NA60 results on ϕ production in the hadronic and leptonic channels in In-In collisions at 158 GeV

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Abstract

The NA60 experiment at the CERN SPS studied ϕ meson production in In-In collisions at 158 A GeV via muon and kaon decay channels. Results in the hadronic channel are presented for the first time. These are discussed in the framework of the so-called ϕ puzzle through the comparison with the previous NA60 measurements in the muon channel. The yield and inverse m_T slopes observed in the two channels are compatible within errors, showing that the large discrepancies seen in Pb-Pb collisions between NA50 (muon pairs) and NA49 (kaon pairs) are not seen in the NA60 In-In data.

Strangeness enhancement was proposed already in 1982 as a signature of the occurrence of the quark gluon plasma phase [1]. Due to its $s\bar{s}$ valence quark content, the ϕ meson is a particularly valuable probe for the measurement of strangeness production.

ϕ production measurements were performed at the CERN SPS by the NA49, NA50 and CERES experiments in lead induced collisions at 158 A·GeV. Discrepancies were observed in the measurements performed by NA50 [2] in the muon channel and by NA49 [3] in the kaon channel, both in Pb-Pb collisions. The ϕ multiplicity measured by NA50 is much higher than the one obtained by NA49. Concerning the transverse mass distributions, NA50 finds an inverse slope of about 230 MeV, almost independent of centrality, while NA49 measures values increasing with the number of participants N_{part} from ~250 MeV to ~300 MeV.

The origin of this discrepancy, known as the ϕ puzzle, has long been discussed. It was suggested that kaons may suffer rescattering and absorption in the medium, resulting in a depletion of kaon pairs, especially at low p_T, that leads to a reduced yield and a hardening of the p_T distribution in the hadronic channel. In this frame, the yield in lepton pairs is expected to exceed the one in kaon pairs by about 50% [4].

Recent results by CERES [5] on ϕ production in Pb-Au collisions via the K^+K^- and e^+e^- decay channels confirm the NA49 results, and thus suggest that there is no ϕ puzzle. However, the results in dielectrons, being affected by large statistical errors, are not conclusive.

The NA60 experiment at the CERN SPS studied ϕ meson production in In-In collisions both in muon and kaon pairs. Details of the apparatus are reported in [6].

The sample used for the results presented in this paper was collected with a 158 A·GeV In beam impinging on a segmented In target, composed of 7 subtargets of 17% total interaction probability placed in vacuum. 230 million triggers, mainly dimuons, were acquired. In order to avoid events with reinteractions of nuclear fragments in the subsequent targets, only events with one vertex in the target region were selected.

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Results for dimuons, already presented in [7], are briefly summarized in the following. The dimuon sample consist of 440000 signal muon pairs. The ϕ yield in the muon channel is measured counting the events in the mass window $0.98 < M_{\mu\mu} < 1.06$ GeV/c^2. The signal/background ratio below the ϕ peak, integrated over centrality, is ∼1/3. To account for the continuum under the ϕ peak, two side windows between $0.88 < M_{\mu\mu} < 0.92$ GeV/c^2 and $1.12 < M_{\mu\mu} < 1.16$ GeV/c^2 are subtracted from the ϕ window. The raw transverse momentum distributions are extracted counting the number of ϕ mesons in several p_T intervals. They are then corrected for the acceptance using an overlay Monte Carlo tuned iteratively such that the resulting distributions reproduce the measured data.

The ϕ multiplicity was obtained either with a direct measurement of the cross section or using the J/ψ as a calibration process. The two methods agree within ∼ 10%.

The analysis in the KK channel is performed assuming that all the charged particles associated with the primary vertex are kaons, and building all the possible pairs among the tracks of each event. This results in a considerable combinatorial background, ranging from ∼ 170 to ∼ 400 times the signal, depending on centrality. The background has to be reduced with an appropriate set of cuts and subtracted with an event mixing technique. For the latter, events from runs taken in homogeneous conditions are grouped in pools according to the position of the target associated to the vertex, the centrality of the collision and the direction of the event plane. Tracks from different events belonging to the same pool are mixed.
Several cuts are applied both to the real and mixed samples. The vertices are required to be within $2\sigma_z$ from the center of the closest target, $\sigma_z \sim 200\ \mu$m being the resolution of the position of the interaction vertex in the longitudinal coordinate. Events with a charged track multiplicity lower than 10 are discarded. The tracks associated with the vertex are selected requiring that the χ^2 of the track fit is lower than 3. A cut on the track rapidity $2.9 < y < 3.7$ is applied. Additional cuts on the pairs are applied requiring that the opening angle θ_{KK} is within the range $0.005 < \theta_{KK} < 0.15$ rad and the transverse momentum is $p_T > 0.9$ GeV/c. The obtained mixed spectra are normalized asking that in the mass region $1.02 < m < 1.06$ GeV/c^2 the number of mixed like-sign pairs coincides with the corresponding one in the real data.

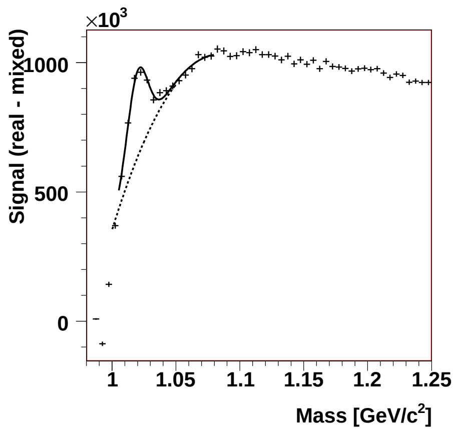

Figure 1: Invariant mass spectrum of the opposite sign kaon pairs integrated in centrality.

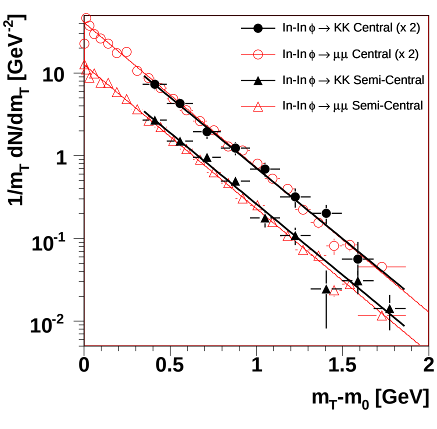

Figure 2: m_T spectra for semi-central (triangles) and central (circles) collisions for $\phi \to KK$ (full symbols) and $\phi \to \mu\mu$ (open symbols).

The invariant mass distribution after background subtraction integrated over centrality is plotted in fig. 1. A clear ϕ peak on top of a residual background can be seen. In order to extract the number of ϕ mesons, the mass spectrum is fitted with a function that describes the shape of the ϕ peak superimposed on an empirical description of the residual background. The shape of the ϕ peak is determined fitting the mass distribution obtained from a Monte Carlo simulation with a gaussian superimposed to an empirical function that takes into account the high mass tail.
Several functions and fit mass ranges have been tested to describe the residual background. In order to check that a given function does not produce artificial bumps in a certain fit range, the fit procedure has been applied to the like-sign invariant mass spectra in several p_T intervals, where no signal is expected. The functions and fit mass range used do not give a fake signal. It has to be noticed that if the ϕ peak position and width are left as free parameters of the fit, the corresponding values, integrated in centrality, are $m_\phi = 1019.5 \pm 0.3$ MeV/c^2 and $\sigma_m = 7.8 \pm 0.3$ MeV/c^2, in good agreement with the simulations. The results shown in the following are obtained fixing m_ϕ and σ_m according to the Monte Carlo values.
In order to extract the m_T distributions, the fit to the invariant mass spectra was performed in several p_T intervals. Due to statistics limitations, a reliable m_T distribution could be extracted only for central and semi-central collisions. Results are reported in fig. 2. The distributions in the $\phi \to \mu\mu$ channel in the same centrality intervals are reported for comparison. The m_T spectra are fitted with the function $1/m_T dN/dm_T \propto e^{-m_T/T}$. The extracted χ^2/ndf is ~ 1 in both cases. The inverse slopes measured in semicentral and central collisions are $253 \pm 11 \pm 5$ MeV and $254 \pm 13 \pm 6$ MeV respectively. The systematic error is dominated by the choice of the function used for the background. Results are in good agreement with the ones obtained in dimuons in the full p_T range ($250 \pm 2 \pm 3$ MeV and $249 \pm 3 \pm 4$ MeV for semicentral and central collisions). Since in presence of radial flow the T value may depend on the p_T range, being higher at low transverse momenta, the fit to the dimuon spectra was restricted to the range $p_T > 0.9$ GeV/c, giving $T = 252 \pm 4$ and 247 ± 3 MeV for semicentral and central collisions, still in agreement with the measurement in kaons.
The raw ϕ multiplicity was determined fitting the mass spectra for $p_T > 0.9$ GeV/c and dividing the number of ϕ mesons obtained by the total number of events selected for this analysis. This value was then corrected for the branching ratio in kaon pairs and for the acceptance in 4π, evaluated through a Monte Carlo simulation. Results are plotted in fig. 3. The main contributions to the systematic errors are given by the uncertainty in the choice of the fit function for the residual background component in the fit of the invariant mass spectra and the variation of the acceptance caused by the error in the inverse slope.
In the same figure, the corresponding results for dimuons are shown. In can be seen that the yields in the hadronic and dileptonic channels are in agreement within the errors. A ratio between the ϕ yields in dimuons and in kaons larger than 1.2 is excluded at 95% C.L.
In order to compare to other collision systems, inverse slope and the enhancement factor $\langle\phi\rangle/N_{part}$ are plotted in fig. 4 as a function of the number of participants for central C-C, Si-Si [8], In-In and Pb-Pb collisions. The inverse slope shows an initial fast increase at low N_{part} values, that becomes less pronounced going towards higher N_{part}. Lower values are observed by NA50 as compared both to the CERES and NA49 measurements in Pb-Pb and to the NA60 In-In points in the hadronic and dileptonic channels. As stated above, in presence of radial flow T depends on p_T. As a consequence, the NA49 and NA50 values can not be directly compared, since the former is dominated by low p_T (< 1.6 GeV/c) while the latter is limited by acceptance to $p_T > 1.1$ GeV/c. However, the NA60 analysis in dimuons, performed in both p_T ranges, showed a difference of about 15 MeV, which can be probably ascribed to a modest radial flow. Radial

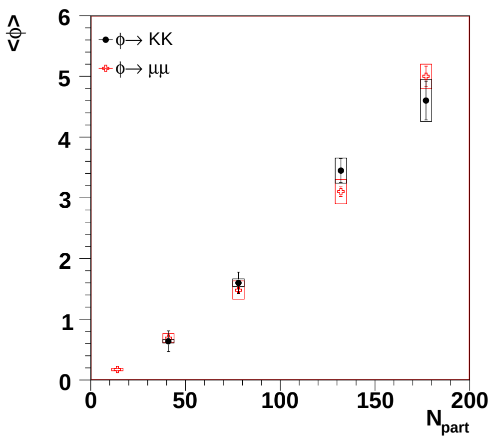

Figure 3: Yield as a function of N_{part} in In-In collisions in the $\phi \rightarrow KK$ (full circles) and $\phi \rightarrow \mu\mu$ channels (open crosses).

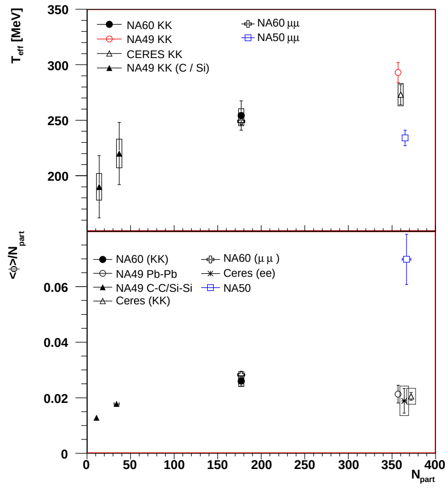

Figure 4: Inverse slope (top) and enhancement factor (bottom) as as function of N_{part}.

flow alone can not justify the large difference (about 70 MeV) seen between kaon and dimuon results in central Pb-Pb collisions. A further flattening caused by kaon rescattering and absorption may lead to larger T values in the NA49 data. However, this effect is not seen when comparing the In-In results in the hadronic and dileptonic channels.

Concerning the enhancement factor, an unambiguous comparison to NA50 can not be performed in full phase space, since the NA50 acceptance is limited to $p_T > 1.1$ GeV/c and there is no consensus on the value of the inverse slope parameter. In fig. 4 the NA50 result is extrapolated to full phase space using a T value of 220 MeV, according to the NA50 measurement in peripheral collisions. Even assuming as an extreme case a T value of 300 MeV, the NA50 enhancement factor would exceed by a factor of ~ 2 the central Pb-Pb values obtained by NA49 and CERES. Moreover, the CERES measurement in dielectrons and kaon pairs are in agreement within the errors, excluding a yield in dileptons exceeding the one in kaons by more than 60%. At present, it is difficult to reconcile all of the observation into a coherent picture, albeit there is some hint for a possible physics mechanism leading to a difference in the two channels in Pb-Pb collisions, while in In-In collisions no remarkable difference is observed.

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