Direct photons in p-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV measured with ALICE/PHOS

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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 pQCD predictions, checking PDF and fragmentation functions. Moreover, the direct photon yield in p-A collisions can be used as a baseline for a 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_{clu} can be decomposed as

$$N_{clu} = N_{\gamma^{dir}} + N_{\gamma^{\pi}} + N_{\gamma^{\eta,\omega,...}} + N_{cont}$$

where $N_{\gamma\ dir}$, $N_{\gamma\ \pi}$ $N_{\gamma\ \eta,\omega,...}$ are the spectra of direct photons, photons from π^0 and other mesons decay respectively, and N_{cont} is the contamination from hadrons. Selecting clusters making a pair with π^0 mass with any other cluster in the event, one produces a spectrum of tagged clusters:

$$N^{tag}_{clu} = N_{\gamma^{\pi}} P_{part}(1 - P_{rand}) + N_{clu} P_{rand}$$

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

$$\delta = \frac{N_{\gamma^{\pi}} P_{part}(1 - P_{rand})}{N^{tag}_{clu}}$$

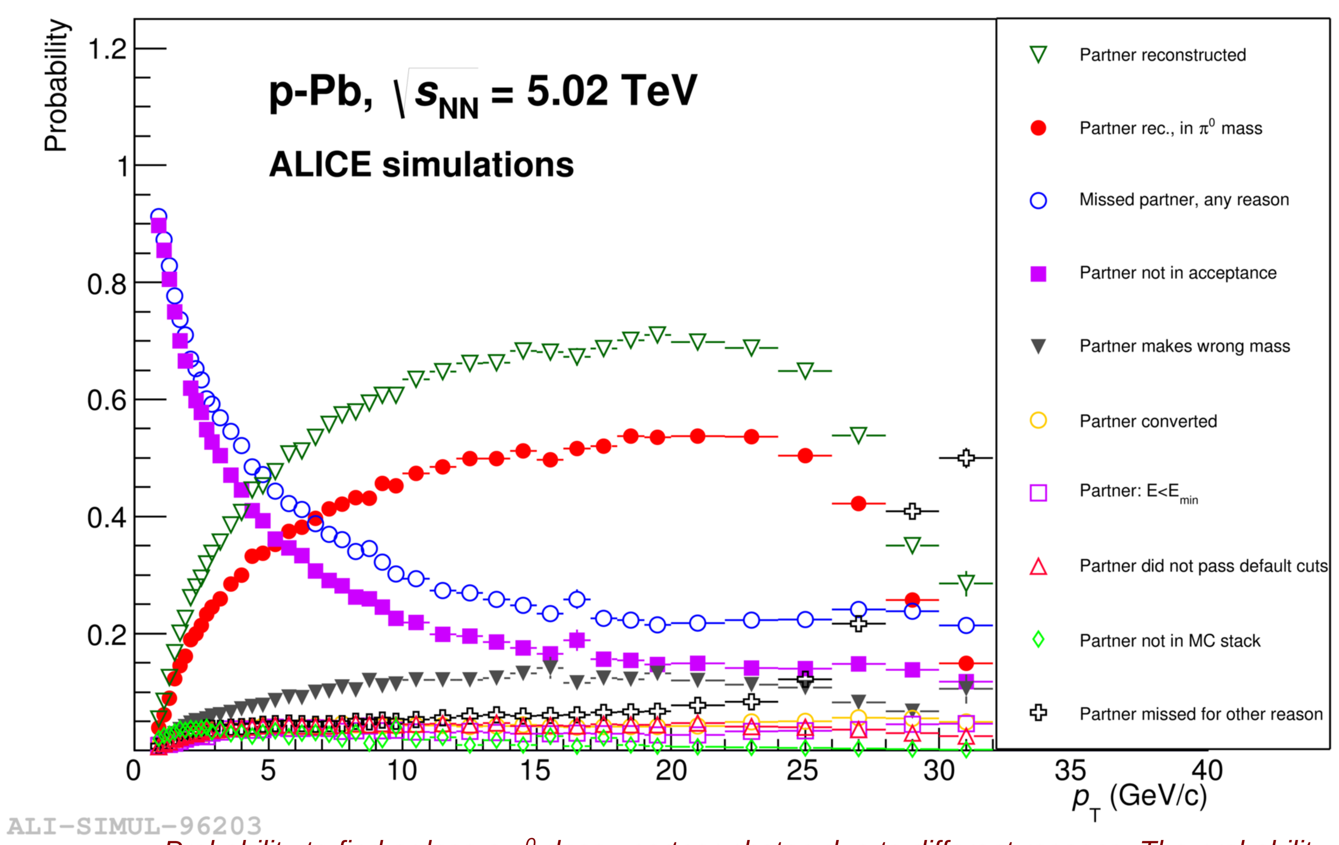
The relative contribution of the heavier mesons to the decay photon spectrum can be estimated from cocktail MC simulation:

$$\beta = \frac{N_{\gamma^{\eta,\omega,...}}}{N_{\gamma^{\pi}}}$$

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:

$$R = \frac{N_{\gamma}}{N_{\gamma^{decay}}} = \frac{P_{part}(1 - P_{rand}) X N_{clu}}{\delta N^{tag}_{clu}(1 + \beta)}$$

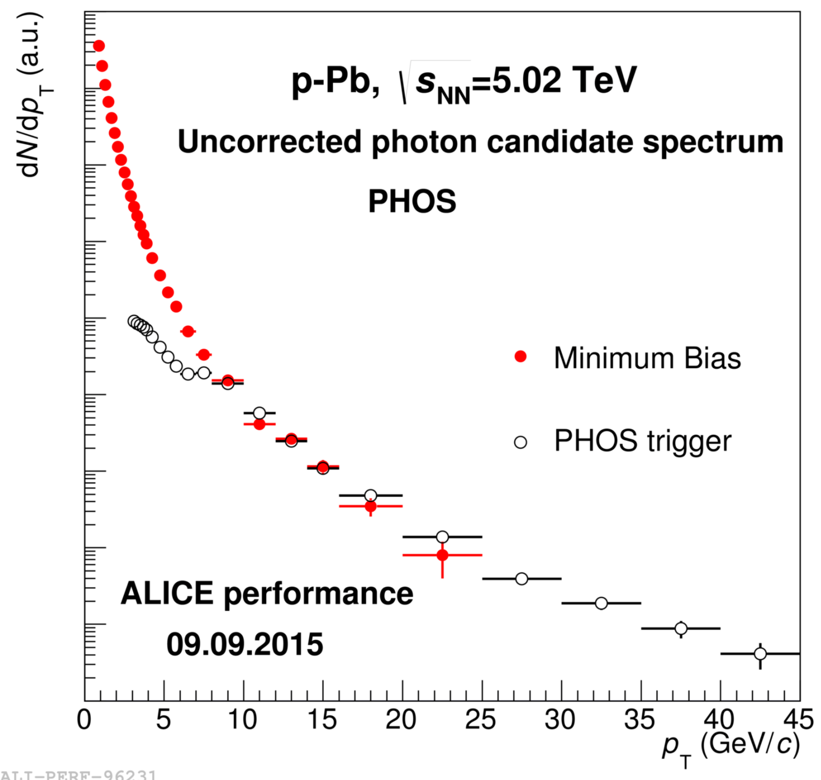
We calculate the probability to reconstruct a partner photon from the π^0 decay, making correct invariant mas, P_{part} using MC simulations. The probability P_{part} depends on the mass window, in which we accept pairs, and a cut on the minimum energy of the partner. In the figure below we use 2σ cut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



Probability to find or lose a π^0 decay partner photon due to different reasons. The probability to reconstruct a π^0 decay partner photon decrease at p_T<5 GeV/c due to the limited acceptance and at p_T>25 GeV/c due to the cluster merging.

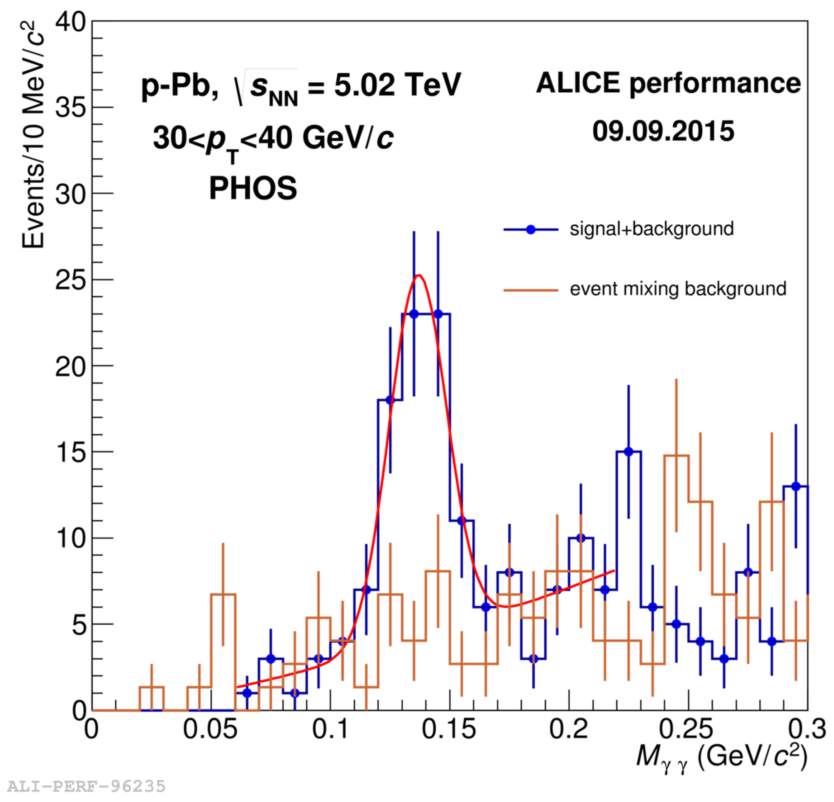
PHOS performance in p-Pb period (2013)

ALICE collected data with minimum bias and rare triggers in p-Pb run of 2013. In total, it was collected approximately 65 Mevents with the minimum bias and 1.9 Mevents with the PHOS photon trigger, available 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 32 scintillator detectors covering the full azimuthal angle in the pseudorapidity regions 2.8<η_{lab}<5.1 and -3.7<η_{lab}<-1.7, where η_{lab} the pseudorapidity in the laboratory frame. Note, that the nucleon-nucleon center-of-mass system was moving in the laboratory frame with a rapidity of y_{NN}= -0.465 in the direction of the proton beam. The PHOS photon trigger required the energy in 2x2 patch be larger than some threshold in accordance with V0A or V0C signals. The threshold was chosen equal to 6 GeV what allowed on one hand to access high p_T range up to 45 GeV/c 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.



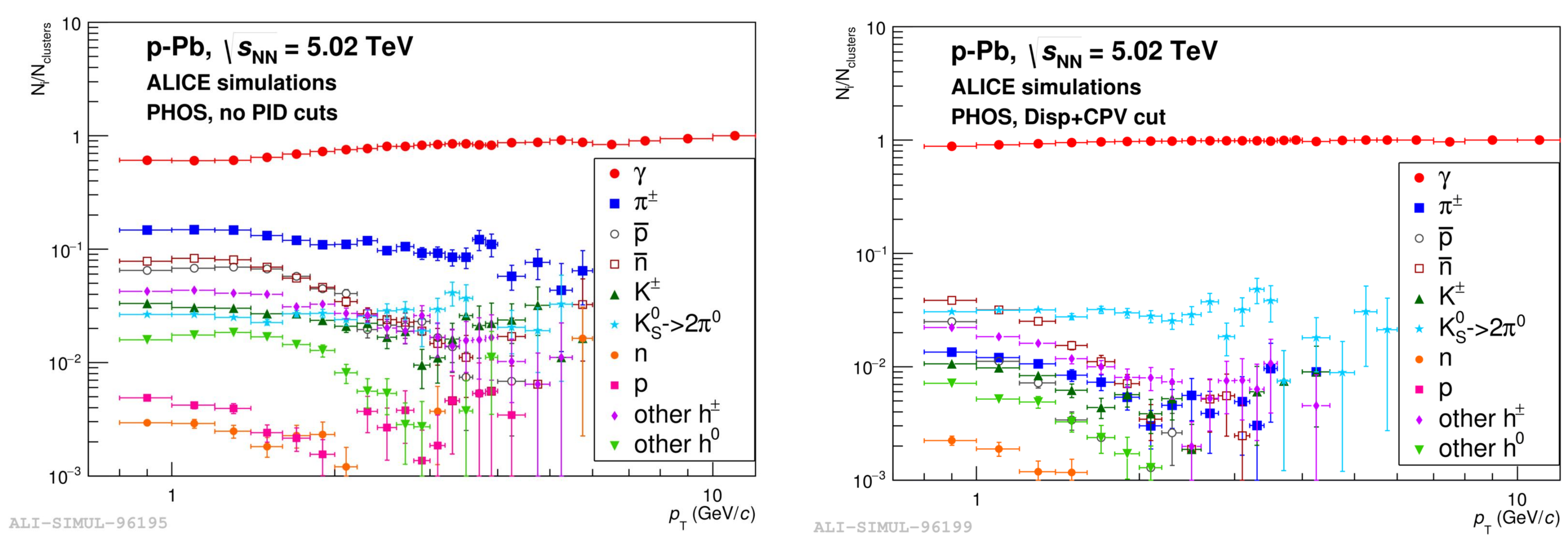
Comparison of the uncorrected photon candidate spectra measured with PHOS in minimum bias and PHOS triggered samples. PHOS trigger allows to measure the photon spectrum up to 45 GeV/c.

The main contribution to the decay photon spectrum comes from the π^0->2γ 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 π^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<p_T<40 GeV/c. More details on the PHOS performance, π^0 analysis in p-Pb collisions and tuning of the Monte-Carlo simulations one can find in the poster of **Tsubasa Okubo**.



Two-photon invariant mass distribution with the π^0 peak in p-Pb collision at high 30 < p_T < 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 aigen values of the dispersion 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 antibaryon annihilation in PHOS. Applying both methods, all contaminations can be reduced down to 1% above p_T>2 GeV.



Purity of the photon spectrum and the most important hadron contaminations of the photon spectrum for two extreme cases: no PID cuts applied (left) and both independent cuts, dispersion and cluster neutrality (right) are applied. Applying both identification criteria reduces all hadron contaminations down to 1% at 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 with direct photon spectrum measured with completely 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 spectrum of isolated photons, measured with ATLAS and CMS collaborations.