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$f_0(980)$ resonance production in pp collisions with the ALICE detector at the LHC

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Abstract

We report on a preliminary study of the production of $f_0(980) \to \pi^+\pi^-$ at mid-rapidity ($|y| < 0.5$) performed with the ALICE detector at the LHC in minimum bias pp collisions at the centre-of-mass energy $\sqrt{s} = 5.02$ TeV. The $f_0(980)$ signal extraction is challenging due to the large background from correlated $\pi^+\pi^-$ pairs from other resonance decays in the invariant mass window under study, as well as due to the combinatorics from uncorrelated pairs. We present the strategy for the signal extraction and first results in terms of p_T-dependent production yields. The results are discussed and compared with production yields of other resonances and stable hadrons.

Keywords: $f_0(980)$, Resonances, Hadronic phase, Particle production mechanism.

1. What can we learn from $f_0(980)$?

The channel with the vacuum quantum numbers $J^{PC} = 0^{++}$ has several resonances, whose structure has been under study for a long time. From the experimental point of view, due to their large decay widths which imply a significant overlap between the signals and the background, the identification of the scalar resonances is a long-standing problem [1]. The $f_0(980)$ is a highly-contested example of a scalar resonance for which the Particle Data Group provides ranges for mass and width: $m_{f_0(980)} = (0.99 \pm 0.02)$ GeV/c^2, $\Gamma_{f_0(980)} = (0.01\text{-}0.1)$ GeV/c^2. Despite a long history of experimental and theoretical studies, the nature of the short-lived $f_0(980)$ resonance is far from being understood: up to now there has been no agreement about its quark structure. According to different models, it has been associated with $q\bar{q}$ structures, considered as a $(q)^2(\bar{q})^2$ tetraquark and as a mixture of $q\bar{q}$ and tetraquark [2, 3]. The debate is not over, even because how to identify the true nature of the resonance is still elusive. Studies in different collision systems are particularly interesting because they can provide information about the nature of this particle. More specifically, based on calculations from the coalescence and statistical models, the yields of exotic hadrons are expected to be lower by two orders of magnitude compared to the results for non-exotic structures ($q\bar{q}$, 3q) and hadronic molecule configurations [4]. Besides the exotic interpretation, the $f_0(980)$ is interesting as a probe because it is expected to decay during the hadronic phase in the evolution of ultra-relativistic heavy-ion collisions. Furthermore, it has a similar mass as the proton and the $\phi(1020)$ meson but different quark composition,

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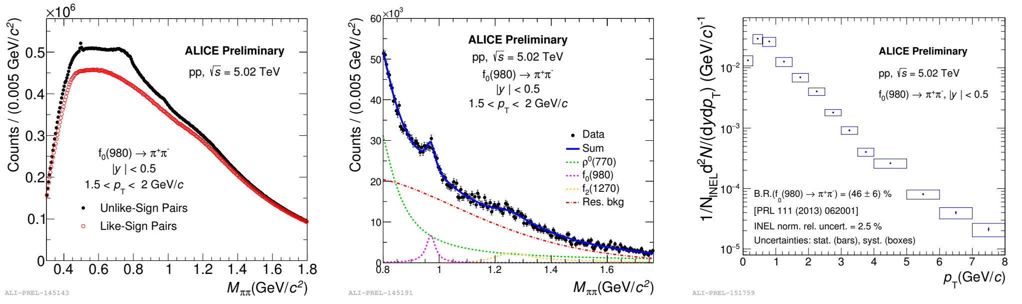

Fig. 1. Left: Unlike-Sign pion Pairs (black) and Like-Sign Pairs (red) distributions. Center: Invariant mass distribution fitted with a function that includes three contributions from $\rho^0(770)$ - green, $f_0(980)$ - magenta, and $f_2(1270)$ - orange, and the residual background - red. Right: Production spectrum of the $f_0(980)$ measured with ALICE at mid-rapidity ($|y| < 0.5$) in inelastic pp collisions at $\sqrt{s}$ = 5.02 TeV.

thus its production might give new insight into particle production mechanism. The analysis in pp collisions performed for the first time with the ALICE detector in inclusive production provides a feasibility check and a baseline for the measurement in larger collision systems (p–Pb, Pb–Pb).

2. Analysis and results

The analysis is based on a sample of inelastic pp collisions collected by ALICE at $\sqrt{s}$ = 5.02 TeV in 2015, which corresponds to $\sim 10^8$ minimum bias events. The resonance was studied by reconstructing its hadronic decay into oppositely charged pions ($f_0(980) \rightarrow \pi^+\pi^-$). In order to obtain the p_T-dependent invariant mass distributions from the combination of primary identified pion pairs, a study of the background was performed. The uncorrelated background was estimated by finding like-sign pion pairs in the same event (using the Like-Sign technique - Fig.1, left). Contributions by other resonances in the invariant mass window under study made the signal extraction very challenging. After background subtraction, the resulting distribution, which exhibits the characteristic peaks of the resonance signals on top of a residual background, was fitted in order to extract the raw yield in each transverse momentum interval (Fig.1, center). The $f_0(980)$ peak was parametrized with a relativistic Breit-Wigner function. Due to the overlap of the tails of the $f_0(980)$ distribution with the broad $\rho^0(770)$ and $f_2(1270)$ mesons, two additional relativistic Breit-Wigner functions were included in the fitting model. A dependence of all the resonance widths on mass was considered in the fitting procedure. Furthermore, due to the fact that ρ^0, f_0 and f_2 can also be produced in $\pi\pi$ scattering during the hadronic phase, thus affecting the final shapes of the reconstructed peaks, the phase space correction was taken into account. The residual combinatorial background was parametrized according to a similar Maxwell-Boltzmann distribution. The total fit function is:

$$f = \left(\frac{M_{\pi\pi}\Gamma(M_{\pi\pi})_{\rho^0} M_{\rho^0}}{(M_{\pi\pi}^2 - M_0^2)^2 + M_0^2\Gamma_{\rho^0}^2} + \frac{M_{\pi\pi}\Gamma(M_{\pi\pi})_{f_0} M_{f_0}}{(M_{\pi\pi}^2 - M_0^2)^2 + M_0^2\Gamma_{f_0}^2} + \frac{M_{\pi\pi}\Gamma(M_{\pi\pi})_{f_2} M_{f_2}}{(M_{\pi\pi}^2 - M_0^2)^2 + M_0^2\Gamma_{f_2}^2} \right) \times PS(M_{\pi\pi}) + bg(M_{\pi\pi})$$

where $\Gamma(M_{\pi\pi})$, $PS(M_{\pi\pi})$ and $bg(M_{\pi\pi})$ are respectively:

$$\Gamma(M_{\pi\pi}) = \left[\frac{(M_{\pi\pi}^2 - 4m_\pi^2)}{(M_0^2 - 4m_\pi^2)} \right]^{(2J+1)/2} \times \Gamma_0 \times (M_0/M_{\pi\pi}) \quad , \quad PS(M_{\pi\pi}) = \frac{M_{\pi\pi}}{\sqrt{M_{\pi\pi}^2 - p_T^2}} exp\left(- \frac{\sqrt{M_{\pi\pi}^2 - p_T^2}}{T} \right)$$

$$\text{and} \quad bg(M_{\pi\pi}) = B\sqrt{(M_{\pi\pi} - m_{cutoff})^n} C^{3/2} exp[-C(M_{\pi\pi} - m_{cutoff})^n]$$

M_0 and Γ_0 are the mass and the width parameters of the fit, respectively. $M_{\pi\pi}$ is the reconstructed $\pi^+\pi^-$ invariant mass. J is equal to 0 for $f_0(980)$, 1 for $\rho^0(770)$ and 2 for $f_2(1270)$. T is the kinetic freeze-out temperature, set to 160 MeV. B, C and n are normalisation factors, m_{cutoff} is a shifting parameter which acts as a low-mass cutoff. The $f_0(980)$ parameters from the unconstrained fit were within the ranges given in the PDG [1]. To improve the fit stability, the f_0 mass was thus fixed to the value resulting from the free fit, while the f_0 width was constrained within the PDG range. The masses of the ρ^0 and f_2 were fixed to the nominal values reported by the PDG ($m_{\rho^0(770)} = 0.775$ GeV/c^2 and $m_{f_2(1270)} = 1.275$ GeV/c^2). In order to evaluate the efficiency for the $f_0(980)$ reconstruction, a Monte Carlo production based on events generated by PYTHIA 6 [5] was adopted. Since the event generator does not provide $f_0(980)$ signals, an $f_0(980)$-injected simulation consisting of 4.5×10^6 events was used. After correction for the detector acceptance and efficiency - (Acc $\times\ \epsilon$)(p_T), the preliminary p_T spectrum (Fig.1, right) was obtained. The differential transverse momentum spectrum is

$$\frac{d^2N_{f_0}}{dydp_T} = \frac{f_{norm}}{N_{evt} \cdot BR \cdot (Acc \times \epsilon)(p_T)} \frac{N_{f_0 \to \pi^+\pi^-}}{\Delta y \Delta p_T}$$

The raw yield in each p_T bin was normalised by dividing it with the number of the total accepted events (N_{evt}). The spectrum was corrected for the branching ratio (BR) assuming the value (46 ± 6)% from [6]. It has to be noted that in order to normalise the yield to the number of inelastic pp collisions, an inelastic normalisation factor (f_{norm}) is needed to correct for the vertex and trigger efficiency for pp. This factor converts the particle yield normalised to the number of triggered events to a yield normalised to the number of inelastic events [7]. The p_T-integrated f_0/π ratio is consistent with LEP results. The Statistical Hadronisation Model [8] slightly underestimates the f_0/π ratio, as in e^+e^- collisions. The p_T-dependent production is compared with the production of pions and $\phi(1020)$ (Fig.2). In particular, the approximately constant behavior of the f_0/ϕ ratio as a function of p_T suggests that ϕ and f_0 have similar spectral shapes. The analysis demonstrates the feasibility of the measurement in inelastic pp collisions over a wide transverse momentum range, from 0 to 8 GeV/c, and opens the possibility to detect the $f_0(980)$ also in larger collision systems.

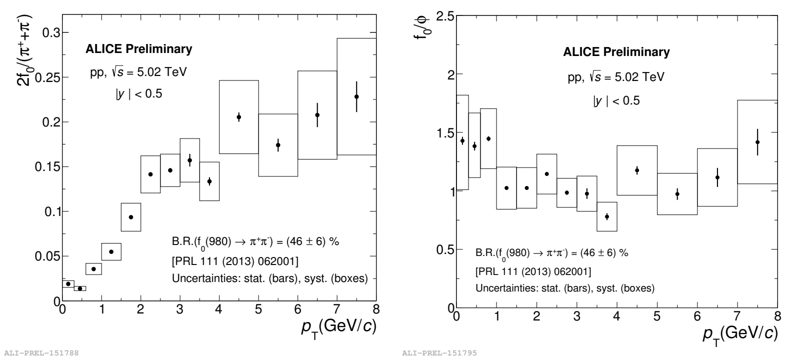

Fig. 2. p_T-dependent f_0/π (left) and f_0/ϕ (right) ratios.

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