Direct photon and light neutral meson production in the era of precision physics at the LHC

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Abstract. In these proceedings we present the latest results from ALICE on direct photon and light neutral meson production in p-Pb and Pb-Pb collisions. The direct photon excess ratio R_γ in different charged particle multiplicity classes of p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV is shown. In addition, we present the direct photon elliptic flow coefficient v_2 in central and semicentral events of Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. An outlook on ongoing and future measurements is given.

Keywords: direct photons, electromagnetic probes, heavy-ion collisions, quark-gluon plasma

1 Introduction

Direct photons, being defined as photons not originating from hadron decays, are a valuable tool to investigate the space-time evolution of the medium created in heavy-ion collisions. The measured elliptic flow coefficient of photons reflects the momentum anisotropy of the source, convoluted with the photon emission rate, integrated over time. Direct photons can also contribute to the effort of testing bulk effects in high multiplicity collisions of small systems.

There are different sources of photons in heavy-ion collisions. Prompt photons are created in initial hard scatterings. In addition, we expect thermal photons from the QGP and the hadron gas phases, which are sensitive to the medium temperature [1]. There will also be photons from hadron decays, which are the vast majority of all photons. The latter originate mostly from decays of the neutral mesons π^0 and η into two photons. Therefore we need to measure their spectra precisely in order to be able to obtain the excess of direct photons over this decay photon background. Due to the different shapes of transverse momentum (p_T) distributions of prompt and thermal photons (power-law and close-to-exponential respectively) they can be distinguished on a statistical basis. Prompt photons dominate direct photons at high $p_T \gtrsim 4$ GeV/ c and thermal photons at low $p_T \lesssim 3$ GeV/ c . Therefore, a direct photon excess at low p_T can be interpreted as thermal photon signal. So far it was assumed that thermal photons are relevant only in AA collisions but after collective effects have been observed also in high-multiplicity pp and p-A collisions (see for example [2]) we can question this assumption.

2 Direct photon R_γ in p–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

Observation of a direct photon signal implies that the ratio of inclusive (γ_{inc}) over decay photons (γ_{dec}) is larger than one. In order to eliminate parts of the uncertainty, we define the double ratio as $R_\gamma = \frac{\gamma_{\text{inc}}}{\gamma_{\text{dec}}} \equiv \frac{\gamma_{\text{inc}}}{\pi^{0,\text{p}}} / \frac{\gamma_{\text{dec}}}{\pi^{0,\text{p}}}$, where $\pi^{0,\text{p}}$ stands for the parametrisation of the measured π^0 spectrum. In the analysis presented here, inclusive photons are measured with three different techniques: PCM, EMCal and PHOS [3]. The EMCal is a sampling calorimeter composed of alternating layers of lead and plastic scintillators. It is placed at a radius of $R = 4.3$ m from the beam and covers a range of $\Delta\varphi = 100^\circ$ in azimuthal angle and $|\eta| < 0.7$ in pseudorapidity. The cell size is about 6×6 cm².

Fig. 1. Direct photon R_γ , labeled by the percentile of the multiplicity distribution.

are taken from the same methods as mentioned above, as well as from one additional hybrid method (PCM-EMC), where one photon is detected with PCM and one with EMCal. The decay photon spectra are then obtained using a Monte Carlo simulation including all relevant hadron decays, based on the measured neutral meson spectra and m_T scaling. For each of the four methods, the R_γ is calculated. In case of the PCM-EMC method, inclusive photons are taken from PCM. After checking that the results from all methods are consistent, they were combined. The analysis was performed in event multiplicity classes of data from p–Pb collisions recorded in 2013. The results are shown in Fig. 1. The dotted blue, red and purple lines, starting at $p_T = 3$ GeV/c show results of different

The Photon Spectrometer PHOS is a homogeneous calorimeter made from PbWO₄ crystals. The acceptance of $\Delta\varphi = 60^\circ$ and $|\eta| < 0.125$ is smaller than the one of EMCal but PHOS has a finer granularity with a cell size of about 2.2×2.2 cm² at $R = 4.6$ m. With the photon conversion method (PCM) we exploit the fact that photons can convert to an electron positron pair in the detector material with a probability of about 8% (for $R < 1.8$ m). We search for secondary vertices characterized by two oppositely charged emerging electron tracks which we detect in the Inner Tracking System (ITS, $|\eta| < 1.2$) and Time Projection Chamber (TPC, $|\eta| < 0.9$). This methods benefits from the large acceptance and the good momentum resolution especially at low p_T . In addition to the inclusive photons, we measure π^0 and η mesons via their decay to two photons, performing an invariant mass analysis of photon pairs.

For this purpose, the photon samples

pQCD calculations. They are all well compatible with the measured points at high p_T . For 0-20% and 0-100% samples a green band is drawn in addition, which shows a prediction from a hydrodynamic model [4] including thermal photon emission at low p_T . The current data are not sensitive to the predicted very small thermal photon signal.

3 Direct photon v_2 in $\sqrt{s_{NN}} = 2.76$ TeV Pb–Pb collisions

The inclusive photon v_2 is obtained using the scalar product method [5]. Reference particles are measured in the V0 scintillation detectors placed in a different pseudorapidity region ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$) [3]. Results from the independent methods PCM and PHOS are combined after they were found to be consistent. In the analysis presented here, Pb–Pb collisions were analyzed in two centrality classes, 0-20% and 20-40%. For PCM, 13.6×10^6 events were available and 18.8×10^6 for PHOS. The direct photon $v_2^{\gamma, \text{dir}}$ can be calculated

Fig. 2. Direct and decay photon v_2 in central (left) and semicentral (right) collisions compared with hydrodynamic and cascade model predictions [6].

by subtracting the $v_2^{\gamma, \text{dec}}$ of decay photons from the $v_2^{\gamma, \text{inc}}$ of inclusive photons using the following formula: $v_2^{\gamma, \text{dir}} = \frac{v_2^{\gamma, \text{inc}} R_\gamma - v_2^{\gamma, \text{dec}}}{R_\gamma - 1}$, where the R_γ measured with PCM and PHOS [7] was used. $v_2^{\gamma, \text{dec}}$ is obtained from a MC simulation including all relevant hadron decays. The simulation is based on hadron spectra and v_2 measurements and uses KE_T scaling [8] when necessary. The results for decay photons and direct photons are shown in Fig. 2. At low p_T , where thermal photons should dominate, we measure a positive $v_2^{\gamma, \text{dir}}$ which is close to $v_2^{\gamma, \text{dec}}$. This indicates an already developed momentum anisotropy of the medium at direct photon production times. At higher p_T , where the prompt photon contribution

increases, the $v_2^{\gamma, \text{dir}}$ decreases. In more peripheral events, the thermal photon v_2 , and therefore also the direct photon v_2 at low p_T , are expected to be larger than in central events because of the more pronounced initial spatial anisotropy of the medium. Because the direct photon signal is smaller in more peripheral events [7] the uncertainties are larger in this case and therefore we cannot yet make a conclusive statement on how the direct photon v_2 changes with centrality. Calculations from different theoretical models are illustrated by the dashed lines. They tend to underestimate the v_2 with respect to the measured values.

4 Summary and outlook

In summary, ALICE has measured the direct photon elliptic flow coefficient v_2 in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. It was found to be consistent with the current knowledge of the space-time-evolution and photon emission rates but smaller uncertainties will be needed to confirm or exclude given model predictions. The direct photon R_γ in high multiplicity p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV is not yet sensitive to the predicted very small thermal photon signal. Analyses of $\sqrt{s_{NN}} = 5.02$ TeV Pb–Pb collisions are ongoing. Neutral pion spectra are a crucial input for the decay photon simulation which is required for direct photon measurements. They are presented in Fig. 3 in different centrality classes. The increased statistics of the $\sqrt{s_{NN}} = 5.02$ TeV dataset will enable us to reduce statistical uncertainties of R_γ and v_2 by one order of magnitude compared to the measurements at $\sqrt{s_{NN}} = 2.76$ TeV. It was investigated that also the systematic uncertainties, which dominate over parts of the p_T range, can be reduced by employing new analysis techniques. This allows to exploit the advantages of the ALICE upgrade in future runs.

Fig. 3. Neutral pion spectra in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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