Λ K Femtoscopy in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the LHC ALICE Experiment

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We present results from a femtoscopic analysis of Lambda-Kaon correlations in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV by the ALICE experiment at the LHC. The femtoscopic correlations are the result of strong final-state interactions, and are fit with a parametrization based on a model by R. Lednicky and V. L. Lyuboshitz [1]. This allows us to both characterize the emission source and measure the scattering parameters for the particle pairs. We observe a large difference in the $\Lambda K+$ and $\Lambda K-$ correlations in pairs at low relative momentum $(k^* \lesssim 100\ MeV)$. The results suggest an effect arising from different quark-antiquark interactions in the pairs, i.e. $s\bar{s}$ in $\Lambda K+$ and $u\bar{u}$ in $\Lambda K-$.

1. Introduction

- Femtoscopic analysis of ΛK correlations
  - ➔ Result of strong final-state interactions
- Study the ΛK interactions
  - ➔ ΛK^0_S and ΛK^{ch}
  - ➔ Scattering parameters never before measured
  - ➔ Compare to theoretical predictions
- Characterize the ΛK pair emission regions
  - ➔ Obey transverse mass (m_T) scaling
    - Signature of hydrodynamic flow
    - Deconfined quarks and gluons
- Investigate striking difference of ΛK+ and ΛK- systems at small relative momemtum (k^*)
  - ➔ Effect arising from $s\bar{s}$ annihilation compared to $u\bar{u}$?

$\Lambda = uds$

$\bar{\Lambda} = \overline{uds}$

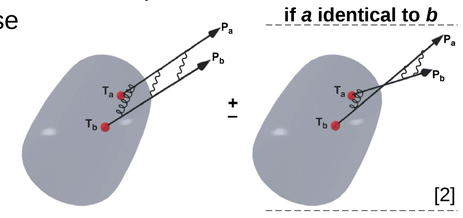
$K+ = u\bar{s}$

$K- = \bar{u}s$

$K^0_S = \frac{1}{\sqrt{2}}(d\bar{s} + s\bar{d})$

2. Femtoscopy (1 fm = 10^{-15} m)

- Space-time characterization of particle-emitting sources on femtometer (10^{-15} m) scale
- Direct measurement of times/positions of fireball impossible
  - ➔ Extremely small size and lifetime
- Momentum difference of emitted particles is measurable
  - ➔ Connected to the time and space properties
- Exploit measured two-particle (or higher) momentum correlations of hadrons to probe freeze-out structure of dynamic matter created in collisions
  - ➔ Most direct link to size and lifetime
  - ➔ Sensitive to quantum statistics, strong and Coulomb interactions
  - ➔ Allows measurement of nuclear scattering parameters
    - For some pairs, difficult, if not impossible, to measure otherwise



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3. Formalism

- Theory:

$$C(k^*) = \int S(\boldsymbol{r}^*)\,|\Psi_{\boldsymbol{k}^*}(\boldsymbol{r}^*)|^2\, d^3\boldsymbol{r}^*$$

  - S(**r***) : source distribution
  - $\Psi_{\boldsymbol{k}^*}(\boldsymbol{r}^*)$: two-particle wave-function
  - k* : momentum of one particle in the pair rest frame

- Experiment:

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

  - A(k*) : signal distribution (same-event)
  - B(k*) : background distribution (mixed events)

- Lednicky and Lyuboshitz formulation [1]
  - ➔ Used as fit function

$$C(k^*) = 1 + \lambda\left[\alpha \exp\left(-4k^{*2}R^2\right) + C_{FSI}(k^*)\right]$$

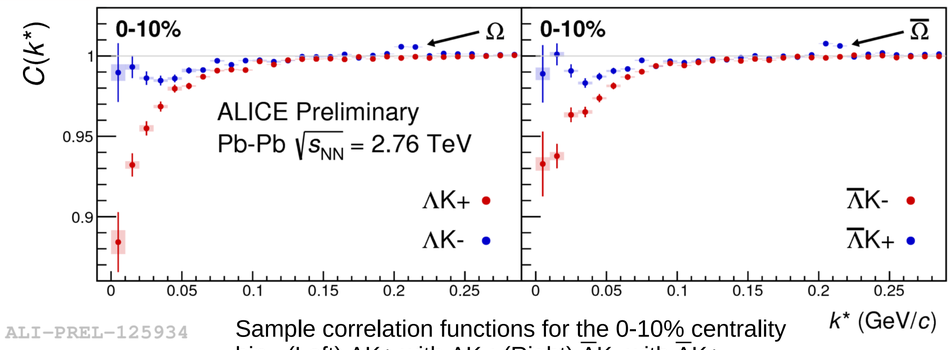
  - λ – rough estimate of primary pair fraction
  - R – source size
  - f_0 – complex scattering length
  - d_0 – effective range of interaction

$$C_{FSI} = (1+\alpha)\left[\frac{1}{2}\left|\frac{f(k^*)}{R}\right|^2\left(1 - \frac{d_0}{2\sqrt{\pi}R}\right) + \frac{2\Re f(k^*)}{\sqrt{\pi}R}F_1(2k^*R) - \frac{\Im f(k^*)}{R}F_2(2k^*R)\right]$$

$$f(k^*) = \left(\frac{1}{f_0} + \frac{1}{2}d_0k^{*2} - ik^*\right)^{-1} \qquad F_1(z) = \int_0^z dx\, \frac{e^{x^2-z^2}}{z} \qquad F_2(z) = \frac{1-e^{-z^2}}{z}$$

- Non-identical particles ➔ α = 0 ➔ $C(k^*) = 1 + \lambda\left[C_{FSI}(k^*)\right]$

4. ΛK+ vs. ΛK-



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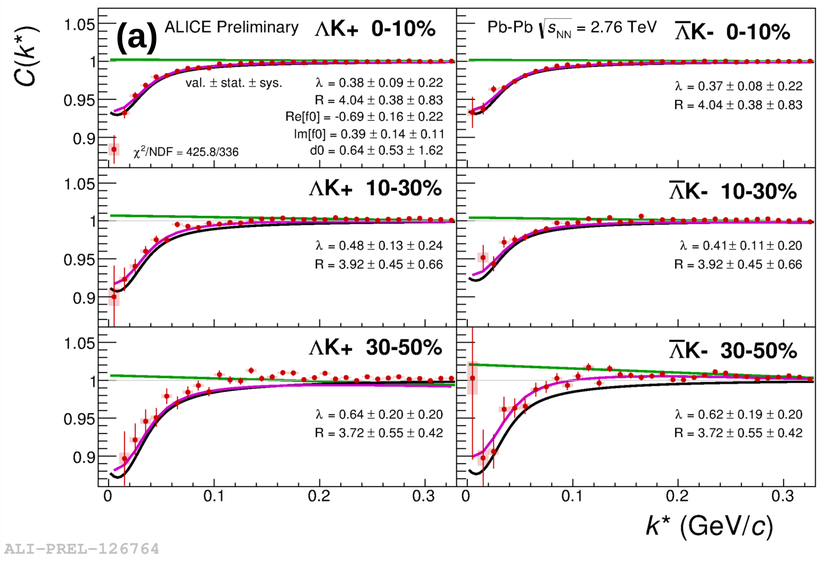
Sample correlation functions for the 0-10% centrality bin. (Left) ΛK+ with ΛK-; (Right) $\bar{\Lambda}$K- with $\bar{\Lambda}$K+.

- ΛK+ shows greater suppression at low k^* compared to ΛK-
  - ➔ Effect arising from $s\bar{s}$ annihilation compared to $u\bar{u}$?
  - ➔ Or S=0 ΛK+ system has more interaction channels than S=-2 ΛK-?
- Ξ^0K^{ch} ideal to further probe $s\bar{s}$ vs. $u\bar{u}$
  - ➔ $\Xi^0 = uss$
  - ➔ Impossible: $\Xi^0 \rightarrow \Lambda\pi^0$
- $\Xi^{ch}K^{ch}$ is next best option
  - ➔ $\Xi- = dss$

5. Measured ΛK Correlations with Fits

Fits to the (a) ΛK+ and $\bar{\Lambda}$K-, (b) ΛK- and $\bar{\Lambda}$K+, and (c) ΛK^0_S and $\bar{\Lambda}K^0_S$. Each pair is fit simultaneously with its conjugate pair across the three centrality bins: 0-10% (top row), 10-30% (middle row), and 30-50% (bottom row). Statistical (lines) and systematic (boxes) uncertainties are shown.



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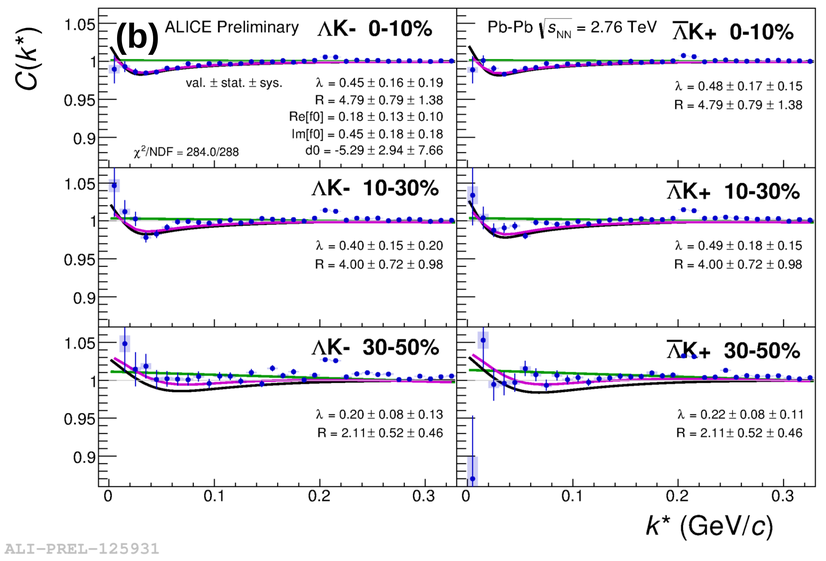

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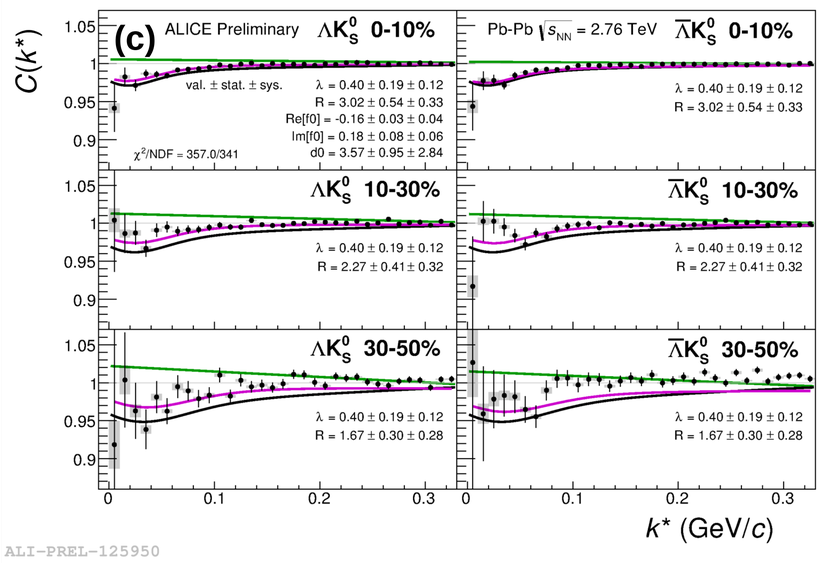

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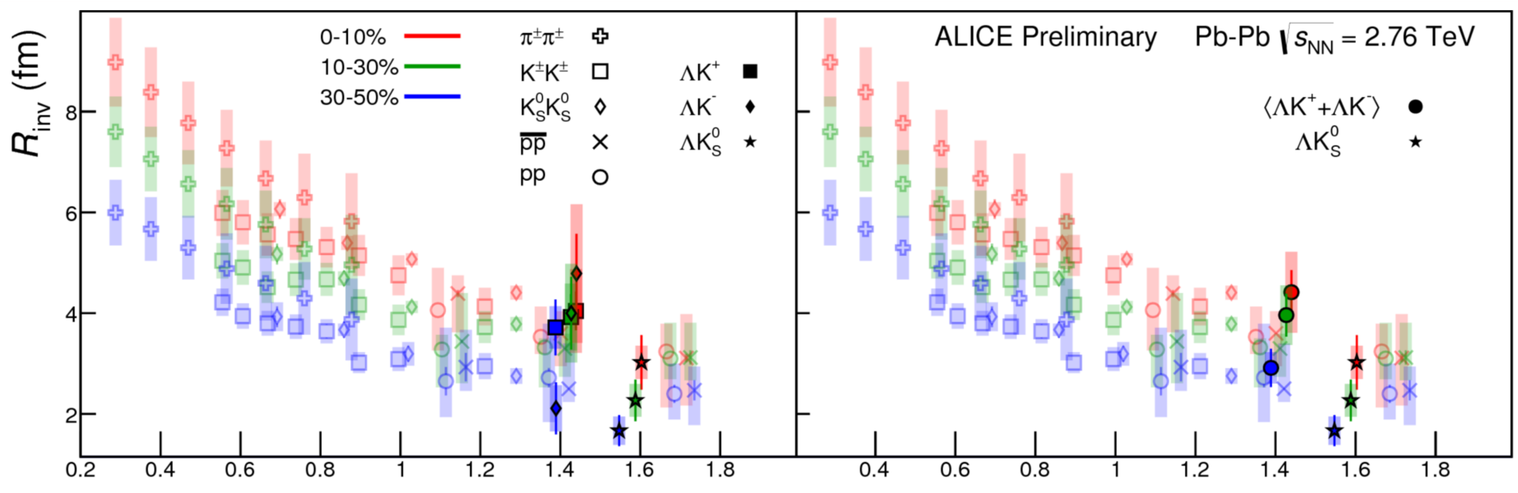
Green = fit to non-flat, non-femtoscopic, background
Black = "raw", uncorrected, fit
Magenta = final fit; momentum resolution and non-flat background corrections applied

Fit Parameters (value ± statistical error ± systematic error)

Pair Type	Centrality	R		
ΛK^+ & $\bar{\Lambda}K^-$	0-10%	4.04 ± 0.38 ± 0.83		
	10-30%	3.92 ± 0.45 ± 0.66		
	30-50%	3.72 ± 0.55 ± 0.42		
		$\Re f_0$	$\Im f_0$	d_0
		-0.69 ± 0.16 ± 0.22	0.39 ± 0.14 ± 0.11	0.64 ± 0.53 ± 1.62
ΛK^- & $\bar{\Lambda}K^+$	0-10%	4.79 ± 0.79 ± 1.38		
	10-30%	4.00 ± 0.72 ± 0.98		
	30-50%	2.11 ± 0.52 ± 0.46		
		$\Re f_0$	$\Im f_0$	d_0
		0.18 ± 0.13 ± 0.10	0.45 ± 0.18 ± 0.18	-5.29 ± 2.94 ± 7.66
ΛK^0_S & $\bar{\Lambda}K^0_S$	0-10%	3.02 ± 0.54 ± 0.33		
	10-30%	2.27 ± 0.41 ± 0.32		
	30-50%	1.67 ± 0.30 ± 0.28		
		$\Re f_0$	$\Im f_0$	d_0
		-0.16 ± 0.03 ± 0.04	0.18 ± 0.08 ± 0.06	3.57 ± 0.95 ± 2.84

- For a given pair and conjugate:
  - ➔ Radii shared amongst like centralities
  - ➔ Scattering parameters (f_0, d_0) shared amongst all
  - ➔ Each correlation function has a unique normalization parameter
- ΛK^{ch} analyses
  - ➔ Each correlation has a unique λ parameter
- ΛK^0_S analyses
  - ➔ All share a single λ parameter to aid in the fitting process

6. m_T Scaling of Radii



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R_{inv} parameters vs m_T for (preliminary) ΛK pairs with ALICE results [3] for $\pi^{ch}\pi^{ch}$, $K^{ch}K^{ch}$, $K^0_SK^0_S$, pp, and $\bar{p}\bar{p}$. ΛK+ (with $\bar{\Lambda}$K-) and ΛK- (with $\bar{\Lambda}$K+) are shown separately in the left, and averaged in the right. Statistical (lines) and systematic (boxes) uncertainties are shown.

$$m_T^2 = \left(\frac{m_{inv}}{2}\right)^2 + \left(\frac{1}{2}\left|\boldsymbol{p}_{T,1} + \boldsymbol{p}_{T,2}\right|\right)^2$$

7. Summary

- ΛK (ΛK+, ΛK-, ΛK^0_S) femtoscopic analysis presented for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
- First measurement of ΛK scattering parameters
- Pair emission source radii extracted for 0-10%, 10-30% and 30-50% centralities
  - ➔ Follow approximate m_T-scaling observed in other systems
- Striking difference in ΛK+ and ΛK- correlations observed at low k^*
  - ➔ Further investigation needed to fully explain

8. Outlook

- Include residual correlations from feed-down in fitting algorithm
  - ➔ ex. $\Sigma^0K \rightarrow \Lambda K$, $\Xi^{0(ch)}K \rightarrow \Lambda K$, $\Omega^{ch}K \rightarrow \Lambda K$, etc.
- If statistics permit, make analyses m_T-dependent
- Continue work on $\Xi^{ch}K^{ch}$ analysis
  - ➔ Fitter greatly complicated by inclusion of Coulomb interaction
- Use $\Xi^{ch}K^{ch}$ analysis to help ΛK anlysis by either
  - ➔ (a) eliminating Λ originating from Ξ^{ch} before fitting, or
  - ➔ (b) using measured $\Xi^{ch}K^{ch}$ data to quantify feed-down in ΛK

References

[1] R. Lednicky and V. L. Lyuboshitz. Sov. J. Nucl. Phys., 35:770, 1982
[2] M. Lisa, et al. Ann. Rev. Nucl. Part. Sci., 55:357, 2005.
[3] J Adam et al. [ALICE Collaboration] Phys. Rev. C., 92:054908, 2015

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