Directed, elliptic and triangular flow of charged hadrons in O+O, Kr+Kr and Xe+Xe collisions at $\sqrt{s_{NN}}$ = 6 GeV in UrQMD model for SPD experiment

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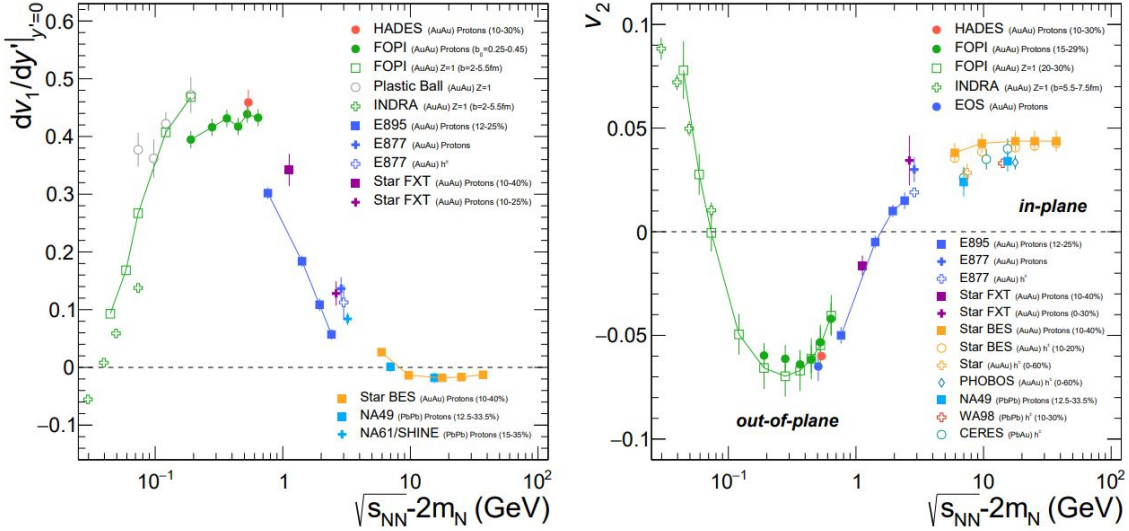
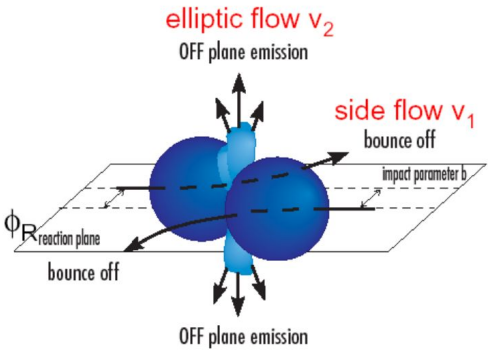
Motivation

HADES [Eur.Phys.J.A 59 (2023) 4, 80](#)

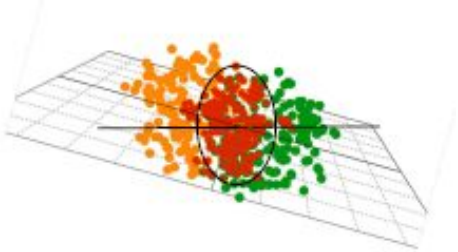


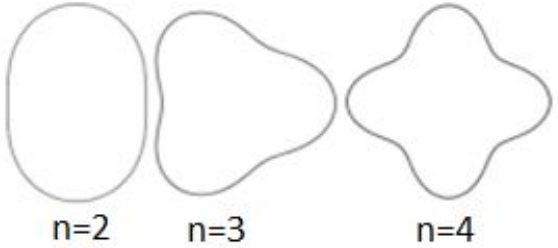


- QGM is not directly detected — needed indirect observables
- $v_n(p_T, \eta, \sqrt{s_{NN}}$, **centrality)** — sensitive to the early stages of collision.
- Important constraint on transport properties: EOS, η/s, ζ/s, etc.
- **At low energies (2 - 10 GeV) strong impact of spectators :**
  - v_1 slope change
  - out-of-plane v_2

New measurements of v_n in this energy range could provide new information of transport properties, particle production mechanisms and improve existing models

Azimuthal anisotropy



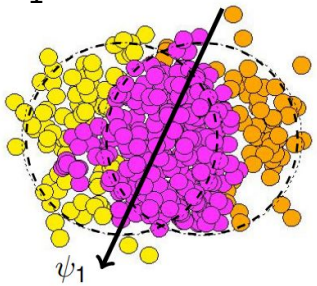


$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi \rangle + \langle r^n \sin n\phi \rangle}{\langle r^n \rangle}}$$

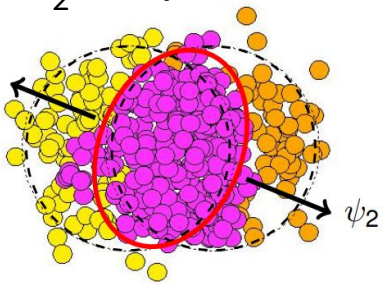
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_{RP})))$$

Initial eccentricity (and its attendant fluctuations), ε_n, drives momentum anisotropy, v_n, with specific viscous modulation

v_1 - directed flow



v_2 - elliptic flow



v_3 - triangular flow

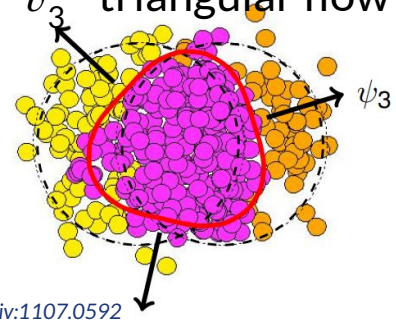


Illustration from M.Luzum arXiv:1107.0592

Flow measurements

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_{\mathrm{RP}})))$$

$$\nu_n = \langle \cos[n(\phi_i - \Psi_{RP})] \rangle$$

$$\nu_n = \langle \cos[n(\phi_i - \Psi_n)] \rangle$$

Ψ_{RP} cannot be obtained directly so Ψ_n is used which can be calculated using flow vectors Q_n

Event plane method:

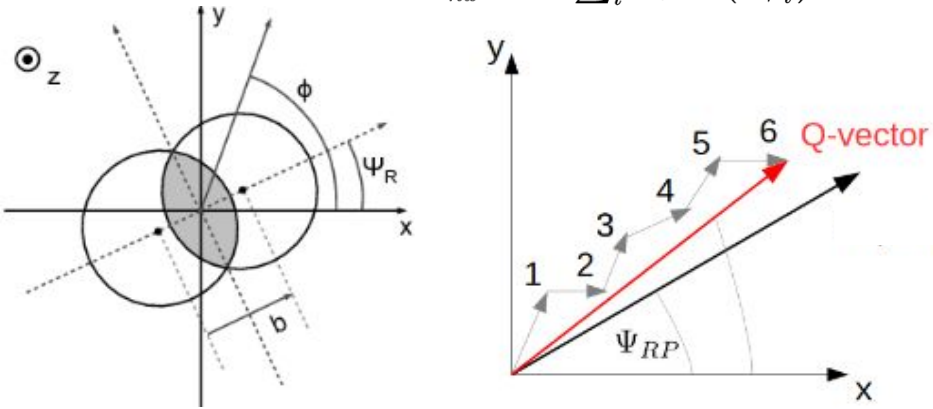
$$tg(n\Psi_n) = \frac{Q_{ny}}{Q_{nx}} = \frac{\sum_i \omega_i sin(n\phi_i)}{\sum_i \omega_i cos(n\phi_i)}$$

in this case, because RP not spin

$$\nu_1 = \langle \cos(\phi_i) \rangle$$

for n = 2, 3 used two sub events

$$\nu_n = \langle \cos[n(\phi_{i,\eta\pm} - \Psi_{n,\eta\mp})] \rangle$$



Datasets

UrQMD, 6 GeV:

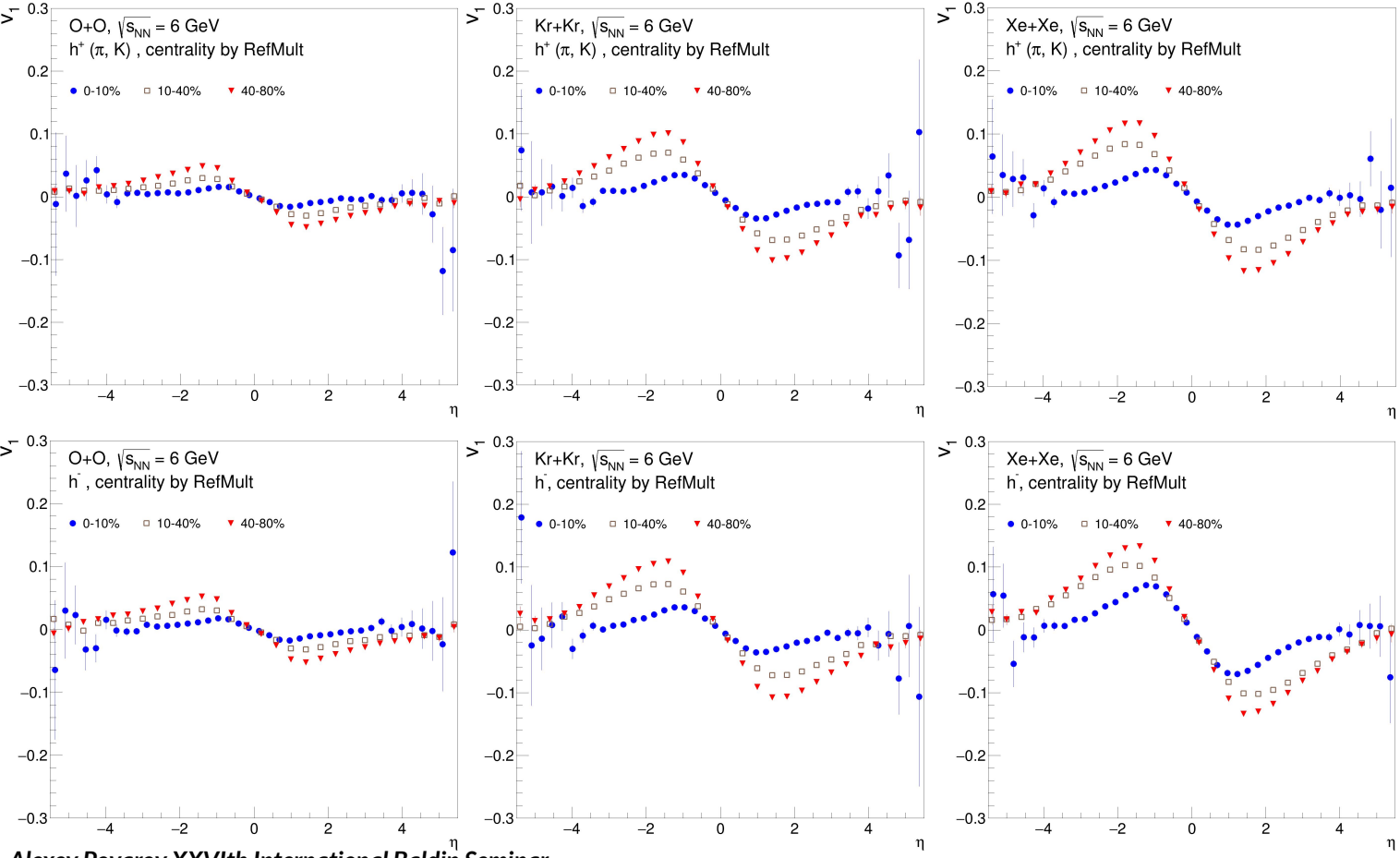
- O+O: ~48M
- Kr+Kr: ~6.6M
- Xe+Xe: ~6.3M

Cuts for RefMult:

- charged particles
- $|\eta| < 1$
- $pT > 0.15$ GeV/c

cent, %	0 - 5	5 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80
O+O Centrality									
RefMult	19 - 48	16 - 19	12 - 16	9 - 12	7 - 9	5 - 7	4 - 5	3 - 4	2 - 3
Kr+Kr Centrality									
RefMult	116 - 181	96 - 116	67 - 96	46 - 67	31 - 46	20 - 31	12 - 20	7 - 12	4 - 7
Xe+Xe Centrality									
RefMult	186 - 294	153 - 186	105 - 153	71 - 105	47 - 71	29 - 47	17 - 29	10 - 17	5 - 10

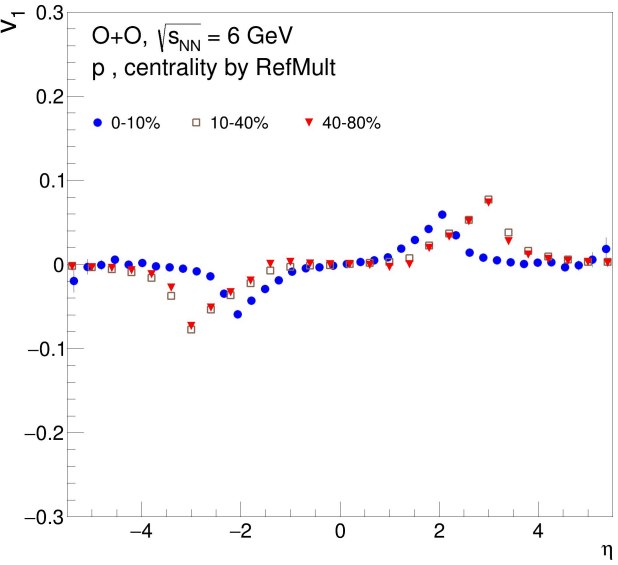
Directed flow of charged hadrons (1)

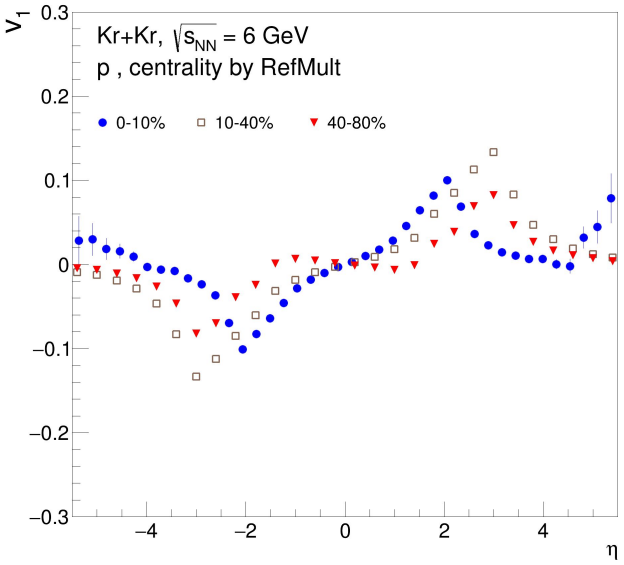


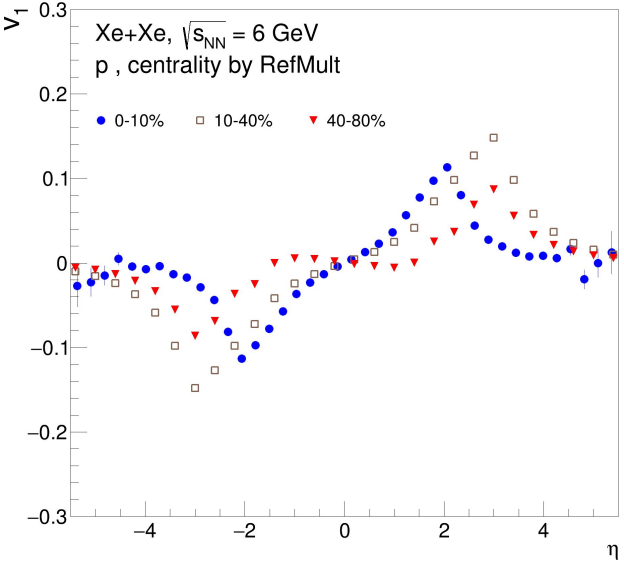
v_1 slope increase from central to peripheral collisions for mid-rapidity $|\eta| < 1$

Directed flow of charged hadrons (2)

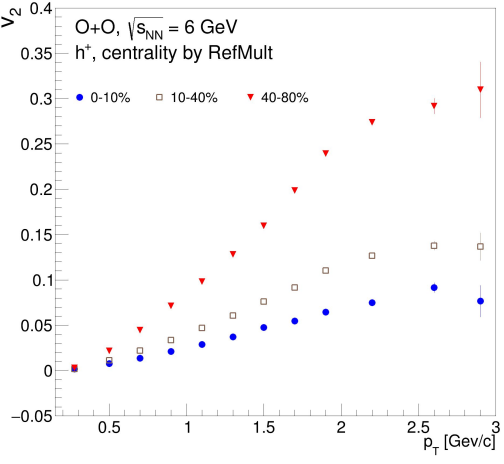
v_1 slope of protons is opposite for 0-10% and 10-40% centrality
Other mechanism of particle production for low energies

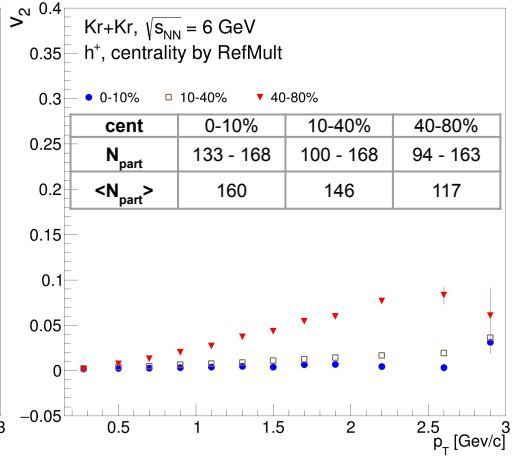




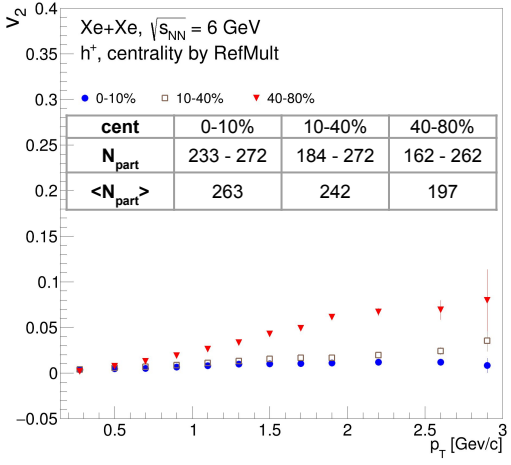


Elliptic flow of charged hadrons

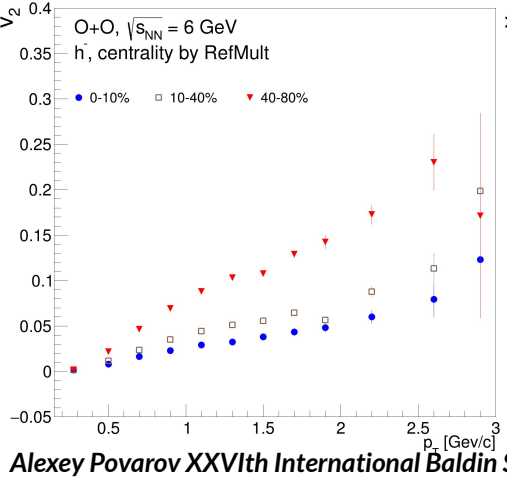


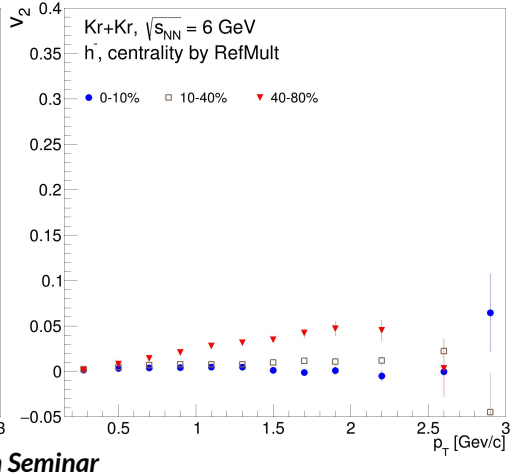


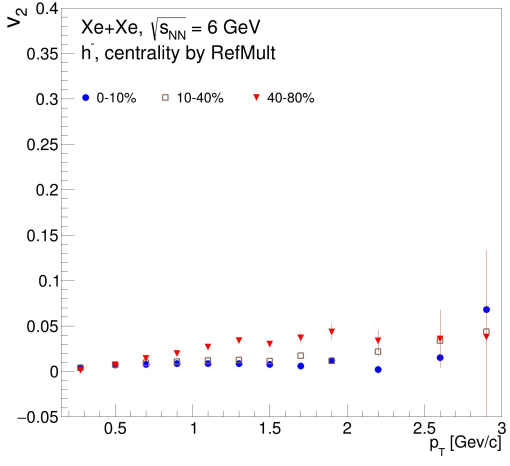
cent	0-10%	10-40%	40-80%
N_{part}	133 - 168	100 - 168	94 - 163
$<N_{part}>$	160	146	117



cent	0-10%	10-40%	40-80%
N_{part}	233 - 272	184 - 272	162 - 262
$<N_{part}>$	263	242	197





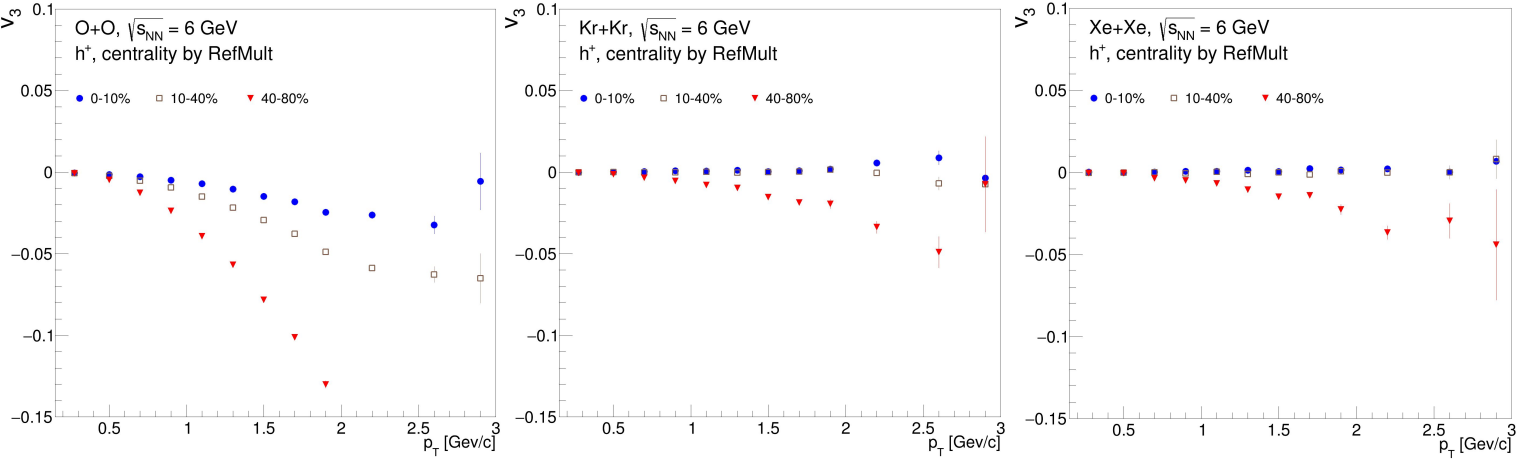


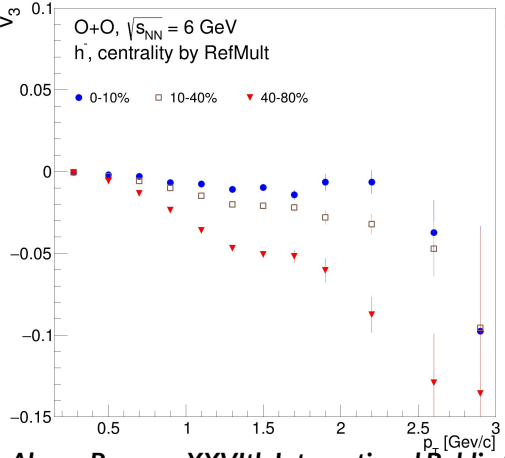
Centrality dependencies is observed for v_2

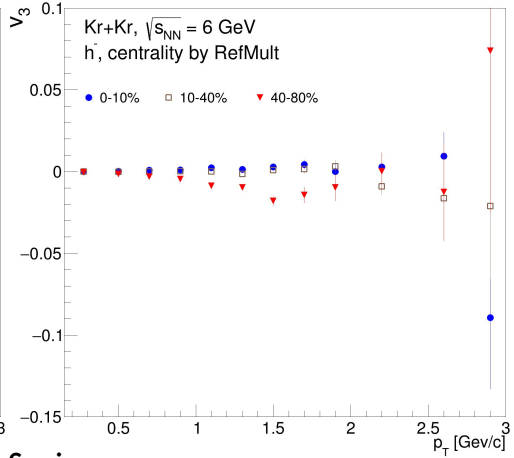
Increase v_2 signal from central to peripheral collisions

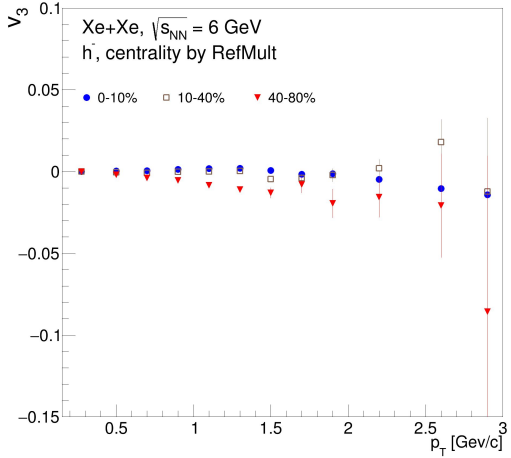
Big signal for O+O collisions =>possible influence of non-flow effects => needs to be checked

Triangular flow of charged hadrons









Mostly negative values, strange behaviour

Probably the influence of fluctuations of the initial state as a function of A?

Big non-flow contribution?
=> needs to be checked

Summary

Results of v_1, v_2 and v_3 in O+O, Kr+Kr and Xe+Xe collisions at $\sqrt{s_{NN}}$ = 6 in UrQMD are presented.

(centrality, p_T, η)-dependence of v_1, v_2 and v_3:

- v_1 slope increase from central to peripheral collisions for |η| < 1. v_1 slope of protons is opposite 0-10% and 10-40% centrality => Other mechanism of particle production for low energies
- For v_2 centrality dependencies is observed. In plans checked influence nucleus eccentricity. Big signal v_2 fo O+O, possible influence non-flow effects, will be checked.
- Mostly negative values v_3 for all collading system, needs to be checked.