Hydrodynamical evolution in heavy ion collions and pp scatterings at the LHC

(Ridges in AA and pp scattering)

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in collaboration with

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After one decade of RHIC experiments (and first results from the LHC) it seems that

heavy ion collisions produce matter
which expands as an almost ideal fluid

mainly because azimuthal anisotropies can be explained on the basis of ideal hydrodynamics (mass splitting etc)

First LHC results:

signs for collective "fluid-like" behavior
in high multiplicty pp events as well ...

We treat pp@LHC as AuAu@RHIC:

Multiple scattering approach EPOS (marriage of pQCD and Gribov-Regge)
used as initial condition for a hydrodynamic evolution, if the energy density is high enough;

event-by-event procedure,
taking into the account
the 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 with a cross-over transition for $\mu_B = 0$, compatible with latest lattice gauge results

(S. Borsanyi, G. Endroedi, Z. Fodor, A. Jakovac, S.D. Katz, S. Krieg, C. Ratti and K.K. Szabo, arXiv:1007.2580)

hadronization,

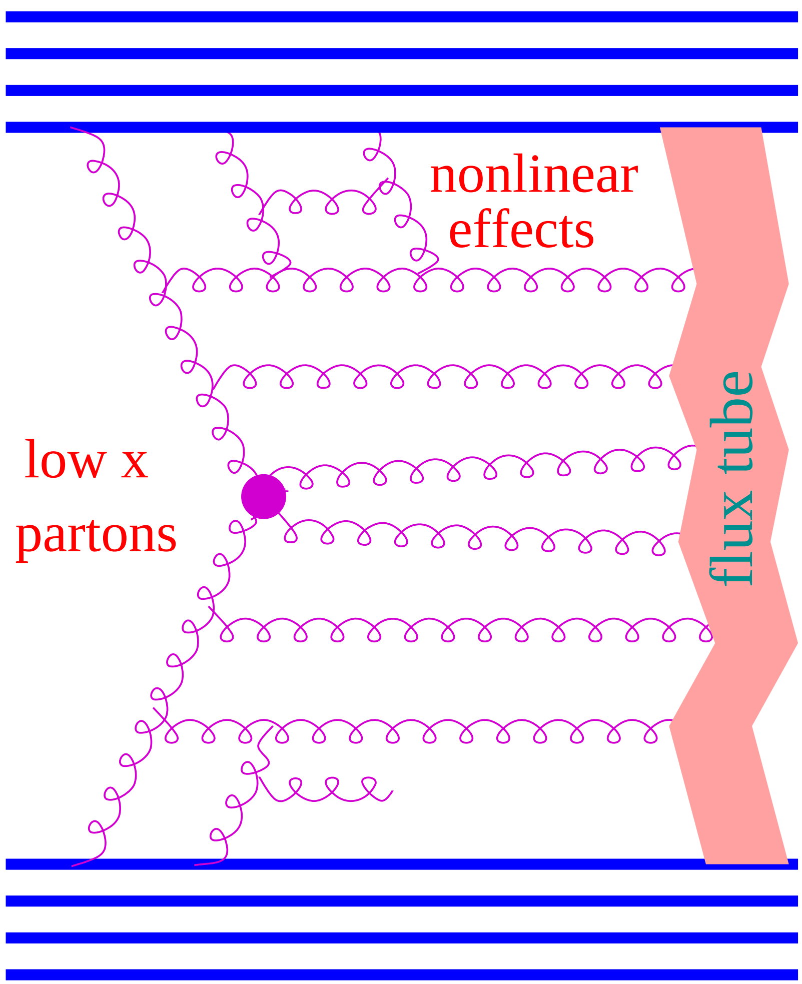
* here: Cooper-Frye, using complete hadron table,
* at an early stage (166 MeV, in the transition region),
* with subsequent hadronic cascade procedure (UrQMD)

details see:

arXiv:1004.0805 (Ridges + many other things at RHIC), PRC 82,044904
arXiv:1010.0400 (Hydrodynamical evolution in pp@LHC), PRC, 2011
arXiv:1011.0375 (Ridges in pp), PRL, 2011

Elementary scatterings - flux tubes

AA - even pp: **many elementary collisions happening in parallel**
elementary scattering = "parton ladder"



- Parton evolutions from the projectile and the target side towards the center (small x)
- Evolution is governed by an evolution equation, in the simplest case according to DGLAP.
- Parton ladder may be considered as a quasi-longitudinal color field, a so-called "flux tube", conveniently treated as a relativistic string.
- The intermediate gluons are treated as kink singularities in the language of relativistic strings, providing a transversely moving portion of the object.
- This flux tube decays via the production of quark-antiquark pairs, creating in this way fragments – which are identified with hadrons

Quantum mechanical treatment of multiple scattering is quite involved

... in particular when the energy sharing between the parallel scatterings is taken into account

Details:

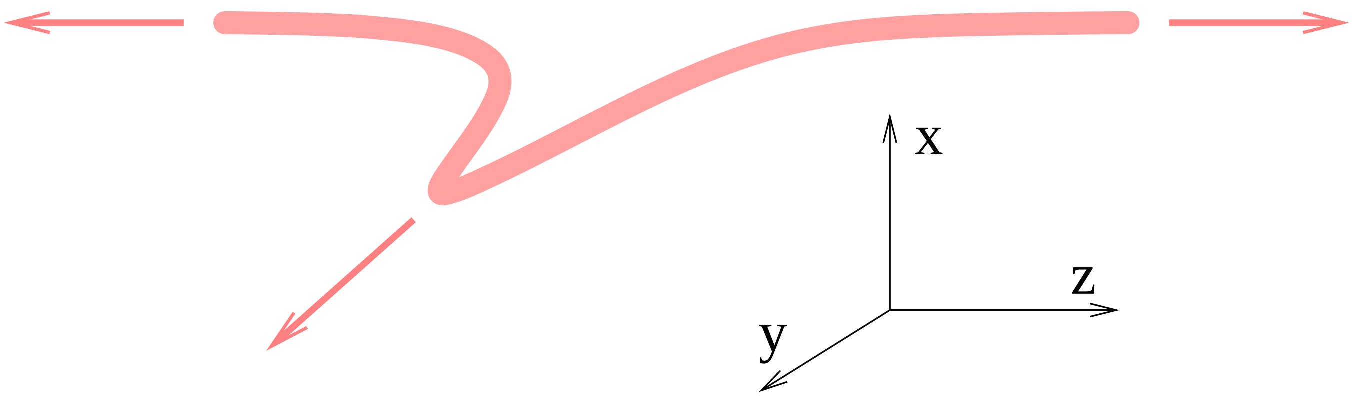
Parton-based Gribov-Regge Theory, H. J. Drescher, M. Hladik, S. Ostapchenko, T.Pierog, and K. Werner, Phys. Rept. 350 (2001) 93-289

- Based on cutting rule techniques, one obtains partial cross sections for exclusive event classes,
- which are then simulated with the help of Markov chain techniques.

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).

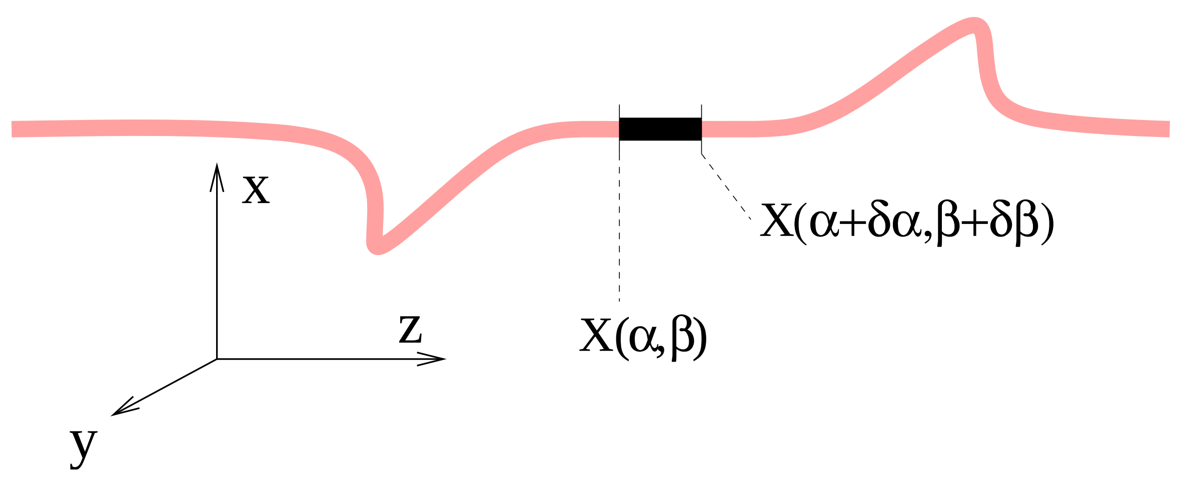


But despite these kinks, most of the string carries only little transverse momentum!

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.

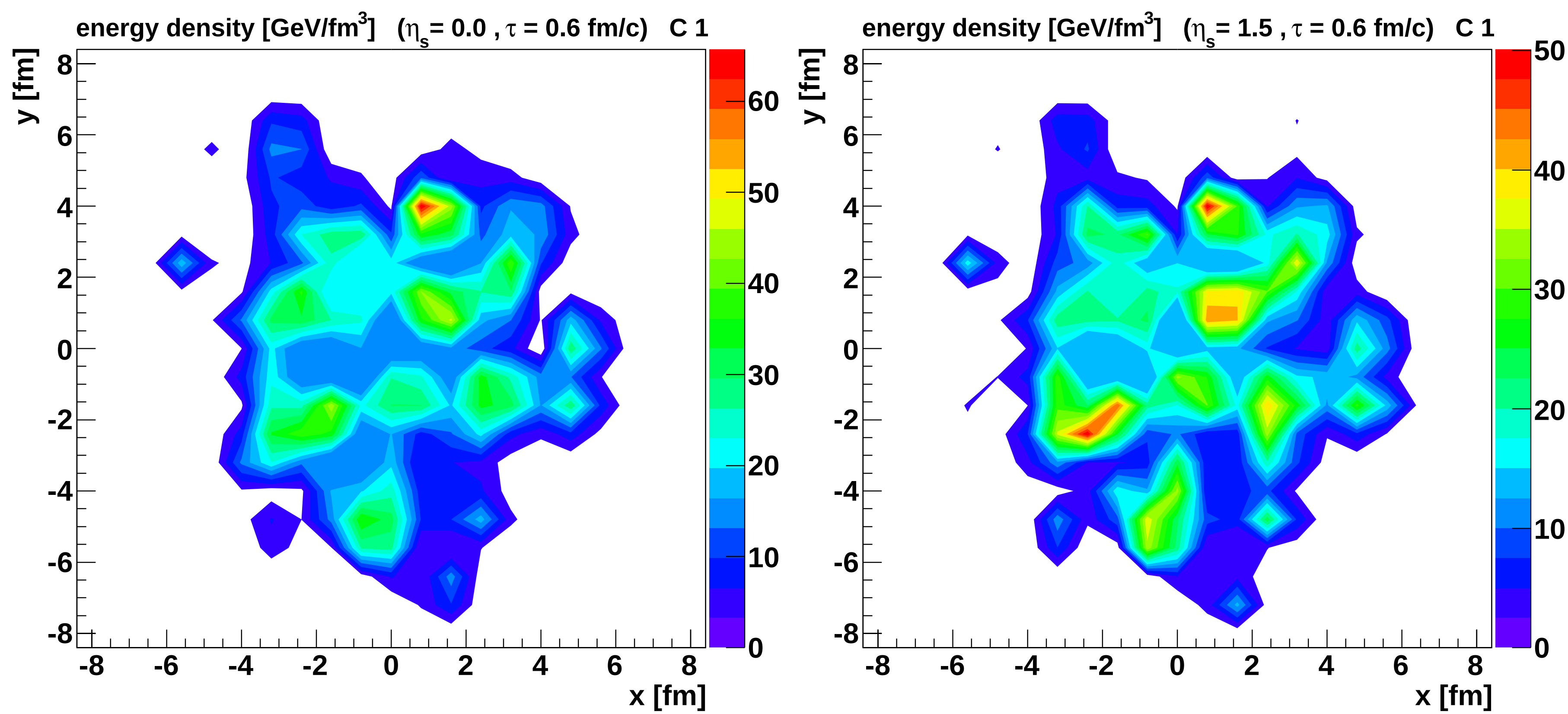
AuAu@200 GeV

We checked successfully hundreds of particle spectra, v2 results ...

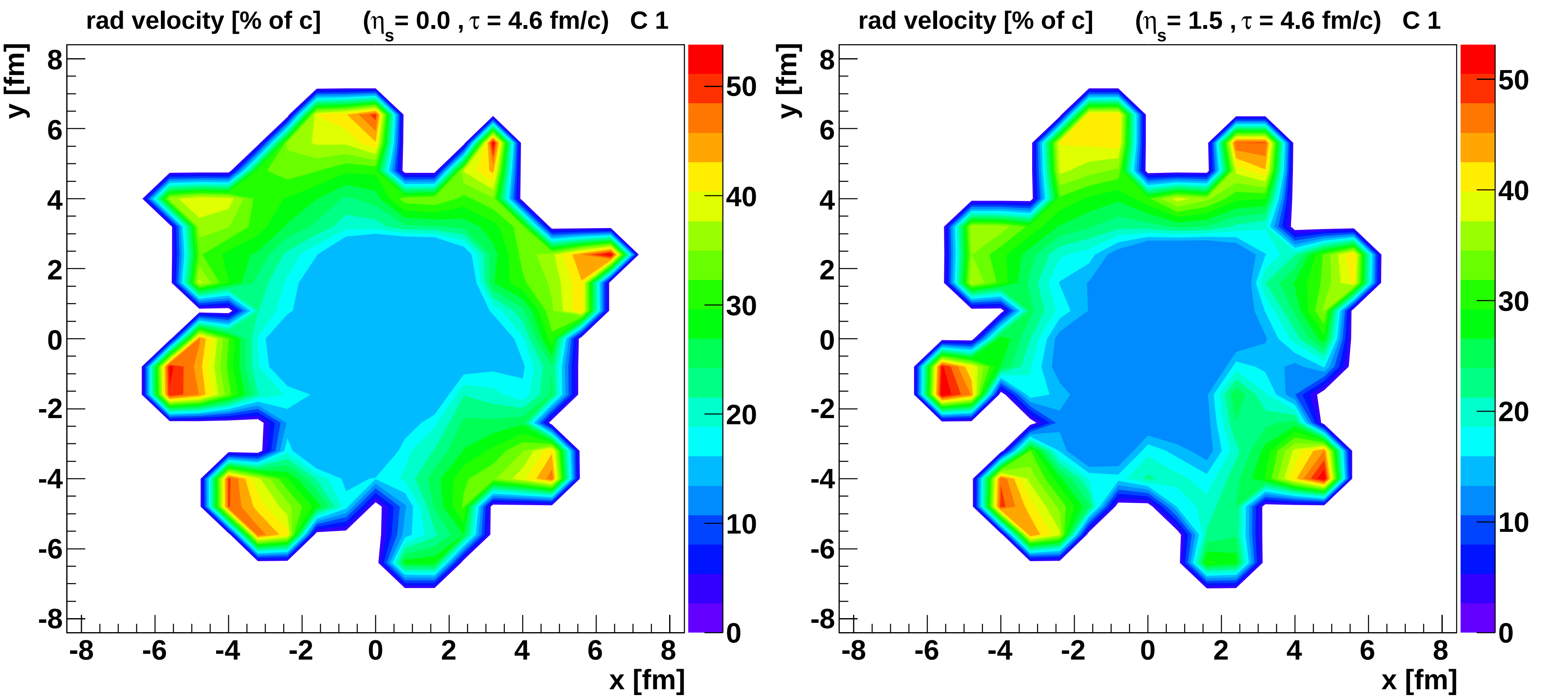
here: **Interesting EbE features**

Bumpy structure of energy density in transverse plane,

but **translational invariance**

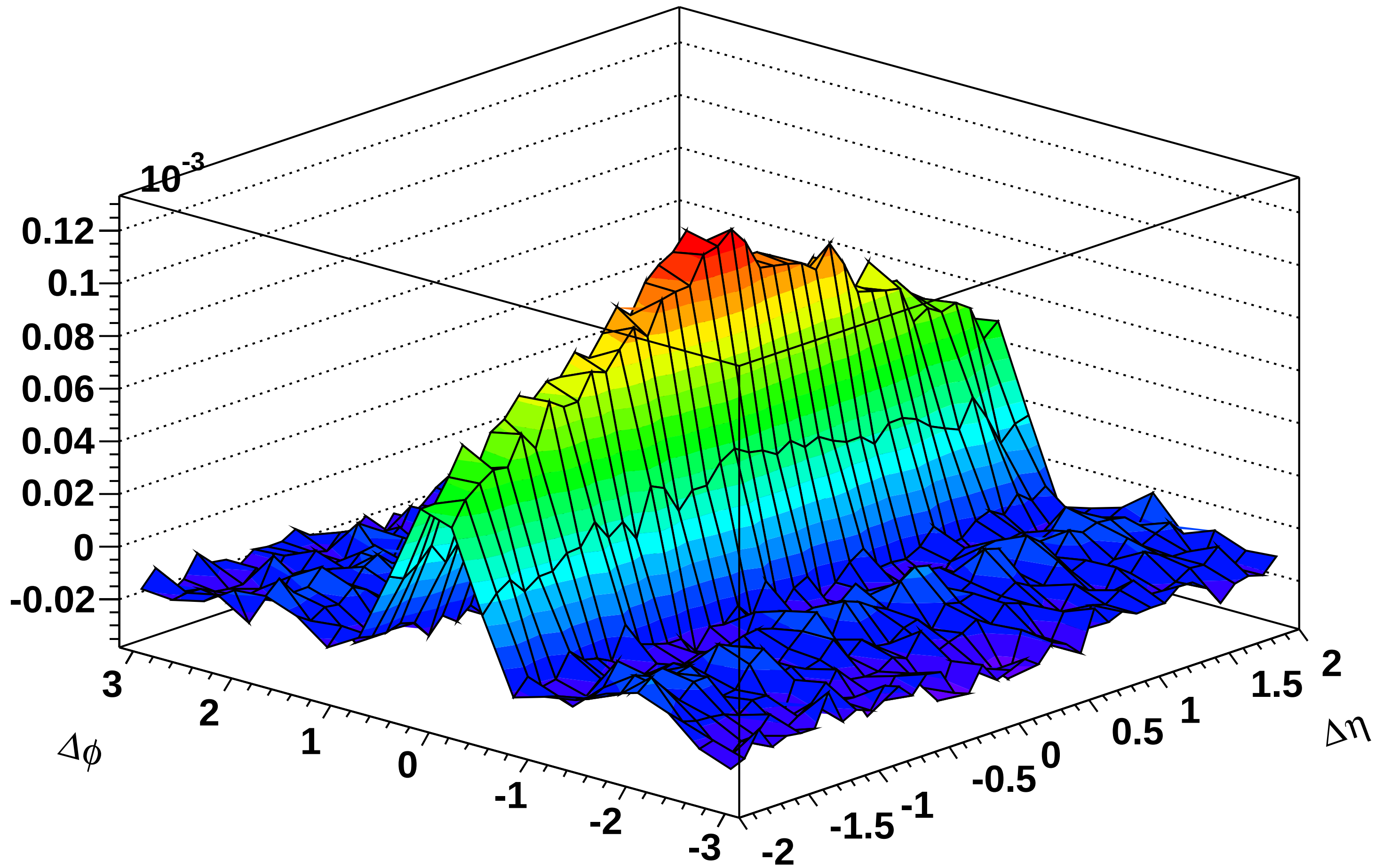


Leads to **translational invariance of transverse flows**



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

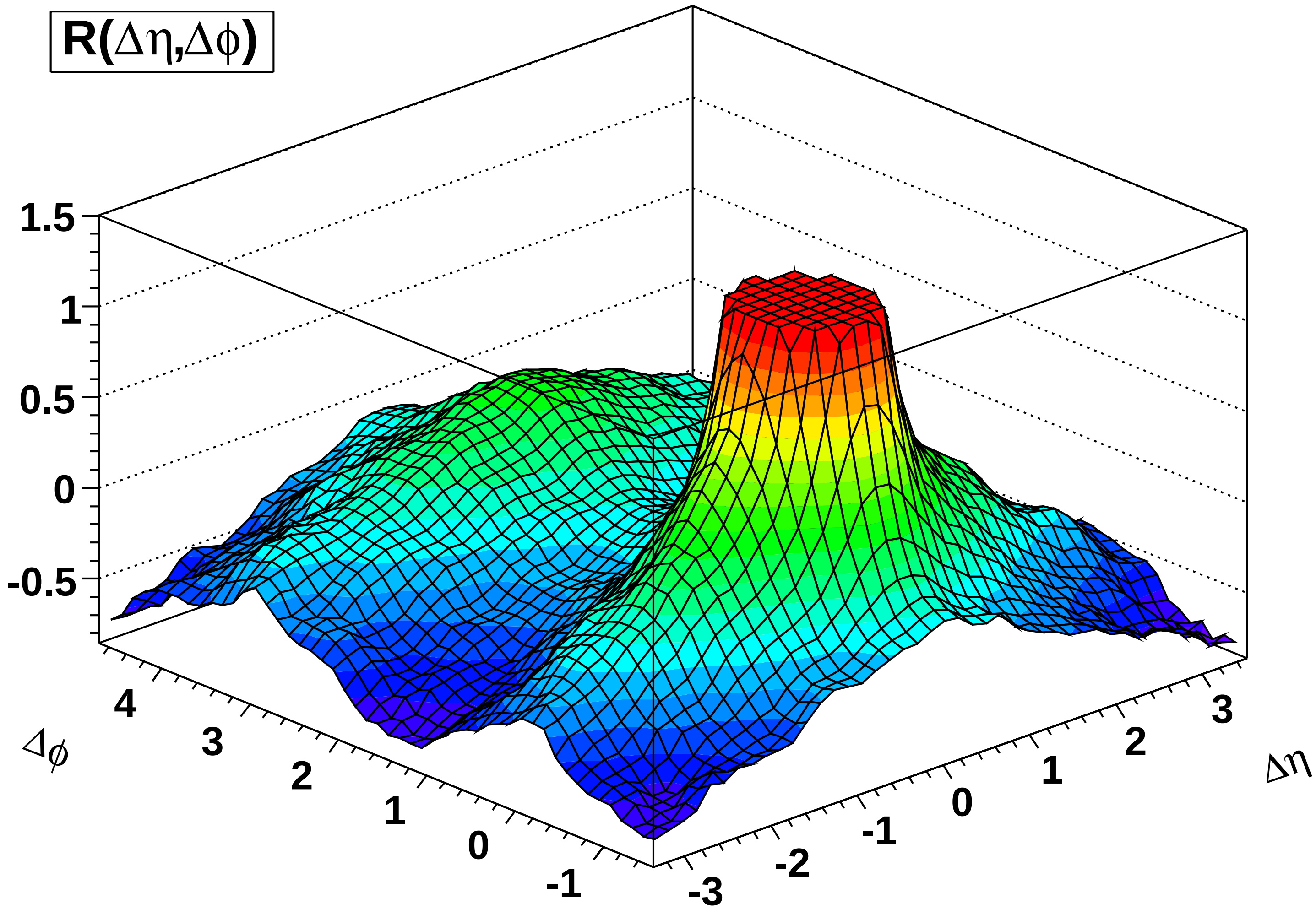
pp@LHC

same procedure:
EbE hydro based on flux tube initial conditions

Particularly interesting:

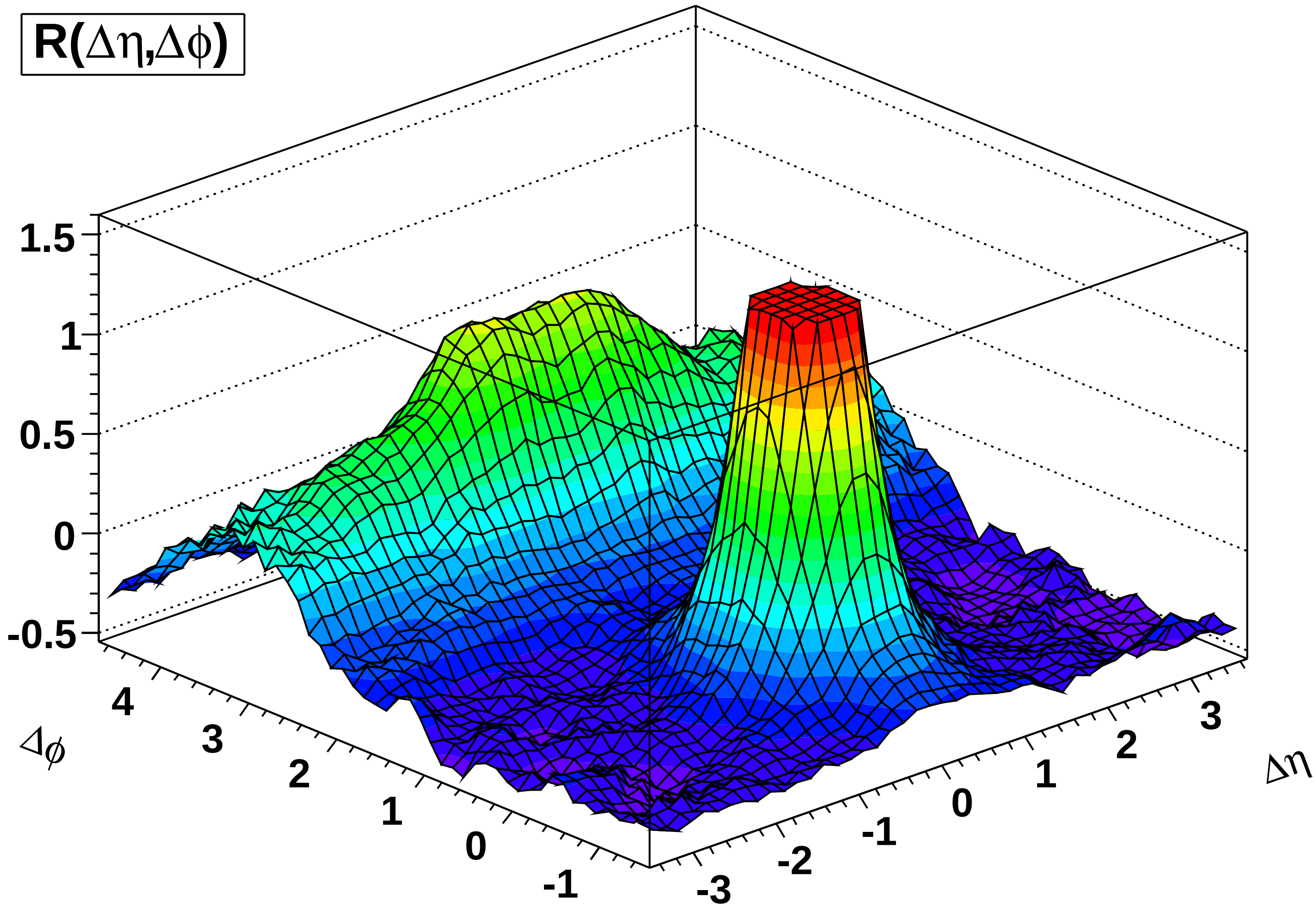
high multiplicity events
= large numbers of scatterings

Our calculation provides a similar ridge structure in pp@7TeV
using particles with $1 < p_t < 3\text{GeV}/c$, for **high multiplicity events**



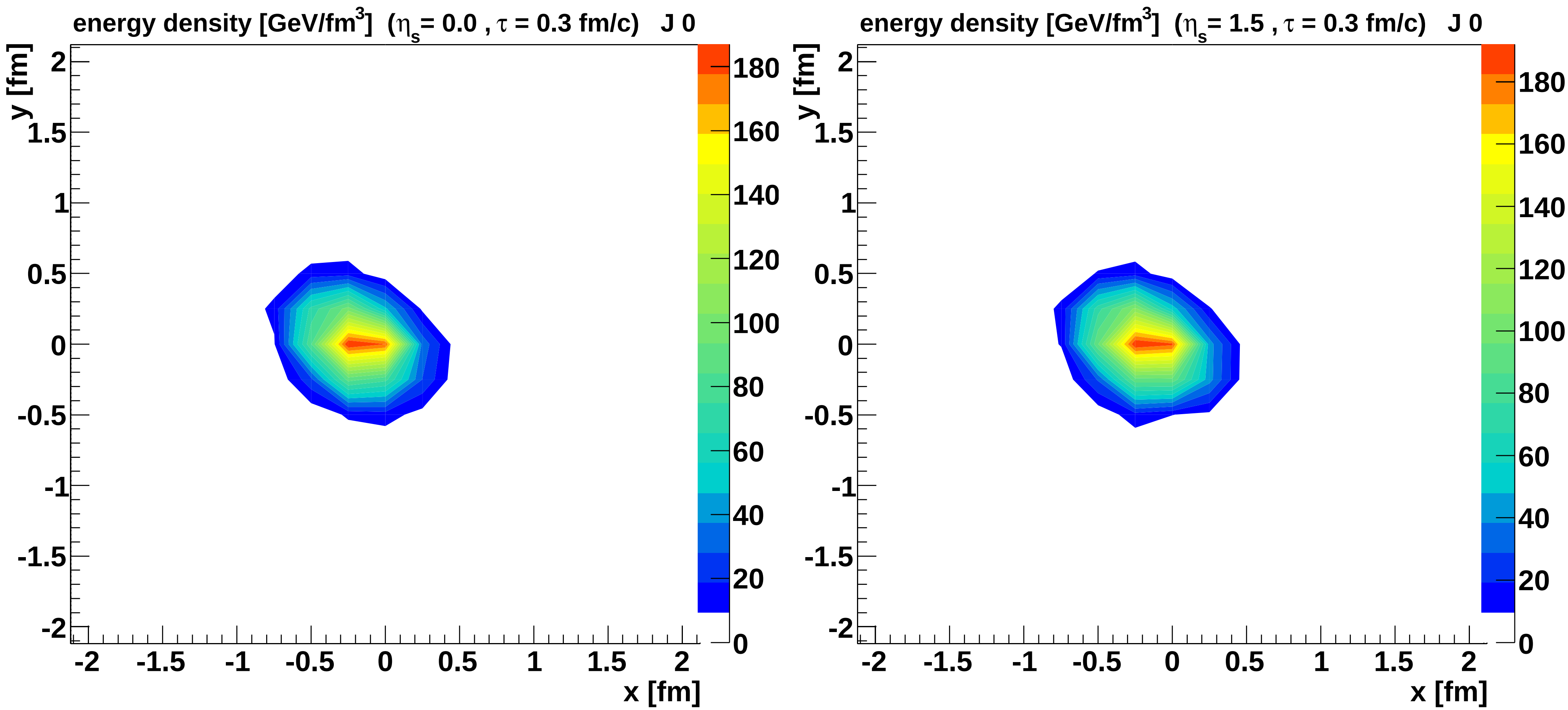
close in form and magnitude compared to the CMS result
(5.3 times mean multipl., compared to 7 in CMS)

Calculation without hydro => NO RIDGE



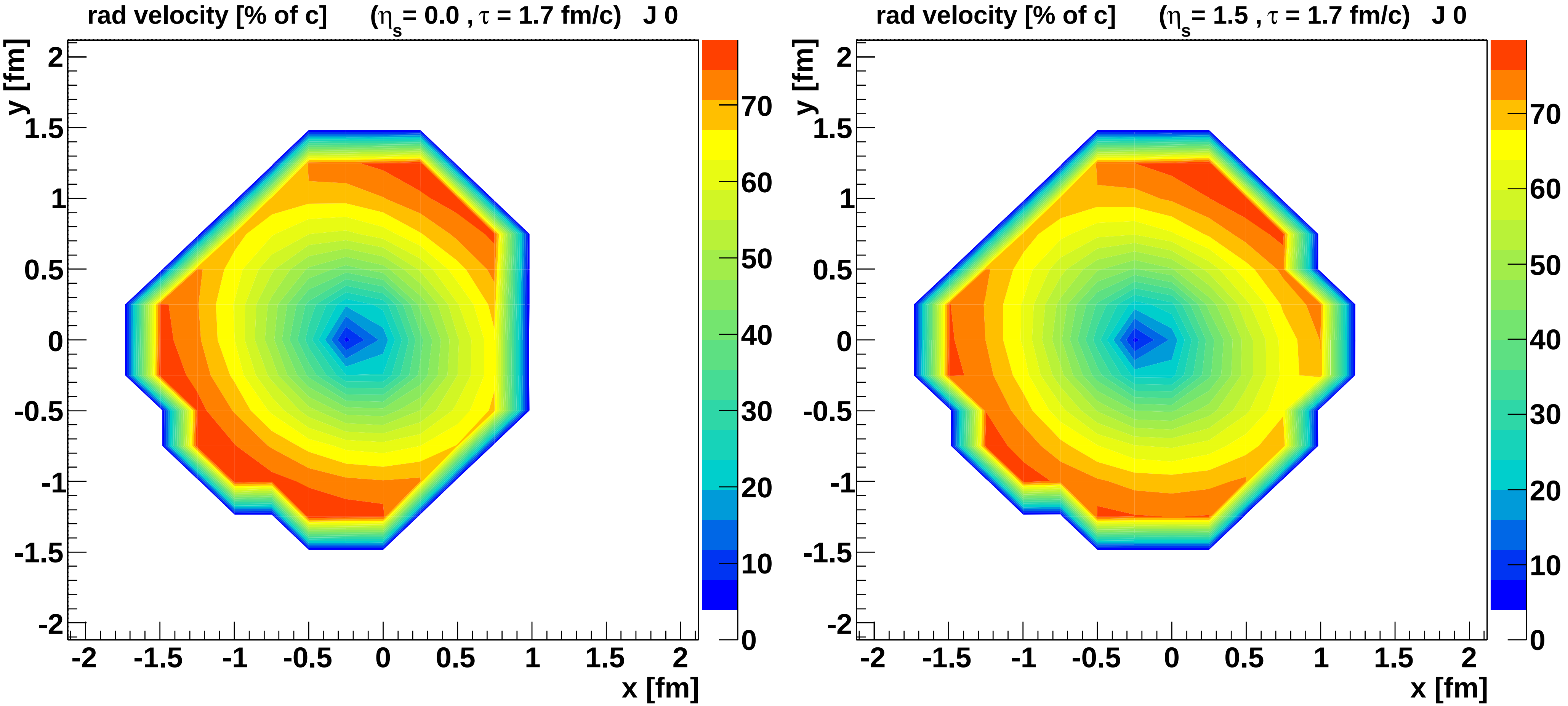
hydrodynamical evolution “makes” the effect! HOW?

Random azimuthal asymmetries of initial energy density
but translationally invariant



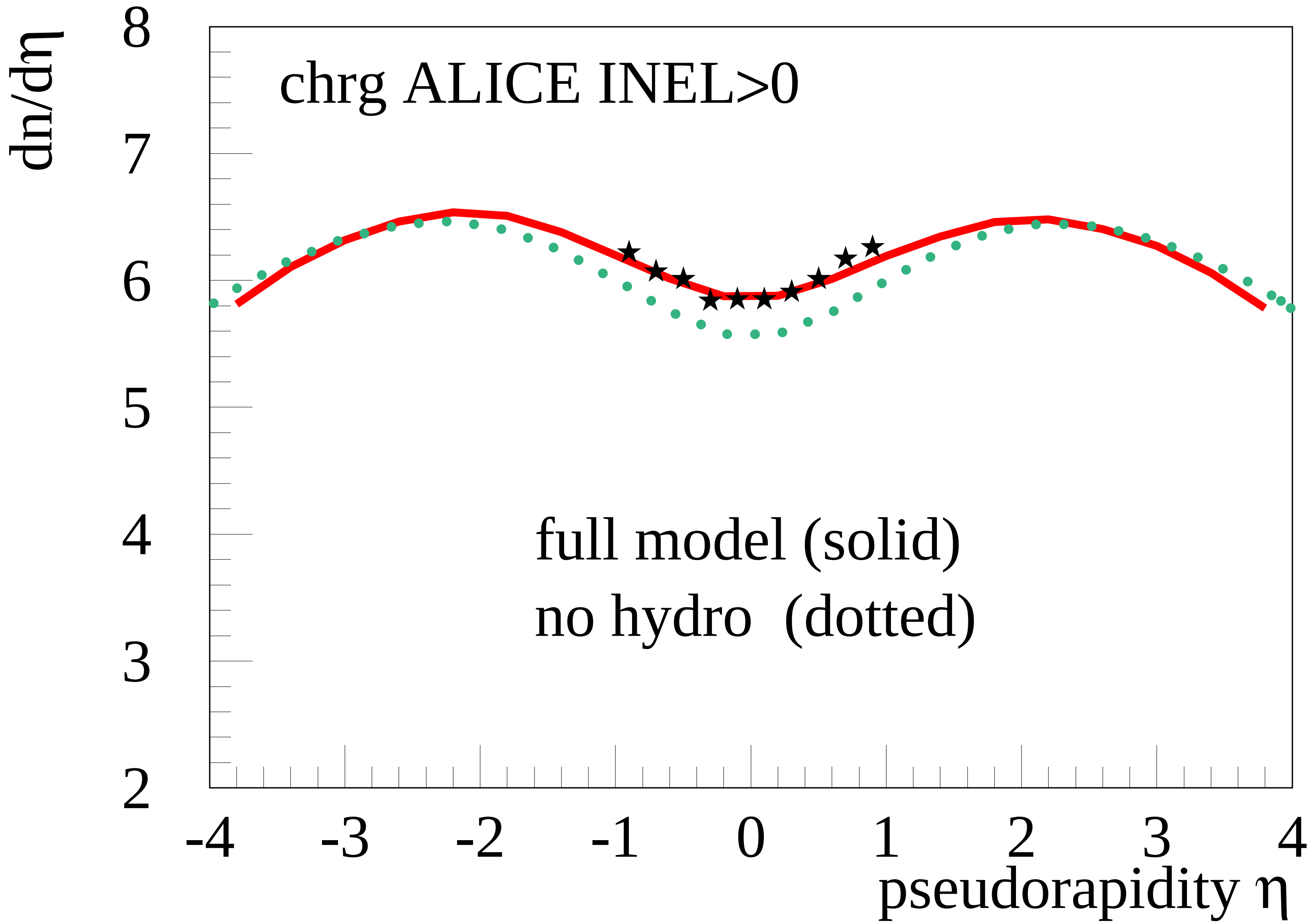
Initial energy density in the transverse plane for two different η_s

Elliptical initial shapes leads to asymmetric flows
as well translationally invariant (in η_s)

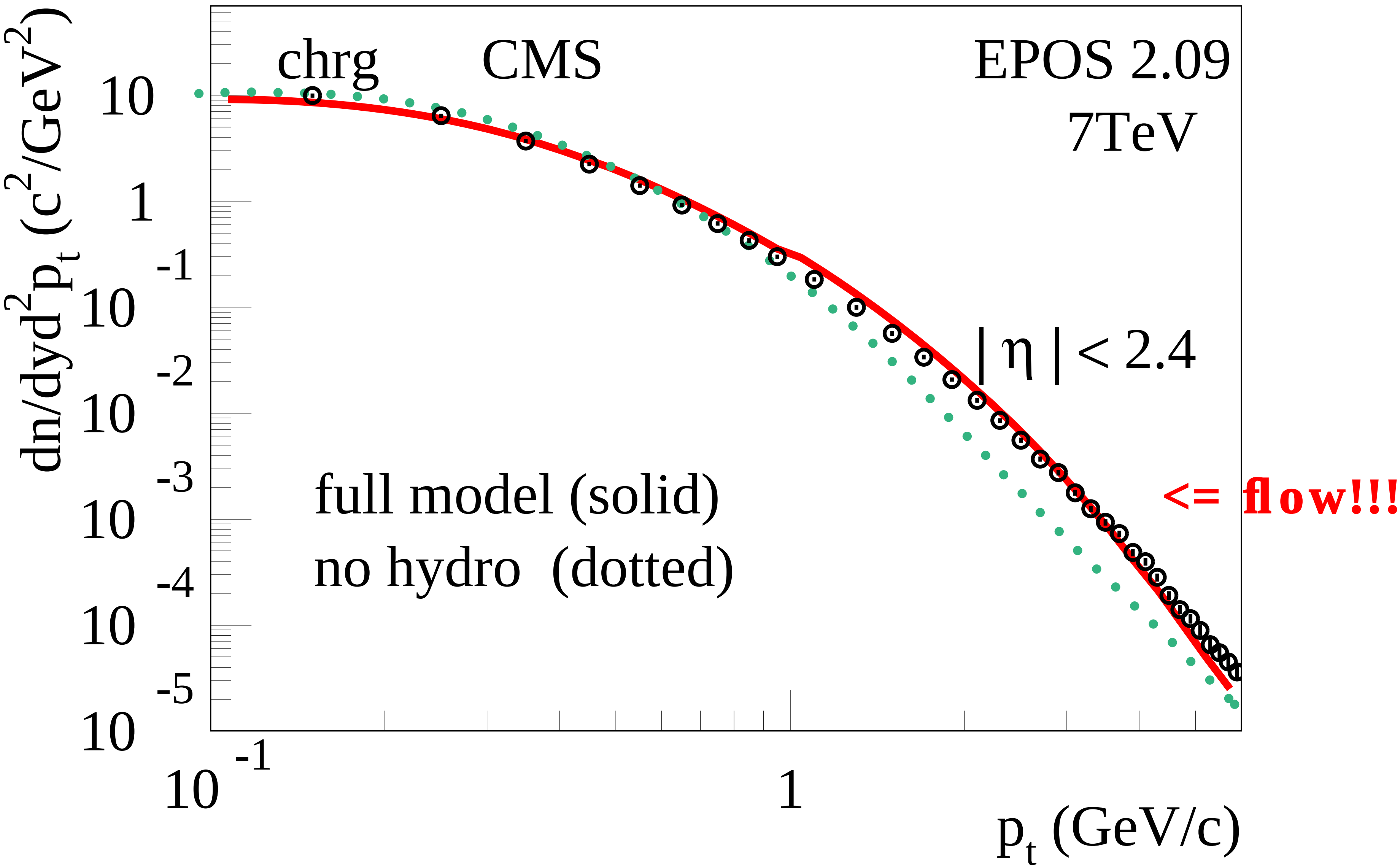


give the same collective push
to particles produced at different values of η_s
at the same azimuthal angle

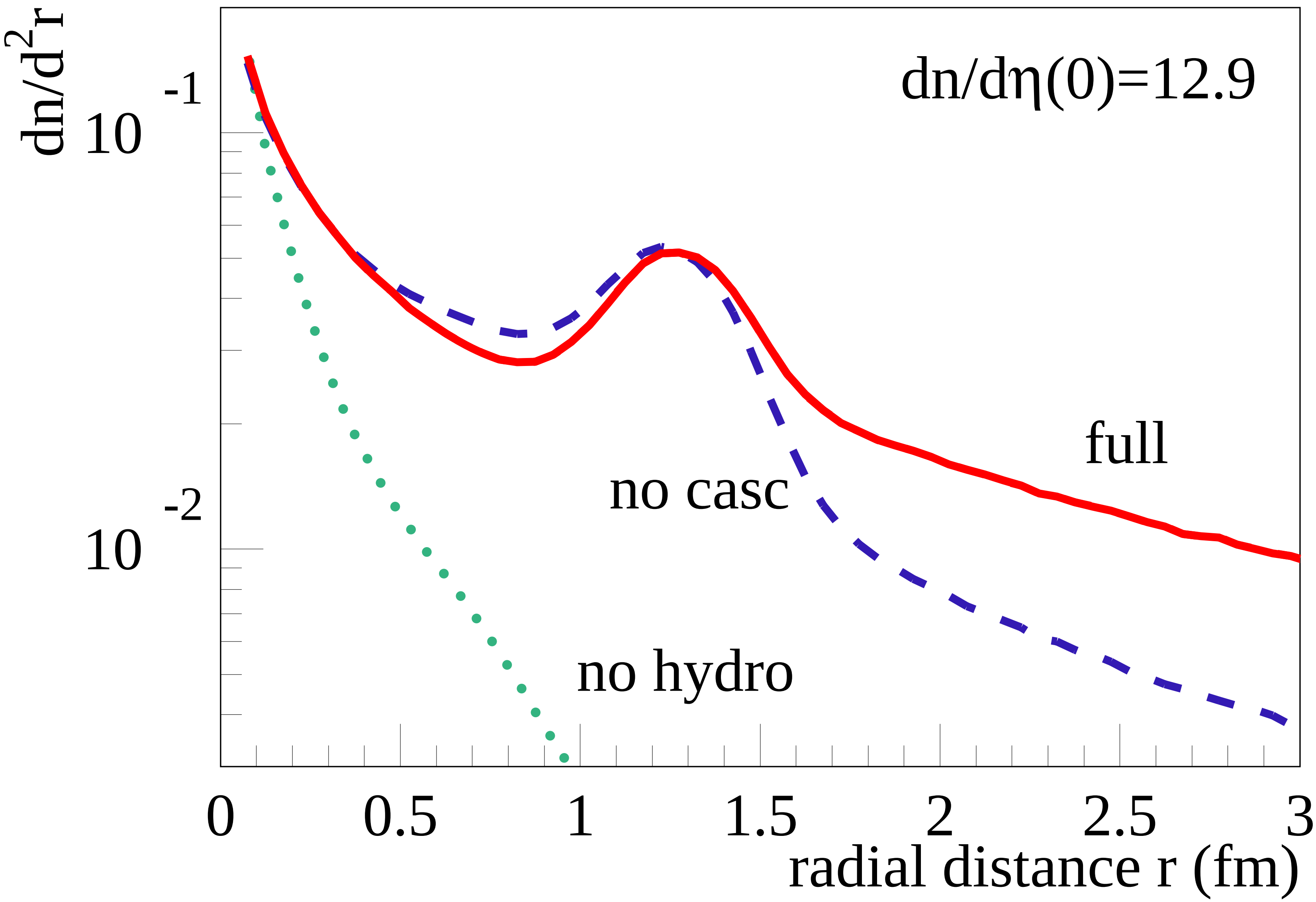
Particle spectra: Little effect of hydro in MB dn/deta



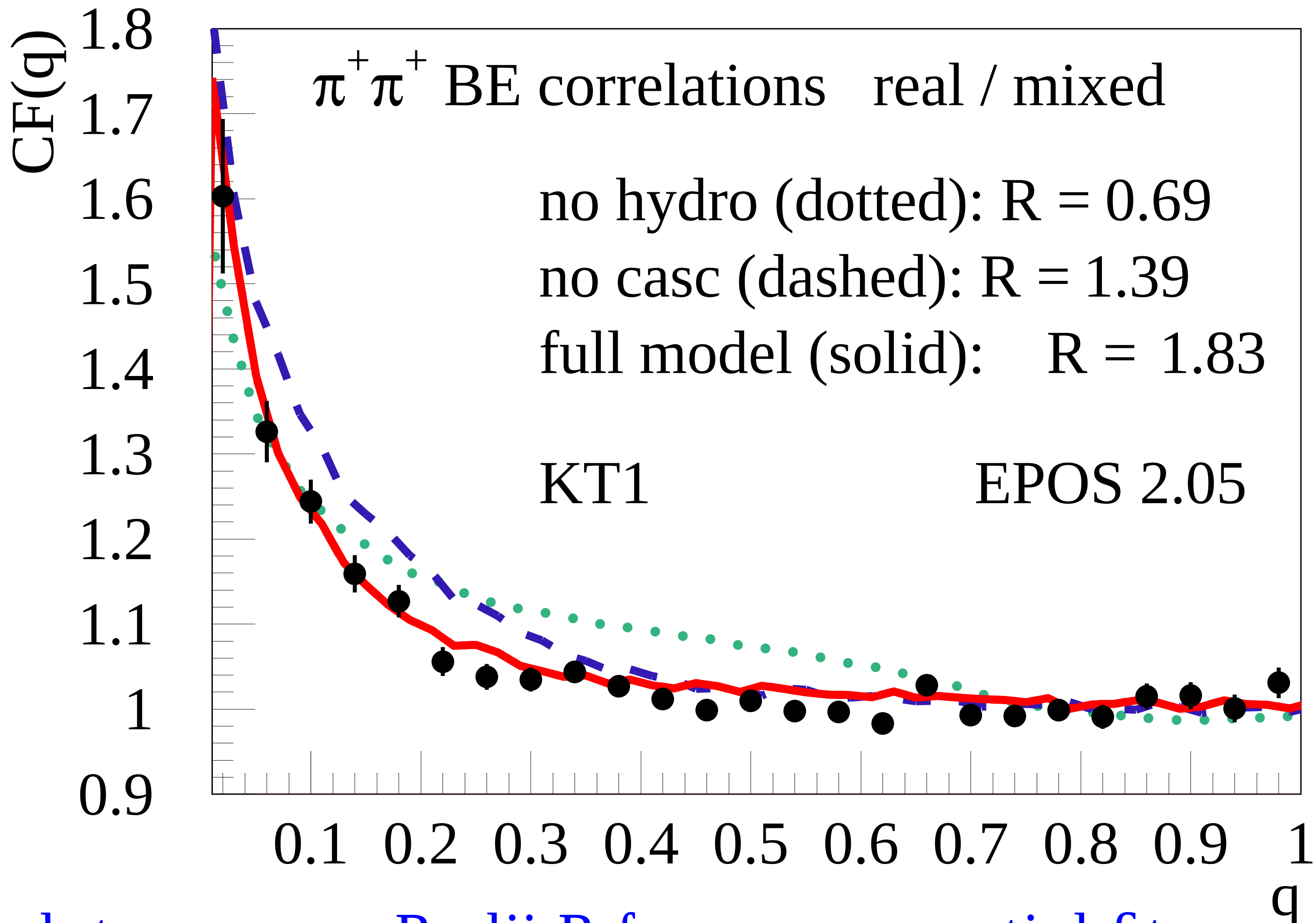
But: big effect for intermediate pt (even for MB)



Space-time structure strongly affected (here 900 GeV)



Consequences for Bose-Einstein correlations



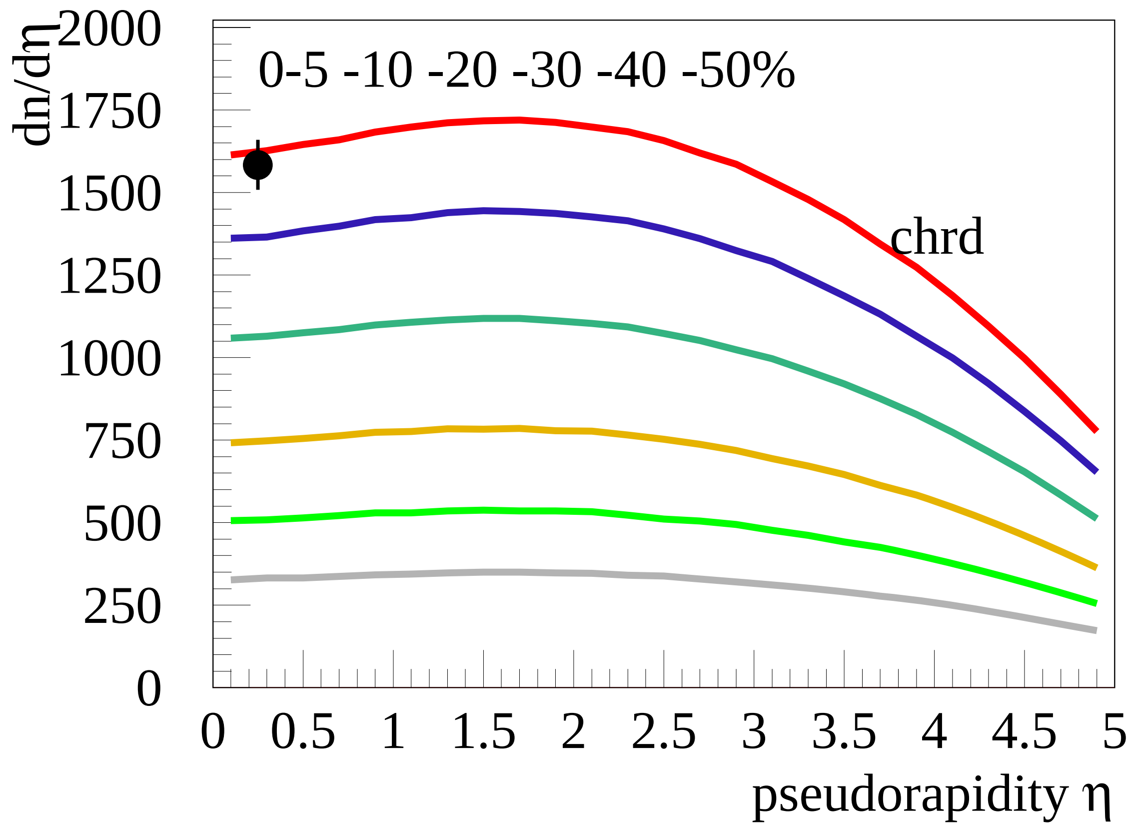
ALICE data. Radii R from exponential fit.

KT1= [100, 250], KT3= [400, 550], KT5= [700, 1000]

PbPb@LHC

same procedure:
EbE hydro based on flux tube initial conditions

Charged particle η distribution



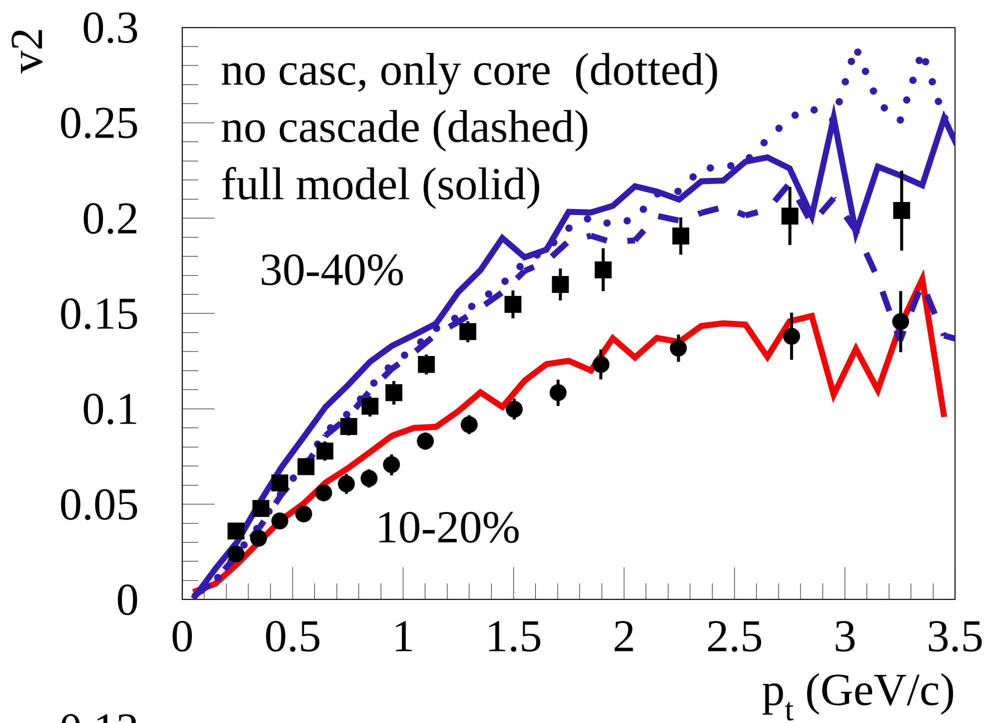
$dn/d\eta(0)$ ok via adjusting screening exponents $\epsilon = \epsilon(s, N_{\text{part}})$ in Pomeron amplitudes $\alpha(x^{+})^{\beta+\epsilon_P}(x^{-})^{\beta+\epsilon_T}$

The only freedom for PbPb@LHC !!

Elliptical flow

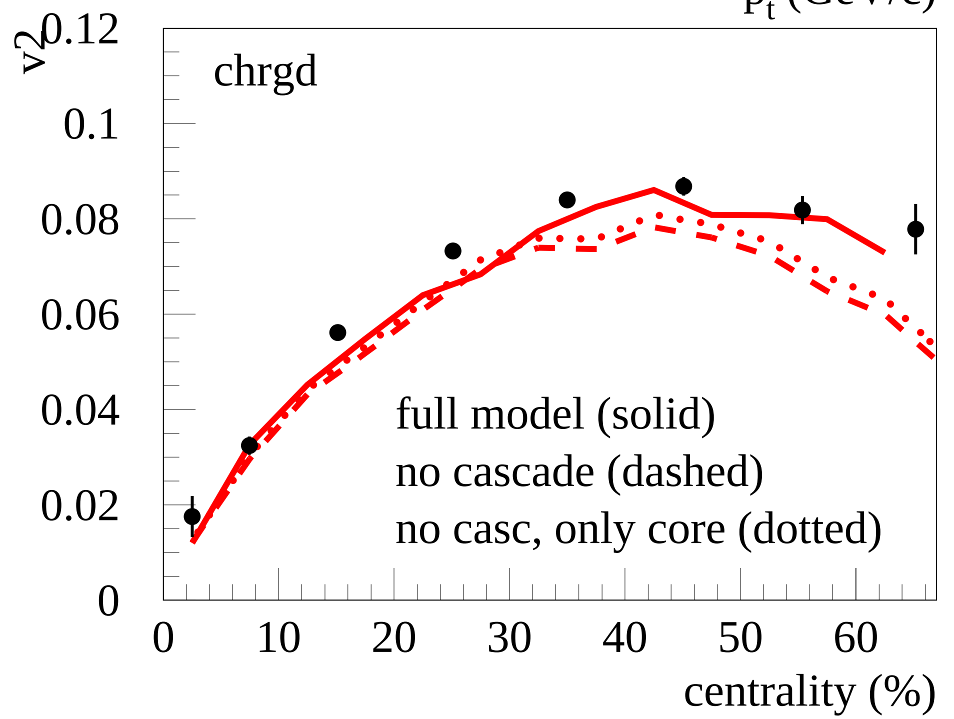
Computed as
$\langle\cos\left(2(\phi-\phi_{EP})\right)\rangle$

comparable to RHIC

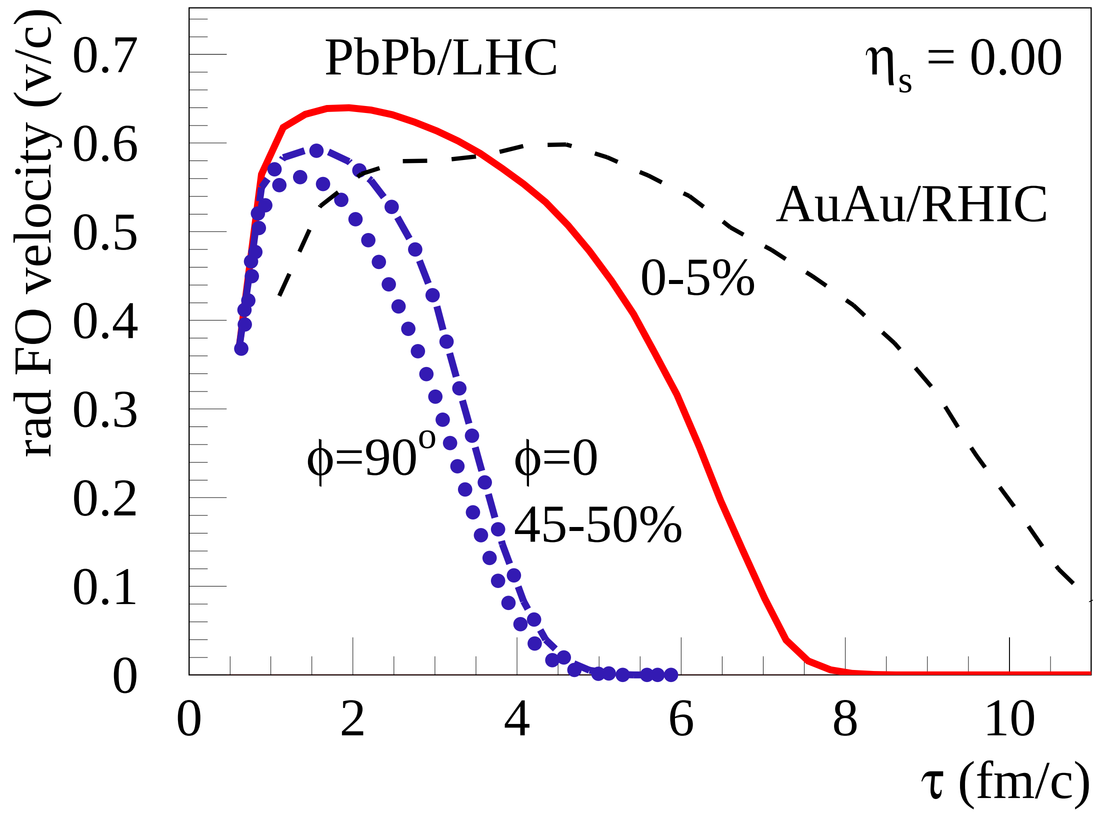


Integrated:

v_2(LHC) > v_2(RHIC)
Higher pt at LHC,
more flow !!



Time evolution of the fluid: radial flow at “freeze out”[a]



LHC: radial flow develops quickly; larger than at RHIC
(here $\tau_0 = 0.35\,\mathrm{fm/c}$ (LHC) $0.6\,\mathrm{fm/c}$ (RHIC),
shorter life time compared to RHIC !!

[a] transition from fluid into hadron cascade

Summary

Multiple scattering approach & hydro (EbE):

- □ **explains naturally nontrivial features as “ridge” correlations (+elliptical flow ...) in AuAu@RHIC**

- □ **explains some nontrivial pp phenomena (ridge, BE correlations)**

- □ **and first PbPb results**

Summary

Multiple scattering approach & hydro (EbE):

- **explains naturally nontrivial features as "ridge" correlations (+elliptical flow ...) in AuAu@RHIC**
- **explains some nontrivial pp phenomena (ridge, BE correlations)**
- **and first PbPb results**

Thank you !!