Two-pion Bose-Einstein correlations in Pb-Pb collisions at 2.76 TeV with ALICE

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Quark Matter · Annecy
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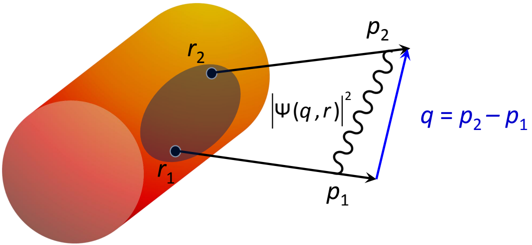
Physics motivation

- Measure the space-time properties of central nuclear collisions by using the Bose-Einstein enhancement of identical pion pairs.
- Look for signatures of collective behavior by studying the source size as a function of particle transverse momentum.
- Compare our measurements to previous ones at lower energies.
- Confront our experimental data with model predictions.

Two-particle interferometry

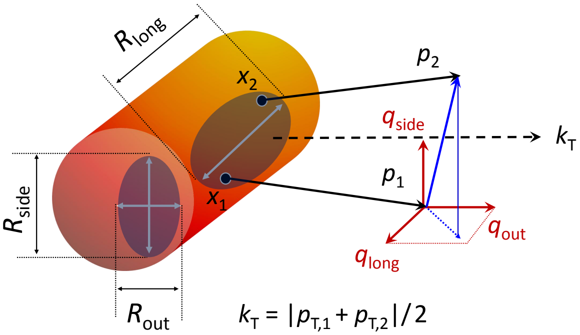


- The space-time properties of the emitting source can be investigated through measurements of the correlation between two identical bosons, reflected in the pair wave function $\Psi(q, r)$, using the correlation function

$$C(q) = \int \mathrm{d}^4 r \, S(q, r) \, |\Psi(q, r)|^2 .$$

- Bose-Einstein (BE) correlations modify the wave function such that it can be used to probe the source, i.e. the source emission function $S(q, r)$ can be deduced from the measured correlation C.

Reference frame and sizes

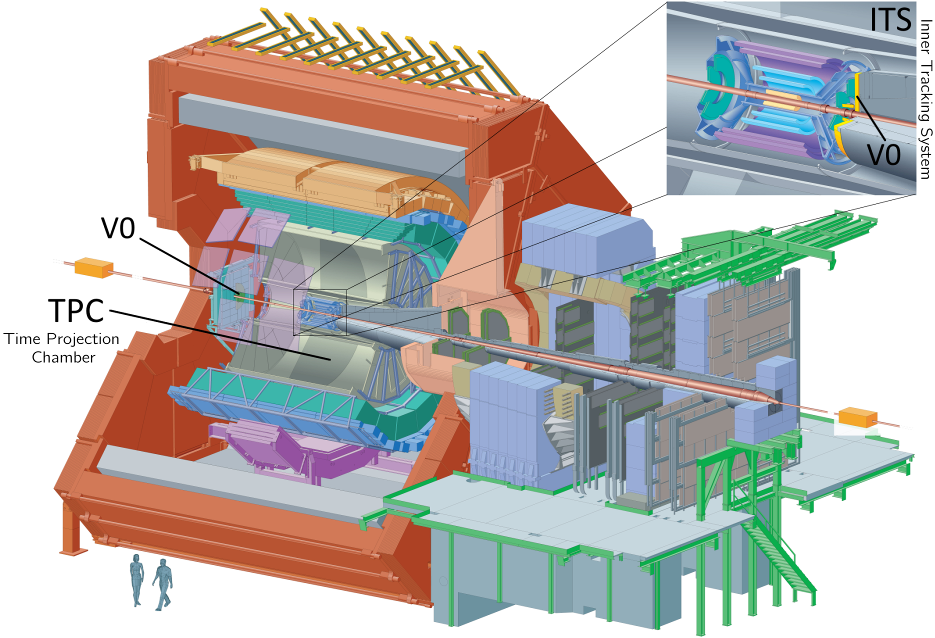


By choosing an appropriate reference frame, three system sizes can be accessed:

- R_{side} is the *geometrical transverse size*.
- R_{long} used to deduce *time of freeze-out*.
- R_{out} depends on both space and time, i.e. has components from *emission duration*.

Experimentally, $C(q) = A(q)/B(q)$, where $A(q)$ is the measured distribution of pair momentum difference $q = p_2 - p_1$, and $B(q)$ is a reference distribution of particles from different events which are expected not to have BE correlations.

ALICE – A Large Ion Collider Experiment

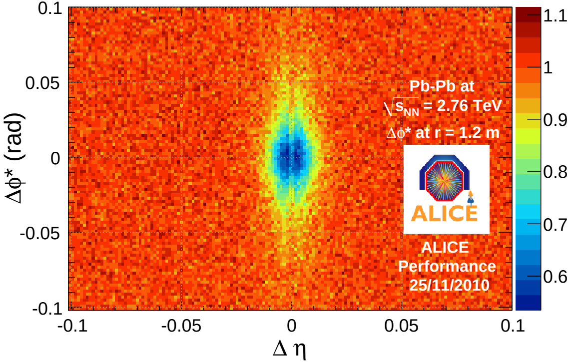


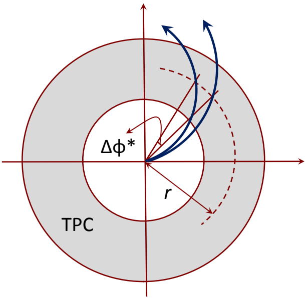
Systematic effects I

Track merging effect: two tracks with very similar trajectories inside the TPC are not reconstructed or are reconstructed as a single track.

- Require a minimum two-track separation within the TPC:

$$\Delta\phi^{\star}(r) = \varphi_2 - \varphi_1 + \arcsin\left(0.075 \cdot r/p_{\mathrm{T},2}\right) - \arcsin\left(0.075 \cdot r/p_{\mathrm{T},1}\right).$$



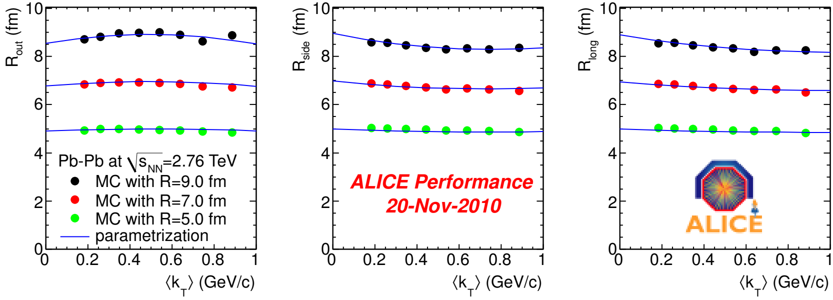


- The pair inefficiency in the separation variable $\Delta\phi^{\star}$ is found to be sharpest at a cylindrical radius $r = 1.2$ m.

Systematic effects II

Momentum resolution effect: the correlation peak appears wider and smaller due to the finite momentum resolution in the TPC.

- Radii reconstructed in Monte Carlo simulations with fixed radii of 5, 7, and 9 fm by applying pair weights.



- A correction by up to 4% applied to the measured radii.

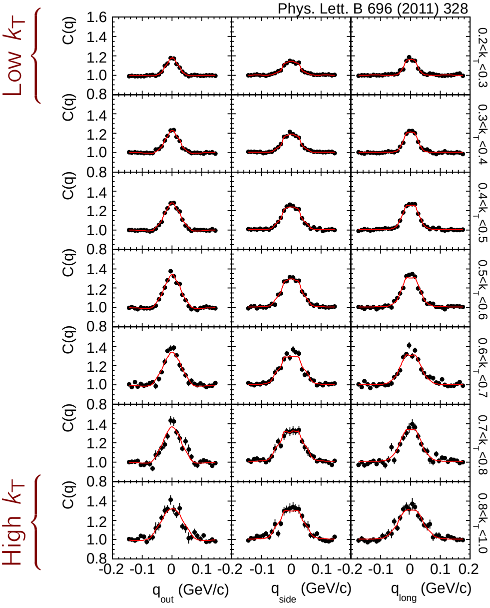
Correlation functions for central Pb-Pb collisions

- Correlation functions measured in three dimensions (out, side, long) at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV.
- Fitted using the Bowler-Sinyukov formula:

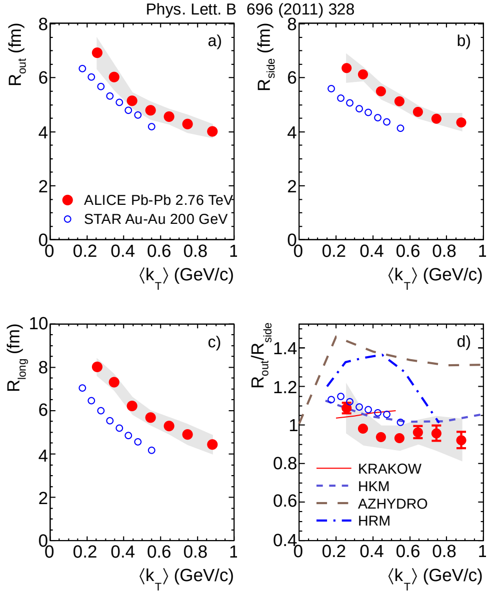
$$C(q) = \mathcal{N}\{(1-\lambda) + \lambda K(q_{\mathrm{inv}})\,[1 + G(q)]\},$$
$$G(q) = \exp\left[-(R_{\mathrm{out}}^2 q_{\mathrm{out}}^2 + R_{\mathrm{side}}^2 q_{\mathrm{side}}^2) + R_{\mathrm{long}}^2 q_{\mathrm{long}}^2)\right],$$

with λ the correlation strength and $K(q_{\mathrm{inv}})$ the Coulomb factor.

- Seven ranges in pair transverse momentum k_{T} ($0.2 - 1.0$ GeV/c).
- BE peak width increases with k_{T}.
- The plot shows projections of the 3D correlation functions (points) as well as of the 3D fits (lines).



Transverse momentum dependence



LHC vs. RHIC radii

- ALICE measures radii up to 35% larger than those measured at RHIC in central Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
- The radii show a decreasing trend with increasing k_T, characteristic feature of expanding particle sources.
- The ratio R_{out}/R_{side} is flat within errors and comparable or smaller than at RHIC.
- Models tuned to reproduce RHIC data still hold at LHC, e.g. KRAKOW, HKM.

Models overview

KRAKOW

Bożek, Chojnacki, Florkowski, et al.
Phys.Lett.B **694**(2010)238

- Hydro-dynamic model.
- Predictions for PbPb are made using LHC pp data and Glauber.
- EoS based on lattice results and hadron-gas model.
- Parameters: $\tau_\mathrm{i} = 0.25$ fm$/c$, $T_\mathrm{f} = 150$ MeV.
- $\langle \mathrm{d}N_\mathrm{ch}/\mathrm{d}\eta \rangle = 2161$ (central).

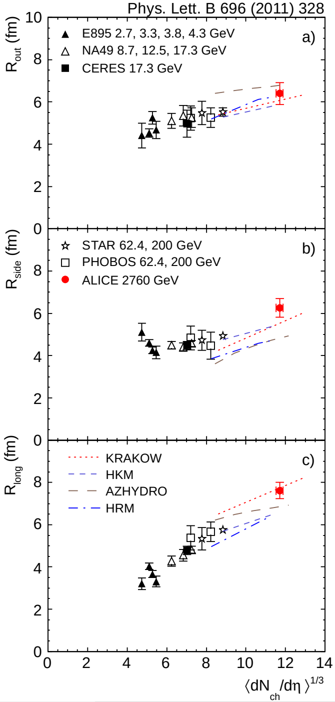
HKM

Sinyukov, Akkelin, and Karpenko
J.Phys.G **35**(2008)054001

- Hydro-kinetic model.
- Continuous 4D particle emission of the expanding fireball.
- Initial conditions from Color Glass Condensate (CGC).
- Parameters: $\tau_0 = 1$ fm$/c$, $T_\mathrm{f} = 165$ MeV.
- $\langle \mathrm{d}N_\mathrm{ch}/\mathrm{d}y \rangle = 1570$ (central).

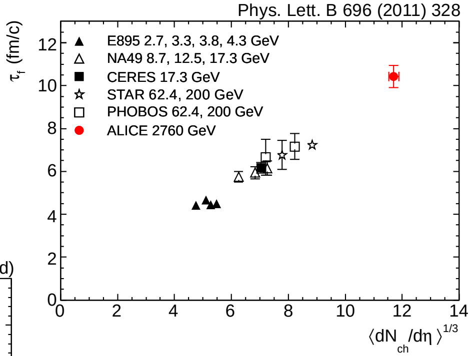
Beam energy dependence

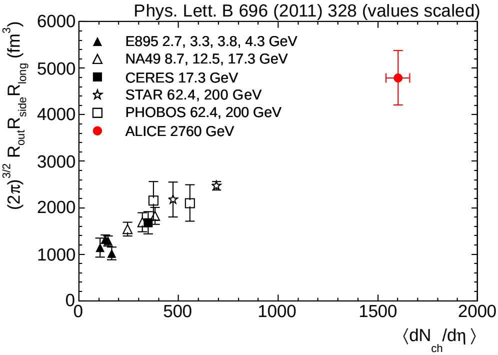
- Radii at $k_T = 0.3$ GeV$/c$ are compared with measurements at lower energies.
- Scaling of the radii with $\langle dN_{ch}/d\eta \rangle^{1/3}$ is observed.
- ALICE measurement significantly extends the range of the radii world systematics.
- The observed growth with energy is roughly reproduced by all model predictions.



Time evolution and homogeneity volume

- R_{long} is proportional to the total duration of the longitudinal expansion.
- The measured decoupling time τ_f is about 40% larger than at RHIC.





- The quantity $(2\pi)^{3/2} R_{\text{out}} R_{\text{side}} R_{\text{long}}$ is related to the volume of the homogeneity region.
- In ALICE, it is found to be about twice the value measured at most central collisions at RHIC.

Summary

ALICE measurements significantly expand the range of the existing radii world systematics.

- The pion source radii measured in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, are larger up to 35% than those at RHIC.
- Transverse momentum dependence is consistent with hydrodynamic models tuned to reproduce RHIC data.
- The homogeneity volume is found to be about twice the size measured at most central collisions at RHIC.
- Besides being larger, the fireball formed in nuclear collisions at LHC lives longer, with a decoupling time that exceeds the one measured at RHIC by 40%.

Backup

Data analysis

- Data sets:
  - Runs 137161/162, 137365/366: $\sim$ 300k events
  - Most central (0-5%): $\sim$ 16k events
  - HIJING LHC10e11: 103032 events
  - THERMINATOR LHC10e15: 86796 events
- Event selection:
  - For 5% centrality: $\langle dN_{ch}/d\eta \rangle = 1601 \pm 60$ (syst.)
  - Primary vertex within ± 12 cm of the nominal IP
  - Pseudorapidity range $|\eta| < 0.8$
- Track selection:
  - Primary pions: $0.2 \leq p_T \leq 2.0$ GeV/c
  - Two-track cut: $\Delta\phi^\star = \pm 0.02$, $\Delta\eta = \pm 0.01$
    ($r\Delta\phi < 1.2$ cm, $z < 2.4$ cm, at $r = 1.2$ cm)

More models

AZHYDRO

Frodermann, Chatterjee, and Heinz
J.Phys.G **34**(2007)2249

- Hydro-dynamic model.
- Vary initial entropy density to control final charged multiplicity.
- EoS with transition from QGP above T_c to hadron resonance gas.
- Predictions defined by initial entropy density s_0.

HRM

Humanic
Phys.Rev.C **79**(2009)044902

- Hadronic rescattering model.
- Superimpose PYTHIA pp events with respect to atomic number, overlap fraction, and geometry.
- Assume all particles have the same proper time for hadronization ($\tau = 0.1$ fm/c).
- Only hadronic degrees of freedom, no partonic contributions.