/c & Linear Fit: (y = ax + b)



pt > 0.4 GeV/c, p < 2.0 GeV/c & Linear Fit: (y = ax)

- **For central collisions, a clear system size dependence is observed for proton among three different colliding systems, at the same collision energy**
- **For peripheral collisions, uncertainties are not sufficient to distinguish among three different collision systems**