Charged kaon femtoscopy with ALICE at LHC

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Overview

- Introduction
- Motivation
- ALICE at LHC
- Analysis details
- Results
  - 1D analysis
  - 3D analysis
- Summary

Motivation: kaon femtoscopy in HI collisions.

- Study of m_T-dependence of correlation radii.

- Strong constraints for hydrodynamic models (models working well for pions should work for heavier mesons and baryons also).

- KK suffer less from the resonance contributions than $\pi\pi$ → clearer signal

- Study of $K^{\pm}K^{\pm}$ and $K_0^s K_0^s$ → consistency check

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

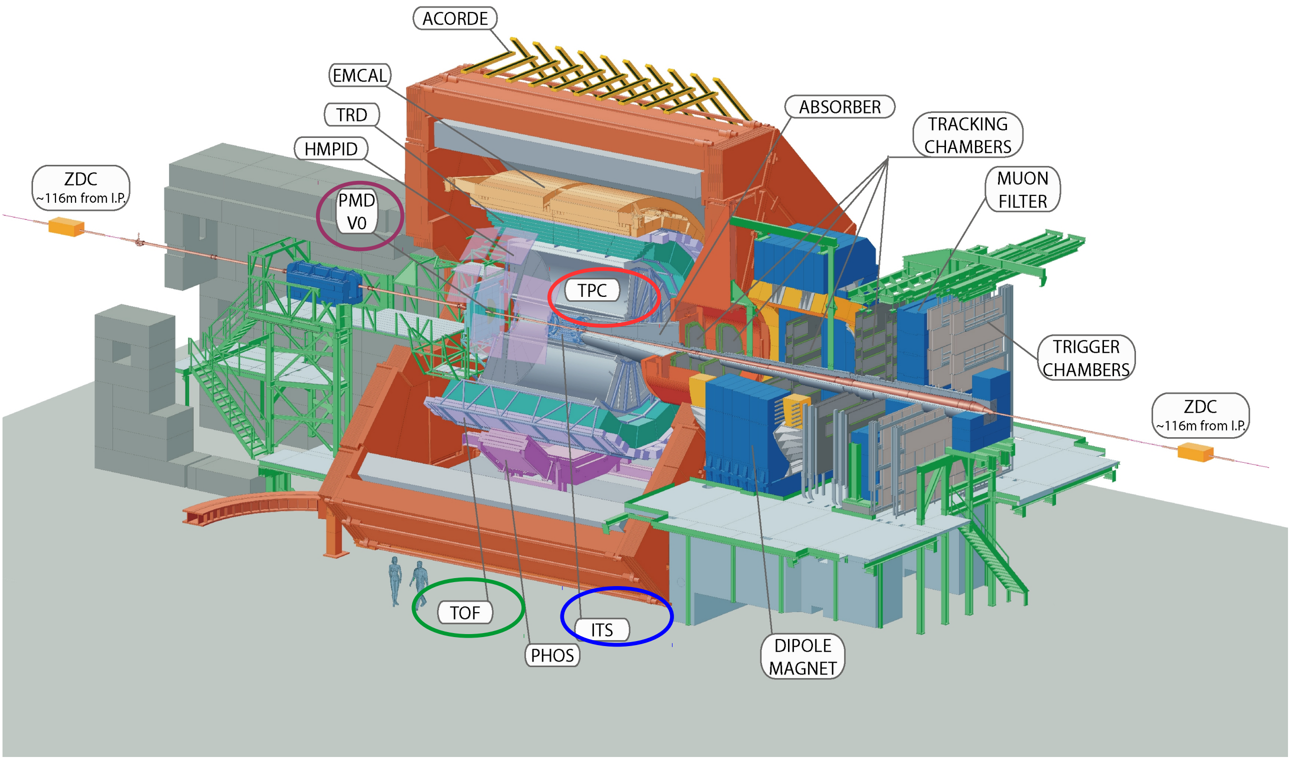
  - Overlapping m_T ranges

  - Different systematics

Motivation: m_T-dependence of correlation radii

- "m_T-scaling" : $R \sim m_T^{\,a}$, $\quad m_T = \sqrt{m^2 + p_T^2}$
- Hydrodynamic models predict exact "m_T-scaling" for R_{long} with **a** =-1/2 (A.N. Makhlin, Yu.M. Sinyukov, Sov. J. Nucl. Phys.46 (1987) 345; Z. Phys.C 39 (1988) 69.. Yu. M. Sinyukov, Nucl. Phys. A 498 (1989) 151.):
  - Negligible transverse flow
  - Longitudinal boost invariance
  - Common freeze-out
- Approximate "m_T-scaling" for different particle species for R_{long}, R_{side}, R_{out} with different **a** was predicted in (A. Kisiel, M. Galazyn, P. Bozek, Phys.Rev. C90 (2014) 064914)
  - Indication of flow dominated freeze-out scenario
- Strong violation of "m_T-scaling" was predicted in (V.M. Shapoval, P. Braun-Munzinger, Iu.A. Karpenko, Yu.M. Sinyukov, Nucl.Phys. A 929 (2014) 1.) due to :
  - Strong transverse flow & resonance decays influence & rescattering phase
  - "k_T-scaling" was predicted instead
- Extraction of emission time from fit $R_{long}^2(m_T)$ using formula generalized for any strong transverse flow (Yu. Sinyukov, V.Shapoval, V.Naboka, arxiv:1508.01812),
  - Indication on importance of rescattering phase

ALICE at LHC



Tracking and vertex

- Time Projection Camber (TPC)

& Inner Tracking System (ITS)

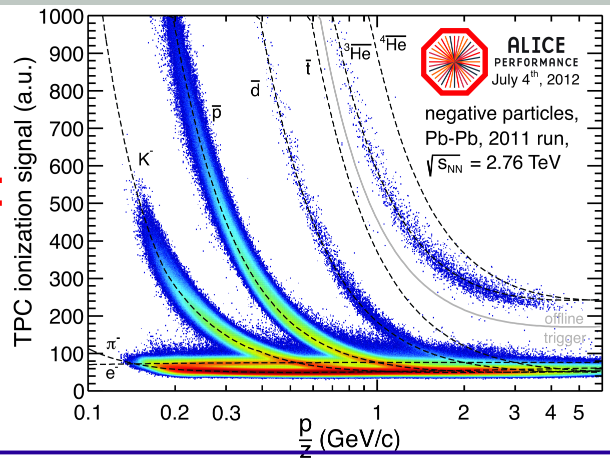
Centrality determination

- V0

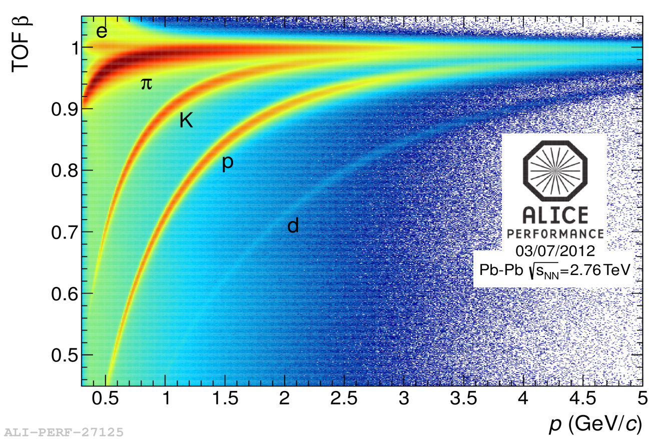
Particle Identification

- TPC and Time of Flight

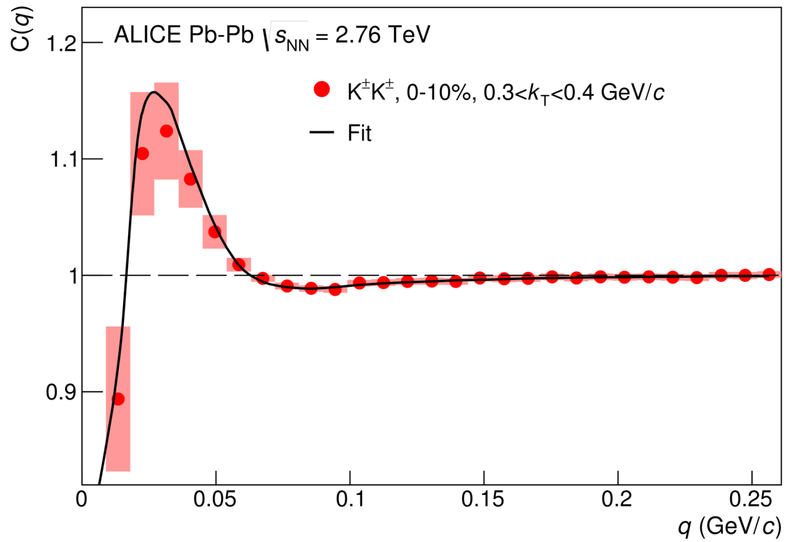
TPC:



TOF:



$K^{\pm}$ and K^0_s CFs



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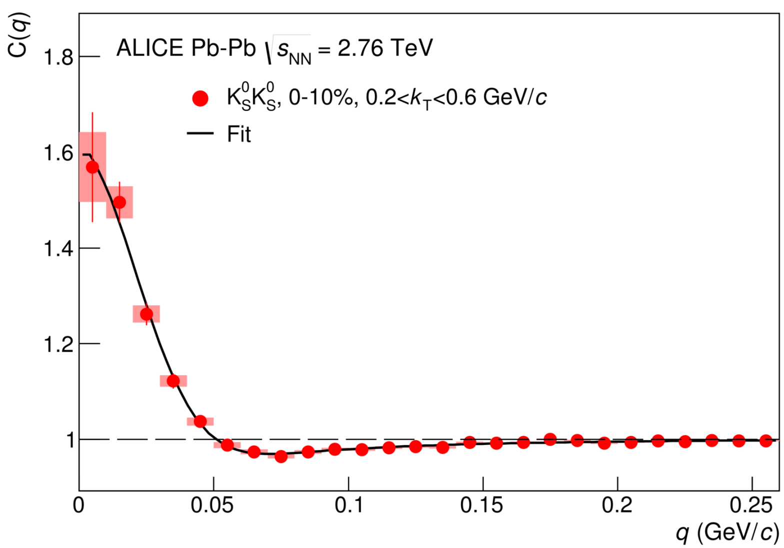

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Results from ArXiv.org:1506.07884

- Example $K^{\pm}K^{\pm}$ & $K^0_sK^0_s$ CFs are shown
- CFs corrected for momentum resolution and purity
- Bose-Einstein enhancement seen for both
- Coulomb FSI: drop at low *q* in $K^{\pm}K^{\pm}$
- Strong FSI: dip below C=1 in $K^0_sK^0_s$
- Curves corresponds to best fit:
  $K^{\pm}K^{\pm}$: Bowler-Sinyukov formula:

$$C(q)=N[1-\lambda+\lambda K(q)(1+\exp(-R_{inv}^2 q^2))],$$

N norm. factor, λ correlation strength,
K(q) symmetrized Coulomb factor

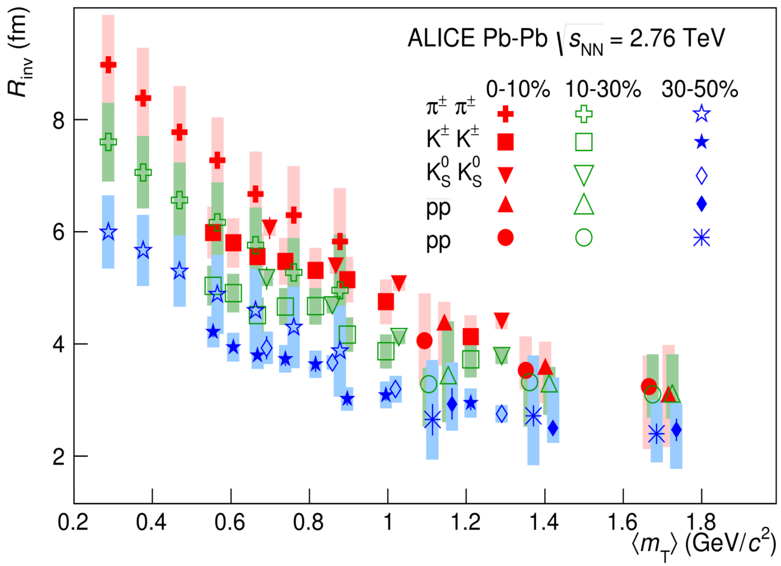
$K^0_sK^0_s$:

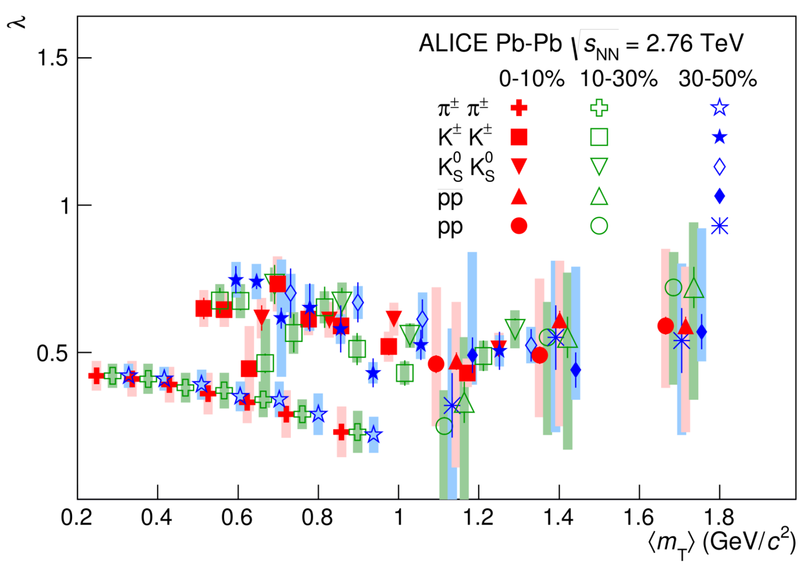
$$C(q)=N[1-\lambda+\lambda C'(q)],$$

$$C'(q)=1+\exp(-R_{inv}^2 q^2)+C_{strongFSI}(q,R)$$

Strong FSI due to resonances $f_0(980)$ and $a_0(980)$

R_{inv} radii vs m_T for $\pi^{\pm}\pi^{\pm}$, $K^{\pm}K^{\pm}$, $K^0_sK^0_s$, pp and $\overline{pp}$





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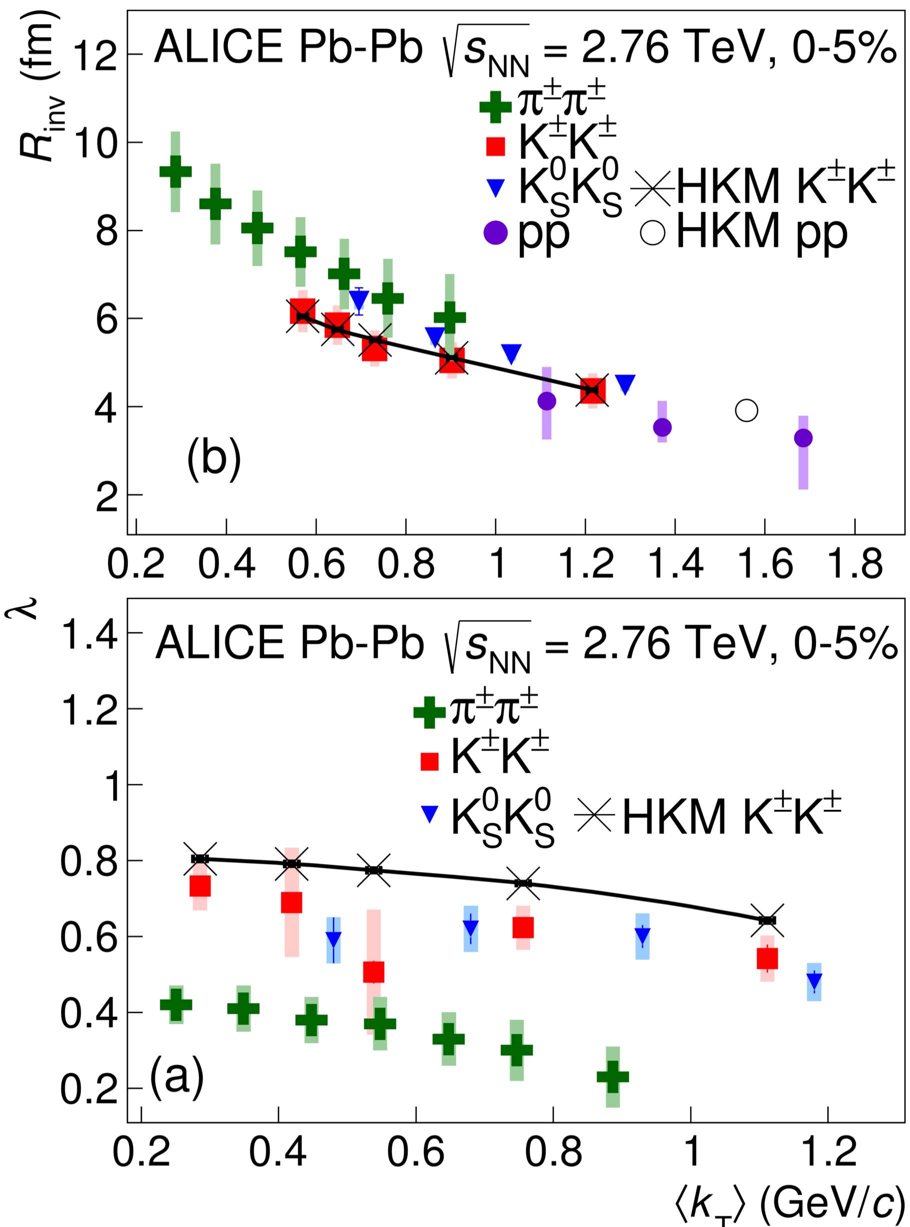
Results from ArXiv.org:1506.07884

- R_{inv} and λ for $\pi^{\pm}\pi^{\pm}$, $K^{\pm}K^{\pm}$, $K^0_sK^0_s$, pp and $\overline{pp}$ vs m_T for several centralities
- Radii decrease with m_T → radial flow
- Increase size with increasing centrality → simple geometric picture of the collisions.
- $R_\pi > R_K$ due to pion Lorrentz factor
- R_p compatible with R_k at same m_T
- All λ lie mostly in 0.3-0.7 due to long-lived resonances, non-Gaussian shape.
- No significant centrality dependence
- λ_π are lower than λ_K due to the stronger influence of resonances

$K^{\pm}K^{\pm}$ and $K^0_s K^0_s$ in Pb-Pb: HKM model



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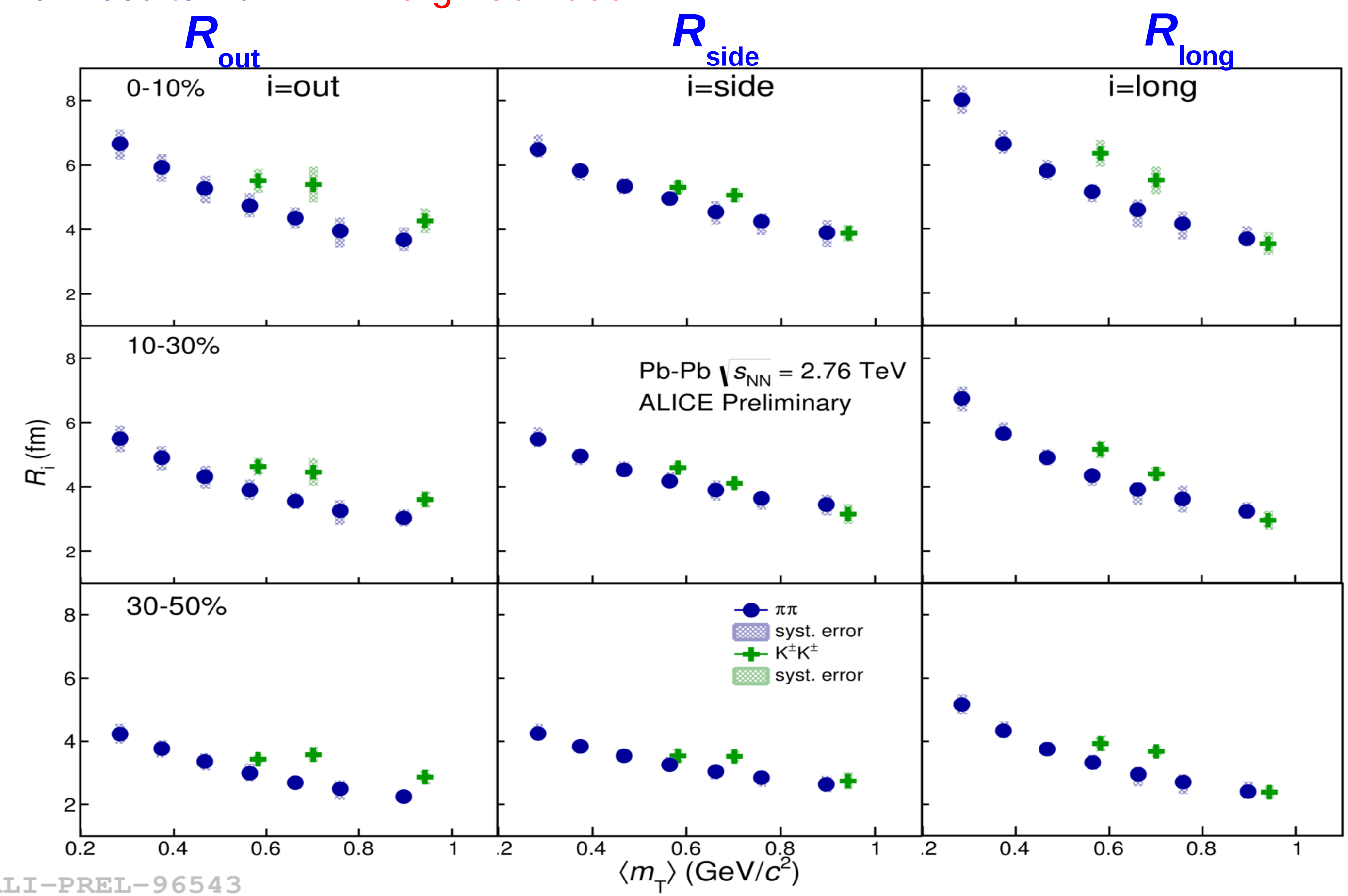
Results from ArXiv.org:1506.07884

- R and λ for $\pi^{\pm}\pi^{\pm}$, $K^{\pm}K^{\pm}$, $K^0_s K^0_s$, pp for 0-5% centrality
- Radii for kaons show good agreement with HKM predictions for $K^{\pm}K^{\pm}$ (Nucl.Phys.A929 (2014))
- λ decreases with k_T, both data and HKM
- HKM prediction for λ slightly overpredicts the data
- λ_{π} are lower λ_K due to the stronger influence of resonances

3D K±K± & ππ radii versus m_T

Pion results from ArXiv.org:1507.06842

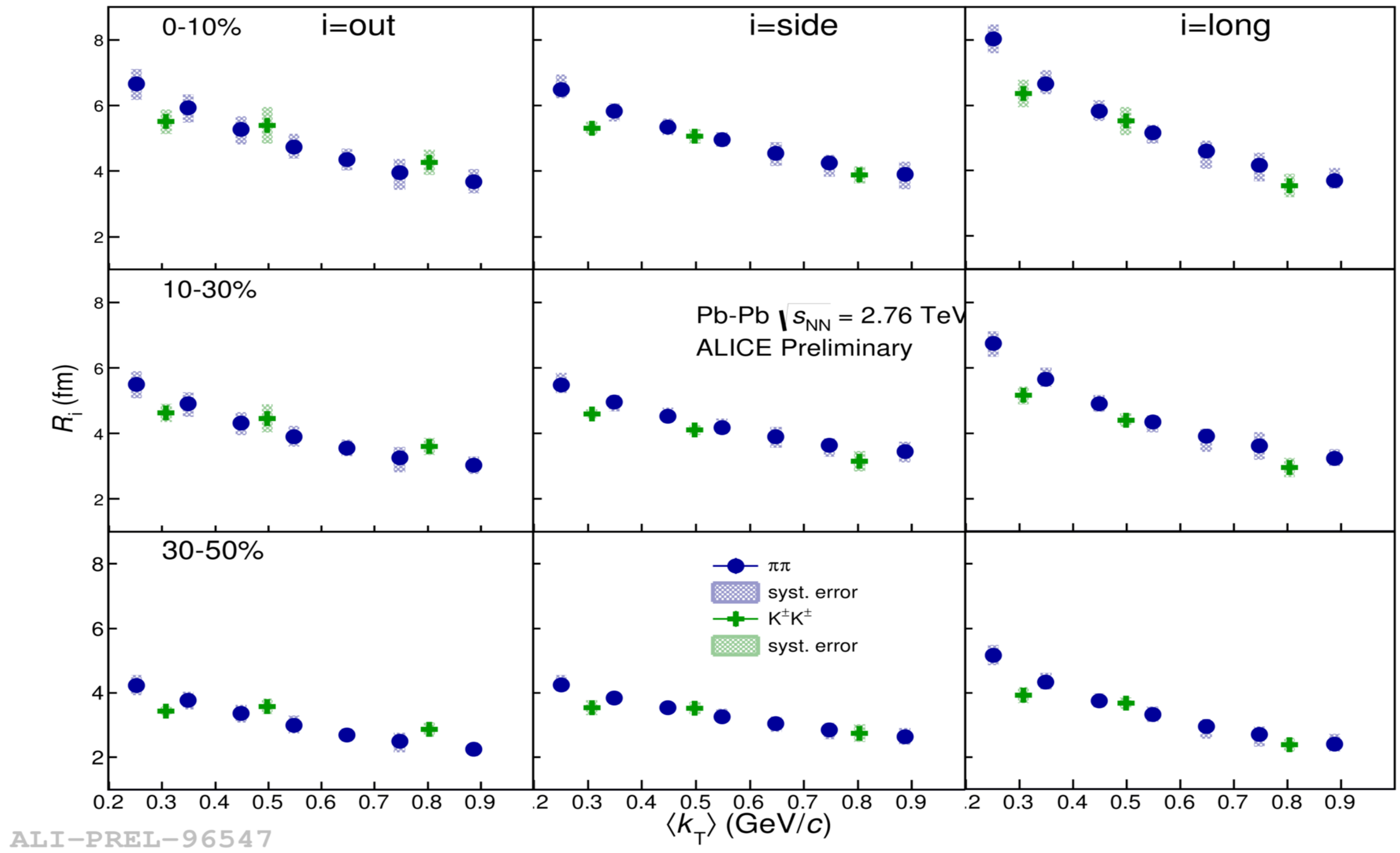


- R_{side} shows approximate m_T scaling;
- R_{out}, R_{long} of K are larger than those of π → m_T scaling is broken;
- This difference increases for more central collisions;
- The effect is more important for R_{long}

3D K±K± & ππ radii versus k_T

Pion results from ArXiv.org:1507.06842

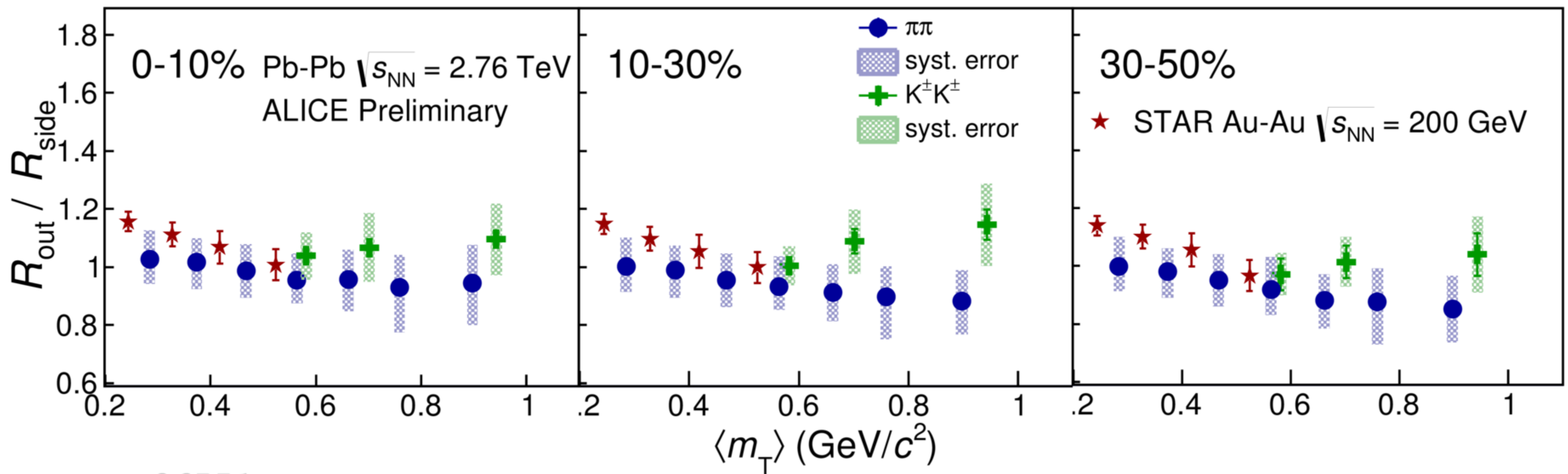
R_{out} R_{side} R_{long}



- Radii scale better with k_T than with m_T according with HKM predictions (V. Shapoval, P. Braun-Munzinger, Iu.A. Karpenko, Yu.M. Sinyukov, Nucl.Phys. A 929 (2014) 1);
- Similar observations were reported by PHENIX at RHIC (arxiv:1504.05168).

R_{out}/R_{side} vs m_T for $K^{\pm}K^{\pm}$ & ππ

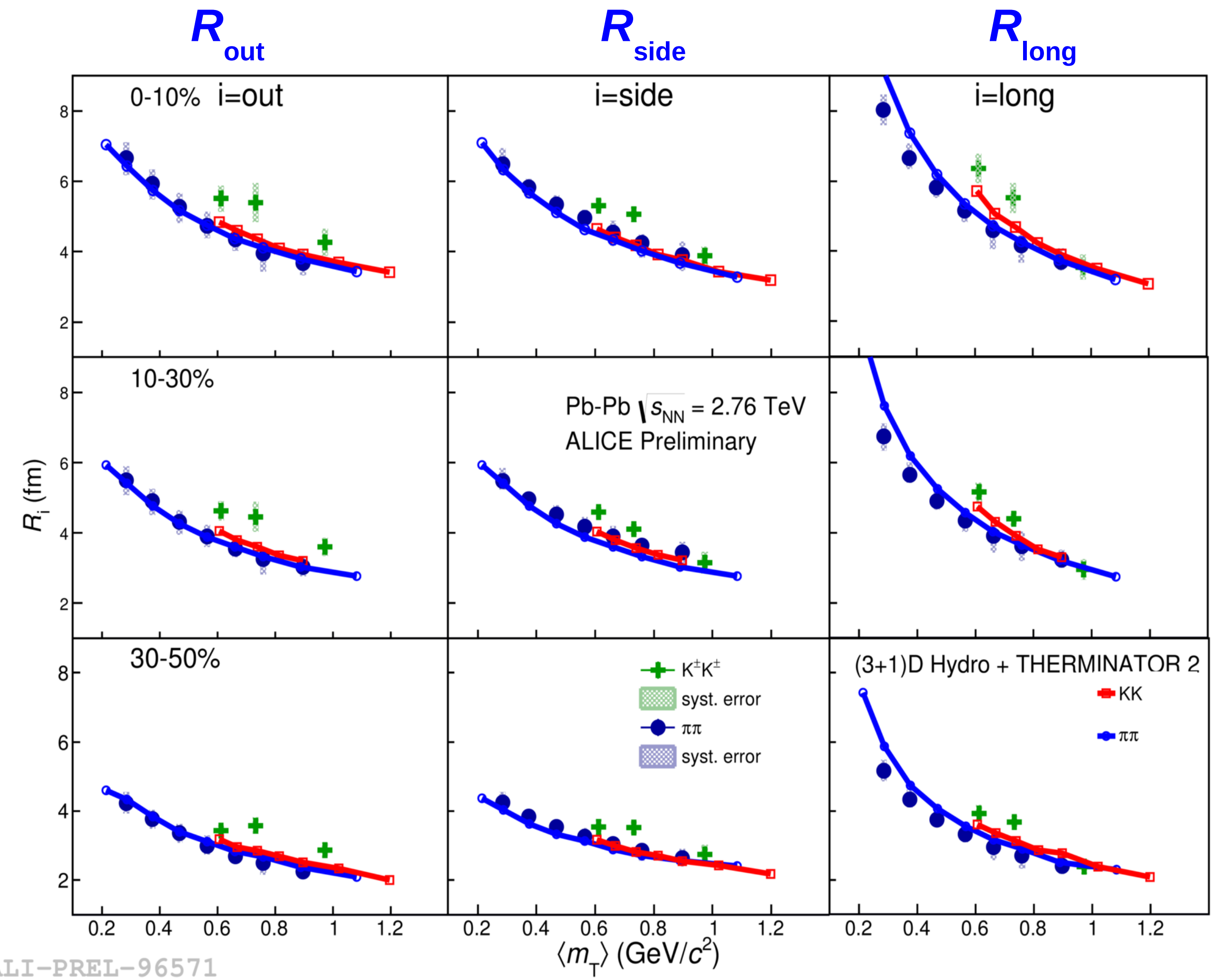
Pion results from ArXiv.org:1507.06842



ALI-PREL-96551

- R_{out}/R_{side} (π) ~ 1 for low k_T; slowly decreasing with k_T
- R_{out}/R_{side} (π) smaller than at RHIC (1.1) → stronger radial flow and emission point r:t correlations according to (A. Kisiel, W. Broniowski, M. Chojnacki, and W. Florkowski, PRC 79 (2009), I. Karpenko and Y. Sinyukov, PLB 688 (2010) 5054)
- Indication : R_{out}/R_{side}(K) > R_{out}/R_{side}(π) → different r:t correlations for pions and kaons
- Similar observations were reported by PHENIX at RHIC (arxiv:1504.05168).

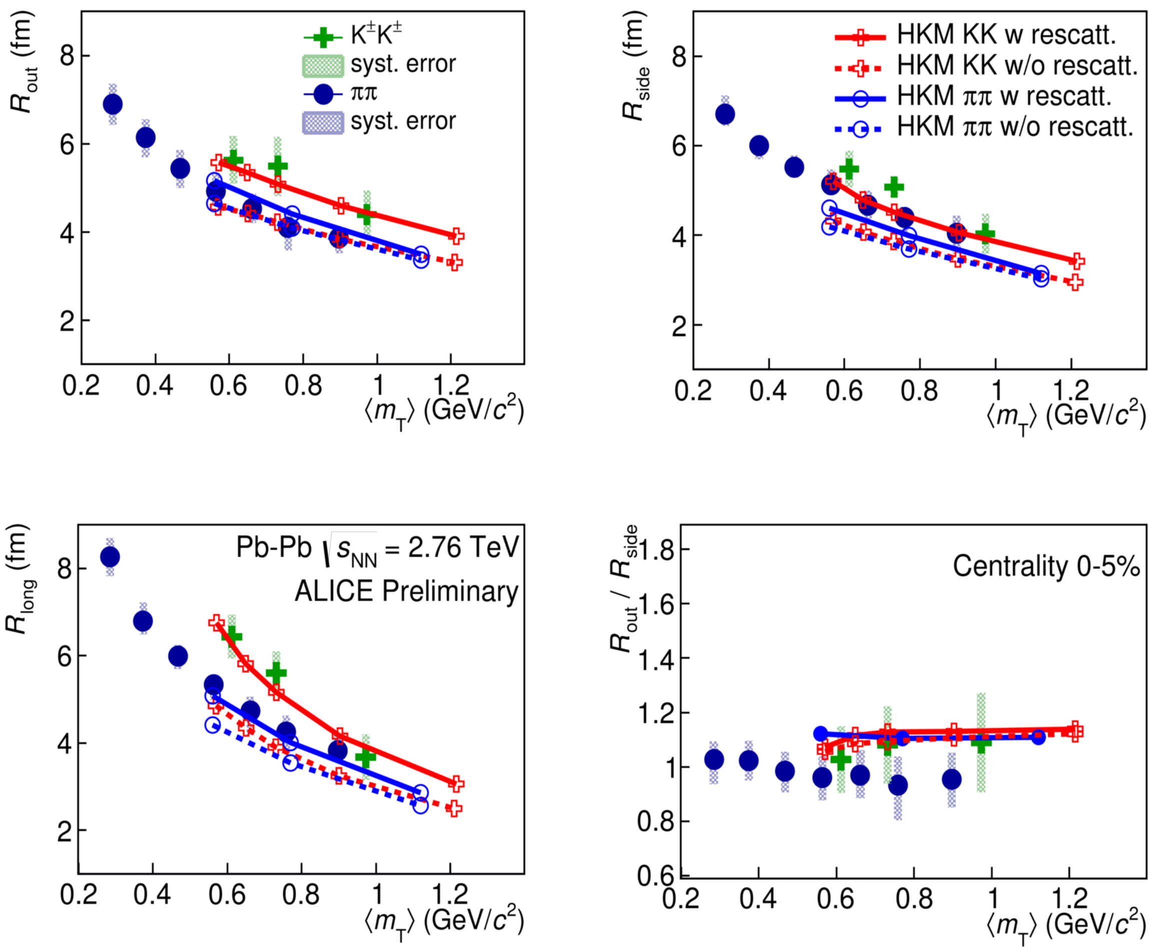
Comparison with (3+1)D Hydro+THERMINATOR2



- Model (A. Kisiel, M. Galazyn, P. Bozek, Phys.Rev. C90 (2014) 064914) includes hydrodynamics and resonances decays
- Good description of pion radii vs. m_T
- Underestimation of kaon radii

- Model demonstrates approximate $R \sim m_T^{a}$ scaling for π & K, with "**a**" being different for R_{out}, R_{side}, R_{long} (A. Kisiel, M. Galazyn, P. Bozek, Phys.Rev. C90 (2014) 064914)

Comparison with HKM for 0-5% centrality



ALI-PREL-96575

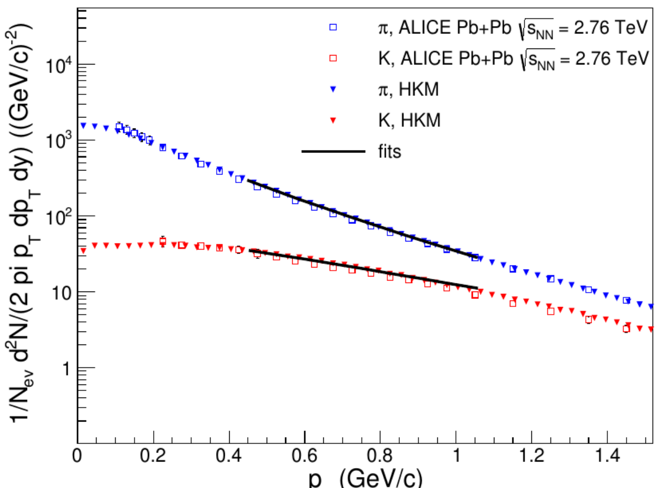
- HKM model with re-scatterings (M. Shapoval, P. Braun-Munzinger, Iu.A. Karpenko, Yu.M. Sinyukov, Nucl.Phys. A 929 (2014) 1.) describes well ALICE π & K data.
- HKM model w/o re-scatterings demonstrates approximate m_T scaling for π & K, but does not describe ALICE π & K data
- The observed deviation from m_T scaling is explained in (M. Shapoval, P. Braun-Munzinger, Iu.A. Karpenko, Yu.M. Sinyukov, Nucl.Phys. A 929 (2014) by essential transverse flow & hadronic rescattering phase.

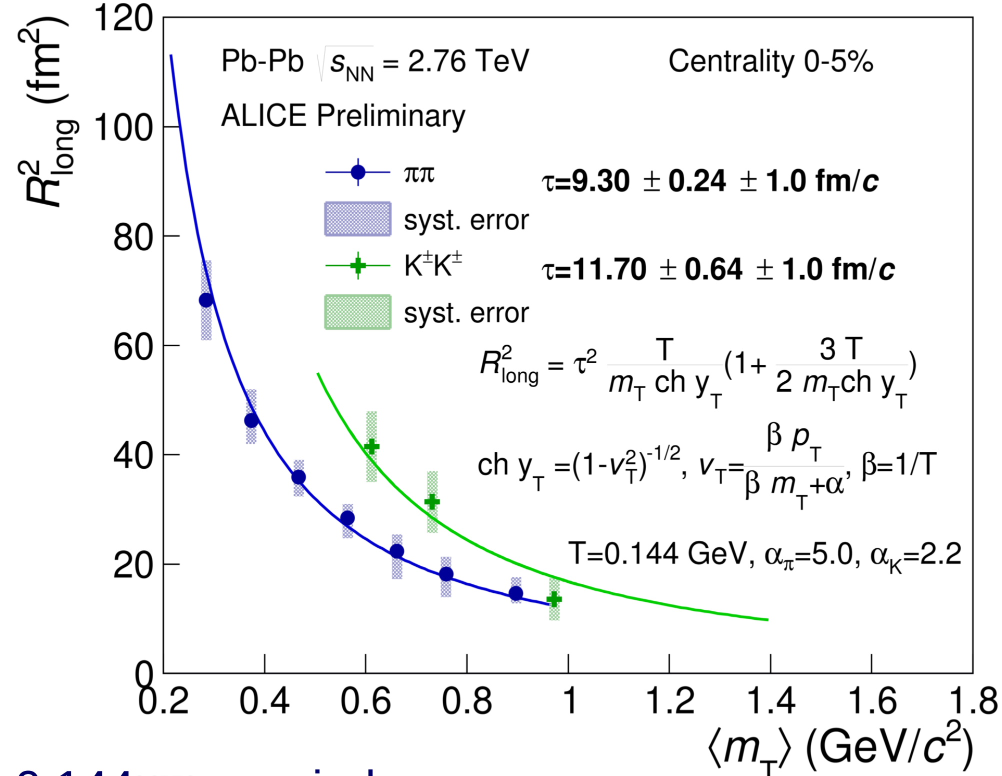
- HKM model slightly underestimates R_{side} → overestimates R_{out}/R_{side} ratio for π

Extraction of emission time from fit $R_{long}^2(m_T)$

ALICE

- The new formula for extraction of the maximal emission time for the case of strong transverse flow was used (Yu. Sinyukov, V.Shapoval, V.Naboka, arxiv:1508.01812)
- The parameters of freeze-out: T and "intensity of transverse flow", α were fixed by fitting π and K spectra (arxiv:1508.01812)





- To estimate the systematic errors: T = 0.144 was varied on ± 0.03 GeV & free α_π, α_K, were used; systematic errors ~ 1 fm/c
- Indication: $\tau_\pi < \tau_K$. Possible explanations (arxiv:1508.01812): HKM includes hadronic rescattering phase (UrQMD cascade): e.g. Kπ→K*(892)→Kπ, KN→K*(892)X; (K*(892) lifetime 4-5 fm/c) [πN→N*(Δ)X, N*(Δ)→πX (N*s(Δs)- short lifetime)]

Summary

- The study performed by ALICE Collaboration on the femtoscopic correlations of heavy particles is a good complement to the pion femtoscopy as it allows one to distinguish between different model scenarios.
- 1D $\pi^{\pm}\pi^{\pm}$, $K^{\pm}K^{\pm}$, $K_0^sK_0^s$, pp and $\overline{pp}$ femtoscopic radii were measured for several centrality and m_T bins in Pb-Pb collisions at 2.76 TeV:

  - decrease with increasing m_T and decreasing system size was observed
- 3D $\pi^{\pm}\pi^{\pm}$ and $K^{\pm}K^{\pm}$ femtoscopic radii were measured for several centrality and m_T bins in Pb-Pb collisions at 2.76 TeV:

  - decrease with increasing m_T and decreasing system size;

  - breaking of approximate m_T-scaling expected by pure hydro-dynamical models;

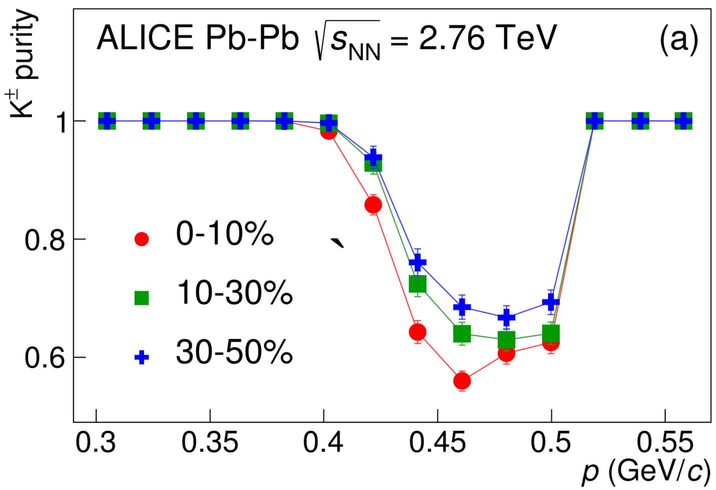
  - scaling of pion and kaon radii with k_T as it was predicted by HKM ;

  - indication of $R_{out}/R_{side}(K) > R_{out}/R_{side}(\pi)$

  - indication of $\tau_{\pi} < \tau_K$ extracted from fit R_{long}^2 vers. m_T
- HKM model describes 3D $\pi^{\pm}\pi^{\pm}$ and $K^{\pm}K^{\pm}$ femtoscopic radii well
- Importance of hadronic rescattering phase for explanation of breaking of m_T-scaling

Additional slides

$K^{\pm}$ and K^0_s PID



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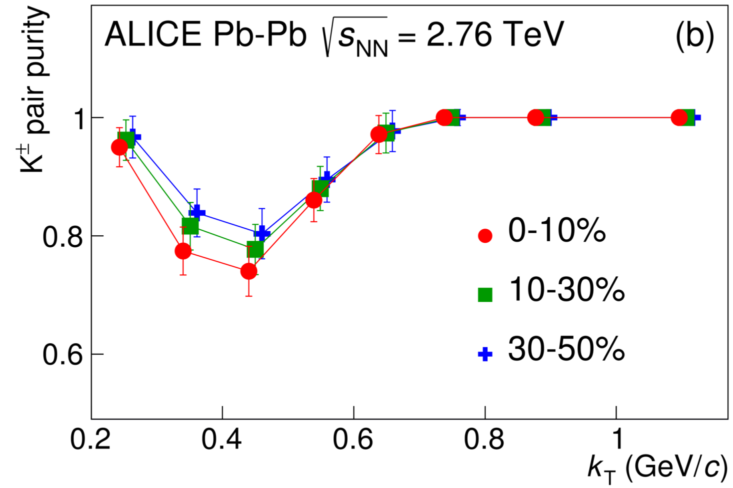
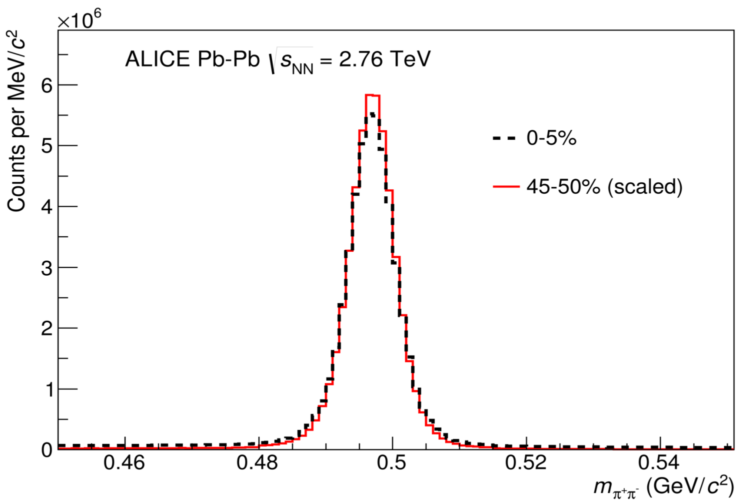
Results from
ArXiv.org:1506.07884



ALI-PUB-94247

- $K^{\pm}$: $0.15<p_T<1.5$ GeV/c, $|\eta|<0.8$, TCP and TOF($p>0.5$GeV/c) $n\sigma$ PID ($n<3$)
- Single and pair purity: main contamination ($0.4<p<0.5$ GeV/c) comes form $e^{\pm}$



-PUB-94251

- $K^0_s \rightarrow \pi^+\pi^-$ ($c\tau$ = 2.7cm)

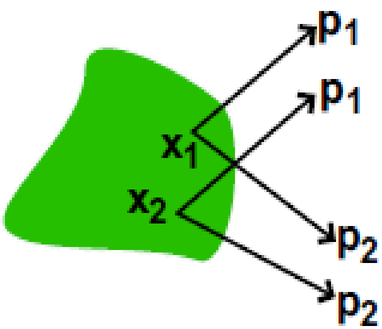
  Daughter π: $p_T>0.15$ GeV/c, $|\eta|<0.8$
- TPC and TOF ($p>0.8$ GeV/c) $n\sigma$ PID

  K^0_s: $|\eta|<0.8$, $\pi^+\pi^-$ DCA<0.3cm,

  DCA to prim. vertex <0.3cm
- decay length<30 cm, cos(point. angle)>0.99
- $0.480<m_{inv}<0.515$ GeV/c^2 ; Purity >95%

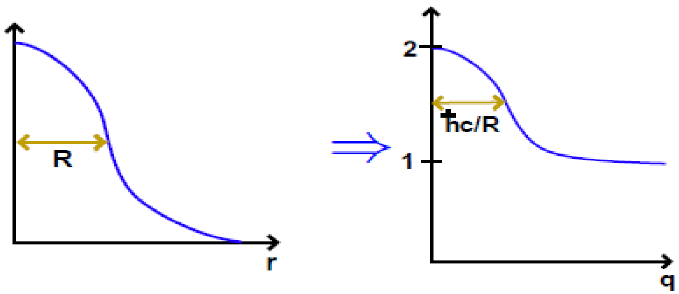
Introduction

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)



- Two particle Correlation Function (CF):

Theory: $C(q)=\frac{N_2(p_1,p_2)}{N_1(p_1)\cdot N_2(p_1)}, C(\infty)=1$



Experiment: $C(q)=\frac{S(q)}{B(q)}, q=p_1-p_2$

S(q) – pairs from same event

B(q) – pairs from different event

- Parametrization:

1D: $C(q_{inv})=1+\lambda\exp(-R^2 q_{inv}^2)$, ***R*** Gaussian radius in Pair Rest Frame (**PRF**), ***λ*** correlation strength parameter

3D: $C(q_{out},q_{side},q_{long})=1+\lambda\exp(-R_{out}^2 q_{out}^2-R_{side}^2 q_{side}^2-R_{long}^2 q_{long}^2)$

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

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