Measurements of two-particle correlations in pp collisions at $\sqrt{s} = 900$ GeV with the ALICE experiment[§]

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on behalf of the ALICE Collaboration

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Physics motivation

- Look for signatures of collective behavior in pp collisions at LHC energies
  - by using the Bose-Einstein enhancement of identical-pion pairs to deduce the size of the pion source, and
  - by studying the source size as a function of event multiplicity and particle transverse momentum.
- Measurement in pp interesting in itself, but also crucial as reference for heavy-ion collisions.

Bose-Einstein correlations

The space-time properties of the emitting source in elementary particle collisions can be investigated through measurements of Bose-Einstein correlations (BEC) between identical bosons.

- The interference is studied using the correlation function (CF)

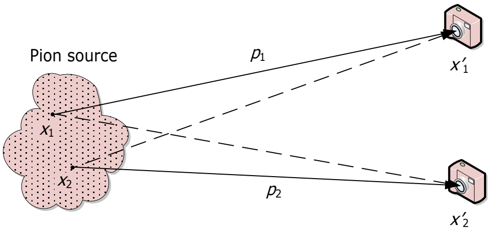
$$C(p_1, p_2) = \frac{N(p_1, p_2)}{N(p_1)N(p_2)}.$$

- Since BEC are manifest at small relative momenta, C is measured using the distribution of the variable q,

$$q = \sqrt{-(p_1 - p_2)^2} = \sqrt{m_{\text{inv}}^2 - 4m_\pi^2}.$$

- Experimentally,

$$C(q) = \frac{A(q)}{B(q)}.$$



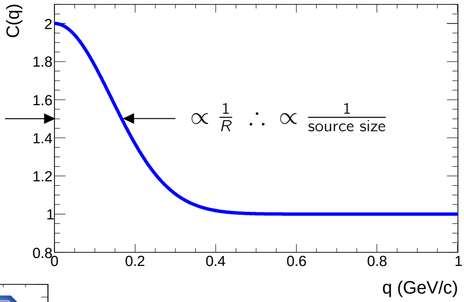
$A(q)$ is the measured distribution of pair momentum difference q, and $B(q)$ is a reference distribution built by using pairs of particles from different events which by construction are expected to have no BEC.

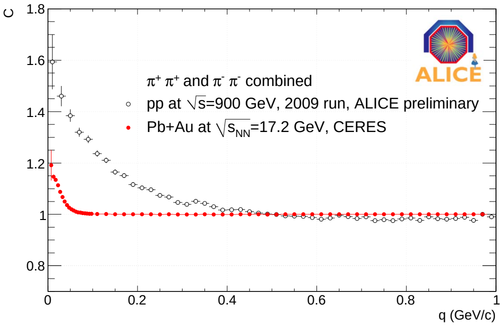
HBT radius

- In this technique, also known as Hanbury Brown-Twiss (HBT) interferometry, a commonly used parametrization of $C(q)$ is

$$C(q) = 1 + \lambda e^{-(Rq)^2},$$

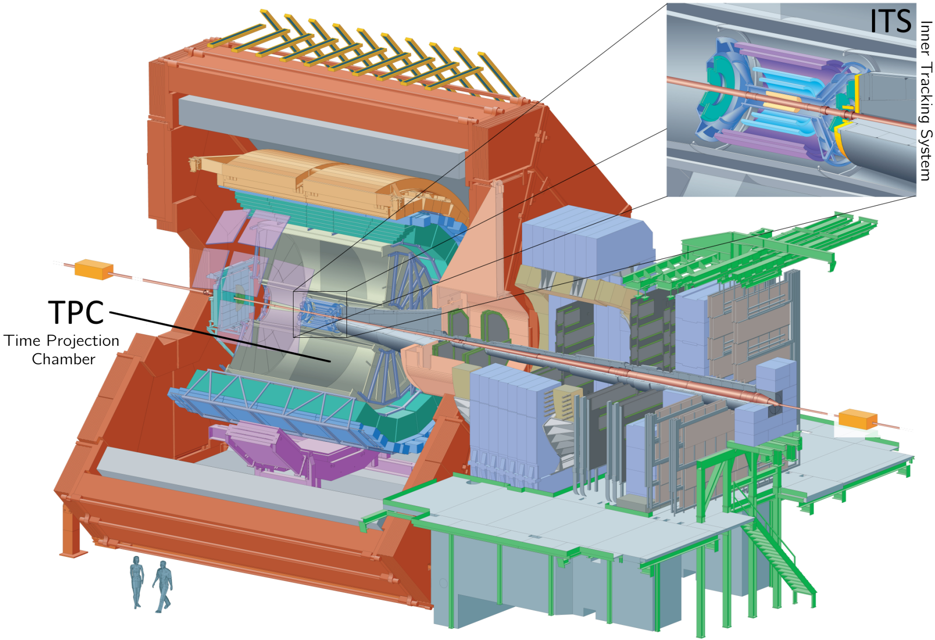
where R is the effective size of the emission region and the parameter λ measures the strength of BEC.





It has been observed that the HBT radius allows to distinguish between different collision systems, e.g. pp and Pb+Au.

ALICE – A Large Ion Collider Experiment



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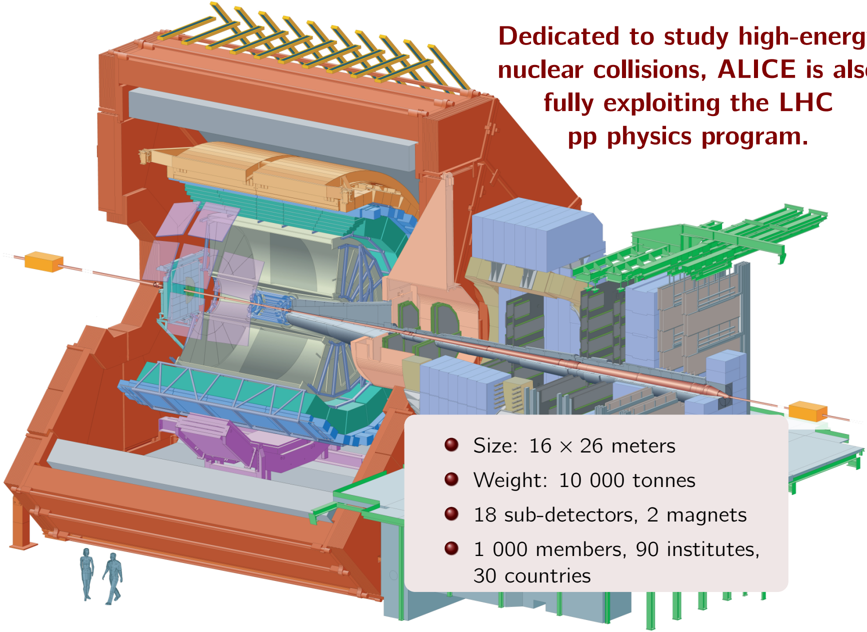
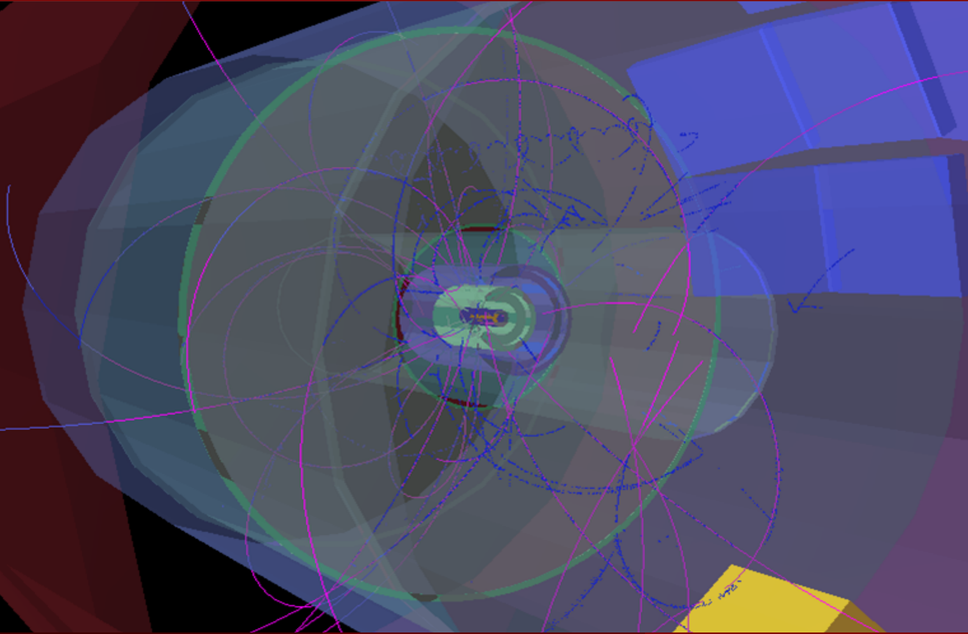


Dedicated to study high-energy nuclear collisions, ALICE is also fully exploiting the LHC pp physics program.

- Size: 16×26 meters
- Weight: 10 000 tonnes
- 18 sub-detectors, 2 magnets
- 1 000 members, 90 institutes, 30 countries

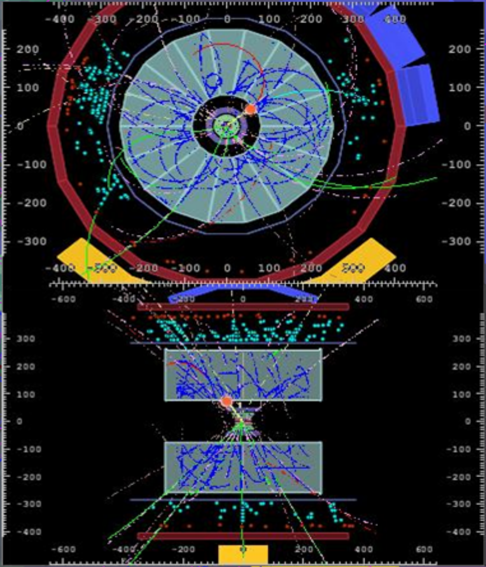
Running conditions



Running conditions

Data collected during the first stable-beam period of the LHC commissioning in December 2009.

- 250k events analyzed.
- Recorded with $B = 0.5$ T.
- Using tracks registered by the ITS and TPC detectors.
- First results limited by available statistics.

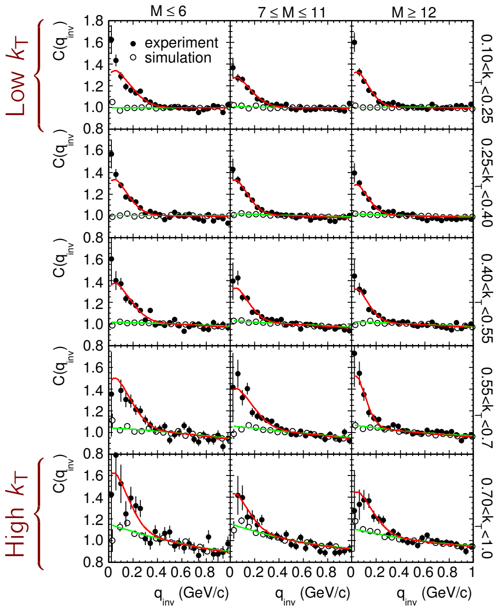


Identical pion correlation functions

- Analysis performed only for the one-dimensional CFs, $C(q_{\text{inv}})$, due to the limited available statistics.
- Combined $\pi^+\pi^+$ and $\pi^-\pi^-$ pairs.
- CFs studied in bins of event multiplicity, M, and of transverse momentum, $k_T = \frac{1}{2}|p_{T,1} + p_{T,2}|$.
- Gaussian function used to fit the BEC peak,

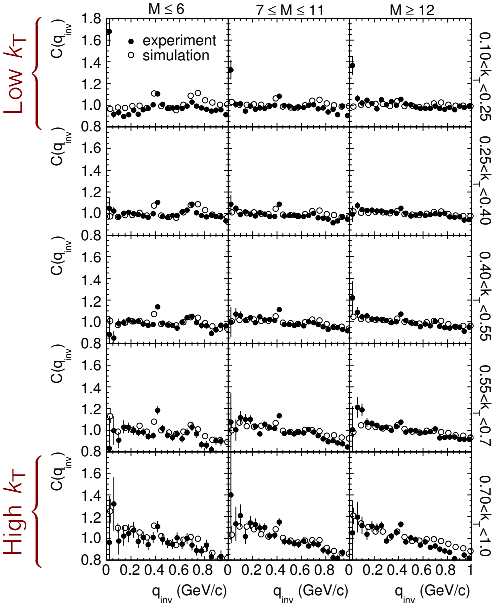
$$G(q_{\text{inv}}) = \lambda \cdot \exp\left(-R_{\text{inv}}^2 q_{\text{inv}}^2\right),$$

  with λ the correlation strength, and R_{inv} the HBT radius.
- Long-range correlations develop as k_T increases.
- Simulations made using PHOJET.

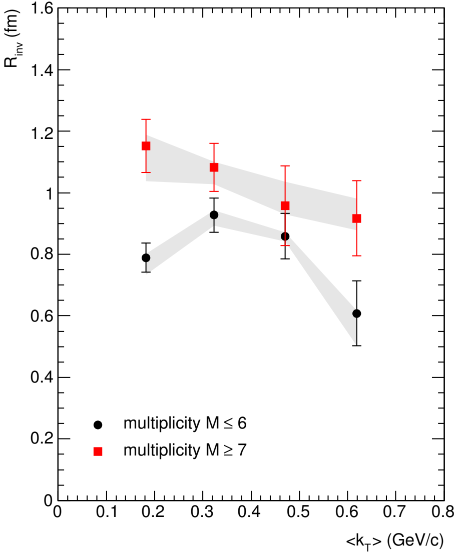


Non-identical pion correlation functions

- $\pi^+\pi^-$ correlations used to verify the description of the CF baseline.
- Mutual Coulomb interaction and meson decay peaks are reproduced reasonably well by PHOJET.
- The same model can be used to describe the correlation baseline for identical pion CFs.
- Since the structures are different in like-sign and unlike-sign pions, the ratio of the two CFs was not used.
- Baseline has to be treated properly.



$R_{\rm inv}$ vs. M and $R_{\rm inv}$ vs. k_T



Extracting the HBT radii

1. Simulation points are fitted with

$$D(q_{\rm inv}) = a + b\, q_{\rm inv} + c\, q_{\rm inv}^2 .$$

2. The experimental CF is fitted by

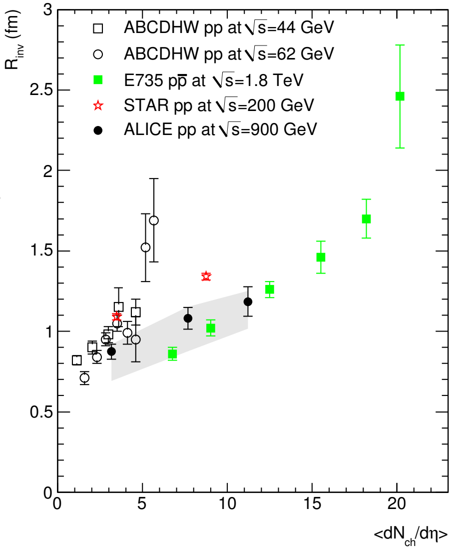
$$C(q_{\rm inv}) = \{(1-\lambda) + \lambda K(q_{\rm inv}) \times \left[1 + \exp\left(-R_{\rm inv}^2 q_{\rm inv}^2\right)\right]\} D(q_{\rm inv}),$$

taking $D(q_{\rm inv})$ from the PHOJET fit and adjusting λ and $R_{\rm inv}$. The factor $K(q_{\rm inv})$ accounts for the Coulomb effect.

- Systematic errors (shaded bands): difference between the fits using PHOJET and PYTHIA backgrounds.
- The multiplicity and k_T dependencies were analyzed separately.

Multiplicity dependence

- Source radius increases with multiplicity, consistent with previous measurements.
- Well known behavior in nuclear collisions.
  - In pp collisions, indicates that the HBT radii depend on multiplicity rather than on collision geometry.
- Systematic error includes contributions from baseline assumption, fitting procedure and background construction.



Gaussian vs. exponential fit

- Extracting the HBT radii using an exponential fit function gives results in close agreement to those obtained from a Gaussian fit.

Gaussian

$$C(q_{\text{inv}}) = \left\{(1-\lambda) + \lambda K(q_{\text{inv}}) \left[1 + \exp\left(-R_{\text{inv}}^2 q_{\text{inv}}^2\right)\right] \right\} D(q_{\text{inv}})$$

$\langle dN_{ch}/d\eta \rangle$	λ	R_{inv} (fm)
3.2	0.386 ± 0.022	0.874 ± 0.047 (stat.) $^{+0.047}_{-0.181}$ (syst.)
7.7	0.331 ± 0.023	1.082 ± 0.068 (stat.) $^{+0.069}_{-0.206}$ (syst.)
11.2	0.310 ± 0.026	1.184 ± 0.092 (stat.) $^{+0.067}_{-0.168}$ (syst.)

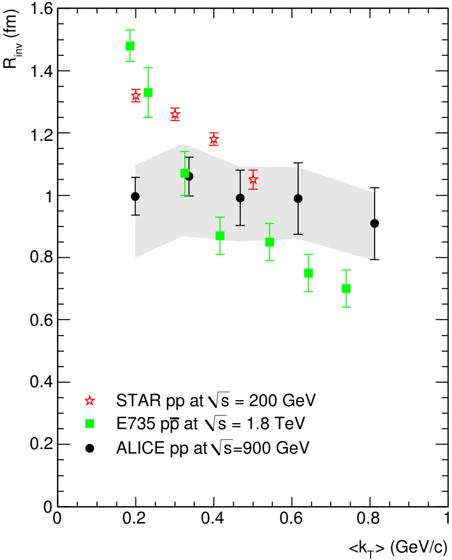
Exponential

$$C(q_{\text{inv}}) = \left[1 + \lambda \exp\left(-R_{\text{inv}} q_{\text{inv}}\right)\right] D(q_{\text{inv}})$$

$\langle dN_{ch}/d\eta \rangle$	λ	$R_{\text{inv}}/\sqrt{\pi}$ (fm)
3.2	0.704 ± 0.048	0.809 ± 0.061 (stat.) $^{+0.049}_{-0.208}$ (syst.)
7.7	0.577 ± 0.054	0.967 ± 0.095 (stat.) $^{+0.071}_{-0.206}$ (syst.)
11.2	0.548 ± 0.051	1.069 ± 0.104 (stat.) $^{+0.063}_{-0.203}$ (syst.)

Transverse momentum dependence

- Dependence on k_T: important to unravel presence of bulk, collective behavior in pp collisions.
- Our HBT radius is practically independent of k_T within the range studied.
- This result crucially depends on the baseline shape assumption.
  - If the baseline is assumed to be flat, an apparent k_T dependence emerges.
  - This is due to non-BEC that give rise to wider CFs which are misinterpreted as smaller radii.



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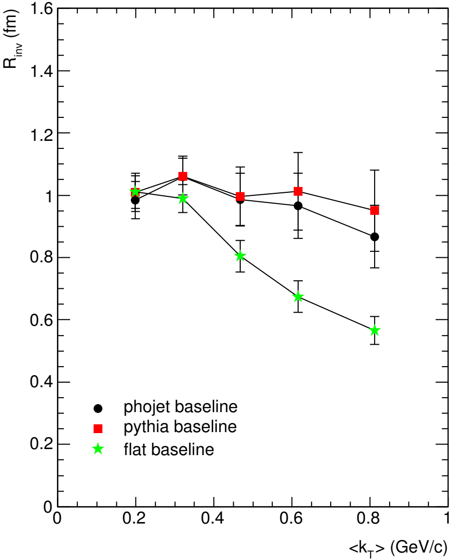

Summary

- ALICE has measured two-pion correlation functions in pp collisions at $\sqrt{s} = 900$ GeV.
- The extracted HBT radii increase with event multiplicity, in agreement with previous measurements.
- Less consistent is the transverse momentum dependence where R_{inv} is practically constant within the errors and range studied.
  - Three-dimensional analysis will give more information.
- Baseline correlations are of crucial importance.
- Results from Gaussian and exponential fits are in good agreement.

The results presented here have been published in Phys. Rev. D **82**, 052001 (2010)

Backup

Data analysis

- Data sets:
  - Runs 104068–104892, 252k events (241k good)
  - PYTHIA LHC10a12, 1762k events (1328k good)
  - PHOJET LHC10a14, 2352k events (1987k good)
- Event selection:
  - 252×10^3 minimum bias pp events
  - Trigger efficiency 95-97%
  - Primary vertex within 10 cm of TPC's center
  - Pseudorapidity range $|\eta| < 0.8$
- Track selection:
  - Transverse impact parameter $r < 2.4$ cm (TPC)
  - Longitudinal impact parameter $z < 3.2$ cm (TPC)
  - Transverse momentum range $0.15 \le p_T \le 0.65$ GeV

Gaussian vs. exponential fit (transverse momentum)

Gaussian

$\langle k_T \rangle$ (GeV/c)	λ	R_{inv} (fm)
0.20	0.35 ± 0.03	1.00 ± 0.06 (stat.) $^{+0.10}_{-0.20}$ (syst.)
0.32	0.33 ± 0.03	1.06 ± 0.06 (stat.) $^{+0.11}_{-0.19}$ (syst.)
0.47	0.30 ± 0.04	0.99 ± 0.09 (stat.) $^{+0.10}_{-0.14}$ (syst.)
0.62	0.35 ± 0.06	0.99 ± 0.11 (stat.) $^{+0.10}_{-0.13}$ (syst.)
0.81	0.31 ± 0.06	0.91 ± 0.12 (stat.) $^{+0.10}_{-0.12}$ (syst.)

Exponential

$\langle k_T \rangle$ (GeV/c)	λ	$R_{inv}/\sqrt{\pi}$ (fm)
0.20	0.63 ± 0.05	0.94 ± 0.07 (stat.) $^{+0.09}_{-0.20}$ (syst.)
0.32	0.58 ± 0.04	0.93 ± 0.07 (stat.) $^{+0.09}_{-0.20}$ (syst.)
0.47	0.55 ± 0.07	0.92 ± 0.10 (stat.) $^{+0.09}_{-0.14}$ (syst.)
0.62	0.70 ± 0.11	0.98 ± 0.14 (stat.) $^{+0.10}_{-0.14}$ (syst.)
0.81	0.60 ± 0.12	0.90 ± 0.16 (stat.) $^{+0.12}_{-0.15}$ (syst.)

Baseline correlations at various energies

- Baseline correlations grow with multiplicity and k_T, probably small at 200 GeV, but strong at 1.8 TeV.