Recent Neutral Meson and Direct Photon Measurements with ALICE

V. Kuskov[a,b] [1] *for the ALICE collaboration*

В.А. Кусков[a,b]

[a] National Research Nuclear University «MEPhI»

[a] Национальный исследовательский ядерный университет «МИФИ»

[b] National Research Center «Kurchatov Institute»

[b] Национальный исследовательский центр «Курчатовский Институт»

In this overview, recent results of the ALICE collaboration on neutral meson and direct photon production are reported. The invariant cross section of π^0 and η meson production in pp collisions $\sqrt{s} = 13$ TeV are measured and compared to pQCD calculations. The direct photon production and two-photons HBT correlations in Pb–Pb $\sqrt{s_{NN}} = 5.02$ TeV are presented as well.

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Introduction

At large transverse momentum (p_{T}), the hadron yields in collisions of relativistic particles are described by perturbative Quantum Chromodynamics (pQCD) calculations, containing parton distribution functions (PDFs) and fragmentation functions (FFs). PDFs and FFs rely on the experimental input of measured production of identified particles. At the ALICE (A Large Ion Collider Experiment) experiment, the production cross sections of π^0 and η mesons are measured in a wide p_{T} range [1], contributing strongly to calculating and testing PDFs and FFs. Moreover, decay photons from neutral mesons cause the largest contamination for the direct photon measurements.

On the other hand, direct photons [2] in the nucleus-nucleus collisions carry information about the hot and dense QCD matter, usually interpret as quark-gluon plasma (QGP). Prompt direct photons from the hard parton interaction on the initial stage of colliding have a power-law p_{T}-spectrum and could also be used for testing of pQCD calculations. In turn, an exponential spectrum ($p_{\mathrm{T}} \lesssim 2$ GeV/c) of thermal direct photons captures the radiation and collective correlations of hot matter at all stages of a collision, as photons do not interact strongly with partons. The correlations of soft photons also provide an estimation of the properties of hot matter. Thus, Hanbury Brown and Twiss (HBT) correlation of direct photons [3] can shed light on the time-space properties of QGP at its earliest stages.

[1] E-mail: vladislav.kuskov@cern.ch

Experimental setup and analysis methods

Photon measurements in the ALICE experiment are based on the following detectors. The tracking detectors allow reconstructing converted in the detector material photons by e^-e^+ pairs, this method is called the photon conversion method (PCM). For this purpose, the Inner Tracking System, the Time Projection Chamber and the Transition Radiation Detector are used for primary vertex reconstruction, charged particle identification, track reconstruction and positioning. The sampling Electromagnetic Calorimeter and DCal (EMCal/DCal) with a large acceptance, together with the highly granulated homogeneous Photon Spectrometer (PHOS), provide measurements of photons by their electromagnetic showers.

The light-neutral mesons, in their turn, are reconstructed by the decay channel $\pi^0(\eta) \to \gamma\gamma$. To estimate yields for a given p_{T} range, the invariant mass distribution ($M_{\gamma\gamma}$) for two photon candidates with energies $E_{1,2}$ and the angle between them θ_{12} is calculated according to

$$M_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta_{12})}. \quad (1)$$

The example of the $M_{\gamma\gamma}$ distribution is shown in Fig. 1 (left). Yields of $\pi^0(\eta)$ mesons are extracted as the area under a peak in $M_{\gamma\gamma}$ distribution around the corresponding mass of a meson.

For π^0 mesons, a complementary approach is used. Exploiting high-energy clusters both in EMCal/DCal and PHOS, a yield of high energy π^0 mesons is extracted [1]. This method assumes that the angle between decay photons from a high-energy π^0-meson is small and showers from two photons in a calorimeter cannot be separated. The contribution of such merged clusters containing overlapped showers from these two photons could be selected by shower shape parameter M_{02} as in Fig. 1 (right), where π^0 mesons dominate over rest sources (black open dots).

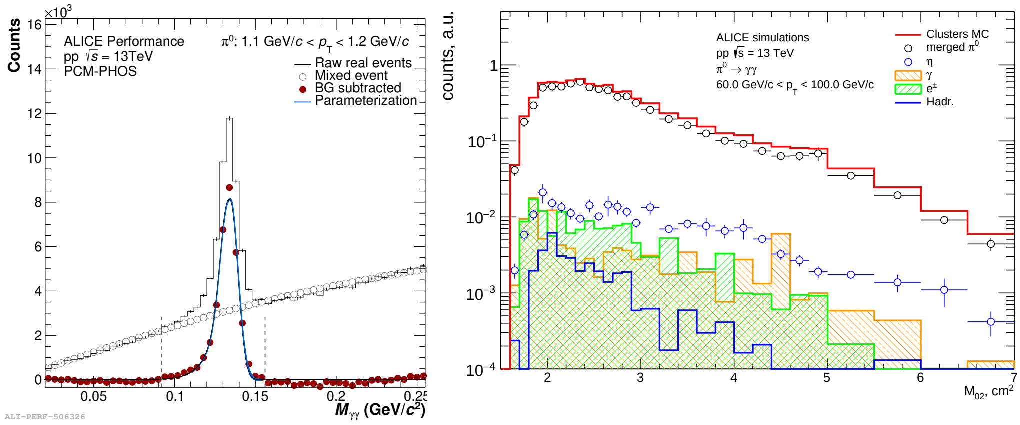

Fig. 1. The reconstruction techniques of neutral mesons: two photon invariant mass method with vertical dashed lines represent integration region (left); merged clusters method (right)

The estimation of direct photons strongly depends on the decay photons contamination (γ_{decay}) over inclusive photons (γ_{inc}). To precisely calculate the contamination, the data-driven Monte-Carlo (MC) calculations are done. The yield of direct photons is calculated as a double ratio (R_γ)

$$R_\gamma = \frac{\gamma_{\rm inc}}{\gamma_{\rm decay}} \approx \frac{\gamma_{\rm inc}/\pi^0_{\rm meas}}{\gamma_{\rm decay}/\pi^0_{\rm sim}}, \tag{2}$$

R_γ taken as number of produced photons in an event per one π^0 meson. The denominator does not contain direct photon yield, while the numerator does. Thus, $R_\gamma > 1$ gives the excess of direct photons.

Results

Based on methods briefly discussed in the previous section, the invariant cross sections of $\pi^0(\eta)$ mesons are measured in pp collisions at $\sqrt{s} = 13$ TeV. In Fig. 2 these cross sections and related calculations are presented as a ratio to the Two Component Model (TCM) [4] parametrization. Next-leading-order calculations with CT18 [5] PDF and NNFF1.0 [6] FF (green band in Fig. 2) agree within uncertainties with the measured spectrum for π^0 meson. However, the same PDF with AESSS [7] FF cannot reproduce the η spectrum (green band in Fig. 2).

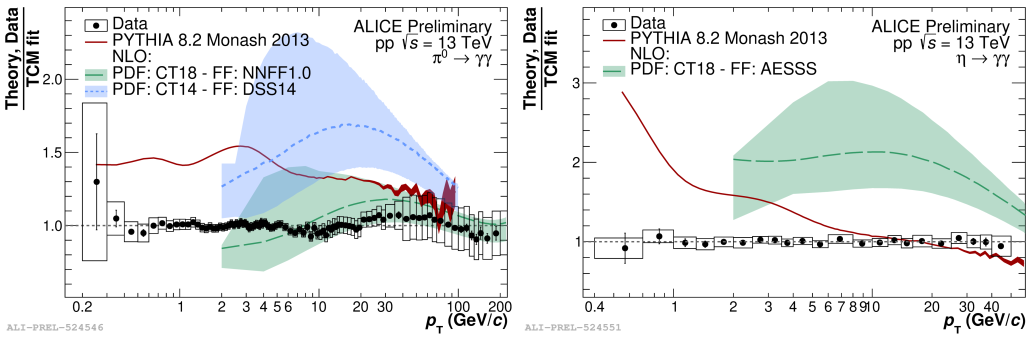

Fig. 2. The measured invariant cross sections of π^0 (left) and η (right) mesons compared to NLO calculations and MC generators predictions

The results on the direct photon production in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV measured by ALICE as a ratio to the hydrodynamic model [8] are given in Fig. 3 in comparison with the PHENIX and STAR results.

The overestimation of measured direct photon yield compared to model predictions at low $p_{\rm T}$ ($p_{\rm T} \lesssim 2$ GeV/c), the so-called direct photon puzzle [9], observed by PHENIX (grey and black dots) is not reproduced by ALICE (red dots) within the current precision.

Direct photon production precision measurements could be improved using complementary methods of photon HBT correlations. The correlation function $C(Q_{\rm inv})$ is given as

$$C(Q_{\rm inv}) = \frac{A(Q_{\rm inv})}{B(Q_{\rm inv})}. \tag{3}$$

where $Q_{\rm inv}$ is the relative momentum of one photon to the momentum of the pair, $A(Q_{\rm inv})$ is correlations of photons in the same event, $B(Q_{\rm inv})$ — in the

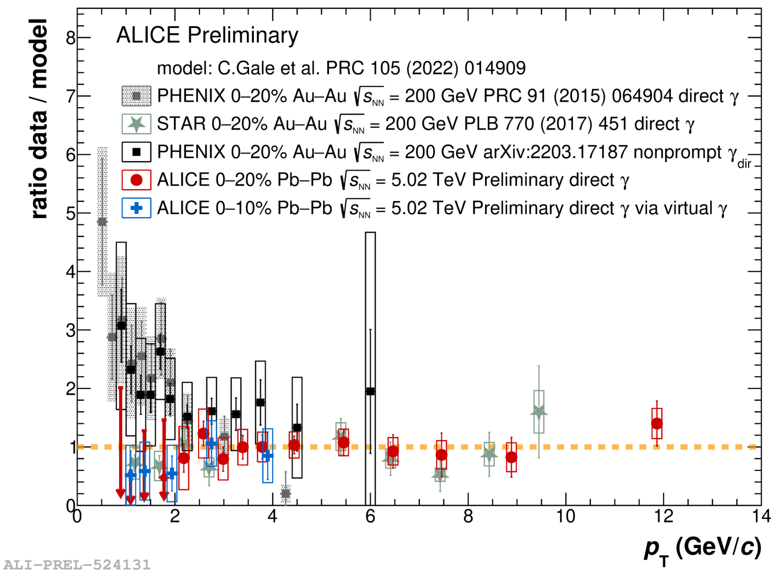

Fig. 3. The compilation of results on direct photon production measured by ALICE, STAR and PHENIX in comparison with hydrodynamic model [8]

mixed event. This function is sensitive to the source size as well as to the direct photon yield [3]. In Fig. 4, $C(Q_{\rm inv})$ is illustrated and fitted with the following function

$$C(Q_{\rm inv}) = 1 + \lambda_{\rm inv} \exp(-R_{\rm inv}^2 Q_{\rm inv}^2), \tag{4}$$

where $\lambda_{\rm inv}$ is the correlation strength which could be implemented for R_γ calculation [3], and $R_{\rm inv}$ corresponds to the gaussian source size.

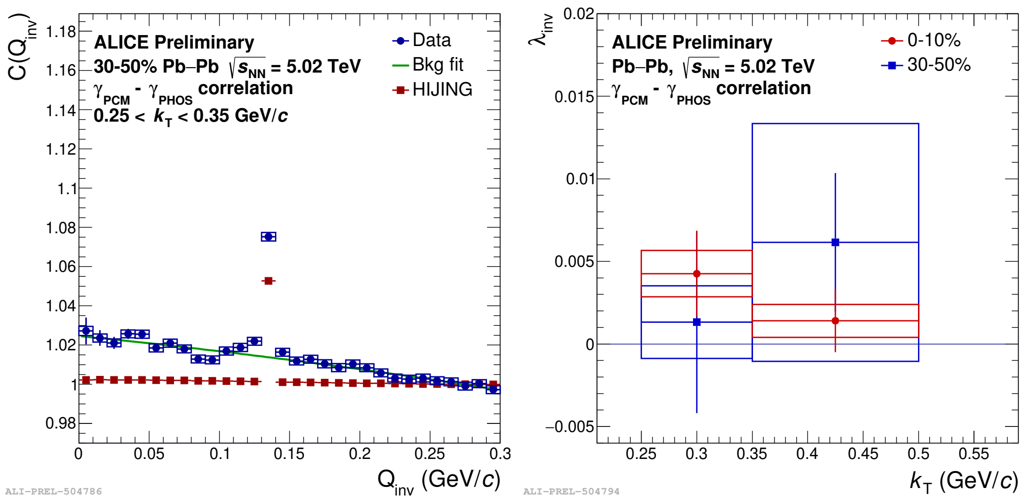

Fig. 4. Two-photons HBT correlations at low $k_{\rm T}$ (left) and extracted correlation strength (right)

The excess over unity at low $C(Q_{\rm inv})$ for Pb–Pb collisions at $\sqrt{s_{NN}} =$ 5.02 TeV in Fig. 4 (left) gives a hint for the HBT-like correlation (blue dots), while the MC generator (HIJING) shows no discrepancy with unity (red dots). The extracted $\lambda_{\rm inv}$ is represented in Fig. 4 (right) for central and semi-central collisions and also shows nonzero $\lambda_{\rm inv}$ for the central collisions at low $k_{\rm T}$ (the half-sum of the photon pair momentum).

Summary

This overview gives the recent results on neutral meson and direct photon measurements with the ALICE experiment. The invariant cross section of π^0 mesons in pp collisions at $\sqrt{s} = 13$ TeV is consistent with pQCD calculations. Nevertheless, η mesons cannot be described with the same PDF as FF, which for η mesons might be incorrect. The direct photon yield in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV shows no significant discrepancy with the hydrodynamic model prediction on the current precision level and does not support PHENIX results. The two-photons HBT correlations in the same colliding system provide evidence of nonzero correlation strength. Thus, such an approach can be used as a complementary method for the direct photon production at low p_{T}.

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