Direct photons

Direct photons are defined as photons not originating from hadron decays, but created in collisions of partons of colliding nucleons or in reactions in hot medium created in heavy-ion collisions. Unlike hadrons, direct photons are produced at all stages of the collision and escape from the hot nuclear matter basically a good tool for tuning QCD predictions, checking PDF and fragmentation functions. Moreover, the direct photon yield in p-A collisions can be used as a baseline for thermal direct photon measurements in Pb-Pb collisions. The direct photon yield can be calculated by subtracting decay photon spectrum, evaluated from measured hadron yields, from the inclusive photon spectrum. This approach, known as statistical subtraction, works well both in pp and AA collisions. Below we discuss modification of this method which aims to avoid subtraction of two close numbers and probably will allow to reduce some systematic uncertainties in low multiplicity environment of p-Pb collisions.

Tagging approach

The spectrum of the measured clusters in PHOS $N_{cl}$ can be decomposed as:

$$N_{cl} = N_{cl}^{pp} + N_{cl}^{pA} + N_{cl}^{AA} + N_{cl}^{cont}$$

where $N_{cl}^{pp}$, $N_{cl}^{pA}$, $N_{cl}^{AA}$ are the spectra of direct photons, photons from $m^0$ and other mess decay respectively, and $N_{cl}^{cont}$ is the contamination from hadrons. Selecting clusters making a pair with $m^0$ mass with any other cluster in the event, one produces a spectrum of tagged clusters:

$$N_{cl}^{tag} = N_{cl}^{pp} + N_{cl}^{pA}(1 - P_{rand}) + N_{cl}^{AA}P_{rand}$$

where $P_{rand}$ is the probability to reconstruct a partner for a $m^0$ decay photon and $P_{cont}$ is the probability to accidentally make a pair with $m^0$ mass with any other cluster in the event. The probability $P_{cont}$ depends on the PHOS acceptance, the reconstruction efficiency and the shape of the $m^0$ spectrum, and should be estimated from the MC simulations. The probability $P_{rand}$ can be estimated from the real data by analysis of two-photon invariant mass distribution. It is convenient to introduce the proportion of “true” tags:

$$\delta = \frac{N_{cl}N_{cl}^{rand}(1 - P_{rand})}{N_{cl}^{tag}}$$

The relative contribution of the heavier mesons to the decay photon spectrum can be estimated fromcocktail MC simulation:

$$\beta = \frac{N_{cl}^{pp} - N_{cl}}{N_{cl}}$$

Finally, we estimate the purity of the photon sample $X$ either from the MC simulations or with the data driven approach. To facilitate comparison with results of the statistical subtraction method, a ratio $R$ of the spectrum of inclusive photons to the spectrum of decay ones is constructed:

$$R = \frac{N_{cl}N_{cl}^{rand}(1 - P_{rand})}{N_{cl}^{tag}(1 + \beta)}$$

We calculate the probability to reconstruct a partner photon from the $m^0$ decay, making correct invariant mass, $P_{rand}$ using MC simulations. This probability $P_{rand}$ depends on the mass window, in which we accept pairs, and a cut $\eta$ on the minimum energy of the partner. In the figure below we use 2$\sigma$ cut on invariant mass of the pair and a cut on the partner minimum energy $E_{min} > 0.3$ GeV.

PHOS performance in p-Pb period (2013)

ALICE collected data with minimum bias and rare triggers in p-Pb run of 2013. In total, it was collected approximately 65 Mevent with the minimum bias and 1.9 Mevent with the PHOS photon trigger, evaluated for PHOS analysis, after all offline selection cuts. The minimum bias trigger was configured to select hadronic events by requiring a signal in either V0A or V0C, two arrays of 33 scintillator detectors covering the full azimuthal angle in the pseudorapidity region $2.6 < \eta < 5.1$ and $3.7 < \eta < 5.7$, where $\eta$ is the pseudorapidity in the laboratory frame. Note that the nucleus-nucleus center-of-mass system was moving in the laboratory frame with a rapidity of $y > 0.465$ in the direction of the photon beam. The PHOS photon trigger required the energy in 2x2 patch to be larger than some threshold in accordance with VSA or VGC signals. The threshold was chosen equal to 6 GeV what allowed on one hand to access high $p_T$ range up to 45 GeV as illustrated in the figure to the left, and on the other hand to have sufficiently large overlap region between the minimum bias and the triggered data samples to calculate the turn-on curves both for photons and neutral pions.

The main contribution to the decay photon spectrum comes from the $e^+e^-$ decays. Simultaneous measurement of the photon and neutral pion spectra in the same detector allows for a considerable reduction of the systematic errors. Because of its high granularity, PHOS is able to resolve photons from $m^0$ decay up to the pion momentum ~50 GeV/c. Presently, the collected statistics is not sufficient yet to reach this limit, but as it is demonstrated in the figure to the right, pairs with invariant mass twice smaller than the pion mass can be measured in the range 30-40 GeV/c. More details on the PHOS performance, $\pi^0$ analysis in p-Pb collisions and tuning of the Monte-Carlo simulations can be found in the poster of Tsukasa Okubo.

Two-photon invariant mass distribution with the $e^+e^-$ peak in p-Pb collisions at high 20-40 GeV/c. For comparison, an estimate of the combinatorial background produced with the mixed event technique is shown.

Photons are identified in PHOS with two independent methods. Neutral clusters are selected by requiring a large distance between the cluster and the closest charged track extrapolation to the PHOS surface. Electromagnetic clusters are identified using the energy dependent 2D cut on alien values of the detection matrix. All combinations of these two methods are used in the analysis to estimate and subtract the hadron contamination and evaluate the related systematic uncertainties. To illustrate the scale of the contamination and the efficiency of these identification criteria, we estimate the contamination of the photon spectrum using the MC simulation with DPMJET event generator, see figures below. If no identification criteria are applied, the main contaminations come from the charged pions and antiproton annihilation in PHOS. Applying both methods, all contaminations can be reduced down to 1% above $p_T > 2$ GeV.

Conclusions

A tagging method is used for the measurement of direct photon spectrum in p-Pb collision with PHOS calorimeter. First estimates show agreement with the direct photon spectrum measured with statistical method and from the hot photon spectrum measured with independent technique -- with photon conversion method.

Statistics of the p-Pb data, collected by ALICE with the minimum bias and rare triggers, is sufficient to measure the direct photon spectrum up to $p_T$ ~30-40 GeV/c, where it can be compared to the spectra of isolated photons, measured with ATLAS and CMS collaborations.