Scaling properties of anisotropic flow at Nuclotron-NICA energies

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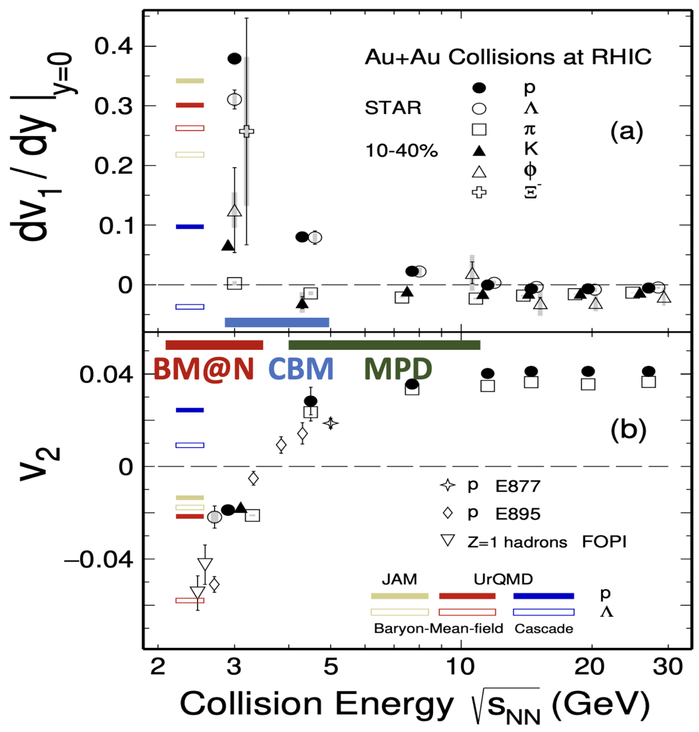
This work was done in INR RAS and supported by the RSF grant No. 22-12-00132

v_n at Nuclotron-NICA energies



$$\frac{dN}{d\varphi} \approx 1 + 2\sum_{n=1} v_n \cos\left[n\left(\varphi - \Psi_{\mathrm{RP}}\right)\right]$$

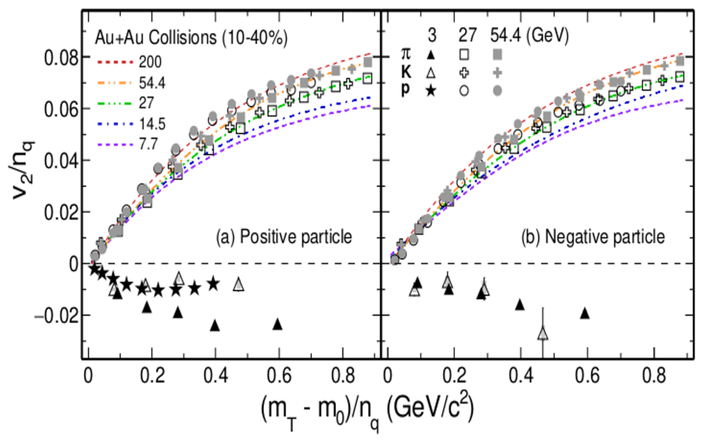
Anisotropic flow v_n at Nuclotron-NICA energies is a delicate balance between:

- The ability of pressure developed early in the reaction zone ($t_{\mathrm{exp}} = \frac{R}{c_s},\ c_s = \sqrt{\frac{dp}{d\varepsilon}}$)
- The passage time for removal of the shadowing by spectators ($t_{\mathrm{pass}} = \frac{2R}{\gamma_{\mathrm{CM}}\beta_{\mathrm{CM}}}$)

Scaling relations provide a useful tool to:

- **separate contribution to $v_n\left(R, \sqrt{s_{NN}}, \mathrm{cent}, \mathrm{PID}, p_T, y\right)$ from different effects**
- **perform comparison between v_n results from the data with different system size, $\sqrt{s_{NN}}$, etc.**

NCQ scaling



NCQ scaling: $v_n(p_T) \to \frac{v_n}{n_q^{n/2}}\left(\frac{KE_T}{n_q}\right)$,

$n_q = 2$ for mesons, $n_q = 3$ for baryons

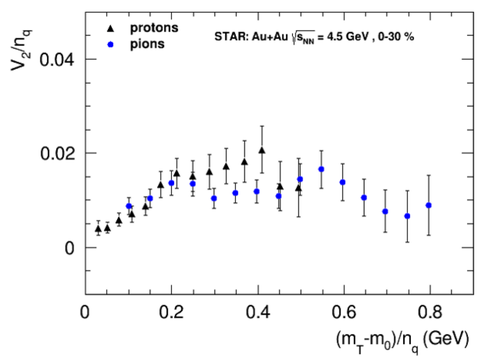
$KE_T = \sqrt{m^2 + p_T^2} - m$

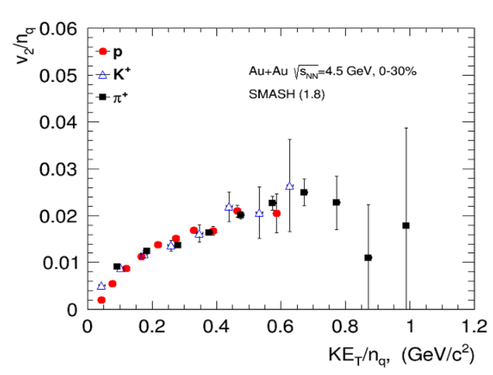
NCQ scaling → to partonic d.o.f.?

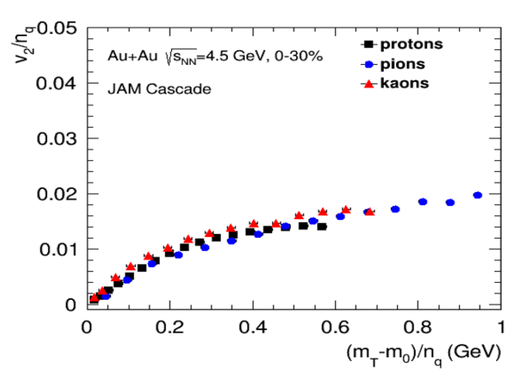
Scaling holds up at $\sqrt{s_{NN}} = 4.5$ GeV in:

- the STAR data
- the pure string/hadronic cascade models (wihtout partonic d.o.f.)

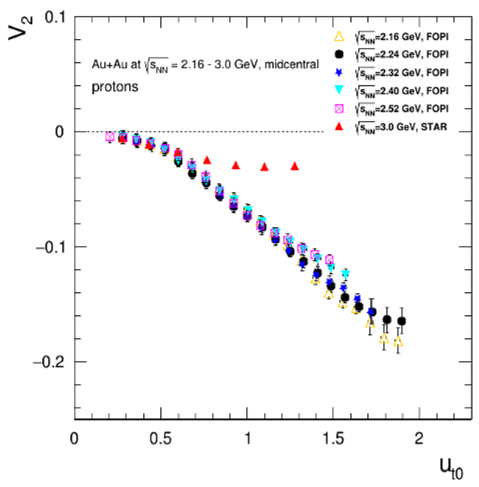
More careful studies at NICA energies are needed!

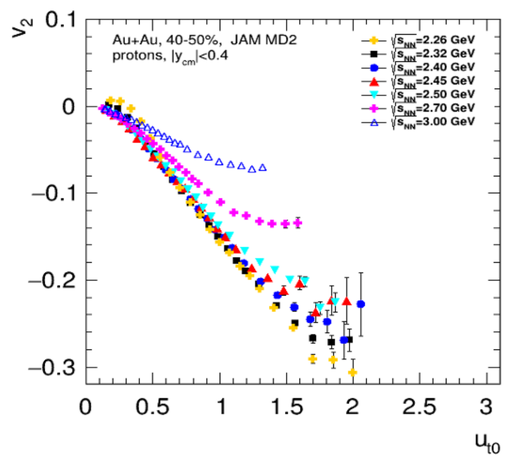


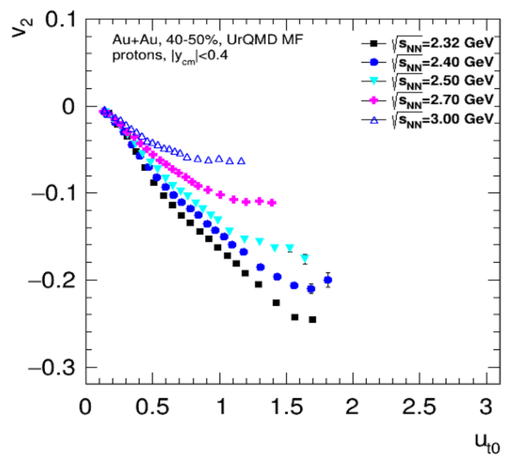




Scaling with t_{pass}





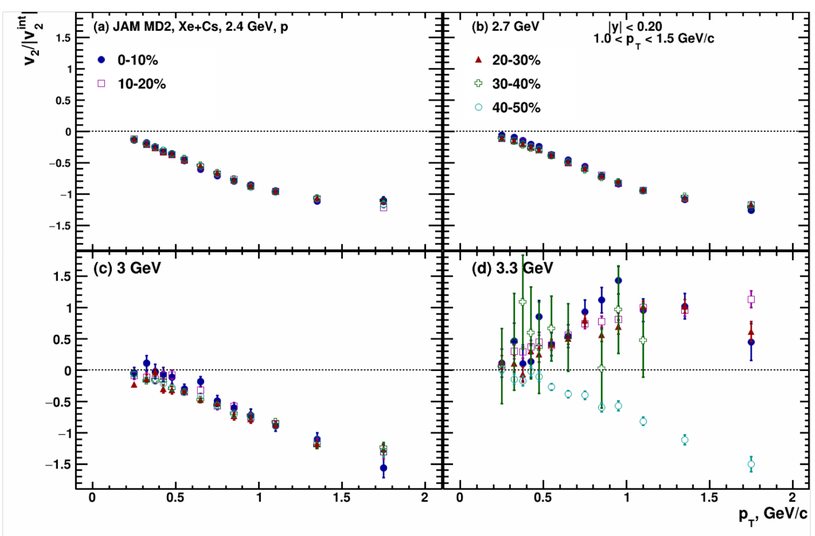


Scaling with u_{t0}: $v_n(p_T) \to v_n(u_{t0})$, $u_{t0} = \frac{p_T}{m\gamma_{\mathrm{CM}}\beta_{\mathrm{CM}} \equiv \frac{pT t_{pass}}{2mR}}$

Rather good u_{t0} scaling suggests that c_s does not change significantly at $\sqrt{s_{NN}} = 2 - 2.7$ GeV

Scaling hols for experimental data for $\sqrt{s_{NN}} = 2-3$ GeV and the mean-field models (JAM, UrQMD) for $\sqrt{s_{NN}} = 2 - 2.7$ GeV – good tool to further constrain models

Scaling with integral v_n

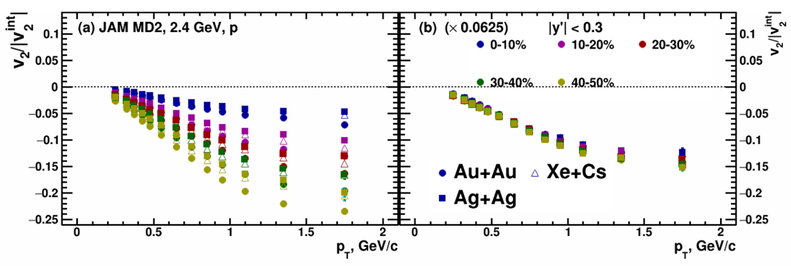


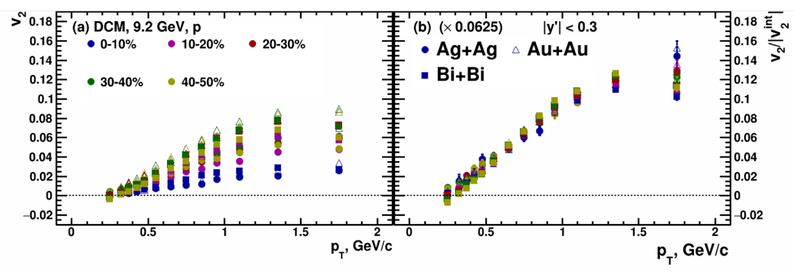
$v_2\left(R, \sqrt{s_{NN}}, \mathrm{cent}, \mathrm{PID}, p_T, y\right) = v_2\left(R, \sqrt{s_{NN}}, \mathrm{cent}\right) \times v_2\left(\mathrm{PID}, p_T, y\right)$?

Scaling holds for a wide energy range, different centralities and colliding systems

Breaks around $\sqrt{s_{NN}} \approx 3.3$ GeV where $v_2 \approx 0$

Useful tool for the additional model constraints and comparison between experimental data with different R, cent, $\sqrt{s_{NN}}$





Conclusions

- **NCQ scaling:** holds at $\sqrt{s_{NN}} > 4$ GeV in both experimental data and models – even in pure string/hadron cascade modes! More thorough studies are needed at the lower energies, scaling at $\sqrt{s_{NN}} > 4.5$ GeV might be accidental.
- **Scaling with t_{pass}:** holds at $\sqrt{s_{NN}} > 2 - 2.7$ GeV and breaks at $\sqrt{s_{NN}}3$ GeV. Shows that the main contribution in $v_n\left(\sqrt{s_{NN}}\right)$ is due to the energy dependence of t_{pass}.
- **Scaling with integral v_n:** holds at a wide beam energy range, breaks only at around $\sqrt{s_{NN}} > 3.3$ GeV. Provides a useful tool to make comparison of v_n results from different colliding systems, centrality classes and beam energies.

Scaling relations will be useful for the future v_n measurements in the BM@N and MPD experiments at NICA