Hydrodynamical evolution with energy and momentum feeding during the fireball expansion

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1. HYDRODYNAMIC MODEL

We present 3+1D event by event ideal hydrodynamic simulation with implemented influence of hard partons as source terms. Four-momentum conservation formula with hard partons' source term is following

$$\partial_\mu T^{\mu\nu} = S^\nu$$

Energy-momentum deposited in medium by hard partons is parametrized[1] and scaled by entropy density ratio *s/s*(0).

$$S^\nu = \int_{\tau_i}^{\tau_f} d\tau \frac{dM^\nu}{d\tau} \delta^{(4)}[x^\mu - x^\mu_{jet}(\tau)] \frac{s(x^\mu)}{s_{ref}}$$

The momentum is generated according to the calculated distributions of the produced hard partons in transverse momentum and rapidity. For rapidity distributions at the LHC we assume that it is uniform in the central two units of rapidity. Transverse momentum spectra have been calculated and the differential cross section for gluon production in nucleus–nucleus collision was parametrized as [2]

$$E\frac{d\sigma_{NN}}{dp^3} = \frac{1}{2\pi}\frac{1}{p_t}\frac{d\sigma_{NN}}{dp_t dy} = \frac{B}{(1+p_t/p_0)^n}$$

where p_0, B and n are parameters. For a simulation at LHC energies we choose B = 14.7 mbarn/GeV^2 , p_0 = 6 GeV, and n = 9.5. The cross section for the production of the leading particle with p_t larger than p_m is then obtained by integrating equation

$$\sigma(p_m) = \int_{p_m}^{\infty}\int_{y_{\min}}^{y_{\max}} \frac{d\sigma_{NN}}{dp_t dy} dp_t dy$$

The mean total number of leading particles with $p_t > p_m$ is then

$$N_j(p_m, b) = \frac{A^2 T_{AA}(b)\sigma(p_m)}{1-(1-T_{AA}(b)\sigma(p_m))^{A^2}}$$

In the last equation we introduced the overlap function

$$T_{AA}(b) = \int_{overlap} T_A(r) T_A(r-b) d^2 r$$

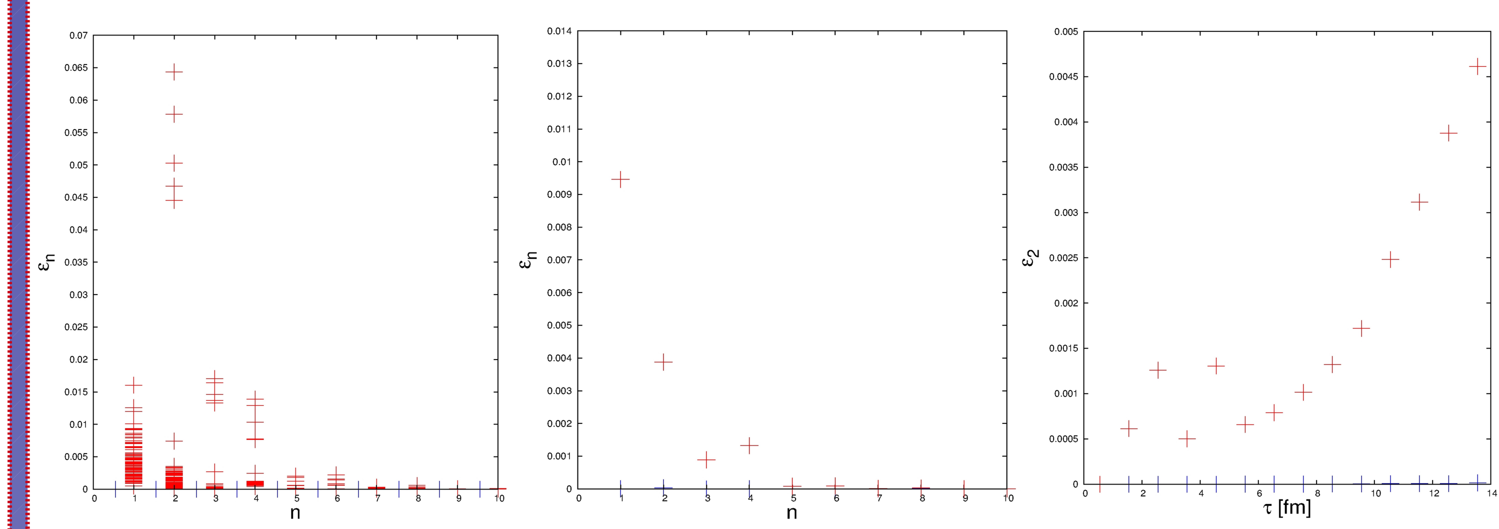
The initial positions of hard partons are distributed according to the density of binary nucleon–nucleon collisions:

$$\rho_b(r) = T_A(r) T_B(r-b)$$

Thus, it is more likely to produce a leading parton at the centre of the overlapping zone than at its edges.

2. FLUCTUATIONS

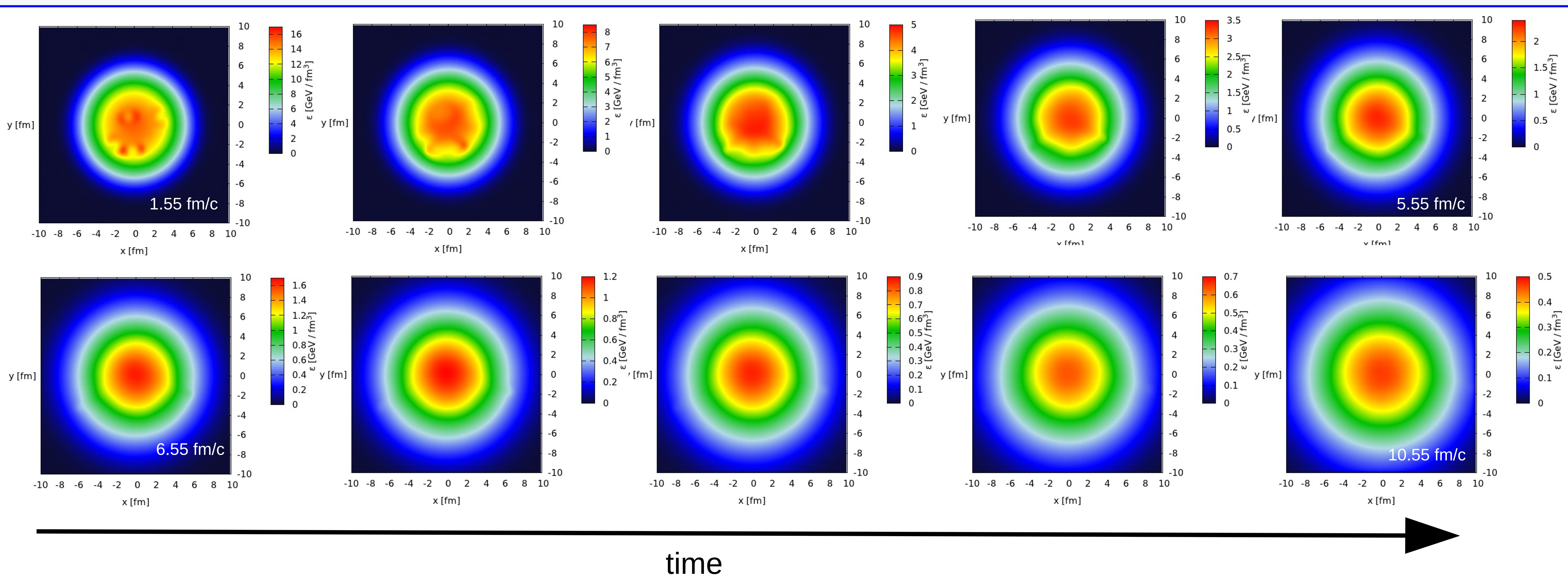
For description of fluctuations induced by hard partons we have implemented 2D Fourier transform of the transverse energy density and expanded it in harmonics and powers of k[4]. Each event is characterized by different set of harmonic eccentricity coefficients ε_n. These coefficients change their values during the hydrodynamic evolution with evolving jets.



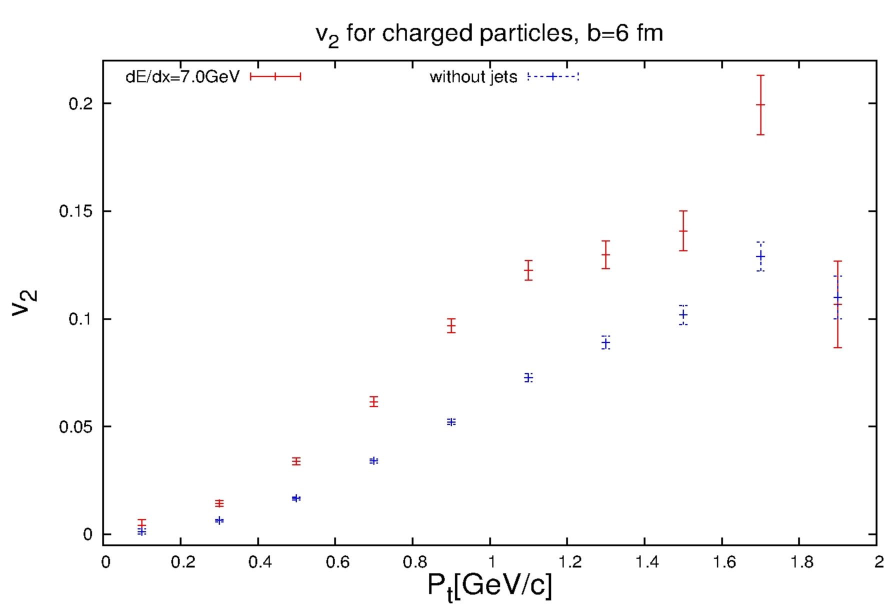
Fluctuations of energy density close to the end of hydrodynamic evolution:
Left: Fluctuations of ε_n in sample of 100 events, blue crosses: events without jets, red crosses: simulation with hard partons
Center: Average values ε_n of in sample of 100 events, blue crosses: events without jets, red crosses: simulation with hard partons
Right: time evolution of ε_2 averaged over sample of 100 events
We show these coeficients for central collisions.

3. RESULTS

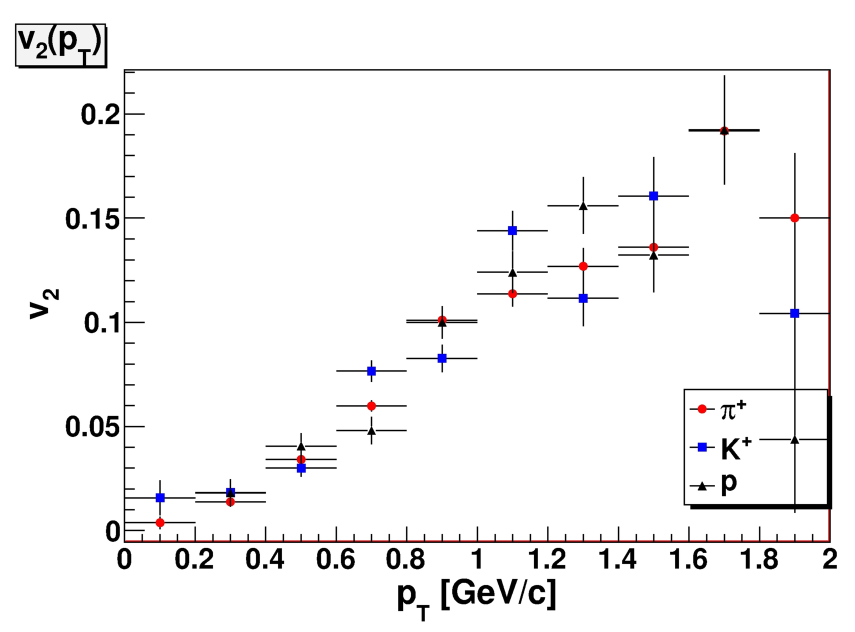
Example of one typical MC central event at LHC, energy density transverse slices shown are for rapidity η=0. First profile is taken after time *t* = 1.55 fm/c. Each other profile is taken after time *Δt* =1.0 fm/c from previous profile. Initial conditions were calculated using optical Glauber model. Equation of state was taken from [5]. Initial energy density *ε* was set to *ε*(0,0,0) = 60.0 GeV.



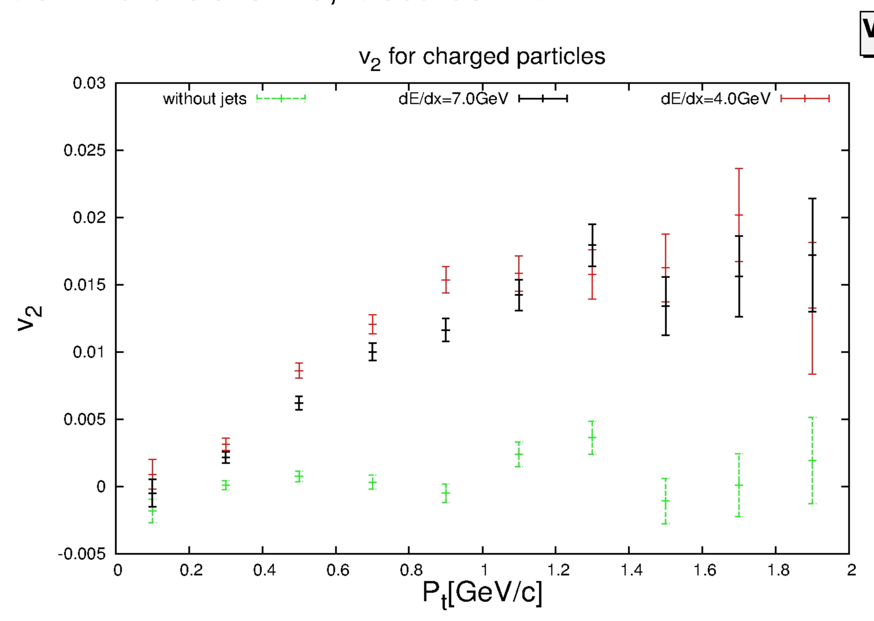
Possible influence of streams which are left behind penetrating hard partons was firstly proposed in [2]. As shown below streams induced by jets contribute to elliptic flow generation. Spectra and elliptic flow coefficient were calculated using a MC event generator THERMINATOR[6]. dE/dx was set to 4.0 GeV/fm at ε = 19.0 GeV/fm3; it scales with T^3.



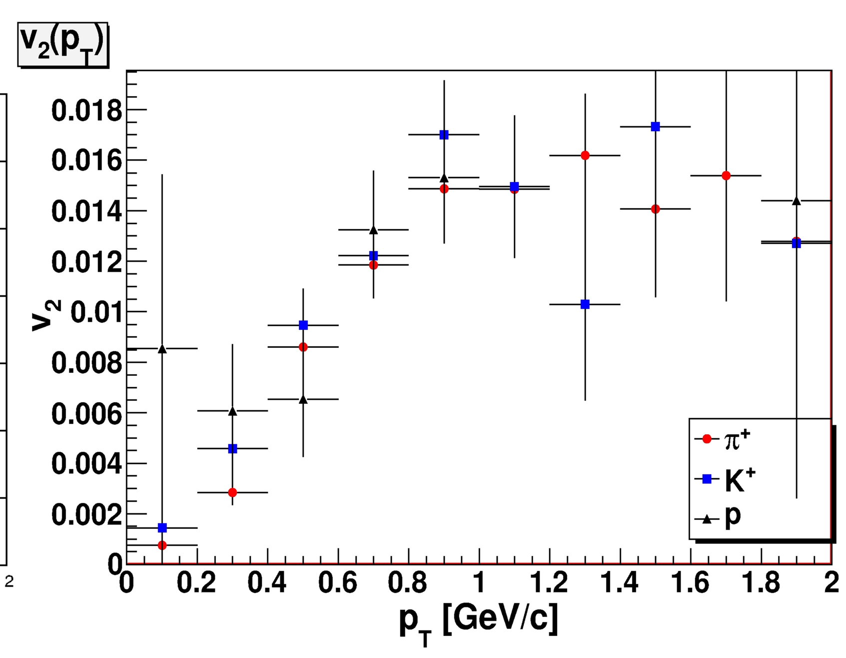
v_2 non-cenral collisions comparison from 300 artificial THERMINATOR[6] events. Impact parameter *b* = 6 fm.



v_2 of charged particles for non-central collisions from 300 artificial THERMINATOR[6] events. Impact parameter *b* = 6 fm.



v_2 comparison from 300 artificial THERMINATOR[6] events.



v_2 of charged particles from 300 artificial THERMINATOR[6] events.

4. CONCLUSIONS

- ✔ Fluctuations induced by jets survive until the end of hydrodynamic simulation.
- ✔ Jets influence does contribute to elliptic flow generation on the level up to 0.04.
- ✔ Elliptic flow is generated in direction of reaction plane, it is related with geometry.
- ✔ Hydrodynamic simulation confirms the scenario by Tomášik and Lévai [2].

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