$K_0^s K_0^s$ correlations in 7 TeV proton+proton collisions from the ALICE experiment at the LHC

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Motivation for studying $K^0_s K^0_s$ correlations in ALICE

- $K^0_s$ is a different kind of boson -> complements $\pi\pi$ and charged KK studies and extends $k_T$ to higher values

- $K^0_s$ is uncharged so no final-state Coulomb effects

- previous $K^0_s K^0_s$ studies suffered from a lack of statistics -- in ALICE, high energy and long running periods allow better statistics

- $K^0_s K^0_s$ state is interesting: $\begin{align*}
|K^0_s K^0_s> &= 1/2 \left( |K^0 K^0> + |K^0 K^0> + |K^0 K^0> + |K^0 K^0> \right) \\
\end{align*}$

\[\begin{align*}
\text{Symmetric due to BE} & \quad \text{Only symmetric part contributes to } K^0_s K^0_s
\end{align*}\]
Results from other experimental $K^0_s K^0_s$ Bose-Einstein studies

* $e^+e^-$ and $e^\pm p$ collisions (figure from Phys.Lett.B652:1-12,2007 )

* Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV (RHIC)

$K^0_s K^0_s$ study is the first to show source parameters for $p+p$ collisions and for different multiplicity and $k_T$ bins
**$K^0_s$ identification (from $V_0 \rightarrow h^+h^-$)**

Fit a Quadratic + Gaussian to the $K^0_s$ mass peak and take the Quadratic to represent the background

Purity $\Rightarrow P = \frac{G}{Q+G}$, calculated in the range $0.49 < \text{mass} < 0.504 \text{ GeV}$

**Cuts used:**
- $|\eta| < 0.8$
- $0.4 < p_T < 3.5 \text{ GeV/c}$
**K^0_s K^0_s** Real and Background pairs distributions and C(Q_{inv})

All multiplicity and k_T

Non-flat baseline as in ππ for 7 TeV p+p
Identity of the “mystery peak” in $K^0_s K^0_s$ real distribution

From PDG: $f_2'(1525)$

mass $= 1525 \pm 5$ MeV/c$^2$

$\Gamma = 73 \pm 6$ MeV/c$^2$

Main decay mode

$f_2'(1525) \rightarrow KK$ (89%)
Use PYTHIA with the Perugia-0 tune to model the baseline for $\mathcal{K}_s^0 \mathcal{K}_s^0$ $C(Q_{\text{inv}})$ as was done for $\pi\pi$ (apply ±10% syst. error)

Quadratic fits to PYTHIA to extract baseline parameters for $C(Q_{\text{inv}})$

$$C(Q_{\text{inv}}) = N\{1 + aQ_{\text{inv}} + bQ_{\text{inv}}^2\} \times F(Q_{\text{inv}})$$

where $F(Q_{\text{inv}})$ is the femtosopic part containing, in general, quantum statistics and strong interaction effects which depend on $R_{\text{inv}}$ and the $\lambda$ parameter.
Gaussian fits to PYTHIA to extract baseline parameters for $C(Q_{\text{inv}})$

$C(Q_{\text{inv}}) = N\{1 + a \exp[(bQ_{\text{inv}})^2]\} \times F(Q_{\text{inv}})$
Gaussian fits to data $C(Q_{\text{inv}})$ with Quadratic PYTHIA baseline

$$C(Q_{\text{inv}}) = N\{1 + aQ_{\text{inv}} + bQ_{\text{inv}}^2\} \times \{1 + \lambda \exp[-(Q_{\text{inv}}R_{\text{inv}})^2]\}$$
Gaussian fits to data
$C(Q_{\text{inv}})$ with Gaussian
PYTHIA baseline

$$C(Q_{\text{inv}}) = N \{ 1 + a \exp[(bQ_{\text{inv}})^2] \} \times \{ 1 + \lambda \exp[-(Q_{\text{inv}}R_{\text{inv}})^2] \}$$

ALICE data
7 TeV p+p
Lednicky fit to data to take into account the $a_0/f_0$ resonance in $K^0\bar{K}^0$ channel

* A strong final-state interaction has an important effect on neutral kaon correlations due to the $f_0(980)$ and $a_0(980)$ resonances which contribute to the $K^0\bar{K}^0$-bar channel.

* Use the Lednicky & Lyuboshitz analytical model and code to take into account this strong FSI assuming s-wave scattering: (R. Lednicky and V.L. Lyuboshitz, Sov.J.Nucl.Phys. 35,770 (1982))

* The code assumes a Gaussian distribution of the $K^0$ source points, and so one fits the model to the experimental correlation function to extract the Gaussian $R$ and $\lambda$ parameters from both quantum statistics and strong FSI.

* STAR used this method to fit their $K^0_s\bar{K}^0_s$ correlation function from RHIC Au+Au collisions (Phys.Rev.C74:054902,2006).
Example of Lednicky fit to data with quadratic baseline model divided out

**Big effect!**
~30% reduction for $R$ and ~50% for $\lambda$

STAR saw a ~20% reduction in $R$ and $\lambda$ for Au+Au collisions.
$R_{\text{inv}}$ and $\lambda$ from Lednicky fits to data for the 12 multiplicity-$k_T$ bins and for Quadratic vs. Gaussian fits to PYTHIA for the baseline statistical error bars.
Averaged $\lambda$ parameters vs. $k_T$ and multiplicity bin from Lednicky code fits
statistical + systematic error bars
(including ±10% shift in baseline parameters)

$\lambda$ shows a mostly flat $k_T$ dependence and is at an overall level of ~ 0.5-0.6 similar to ALICE $\pi\pi$ results.
Averaged $R_{\text{inv}}$ vs. $k_T$, $m_T$ and multiplicity bin from Lednicky code fits compared with ALICE $\pi\pi$ correlation data statistical + systematic error bars (including $\pm 10\%$ shift in baseline parameters)
Summary for $K^0_s K^0_s$ 7 TeV p+p analysis

* The present $K^0_s K^0_s$ study is the first to show source parameters for p+p collisions and for different multiplicity and $k_T$ bins.

* The $K^0_s K^0_s$ results for the $\lambda$ parameter show a mostly flat $k_T$ dependence which is at an overall level of $\sim 0.5 - 0.6$, similar to that seen in the ALICE $\pi\pi$ results for 7 TeV p+p.

* The $K^0_s K^0_s$ results for $R_{\text{inv}}$ suggest a slight tendency for $R_{\text{inv}}$ to decrease with increasing $k_T$ and to increase for increasing event multiplicity bin as also seen in the ALICE $\pi\pi$ results for 7 TeV p+p and in heavy-ion collisions.

* Comparing with $\pi\pi$, the $K^0_s K^0_s$ results for $R_{\text{inv}}$ extend the covered range of $k_T$ to $\sim 2$ GeV/c ($3 \times$ larger than $\pi\pi$). No discontinuity for the $k_T$ dependence of $R_{\text{inv}}$ is seen between $\pi\pi$ and $K^0_s K^0_s$.

see L. Malinina poster on charged KK correlations in 7 TeV p+p, Tuesday Poster Session
Backup slides
Details of the analysis: $7$ TeV $p+p \rightarrow K^0_s K^0_s$

$K^0_s$ Cuts:
* $|\eta| < 0.8$, $0.4 < p_T < 3.5$ GeV/c
* Identification: $K^0_s \rightarrow \pi^+\pi^-$ ($V_0 \rightarrow h^+h^-$)
* $0.490 <$ Reconstructed $V_0$ mass $< 0.504$ GeV/c$^2$
* DCA of $V_0$ daughters $< 0.1$ cm

Correlation function:
* $C(Q_{inv}) = R(Q_{inv})/B(Q_{inv})$
  $R \rightarrow$ real pairs per event, $B \rightarrow$ pairs from 10 mixed events
* Form in 3 event multiplicity x 4 $k_T$ bins

Fits used to extract $R$ and $\lambda$ from $C(Q_{inv})$:
* $C(Q_{inv}) = N[1 + aQ_{inv} + bQ_{inv}^2] \times \{1 + \lambda \exp[-(Q_{inv}R_{inv})^2]\}$
* $C(Q_{inv}) = N[1 + a \exp[(bQ_{inv})^2]] \times \{1 + \lambda \exp[-(Q_{inv}R_{inv})^2]\}$
* $C(Q_{inv}) = N\{ \text{baseline} \} \times \{ \text{Lednicky code with } a_0/f_0 \text{ resonance decay} \}$
  where the baseline parameters $a$ and $b$ are fixed by fits to PYTHIA with the Perugia-0 tune.
R and $\lambda$ from data using the various fitting functions and for several multiplicity bins.