Nature of particles azimuthal anisotropy at low and high transverse momenta in ultrarelativistic A+A collisions

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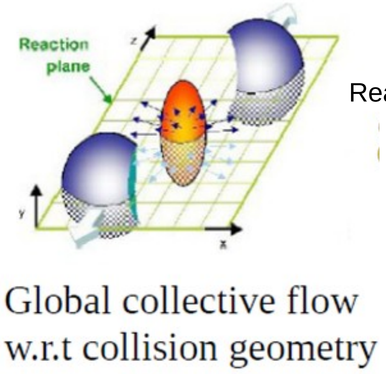
A number of observables is employed for investigation of the medium, created in nuclear-nucleus collisions. Two of them are:

Azimuthal anisotropy of particles.

- Soft prosesses,
- Low transverse momenta p_T.

Hydrodynamical expansion of the medium in accordance to initial system geometry.



Reaction plane is not known in experiment.

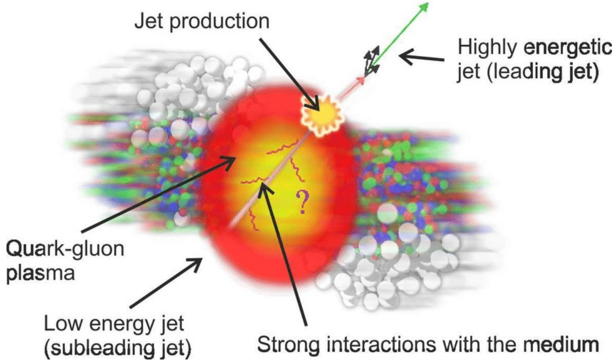
The value of anisotropic flow is characterized with Fourier coefficients:

$$E\frac{d^3N}{d^3p} = \frac{1}{\pi}\frac{d^2N}{dp_t^2dy}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Psi_n)\right]$$

v_2 is elliptic flow, v_3 is triangular flow and so on..

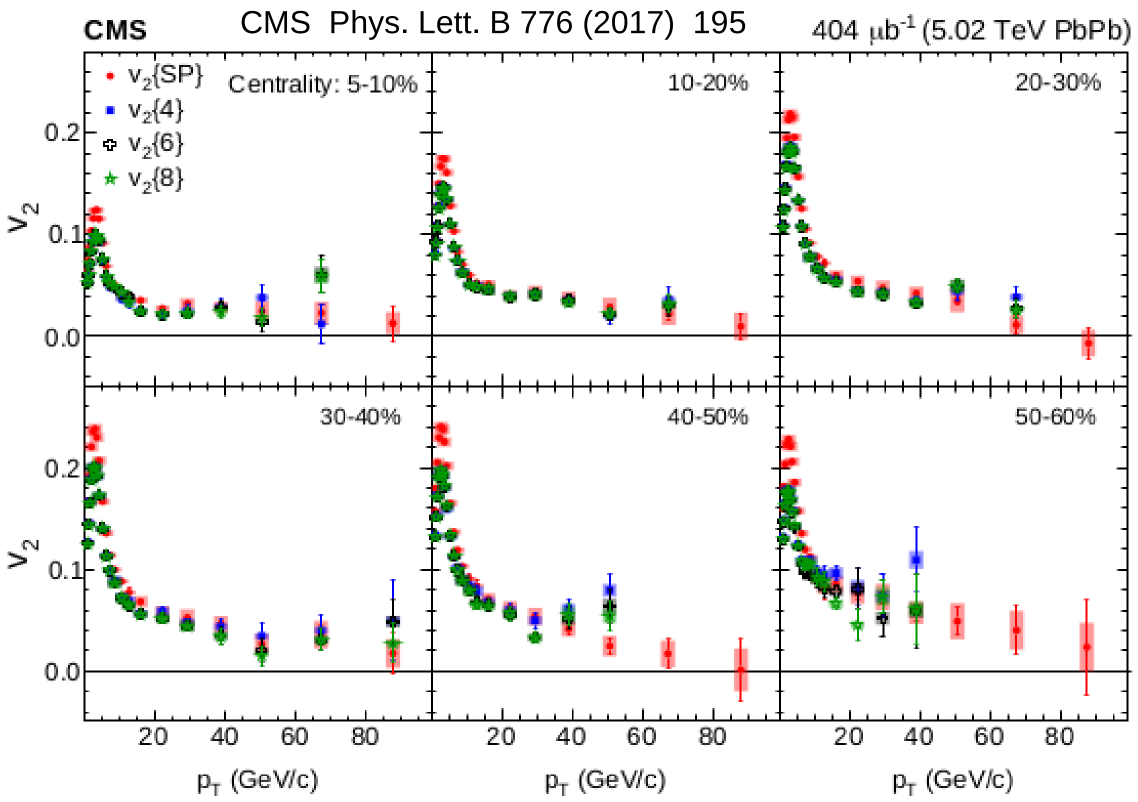
jet quenching.

- Hard parton-parton interactions,
- High transverse momenta p_T.



When transversing quark-gluon medium, hadrons suffer energy losses. In anisotropic medium the hadron yield assymetry is expected to be observed with respect to reaction plane (energy losses differ in different directions).

Elliptic flow at low and high transverse momenta



The flow $v_2(p_T)$ is measured experimentally up to high $p_T \approx 100$ GeV/c.

- For the first time in CMS experiment the cumulant method is applied at high p_T.
- Cumulants larger than 4th order gives similar results.

Experimental methods for v_2 measurement include the methods with reaction plane estimation as well as many-particle correlation methods.

Cumulant method

- 2 and 4-particles correlations:

$$\langle\langle 2\rangle\rangle = \langle\langle e^{in(\varphi_1-\varphi_2)}\rangle\rangle, \qquad \langle\langle 4\rangle\rangle = \langle\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)}\rangle\rangle$$

Double brackets here are averaging on particles and events.

$\langle\langle 2'\rangle\rangle$ and $\langle\langle 4'\rangle\rangle$ are differential correlations, where one of the particle is in a given p_T -bin.

- Cumulants of 2nd and 4th order:

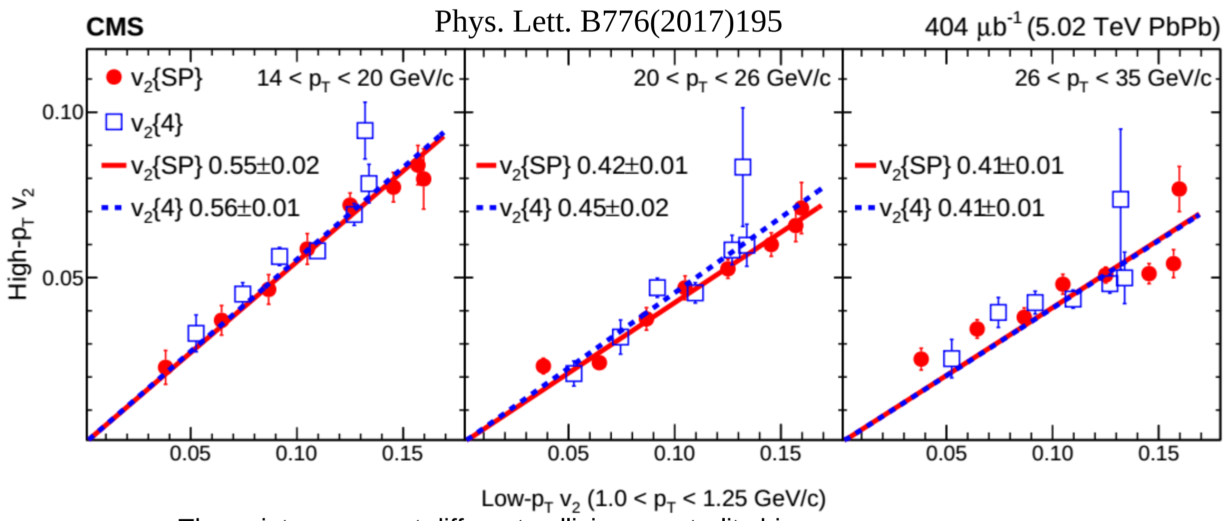
$$c_n\{2\} = \langle\langle 2\rangle\rangle, \qquad c_n\{4\} = \langle\langle 4\rangle\rangle - 2\times\langle\langle 2\rangle\rangle^2$$

$$d_n\{4\} = \langle\langle 4'\rangle\rangle - 2\times\langle\langle 2'\rangle\rangle\times\langle\langle 2\rangle\rangle$$

- Elliptic flow by cumulants of 4th order:

$$v_n\{4\}(p_T) = -d_n\{4\}\times(-c_n\{4\})^{-3/4}$$

Elliptic flow correlation at low and high p_T in CMS experiment



The points represent different collisions centrality bins:
0–5, 5–10, 10–15, 15–20, 20–30, 30–40, 40–50 и 50–60%

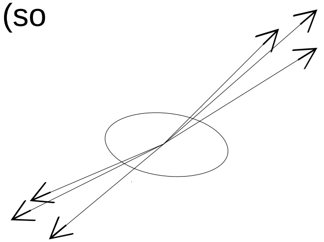
- v_2 at high and low p_T are correlated.
- These correlations can be approximated by liner function.
- The liner slope decreases for higher p_T ranges.
- It is suggested that the initial-state geometry is likely to be the common cause of particles anisotropy both at low and high p_T.

*We used **HYDJET++ model** to study (hight-p_T v_2)– (low p_T v_2) correlation.*

Elliptic flow at low and high transverse momenta

What do we measure at high p_T?

Back-to back jets give azimuthal anisotropy and may lead to large v_2 coefficient of non-hydro origin (so called non-flow correlations).



On the other hand, methods for v_2 measurements employ correlations with low-p_T particles, which suggest that v_2 is measured with respect to the common collective geometry (asymmetry arises due to path length dependence of energy losses).

Experimentally measured v_2 at high p_T two contributions may present:

- Asymmetry with respect to back-to-back jet axis (not correlated with v_2 at low p_T)
- Asymmetry with respect to common reaction plane (correlated with v_2 at low p_T)

It is considered that the cumulants of high order suppress non-flow contribution very well. **Is this true at high p_T ?**

Cumulants and azimuthal asymmetry

When we have a pronounced jet-axis direction, we can approximate azimuthal distribution:

$$\frac{dN}{d\varphi} = N_0\Big(1 + 2v_2^{RP}\cos\left[2(\varphi - \Psi_2^{RP})\right] + 2v_2^{jet}\cos\Big[2(\varphi - \Psi_2^{jet})\Big]\Big),$$

Azumuthal asymmetry, associated with jets may contribute to cumulants:

$$\langle\langle 2\rangle\rangle \simeq (v_2^{RP})^2 + (v_2^{jet})^2, \qquad \langle\langle 4\rangle\rangle \simeq [(v_2^{RP})^2 + (v_2^{jet})^2]^2$$

HYDJET++ model for nuclear nucleus collision (HYDrodynamics + JETs)

I.Lokhtin, L.Malinina, S.Petrushanko, A.Snigirev, I.Arsene, K.Tywoniuk, Comp.Phys.Comm. 180 779 (2009)

http://cern.ch/lokhtin/hydjet++

Event generator to simulate heavy ion event as merging of two independent component.

Hard “jet” component:

PYTHIA w/o hadronization

↓

PYQUEN **(PYthia QUENched)**

http://lokhtin.web.cern.ch/lokhtin/pyquen/

I.P.Lokhtin, A.M.Snigirev, Eur. Phys. J. 45 (2006) 211

Parton rescattering & energy loss (collisional, radiative) + emitted gluons

↓

Parton hadronization and final particle formation
PYTHIA6.4 with hadronization

Soft hydro-type component:
is based on the adapted **FAST MC** model

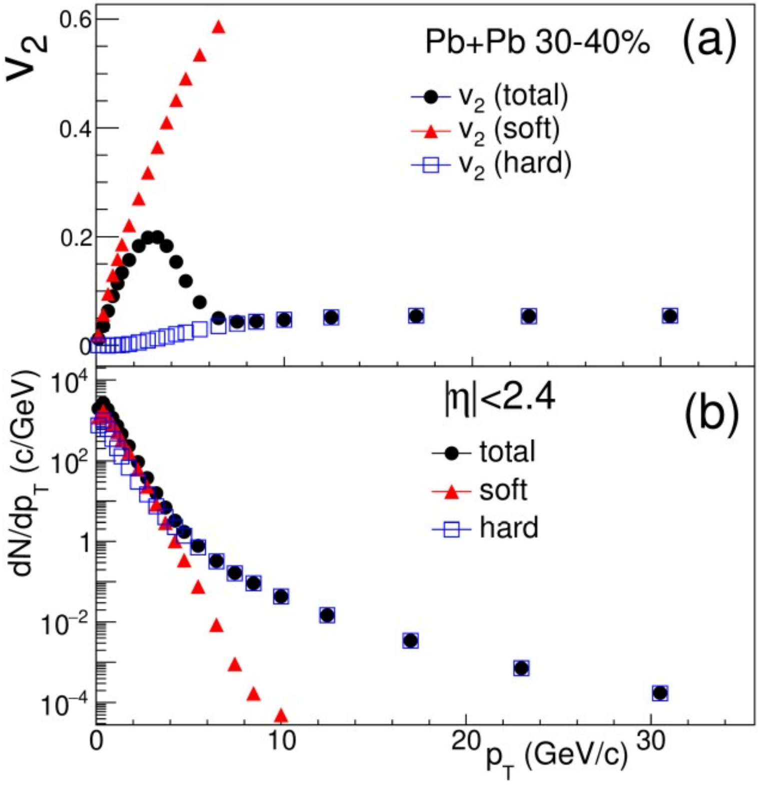
N.S.Amelin, R.Lednisky, T.A.Pocheptsov, I.P.Lokhtin, L.V.Malinina, A.M.Snigirev, Yu.A.Karpenko, Yu.M.Sinyukov, Phys. Rev. C 74 (2006) 064901, N.S.Amelin, R.Lednisky, I.P.Lokhtin, L.V.Malinina, A.M.Snigirev, Yu.A.Karpenko, Yu.M.Sinyukov, I.C.Arsene, L.Bravina, Phys. Rev. C 77 (2008) 014903

- multiplicities are determined assuming thermal equilibrium;
- hadrons are produced on the hypersurface represented by a parameterization of relativistic hydrodynamics with given freeze-out conditions;
- decays of hadronic resonances are taken into account (360 particles from SHARE data table) with “home-made" decayer;
- Set of parameters is tuned in order to describe experimental data

Contributions of two components are regulated by a parameter: minimal p_T of hard parton-parton scattering.

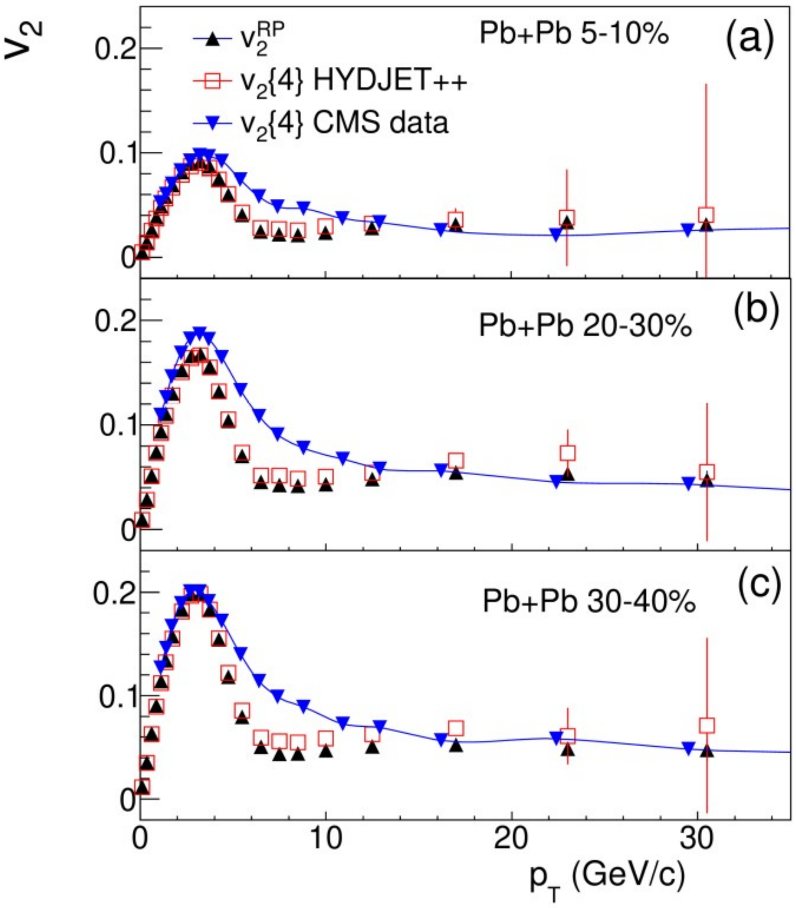
HYDJET++ model for nuclear nucleus collision

Elliptic flow and spectra in the model, made up with 2 components



- For low transverse momentum region soft component is dominant.
- In the high transverse momentum region hard processes dominate.
- In the intermediate p_T region the result is obtained by a simple superposition of two independent contributions.

HYDJET++ model
Elliptic flow in PbPb collisions at $\sqrt{s_{NN}}$=5.02 TeV



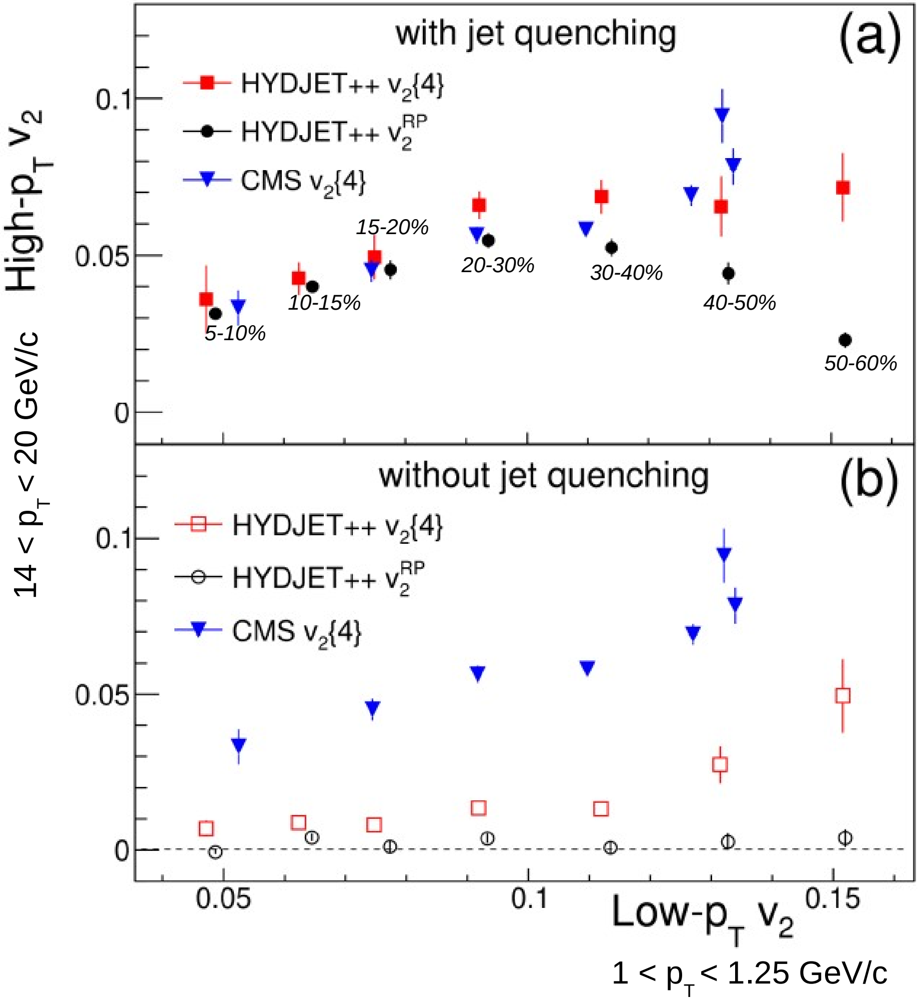
- One of preliminary parameter sets was used to calculate elliptic flow $\sqrt{s_{NN}}$=5.02 TeV.
- In momentum regions 0< p_T <5 , 13 < p_T < 35 GeV/c the description is satisfactory
- In the momentum region 5 < p_T < 13 GeV/c additional tuning of parameters is needed. This region is not important for the given investigation.

The elliptic flow was calculated:

- Directly with respect to known in the model reaction plane angle v_2^{RP} .
- With the cumulants of 4th order.

For high p_T the v_2^{RP} value gives information on anisotropy of hadrons due to jet quenching effect in anisotropic volume.

Elliptic flow correlation at low and high p_T



- At high p_T ($14<p_T<20$ GeV/c) anisotropy due to jet quenching increases with centrality, but for centralities > 40% begins to decrease, since energy losses decrease in more peripheral collisions.
- Anisotropy calculated with the cumulant $v_2\{4\}$ continues to grow with centrality.

- When the jet quenching is off in the model, the anisotropy $v_2^{RP} = 0$ at high p_T .
- The cumulant method $v_2\{4\}$ gives non-zero anisotropy which grows with centrality.
- This points to the presence of azimuthal correlation at high p_T. This is correlation of hadrons with respect to jet axis.
- There are more jet pairs (with random axes) in more central collisions, hence azimuthal distribution of high p_T hadrons is more isotropic.

Conclusions

- It is shown that for high p_T the cumulnat method of elliptic flow calculation $v_2\{4\}$ is sensitive both to anisotropy with respect to global reaction plane and anisotropy with respect to jet axis.
- For centralities < 40% $v_2\{4\}$ is sensitive mainly to anisotropy with respect to global reaction plane.
- For centralities >40% the contribution of anisotropy with respect to jet axis into $v_2\{4\}$ begins substantial.
- The combination of two contributions into $v_2\{4\}$ may describe the correlation between $v_2(hight\text{-}p_T)$ *and* $v_2(low\ p_T)$ at all centralities.

Thank you!