Hydrodynamical evolution and hadronization in heavy ion collisions and pp scatterings

Klaus Werner <werner@subatech.in2p3.fr>

in collaboration with

Iu. Karpenko, T. Pierog, M. Bleicher, K. Mikhailov

Important topics concerning the hydrodynamic evolution:

initial conditions here obtained from a flux tube approach (EPOS), compatible with the string model used since many years (e^+e^-, pp), and the color glass condensate picture;

event-by-event procedure, taking into the account the highly irregular space structure of single events, leading to so-called ridge structures in two-particle correlations;

core-corona separation, considering the fact that only a part of the matter thermalizes;

3+1 D hydro evolution, including the conservation of baryon number, strangeness, and electric charge;

parton-hadron transition

- * realistic equation-of-state,
  compatible with lattice gauge results,
- * with a cross-over transition from the hadronic to the plasma phase;

hadronization,

- * here: Cooper-Frye, using complete hadron table,
- * at an early stage (166 MeV, in the transition region),
- * with subsequent hadronic cascade procedure (UrQMD)

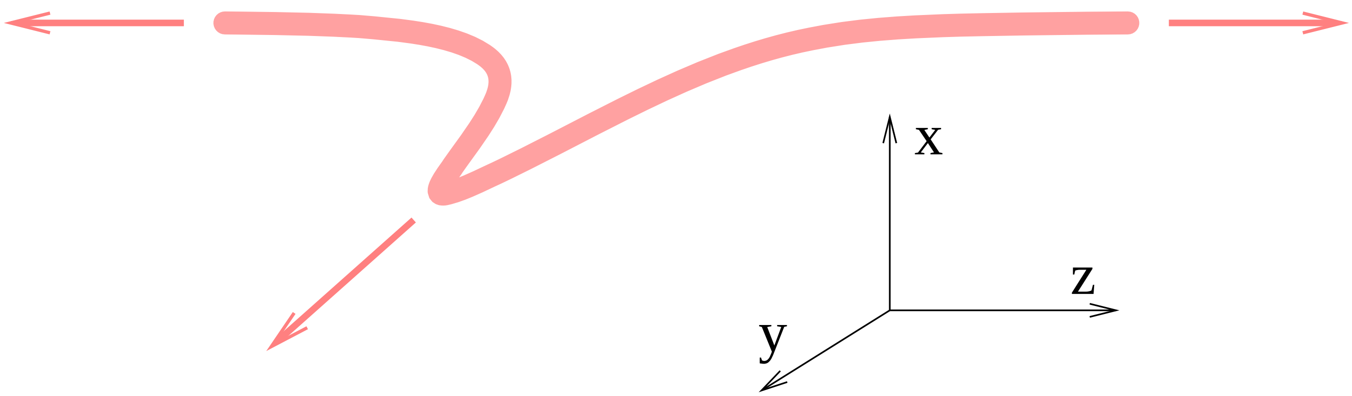
=> **EPOS 2**

details see: http://arxiv.org/abs/1004.0805

Parton ladder -> flux tube -> kinky string:

mainly longitudinal object (here parallel to the z-axis)

but due to the kinks there are string pieces moving transversely
(in y-direction in the picture).

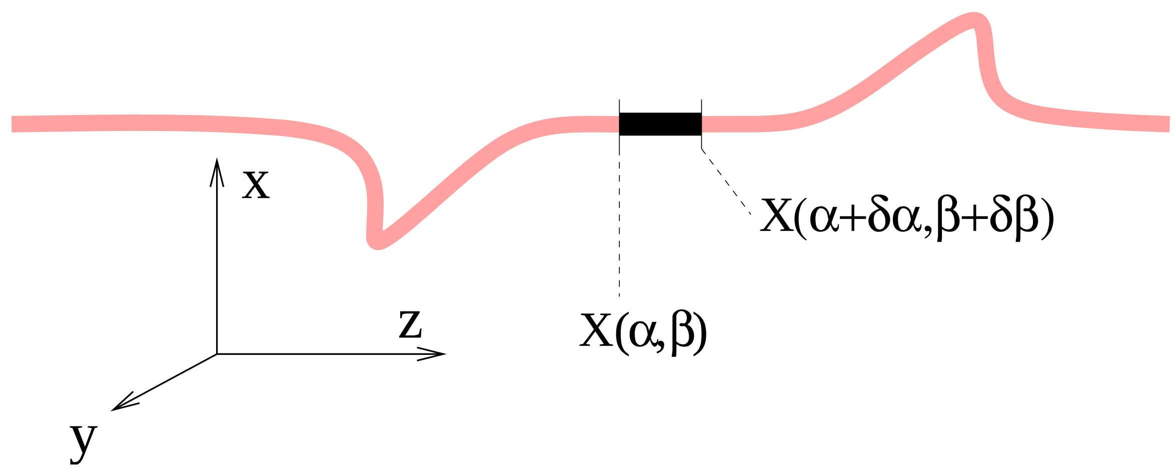


But despite these kinks, most of the string carries only little transverse momentum!

Heavy ion collisions or very high energy proton-proton scattering:

the usual procedure has to be modified,
since the density of strings will be so high
that they cannot possibly decay independently

We split each string into a sequence of string segments, corresponding to widths $\delta\alpha$ and $\delta\beta$ in the string parameter space



For core part, $T^{\mu\nu}$ and the flavor flow at initial proper time $\tau = \tau_0$:

$$T^{\mu\nu}(x) = \sum_i \frac{\delta p_i^\mu \delta p_i^\nu}{\delta p_i^0} g(x - x_i), \quad \delta p = \left\{ \frac{\partial X(\alpha,\beta)}{\partial \beta} \delta\alpha + \frac{\partial X(\alpha,\beta)}{\partial \alpha} \delta\beta \right\}$$

$$N_q^\mu(x) = \sum_i \frac{\delta p_i^\mu}{\delta p_i^0} q_i \, g(x - x_i), \quad q \in \{u, d, s\}$$

Evolution according to the equations of ideal hydrodynamics:

$$\partial_\mu T^{\mu\nu} = 0, \quad \text{using } T^{\mu\nu} = (\epsilon + p)\, u^\mu u^\nu - p\, g^{\mu\nu}$$

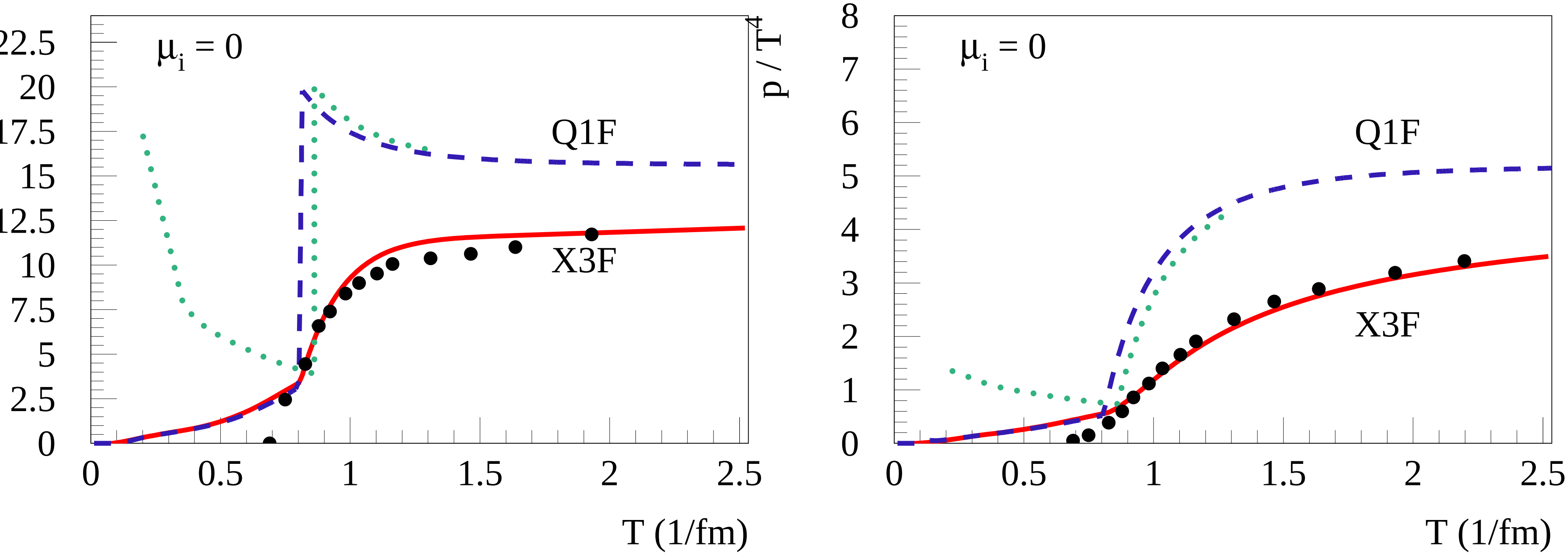
$$\partial N_k^\mu = 0, \quad N_k^\mu = n_k u^\mu,$$

with $k = B$, S, Q referring to respectively baryon number, strangeness, and electric charge. $\rightarrow$ **Iu. Karpenko**

EoS X3F:

$$p = p_Q + \left\{ \exp\left(-\frac{T - T_c}{\delta} \right) \Theta(T - T_c) + \Theta(T_c - T) \right\} (p_H - p_Q),$$

$$S = \frac{\partial p}{\partial T},\ n^i = \frac{\partial p}{\partial \mu^i},\ \varepsilon = TS + \sum_i \mu^i n^i - p,$$



The symbol X3F stands for “cross-over” and “3 flavor conservation”
Q1F: simple first order equation-of-state, with B conservation
dotted lines: EoS used by Hirano et al

- **Check basic “soft physics” RHIC data** (http://arxiv.org/abs/1004.0805)

  - **Particle yields and eta distributions**

    * STAR and PHENIX
      average yields and mean pt of pions, kaons, protons, lambdas, xis vs centrality
    * BRAHMS
      eta distr for different centralities 0-5% 5-10% 10-20% 20-30% 30-40% 40-50%
      rapidity distr of pions, kaons, protons(central)
      mean pt vs rapidity of pions, kaons (central)

  - **pt spectra**

    * PHOBOS: pt distributions of charged particles at centralities 0-6%, 6-15%, ..., 45-50%
    * BRAHMS: pt distributions of pions, kaons, protons at given rapidity (central)
    * PHENIX: pt distributions of pions, kaons, protons for different centralities:
      0-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-92%
    * STAR: mt distributions of pions, kaons, protons for different centralities
      0-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80 %
    * STAR pt distributions of strange baryons for different centralities:
      0-5%, 10-20%, 20-40%, 40-60%, 60-80%

  - **v2:**

    * PHOBOS: v2 vs eta for different centralities: MB, 3-15, 15-25, 25-50, 0-40
      v2 vs centrality v2 vs pt of charged particles, 0-50
    * STAR v2 vs pt of pi, K, prt for different centralities
      MB, 0-5, 20-30, 40-50; Λ and K_s 10-40, 40-80
    * PHENIX v2 vs pt of π, K, p for 0-60, 20-60

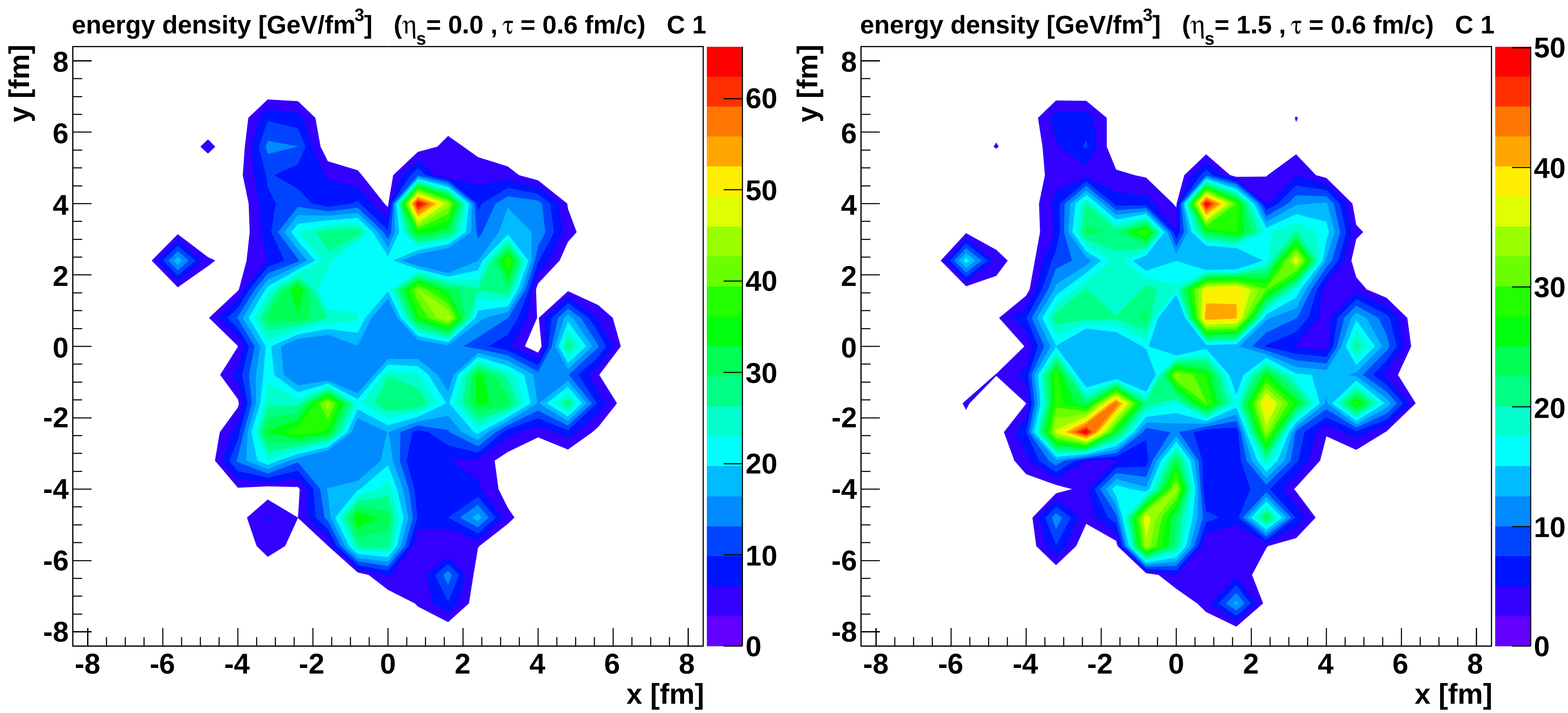
=> early hadronization (166 MeV), subsequent hadronic cascade

=> confirmed from BEC studies (HBT radii)

Interesting EbE features:

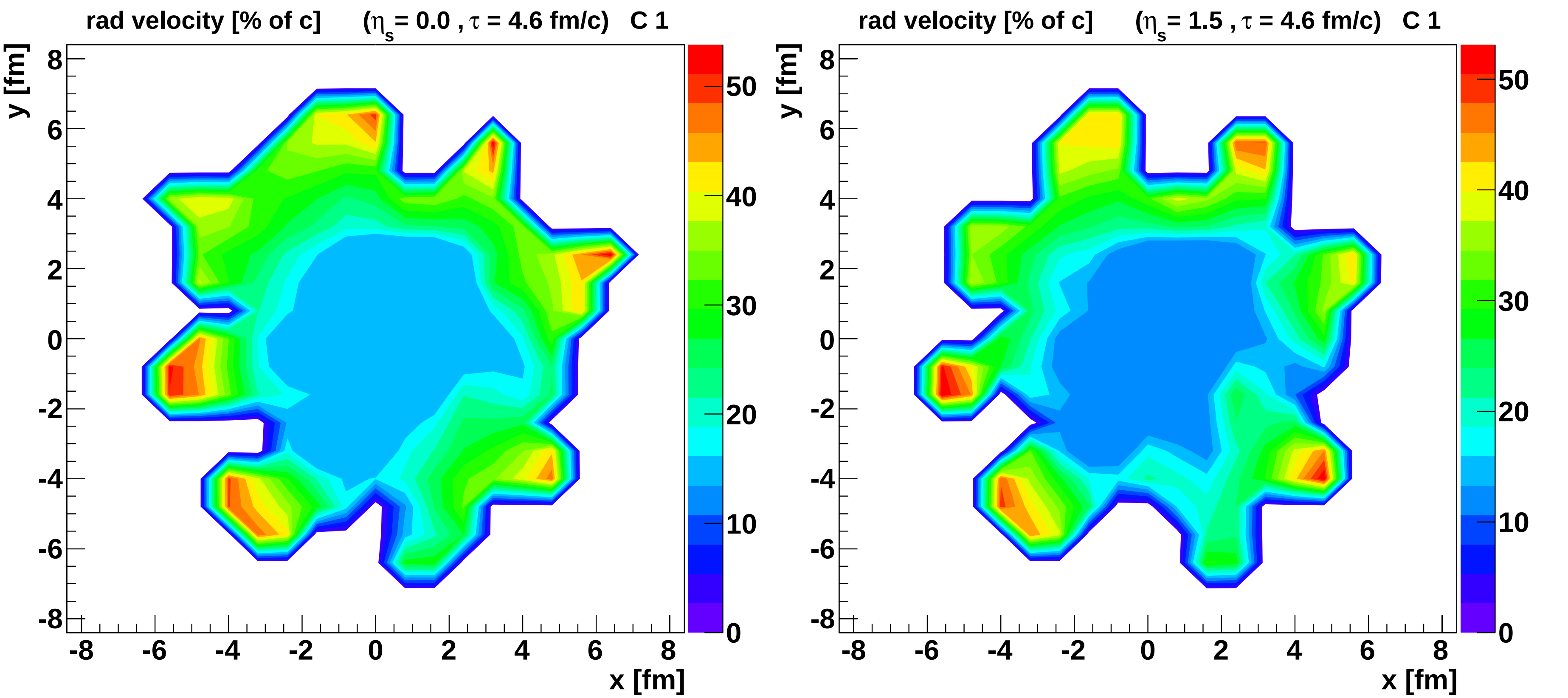
Bumpy structure of energy density in transverse plane,

but **translational invariance**



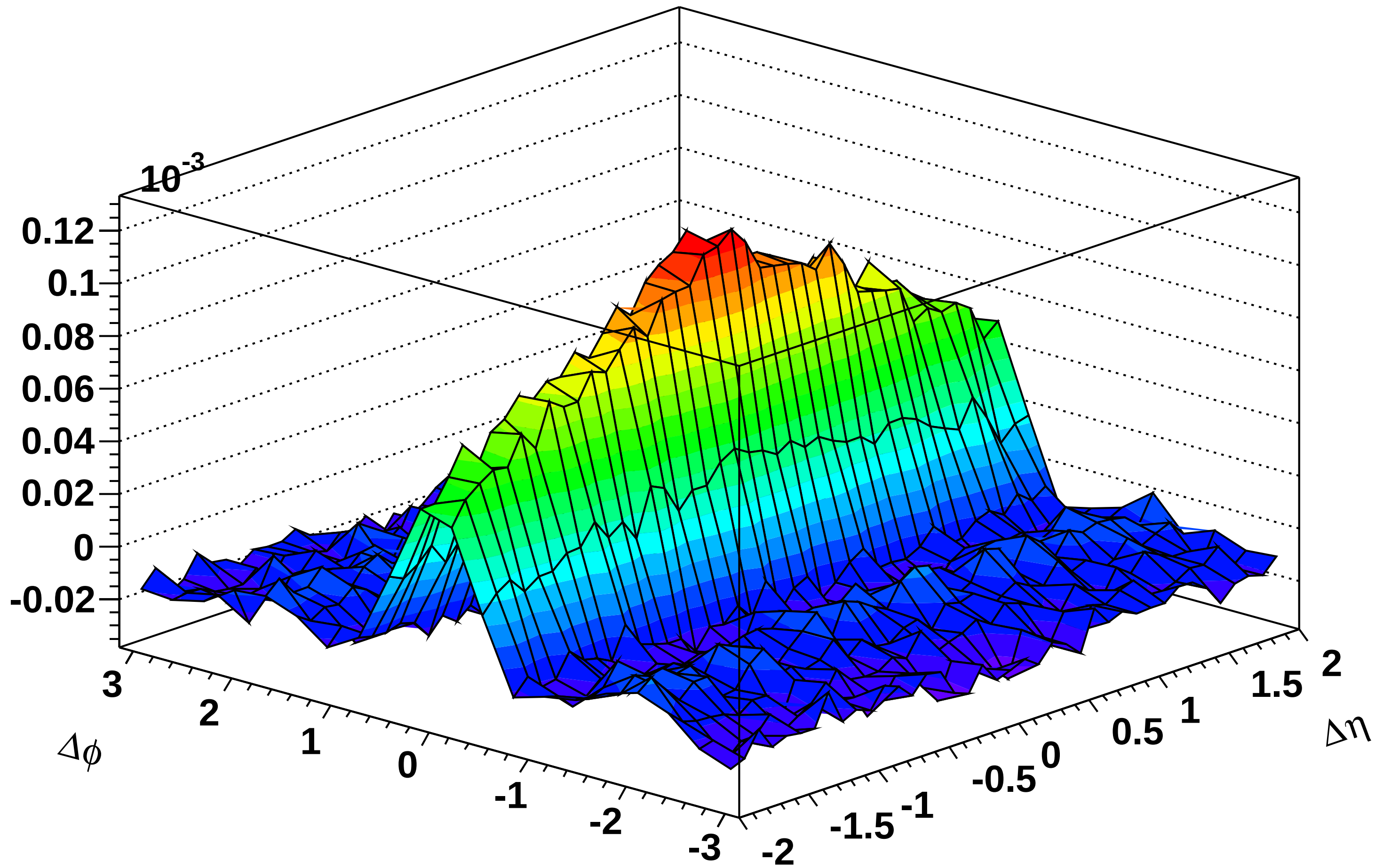
more plots: http://arxiv.org/abs/1004.0805

Leads to **translational invariance of transverse flows**



give the same collective push
to particles produced at different values of η_s
at the same azimuthal angle

=> ridge-structure in the dihadron correlation $dN/d\Delta\eta\, d\Delta\phi$ **for free**

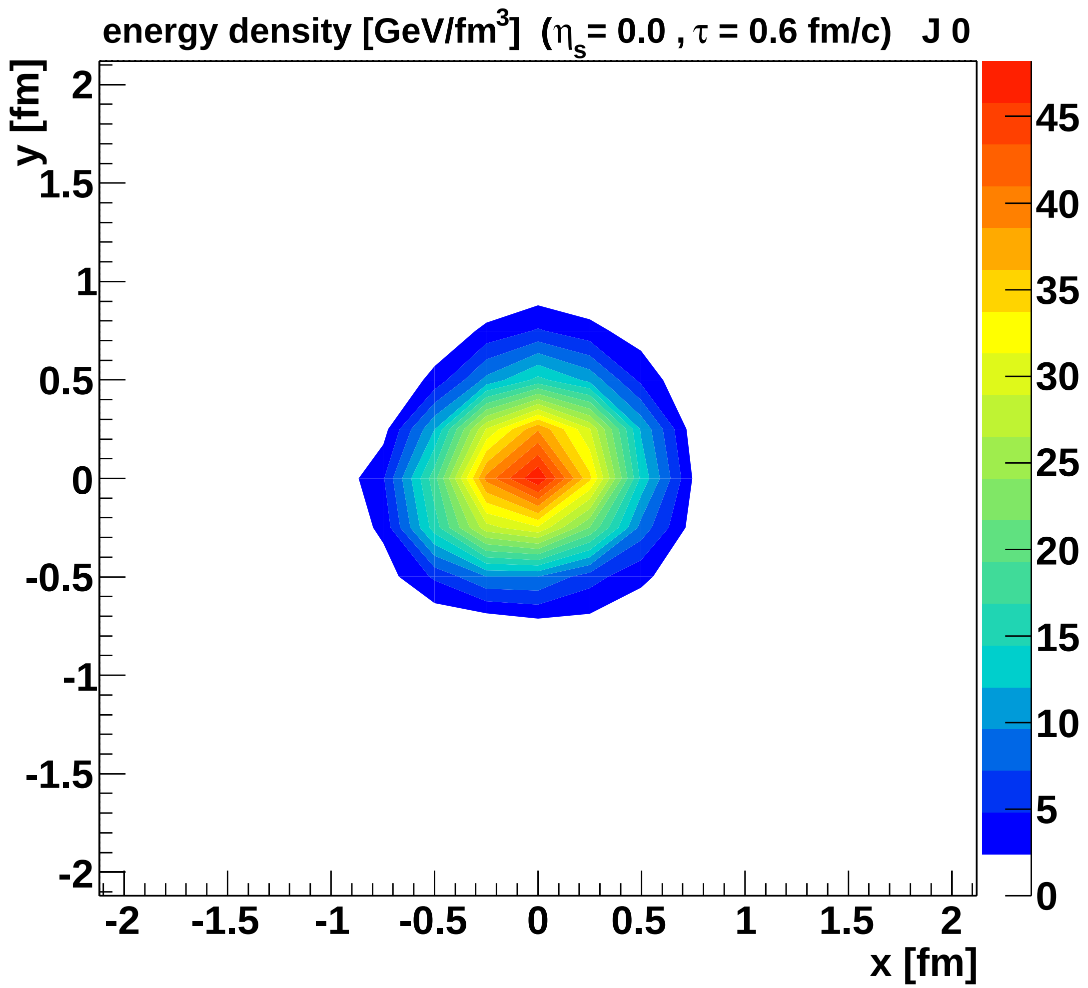


trigger particles with transverse momenta between 3 and 4 GeV/c,
assoc particles with transverse momenta between 2 GeV/c and p_t of the trigger,
in central Au-Au collisions at 200 GeV

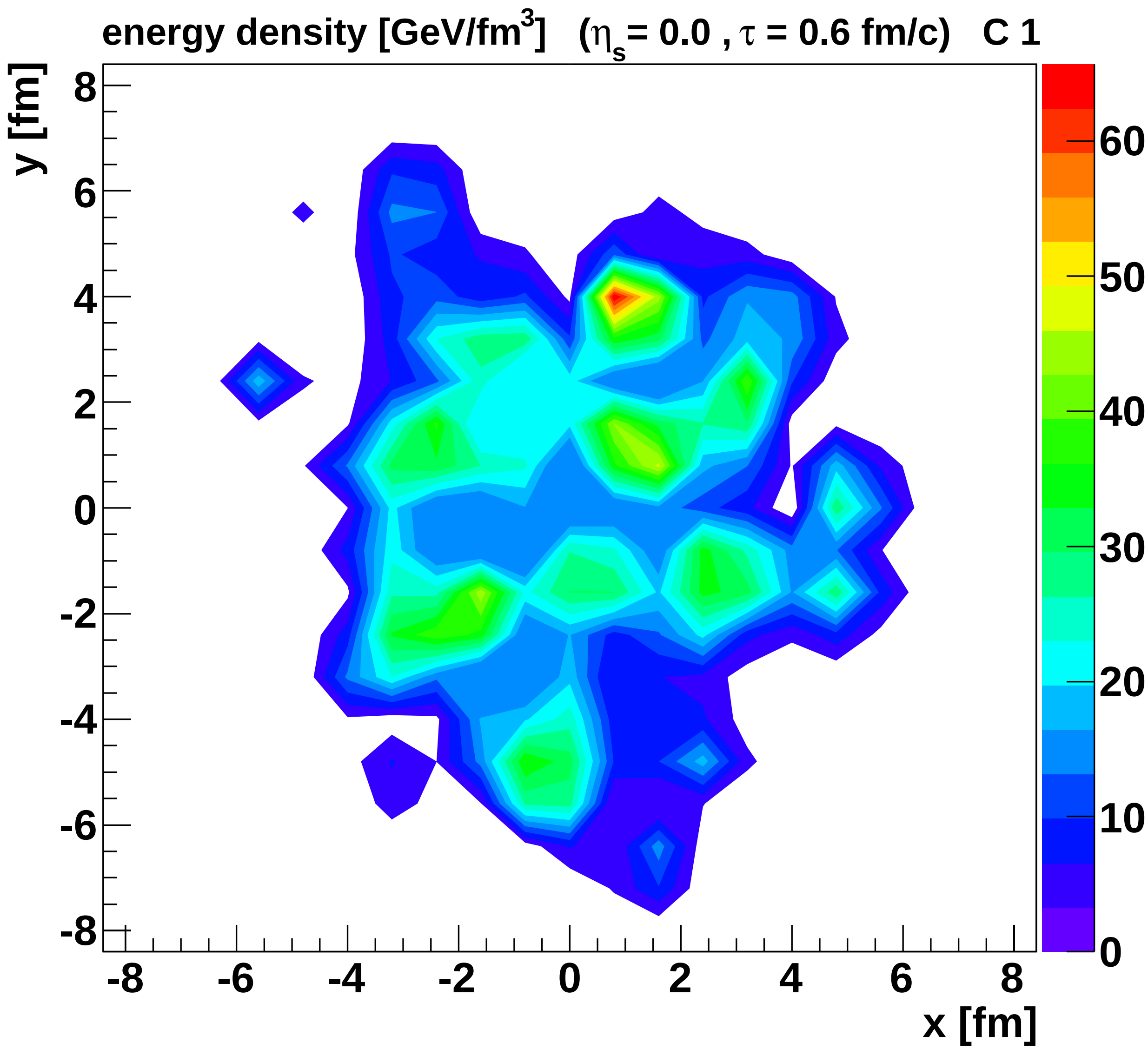
pp@LHC

high multiplicity pp **at 900 GeV** $(dn/d\eta(0) = 12.9)$

multiple scattering → many flux tubes → high densities



$AuAu$ at 200 GeV, central event

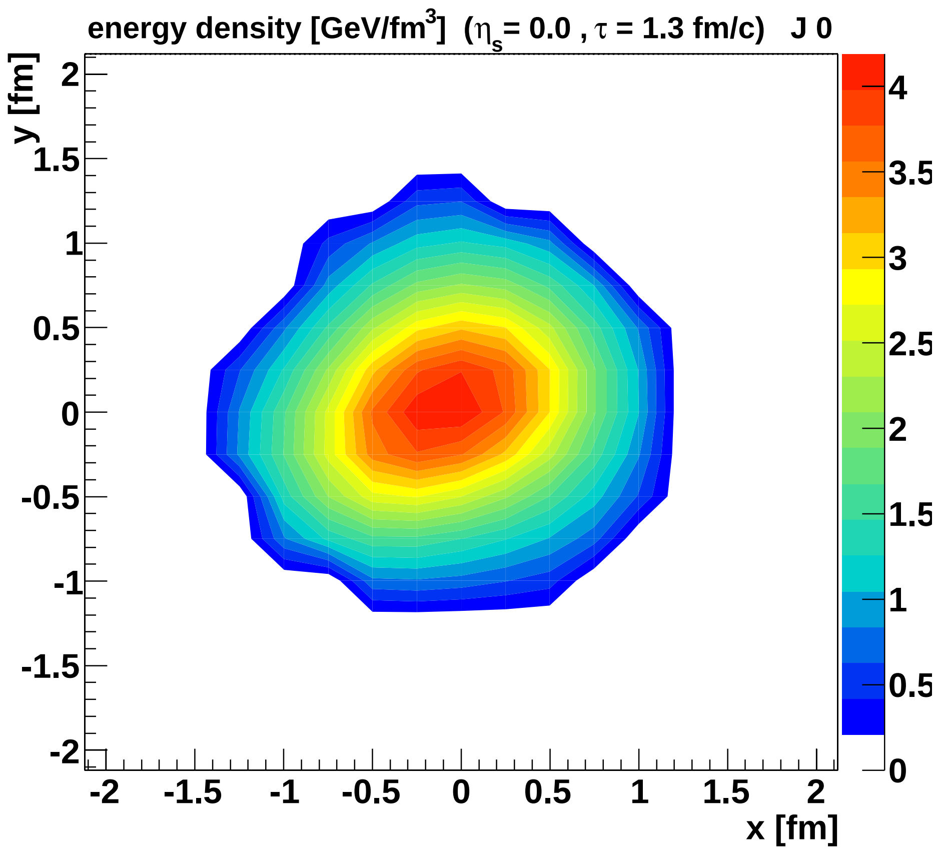


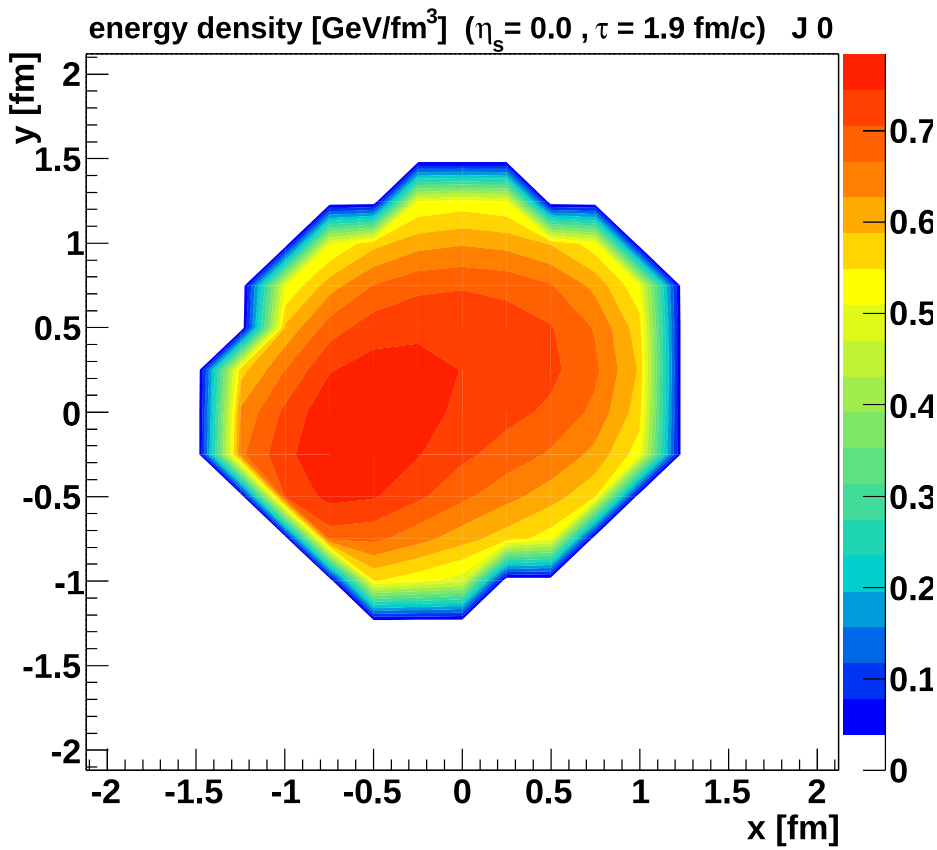
Size of the fluctuations in AuAu small, similar to sizes in pp@LHC

If hydro is applicable for AuAu@RHIC, it should be so for pp@LHC ...

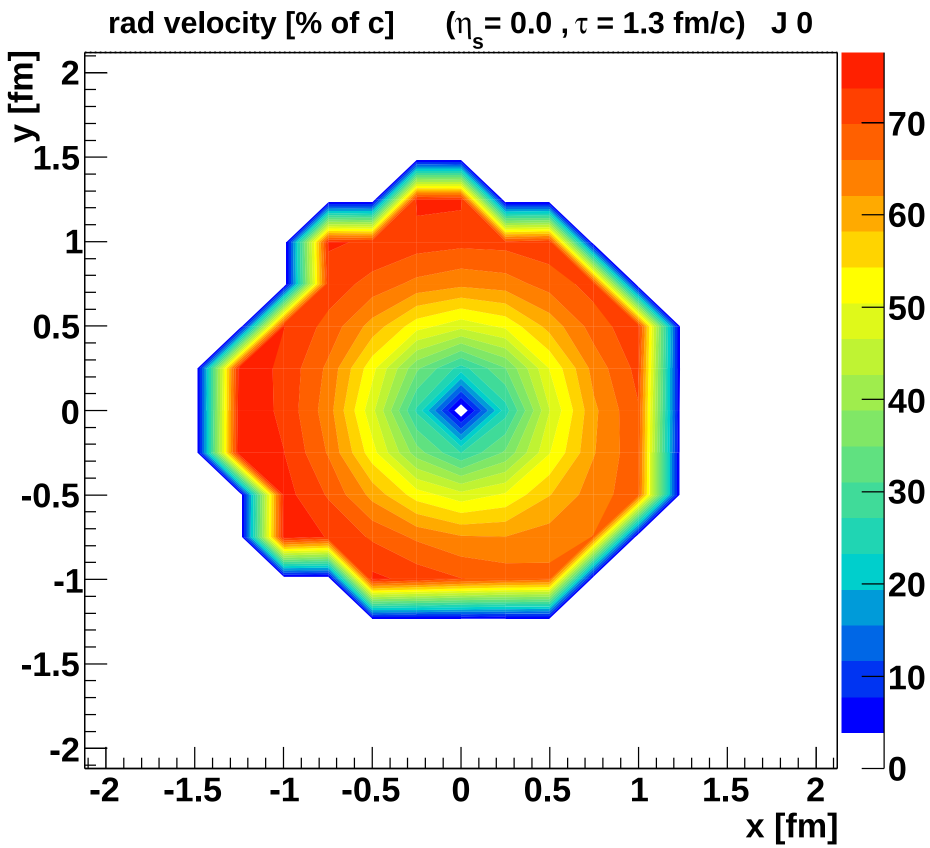
so:
let's do hydro for pp

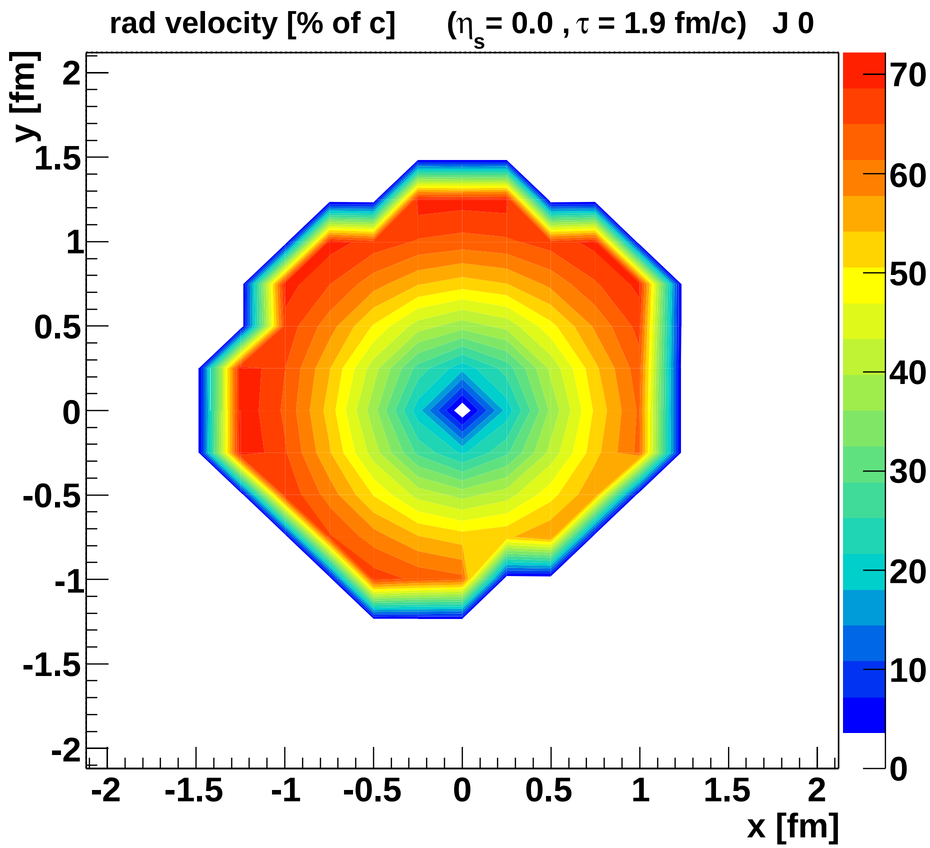
Time evolution of the energy density





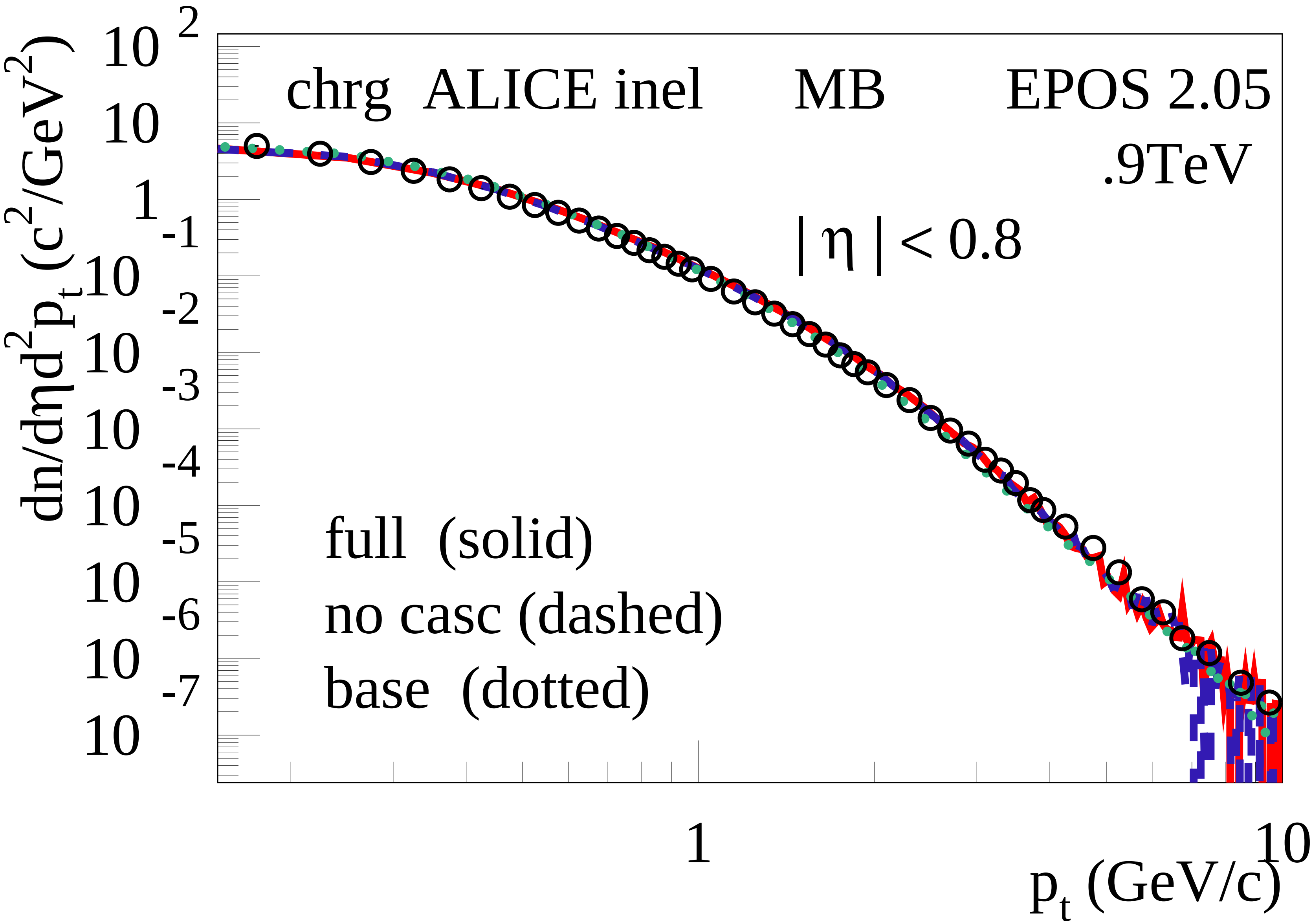
Time evolution of the radial flow



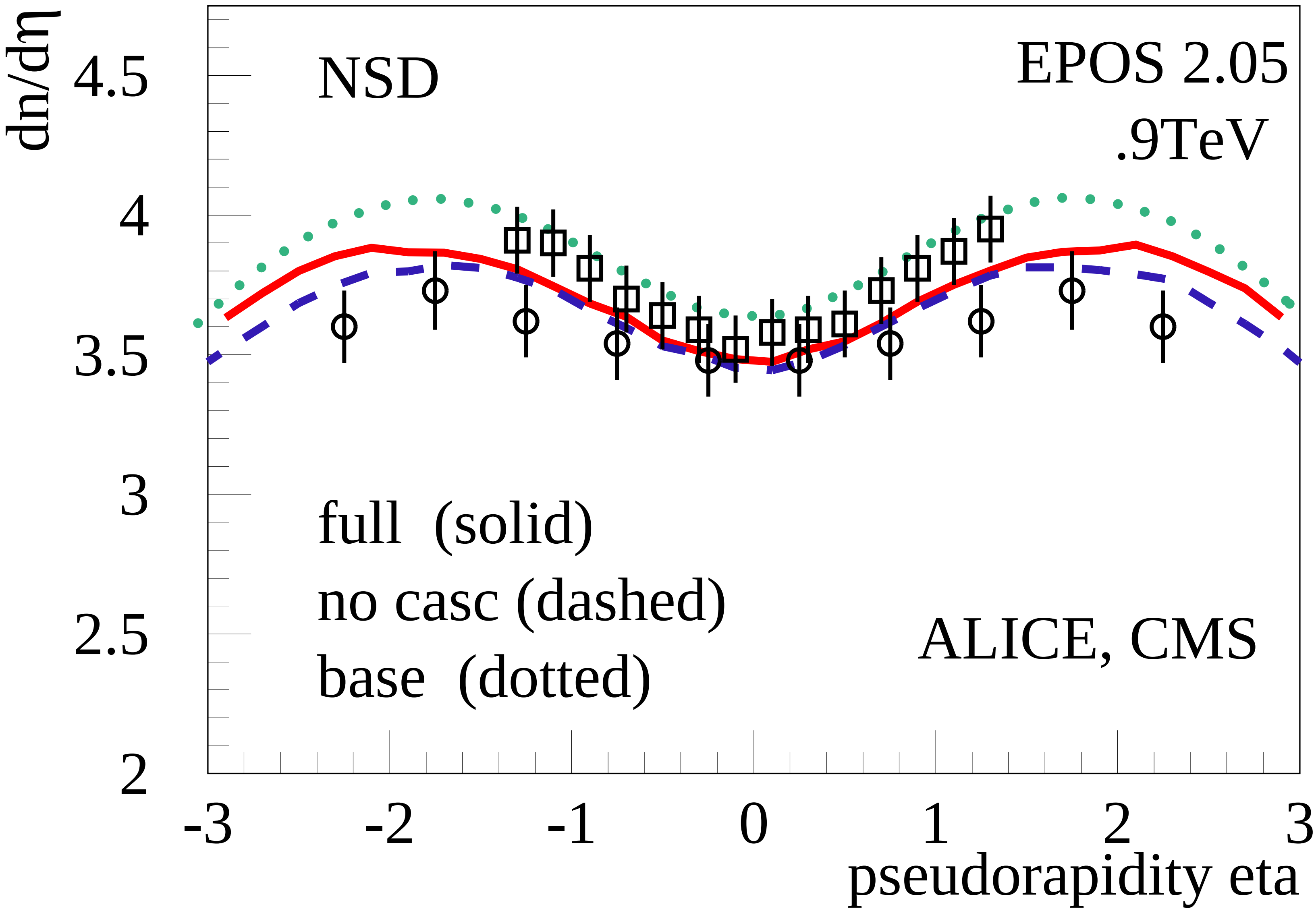


visible consequences ?

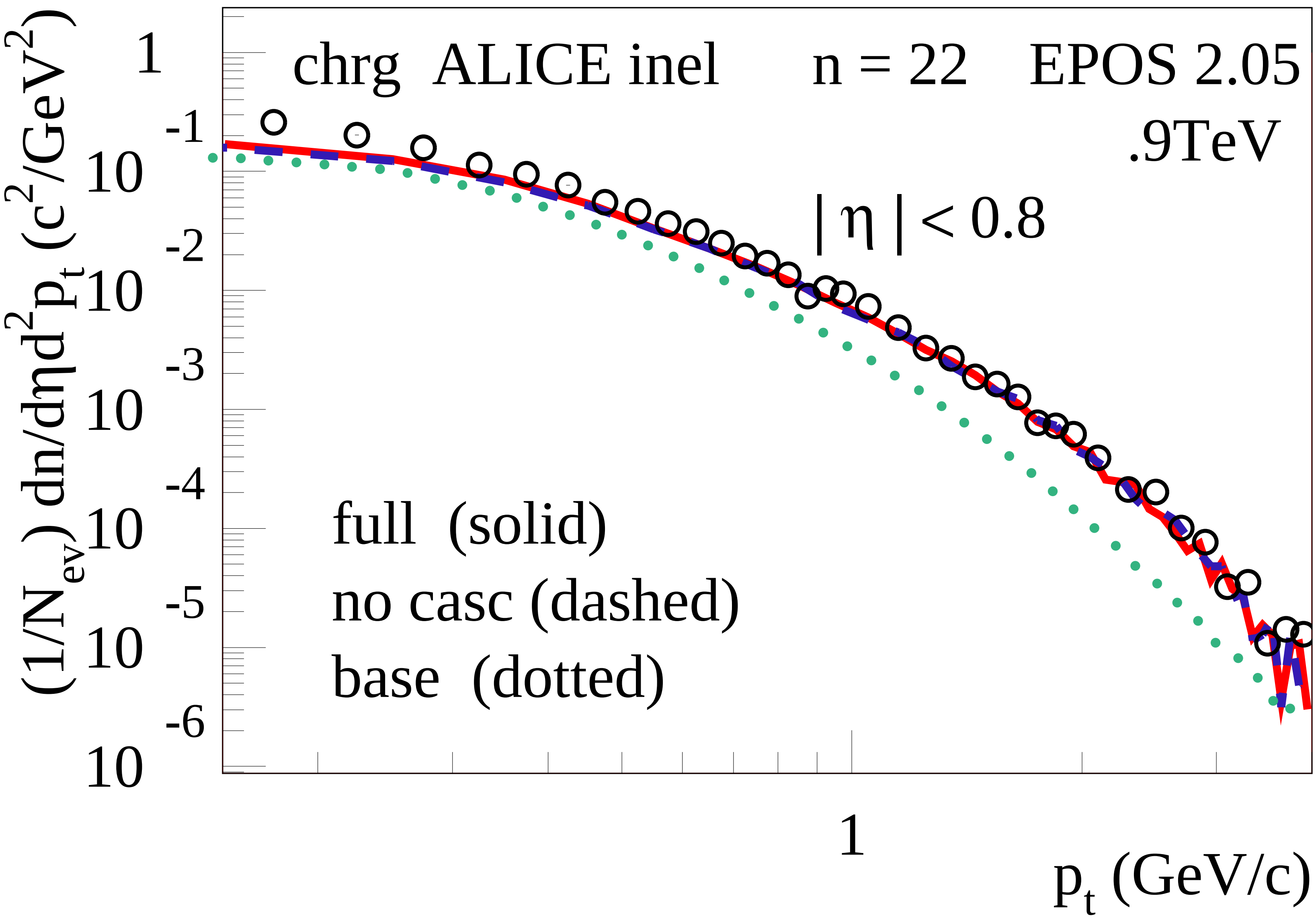
Little effect in MB charged ptl pt distributions



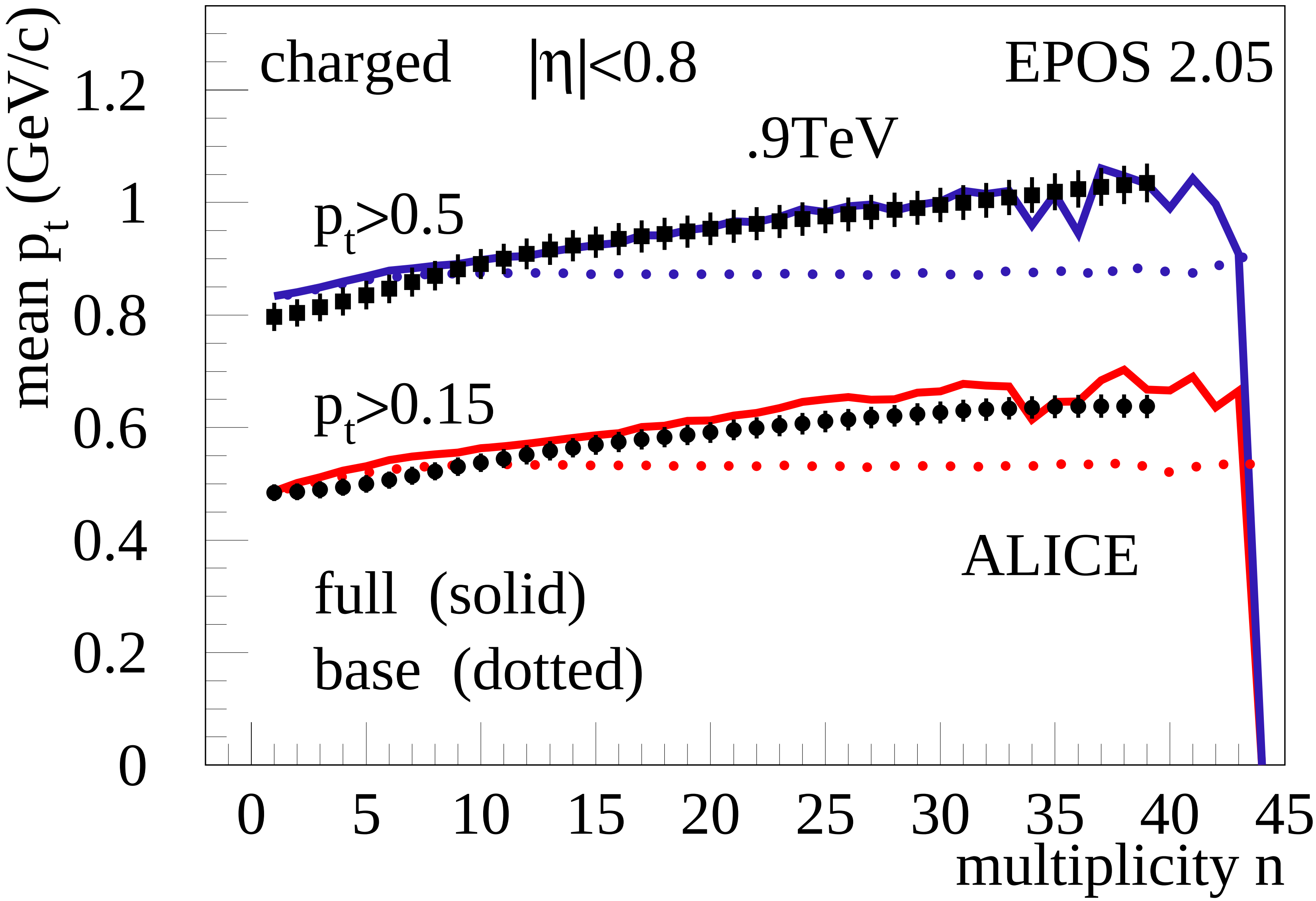
but visible...


dn/dη
4.5
4
3.5
3
2.5
2
-3
-2
-1
0
1
2
3
pseudorapidity eta
NSD
EPOS 2.05
.9TeV
full (solid)
no casc (dashed)
base (dotted)
ALICE, CMS

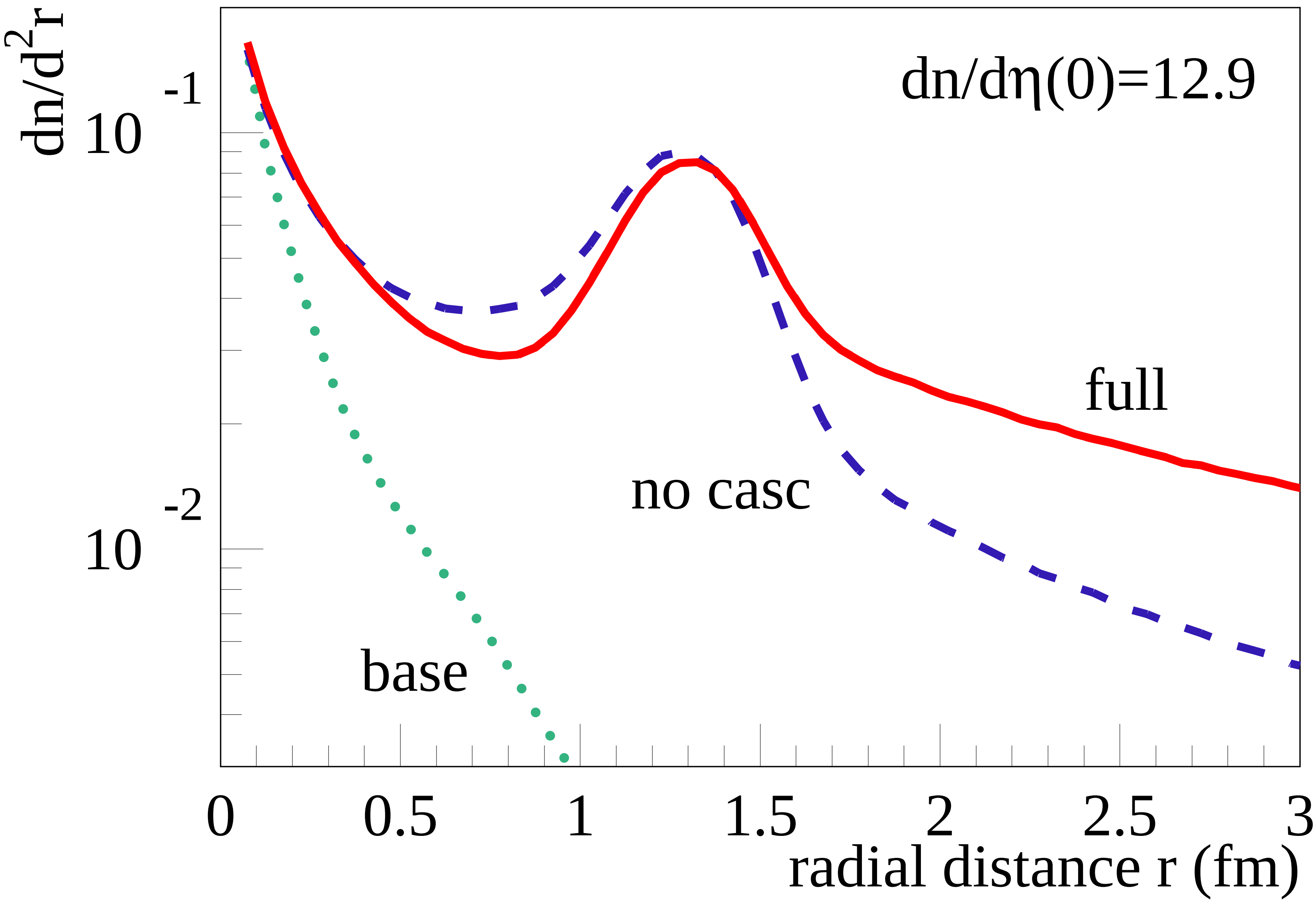
Pt distribution for high multiplicity events



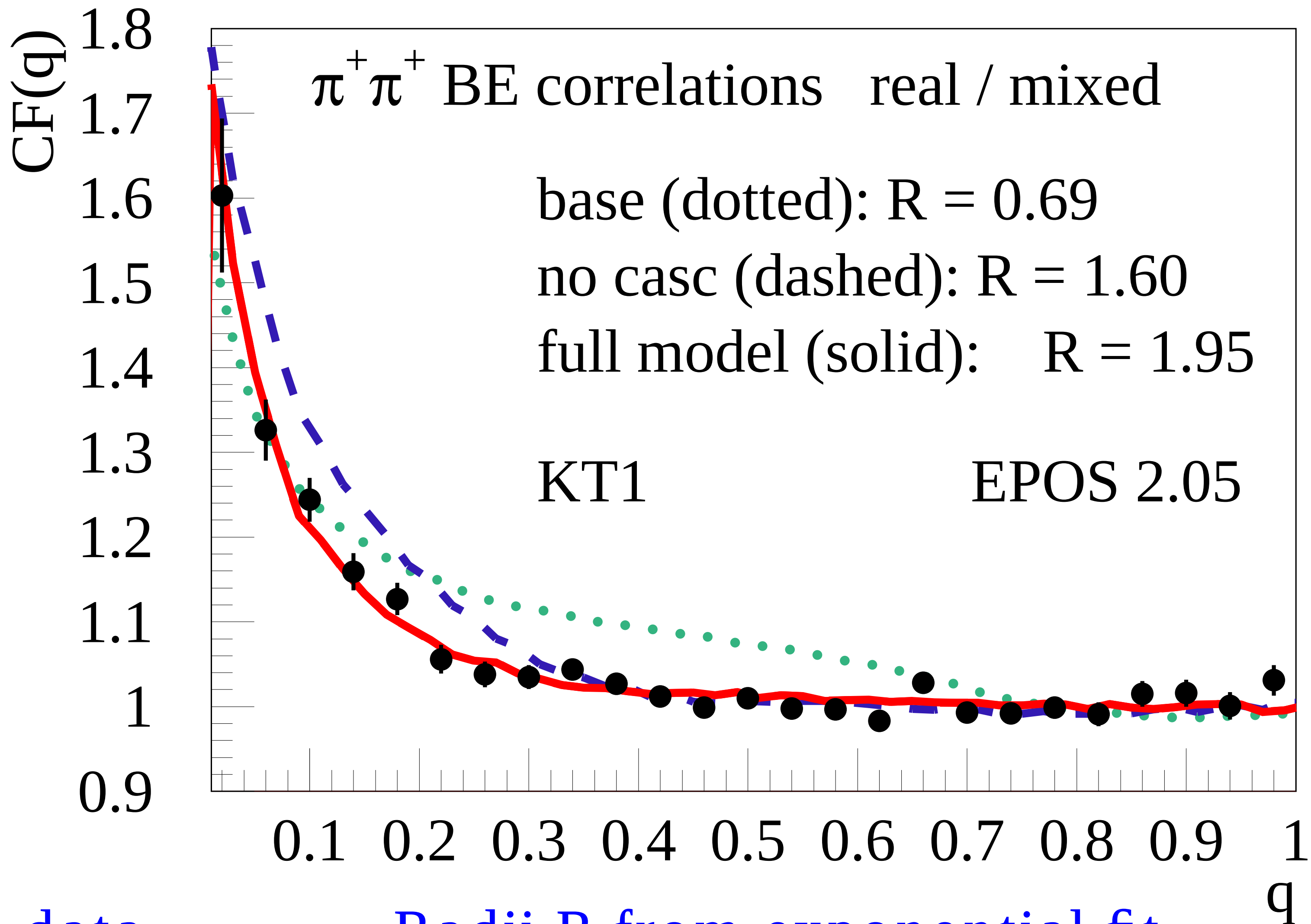
summarized in <pt> versus multiplicity



Space-time structure strongly affected



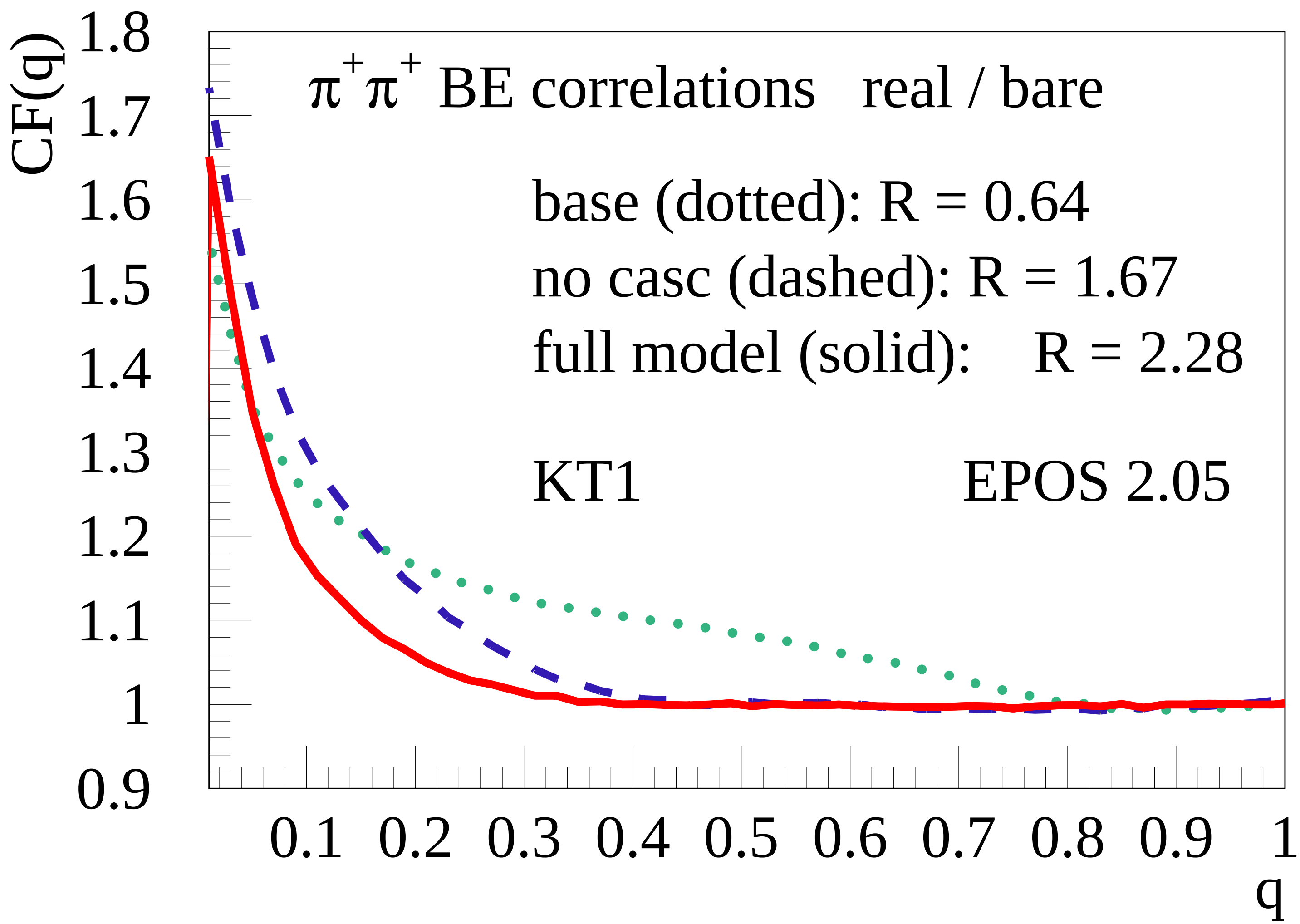
Consequences for Bose-Einstein correlations



ALICE data. Radii R from exponential fit.

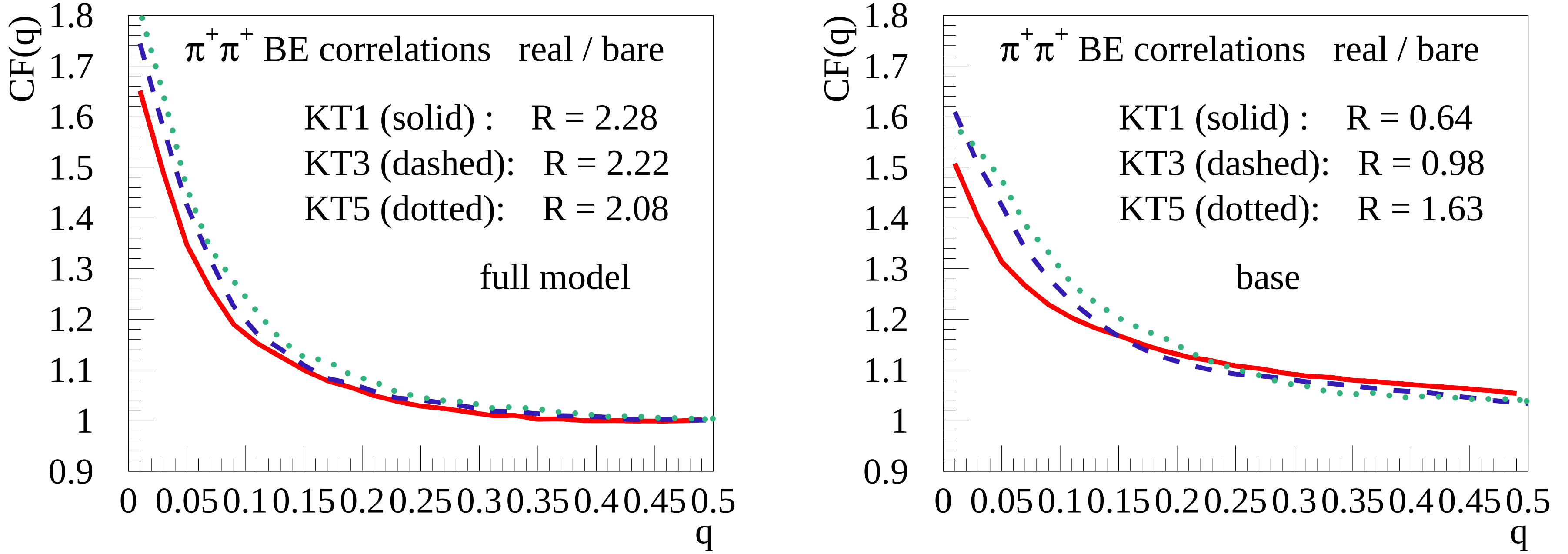
$\mathrm{KT1} = [100, 250]$, $\mathrm{KT3} = [400, 550]$, $\mathrm{KT5} = [700, 1000]$

Better: normalize via “bare” case (simulation without BE)



flat for large q

kT dependence (pair transv momentum)



full case: Little kT dependence, base model: increasing radii

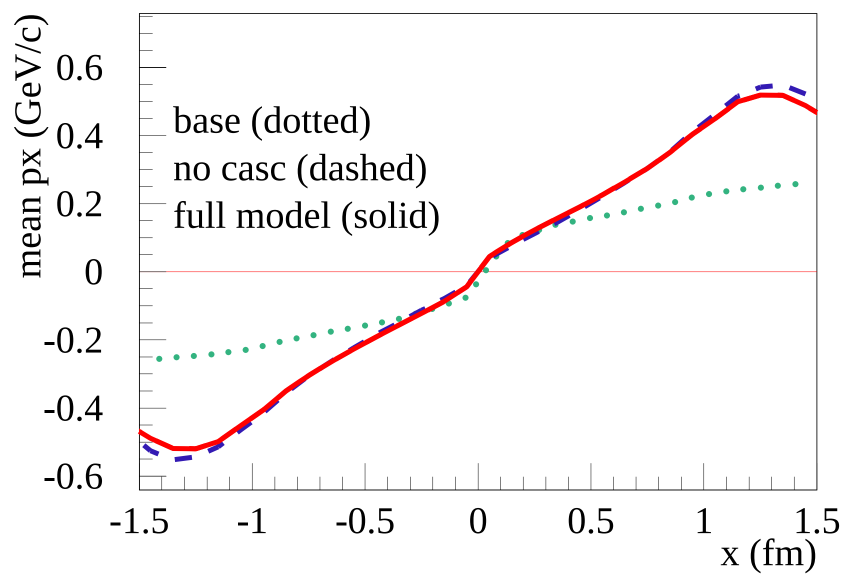
because the distribution of formation positions is broader for high p_t particles (high p_t resonances live longer)

Effect is in principle also present in AuAu scattering, but much more visible for the small pp system.

In pp two competing effects:

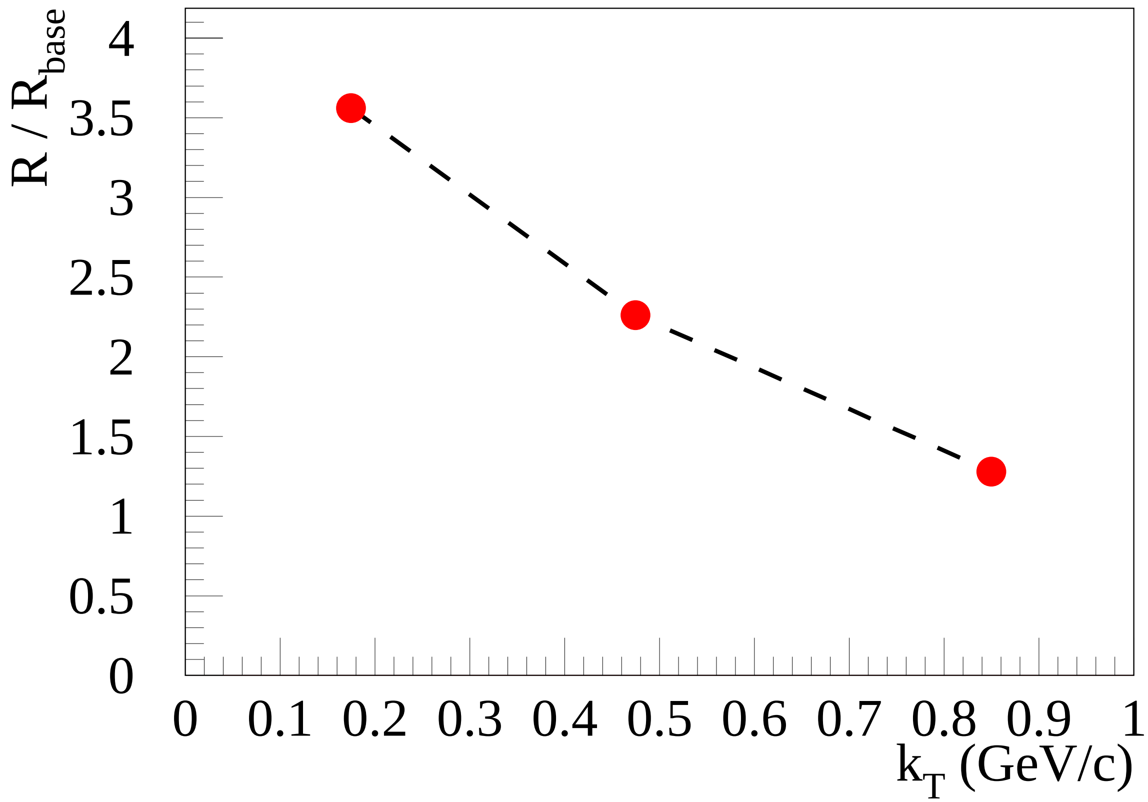
- radii increase with k_T, due to the bigger size of the source of the high p_t particles compared to the low p_t ones,
- radii decrease with k_T, as in AuAu, due to the p-x correlation.

$p - x$ correlation exists indeed for the case of hydrodynamic evolutions, and is much smaller in the basic scenario.



In this sense, the flatness of R is a manifestation of the $p-x$ correlation
(and of flow)

otherwise the radii would increase

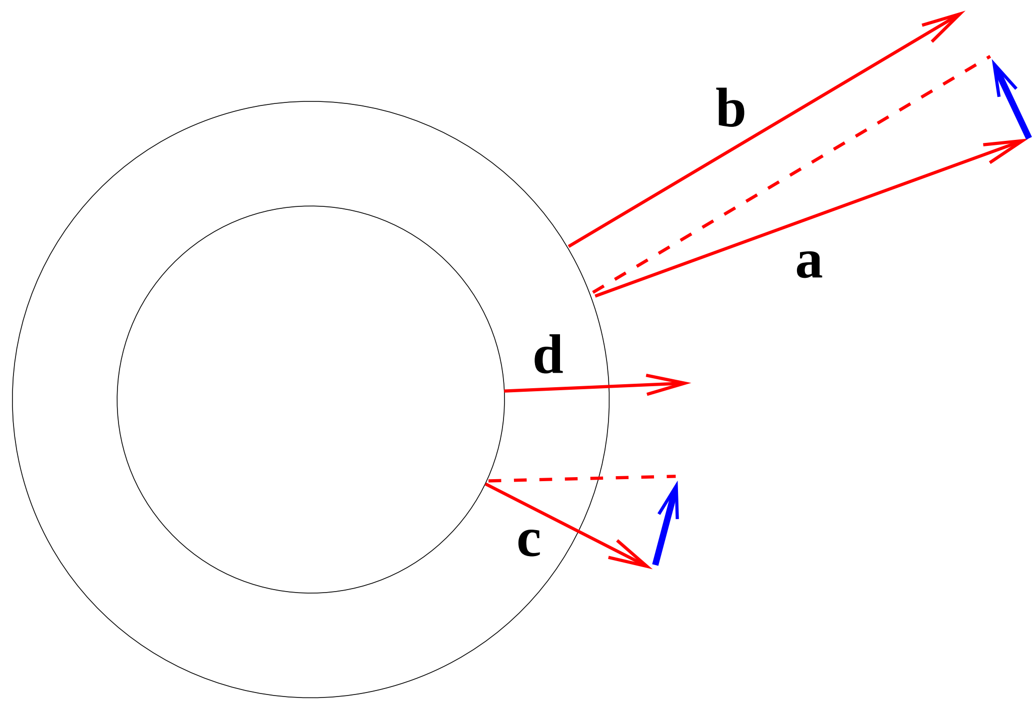


better plot ratio

$R_{\text{full model}}$ **/** R_{base}

Thank you !!

Radial flow effect on m_T dependence of femtoscopic radii:



distances get smaller outwards for fixed momentum differences