Femtoscopy of Pb-Pb and pp collisions at the LHC with the ALICE experiment

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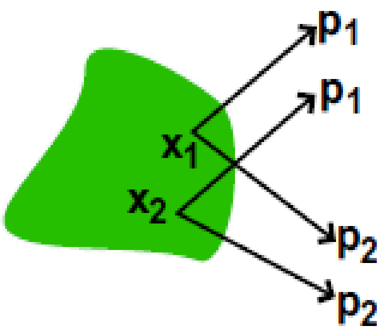
Overview

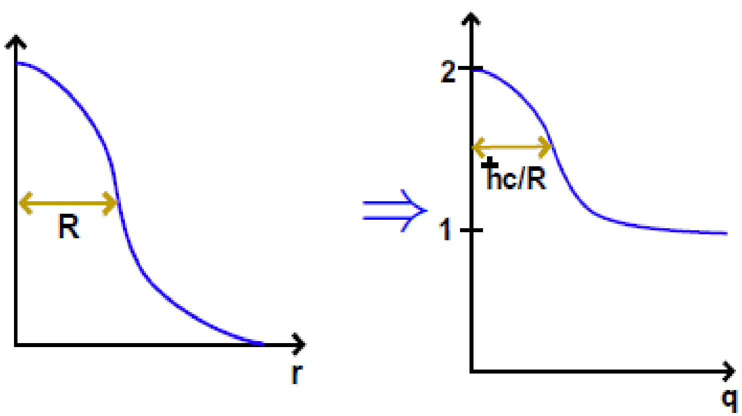
- Introduction
  - What is femtoscopy : physical motivation in HI & pp collisions
- ALICE experiment at LHC
- Main ALICE results in Pb-Pb collisions
- Main ALICE results in pp collisions
- Conclusions

Introduction



Correlation femtoscopy : measurement of space-time characteristics R, cτ ~fm of particle production using particle correlations due to the effects of quantum statistics (QS) and final state interactions (FSI)

(First experimental observation: G. Goldhaber, S. Goldhaber, W-Y Lee, A. Pais (Phys.Rev. 120 (1960) 300); V.G. Grishin, G.I. Kopylov, and M.I. Podgoretsky showed analogy (Sov.J.Nucl.Phys. 13 (1971) 638) and difference (G.I. Kopylov and M.I. Podgoretsky, Sov.J.Nucl.Phys. 15 (1972) 219) between femtoscopy in particle physics and HBT effect in astronomy (R. Hanbury-Brown and R.Q. Twiss, Phil.Mag. 45 (1954) 633))



two-particle correlation function:

theory : $C(q) = \dfrac{N_2(p_1, p_2)}{N_1(p_1)N_2(p_2)}, \quad C(\infty) = 1$

experiment : $C(q) = \dfrac{S(q)}{B(q)}, \quad q = p_1 - p_2$

S - distribution of pair momentum difference of particles from the same events
B - reference distribution, built by mixing particles from different events

Femtoscopy: frequently used parametrizations

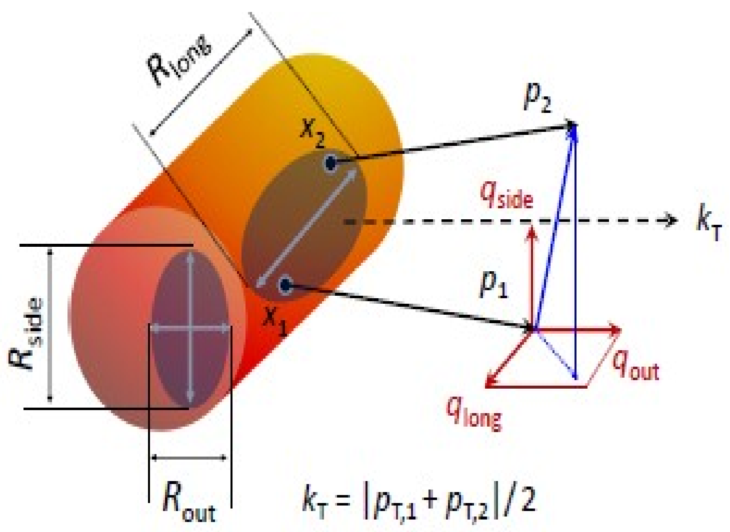
$$C(q) = 1+\lambda \exp(-R_{inv}^2 q_{inv}^2),$$ λ– correlation strength,

R_{inv}, Gaussian radius in Pair Rest Frame (**PRF**)

1d- analysis is only sensitive to the system size averaged over all directions ;

$$C(q) = 1+\lambda \exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2),$$

where both R and q are in Longitudinally Co-Moving Frame (**LCMS**)



long || beam;
out || transverse pair velocity $\mathbf{v}_T$
side normal to out,long

3D- analysis

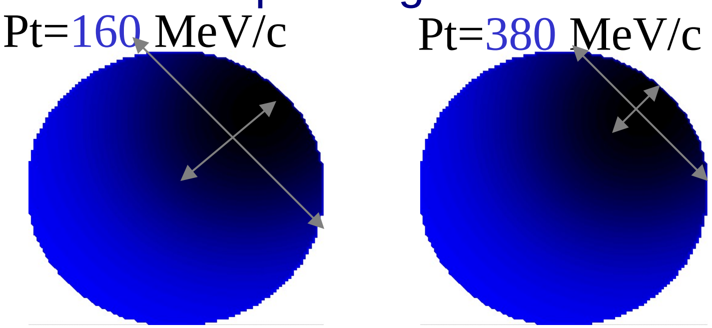
R_{side} sensitive to geometrical transverse size.

R_{long} sensitive to time of freeze-out.

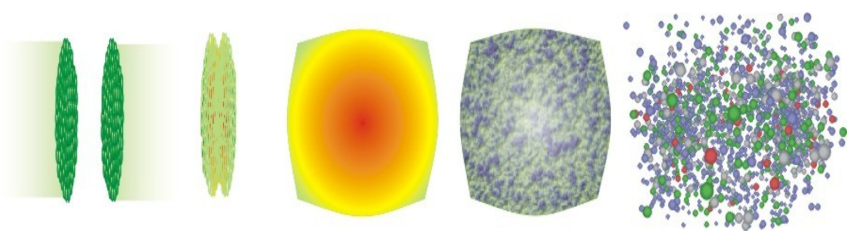
R_{out} / R_{side} ~ sensitive to emission duration.

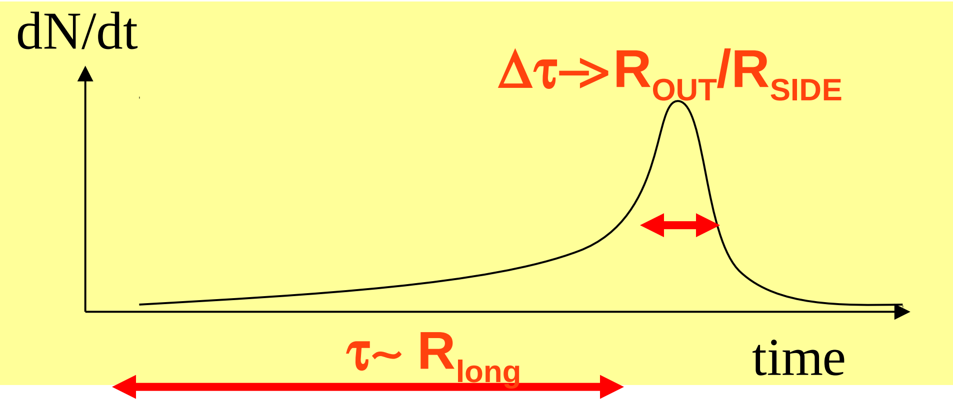
Femtoscopy: physics motivation

Expanding source



Interference probes only a part of the source - homogeneity region; radii decrease with pair velocity





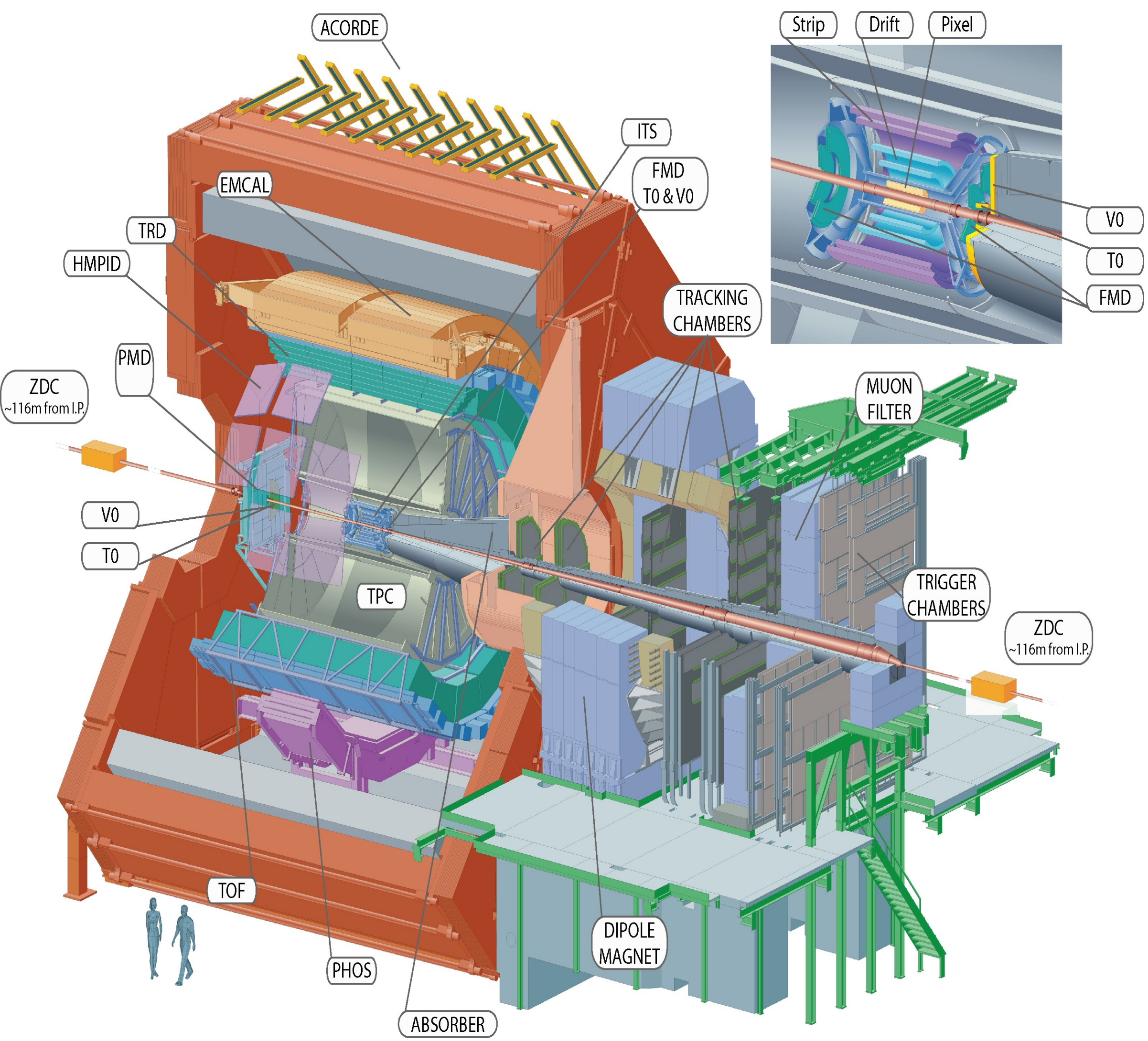
HI collisions

- Measure the size of the homogeneity region from which the volume of the QGP can be inferred
- Study of radii dependence on transverse momentum -> manifestation of collective motion of matter
- Study of transverse mass dependence for different particle types (π, K, p, ...) -> scaling in m_T ->additional confirmation of the hydrodynamic type of expansion.
- constraints on model parameters:

pp collisions

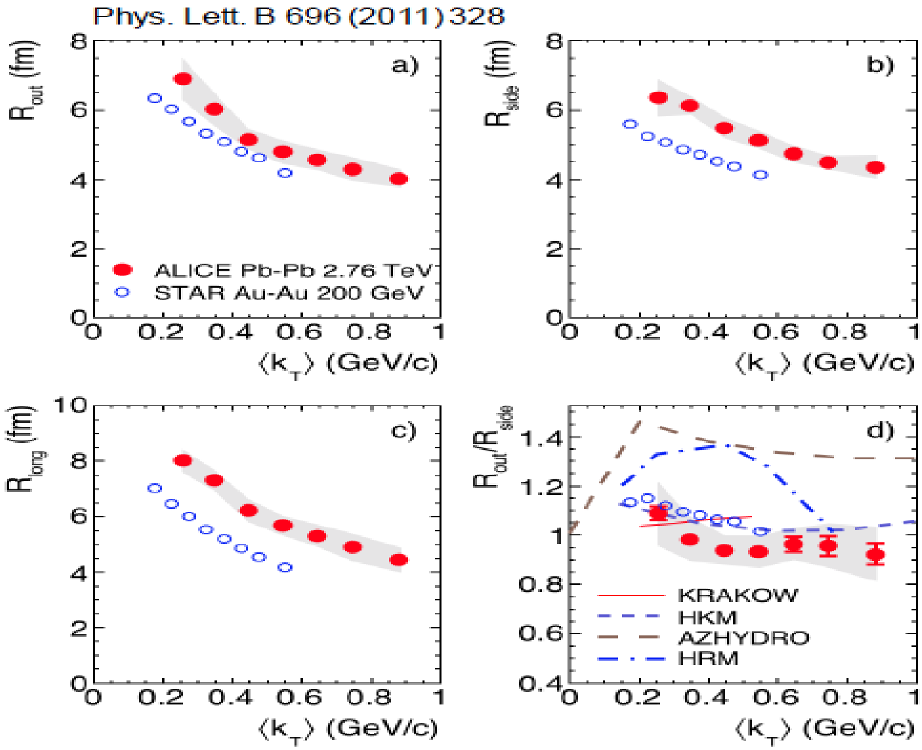
- Study space-time characteristics of particle production in “elementary process”
- Multiplicities, comparable to peripheral AA collisions: **collectivity in pp as in AA ?**

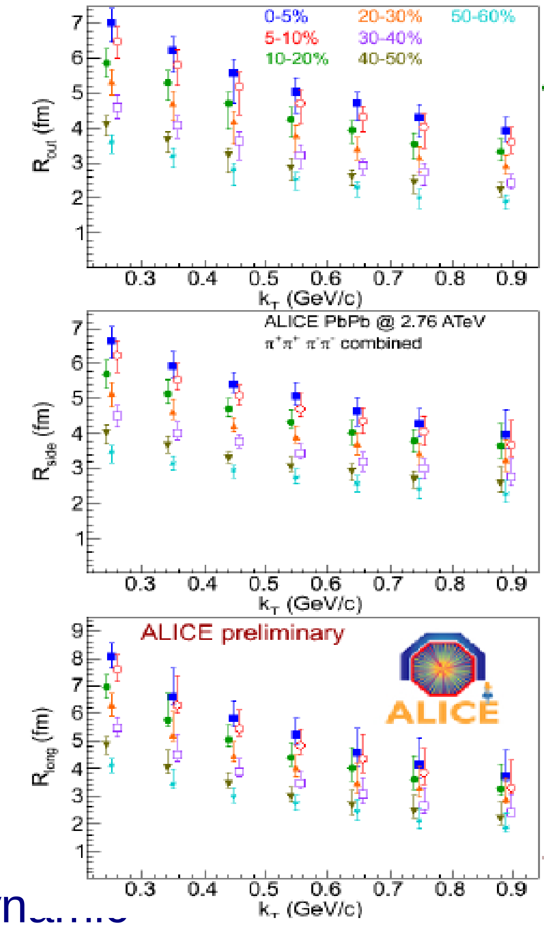
ALICE at LHC



- Main tracking detector:
  Time Projection Chamber(TPC)
- Vertexing and tracking:
  Inner Tracking System (ITS)
- Trigger and centrality:
  VZERO, ZDC, ITS
- Particle identification (PID):
  TPC & ITS (energy loss)
  Time-of-Flight (TOF)

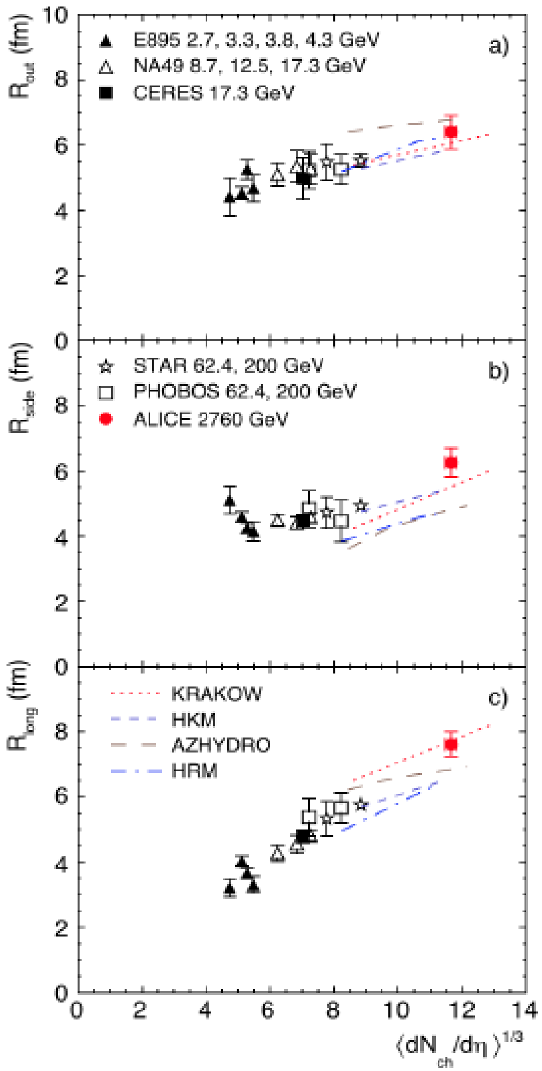
Main ALICE results of the pion femtoscopy analysis in Pb-Pb: radii versus k_T

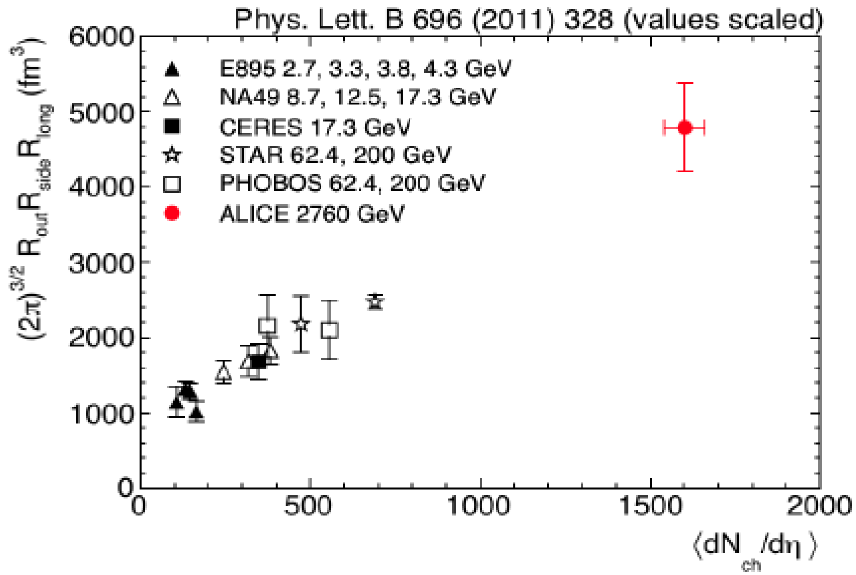




- Strong k_T dependence of radii - sign of transverse flow
- Decrease of size with decreasing multiplicity
- Linear scaling of radii with $dN_{ch}/d\eta$ – similar to hydrodyn...
- Rout/Rside smaller then at RHIC

Main ALICE results of the pion femtoscopy analysis in Pb-Pb: radii versus $dN_{ch}/d\eta$





- Homogeneity volume 2 times larger than at RHIC
- Scaling of the radii with$(dN_{ch}/d\eta)^{1/3}$
- ALICE significantly extends the range of the radii world systematics.
- R_{long} is proportional to the total duration of the longitudinal expansion.
- Decoupling time τ ~ 40% larger than at RHIC.

Physical motivation for femtoscopy with heavier particles (kaons, protons...)

ALICE

- **Wide range of pair transverse mass (m_T): strong constrains for hydrodynamic model predictions (its should work for heavier mesons and baryons)**

- **Consistency checks:**

- Different sources of correlations: Quantum Statistics (QS), Coulomb and Strong Final State Interactions (FSI)

- Complementary systems (e.g. charged and neutral kaons)

- Overlapping m_T ranges

- Different systematics

$K^{\pm}K^{\pm}$, $K^0_s K^0_s$, pp in Pb–Pb

Neutral kaons:

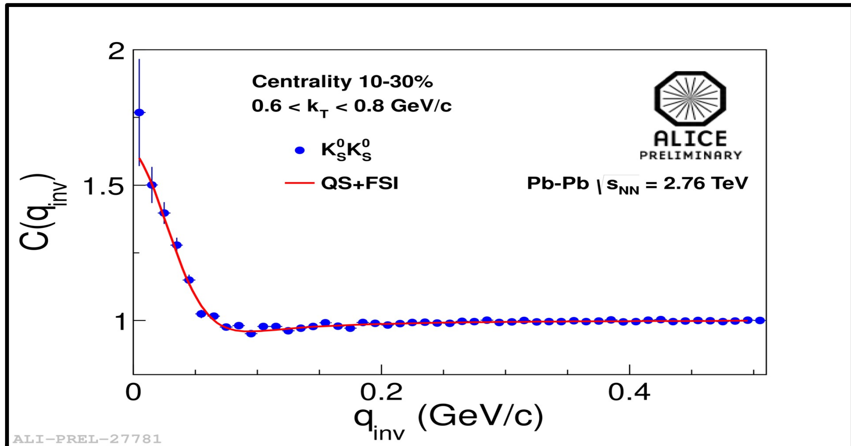
- PID via $\pi+\pi-$ decay channel (purity~95%), p_T up to 2.0 GeV/c
- **strong FSI and QS** lead to femtoscopic effect, both included in the fit (Lednicky &Lyuboshitz model, Sov.J.Nucl.Phys. 35(1982)770)
- **no Coulomb suppression**

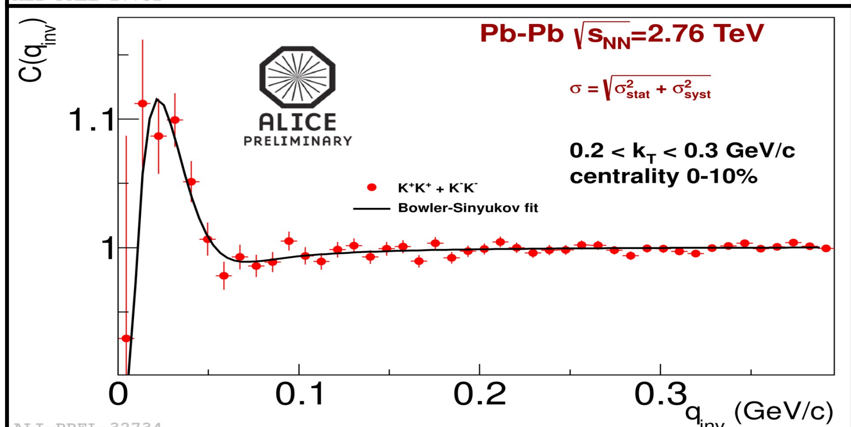
Charged kaons:

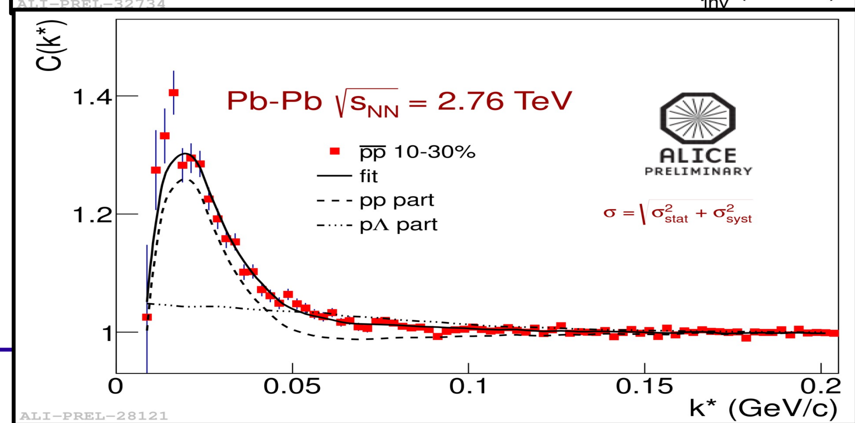
- PID: TPC+TOF, p_T range up to 1.5 GeV/c
- **QS and Coulomb repulsion**, Bowler-Sinyukov fit: $C(q_{inv}) = (1-\lambda) + \lambda K(q_{inv})(1 + exp(-R^2 q_{inv}^2))$, $K(q_{inv})$ - Coulomb function,

Protons ((anti-) protons]

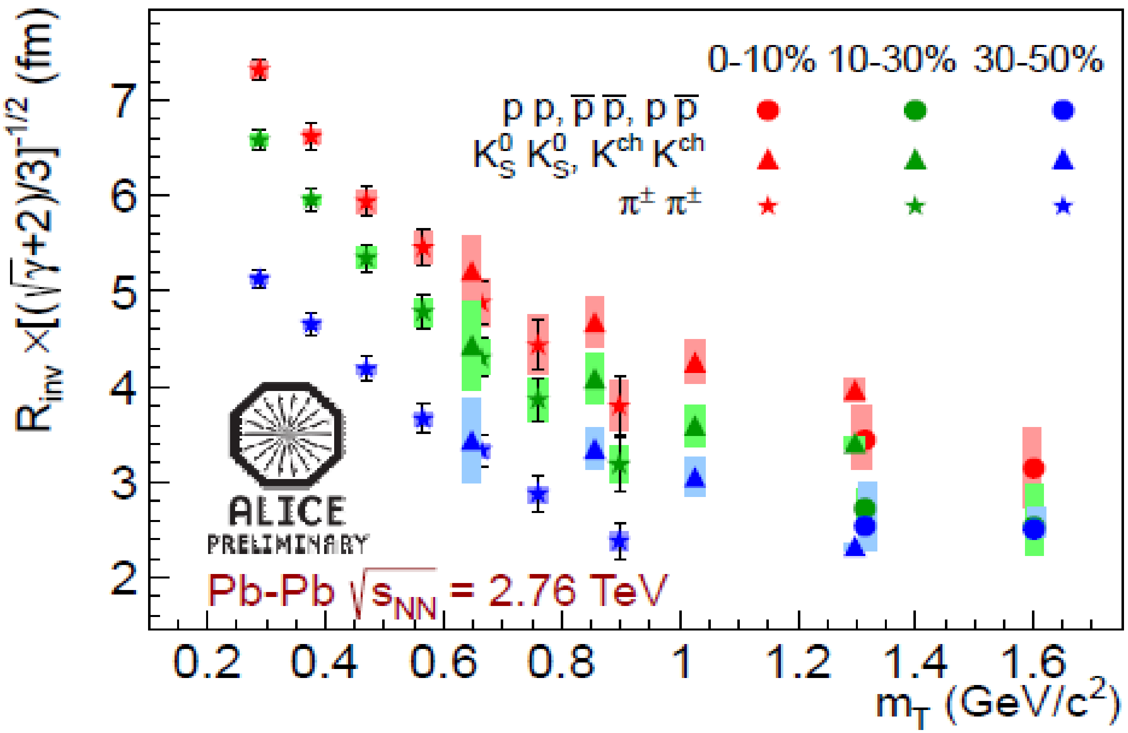
- PID: TPC+TOF
- **QS, Coulomb and Strong FSI** included in the fit, fit includes also residual pΛ correlations







m_T scaling with different masses in Pb-Pb

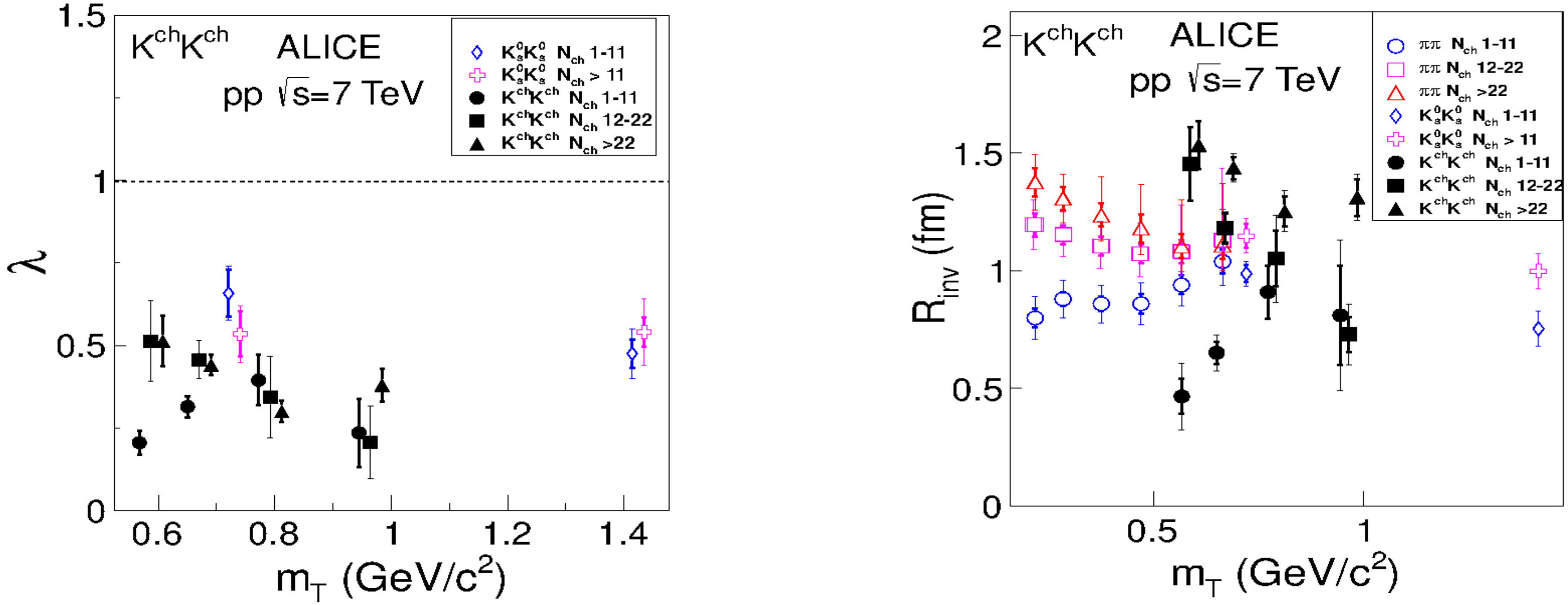


Approximate m_T scaling after taking into account kinematics.

(see THERMINATOR: A. Kisiel, T. Taluc, W. Broniowski, W. Florkowski: Comput.Phys.Commun. 174 (2006) **669-687**; and also Maciej Szymanski's QM2012 talk "Meson and baryon femtoscopy in heavy-ion collisions at ALICE").

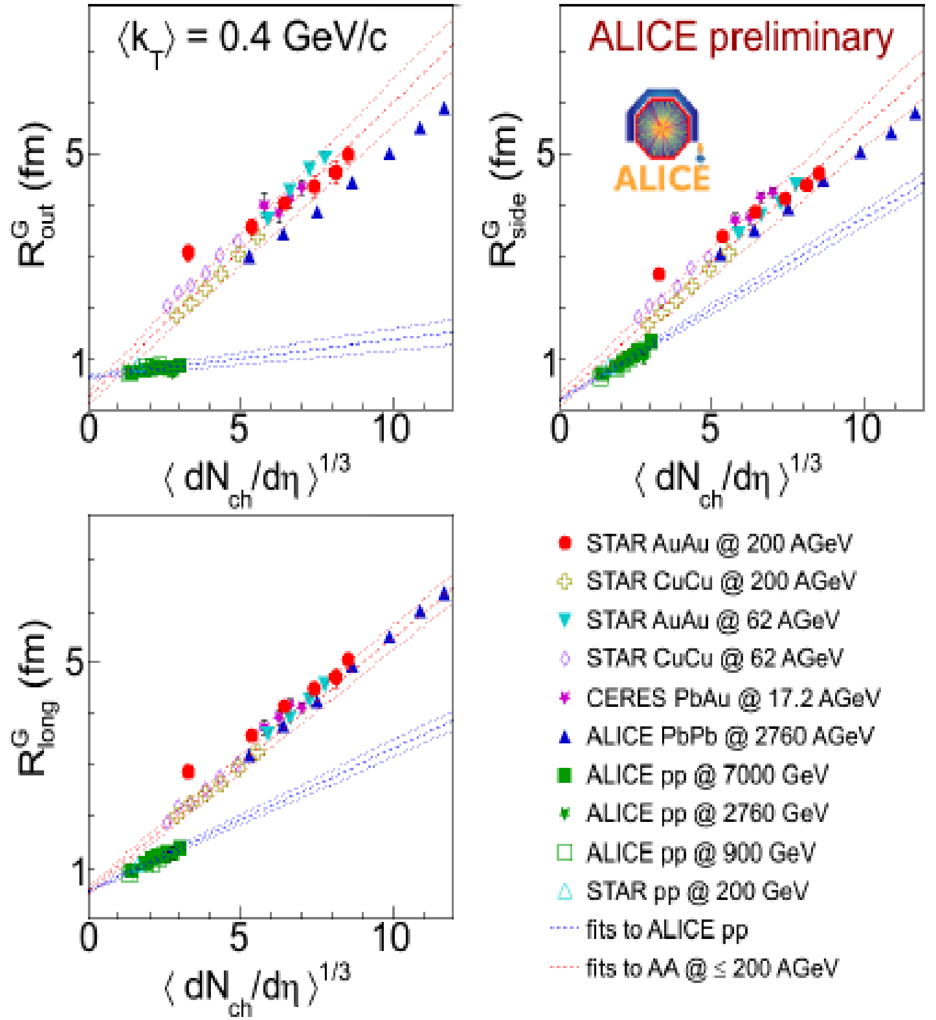
m_T-dependence in pp @ 7 TeV

From : B. Abelev et al. (ALICE Collaboration) Phys. Rev. D 87, 052016 (2013)



- k_T dependence of radii is different at small and large multiplicity bins
- decrease of size with decreasing multiplicity
- indication on breaking of m_T scaling $R_K > R_\pi$

Comparison of femtoscopy radii in heavy ion and pp collisions



- Linear scaling with $(dN_{ch}/d\eta)^{1/3}$ is observed both in pp and Pb-Pb
- Radii increase with multiplicity both in pp and Pb-Pb but with different slopes

Summary

- ALICE measurements significantly expanded the existing radii world systematics in HI collisions: homogeneity volume 2 times larger than at RHIC

- R_{inv} decreases with increasing transverse mass and increases with increasing multiplicity
- Approximate m_T scaling for pions, kaons and protons is observed

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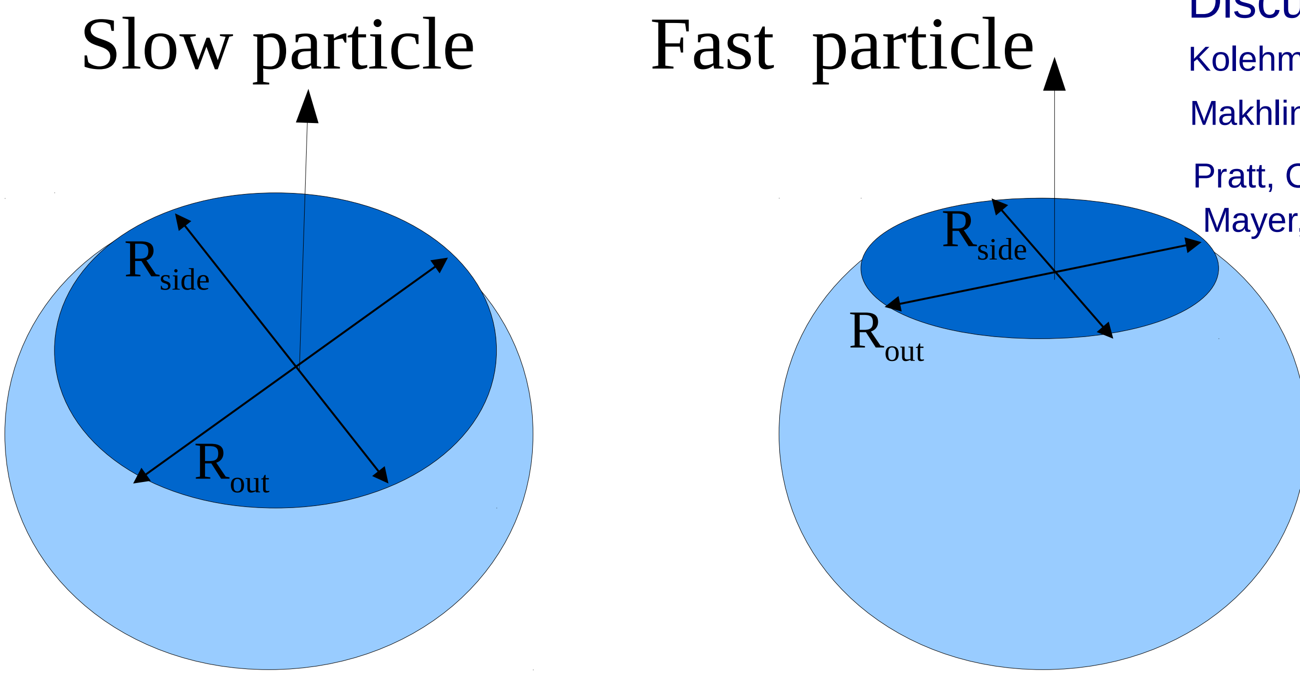
- In pp collisions R_{inv} increases with increasing multiplicity similarly to HI
- k_T dependence of radii is different at small and large multiplicity bins
- Indication on breaking of m_T scaling was observed

Additional slides

Femtoscopy: expanding source

- **x-p** correlations -> interference dominated by particles from nearby emitters.
- interference probes only parts of the source at close momenta – **homogeneity regions.**
- longitudinal and transverse expansion of the source -> significant reduction of the radii with increasing pair velocity, consequently with k_T (or $m_T=(m^2+k_T^{2})^{1/2}$)



Discussed in e.g.:

Kolehmainen, Gyulassy'86

Makhlin-Sinyukov'87

Pratt, Csörgö, Zimanyi'90

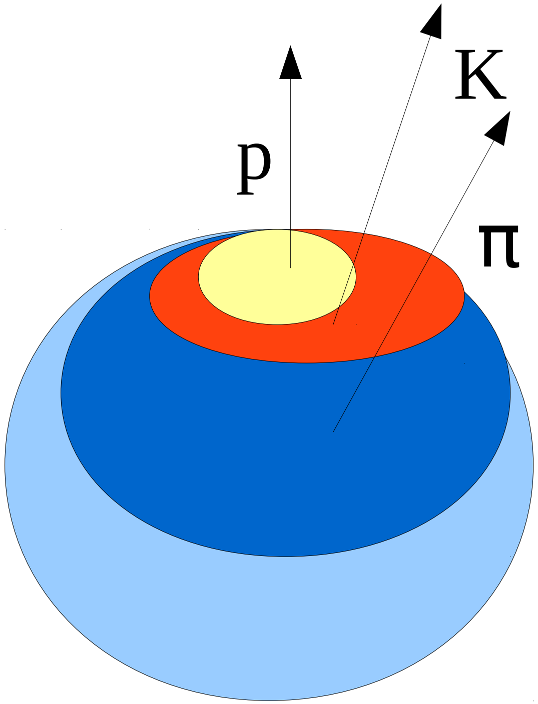
Mayer, Schnedermann,Heinz'92

$R_{side} \sim R/(1+m_T\beta_T^{2}/T)^{½}$ $\quad$ β_T collective transverse flow

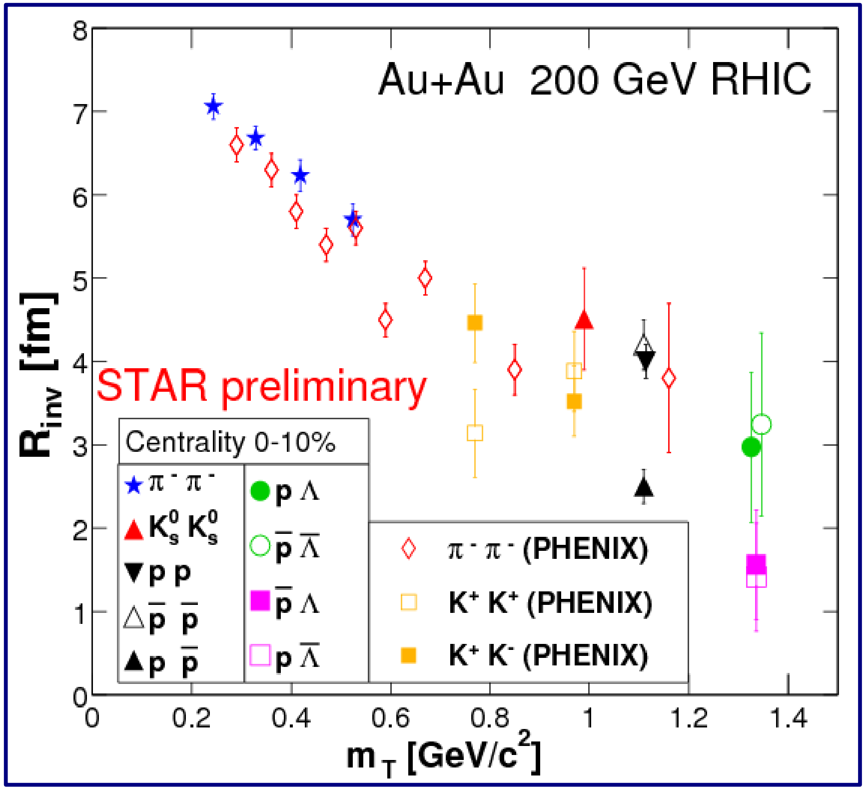
$R_{long} = \tau\ (T/m_T)^{1/2}$, assuming a longitudinal boost invariant expansion

Femtoscopy: expanding source

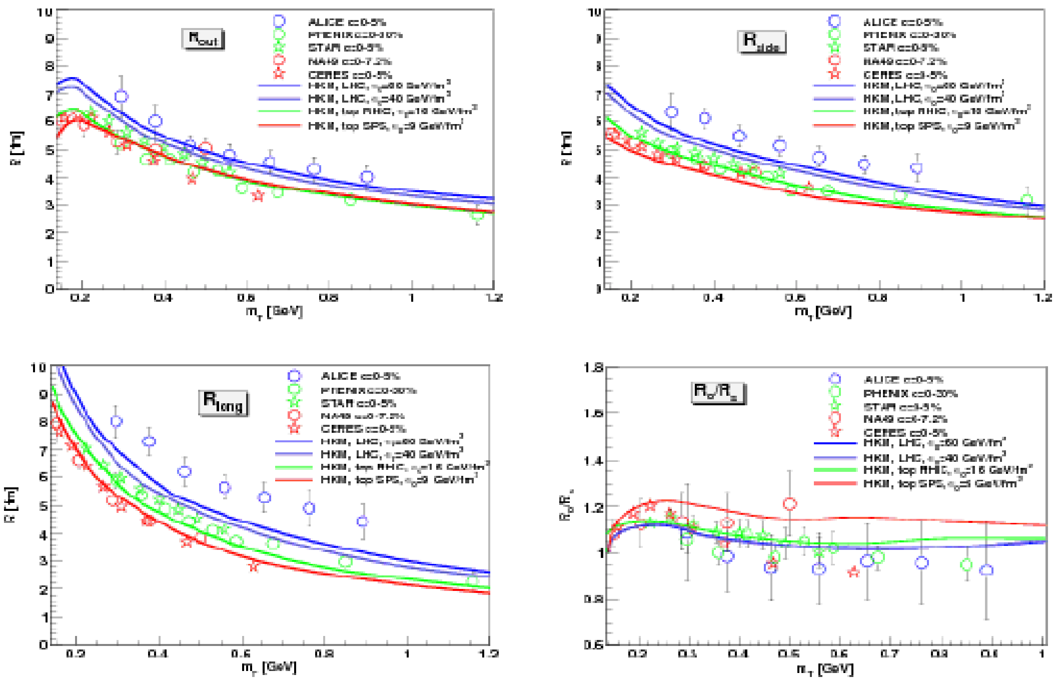
- Study of m_T-dependence of correlation radii. In heavy ions collisions at RHIC & SPS approximate m_T-scaling was observed: $m_T(KK) > m_T(\pi\pi)$, $R(KK) < R(\pi\pi)$ – indication on effects of hydrodynamic expansion.

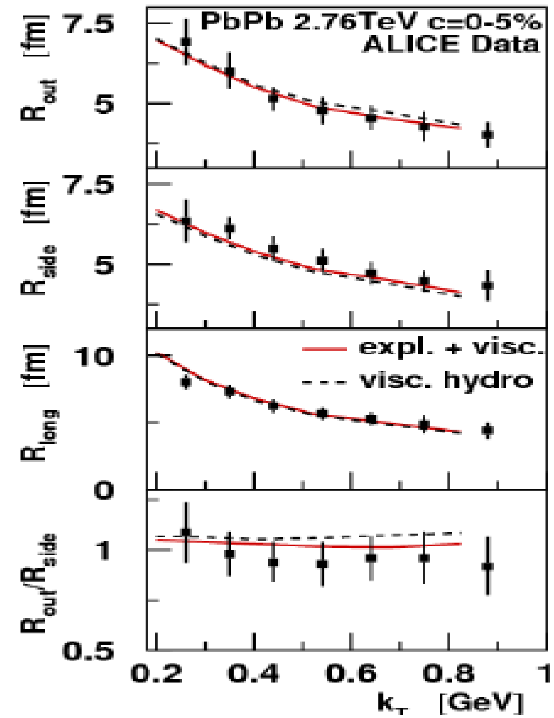


Eur. Phys. J. C 49, 75 (2007)



Theoretical interpretations





Yu. Karpenko, Yu. Sinyukov, Phys.Lett. B688 (2010) 50-54

Hydro-Kinetic Model: **the same hydrokinetic basis as was used for RHIC** supplemented by hadronic cascade model at the latest stage of the evolution:.**The following factors are important**: a presence of prethermal transverse flow, a crossover transition between quark-gluon and hadron matters, non-hydrodynamic behavior of the hadron gas at the latest stage, and correct matching between hydrodynamic and non-hydrodynamic stages.

P. Bożek,Phys.Rev. C83 (2011) 044910

3D relativistic viscous hydrodynamics

Glauber model initial conditions

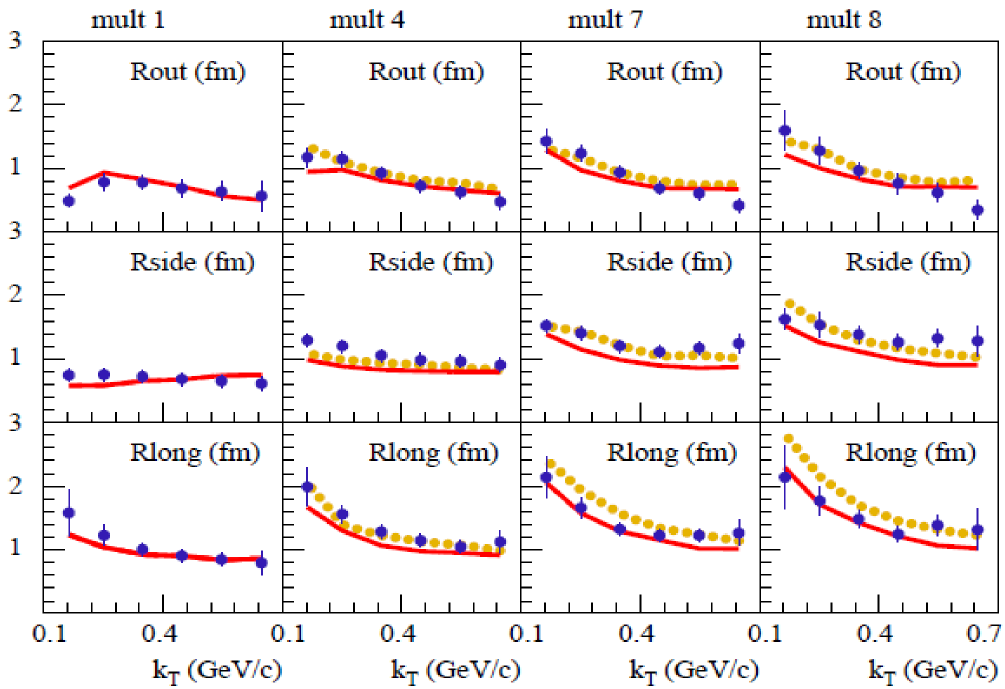
EoS based on lattice results and hadron-gas model- crossover.

The viscosities and the EoS are the same as used for RHIC energies.

Theoretical interpretations: EPOS

K. Werner, K. Mikhailov, Yu. Karpenko, T. Pierog arXiv:1104.2405

Modified EPOS model combining string dynamic, hydrodynamics and hadron cascade



	N_c	$dN_{ch}/d\eta$
mult1	1-11	3.2
mult4	23-29	13.6
mult7	45-57	24.3
mult8	58-149	31.1

At large multiplicity bins in pp high string density => the usual string models has to be modified ! Rather than breaking independently, the strings will constitute multiple flux tubes matter used as initial conditions for hydrodynamical evolution