Non-identical particle femtoscopy in Pb–Pb collision at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE at the LHC

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Introduction

What is non-identical particle femtoscopy?

- Tool to measure the space−time dimension of the particle emitting source as well as emission asymmetries between particles

Two-particle correlation function:

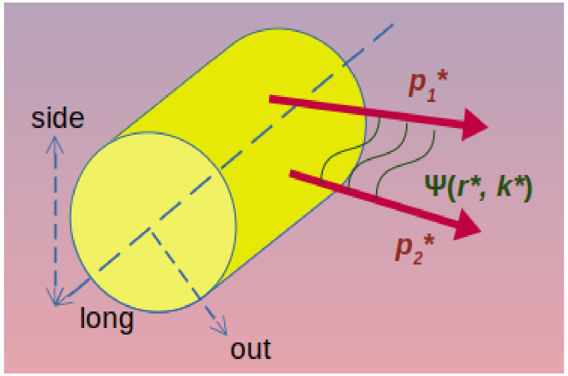
$$C(\boldsymbol{k^*}) \sim \frac{A(\boldsymbol{k^*})}{B(\boldsymbol{k^*})}$$

$A(\boldsymbol{k^*}) \rightarrow$ ***Signal***

$B(\boldsymbol{k^*}) \rightarrow$ ***Background***

Coordinate system: Pair Rest Frame (*)

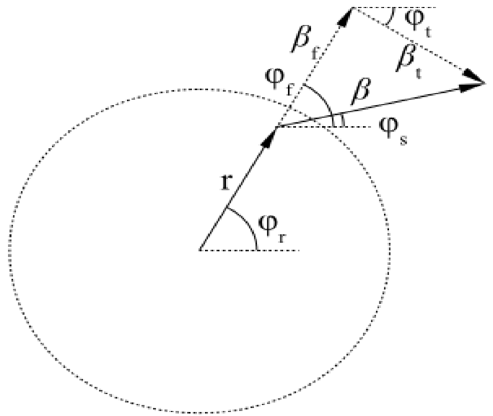
$$\boldsymbol{p_1^* = -p_2^*},$$
$$\boldsymbol{k^* = (p_1^* - p_2^*) / 2}$$



Adam Kisiel, Phy.Rev.C 81, 064906 (2010)

Pair-emission asymmetry

- The particles emitted from the source have same radial velocity (β_f) and random thermal velocities (β_t).



Adam Kisiel, Phy.Rev.C 81, 064906 (2010)

- The mean emission point of a particle:

$$<x_{out}> \propto \frac{1}{<\sqrt{(\beta_f^2+\beta_t^2)}>} \propto \frac{1}{<\sqrt{(\beta_f^2+(T/m_T)}>}$$

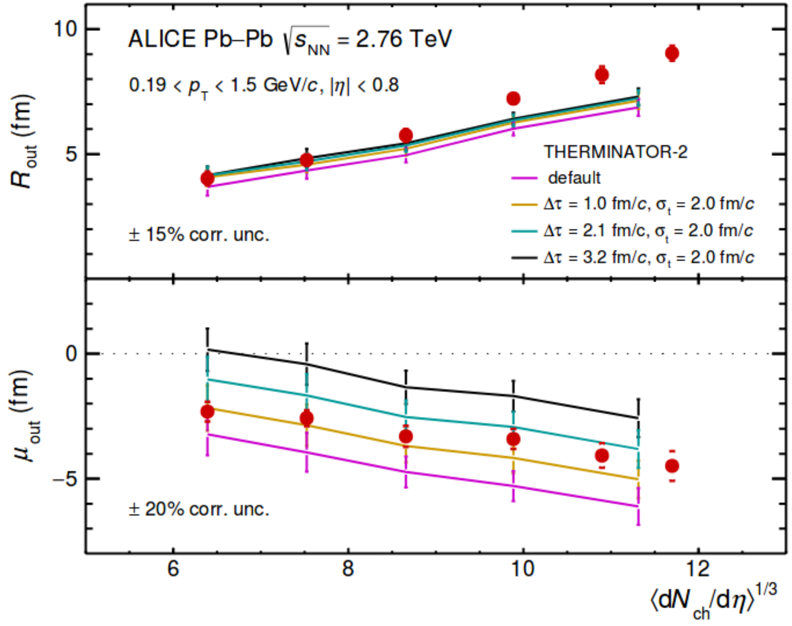
- T/m_T is smaller for heavier particles. Hence, $<x_{out}>^{light}$ is less than $<x_{out}>^{heavy}$

- The emission asymmetry between particles with different masses:

$$<\mu_{out}^{light,heavy}> = <x_{out}^{light} - x_{out}^{heavy}>$$

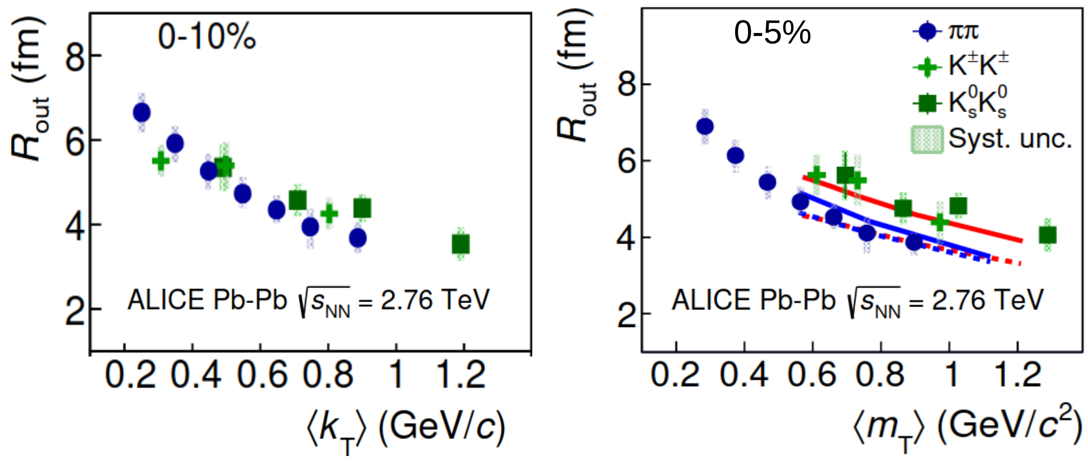
Motivation

Pion-kaon (non-identical) femtoscopy



- Source size increases with multiplicity
- Negative pair-emission asymmetry
- Presence of rescattering phase along with the radial flow

Identical pion and kaon femtoscopy



- k_T scaling of the radii
- “broken” m_T scaling of the radii

(1) ALICE Collaboration, S. Acharya et al., Phys. Lett. B 813, 136030 (2021)
(2) ALICE Collaboration, S. Acharya et al., Phys. Rev. C 96, 064613 (2017)

Focus of this analysis

- **Studying femtoscopic correlation function (in the basis spanned by spherical harmonics) for all pair combinations of charged pions and kaons in Pb−Pb collision at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV**

- **Investigating the beam-energy dependence**

- **Observing the k_{T} dependence of femtoscopic parameters**

Spherical harmonics representation of correlation function

Advantages:

- Utilises lesser statistics
- Most of the components vanish
- Only a few lower harmonics required to extract femtoscopic information

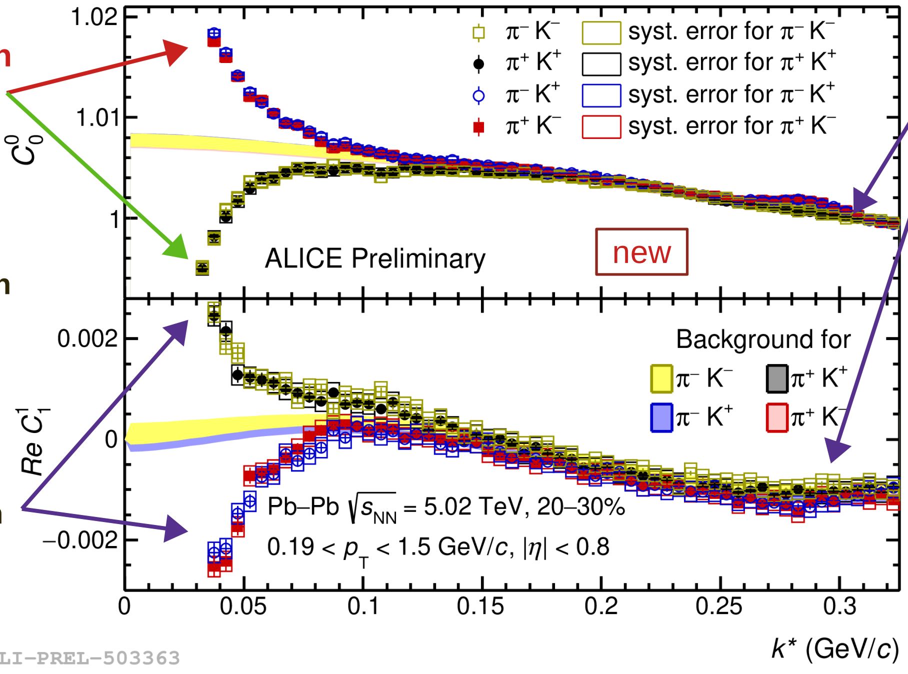
Several harmonics:

- C_0^0 $\longrightarrow$ Growth of the system size
- $Re\,(C_1^0)$ $\longrightarrow$ Longitudinal asymmetry signal
- $Re\,(C_1^1)$ $\longrightarrow$ Transverse asymmetry signal
- $Im\,(C_1^1)$ $\longrightarrow$ Should be zero, signals detector effect

Femtoscopic correlation functions (20–30% centrality)

Final-State Interaction
(Coulomb and Strong)

- **Attractive for unlike-sign pairs, repulsive for like-sign pairs**
- **Source size extraction**
- **Pair-emission asymmetry extraction**



Non-femtoscopic background [1]
(due to elliptic flow, residual correlations, etc.)

$$C^{ij}_{exp} = C^{ij}_{real} + B^{ij}$$

$$B^{ij} = a^{ij}_0 + \sum_{l=1}^{5} a_l x^{(l+1)}$$

$$C^{ij}_{real} = C^{ij}_{exp} - B^{ij}$$

- C_{exp} : experimental correlation function
- B : 6^{th}-order polynomial background (BG)
- C_{real} : BG minimised correlation function
- i, j : combinations of (+)ve and (-)ve pions and kaons forming pairs

- **BG minimised correlation functions used for fitting (see next slide)**

[1]. A. Kisiel, Acta Phys. Polon. B 48, 717 (2017)

Fitting: CorrFit Input

ALICE

- Final-State Interactions : Strong, Coulomb

  (Strong interaction is expected to be small)

- Fitting range (in *k**) : (0.0, 0.10) GeV/*c*
- Normalisation range (in *k**) : (0.15, 0.2) GeV/*c*
- Fraction of primary particles
- Momentum resolution correction

$$C(k^*) = \int S(k^*, r^*)|\Psi(k^*, r^*)|^2 d^3 r^*$$

measured correlation

pair-wave function
(interaction known)

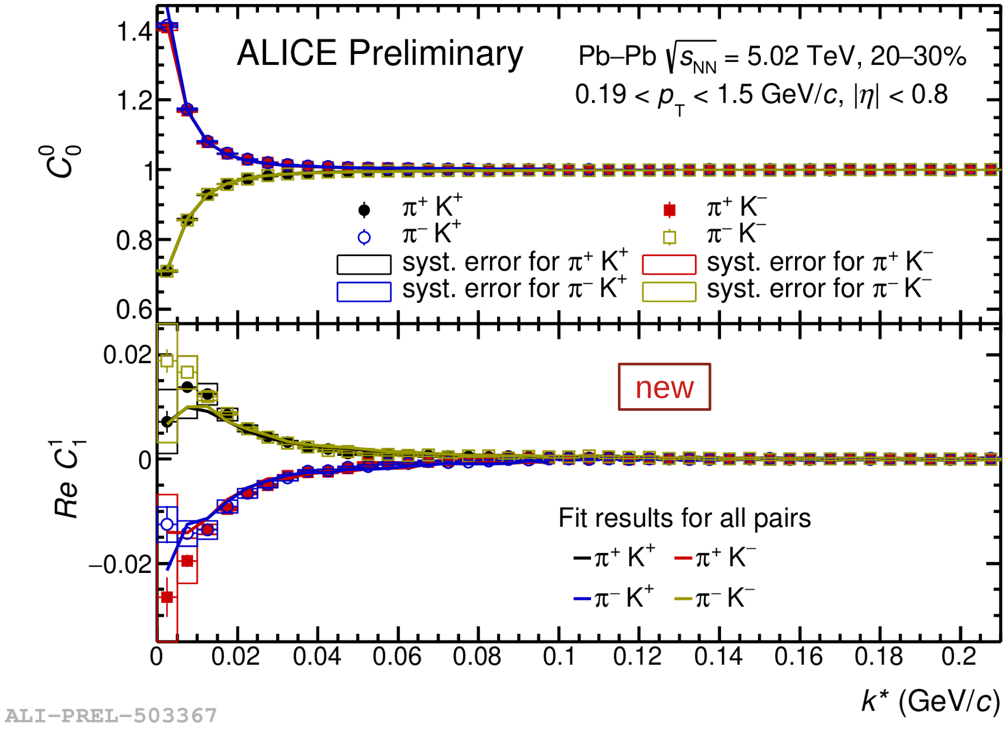
$$S(\mathbf{r}) = exp\left(-\frac{(r_{\text{out}} - \mu_{\text{out}})^2}{R_{\text{out}}^2} - \frac{r_{\text{side}}^2}{R_{\text{side}}^2} - \frac{r_{\text{long}}^2}{R_{\text{long}}^2}\right)$$

- $R_{side} = R_{out}$, $R_{long} = 1.3R_{out}$, provided as the input parameter, based on identical particle 3D femtoscopic results for pions from ALICE
- Two parameters, R_{out} and μ_{out}, have been fitted

(1) A.Kisiel, Phys. Rev. C 81, 064906 (2010)

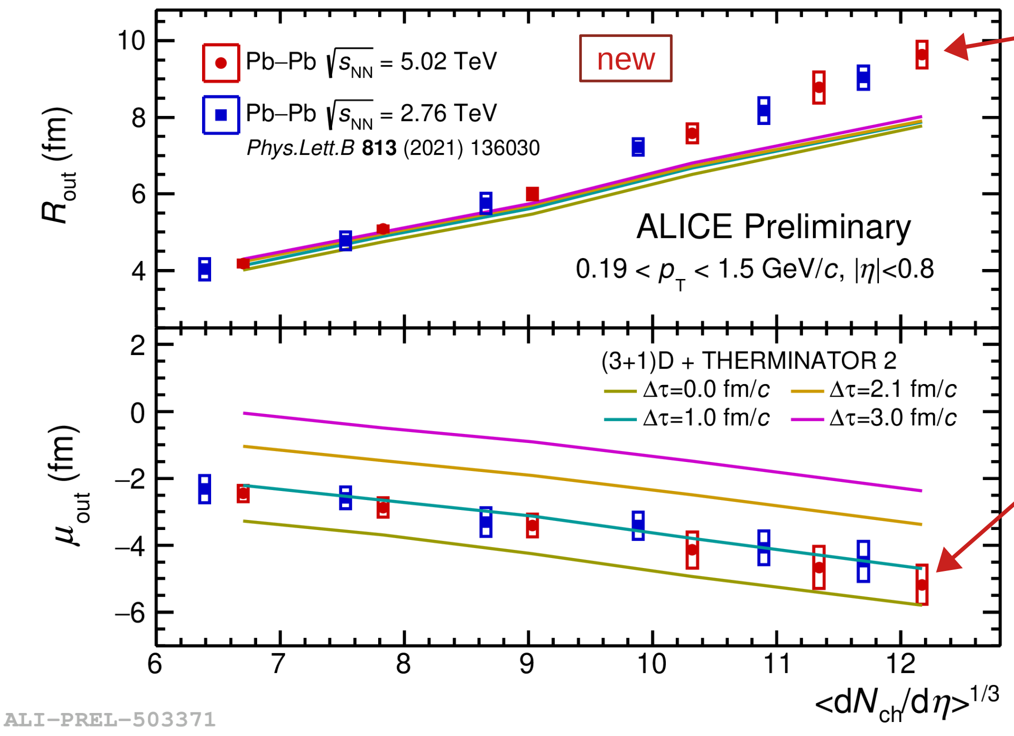
(2) ALICE Collaboration, J. Adams et al., Phys. Rev. C 93, 024905 (2016)

Fitting of correlation functions (20–30% centrality)



- Fit results from the CorrFit describe the experimental CF very well

Result: source size and pair-emission asymmetry



R_{out}

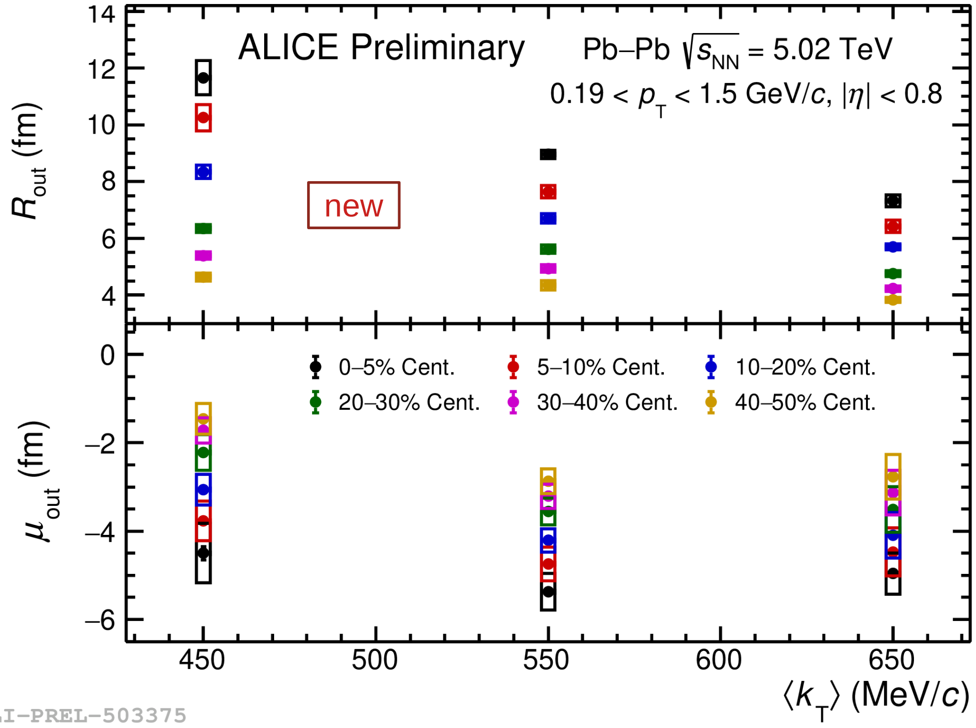
- Increases with multiplicity
- Agrees with the predictions from (3+1)D + THERMINATOR 2 model calculations for peripheral events

μ_{out}

- Negative, implying pion emitted closer to the center of the system
- Indicates the presence of radial flow
- Trend agrees with the predictions with additional delay in kaon emission, corresponds to the hadronic rescattering phase of the system

- No beam-energy dependence of the results found

Result: Femstoscopic parameters vs k_T



- Source size decreases with increasing k_T and decreasing centralities
- Emission asymmetry is smallest at k_T bin: 400-500 MeV/c

Summary:

- System size, R, and the pair-emission asymmetry, μ, increase with multiplicity, no beam-energy dependence is found
- Measurement of R agrees with the predicted ones from (3+1)D + THERMINATOR 2 model calculation for peripheral events
- R decreases with increasing k_T
- The negative value of μ indicates that pion is emitted closer to the center of the system
- Predictions of μ suggest the presence of hadronic rescattering phase along with radial flow

Thank you :)

Back Up

Spherical Harmonics (SH) representation of correlation function

$$C(k^*) = \frac{T(k^*)}{M(k^*)} \quad \longleftrightarrow \quad T(k^*) = M(k^*)C(k^*)$$

$$T(\mathbf{k}^*) = T(k^*, \theta, \phi) = \sqrt{4\pi} \sum_{l,m} T_{lm}(k^*) Y_{lm}(\theta, \phi)$$

$$M(\mathbf{k}^*) = M(k^*, \theta, \phi) = \sqrt{4\pi} \sum_{l,m} M_{lm}(k^*) Y_{lm}(\theta, \phi)$$

$$T_{lm}(k^*) = \sum_{l'm'} \tilde{M}_{lml''m''}(k^*) C_{l''m''}(k^*)$$ [1]

$$T_{l,m} = T^*_{l,-m}$$

A. Kisiel, and D. A. Brown, Phys. Rev. C, 80, 064911 (2009)