ϕ production in p-A and In-In collisions

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The NA60 experiment studied ϕ meson production in p-A and In-In collisions at the CERN SPS. The ratio ϕ/ω shows an increase by a factor ~ 2 from peripheral to central collisions. The inverse slope parameter T of the p_T spectrum increases with centrality, and seems to agree with the previous NA49 measurements.

The study of ϕ meson production in heavy ion collisions is motivated by the fact that it is directly related to the strangeness enhancement expected in the quark-gluon plasma [1]. At the CERN SPS, ϕ production was studied in Pb-Pb collisions through its decay into kaon or muon pairs. The former channel was measured by the NA49 collaboration [2] which extracted the ϕ/π ratio and the inverse slope parameter T of the transverse momentum distribution as a function of the number of participants. The NA50 experiment [3] detected the ϕ through its decay in muon pairs, in an acceptance window limited to high transverse momenta ($m_T > 1.5$ GeV). NA50 measured the $\phi/(\rho+\omega)$ ratio and the parameter T as a function of centrality.

The two experiments obtained different results for the T parameter, both in the absolute value and in the trend as a function of the number of participants. NA49 observes a significantly higher T parameter value, and an increase with centrality, while NA50 observes no dependence on centrality. The incompatibility between the two measurements originated the so-called ϕ-puzzle. It has been argued that the difference may be attributed to the different channels probed [4].

The NA60 experiment can cleanly measure the $\phi \to \mu\mu$ channel and has access to the kaonic one. The NA60 apparatus is fully described elsewhere [5]. The main detectors used in this analysis are the zero-degree calorimeter (ZDC) and muon spectrometer previously used in the NA50 experiment, and a silicon pixel telescope, which is used to track charged particles in the vertex region inside a 2.5 T dipole magnet. Tracking in the vertex region significantly improves the $\mu\mu$ mass resolution and the signal-to-noise ratio, the former by matching muon tracks before and after the absorber and the latter by rejecting muons from π and K decays, the main source of background. Its vertexing capability lead to a resolution in the vertex position which is around 200 μm for the z coordinate and $\sim$ 20 μm in the transverse plane. The mass resolution at the ϕ peak is 23 MeV in In-In collisions. Moreover, the dipole field in the target region deflects some of the muons with high rapidity and low transverse momentum into the acceptance region of the apparatus, thus enhancing the dimuon acceptance at low mass and transverse momentum. Finally, NA60 can study also the $\phi \to KK$ channel using the unidentified charged tracks in the vertex telescope. Due to these characteristics, NA60 is well placed to help solving the ϕ puzzle.

NA60 collected data with a 400 GeV proton beam on Be, In and Pb targets, and with a 158 A·GeV Indium beam on an Indium target. The proton data were collected in four days in 2002. The muon pairs in the muon spectrometer were matched to the tracks in the vertex telescope. The combinatorial background, due to uncorrelated pion and kaon decays into muons, was estimated through an event mixing technique. After applying strict phase space cuts and subtracting the combinatorial background (consisting of few percent under the ω and ϕ peaks), the final sample consisted of $\sim$15000 opposite sign muon pairs. It should be stressed that during the 2004 proton run we collected a statistics which is around a factor 100 higher.

The mass spectra were fit with a superposition of the known sources, namely the light meson decays into muon pairs and the $D\bar{D}$ contribution. The ϕ/ω ratios extracted from the fit are (0.062 ± 0.004), (0.083 ± 0.007) and (0.081 ± 0.006) in p-Be, p-In and p-Pb respectively, where the quoted errors are only statistical. The p-Be value is in good agreement with the previous HELIOS-1 measurement [6]. An enhancement of the ϕ/ω ratio is already observed in p-A collisions when going from lighter to heavier targets.

The In-In data were collected in the 2003 run. The analyzed data sample amounts to 570000 events after background subtraction. The overall ratio between signal and background is about 1/4. In this sample an additional source of background must be taken into account: it is due to the muons detected in the muon spectrometer incorrectly matched to the tracks in the vertex telescope. This contribution is estimated for each process by generating a Monte Carlo event sample on top of real data and performing the reconstruction and track matching. It ranges from 5% to 30% under the ϕ, when going from peripheral to central collisions.

The data sample was divided in four centrality classes, and in each of them the mass spectrum was fit with a superposition of the conventional sources, leaving as free parameters the cross section ratios η/ω, ρ/ω and ϕ/ω, besides the continuum normalization. The results from a fit to the peripheral bin show a good agreement with the expected sources and a flat trend as a function of p_T, with the exception of the ρ/ω ratio that shows an excess at low transverse momenta. This effect is due to the presence of $\pi\pi$ annihilation, that gives an important contribution at low p_T even in the most peripheral bin. More details are reported in [7]. In most central collisions this effect is more remarkable, lead-

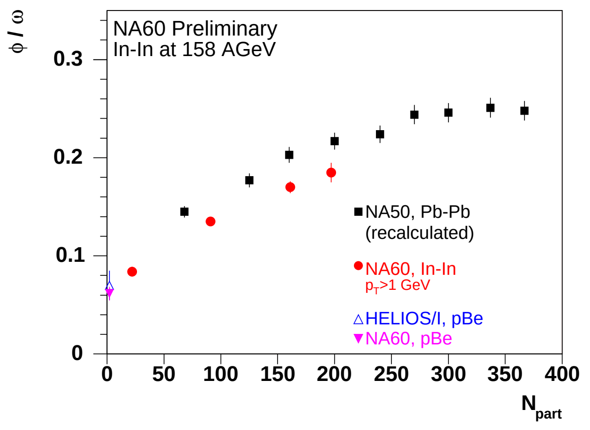

Figure 1. ϕ/ω ratio as a function of N_{part} in p-Be (NA60, HELIOS-1), In-In (NA60) and Pb-Pb (NA50) collisions (see text for details).

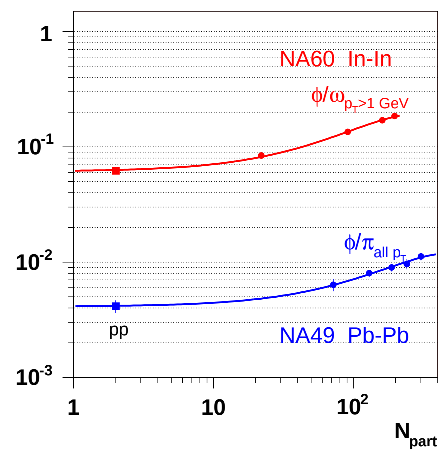

Figure 2. ϕ/ω ratio measured by NA60 (In-In) compared to the ϕ/π ratio measured by NA49 (Pb-Pb).

ing to a complicated continuum under the ω peak. However, due to the excellent mass resolution, it is possible to extract a robust ω yield, in particular for $p_T > 1$ GeV/c.

The ratio ϕ/ω is reported in fig. 1 as a function of the number of participants, for $p_T > 1$ GeV/c. An increase of around a factor 2 is seen when going from peripheral to central In-In collisions. In the same plot, the HELIOS-1 and NA60 p-Be results are displayed, showing a smooth trend compared to In-In pattern. In order to compare our results to the NA50 measurement of the $\phi/(\rho+\omega)$ ratio for $m_T > 1.5$ GeV, the latter was converted to the NA60 p_T window assuming $T = 228$ MeV, the NA50 value. The ratio $\phi/(\rho+\omega)$ was then converted to ϕ/ω assuming $\sigma_\rho = 1.2\sigma_\omega$, as obtained in NA60 peripheral data for $p_T > 1$ GeV/c. This correction should be considered as a lower limit for the NA50 ϕ/ω ratio, since the contribution of the ρ from $\pi\pi$ annihilation becomes more important when the collision centrality increases.

The NA50 data show the same trend as a function of N_{part}, while the absolute value is around 10% higher. However, a direct comparison is difficult, due to the contribution of pion annihilation that NA50 cannot isolate, and that is expected to be even more important in Pb-Pb collisions.

In fig. 2 the NA60 results are compared with the ϕ/π ratio, as measured by NA49. Both ratios show the same trend, indicating that the ratio ω/π is constant. If this ratio is set to 0.07–0.08, as suggested by statistical models, the ϕ yield measured by NA60 is a factor 1.5–2 higher than the corresponding NA49 value.

The ϕ p_T spectra were extracted considering the events in the mass window $0.98 < M_{\mu\mu} < 1.06$ GeV, after combinatorial background subtraction. The contribution from the underlying physical processes was estimated selecting two side windows, $0.88 < M_{\mu\mu} < 0.92$ GeV and $1.12 < M_{\mu\mu} < 1.16$ GeV, and subtracted from the ϕ window. The resulting spectra were then corrected for the acceptance using a 2-dimensional y vs. p_T correction, converted in $1/p_T dN/dp_T$ and fit with the functional form $1/p_T dN/dp_T \sim e^{-p_T/T}$ (fig. 3).

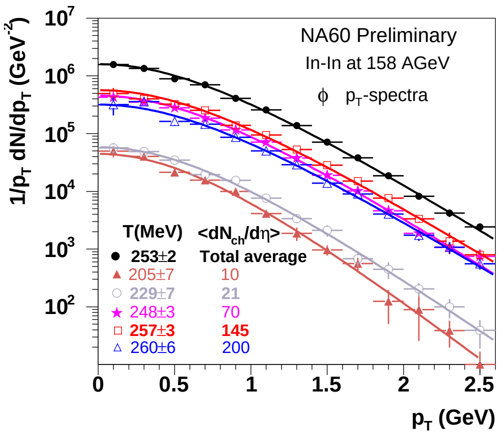

Figure 3. Transverse momentum distributions in In-In collisions for different centralities.

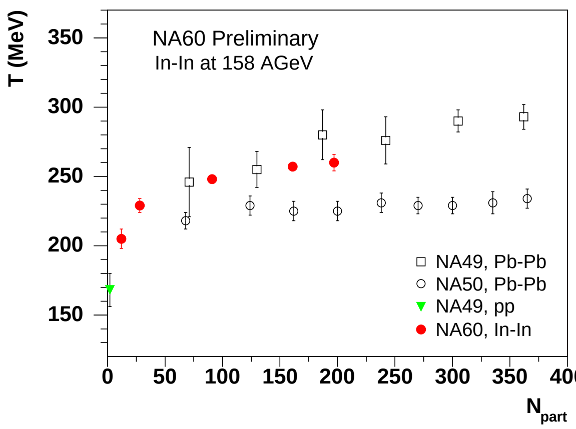

Figure 4. Inverse slope T as a function of number of participants, as measured by NA60, NA49, NA50.

The T values extracted from the fit are plotted in fig. 4 as a function of N_{part}, together with the NA49 and NA50 measurements. The T parameter increases with centrality, in agreement with the NA49 data. The NA60 In-In value integrated over all centralities is $T = 253 \pm 2$ MeV, and lies between the Si-Si and Pb-Pb values measured by NA49 (~ 220 and 290 MeV, respectively), as expected, while the NA50 Pb-Pb point ($T \approx 228$ MeV) is lower than expected from the the general trend of the T parameter as a function of the mass. From these considerations we conclude that the NA60 measurement seems to agree with the NA49 values, so that the difference between the NA49 and NA50 measurements cannot be attributed to the different decay channels probed.

NA60 can access the $\phi \to KK$ using the tracks reconstructed in the vertex telescope. Since no particle identification can be performed, all tracks are assumed to be kaons, and combined to extract the invariant mass. The huge combinatorial background can be reduced applying appropriate kinematical selection cuts and subtracted using the event mixing technique. This is still work in progress. Once the quality of the background subtraction will be good enough, it will be possible to extract the ϕ signal in this second decay channel.

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